ALICE TPC Simulation and Reconstruction

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Summary

- We propose to build a copy of the ALICE gas TPC, using the ALICE readout planes
- ALICE is a highly capable three-dimensional detector which performs very well in pp and heavy-ion collisions at the LHC
- ALICE's software is publicly available and ALICE collaborators are friendly and helpful
- Full GEANT4 simulation + realistic calibration and full reconstruction battle-tested: used to produce ALICE physics results.
- But ALICE's physics program is dedicated to measuring high-momentum tracks originating from their beam collision point and in a central angular region. The software works very well for this. But not for other tracks.
- We want to detect lower-momentum tracks at all positions and angles.

ALICE

J. Alme et al. / Nuclear Instruments and Methods in Physics Research A 622 (2010) 316–367

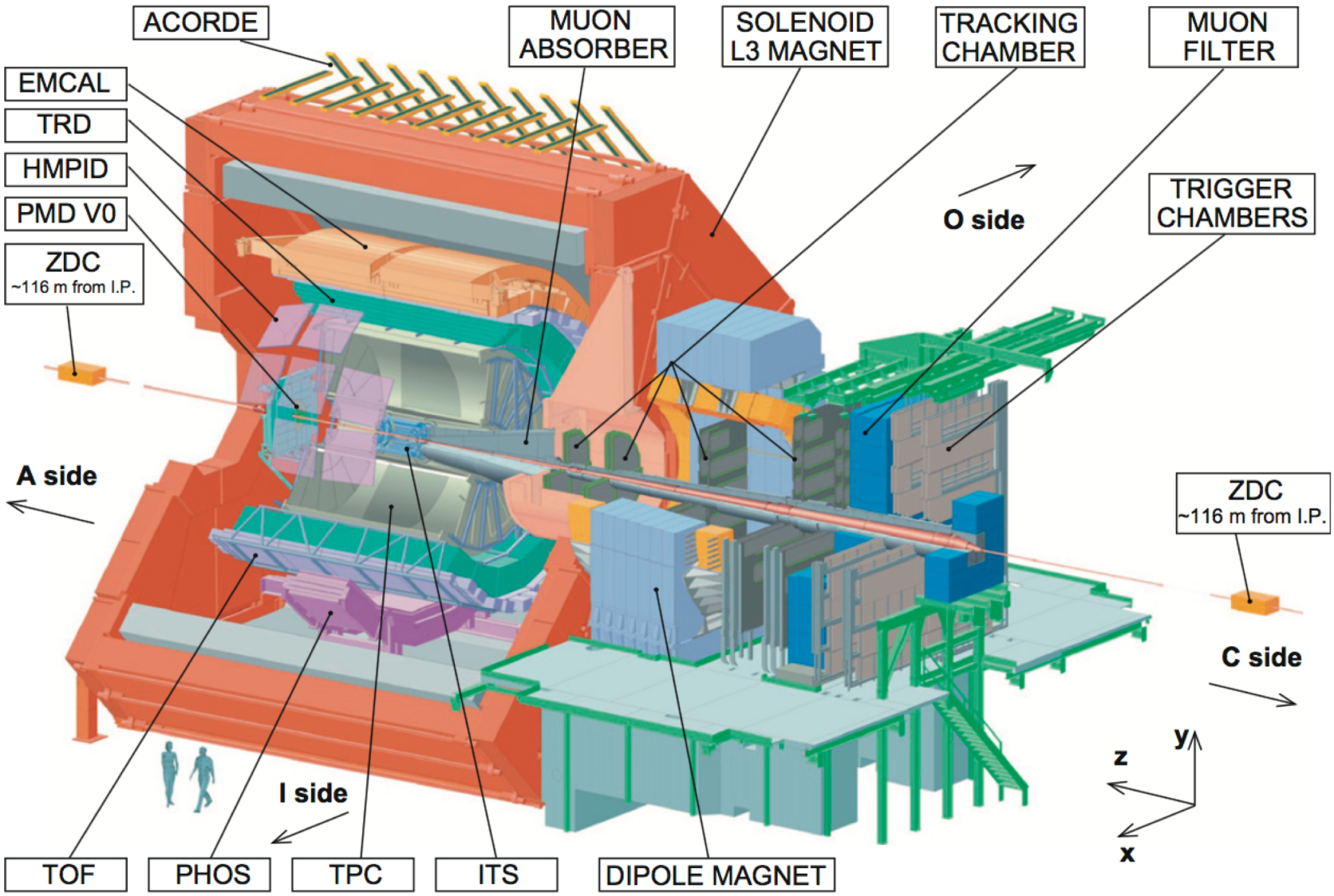
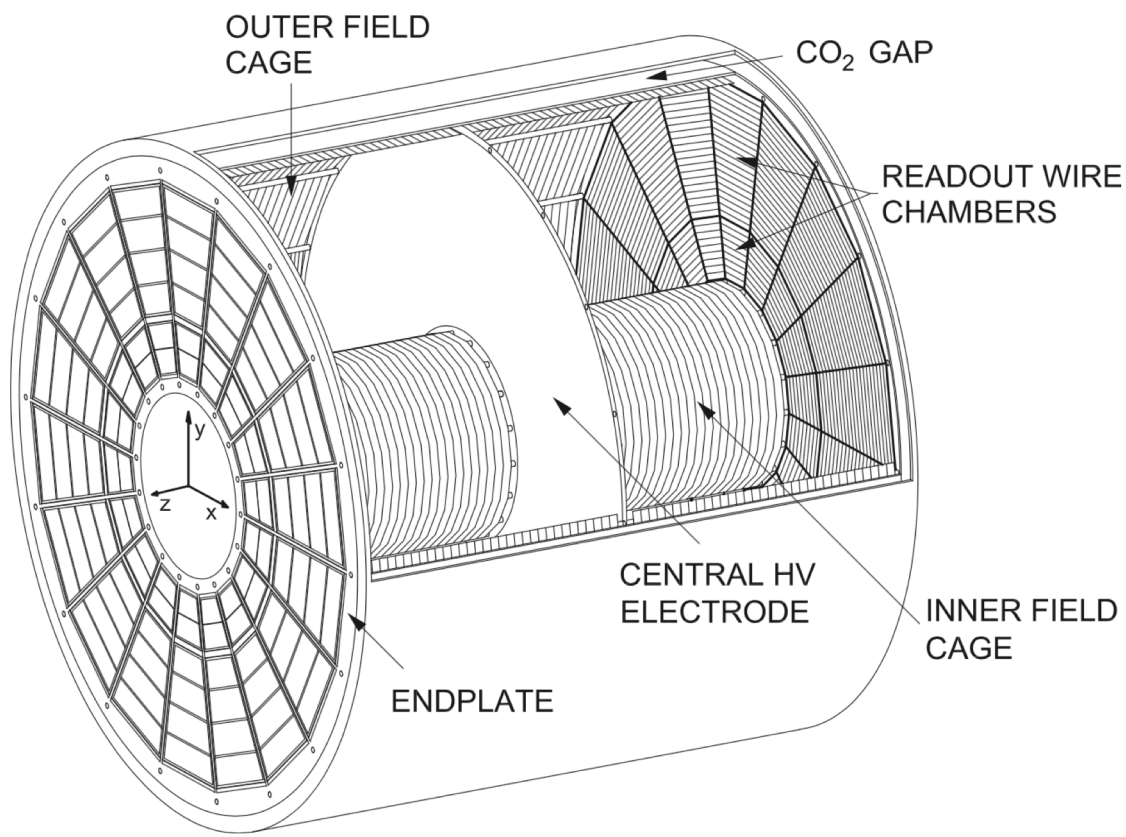


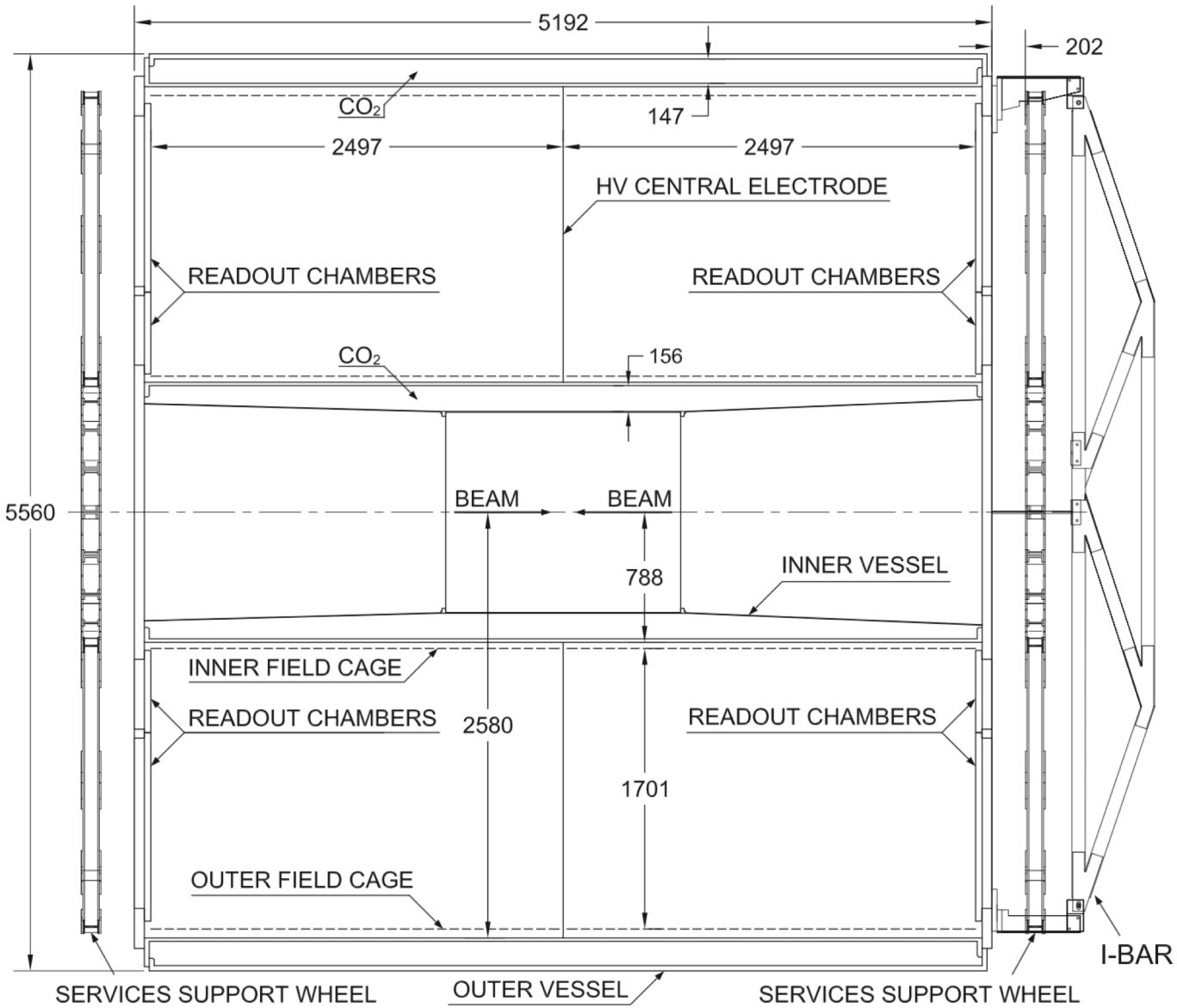
Fig. 1. ALICE schematic layout [2].

The ALICE TPC at CERN

- 18 Sectors, two sides. Anodes on either end, cathode in the middle.
- Outer radius: 2.58 meters, inner radius 0.788 meters (1.7 meters active).
- Length: 5.19 meters
- Gas 1 Atm Ne (+CO_2+N_2)
- B = 0.5 Tesla
- Alice will upgrade the readout chambers for HL-LHC.
- Pad readout: total 557,568 channels



Side View of the ALICE TPC



ALICE TPC Readout Plane

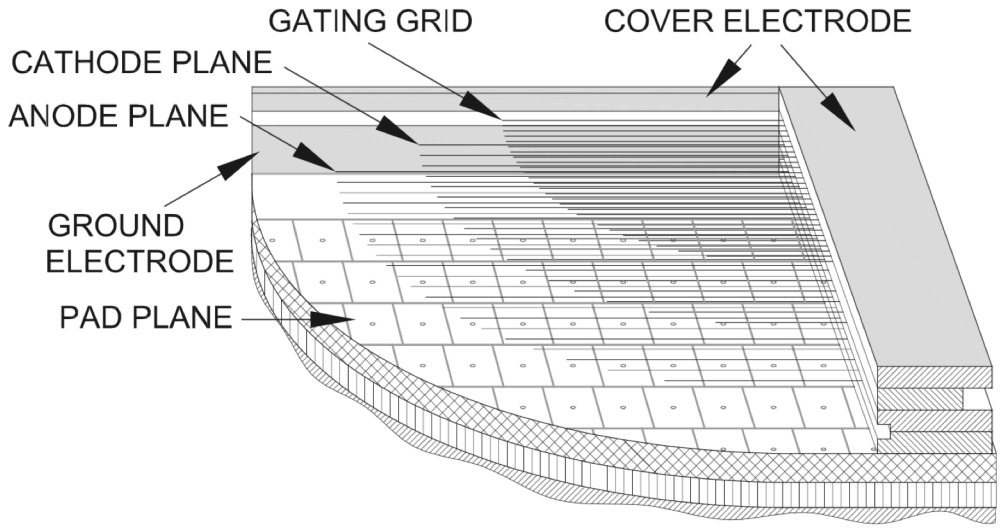
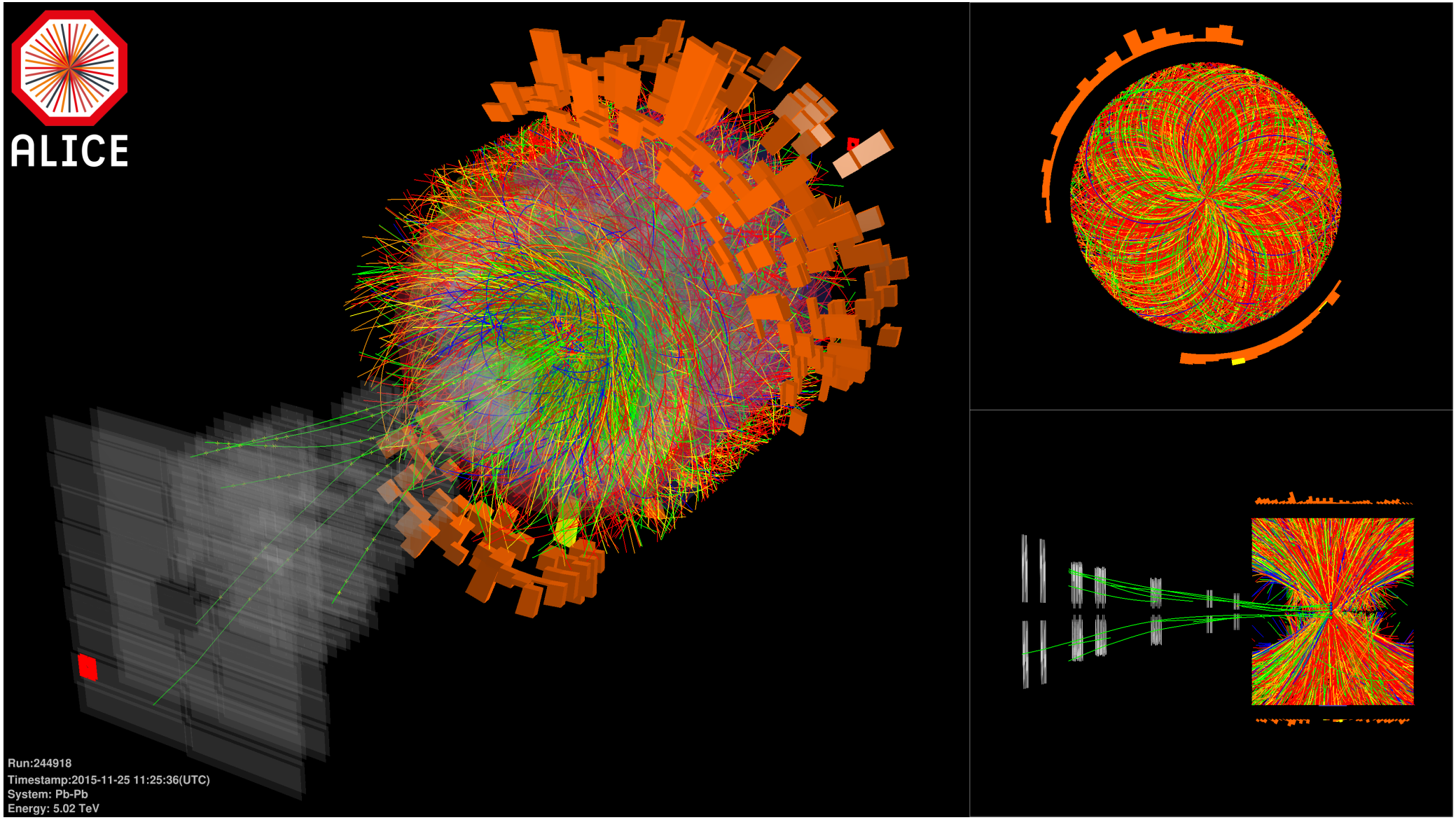


Fig. 9. Cross-section through a readout chamber showing the pad plane, the wire planes and the cover electrode.

For one sector
(1/18 of one side):

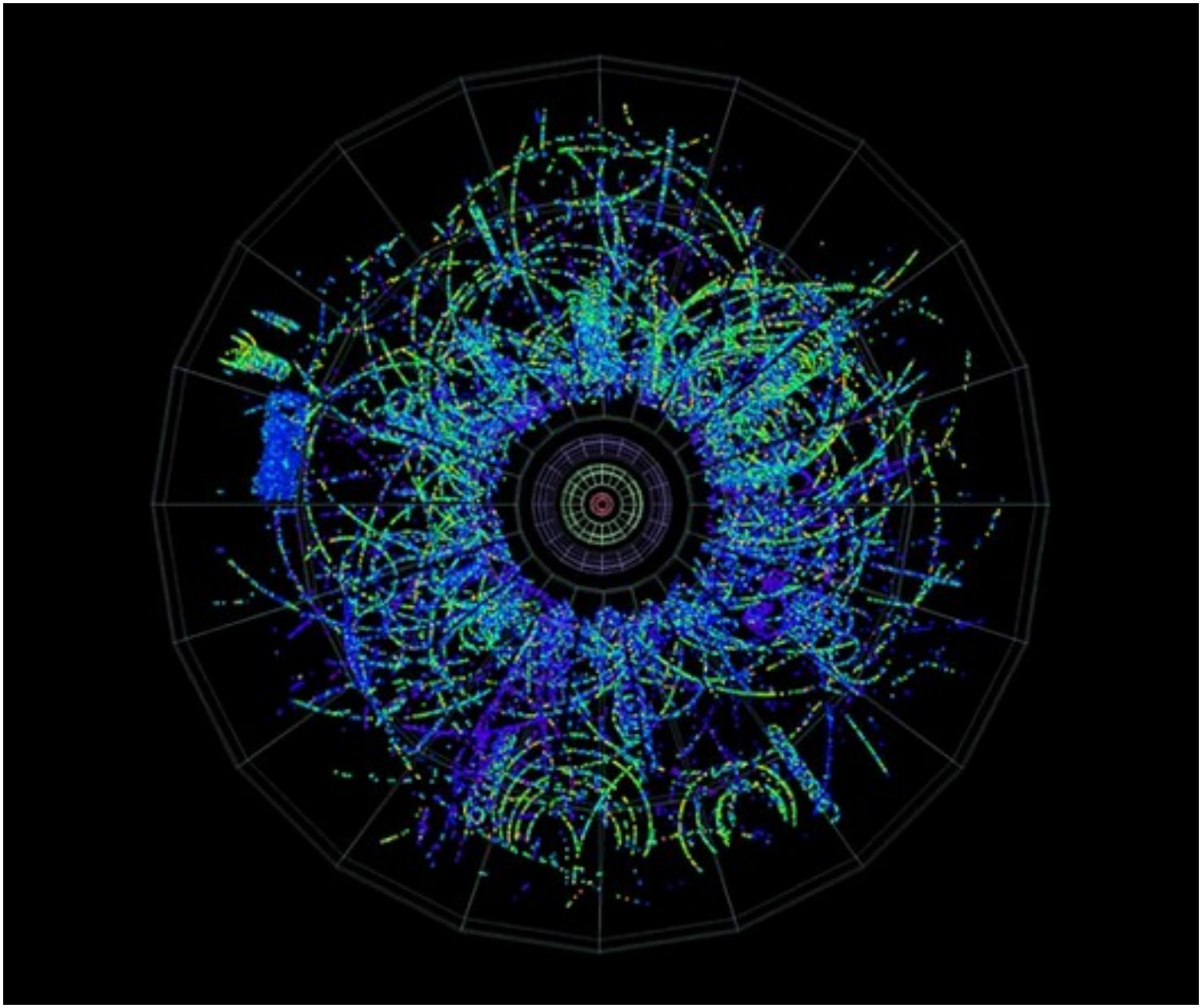
Inner readout chamber geometry	Trapezoidal, $848 < r < 1321$ mm active area
Pad size	$4 \times 7.5\ \mathrm{mm}^2$ ($r\varphi \times r$)
Pad rows	63
Total pads	5504
Outer readout chamber geometry	Trapezoidal, $1346 < r < 2466$ mm active area
Pad size	6×10 and $6 \times 15\ \mathrm{mm}^2$ ($r\varphi \times r$)
Pad rows	64 + 32 = 96 (small and large pads)
Total pads	5952 + 4032 = 9984 (small and large pads)

Pb-Pb collision in ALICE -- up to 8000 tracks per unit rapidity



One of the first p-Pb collision events in ALICE (raw data)

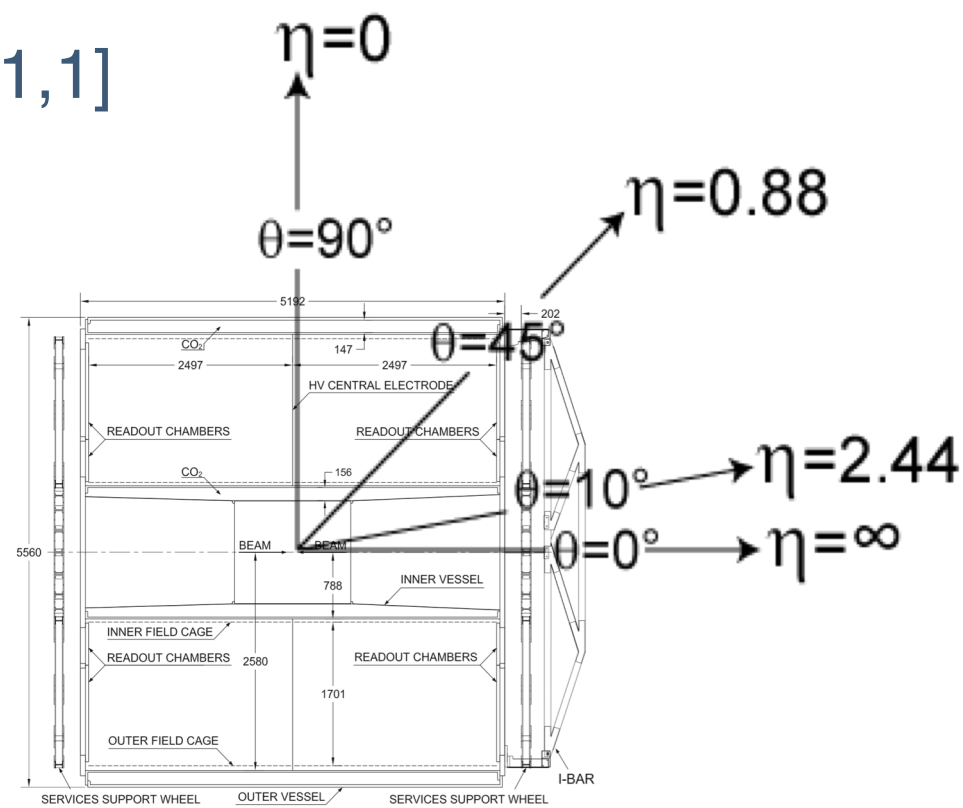
The hits are all there!



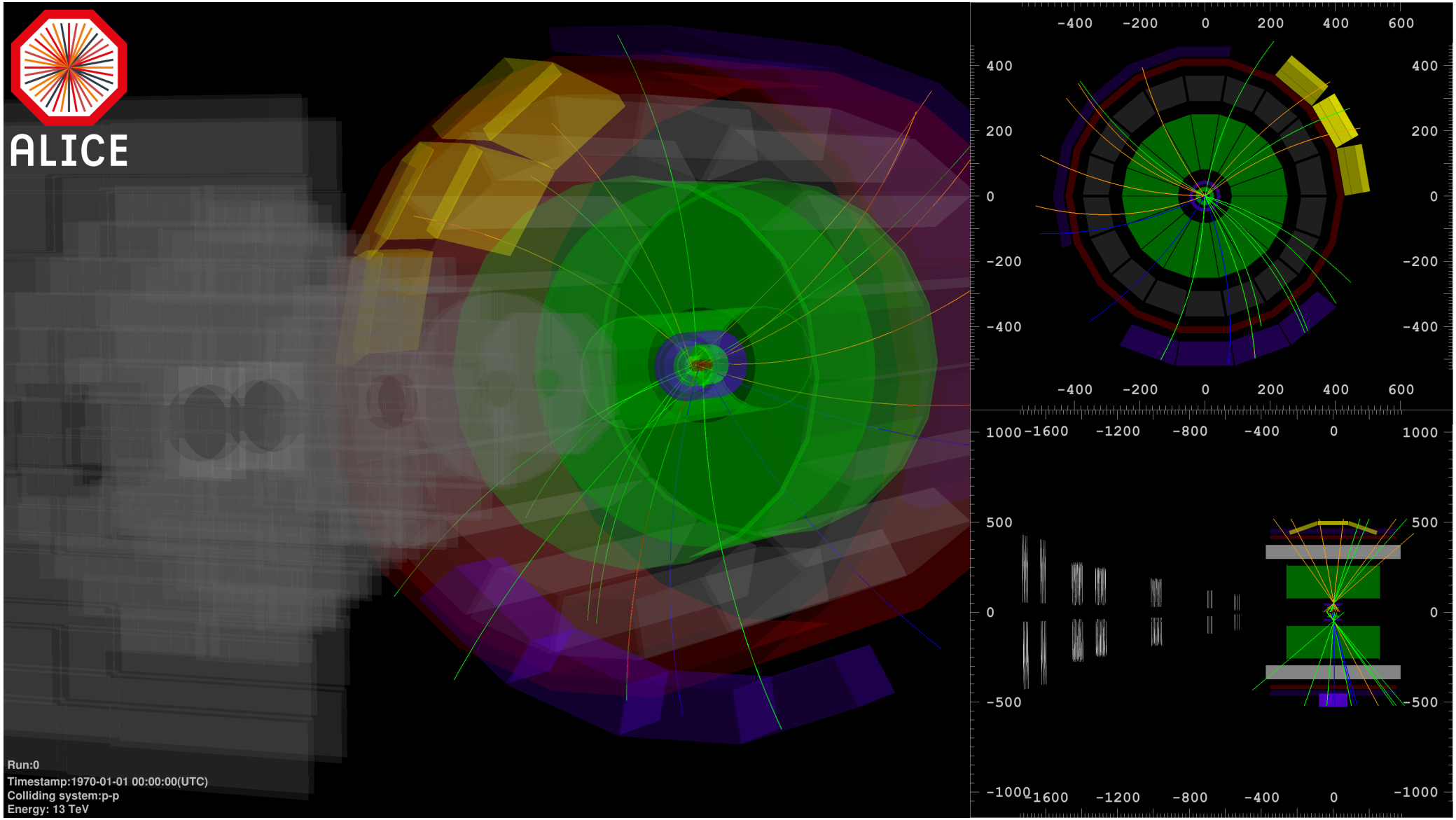
A First Test: Throwing Softballs

- 20 μ^-/event
- Starting at (x,y,z)=(0,0,0)
- P_T uniformly distributed between 1 and 2 GeV
- η = -ln(Tan(θ/2)) is uniform in [-1,1]
- ϕ is uniform in [0,2π]

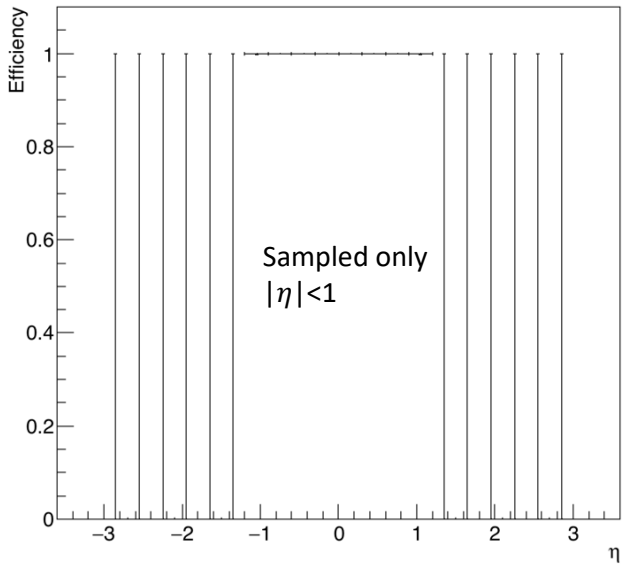
z axis =
E Field direction =
B Field direction =
LHC Beam direction

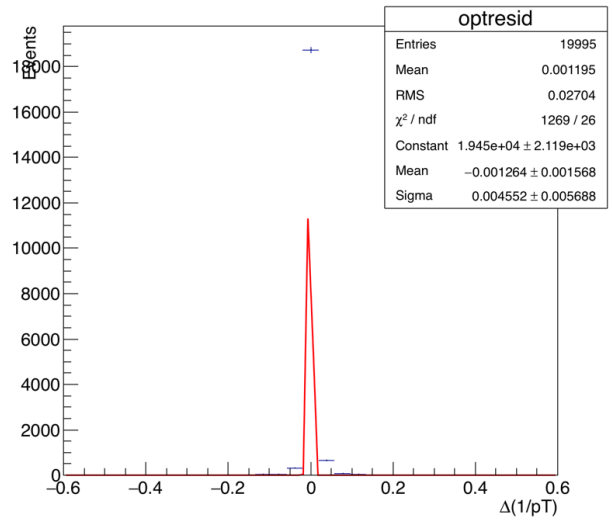


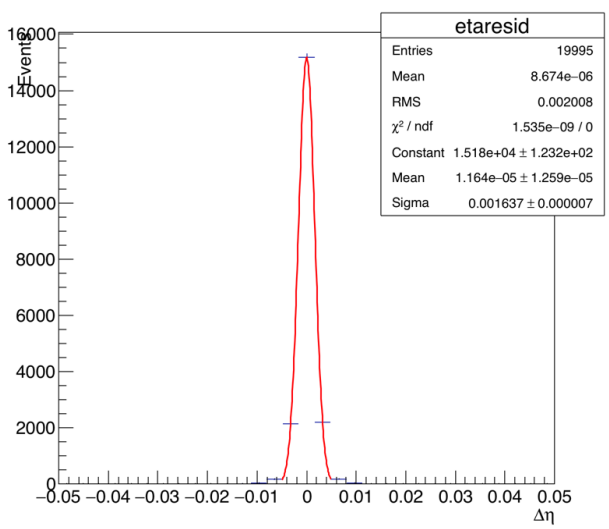
An Event with 20 easy muons

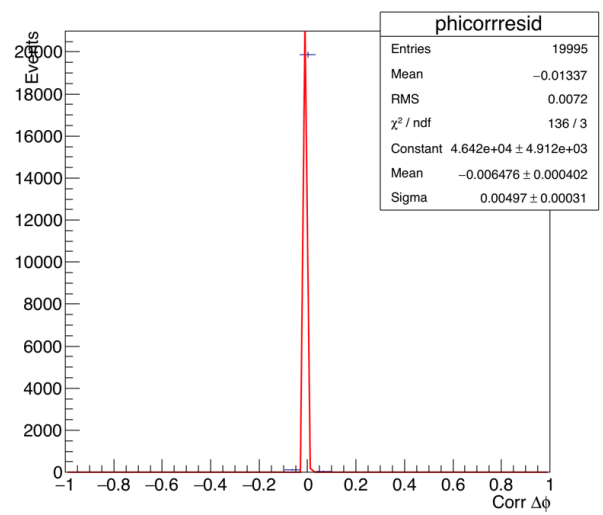


Central Muons: 100% Efficiency, Excellent Resolution









And are very well measured:

Better than 1% p_T resolution, better than 2 mrad in η and 5 mrad in phi

A Sample of Non-Central Muons

Neutrino events will occur throughout the detector

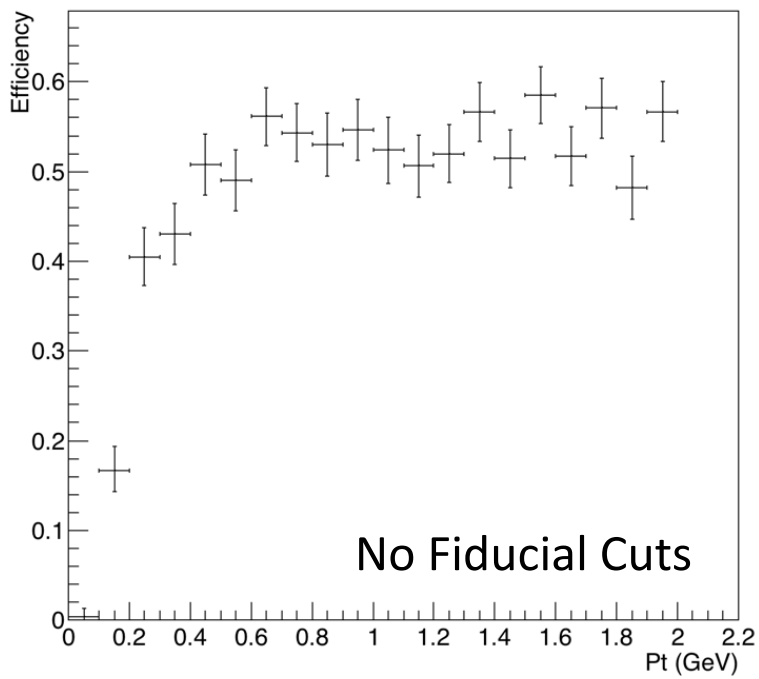
We also want to detect low-momentum particles

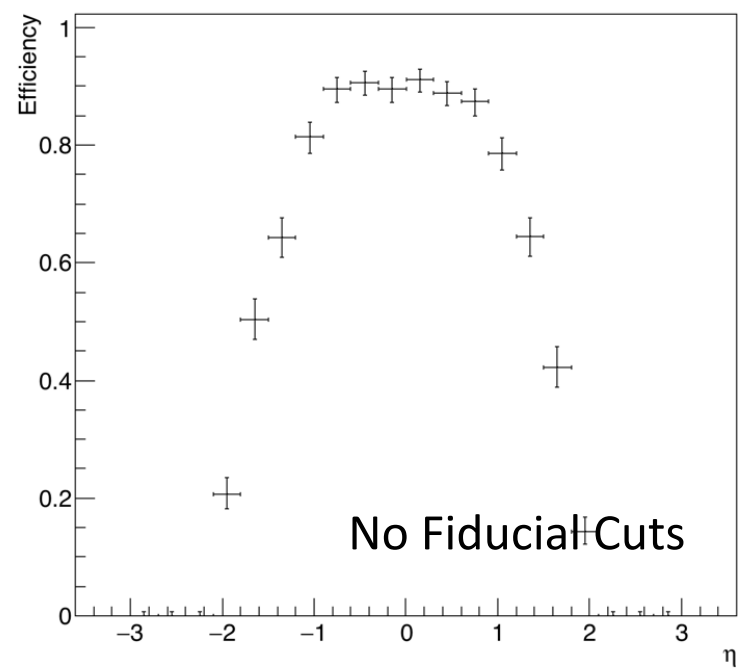
We are testing ALICE's software's ability beyond its standard envelope.

- I generated 5000 events, each with one μ^-
- Starting radius is uniformly distributed between 50 cm and 150 cm.
- The p_T distribution is uniform between 10 MeV and 2 GeV.
- η is uniform on [-3,3]
- ϕ_{position} and ϕ_{momentum} are uniform on $[0,2\pi]$ and independent
- z of particle origin is uniformly distributed from -100 cm to +100 cm

Tracking Efficiencies in p_T and η

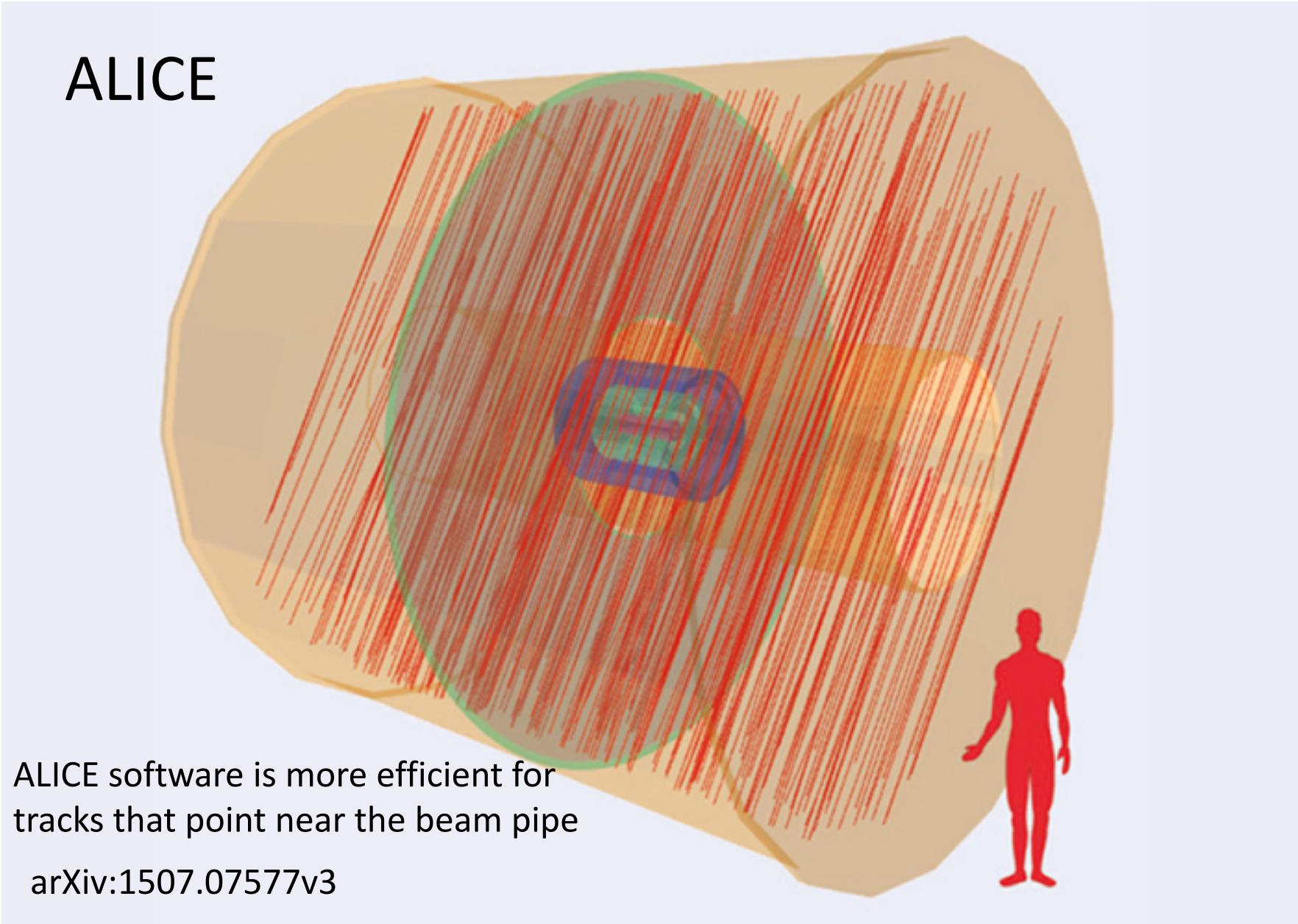
using "beam-off" ALICE reco. Thanks to Ruben Shahoyan of ALICE for help!
arxiv:1507.07577 (high-mult cosmic-ray paper) 50-degree cut wrt zenith: $|\eta|<1$
QA plots https://twiki.cern.ch/twiki/bin/view/Main/QA:ChargedTracks don't go out past $|\eta|=1$





ALICE Software is optimized for pp and heavy-ion events. Isotropic efficiency and low-P_T reco not optimized

276 reconstructed muons in an air shower



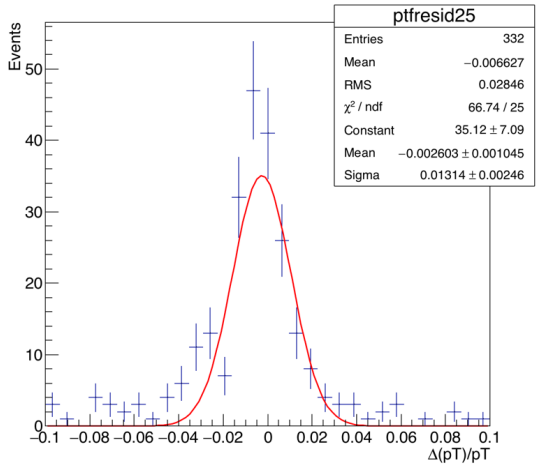
ALICE software is more efficient for tracks that point near the beam pipe

arXiv:1507.07577v3

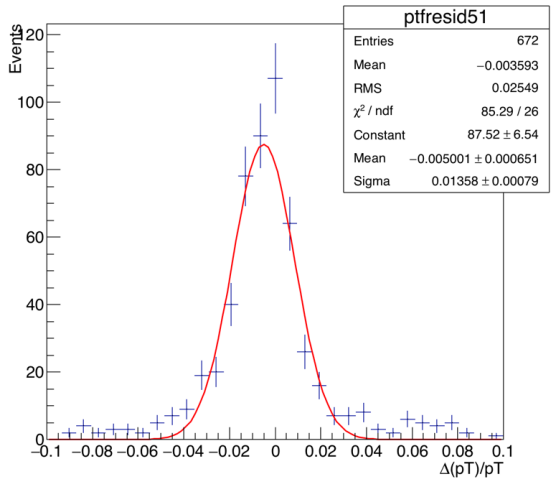
Momentum Resolution Is Really Good (No Fiducial Cuts)

Residual = $\frac{P_T^{rec} - p_T^{MC}}{P_T^{MC}}$

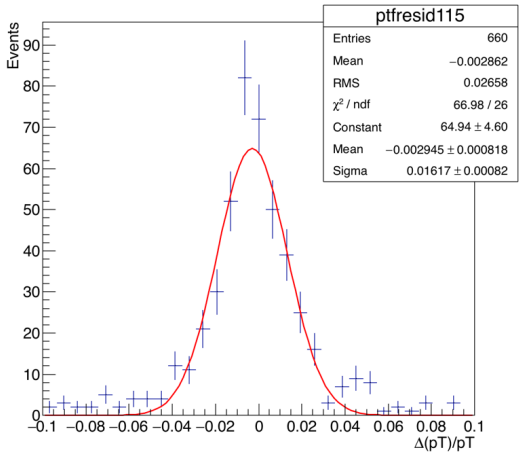
200 MeV < p_T < 500 MeV



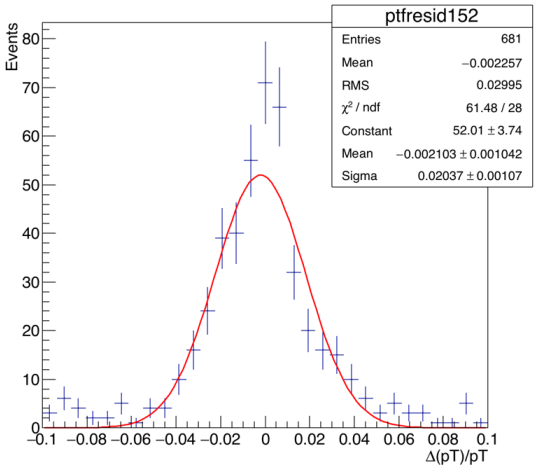
500 MeV < p_T < 1 GeV



1 GeV < p_T < 1.5 GeV



1 GeV < p_T < 2 GeV

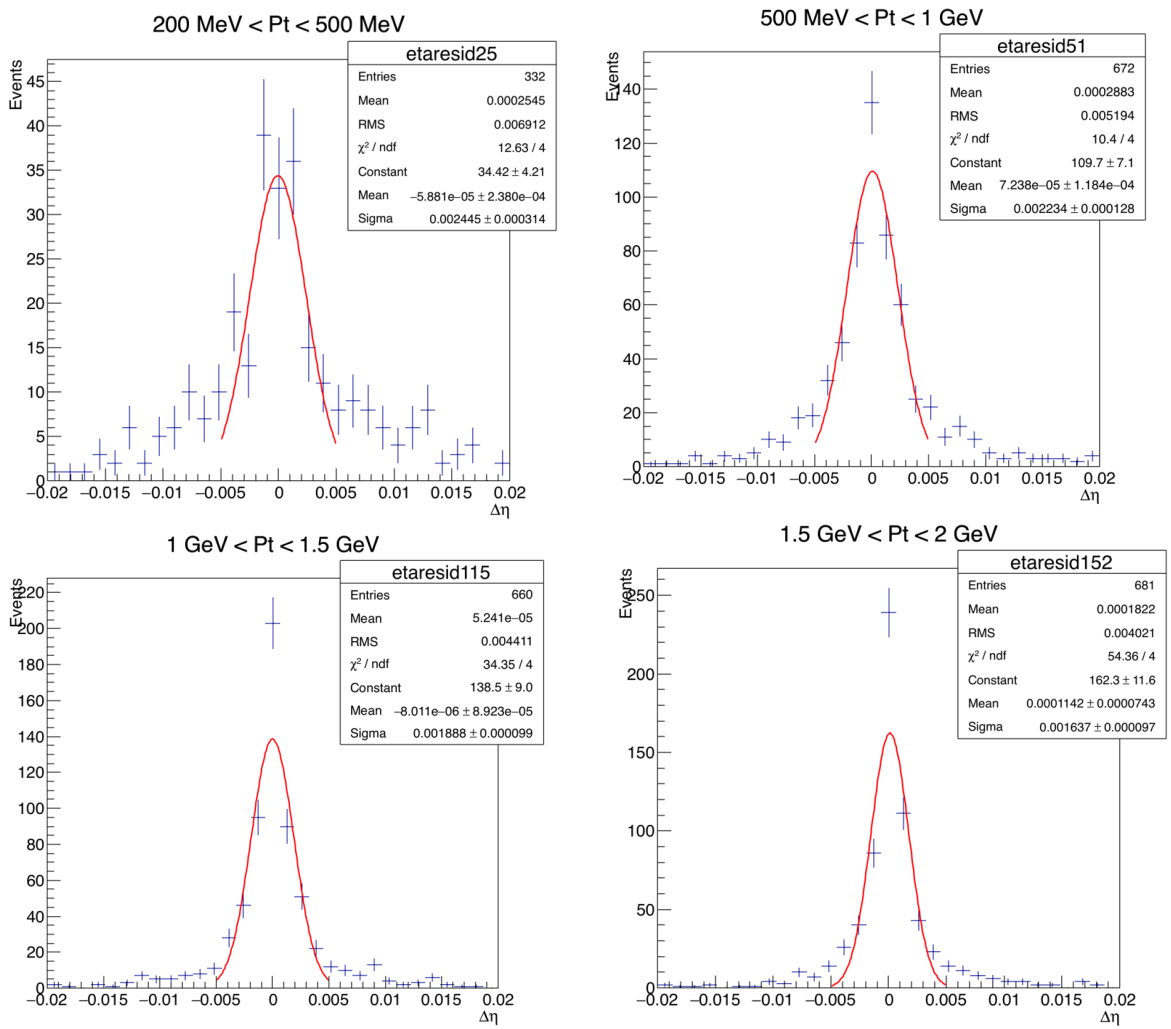


P_T Range	Fractional Momentum Resolution
0.2-0.5 GeV	1.3%
0.5-1.0 GeV	1.4%
1.0-1.5 GeV	1.6%
1.5-2.0 GeV	2.0%

Not dominated by scattering
Possibly widened by track-length issues

Resolution of η as a function of p_T

residual = η_{reco} - η_{MC}



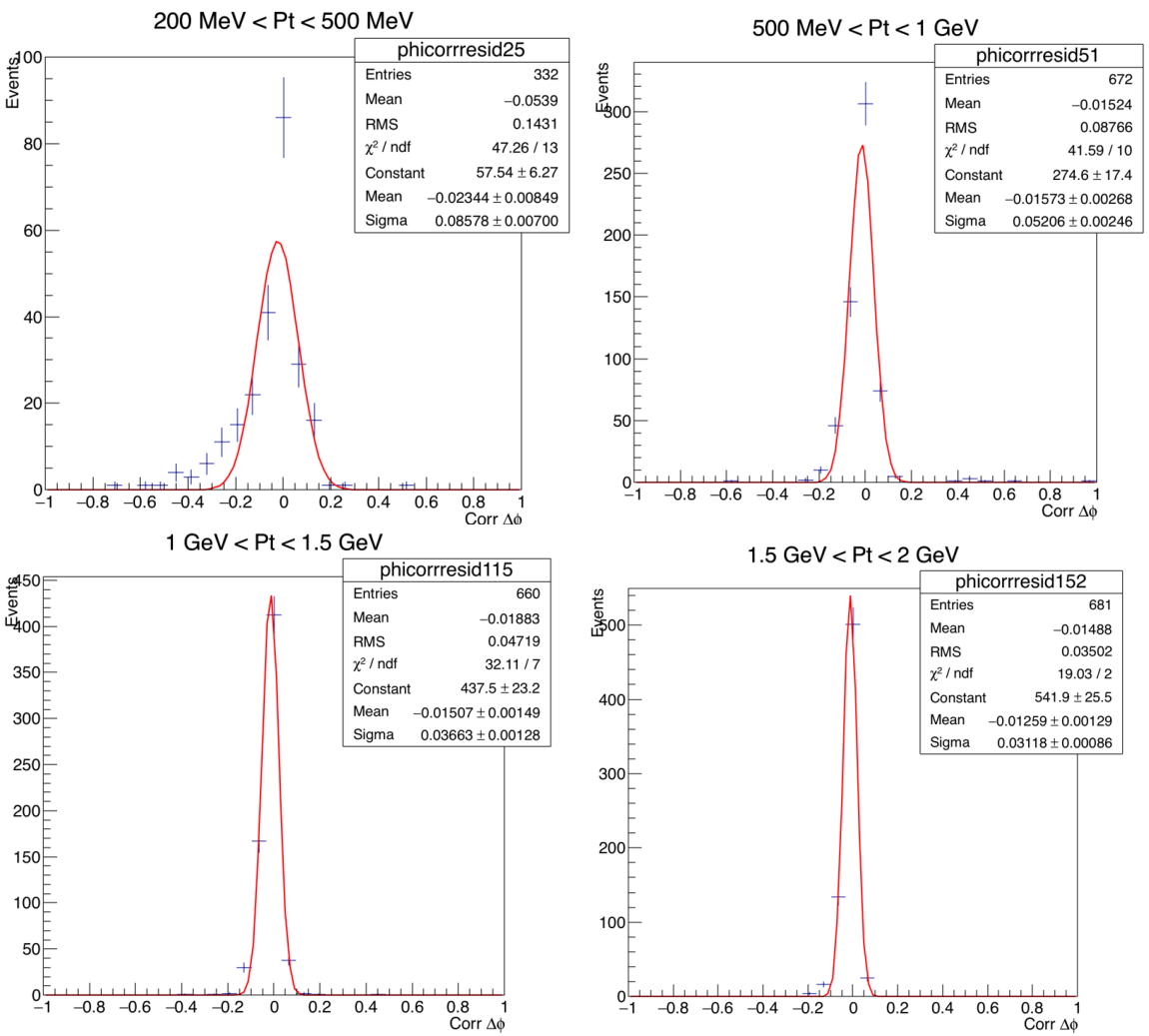
No Fiducial Cuts

P_T Range	η Resolution
0.2-0.5 GeV	0.0024
0.5-1.0 GeV	0.0022
1.0-1.5 GeV	0.0019
1.5-2.0 GeV	0.0016

at η=0, dη/dθ = 1
So roughly 2 mrad

Resolution of ϕ as a function of p_T

residual = ϕ_{reco} - ϕ_{MC}



No Fiducial Cuts

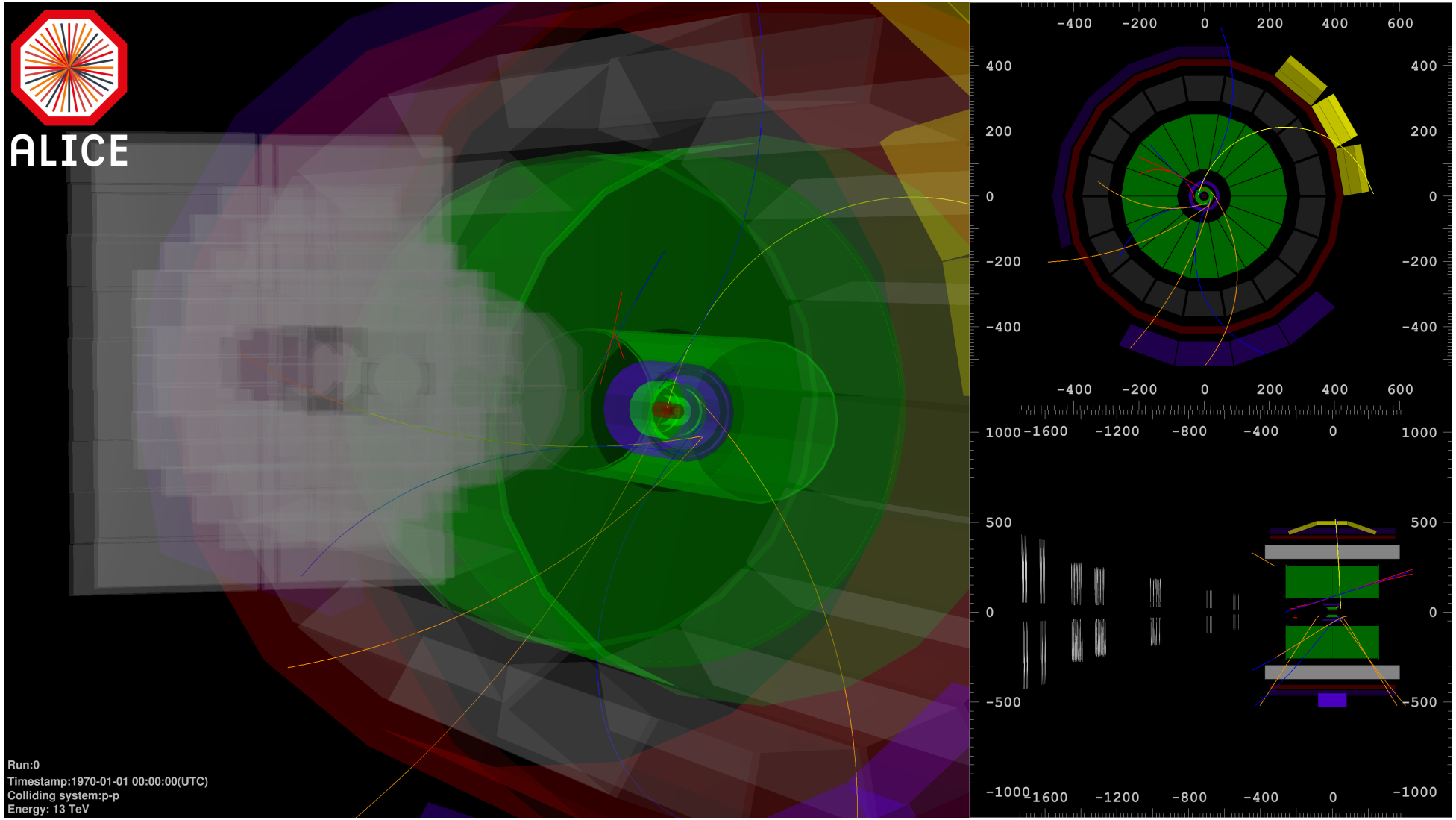
P_T Range	ϕ Resolution (rad)
0.2-0.5 GeV	0.086
0.5-1.0 GeV	0.052
1.0-1.5 GeV	0.036
1.5-2.0 GeV	0.031

Tracks bend in the magnetic field – biggest effect is quoting ϕ at the same point as the MC.

Simulating π^0's

- Want to know what the background to ν_eCC events from photon conversions, Compton scatters, and Dalitz decays is.
- Simulated 5000 events, each with 200 π^0's – 1M π^0's
- P_T uniformly distributed between 10 MeV and 2 GeV
- $-3 < \eta < 3$ (uniform)
- ϕ is uniform (position and momentum)
- R is uniform between 50 cm and 150 cm
- *z* is uniformly distributed from -100 cm to +100 cm

A 200 π^0 Event

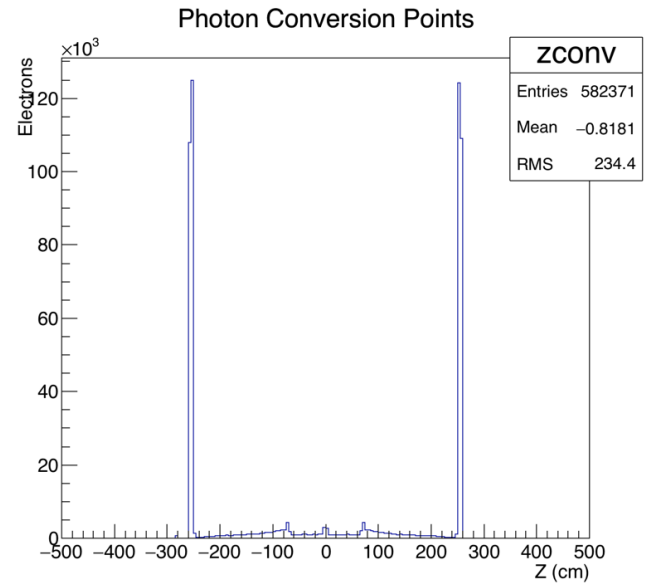


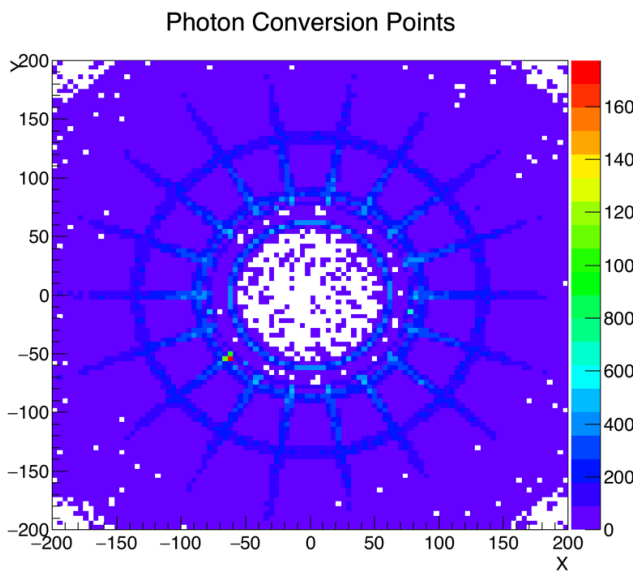
Photon Conversions

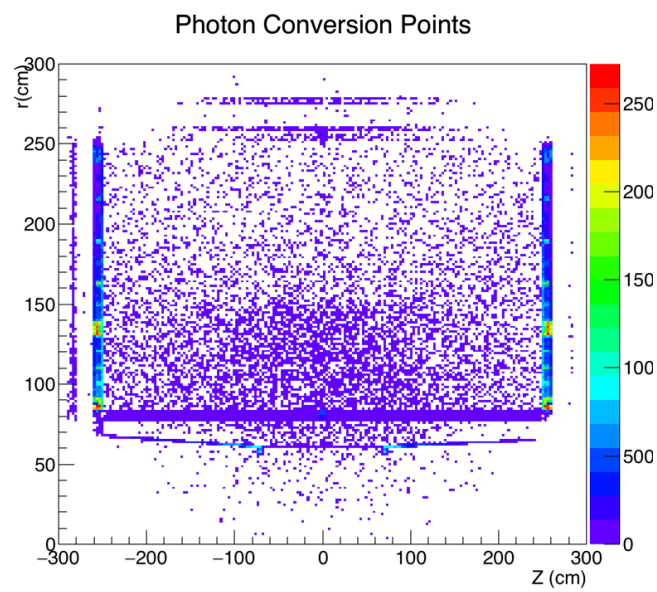
Most photons convert on the walls of the chamber.

0.39% convert in the active gas volume (~1 bar Ne)

Scaling to 10 bar of Argon (~pZ^2), 12.5% of photons from π^0 decay will convert in the active gas volume.





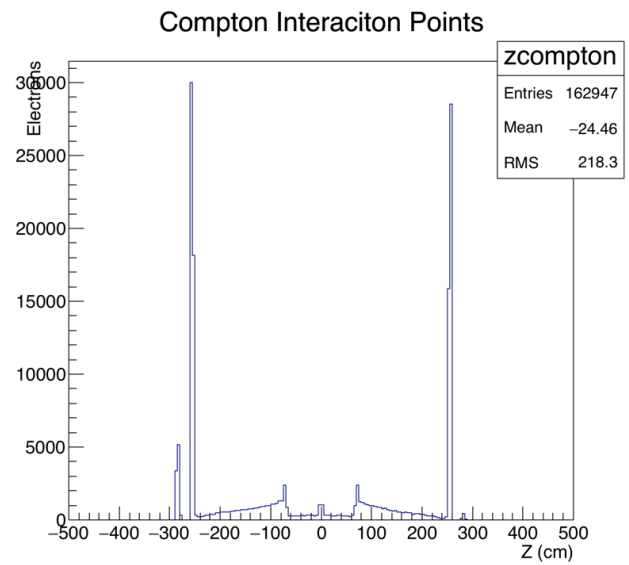


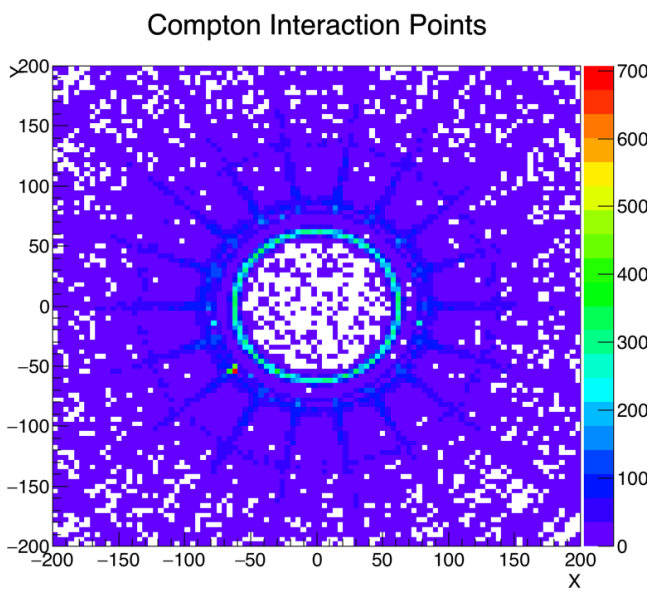
non-uniform density in gas caused by sample definition

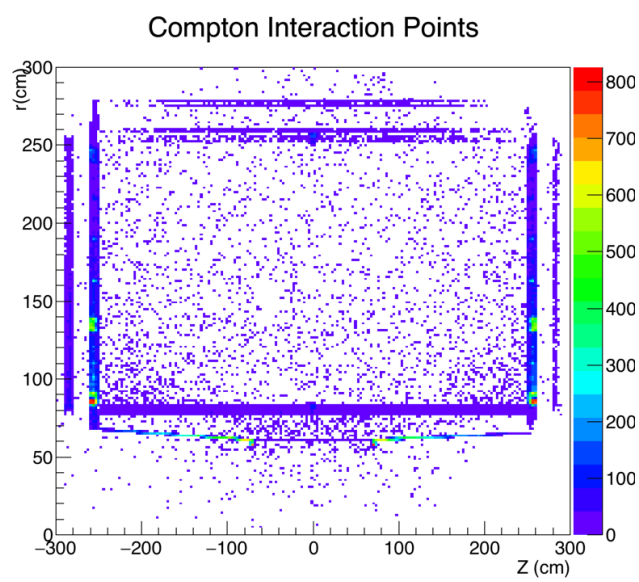
Compton Scatters

0.12% undergo Compton scattering in the active gas volume (~1 bar Ne)

Scaling to 10 bar of Argon (~pZ) , 2.1% of photons from π^0 decay will convert in the active gas volume.

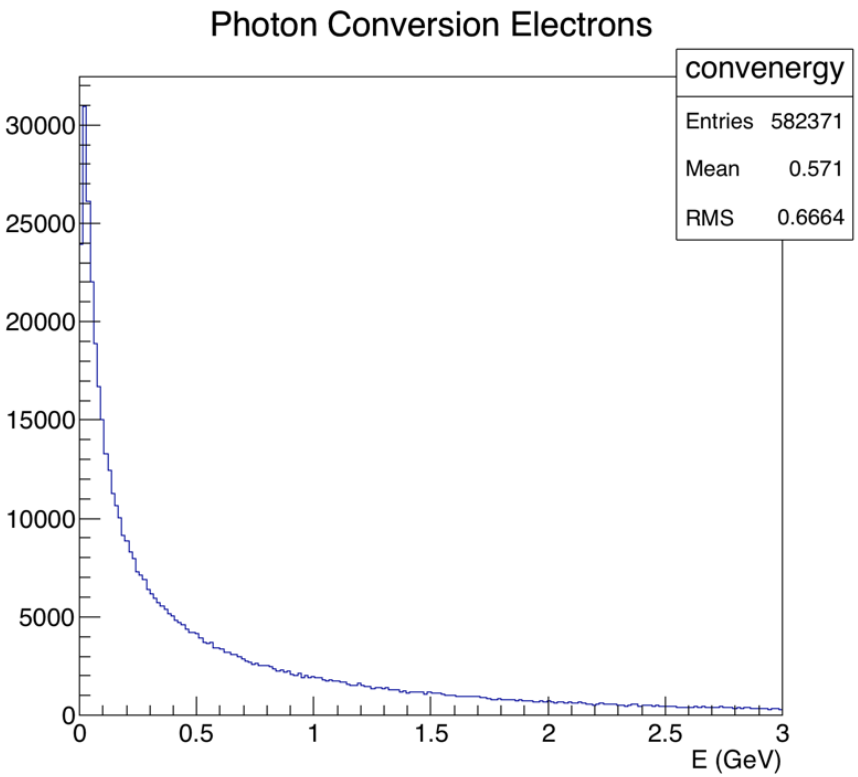


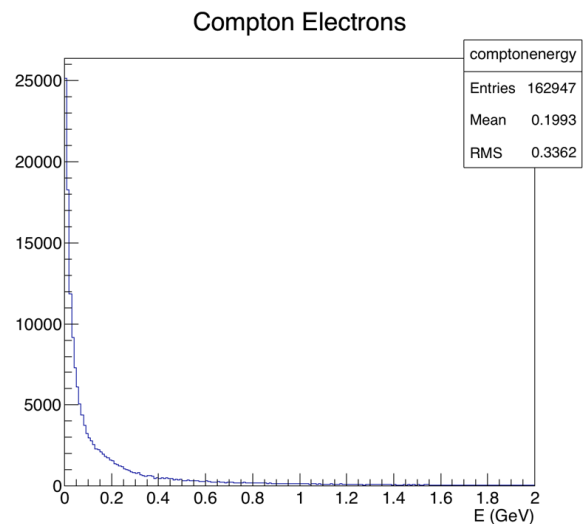


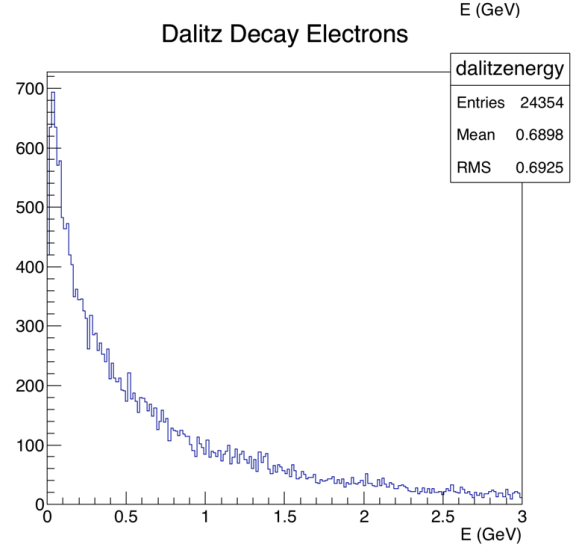


non-uniform density in gas caused by sample definition

Electron Energies: Conversions, Comptons, and Dalitz Decay

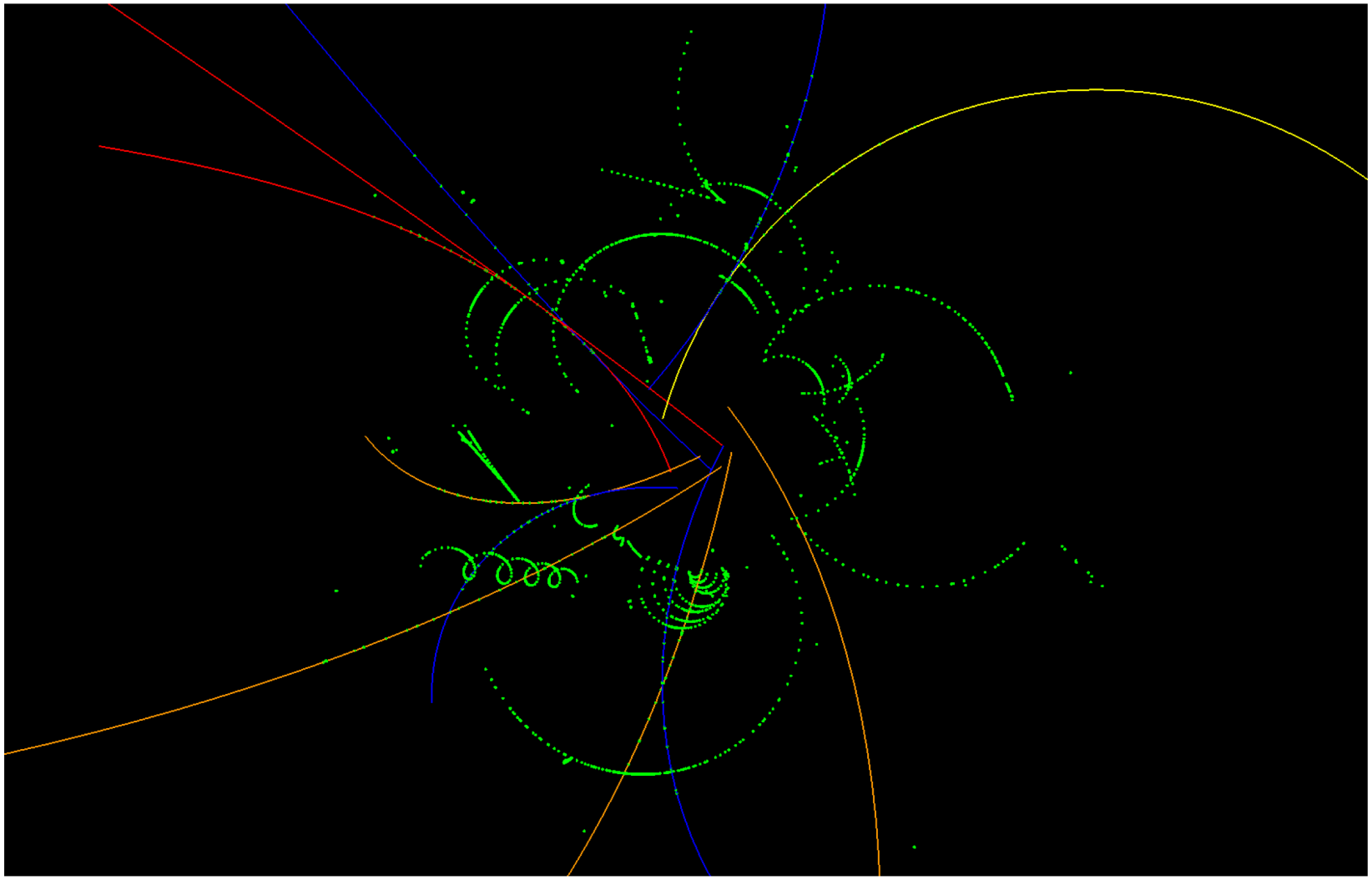






Event Display Showing MC True Edep

Same 200 π^0 event from before



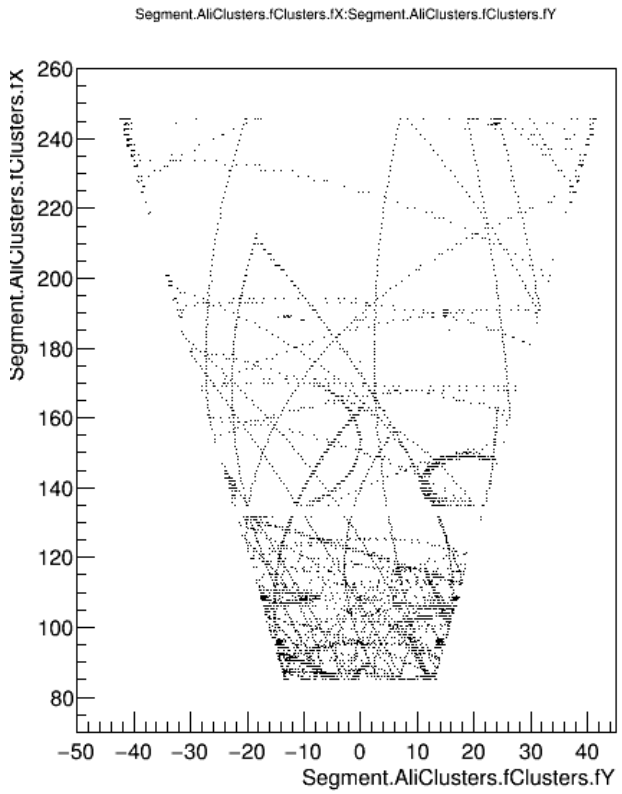
MC Hits shown in green

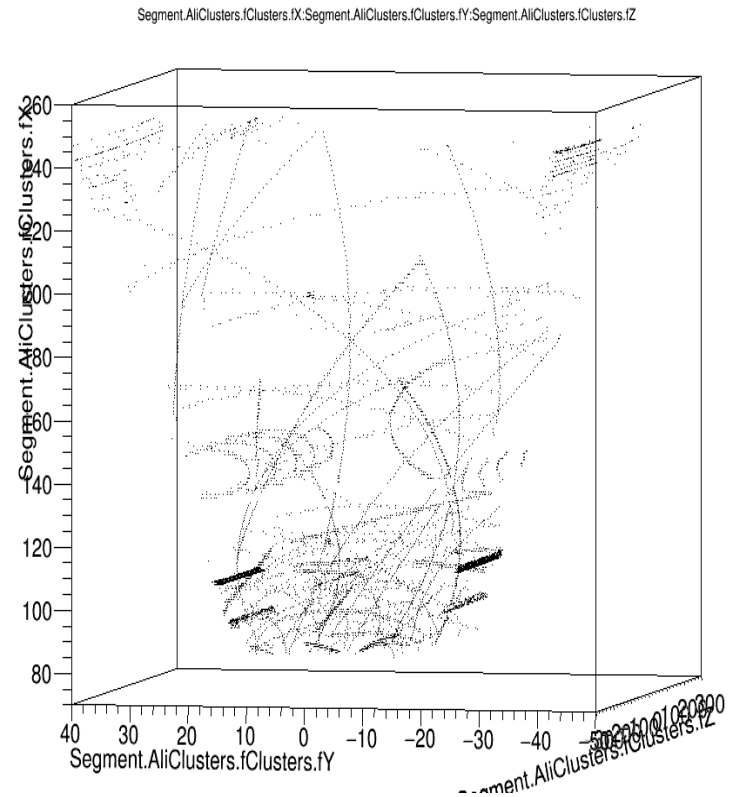
But still not all of them! ALICE evd cuts out "irrelevant" ones.

Getting away from ALICE sw

- Export 3D reco points: TPC.RecPoints*.root
- Same event as on previous page

First step in reco: Points are all found

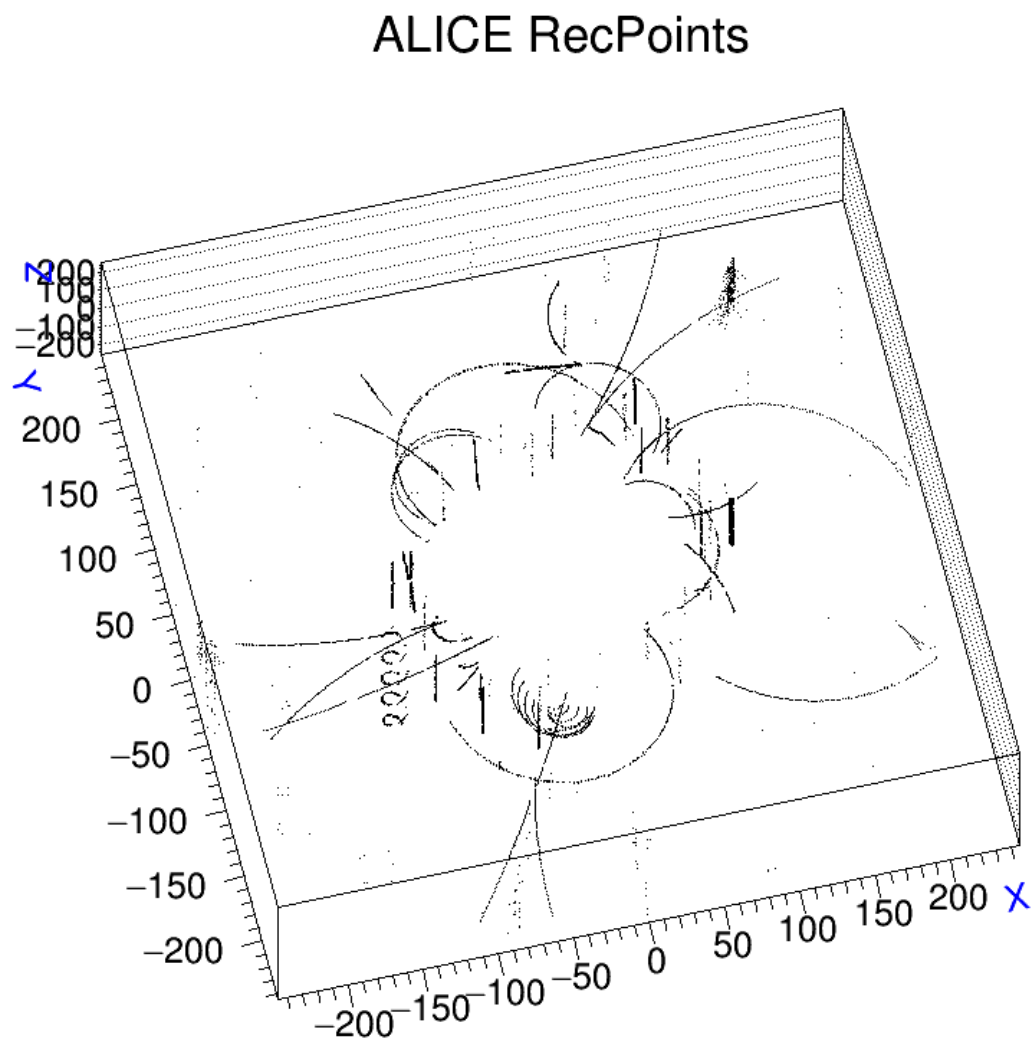




Coordinates are relative to the segment. The "detector" variable goes from 0:71. (4*18-1). Inner, outer, +z, -z.

Reading Reco Points in a Standalone Application

- Export reco points and draw them in global coordinates
- 18 detector segments
- 3D information is easy to understand; Tracks are all visible



ALICE Software: Benefits

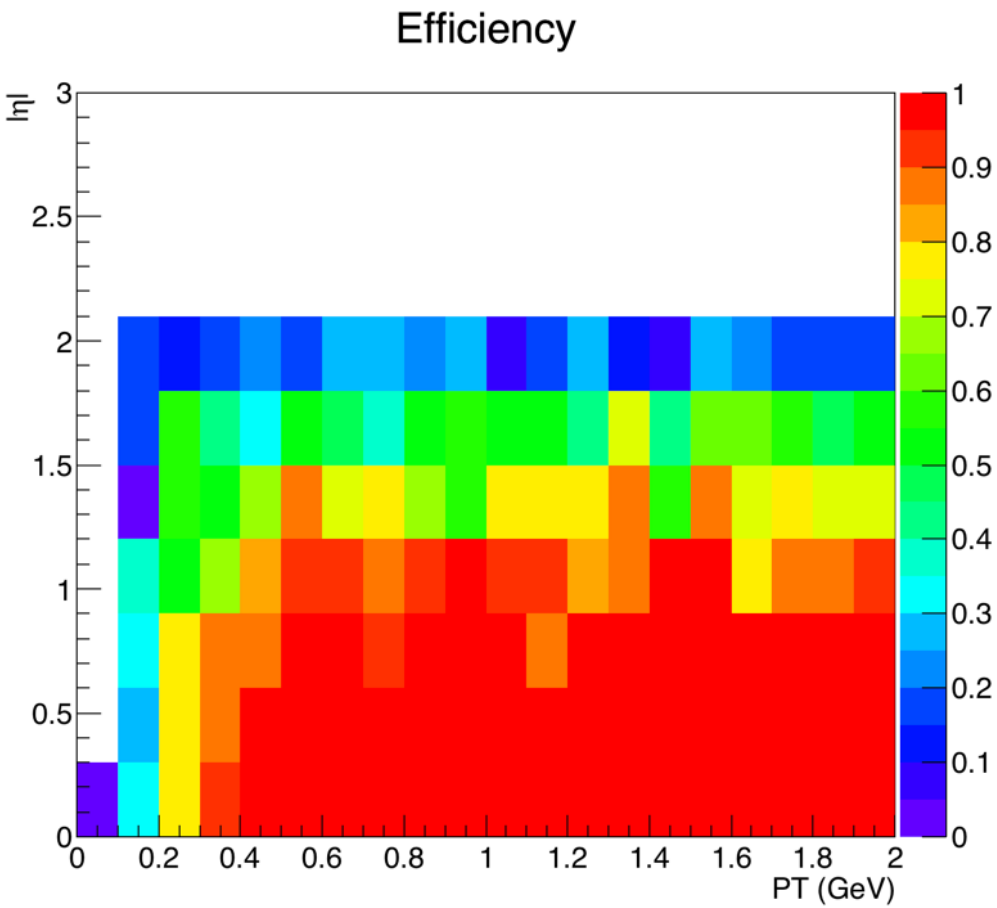
- Full GEANT4 simulation, realistic drift, electronics, and calibrations. Full reconstruction as used on ALICE data.
- The ALICE detector is good at measuring tracks in high-multiplicity environments
- The momentum resolution is ~1% and the angular resolution is better than 2 mrad (in η)
- The energy deposits are there even if ALICE software doesn't find the tracks, and they get put in 3D space unambiguously
- With optimized tracking software we believe we can obtain high efficiency for tracks currently ignored by ALICE software
- ALICE software is fast and writes compact data files

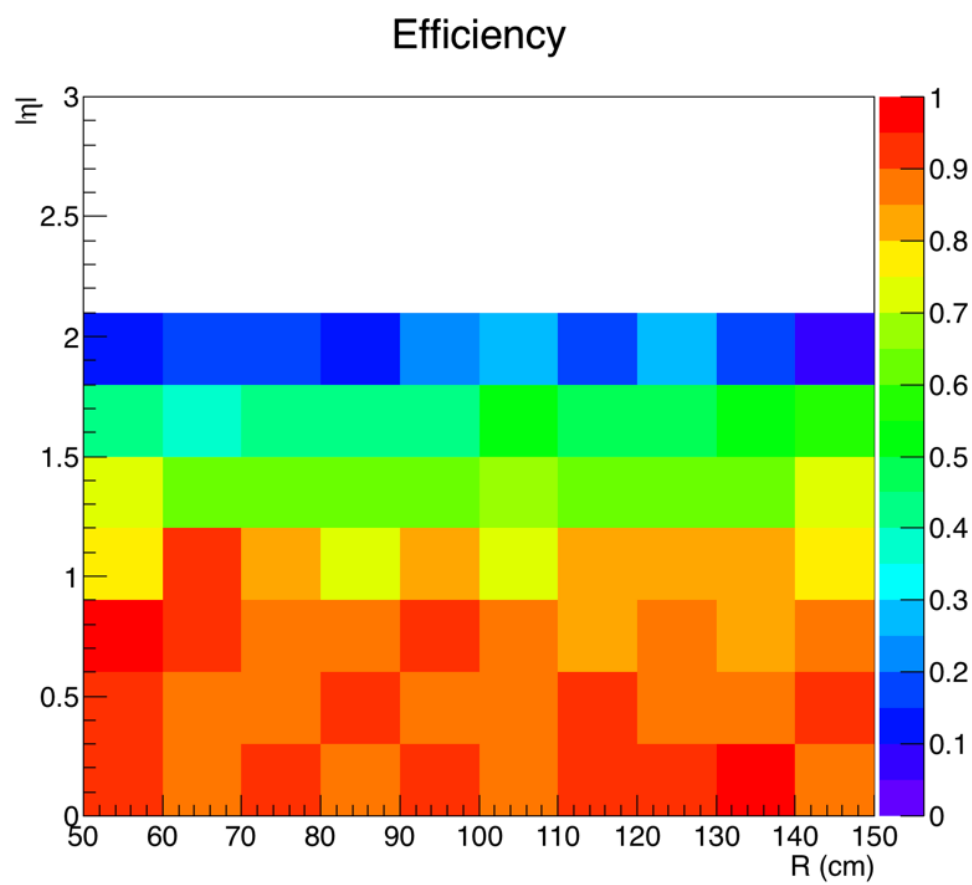
The To-Do List

- Empty hole in the middle: We'll fill it in with more TPC readout
- Gas: 1 bar of $Ne+CO_2+N_2$ and it's rather baked in to the ALICE code + files. We need 10 bar of Ar
- Improve track-finding at large $|\eta|$ and low P_T
- We have a great foundation of useful ideas from ALICE
- We should write our own software. We welcome interested collaborators!

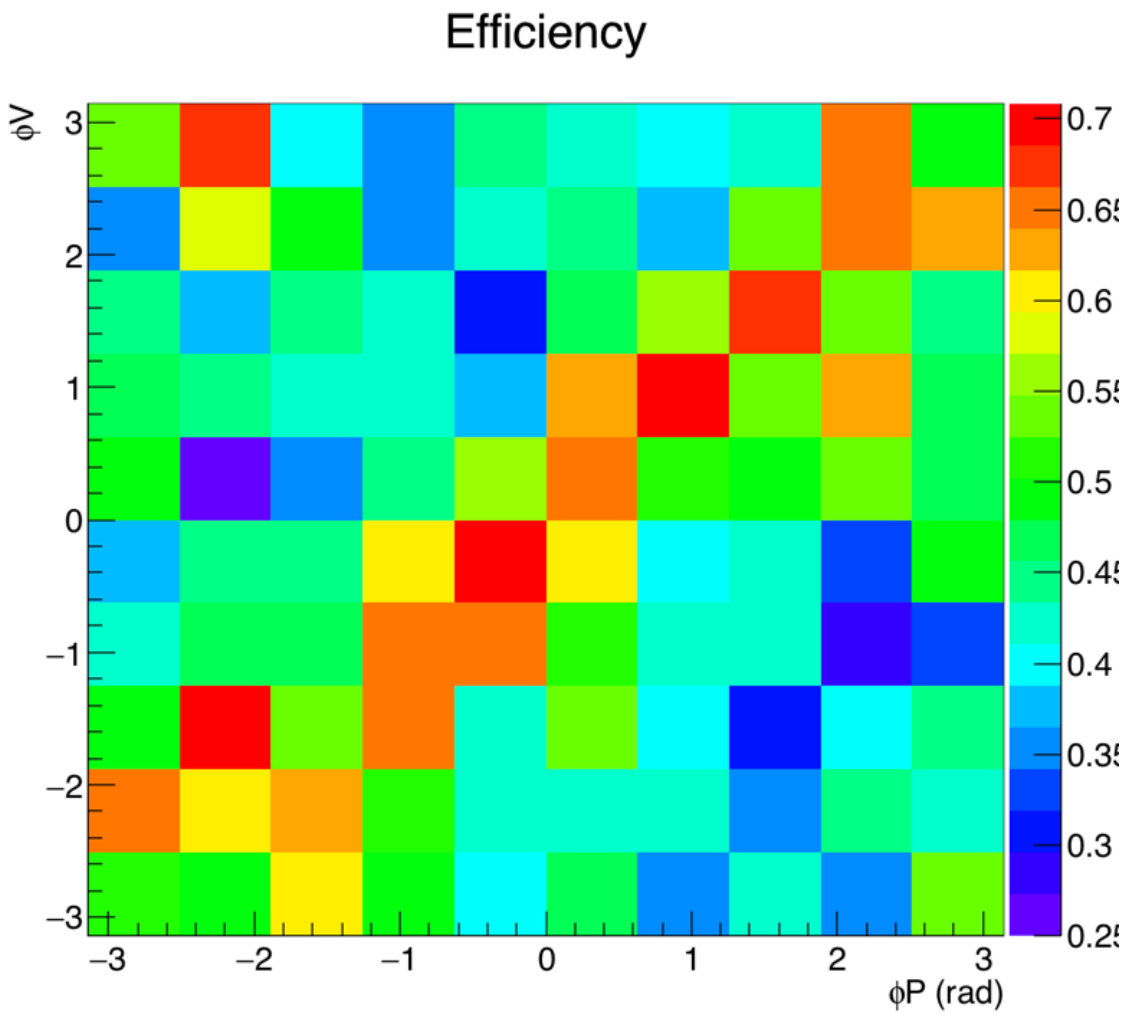
Extras

Efficiency Dependency on P_T, $|\eta|$ and R





Pointing Preference



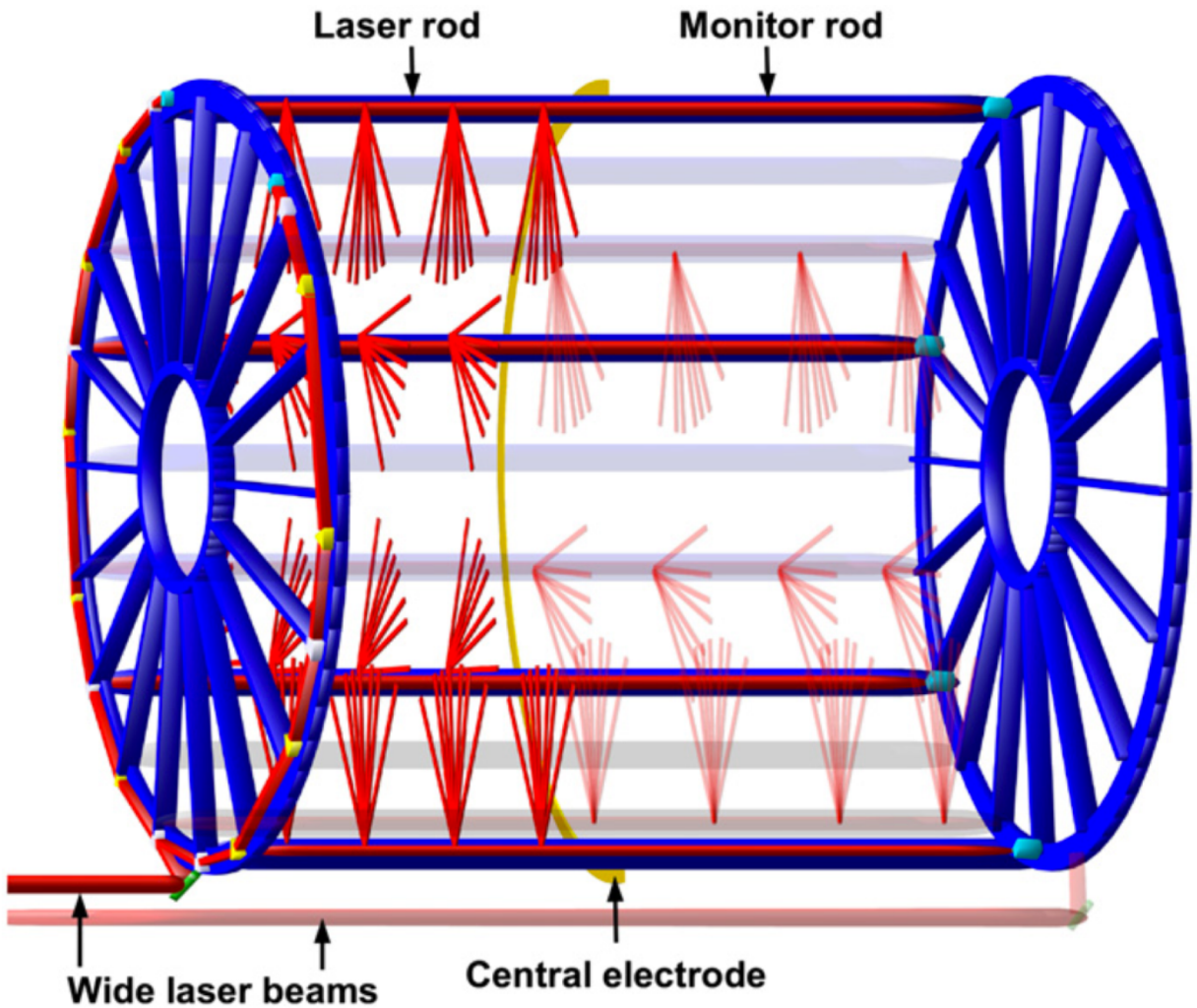


Fig. 45. Schematic 3D view of the TPC and the laser system. Two wide pulsed laser beams enter horizontally at the bottom of the TPC and are guided around the two end-caps by mirrors, prisms and beam splitters before entering the TPC. Bundles of micromirrors in the hollow laser rods intersect the beams and generate a large number of thin rays in the TPC drift volume. The undeflected part of the beams continue through the monitor rods to cameras at the far end. All elements are fixed mechanically, except for the remote controllable entrance mirrors at the bottom.

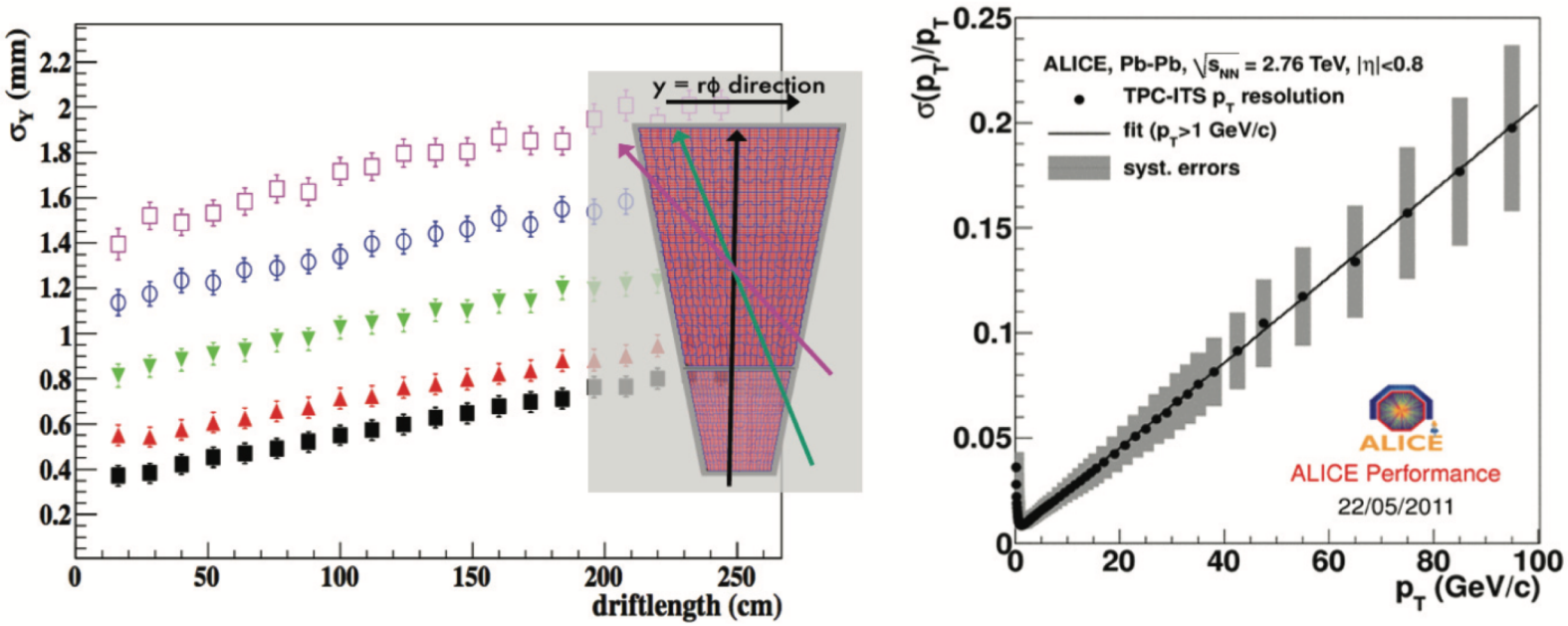
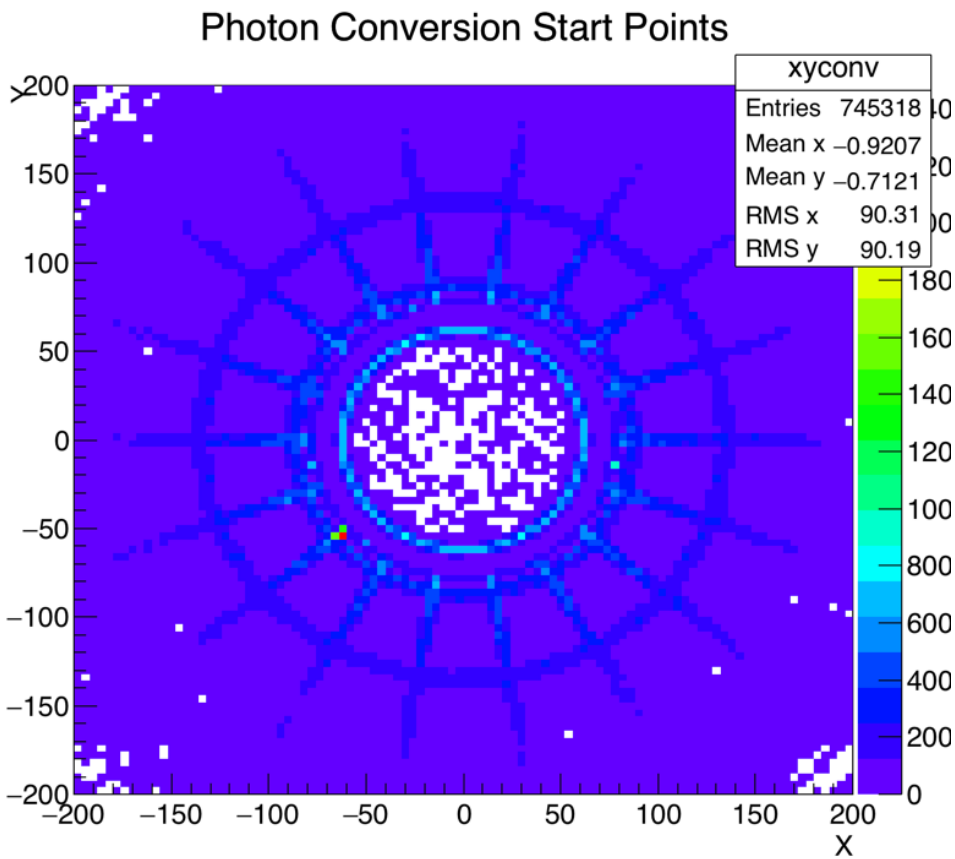


Figure 6: Left: Space point resolution of the TPC. This value depends on the drift length (due to diffusion) and on the inclination angle (as shown in the inlay). The data sample analyzed was collected with a cosmic trigger in the year 2009 and shows a space point resolution of 400 to 800 μm for tracks that are crossing the pad rows almost perpendicularly as high-p_t tracks do. Right: Transverse momentum resolution in the central rapidity region ($|\eta| < 0.8$) for TPC tracks combined with hits in the ALICE Inner Tracking System (ITS). The current status yields a resolution of $\sigma(p_t)/p_t = 20\%$ at $p_t = 100\,\mathrm{GeV}/c$.

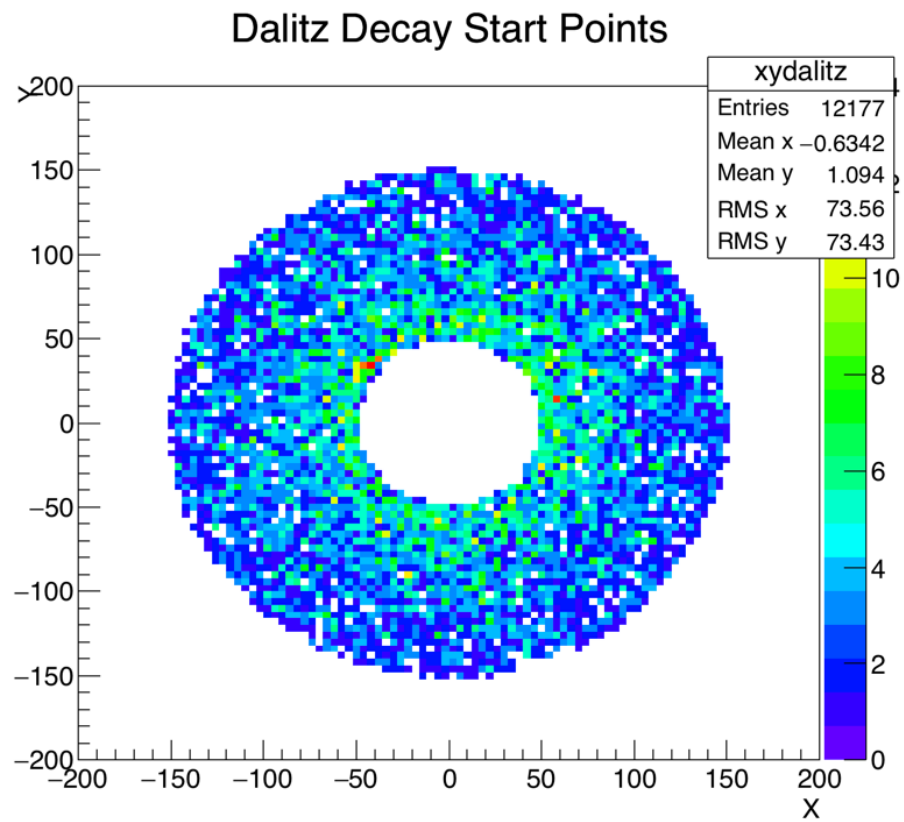
C. Lippmann, Physics Procedia 37 (2012) 434-441

(x,y) Locations of Conversions and Dalitz Decays

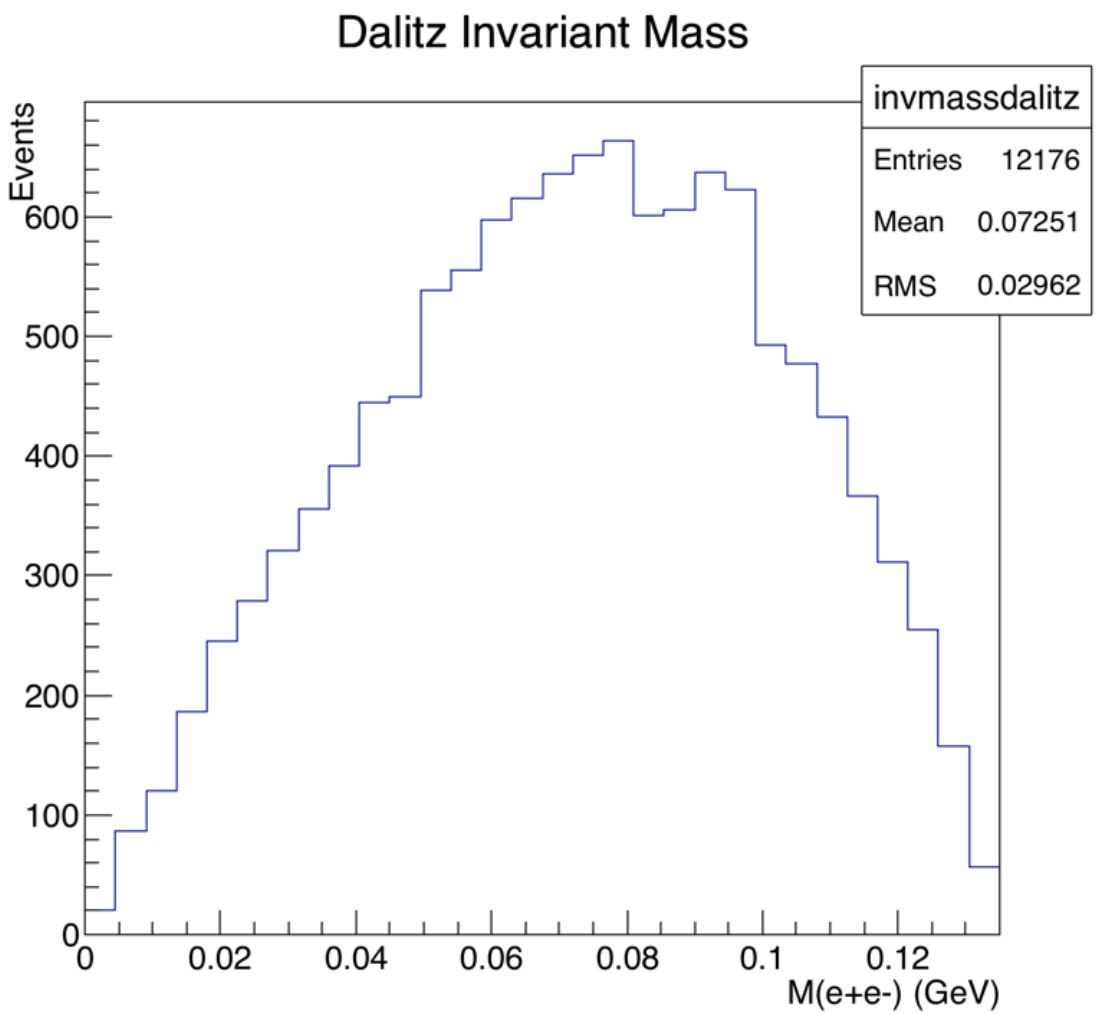
Includes Compton Scatters



Give total photon count

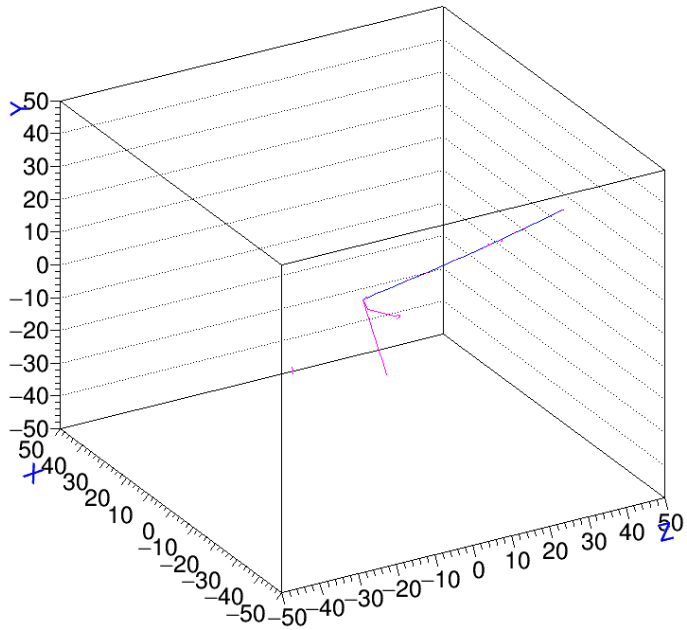


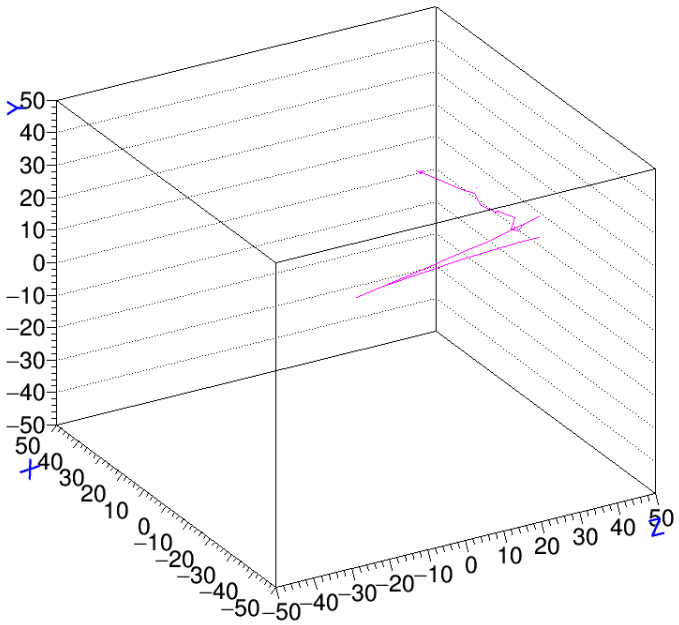
Invariant Mass of Dalitz e^+e^- Pairs



Example NC events with Dalitz Decay

10 bar of Ar
B=0.4 T
Blue: proton
Magenta: electrons





Fractional Momentum Resolution by Species and P_T Range

$$\sigma(\Delta P_T/P_T)$$

P_T Range	Muons	Protons	Charged Pions	Electrons
0.2-0.5 GeV	1.3%	3.1%	1.7%	1.2%
0.5-1.0 GeV	1.4%	2.0%	1.5%	1.6%
1.0-1.5 GeV	1.6%	1.8%	1.9%	1.9%
1.5-2.0 GeV	2.0%	1.9%	2.0%	2.5%

η Resolution by Species and P_T Range

$$\sigma(\Delta\eta)$$

P_T Range	Muons	Protons	Charged Pions	Electrons
0.2-0.5 GeV	0.0024	0.0037	0.0026	0.0027
0.5-1.0 GeV	0.0022	0.0022	0.0020	0.0021
1.0-1.5 GeV	0.0019	0.0019	0.0018	0.0017
1.5-2.0 GeV	0.0016	0.0019	0.0017	0.0017

ϕ Resolution by Species and P_T Range

$$\sigma(\Delta\phi)$$

P_T Range	Muons	Protons	Charged Pions	Electrons
0.2-0.5 GeV	0.086	0.094	0.094	0.073
0.5-1.0 GeV	0.052	0.046	0.047	0.052
1.0-1.5 GeV	0.037	0.035	0.035	0.036
1.5-2.0 GeV	0.031	0.032	0.032	0.031