Fundamental interactions from nuclear transitions

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(MTA Atomki)

NIKHEF

CERN

MTA atomki DEBRECEN

3 main divisions:

- Nuclear Physics Division
- Atomic Physics Division
- Applied Physics Division

Size: 100 scientists, 100 other staff

In the downtown of Debrecen, www.atomki.mta.hu

Introduction

- The atomic nucleus as a „femto laboratory” for studying maybe all interactions in Nature. It is a small „discovery machine” like LHC at CERN, but for low energy.
- The strong and weak interactions were „discovered” already in the atomic nucleus…
- Our results published in 2016. -- Connection with dark matter.
- Our recent experimental results confirming the existence of X17
- Promising outlook

Observation of Anomalous Internal Pair Creation in

Overview of attention for article published in Physical Review Letters, January 2016

SUMMARY | News | Blogs | Twitter | Facebook | Goo

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. Ketel, A.... [
Abstract	Electron-positron angular correlations were measured for the isovector magnetic dipol (J^{... [show]

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MORE...

Mentioned by

- **55** news outlets
- **19** blogs
- **89** tweeters
- **6** Facebook pages

TWITTER DEMOGRAPHICS | MENDELEY READERS

The data shown below were collected from the profiles of **89** tweeters who shared t
about how the information was compiled.

NATURE | NEWS

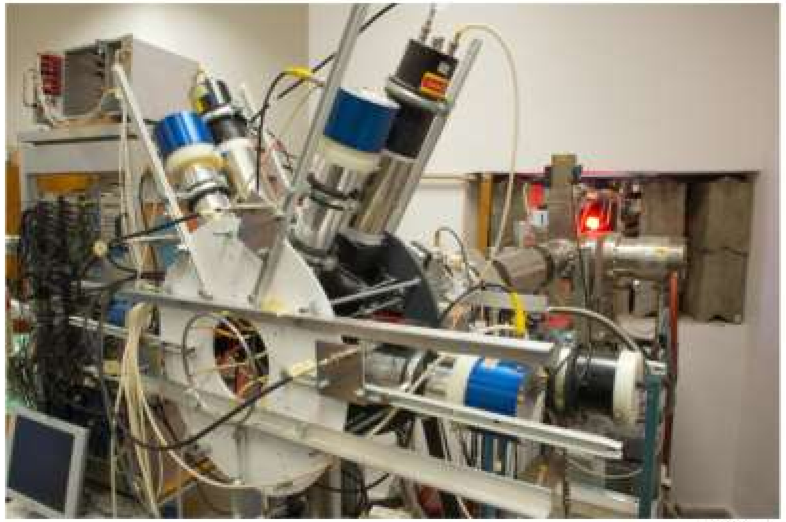
Has a Hungarian physics lab found a fifth force of nature?

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

Edwin Cartlidge

25 May 2016

Print



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.

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

thinking about different ways to check it," he says. Groups in Europe and the United States say that they should be able to confirm or rebut the Hungarian experimental results within about a year.

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

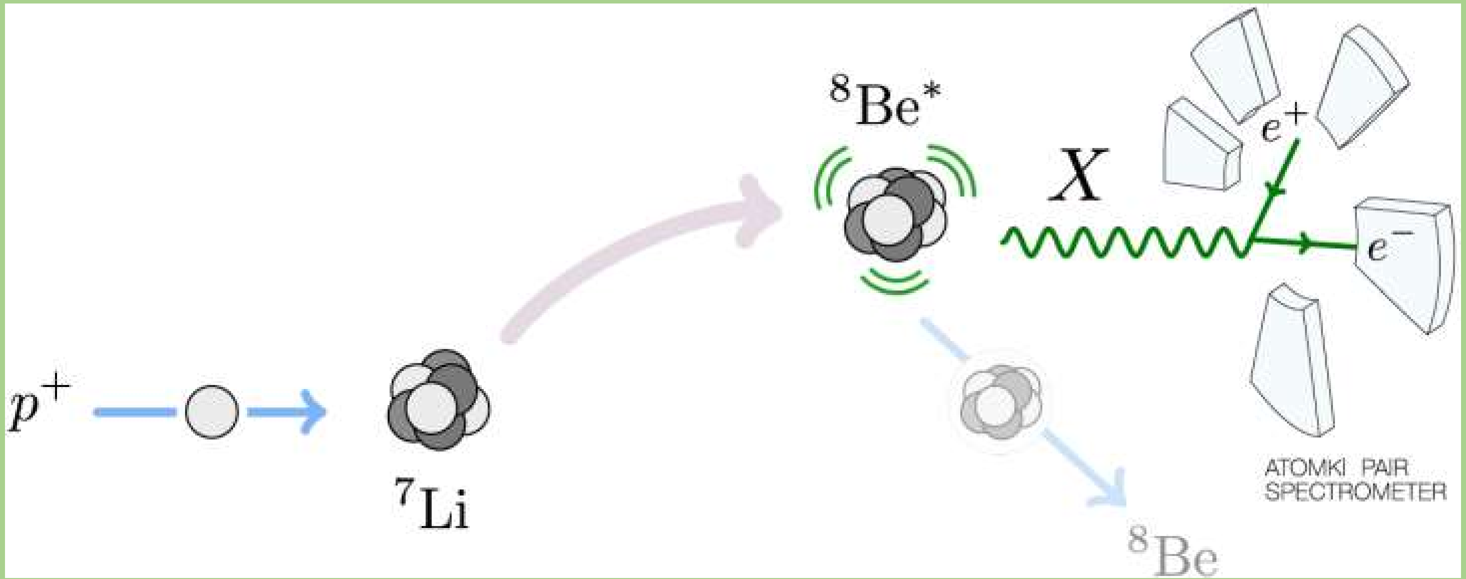
Evidence for a Protophobic Fifth Force from ^{8}Be Nuclear Transitions

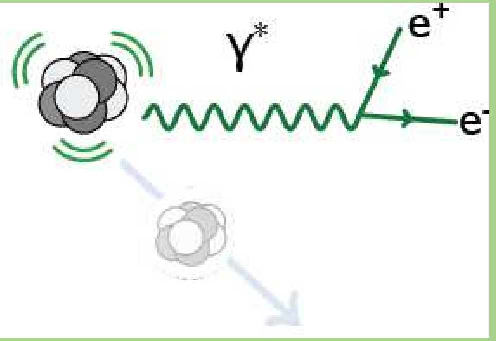
Jonathan L. Feng,[1] Bartosz Fornal,[1] Iftah Galon,[1] Su
Jordan Smolinsky,[1] Tim M. P. Tait,[1] and Phili
[1]*Department of Physics and Astronomy, University of California, Irvin*
[2]*Department of Physics and Astronomy, University of Kentucky, Lexingt*

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

Phys. Rev. Lett. 117, 071803

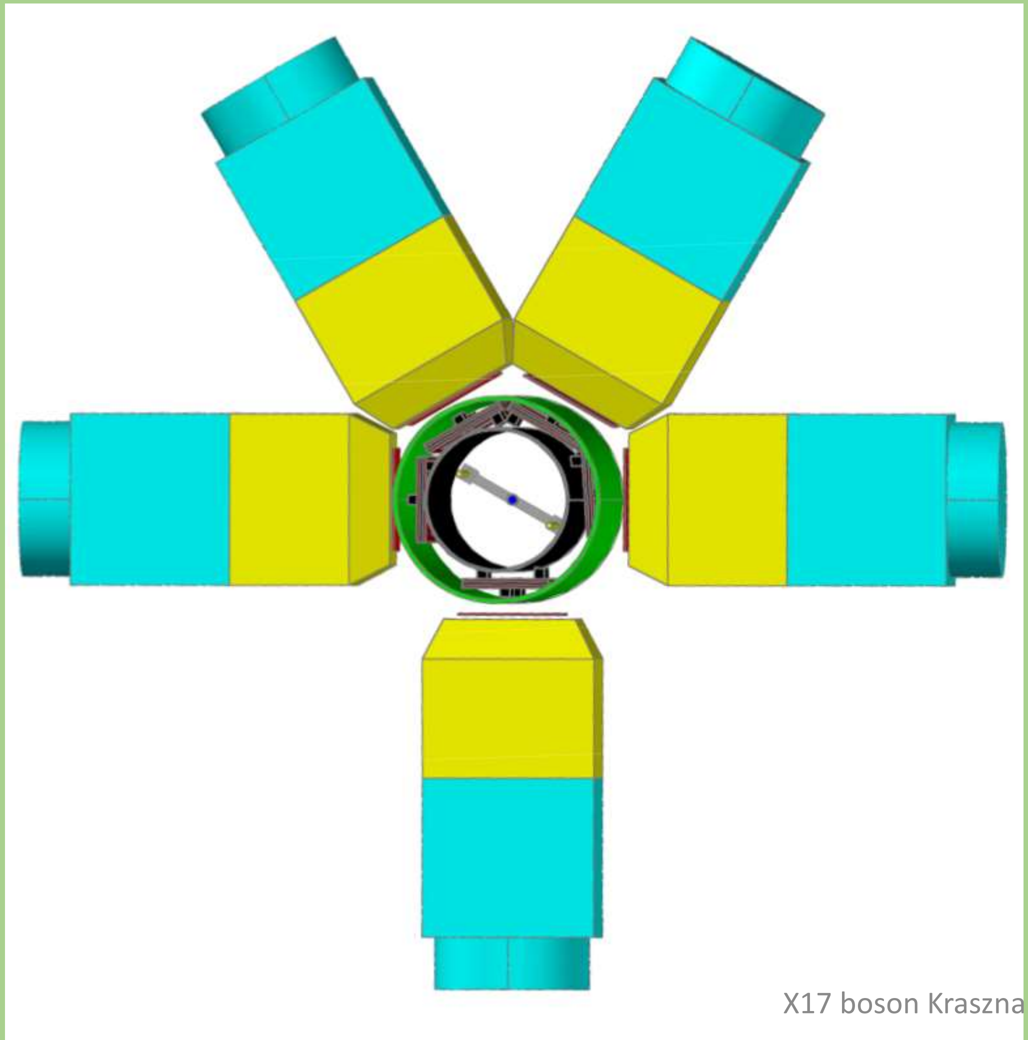
The creation and decay of $^{8}Be^{*}$





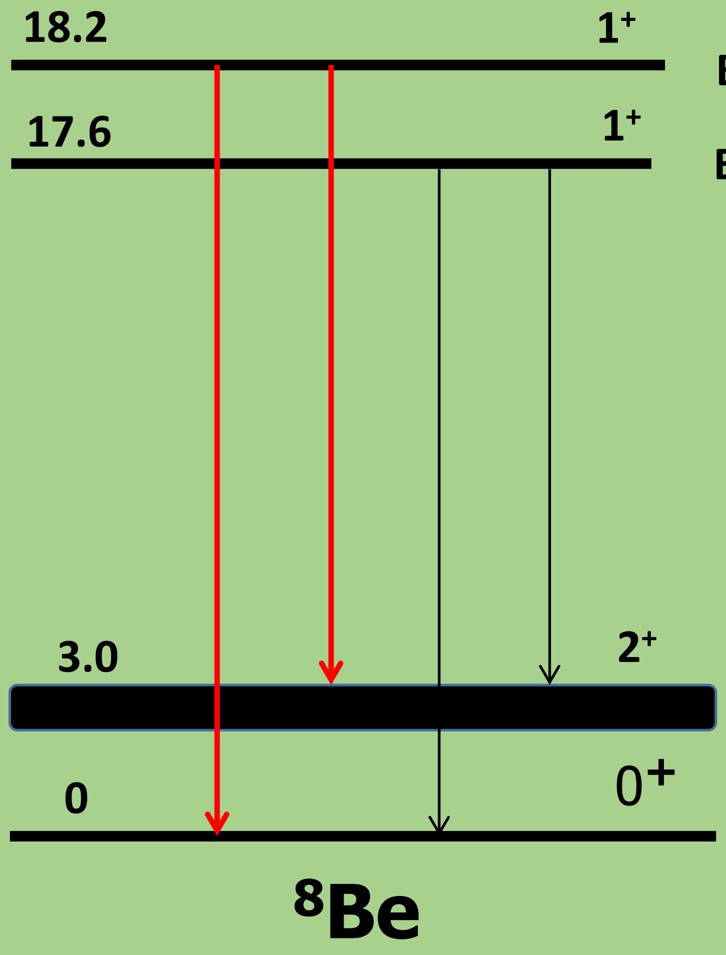
- Proton decay: B(p + ^{7}Li) ≈ 100%
- γ-decay: B(^{8}Be + γ) ≈ 1.5 x 10^{-5}
- Internal pair creation: B(^{8}Be + e^{+} e^{-}) ≈ 5.5 x 10^{-8}
- Ejection of a new particle: B(^{8}Be + X) ≈ 5.5 x 10^{-10}

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



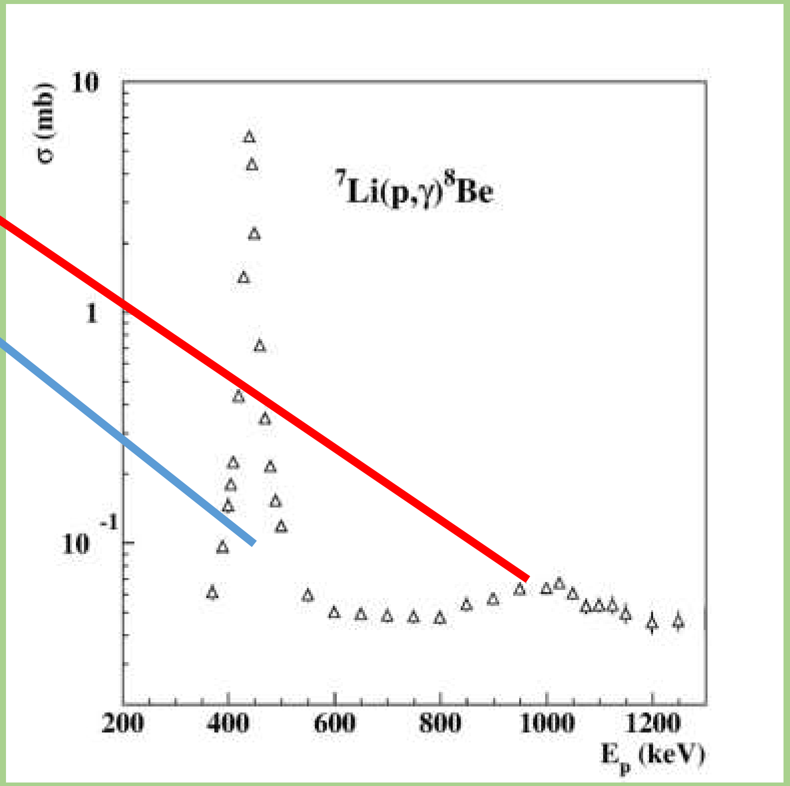
Study the ^{8}Be M1 transitions

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

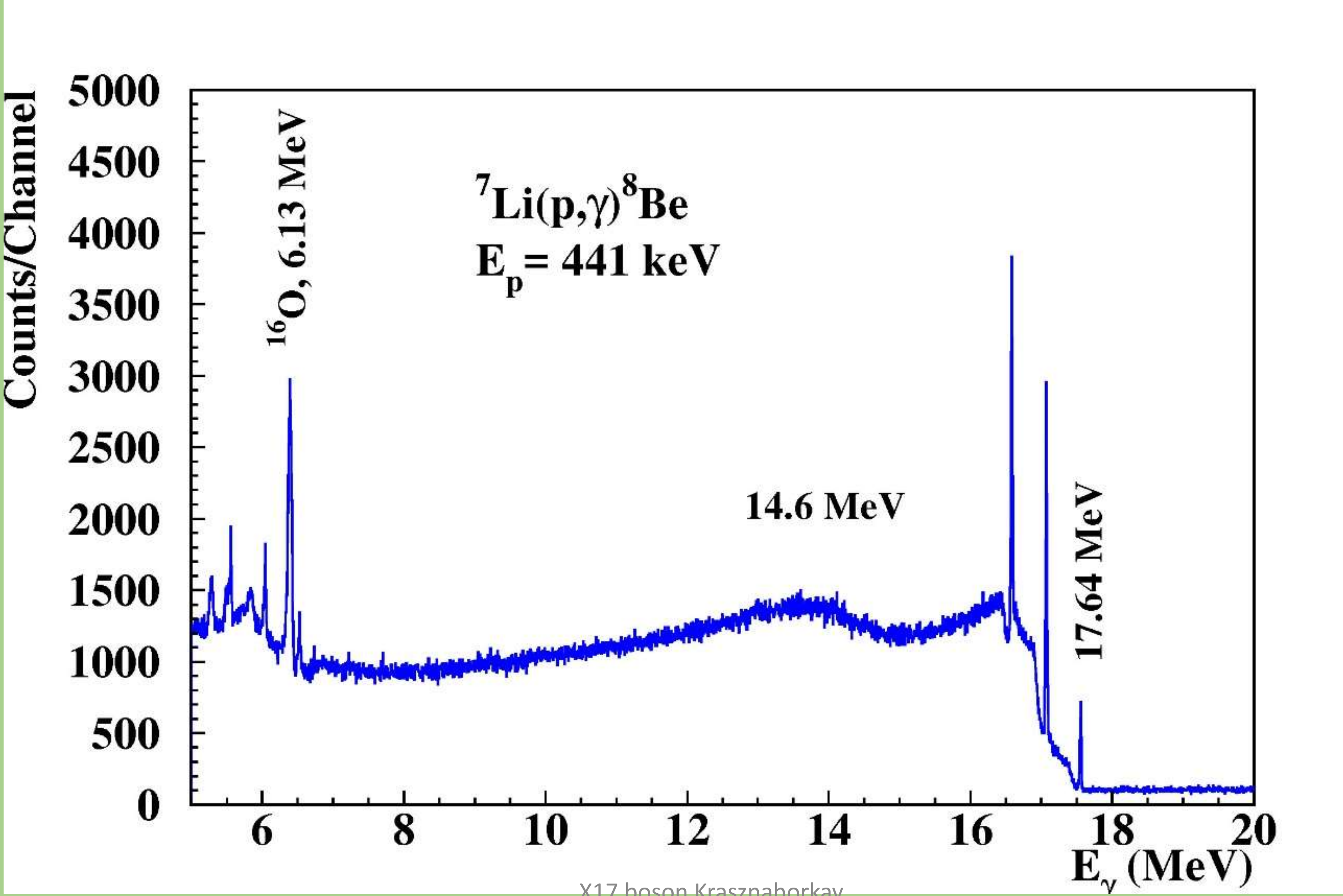


Ep= 1030 keV

Ep= 441 keV

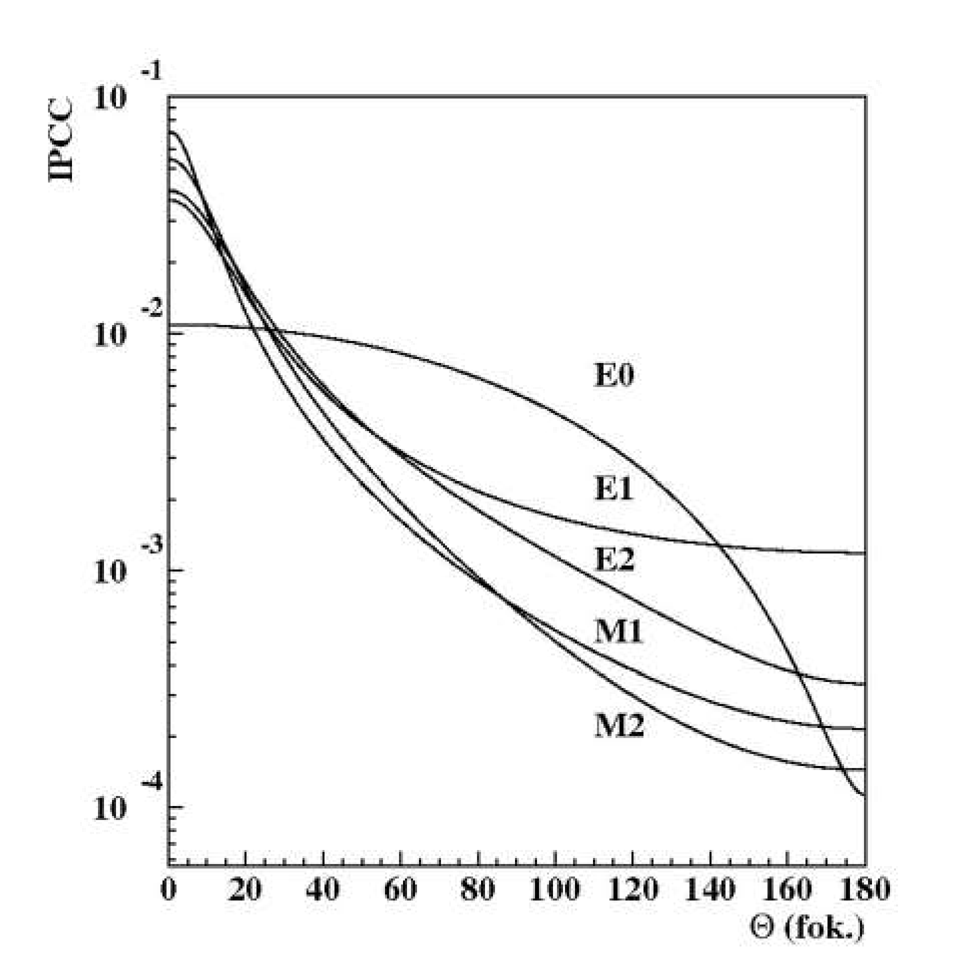


γ-ray spectrum measured with a 100% HpGe detector

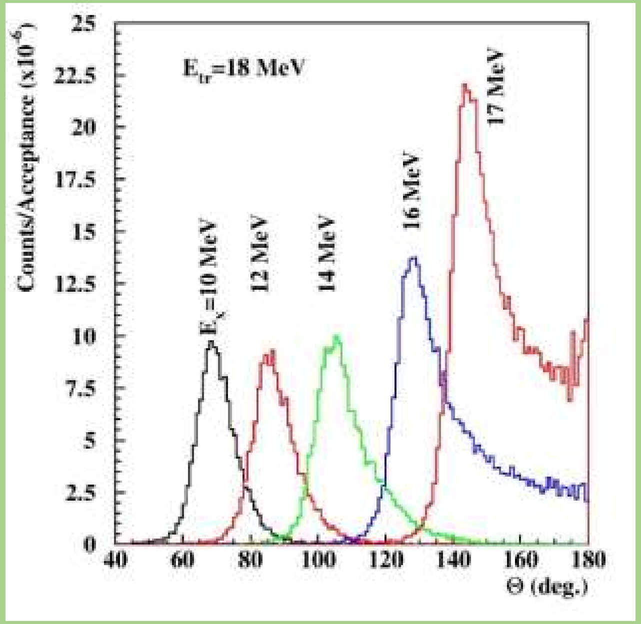


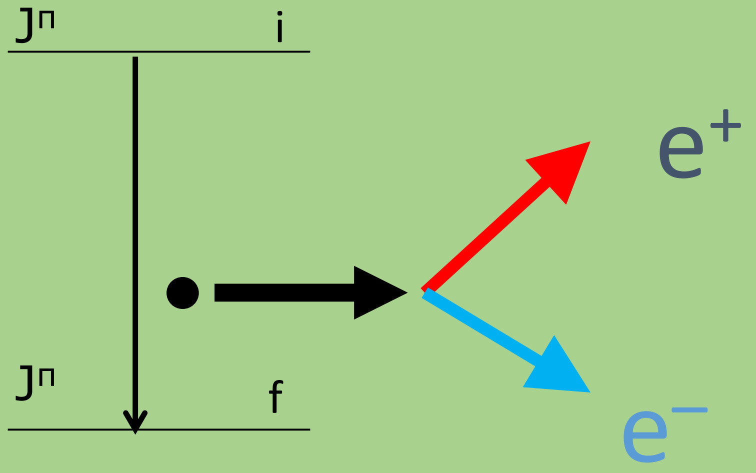
Study the ^{8}Be M1 transitions

Background



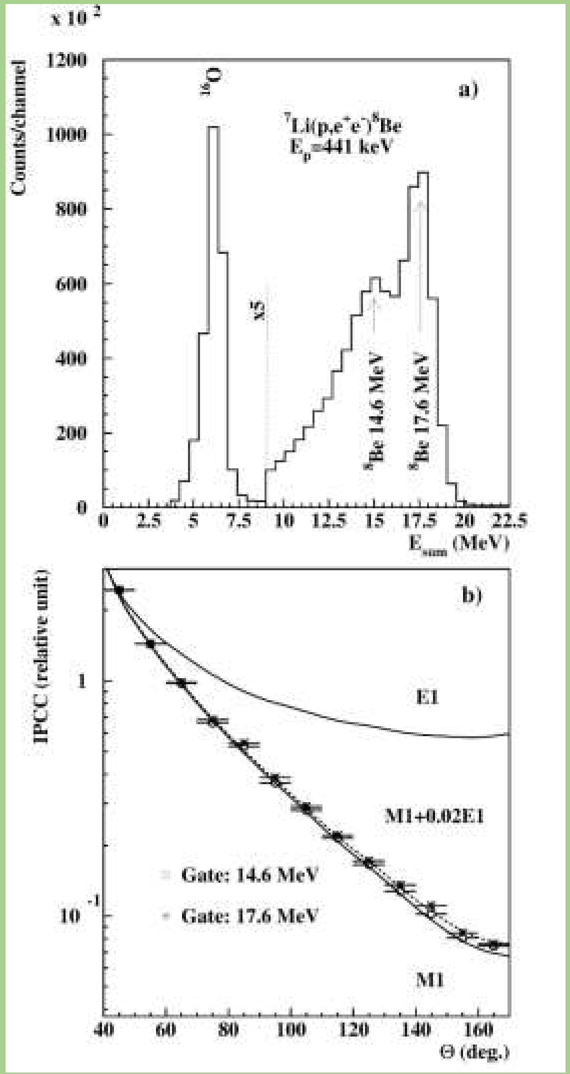
Signature





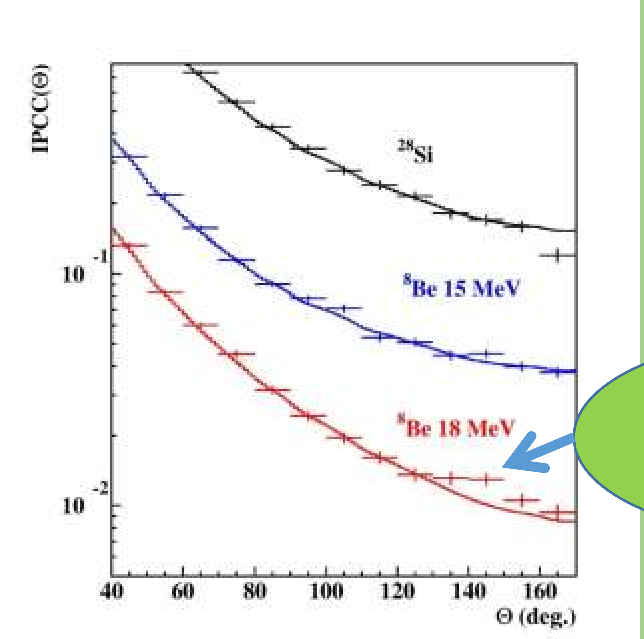
Results

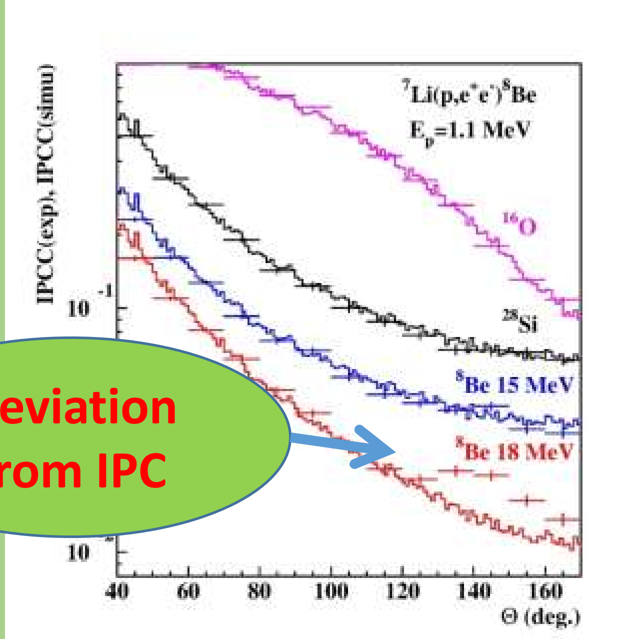
e^+ - e^- sum energy spectra and angular correlations



Ep=1.04 MeV

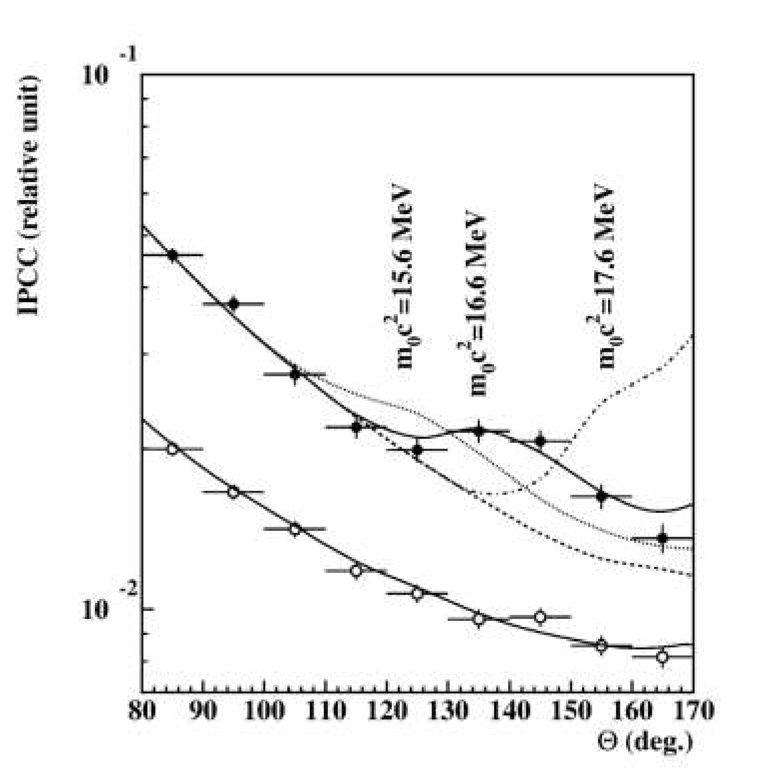
Ep=1.10 MeV

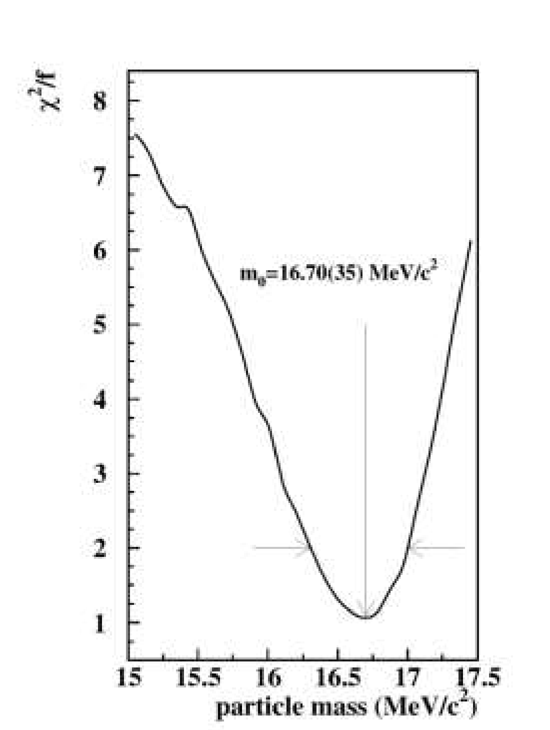


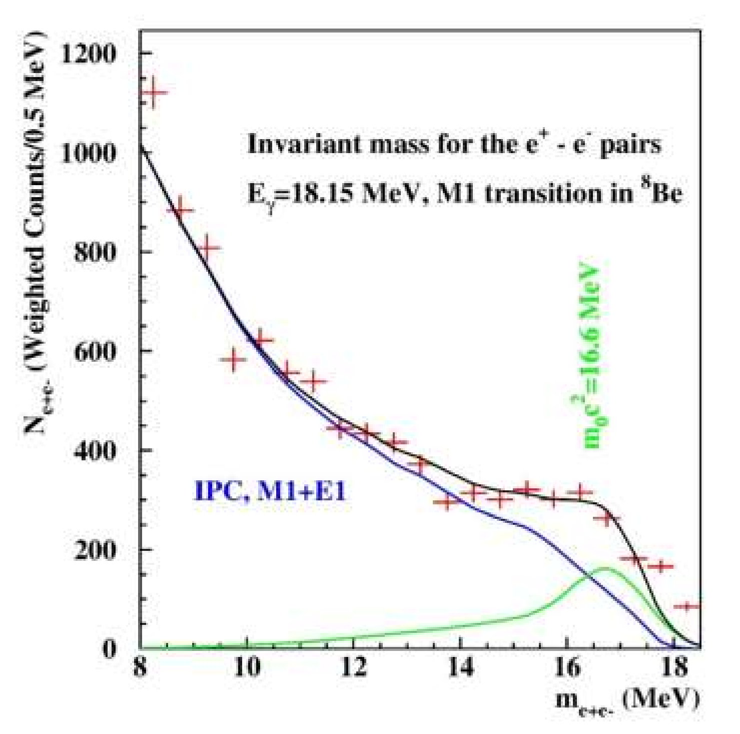


Deviation from IPC

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 X^2/f method

$$m^2 \approx (1-y^2)E^2\sin(\Theta/2)$$

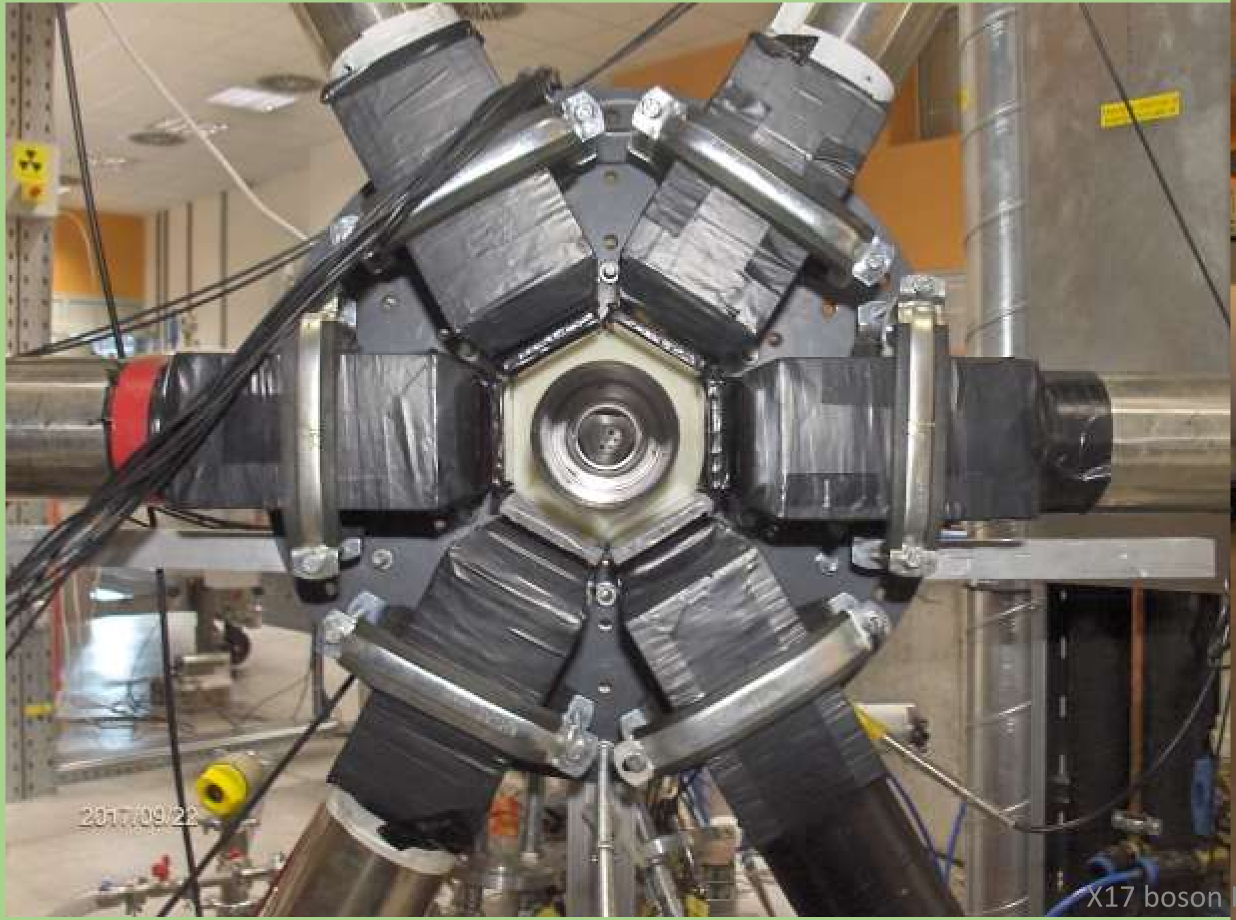
$$Y=\frac{E_+ - E_-}{E_+ + E_-}$$

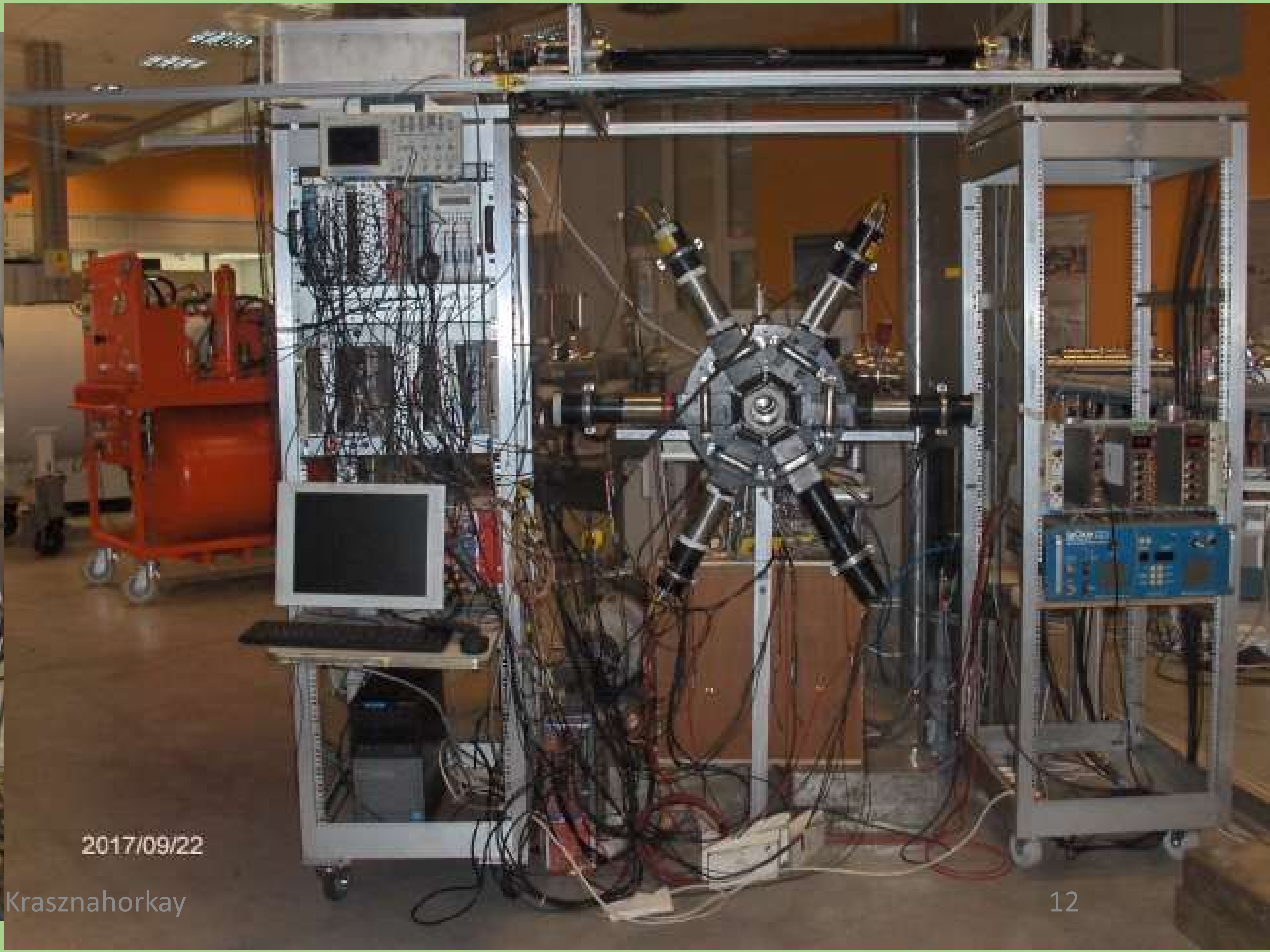
Repeating the experiments at a new Medium-Current Tandetron Accelerator in Atomki

Main specifications:

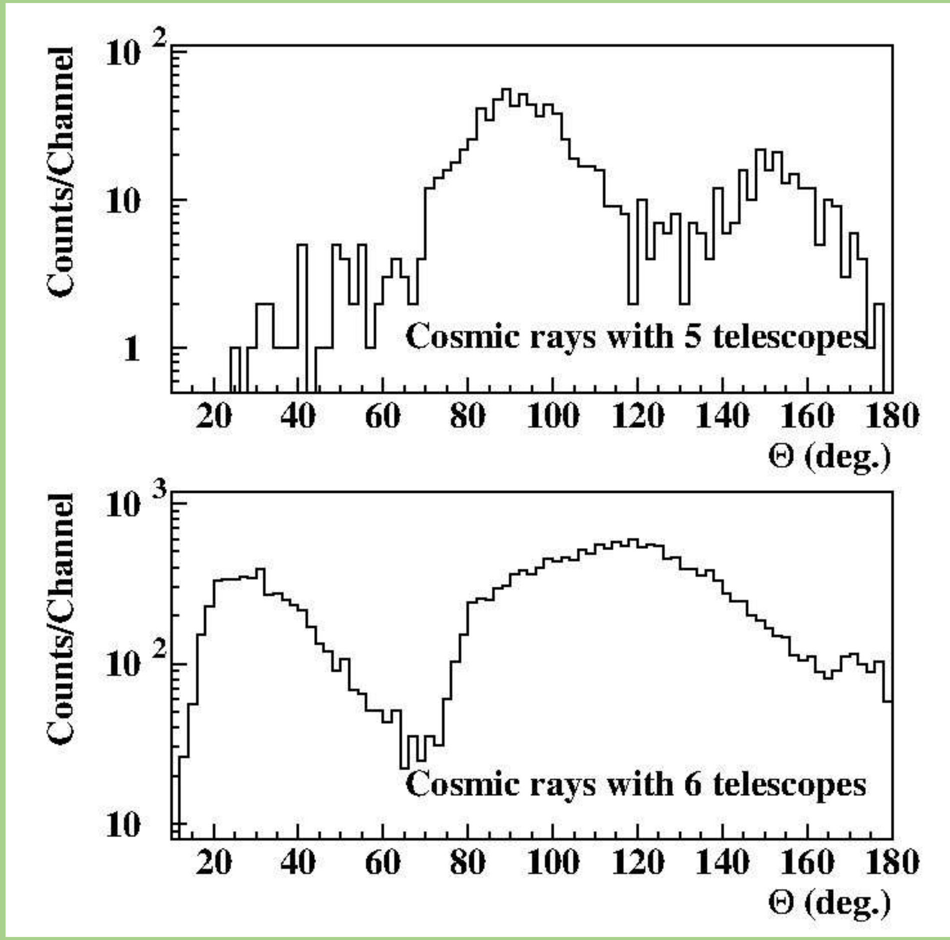
- TV ripple: 25 $V_{RMS,}$ TV stability: 200 V (GVM), 30 V (SLITS)
- Beam current capability at 2 MV: 200 µA proton, 40 µA He

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



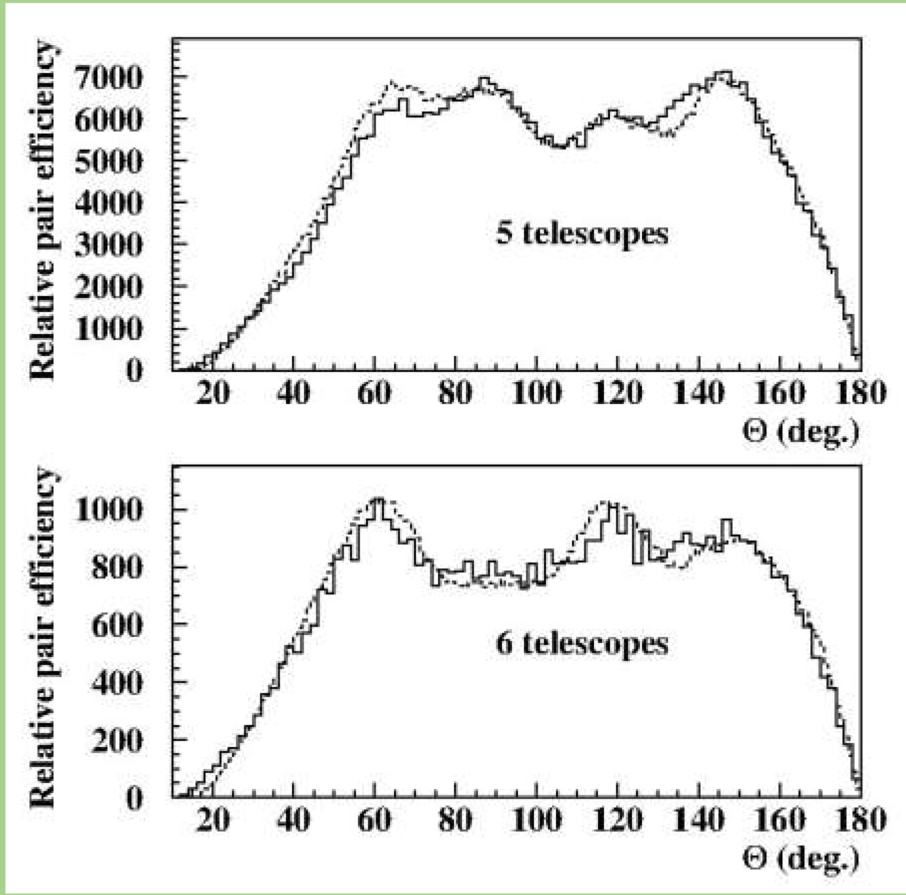


Background from cosmic rays in the setups with 5 and 6 telescopes



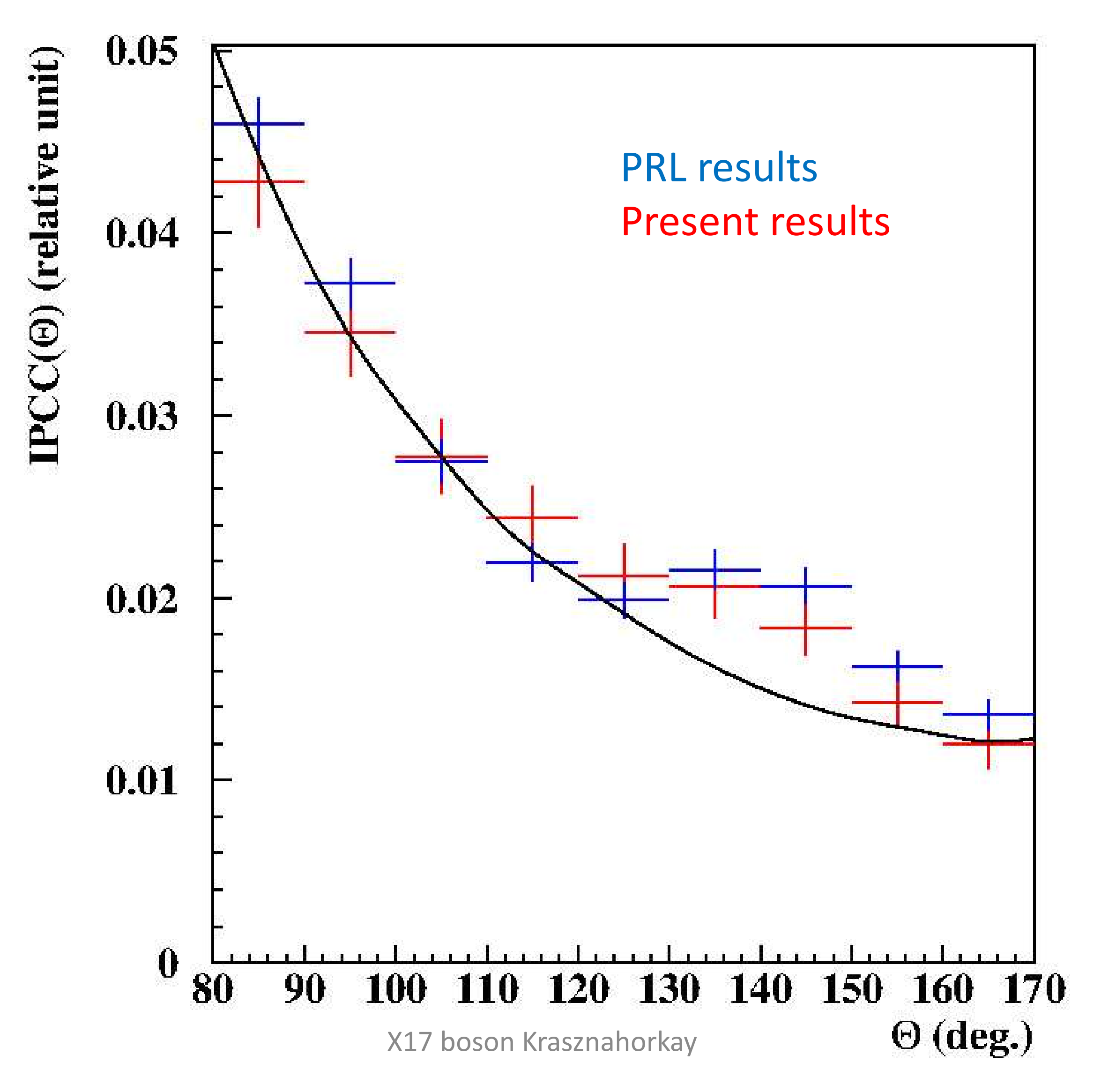
Efficiency curves for the setups with 5 and 6 telescopes

Relative numbers!
The absolute efficiency for 6 detectors is certainly larger!

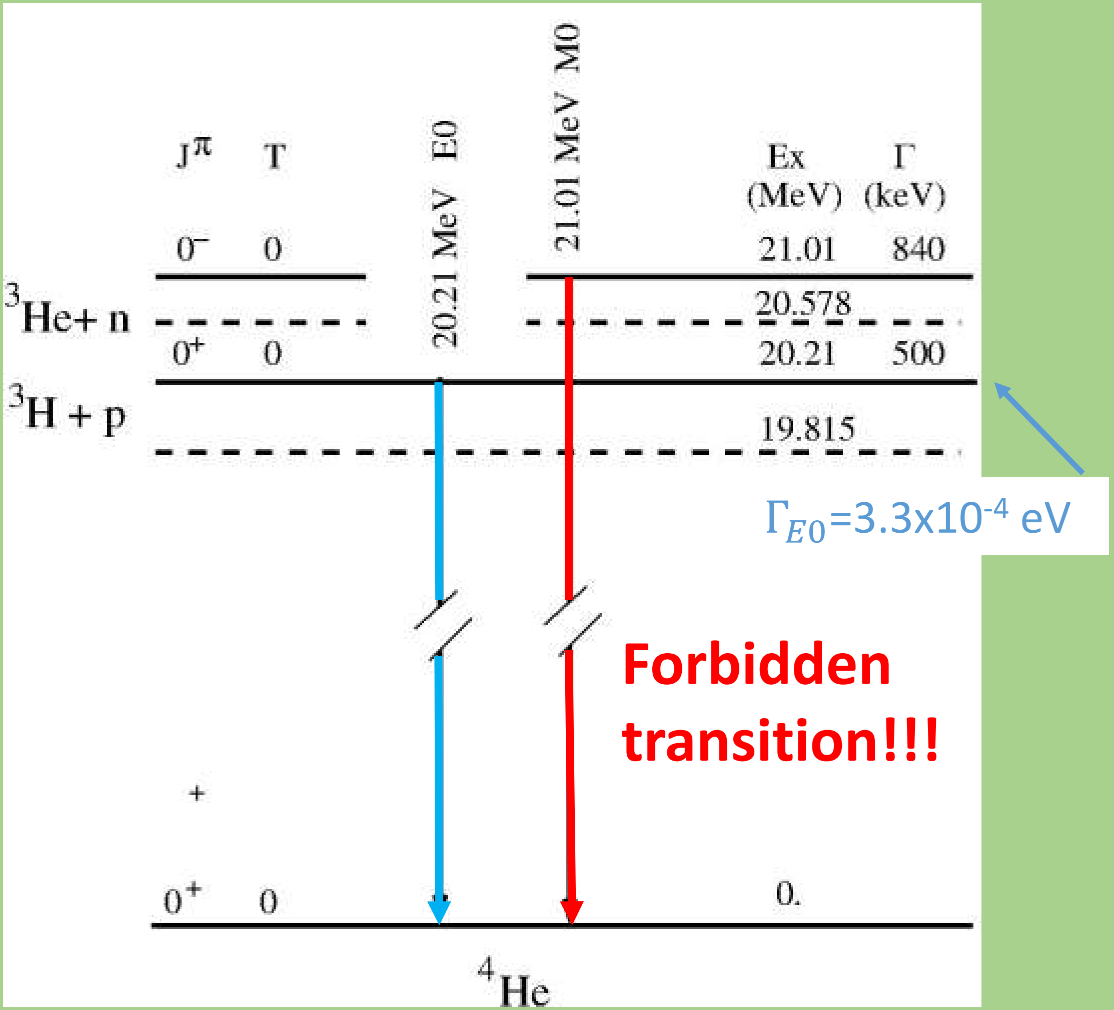


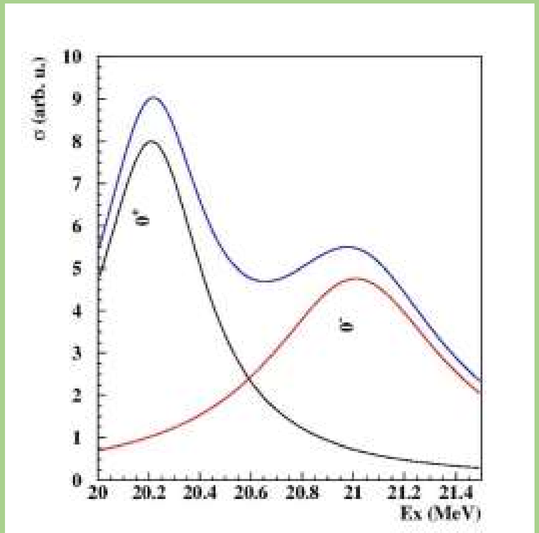
The results of the present experiment can be considered independent from the one we published in PRL in 2016.

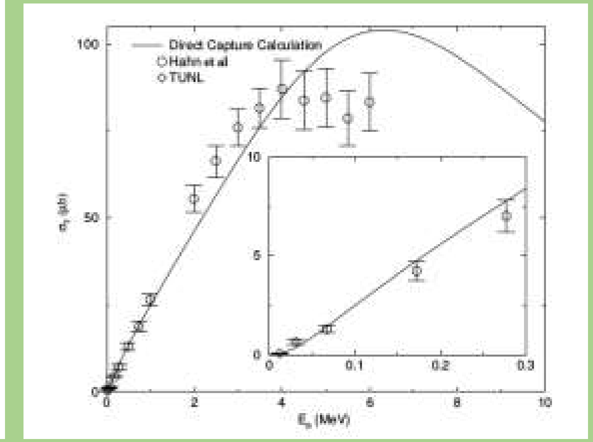
Recent results for the 18.15 MeV transition



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

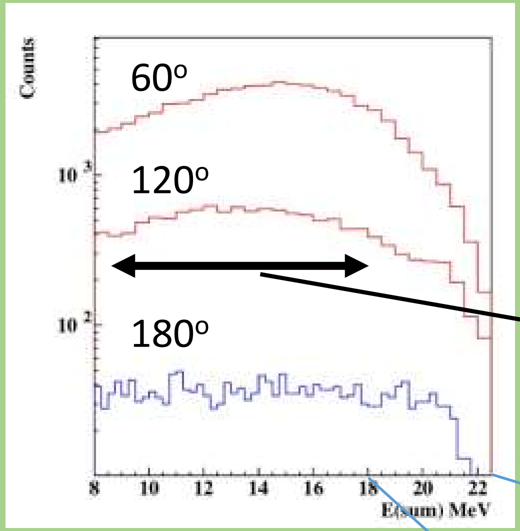




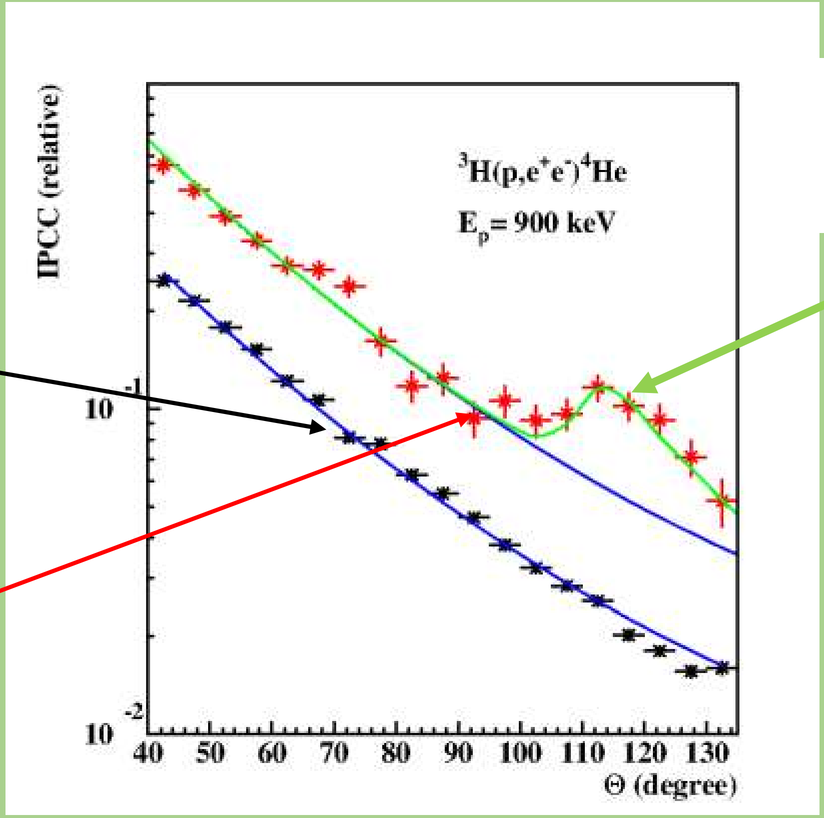


γ-ray production with direct proton capture. The main source of background produced by external pair creation on the backing of the target and on the other surrounding materials. **GEANT simulations.**

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



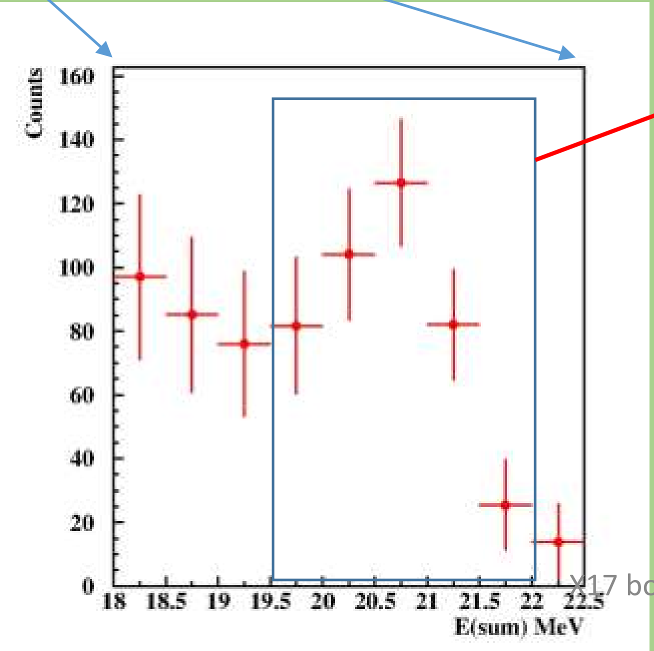
Measured e^+e^- sum-energy spectra for different detector combinations.



Simulation for m_0c^2= 17.0 MeV

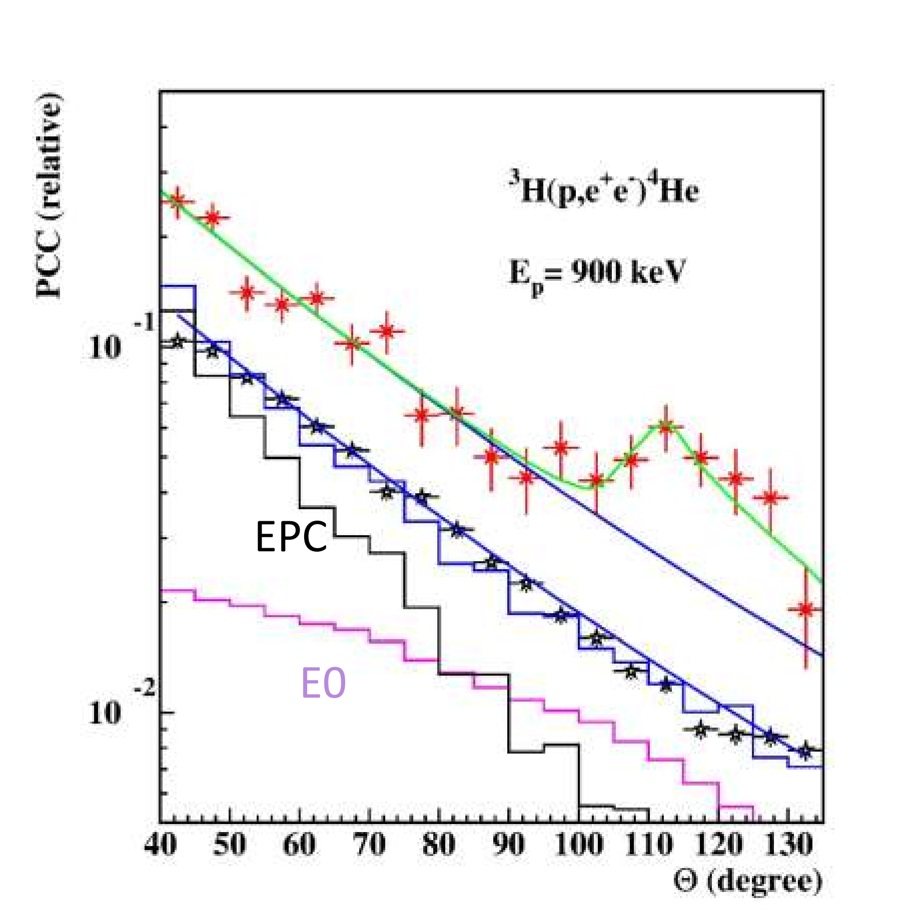
Significance: 7.6 σ

Difference between spectra measured at 120° and 60°.



Measured (gated) e^+e^- pair correlation for the full energy pairs.

On the partial width (Γ_X) of the X17 particle



$$\Gamma_X/\Gamma_{E0}=\left(\frac{\sigma(x17)}{\sigma(E0)}\right)_{exp.}\left(\frac{\sigma(0^+)}{\sigma(0^-)}\right)_{th.}$$

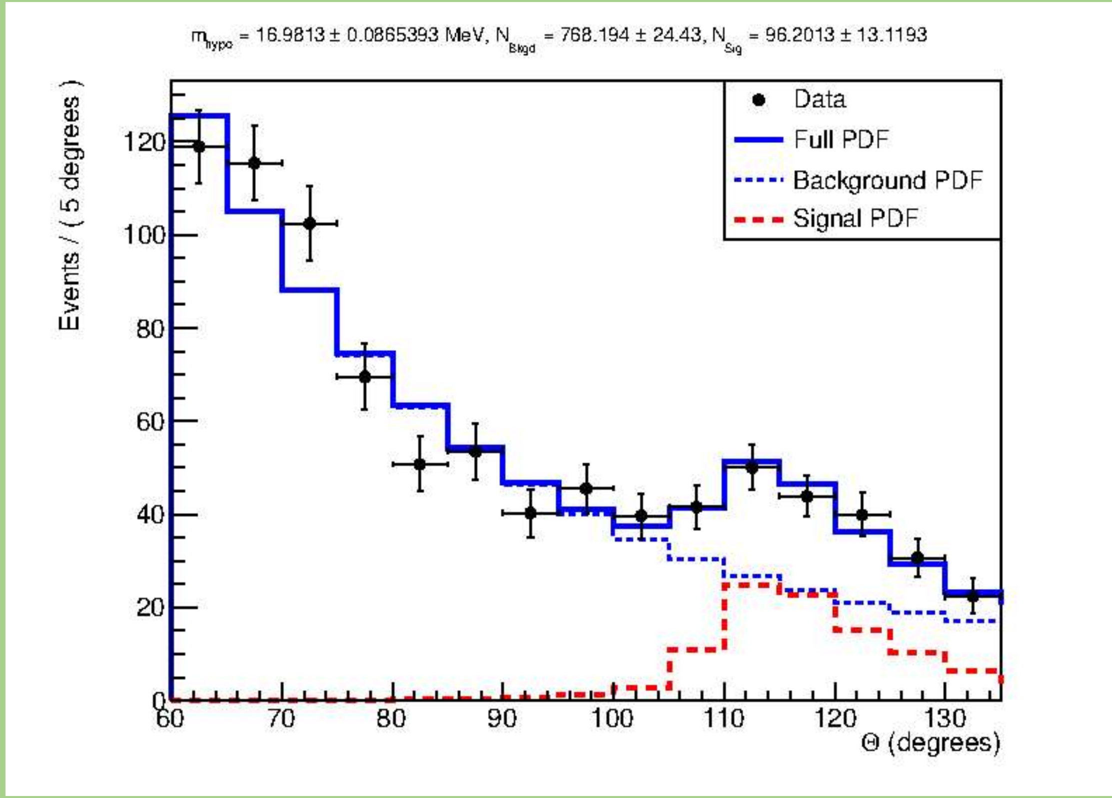
$$\left(\frac{\sigma(x17)}{\sigma(E0)}\right)_{exp.}=0.20$$

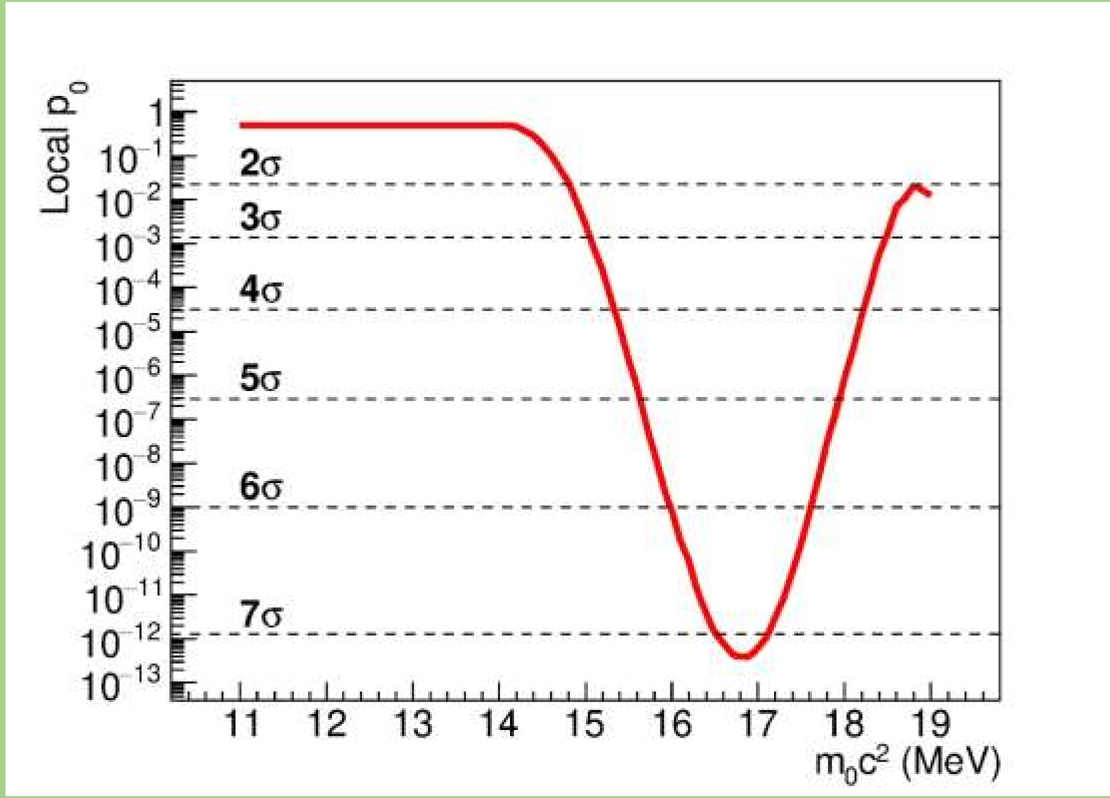
$$\left(\frac{\sigma(0^+)}{\sigma(0^-)}\right)_{th.}=\frac{\Gamma_{tot}(0^+)}{\Gamma_{tot}(0^-)}=0.59$$

Since: Γ_{E0}=3.3x10^{-4} → Γ_X= 3.9x10^{-5} eV

In ^{8}Be it was: $\Gamma_X=\Gamma_\gamma$xB_x=1.9x6x10^{-6} eV= 1.2x10^{-5} eV (role of the phase space correction factor)

Details of the fit performed by RooFit

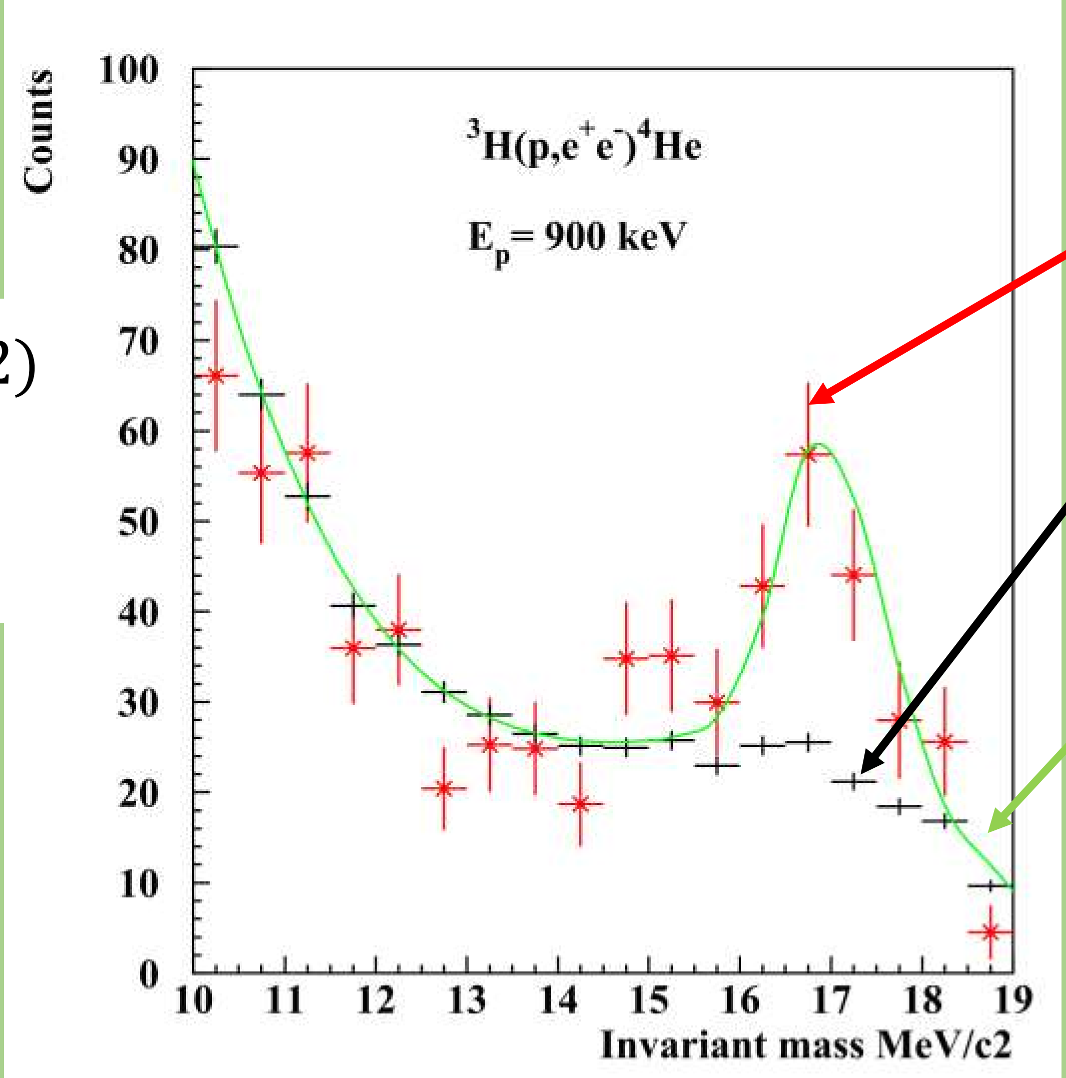




Invariant mass distribution

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

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



Gated invariant mass distr. for full energy pairs.

Gated invariant mass distr. for external pairs.

Simulated result for m_0c^2= 17.0 MeV

Study the $\gamma\gamma$-decay of X17 in ^{4}He

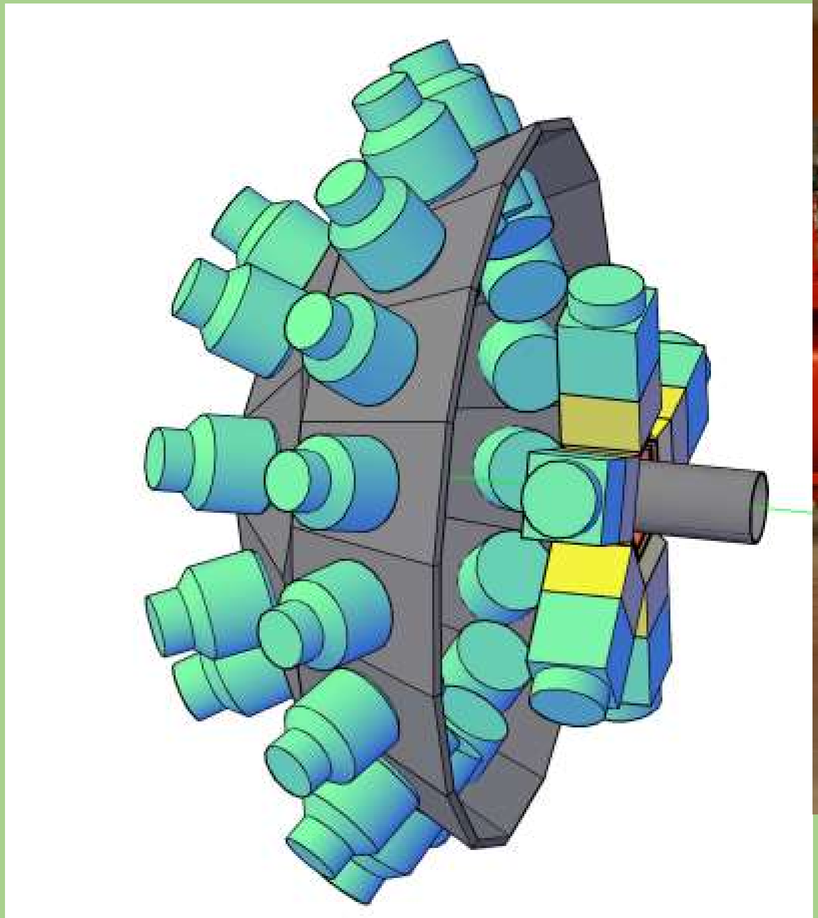
- Vector particle (1+) or axialvector (0-)? If axialvector than it can decay by $\gamma\gamma$ emission.

- $\gamma\gamma$-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 (Decay *Nature* **526**, 406 (2015)

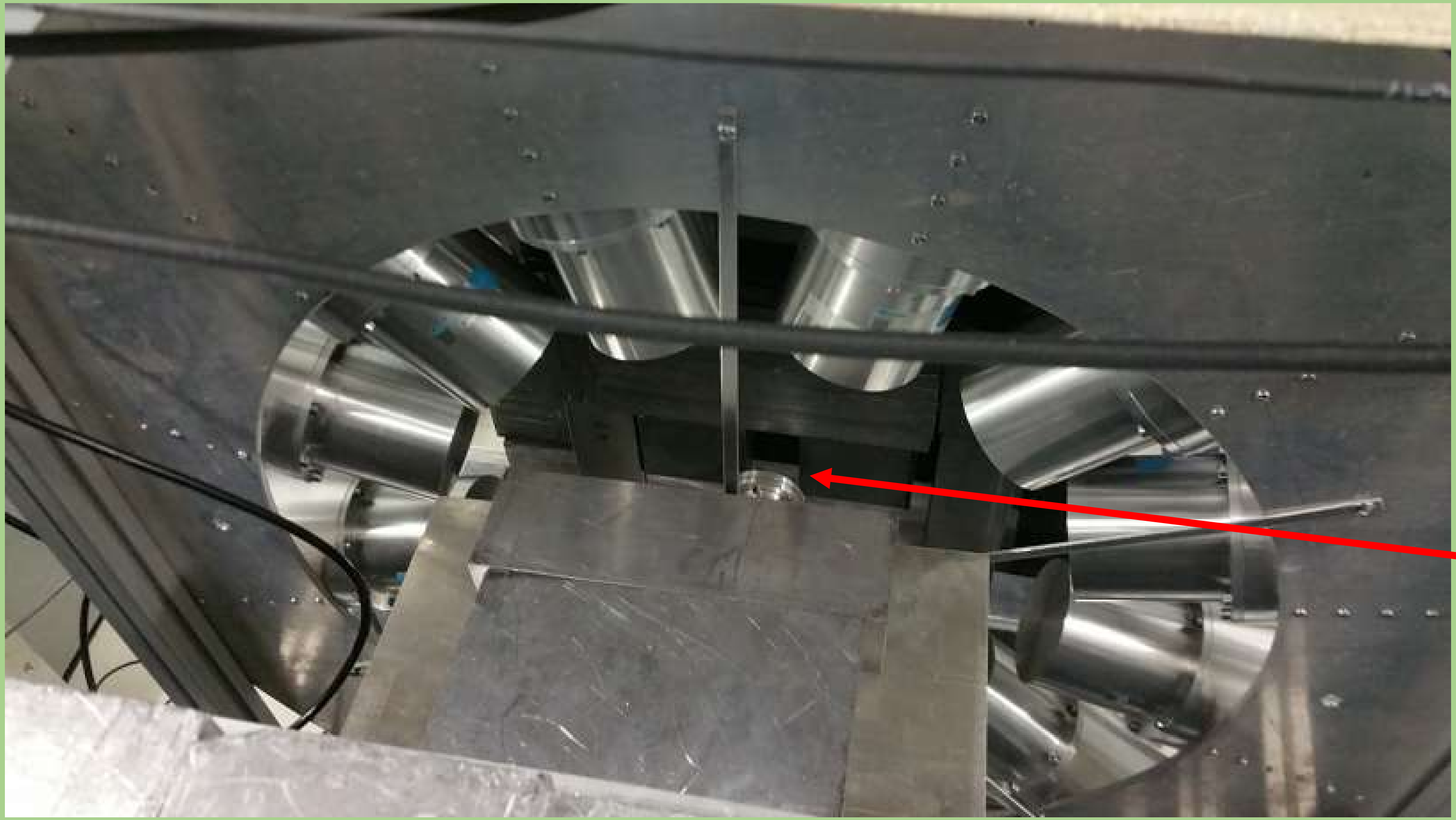
$$\cos(\Theta) = 1 - \frac{m_x^2}{2E_1E_2}$$

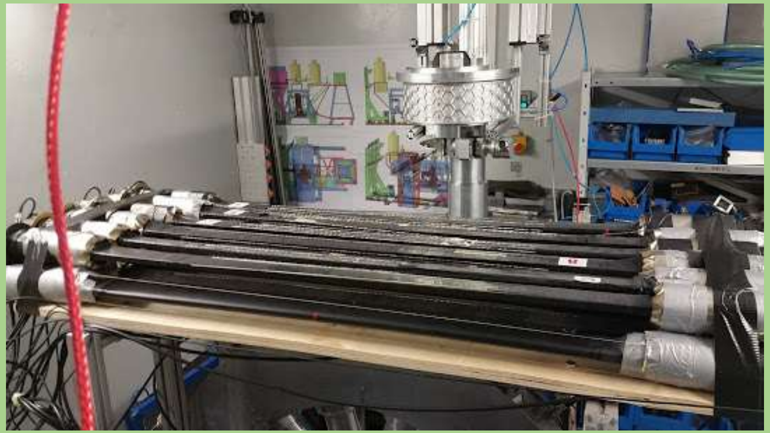
Study the angular correlation with state of the art 3"x3" $LaBr_3$ detectors!

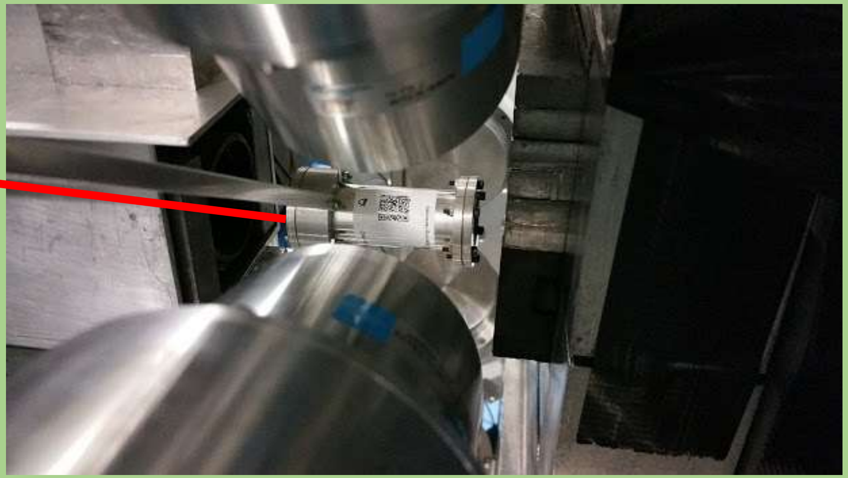
The experimental setup in Debrecen including both the e^+e^- and the γ-ray spectrometers



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



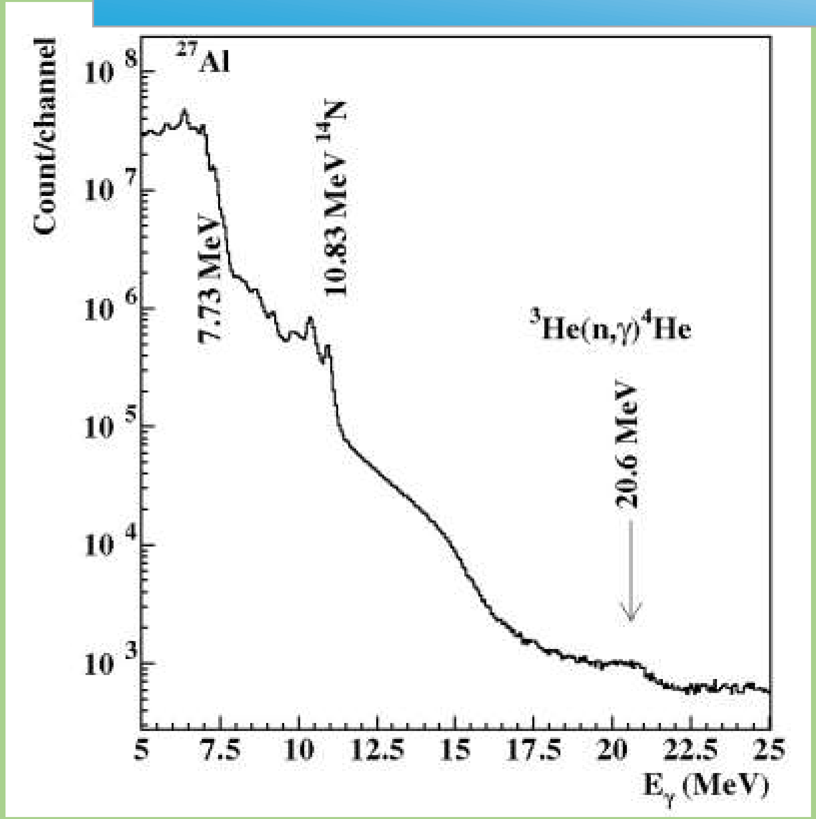


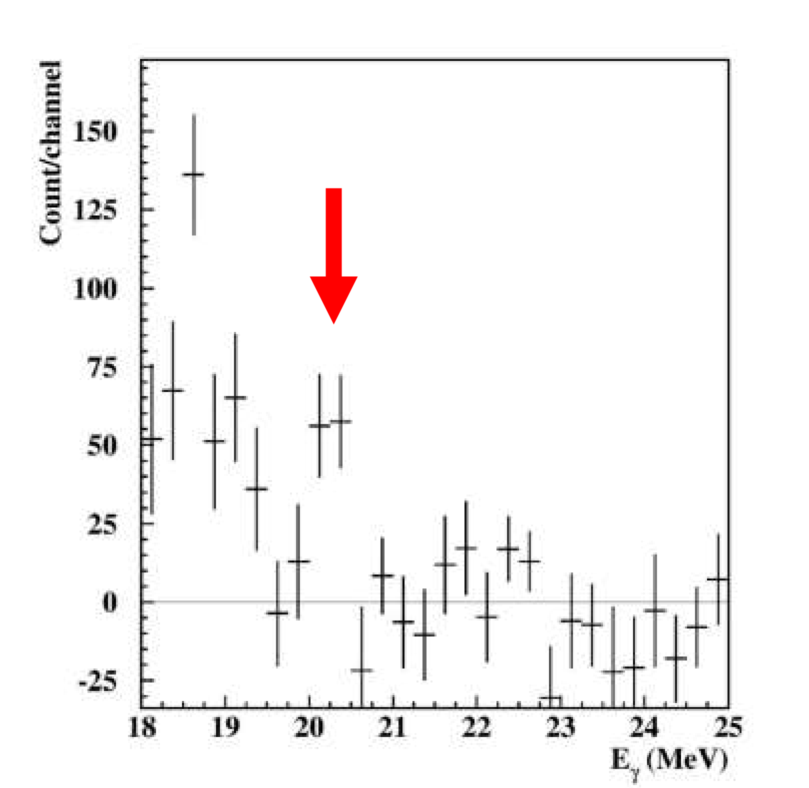


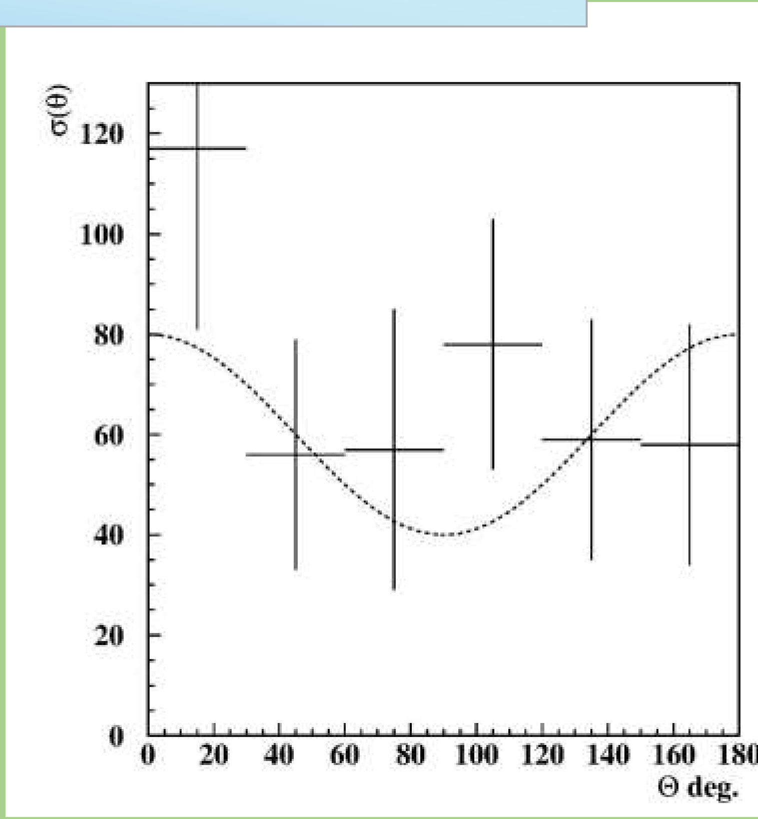
Coincidence γ-ray spectrometer with twelve 3”x3” LaBr3 detectors. The angle between the detectors is 30 degree, and the detector plain Is perpendicular to the beam.

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

The first (very preliminary) results obtained in Garching







A typical singles γ-ray spectrum

Typical sum-energy spectra for coincident detectors

Preliminary γγ-angular correlation

Promising outlook

Search for a new $X(16.7)$ boson and dark photons in the NA64 experiment at CERN

D. Banerjee,[4] V. E. Burtsev,[11] A. G. Chumakov,[11] D. Cooke,[13] P. Crivelli,[13] E. Depero,[13] A. V. Dermenev,[5] S. V. Donskov,[10] R. R. Dusaev,[11] T. Enik,[2] N. Charitonidis,[3] A. Feshchenko,[2] V. N. Frolov,[2] A. Gardikiotis,[9] S. G. Gerassimov,[6,8] S. N. Gninenko**,[5] M. Hösgen,[1] M. Jeckel,[3] A. E. Karneyeu,[5] G. Kekelidze,[2] B. Ketzer,[1] D. V. Kirpichnikov,[5] M. M. Kirsanov,[5] I. V. Konorov,[6,8] S. G. Kovalenko,[12] V. A. Kramarenko,[2,7] L. V. Kravchuk,[5] N. V. Krasnikov,[5] S. V. Kuleshov,[12] V. E. Lyubovitskij,[11,12] V. Lysan,[2] V. A. Matveev,[2] Yu. V. Mikhailov,[10] D. V. Peshekhonov,[2] V. A. Polyakov,[10] B. Radics,[13] R. Rojas,[12] A. Rubbia,[13] V. D. Samoylenko,[10] V. O. Tikhomirov,[6] D. A. Tlisov,[5] A. N. Toropin,[5] A. Yu. Trifonov,[11] B. I. Vasilishin,[11] G. Vasquez Arenas,[12] P. V. Volkov,[2,7] V. Volkov,[7] and P. Ulloa[12]

(The NA64 Collaboration)

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[13] *ETH Zürich, Institute for Particle Physics and Astrophysics, CH-8093 Zürich, Switzerland*

(Dated: March 22, 2018)

We report the first results on a direct search for a new 16.7 MeV boson (X) which could explain the anomalous excess of e^+e^- pairs observed in the excited $^8\mathrm{Be}^*$ nucleus decays. Due to its coupling to electrons, the X could be produced in the bremsstrahlung reaction $e^-Z \to e^-ZX$ by a 100 GeV e^- beam incident on an active target in the NA64 experiment at the CERN SPS and observed through the subsequent decay into a e^+e^- pair. With 5.4×10^{10} electrons on target no evidence for such decays was found, allowing to set first limits on the $X-e^-$ coupling in the range $1.3\times10^{-4} \lesssim \epsilon_e \lesssim 4.2\times10^{-4}$ excluding part of the allowed parameter space. We also set new bounds on the mixing strength of photons with dark photons (A') from non-observation of the decay $A' \to e^+e^-$ of the bremsstrahlung A' with a mass $\lesssim 23$ MeV.

PACS numbers: 14.80.-j, 12.60.-i, 13.20.-v, 13.35.Hb

Recently, the NA64 experiment at CERN presented the first direct search with a 100 GeV/*c* e^- beam for this hypothetical 16.7 MeV/c^2 boson and excluded part of its allowed parameter space, but leaving the still unexplored region

$4.2\times10^{-4}<\varepsilon_e<1.4\times10^{-3}$ as quite an exciting prospect for further research.

Resonant production of X17 in positron beam dump experiments

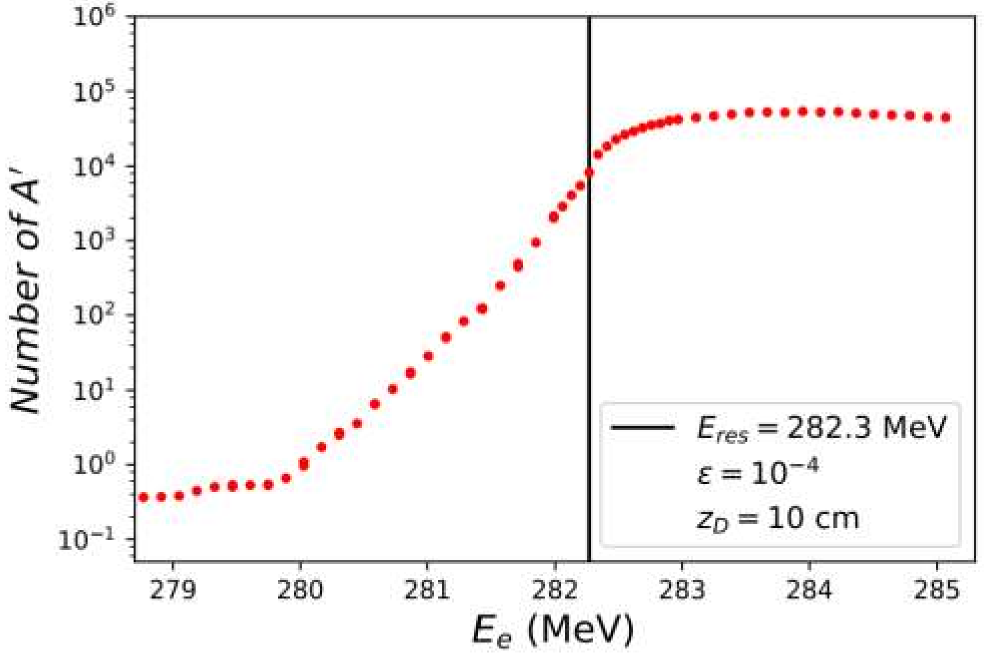


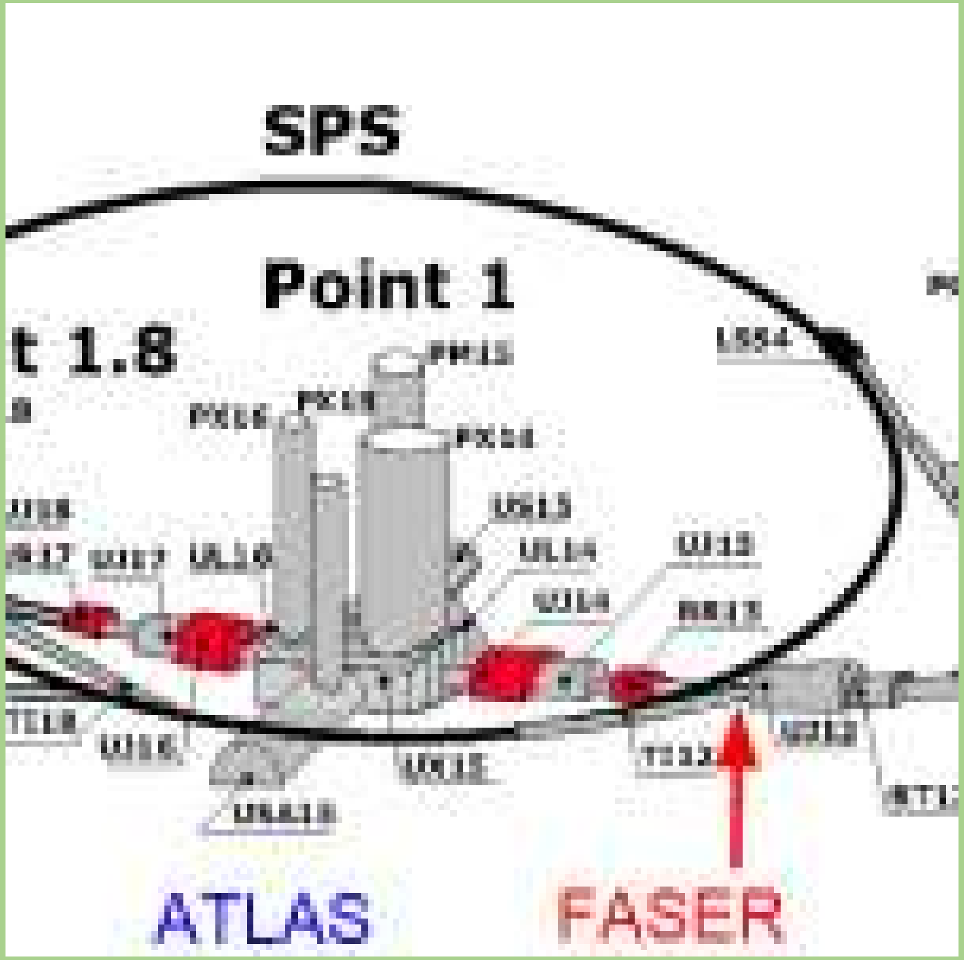
Figure 2. The number of DP decaying outside the dump as a function of the beam energy for $\epsilon = 10^{-4}$. The vertical line corresponds to the energy for resonant production of a 17 MeV DP. A dump length $z_D = 10$ cm and a background free measurement have been assumed.

PADME experiment in Frascati

It is running and taking some test data

The project will be improved for mc^2<20 MeV/c2, and after the experimental setup will be moved to Cornell and/or JLAB.

ForwArd Search ExpeRiment (FASER) at the LHC



FASER can discover ALPs with masses m_a~10–400 MeV

Exp. Starts at 2023.

A few other planned experiments to study X17

- **Mu3e** is a particle physics experiment at the Paul Scherrer Institute, searching for decays of anti-muons (*Mu*) to an electron and two positrons (*3e*).
- DarkLight is an experiment at the JLAB in USA using electron–proton collisions.
- VEPP-3 is planned experiment in Vladivostok, Russia. They are planning to use intense positron beams.

Annual Conference on Large Hadron Collider Physics - LHCP2019,
Jürgen Engelfried, Dark sector searches in non-LHC experiments,

https://scholar.google.hu/scholar?hl=hu&as_sdt=2005&sciodt=0,5&cites=17391295264019262192&scipsc=&q=

Conclusion

- The ^{8}Be anomaly has been reproduced with an upgraded 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 21.01 MeV $0^- \rightarrow 0^+$ transition at a correspondingly smaller angle. The significance of the peak is 7.6 σ.
- We are planning to study the $\gamma\gamma$-decay of X17 to determine their spin.
- Promising outlook.

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To ^{8}Be continued…

Thank you very much for your attention