ANTIMATTER FROM PRIMORDIAL BLACK HOLES

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Work in collaboration with the LABORATOIRE D'ANNECY DE PHYSIQUE THEORIQUE (F. Donato, D. Maurin, P. Salati, R. Taillet) and the STERNBERG ASTRONOMICAL INSTITUTE of MOSCOW STATE UNIVERSITY (S. Alexeyev, O. Khovanskaya, M. Sazhin)

A black hole is a massive object which prevents anything to escape from within the horizon

Unless…………..

PBH could have formed in the early Universe

* Standard mass spectrum in a radiation dominated era

$$P(d) = \frac{1}{\sqrt{2p}\, s} e^{-\frac{d^2}{2s^2}}$$

$$b_i = \int_{d_c}^{1} P(d)\,dd \approx s\, e^{-\frac{d_c^2}{2s^2}}$$

$$n_{BH}(M_{BH}) = (a-2)\left(\frac{M_{BH}}{M_*}\right)^{-a} M_*^{-2}\, r_c \Omega_{PBH}$$

* Near critical phenomena

$$M_{BH} = k(d' - d_c)^{g_k}$$

Hawking evaporation law

$$\frac{d^2N}{dQdt} = \frac{\Gamma_s}{h\left(e^{\frac{Q}{hk/4p^2c}} - (-1)^{2s}\right)}$$

$$\frac{d^2N}{dQdt} \propto M^2 Q^2 e^{-\frac{Q}{T}}$$

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

$$T = \frac{hc^3}{16pkGM}$$

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

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

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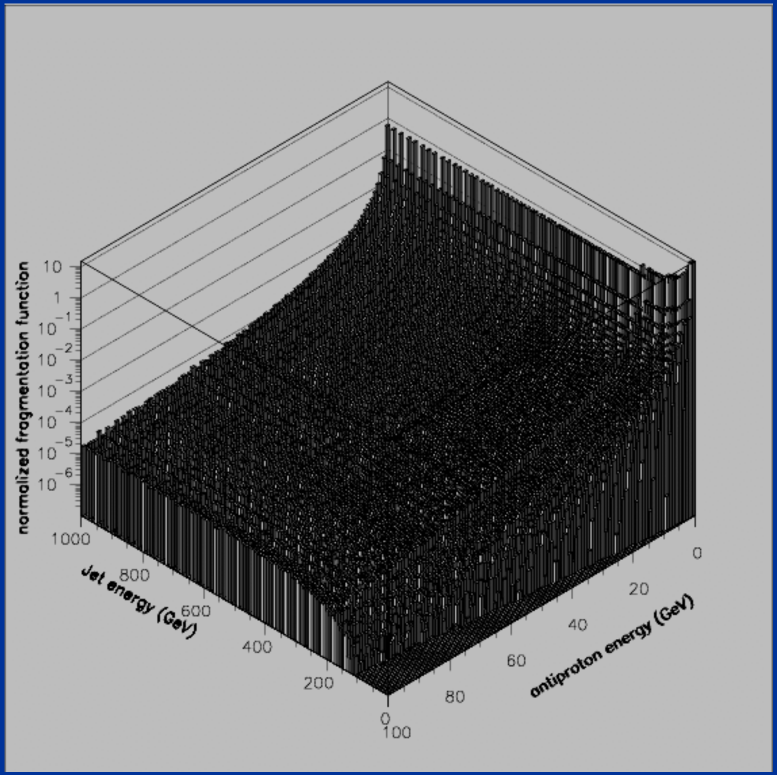
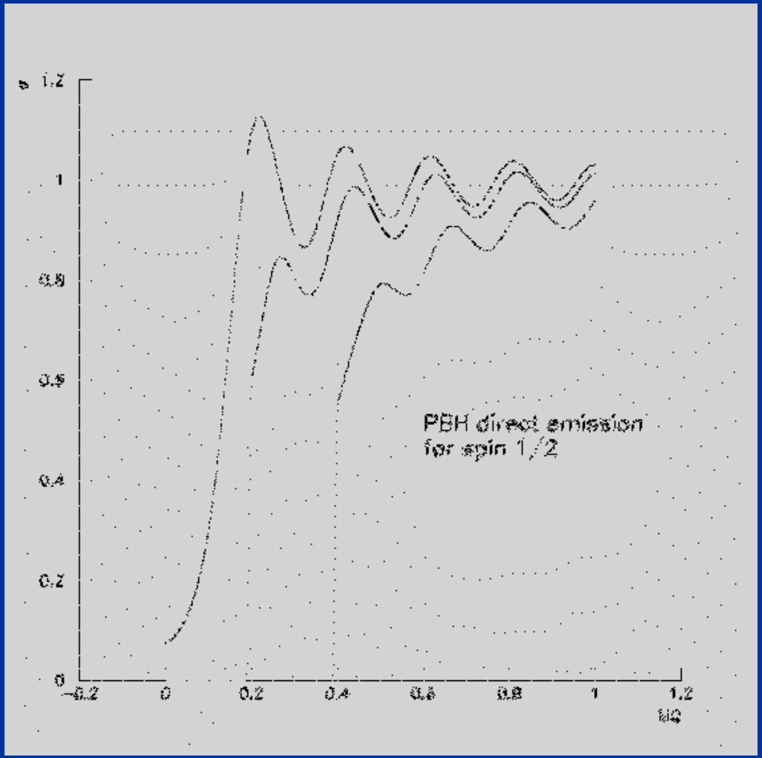
Antiproton individual emission

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





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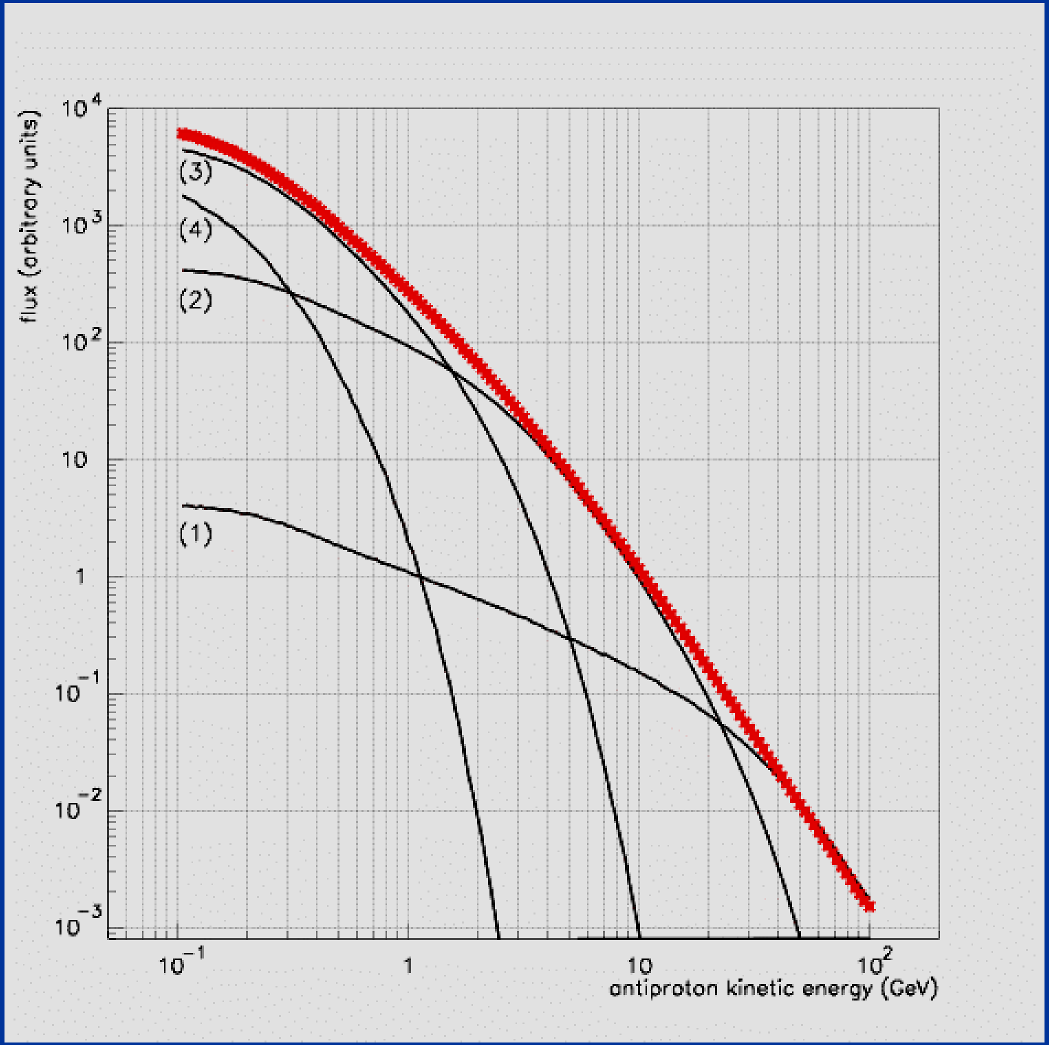
Cumulative source effect



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

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

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

$$\frac{dn}{dM} \propto M^{-\frac{5}{2}} \leftrightarrow M > M_*$$

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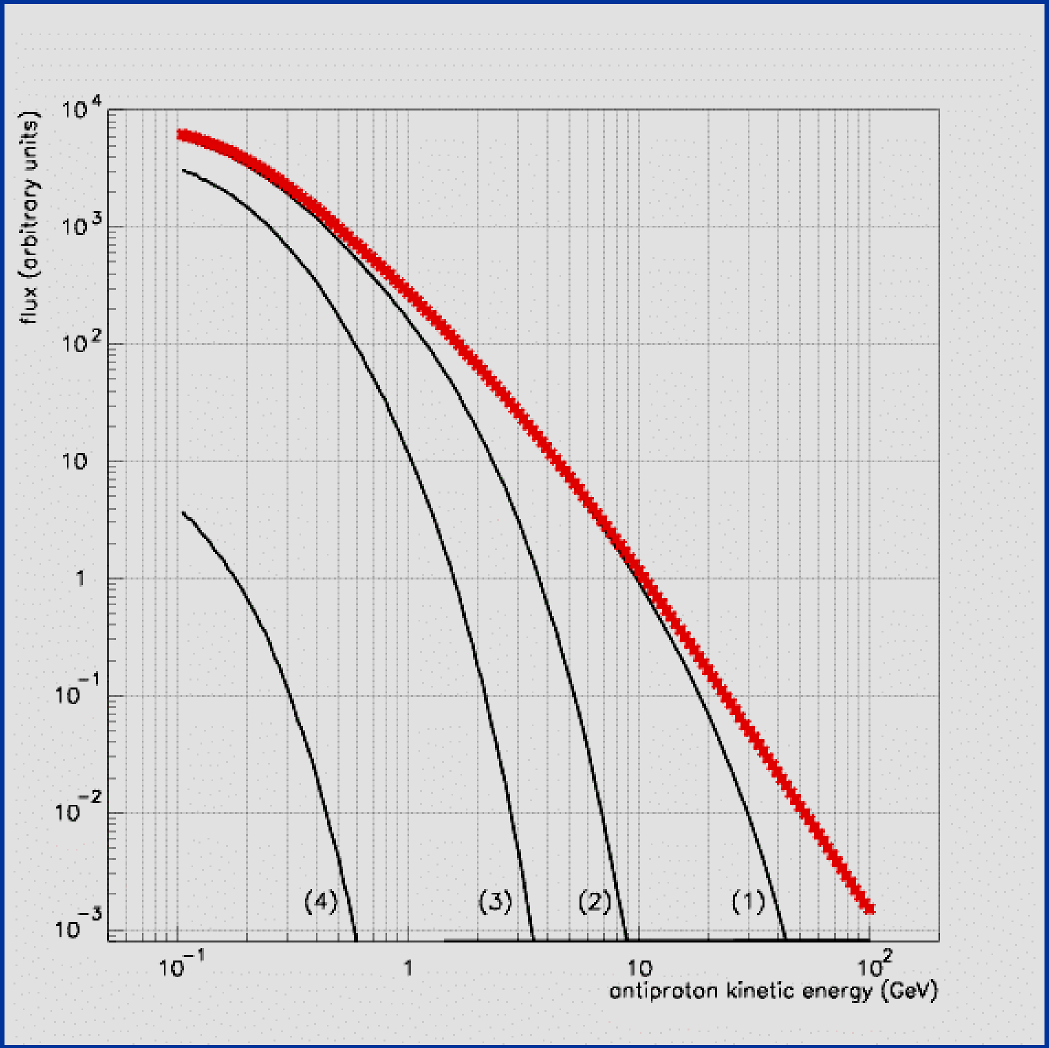
Horizon size after inflation ?



$$M = \frac{1}{8}\frac{M_{Pl}}{t_{Pl}}t$$

$$t_{RH} \approx 0.3 g^{-\frac{1}{2}} \frac{M_{Pl}}{T_{RH}^2}$$

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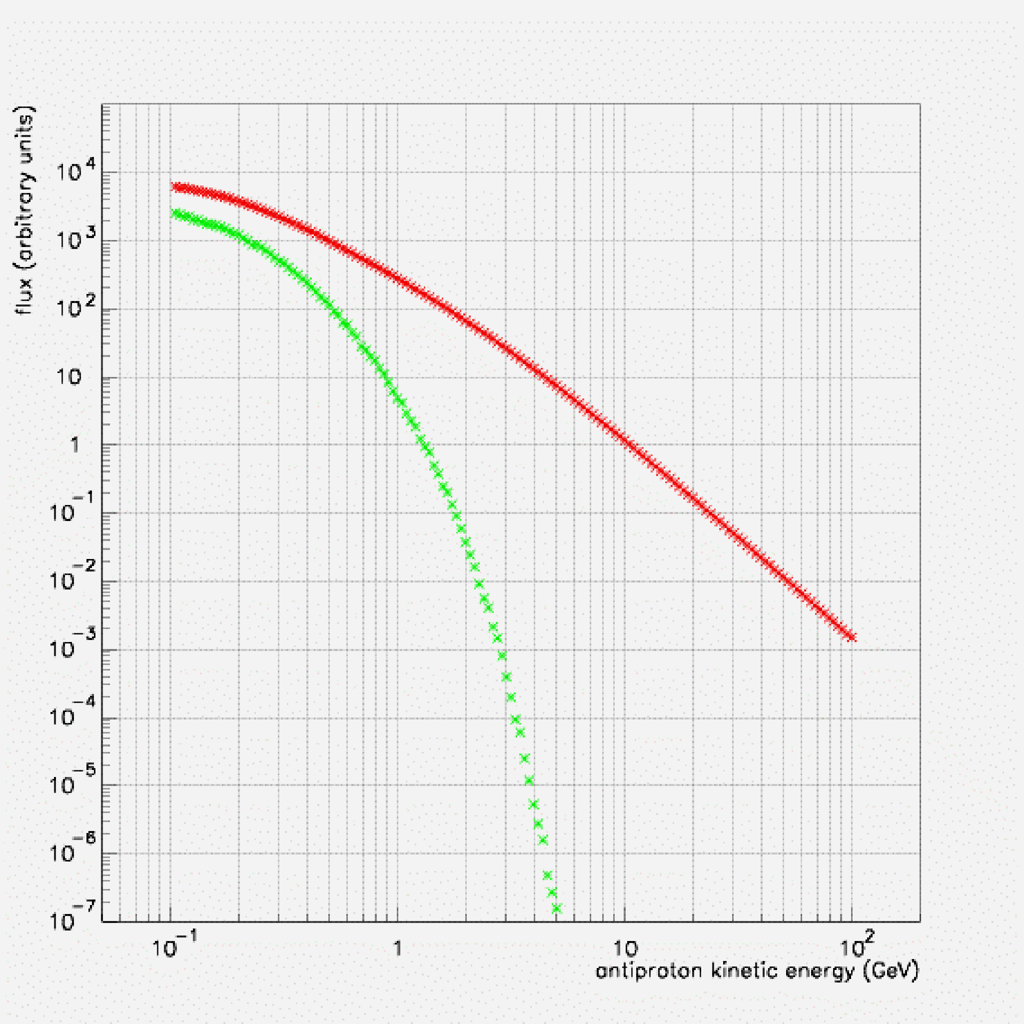
What about a QCD halo ?



$$\frac{d^2N}{dEdt} \propto e^{-\frac{E}{T_0}}$$

$$P(T) \approx 8.6 \frac{T}{(1GeV)}$$

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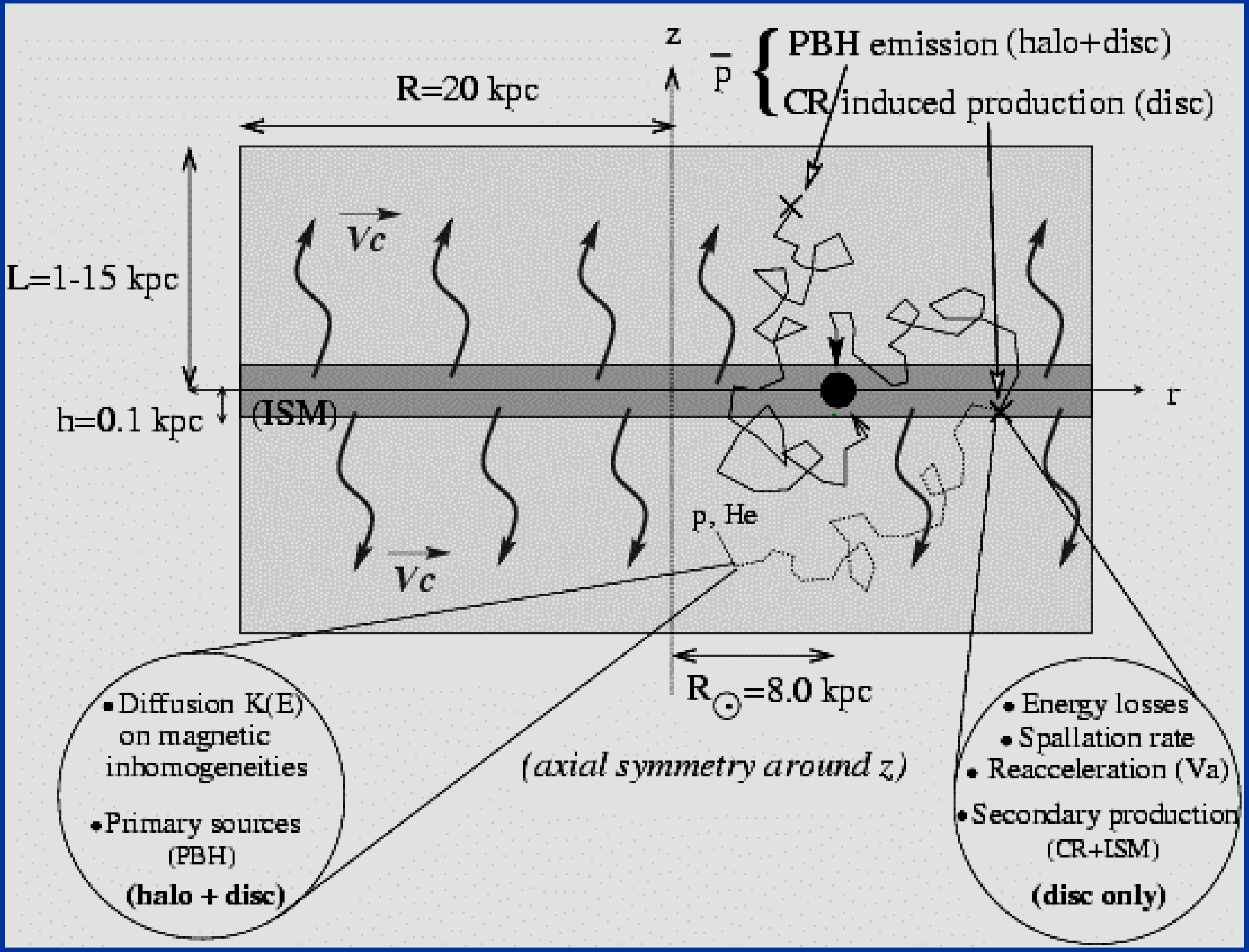
Now, let the antiprotons propagate in the Milky way…



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Secondary antiprotons

$$2hd(z)q(r,0,E) = 2hd(z)\Gamma^{ine}_{\bar{p}} N(r,0,E) + \left\{ V_c \frac{\partial}{\partial z} - K\left(\frac{\partial^2}{\partial z^2} + \frac{1}{z}\frac{\partial}{\partial r}\left(r \frac{\partial}{\partial r} \right) \right) \right\} N(r,z,E)$$

p-p interactions :

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

p-He, He-p and He-He interactions : evaluated with DTUNUC

Tertiaries :

$$q(r,E) = \int_{E}^{\infty} \frac{ds_{\bar{p}H \rightarrow \bar{p}X}}{dE} \left\{ E' \rightarrow E \right\} n_H v_{\bar{p}}' N(r,E') dE' - s_{\bar{p}H \rightarrow \bar{p}X} \left\{ E \right\} n_H v_{\bar{p}} N(r,E)$$

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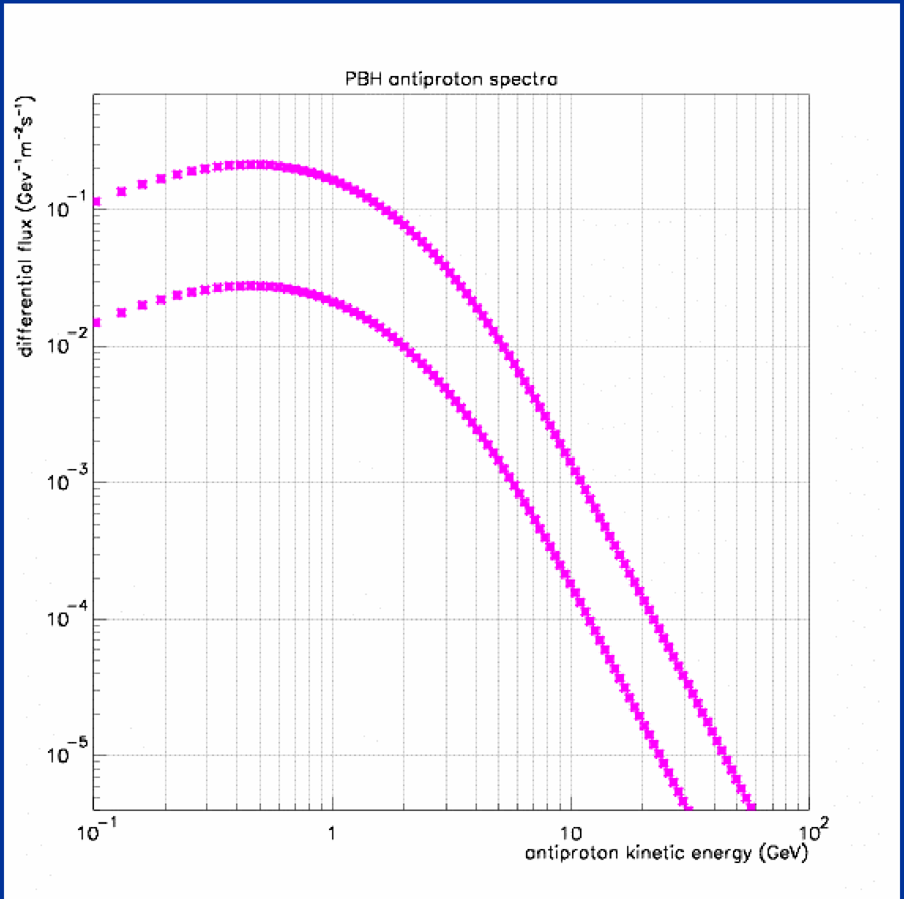
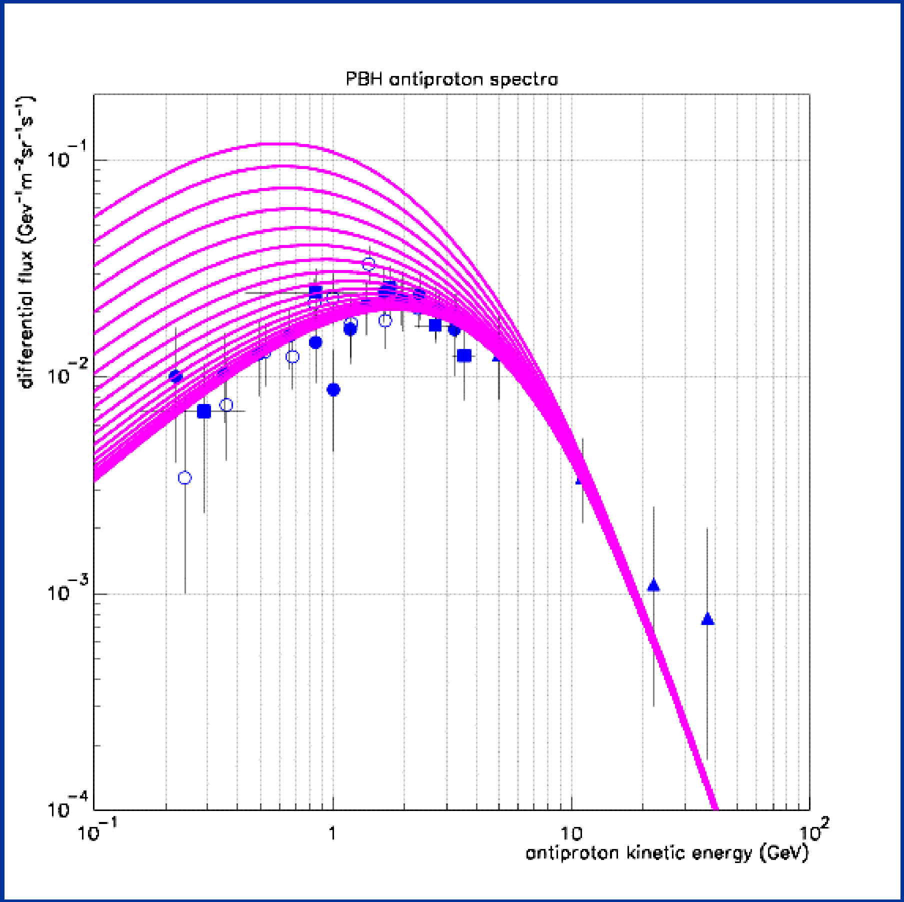
Top of atmosphere spectrum





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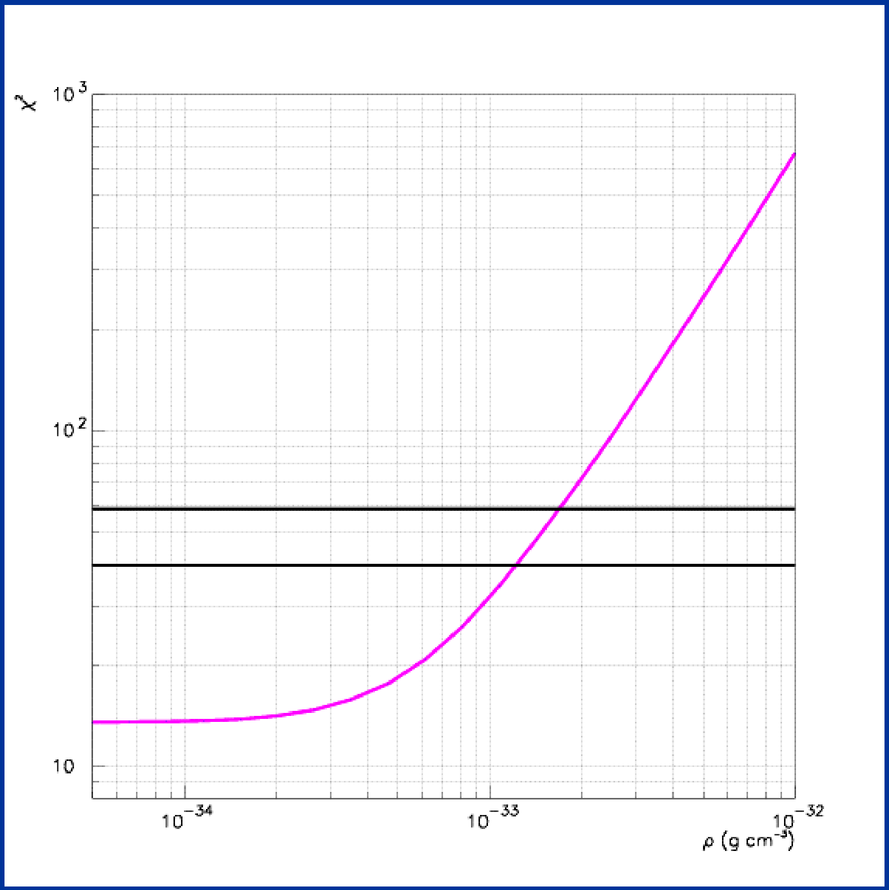
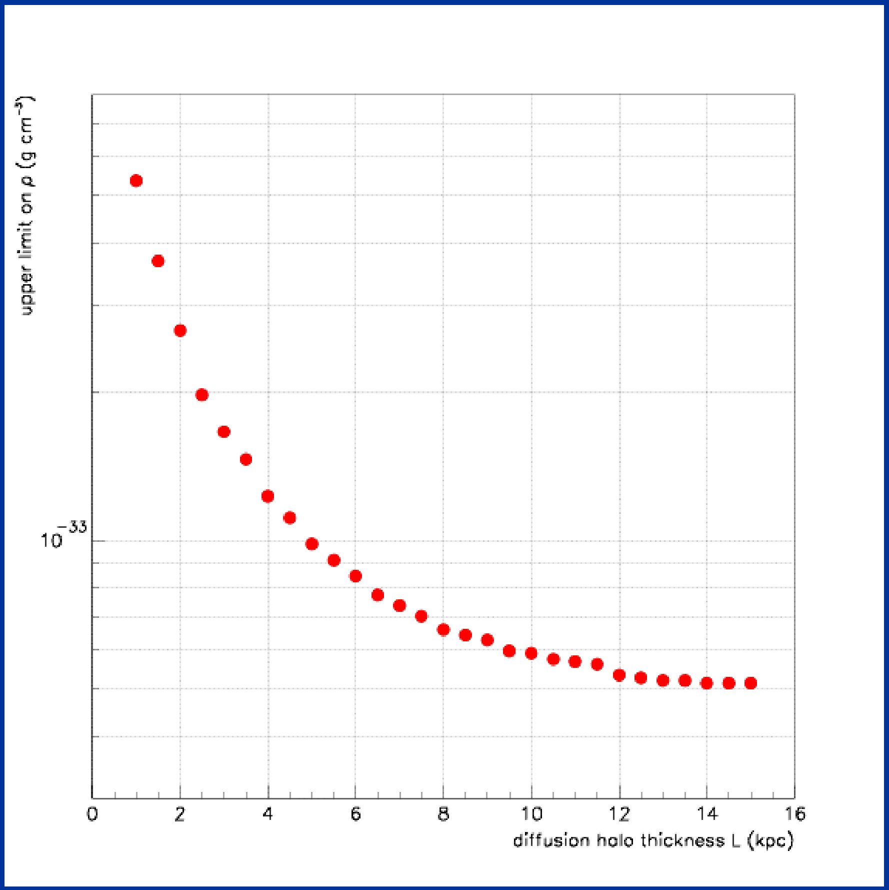
Upper limit on the PBH density





$r < 5 \cdot 10^{-33} - 5 \cdot 10^{-34}\, g.cm^{-3}$

$n < 4 \cdot 10^{-51}\, cm^{-3} (L = 3kpc)$

$\Omega < 10^{-8}$

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Cosmological consequences

→ Spectral index of scalar perturbations : $n < 1.24$

→ Inflation models with a scale :

-Step

- change in the spectral index

→ Details of gravitational collapse

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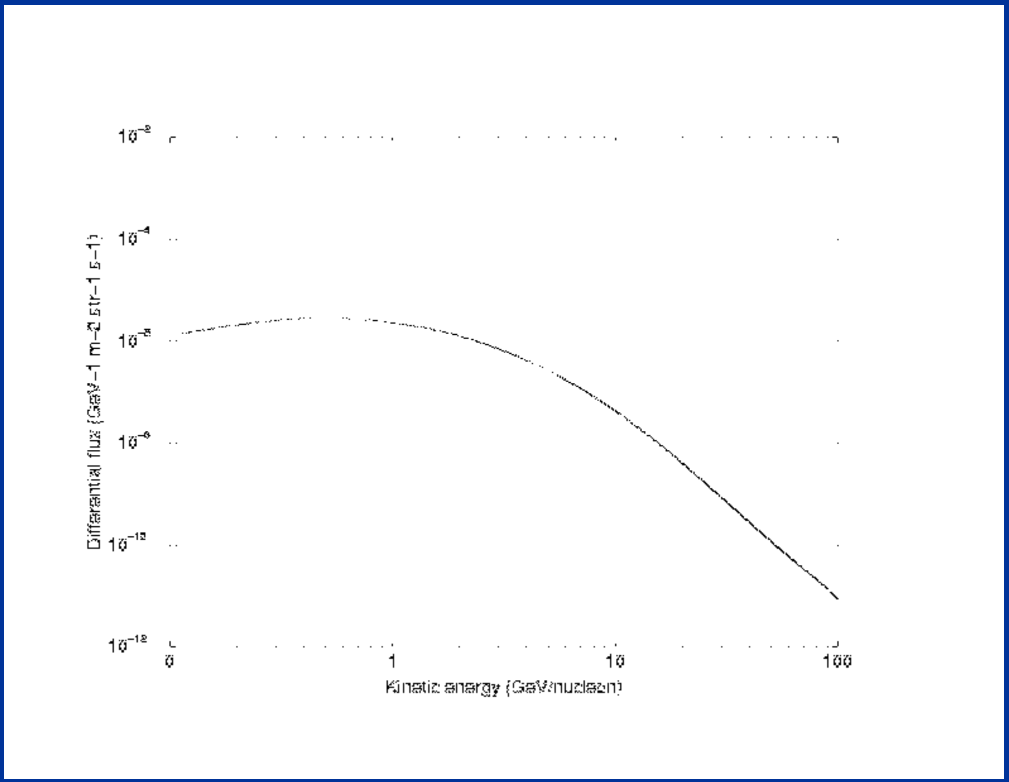
A new hope for detection : antideuterons



- Extremely low background (kinematics)
- Coalescence scheme in the parton jets : 60 MeV < P < 300MeV
- A few events expected in AMS, depending on L, P and n
- GASP ?

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PBHs as probes for quantum gravity : EDGB black holes

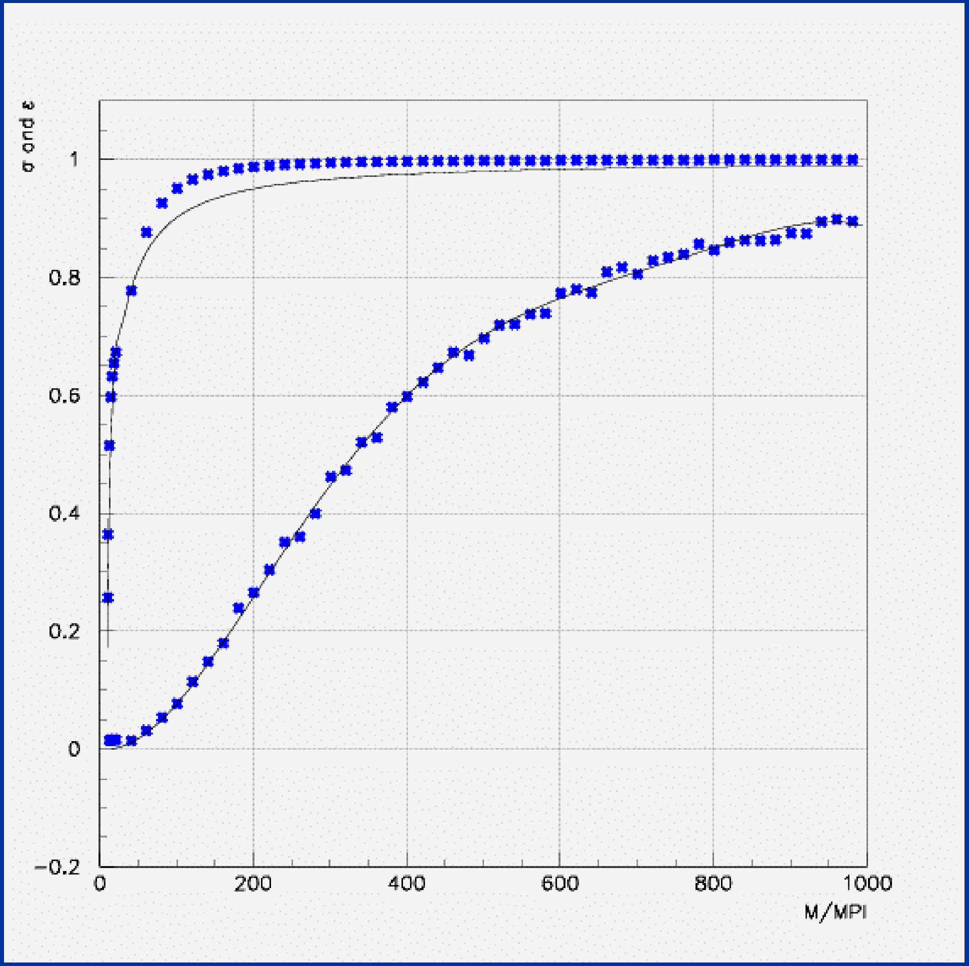
$$S = \int d^4x\sqrt{-g}\left\{-R + 2\partial_m\partial^m\Phi + l\,e^{-2\Phi}S_{GB}\right\}$$

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

$$ds^2 = \Delta dt^2 - \frac{s^2}{\Delta}dr^2 - r^2(dJ^2 + \sin^2 q\, dj^2)$$

Effects of Moduli fields, higher order curvature corrections and time perturbations OK

Metric functions revisited



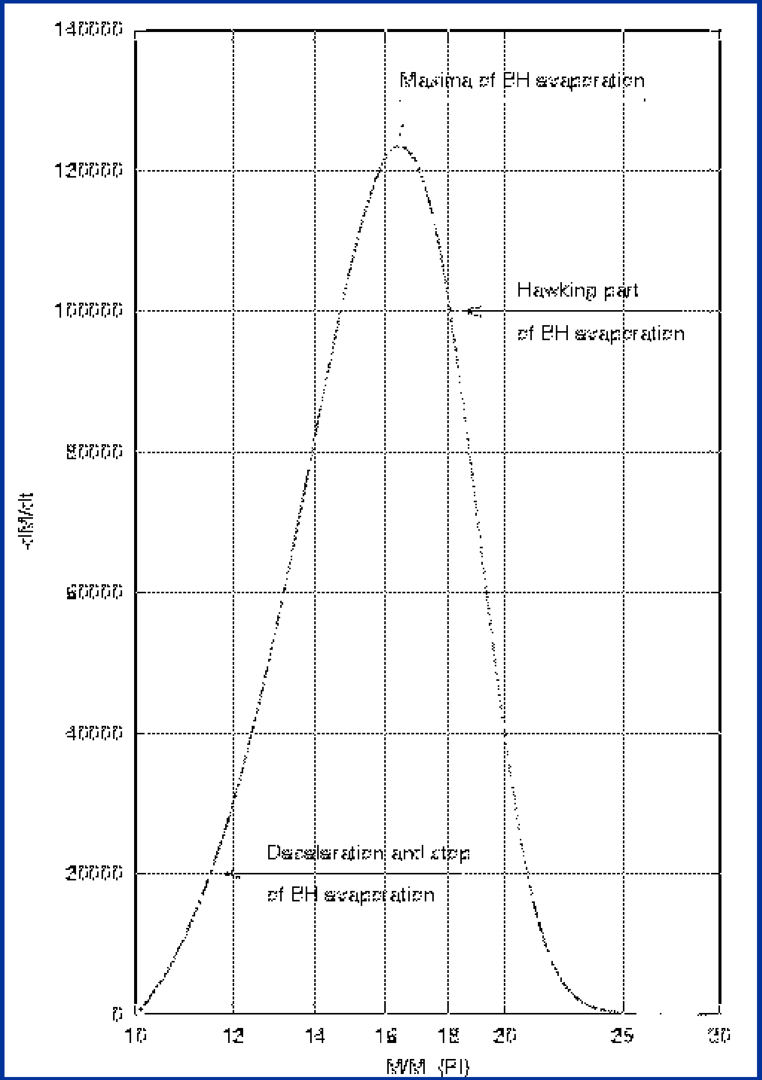
$$r_h^{\inf} = \sqrt{l}\sqrt{4\sqrt{6}\Phi_h(\Phi_\infty)}$$

$$\Delta = d_1(r - r_h) + d_2(r - r_h)^2 + \ldots$$

$$s = s_0 + s_1(r - r_h) + \ldots$$

$$f = f_{00} + f_1(r - r_h) + f_2(r - r_h)^2 + \ldots$$

Evaporation law in the Planck era



$$\mathrm{Im}(S) = \mathrm{Im} \int_{M}^{M-w} \int_{r_{in}}^{r_{out}} \frac{dr}{\dot{r}} dH$$

$$\mathrm{Im}(S) \approx k(M - M_{\min})^3$$

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Integrated relic flux

$$M = M_{\min} + \sqrt{\frac{9kp\hbar^5c^2}{8M_{\min}^4G^4M_{Pl}^3t}}$$

$$\frac{d^2N}{dEdt} \approx \frac{32}{3p}\left(\frac{8}{9p}\right)^{\frac{3}{2}} G^{10}\hbar^{-\frac{25}{2}}c^{-15}M_{Pl}^{\frac{15}{2}}M_{\min}^{10}k^{-\frac{5}{2}}t^{\frac{3}{2}}E^4\Theta\left(\sqrt{\frac{9kp\hbar^5c^6}{8M_{\min}^4G^4M_{Pl}^3t}} - E\right)$$

$$F = \int_0^{R_{\max}} \frac{d^2N}{dEdt}\left(E(1+z), t_{univ} - \frac{R}{c}\right)\frac{r(R)pR^2\tan^2(J)}{4pR^2}\,dR$$

$$F \approx 1.1\cdot 10^7\, J^{-1}s^{-1}m^{-2}sr^{-1}$$

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If PBH do not exist, why not creating them ?

If the spacetime structure is made of numerous large dimensions :
Mp ~ TeV if D=10 and V6=1fm^6

$$r_h \underset{J\to 0}{=} \left\{ \frac{4(2p)^{D-4} M}{(D-2)\Omega_{D-2} M_{Pl}^{D-2}} \right\}^{1/(D-3)} \qquad T_H \underset{J\to 0}{=} \frac{D-3}{4pr_h}$$

$$NS \propto \exp(M^{(D-2)/(D-3)})$$

Experimental detection

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