

# MPD TPC Hit Resolution Studies

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# GArSoft Tracking Simulation

- What's there
  - GENIE, CRY, radiologicals, text-file generators
  - GEANT4 interactions in gas and calorimeter – fairly detailed geometry
  - LArSoft-style drift, attachment, diffusion simulation. Each electron is drifted separately (as ALICE does). LArSoft groups them together to speed calcs. Transverse diffusion: 1.6 mm sigma at a drift of 1 m.
  - Pad-response functions ← NEW
  - Digitization and zero-suppression of raw waveforms
  - Saved to output: ZS waveforms, MC particles, neutrino info, true energy deposits.
- What's lacking
  - Realistic pulse shapes
  - Noise
  - LArPix-style electronics simulation
  - Magnetic Field Map

# GArSoft Tracking Reconstruction

- What's there:
  - Raw Digits → Hits. A "hit" belongs to a particular pad, similar to a LArSoft "recob::Hit".
  - Hits → TPCClusters

The centroid of the charge deposited on several neighboring channels has much better resolution than just using the pad centers.
  - TPCClusters → Vector Hits. "tracklets" up to 20 cm long
  - Vector Hits → PatRec Tracks:
  - PatRec Tracks → Fitted Tracks. 3D Kalman fitter using TPCClusters associated with PatRec tracks. Each track is fitted both ways.
  - Vertex finder and fitter.
  - Extrapolation to ECAL
  - Event Display. (two of them!)

# ALICE TPC Readout Chambers

From the ALICE TDR  
CERN/LHCC 2000-001  
CERN-OPEN 2000-183  
<http://cds.cern.ch/record/451098>

Outer Outer Readout Chamber  
pad dimensions:  $6 \times 15 \text{ mm}^2$

Inner Outer Readout Chamber  
pad dimensions:  $6 \times 10 \text{ mm}^2$

Inner Readout Chamber  
pad dimensions:  $4 \times 7.5 \text{ mm}^2$

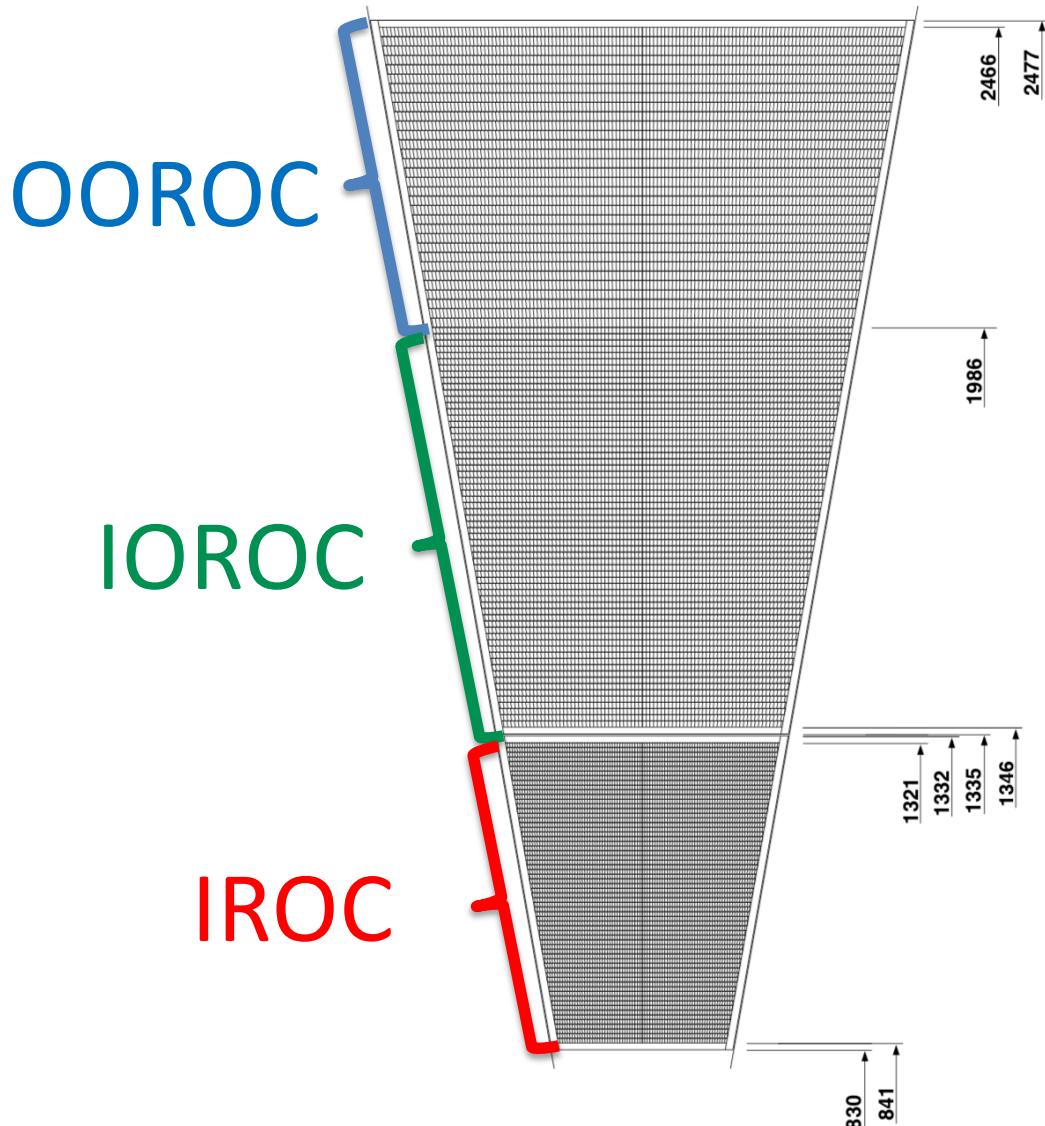
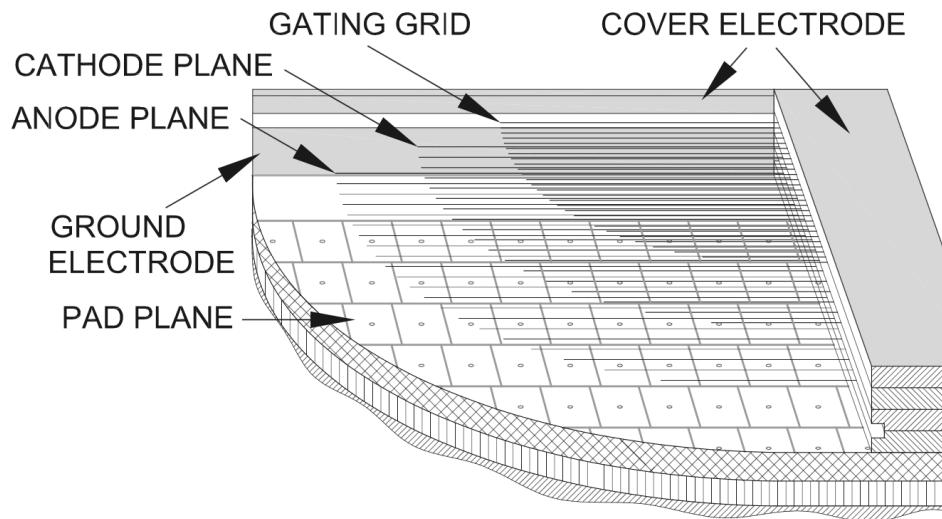


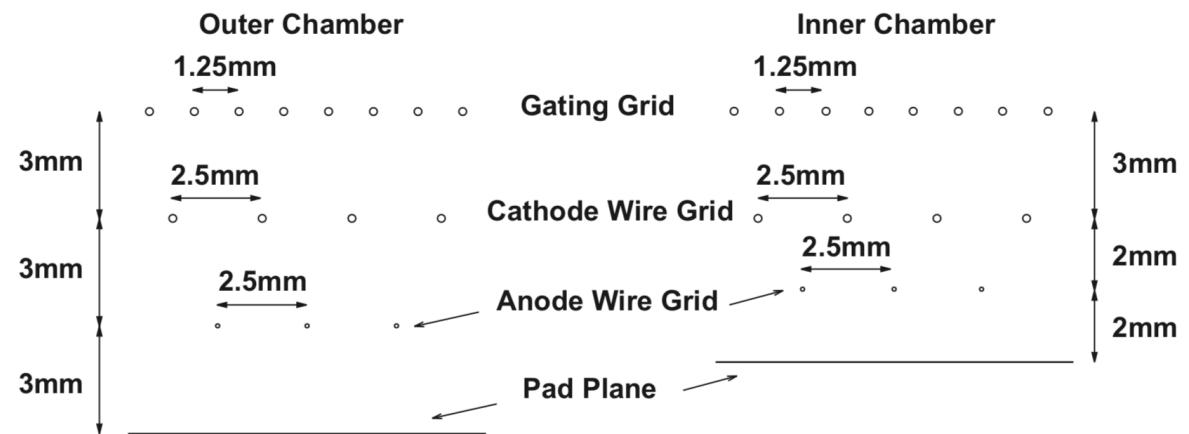
Figure 4.12: Pad layout of the ALICE TPC readout chambers. Distances from the beam axis are in mm.

# Readout Geometry



J. Alme *et al.*, NIM A 622 (2010), 316-367

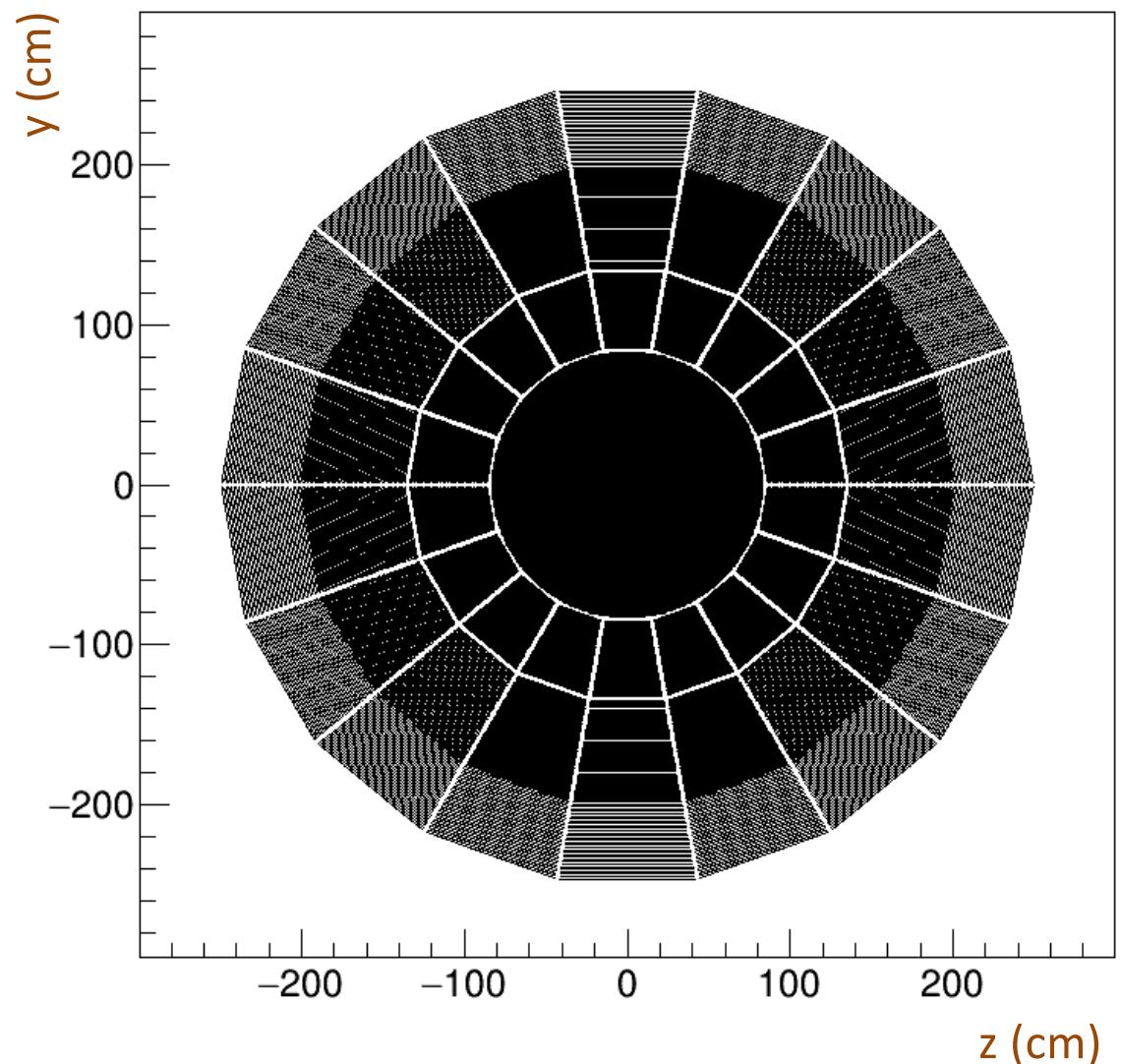
**Fig. 9.** Cross-section through a readout chamber showing the pad plane, the wire planes and the cover electrode.



**Fig. 10.** Wire geometries of the outer (left) and inner (right) readout chambers.

# Channel positions

- 18 Sectors of IROC and OROC channels now using ALICE nominal geometry
- Rectangular array of pixels in a disk in the center
- Pixel size: 6mm x 6mm c.f. 4 mm x 7.5mm for inner pad rows.
- Total channels per side is now 339068.
- Total on both sides: 678136
- About 18% of channels are in the disk.



Geometry service now has a "Gap channel ID" to indicate locations where charge is lost.

# Pad Response Function

From the ALICE TDR: Charge Induction Response and IROC pad response

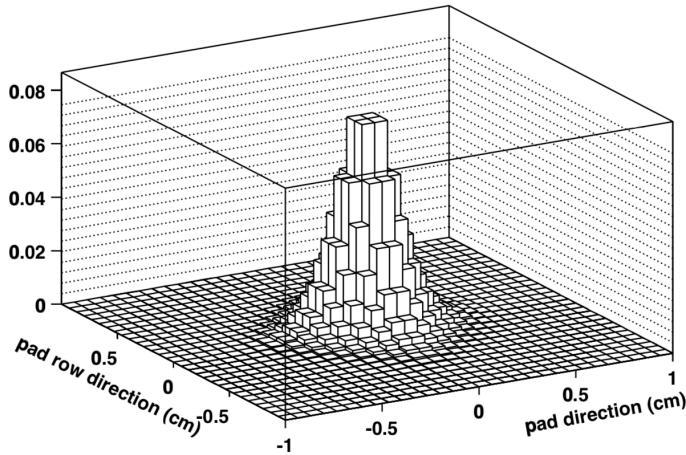


Figure 7.6: Induced-charge distribution according to Ref. [11]. Normalization is arbitrary.

$Q(x,y)$  function

Width  $\sim 1.2$  mm, with a small tail

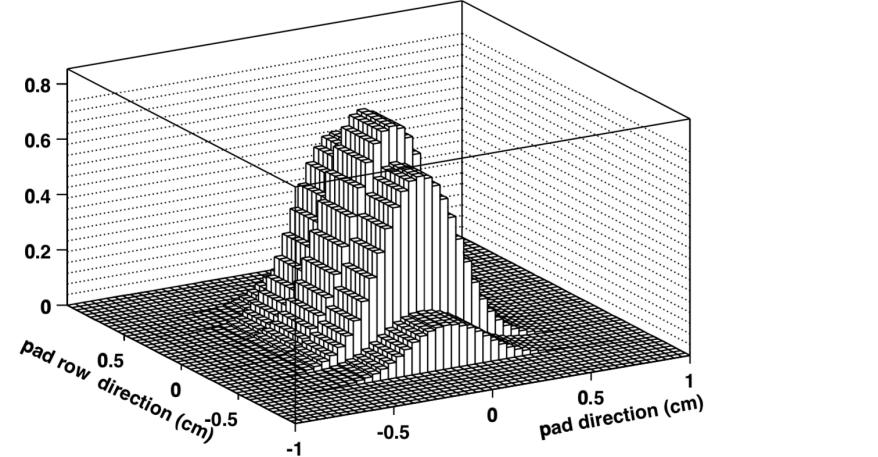


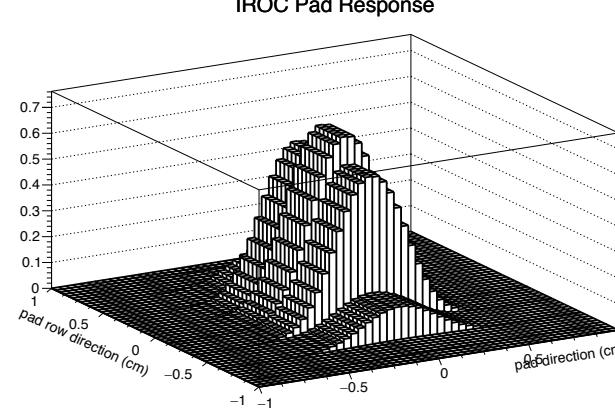
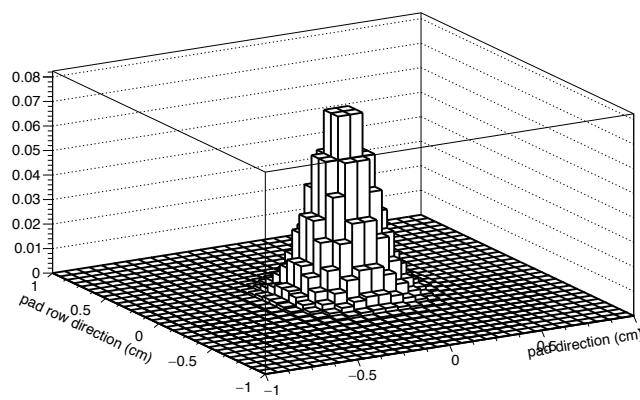
Figure 7.7: Pad response function for rectangular  $4 \times 7.5$  mm<sup>2</sup> pads. Normalization is to unity.

Anode-plane wires are spaced  
2.5 mm apart  $\rightarrow$  discretization along  
the pad row direction

$$\text{PRF}(x,y) = \int_S Q(x',y') dS,$$

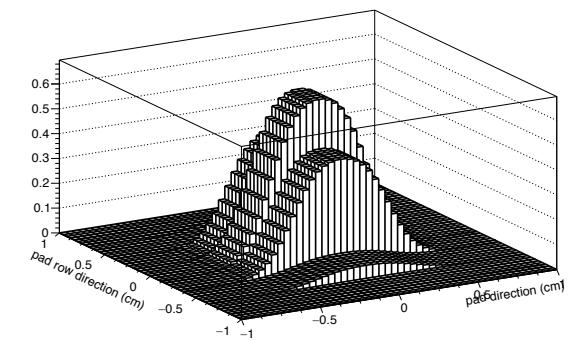
# Pad Response Functions (PRF)

Replica of ALICE TDR plots



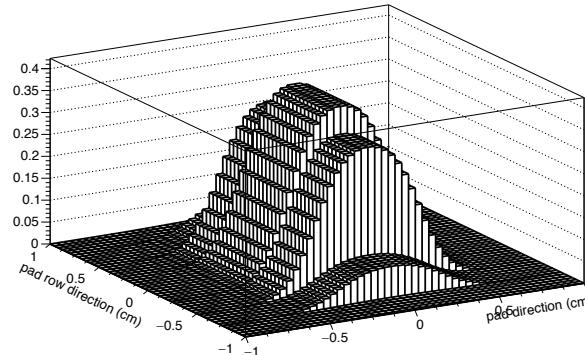
6x6 mm<sup>2</sup>  
hole-filler PRF

HFILL Pad Response

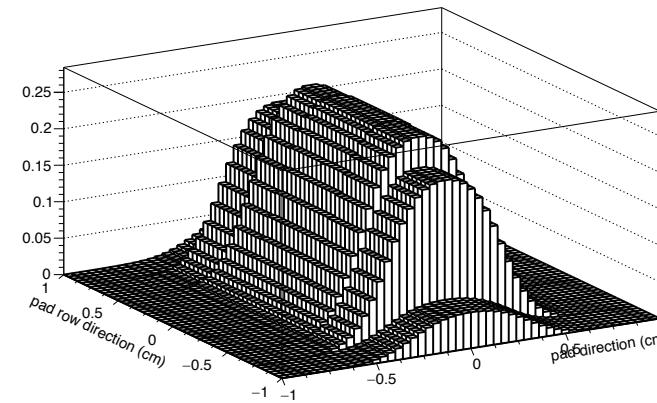


Extrapolation to IOROC and OOROC

IOROC Pad Response



OOROC Pad Response



# Space-Point Resolution Parameterization from ALICE

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

Separately parameterized perpendicular to the pad axis and along the drift direction.  
I cannot find documentation about the resolution along the pad axis.

$$\sigma_{\text{COG}}^2 \propto p_0^2 + p_L^2 L_{\text{Drift}} + p_A^2 \tan^2 \alpha$$

$$p_L^2 \propto \frac{\sigma_D^2 G_g}{N_{\text{ch}}}$$

$$p_A^2 \propto \frac{L_{\text{pad}}^2 G_{\text{Lfactor}}}{N_{\text{eprim}}}$$

where  $N_{\text{ch}}$  is the number of electrons created during the amplification process,  $L_{\text{pad}}$  is the pad length, and  $N_{\text{eprim}}$  is the number of primary electrons per pad. There are three main factors which degrade the space-point resolution, namely the gas gain

fluctuations (factor  $G_g \approx 2$ ), the Landau fluctuations of the ionization energy loss (factor  $G_{\text{Lfactor}}$ ) and the diffusion  $\sigma_D$  (here, normalized to the drift length). One should note that:

$$N_{\text{ch}} \propto L_{\text{pad}}$$

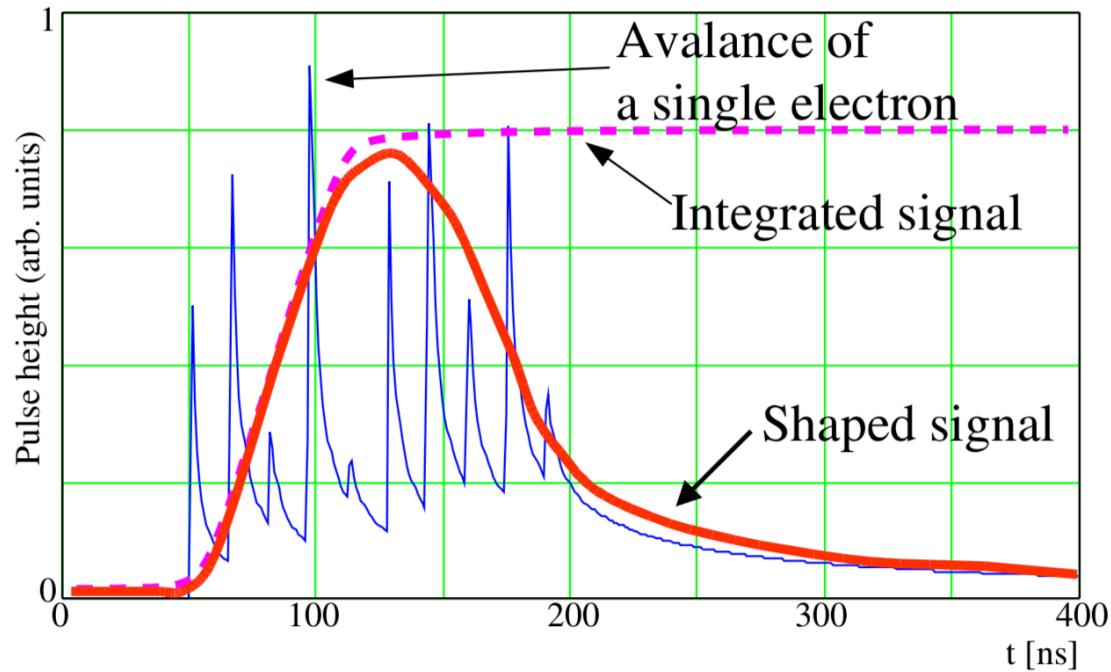
$$N_{\text{eprim}} \propto L_{\text{pad}}$$

and therefore

$$p_L \propto \frac{1}{\sqrt{L_{\text{pad}}}}$$

$$p_A \propto \sqrt{L_{\text{pad}}} \quad (6)$$

# From Jens Weichula's Thesis

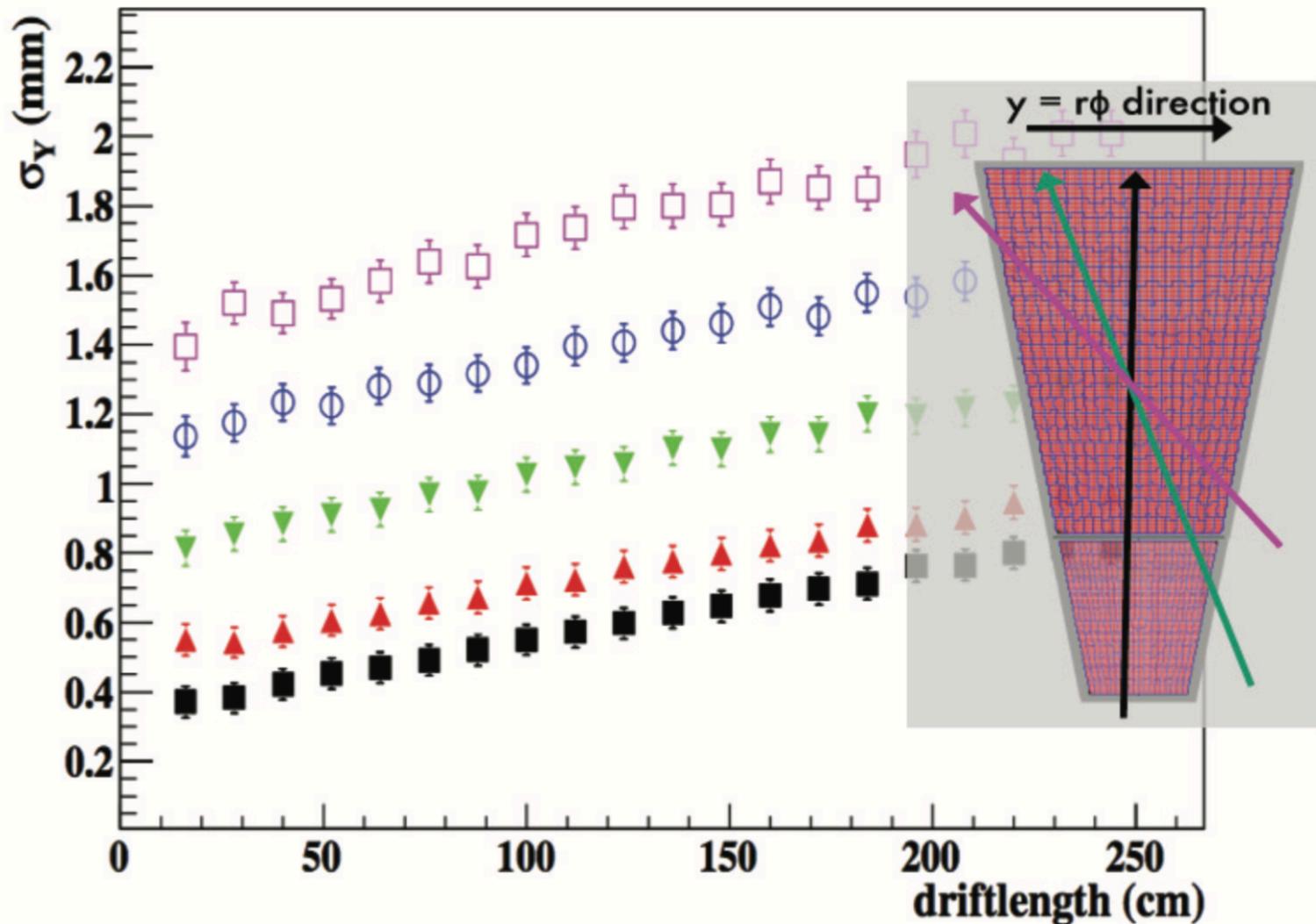


**Figure 3.7:** Sketch of a pad signal. The blue curve shows the signal directly at the pad. The avalanches of each single electron is clearly visible. The magenta curve shows schematically the integrated signal after the pre-amplifier and the red curve shows schematically the shaped (final) signal [35].

MPD runs with 10 bars of Ar – many more electrons will arrive at the pads. Diffusion and anode-wire spacing introduce random offsets, that when averaged, improve the resolution over the pad size discretization. With few electrons arriving at the pads, the resolution worsens with diffusion.

# ALICE TPC Cluster Resolution

C. Lippmann, TIPP 2011 Physics Procedia 37 (2012), 434



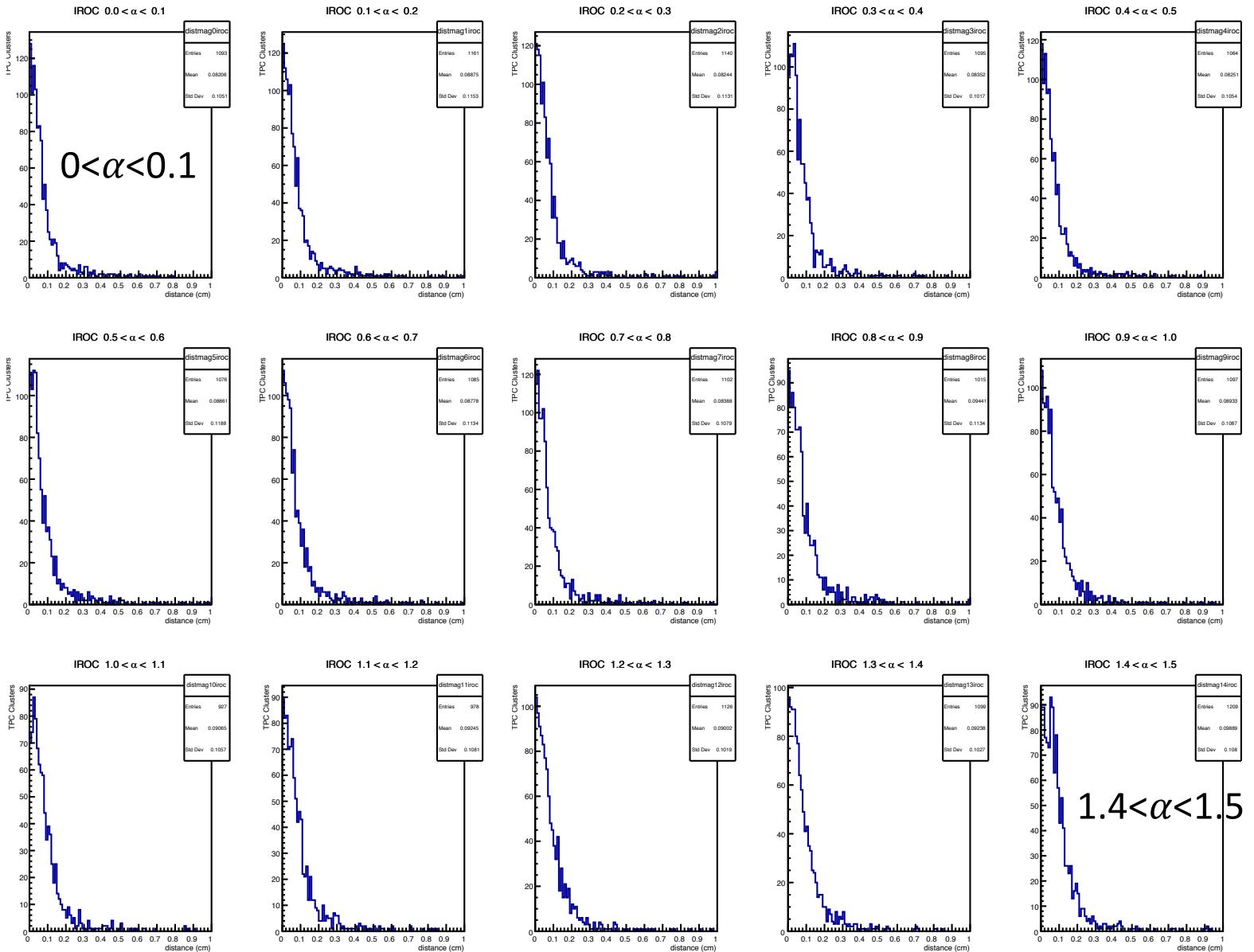
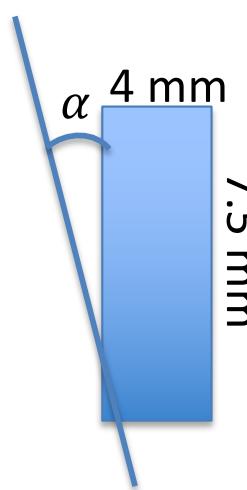
Expect somewhat better perf for MPD at high pressure due to more electrons arriving.

# GArSoft Point Resolution Study Methodology

- 5000 events generated with 200 MeV pions uniformly distributed throughout the TPC, isotropically distributed in angle
- Tracks are isolated – residuals do not reflect crowded environments (except to the extent delta rays and other interactions clutter things up)
- TPC Clusters are also found with generous averaging: 4 cm in (y,z) and 2 cm in x. Probably doesn't have to be this broad. Future work: fit TPC cluster positions with Gaussians
- Residual distributions on next pages are absolute values of the distance between a TPC cluster and the nearest MCParticle trajectory. The ALICE plot only shows the  $r\phi$  component.

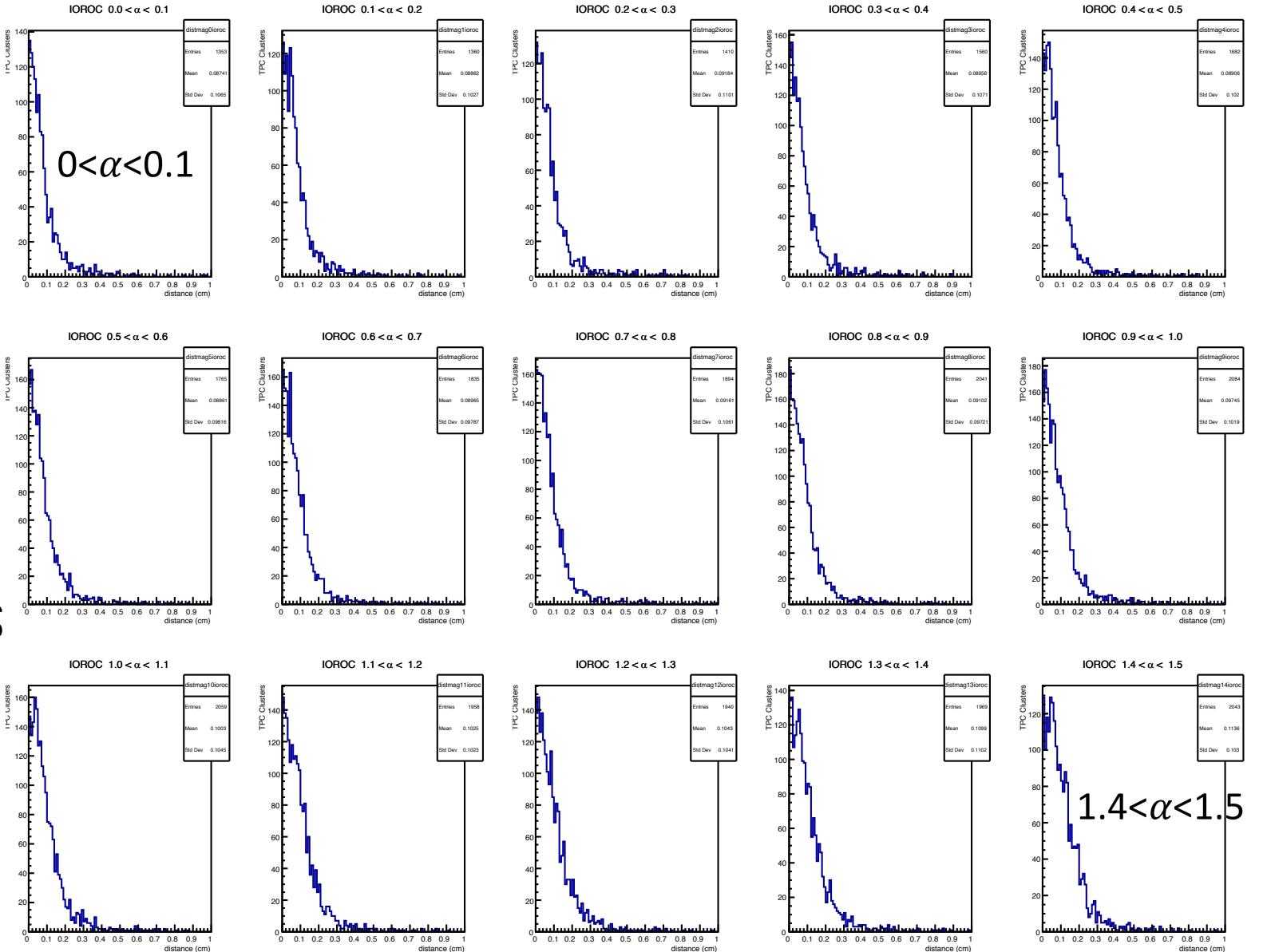
# TPC Cluster Residuals vs. Angle: IROC

Pad center  
location bug  
affecting collab  
mtg talk fixed now.



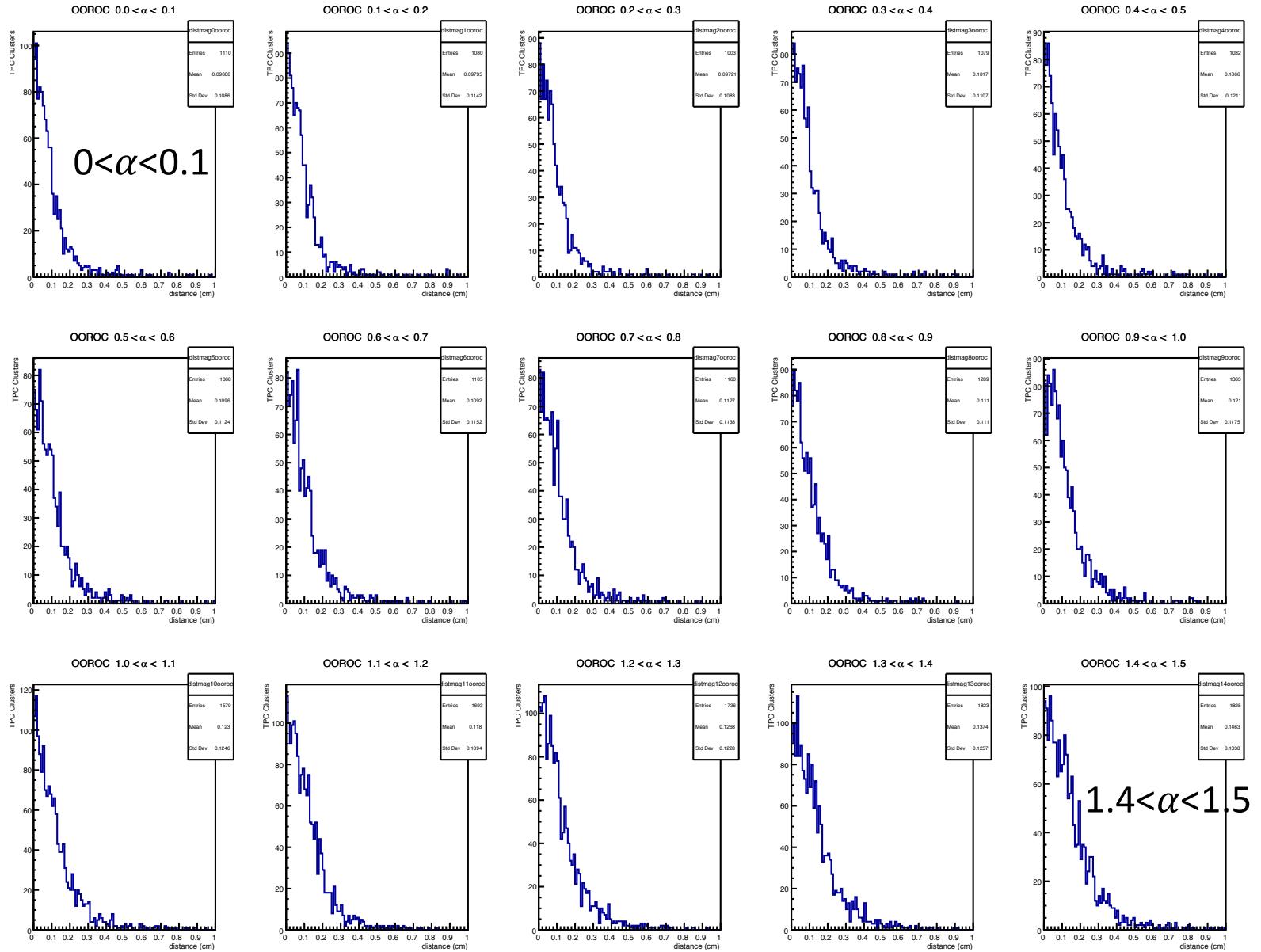
Wide hit clustering: 4 cm (transverse) x 2 cm (longitudinal)  
search window

# TPC Cluster Residuals vs. Angle: IOROC

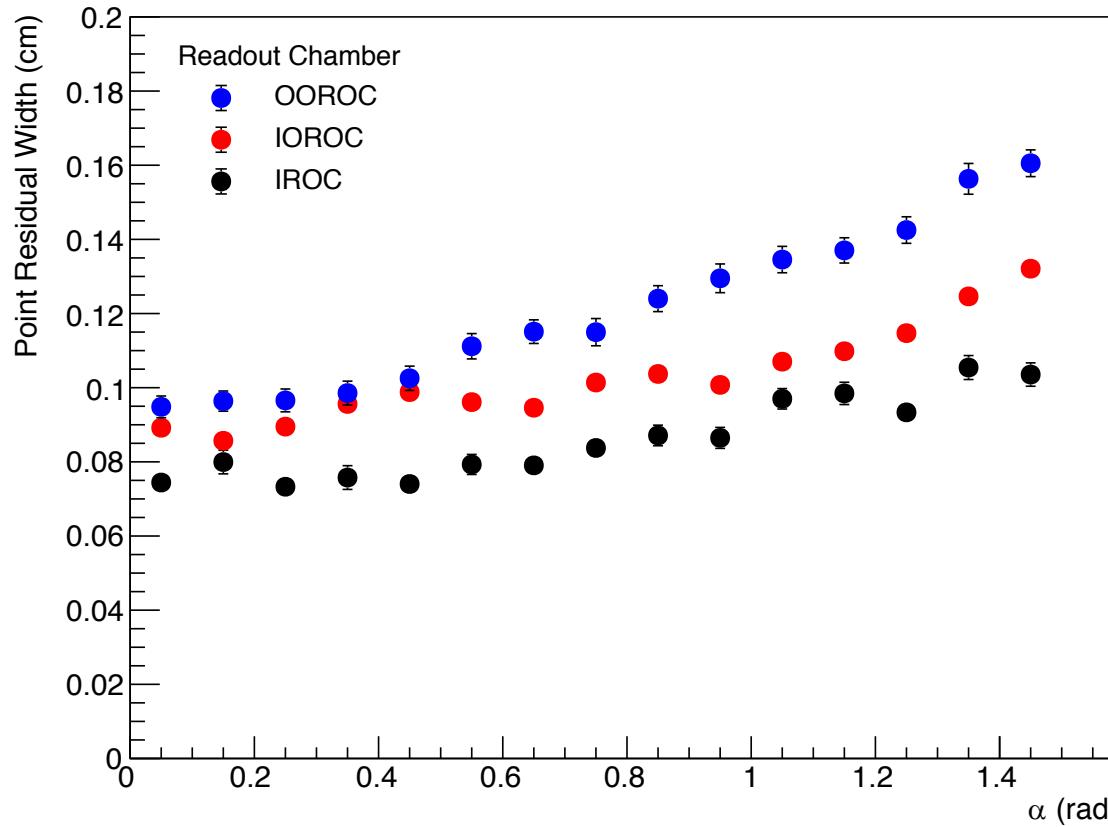


Wide hit clustering: 4 cm (transverse) x 2 cm (longitudinal)  
search window

# TPC Cluster Residuals vs angle: OOROC



# Point Resolution Summary



Residuals perp  
to track, *not*  
just  $r\phi$

Widths of fits of Gaussians to the abs val. residuals on previous pages

Resolution of OOROC for tracks 90° from the pad axis is still good – 1.6 mm.

Optimization of TPC Clustering algorithm expected to improve all resolutions.

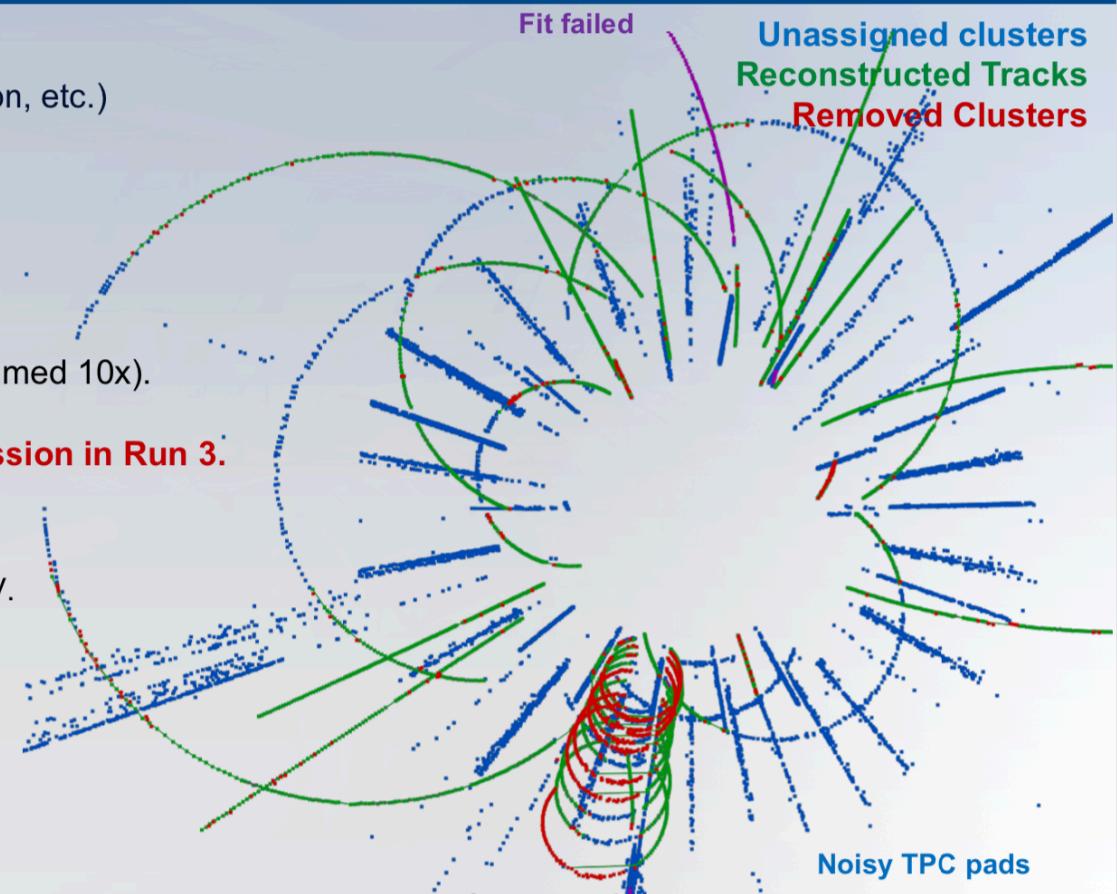
Fiducial volume cuts (already in the 1 ton definition) ensure enough hits are on tracks to make a good momentum measurement.

# From the TPC Mini-Workshop

## TPC Data Compression



- TPC Data compression involves 3 steps:
  - Entropy reduction (Track model, logarithmic precision, etc.)
  - Entropy encoding (Huffman, Arithmetic, ANS)
  - Removal of tracks not used for physics.
- Steps 1 + 2 implemented for Run 2.
  - Current compression factor **8.3x**.
  - Prototype for Run 3 achieves factor **9.1x** (TDR assumed 10x).
- Step 3 must close the gap to the required compression in Run 3.**
  - Remove clusters from background / looping tracks.
    - Adjacent to low- $p_T$  track  $< 50$  MeV.
    - Adjacent to secondary leg of low- $p_T$  track  $< 200$  MeV.
    - Adjacent to any track with  $\varphi > 70^\circ$  in the fit.
  - Protect clusters of physics tracks.
    - Not Adjacent to any physics-track (except  $\varphi > 70^\circ$ ).
- In addition:
  - Use reconstructed track quantities to reduce entropy.

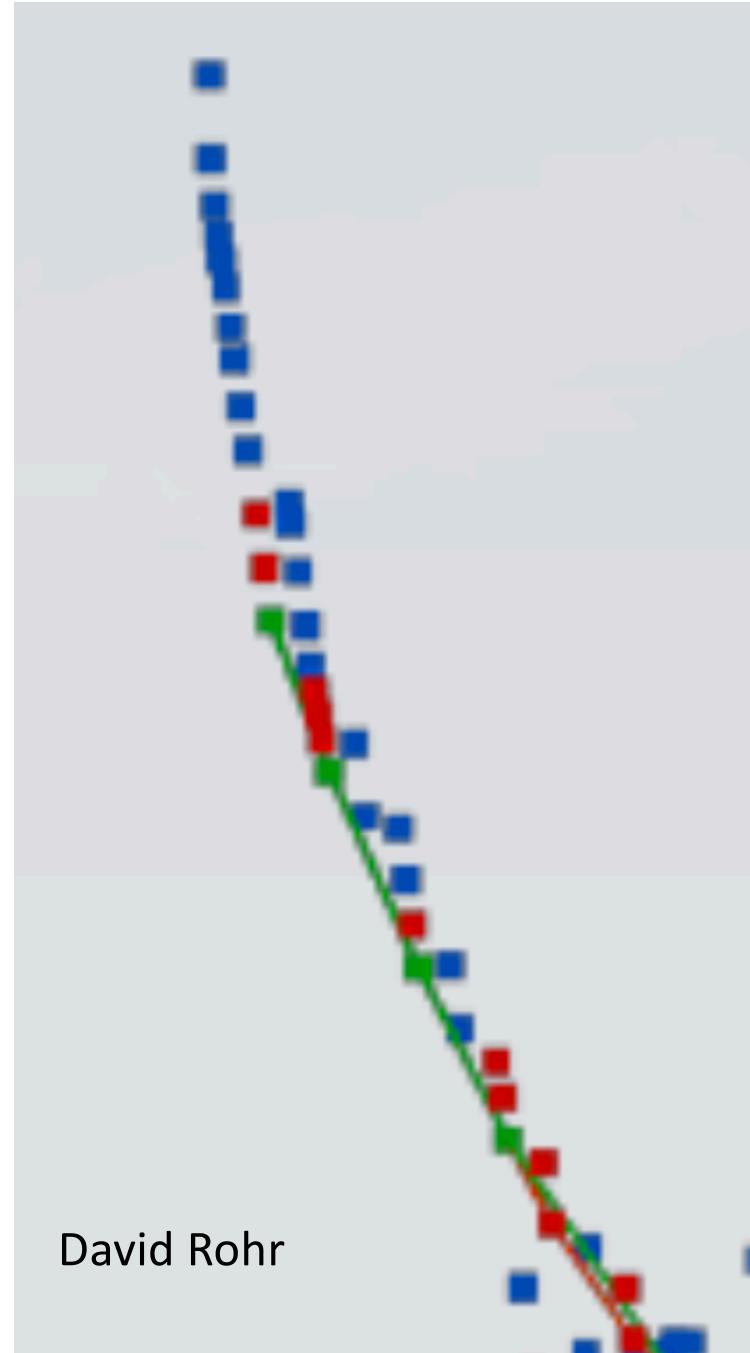


# Zooming in

Track traveling along pad rows  
clearly has its TPC Clusters  
locked in to the pad-row positions

Hops discretely from one pad row  
to another.

This is ALICE data – effect seen  
in GArSoft simulations too



# Effects of Pad Row Discretization

- Tracklet pattern recognition sometimes locks onto strings of hits that follow pad rows instead of the track direction.
- We expect this issue to be solvable by allowing the track fitter to reassign TPC clusters to tracks, since the fitted track has more information than a short tracklet.
- Resolution of an  $\alpha=1.5$  radian track in the OOROC is 1.6 mm, which is better than the naive  $15 \text{ mm}/\sqrt{12}$ , due to diffusion, the pad response function, and the fact that many electrons contribute to each TPC cluster. Tracks appear straighter than they really are however; the 1.6mm is not uncorrelated from cluster to cluster.
- This resolution is likely to get better with algorithm improvements

# Extras