Pad Response Function
PRF

A. Bellerive - M. Dixit - P. Hayman - N. Shiell

December 11, 2012

Outline

- Intro: Signal Pulse
  - **Definition of amplitude and time (A_i,t_i) for a pad**
  - **Conceptual Pad Response Function (PRF)**
  - **Scaling of PRF**
- Determination of PRF parameters (calibration)
  - **Parameterization of PRF**
  - **Seed track**
  - **X^2 minimization and number of d.o.f.**
- Development and Future
  - **Handling Error from (A,t) → (PRF,t) → (x,y,z) for a hit to unbiased track estimators (d0, φ, CU, z, λ)**
  - **Calibration PRF Module and Simulation**
- Summary

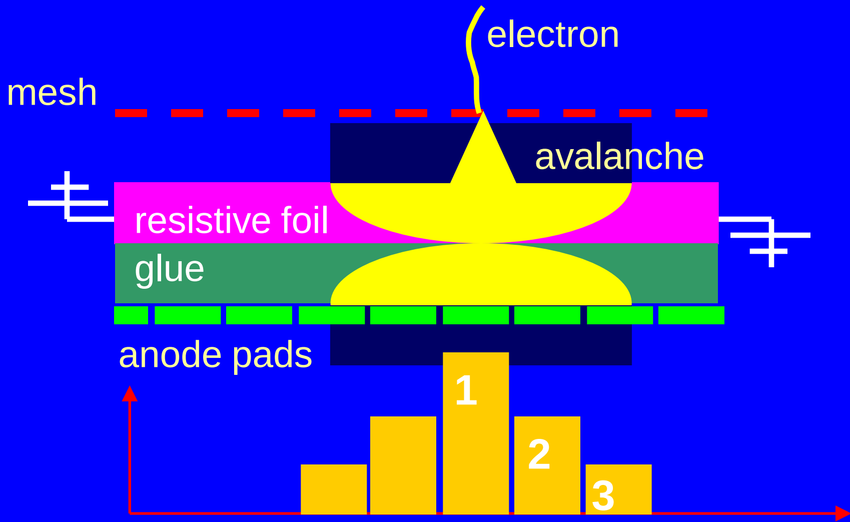
Charge dispersion

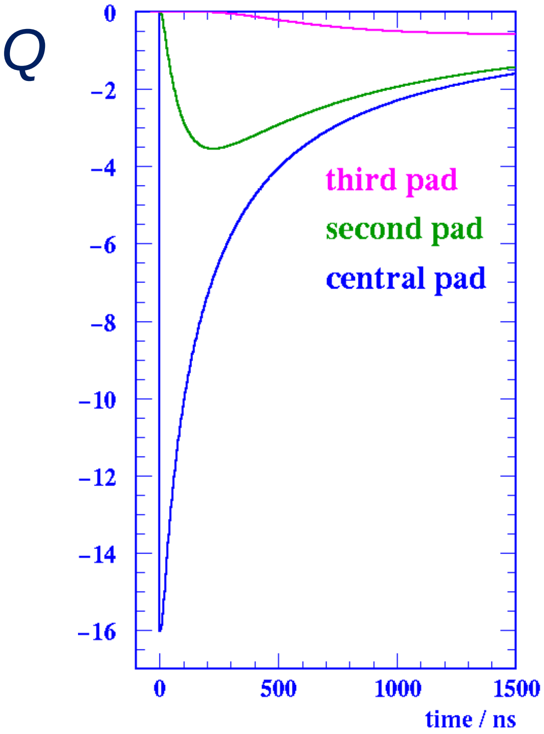
- A high resistivity film bonded to a readout plane with an insulating spacer
- 2D continuous RC network defined by material properties and geometry.
- point charge at r = 0 & t = 0 disperses with time.

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

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

Micromegas + resistive anode





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

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

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

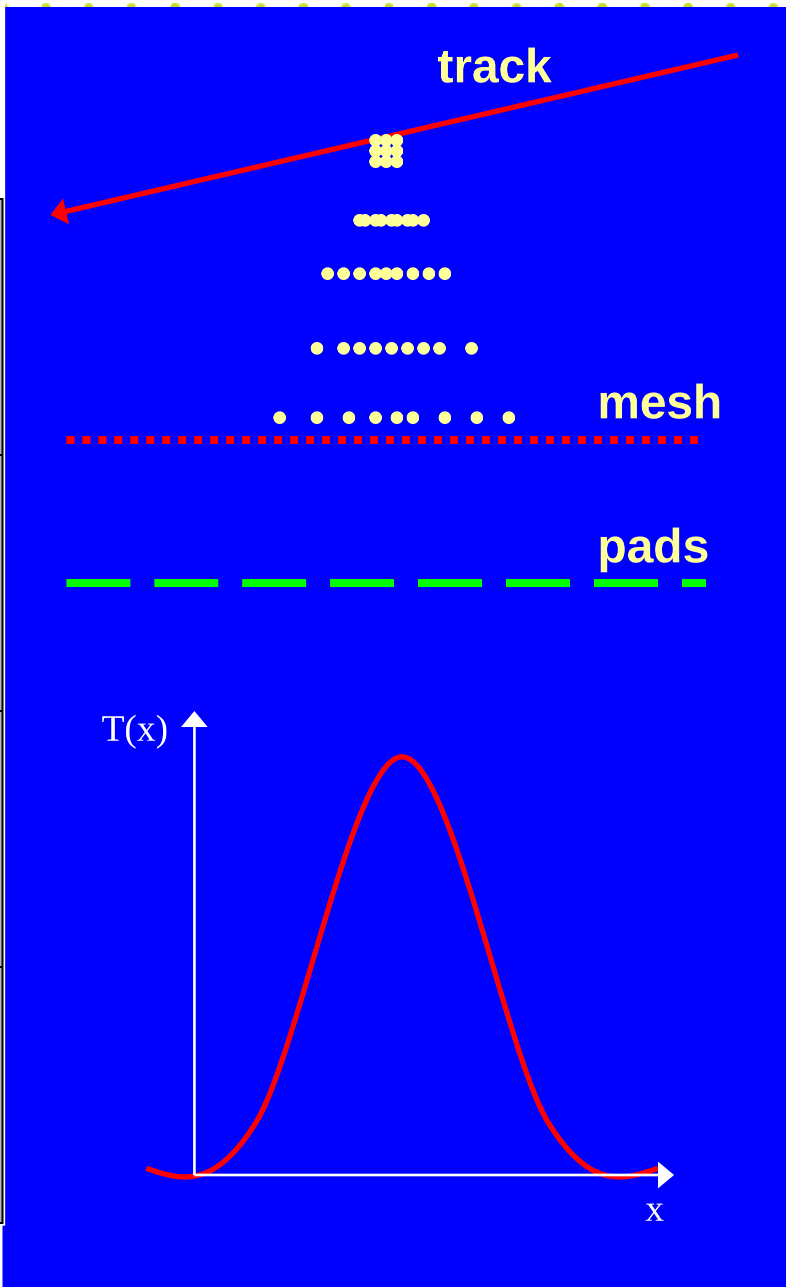
Preamplifier Response

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

Resistive foil + glue

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

$$h = 1/RC$$



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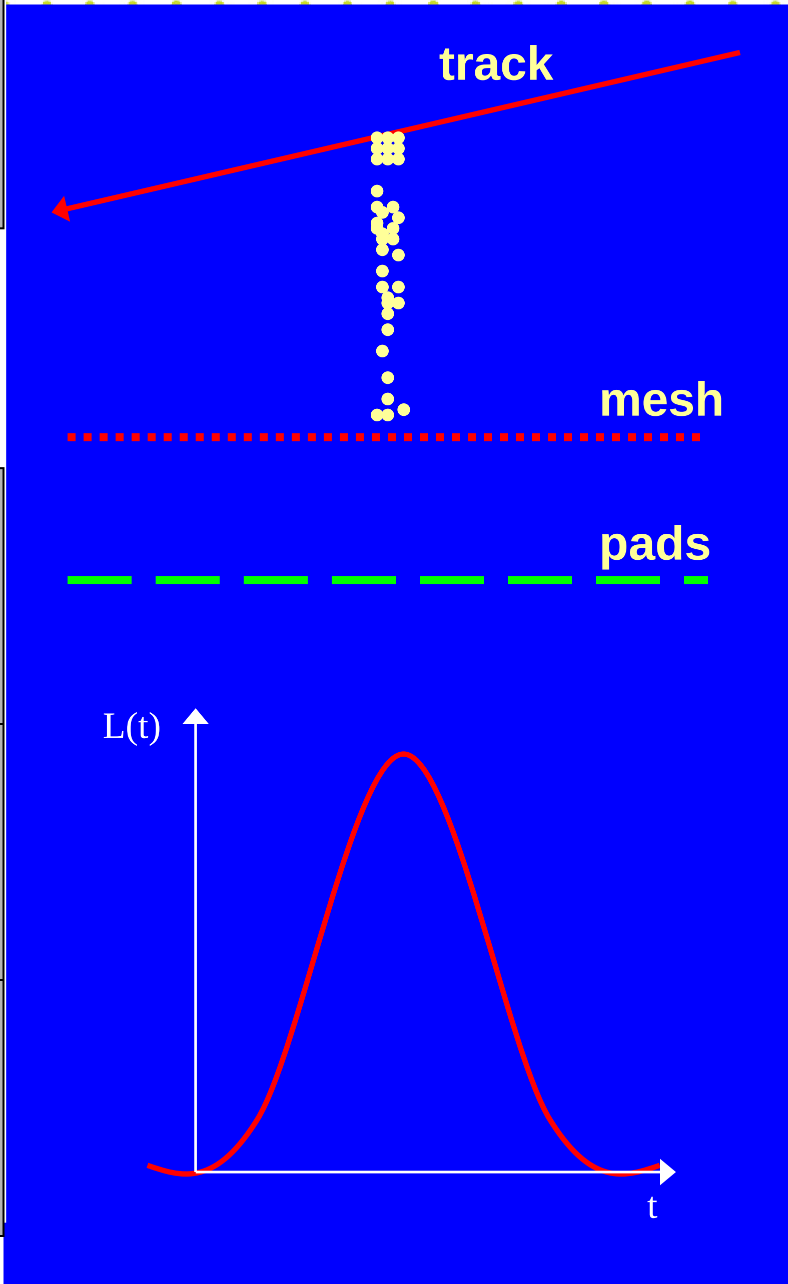

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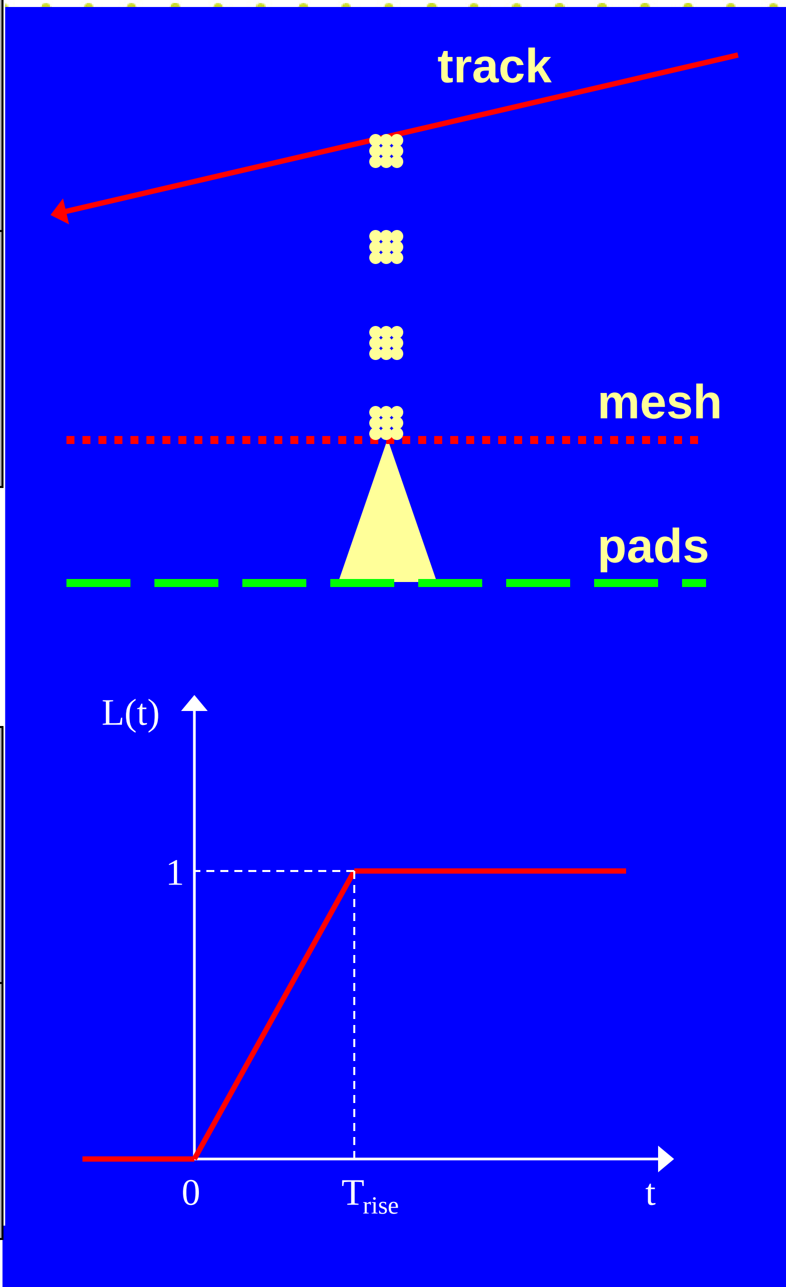

Pulse shape origin

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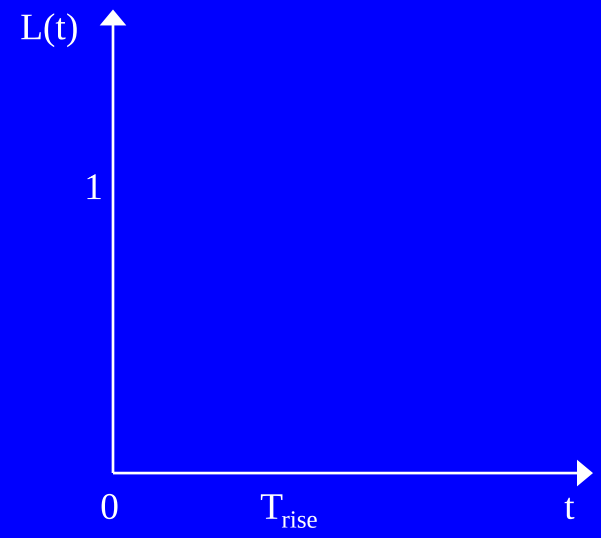


Pulse shape origin

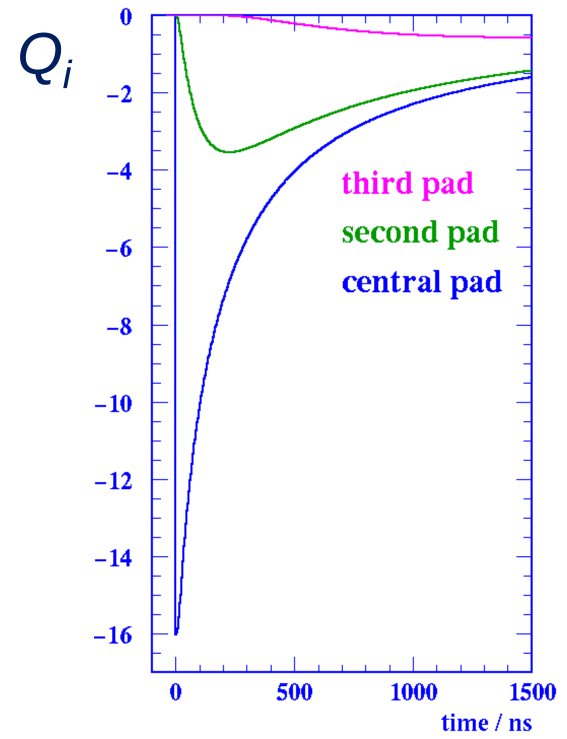
Transverse diffusion	$T(x) = \frac{1}{\sigma_x \sqrt{2\pi}} \exp(\frac{-x^2}{2\sigma_x^2})$
Longitudinal diffusion	$L(t) = \frac{1}{\sigma_t \sqrt{2\pi}} \exp(\frac{-t^2}{2\sigma_t^2})$
Induction gap	$R(t) = \frac{t}{T_{rise}} \quad 0 < t < T_{rise}$ $= 1 \quad t > T_{rise}$ $= 0 \quad t < 0$
Preamplifier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

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

$h = 1/RC$

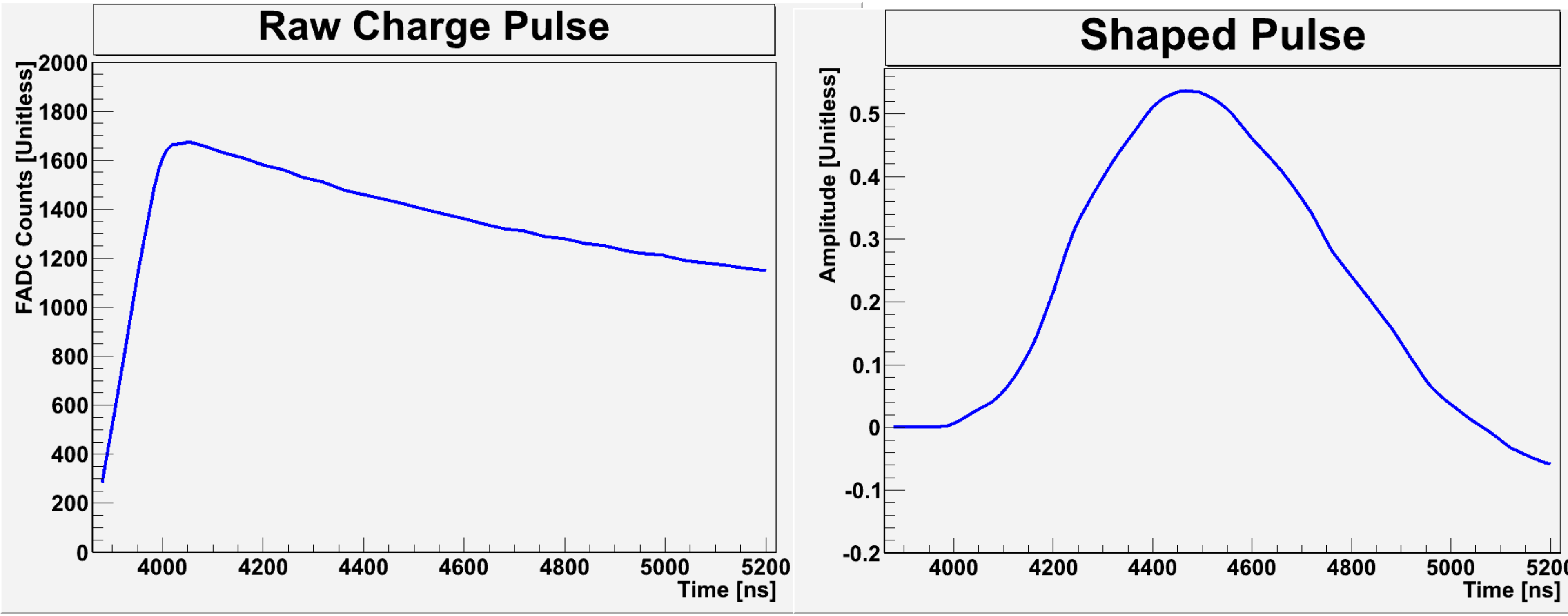
$$Q_i = \int \rho_i(r)\, dr$$

Stand alone simulation



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

Raw Charge Shape versus Shaped Pulse



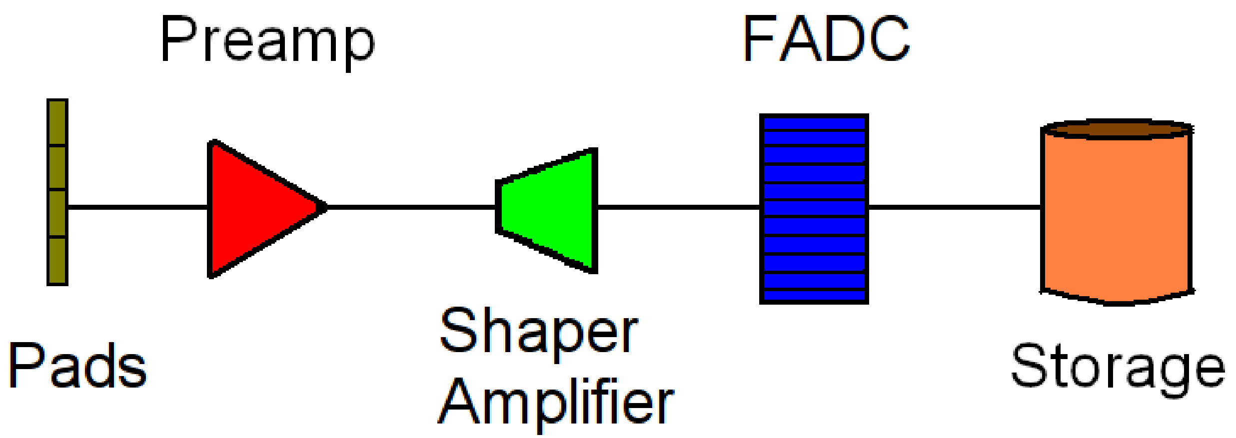
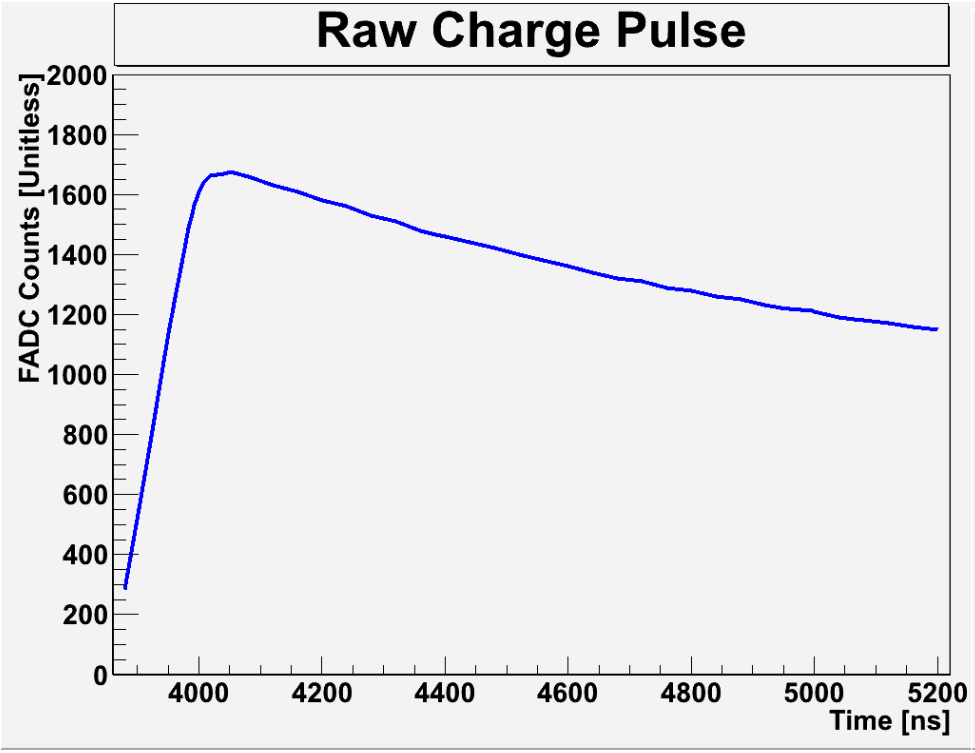
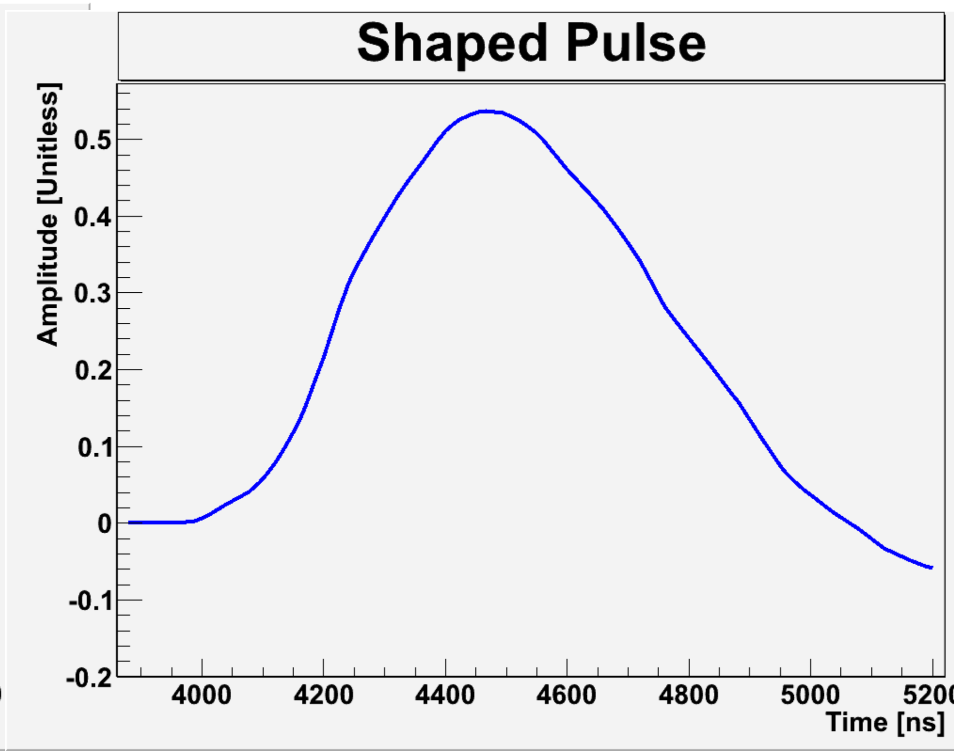


Figure: N. Shiell

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 (2011)

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

??? Measured value in the lab ???

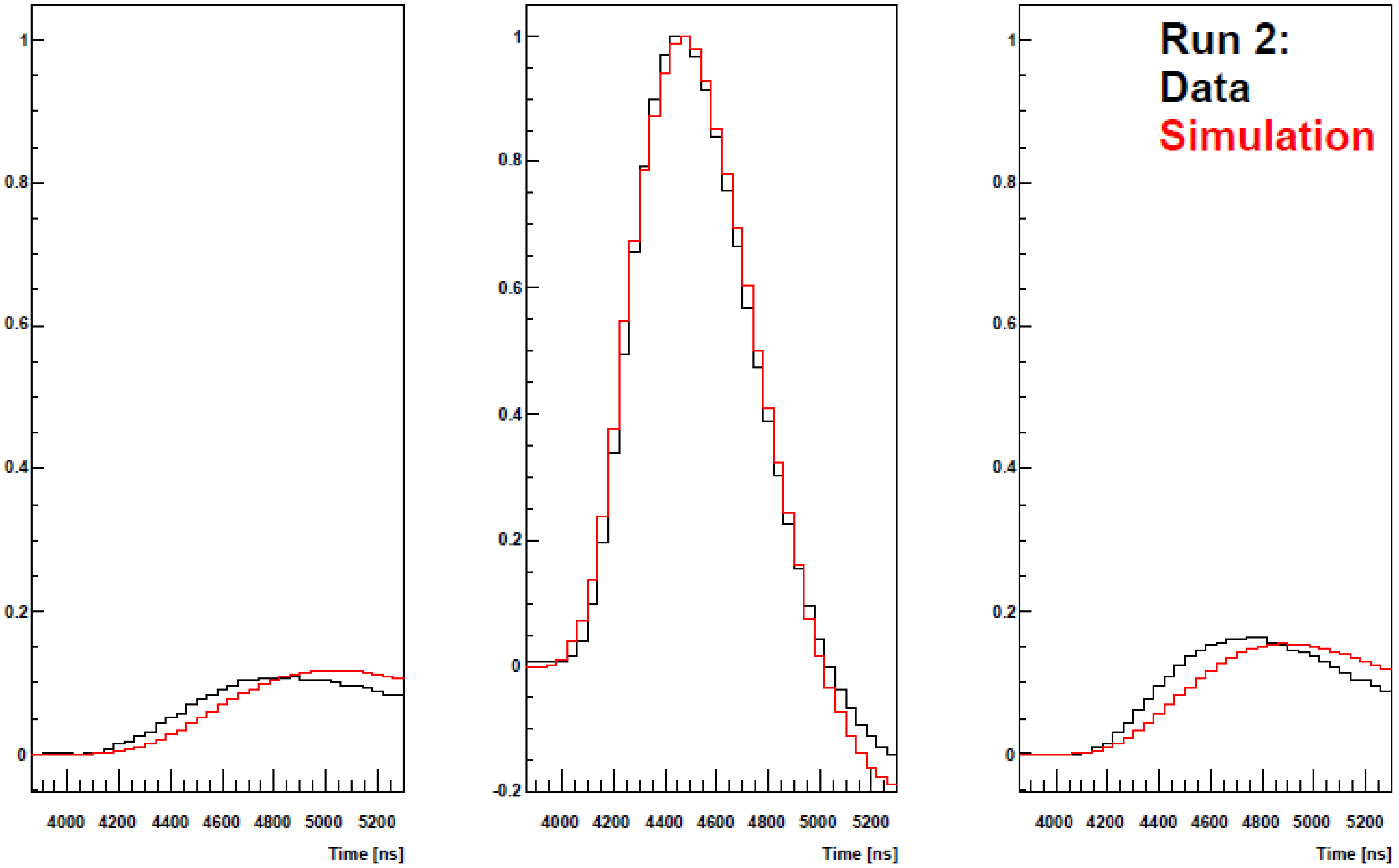
2.66 ↔ 2.09

166 ns ↔ 199 ns

3.42 ↔ 3.33

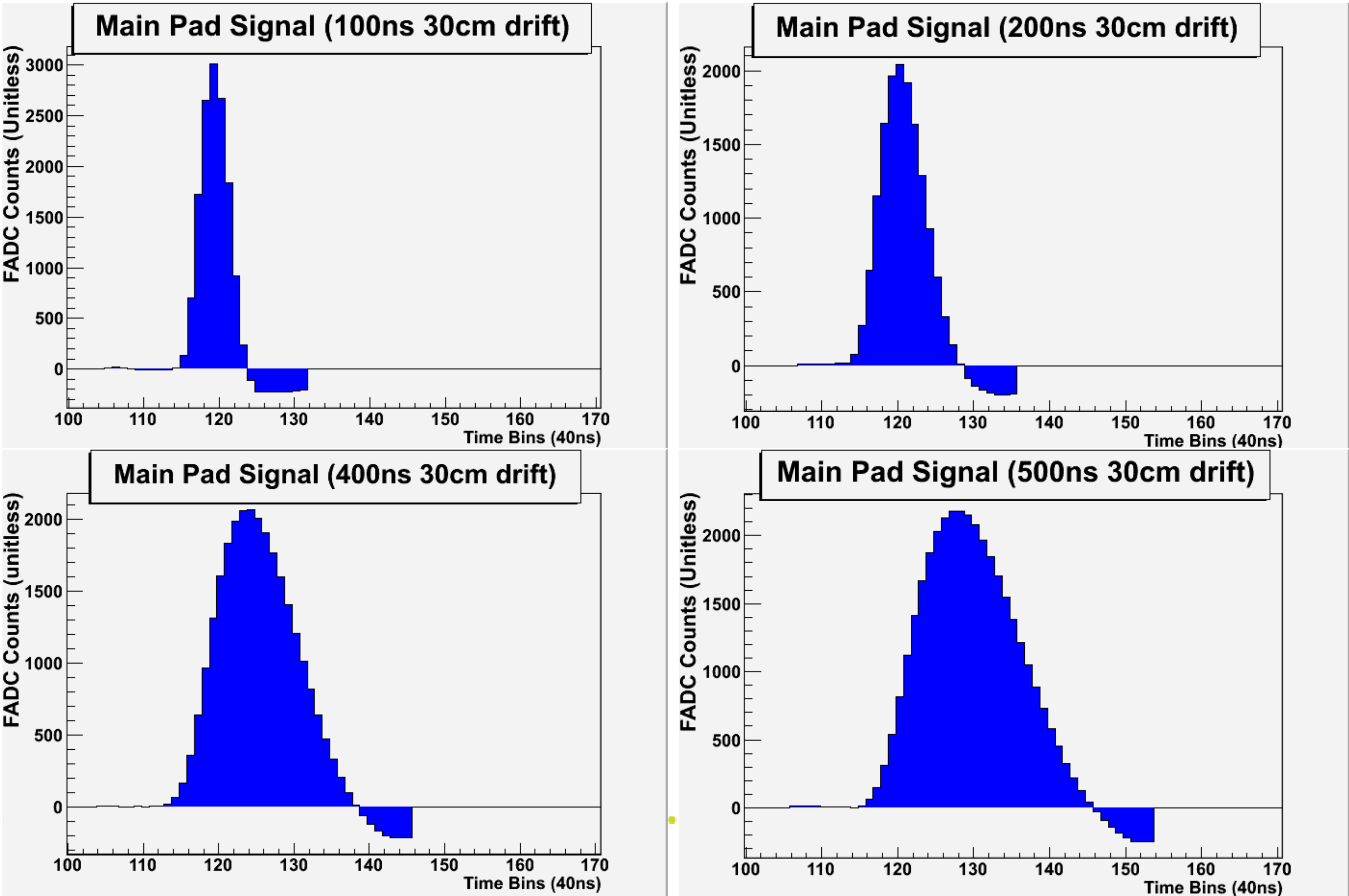
NEED INPUT OF DESIGN ENGINEER AND ELECTONIC EXPERT

Stand-Alone Calculation (2011)

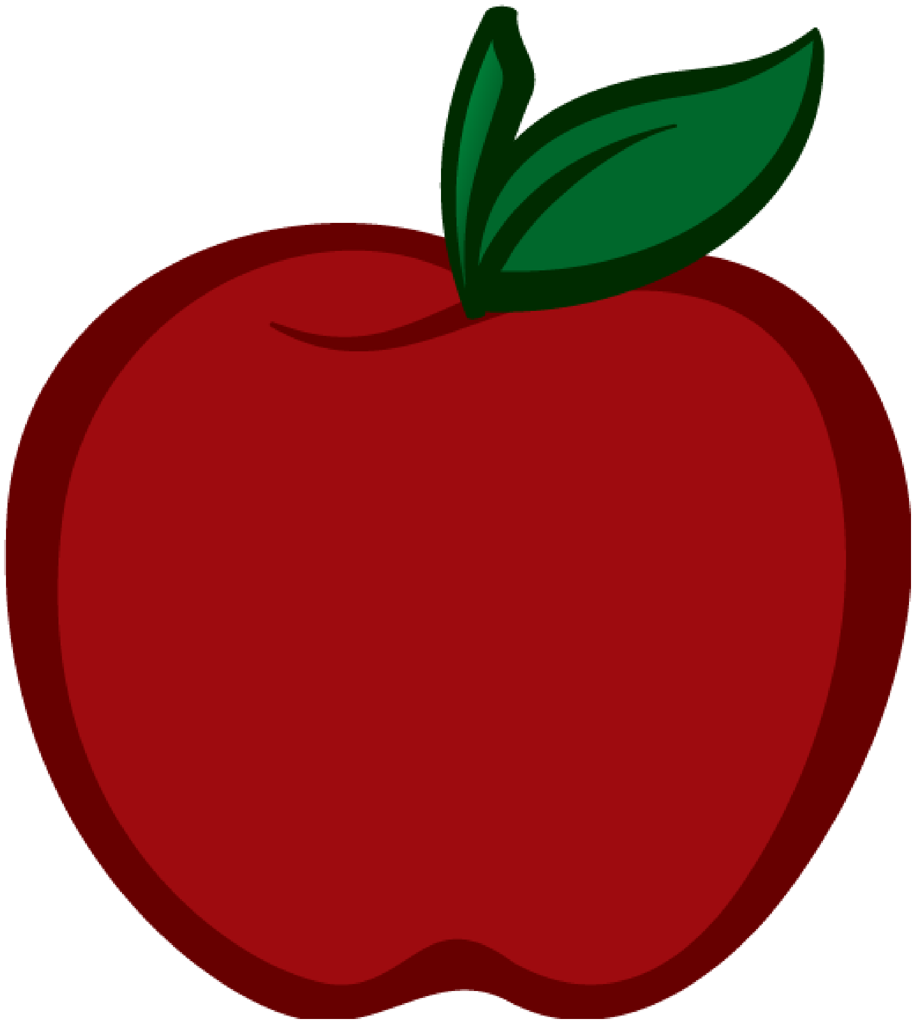


CRUCIAL TO CHARACTERIZE DETECTOR PARAMETERS

Shaped Pulse (for different shaping time)



Pad Amplitude

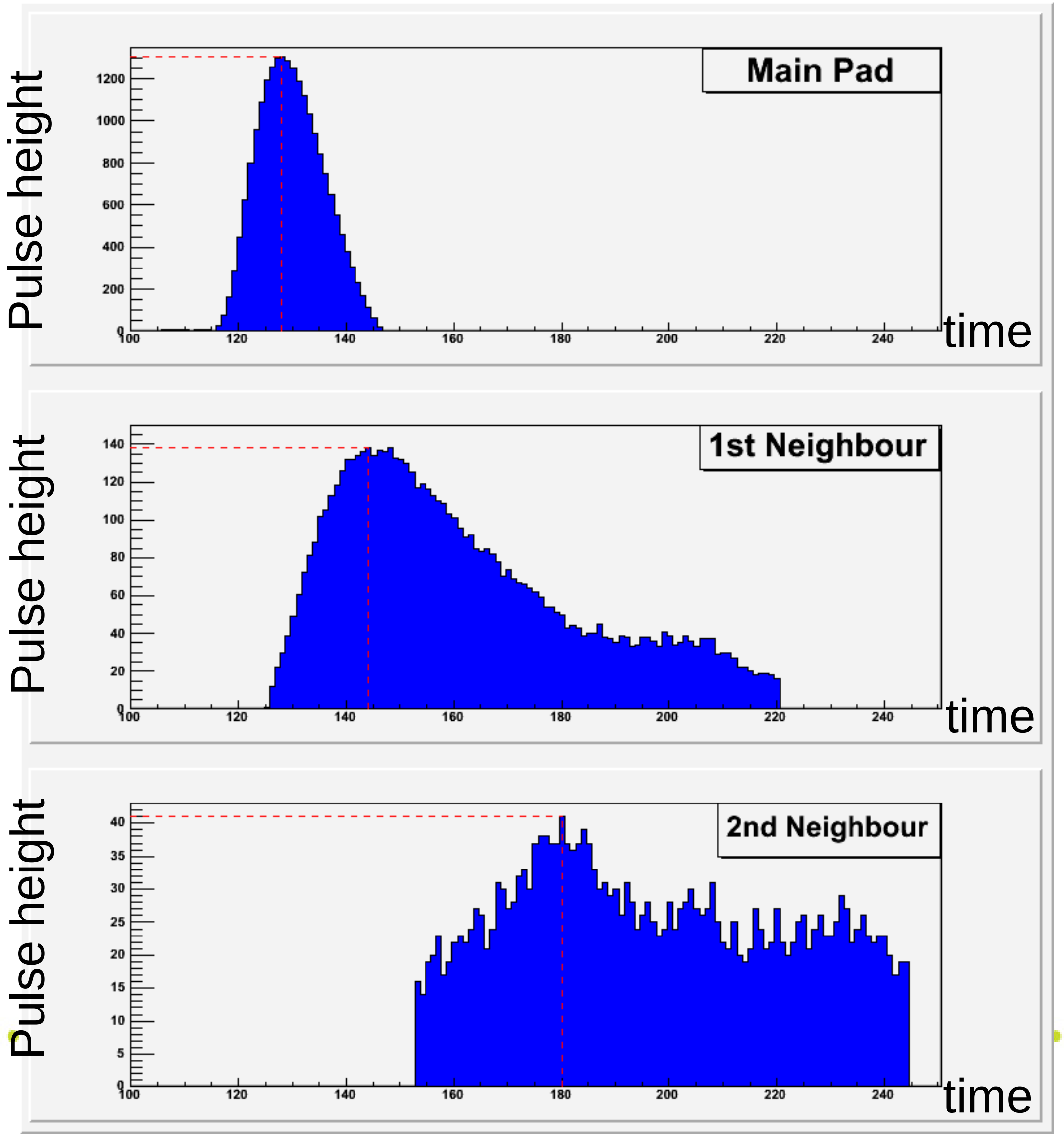


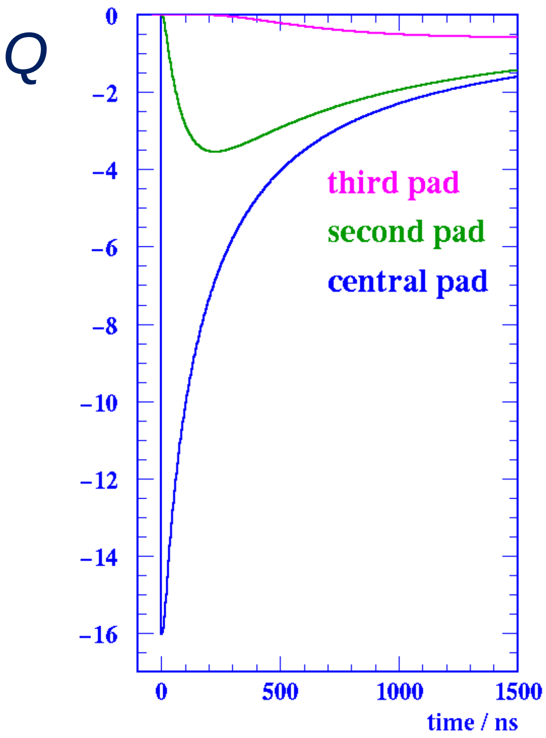
Pad Amplitude

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

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

method used here



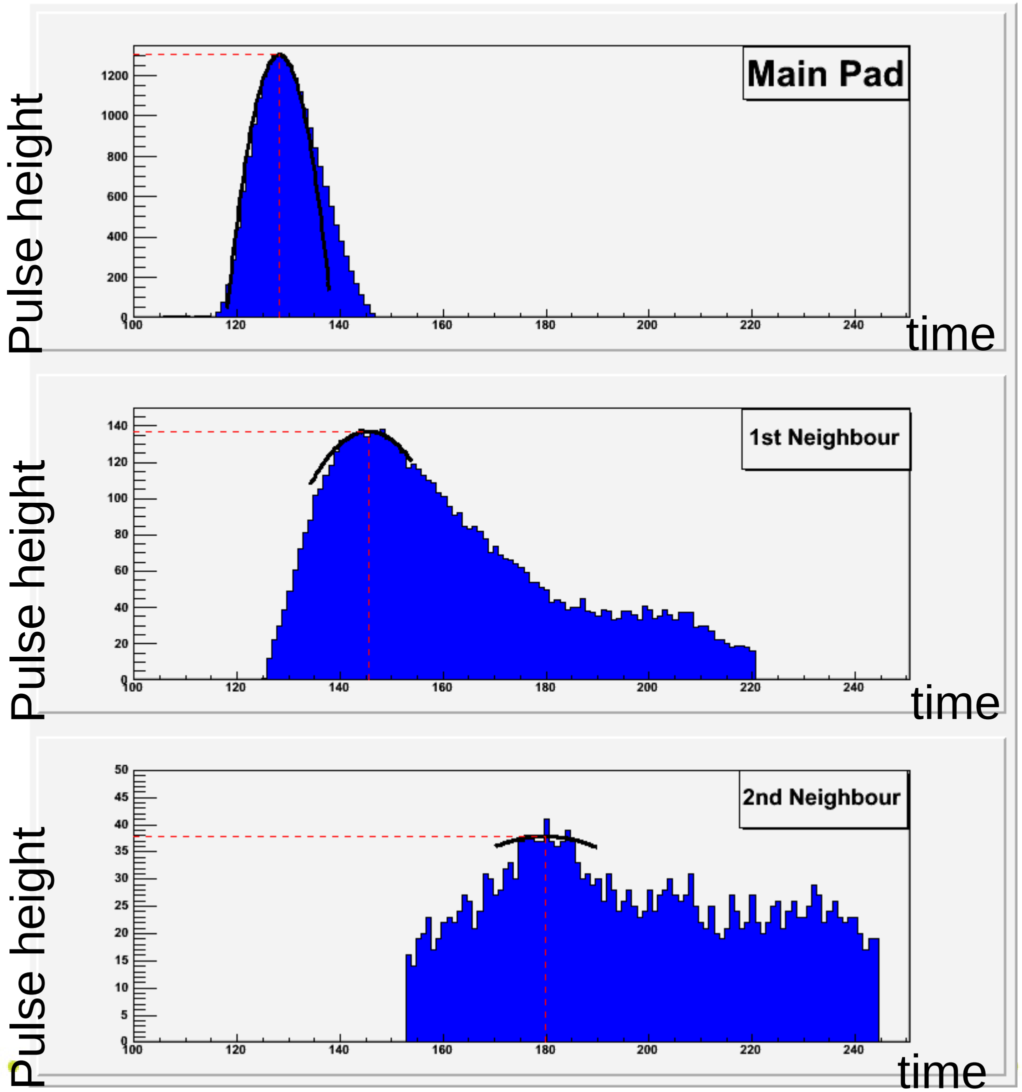


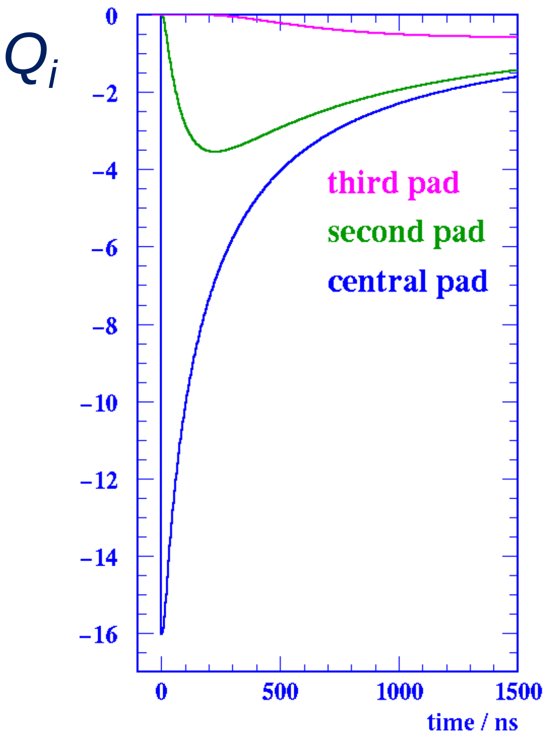
2) Maximum of Parabola
Quadratic Fit Method (QFM)

A_i = max of parabola P(i)

Pad Amplitude

Method use pre-2011



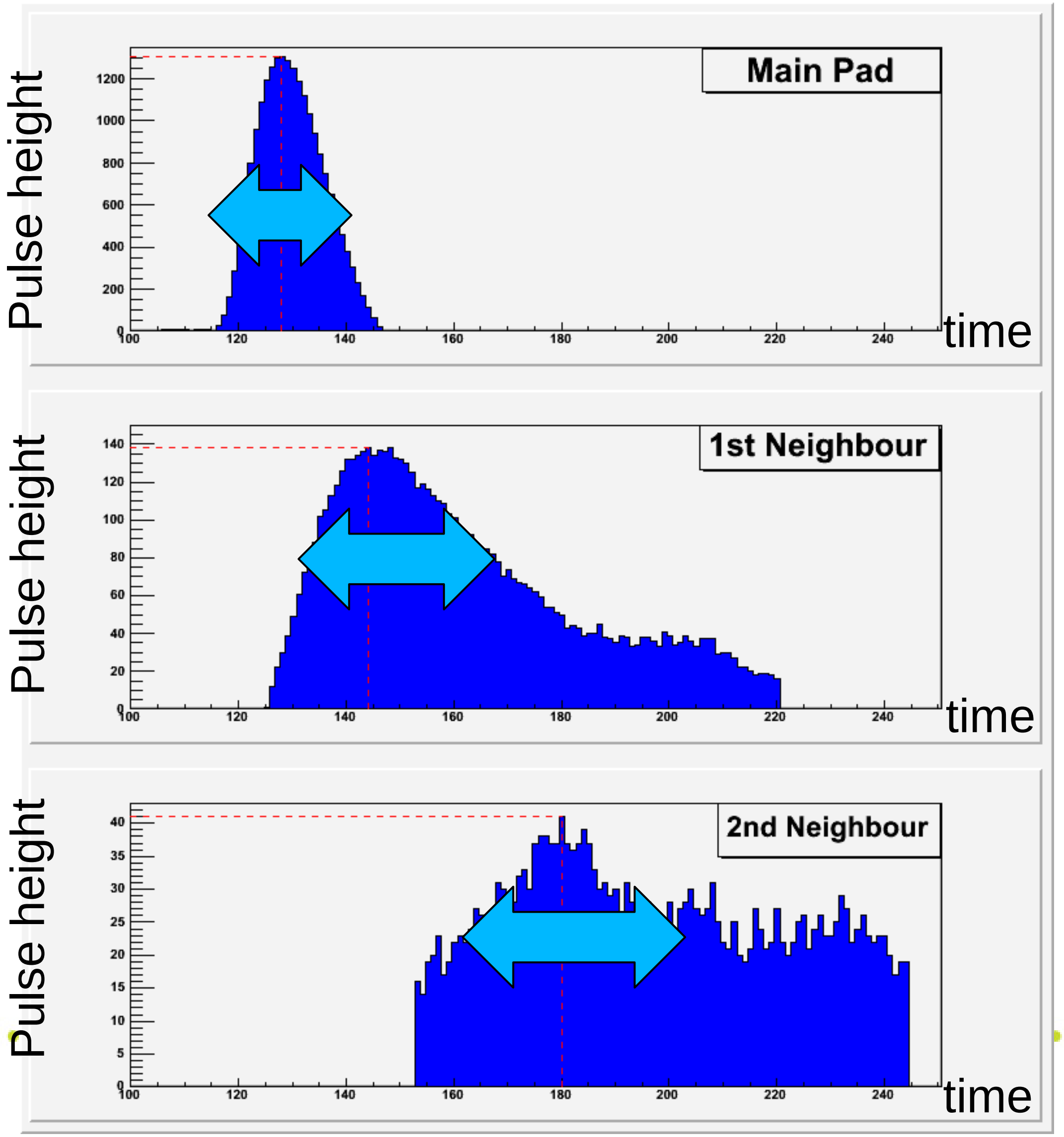


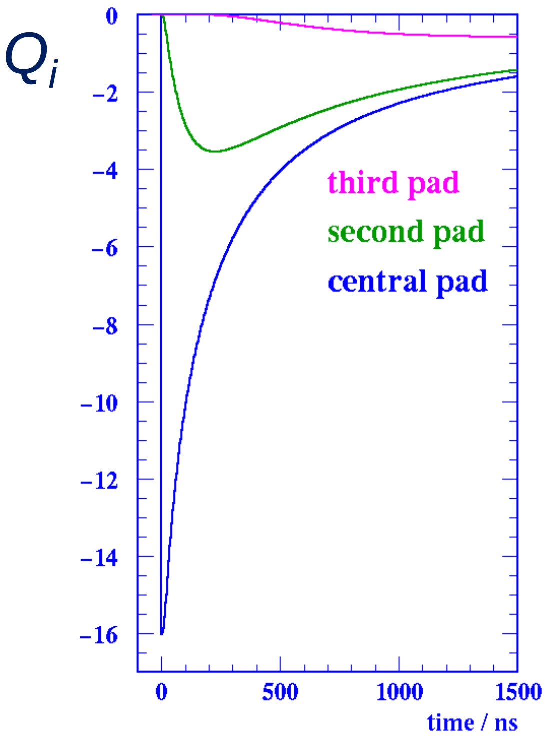
3) Integrate above threshold
Re-integration method (RM)

A_i = Sum P(i)

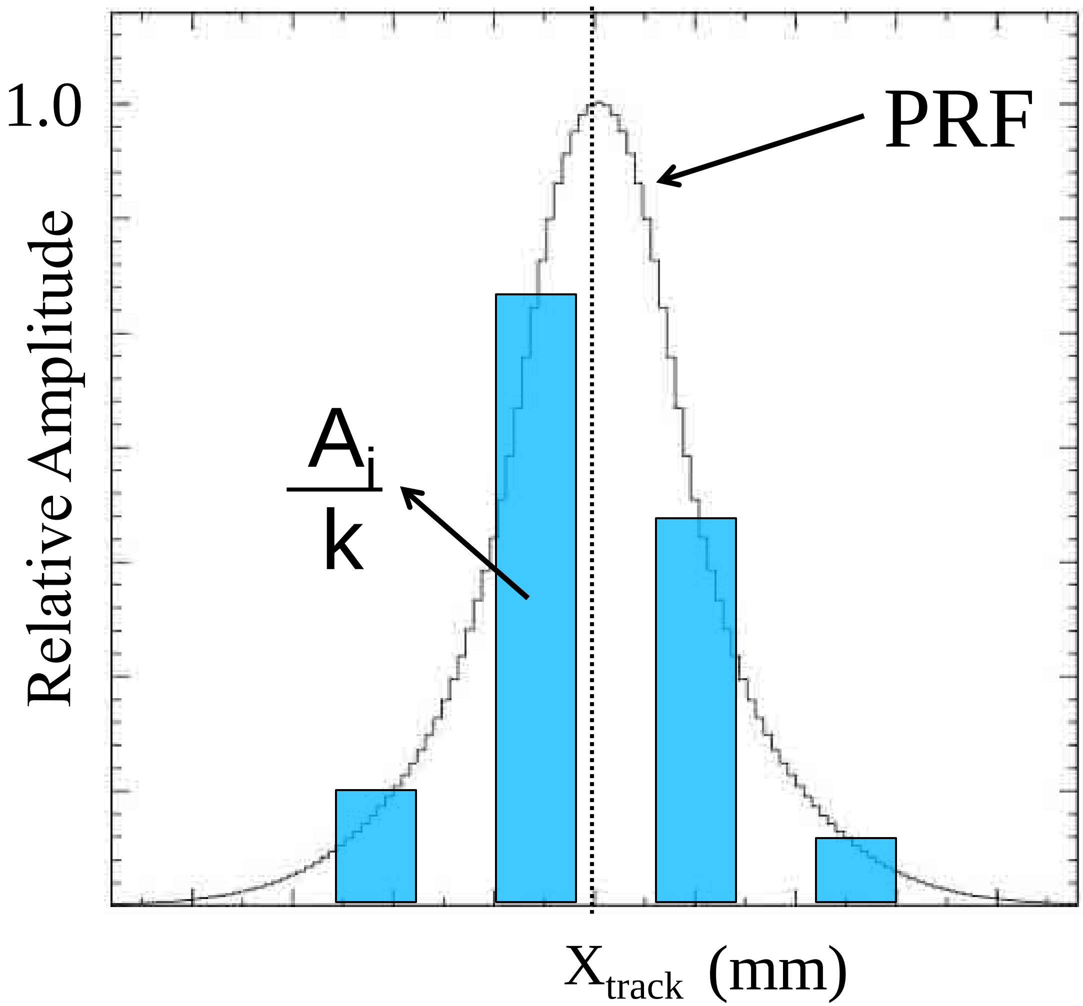
Pad Amplitude

Method use in 2011



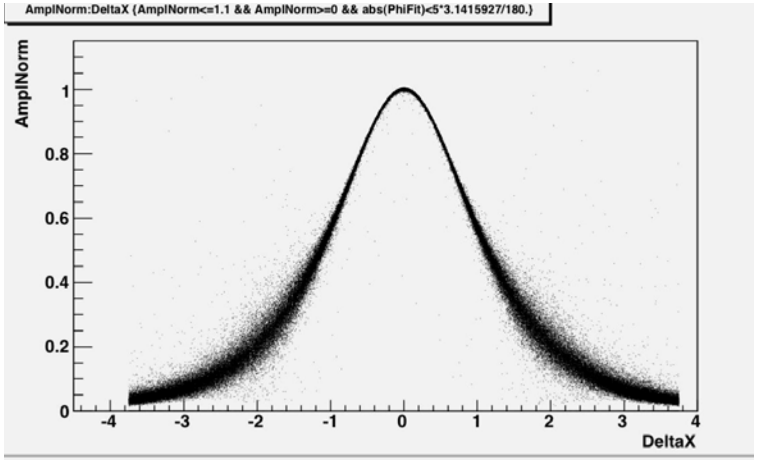


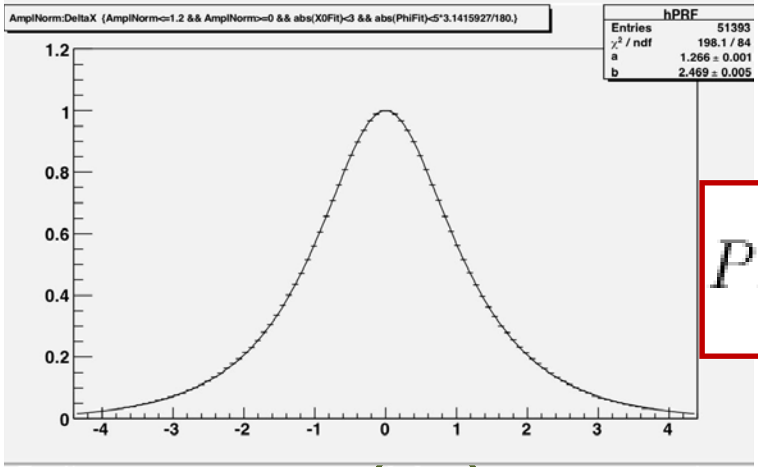
Pad Response Function (PRF)



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

Pad Response Function (model)





(mm)

$$\mathrm{PRF}(x,\Gamma,\Delta,a,b) = \frac{1 + a_2x^2 + a_4x^4}{1 + b_2x^2 + b_4x^4}$$

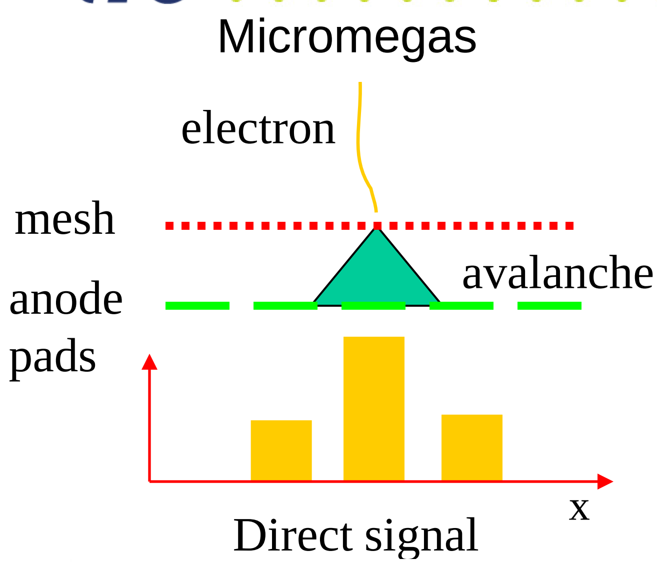
$$PRF(x,a,b) = b^2\,\frac{e^{\frac{-x^2}{2a^2}}}{x^2+b^2}$$

new (used here)

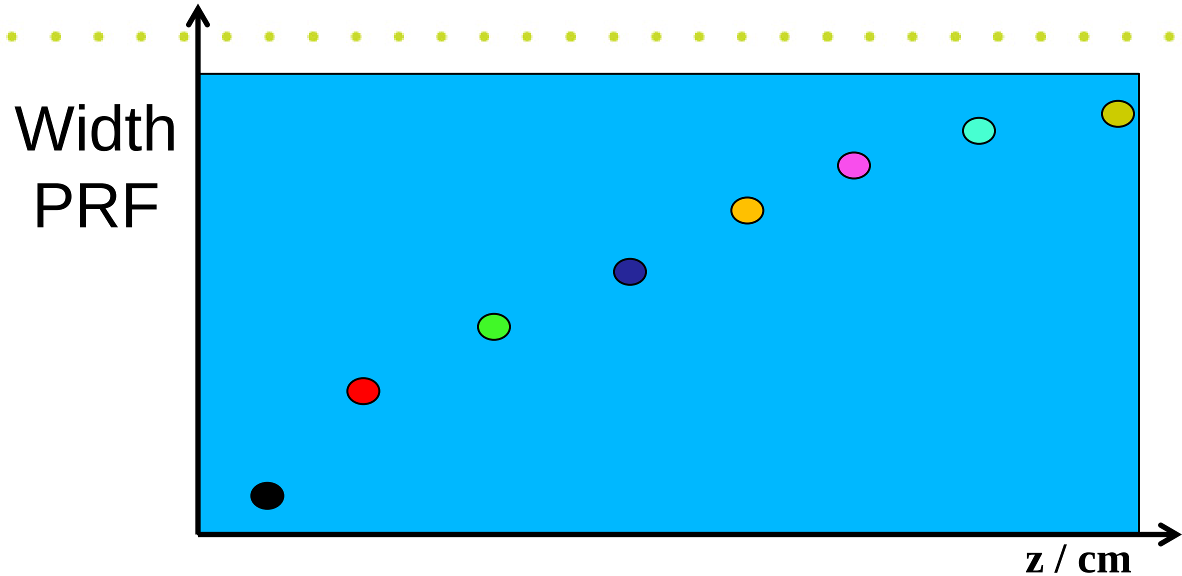
$$PRF(x;r,w) = \frac{exp(-4ln(2)(1-r)x^2/w^2)}{1+4rx^2/w}$$

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

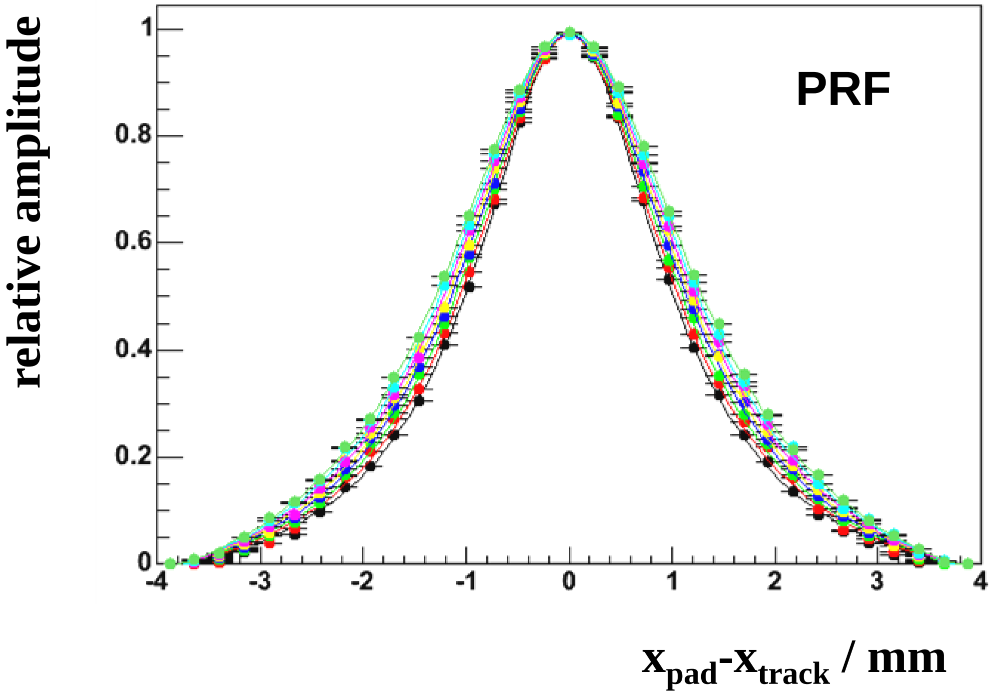
PRF versus Z



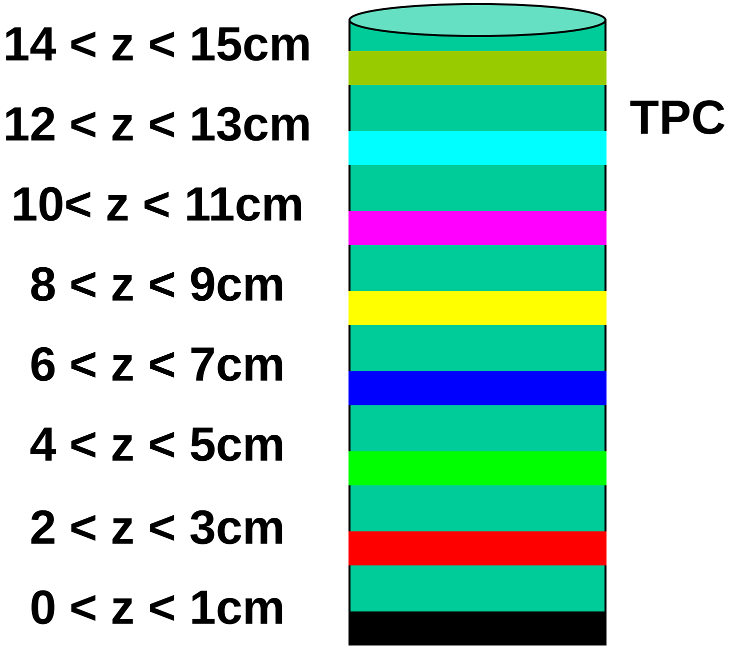
Micromegas
electron
mesh
anode
pads
avalanche
x
Direct signal



Width
PRF
z / cm



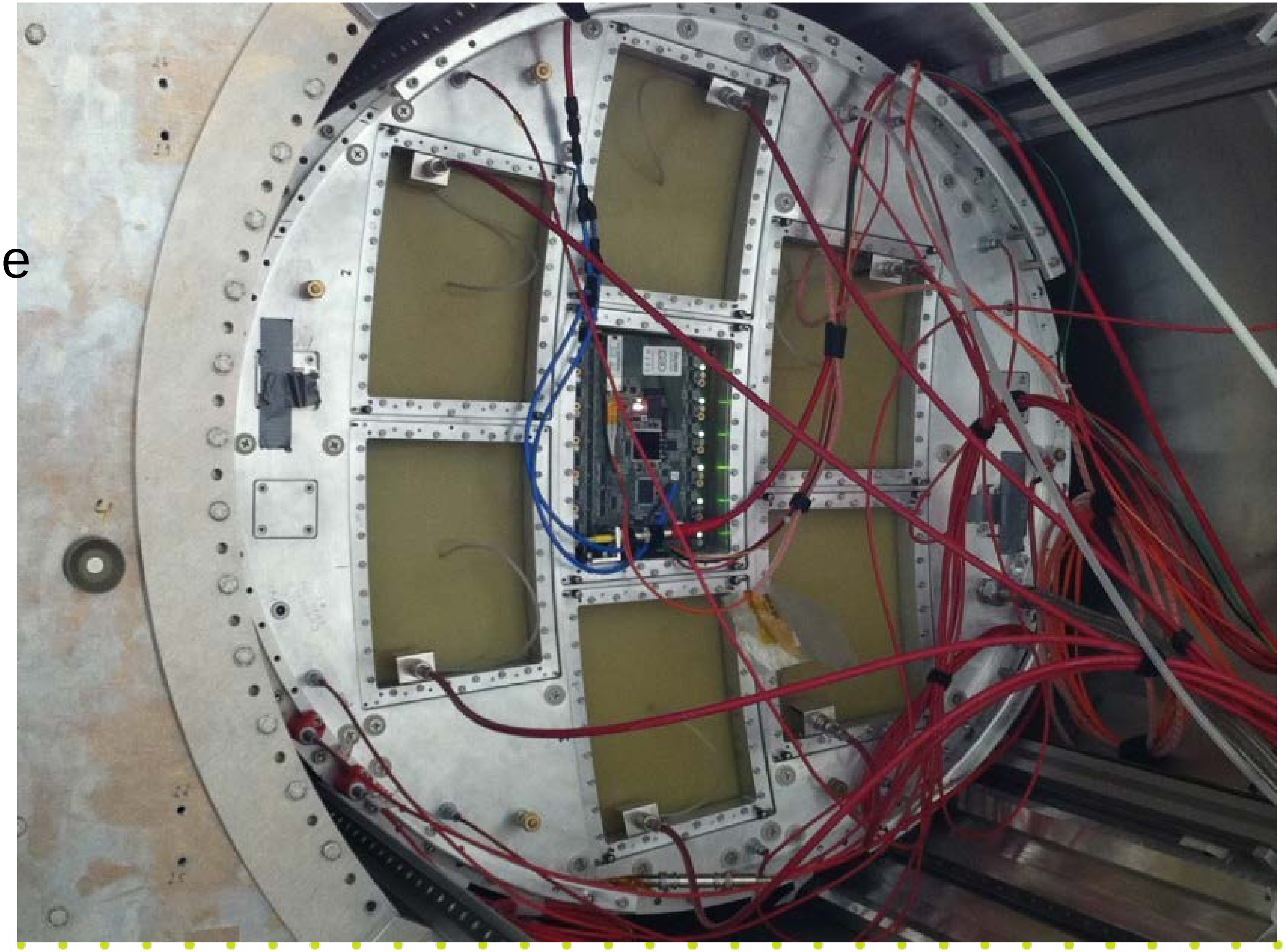
relative amplitude
PRF
0
0.2
0.4
0.6
0.8
1
-4
-3
-2
-1
0
1
2
3
4
x_{pad}-x_{track} / mm



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

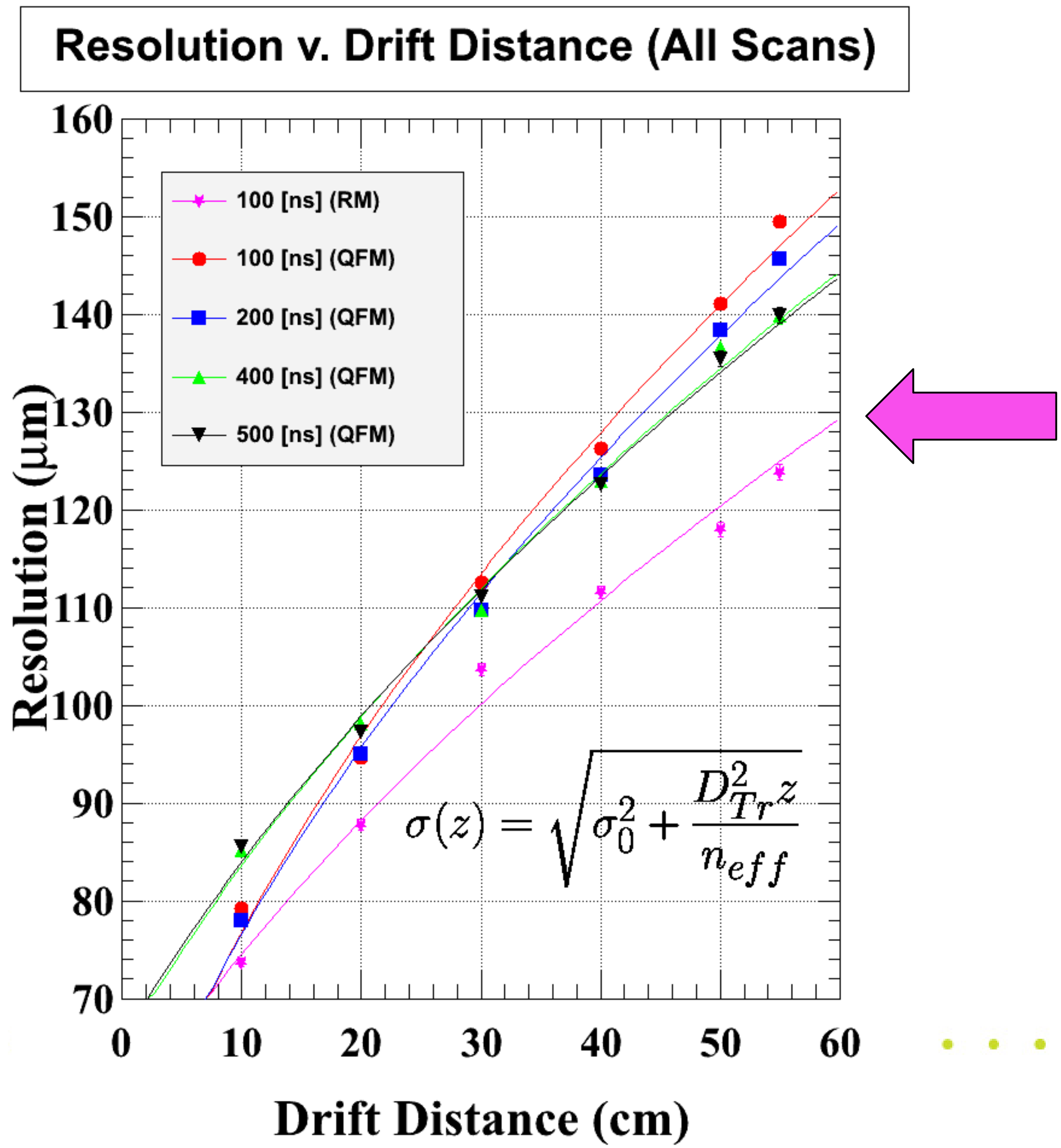
LCTPC Transverse Resolution

2011 data
Single module



Transverse Resolution

2011 data
Single module

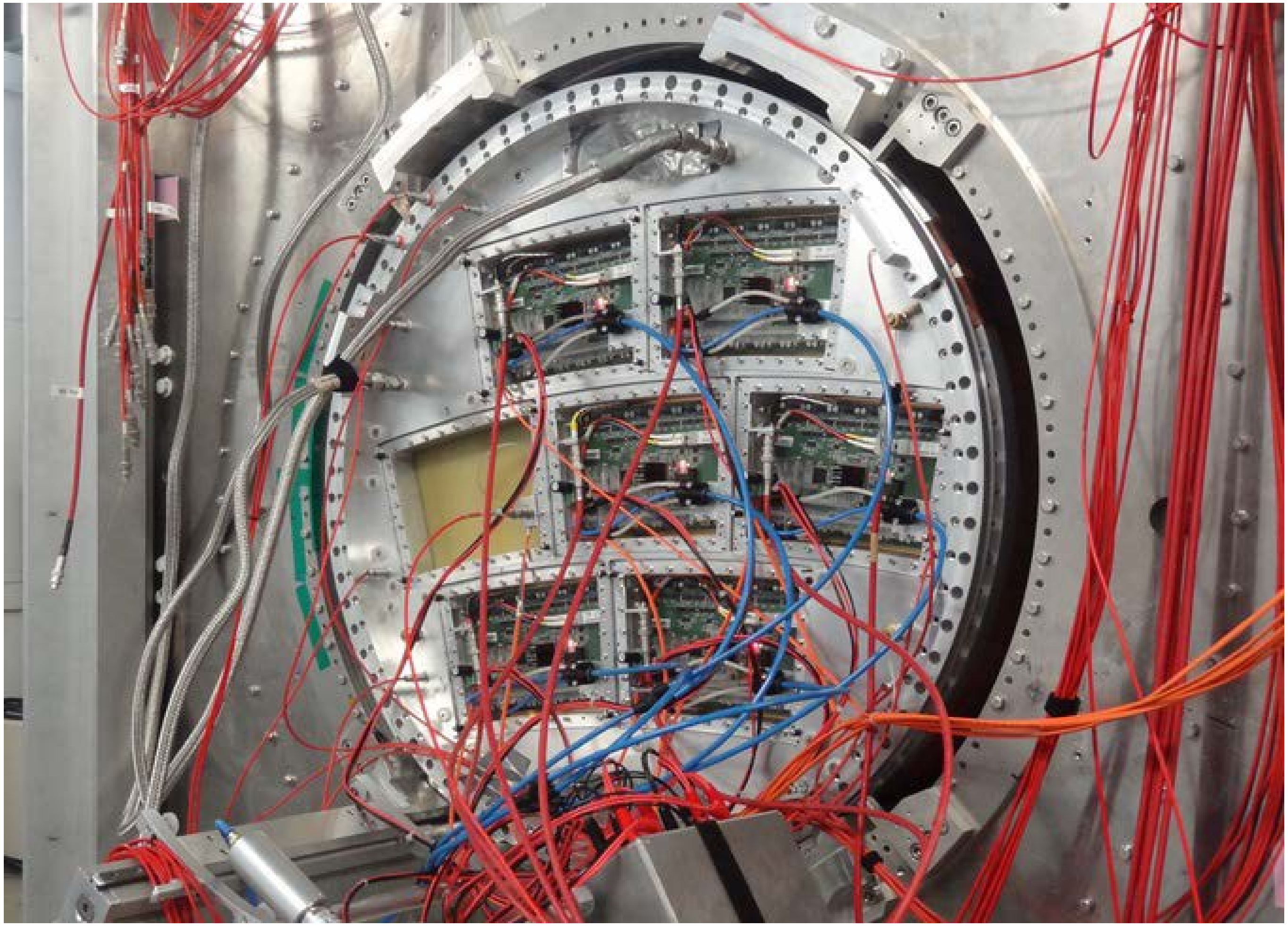


Source:
Nicholi Shiell
M.Sc. Thesis
Carleton University

Carleton UNIVERSITY

7-module LCTPC

2012 data
7-module



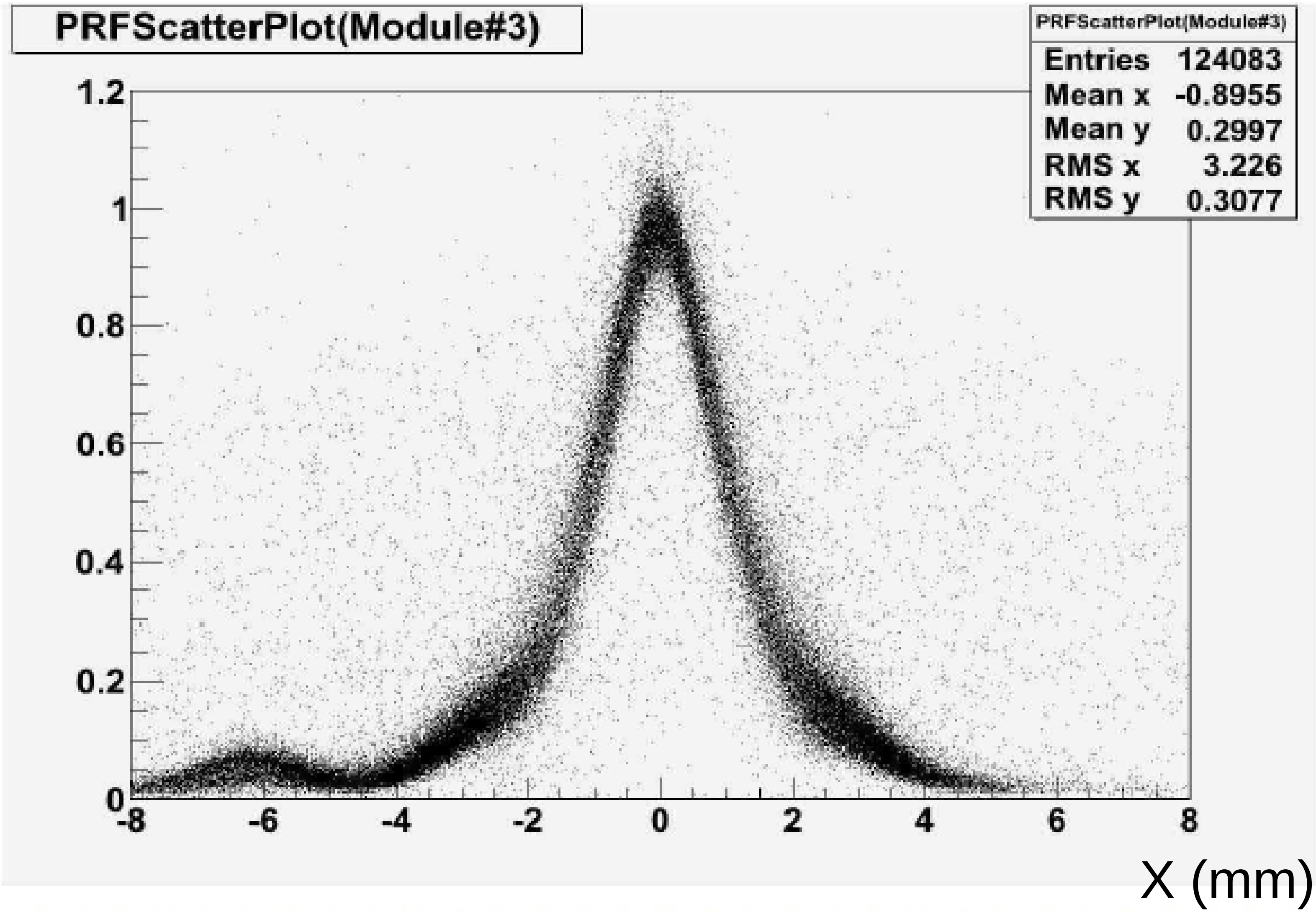
MarlinTPC

- MarlinTPC 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, now seems to be the optimal time to no longer rely on stand alone code with hardcoded geometry, stand alone track-fit algorithm, calibration constants, etc…
- Goal to have processors: calibration for PRF determination, bias corrections and resolution determination (transverse and longitudinal)

MarlinTPC

- **NativeToLCIO**
  - Converts data from the native file format of the detector hardware to the LCIO standard
- **Main Code (i.e. Processor)**
  - DD: creates dense data files from LCIO
  - Need a seed track
  - PRF: determines track parameters and/or pad response function (PRF)
  - BIAS: calculates and saves values used for bias and reso ROOT scripts
- **ROOT Scripts:**
  - BIAS: calculates and corrects for signal bias inherent to the detector
  - RESO: calculates the resolution

PRF first look



X^2 fit

$$X^2 = \sum \left[\frac{A_i - k\, PRF(x_i, r, w,)}{A_i} \right]^2$$

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

x_i = position of track on row I

r = fraction of Lorentzian (r=1 pure lorentzian

r=0 pure gaussian)

w = width

where we assumed $\sigma^2(A_i) = A_i$

Seed track (initial position "x" of the track) is obtained via a weighted mean of amplitudes on a row

Remark: Need to implement "eta" correction for determination of the weighted mean per row for avoiding small bias.

Amplitude Determination

$$k f_i = A_i$$

$$k = \frac{A_i}{f_i}$$

K – Constant coefficient of the PRF
A_i – Pad Amplitude
f_i - PRF evaluated at position of i^{th} pad

Define PRF coefficient as:

$$k = \frac{\sum A_i}{\sum f_i}$$

Remark: In the old method "k" computed by setting $\frac{d\chi^2}{dk} = 0$

$$k = \frac{\sum_j^m \frac{A_j PRF(x_j)}{\sigma_{A_j}^2}}{\sum_j^m \frac{PRF^2(x_j)}{\sigma_{A_j}^2}} = \frac{\sum \frac{f_j}{A_j}}{\sum (\frac{f_j}{A_j})^2} \approx \frac{\sum A_j}{\sum f_j}$$

since $\sum f_i \approx \int f \, dx = \text{constant}$
with $\sigma(A_j) = A_j$

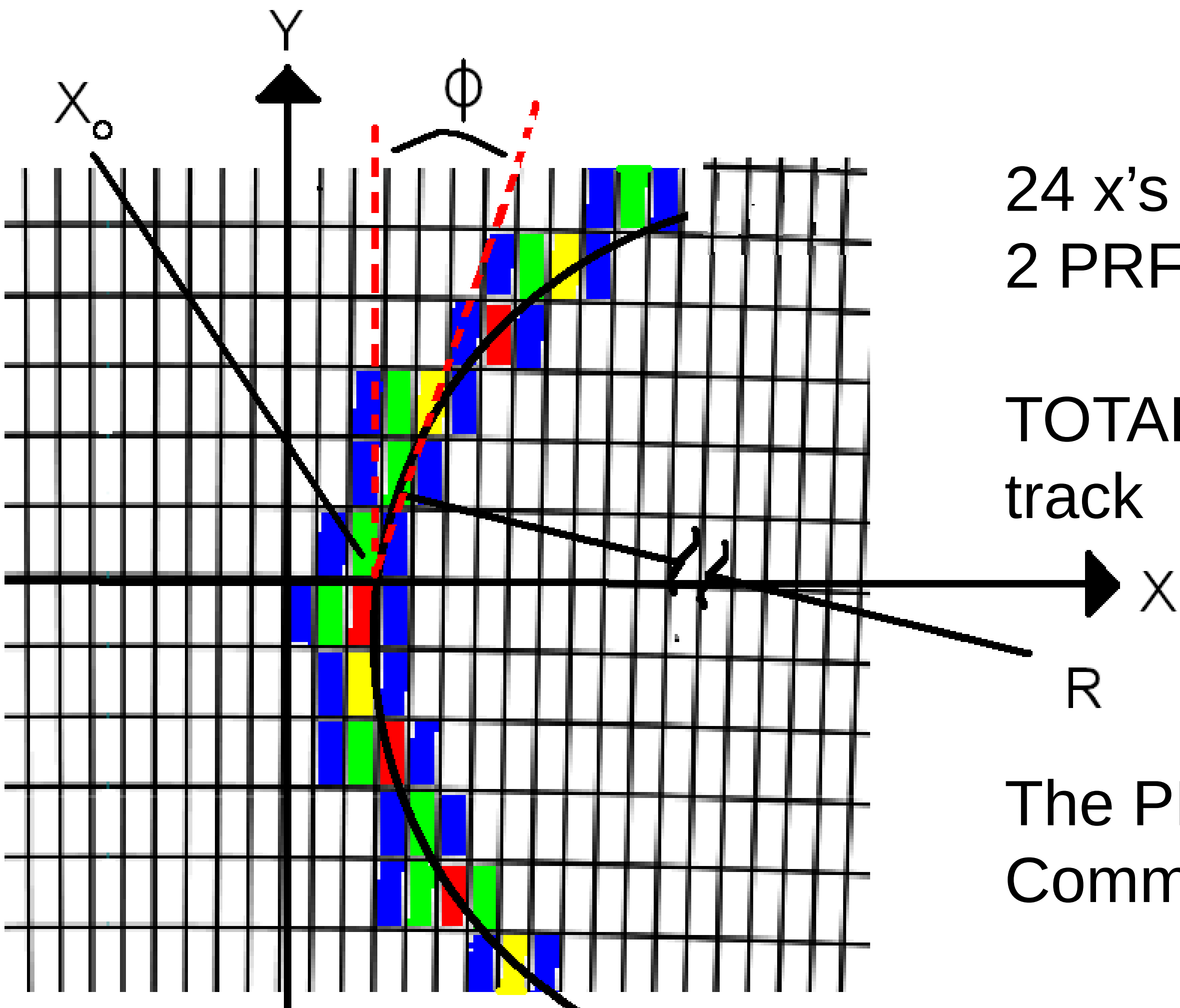
3 Pad Example (e.g.)

$$kf_1 = A_1 \qquad kf_1 - A_1 = 0$$
$$kf_2 = A_2 \quad \Rightarrow \quad kf_2 - A_2 = 0$$
$$kf_3 = A_3 \qquad kf_3 - A_3 = 0$$

Since all equations equal 0 adding them together should also give zero:

$$kf_1 - A_1 + kf_2 - A_2 + kf_3 - A_3 = 0$$
$$kf_1 + kf_2 + kf_3 = A_1 + A_2 + A_3$$
$$k(f_1 + f_1 + f_3) = A_1 + A_2 + A_3$$
$$k = \frac{A_1 + A_2 + A_3}{f_1 + f_2 + f_3}$$

PRFBasedHitFinderProcessor



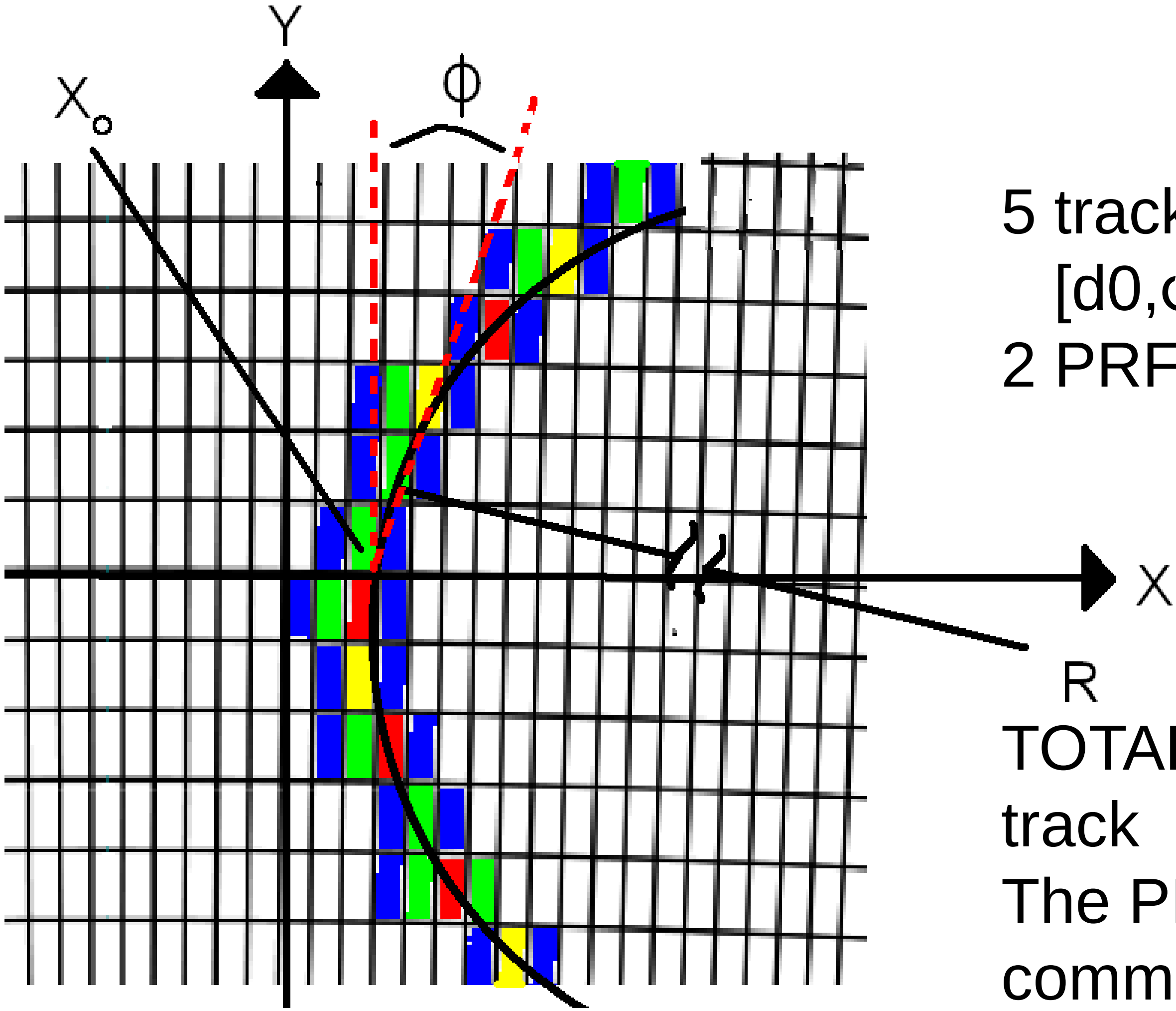
24 x's [one position per row]
2 PRF parameters

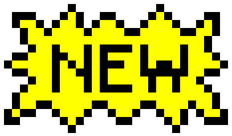
TOTAL of 26 parameters per track

The PRF parameters r and w
Common to all track

PRF weakly constrained

PRFBasedTrackFinderProcessor





5 track parameters
[d0,φ,CU λ,Z]
2 PRF parameters

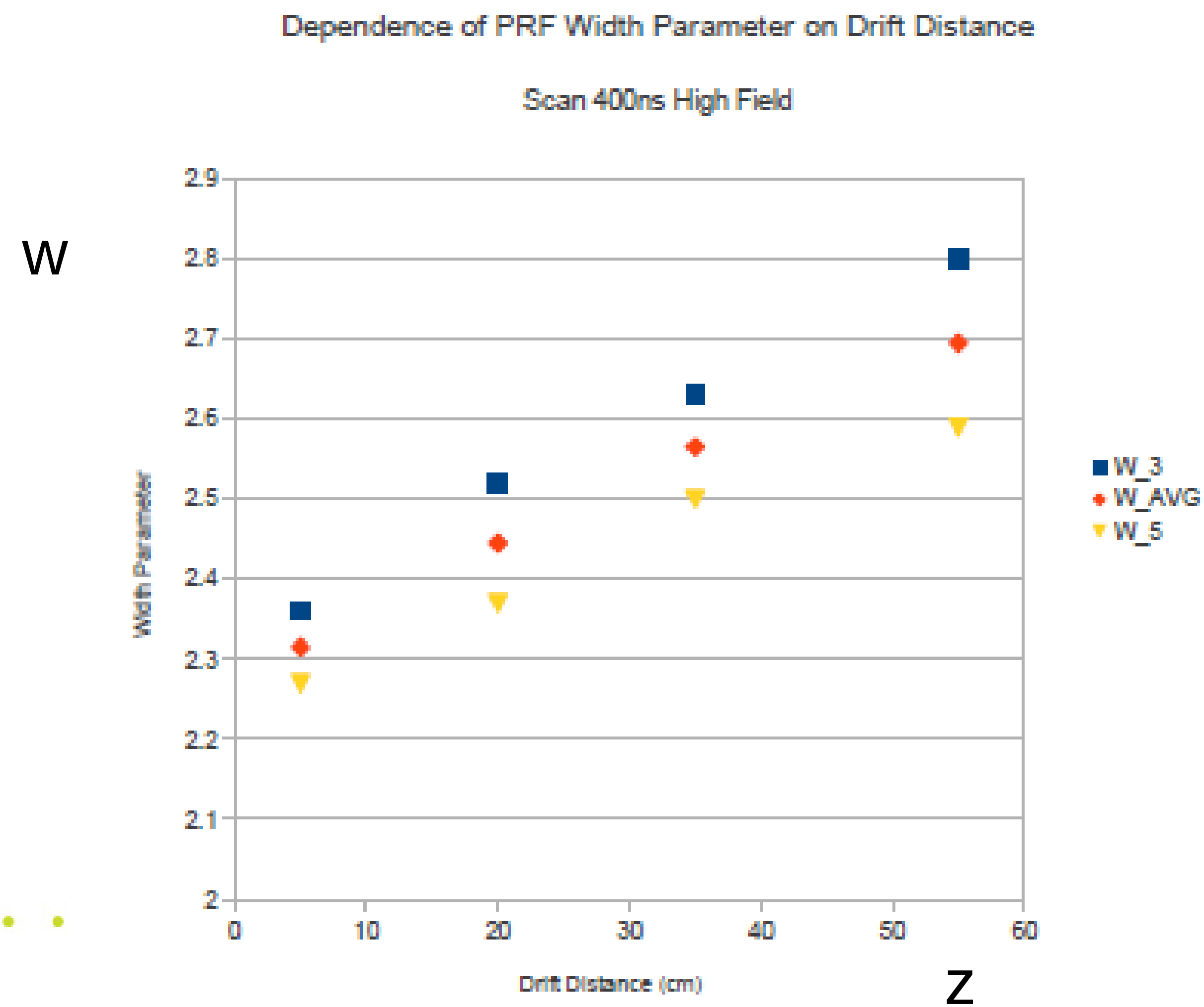
TOTAL of 7 parameters per track
The PRF parameters r and w common to all track

PRF very well constrained

PRF width parameters

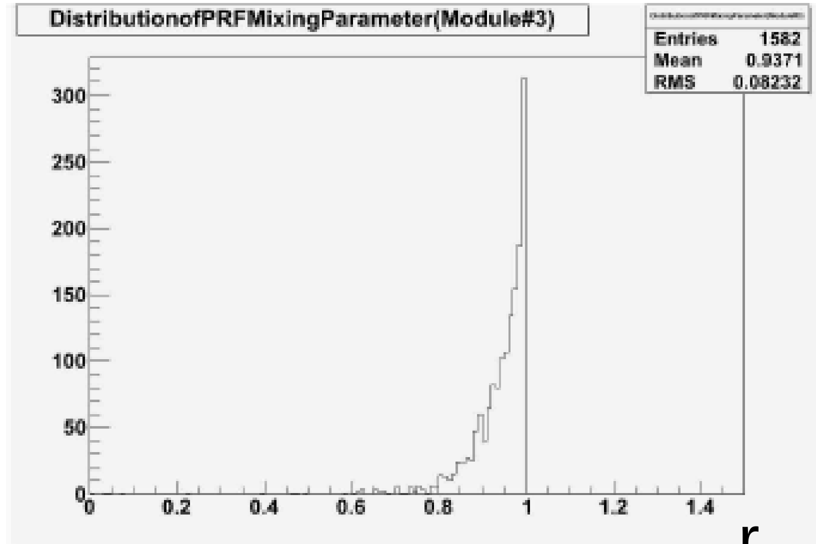
Run #	Drift Distance (cm)	W_3	W_5	W_AVG
2180	5	2.36	2.27	2.315
2182	20	2.52	2.37	2.445
2186	35	2.63	2.5	2.565
2188	55	2.799	2.59	2.6945

r ≈ 0.93

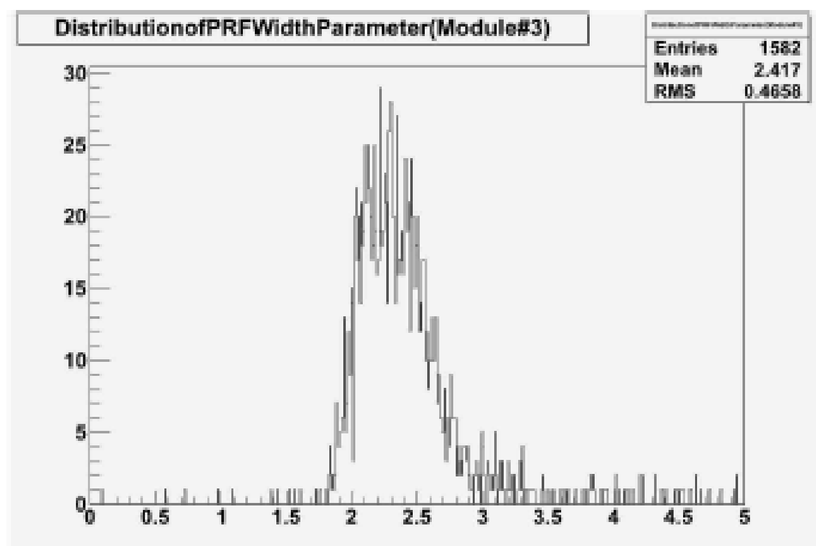


PRF “new”

Run 2180 (Peaking = 400ns Drift = 5cm R < 1.0)

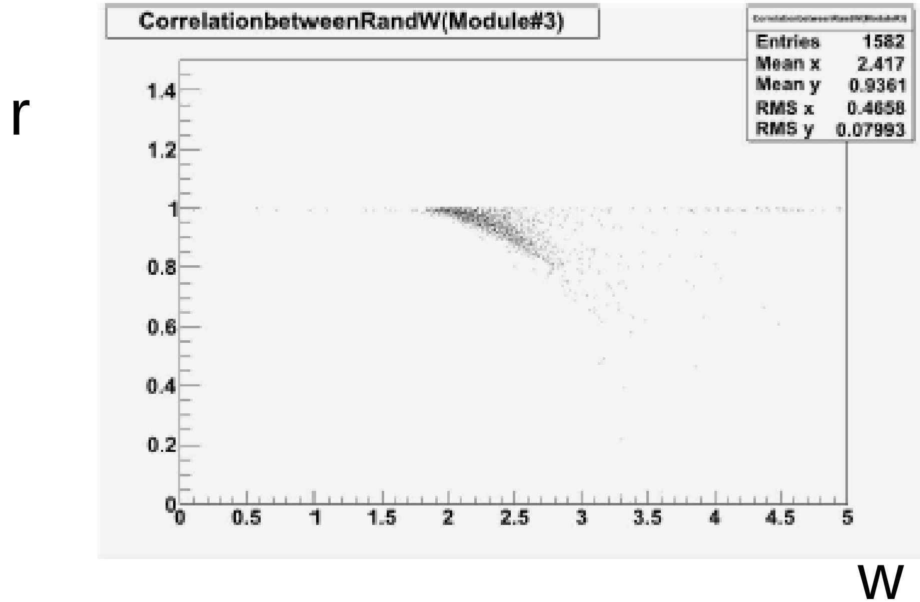


r

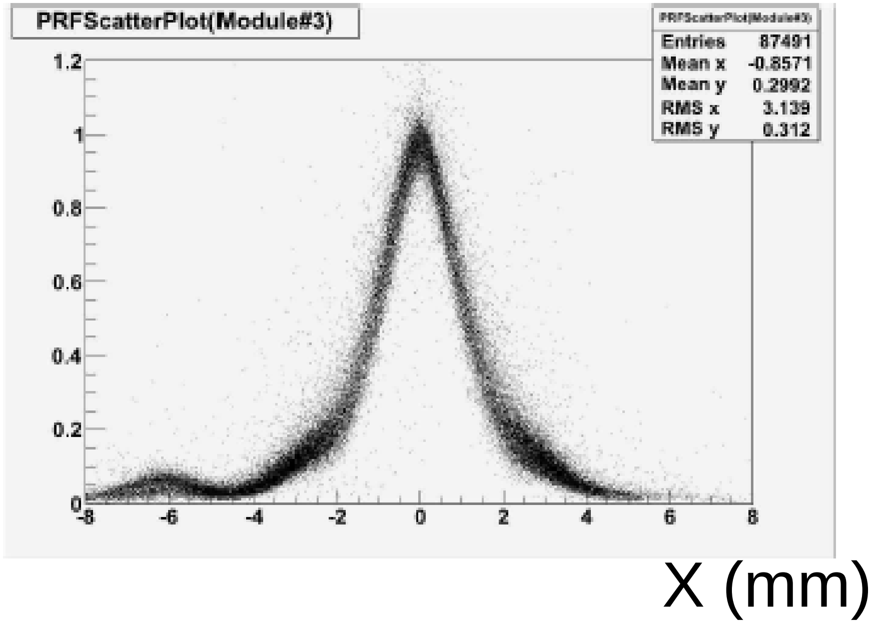


w

PRF “new”

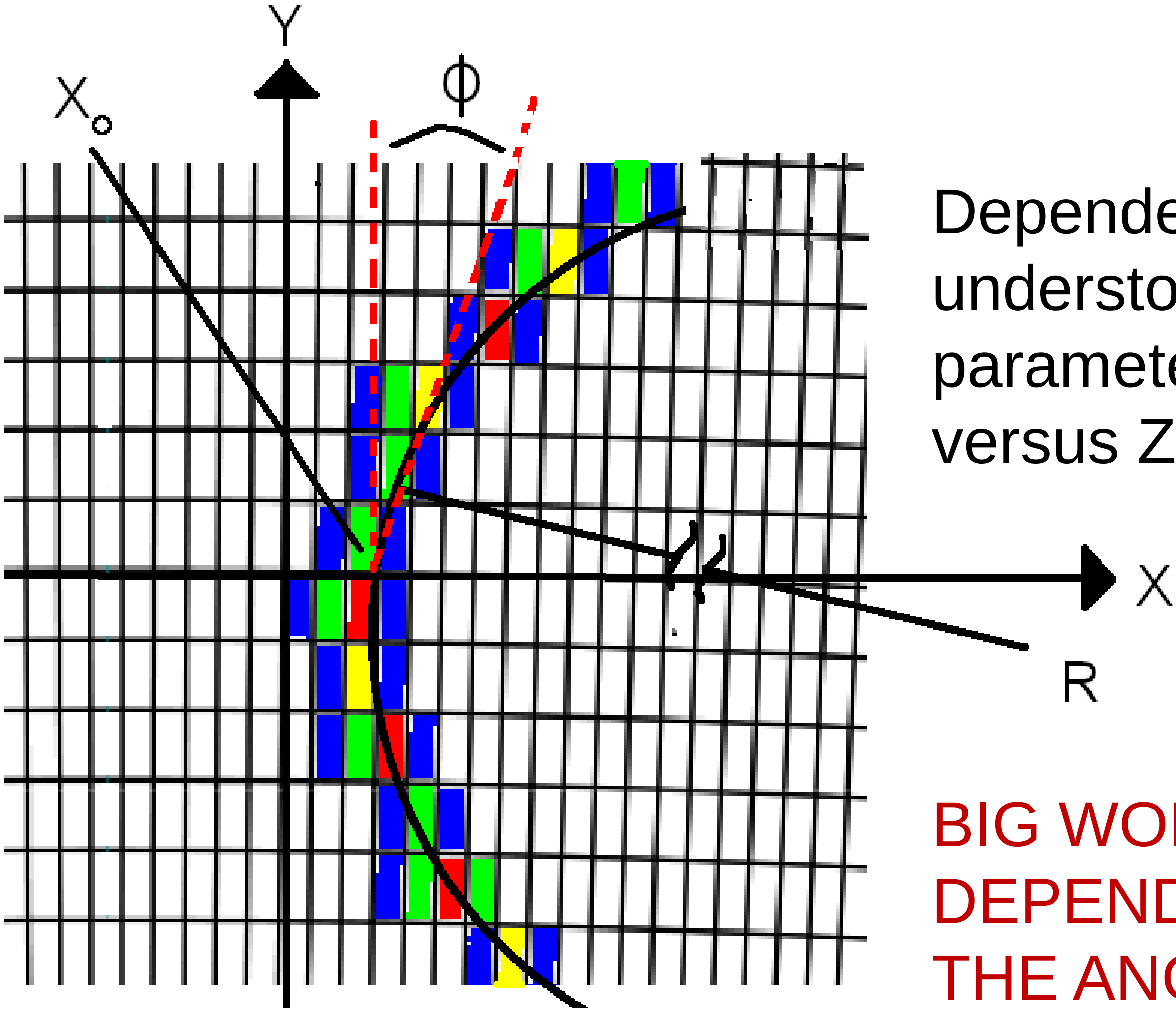


CorrelationbetweenRandW(Module#3)
Entries 1582
Mean x 2.417
Mean y 0.9361
RMS x 0.4658
RMS y 0.07993
r
w



PRFScatterPlot(Module#3)
Entries 87491
Mean x -0.8571
Mean y 0.2992
RMS x 3.139
RMS y 0.312
X (mm)

PRF dependency in φ

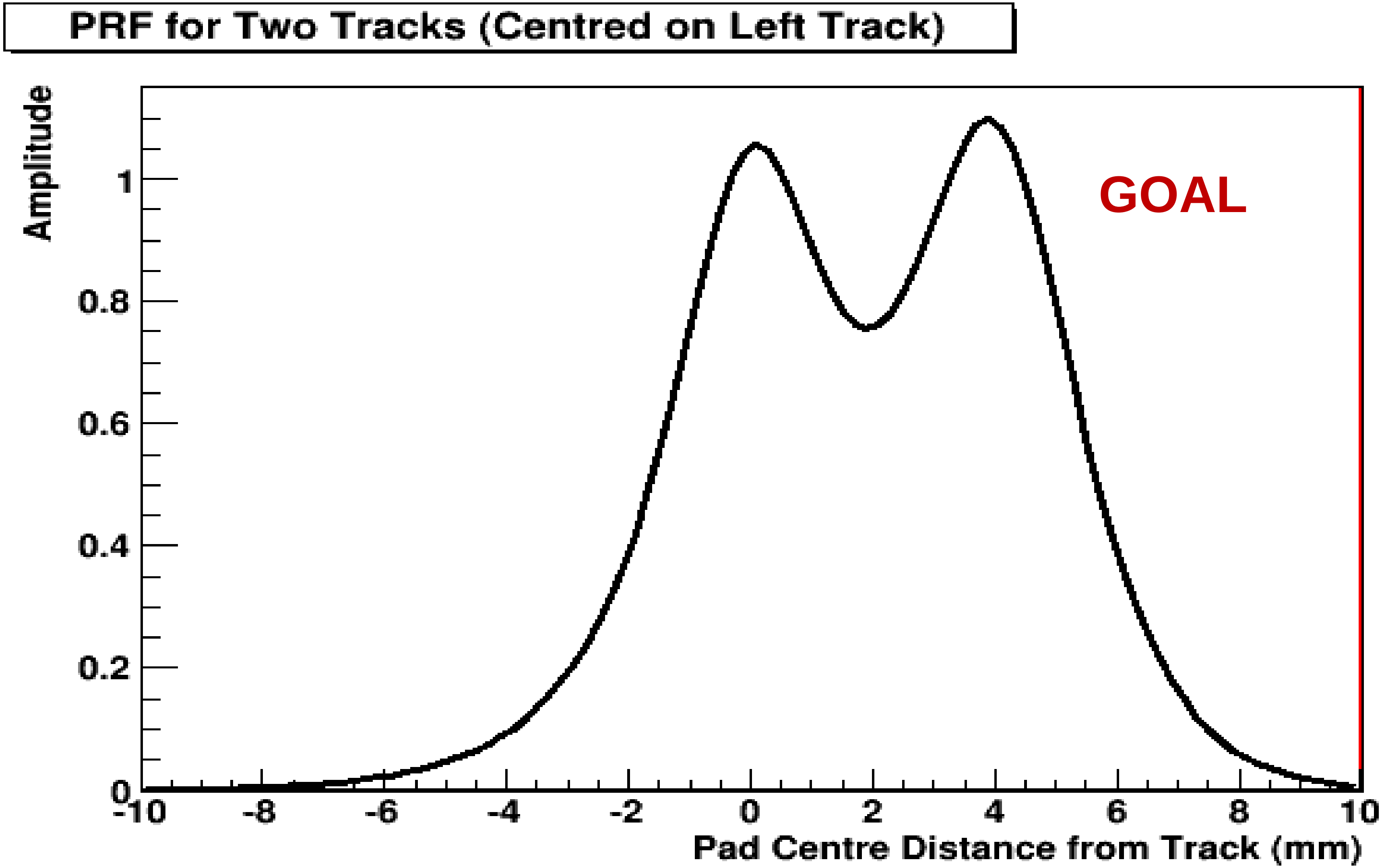


Dependency in Z (and λ) understood. Smooth parameterization or w (and r) versus Z

To be studied…

BIG WORRY IS THE DEPENDENCE VERSUS THE ANGLE φ

Example: Two-track finding per row



Future Plans

- Implement PRF Parameterization with Errors
  - **Reconstruction in 3D (x,y,z) and properly account for errors when calibrating the PRF, such that the PRF can be used to find 3D hits and their errors in Marlin**
- Implement PRF Calibration in Marlin
  - **The calibration process formaly done in the FTPC code now ported to Marlin. This will allow direct calibration with the multi-module prototype, which could potentially return better parameterizations from previous prototypes**
- Simulation Signals: $N_{electron/ion} \rightarrow (A,t) \rightarrow PRF$
  - **Full understanding of ionization, transport, geometry, and electronics response for 3D tracks**

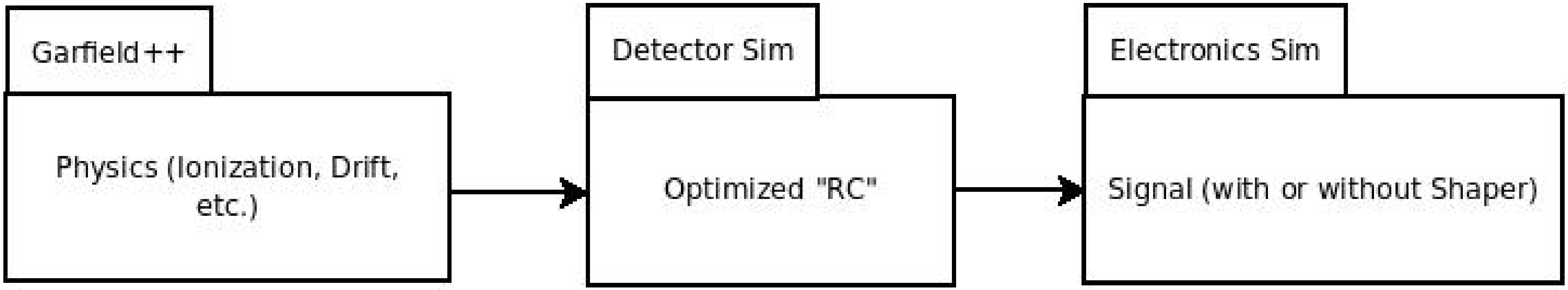
Future – Simulation

- Concurrently developing simulation of Micromegas detector

- The procedure for the analysis is, basically

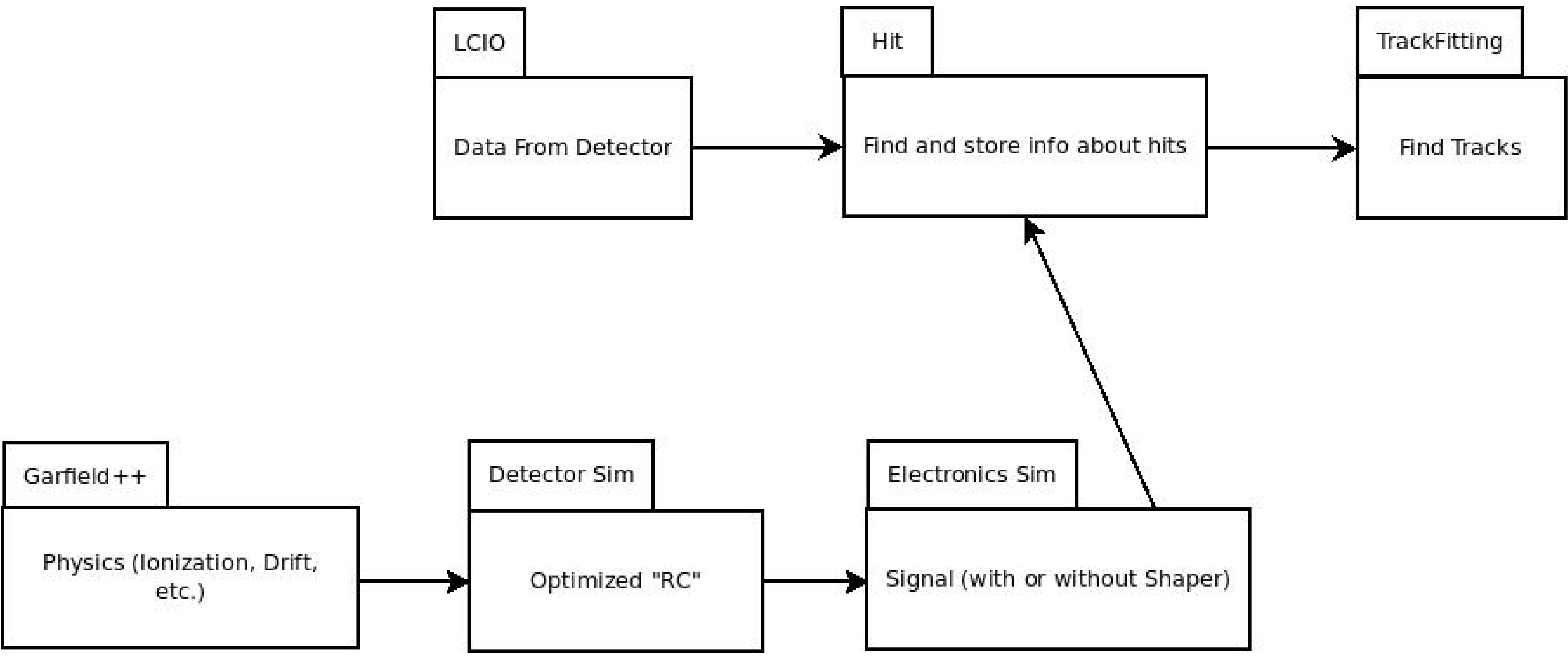
Simulation

The simulation will perform the following calculations,



And this will fit in with the analysis work, by simply replacing the detector data with the simulated data in the analysis procedure.

Simulation

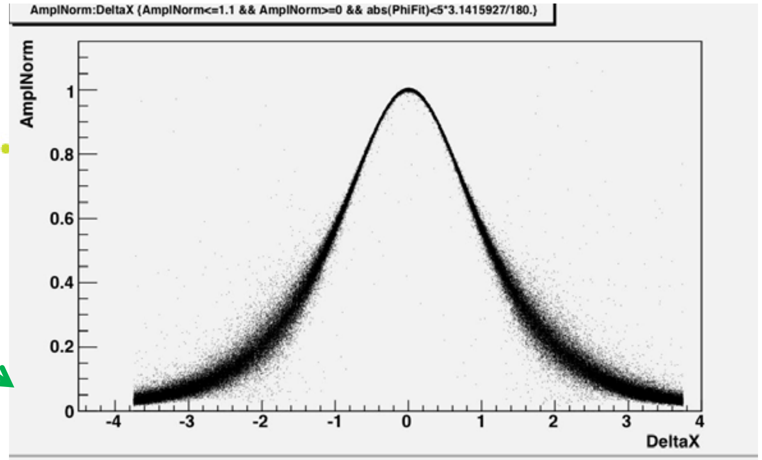


LCIO
Data From Detector
Hit
Find and store info about hits
TrackFitting
Find Tracks
Garfield++
Physics (Ionization, Drift, etc.)
Detector Sim
Optimized "RC"
Electronics Sim
Signal (with or without Shaper)

Summary

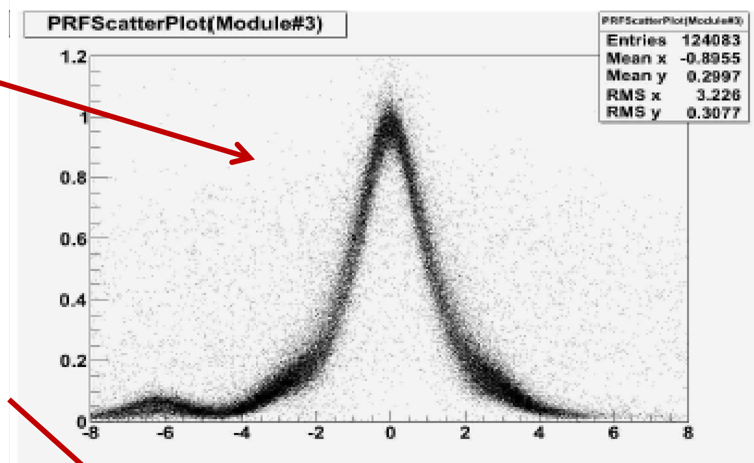
2011 (single module)
Average number of pad per hit per row is **4.5**

(x=-6) ?



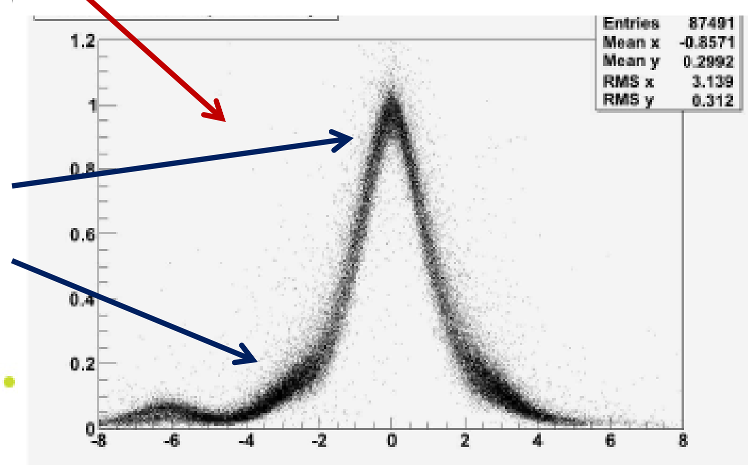
2012 (7-module)
First look hit based
Average number of pad per hit per row is **2.1**
leads to artificial narrower PRF [less stat]

More "triangular" looking PRF in 2012 due to less pad hits per row



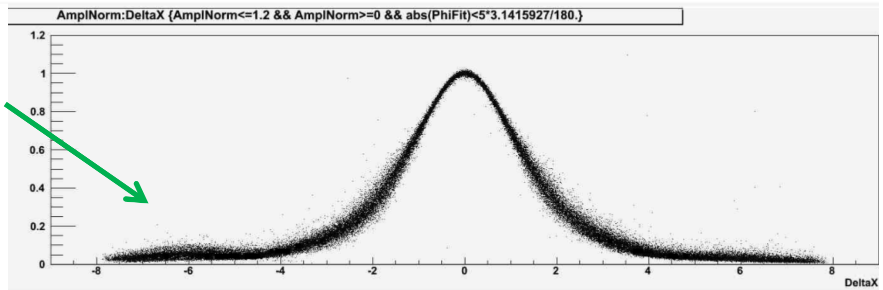
2012 (7-module)
New MarlinTPC Track/PRF fit

Small bias of track position to be on pads



Summary

Is was there smaller ?



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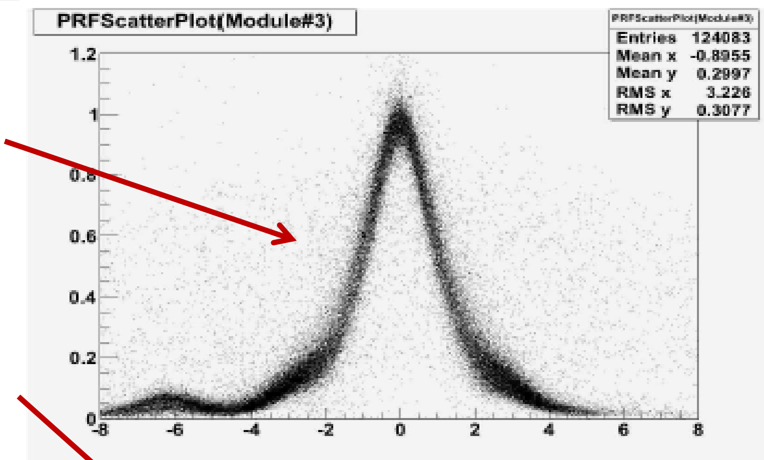

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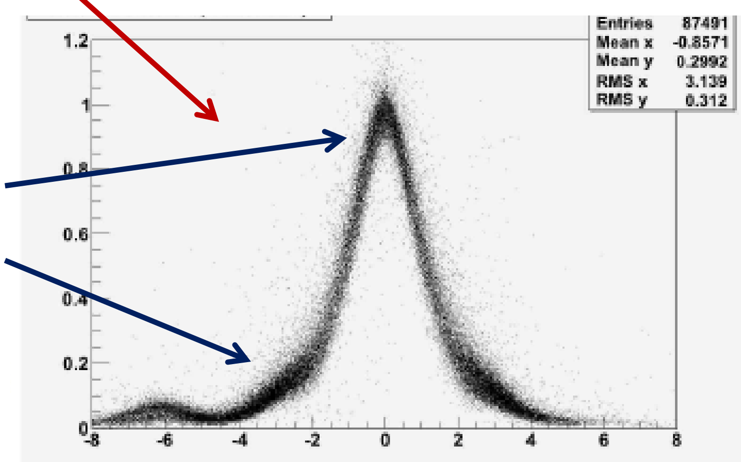
First look hit based
Average number of pad per hit per row is **2.1** leads to artificial narrower PRF [less stat]

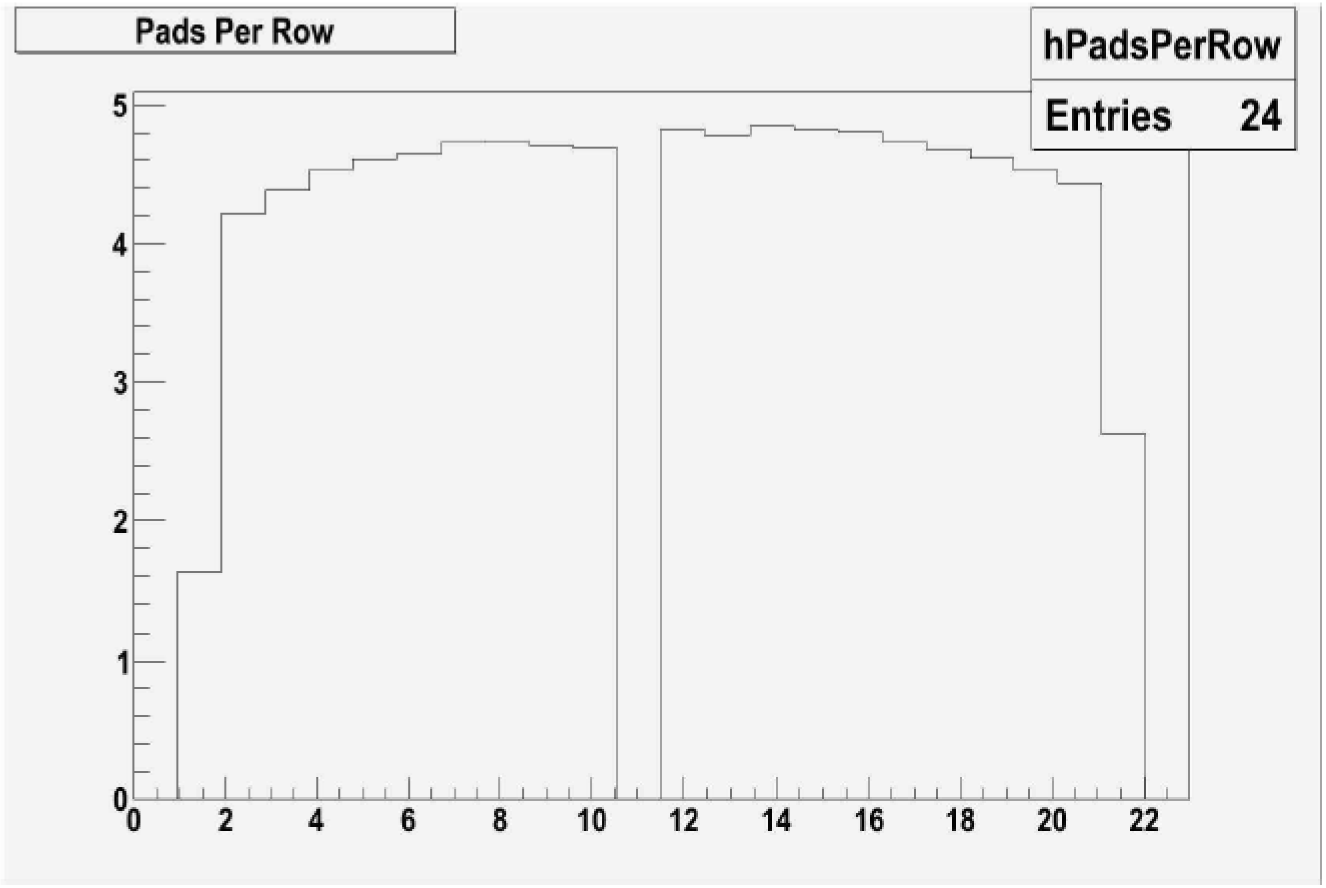
Small bias of track position to be on pads



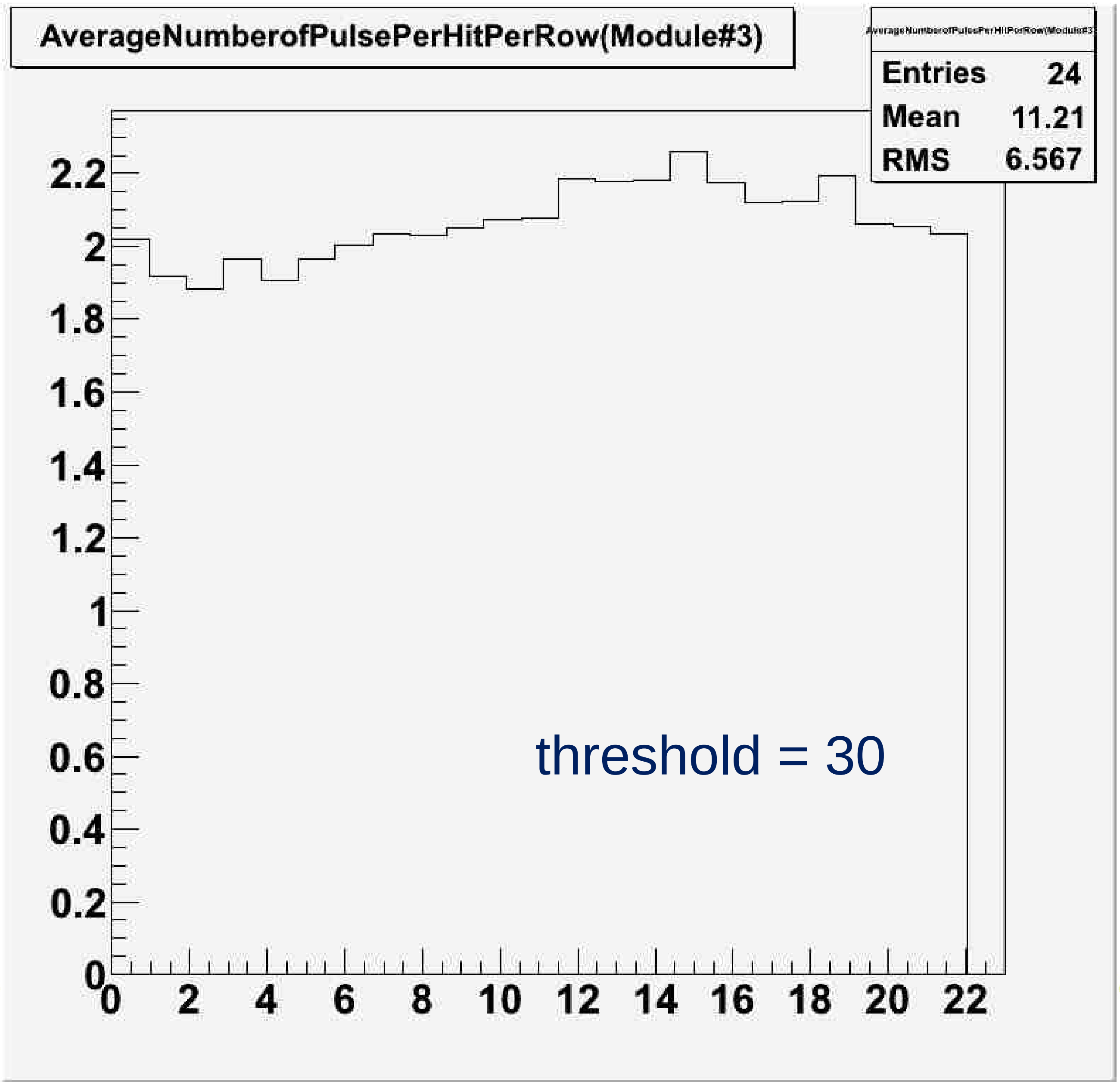
2012 (7-module)
New MarlinTPC Track/PRF fit
Pad cross-talk

Averge hit per row (2011) **= 4.5**

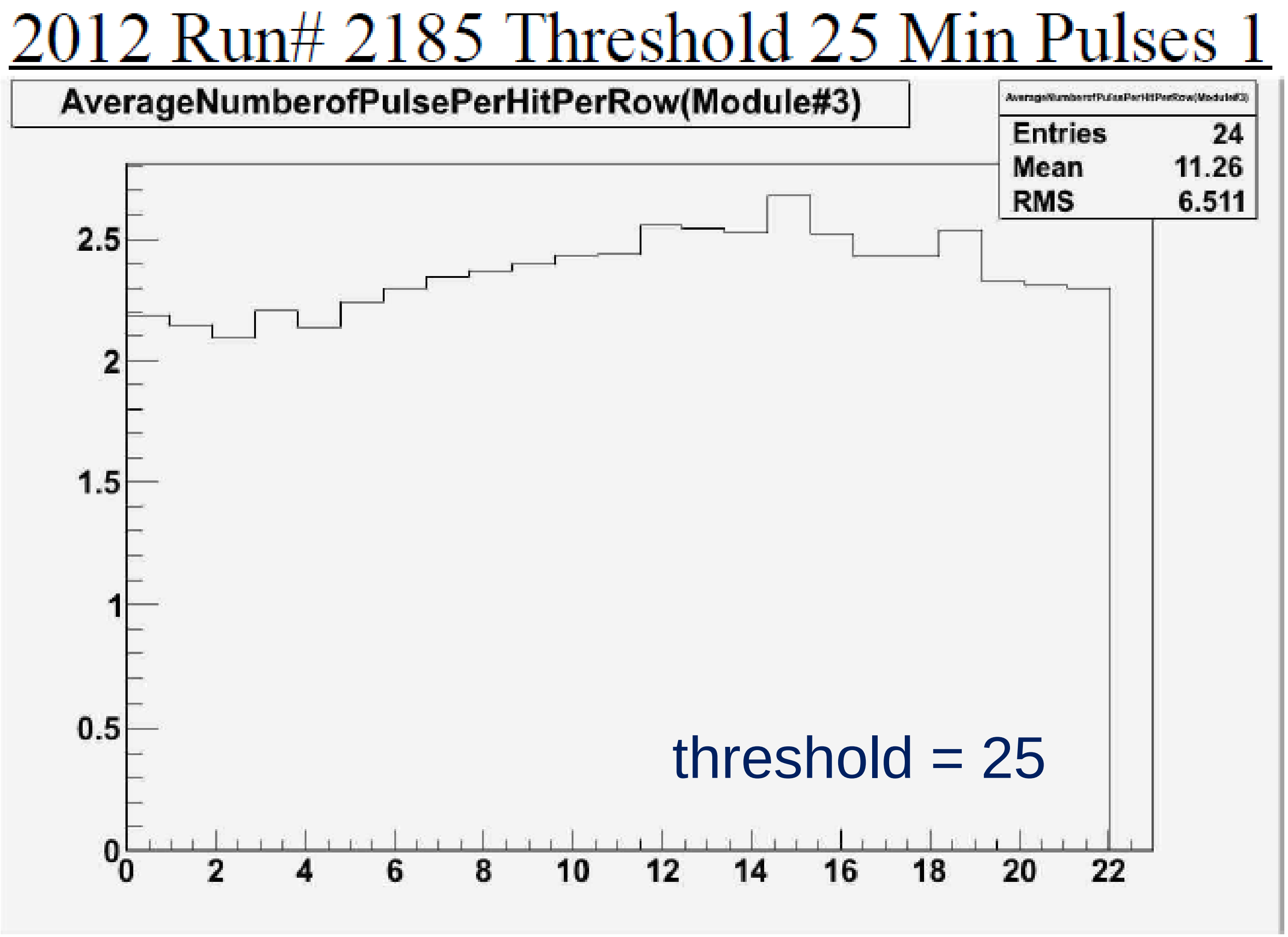
2011 Run# 1229 No Cut



Hit per row (2012) **= 2.1**



Hit per row (2012) = 2.4



OVERVIEW

- Look at 2012 data
  - **Resolution acceptable (see Wenxin's talk)**
  - **MarlinTPC used for data analysis of 7-module data**
  - **Now can fit PRF and/or tracks**
- Diagnostics:
  - **Need to measure the characteristics of the resistive layer and induction gap (need feedback from engineers and design electronic experts)**
  - **More noise so higher threshold**
  - **It leads to less hit per row (4.5 → 2.1)**
  - **Narrower PRF**
  - **Other effects to be investigated and corrected**
    - Cross talk
    - Bias estimators (position on row)

Still to do…

- Future…
  - Alignment is a easy extension of (extra d.o.f.) **PRFBasedTrackFinderProcessor**
  - Two tracks resolution
  - Synthetic data (test full fit)
  - dE/dx
  - etc…

Conclusion

- Progress toward **PRFBasedTrackFinderProcessor**
  - **Second implementation in MarlinTPC soon completed**
  - **Investigation of error on amplitude and time (A,t)**
  - **Pad Response Function (PRF) to define a hit in 3D**
  - **Investigate φ dependency**
  - **Transverse resolution versus Z (σ_0 and N_{eff}) of a hit as well as longitudinal resolution (time resolution) to be used for later "track fitting" (PRF-track is chicken-egg)**
  - **Ready for 9-module testbeam (end of January 2013)**
  - **Expect improvement for new modules**
- Long Term:
  - **Handling Error from (A,t) → (PRF,t) → (x,y,z) for a Hit to find unbiased track estimators and their uncertainties**
  - **Simulation of amplitude and time (A,t) to close the loop**