Dark matter research in nuclear physics laboratories

Attila Krasznahorkay

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

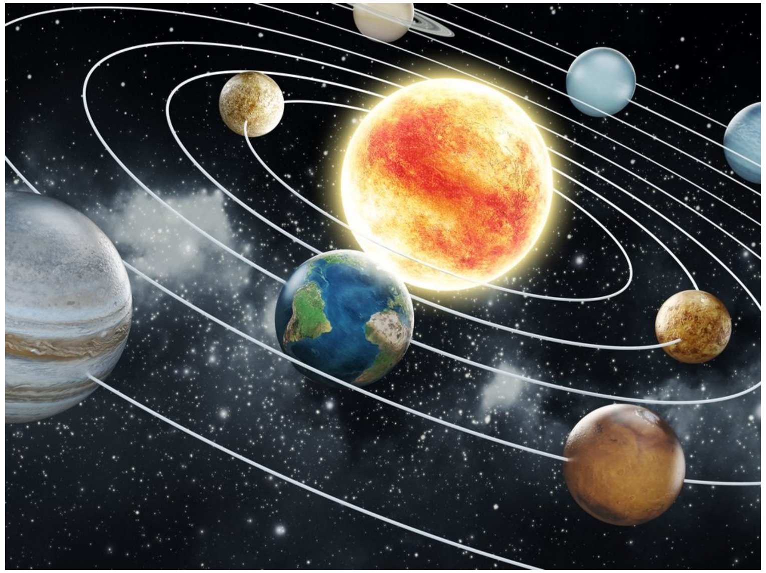
4 main divisions:

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

Size: 100 scientists, 100 other staff

www.atomki.mta.hu

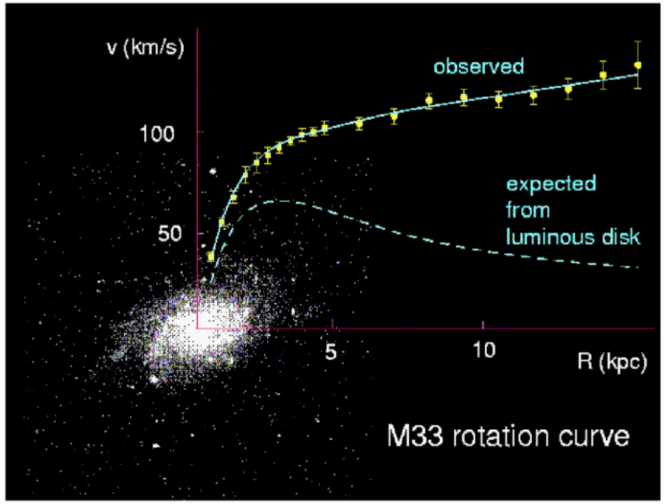
The first motivation to search for the dark matter



In grammar school we learned that the movements of planets around the Sun can be interpreted precisely with the Newton's laws

Andromeda galaxies
Mass: 370 milliárd $M_{\odot}$
Distance: 2.5 million Light year

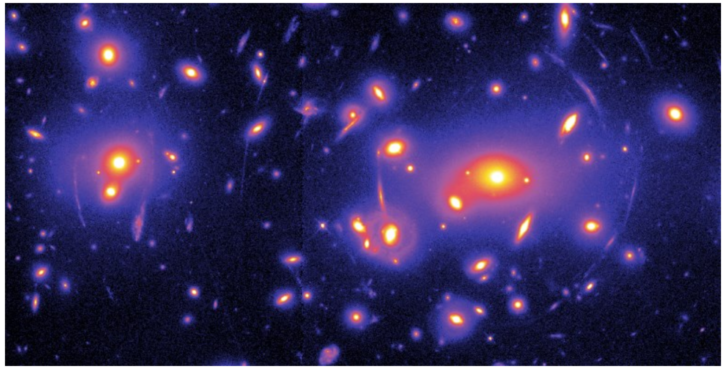
- Study of the rotational curves
- Dark matter should be introduced
- Modified Newtonian Dynamics ?



Census in the Universe
Stars and galaxies: 0.5 %
Visible matter: 5 %
Dark matter: ≈ 30 %
Dark energy: ≈ 65 %

Gravitational lensing

Dark galaxies



What do we know and what we do not about the dark matter?

- We observe its gravitational effect on the visible stars. Their contribution to the mass of the Universe is huge (95%)
- We are searching diligently for the associated particles with more and more sensitive detectors.

- What particle (s) are they consist of?
- What (new) interactions affect these particles?

- Very recently, a distant galaxy that appears completely devoid of dark matter has baffled astronomers: P. van Dokkum et al., Nature volume 555, 629 (29 March 2018). The general validity of Modified Newtonian Dynamics as an alternative to dark matter is now disproved, thus further supporting the idea of dark matter.

Searching from the basement to the attic already for 30 years, every corner with tremendous strength ...

- With state-of-the-art underground detectors,

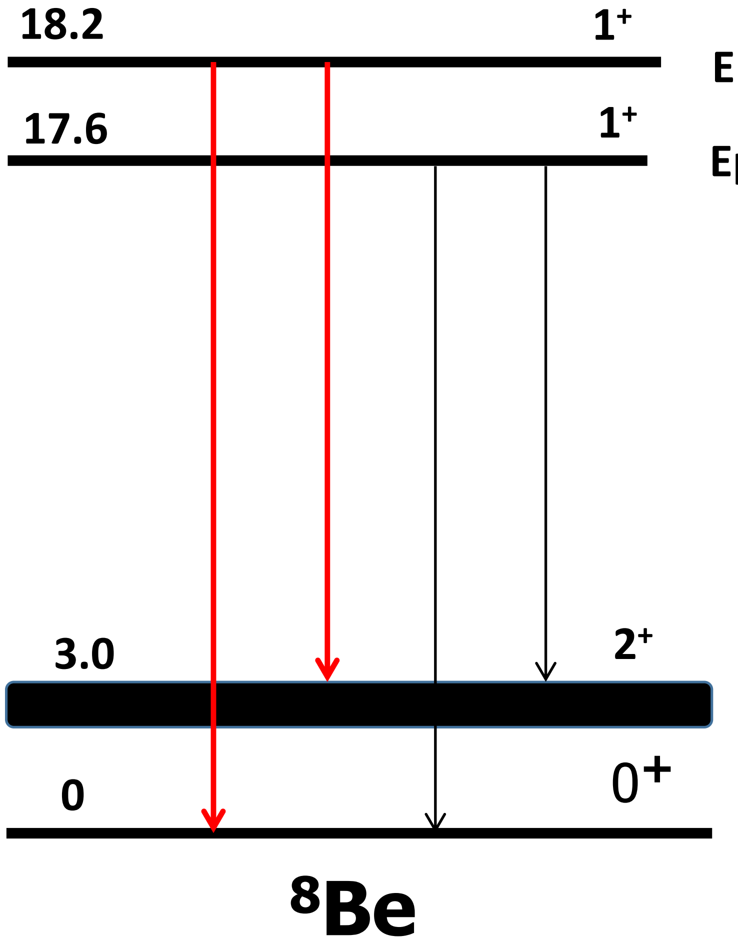
with high-sensitivity spectrometers built in space

Searching for new particles created in nuclear transitions has a very long history…

- The axion particle was proposed by Weinberg and by Wilczek as one mechanism for preserving CP invariance of strong interactions in the presence of instantons almost 40 years ago.
- The search for axions in nuclear transitions culminated in 1982.
- It turned out that nuclear transitions provide a useful laboratory to search for light particles which couple to quarks and/or gluons. The spin and parity of a particle emitted in nuclear decay can be constrained by an appropriate choice of the nuclear transition.
- 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.

Study the ^{8}Be M1 transitions

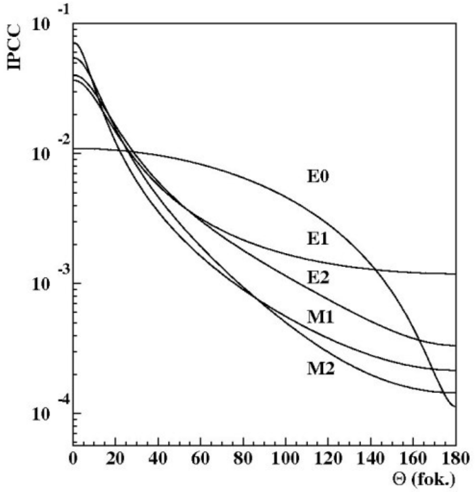
Excitation with the
^{7}Li(p,γ)^{8}Be reaction



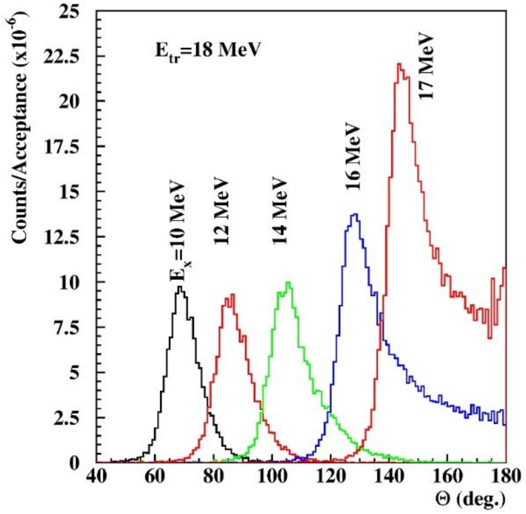
Ep= 1030 keV

Ep=   441 keV

Background



Signature



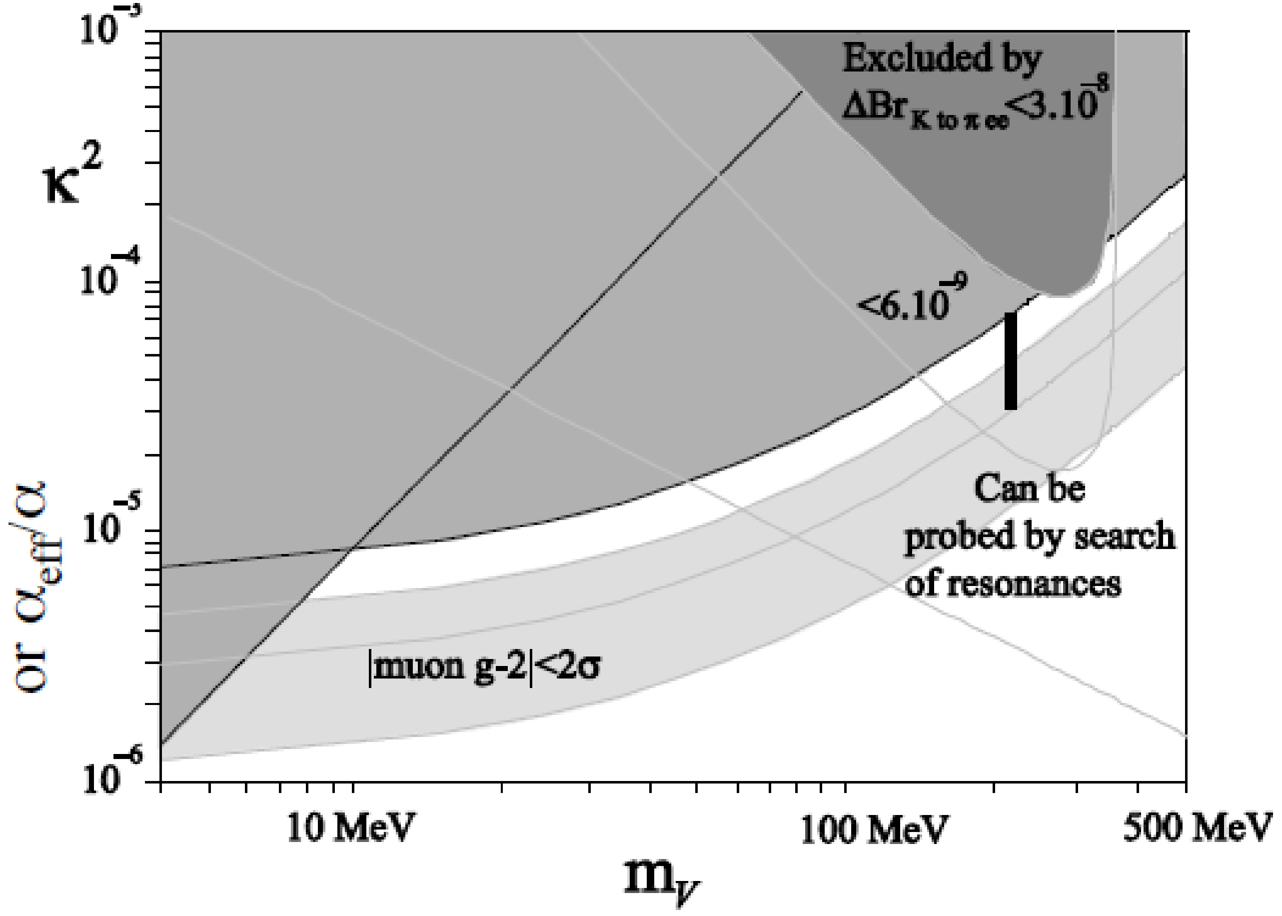
It has been suggested previously that pairs produced from the decay of a light particle can be distinguished from internal pairs by their angular correlation.

For a transition energy significantly 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.


Dark Forces at Accelerators
16th - 19th, October 2012
Laboratori Nazionali di Frascati, INFN
Frascati (Rome), Italy
INFN
Istituto Nazionale
di Fisica Nucleare
Laboratori Nazionali di Frascati
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.

Explanation of the g-2 anomaly by introducing a light particle (dark photon, or dark Z')
https://sites.google.com/site/zprimeguide/



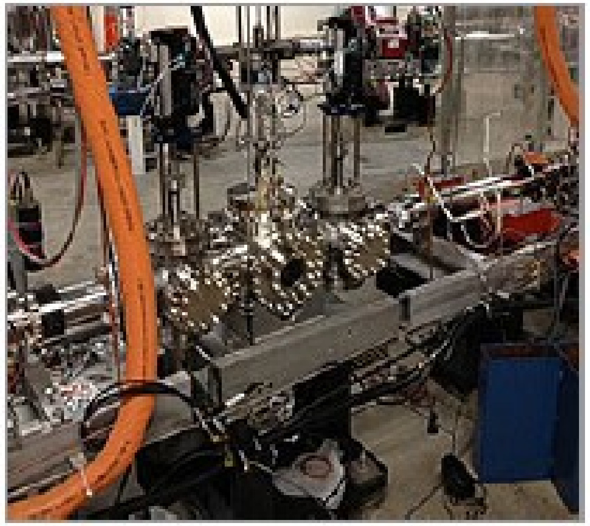
Light and dark:
ideas for new physics in O(1-100 MeV)

DOE Pulse

Science and Technology Highlights from the DOE National Laboratories

Number 401 | November 18, 2013

DarkLight attempts to bridge visible universe with dark matter



For thousands of years, humanity has relied on light to reveal the mysteries of our universe, whether it's by observing the light given off by brightly burning stars or by shining light on the very small with microscopes.

Yet, according to recent evidence, scientists think that only about five percent of our Universe is made of visible matter: ordinary atoms that make up nearly everything we can see, touch and feel. The other 95 percent is composed of the so-called dark sector, which includes dark matter and dark energy. These are described as "dark" because we observe their effects on other objects rather than by "seeing" them directly. Now, to study the dark, scientists are turning to what they know about light, and they are pointing to a recently successful test of experimental equipment that suggests an exploration of the dark sector may be possible at DOE's Jefferson Lab.

Dark Force searches in the Labs

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"

Observation of Anomalous Internal Pair Creation in

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

About this Attention Score

In the top 5% of all research outputs scored by Altmetric

MORE...

Mentioned by

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

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]

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.

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] Susan Gardner,[1,2] Jordan Smolinsky,[1] Tim M. P. Tait,[1] and Philip Tanedo[1]

[1] Department of Physics and Astronomy, University of California, Irvine, California 92697-4575 USA
[2] Department of Physics and Astronomy, University of Kentucky, Lexington, Kentucky 40506-0055 USA

Phys. Rev. Lett. 117, 071803

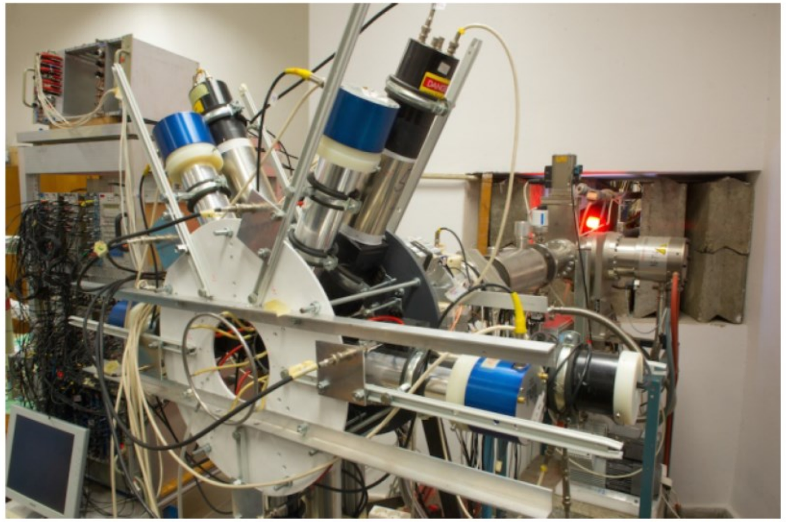
NATURE | NEWS

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.

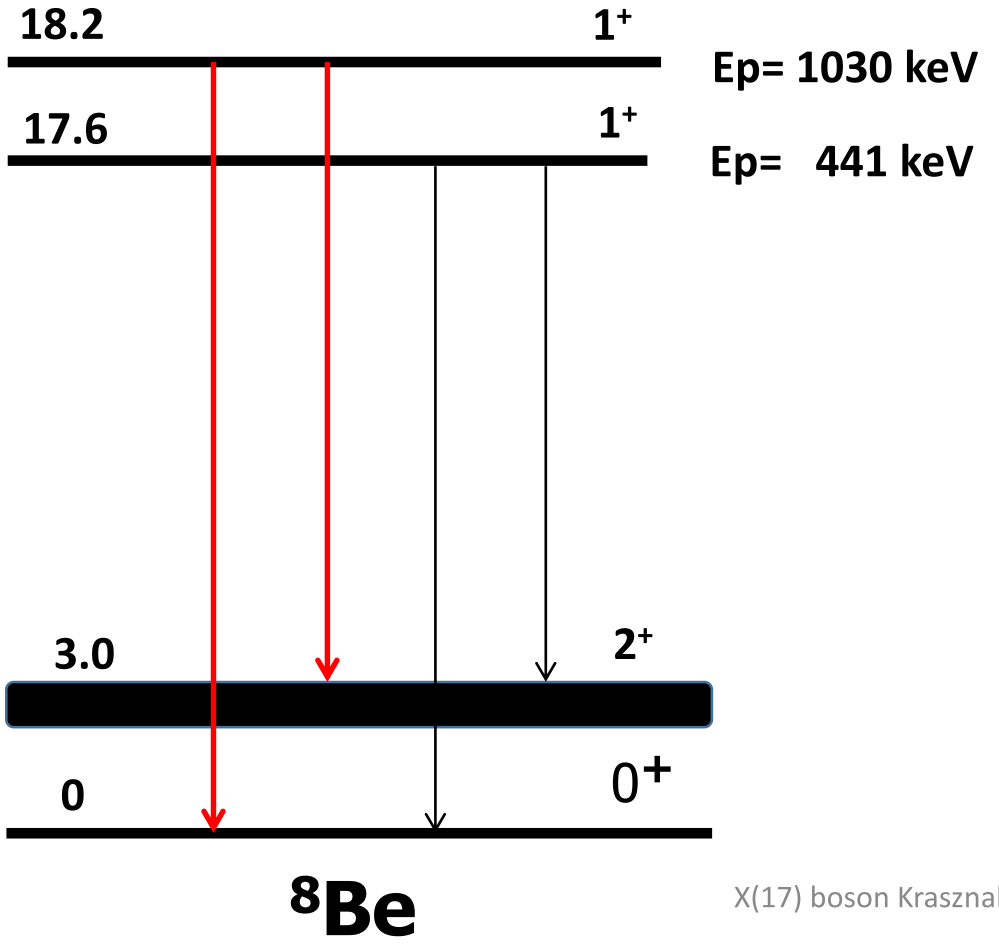
Then, on 25 April, a group of US theoretical physicists brought the finding to wider attention by publishing its own analysis of the result on arXiv[2]. The theorists showed that the data didn't conflict with any previous experiments – and concluded that it could be evidence for a fifth fundamental force.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

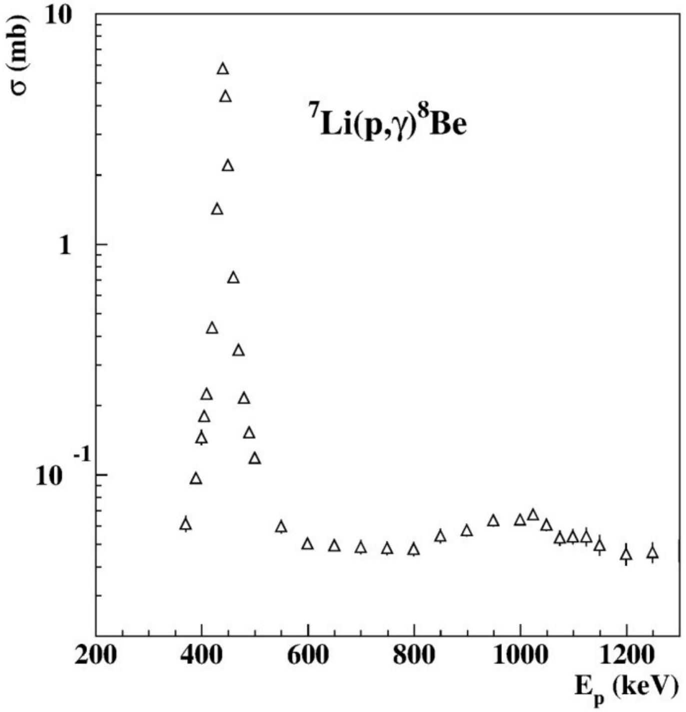
Dark matter may feel a "dark force" that the rest of the Universe does not

Four days later, two of Feng's colleagues discussed the finding at a workshop at the SLAC National Accelerator Laboratory in Menlo Park, California. Researchers there were sceptical but excited about the idea, says Bogdan Wojtsekhowski, a physicist at the Thomas Jefferson National Accelerator Facility in Newport News, Virginia. "Many participants in the workshop are 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.

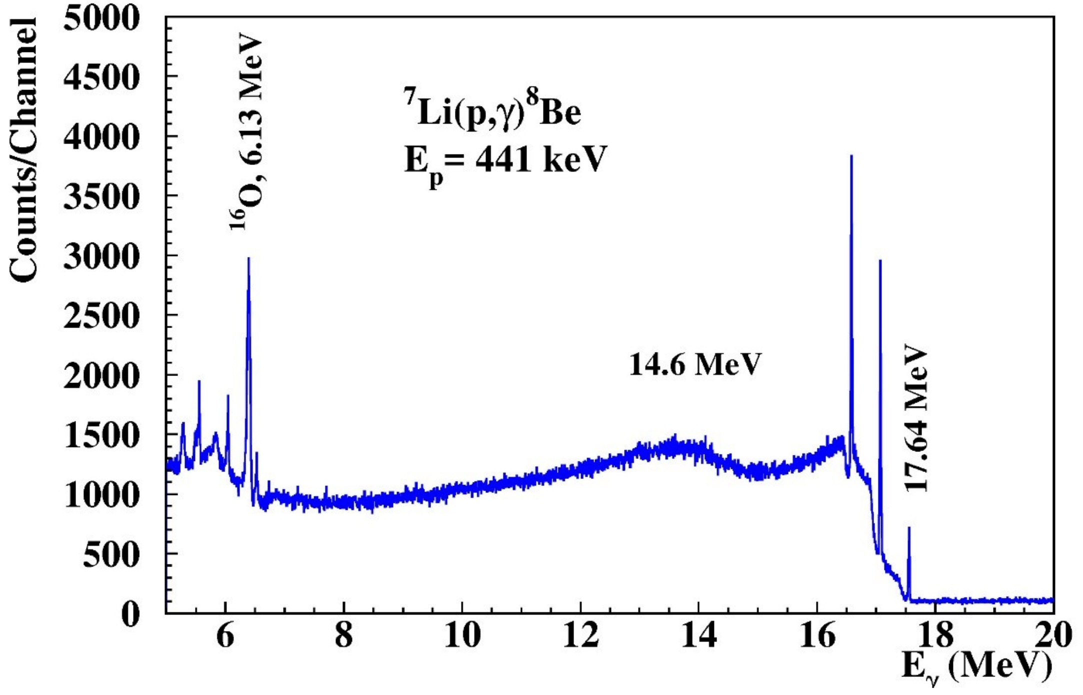
Study the ^{8}Be M1 transitions

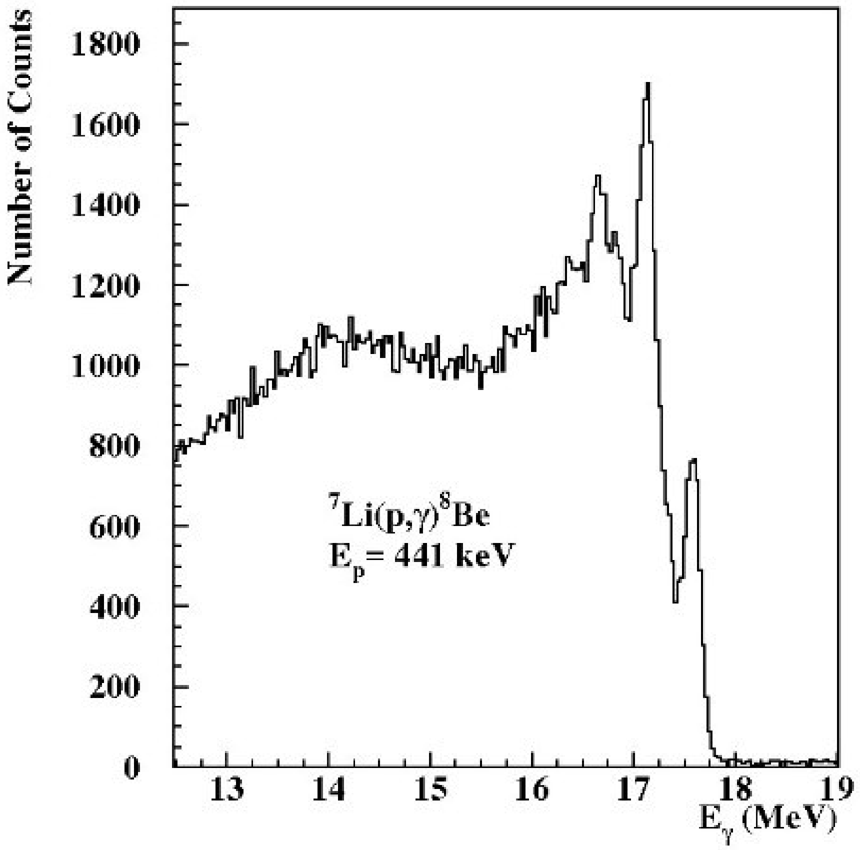
Excitation with the ^{7}Li(p,γ)^{8}Be reaction



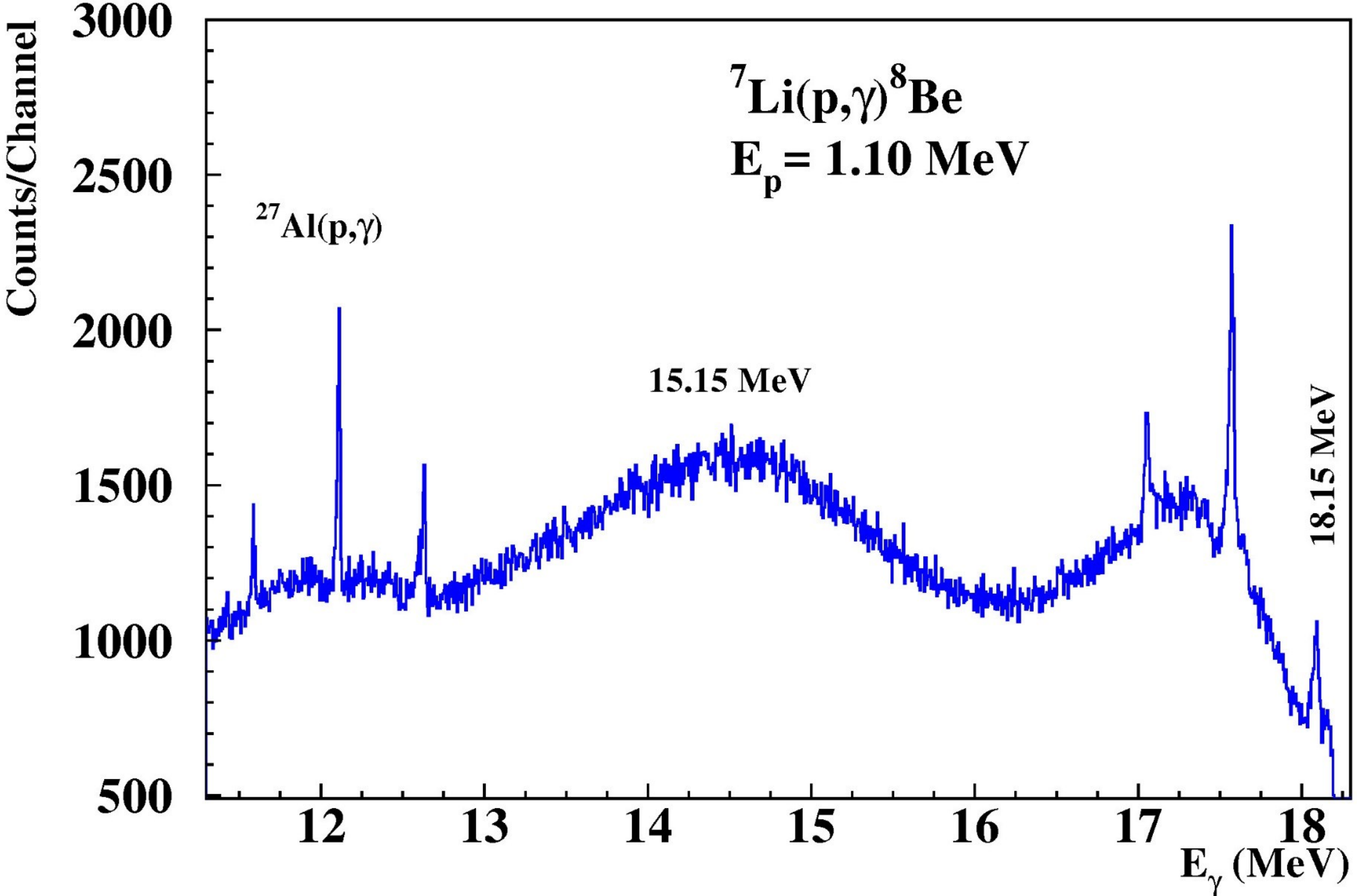


γ-ray spectra measured with a 100% HpGe detector and a 3”x3” $LaBr_3$ one

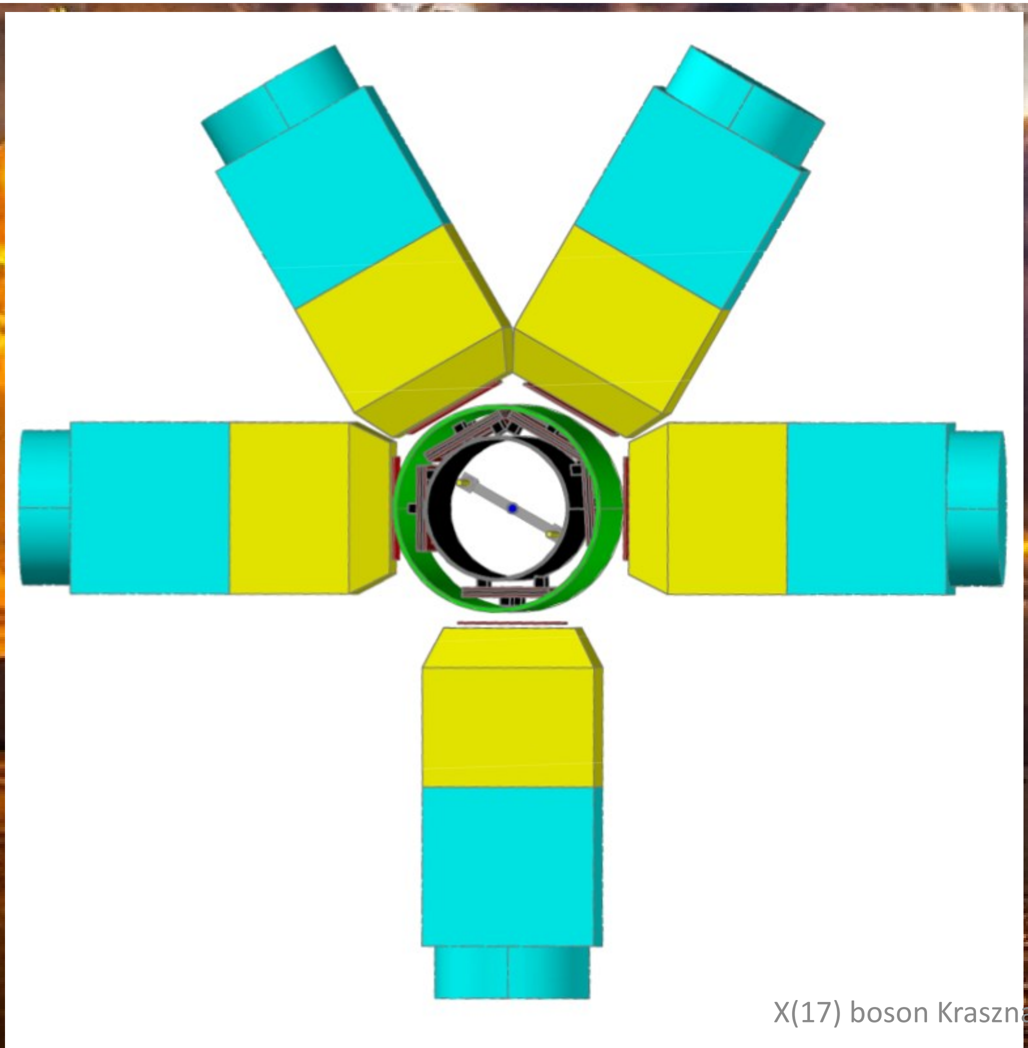




γ-ray spectra measured with the 100% HpGe detector

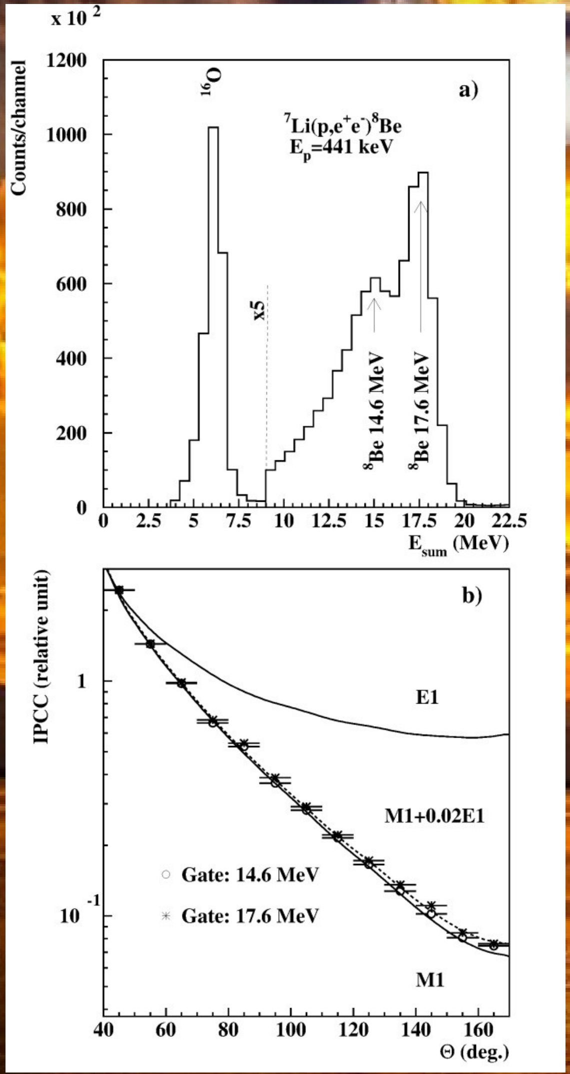


Geometrical arrangement of the scintillator telescopes (NIM, A808 (2016) 21)

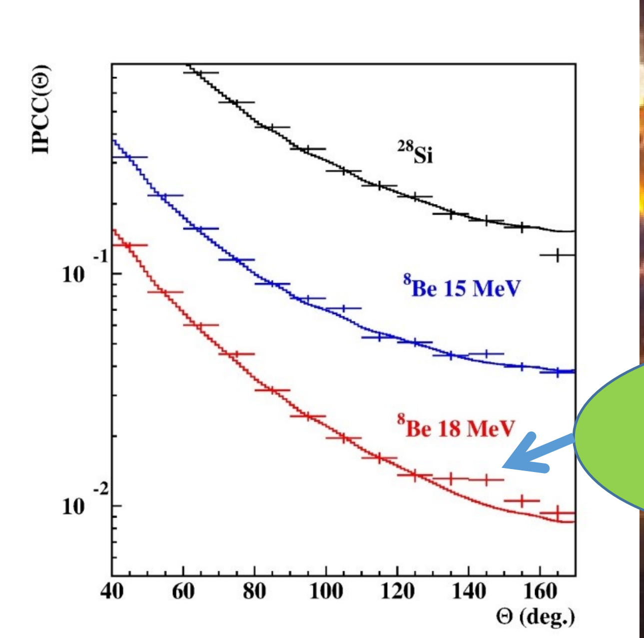


Results

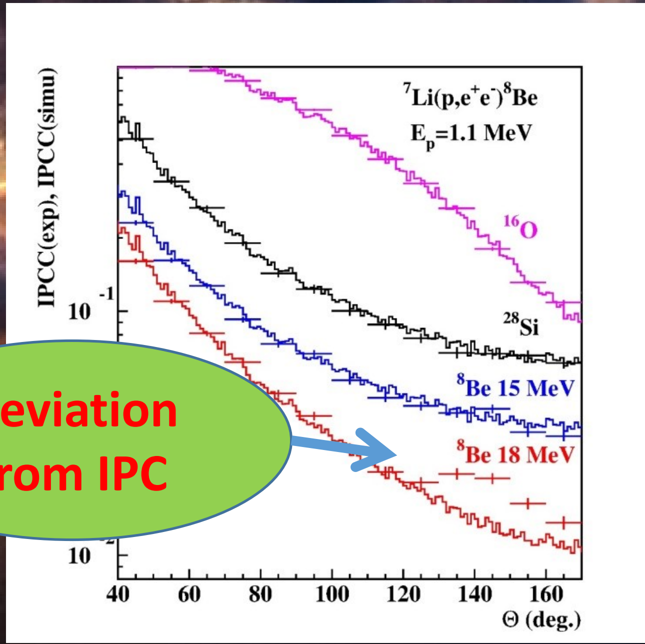
e^+ - e^- sum energy spectra and angular correlations



Ep=1.04 MeV



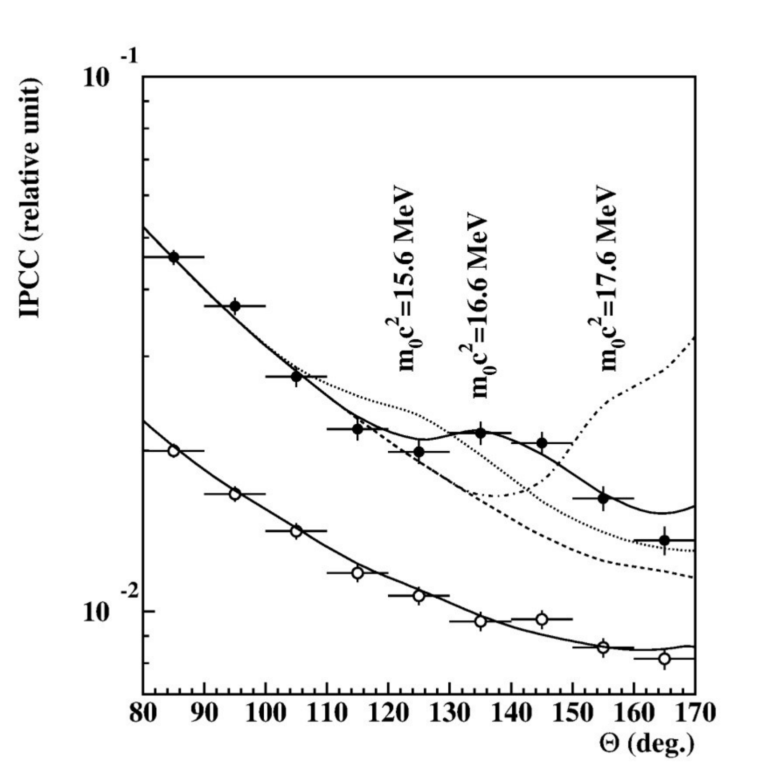
Ep=1.10 MeV



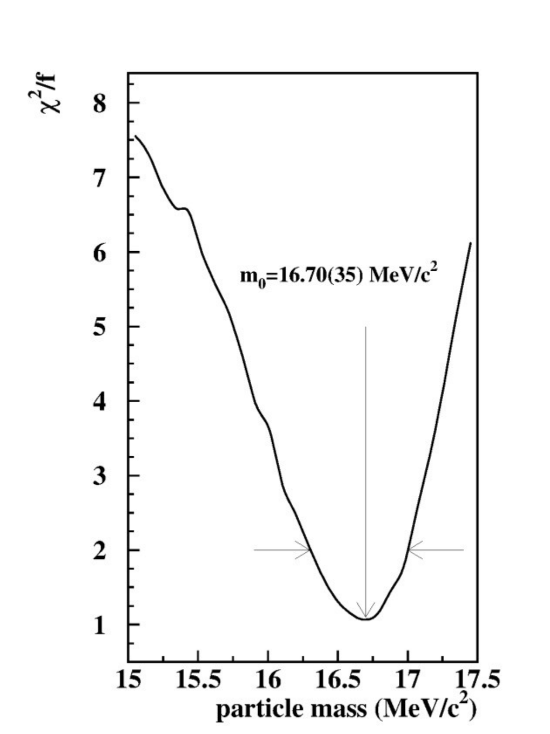
Deviation from IPC

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

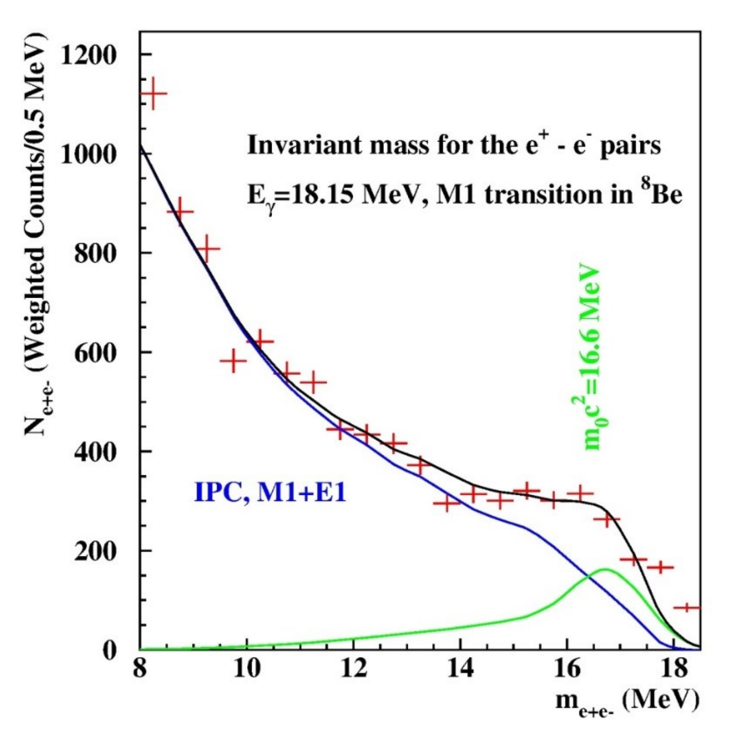
How can we understand the peak like deviation? Fitting the angular correlations



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 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))

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

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

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

Branching ratio:

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

$$|\varepsilon_p + \varepsilon_n| \approx 0.011$$

$$|\varepsilon_u + \varepsilon_d| \approx 3.7 \times 10^{-3}$$

Pion decay constrain:

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

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

Promising Outlook

IPC:

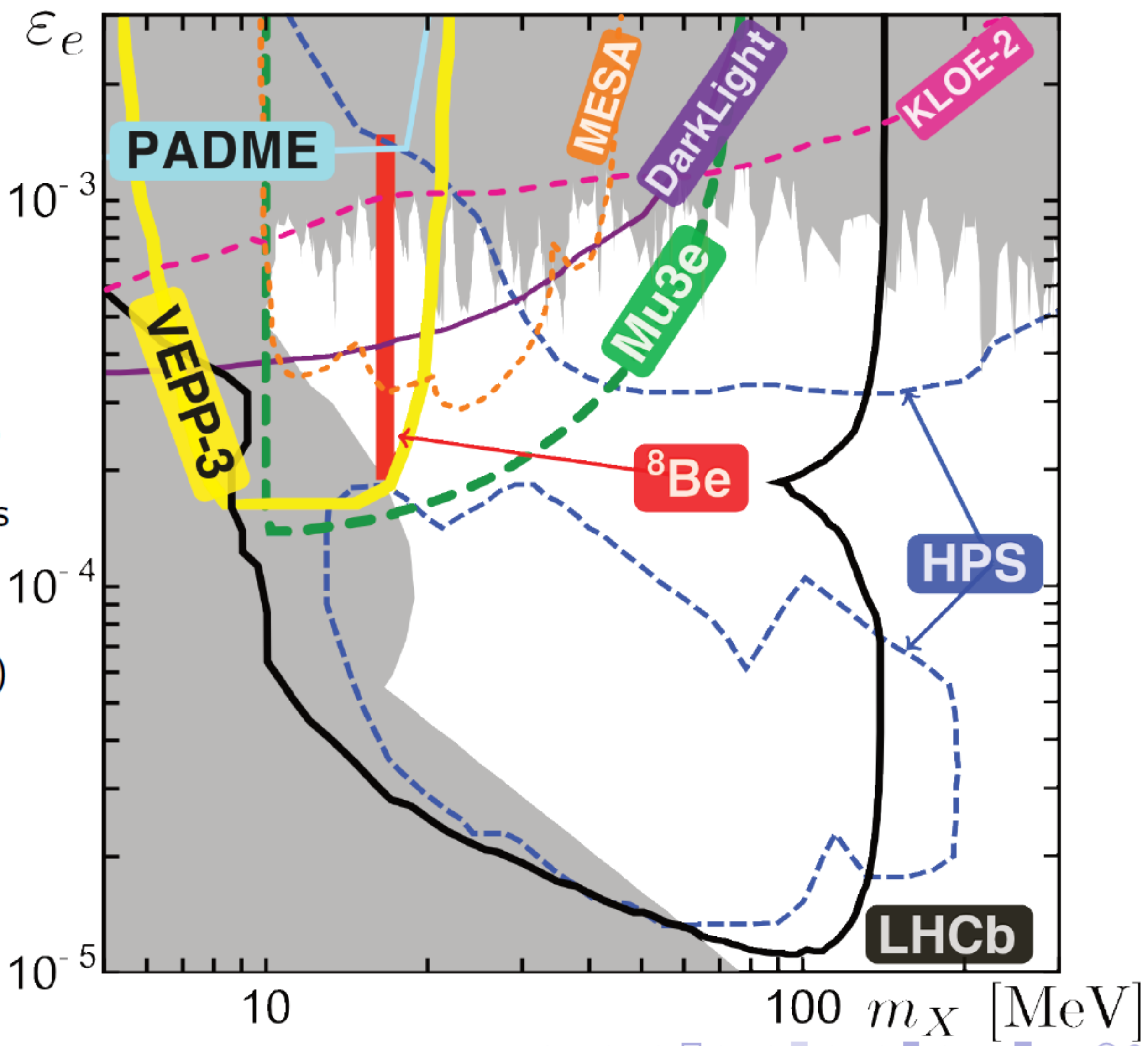
- verify ^{8}Be
- ^{10}B : 19.3 MeV
- ^{10}Be : 17.79 MeV

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



Planned experiments to study X(17)

- **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*).

- VEPP-3 is planned experiment in Vladivostok, Russia. They are planning to use intense positron beams.

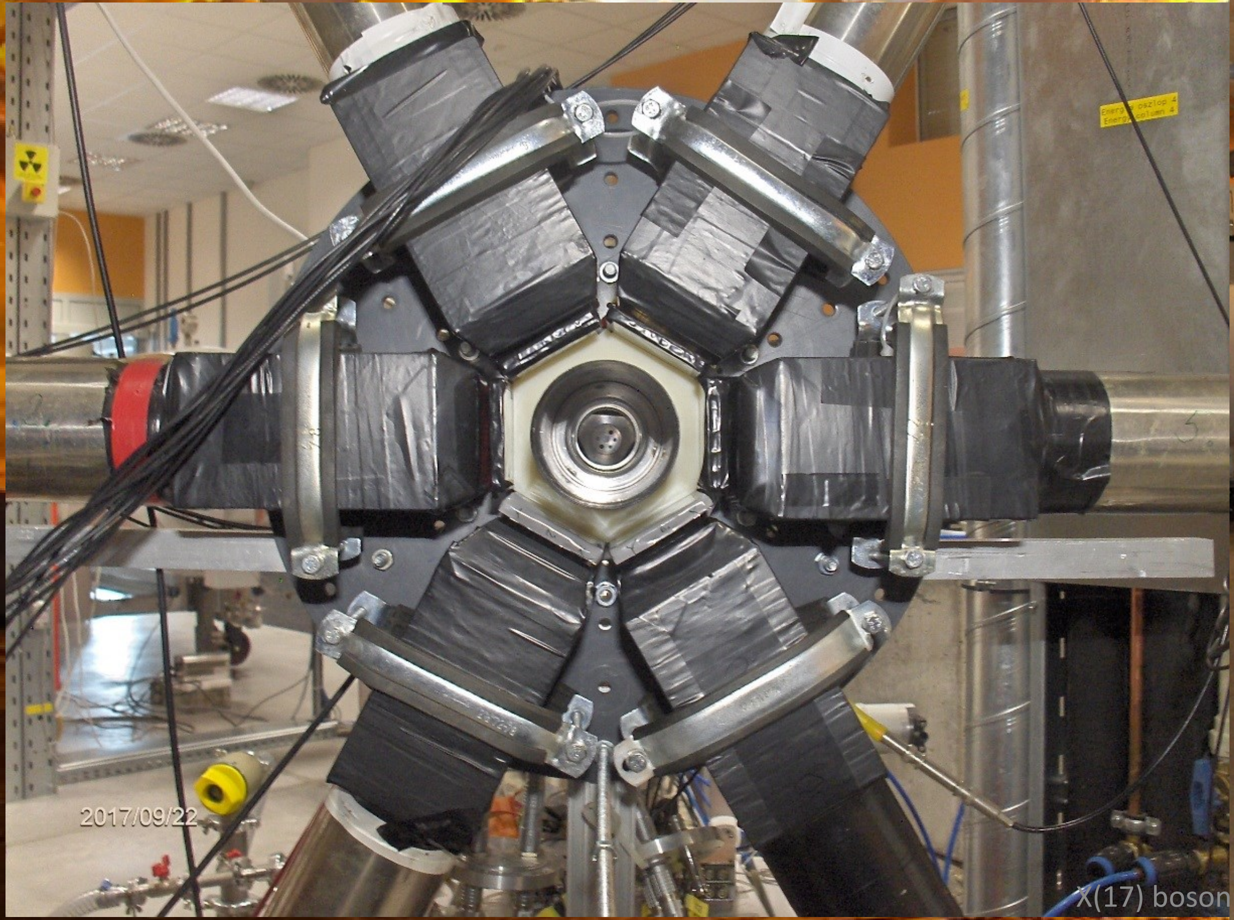
- DarkLight is an experiment at the JLAB in USA using electron–proton collisions.

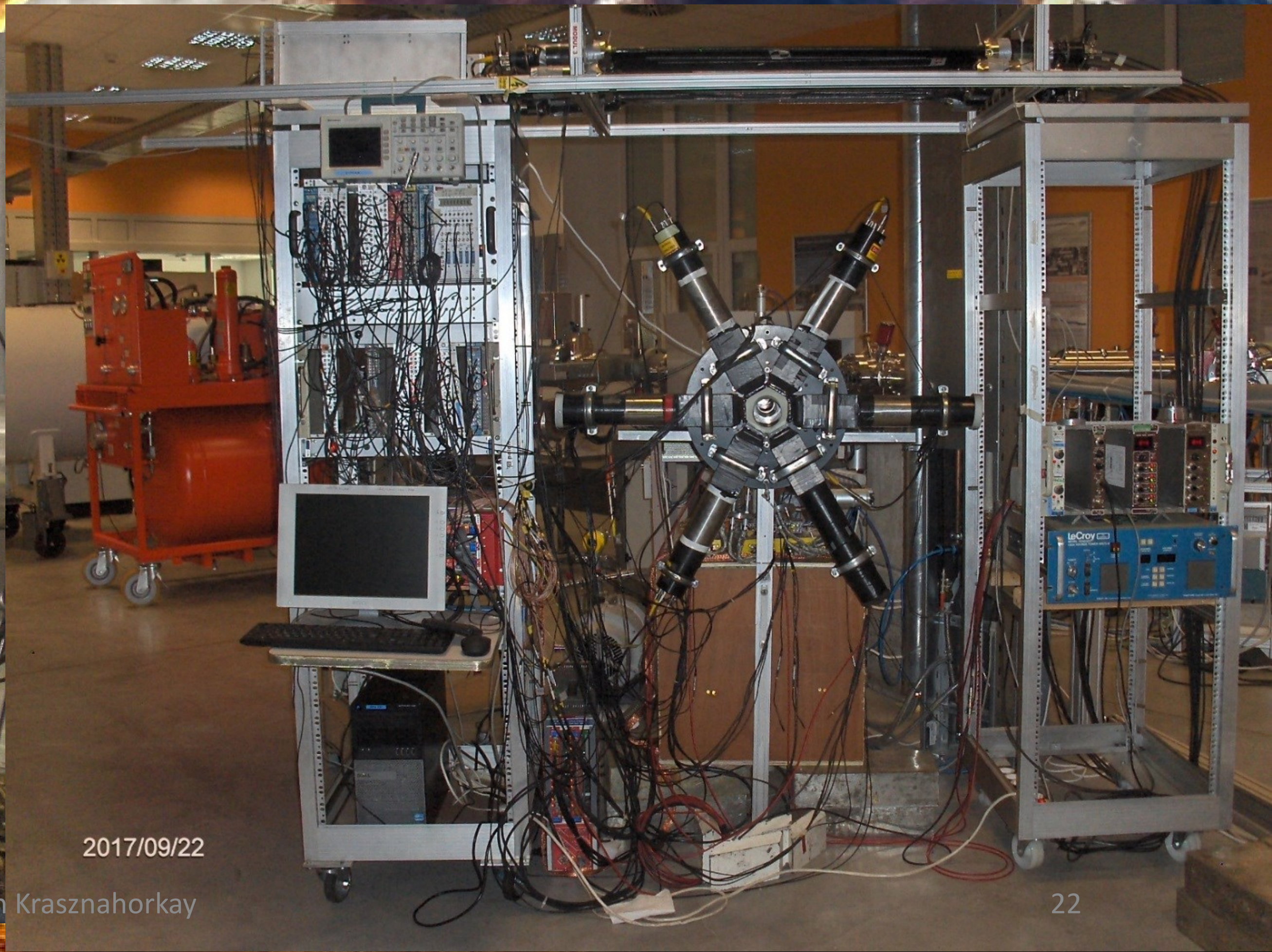
Repeating the experiments at a new Medium-Current Tandetron Accelerator System

Main specifications:

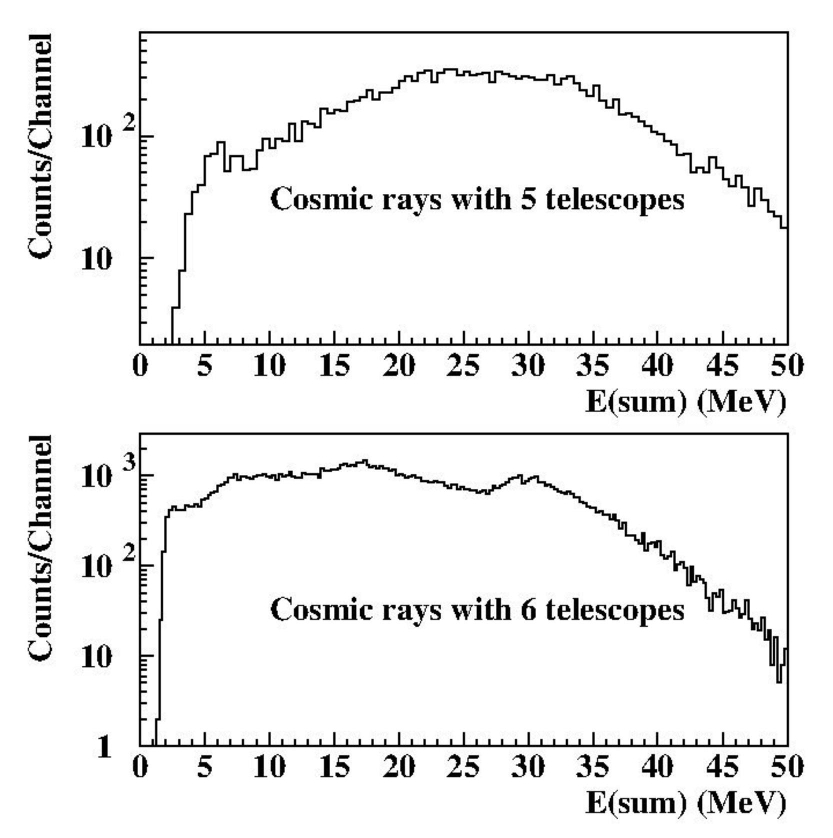
- TV ripple: 25 V_{RMS}, TV stability: 200 V (GVM), 30 V (SLITS)
- Beam current capability at 2 MV: 200 µA proton, 40 µA He

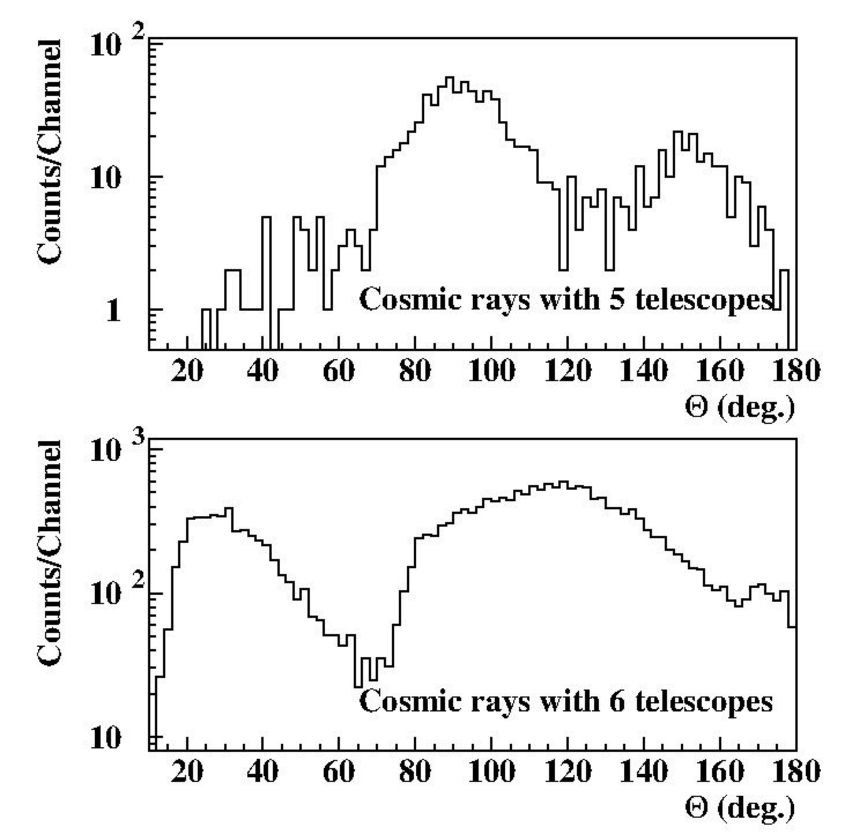
The new e^+e^- pair spectrometer with six telescopes equipped with Si DSSD's



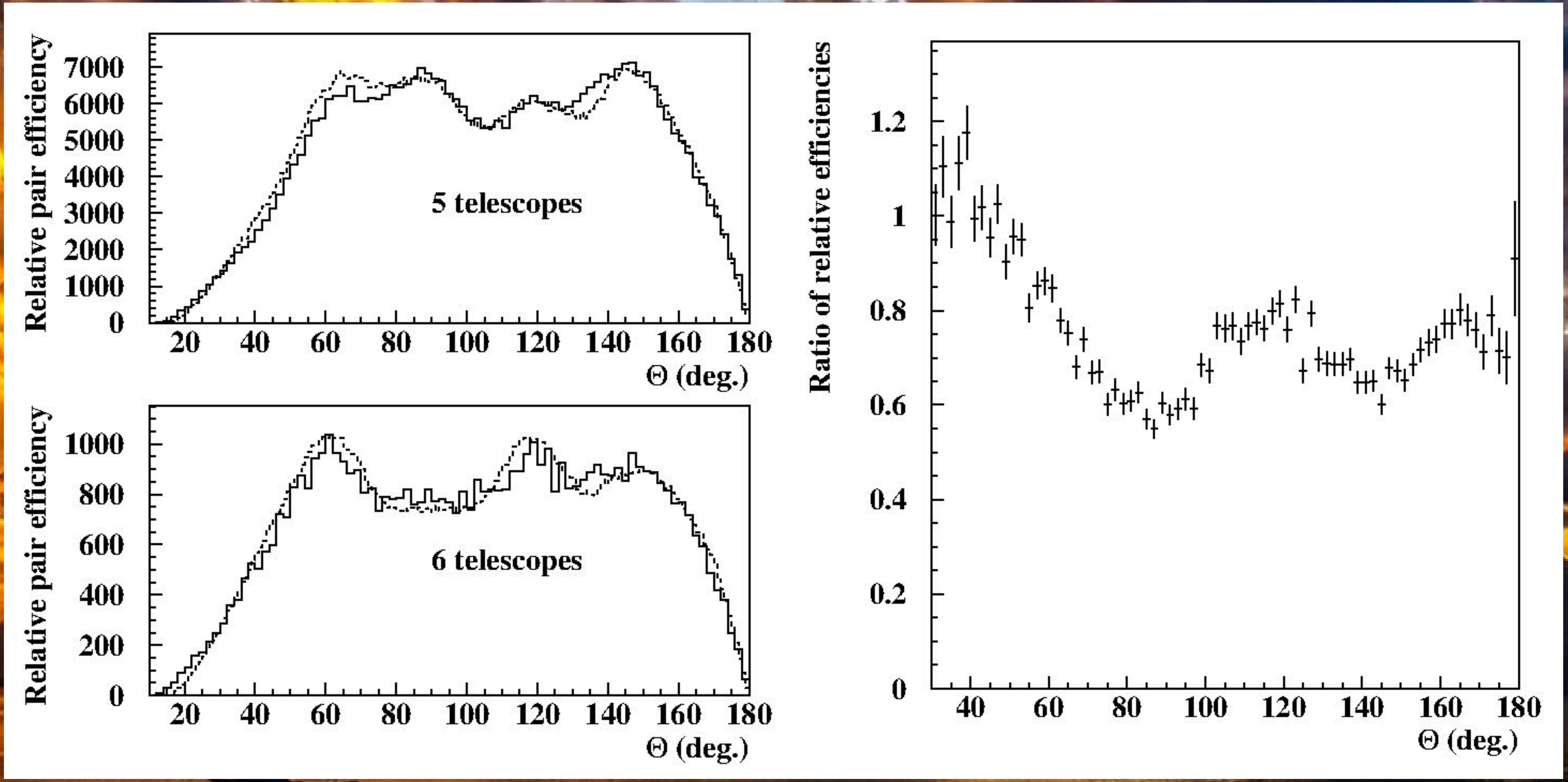


Background from cosmic rays in the setups with 5 and 6 telescopes



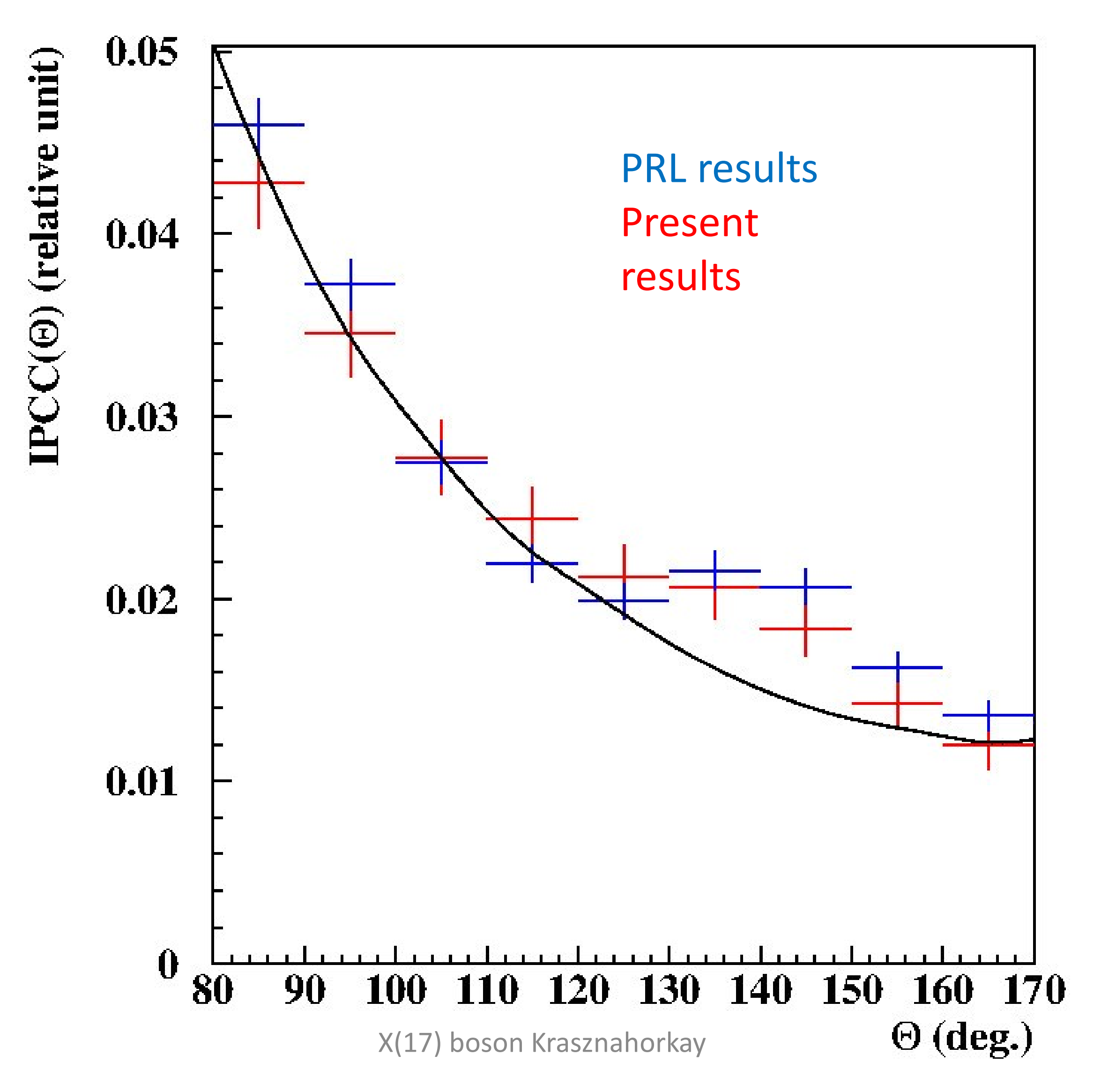


Efficiency curves for the setups with 5 and 6 telescopes

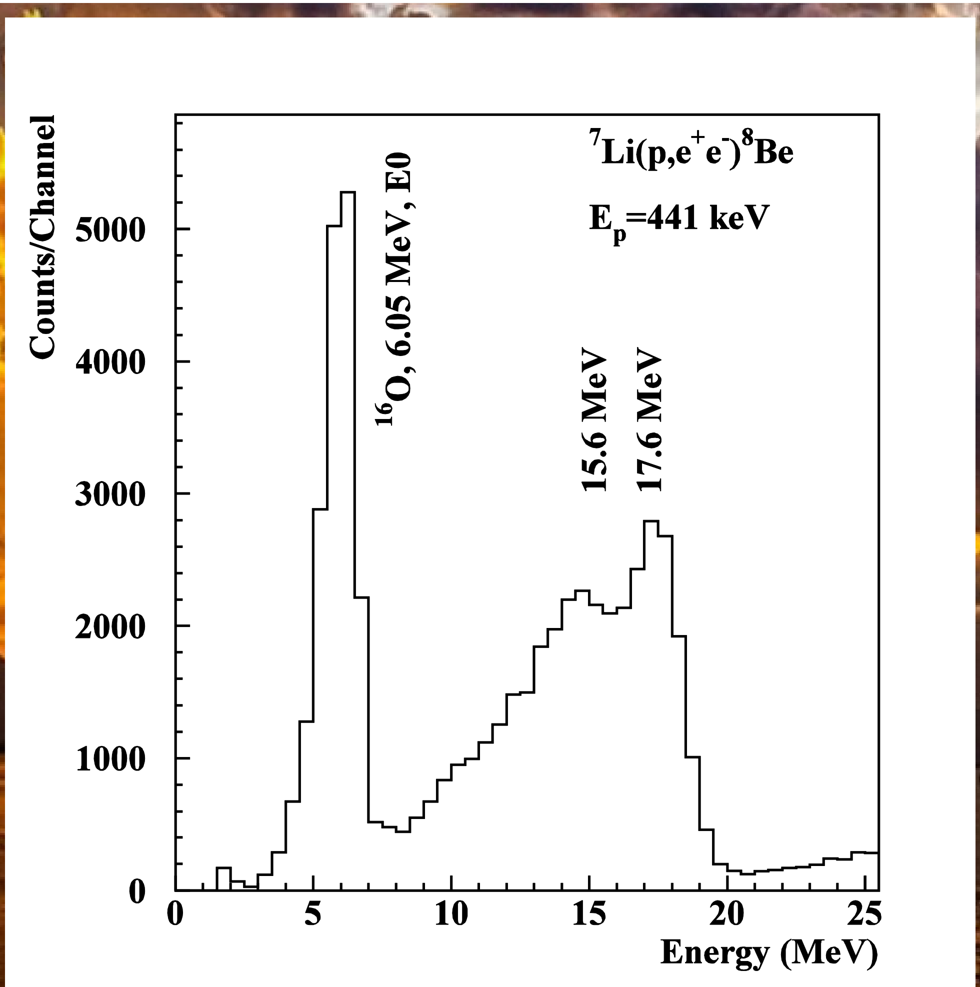


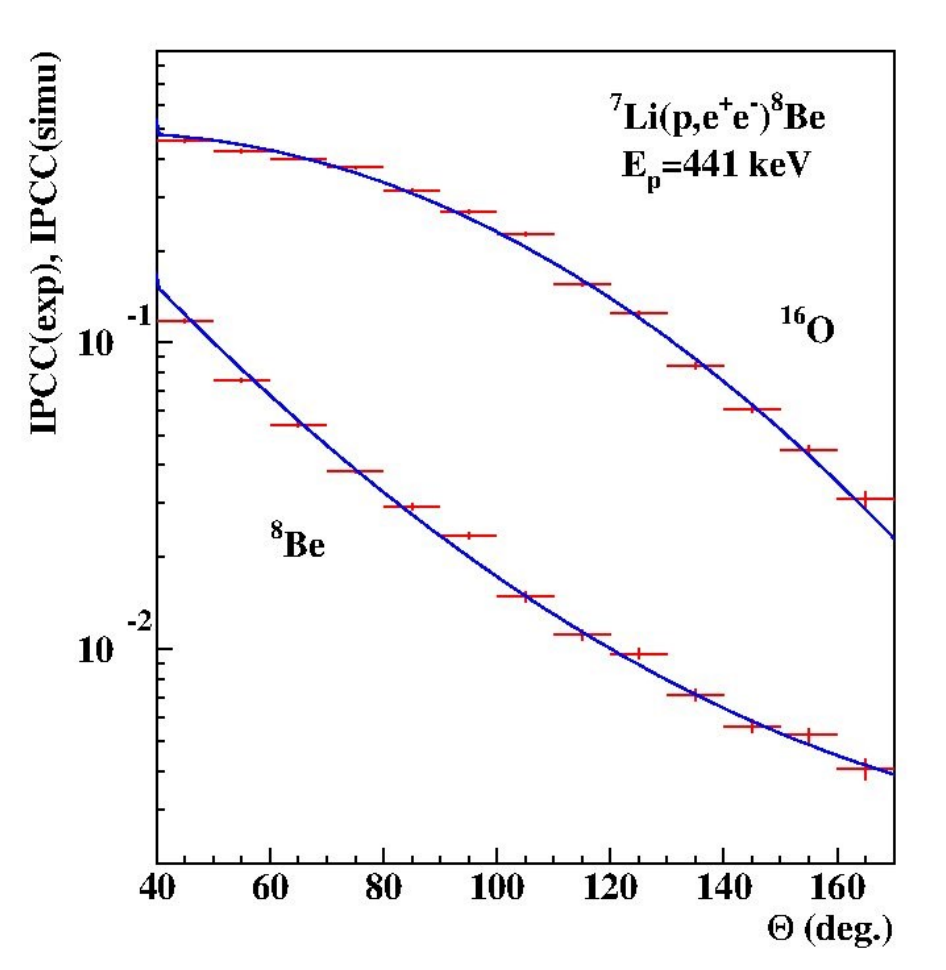
The results of the present experiment can be considered independent from the one we published in PRL in 2016.

Recent (preliminary) results for the 18.15 MeV transition

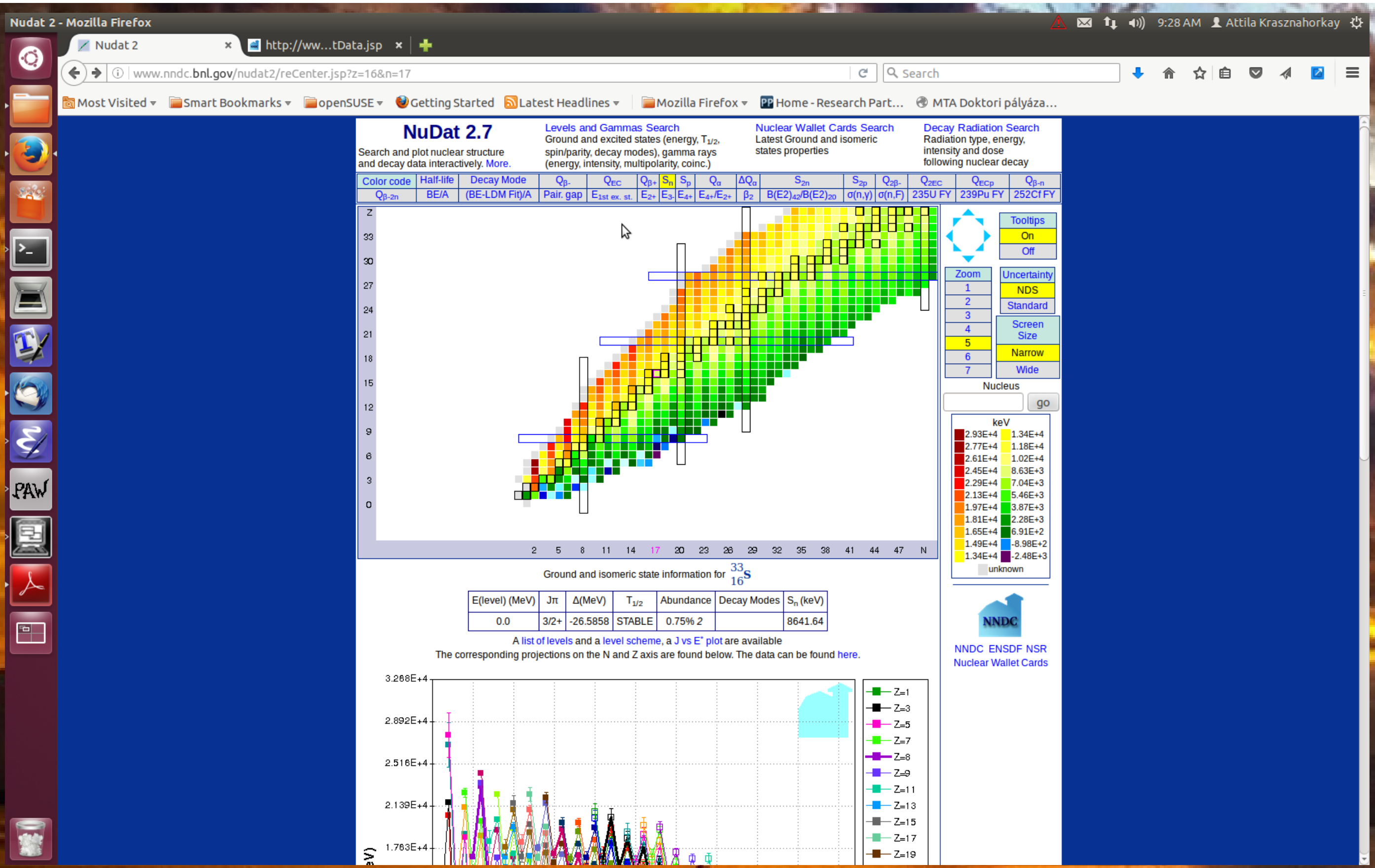


Recent (preliminary) results for the 17.6 MeV transition





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

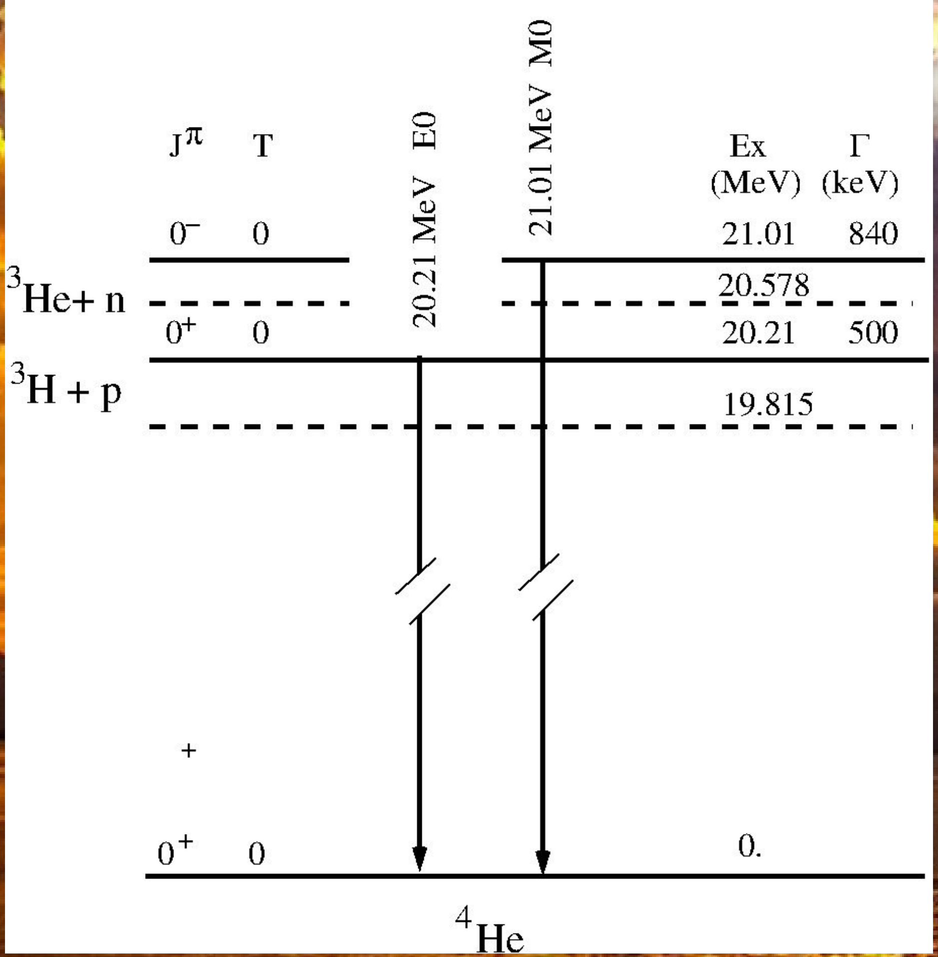


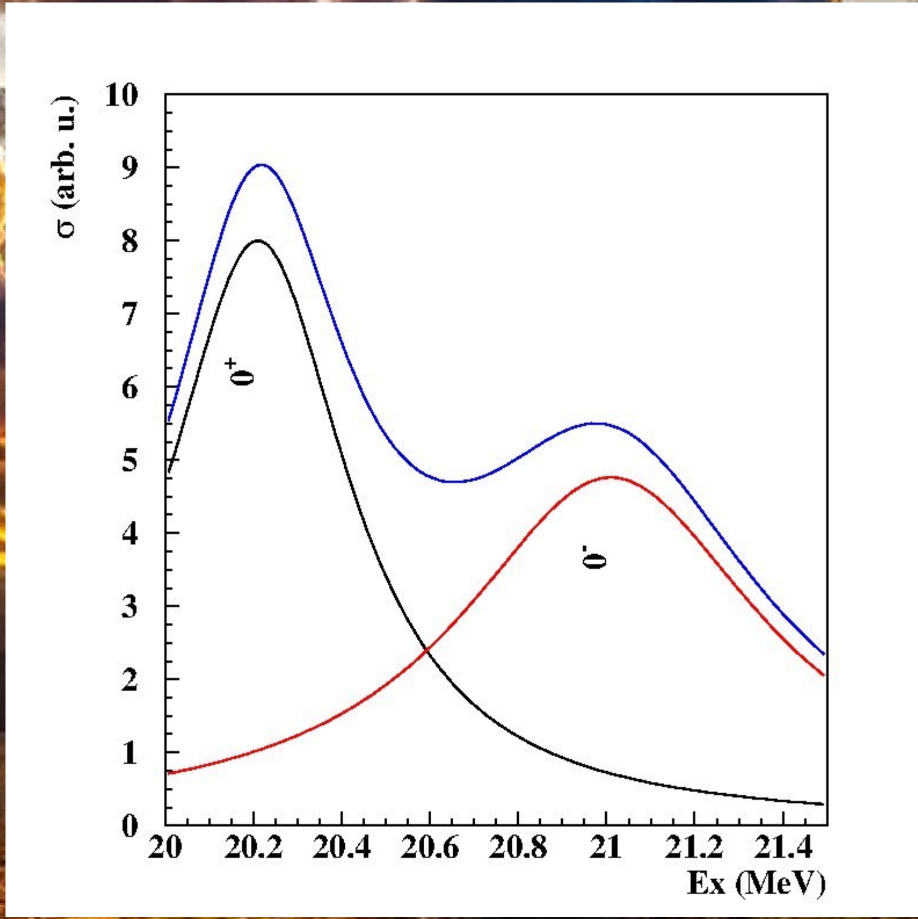
- Long lived excited state

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

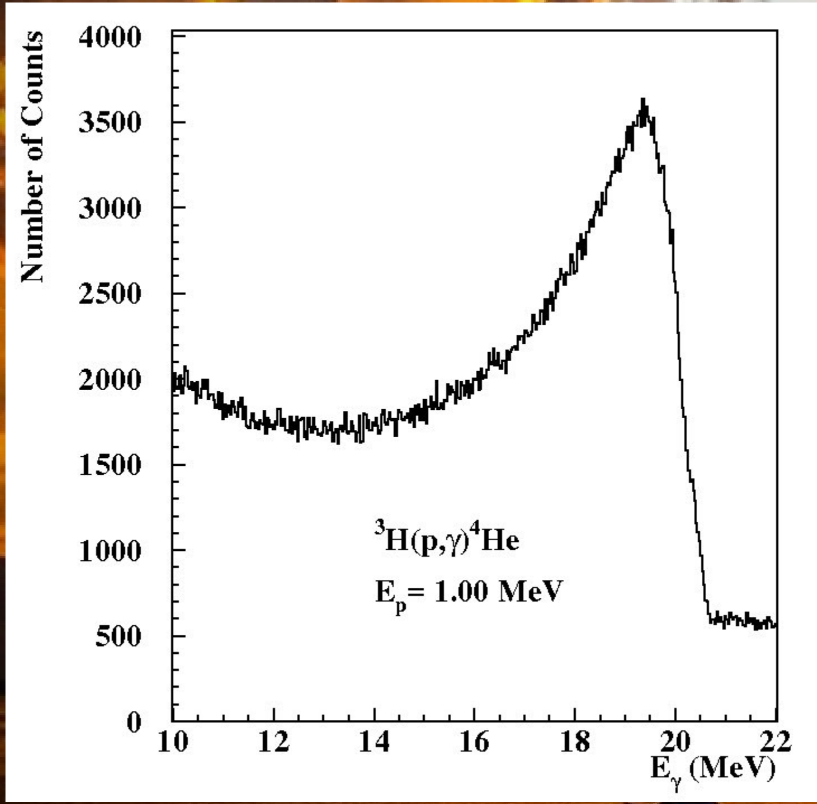
- M1 or M0 transitions
- Proper reaction for the excitation
- No background reactions

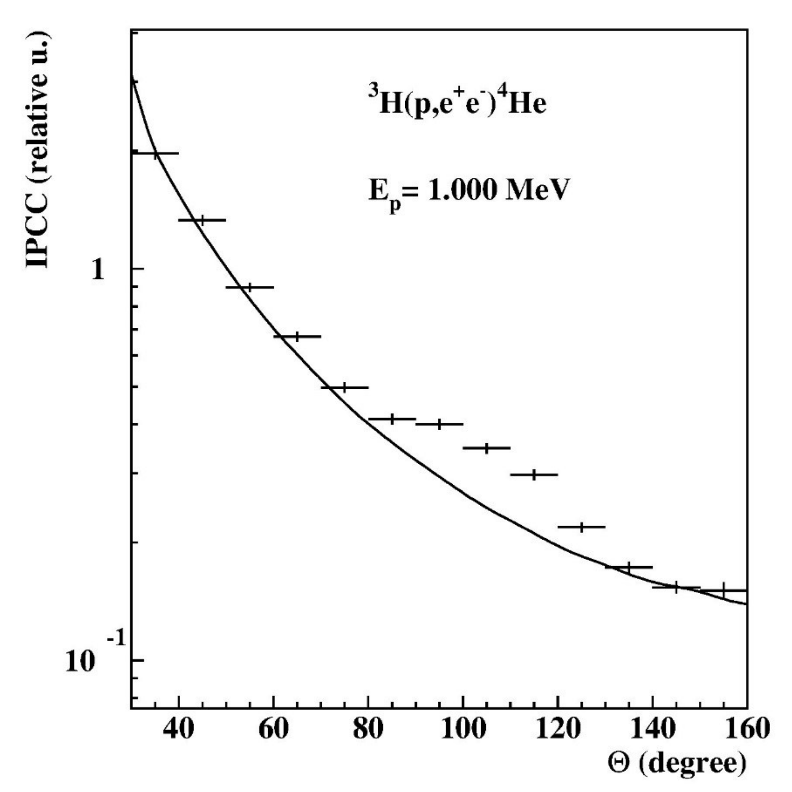
Study of the 21.01 MeV M0 transition in ^{4}He excited by ^{3}He+n, and t+p reactions

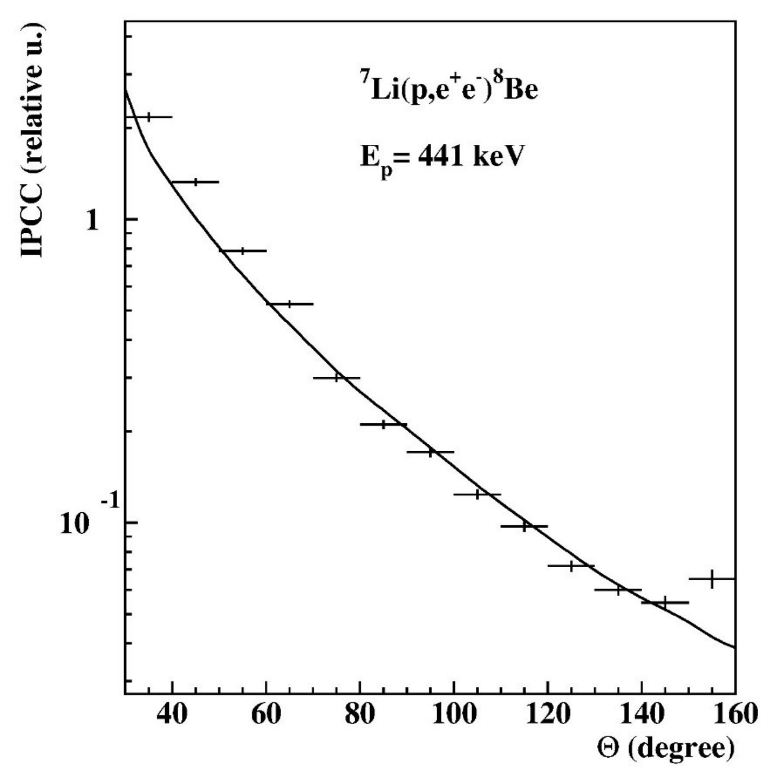




Preliminary results for the ^{4}He M0 transition

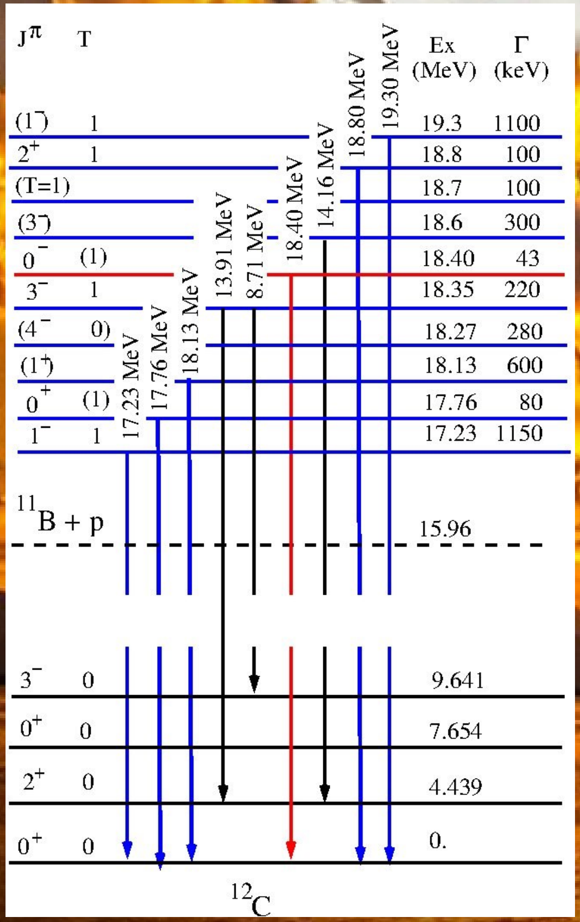


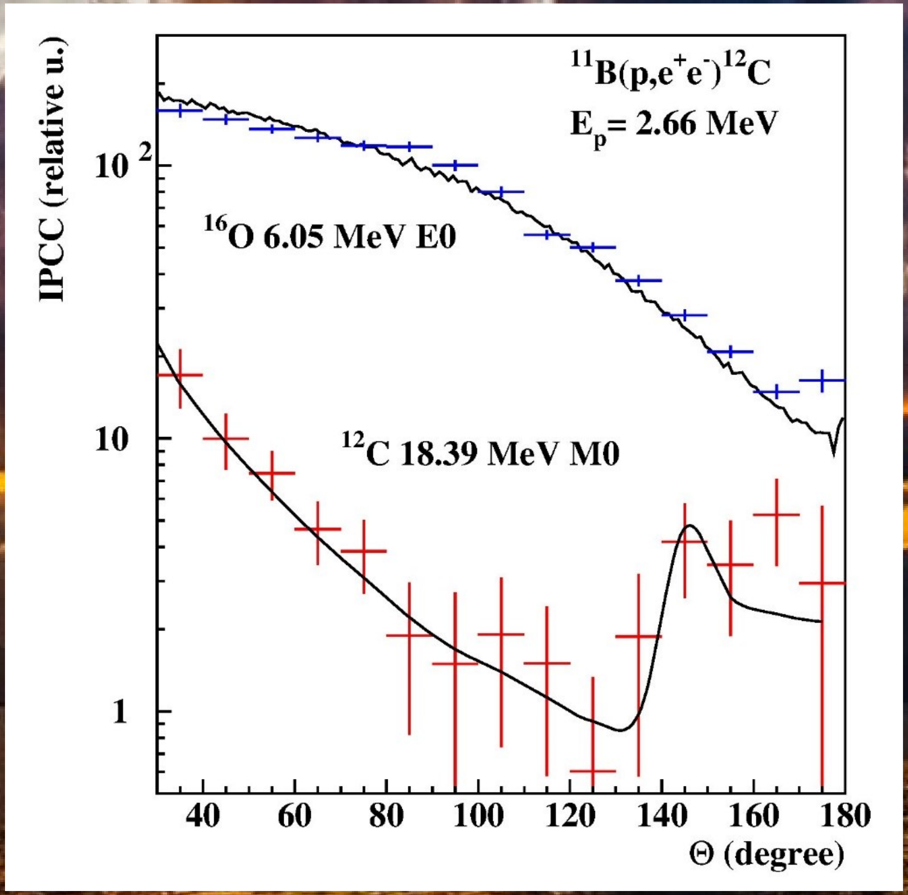




γ-ray spectrum | e+e- angular correlation | e+e- (reference) angular correlation

^{12}C very preliminary results





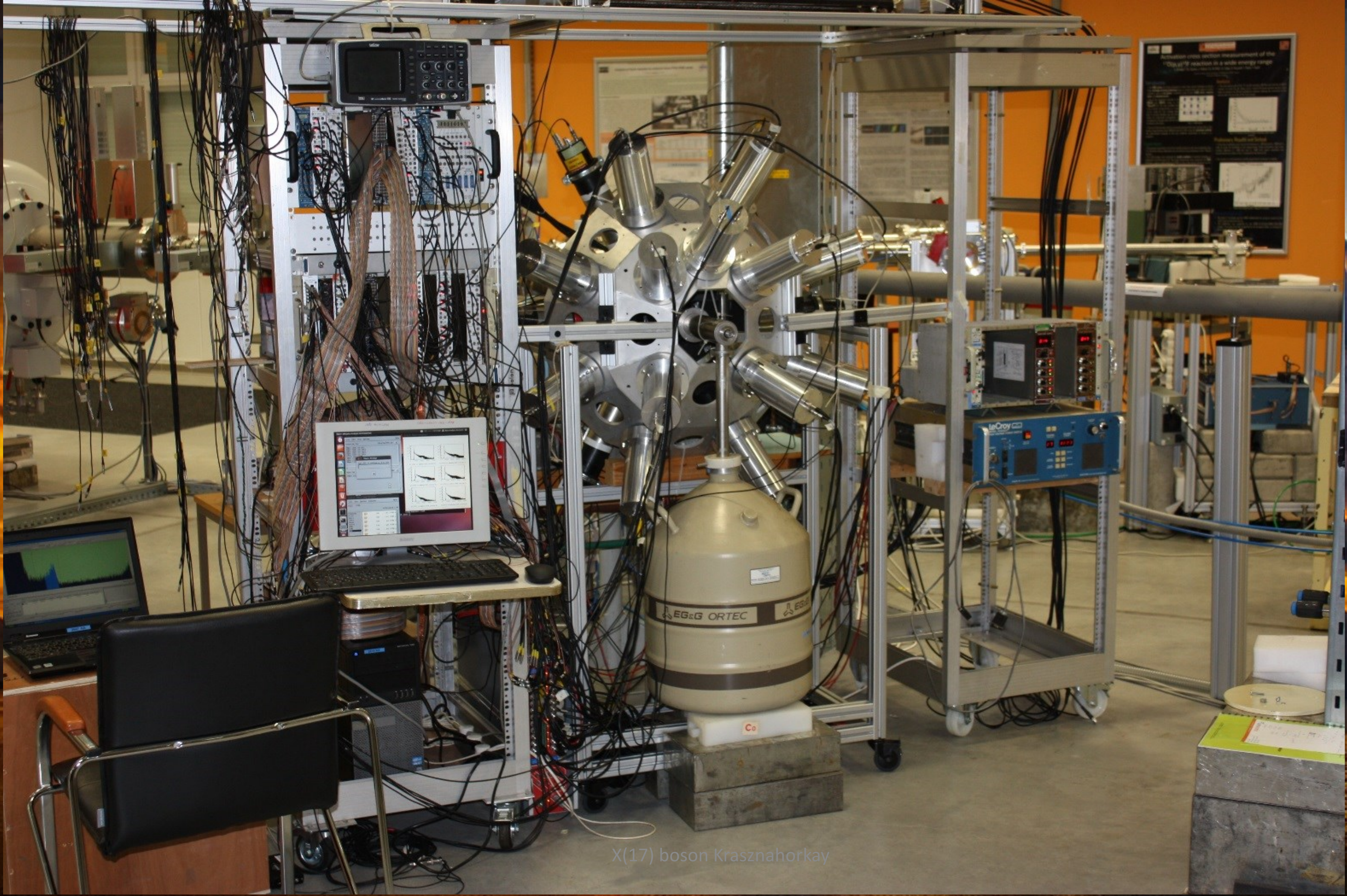
Study the $\gamma\gamma$-decay of X(17) in ^{4}He

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

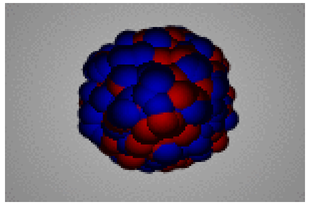
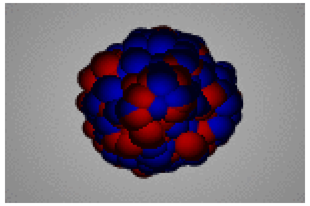
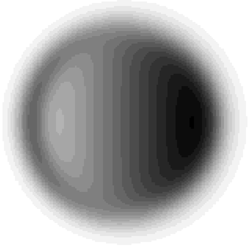
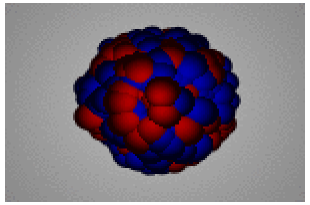
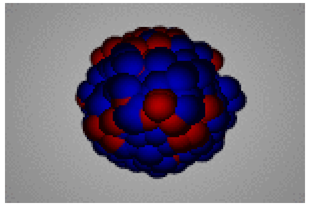
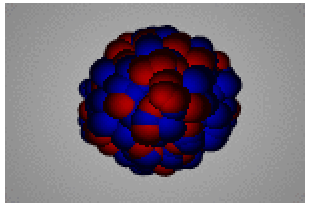
- $\gamma\gamma$-decay only known in a special case: $0^+ \rightarrow 0^+$ (^{90}Zr, ^{40}Ca, ^{16}O) ^{4}He
- *J. Schirmer et al., PRL 53, 1897 (1984)*
- *J. Kramp et al., NPA 474, 412 (1987)*
- Walz, N. Pietrala et al., Competitive Double-Gamma' ($\gamma\gamma/\gamma$) Decay *Nature* **526**, 406 (2015)

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

Study the angular correlation with $LaBr_3$ detectors.


EG&G ORTEC
LeCroy

Electric Giant Resonances

	Isoscalar	Isovector
Monopole		
Dipole		
Quadrupole		

Fundamental high-frequency modes of nuclear excitation.

Description macroscopically: liquid-drop model.

Microscopically: Particle-hole coherent oscillations.

$$\Delta W = \alpha A - \beta A^{2/3} - \gamma \frac{Z^2}{A^{1/3}} - \zeta \frac{(A/2-Z)^2}{A} + \delta A^{3/4}$$

To [8]Be continued…

Thank you very much for your attention