Overview of experimental results for the X17 particle

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Debrecen, Hungary

Workshop at 1 GeV scale: From mesons to axions
Sep 19 – 20, 2024
Faculty of Physics, Astronomy and Computer Science, Jagiellonian University

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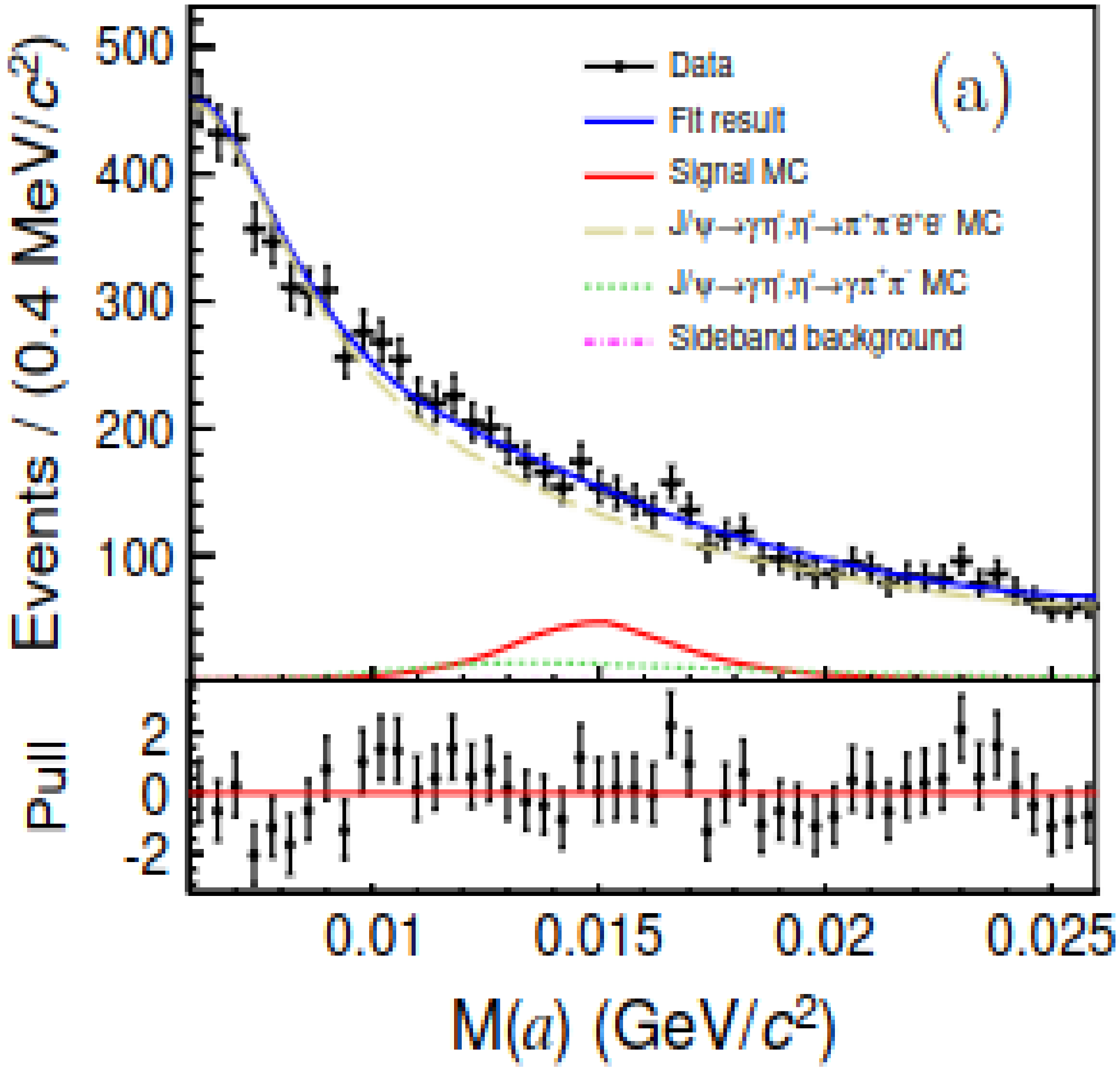
Study of $\eta' \to \pi^+\pi^- l^+ l^-$ decays at BESIII

The BESIII collaboration



With a sample of $(10087 \pm 44) \times 10^6$ J/ψ events, the branching fractions of $\eta' \to \pi^+\pi^- l^+l^-$ (with $l = e, \mu$) are determined to be $B(\eta' \to \pi^+\pi^- e^+e^-) = (2.45 \pm 0.02(\text{stat.}) \pm 0.08(\text{syst.})) \times 10^{-3}$ and $B(\eta' \to \pi^+\pi^-\mu^+\mu^-) = (2.16 \pm 0.12(\text{stat.}) \pm 0.06(\text{syst.})) \times 10^{-5}$, which are in good agreement with the theoretical predictions [1, 4] and the previous measurements [5–8], as shown in fgure 10 (a).

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.

ABOUT NEWS

News › News › Topic: Physics

Voir en français

The plot thickens for a hypothetical "X17" particle

Additional evidence of an unknown particle from a Hungarian lab gives a new impetus to NA64 searches

27 NOVEMBER, 2019 | By Ana Lopes

CERNCOURIER Reporting on international high-energy physics

Physics ▾ Technology ▾ Community ▾ In focus Magazine

SEARCHES FOR NEW PHYSICS | NEWS

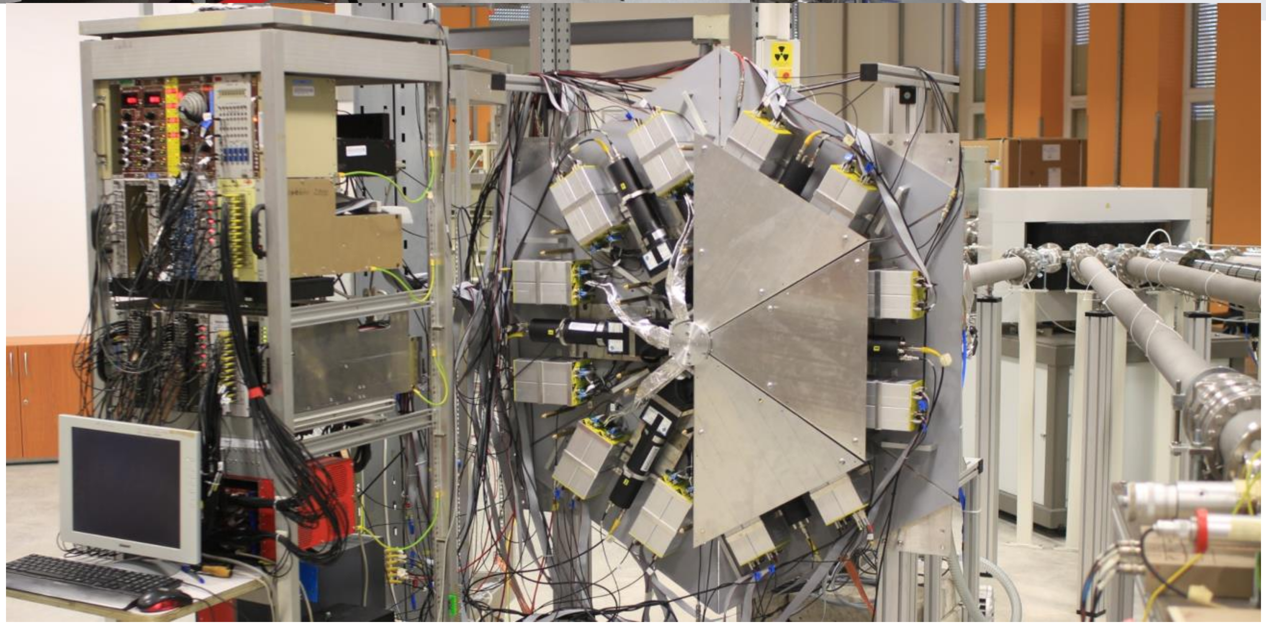
Rekindled Atomki anomaly merits closer scrutiny

20 December 2019

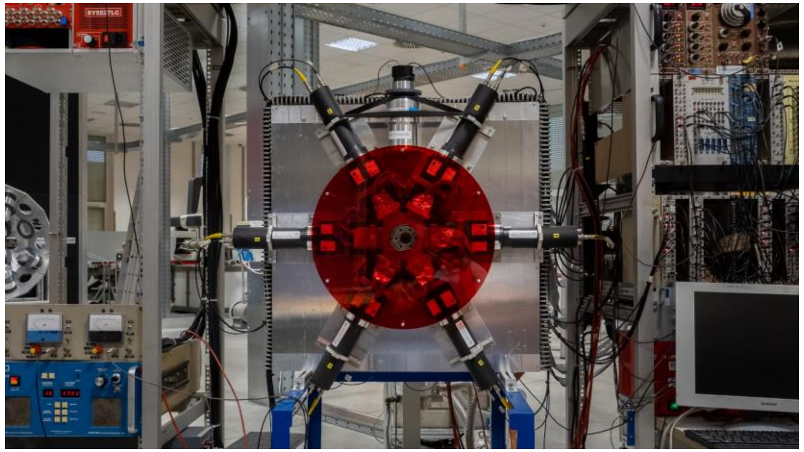
The ATOMKI anomaly → signals for a new 17 MeV boson → gauge boson of a new fundamental force of nature

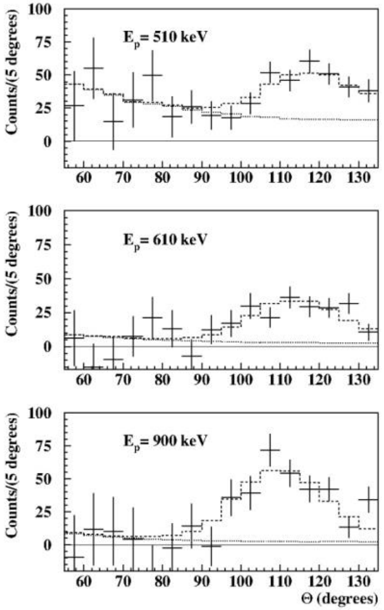
Article in Nature, CNN news, boom in the media

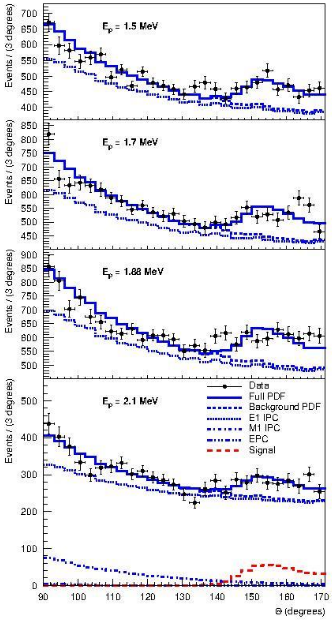
The newly built tandetron lab. in ATOMKI and the newest version of the e^+e^- spectrometer

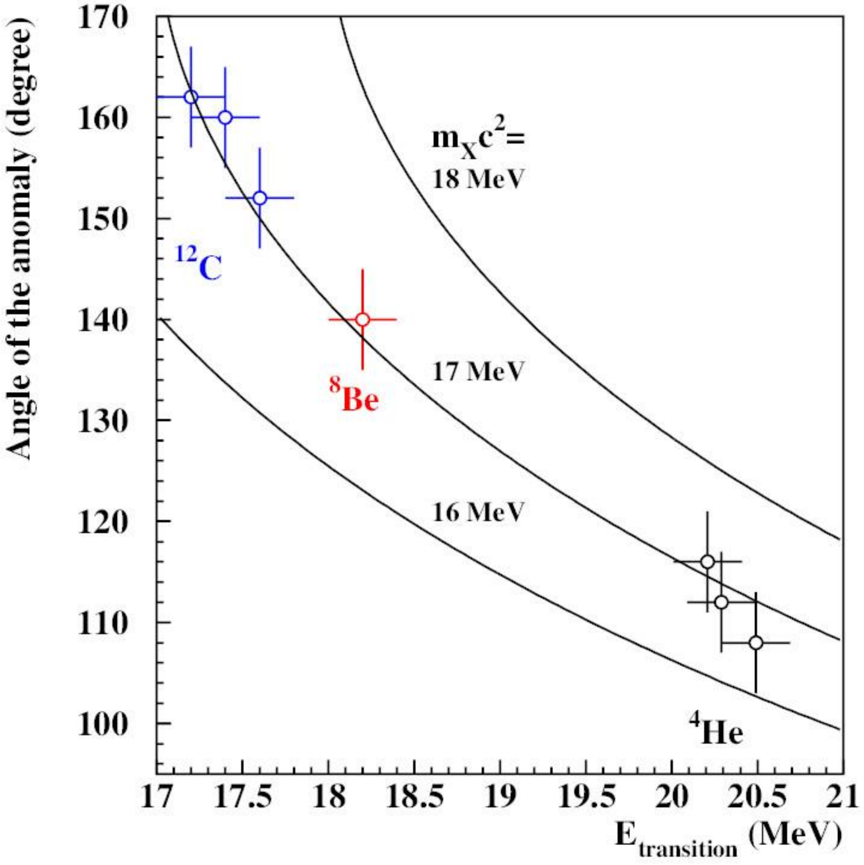


Recent experimental results









Nucl. Phys. News.

Frontiers of Fundamental Physics (FFP16), Conf. Proc. 2024

^{4}He Phys. Rev. C 104, 044003 (2021)

^{12}C Phys. Rev. C 106, L061601 (2022)

Kinematical evidence for the X17 particle

Theoretical interpretation of the results

Our results were first interpreted theoretically with a new vector gauge boson by Feng and co-workers, which would mediate a fifth fundamental force with some coupling to standard model (SM) particles. The possible relation of the X17 boson to the dark matter problem triggered an enormous interest in the wider physics community and resulted in also many other interpretations, the complete survey of which is beyond the scope of my talk.

It would be good to measure first if it is a vector or axial-vector particle or a QCD meson or a dressed radiation quanta with a rest mass of 17.0087 MeV/c^2 obtained from the exact solutions of the Dirac equation of the joint system of a charged particle and plane waves of the quantized electromagnetic radiation.

I am going to speak about the current status of checking the existence of the hypothetical X17 particle with nuclear physics methods.

Experiments/Institutes connected to the X17 particle

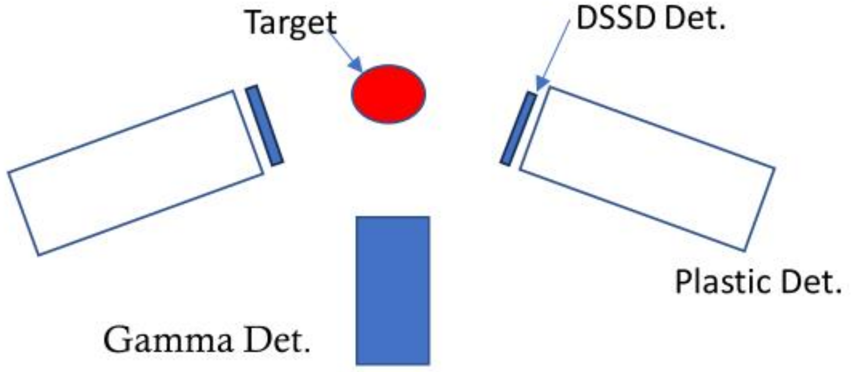
Leitmotiv: Since Galileo, we have known that one of the most effective ways to learn about the world around us is to conduct experiments. If we don't know something, let's ask nature itself. That's what experiments are for.

1. HUS, Hanoi, Vietnam
2. JINR, Dubna, Russia
3. MEG II, PSI, Willigen, Switzerland
4. PADME, Rome, Italy
5. New JEDI projekt , GANIL, France
6. INFN, Legnaro, Italy
7. DAFNE, Montral, Canada
9. CTU, Prague, Czechia
10. nTOF, CERN, Switzerland
11. NA64, CERN, Switzerland
12. NA62, CERN, Switzerland
13. BES-III, Beijing, China
14. FASER, CERN, Switzerland
15. SUPER-X, ANU, Canberra, Australia
16. DARKLIGHT, GLAB, USA
17. PRad, GLAB, USA
18. REDTOP, USA, Purdue, USA
19. Belle-II, SuperKEKB, Japan
20. NA48, CERN, Switzerland
21. MAGIX, Dark MESA, Mainz, Germany
22. VEPP-3, Vladivostok, Russia

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

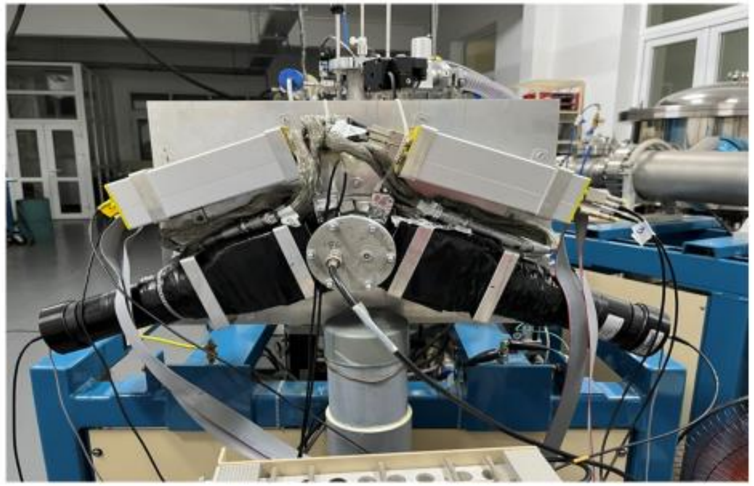
We used p-beam with different energies to bombard the Li-target to populate 18.15 and 17.6 MeV ^{8}Be excited states with resonant proton capture.

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



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

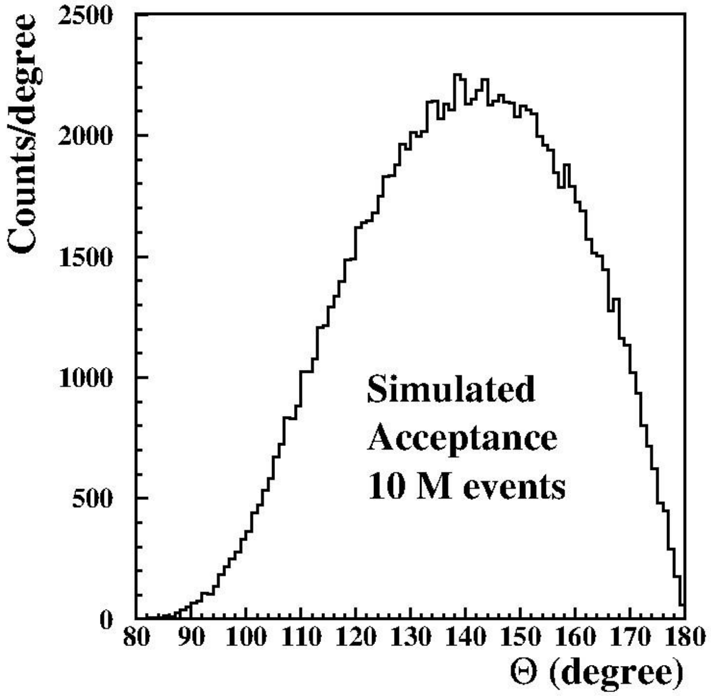
Why did we arrange the Det-system like this?



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

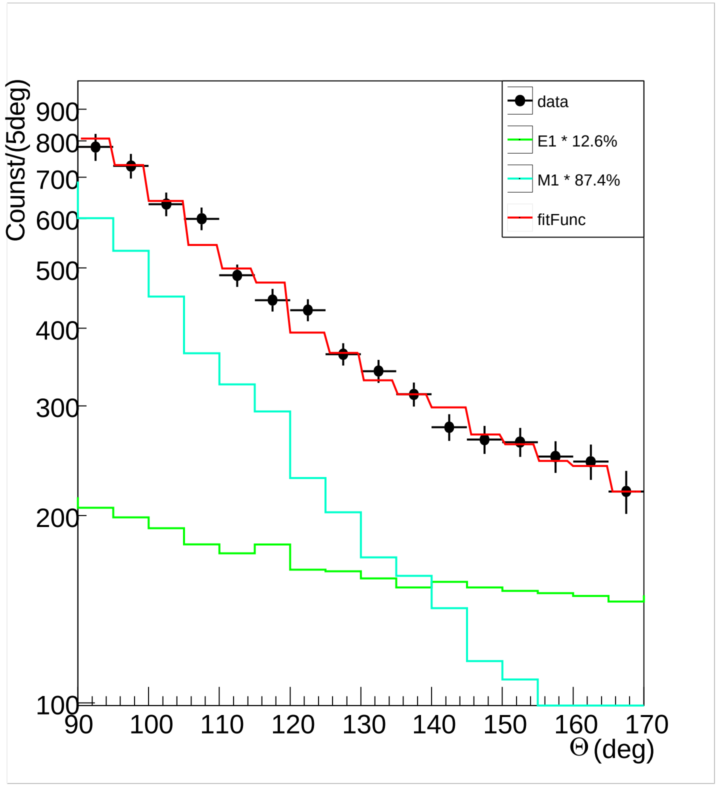
The idea of the new e^+e^- spectrometer with two arms

- 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.

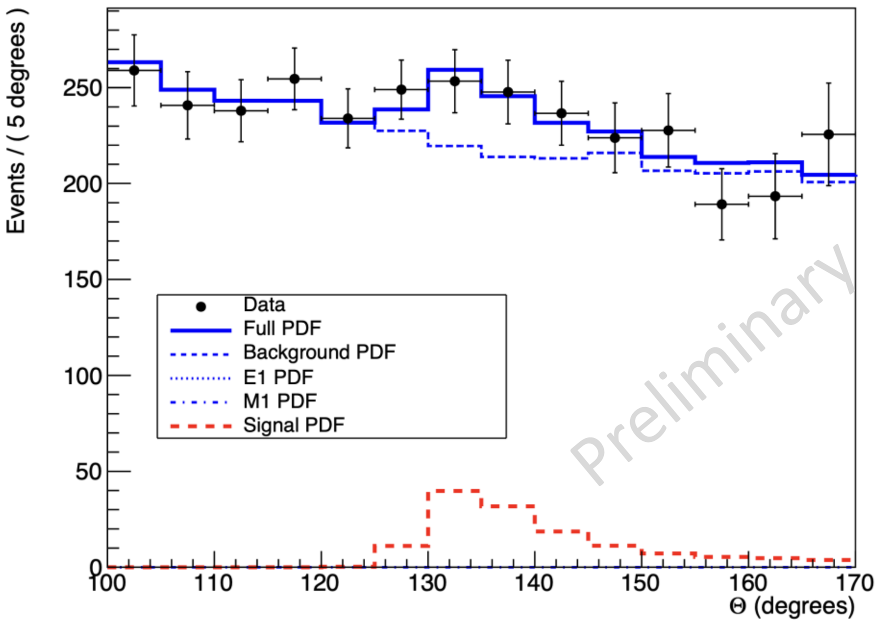


The simulation curve of acceptation before making setup

Aceptance corrected angular correlations



E_p=441 keV
No anomaly



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

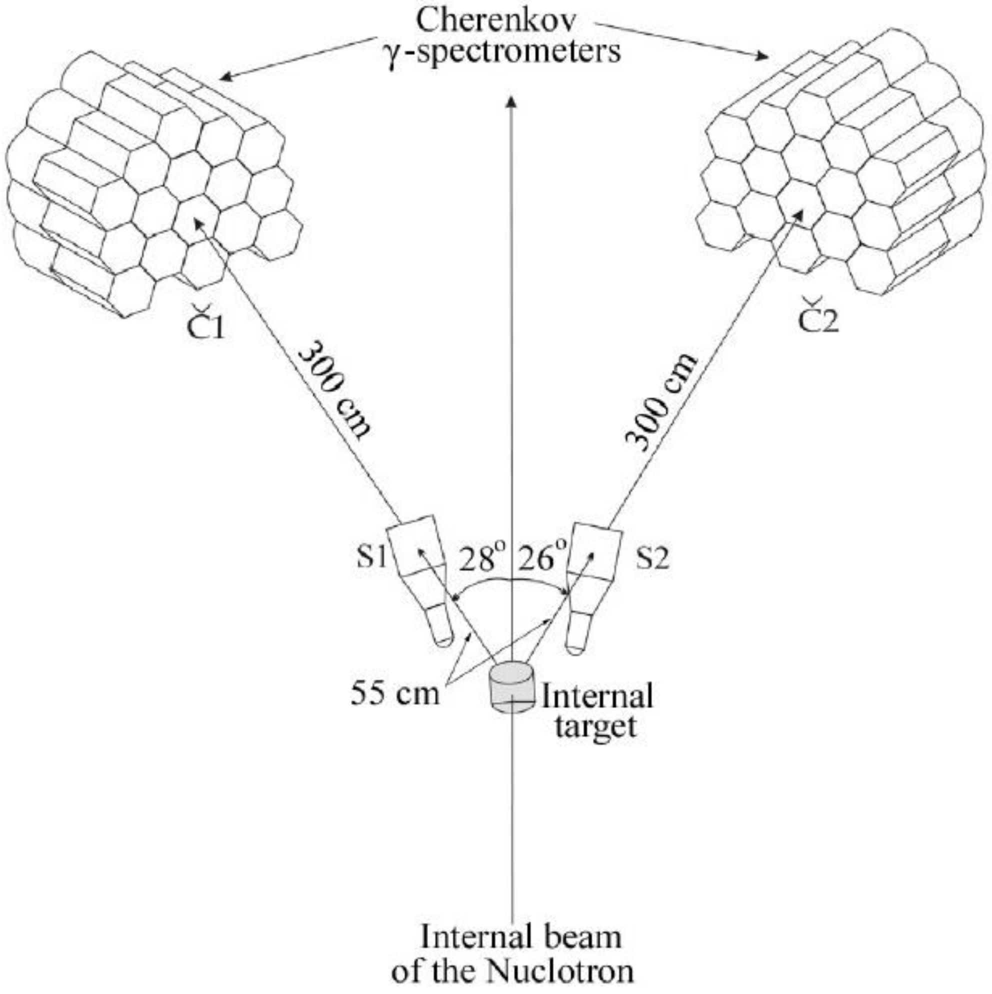
m_{boson}=16.7 ± 0.47 (MeV)
Significance: 4-5σ

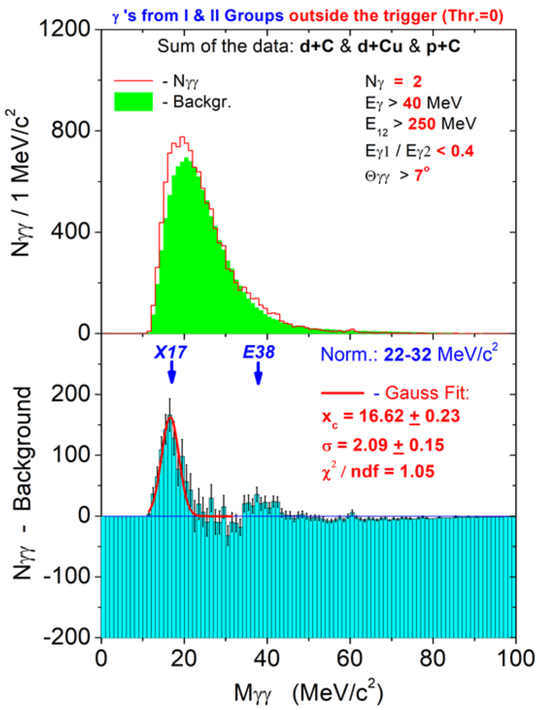
Tran The Anh et al., Universe 2024, 10(4) 168.

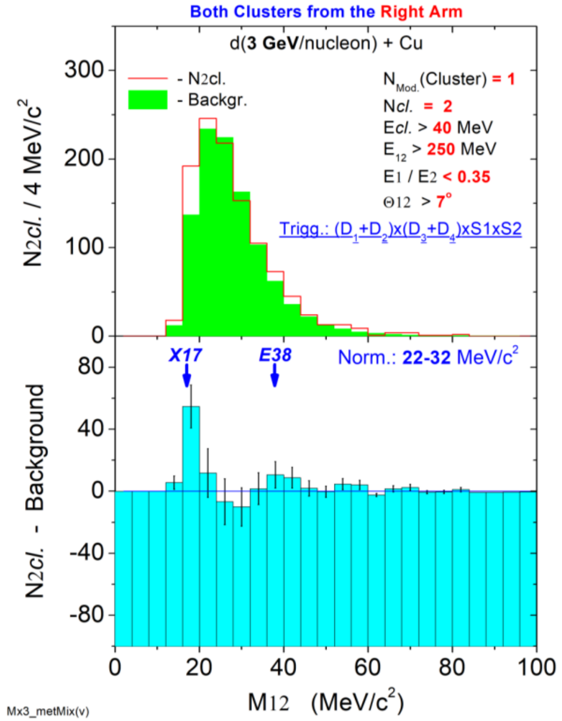
Joint Institute for Nuclear Research

SCIENCE BRINGS NATIONS TOGETHER

Confirmation of the X17 particle in the Dubna experiment





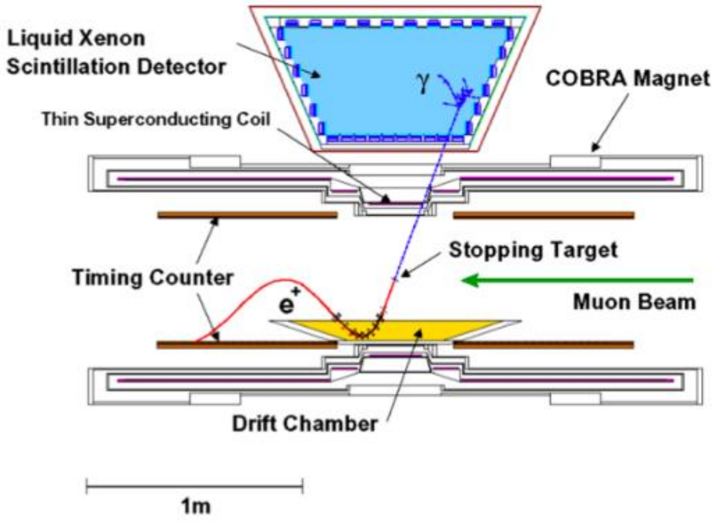


Confirms our results on the $\gamma\gamma^-$ -decay of X17

Confirms our results on the e^+e^- -decay of X17

Abraamyan et al., Phys. Part. and Nuclei, 2024, **55**, 4.

Search for the X(17) particle in the $^{7}Li(p,e^{+}e^{-})^{8}Be$ reaction with the MEG II detector (PSI, Willigen, Switzerland)



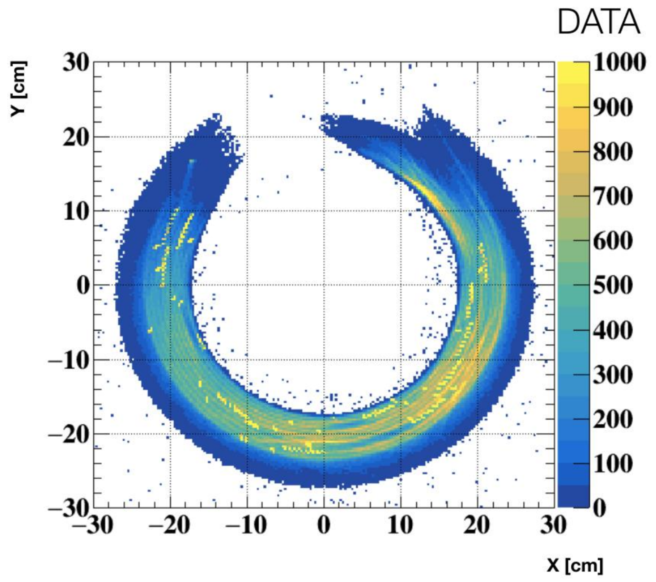
Collected data sample

- **Pivotal** run **2022**: Proton beam tuning, Mechanical/integration test of the new parts, LiF and LiPON target test, Different trigger settings, Optimised Data Taking and Reconstruction Algorithms

- **Physics** run **2023**: 4 weeks producing mainly the 17.6 MeV gamma-line
  - Proton energy at 1080 keV
  - Beam composition: H+ (~75%) and H2+(~25%)
  - Thick LiPON (~7 um)
  - Both 440 keV and 1030 keV excited simultaneously

- Statistics:
  - ~75 M Events
  - ~**300 K** Events Reconstructed pairs

- On full range of the Esum and Angular Opening angle observables:
  - ~60% EPC (14.6 + 17.6 MeV)
    - Dominant at low angle, negligible in the signal region
  - ~40% IPC (14.6 + 17.6 MeV)
    - Dominant in the signal region



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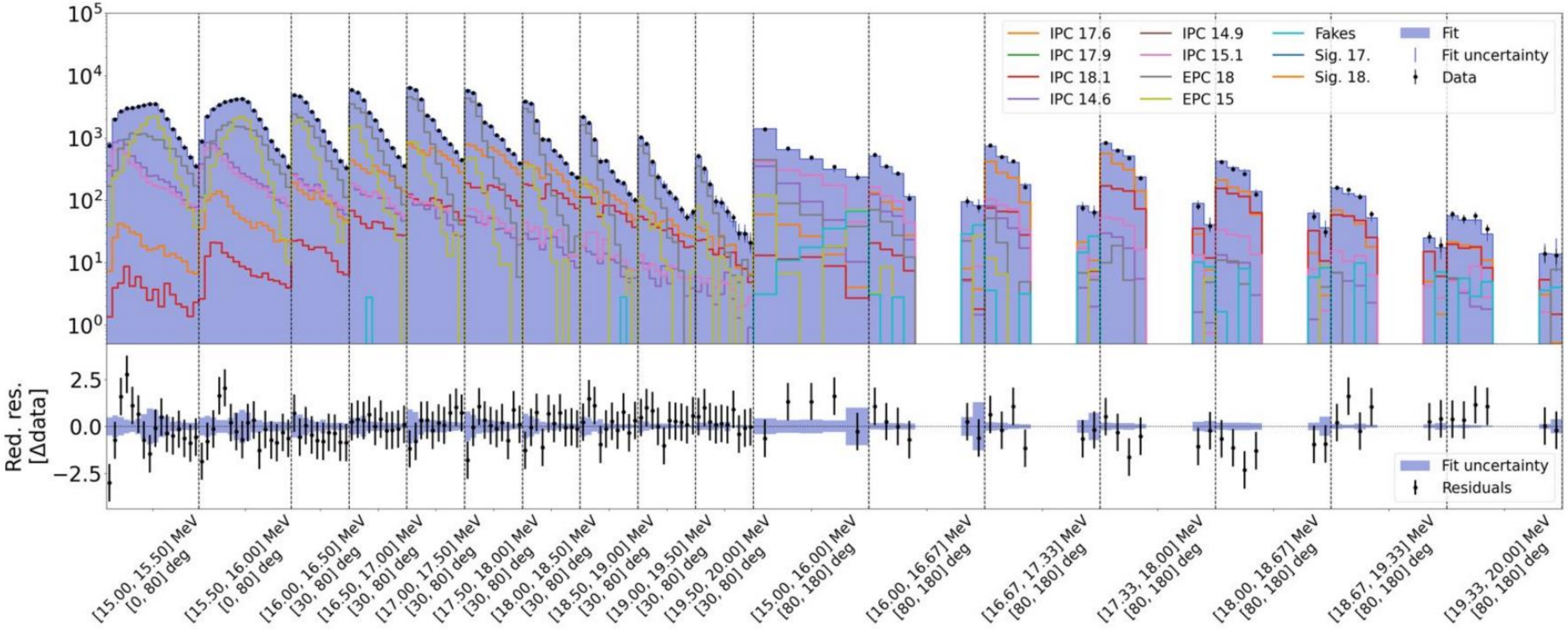
X17 analysis: A bit more on the sidebands

- Best US+DS fit with all MC statistics
  - Side bands reproduced
  - Sample of **17.6 MeV** [79.2%] **and 18.1 MeV** [20.8%]

DATA



ICHEP Conference 18-24 July 2024, Prague

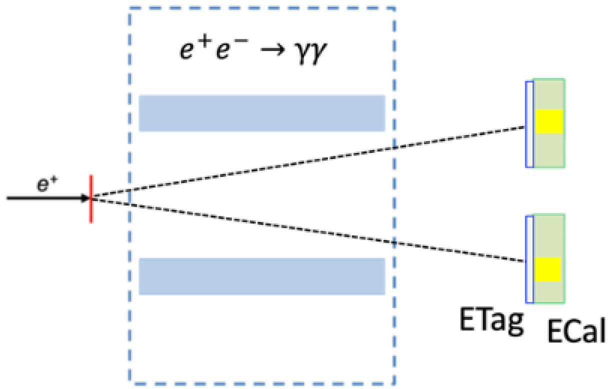
Current status and outlook

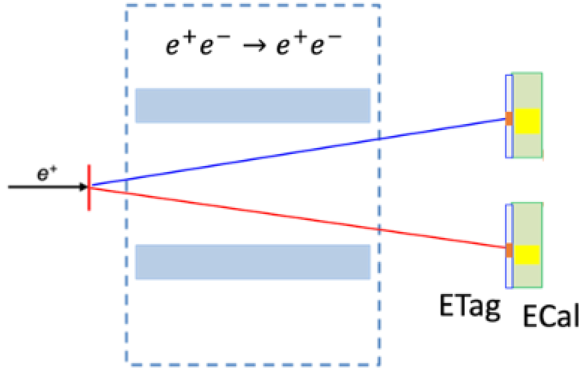
- Analysis Data 2023 well advanced
- Ready to report the results
- A X17 data collection fully exploiting the 1030 keV is foreseen during the first part of 2025 (Physics Run 2025)

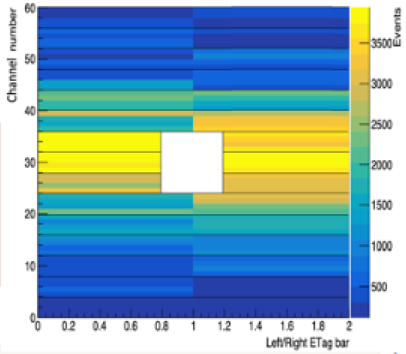
Resonant search for the X17 boson at PADME

- Using PADME veto is impossible to reconstruct $e^+ e^-$ mass having no vertex info
- Idea: identify $e^+e^- \to e^+e^-$ using the BGO calorimeter only, as for $\gamma\gamma$ events in Run II

- Switch the PADME dipole **magnet off**
- Both positron and electron will reach the ECal
  - Can measure precisely (3%) electron-positron pair momentum and angles
  - Can reconstruct invariant mass of the pairs precisely (small pile-up)
- **Identify clusters** in ECal from photons or electrons
  - New detector, plastic scintillators, similar to PADME vetos (Electron tagger, ETag) with vertical segmentation and covering the fiducial region of ECal







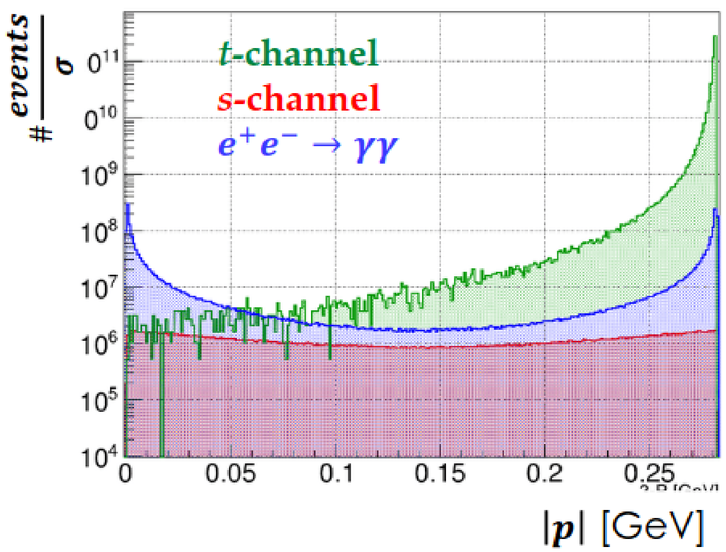
- Thanks to the enhanced production cross section can reduce N_{POT}/bunch by factor 10.
- Much lower pile-up and better energy resolution

The mass scan X17 search strategy

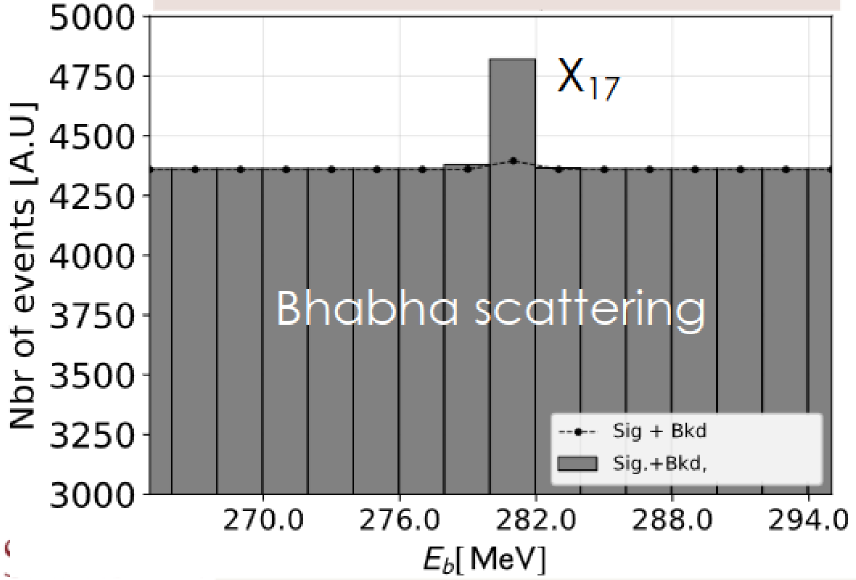
PADME, can use resonant X17 production process

- Extremely effective in producing X17 but in a very small mass range
- Scan E_{beam}=260–300 MeV in <1 MeV steps

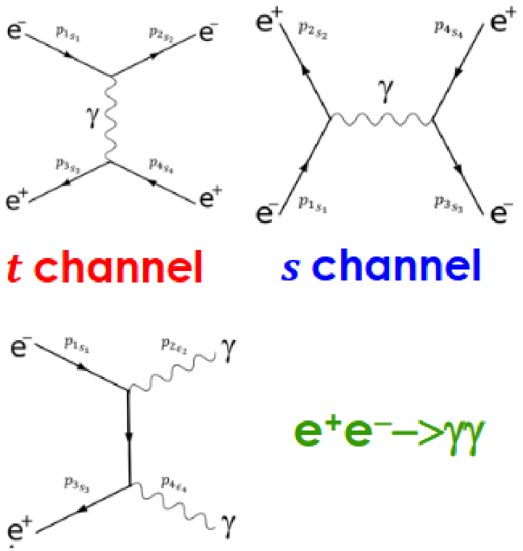
- Completely data driven no theory or MC input
- Signal should emerge on top of **Bhabha** BG in one or more points of the scan.
- Background estimated from surrounding bins



Cartoon view of the technique



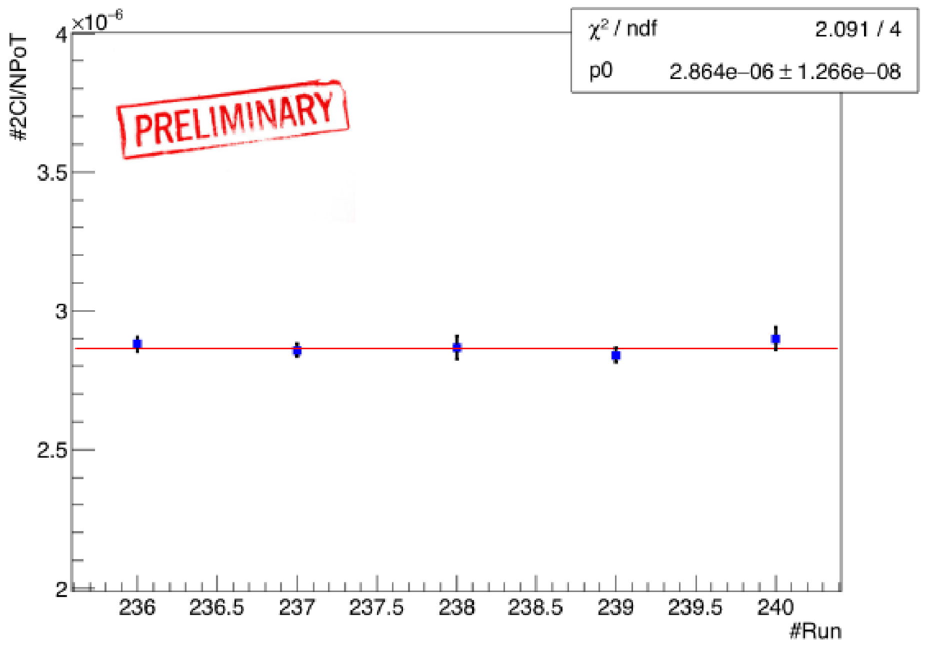
Bhabha scattering



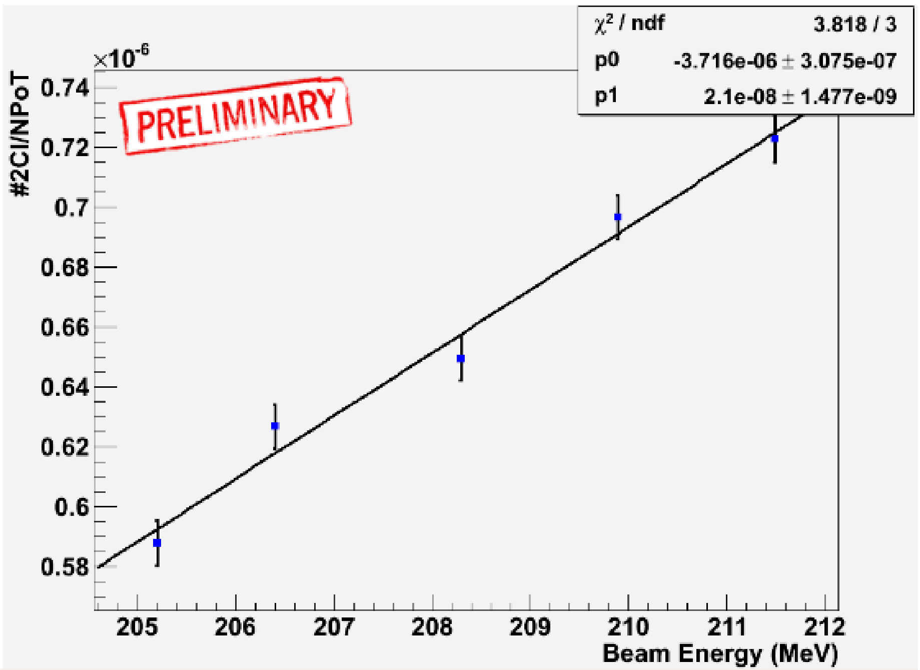
The expected peak to background ratio (assuming a vector particle) is only about 0.6-2.0% for the allowed coupling constant region, making it very challenging to find this resonance.

First look out of resonance data sets

Over resonance 402 MeV



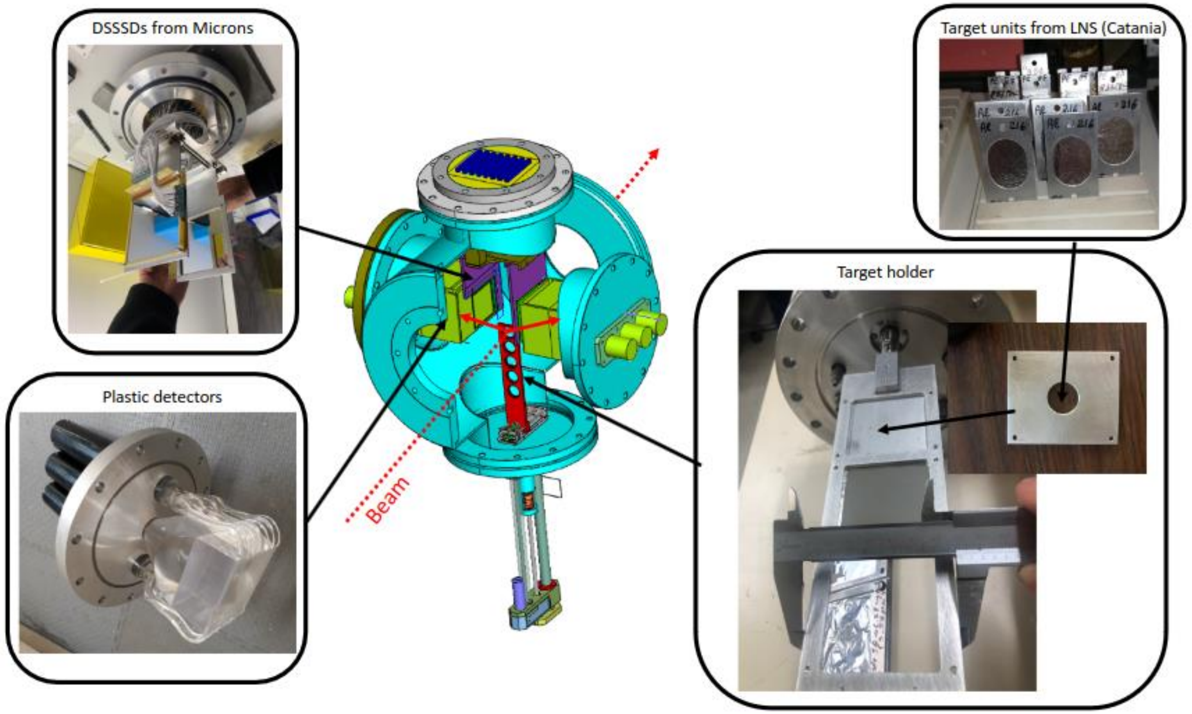
Below resonance



- **RMS ~0.7%** over the 5 runs
  - compatible with pure statistic
- Constant **fit has a good χ^2**
  - No significant systematic errors
- Vertical scale arbitrary:
  - No acceptance correction applied

- **RMS <1%** over the 5 energies
  - computed on residuals wrt the fit
- Good χ^2 of the linear fit
  - Trend due to acceptance
  - Trend is reproduced by MC
- Vertical scale arbitrary:

The New JEDI (Judicious Experiments for Dark sectors Investigations) project (GANIL, France)



The two set of Double-Sided Silicon Strips Detectors (DSSSDs) of the New JEDI setup provides energy losses and angles of the detected electrons and positrons. In addition, the sets of plastic detectors with SiPM readout is used to measure the residual energy of electrons and positrons.

We plan to develop a long-term research program in the MeV terra incognita energy range at the new SPIRAL2 facility, that will deliver unique high-intensity beams of light, heavy-ions and neutrons in Europe.

In practice, three experiments using the New JEDI setup concerning the existence of the X17 Dark Boson are envisaged…

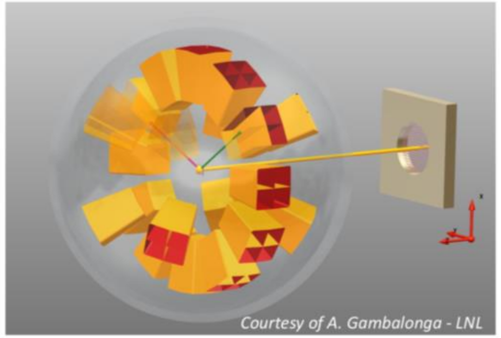
A new setup: proposal

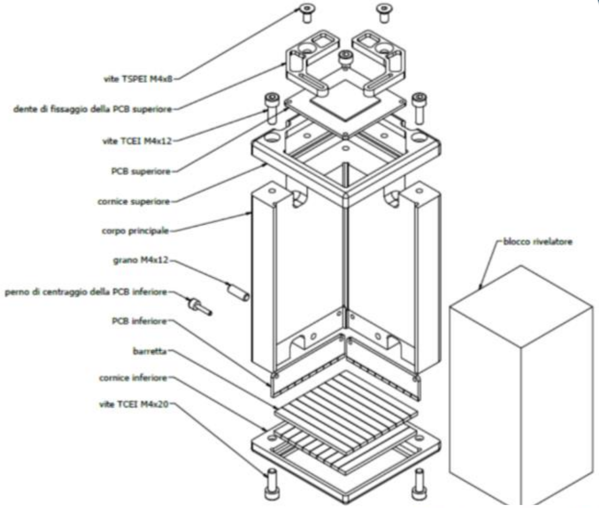
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

- Improve angular resolution by reducing material budget.
- Improve angular coverage and measure out-of-plane correlation
- Improve confidence on target composition.

- Allow future coupling with a magnetic field.

- Focus on ^{8}Be and, possibly, ^{12}C cases.

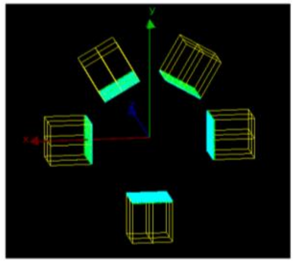

Courtesy of A. Gambalonga - LNL

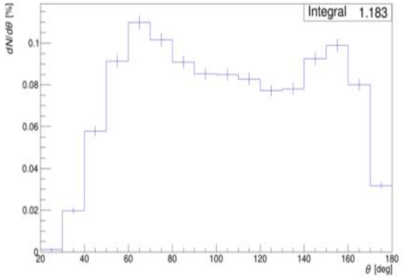


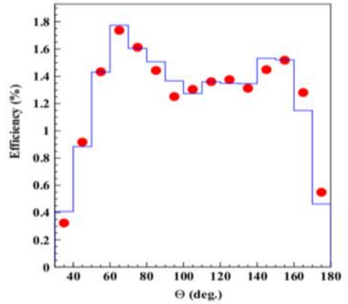
DSSD + Plastic sci. with SiPM readout.

Pair detection efficiency: two angular configurations

A – Angles: 0° - 60° - 120° - 180° - 270° (Atomki configuration)

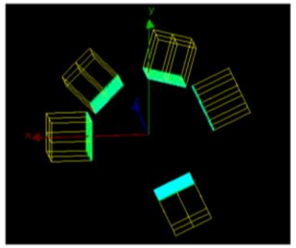


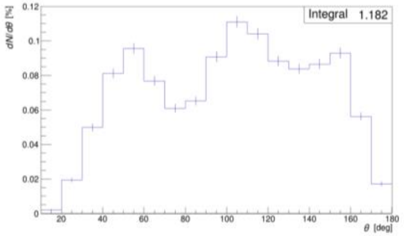




Good compatibility in shape with respect to the Atomki configuration. [J. Gulyás et al, NIM A 808, 21 (2016)]

B – Angles: 0° - 45° - 105° - 155° - 245°



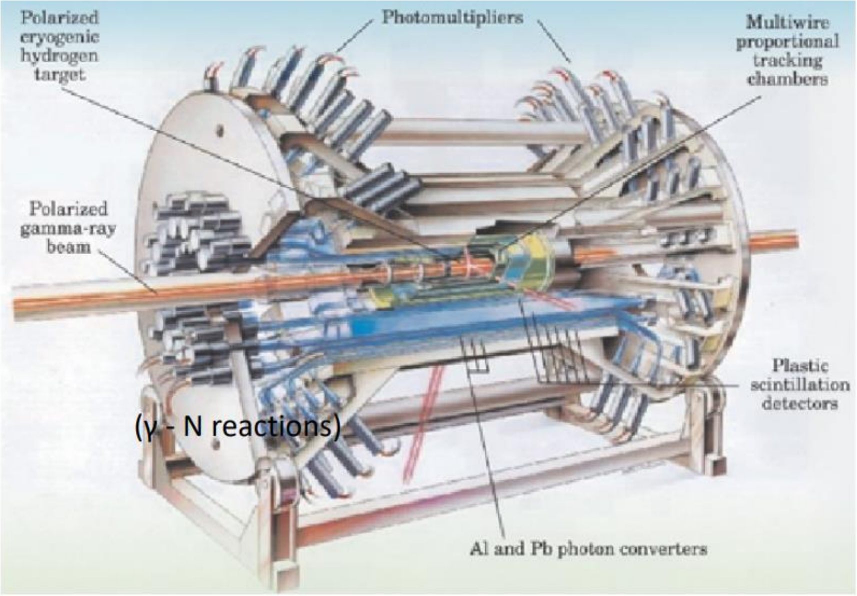


Estimated Pairs detection efficiency

$\varepsilon_{pairs} = 1.18\ \%$

The Montreal X-17 Project

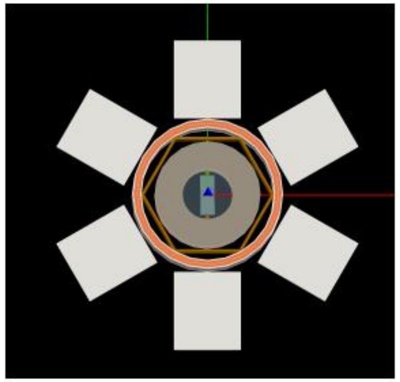
- Use parts of the DAPHNE experiment (Saclay/Mainz*)
- Tracking MWPC chamber & 16 scintillators (NE102A)
- Scints & MWPC from U. Mainz → now @ Montreal
- Phototubes and some ADC/TDC's borrowed from TRIUMF

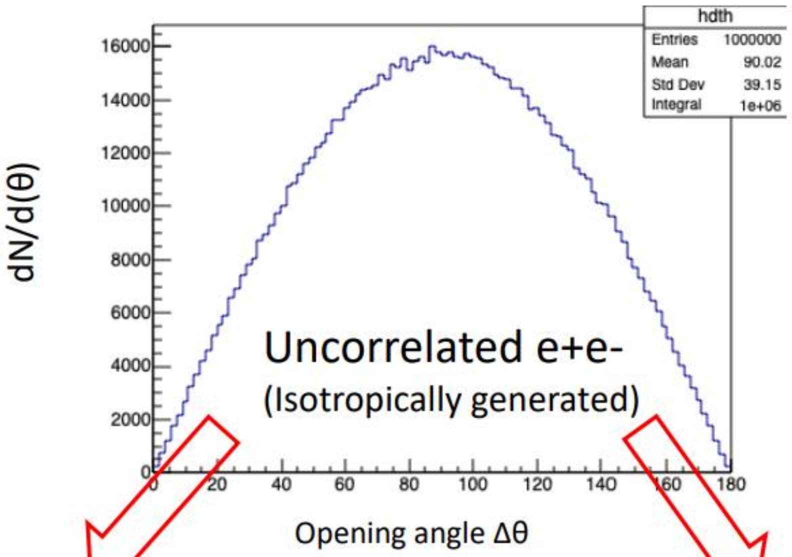


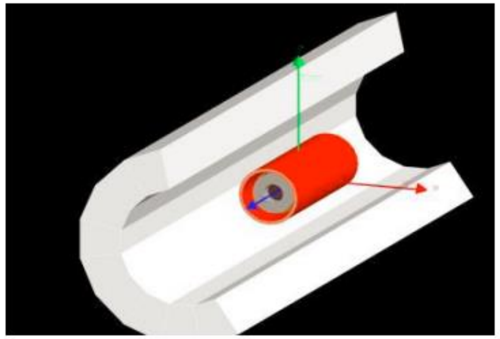
Large solid angle coverage → 0.95 x 4π

*Many thanks to
L. Doria & U. Mainz!

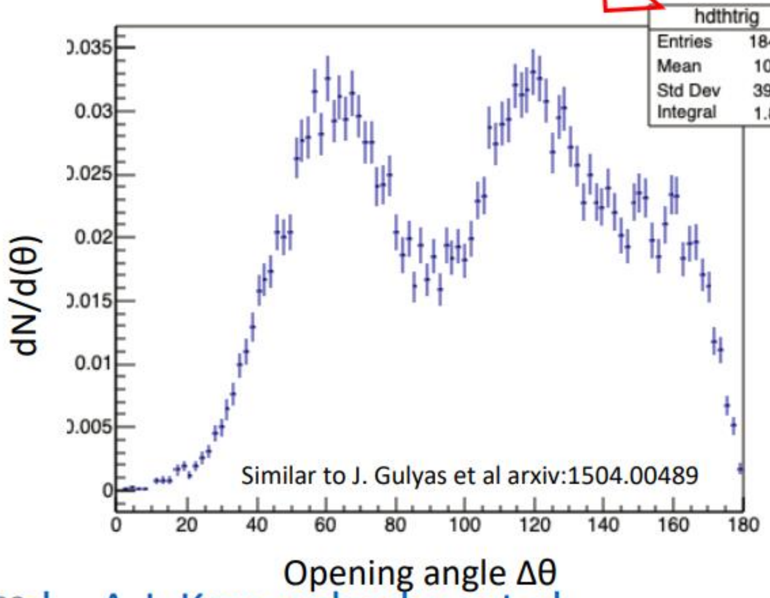
Geant4 Simulation: Acceptances



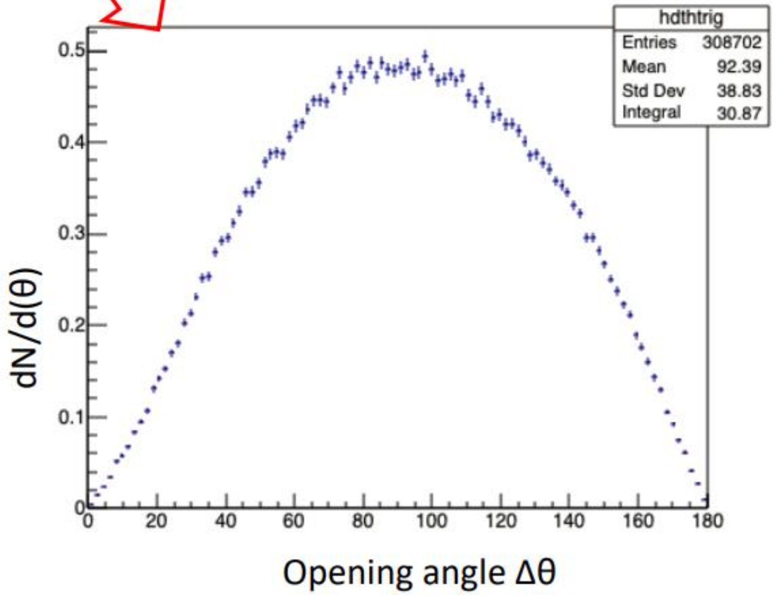




ATOMKI geometry

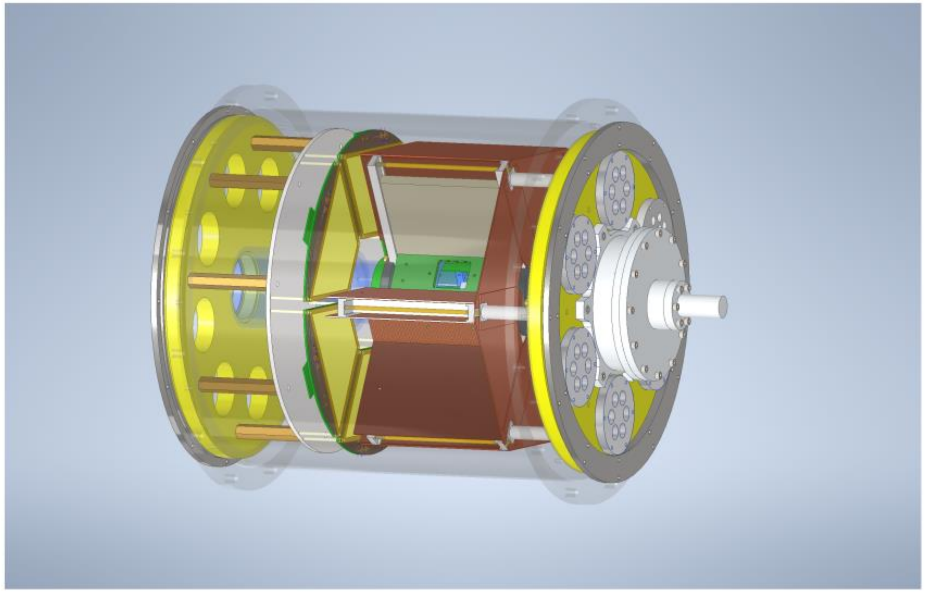


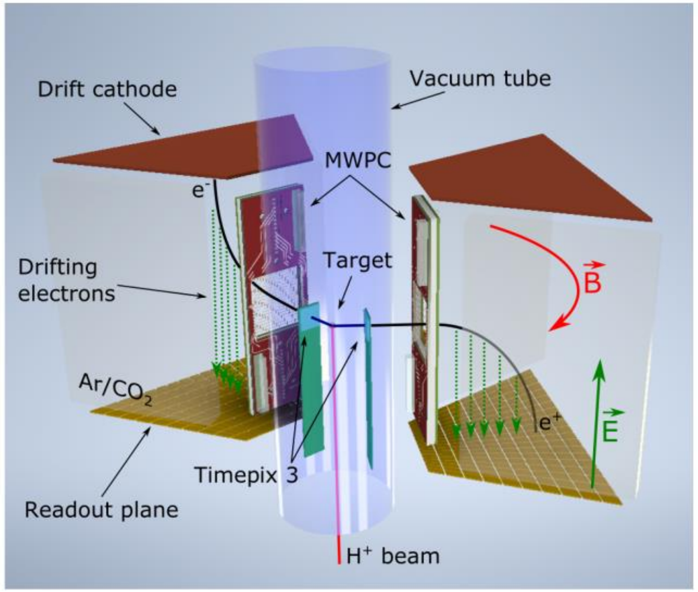
Montreal geometry



Gulyás J, et al. , A.J. Krasznahorkay et al.

A detector to measure e^-e^+ angular corelations

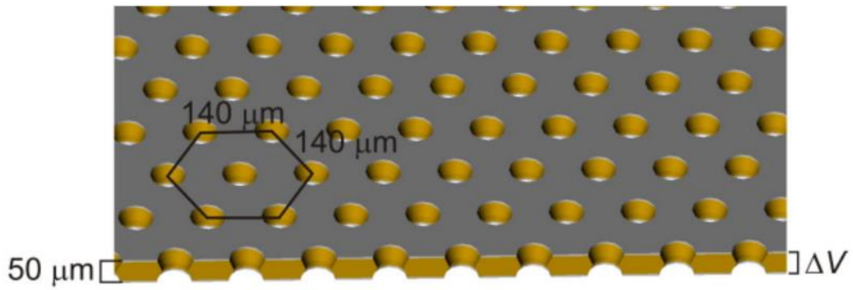


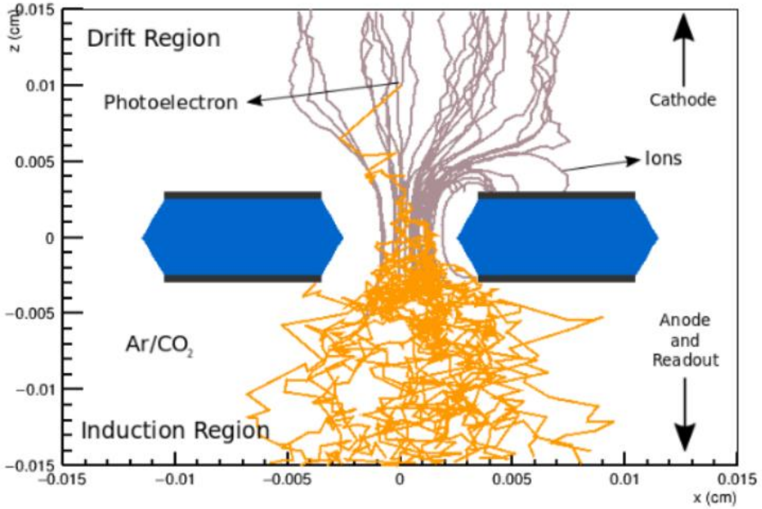


Completion of setup built in ATOMKI

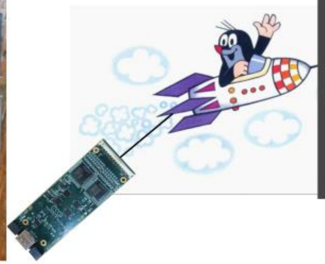
- Three layers of detectors:
  - Timepix3 (angle measurement),
  - Multiwire Proportional Counter (angle and scattering measurement),
  - Time projection Chamber (energy measurement and particle Id)
- Azimuthal angle divided in sextants,
- Toroidal B-field with permanent magnets,
- State of the art TPC readout.

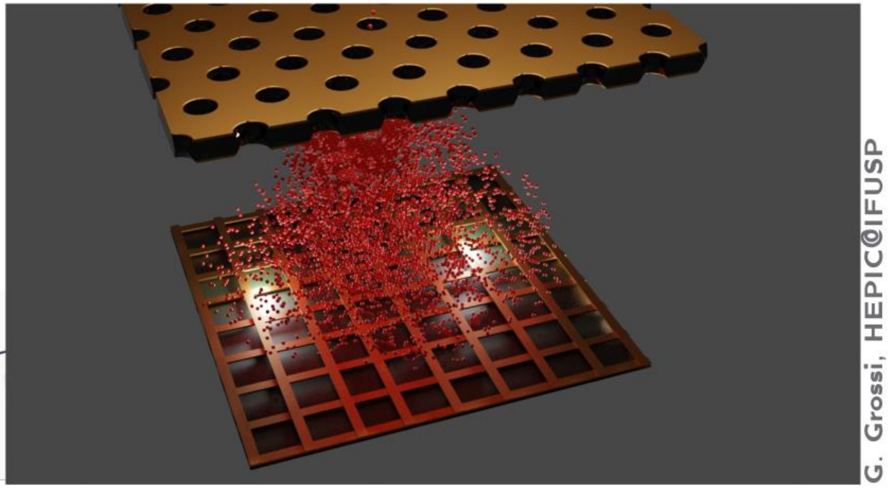
The Time ProjectionChamber





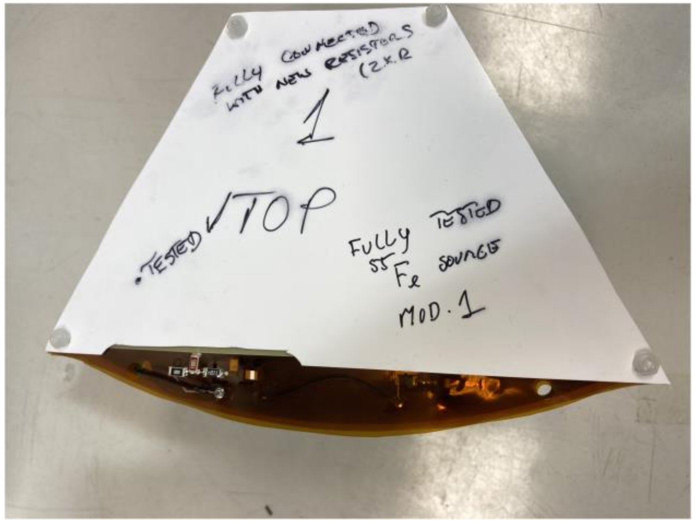
- Triple GEM stack
- Voltage divider's SMD resistors in foils
- Readout with SAMPA chip (developed by USP for ALICE).

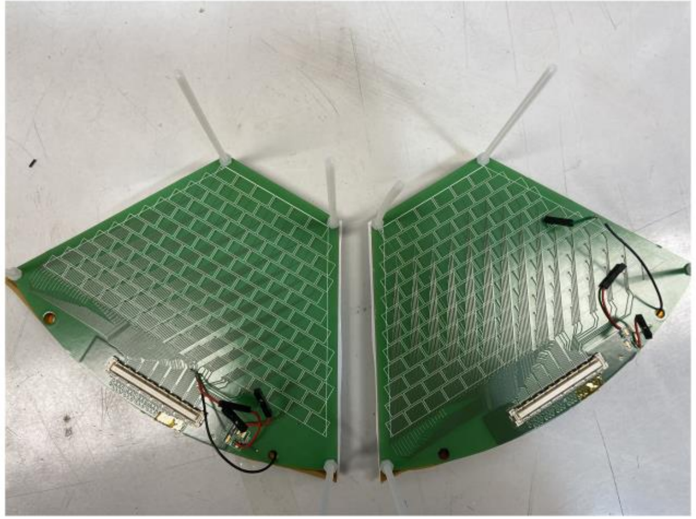


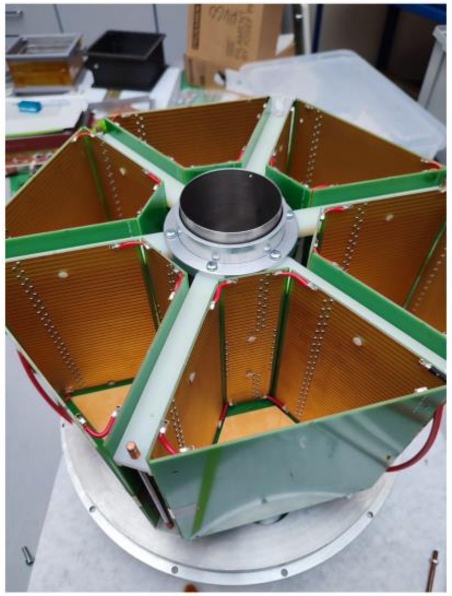


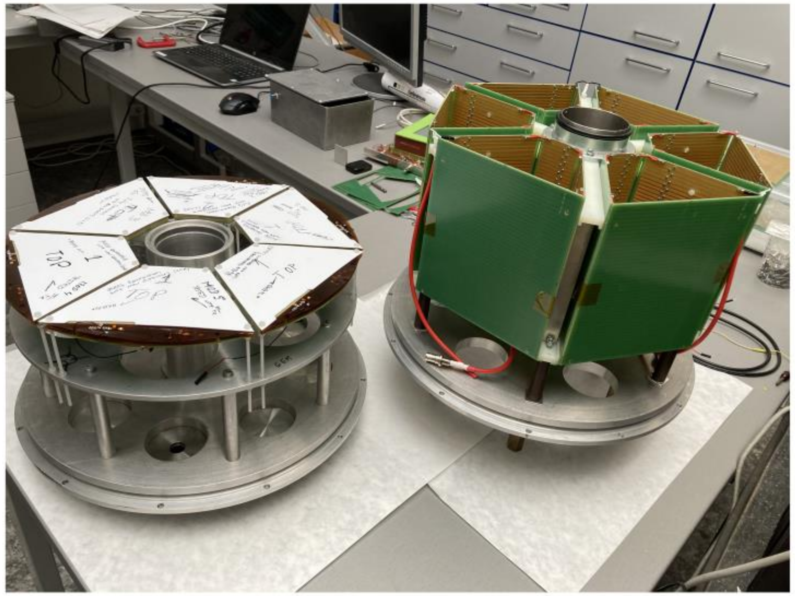
G. Grossi, HEPIC@IFUSP

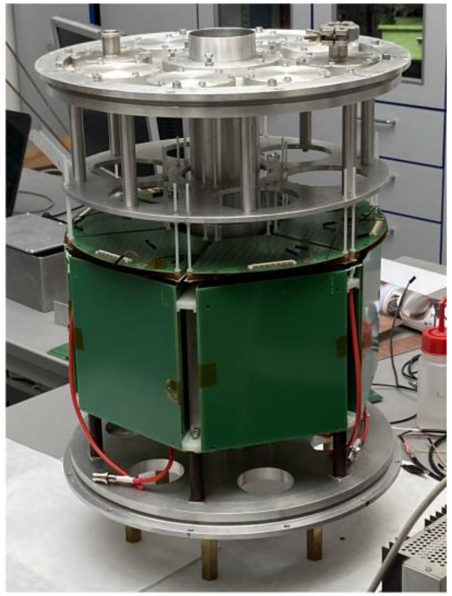
Status of the assembly of the full detector











Searching for X17 anomaly at nTOF experiment

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- P. Mastinu (INFN LNL)
- C. Gustavino (INFN ROMA)
- A. Mengoni (ENEA)
- C. Massimi (UNIBOLOGNA)
- N. Colonna (INFN BARI)
- S. Fiore (ENEA ROMA)
- A. Mazzone (CNR BARI)

} n_TOF and LUNA

- L. E. Marcucci (UNIPISA)
- M. Viviani (INFN PISA)
- A. Kievsky (INFN PISA)
- L. Girlanda (UNISALENTO)

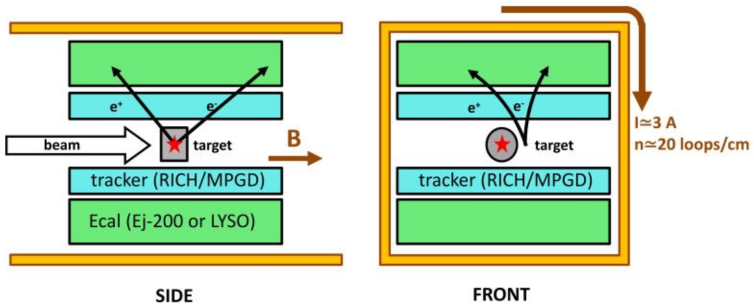
} Theoretical group

- E. Cisbani (ISS)
- F. Renga (INFN ROMA)

} Detector R&D

Working group (in evolution)

DETETCOR Conceptual design



High intensity neutron beam $0<E_n[MeV]<3$
High density target $\rho=10^{21}$ atoms/cm^3
Tracking (vertex and Pairs aperture angle energy)
4-momenta

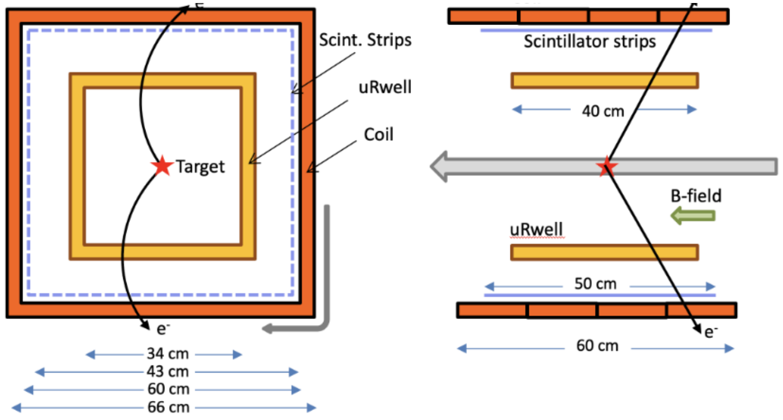


Figure 10. Setup for the study of the ^{3}He(n,e$^+$e$^-$)^{4}He. It consists of 4 large µRwells, surrounded by an array of scintillating bars. The detectors are inside a coil with a squared section, providing a magnetic field up to 500 Gauss. See text.

Report of the EUROLABS experiment (S/N=3) at ATOMKI
12-24 May 2024

Validation of a X17 boson demonstrator at n_TOF

C. Gustavino, G. Gervino, P. Mastinu, F. Renga, S. Scarpellini,

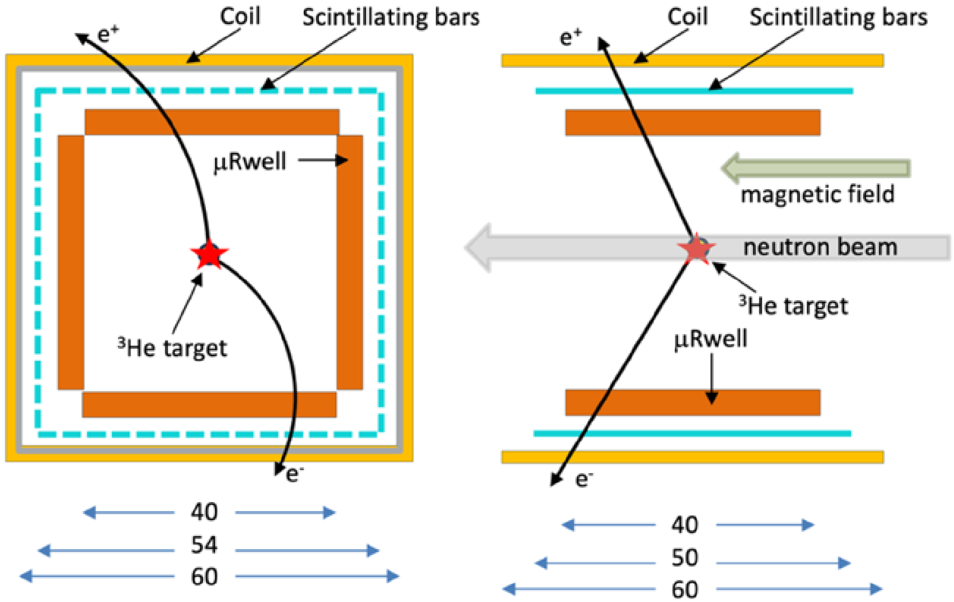
Istituto Nazionale Fisica Nucleare, Turin University

ATOMKI staff: A.J. Krasznahorkay, P. Hajdu, I. Rajta, I. Vajda

The ATOMKI measurements have been done in the framework of a program towards a forthcoming measurement of the ^{3}He(n,e^{+}e^{-})^{4}He at the neutron beam facility n_TOF at CERN.

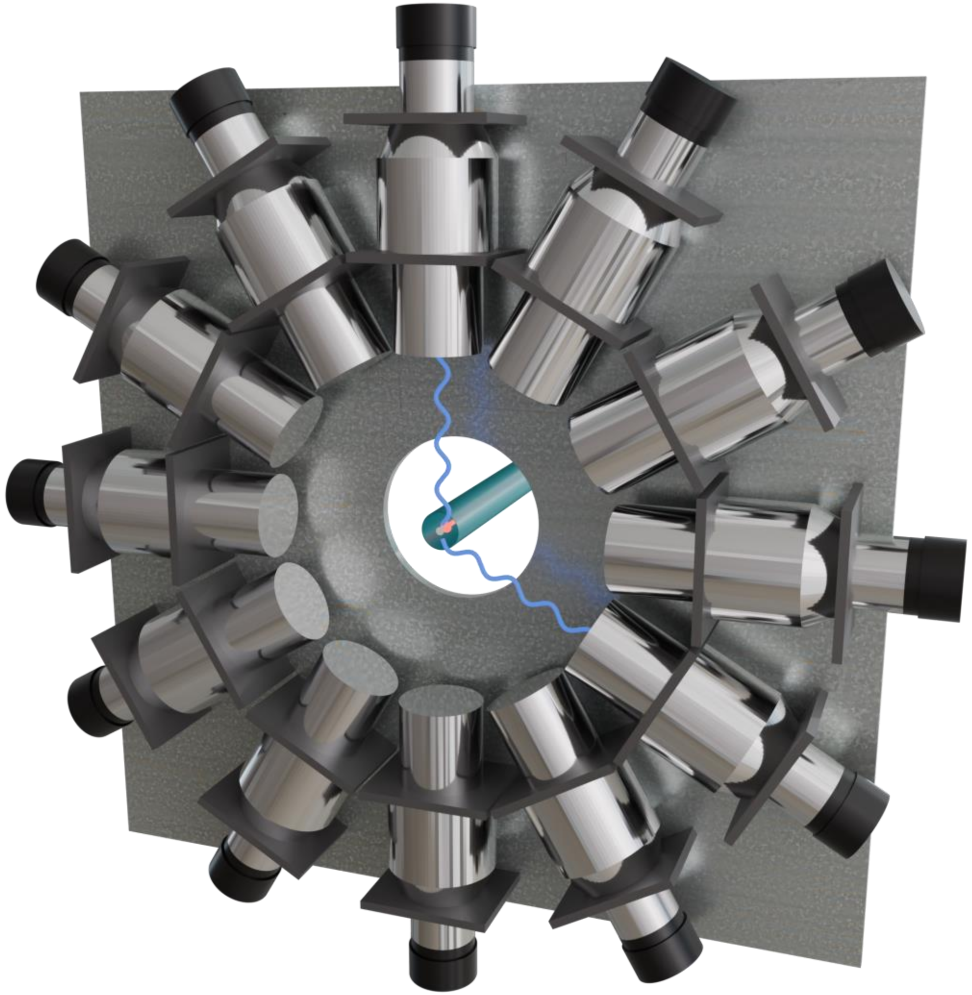
The detector is composed by:
-4 large uRwell (tracking);
-A scintillator system (trigger and TOF);
-A coil (e^{+}e^{-} identification and 4-momenta).

The aim of ATOMKI test is to validate this detector using the ^{3}Li(p,e^{+}e^{-})^{8}Be process and a detector demonstrator.



-Good tracking performance of uRwell;
-Low sensitivity of scintillator bars to ~18 MeV gammas;
ATOMKI measurements have been inserted in the CDR the final detector and submitted to INFN referees.

New experiments in HUN-REN ATOMKI
Study the γγ-decay of the X17 particle



The Dubna results for 2γ decay …
X17 is a QED meson ???
Cheuk-Yin Wong, MDPI, Universe, 2024, 10, 173

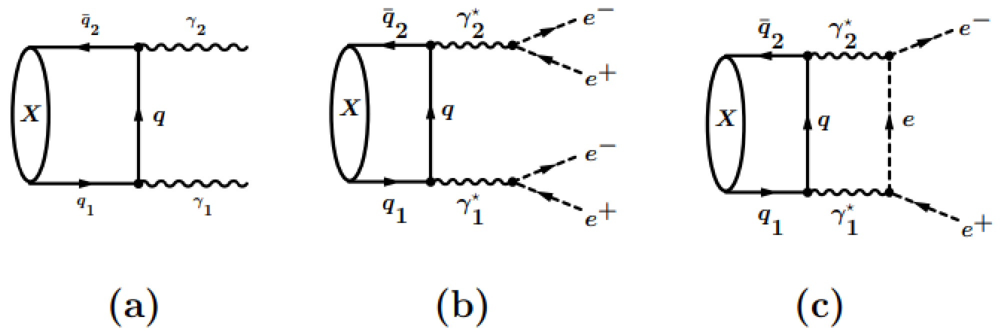


Figure 2. (**a**) A QED meson X can decay into two real photons $X \to \gamma_1 + \gamma_2$. (**b**) It can decay into two virtual photons, each of which subsequently decays into a (e^+e^-) pair, $X \to \gamma_1^* + \gamma_2^* \to (e^+e^-) + (e^+e^-)$, and (**c**) it can decay into a single (e^+e^-) pair, $X \to \gamma_1^* + \gamma_2^* \to e^+e^-$.

Conclusion

- I am very happy that there are many nuclear and particle physics laboratory in which physicists are checking the existence of the X17 particle, and trying to understand their properties.
- In two cases the existence of the X17 particle already confirmed.
- In the coming years we are expecting more results also for the spin and parity of the particle.
- I am especially delighted that our Polish friends are also going to study X17 with their professional HADES spectrometer at FAIR.

Thank you very much for your kind attention.