The X17 search with the MEG-II apparatus at PSI

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Presentation

- Hicham Benmansour: From Paris, France - French-Algerian
- **Bachelor's Degree** in Engineering at *Ecole Centrale de Lyon*, France
- **Master's Degree** in Engineering at *Ecole Centrale de Lyon*, France
- **Master's Degree** in Physics at *Queen's University*, Canada

—> Master Thesis on DEAP-3600, dark matter direct detection experiment
—> studies of WLS fluorescence

- Since September 2021: **PhD** in Particle Physics at *University of Pisa*, Italy

—> PhD Thesis on the MEG-II experiment: hands-on work and data analysis

Courses and Lectures

- **Particle Physics** - exam: July 4th
- **Instrumentation for Fundamental Interaction Physics** - exam: July 4th
- **Italian, A2 level** - exam: June 14th

Conferences and trainings

- International Workshop on Cosmic-Ray Muography, Ghent - November 2021
- 15th Pisa meeting on Advanced Detectors, Elba - May 2022
- International Conference on High Energy Physics XLI, Bologna - July 2022
- PSI Particle Physics Summer School - Vision and Precision - Zuoz (CH) - September 2022

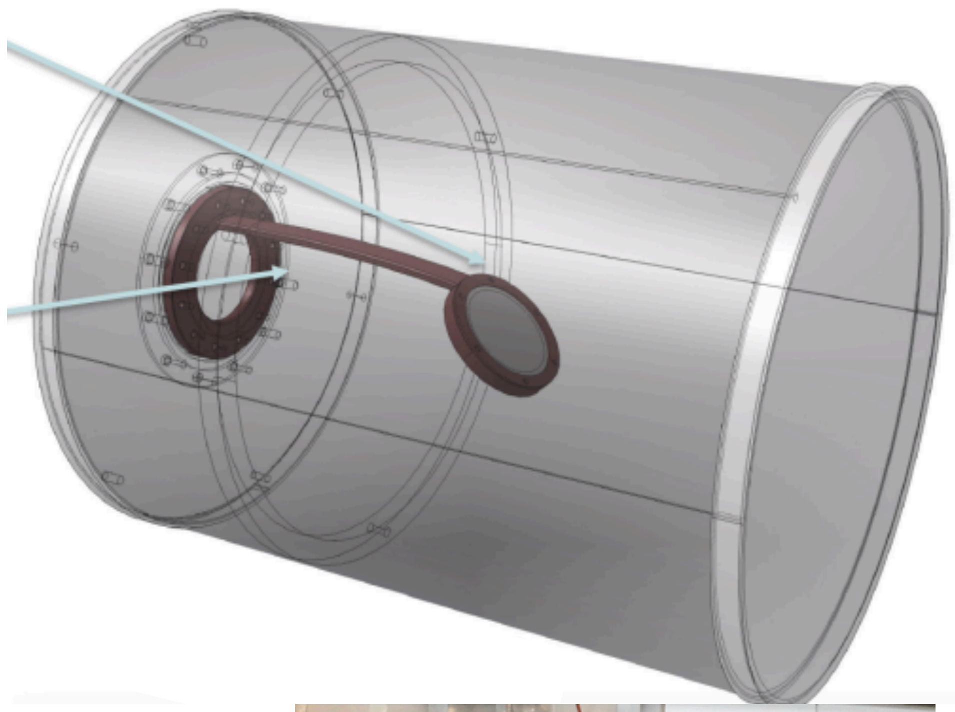
Outline

1) The X17 anomaly at ATOMKI

2) The X17 search with MEG-II

3) **Data collection and analysis**

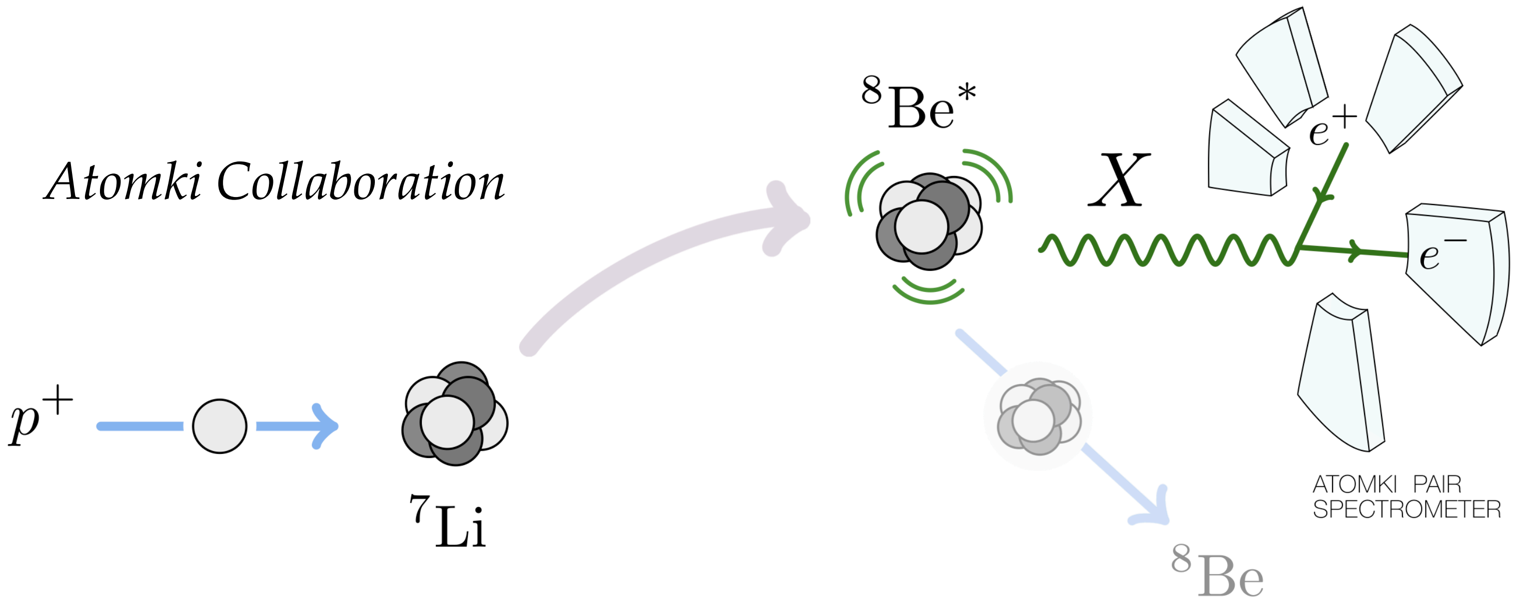
- Analysis procedure
- Gamma rate from BGO analysis
- Trigger rate estimate
- Optimized trigger
- Significance estimate
- First observables from data



1) The X17 anomaly at ATOMKI

The Beryllium Anomaly

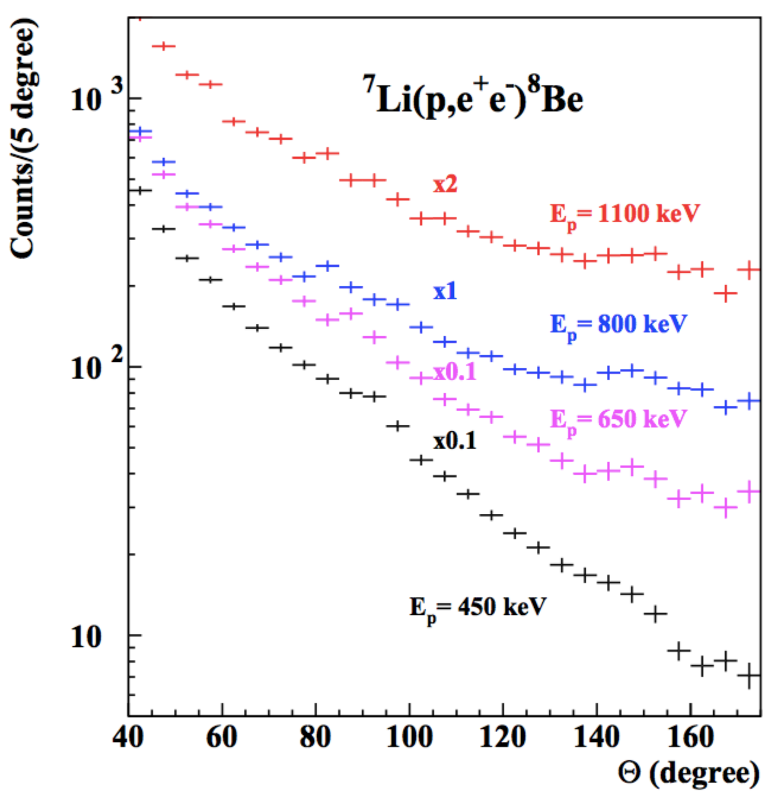
Atomki Collaboration

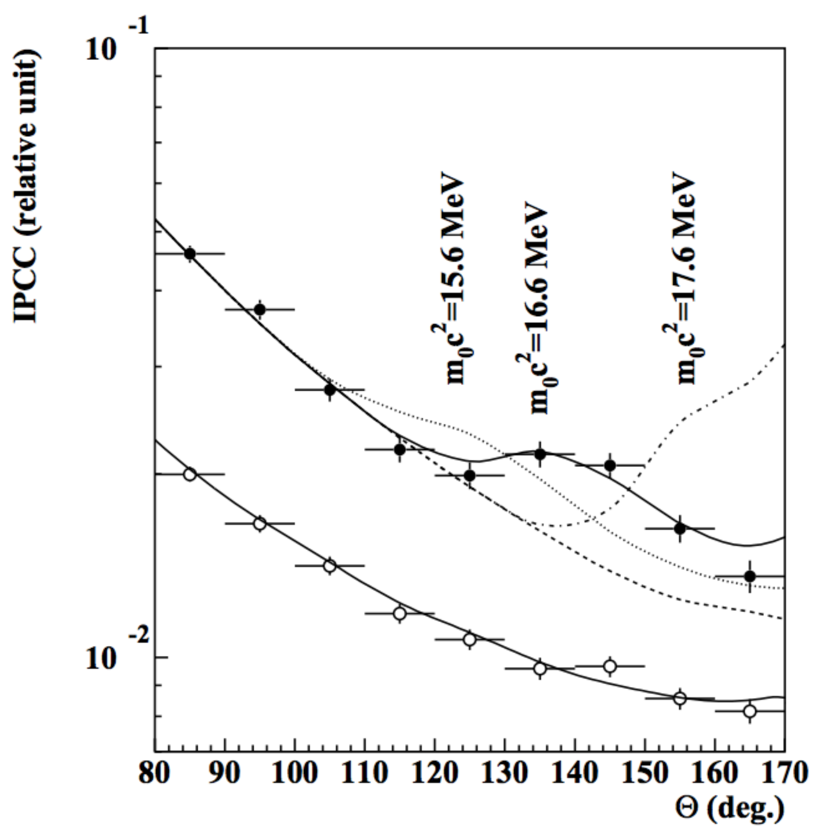


$^7\text{Li}(p, e^+e^-)^8\text{Be}$ studied at

$E_p = 450,\ 650,\ 800,\ 1100$ keV

→ e+/e- energy sum and angular correlation Θ





- Internal Pair Conversion (IPC) distribution shows excess at $\Theta \sim 140°$ at several beam energies

→ decay of a light particle emitted during proton capture

→ best fit $m_X = 16.95\ \text{MeV/c}^2$, $BR(X) = 6 \times 10^{-6}$

→ protophobic vector boson X17? mediator of a fifth force?

arXiv:2205.07744 Phys. Rev. Lett. 116, 042501 Phys. Rev. D 95, 035017

2) The X17 search with MEG-II

The MEG-II experiment

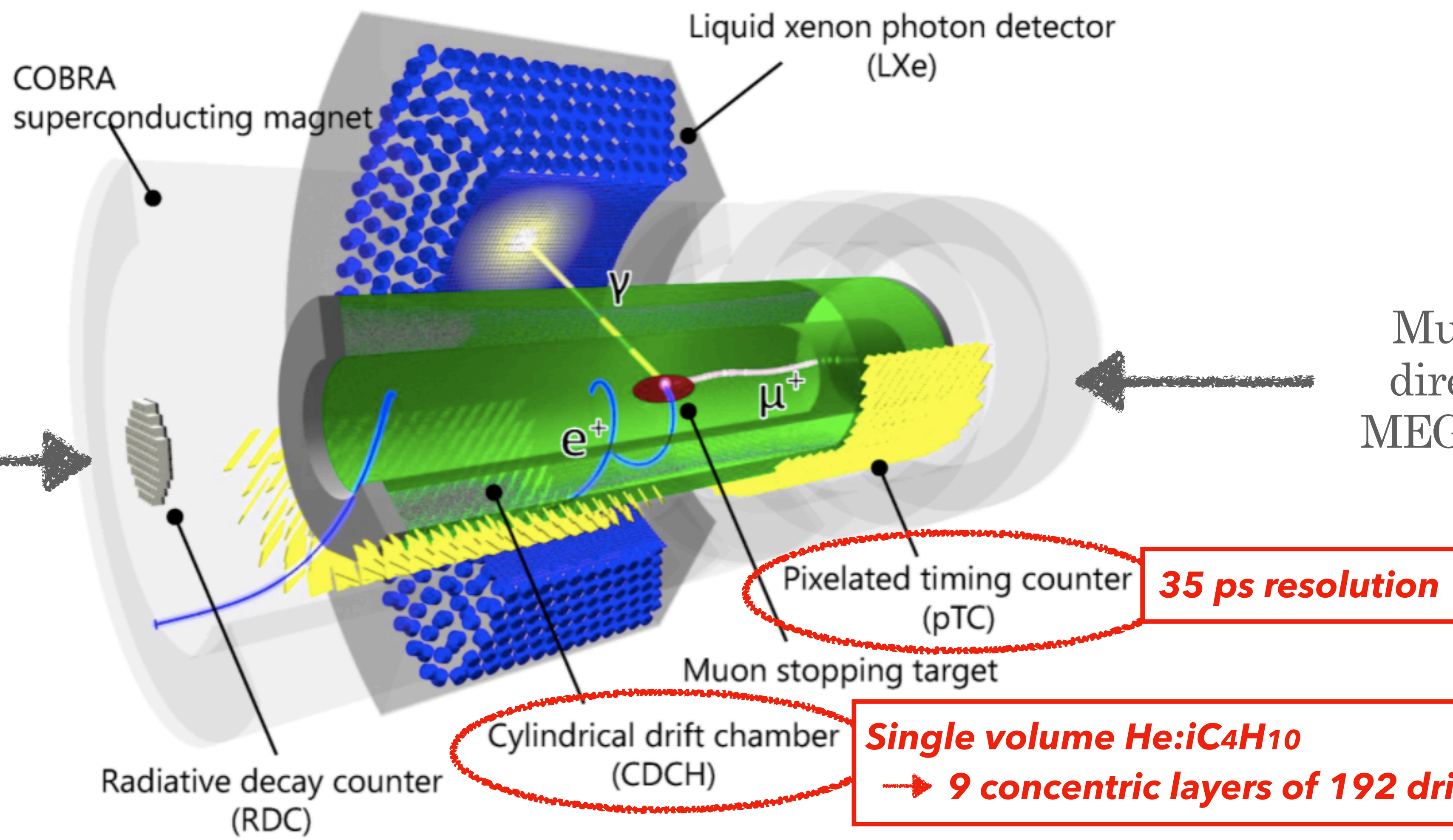
- MEG-II experiment searches for charged lepton flavour violating decay: $\mu \longrightarrow e\gamma$
- 1 order of magnitude sensitivity improvement wrt MEG: $BR(\mu \longrightarrow e\gamma) \rightarrow 6 \times 10^{-14}$

Eur. Phys. J. C, 76(8):434

Eur. Phys. J. C 78, 380

MEG-II results from an intense upgrade program

Proton beam direction for X17 search



Muon beam direction for MEG-II search

- The new MEG-II highly performing spectrometer can be used for X17-boson search:
  - → X17-dedicated target in place of the muon target
  - → MEG-II CW accelerator as proton beam
  - → adjusted magnetic field
  - → gamma auxiliary detectors
  - → optimized TDAQ

3) Data collection and analysis

- X17 runs from February 10th to February 22nd: sample of 90 M events
  → 10-17: LiF target (55 M) → 17-22: LiPON target (35 M)

- Signal

17 MeV neutral boson:
*Li + p –> Be + **X17***
***X17** –> e+ e-*

- Two types of backgrounds

IPC = Internal Pair Conversion
–> direct e+/e- pair creation

EPC = External Pair Conversion
–> gamma conversion outside nucleus

Analysis procedure

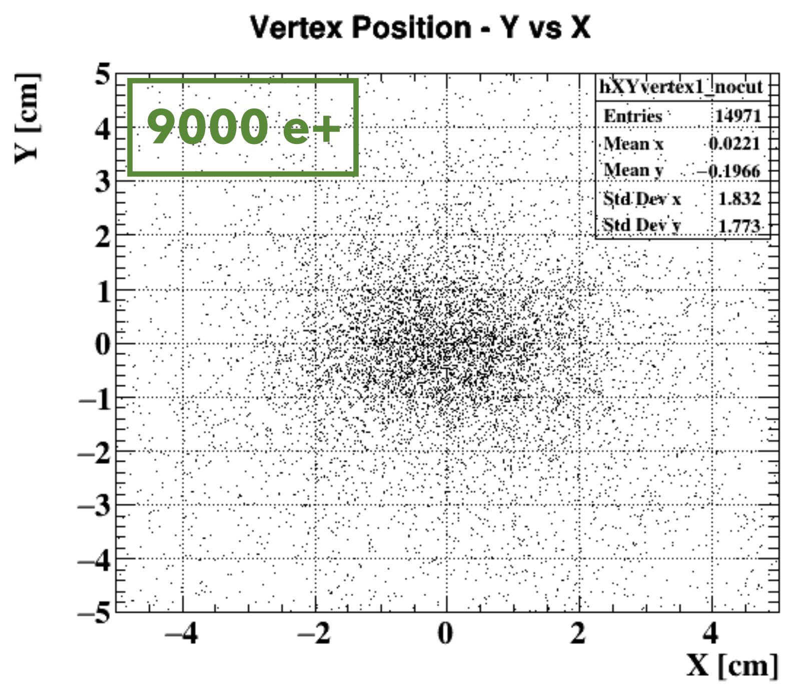
→ Electron and positron tracking
→ Example of reconstructed pairs

Analysis procedure: from MC

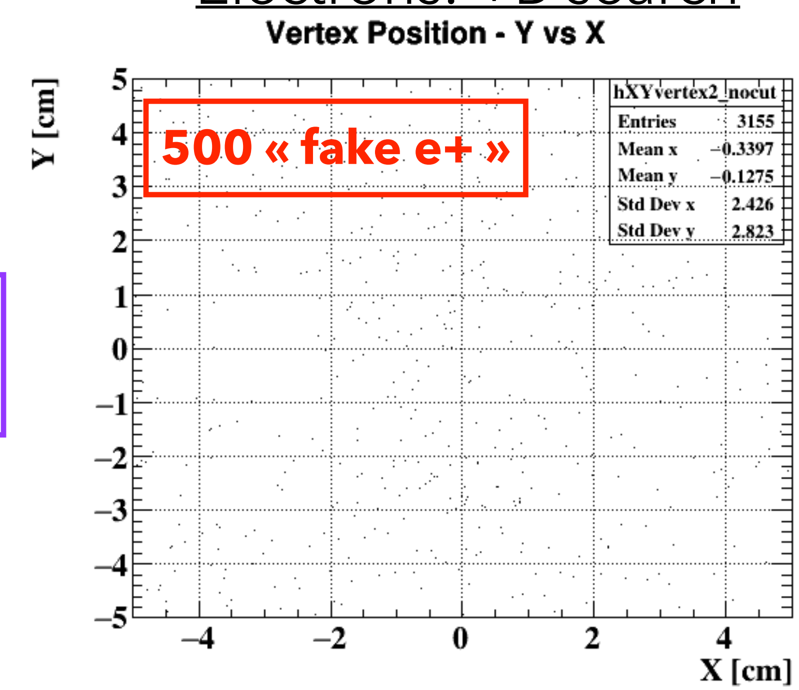
MEG reconstruction focuses on e+. It was adapted for e-. Performance was evaluated.

MC: 9 MeV e+/e-

Positrons: +B search



Electrons: +B search

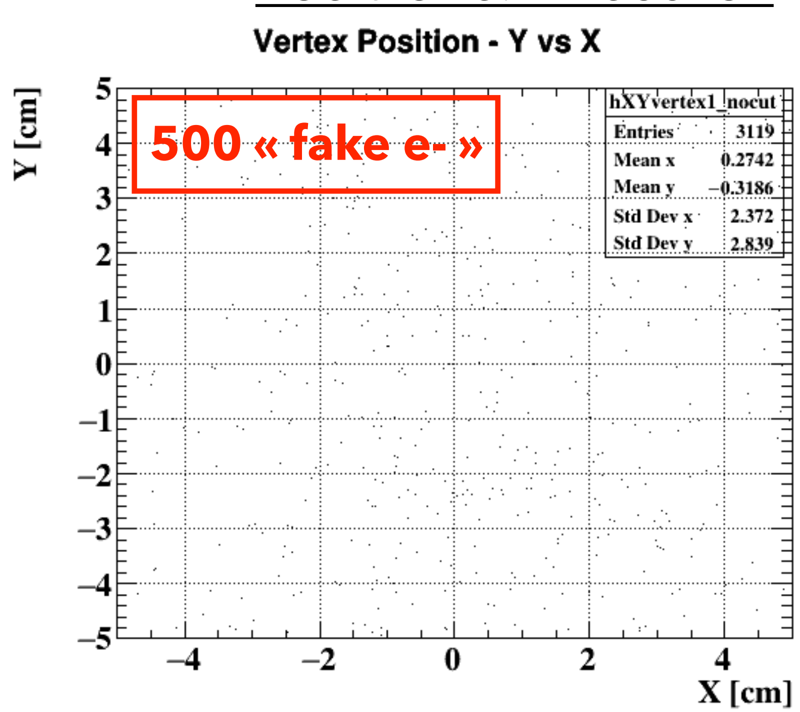


5% relative contamination

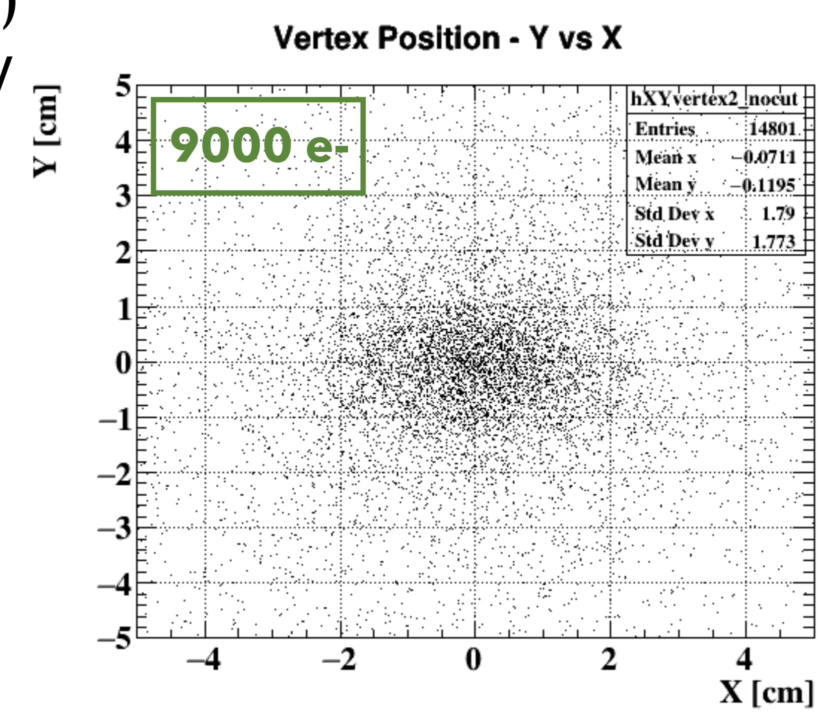
θ~90° (orthogonal to beam) are tricky to identify

Mitigated by checking track correlation (+B/-B)

Positrons: -B search



Electrons: -B search

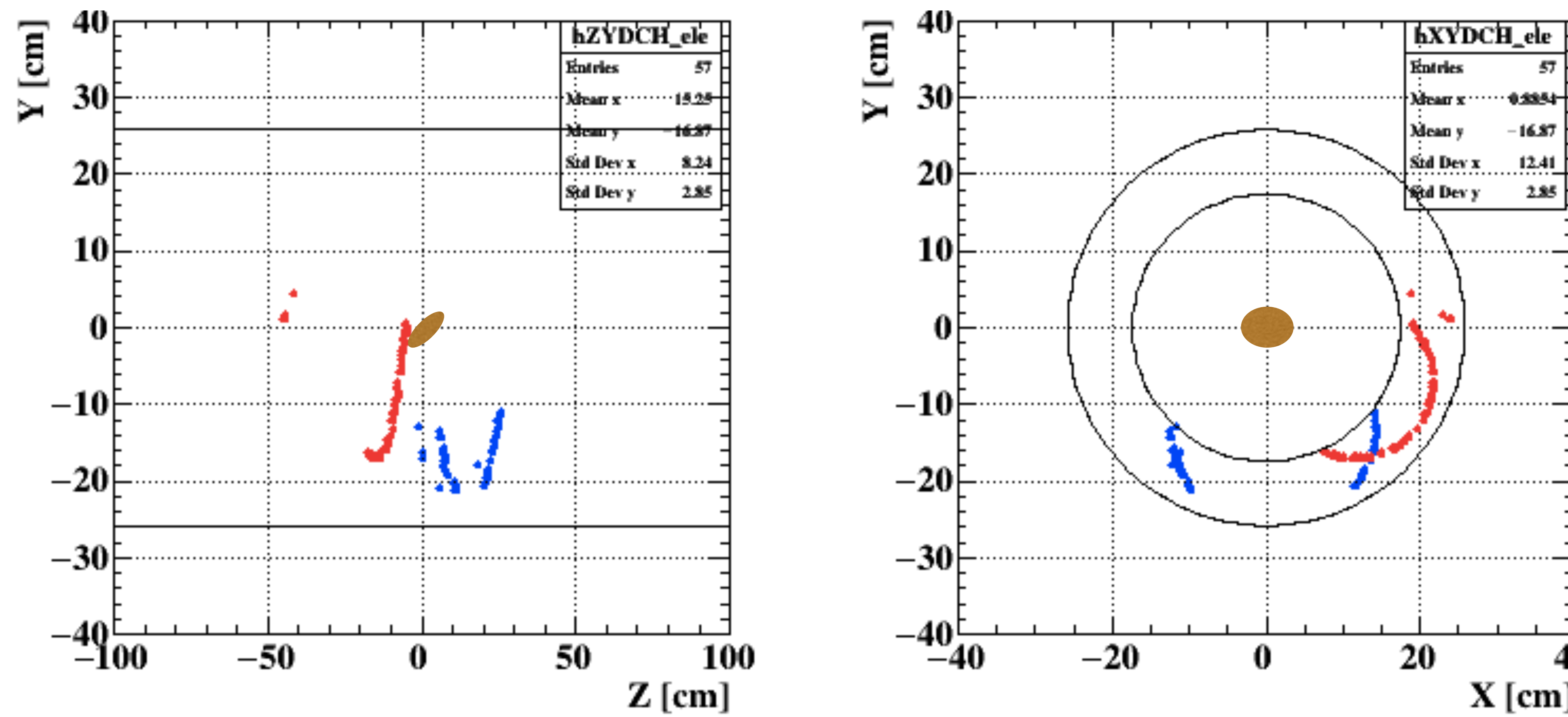


Reconstructed pair events from data

LiPON data 02/22

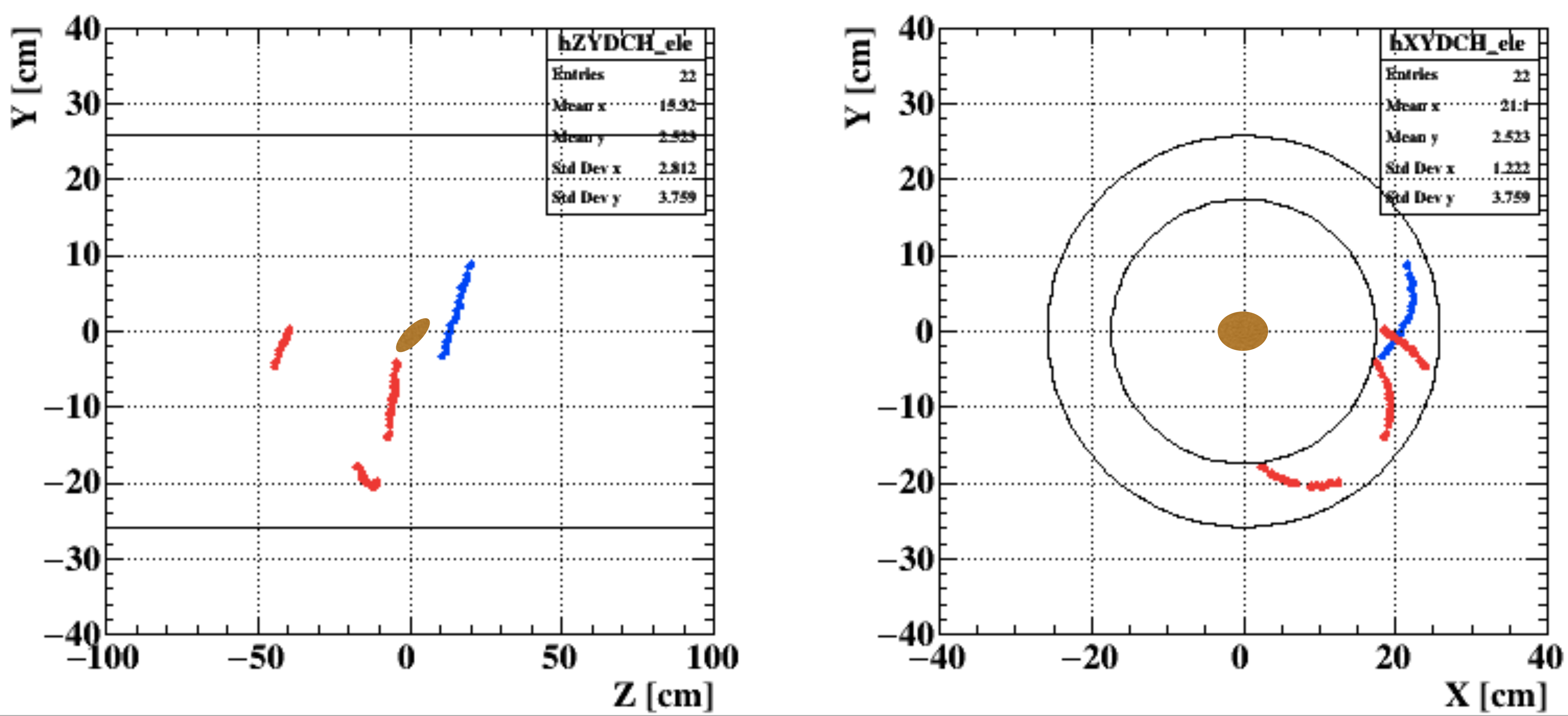
- Event A

p+ = 6.7 MeV
p- = 8.3 MeV
angle = 141°



- Event B

p+ = 6.7 MeV
p- = 6.9 MeV
angle = 101°



- e+ hit
- e- hit

target

Gamma rate from BGO analysis

Why a gamma detector?

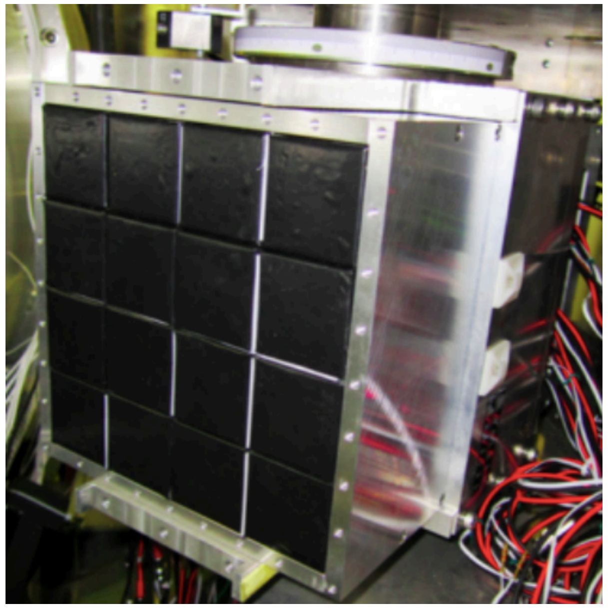
- Understanding of background
- Stability monitoring
- Signal normalisation

Gamma detectors

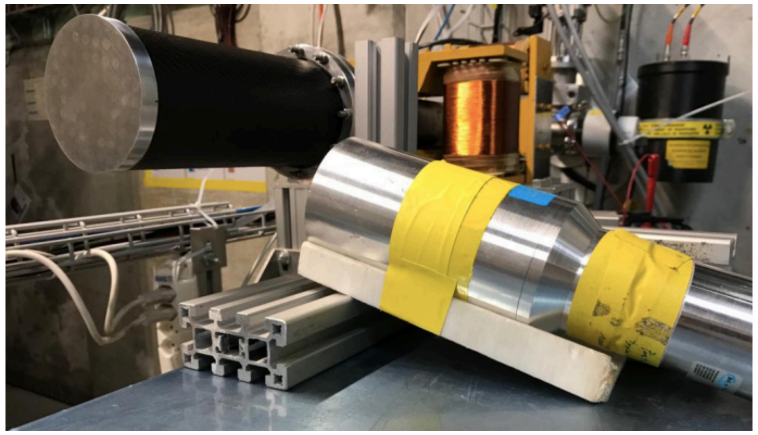
- Two gamma detectors

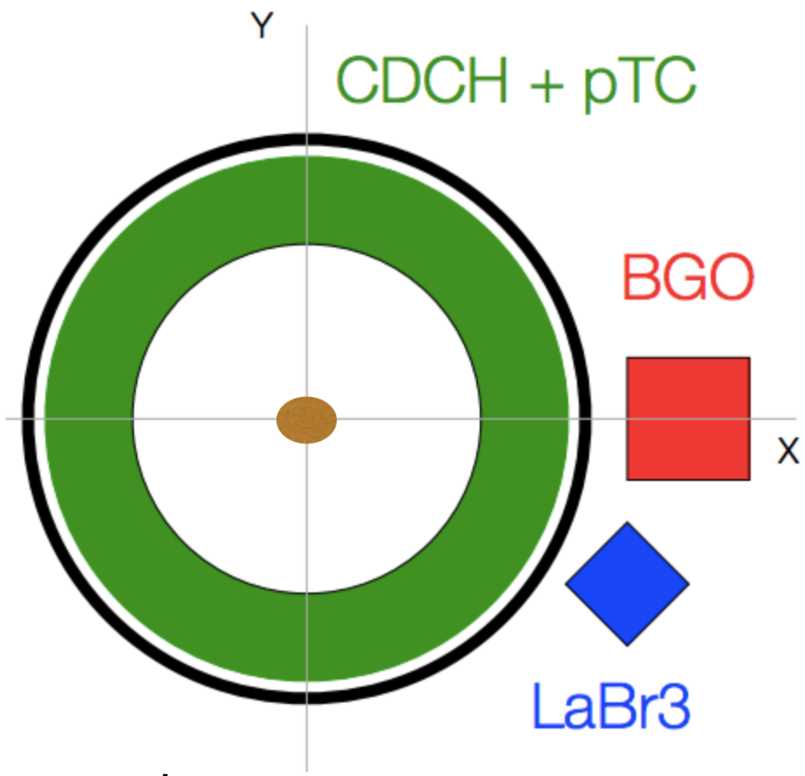
→ Understanding of background → Stability monitoring → Signal normalisation

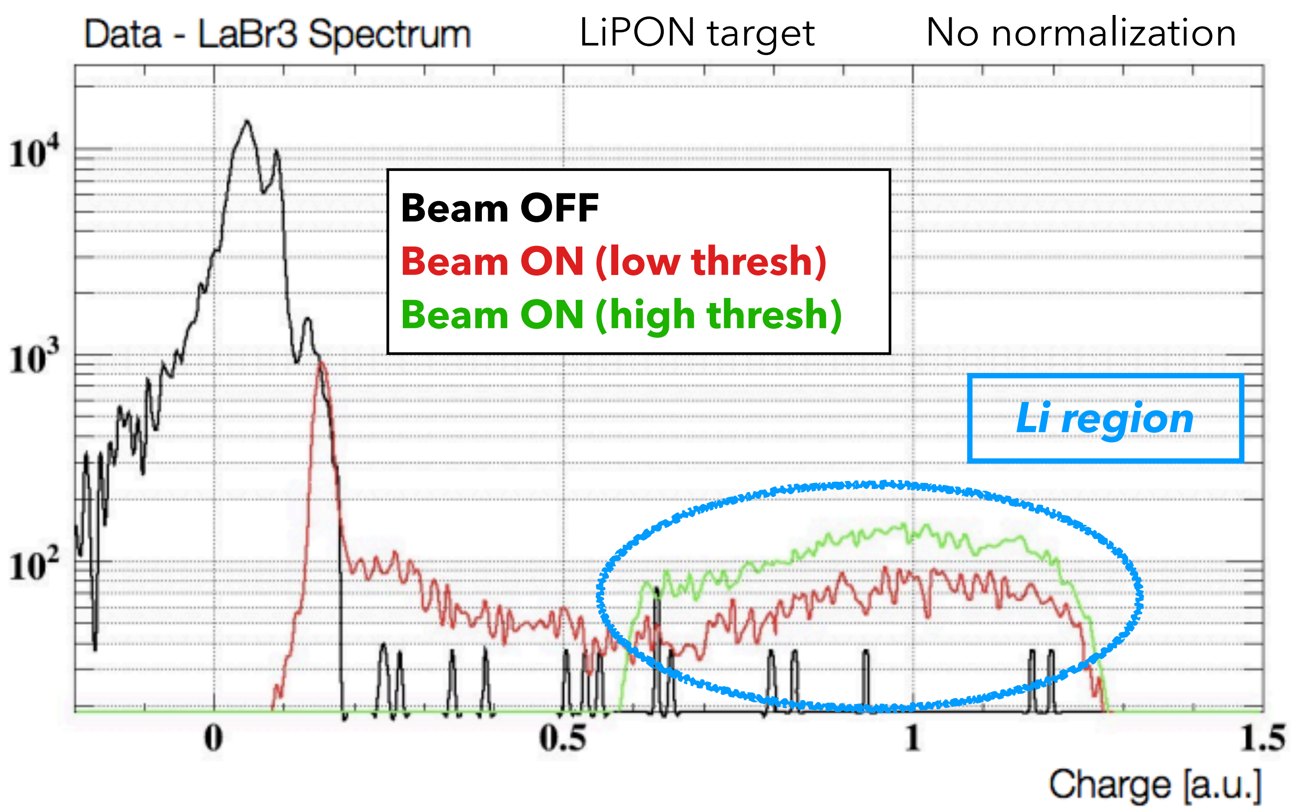
Bismuth Germanate (BGO) crystal matrix (4x4)



Lanthanum Bromide (LaBr3) crystal

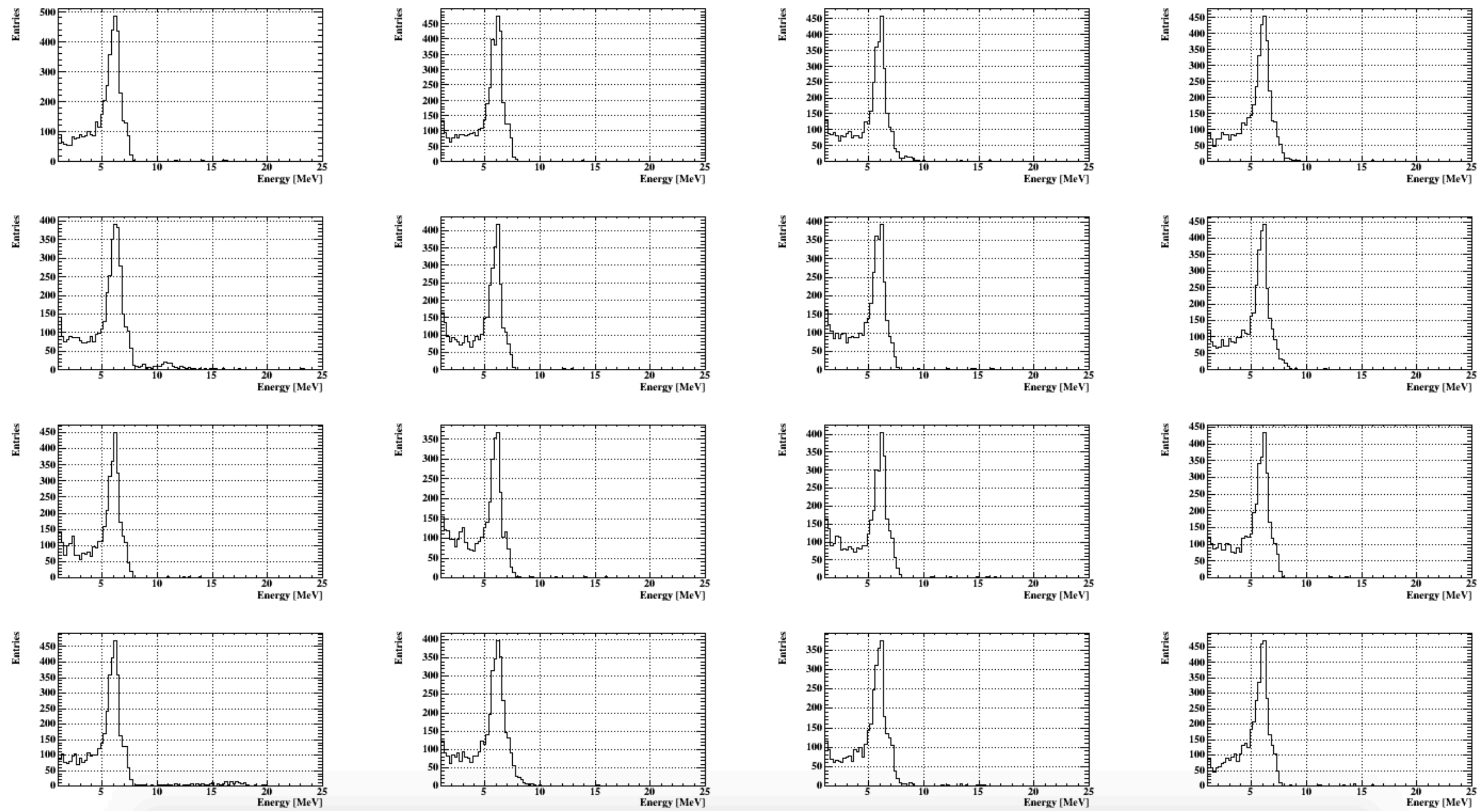


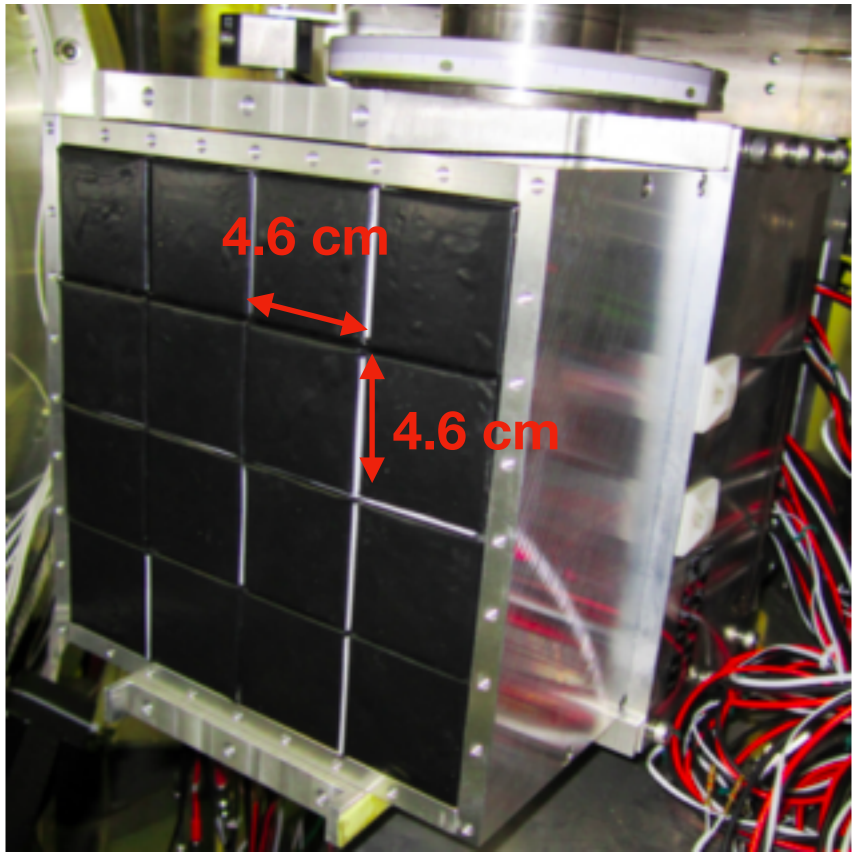




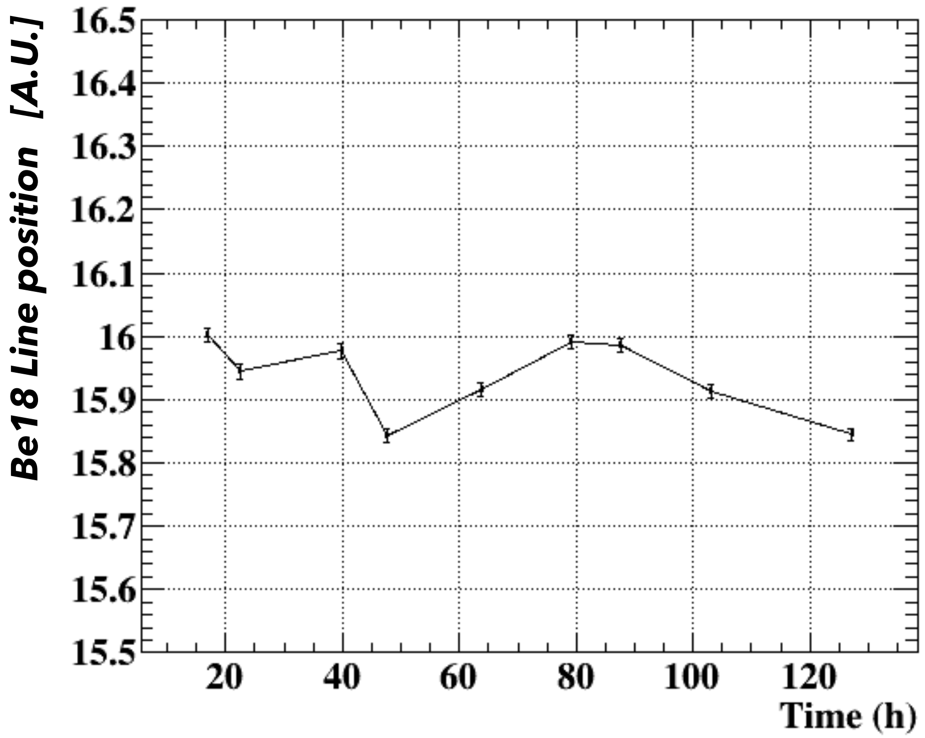
- LXe calorimeter on maintenance during run

BGO analysis

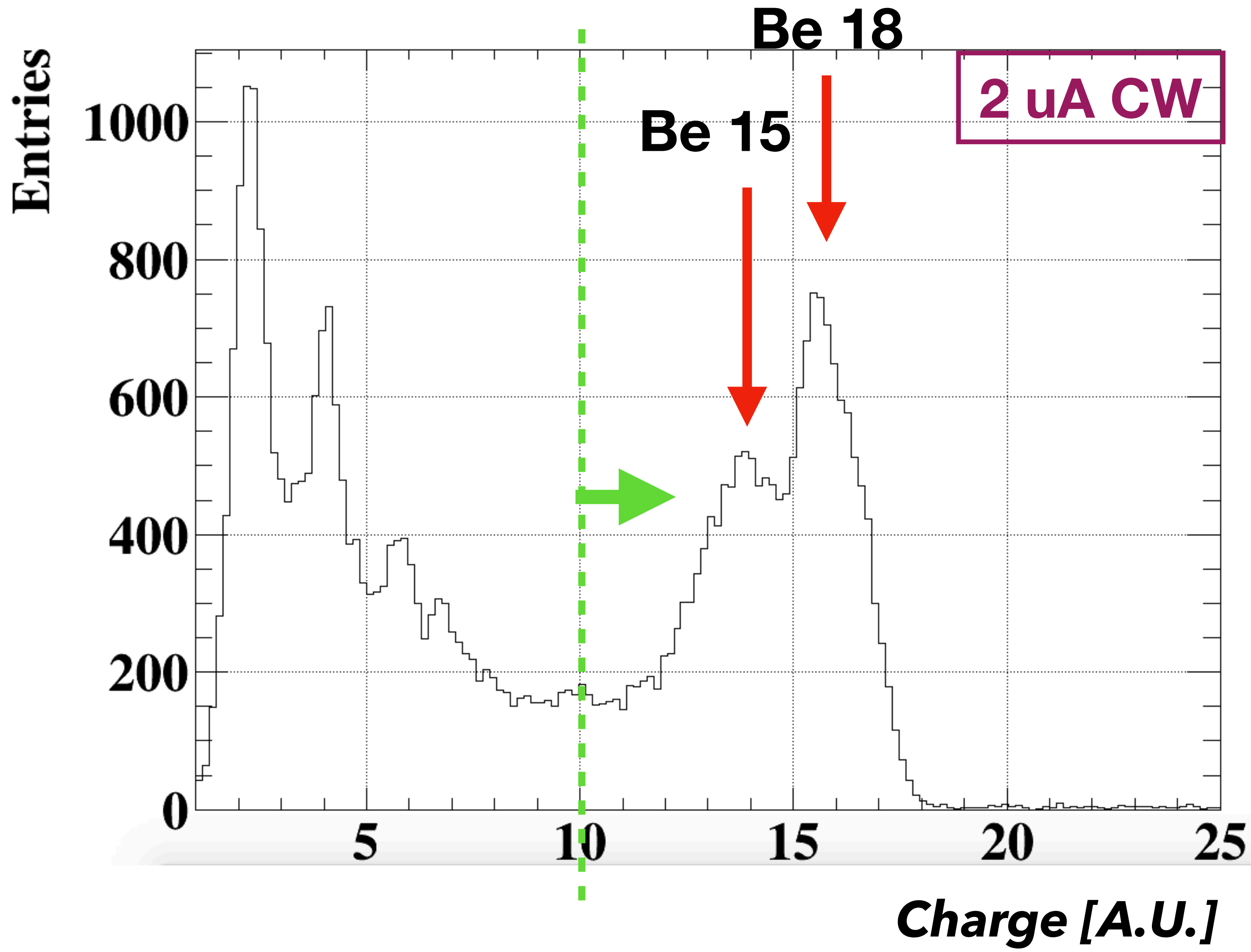


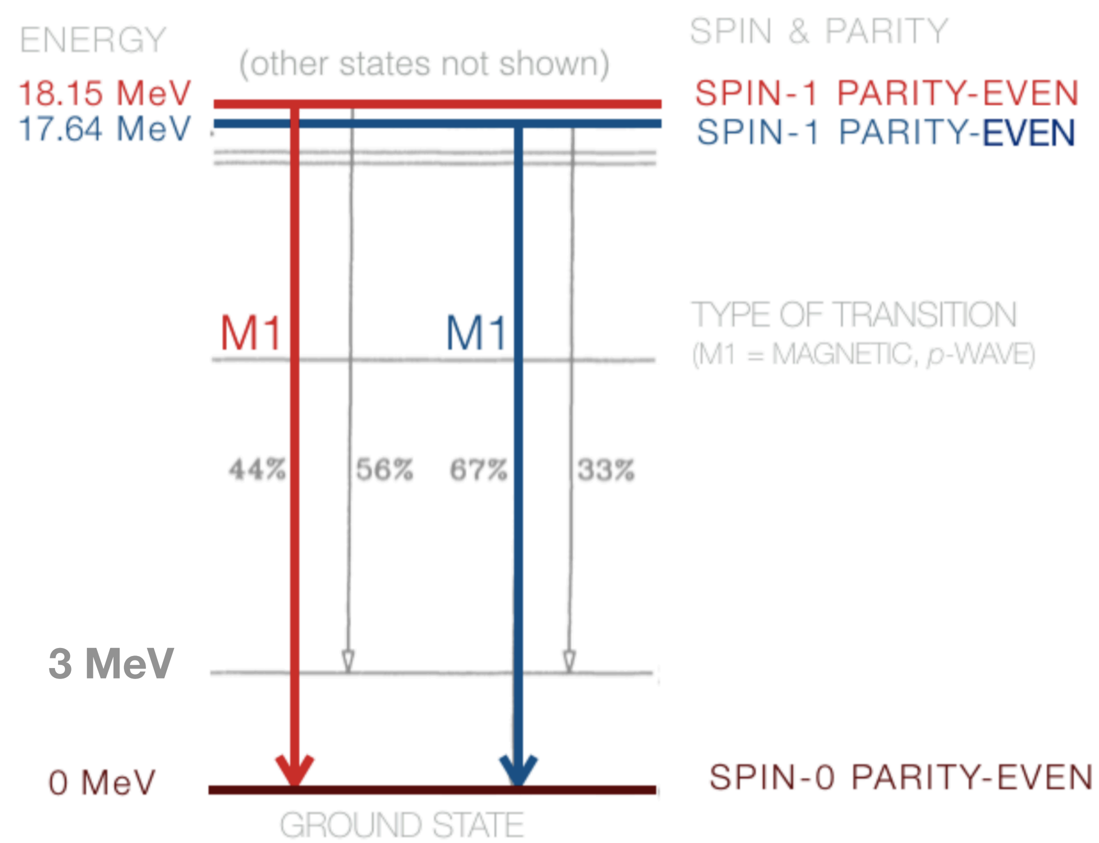


- BGO run (50k events) taken 1-2 times per day
- Crystals calibrated with F line at 6 MeV
- Sum on crystals
- Events with maximal energy release in the 4 central crystals
- Energy scale still to be corrected
- BGO 70 cm away from COBRA center –> 4 central crystals: **0.14%** of full solid angle



Gamma rate estimate from LiPON data





Rate of gammas from Be15+18 = **16 Hz** (0.14% of full solid angle)

- **12 kHz** on full solid angle
- consistent with Brillance rate

Assuming perfect efficiency and isotropic emission

Trigger rate estimate

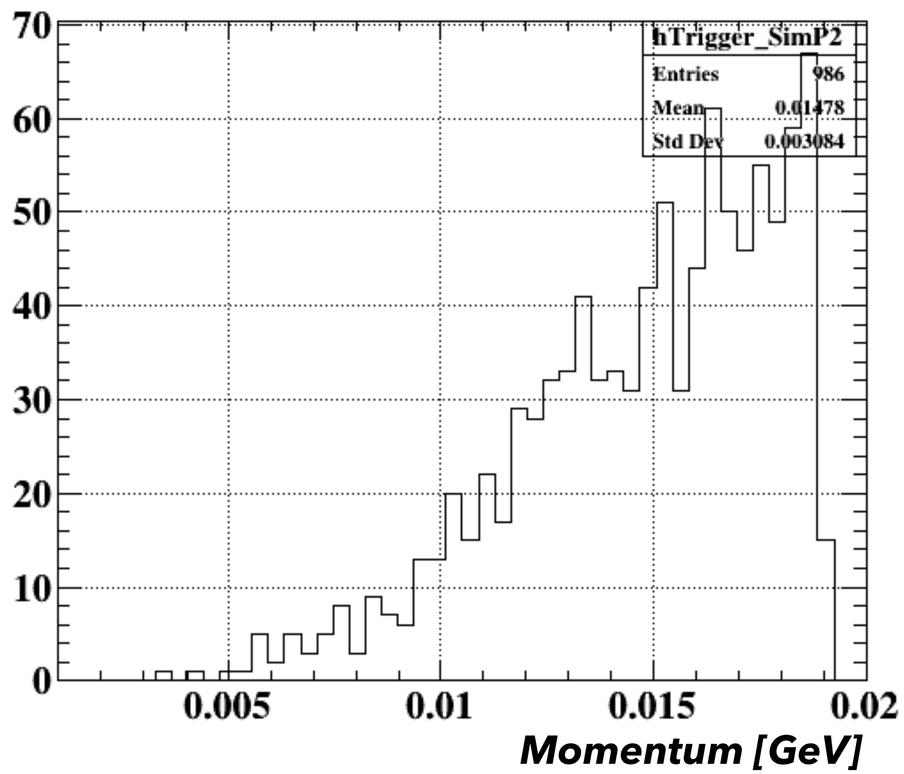
- % of triggered events from MC
- Combination with BGO gamma rates
- Comparison with trigger rates from data

Trigger rate estimate

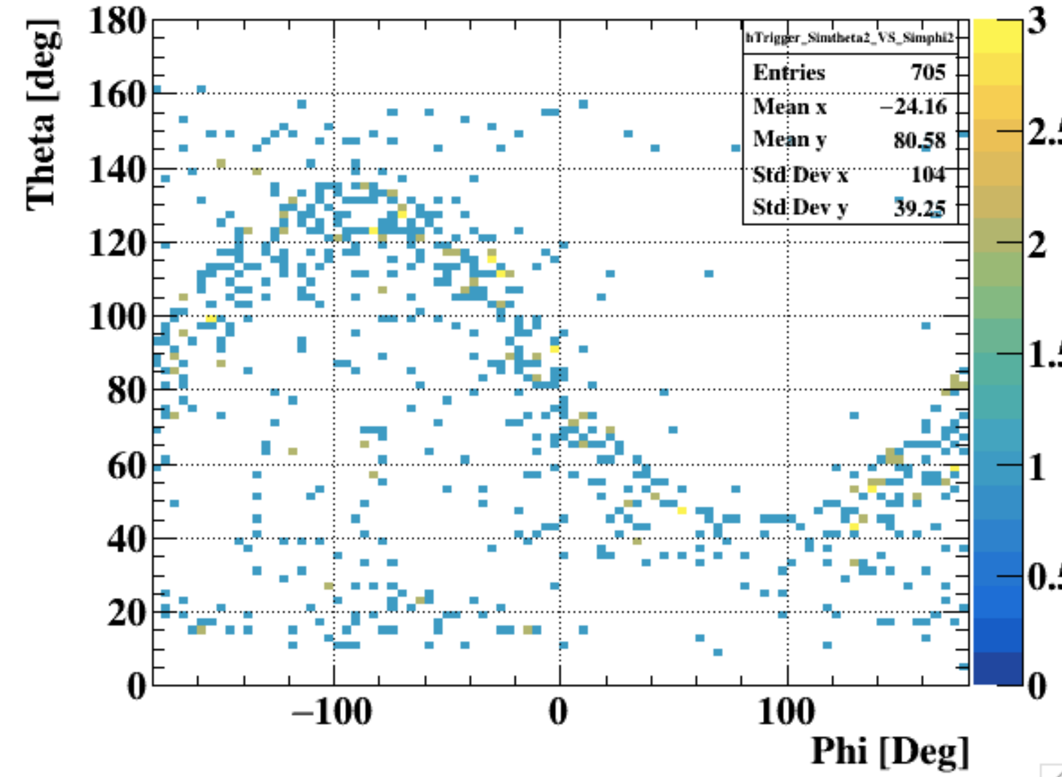
MC with gammas generated isotropically and uniformly [1,19MeV]

Combined trigger (1 SPX and 10&10 DCH)

#events triggered as a function of the generated gamma momentum



direction of gamma leading to trigger



- **0.35%** of all 18 MeV gammas lead to trigger through EPC and Compton
- **High energy** gammas induce trigger
- Gammas convert through the **copper ring**

Estimated rates

–> 12 kHz (gammas on full solid angle)

–> 42 Hz in trigger

Raw rate from data

LiPON/ 2uA (#418137)
66 Hz

- DAQ dominated by **EPC and Compton**: trigger needs to be optimized

Optimized trigger

→ A better choice of trigger for a potential next data taking

Increasing CDCH multiplicity

EPC MC: 200k gammas generated

Trigger 1 SPX hit n&n DCH hits	Triggered events (%)	#pairs in signal region
n = 10	0.35 %	0
n = 30	0.10 %	0
n = 50	0.025 %	0

EPC/Compton rate **divided by 14** going from 10&10 to 50&50

X17 MC: 50k pairs generated

Trigger 1 SPX hit n&n DCH hits	Triggered events (%)	#pairs in signal region
n = 10	18 %	136 (1.5%)
n = 30	12 %	135 (1.5%)
n = 50	8 %	105 (2.6%)

X17 rate **divided by 2** going from 10&10 to 50&50

Signal region:
- 16 MeV < **Esum** < 20 MeV
- 15 MeV < **InvMass** < 18 MeV
- 120° < **Angle** < 160°

Advantages

- → Background largely removed from trigger while only losing 25% of signal
- → Can be compensated by increasing proton current

Significance estimate

- significance from last data taking
- challenge: get best significance while keeping trigger rate below limit
- significance with optimized trigger

Significance from last data taking

Trigger 10&10 and 2uA (I_{CW}) - prescaling 2 (last data taking)

Total trigger rate: 24 Hz

All

- EPC + Compton:

6 kHz —> 21 Hz in trigger —> **0 pairs**

0.35% induce trigger *0% signal pair reco*

- IPC18+15:

6 kHz —> 18 IPC generated —> 2.7 Hz trigger

BR 3e-3 *15% induce trigger*

---

18 MeV line

- IPC18:

3 kHz —> 9 IPC generated —> 1.4 Hz trigger **—> 5.4e-4** pairs/s

BR 3e-3 *15% induce trigger* *0.04% signal pair reco*

- X-Boson:

3 kHz —> 1.8e-2 X17 generated —> 3.2e-3 Hz trigger **—> 4.9e-5** pairs/s

BR 6e-6 *18% induce trigger* *1.5% signal pair reco*

Significance

In 10 days:

- significance = S/sqrt(S+B) = **1.9**

For 5 sigma:

T = **71 days**

—> to compare with data from last February (<1 sigma)

Significance with optimized trigger

Trigger 50&50 and 10 uA (I_{CW})

Total trigger rate: 20 Hz

—> increases by **x10 (I_{CW} and no prescaling)**
—> decreases by **x14 (more constraining trigger)**

All

- EPC + Compton:

60 kHz —> 15 Hz in trigger —> **0 pairs**

0.025% induce trigger *0% signal pair reco*

- IPC18+15:

60 kHz —> 180 IPC generated —> 5 Hz trigger

BR 3e-3 *3% induce trigger*

---

18 MeV line

- IPC18:

30 kHz —> 90 IPC generated —> 2.7 Hz trigger **—> 4.5e-3** pairs/s

BR 3e-3 *3% induce trigger* *0.17% signal pair reco*

- X-Boson:

30 kHz —> 1.8e-1 X17 generated —> 1.4e-2 Hz trigger **—> 3.8e-4** pairs/s

BR 6e-6 *8% induce trigger* *2.6% signal pair reco*

Significance

In 10 days:

- significance = S/sqrt(S+B) = **5.1**

Observables from data

→ What were we able to extract from the data we have?

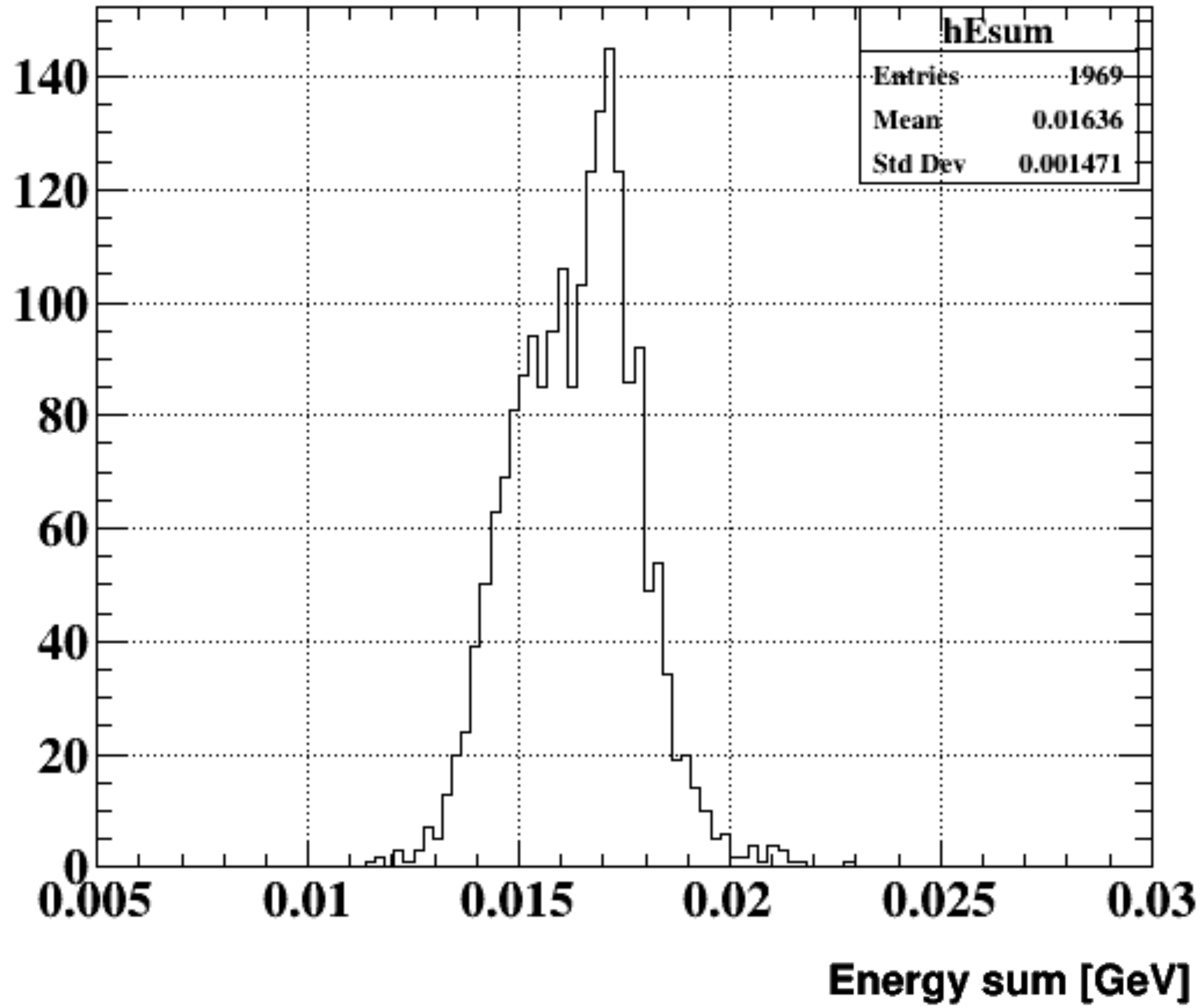
Observables from LiPON data

LiPON data - 2.1M events - 02/22 - All statistics from 22 hours of non-ZS LiPON data

Selection on:
–> ngoodhits
–> vertices positions and distance
–> z position

→ In pair events, e+ and e- energy can be summed to reconstruct the transition energies (including some energy loss)

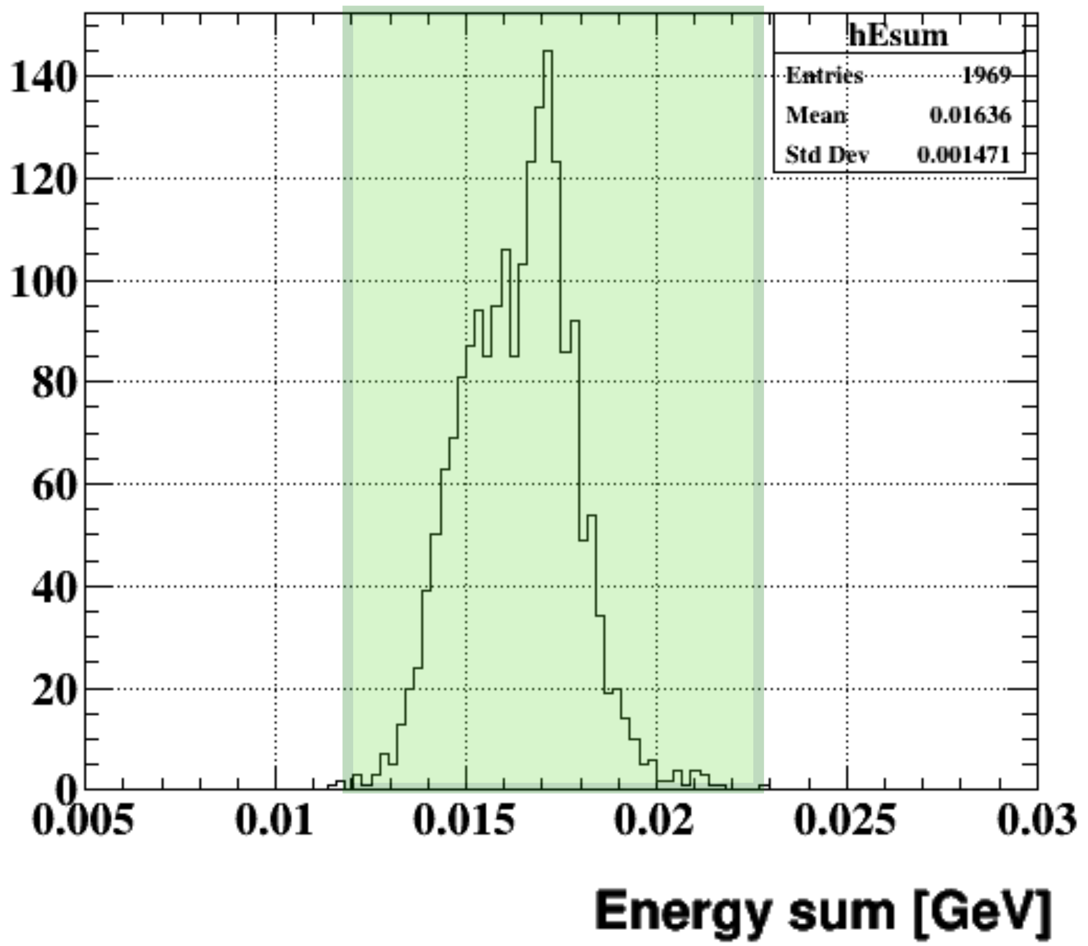
From CDCH track reconstruction



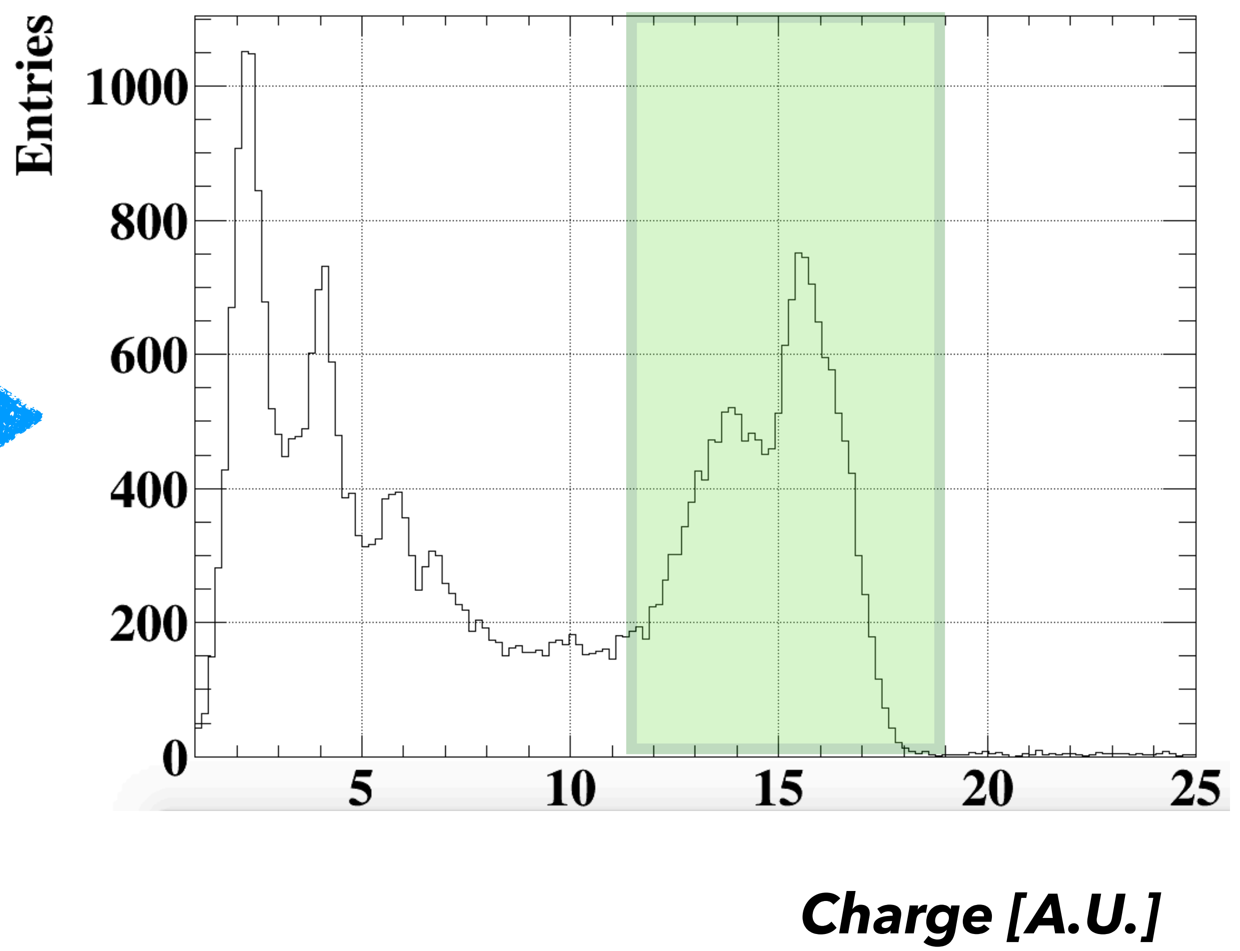
Observables from LiPON data

LiPON data - 2.1M events - 02/22 - All statistics from 22 hours of non-ZS LiPON data

From CDCH track reconstruction



From BGO analysis

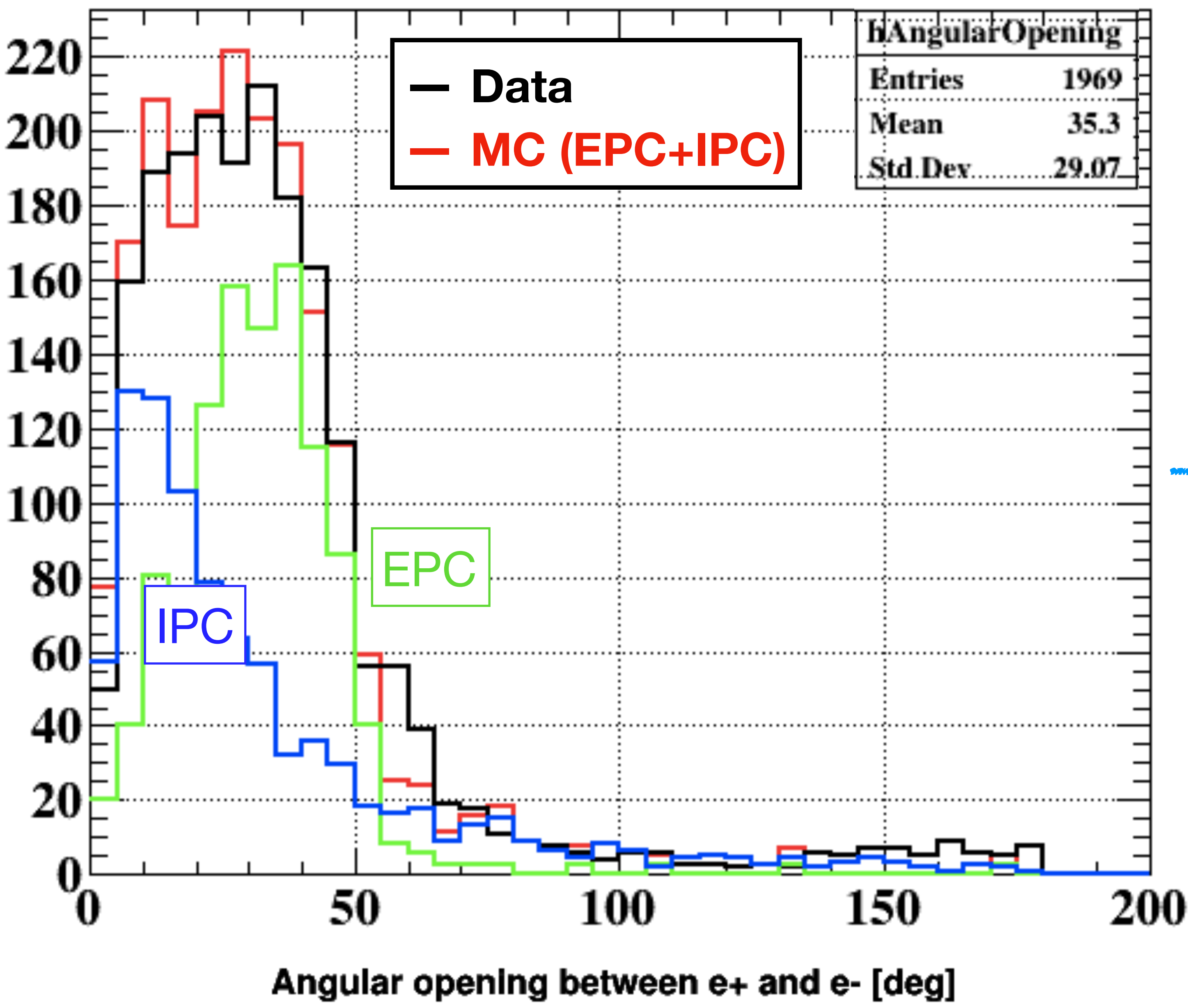


- In pair events, e+ and e- energy can be summed to reconstruct the transition energies (including some energy loss)

- Consistent with Be15 and Be18 gamma lines

Angular opening: data vs MC

LiPON data - 2.1M events - 02/22 - All statistics from 22 hours of non-ZS LiPON data



Assuming same angular opening distributions for IPC18 and IPC15

→ Data consistent with a mix of EPC and IPC (~55%/45%)

Conclusion

Summary:

- e+/e- tracking procedure was developed
- **data-MC consistent**
- from BGO analysis, **gamma rate estimated**
- with MC, **trigger rate understood** and optimized trigger identified for next data taking: **5σ in O(few weeks)**

Next:

- characterize fake pairs

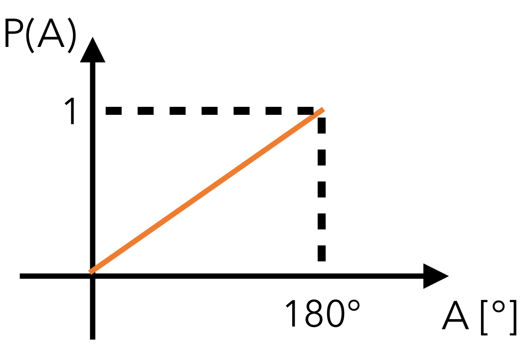
Backup

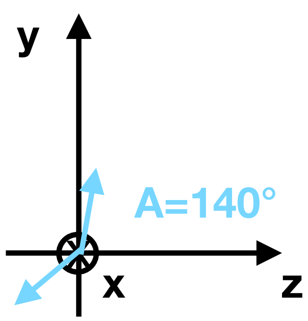
Fake pairs rejection

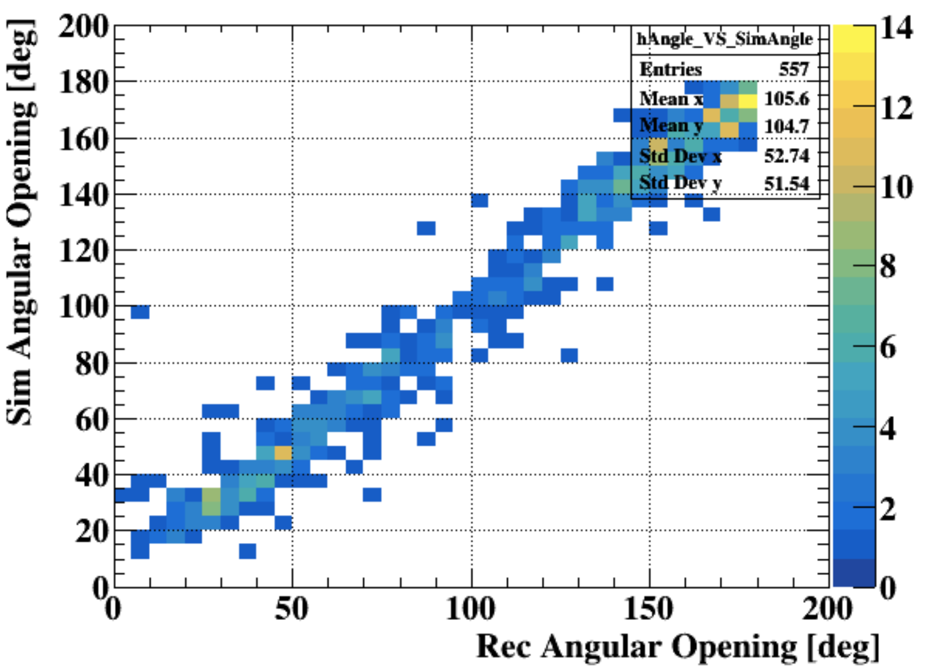
θ~90° tracks lead to **fake pairs** (two pieces of tracks seen as opposite sign)

What if we request 1 particle US and 1 particle DS: ze+ x ze- < 0

P(A): probability that a pair with angular opening A has two particles going in opposite sides of the CDCH







Simulated vs reconstructed opening angle from MC requesting ***Ze+ X Ze- < 0***

Estimated advantages:

–> we lose mostly low opening angles
–> we get rid of fake pairs
–> we lose only ~20% of signal
(X17 expected **opening angle ~140°**)

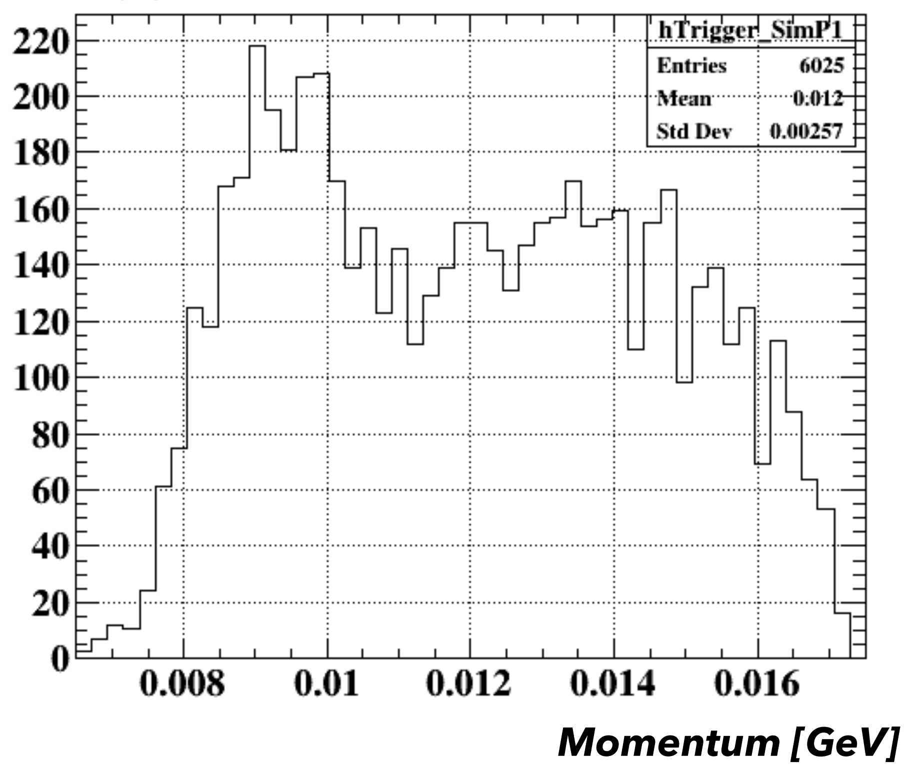
Still work in progress

Increasing CDCH multiplicity

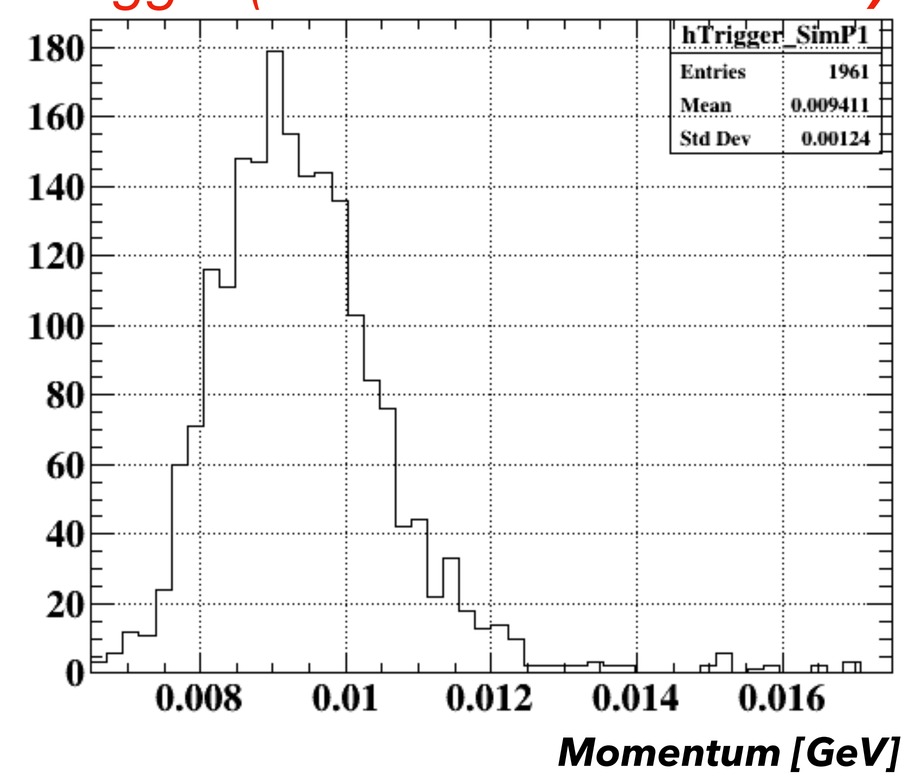
IPC MC —> [2-16] MeV energy range

Generated momentum of reconstructed particles

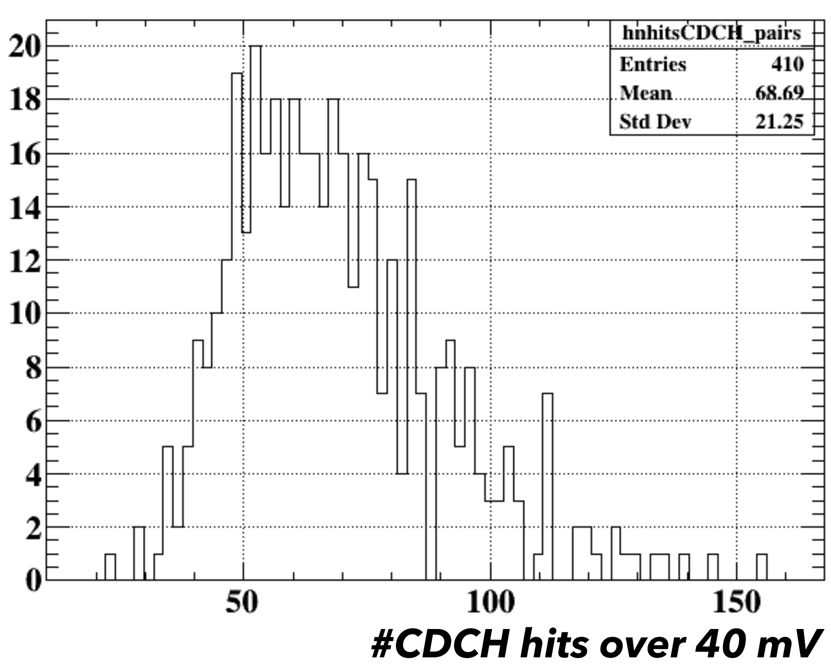
*Trigger (1 SPX and **10&10 DCH)***



*Trigger (1 SPX and **50&50 DCH)***



CDCH multiplicity to reconstruct X17 pairs



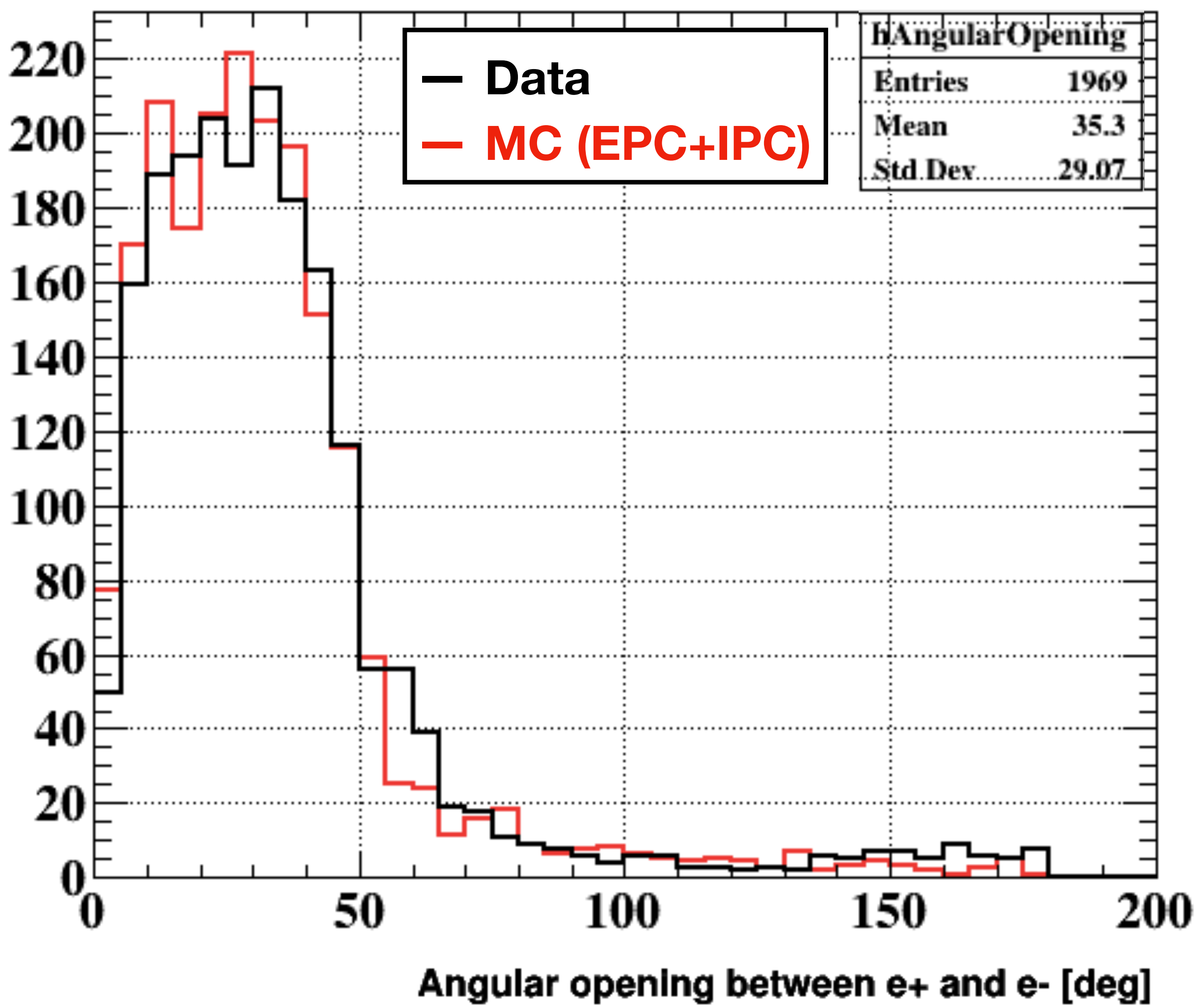
We're looking for X17 signal as symmetric energy particles (8-10 MeV)

Requesting 50&50:

- Gets rid of high energy particles (for which pairs cannot be reconstructed)
- Little loss on 8-10 MeV particles
- Hard to reconstruct pairs with low CDCH multiplicity anyway

Angular opening: data vs MC

LiPON data - 2.1M events - 02/22 - All statistics from 22 hours of non-ZS LiPON data



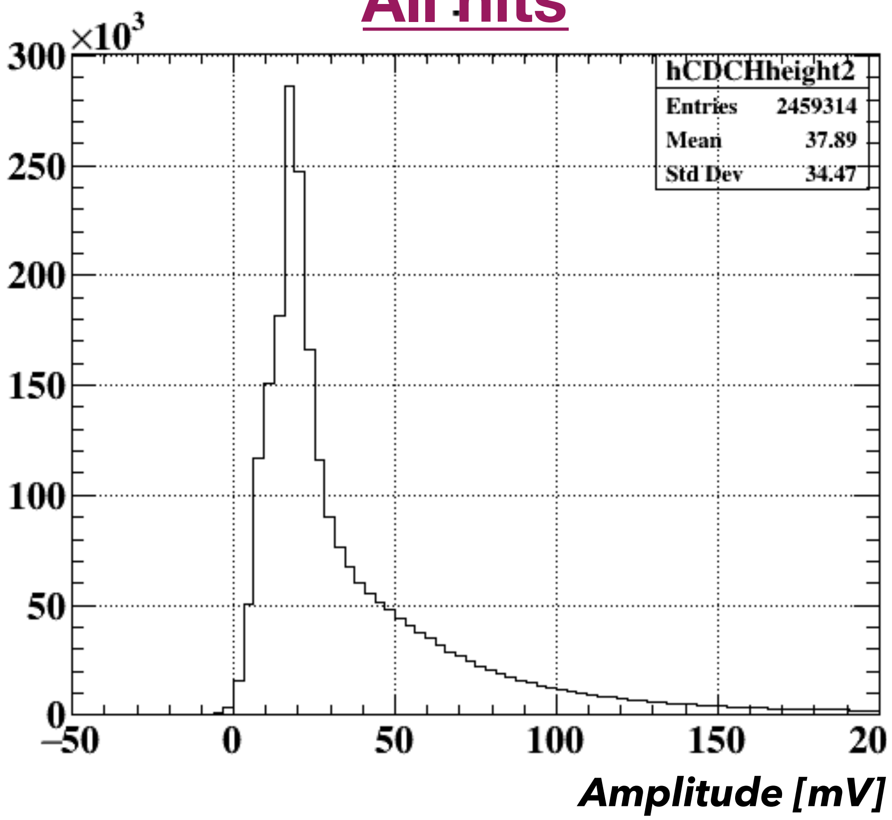
Assuming same angular opening distributions for IPC18 and IPC15

→ Data consistent with a mix of EPC and IPC (~55%/45%)

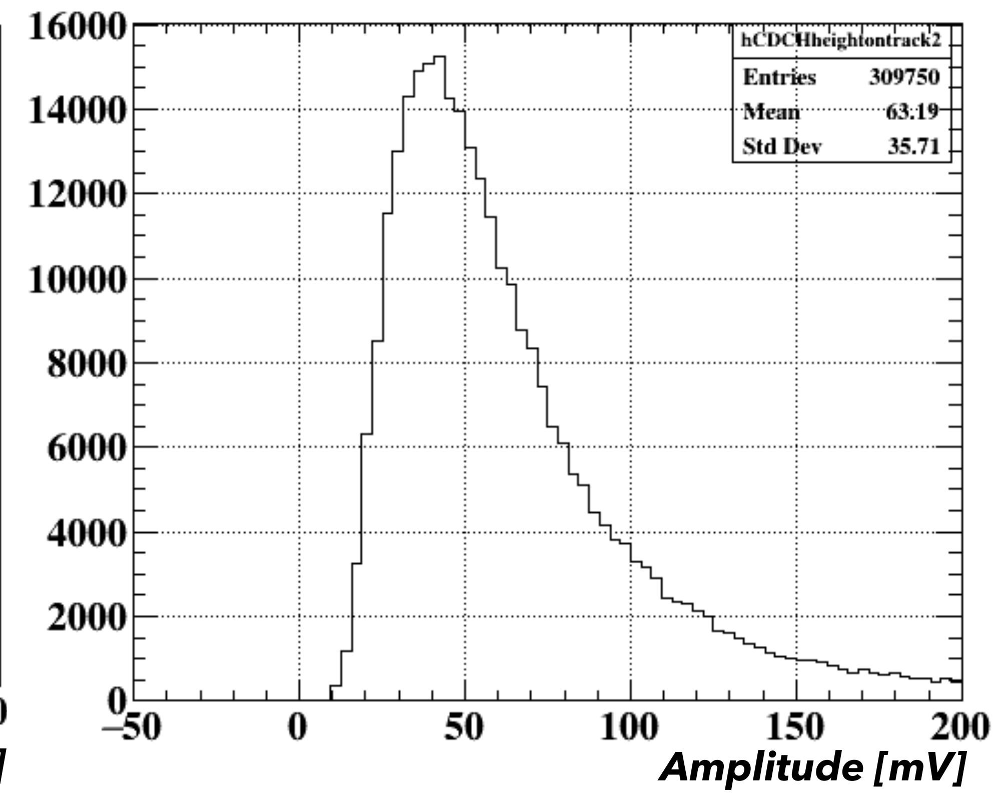
Zero-suppression

For LiPON data, trigger was **10 CDCH hits over 40 mV** (US and DS) and 1 SPX hit over 70mV
–> with zero-suppression all **waveforms below 40 mV were suppressed**

All hits



Good hits



→ Most hits at 20mV (likely to be largely noise)

→ Hits on a fitted track

→ Good hits also below 40 mV

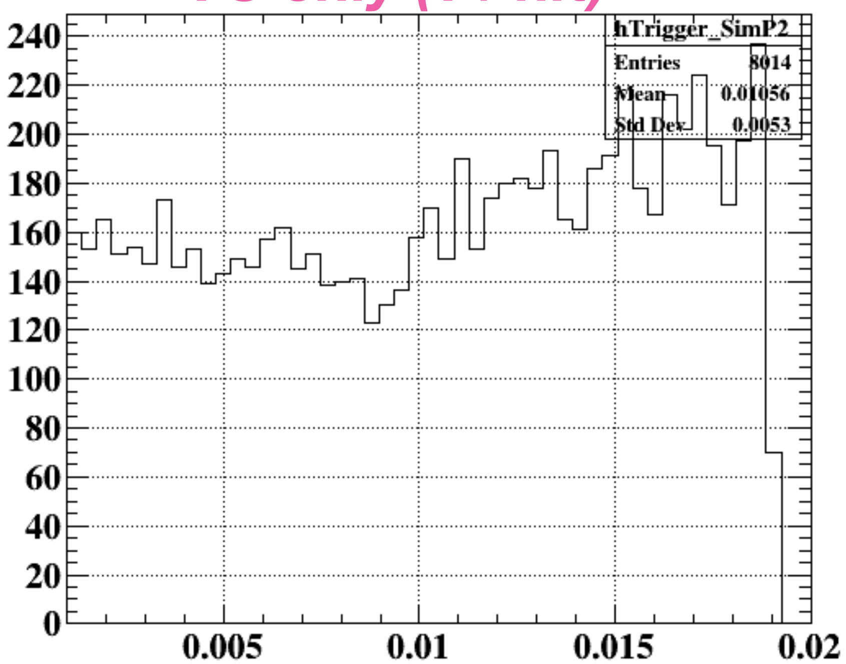
Likely to explain a **factor 20 less events** reconstructed in ZS data compared to non ZS-data

Trigger rate estimate

Gammas only generated isotropically and uniformly [1,19MeV]

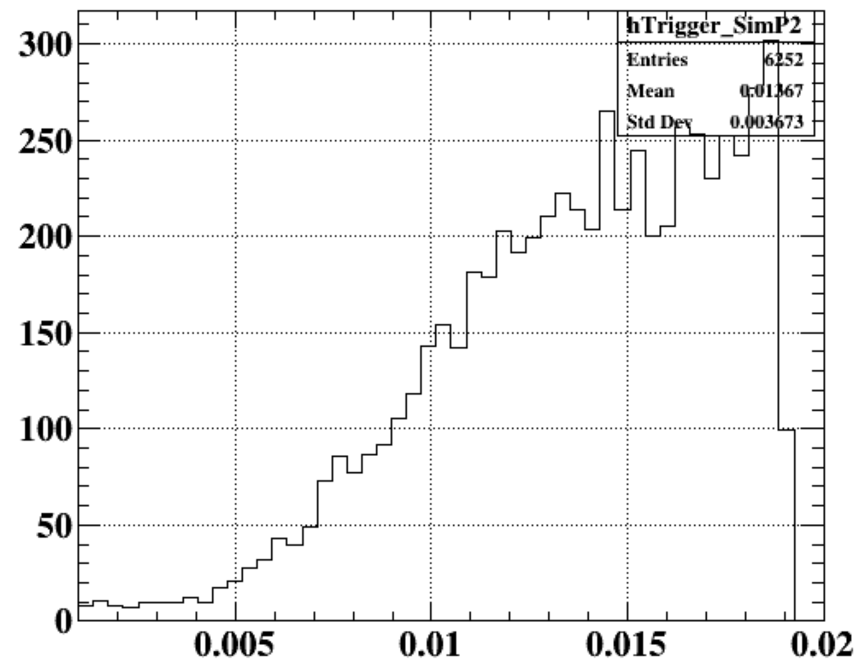
#events triggered as a function of the generated gamma momentum

TC only (1+ hit)



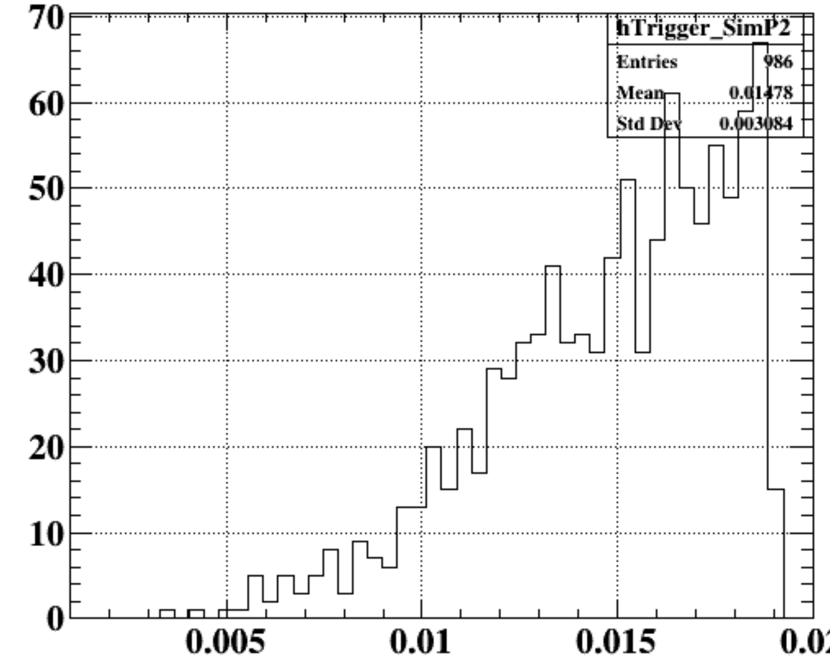
—> 1.2% of **all 18 MeV gammas** lead to **trigger**

CDCH only (10&10)



—> 1.5% of **all 18 MeV gammas** lead to **trigger**

Combined



—> 0.35% of **all 18 MeV gammas** lead to **trigger**

Gamma rate

–> 12 kHz (on full solid angle)

–> 180 Hz in CDCH single

–> 140 Hz in TC single

–> 42 Hz in trigger

RAW RATE

LiPON/ 2uA (#418137)

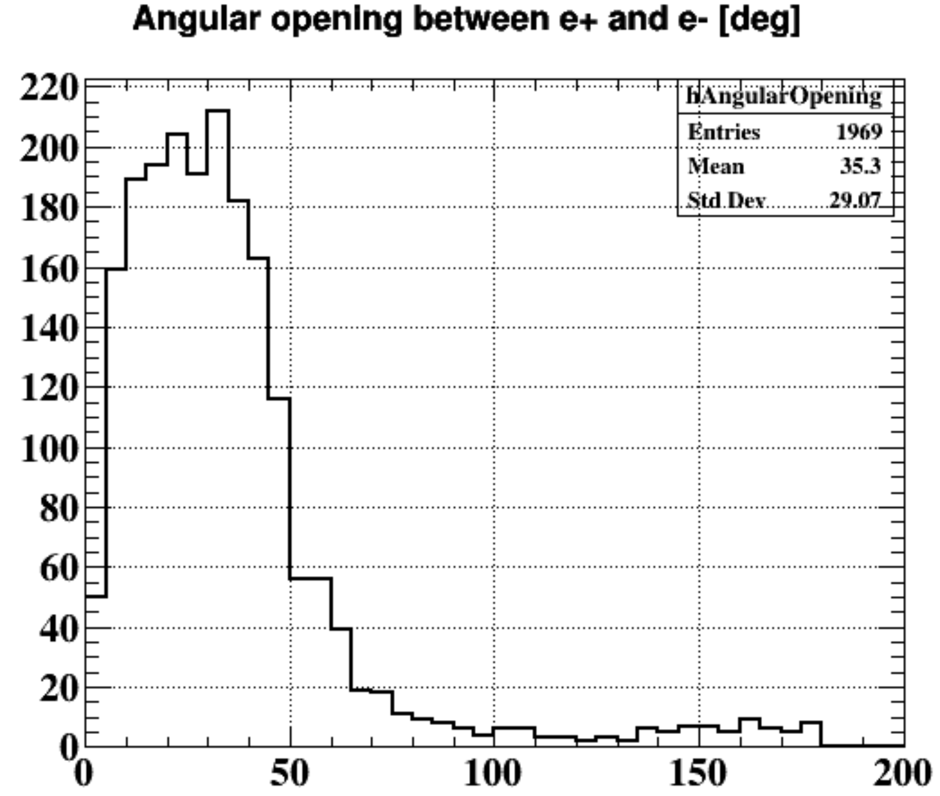
CDCH trigger: 1.6 kHZ

TC single: 580 Hz

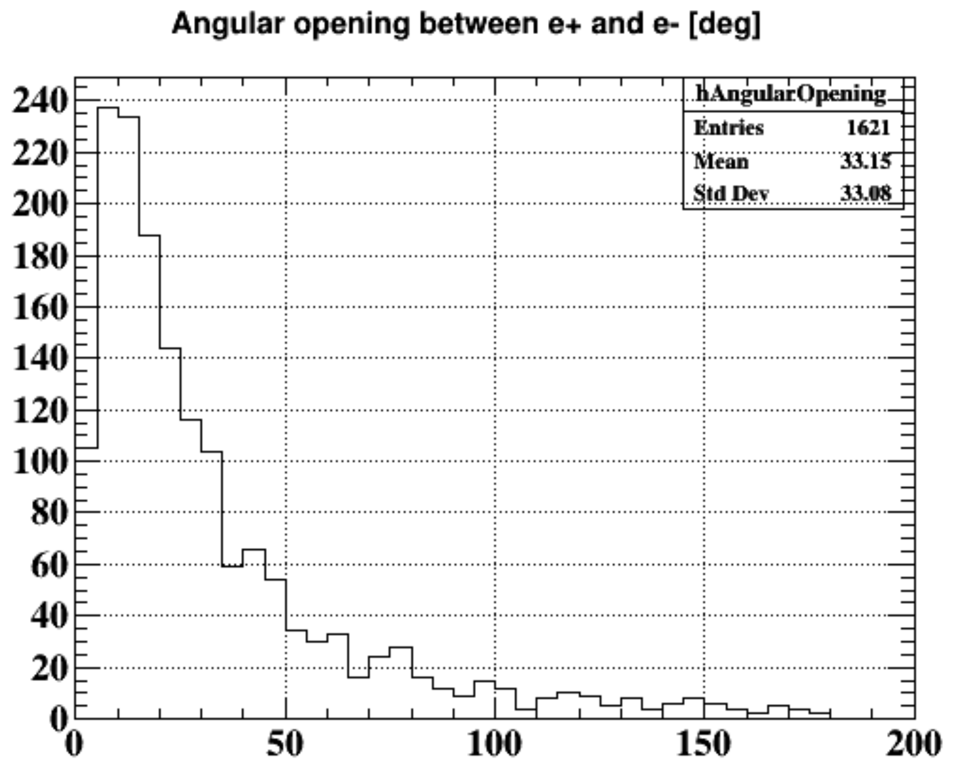
« Michel »: 66 Hz

Observables from data

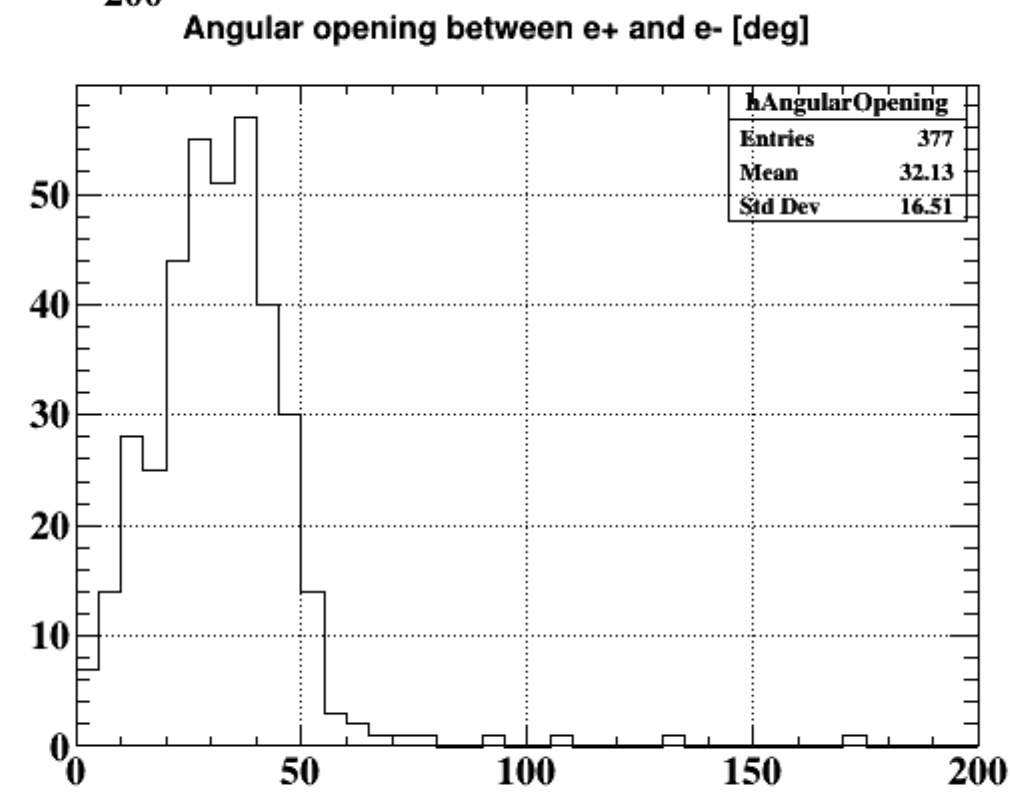
Data



IPC



EPC



Angular opening: data vs MC

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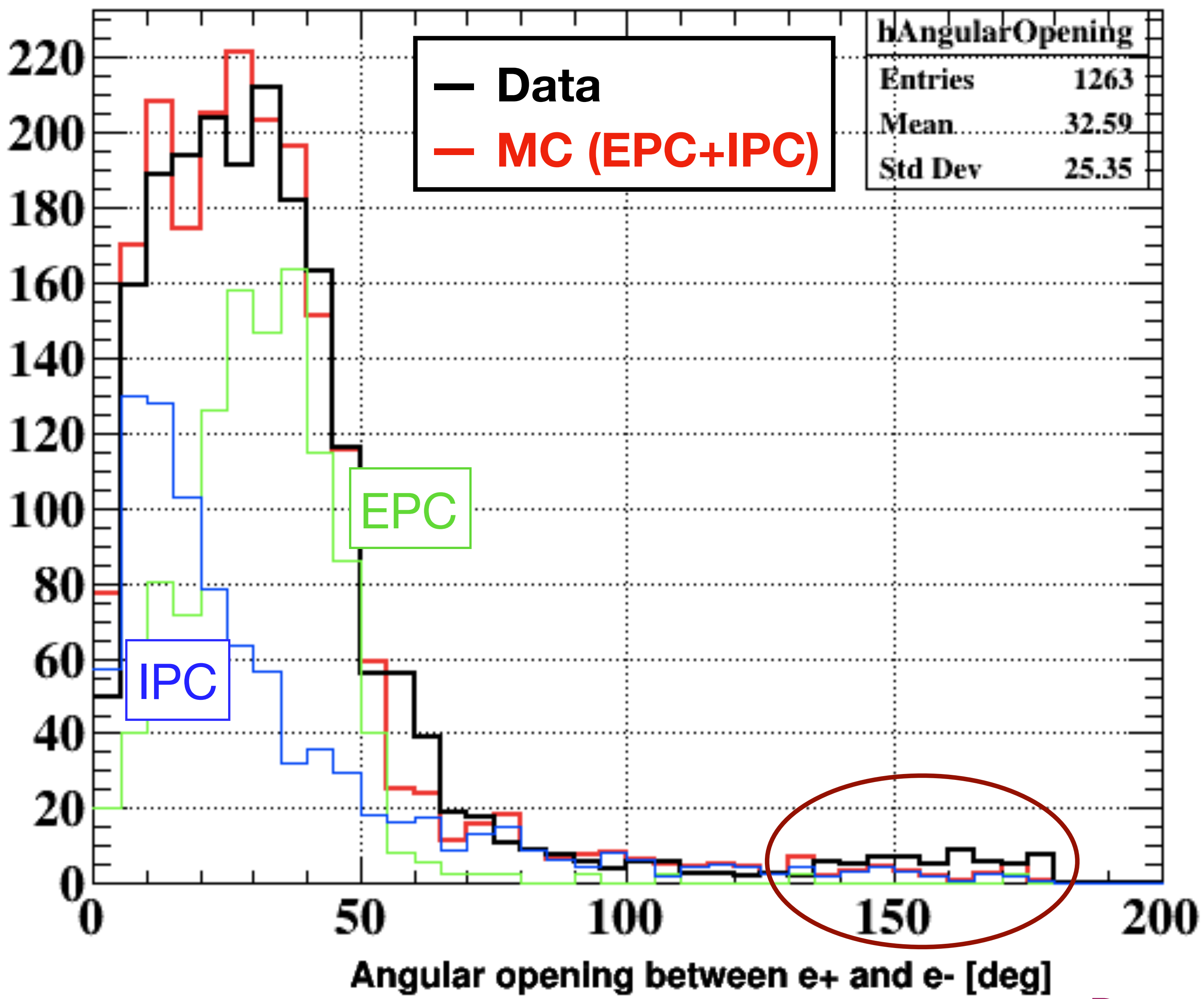

→ Data consistent with a mix of EPC and IPC (~50/50)

→ A fraction of pairs at large angles are **artifacts** from reconstruction (two pieces of tracks seen as opposite sign)

Potential solution

→ Request 1 particle US and 1 particle DS

→ Work still ongoing