Finding An Anomaly

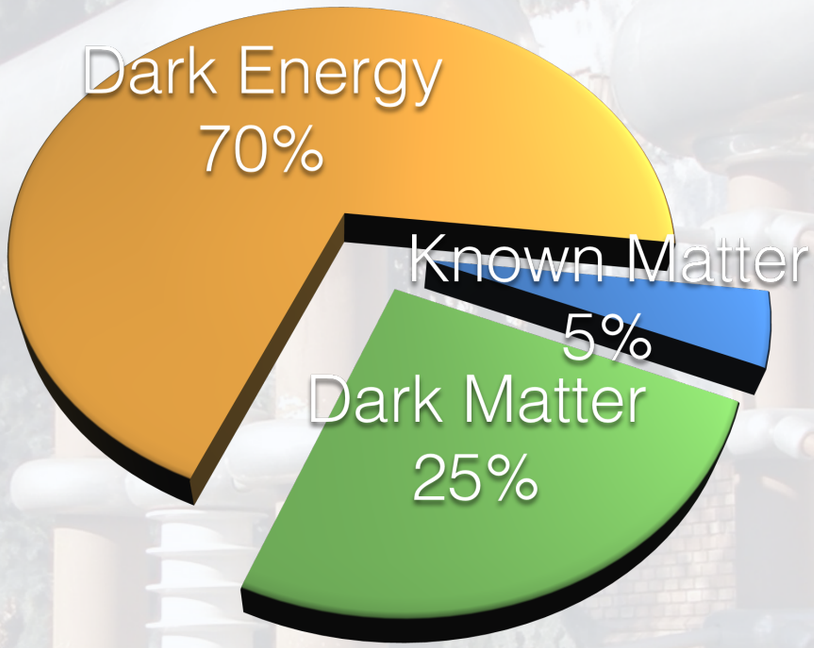
Anomalous Internal Pair Creation in ^{8}Be

Attila Krasznahorkay
on behalf of the entire experimental group

HEP-exp Seminar
UCLouvain, 2017.03.16.

Searching for Dark Matter

- Should not have to defend this too much…



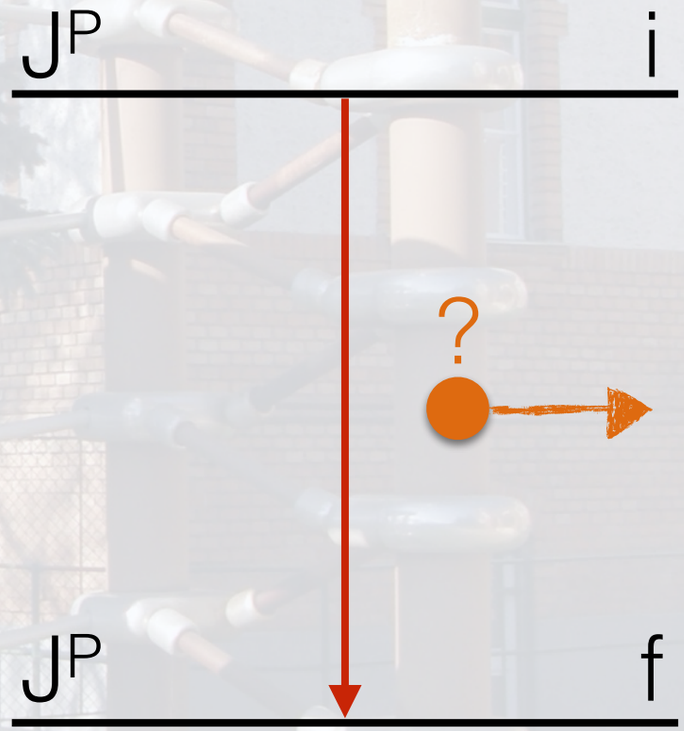
- In our current understanding the known universe is made up mostly of things we do not yet understand
- What we know, we get mostly from astrophysics
  - Not short lived, as it didn't disappear
  - Not hot, to explain the gravitational structure observed in galaxies
  - Not baryonic, as what we see is just not enough

Light, Weakly Interacting DM

- DM searches at the LHC didn't find anything significant so far
- However, multiple proposals for light (MeV scale), feebly interacting particles, for explaining
  - The (g_μ-2) anomaly (link1, link2)
  - The deficit of high energy cosmic neutrinos, reported by IceCube (link)
  - The disagreement in the measurement of the proton radius (link)
  - The surprising lack of Lithium in the universe (link)
- Making it very viable to search in the 10 MeV mass range for weakly interacting particles

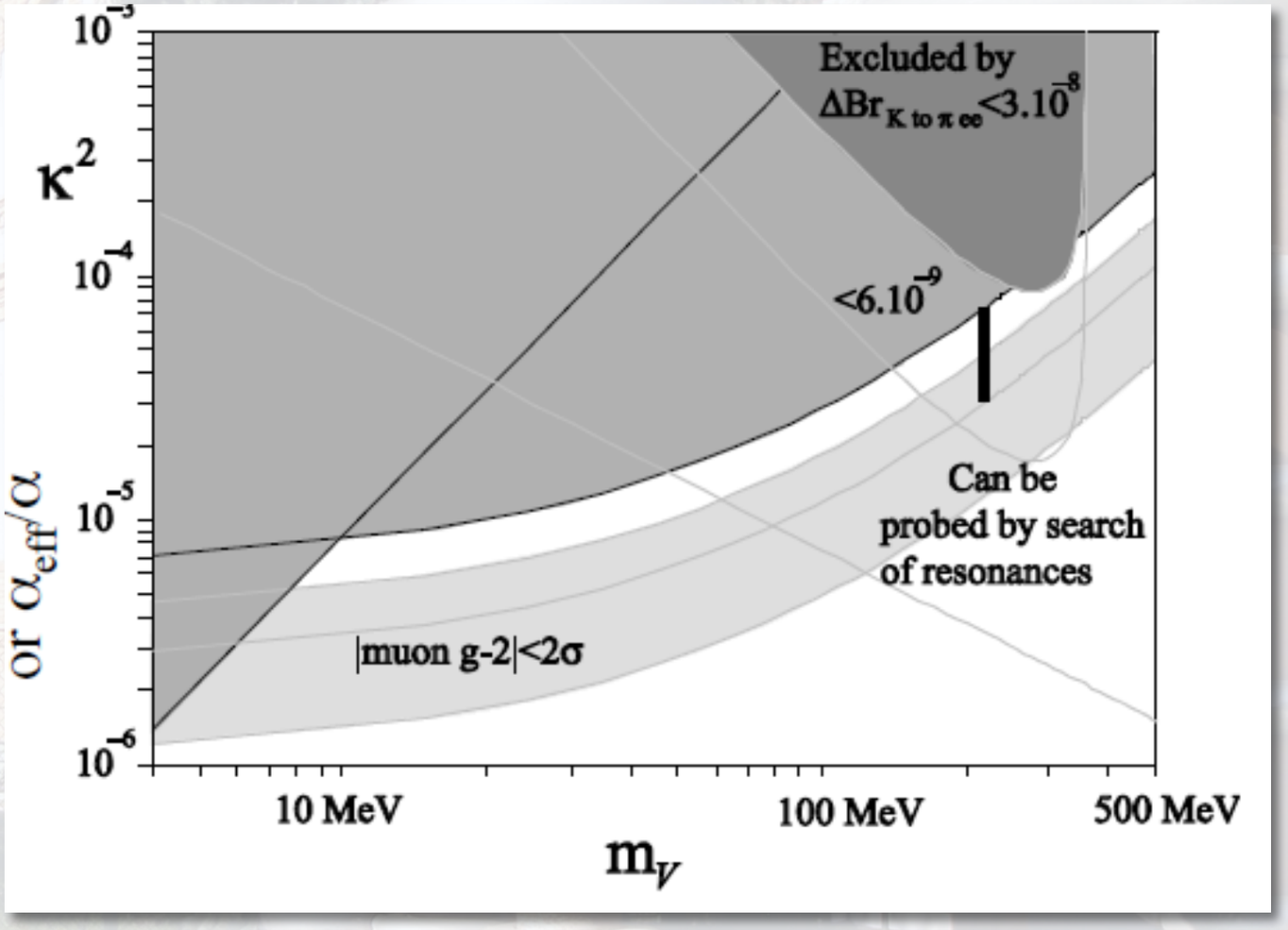
Nuclear Physics for Discovery

- Light particles can be produced during the de-excitation of nuclei
  - Even simple α, β and γ radiation is, in the end, an effect of this
- Searching for yet undiscovered light particles is technically very possible in nuclear physics reactions
  - Although most of the available phase space is already excluded for new discoveries



Why Light Nuclei?

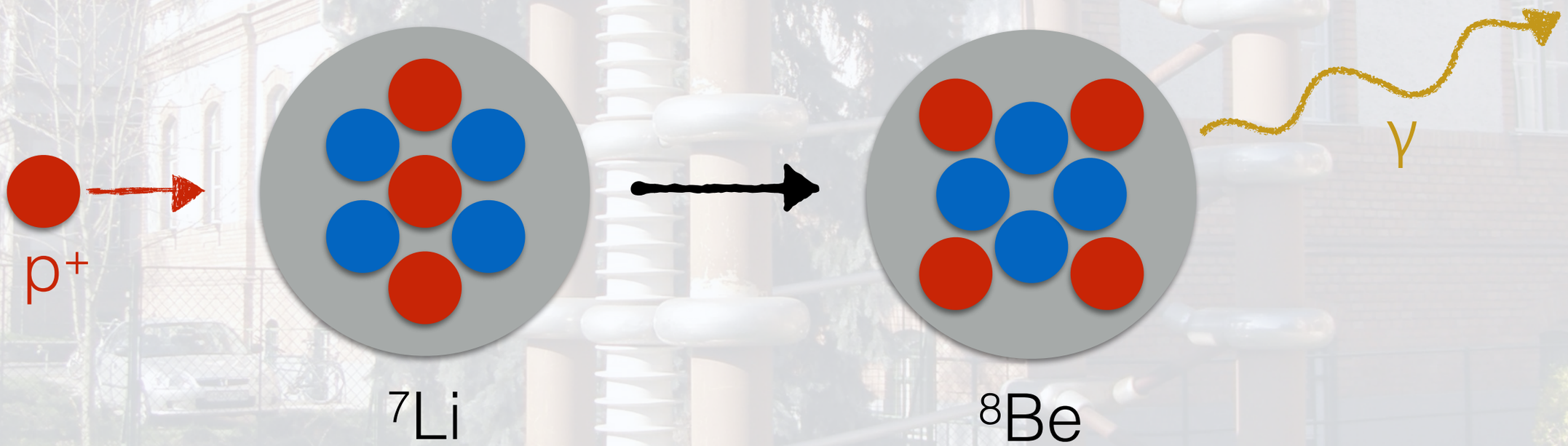
- We were originally looking for a dark photon-like particle



- The very light (~10 MeV) region can be probed nicely with transitions in light nuclei
  - Which is a region especially favoured by the g_μ-2 measurements

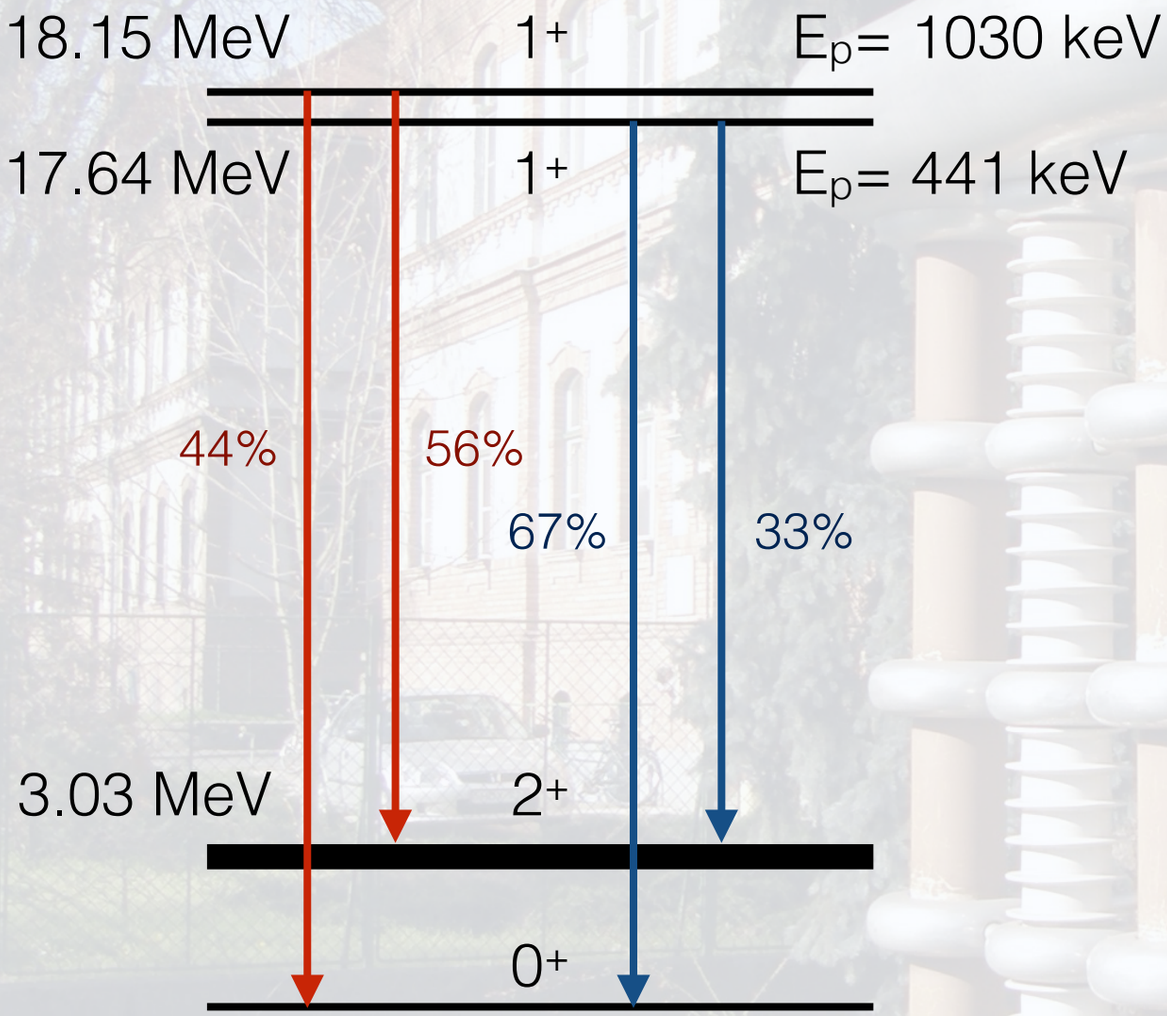
Producing Excited ^{8}Be

- Could be done in some different ways, but the simplest is to use the ^{7}Li(p,γ)^{8}Be reaction

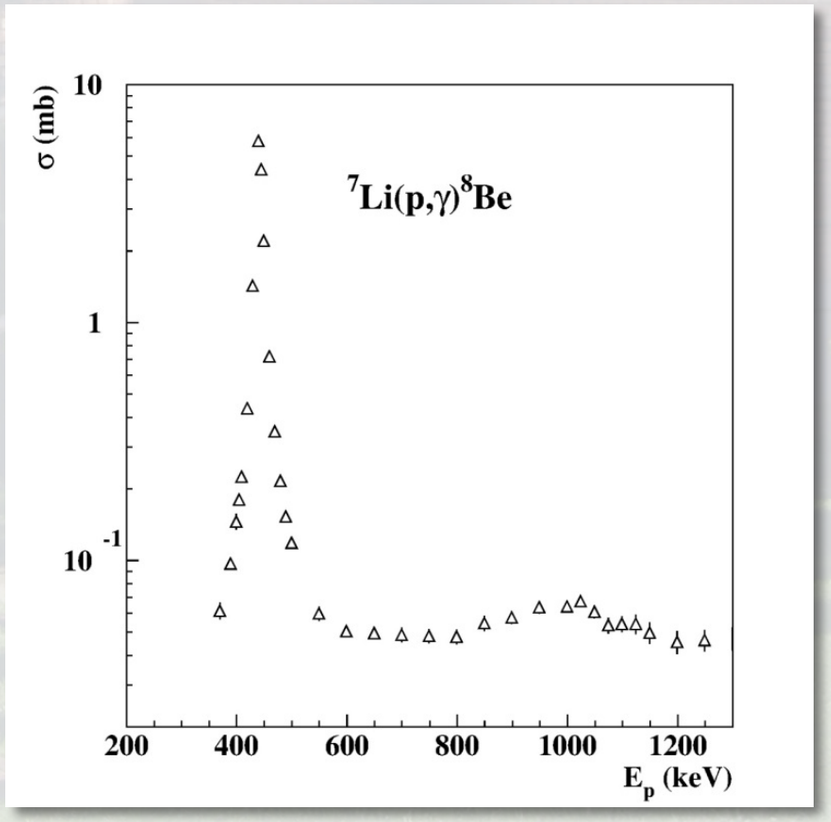


- Selecting the proton energy correctly allows us to excite one particular state of ^{8}Be

Producing Excited ^{8}Be

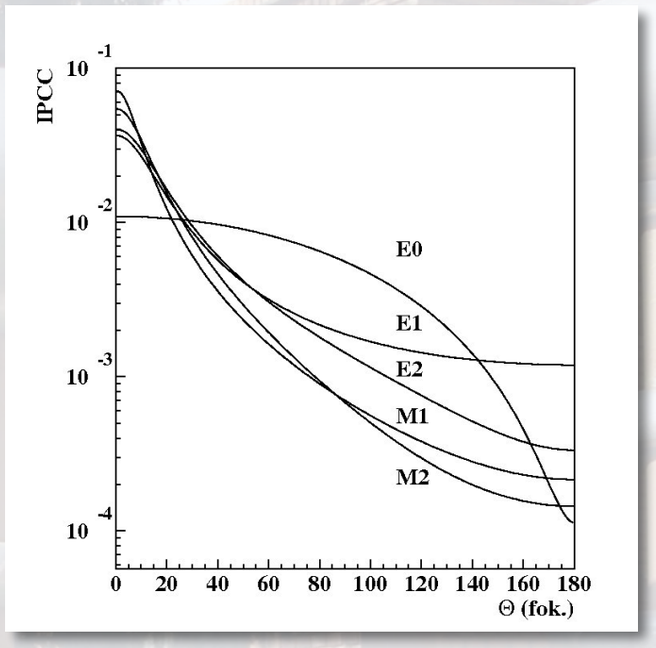


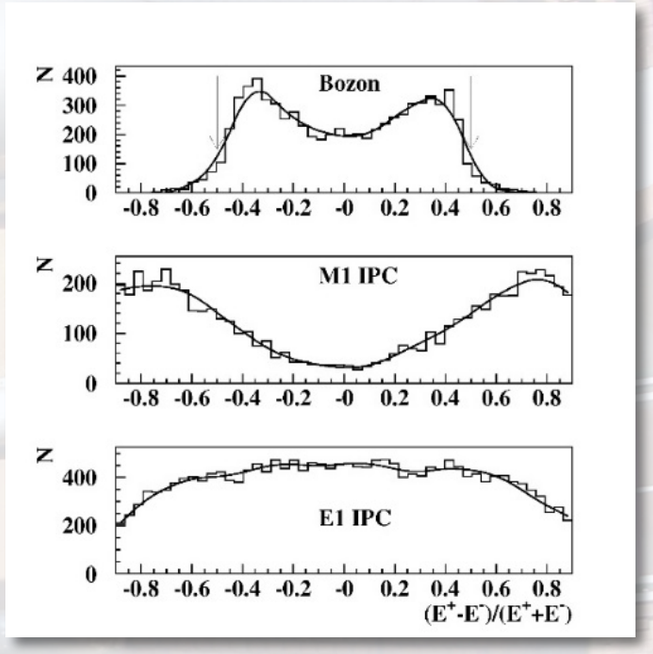
- These 2 states of ^{8}Be can be easily produced at our institute
  - We made measurements with both over time
- The 17.64 MeV state can be produced with a narrower resonance though

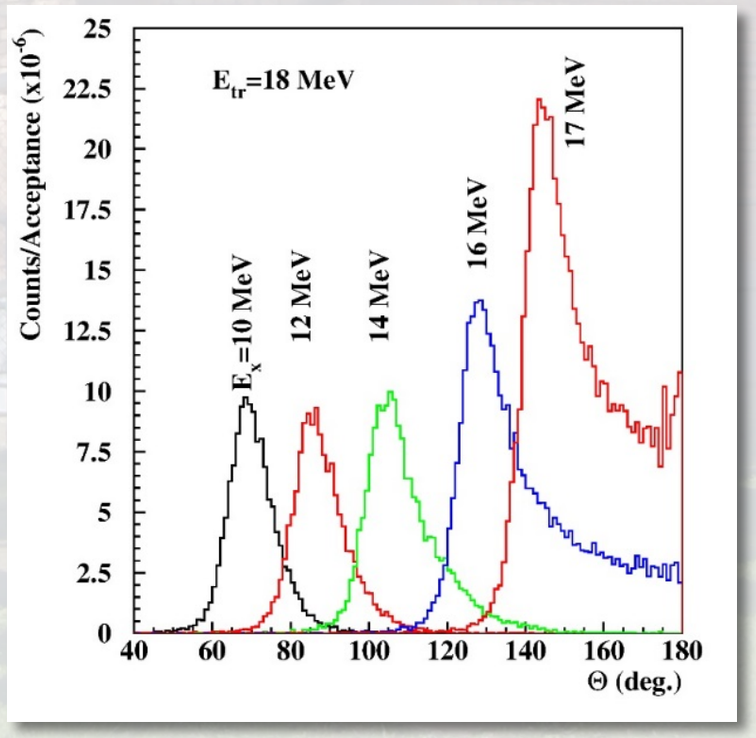


Why Electron Pairs?

- All of these transitions can happen via gamma emission
  - Which is allowed to produce e^+e^- pairs via internal pair creation
- The angular distribution of such e^+e^- pairs is well known
  - And is very different from the distribution that one would expect from an intermediate particle that could decay into an electron pair
    - The originally targeted dark photons are like that…
- Both in the angular and in the energy distributions

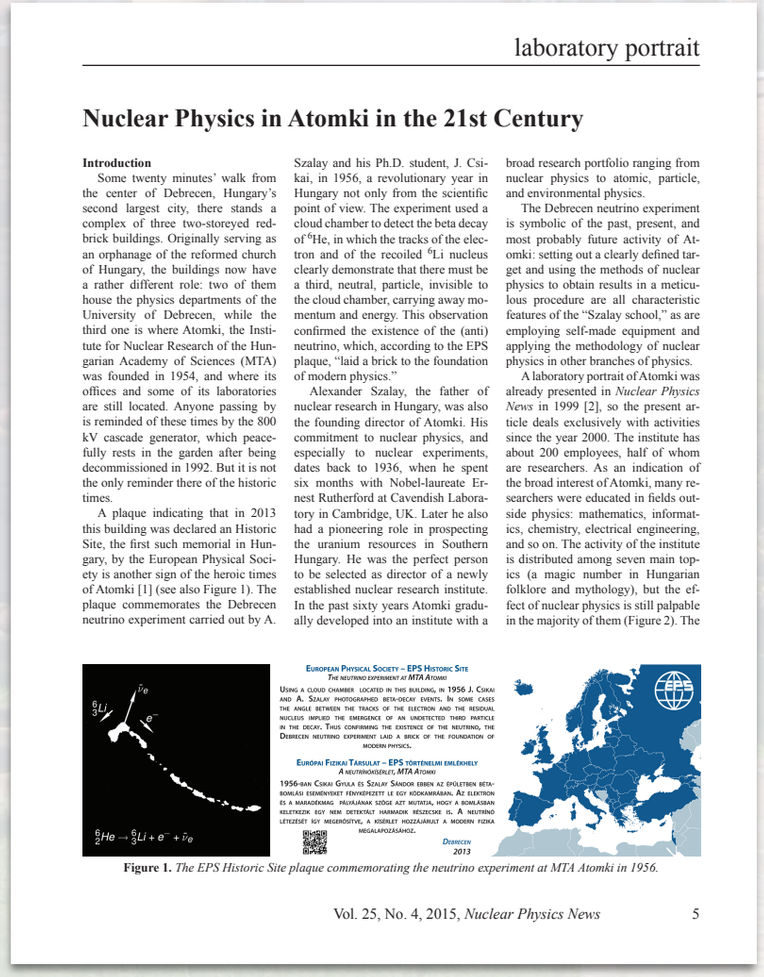






Infrastructure at Atomki

- "Institute for Nuclear Research",
  in the downtown of Debrecen, Hungary
  - http://www.atomki.mta.hu/en
  - http://www.nupecc.org/npn/npn254.pdf
- 4 main divisions in the institute
  - Nuclear physics
  - Atomic physics
  - Applied physics
  - Accelerator center
- ~100 scientists, and ~100 other staff



laboratory portrait

Nuclear Physics in Atomki in the 21st Century

Introduction

Some twenty minutes' walk from the center of Debrecen, Hungary's second largest city, there stands a complex of three two-storeyed red-brick buildings. Originally serving as an orphanage of the reformed church of Hungary, the buildings now have a rather different role: two of them house the physics departments of the University of Debrecen, while the third one is where Atomki, the Institute for Nuclear Research of the Hungarian Academy of Sciences (MTA) was founded in 1954, and where its offices and some of its laboratories are still located. Anyone passing by is reminded of these times by the 800 kV cascade generator, which peacefully rests in the garden after being decommissioned in 1992. But it is not the only reminder there of the historic times.

A plaque indicating that in 2013 this building was declared an Historic Site, the first such memorial in Hungary, by the European Physical Society is another sign of the heroic times of Atomki [1] (see also Figure 1). The plaque commemorates the Debrecen neutrino experiment carried out by A. Szalay and his Ph.D. student, J. Csikai, in 1956, a revolutionary year in Hungary not only from the scientific point of view. The experiment used a cloud chamber to detect the beta decay of ^{6}He, in which the tracks of the electron and of the recoiled ^{6}Li nucleus clearly demonstrate that there must be a third, neutral, particle, invisible to the cloud chamber, carrying away momentum and energy. This observation confirmed the existence of the (anti) neutrino, which, according to the EPS plaque, "laid a brick to the foundation of modern physics."

Alexander Szalay, the father of nuclear research in Hungary, was also the founding director of Atomki. His commitment to nuclear physics, and especially to nuclear experiments, dates back to 1936, when he spent six months with Nobel-laureate Ernest Rutherford at Cavendish Laboratory in Cambridge, UK. Later he also had a pioneering role in prospecting the uranium resources in Southern Hungary. He was the perfect person to be selected as director of a newly established nuclear research institute. In the past sixty years Atomki gradually developed into an institute with a broad research portfolio ranging from nuclear physics to atomic, particle, and environmental physics.

The Debrecen neutrino experiment is symbolic of the past, present, and most probably future activity of Atomki: setting out a clearly defined target and using the methods of nuclear physics to obtain results in a meticulous procedure are all characteristic features of the "Szalay school," as are employing self-made equipment and applying the methodology of nuclear physics in other branches of physics.

A laboratory portrait of Atomki was already presented in *Nuclear Physics News* in 1999 [2], so the present article deals exclusively with activities since the year 2000. The institute has about 200 employees, half of whom are researchers. As an indication of the broad interest of Atomki, many researchers were educated in fields outside physics: mathematics, informatics, chemistry, electrical engineering, and so on. The activity of the institute is distributed among seven main topics (a magic number in Hungarian folklore and mythology), but the effect of nuclear physics is still palpable in the majority of them (Figure 2). The

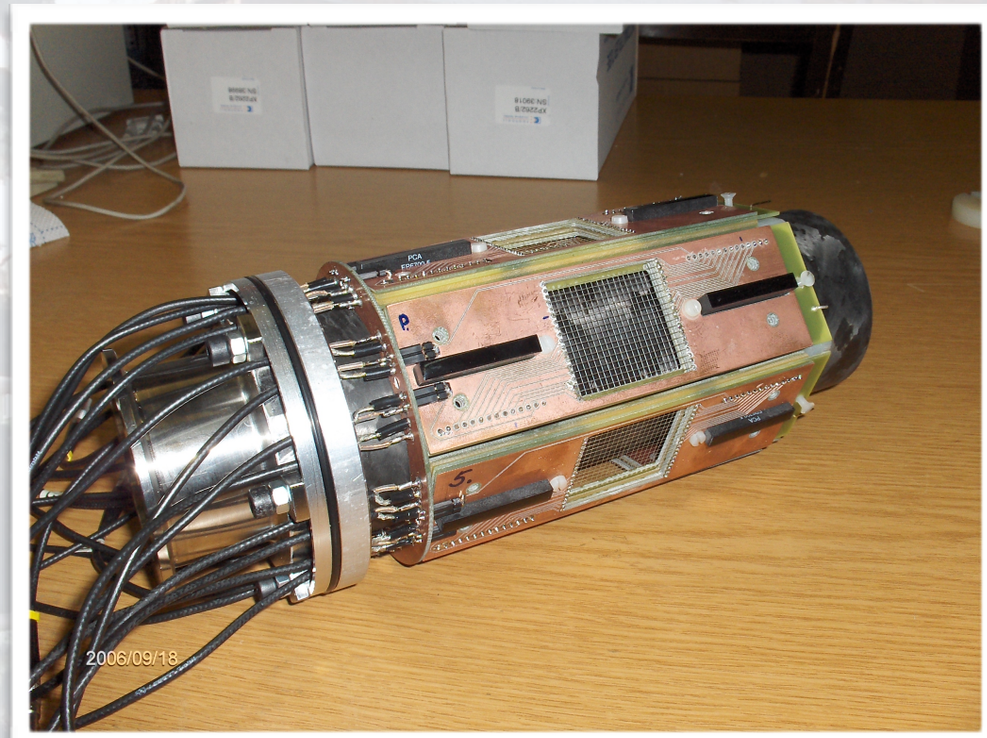
Figure 1. *The EPS Historic Site plaque commemorating the neutrino experiment at MTA Atomki in 1956.*

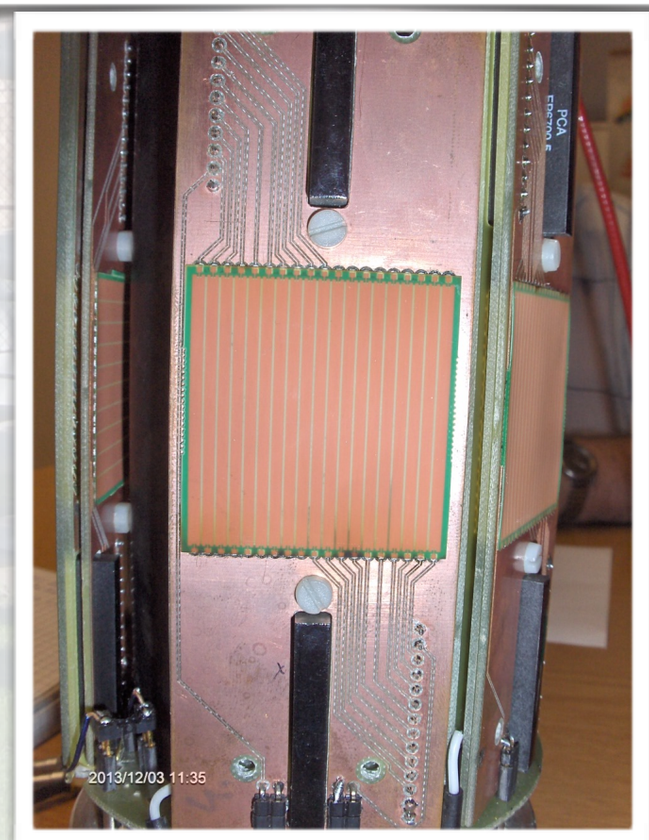
Building an Experiment

- In a small experiment you have to do everything yourself…
  - Getting beam time, arranging for the right beam and right target
  - Building/equipping all the detectors, the power and readout electronics
  - Writing data acquisition software for the experiment, and storing the experimental data
  - Writing all of the data analysis software, including simulation code for the experiment
- In a big collaboration one is usually only involved in 1-2 of these

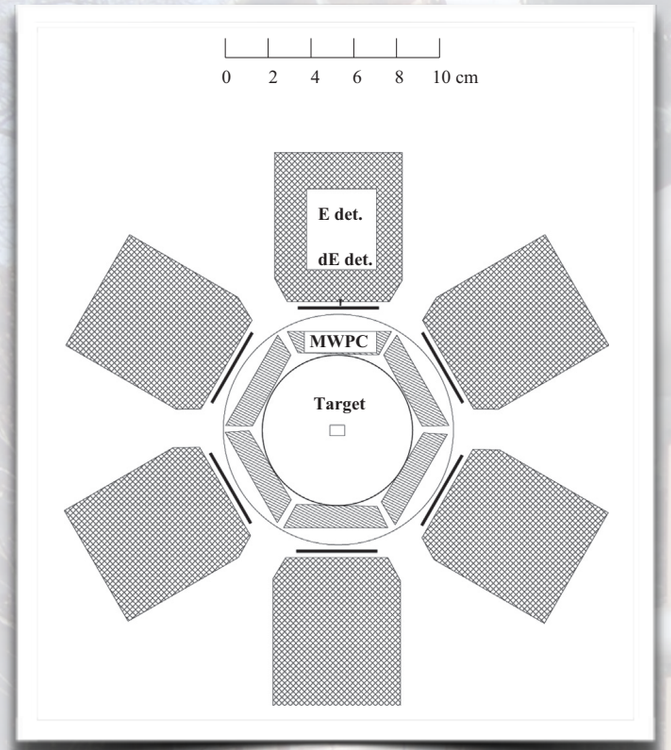
The Detectors

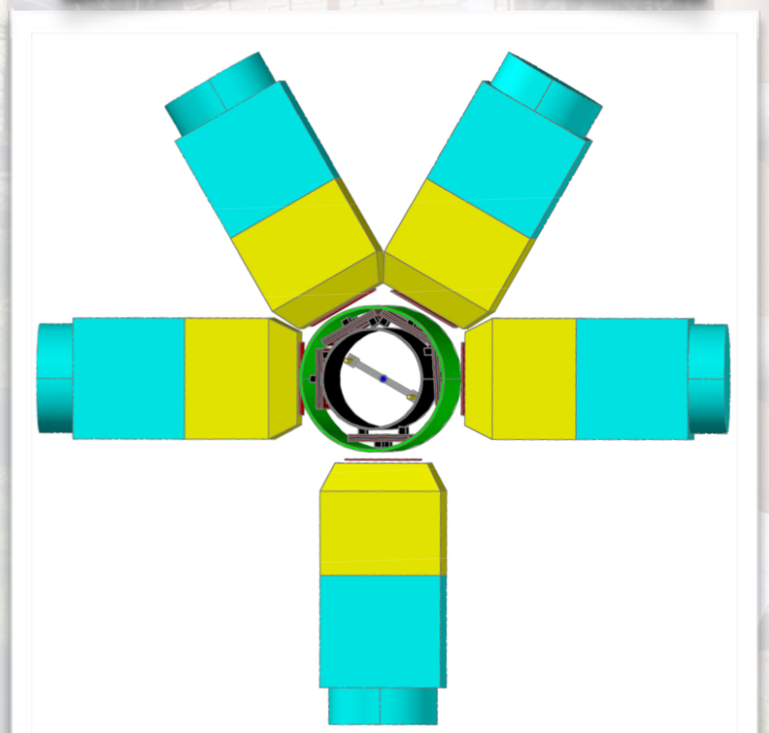
- We need to
  - Identify electrons as electrons;
  - detect their direction;
  - and their energy
- The spectrometer is described in NIM A808 (2016) 21
- For the positions, we originally used (relatively) simple wire chambers (MWPC) put around the target
- These were exchanged for Double Sided Strip Detectors (DSSD) in the latest data taking



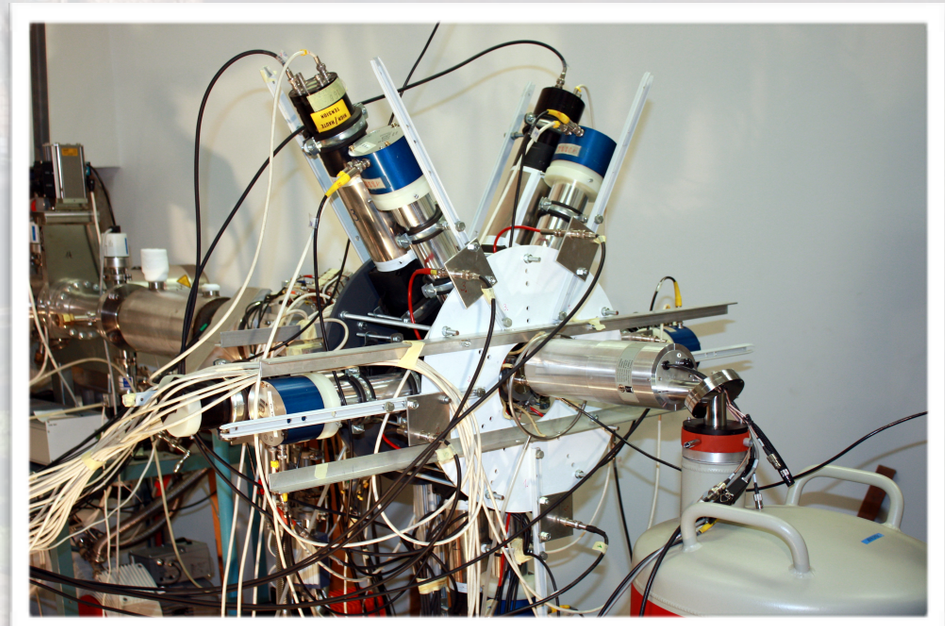


The Detectors

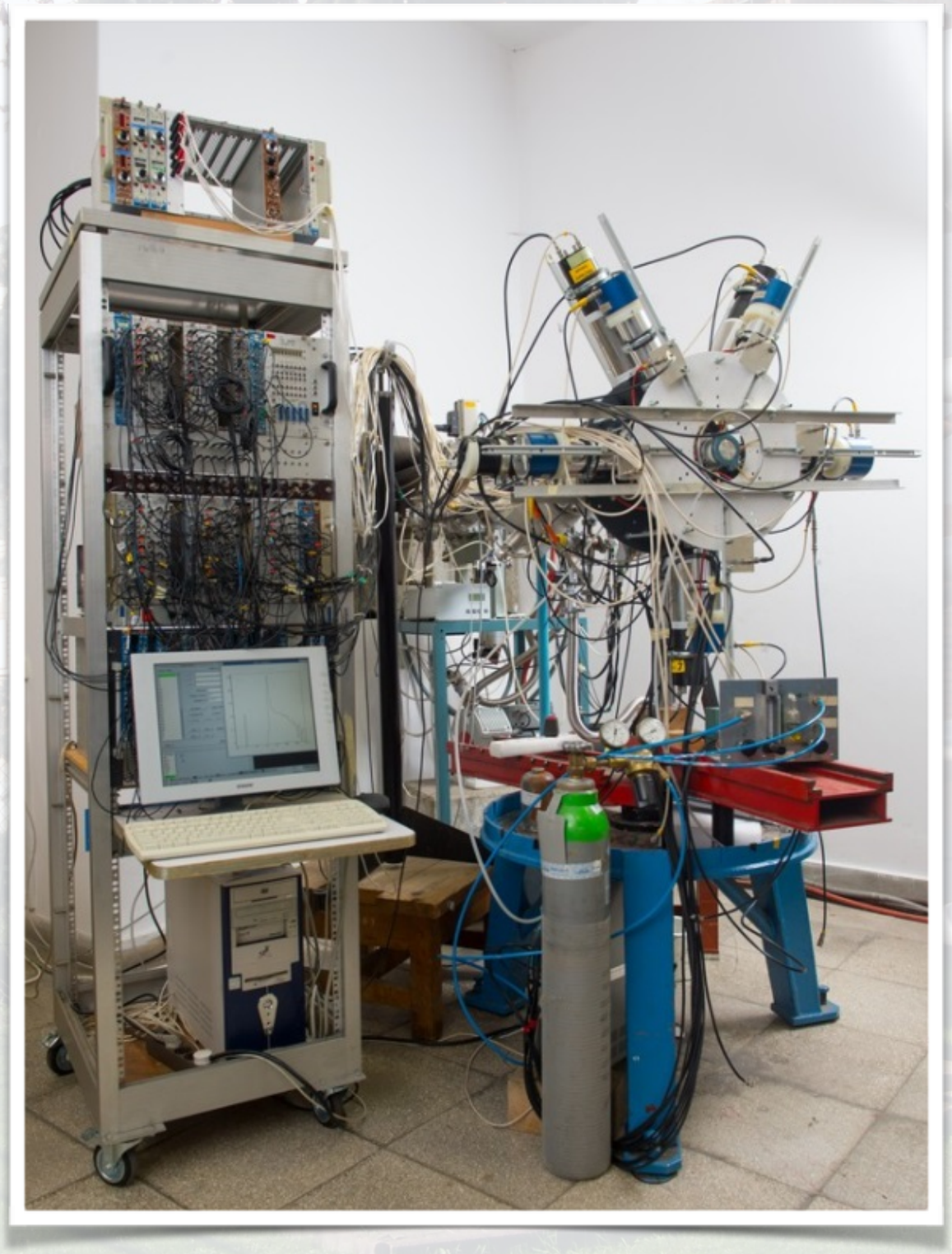




- The electrons are then absorbed in scintillators, measuring their total energy
  - There is also a ΔE detector in front of each scintillator to make sure that we detect electrons “flying in the right direction”
- The layout of these was updated a bit over time

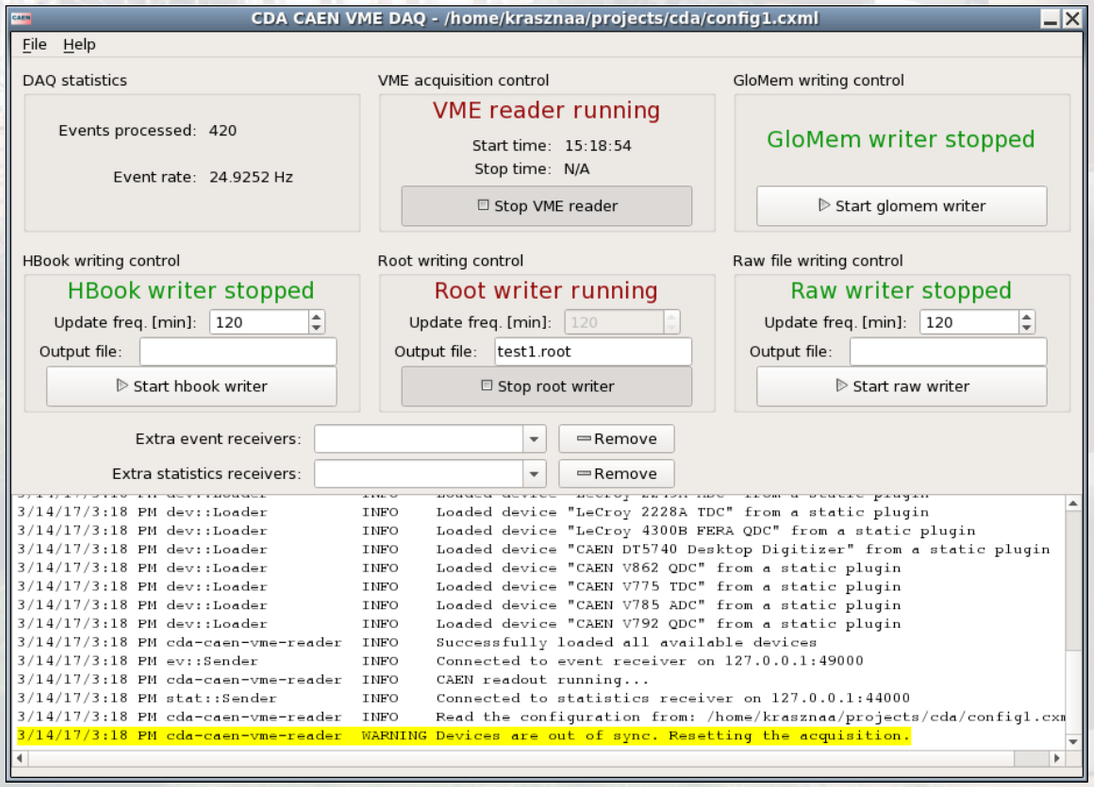


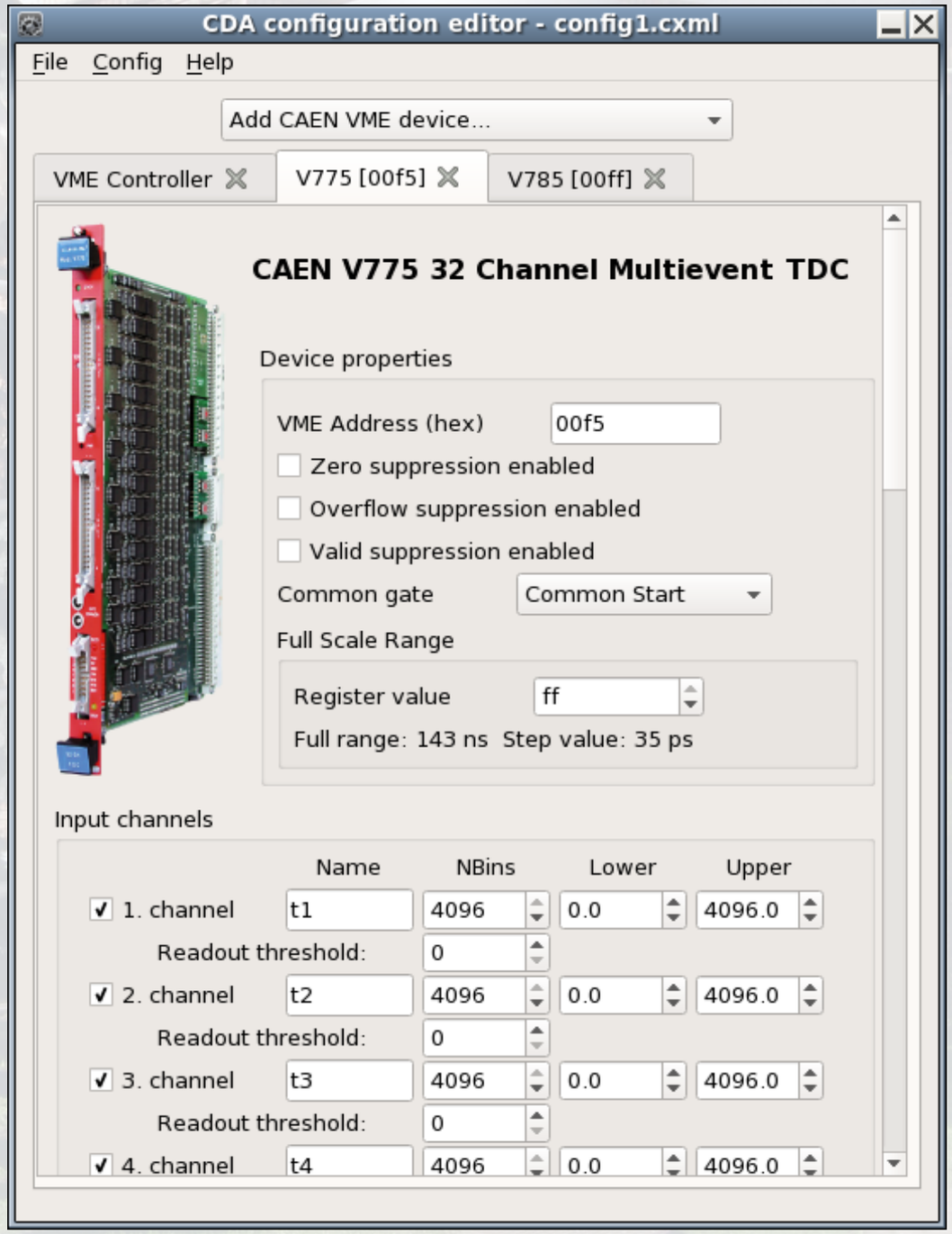
The Full Setup



Data Readout

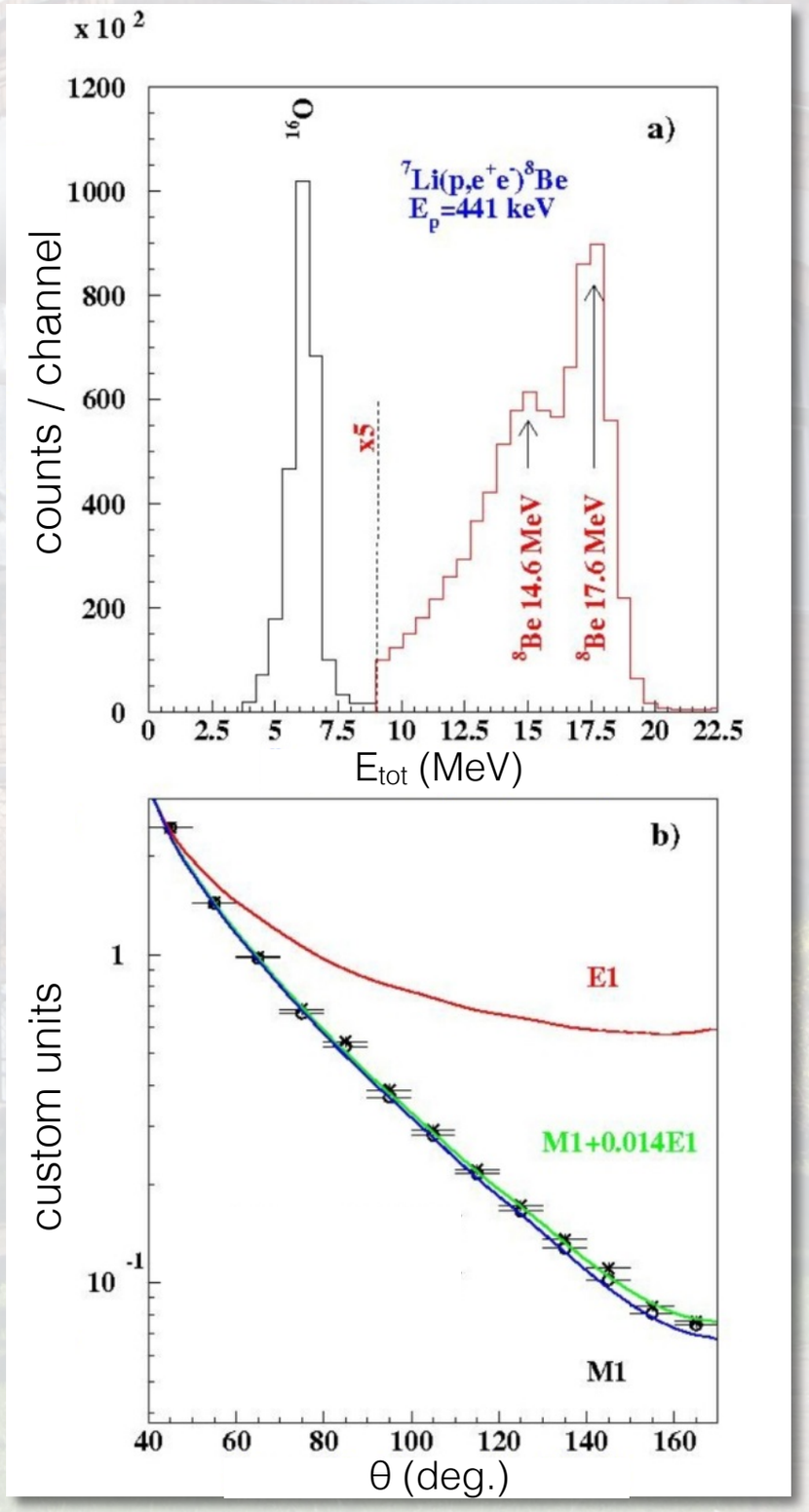
- Is one of the places where I contributed a lot…
- Done with a custom (and relatively simple) DAQ software written for the specific hardware that the group has
  - https://sourceforge.net/projects/at-cda/



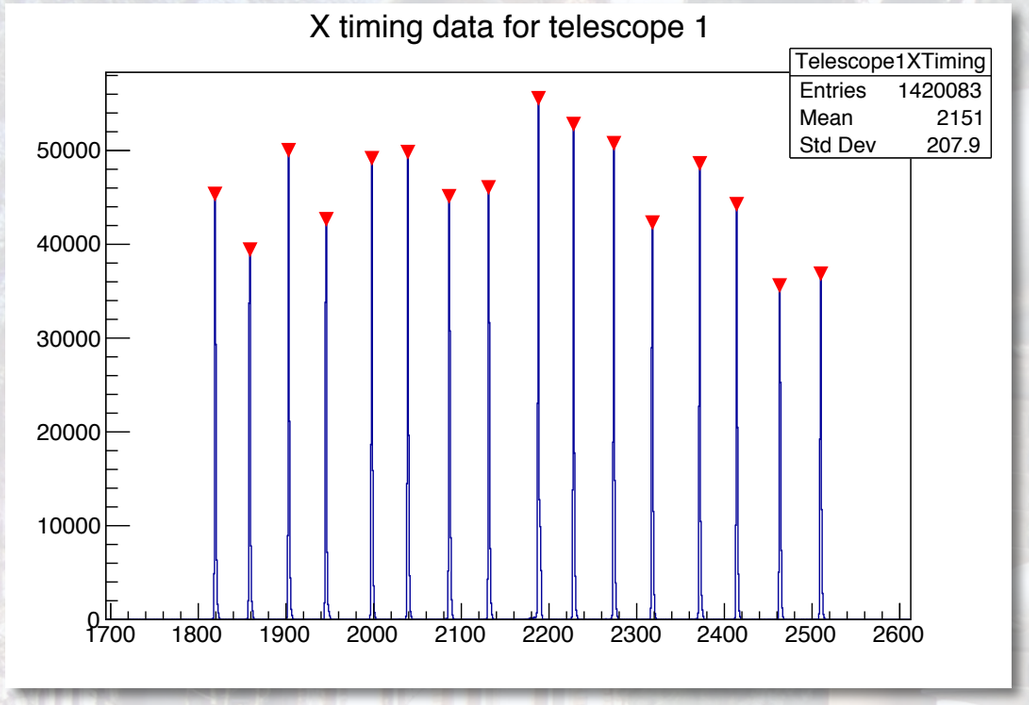


Analysing The Data

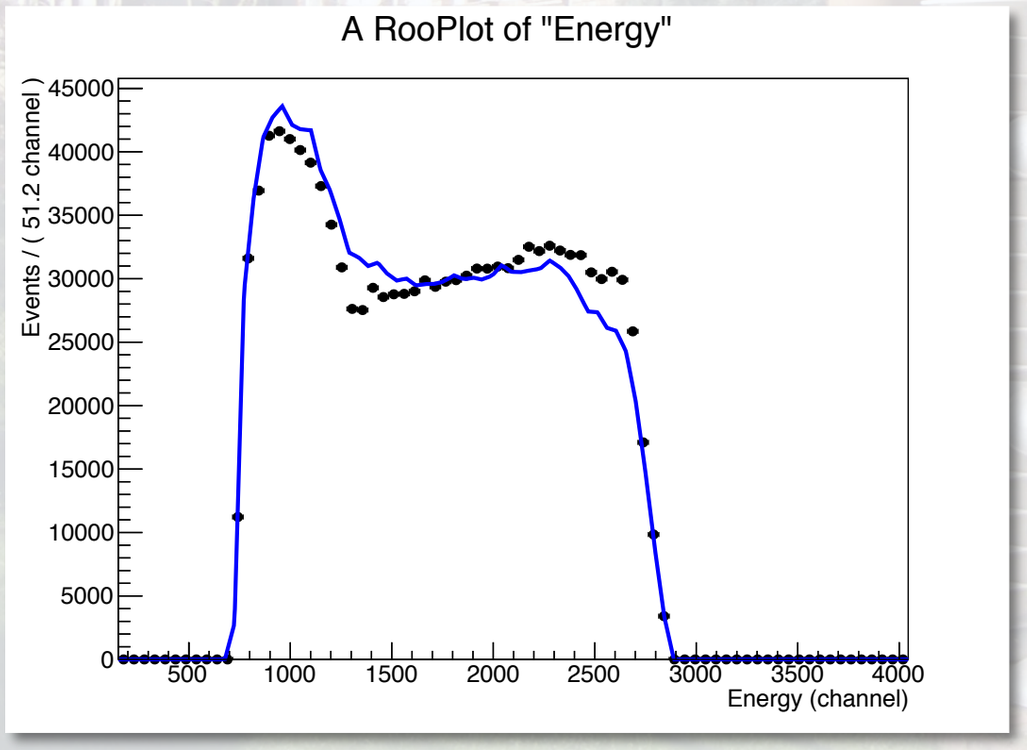
- Have to start with calibrating all the detectors of course
  - Both for the position and energy measurements
- The target is not pure ^{7}Li
  - So many of the events will not be coming from the interaction we're interested in
- Only select events in which
  - The detector timing is okay
  - The position sensitive detectors picked up a valid signal
  - The $e^{+}e^{-}$ total energy corresponds to the transition we're interested in

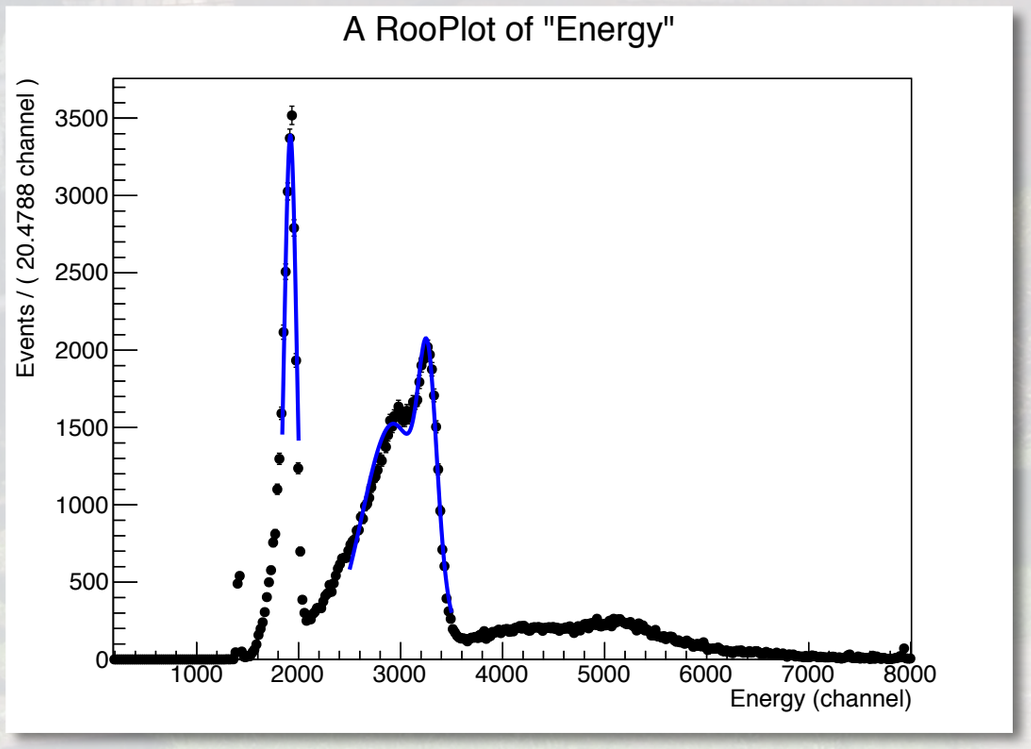


More About Calibration

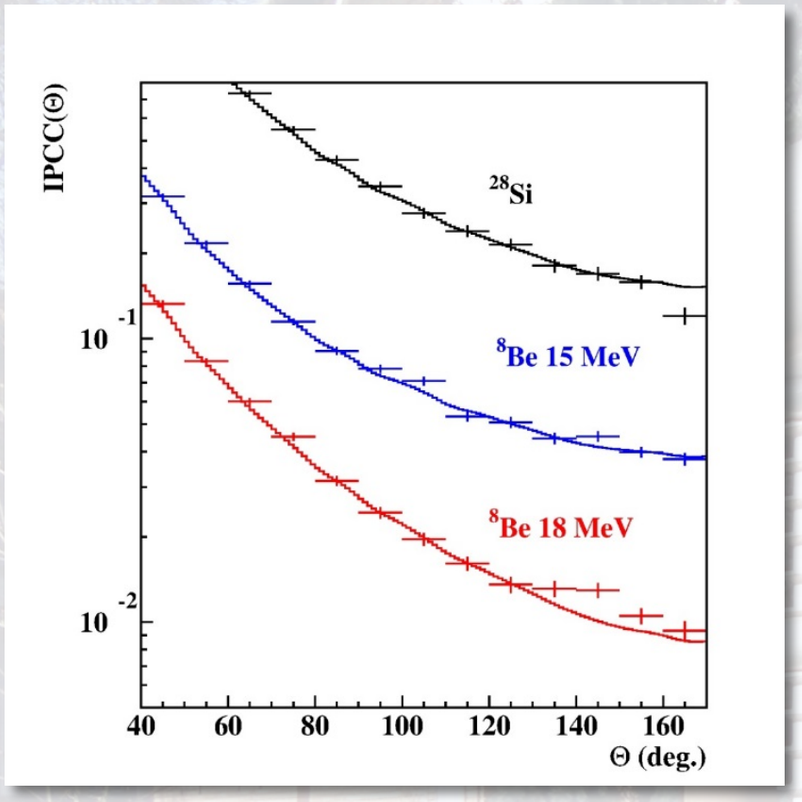


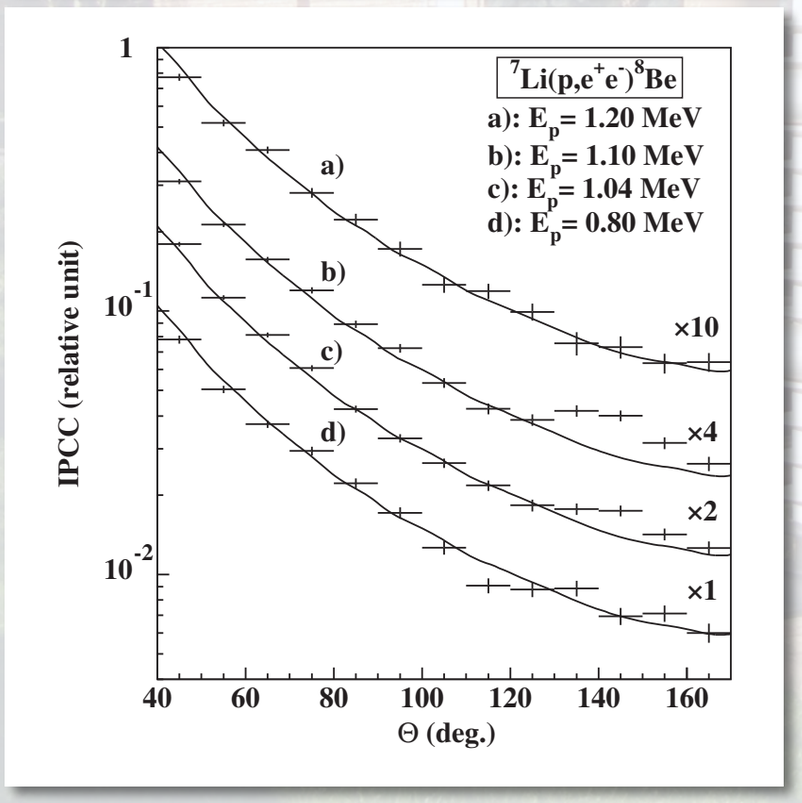
- Identify the 16 strips in the DSSD data
- Perform a relative energy calibration between the scintillators
- Perform an absolute energy calibration of the scintillators



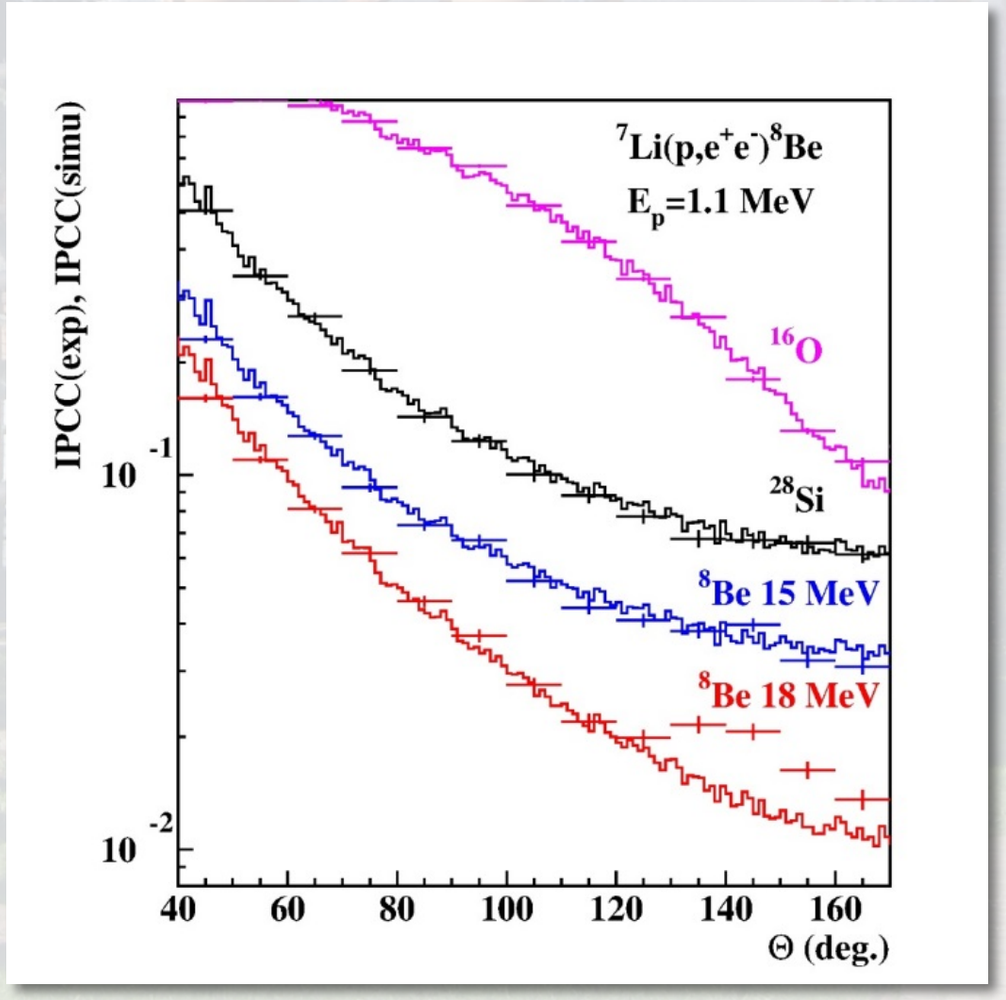


Results From The Paper



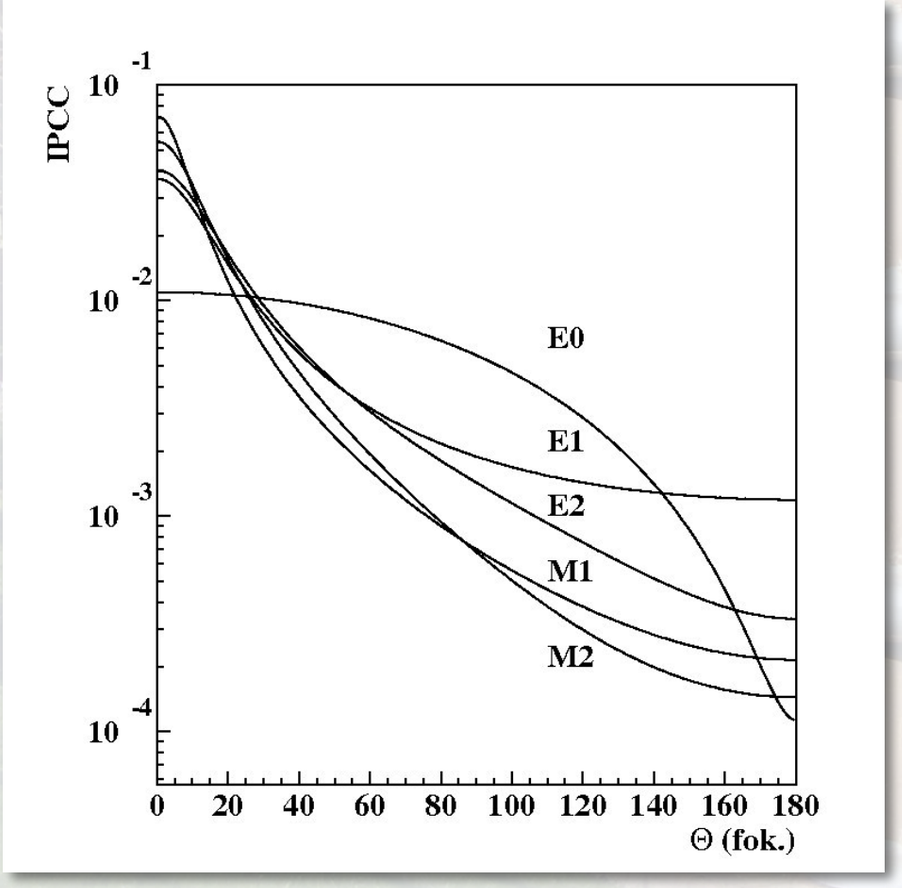


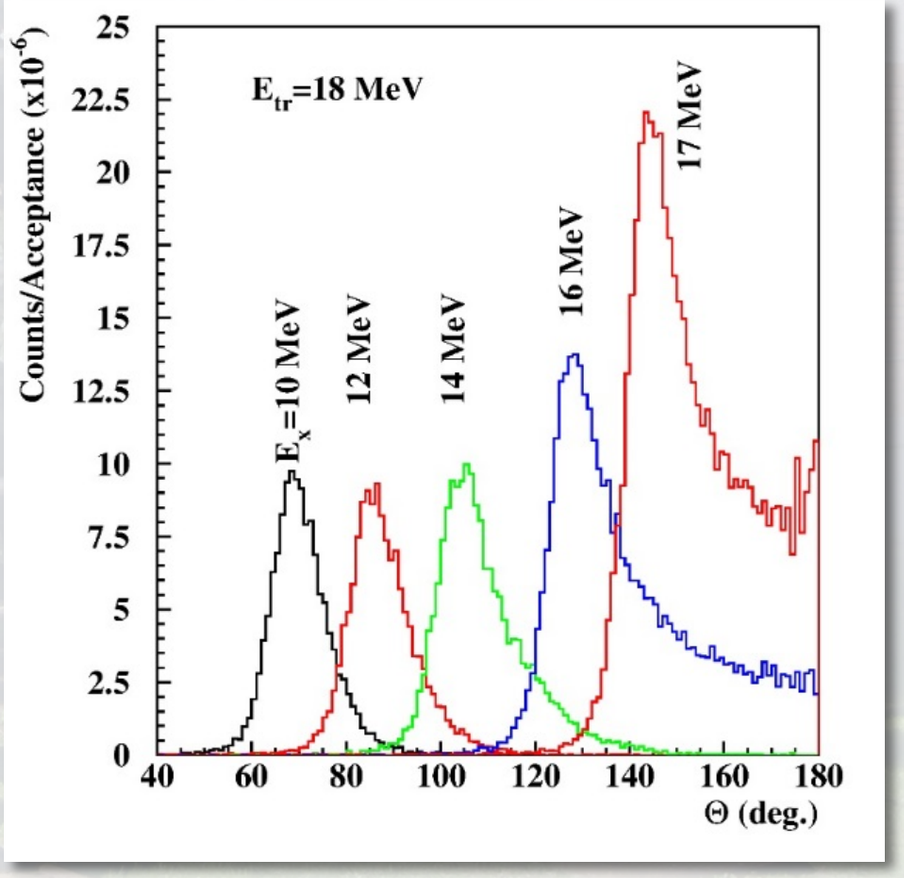
- The e^+e^- opening angle distribution was measured under a **lot** of different conditions
- And a discrepancy was found under some of them



Simulation

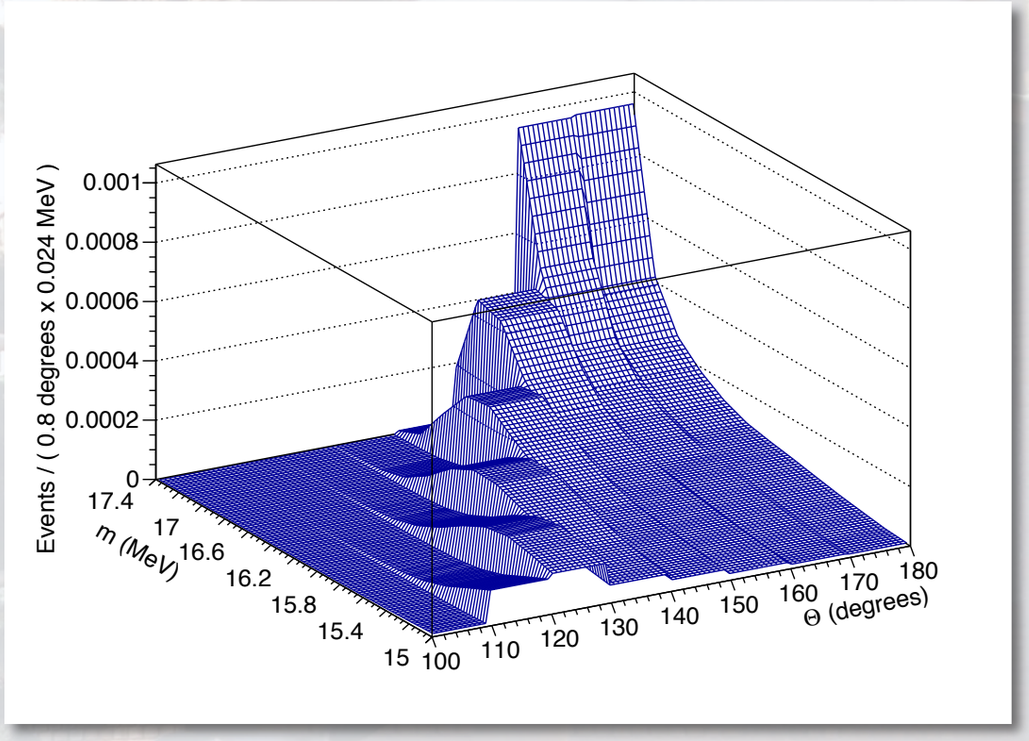
- The decay with internal pair creation and with possible intermediate particles was simulated using Geant
  - Exactly how data is analysed in larger experiments as well
- These produced the reference distributions for the e^+e^- opening angles shown before

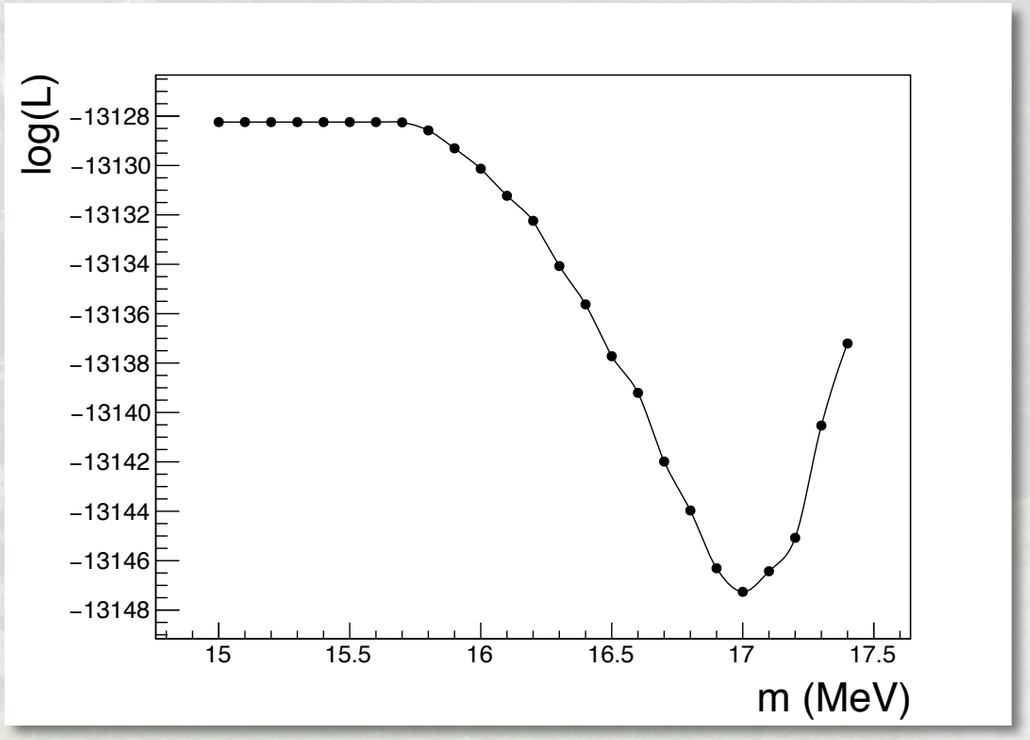




Fitting The Results

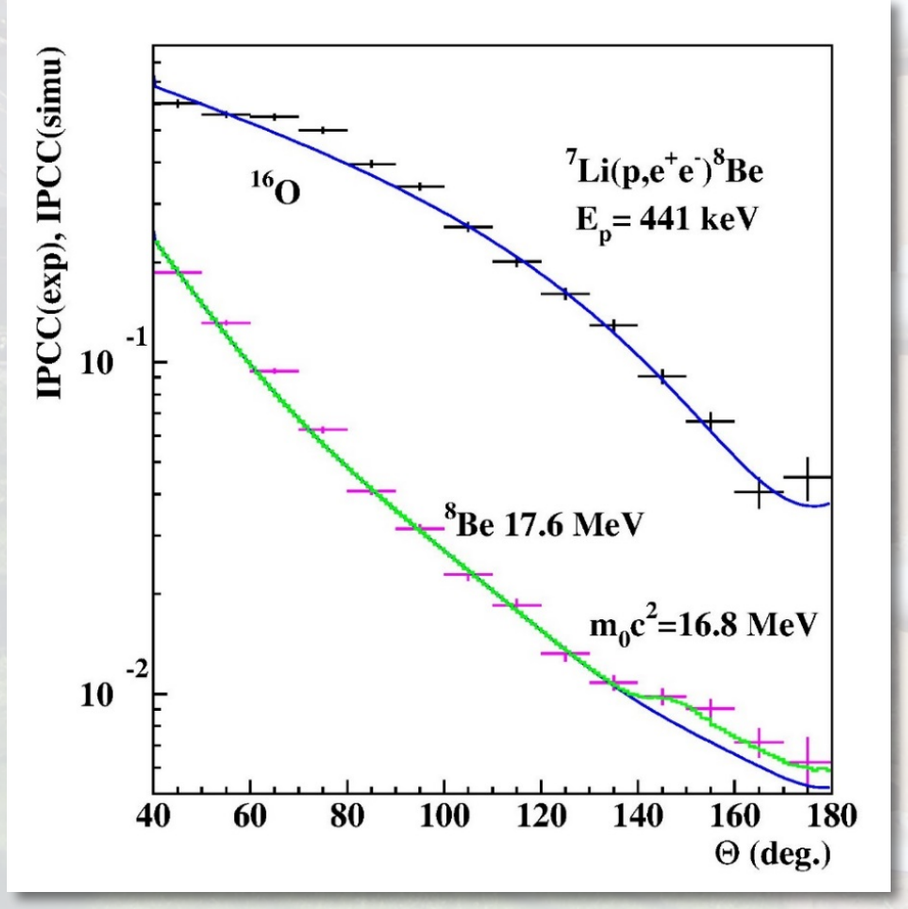
- The measured distributions (with the bump) can not be fitted closely by only considering IPC
- Instead, we try to fit the distribution with an IPC+X PDF
- The distributions that we get for different (discreet) theoretical particle masses were put into a 2 dimensional RooFit PDF
  - Which linearly interpolates between the discreet distributions
- The data distribution was then fitted by fixing the theoretical particle mass at different values
  - This results in a clear best fit at a certain hypothetical mass

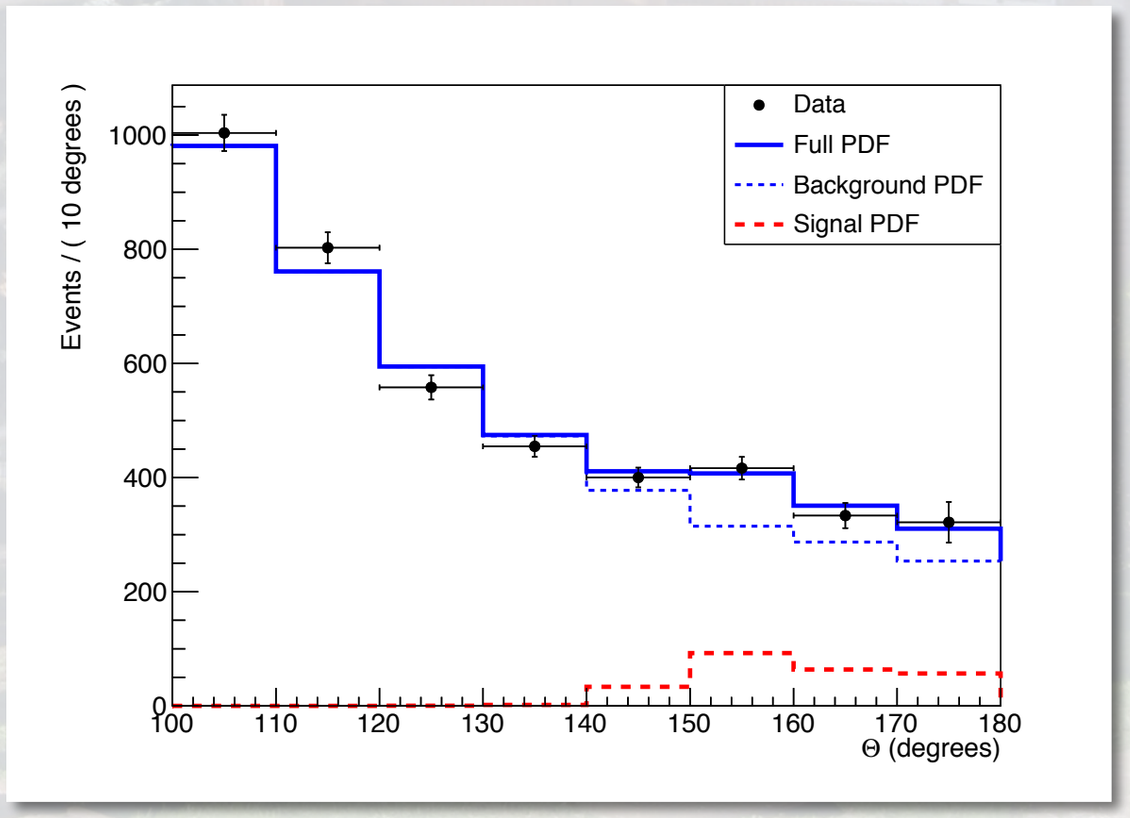




The New Measurements

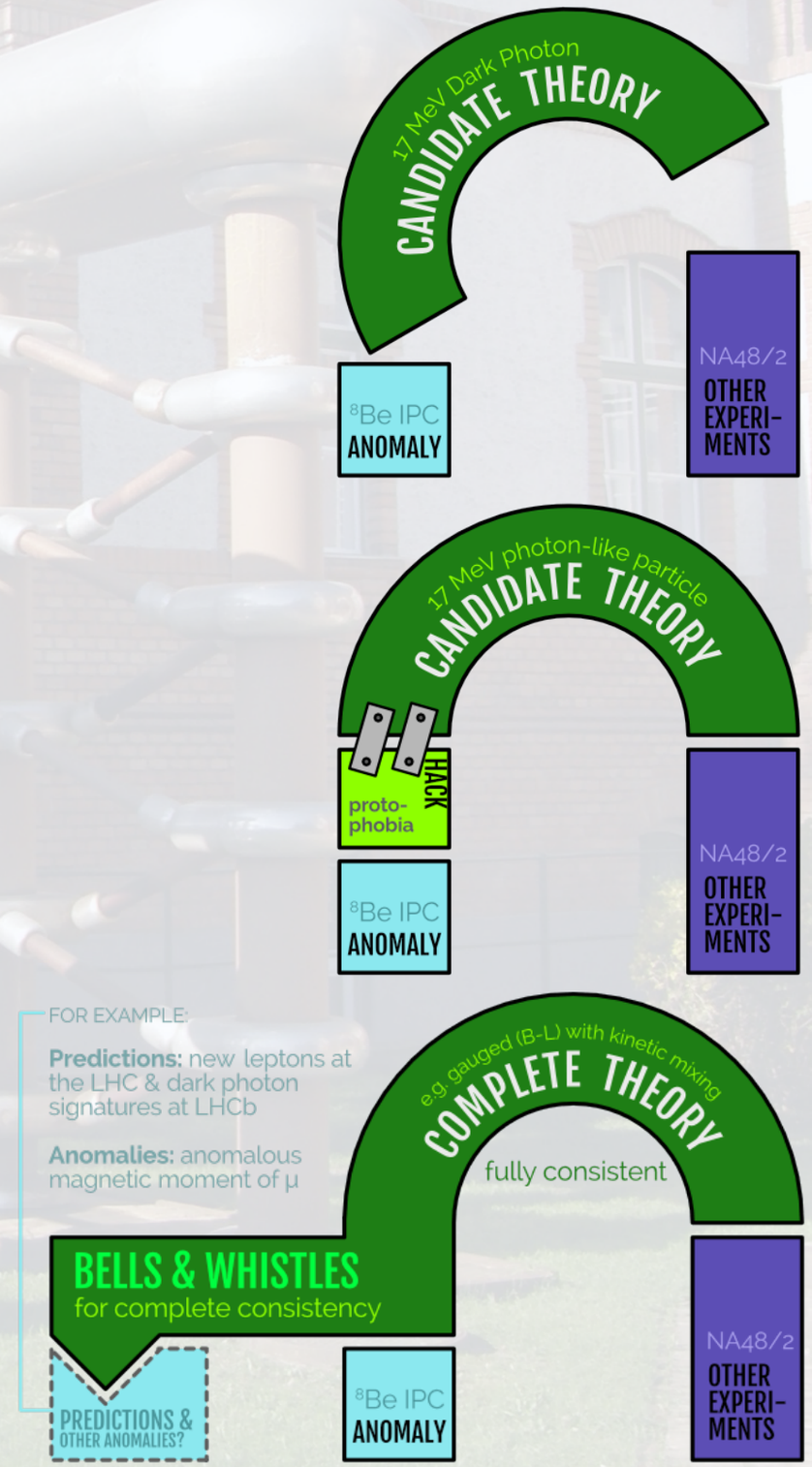
- The original measurement was observing the discrepancy from the 18.15 MeV excited state of ^{8}Be
- But for the new particle prediction to be plausible, it would need to show up from the 17.64 MeV state as well
  - This is what was tested most recently with an updated experimental setup
  - The discrepancy shows up here as well, in a bit more subtle way





Interpretation(s)

- We originally thought of searching for dark-photon-like particles
  - But theoretically this is not easy to use as an explanation for the observations
  - A (“regular”) dark photon with such a mass would’ve been seen in other experiments as well
- It can be worked around by introducing protophobia for the new particle
  - But its hack-ish nature doesn’t make it appealing
- Hence the 5th force explanation was proposed
  - Receiving quite a lot of attention…
- A very nice writeup is available here

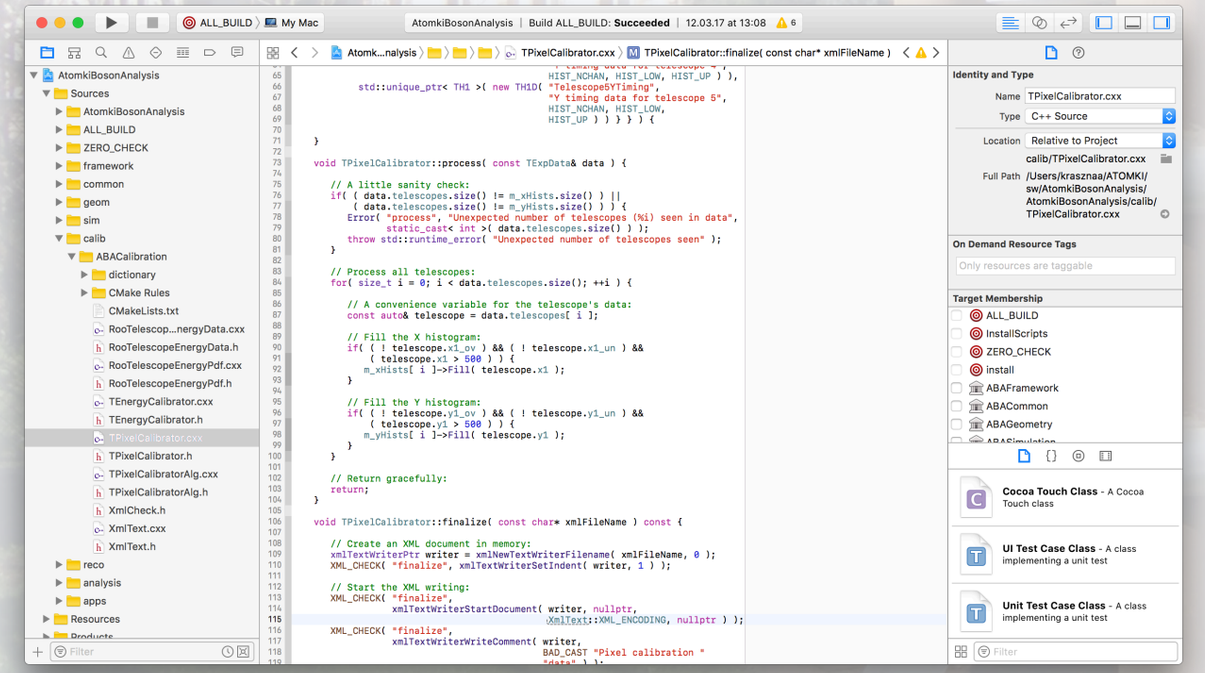


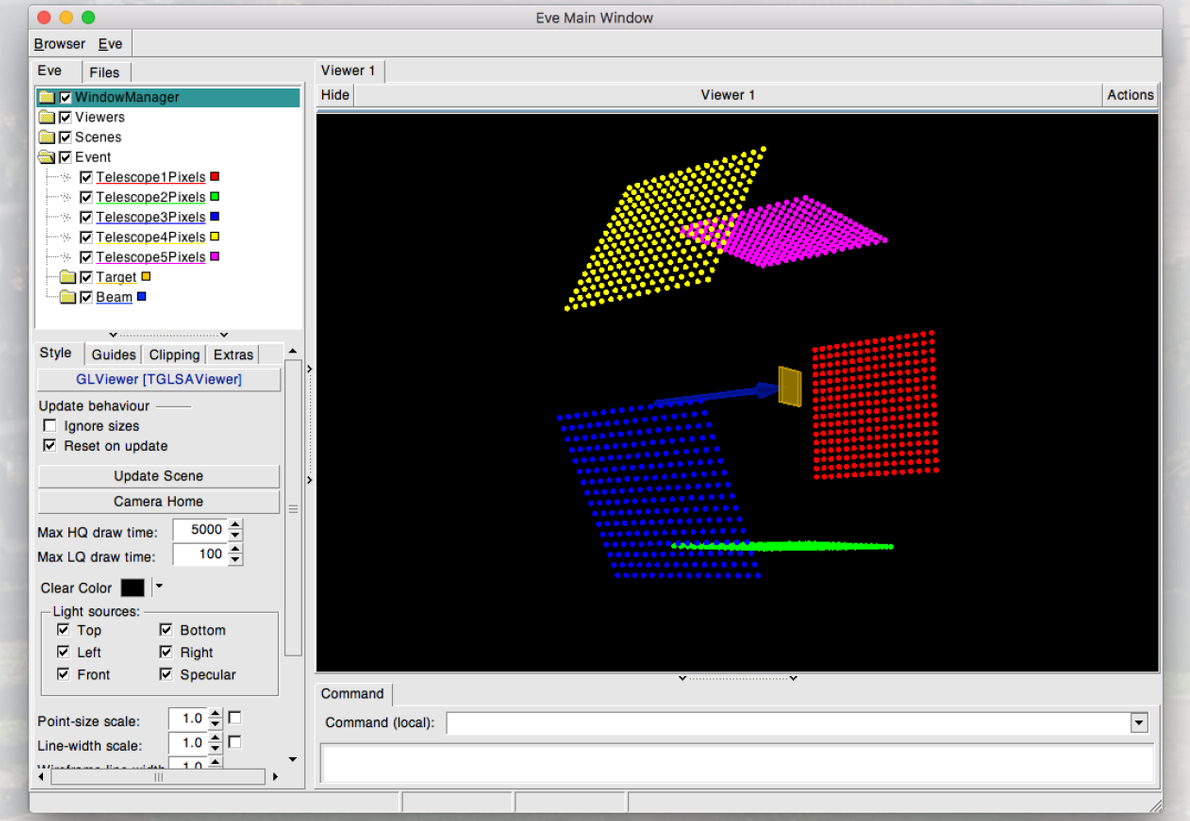
Updating The Experiment

- The Hungarian National Development Agency awarded ~1.5 MEur to updating the experimental setup
  - Was the source for the new DSSD modules already
  - Will be used to improve the geometrical acceptance by adding more telescopes
- A new detector setup (COmpact Positron Electron spectrometer, COPE) is in the planning, which should improve the angle and energy measurements considerably
  - Such a light particle would produce a very narrow (O(eV)) resonance
  - The current angular (~10 degrees due to multiple scattering) and energy resolution ($\Delta E/E \cong 10\%$) limit our invariant mass measurement significantly

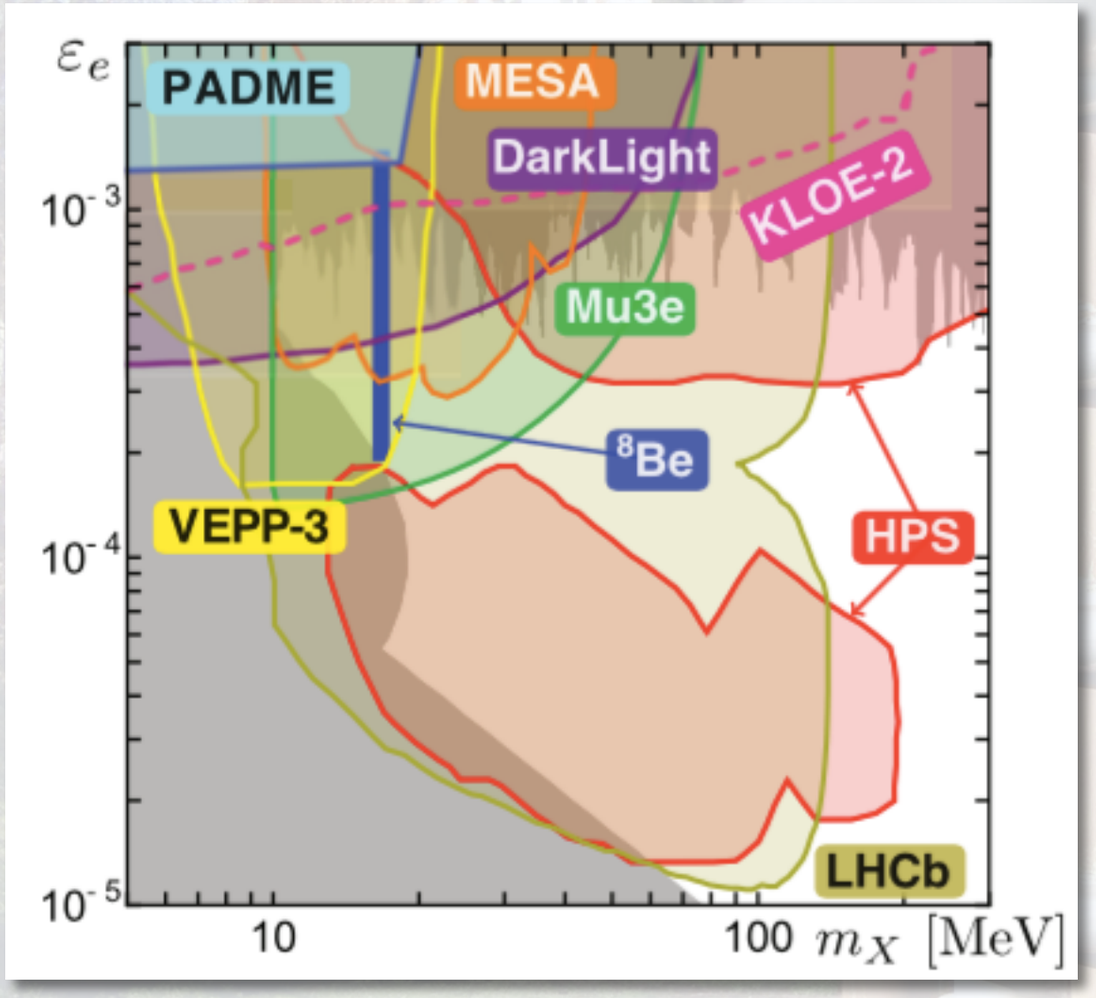
Updating The Analysis

- All published results (apart from the final fits) were produced using quite old style analysis code
  - Written in Fortran, using PAW / Geant3
- Have recently started looking at creating a more modern implementation
  - Relying on C++, ROOT and Geant4
- Only doing it in my spare time though, so still lot's to do…





Upcoming Experiments



- A number of new/updated experiments will be able to look for the anomaly in the near future
  - Both in similar and very different channels to how we've seen it
- The particle, if real, should show up in other processes as well
  - As a cross check, we plan to test using the ^{10}Be(d,α)^{8}Be reaction
  - Plan to look for the discrepancy in ^{3}H(p,γ)^{4}He and ^{3}He(n,γγ)^{4}He
  - Check the E_x = 18.15 MeV state of ^{10}Be

Summary

- We found a significant deviation from the expectations while studying the angular correlations of e^+e^- pairs emitted by excited states of ^{8}Be
- The results (rightfully) make people cautious
  - It is still absolutely possible that the result turns out to be something non interesting
- Repeating the experiment with an updated detector, and looking at a different excited state of ^{8}Be found a deviation from IPC expectations as well
  - Resulting in a particle hypothesis compatible with the previous results
- The group has a long program ahead of it, systematically looking for the hypothetical new particle in new decay channels with new/updated detectors
  - While other experiments will look for the effect as well

References

- https://arxiv.org/abs/1504.01527
- https://arxiv.org/abs/1504.00489
- https://arxiv.org/abs/1604.07411
- https://particlebites.com/?p=3970
- http://www.nature.com/news/has-a-hungarian-physics-lab-found-a-fifth-force-of-nature-1.19957