Motivations and timeline for LXe prototype

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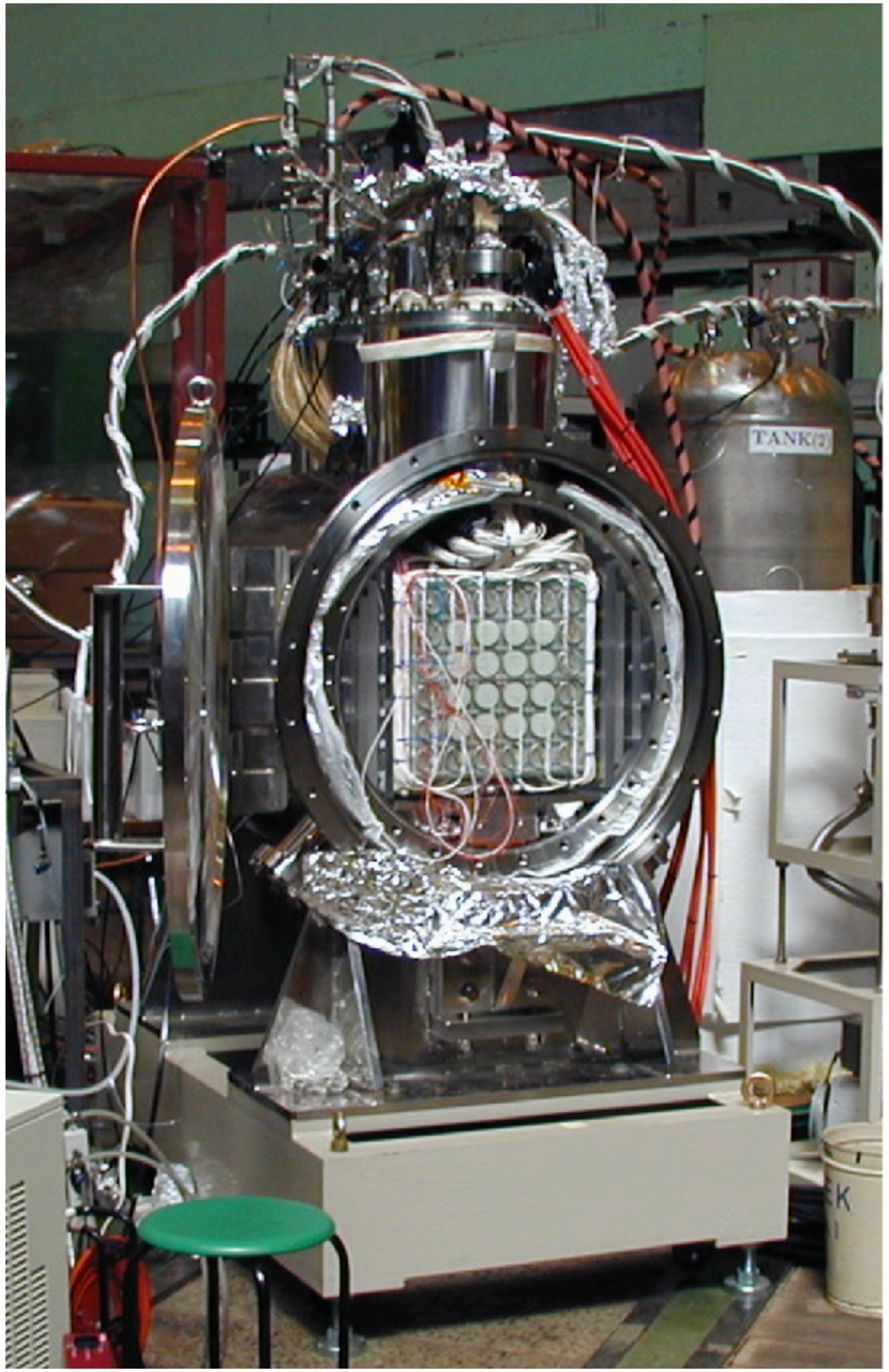
THE UNIVERSITY OF TOKYO

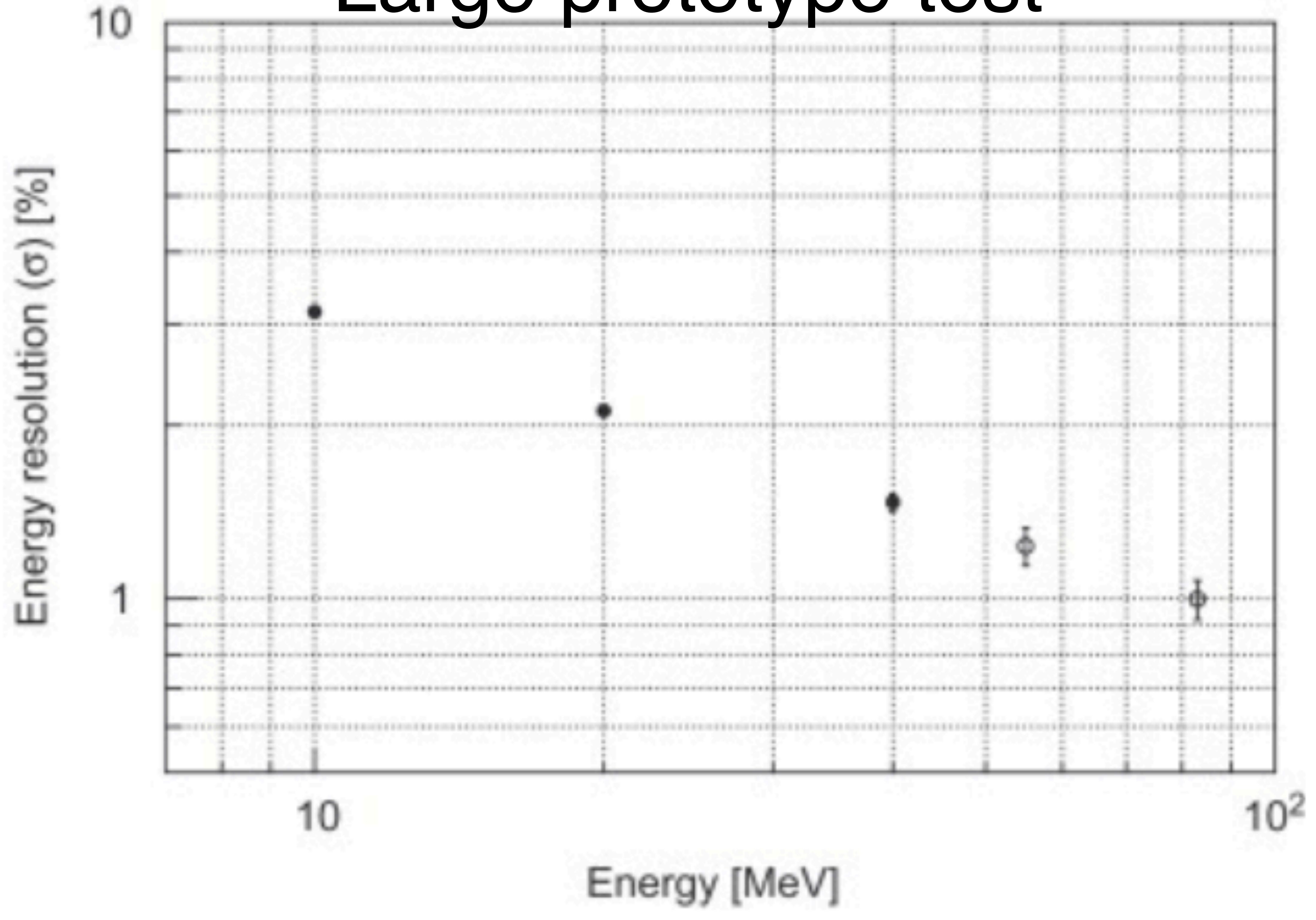
Motivations for large prototype test

- Performance evaluation at a large scale
  - Energy resolution at 70 MeV e^+ beam at PSI
    - MEG/MEG II measures 52.8 MeV γ, energy resolution is evaluated by 55, 83 MeV γ from π^0 decay
  - Shower leakages (resolution versus angle).
    - Large prototype is mounted on a caster base
  - Test of thin entrance window
- Photonuclear effect and tail component evaluation
- Operation experience for the detector
  - cabling, material for PMT supports, purity monitor
  - purification system
  - calibration
- Further improvements for the final detector design



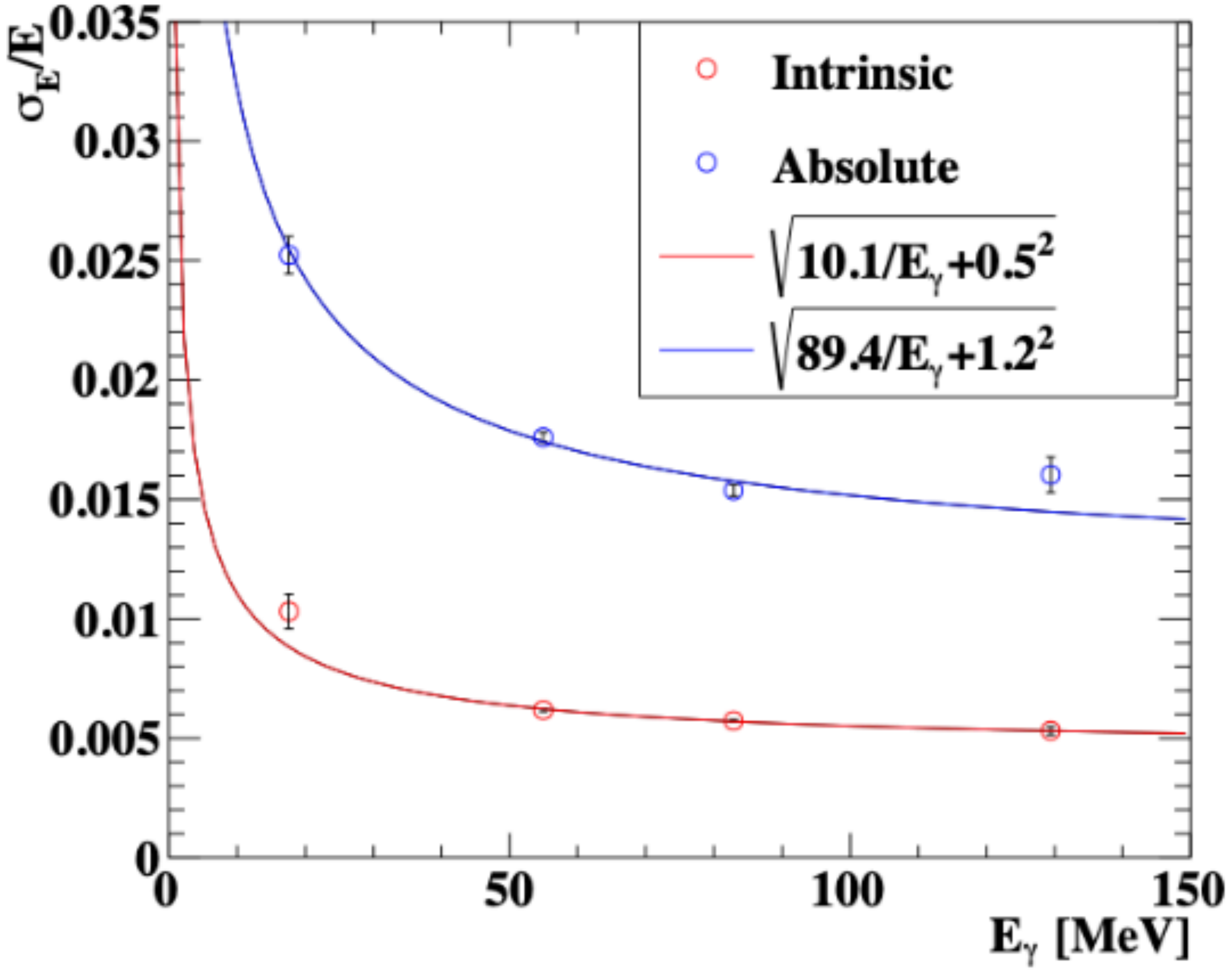
Energy resolution @ LXe detector

Large prototype test



R. Sawada, NIMA581(2007)522

MEG II



S. Kobayashi, PhD thesis 2022

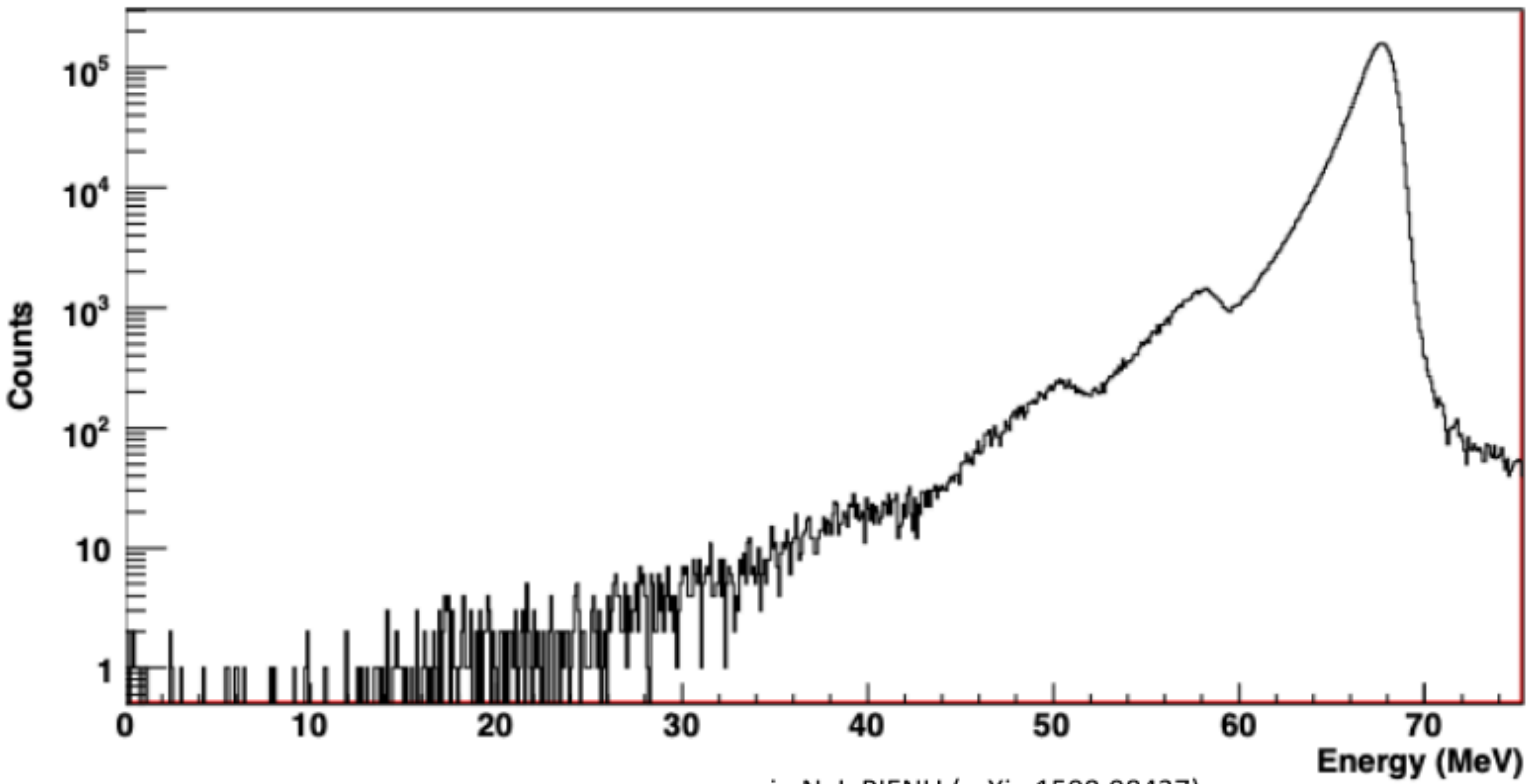
- Energy resolution of 1.2% at 55MeV in the large prototype test, ~2% in MEG II
- Geometrical difference, scintillation characteristics,
- Intrinsic resolution $\Delta E = (E_{even} - E_{odd})/(E_{even} + E_{odd})$ shows a good resolution
  - $\sigma_{absolute} = \sigma_{intrinsic} + \sigma_{coherent}$, $\sigma_{coherent}$: noise, shower development, reflection and scattering of the scintillation light

Photonuclear effect

Neutron Escape

Lukas(20230614)
https://pioneer.npl.washington.edu/cgi-bin/private/ShowDocument?docid=176

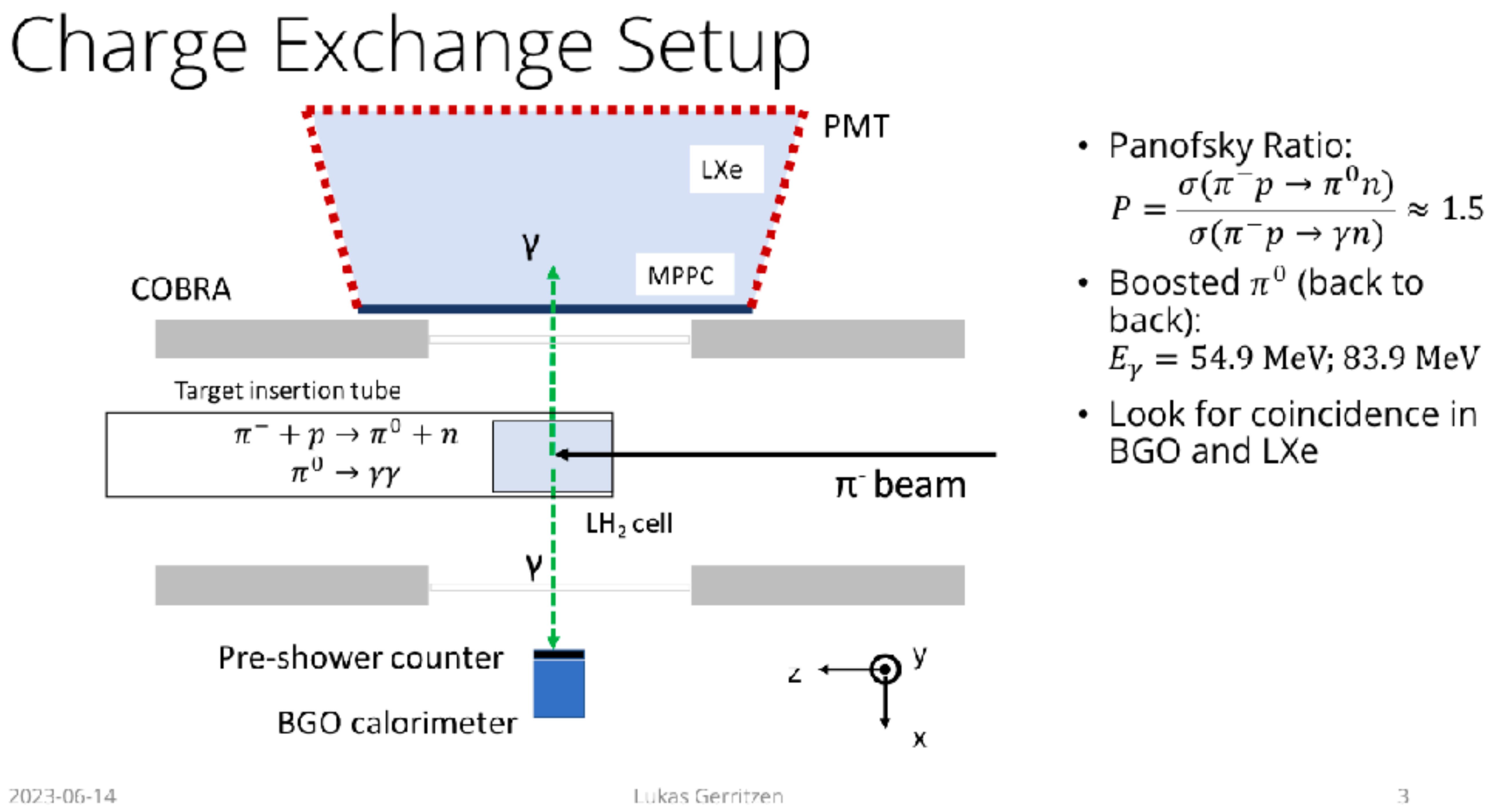
- In Xe: Bumps at E – (n × 8.4 MeV)
- Good understanding necessary
- Can we use the MEG II LXe calorimeter to measure this?



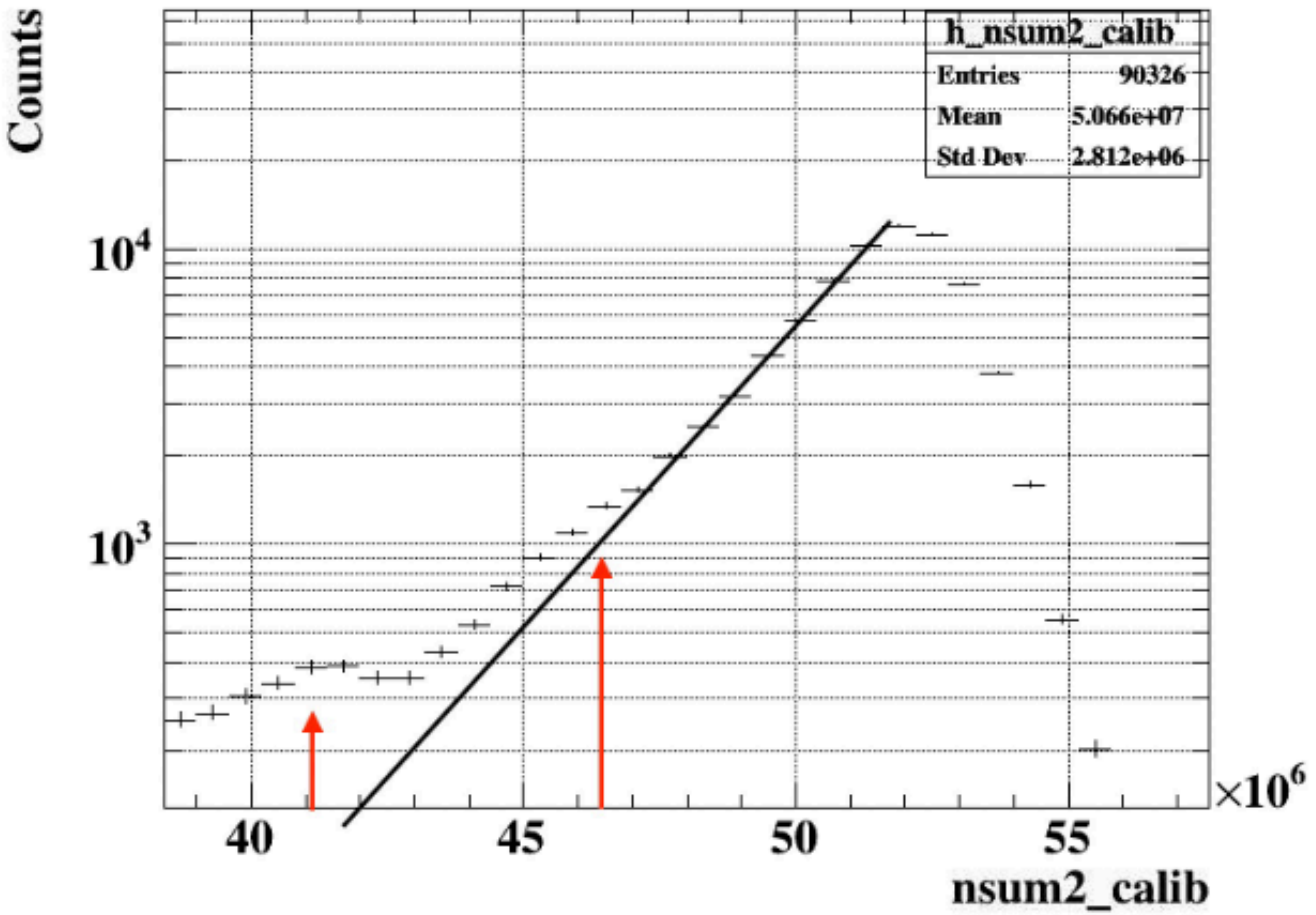
n escape in NaI, PIENU (arXiv:1509.08437)

83 MeV peak in 2022 CEX run

Lukas(20230614)
https://pioneer.npl.washington.edu/cgi-bin/private/ShowDocument?docid=176



2022 CEX run 83MeV peak

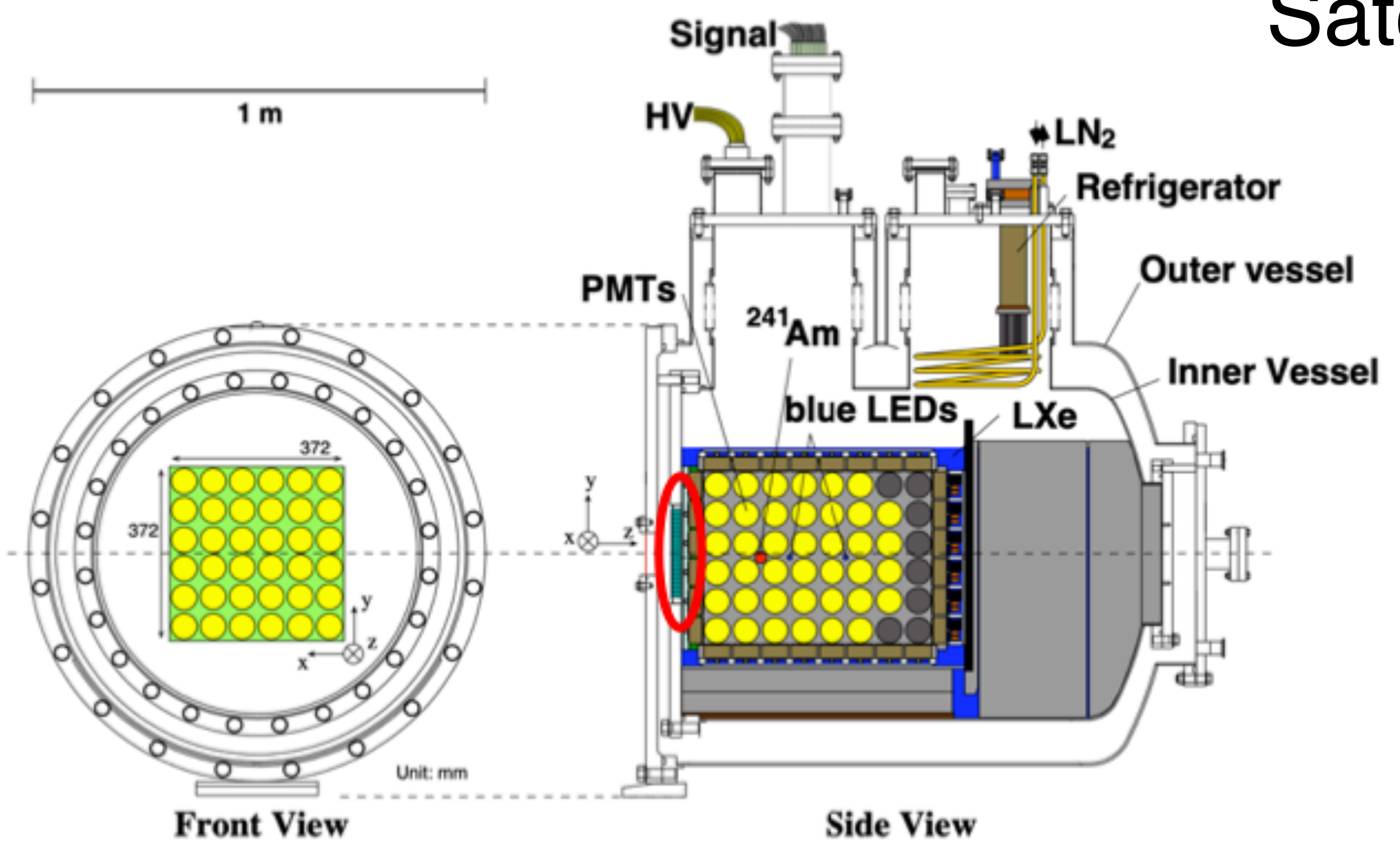


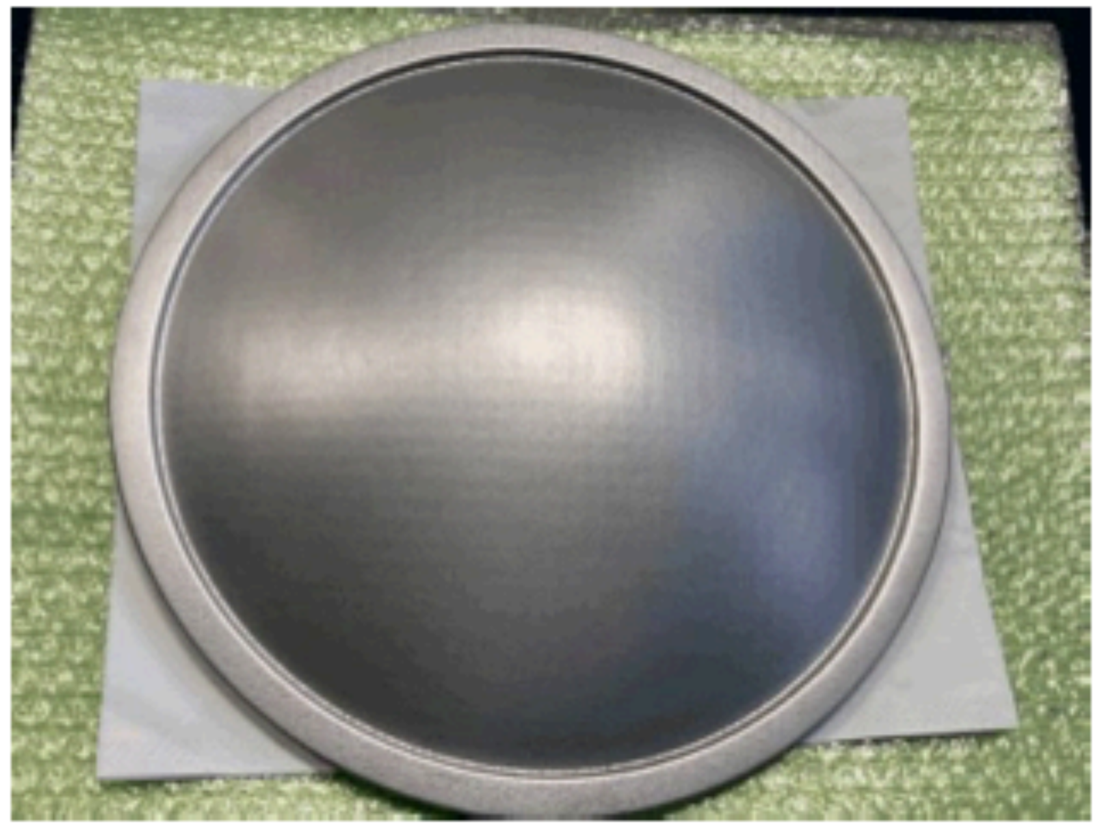
- This can be directly measured by the 70 MeV/c positron beam test
- The 83 MeV CEX data analysis was not the final one, and the updated results will come soon

Thin window

Satoshi

- Metal honeycomb panel used in MEG prototype (Steel)
- Recent KEK R&D for beam vacuum window
    - Ti-6AL-4V 3d-printed window
        - 6wt% Al (X0=8.9cm), 4wt% Vanadium (X0=2.6cm) are added to Ti (X0=3.6cm)
        - 4.43 g/cm3
        - 0.2mm ground down from 0.5mm
    - Al 3d-printed window ~0.2mm
    - Tolerable up to 0.3MPa
- Window production for LP with Ti64 with the thinnest thickness
    - 0.15-0.2mm, pressure, leak test in 2024

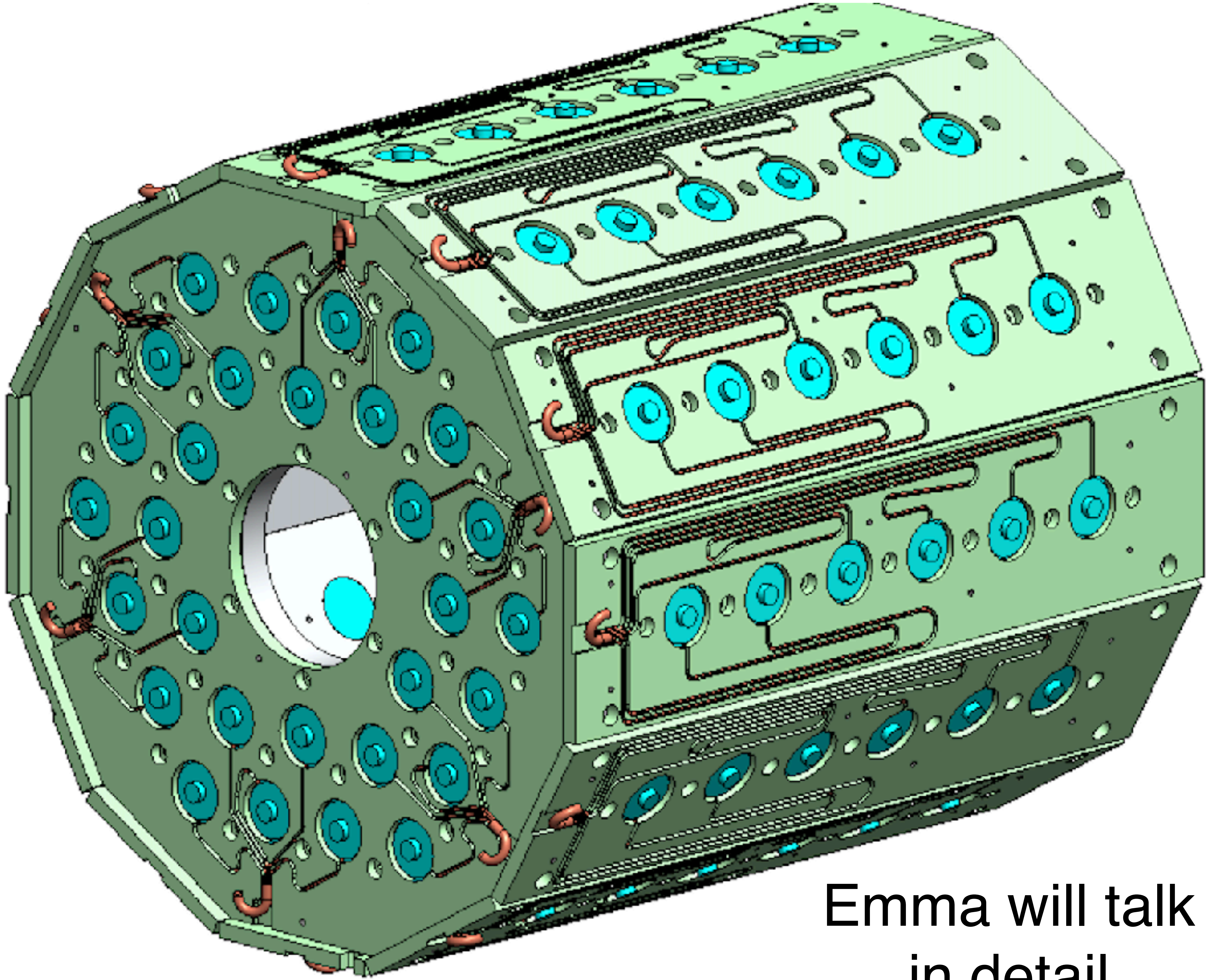




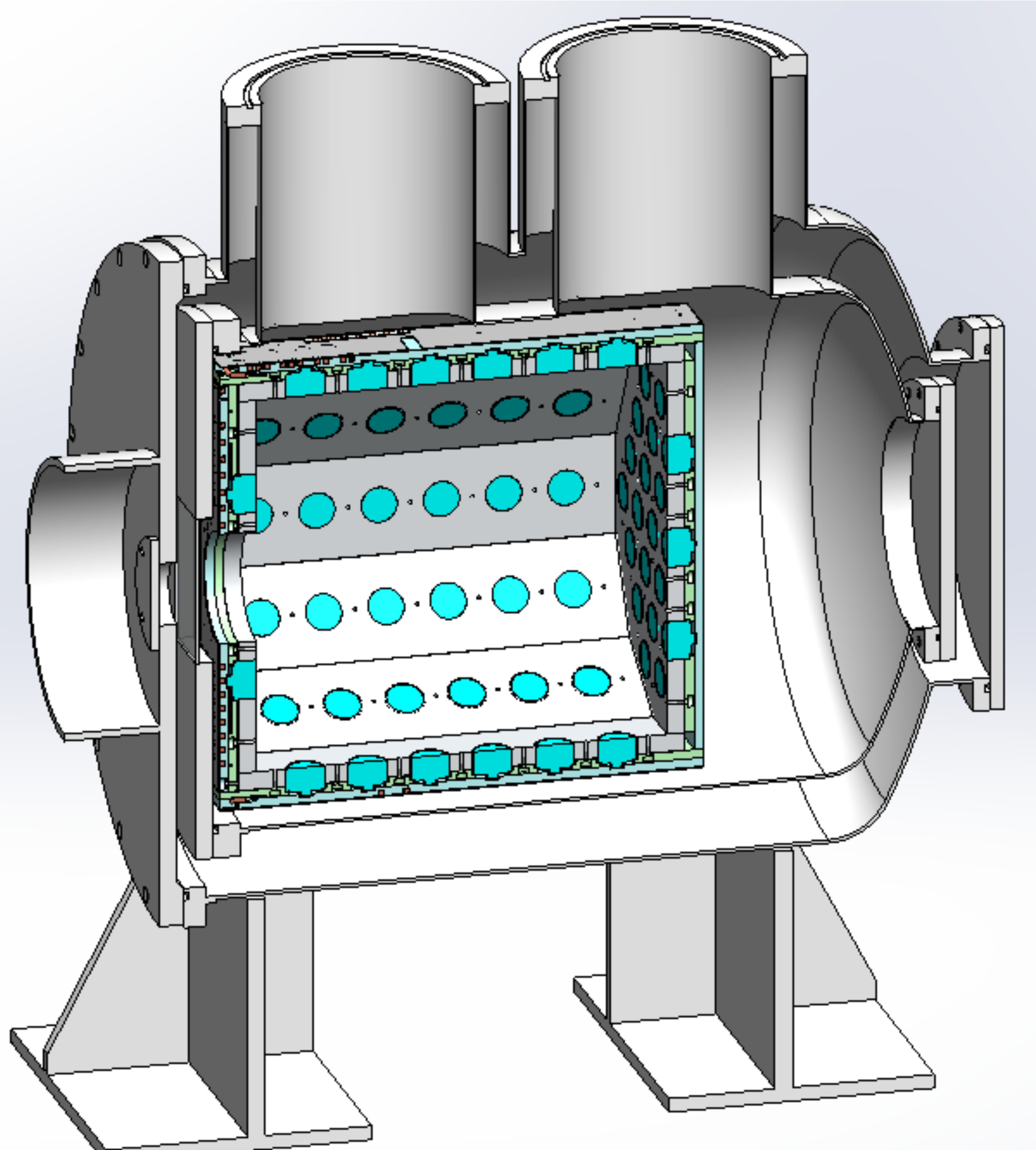
0.5mm 64Ti window

0.15mm Al Rupture disk

Design of the large prototype



Emma will talk
in detail



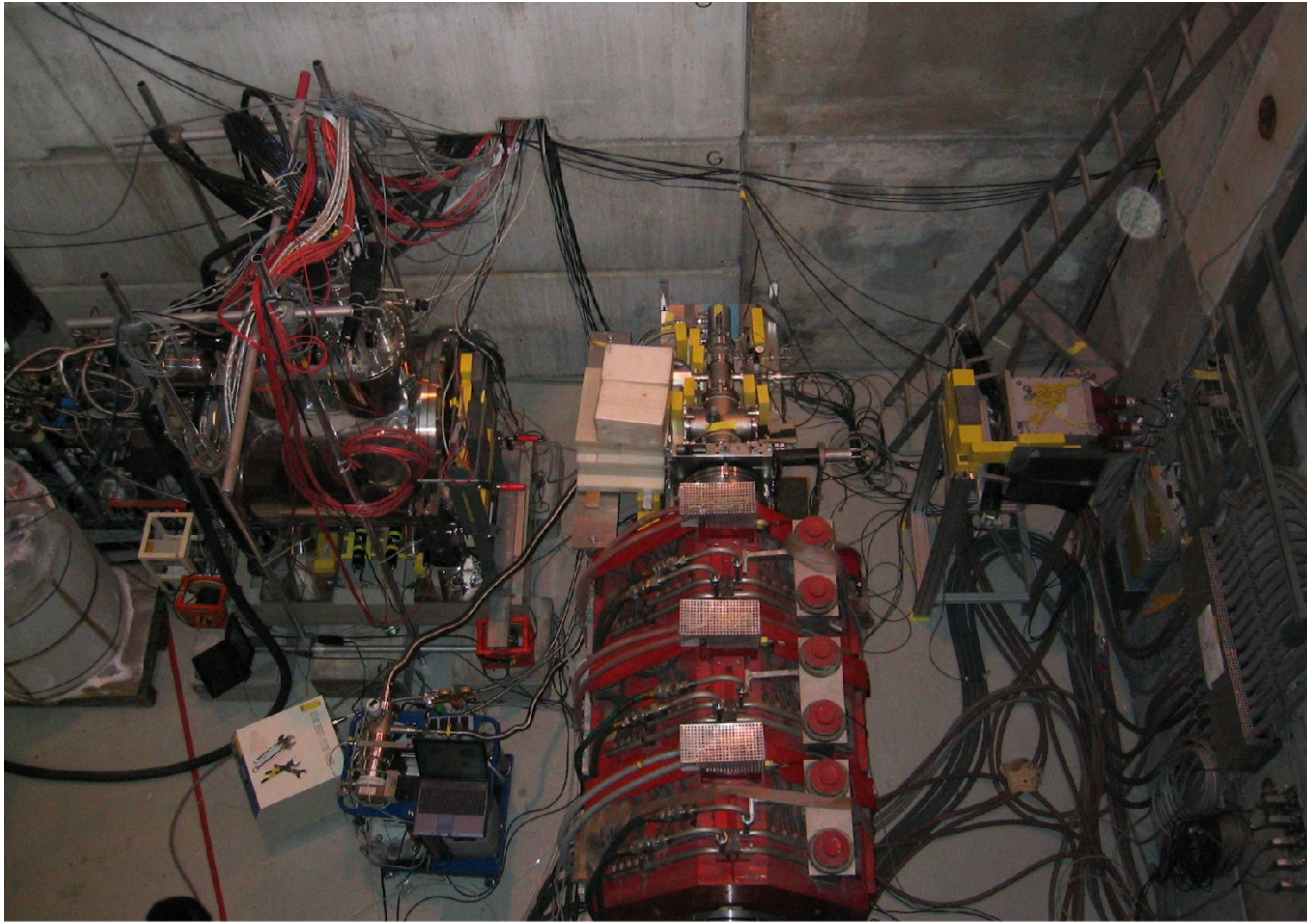
Xenon procurement

- BNL has 20 liter
- ICEPP + KEK will purchase 60 liter
- TRIUMF will purchase 40 liter

- In total ~120 liter should be available
  - We will continue the effort to get more xenon

- Chinese company (WISCO)
  - First trial by UTokyo to buy 20 liter from WISCO through PSI purchase department underway

Prototype beamtest with CEX reaction at PiE5 in 2004



- Timeline
  - Installation to PiE5
  - Connection and evacuation
    2 weeks
  - Precooling/Liquefaction
    1 week
  - Beam tuning, hydrogen target
    1 week
  - Calibration/trigger setup/ DAQ
    1 month
- Once the detector is ready, 2 month would be sufficient for the beam test
- We need to evaluate how long it will take to prepare the detector outside the are including the purification

PROTOTYPE TIMELINE

1 Freeze prototype design (August 2024)

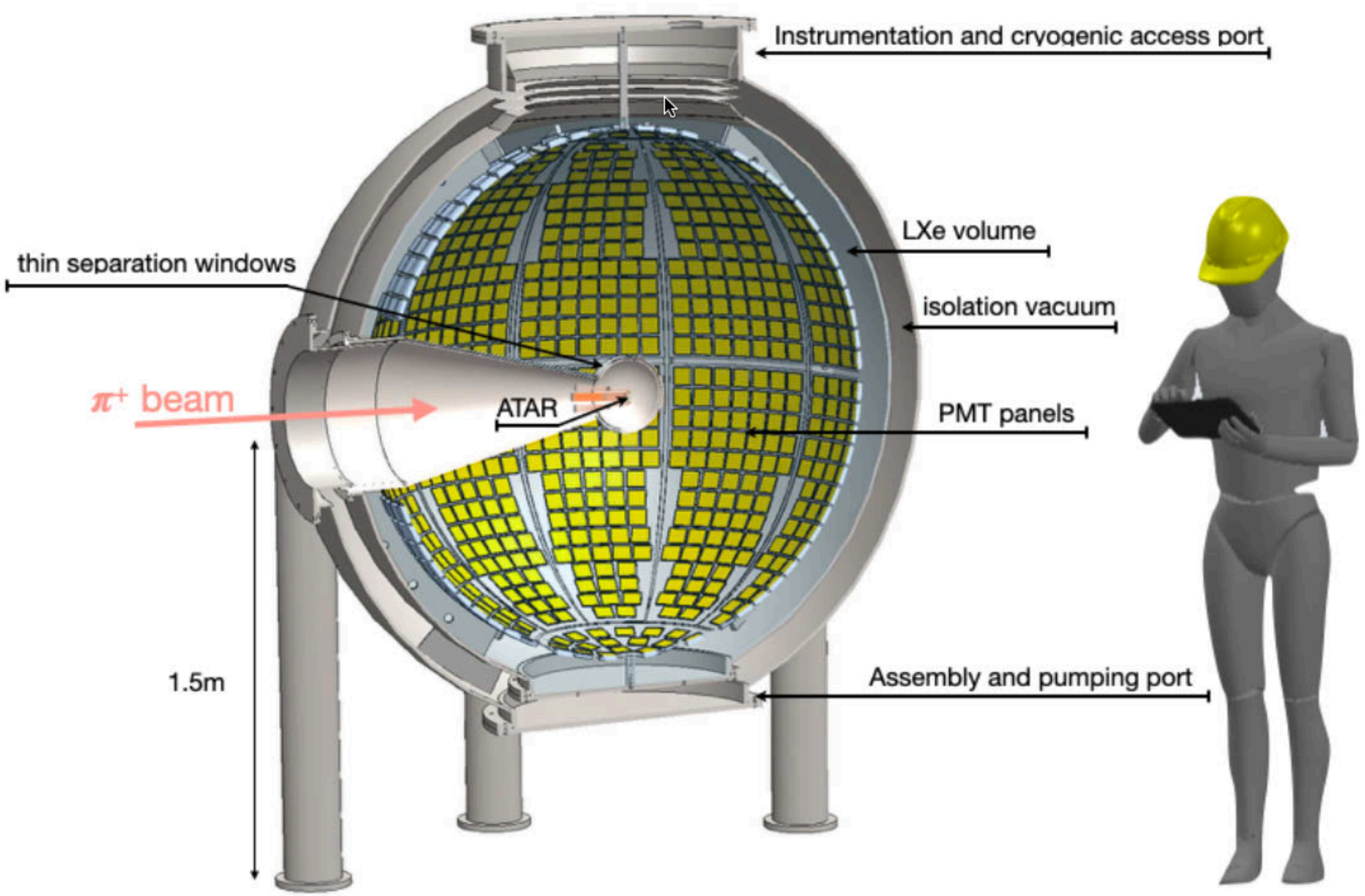
2 Finalized assembly of detector (PMT->DAQ) (by end of 2024)

3 Detector and windows ready (by Feb/March 2025)

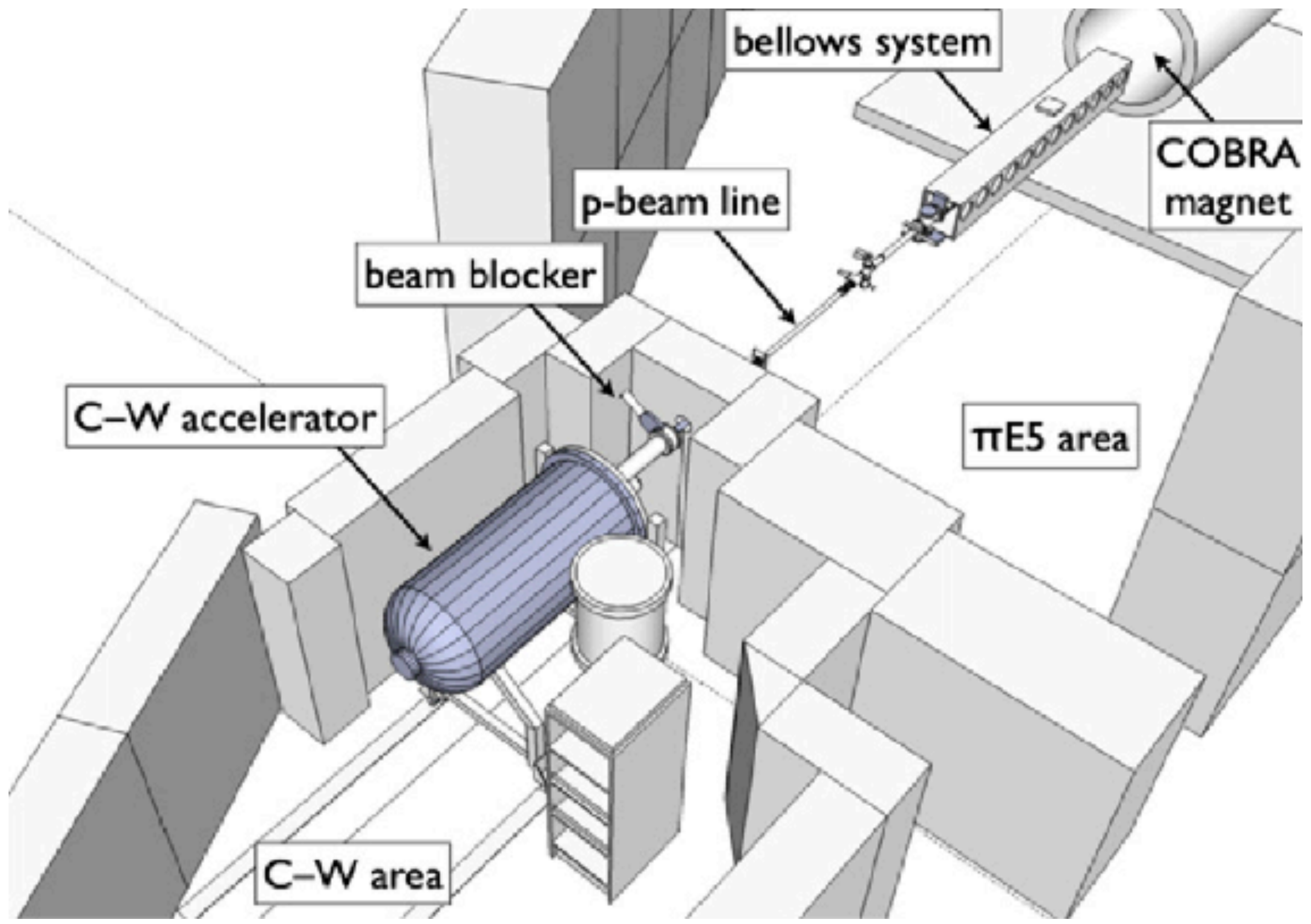
4 Prototype ready for beamtime (by Sept/Oct 2025)

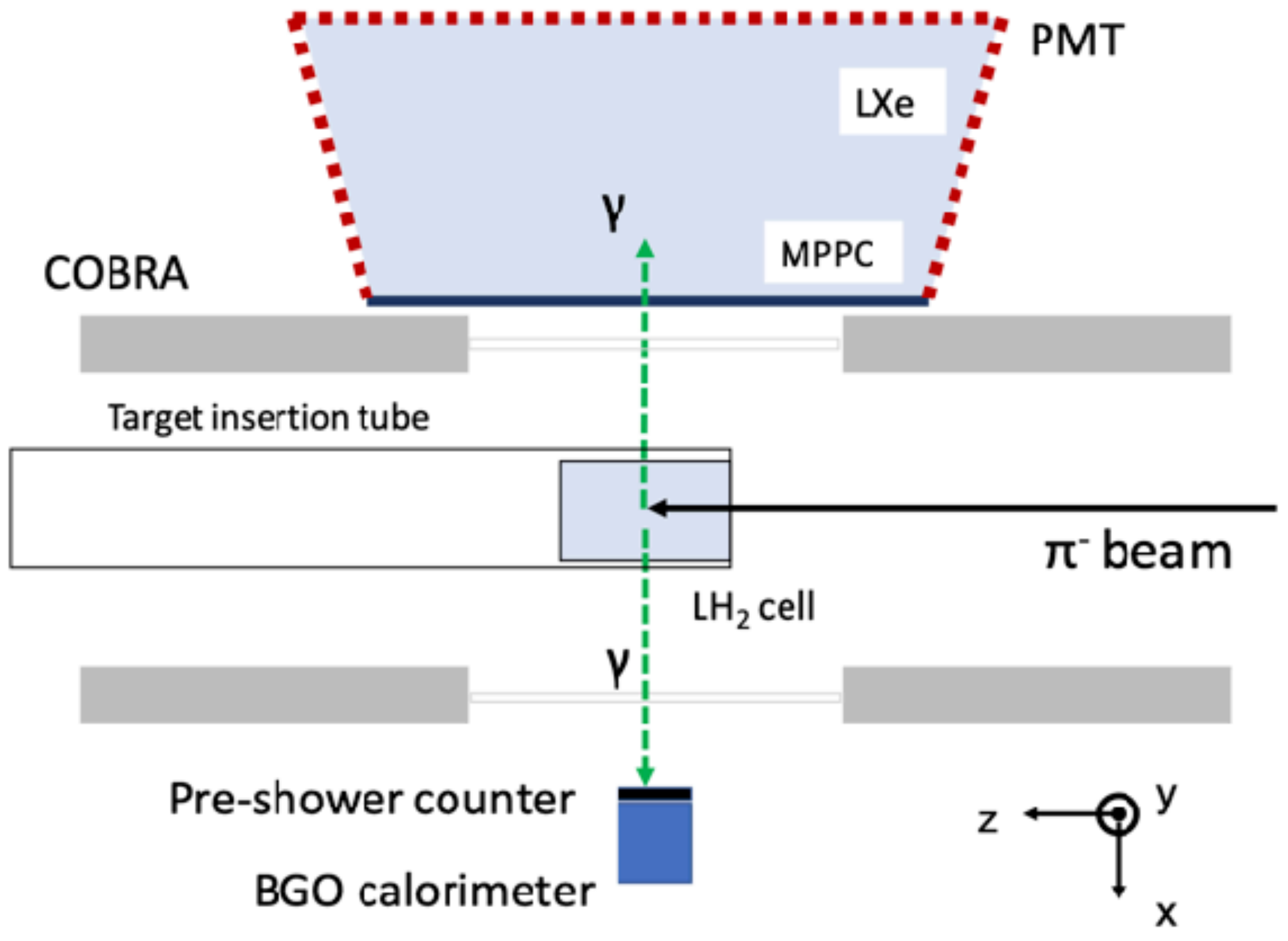
Calibration study

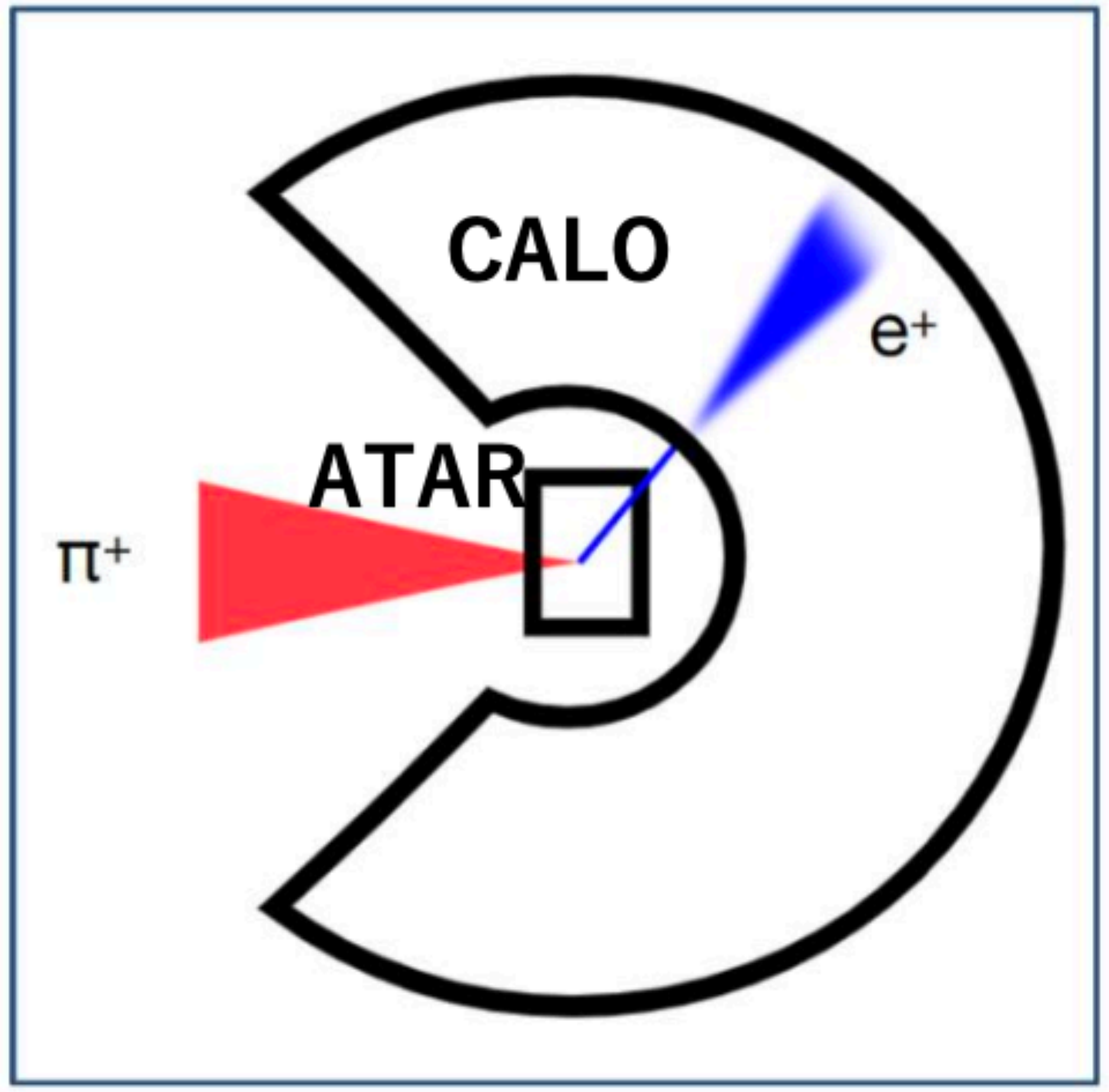
- Photo sensor calibration
  - Emma will cover the topic
- Energy calibration
  - 17.6 MeV γ from CW Li, 55&83 MeV γ from π^0 decay
  - Dedicated targets must be introduced
- Any uniform monochromatic positron sources for the calibration of the LXe detector?
  - Methods in MEG II are based on γ
  - Michel decay (Edge shape of 53MeV isotropically)
  - Direct positron beam (mainly downstream side) or Mott scattering
  - γ (CW/π^0) with active converter

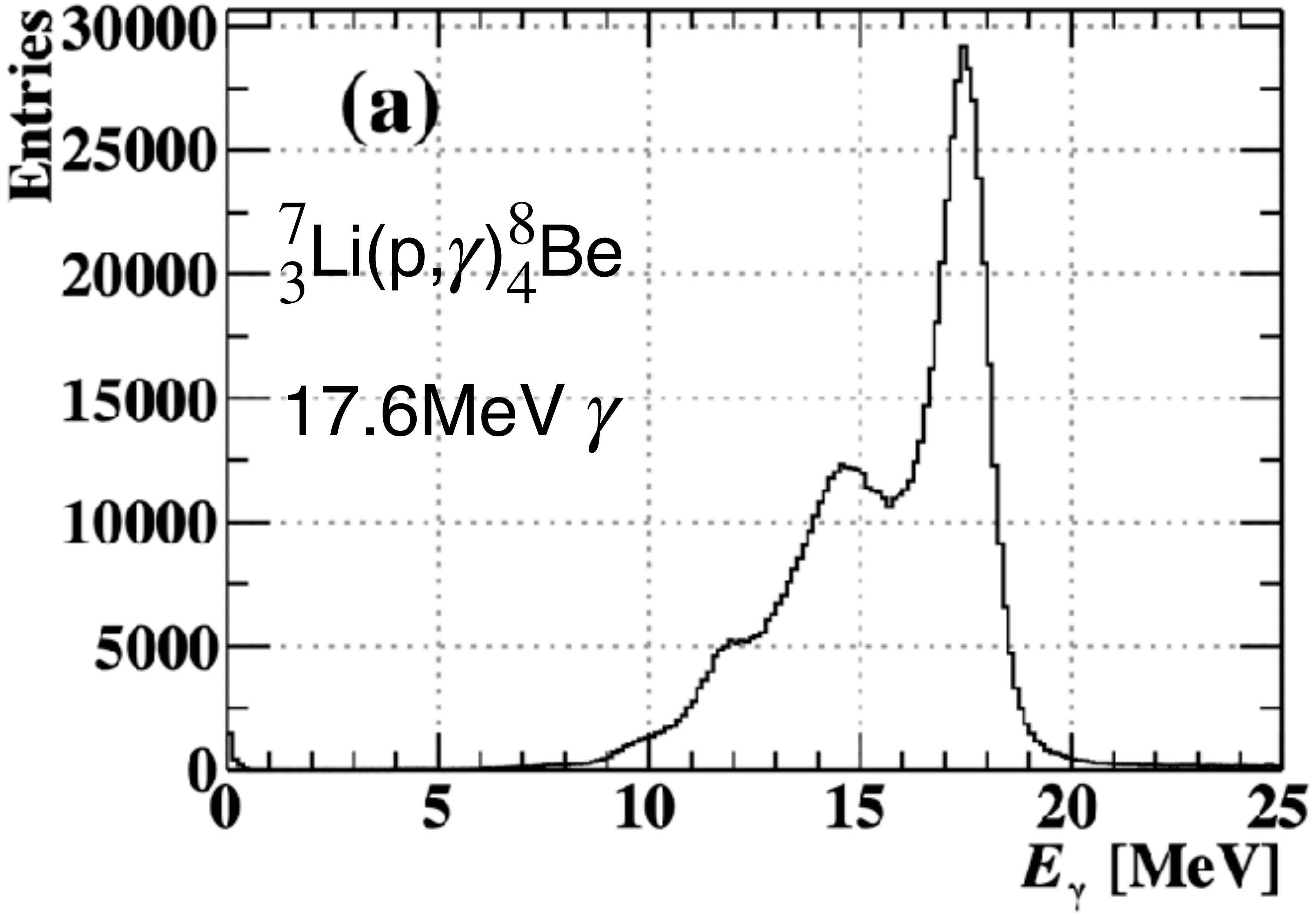


Energy calibration

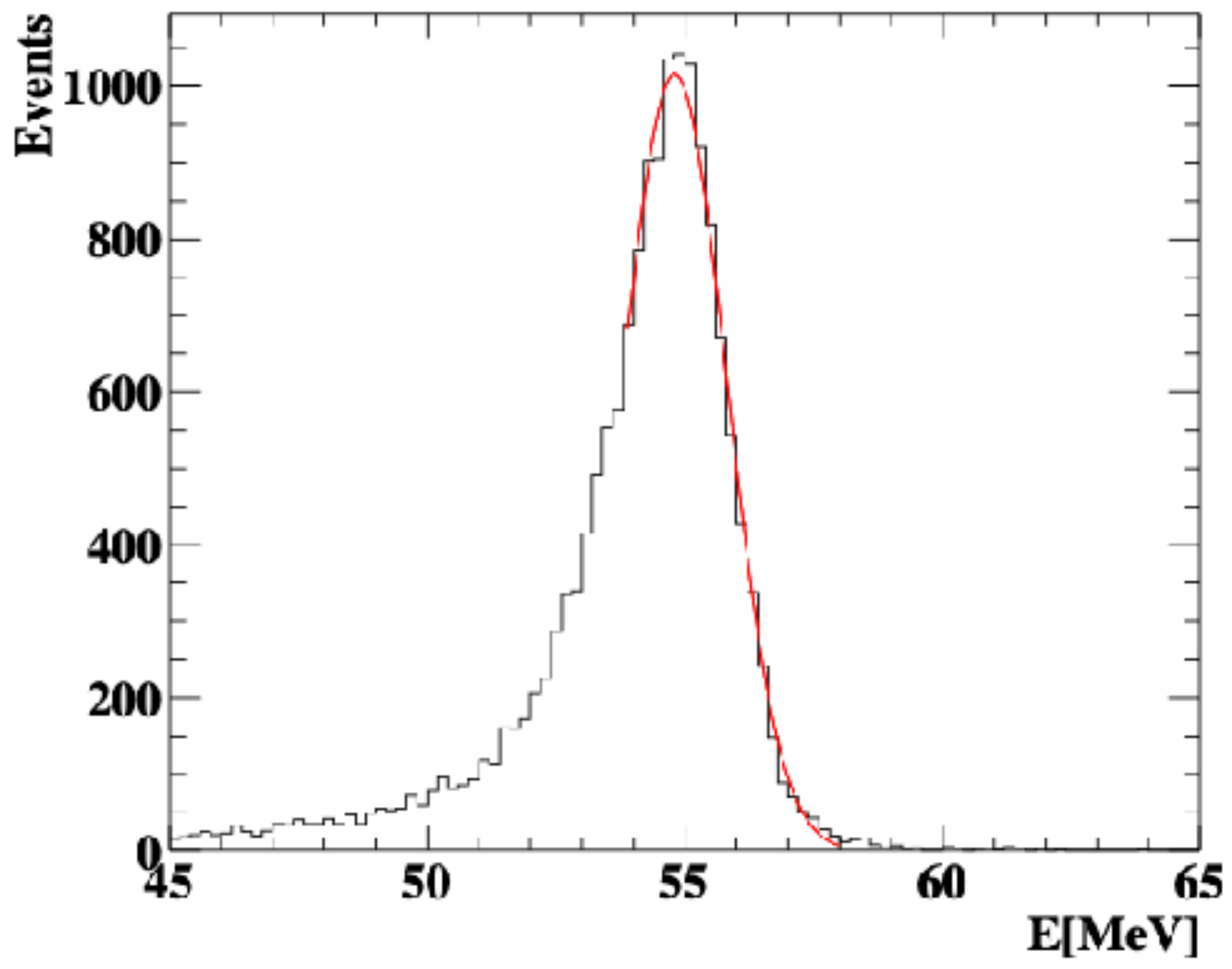


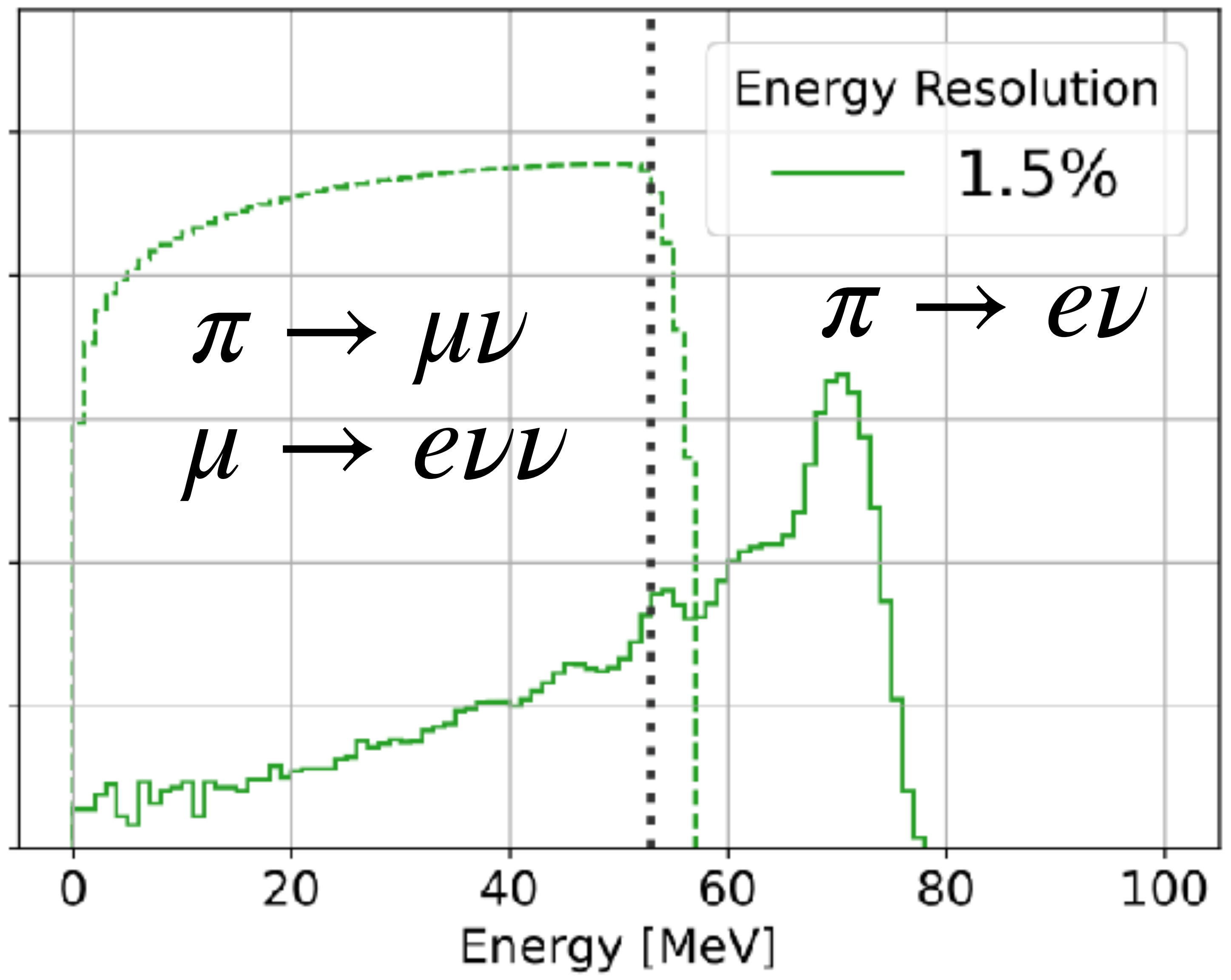




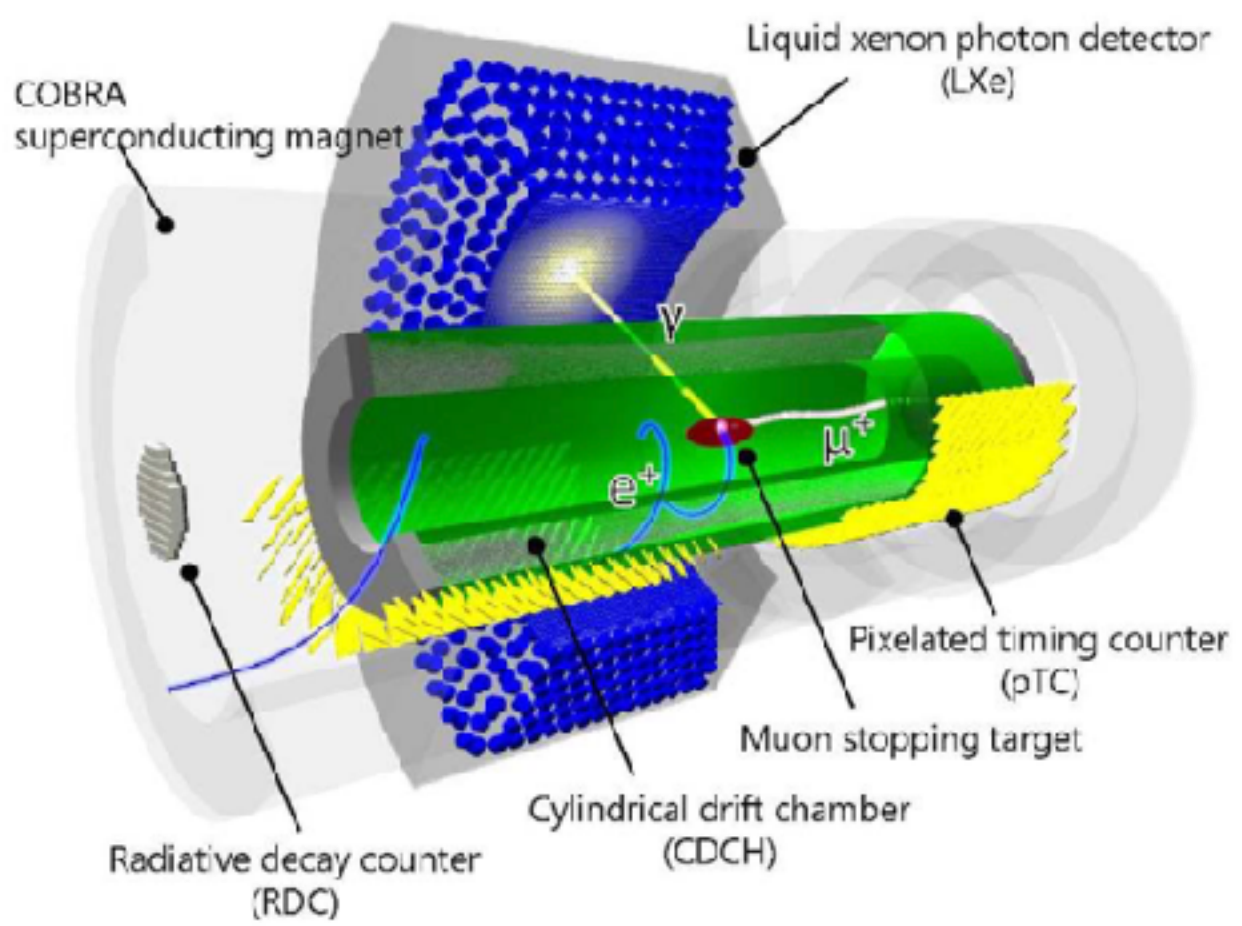


$$\pi^- + p \rightarrow \pi^0 + n \rightarrow \gamma + \gamma + n$$





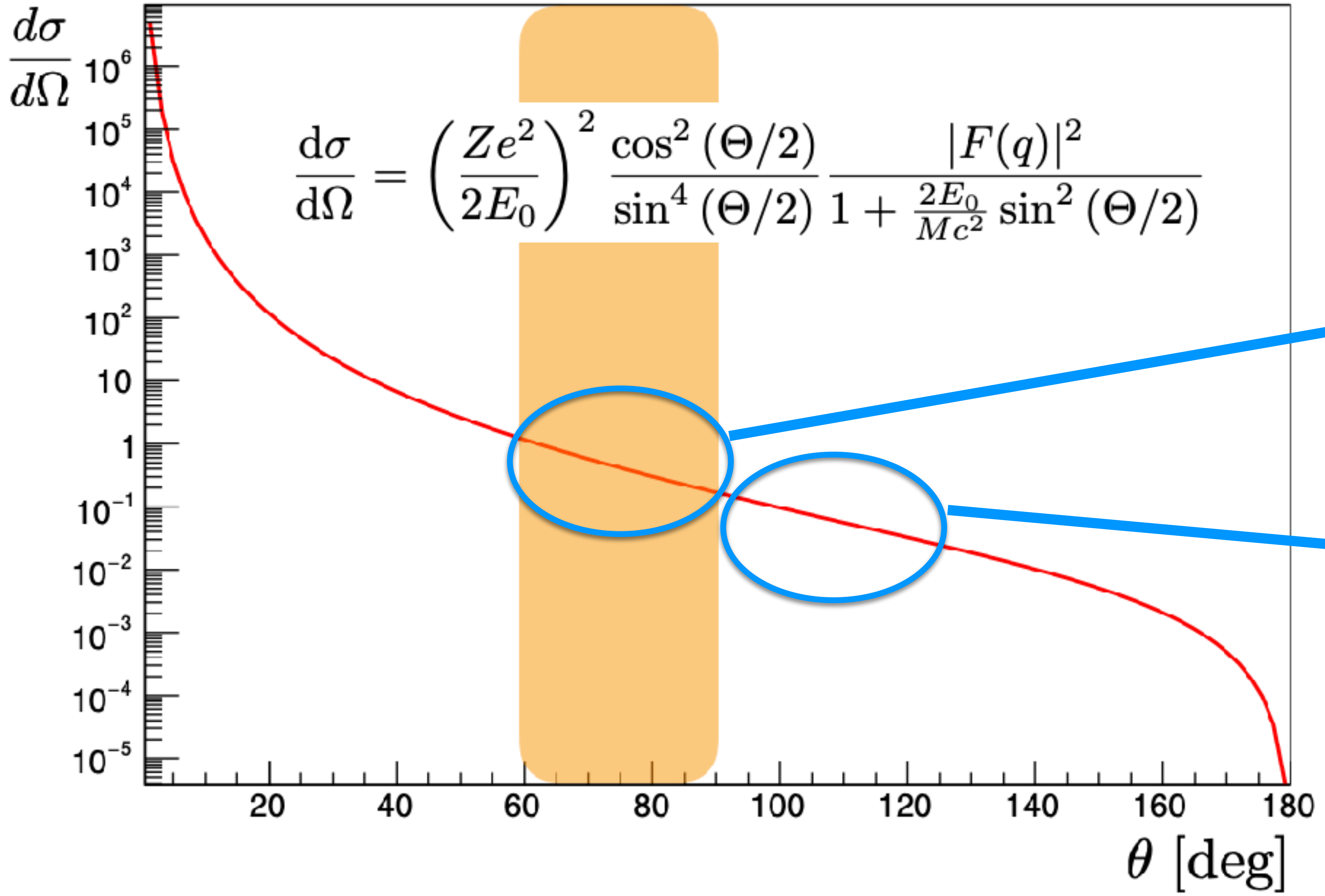
Mott scattered positrons / 2017 pre-eng run



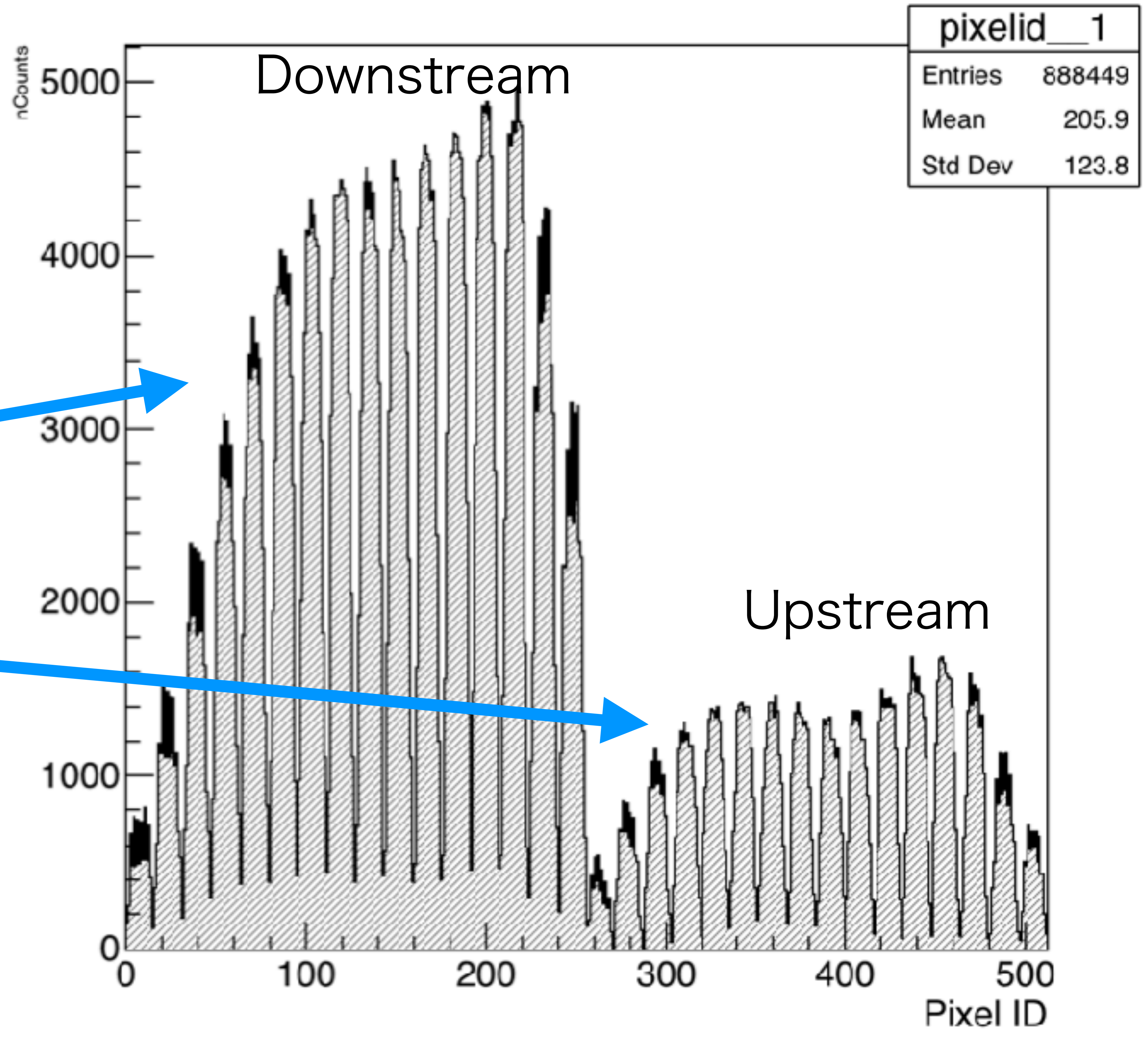
Mott scattered positrons were tested in MEG

- pTC-DS only rate estimate: O(KHz) at 10^8

$$\frac{d\sigma}{d\Omega} = \left(\frac{Ze^2}{2E_0}\right)^2 \frac{\cos^2(\Theta/2)}{\sin^4(\Theta/2)} \frac{|F(q)|^2}{1 + \frac{2E_0}{Mc^2}\sin^2(\Theta/2)}$$

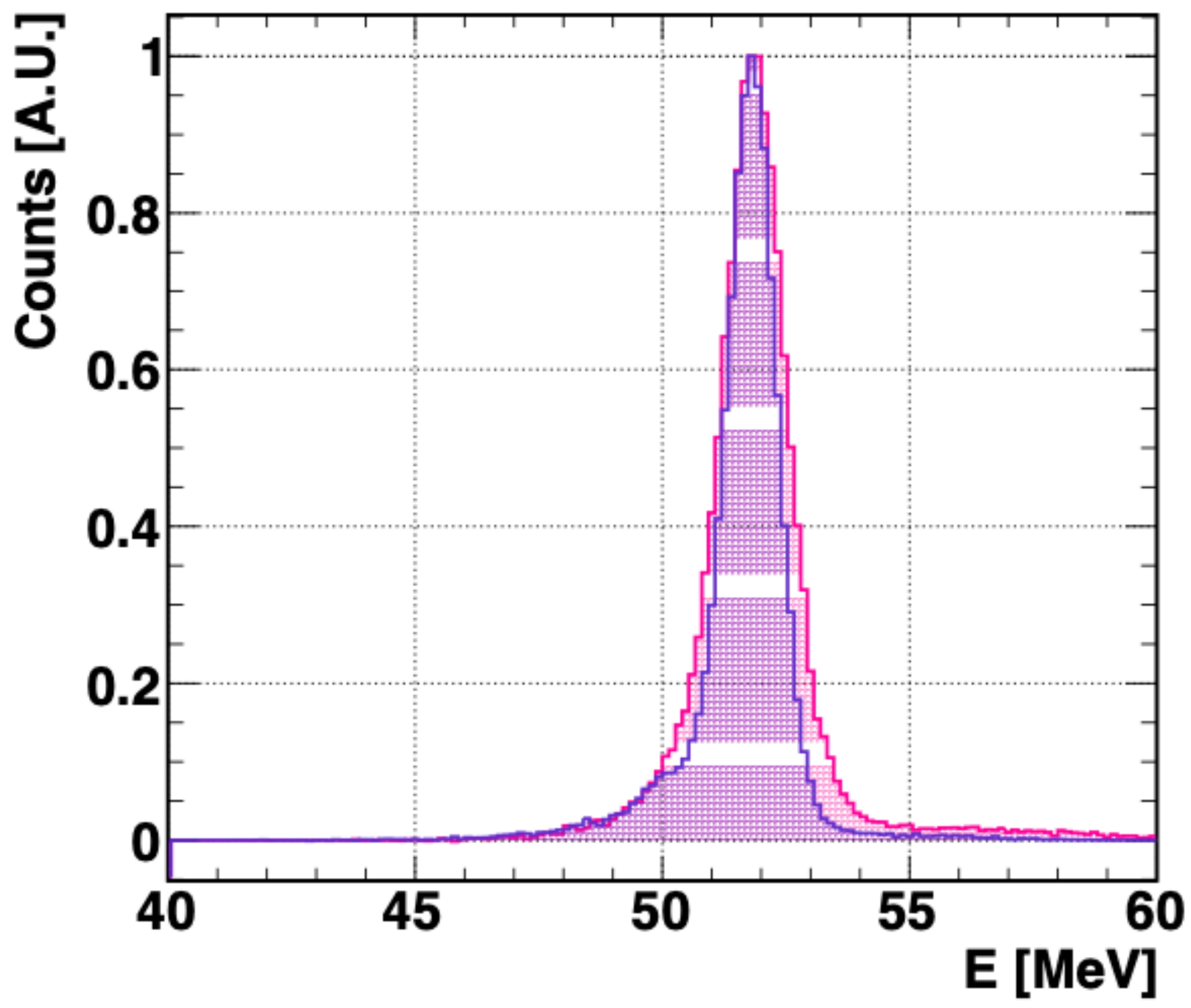


n_fired pixels/track > 2; Mean ~ 10



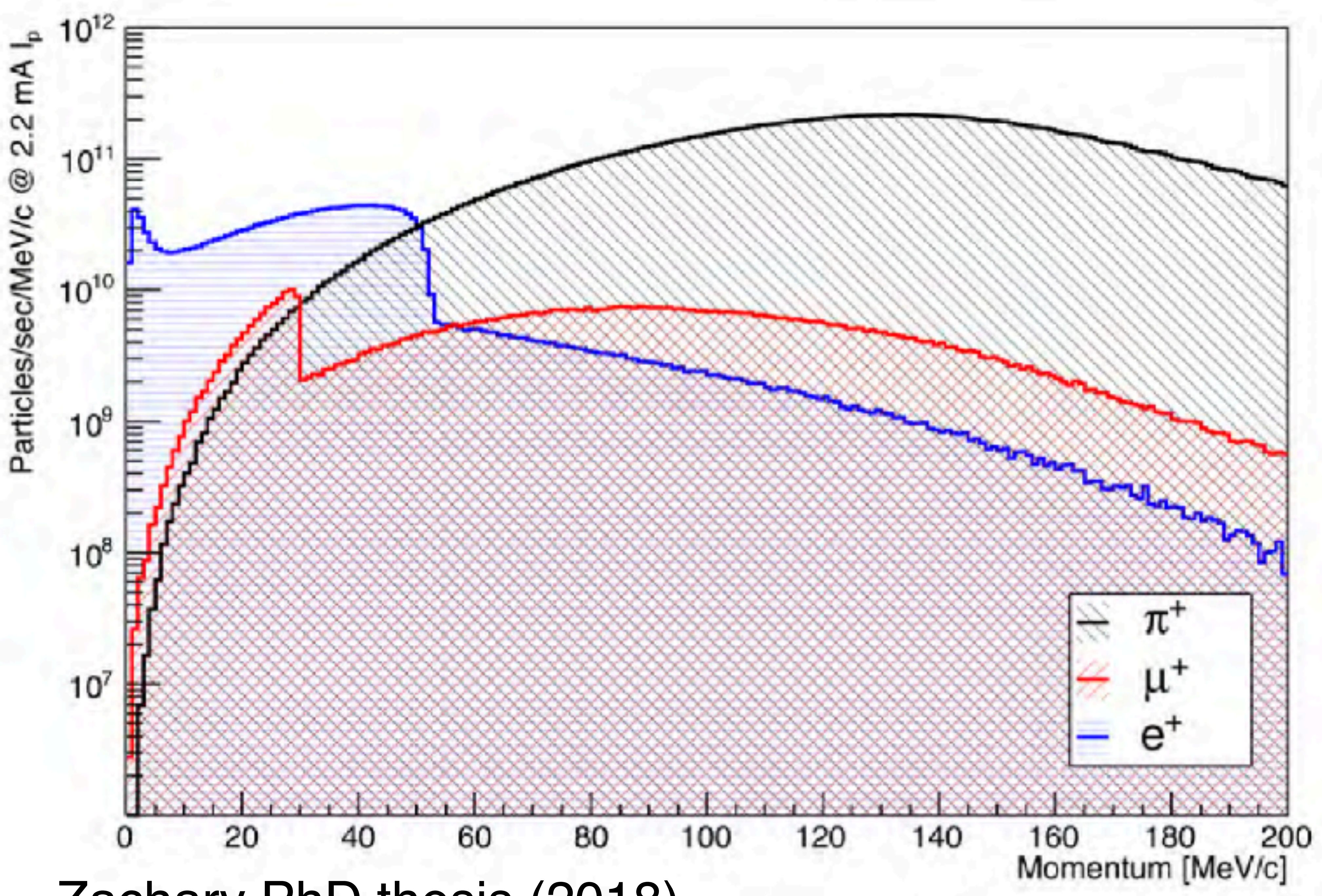
Mott in MEG

- Mott monochromatic energy spectrum
  - Data in 2012 and in 2013
  - Positron beam momentum of p ~ 52MeV/c
  - Scattered by MEG target (CH_2)
  - spectrometer energy resolution ~ 300keV
  - Spread from the beam ~ 400-500keV

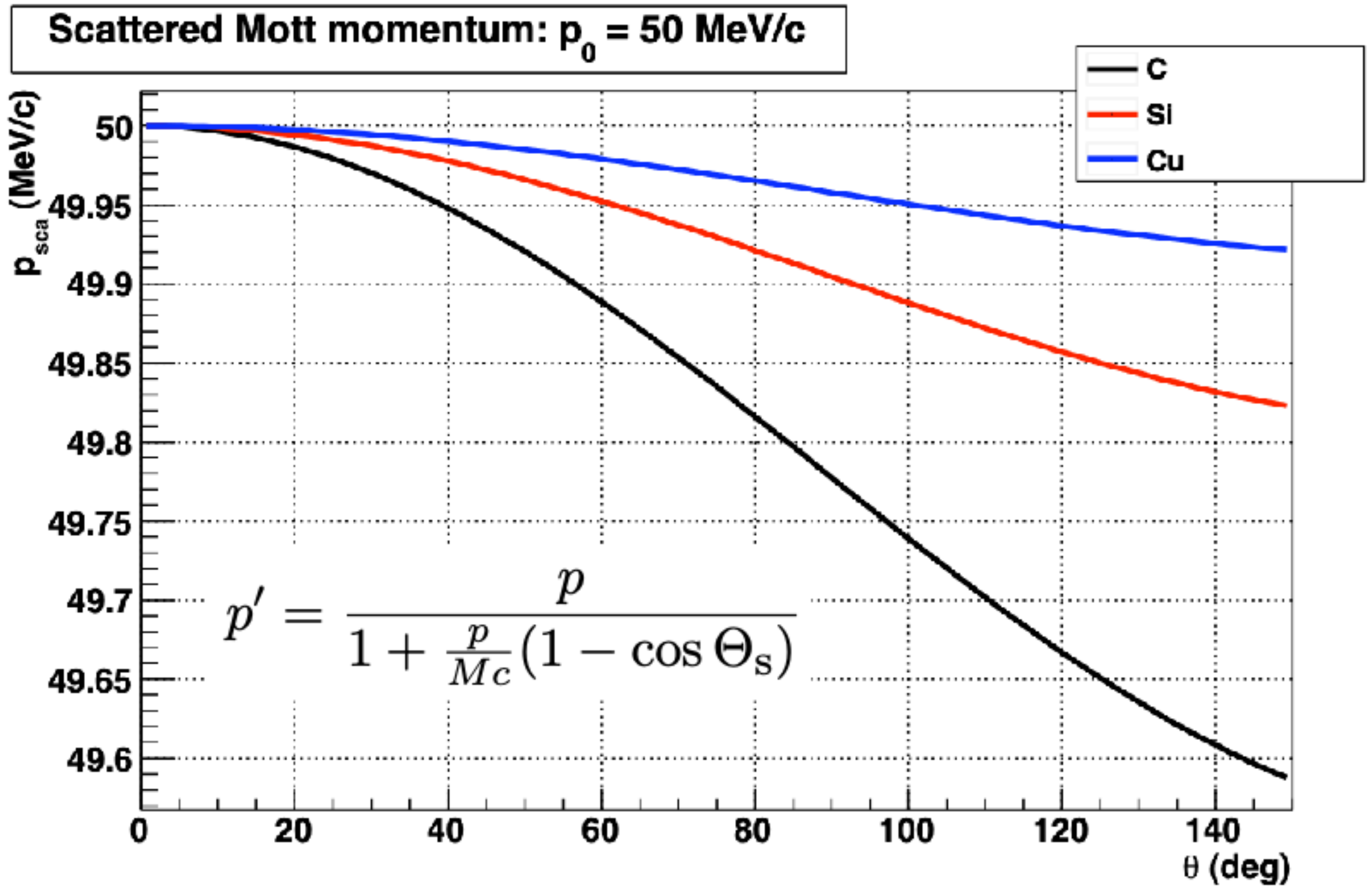


b) Run 2012 vs. 2013

Mott scattering for PIONEER



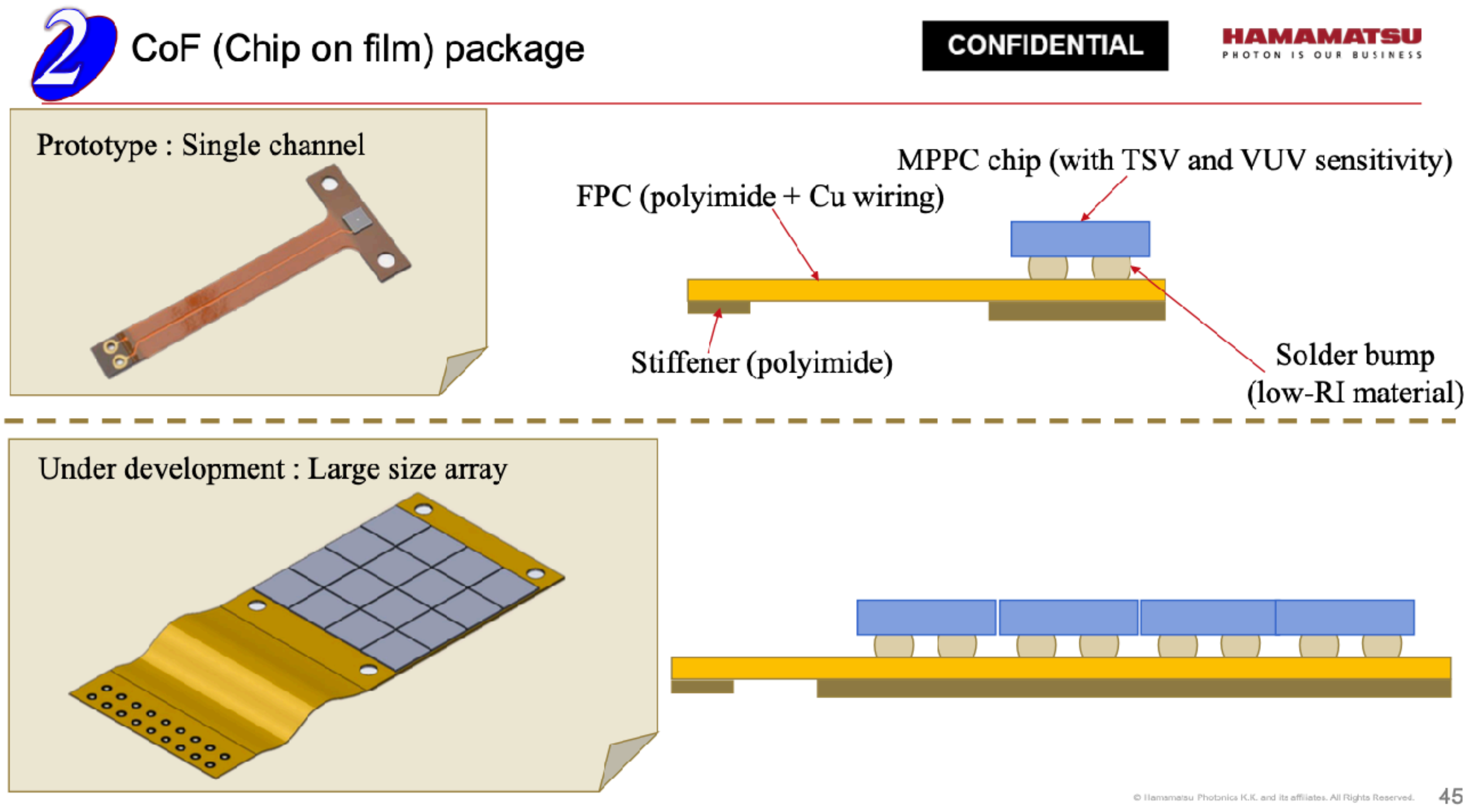
Zachary PhD thesis (2018)



- Event rate @ 70MeV/c should be sufficient (1kHz@53MeV/c at MEG)
- Scattered momentum on silicon larger than that on carbon
- Strong angle dependence
  - Events with forward direction will be dominant
- Detailed estimates with MC necessary

Thin MPPC can be installed in the inner sphere?

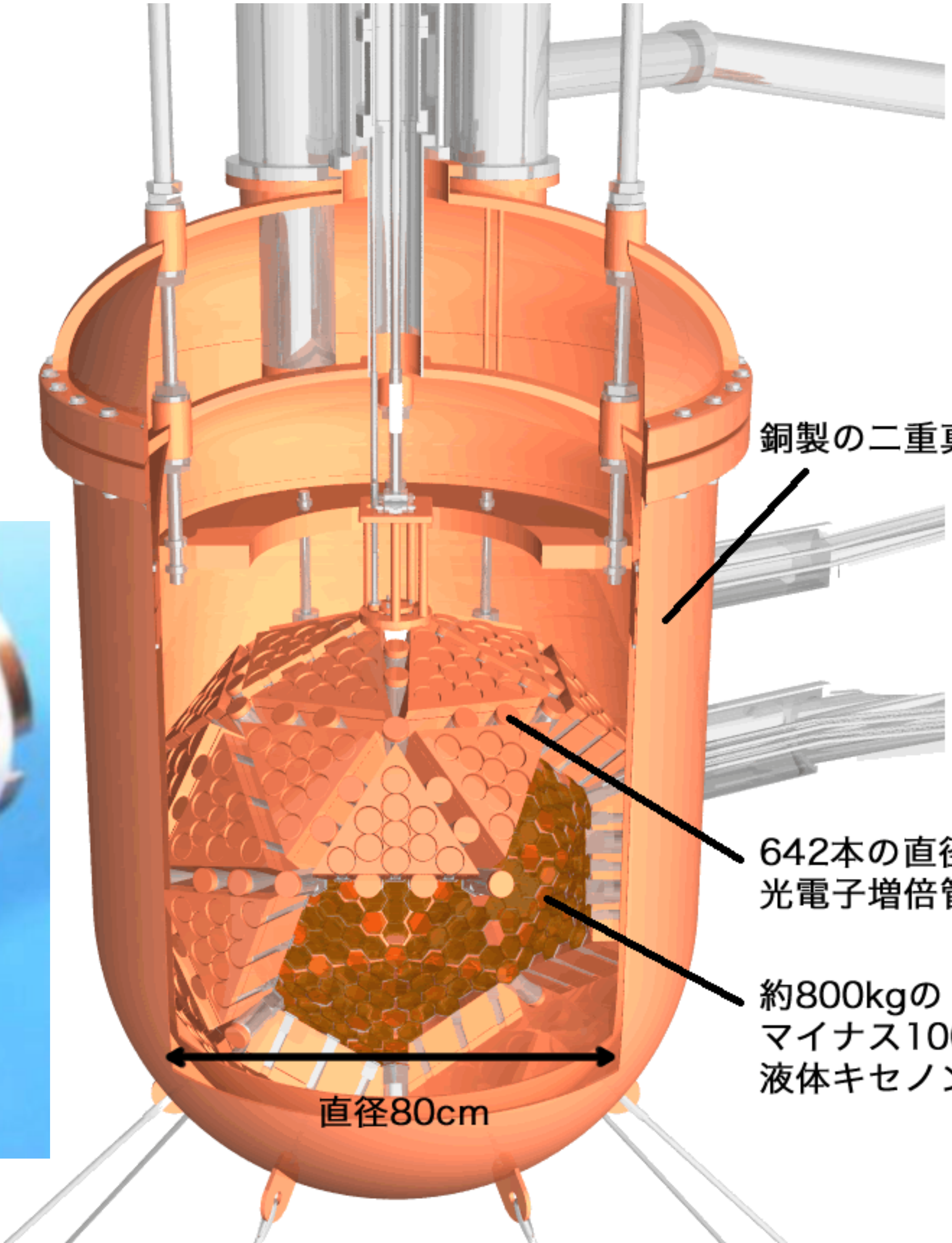
- Can we put some photosensors on the inner target sphere?
- Wataru contacted Hamamatsu for this
  - MPPC chip: 200µm
  - Solder bump: 150µm
  - Stiffener: < 270µm
- Radius of 15cm
  - Area : 2500 cm2
  - 6000 MPPCs with 6x6mm2 ~0.2M USD
- Prototype samples will be provided by Hamamatsu
  - Those samples will be tested in the liquid xenon



XMASS PMTs

- R10789 still installed in the detector (~600)
  - 2 inch, hex shape photo-cathode (58.4mm × 126.6mm)
  - QE: 28–39%
  - need human resources and budgets to remove them from the detector
    - For the construction, it costed 0.13MUSD (20MJPY)
  - The XMASS people will investigate it more if we are interested in using them

  - mBq/PMT amount of radioactivity for them is a problem, but is not for us.



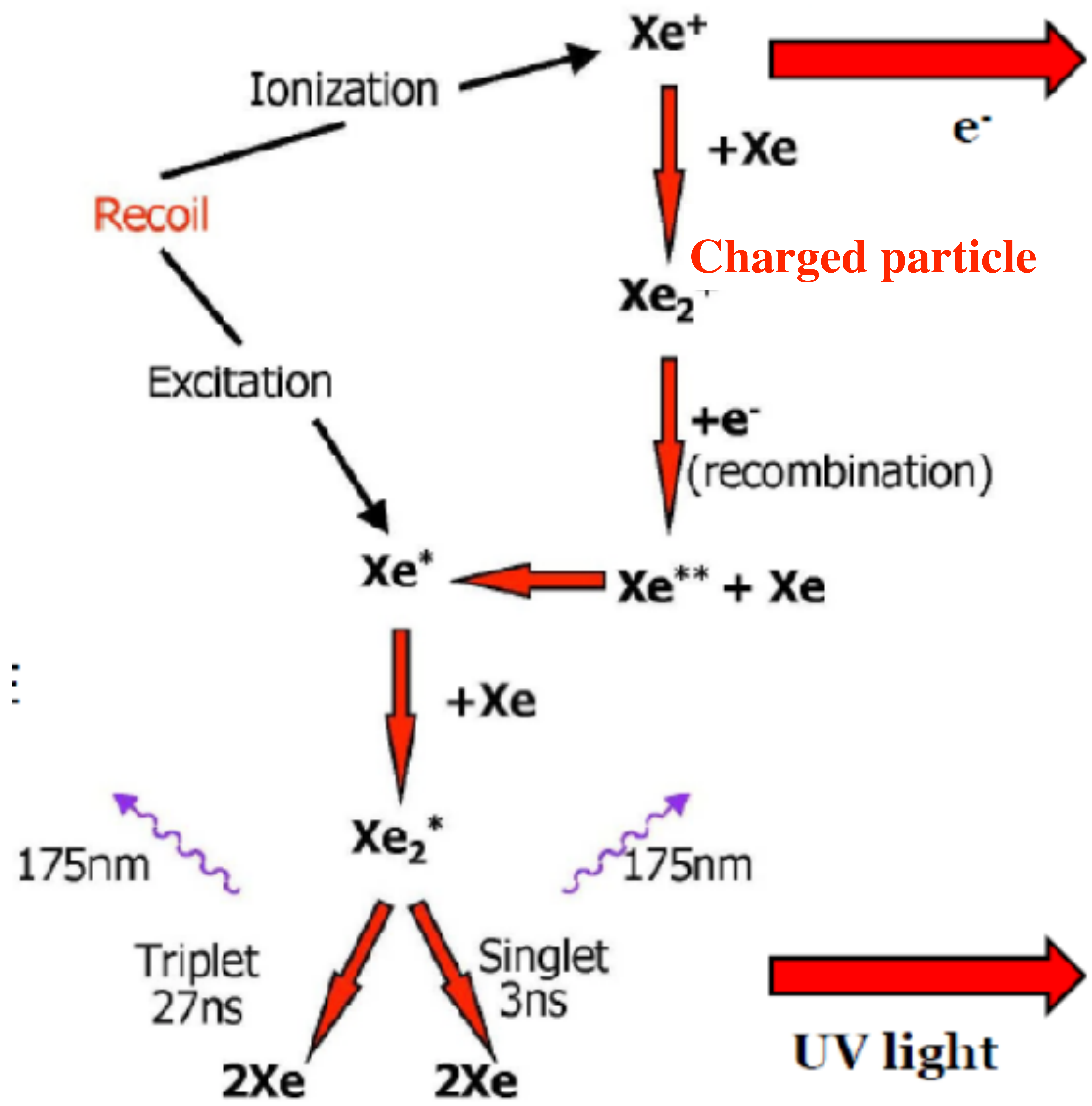
Prices of photo sensors

- S13371-6050/75CQ-02 (MEG II MPPC)
  - 100 USD (10,000-13,000pcs), updated in 2024 June
  - 12x12mm2
- R12699-406-M4 (Flatpanel PMT)
  - 3000 USD
  - 48.5x48.5mm2 ~ 183 USD/12x12mm2
- R9869 (MEG PMT)
  - ~~2000 USD~~ unfortunately, it is discontinued.
  - ~~ϕ46mm ~ 181 USD/12x12mm2~~

Summary

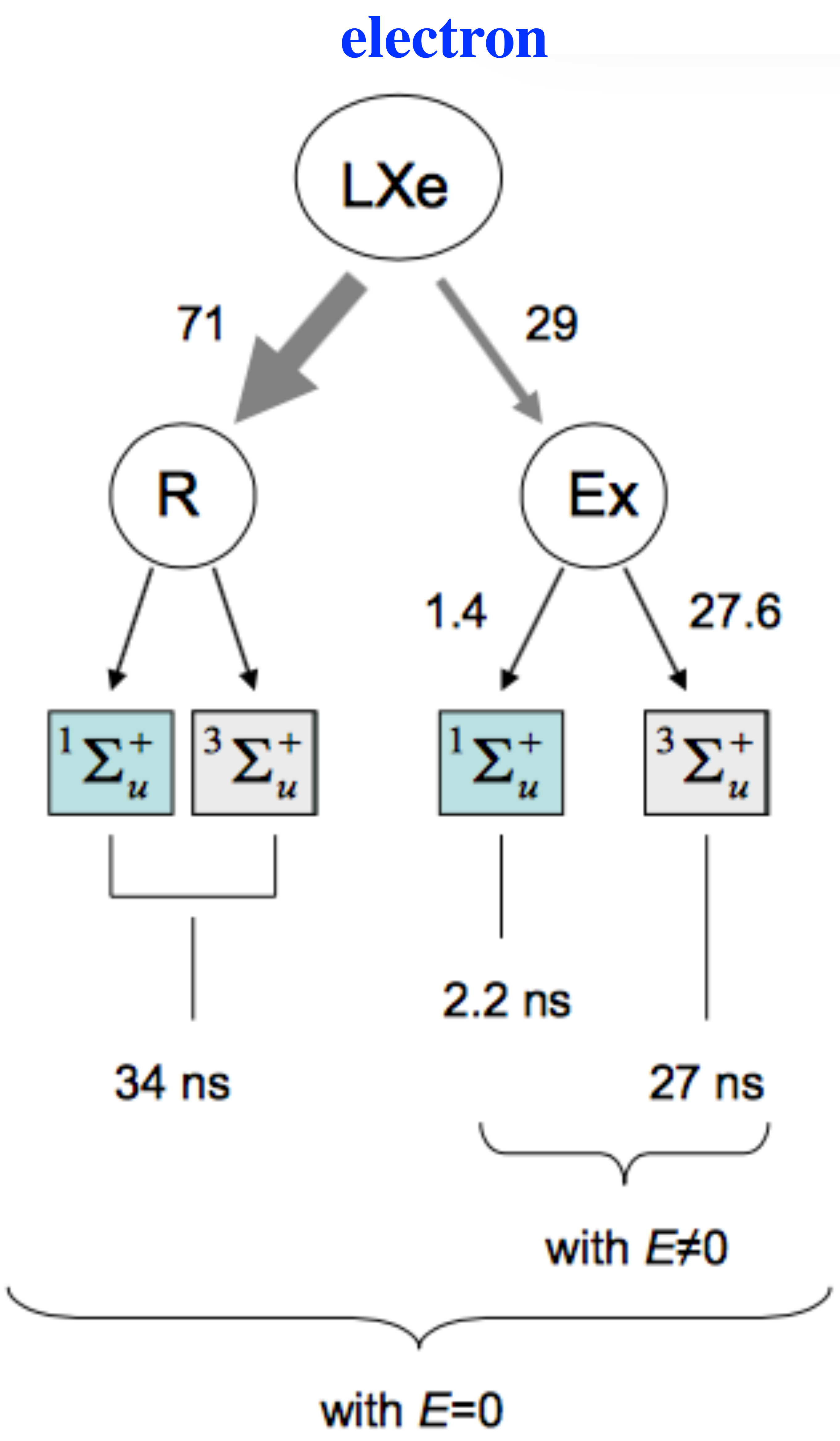
- We can learn a lot of things in the prototype test
  - Energy resolution
  - Photo nuclear interaction
  - Thin window test
  - Operation experience
- Prototype design will be finalized soon, and we aim at beam test in 2025
- Calibration methods
  - Cockcroft Walton + Li target (17.6MeV γ), Charge Exchange reaction (55, 83MeV γ), Monochromatic positron beam, Mott scattering, γ conversion into e+e-
- Possible improvements
  - Thin MPPC installation into the inner sphere
- Cost reduction
  - Investigation of the photo sensors

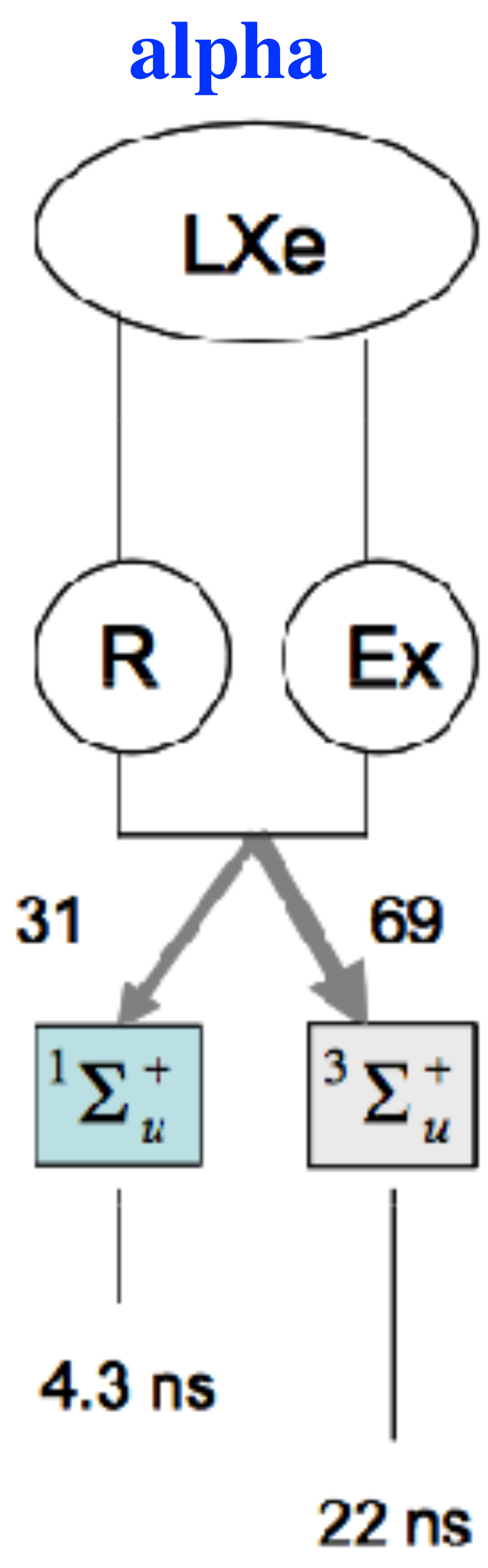
Scintillation and Ionization

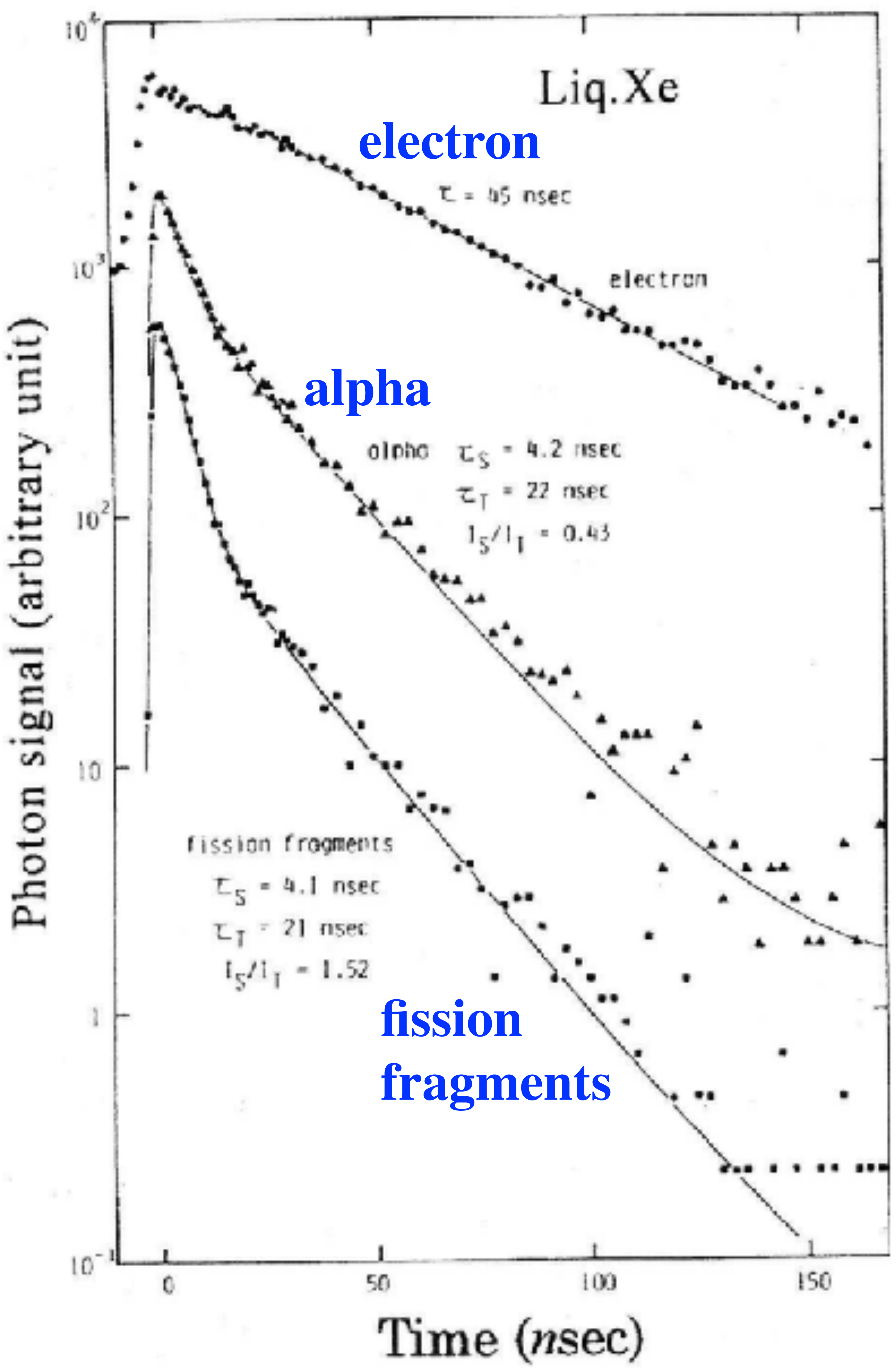


Scintillation

Phys. Rev. B 27 (1983) 9







arXiv:1207.2292

Status for large prototype test

- Available
  - Cryostat
  - PMTs: 1/3 PMT tested at RT (109 R9288 PMTs)
  - Power supply: 206 working positive channels
  - Pulse tube refrigerator & rotary valve
  - Compressor for the refrigerator (at PSI)
  - Gaseous purification panel
  - LN2 pipes
- To be prepared
  - 10x5 WFD channels available (probably ~1/2 of the total channels we need)
  - Thin window
  - PMT support structure, cables, feedthrough
  - Xenon storage tank
  - Stage to transport a set of the measurement setup into the beam line w/o disconnecting pipes

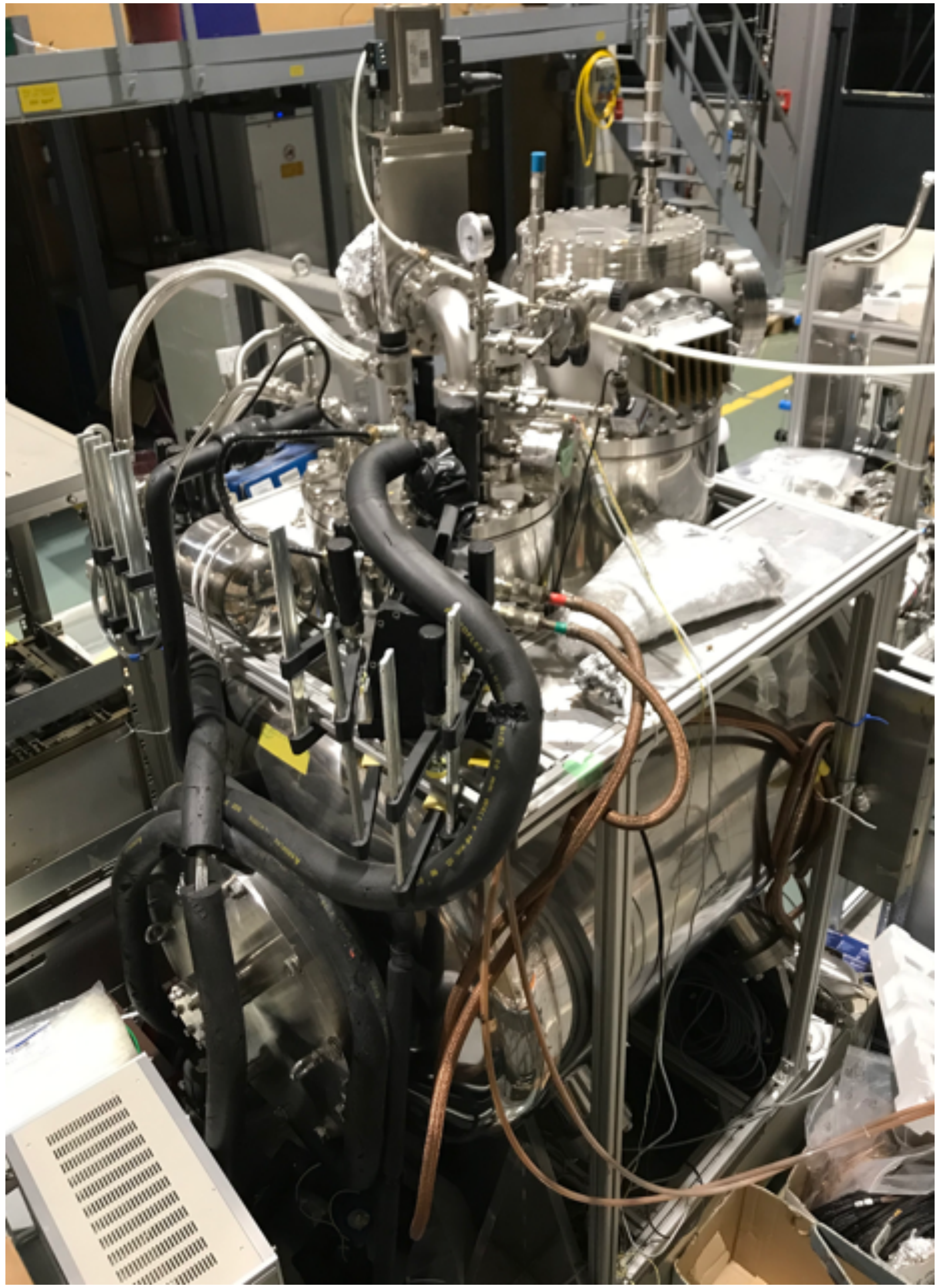
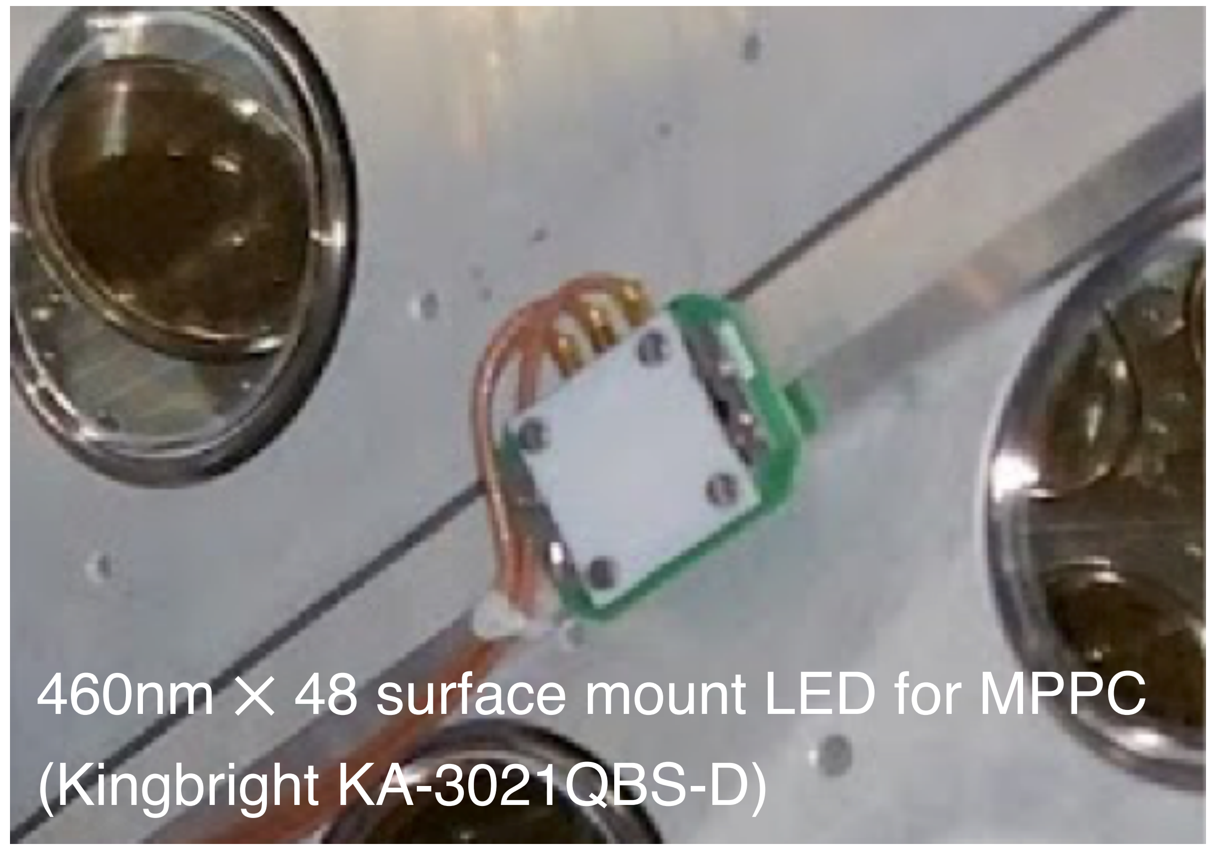
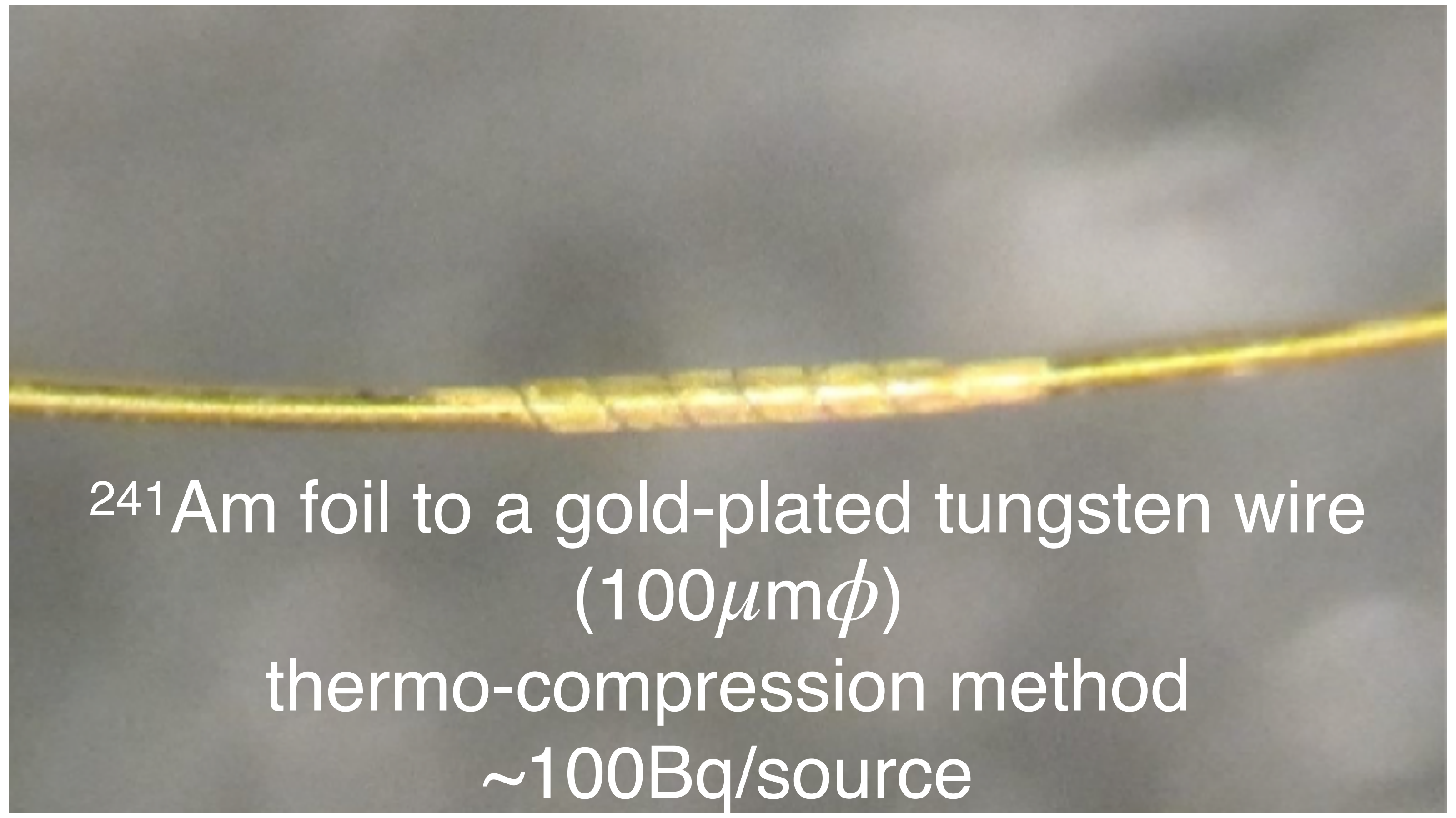
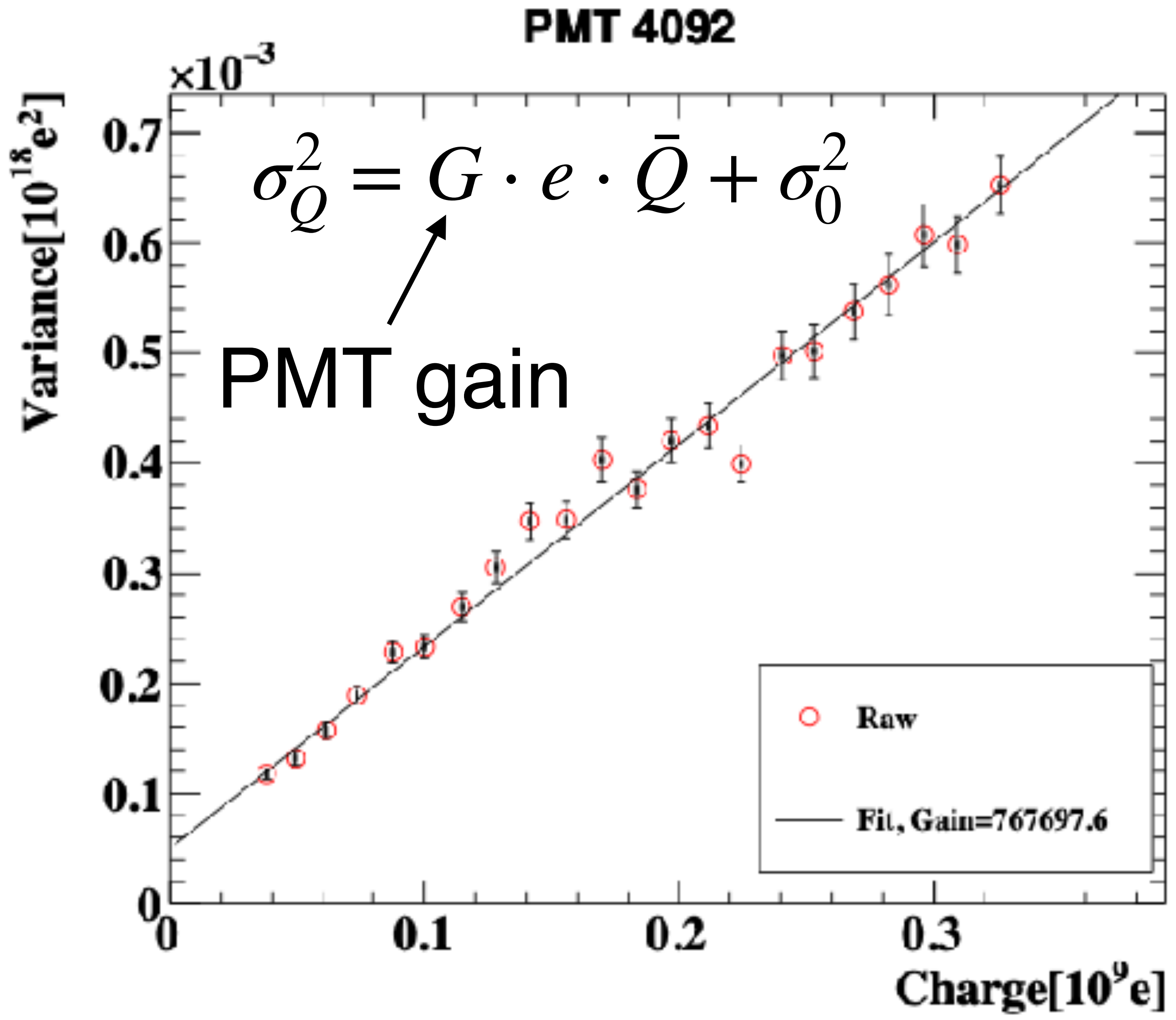


Photo-sensor calibration

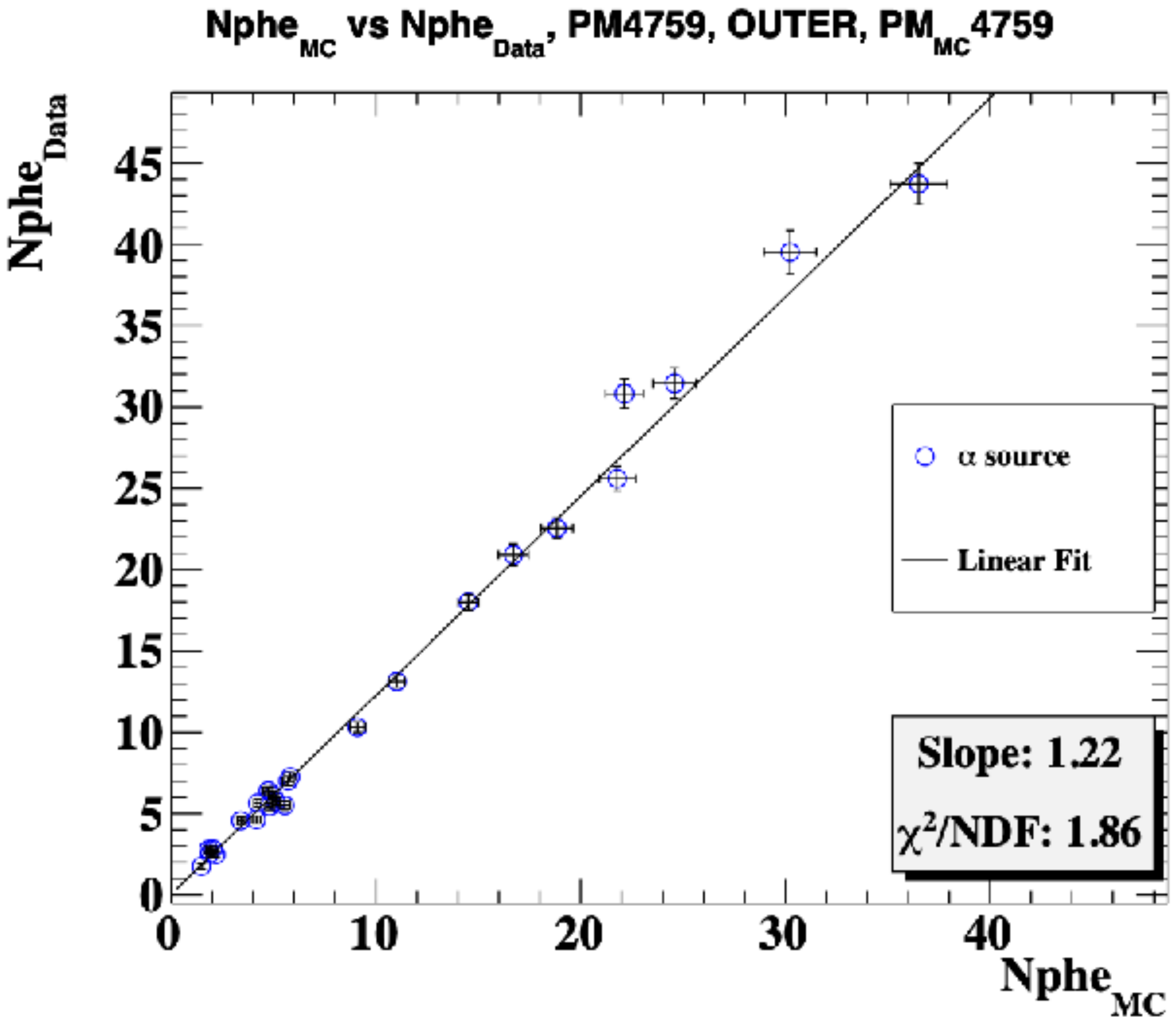




Variance vs Charge mean
w/ different LED intensities

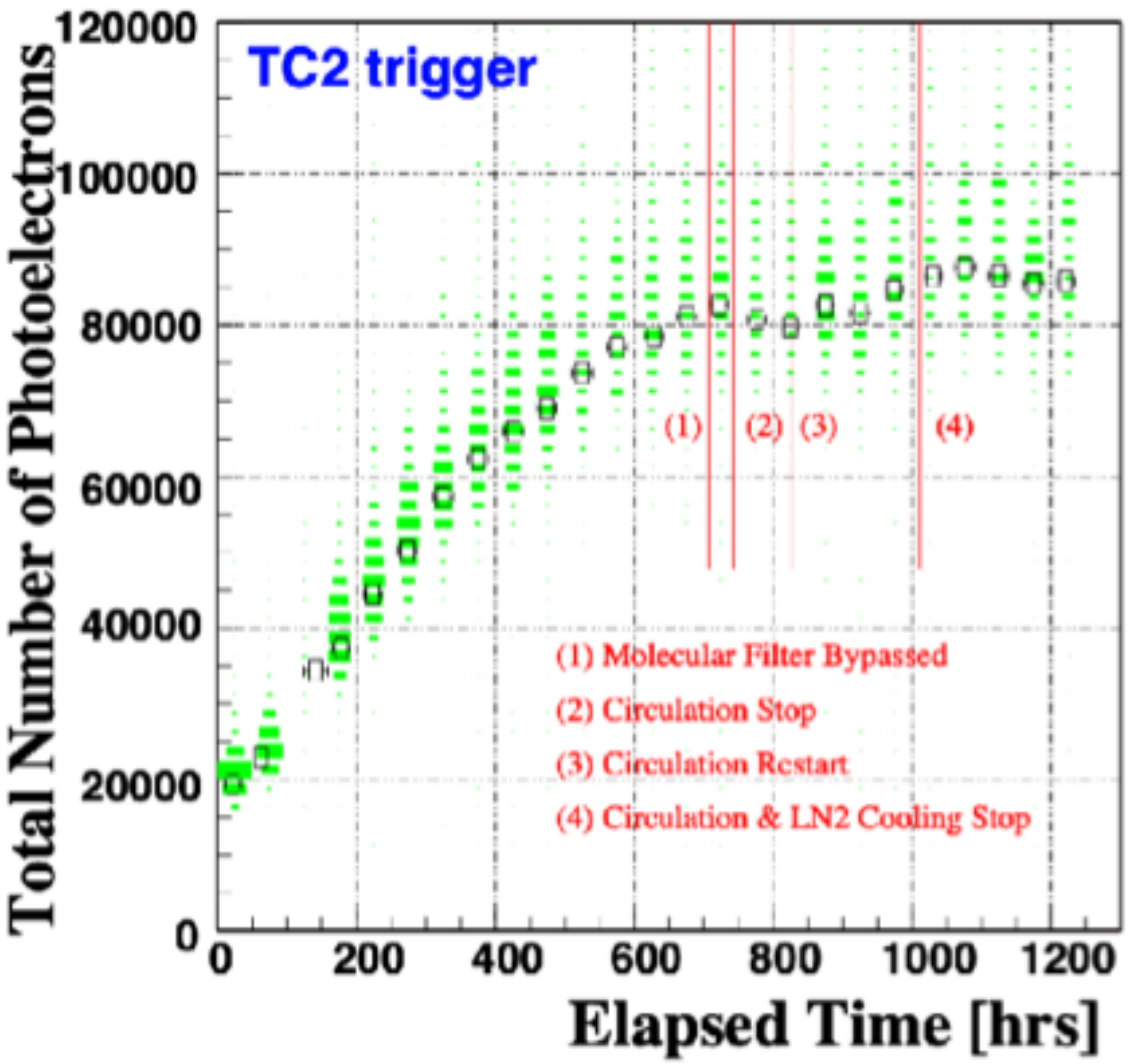


Ratio of data/MC for a PMT



Purification

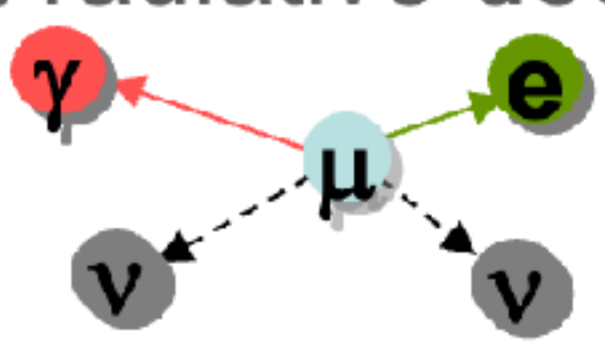
- Gaseous xenon purification
    - 1 month to reach a plateau
- New getter and new pump to improve the purification speed

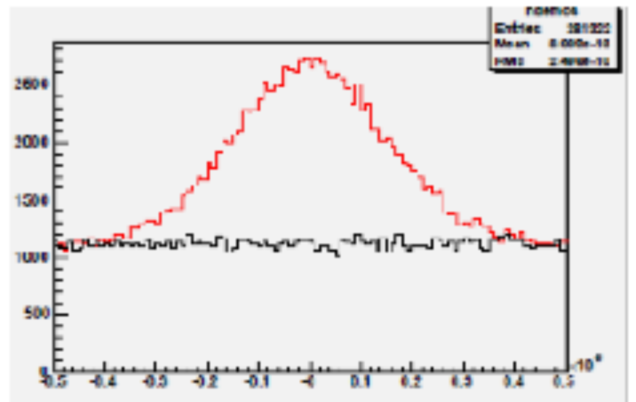


By Satoshi

Xenon Calibration

μ radiative decay





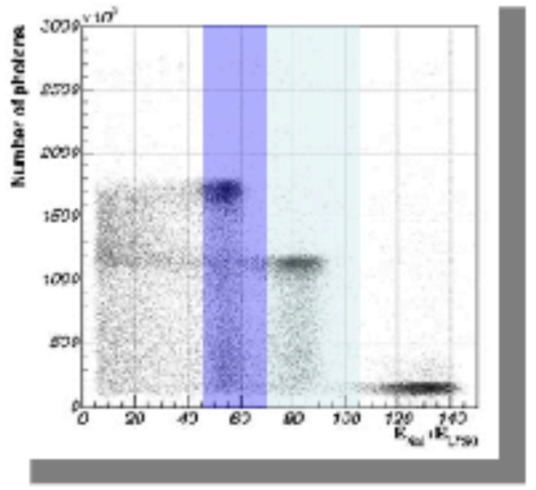
Lower beam intensity < 10^7

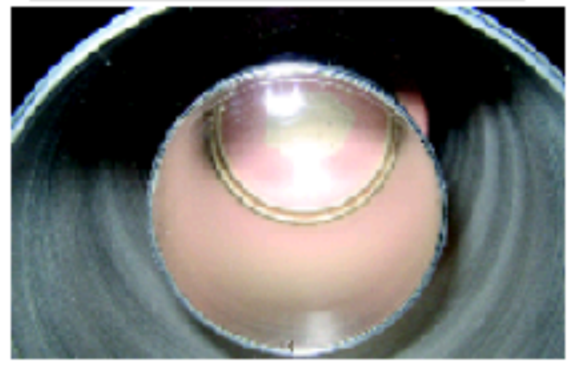
Is necessary to reduce pile-ups

Better σ_t, makes it possible to take data with higher beam intensity

A few days ~ 1 week to get enough statistics

$\pi^0 \rightarrow \gamma\gamma$





$\pi^- + p \rightarrow \pi^0 + n$

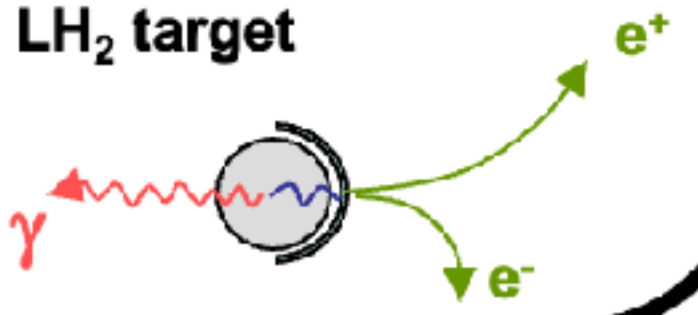
$\pi^0 \rightarrow \gamma\gamma$ (55MeV, 83MeV)

$\pi^- + p \rightarrow \gamma + n$ (129MeV)

10 days to scan all volume precisely

(faster scan possible with less points)

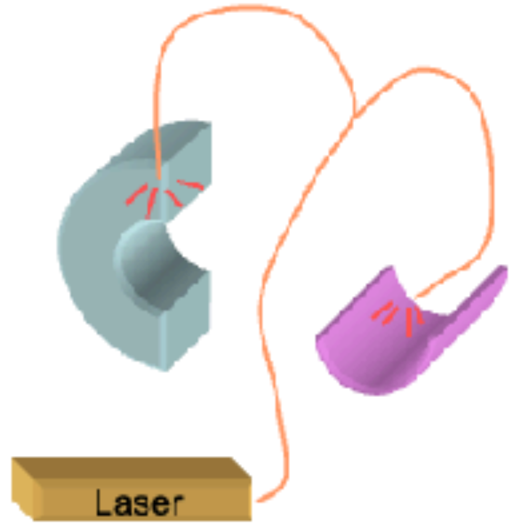
LH_2 target



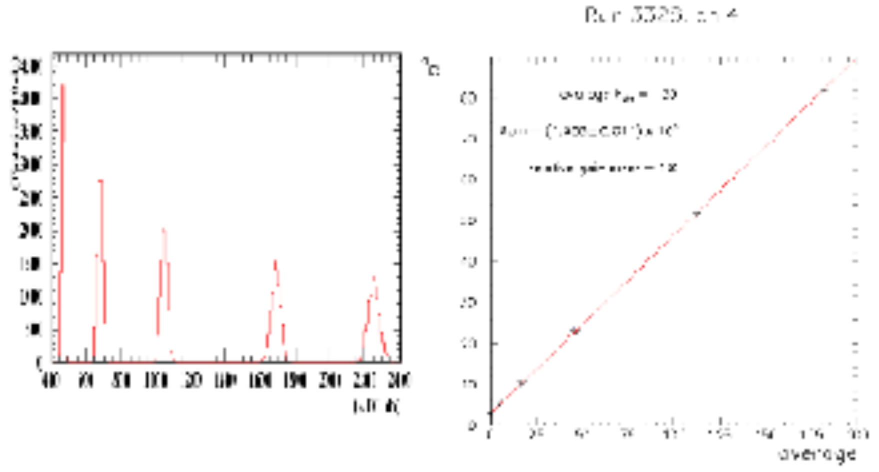
Laser

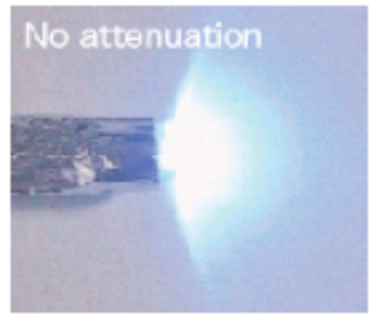
(rough) relative timing calib.

< 2~3 nsec



LED

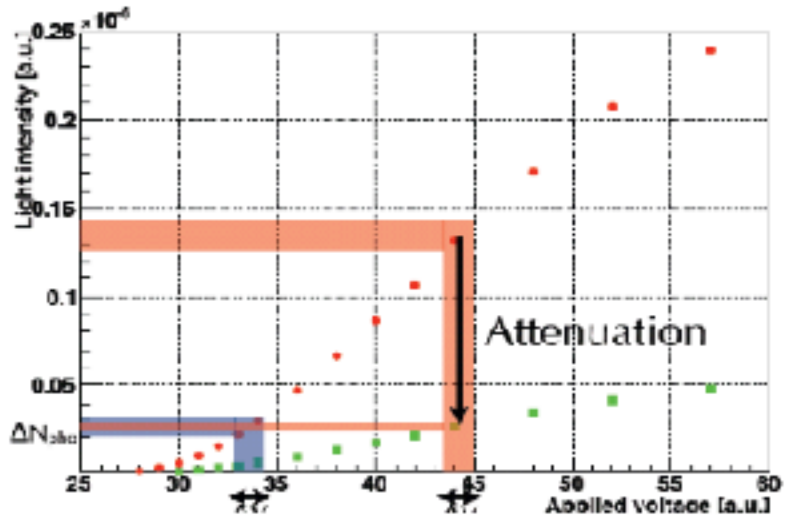


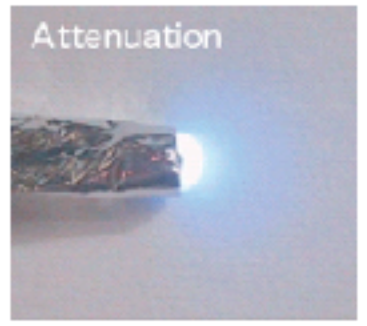


PMT Gain

Higher V with light att.

Can be repeated frequently



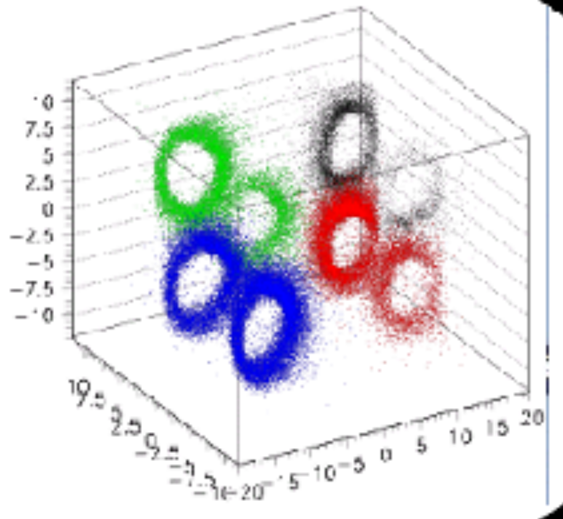


alpha

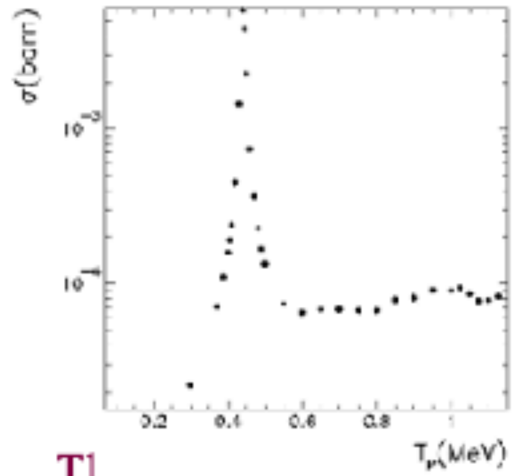
PMT QE & Att. L

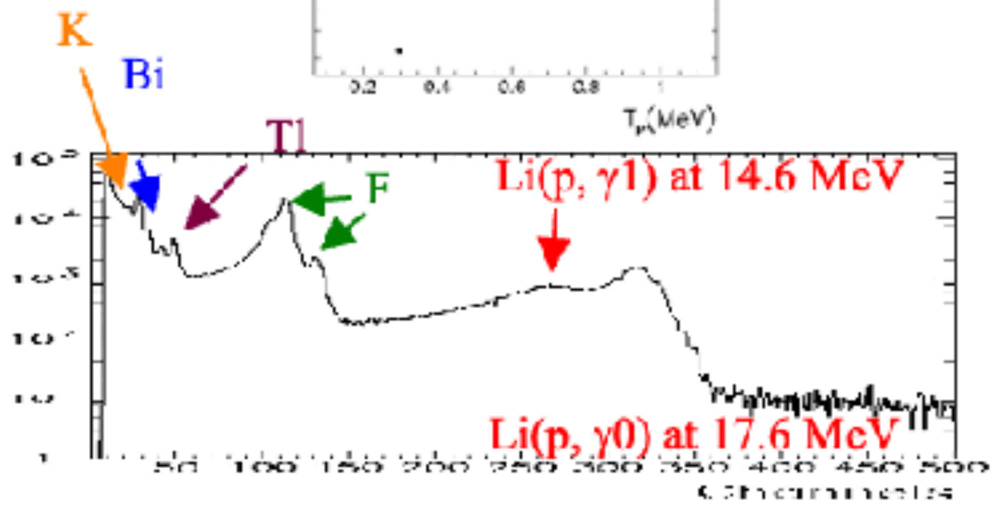
Cold GXe

LXe



Proton Acc





Li(p,γ)Be

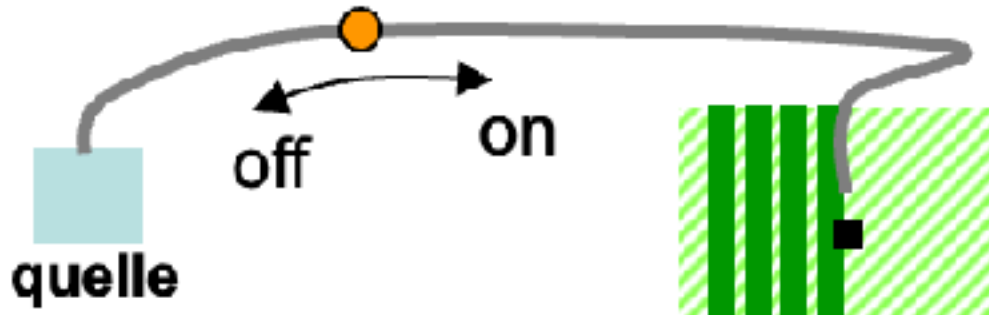
LiF target at COBRA center

17.6MeV γ

~daily calib.

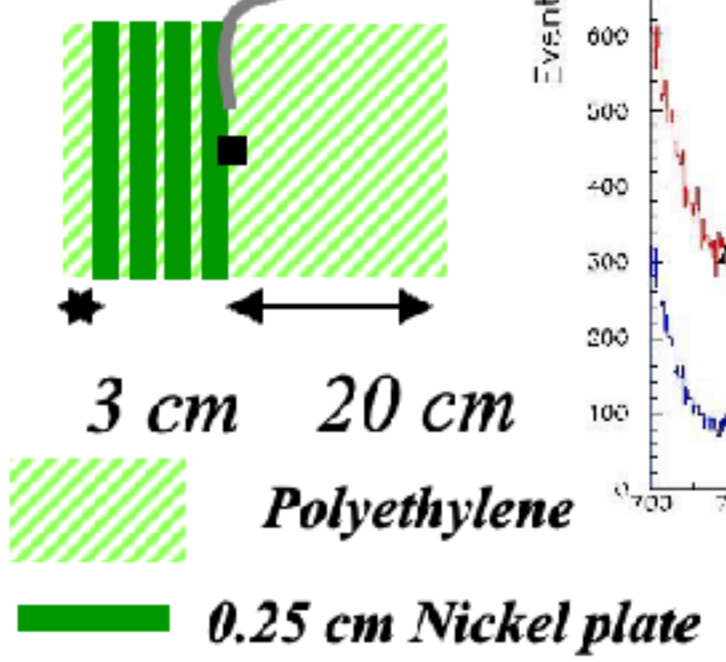
Can be used also for initial setup

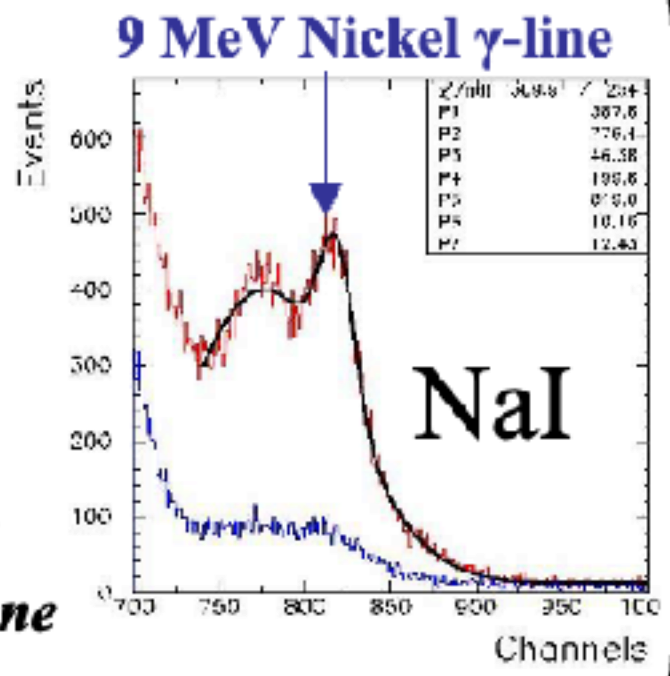
Nickel γ Generator



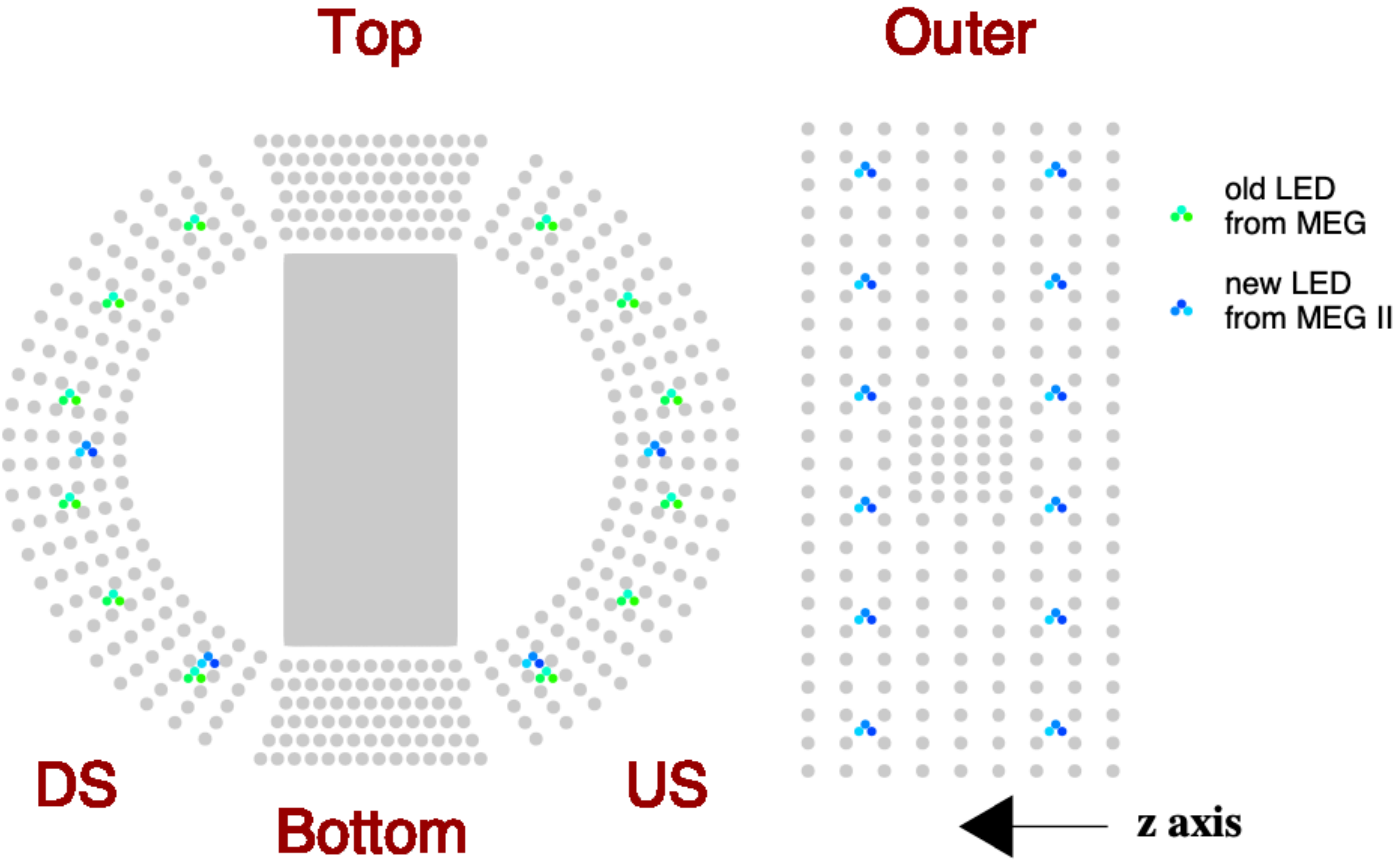
Illuminate Xe from the back

Source (Cf) transferred by comp air → on/off

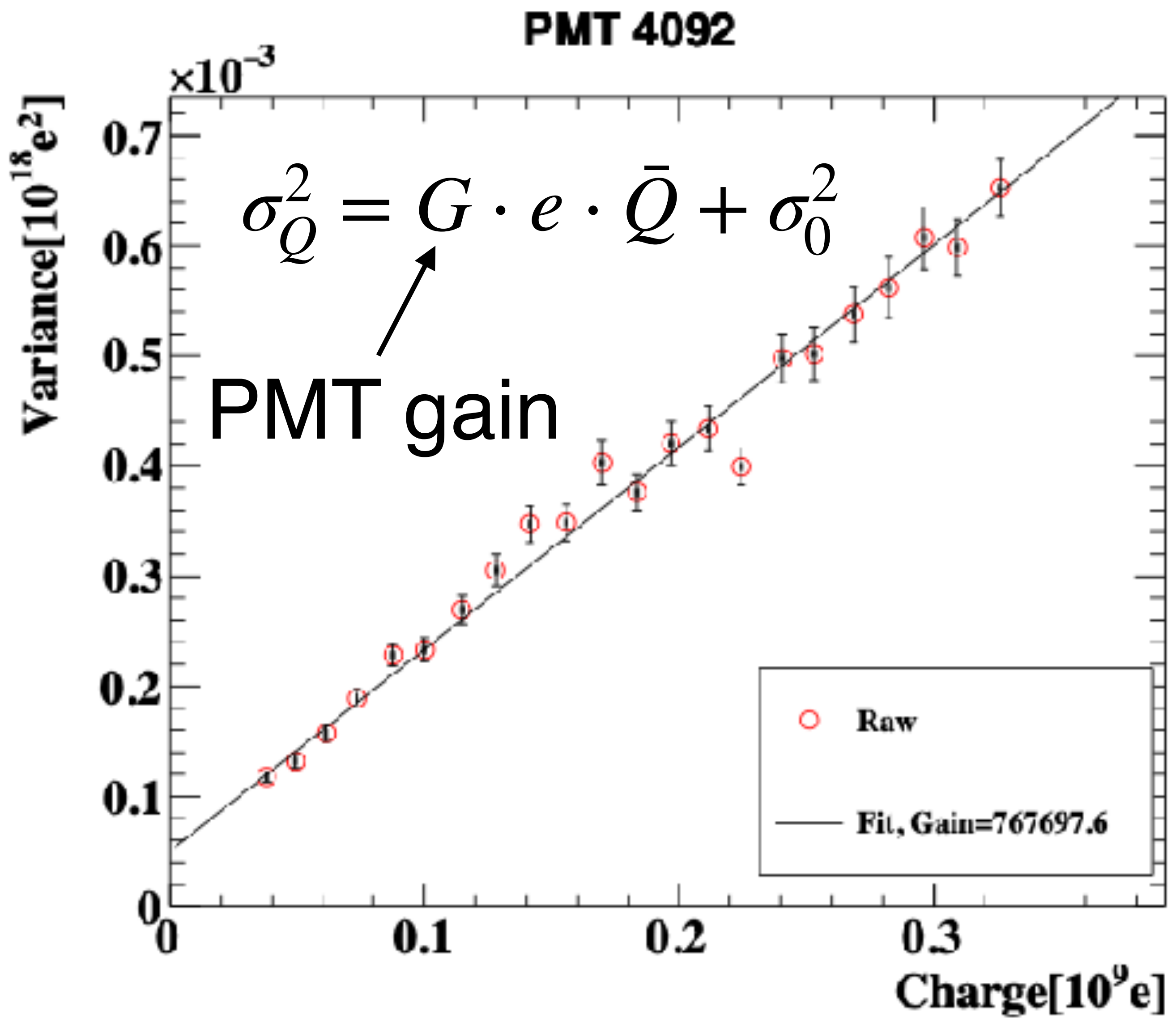




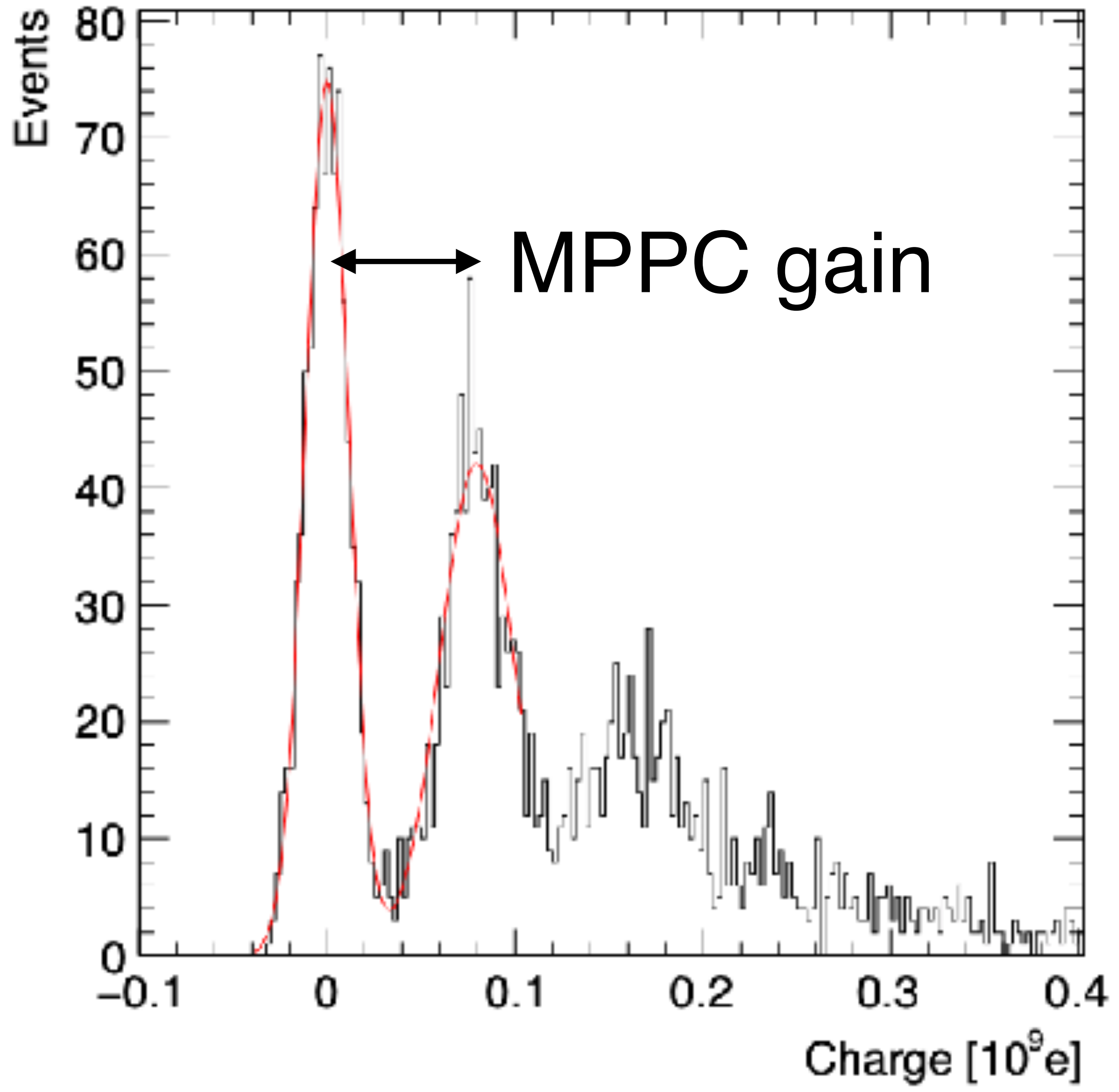
LED

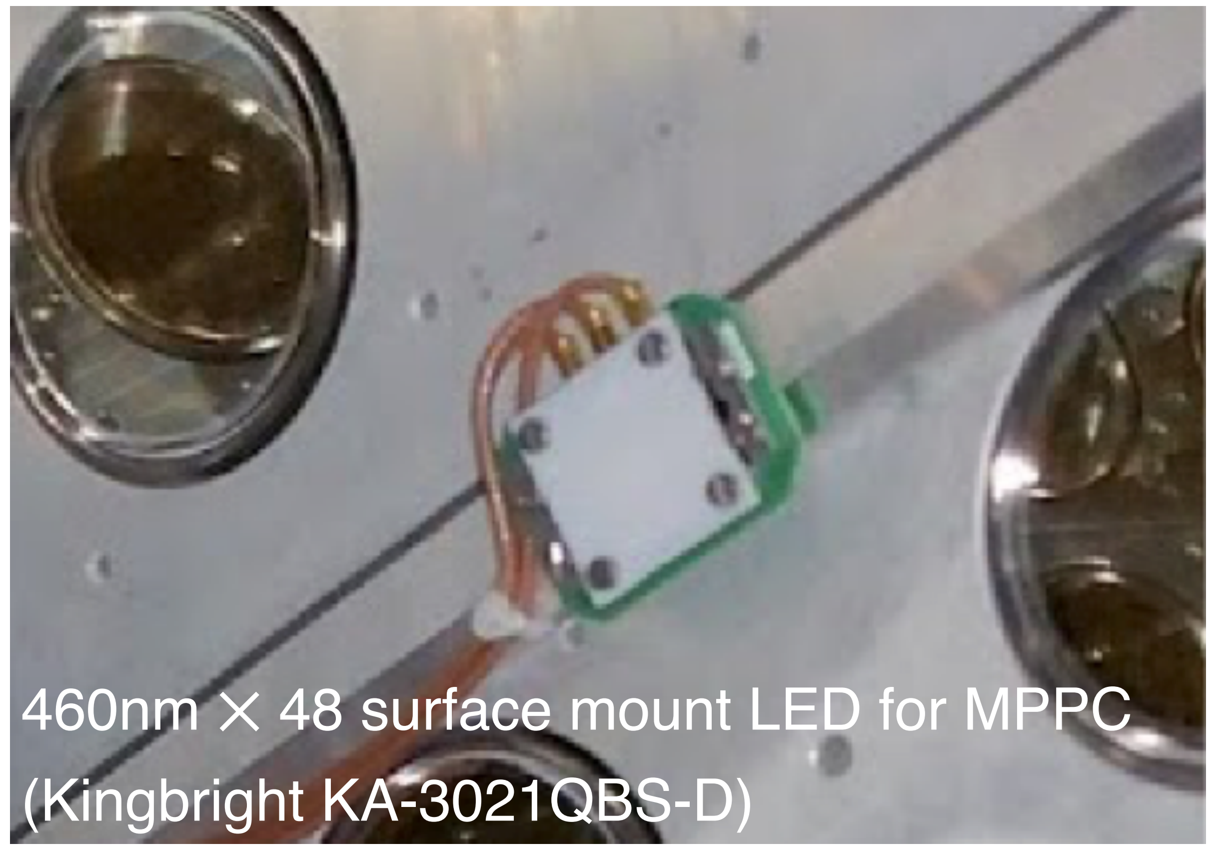


Variance vs Charge mean
w/ different LED intensities



Charge spectrum
w/ low intensity LED

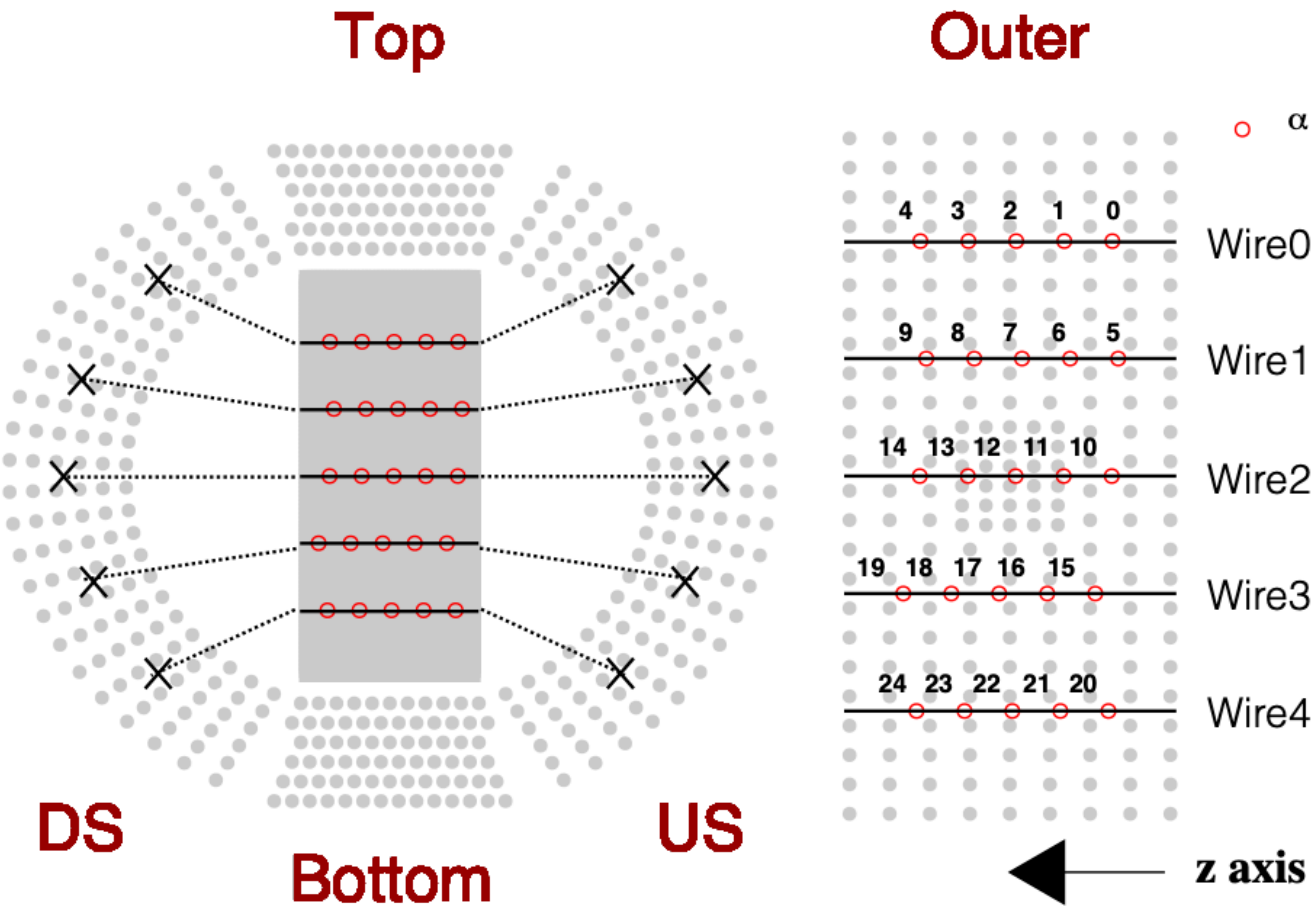



460nm × 48 surface mount LED for MPPC
(Kingbright KA-3021QBS-D)

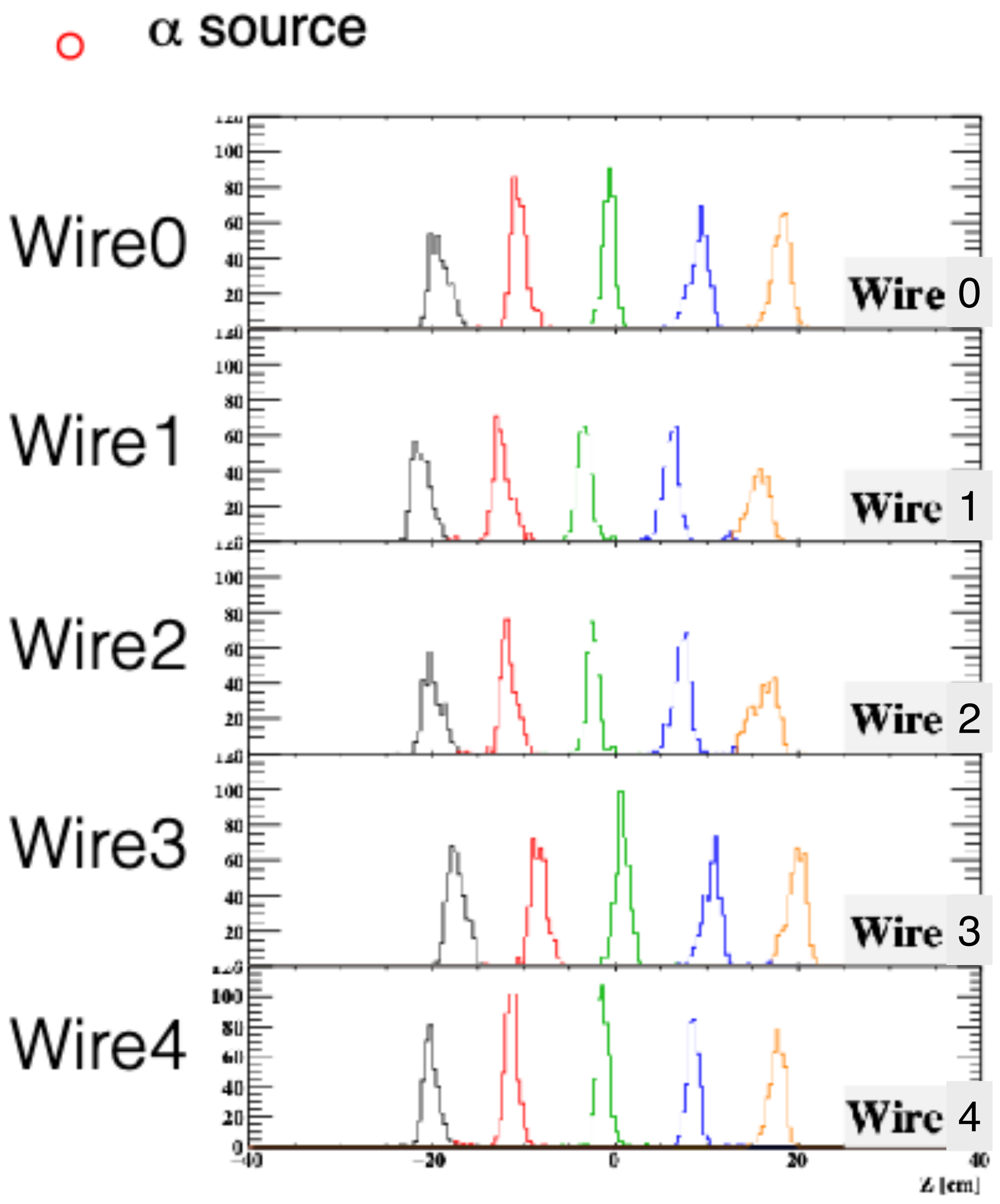

470nm × 36 for PMT
(Toyoda Gosei E1L493B1A02)

- PMT/MPPC gain, MPPC cross talk/after pulse measurements
- PMT gain decreases under muon beam
- LEDs can be installed to PIONEER easily

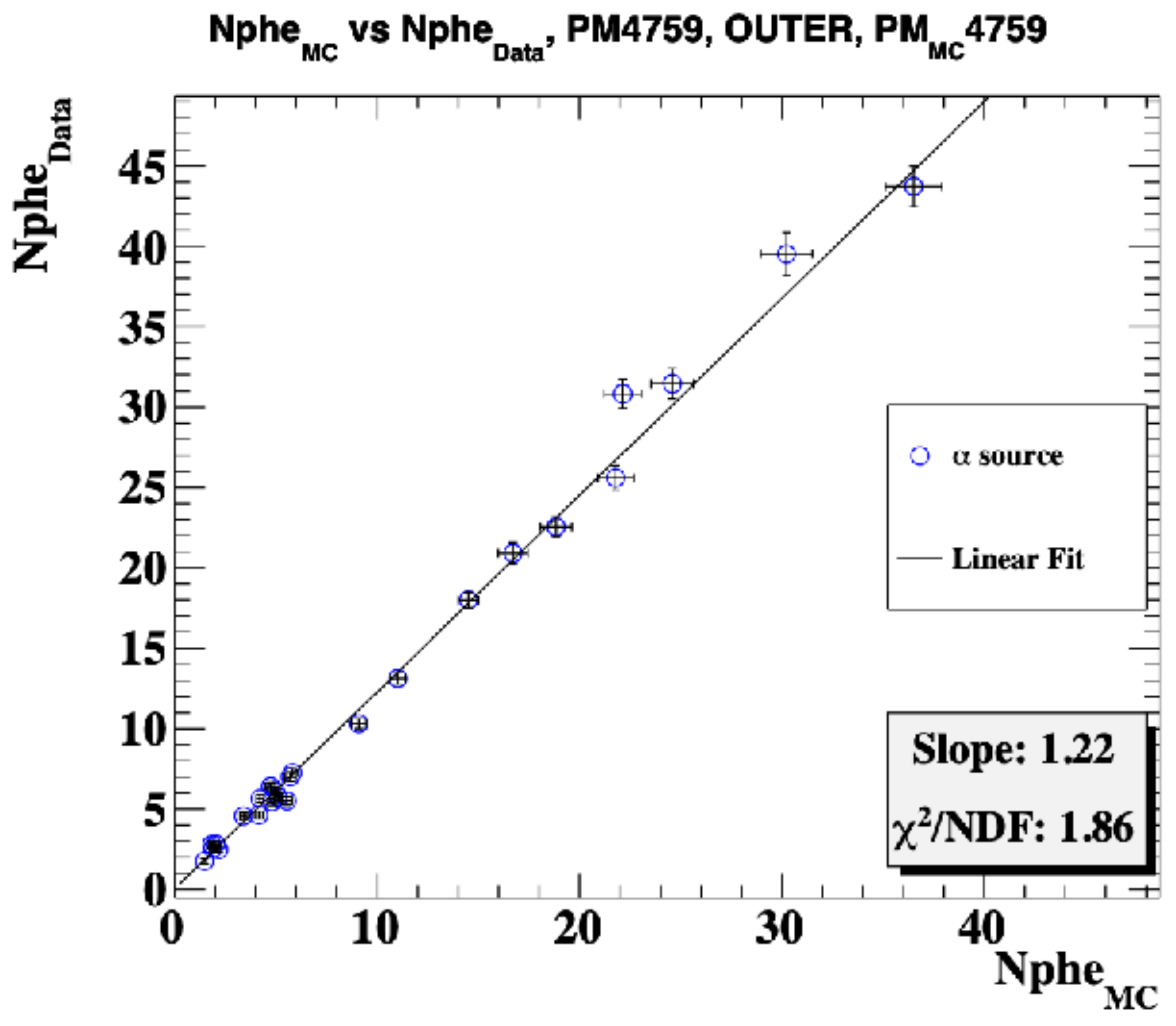
α sources

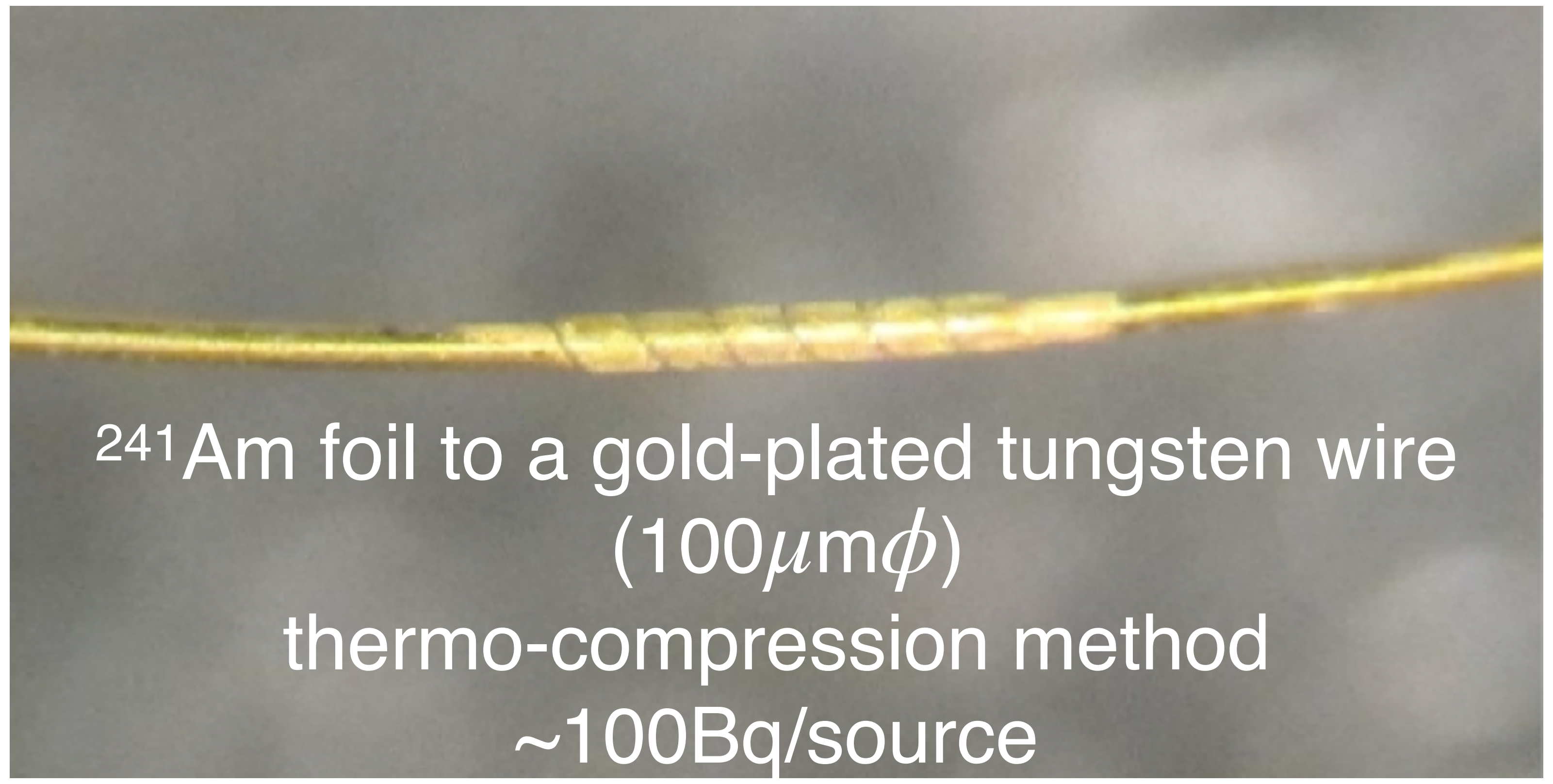


Reconstructed z position of α sources



Ratio of data/MC for a PMT

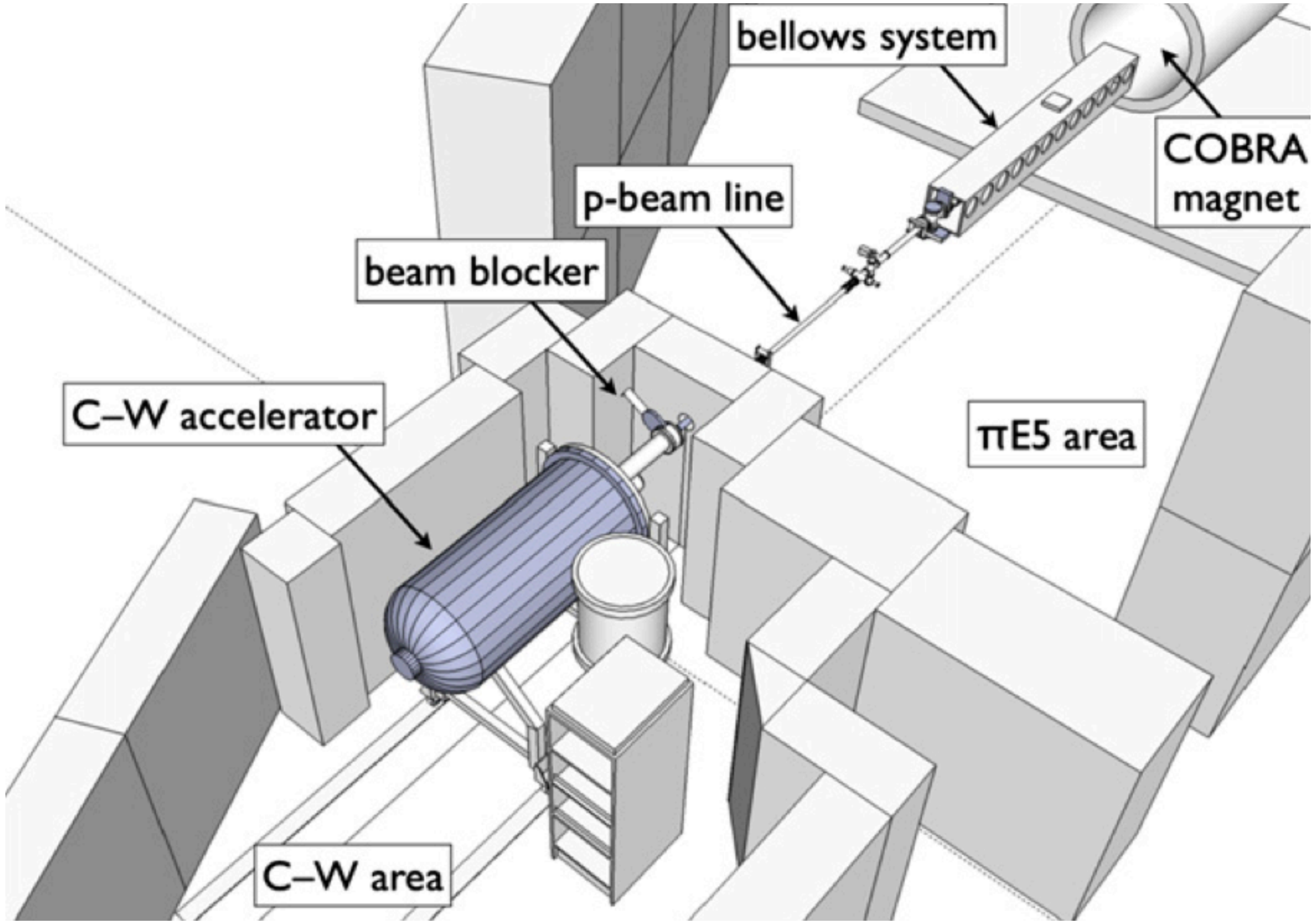


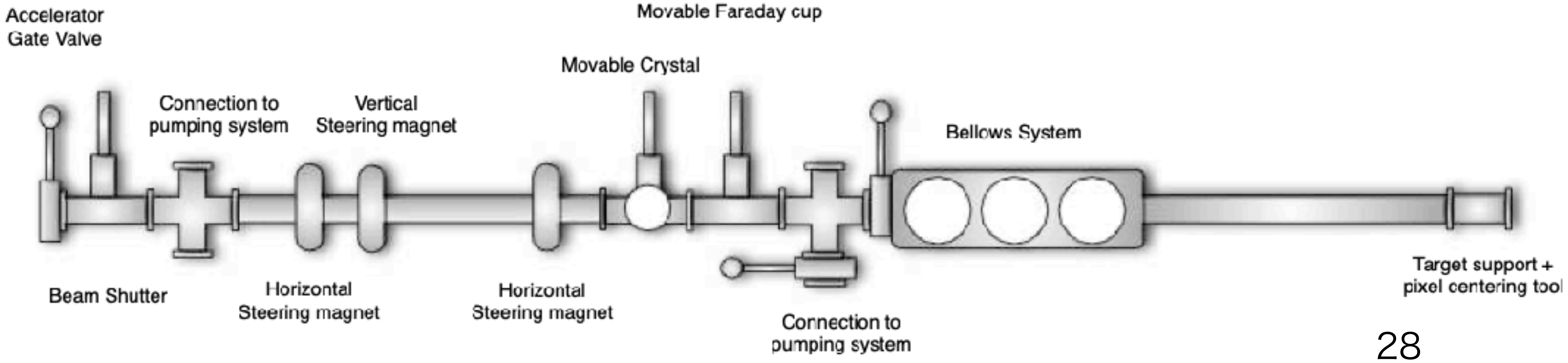


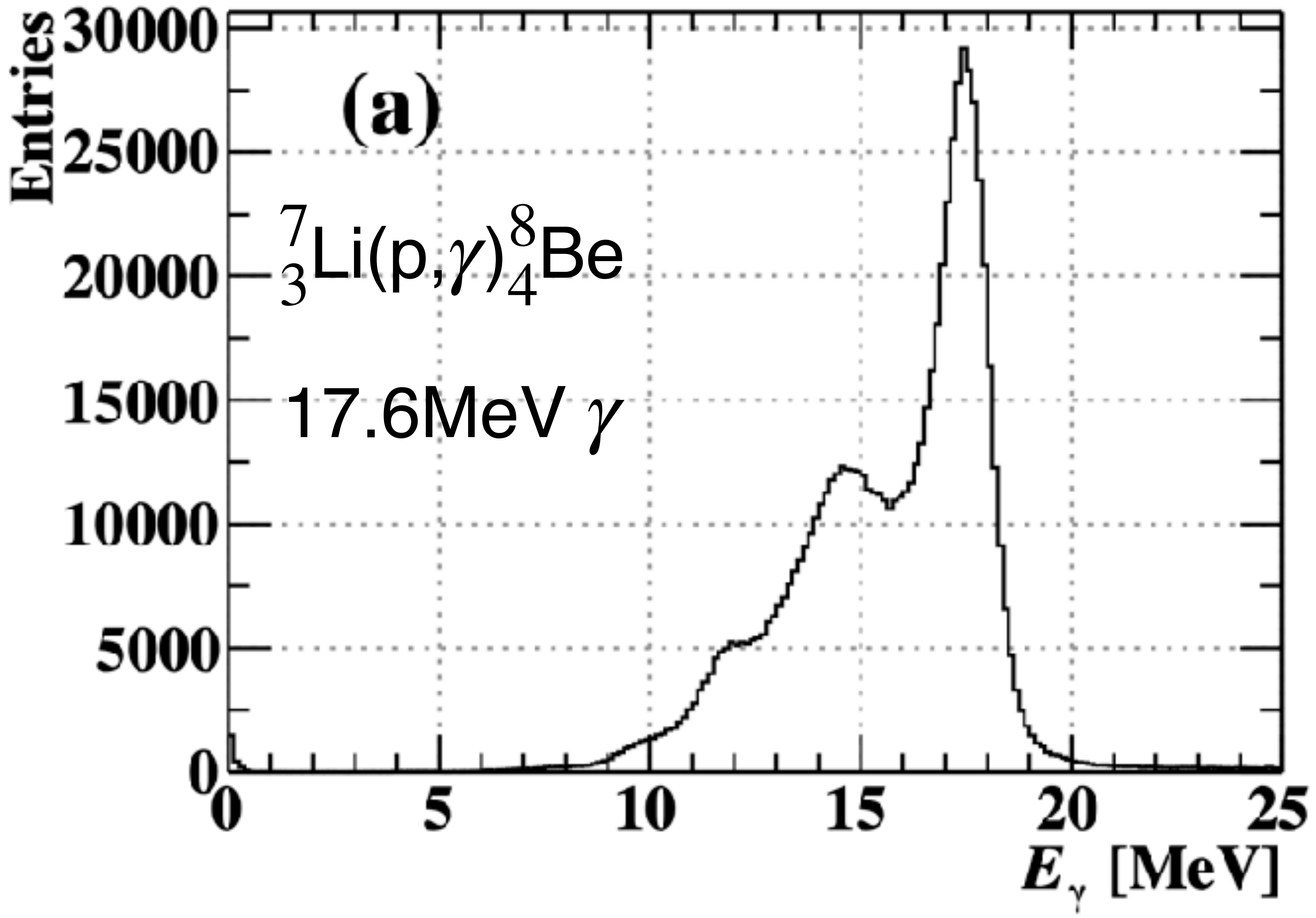
- PMT QE/MPPC PDE including LXe light yield extracted from ^{241}Am α sources
- MPPC PDE decreases under muon beam

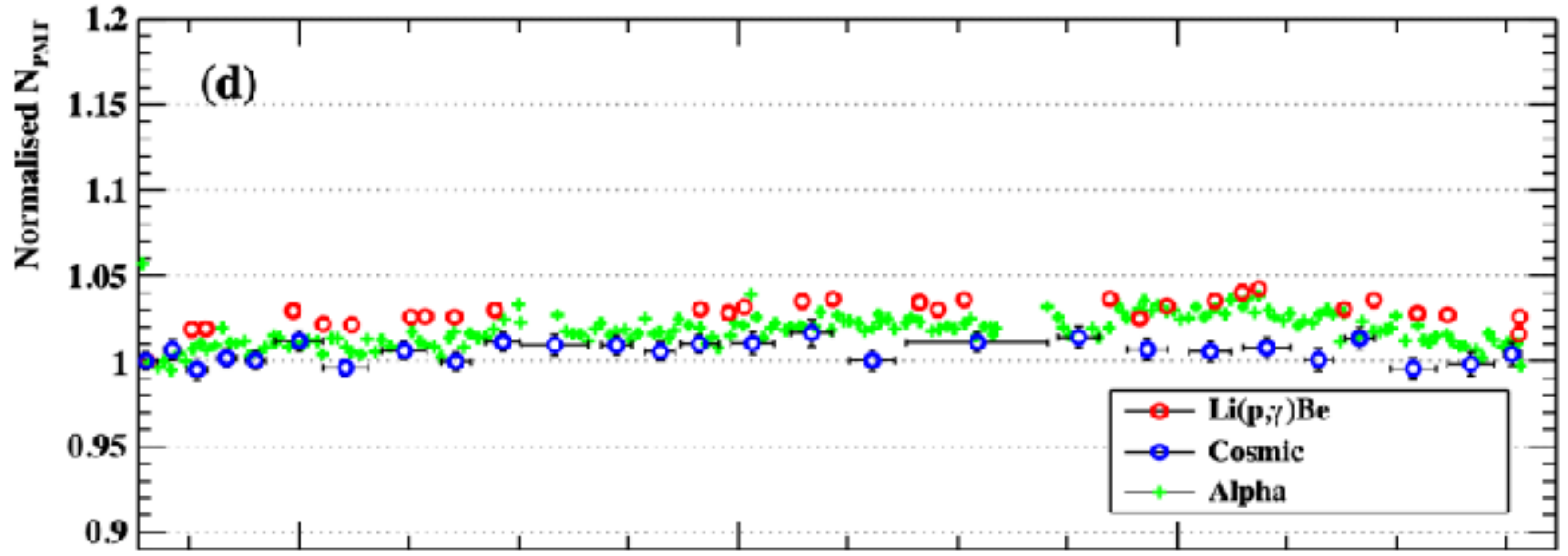
- Better to install α sources in the PIONEER. The problem might be the source production (Sorad Ltd. which produced the MEG α sources does not exist anymore)

Cockcroft Walton proton accelerator + Li target





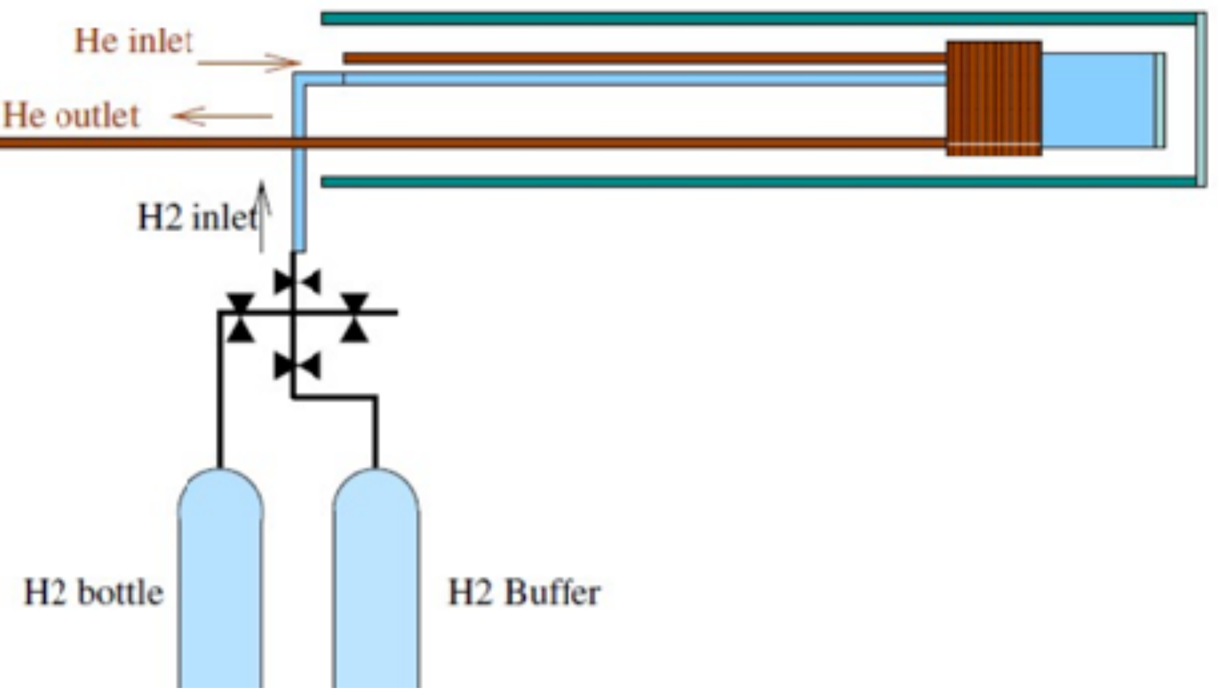


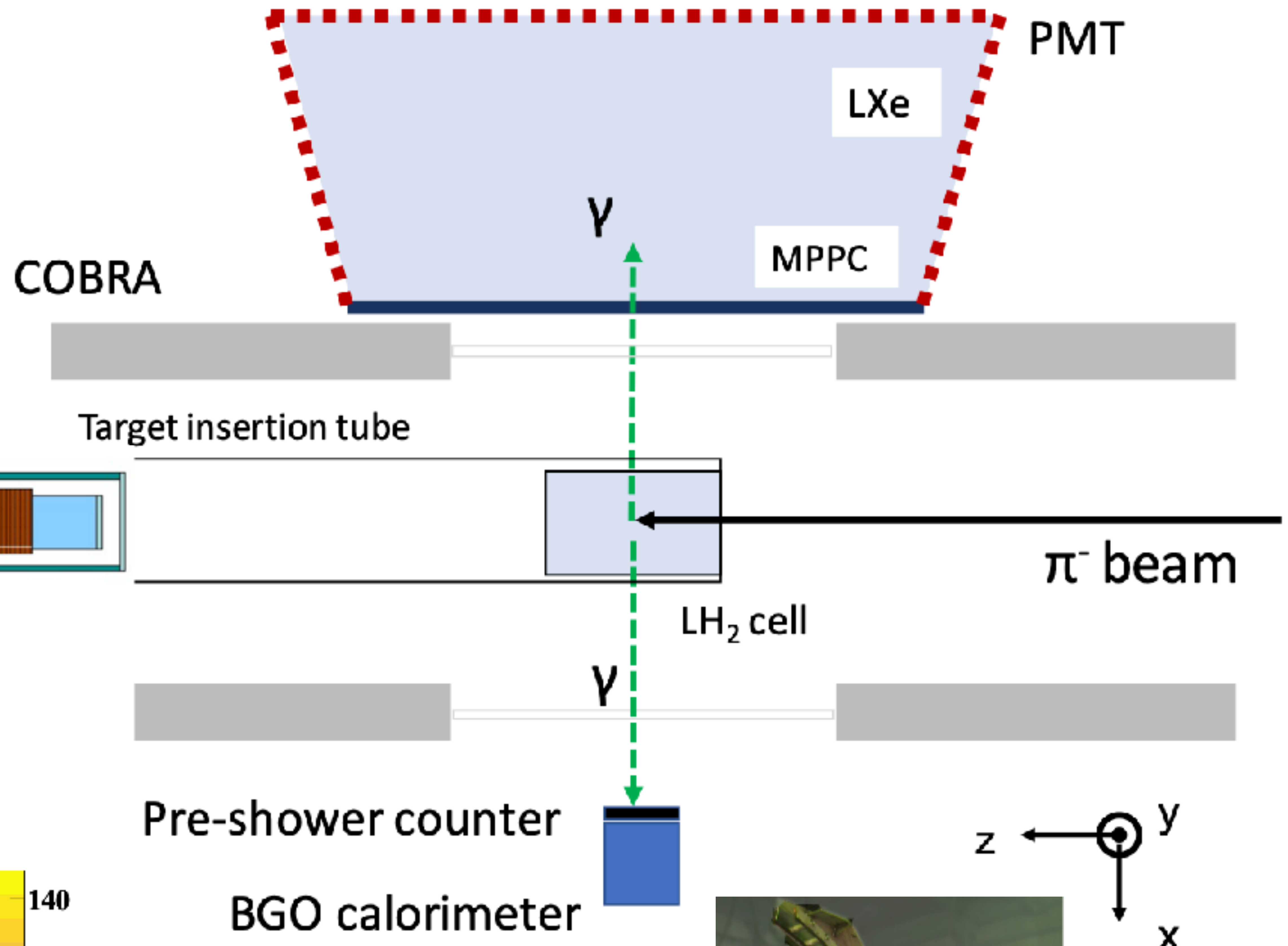


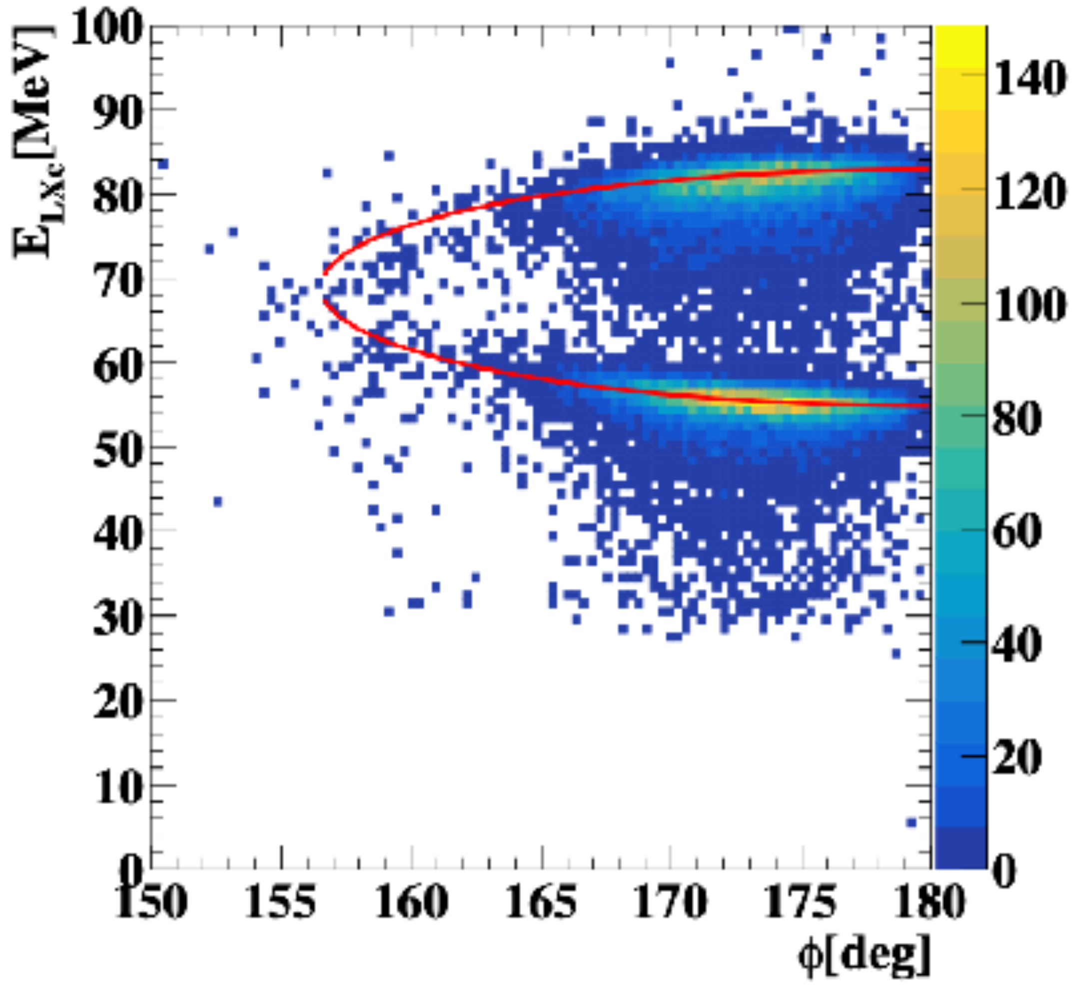
- γ energy scale and resolution monitoring at 17.6MeV three times per week

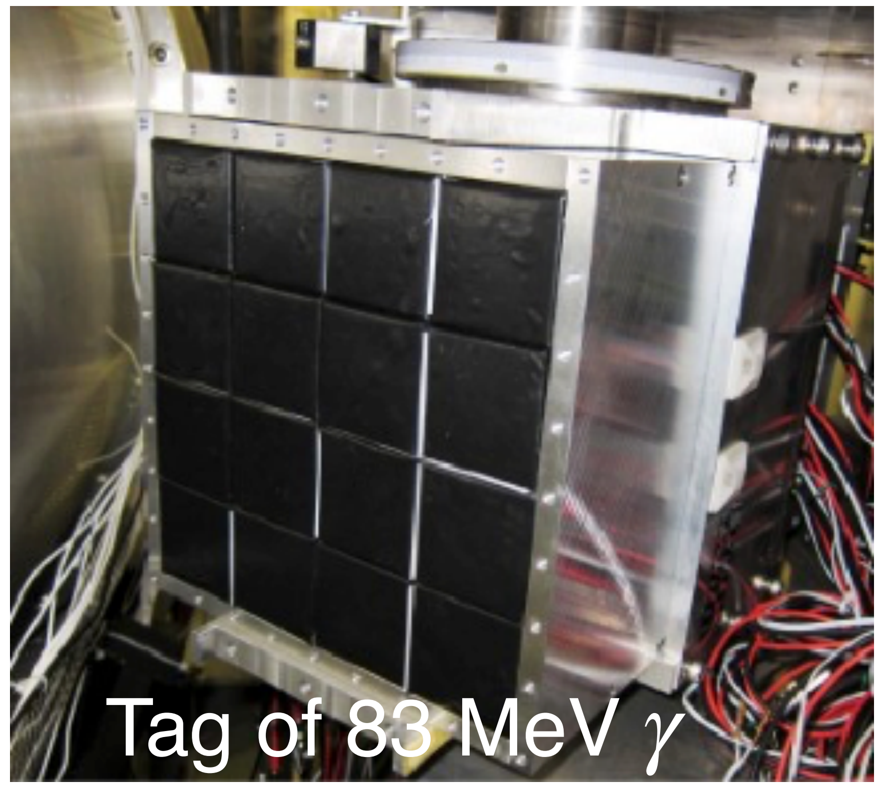
Back-to-back photons from π^0 decay

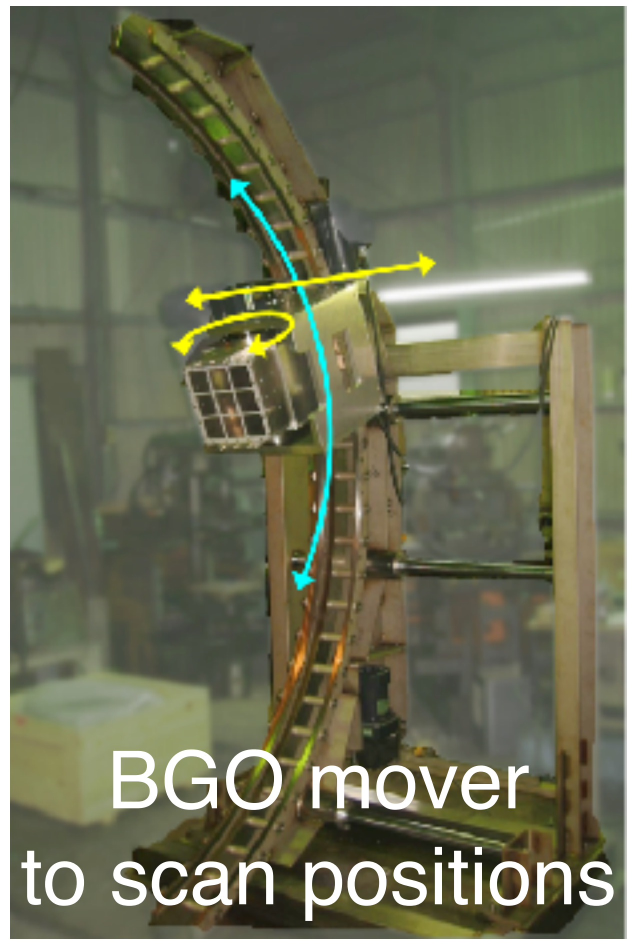
$$\pi^- + p \rightarrow \pi^0 + n$$
$$\rightarrow \gamma + \gamma + n$$

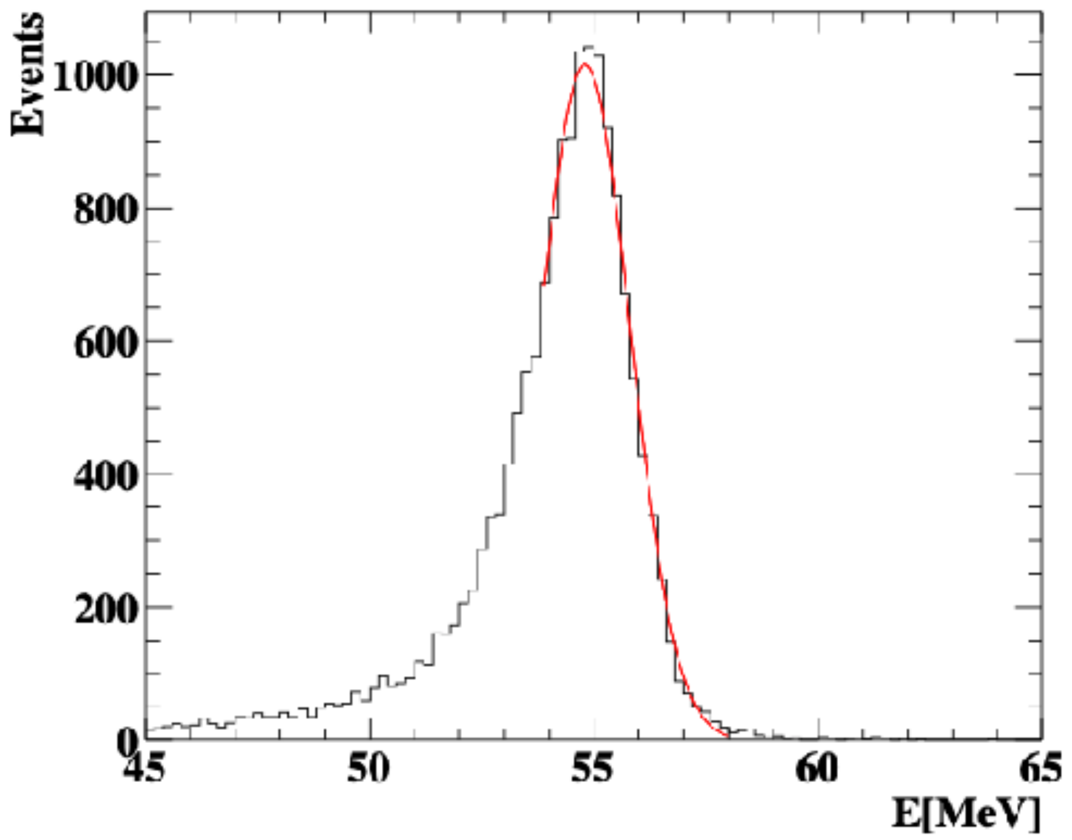


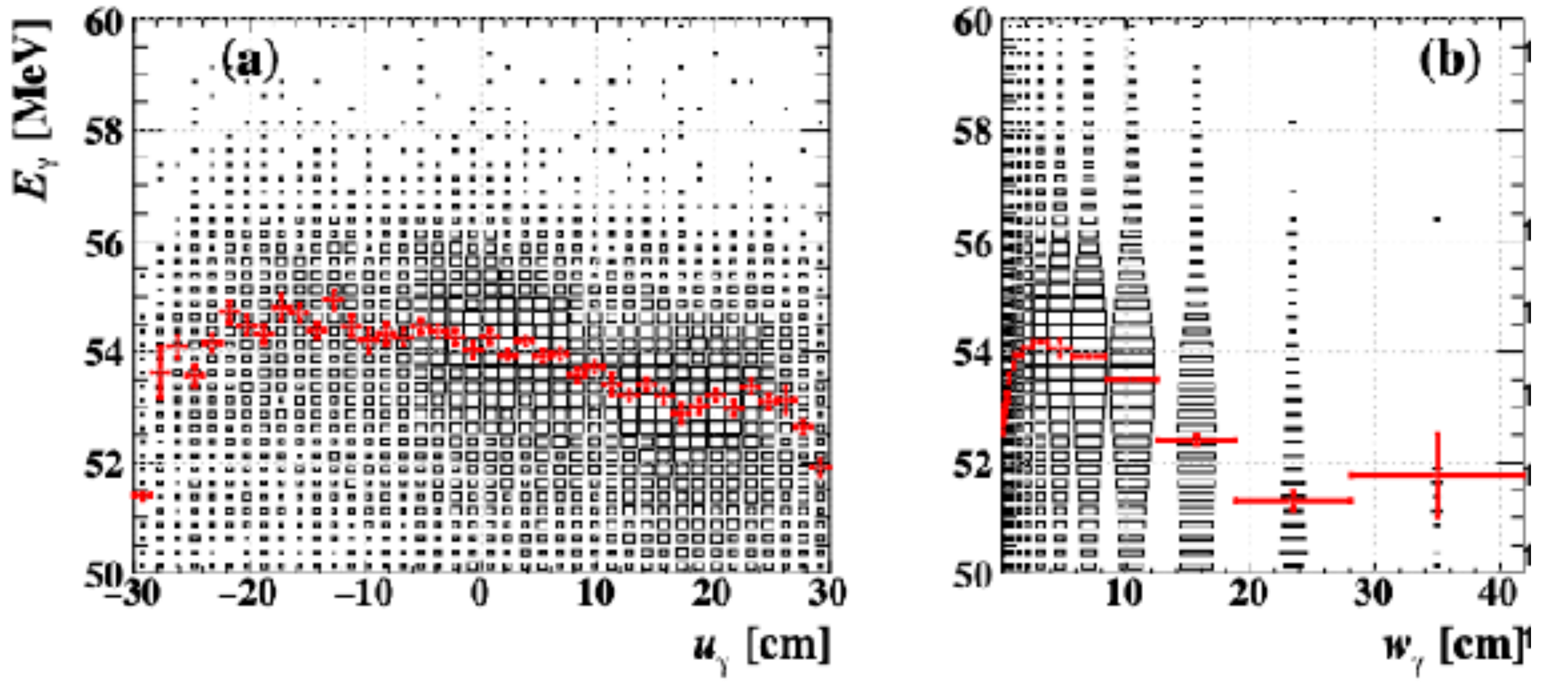


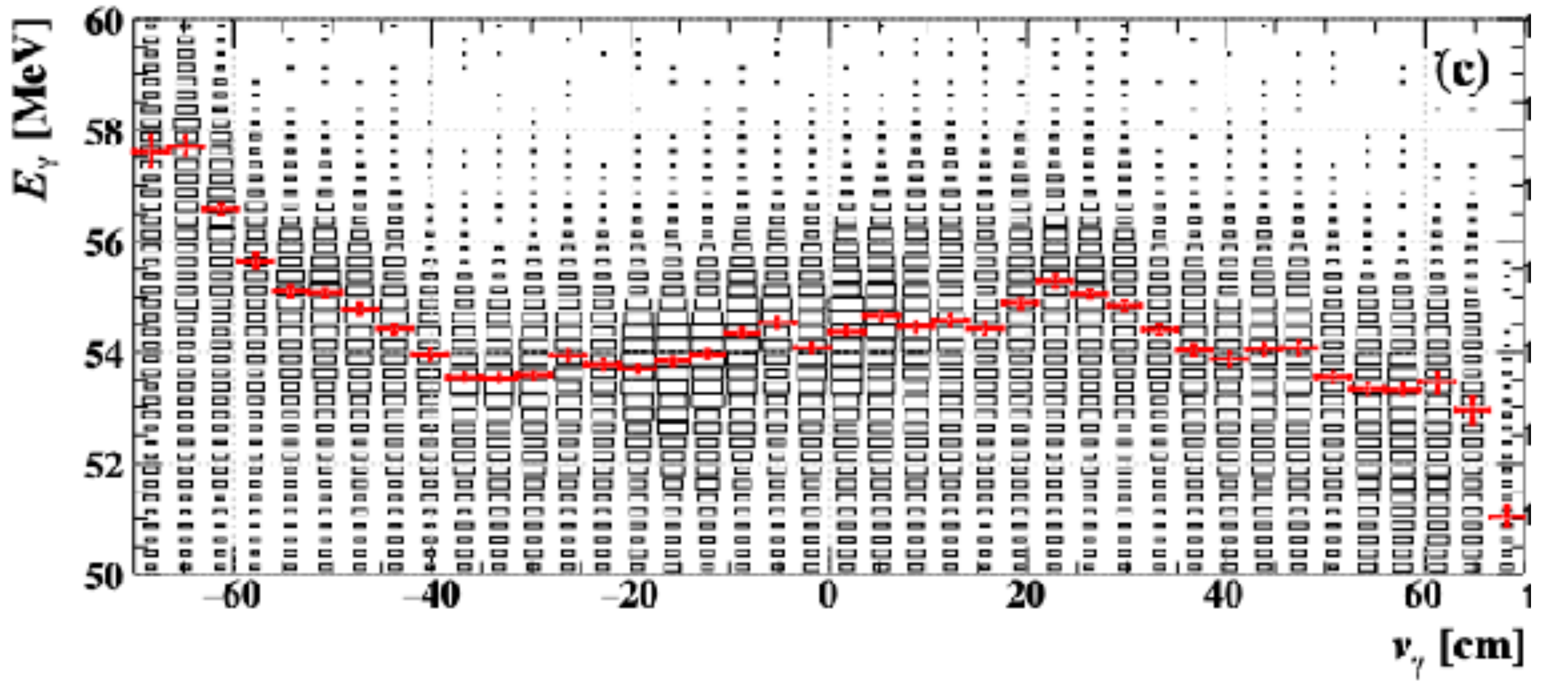








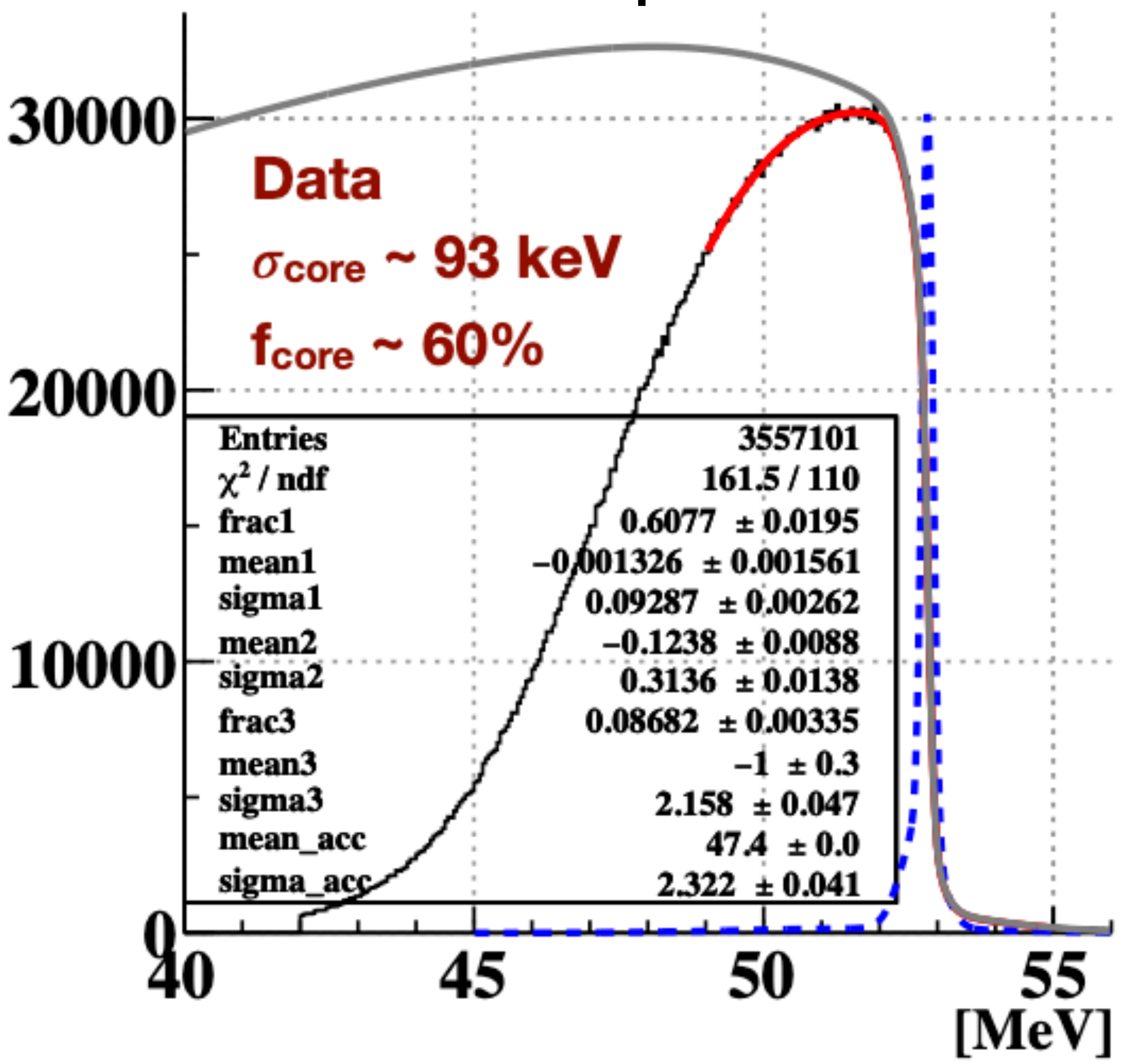


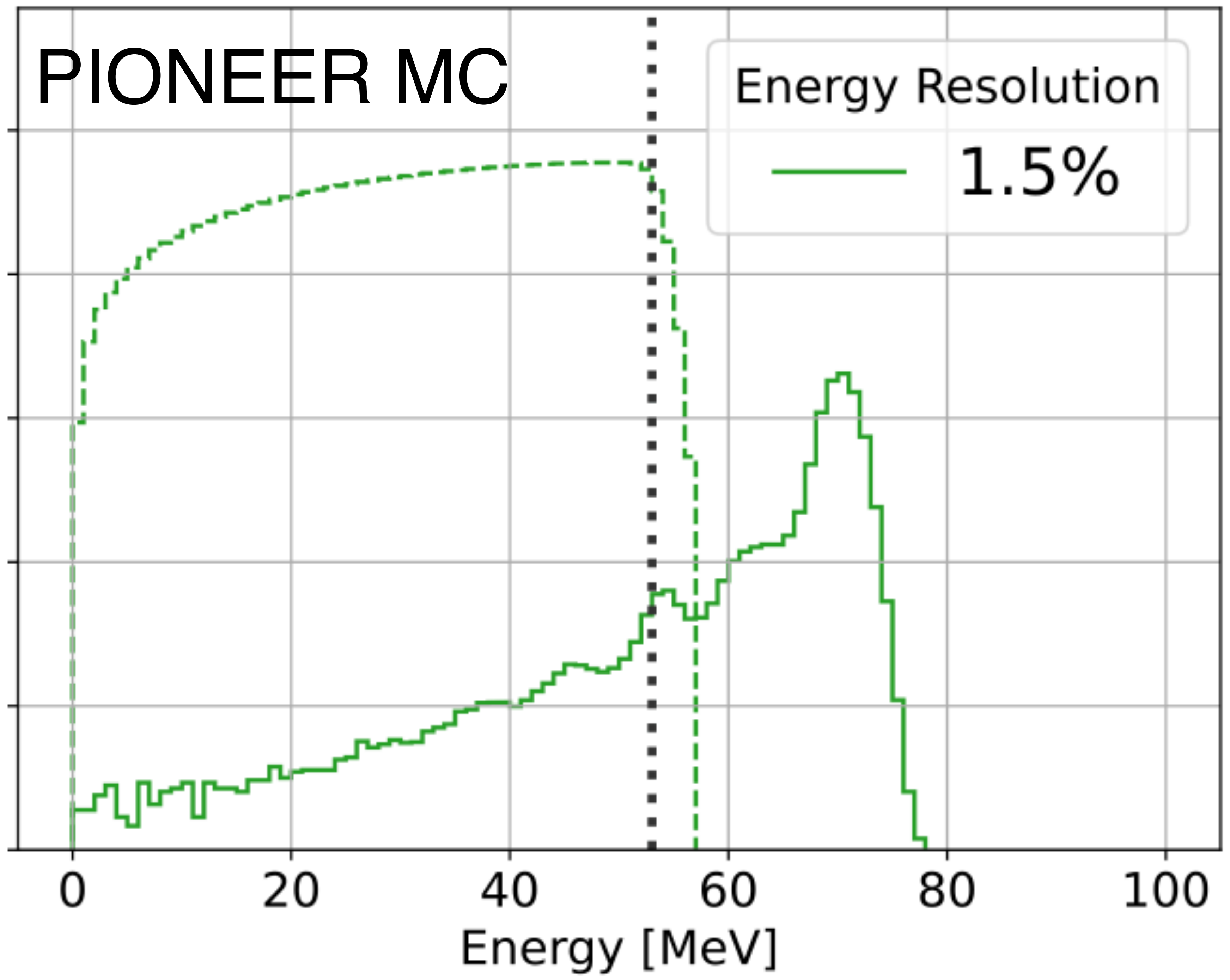


- γ energy scale, uniformity and resolution measurements at 55MeV once per year

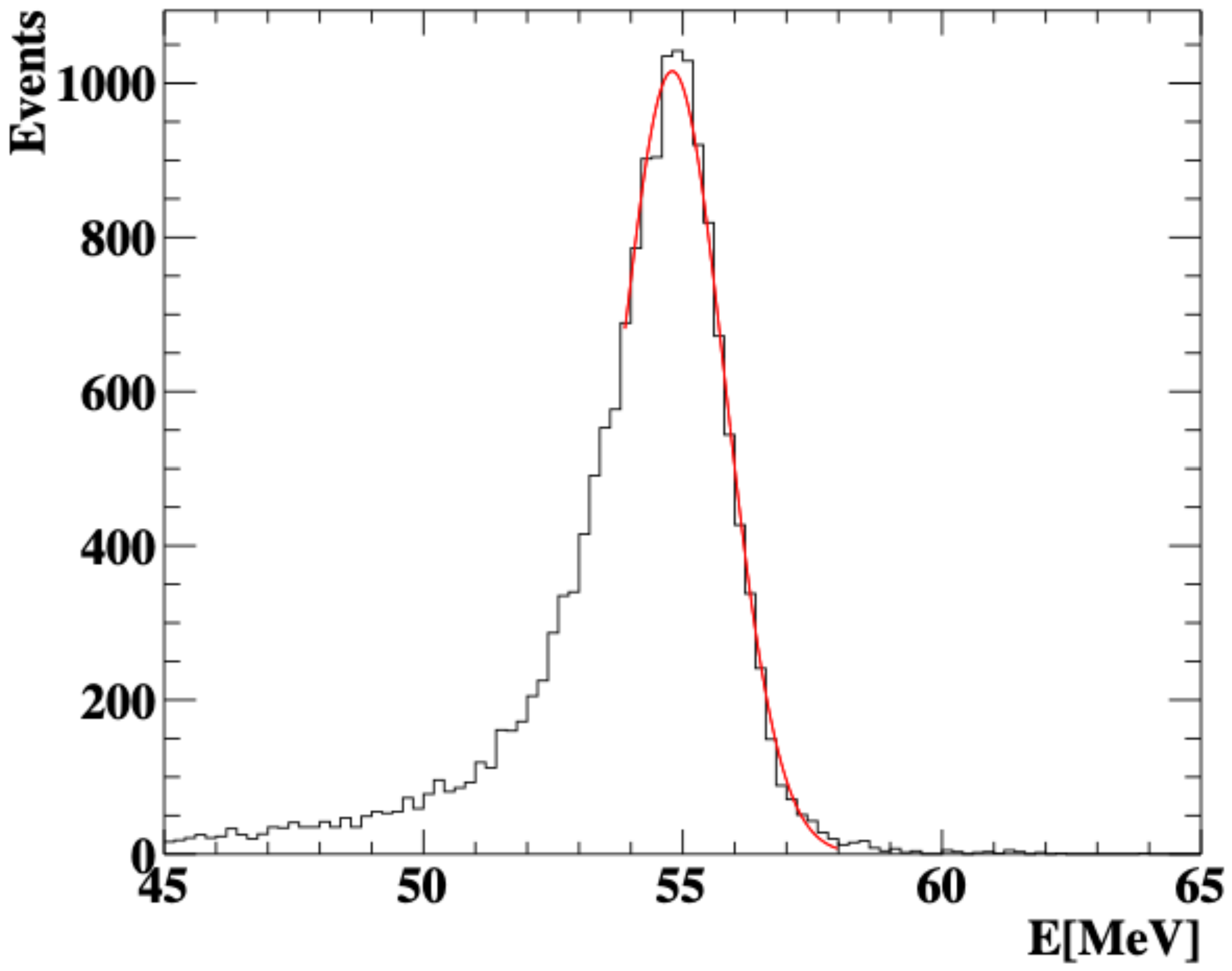
PIONEER case

MEG e^+ spectrum





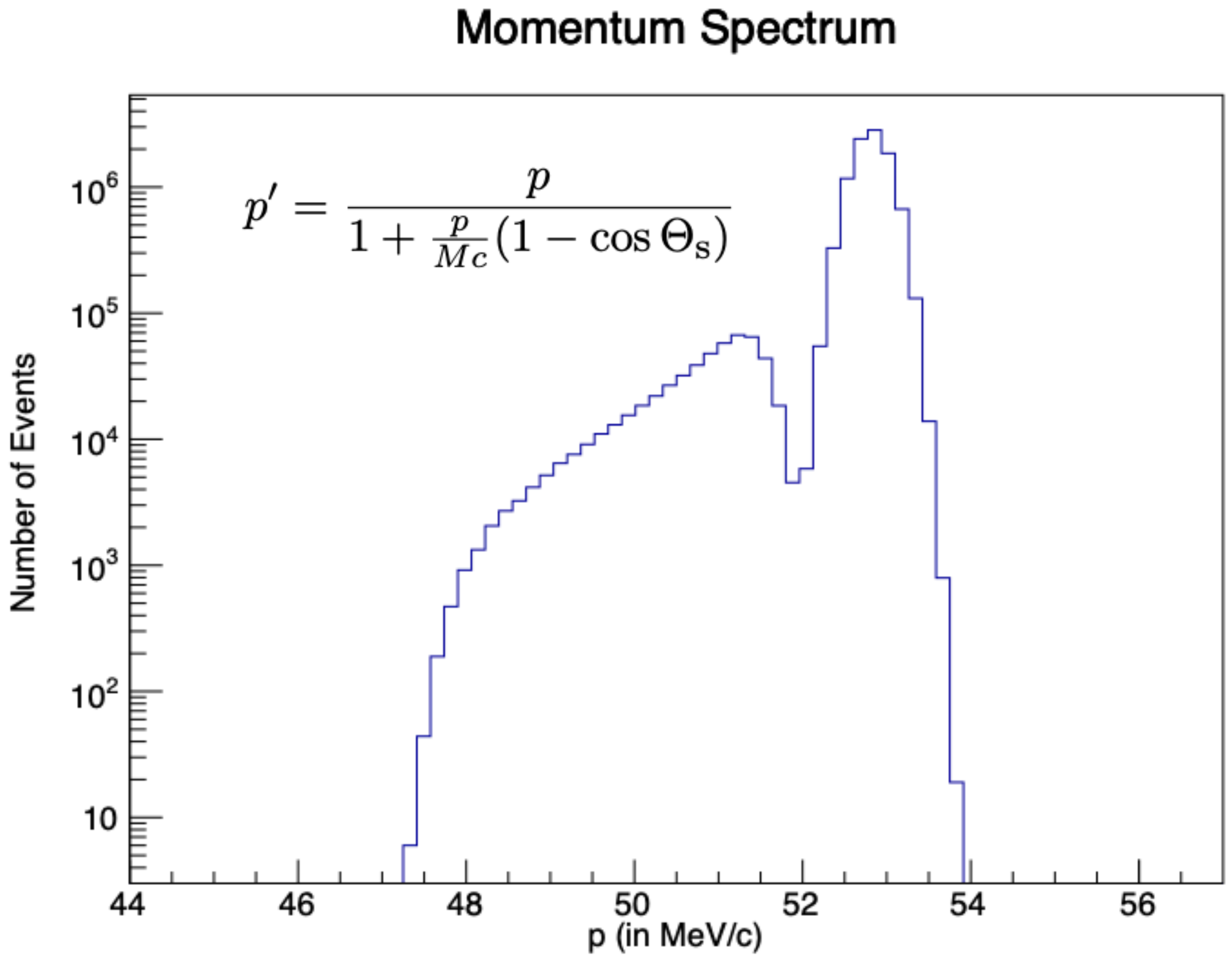
MEG γ spectrum

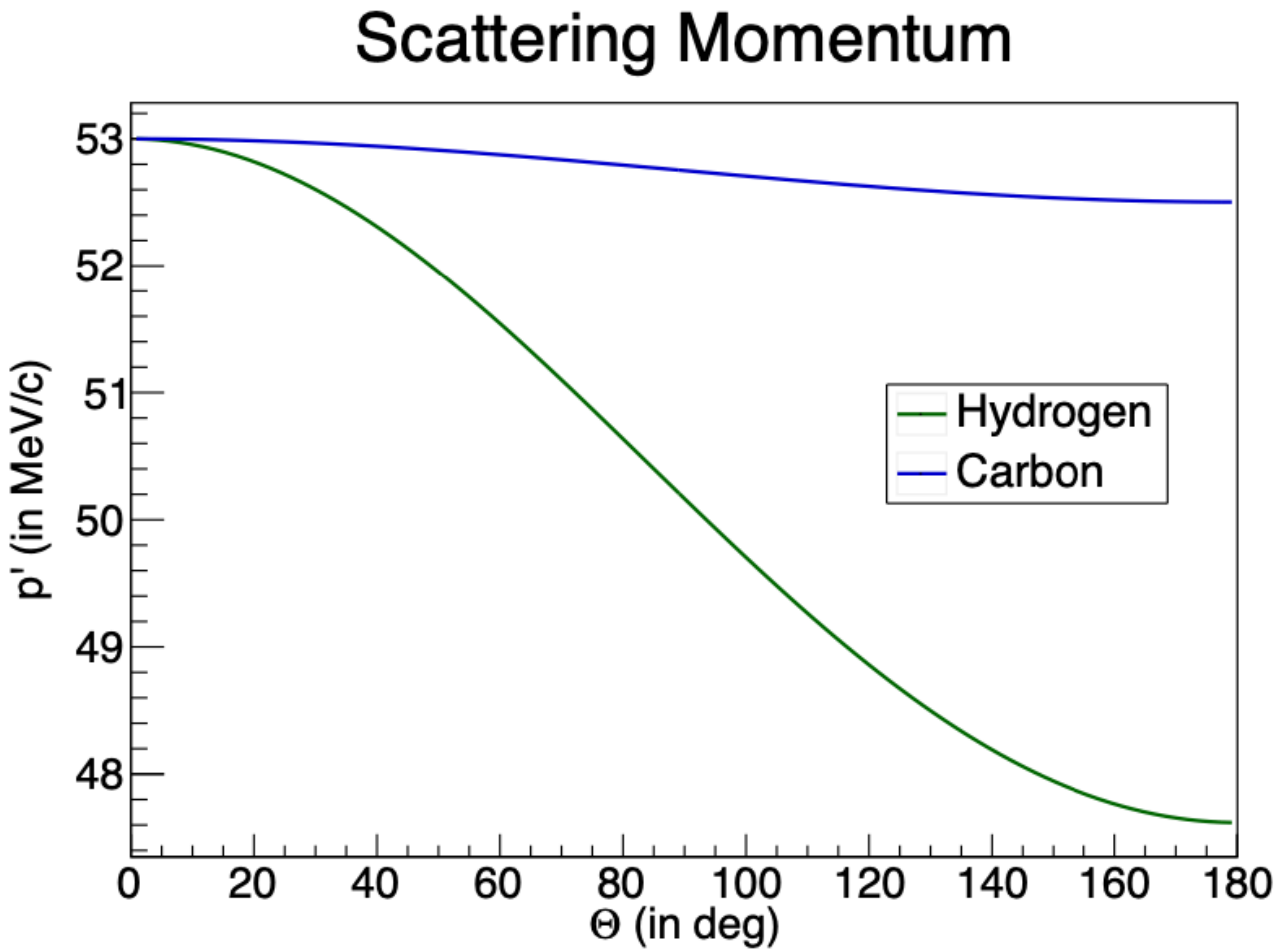


- Energy scale, resolution can be directly extracted from 70 MeV peak and from 53MeV Michel edge in PIONEER (robust calibration possible)
- Sensor calibration, LXe light yield monitoring by LED, α crucial
- Other γ calibration sources (AmBe 4.4MeV, Ni 9MeV, Li 17.6MeV, π^0 55MeV, Cosmics) are optional
- Positron incident position can be measured by trackers
- Each photo sensor time offset might be available from the LGAD time as a reference

Tail from Mott scattering?

Patrick PhD thesis (2021)





A spread of $\sigma = 0.2\,\mathrm{MeV/c}$ on the incoming momentum of the beam is assumed.