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Hit finding and pad response function for the LCTPC using resistive Micromegas

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CEA Saclay

On behalf of the LCTPC collaboration

A. Bellerive – ECFA LC April 27, 2013

Outline

- Intro: **LCTPC Collaboration and MPGD**
- Charge dispersion and Signal Pulse
  - **Electronic response**
  - **Definition of amplitude and time (A_i,t_i) for a pad**
  - **Conceptual Pad Response Function (PRF)**
- Determination of PRF parameters (calibration)
  - **Parameterization of the PRF**
- Results
  - **Field distortions**
  - **Transverse resolution**
- Summary

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:

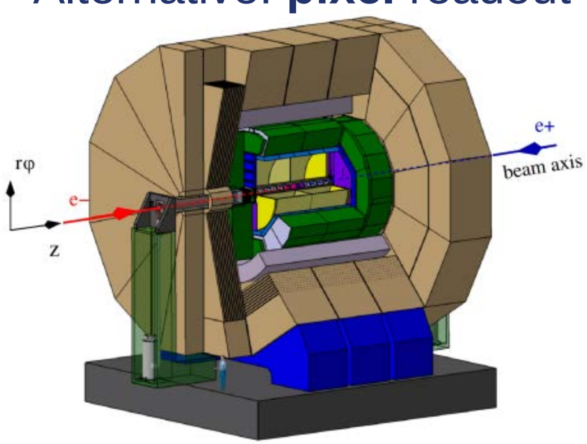
– **GEM:** 1.2×5.8 mm² pads

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

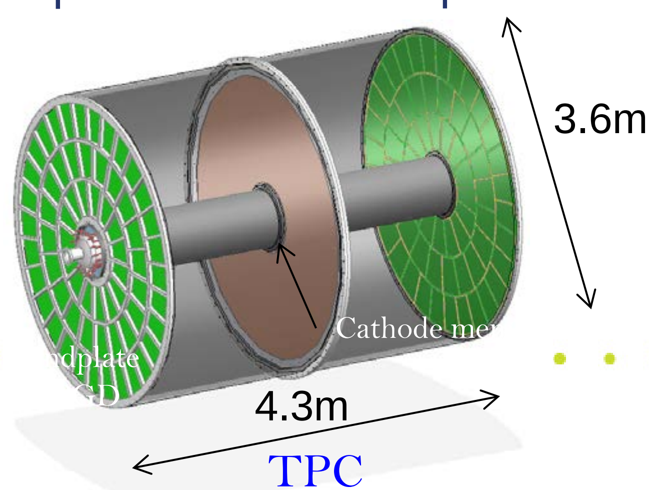
- Alternative: **pixel** readout with pixel size ~55×55 μm²

TPC Requirements :

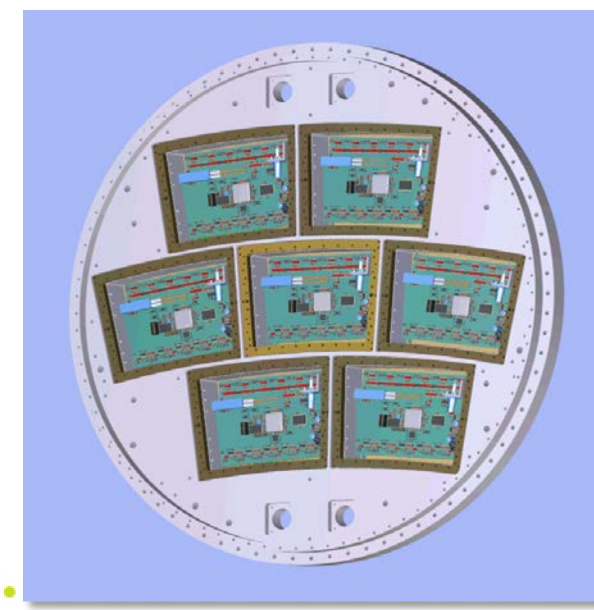
- **Momentum resolution**: $\delta(1/p_T) < 9\times10^{-5}$ GeV^{-1}
- **Single hit resolution 3.5T**: $\sigma(r\phi) < 100$ μm, $\sigma(z) < 500$ μm
- **Tracking eff.** for $p_T > 1$ GeV: 97%
- **dE/dx resolution** ~5%



ILD



TPC



Large Prototype

Micro Pattern Gas Detector (MPGD)

Technology choice for TPC readout: Micro Pattern Gas Detector

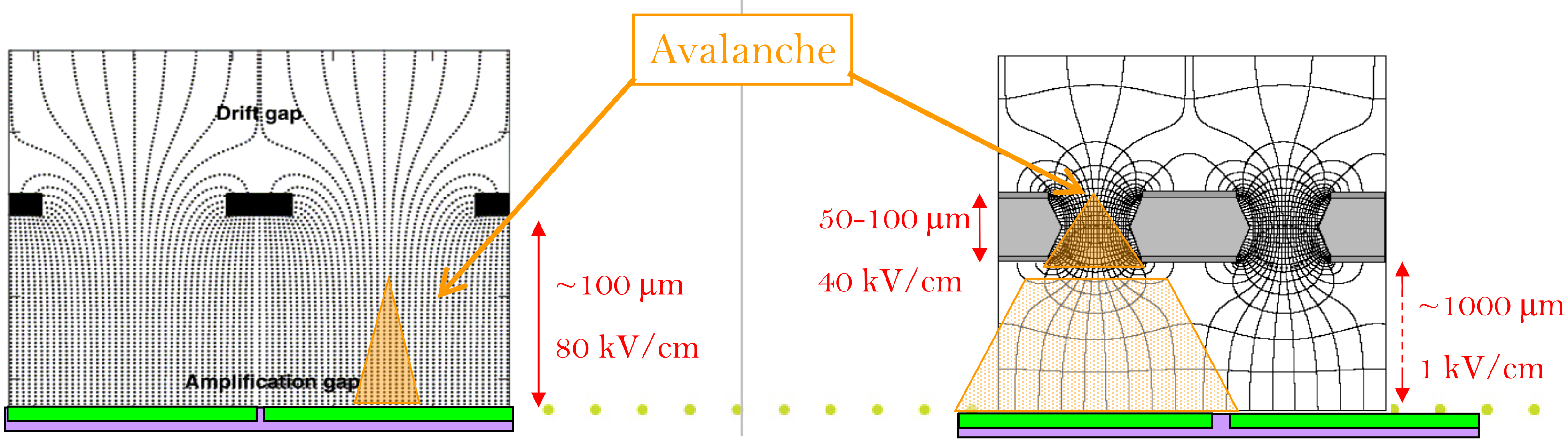
- more robust than wires
- fast signal & high gain
- better ageing properties
- no E×B effect
- low ion backdrift
- easier to manufacture

Micromegas (MM)

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

GEM

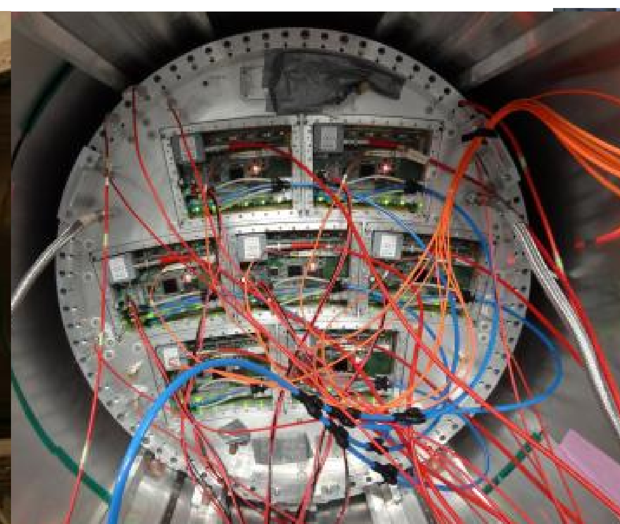
- Gas Electron Multiplier
- 2 copper foils separated by kapton
- multiplication takes place in holes, with 2-3 layers needed



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

Large Prototype TPC

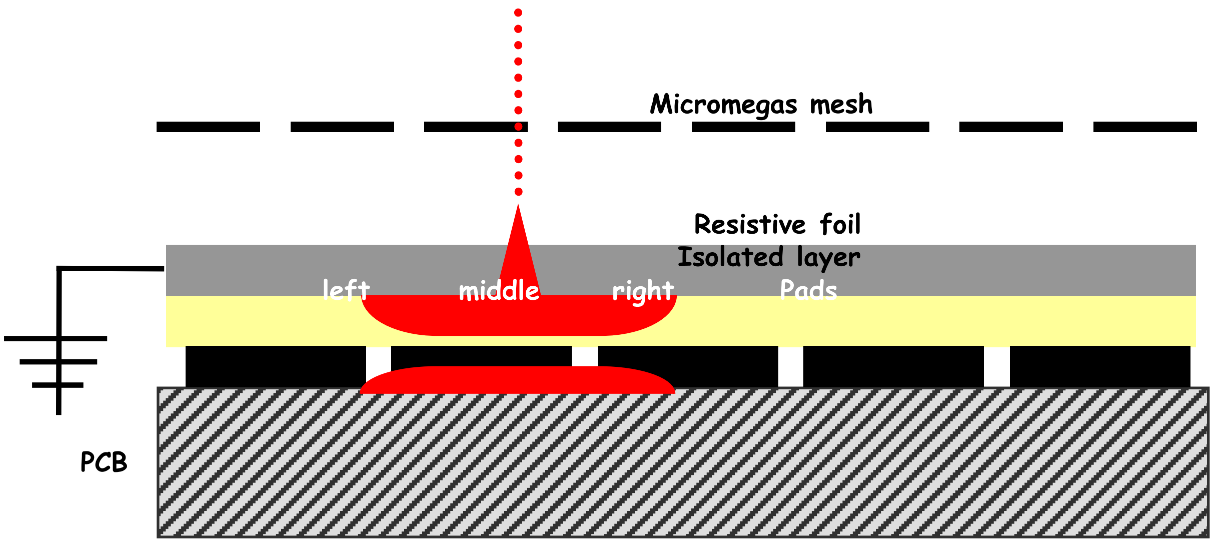


Endplate + 7 Micromegas modules

1T PCMagnet

Charge Dispersion

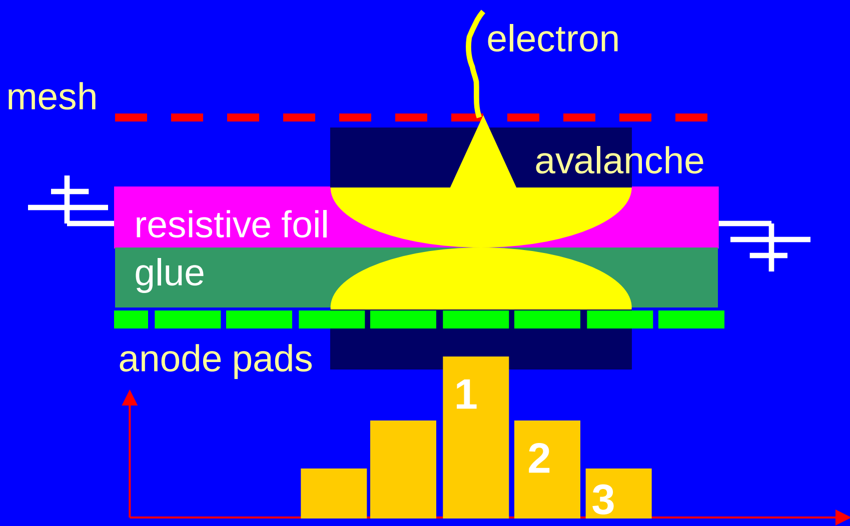
Resistive Anode



Charge dispersion

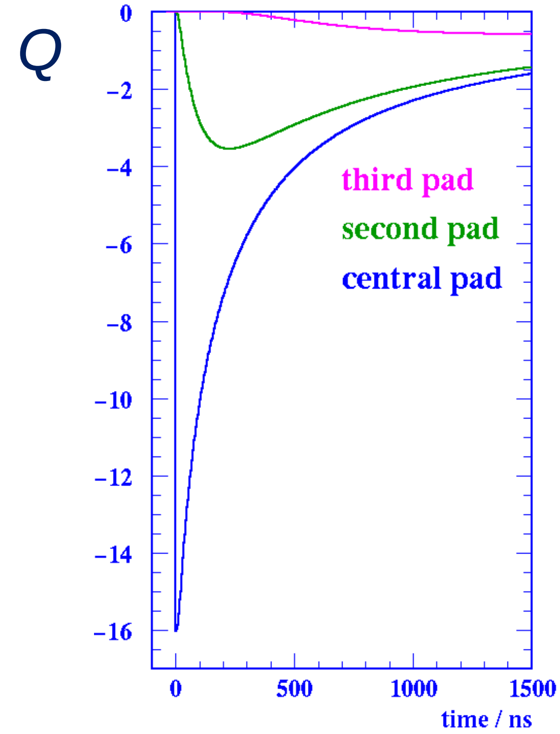
- A high resistivity film bonded to a readout plane with an insulating spacer
- 2D continuous RC network defined by material properties and geometry.
- point charge at r = 0 & t = 0 disperses with time.

Micromegas + resistive anode



$$\frac{\partial \rho}{\partial t} = \frac{1}{RC}\left[\frac{\partial^2 \rho}{\partial r^2} + \frac{1}{r}\frac{\partial \rho}{\partial r}\right]$$

$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$



M.S. Dixit et.al., NIM A518, 721 (2004)
M.S. Dixit & A. Rankin, NIM A566, 281 (2006)

Pulse shape origin

Transverse diffusion

$$T(x) = \frac{1}{\sigma_x \sqrt{2\pi}} \exp\left(\frac{-x^2}{2\sigma_x^2}\right)$$

Longitudinal diffusion

$$L(t) = \frac{1}{\sigma_t \sqrt{2\pi}} \exp\left(\frac{-t^2}{2\sigma_t^2}\right)$$

Induction gap

$$R(t) = \frac{t}{T_{rise}} \qquad 0 < t < T_{rise}$$
$$= 1 \qquad t > T_{rise}$$
$$= 0 \qquad t < 0$$

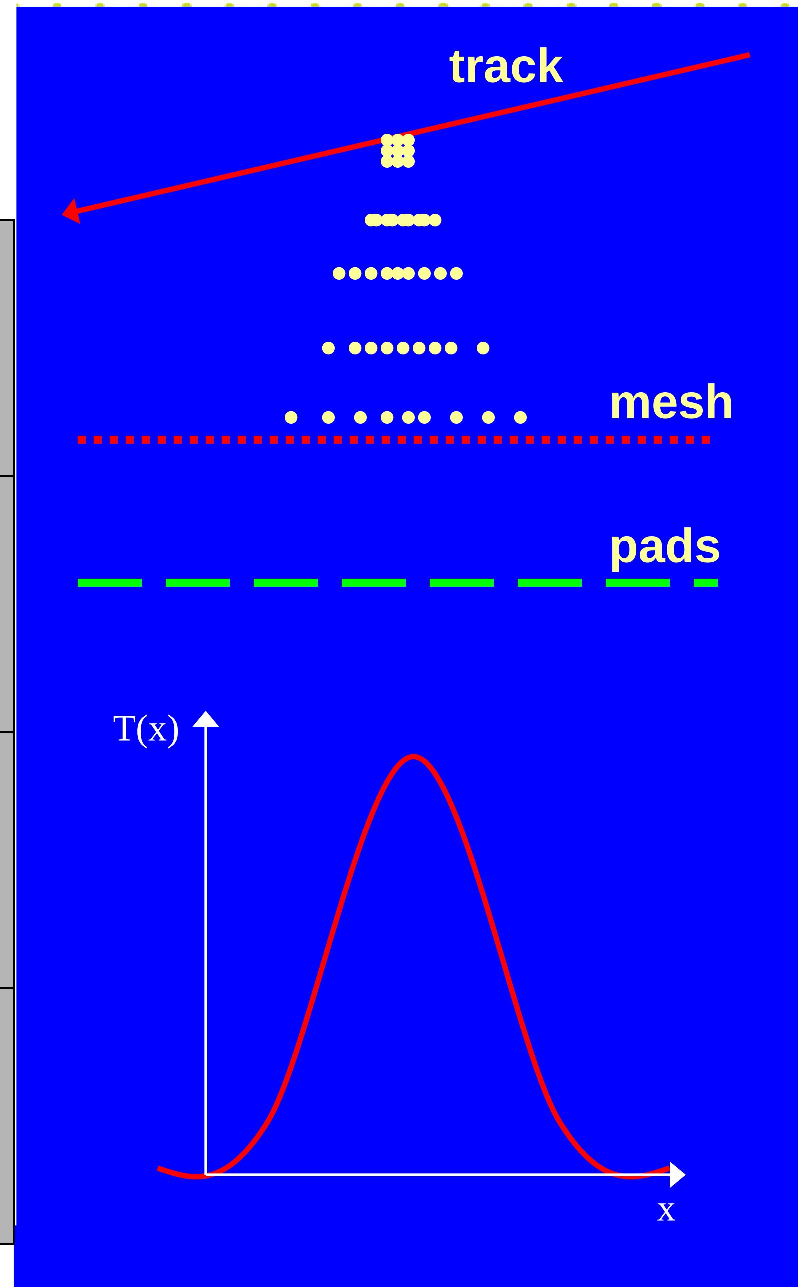
Preamplifier Response

$$H(t) = \exp\left(-\frac{t}{t_f}\right)\left(1 - \exp\left(\frac{t}{t_r}\right)\right) \qquad t > 0$$
$$= 0 \qquad t < 0$$

Resistive foil + glue

$$\rho(x,y,t) = \left(\frac{1}{\sigma_t \sqrt{\pi t h}}\right)^2 \exp\left(\frac{-(x^2+y^2)}{4th}\right)$$

$$h = 1/RC$$



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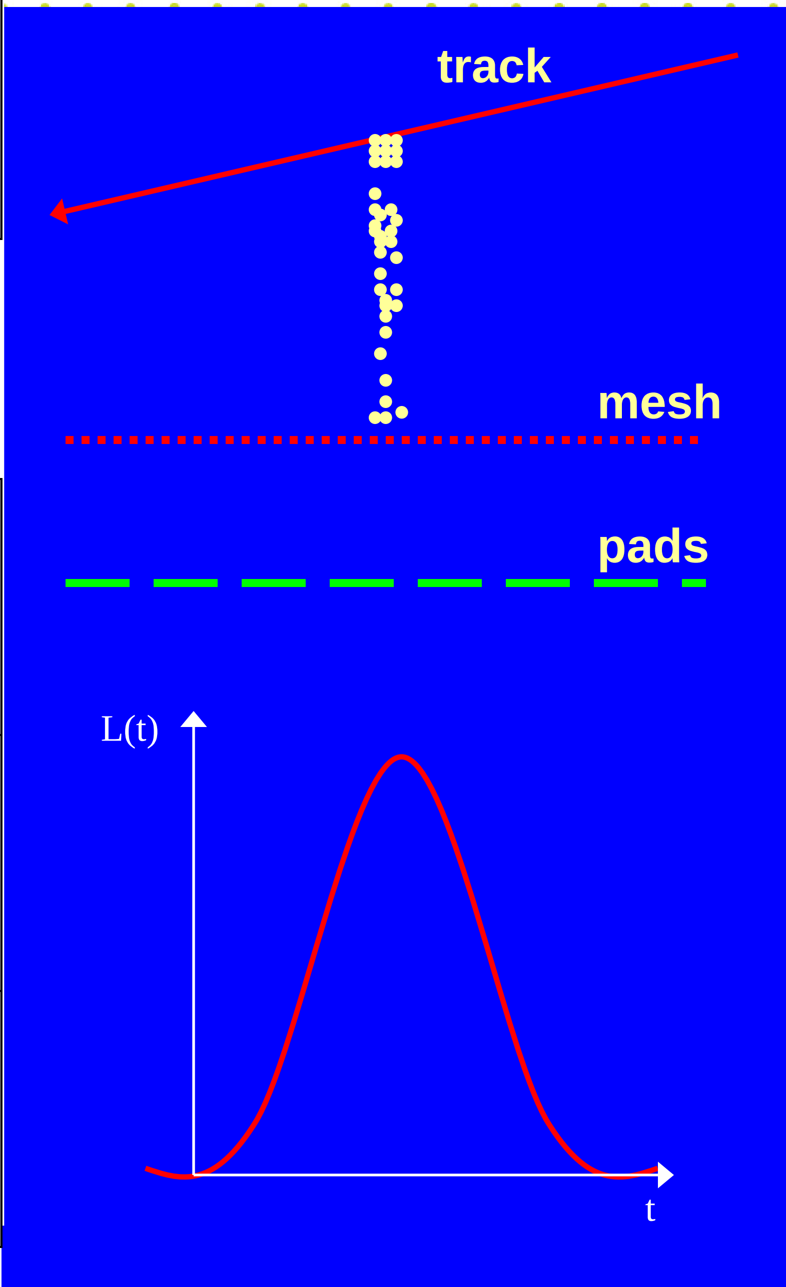

Pulse shape origin

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Longitudinal diffusion

$$L(t) = \frac{1}{\sigma_t\sqrt{2\pi}}\exp(\frac{-t^2}{2\sigma_t^2})$$

Induction gap

$$R(t) = \frac{t}{T_{rise}} \quad 0 < t < T_{rise}$$
$$= 1 \quad t > T_{rise}$$
$$= 0 \quad t < 0$$

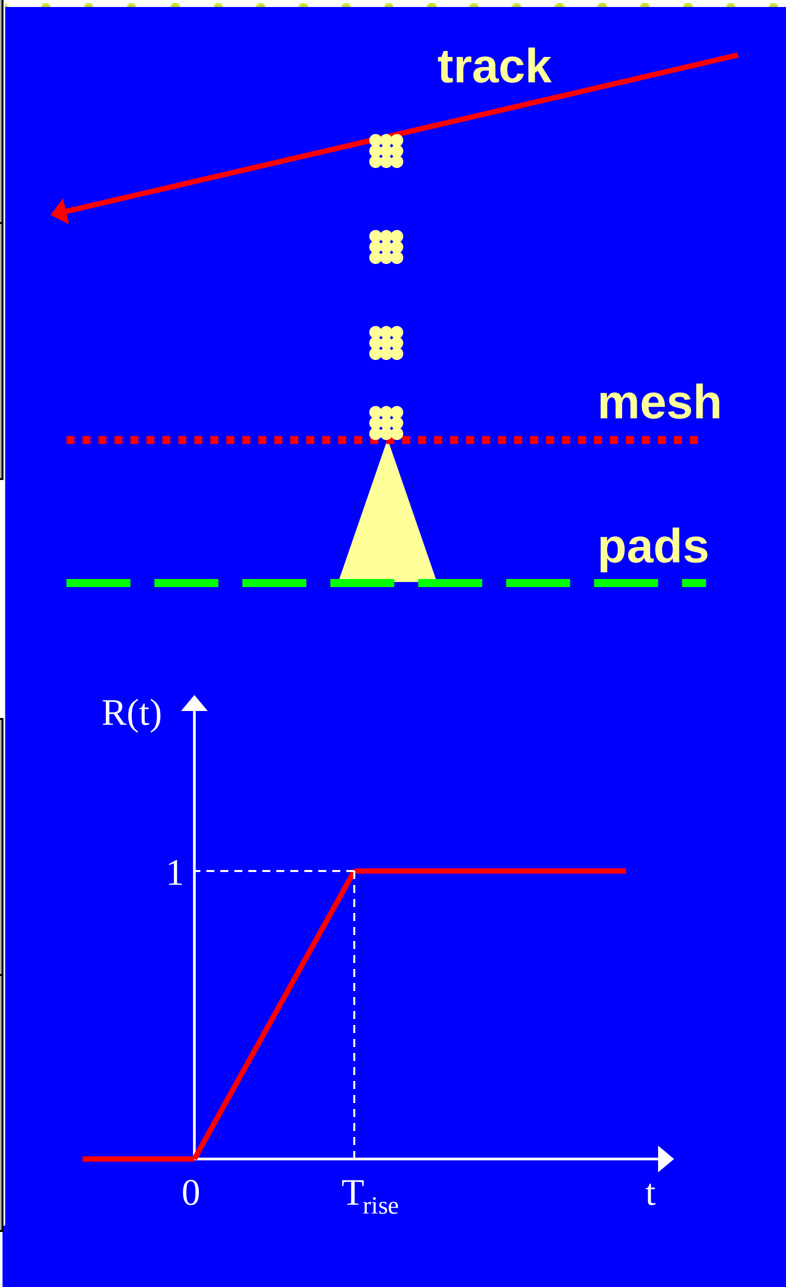
Preamplifier Response

$$A(t) = \exp\left(-\frac{t}{t_f}\right)\left(1-\exp\left(\frac{t}{t_r}\right)\right) \quad t > 0$$
$$= 0 \quad t < 0$$

Resistive foil + glue

$$\rho(x,y,t) = \left(\frac{1}{\sigma_t\sqrt{\pi t h}}\right)^2 \exp\left(\frac{-(x^2+y^2)}{4th}\right)$$

$$h = 1/RC$$



Pulse shape origin

Transverse diffusion

$$T(x) = \frac{1}{\sigma_x \sqrt{2\pi}} \exp\left(\frac{-x^2}{2\sigma_x^2}\right)$$

Longitudinal diffusion

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Induction gap

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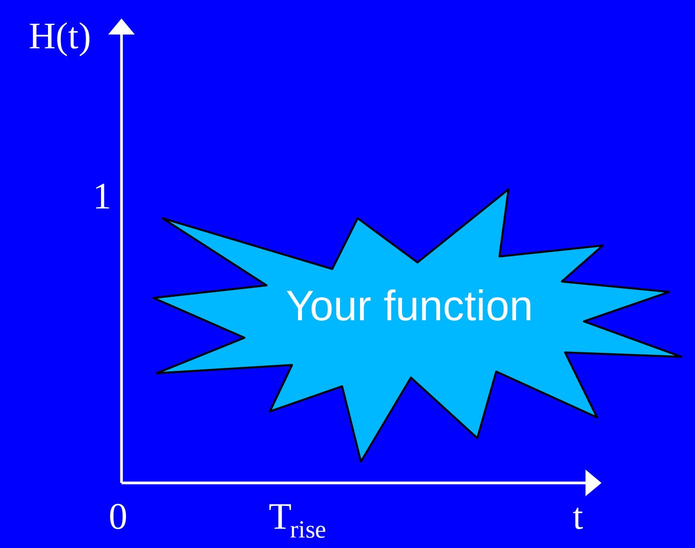


Pulse shape origin

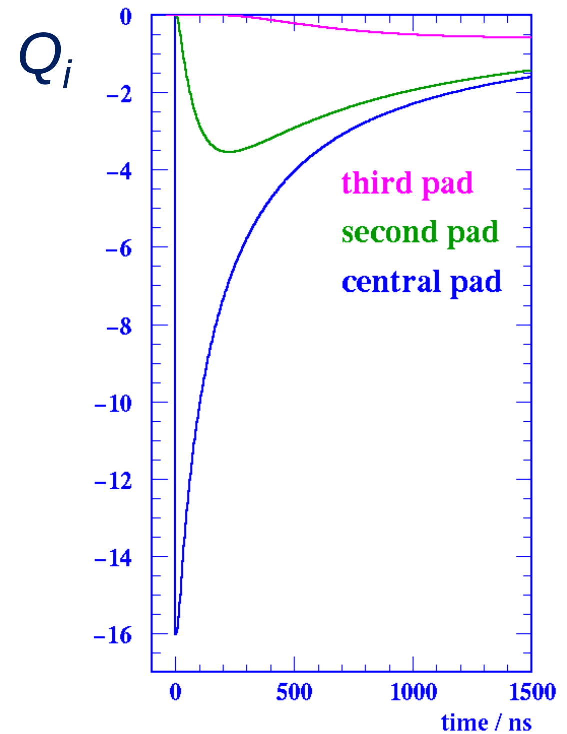
Transverse diffusion	$T(x) = \frac{1}{\sigma_x\sqrt{2\pi}}\exp(\frac{-x^2}{2\sigma_x^2})$
Longitudinal diffusion	$L(t) = \frac{1}{\sigma_t\sqrt{2\pi}}\exp(\frac{-t^2}{2\sigma_t^2})$
Induction gap	$R(t) = \frac{t}{T_{rise}} \quad 0 < t < T_{rise}$ $= 1 \quad t > T_{rise}$ $= 0 \quad t < 0$
Preamplifier Response	$H(t) = \exp\left(-\frac{t}{t_f}\right)\left(1-\exp\left(\frac{t}{t_r}\right)\right) \quad t > 0$ $= 0 \quad t < 0$

Resistive foil + glue $\rho(x,y,t) = \left(\frac{1}{\sigma_t\sqrt{\pi t h}}\right)^2 \exp\left(\frac{-(x^2+y^2)}{4th}\right)$

$h = 1/RC$

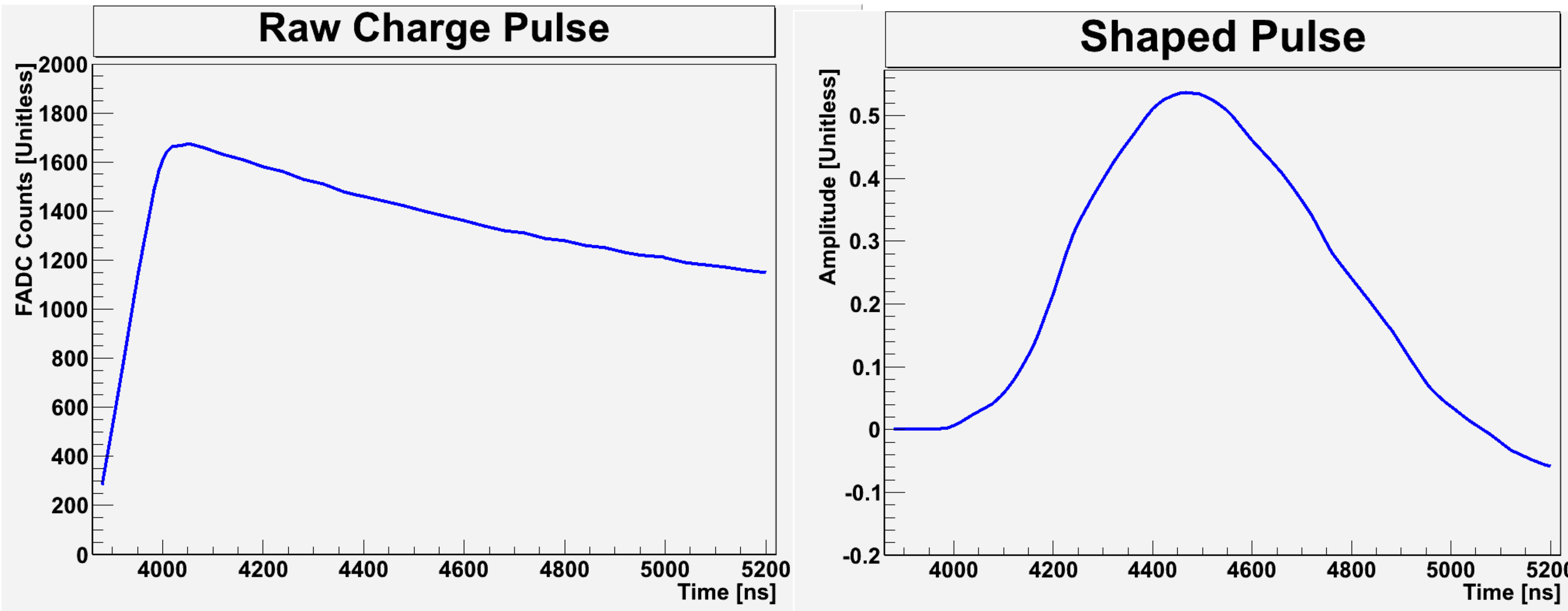
$$Q_i = \int \rho_i(r)\,dr$$

Stand alone simulation



M.S. Dixit & A. Rankin, NIM A566, 281 (2006)

Raw Charge Shape versus Shaped Pulse



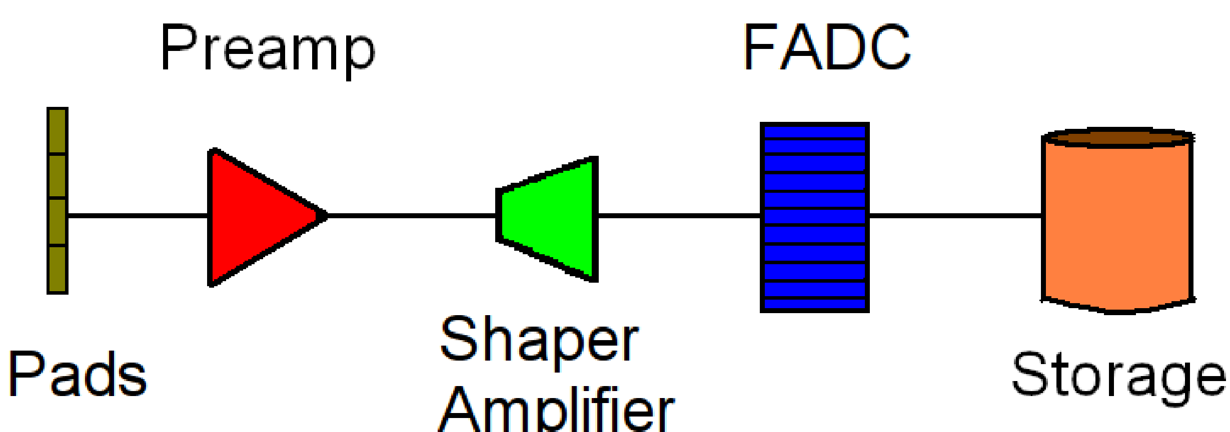
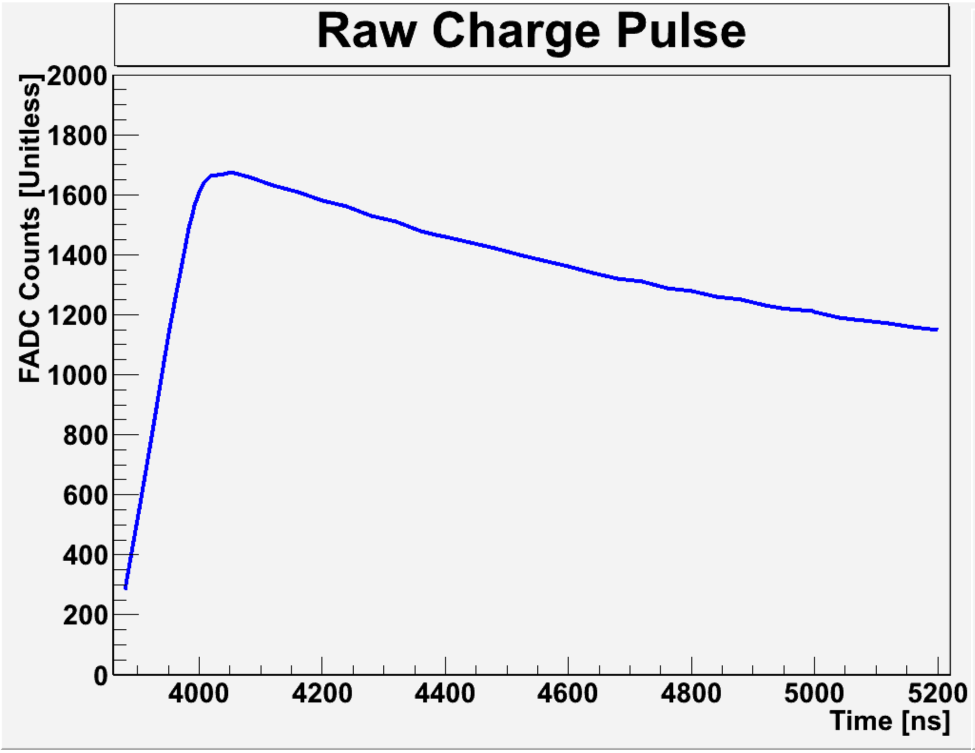
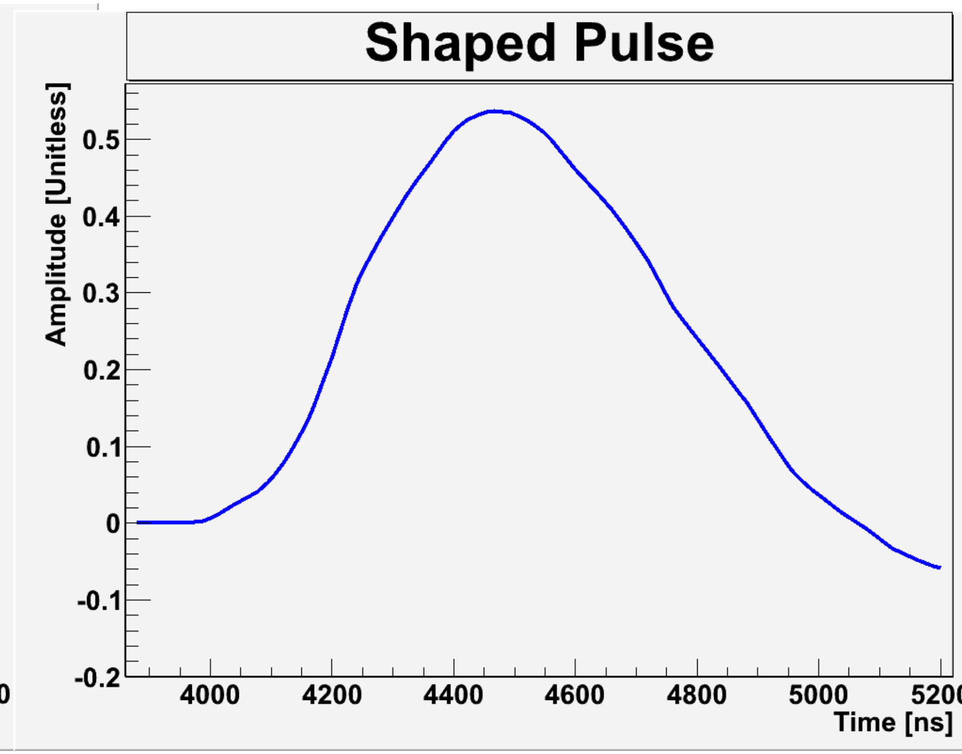


Figure: N. Shiell

Raw Charge Shape versus Shaped Pulse

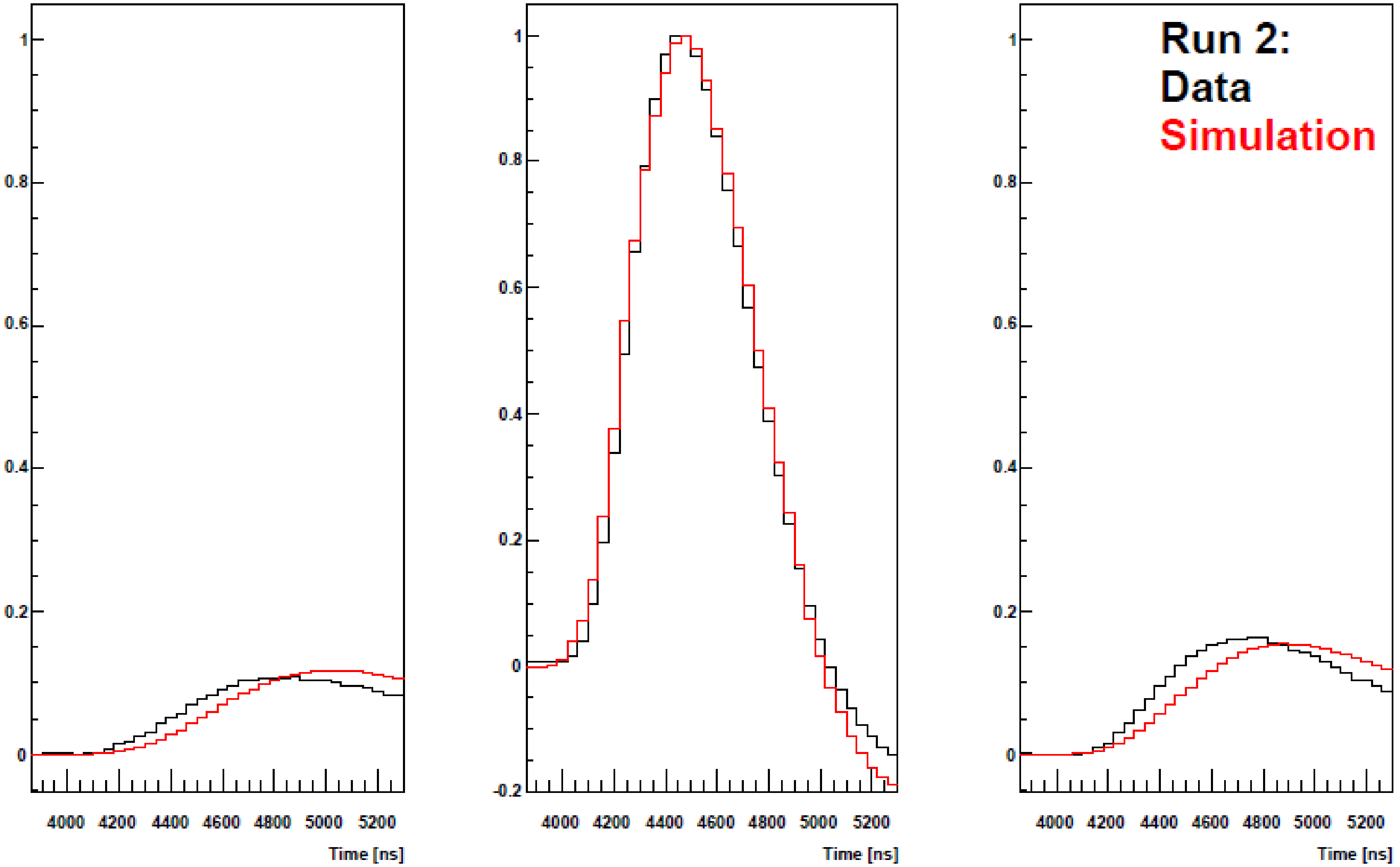




$$H(t) = A_0 \left(\frac{t}{\tau}\right)^3 \sin\left(\frac{t}{b\tau}\right) \exp\left(-\frac{t}{\tau}\right)$$

from Eric Delagnes etal at Saclay

Stand-Alone Calculation



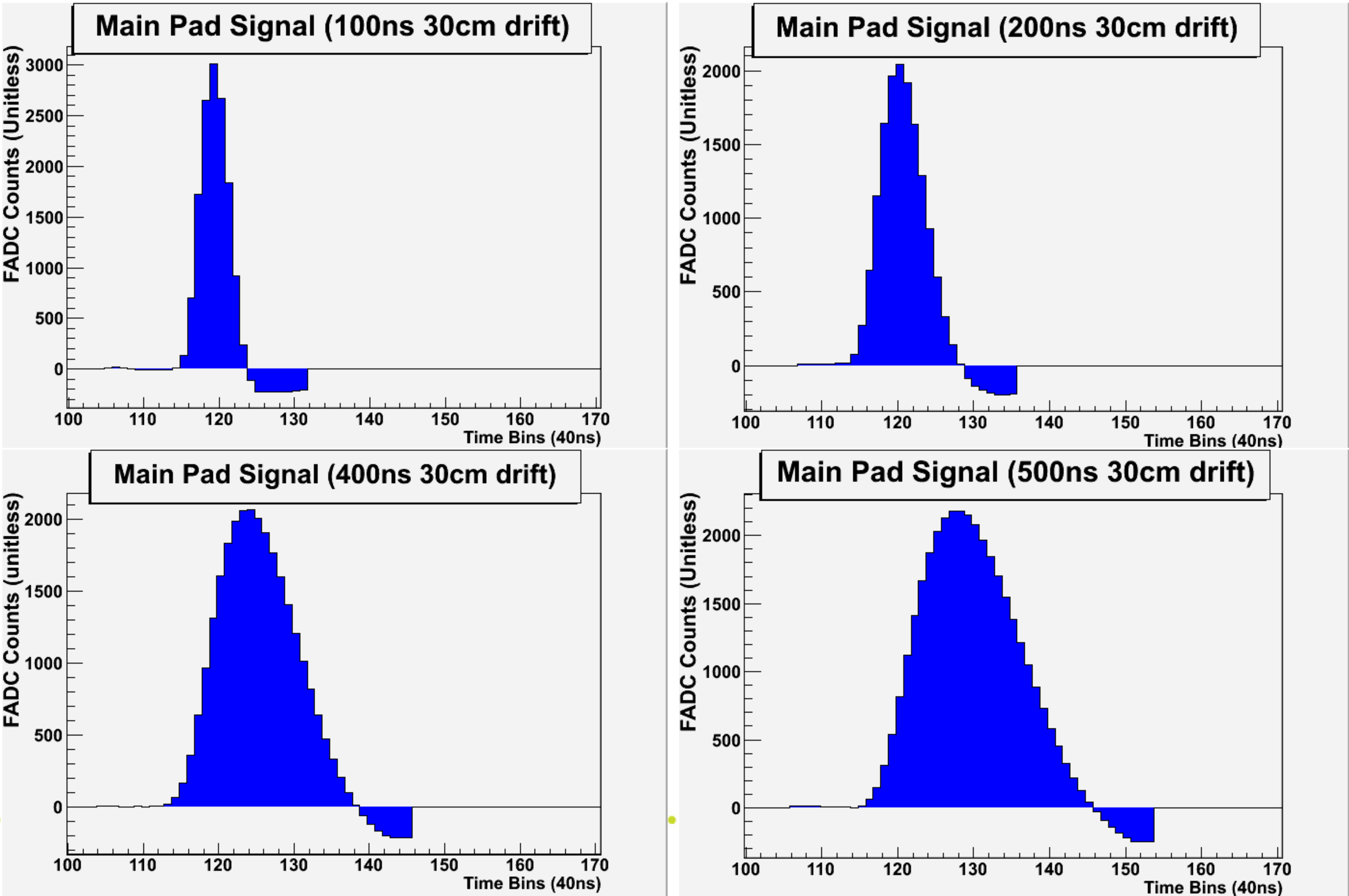
CRUCIAL TO CHARACTERIZE DETECTOR PARAMETERS

Stand-Alone Calculation

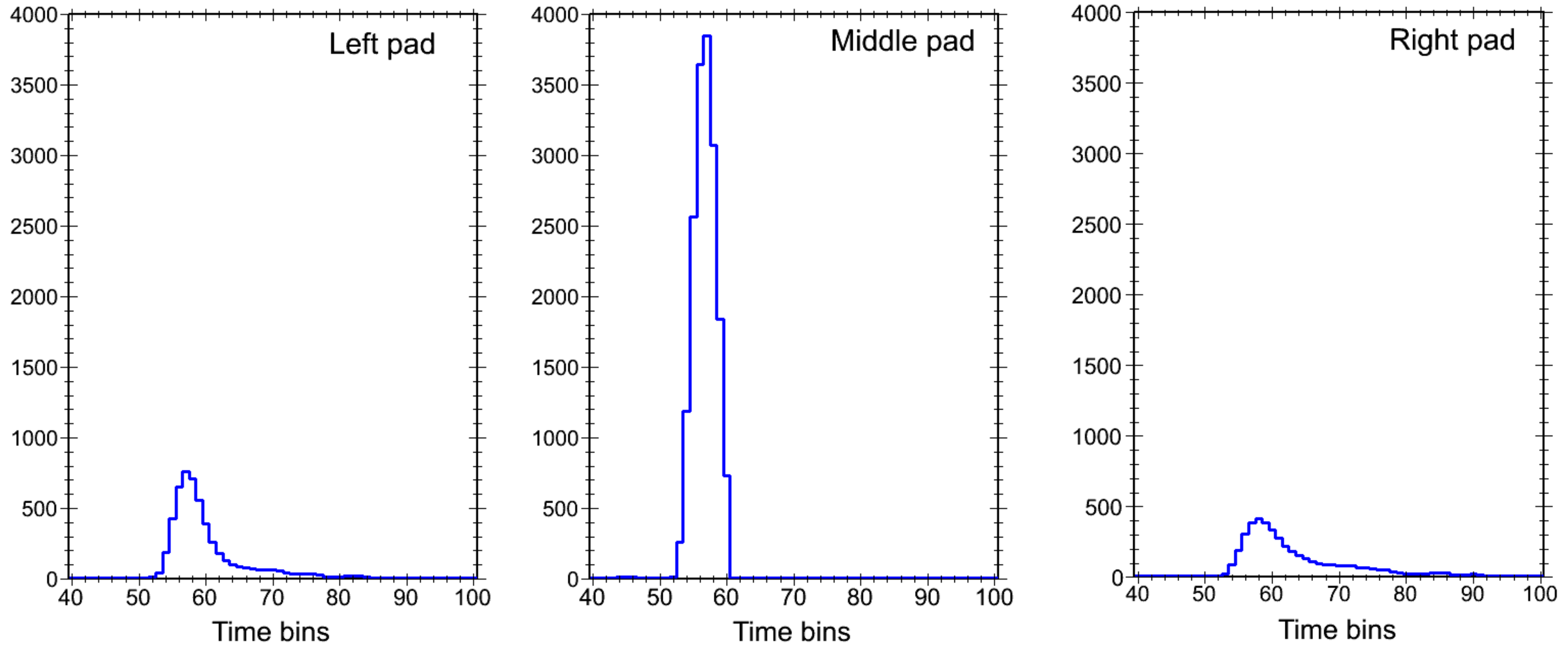
Parameter	Initial value	Final value
Drift speed	76.98 um/ns	fixed
Transverse diffusion	95.4 um/root(cm)	fixed
Longitudinal diffusion	231.289 um/root(cm)	fixed
Resistivity	2.9 MOhm/sq	fixed
Glue thickness	75 um	fixed
Dielectric constant	**4.5**	**2.66**
Induction time	**120 ns**	**166 ns**
b (shaper)	**3.7**	**3.42**
τ (shaper)	**151 ns**	**151 ns**
Pad angular width	0.001984 rad	fixed
Pad height	6.84 cm	fixed
Lower radius of bottom row	1.522457785 m	fixed
X_0 track	event dependent	
ϕ track	event dependent	
Drift distance	30 cm	30 cm

NEED INPUT OF DESIGN ENGINEER AND ELECTONIC EXPERT

Shaped Pulse (for different shaping time)



Pad Amplitude

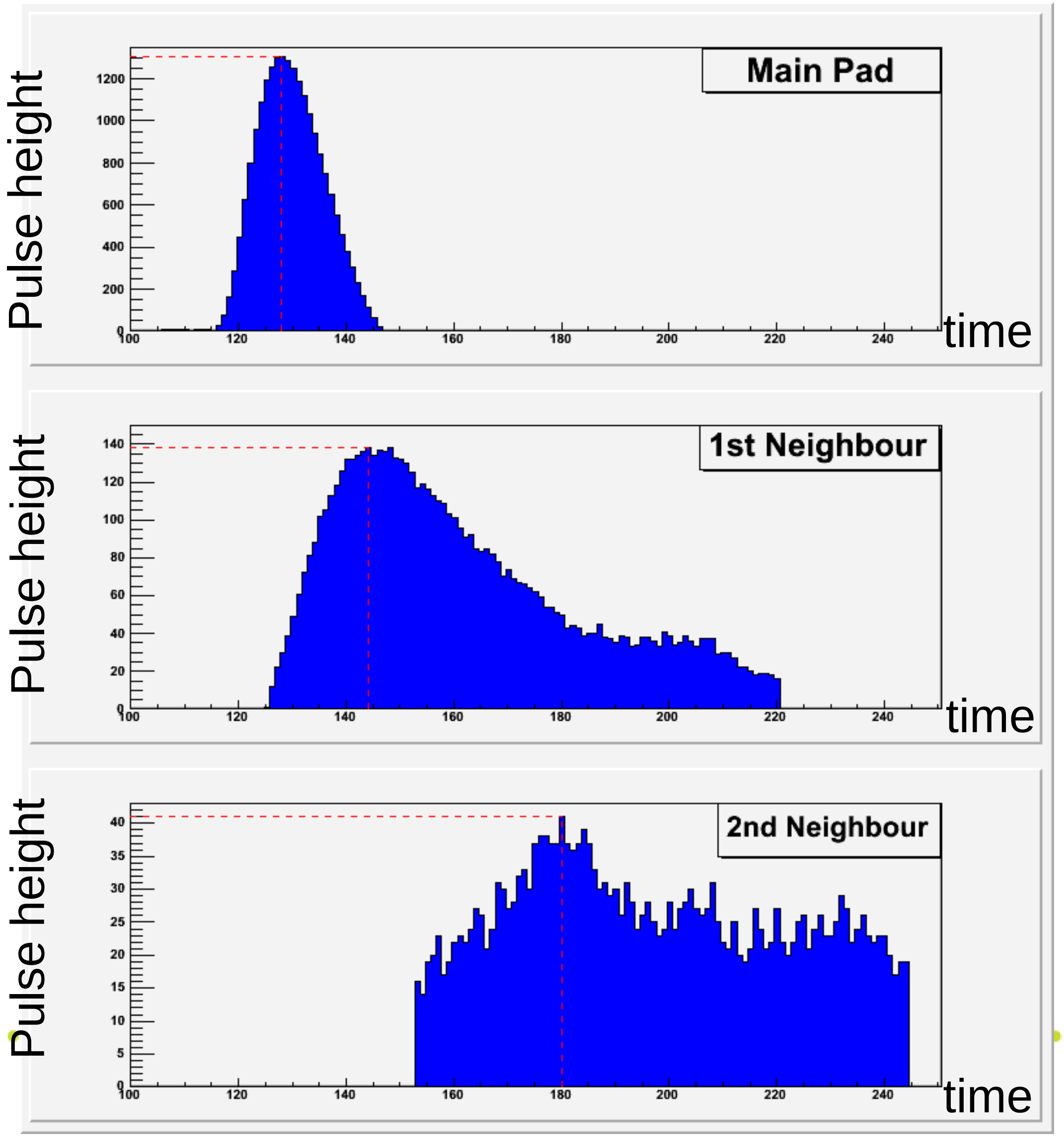


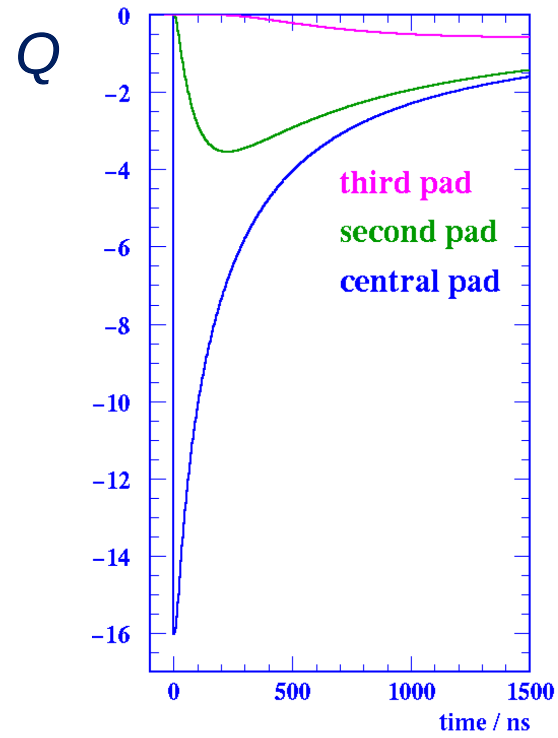
Pad Amplitude

1) Use the maximum as the amplitude
Single Point Maximum(SPM)

$$A_i = \text{max pulse height } P(i)$$

method used here



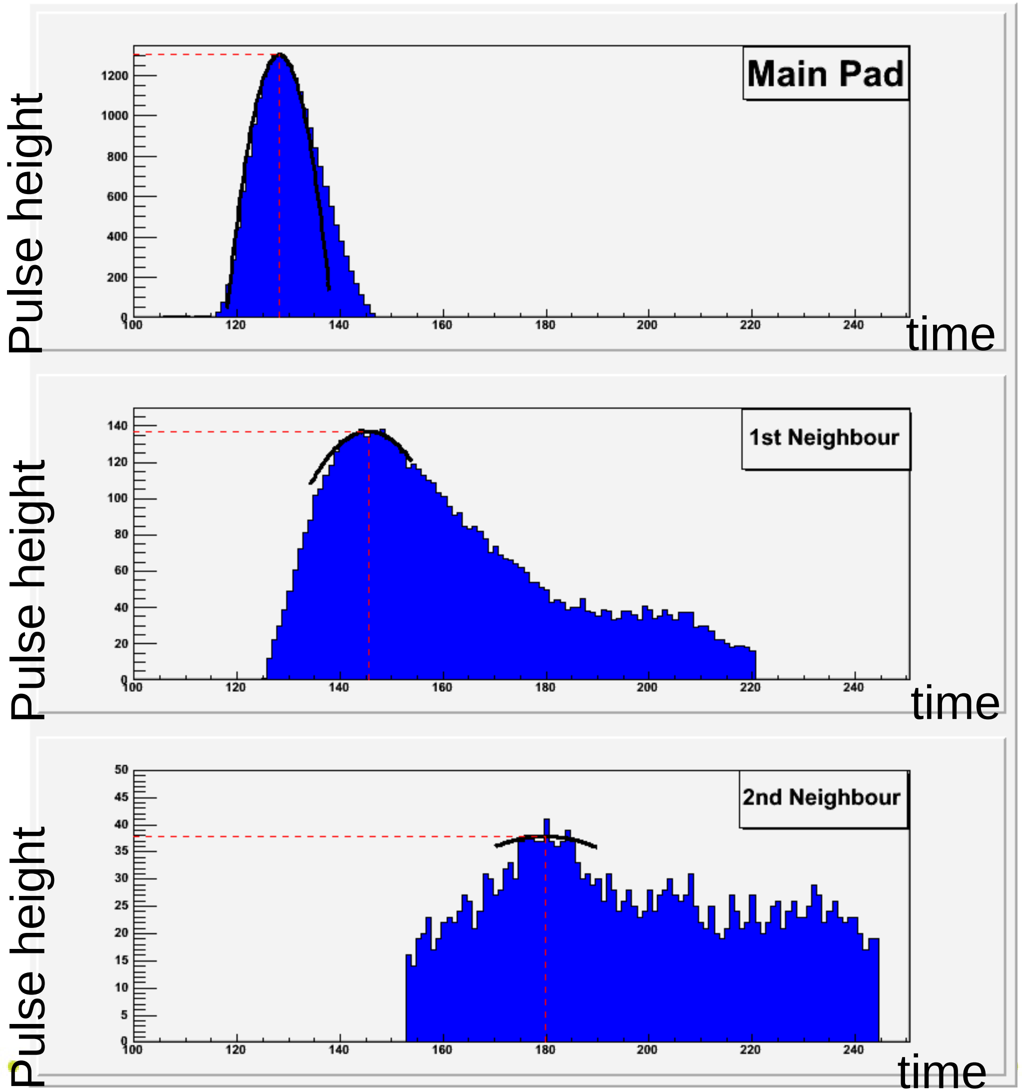


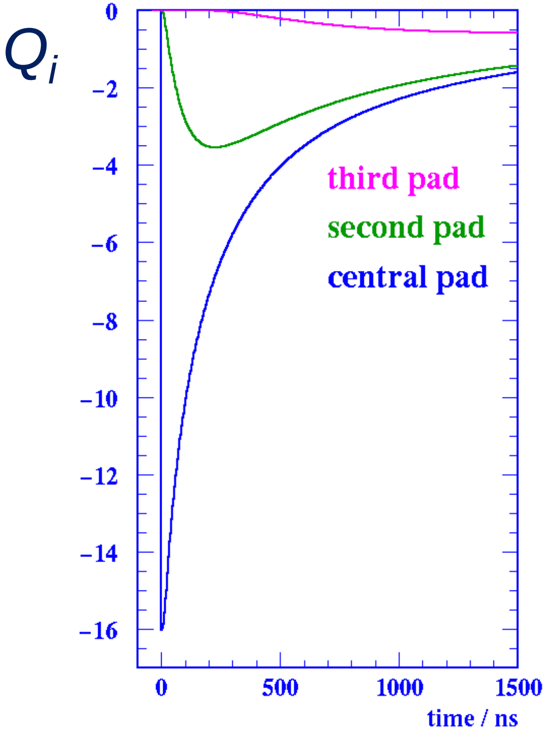
2) Maximum of Parabola
Quadratic Fit Method (QFM)

A_i = max of parabola P(i)

Pad Amplitude

Method use pre-2011





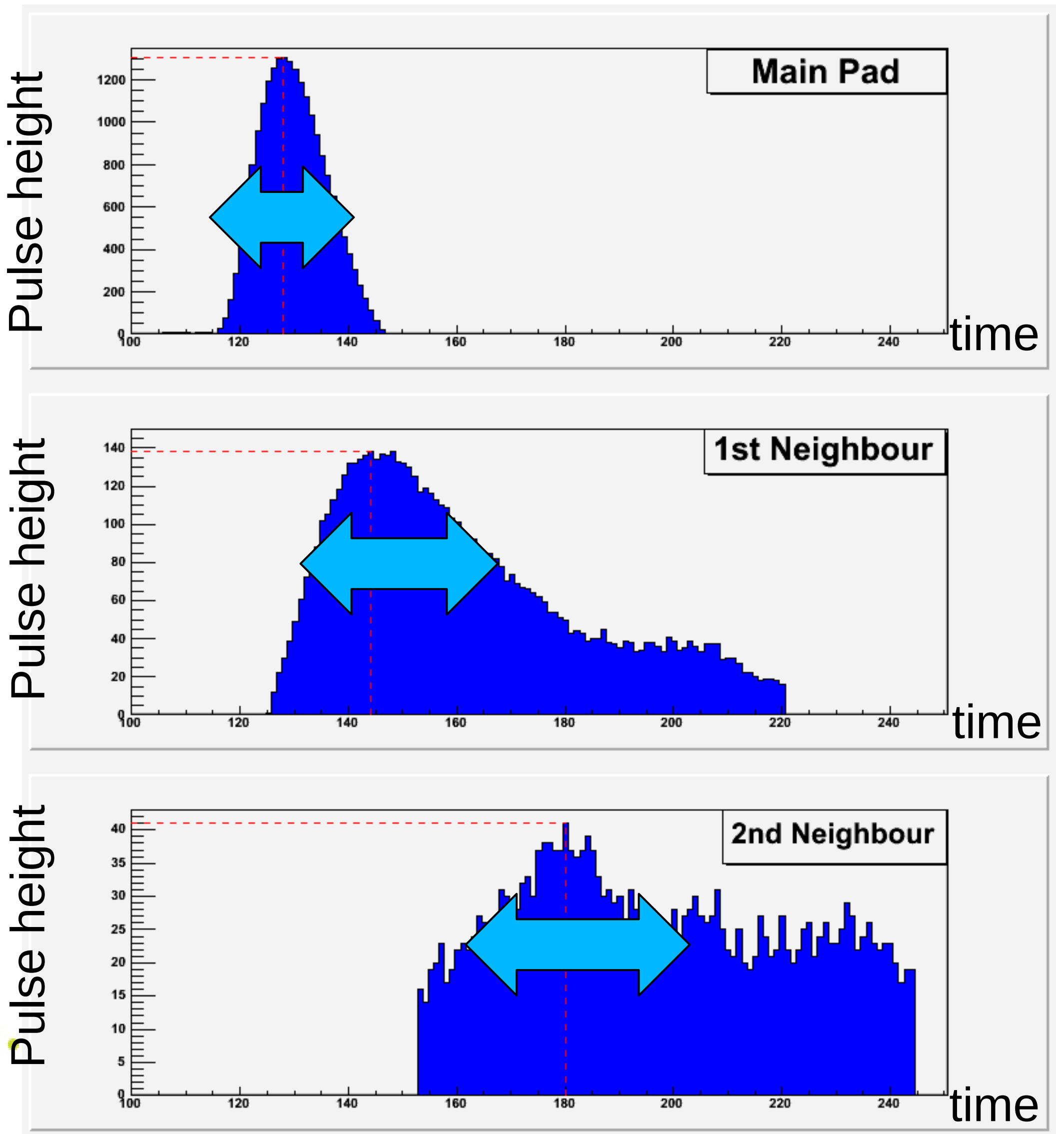
Pad Amplitude

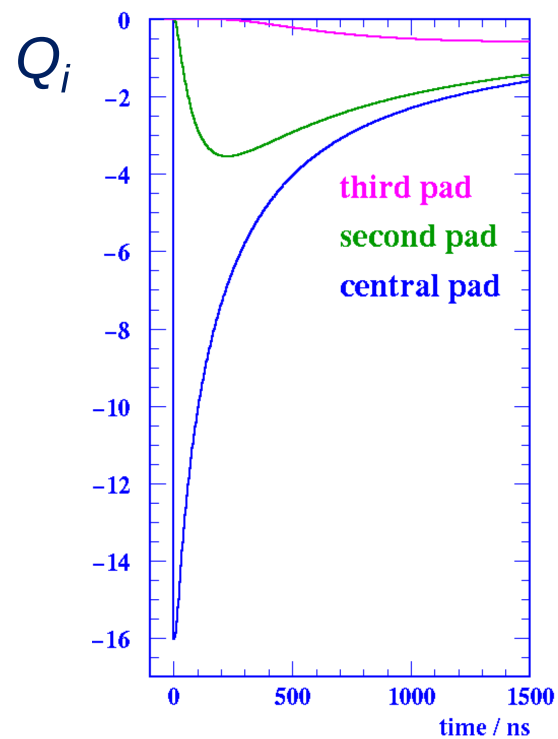
3) Integrate above threshold

Re-integration method (RM)

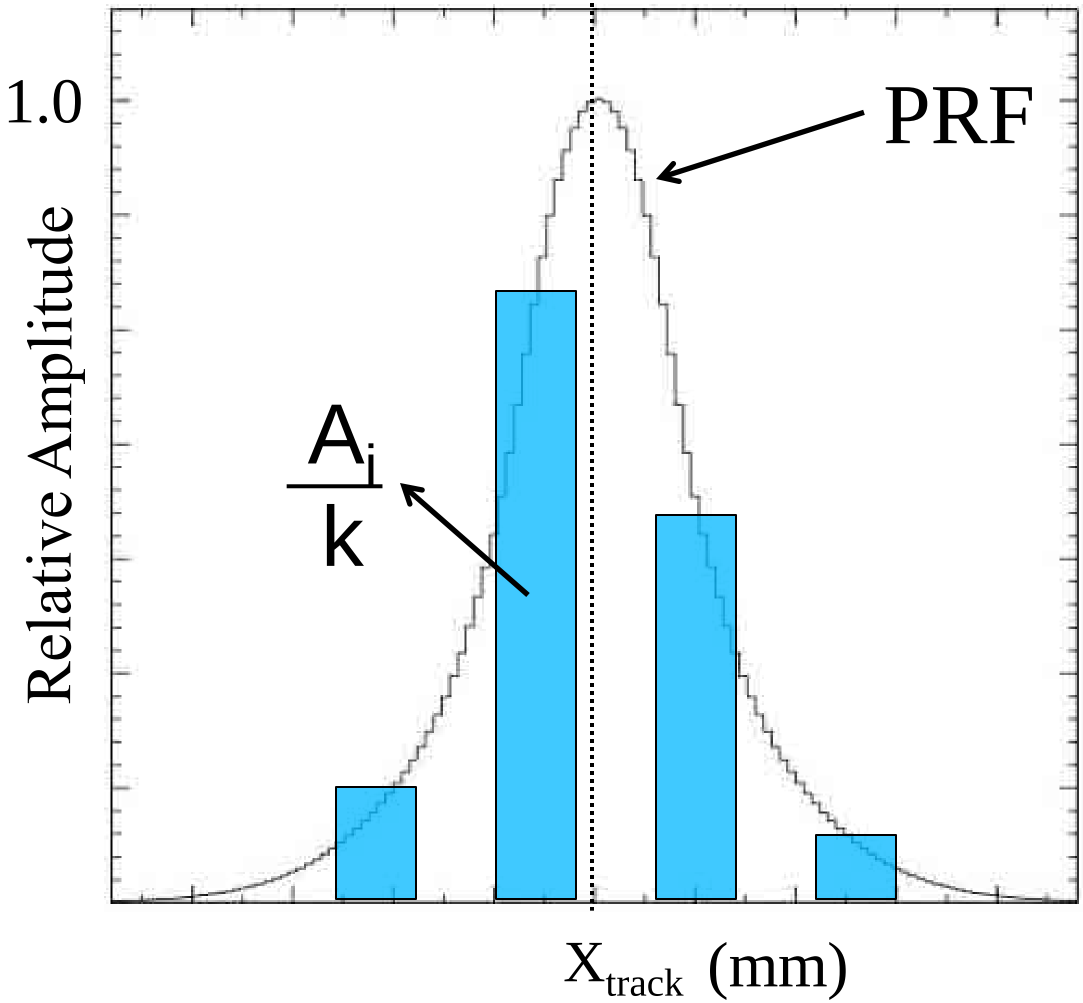
$$A_i = \text{Sum } P(i)$$

Method use in 2011



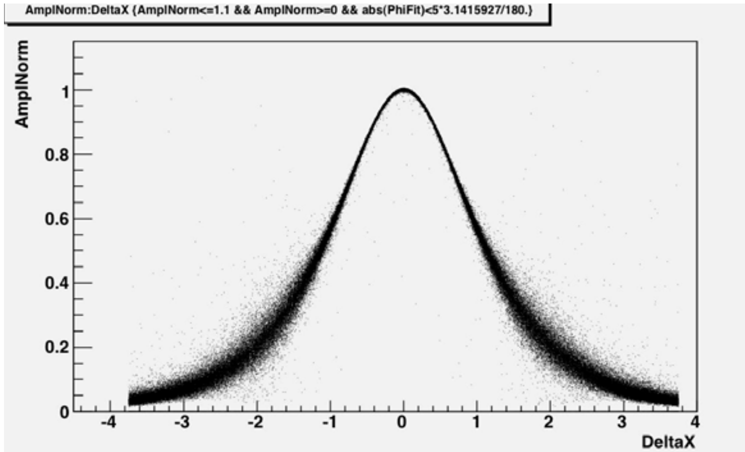


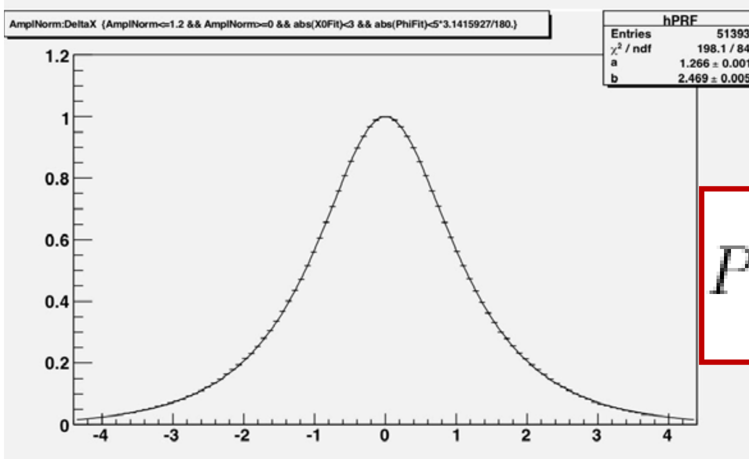
Pad Response Function (PRF)



For a given X_{track} (known position) the PRF is defined to be unity

Pad Response Function (model)





(mm)

$$\mathrm{PRF}(x, \Gamma, \Delta, a, b) = \frac{1 + a_2 x^2 + a_4 x^4}{1 + b_2 x^2 + b_4 x^4}$$

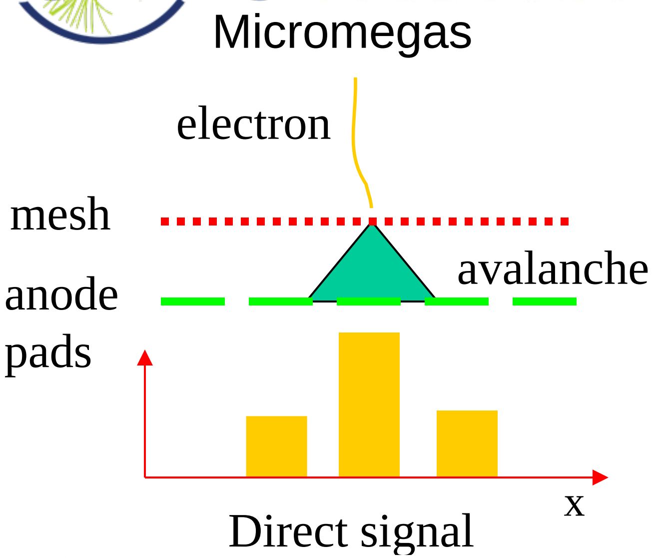
$$PRF(x, a, b) = b^2 \frac{e^{\frac{-x^2}{2a^2}}}{x^2 + b^2}$$

new (used here)

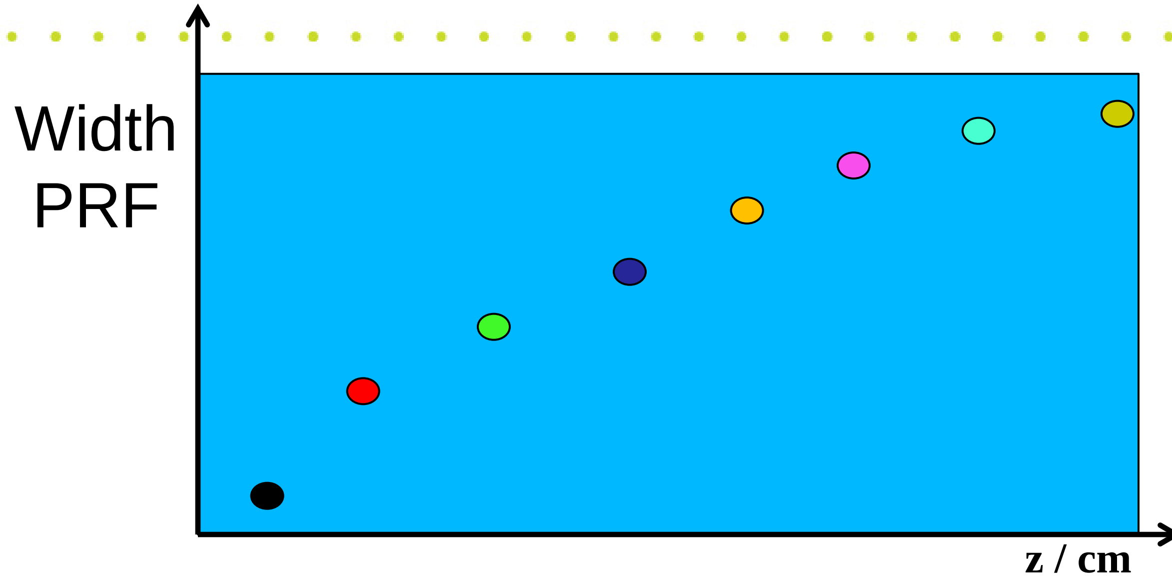
$$PRF(x; r, w) = \frac{exp(-4ln(2)(1-r)x^2/w^2)}{1 + 4rx^2/w}$$

- Only two parameters (simpler model)
- Easier to work with
- Better fits to data

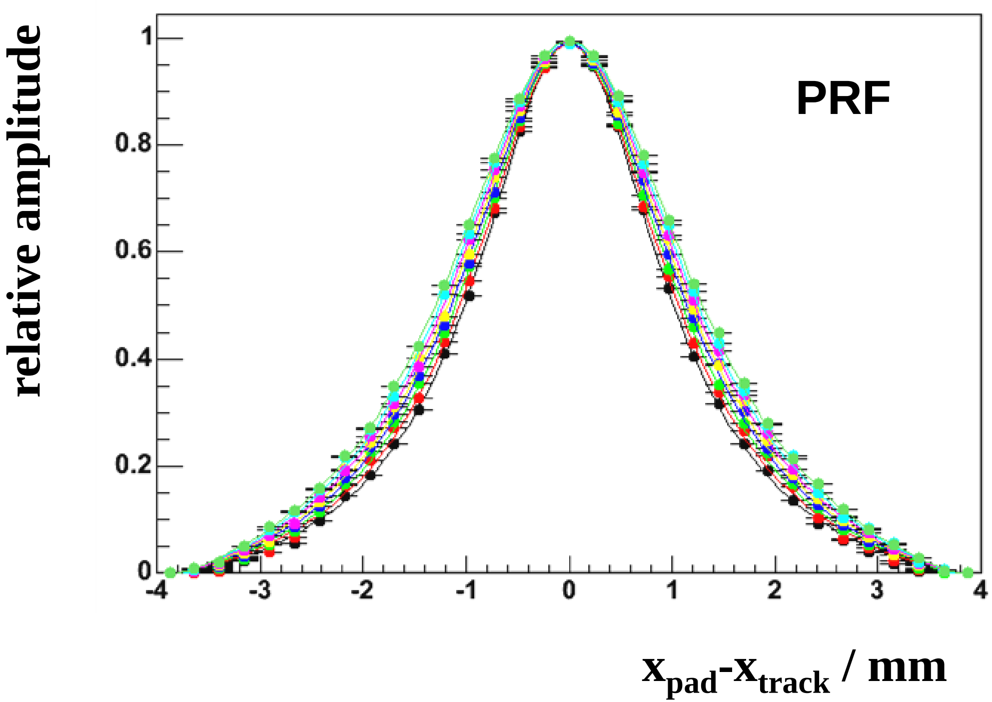
PRF versus Z



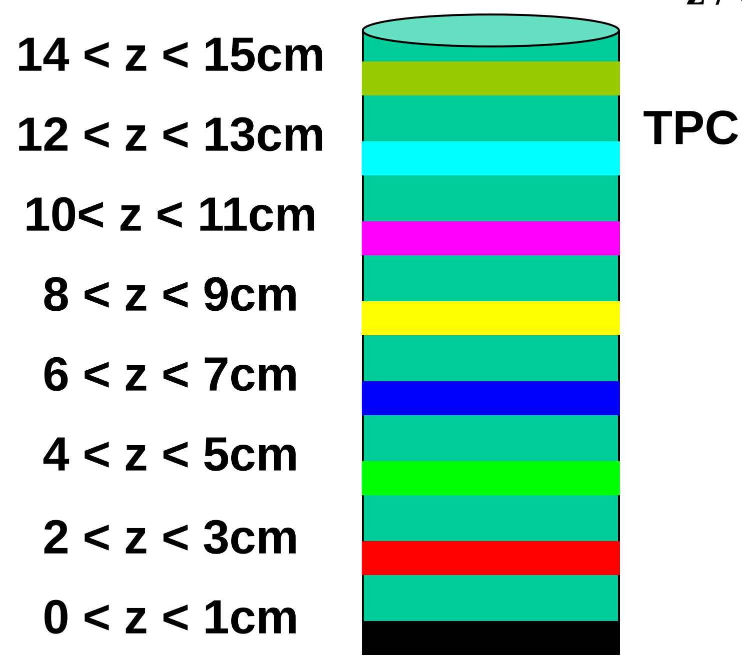
Micromegas
electron
mesh
avalanche
anode
pads
x
Direct signal



Width
PRF
z / cm



PRF
relative amplitude
x_{pad}-x_{track} / mm

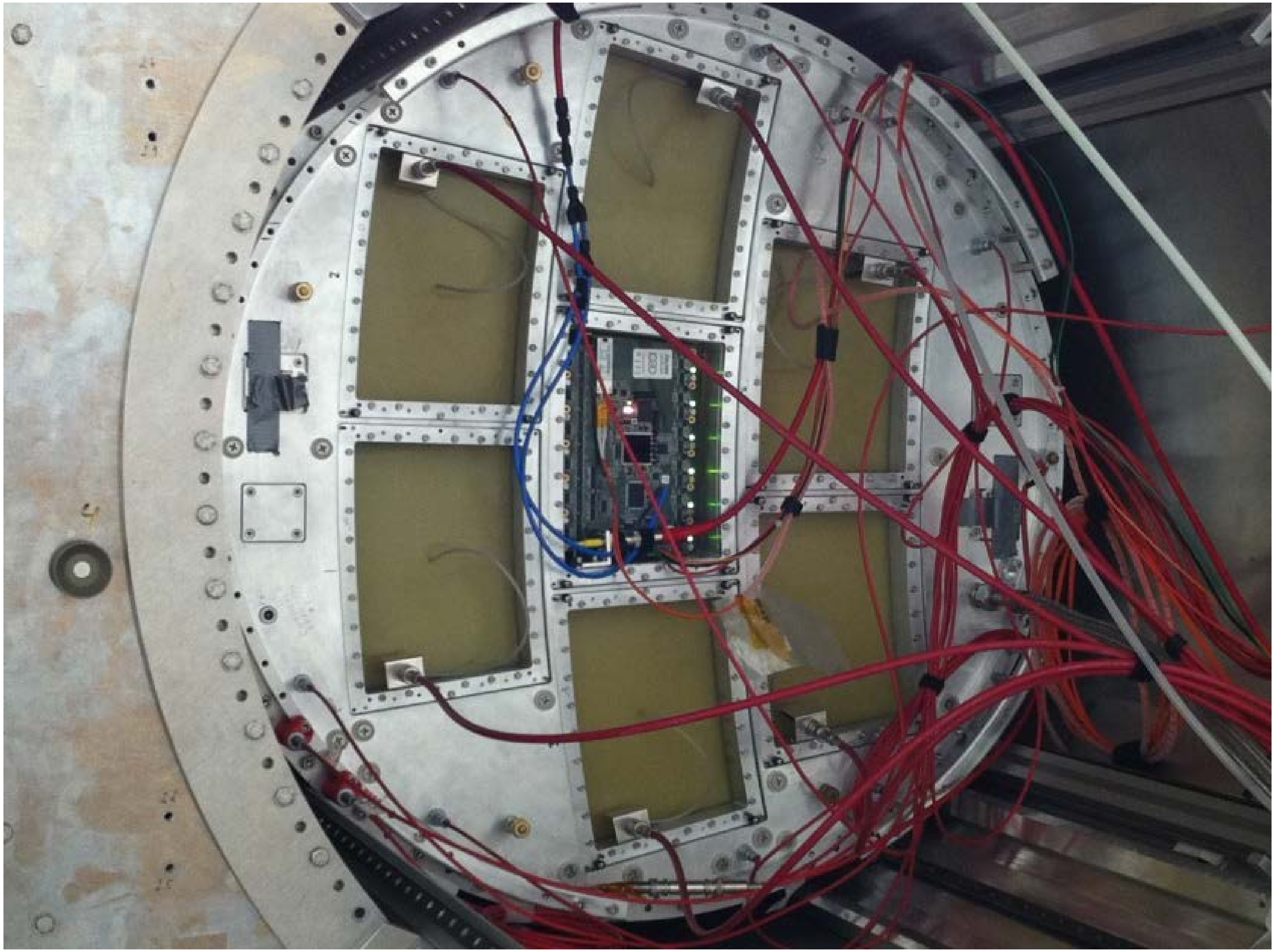


14 < z < 15cm
12 < z < 13cm
10< z < 11cm
8 < z < 9cm
6 < z < 7cm
4 < z < 5cm
2 < z < 3cm
0 < z < 1cm
TPC

Single Module LCTPC (MM)

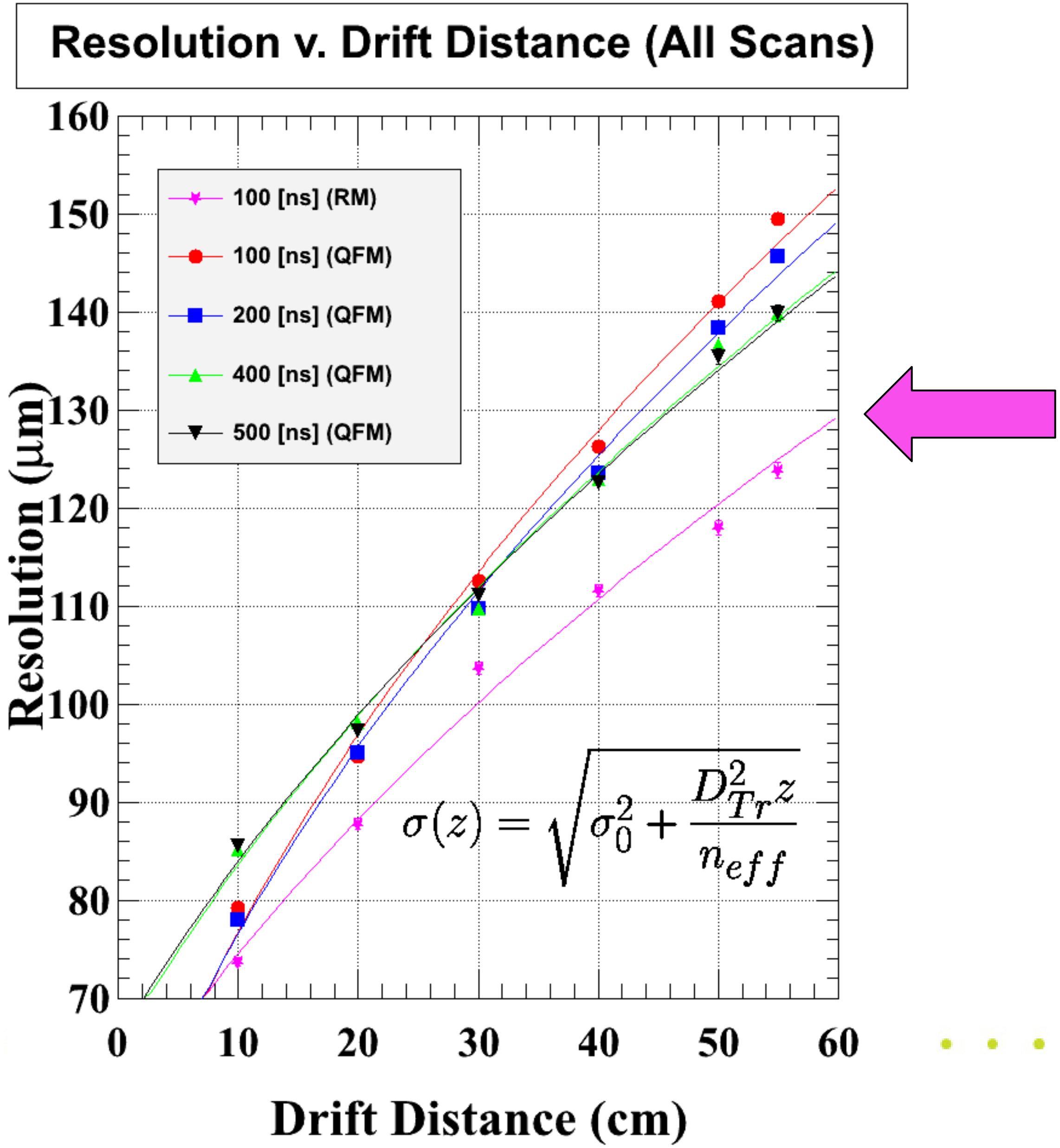
Period:
2008-2011

2011 data
Single module



Transverse Resolution MM

2011 data
Single module

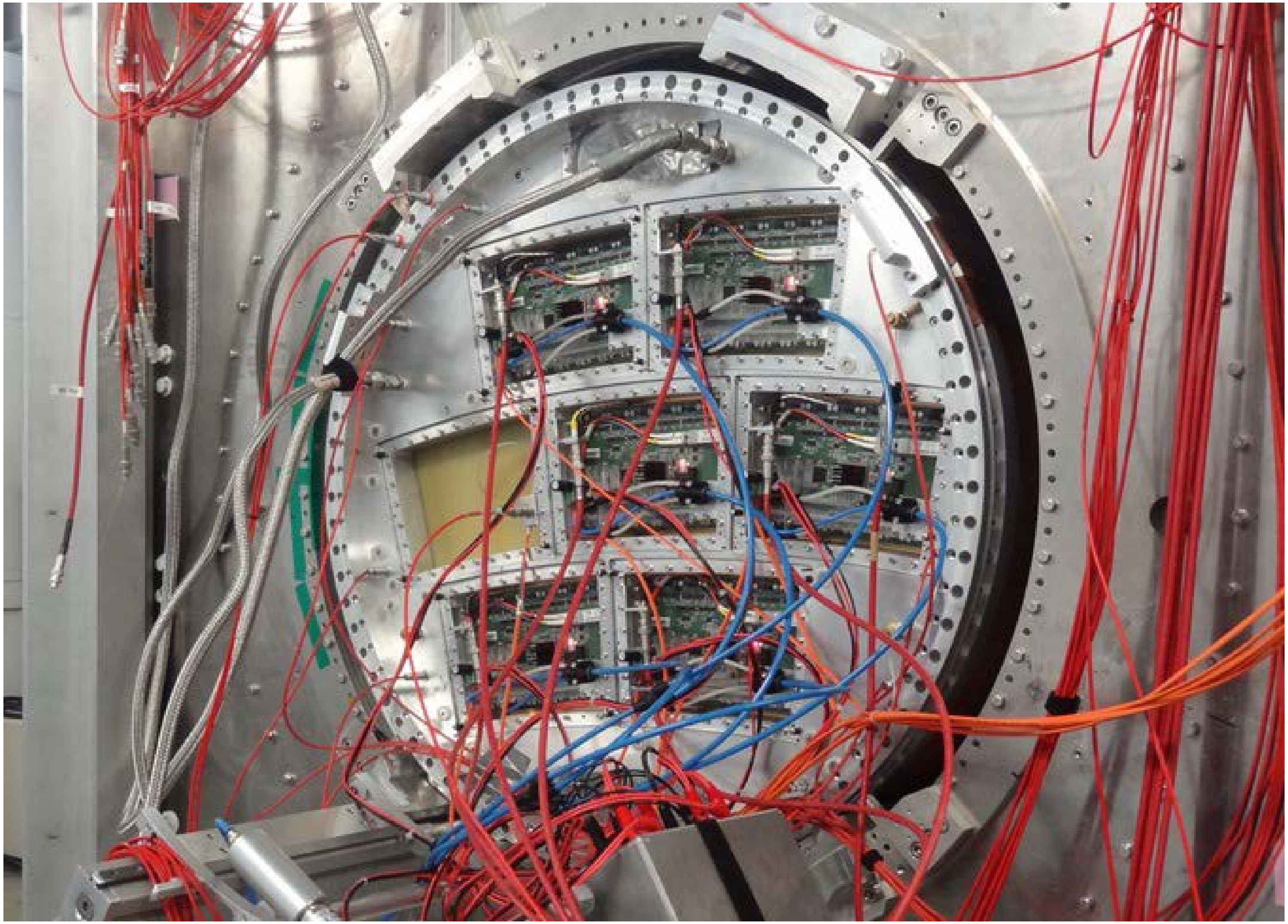


Source:
Nicholi Shiell
M.Sc. Thesis
Carleton University

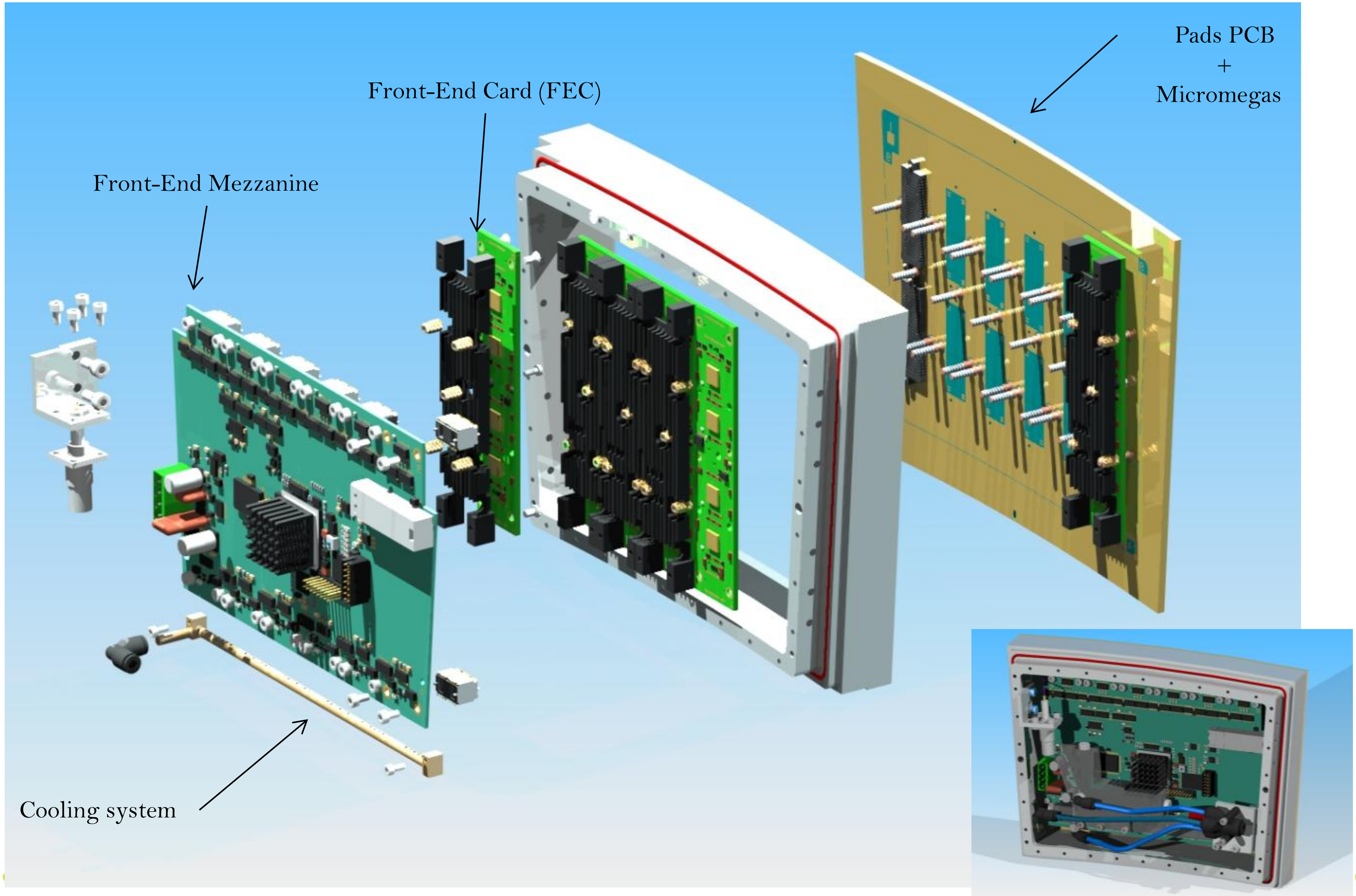
7-module LCTPC (MM)

Period
2012-2013

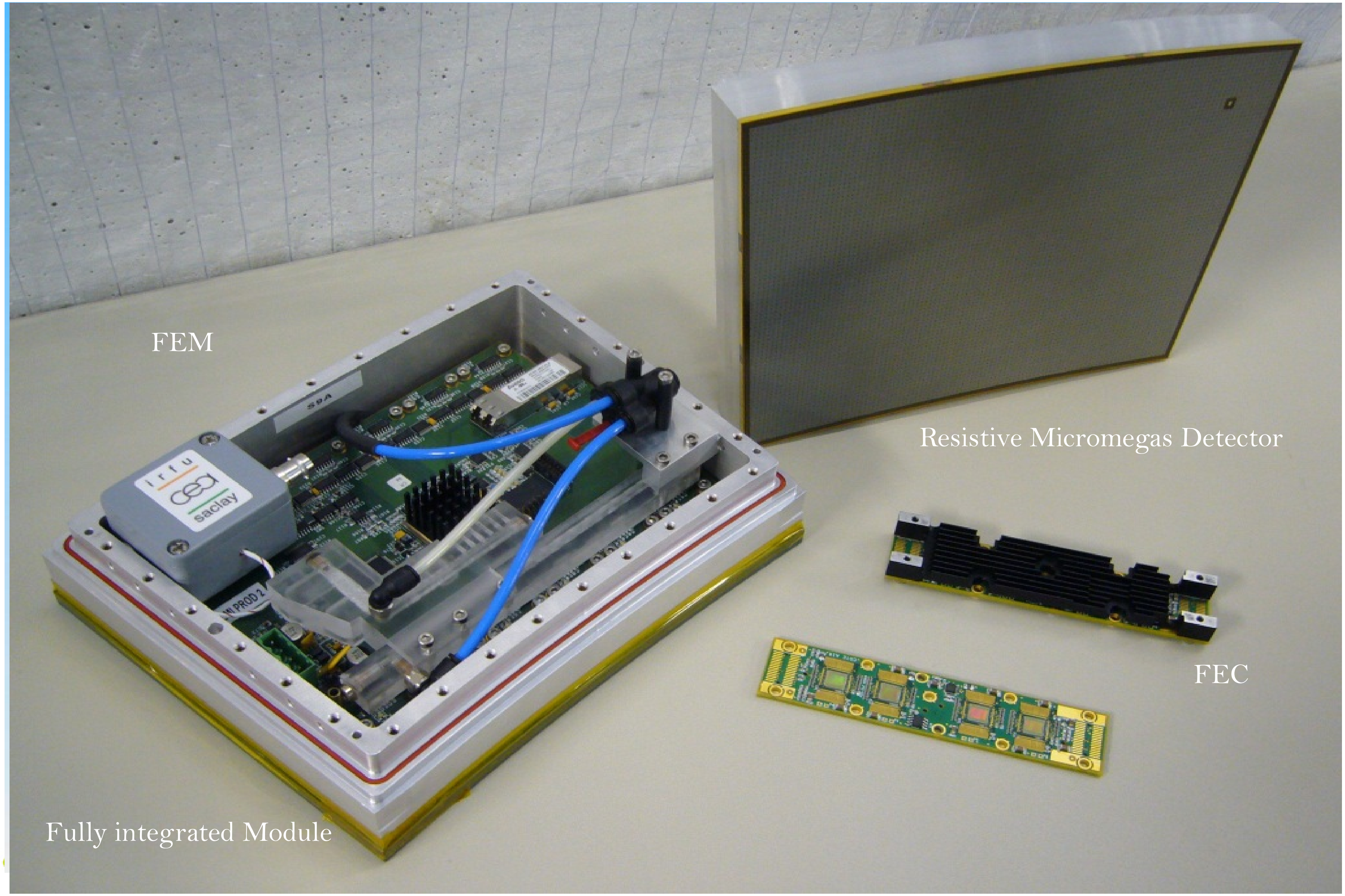
2013 data
7-module



Resistive MM: Module Design



Resistive MM: Module Design

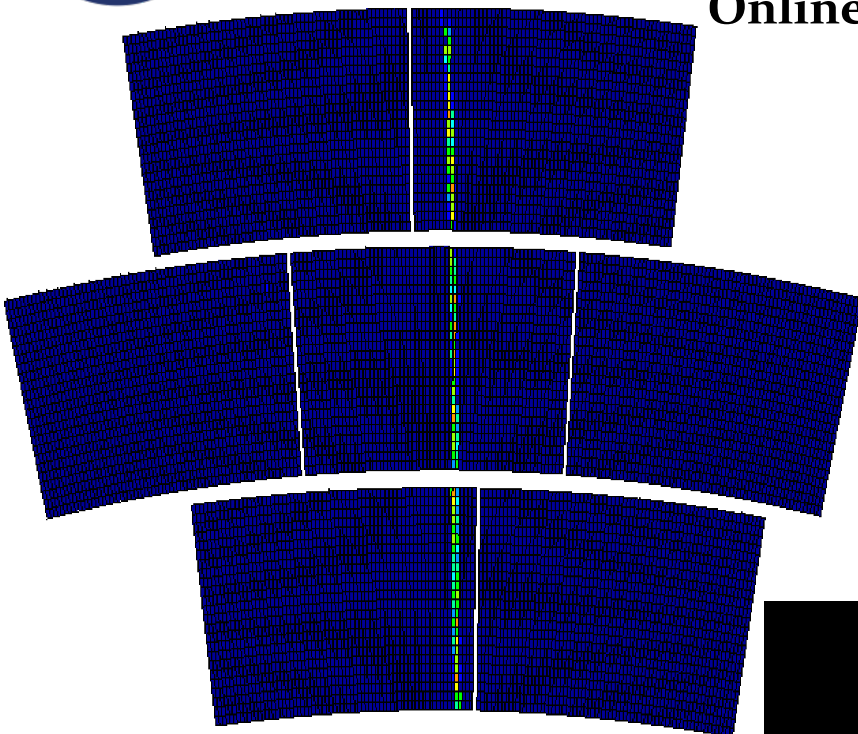


Analysis Framework: MarlinTPC

- MarlinTPC (LCIO) is the global effort to develop a single analysis code package for all the different prototype TPCs being developed.
- It is far from complete, but it has a solid foundation
- Furthermore, not sustainable to rely on stand alone code with hardcoded geometry, stand alone track-fit algorithm, calibration constants, etc…
- MarlinTPC processors: calibration for PRF determination, bias corrections and resolution determination (transverse and longitudinal)

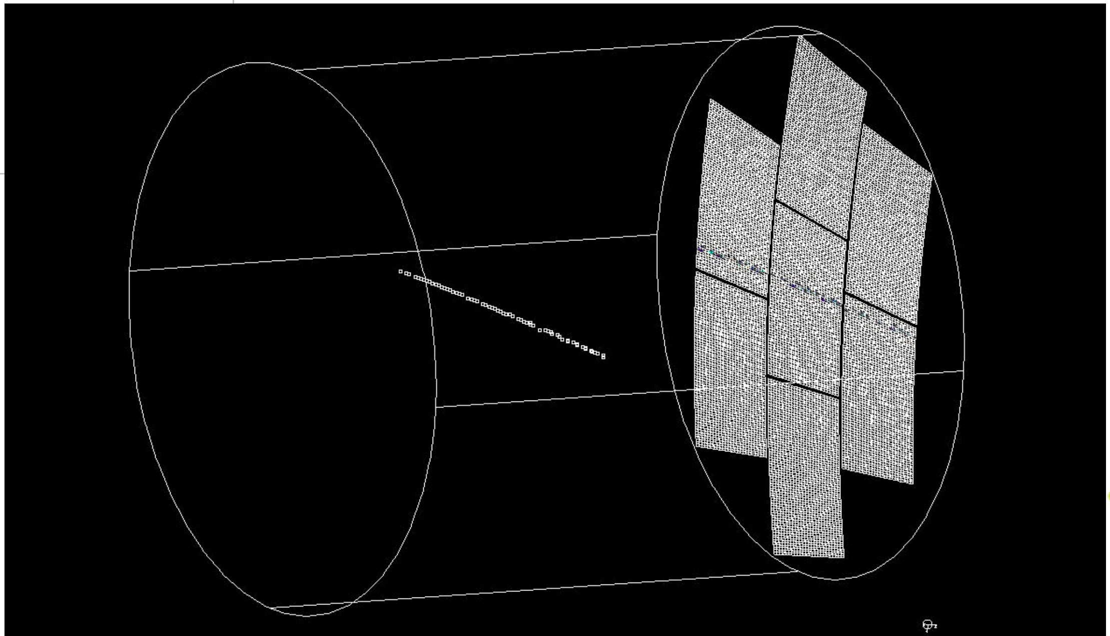
Event Display: MarlinTPC

Online monitor



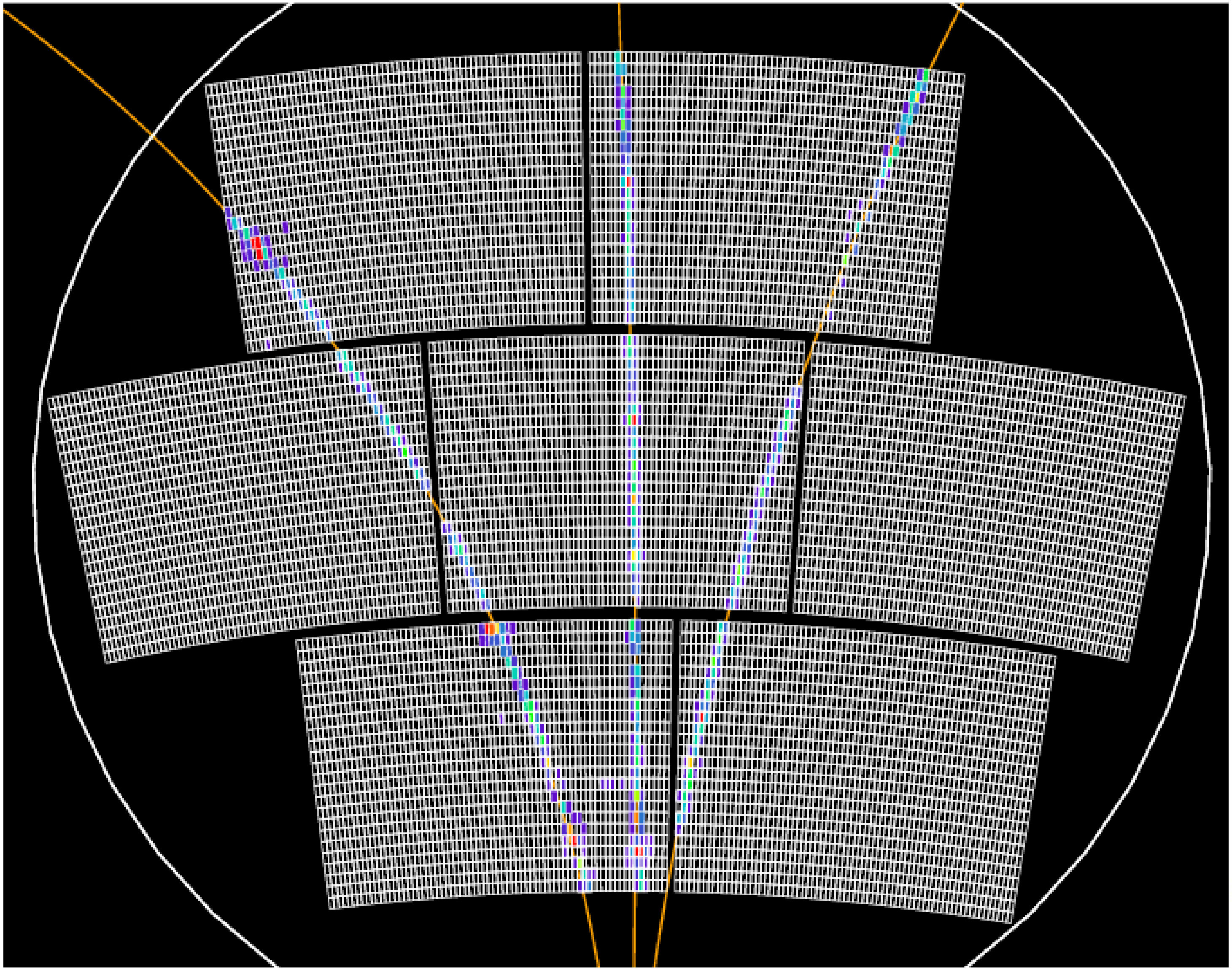
2D or 3D display software available

Offline monitor



Multi-track Pattern Recognition

Kalman Filter within MarlinTPC – LCIO geometry

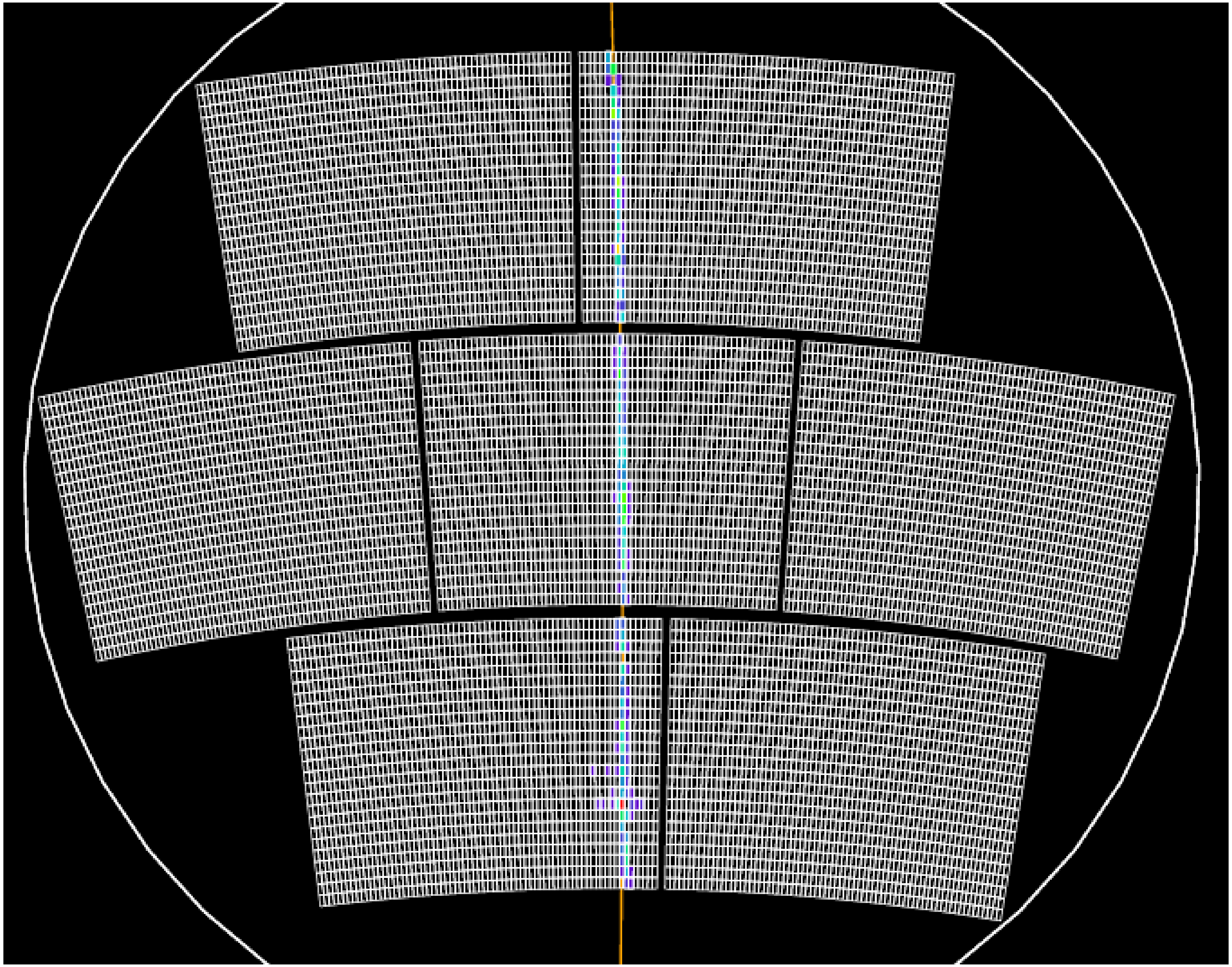


Acknowledment:
Bo Li
Keisuke Fujii
Martin Killenberg

Carleton UNIVERSITY

Single-track events for calibration

PRF calculation – bias – resolution study



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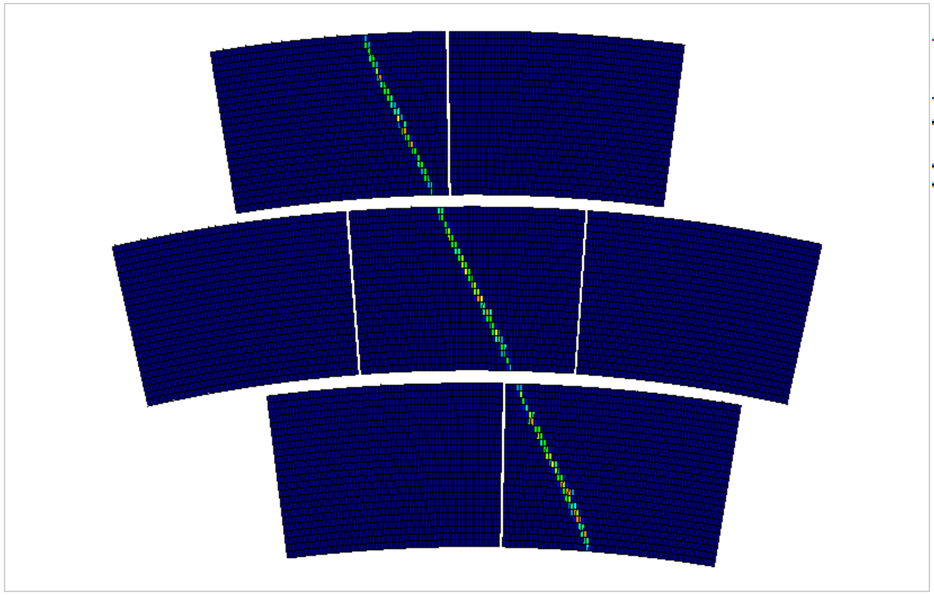
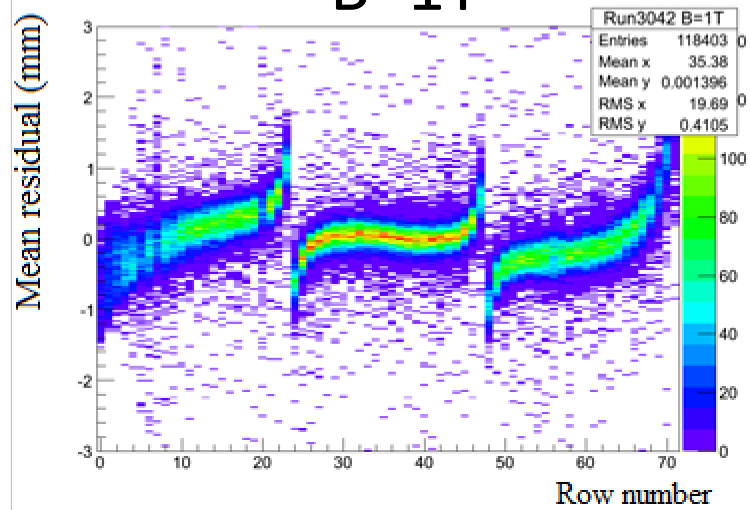
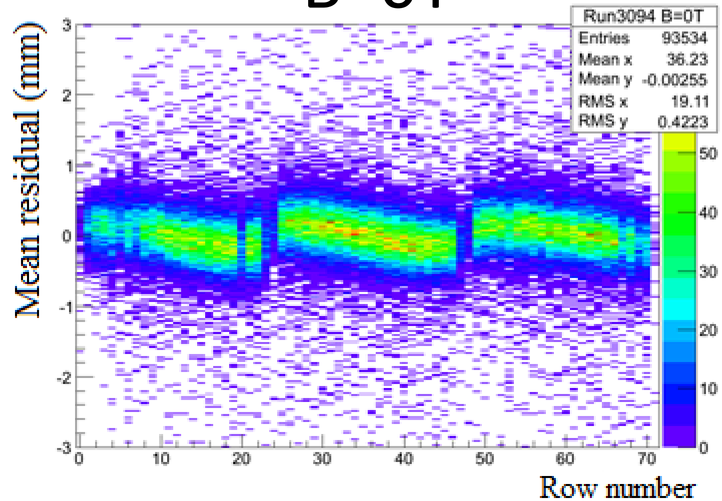
Field Distortions (E x B effect)



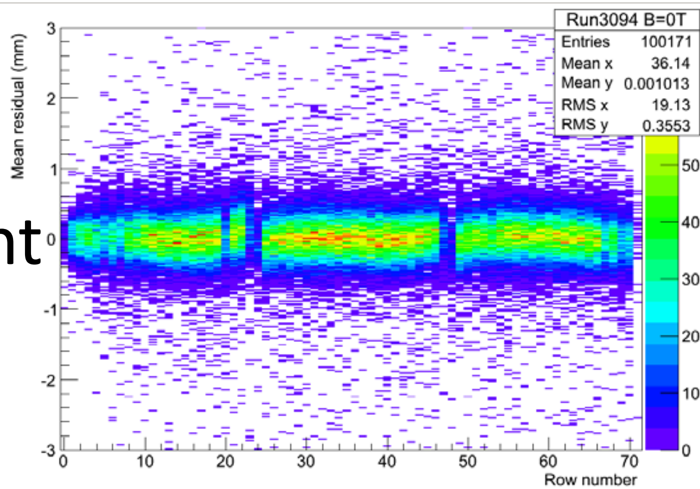
B=1T



B=0T

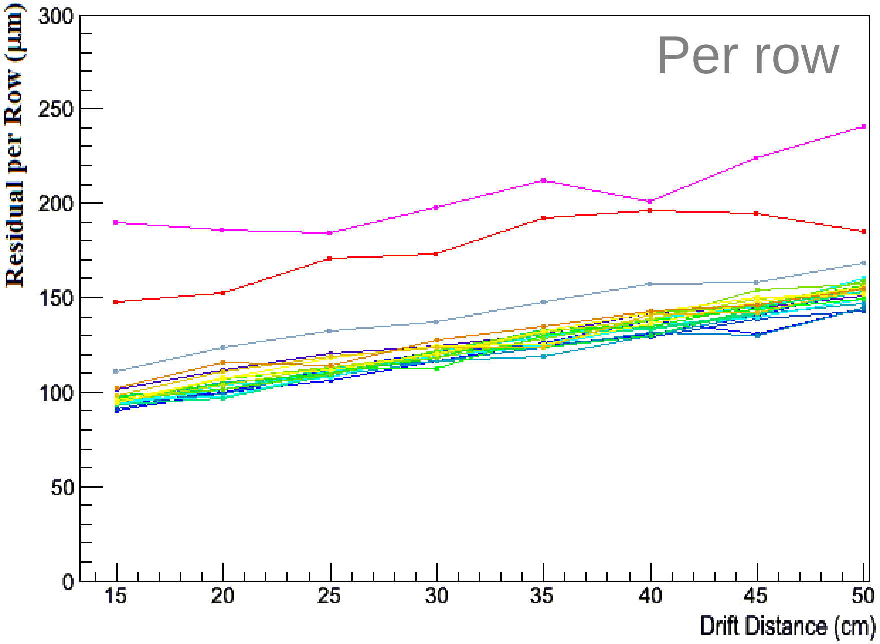


After alignment

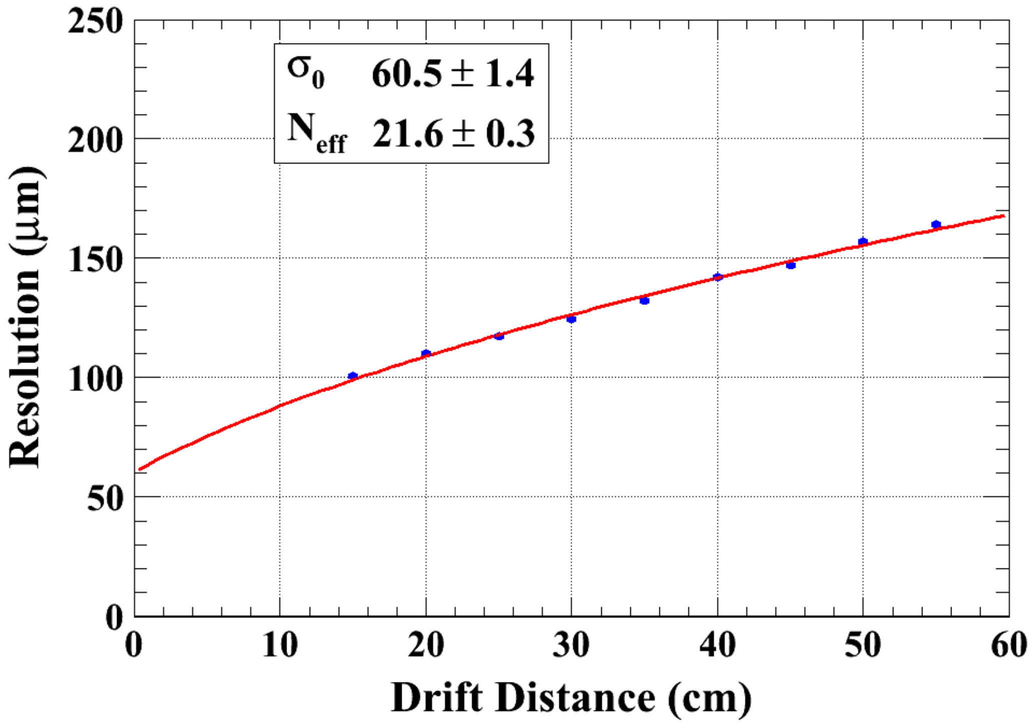


Transverse Resolution MM

2013 data
7 module



B=1 T C_d = 94.2 μm/√cm (Magboltz)



$$\sigma = \sqrt{\sigma_0^{\ 2} + \frac{C_d^2 \cdot z}{N_{eff}}}$$

σ_0 : the resolution at Z=0
N_{eff} : the effective number of electrons

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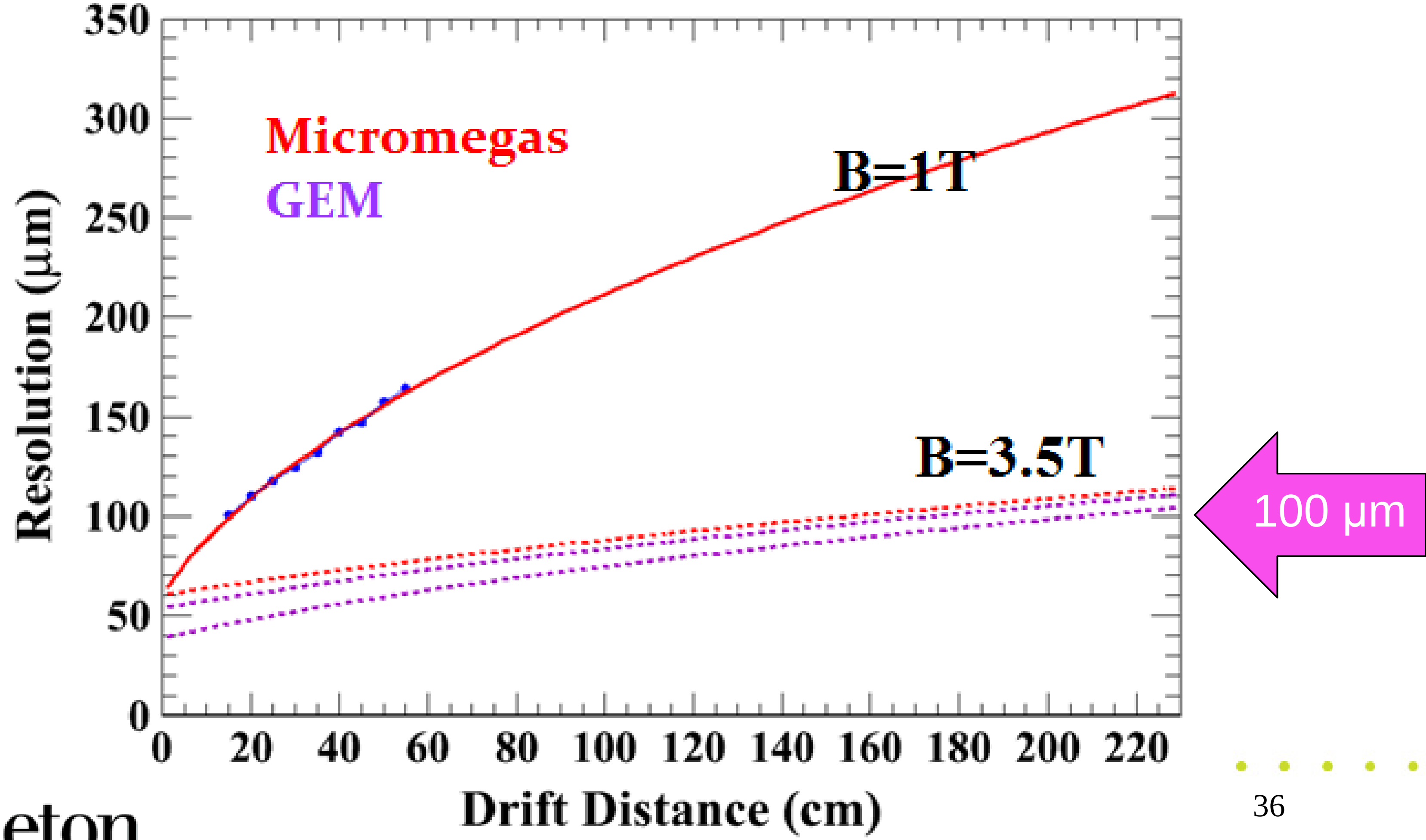
Transverse Resolution

Micromegas (MM) versus GEM

Extrapolate to B=3.5T



Summary

- A lot of experience has been gained in building and operating Micromegas TPC panels.
- The characteristics of the Micromegas modules, such as the uniformity, spatial resolution, stability have been studied in detail.
- 7 modules have been successfully tested with full integration of the electronics at the same time. The modules have been manufactured and characterized in a quasi-industrial process.
- Thanks to the resistive technology, the measured resolution is about 60 microns at zero drift distance with 3 mm wide pads. This meets ILC requirements of 100 μm single hit resolution in rϕ (over 2 m drift).

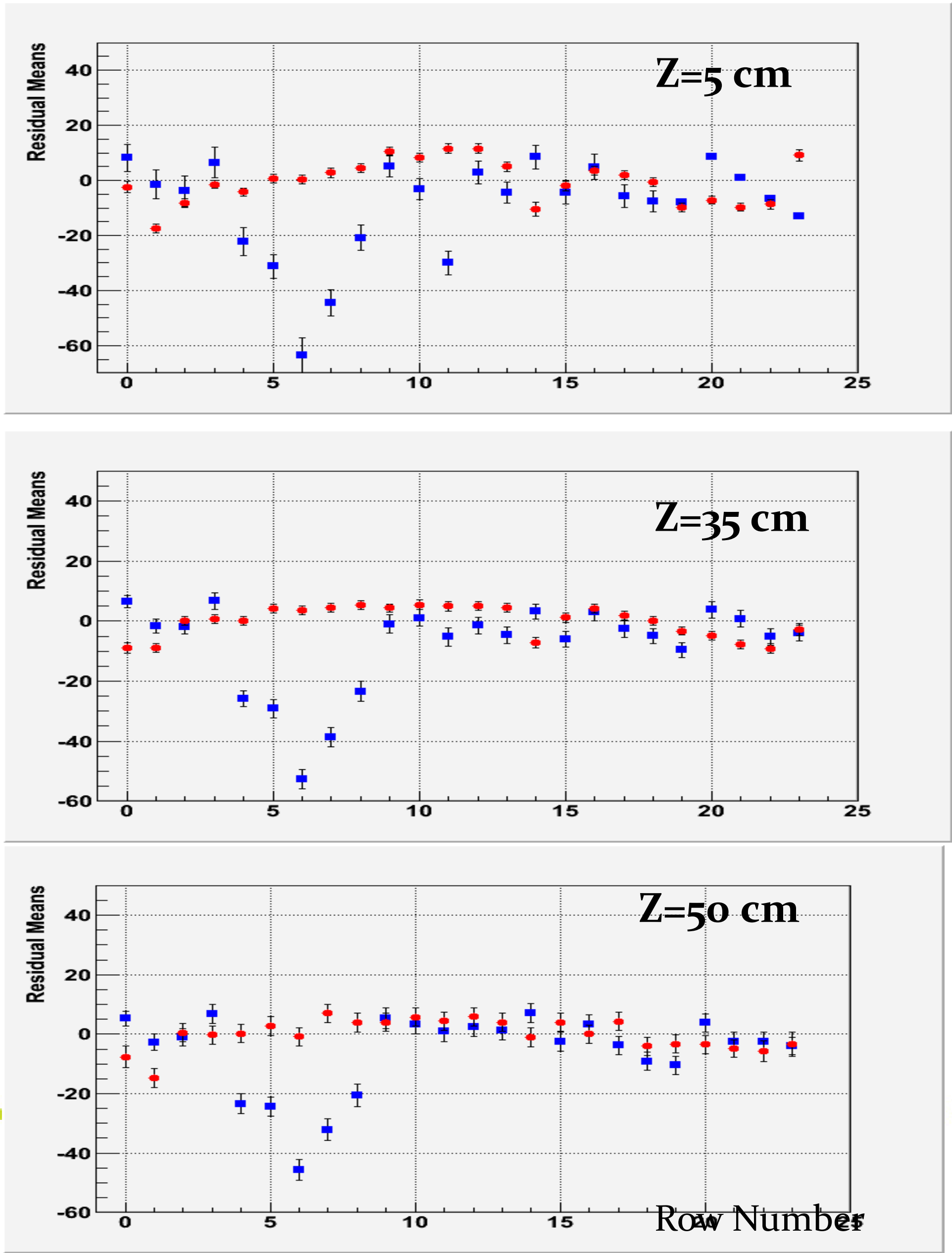
Uniformity of Resistive Anode

Mean Residual vs Row Number

Z-independent distortions

Distortions up to 50 microns for resistive ink (blue points)

RMS of 7 microns for CLK film (red points)



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