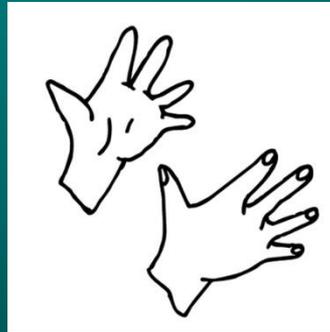


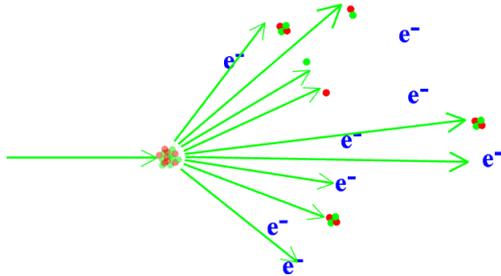
# La Physique des Accélérateurs



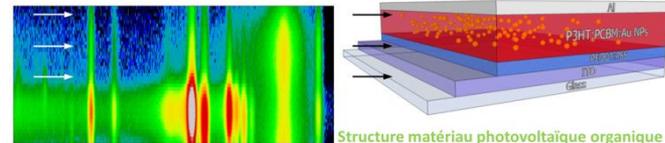
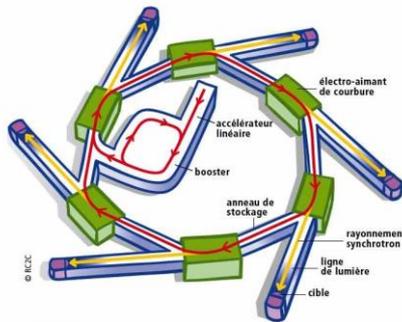
... avec les mains

# Utilisations

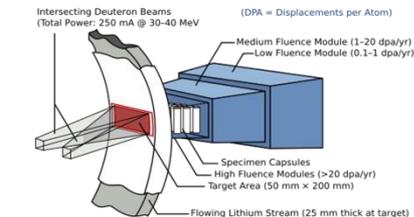
## Etude de la matière → collisions



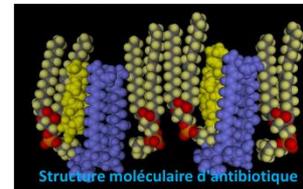
## Production rayonnement synchrotron



## Irradiation

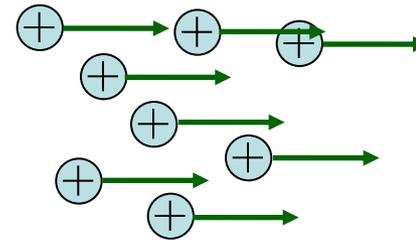
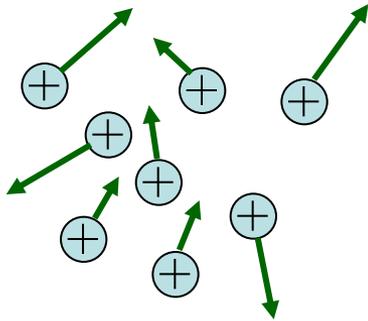


Etude nouveau matériau pour la fusion thermonucléaire

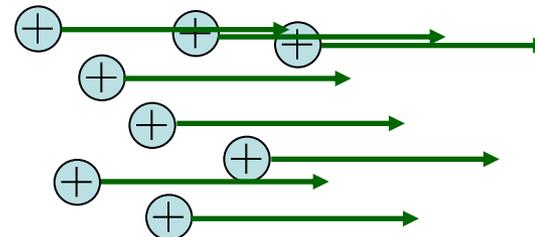


# Faisceau accéléré

**Faisceau** : ensemble de particules **chargées** douées d'une **vitesse d'ensemble**

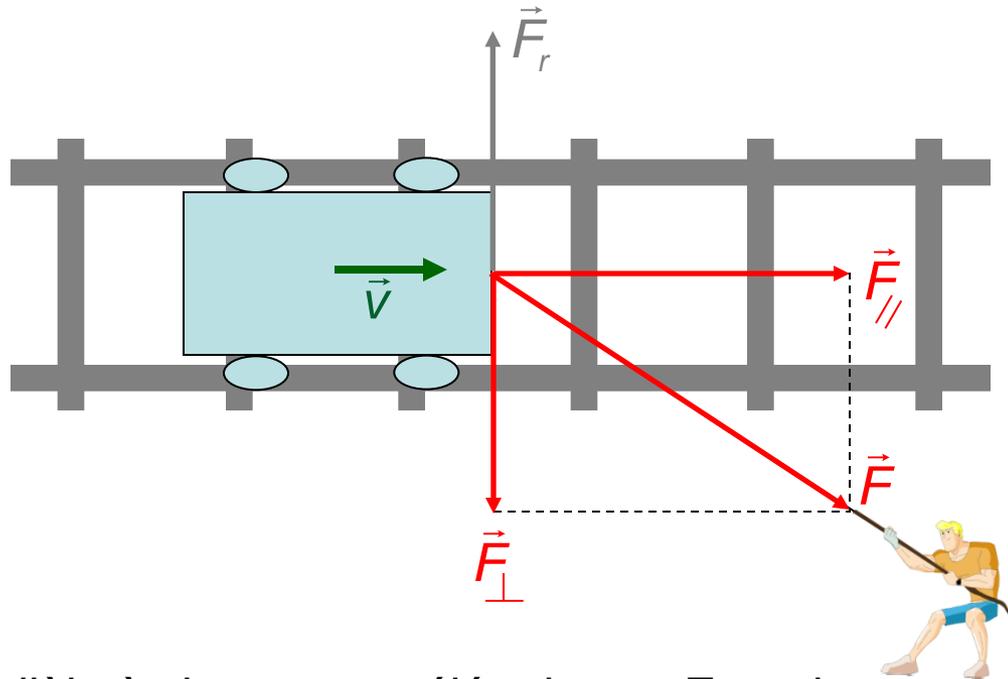


**Accélérer** : augmenter la vitesse d'ensemble



**Jargon!** : Energie  $\equiv$  Energie cinétique  $\equiv$  Energie liée à la vitesse

# Accélération



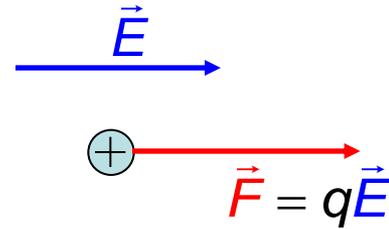
Force parallèle à vitesse : accélération  $\rightarrow$  Energie augmente

Force perpendiculaire à vitesse : guidage, focalisation  $\rightarrow$  Energie constante

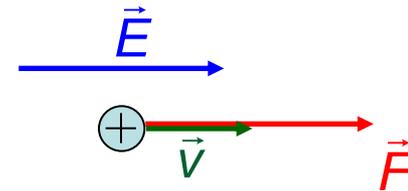
**Jargon!** : Un Accélérateur  $\equiv$  Un Créateur-Guideur-Focaliseur-Accélérateur

# Champ Electrique

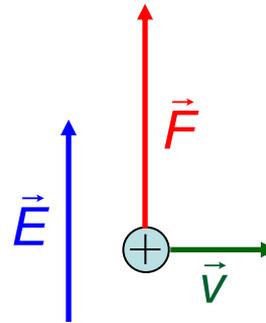
Charge dans un champs électrique  $\vec{E}$



➔ Champ électrique accélérateur



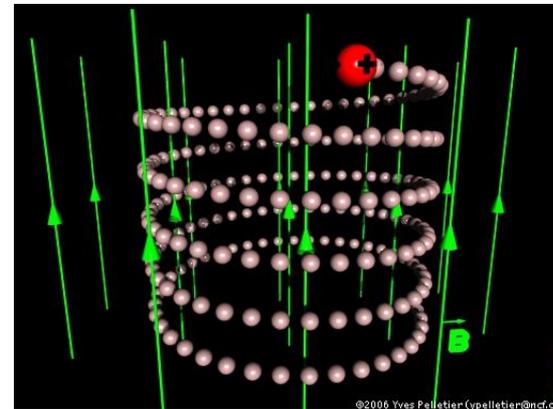
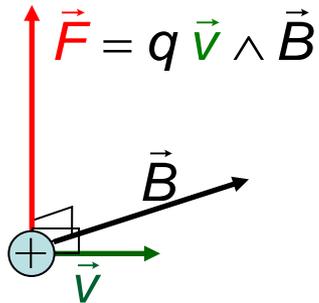
➔ Champ électrique guideur ou focaliseur



# Champ Magnétique

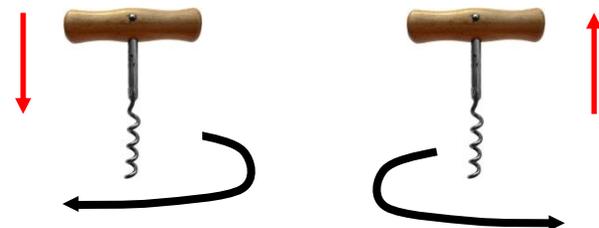
Charge dans un champs magnétique  $\vec{B}$

Force **toujours** perpendiculaire à la vitesse



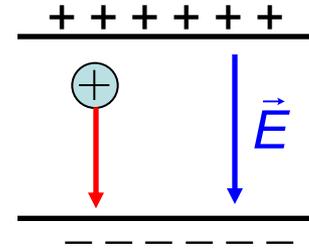
➔ Champ magnétique **uniquement** guideur ou focaliseur

Produit vectoriel : règle du tire-bouchon

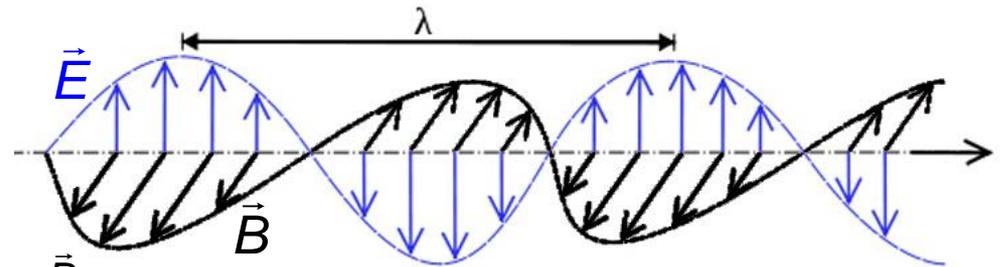


# Pour produire un Champ Electrique

2 plaques électriques chargées + et -



Onde électromagnétique RF

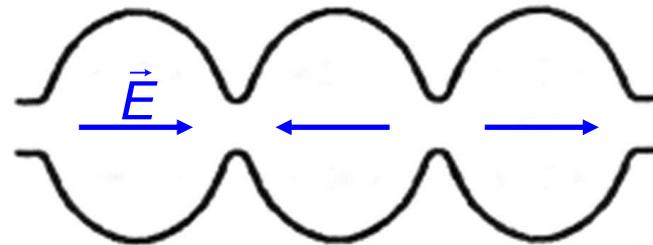


Loi de Maxwell avec les  :  $\vec{E}$  variable  $\leftrightarrow$   $\vec{B}$  variable

Signal radio, télévision, téléphone, four micro-onde



Onde électromagnétique RF piégée dans une cavité résonante



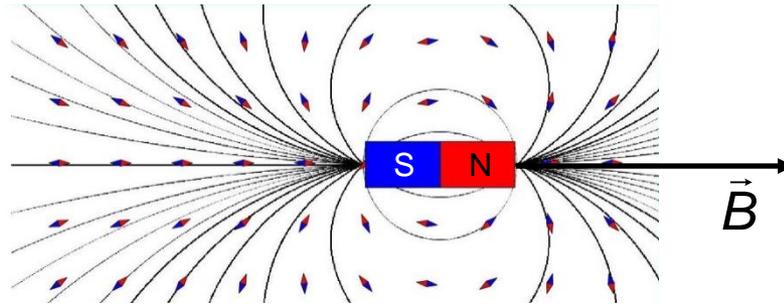
Ondes acoustiques piégées dans caisse de résonance d'instrument de musique



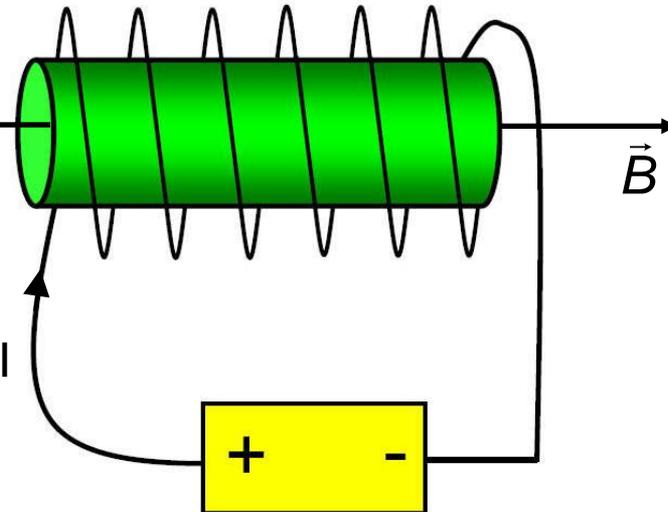
# Pour produire un Champ Magnétique

Champ magnétique terrestre ~ 0.5 Gauss

Aimant permanent  
1 - 10 000 Gauss



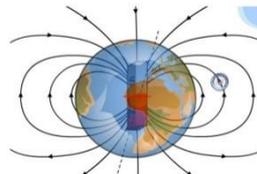
Bobine magnétique (Solenôïde)  
Force variable



dynamo  
vélo, EDF

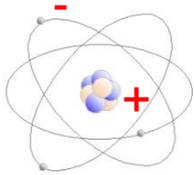


dynamo inverse  
planètes, étoiles

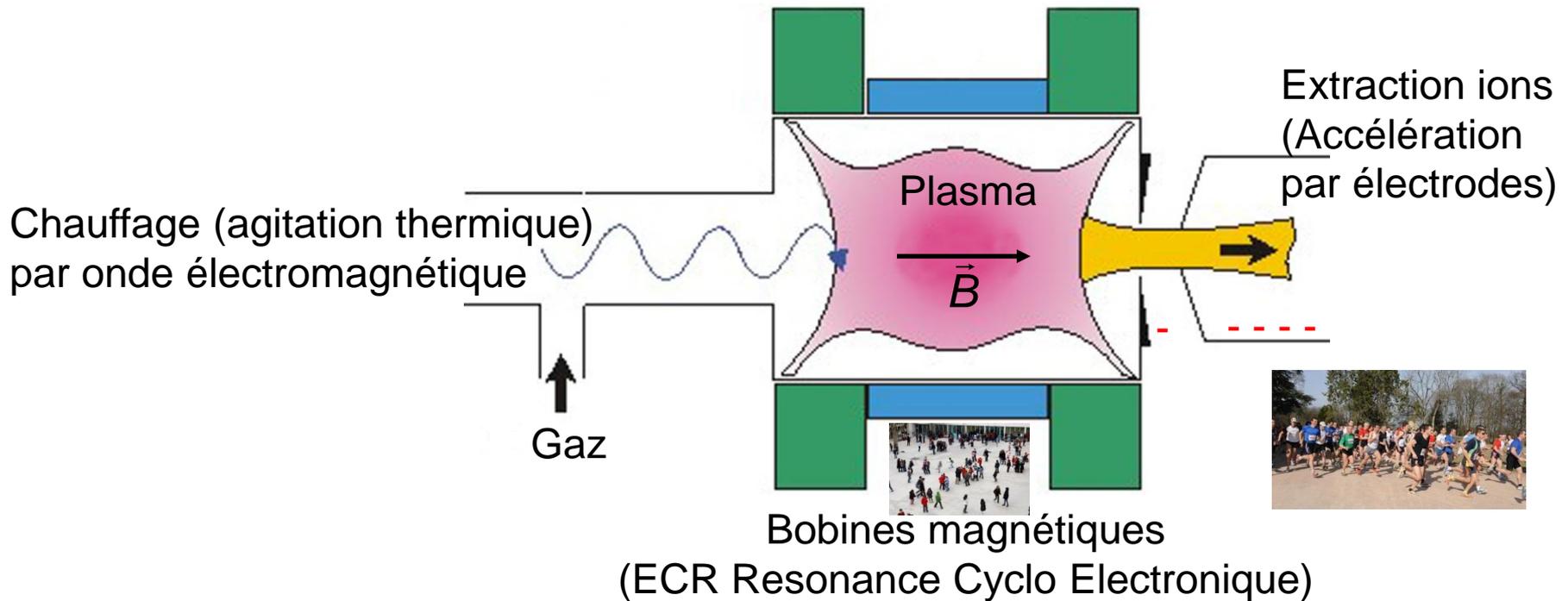
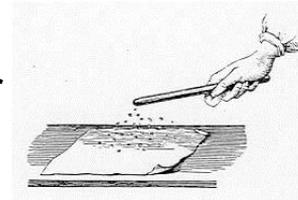


# Création de particules chargée

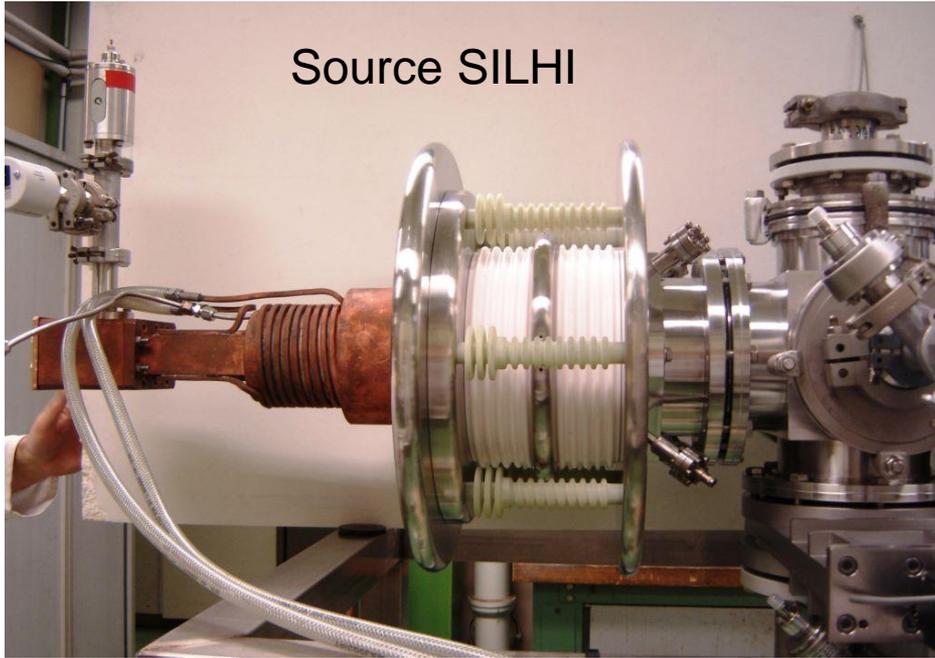
atome neutre → enlever 1 électron ou plus → particules chargées



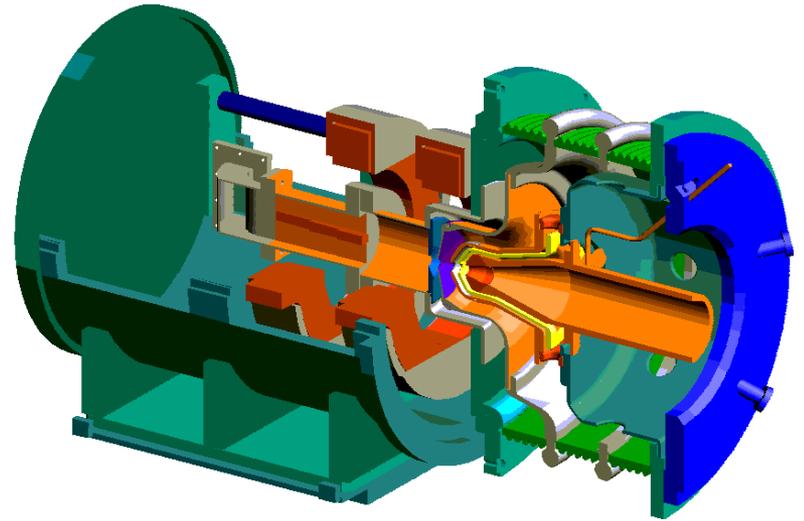
→ Frotter, Chauffer, Collisionner



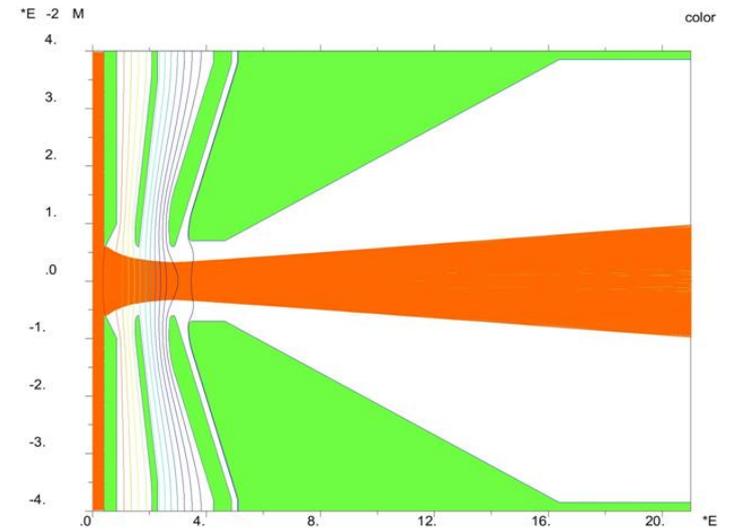
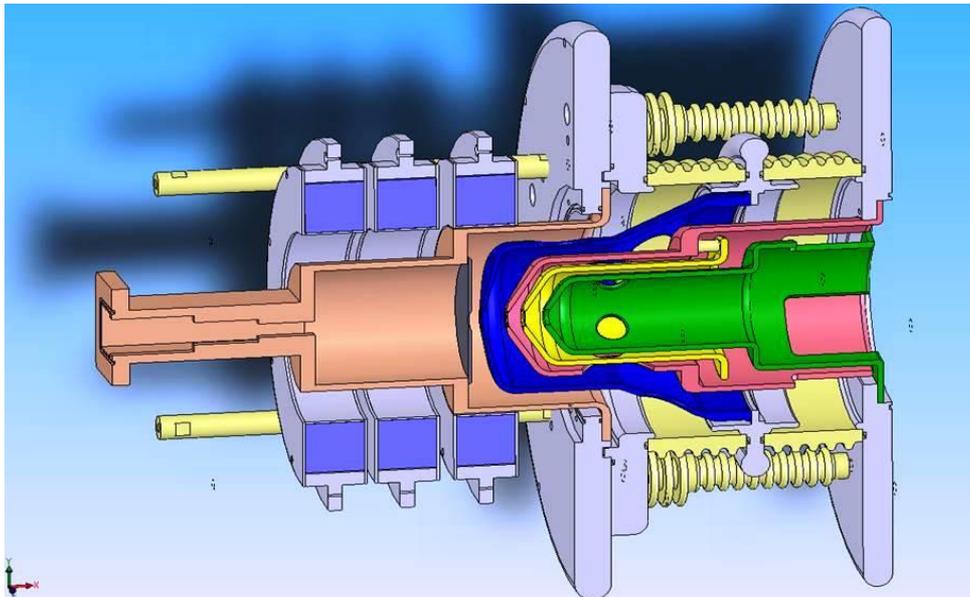
Source SILHI



Source IFMIF

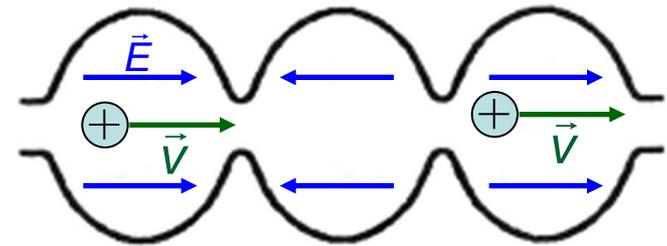


Extraction IFMIF

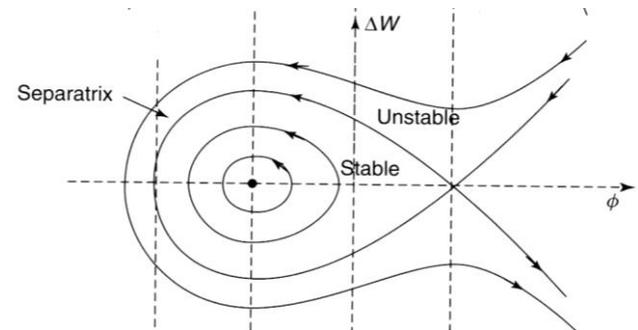
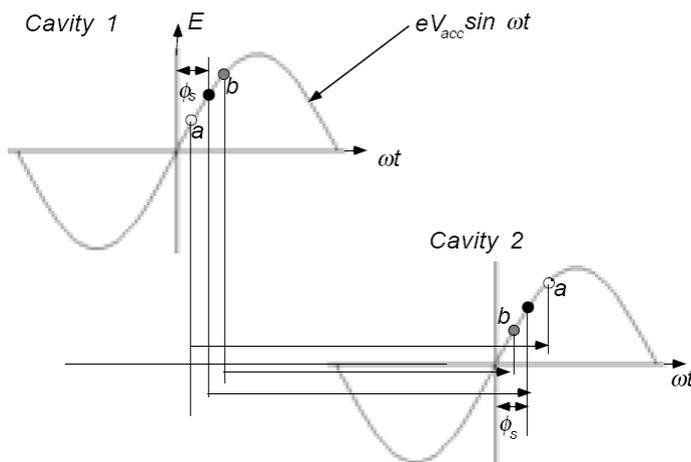


# Accélération

## Cavité RF



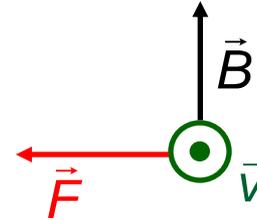
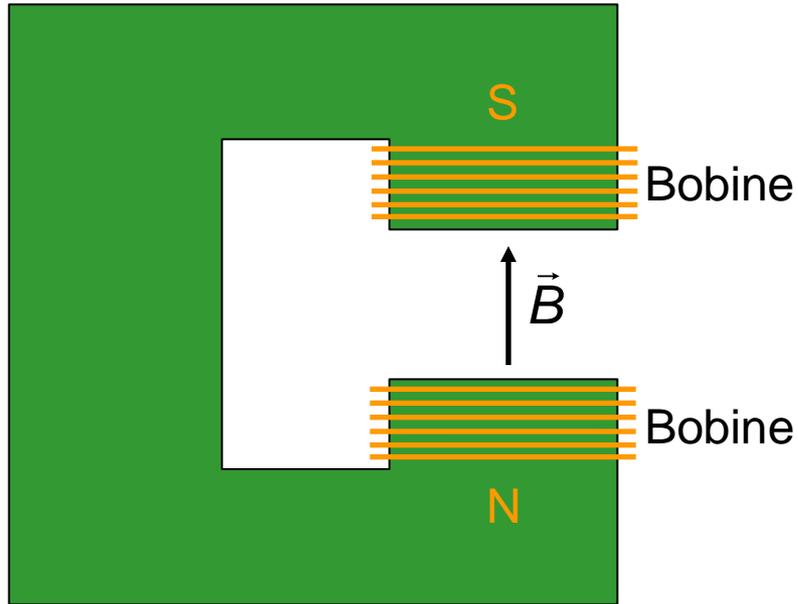
Accélération par  $\vec{E}$  RF  $\Rightarrow$  Mise en paquets (focalisation longitudinale)



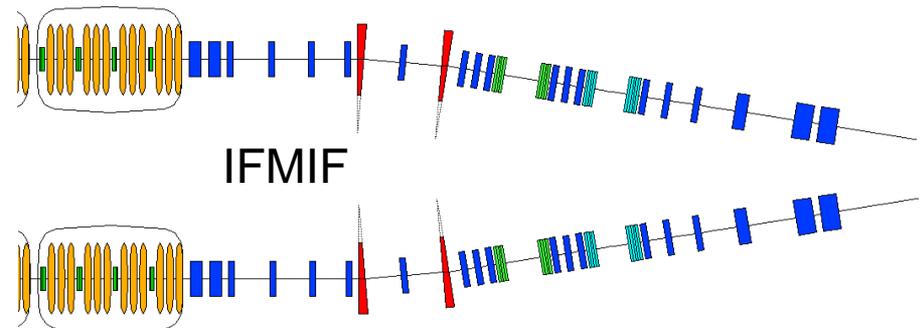
Oscillations longitudinales (synchrotron) avant-arrière

# Guidage

Dipôle



SOLEIL

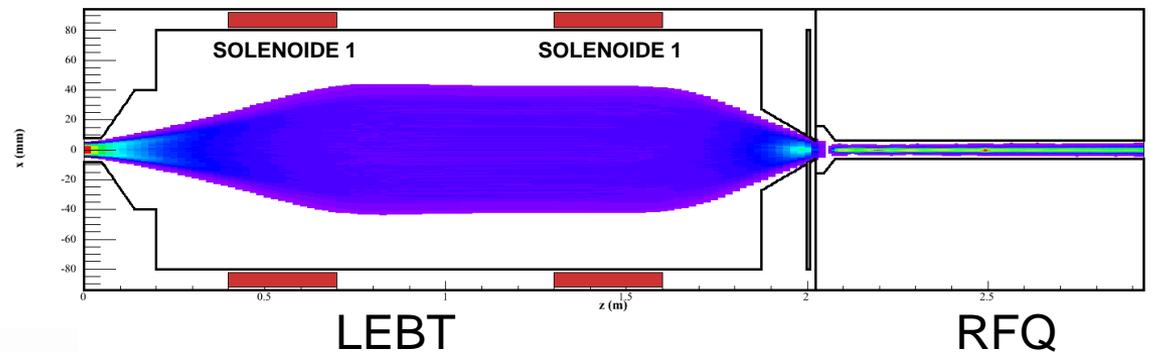
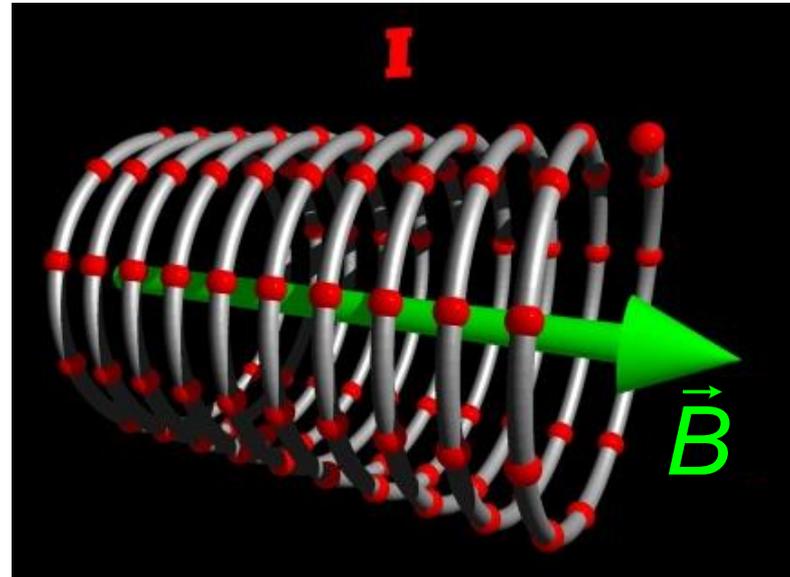
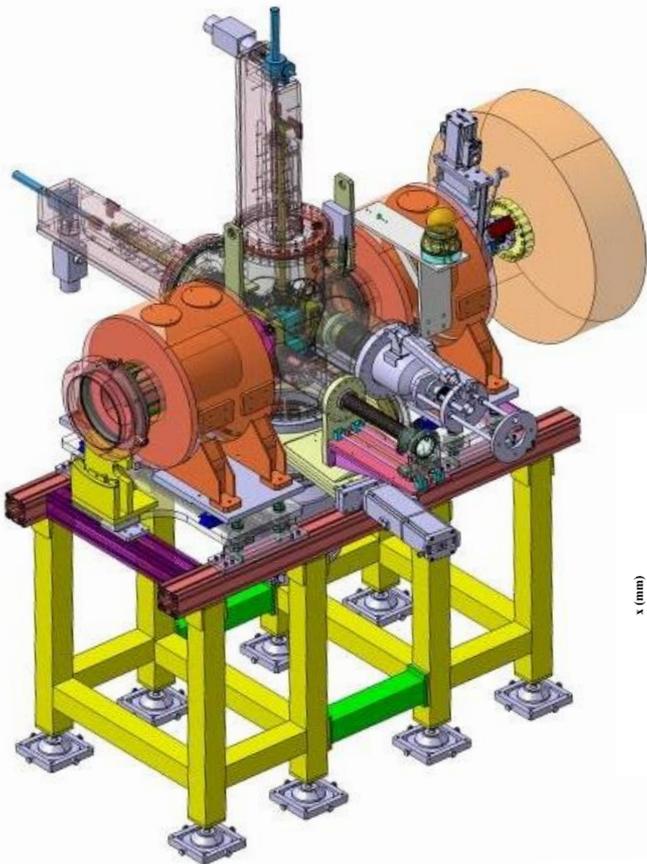


Guidage  $\Rightarrow$  Trajectoire de référence

# Focalisation

## Solenoïde

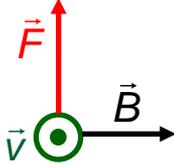
LEBT IFMIF



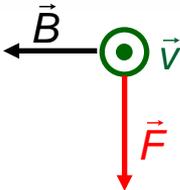
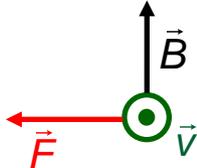
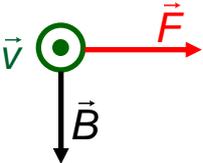
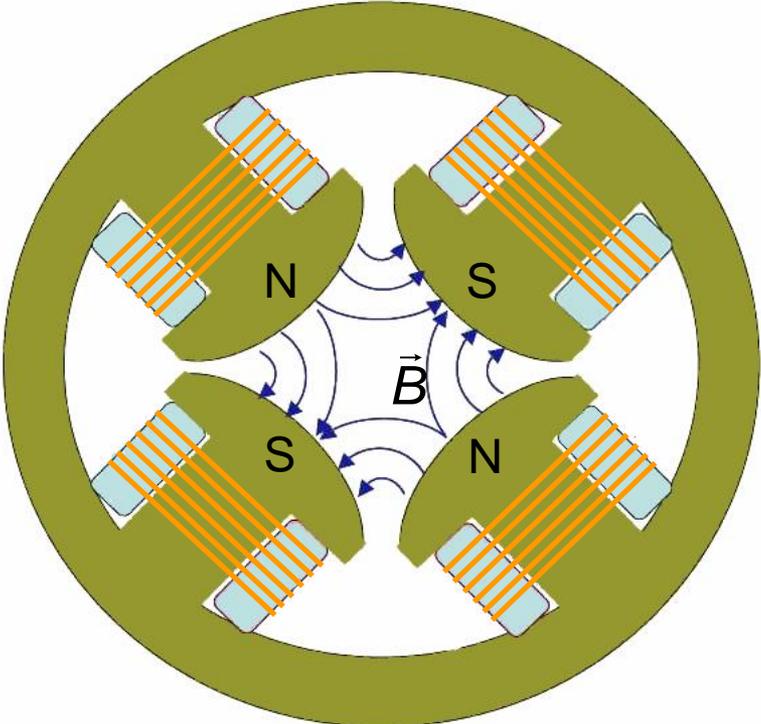
Focalisation  $\Rightarrow$  Oscillations transverses (betatron)

# Focalisation

Quadrupôle



Exemple de quadrupôle  
Focalisant en horizontal  
Défocalisation en vertical

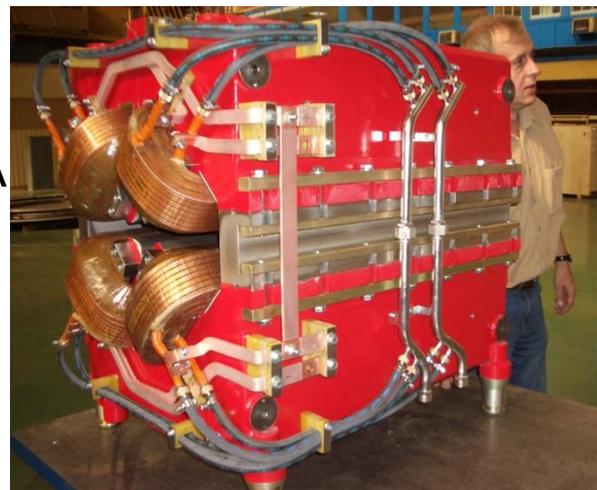


Focalisation  $\Rightarrow$  Oscillations transverses (betatron)

SOLEIL

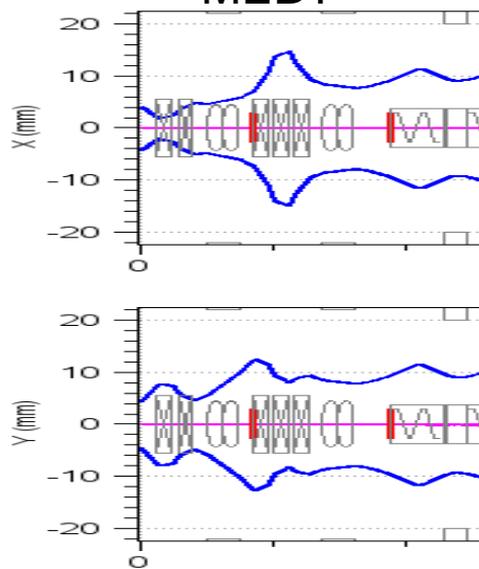


PETRA

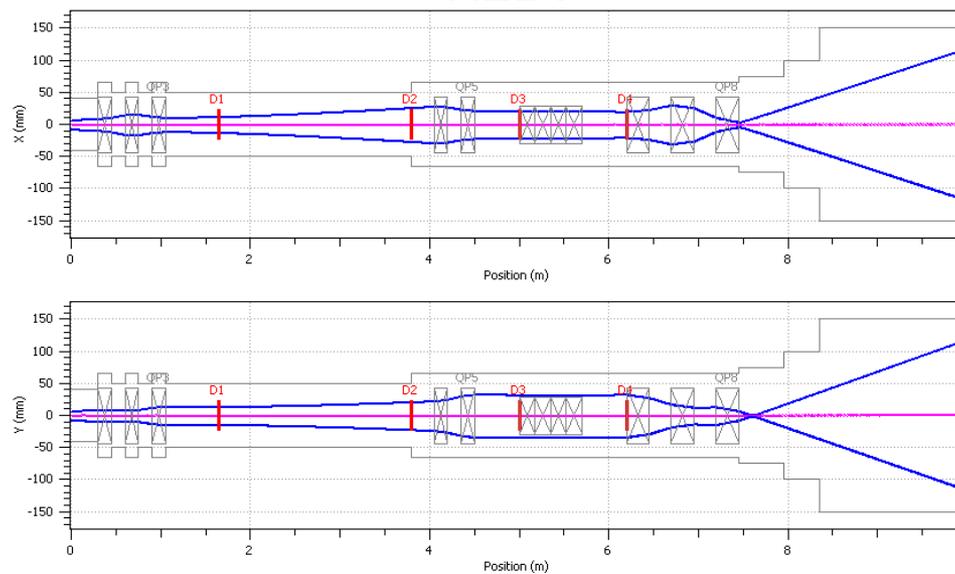


IFMIF-EVEDA

MEBT

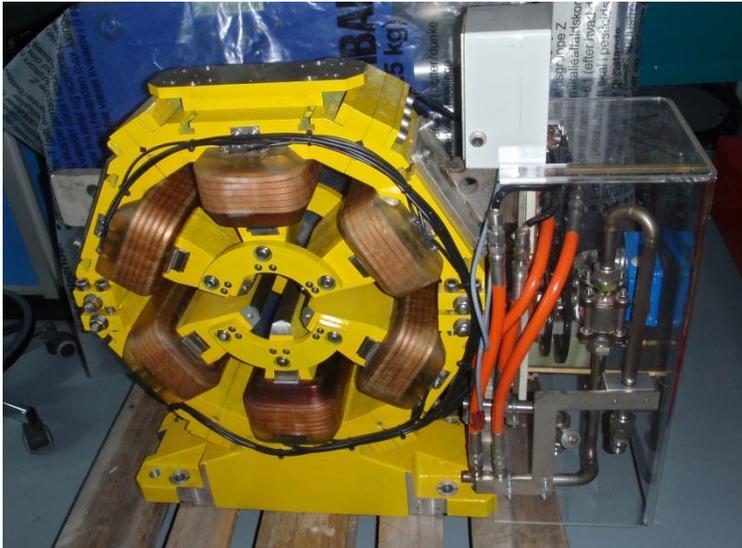


HEBT

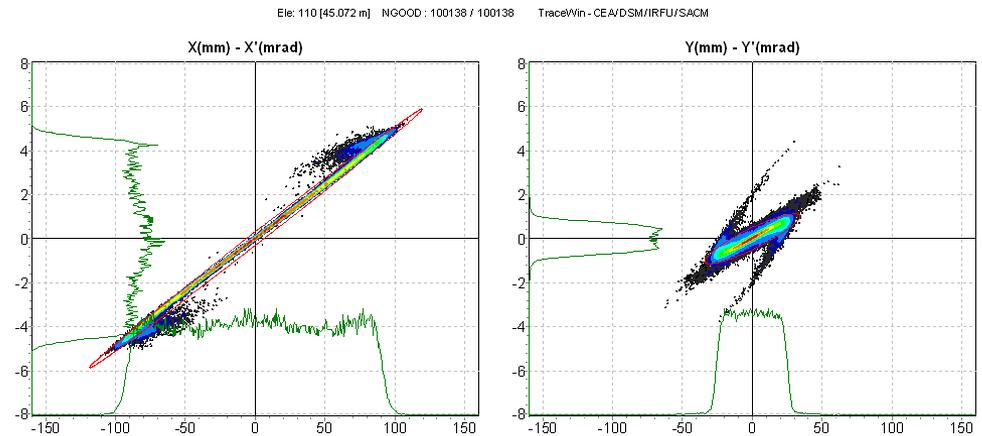


# Sextupôle, Octupôle, Décapôle, Dodécapôle

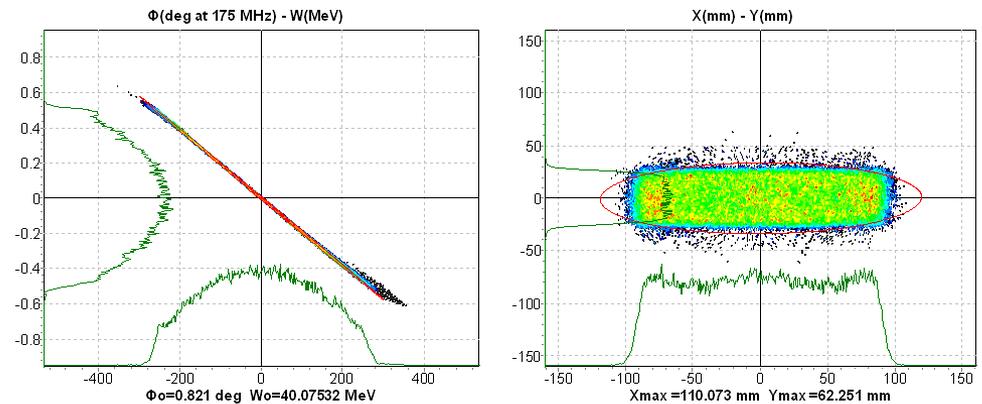
Focalisation plus forte au bord qu'au centre



SOLEIL

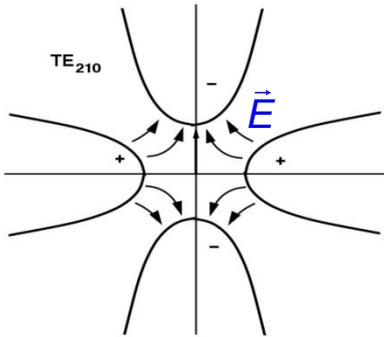


IFMIF  
Tache Faisceau sur cible  
avec 2 octupôles et 2 dodécapôles

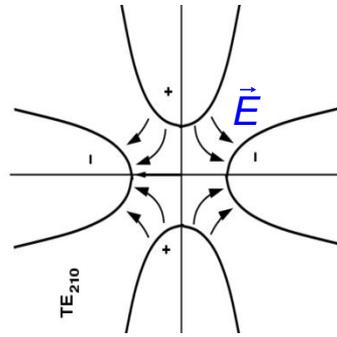


# Accélération et Focalisation

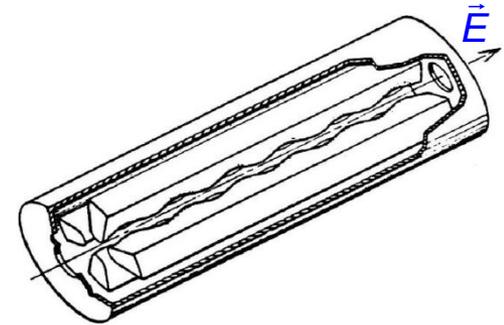
**RFQ**: Radio Frequency Quadrupole  
→ Cavité RF (électrique) à 4 pôles



Focalisation en horizontal  
Défocalisation en vertical



Défocalisation en horizontal  
Focalisation en vertical

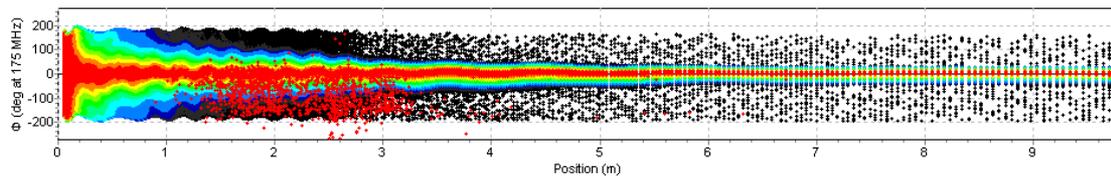
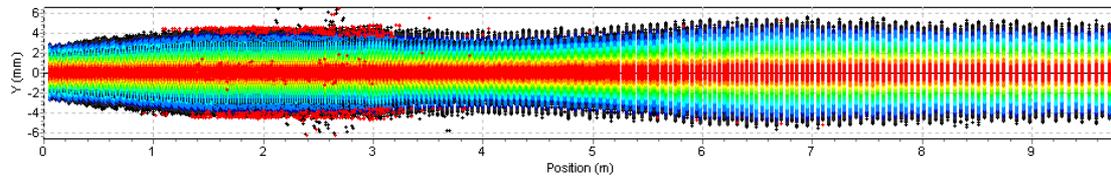
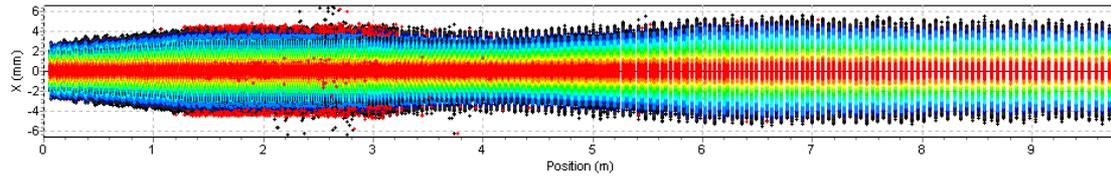
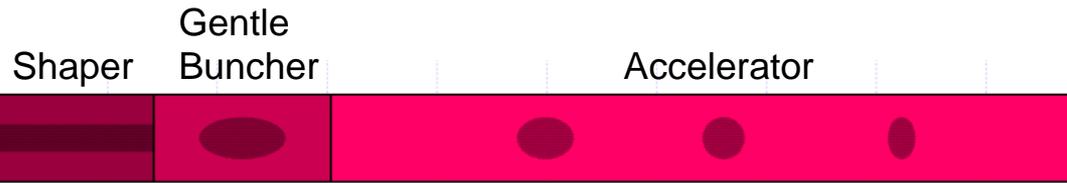
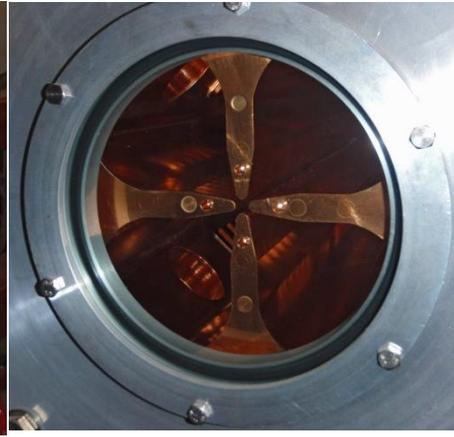
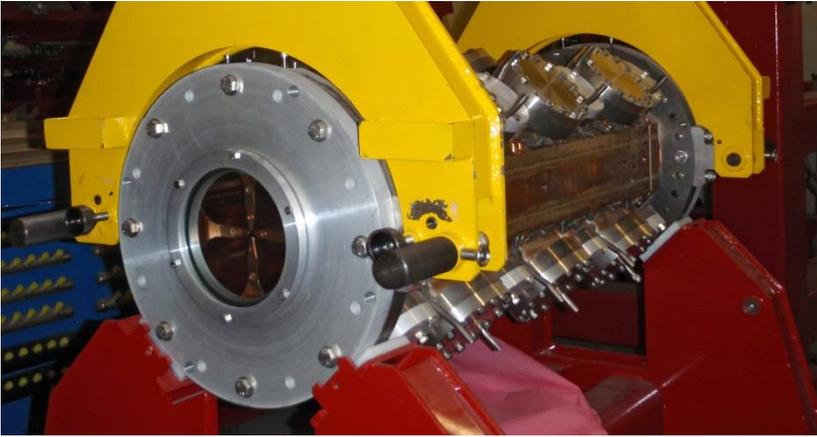


Modulation des pôles ⇒  
Champ longitudinal accélérant

**→** Accélère et focalise en même temps

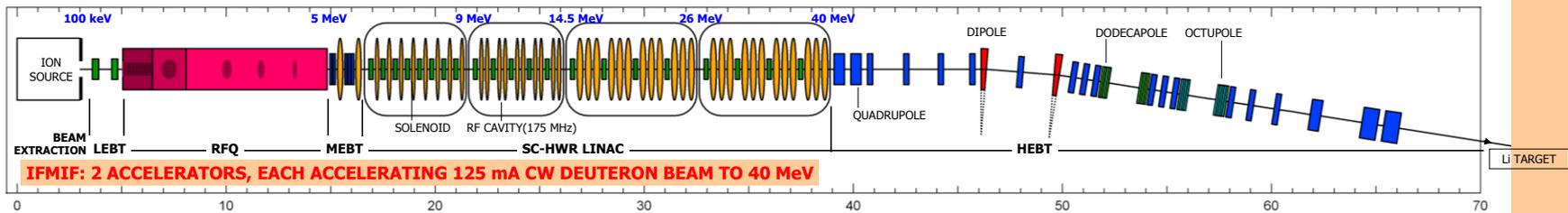
Utile pour basse énergie où la charge d'espace est la plus forte

# RFQ IPHI

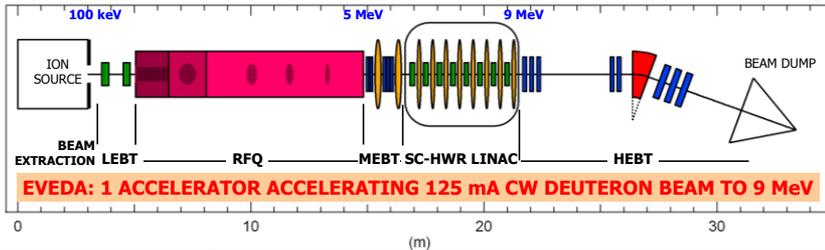


# RFQ IFMIF

# IFMIF-EVEDA



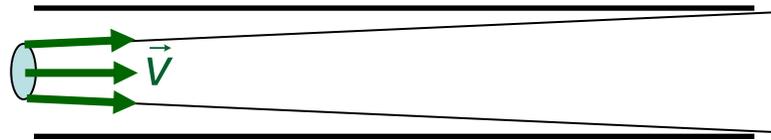
**IFMIF: 2 ACCELERATORS, EACH ACCELERATING 125 mA CW DEUTERON BEAM TO 40 MeV**



**EVEDA: 1 ACCELERATOR ACCELERATING 125 mA CW DEUTERON BEAM TO 9 MeV**

# Faisceau à 6 dimensions

3 tailles + 3 angles

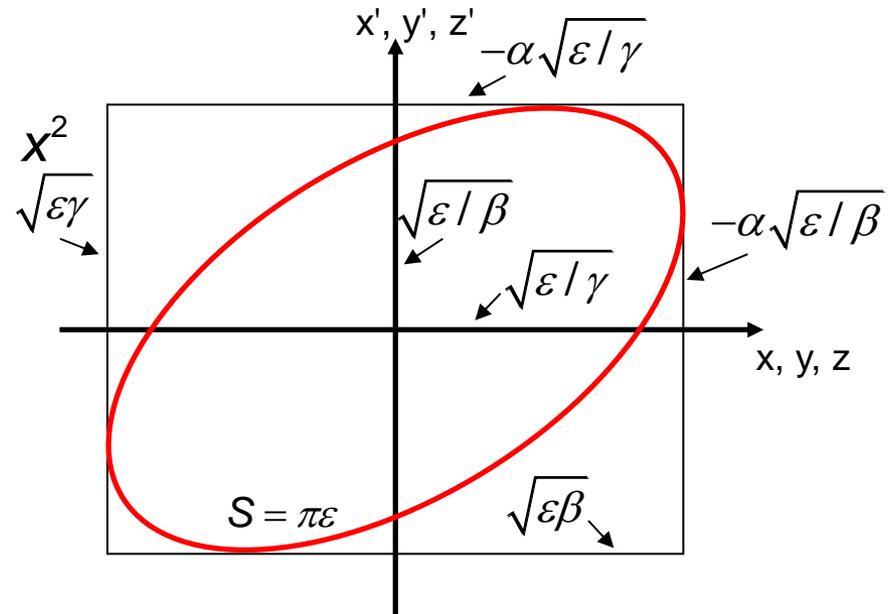


## Espace de phase

Ellipse de phase → 3 paramètres : orientation, proportion, taille

Paramètres de Twiss :  $\alpha, \beta, \gamma$  **et** Emittance  $\varepsilon$

$$\alpha = -\frac{\beta'}{2} \quad \gamma = \frac{1 + \alpha^2}{\beta} \quad \varepsilon = \gamma y^2 + 2\alpha y y' + \beta y'^2$$



Ellipse de concentration

$$\langle x^2 \rangle = \varepsilon \beta$$

$$\langle x'^2 \rangle = \varepsilon \gamma$$

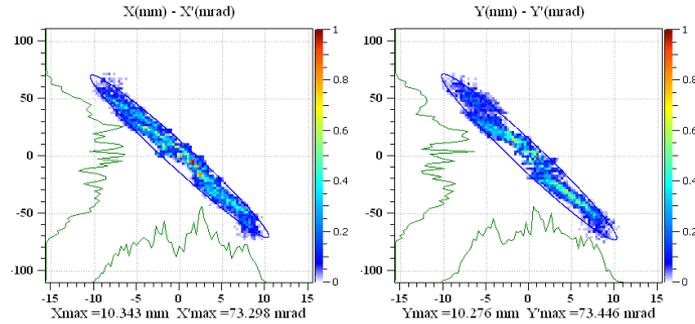
$$\langle x x' \rangle = \varepsilon \alpha$$

$$\varepsilon = \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle x x' \rangle^2}$$

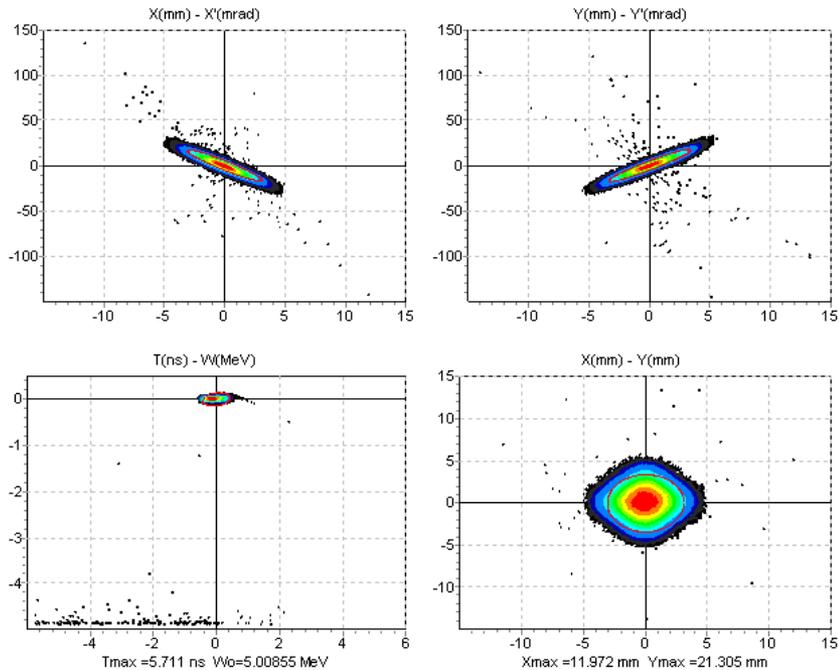
Oscillations dans l'espace de phase à 6 dimensions !!

# Quelques portraits de famille ...

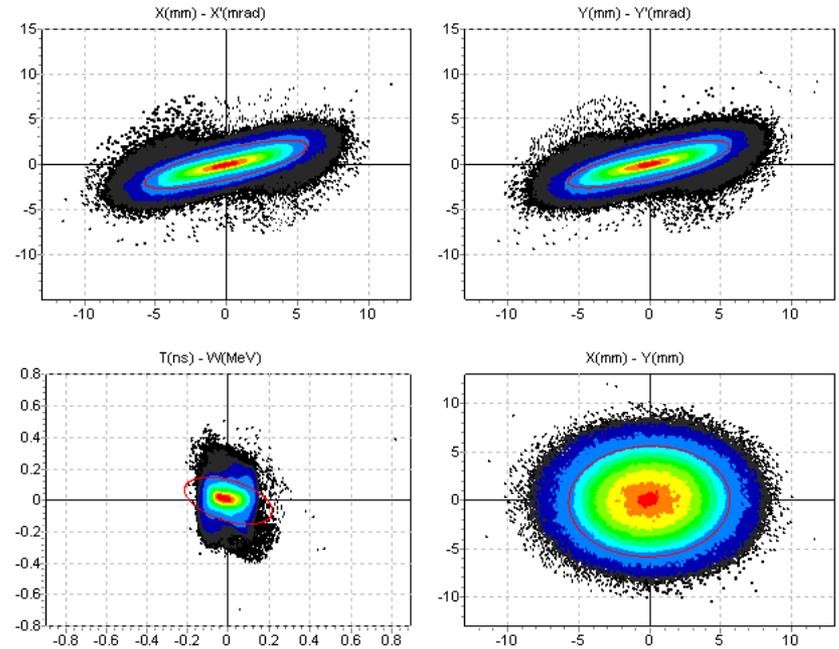
## Sortie LEBT



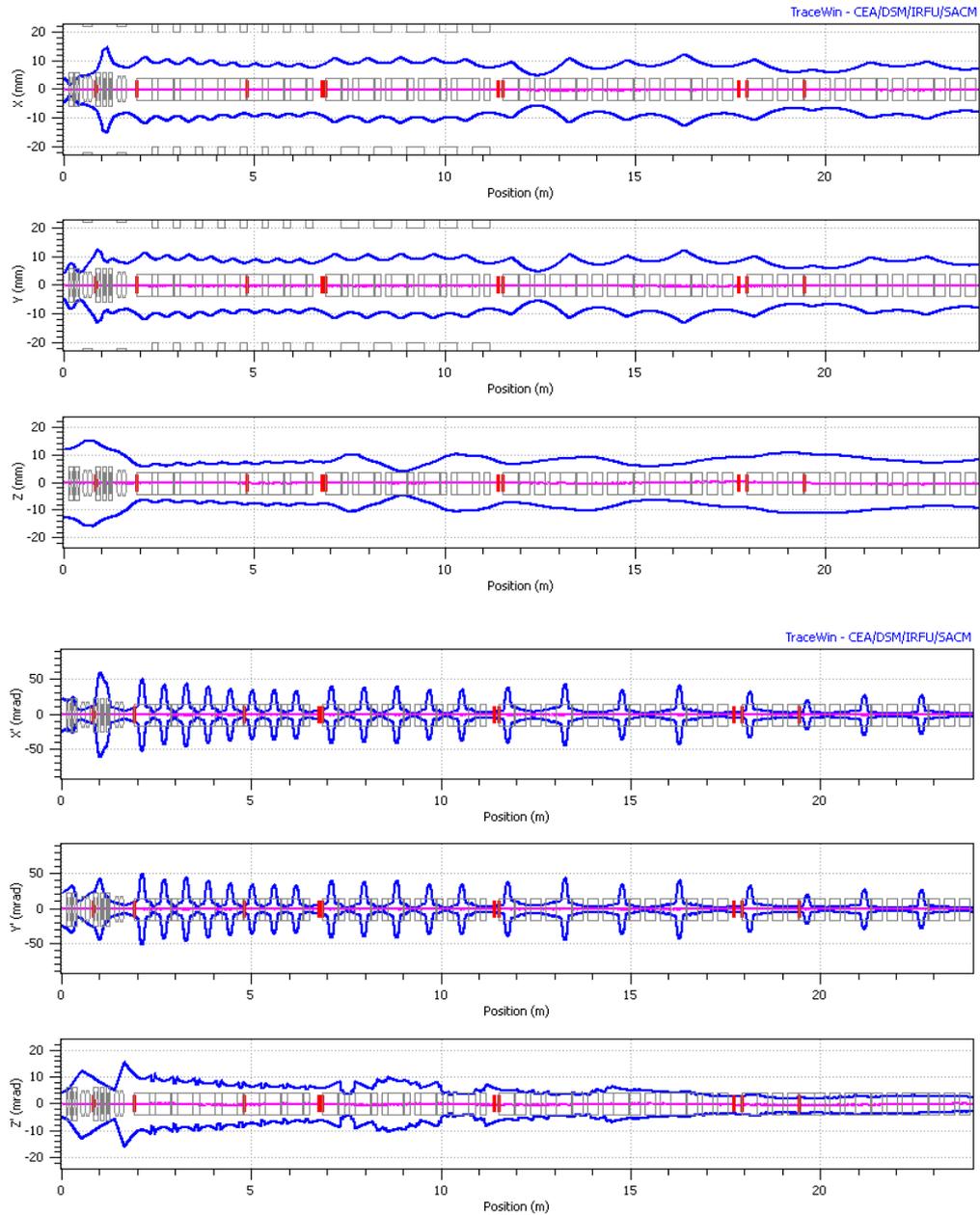
## Sortie RFQ

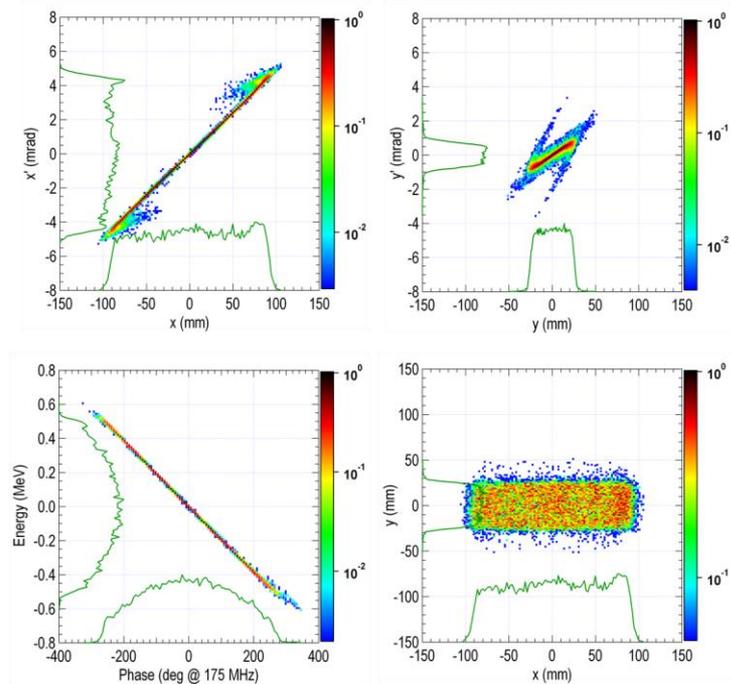
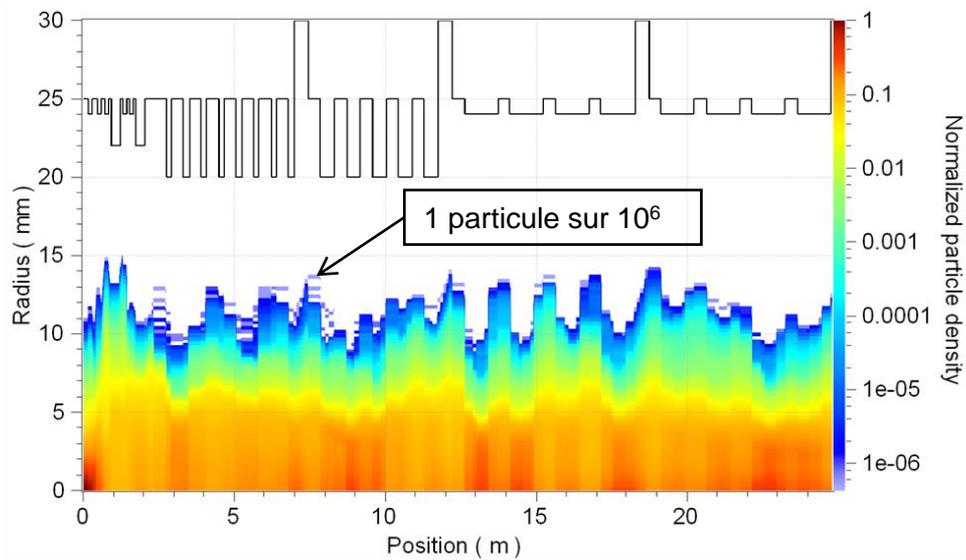


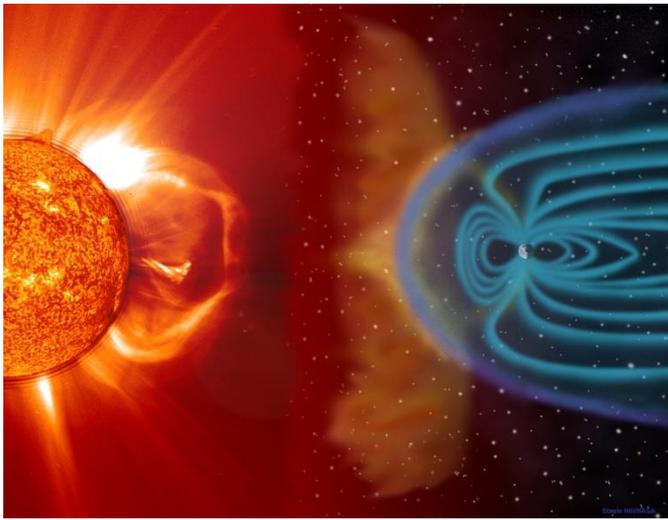
## Sortie HWR-Linac



# Variations des dimensions du faisceau, le long du MEBT + HWR-Linac







**Merci de votre attention**

