Zakopane Conf. on Nucl. Phys. 2018

On a new light particle observed in high energy nuclear transitions

Attila Krasznahorkay

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(MTA-Atomki)

www.atomki.mta.hu

- Introduction
- Previous results
- Repeating the experiments with better conditions
- New results for ^4He using the $^3H(p,\gamma)^4He$ and the $^3He(n,\gamma)$ reactions
- e^+e^- and $\gamma\gamma$ results
- Conclusion

https://aps.altmetric.com/details/3886365

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

SUMMARY | News | Blogs | Twitter | Facebook

Title	Observation of Anomalous Internal Pair Creation in <span class
Published in	Physical Review Letters, January 2016
DOI	10.1103/physrevlett.116.042501
Pubmed ID	26871324
Authors	A. J. Krasznahorkay, M. Csatlós, L. Csige, Z. Gácsi, J. Gulyás, M. Hunyadi, T. J. Ket
Abstract	Electron-positron angular correlations were measured for the isovector magne (J^{... [show]

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Evidence for a Protophobic Fifth Force from ^{8}Be Nuclear Transitions

Jonathan L. Feng,[1] Bartosz Fornal,[1] Iftah Galon,[1] Susan Gardner,[1,2] Jordan Smolinsky,[1] Tim M. P. Tait,[1] and Philip Tanedo[1]

Department of P ... nia 92697-4575 USA
Department of Ph ... cky 40506-0055 US

Phys. Rev. Lett. 117, 071803

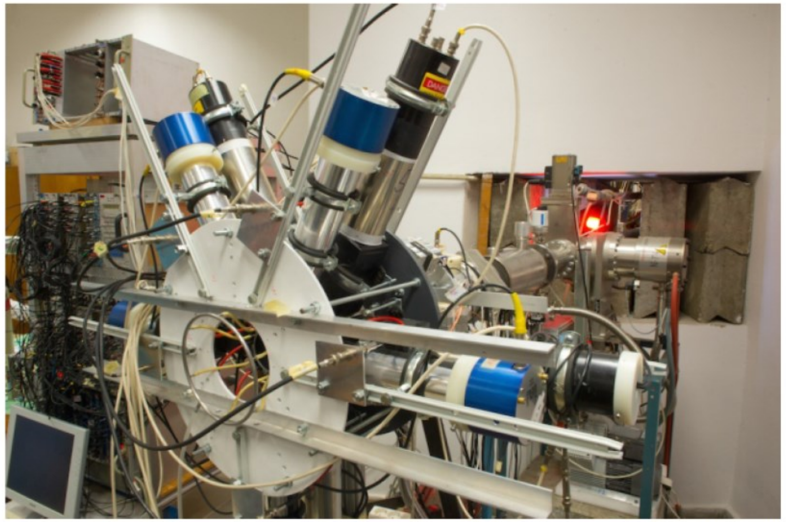
NATURE | NEWS

Has a Hungarian physics lab found a fifth force of nature?

Radioactive decay anomaly could imply a new fundamental force, theorists say.

Edwin Cartlidge

25 May 2016



MTA-Atomki

Physicists at the Institute for Nuclear Research in Debrecen, Hungary, say this apparatus — an electron-positron spectrometer — has found evidence for a new particle.

Print

A laboratory experiment in Hungary has spotted an anomaly in radioactive decay that could be the signature of a previously unknown fifth fundamental force of nature, physicists say – if the finding holds up.

Attila Krasznahorkay at the Hungarian Academy of Sciences's Institute for Nuclear Research in Debrecen, Hungary, and his colleagues reported their surprising result in 2015 on the arXiv preprint server, and this January in the journal *Physical Review Letters*[1]. But the report – which posited the existence of a new, light boson only 34 times heavier than the electron – was largely overlooked.

Then, on 25 April, a group of US theoretical physicists brought the finding to wider attention by publishing its own analysis of the result on arXiv[2]. The theorists showed that the data didn't conflict with any previous experiments – and concluded that it could be evidence for a fifth fundamental force. "We brought it out from relative obscurity," says Jonathan Feng, at the University of California, Irvine, the lead author of the arXiv report.

Dark matter may feel a "dark force" that the ...st of the Universe ...es not

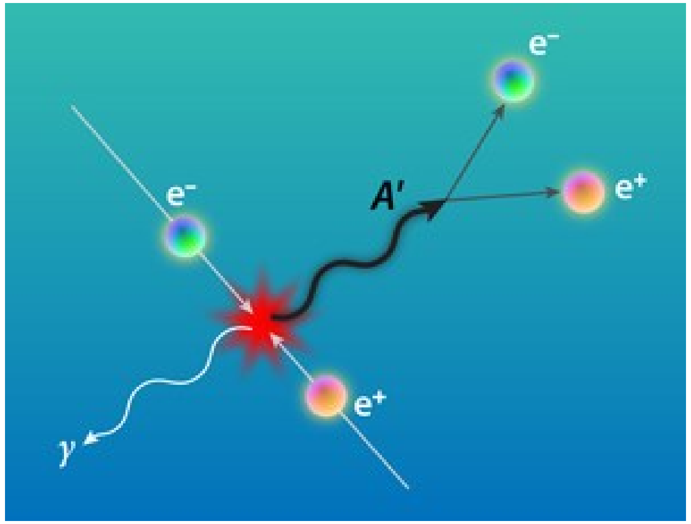
Four days later, two of Feng's colleagues discussed the finding at a workshop at the SLAC National Accelerator Laboratory in

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

Searching for Dark Matter

- Should not have to defend this too much…

Searching from the basement to the attic already for 30 years, every corner with tremendous strength, but didn’t find anything significant so far …



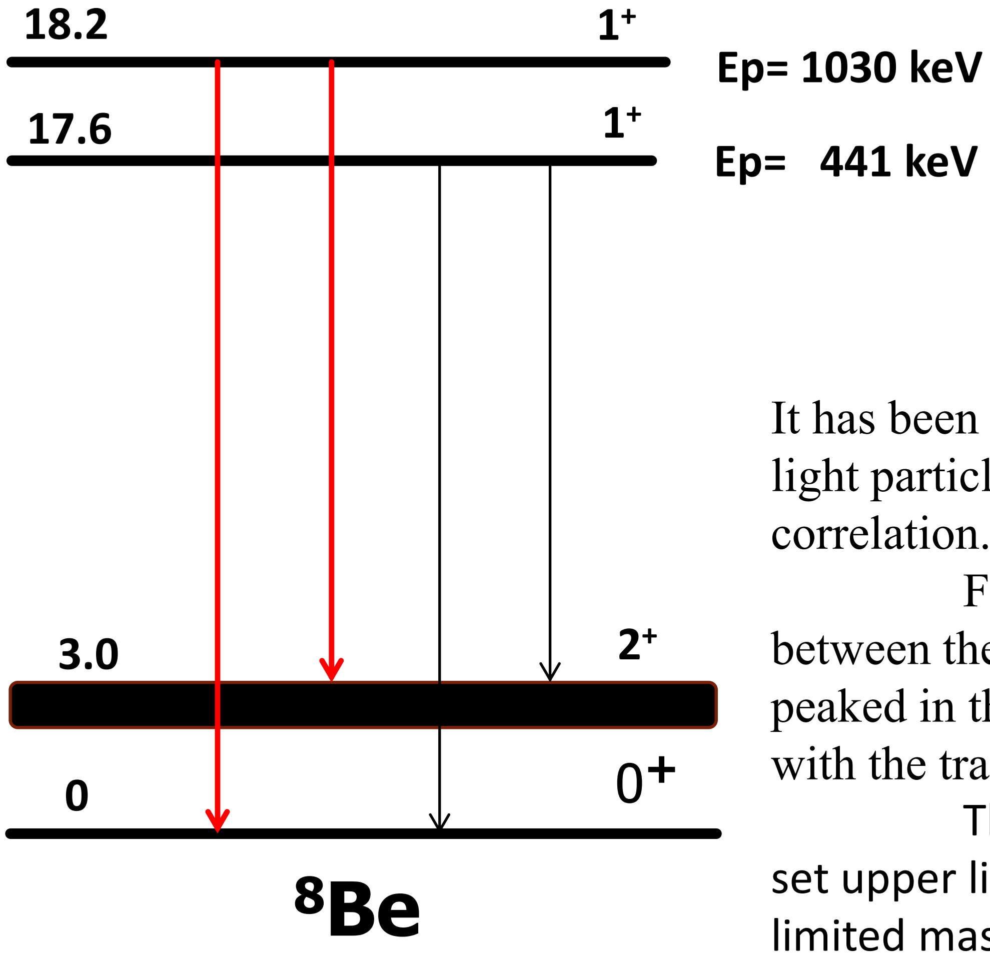
Light, Weakly Interacting DM, the dark photon concept

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

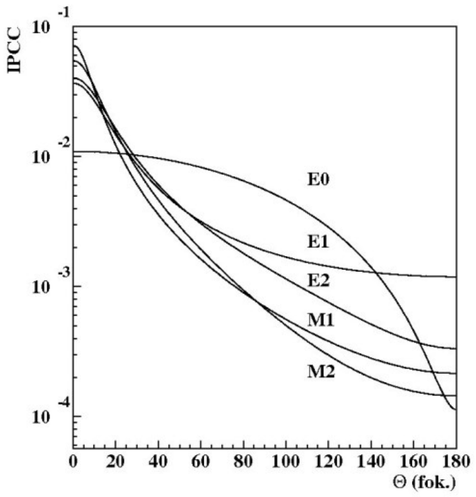
M. Pospelov and A. Ritz, “Astrophysical Signatures of Secluded Dark Matter,” Phys. Lett. B **671**, 391 (2009)

Study the ^{8}Be M1 transitions

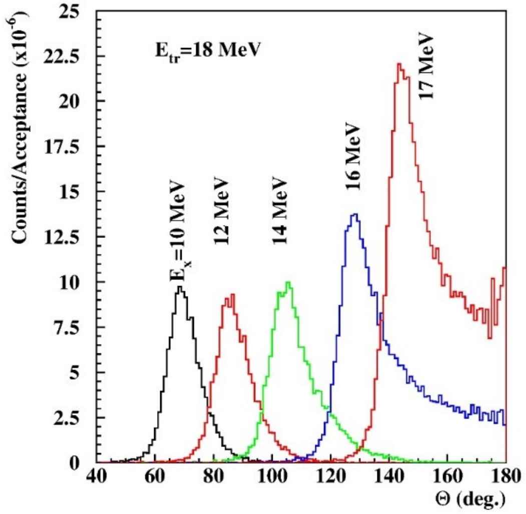
Excitation with the ^{7}Li(p,γ)^{8}Be reaction



Background



Signature

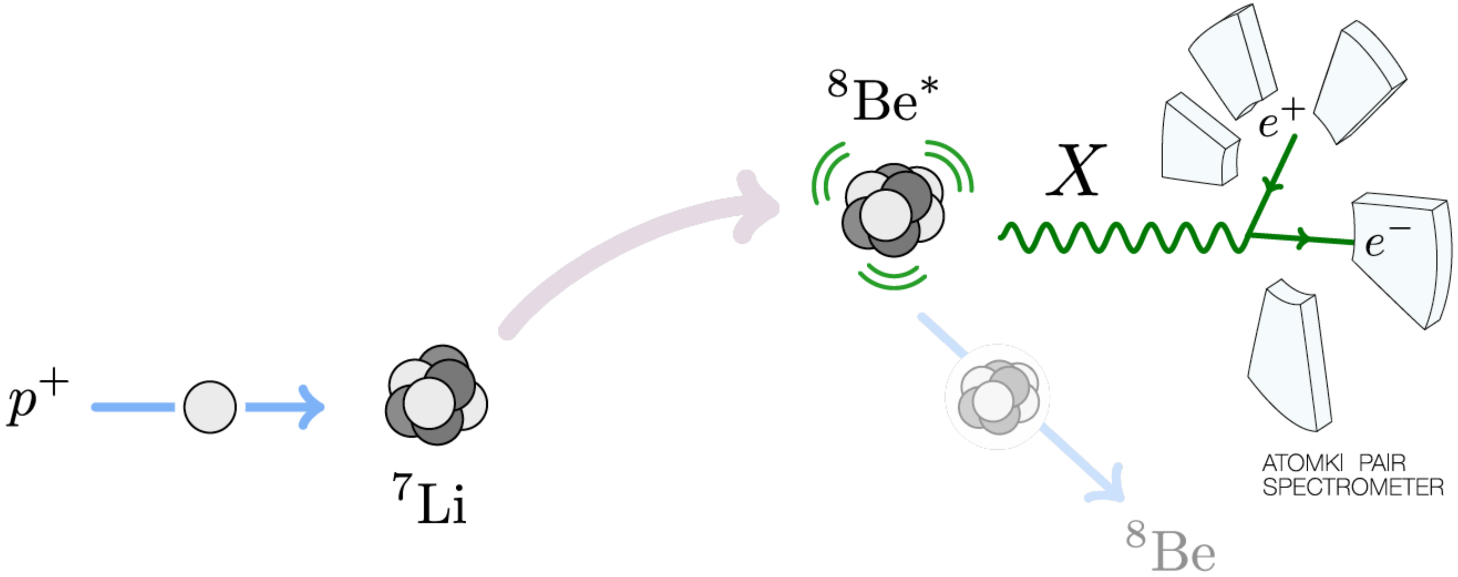


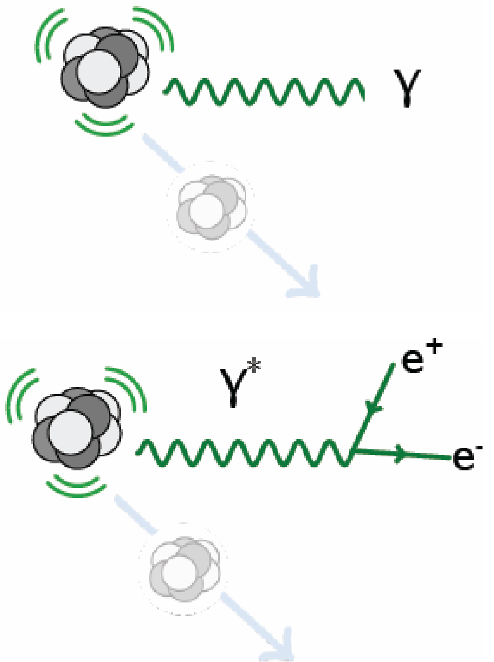
It has been suggested previously that pairs produced from the decay of a light particle can be distinguished from internal pairs by their angular correlation.

For a transition energy larger than M_x, the angular correlation between the electron and positron produced in the X decay is sharply peaked in the laboratory frame at a nonzero angle that varies inversely with the transition energy.

This method has been used previously by several groups to set upper limits on the branching ratio to such particles within certain limited mass and lifetime regions.

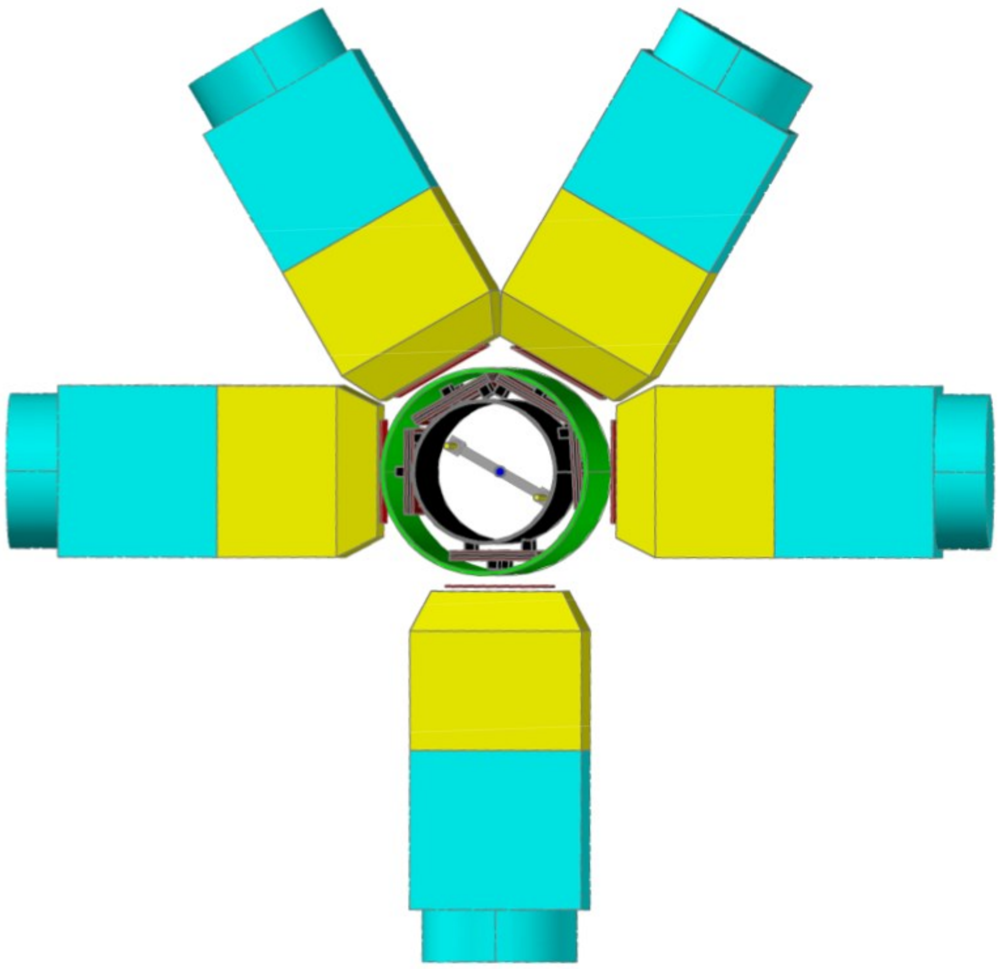
The creation and decay of ^{8}Be*





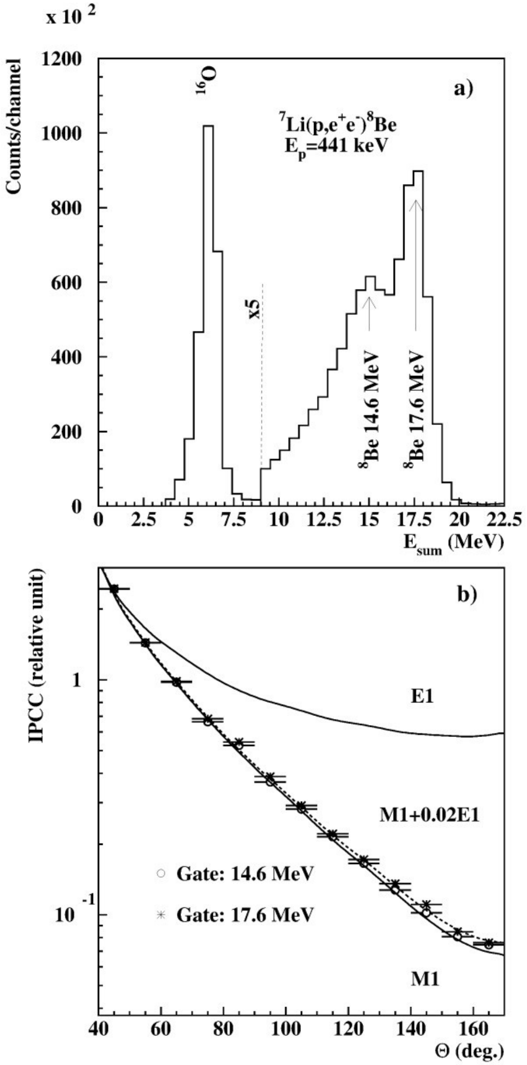
- Proton decay: B(p + ^{7}Li) ≈ 100%
- γ-decay: B(^{8}Be + γ) ≈ 1.5 x 10^{-5}
- Internal pair creation: B(^{8}Be + e^+ e^-) ≈ 5.5 x 10^{-8}
- Ejection of a new particle: B(^{8}Be + X) ≈ 5.5 x 10^{-10}

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

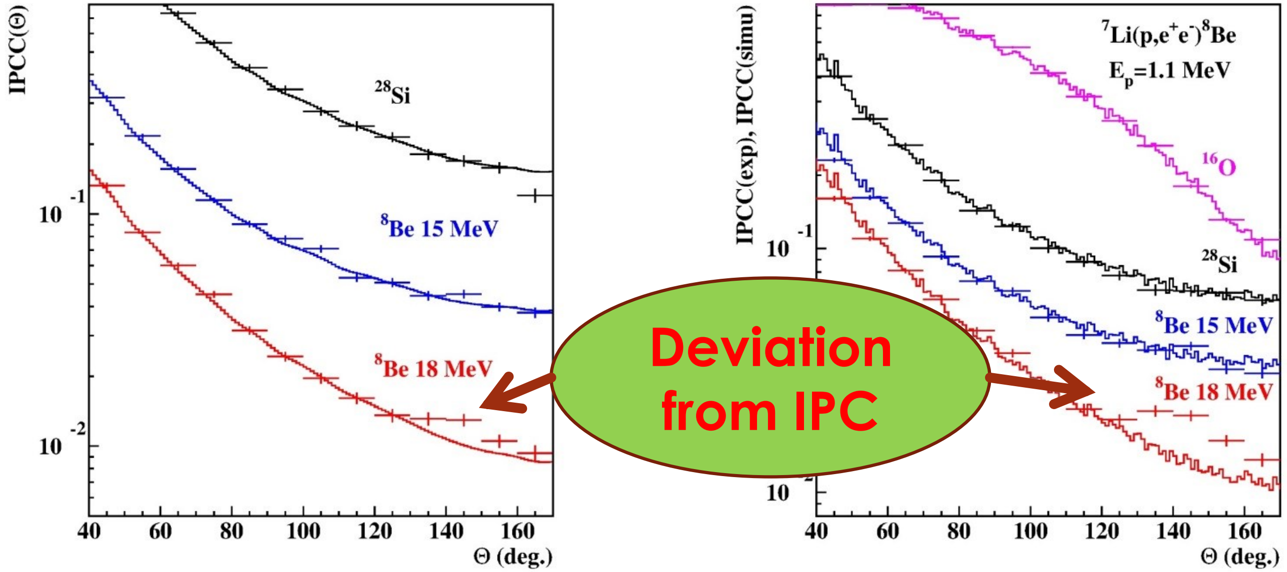


Results

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

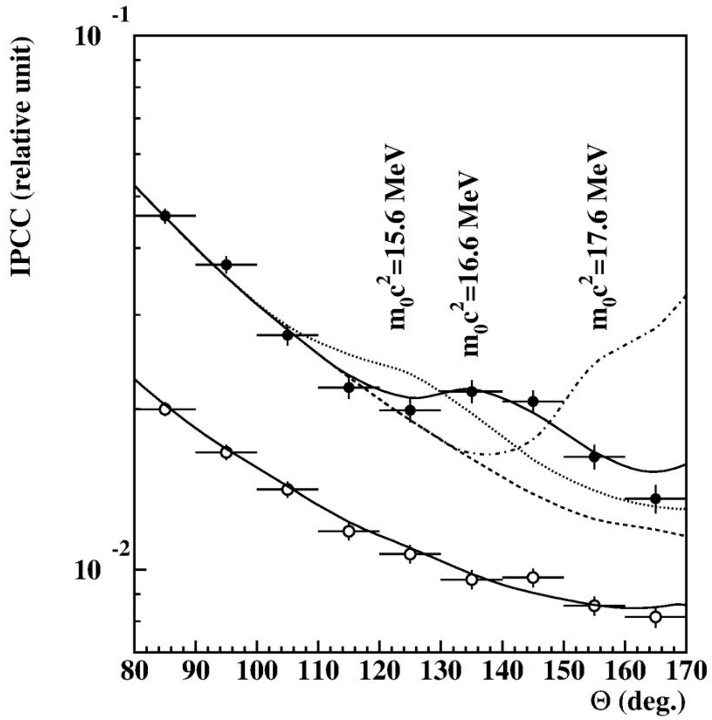


Ep=1.04 MeV Ep=1.10 MeV

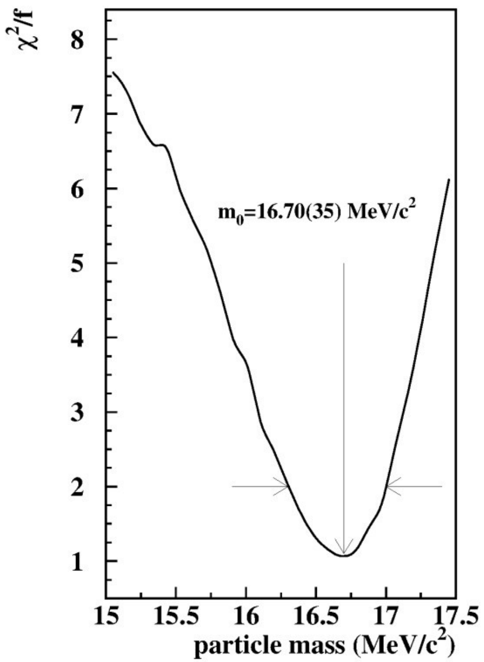


- Can it be some artificial effect caused by γ-rays?
- Can it be some nuclear physics effect?
- …

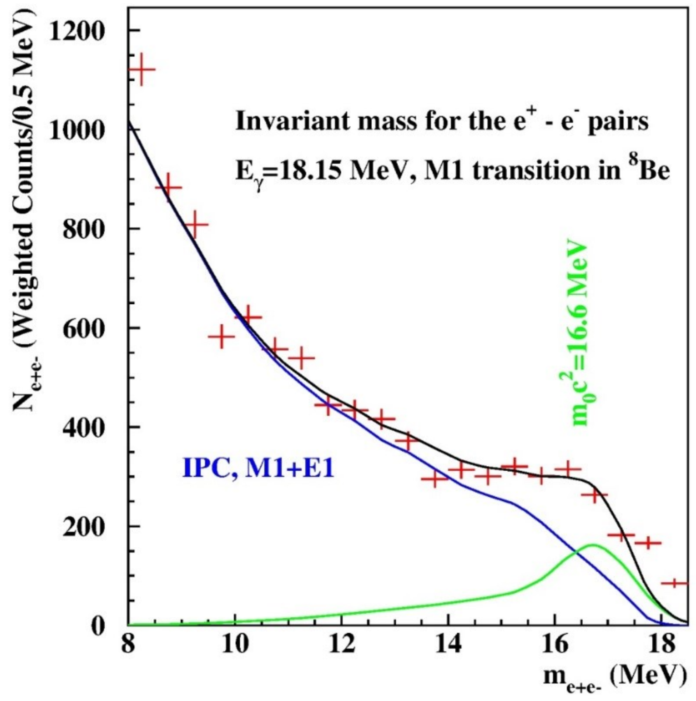
How can we understand the peak like deviation? Fitting the angular correlations



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), where y=(E1-E2)/(E1+E2).



Determination of the mass of the new particle by the X²/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: $\frac{B(^8\mathrm{Be}^* \to {}^8\mathrm{Be}\, X)}{B(^8\mathrm{Be}^* \to {}^8\mathrm{Be}\, \gamma)} = (\varepsilon_p + \varepsilon_n)^2 \frac{|\vec{p}_X|^3}{|\vec{p}_\gamma|^3} \approx 5.6 \times 10^{-6}$

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

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

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

Physics Letters B 773 (2017) 159–165

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Can nuclear physics explain the anomaly observed in the internal pair production in the Beryllium-8 nucleus?

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ABSTRACT

Recently the experimentalists in Krasznahorkay (2016) [1] announced observing an unexpected enhancement of the e^+–e^- pair production signal in one of the ^{8}Be nuclear transitions. The subsequent studies have been focused on possible explanations based on introducing new types of particle. In this work, we improve the nuclear physics modeling of the reaction by studying the pair emission anisotropy and the interferences between different multipoles in an effective field theory inspired framework, and examine their possible relevance to the anomaly. The connection between the previously measured on-shell photon production and the pair production in the same nuclear transitions is established. These improvements, absent in the original experimental analysis, should be included in extracting new particle's properties from the experiment of this type. However, the improvements can not explain the anomaly. We then explore the nuclear transition form factor as a possible origin of the anomaly, and find the required form factor to be unrealistic for the ^{8}Be nucleus. The reduction of the anomaly's significance by simply rescaling our predicted event count is also investigated.

Promising Outlook (It will take several years to get results...)

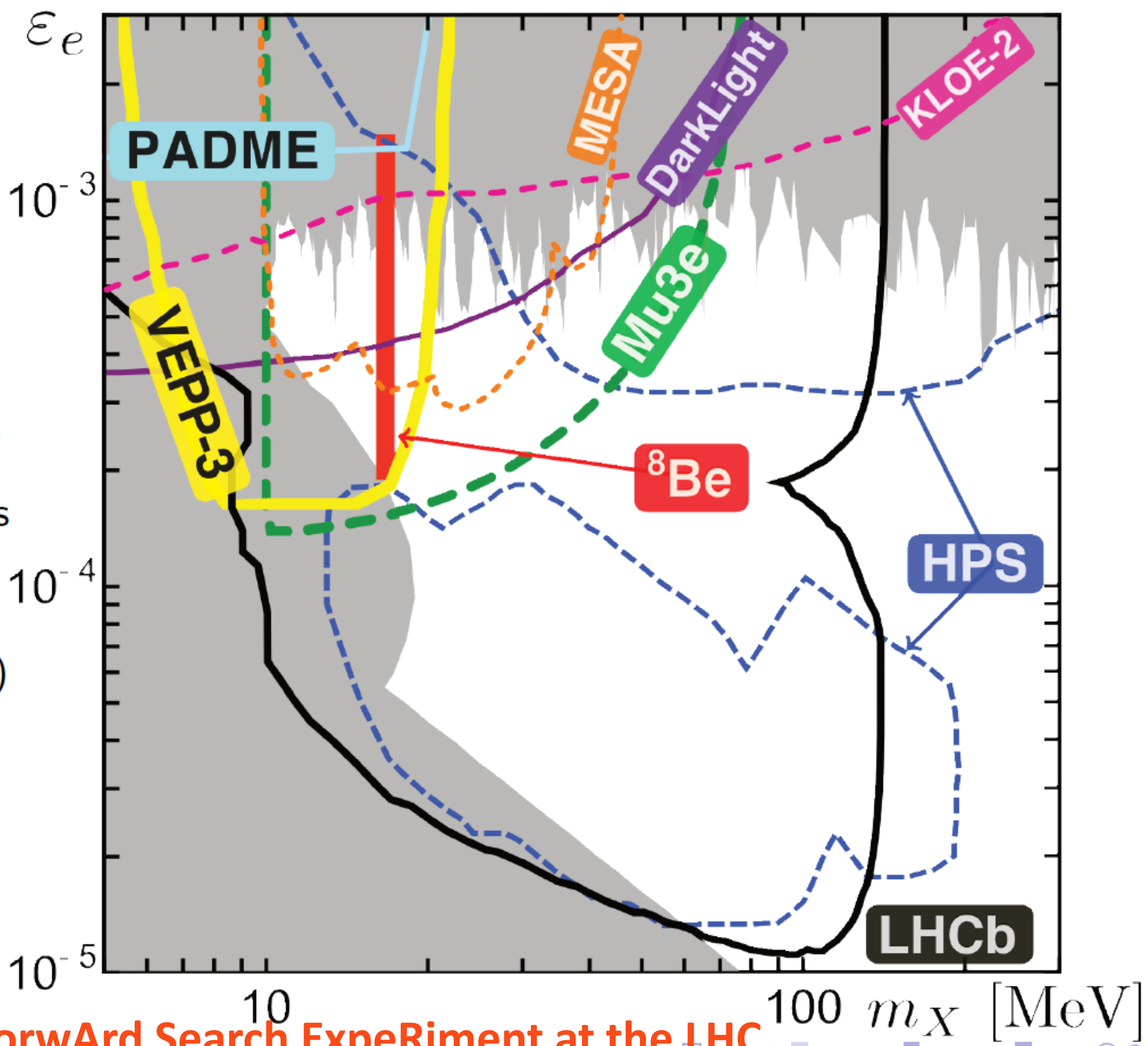
IPC:

- verify $^{8}\mathrm{Be}$
- $^{10}\mathrm{B}$: 19.3 MeV
- $^{10}\mathrm{Be}$: 17.79 MeV

Purdue Univ., USA
Hanoi, Vietnam
Orsay, France

More Exp:

- TUNL (HIGS facility γ *Nuc*)
- TREK@JPARC: K^{+} Decays
- SHIP
- SeaQuest (Gardner & Holt)
- VdG UK
- BESIII (arXiv:1607.03970)



Prob UV

- ATLAS, CMS, FASER: ForwArd Search ExpeRiment at the LHC

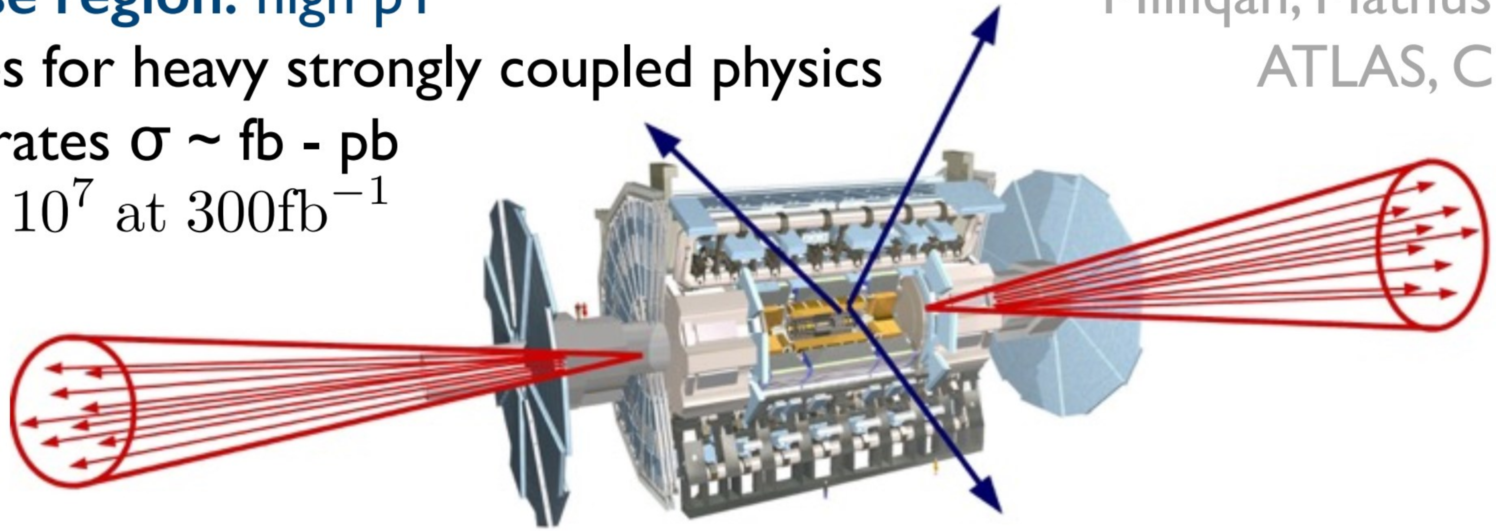
Searching for light particles (dark photos, X17, APS's) at LHC

transverse region: high pT

- searches for heavy strongly coupled physics
- typical rates σ ~ fb - pb

$$N_H = 10^7 \text{ at } 300\text{fb}^{-1}$$

Milliqan, Mathusla, Codex-b
ATLAS, CMS



forward region

- mostly used for SM measurement

LHCf, TOTEM, ALFA, CASTOR

- **enormous** event rates: $\sigma_{inel} \sim 75\text{ mb}:\ N_\pi = 10^{17} \text{ at } 300\text{fb}^{-1}$

→ extremely weakly-coupled **long-lived** particles may be produced sufficiently

- most particles have small pT $\sim \Lambda_{QCD}$

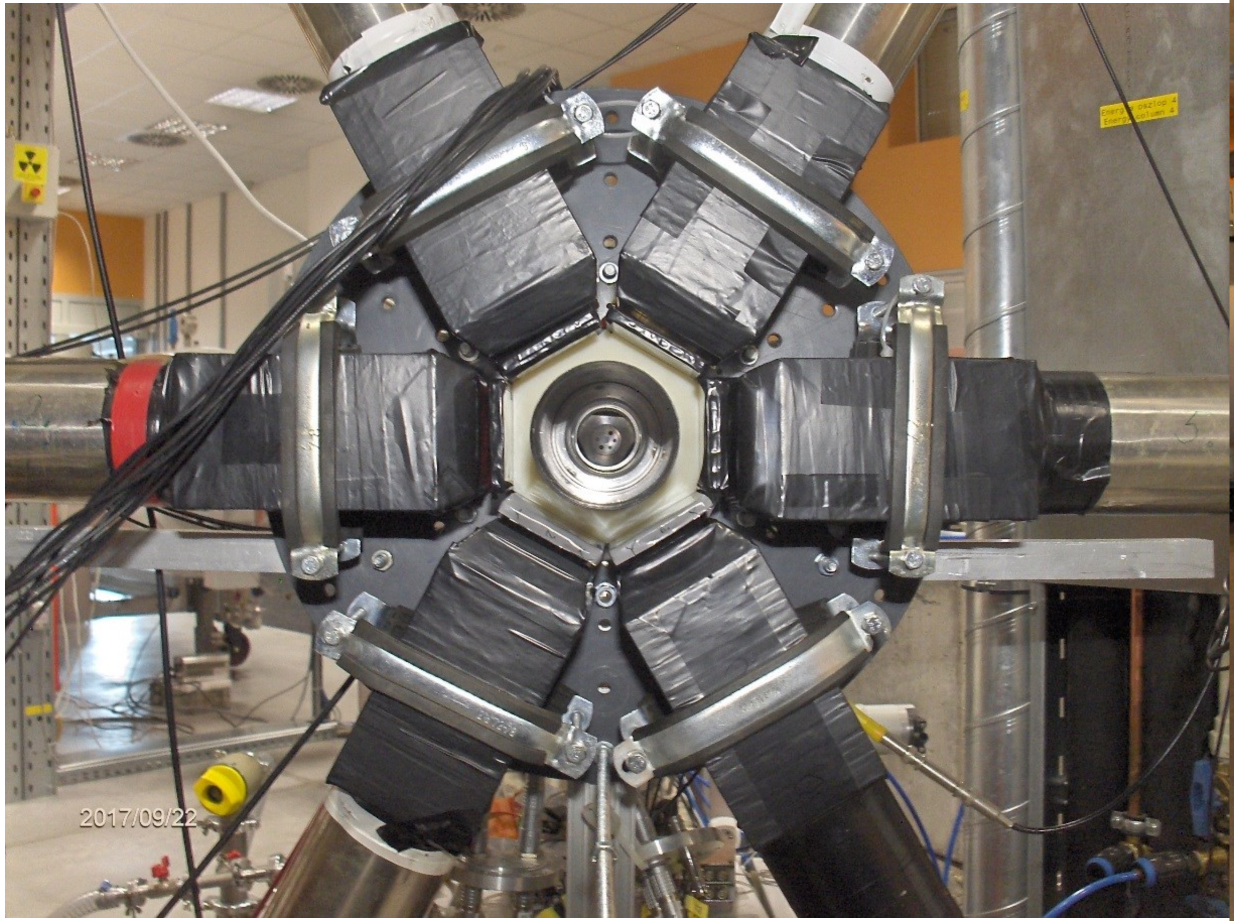
→ energetic particles highly **collimated** $\theta \sim \Lambda_{QCD}/E \sim \text{mrad}$ for $E \sim \text{TeV}$

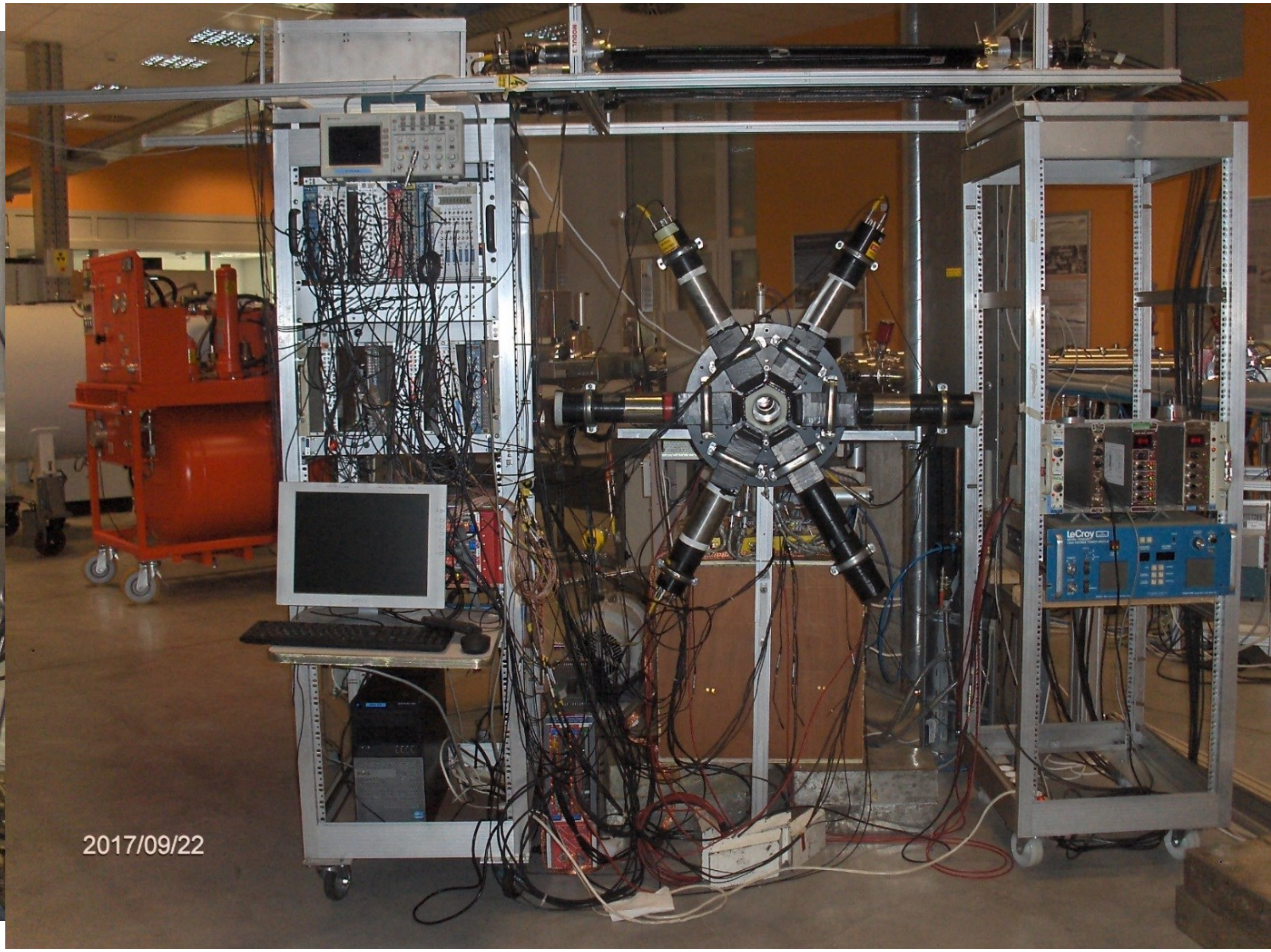
- we propose small ($\sim 1\text{ m}^3$) inexpensive detector a few 100 m downstream

→ **FASER: F**orw**A**rd **S**earch **E**xpe**R**iment at the LHC

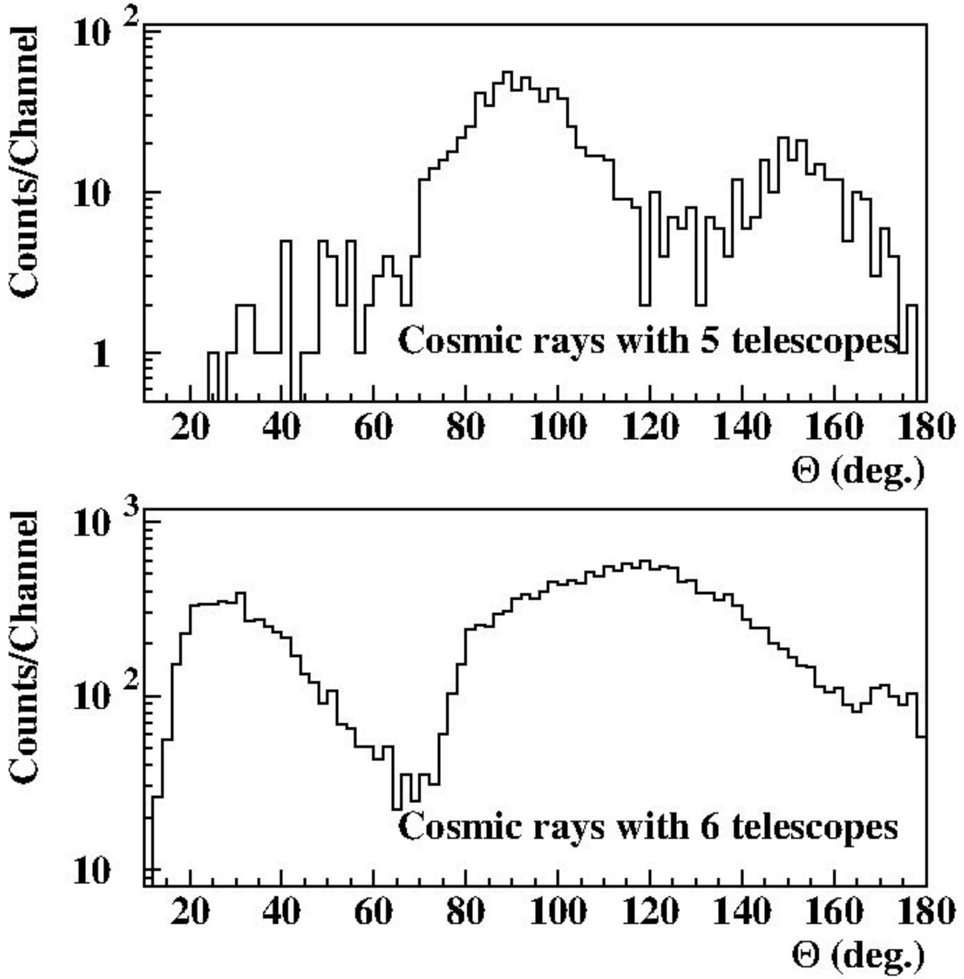
Repeating the experiments at a new Medium-Current Tandetron Accelerator System in Atomki Debrecen

The new e^+e^- pair spectrometer with six telescopes equipped with Si DSSD's

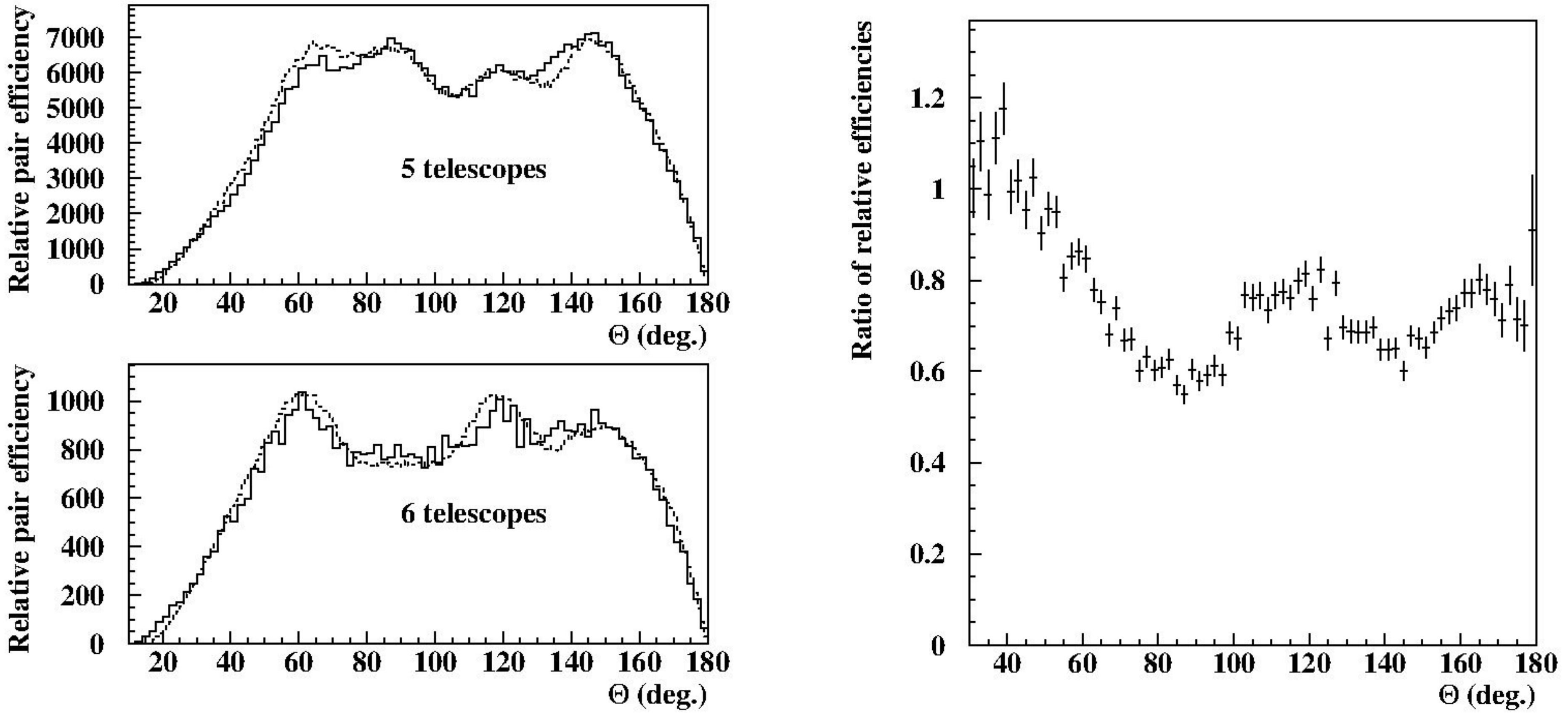




Background from cosmic rays in the setups with 5 and 6 telescopes

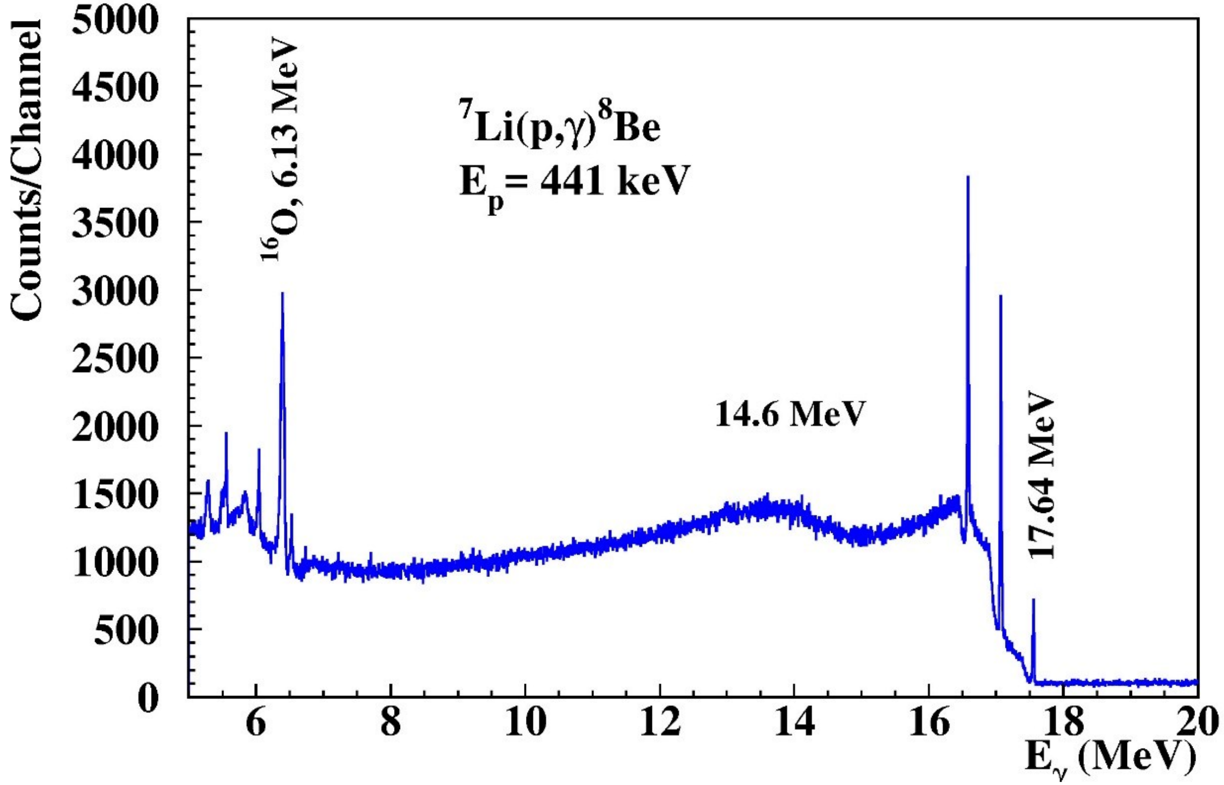


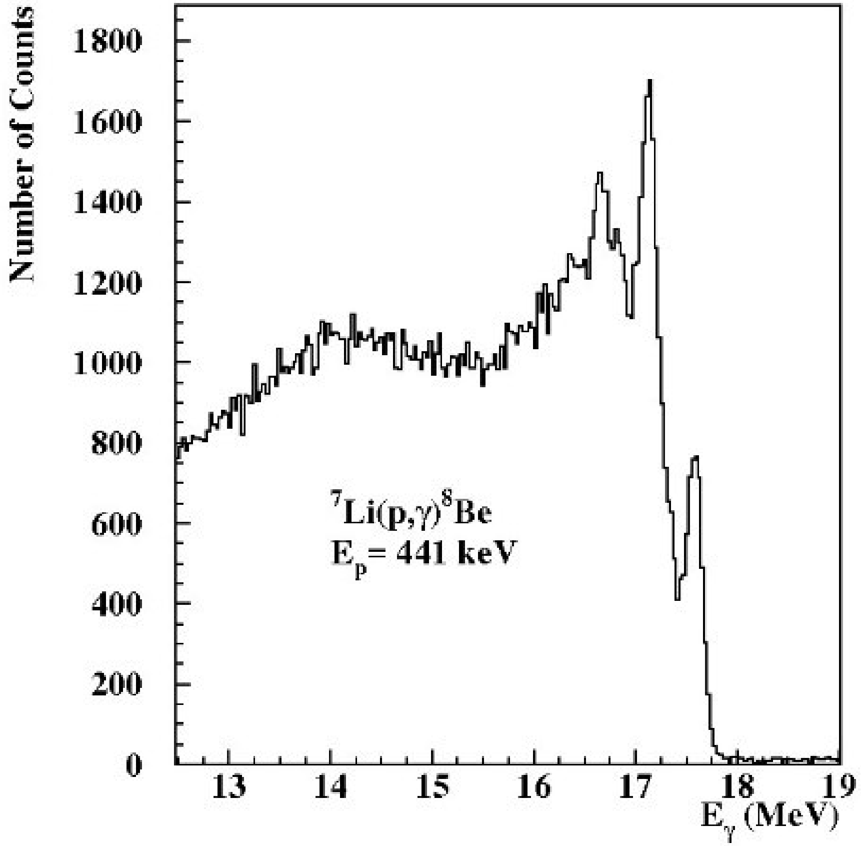
Efficiency curves for the setups with 5/6 telescopes



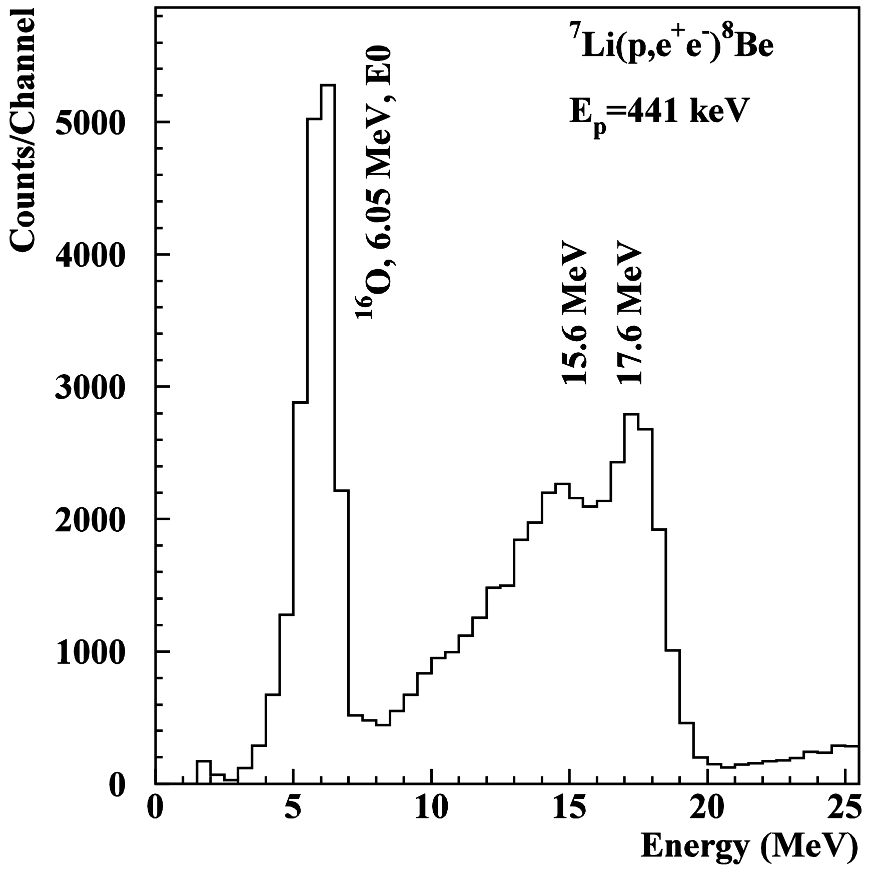
The results of the present experiment can be cosidered independent from the one we published in PRL in 2016.

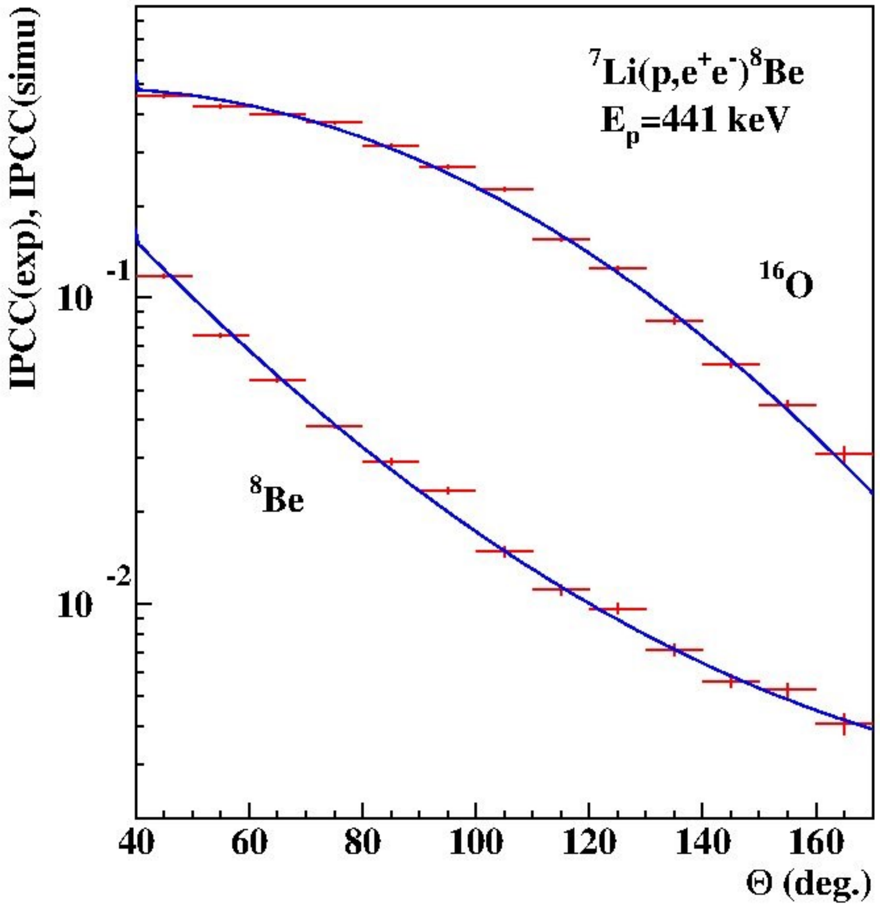
γ-ray spectra measured with a 100% HpGe detector and a 3”x3” $LaBr_3$ one



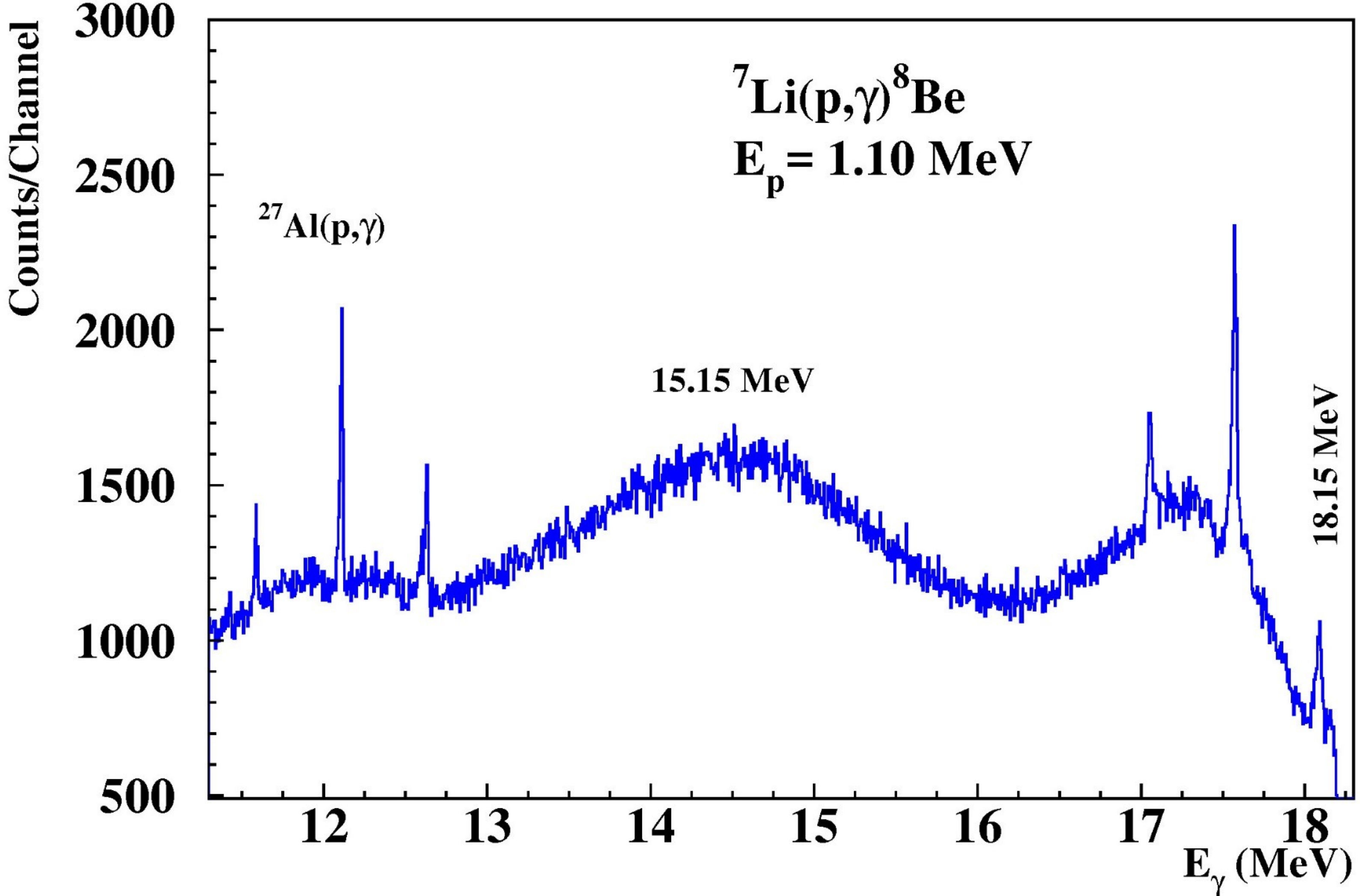


Recent results for the 17.6 MeV transition

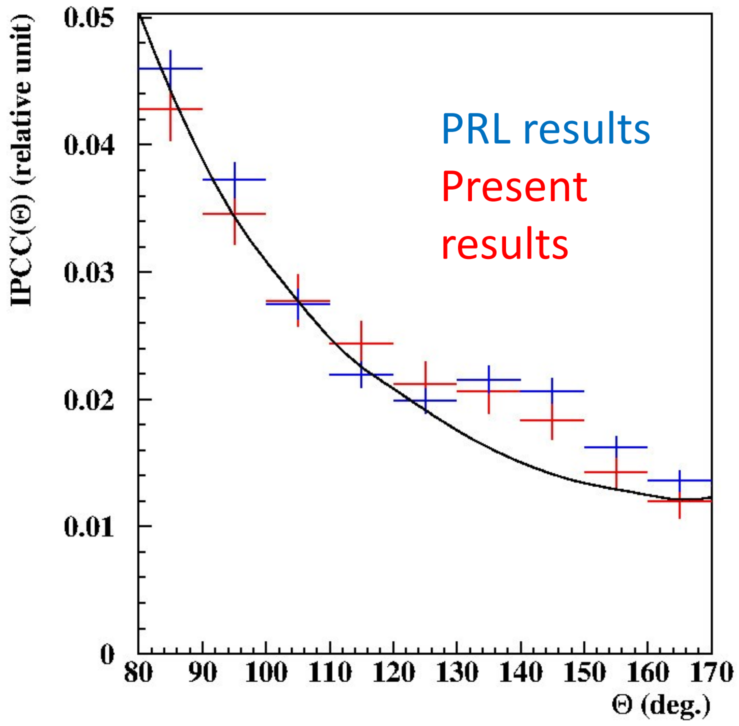




γ-ray spectrum measured at the E_p=1.04 MeV resonance with a 100% HpGe detector



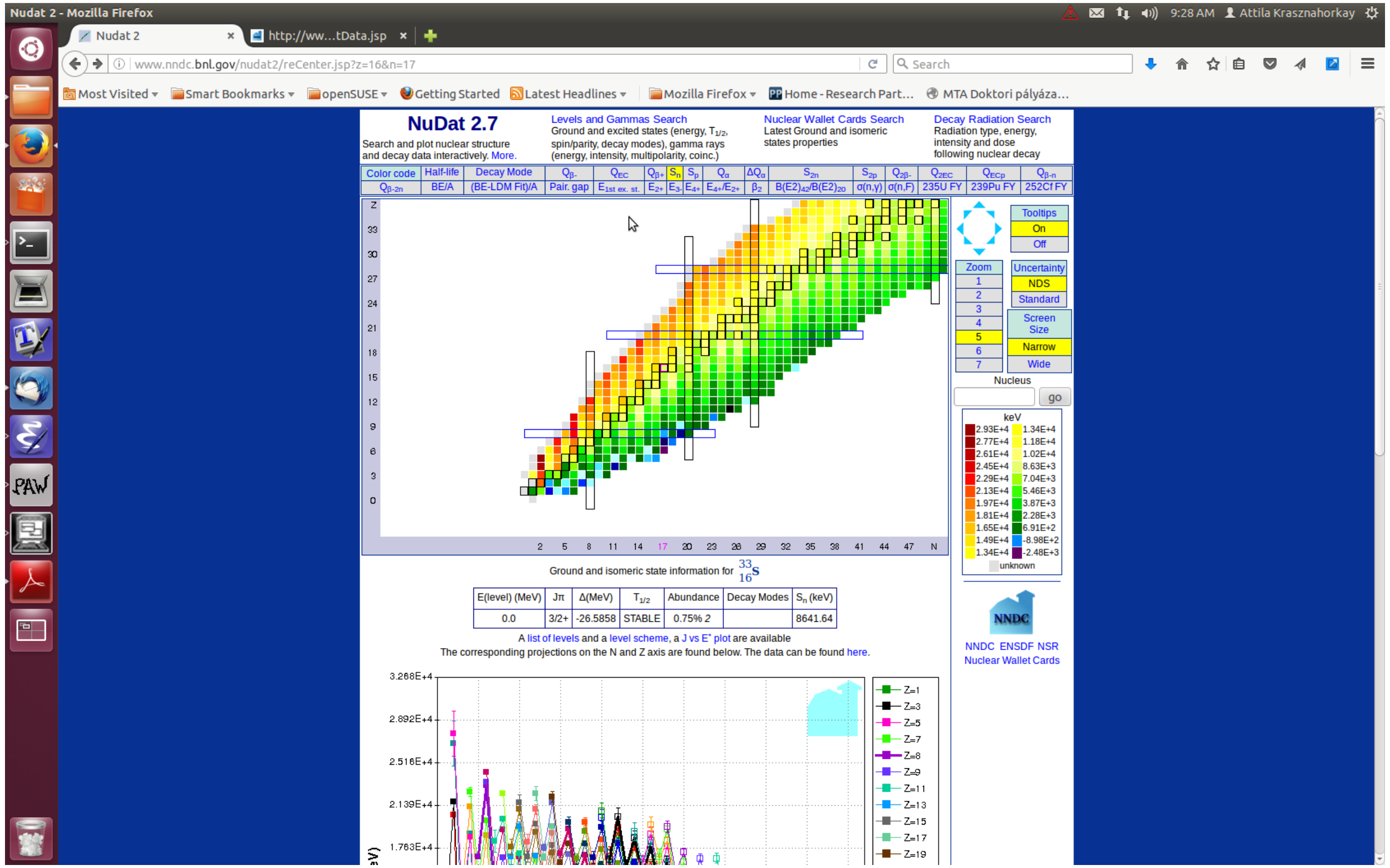
Recent results for the 18.15 MeV transition



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

	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	

How to proceed? S(n) and S(p) data from NuDat 2.7

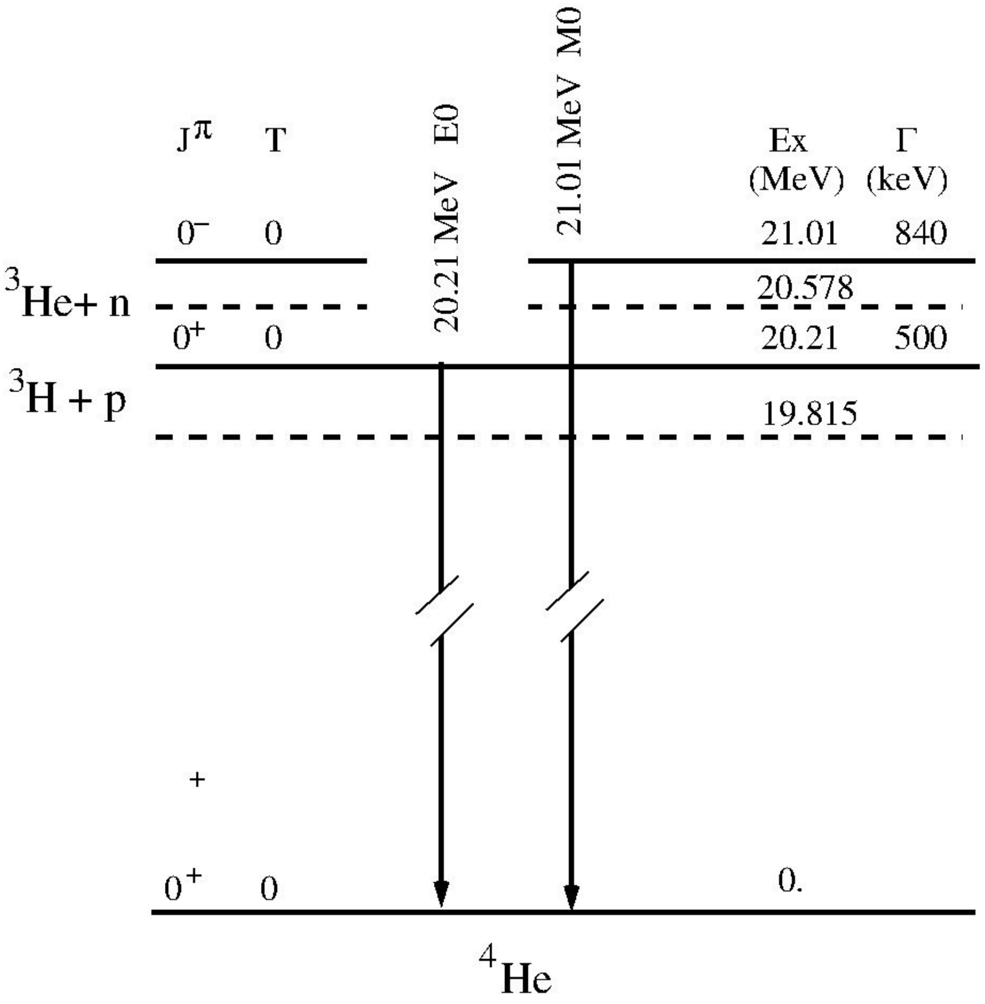


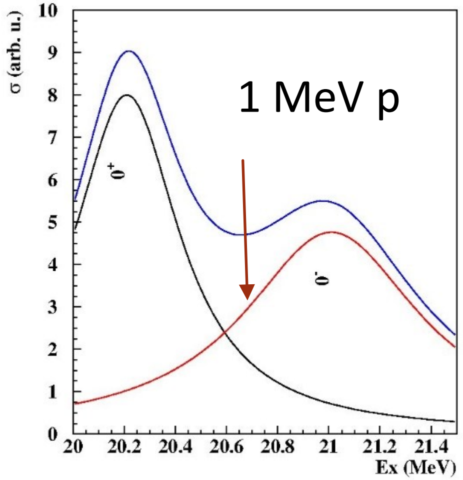
- Long lived excited state

Isotope	S(n)	S(p)
^{4}He	20.6 MeV	19.8 MeV
^{8}Be	18.9 MeV	17.3 MeV
^{12}C	18.7 MeV	16.0 MeV

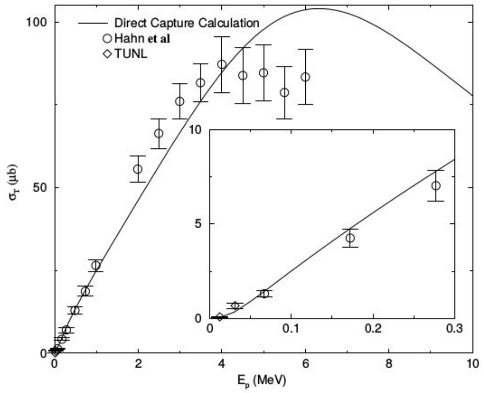
- M1 or M0 transitions
- Proper reaction for the excitation
- No background reactions

Study of the 21 MeV M0 transition in ^{4}He excited by ^{3}He+n, and t+p reactions





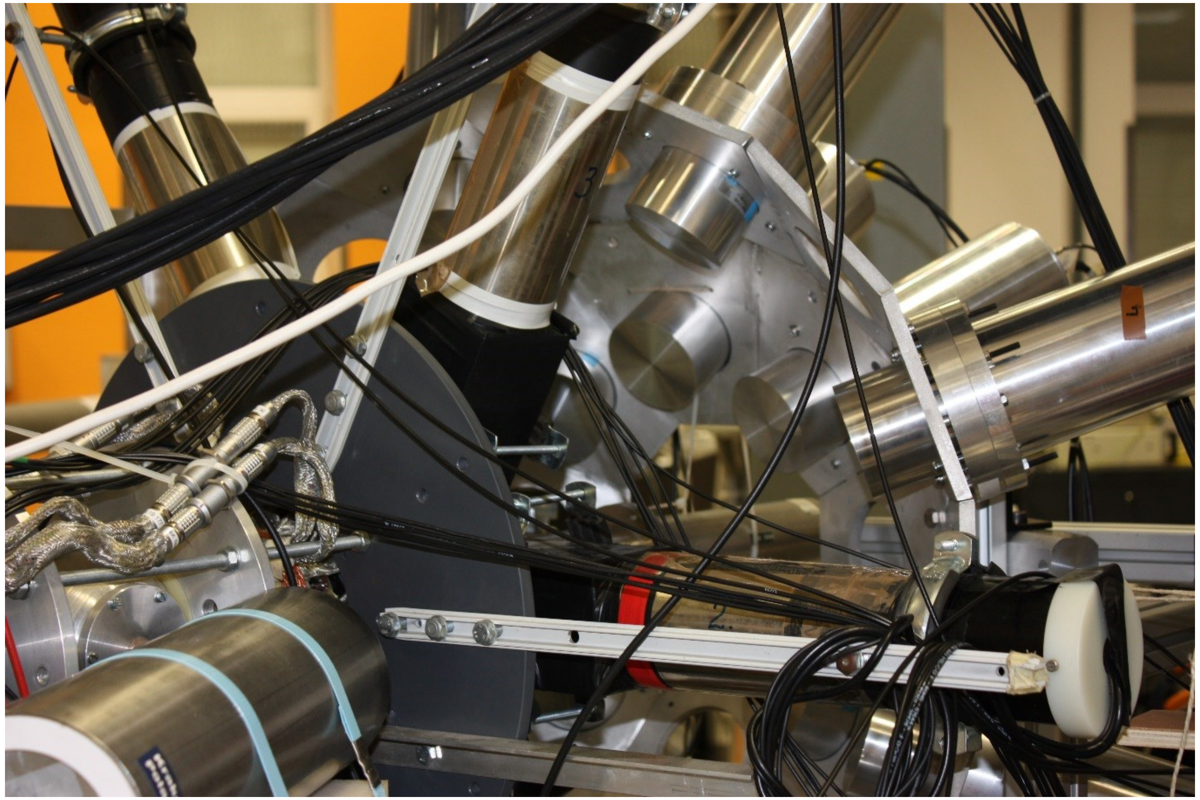
Overlapping 0^+ and 0^- states



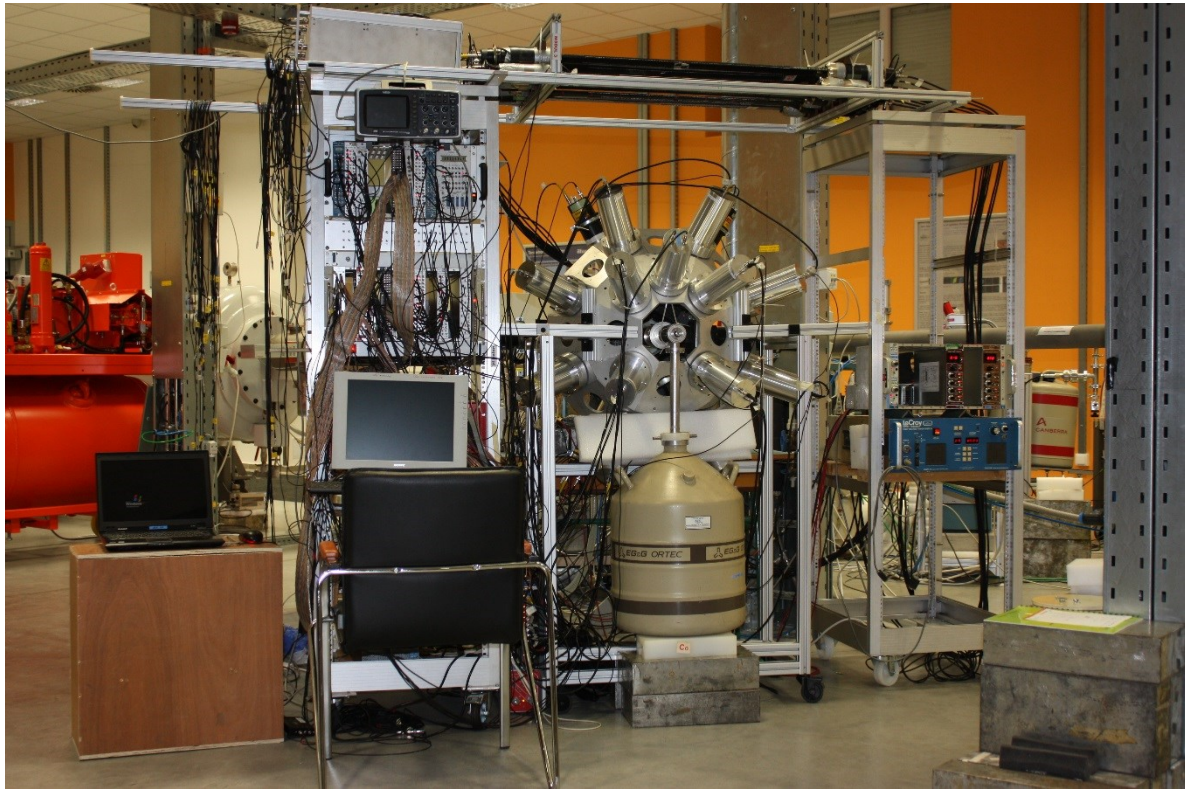
γ-ray production with direct proton capture. A source of background.

The ^{3}H(p,γγ)^{4}He experiment in Debrecen

Cooled (LN_2), ^{3}H absorbed in Ti (3 mg/cm2) on a 0.4 mm thick Mo disc (target for neutron generator)

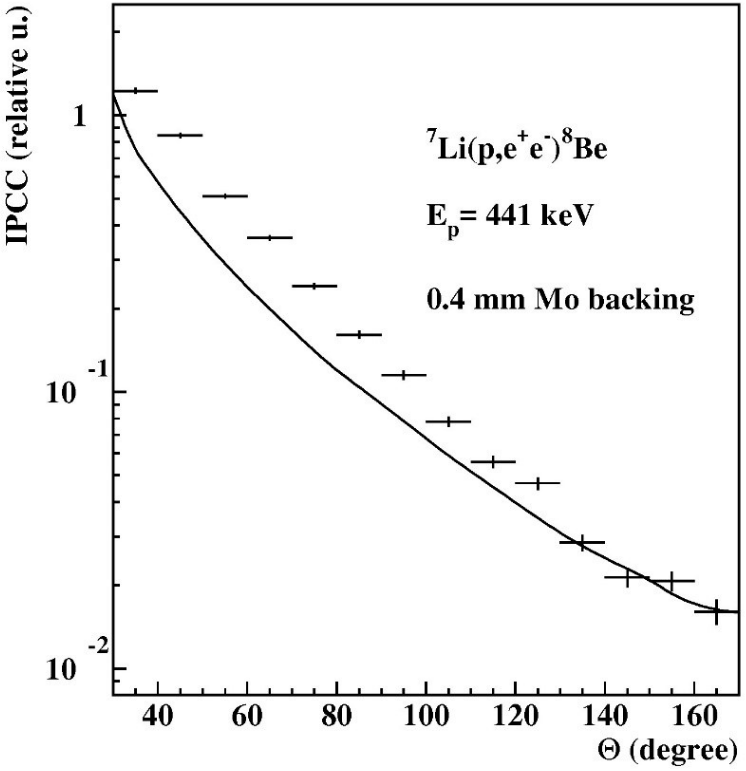


e+ e- spectrometer with six DSSD+calorimeter telescopes



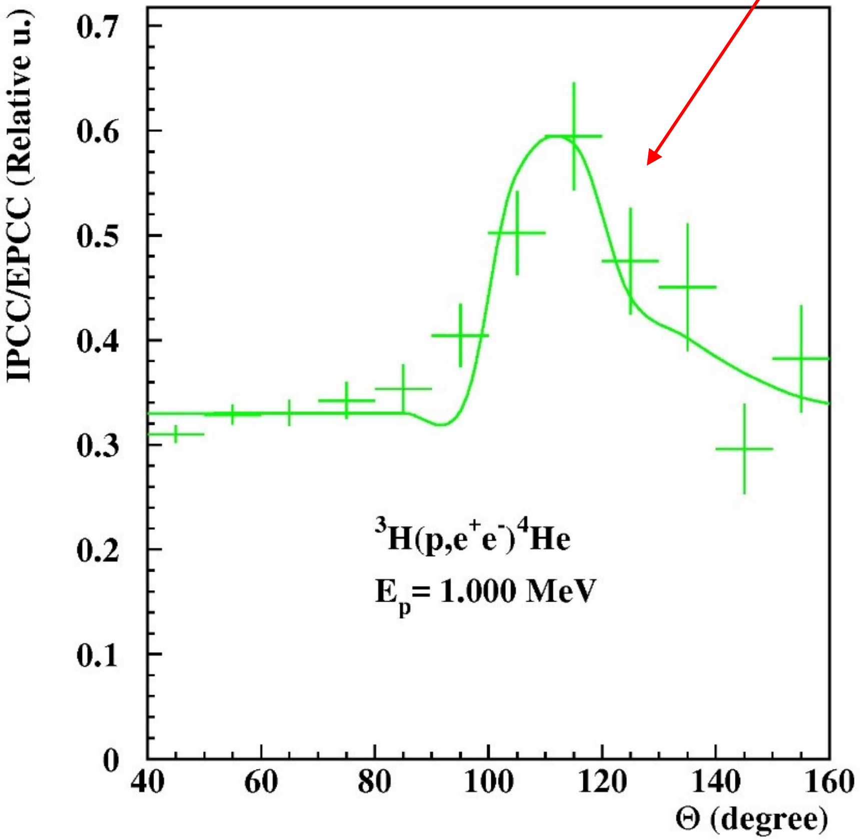
γ-spectrometer with twelve, 3”x3” and two 3.5”x6” LaBr3 detectors

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



The external pair creation in the Mo target backing was about 5 times stronger the IPC.

M_0c^2= 16.6 MeV



Measured e+e- pair correlation divided by the external pair creation.

How can we choose between the different interpretations?

PRL **117,** 071803 (2016) PHYSICAL REVIEW LETTERS week ending 12 AUGUST 2016

Protophobic Fifth-Force Interpretation of the Observed Anomaly in ^{8}Be Nuclear Transitions

Jonathan L. Feng,[1] Bartosz Fornal,[1] Iftah Galon,[1] Susan Gardner,[1,2] Jordan Smolinsky,[1] Tim M. P. Tait,[1] and Philip Tanedo[1]
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Possible explanation of the electron positron anomaly at 17 MeV in ^{8}Be transitions through a light pseudoscalar

Ulrich Ellwanger[a,b] and Stefano Moretti[b]

Axions and other very light axion-like particles appear in many extensions of the Standard Model, and are leading candidates to compose part or all of the missing matter of the Universe.

The lack of positive signal of new physics at the high energy frontier, and in underground detectors searching for weakly interacting massive particles, is also contributing to the increase of the interest in axion searches.

The experimental landscape is rapidly evolving, with many novel detection concepts and new experiments being proposed lately.

Study the $\gamma\gamma$-decay of X(17) in ^{4}He

- Vector particle (1+) or axialvector (0-)?
- If vector particle then $\gamma\gamma$ emission is forbidden (Landau-Yang theorem).
- If axialvector then it can decay by $\gamma\gamma$ emission.

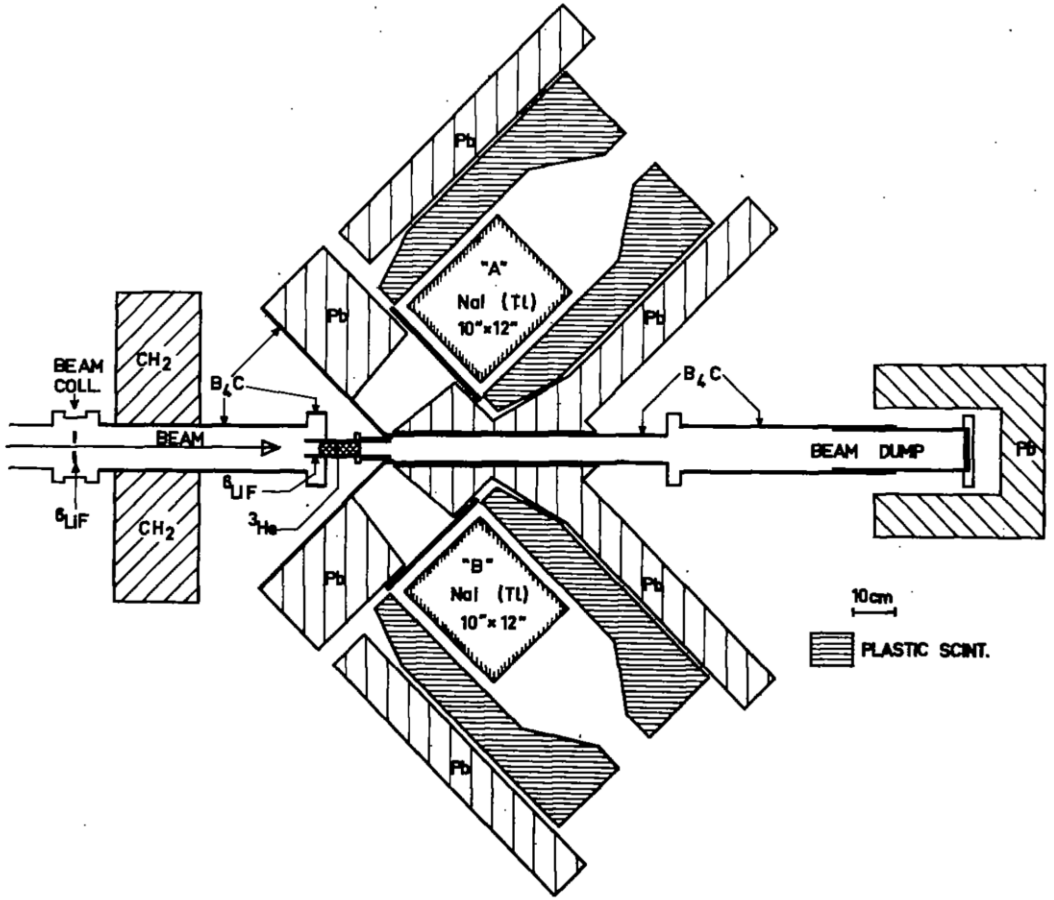
- $\gamma\gamma$-decay only known in a special case: $0^+ \rightarrow 0^+$ (^{90}Zr, ^{40}Ca, ^{16}O) ^{4}He
  - *J. Schirmer et al., PRL 53, 1897 (1984)*
  - *J. Kramp et al., NPA 474, 412 (1987)*
- Walz, N. Pietrala et al., Competitive Double-Gamma' ($\gamma\gamma/\gamma$) Decay *Nature* **526**, 406 (2015)

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

Study the angular correlation with $LaBr_3$ detectors.

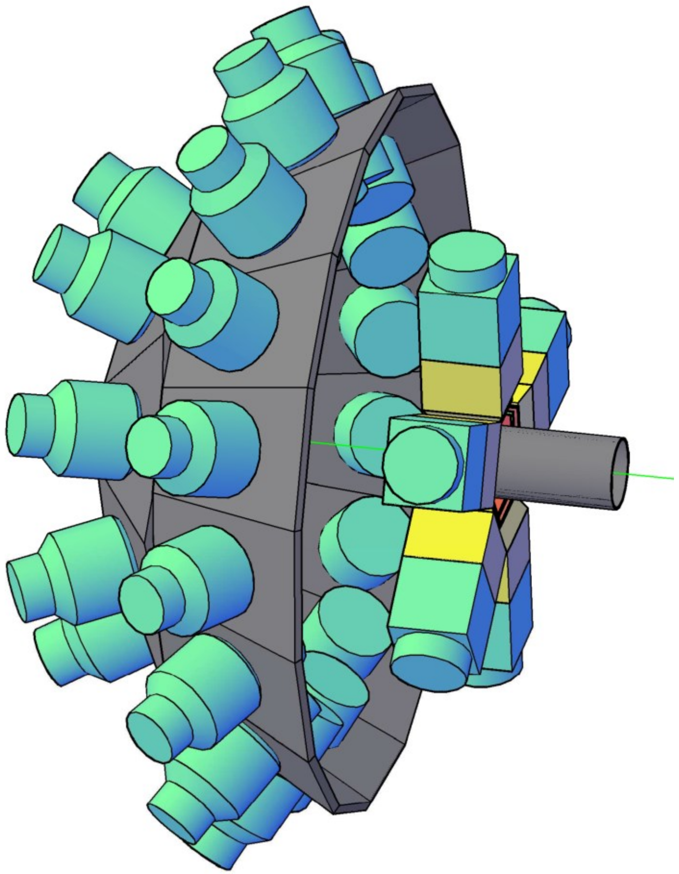
Double γ-decay in ^4He

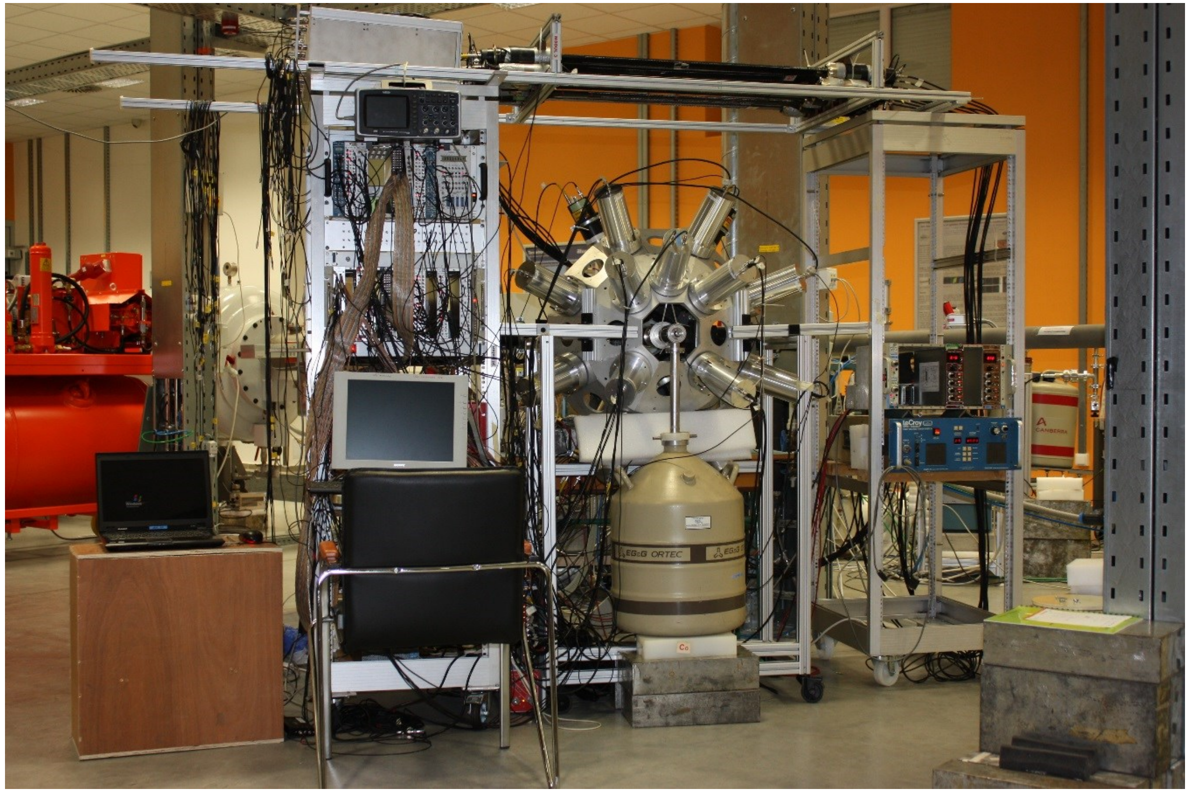
(M. Suffert and R. Berthollet, Nucl., Phys. A318 (1979) 54.)



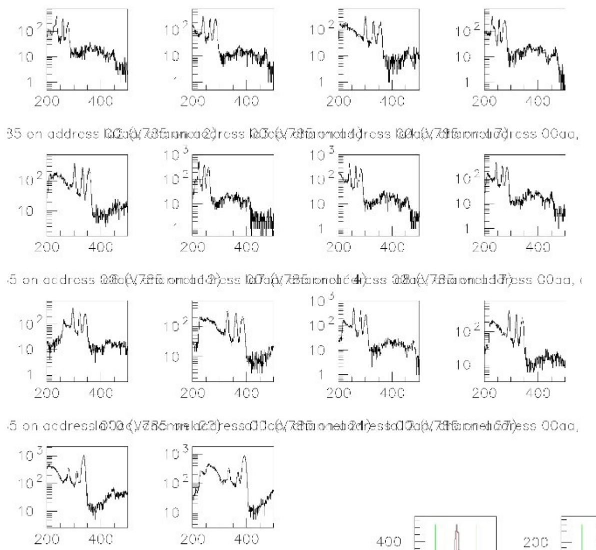
The most recent theoretical calculations taking into account the p+ ^3H resonance at E≈ 20 .2 MeV give Q(2γ) = 1 .18 μb and R ≈ 0.03 i.e . about ten times less .

The experimental setup in Debrecen including both the e^+e^- and the γ-ray spectrometers

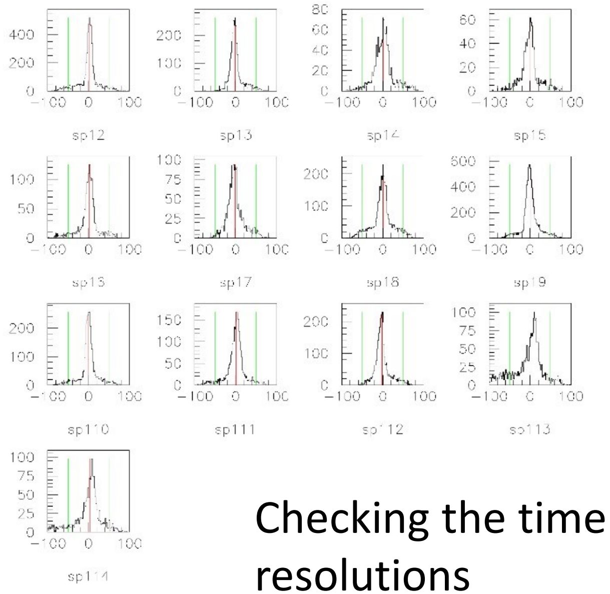




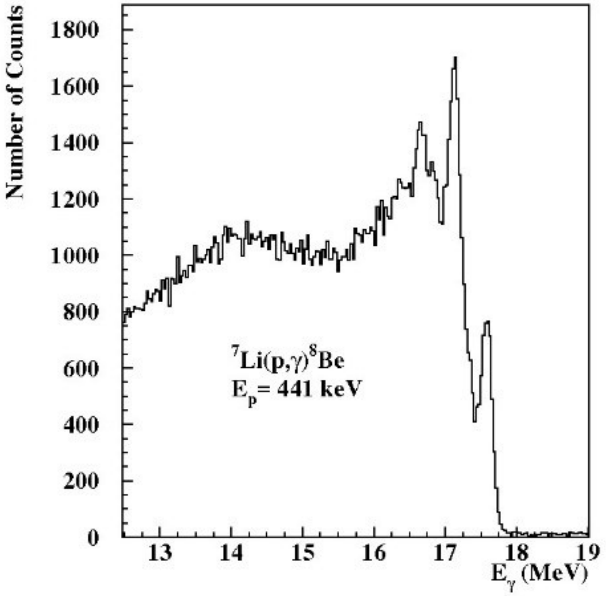
Calibration of the $LaBr_3$ γ-ray spectrometers



Checking the energy resolutions with a ^{60}Co source

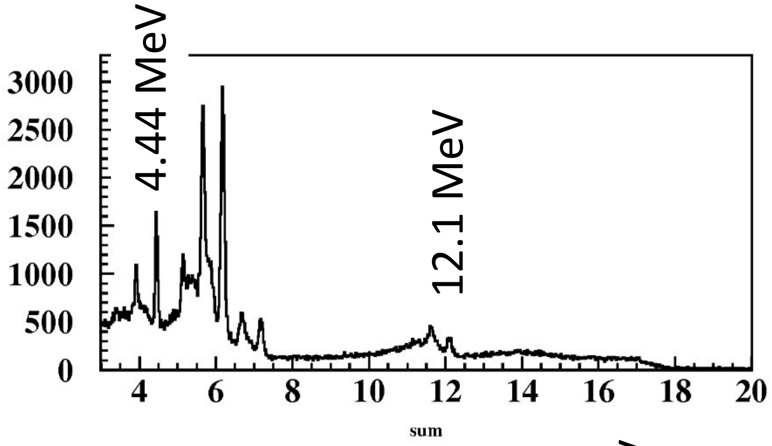


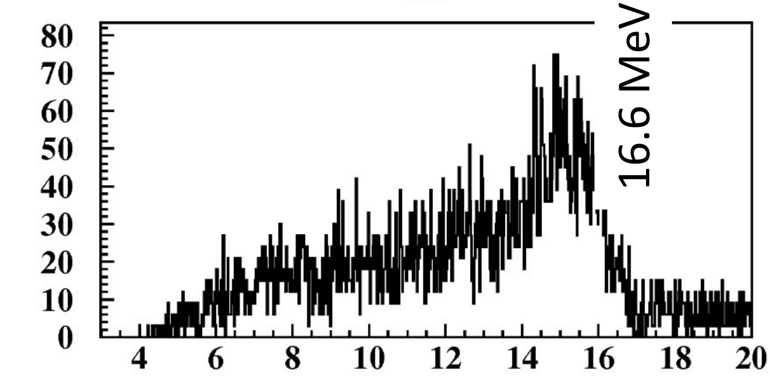
Checking the time resolutions



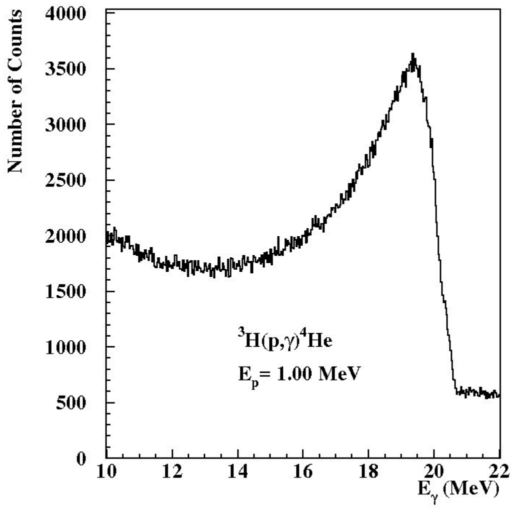
Calibration with the 17.6 MeV transition in ^{8}Be

Calibration with the 12.1 – 4.44 MeV γγ cascade in ^{12}C using the 11B(p,γ) reaction at E_p=675 keV.

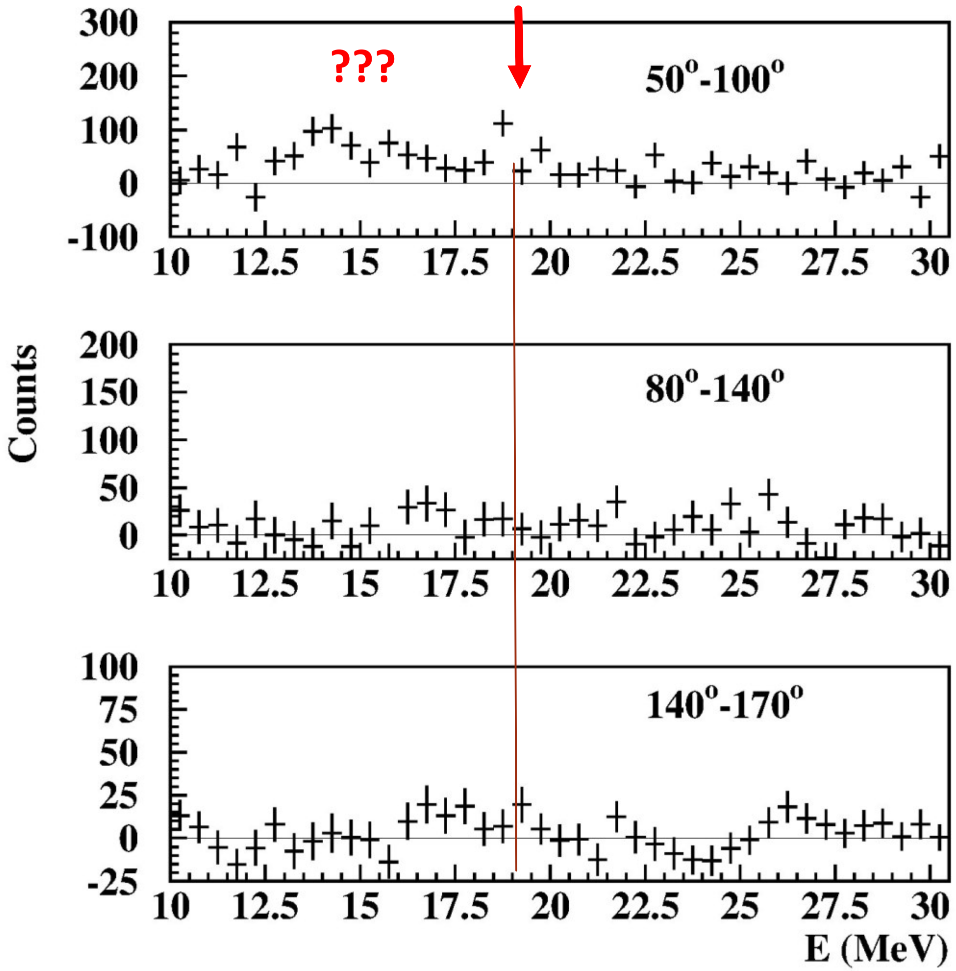




Two photon sum-energy distributions measured at different angular regions (very preliminary)



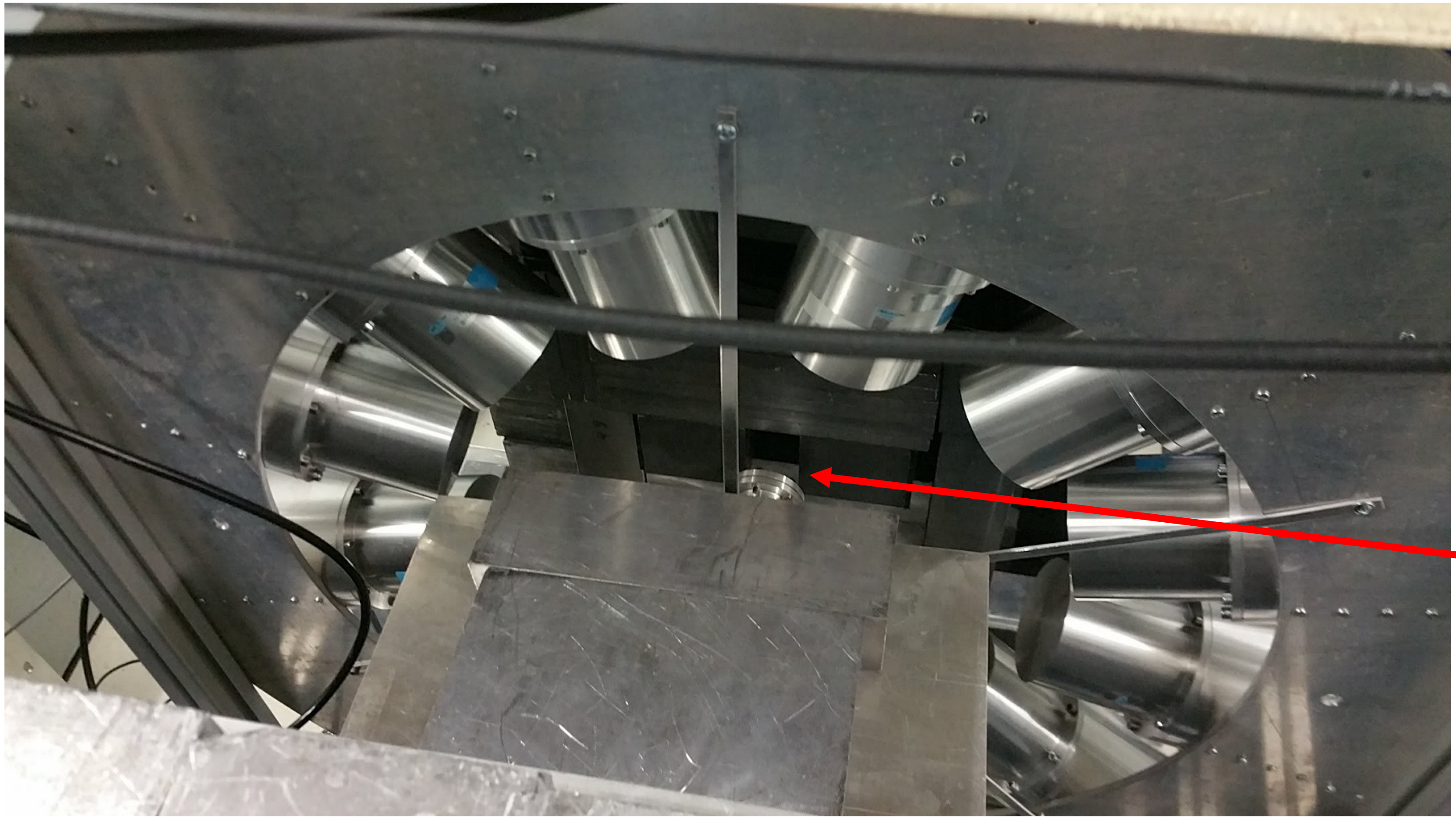
A typical γ-ray spectrum.
(The proton energy loss in the target was about 400 keV, so the photo peak was washed out.)



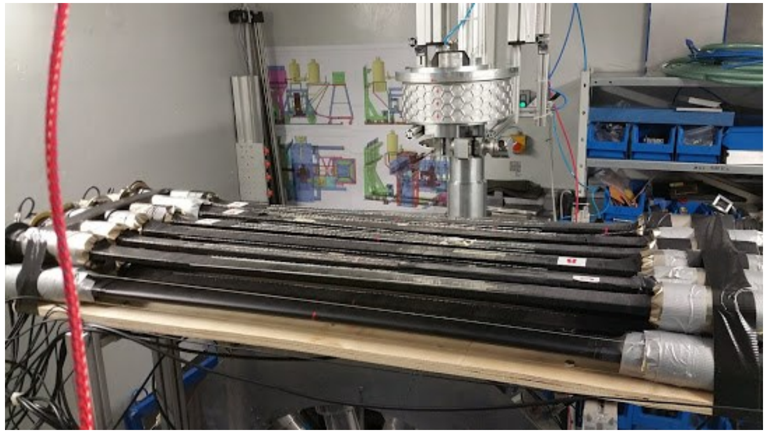
Sum energy spectra for coincident detectors.

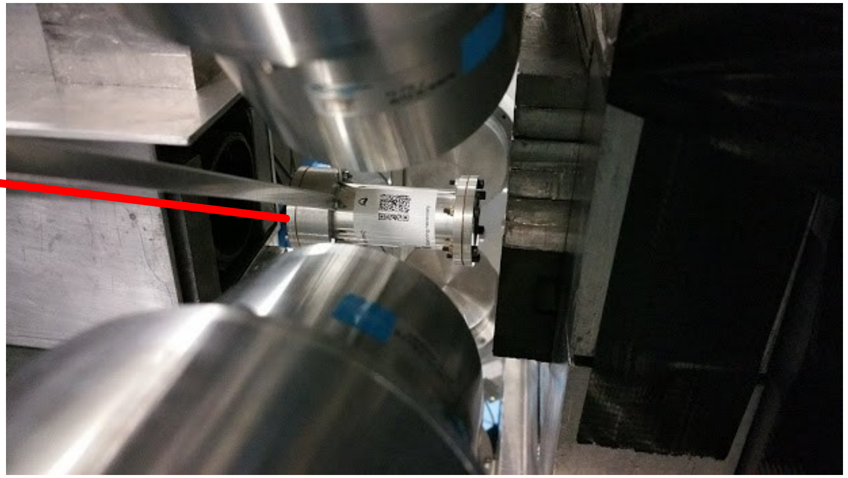
Problems with the background (random, cosmic) subtraction???

The $^{3}He(n,\gamma\gamma)^{4}He$ experiment in Garching with the FRM II High Flux Reactor (10^{10} cold n/cm2)



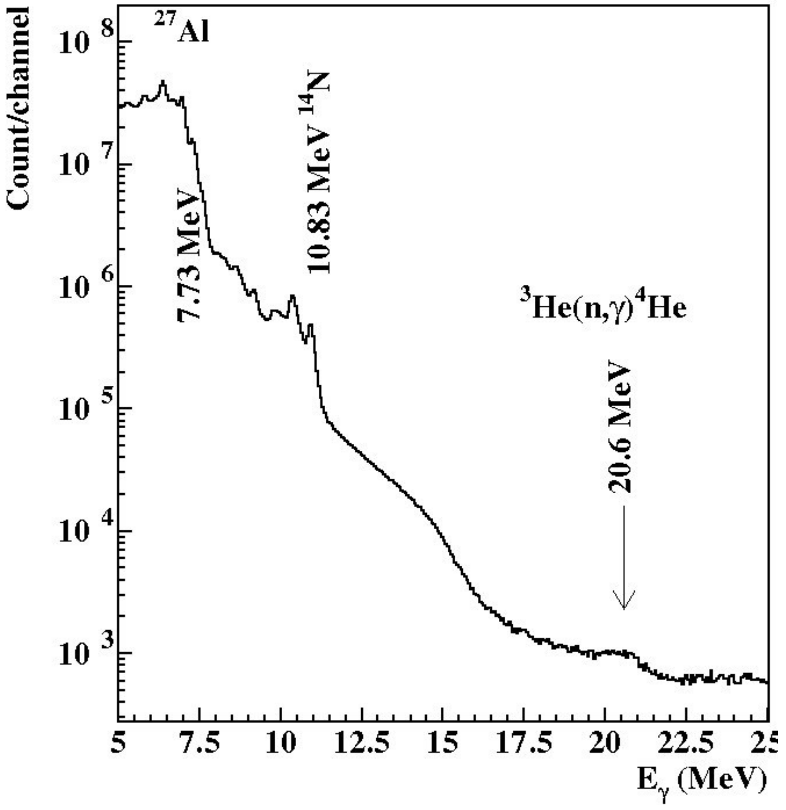
Coincidence γ-ray spectrometer with twelve 3”x3” LaBr3 detectors. The angle between the detectors is 30 degree, and the detector plain Is perpendicular to the beam.



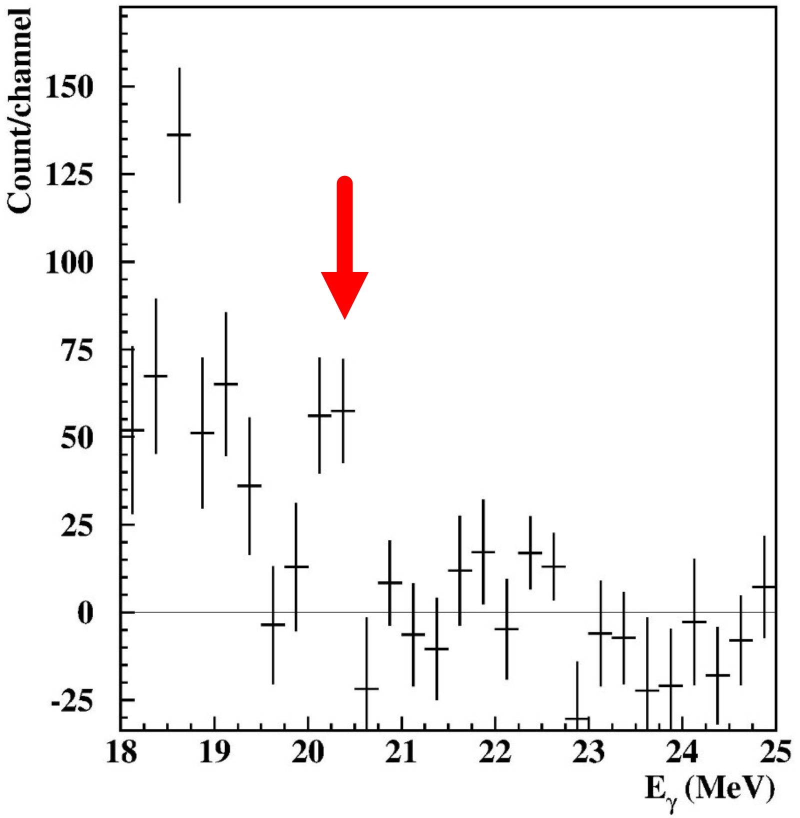


The pressurized (2 bar) ^{3}He target located in the middle of the spectrometer, and the active cosmic-ray shield (above).

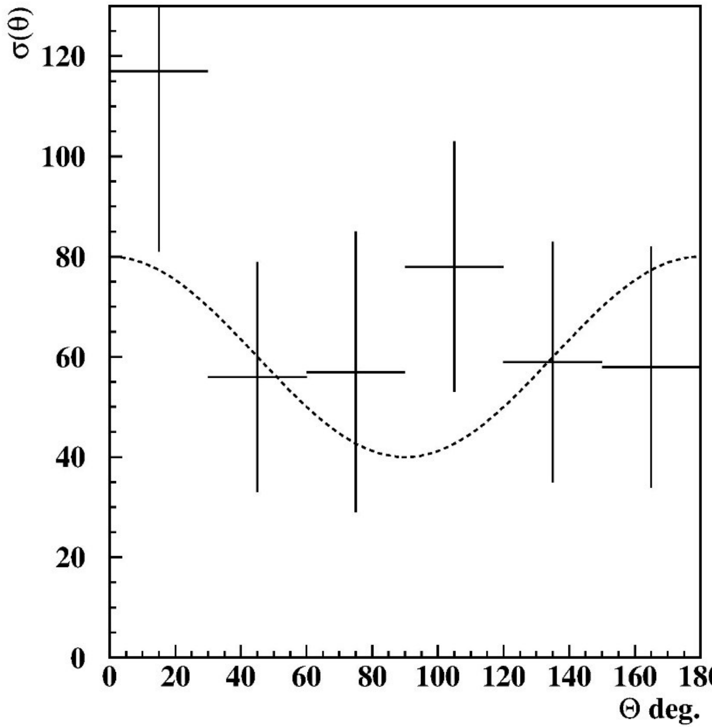
The first results in Garching



A typical singles γ-ray spectrum



Typical sum-energy spectra for coincident detectors

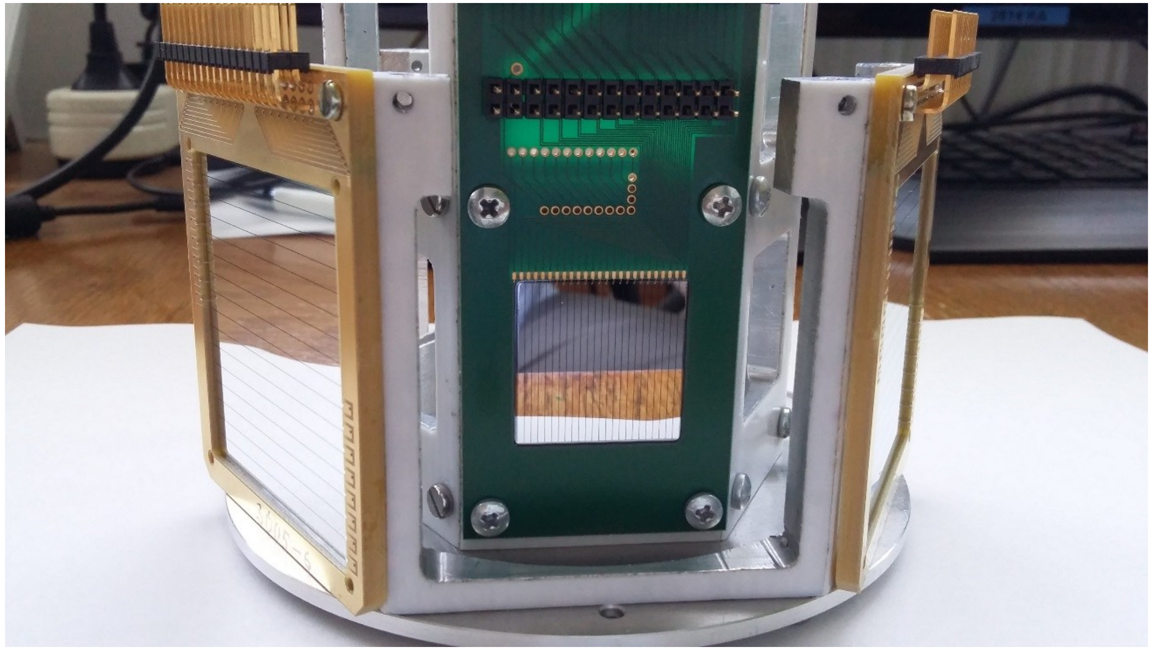


Preliminary γγ-angular correlation

Conclusion

- The ^{8}Be anomaly could be reproduced with an independent spectrometer.
- The effect can not be explained within nuclear physics.
- The anomaly can be successfully described by a new particle called X17.
- The effect of X17 was observed also in ^{4}He in a 20.6 MeV $0^{-} \rightarrow 0^{+}$ transition at a correspondingly smaller angle. The X17 was emitted with L=1 angular momentum ($\lambda/2\pi$ =16 fm !) , which shows a long range of the interaction.
- The γγ-decay of X17 was studied, but could not be cleanly observed. We are planning further studies.
- The atomic nucleus can be considered as a femto-laboratory including probably all of the interactions in Nature. A real discovery machine like LHC, but at low energy.

To ^{8}Be continued...



Thank you very much for your attention