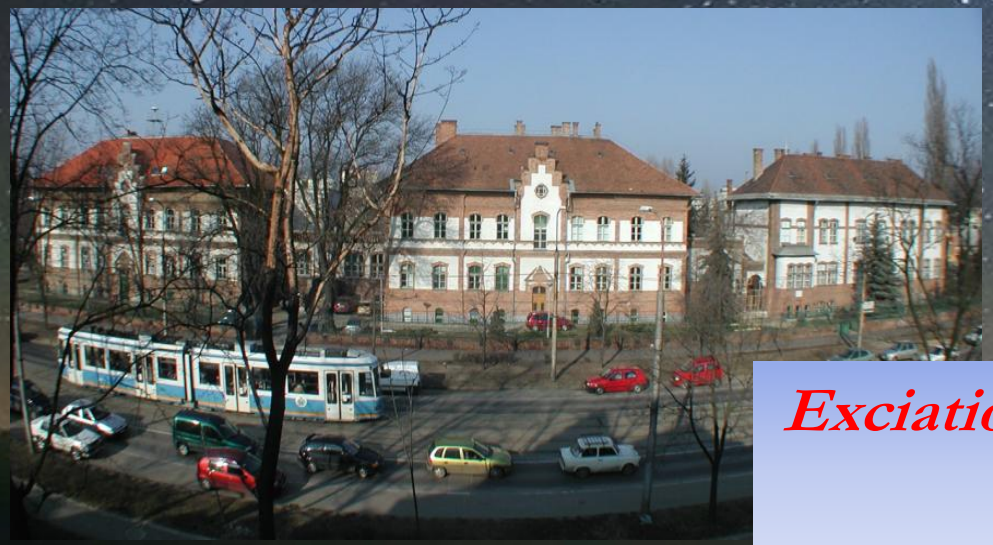
Experiments to detect the X17 particle

A.J. Krasznahorkay, for the ATOMKI collaboration

HUN-REN Inst. for Nucl. Res. (HUN-REN ATOMKI)

Debrecen, Hungary



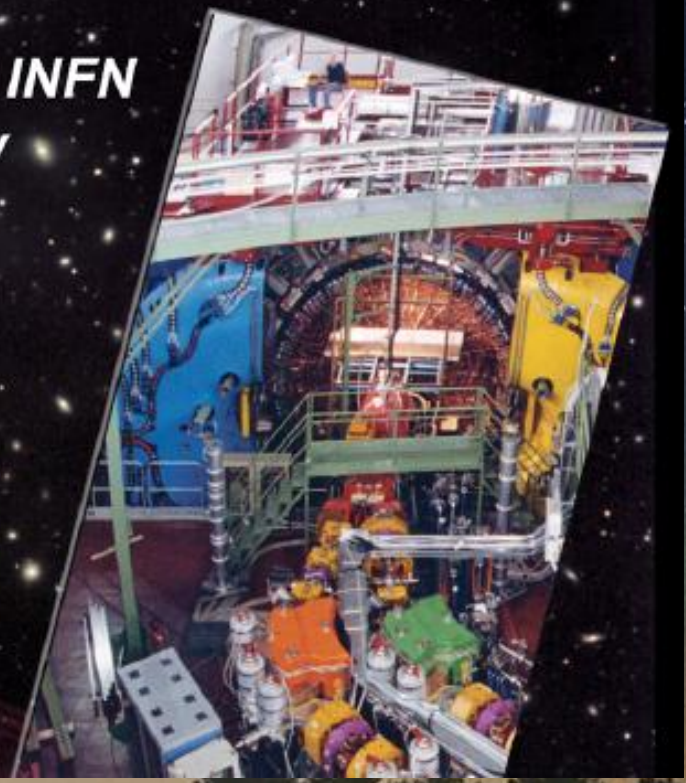
Exciation of Giant Resonances in exotic nuclei

ECT* Trento, 2012

Dark Forces at Accelerators

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

16th - 19th, October 2012
Laboratori Nazionali di Frascati, INFN
Frascati (Rome), Italy



The workshop will focus on experimental searches of new gauge bosons with masses in the MeV to GeV range. The connection of these studies to the search for dark matter will also be addressed.

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

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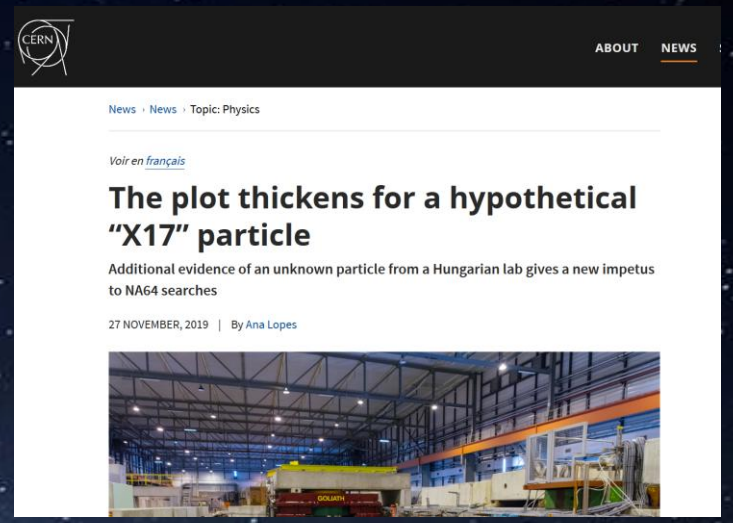
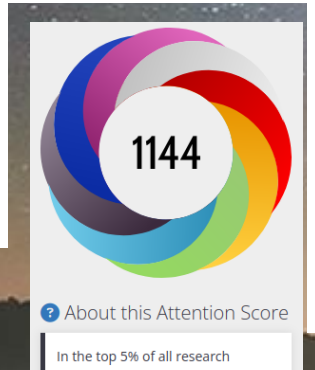
(Received 7 April 2015; published 26 January 2016)

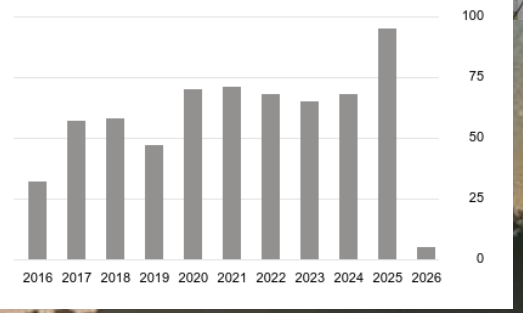
Electron-positron angular correlations were measured for the isovector magnetic dipole 17.6 MeV ($J^\pi = 1^+$, $T = 1$) state → ground state ($J^\pi = 0^+$, $T = 0$) and the isoscalar magnetic dipole 18.15 MeV ($J^\pi = 1^+$, $T = 0$) state → ground state transitions in ^{8}Be. Significant enhancement 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 $16.70 \pm 0.35(\text{stat}) \pm 0.5(\text{syst})$ MeV/c^2 and $J^\pi = 1^+$ was created.



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

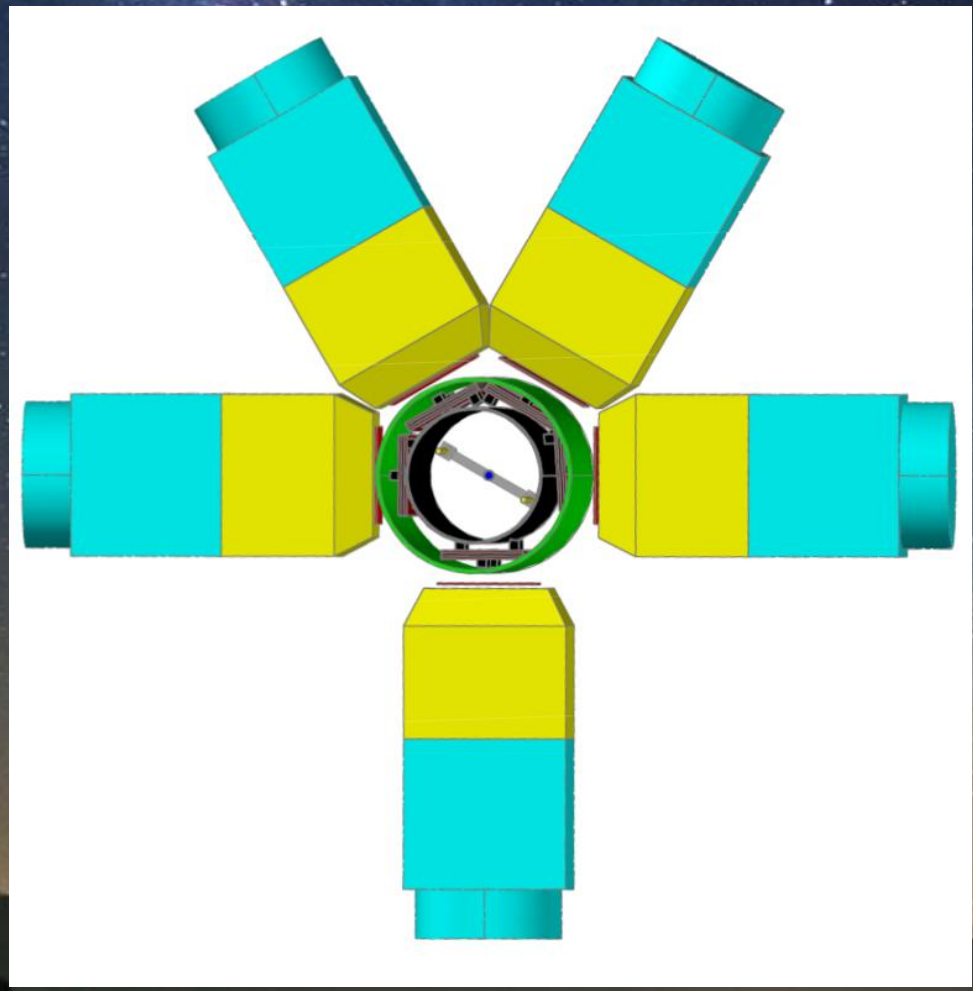
Attention score





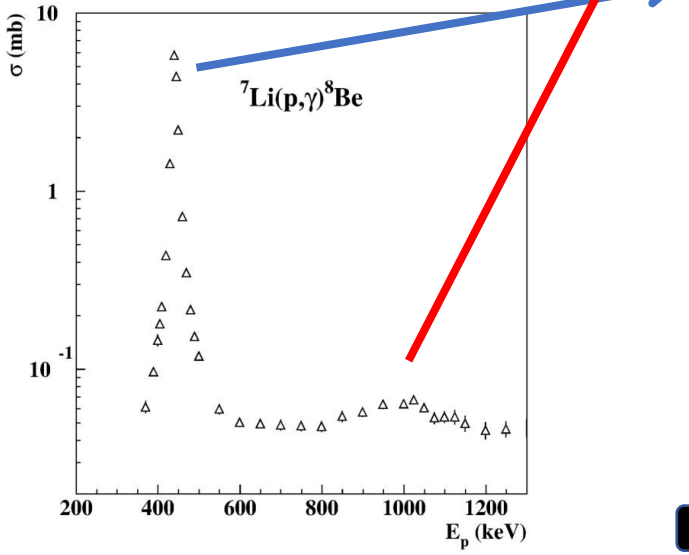
Article in Nature, CNN news, boom in the media

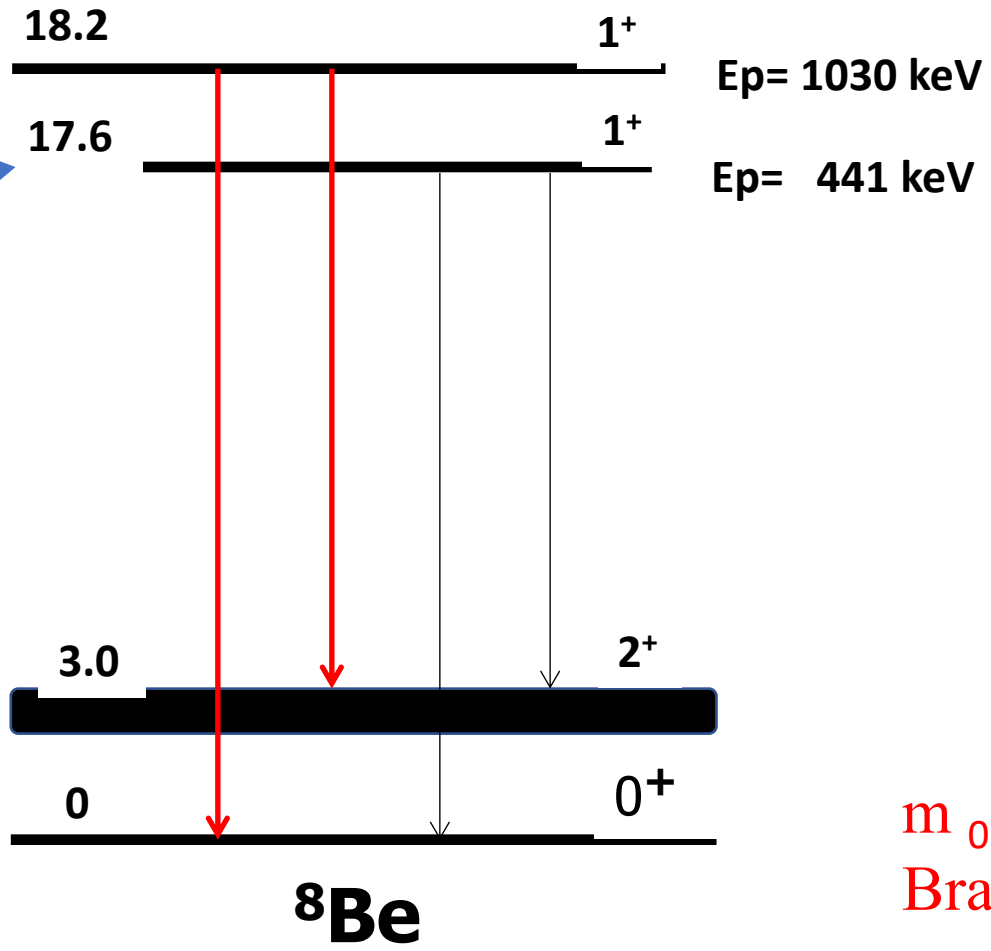
An e^-e^+ spectrometer constructed by Multi Wire Proportional Counters and plastic scintillator telescopes



Study of the ^{8}Be M1 transitions

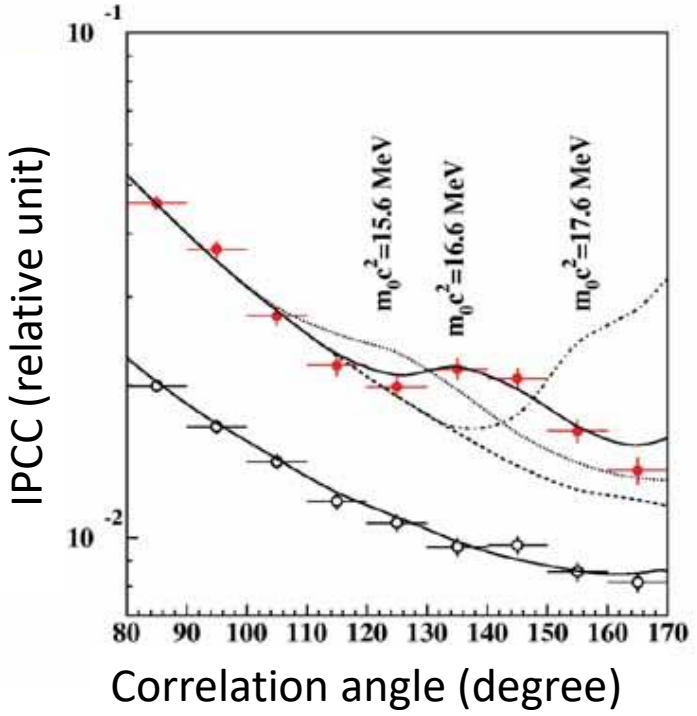
Excitation with the ^{7}Li(p,γ)^{8}Be reaction





Ep= 1030 keV

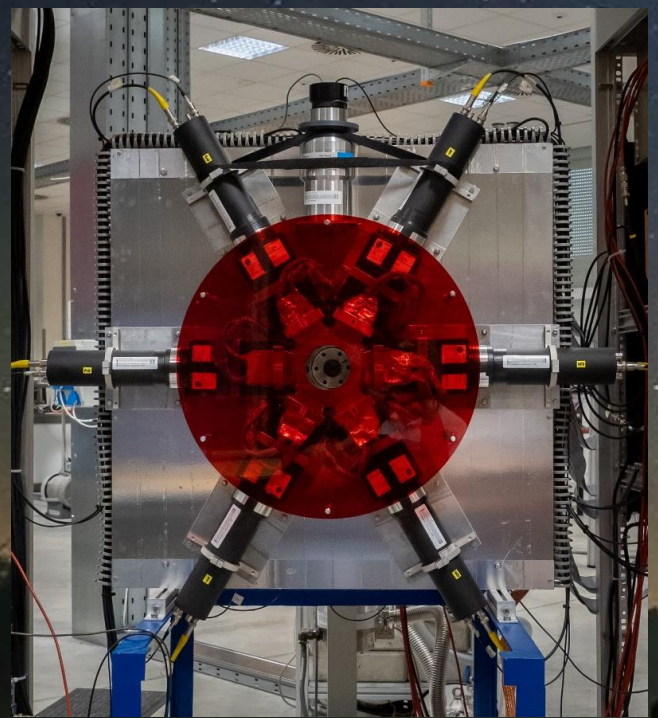
Ep= 441 keV



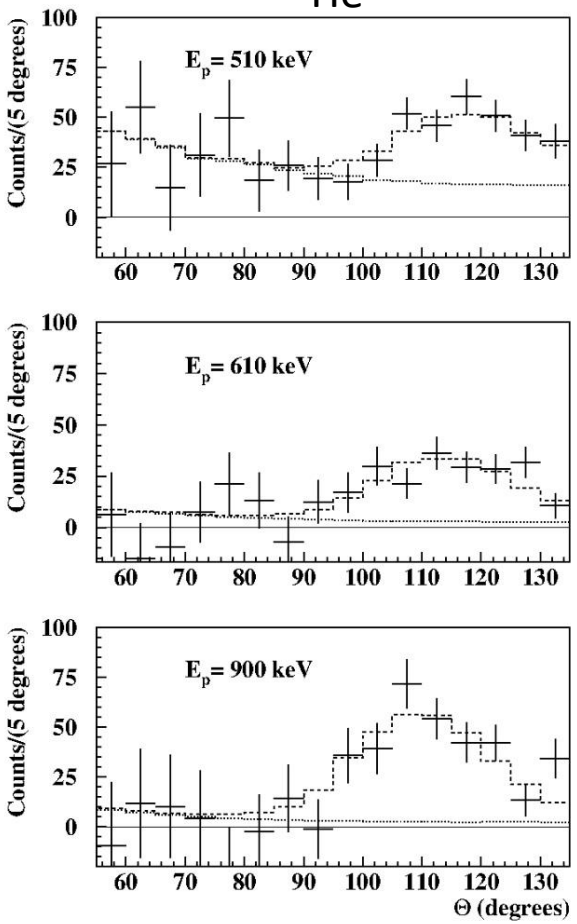
m_0c^2=16.7 ±0.35(stat)±0.5(syst.)

Branching ratio: 6×10^{-6}

Experimental results obtained at the Tandetron

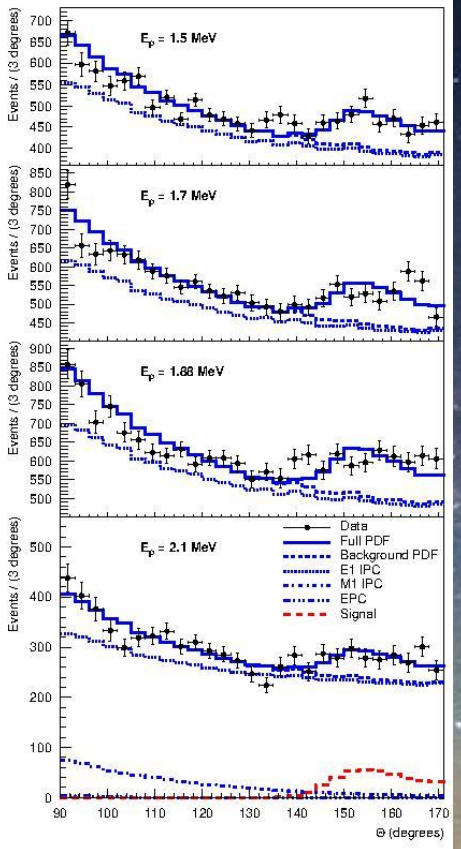


^{4}He



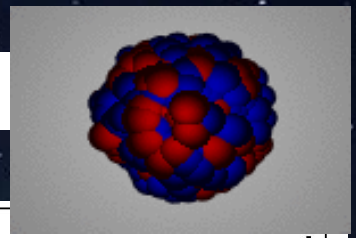
Phys. Rev. C 104, 044003 (2021)

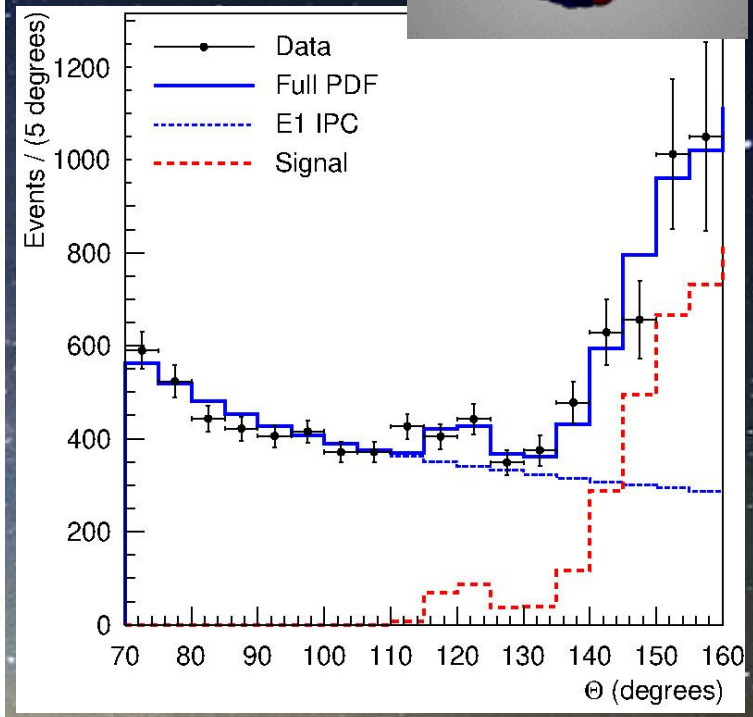
^{12}C



Phys. Rev. C 106, L061601 (2022)

^{8}Be, GDR

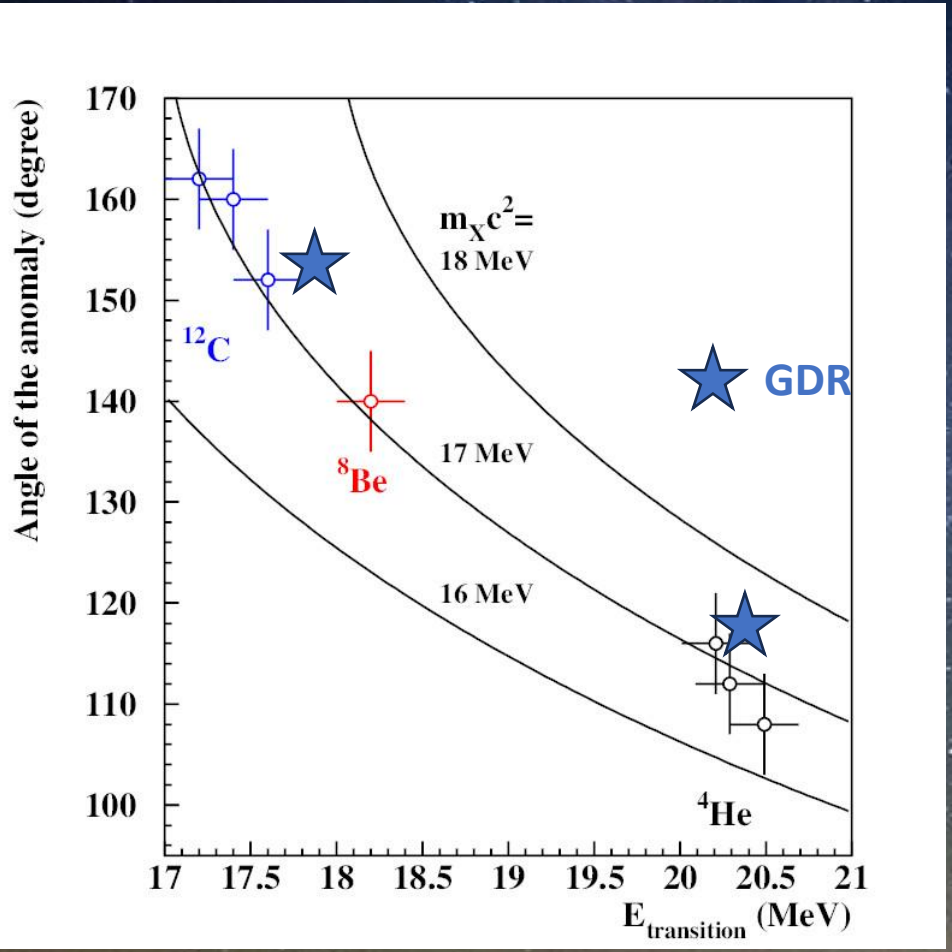




Universe 210 (11), 409, (2024)

6

Kinematical evidence for the X17 particle



A.J. Krasznahorkay et al. : An Update of the Hypothetical X17 Particle

Universe **2024**, *10*(11),409;
https://doi.org/10.3390/universe10110409
Nucl. Phys. News. 32, 10 (2022)
Frontiers of Fundamental Physics (FFP16), Conf. Proc. 2024

Future plans

1) What is the lifetime of X17?

2) Better precision for the mass of X17?

3) What is the spin and parity of X17?

Confirmation our results in Hanoi, Vietnam

The idea of the new e^+e^- spectrometer with only two arms

- Concentrate on the 140 degree region.
- Put the detectors closer to the target 30 mm than they were used in Debrecen (60 mm).
- We can have similar acceptance at 140 degree in this way for the two cases.

Experimental setup built at the Hanoi University of Science, Vietnam in collaboration with ATOMKI, Debrecen, Hungary

We used p-beam with different energies to bombard the Li-target to populate 18.15 and 17.6 MeV ^{8}Be excited states with resonant proton capture.

^{7}Li(p,e e)^{8}Be

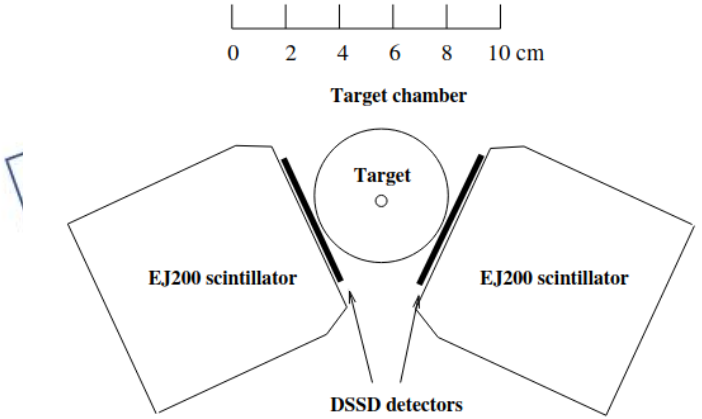
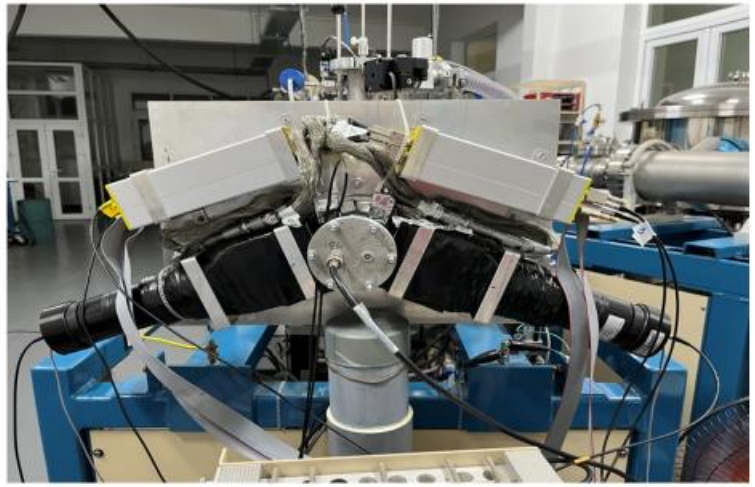


Figure 1. Schematic diagram of the $e^{+}e^{-}$ spectrometer focusing on the 140 degree region.

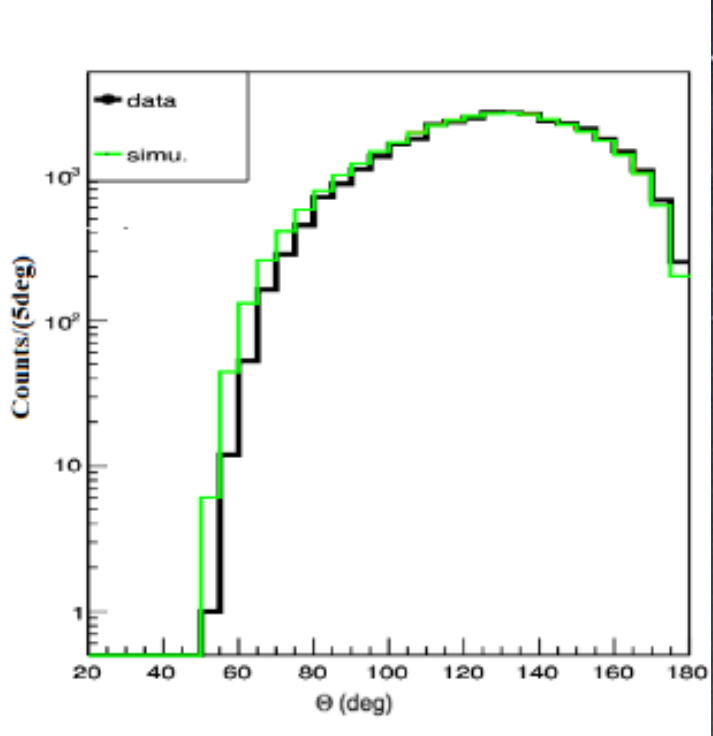
Detector setup to measure the energies and the angle between the e^{+} e^{-} particles.

Why did we arrange the Det-system like this?

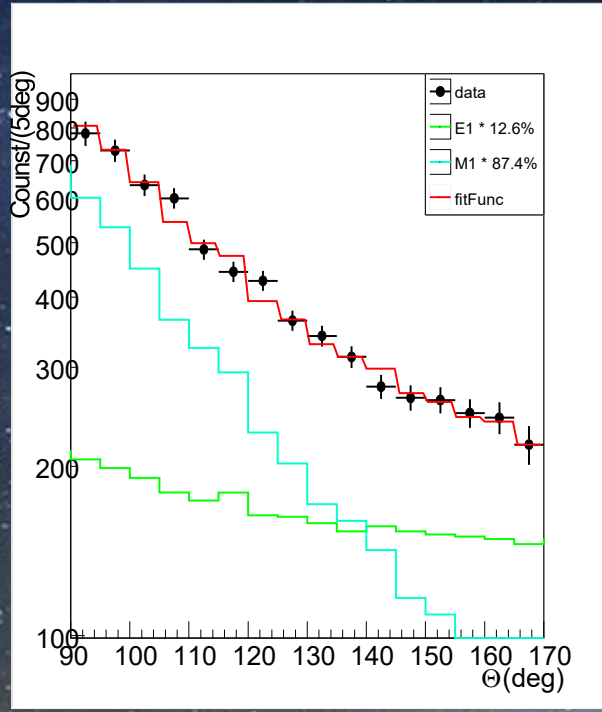


Picture in lab of the detector system and the DAQ connected to Pelletron

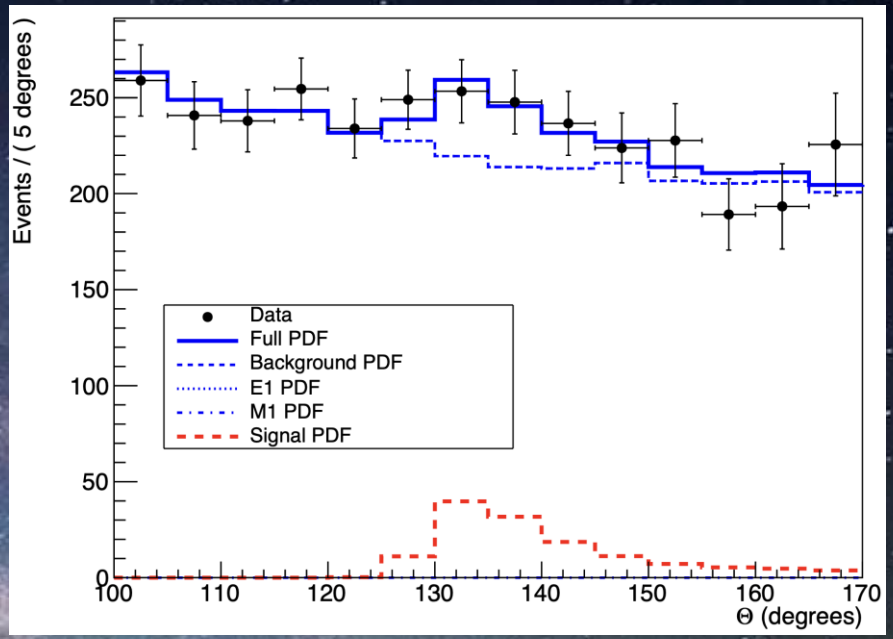
Aceptance corrected angular correlations



Experimental and simulated acceptances



E_p=441 keV
No anomaly

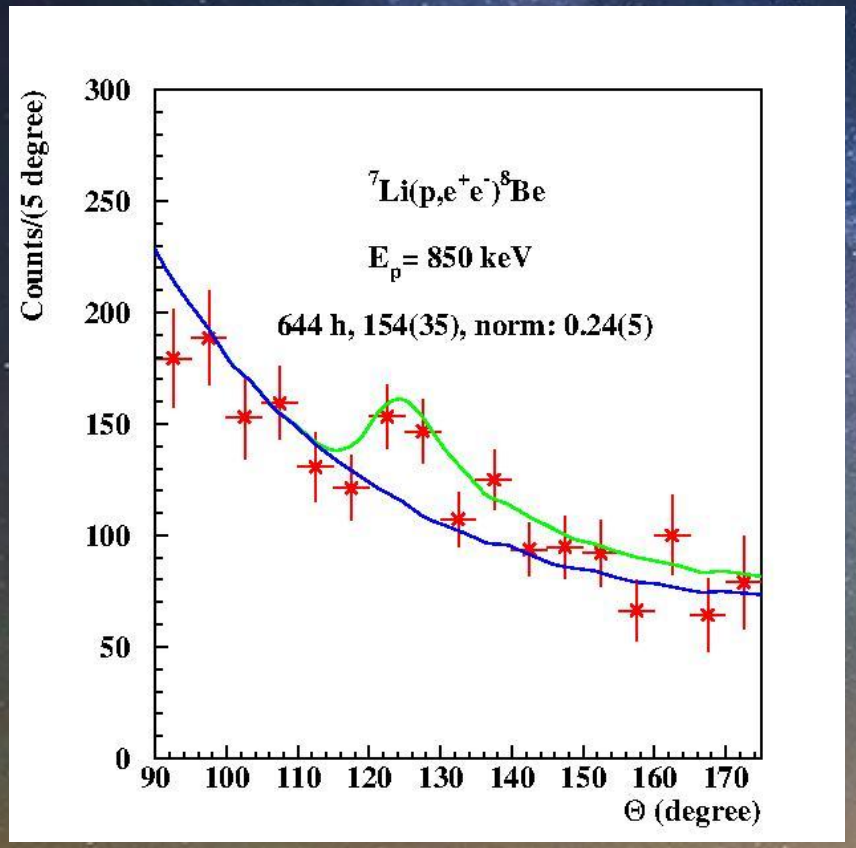


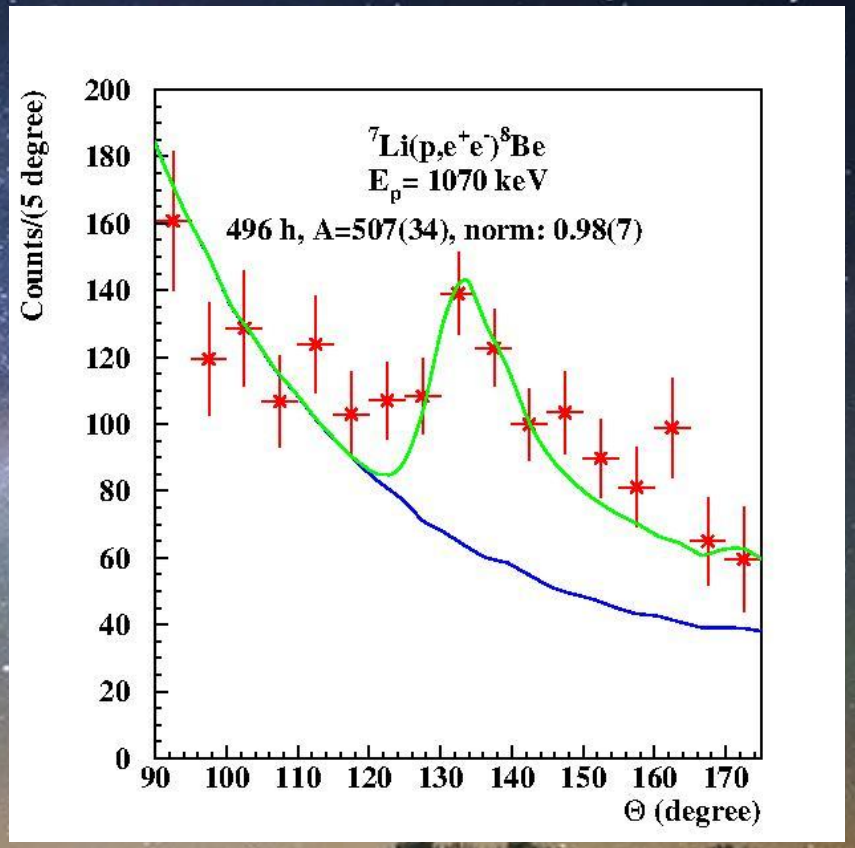
E_p=1.04 MeV. Background: M1+E1
The anomaly appears at angle around 140^o (*)

m_{boson}=16.7 ± 0.47 (MeV)
Significance: 4-5σ

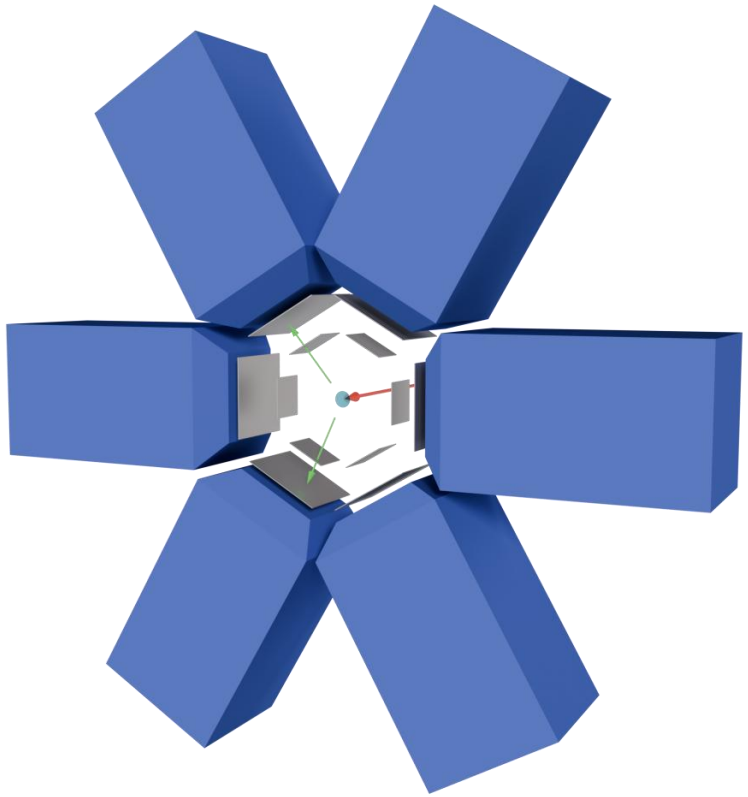
Tran The Anh et al., Universe 2024, 10(4) 168.

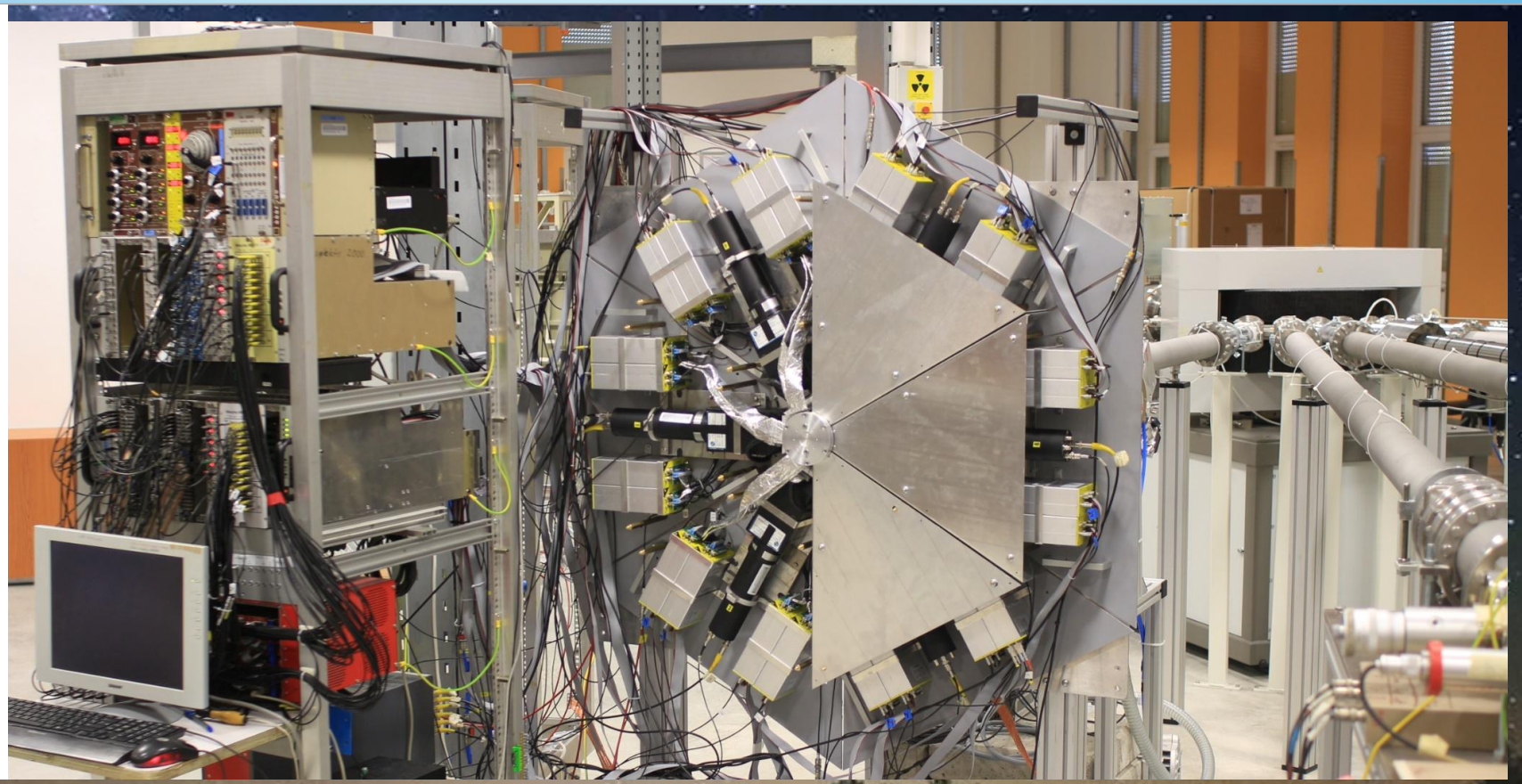
New results from Hanoi





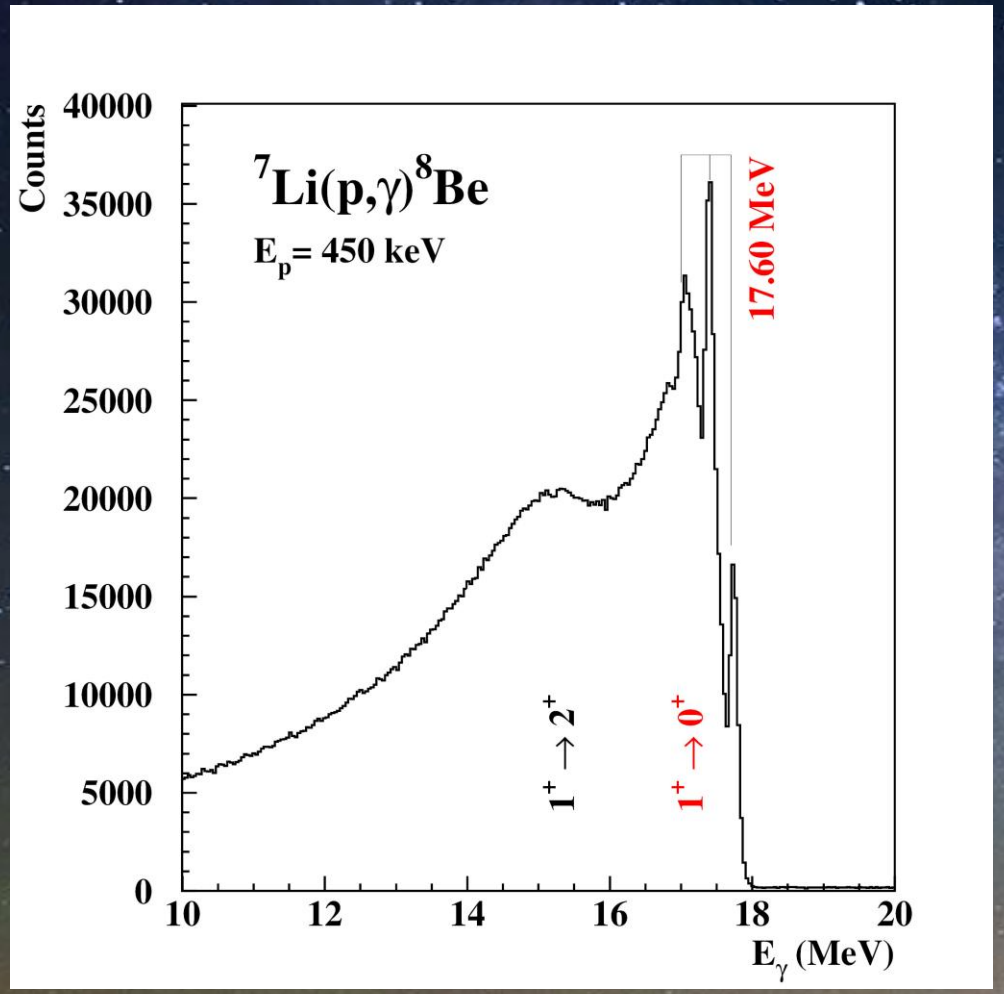
The newest version of our COmpact Positron Electron (COPE) spectrometer with two DSSD layers at each telescopes (NIM 1084, 171232 (2026))

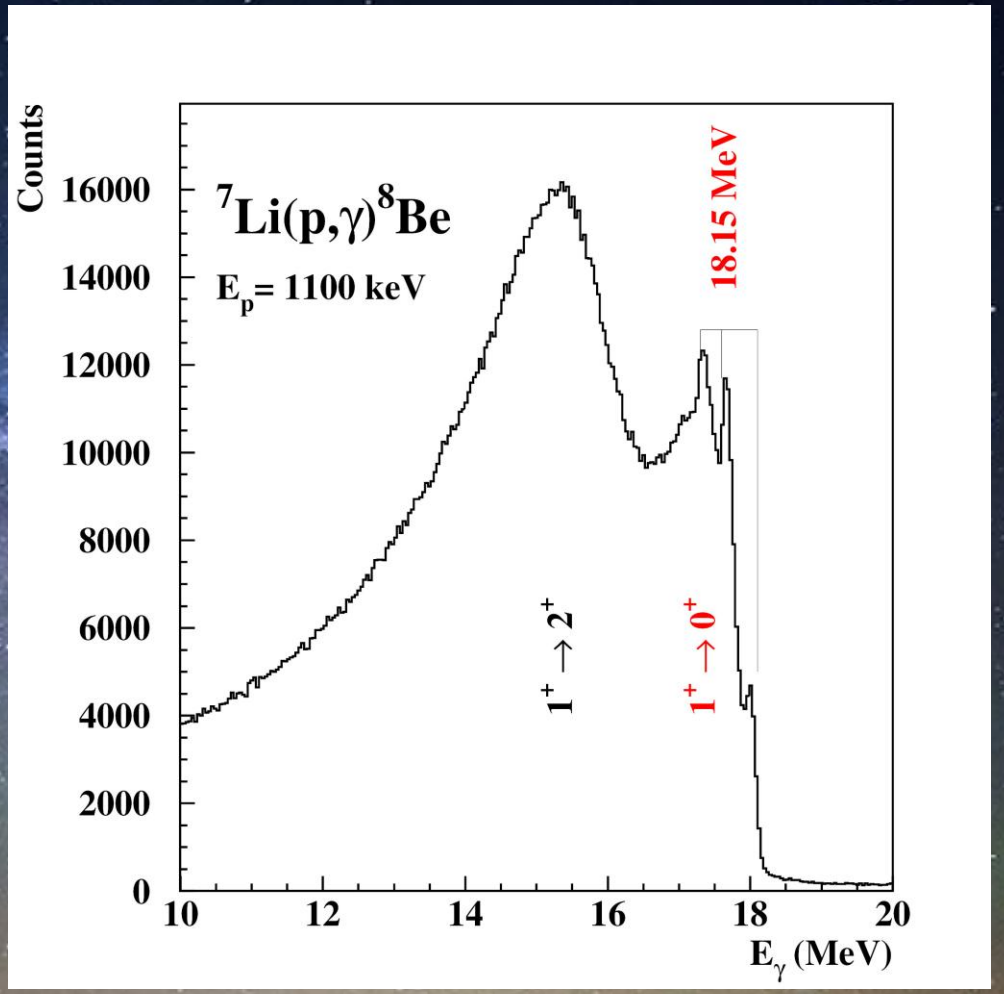




Using such a spectrometer we want to cope with the questions connected to the X17 particle

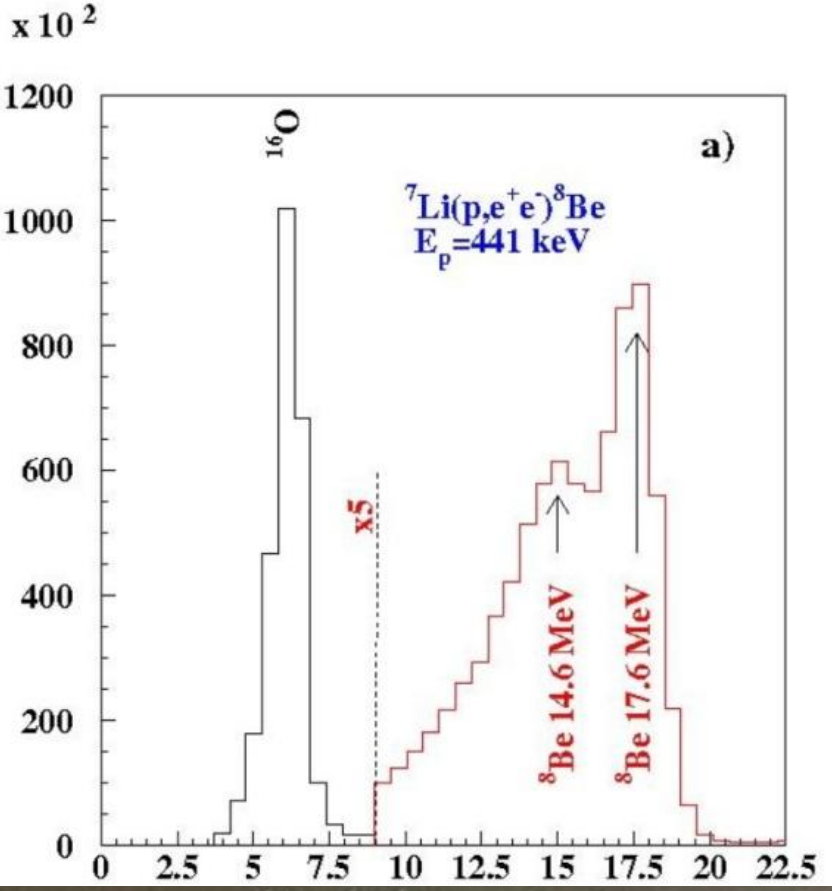
New experiments for ^{8}Be

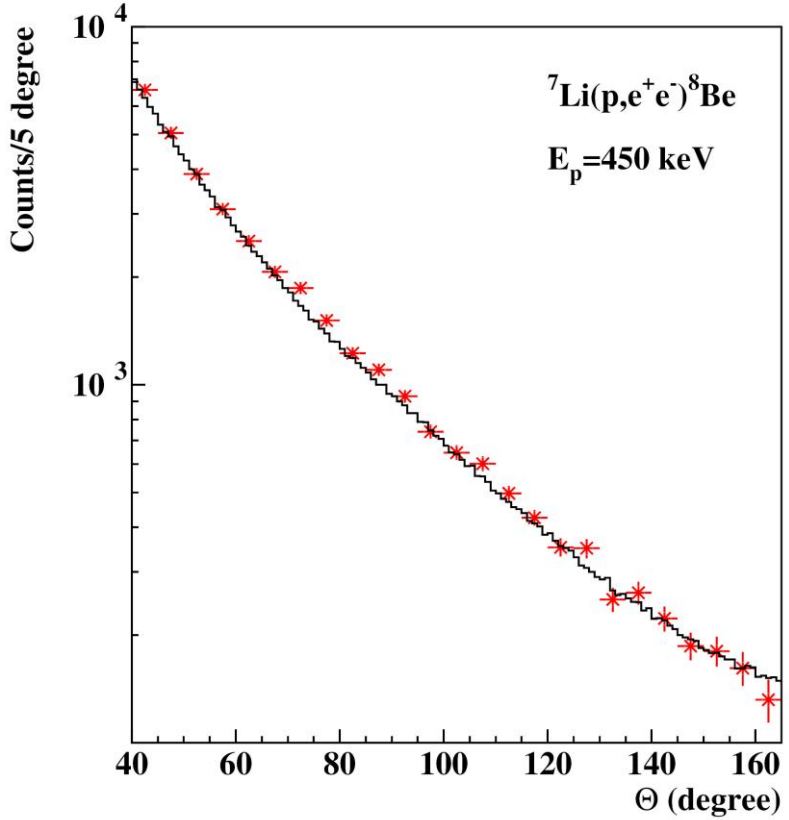


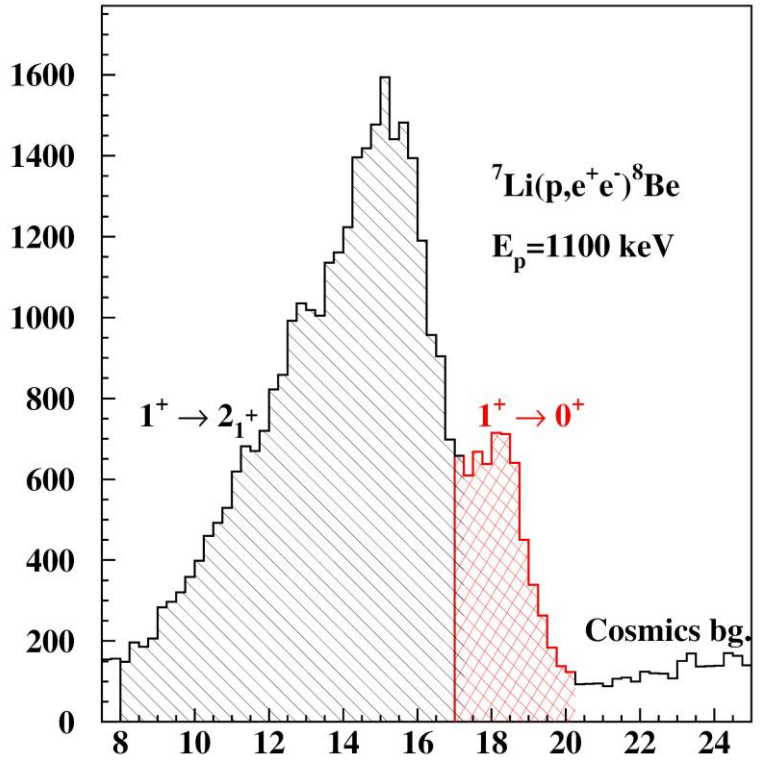


ɣ-ray spectra measured with 3”x3” $LaBr_3$ detectors for the two resonances in ^{8}Be

New results for ^{8}Be

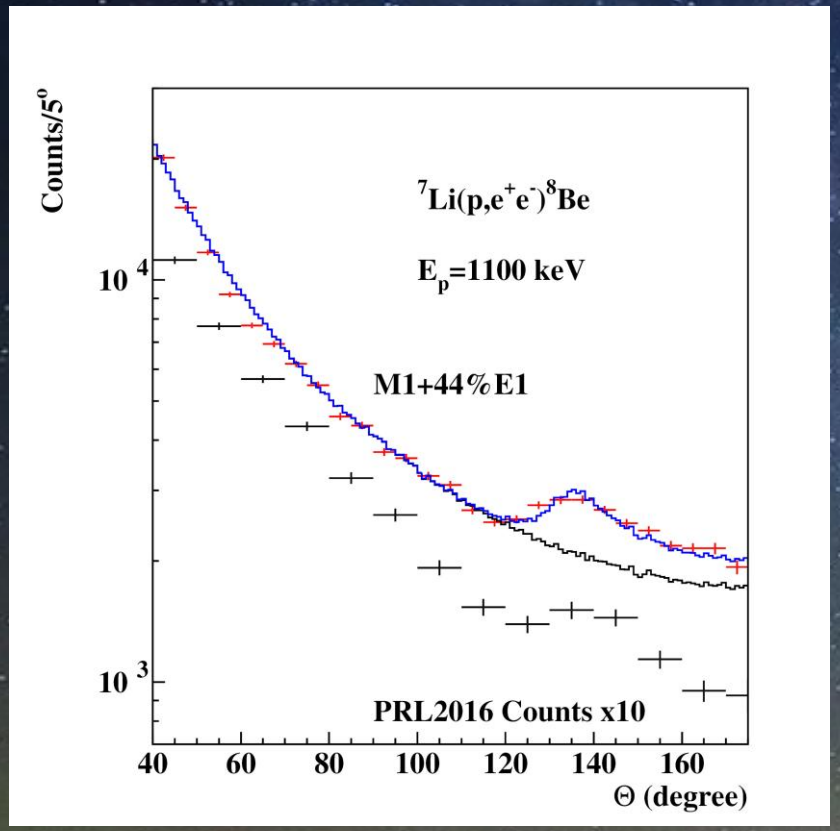


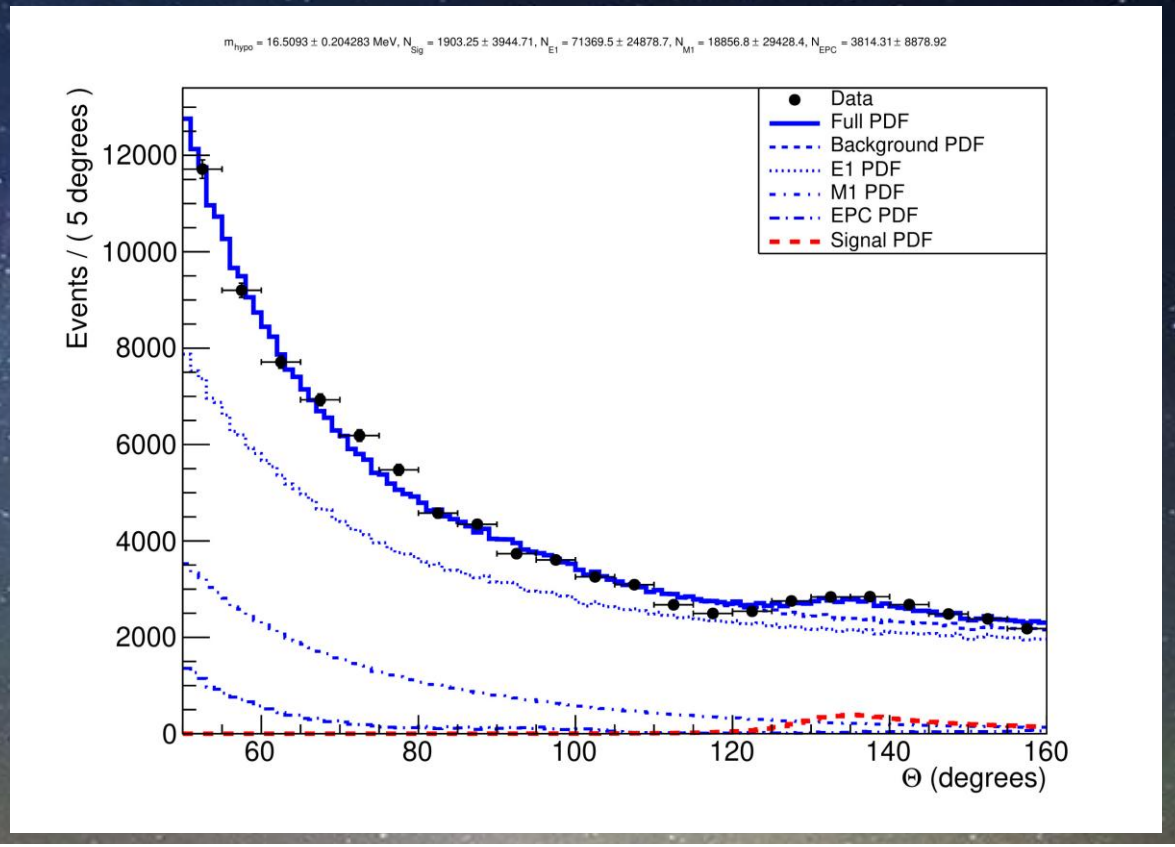




$e^{+}e^{-}$ sum spectra,and angular correlations measured for the two resonances in ^{8}Be

The anomaly in ^{8}Be was confirmed with 10 times better statistics





Angular correlation of the $e^{+}e^{-}$ pairs measured for the 18.15 MeV transition in ^{8}Be

$$m_0c^2=16.5\pm0.20(stat)\pm0.3(syst.)$$

Determination of the lifetime of the X17 particle (motivations)

For the E=18.15 MeV transition and m_x= 17 MeV/c^2 the Lorentz Factor is: $\gamma = E / m_X \approx 1.067$, so the velocity of the particle is: $\beta = \sqrt{(1 - \gamma^{-2})} \approx 0.35c$.

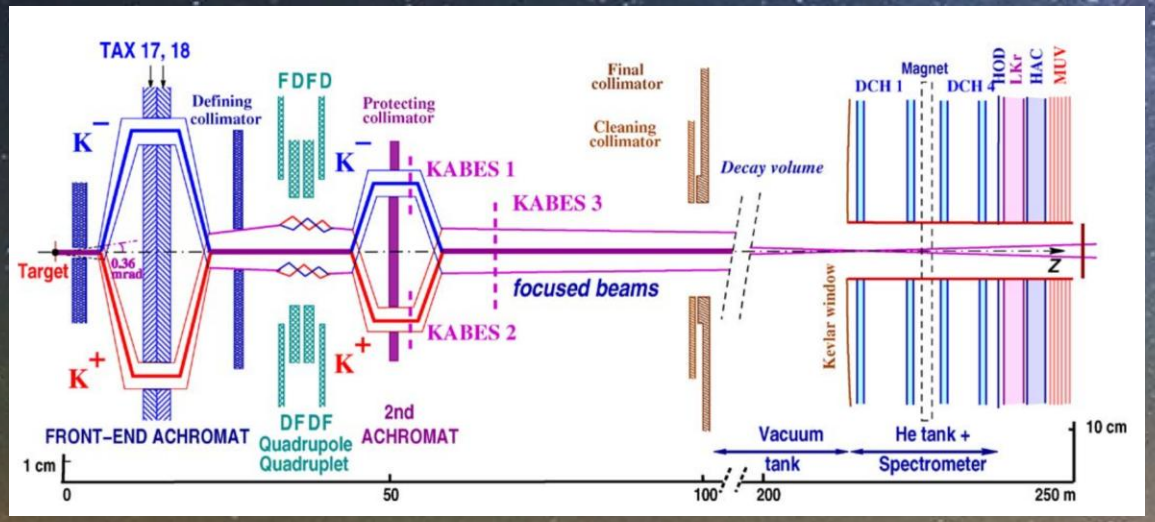
Assuming the particle has a laboratory decay length of $L_{lab} \approx 0.5$ cm (consistent with the ATOMKI vertex reconstruction), the proper rest-frame decay length ($c\tau$) is: $c\tau = L_{lab} / (\beta\gamma) \approx 0.5 \text{ cm} / (0.35 \times 1.067) \approx 1.35$ cm, and τ= 45 ps.

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

This decay occurs cleanly within the prompt, wide-angle tracking acceptance of the ATOMKI spectrometer, allowing for clear pair resolution, detected and the Θ measurements are not distorted.

Excluded regions for pseudoscalar bosons

E141 experiment,
E. M. Riordan et al.,
Phys. Rev. Lett. 59, 755 (1987).



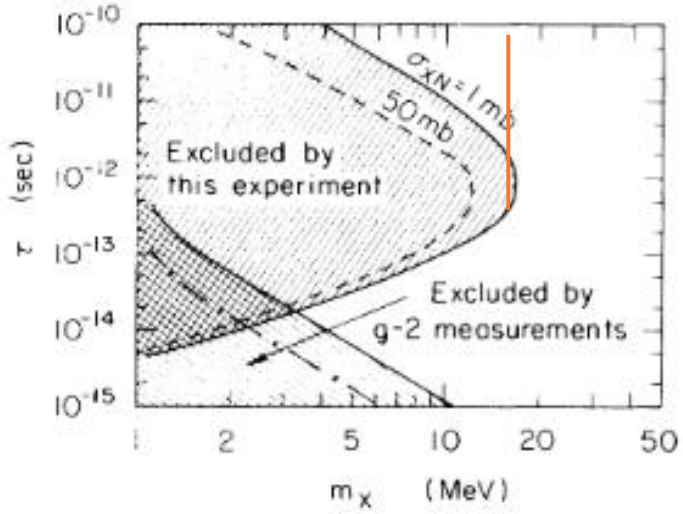
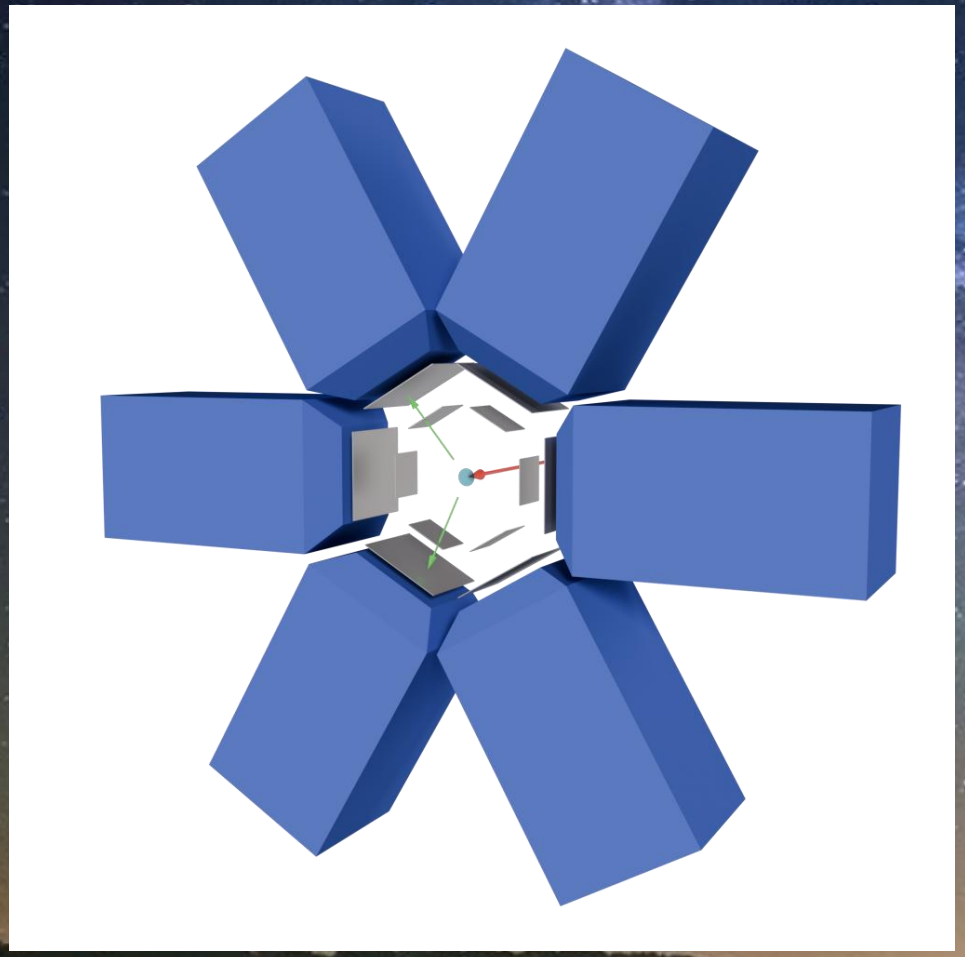
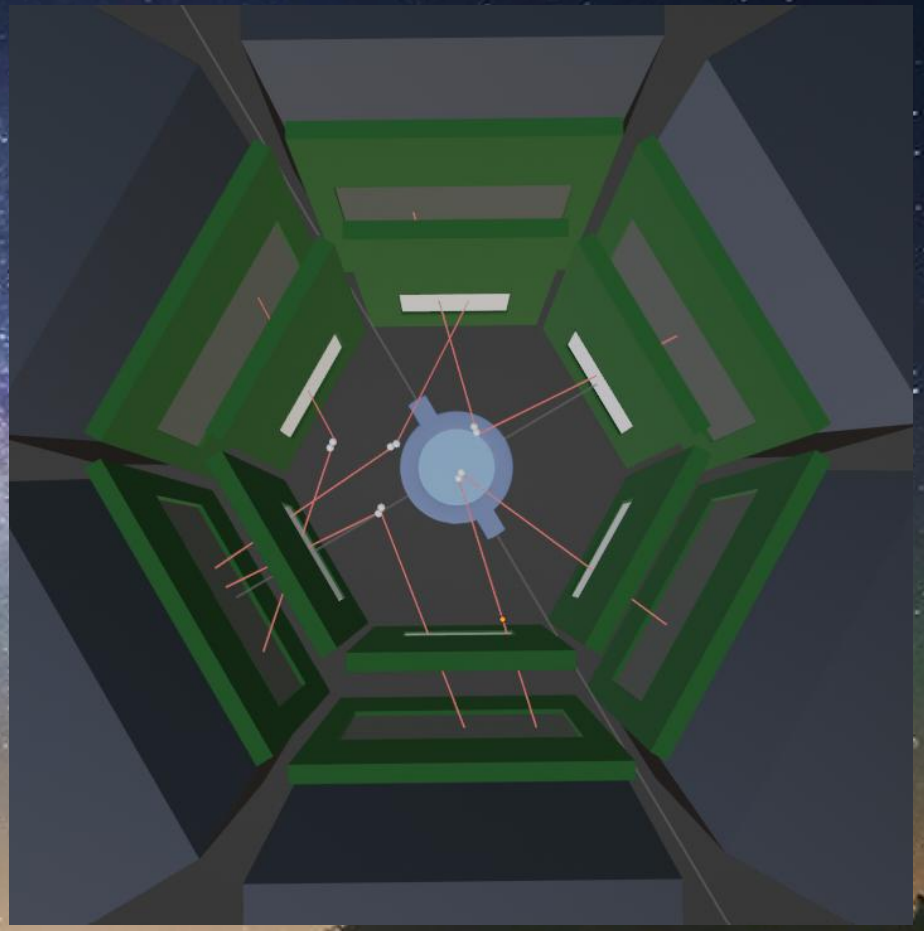


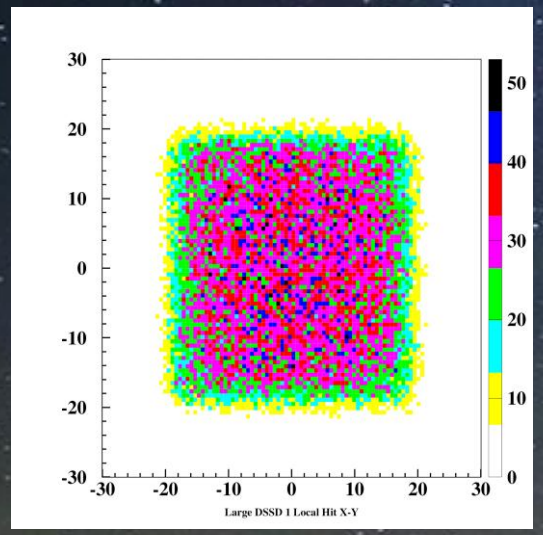
FIG. 2. Regions of m_X and τ, for a light pseudoscalar boson X^0 decaying predominantly to e^+e^-, that are excluded by this experiment, assuming an absorption cross section of $\sigma_{XN} = 1$ and 50 mb per nucleon. Also shown are regions excluded by electron $g-2$ measurements by use of two assumptions (see Refs. 14 and 15) for the possible discrepancy between theory and experiment.

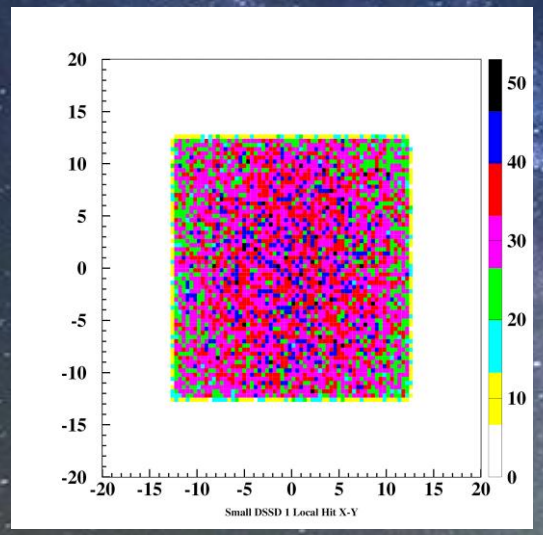
The idea of the experiment, determination of the vertex distributions

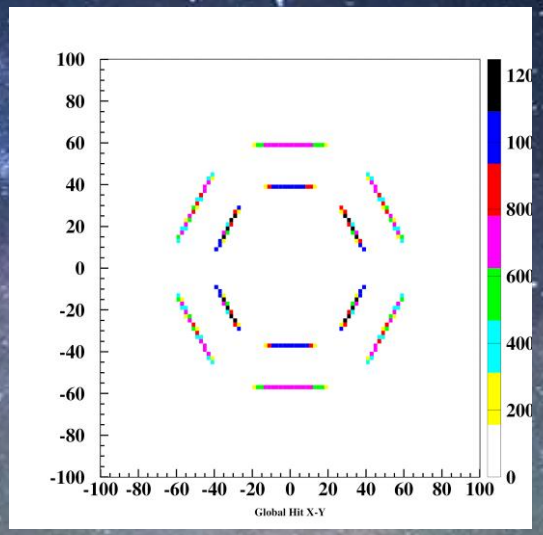


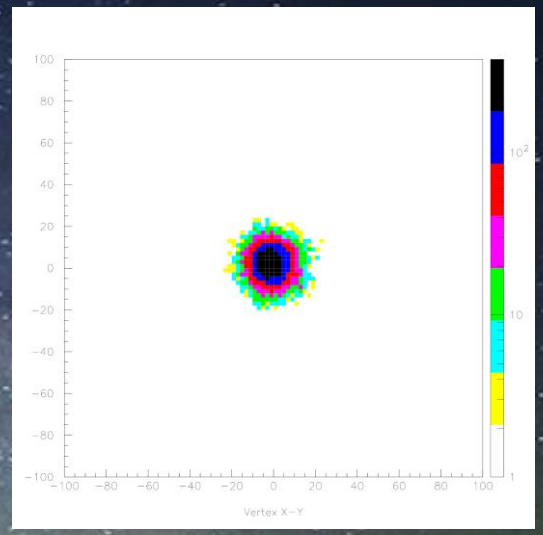


Local and global hit distributions

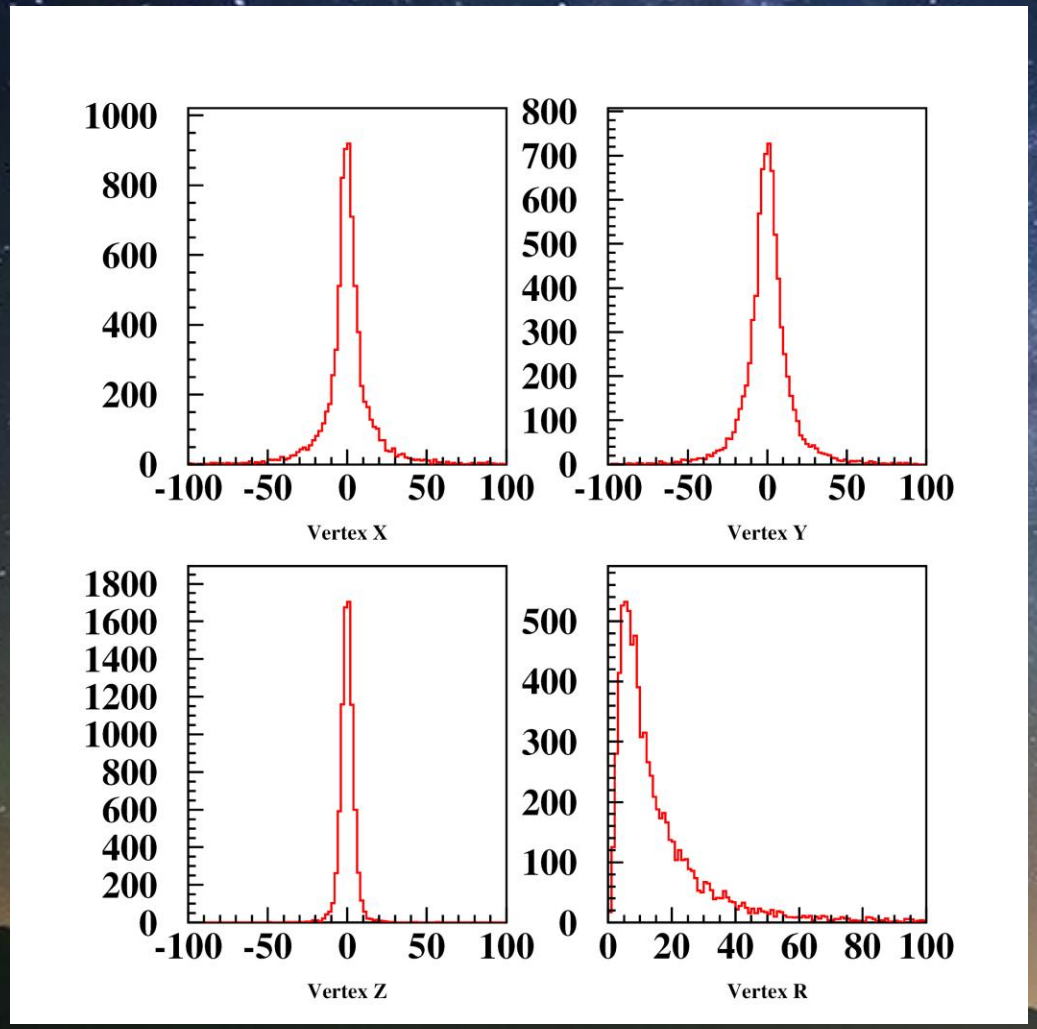


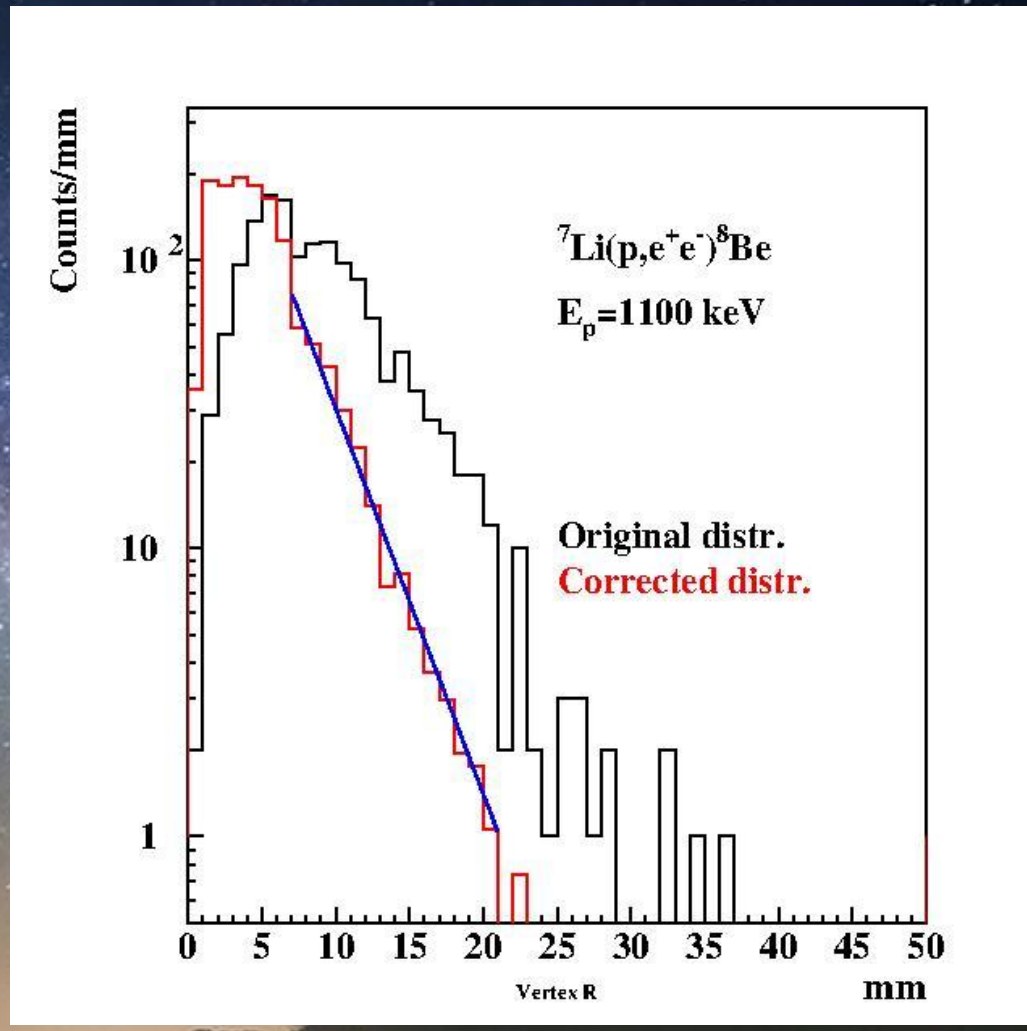






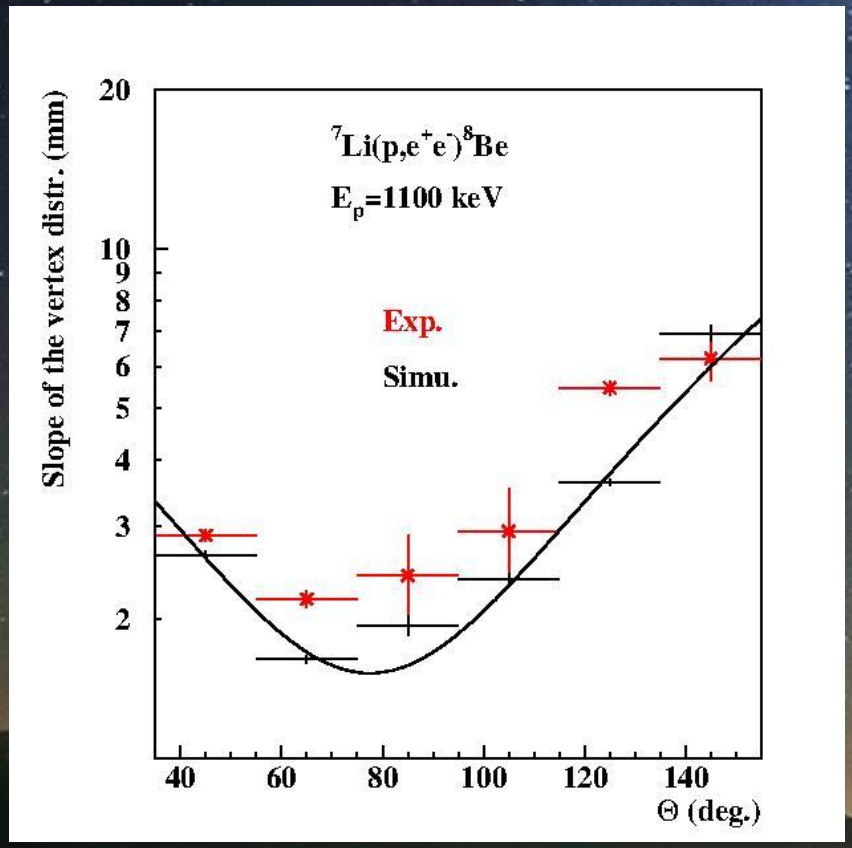
Correction of the R distribution by $1/R^2\pi$ (phase space) to get the real distributions.





Determination of the lifetime of the X17 particle

$$(f * g)(n) = \sum_{k \in D} f(k) g(n - k)$$



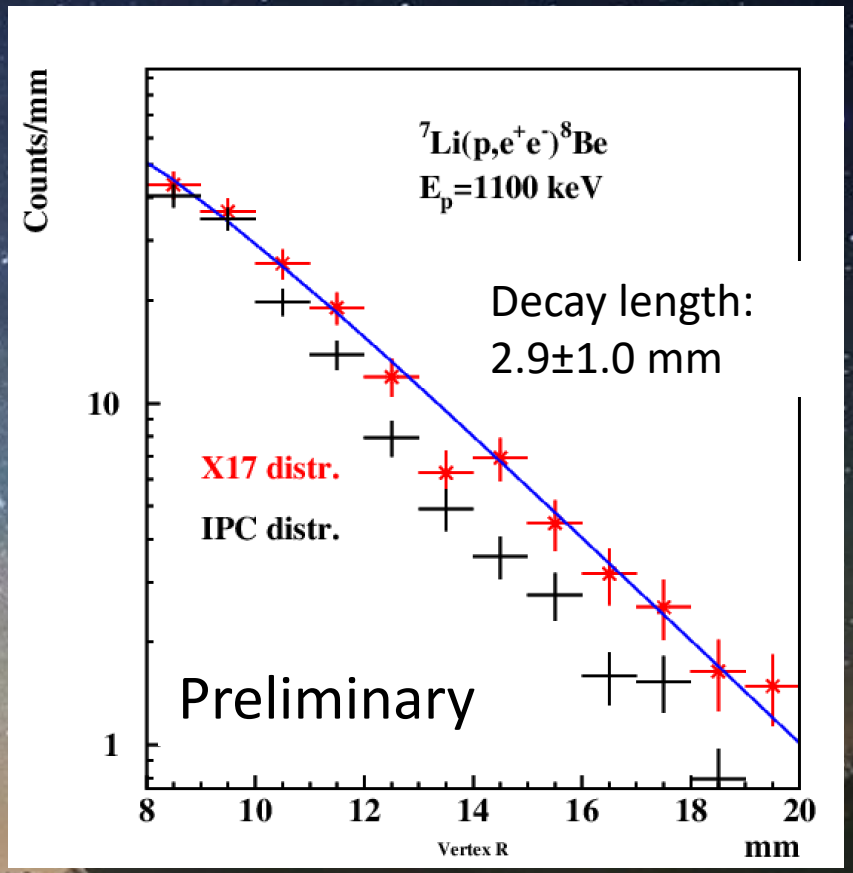
Lorentz Factor:
$\gamma = E / m_X \approx 1.067$

Velocity:
$\beta = \sqrt{(1 - \gamma^{-2})} \approx 0.35$

$c\tau = L_{lab} / (\beta\gamma) = 2.9 \text{ mm} / (\beta\gamma) = 7.8 \text{ mm}$

$\tau = 26 \pm 9$ ps

$\epsilon = (2.5 \pm 0.8) * 10^{-5}$



D. Banerjee et al., (NA64) PRL 120, 231802 (2018); PRD 071101(R) (2020)

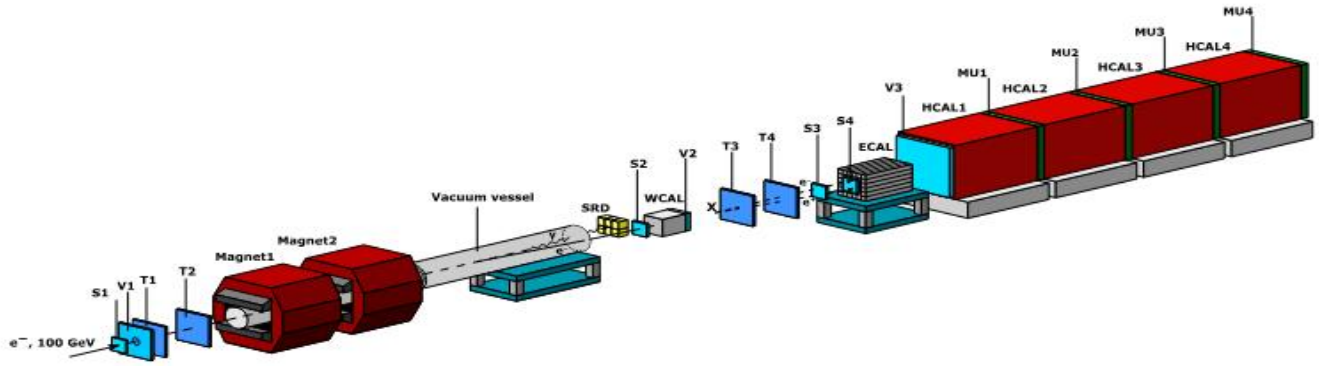


FIG. 1. Schematic illustration of the NA64 setup to search for the A', $X \to e^+e^-$ decays.

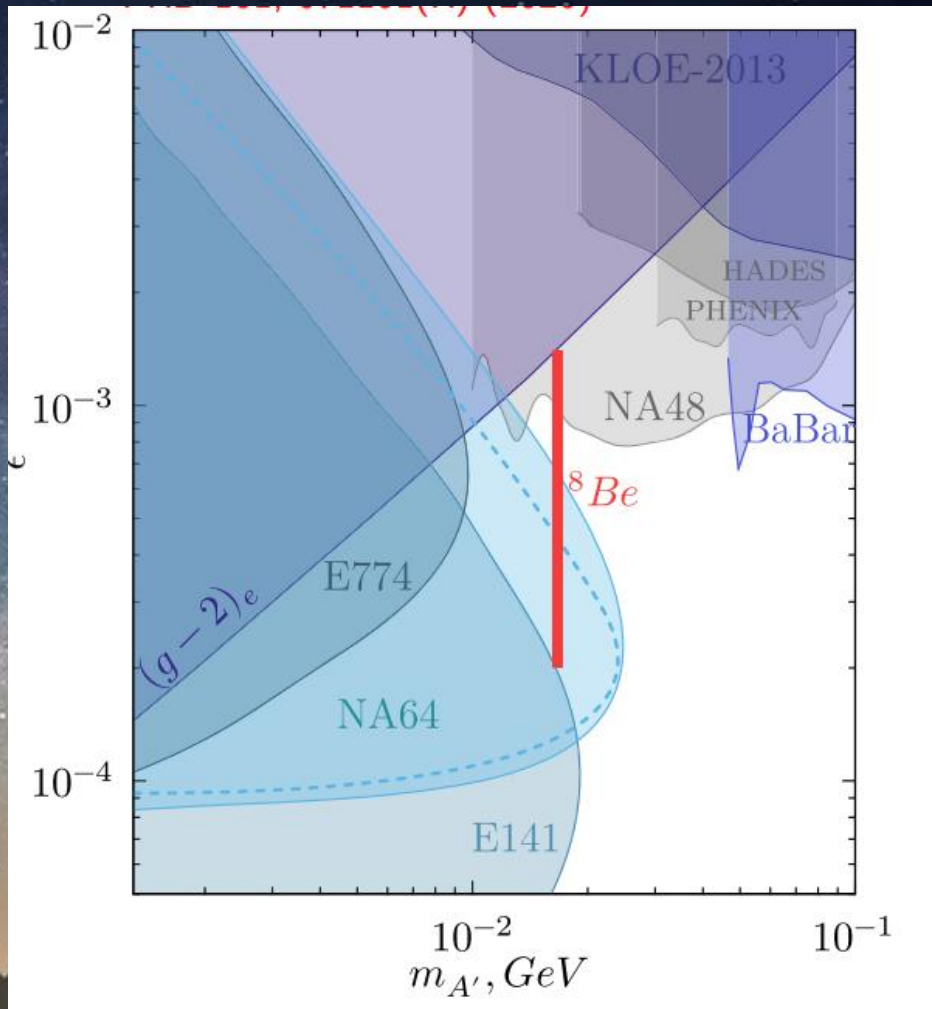
NA64 at CERN attempt to produce dark sector particles via bremsstrahlung-like processes using highly relativistic electron beams (e.g., 50 GeV).

If a 17 MeV particle is produced in a 50 GeV collision, it inherits a massive forward momentum. The kinematics change drastically:

Lorentz Factor: γ = E / m_X = 50,000 MeV / 17 MeV ≈ 2941

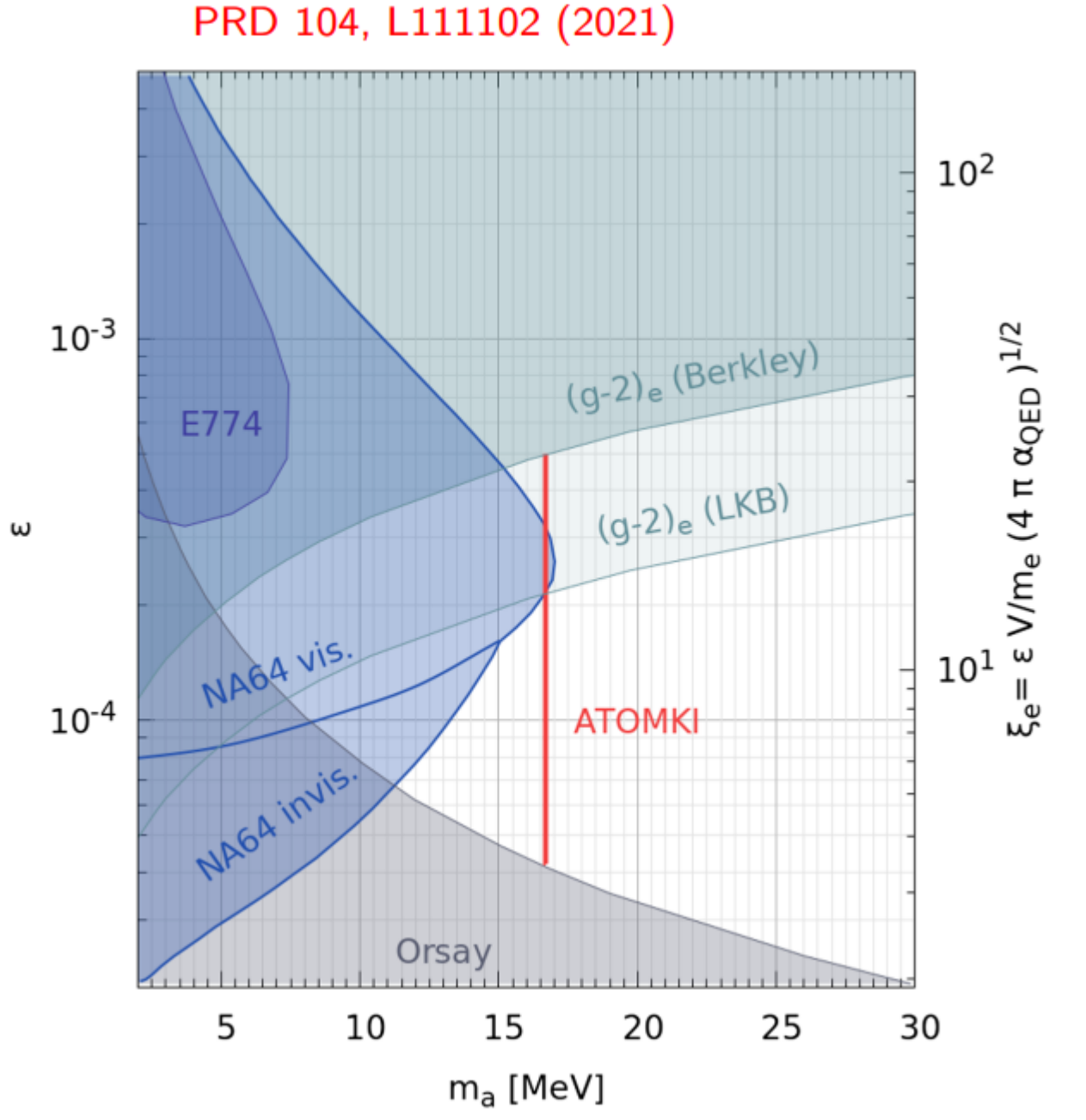
Velocity: β ≈ 1.0

Laboratory Decay Length: L_lab = γ(cτ) ≈ 2941 × 0.29 cm ≈ 8.5 **meters**.



NA64 conclusion

- Due to extreme time dilation, the vast majority of X17 particles produced in the WCAL target will physically outrun the fiducial decay volume of the detectors. They will decay deep inside the hadronic calorimeters rendering them geometrically invisible to the tracking layers.



Future plans 2: determination of the mass of the X17 particle more precisely

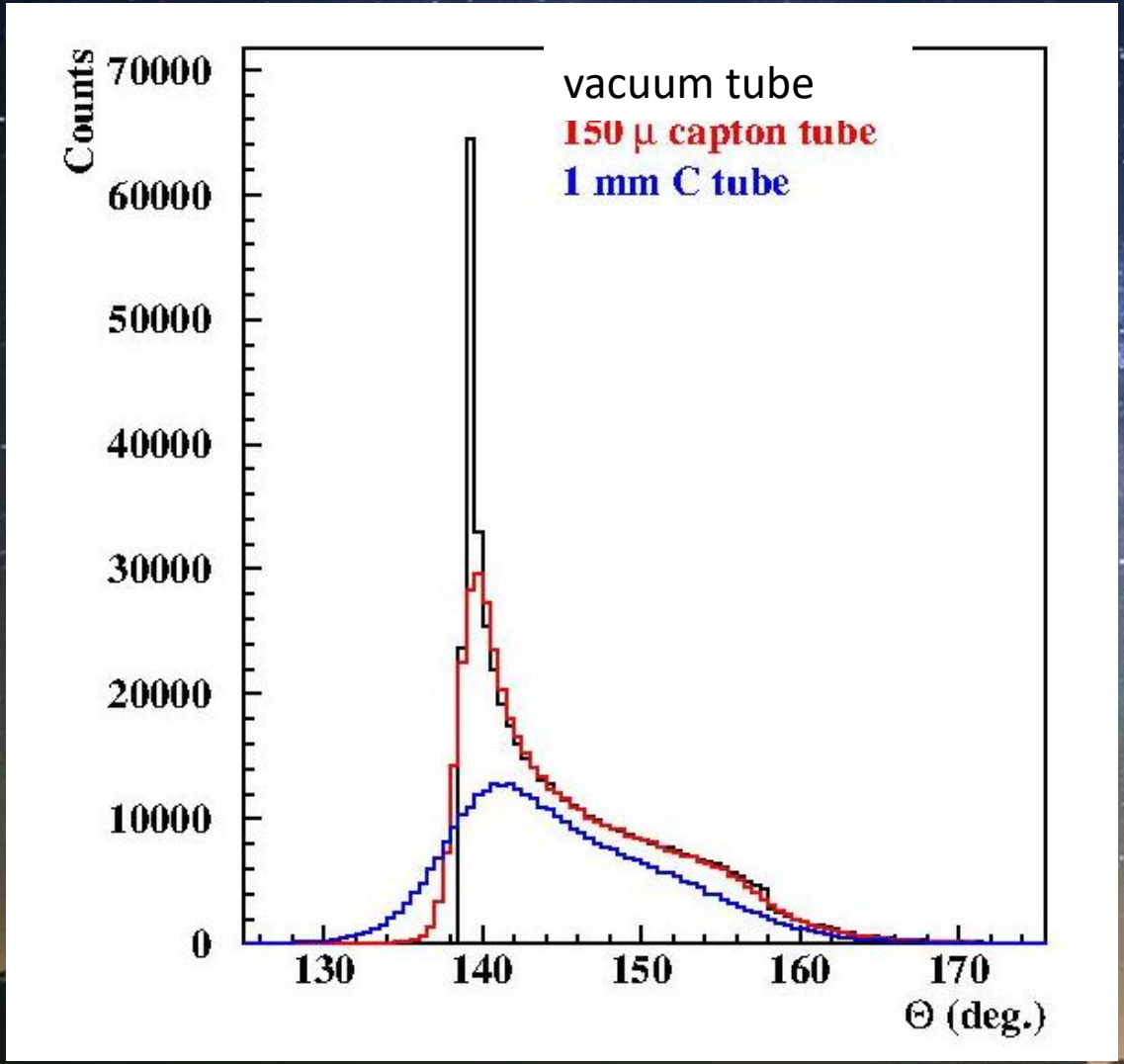
The invariant mass of the particle can be determined from the data we measure using the following expression:

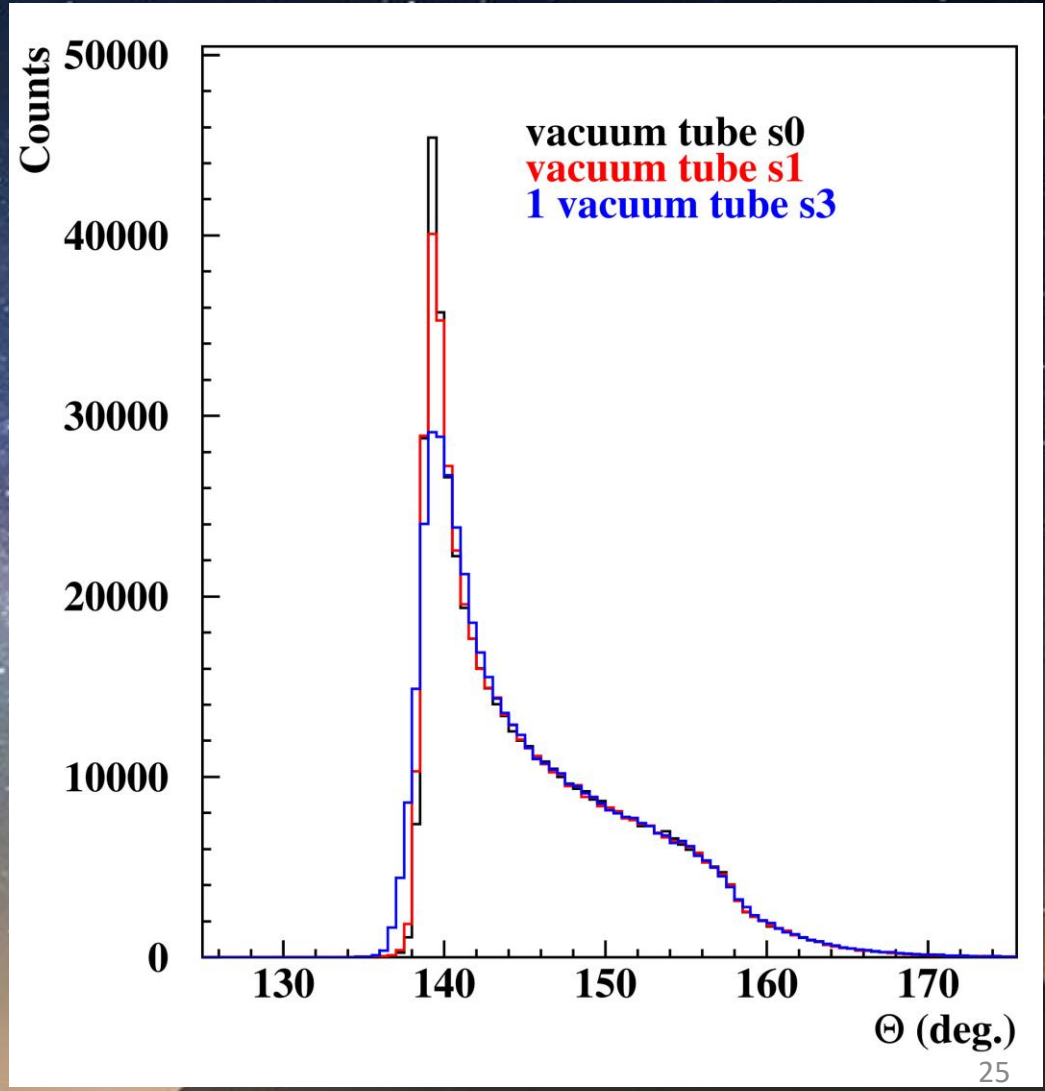
$$mc^2=\sqrt{(1-y^2)}E\sin(\Theta/2)$$

$$y=\frac{E_+-E_-}{E_++E_-}$$

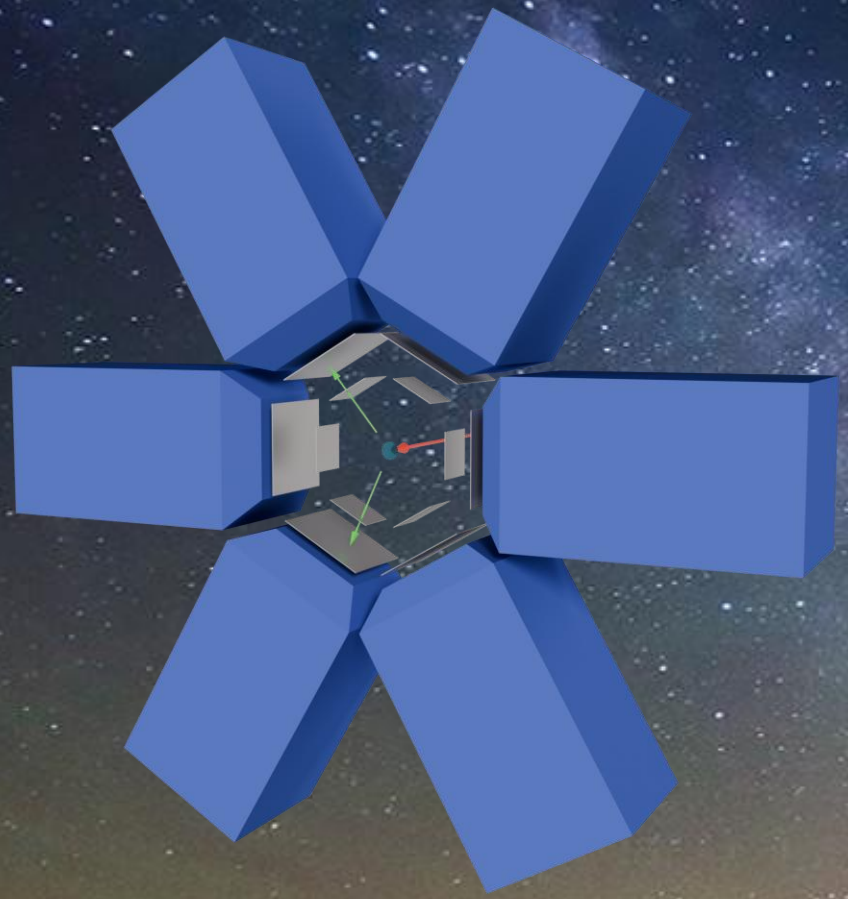
Since the sum of the kinetic energies (E), in our case the energy of the nuclear transition, is precisely known, the accuracy of the mass determination primarily depends on the accuracy of the angle measurement. Using state-of-the-art Double-sided Silicon Strip Detectors (DSSDs), allowing us to better track the particles and to increase the angular resolution of the spectrometer.

From bump to saw-tooth





Future plans 3: Measuring the angular momentum of the ejected X17 particle



The X17 can be emitted with L=0, L=1 …

We need a new spectrometer with larger angular coverage to measure the angular distribution of the X17 particle and determine the L value.

We are planning to buy longer DSSD detectors (along the beam axis) and use more plastic scintillators.

To ^{8}Be continued...

Thank you very much for your attention!

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