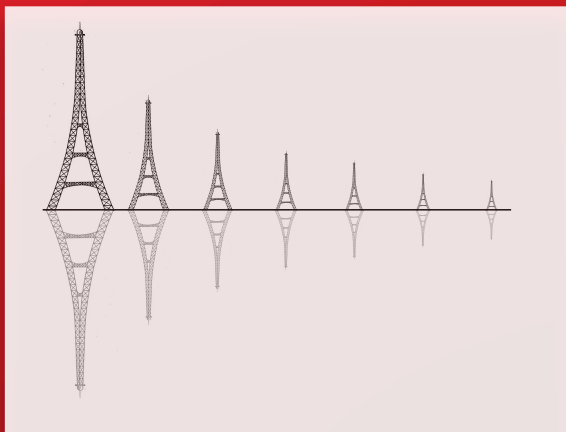


DE LA RECHERCHE À L'INDUSTRIE

cea



www.cea.fr

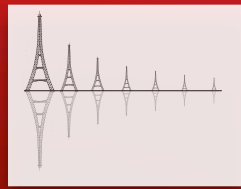
INSTRUMENTATION INNOVANTE POUR LA RÉSONANCE MAGNÉTIQUE: AIMANTS PERMANENTS

Dimitrios SAKELLARIOU

(DSM / IRAMIS / NIMBE - SIS2M / LSDRM)

SACM - IRFU - CEA Saclay | 11 Juin 2014

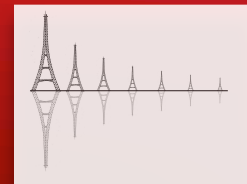




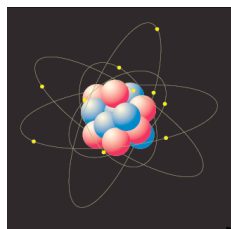
- RMN/IRM modernes à haut champ et besoins
- Le besoin de la **Sensibilité** : Micro-détecteurs en Rotation (pas traité aujourd'hui)
- Le besoin de la **Portabilité** : RMN et IRM à aimants permanents
- Le besoin de la **Résolution** : RMN et IRM à champ tournant
- Innovation

ETAT DE L'ART

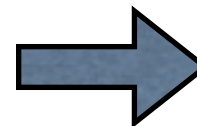
QU'EST-CE QUE LA RMN?



Magnétisme des noyaux (spin)



Aimant homogène supraconducteur
Electroaimants pulsés



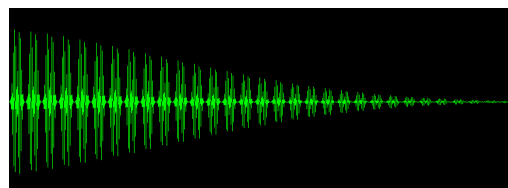
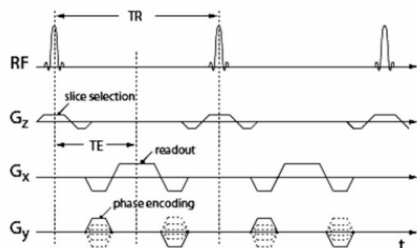
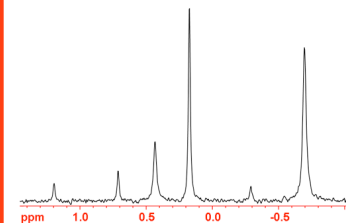
Images



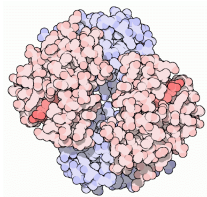
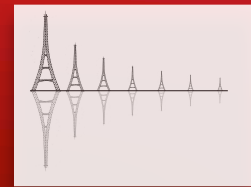
Impulsions Ondes Radio-fréquences+
Impulsions gradients champ B_0

Signaux Radio-fréquences

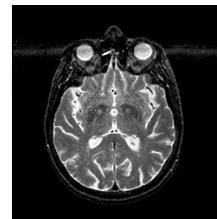
Spectres



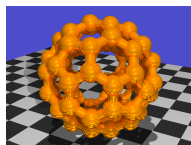
RMN ET IRM AUJOURD'HUI



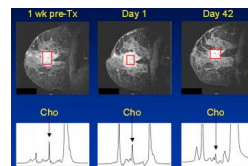
Bio-molécules



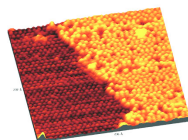
IRM anatomique



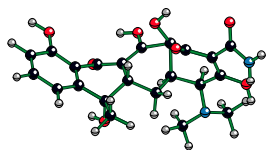
Matériaux



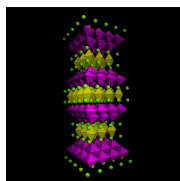
IRM Spectroscopique



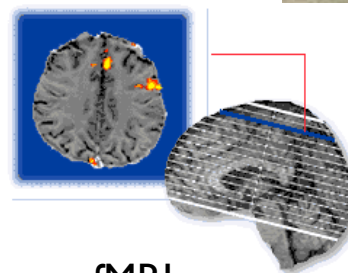
Surfaces



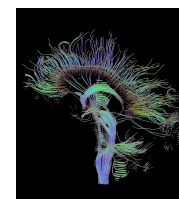
Poudres Organiques



Structures Inorganiques

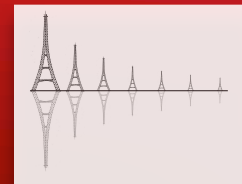


fMRI

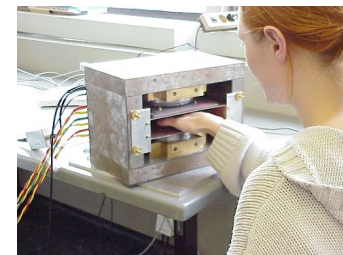


DTI

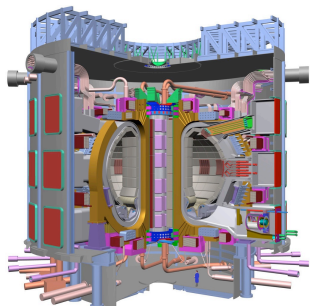
AUTRES BESOINS EN DEHORS DU LABO



Energie



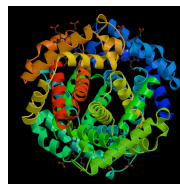
Santé



Heritage
(non destructive analysis)



Espace



Nano-quantités

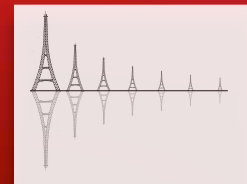


Défense

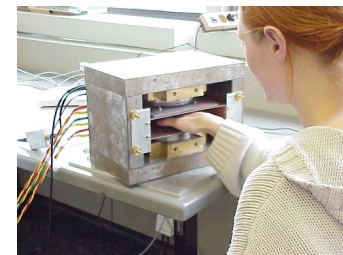
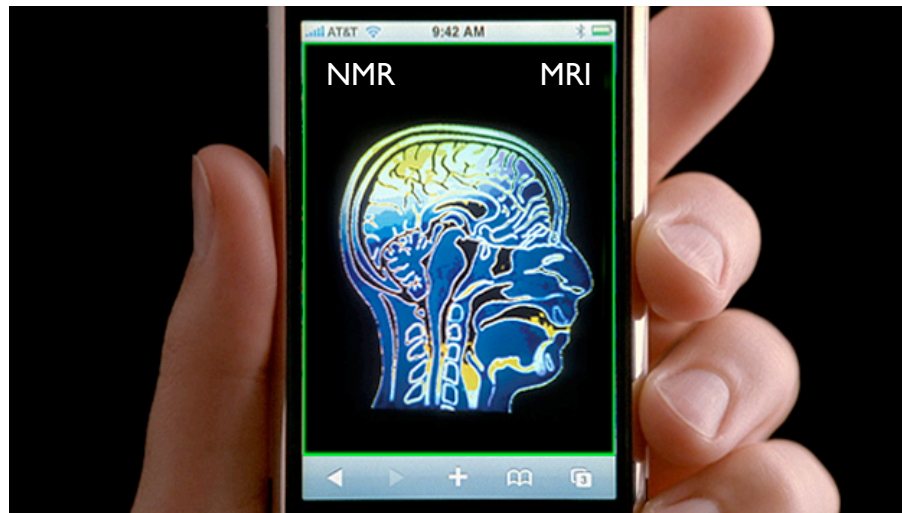
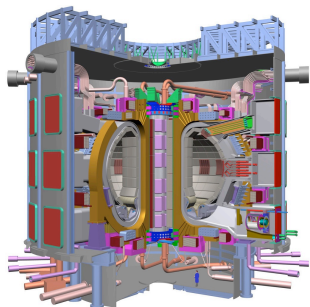


Environnement

AUTRES BESOINS EN DEHORS DU LABO



Energie



Santé



Miniaturisation !

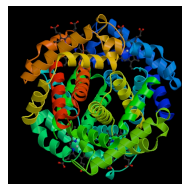


Heritage

(non destructive analysis)



Espace



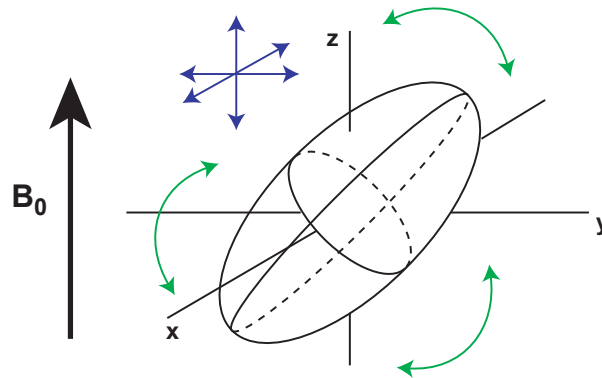
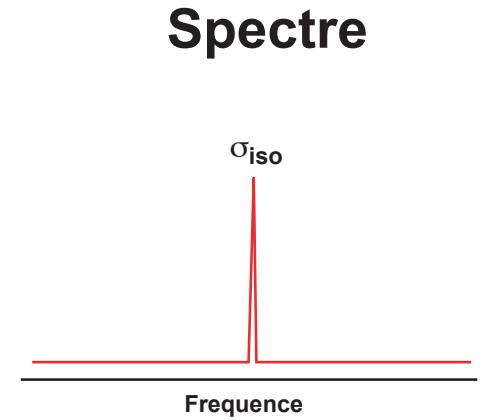
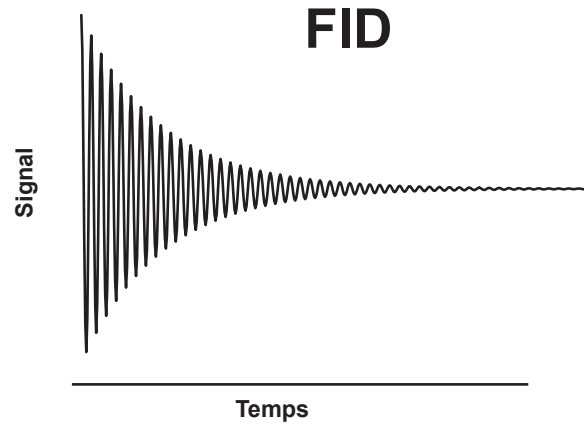
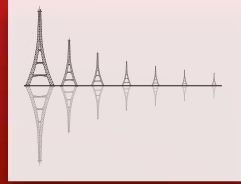
Nano-quantités



Défense

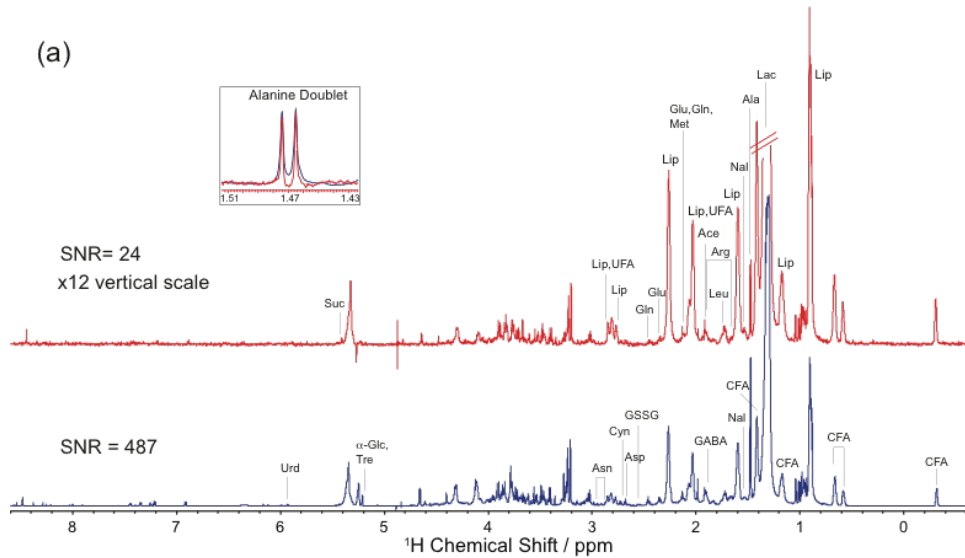
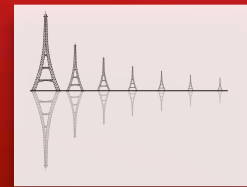


Environnement



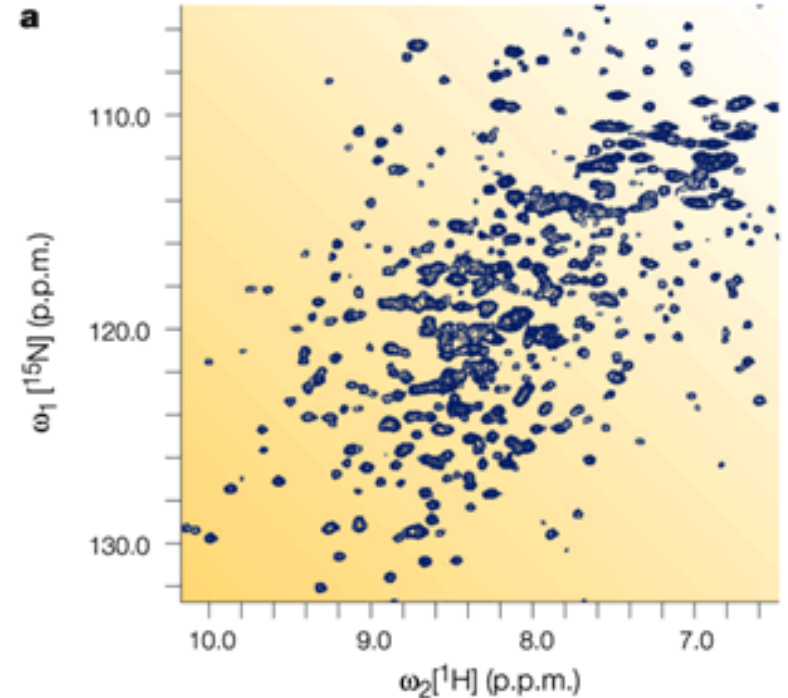
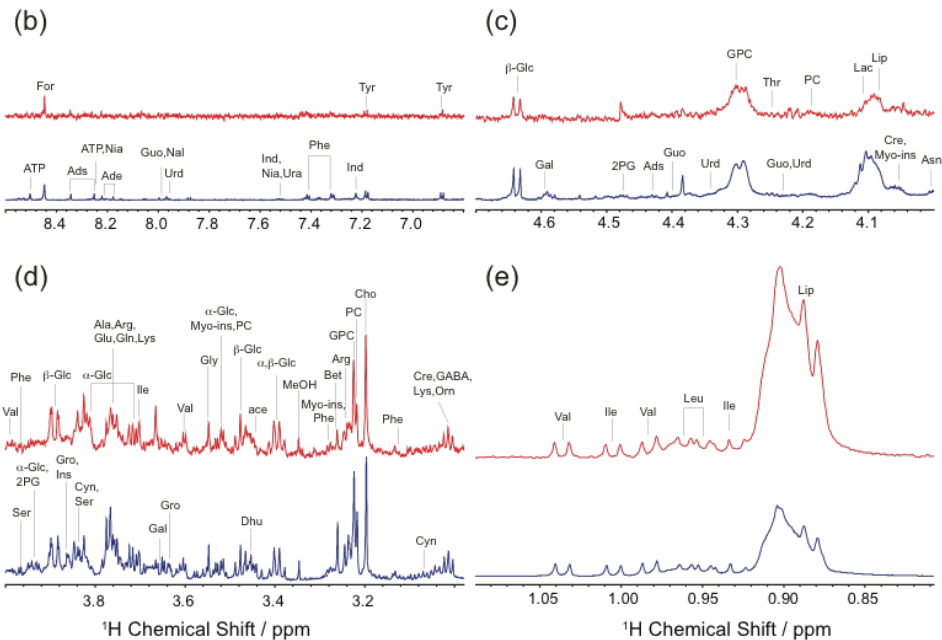
Les spectres sont fins, et l'information est visible

EXEMPLES : SPECTRES 1D ET 2D

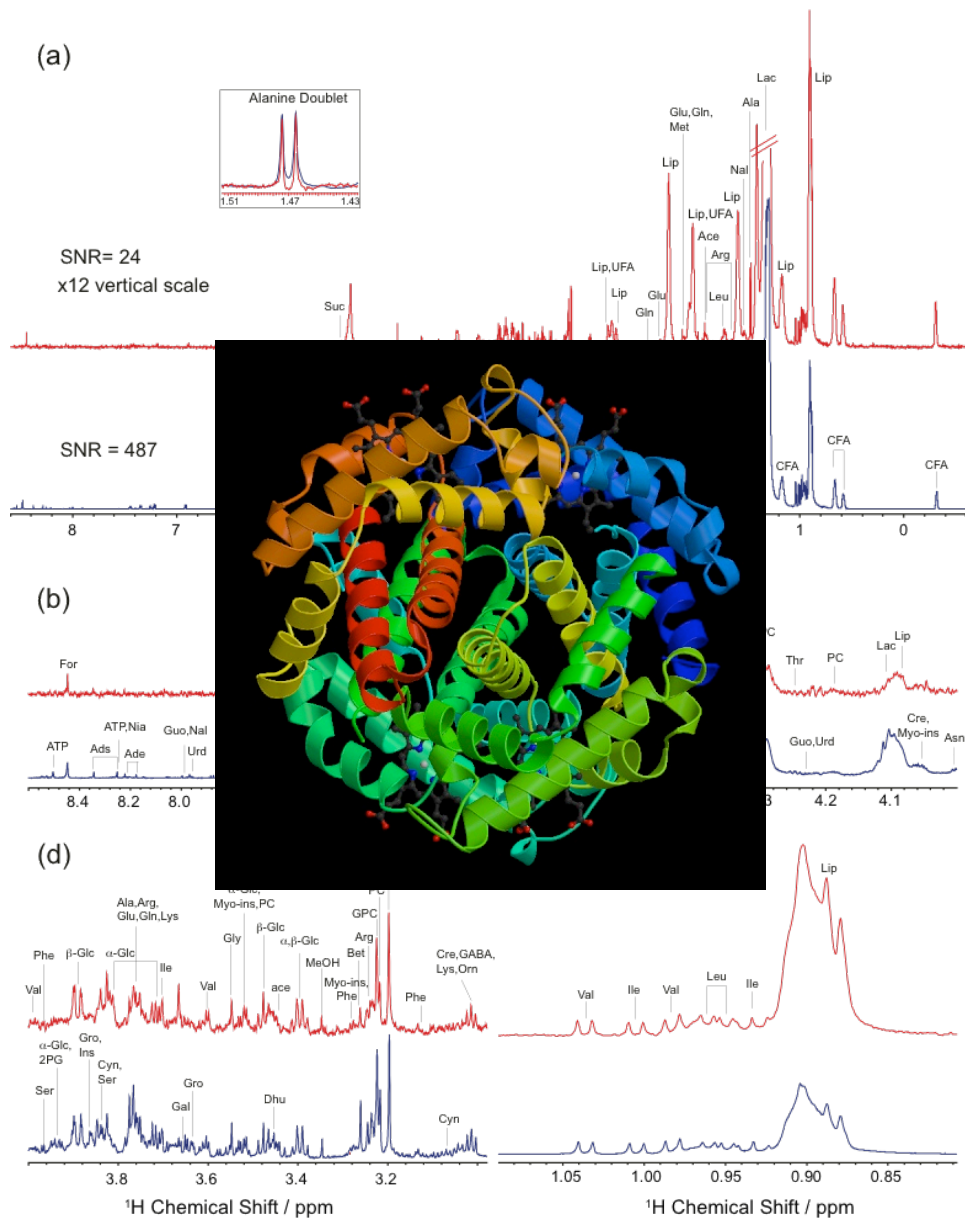
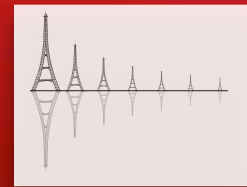


On doit pouvoir discriminer des fréquences très proches:

La RMN a besoin d'une uniformité du champ meilleure que le ppb dans le volume de l'échantillon !

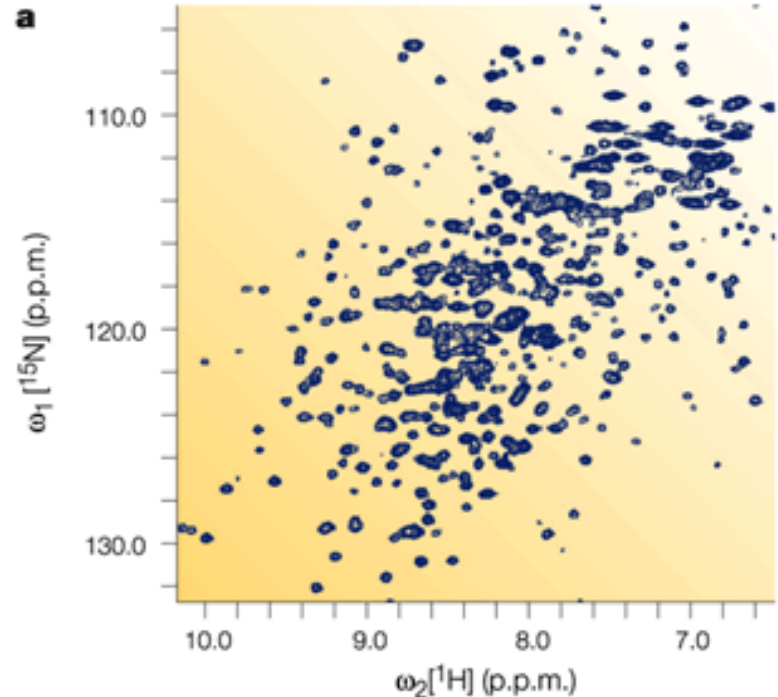


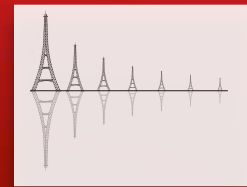
EXEMPLES : SPECTRES 1D ET 2D



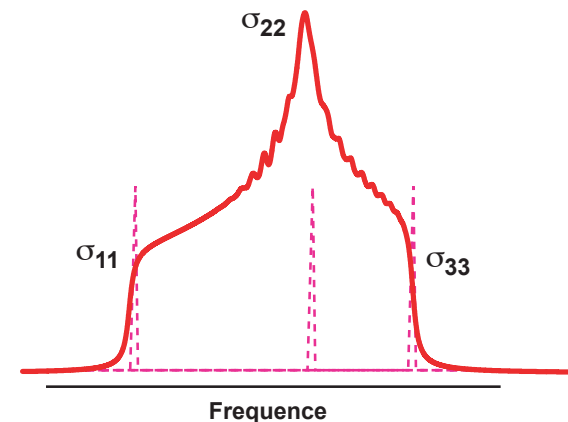
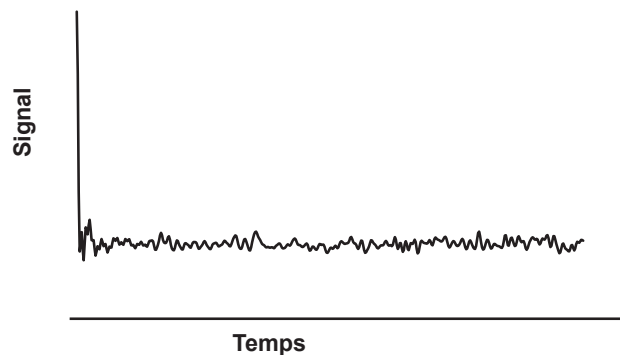
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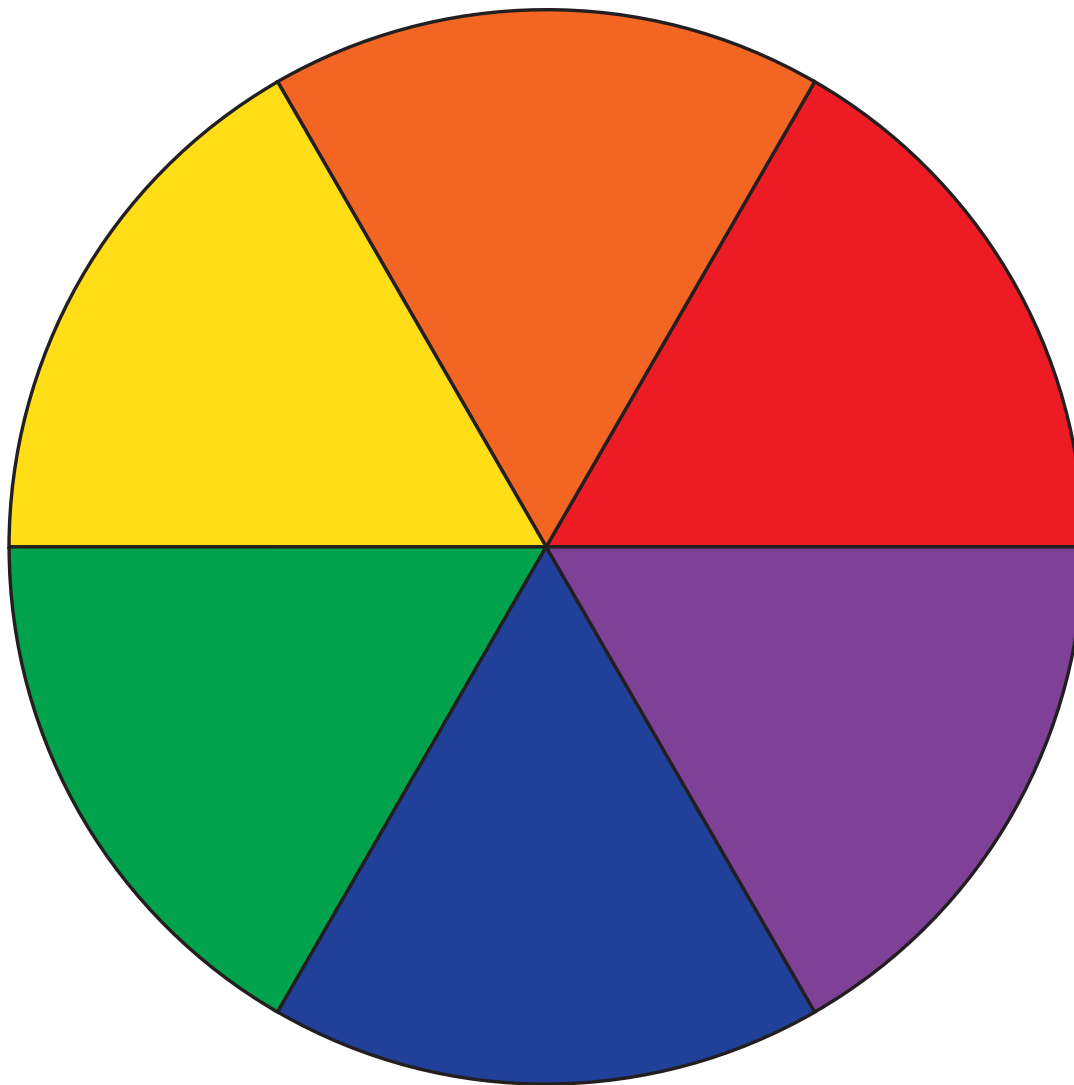
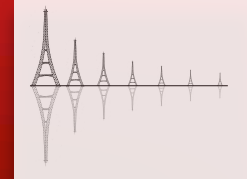


Poudres, solides, cristaux liquides, matériaux poreux, interfaces entre tissus, bio-minéraux, suspensions cellulaires etc.

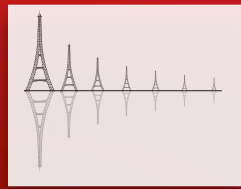


Les spectres sont larges, et l'information chimique cachée

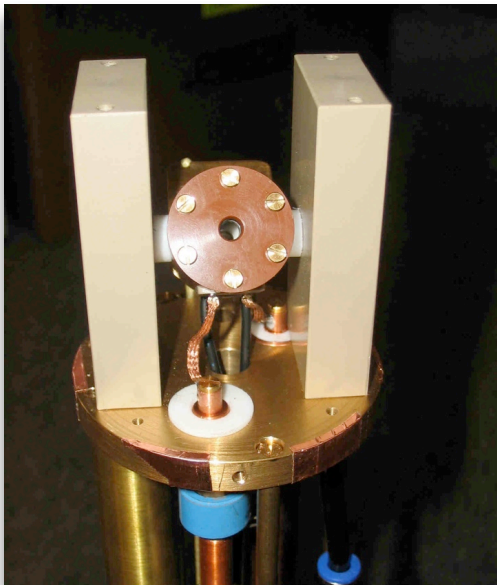
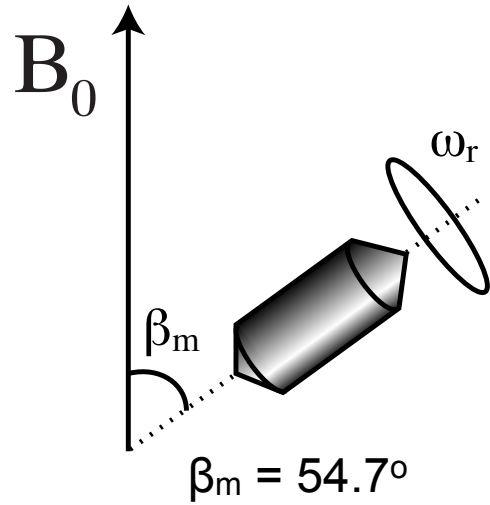
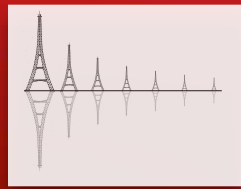
ET SI ON TOURNAIT ?



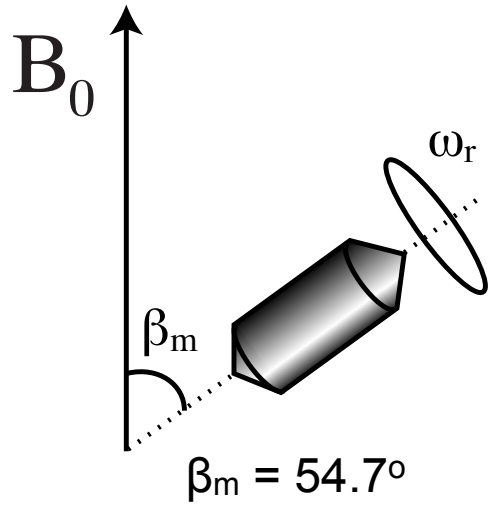
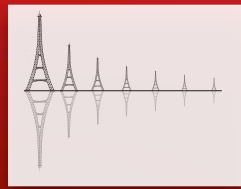
ET SI ON TOURNAIT ?



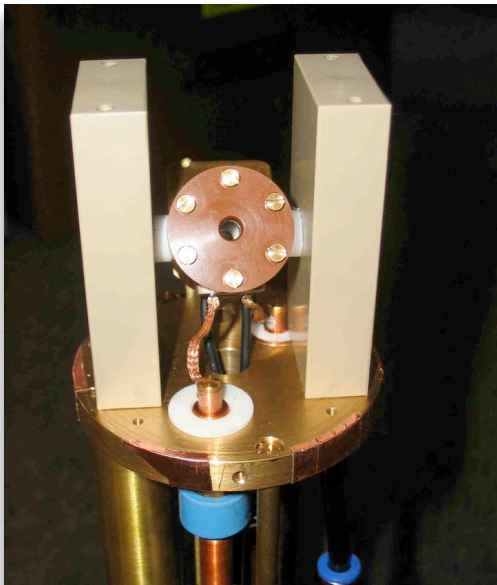
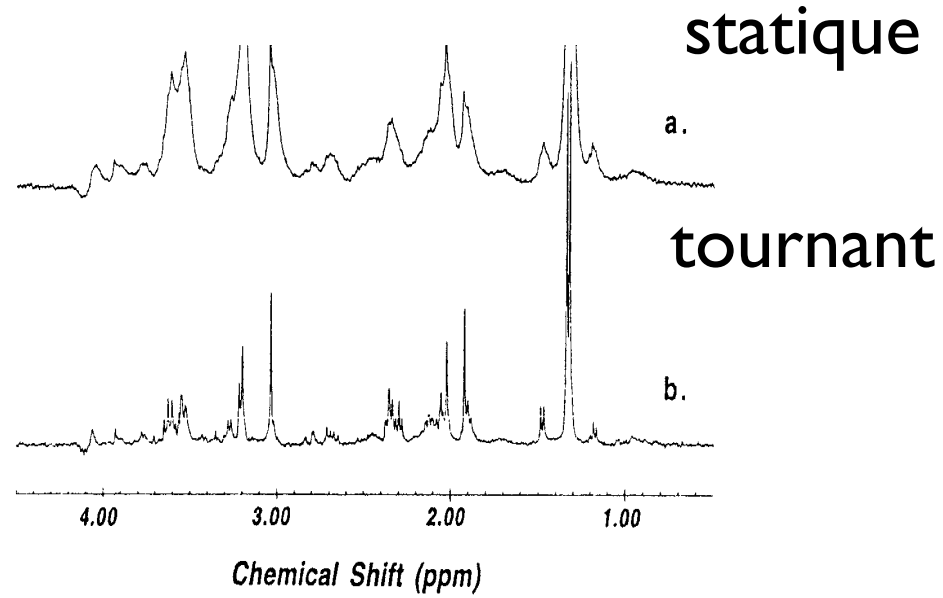
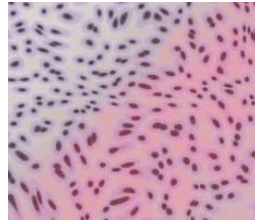
MAGIC ANGLE SAMPLE SPINNING



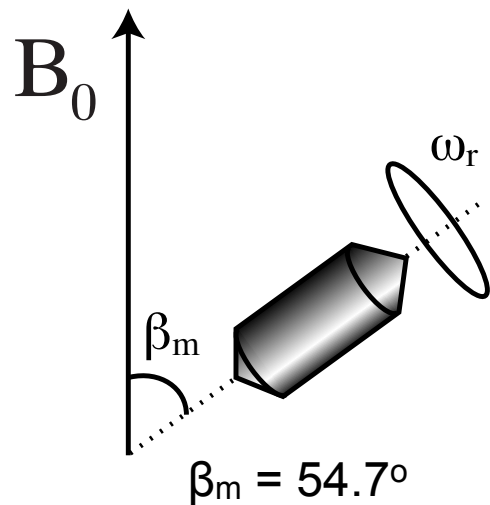
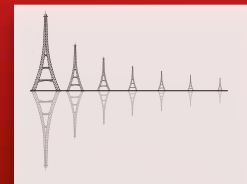
MAGIC ANGLE SAMPLE SPINNING



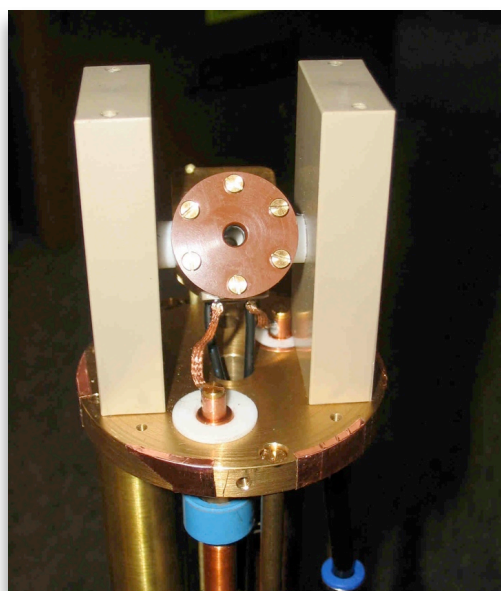
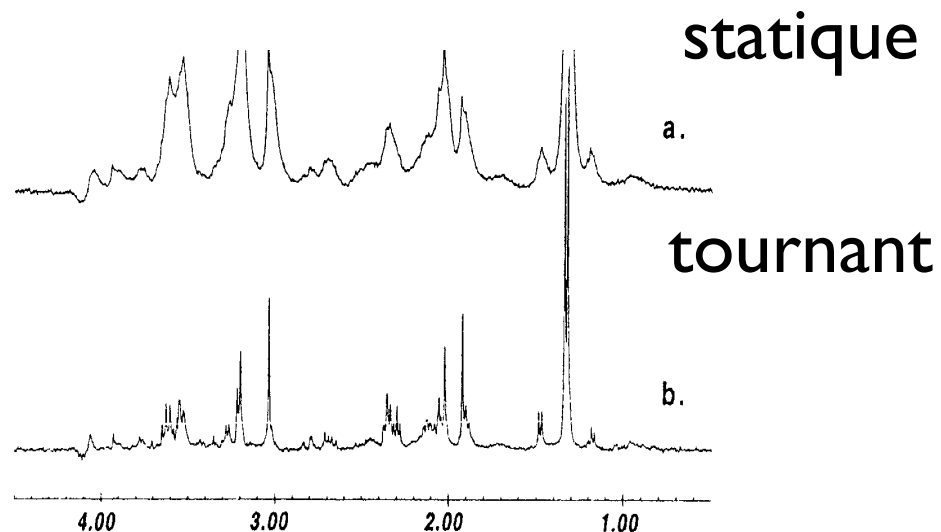
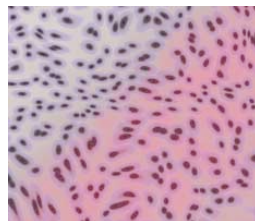
Cellules



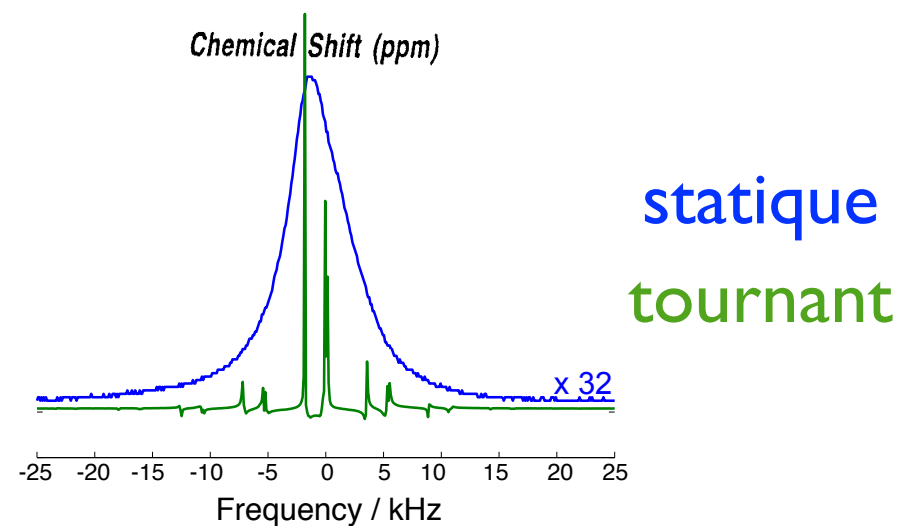
MAGIC ANGLE SAMPLE SPINNING



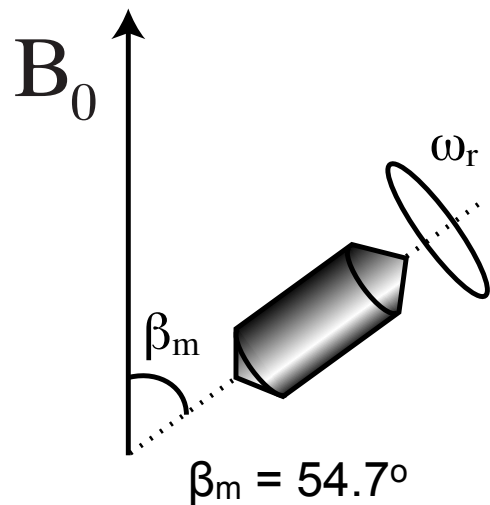
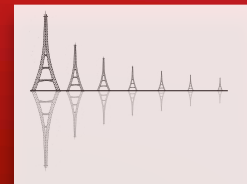
Cellules



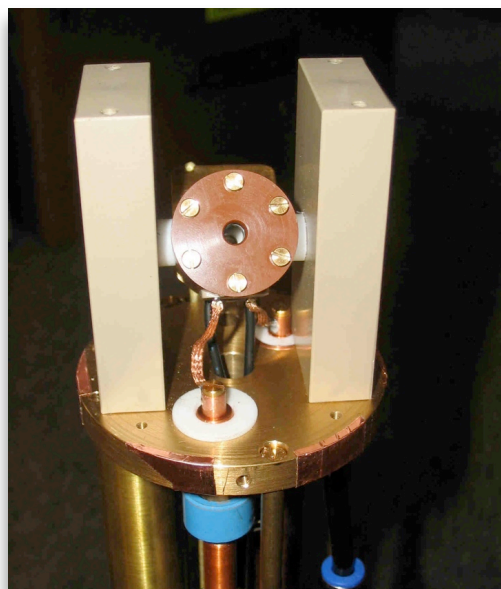
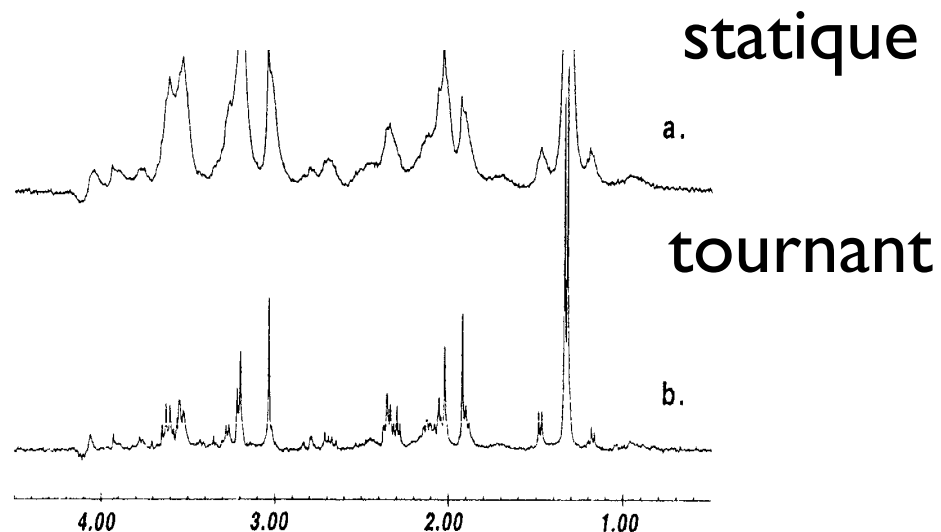
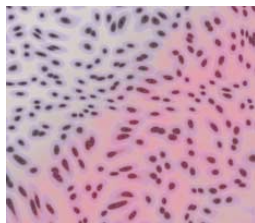
Solides Poreux



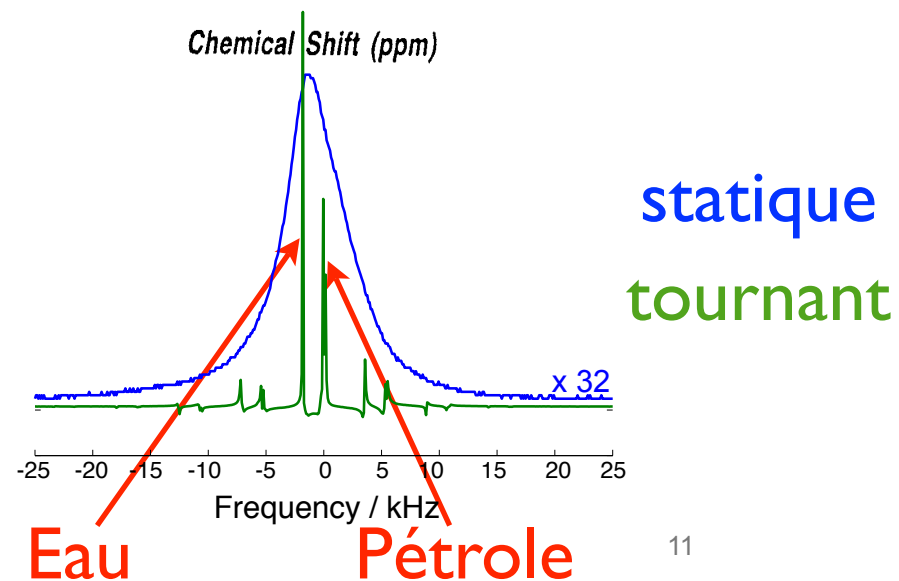
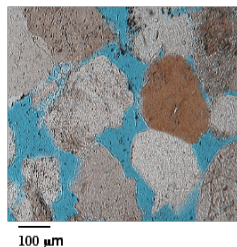
MAGIC ANGLE SAMPLE SPINNING



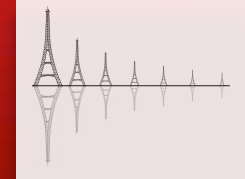
Cellules



Solides Poreux

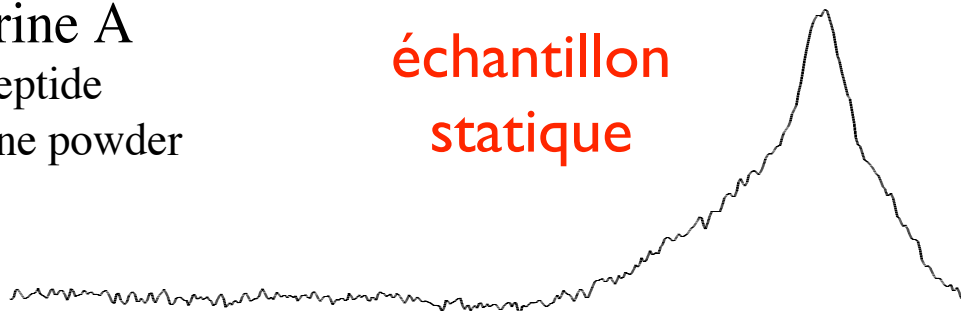


ROTATION DE L'ÉCHANTILLON À L'ANGLE MAGIQUE

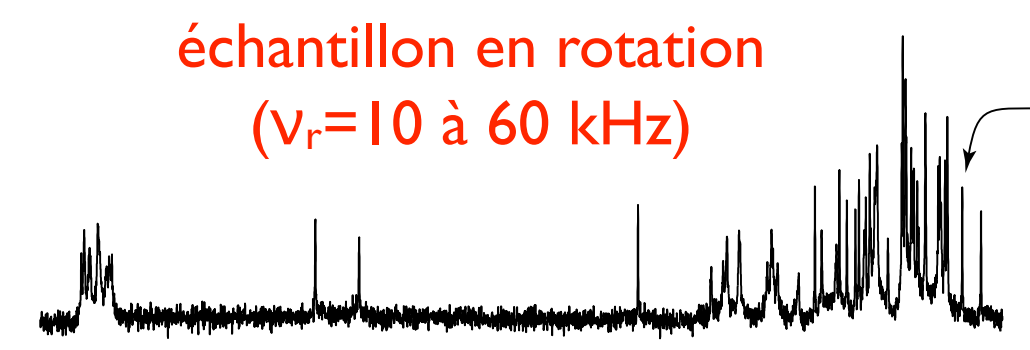


Cyclosporine A
Cyclic 11-Peptide
Polycrystalline powder

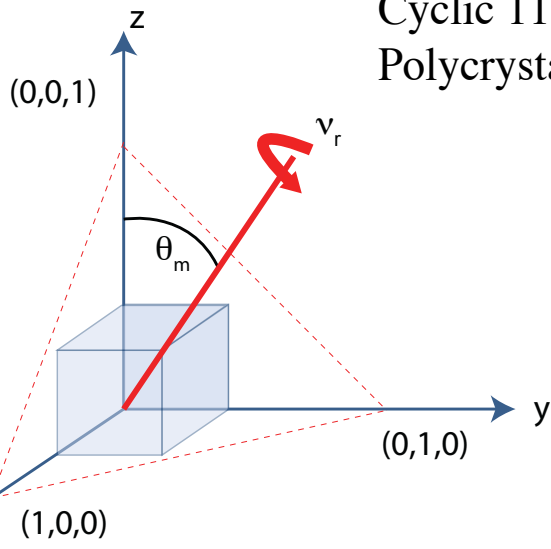
échantillon
statique



échantillon en rotation
($\nu_r = 10$ à 60 kHz)



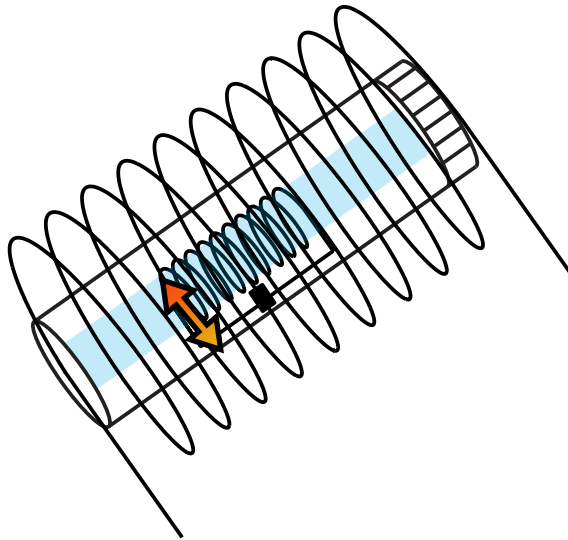
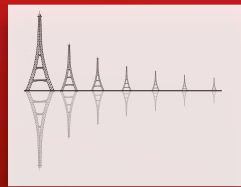
Déplacement chimique ^{13}C



$$\frac{1}{2}(3 \cos^2 \theta_m - 1) = 0$$

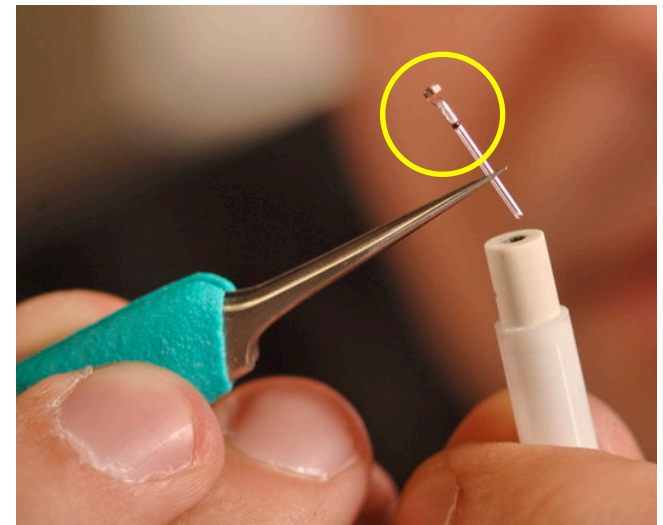
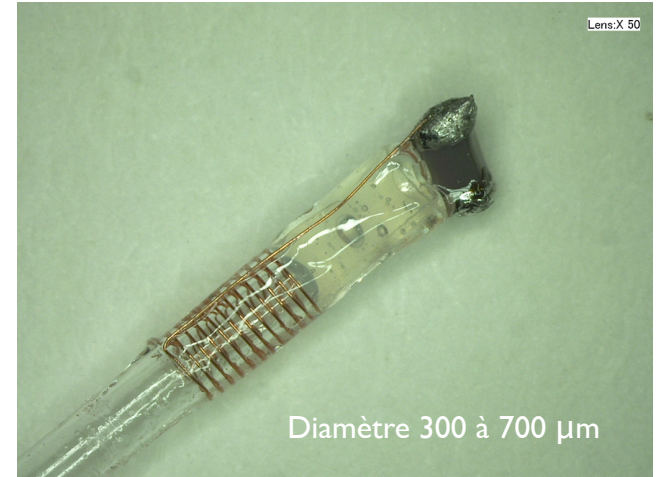
**LE BESOIN DE LA SENSIBILITÉ :
MICRODÉTECTEURS EN ROTATION
(RMN DU SOLIDE - HAUT CHAMP)**

MAGIC ANGLE COIL SPINNING

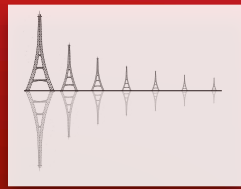


Wireless (inductive) coupling allows for efficient rf-transmission and optimal filling factor reception while magic angle sample and coil spinning.

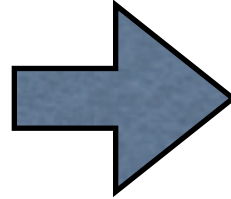
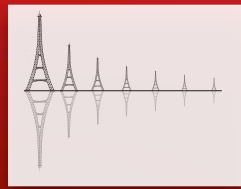
On utilise des microbobines aussi pour caractériser les profils du champ magnétique des aimants permanents !



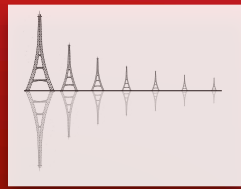
**LE BESOIN DE LA PORTABILITÉ :
RMN ET IRM À AIMANTS PERMANENTS
(RMN BAS CHAMP DEDIEÉE)**



- Industrie: Inspection dans conteneurs, exploration pétrolière, imagerie en-line, contrôle qualité, rhéologie, matériaux radioactifs.
- Medical: Scanners mobiles, dans ambulances, formation et éducation, “cost-effective devices” dédiés, casques etc, possibilité d’imagerie multimodale (CT/PET), agents de contraste.
- Environnement: Analyse non-invasive dans le terrain pour arbres, sol, micro-organismes
- Défense: détecteurs pour explosives (type RQN) et matériaux dangereux, analyseurs portatifs pour fluides.
- Heritage Culturel: non-destructive “profiling” / “monitoring”.



Pas facile ... mais on y travaille !



- Pas besoin d'électricité / cryogénie
- Pas de “quench” (perte de supra-conductivité)
- Matériaux terres-rares offrent des champs importants (aimants allant jusqu'à: 2T - fermés, 0.4T - unilatéraux)
- Bas champ, moins de problèmes (susceptibilité, RF, SAR)
- Possibilités d'explorer des champs autres à 1.5T (IRM Clinique) : Développement de nouveaux agents de contraste.
- **Le champ ne diminue pas avec la taille de l'aimant ! (facile à miniaturiser sans perte en champ) = Portabilité**

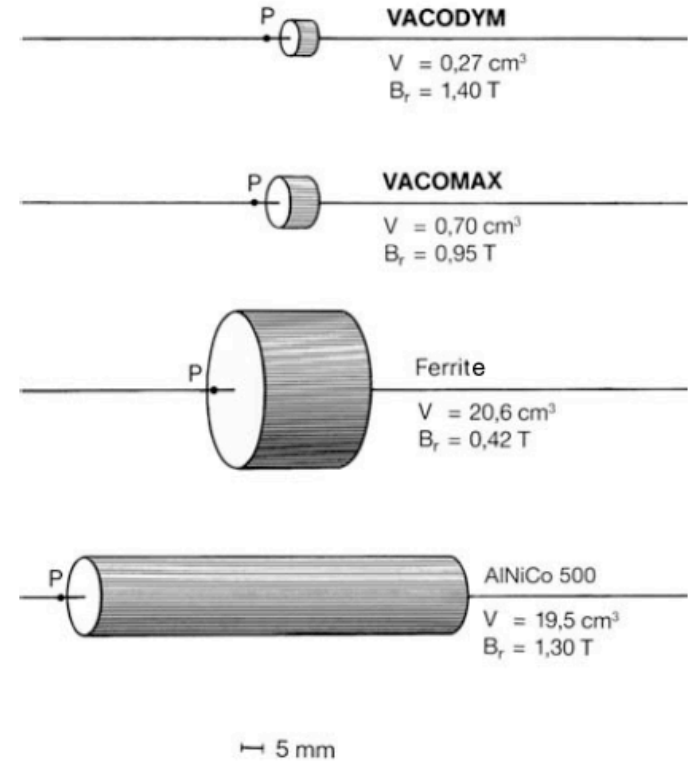
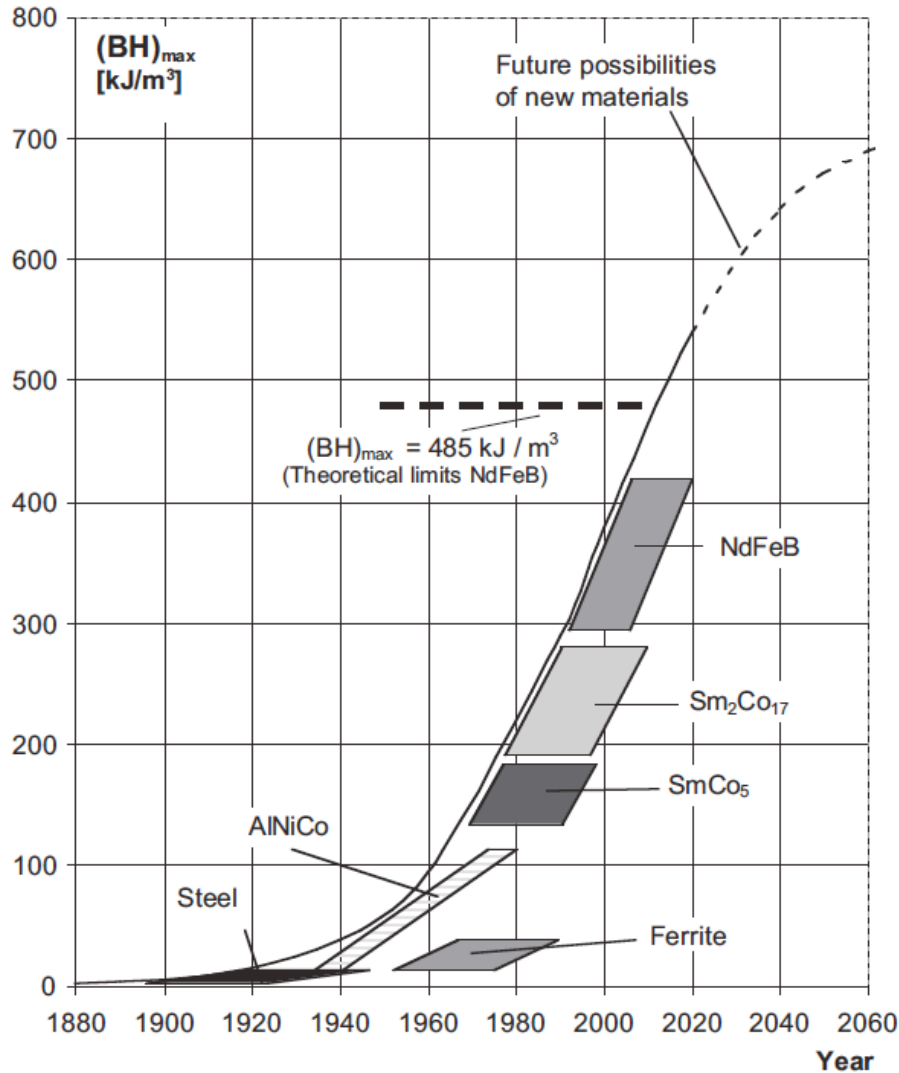
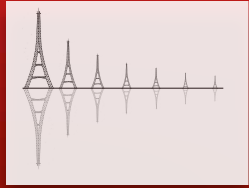
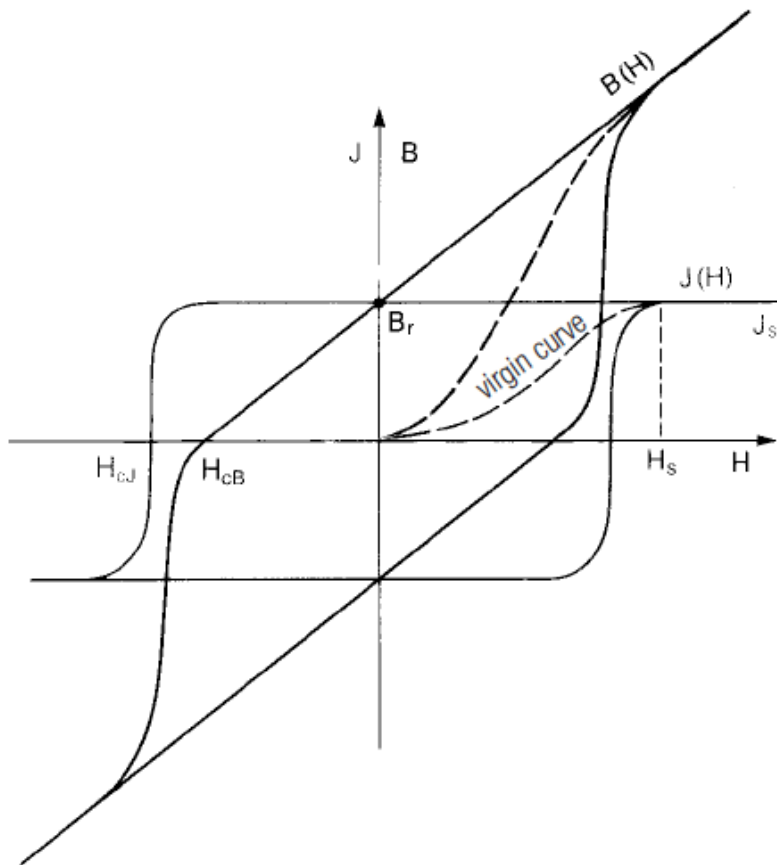
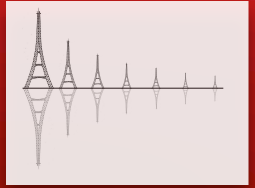
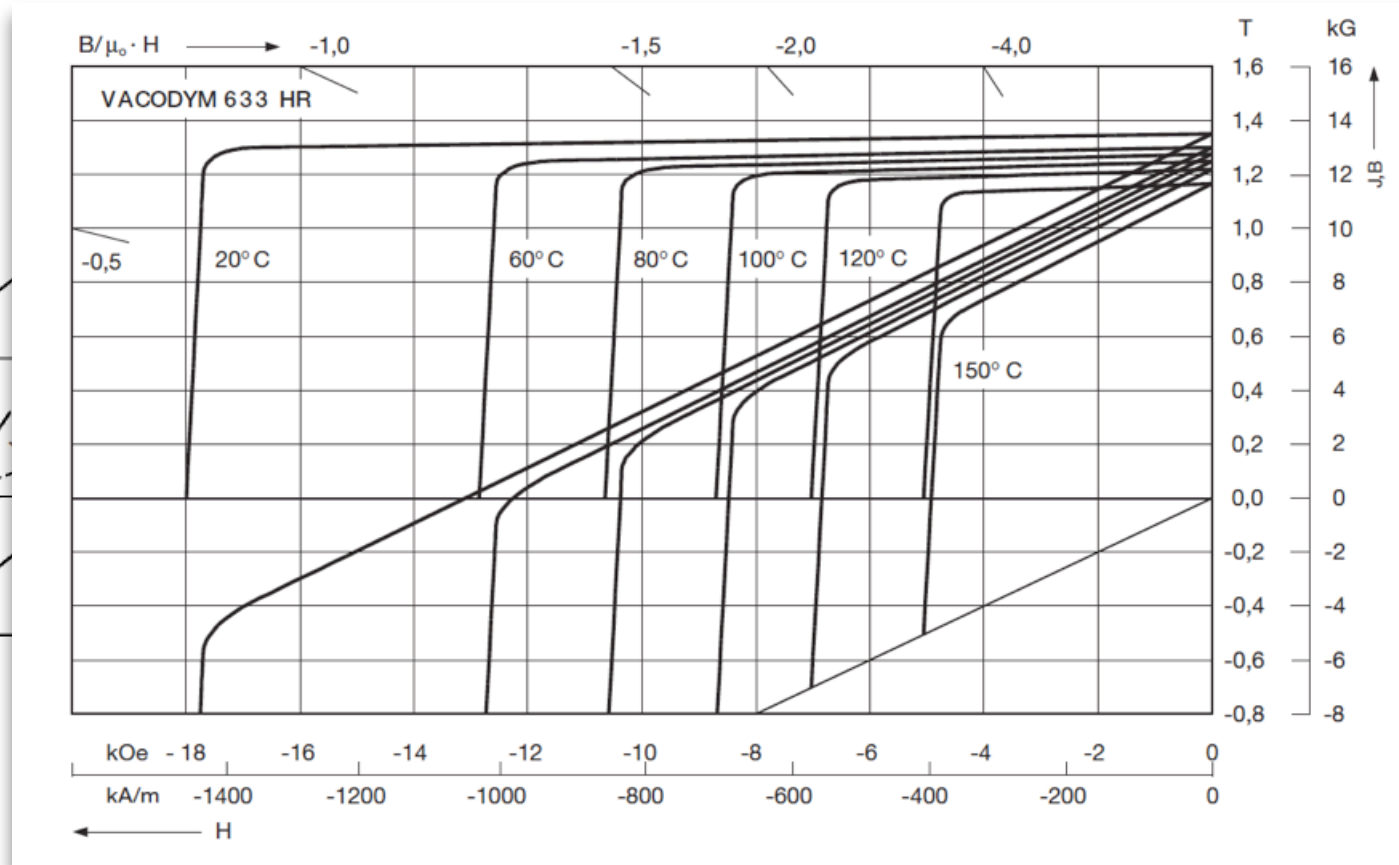
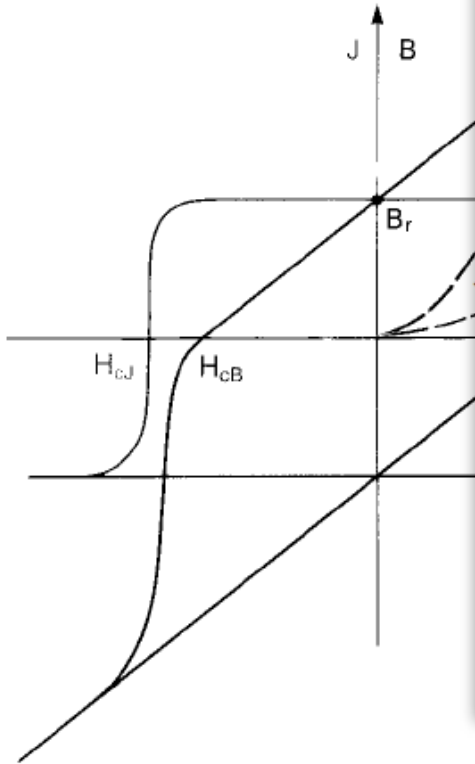
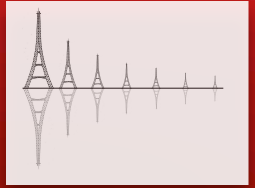
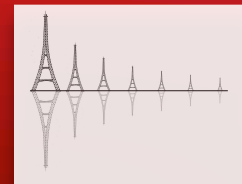


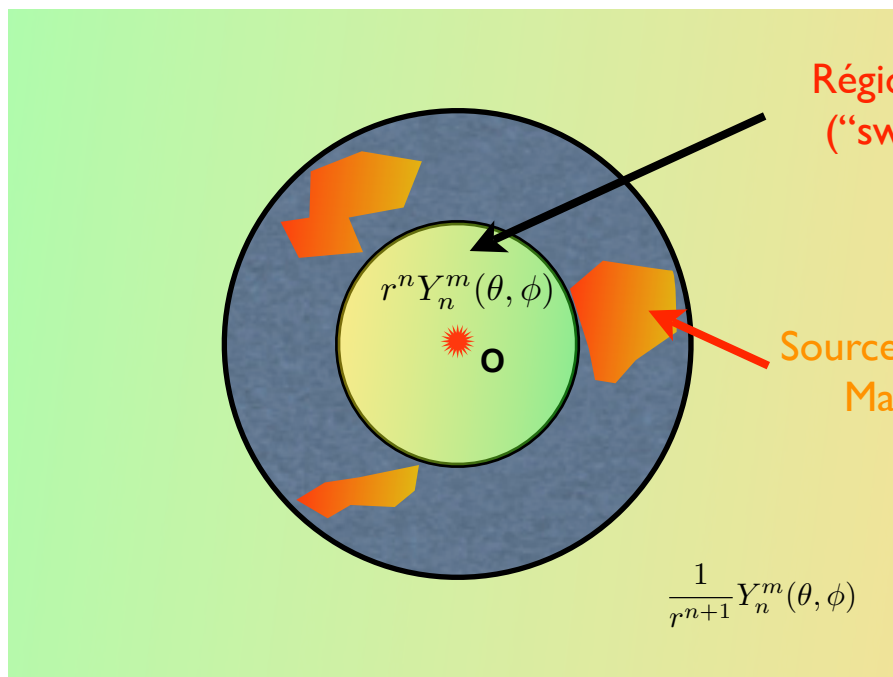
Fig. 5:
Example illustrating the volume reduction achieved with VACODYM and VACOMAX: each magnet is designed to produce a field of 100 mT at the reference point P = 5 mm from the surface of the pole



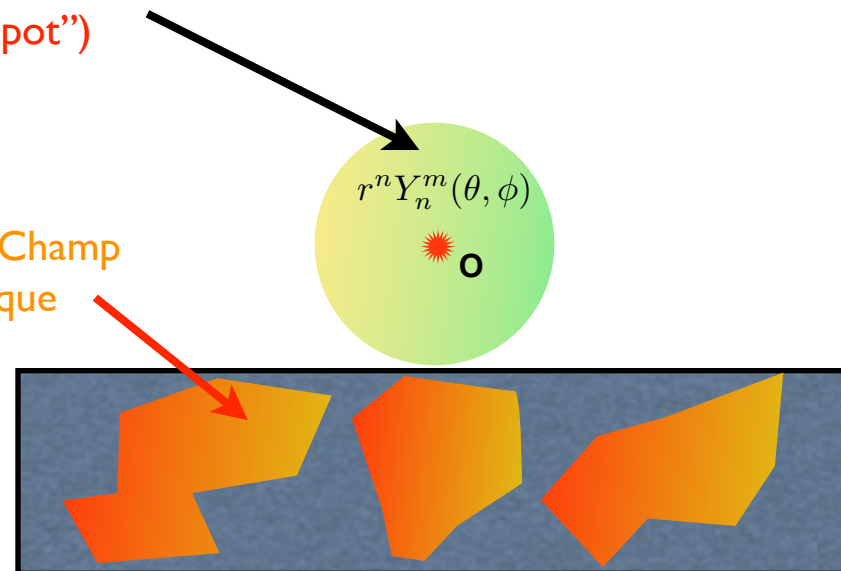




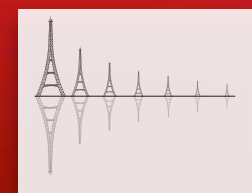
Cas In-situ (aimants fermés)



Cas Ex-situ (aimants unilatéraux)

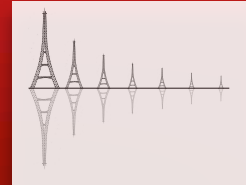


Le Champ Magnétique peut toujours être décrit en Séries d'Harmoniques Sphériques dans les régions d'espace d'intérêt (multiples cours de Guy AUBERT ! Grand Merci !)

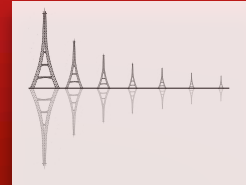


Z_n		X_n^m						Y_n^m							
n		n\m	1	2	3	4	5	6	n\m	1	2	3	4	5	6
0	B_0	1							1						
1		2							2						
2		3							3						
3		4							4						
4		5							5						
5		6							6						
6															


n^2+2n termes



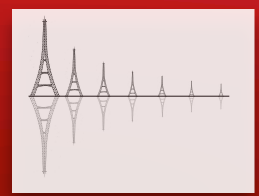
$$\Phi_{\text{inner}}^*(r, \theta, \phi) = \frac{1}{\mu_0} \sum_{n=1}^{\infty} r^n \left[Z_n P_n(\cos \theta) + \sum_{m=1}^n (X_n^m \cos m\phi + Y_n^m \sin m\phi) P_n^m(\cos \theta) \right]$$



$$\Phi_{\text{inner}}^*(r, \theta, \phi) = \frac{1}{\mu_0} \sum_{n=1}^{\infty} r^n \left[Z_n P_n(\cos \theta) + \sum_{m=1}^n (X_n^m \cos m\phi + Y_n^m \sin m\phi) P_n^m(\cos \theta) \right]$$

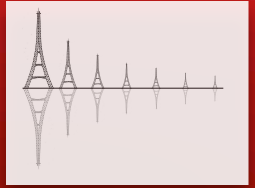


Axial terms



$$\Phi_{\text{inner}}^*(r, \theta, \phi) = \frac{1}{\mu_0} \sum_{n=1}^{\infty} r^n \left[Z_n P_n(\cos \theta) + \sum_{m=1}^n (X_n^m \cos m\phi + Y_n^m \sin m\phi) P_n^m(\cos \theta) \right]$$

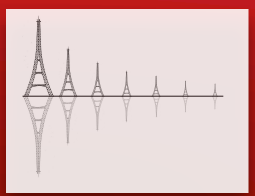
Axial terms
Skewed terms



$$\Phi_{\text{inner}}^*(r, \theta, \phi) = \frac{1}{\mu_0} \sum_{n=1}^{\infty} r^n \left[Z_n P_n(\cos \theta) + \sum_{m=1}^n (X_n^m \cos m\phi + Y_n^m \sin m\phi) P_n^m(\cos \theta) \right]$$

Axial terms
Skewed terms

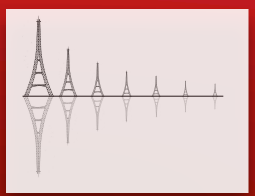
- k-fold axial symmetry cancels skewed terms up to order k-1



$$\Phi_{\text{inner}}^*(r, \theta, \phi) = \frac{1}{\mu_0} \sum_{n=1}^{\infty} r^n \left[Z_n P_n(\cos \theta) + \sum_{m=1}^n (X_n^m \cos m\phi + Y_n^m \sin m\phi) P_n^m(\cos \theta) \right]$$

Axial terms
Skewed terms

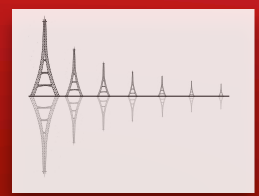
- k-fold axial symmetry cancels **skewed** terms up to order k-1
- Planar symmetry (antisymmetry) cancels odd (even) **axial** terms



$$\Phi_{\text{inner}}^*(r, \theta, \phi) = \frac{1}{\mu_0} \sum_{n=1}^{\infty} r^n \left[Z_n P_n(\cos \theta) + \sum_{m=1}^n (X_n^m \cos m\phi + Y_n^m \sin m\phi) P_n^m(\cos \theta) \right]$$

Axial terms
Skewed terms

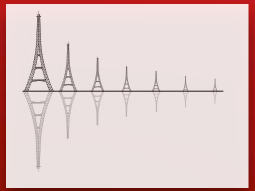
- k-fold axial symmetry cancels **skewed** terms up to order k-1
- Planar symmetry (antisymmetry) cancels odd (even) **axial** terms
- La taille du “sweet spot”, dicte l’ordre max du développement.



$$\Phi_{\text{inner}}^*(r, \theta, \phi) = \frac{1}{\mu_0} \sum_{n=1}^{\infty} r^n \left[Z_n P_n(\cos \theta) + \sum_{m=1}^n (X_n^m \cos m\phi + Y_n^m \sin m\phi) P_n^m(\cos \theta) \right]$$

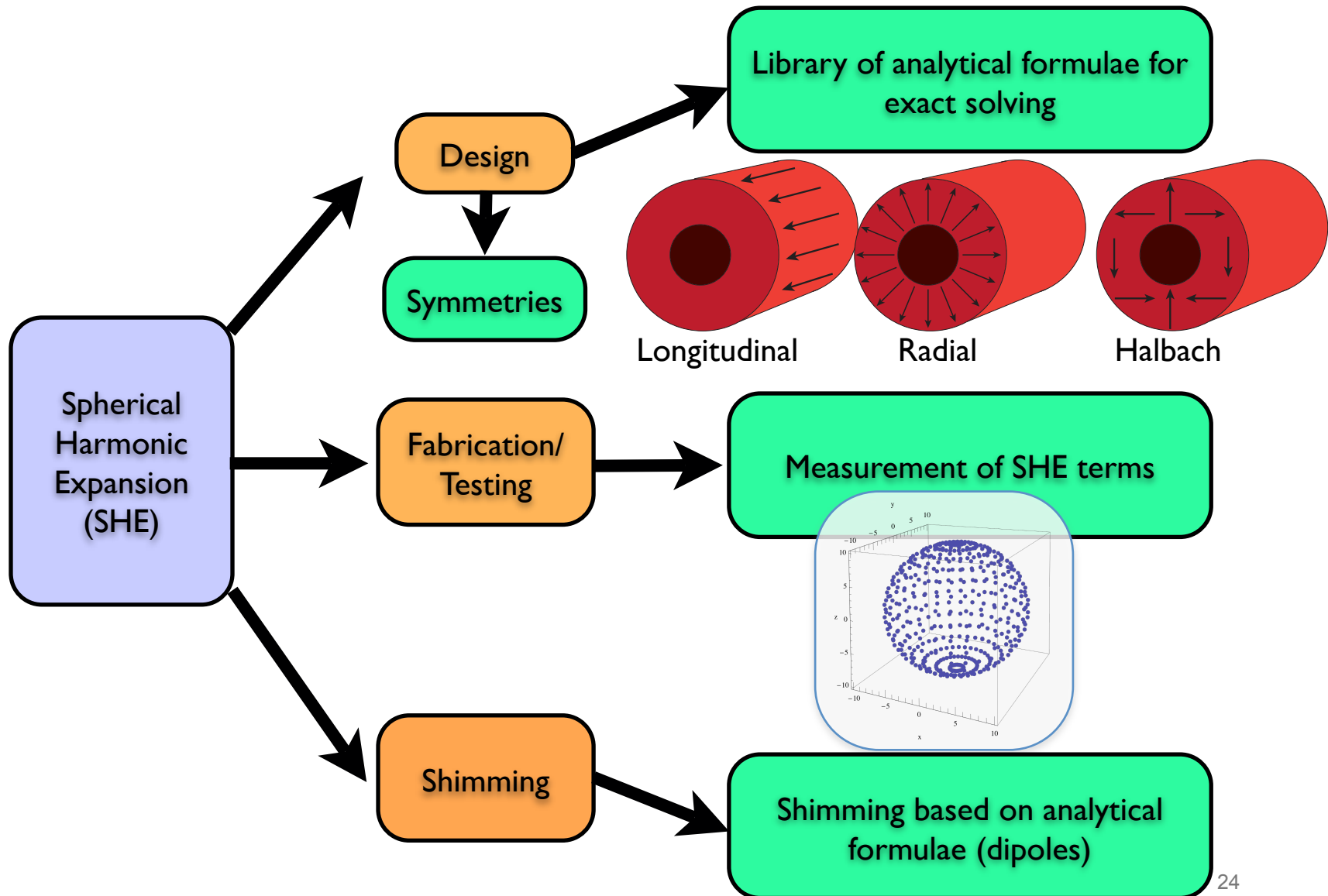
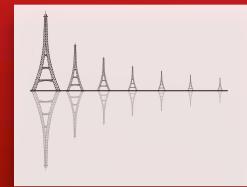
Axial terms
Skewed terms

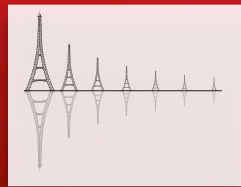
- k-fold axial symmetry cancels **skewed** terms up to order k-1
- Planar symmetry (antisymmetry) cancels odd (even) **axial** terms
- La taille du “sweet spot”, dicte l’ordre max du développement.
- Le reste des termes doit être “éliminé” numériquement.



$$\Phi_{\text{inner}}^*(r, \theta, \phi) = \frac{1}{\mu_0} \sum_{n=1}^{\infty} r^n \left[\underbrace{Z_n P_n(\cos \theta)}_{\text{Axial terms}} + \sum_{m=1}^n \underbrace{(X_n^m \cos m\phi + Y_n^m \sin m\phi)}_{\text{Skewed terms}} P_n^m(\cos \theta) \right]$$

- k-fold axial symmetry cancels **skewed** terms up to order k-1
- Planar symmetry (antisymmetry) cancels odd (even) **axial** terms
- La taille du “sweet spot”, dicte l’ordre max du développement.
- Le reste des termes doit être “éliminé” numériquement.
- **La méthodologie est applicable à tout système d’aimant**





Spécifications

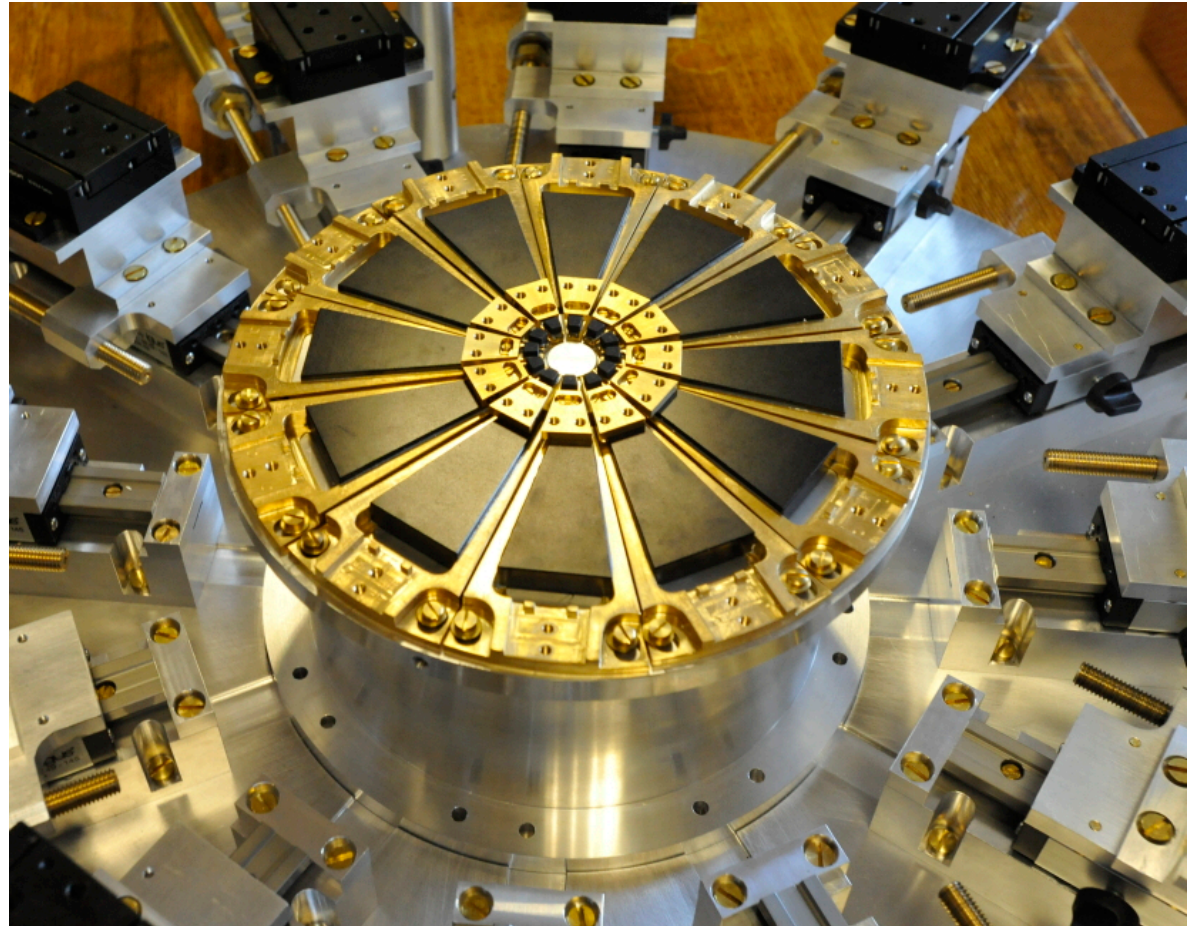
Champ Longitudinal = 0.33T
(~14MHz ^1H Larmor)

Gradient = 3.3 T/m

“Sweet spot” à 20mm de
la surface de l’aimant

Gradient* **Concomitant**
Uniformité <50 ppm

Poids ~40kg

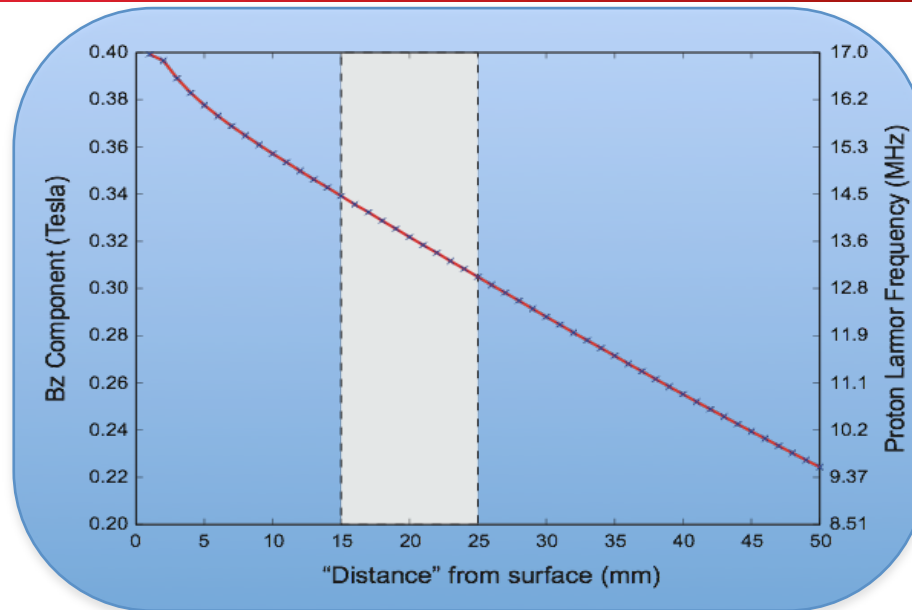
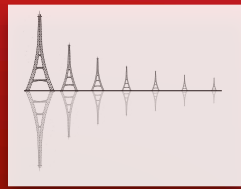


* Ask me what this exactly means !

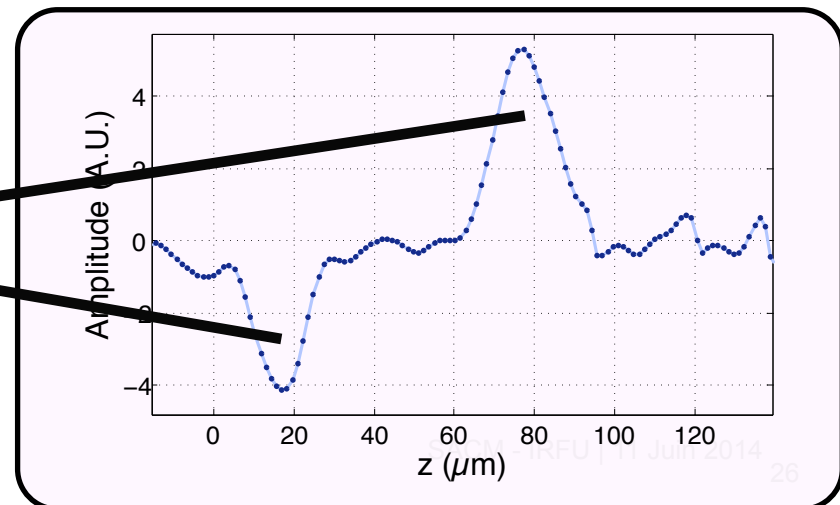
C. Hugon, G. Aubert and D. Sakellariou, AIP Proceedings of MRPM10, **1330**, 105 (2011).

C. Hugon, G. Aubert and D. Sakellariou, J. Magn. Reson. **214**, 124 (2012).

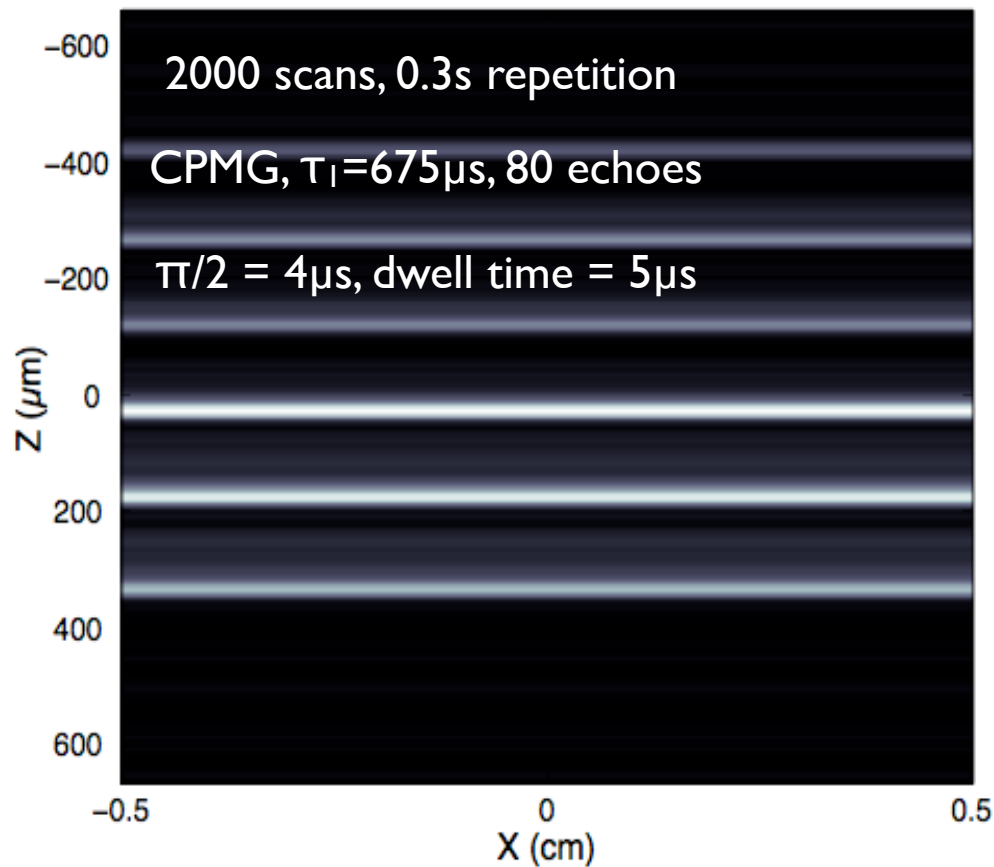
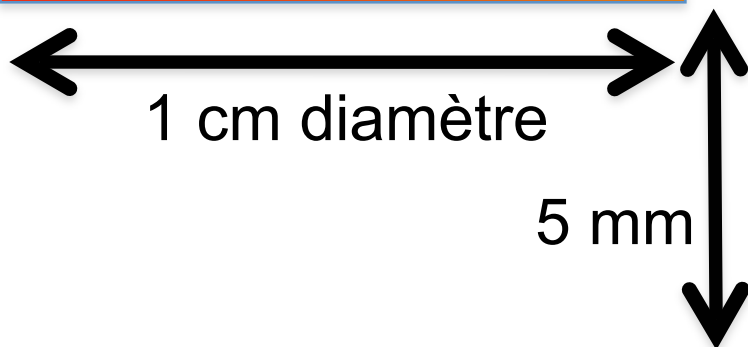
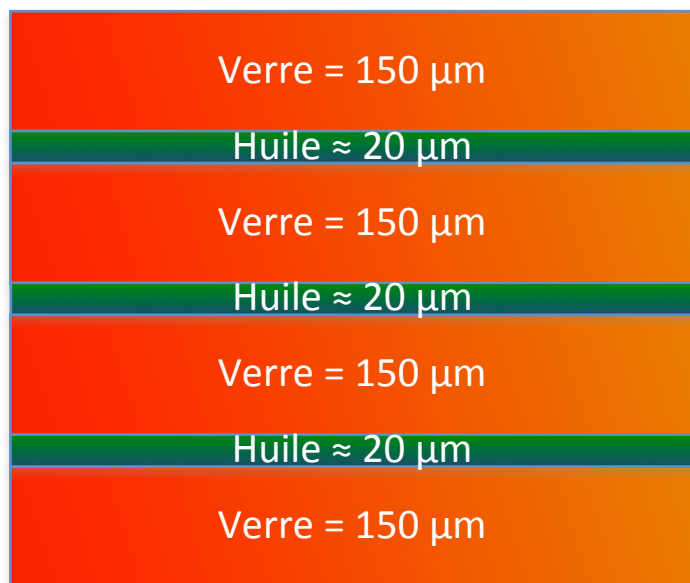
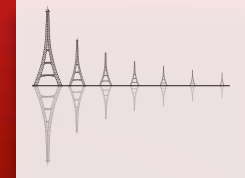
1 patent application



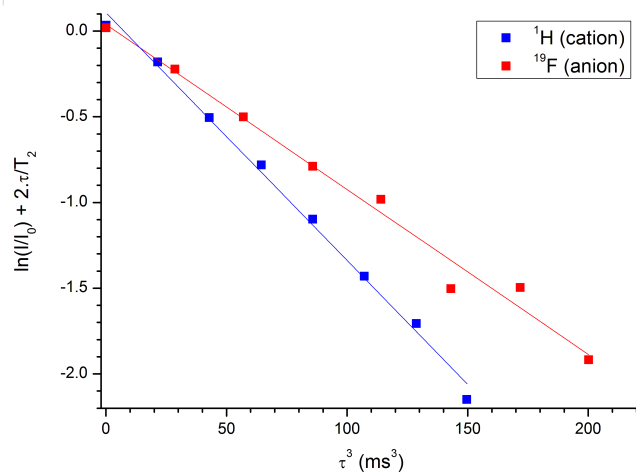
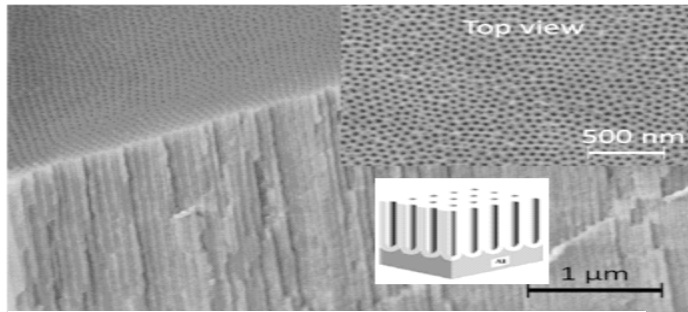
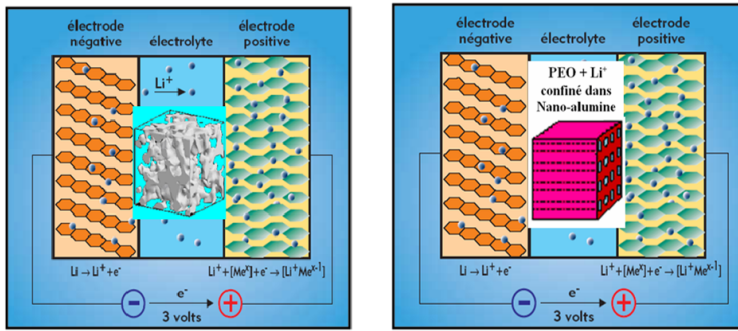
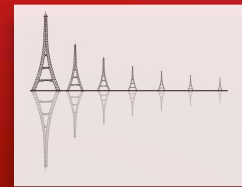
Point Spread Function (PSF)
mésure expérimentale



PREMIERS RÉSULTATS: PROFILES EN Z À SCAN UNIQUE



Antenne RF

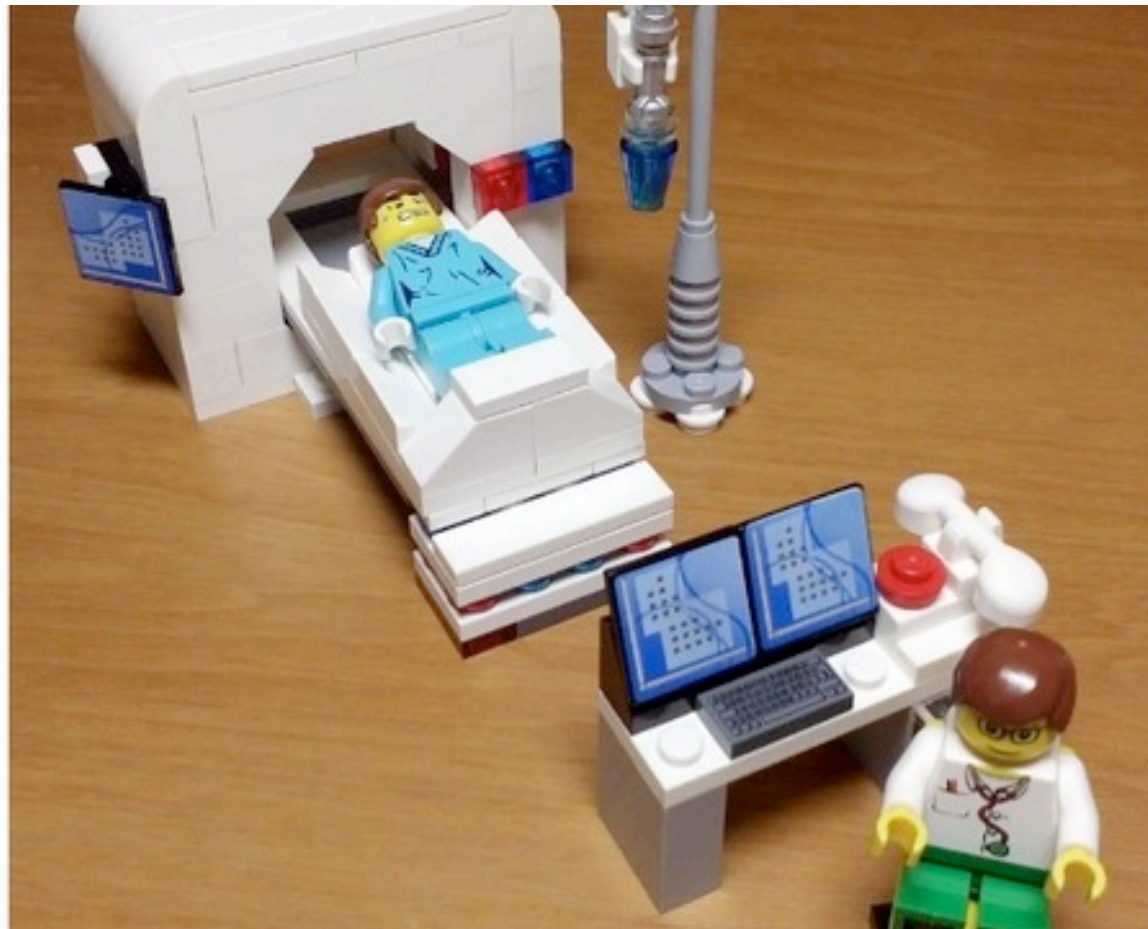


	Diffusion coefficient at 25°C (cm ² s ⁻¹)	
	Experiment	Literature
Water	$(2.5 \pm 0.1) \times 10^{-5}$	2.299×10^{-5}
Ethanol	$(1.1 \pm 0.1) \times 10^{-5}$	1.08×10^{-5}
Acetone	$(4.4 \pm 0.1) \times 10^{-5}$	4.57×10^{-5}

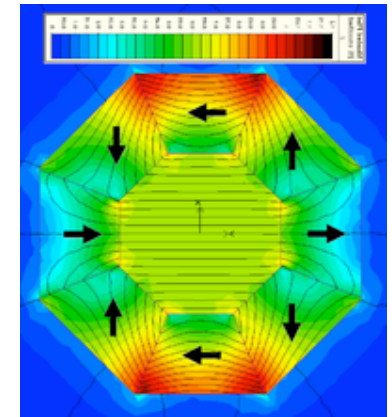
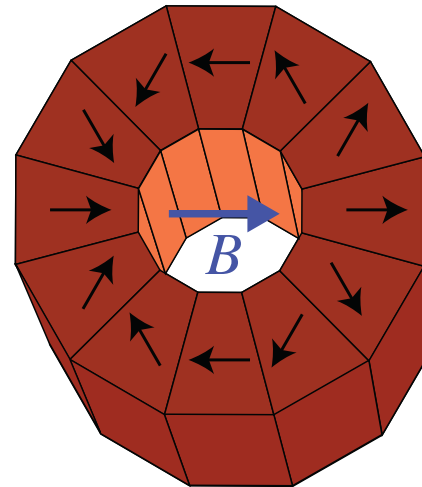
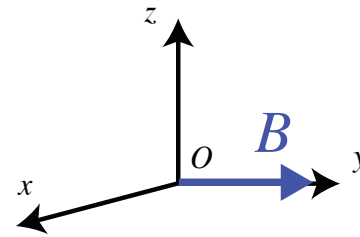
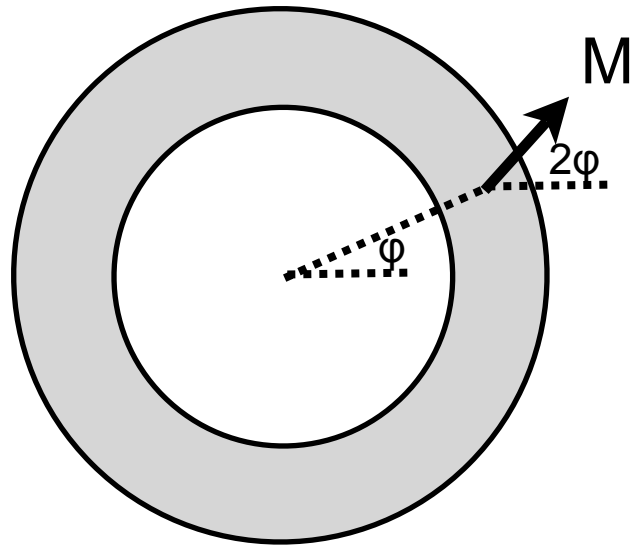
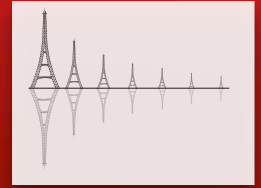
Bulk BMIM-TFSI

	D(T=25°C) 10 ⁻⁷ cm ² s ⁻¹	
	Measured	Literature
Cation	(2.8 ± 0.1)	2.75
Anion	(2.1 ± 0.1)	2.18

FESONS NOTRE AIMANT RMN HAUTE RÉOLUTION !



LA CONFIGURATION CLASSIQUE : DIPOLE DE HALBACH

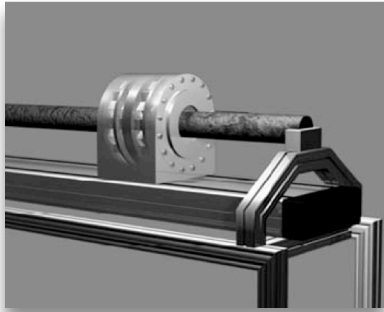
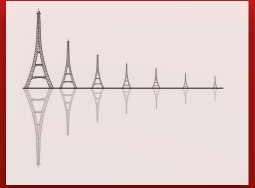


$$B = B_r \ln \frac{R_{out}}{R_{in}}^*$$

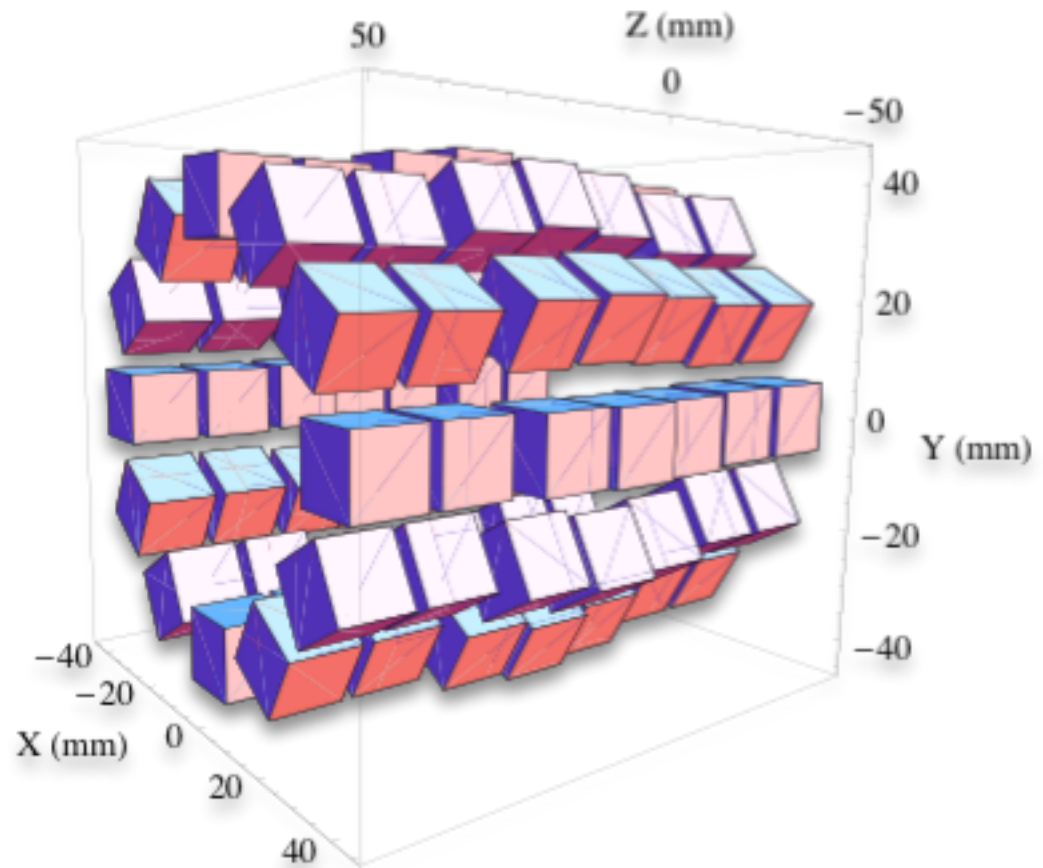
Halbach, *Nuclear Instrum. Methods*, 1980, 169, 1-10

Danieli, et al, *Angew. Chem. Int. Ed.*, 2010, 49, 4133-4135

*si infiniment long et continu...
(pour des aimants homogènes à longueur finie
cette valeur ne peut pas être atteinte)



Anferova et al , JMR (2007).

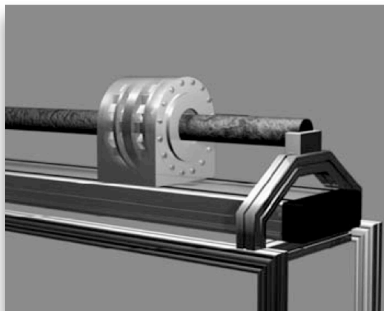
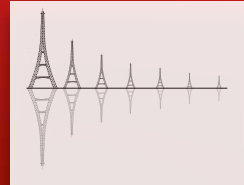


Collaboration

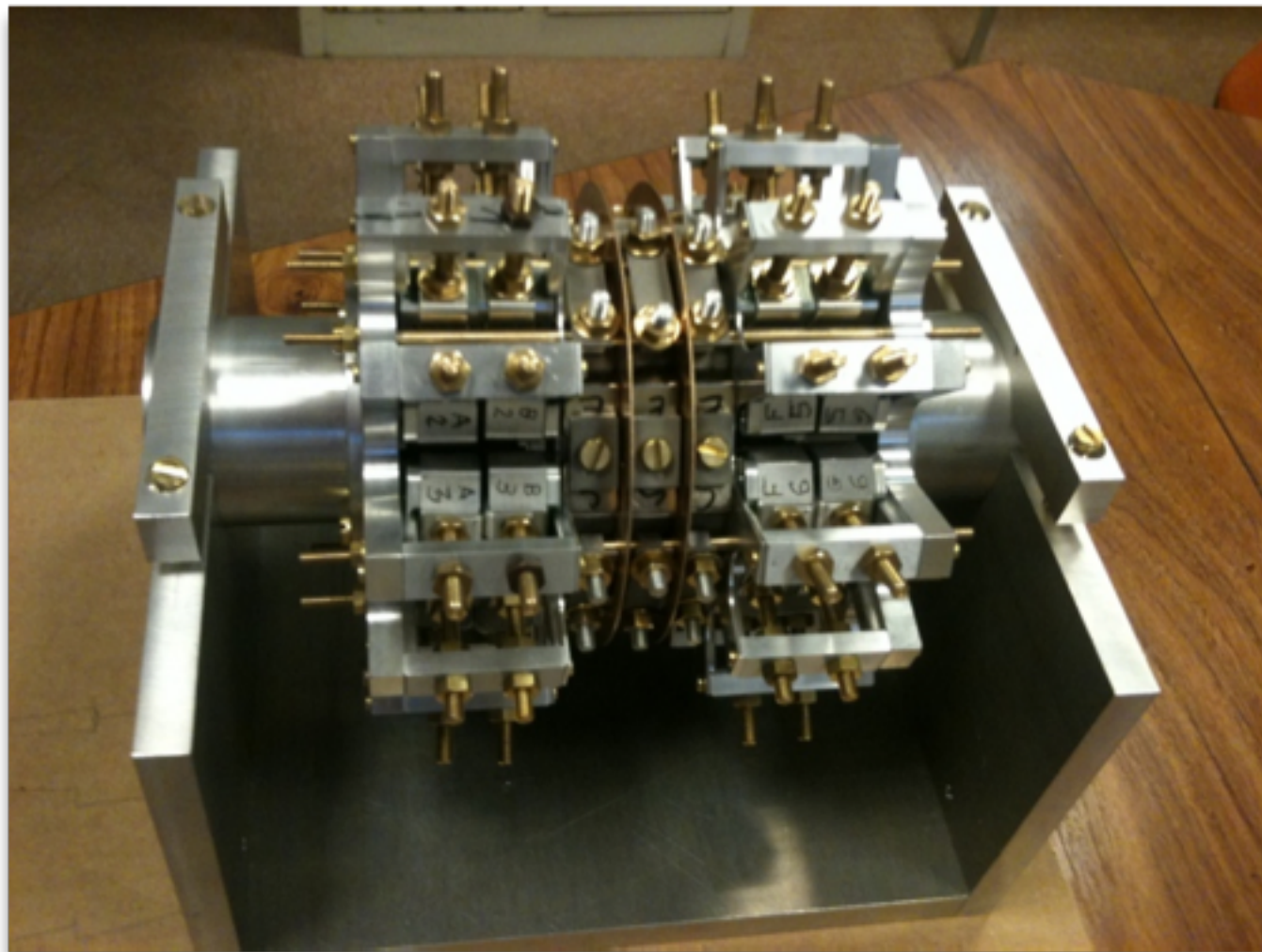
G. Papavassiliou

National Lab.
Democritos

UN ANALYSEUR POUR LE CIMENT



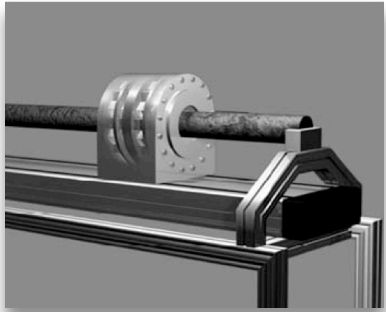
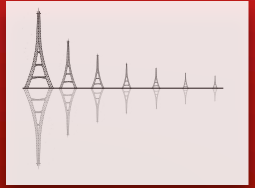
Anferova et al , JMR (2007).



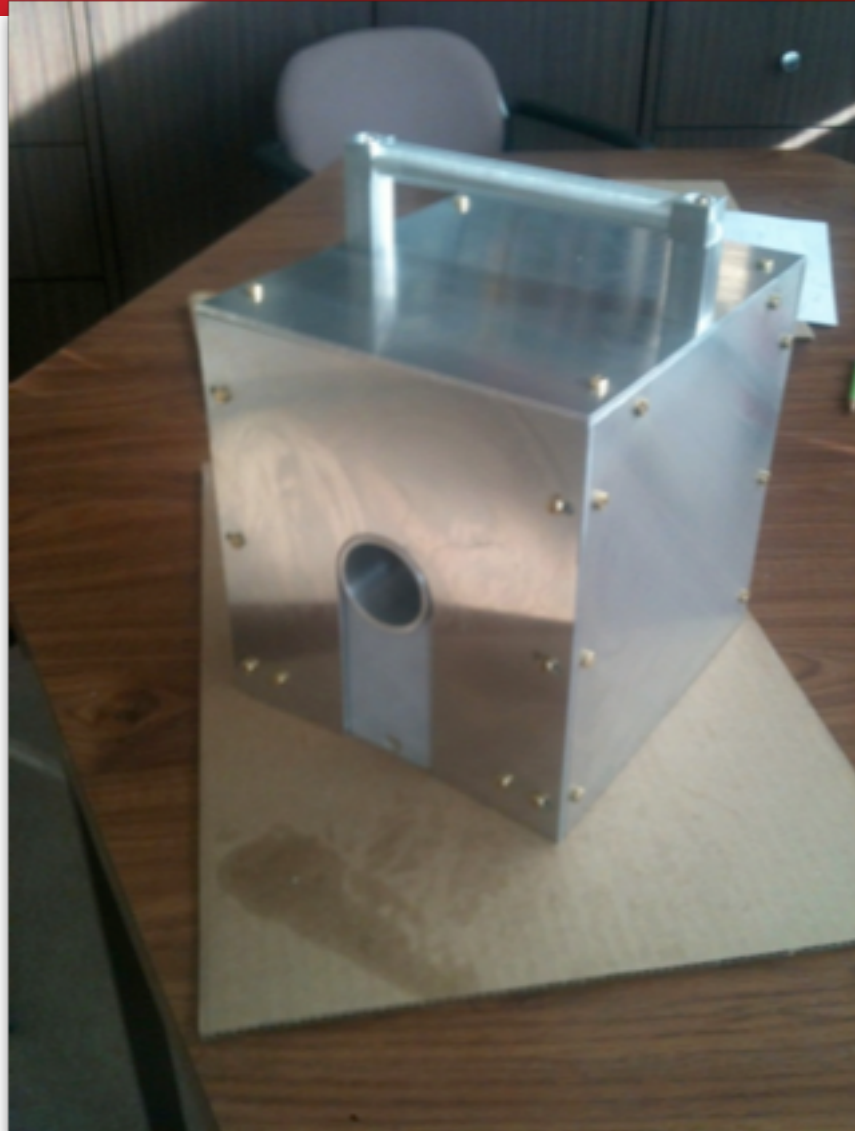
Collaboration

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Democritos



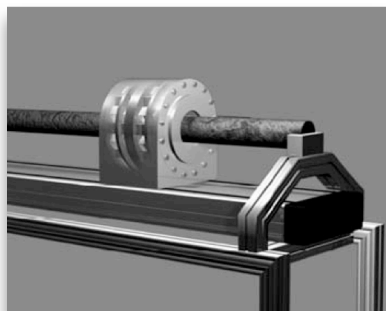
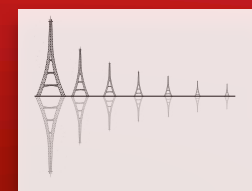
Anferova et al , JMR (2007).



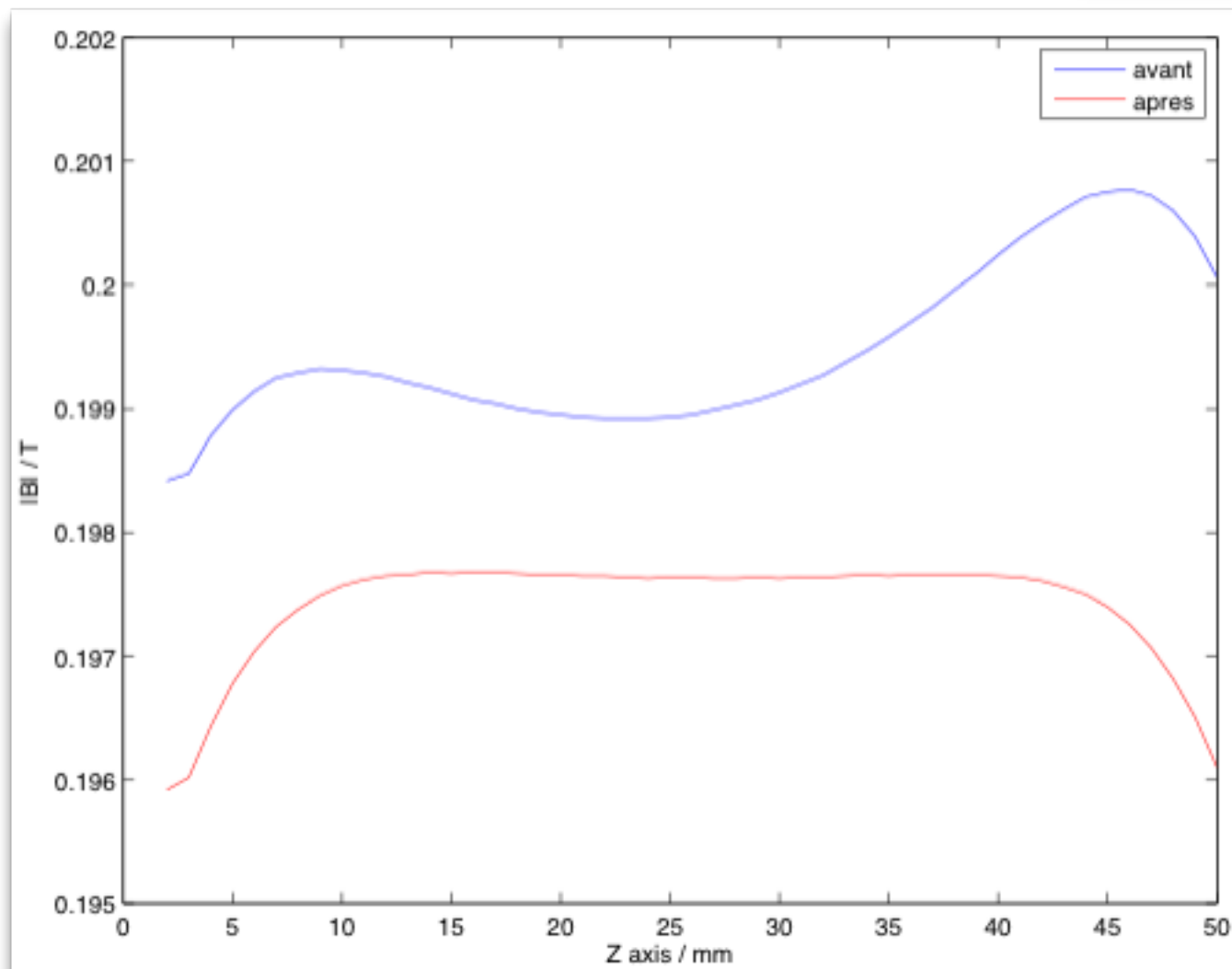
Collaboration

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Democritos



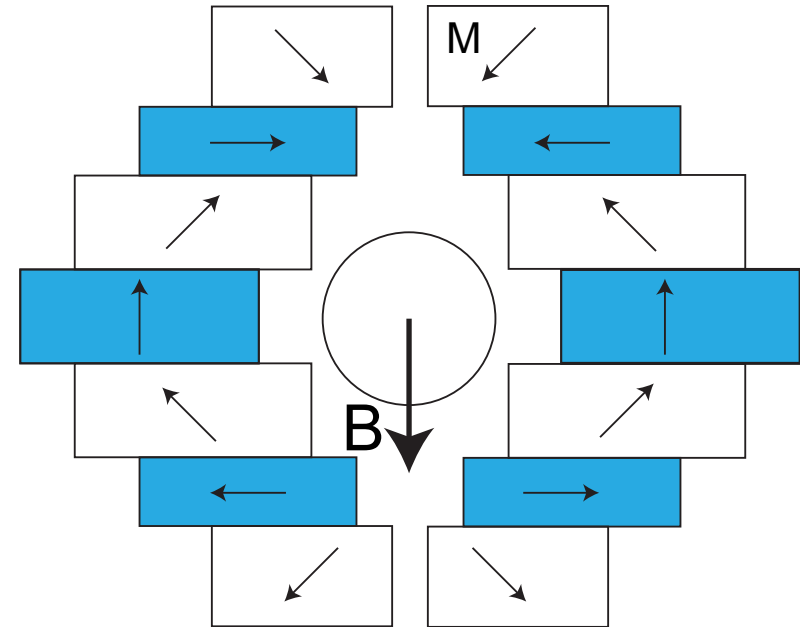
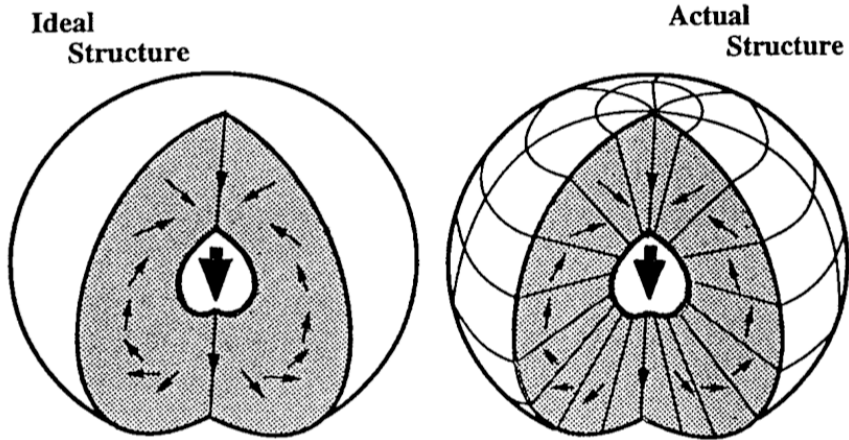
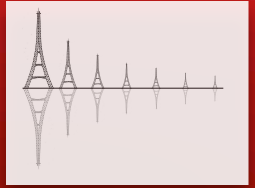
Anferova et al , JMR (2007).



Collaboration

G. Papavassiliou

National Lab.
Democritos

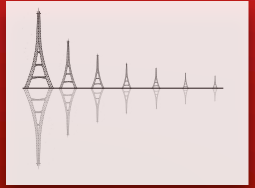


$$B = \frac{4}{3} B_r \ln \frac{R_{out}}{R_{in}} *$$

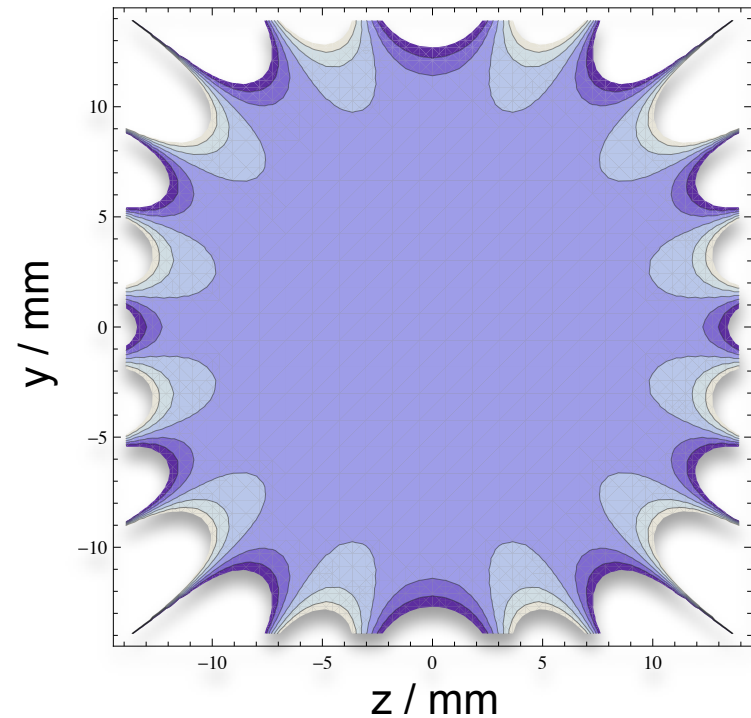
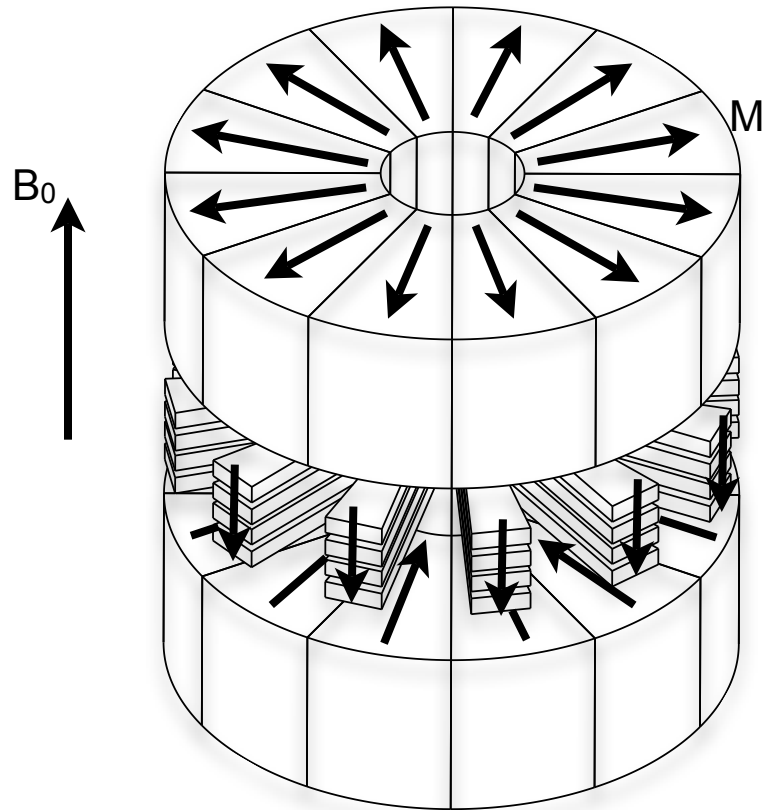
Zijlstra, *Philips J. Res.*, 1985, 40, 259-288

*Ceci est encore une fois théorique.
Les réalisations pratiques homogènes
sont moins efficaces.

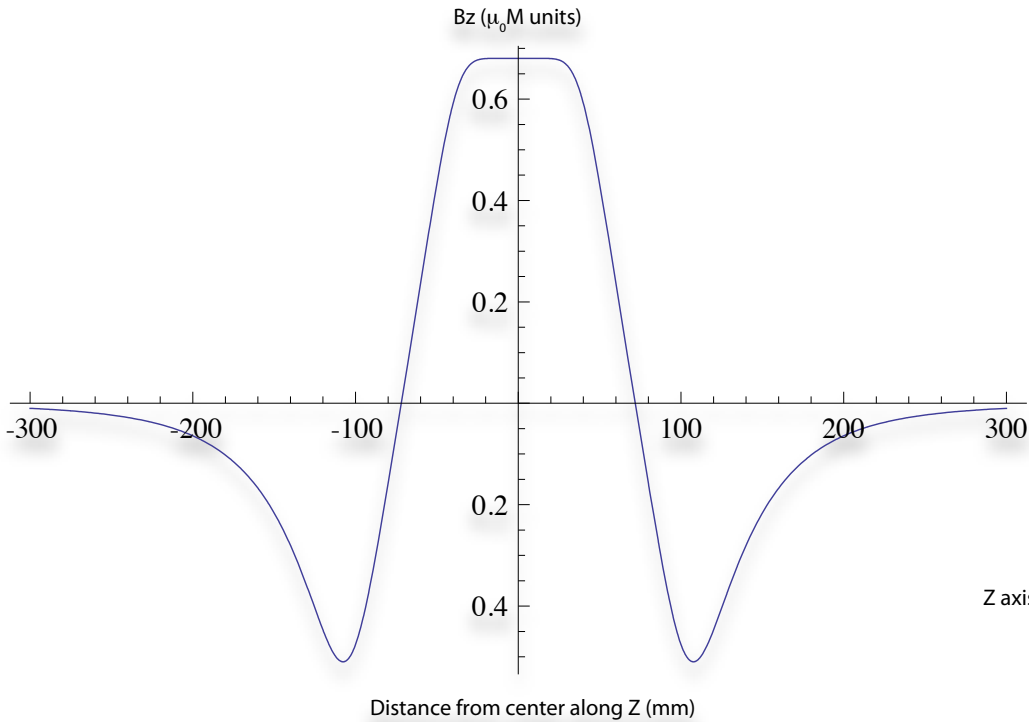
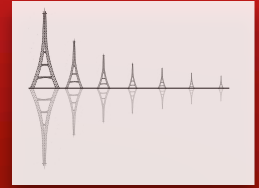
WO2011/023912



Homogène à l'ordre 12:
(offre un "sweet spot" qui fait la moitié du tube)

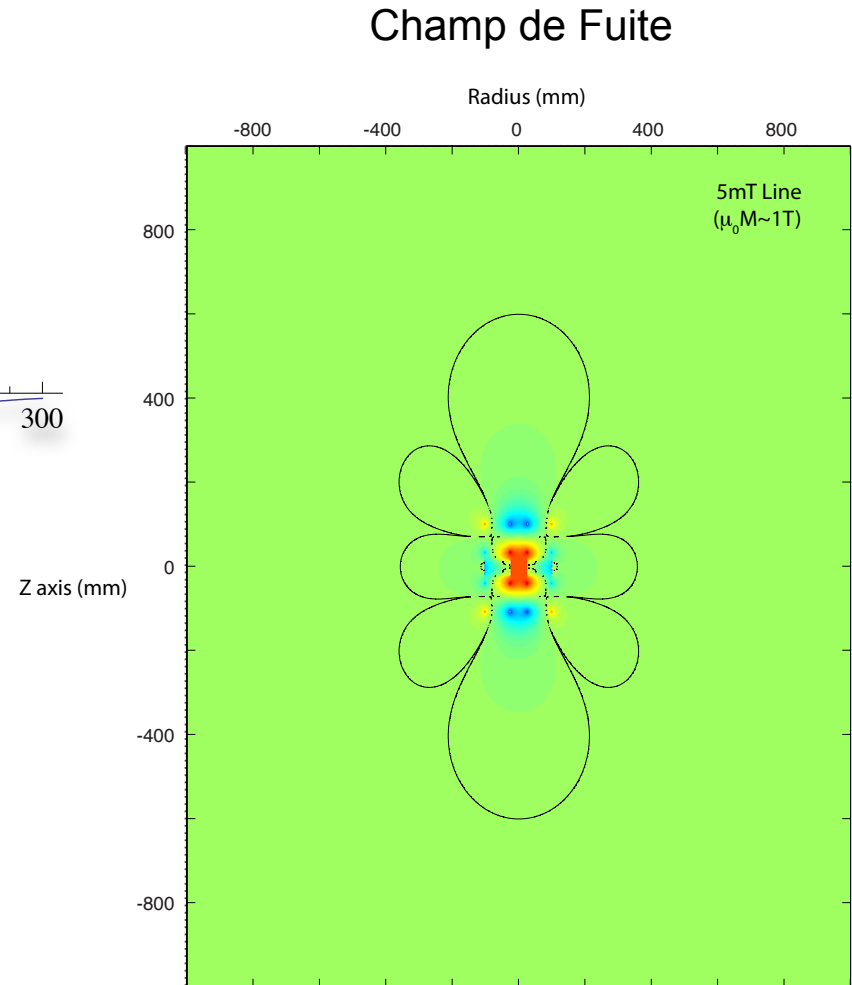


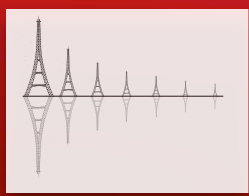
En théorie : $Z_{1 \text{ to } 11} = X_{1 \text{ to } 11}^m = Y_{1 \text{ to } 11}^m = 0$



$$B_0 = 0.65 \mu_0 M$$

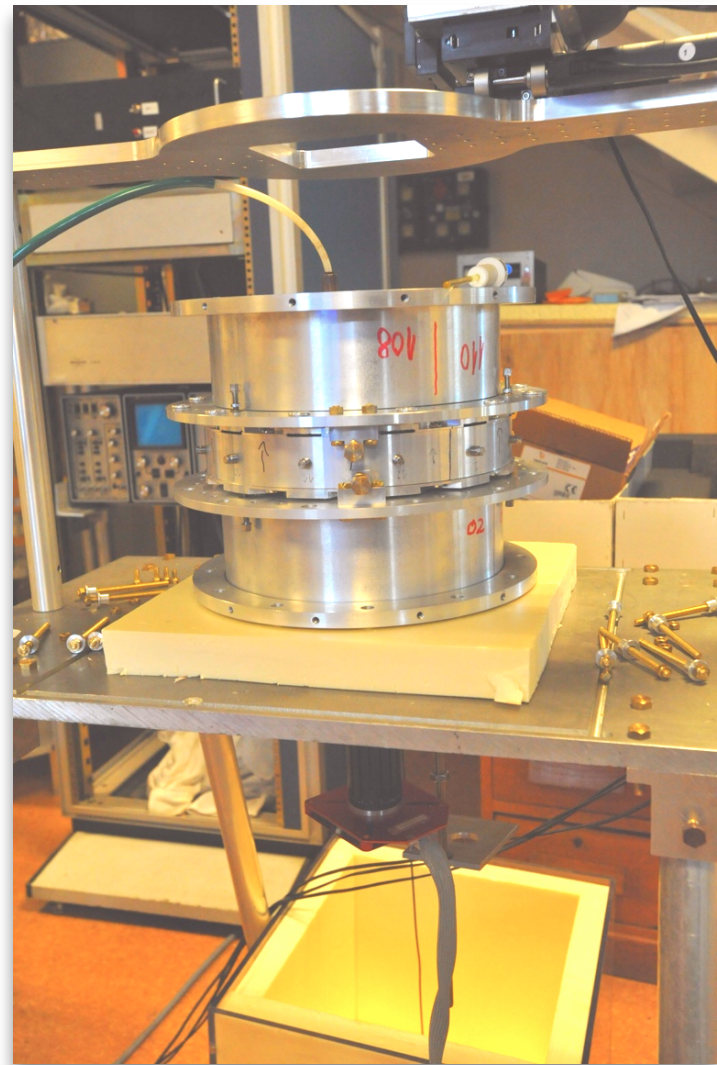
$$B_0 = 0.9T \text{ avec } B_r = 1.3T$$

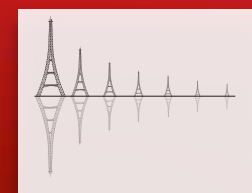




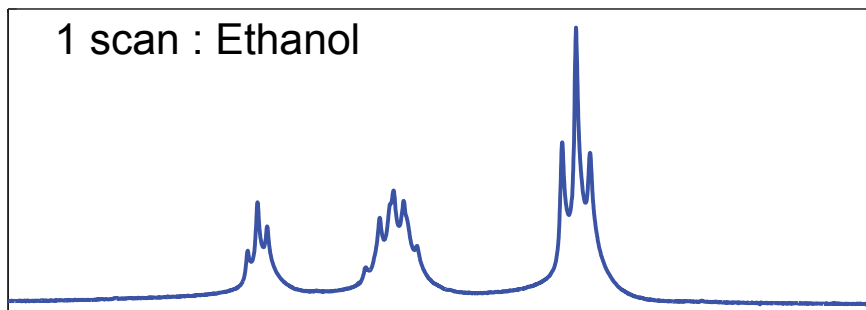
Spécifications

- **0.9 Tesla (38MHz ^1H Larmor)**
- **54mm bore (standard NB), 20mm DSV**
- **0.05ppm** résolution (échantillon tournant)
- **0.5ppm** résolution (échantillon statique)
- Echantillons liquides de diamètre 5mm ou 10mm (rotation verticale)
- **Echantillon solides 7mm MAS**
- Fourreau de shims standard
- Bobines de gradients standards pour IRM etc.
- Poids 50 kg

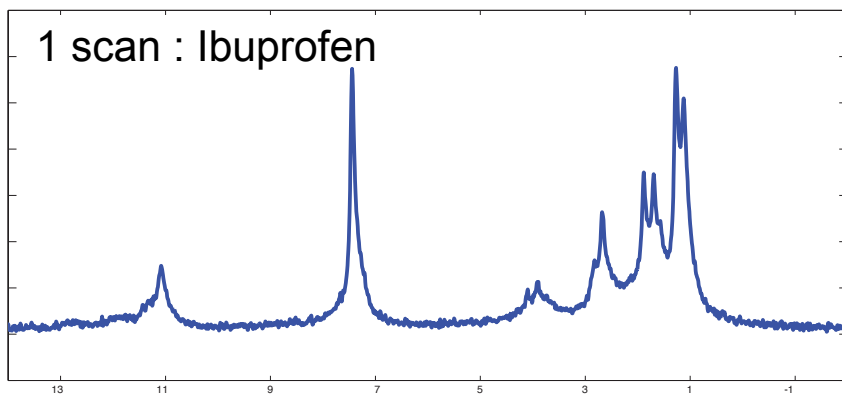




Echantillon pur
rotor de diamètre 7mm



Echantillon 0.5M
rotor de diamètre 7mm



Déplacement Chimique / ppm

Résolution 0.05ppm
Excellente Sensibilité

Le “shimming” implique les bobines suivantes:

Z1, X
(1st order at the MAS frame)

X2-Y2, ZX
(2nd order at the MAS frame)

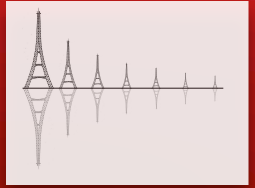
Z3,Z2X, Z(X2-Y2), X3
(3rd order at the MAS frame)

comme pour toute sonde HRMAS.

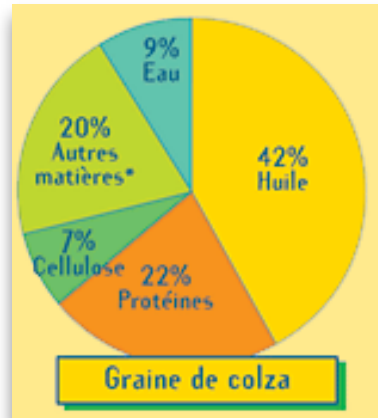


APPLICATION AUX GRAINES

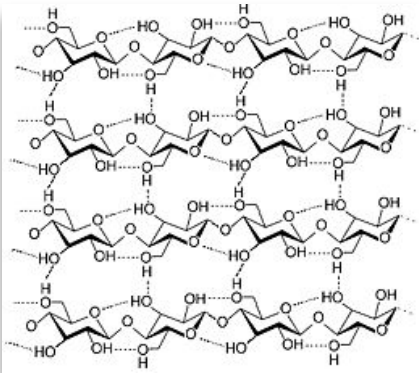




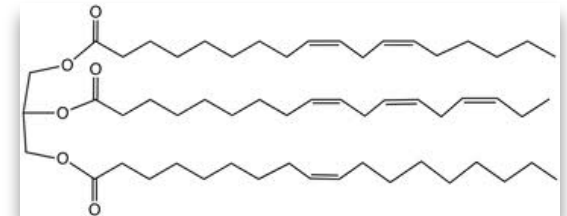
Eau + Composés "Solides"



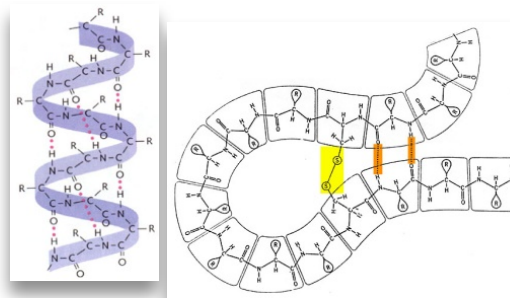
Cellulose
(polymère rigide
signaux ¹H larges)

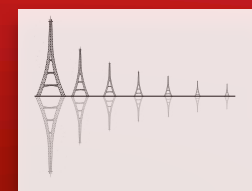


Triglycérides
(chaines hydrophobes mobiles)

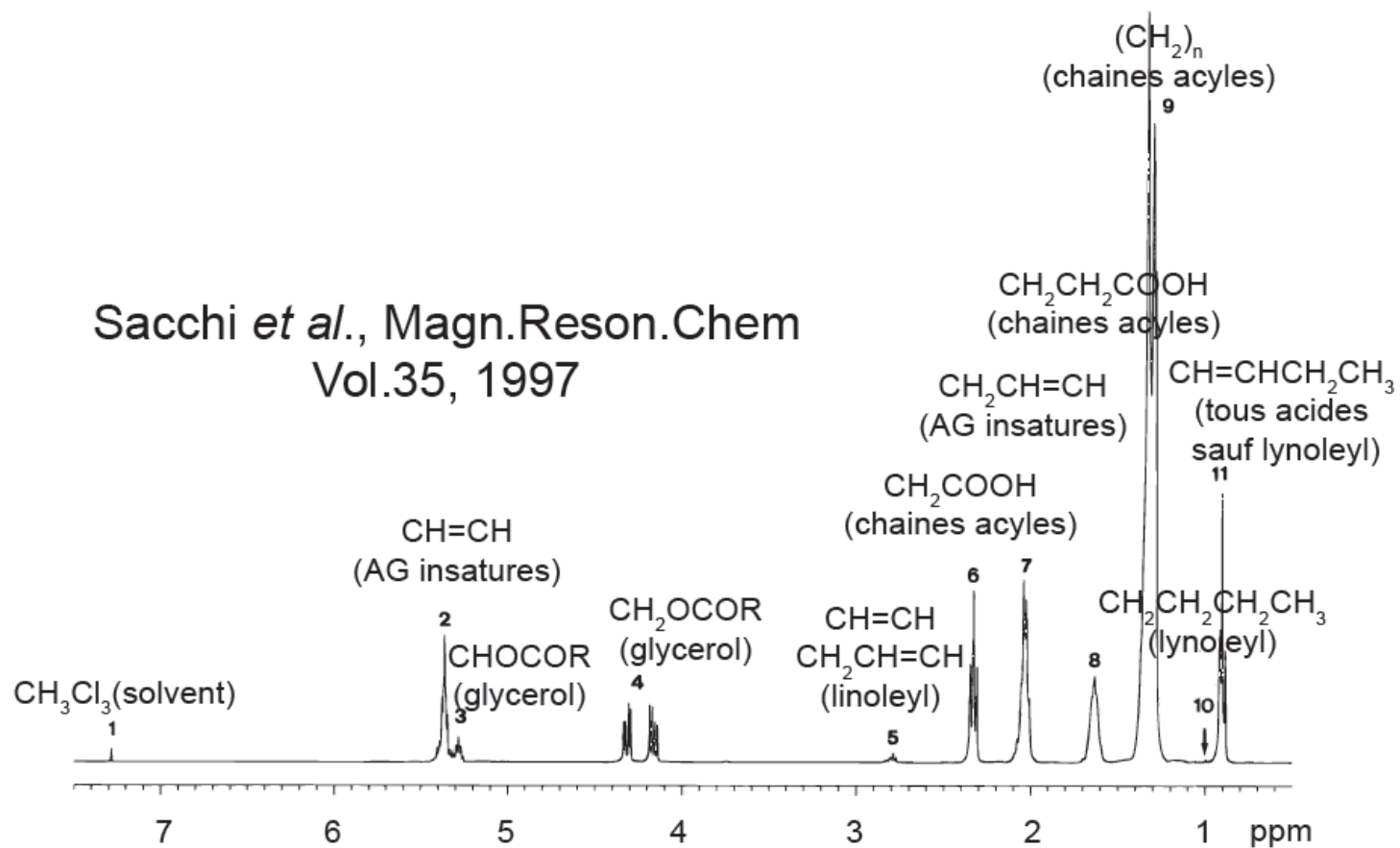


Protéines
(structures rigides
signaux ¹H larges)

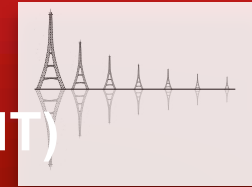




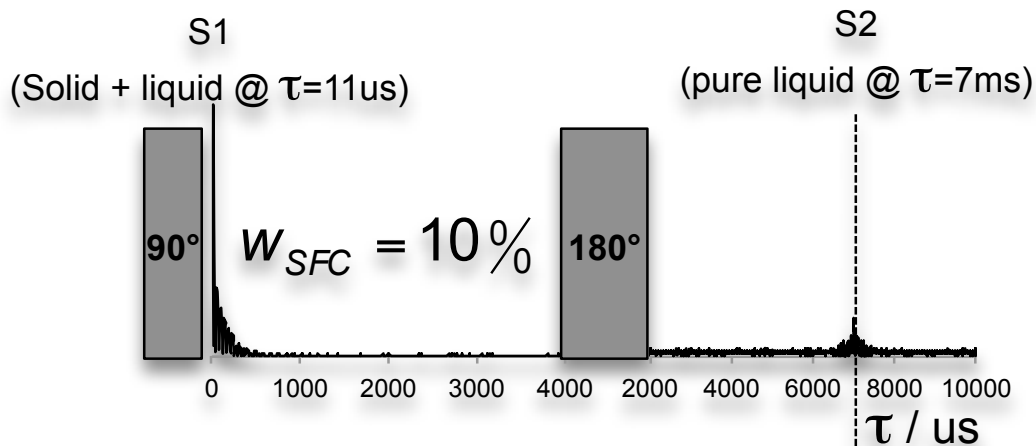
Huile d'Olive (400MHz)



ANALYSE RMN BAS CHAMPS: MEASURE DU RAPPORT SFC (SOLID FAT CONTENT)

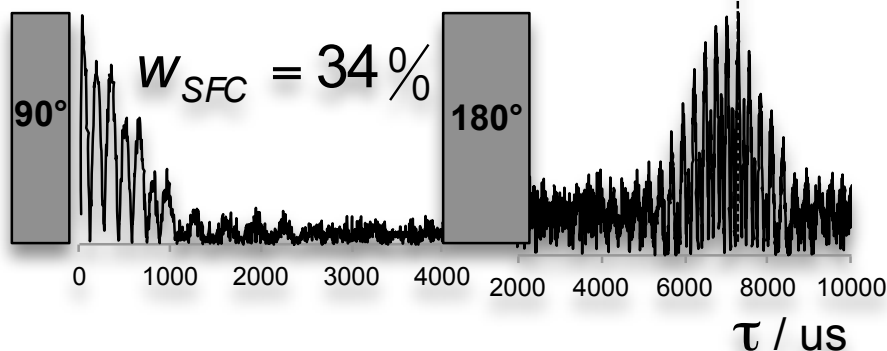


Weat (lipic content ~2%)

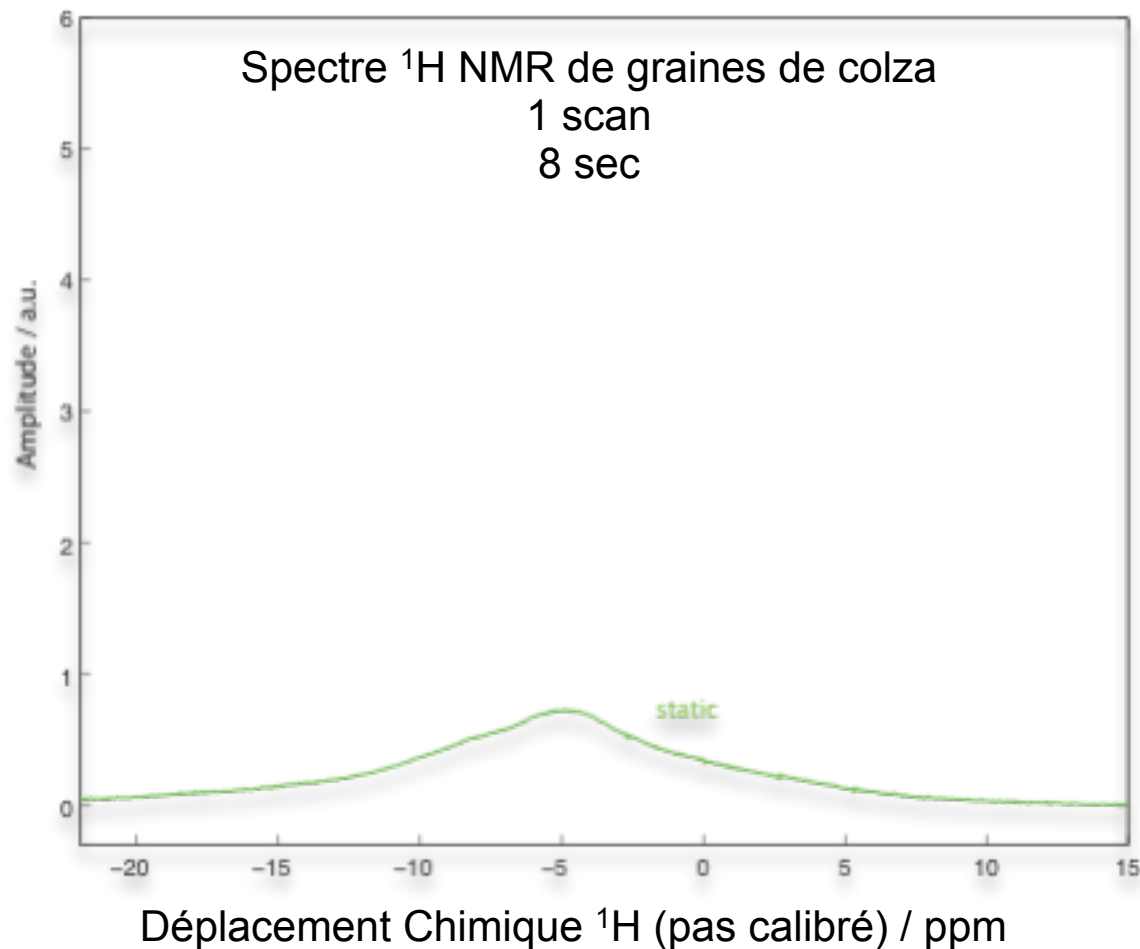
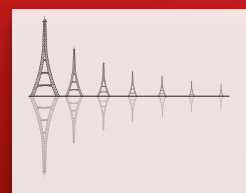


$$W_{SFC} = \frac{(S1 - S2)}{S1} \times 100$$

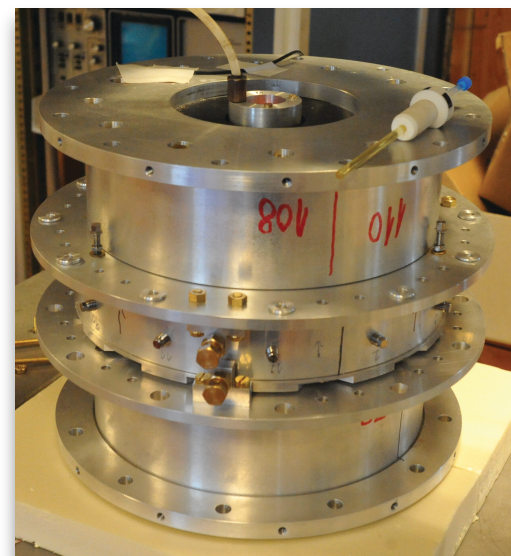
Colza (lipic content ~35 to 45%)



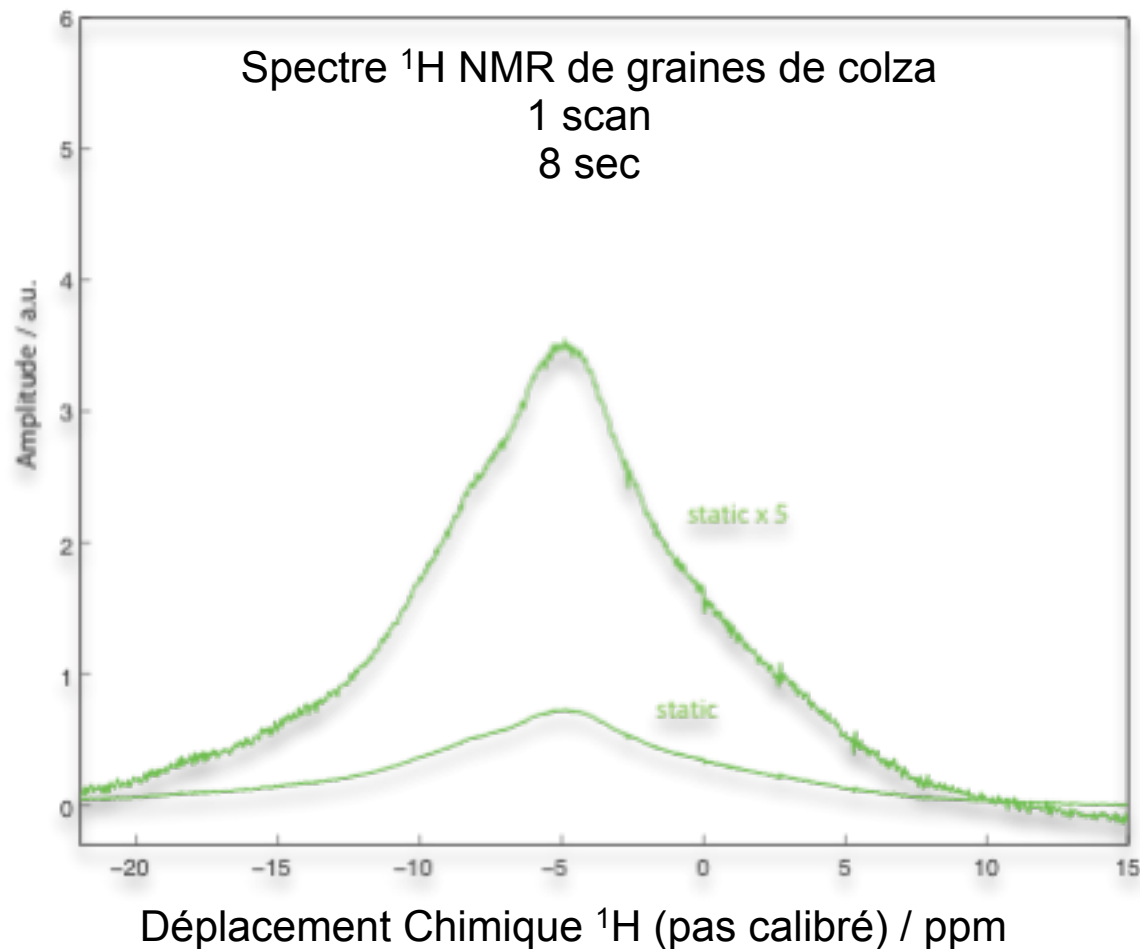
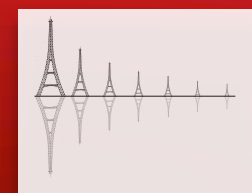
$$W_{SFC}^{corr} = \frac{f(S1 - S2)}{f(S1 - S2) + S2} \times 100$$



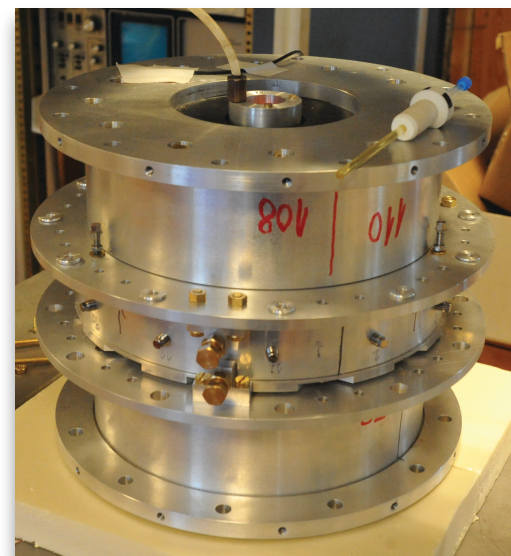
La préparation de l'échantillon peut être un problème:
RMN sur matière première



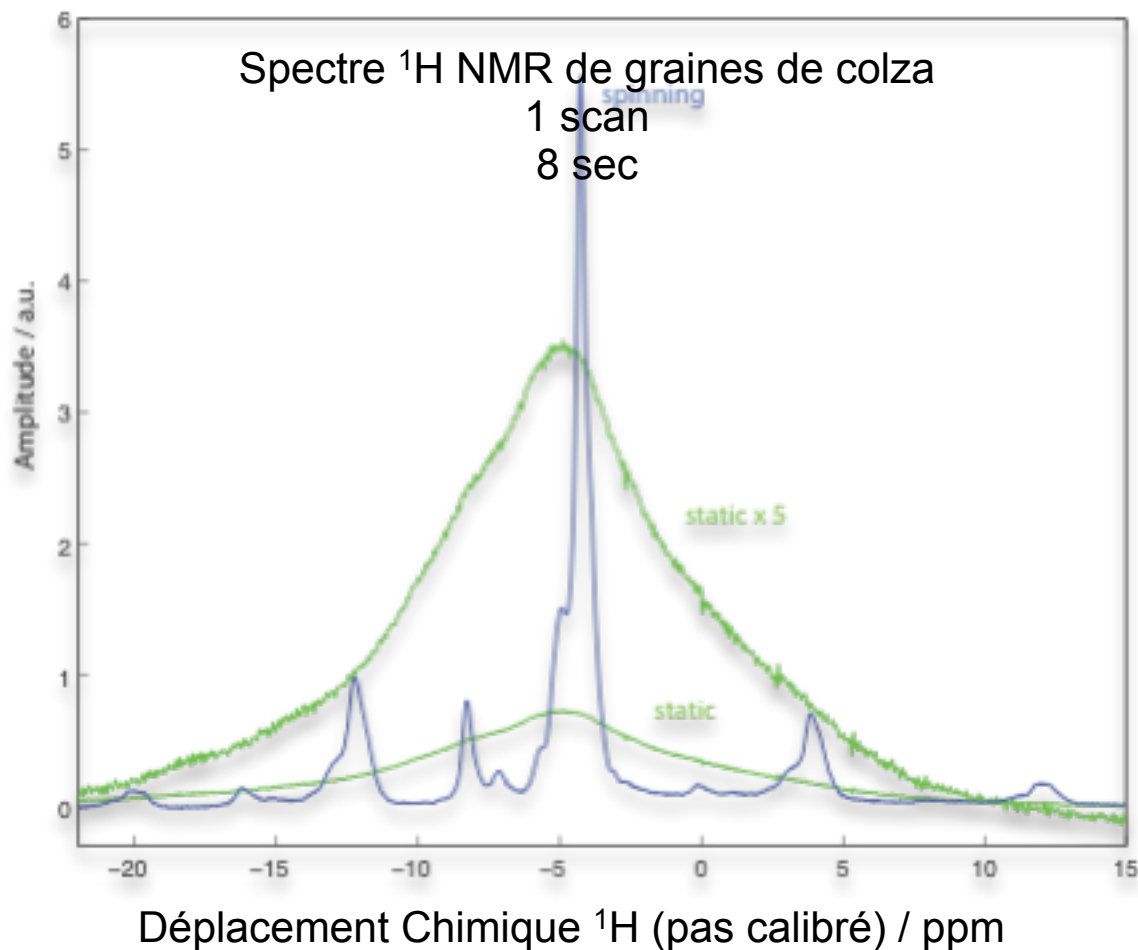
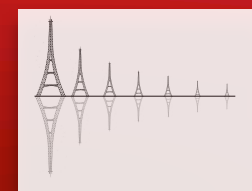
Gain en résolution ~ 10
Rotor de diamètre 7mm
Fréquence de rotation échantillon
entre 300 et 600 Hz



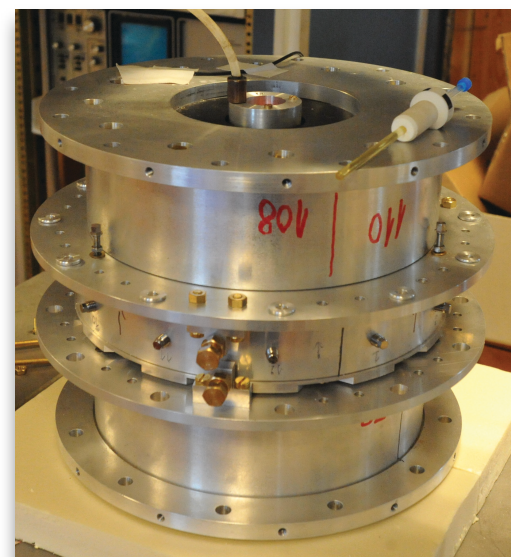
La préparation de l'échantillon peut être un problème:
RMN sur matière première



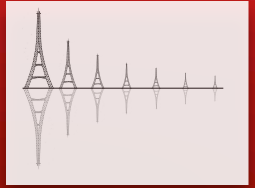
Gain en résolution ~ 10
Rotor de diamètre 7mm
Fréquence de rotation échantillon
entre 300 et 600 Hz



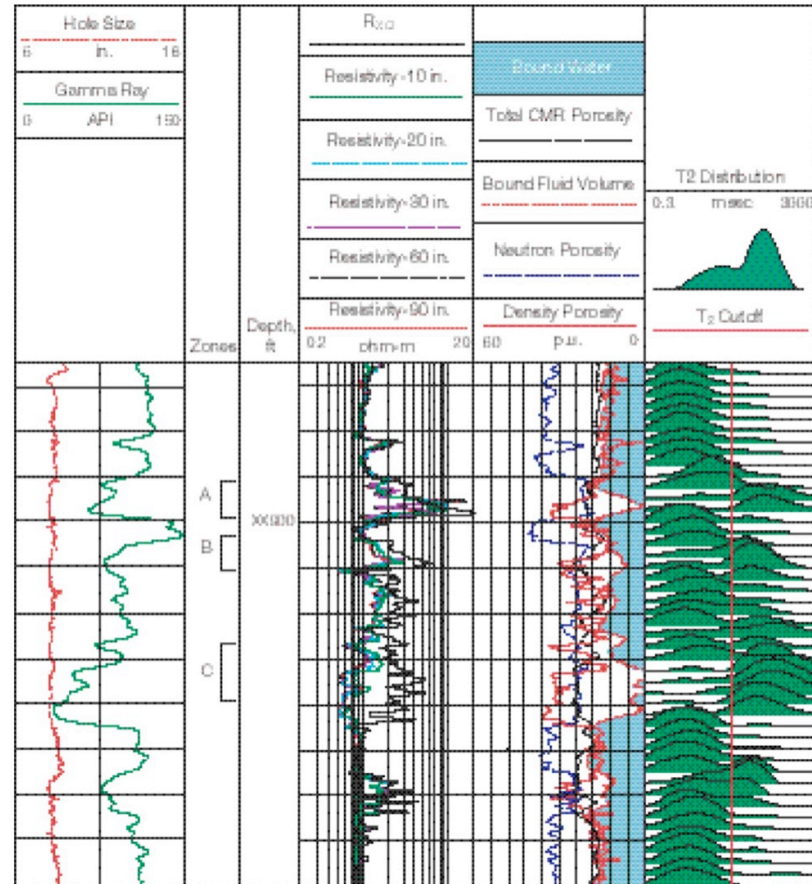
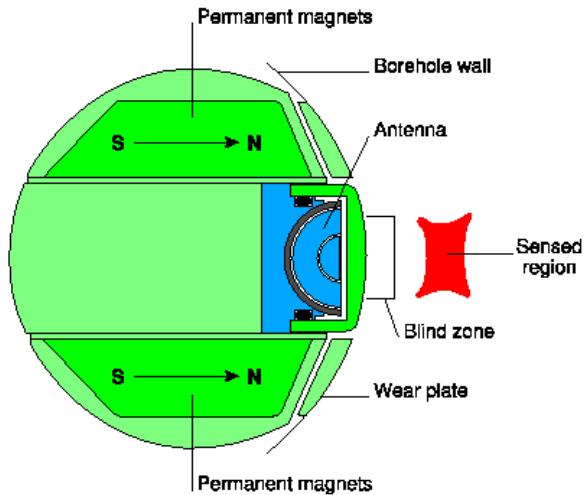
La préparation de l'échantillon peut être un problème:
RMN sur matière première

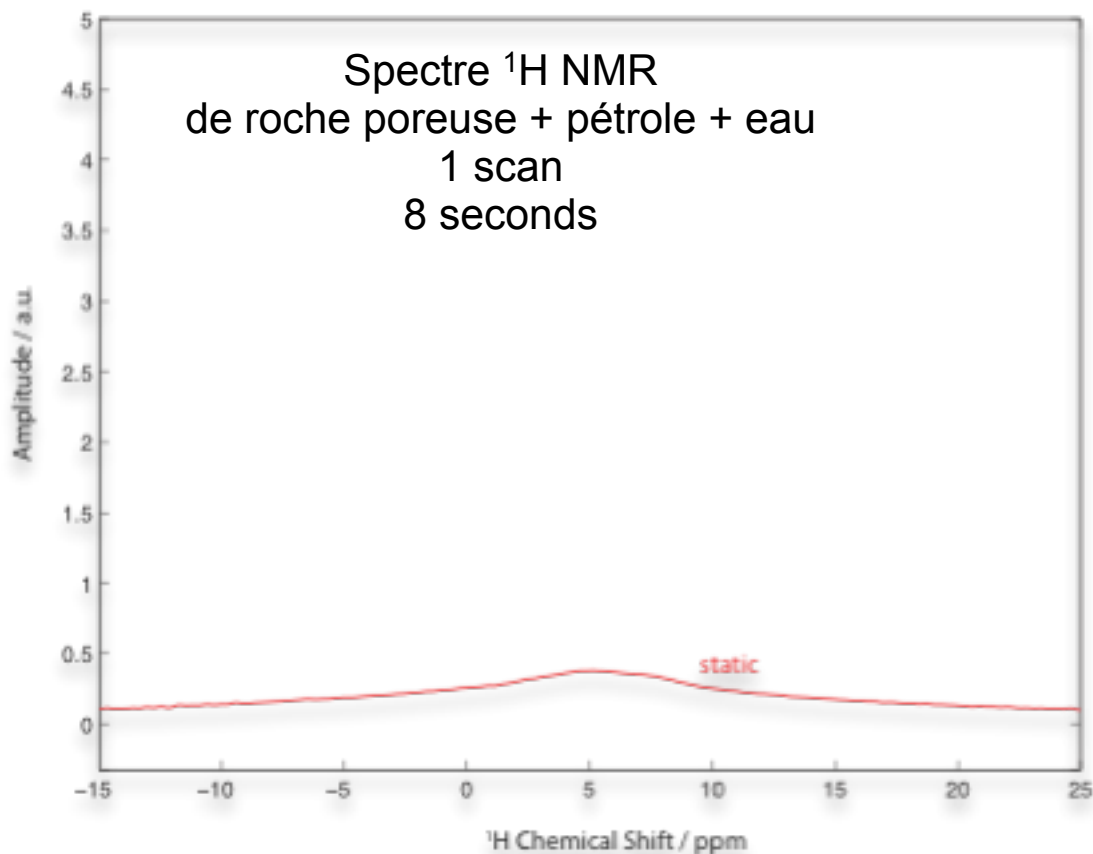
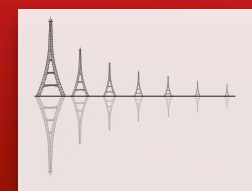


Gain en résolution ~ 10
Rotor de diamètre 7mm
Fréquence de rotation échantillon
entre 300 et 600 Hz

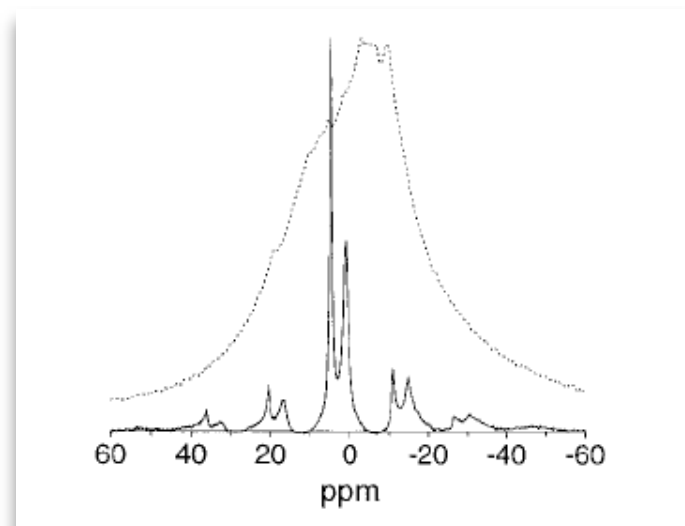


100 μm



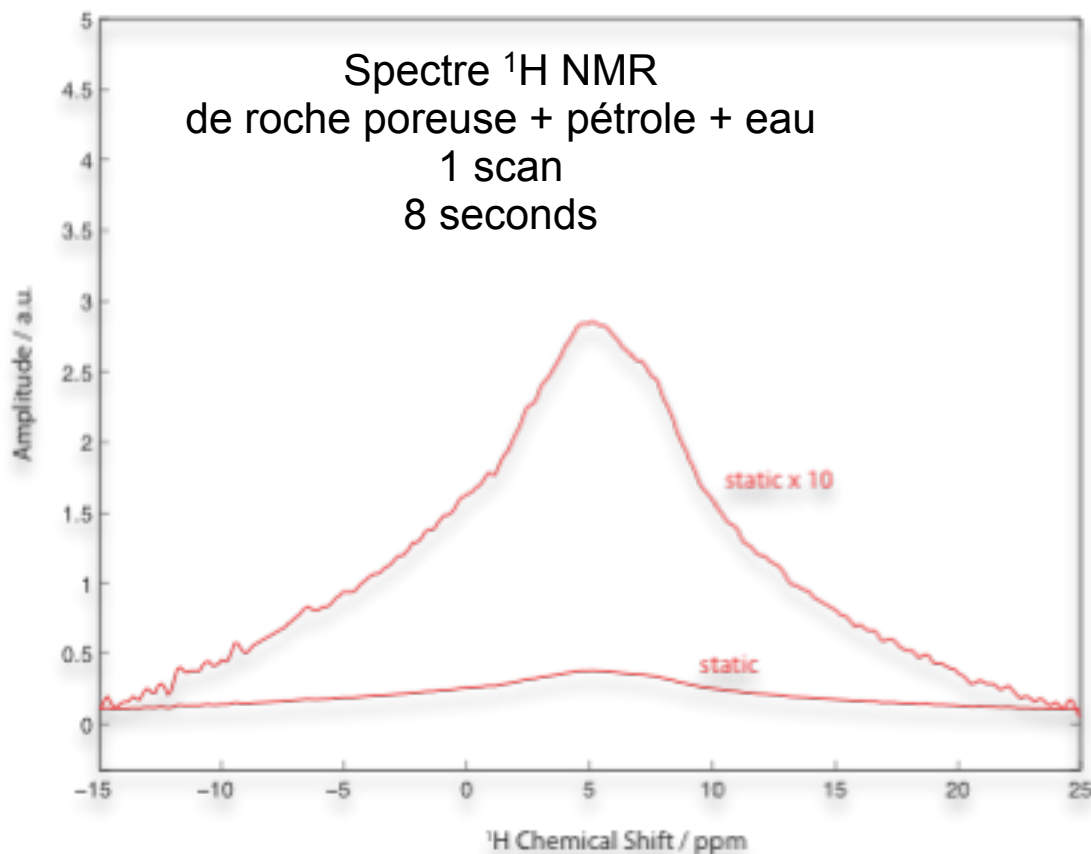
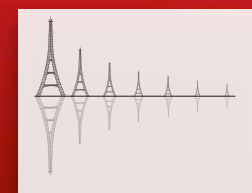


Etude RMN MAS à haut-
champ (aimant supras)

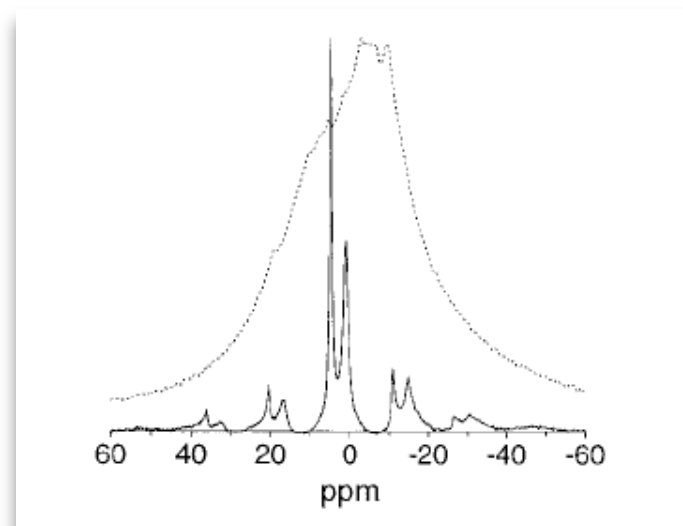


de Swiet et al, *J. Magn. Reson.*, **1998**, 133, 385-387

Fréquence de rotation de l'échantillon
entre 300 et 400 Hz
Rotor de diamètre 7mm

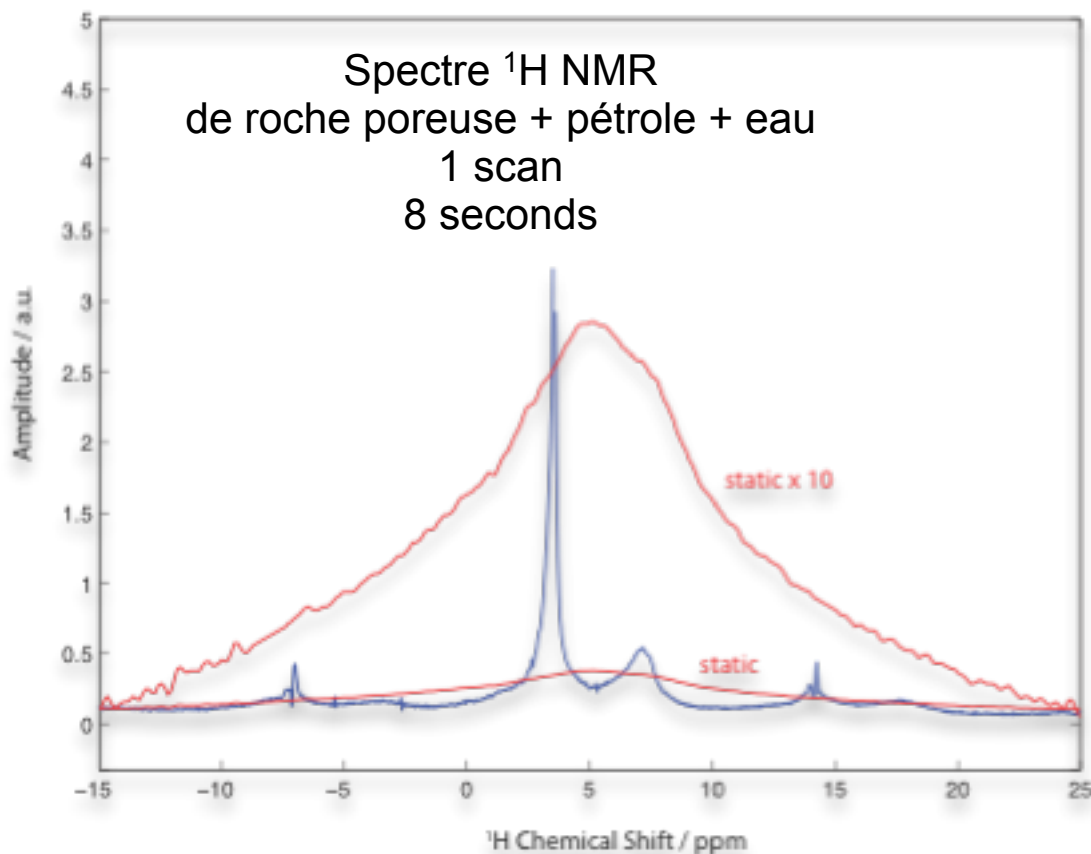
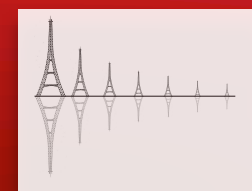


Etude RMN MAS à haut-
champ (aimant supras)



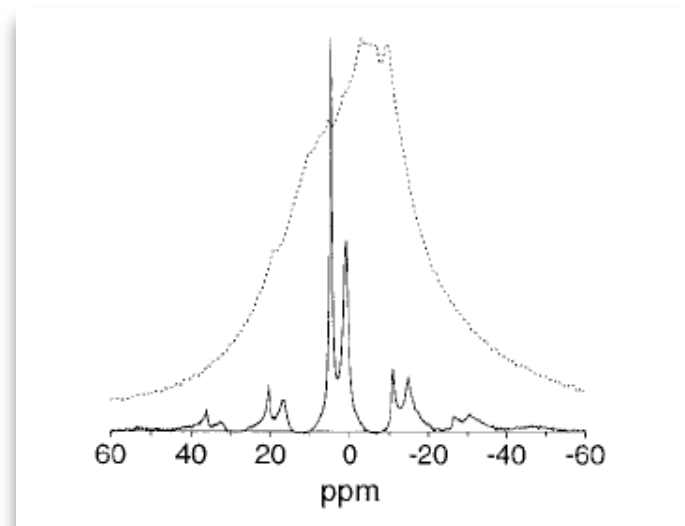
de Swiet et al, *J. Magn. Reson.*, **1998**, 133, 385-387

Fréquence de rotation de l'échantillon
entre 300 et 400 Hz
Rotor de diamètre 7mm



Fréquence de rotation de l'échantillon
entre 300 et 400 Hz
Rotor de diamètre 7mm

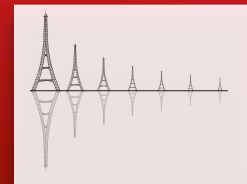
Etude RMN MAS à haut-
champ (aimant supras)



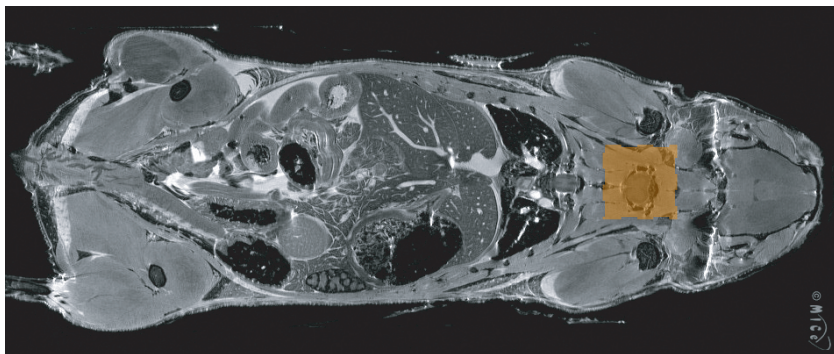
de Swiet et al, *J. Magn. Reson.*, **1998**, 133, 385-387



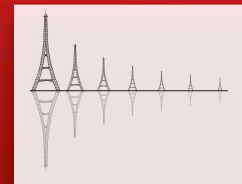
**LE BESOIN DE LA RÉOLUTION :
RMN ET IRM À CHAMP B_0 TOURNANT
(RMN BAS CHAMP TOURNANT)**



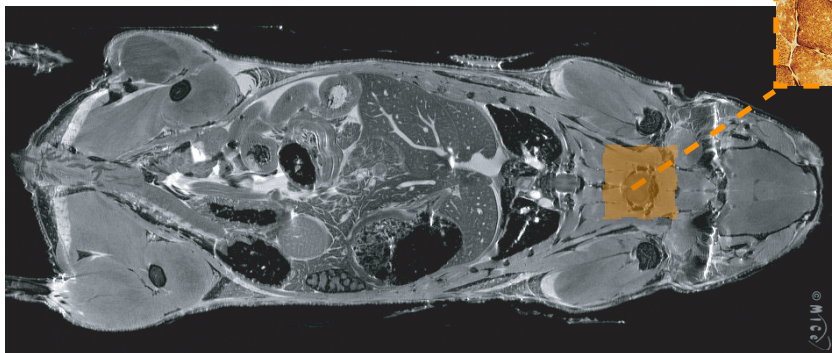
In-vivo



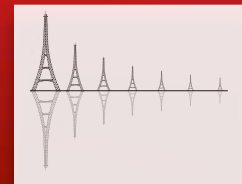
SPECTROSCOPIE LOCALISÉE HAUTE RESOLUTION EN MAS ?



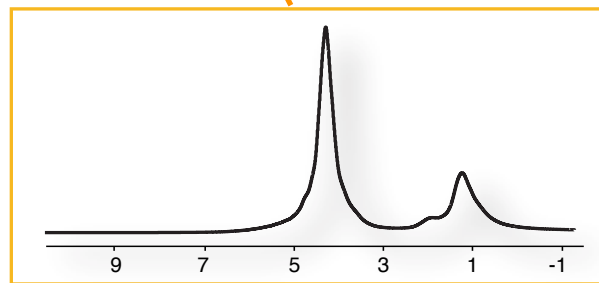
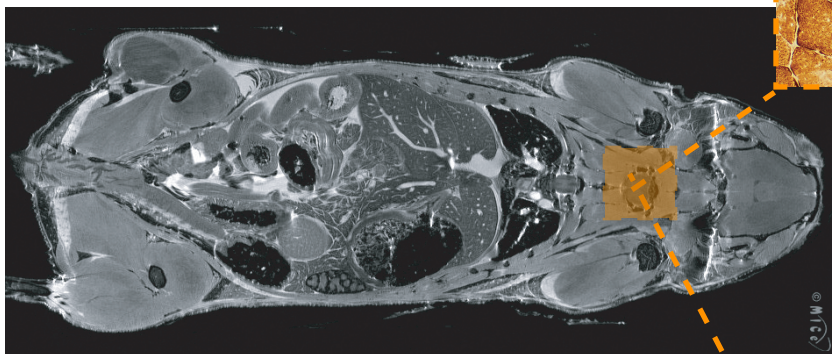
In-vivo



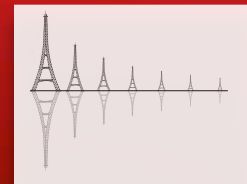
SPECTROSCOPIE LOCALISÉE HAUTE RESOLUTION EN MAS ?



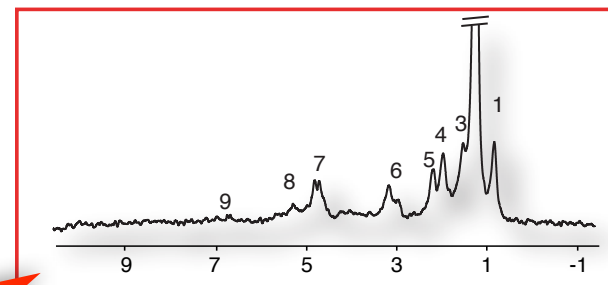
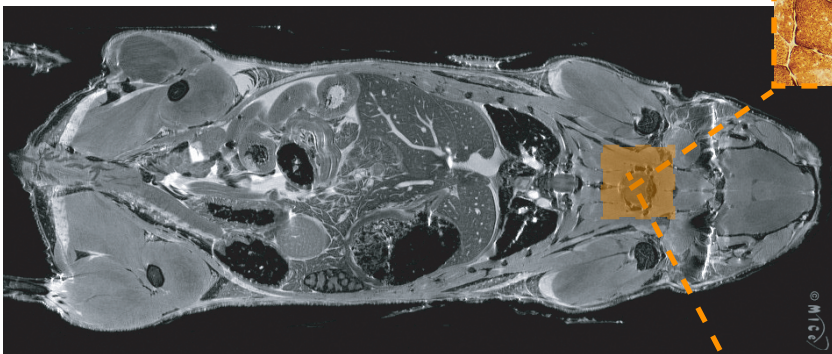
In-vivo



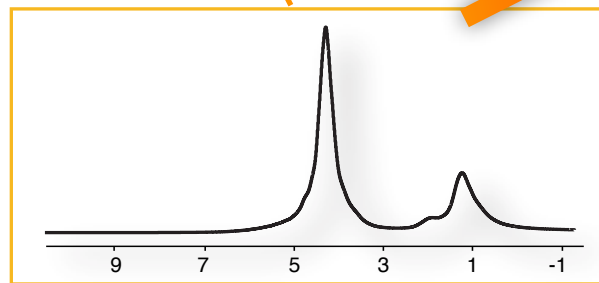
SPECTROSCOPIE LOCALISÉE HAUTE RESOLUTION EN MAS ?



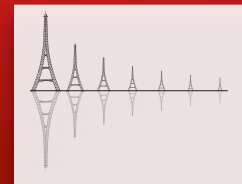
In-vivo



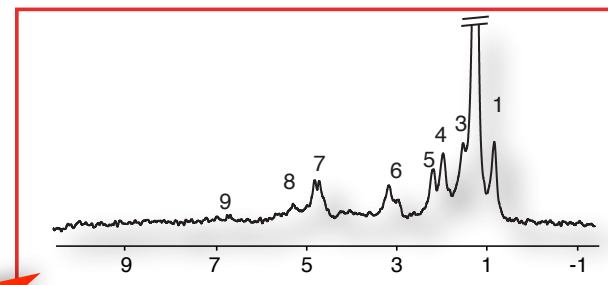
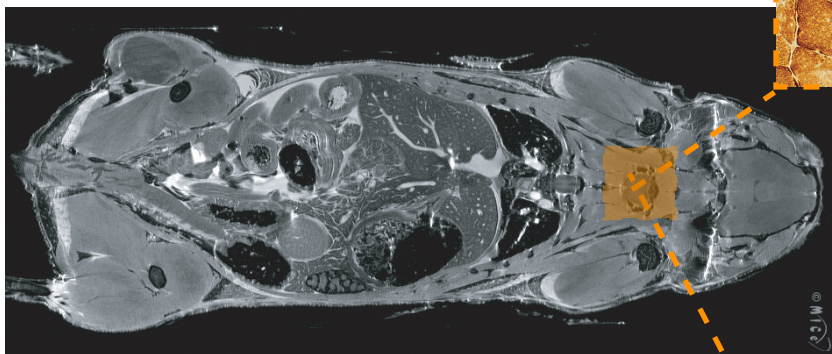
?



SPECTROSCOPIE LOCALISÉE HAUTE RESOLUTION EN MAS ?

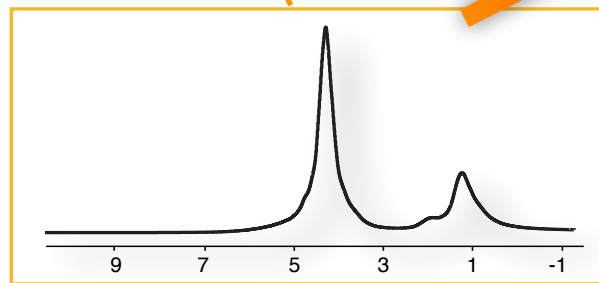


In-vivo

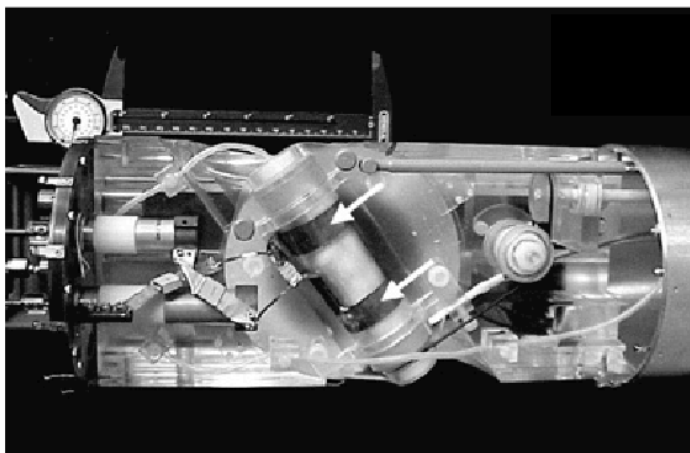
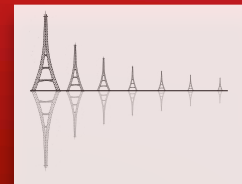


?

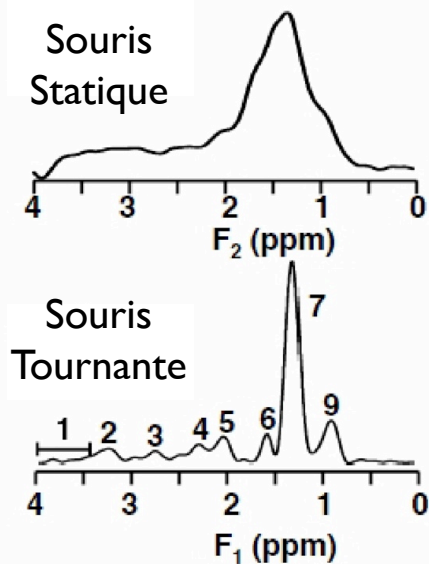
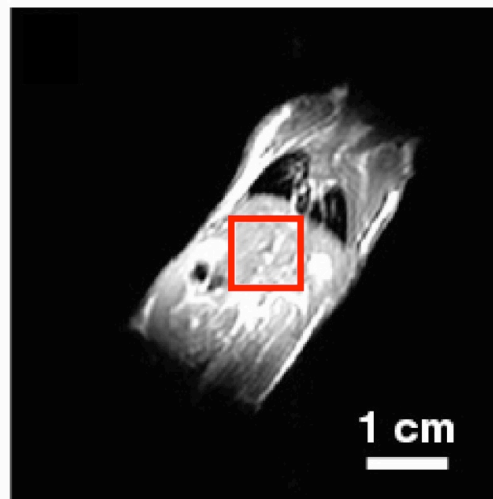
Spectre HRMAS
de métabolites
de biopsies



TOURNER À L'ANGLE MAGIQUE UNE SOURIS VIVANTE !

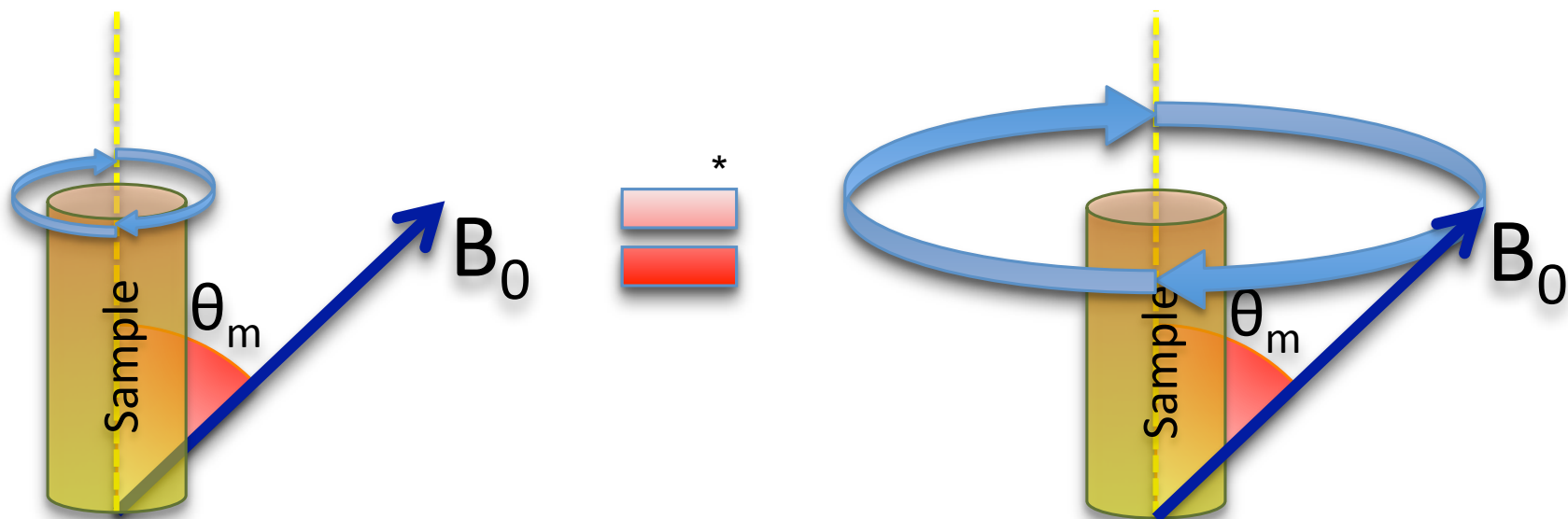
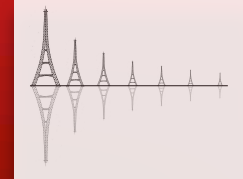


Rotation = 4 Hz
Electroaimant = 2T
VOI: 8x8x8 mm³

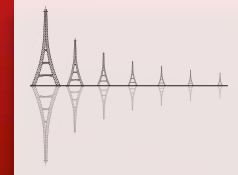


R.Wind et al. Magn. Reson. Med. 2006

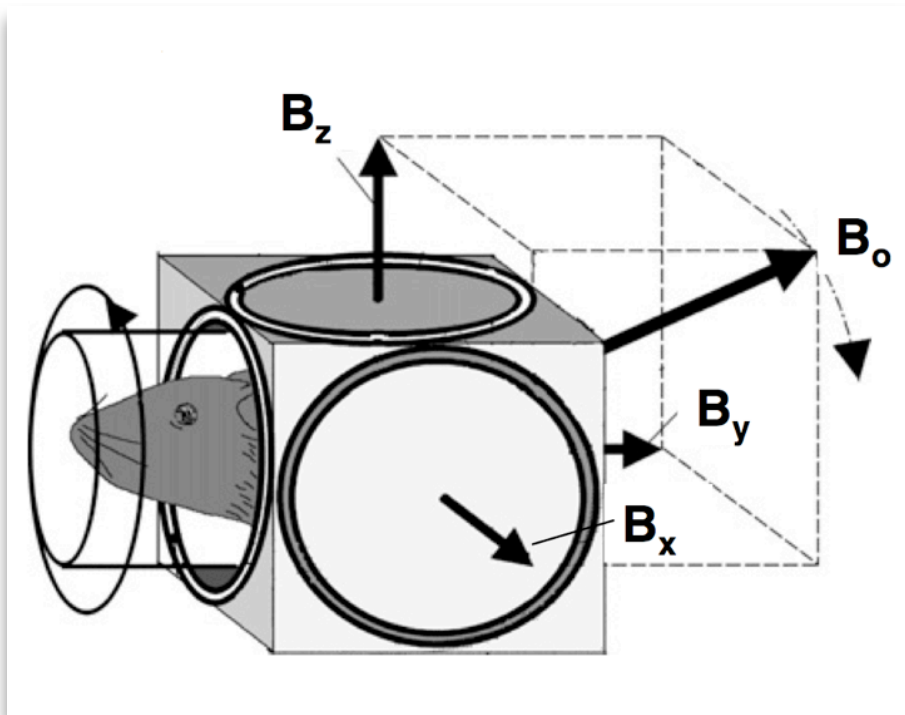
TOURNER À L'ANGLE MAGIQUE: L'ÉCHANTILLON OU LE CHAMP ?



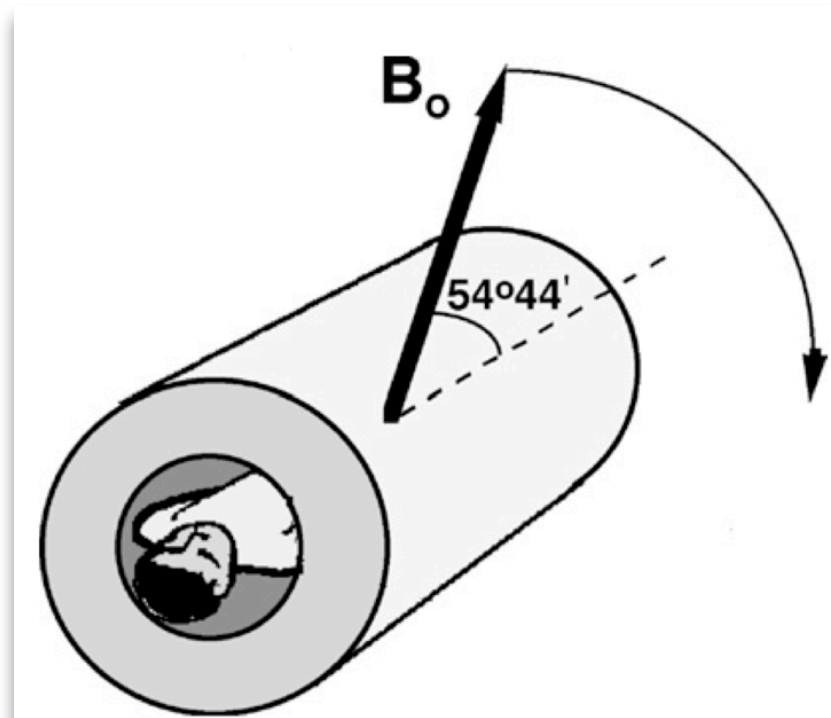
* l'équivalence est proprement valide lorsque la fréquence de rotation est faible devant la fréquence de Larmor !
(régime adiabatique)



Rotation Electromagnétique

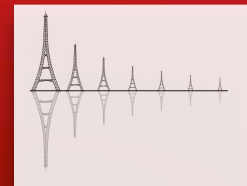


Rotation Mécanique

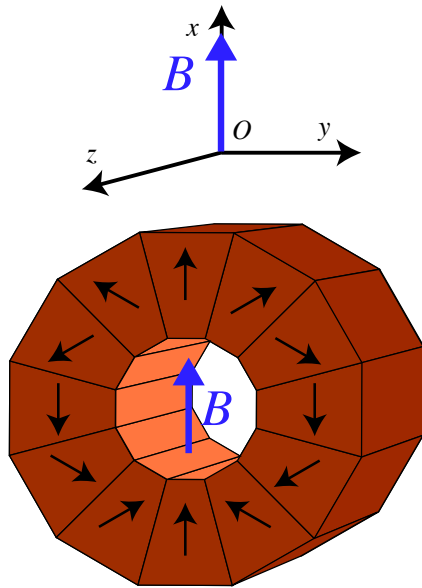
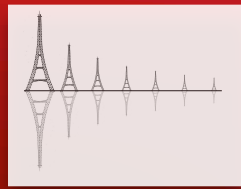


Meriles *et al*, J. Magn. Reson. **169**, 13 (2004).
Sakellariou *et al*, Magn. Reson. Imag. **23**, 295 (2005).

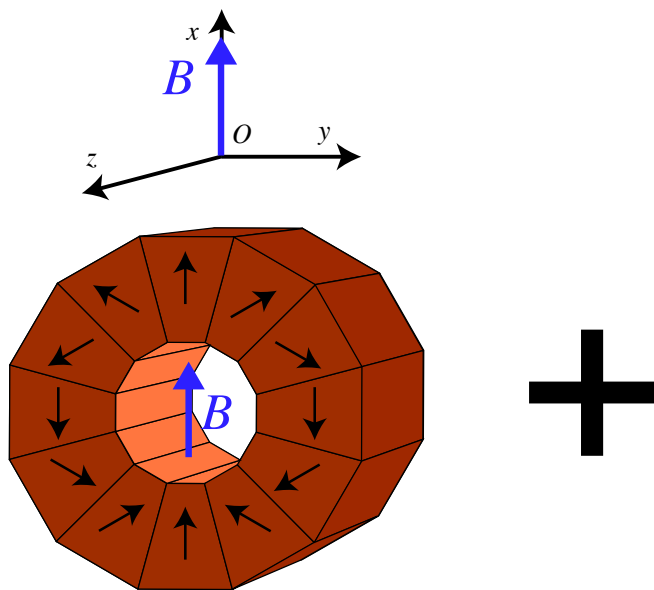
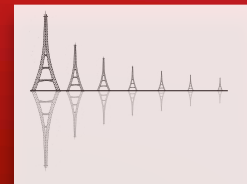
COMMENT DESSINER UN AIMANT MAGIQUE ?



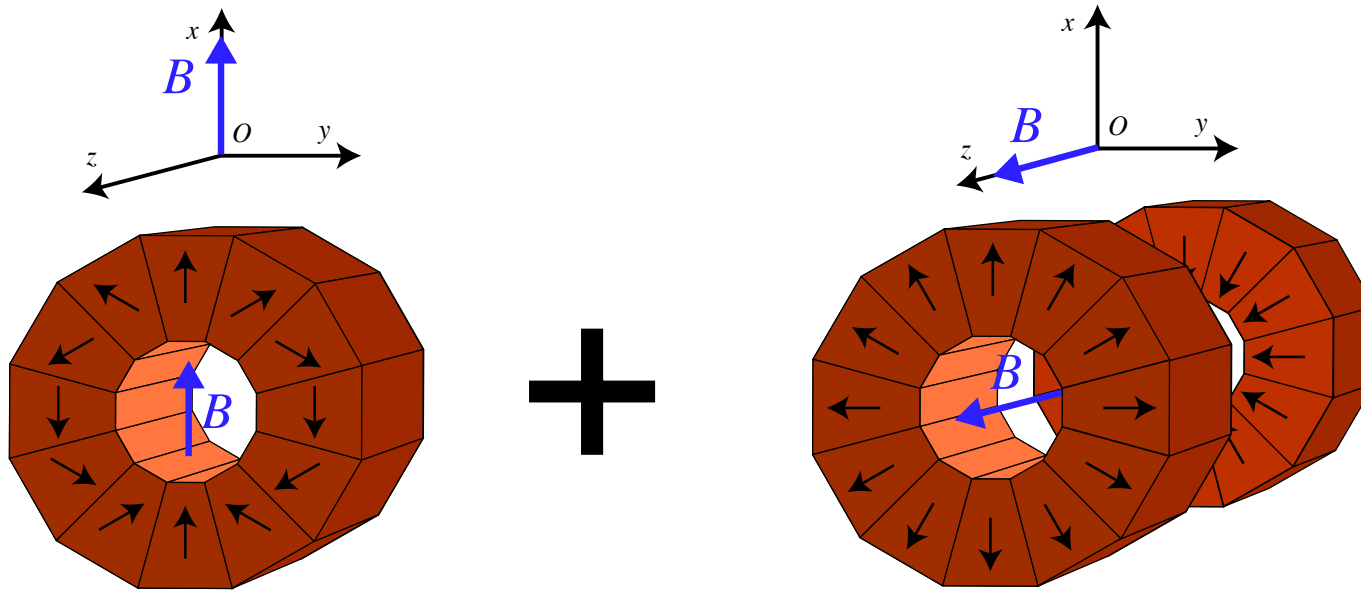
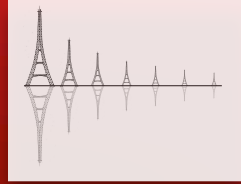
COMMENT DESSINER UN AIMANT MAGIQUE ?



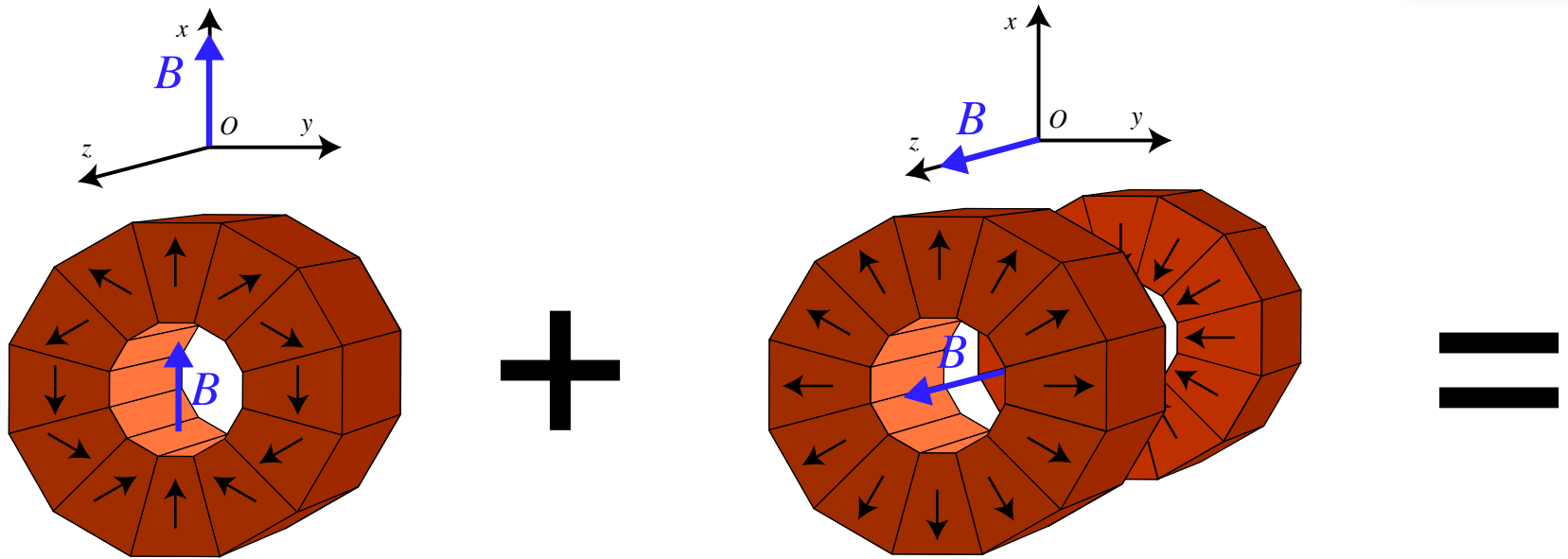
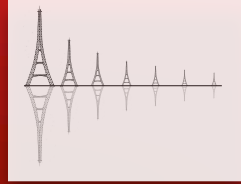
COMMENT DESSINER UN AIMANT MAGIQUE ?



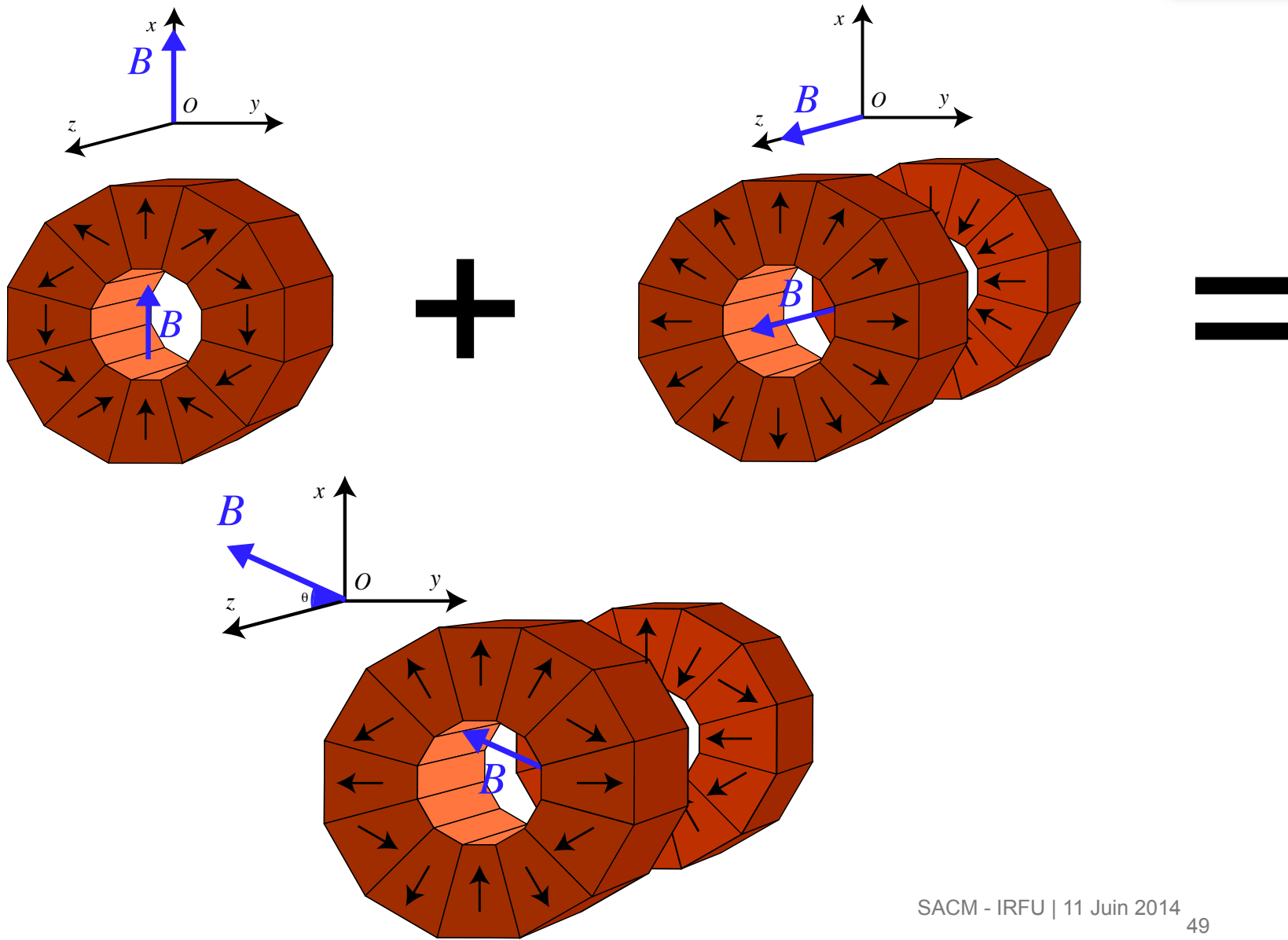
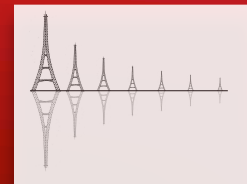
COMMENT DESSINER UN AIMANT MAGIQUE ?

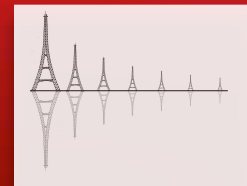


COMMENT DESSINER UN AIMANT MAGIQUE ?



COMMENT DESSINER UN AIMANT MAGIQUE ?





Spécifications

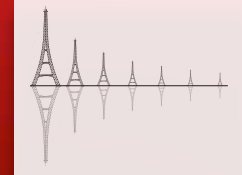
Champ Incliné = 0.22T
(9.8 MHz ^1H Larmor)

30mm diamètre libre

Homogénéité:
~20ppm DSV 1mm

Poids < 1kg

Cout : Très Faible !



Spécifications

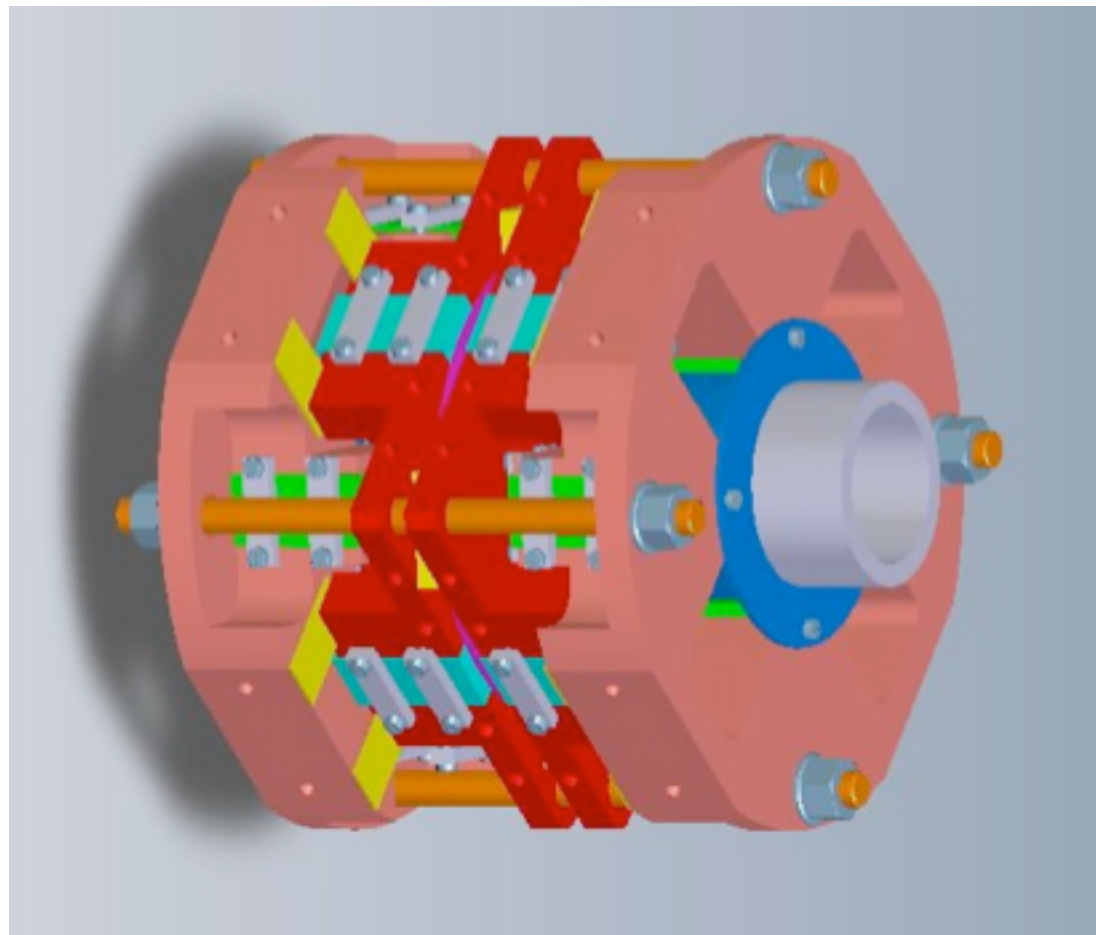
Champ Incliné = 0.22T
(9.8 MHz ^1H Larmor)

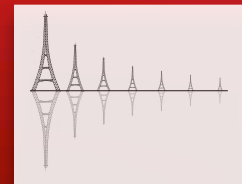
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Spécifications

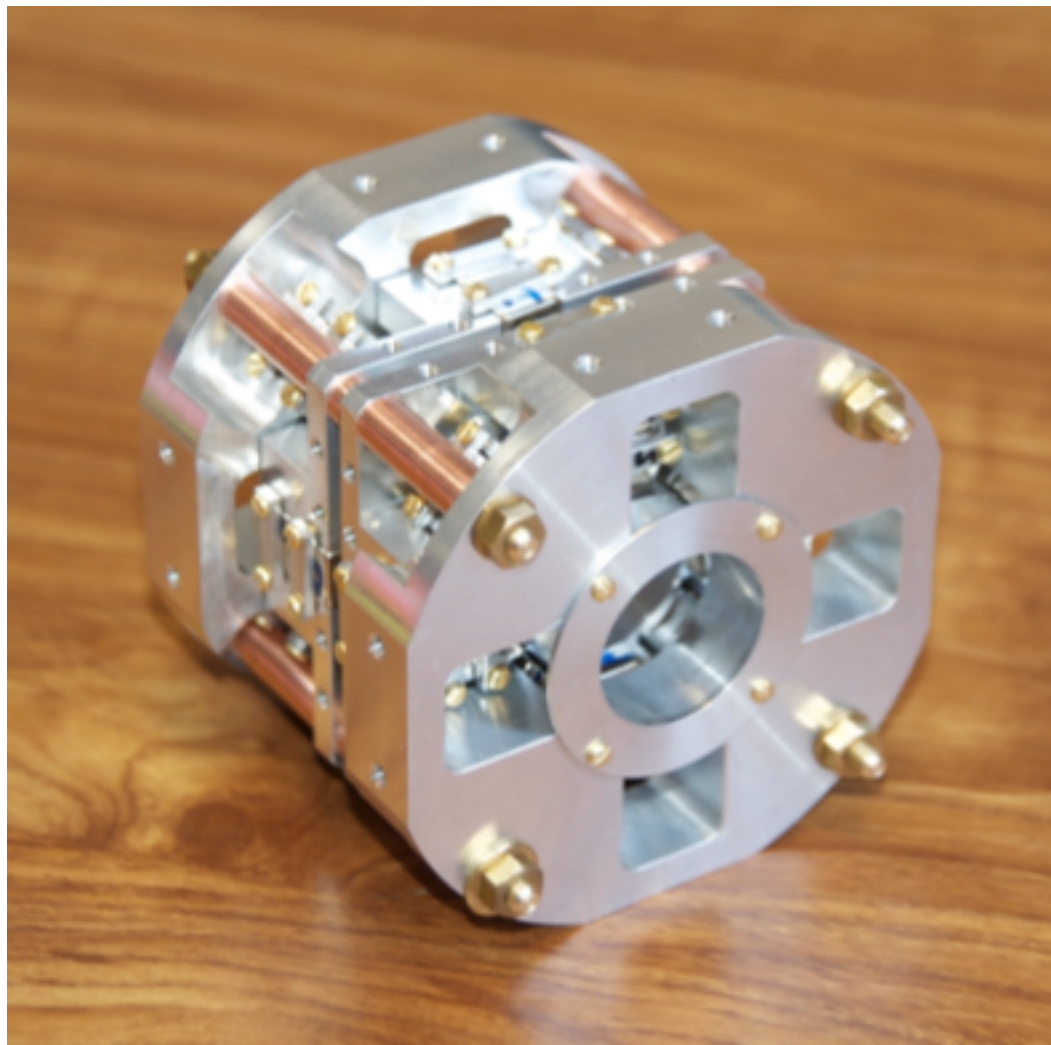
Champ Incliné = 0.22T
(9.8 MHz ^1H Larmor)

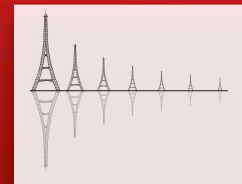
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Spécifications

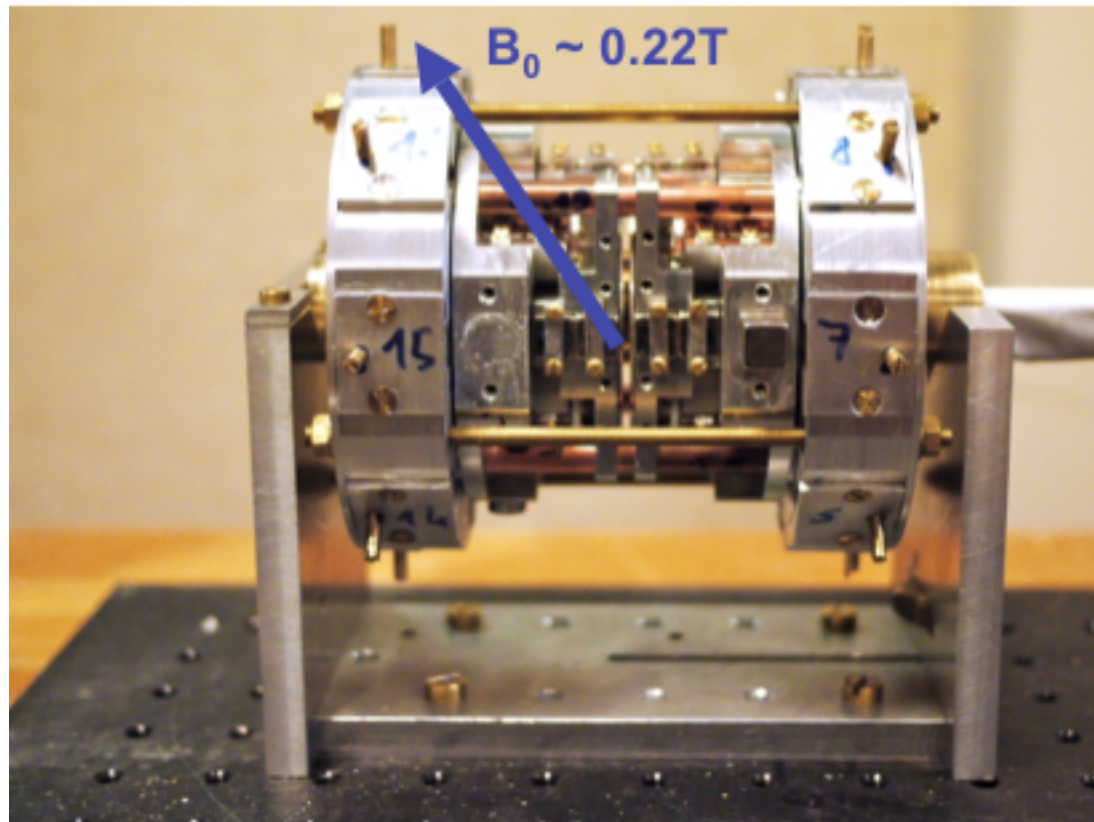
Champ Incliné = 0.22T
(9.8 MHz ^1H Larmor)

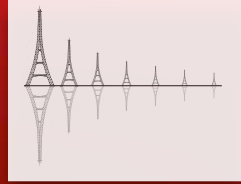
30mm diamètre libre

Homogénéité:
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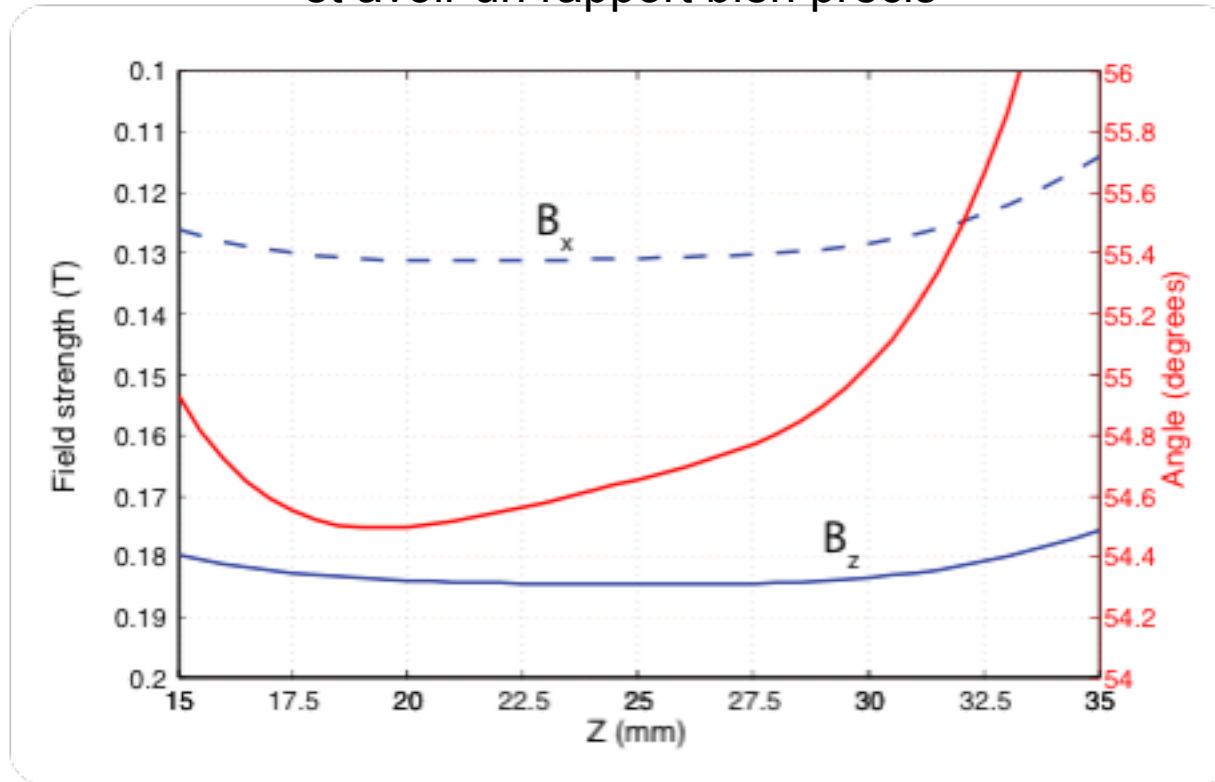
Poids < 1kg

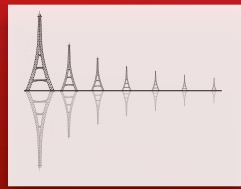
Cout : Très Faible !



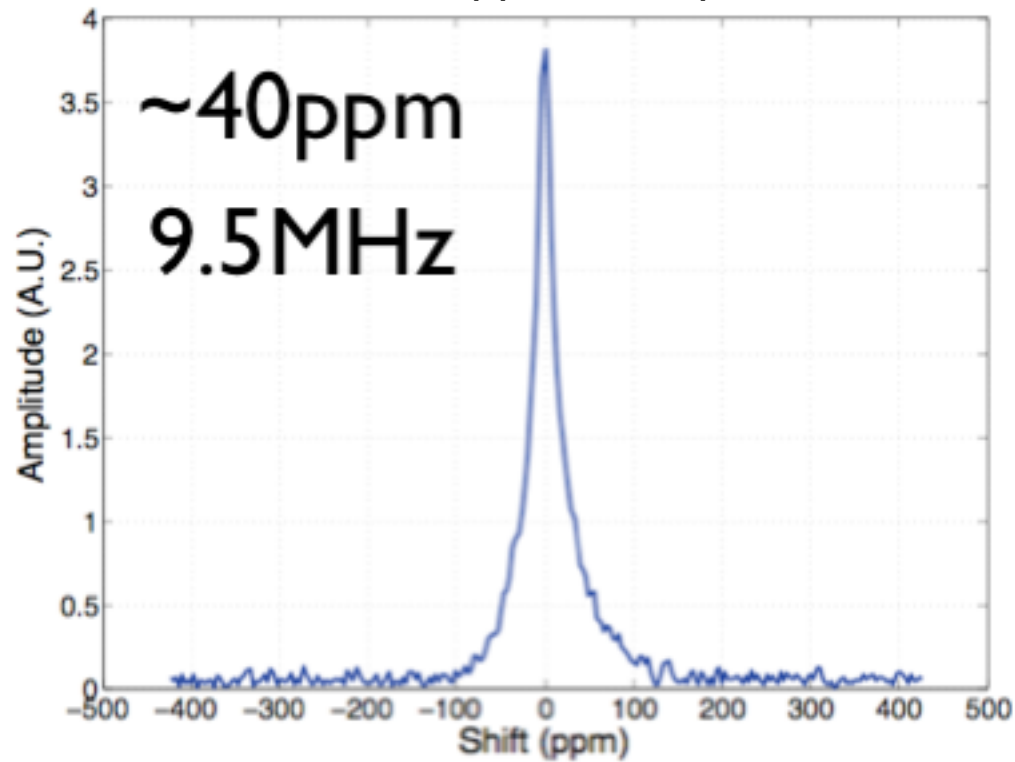


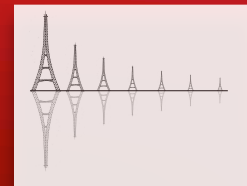
Défis: Les deux composantes doivent être homogènes et avoir un rapport bien précis



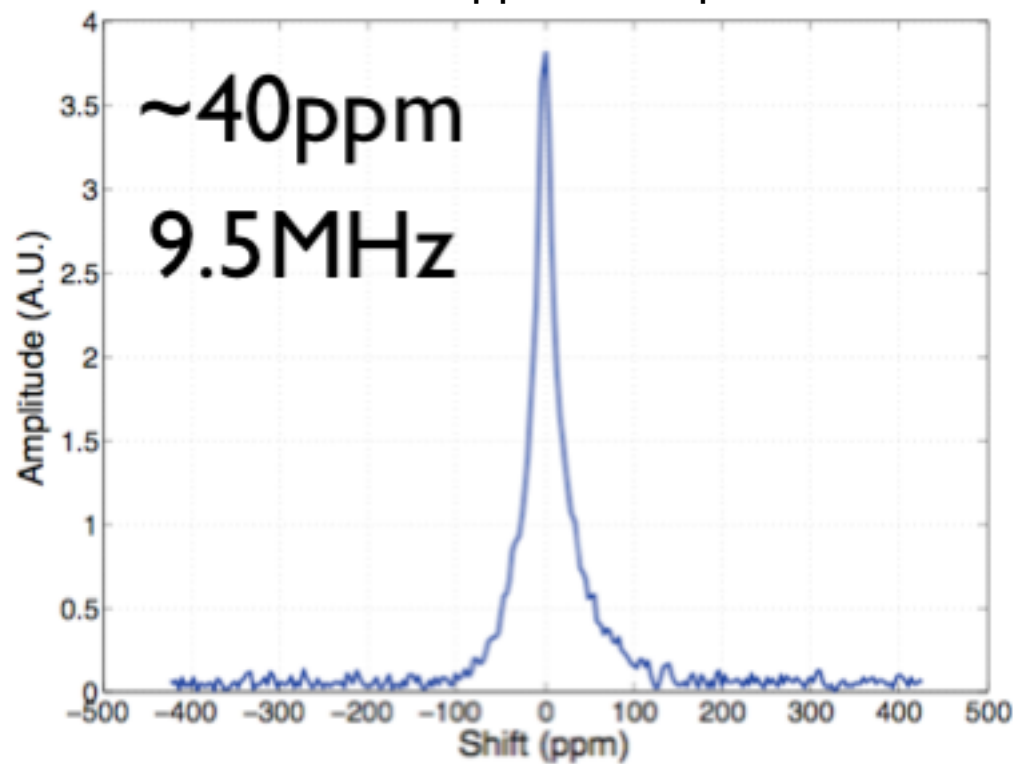


Défis: Les deux composantes doivent être homogènes
et avoir un rapport bien précis





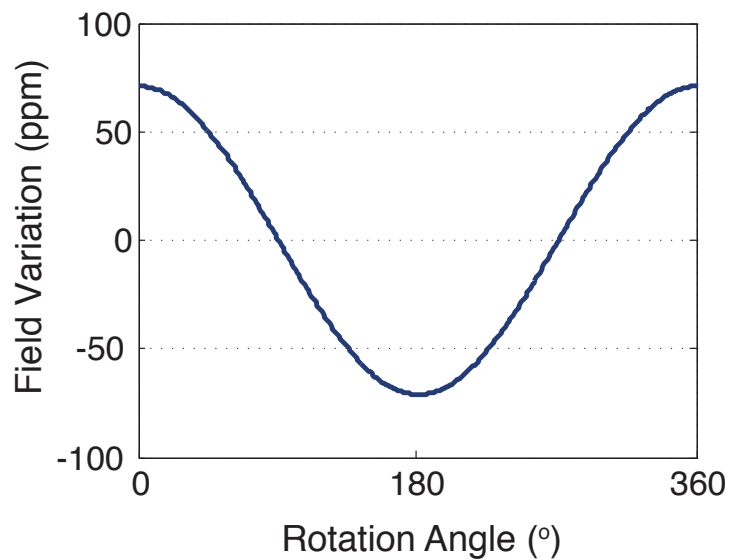
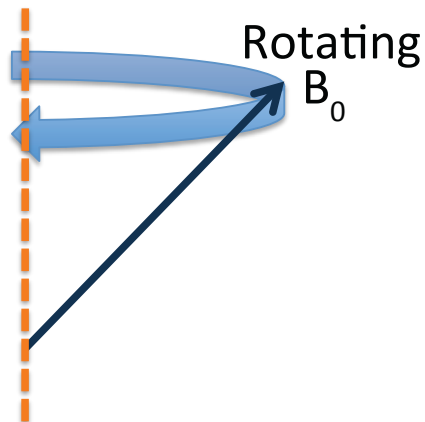
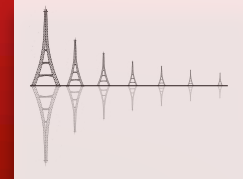
Défis: Les deux composantes doivent être homogènes et avoir un rapport bien précis



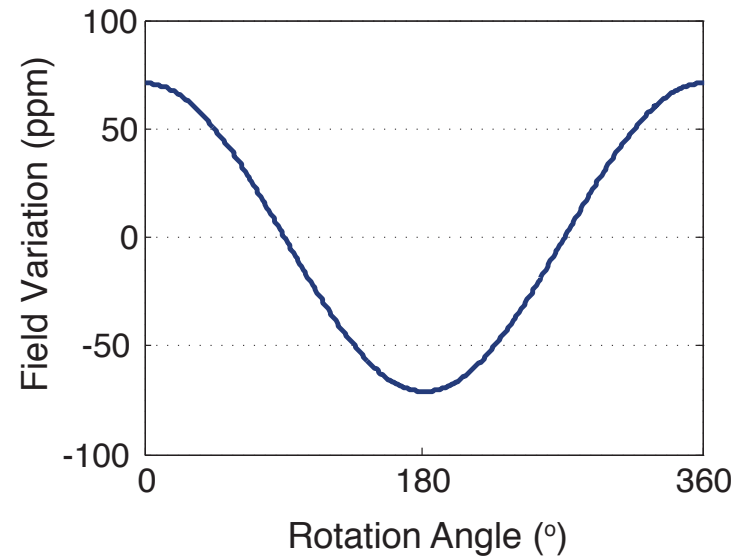
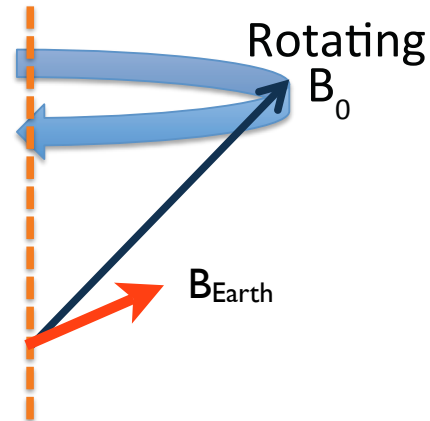
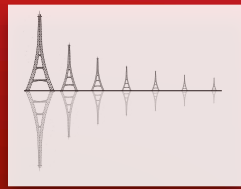
$$\theta = 54.7^\circ$$

$$|B| = 0.22 \text{ Tesla}$$

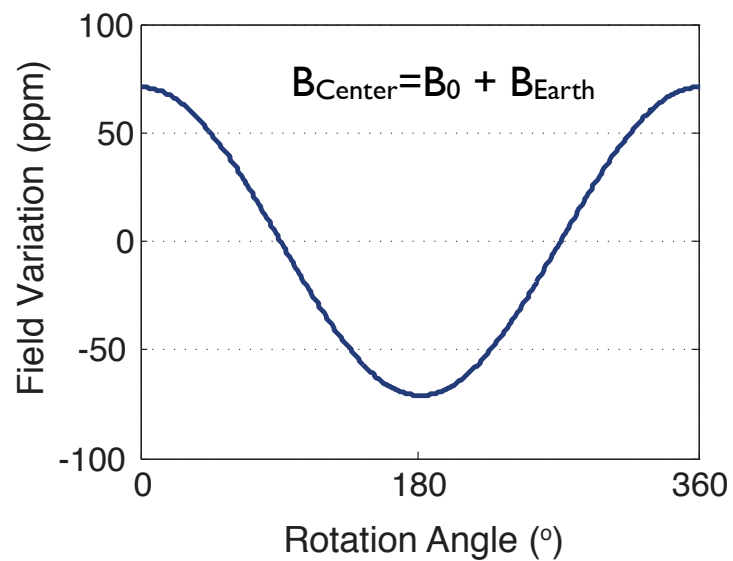
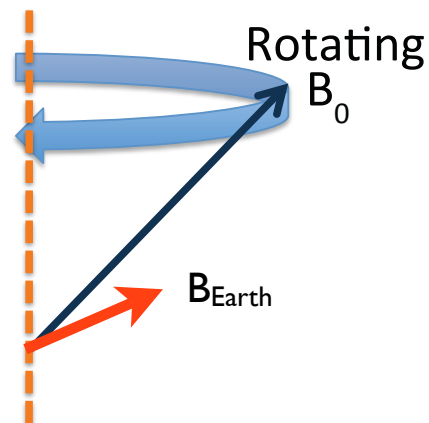
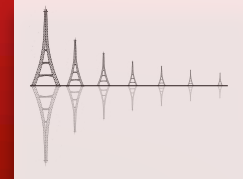
MODULATION DU CHAMP MAGNÉTIQUE NOUS SOMMES SUR LA TERRE !



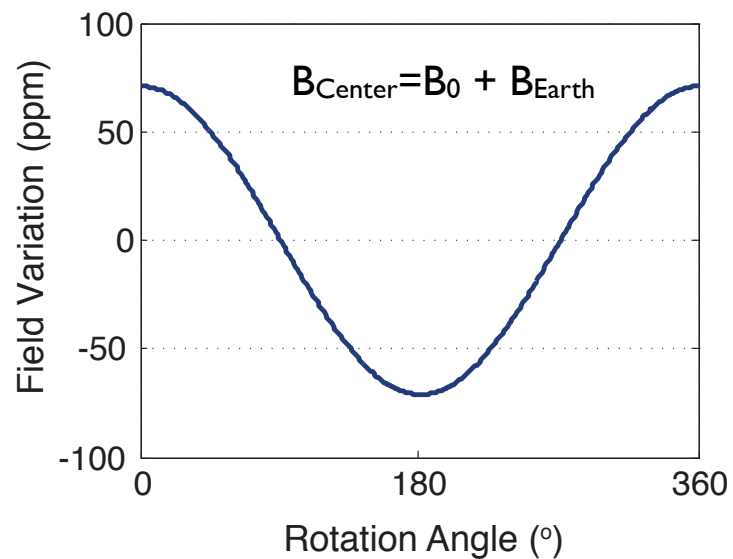
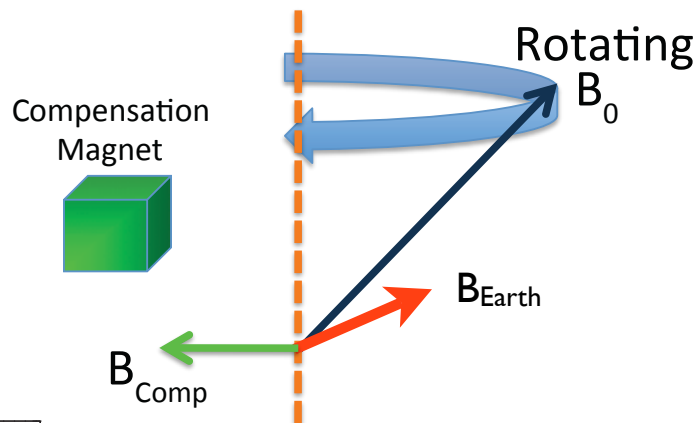
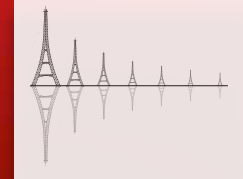
MODULATION DU CHAMP MAGNÉTIQUE NOUS SOMMES SUR LA TERRE !



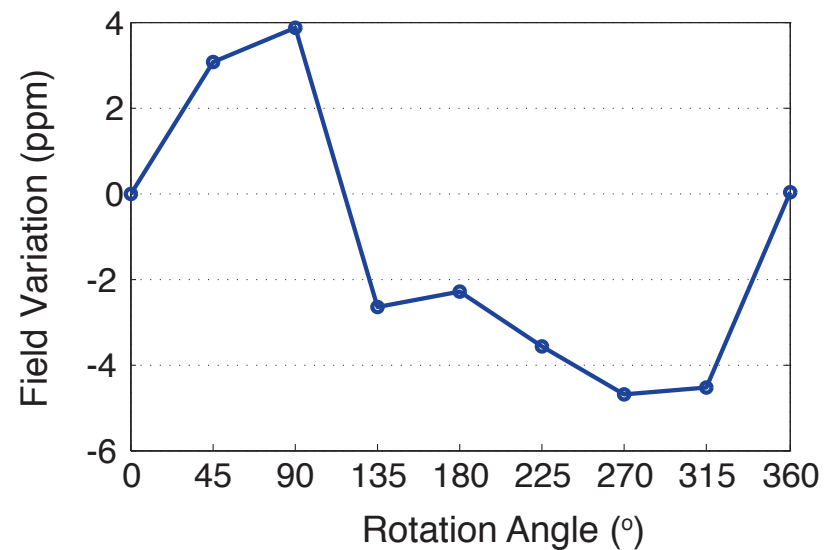
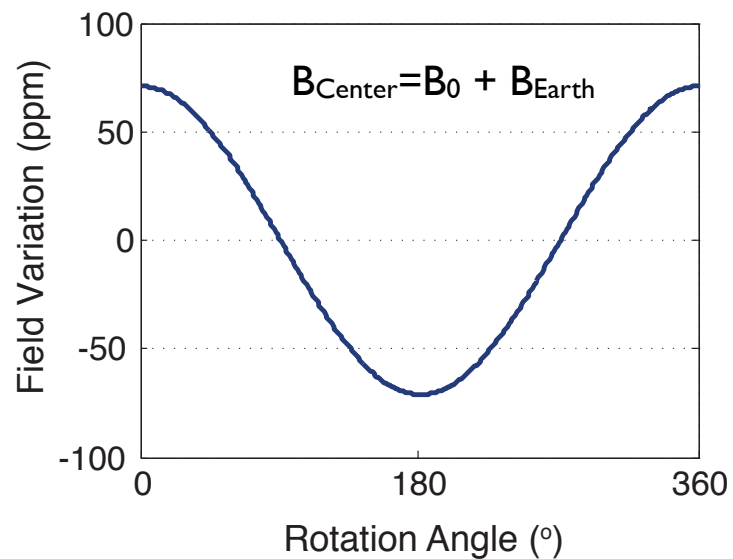
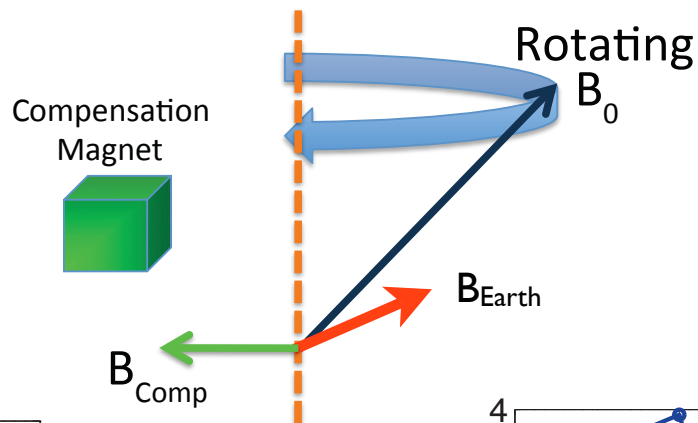
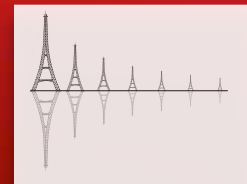
MODULATION DU CHAMP MAGNÉTIQUE NOUS SOMMES SUR LA TERRE !

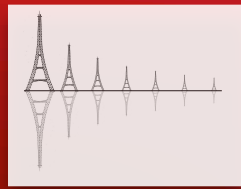


MODULATION DU CHAMP MAGNÉTIQUE NOUS SOMMES SUR LA TERRE !



MODULATION DU CHAMP MAGNÉTIQUE NOUS SOMMES SUR LA TERRE !





Spécifications

Composants non-magnétiques

Paliers pneumatiques

Rotation ≤ 50 Hz

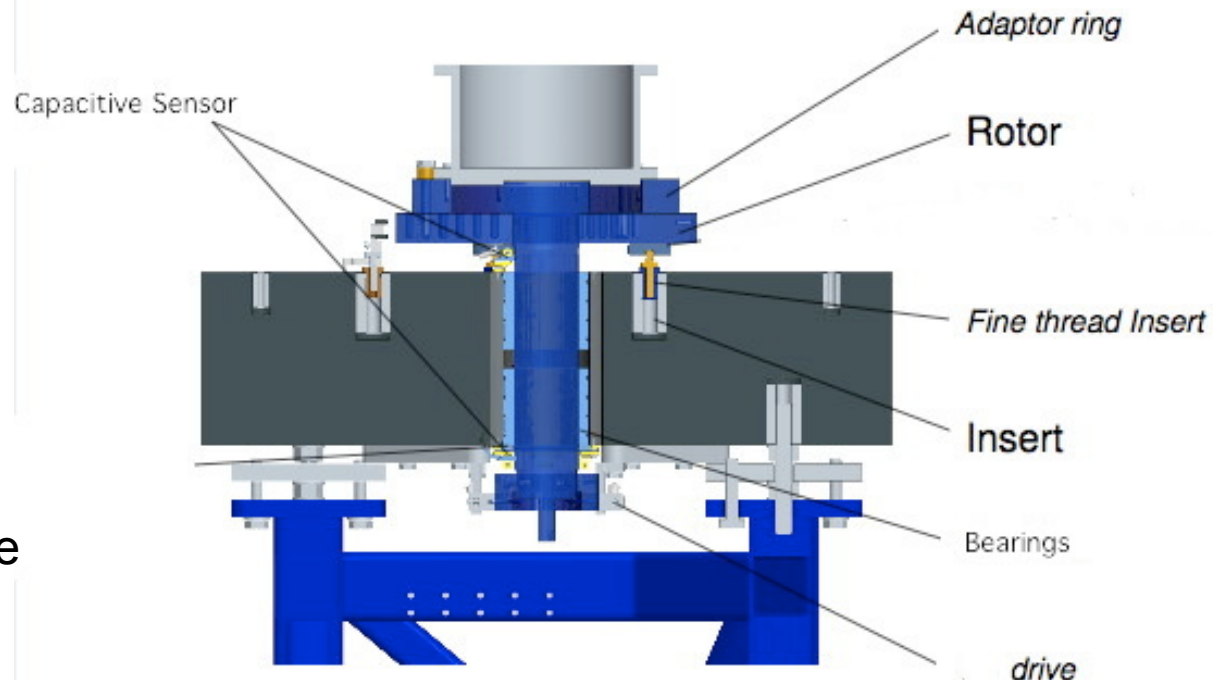
Stabilité $> 0.1\%$

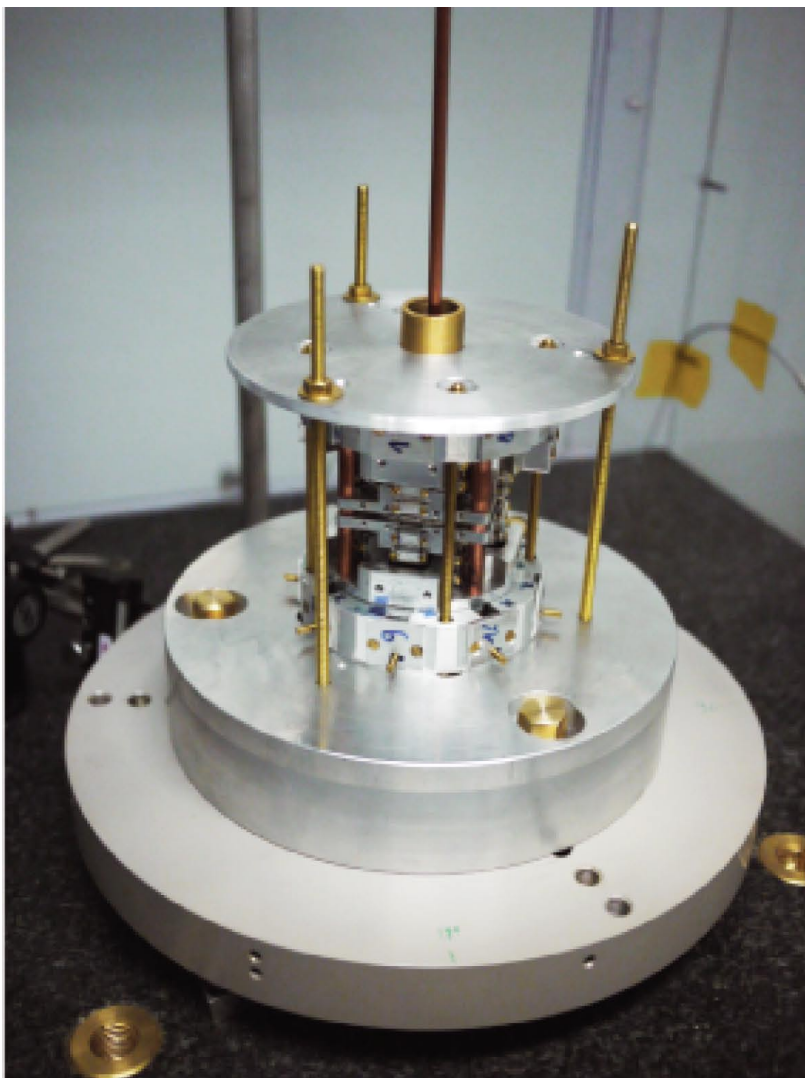
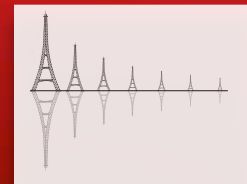
Poids < 100 kg

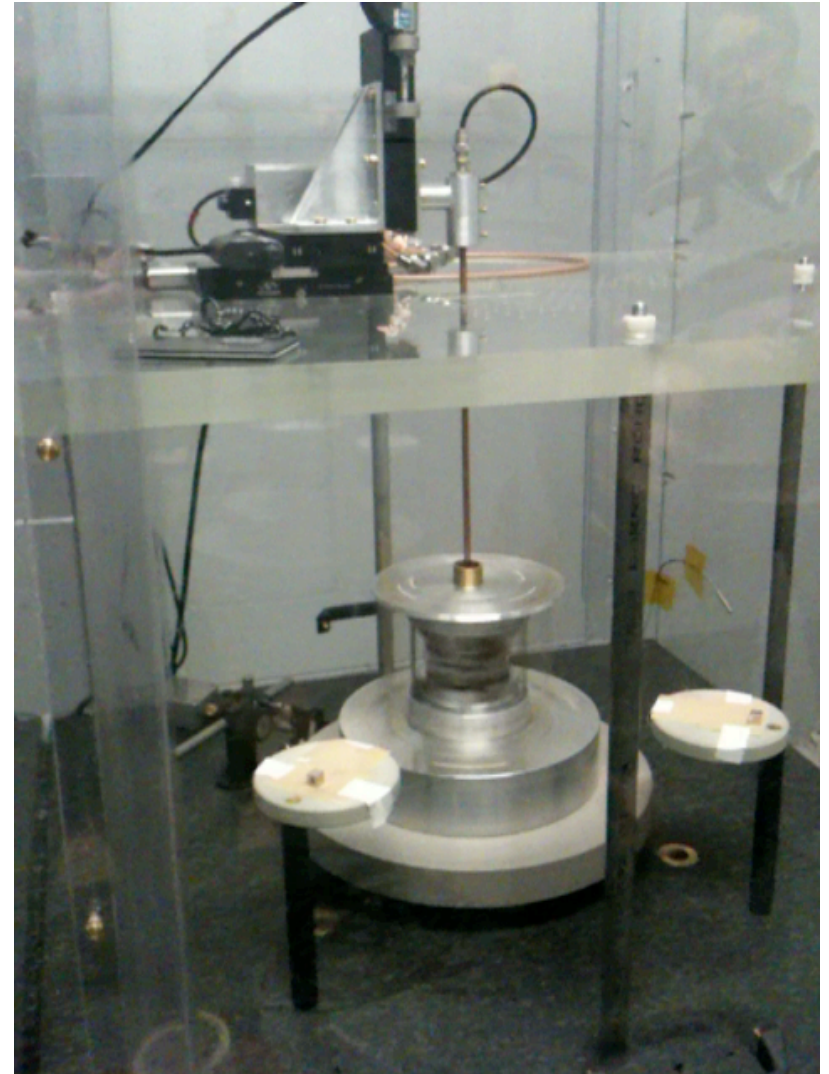
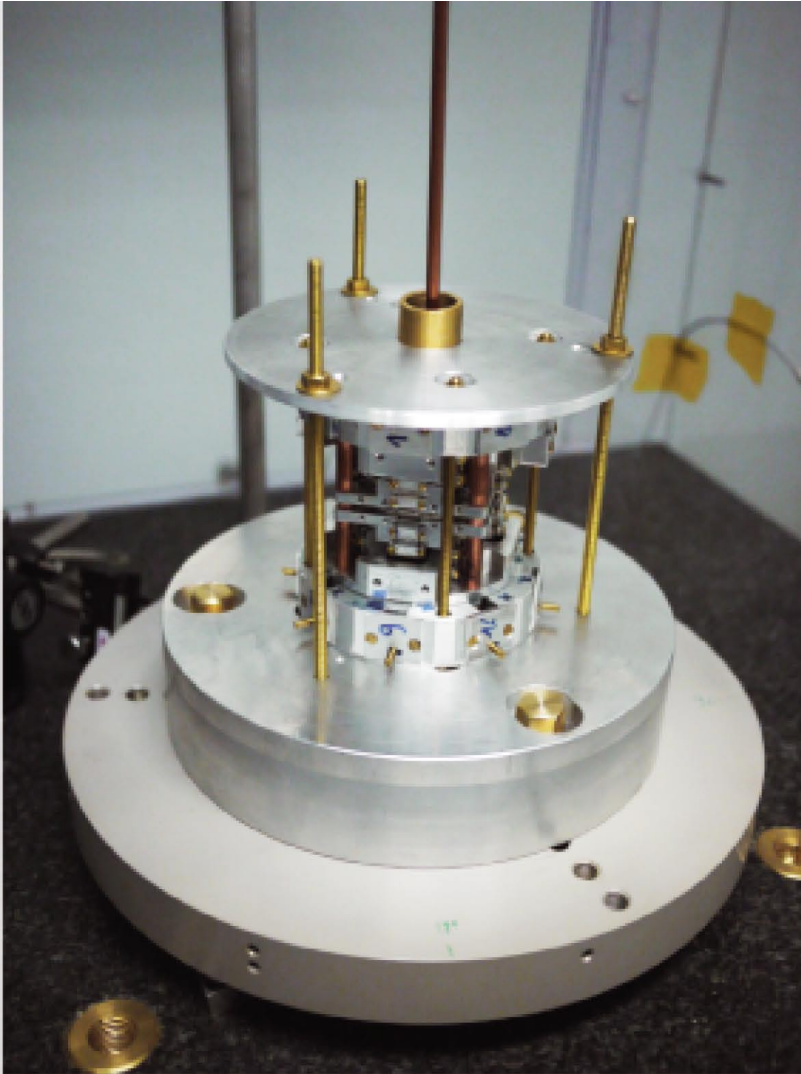
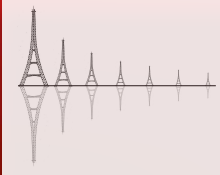
Sécurité: contrôle mieux que $10 \mu\text{m}$ de déplacement

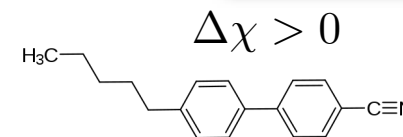
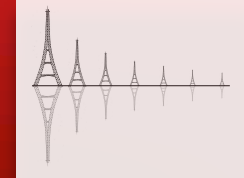
Bruit: moteur "mu-Shielded" ou turbine

Accélération: 0 à 50Hz dans < 50 s, (50kg charge).



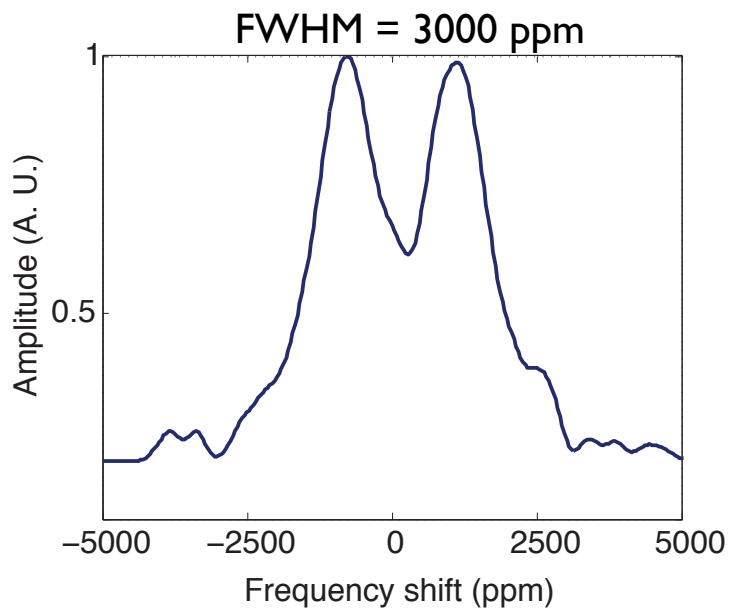
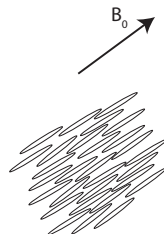






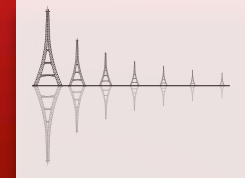
Champ Statique

^1H NMR @9.8MHz
capillaire i.d. 2mm



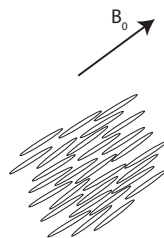
$$P_2(\cos 53.7^\circ) \approx 2.5\%$$

RMN EN CHAMP TOURNANT SUR UNE CRYSTAL LIQUIDE NEMATIC (5CB)

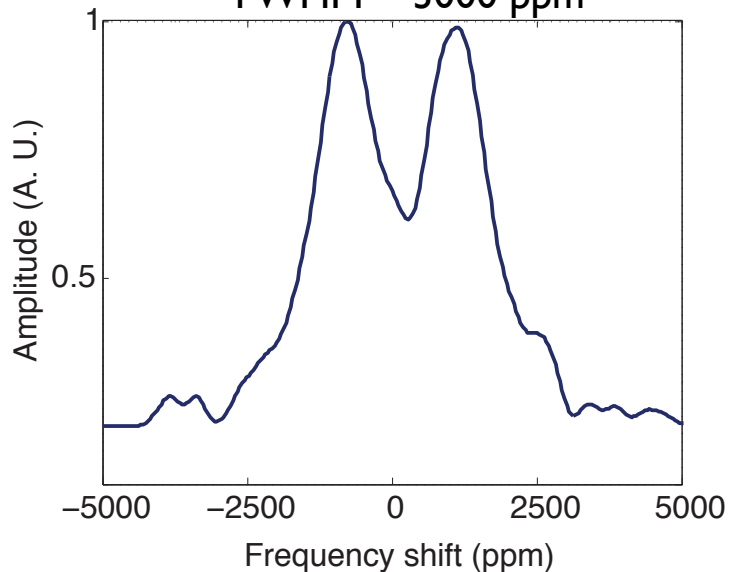


Champ Statique

^1H NMR @9.8MHz
capillaire i.d. 2mm

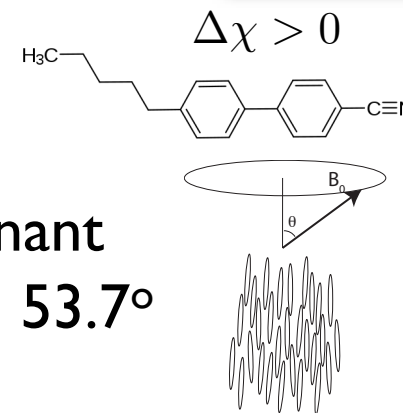


FWHM = 3000 ppm

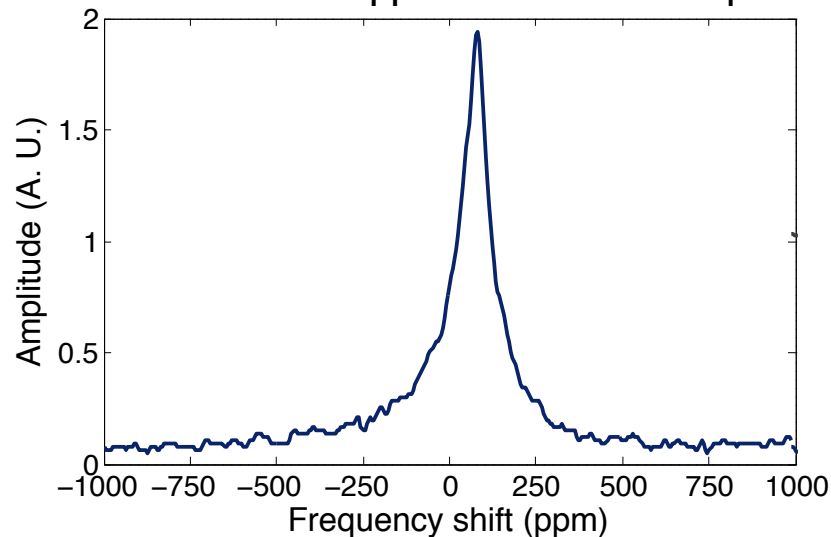


Champ Tournant

$\nu = 0.5\text{Hz}$, $\theta = 53.7^\circ$

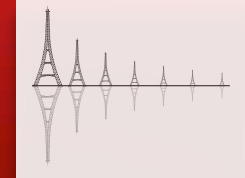


FWHM = 105 ppm = 3.5% du statique



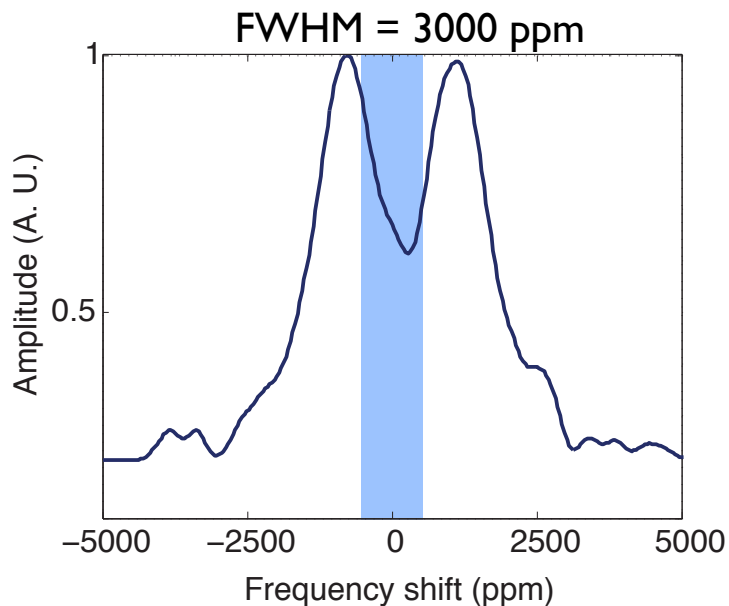
$$P_2(\cos 53.7^\circ) \approx 2.5\%$$

RMN EN CHAMP TOURNANT SUR UNE CRYSTAL LIQUIDE NEMATIC (5CB)



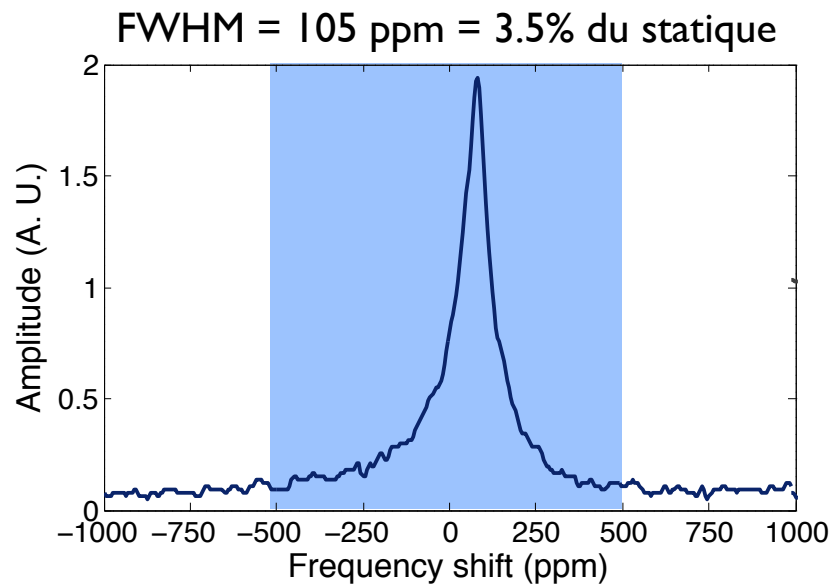
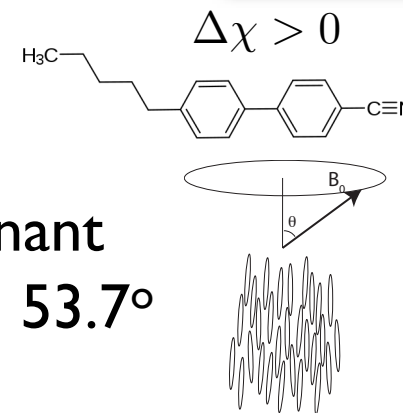
Champ Statique

^1H NMR @9.8MHz
capillaire i.d. 2mm

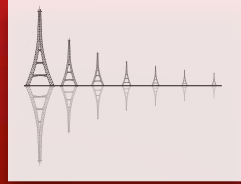


Champ Tournant

$\nu = 0.5\text{Hz}$, $\theta = 53.7^\circ$



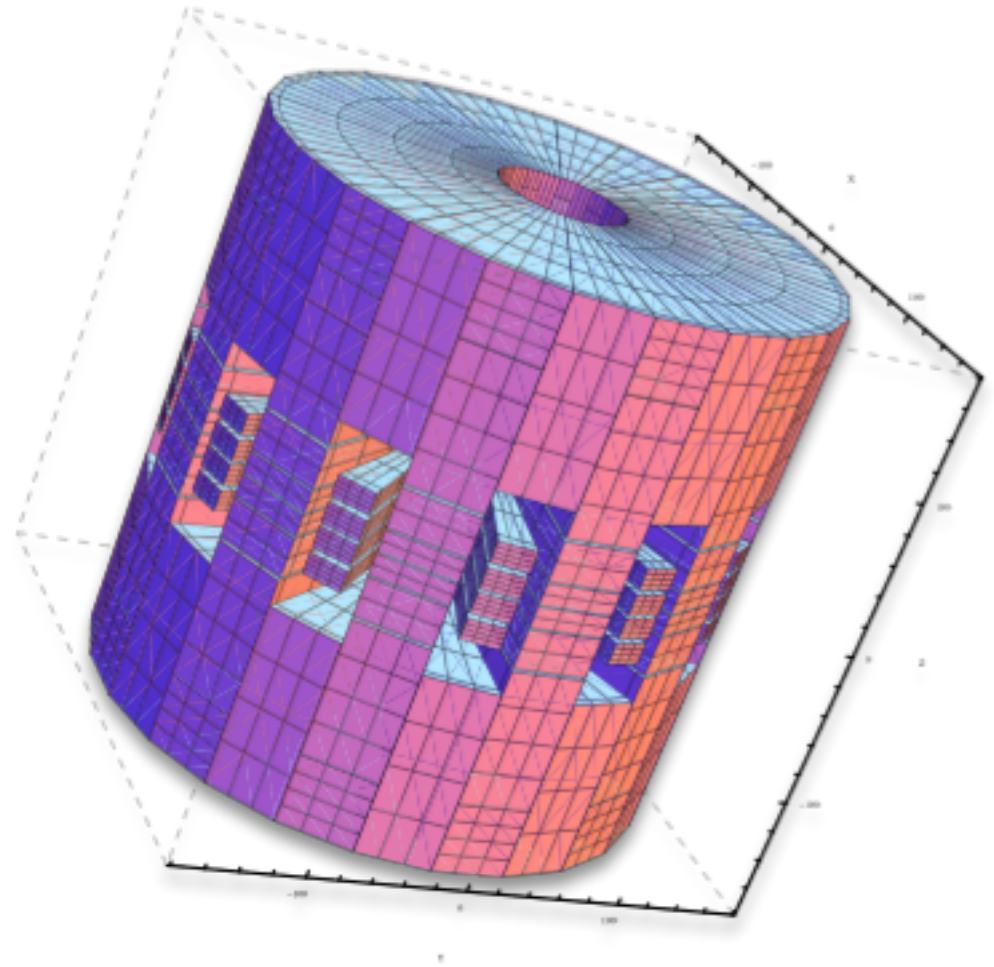
$$P_2(\cos 53.7^\circ) \approx 2.5\%$$



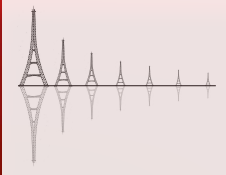
Spécifications:

- 1.0T @ angle magique, avec $B_r = 1.3T$
- 168 pièces magnétiques collées
- 200 kg de NdFeB
- 150 kg Mécanique de structure / ajustement
- Fréquence de rotation < 5 Hz
- 75 mm diamètre (trou libre)

$$\begin{aligned} B_0 &= 1.0 \text{ T @ } 54.7^\circ \\ B_x &= 0.8164 \text{ T} \\ B_z &= 0.5773 \text{ T} \end{aligned}$$



Conception mécanique : IRFU
Fabrication et réalisation aimant: Vacuumschmeltze



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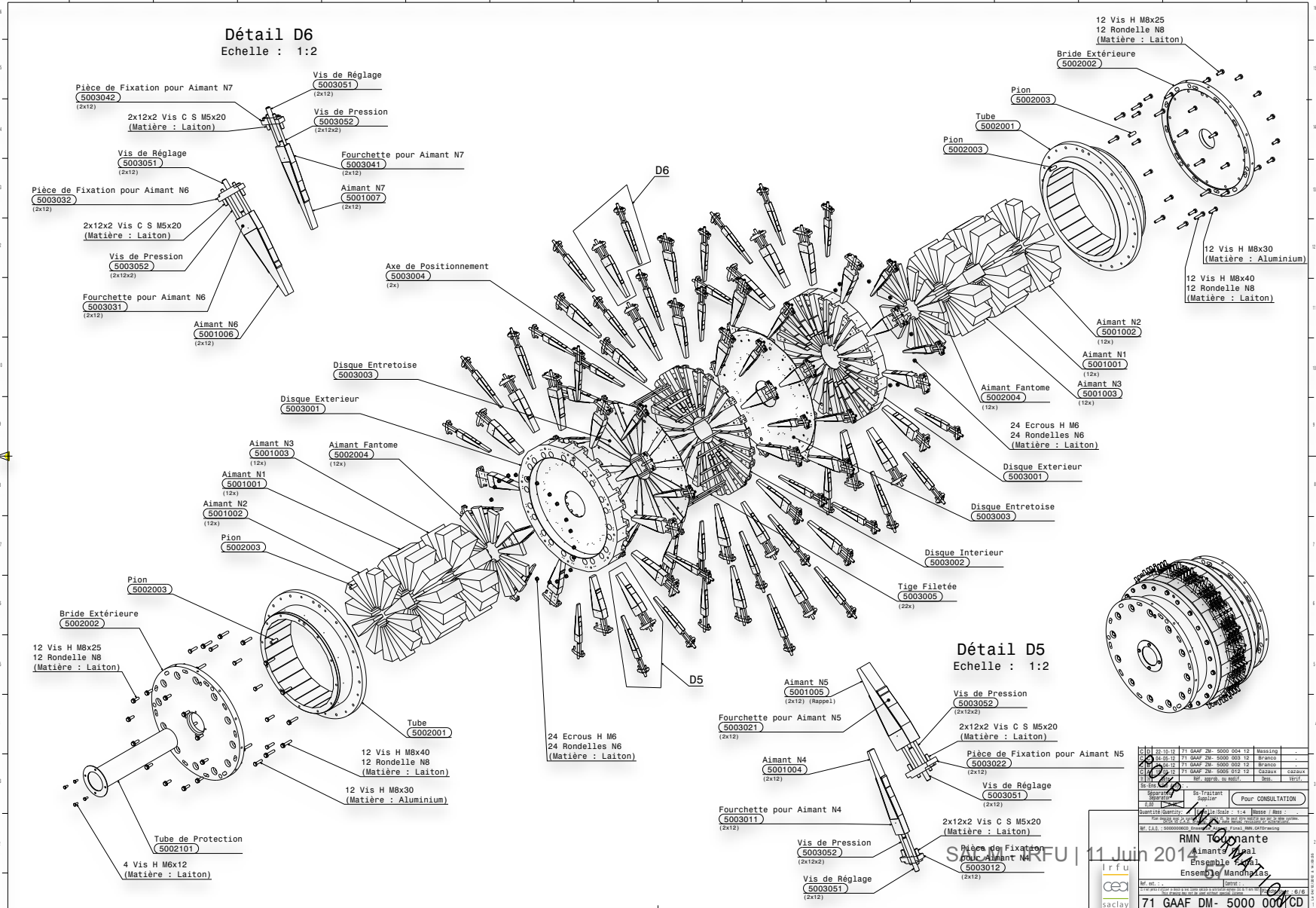
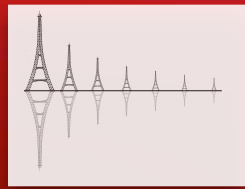
$$B_x = 0.8164 \text{ T}$$

$$B_z = 0.5773 \text{ T}$$



Conception mécanique : IRFU
Fabrication et réalisation aimant: Vacuumschmeltze

UNE STRUCTURE COMPLIQUÉE

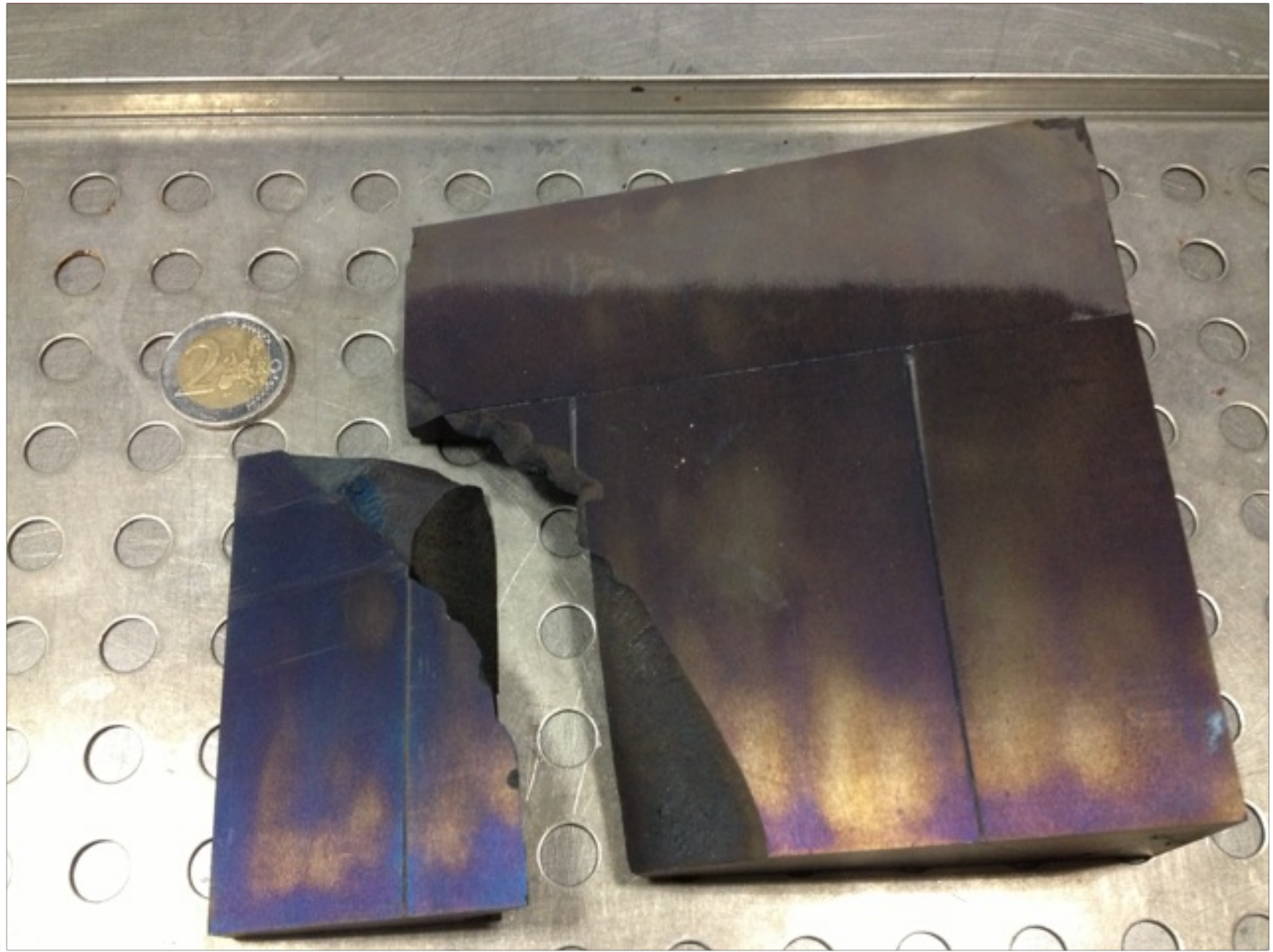


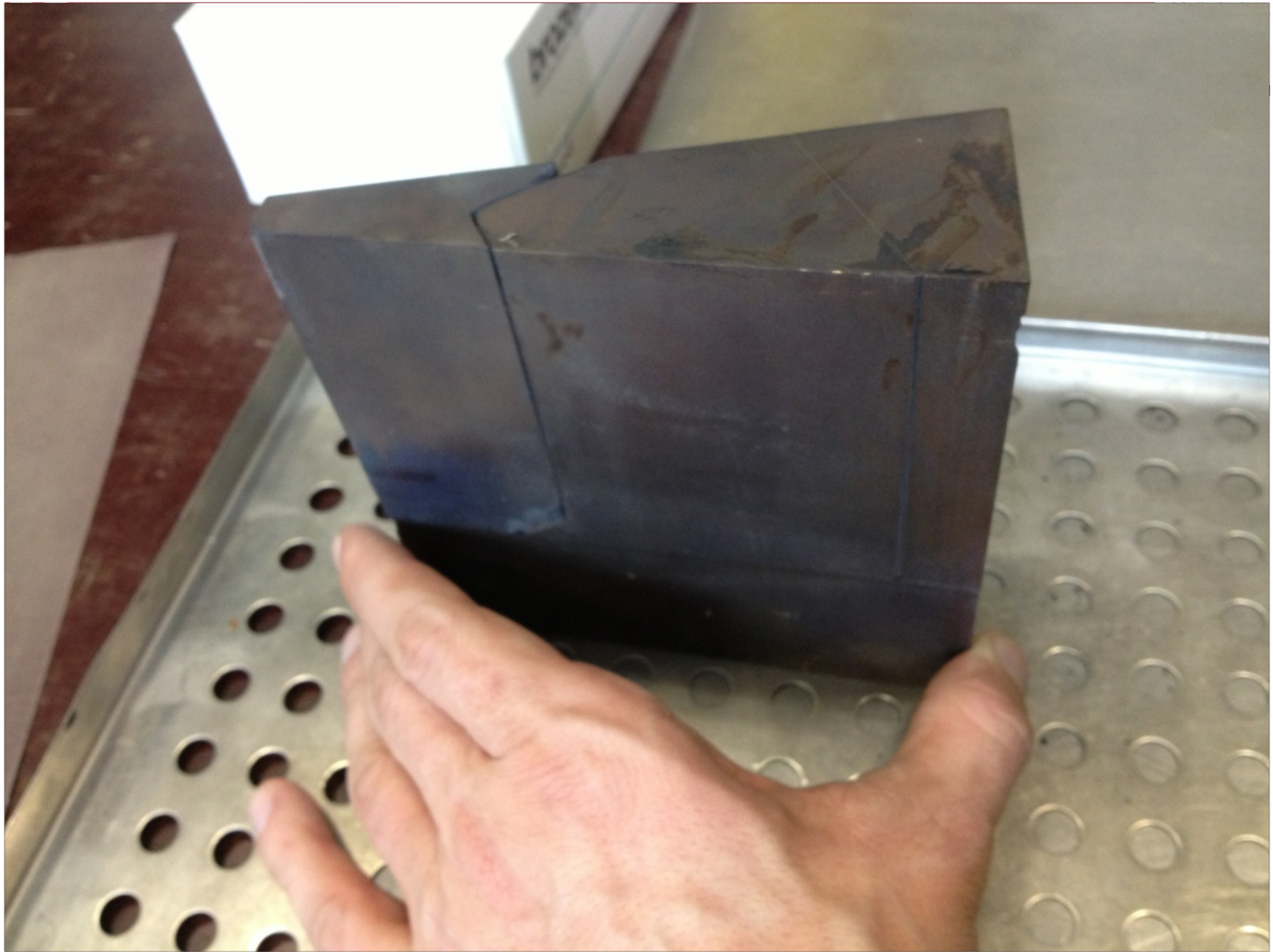
Cl.	Quantité	Designation	Ref. Client	Ref. Interne	Statut	Observations
01	1	12 Vis H M8x25	71 GAAF DM- 5000 004 12	Mission		
02	1	12 Rondelle N8	71 GAAF DM- 5000 003 12	Brancu		
03	1	12 Vis H M8x30	71 GAAF DM- 5000 005 12	Brancu		
04	1	12 Vis H M8x40	71 GAAF DM- 5000 012 12	Cazaux		
05	1	12 Rondelle N8	71 GAAF DM- 5000 011 12	Brancu		
06	1	12 Vis H M8x25	71 GAAF DM- 5000 004 12	Mission		
07	1	12 Rondelle N8	71 GAAF DM- 5000 003 12	Brancu		
08	1	12 Vis H M8x30	71 GAAF DM- 5000 005 12	Brancu		
09	1	12 Vis H M8x40	71 GAAF DM- 5000 012 12	Cazaux		
10	1	12 Rondelle N8	71 GAAF DM- 5000 011 12	Brancu		

RMN 160mmte
Ensemble d'aimants
Ensemble Mandriles

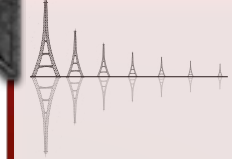
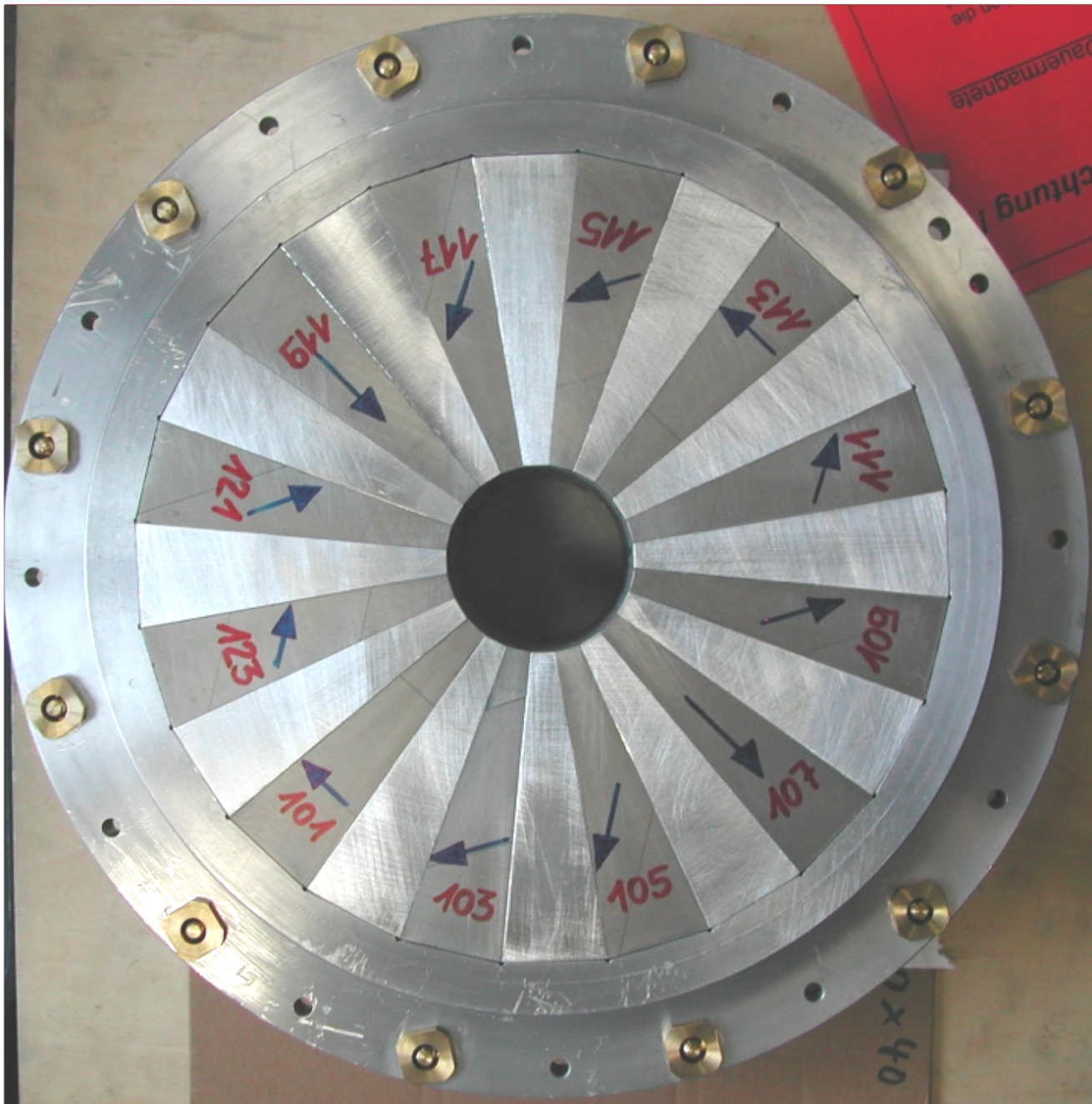
11 Juin 2014

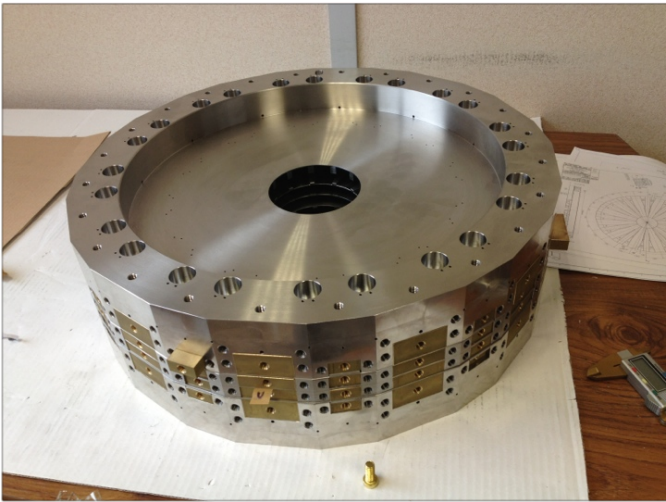
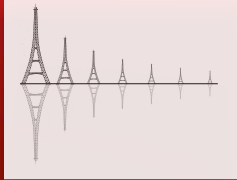
71 GAAF DM- 5000 000/CD

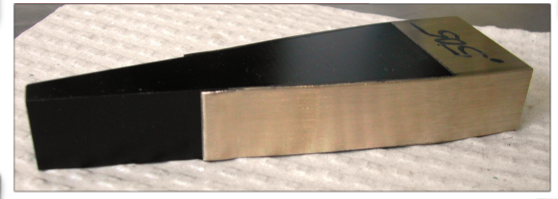
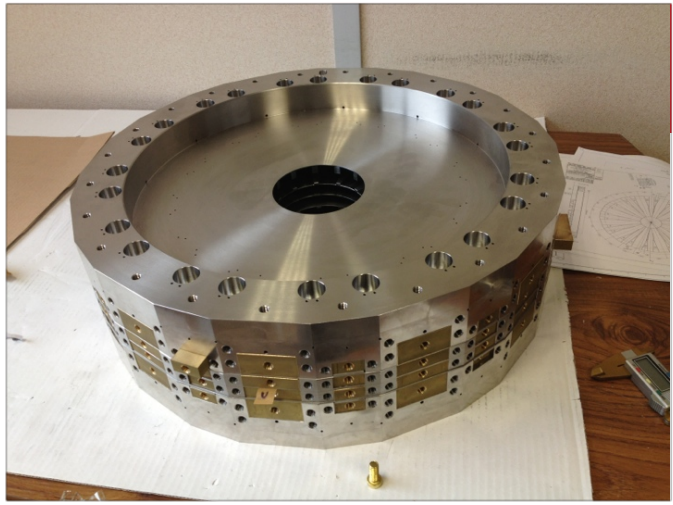


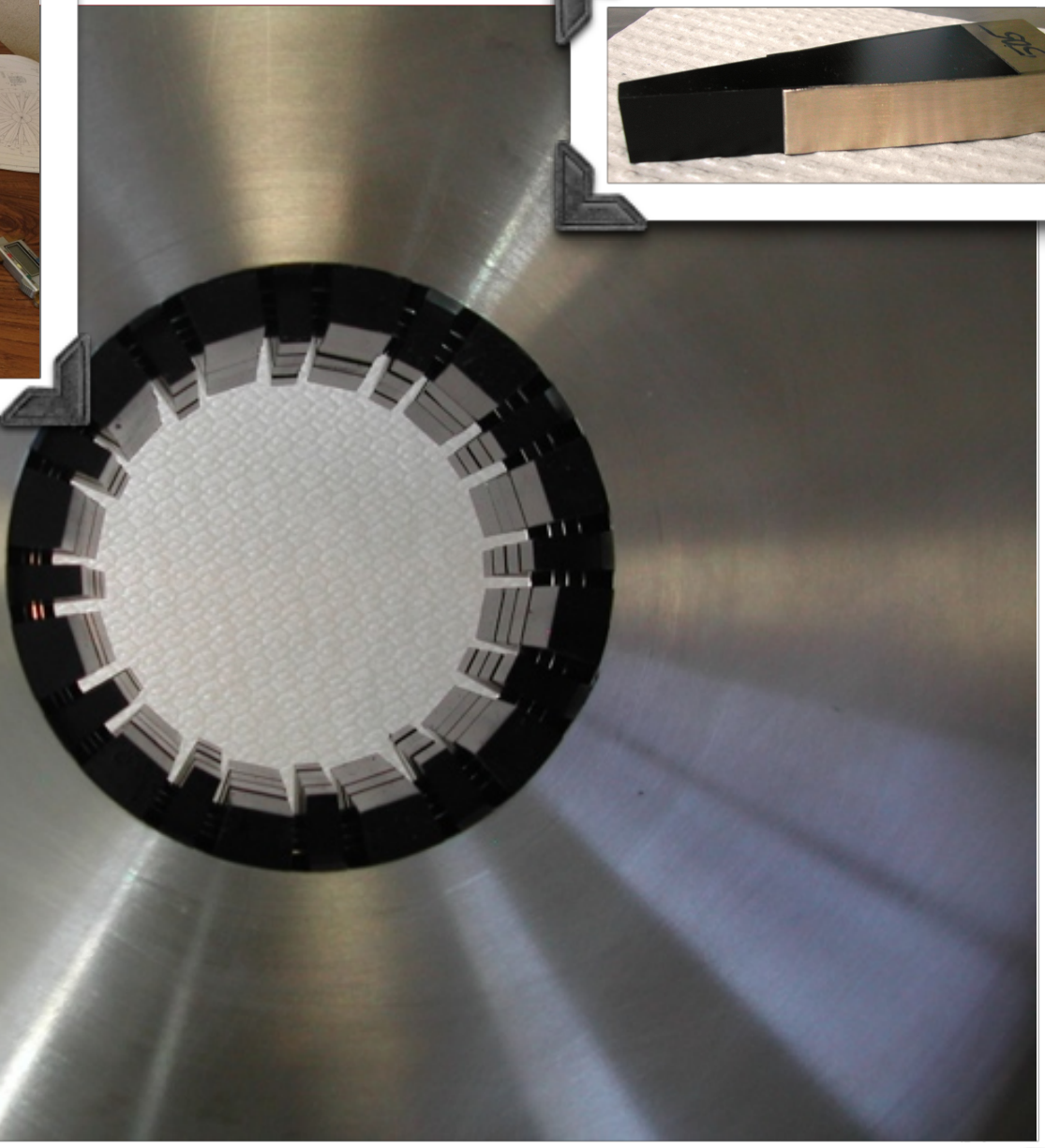
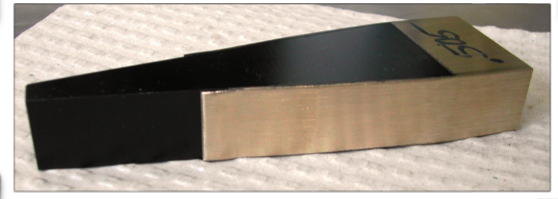
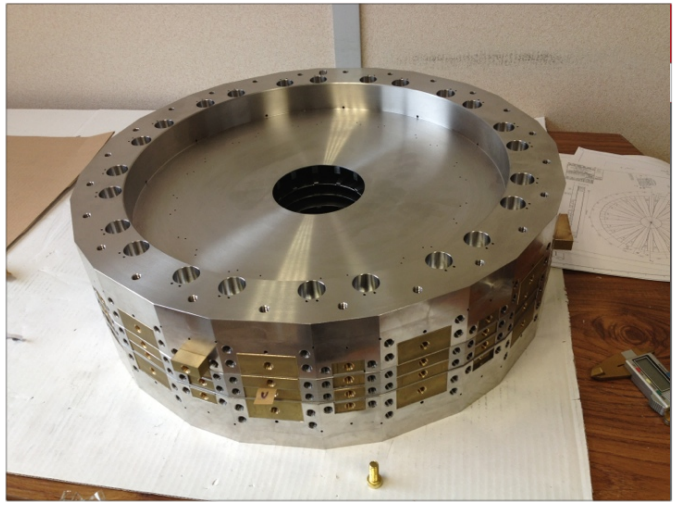


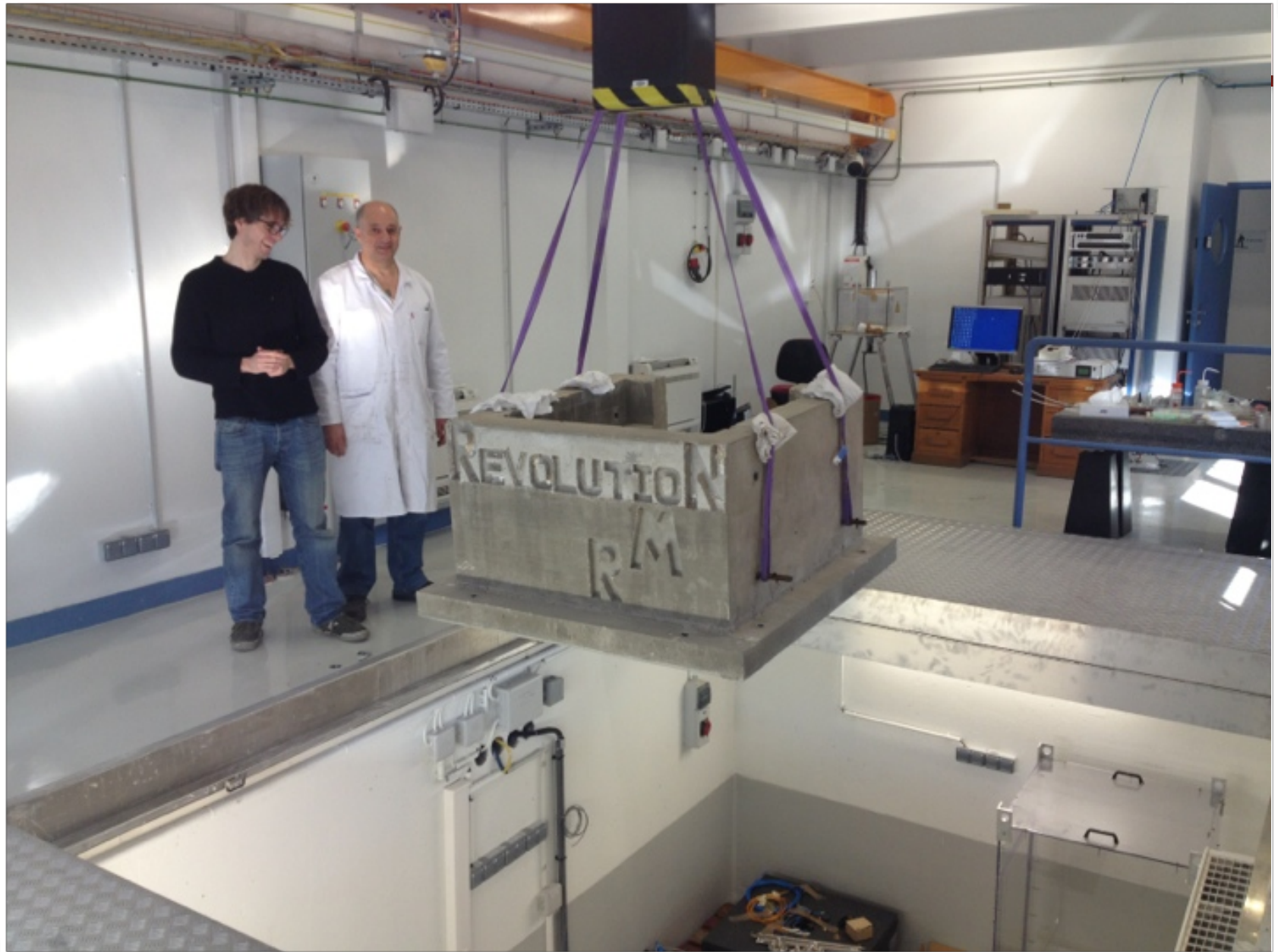


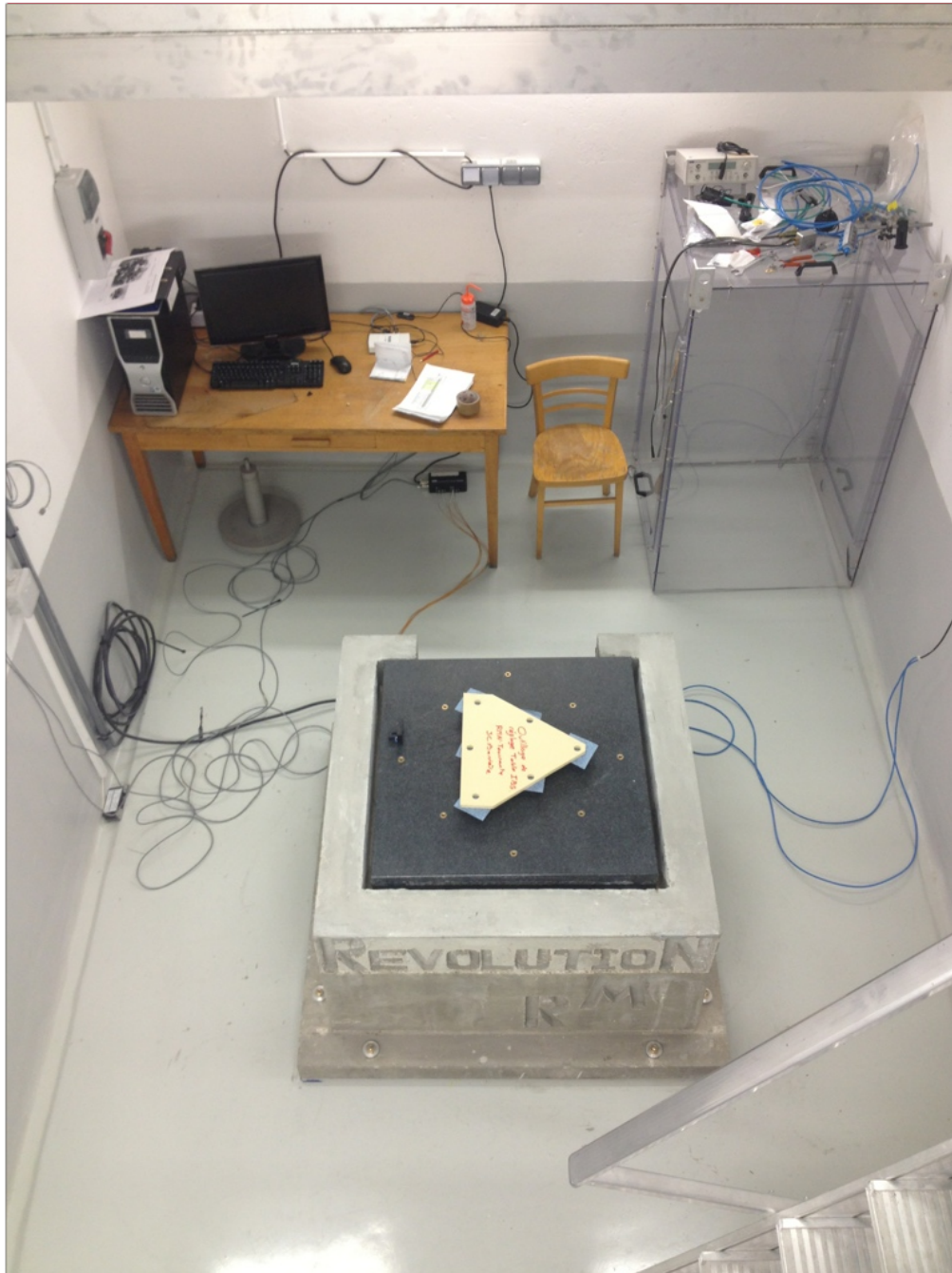
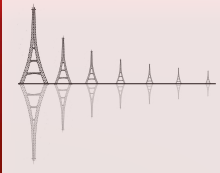




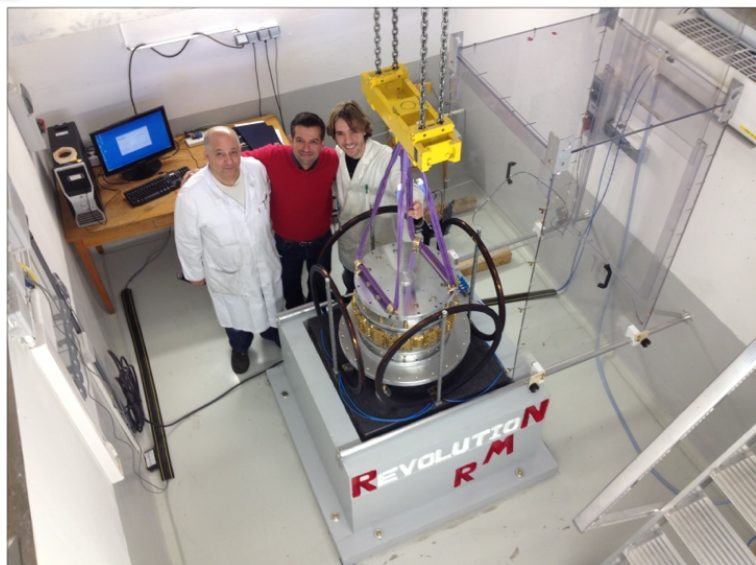
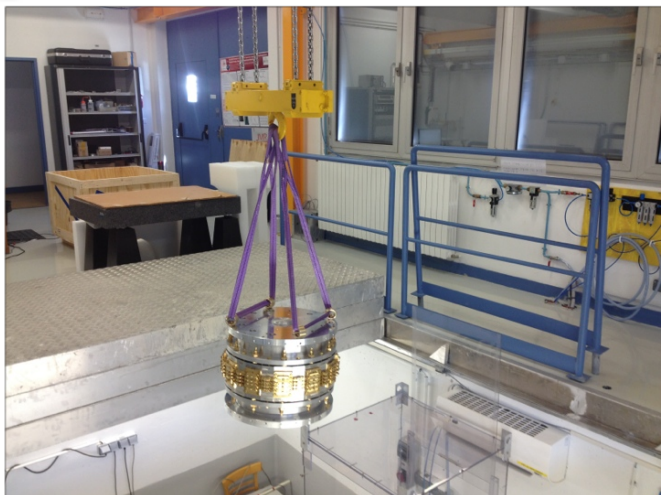
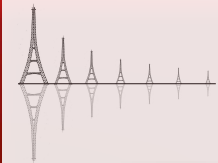




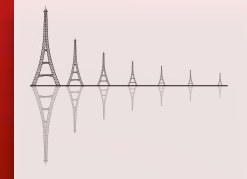




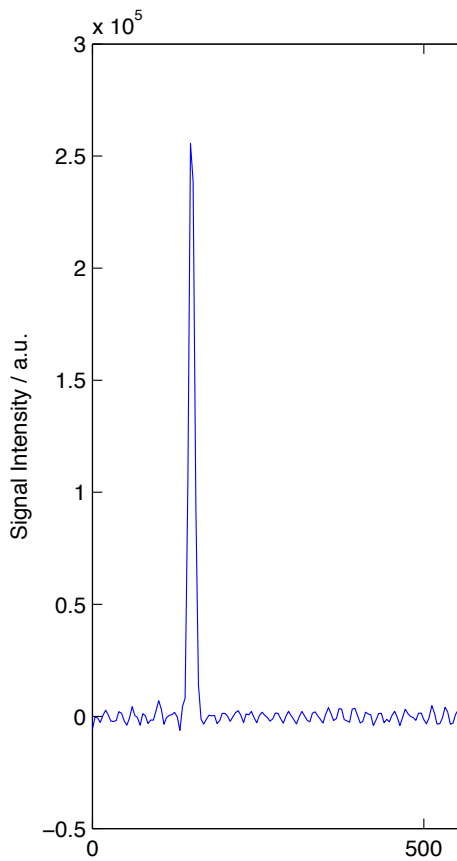




PREMIERS RÉSULTATS RMN

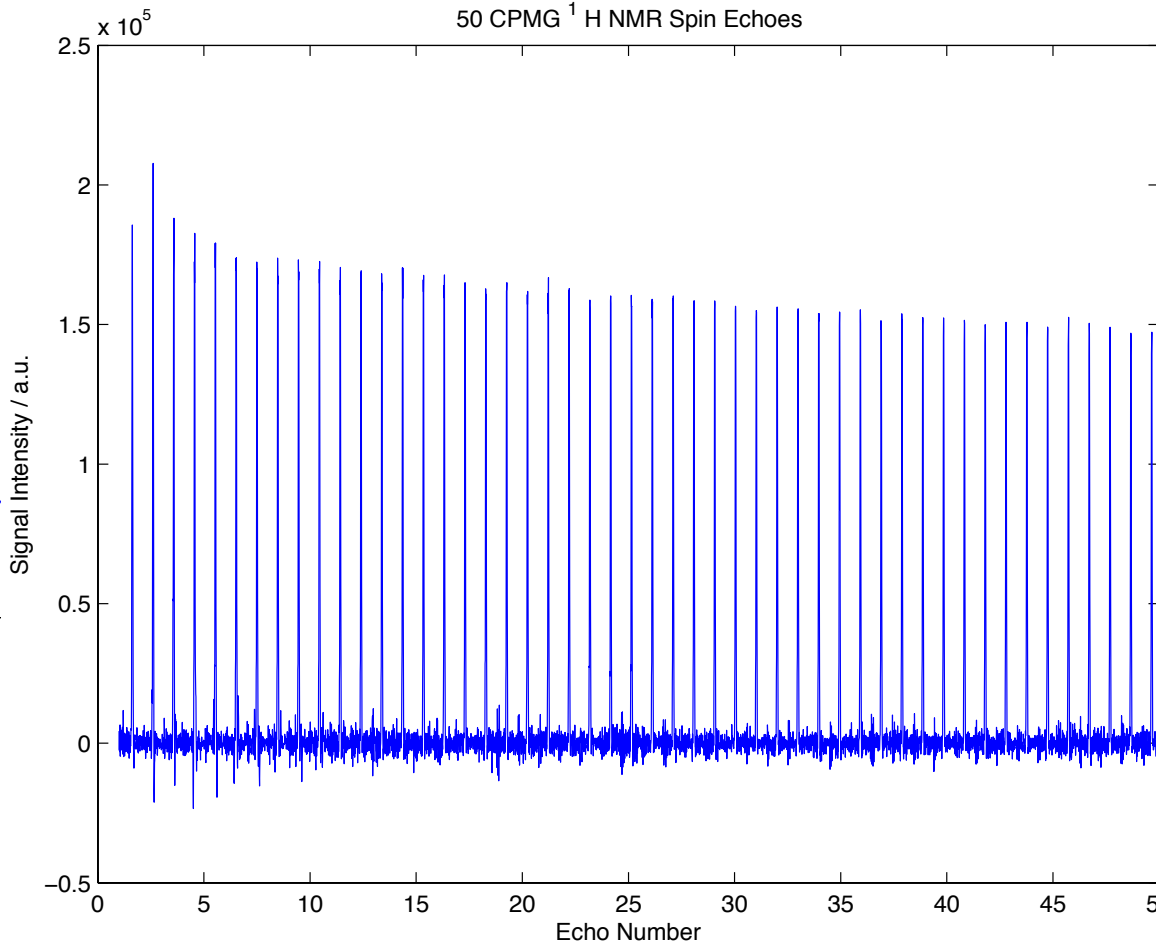


First ^1H NMR Spin Echo

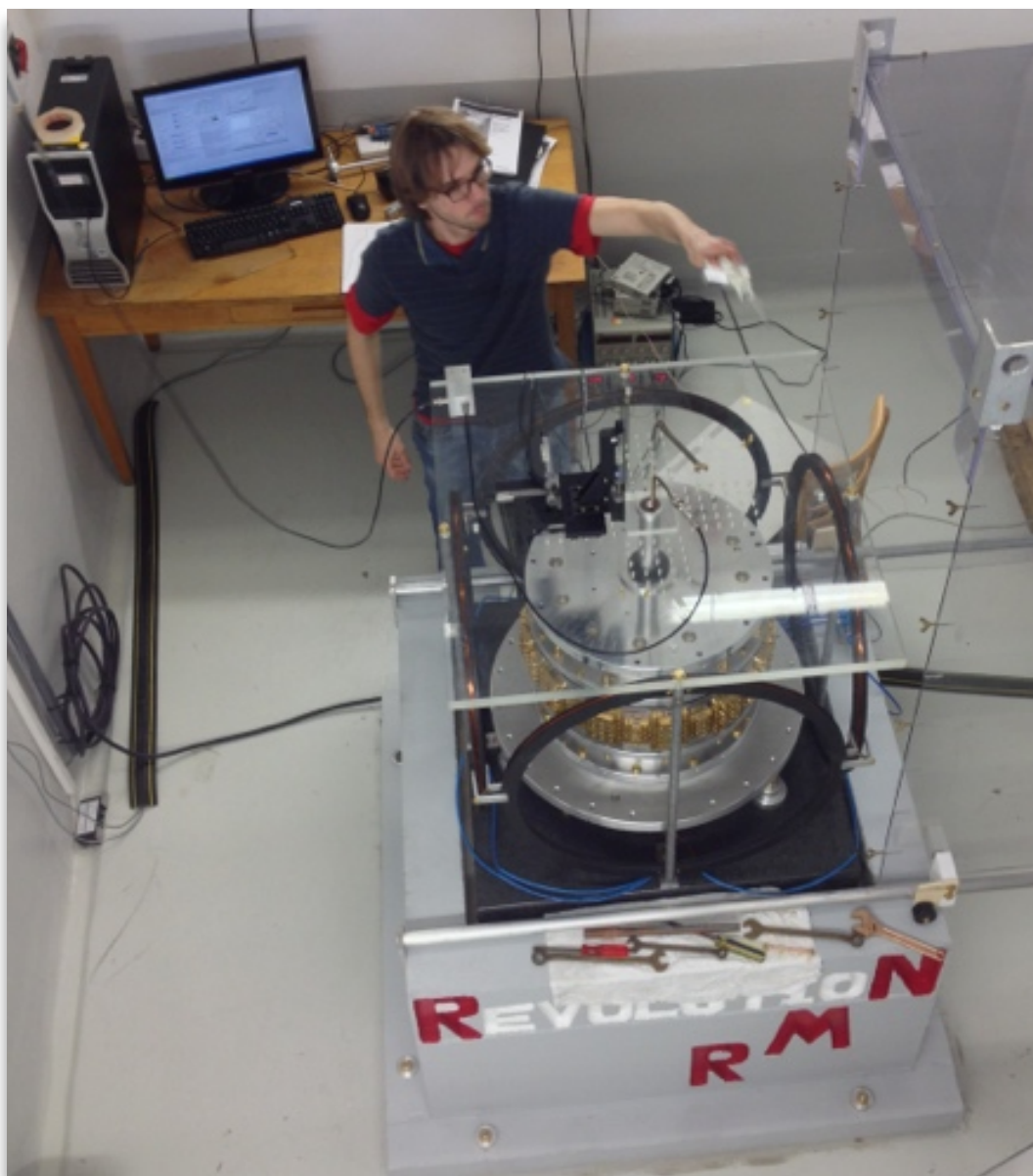
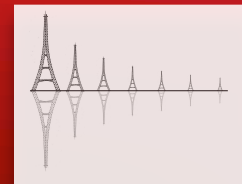


Fréquence de Larmor
43.15 MHz

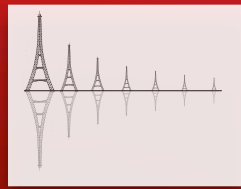
50 CPMG ^1H NMR Spin Echoes

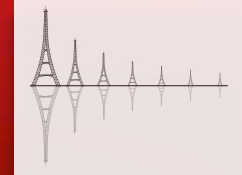


RESONANCE MAGNÉTIQUE NUCLÉAIRE EN CHAMP INCLINÉ

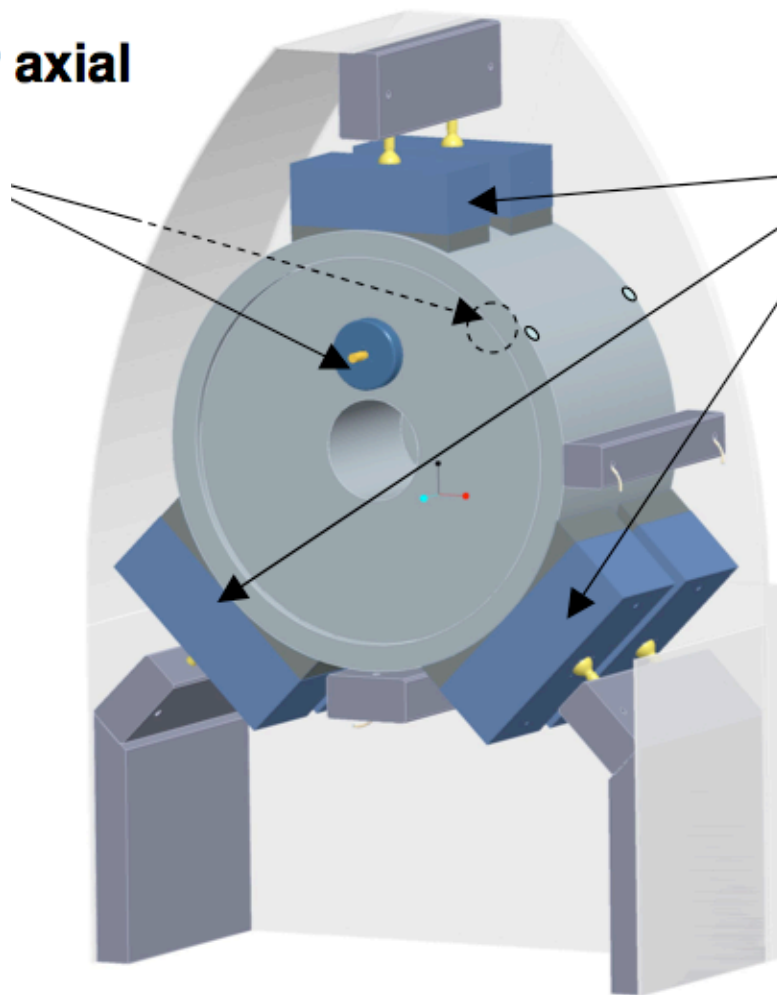


I HAVE A DREAM !





Palliers à air axial



Pallier à air radial



The Sakellariou group



Micro-bobines

Alan Wong
Xiaonan Li
Jacques-Francois Jacquinot

Aimants / Instrumentation

Javier Alonso
Cedric Hugon

Applications

Anne Soleilhavoup
Kuldeep Panesar

Instrumentation / Relaxometrie

Chingyu Chou

Usinage / Montage / Ajustement

Angelo Guiga

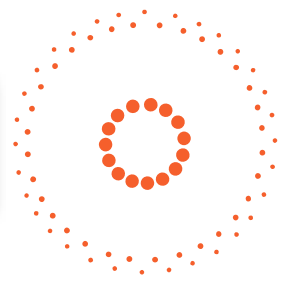
Collaborateurs



G. Aubert
S. Cazaux
J-C. Barriere
D. Loiseau
M. Massinger
P. Daniel-Thomas
P. Hardy
A. Branco
et autres !

University of Bergen:

R. Lewis
J. Seland



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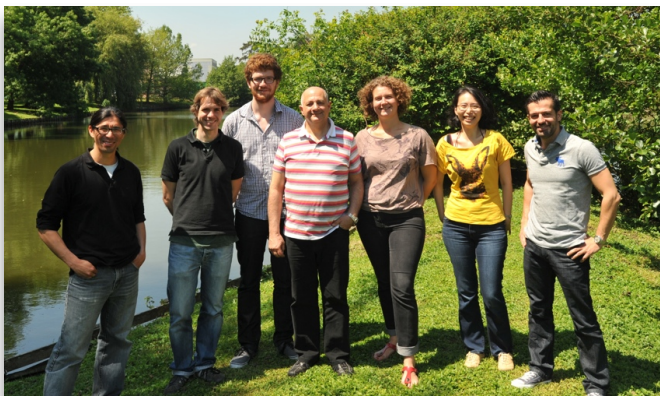
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Visitez nous: dsakellariou.free.fr



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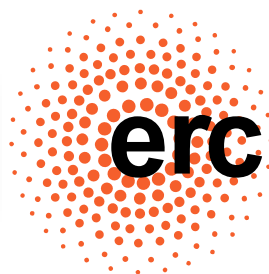
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