Observation of anomalous internal pair creation in ^{8}Be: indication of a light neutral boson

A.J. Krasznahorkay

Inst. for Nucl. Res., Hung. Acad. of Sci. (MTA-Atomki)

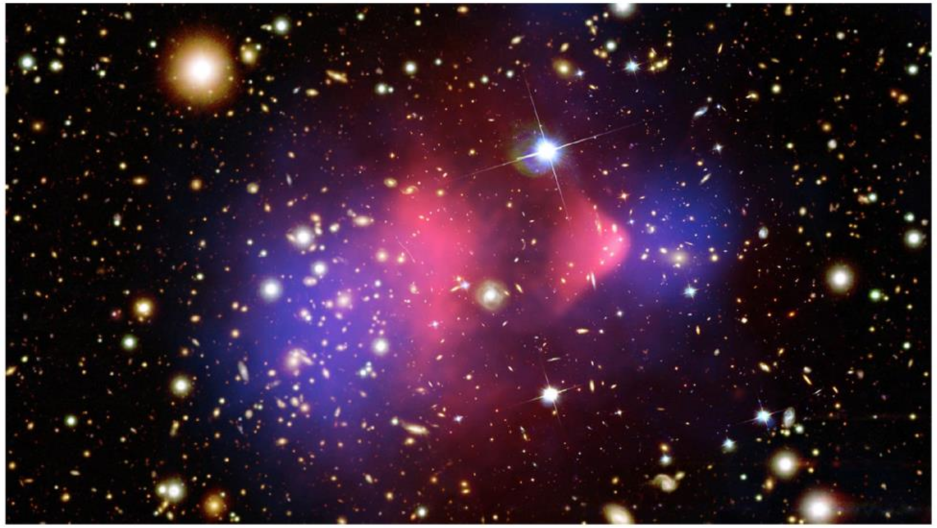
Introduction

- The discovery of the Higgs boson in 2012 (50 years after the prediction)
- The standard model is completed, but it describes only the visible world (5%)
- The new challenge is to study the structure of dark matter
- There is no real theoretical prediction
- New physics, searching for new particles
- plenty of rumors → the effect disappears (e.g. LHC 2015 December „bump" at 750 GeV, article in Nature, dreams are crushed recently)

The Atomki anomaly → signals for a new 17 MeV boson → gauge boson of a new fundamental force of nature

The Atomki anomaly | symmetry magazine http://www.symmetrymagazine.org/article/the-at

symmetry
dimensions of particle physics



NASA

The Atomki anomaly

07/27/16 | By Kathryn Jepsen

A result from an experiment in Hungary catches the attention of a group of theorists in the United States.

PRL 116, 042501 (2016) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2016

Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson

A. J. Krasznahorkay,* M. Csatlós, L. Csige, Z. Gácsi, J. Gulyás, M. Hunyadi, I. Kuti, B. M. Nyakó, L. Stuhl, J. Timár, T. G. Tornyi, and Zs. Vajta
Institute for Nuclear Research, Hungarian Academy of Sciences (MTA Atomki), P.O. Box 51, H-4001 Debrecen, Hungary

T. J. Ketel
Nikhef National Institute for Subatomic Physics, Science Park 105, 1098 XG Amsterdam, Netherlands

A. Krasznahorkay
CERN, CH-1211 Geneva 23, Switzerland and Institute for Nuclear Research, Hungarian Academy of Sciences (MTA Atomki), P.O. Box 51, H-4001 Debrecen, Hungary
(Received 7 April 2015; published 26 January 2016)

Electron-positron angular correlations were measured for the isovector magnetic dipole 17.6 MeV ($J^\pi = 1^+$, $T = 1$) state → ground state ($J^\pi = 0^+$, $T = 0$) and the isoscalar magnetic dipole 18.15 MeV ($J^\pi = 1^+$, $T = 0$) state → ground state transitions in ^{8}Be. Significant enhancement relative to the internal pair creation was observed at large angles in the angular correlation for the isoscalar transition with a confidence level of $> 5\sigma$. This observation could possibly be due to nuclear reaction interference effects or might indicate that, in an intermediate step, a neutral isoscalar particle with a mass of $16.70 \pm 0.35(\text{stat}) \pm 0.5(\text{syst})\ \text{MeV}/c^2$ and $J^\pi = 1^+$ was created.

Scientists at the Large Hadron Collider aren't the only ones investigating a possible sign of a new particle.

In a result published in *Physical Review Letters* earlier this year, scientists on the Atomki nuclear physics experiment in Hungary claimed to have turned up potential evidence of a particle that could point to an entirely new fundamental force of nature.

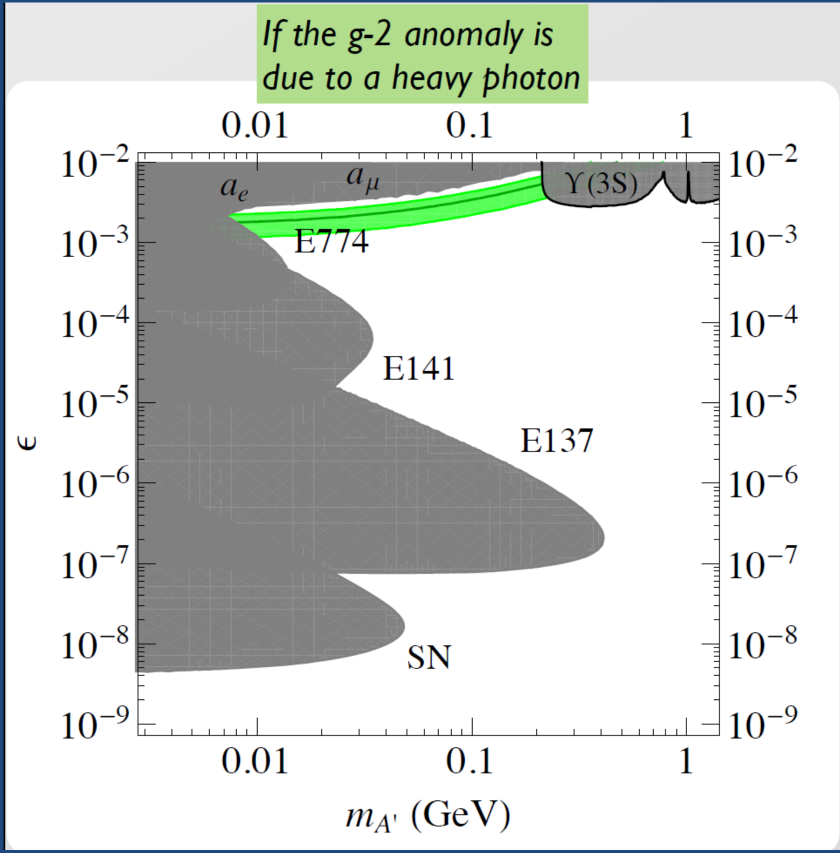
Searching for weakly interacting massive particles (WIMP)

- Scientists' biggest search for dark matter to date just turned up nothing
- They were the currently considered most viable candidate for dark matter

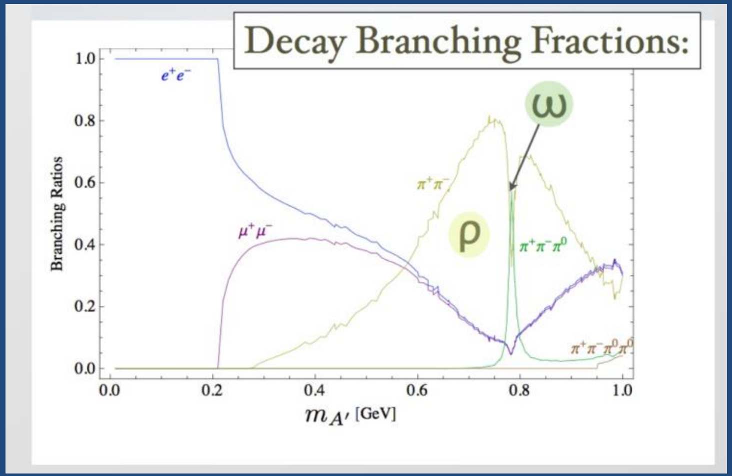
→ Searching for light dark matter (1 MeV/c^2 – 1 GeV/c^2) → dark photon

- Kinetic mixing from the vector portal: if there is an additional U(1) symmetry in nature, there will be mixing between the photon and the new gauge boson (Holdom, Phys. Lett B166, 1986)

Dark photons and the g-2 anomaly



Branching ratio

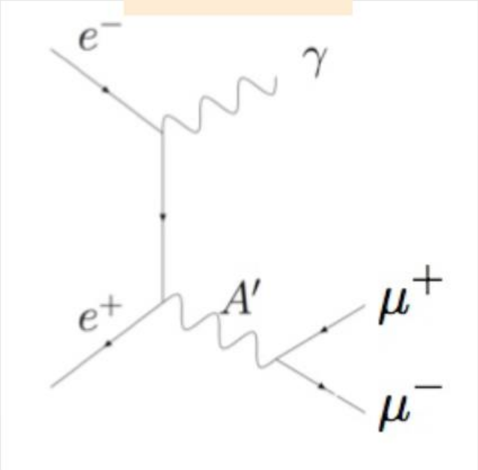


Lifetime

$$\gamma c\tau \propto \left(\frac{10^{-4}}{\epsilon}\right)^2 \left(\frac{100\ \mathrm{MeV}}{m_{A'}}\right)^2$$

Wherever there is a photon there is a dark photon...

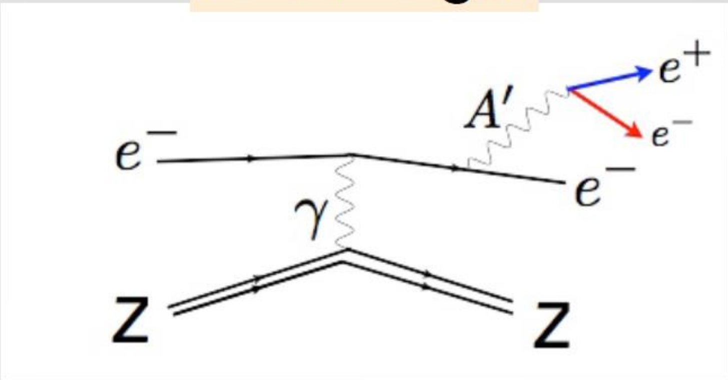
Collider



$$\sigma \sim \frac{\alpha^2 \epsilon^2}{E^2} \sim O(10\ fb)$$

$O\ ab^{-1}$ per ~~decade~~ month

Fixed Target



$$\sigma \sim \frac{\alpha^3 Z^2 \epsilon^2}{m^2} \sim O(10\ pb)$$

$O\ ab^{-1}$ per day

...much higher backgrounds

Dark Force searches in the Labs

https://sites.google.com/site/zprimeguide/ Hye-Sung Lee (JLAB)

Many searches for Dark Force in the Labs around the world (ongoing/proposed).

Typical searches for Dark Force exploit the small Z' coupling to the SM particles (rather than using the DM particles).

Particularly attractive: One of the New physics scenarios that can be tested with Low-energy experimental facilities (Nuclear/Hadronic physics labs).

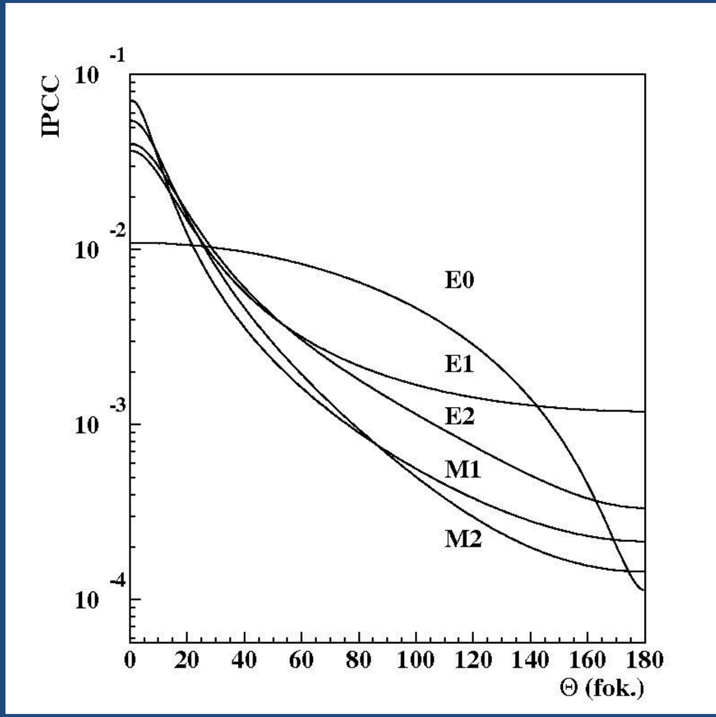
[Dark force carrier Z' scale (GeV) ≈ 1/1000 × Typical new physics scale (TeV)]

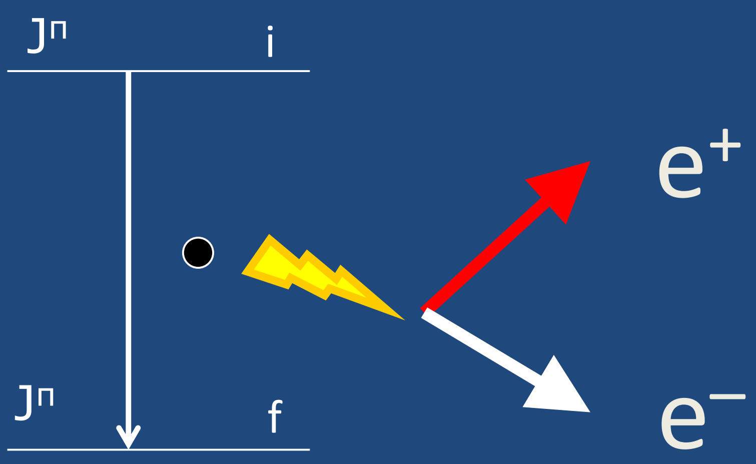
"various Low-E Labs" "LHC"

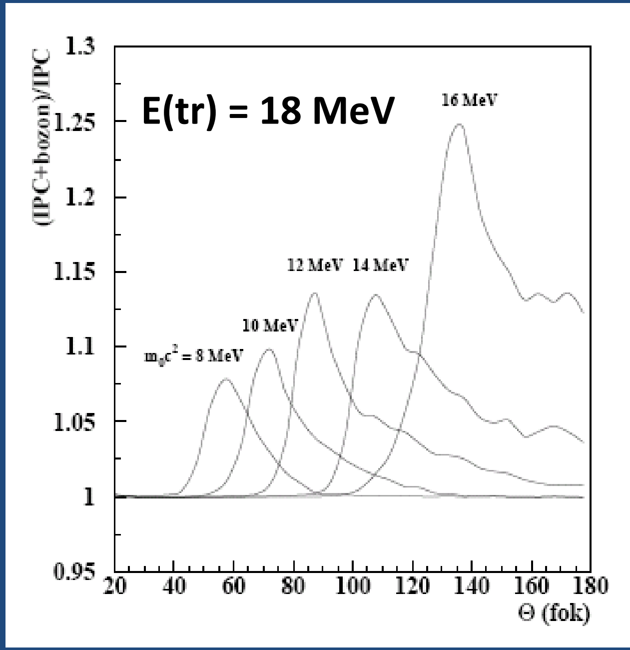
Search for the e^+-e^- decay of the dark photon in nuclear transitions

e^+-e^- internal pair creation

The atomic nucleus is a femto-laboratory including all of the interactions in Nature. A real discovery machine like LHC, but at low energy.

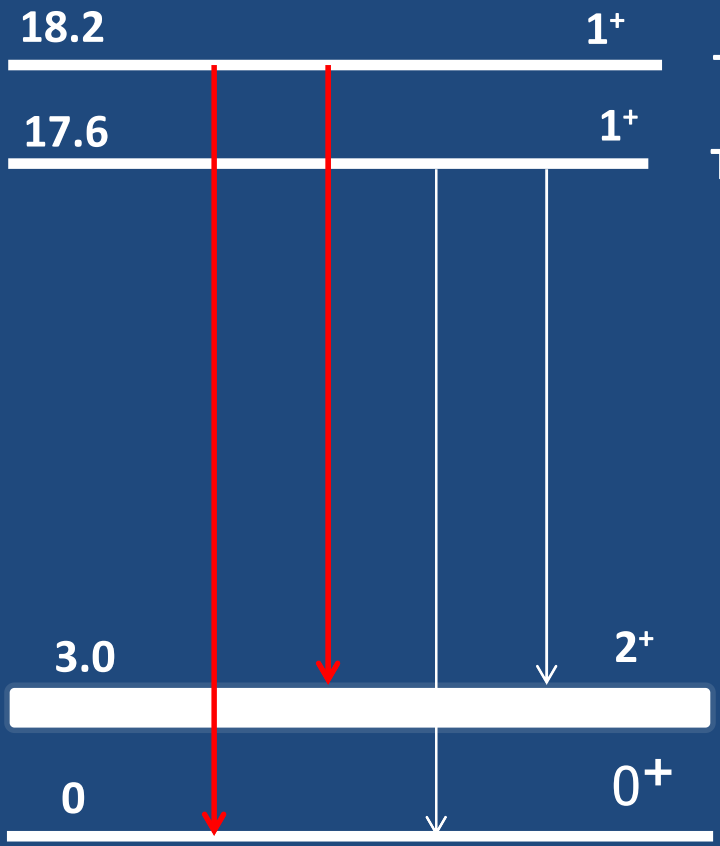






M.E. Rose Phys. Rev. 76 (1949) 678
E.K. Warburton Phys. Rev. B133 (1964) 1368.
P. Schlüter, G. Soff, W. Greiner, Phys. Rep. 75 (1981) 327.

Study the ^{8}Be M1 transitions



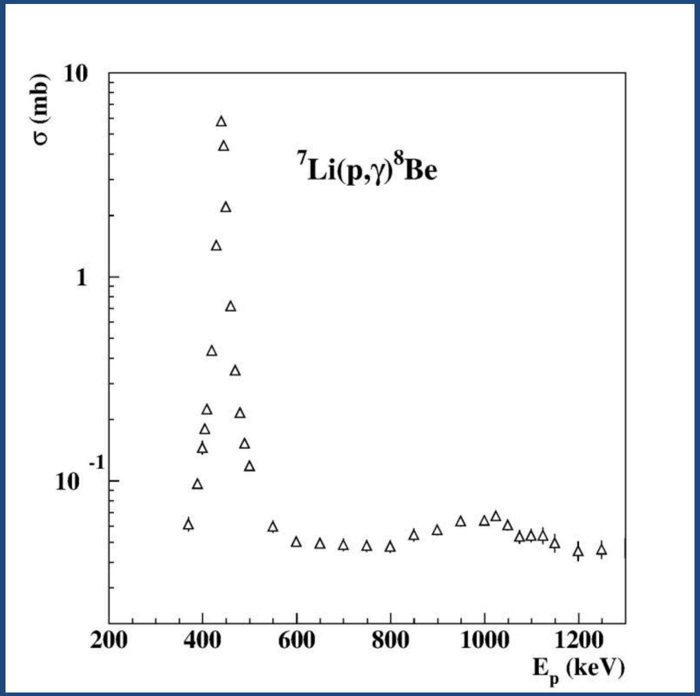
T=0 Ep= 1030 keV

T=1 Ep= 441 keV

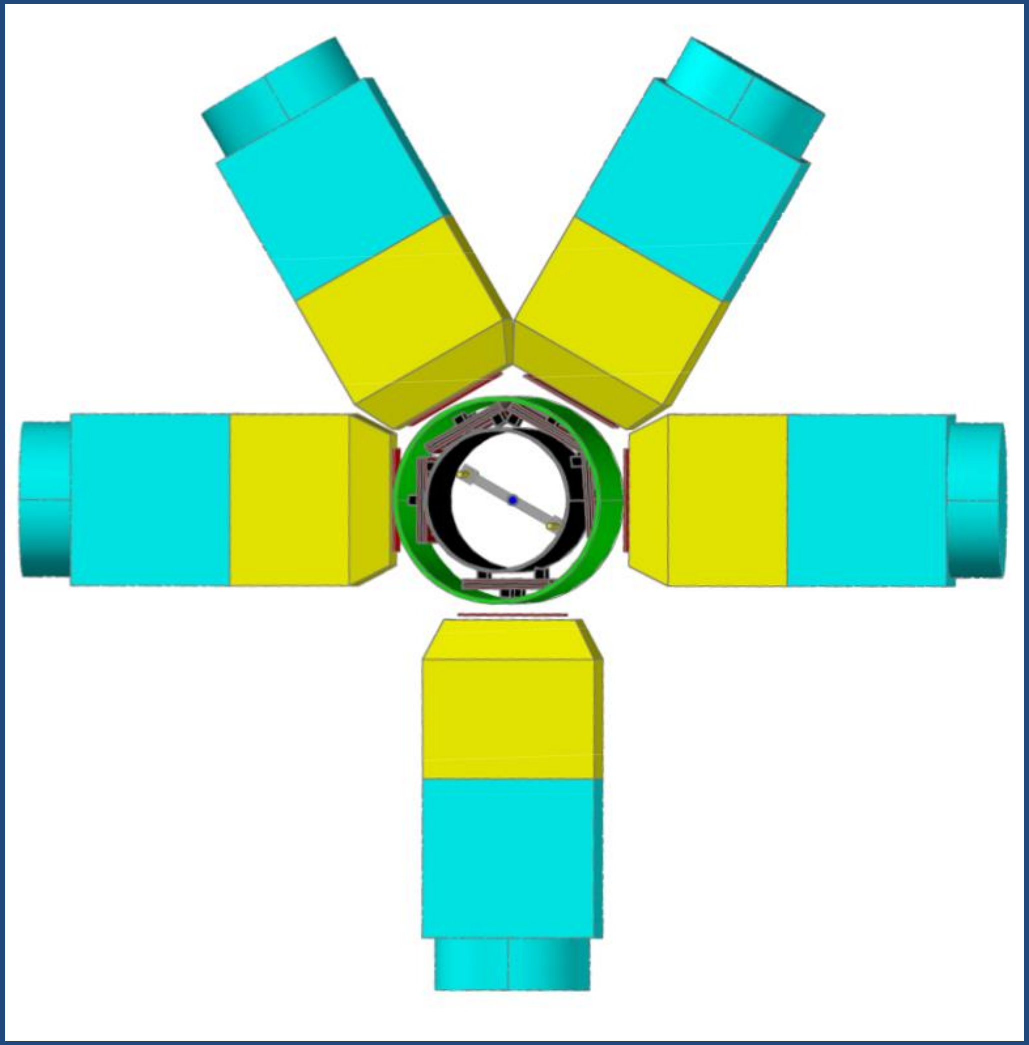
^{8}Be

Excitation with the ^{7}Li(p,γ)^{8}Be reaction

^{7}Li, p3/2^{-} + p

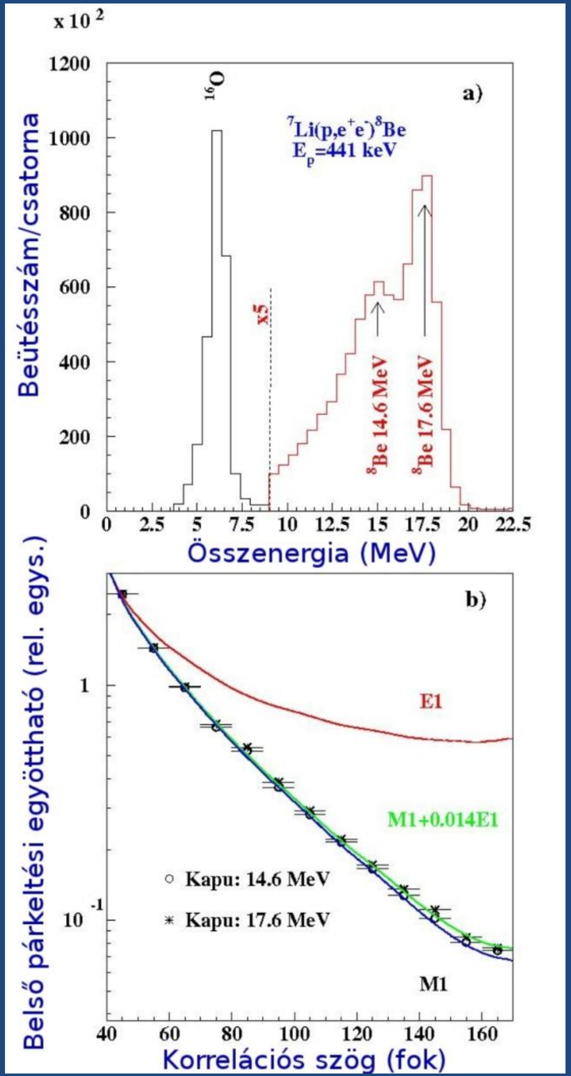


Geometrical arrangement of the scintillator telescopes (NIM, A808 (2016) 21)

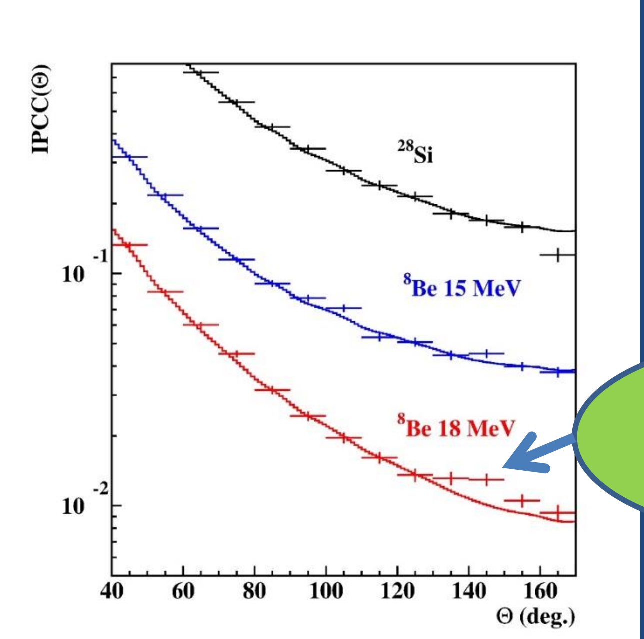


Results

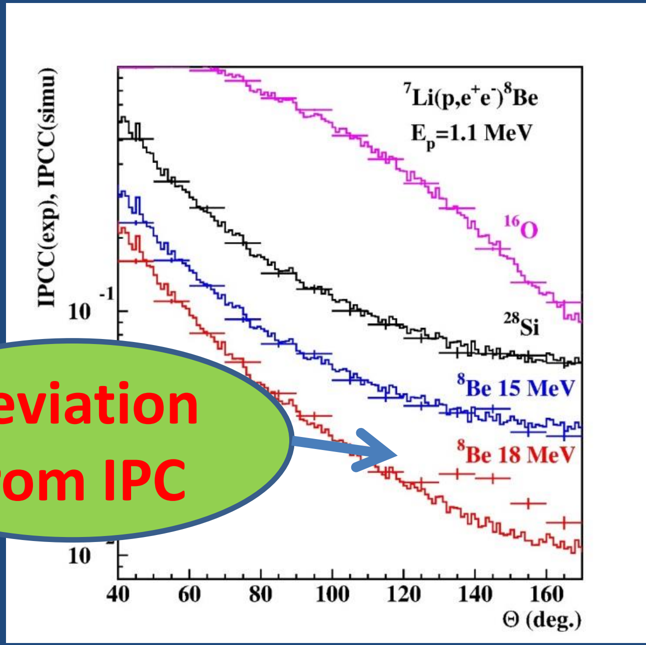
e^+ - e^- sum energy spectra and angular correlations



Ep=1.04 MeV



Ep=1.10 MeV



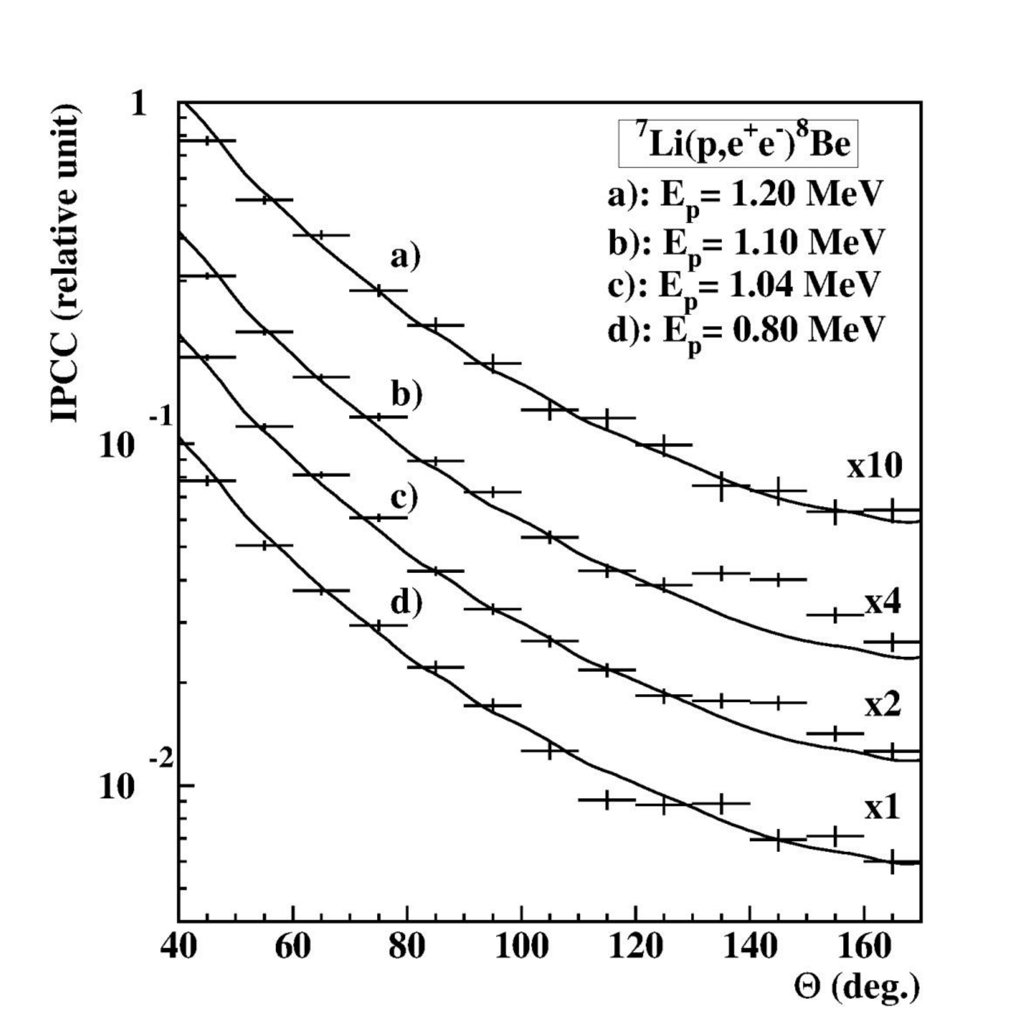
Deviation from IPC

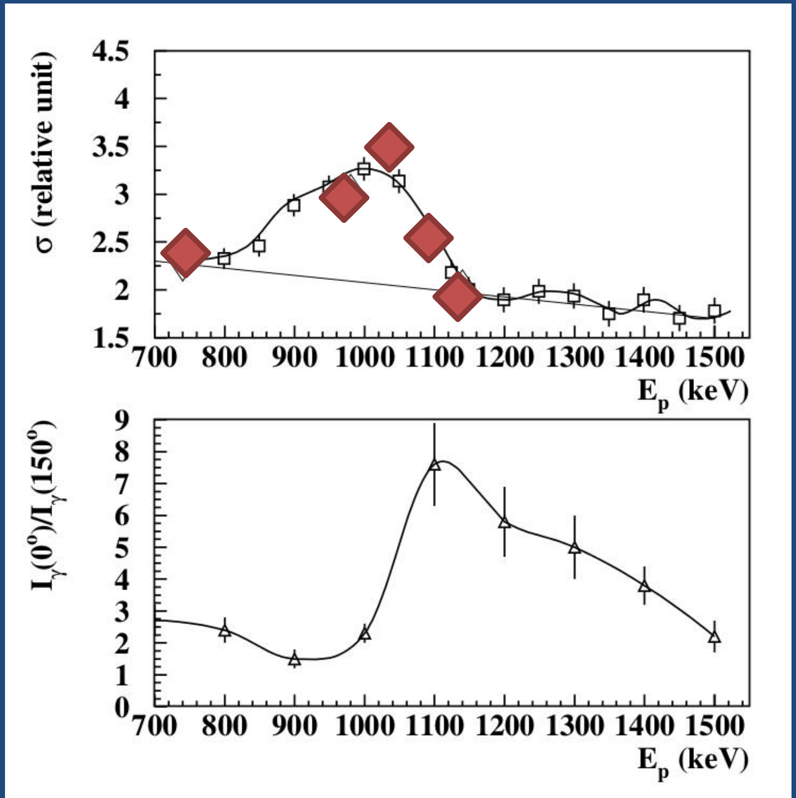
- **Can it be some artificial effect caused by γ-rays?**

→ No, since we observed it at Ep= 1.1 MeV but not at 0.441 MeV.

- **Can it be some nuclear physics effect?**
- **Let's investigate that at different bombarding energies!**

Can it be some kind of interference effect between transitions with different multipolarities?

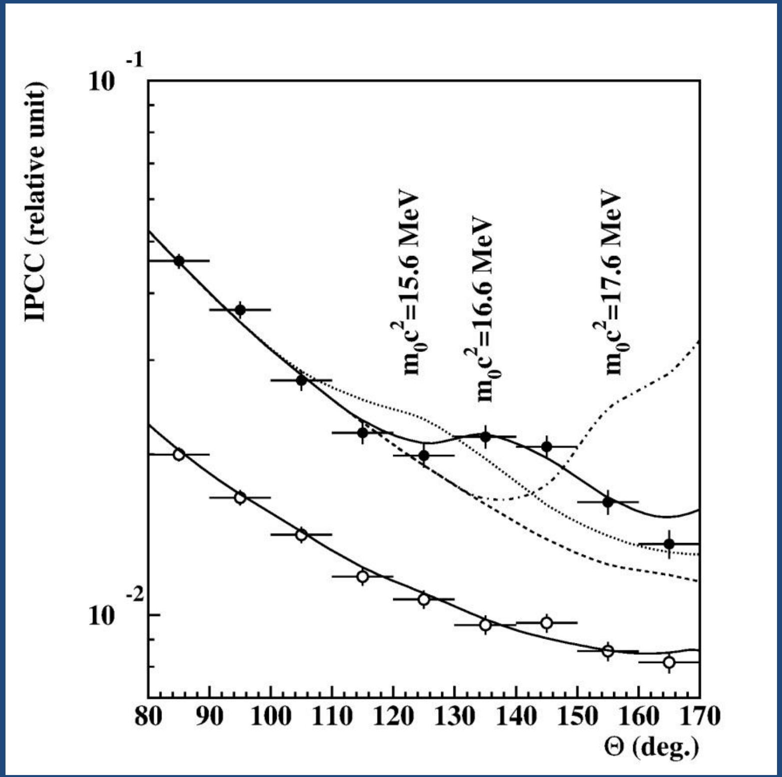




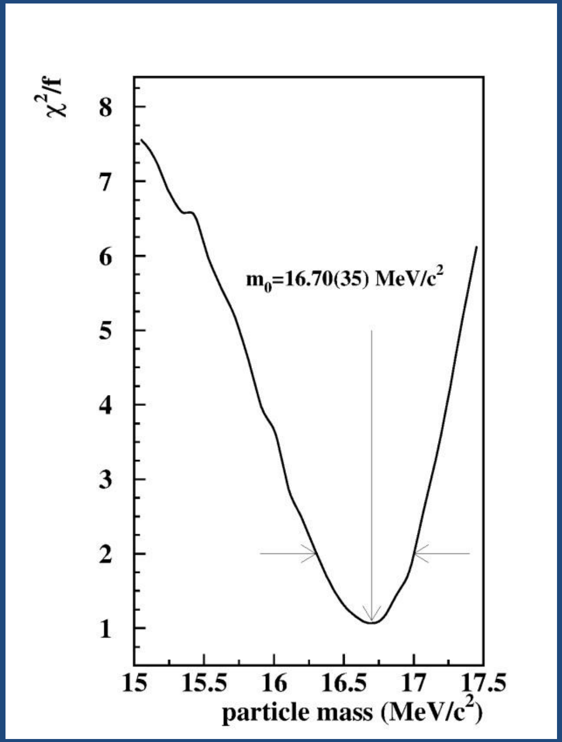
Most probably not. In case of any interference the peak should behave differently.

How can we understand the peak like deviation? Fitting the angular correlations

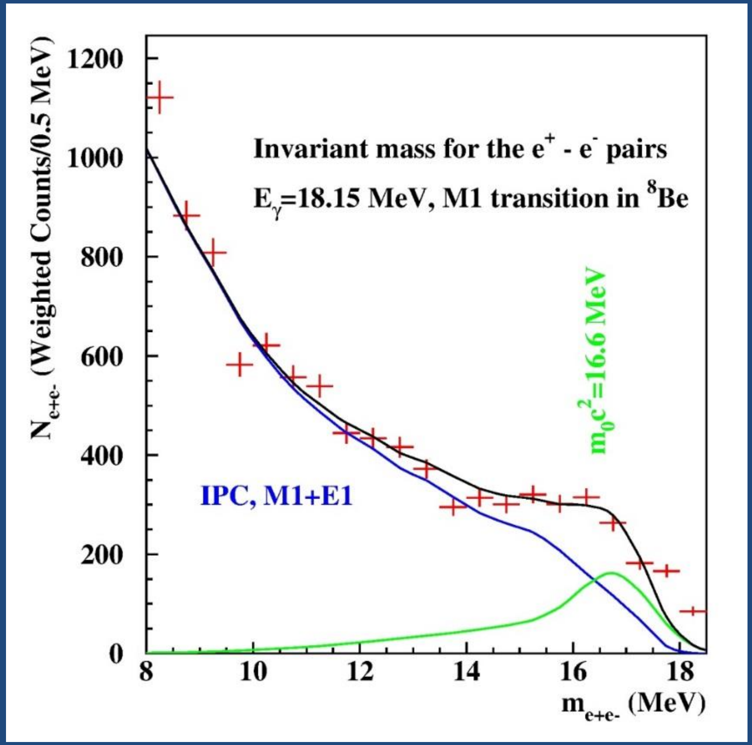
$$y=\frac{E^{+}-E^{-}}{E^{+}+E^{-}}$$



Experimental angular e^+e^- pair correlations measured in the $^7Li(p,e^+e^-)$ reaction at Ep=1.10 MeV with -0.5< y <0.5 (closed circles) and |y|>0.5 (open circles). The results of simulations of boson decay pairs added to those of IPC pairs are shown for different boson masses.

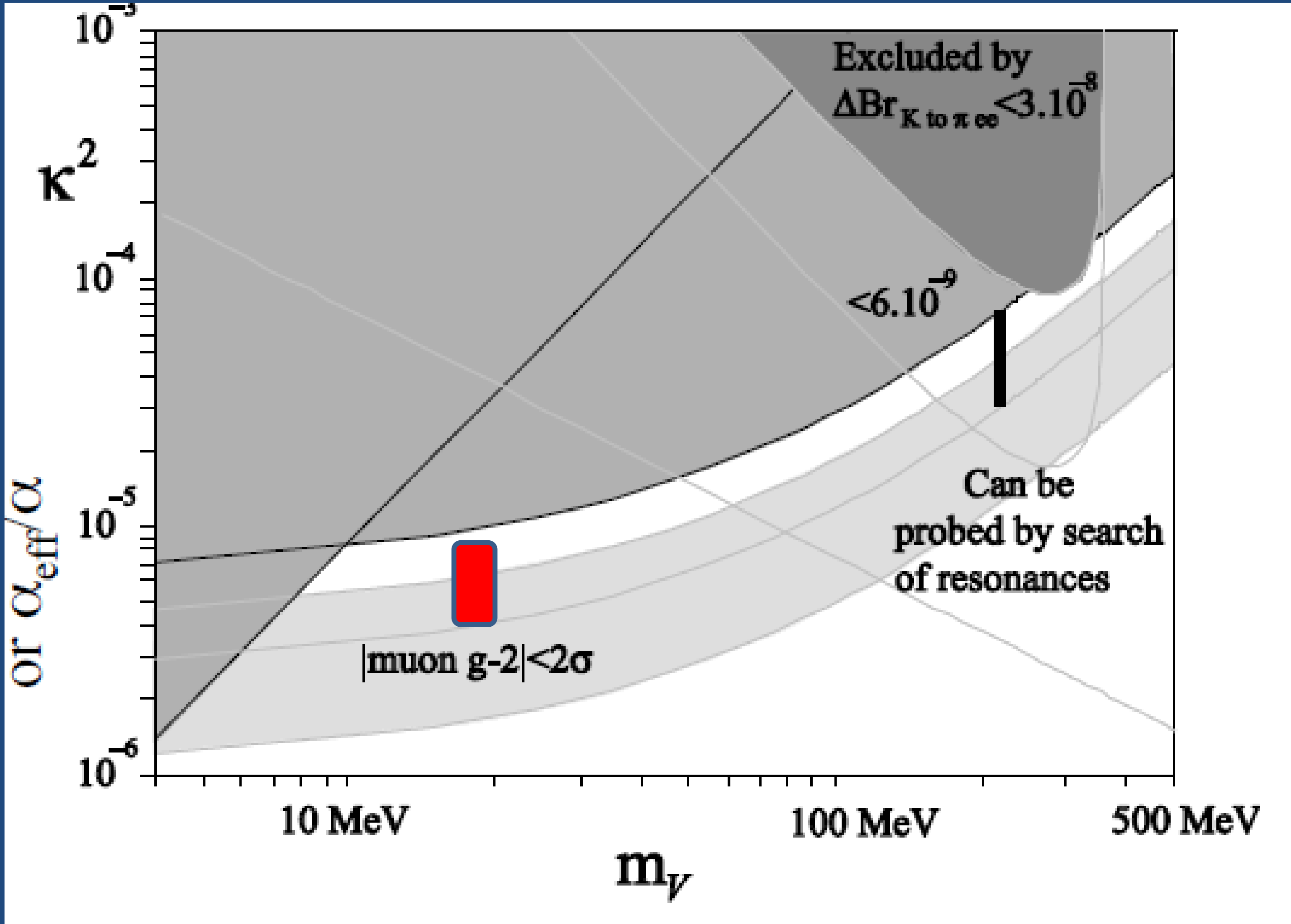


Determination of the mass of the new particle by the X2/f method

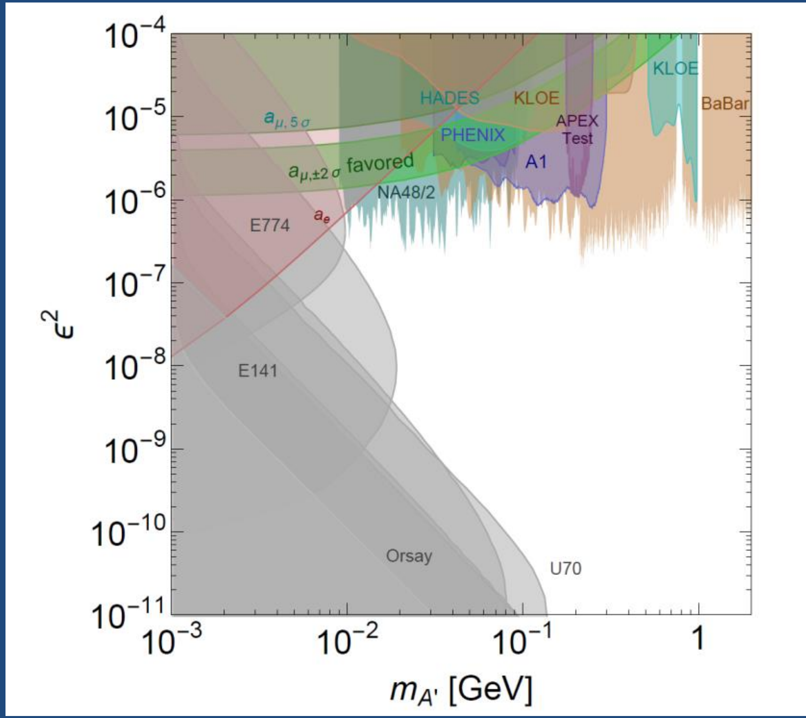


Invariant mass distribution plot for the electron-positron pairs

The coupling constant



Search for a dark photon in the $\pi^0 \rightarrow e^+e^- \gamma$ decay, NA48/2 Collaboration, Phys. Lett. B 746, 178 (2015).



Introduction of the protophobic fifth force (J. Feng et al.PRL 117, 071803, (2016))

$$\mathcal{L} = -\frac{1}{4} X_{\mu\nu} X^{\mu\nu} + \frac{1}{2} m_X^2 X_\mu X^\mu - X^\mu J_\mu ,$$

$$\varepsilon_p = 2\varepsilon_u + \varepsilon_d \qquad \varepsilon_n = \varepsilon_u + 2\varepsilon_d$$

$$\Gamma(^8\mathrm{Be}^* \to {}^8\mathrm{Be}\, X) = \frac{(e/2)^2 (\varepsilon_p + \varepsilon_n)^2}{3\pi\Lambda^2} |\mathcal{M}|^2 |\vec{p}_X|^3$$

What are the properties of the interaction?

Branching ratio:

$$\frac{B(^8\text{Be}^* \to {}^8\text{Be}\, X)}{B(^8\text{Be}^* \to {}^8\text{Be}\, \gamma)} = (\varepsilon_p + \varepsilon_n)^2 \frac{|\vec{p}_X|^3}{|\vec{p}_\gamma|^3} \approx 5.6 \times 10^{-6}$$

$$|\varepsilon_p + \varepsilon_n| \approx 0.011 \qquad |\varepsilon_u + \varepsilon_d| \approx 3.7 \times 10^{-3}$$

Lifetime: $v \approx 0.35c$ $L \lesssim 1$ cm

$$|\varepsilon_e| \gtrsim 1.3 \times 10^{-5}$$

Pion decay: $|2\varepsilon_u + \varepsilon_d| < \varepsilon_{\text{max}} = 8 \times 10^{-4}$

$$-2.3 < \frac{\varepsilon_d}{\varepsilon_u} < -1.8\,, \quad -0.067 < \frac{\varepsilon_p}{\varepsilon_n} < 0.078$$

Prophobic particle

Conclusions

- The search for new gauge bosons has a long history over a huge range of mass scales
- Something like a ***dark photon*** is very well theoretically motivated
- The observed deviation between the experimental and theoretical angular correlations is significant and can be described by assuming the creation and subsequent decay of a boson with mass m_0c^2 =16.70±0.35(stat)±0.5(sys) MeV.
- The branching ratio of the e^+e^- decay of such a boson to the γ decay of the 18.15 MeV level of ^{8}Be is found to be 5.8×10^{-6} for the best fit.
- The lifetime of the boson with the observed coupling strength is expected to be in the order of 10^{-14} s. This gives a flight distance of about 30 μm in the present experiment, and would imply a very sharp resonance (Γ~ 0.07 eV) in the future e^+e^- scattering experiments.

To be continued …

- More telescopes, even bigger efficiency
- Si detectors for tracking the particles
- Constraining the mass of the particle
- Can we see anything in the 17.6 MeV transition?
- Constraining the lifetime of the particle
- Can we see particle creation in E1 transitions ($^{11}B(p,\gamma)^{12}C$) ? Parity conservation?

Thank you very much for your attention