X17: *Searching for New Physics in Nuclear Transitions*

Attila Krasznahorkay
On behalf of a number of people

What I Will Be Talking About

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

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New evidence supporting the existence of the hypothetic X17 particle

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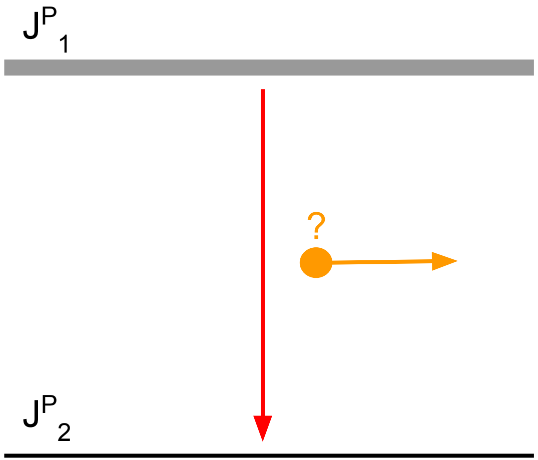
But first, a bit of context…

Atomki

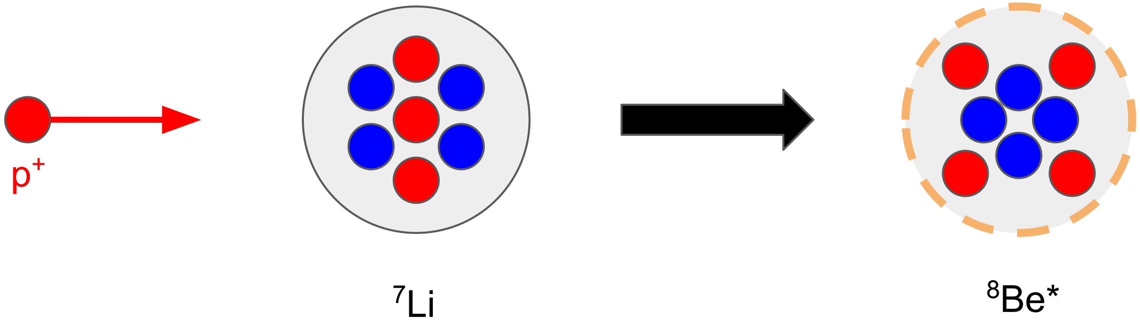
- The [Institute for Nuclear Research (Atomki)] is one of two places in Hungary performing basic nuclear research
    - With the other being the [Wigner Research Center for Physics]
- Has multiple different types of O(MeV) accelerators
    - http://www.atomki.hu/en/accelerators
    - The two published results actually came from two different accelerators

Nuclear Physics for Discovery?



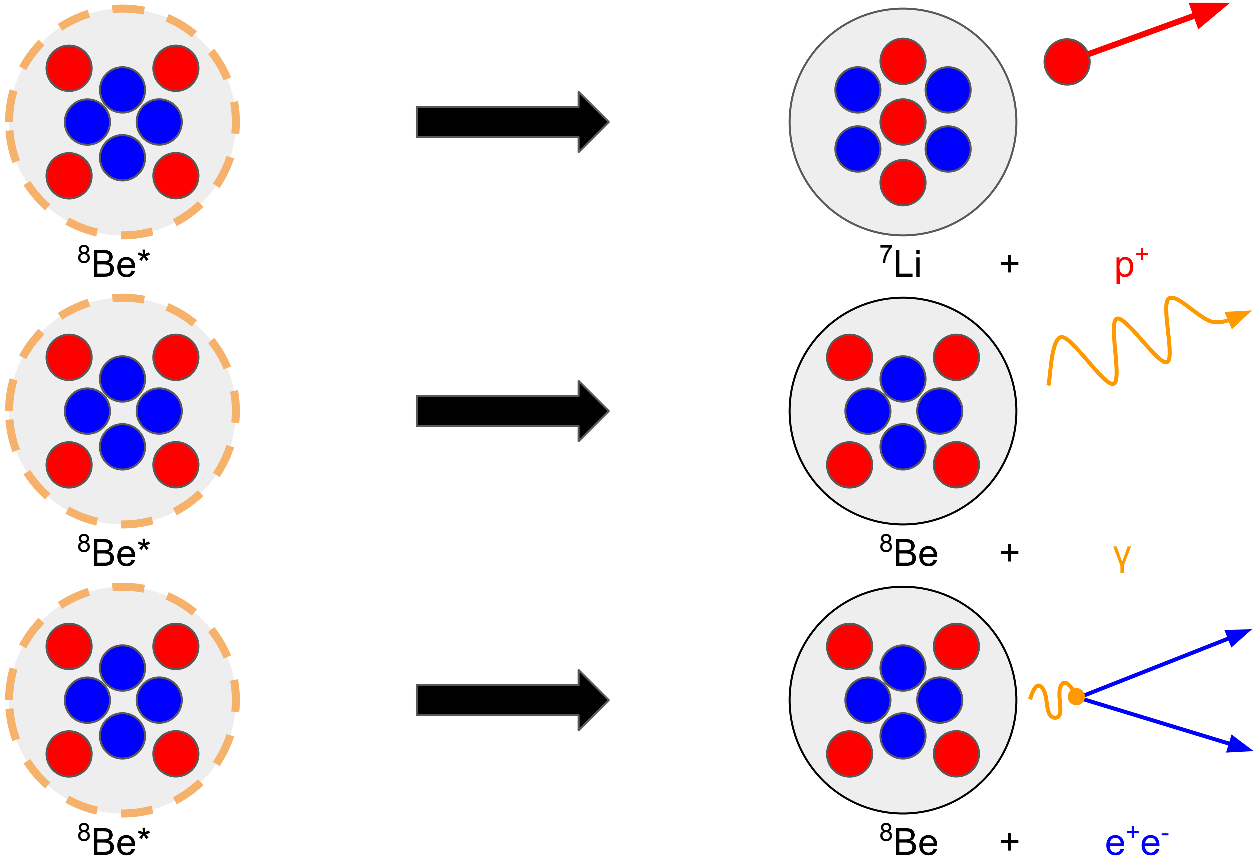
- Excited nuclear states have to emit "something" to lose energy
  - This is where α, β and γ radiation comes from of course
- So searching for yet undiscovered light particles is technically very possible in such reactions
  - Although of course practically all of the available phase space was probed by now

Studying Nuclear Excitations

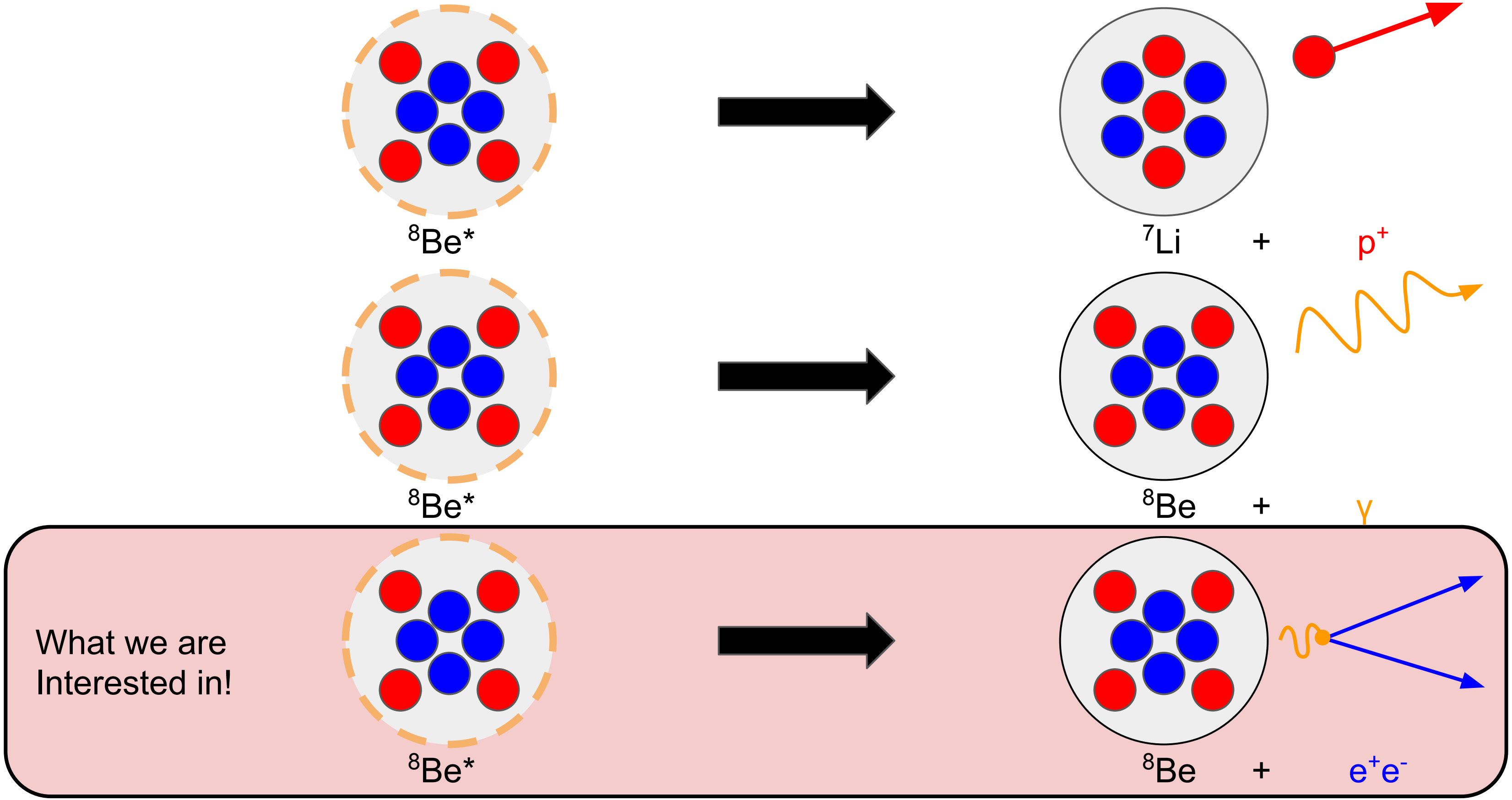


- Possible to do in a number of ways. But one of the simplest is to shoot protons at a target.
  - Using a target of the appropriate isotope for producing the excited nuclei of interest

Things That May Happen

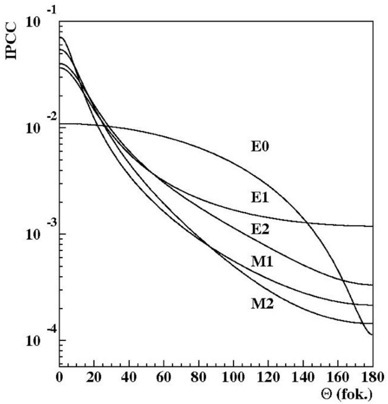


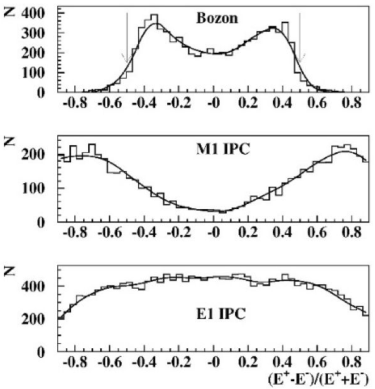
Things That May Happen

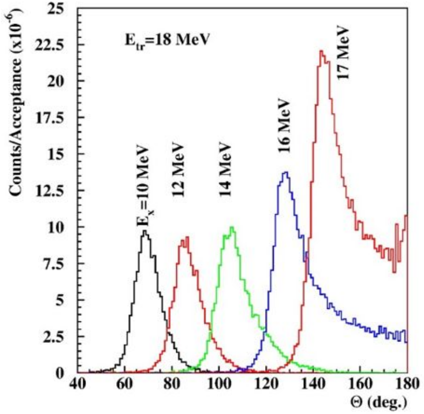


Why Electron Pairs?

- Internal/external pair creation in nuclear de-excitation is a very well understood process
    - And produces very different observable distributions than what one would expect when an intermediate particle decays into an electron pair
        - Both in the angular and energy distributions

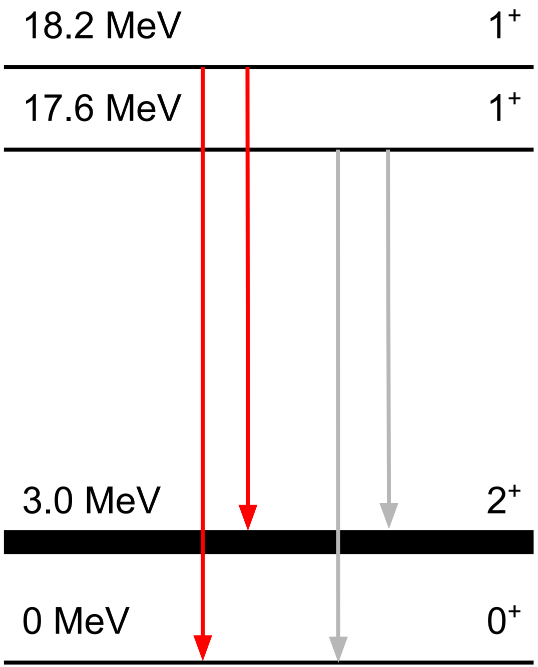




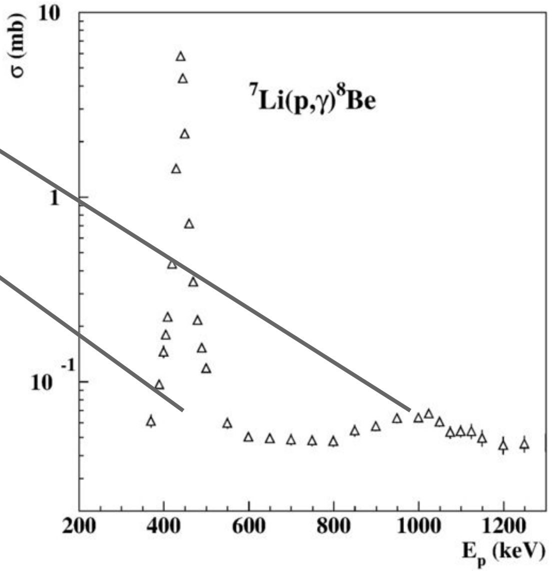


The Experiments

Studying the ^{8}Be M1 Transition

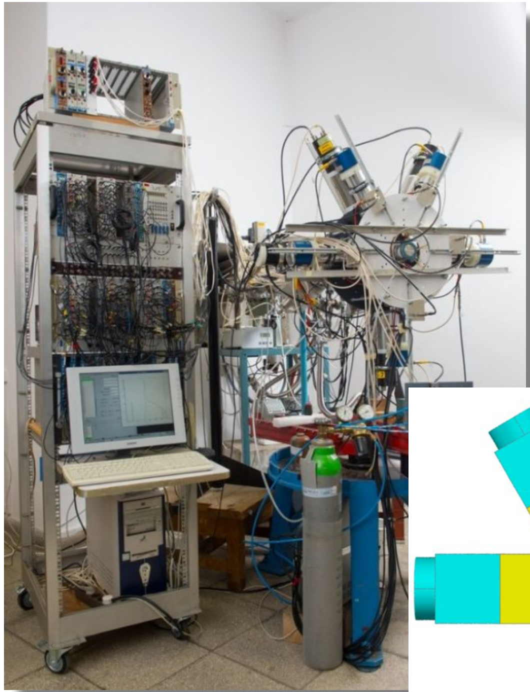


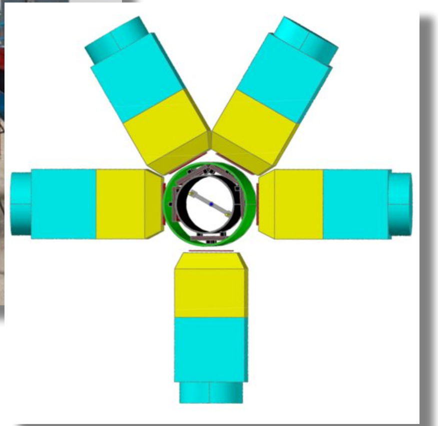
- Two close-by energy states of ^{8}Be can be created with 1030 and 441 keV protons, respectively
  - We were interested in producing the more energetic state



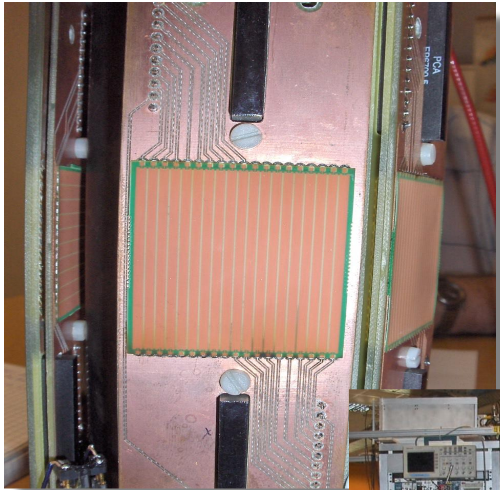
The 2016 Spectrometer/Experiment

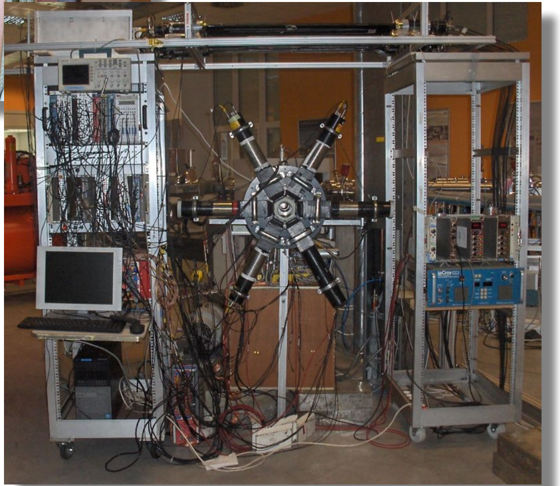
- We were using the 5 MV Van de Graaff accelerator for producing the proton beam
- Placed 5 telescopes perpendicular to the beam direction
  - Each of them composed of a position sensitive MWPC detector, followed by ΔE/E plastic scintillators
  - The setup was described in: https://doi.org/10.1016/j.nima.2015.11.009





The 2019 Spectrometer/Experiment

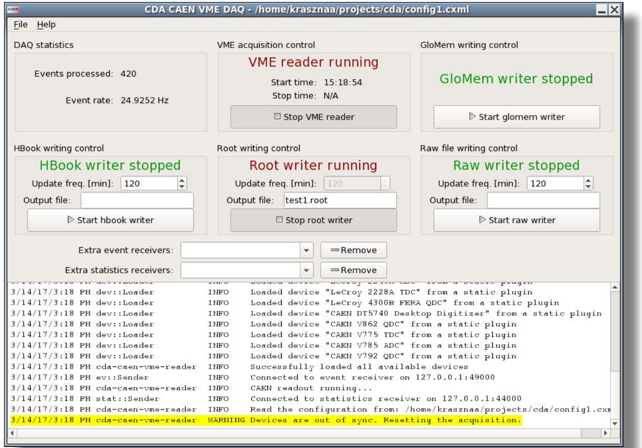


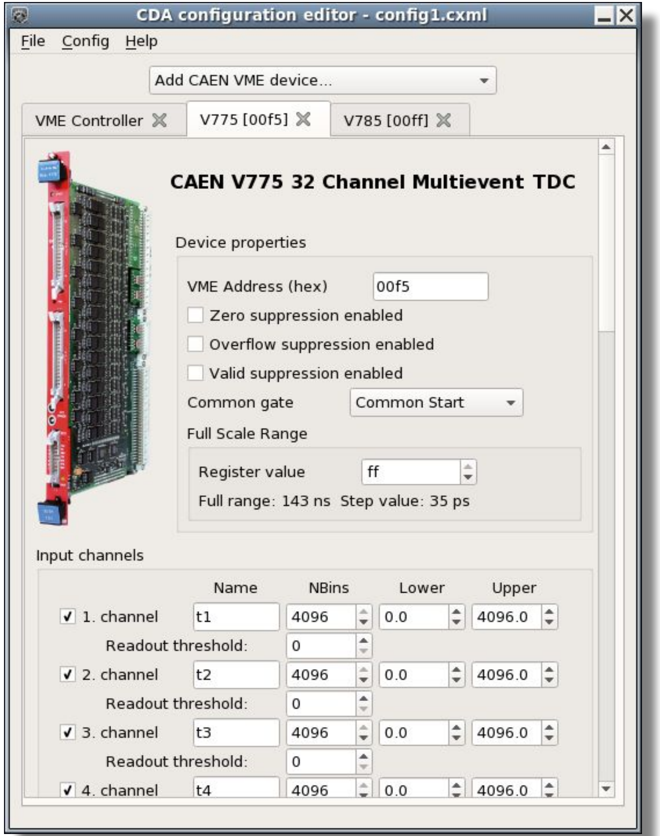


- The target/experiment was moved to the new medium-current Tandetron accelerator of the institute
  - Which is capable of producing much higher current proton beams than we had before
- Built a “full” 6 telescope spectrometer this time around
  - The multi-wire chambers were replaced with DSSDs
  - The readout system was also quite fundamentally changed

Data Readout

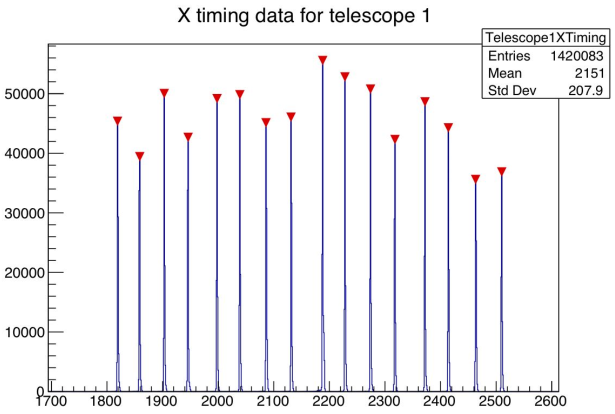
- Is one of the places where I contributed a lot 😛
- Done with a custom (and reasonably simple) DAQ software written for the specific hardware that the group has
    - https://gitlab.com/atomki-nuclear-phys/cda

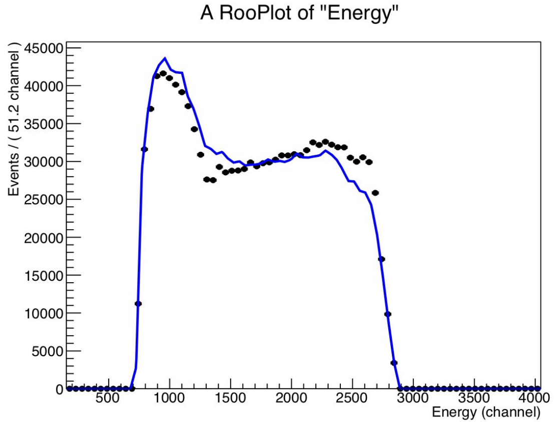




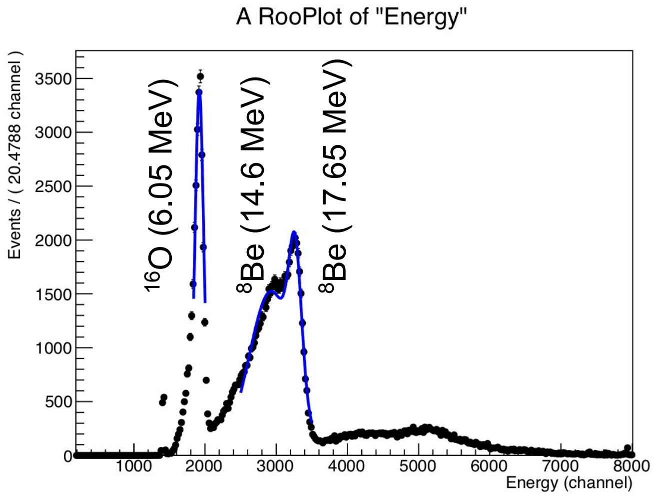
The Data Analysis

Detector Calibration 1



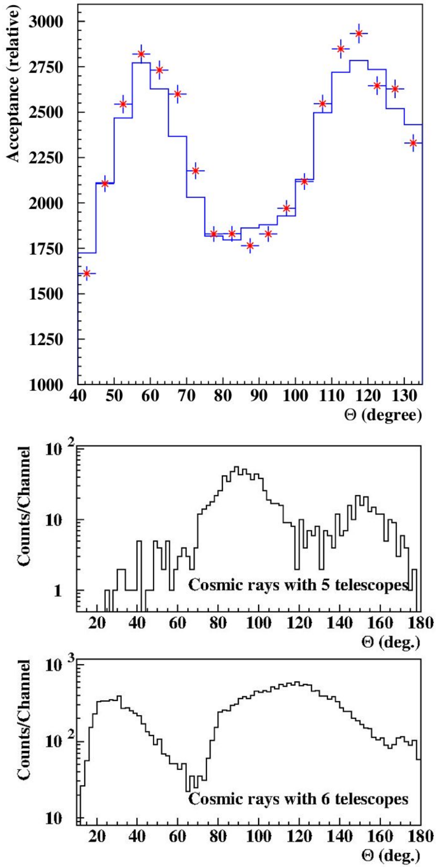


- First off, you need to calibrate your position sensitive detector, and your energy measurements
  - Much simpler than calibrating all of [ATLAS](), but still a bit of work 😛



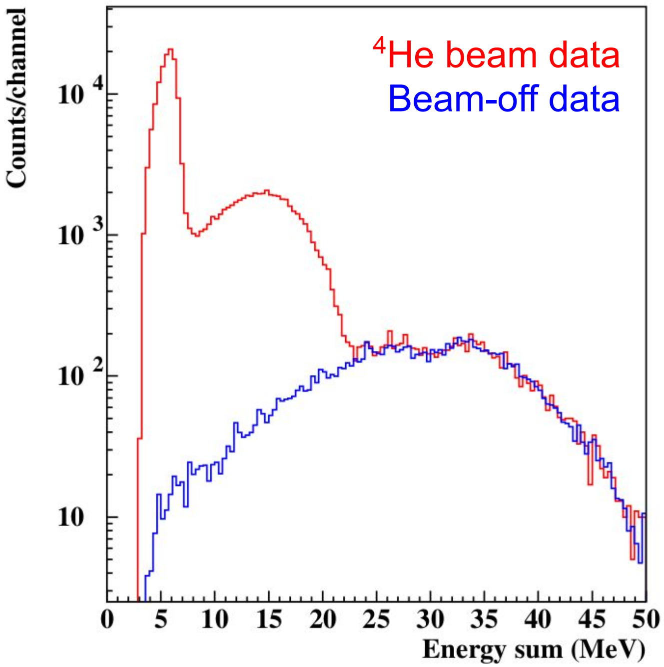
Detector Calibration 2

- In order to correct the e^+e^- opening angle distributions, we also have to take 2 effects into account
  - The spectrometer's detection efficiency is not flat wrt. the e^+e^- opening angle ☹️
    - We need to make sure that we can model this efficiency correctly in our simulations
    - Its measurement from data is explained in https://doi.org/10.1016/j.nima.2015.11.009
  - Cosmic muons also leave an irreducible background
    - With a non-trivial distribution, since the spectrometer can't detect the direction of the particles
    - We do have a veto for cosmics, but even so…



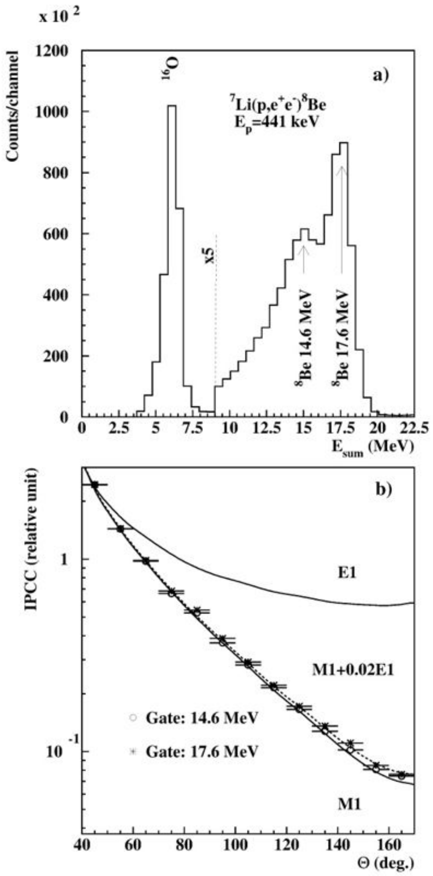
Solid lines: G4 Sim.
Markers: Data

Detector Calibration 3



- To estimate the shape / amplitude of the cosmic background, took O(1 week) of data with the beam off
  - With the same data taking conditions as we use for the data taking with beam
- Above a certain energy in the e+e- energy sum spectrum only the cosmic background plays a role
  - This allows us to normalise the non-beam distributions to the one with beam

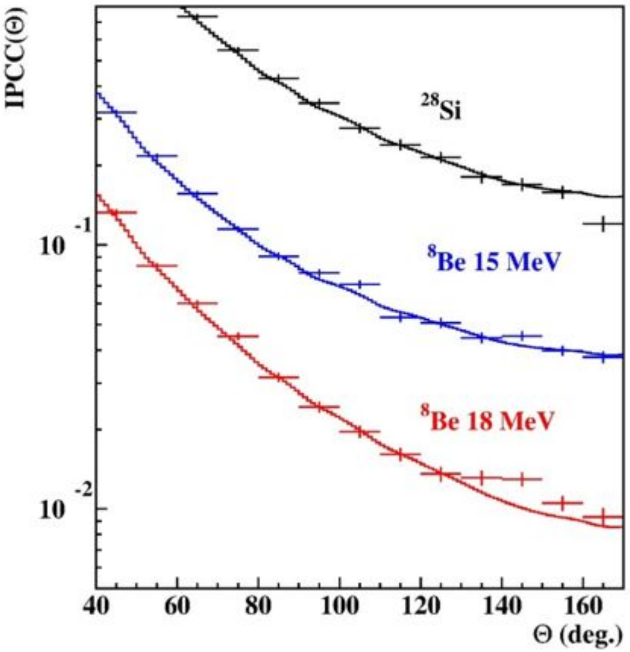
Event Selection



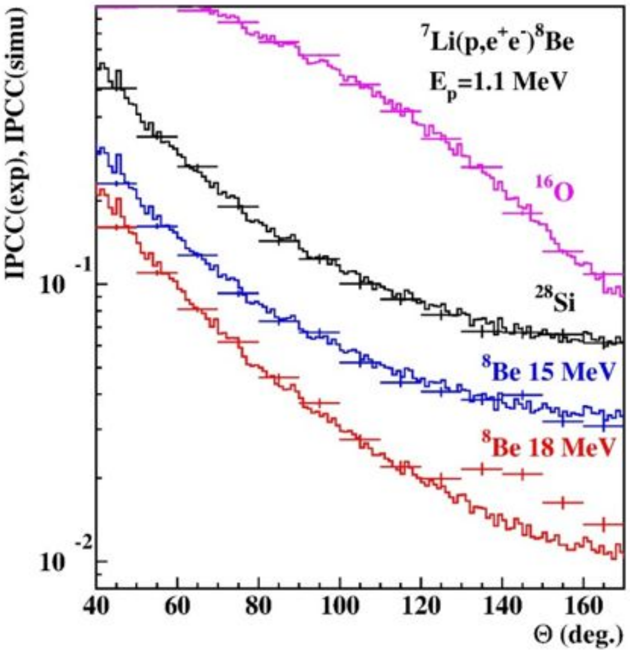
- Just like in HEP experiments, we have to select the events that we're actually looking for, from a lot of junk
- Even after we selected (mostly) just the events in which an e^+e^- pair is created, those are still coming from multiple sources
  - From the two different de-excitations of ^{8}Be
  - From other nuclei in the "target assembly", here for instance from: ^{19}F(p, α e^+e^-)^{16}O
  - Luckily we can fairly easily distinguish between these by selecting specific windows in the e^+e^- sum energy spectrum
- We also need to consider a mixture of M1+E1 IPC events
- Though notice that none of these considerations change the distributions from IPC significantly

The 2016 Results

E_p = 1.04 MeV



E_p = 1.10 MeV



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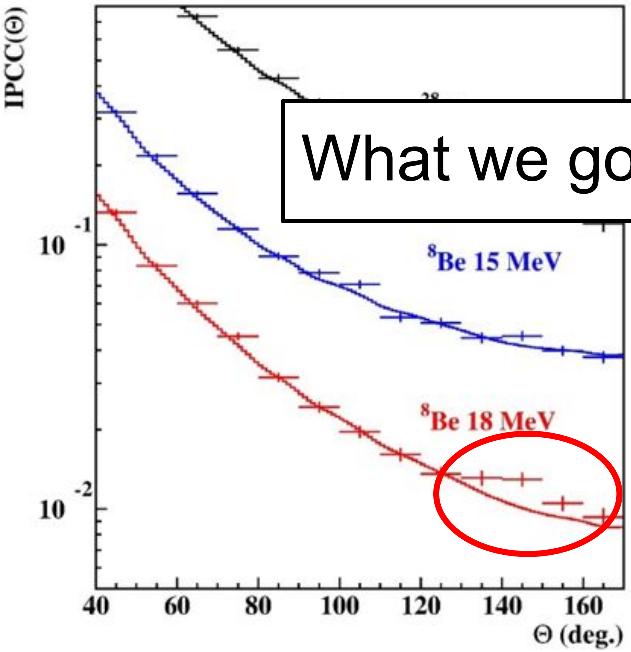

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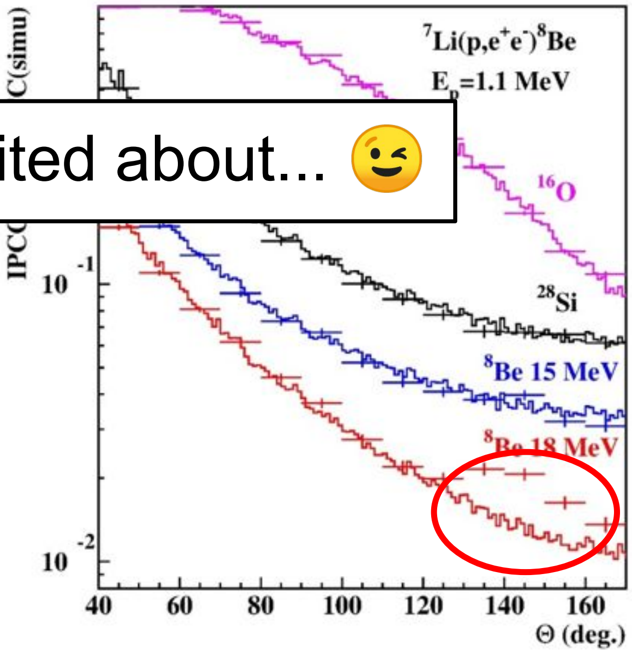
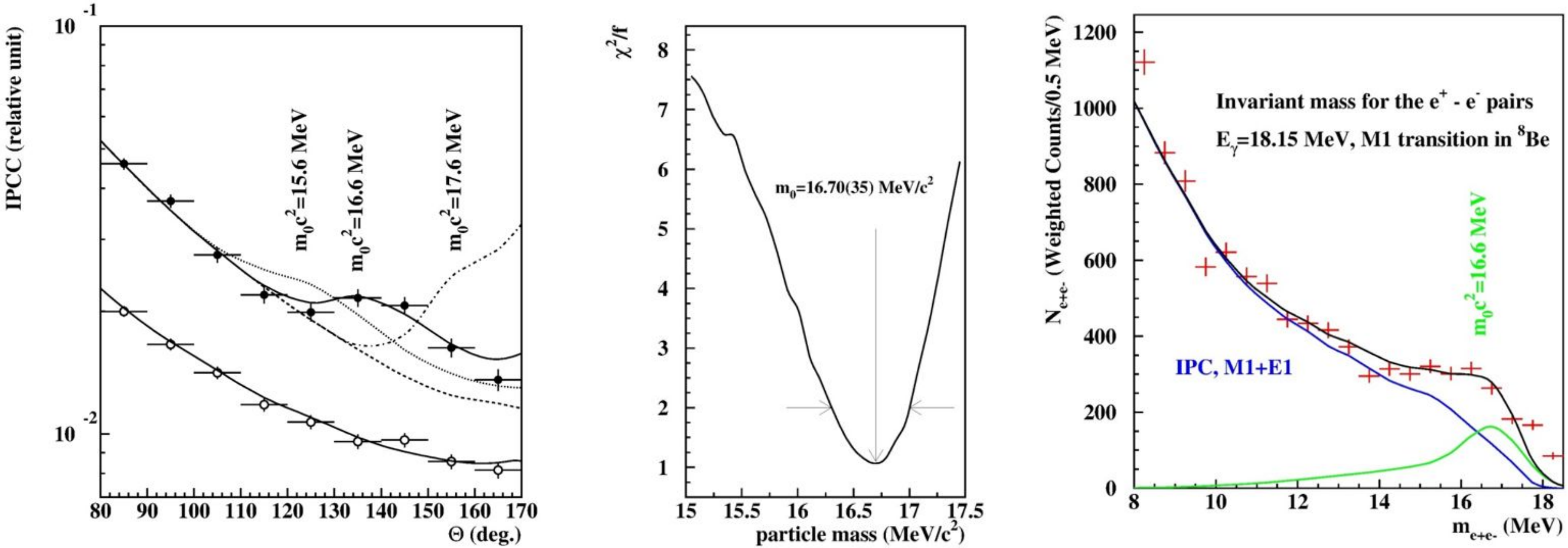


What we got excited about... 😉

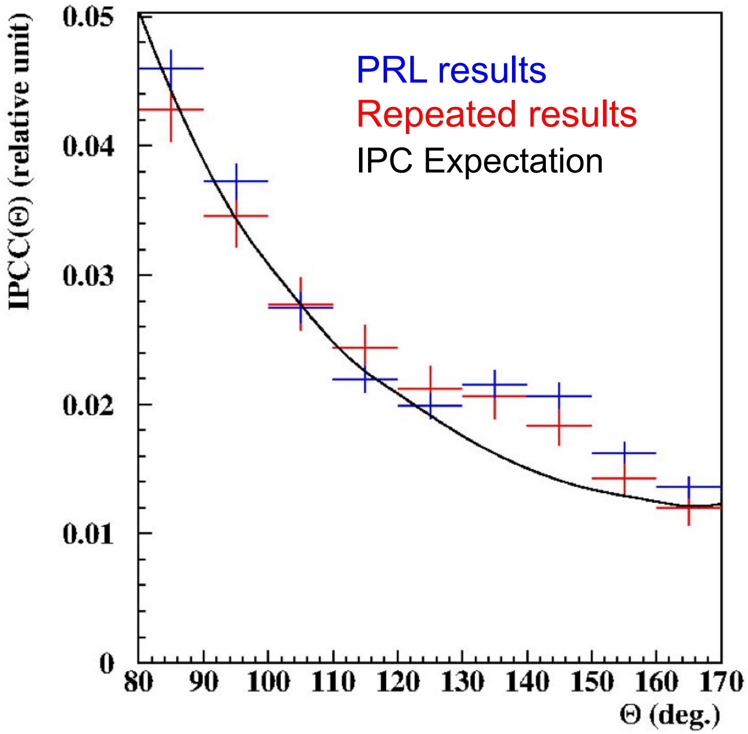
The 2016 Interpretation



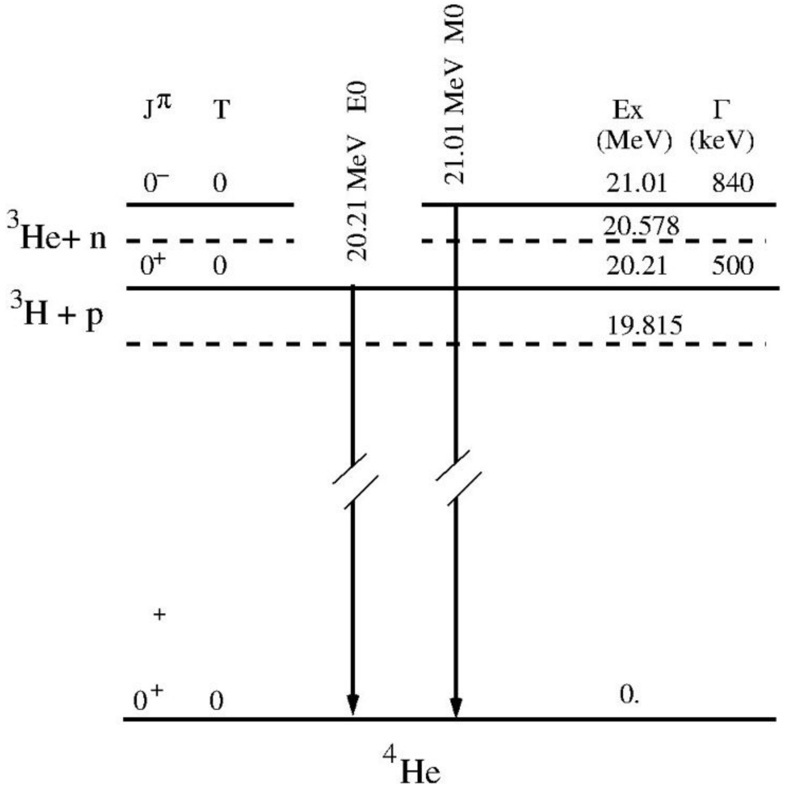
Filled circles: $|y| < 0.5$,
Open circles: $|y| > 0.5$,
$y = (E_1 - E_2) / (E_1 + E_2)$

The 2019 Results

- First we tried to reproduce the earlier results using ^{8}Be, with the new
  - Accelerator
  - Spectrometer
  - DAQ system
- Luckily we once again got the same results 🤞
  - Making the probability of an obvious experimental mistake ever smaller



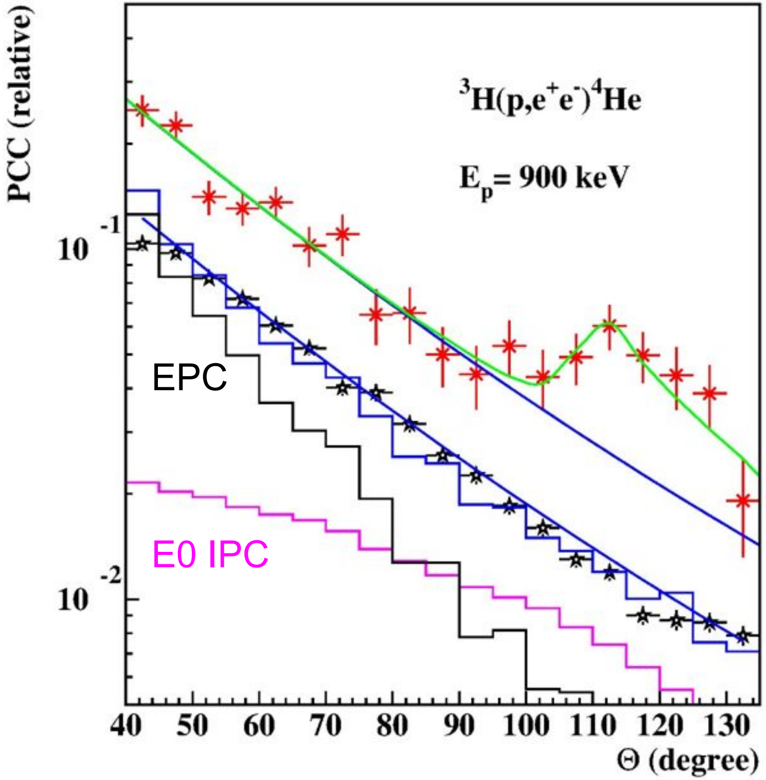
The ^{4}He 21 MeV M0 Transition



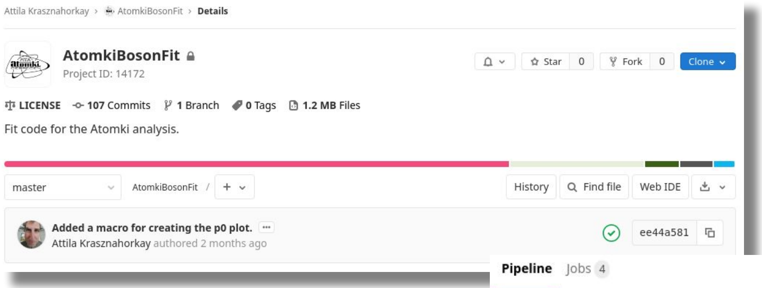
- We were targeting the 21 MeV transition in ^{4}He as the next place to look for an effect
  - Note that this transition is forbidden "at tree level", with a single γ (or IPC) emission
  - Also note that both of the pictured excited states are quite wide
    - We do get some amount of background from the E0 IPC transition in our measurement
  - Of course we know about no such exclusion for our hypothetical particle, so this seemed like an excellent reaction to look at

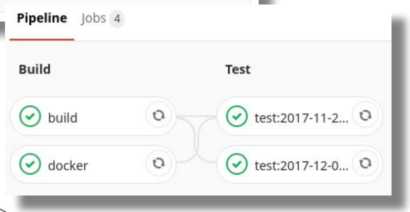
The 2019 ^{4}He Result

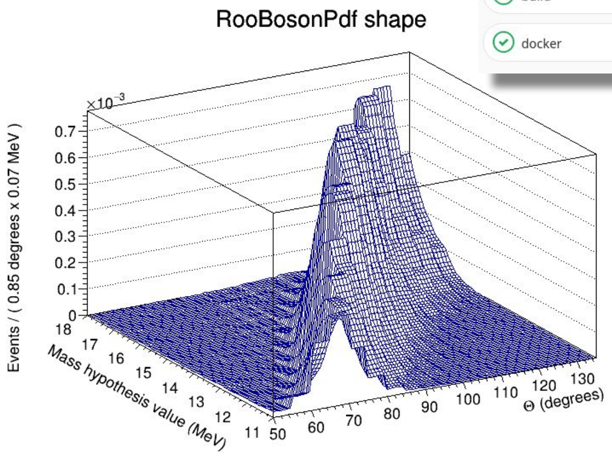
- Once again going through the same analysis method, selecting events just from the correct E_{sum} range, with the correct |y| value, we get the red measurement points
    - The black star measurement come from the background event selection



About the Statistical Analysis

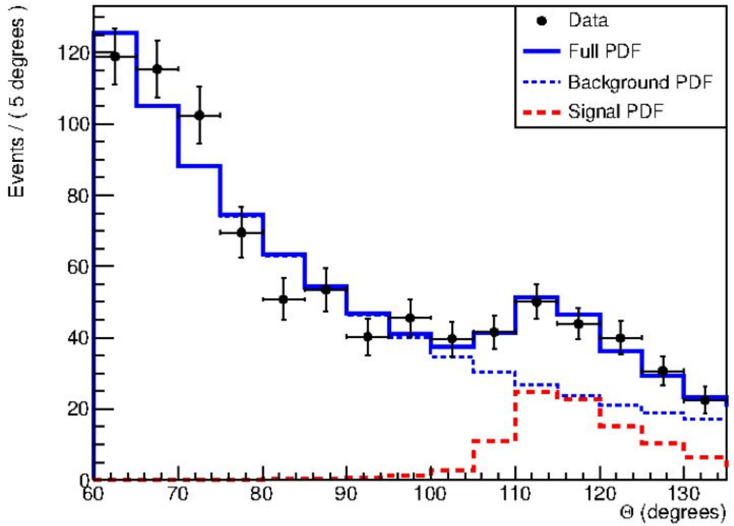


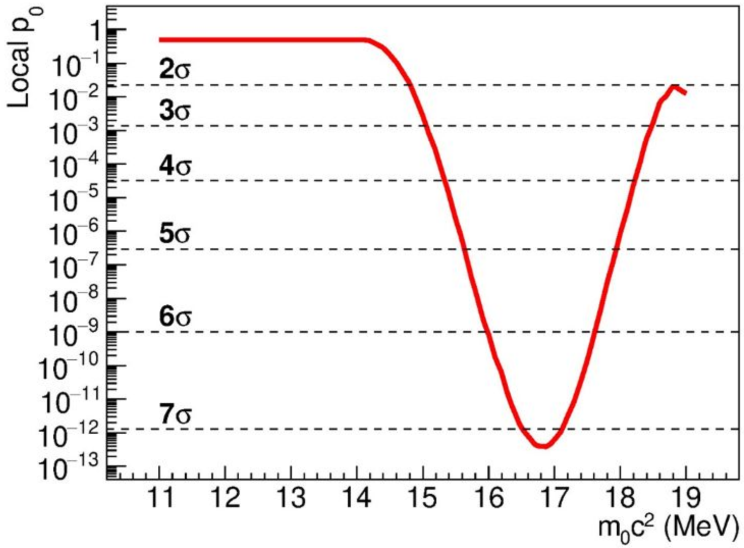




- This was my second major contribution 😉
- Did similarly to how early ATLAS Higgs searches were made
  - Constructed a 2D “signal” PDF as a function of Θ and m_X
  - Used that together with a background PDF to fit the measured distribution
- Using many of the same techniques that we manage ATLAS analysis software with…

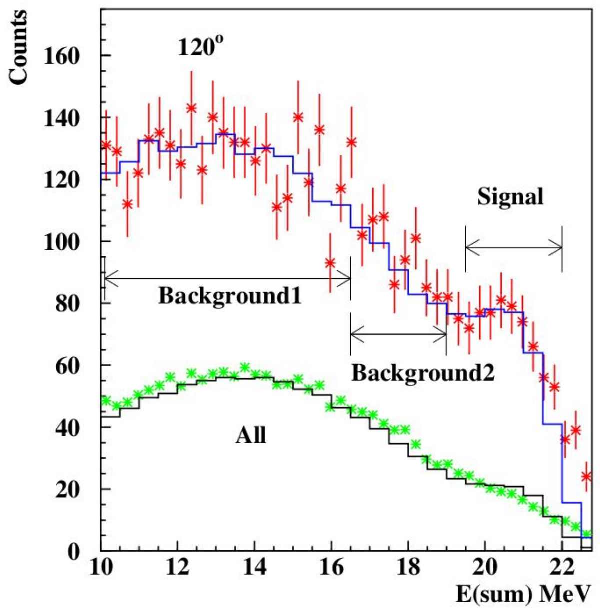
^{4}He Fit Results

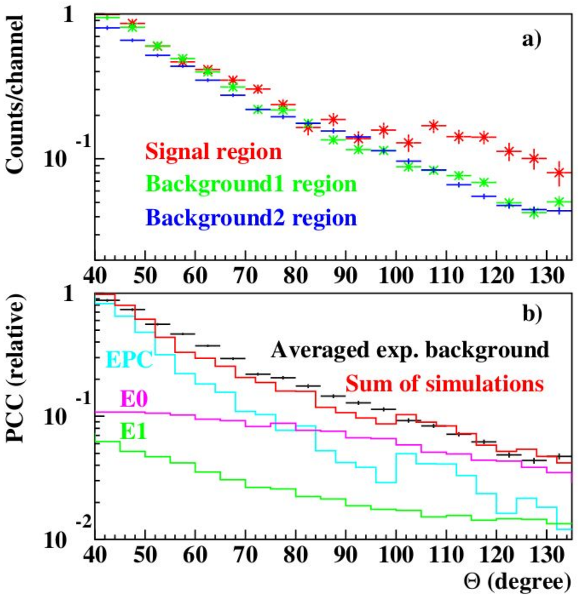




Cross-Checks 1

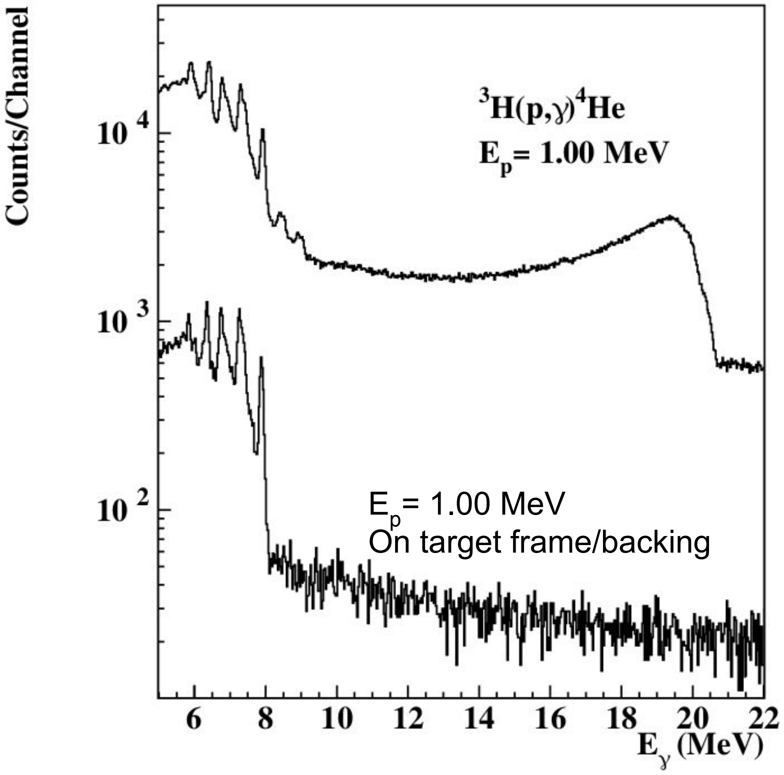
- For the ongoing PRL review we've done some additional checks in the last month on the ^{4}He measurement data, using a new G4 simulation setup





Cross-Checks 2

- To make sure that only nuclear states that we expect are getting de-excited, we monitored the ɣ spectrum coming from the target independent of the spectrometer's data taking
  - To make sure that in the "signal" energy window no unexpected peaks would be present
- Performed the data taking with an empty target as well, having the same setup as the normal target, just no ^3H on it…



Summary

- We found a pretty significant bump over the well known processes that create e^+e^- pairs in certain nuclear de-excitations
- The deviation can be well modeled assuming that a new particle is emitted by the nuclei, which then decays to an e^+e^- pair
- The deviation only appears under very particular circumstances from both the ^8Be and ^4He decays
  - With all other types of event selections we can reproduce our results with simulations of known processes very well

Outlook

- This result has received some attention since the 2016 publication, but things definitely heated up in the last months
    - This should speed up other experiments to look at this effect as well
- So far only the NA64 experiment made one analysis that could have been sensitive to this effect
    - Depending on the hypothetical particle's coupling to electrons. But apparently it is weaker than what the NA64 study would have been sensitive to.
- (If all goes well) Other experiments should be able to also detect the effect in the coming years
    - Even LHC experiments, with LHCb and possibly FASER…
- We ourselves will be looking for 2ɣ decays next

http://home.cern