A new elementary particle is being born

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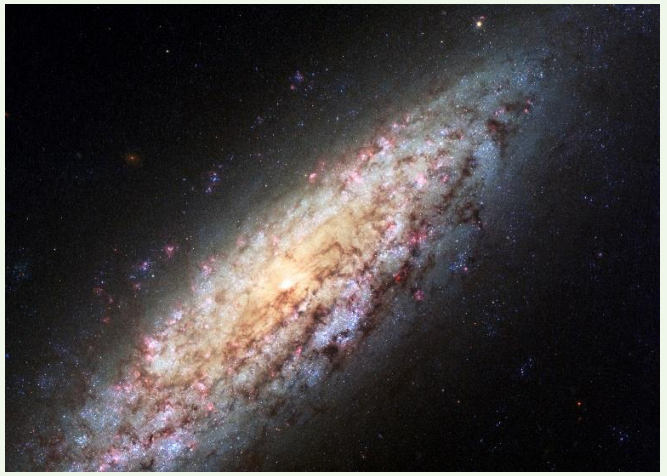
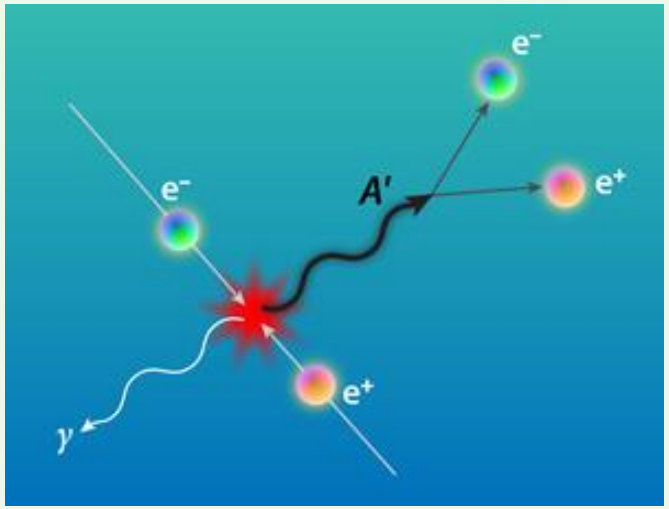
Searching for Dark Matter



- Should not have to defend this too much…

Searching already for more than 30 years, with tremendous strength, but didn't find anything significant so far …
They were searching for heavy particles, WIMP's heavier than protons. Could that be the problem?

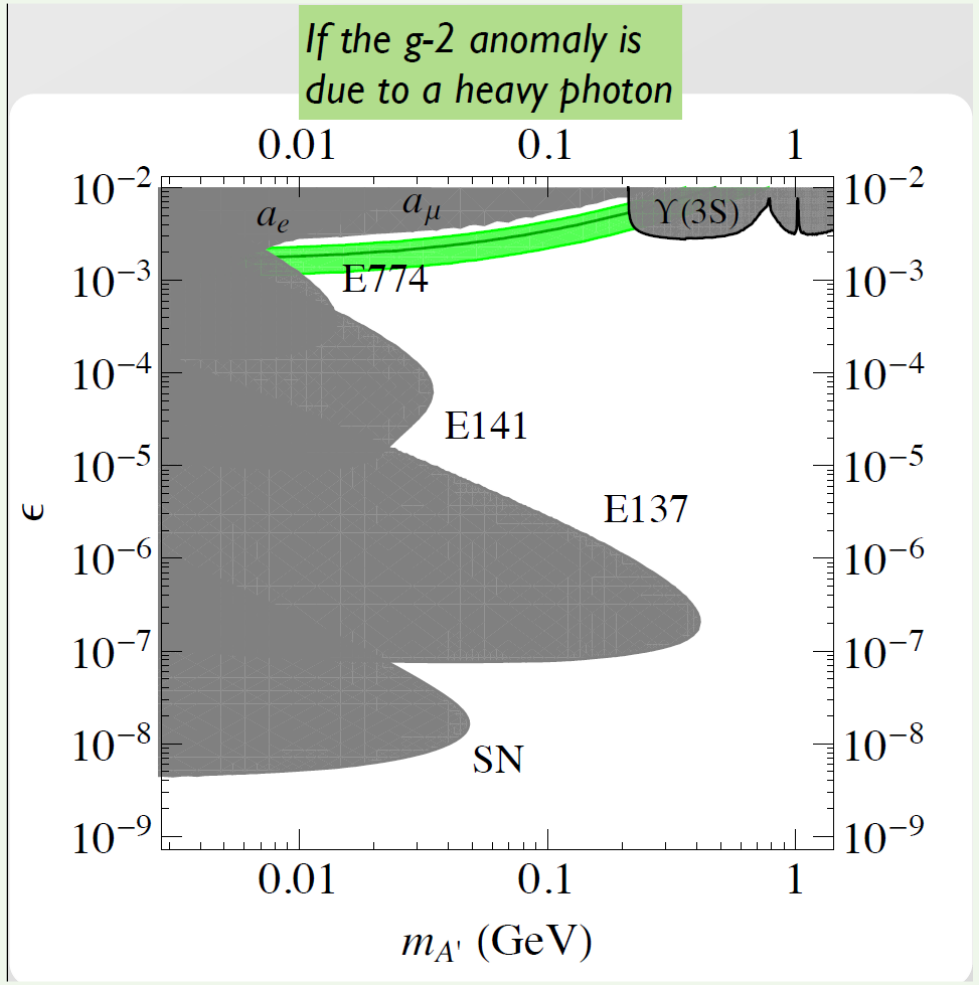


Light, Weakly Interacting DM, the dark photon concept

It is speculated that within dark matter there might be a family of particles and forces—a so-called "dark sector"—that has thus far escaped detection. In analogy with electromagnetism, for which the massless photon is the force carrier between charged particles, there could be a dark electromagnetism with a possibly massive dark photon that transmits the forces between dark particles

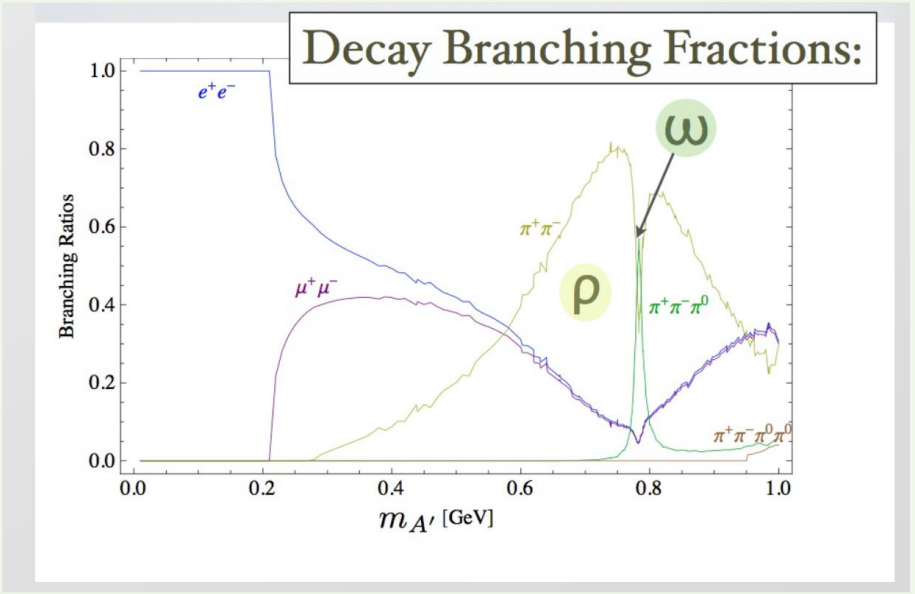
M. Pospelov and A. Ritz, "Astrophysical Signatures of Secluded Dark Matter," Phys. Lett. B **671**, 391 (2009)

Theoretical predictions for the dark photon



Allowed (green) and excluded (black) regions for the dark photon

Branching ratio



Lifetime

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

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

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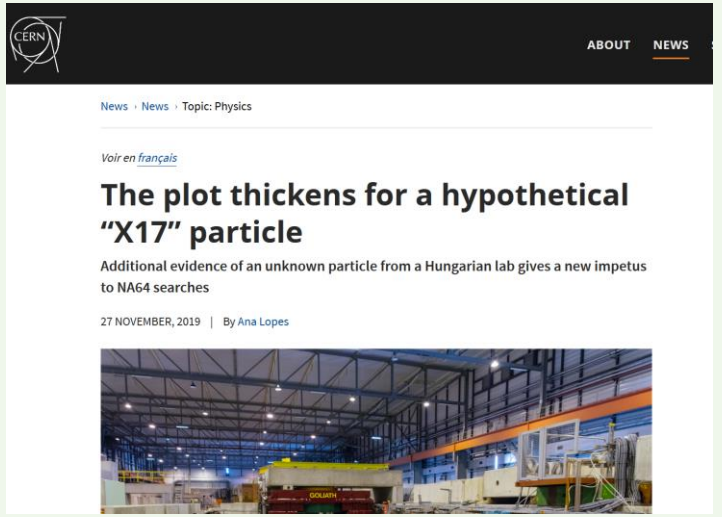
(Received 7 April 2015; published 26 January 2016)

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.



(J. Feng et al. PRL 117, 071803, (2016))

The ATOMKI anomaly → signals for a new 17 MeV/c^2 boson → gauge boson of a new fundamental force of nature → connection with light dark matter (Jonathan Feng)

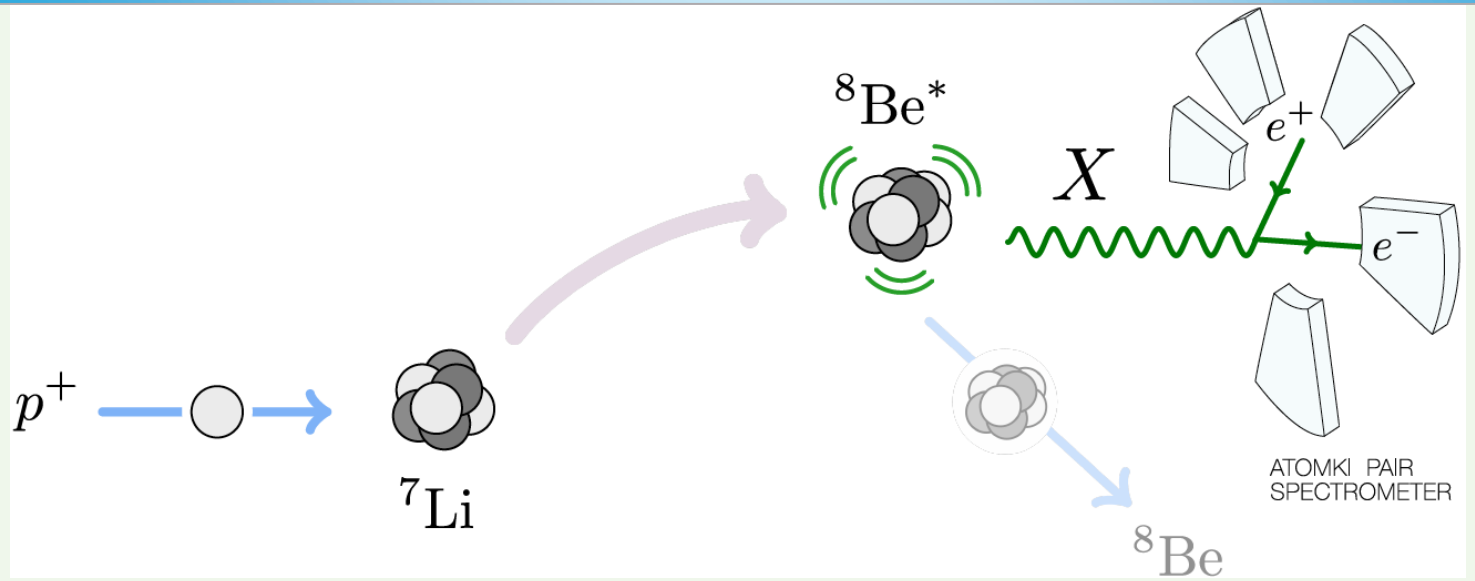
Our experimental results support the existence of the X17 particle

Layout of my talk

1. ^{8}Be (PRL 116, 042501 (2016))
2. γγ-decay of X(17) in ^{4}He (Nuovo Cimento, 42 : 2-3 124 , (2019))
3. ^{4}He (PRC 104, 044003 (2021))
4. off resonance region of ^{8}Be (arXiv: 2205.07744)
5. ^{12}C (preliminary, not published yet)

Creation and decay of ^{8}Be*

^{8}Be

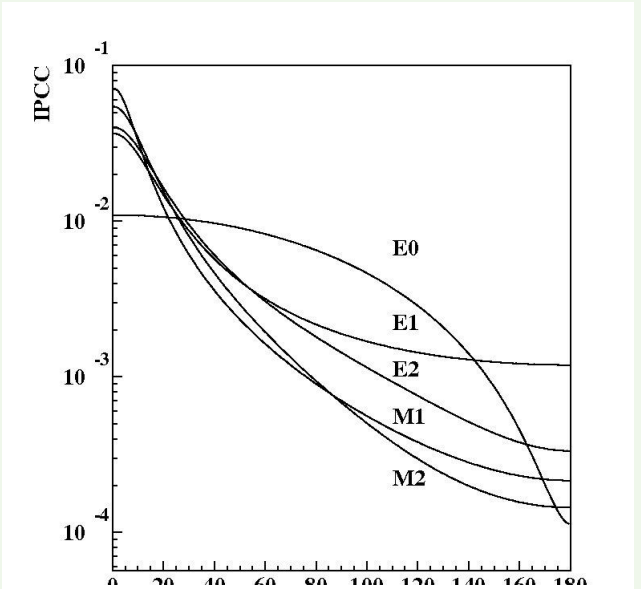


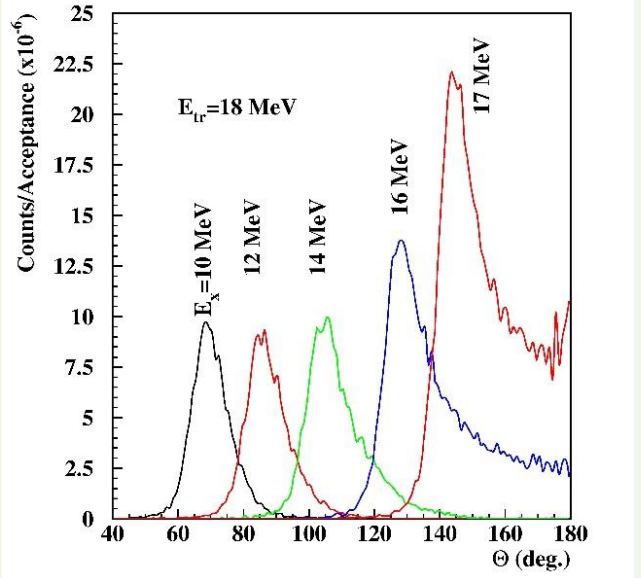
- Decay with 2α emission: ≈ 100%
- With γ-radiation: B(^{8}Be + γ) ≈ 1.5 x 10^{-5}
- With internal pair creation: B(^{8}Be + e^+ e^-) ≈ 5.5 x 10^{-8}

→ Smooth, gradually decreasing angular correlation

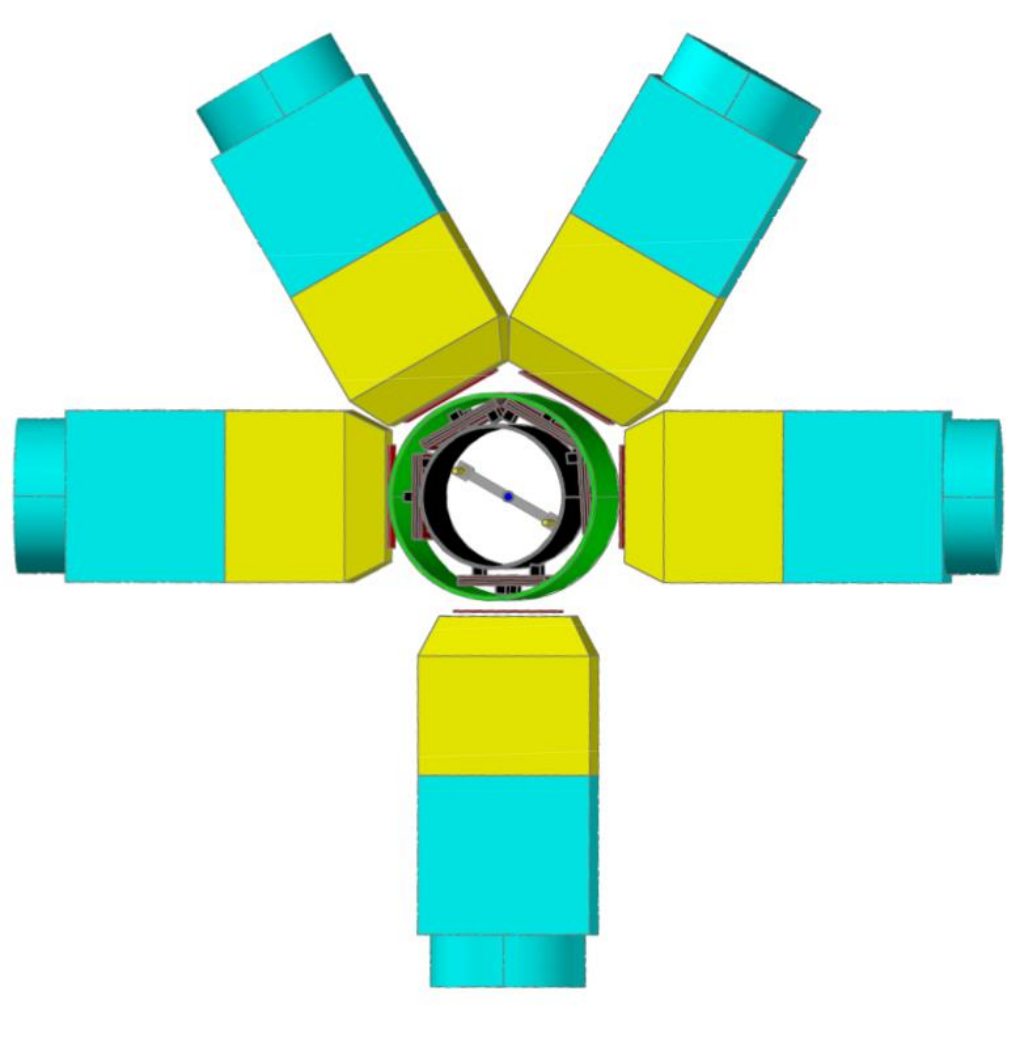
- Creating a dark photon: B(^{8}Be + X) ≈ 5.5 x 10^{-10}

→finding a peak on the curve

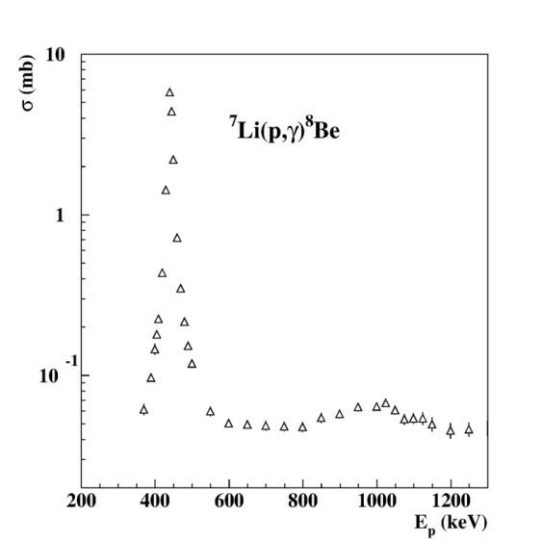


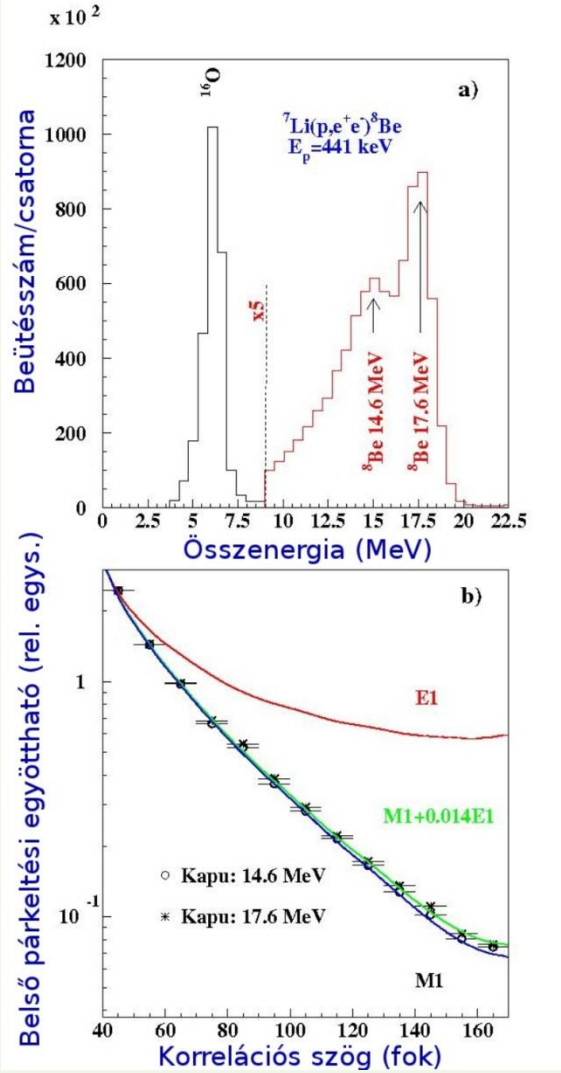


Geometrical arrangement of the scintillator telescopes (NIM, A808 (2016) 21)

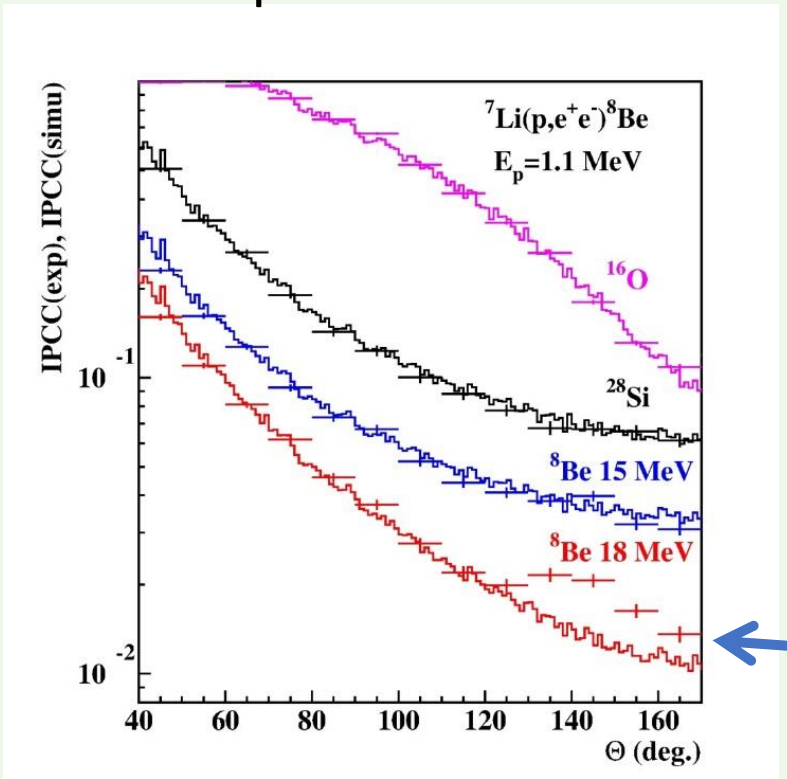


Results: e^+ - e^- sum energy spectra and angular correlations



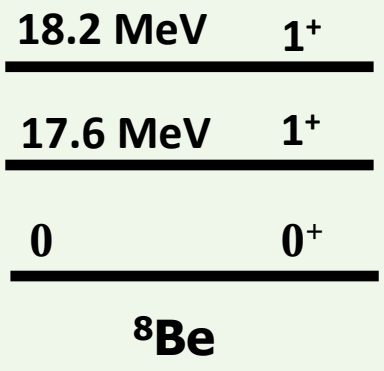


Ep=1.10 MeV



Deviation from IPC

- Can it be some artificial effect caused by γ-rays?
- Can it be some nuclear physics effect?
- …

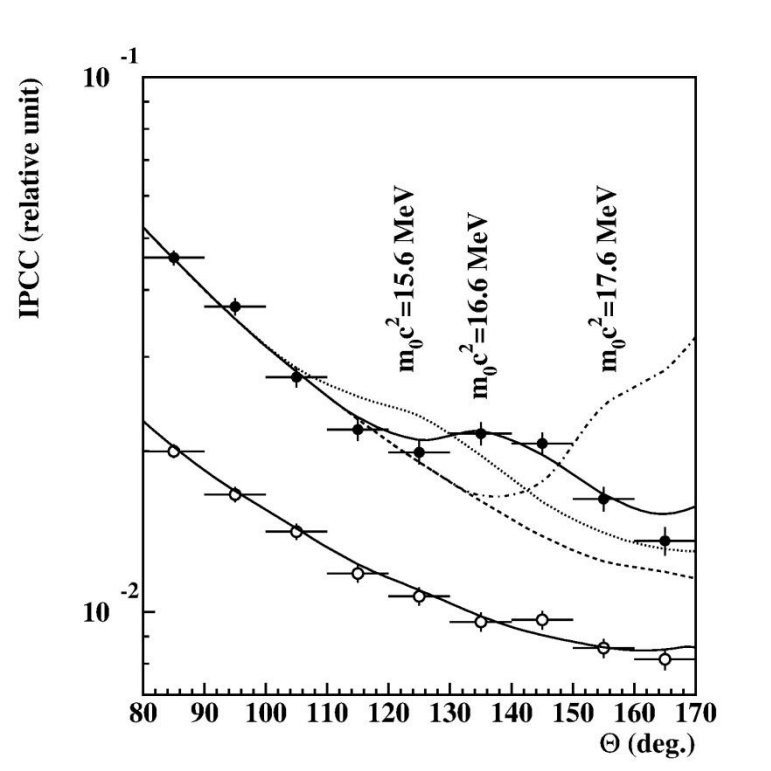


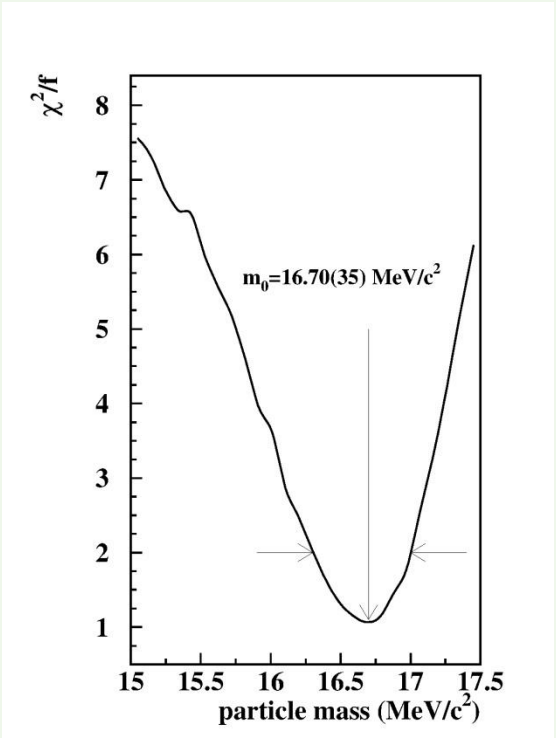
Ep= 1030 keV

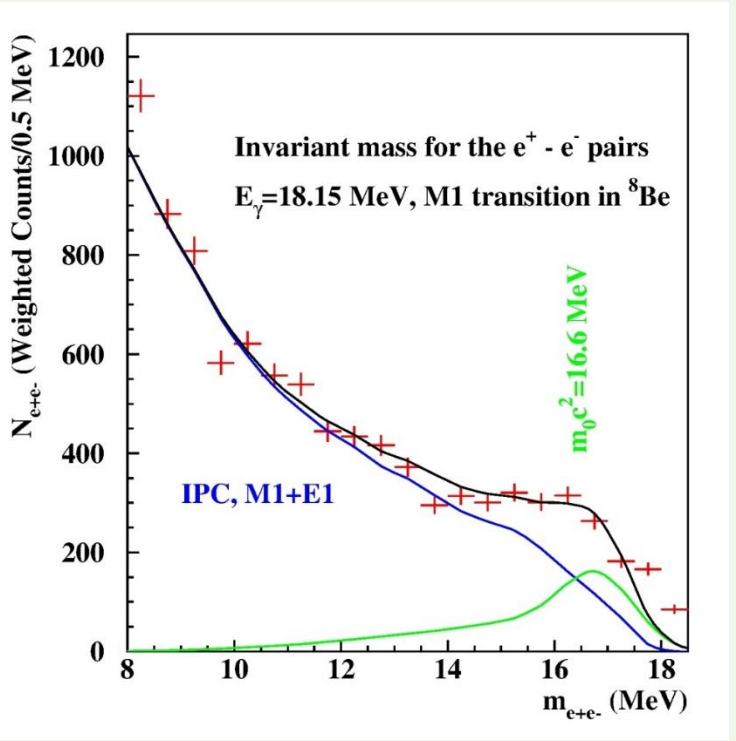
Ep= 441 keV

Fitting the angular correlations

^{8}Be







Experimental angular e^+e^- pair correlations measured in the ^{7}Li(p,e^+e^-) reaction at Ep=1.10 MeV with -0.5< y <0.5 (closed circles) and |y|>0.5 (open circles).

Determination of the mass of the new particle by the X^2/f method

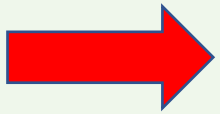
Invariant mass distribution plot for the electron-positron pairs

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

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

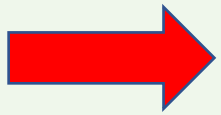
$$\varepsilon_p = 2\varepsilon_u + \varepsilon_d \qquad \varepsilon_n = \varepsilon_u + 2\varepsilon_d$$

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



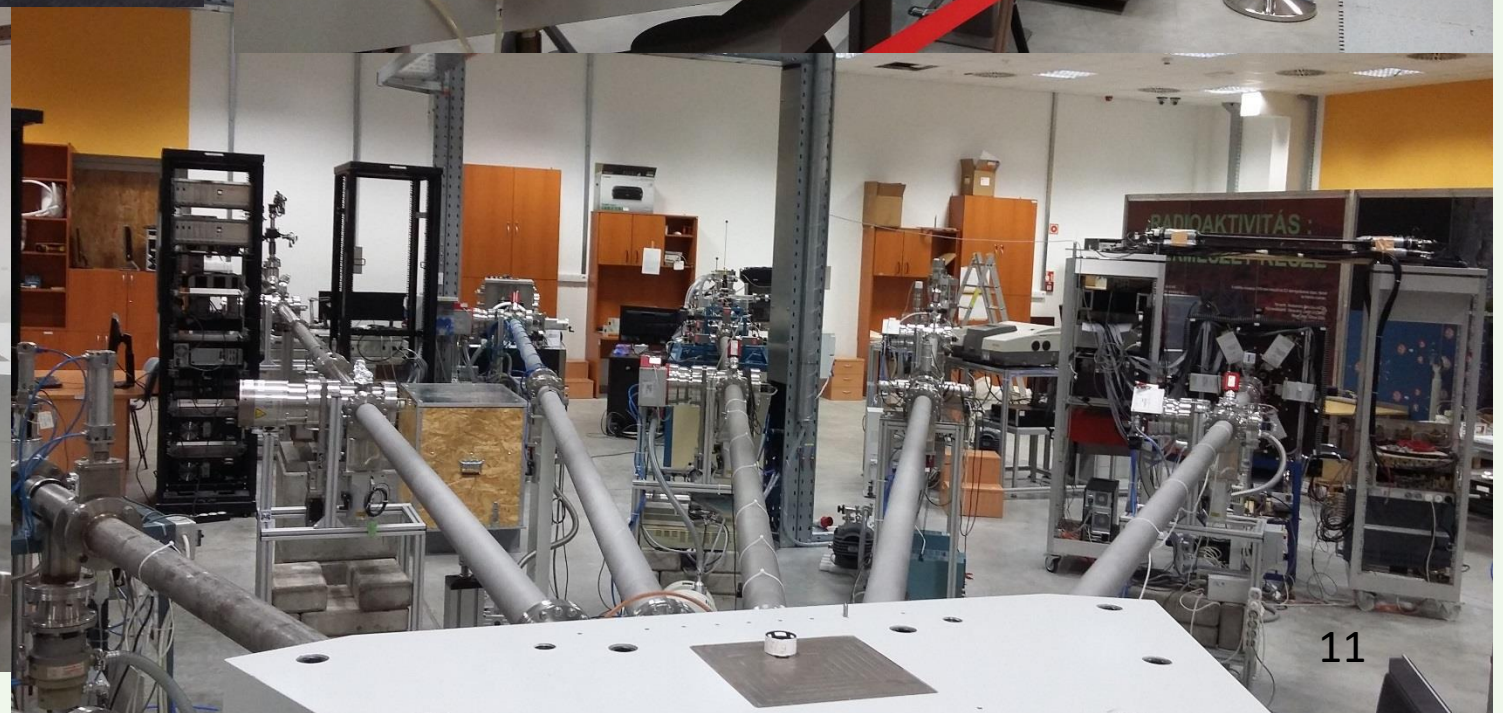
$|\varepsilon_p + \varepsilon_n| \approx 0.011$ $\quad |\varepsilon_u + \varepsilon_d| \approx 3.7 \times 10^{-3}$

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

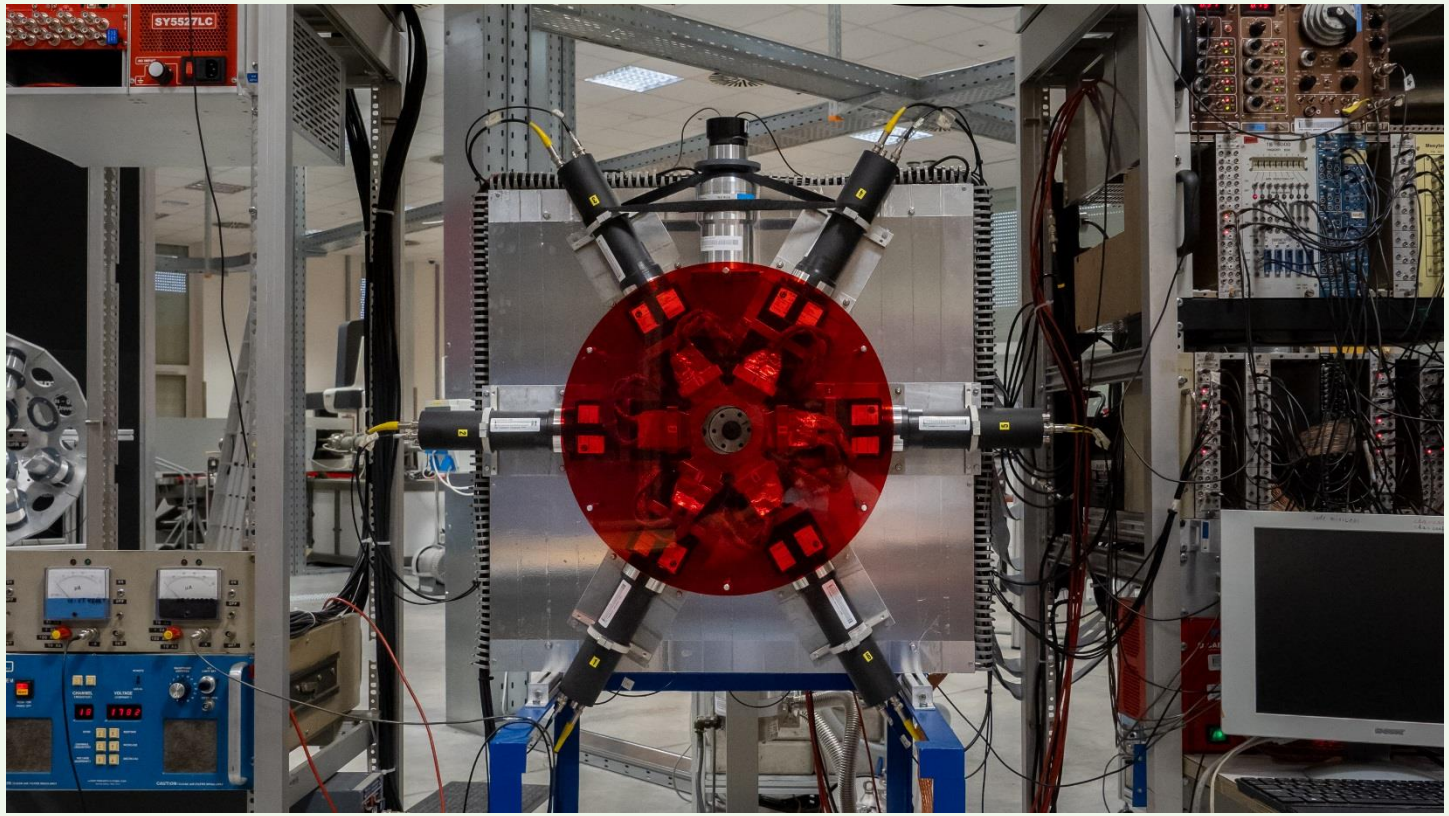


$-2.3 < \frac{\varepsilon_d}{\varepsilon_u} < -1.8\,, \quad -0.067 < \frac{\varepsilon_p}{\varepsilon_n} < 0.078$

Our new Tandetron laboratory



An improved version of the spectrometer

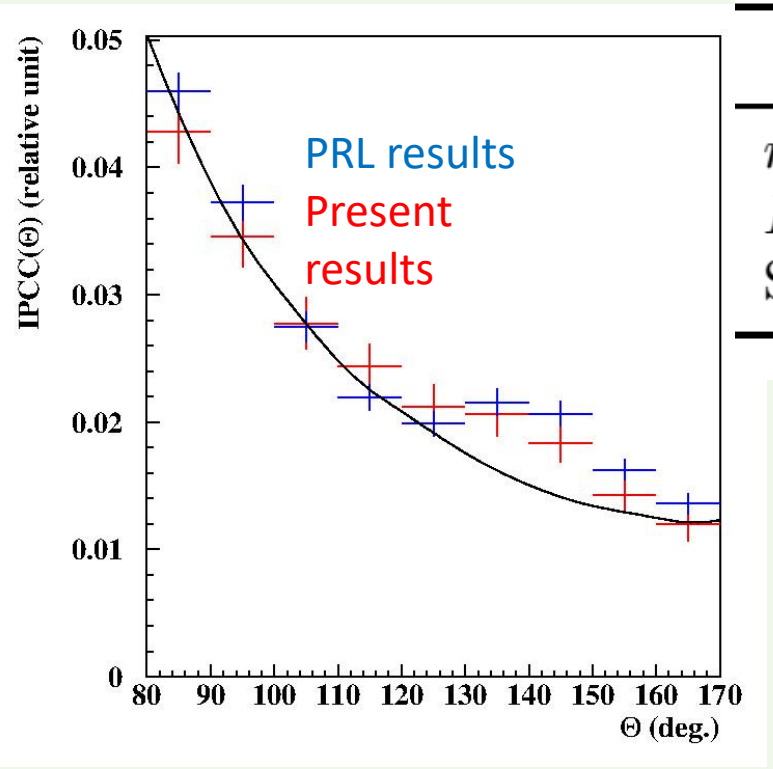


New scintillation and DSSD detectors, new DAQ.

The DSSD detectors in the heart of the spectrometer

New results for the 18.15 MeV transition

^{8}Be



	Exp1	Exp2	Average
$m_0c^2(MeV)$	16.86(6)	17.17(7)	17.01(16)
B_x	$6.8(10) \times 10^{-6}$	$4.7(21) \times 10^{-6}$	$6(1) \times 10^{-6}$
Significance	7.37σ	4.90σ	

Journal of Physics: Conf. Series **1056** (2018) 012028

The results of that experiment can be considered independent from the one we published in PRL in 2016.

Is X17 a vector boson?

- Introduction a **new vector boson** carrying a protophobic fifth force

(J. Feng et al. PRL 117, 071803, (2016))

- Possible explanation of the electron positron anomaly at 17 MeV in ^{8}Be transitions through a **light pseudoscalar**

(U Ellwanger, S Moretti - Journal of High Energy Physics, 2016)

- **Light axial vector bosons**, nuclear transitions, and the 8Be Anomaly

(J Kozaczuk, DE Morrissey, SR Stroberg - Physical Review D, 2017)

- **A viable QCD axion** in the MeV mass range

(DSM Alves, N Weiner - Journal of High Energy Physics, 2018)

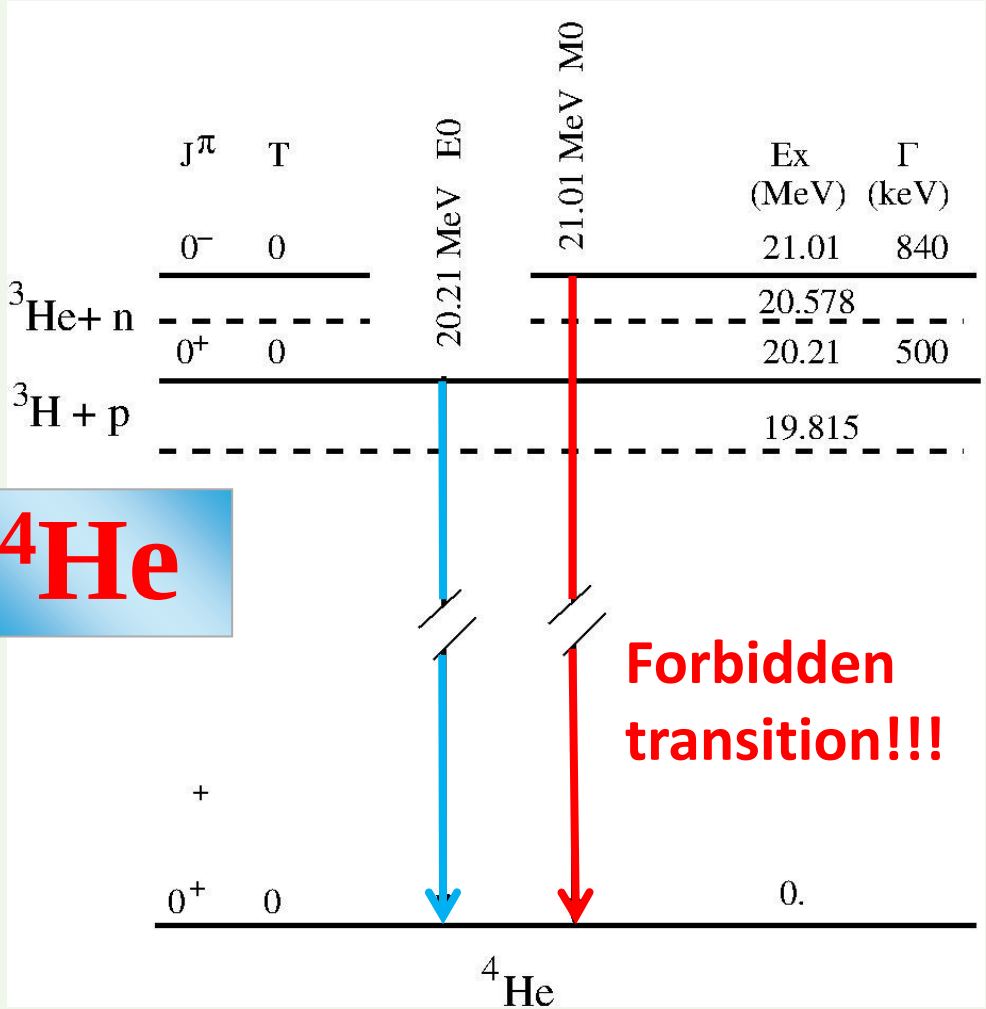
Study the γγ-decay of X(17) in ^{4}He

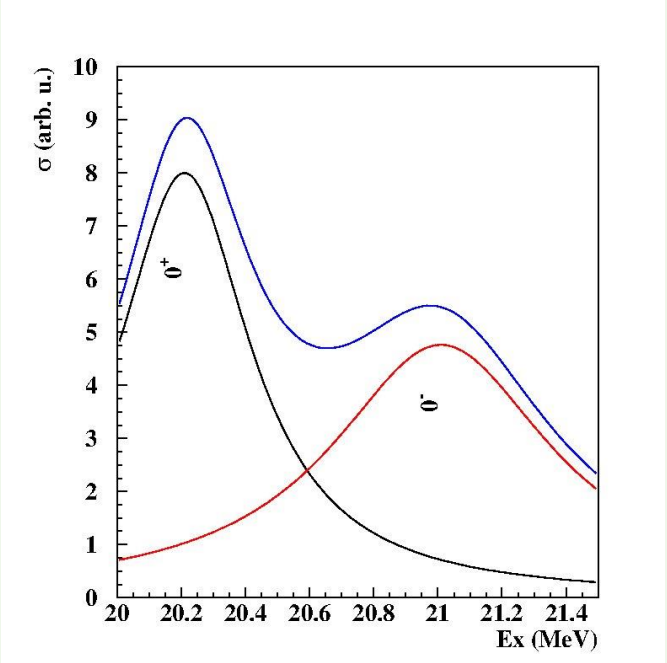
- Vector particle (1^+) or axialvector (0^-)?
- For a vector particle the γ emission is forbidden (Landau-Yang theorem).
- If axialvector than it can decay by γγ emission.
- γγ-decay only known in special cases: $0^+ \rightarrow 0^+$ (^{90}Zr, ^{40}Ca, ^{16}O) and in ^{4}He
- J. Schirmer et al., PRL 53, 1897 (1984)
- J. Kramp et al., NPA 474, 412 (1987)
- Walz, N. Pietrala et al., Competitive Double-Gamma' (□□/□) Decay *Nature* **526**, 406 (2015)

$$\cos(\Theta) = 1 - \frac{m_x^2}{2E_1E_2}$$

→ Study the angular correlation with big, state of the art $LaBr_3$ detectors. → We have got some preliminary results, but due to the COVID we had to stop the experiments.

Study of the 20 MeV transitions in ^{4}He excited by ^{3}H(p,e$^+$e$^-$)^{4}He reaction

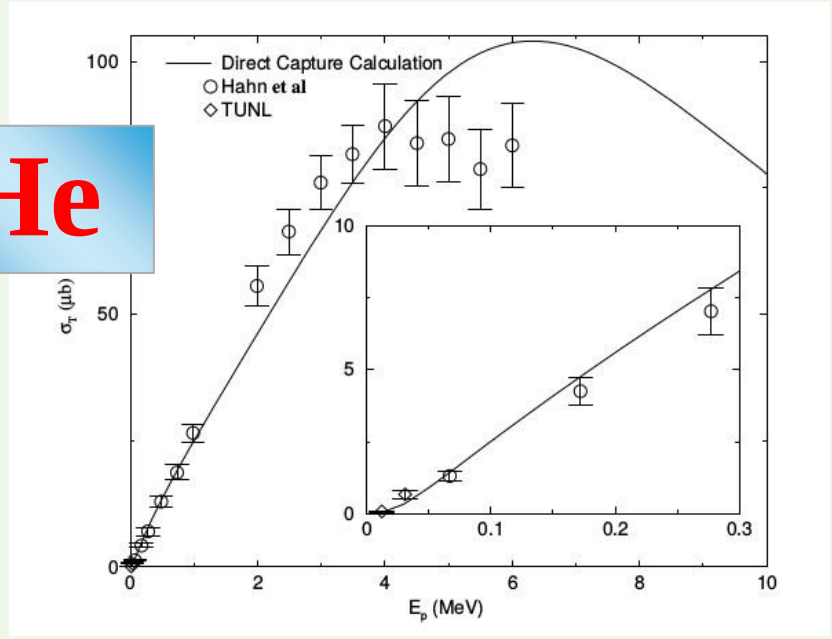




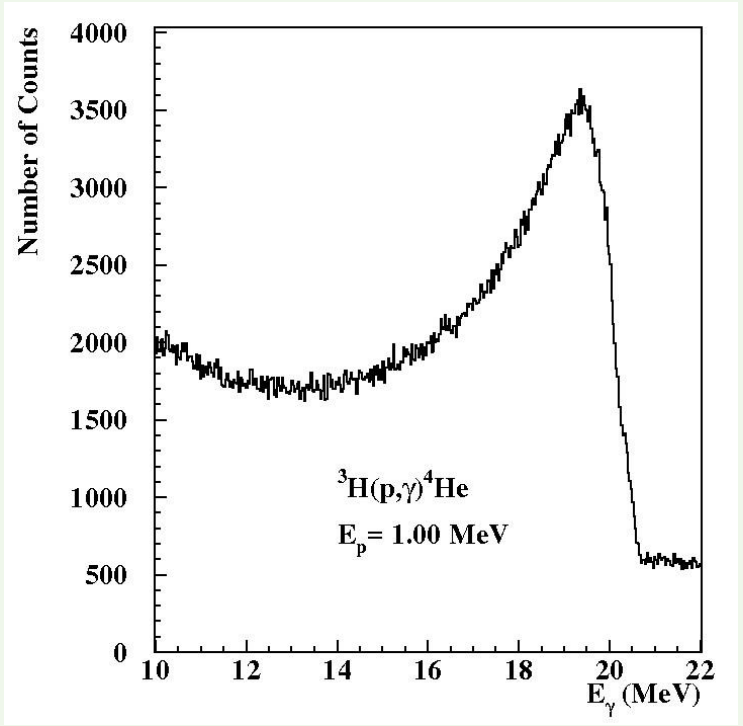
^{3}H target absorbed in Ti on a 0.4 mm thick Mo backing cooled by LN_2

γ-ray production in the $^3H(p,\gamma_0)^4He$ reaction

^4He



γ-ray production with direct proton capture.



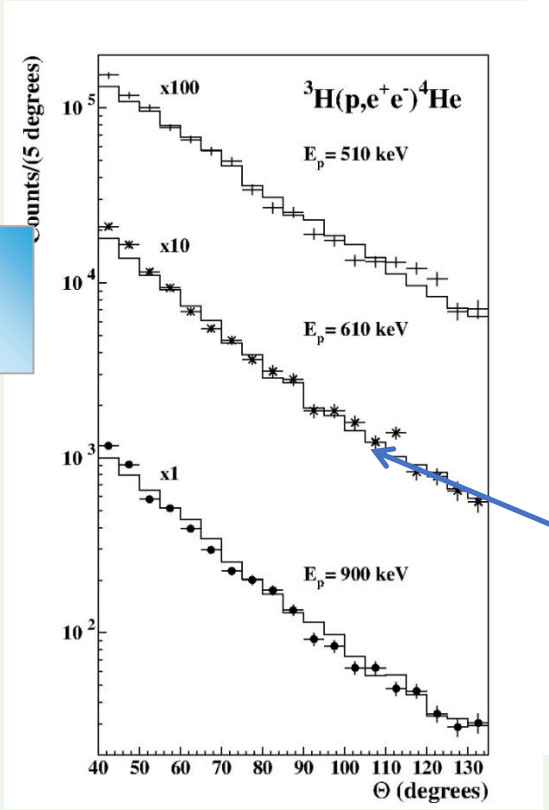
A typical γ-ray spectrum. The proton energy loss in the target was about 400 keV, so the photo-peak was washed out.

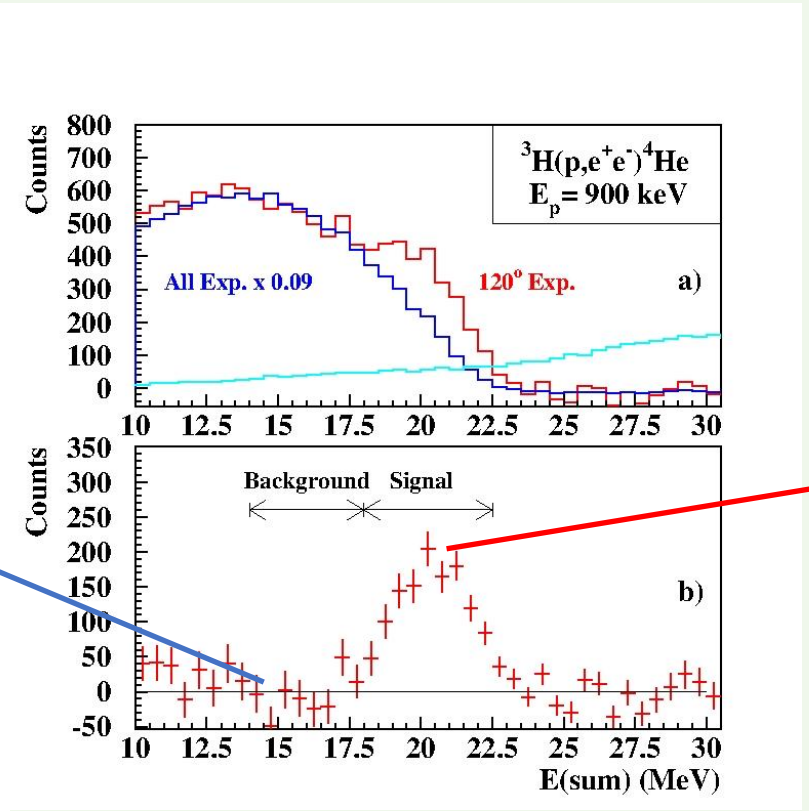
In the e^+e^- spectra the main source of background was produced by external pair creation on the backing of the target and on the other surrounding materials.

We performed extensive **GEANT** simulations for that.

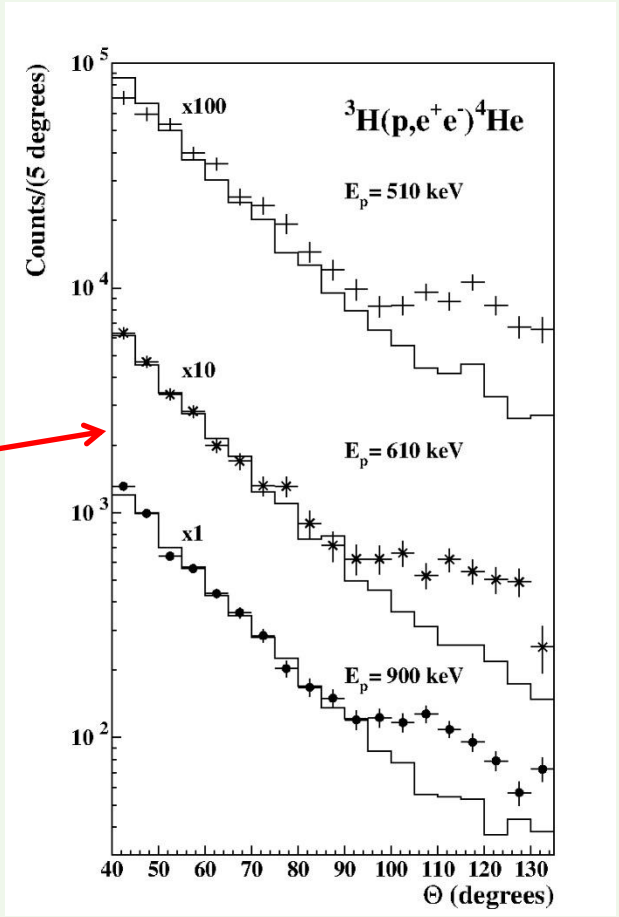
Results for the e^+e^- decay measured in Debrecen

^{4}He





Difference between spectra measured at 120° and 60°.



Measured e^+e^- pair correlation for the signal and background regions.

Results of the fit performed by RooFit

^{4}He

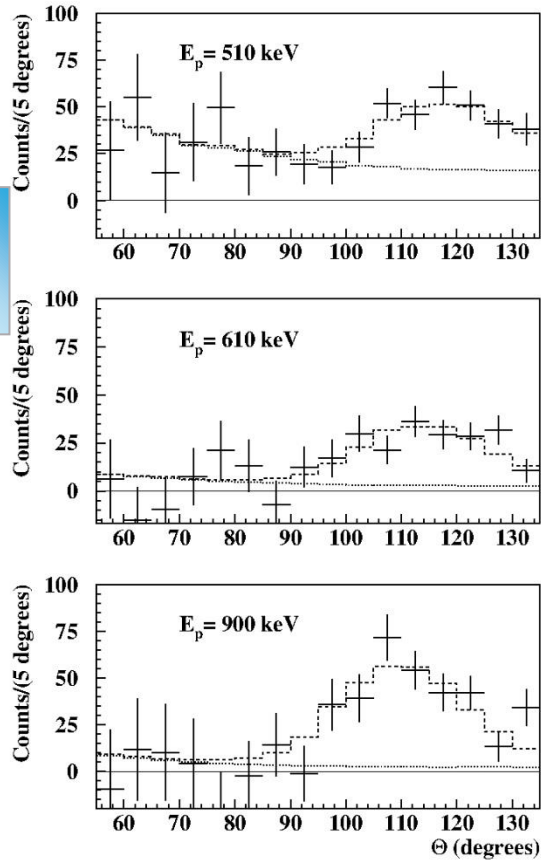


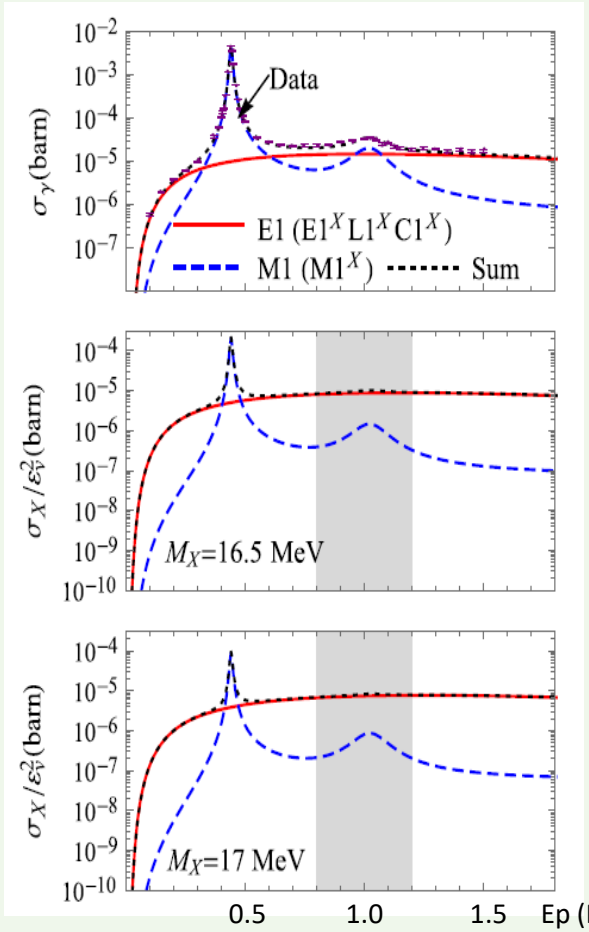
TABLE I. Internal Pair Creation Coefficients (IPCC), X17 Boson branching ratios (B_x), masses of the X17 particle, and confidences derived from the fits.

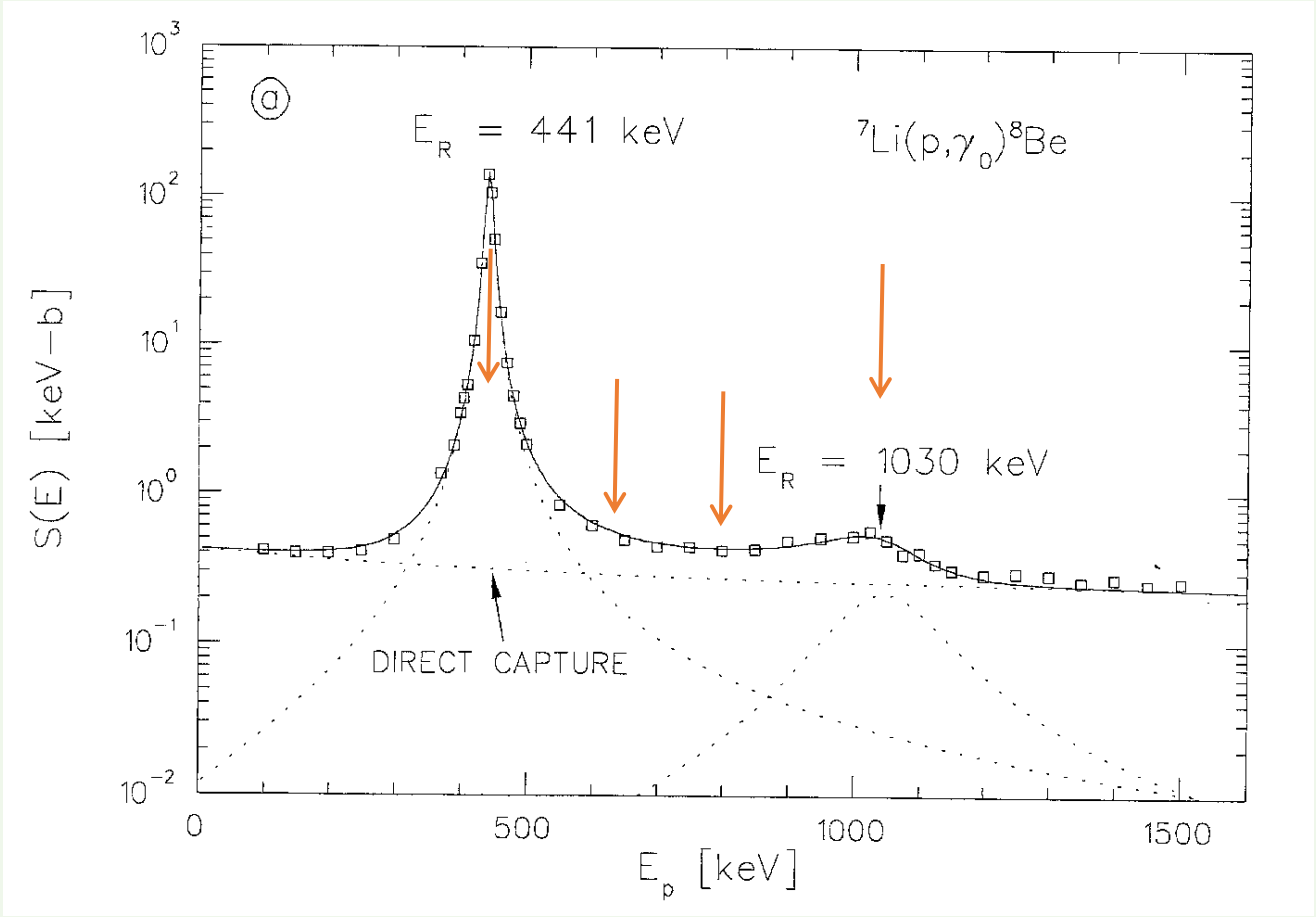
E_p (keV)	IPCC $\times 10^{-4}$	B_x $\times 10^{-6}$	Mass (MeV/c^2)	Confidence
510	2.5(3)	6.2(7)	17.01(12)	7.3σ
610	1.0(7)	4.1(6)	16.88(16)	6.6σ
900	1.1(11)	6.5(20)	16.68(30)	8.9σ
Averages		5.1(13)	16.94(12)	
^{8}Be values		6	16.70(35)	

A.J. Krasznahorkay et al., Phys. Rev. C 104, 044003 (2021)

New experiments for ^{8}Be performed on and off resonances

^{8}Be





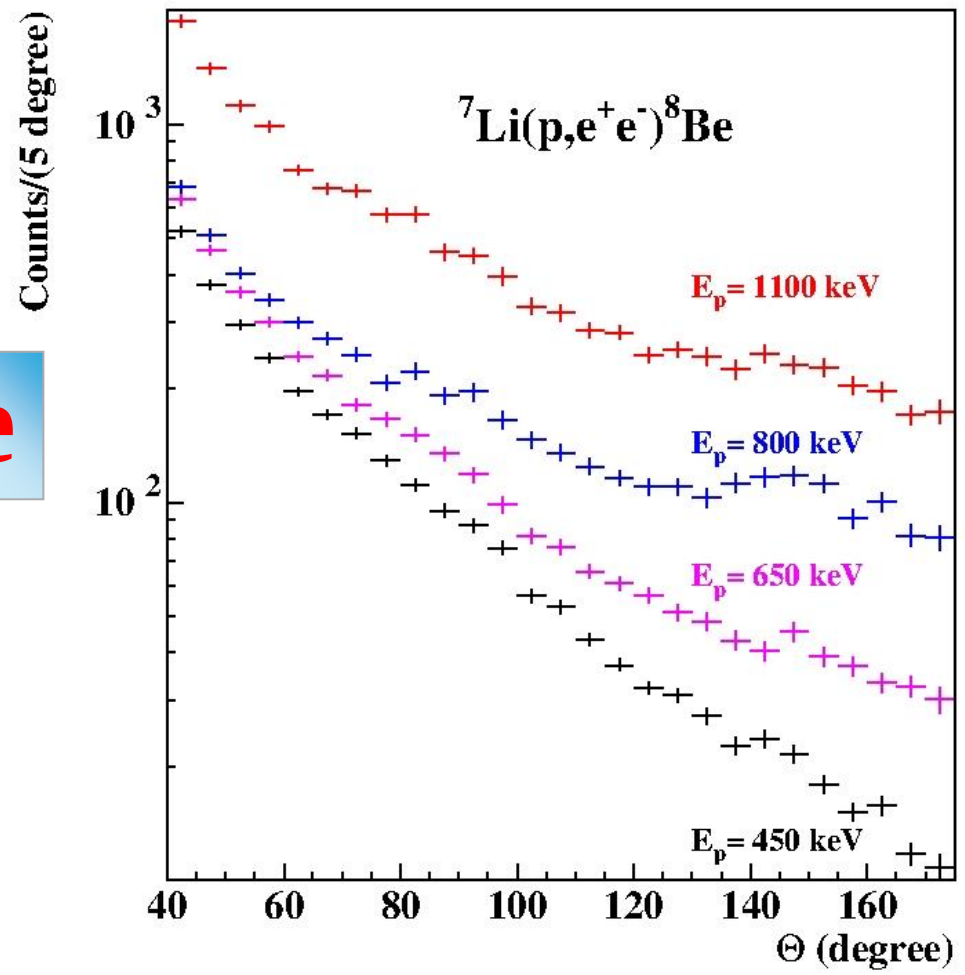
Can a protophobic vector boson explain the ATOMKI anomaly?

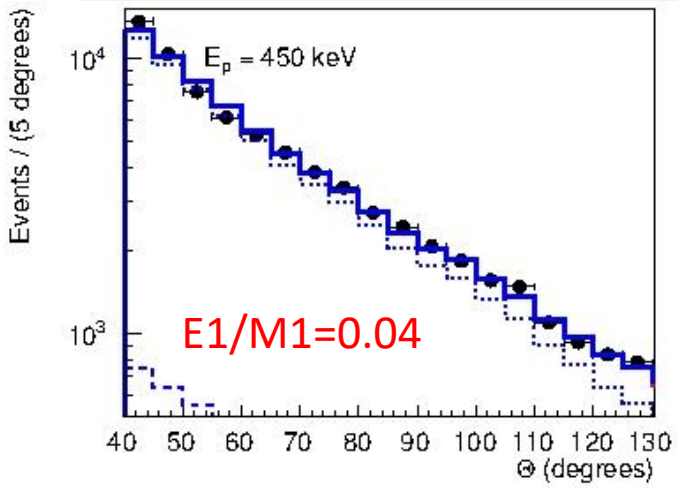
X Zhang, GA Miller - Physics Letters B 813 136061 (2021)

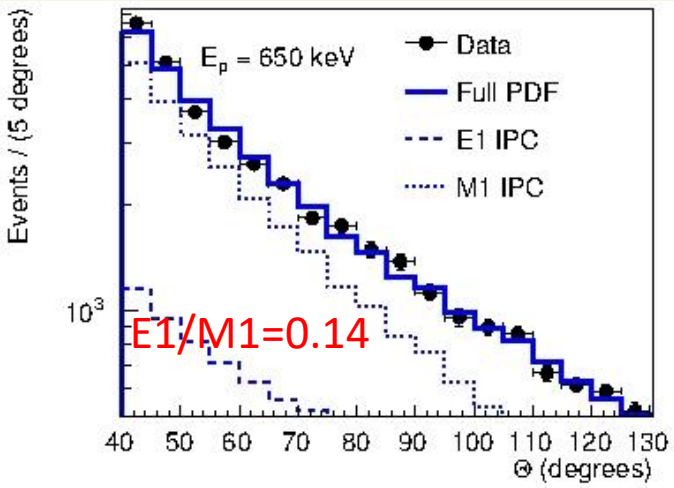
Do the experiments with the same Li_2O target!

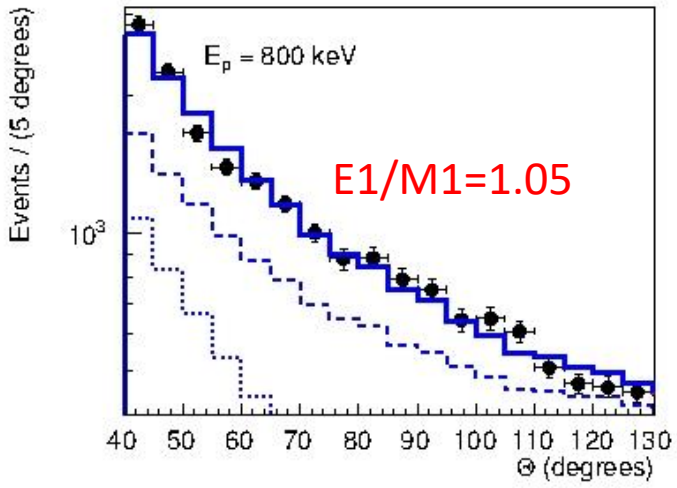
e^+e^- angular correlations for the different bombarding proton energies

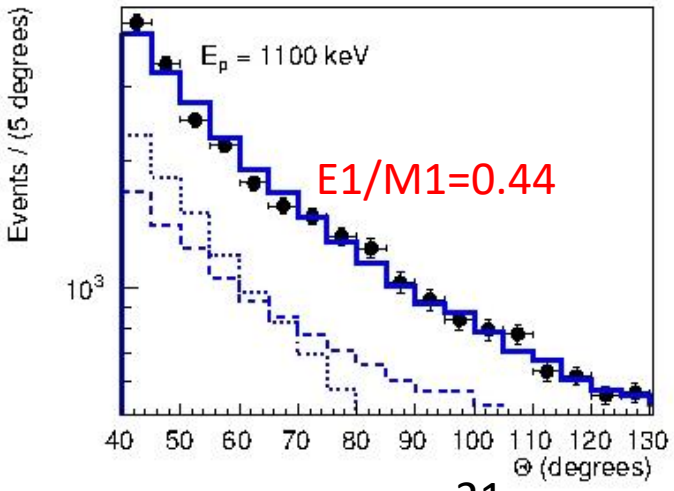
^{8}Be



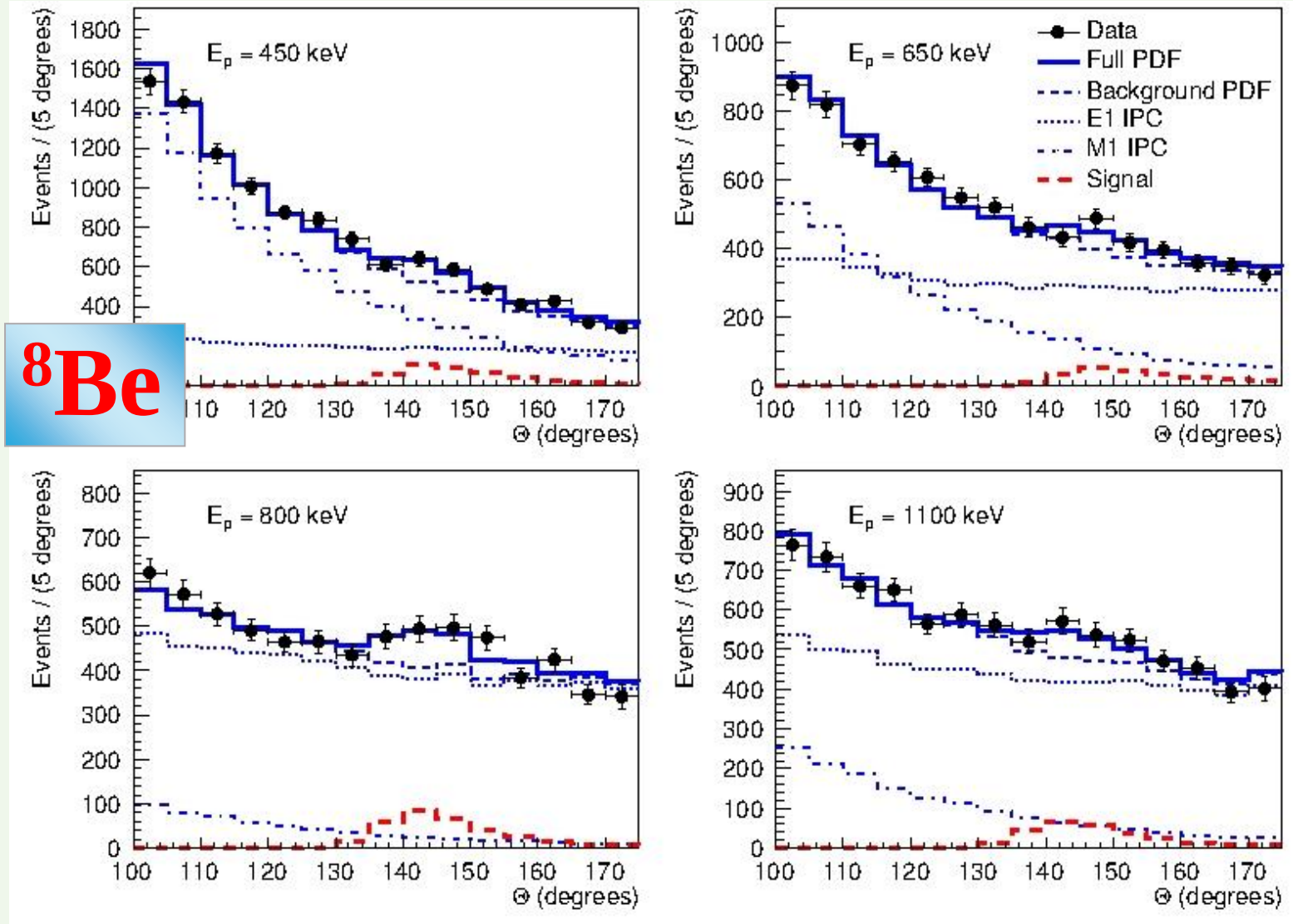








Fitting the e^+e^- angular correlations, measured at different bombarding energies, with simulated E1 and M1 distributions



Ep (keV)	m_0c^2(X17) (MeV)	E1/M1	X17/E1
450	16.6(3)	0.04	0.14(16)
650	16.94(14)	0.14	0.05(3)
800	16.81(9)	1.05	0.053(14)
1100	17.11(12)	0.44	0.041(13)

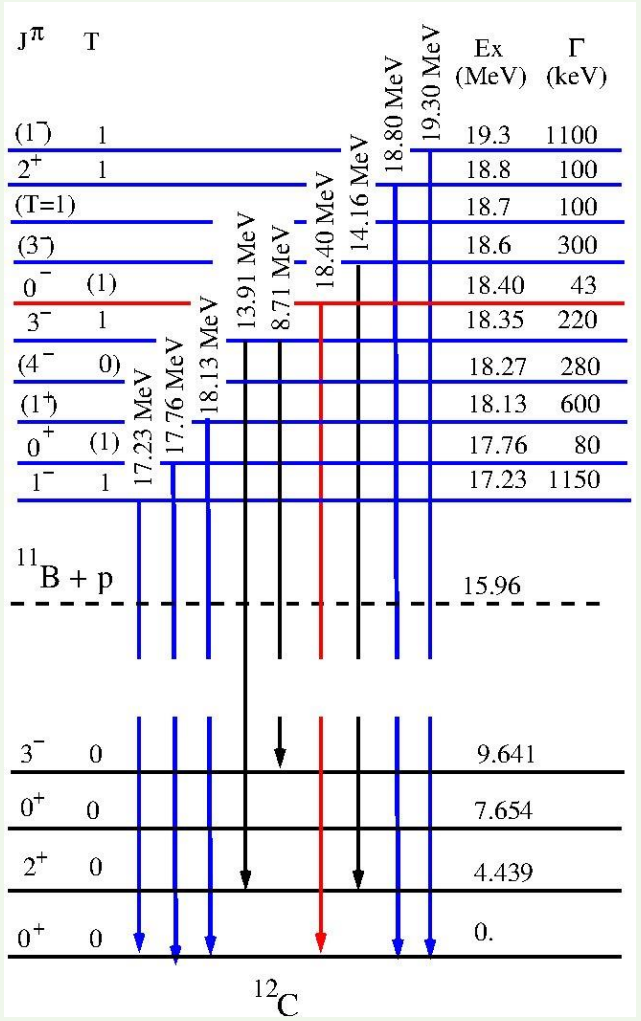
The X17 contribution seems to correlate with the amplitude of the E1 multipolarity and not with the M1 one. → the X17 particle has a vector character and not axial vector one.

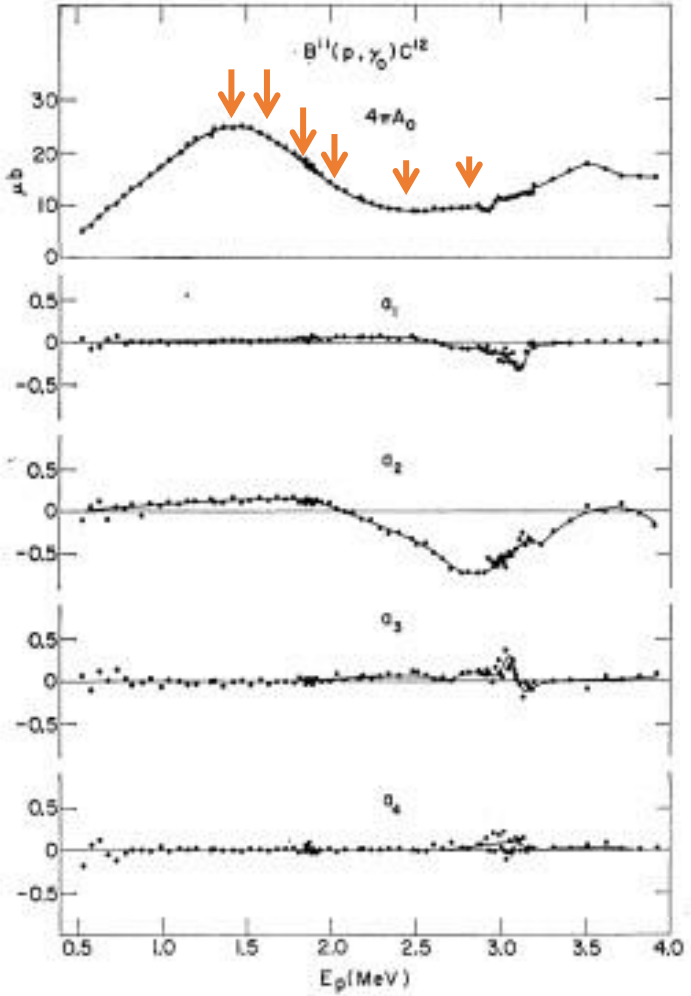
arXiv: 2205.07744

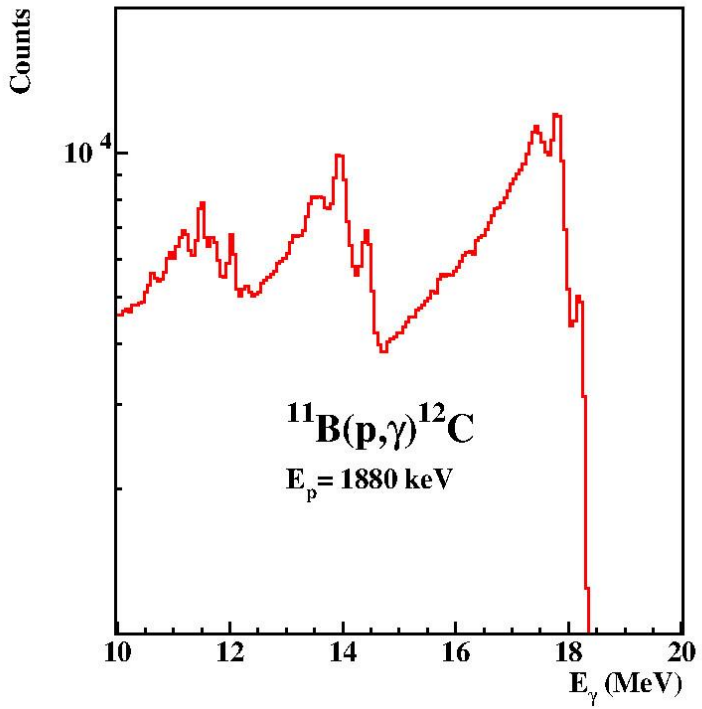
Preliminary results for $^{11}B(p,e^+e^-)^{12}C$ reaction

(Suggested by J. Feng et al., Phys. Rev. D102, 036016 (2020))

^{12}C



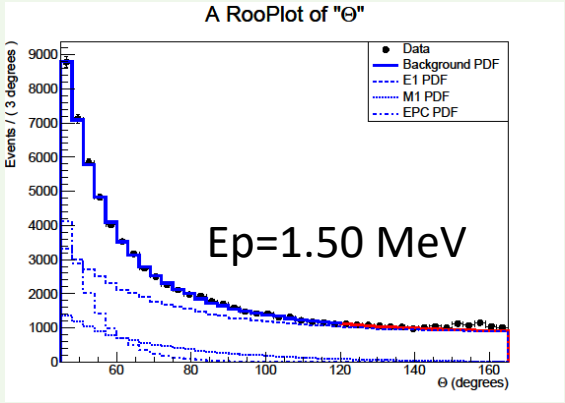


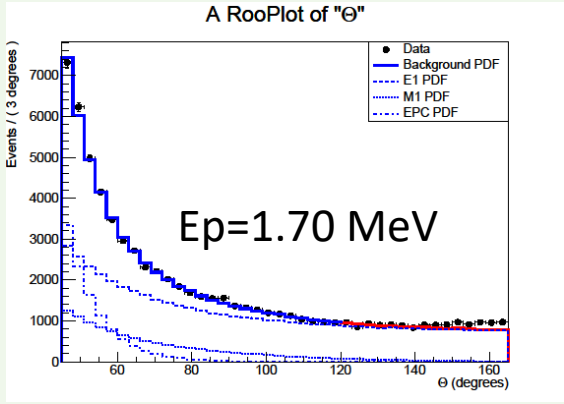


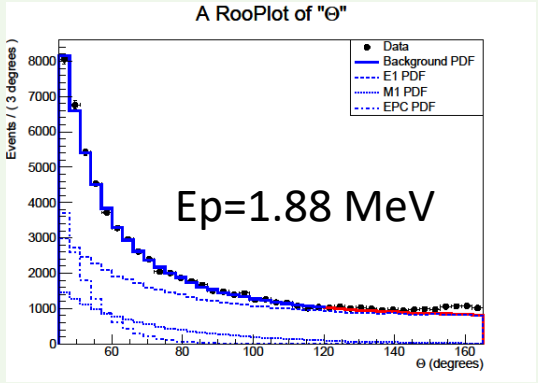
γ-ray spectrum taken with a 3”x3” $LaBr_3$ detector.

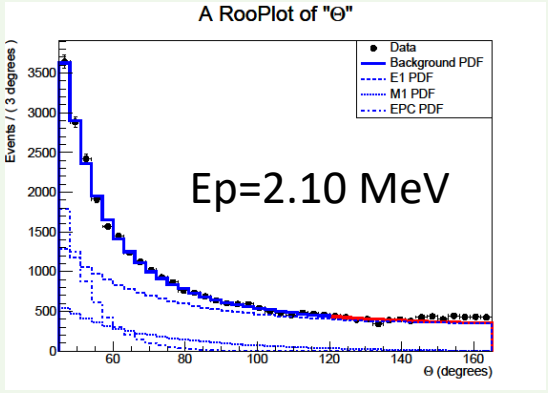
Fitting the „background” with RooFit

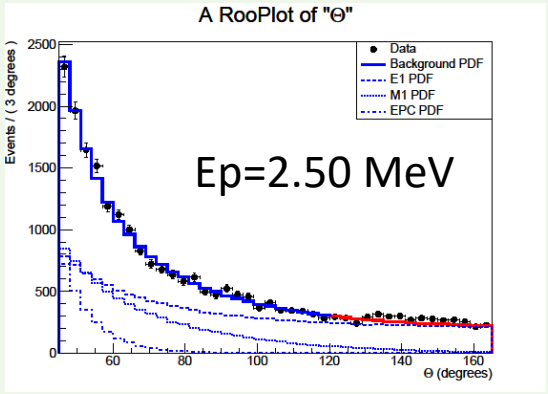
^{12}C

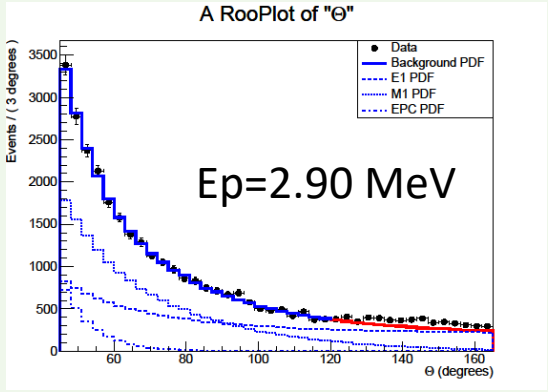






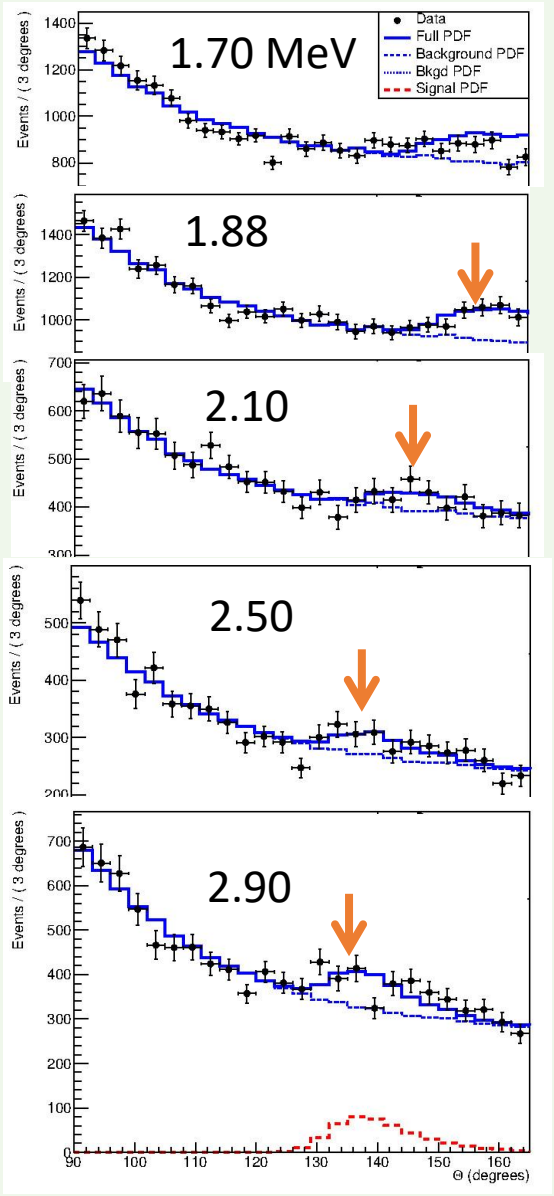


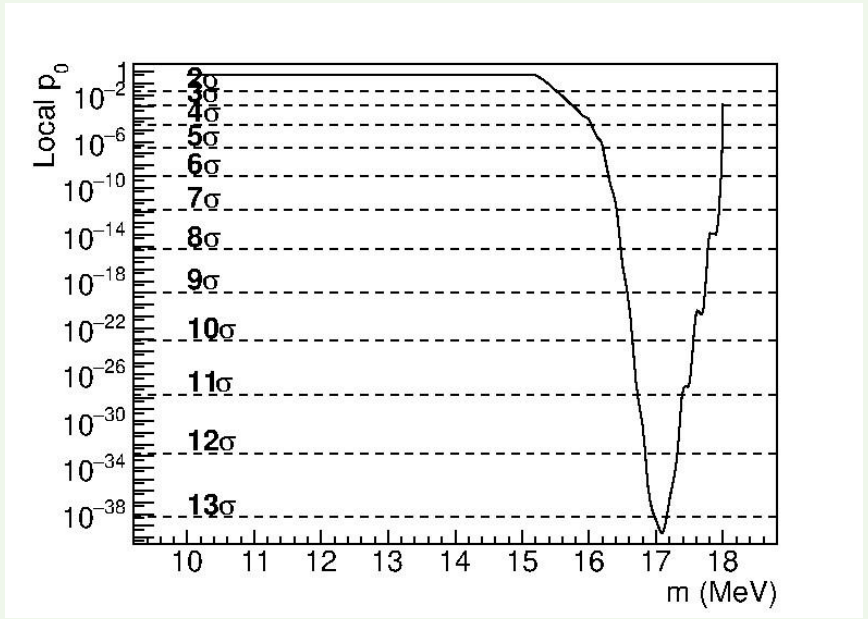




Results of the fitting with RooFit

^{12}C

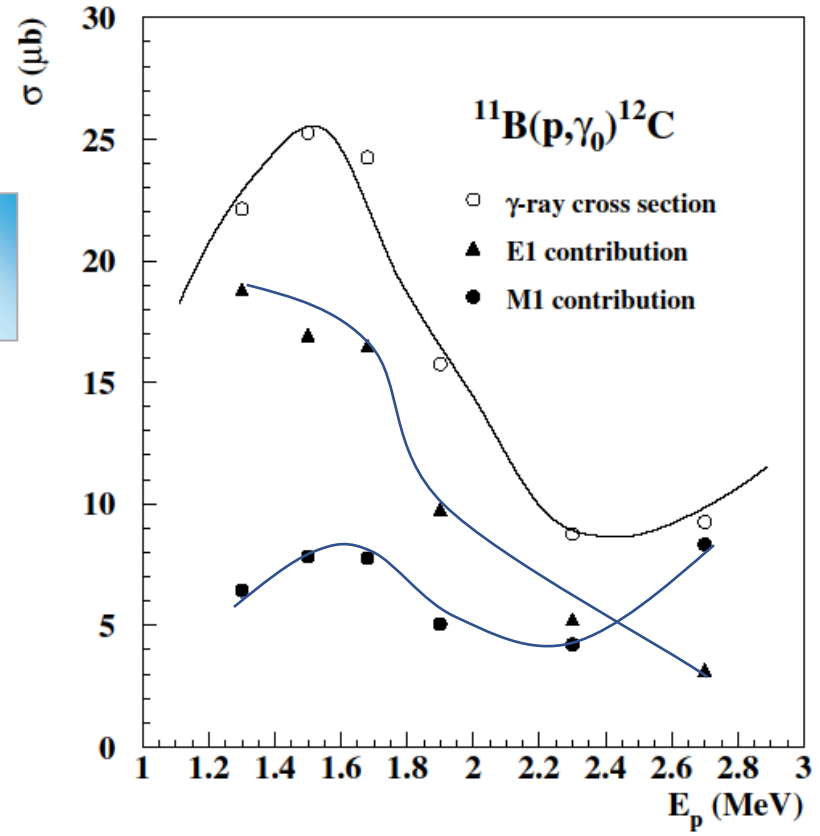


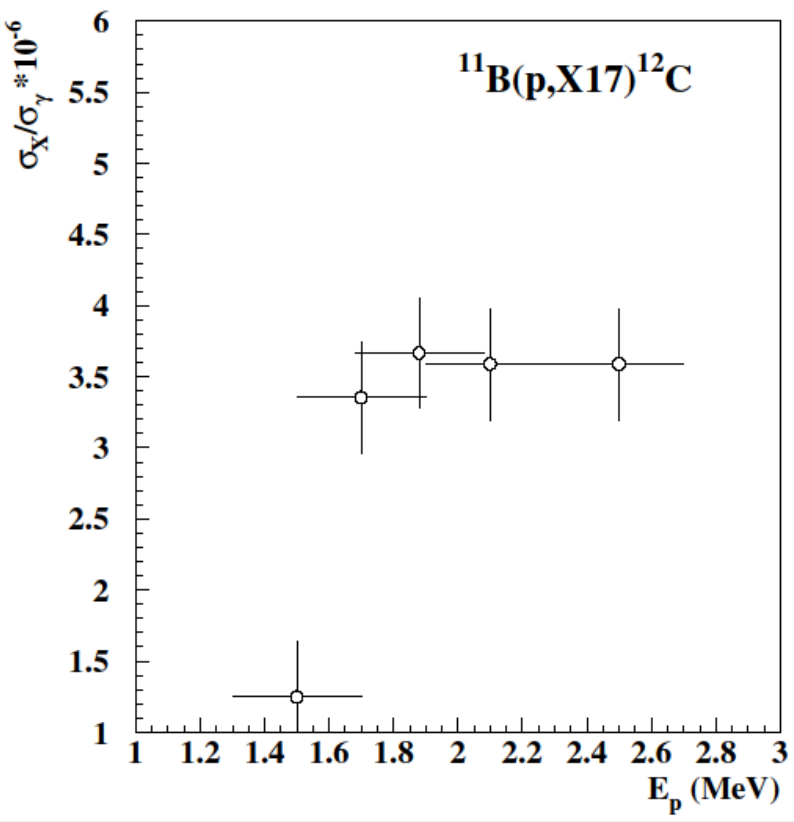


Ep (MeV)	1.70	1.88	2.10	2.50	2.90
$M_X c^2$ (MeV)	16.64	16.86	16.94	17.14	16.80
Average			16.88(15)		

Cross section of the $^{11}B(p,\gamma_0)^{12}C$ reaction and decomposition of the γ-rays into E1 and M1 multipolarities

^{12}C

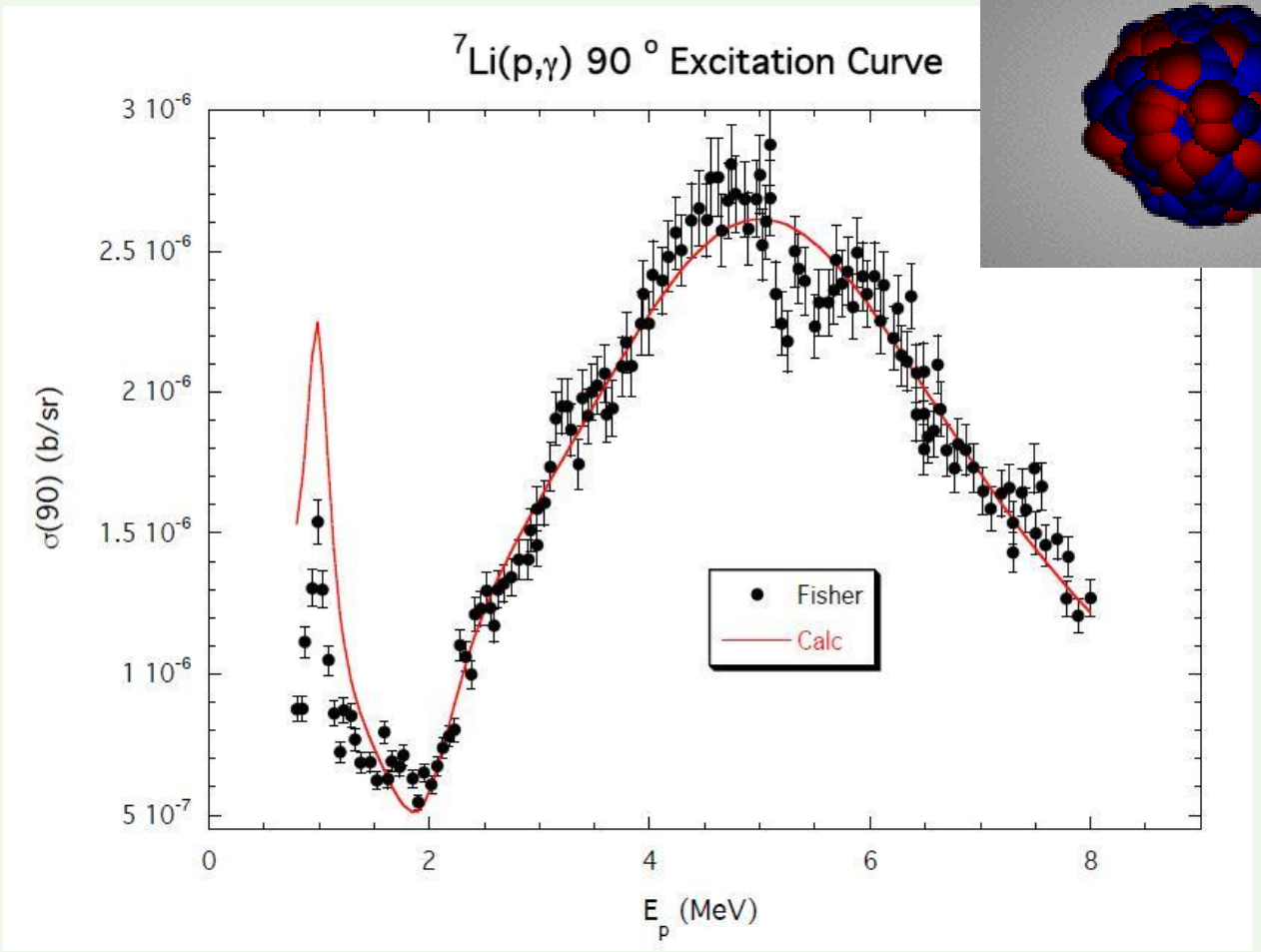


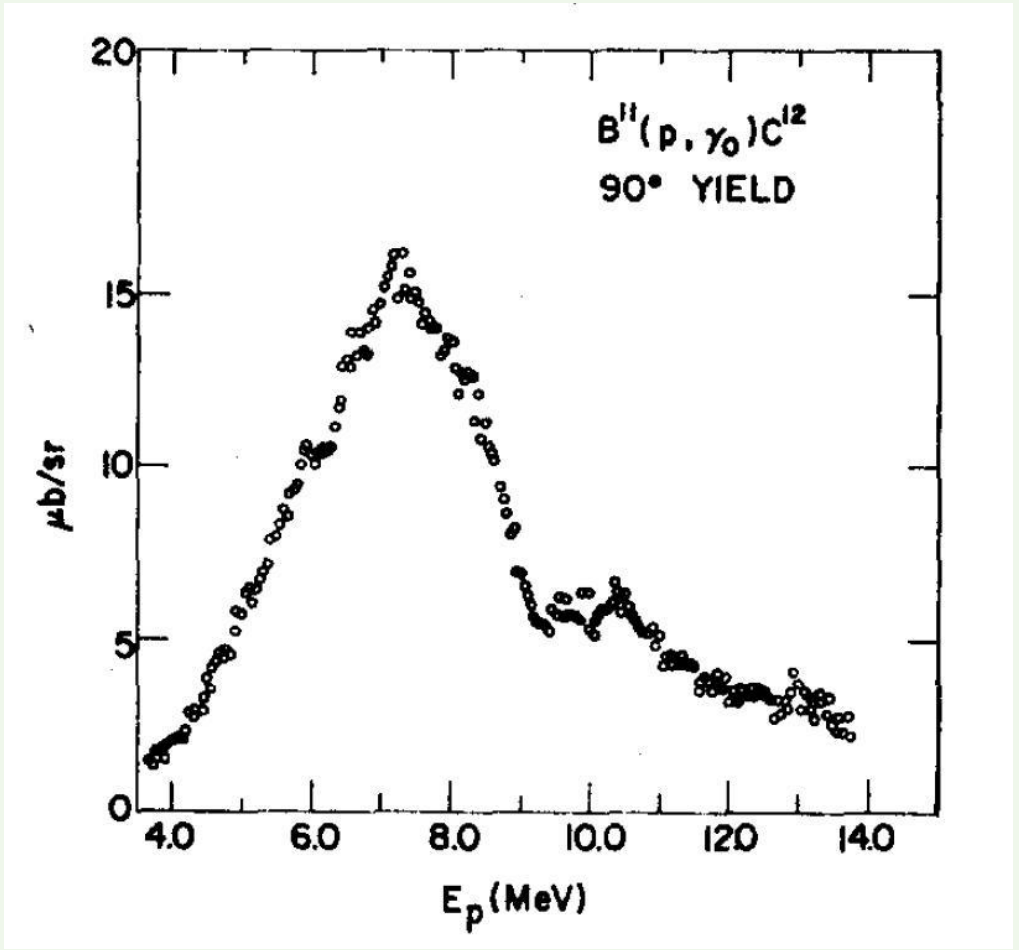


Conclusions

- Anomalous internal pairing was first observed during the excitation of the M1 multipolarity transition of 8Be at 18.15 MeV. A peak-like deviation was found in the e^+e^- angular correlation at large angles (140 degrees). The anomaly was later confirmed in an experiment with our upgraded spectrometer at a new accelerator.
- For ^{4}He, at an excitation energy of 20 MeV, the anomaly appeared at smaller angles (115 degrees), but could be explained by the formation and decomposition of a particle of the same mass (17 MeV). This provided kinematic evidence for the formation of the X17 particle. It was also found that the anomaly may have occurred in the direct capture of the proton and was not related to the excited states of 0^+ or 0^- in ^{4}He.
- The anomaly observed in the ^{7}Li (p, e^+e^-)^{8}Be reaction was later examined at off-resonance energies and was detected there. It turned out that the anomaly did not occur in the 18.15 MeV transition, but in the E1 transition generated during direct proton capture.
- The possibility of an anomaly (X17 particle generation) was also examined at the ^{12}C 17.2 MeV E1 transition, and we were able to detect it there as well. This 17.2 MeV E1 radiation was generated by the decay of a broad resonance, so we were able to change its energy by changing the energy of the proton.
- The intensity of the anomaly is constant relative to the IPC value of the E1 transition, which is consistent with the calculations reported by Zhang and Miller in 2021. The strength of the 1^- resonance decreased significantly in the case of the studied energies, but the X17 branching ratio relative to that stayed constant. This also provided dynamic evidence for the existence of the X17 particle, and confirmed that the X17 particle is created in the E1 transition, so it has indeed a vector character.

Plans for studying the X17 particle in the e^+e^- decay of the Giant Dipole Resonance (GDR)





Thank you very much for your kind attention!

To ^{8}Be continued!

Stay tuned!