Status of two-track separation simulation with resistive Micromegas

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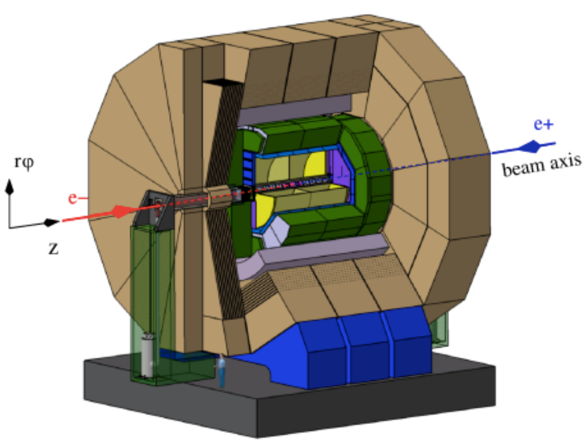
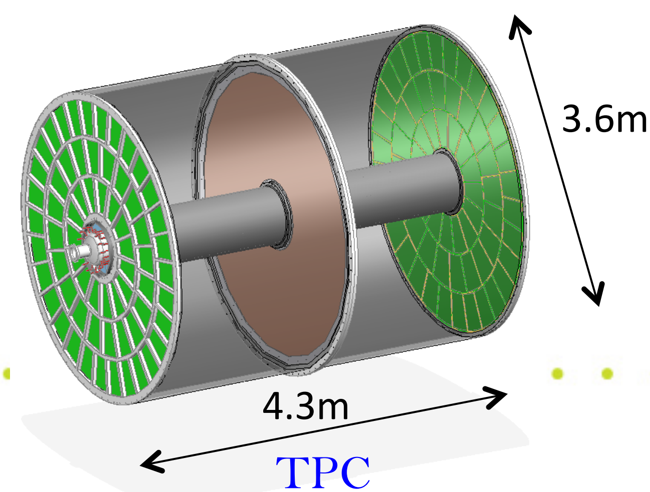
Outline

- Introduction and requirement for ***LCTPC*** at ***ILD***
- Will **ask** these **3** questions:
  - 1) What is the optimal pad size and pad layout?
  - 2) How is electronics signal sampled, shaped and optimized?
  - 3) How to study the LCTPC ability to reconstruct multiple tracks in both the r-Φ and r-Z planes?
- Description of simulation for future study of **two-track** separation with ***LCTPC***



ILD



TPC

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

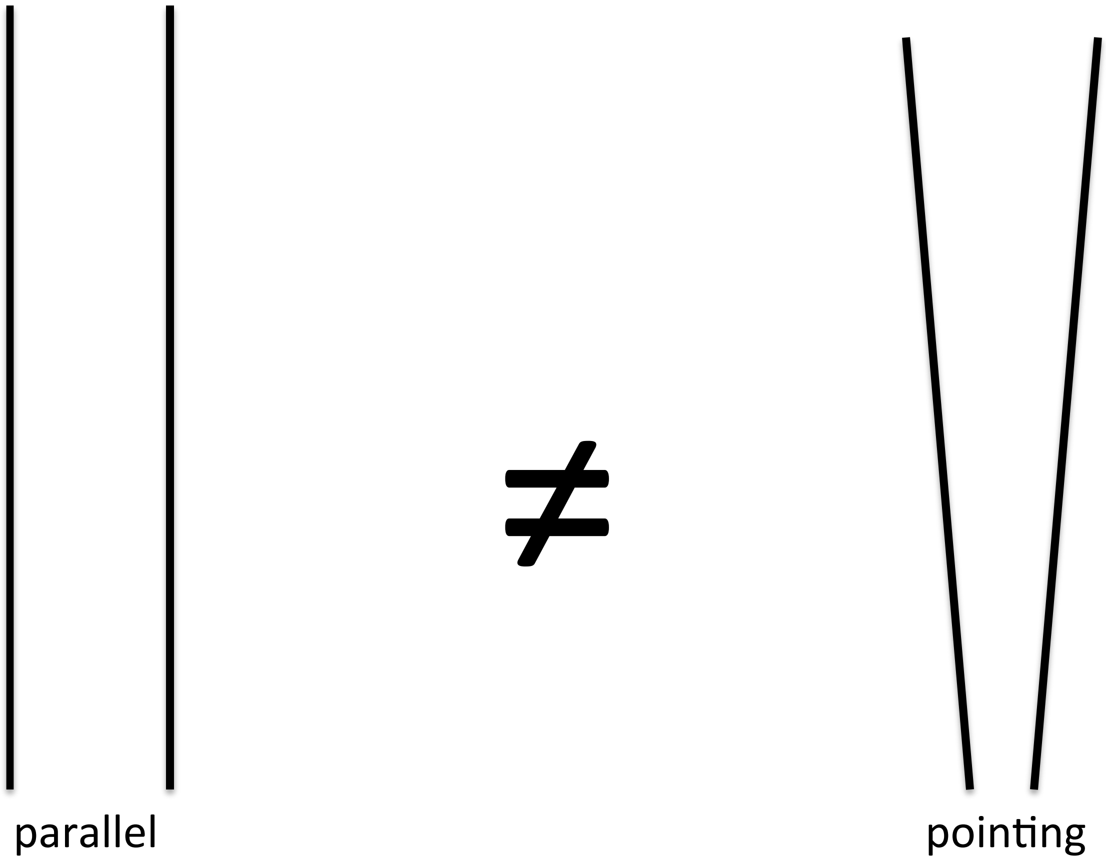
TPC Requirements :

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

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

Topology



Pattern recognition (Kalman fitter): go from outer to inner to resolved two track if track are forced to point at the IP

r-Φ plane

- In the r-Φ **two-track** separation is limited by the pad pitch and therefore by the pad geometrical & arrangement

- For best single hit resolution requires at least 3 pads per hits: charge sharing allows for much better **single-hit** resolution than $d/\sqrt{12}$

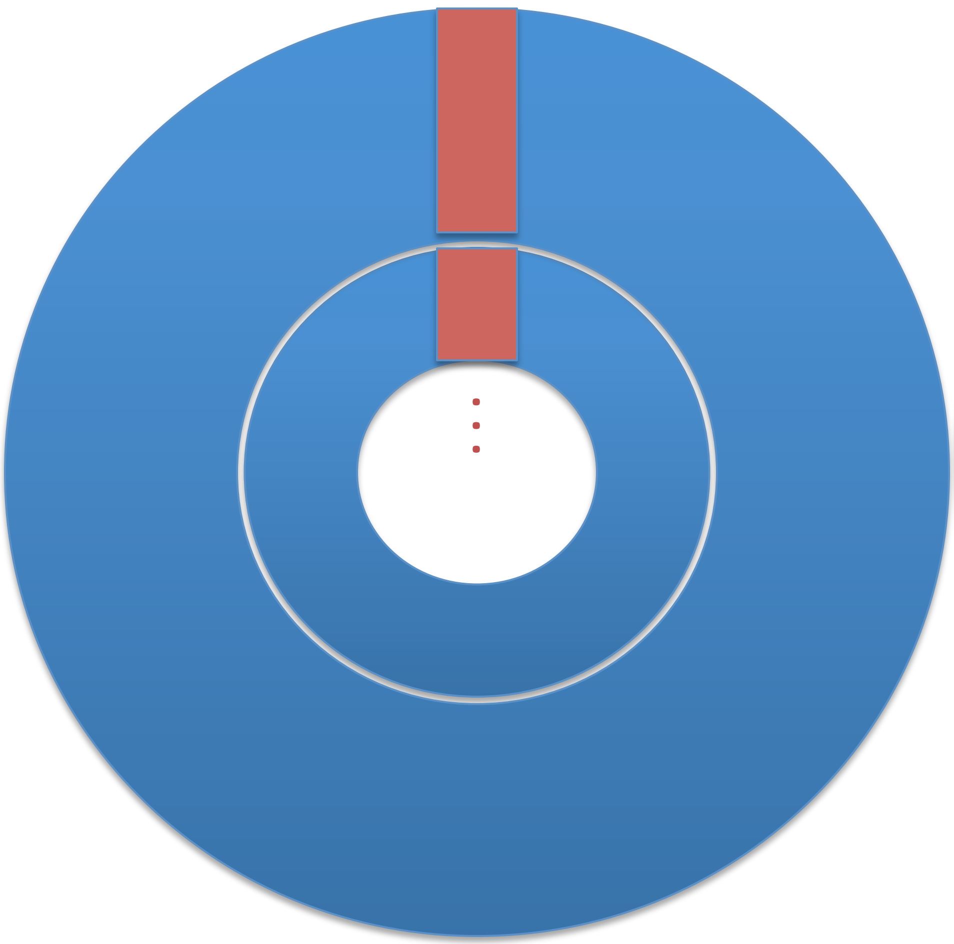
- Over all for pad of pitch *d*, significant information can be extracted from a pad row when **two tracks** are as near as about 1.5 *d* in that row

- **Should look at pad pitch versus radius**

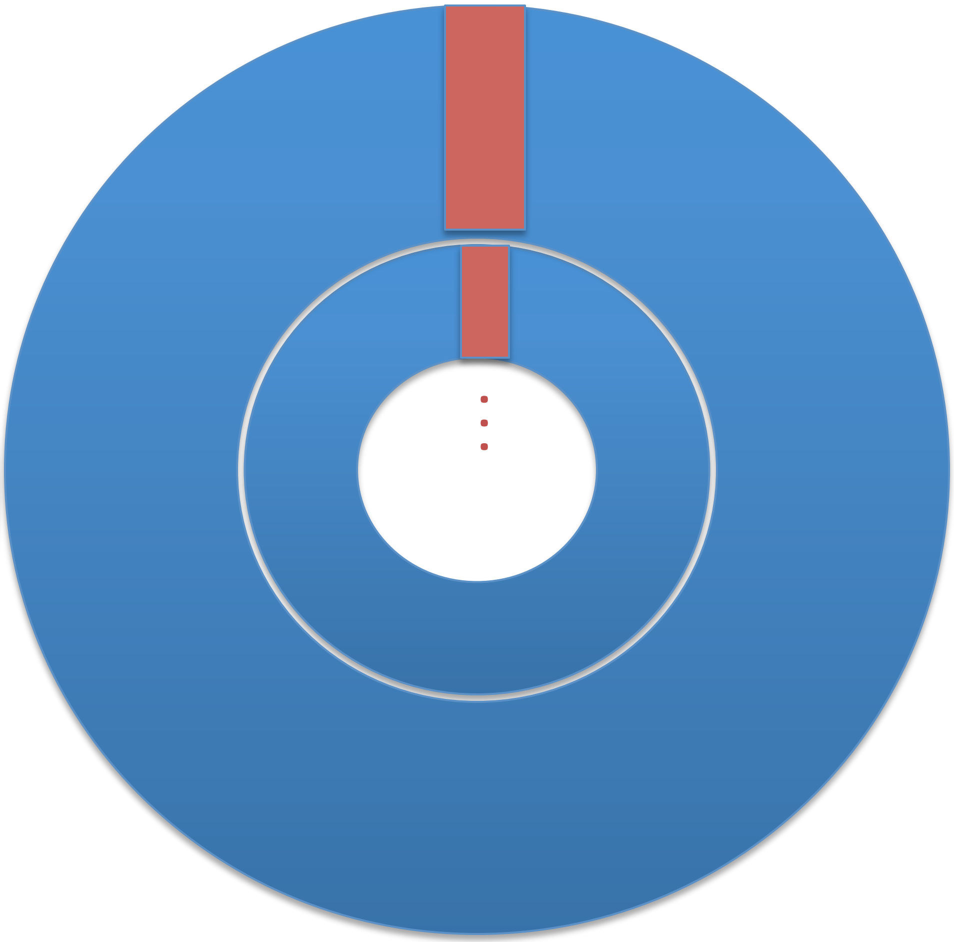
- Larger occupancy and more curlers at smaller radius

- Connect track segments with high resolution Silicon Inner Tracker (SIT) and the Silicon External Tracker (SET)

r-Φ plane (track matching)



Same pad pitch versus radius
Simplify module design and construction



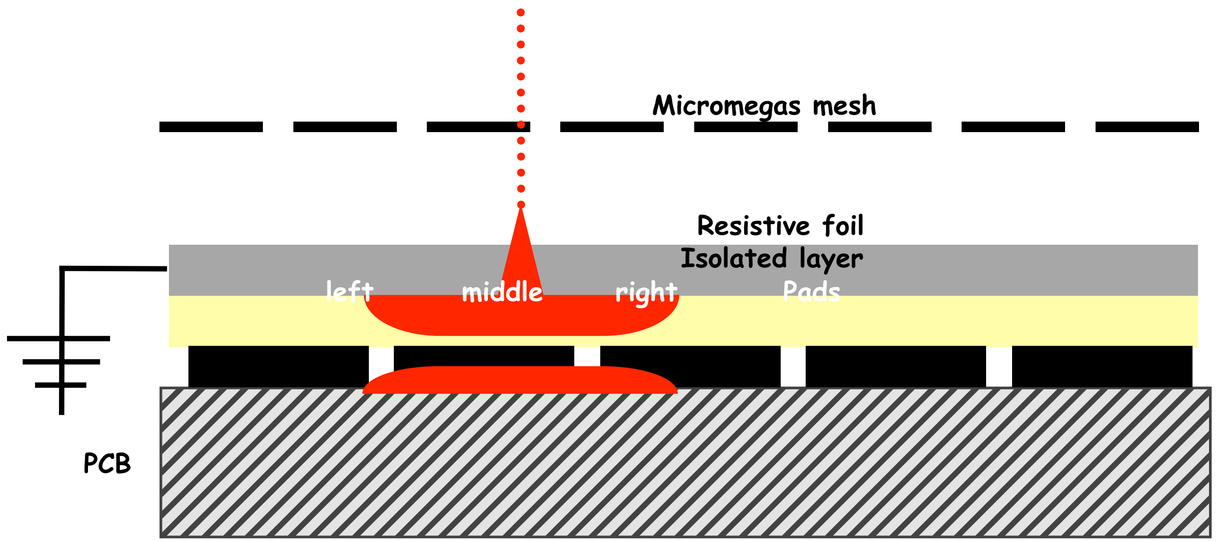
Pad pitch varies versus radius
Allow better match with inner tracker

r-z plane

- In the r-z the resolution is driven by our ability to precisely measure the **drift time**
- For each pad we have charge (ADC) as a function of fixed time intervals (25 – 40 ns)
- Fit rise of pulse to get Z with better single hit resolution than the sampling time
- Sampling time the same for each module (cannot be better at smaller radius… can it?)
- Prone to use fast shaping time electronics (100 ns)
- GEM: all pads in a hit have identical signal shape
- MM with resistive layer: neighboring pads have **delayed** signals

Charge Dispersion Resistive Anode

r-Φ plane



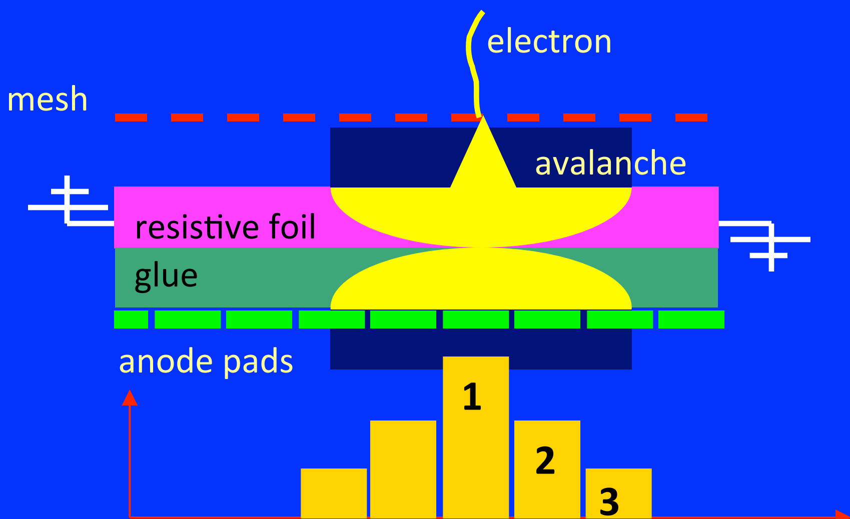
Charge dispersion

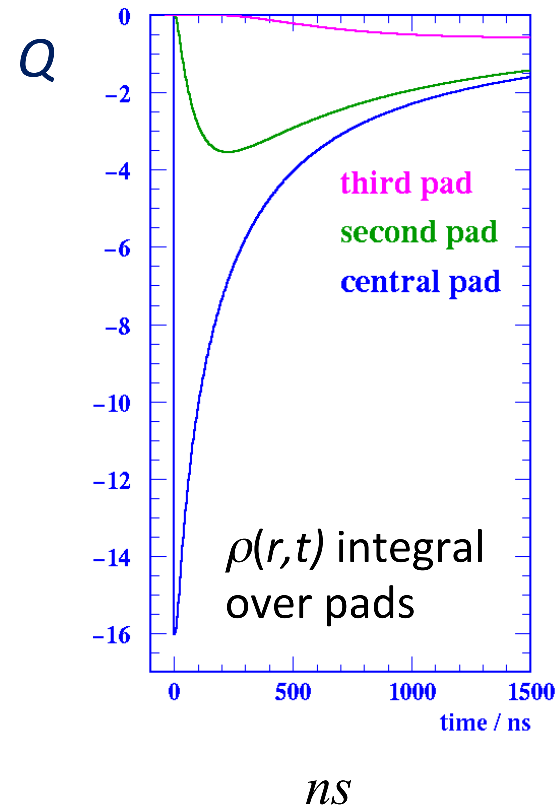
- A high resistivity film bonded to a readout plane with an insulating spacer
- 2D continuous RC network defined by material properties and geometry.
- point charge at r = 0 & t = 0 disperses with time.

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

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

Micromegas + resistive anode





Pulse shape origin

Transverse diffusion

Transverse diffusion

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

Longitudinal diffusion

Longitudinal diffusion

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

Intrinsic rise time

Induction gap

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

Preamplifier effect

Preamplifier Response

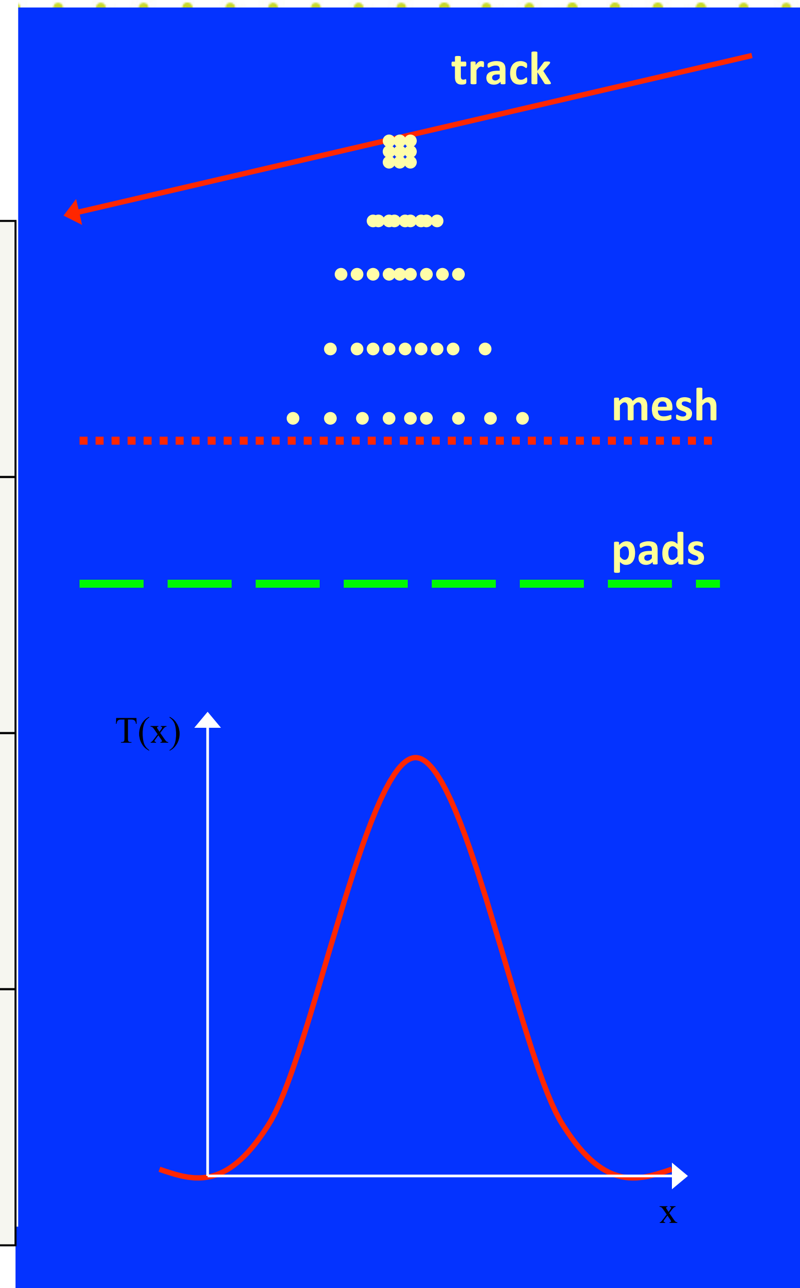
$$H(t) = \exp\left(-\frac{t}{t_f}\right)\left(1 - \exp\left(\frac{t}{t_r}\right)\right) \quad \text{for} \quad t > 0$$
$$= 0 \quad \text{for} \quad t < 0$$

Resistive foil + glue

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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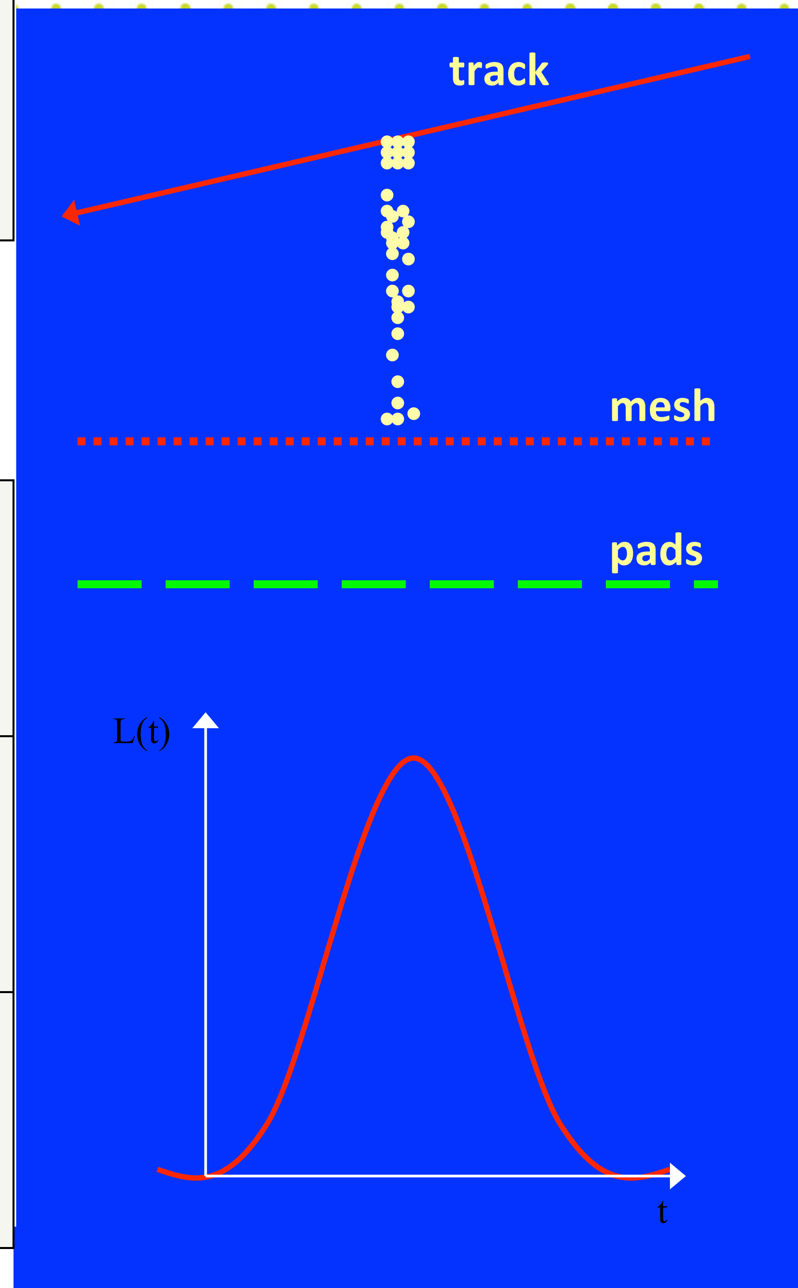

Pulse shape origin

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Preamplifier effect

Preamplifier Response

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

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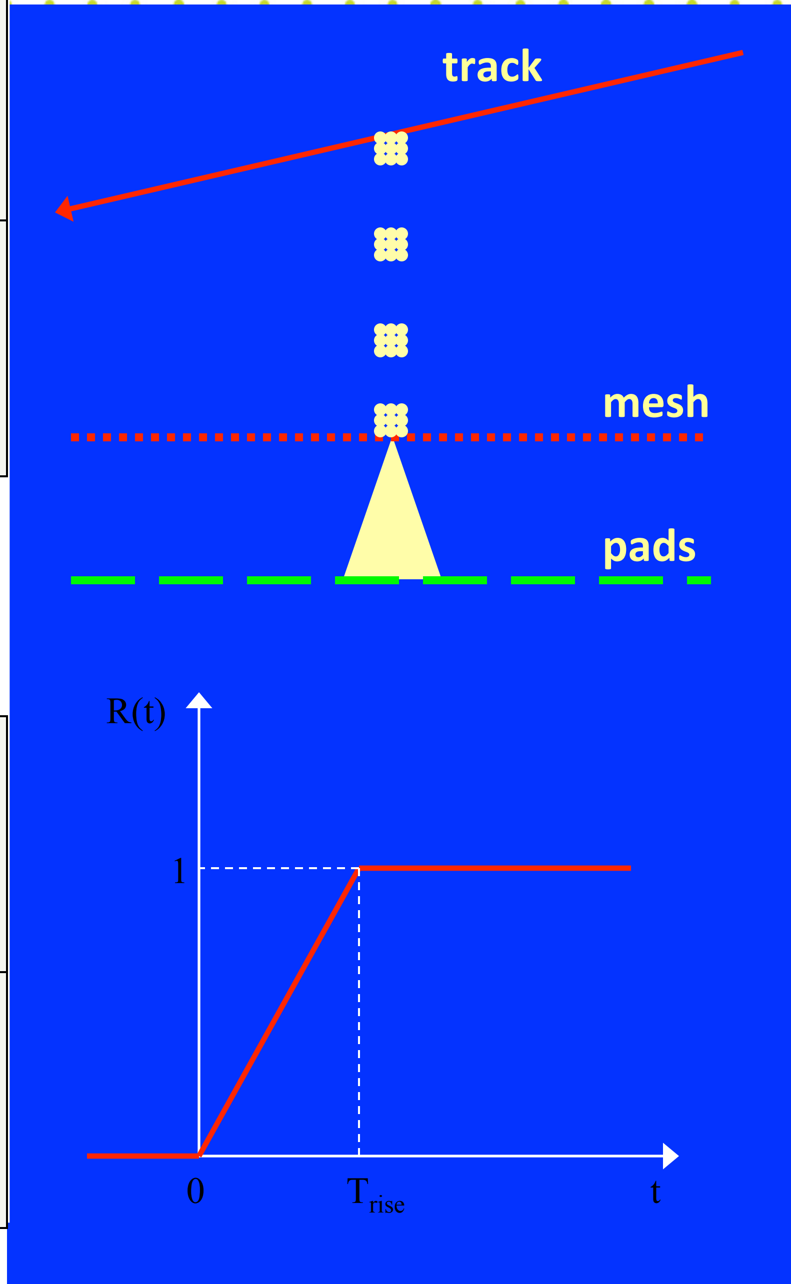

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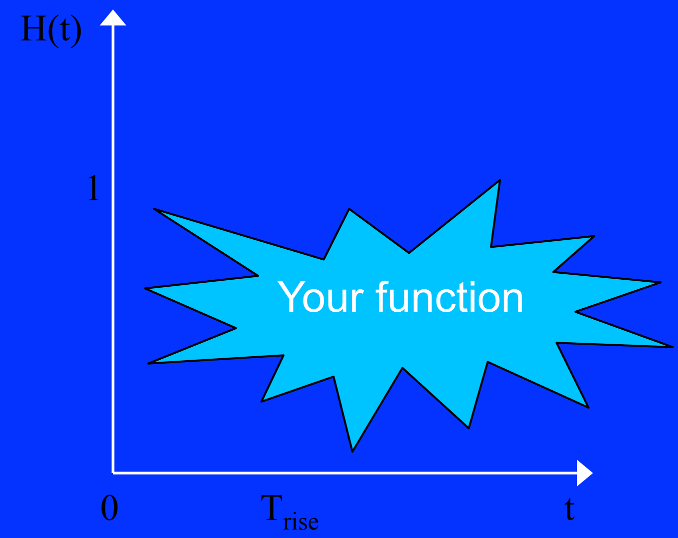

Pulse shape origin

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

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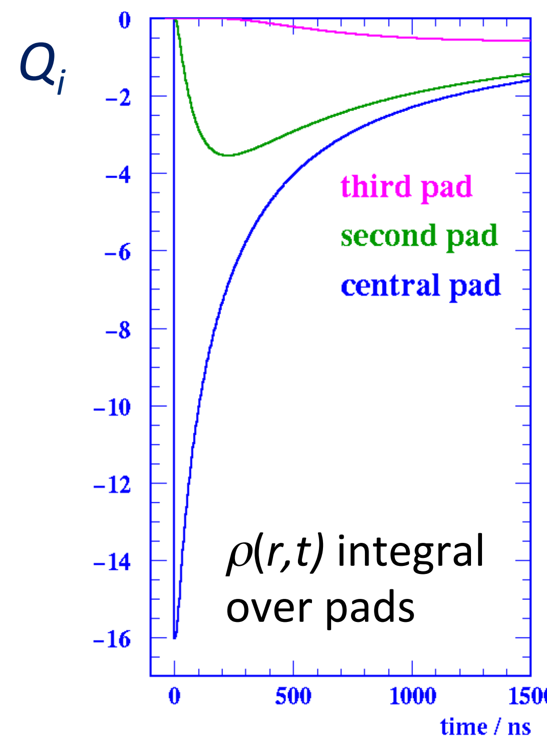
$$h = 1/RC$$

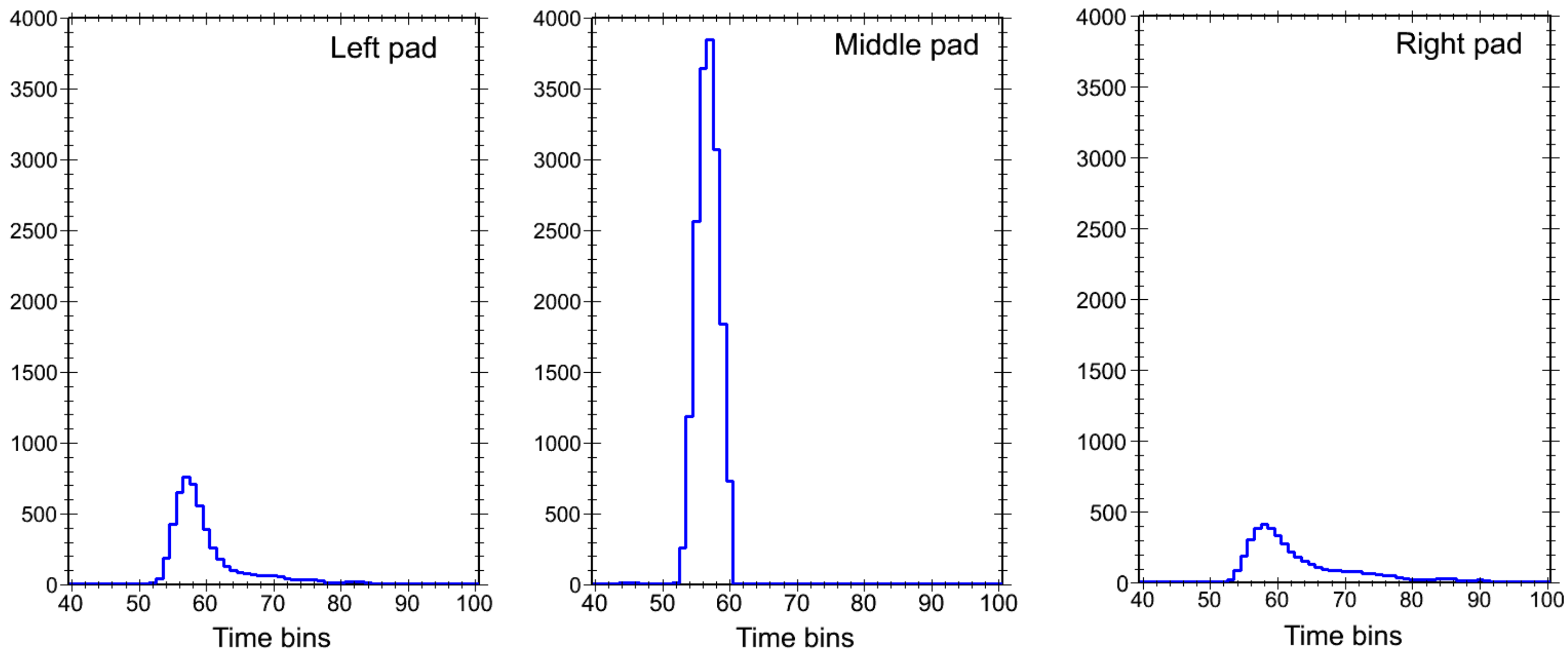
$$Q_i = \int \rho_i(r)\, dr$$

Stand alone simulation



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

Pad Amplitude

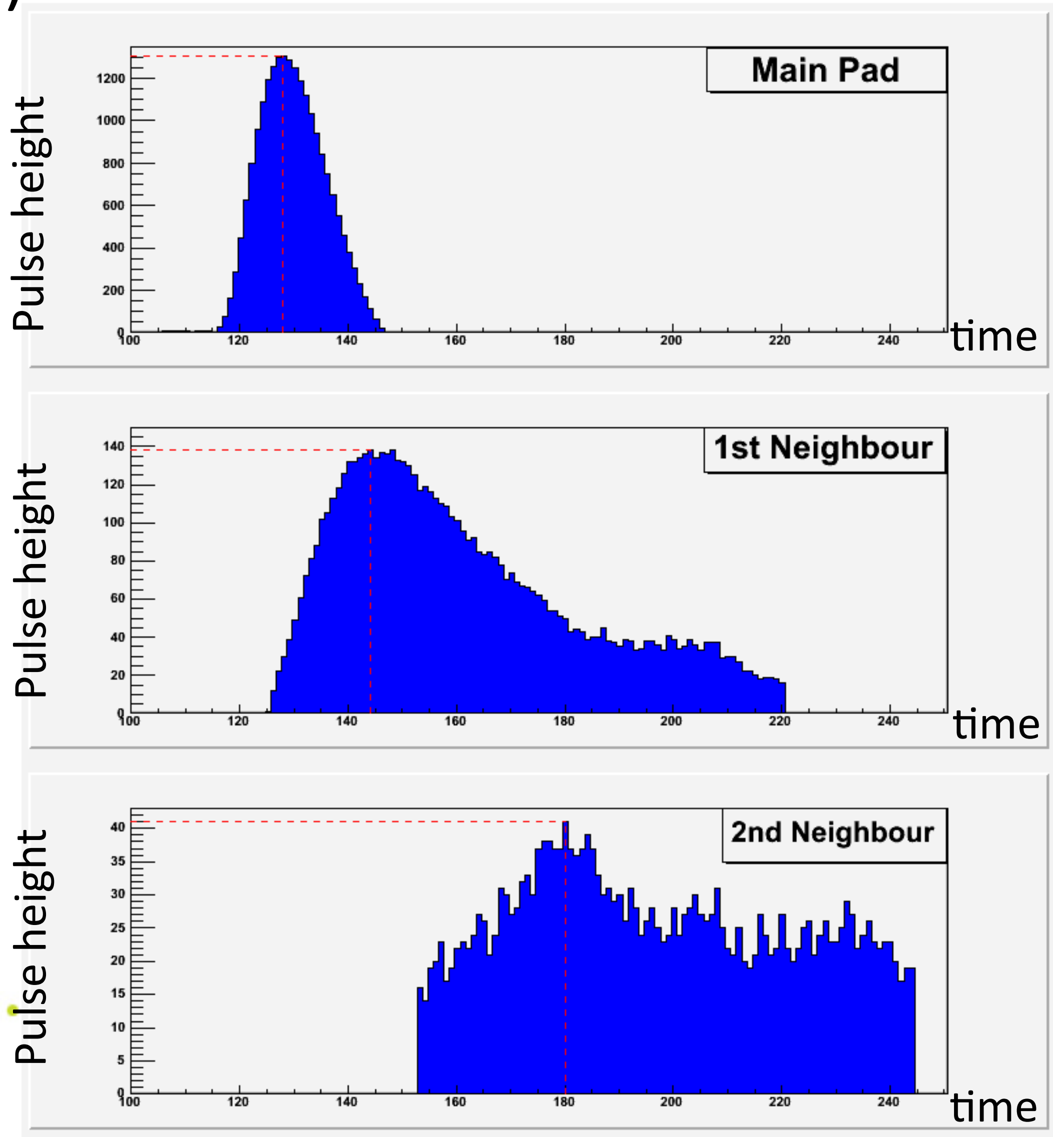


Pad Amplitude

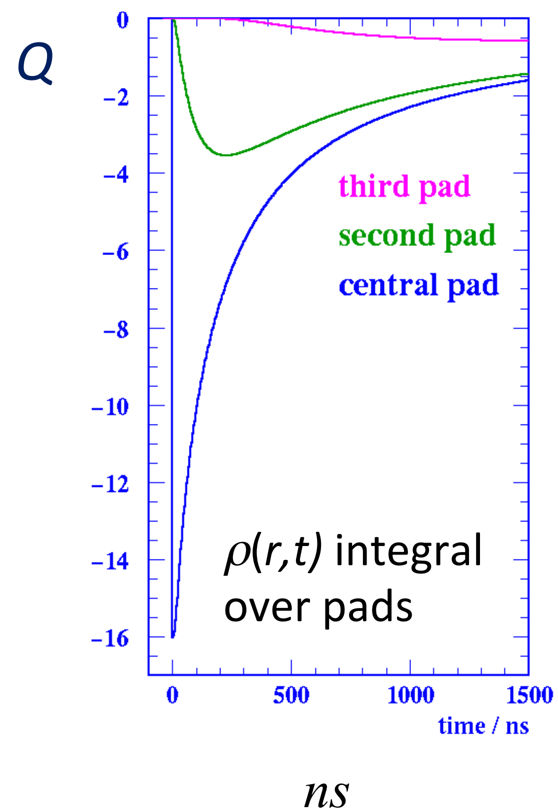
1) Use the maximum as the amplitude
Single Point Maximum(SPM)

A_i = max pulse height

P(i)



Default method used in MarlinTPC

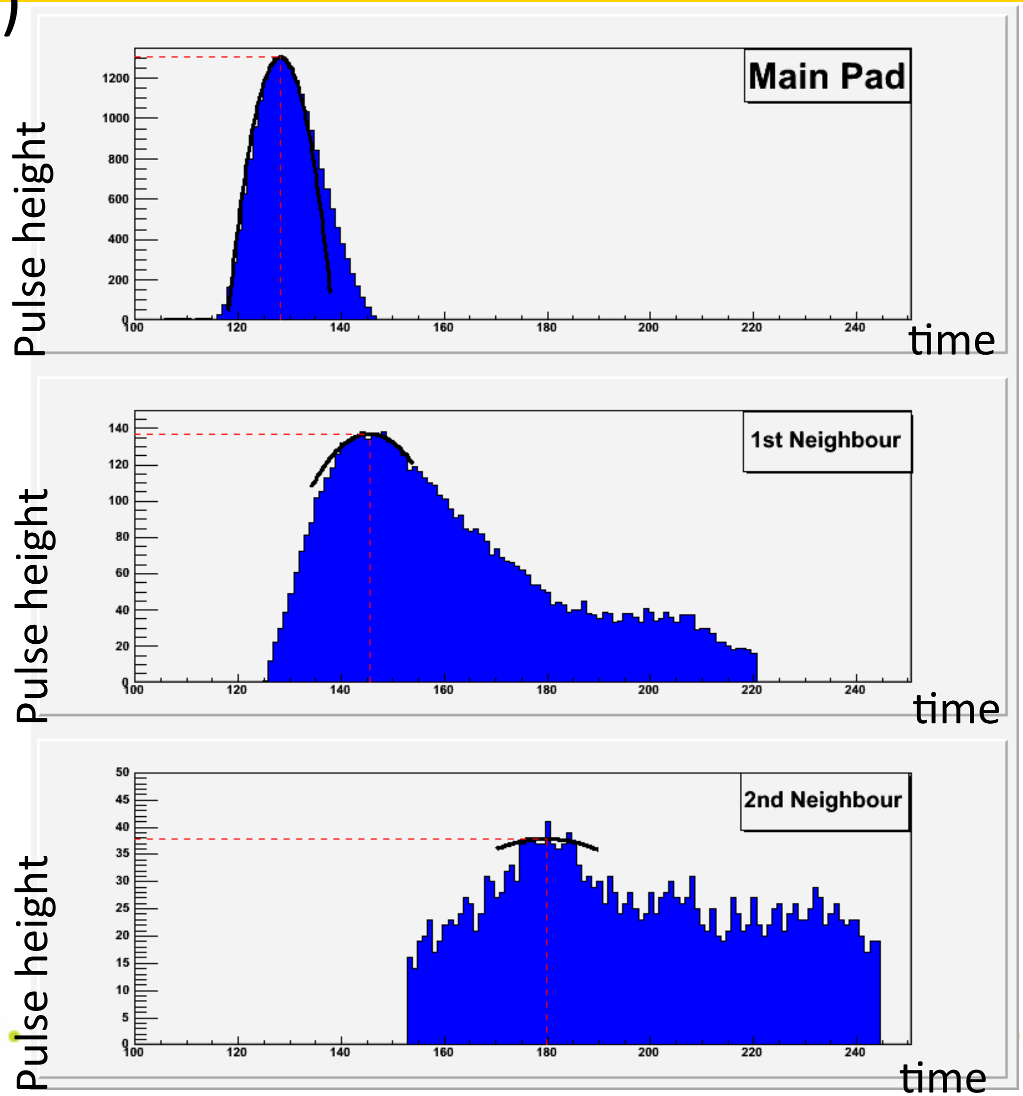


Pad Amplitude

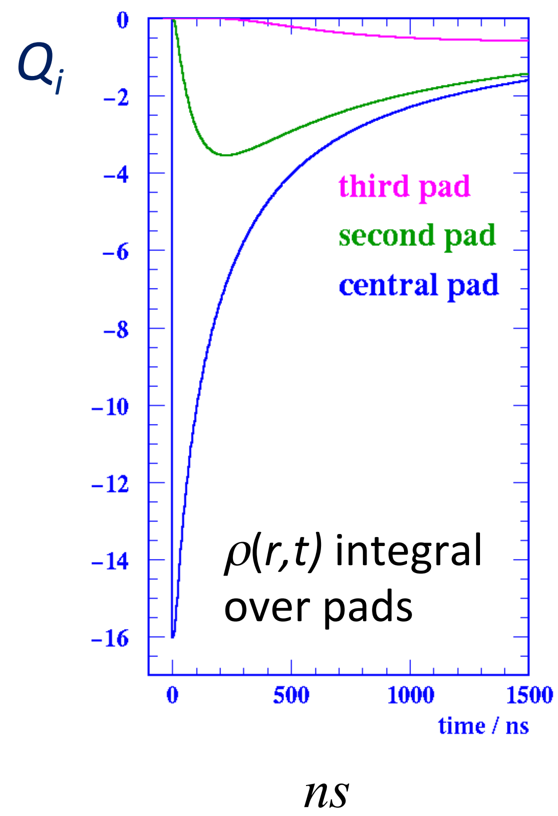
2) Maximum of Parabola
Quadratic Fit Method (QFM)

A_i = max of parabola

P(i)



Method use pre-2011



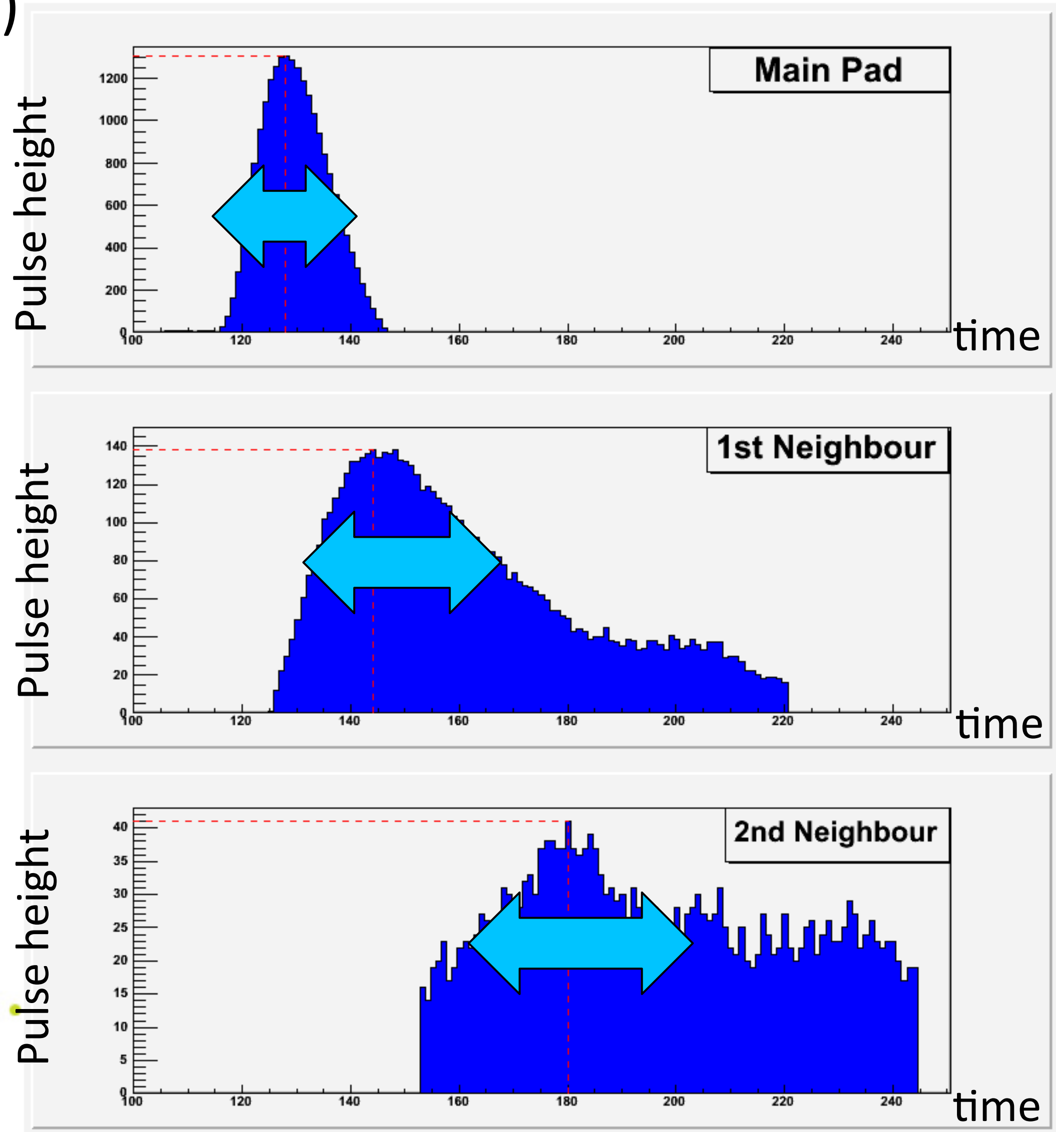
3) Integrate above threshold

Re-integration method (RM)

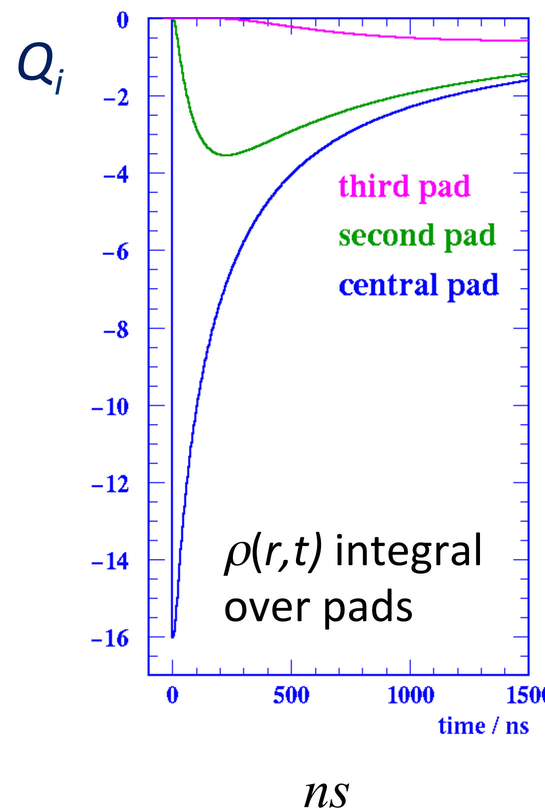
$$A_i = \text{Sum } P(i)$$

Pad Amplitude

P(i)

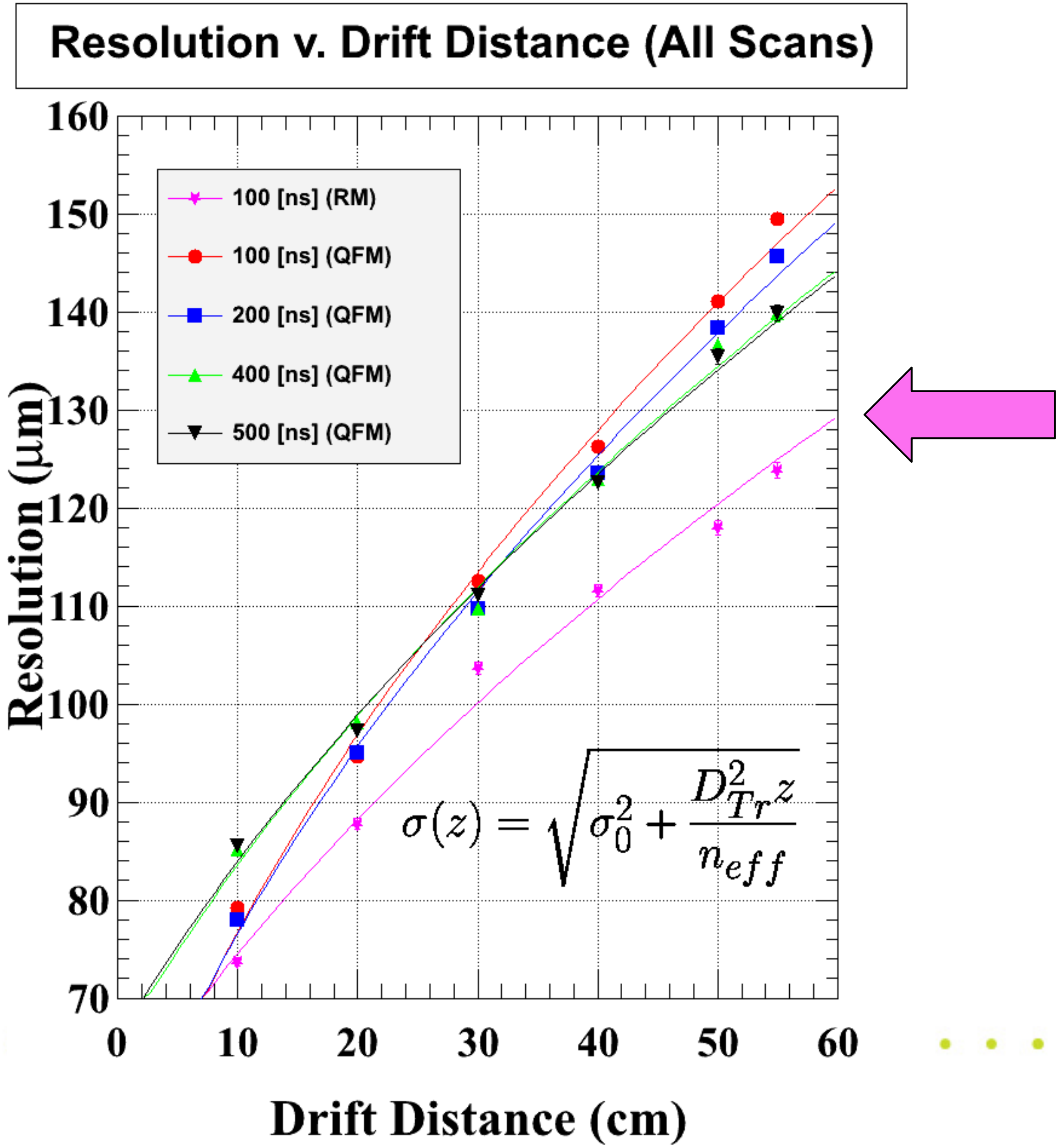


Method use in 2011 (still to be implemented for the 2015 data)



Transverse Resolution MM

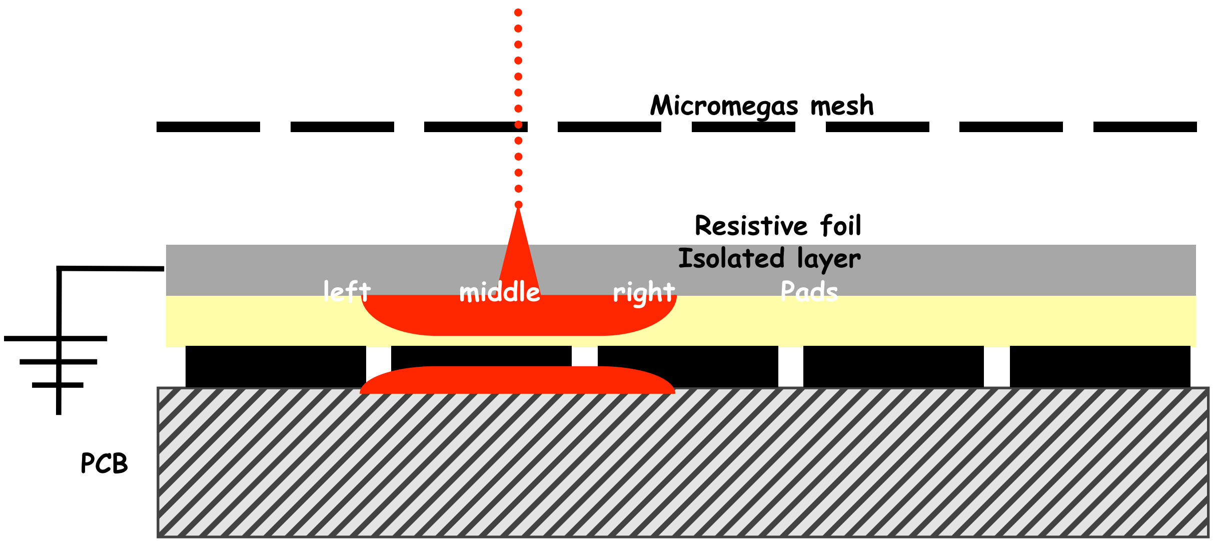
2011 data
Single module



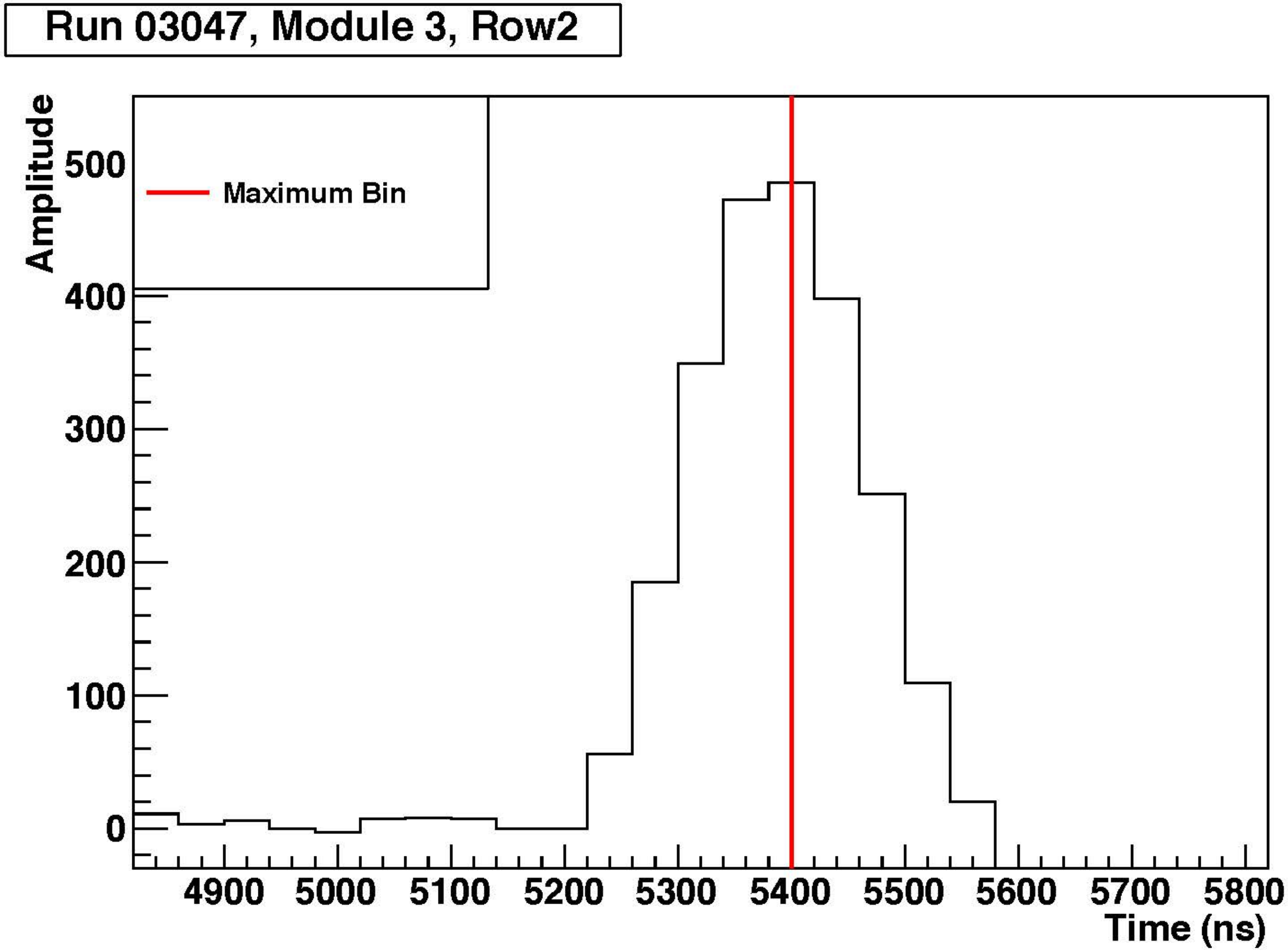
Source:
Nicholi Shiell
M.Sc. Thesis
Carleton University

Charge Dispersion Resistive Anode

r-z plane



Time estimators



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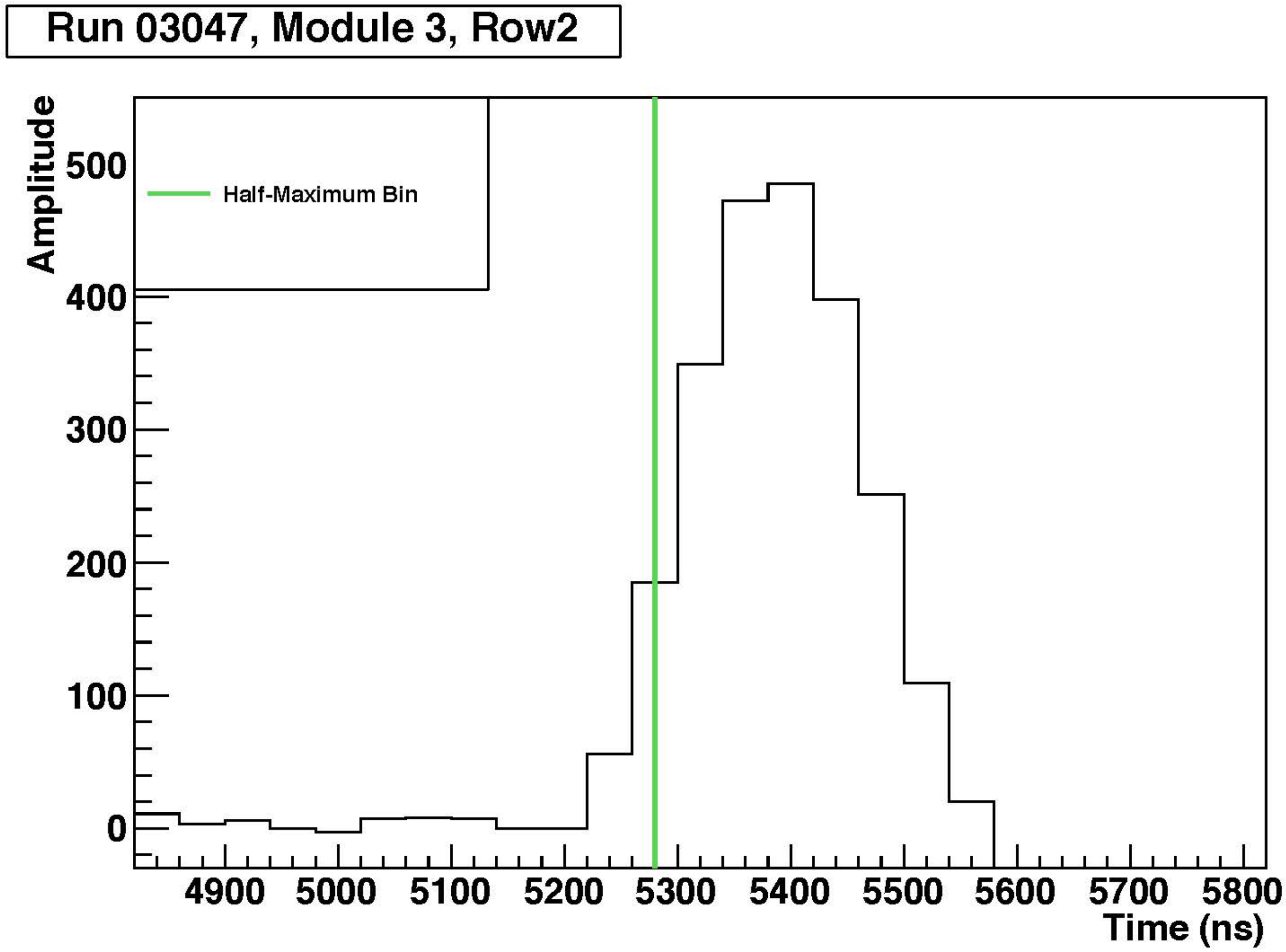

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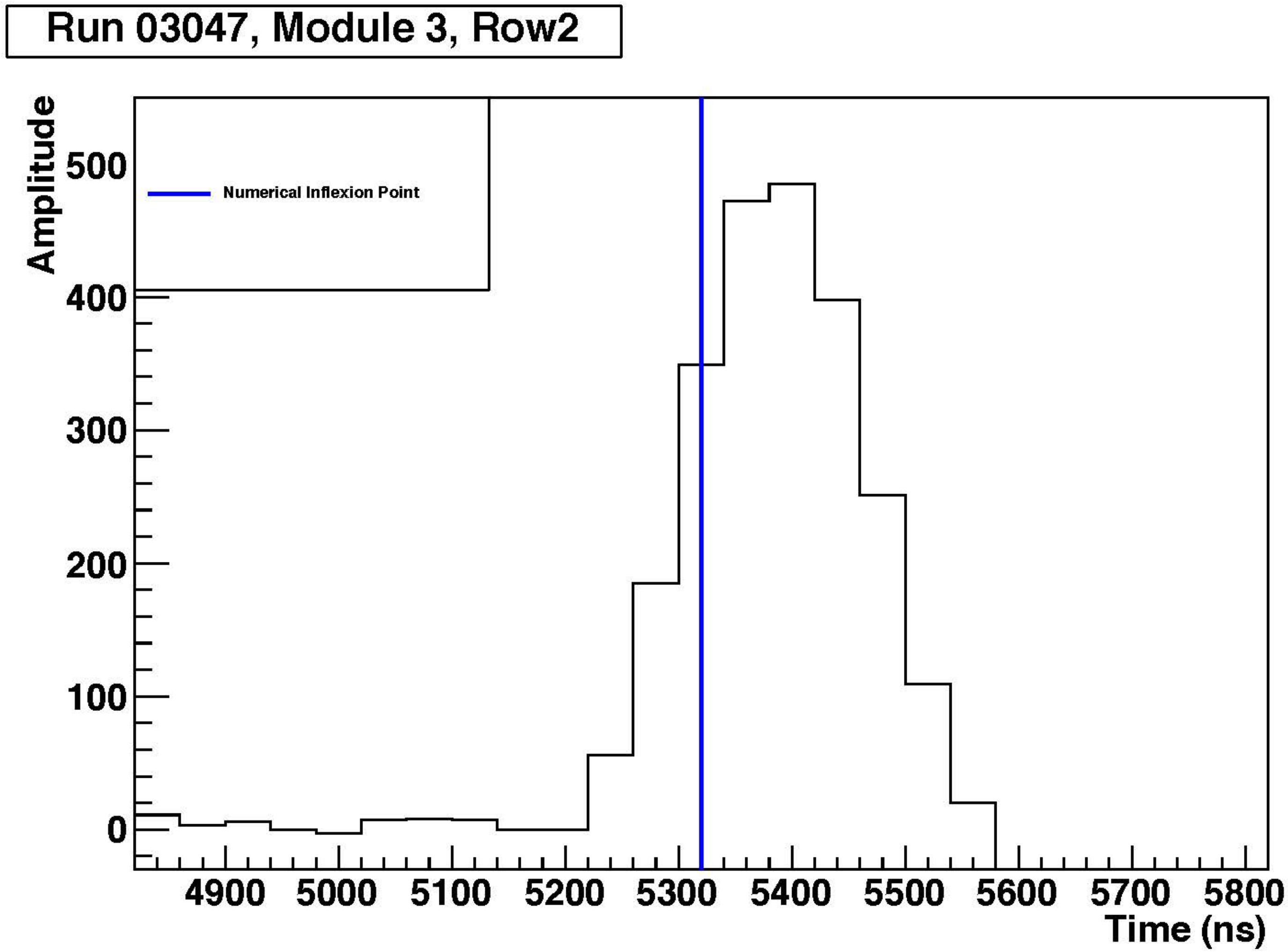

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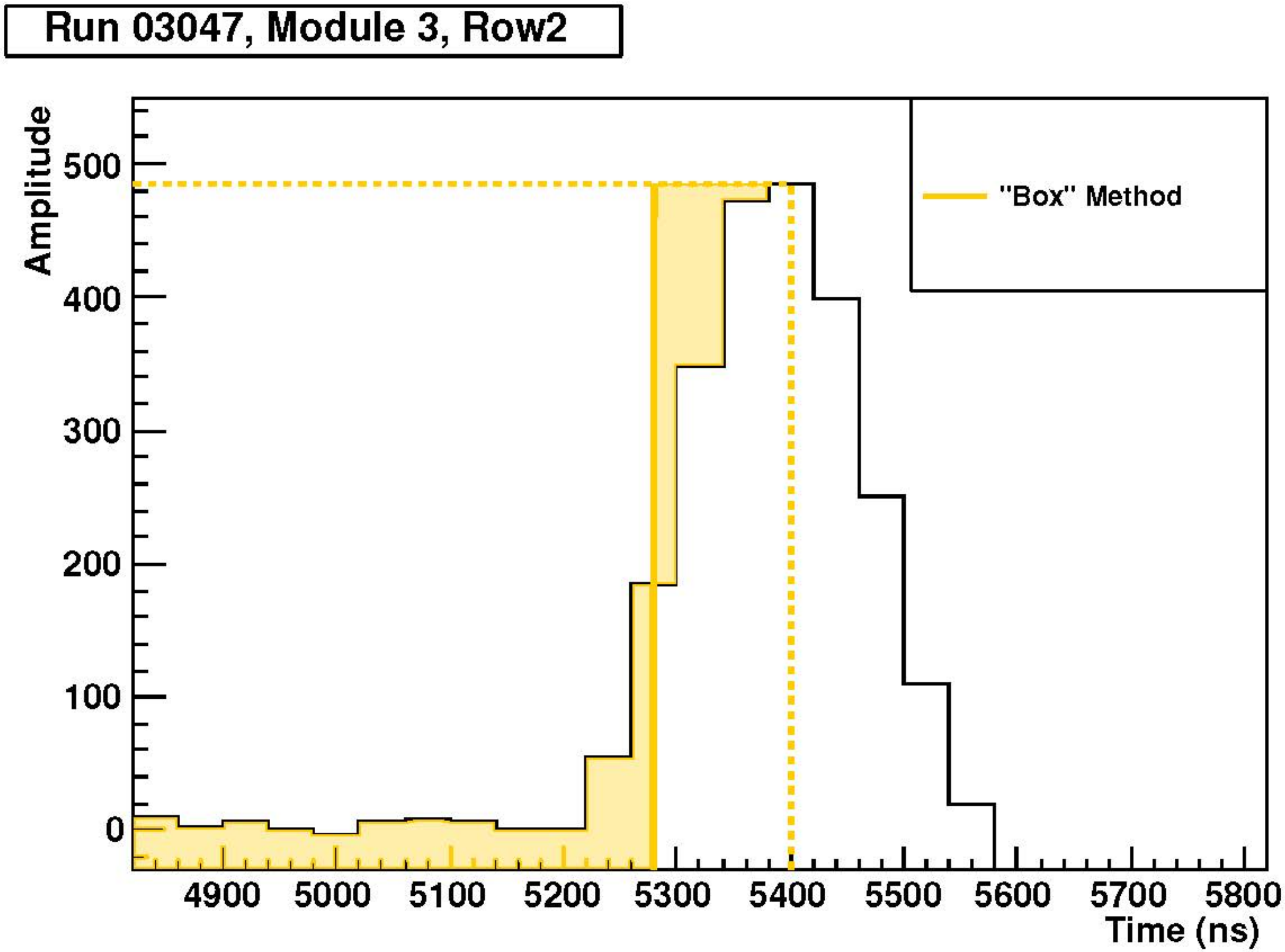

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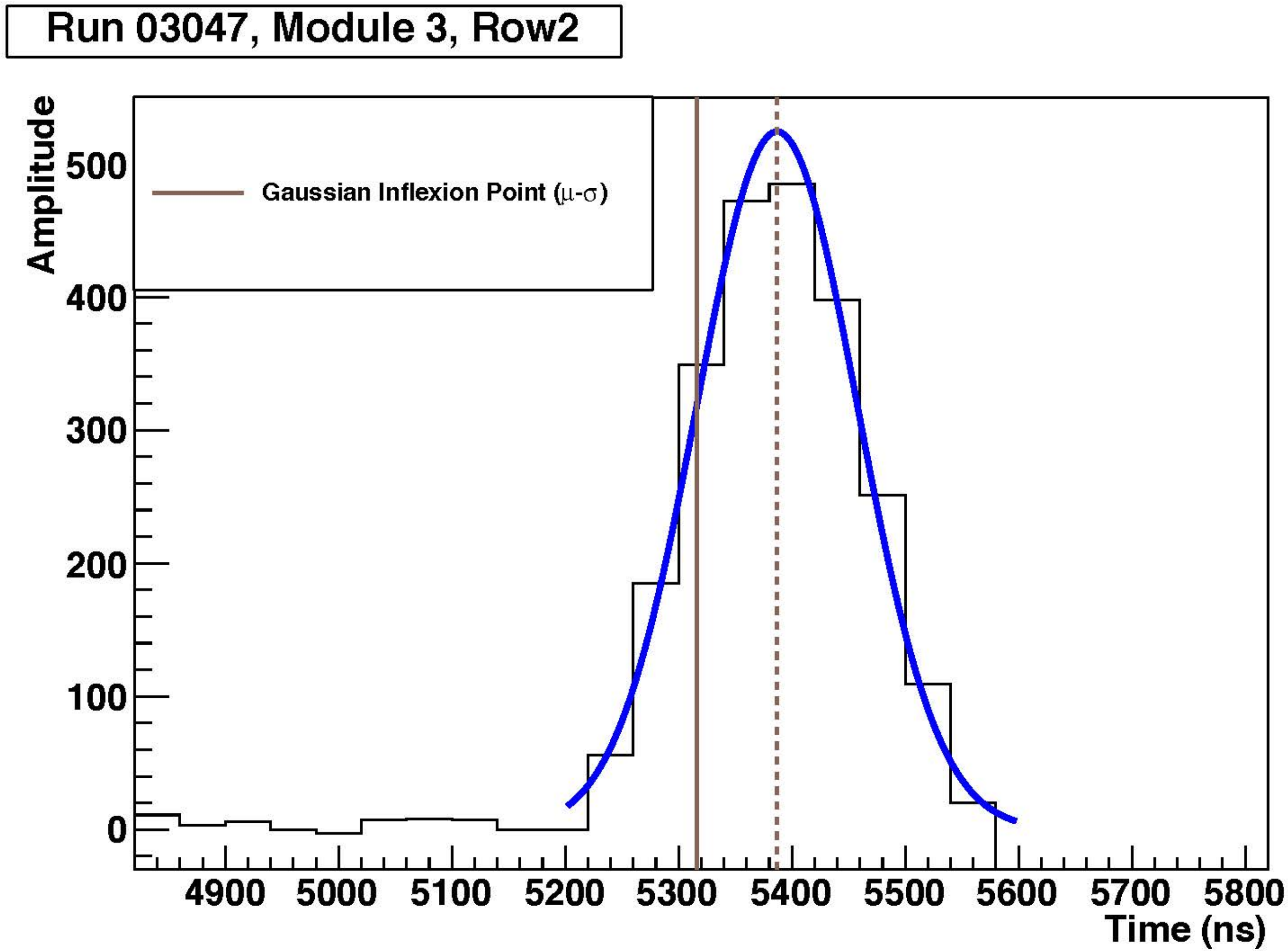
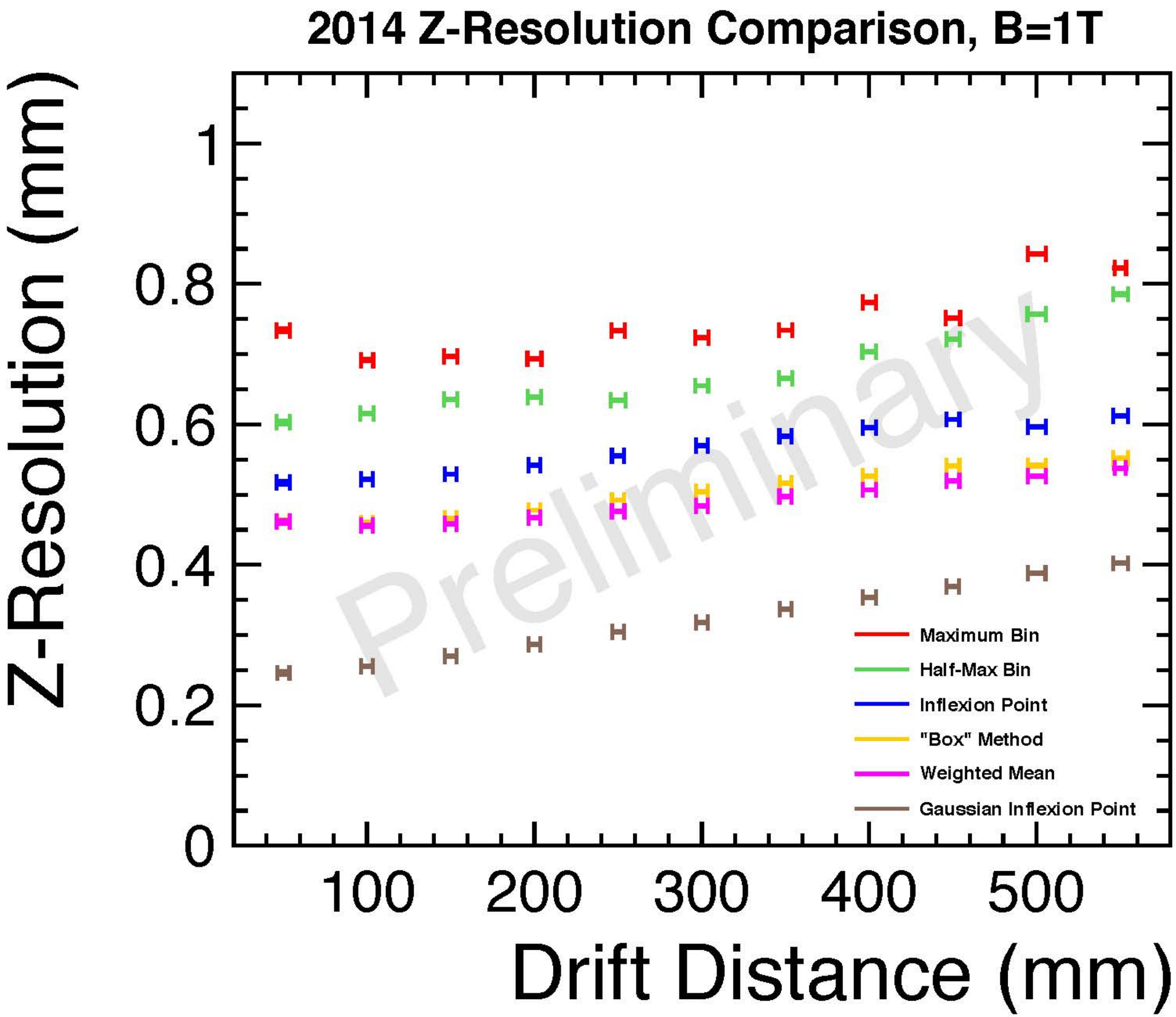
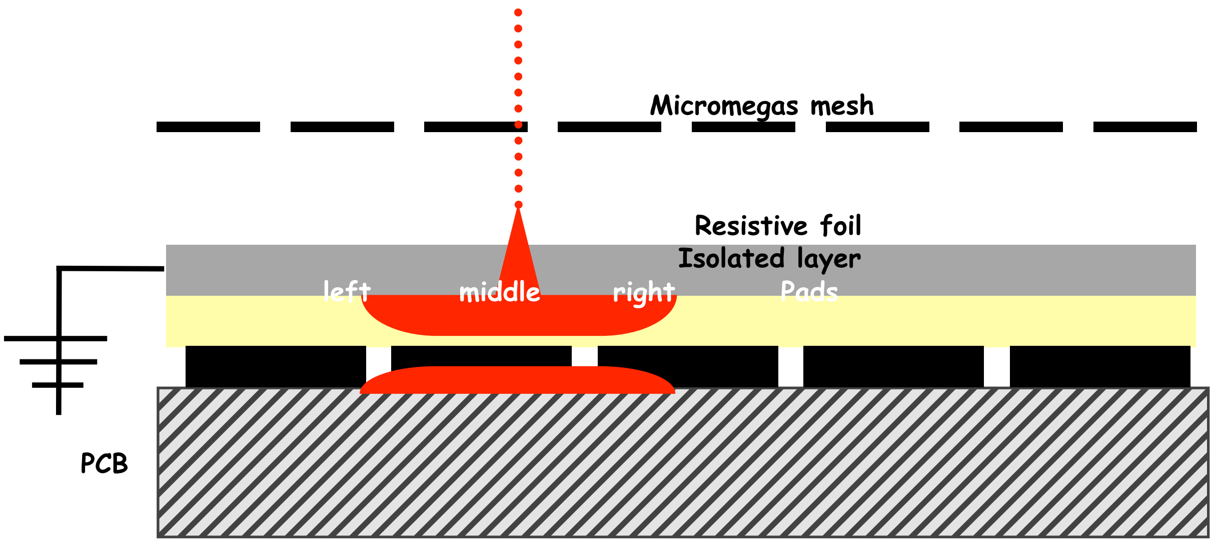


Z resolution

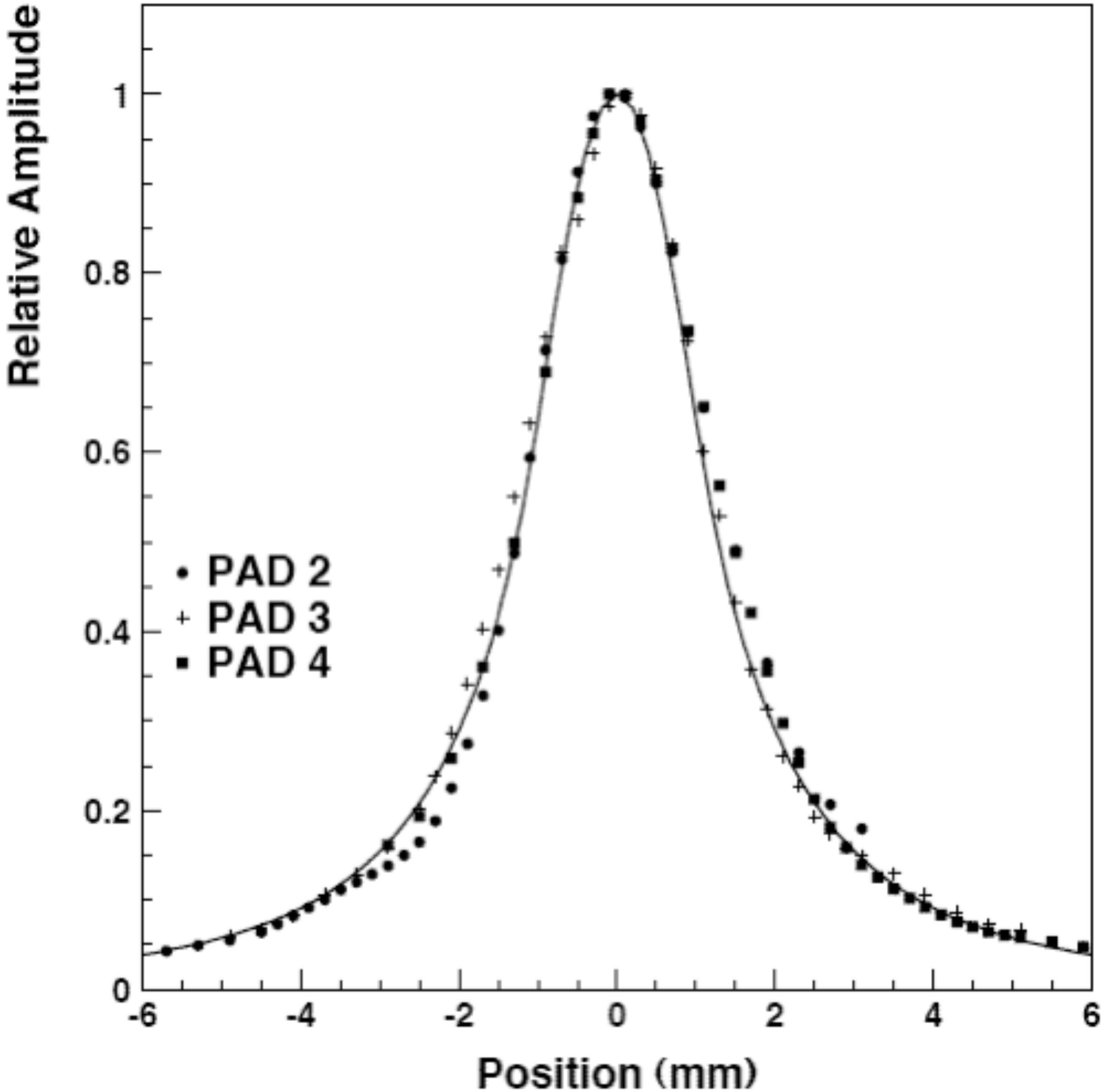


Charge Dispersion Resistive Anode

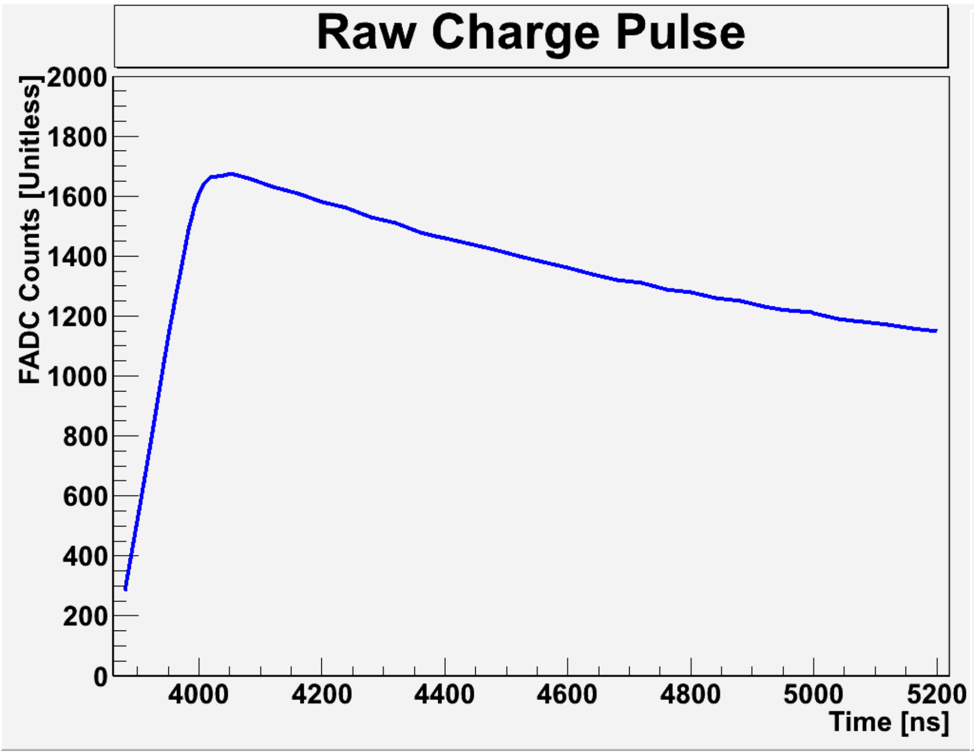
Simulation

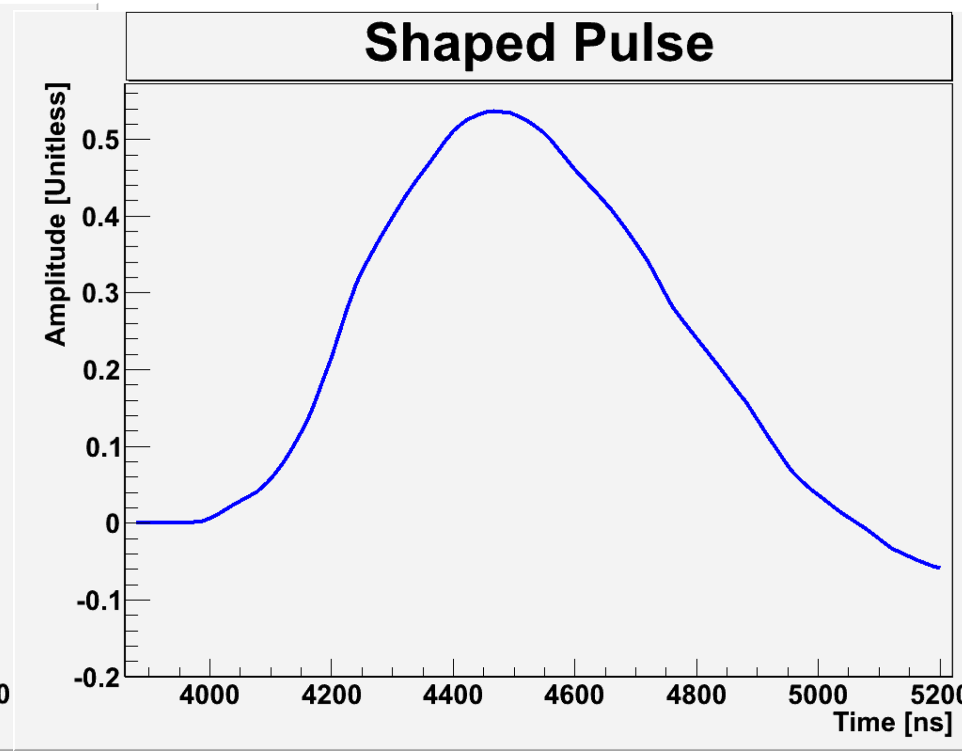


Simulation – PRF (ok)



Raw Charge Shape versus Shaped Pulse





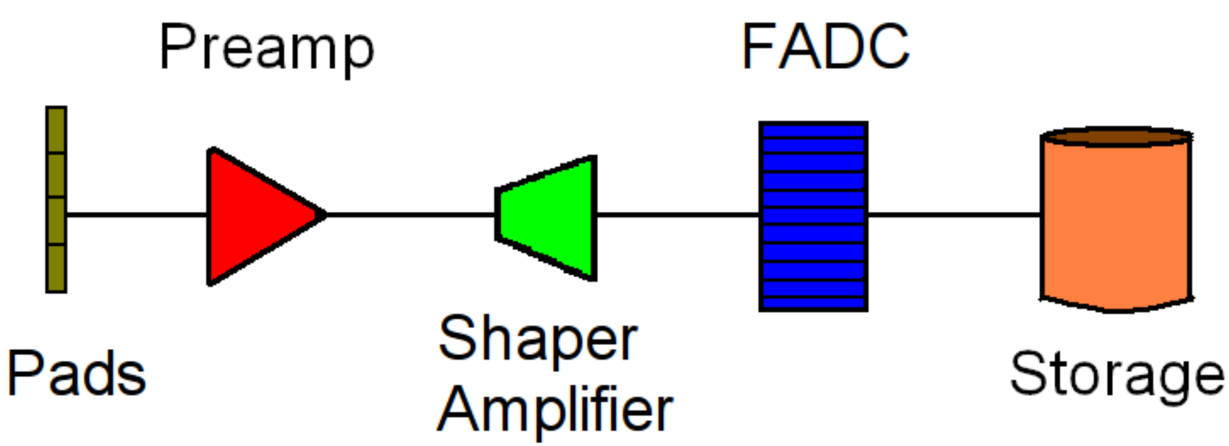
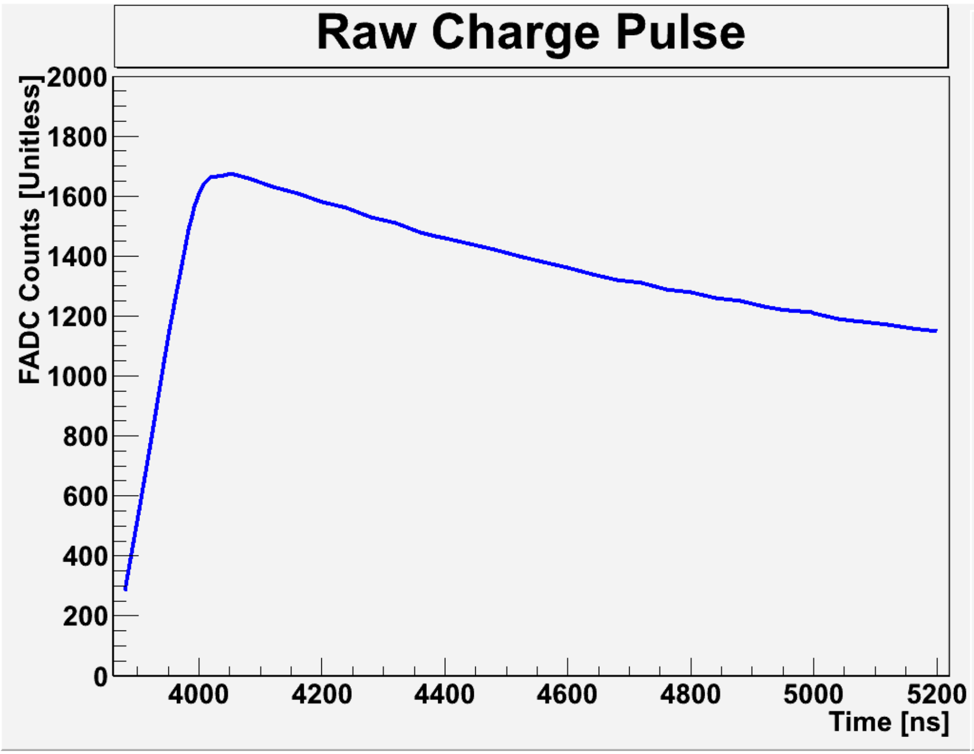
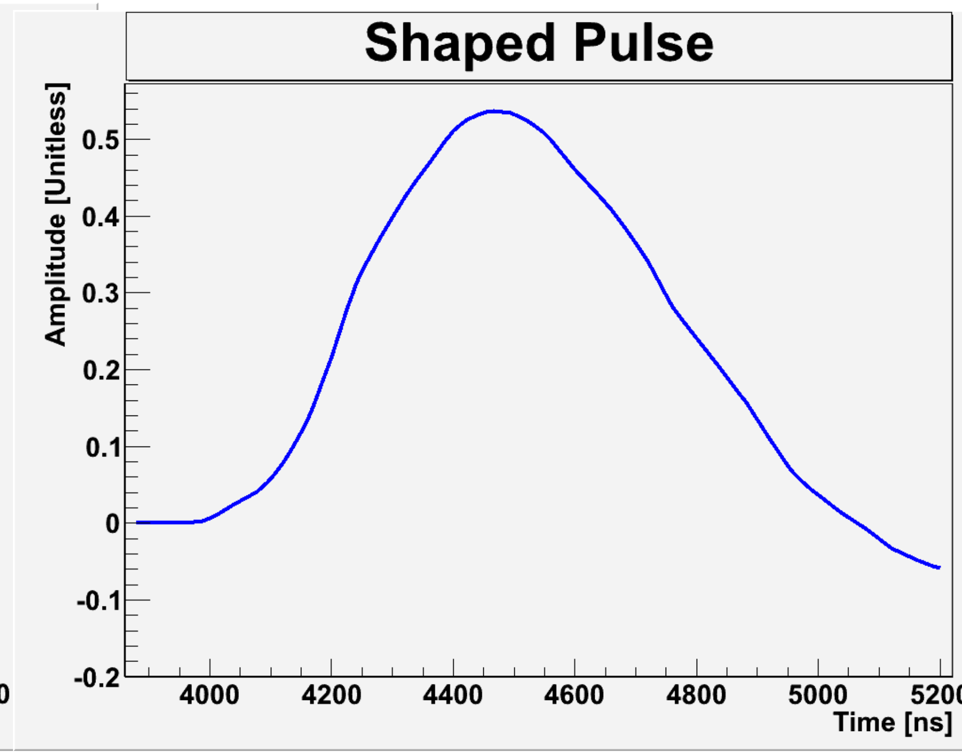


Figure: N. Shiell

Raw Charge Shape versus Shaped Pulse

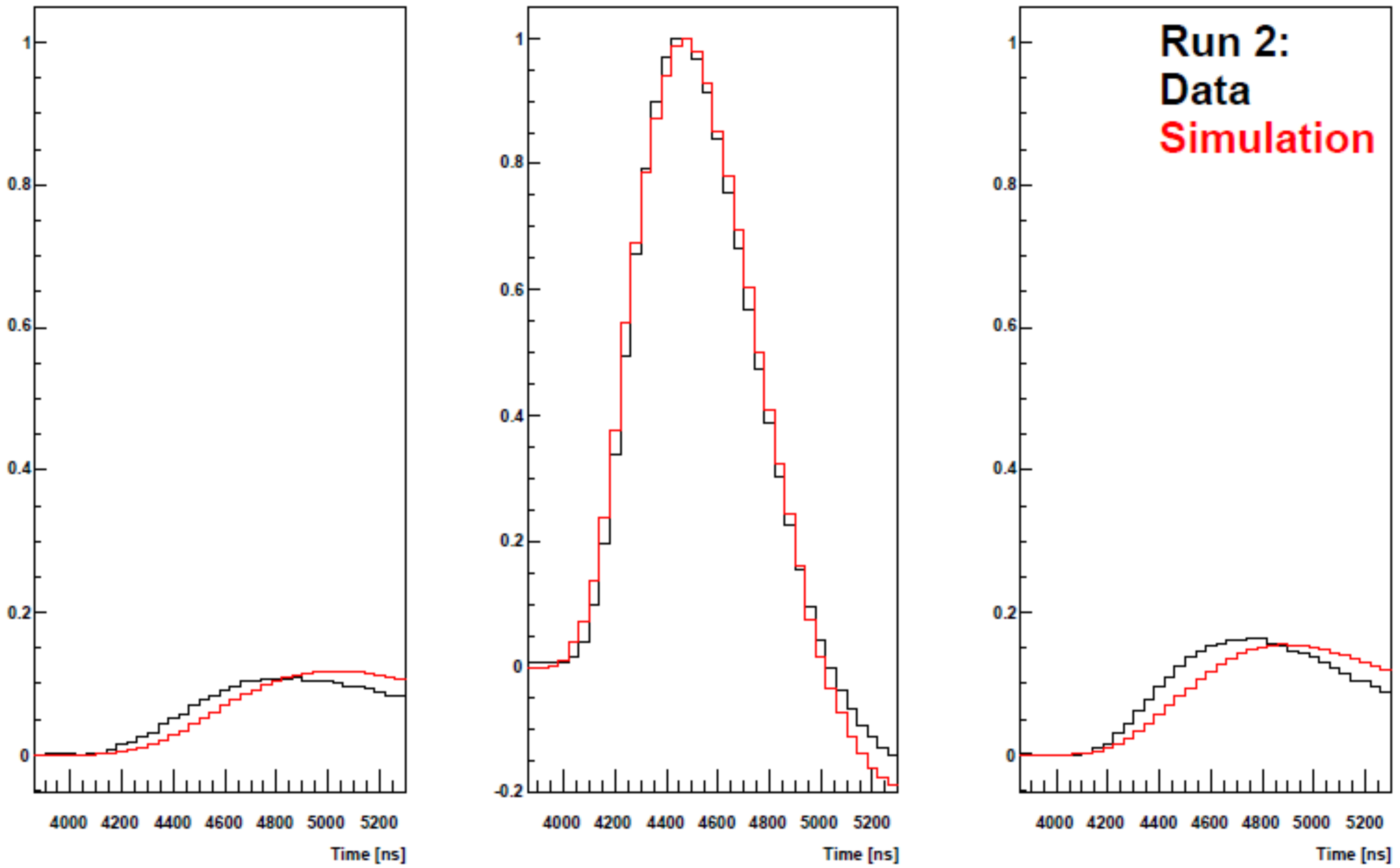




$$H(t) = A_0 \left(\frac{t}{\tau}\right)^3 \sin\left(\frac{t}{b\tau}\right) \exp\left(-\frac{t}{\tau}\right)$$

from Eric Delagnes etal at Saclay

Simulation pulses (ok)



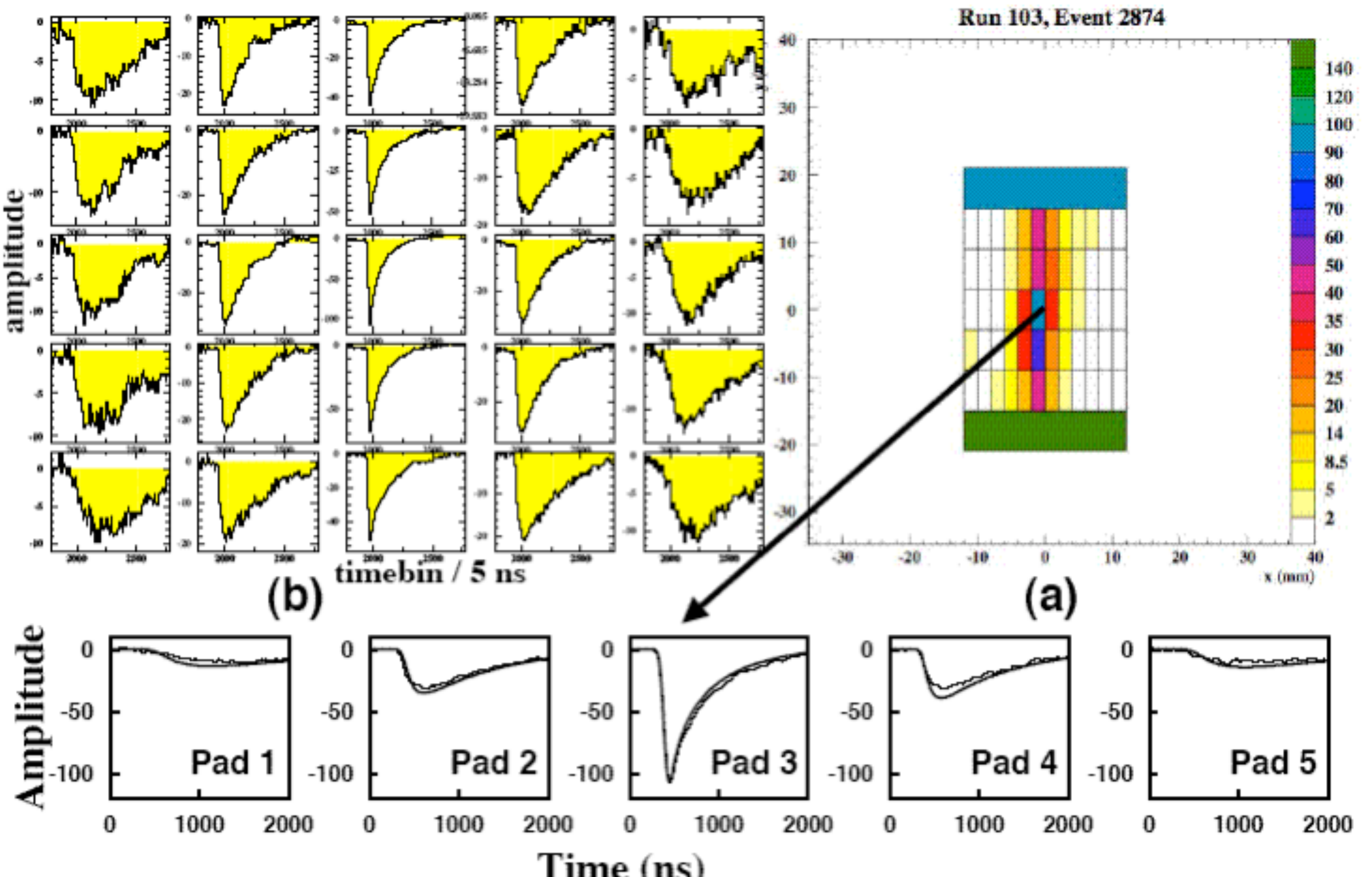
CRUCIAL TO CHARACTERIZE DETECTOR PARAMETERS

Simulation pulses

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

Simulation – hits along tracks (ok)



Overview of Simulation

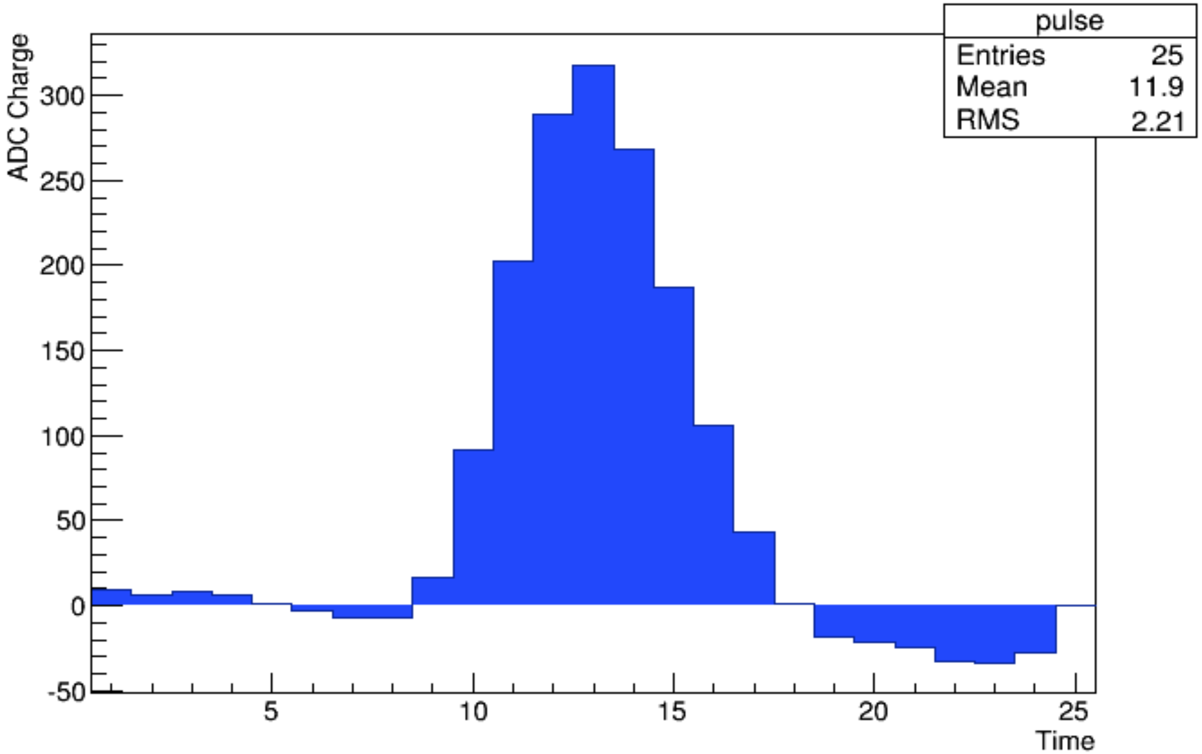
- For each pad we have ***charge*** (ADC) as a function of ***time*** (40 ns intervals)
- Define pad geometry (to do)

Steps from **ionization** to **tracks:**

1) Generate ionization along tracks (ok)
2) Drift ions: longitudinal & transverse diffusion (ok)
3) Signal pulse: induction gap, resistive layer and electronics shaping (ok)
4) Determine ***amplitude*** and ***arrival time*** of each pad pulse (in dev: algorithm to deal with overlapping pulses)
5) Group ***pulses*** on each row into ***hits***
6) Use hit positions to fit ***tracks***
7) Get two-track resolution / single-hit resolution

Pulse Amplitude/Time Determination

- Each readout pad produces an **electronic pulse** which encodes the charge
- Need to determine the **amplitude/time** of this pulse
- **New method:** *Reintegration* over fixed time interval and *Gaussian Inflection* (assume negligible error on time zero)



Conclusions

- Simulation of restive layer validated with data
- The basic framework for producing hits is in placed
- Still need to fine-tune pulse finding in mutli-track environment
- Define geometry: using GEAR file LCTPC
- Project for new M.Sc. Student at Carleton
- Benchmarked two-track separation power of the MM with resistive layer