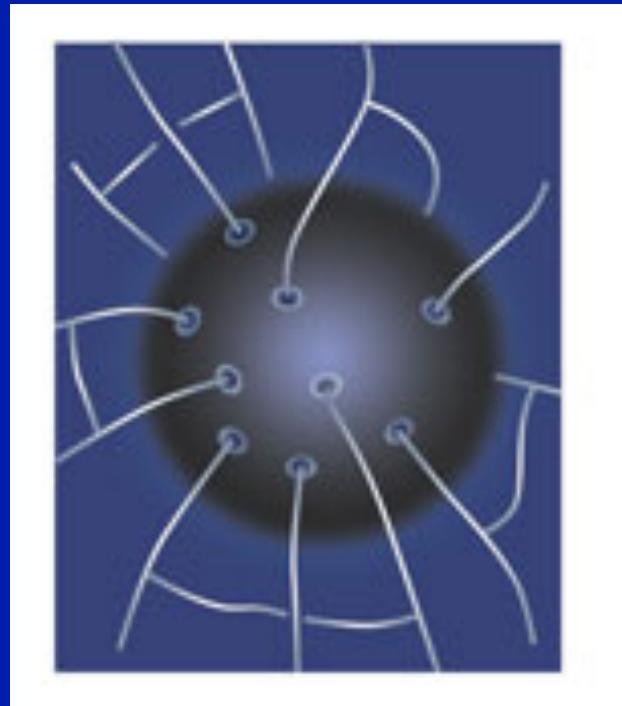


# Quelques “exotiques” pour AMS: secteur gravitationnel et secteur QCD



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# Black holes do evaporate

- Emission spectrum

$$\frac{d^2N}{dQdt} = \frac{\Gamma(Q, s, M)}{h\left(e^{\frac{Q}{k_B T}} - (-1)^{2s}\right)}$$

$$T = \frac{\hbar c^3}{8\pi k_B GM}$$

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Non-thermal part: probability to escape  
from the BH in the intricate metric  
Greybody factors

Thermal part: breaking the vacuum  
fluctuations with tidal forces

$$T = \frac{\hbar c^3}{8\pi k_B G M}$$

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$$T = \frac{\hbar c^3}{8\pi k_B GM}$$

- Mass loss rate

$$\frac{dM}{dt} = -\frac{\alpha(M)}{M^2}$$

$$M = 10^{16} g \rightarrow T = 10^{-1} GeV \rightarrow t = 10^{21} s$$

$$M = 10^9 g \rightarrow T = 10^4 GeV \rightarrow t = 1s$$

# Greybody factors: example of scalar fields on the brane

Schwarzschild metric

$$ds^2 = h(r)dt^2 - \frac{dr^2}{h(r)} - r^2 d\Omega_{D-2}^2$$

Field equation with this background metric → taking into account the symmetries

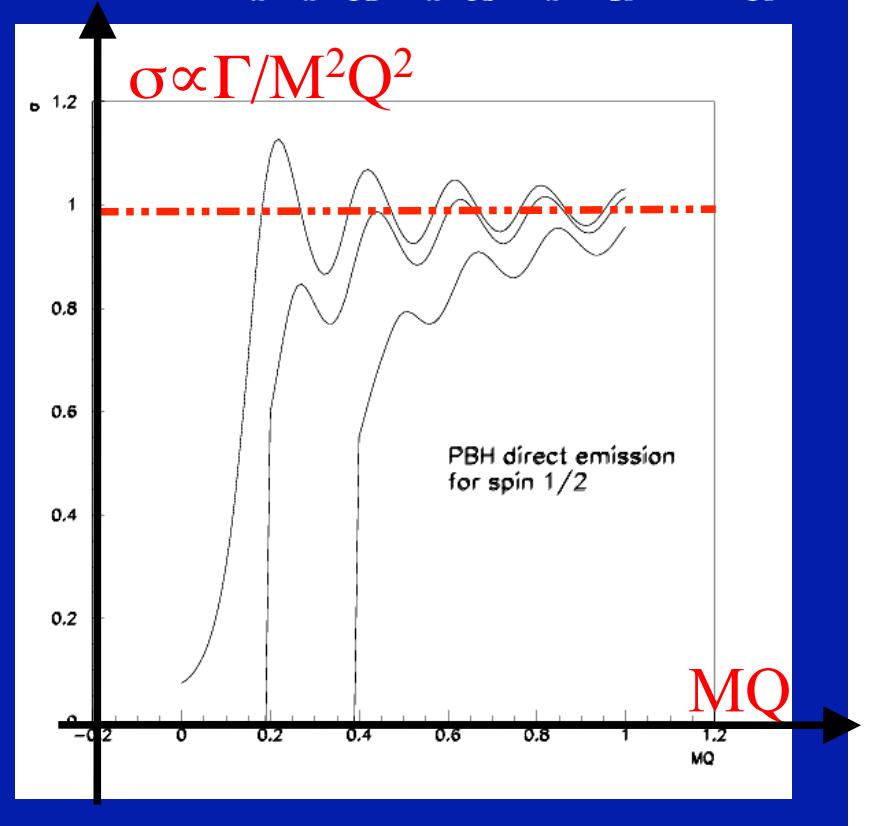
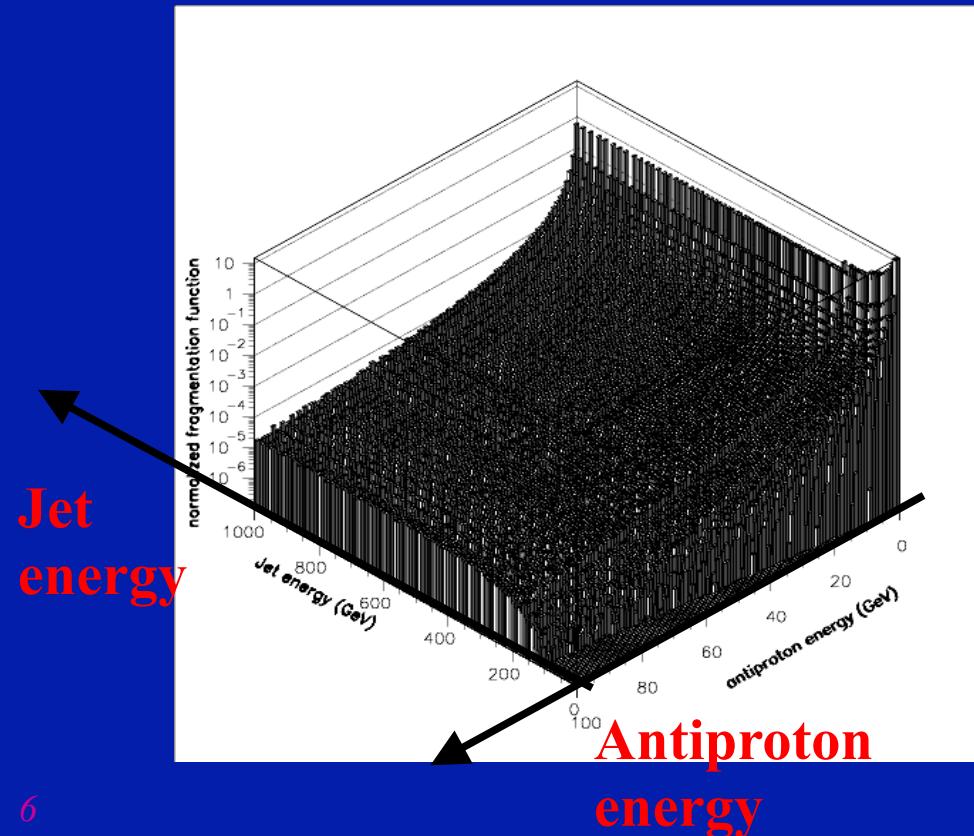
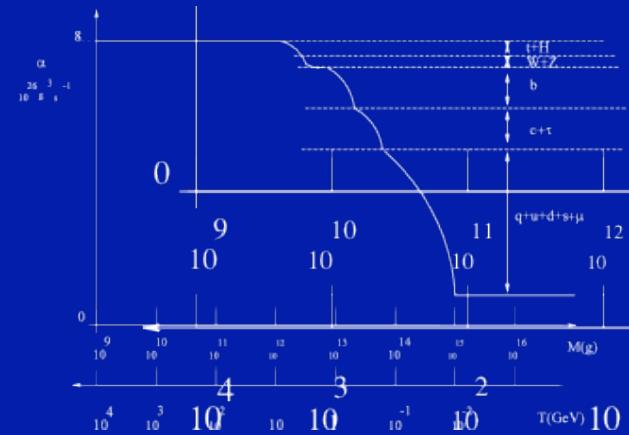
$$\frac{1}{\sqrt{-g}} \partial_\alpha \left[ \sqrt{-g} g^{\alpha\beta} \partial_\beta \Phi \right] + \mu^2 \Phi = 0 \text{ avec } \Phi \equiv e^{-i\omega t} Y_m^\ell(\theta, \varphi) R(r)$$

- Changement de variable : problème de diffusion (potentiel = fonction de la métrique)
- Résolution WKB ou numérique
- Particules spinnées : tétrades de Penrose

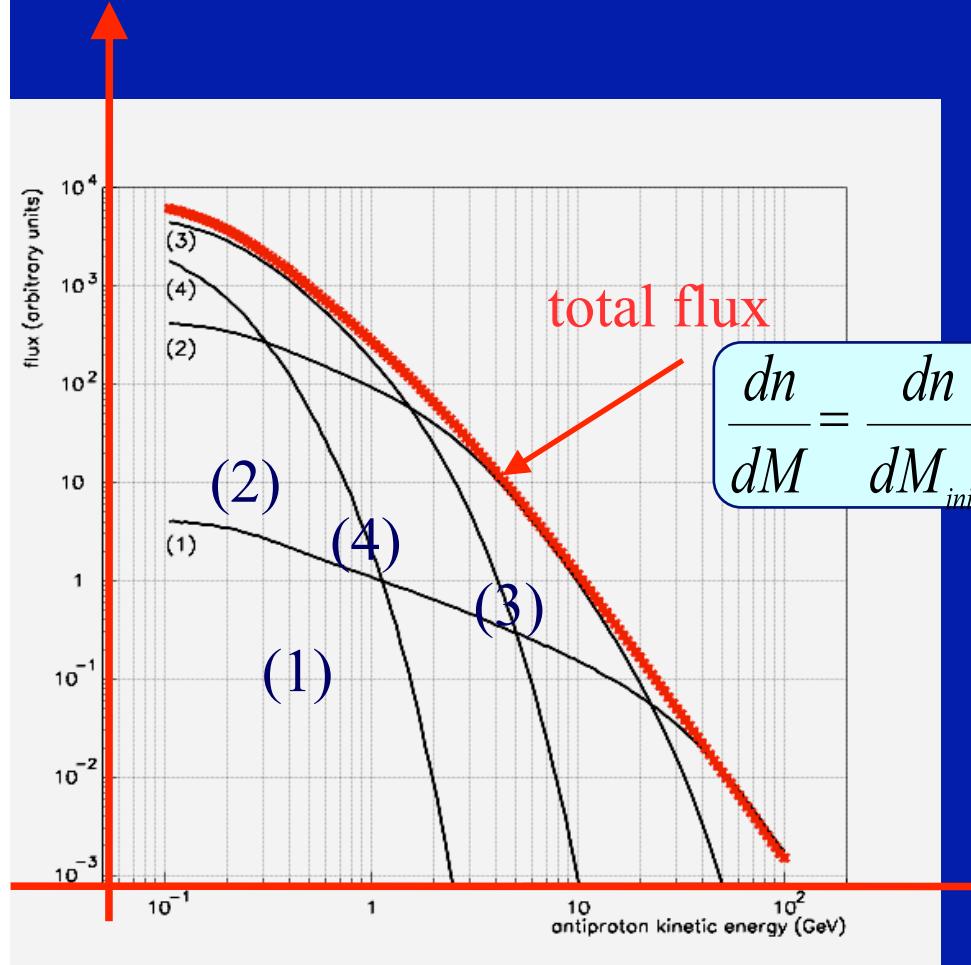
# Antiproton individual emission

Antiprotons are rare : good S/N

$$\frac{d^2N_{\bar{p}}}{dEdt} = \sum_j \int_{Q=E}^{\infty} \alpha_j \frac{\Gamma_j(Q,T)}{h} \left( e^{\frac{Q}{kT}} - (-1)^{2s} \right)^{-1} \frac{dg_{j\bar{p}}(Q,E)}{dE} dQ$$



# Cumulative source



$$q^{prim}(r, z, E) = \int \frac{d^2 N(M, E)}{dEdT} \frac{d^2 n(r, z)}{dM dV} dM$$

$$M_* \approx 5 \times 10^{14} g$$

$$\frac{dn}{dM} = \frac{dn}{dM_{init}} \frac{dM_{init}}{dM}$$

$$\frac{dn}{dM} \propto M^2 \leftrightarrow M < M_*$$

$$(1) \rightarrow M \in [M_{Pl}, 10^{12} g]$$

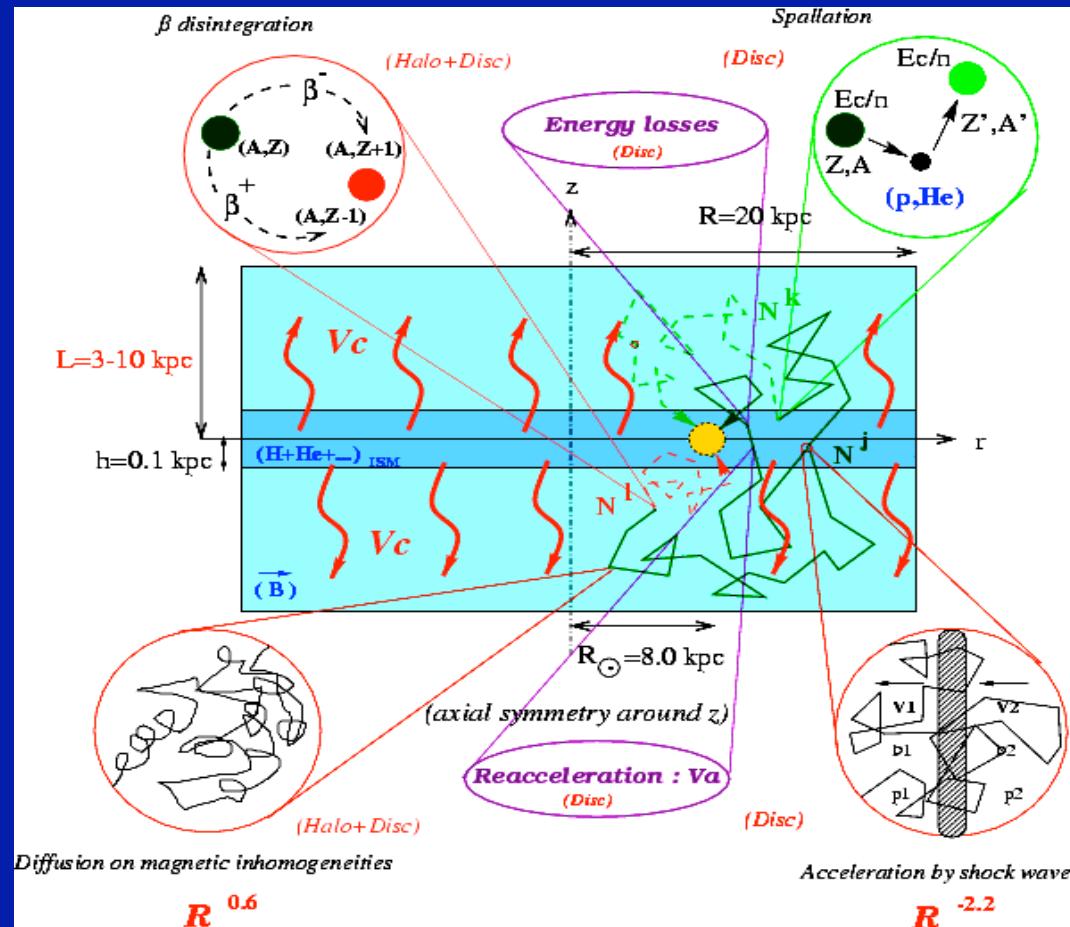
$$(2) \rightarrow M \in [10^{12} g, 10^{13} g]$$

$$(3) \rightarrow M \in [10^{13} g, 5 \times 10^{13} g]$$

$$(4) \rightarrow M > 5 \times 10^{13} g$$

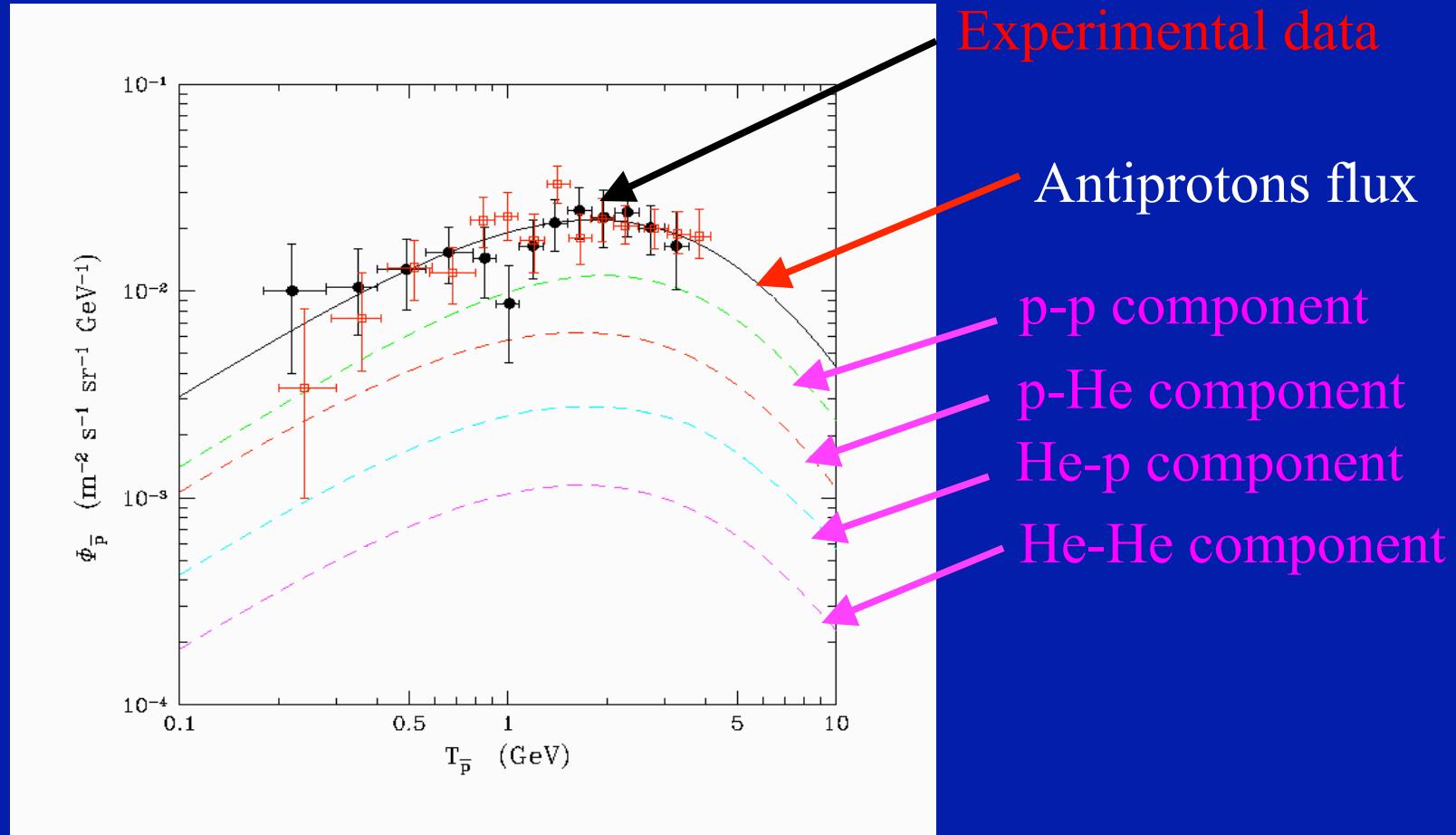
- The horizon size after inflation is also taken into account
- A possible QCD halo around the BH is also considered

# Now, let the antiprotons propagate in the Milky way...



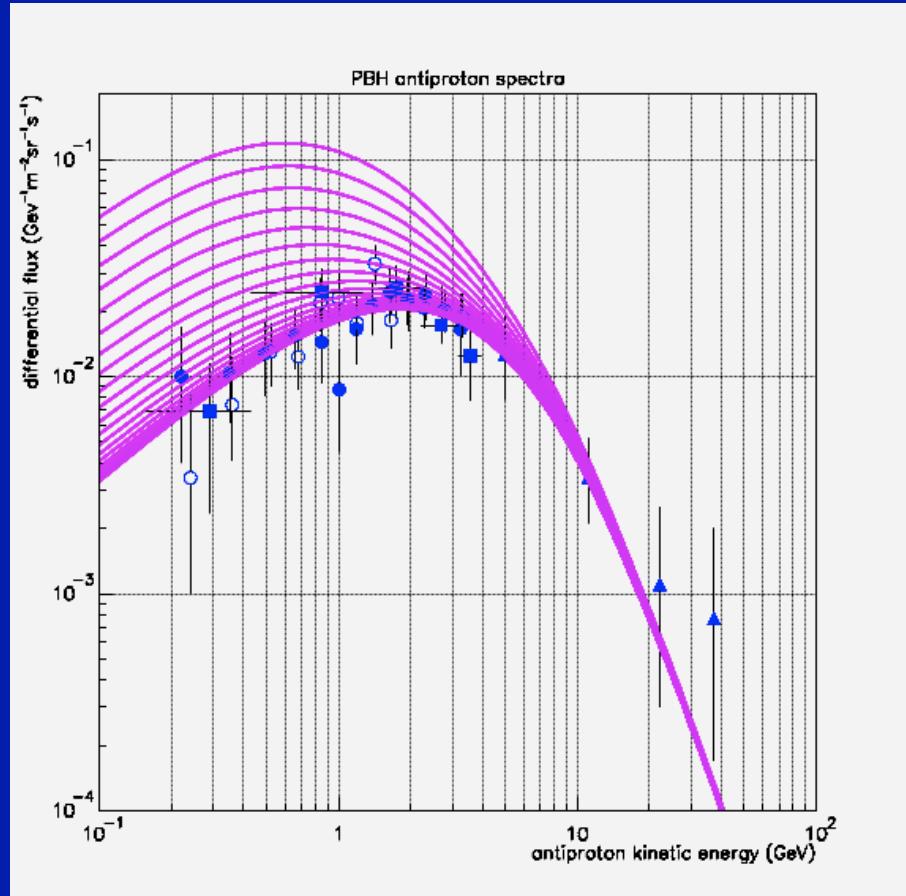
Maurin, Taillet, Donato, Salati, A.B., Boudoul, review article for “Research Signpost” (2002) [astro-ph/0212111]

# Secondary antiprotons flux



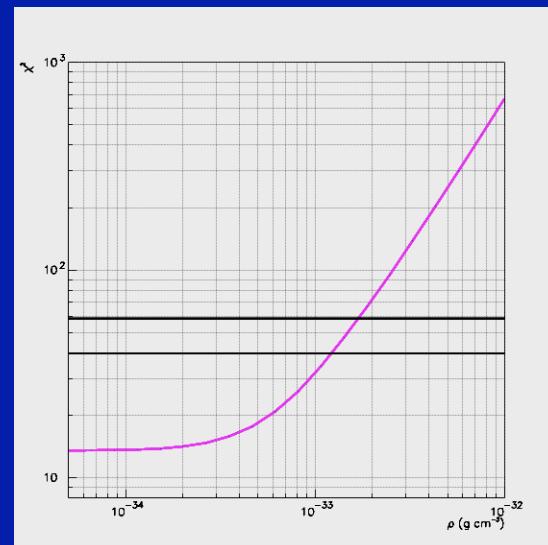
F.Donato, D. Maurin, P. Salati, A. B., G. Boudoul, R.Taillet, *Astrophys. J.* (2001) 536, 172

# Spectrum and limit on the PBH density



$$2h\delta(z)q(r,0,E) = 2h\delta(z)\Gamma_{\bar{p}}^{ine}N(r,0,E) + \left[ V_c \frac{\partial}{\partial z} - K \left( \frac{\partial^2}{\partial z^2} + \frac{1}{z} \frac{\partial}{\partial r} \left( r \frac{\partial}{\partial r} \right) \right) \right] N(r,z,E)$$

$$q(r,E) = \int_{Threshold}^{\infty} \frac{d\sigma}{dE} \left\{ p(E') + H_{ISM} \rightarrow \bar{p} \right\} n_H \left\{ 4\pi \Phi_p(r,E') \right\} dE'$$



+ tertiaries

$$\Omega < 4 \times 10^{-9}$$

A.B., G. Boudoul, F. Donato, D. Maurin, P. Salati, Astronom. Astrophys., 388, 767 (2002)

# Gamma-ray new upper limit

Taking into account the expected background from (Pavlidou & fields, ApJ 575, L5-8 (2002)):

- galaxies
- quasars

The EGRET gamma-ray flux at 100 MeV can be converted into (after integration over redshift, evolution and absorption) :

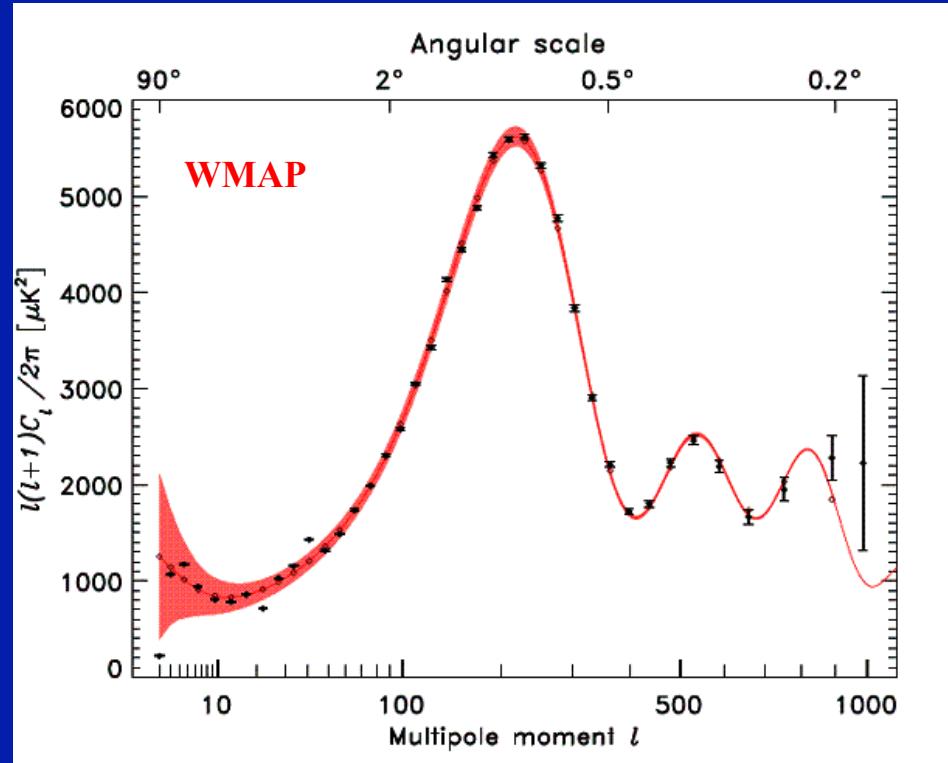
$\Omega_{\text{PBH}} < 3.3 \times 10^{-9}$ , improving by a factor 3 the Page & MacGibbon upper limit.

This limit is nearly the same as with antiprotons but it relies on very different physics and assumptions.

A.B., IRCR 2003 proc., [astro-ph/0304528]

# COSMOLOGICAL CONSEQUENCES

Unlike the CMB or the large scale structures, PBH give information on small scale

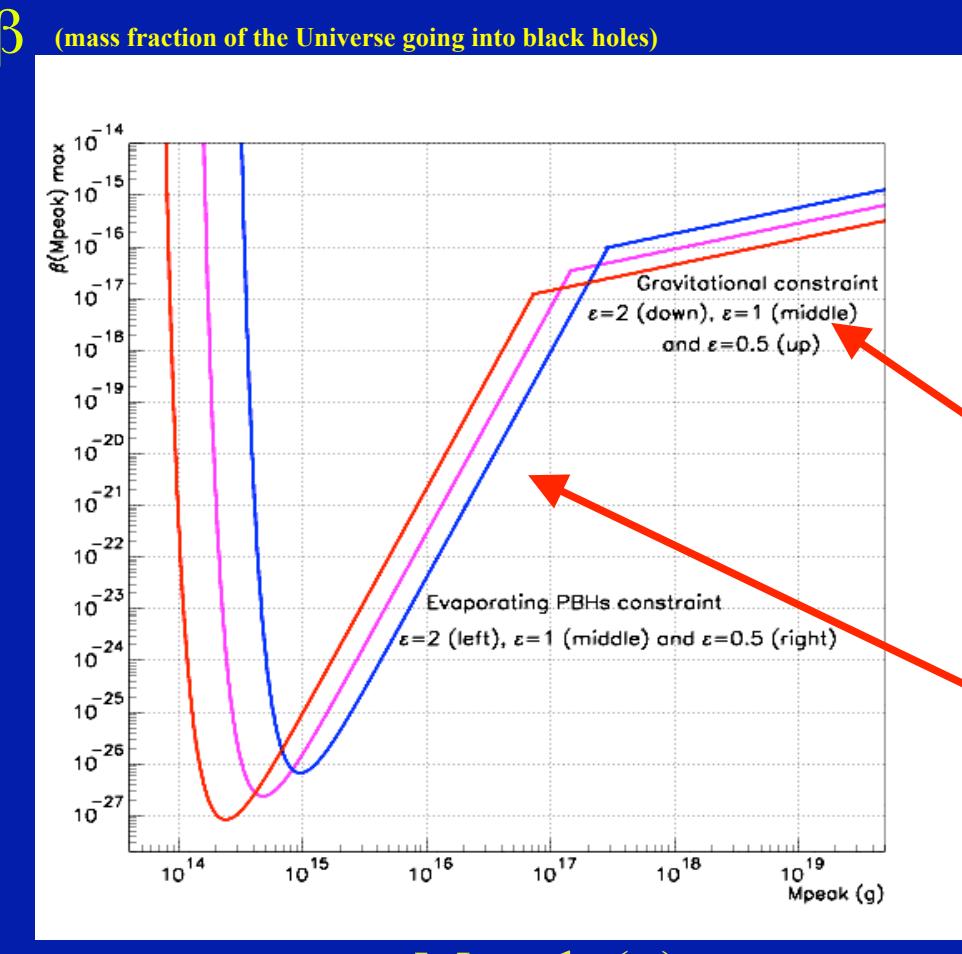
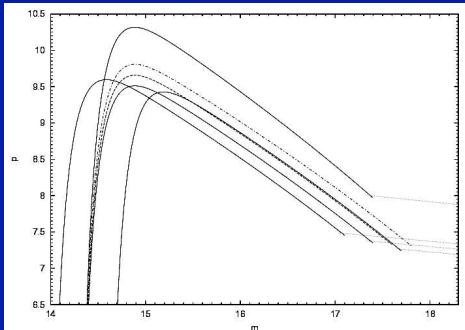


**PRIMORDIAL BLACK HOLES ARE A UNIQUE  
COSMOLOGICAL PROBE**

# Density fluctuations in the early Universe constrained by PBHs

Using  
Starobinsky  
model for the  
Bump

No positive  
Running of the  
index



A.B., Blais, Boudoul, Polarski, Phys. Lett. B, 551, 218 (2003)

# Dark Matter

In the BSI framework, PBHs can be reconsidered as CDM candidates  
In two different scenarios

A. Barrau, D.Blais, G.Boudoul , D. Polarski  
Ann. Phys. 13, 115 (2004)

If  $M_{RH}$  is very large (greater than  $10^{15}$  g) , PBHs become good candidates

$$p \approx \frac{\sigma_{H, COBE}}{\delta_{\min}} \sqrt{LW \left\{ \frac{5.3 \times 10^{-6}}{2\pi \Omega_{PBH}^2} \left[ \frac{10^{15}}{M_{H,e}} \right]^3 \right\}}$$

Pour  $M_{H,e} = 10^{-15}$  g  
 $p \approx 6.5 \times 10^{-4}$

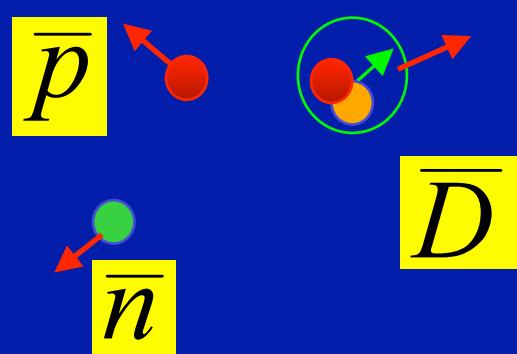
Experimental investigations possible above  $10^{22}$  g  
by detection of gravitational waves

If  $M_{RH}$  is small (smaller than  $10^9$  g) , stable relics become good candidates

Very large parameter space (of masses) for PBH/relics dark matter. But fine tuning of the « jump » required (unnatural ? Caution in cosmology !)

# A new hope for detection ? Antideuterons !

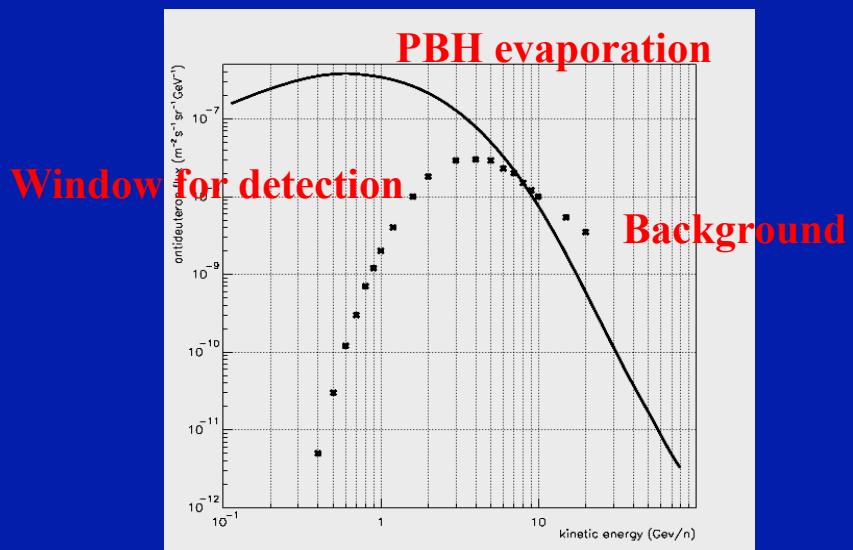
→ Secondary noise very small (kinematics)



$$\frac{d^2N_{\bar{D}}}{dEdt} = \sum_j \int_{Q=E}^{\infty} \alpha_j \frac{\Gamma_j(Q, T)}{h} \left( e^{Q/kT} - (-1)^{2s_j} \right) \times \frac{dg_{j\bar{D}}(Q, E, P_0)}{dE} dQ$$

$\bar{D}$

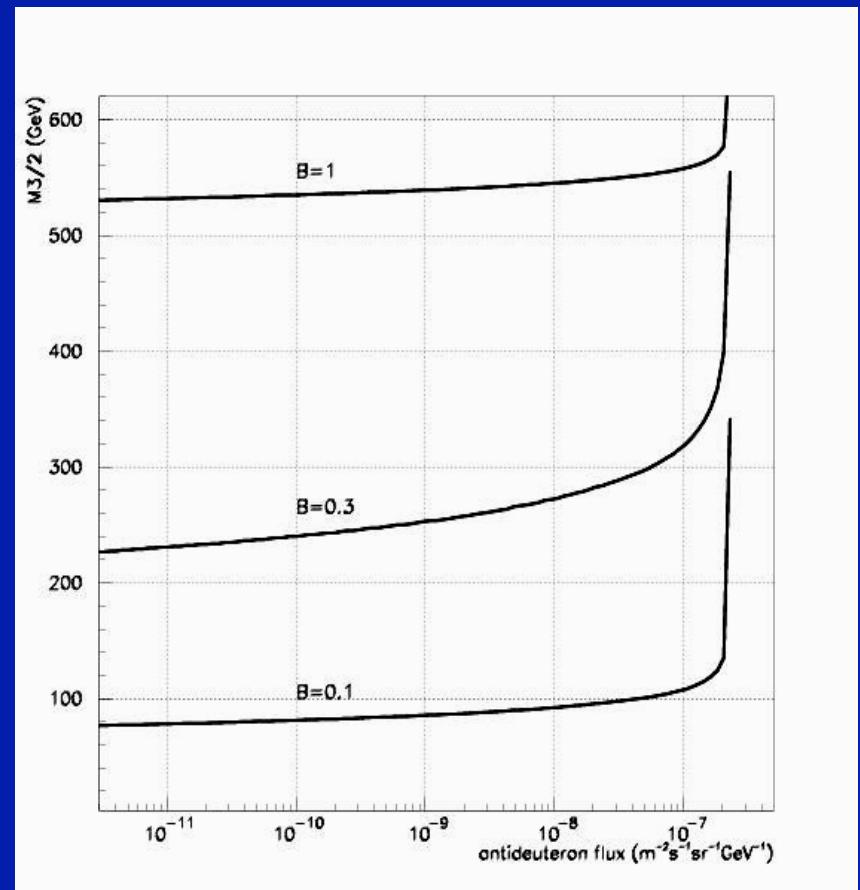
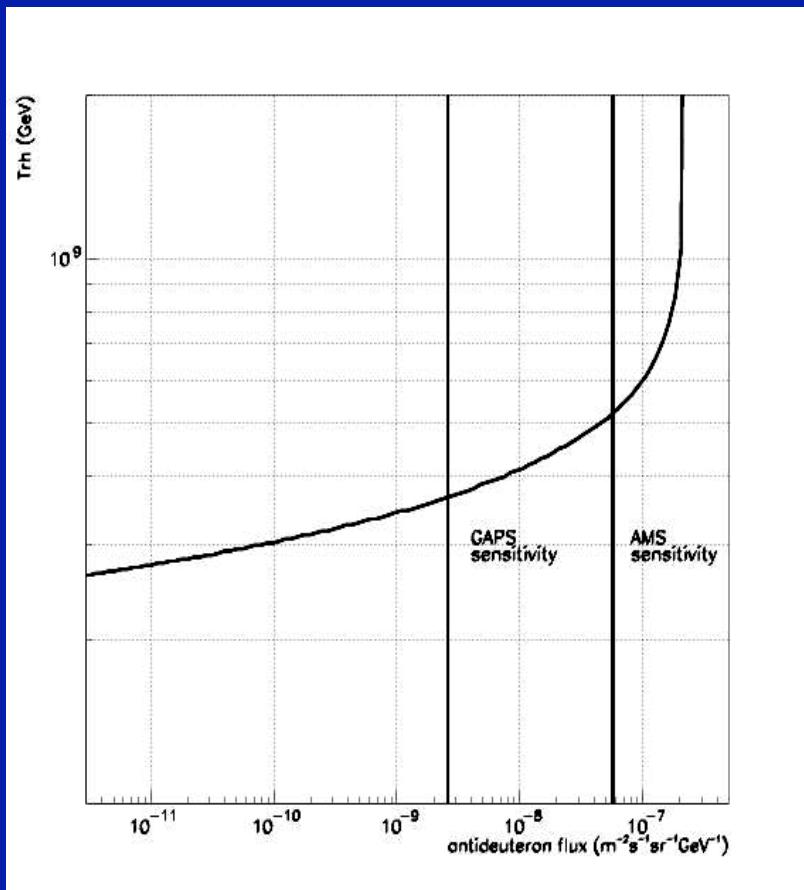
Relativistic coalescence model in the MC



Improvement in sensitivity of  
1-2 orders of magnitude

A.B., G. Boudoul, F. Donato, D. Maurin, P. Salati,  
Astronom. Astrophys. 398, 403 (2003)

# Constraints on SUGRA



Lower limit on the reheating temperature as a function  
of the 100 MeV antideuteron flux

A.B. & Ponthieu, Phys. Rev. D 69 (2004) 105021

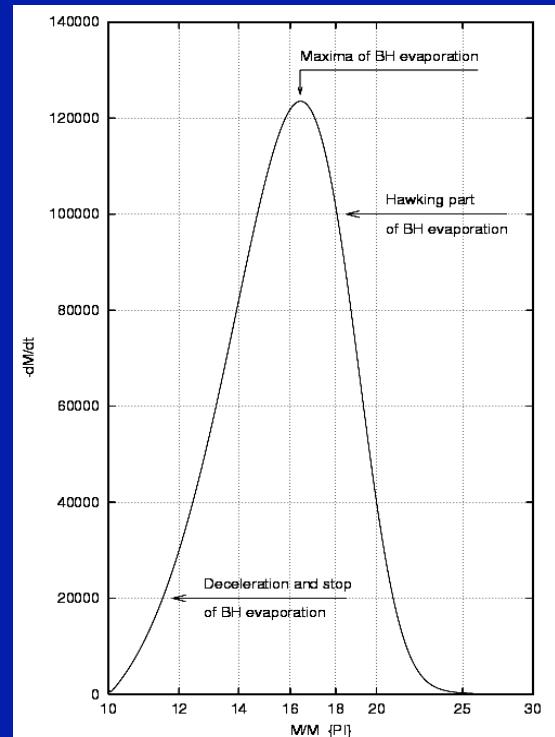
# We are safe with...

- Modified gravity:
- Quantum effects (LQG, etc.)
- Generalized action ( $f(R)$ )

$$S = \int d^4x \sqrt{-g} \left\{ R + 2\partial_\mu \partial^\mu \Phi + \lambda e^{-2\Phi} S_{GB} \right\}$$

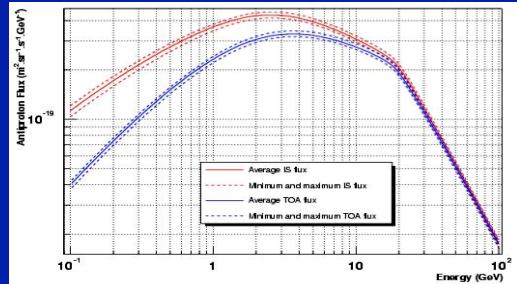
$$S_{GB} = R_{ijkl}R^{ijkl} - 4R_{ij}R^{ij} + R^2$$

A. B., S. Alexeyev, O. Khovanskaya, M. Sazhin, Class. Quantum Grav. 19 (2002) 4444



## -Extra-dimensions (ADD)

$$\frac{dN_{\bar{p}}}{dQ' dt} \equiv \left\{ \frac{dN_{CR}}{dE} \otimes [\sigma_{BH}(E) \times n(ISM)] \right\} \otimes \left\{ Boosted \left( \frac{d^2 N_{q,g}}{dE' dt} \otimes f_{E'}(Q) \right) (Q') \right\}$$



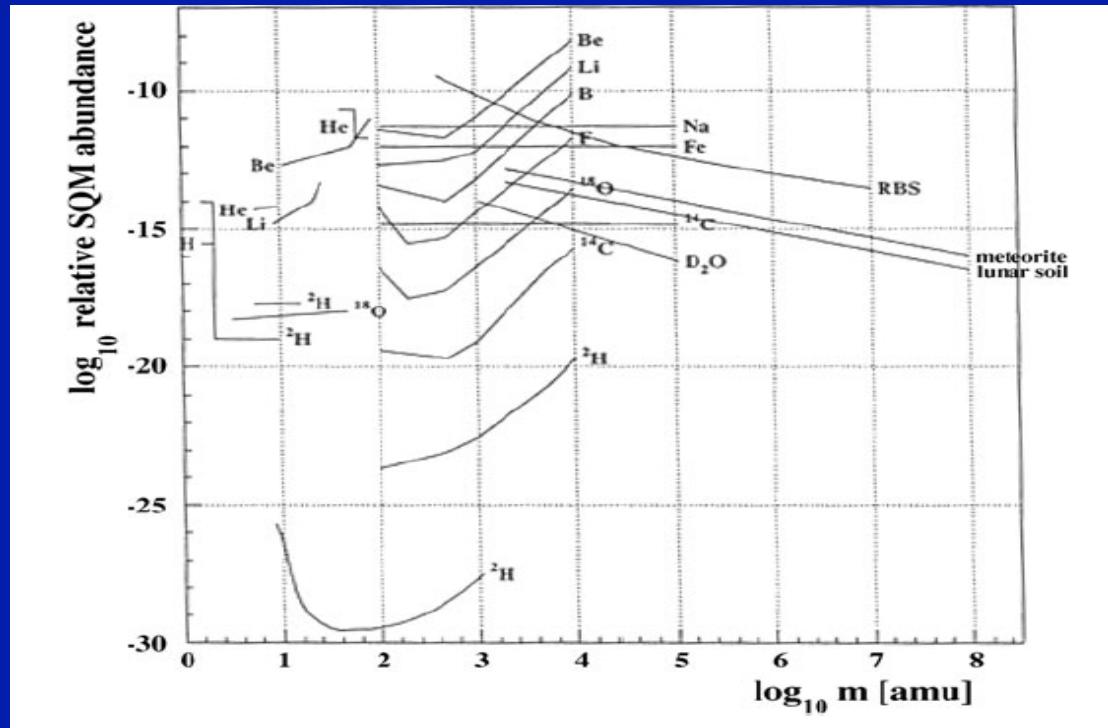
Khlopov & A.B., Class. Quantum Grav. 23 (2006) 1875

A. B., J. Grain, C. Féron, Astrophys. J. 630 (2005) 1015

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# Strangelets

Possibly stable state of hadronic matter made of 1/3 of u,d,s quarks  
Partially confirmed in QCD (MIT Bag Model + CFL)  
Typically  $A = 50-10^6$



Witten, Phys. Rev. D, 30, 272 (1984)  
Madsen et al.

**AMS-I candidate : 54 O (Z=8, A=54 +/- 7)**

**Not compatible with lunar foil.**

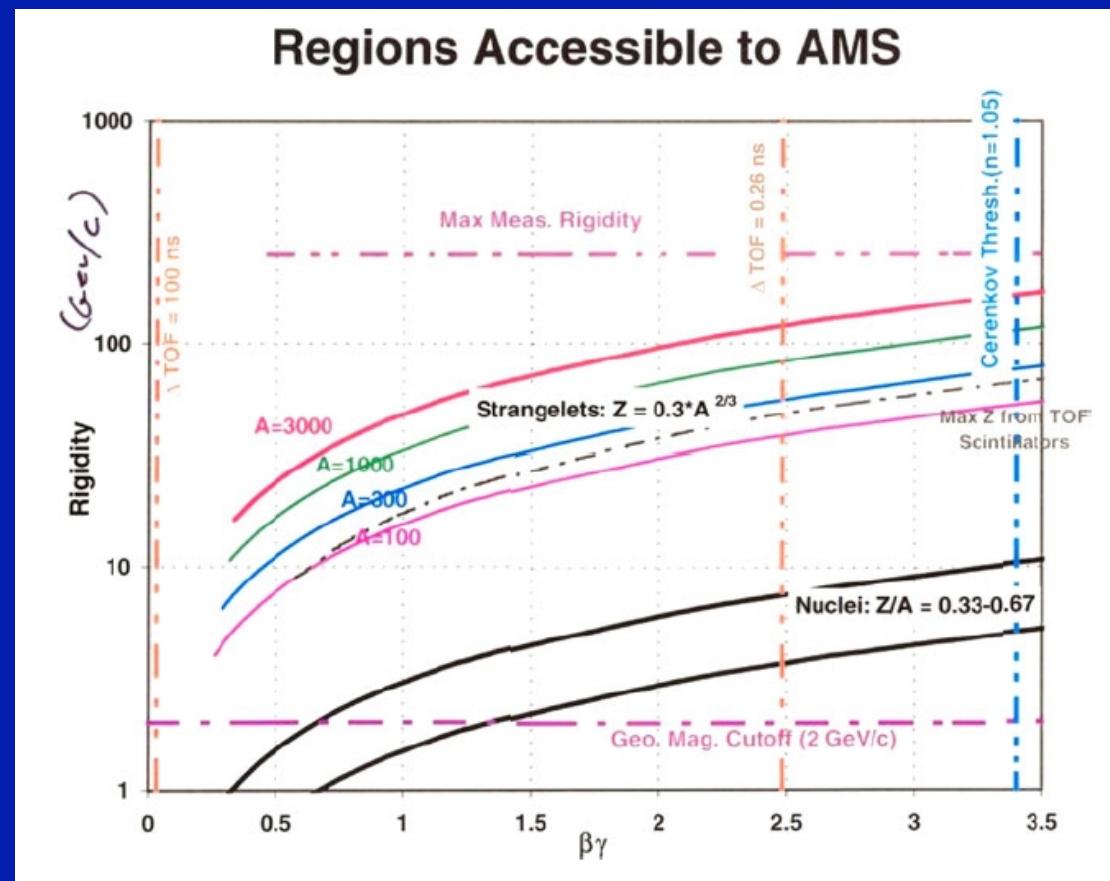
Han et al., Phy. Rev. Lett. 103, 092303 (2009)

Very large uncertainties (3 parameters fitted on hadrons)

Expected flux:  $F = \text{a few } 1000 R_4^* M_2^* (1/V_{100})^* t_7 / (\text{m}^2/\text{str}/\text{yr})$

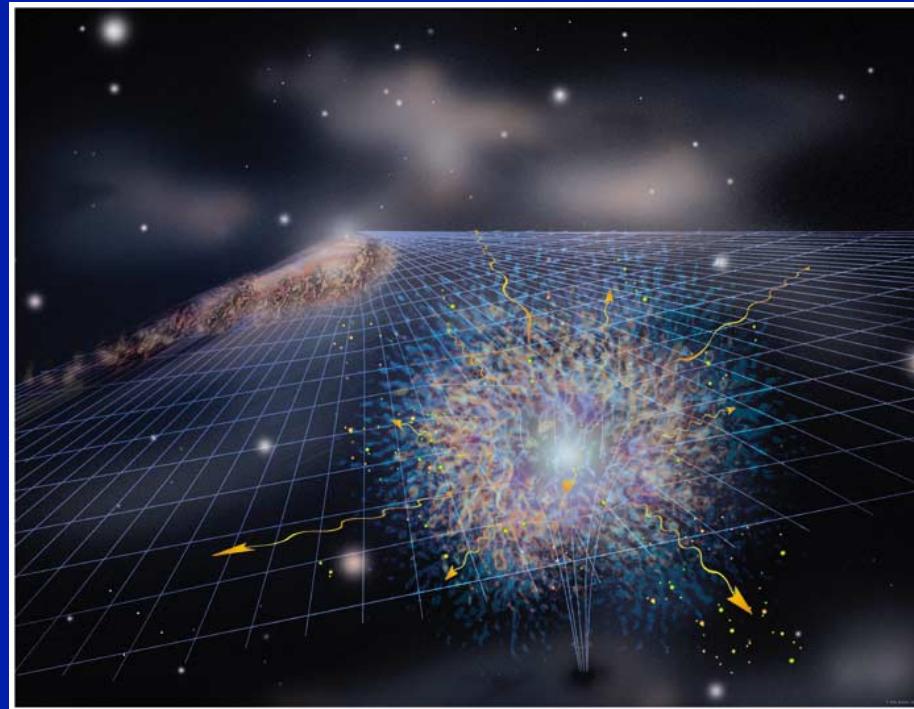
Easy detection (3 regions : TOF, RICH, “intermediate”)

AMS-II : “definitive” strangelet experiment



J. Sandweiss, Nucl. Part. Phys. 30, S51 (2004)

# Conclusion ?



Unexpected physics is... expected !