H2020 MSCA ITN
G.A. 858199

X17 analysis status

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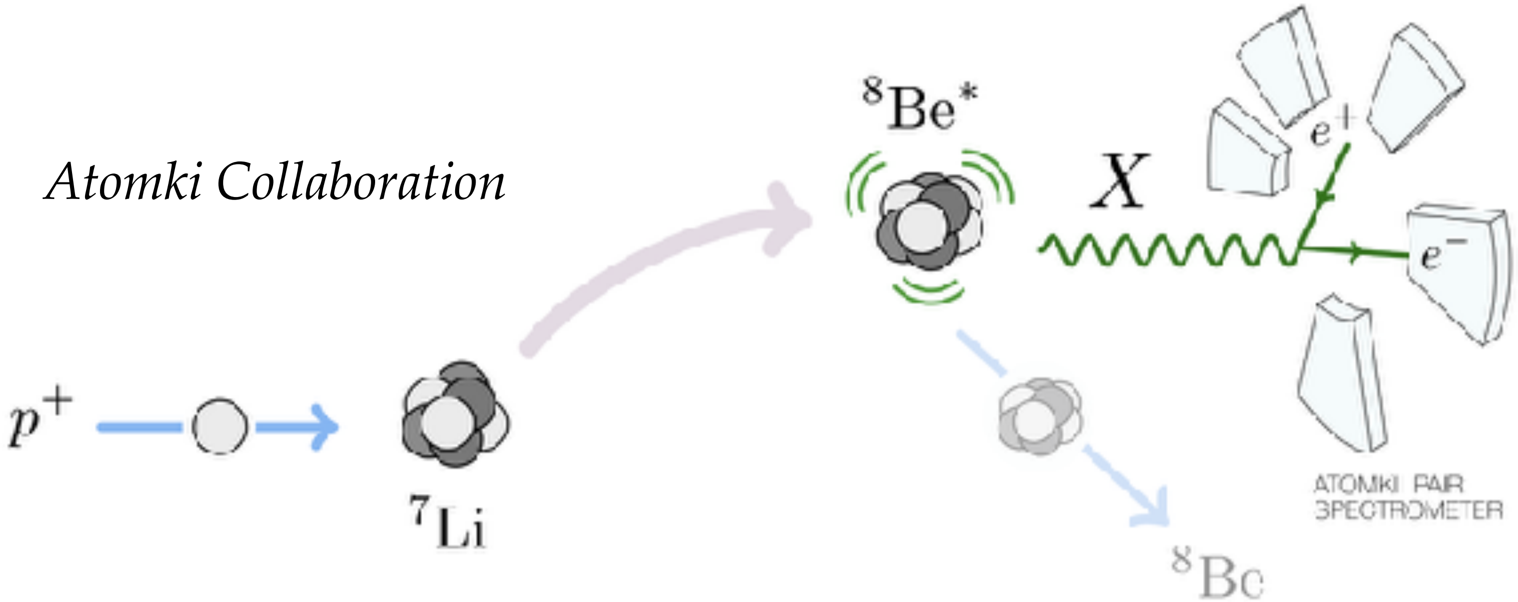
The Beryllium Anomaly

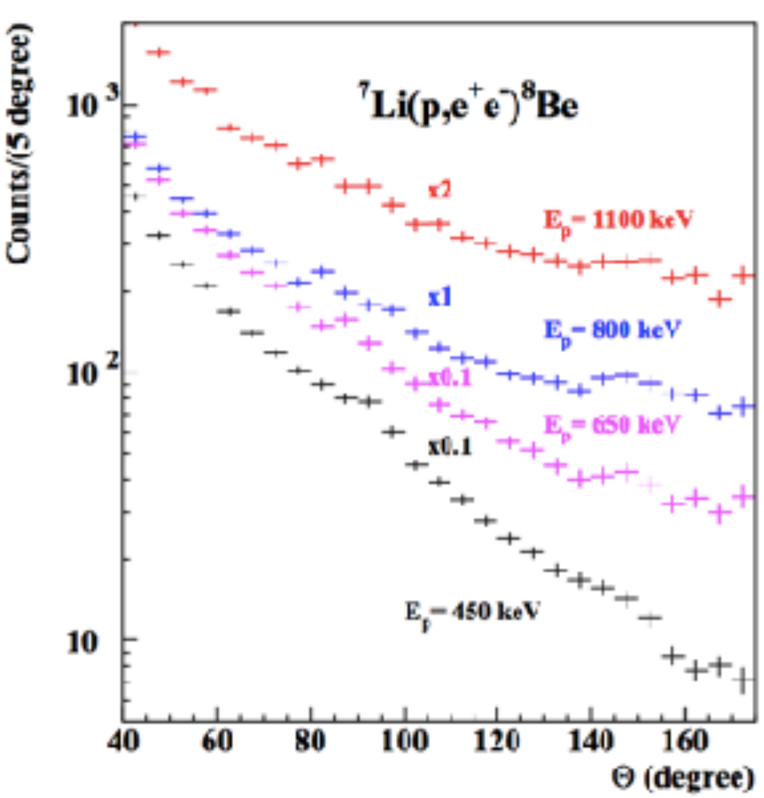
Atomki Collaboration

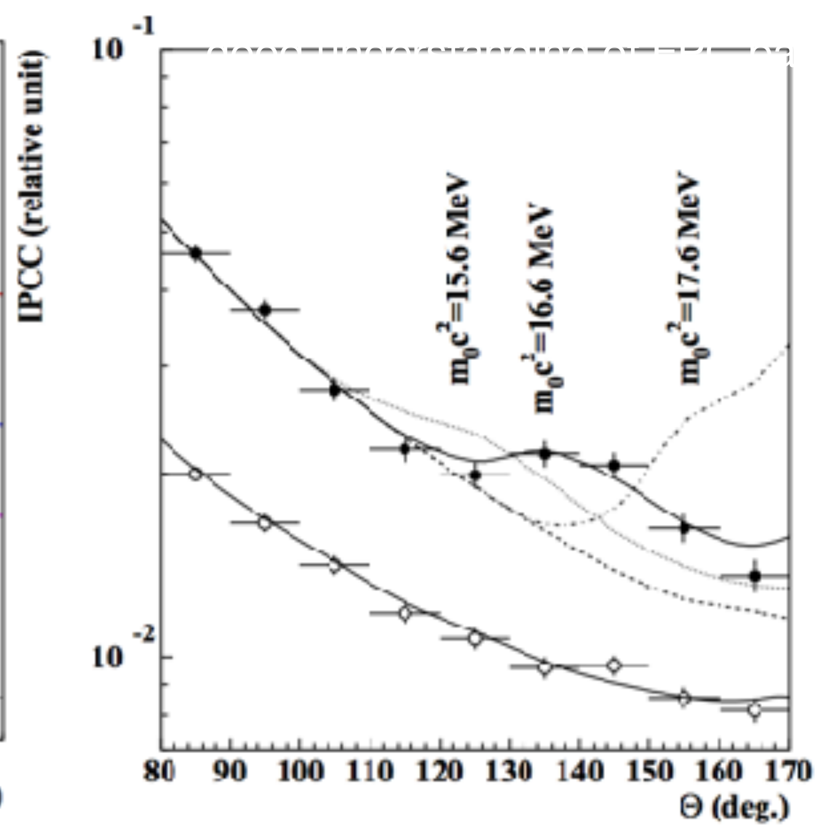


$^7\mathrm{Li}(p, e^+e^-)^8\mathrm{Be}$ studied at

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

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





- Internal Pair Conversion (IPC) distribution shows excess at Θ~140° at several beam energies

→ decay of a light particle emitted during proton capture

→ best fit $m_X = 16.95$ 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

Outline

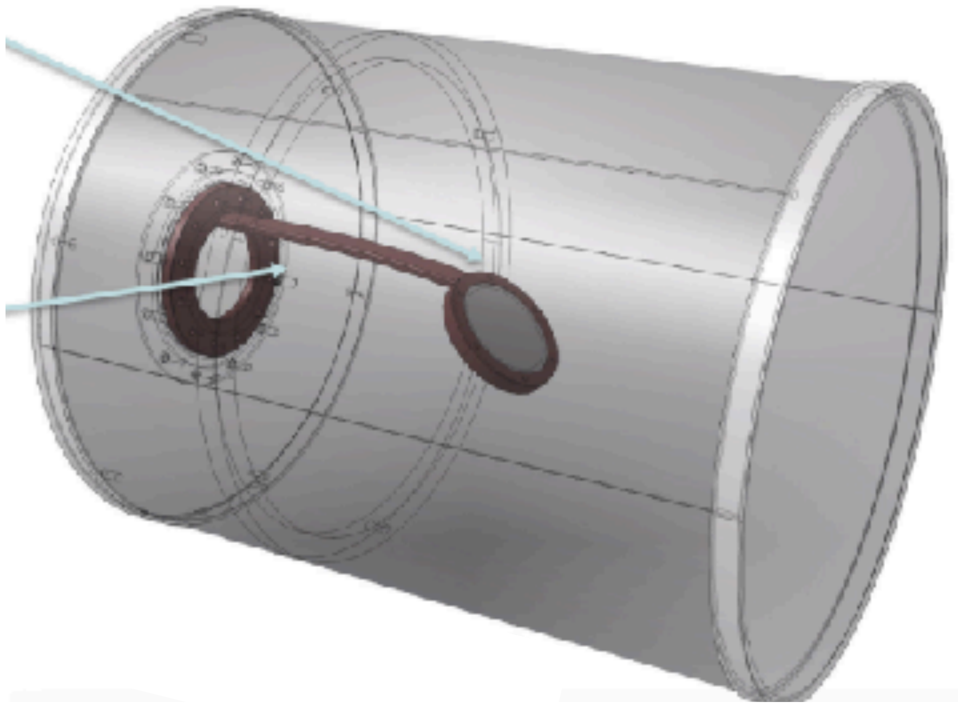
1) Track selection

2) MC vs Data in sidebands

3) Beam spot on target

4) Vertexing of electron-positron pair

5) Significance estimates



Strategy

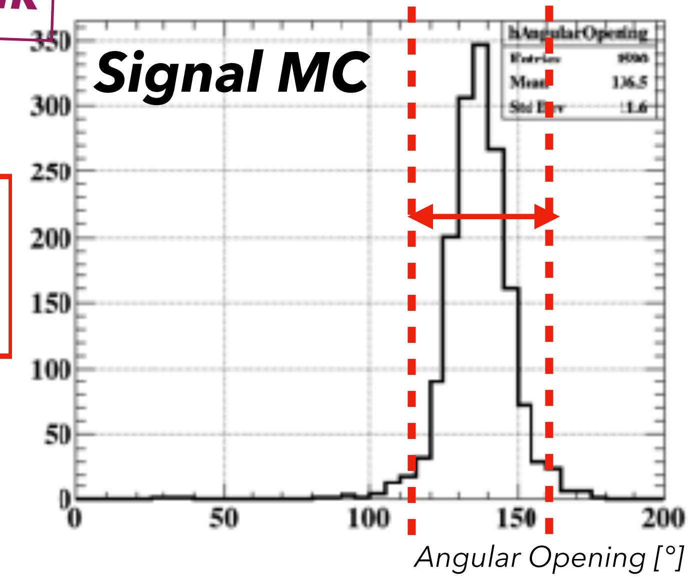
- **2D likelihood minimization: E*sum* vs Angle (feasibility under investigation)**

details in Giovanni's talk

- **Blinded signal region** defined as:

Signal Region

- **16 MeV < E*sum* < 20 MeV**
- **115° < Angle < 160°**



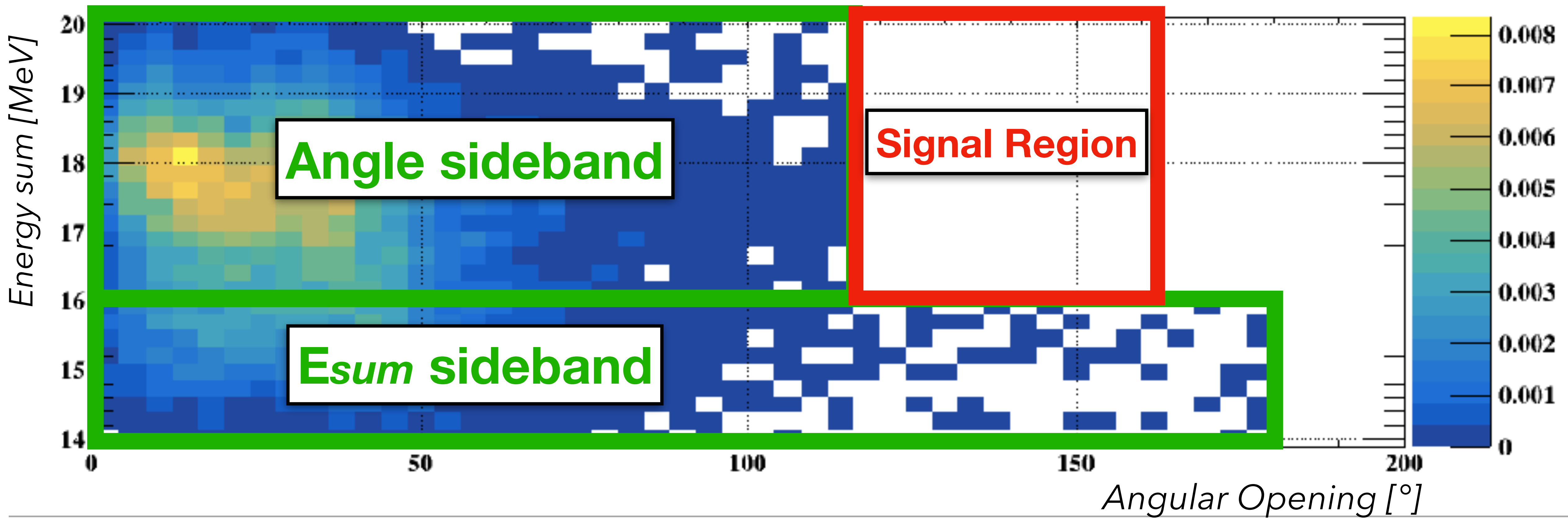
- Before unblinding, understanding of background will be done in two sidebands

Angle sideband

- **16 MeV < E*sum* < 20 MeV**
- **0° < Angle < 115°**

E*sum* sideband

- **14 MeV < E*sum* < 16 MeV**
- **Full angle range**



1) Track selection

Track and pair selection

–> e+ and e- go through large MS in O(20cm) of air before reaching the CDCH
–> a fraction of fitted tracks don't propagate to the physical target (or a finite target plane)
–> but most tracks should have a z axis POCA: we request propagation there instead

Base selection

Single tracks

- ToVertex = 1
- ngoodhits >= 6
- $|z_{vertex}|$ < 2.5 cm
- propagation length to vertex < 35 cm
- chi2/dof<4

Pairs

- no hits in common between the tracks
- vertex distance < 3 cm

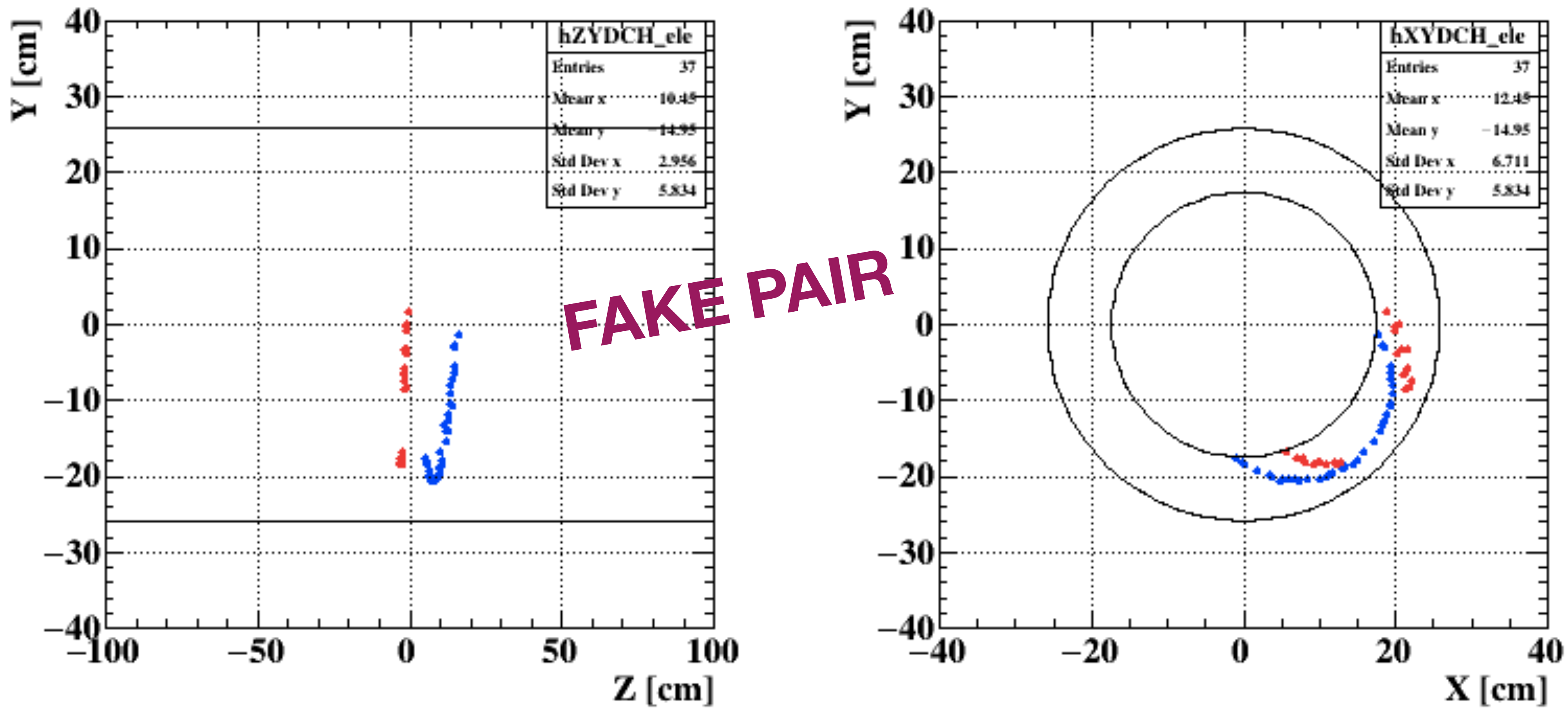
Fake pairs: two pieces of the same track are reconstructed with opposite signs

–> allowed by hit z resolution O(10cm)
–> fake pair reconstructed at large angles (almost back-to-back and close to SR): can be challenging to handle
–> additional selection is needed to reject these

Rejection of fake tracks

Base selection

- T0*lasthit* > T0*firsthit*
- |z*lasthit*| > |z*firsthit*|
- track DS(US) if θ<90°(>90°)



Fake tracks characteristics

–> <u>short</u>

–> if longer, <u>little dense</u>

–> <u>consecutive hits distance large</u>

–> <u>close to z=0</u>

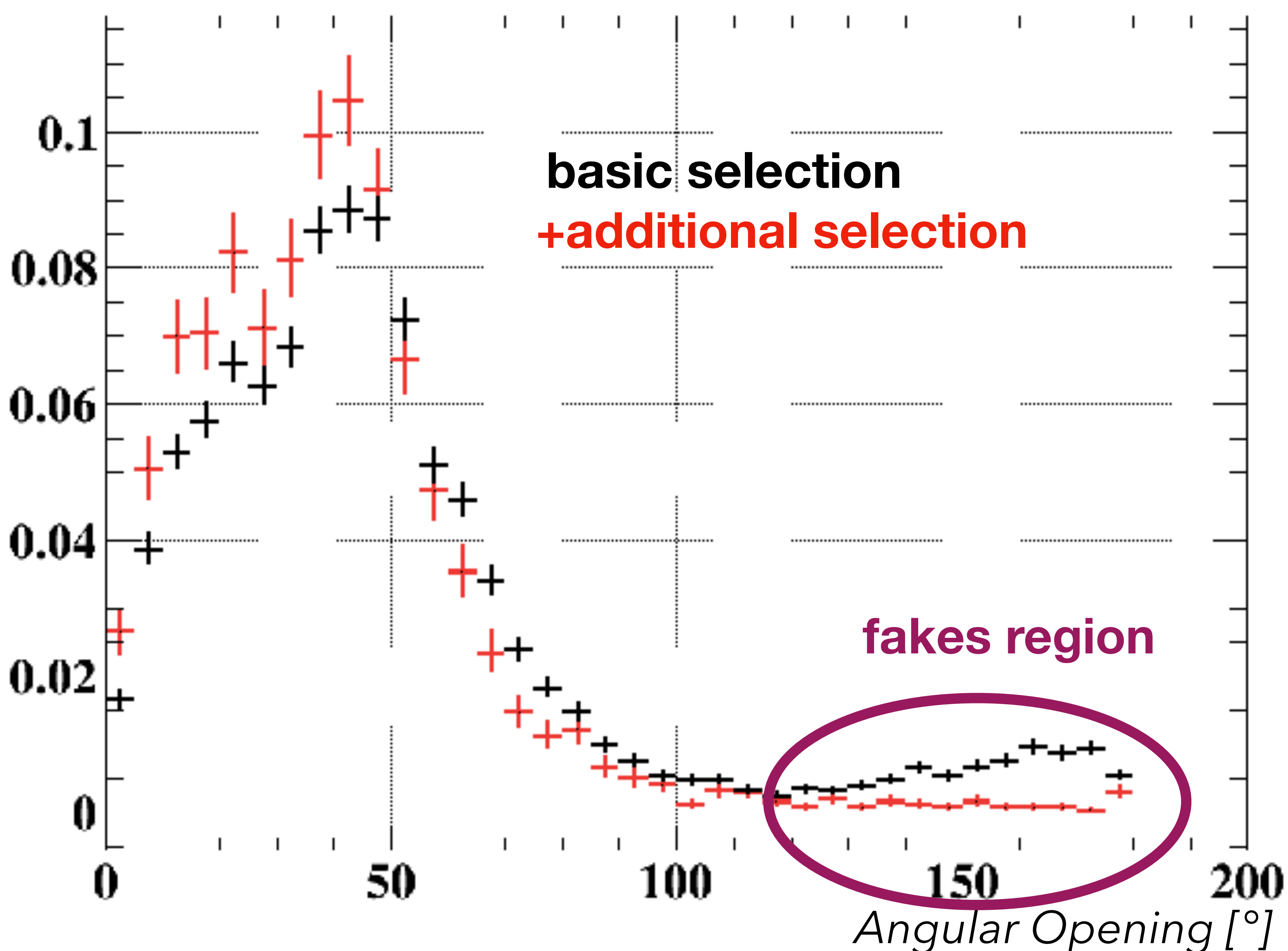
Additional selection

- ngoodhits >= 10
- half-turn density > 1.1 cm^{-1}
- std of cons. hit distance for half-turns < 0.9 cm
- z*firsthit* > 2.5 cm

Rejection of fake tracks

LiPON23 data in E*sum* sideband

6% of 2023 data are used



E*sum* sideband

- **14 MeV < E*sum* < 16 MeV**
- **Full angle range**

–> updated selection allows strong rejection of fakes

–> monotonously decreasing background shape is recovered

–> 1/3 of signal lost (based on signal MC)

–> comparisons with MC will be carried out to ensure fakes are negligible wrt to bkg and signal

2) MC vs data in sidebands

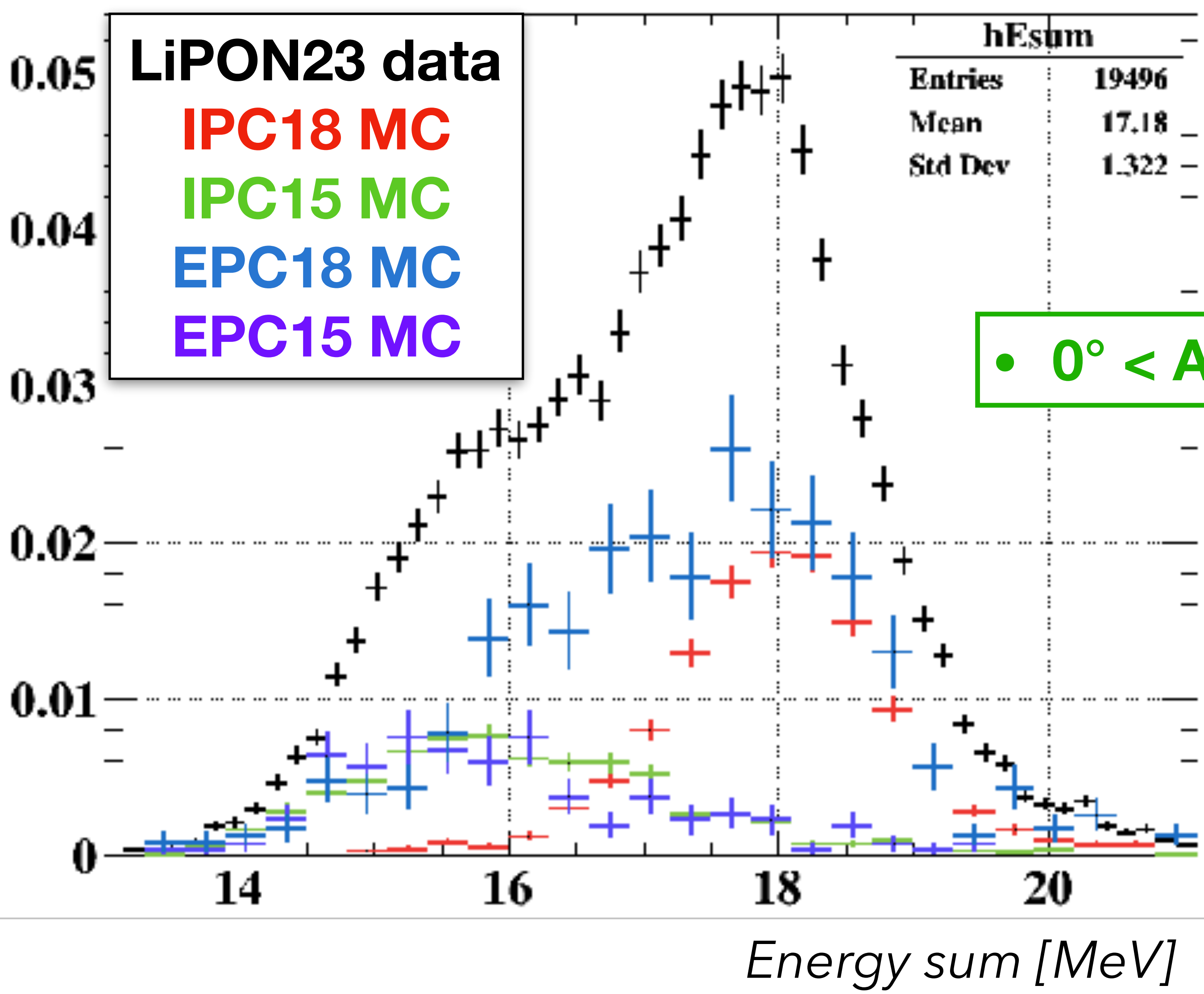
Esum spectrum

- **Esum = Ee+ + Ee-**
  - **Proportions of all 4 backgrounds from fit of Angular Opening at low and high Esum**
  - **Ad-hoc rescaling of BField based on single particles momentum (0.150B —> 0.155B)**

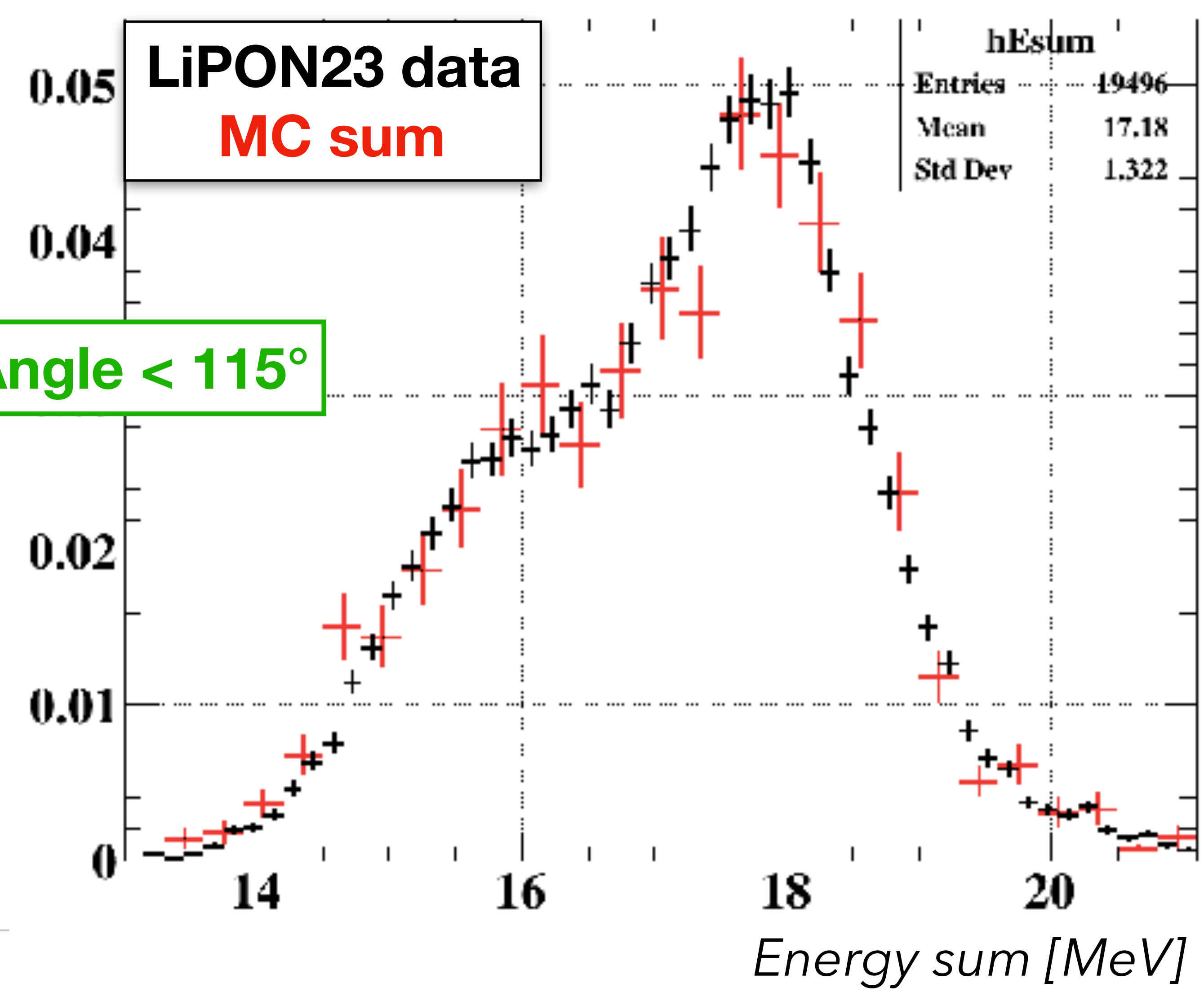
in coming slides, 6% of 2023 data are used

Proportions from fit
–> IPC18: 25%
–> EPC18: 49%
–> IPC15: 14%
–> EPC15: 13%

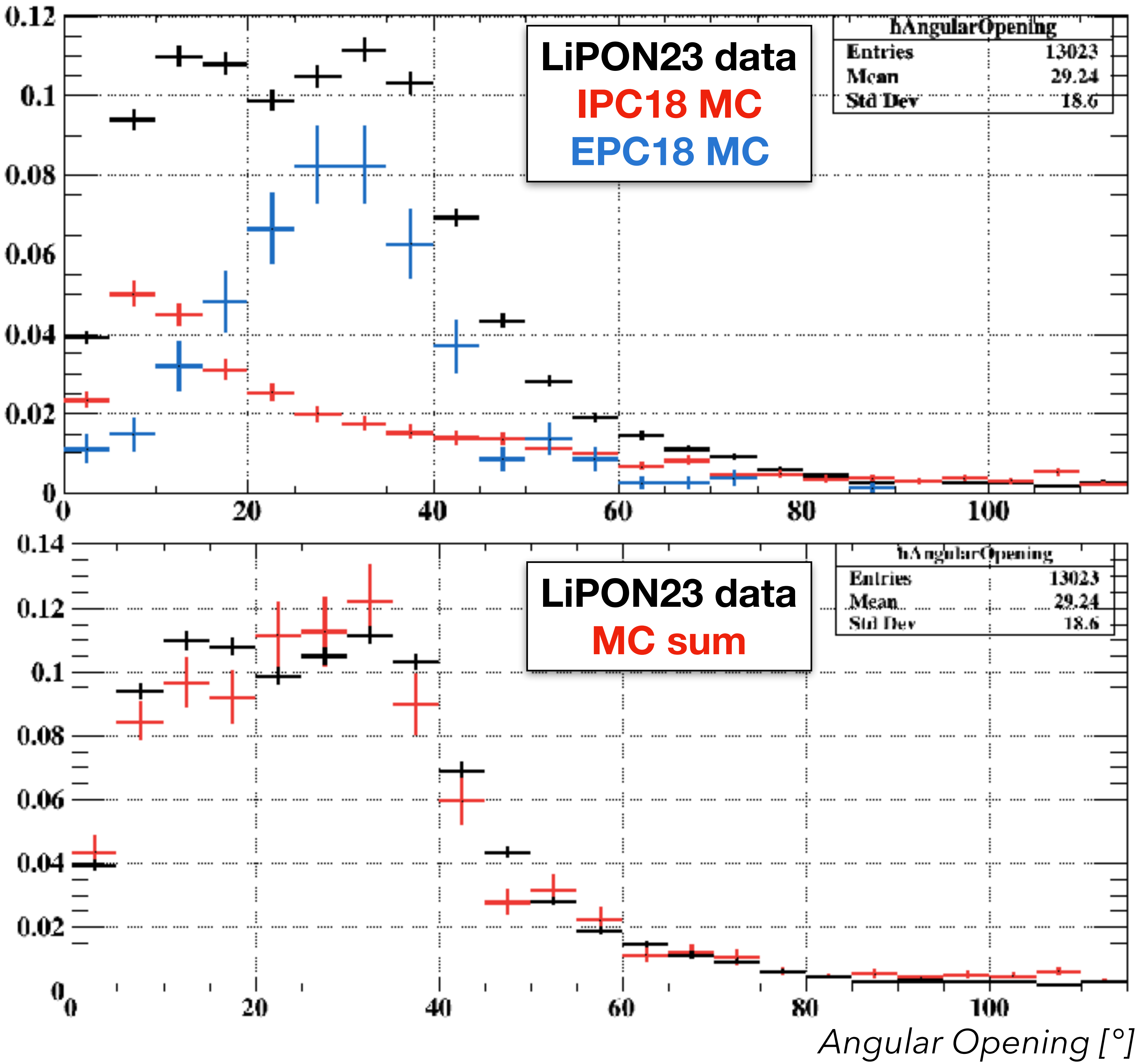
As reference,
Proportions from MC
–> IPC18: 34%
–> EPC18: 37%
–> IPC15: 18%
–> EPC15: 11%



- 0° < Angle < 115°



Angle sideband: angle < 115°



Angle sideband

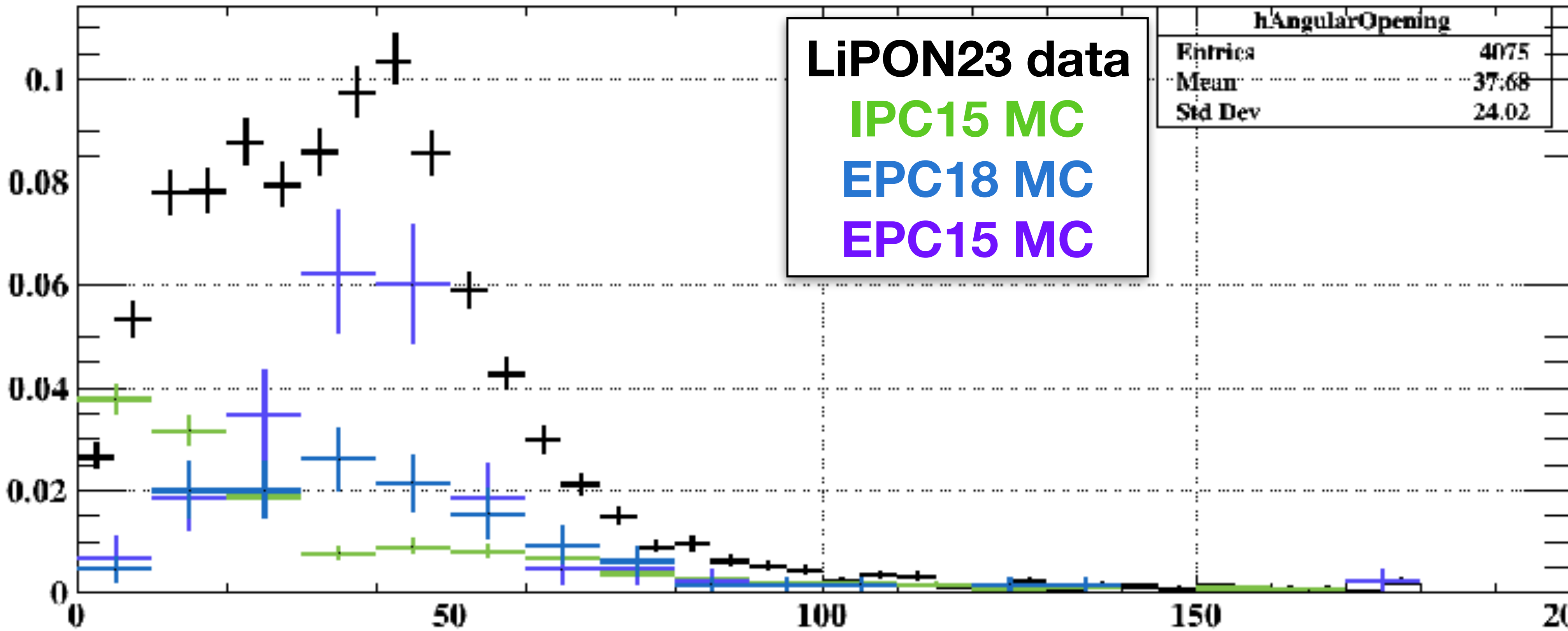
- 16 MeV < Esum < 20 MeV
- 0° < Angle < 115°

–> IPC dominant over 80°

–> background shapes to be refined with higher statistics MC ***(in ~2 weeks)***

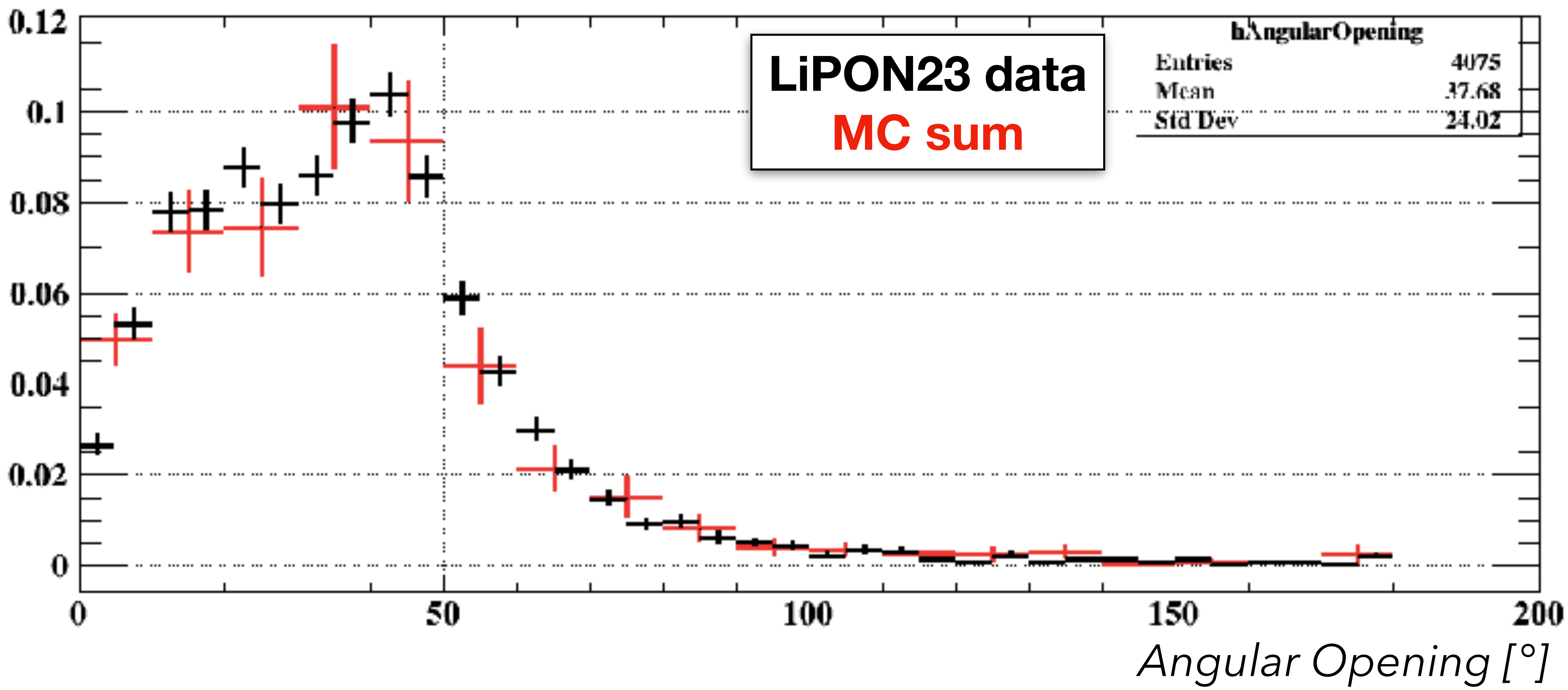
–> angular acceptance data and MC to be compared

E_{sum} sideband: 14 MeV < E_{sum} < 16 MeV



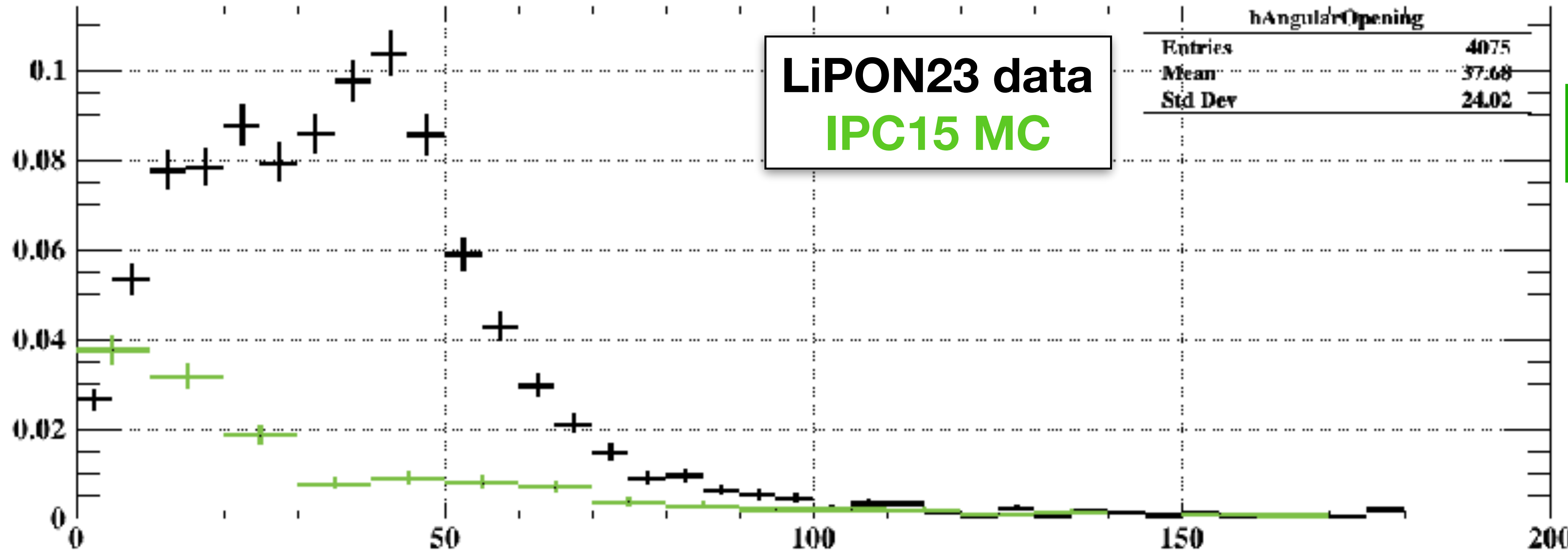
E_{sum} sideband

- **14 MeV < E_{sum} < 16 MeV**
- **Full angle range**



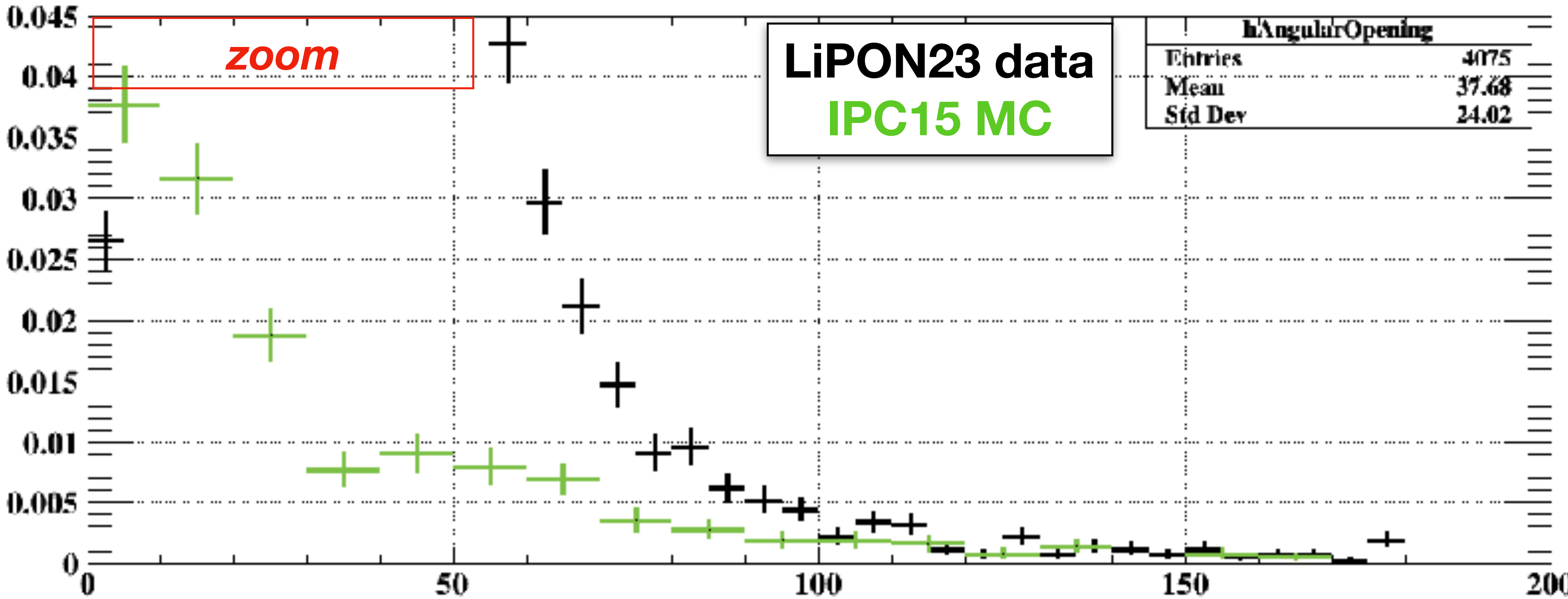
–> monotonously decreasing IPC tail

E_{sum} sideband: focus on IPC contribution



E_{sum} sideband

- 14 MeV < E_{sum} < 16 MeV
- Full angle range



–> no significant discrepancy data/MC at large angles
–> fakes largely removed

Angular Opening [°]

MC vs data comparisons

- **comparisons MC vs data in Angle and E*sum* sidebands**

–> overall understanding of the backgrounds and shapes:
mix of EPC (mostly at low angles) and IPC (dominant background in signal region)
–> fakes largely rejected

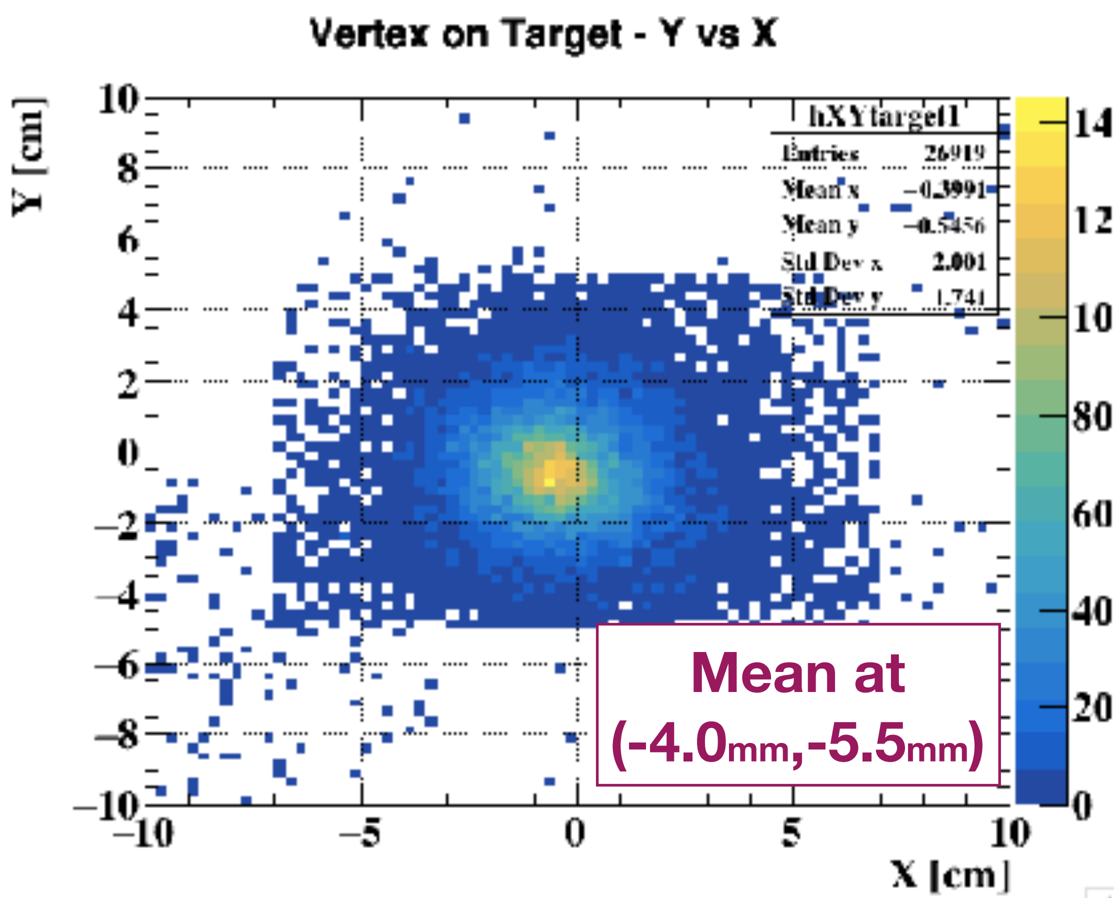
- **for refined comparisons:**

–> use higher MC statistics to extract shapes
–> compare angular opening acceptance for MC and data

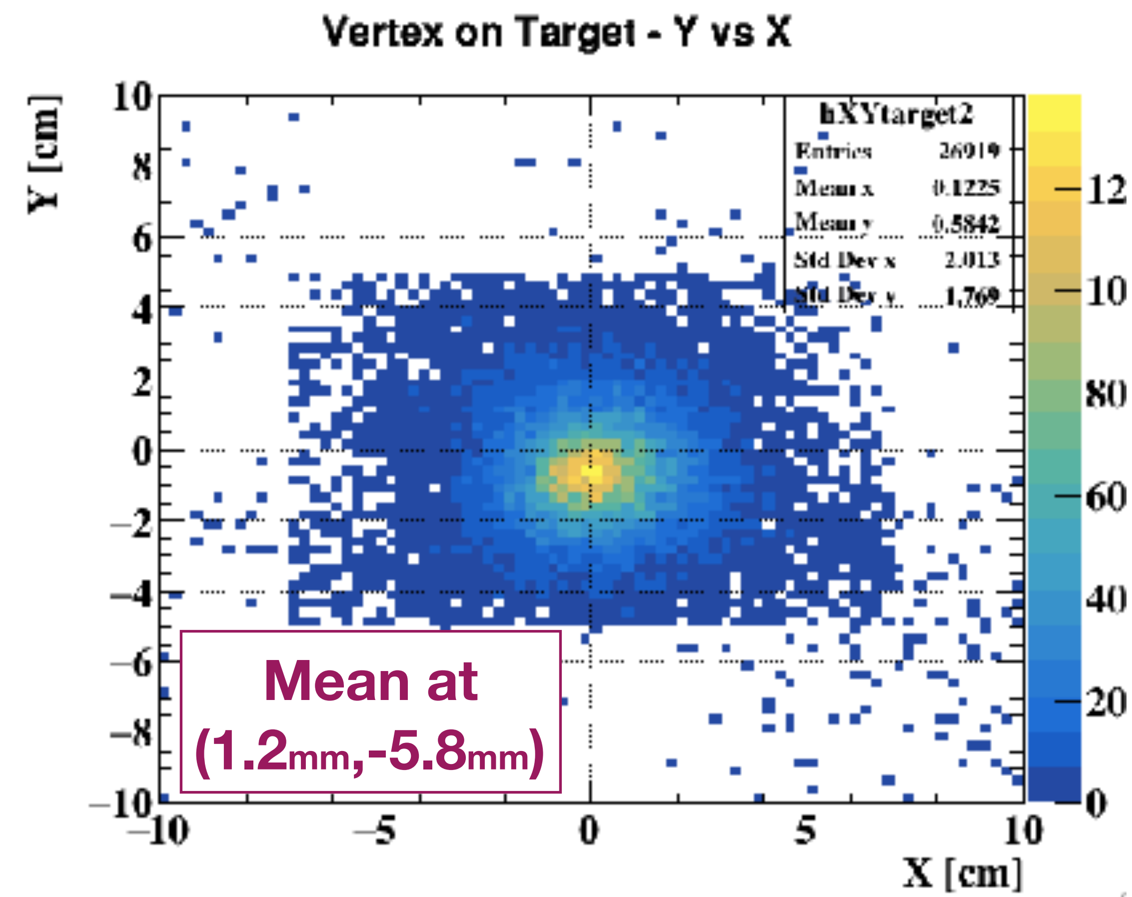
3) Beam spot on target

LiPON23 - all angles

Positrons



Electrons



- Reconstructed vertices on target are <u>off-center by ~7mm</u>
- Positron and electron vertices distributions are <u>shifted wrt one another</u>
- Where is the true beam spot?

<u>From MC</u>
- IPC vertices **correctly reconstructed (within 1mm)**
- EPC vertices are:

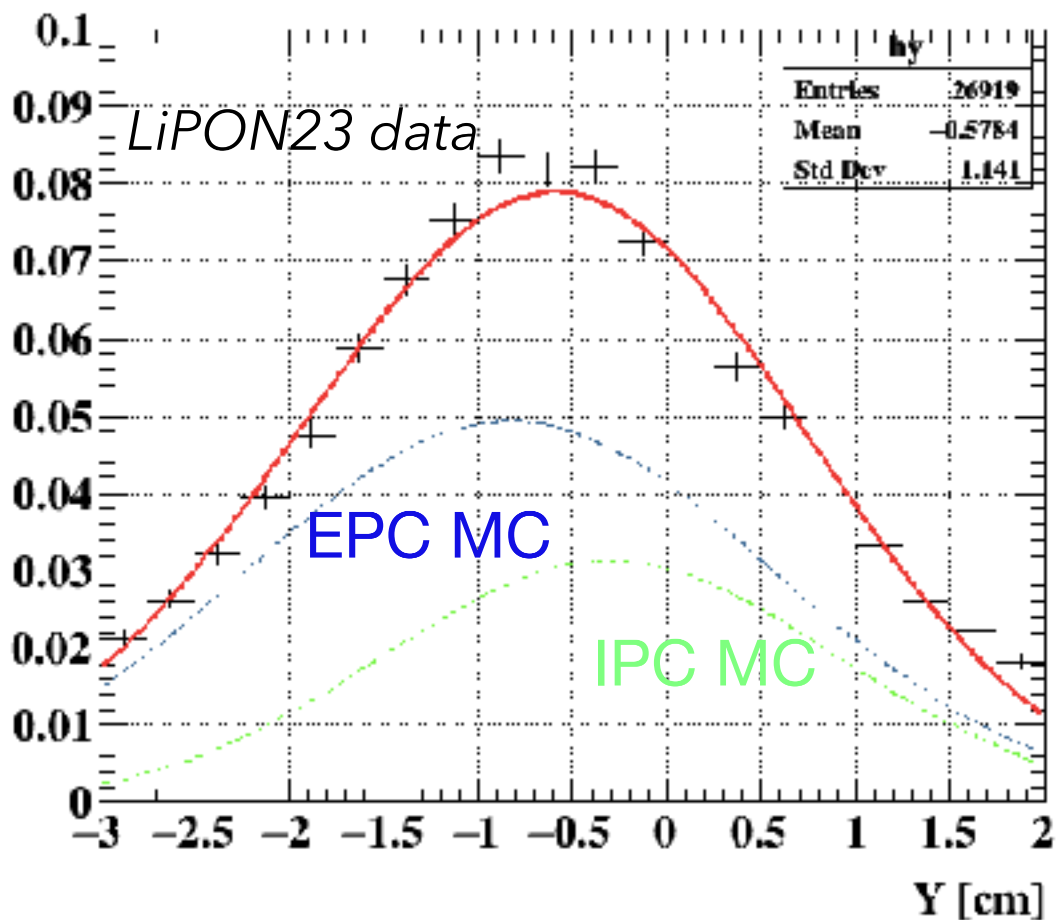
–> reconstructed with systematic shift towards -y (trigger bias and gamma fwd asymmetry)
–> shifted for e+ and e-

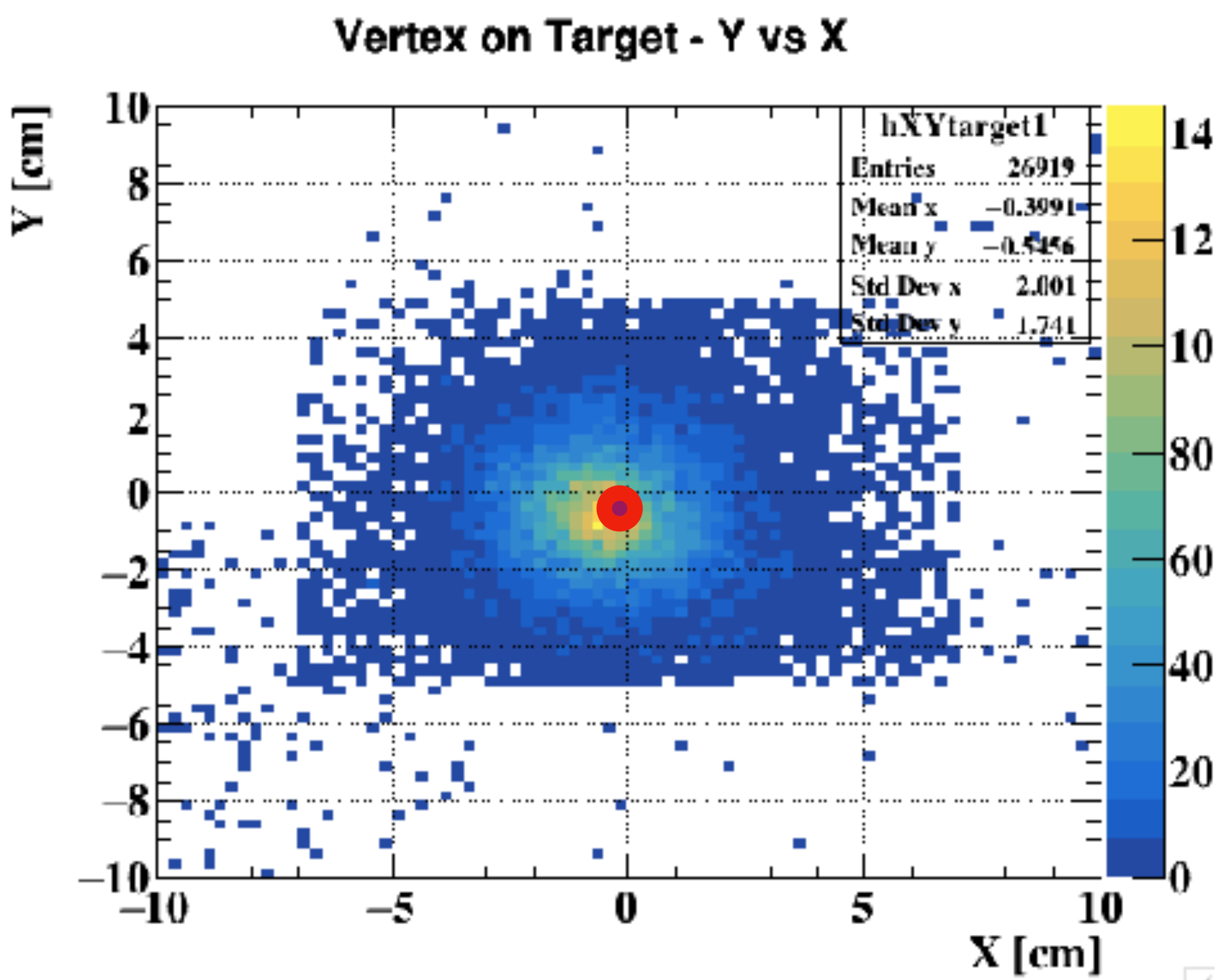
Beam spot on target

- **x** of beam spot was extracted from IPC-enriched sample of data (low angular opening)

x_{beam} = -2 mm

- **y** of beam spot can be extracted from fit of data with MC distribution considering EPC:IPC 60:40





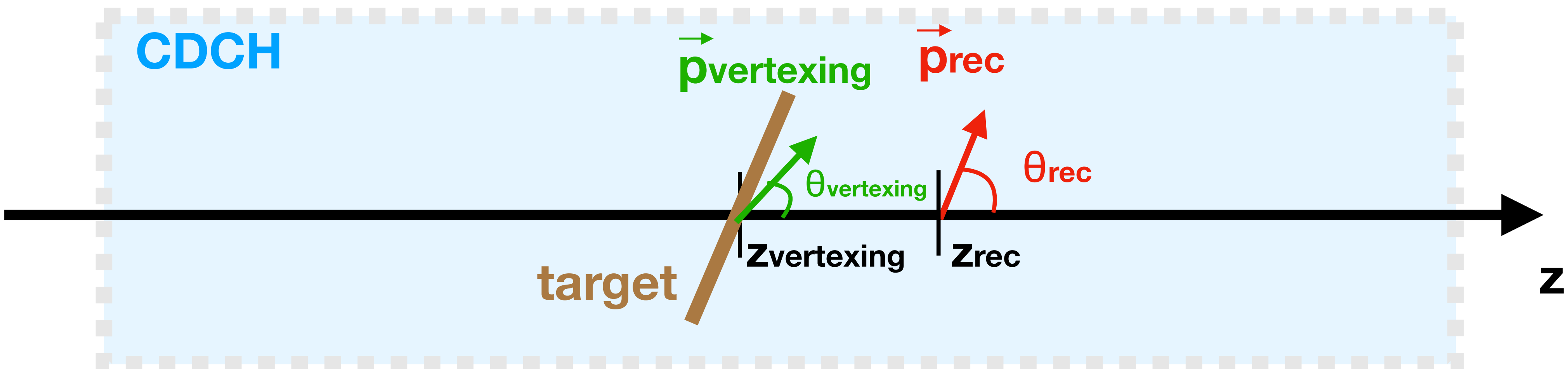
y is then extracted from IPC mean: **y_{beam} = -3 mm**

● **beam spot position**

4) Vertexing

Vertexing

due to O(20cm) of air between target and CDCH and large multiple scattering
–> tracks are reconstructed **O(cm) away from the true vertex**



Objective: find e+ and e- common vertex
How: use e+ and e- state at z axis POCA + beam spot information
Why: improve resolutions

Procedure

- all tracks are fitted separately to the z axis POCA
- selection of best e+ and e- track
- search for a possible common vertex within a beam spot constraint
- vertexing tool implemented with the help of Fedor (thanks!):

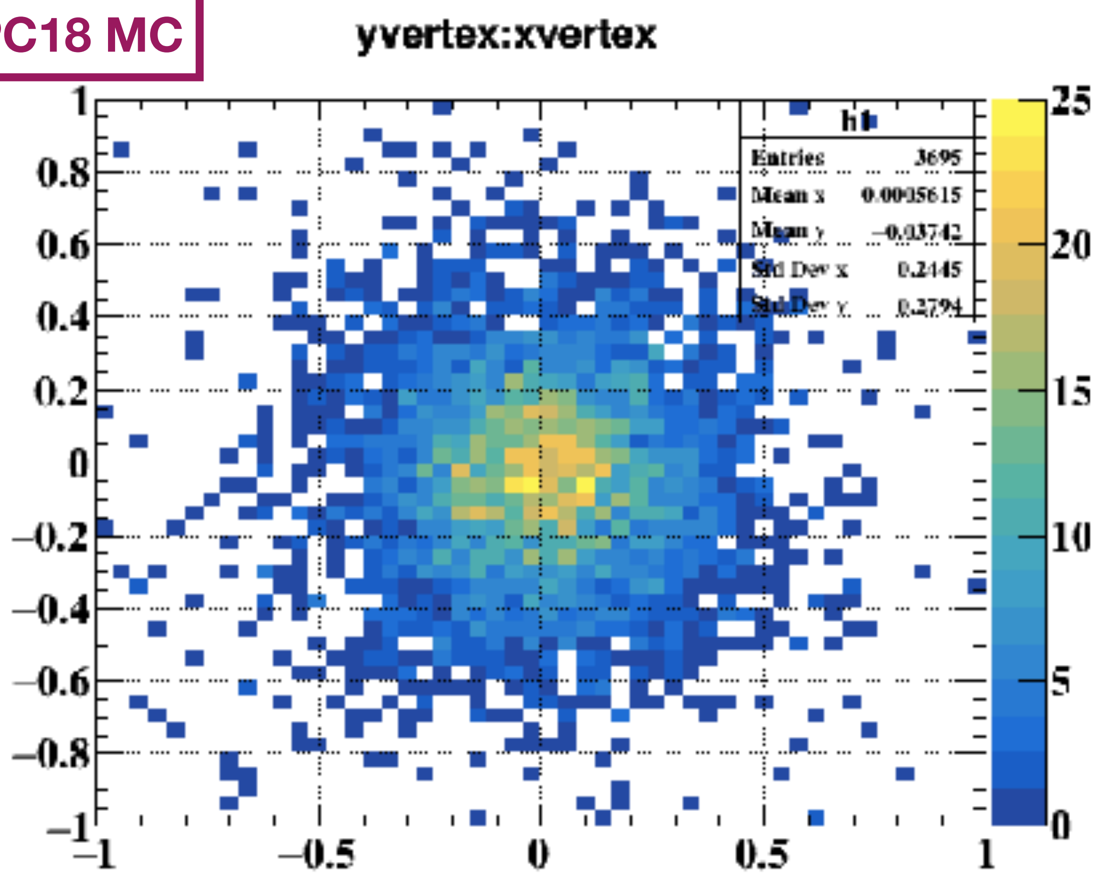
–> **RAVE (Reconstruction (of vertices) in Abstract Versatile Environments)**
–> compatible with GENFIT
–> input is position, momentum and associated covariance

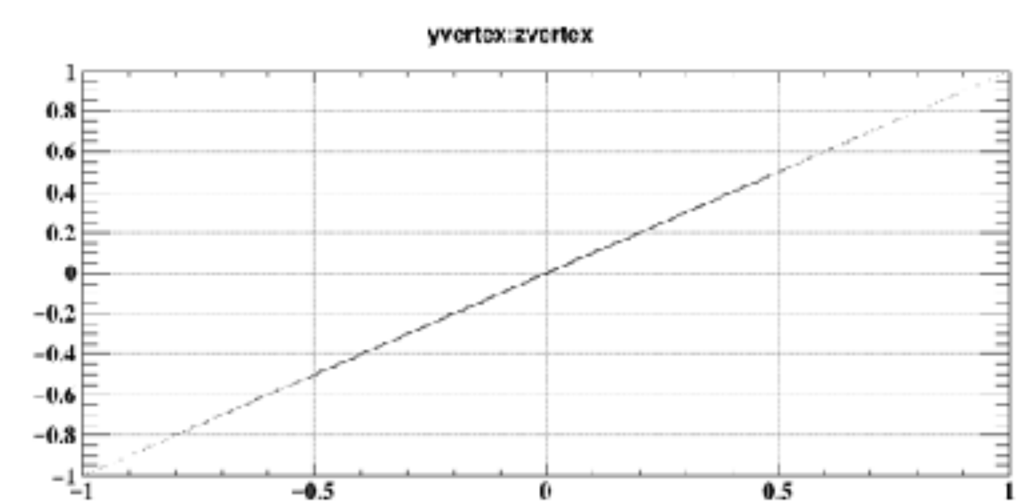
Vertexing

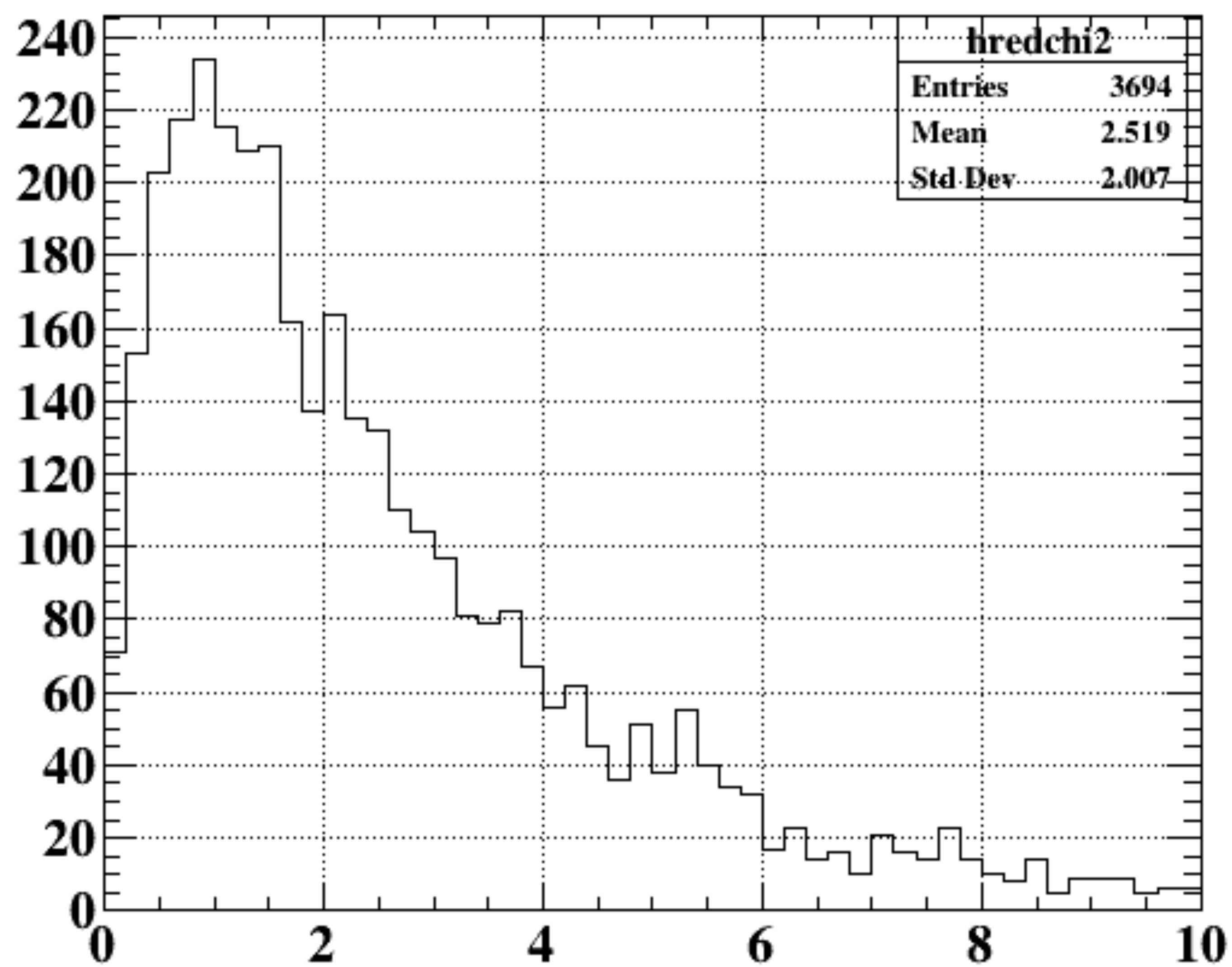
–> **MEG BField** scaled by 0.15
–> **MEG+XBoson geometry** implemented

Beam spot constraint defined as (x,y,z) + cov. matrix
–> vertexing on **target plane**
–> **3mm sigma beam** spot constraint

IPC18 MC







chi2/dof of vertexing

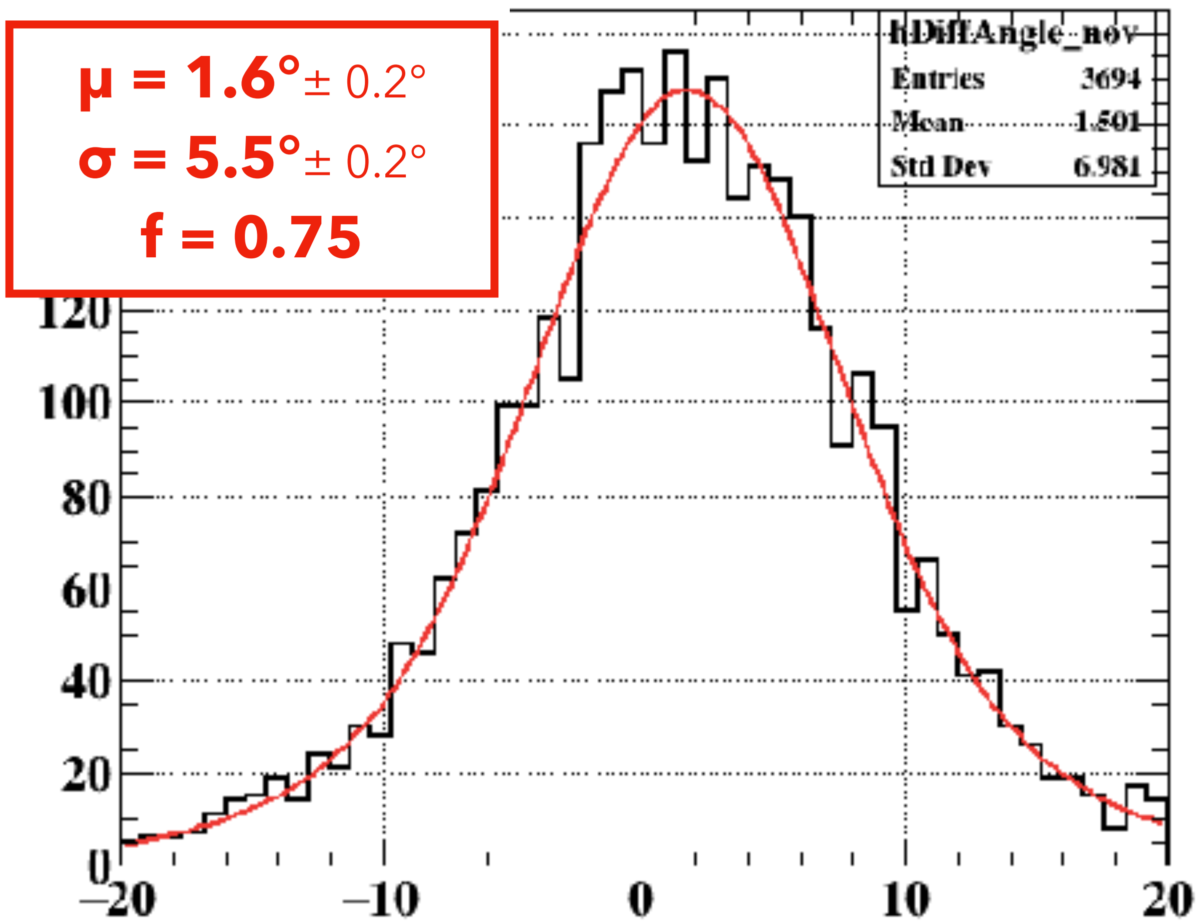
Angular Opening resolutions

IPC18 MC

No vertexing

DOUBLE GAUSSIAN

μ = 1.6° ± 0.2°
σ = 5.5° ± 0.2°
f = 0.75



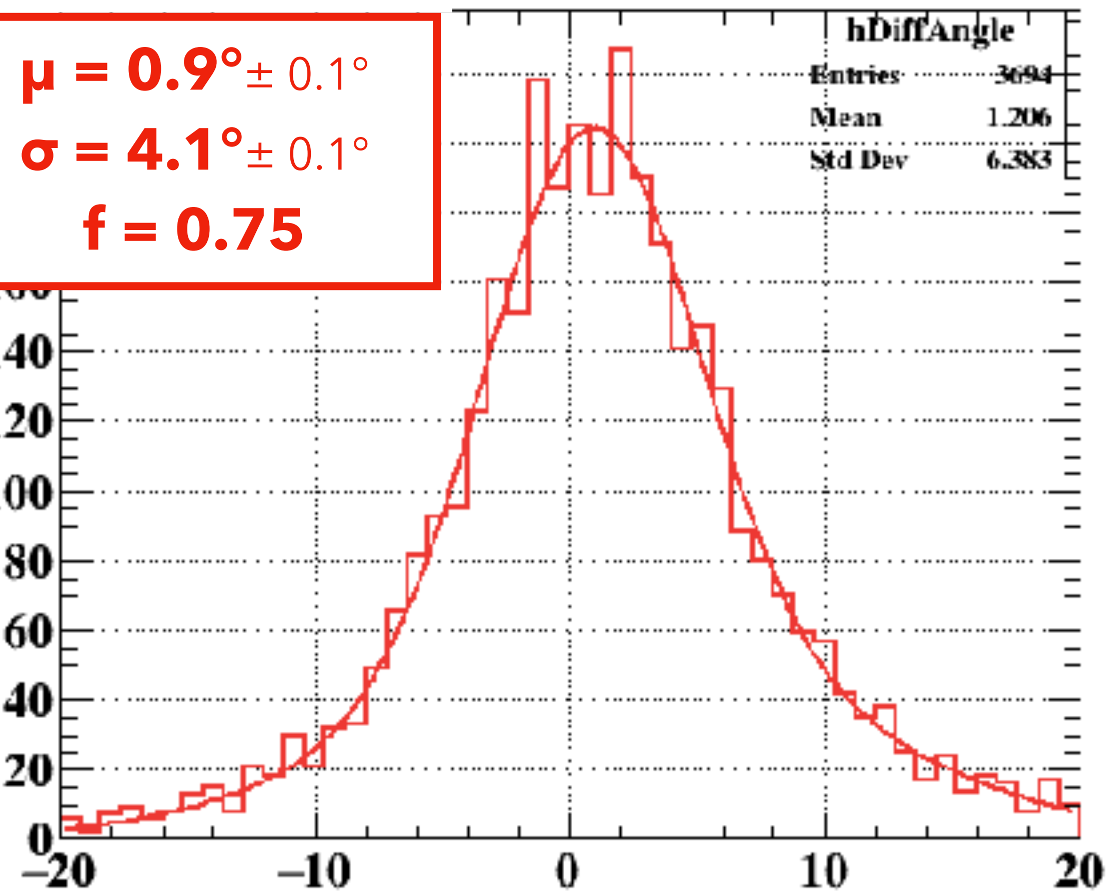
σ_2 = 10.3° ± 1.0°

RecAngle - SimAngle [deg]

With vertexing

DOUBLE GAUSSIAN

μ = 0.9° ± 0.1°
σ = 4.1° ± 0.1°
f = 0.75



σ_2 = 9.2° ± 0.2°

RecAngle - SimAngle [deg]

–> 25% improvement on core gaussian

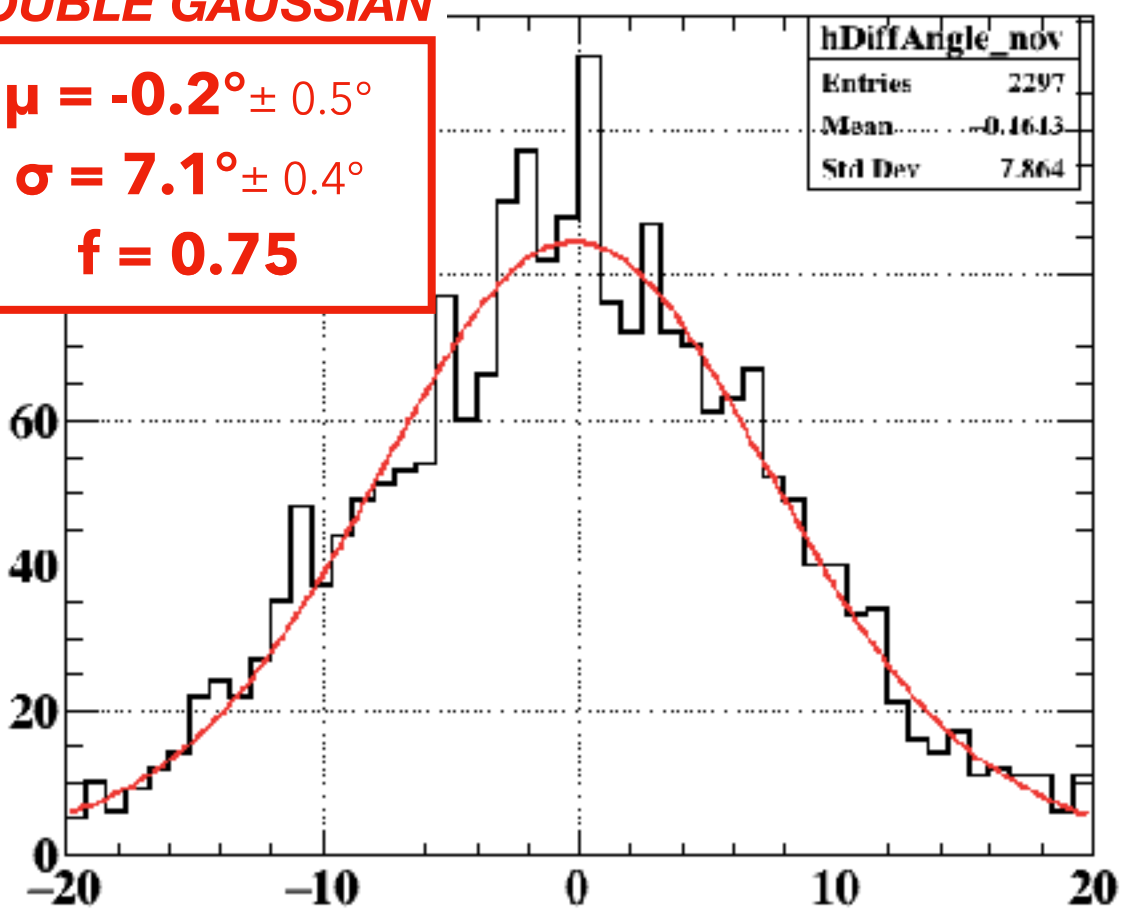
Angular Opening resolutions

X17 MC

No vertexing

DOUBLE GAUSSIAN

μ = -0.2° ± 0.5°
σ = 7.1° ± 0.4°
f = 0.75



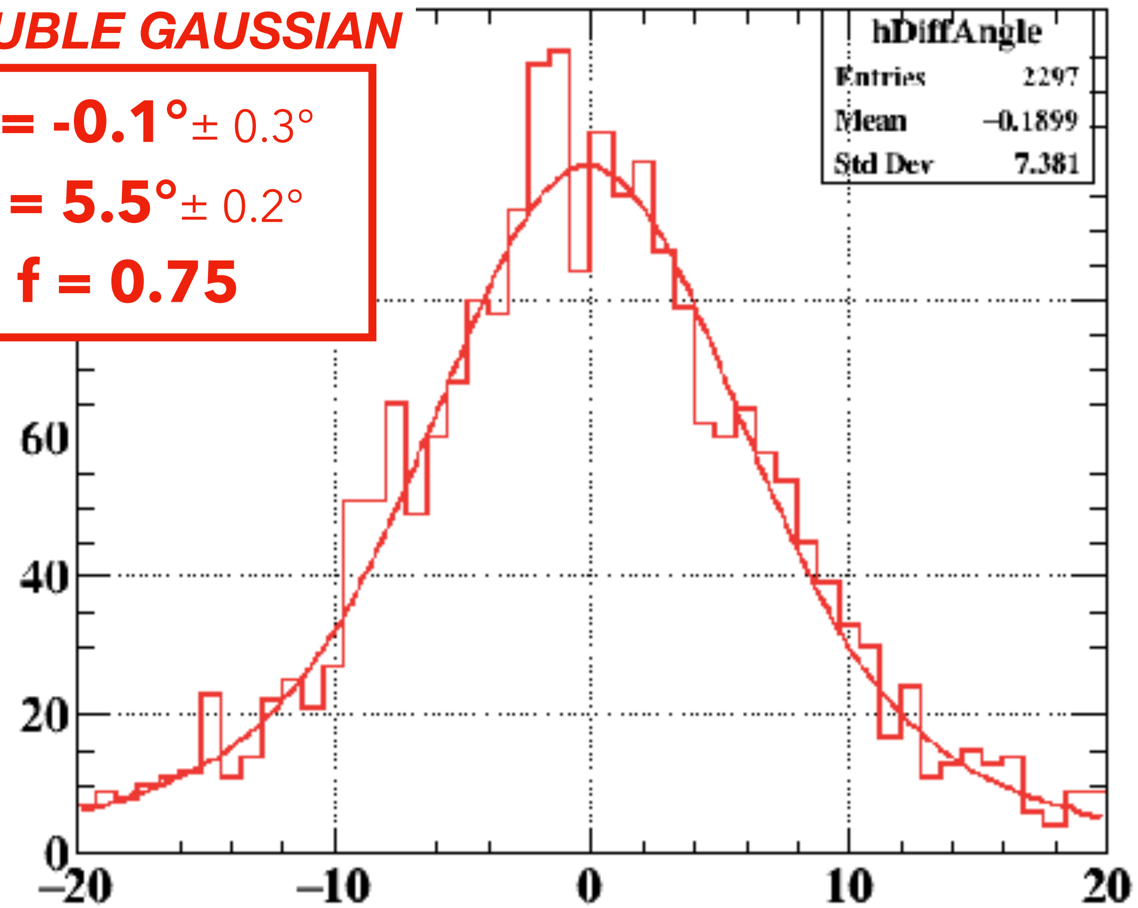
σ_2 = 11.3° ± 1.1°

RecAngle - SimAngle [deg]

With vertexing

DOUBLE GAUSSIAN

μ = -0.1° ± 0.3°
σ = 5.5° ± 0.2°
f = 0.75



σ_2 = 11.6° ± 0.5°

RecAngle - SimAngle [deg]

–> 25% improvement on core gaussian

5) Significance estimate

Significance estimate

- Final significance will be extracted from likelihood analysis
- A first estimate of the sensitivity can be extracted from a cut & count analysis

- Number of signal events

$$N_S = N - N_{IPC}^{sig}$$

with

N *total number of events in signal region*

N_{IPC}^{sig} *number of IPC events in signal region*

- Uncertainty on N_S

$$\sigma_{N_S} = \sqrt{N + \sigma^2_{N_{IPC}^{sig}}}$$

- Uncertainty on N_{IPC}^{sig} comes from estimation in sideband

$$\sigma_{N_{IPC}^{sig}} = \sqrt{\beta^2 \sigma^2_{N_{IPC}^{side}} + (N_{IPC}^{side})^2 * \sigma^2_\beta}$$

largely dependent on control over EPC background

with

$$\beta = \frac{N_{IPC}^{sig}}{N_{IPC}^{side}}$$ *(from MC)*

N_{IPC}^{side} *number of IPC in sideband*

Significance estimate

LiPON 2023 full dataset	N	N_S	N_{IPC}^{sig}	β	$\sigma_{N_{IPC}^{side}}$	$\sigma_{N_{IPC}^{sig}}$	σ_N	Significance
Scenario 1 negligible uncertainty from EPC background	4400	400	4000	0.65	78	**64**	**66**	**4.3**
Scenario 2 non-negligible uncertainty from EPC background	4400	400	4000	0.65	156	**109**	**66**	**3.1**

- improvement can be expected with larger MC production
- likely an underestimate compared to results from likelihood analysis

Conclusion

- **Selection** for tracks and pairs updated: strong rejection of fake pairs
- Comparisons of **E*sum*** and **Angular Opening** between MC and data in sidebands: overall understanding of backgrounds - next: compare acceptance
- **Beam spot position** was extracted
- **Vertexing for electron-positron pair** was developed: improves angular resolutions
- **Significance estimated** from simplified cut & count analysis
- **Official reprocessing of 2023 data** has started thanks to Yusuke and should take ~1month
- Mass MC production **in ~2 weeks**

Backup