UHE photon interaction: The Uncertainties.

CREDO Inauguration Meeting

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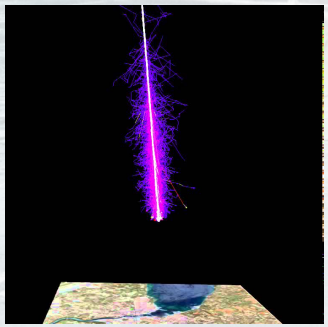

August 30, 2016

Contents:

Why Magnetic Monopole? $\Rightarrow$ Electric charge has to be quantized.

- Paul Dirac showed, that if "at least" one magnetic monopoles exist, then the electric charge is necessarily quantized:

$$e \cdot g = n \cdot \frac{\hbar c}{2} \quad \Rightarrow \quad g = n \cdot \frac{\hbar c}{2e}$$

There are no predictions of their mass in the original Dirac theory.

- In Grand Unification Theories the mass of MM can be estimated:
  - Magnetic Monopoles would have masses from 10^5 until 10^{17} GeV.

Due to the large expected masses, GUT monopoles can only be searched in High Energy Experiments as IceCube, ANTARES, Pierre Auger, Baikal-GVD and CREDO.

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If MM exist Maxwell's equations become symmetrical and invariant under a Dual Transformation:

$$\vec{E}' = \vec{E}cos(\alpha) + c\vec{B}sin(\alpha) \quad ; \quad c\vec{B}' = c\vec{B}cos(\alpha) - \vec{E}sin(\alpha)$$

$$cq'_e = cq_e cos(\alpha) + q_m sin(\alpha) \quad ; \quad q'_m = q_m cos(\alpha) - cq_e sin(\alpha)$$

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho_e}{\epsilon_0} \quad ; \quad \vec{\nabla} \times \vec{B} = \frac{1}{c^2}\frac{\partial \vec{E}}{\partial t} + \mu_0 \vec{J}_e$$

$$-\vec{\nabla} \times \vec{E} = \frac{\partial \vec{B}}{\partial t} + \mu_0 \vec{J}_m \quad ; \quad \vec{\nabla} \cdot \vec{B} = \mu_0 \rho_m$$

Magnetic Monopoles in the Earths Electric-Magnetic Fields

The symmetry in the Maxwell equation implies a symmetrical Lorentz force:

$$\vec{F} = q_e\left(\vec{E} + \vec{v} \times \vec{B}\right) + q_m\left(\vec{B} - \frac{v}{c^2} \times \vec{E}\right)$$

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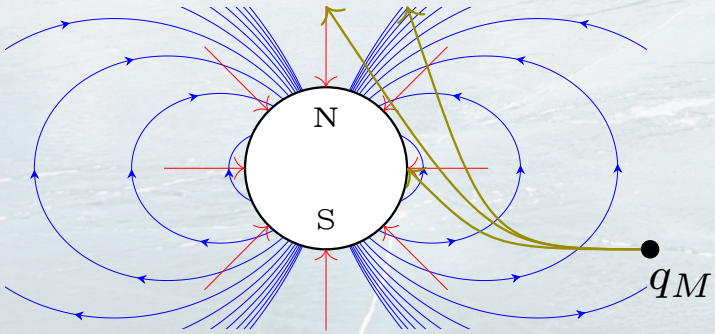
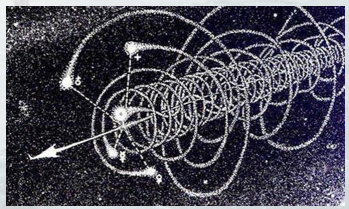
$q_m\vec{B}$

Accelerated in galactic and extragalactic magnetic fields.



$$-q_m\left(\frac{v}{c^2}\times\vec{E}\right)$$

Spiral motion.



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- If there were no galactic magnetic field, one would expect monopoles in the galaxy to have velocities of the order of $10^{-3}c$, but there is, then:

$$v = \begin{cases} 10^{-3}c\left(\frac{10^{17}GeV}{M_M}\right)^{1/2} & \text{if } M_M \geq 10^{11}GeV \\ c & \text{if } M_M \leq 10^{11}GeV \end{cases}$$

Magnetic Monopoles in the Earths Electric-Magnetic Fields

$$-q_m \left(\frac{v}{c^2} \times \vec{E} \right)$$

Some natural question arises:

- Is there a MM synchrotron radiation (Electric-Bremsstrahlung)?
  - Catastrophic emission, can we expect the same for MM?

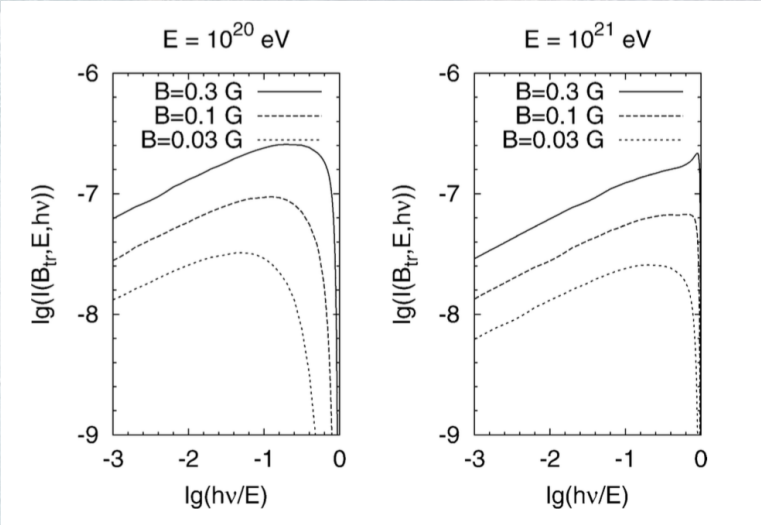


Figure: Bremsstrahlung spectral distribution (P. Homola et al. CPC 173 (2005) 71-90).

Magnetic Monopoles in the Earths Electric-Magnetic Fields

$$-q_m \left(\frac{v}{c^2} \times \vec{E} \right)$$

Some natural question arises:

- If there is Catastrophic emission, What about energy loss?

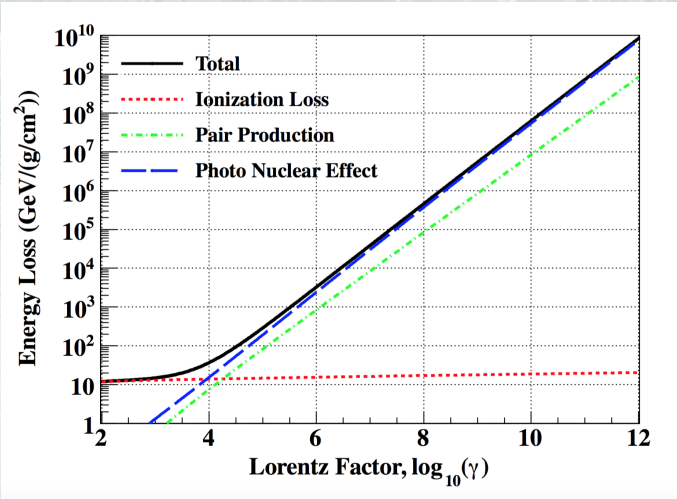


Figure: Energy loss of a magnetic monopole in air as a function of its Lorentz factor (T. Fujii for Pierre Auger Collaboration)


Is dark matter so dark?

Is dark matter so dark?

Motivations of Very Heavy Dark Matter:

- Observation of Ultra High Energy Cosmic Rays.
  - The source of these particles can not be in a distance larger than ~ 50 [Mpc], otherwise, interaction with CMB and IR photons considerably reduces the energy of the primary particles (GZK cutoff at energies around $\sim 10^{18}$ to 10^{20} [eV]).
  - In fact, observation shows a local minimum in the spectrum around these energies, but unexpectedly it rises again at higher energies.
- N. Hayashida et al. reports a excess of 4% for UHECRs with energies $\sim 10^{18}$ [eV] in the direction of the Galactic Center and Cygnus region.

Is dark matter so dark?

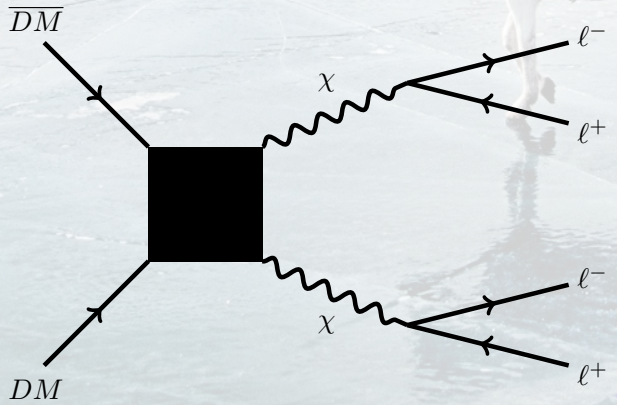
Is over there a hypothetical elementary particle called dark photon X?, which carries the electromagnetic force to dark matter.

$$\mathcal{L} \sim -\frac{1}{4} W^a_{\mu\nu} W^{a,\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} + \frac{1}{2} \frac{m_W^2}{g^2} (-g W^3_\mu + g' B_\mu)^2 + \frac{1}{2} m_W^2 (W^1_\mu W^{1,\mu} + W^2_\mu W^{2,\mu})^2 + SM\ matter\ and\ Higgs\ terms$$

$$-\frac{1}{4} X_{\mu\nu} X^{\mu\nu} + \frac{m_X^2}{2} X_\mu X^\mu - \frac{Y}{2} B_{\mu\nu} X^{\mu\nu}$$

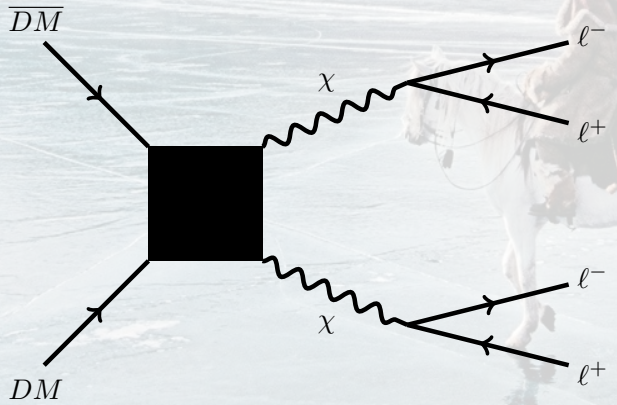
coupling, Dark Photon, SM Photon

It is important to note, that the addition of a new $U(1)$ symmetry group, not give extra information about DM nature (fermion, scalar, etc).



Is dark matter so dark?

- Which kind of processes are hidden in the Black-Box?
  - ⇒Depend on the MODEL:
    - LanHEP[Sema]: Program for Feynman rules generation in momentum representation.



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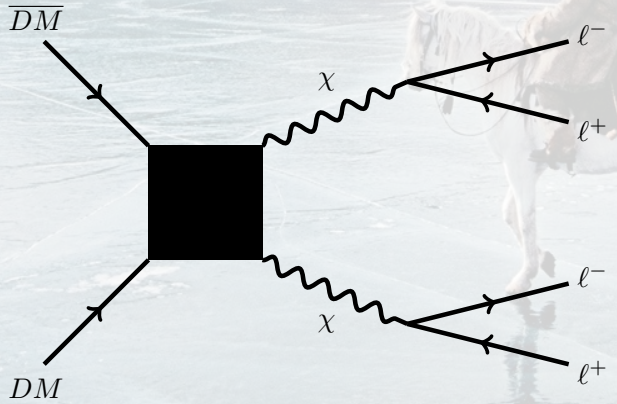

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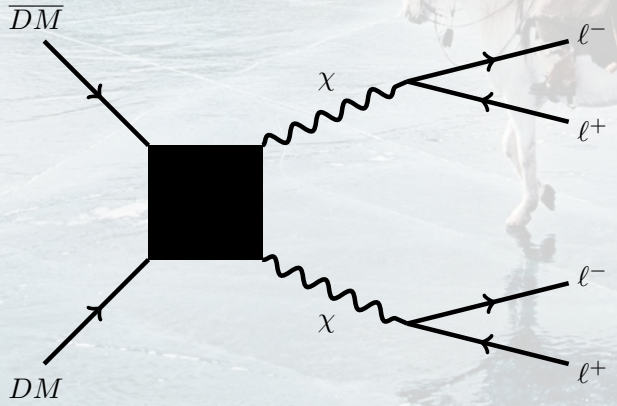
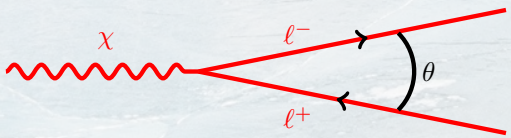
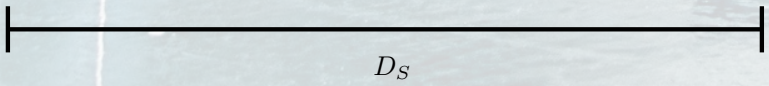
  - At this point, we can simulate the process involving dark matter and calculate the cross section and production rates in terms of their couplings.



Is dark matter so dark?

- How we can connect it, with the experiments?
  - Can we constrain the dark photon decay angle with some global detection strategy?
    - For relativistic Dark Photons $\theta = 2/\gamma$ become very small (almost zero).
  - If we can detect an extended front of simultaneous low energy particles (super-preshowers), could it be a unique signature of Dark Photons? at high energy scale.
    - No Detection $\Rightarrow$ Constrain over parameters as D_s, M_{DP}, and couplings.
    - Detection $\Rightarrow$ Estimation of M_{DM}, couplings.





Conclusions:

- A deep study of the Magnetic Monopoles synchrotron radiation have to be done. P. Homola (Krakow), D. Alvarez & J. Zamora (Dubna).
- A full simulation of the production and processes related with Dark Photon will be done. P. Homola (Krakow), F. Rojas (South Hampton U) & J. Zamora (Dubna).

Thank You

Backup

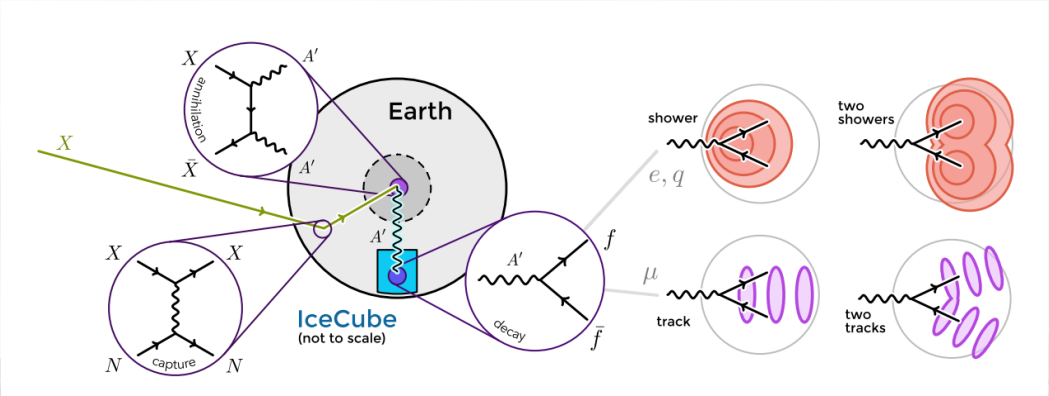


Figure: Feng, Jonathan. et al. [FST16a]

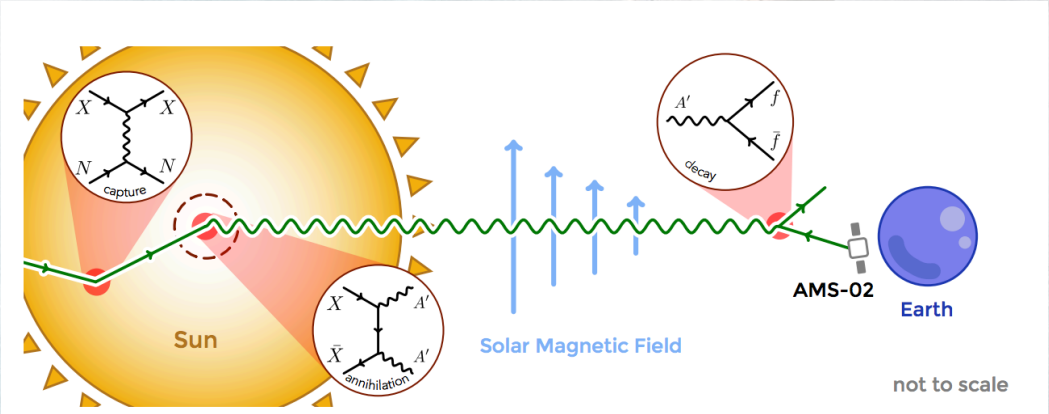


Figure: Feng, Jonathan et al. [FST16b]

References I


Jonathan L. Feng, Jordan Smolinsky, and Philip Tanedo, *Dark Photons from the Center of the Earth: Smoking-Gun Signals of Dark Matter*, Phys. Rev. **D93** (2016), no. 1, 015014.


_____, *Detecting dark matter through dark photons from the Sun: Charged particle signatures*, Phys. Rev. **D93** (2016), no. 11, 115036.


A. Semenov, *LanHEP: A Package for the automatic generation of Feynman rules in field theory.*, `http://theory.sinp.msu.ru/~semenov/lanhep.html`.


_____, *MicrOMEGAs: a code for the calculation of Dark Matter Properties including the relic density, direct and indirect rates in a general supersymmetric model and other models of New Physics .*, `https://lapth.cnrs.fr/micromegas/`.