Spatial resolution for the LCTPC using resistive Micromegas

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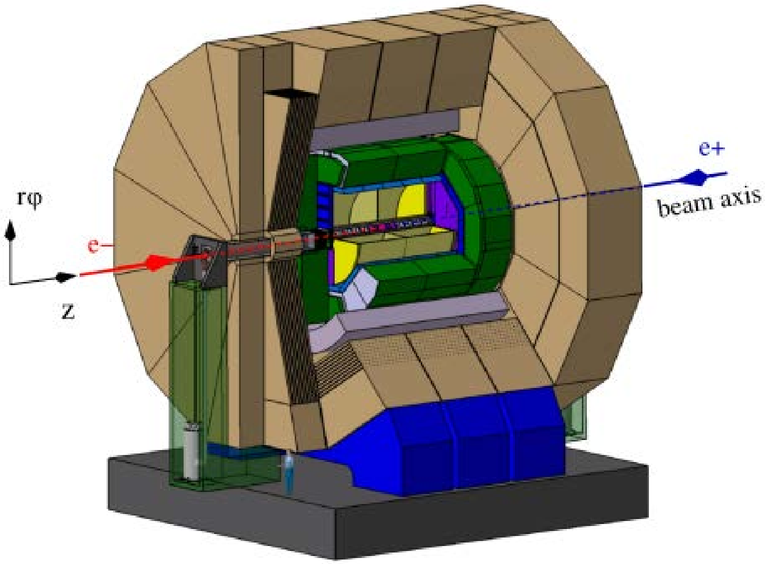
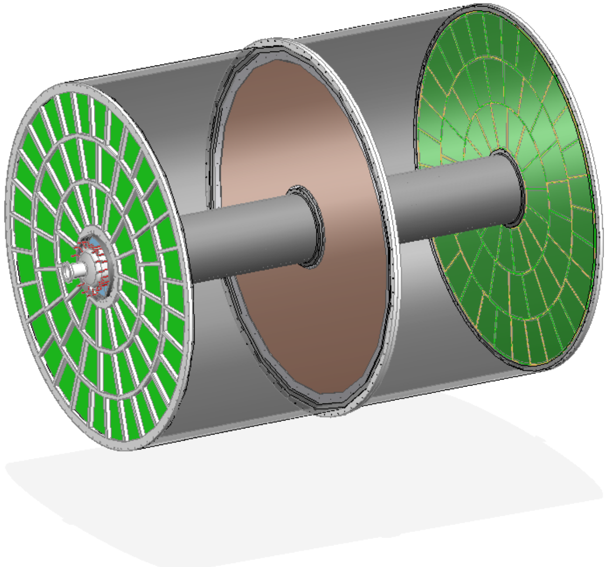
On behalf of the LCTPC collaboration

Outline

- Will answer these **3** questions:
  - –1) What is the requirement for ***LCTPC*** at ***ILD***?
  - –2) How is a **signal** obtained from the LCTPC prototype?
  - –3) How is the **resolution** of the detector determined?

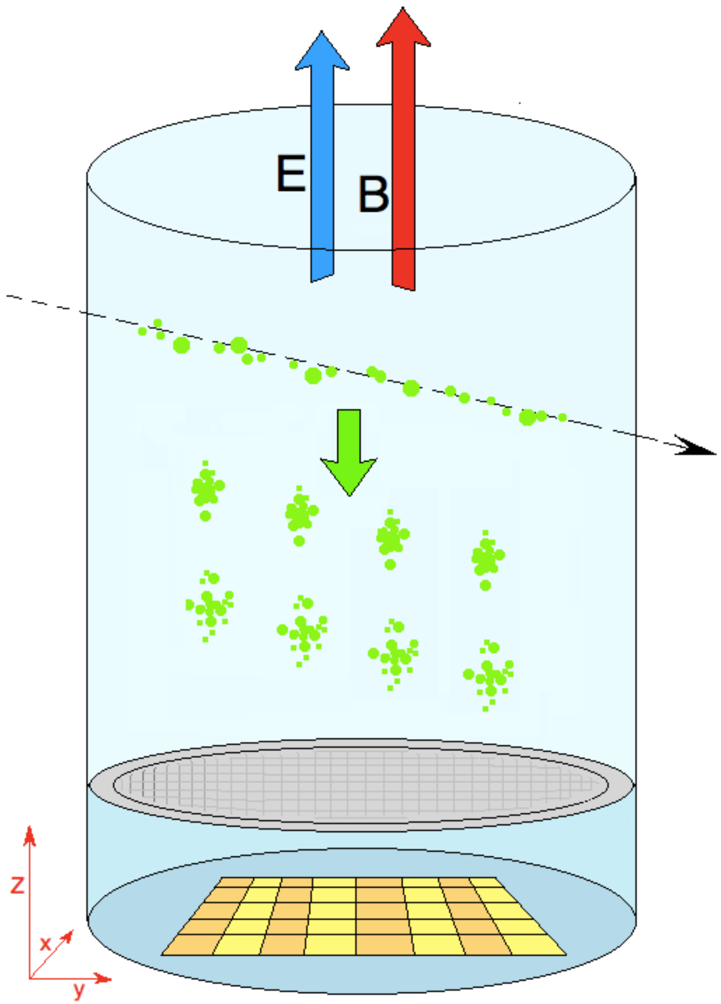
- Results of **resolution** study and conclusions





TPC Principle

•A **Time Projection Chamber** (TPC) is a detector consisting of a cylindrical gas chamber and a position sensitive readout endcaps



• The TPC acts as a **3D** camera taking a snapshot of the passing particle

• **XY position**: Charged particles ionize the gas, a longitudinal electric field causes ionization e^- to drift towards endcap where they are detected [transverse resolution]

• **Z Position**: Measure time between ionization and detection, multiply by drift speed [longitudinal resolution]

Time Projection Chamber (TPC) for ILD

TPC is the central tracker for International Linear Detector

– Large number of 3D points → continuous tracking

– Good track separation and pattern recognition

- Low material budget inside the calorimeters (*c.f.* PFA)

– Barrel: ~5% X_0

– Endplates: ~25% X_0

- Two options for endplate readout:

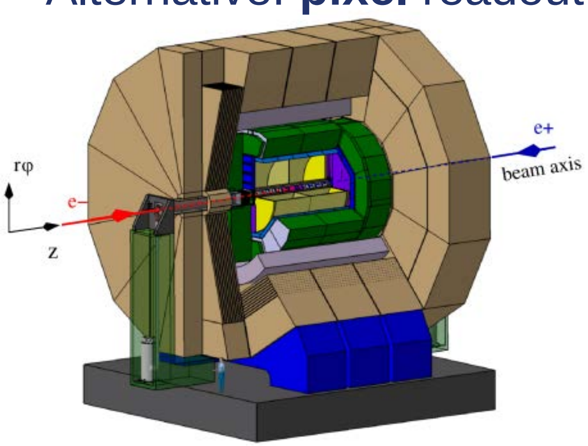
– **GEM:** 1.2×5.8 mm² pads

– **Resistive Micromegas:** 3×7 mm² pads

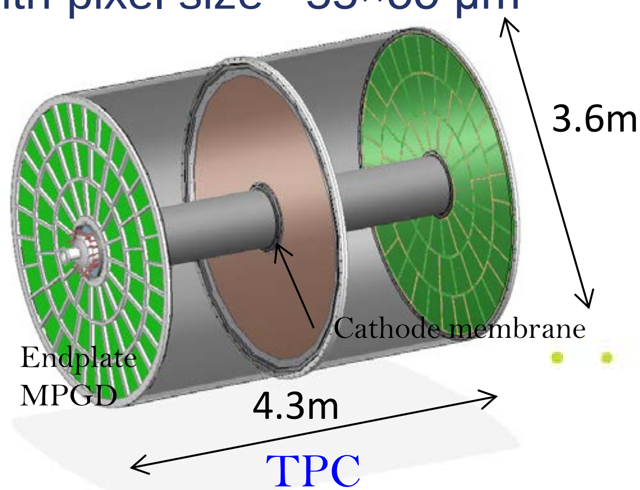
- Alternative: **pixel** readout with pixel size ~55×55 μm²

TPC Requirements :

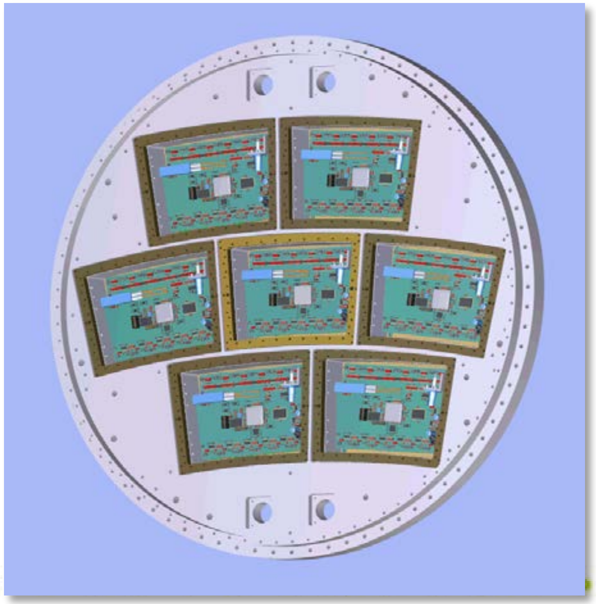
- **Momentum resolution**: $\delta(1/p_T) < 9\times10^{-5}$ GeV^{-1}
- **Single hit resolution 3.5T**: $\sigma(r\phi) < 100$ μm (overall) $\sigma(z=0) \approx 400$ μm
- **Tracking eff.** for p_T>1 GeV: 97%
- **dE/dx resolution** ~5%



ILD

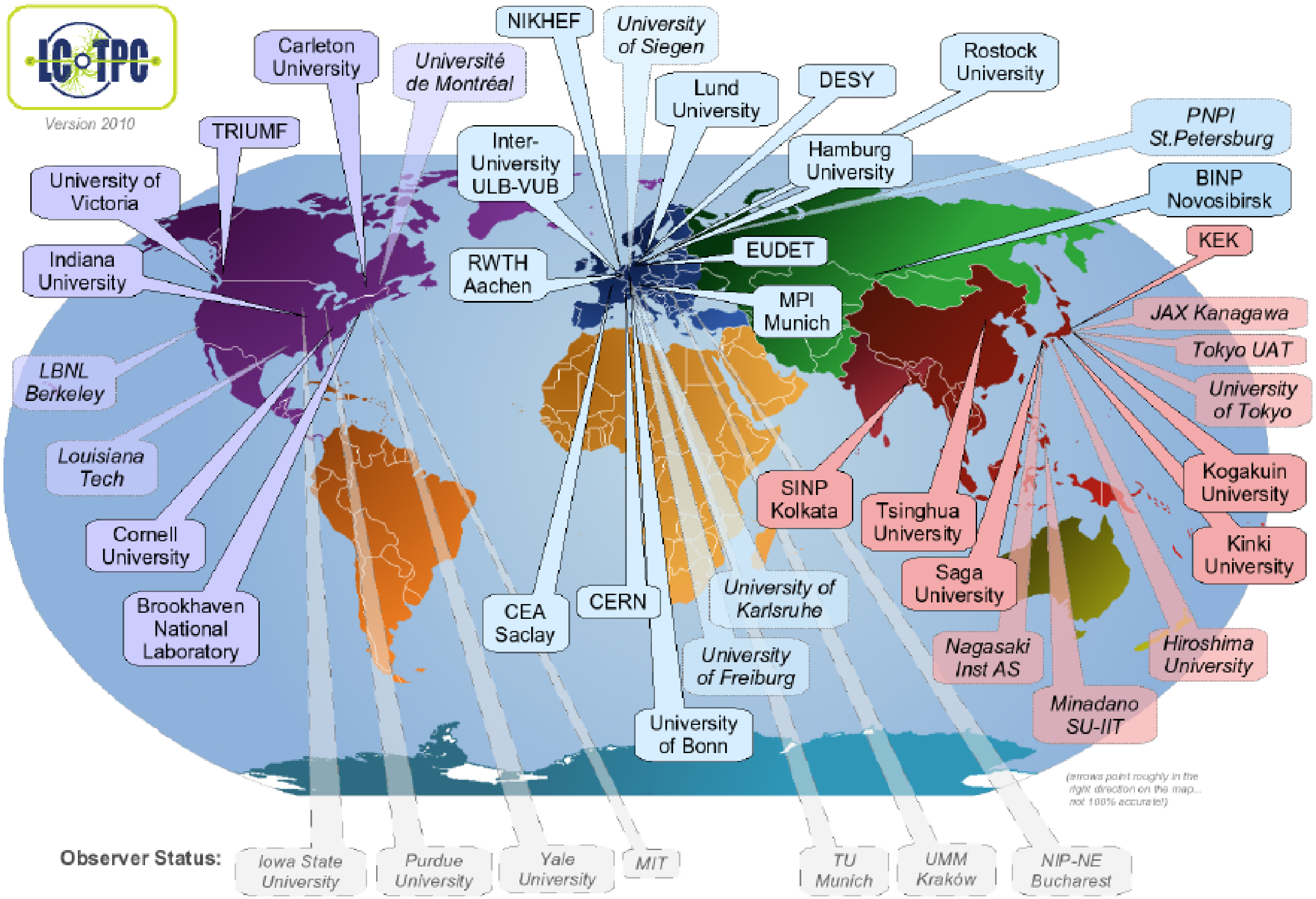


TPC



Large Prototype

LCTPC Collaboration

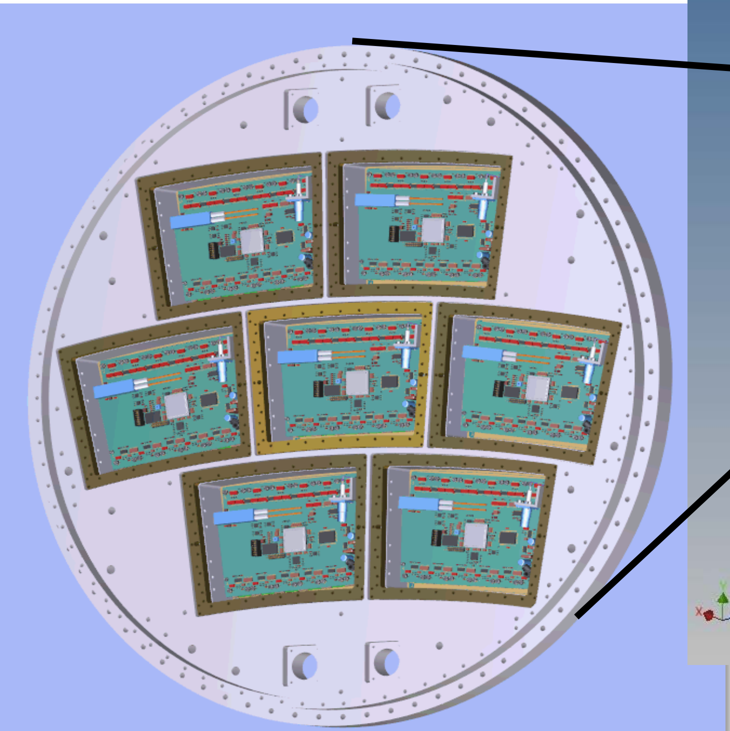


Total of 12 countries from 38 institutions members + 7 observer institutes

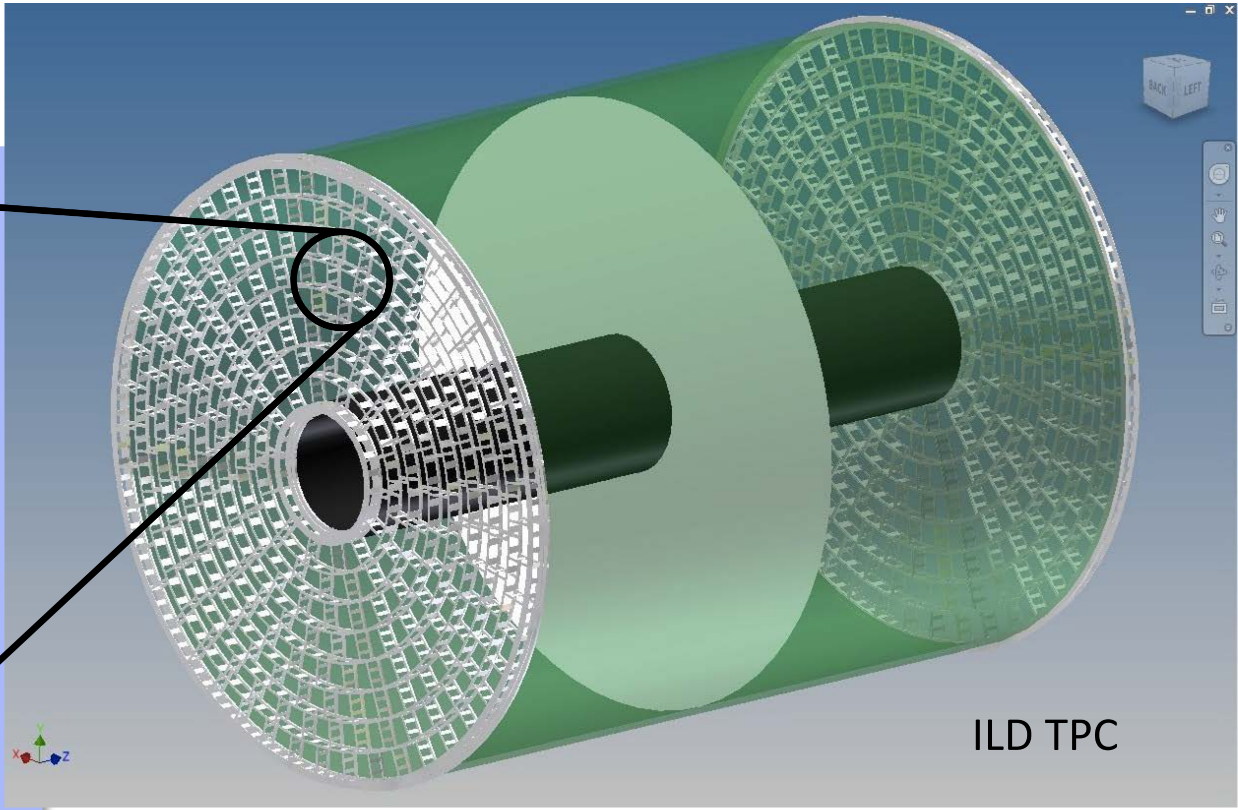
Large Prototype at DESY

- Two options for endplate readout with **pads**:
  - **GEM:** 1.2×5.8 mm² pads (smaller pad – more electronics)
  - **Resistive Micromegas:** 3×7 mm² pads (larger pads – less electronics)
- Alternative: **pixel** readout with pixel size ~55×55 µm²

Large Prototype TPC



Endplate of 7 panels, ø = 80 cm



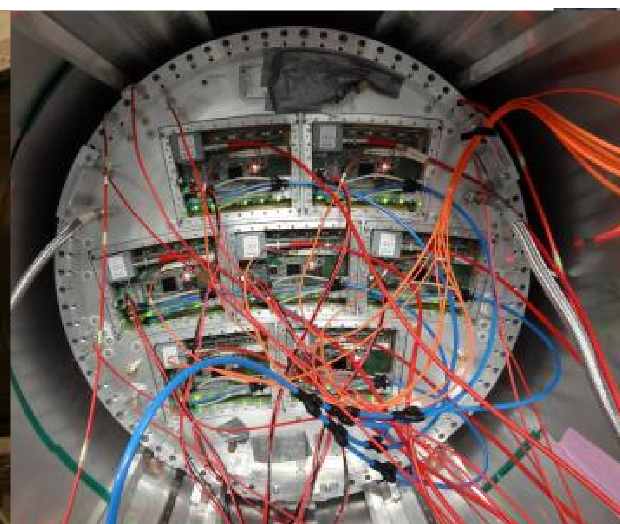
ILD TPC

MPGD readout modules under studied

Readout		Pad Size	Electronics	Groups
MPGDs	Double GEMs (Laser-etched)	(~ 1 × 6 mm^2 Pad)	ALTRO	Asia
	Triple GEMs (wet-etched)			DESY
★	Micromegas (Resistive anode)	(~ 3 × 7 mm^2 Pad)	AFTER	Saclay-Carleton

LCTPC setup at DESY testbeam facility

Large Prototype TPC



Endplate + 7 Micromegas modules

1T PCMagnet

Micro Pattern Gas Detector (MPGD)

Technology choice for TPC readout: Micro Pattern Gas Detector

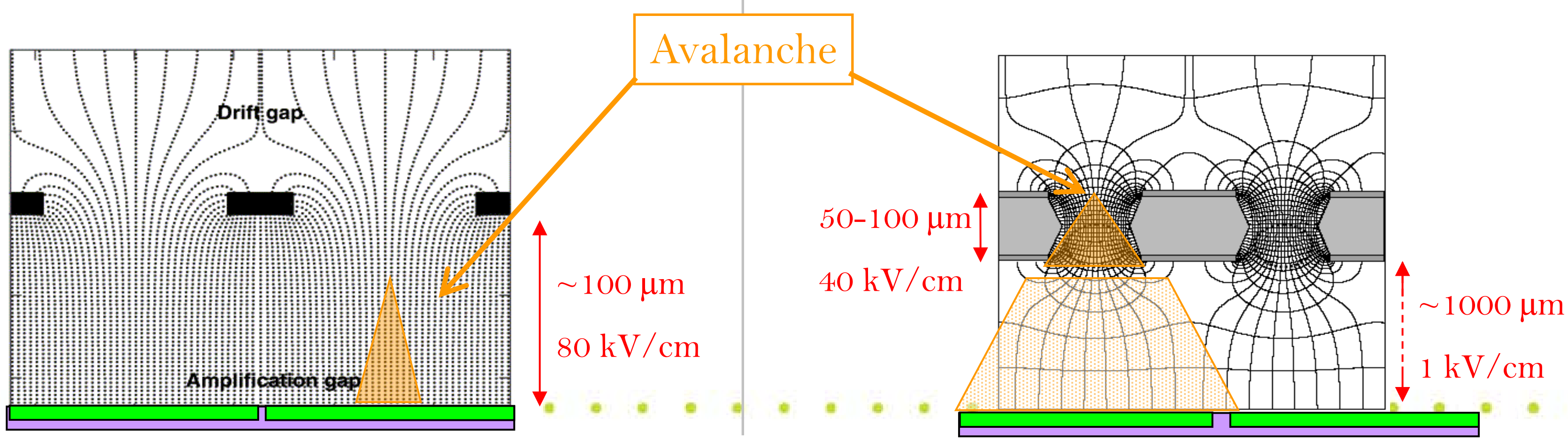
- more robust than wires
- fast signal & high gain
- better ageing properties
- no E×B effect
- low ion backdrift
- easier to manufacture

Micromegas (MM)

- MICROMEsh GAseous Structure
- metallic micromesh (typical pitch 50µm)
- supported by 50 µm pillars, multiplication between anode and mesh, high gain

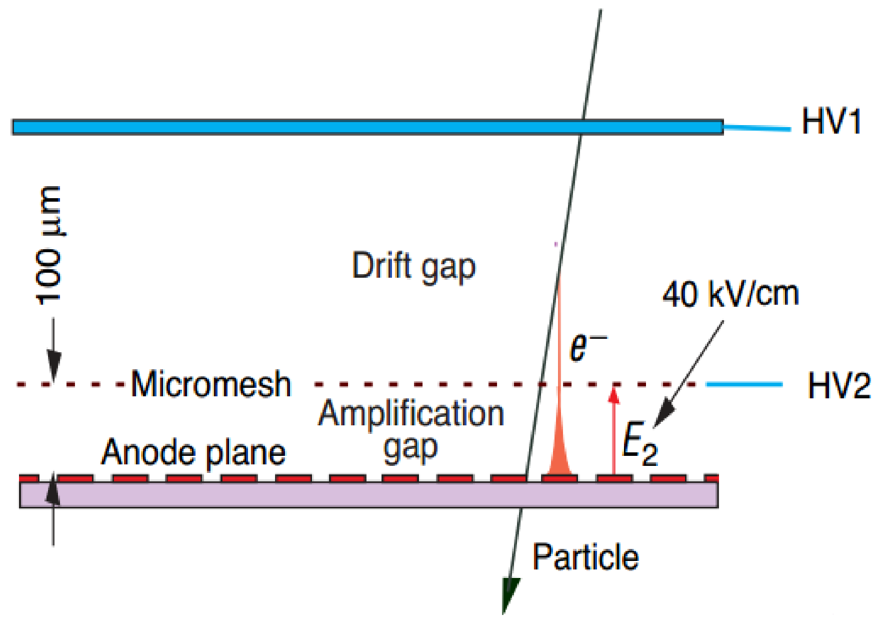
GEM

- Gas Electron Multiplier
- 2 copper foils separated by kapton
- multiplication takes place in holes, with 2-3 layers needed



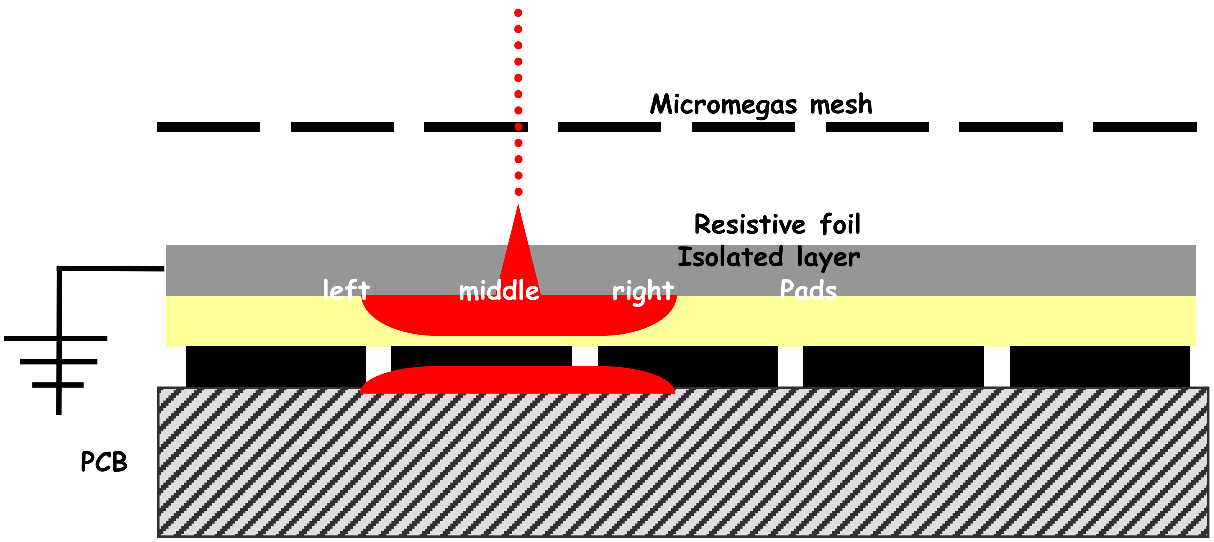
Readout Technology (Micromegas)

- At the ends of the **TPC** are ***Micromegas*** (MICRO-MEsh GASeous detector)
- Charged particles ionize the gas creating primary **e^- ion pairs**, as the e^- nears the mesh it is accelerated and creates **secondary pairs**
- The signal from the **secondary ions** is recorded on the pads
- Resistive anode layer spreads the charge over **multiple readout pads**



Charge Dispersion

Resistive Anode



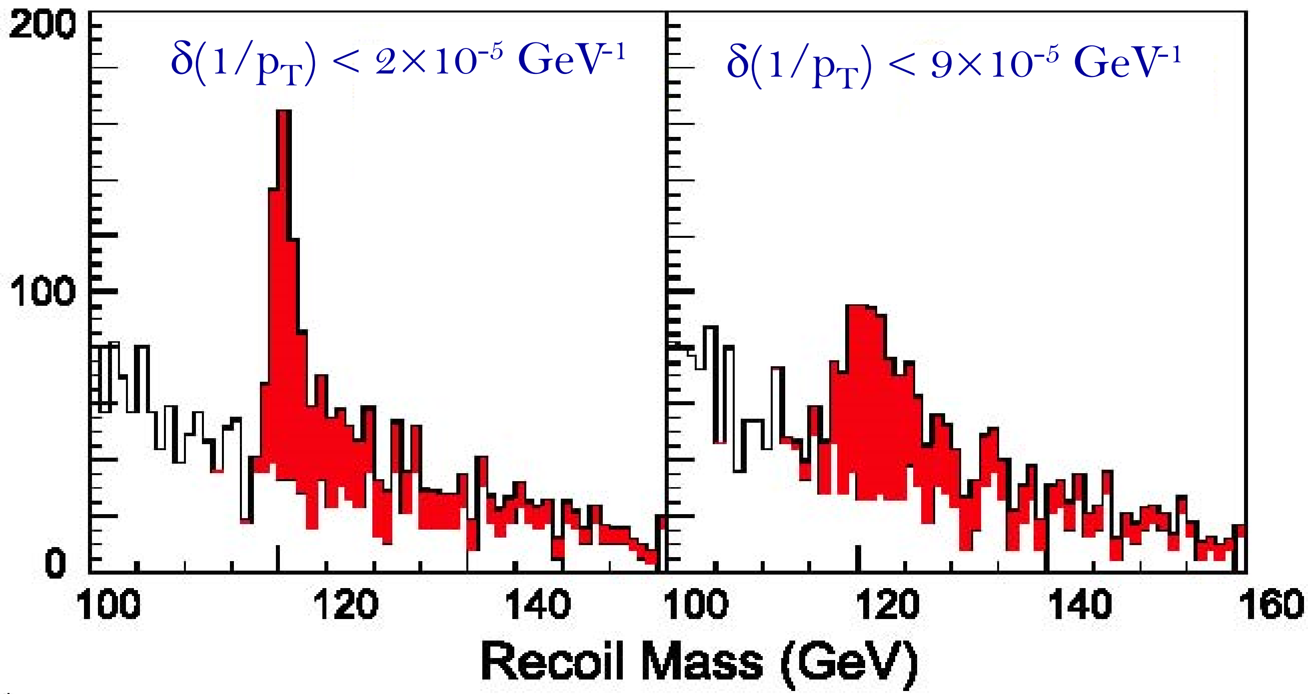
Goal: Resolution Measurement

- **Resolution** is the precision to which the **position** of a passing particle can be measured
- Requirements of the TPC (at 3.5T) are:
  - **Transverse** (xy) resolution of 100 microns over 2m of drift, **60 microns** at Z=0
  - **Longitudinal** (z) resolution of 1400 microns over 2m of drift, **400 microns** at Z=0

Why is Resolution important?

- A good resolution allows for more precise measurements of particle momentum [cartoon e.g. Higgs mass reconstruction]
  - The **curvature of the track** determines the **momentum of the charged particle** passing through the detector
  - Precise **momentum** → precise particle **mass** reconstruction

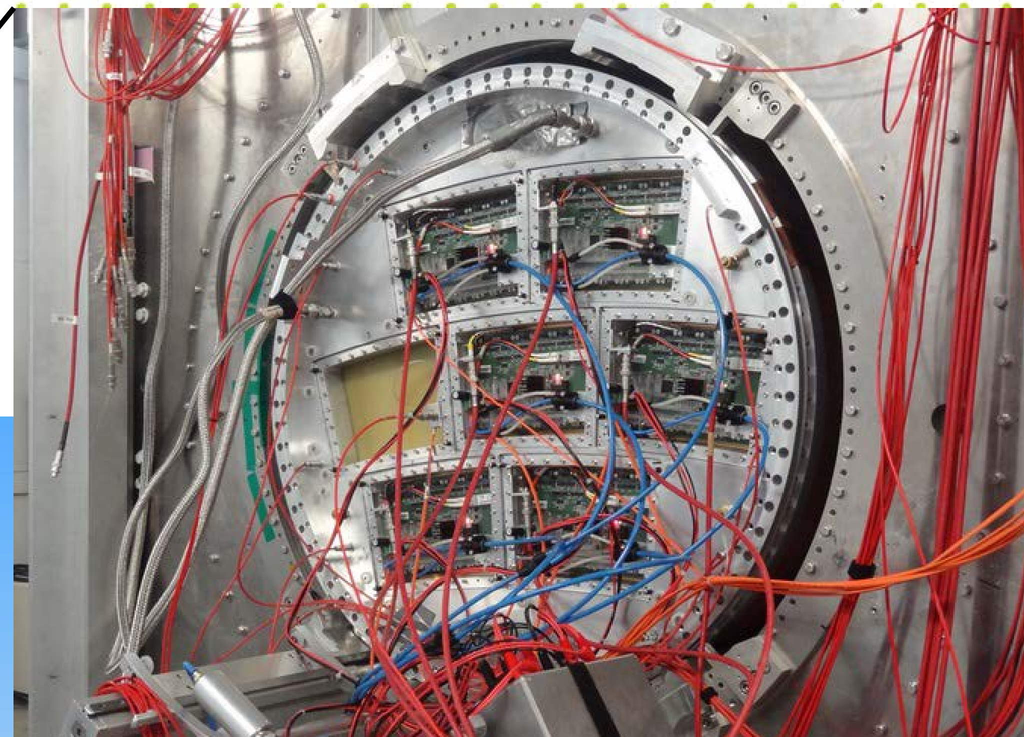
$$H\,Z \rightarrow \ell\,\ell\,X$$

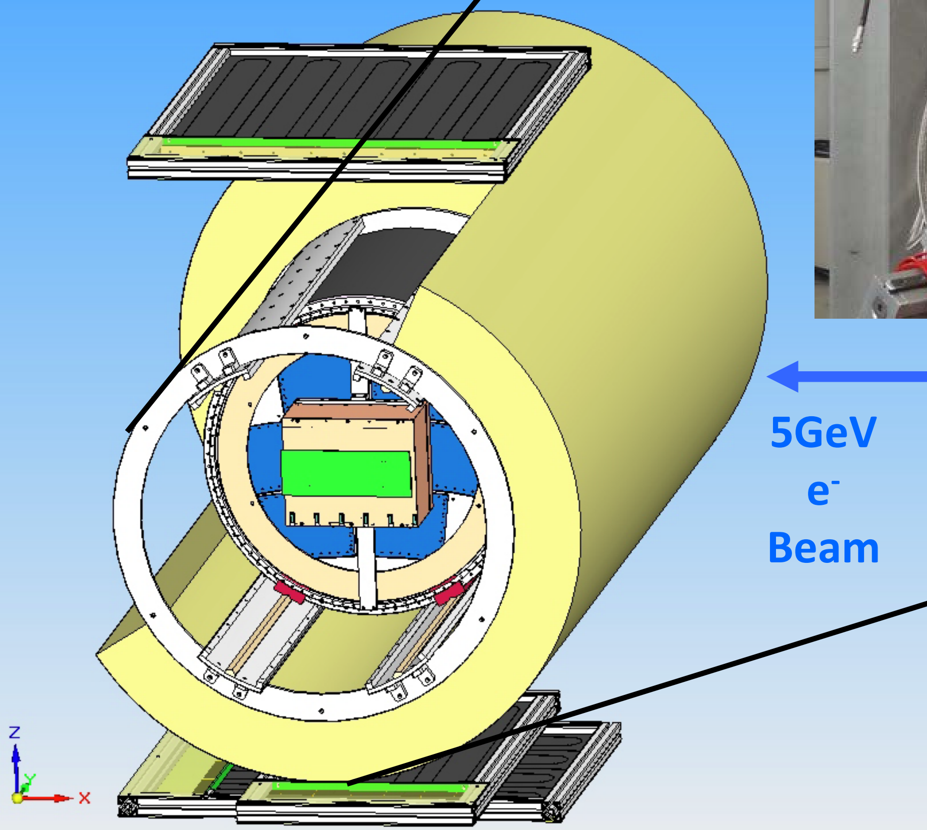


Multi-modules LCTPC (MM)

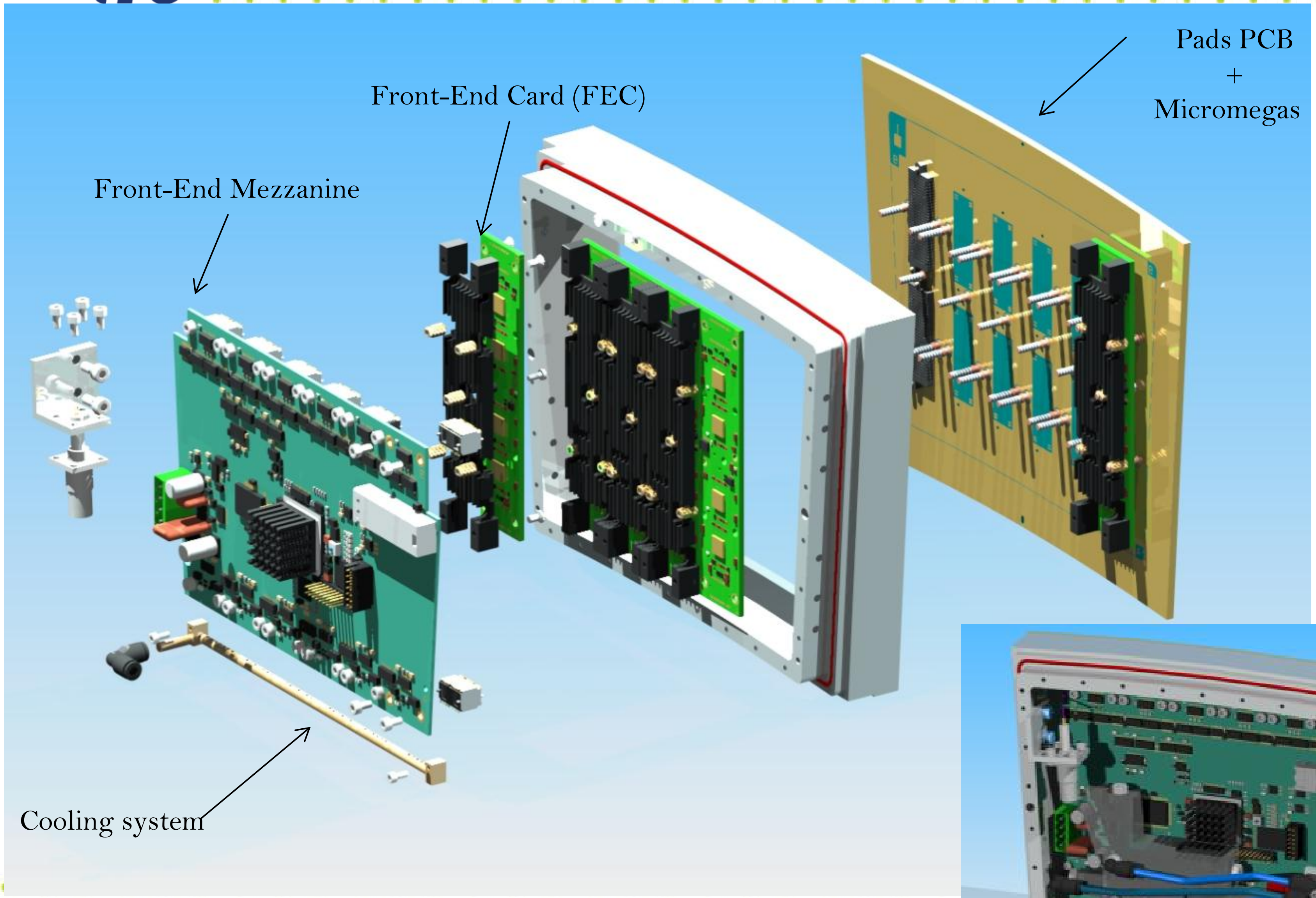
B = 1 Tesla

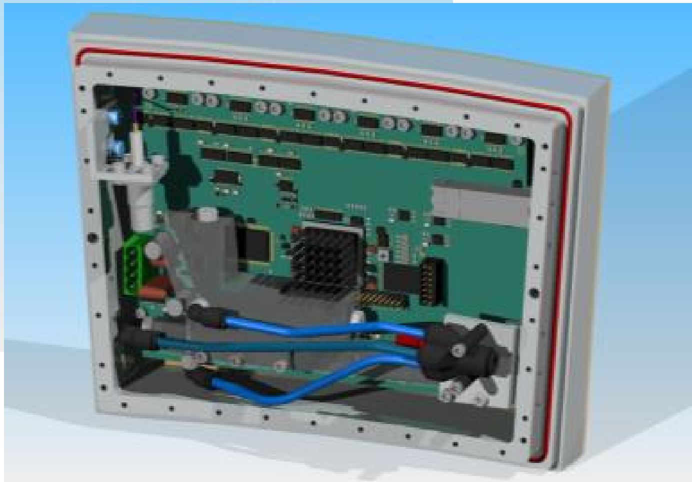
2013 data
Multi-module



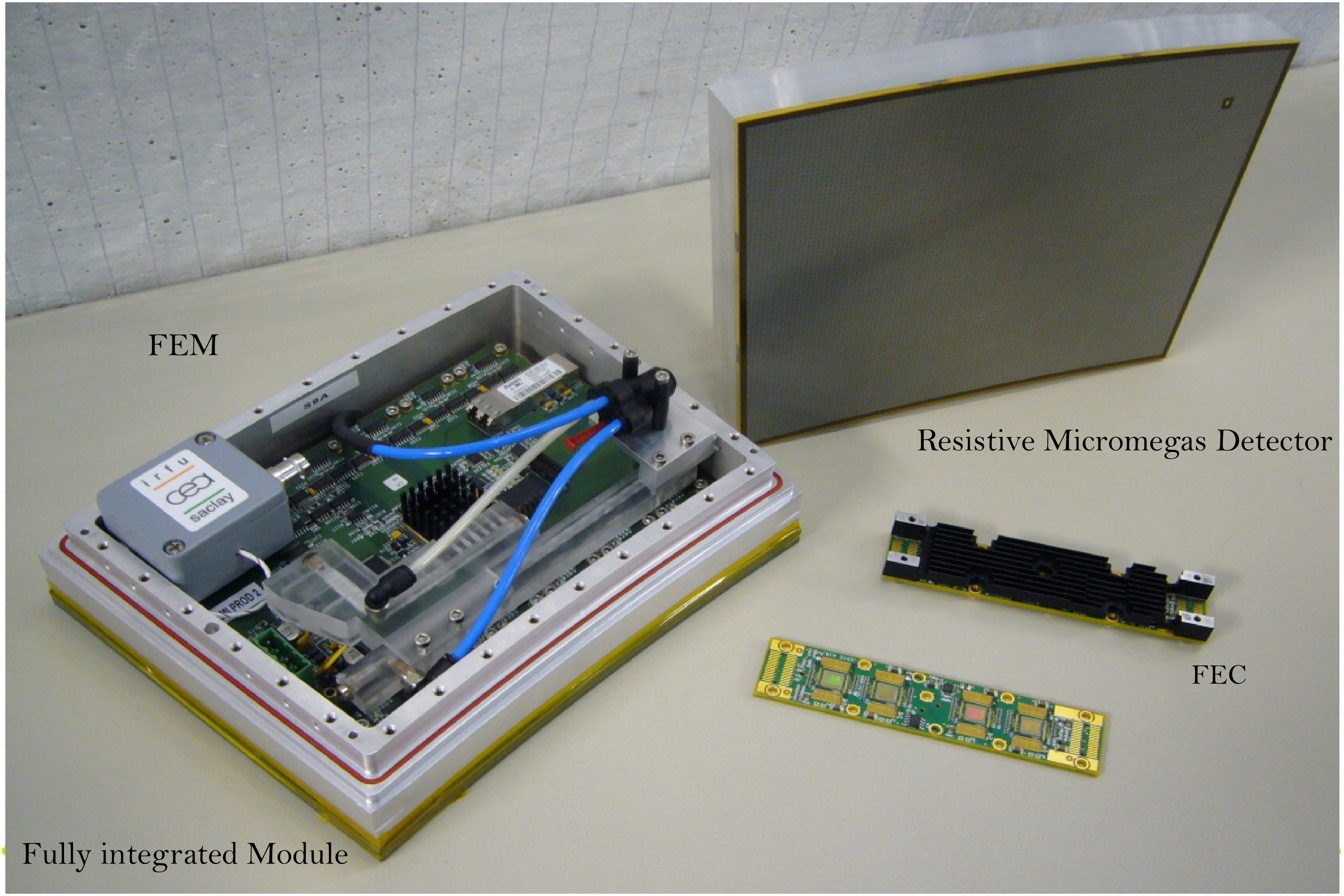


Resistive MM: Module Design

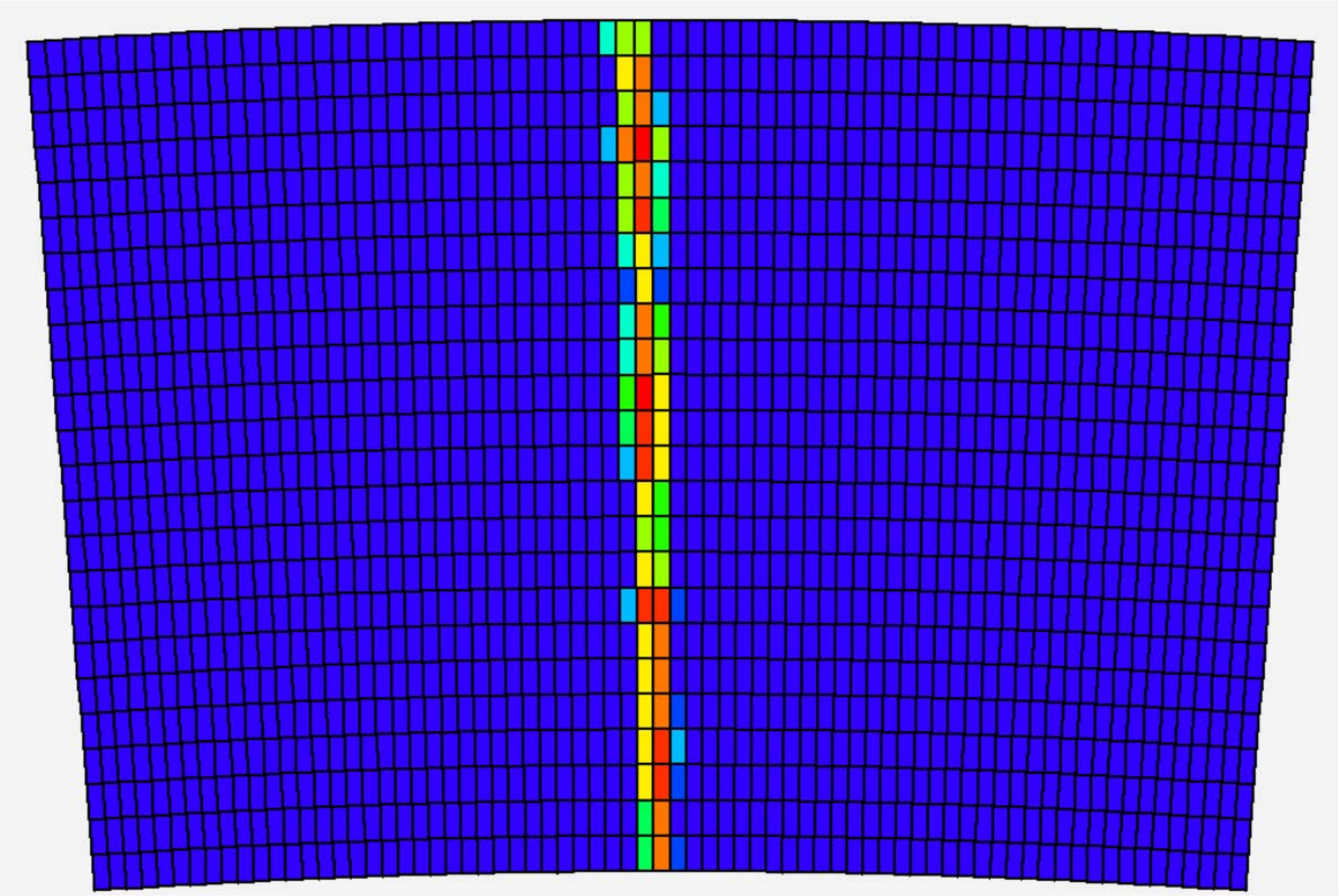




Resistive MM: Module Design



LCTPC Large Prototype Event



Overview of Resolution Analysis

- For each pad we have ***charge*** (ADC) as a function of ***time*** (40 ns intervals)
- **4** steps from **raw data** to **resolution:**

1) Determine ***amplitude*** and ***arrival time*** of each pad pulse

2) Group ***pulses*** on each row into ***hits***

3) Use hit positions to to fit ***tracks***

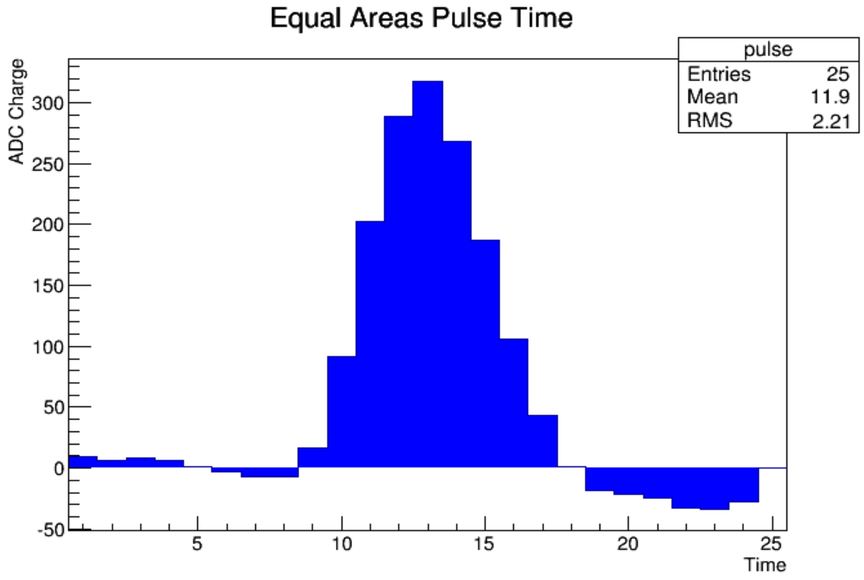
4) Find ***residuals*** from track fits and calculate ***resolution***

(1) Pulse Amplitude Determination

- Each readout pad produces an **electronic pulse** which encodes the charge
- Need to determine the **amplitude** of this pulse
- **Simple method:** Take peak value as amplitude
- **New method:** *Reintegration*; Sum charge over fixed time interval

- Reintegrating pulses gives a better measurement of the total charge seen on the readout pad
  - Reintegration charge is a sum of charge bins in the signal region

$$A = \sum_{i=0}^{N} q_i$$



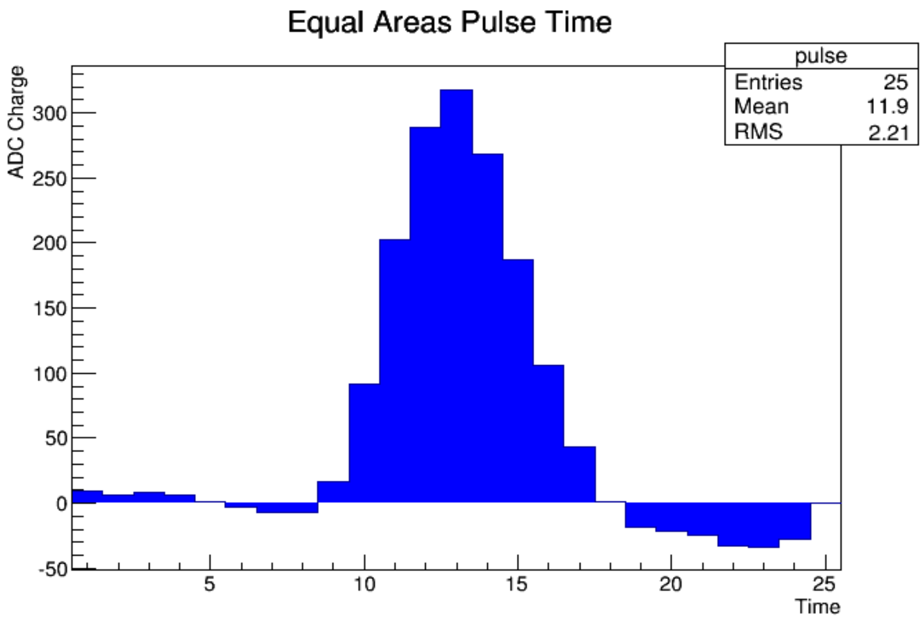
(1) Pulse Timing Determination

• To preform a track fit in the longitudinal plane we require a consistent method of determining the time of the charge signal

• **Simple method:** Time of peak time bin or, first bin above threshold

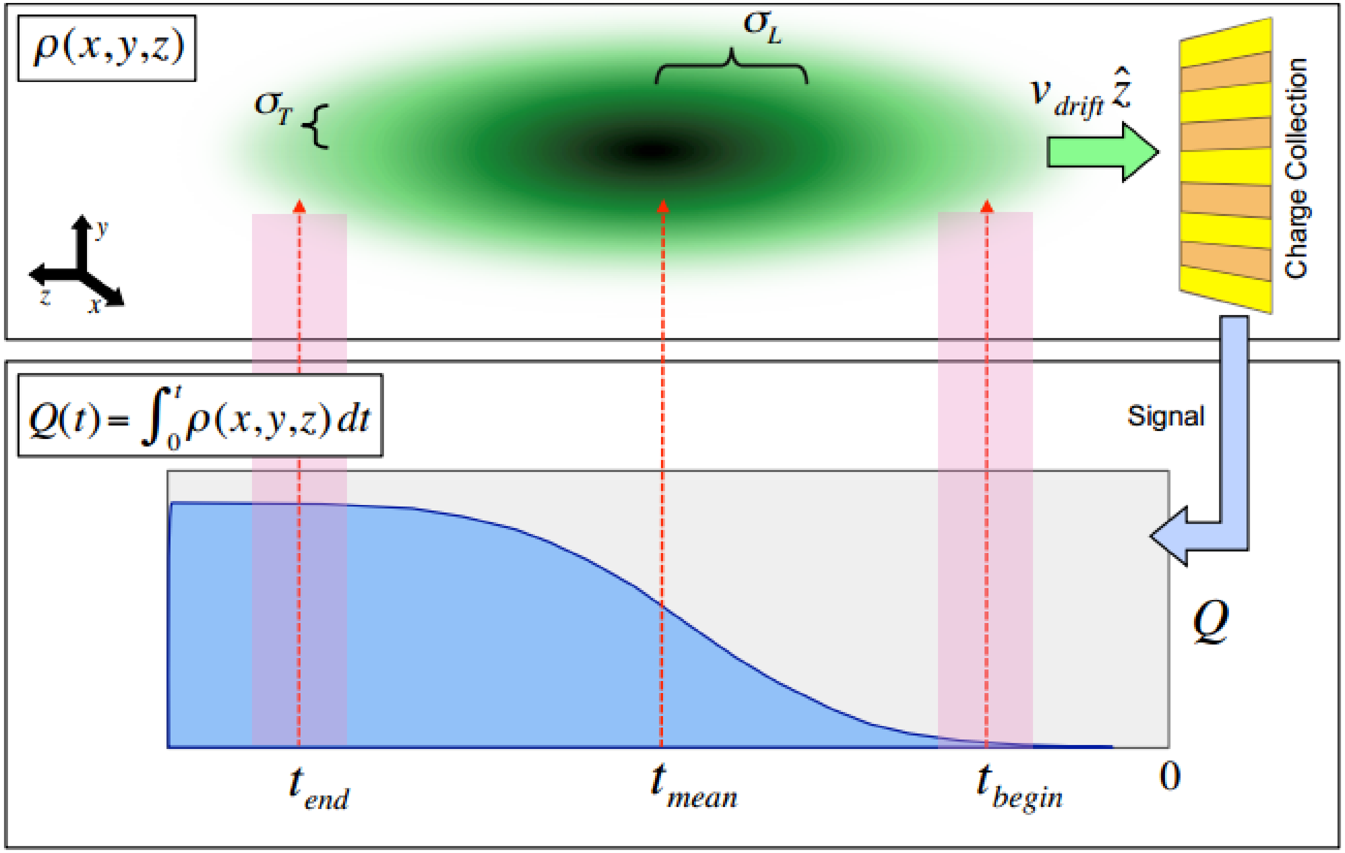
• **Better method:** Equal areas approach

➢ **Fast** and **Stable**



(1) Pulse Timing Determination

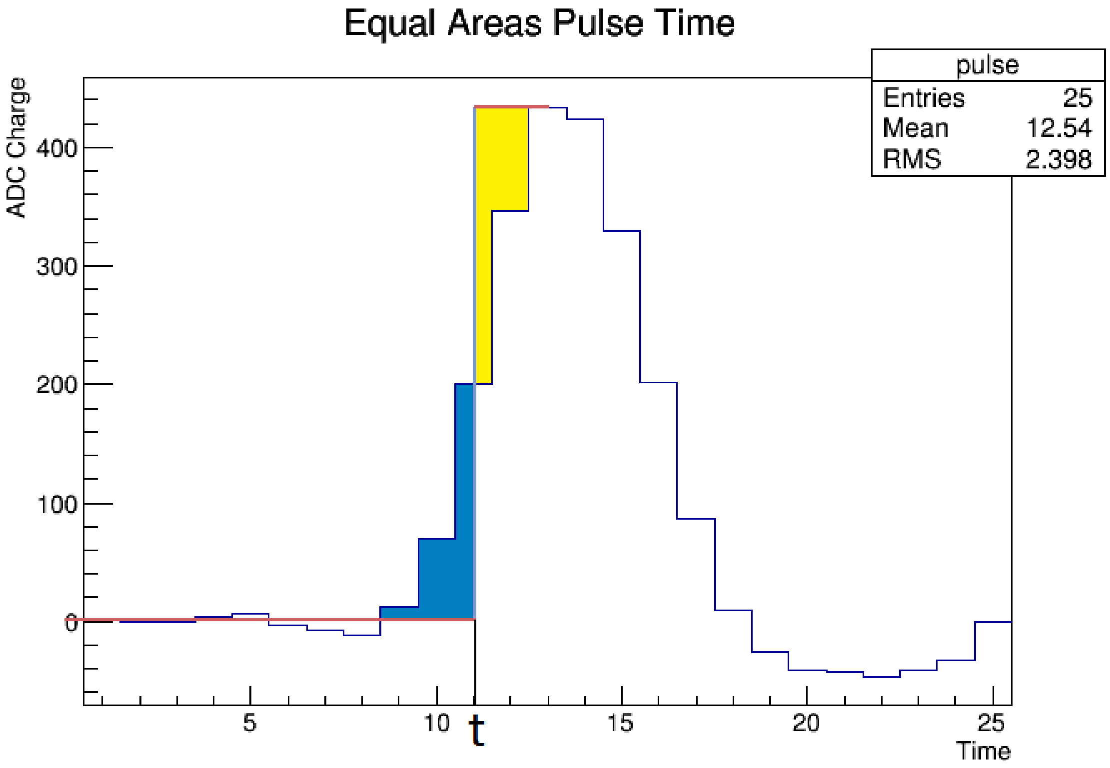
- The **charge** arrives as a *Gaussian* packet to the **detector**
- The **center** of the packet corresponds to the **inflection point** of charge pulse



(1) Equal Areas Timing Method

•Determine the **inflection point** by equating two areas:

1. Area **above the pulse** after the inflection point (Yellow)
2. Area **below the pulse** before the inflection point (Blue)

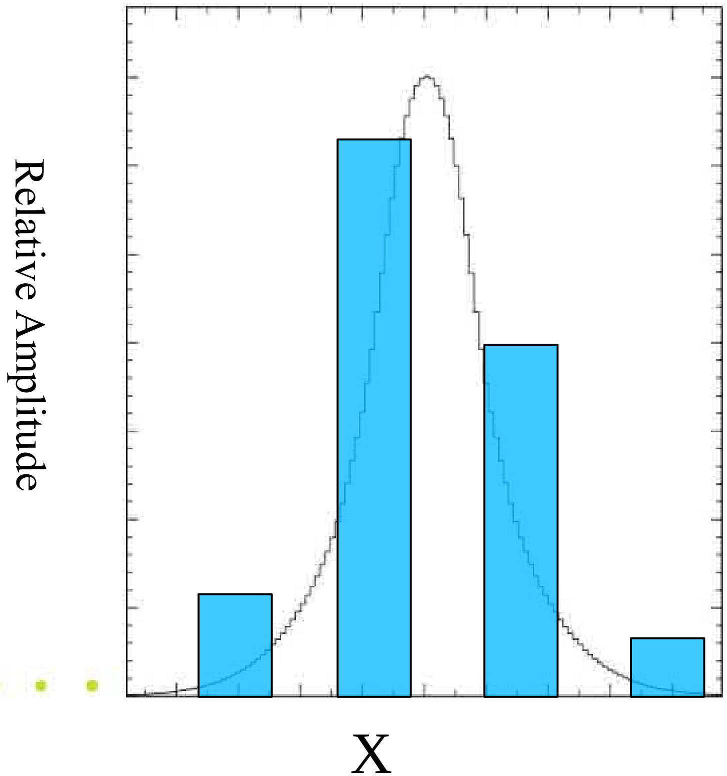


(2) Hit Finding

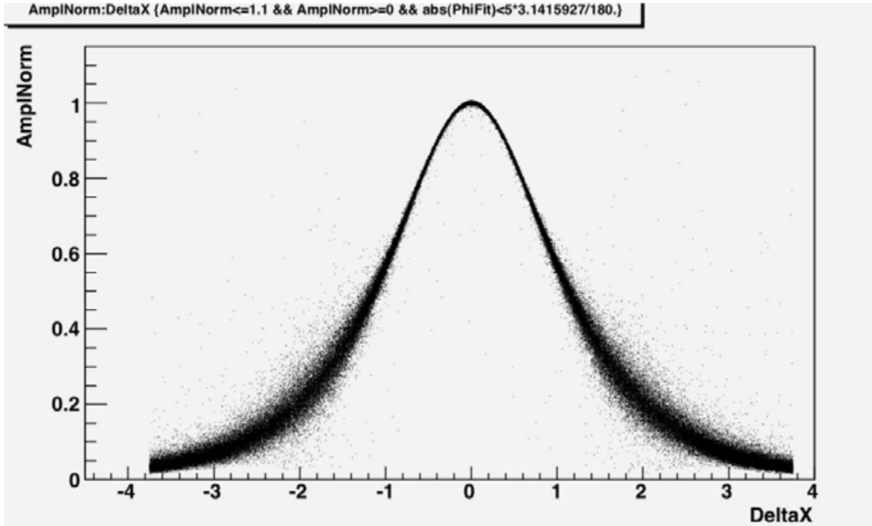
- **Hit Finding Procedure**:
  – First group adjacent pulses
  – Fit a Pad Response Function (**PRF**) to the pulse amplitudes

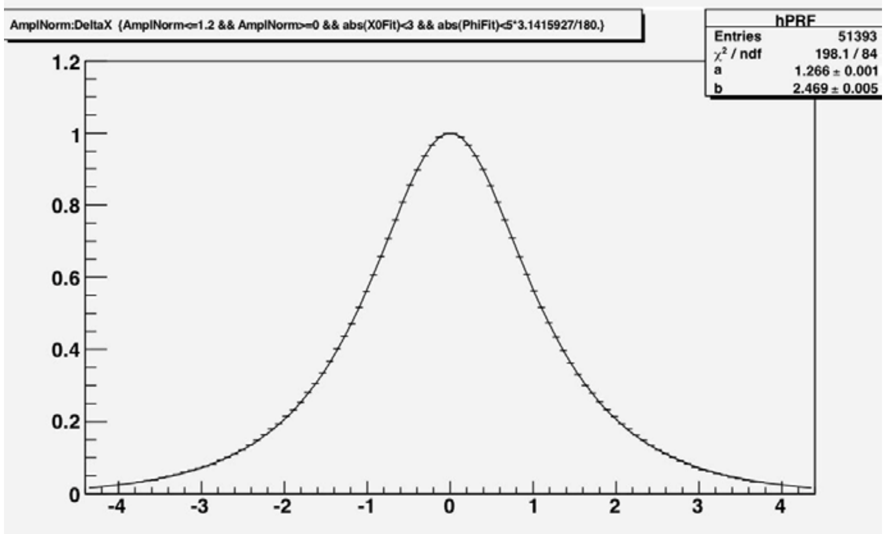
$$PRF = \frac{exp(-4ln(2)(1-r)x^2/w_G^2)}{1+4rx^2/w_L^2}$$

- **PRF** is a *Gaussian* (diffusion) times a *Lorentzian* (noise)
  – **3 Parameters**: Mixing (r), Gaus Width, Lorentz Width



(3) Track Fitting/PRF Calibration





- The PRF has 3 parameters which can vary from run to run so they need to be **calibrated from the data**
- A scatter plot of **Δx vs A** is fit with the PRF to determine the calibrated parameters

$$A_{norm} = A_{pad}/A_{peak}$$

$$\Delta x = x_{pad} - x_{track}$$

$$PRF = \frac{exp(-4ln(2)(1-r)x^2/w_G^2)}{1+4rx^2/w_L^2}$$

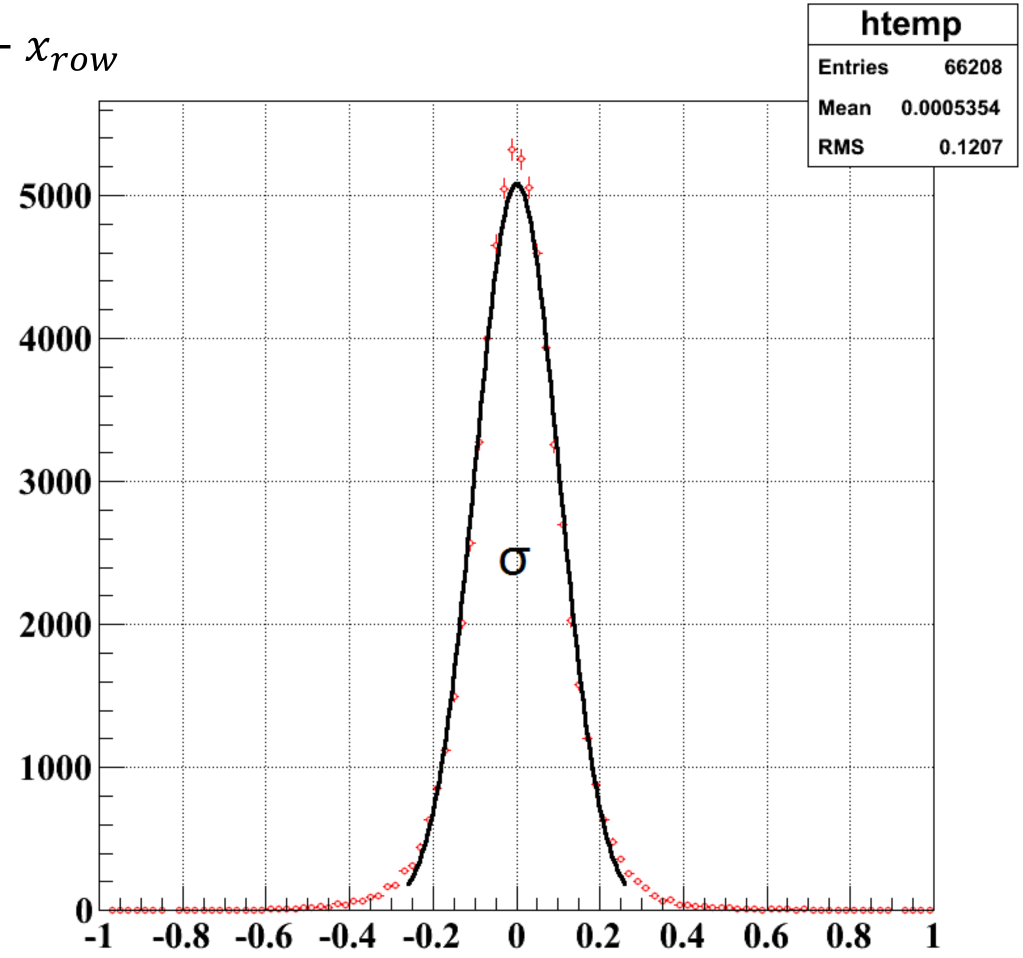
(4) Residuals and Resolution

- *Inclusive* Residual: $\Delta x^i = x^i_{track} - x_{row}$
- *Exclusive* Residual: $\Delta x^e = x^e_{track} - x_{row}$

➢ Fit for the **width** of the residual distribution

➢ Calculate resolution: $R = \sqrt{\sigma^e \sigma^i}$

- Repeat for **Longitudinal** (zy) and **Transverse** (xy) planes



Transverse Resolution Results

• Reintegration was implemented in new analysis software (Marlin-TPC)

• Two methods of pulse amplitude determination were compared:

– **Maximum amplitude**

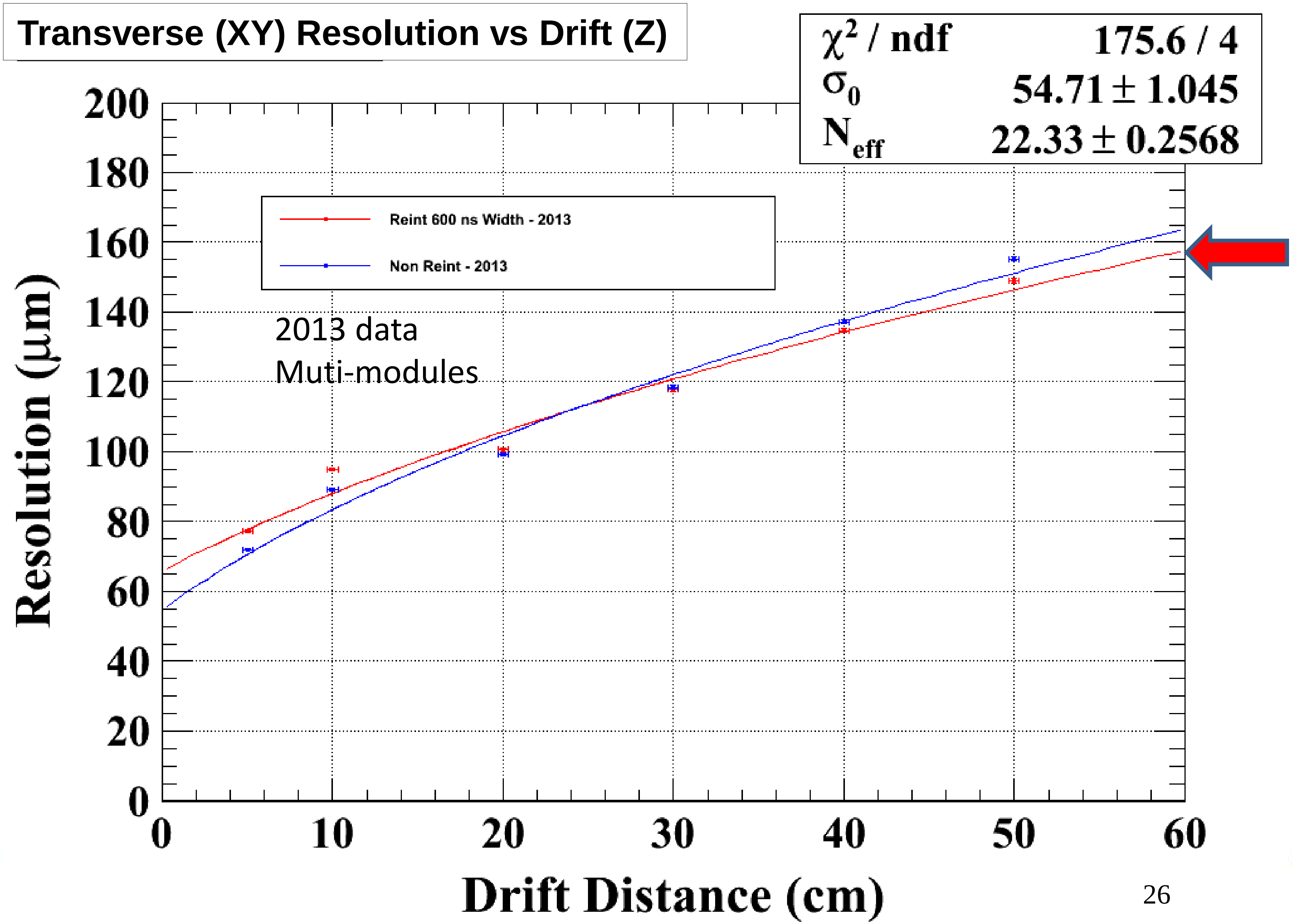
– **Reintegration**

• Resolution ***degrades*** with increasing drift distance because of charge ***diffusion***

• **Transverse diffusion** is suppressed in the TPC because of the **magnetic field**

$$\sigma(z) = \sqrt{\sigma_0^2 + \frac{D_{tr}^2 z}{N_{eff}}}$$

Maximum Amplitude vs Reintegration Resolution



Longitudinal Resolution Results

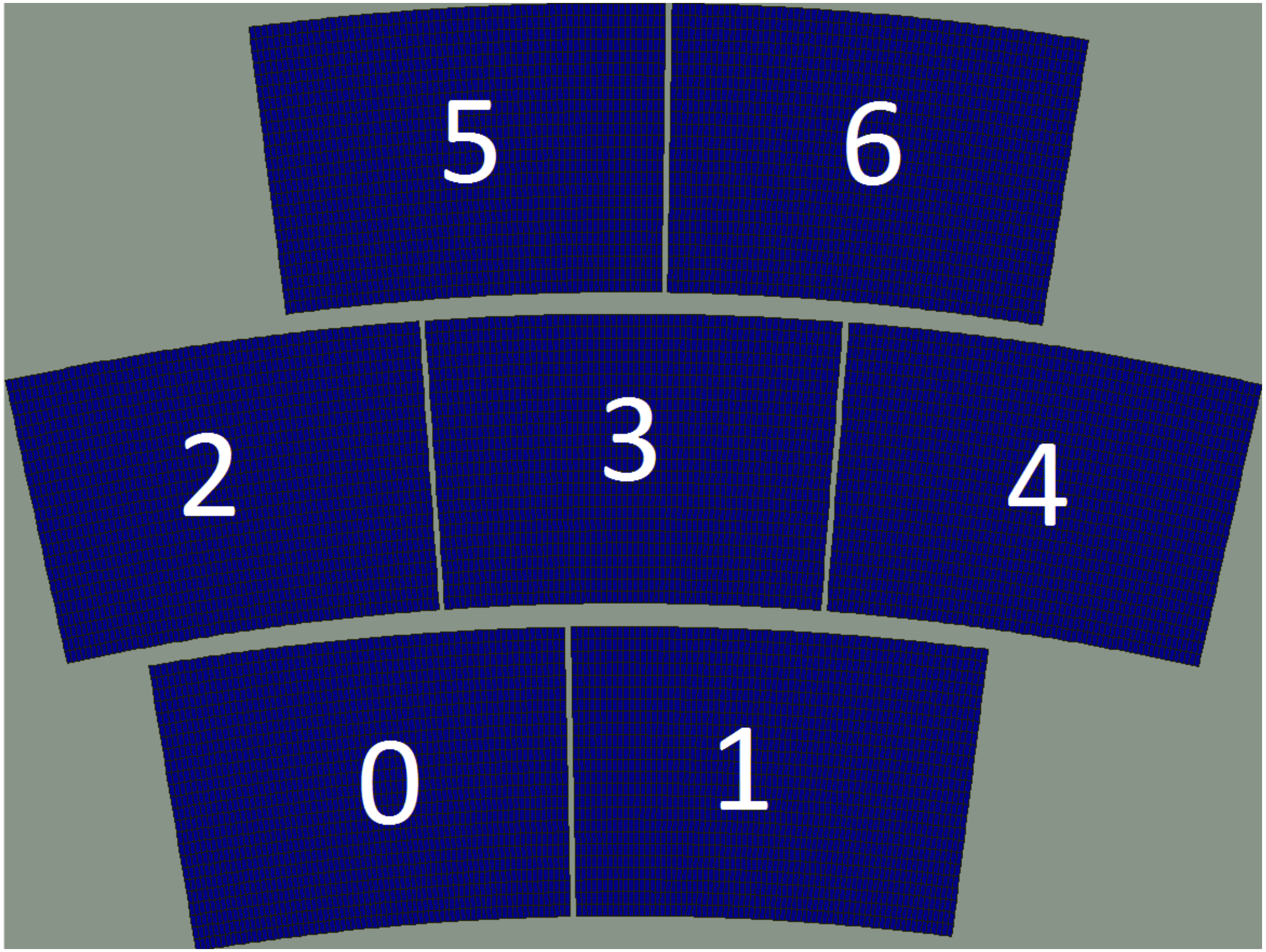
- Goal of longitudinal resolution study:
  - Create a simple linear track fit in the longitudinal plane
  - Determine resolution from simple fit
  - Compare to established method (Kalman filter)

- Longitudinal resolution also **increases** with drift distance **(z)** due to **diffusion** of the pulse

- The linear z fit gives a *clear benchmark* resolution measurement (check)

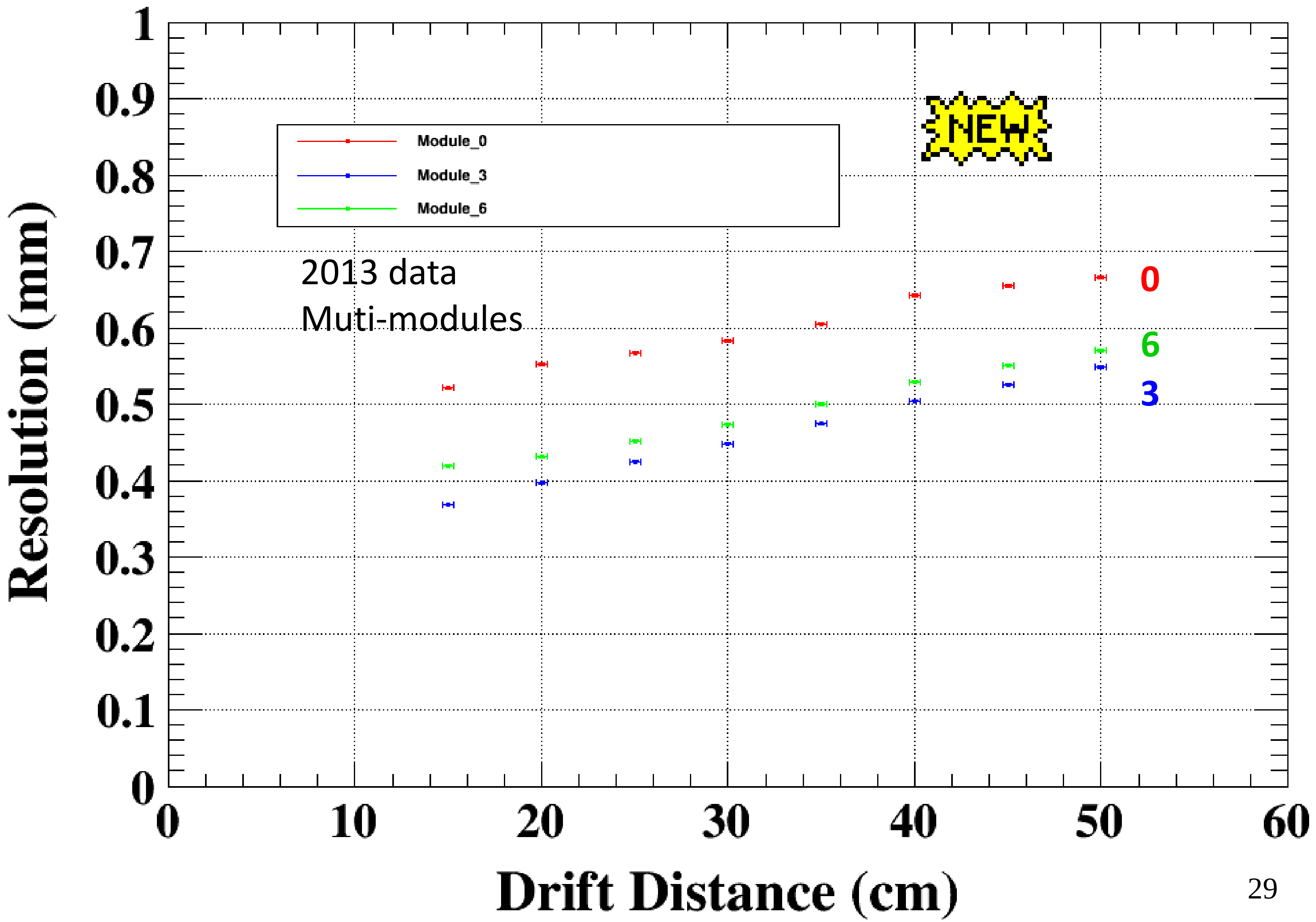
- More precise 3D track fits should produce **better resolution (e.g. Kalman algorithm)**

TPC Modules



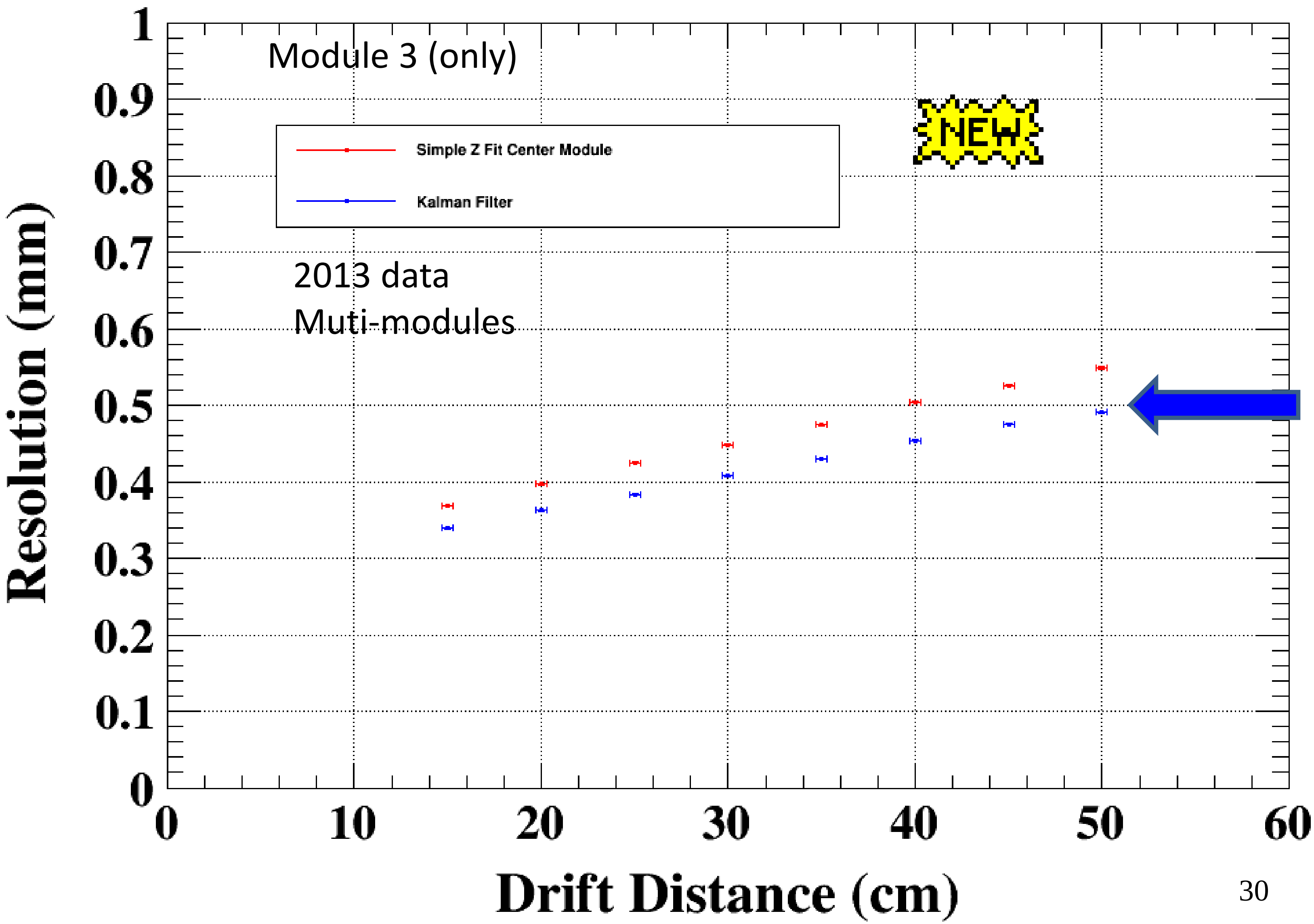
Simple Z fit Resolution

Longitudinal (Z) Resolution vs Drift (Z)



Simple Z fit vs. Kalman Filter

Longitudinal (Z) Resolution vs Drift (Z)



Conclusions

- Confirm that the **ILC TPC** resolution goals are achievable

  - **Transverse** (xy) resolution of 100 microns over 2m of drift, **60 microns** at Z=0 [extrapolated to 3.5 T]
  - **Longitudinal** (z) resolution of 1400 microns over 2m of drift, **400 microns** at Z=0 [extrapolated to 3.5 T]

- Pulse reintegration produces slight resolution improvements at long (>40cm) drift distance

– the improvement should be significant at **2m**

- The longitudinal resolutions slightly better with the Kalman filter as expected (compare to simple straight-line)