The search for GUT Magnetic Monopoles and quantum black holes

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Workshop on Exotic Physics with Neutrino Telescopes

Institute for Space Sciences (ISS) in Bucharest-Magurele, Romania

Contents

• Short intro

• "The magnetic monopole is the **Yeti** of the subatomic world - avidly sought but never incontrovertibly seen." (Devin Powell - http://physics.aps.org/articles/v6/34)

• GUT Magnetic Monopols: massive particles (Mmon ~ 10^17 – 10^18 GeV) that could have been produced in the early universe.

• MM can interact with an nucleon and lead to nucleon decay with a cross-section of ~ 10^-56 cm^2.

• Using the Rubakov–Callan mechanism the decay process has a more higher cross-section leading to a possible detection.

$$\sigma_{\Delta B \neq 0} = \frac{\sigma_0}{\beta} \qquad \beta = v/c$$

• Important decay channels: $MM + p \rightarrow e^+ \pi^0 MM$

$MM + p \rightarrow \mu^+ K^0 MM$

- Short intro

- Astrophysical and Cosmological Bounds:

Parker bound: $$F < \left[\frac{M}{10^{17}\mathrm{GeV}} + (3 \times 10^{-6})\right] 10^{-16}\,\mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{sec}^{-1}$$

Total mass of MM in the universe:

$$F_{\mathrm{uniform}} = 1.3{\times}10^{-16}\Omega_M \left(\frac{10^{17}\ \mathrm{GeV}}{M}\right)\left(\frac{v}{10^{-3}c}\right)\mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{sec}^{-1}$$

Neutron stars, white dwarfs, and Jovian planets bounds:

$$F\left(\frac{\sigma_{\Delta B}\beta}{10^{-27}\mathrm{cm}^2}\right) \sim (10^{-18} - 10^{-29})\mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{sec}^{-1}$$

• Short intro

• MM detection limits (no MM found …. yet):

- Cosmic rays search: MACRO, OHYA, SLIM, AMANDA II, RICE, ANITA II

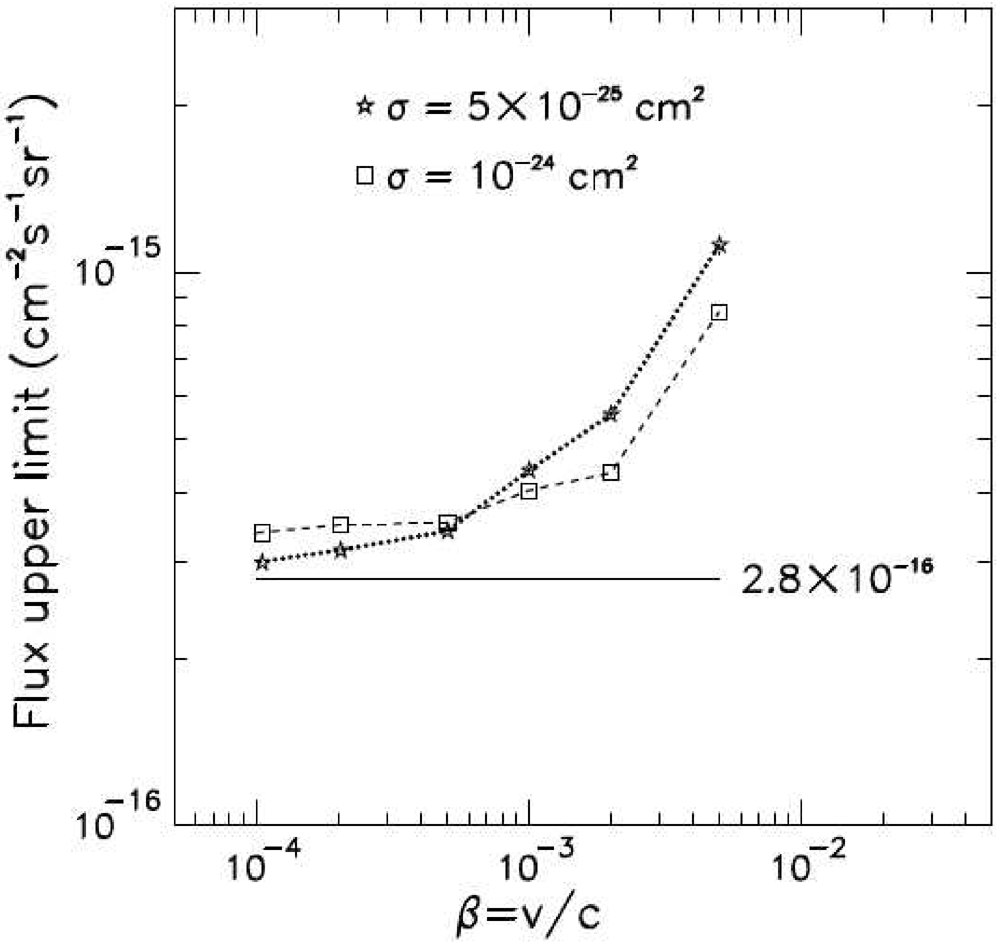
with limits ~ $3 \cdot 10^{-16}$ ($cm^{-2}\ s^{-1}\ sr^{-1}$) to $9 \cdot 10^{-16}$ ($cm^{-2}\ s^{-1}\ sr^{-1}$)

- Catalysis search of Nucleon-Decay: Soudan, MACRO, Kamiokande, IMB, Lake Baikal

with limits ~ $6 \cdot 10^{-17}$ ($cm^{-2}\ s^{-1}\ sr^{-1}$) to $9 \cdot 10^{-14}$ ($cm^{-2}\ s^{-1}\ sr^{-1}$)

- Direct and indirect searches at colliders: hadron-hadron, electron-positron, Lepton-hadron.

- Short intro

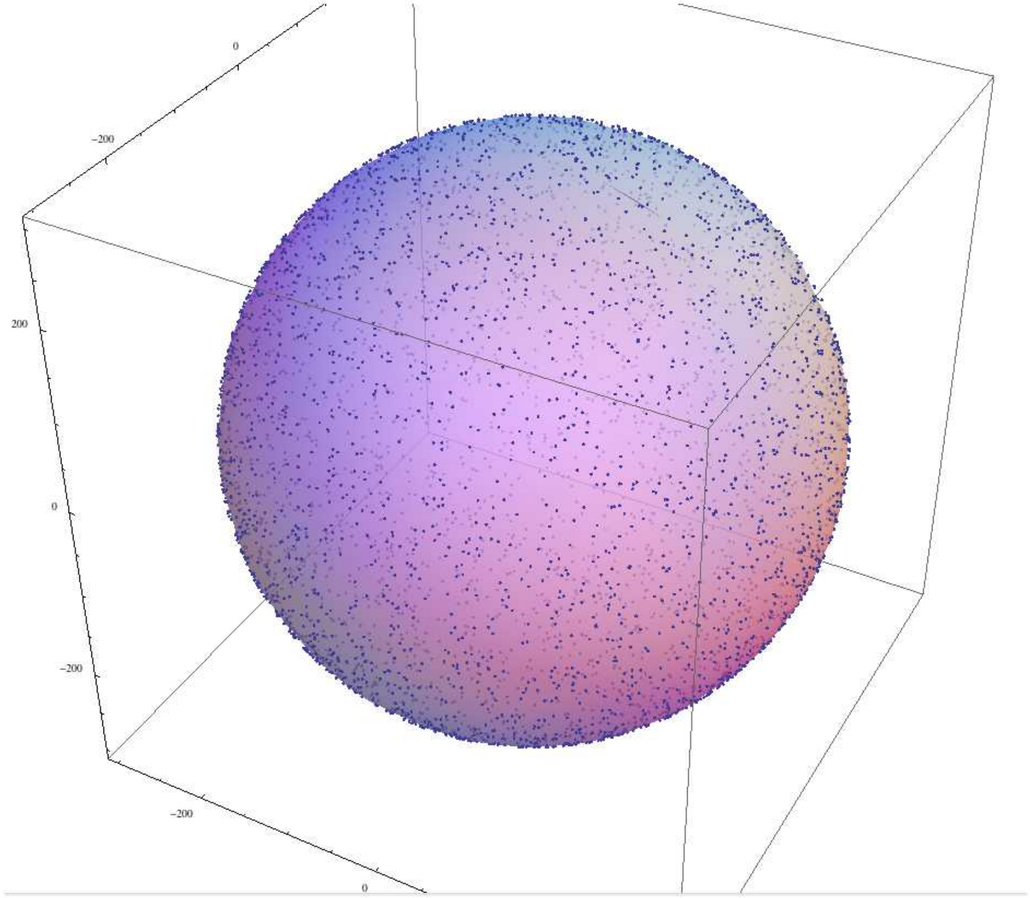


σ = {10^-26, 10^-25 5*10^-25 and 10^-24} cm^2

β = {10^-2, 5*10^-3 10^-3, 5*10^-4 and 10^-4}

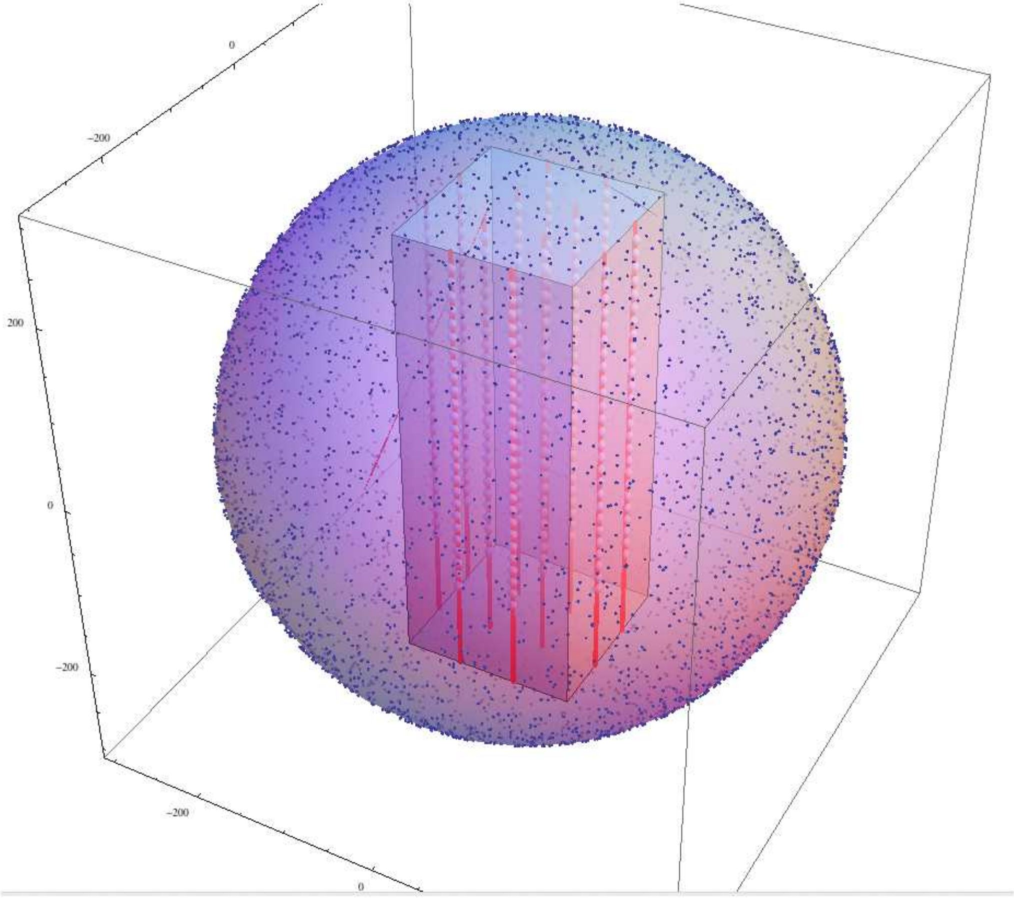
MACRO flux limit for the GUT magnetic monopoles: upper limits to the MM flux as a function of the MM velocity for two values of the catalysis cross section

• Uniform distribution of points on a sphere



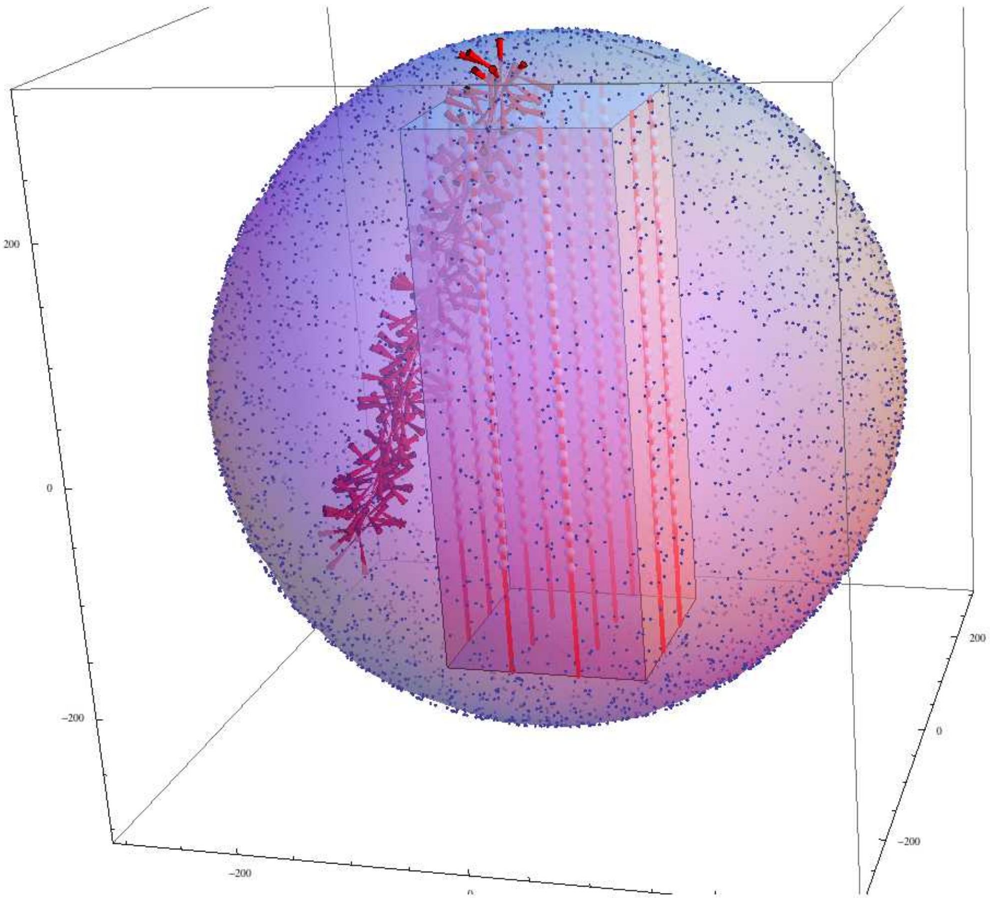
Mathematica representation of 5000 points uniformly distribute on a sphere

• Random direction crossing the Antares detector



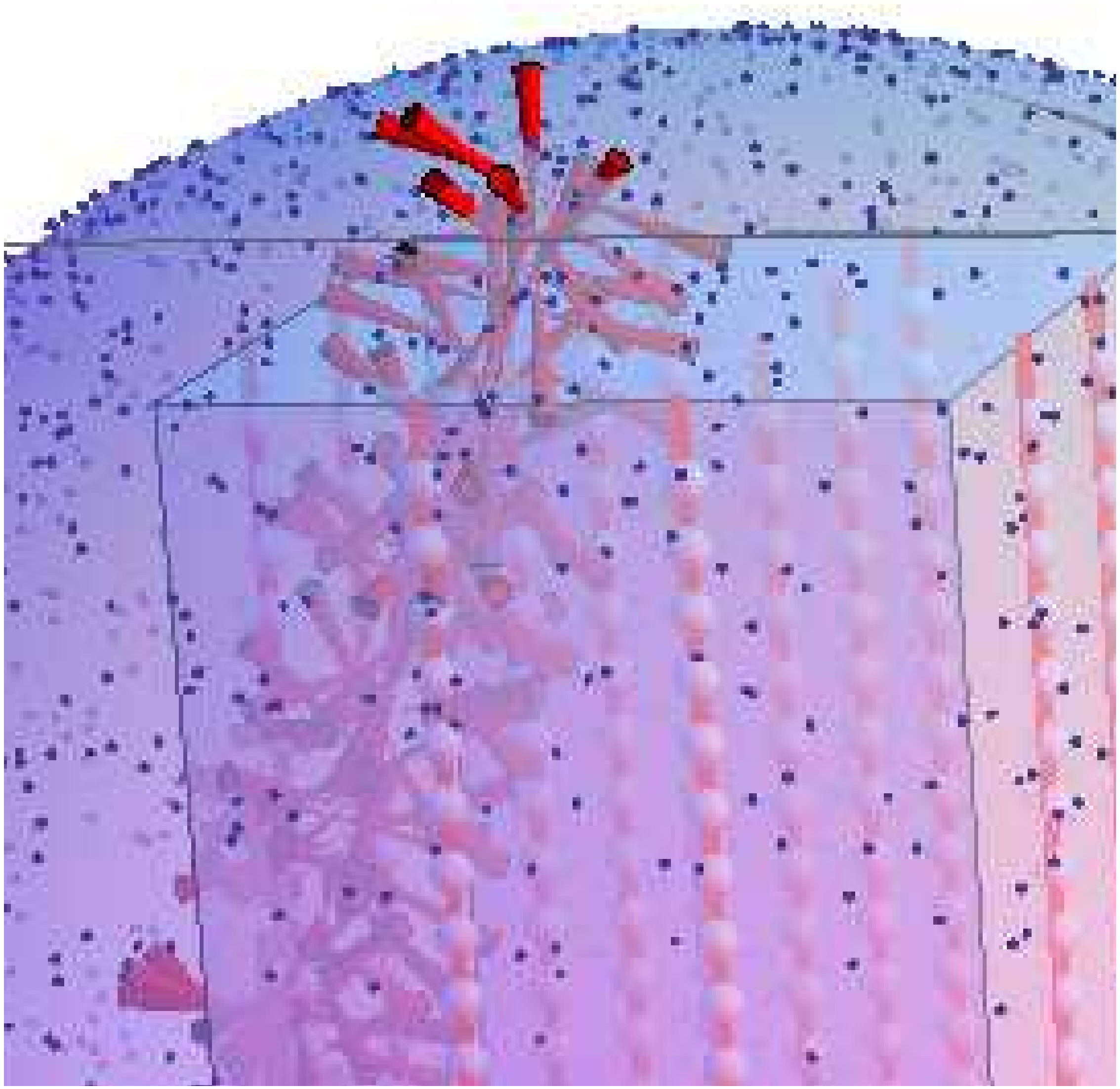
Mathematica representation of 5000 points uniformly distribute on a sphere and a random direction containing the distribution of magnetic monopol interaction points with protons.

- Random back-to-back light cones crossing the Antares detector



Mathematica representation of 5000 points uniformly distribute on a sphere and a random direction containing the distribution of magnetic monopol interaction points with protons and the random back-to-back light cone.

- Random back-to-back light cones crossing the Antares detector



- Specific signal given by correlation:
  - in *space*: given by the mean free path

and

  - in *time*: given by the specific β

- Summary movie

The Movie →

• TeV scale Black Holes

- In 4D the scale of gravity is approximately 10^16 TeV.

- TeV range micro Black Holes appear in brane world models.

  - Standard Model fields live on our "brane" while gravity propagates in the large extra-dimensional volume and so the Planck scale can be anywhere between a few TeV and 10^16 TeV.
  - Black holes can have any mass above MPL:
    - MPL < M < 5 MPL: quantum black holes;
    - M > 5 MPL: semi-classical black holes.
  - Hoop conjecture: "a black hole forms whenever the impact parameter b of two colliding objects (of negligible spatial extension) is shorter than the radius of the would-be-horizon (roughly, the Schwarzschild radius, if angular momentum can be neglected) corresponding to the total energy M of the system."

$$b \lesssim \frac{2\, l_{Pl}\, M}{M_{Pl}}$$

Non-thermal Black Holes @ the LHC

No non-thermal Black holes @ the LHC!

...so far! (upgrades in progress!)

- At cosmic ray observatories:
  - Ground based;
  - Space based.
- Neutrino telescopes.

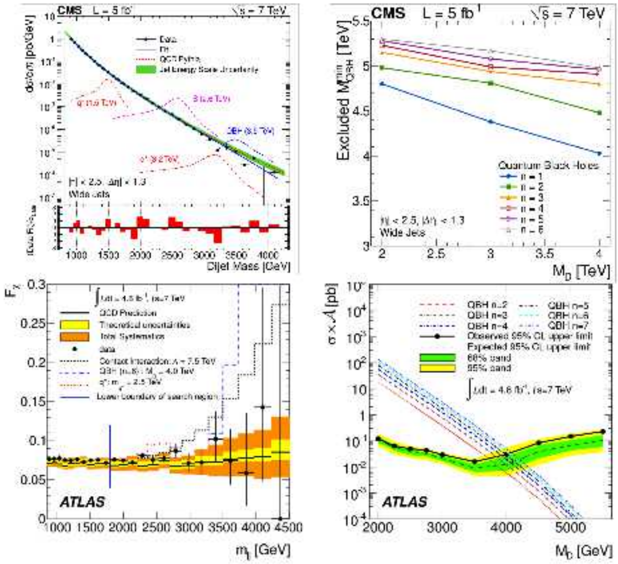
Non-thermal Black Holes (QBH)

- LHC parton energy needs to be high relative to M_D for black hole to Hawking evaporate thermally.
- Black holes with threshold mass M_{th} near M_D probably do not decay thermally.
- Dijet decays assumed so far.
- QBH appears as bump in dijet mass spectrum.
- Increased discrimination power by using angles.
  - Define central region $\chi = \exp(|y_1 - y_2|) < 30.0$.

$$F_\chi(m_{jj}) \equiv \frac{dN_{central}/dm_{jj}}{dN_{total}/dm_{jj}}$$

18 March 2013 Doug Gingrich (COST Workshop)

Non-thermal Black Holes Results



JHEP 01 (2013) 013

$M_{th} > 4$-5.3 TeV
($n = 1$-6, $M_{th} > M_D$, $M_D = 2, 3, 4, 5$ TeV)

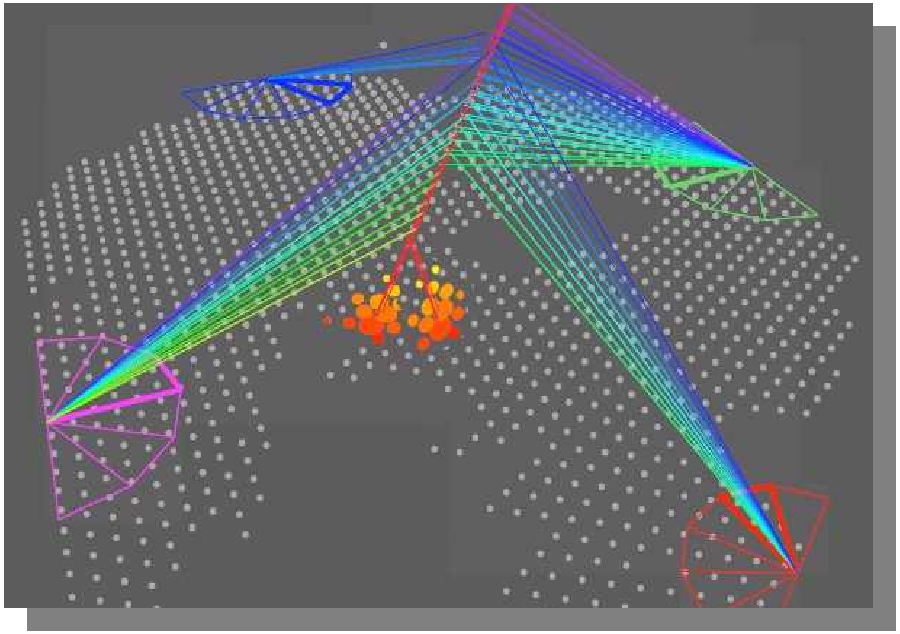
JHEP 01 (2013) 029

$M_{th} > 3.71$-4.07 TeV
($n = 2$-7, $M_{th} = M_D$)

18 March 2013 Doug Gingrich (COST Workshop) 18/21

Micro black holes in cosmic rays & neutrino data

- COST (BLACK HOLES IN A VIOLENT UNIVERSE) meeting in Manchester, Caramete L. & Xavier Calmet, the idea of a unique micro black hole signature which could be discovered in the cosmic rays data came up.
  - If micro black holes with the masses close to the Planck mass, which are non-thermal, are formed in high energy collisions, the main decay channel for these objects is a „back-to-back“ decay into two particles!



- If a black holes form as a result of the impact between UHECRs or neutrinos with particles in the upper atmosphere, it is possible for simultaneous double shower events to be observed!

Micro black holes in cosmic rays & neutrino data

X. Calmet, L.I. Caramete and O. Micu. JHEP 1211, 104 (2012); arXiv:1204.2520 [hep-ph].

- The number of events expected to seen by a cosmic rays experiment:

$$N = \int dE N_A \frac{d\Phi}{dE} \sigma(E) A(E) T$$

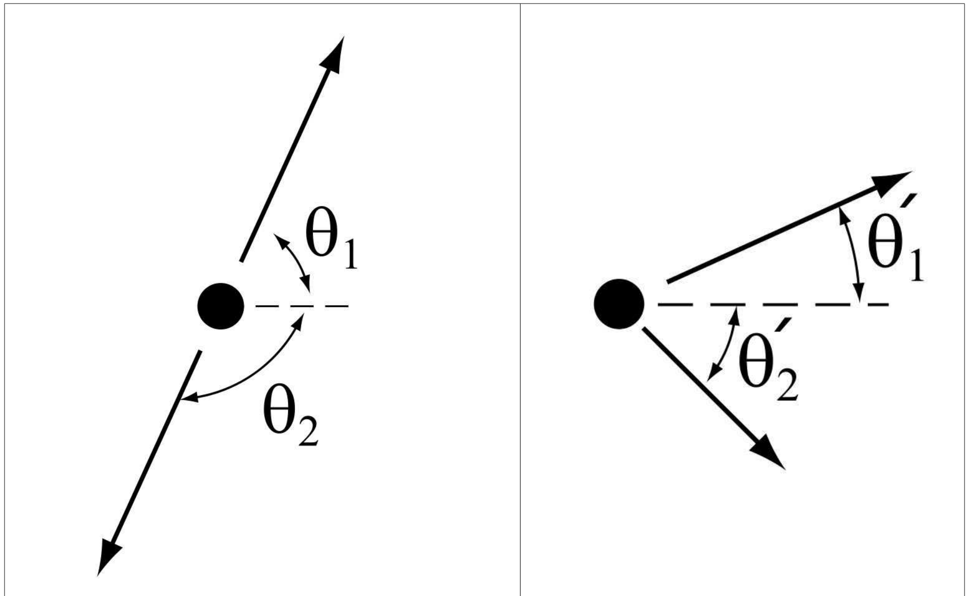
- Assuming the collision between a particle $(\gamma_1 m_1 c, \gamma_1 m_1 \vec{v})$ with a particle $(m_2 c, 0)$ at rest, the resulting black holes...
  - Have a mass of:

$$M_{BH} = \sqrt{m_1^2 + m_2^2 + 2\gamma_1 m_1 m_2}$$

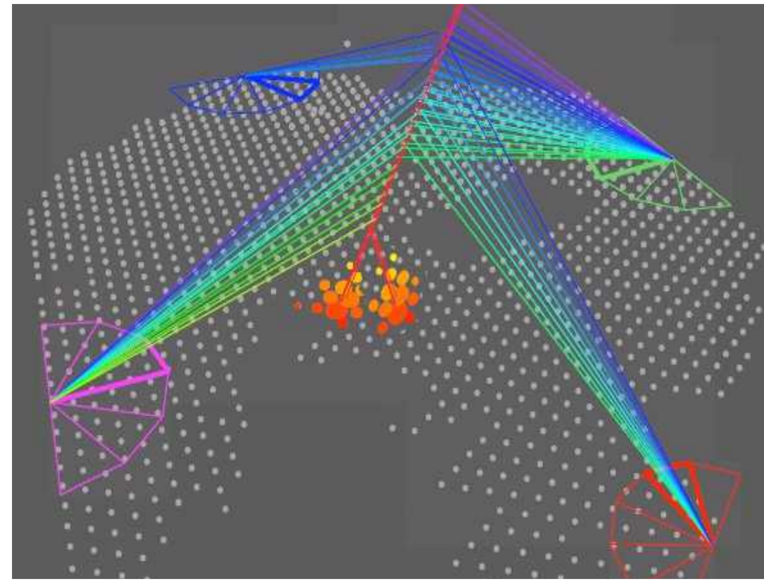
  - And move relativistically with a Lorentz factor of:

$$\gamma_{BH} = \frac{\gamma_1 m_1 + m_2}{M_{BH}}$$

Micro black holes in cosmic rays & neutrino data



Center of Momentum Frame | Laboratory/Earth Frame

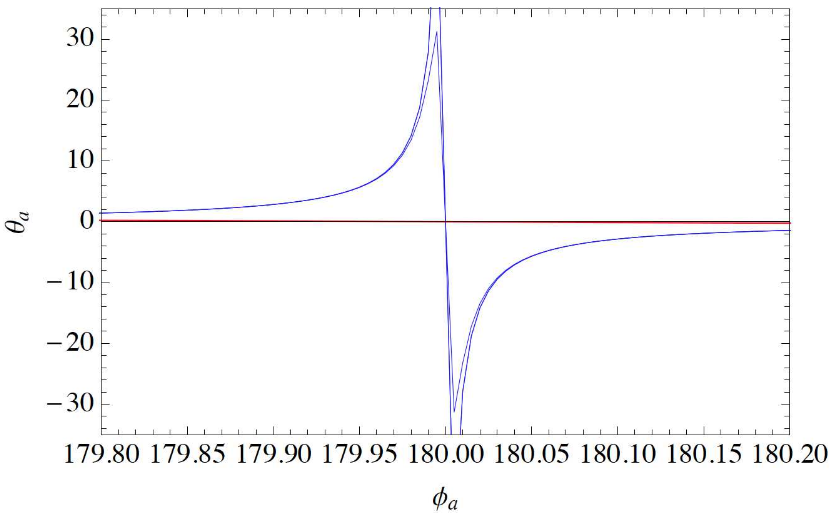


- Lorentz transformed angles

$$\tan\theta_i' = \frac{\sin\theta_i}{\gamma_{BH}\beta_{BH}\frac{E_i}{p_i} + \gamma_{BH}\cos\theta_i}$$

Micro black holes in cosmic rays & neutrino data

- For the Planck mass in the 10 TeV range,
- UHECR or neutrino energies larger than 10^6 TeV



Angle θ'_1 as function of the mass m_1 for m_d = 4.8 MeV, m_{muon} = 105.7 MeV, m_{tau} =1.777 GeV (all in blue) and m_{top} = 171 GeV (in red).

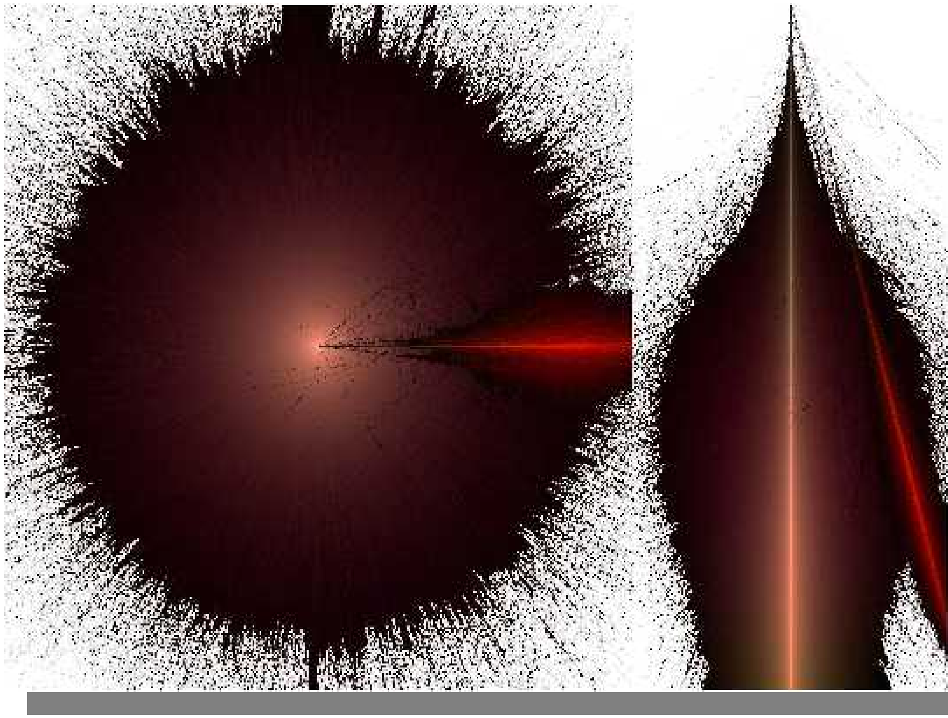
- Back-to-back decay into two standard model particles
- Two showers can be observed for about 0.11% of the total number of back-to-back decays!

No. of extra dimensions	No. of events/year
0	11
1	81
4	460
5	609
6	765
7	925

Micro black holes in cosmic rays & neutrino data

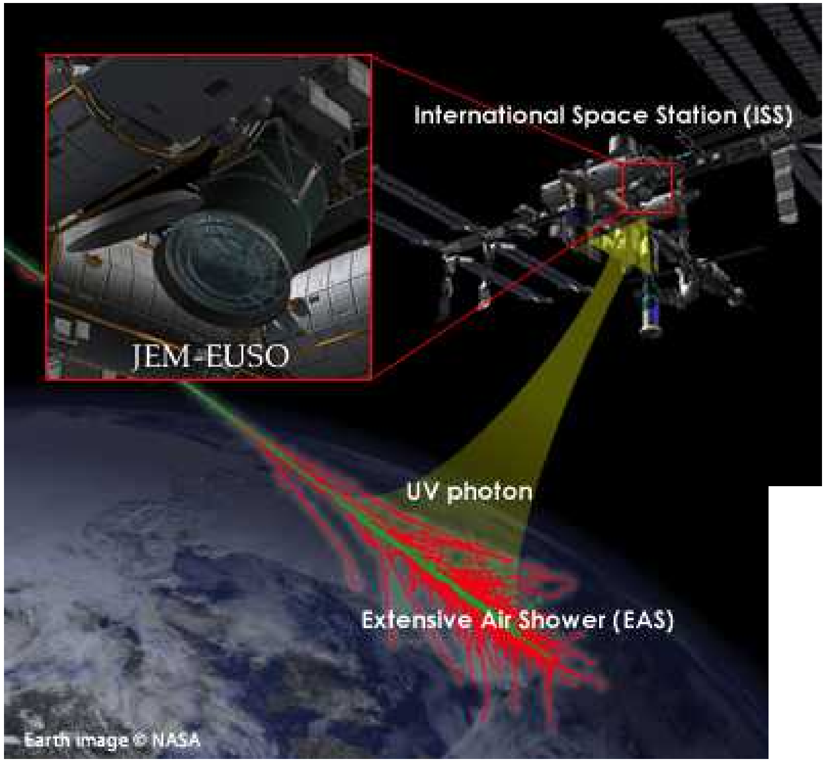
Back-to-back decay simulations
CORSIKA COsmic Ray SImulations for Kascade (20º separation between the showers)

- Showers overlap for large parts of their development!
- For smaller angles they overlap even more!
- The identification of the two separate showers by the ground detectors depends on the altitude at which they are produced!
- One will have to also tell apart oval shaped imprints due to two showers from single showers oriented at an angle wrt. the Earth.



CORSIKA simulations of two showers (10^{13} eV & 9×10^{16} eV) developing from a height of 30 Km. The angle between the showers in the Earth frame is 20º.

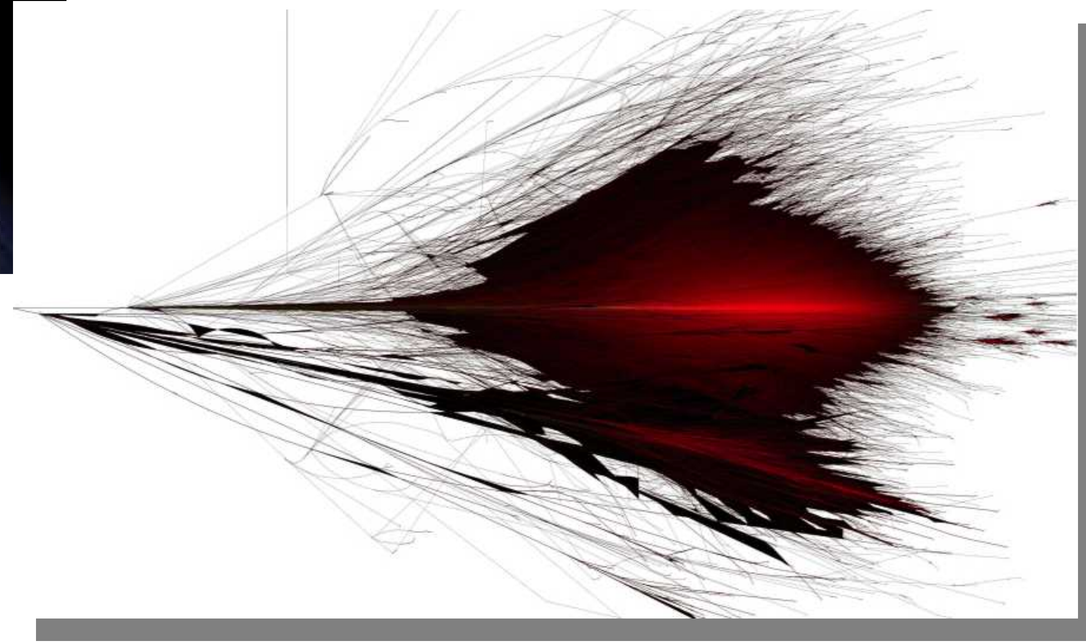
Micro black holes in cosmic rays & neutrino data



Advantages:

- A more than 20 times larger acceptance!
- The entire fluorescence showers would be visible which would make the features of a shower event to be distinguishable!

JEM-EUSO
Extreme Universe Space Observatory
http://jemeuso.riken.jp/en/
Will observe a volume 50 – 250 times larger than the Pierre Auger O.



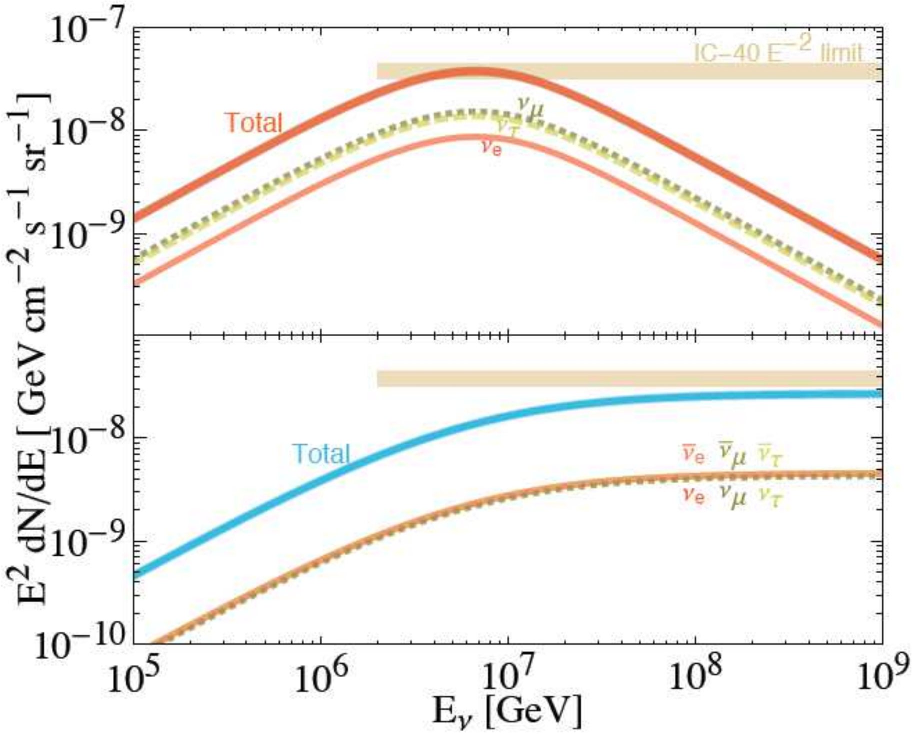
Micro black holes in cosmic rays & neutrino data

N. Arsene, X. Calmet, L.I. Caramete and O. Micu. arXiv:1303.4603 [hep-ph].

QBHs produced by highly energetic neutrinos:

Neutrino observatories (telescopes)

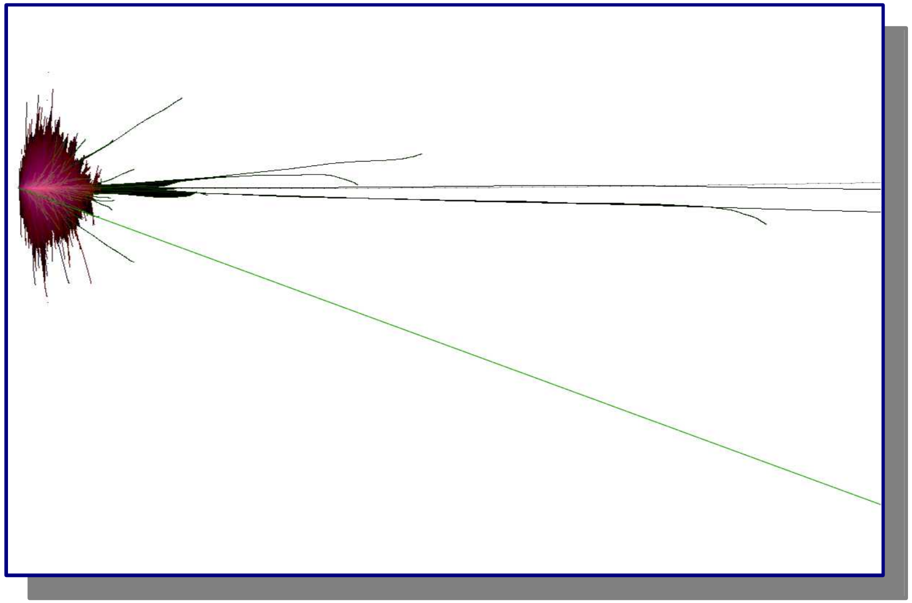
- Detect the muons induced by high energy neutrinos (Cherenkov light).
- The direction of propagation is derived with high accuracy.
- There are many models which lead to very different values for the flux at high energies.



Neutrino flux at high energies:

M. Kistler, T. Stanev, H. Yüksel. arXiv:1301.1703 [astro-ph]

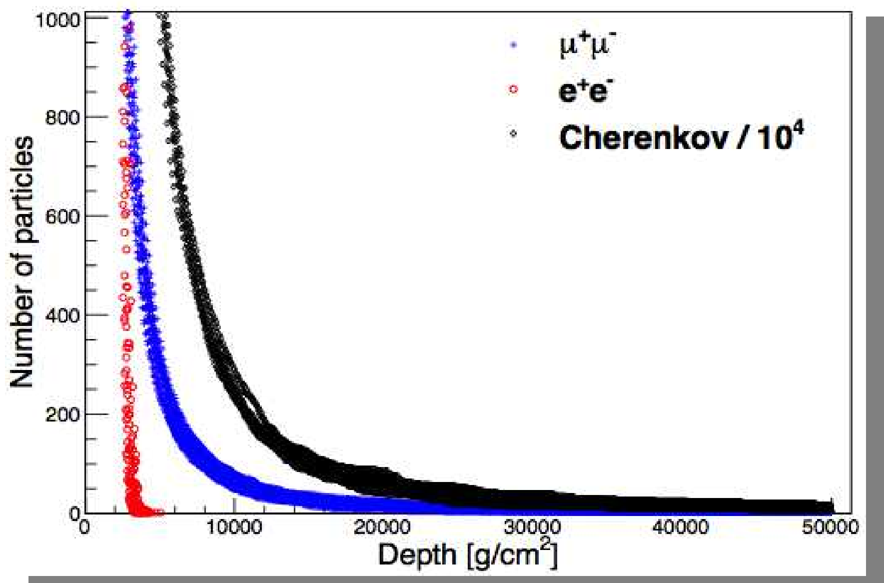
Micro black holes in cosmic rays & neutrino data

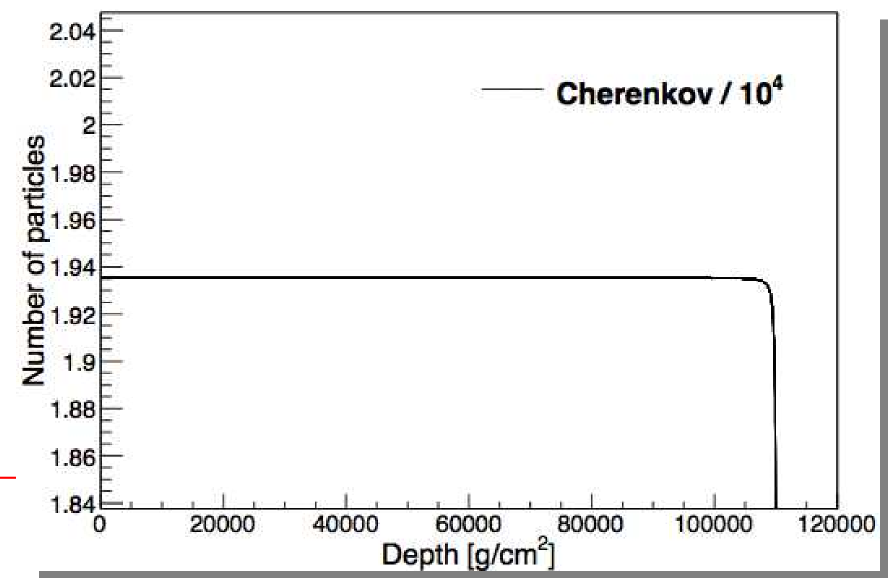


$QBH \rightarrow \mu^- + p^+$ in water (CORSIKA – DESY version).

10^{17} eV proton + 3 x 10^{11}eV muon

- Angle in the Earth Frame: 5º.
- The EM component of the p^+ shower dies out in about 50 meters.
- Muons propagate for distances of 1- 2 km emitting Cherenkov light!





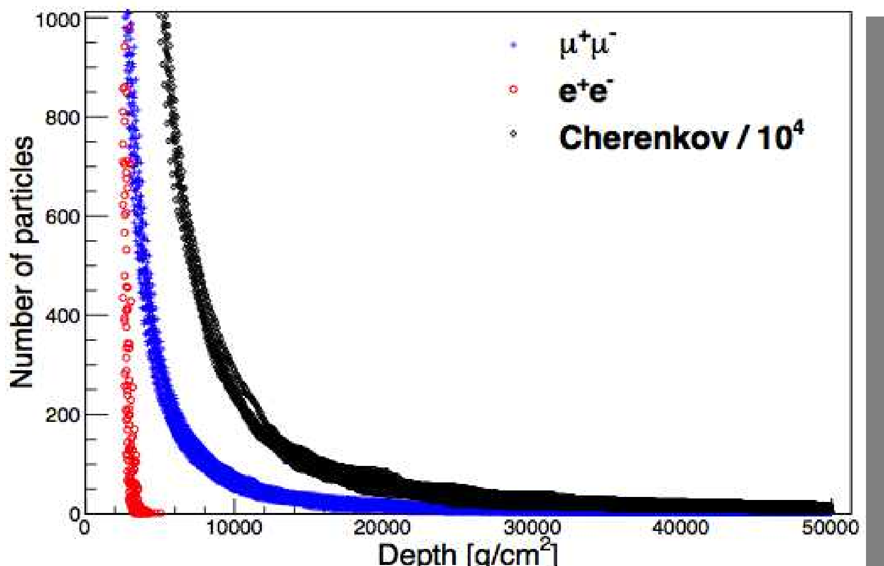
Micro black holes in cosmic rays & neutrino data

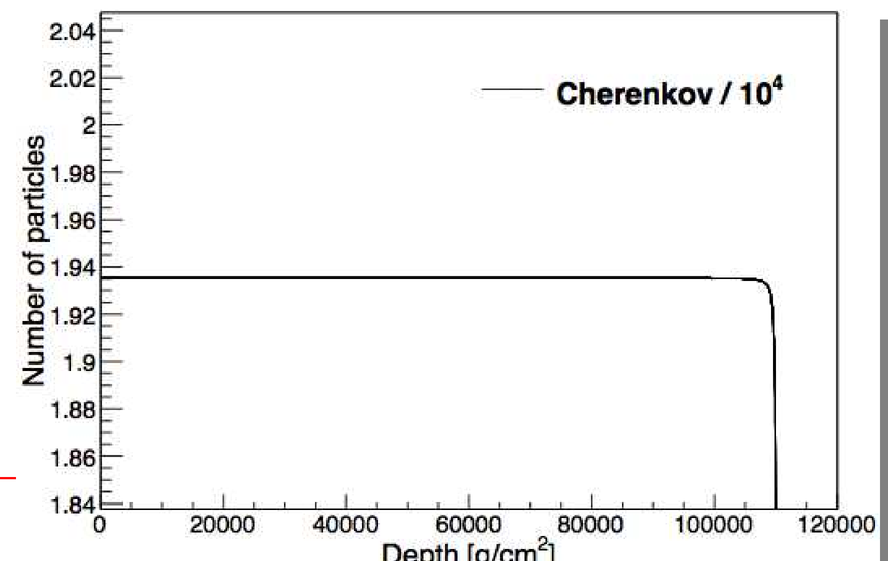
No. Extra-dimensions	Expected events @ IceCube
0	1
1	21
2	81
3	179
4	311
5	440
6	623

$QBH \rightarrow \mu^- + p^+$ in ice.

10^{17} eV proton + 3 x 10^{11}eV muon

- Angle in the Earth Frame: 5°.
- The EM component of the p^+ shower dies out in about 50 meters!
- Muons propagate for distances of 1- 2 km emitting Cherenkov light!





• Conclusions&Discussion

- GUT magnetic monopoles still are elusive
    - Antares has the possibility to detect or further constrain the flux of MM
- The back-to-back decay signature of Quantum Black Holes has some unique features:
    - Two simultaneous particle showers oriented at an angle and pointing to a common origin;
    - The reconstructed energies for the showers have specific values!
    - @ Cosmic Rays experiments, Pierre Auger Observatory;
      @ Future Space observatories, JEM-EUSO
      @ neutrino observatories, Antares, KM3NeT, IceCube

- More info

http://www.science-side.com/

http://www.spacescience.ro/new1/cosmo/

http://www.mpifr-bonn.mpg.de/div/theory/