Saclay, le 23 avril 2007
S. Loucatos

Résumé de Moriond Electrofaible:

neutrino, astroparticules,
mesures de précision

et quelques résultats récents

http://moriond.in2p3.fr/
Résumés par B. Mansoulié, A. Masiero

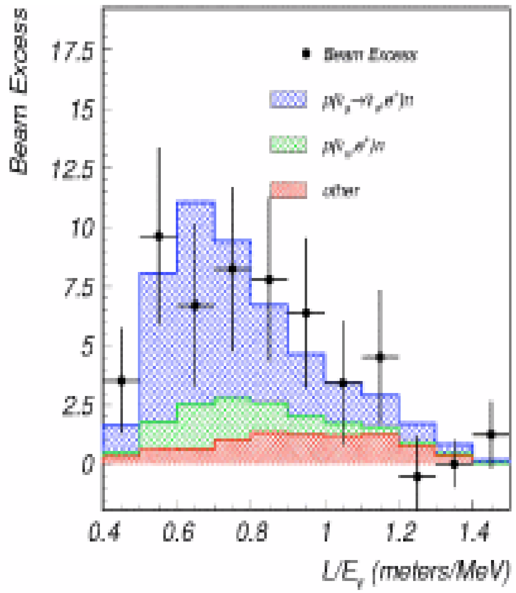
MiniBoone

an excess of $\bar{\nu}_e$ events in a $\bar{\nu}_\mu$ beam,

$87.9 \pm 22.4 \pm 6.0 \ (3.8\sigma)$

which can be interpreted as $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations:

Simulation du signal attendu:



Points -- LSND data

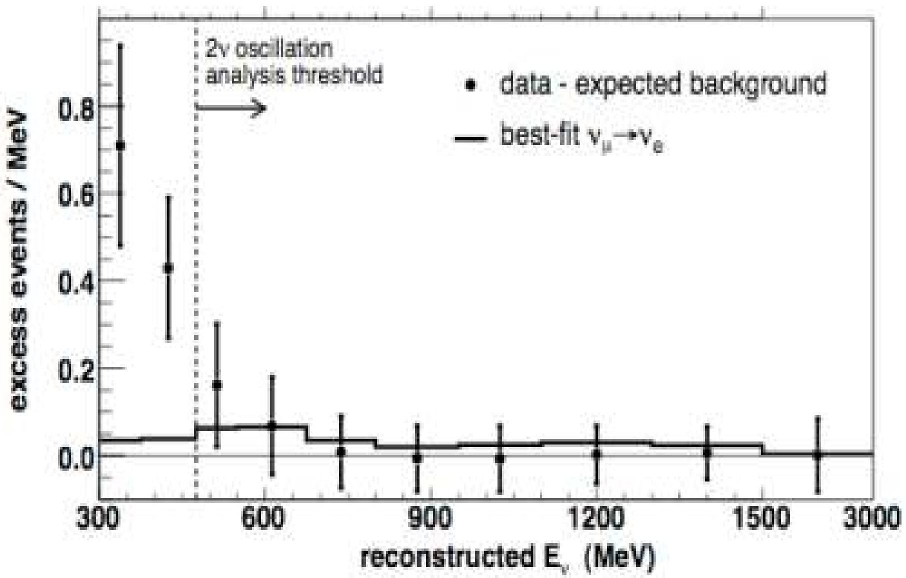
Signal (blue)

Backgrounds (red, green)

LSND Collab, PRD 64, 112007

Résultat (11/4/07)

Within the energy range defined by this oscillation analysis, the event rate is consistent with background.



The observed low energy deviation is under investigation.

MINOS, K2K/T2K

- – Résultats MINOS, **final K2K:**
- **Confirment l'oscillation**

- 1^{er} faisceau T2K **Avril 2009**

Recherche de double désintégrations β sans neutrino

– **Progrès récents dans les calculs des éléments de matrice**
Incertitude ~facteur 2 à 4

– **Résultats expérimentaux:**
• Heidelberg Moscow (76Ge , 10 kg, Gran Sasso)
– Signal controversé
• NEMO-3 ("track-calo", 10 kg, Modane)
– Limites en Mo : >4.6 10^{23} years **=> $<m_\nu> < 0.66 – 2.8$ eV**
• Cuoricino (TeO2 bolomètres, 10 kg, Gran Sasso)
– > 2.4 10^{24} years **$<m_\nu> < 0.18 - 0.94$ eV**

– **Projets:**
• GERDA (76Ge), CUORE (TeO2) : but: 1 tonne.an
⇒Peuvent atteindre le domaine de la hierarchie inversée
⇒ 0.01-0.1 eV

Astronomie γ H.E.: HESS - Magic

- Big observational step within the last year:
  - quantitative (tripling number of detected sources)
  - qualitative (extremely high quality => unprecedented detailed studies).

=> **DAWN OF A <u>GOLDEN AGE</u> FOR CHERENKOV TELESCOPES !**

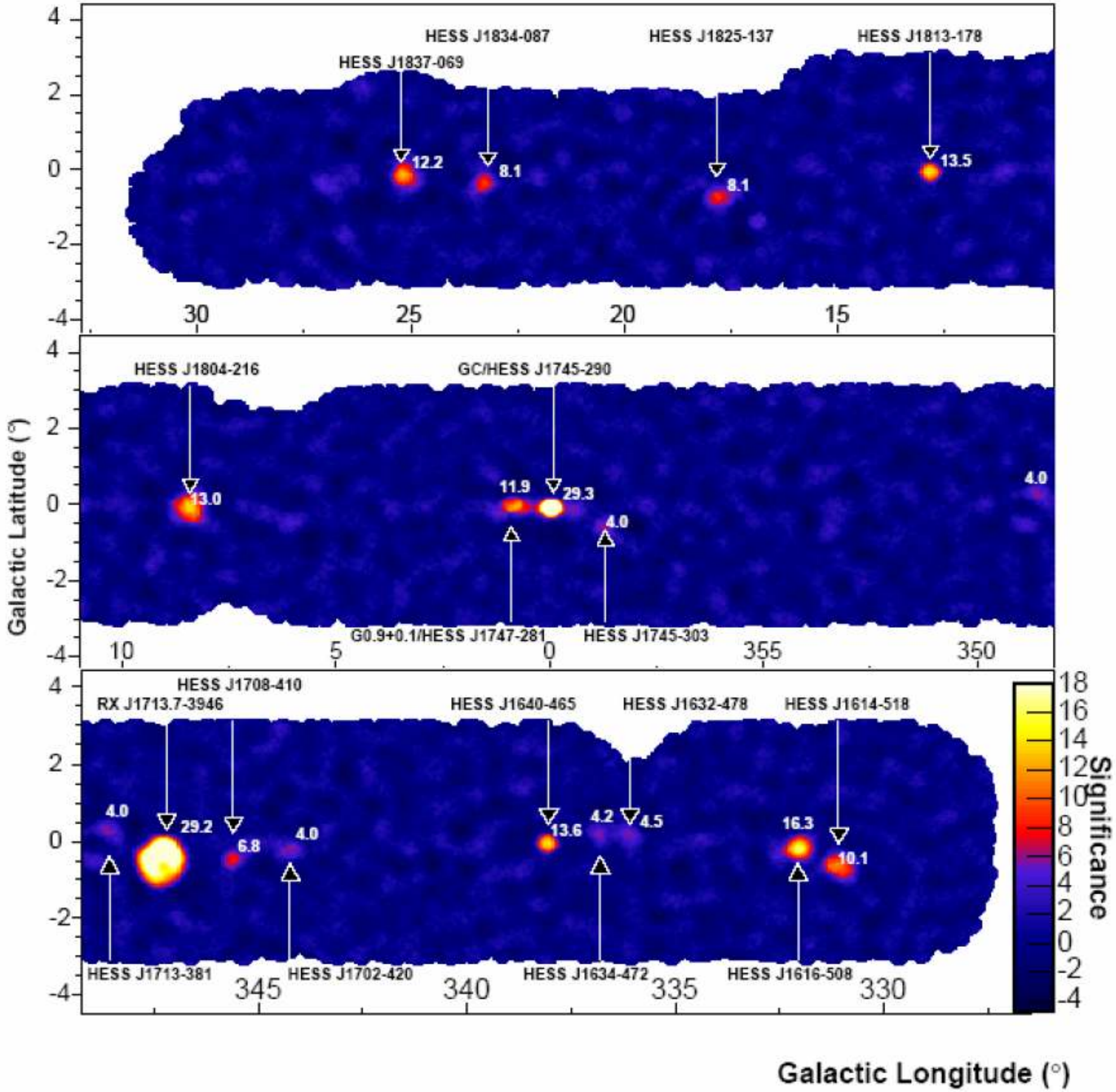
HESS Galactic Plane Survey

Sources > 6 sigma:
9 new, 11 total

Sources > 4 sigma:
7 new

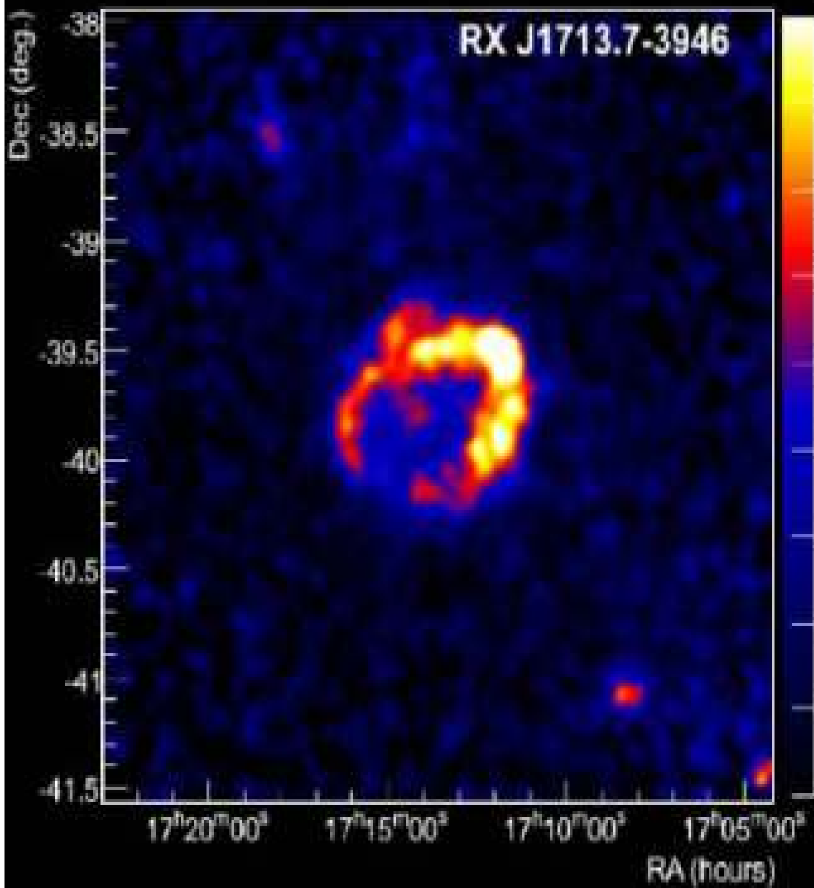
Most sources:

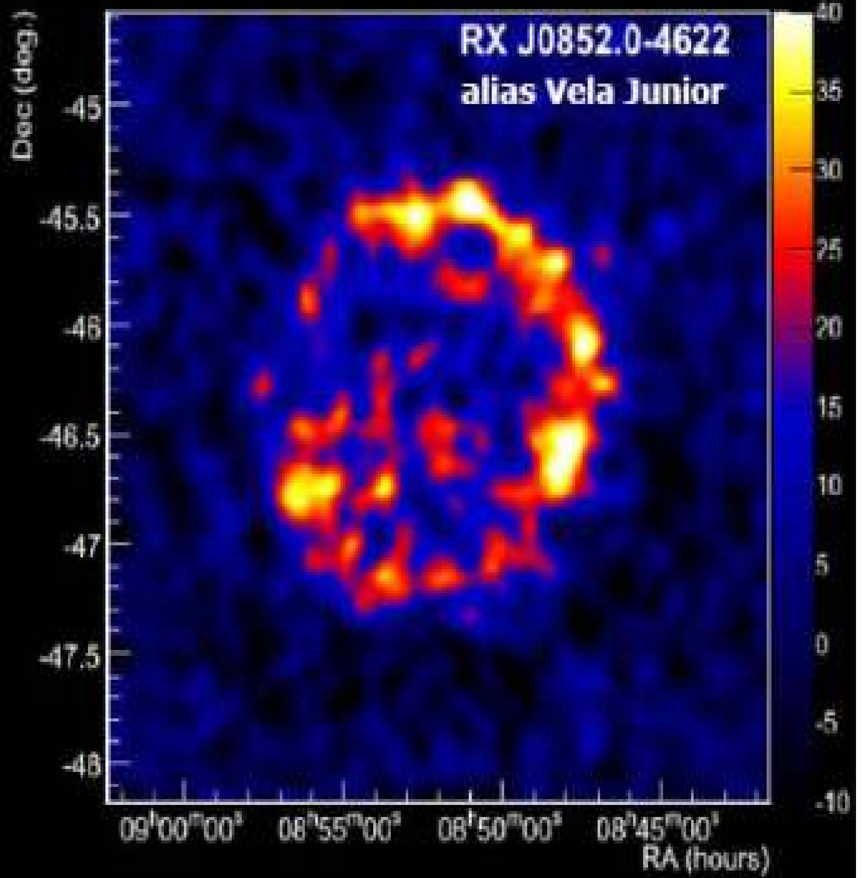
- Shell-type SNR
- Pulsar-Wind-Nebulae
- Unidentified
- New objects



Supernova remnant shells

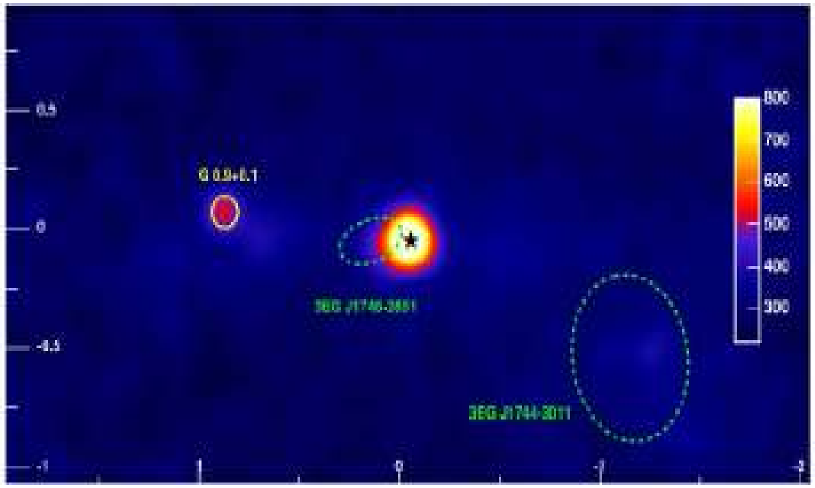
γ-ray morphology ≅ morphology in non-thermal X-rays



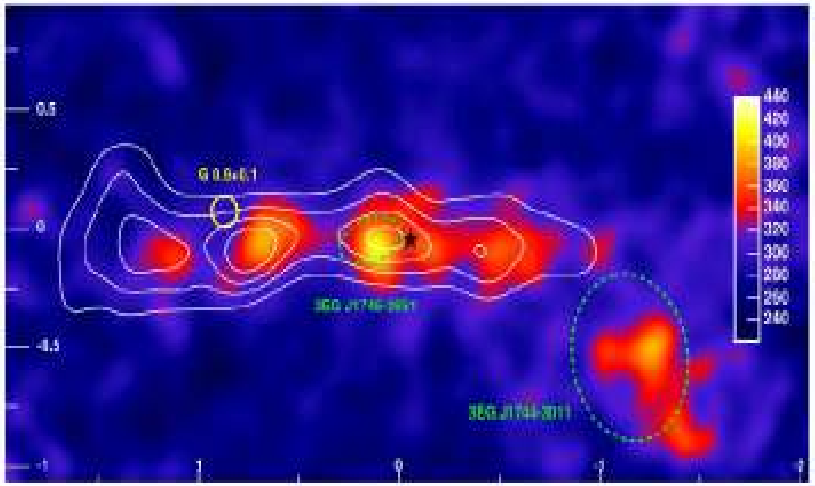


Le centre galactique

HESS



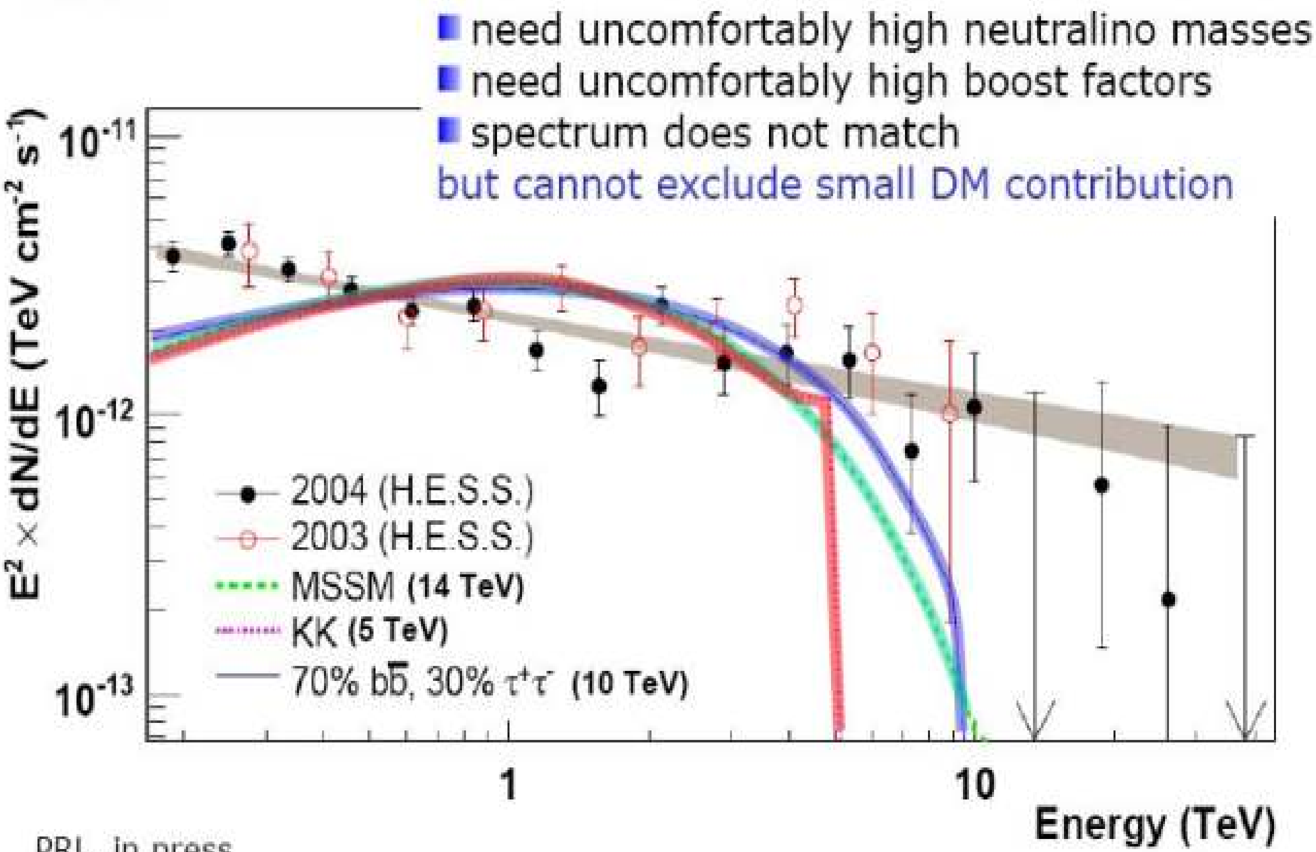
Carte en gamma



La même après soustraction des 2 sources. Correlation nette avec le gaz moléculaire vu par émission CS (interférométrie antenne radio mm monosulfure de carbone)

A l'étude: signe d'une source hadronique de RC au CG?

Spectre en énergie: $E^{-2.3}$ entre 0.1 et 10 TeV =>
Une source forte cache un éventuel signal de matière noire

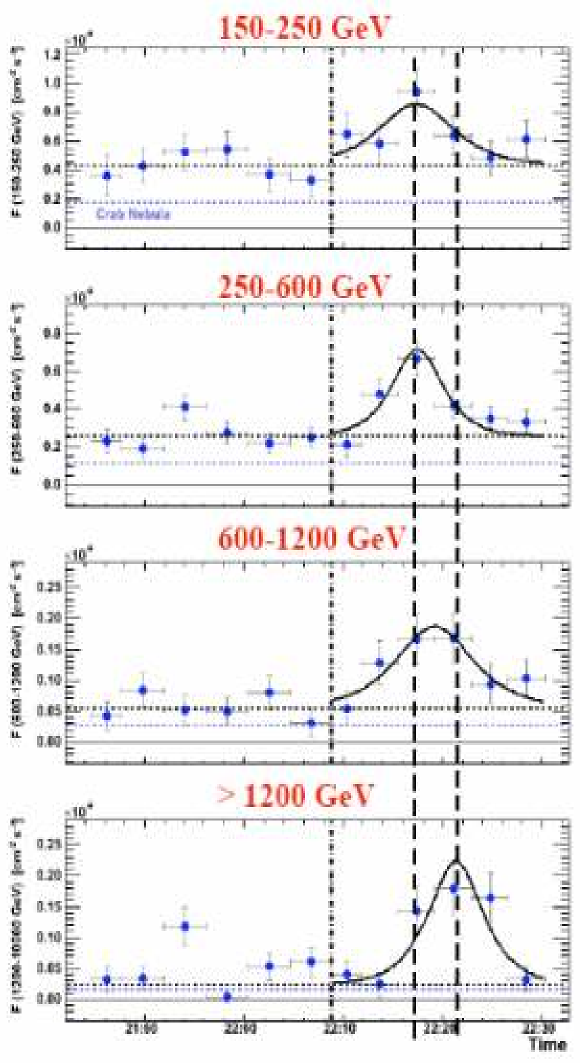


PRL, in press

On a vu la gravitation quantique?

- Sursauts du Blazar Mkn 501 en 2005:

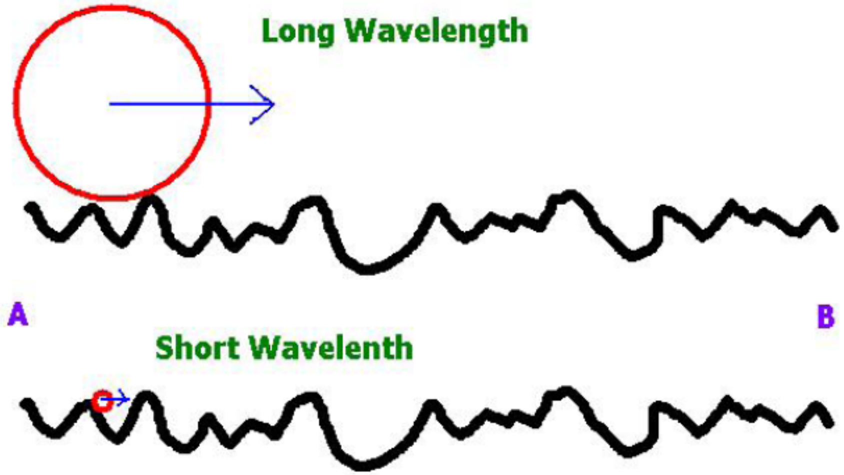
Temps d'arrivée dépendents de l'énergie observés par Magic : 4 ±1 min



Energy dependence of the Speed of light

• Space-time at large distances is "smooth" but, if Gravity is a quantum theory, at very short distances it might show a very complex ("foamy") structure due to Quantum fluctuations.

• A consequence of these fluctuations is the fact that the speed of light in vacuum becomes energy dependent.



• The energy scale at which gravity is expected to behave as a quantum theory is the Planck Mass

$$E_{QG} = O(M_P) = O(10^{19})\ \text{GeV}$$

- From a purely phenomenological point of view, the effect can be studied with a perturbative expansion. The arrival delay of γ–rays emitted simultaneously from a distant source should be proportional to the path L to the source and a power n of their energy difference ΔE and :

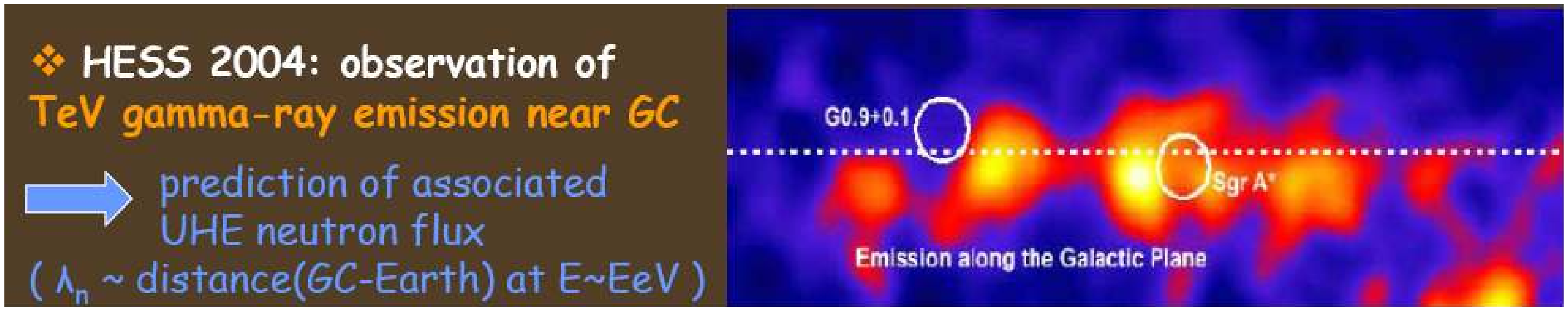
$$\Delta t \sim \left(\frac{\Delta E}{E_{QG}} \right)^{n} \frac{L}{c}$$

- The expected delay is very small and to make it measurable one needs to observe very high energy γ-rays coming from sources at cosmological distances.

Auger

- 1000 réservoirs d'eau /1600
- **Pas de résultat sur la coupure GZK**

- **Anisotropie:** suivant HESS

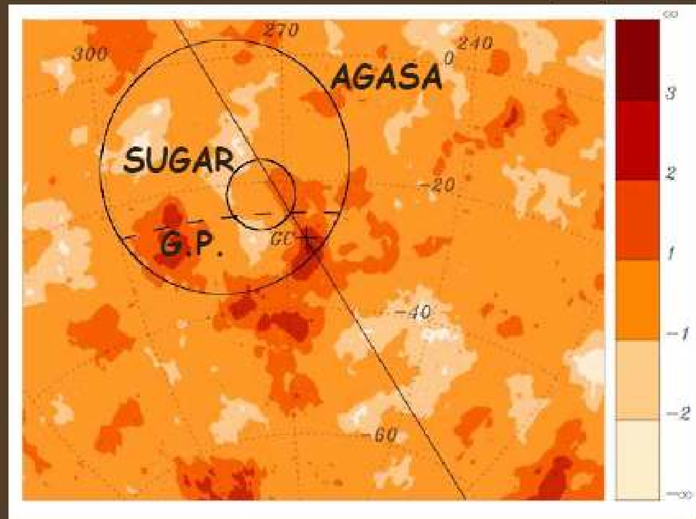


Résultat Auger

❖ **Around the Galactic Center/Plane:**

5°, top-hat

- test of AGASA: obs/exp = 2116/2159.5
  R = 0.98 ± 0.02 ± 0.01
  NOT CONFIRMED (with 3x more stats)
- test of SUGAR: obs/exp = 286/289.7
  R = 0.98 ± 0.06 ± 0.01
  NOT CONFIRMED (with 10x more stats)
- Galactic Center as a point source (σ=1.5°):
  obs/exp = 53.8/45.8
  R = 1.17 ± 0.10 ± 0.01
  NO SIGNIFICANT EXCESS



upper limit on the flux of neutrons coming from GC:

$\Phi_s < 0.08\ \xi\ km^{-2}\ yr^{-1}$ at 95% C.L.

astro-ph/0607382
(Astropart. Phys., 2007)

- Galactic Plane: NO SIGNIFICANT EXCESS

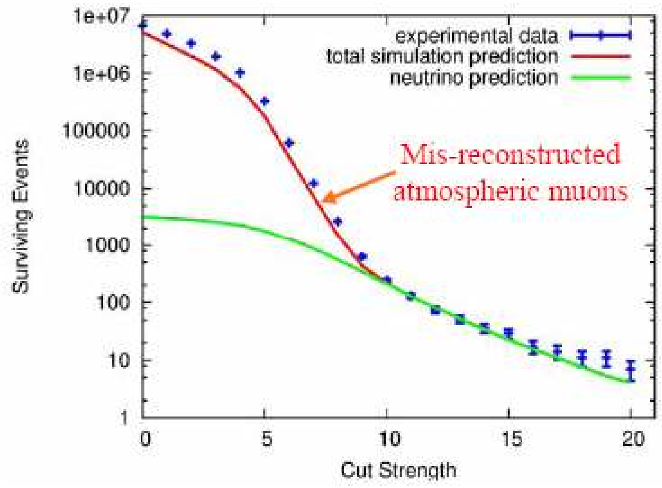
❖ **All-sky blind searches:** NO EXCESS FOUND

❖ **Other searches on prescriptions:** NO EXCESS FOUND
(predefined targets & statistical significance: NGC253, NGC3256, Cen A)

Amanda/Icecube

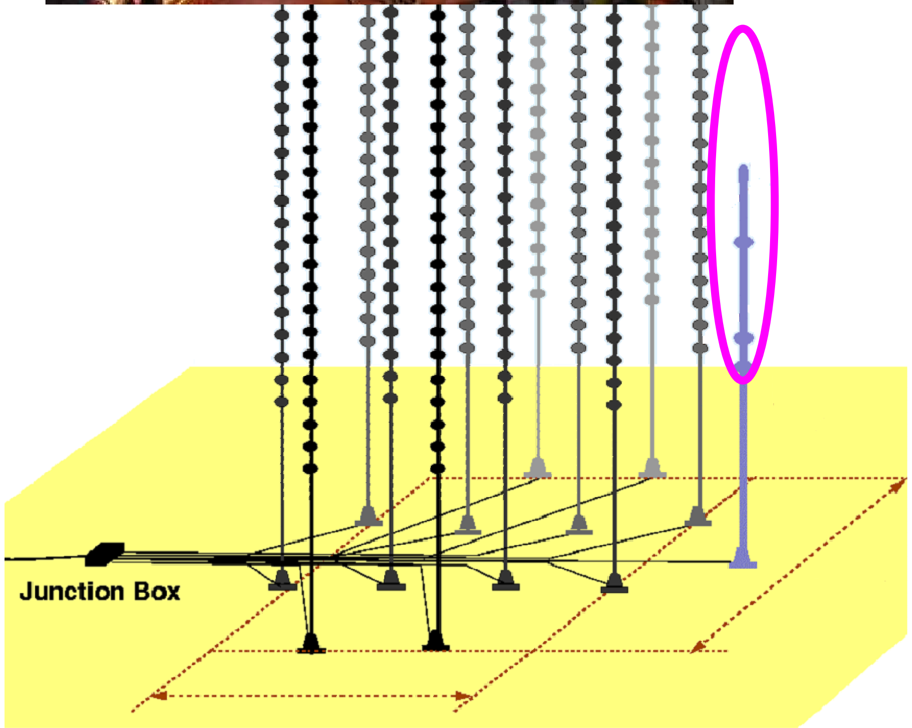
- – **Amanda operational since 2000 (19 lines)**
- • - Icecube-9 see muon neutrinos

- • IceCube successfully deployed 13 more strings, now 22
- - 25% of the detector deployed, ~1 km3·yr of data in ~2 years
- - New strings “surround” AMANDA, look at contained events
- - On schedule for completion in 2011 (as planned)
- • no point source found
- • limit on diffuse flux

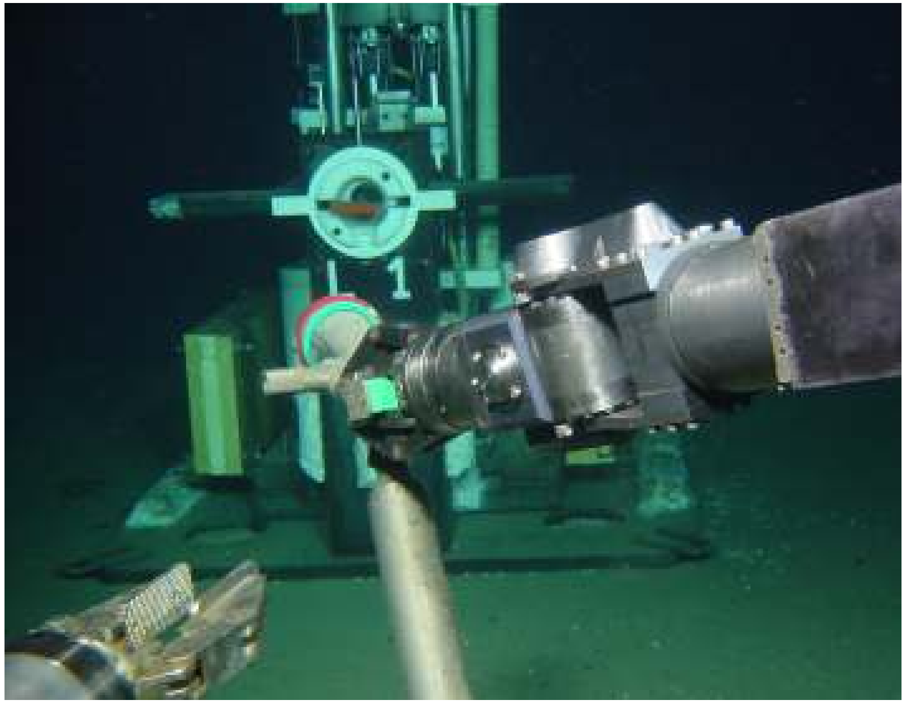


234 up-going ν_μ in 137.4 live-days of data
(purity of neutrino sample > 95%)

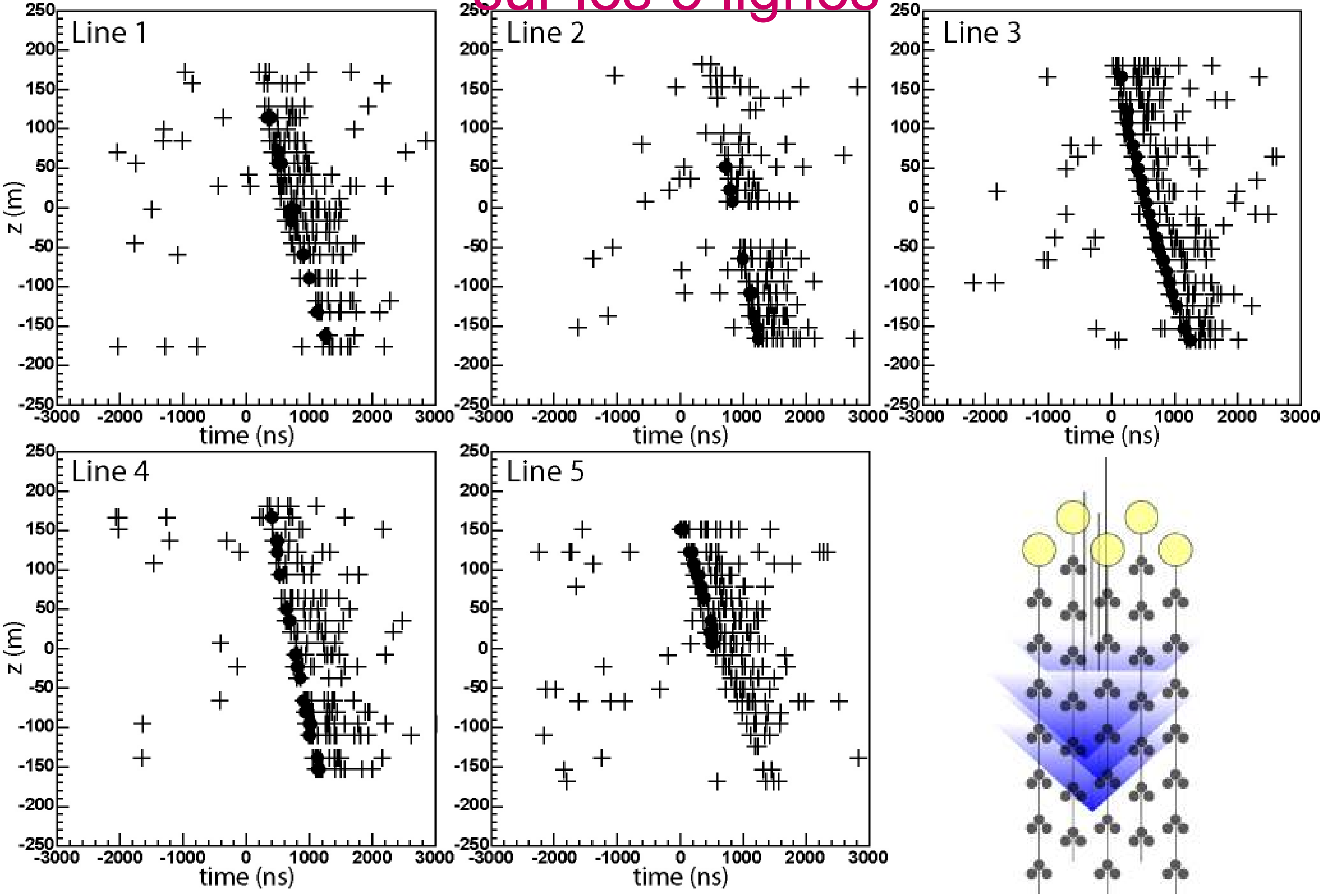
ANTARES: installation



- *Line 2* connected September 2006
- Lines 3,4,5 connected January 2007
- Lines 6,7 deployed March, April
- Mini Instrumentation Line/OM retrieved, April.

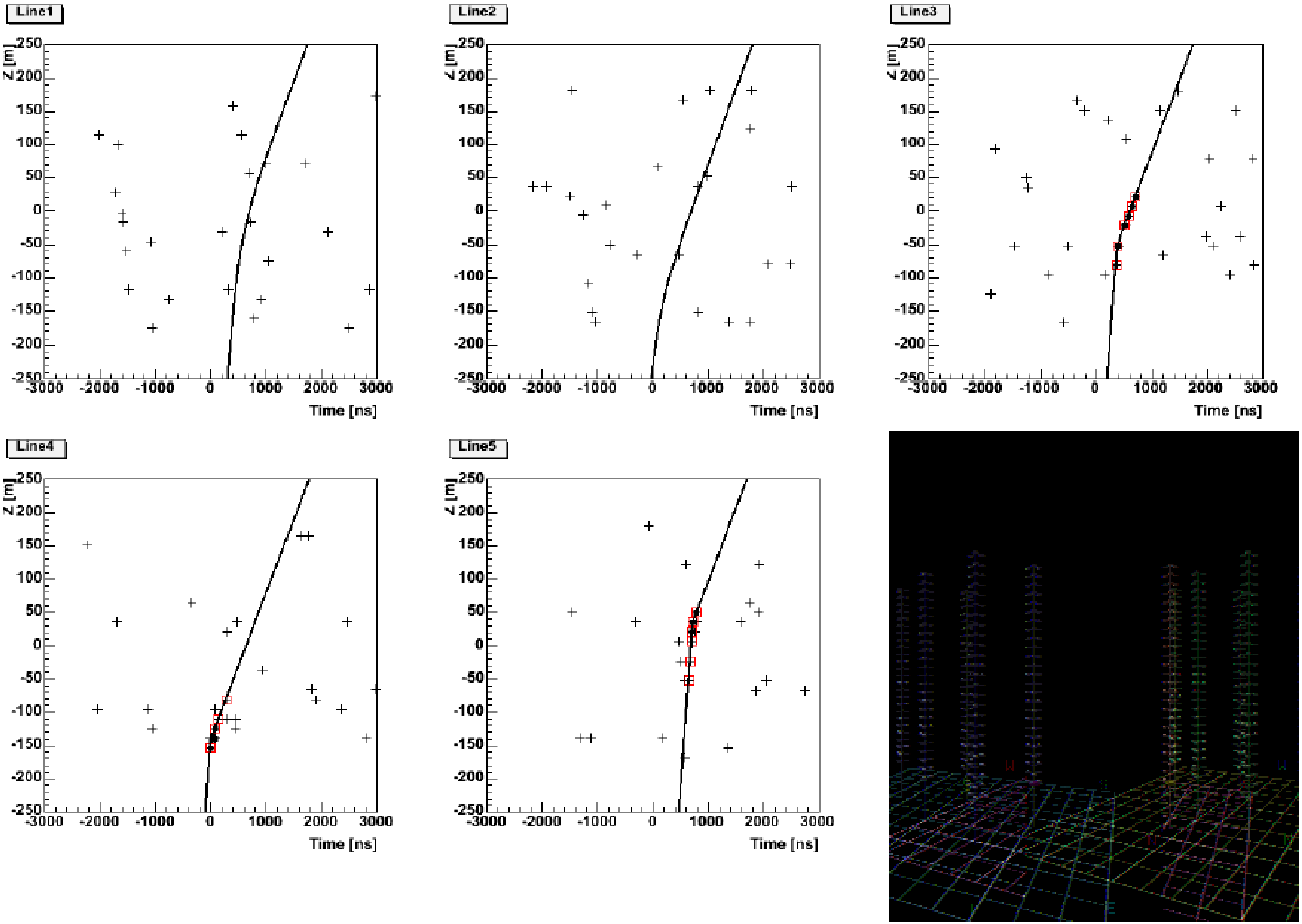


Gerbe de muons atmospheriques sur les 5 lignes

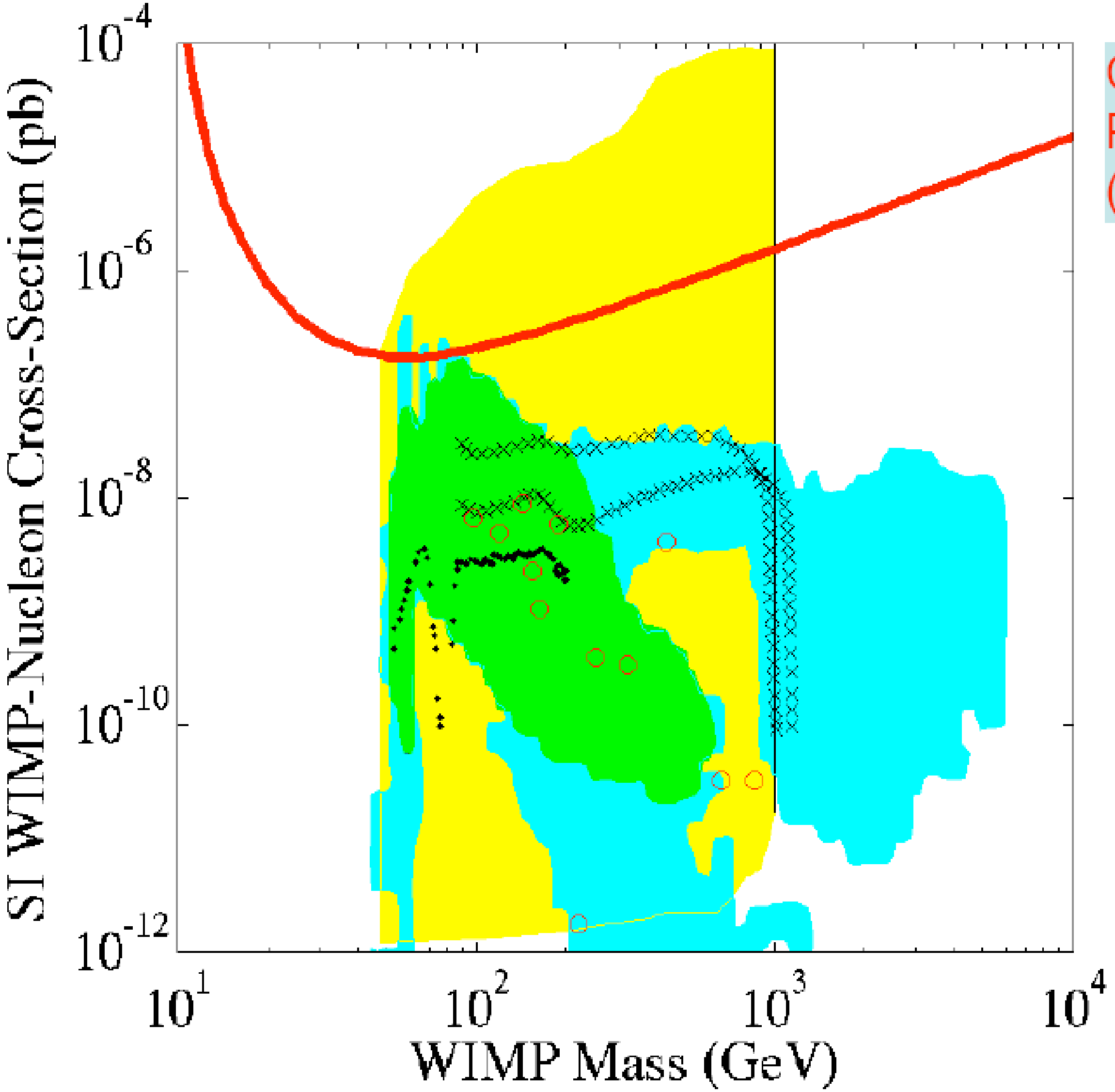


Θ=35°

Candidat neutrino atmosphérique



Matière noire



Current CDMS II limit
PRL 96, 011302 (2006) ***(Ge froid)***
(~20 attobarn^{-1})

Kim et al. 2002
yellow (MSSM scan)

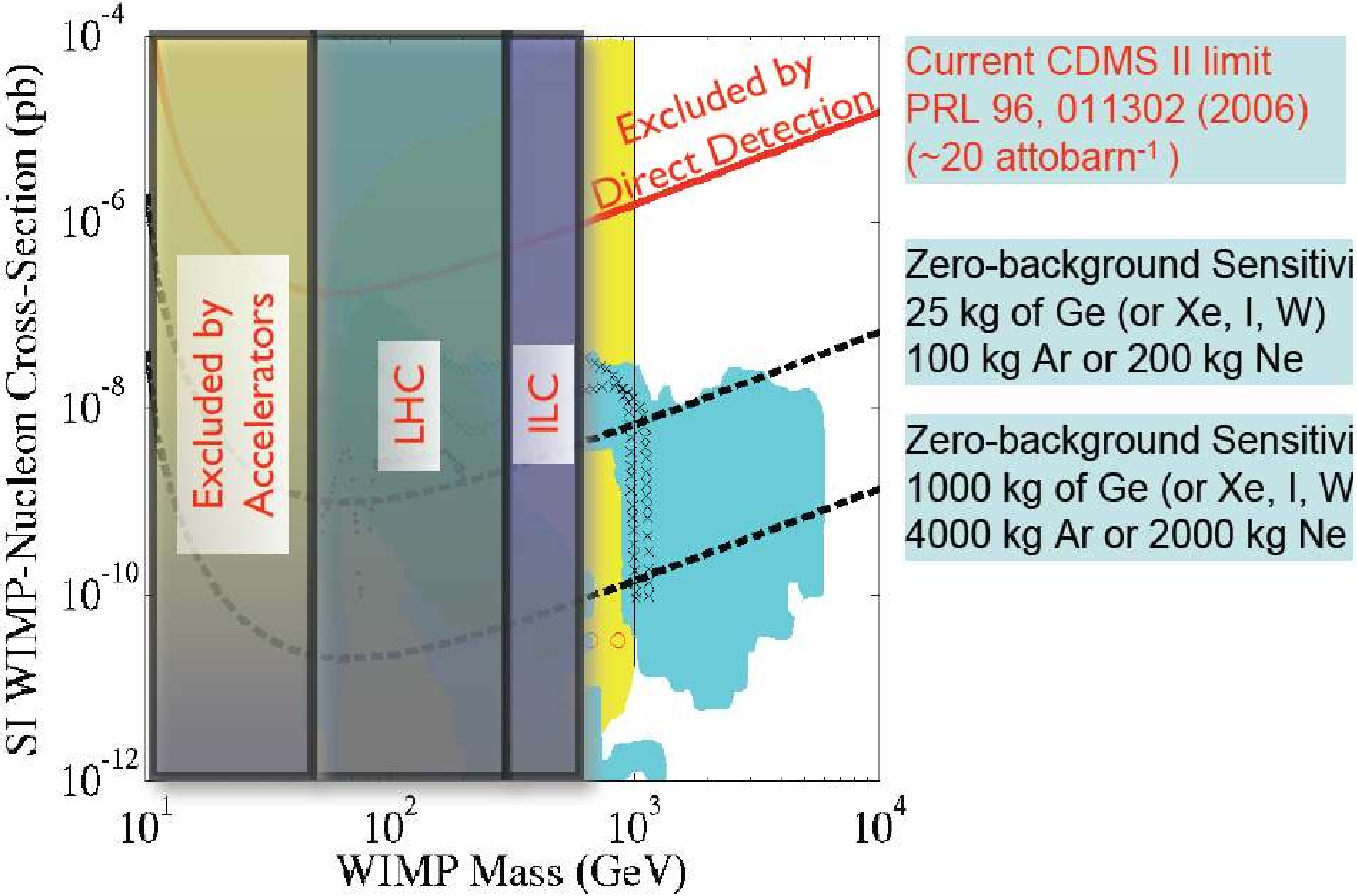
Baltz & Gondolo 2004
cyan (mSUGRA)
green (with g-2 constraint

Battaglia et al. 2004
red circles (post-LEP bench
points)

Guidice & Romanino 200
black crosses (split SUS

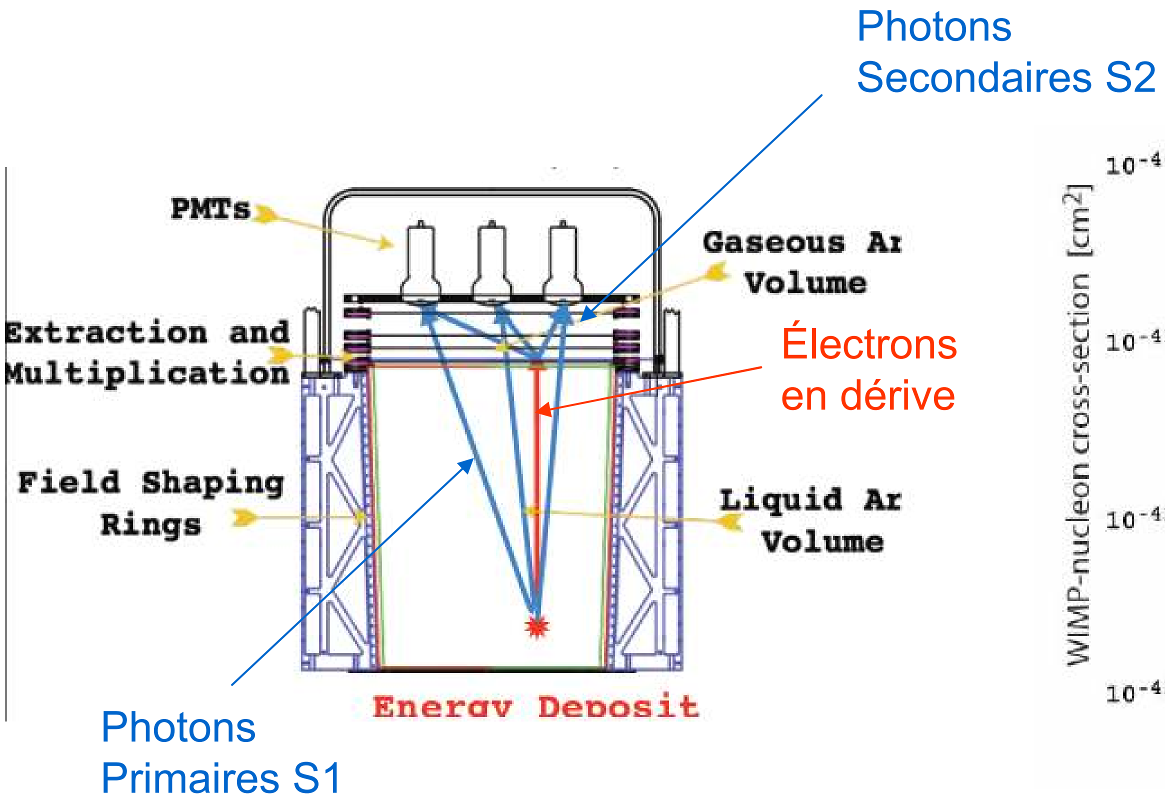
Pierce 2004
black dots (split SUSY)

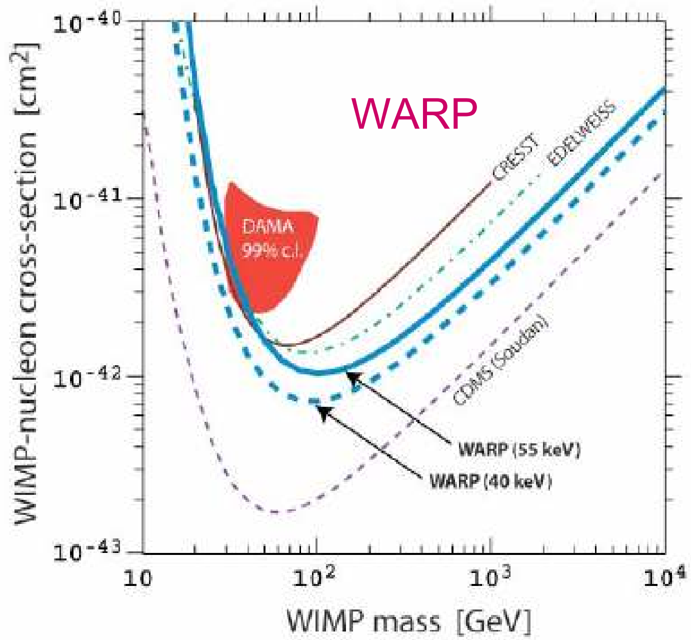
Many models 10^{-8}-10^{-10} p



Current CDMS II limit
PRL 96, 011302 (2006)
(~20 attobarn-1)
Zero-background Sensitivi
25 kg of Ge (or Xe, I, W)
100 kg Ar or 200 kg Ne
Zero-background Sensitivi
1000 kg of Ge (or Xe, I, W
4000 kg Ar or 2000 kg Ne
Excluded by Direct Detection
Excluded by Accelerators
LHC
ILC
SI WIMP-Nucleon Cross-Section (pb)
WIMP Mass (GeV)
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{1}
10^{2}
10^{3}
10^{4}

WARP, détecteur du futur?

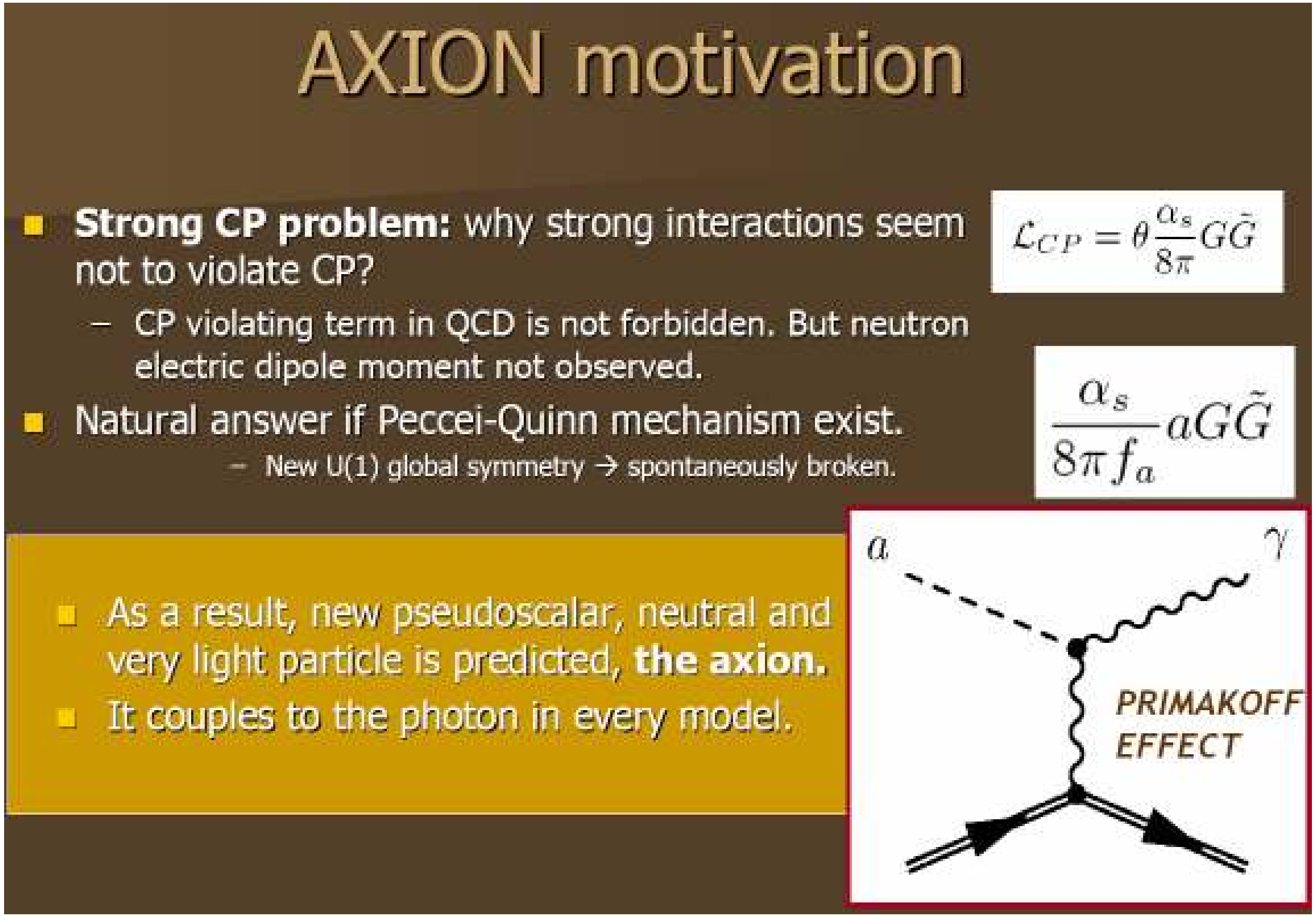




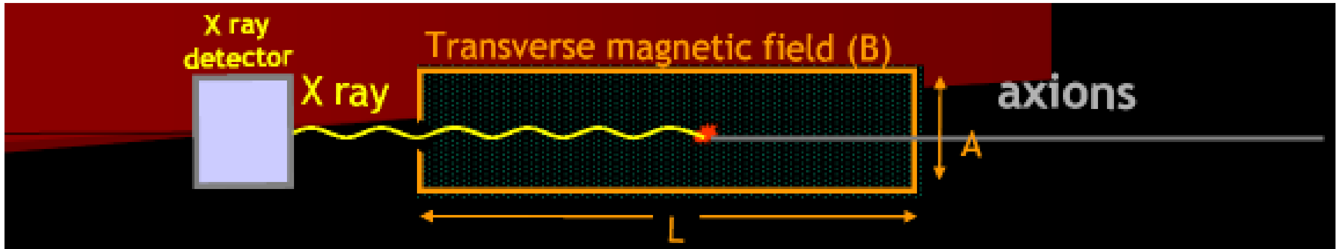
Autres expériences:
CRESST, XENON, XMAS

Edelweiss II
10 kg cette année
30 kg dans 3 ans

Axions


AXION motivation
Strong CP problem: why strong interactions seem not to violate CP?
– CP violating term in QCD is not forbidden. But neutron electric dipole moment not observed.
Natural answer if Peccei-Quinn mechanism exist.
– New U(1) global symmetry → spontaneously broken.
$\mathcal{L}_{CP} = \theta \frac{\alpha_s}{8\pi} G\tilde{G}$
$\frac{\alpha_s}{8\pi f_a} aG\tilde{G}$
As a result, new pseudoscalar, neutral and very light particle is predicted, the axion.
It couples to the photon in every model.
a
γ
PRIMAKOFF EFFECT

CAST



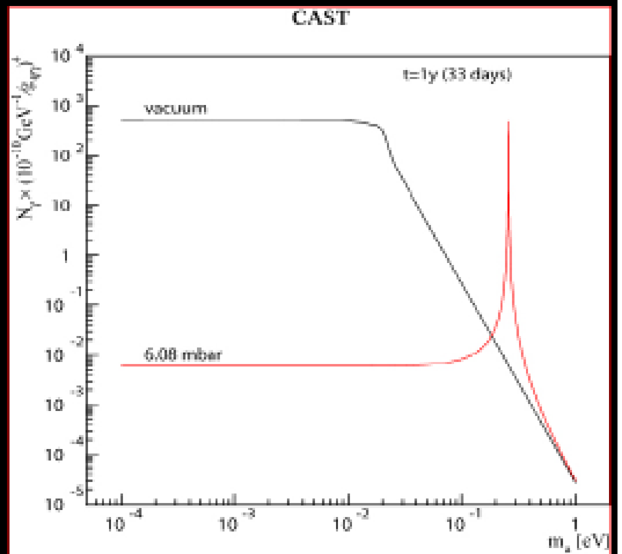
Extending the coherence to higher axion masses...

• Coherence condition ($qL << 1$) is recovered for a narrow mass range around m_γ

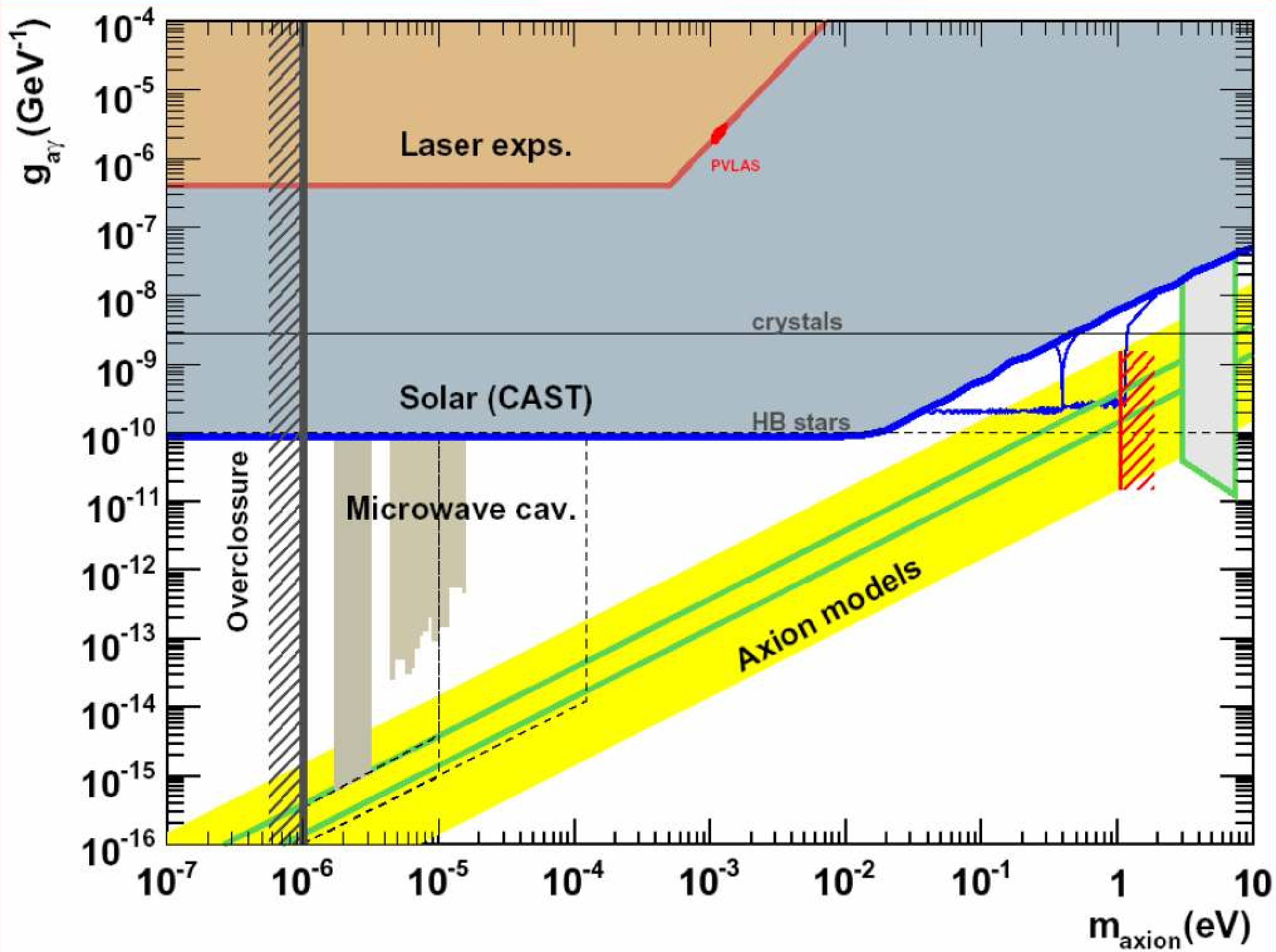
$$|q| = \frac{m_a^2 - m_\gamma^2}{2E}$$

$$m_\gamma \approx \sqrt{\frac{4\pi\alpha N_e}{m_e}} = 28.9\sqrt{\frac{Z}{A}\rho} \quad \text{eV}$$

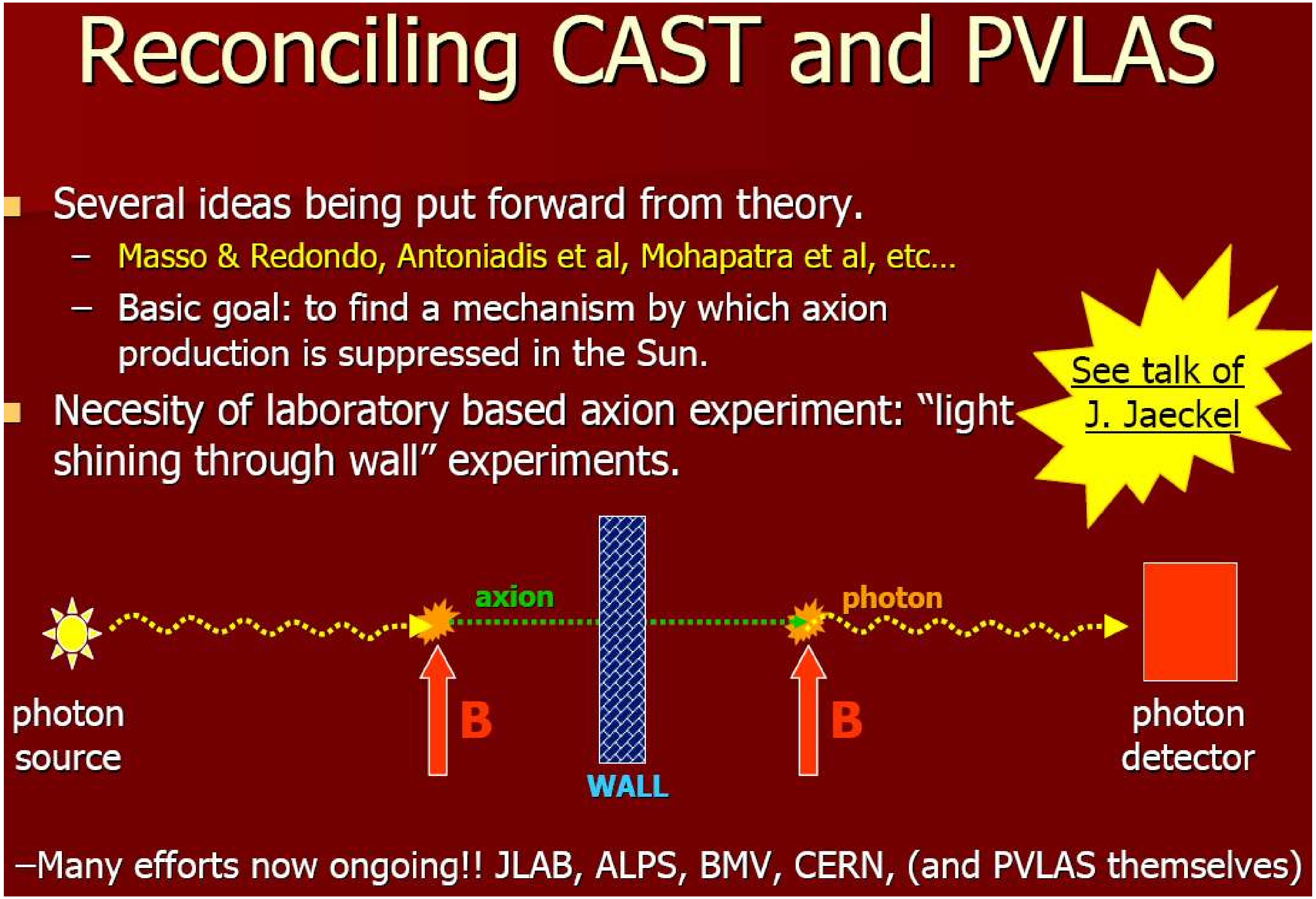
N_e: number of electrons/cm³
ρ: gas density (g/cm³)



Limits on axions: overall view



- **PVLAS** : ellipticité et dichroisme dans un champ magnétique. Signal observé.



ADMX: recherche de Matière Noire d'Axions de faible masse

The Sikivie axion detector is a tunable resonant cavity threaded by a static magnetic field coupled to a ultra-low noise microwave receiver. Axions in our galactic halo enter the cavity, scatter off photons in the magnetic field, and thereby convert into microwave photons. The conversion into microwave photons is enhanced by the resonant cavity (quality factor for our critically coupled cavity is about 105) and the strength of the static magnetic field; the excess microwave photons above thermal background from axion conversion are then detected by the receiver.

g-2

- Electron: Gabrielse
- Muon: D. Hertzog, revue par Z. Zhang (Orsay)

Why Anomalous Magnetic Moment g-2 ?

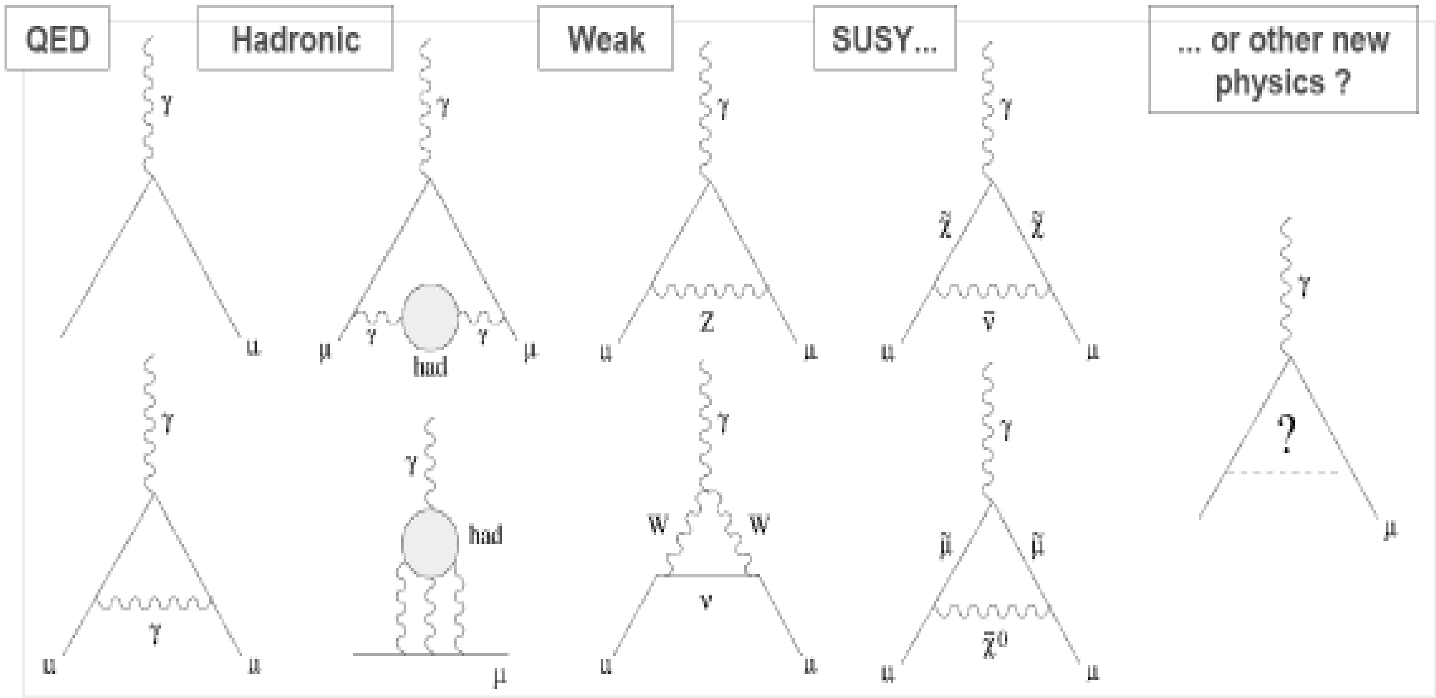
$\vec{\mu} = g \frac{\pm e}{2m} \vec{s}$ $\qquad g = 2 + \cdots$ → Anomalous Magnetic Moment: a=(g-2)/2

a_μ: precisely measured and predicted (within the SM)

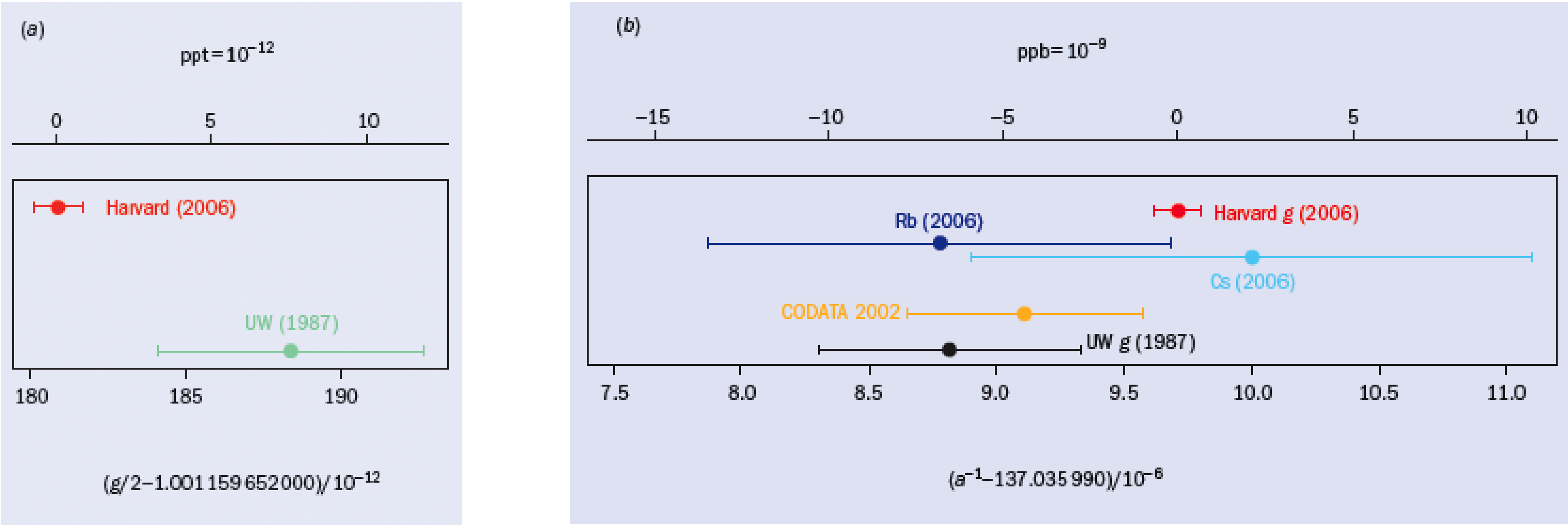
(a_e is better measured but a_μ is more sensitive to new physics effects by $(m_\mu/m_e)^2 \sim 4.3 \cdot 10^4$)

a_μ^{mea} vs. a_μ^{th}: test the SM & signal new physics effects

$$a_\mu^{th} = a_\mu^{SM} + a_\mu^{non\text{-}SM}, \qquad a_\mu^{SM} = a_\mu^{QED} + a_\mu^{had} + a_\mu^{Weak}$$



g-2 de l’électron



g-2 de l'électron: mesure

- Un e^- stocké pendant des mois, r<0.1μm,

E_e = 100 mK. Transitions quantiques entre états cyclotron et états de spin.

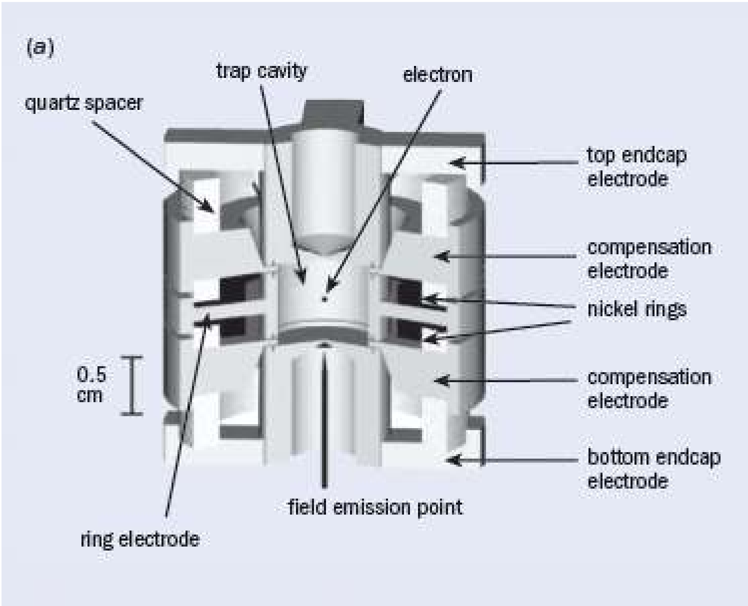
Stimulation de transitions f_c par photons microondes et de spin-flip f_a par une fréquence radio.

Spectrosopie des transitions quantiques: nombre de sauts/essai en fonction de la fréquence. Détection par décalage causé sur une fréquence d'oscillation orthogonale.

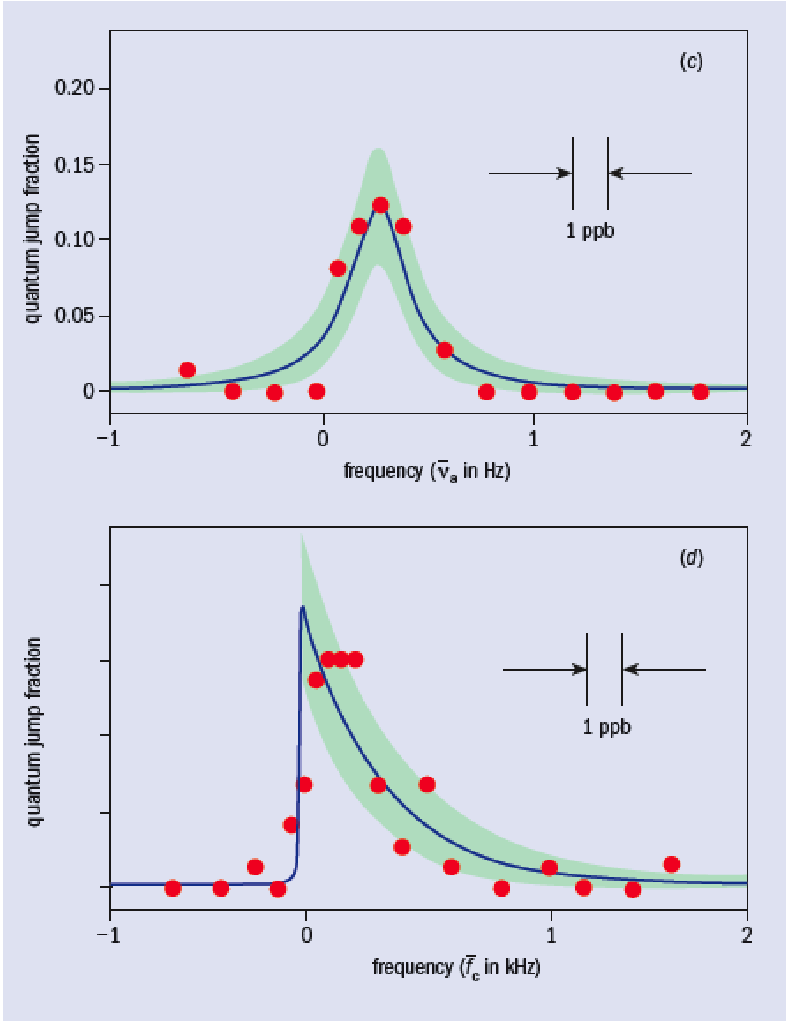
Courbes de résonnance pour f_a et f_c

Et $g/2 = 1 + f_a / f_c$

G Gabrielse et al. 2006 Phys. Rev. Lett. ***97*** *030802.*
B Odom et al. 2006 Phys. Rev. Lett. ***97*** *030801.*



Stockage de l'électron



Spectrosopie des transitions quantiques

SM Predictions: $a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{had}} + a_\mu^{\text{Weak}}$

1st order known since 1948
[J. Schwinger, PR73(48)416]

4th order only known numerically
T. Kinoshita et al calculated in 80's

5th order estimated recently, T. Kinoshita & M. Nio, PRD73(06) 053007

Up to 3rd order known analytically

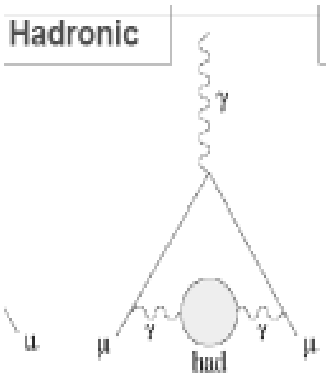
$$a_\mu^{\text{QED}} = \frac{\alpha}{2\pi} + 0.76585741(3)\left(\frac{\alpha}{\pi}\right)^2 + 24.0505096(4)\left(\frac{\alpha}{\pi}\right)^3 + 131.01(1)\left(\frac{\alpha}{\pi}\right)^4 + 663(20)\left(\frac{\alpha}{\pi}\right)^5 + \cdots$$

$$= 11\,658\,471.90 \;\pm 0.01_{5^{th}\,order} \;\pm 0.04_{\delta\alpha} \;\times 10^{-10}$$ [PDG '06]

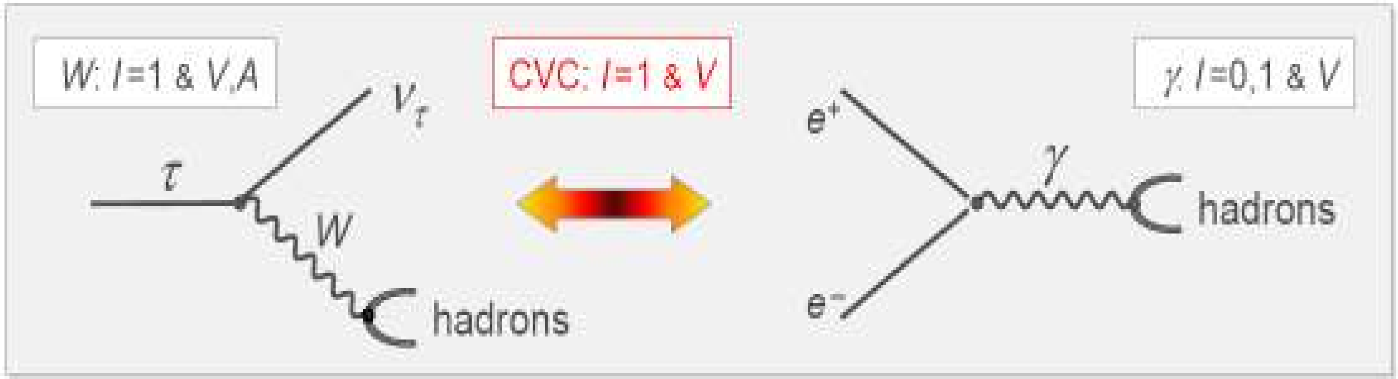
$$= 11\,658\,471.809 \pm 0.014_{5^{th}\,order} \pm 0.008_{\delta\alpha} \times 10^{-10}$$

[Using α extracted from latest a_e]
(Gabrielse et al PRL97(06)030801)

Extraction des corrections hadroniques à partir de $e^+e^- \rightarrow$hadrons



Connect τ and e^+e^- Data through CVC – SU(2)



Hadronic physics factorizes in Spectral Functions :

Isospin symmetry connects I=1 e^+e^- cross section to vector τ spectral functions:

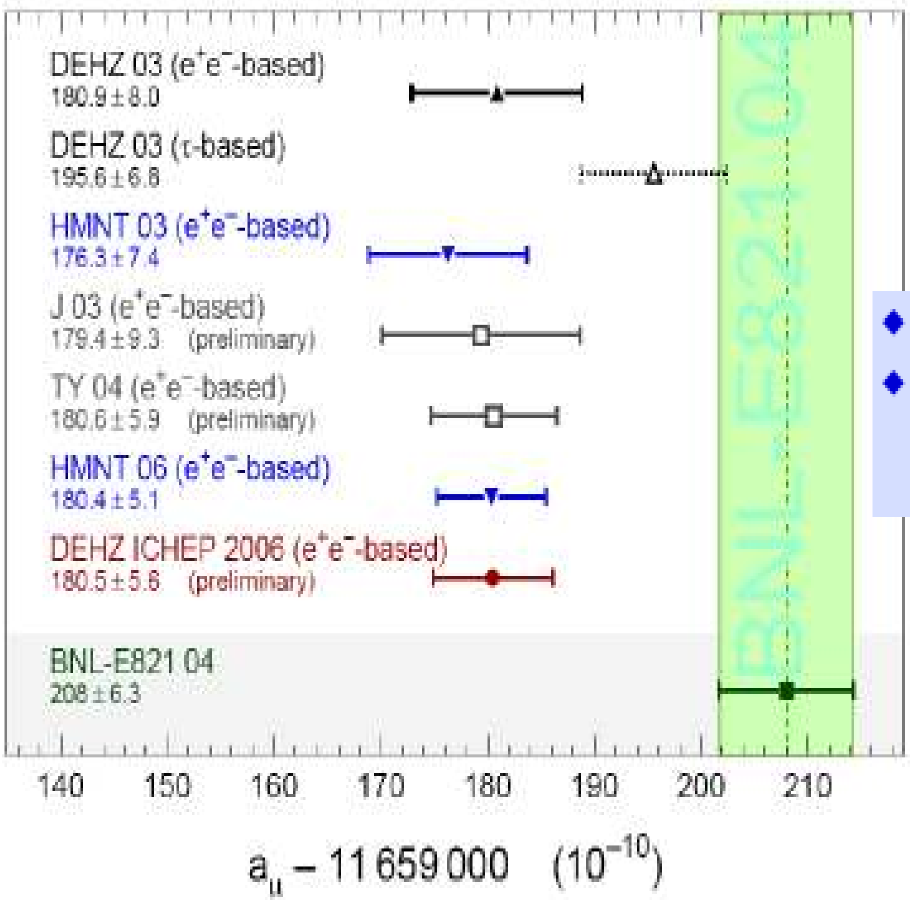
$$\sigma^{(I=1)}\left[e^+e^- \to \pi^+\pi^-\right] = \frac{4\pi\alpha^2}{s}\,\upsilon\left[\tau^- \to \pi^-\pi^0\nu_\tau\right]$$

fundamental ingredient relating long distance (resonances) to short distance description (QCD)

$$\upsilon\left[\tau^- \to \pi^-\pi^0\nu_\tau\right] \propto \frac{\mathrm{BR}\left[\tau^- \to \pi^-\pi^0\nu_\tau\right]}{\mathrm{BR}\left[\tau^- \to e^-\bar{\nu}_e\nu_\tau\right]}\;\frac{1}{N_{\pi\pi^0}}\frac{dN_{\pi\pi^0}}{ds}\;\frac{m_\tau^2}{\left(1-s/m_\tau^2\right)^2\left(1+s/m_\tau^2\right)}$$

branching fractions — mass spectrum — kinematic factor (PS)

Status of g_μ-2



- Δa_μ(expt-thy) = (27.6 ± 8.1) x 10^{-10} (3.4 σ)
- E969 in future: 2-fold improvement in expt and theory
  - Awaits funding opportunity

Whereas τ based prediction agrees with the measurement within 1σ
all recent e+e- based predictions have a deviation with data at over 3σ

Summary

- Hadronic vacuum polarization is still the dominant systematics for SM prediction of the muon $g - 2$
- Precision of SM prediction (±5.6) now exceeds experimental precision (±6.3)
- SM prediction for a_μ differs by ~3.3 σ [e^+e^-] from experiment (BNL 2004)

- Discrepancy with τ data (ALEPH & CLEO & OPAL) is still an open issue
- What is behind the 4.5 σ discrepancy between BR($\tau^- \to \nu_\tau \pi^- \pi^0$) and the isospin-breaking corrected spectral function from $e^+e^- \to \pi^+\pi^-$?

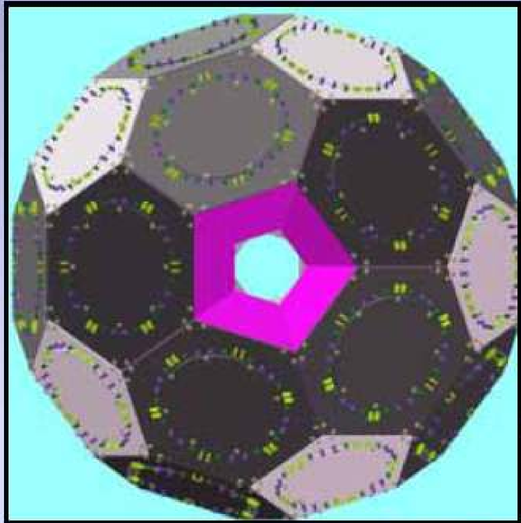
- The current e^+e^- data are mostly obtained using energy scan method
- Important to cross check these data with other data/method (e.g. radiative return method from KLOE & BaBar)

Precision Muon Physics: New results and a hint at things to come

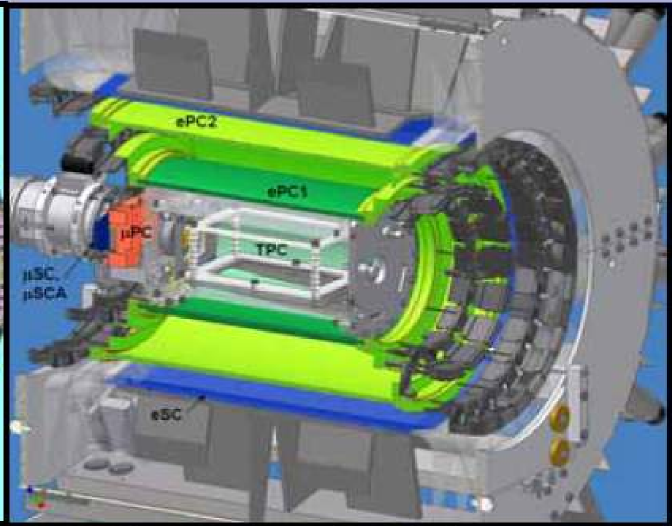
David Hertzog

University of Illinois at Urbana-Champaign

τ_μ



MuLan



g_P

MuCap

a_μ

Muon g-2

The predictive power of the Standard Model depends on well-measured input parameters

The most precise electroweak parameters…

G_F	α	M_Z
9 ppm	0.0007 ppm	23 ppm

Precision μ^+ lifetime

A connection in technique

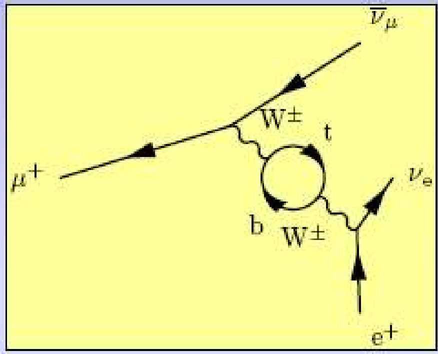
What is the weak-nucleon charged current?

g_p

Precision μ^- lifetime in ultra-pure hydrogen gas (capture)

The Fermi constant is related to the electroweak gauge coupling *g* by

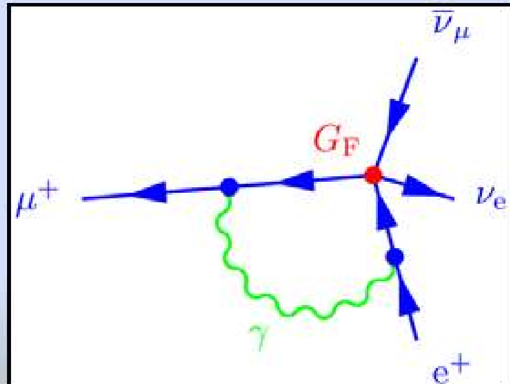
$$\frac{G_{\mathrm{F}}}{\sqrt{2}} = \frac{g^2}{8M_{\mathrm{W}}^2}\left(1+\Delta r(m_{\mathrm{t}}, m_{\mathrm{H}}, \ldots)\right)$$



Contains all weak interaction loop corrections

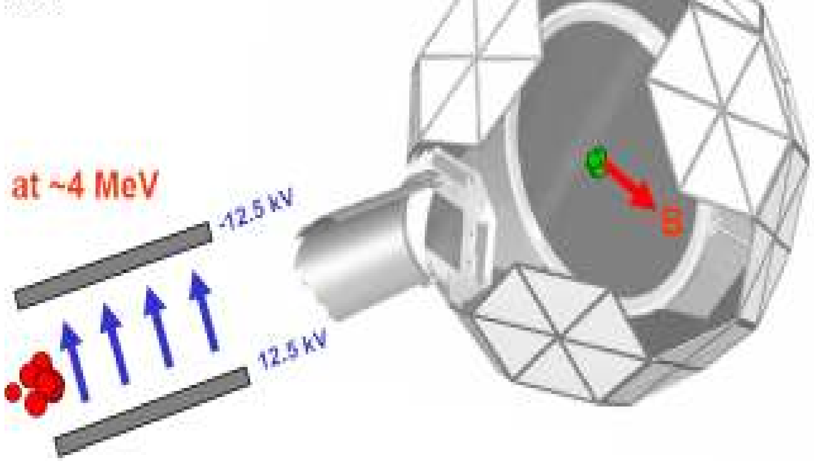
In the Fermi theory, muon decay is a contact interaction

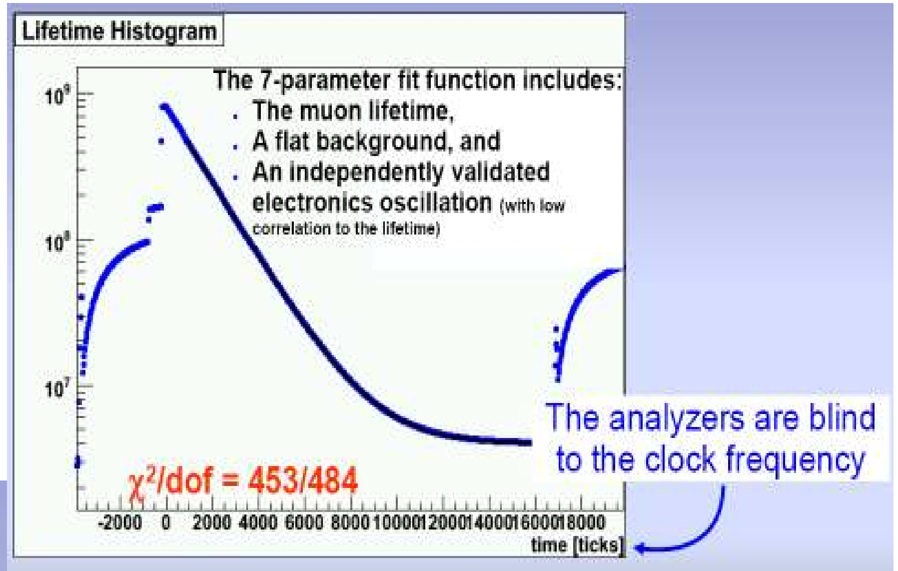
$$\frac{1}{\tau_{\mu^+}} = \frac{G_{\mathrm{F}}{}^2 m_\mu^5}{192\pi^3}$$



In 1999, van Ritbergen and Stuart completed full 2-loop QED corrections reducing the uncertainty in G_F from theory to < 0.3 ppm (it was the dominant error before)

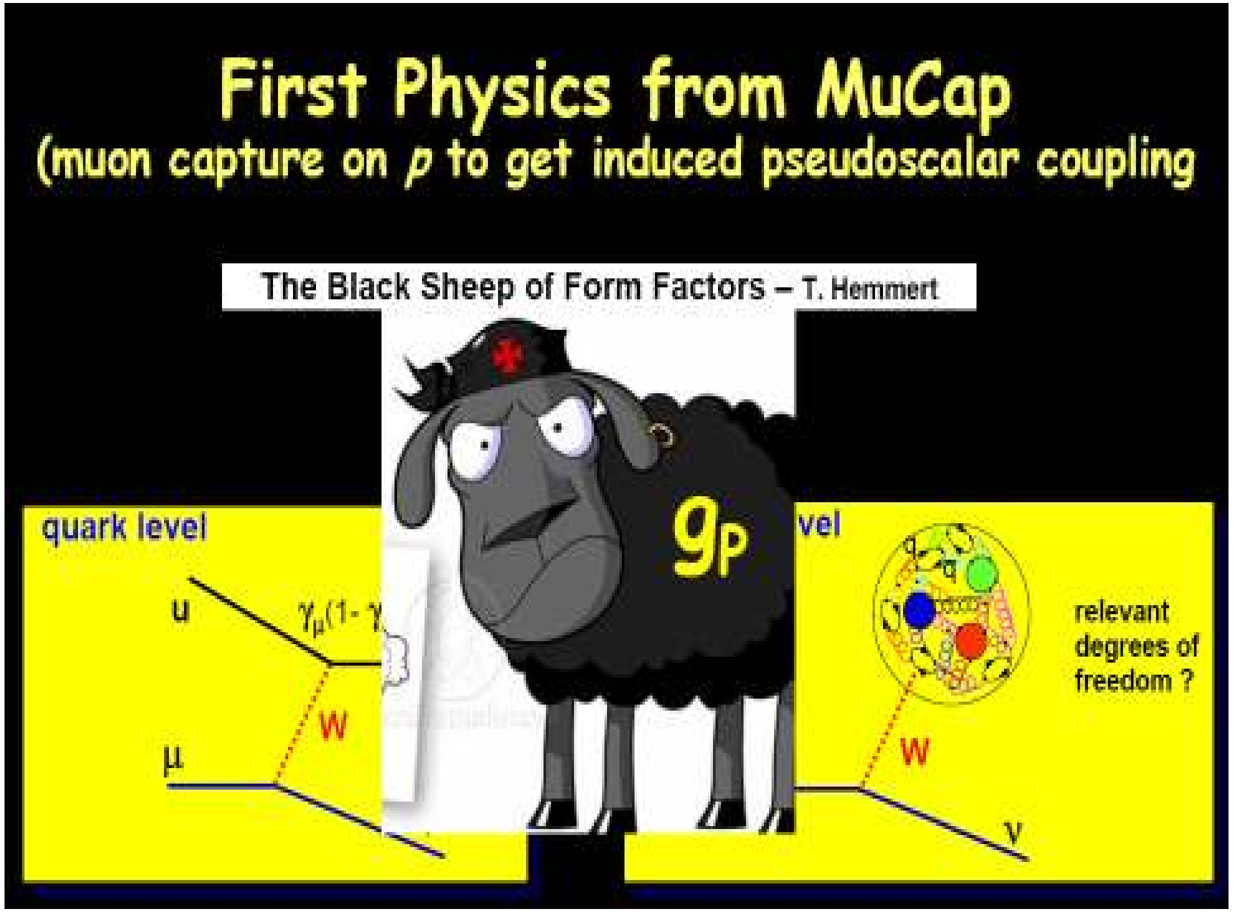
MuLan





- **First G_F update in > 23 years**
  - τ_μ = 2.197 013(24) μs (11 ppm)
  - G_F = 1.166 372(6) x 10^{-5} GeV^{-2} (5 ppm)

Article Chitwood et al, Mars 07



- ♦ First g_P with non-controversial interpretation
  - $g_P = 7.3 \pm 1.0$
  - Agrees with χPT expectation