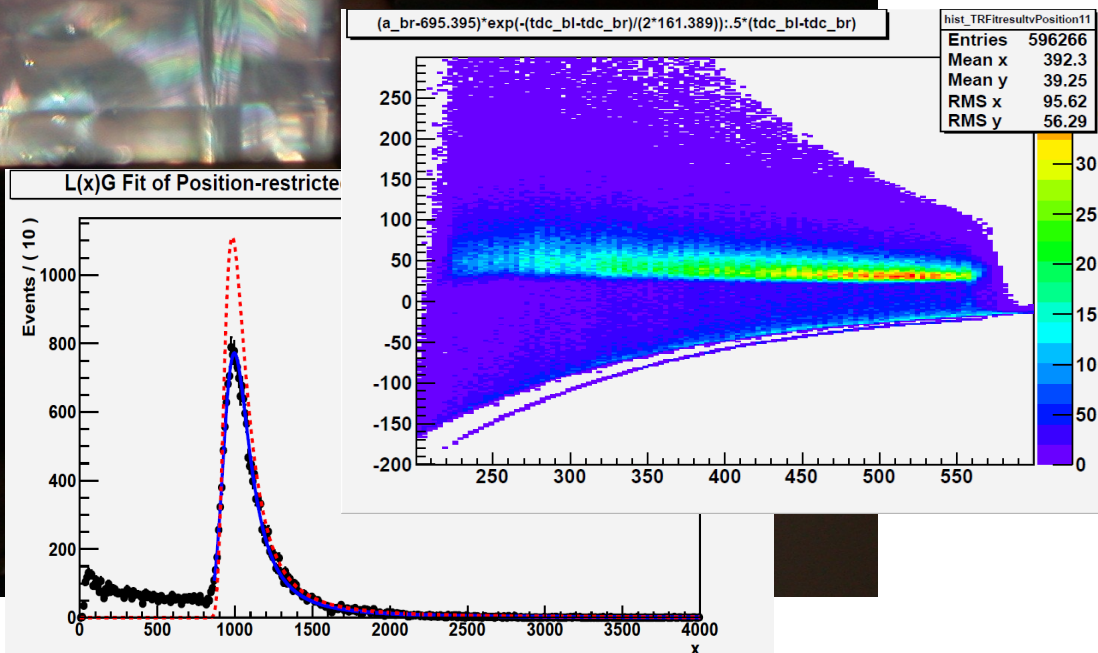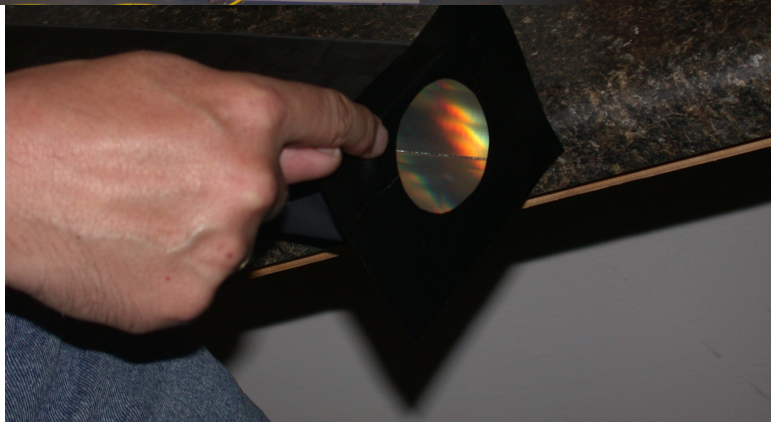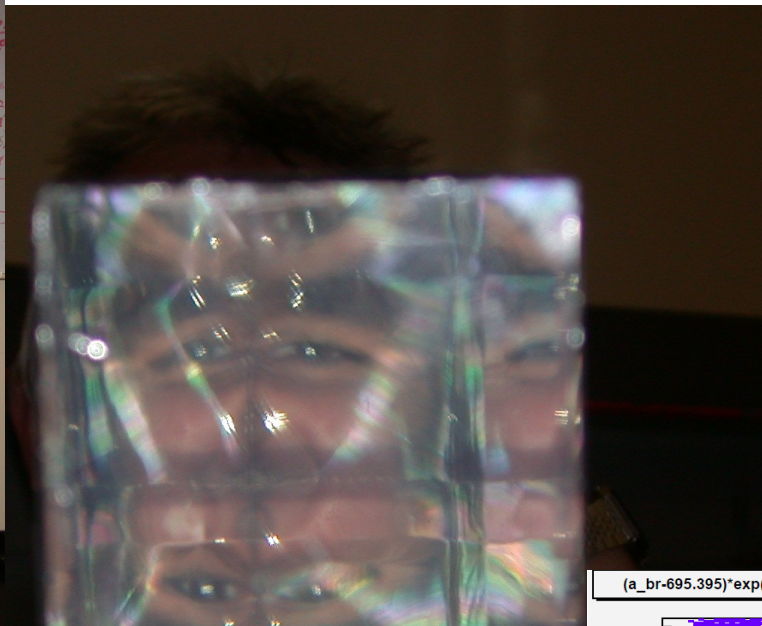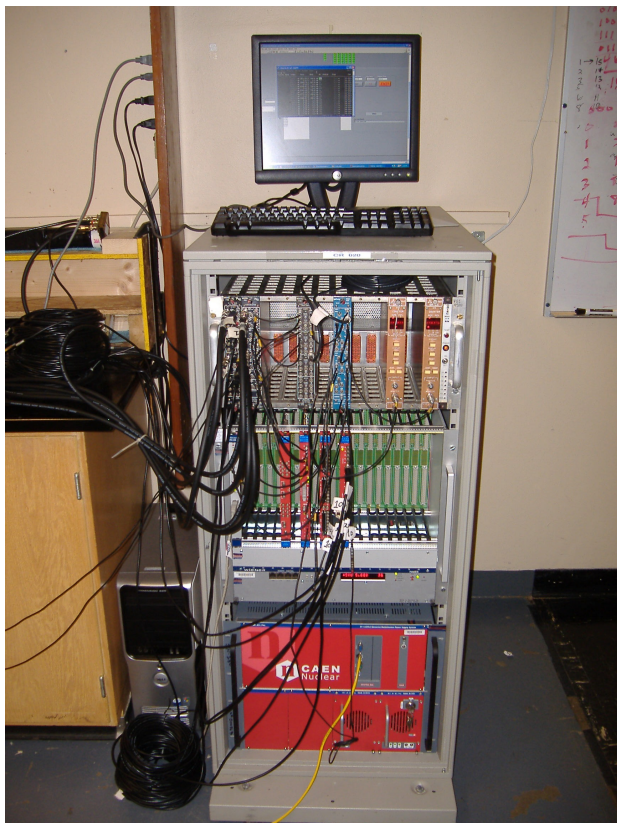# CLAS12 FTOF at USC:
Time Resolution Measurements

Evan Phelps

University of South Carolina
Department of Physics and Astronomy
phelps@physics.sc.edu

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TOF12 Project at USC

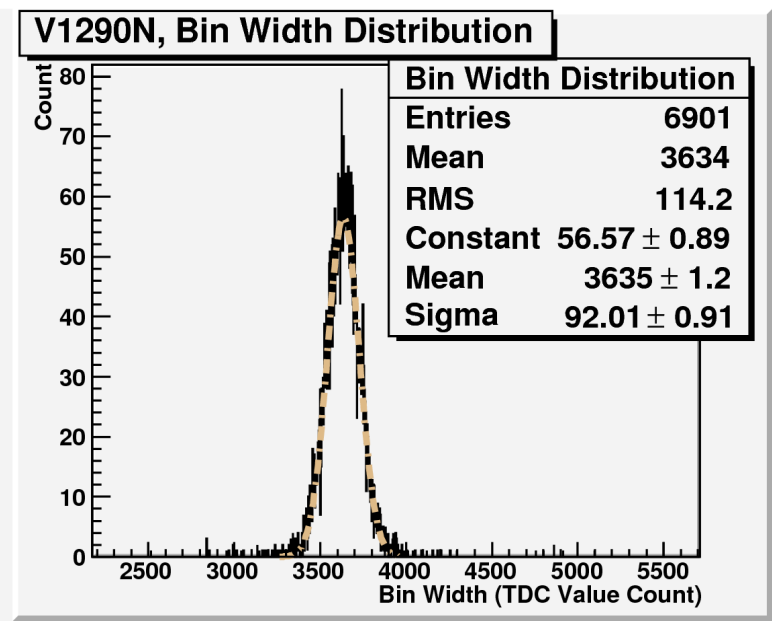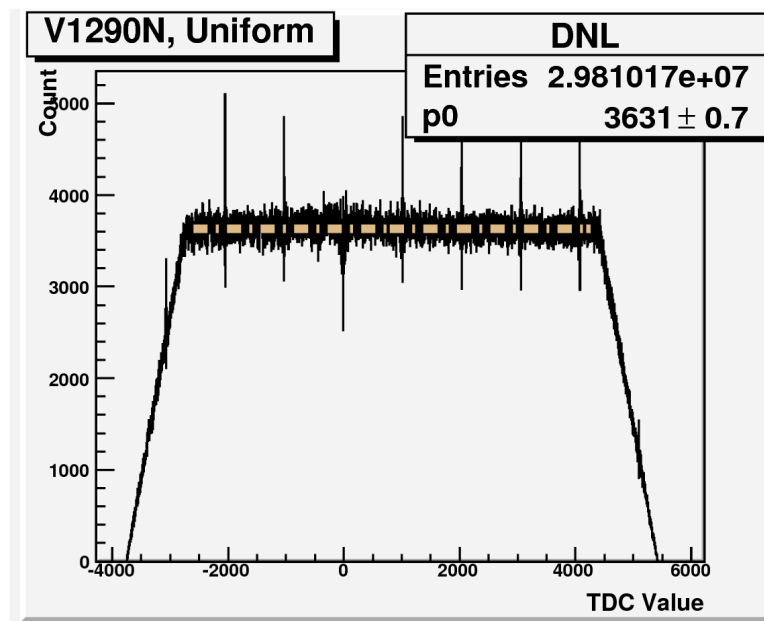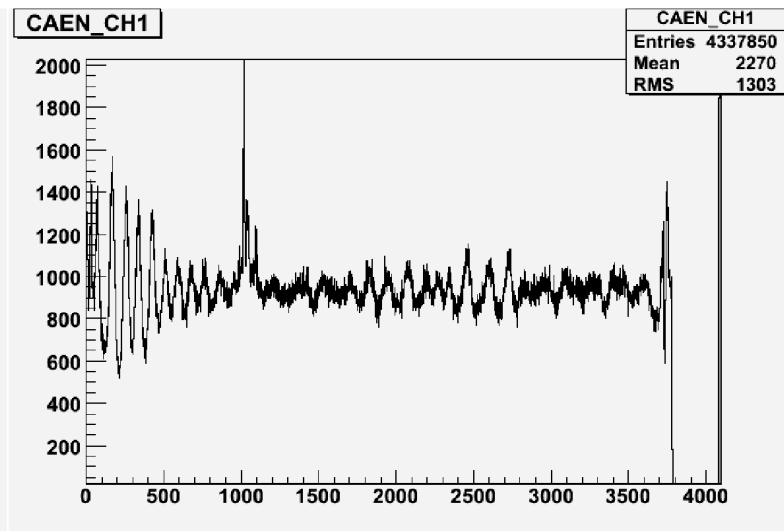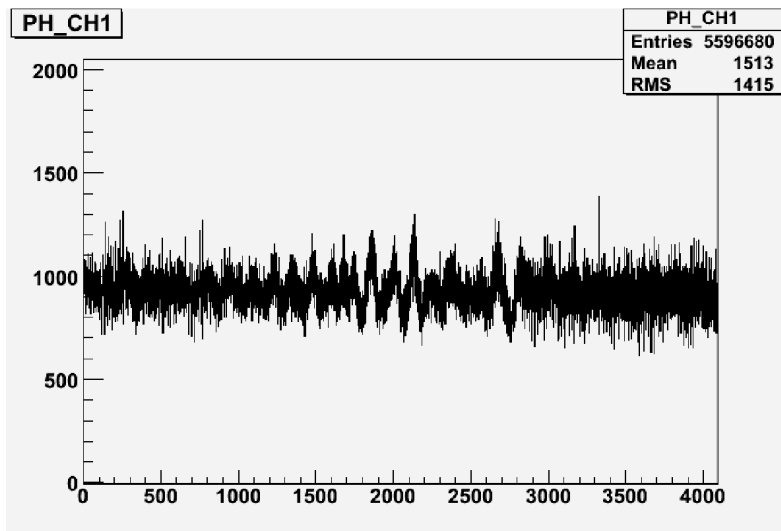# TDC Differential Nonlinearity

Random
Start

+

Periodic
Stop

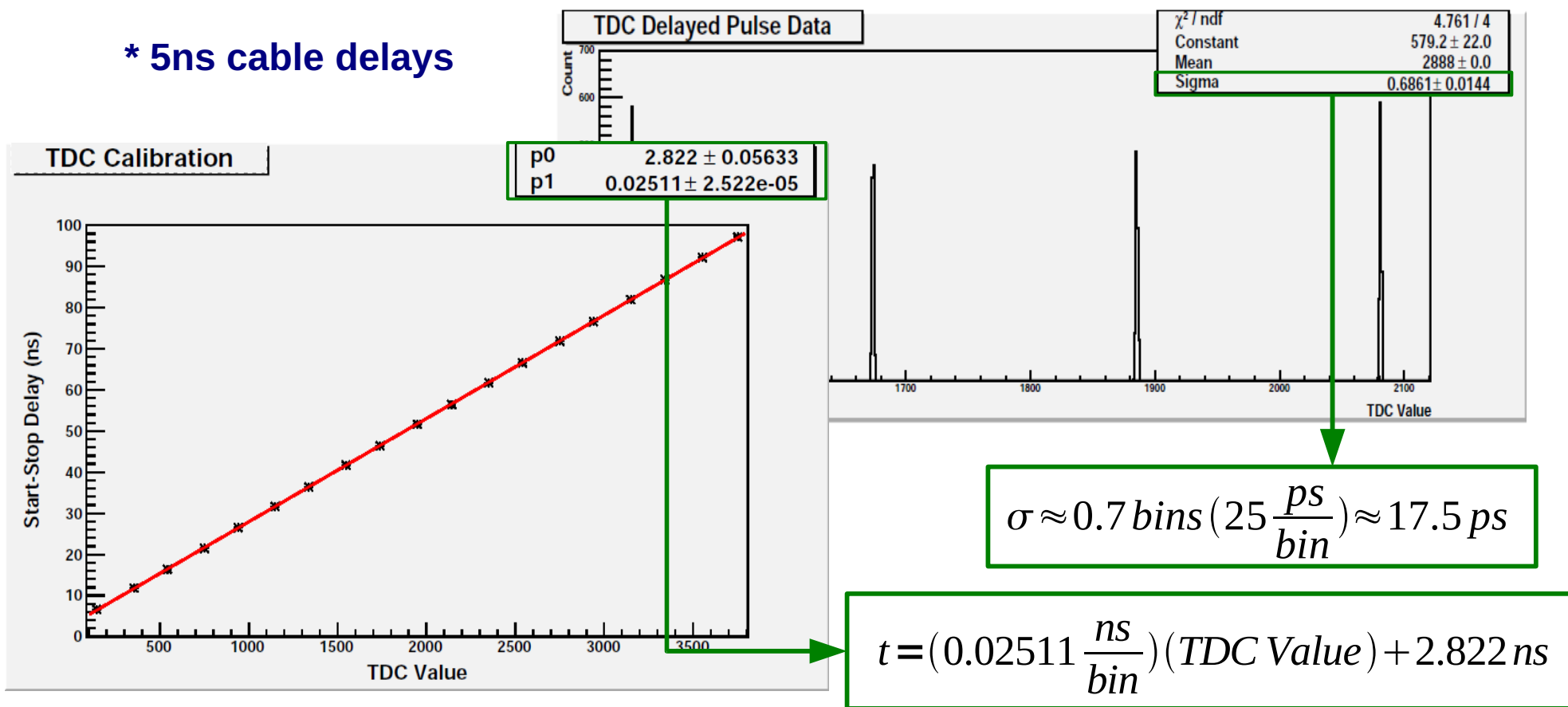Uniform
Distribution

+

**DNL
Fluctuations**

+

Statistical
Fluctuations

TDC Calibration and Resolution

* 5ns cable delays

TDC Delayed Pulse Data

χ² / ndf	4.761 / 4
Constant	579.2 ± 22.0
Mean	2888 ± 0.0
Sigma	0.6861 ± 0.0144

p0	2.822 ± 0.05633
p1	0.02511 ± 2.522e-05

TDC Calibration

$$\sigma \approx 0.7\,bins\,(25\,\frac{ps}{bin}) \approx 17.5\,ps$$

$$t = (0.02511\,\frac{ns}{bin})(TDC\,Value) + 2.822\,ns$$

Model	DNL_σ	DNL_{max}	Range(ns)	Offset(ns)	Bin Size(ps)	Resolution(ps)
PS7186	9.8%	48.9%	100	18-21	24.98	19.0
C414	8.9%	135.6%	72	0-5	25.11	17.5
V1290N	1.9%	41.1%	N/A	N/A	24.75	32.5

ADC Calibration

V792N testing: Single channel example

Pedestal=63, External DC Offset = -22.55mV

χ^2 / ndf	49.37 / 44
Constant	172.7 ± 4.0
Mean	317 ± 0.1
Sigma	6.389 ± 0.086

DC Offset versus ADC Value, Pedestal=63

χ^2 / ndf	0.01472 / 2
p0	-4.606 ± 0.1462
p1	-0.05422 ± 0.0002822

Pedestal versus Virtual Ground

χ^2 / ndf	0.03305 / 2
p0	-6.142 ± 0.1566
p1	0.02441 ± 0.0008983
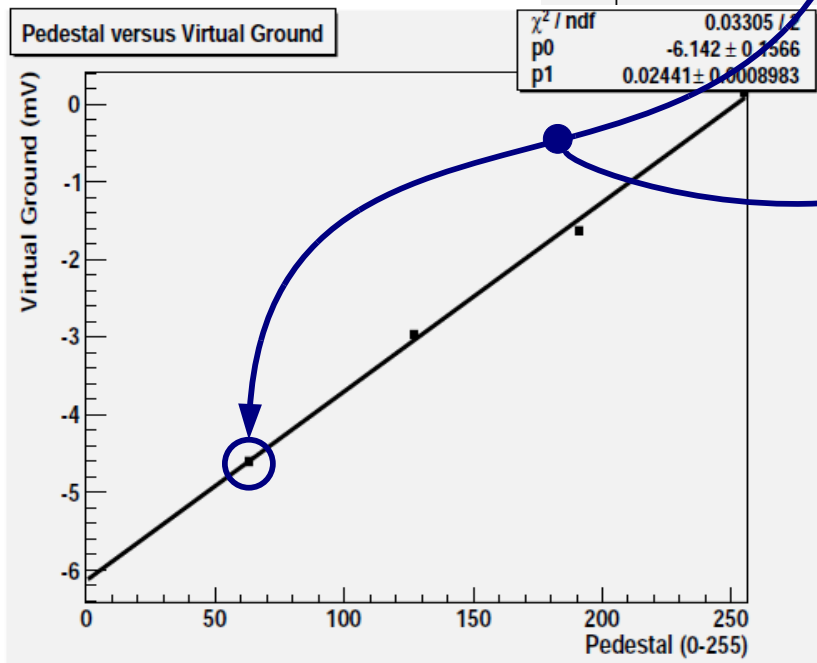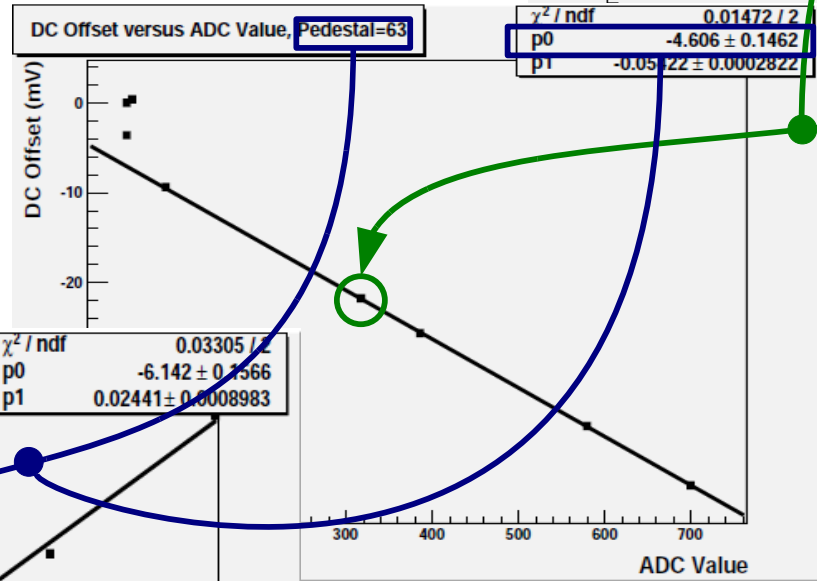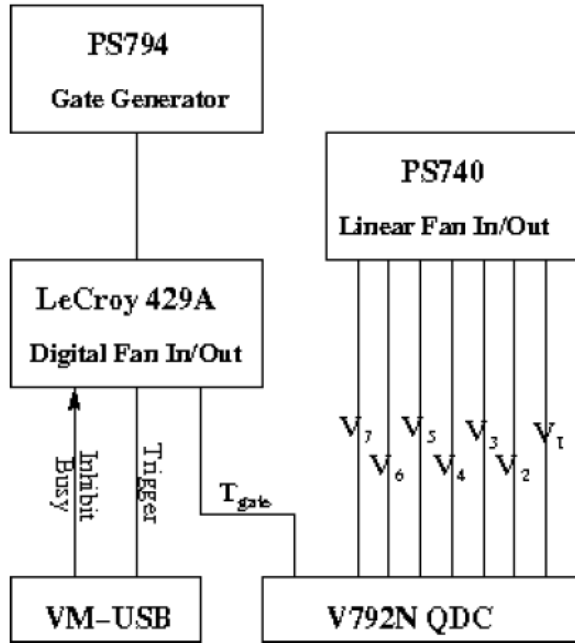
sensitivity
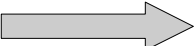
$$Q = \left(-4.606 \, \frac{mV}{bin} x - 0.0542 \, mV \right) \left(\frac{T_{gate}}{R} \right) = -9.2 \, \frac{pC}{bin} x - 0.11 \, pC$$

Adjustable pedestal range is insufficient to push system charge offset above the threshold.

Time Resolution Measurement Methods

- Coordinate method

  →

  Independent position measurements
  High statistics.
  Requires multiple runs per counter.
  Energy deposit signature does not match
  CLAS experimental conditions.

- Reference counter methods

  →

  Independent position measurements.
  Energy deposit signature matches CLAS
  experimental conditions.
  Very to extremely low statistics.
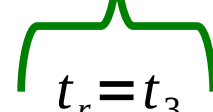 Requires multiple runs per counter.

  - One reference

  - Two reference

- Three-bar cosmic ray method

  →

  Energy deposit signature matches CLAS
  experimental conditions.
  High statistics.
  Requires only one data run for full bar.
  Does not incorporate independent
  position measurements.

Three-bar Method Concept
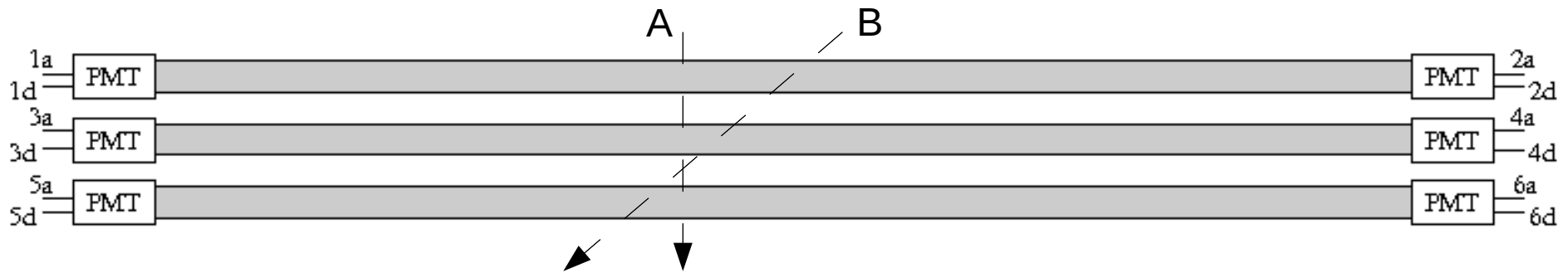
$$T = \frac{t_t + t_b}{2} - t_m = \frac{t_1 + t_2 + t_5 + t_6 - 4t_r}{4} - \frac{t_3 + t_4 - 2t_r}{2} = \frac{t_1 + t_2 + t_5 + t_6}{4} - \frac{t_4 + t_3}{2}$$
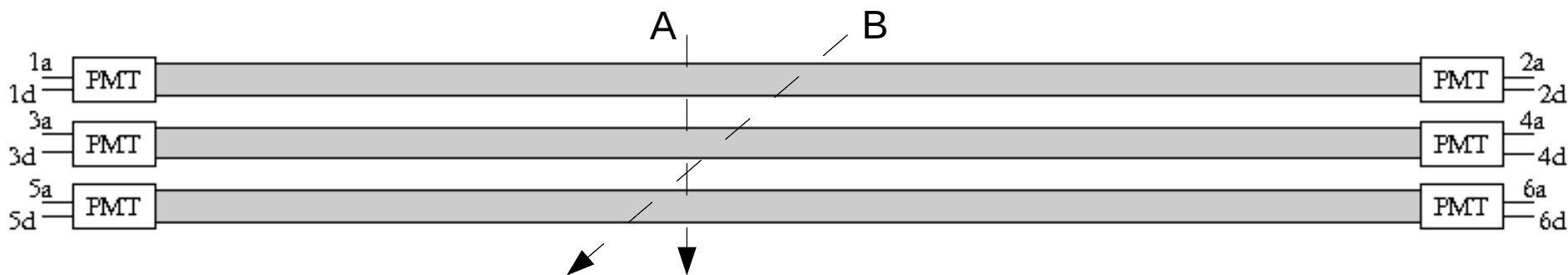
$$t_r = t_3$$

$$\sigma_{counter} = \frac{\sigma_{pmt}}{\sqrt{2}}$$

$$t_t = \frac{t_{tl} + t_{tr}}{2} \qquad t_{tl} = t_1 - t_r$$
$$t_{tr} = t_2 - t_r$$
$$t_m = \frac{t_{ml} + t_{mr}}{2} \qquad t_{ml} = t_3 - t_r$$
$$t_{mr} = t_4 - t_r$$
$$t_b = \frac{t_{bl} + t_{br}}{2} \qquad t_{bl} = t_5 - t_r$$
$$t_{br} = t_6 - t_r$$

$$\sigma_{tb} = \sigma_1 = \sigma_2 = \sigma_5 = \sigma_6$$
$$\sigma_m = \sigma_3 = \sigma_4$$

$$\sigma_T^2 = \frac{1}{4}\sigma_{tb}^2 + \frac{1}{2}\sigma_m^2$$

$$\sigma_{counter} = \sqrt{\sigma_T^2 - \frac{1}{2}\sigma_{ref}^2}$$
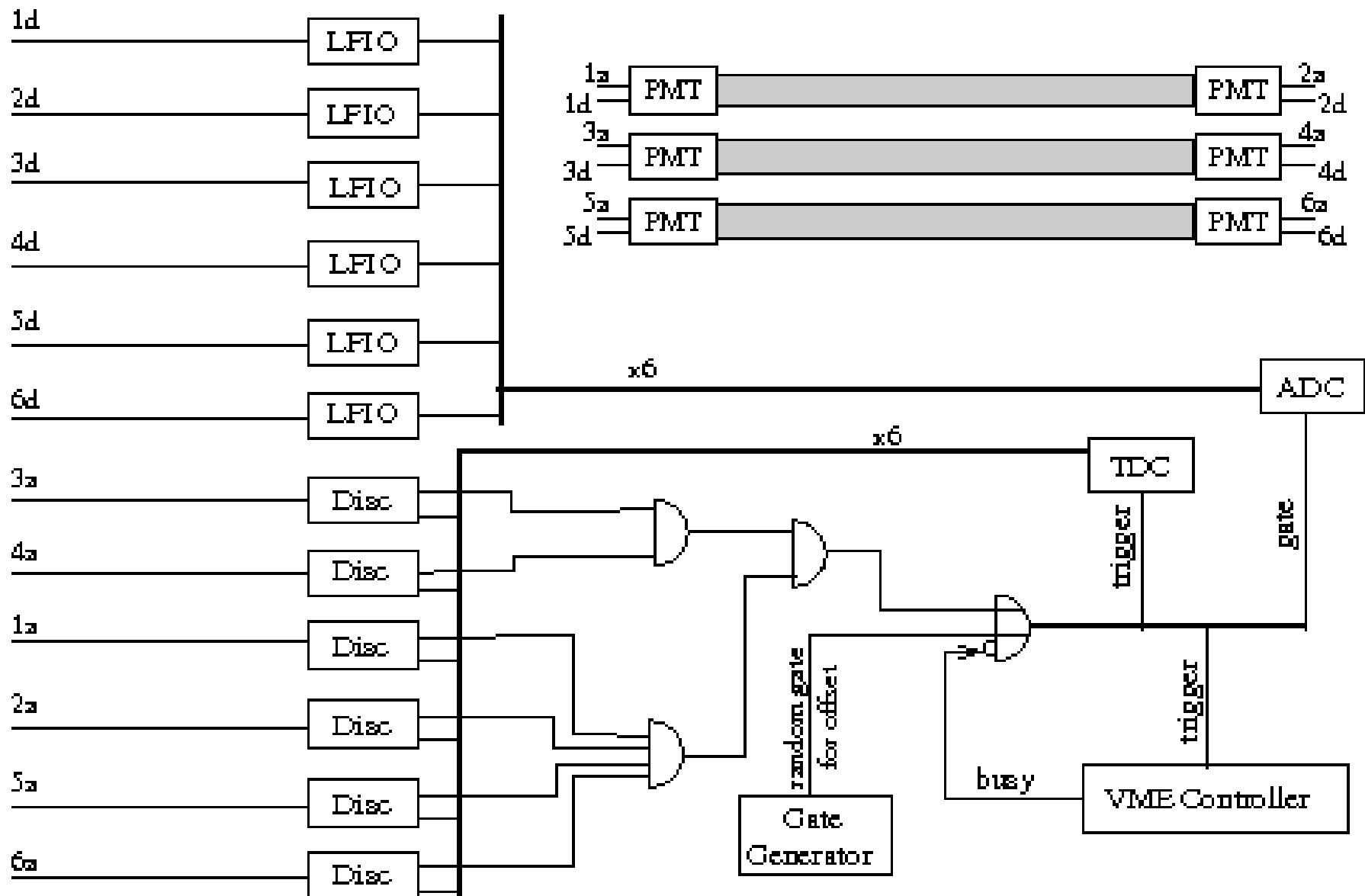
Reference Counter Resolution

A   B

$$\sigma_{counter} = \sqrt{\sigma_T^2 - \frac{1}{2}\sigma_{ref}^2}$$

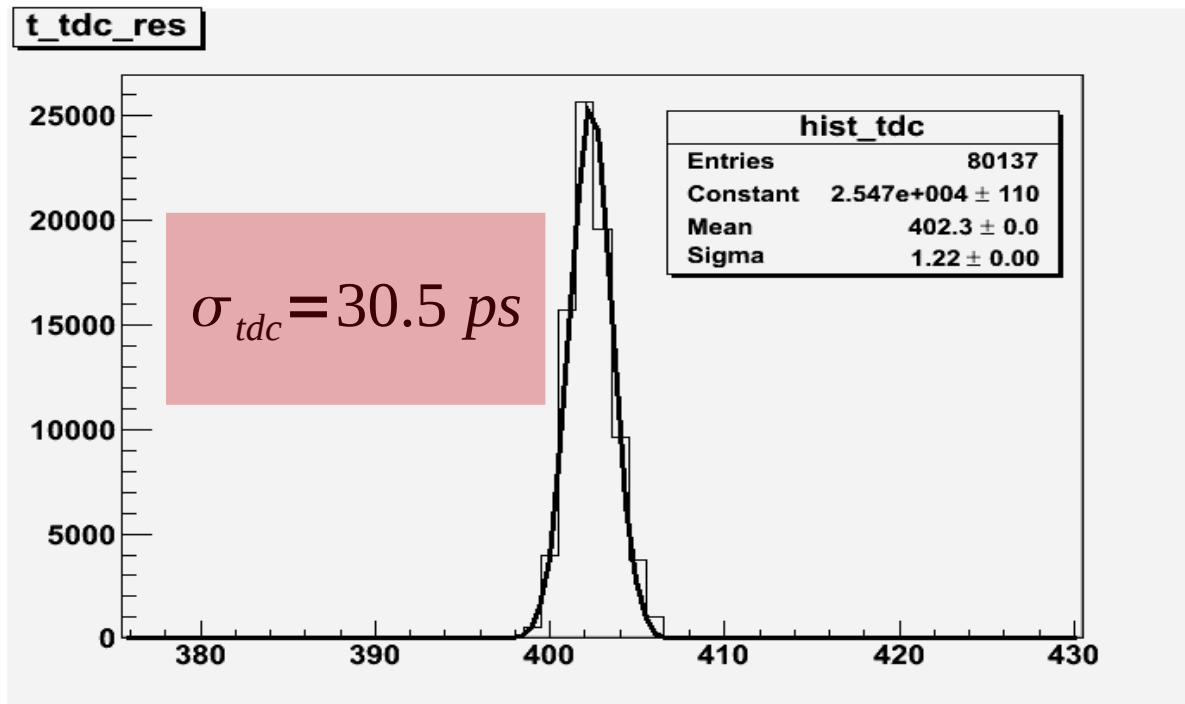The middle counter is the one being evaluated; the top and bottom are reference counters of known resolution.

When all three counters are identical...

$$\sigma_{counter} = \sqrt{\frac{2}{3}}\sigma_T$$

# Three-bar Method Implementation

Base Resolution

$$\sigma_{tdc} = 30.5\ ps$$

t_tdc_res

hist_tdc	
Entries	80137
Constant	$2.547e{+}004 \pm 110$
Mean	402.3 ± 0.0
Sigma	1.22 ± 0.00

TDC resolution, between 30ps and 35ps, contributes to the resolution measurements.

hist_electronic	
Entries	80137
Constant	$1.241e{+}004 \pm 62$
Mean	3256 ± 0.0
Sigma	2.289 ± 0.008

$$\sigma_{electronics} = 57.2\ ps$$

Total electronics resolution is measured, but does not contribute to the resolution measurements.
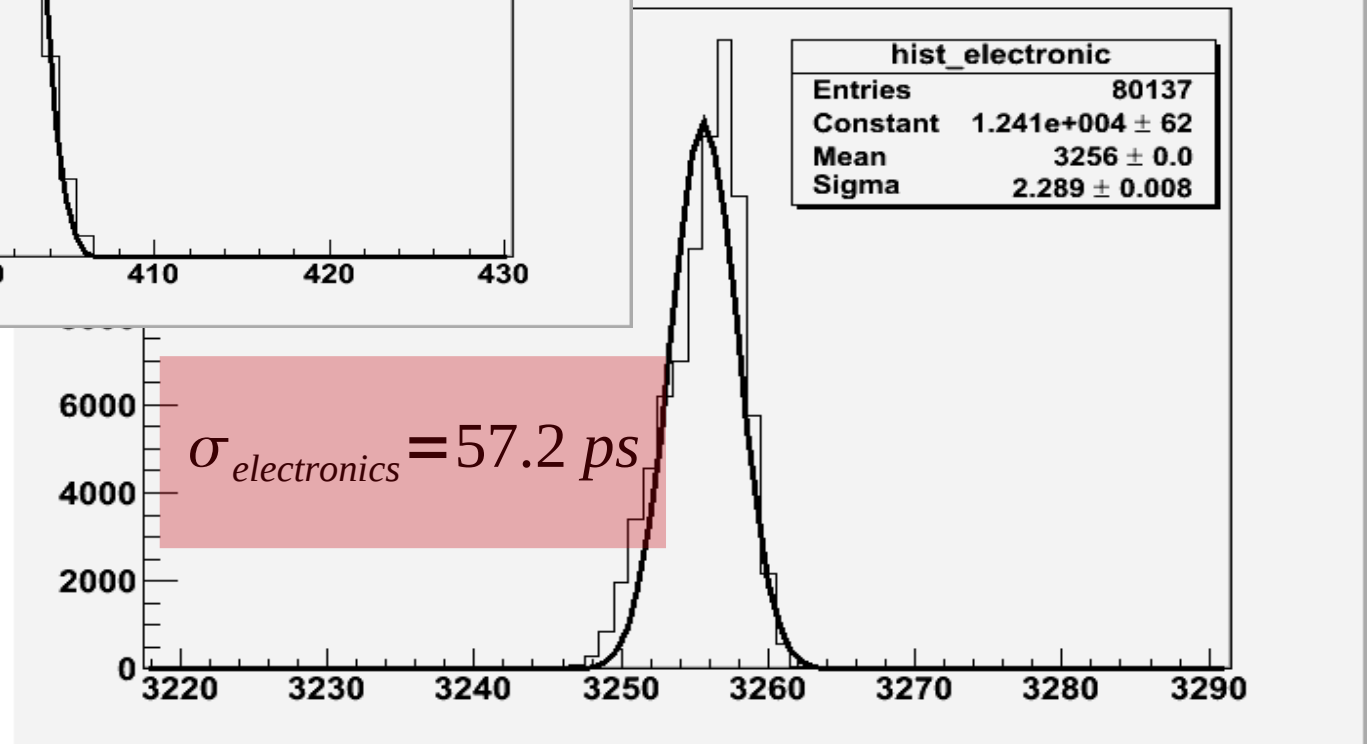
Three-bar System ADC Offset

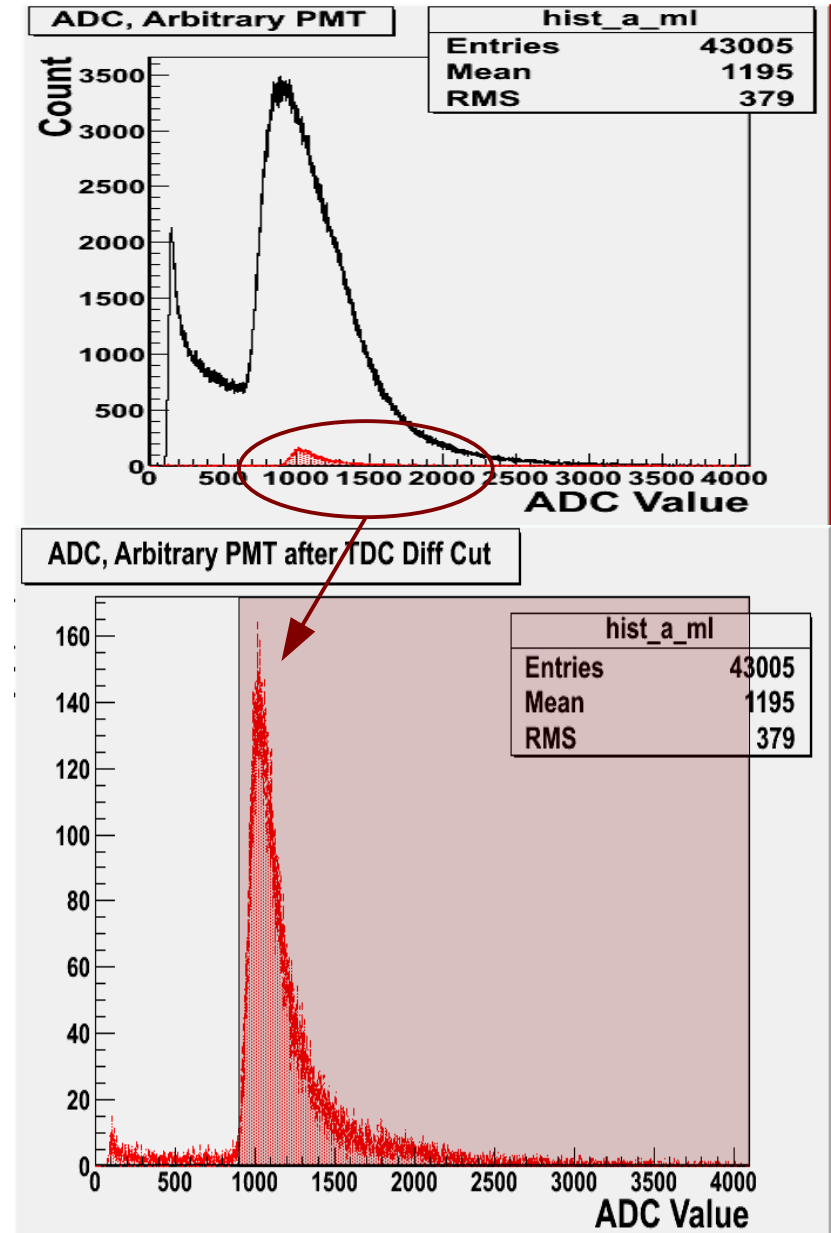**in-situ offset measurements**

σ = 6.435 bins
μ = 63.44 bins
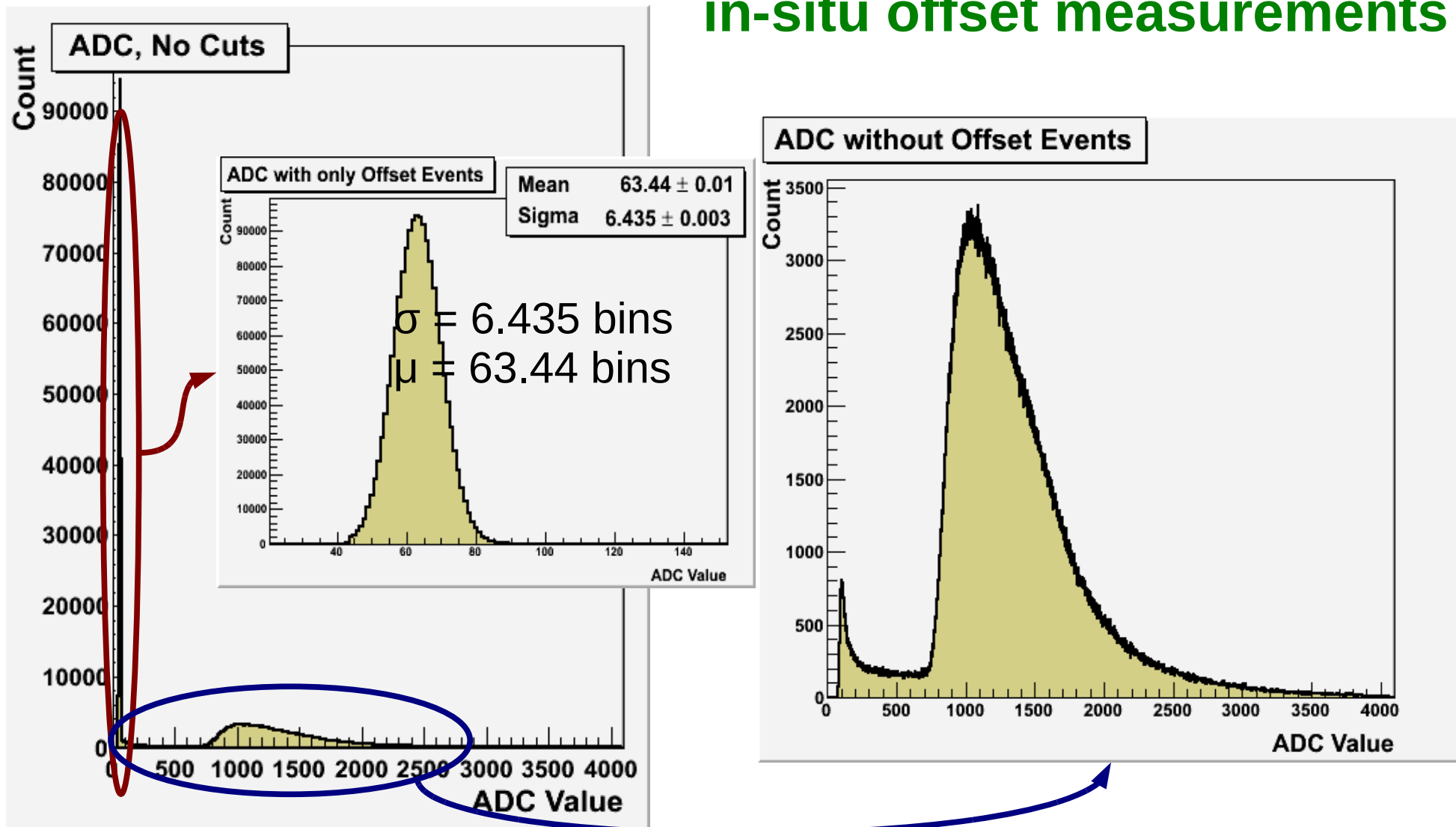
Position-specific Event Selection

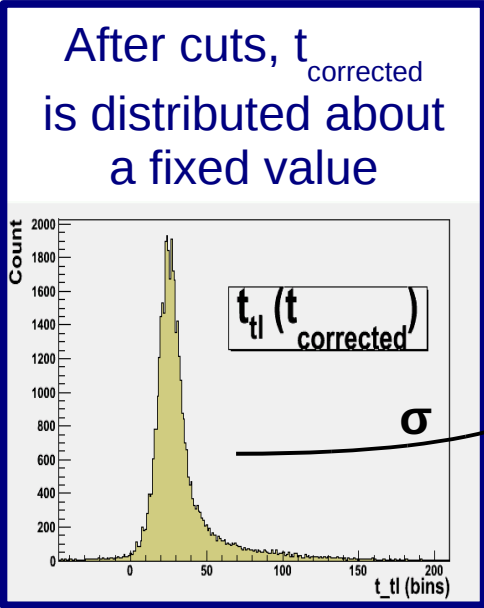**Position Cuts via TDC Difference**
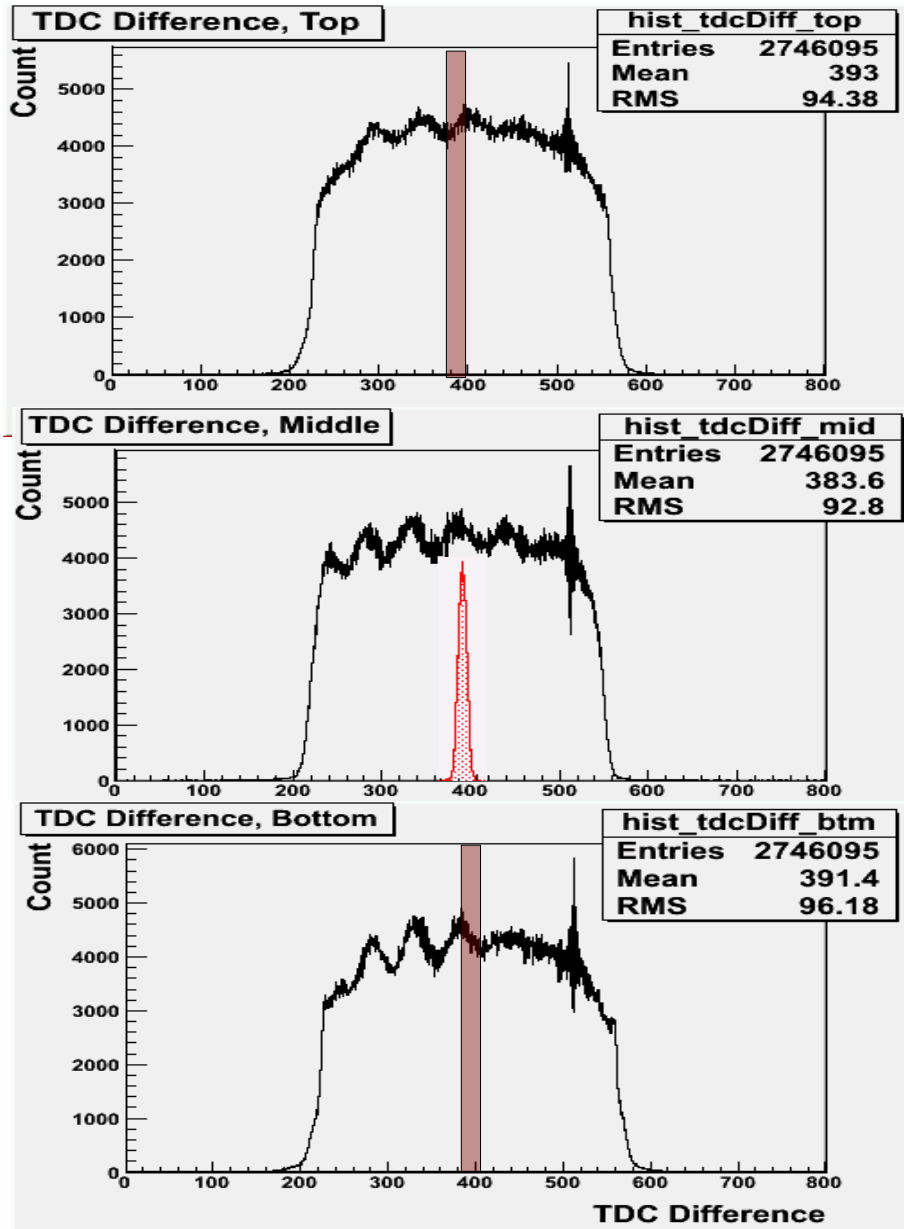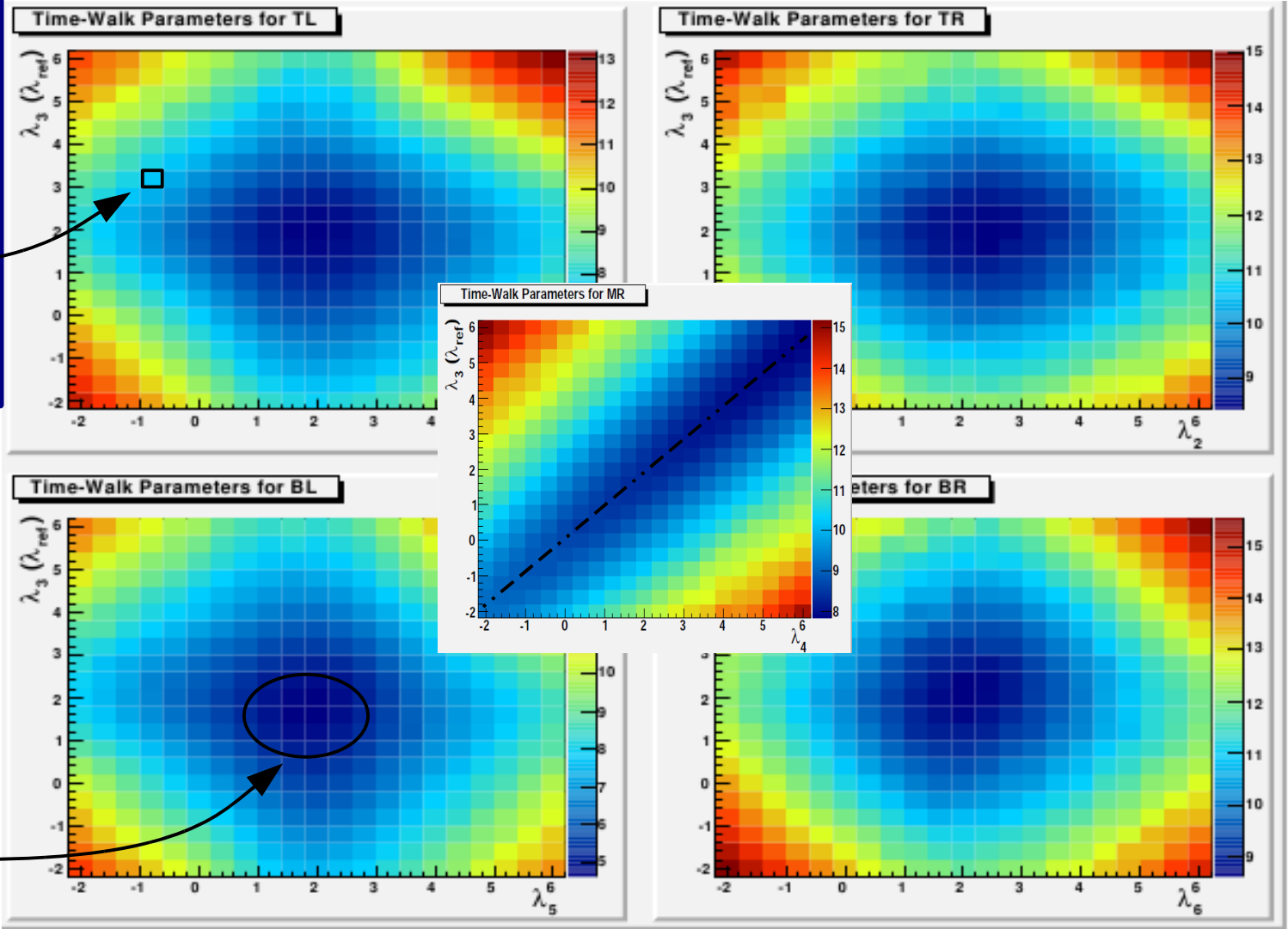
Full-width Trajectory Cuts via ADC Minimums
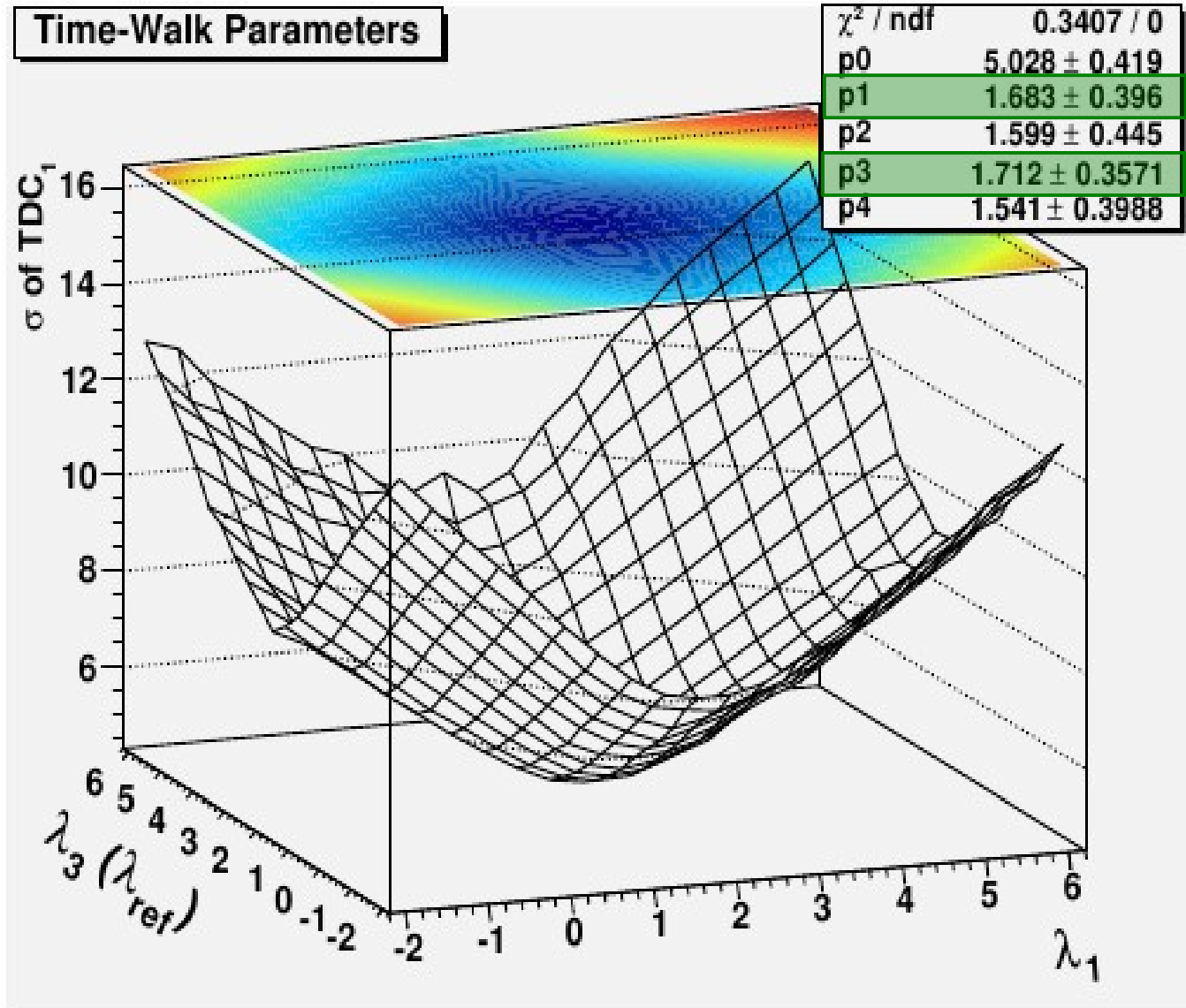
Position-specific Timewalk Correction

$$t_{corrected} = \left(TDC_i - \frac{\lambda_i}{\sqrt{ADC_i}}\right) - \left(TDC_3 - \frac{\lambda_3}{\sqrt{ADC_3}}\right)$$

After cuts, $t_{corrected}$ is distributed about a fixed value

$t_{tl} (t_{corrected})$

σ

TW parameters λ_i and λ_3 are varied for each of tl, tr, bl, br, and mr to determine values leading to minimum $t_{corrected}$ spreading.

Time-Walk Parameters for TL

Time-Walk Parameters for TR

Time-Walk Parameters for MR

Time-Walk Parameters for BL

eters for BR

Position-specific Timewalk Correction

A paraboloid fit is sufficient to obtain the minimum value and corresponding TW parameters.
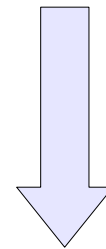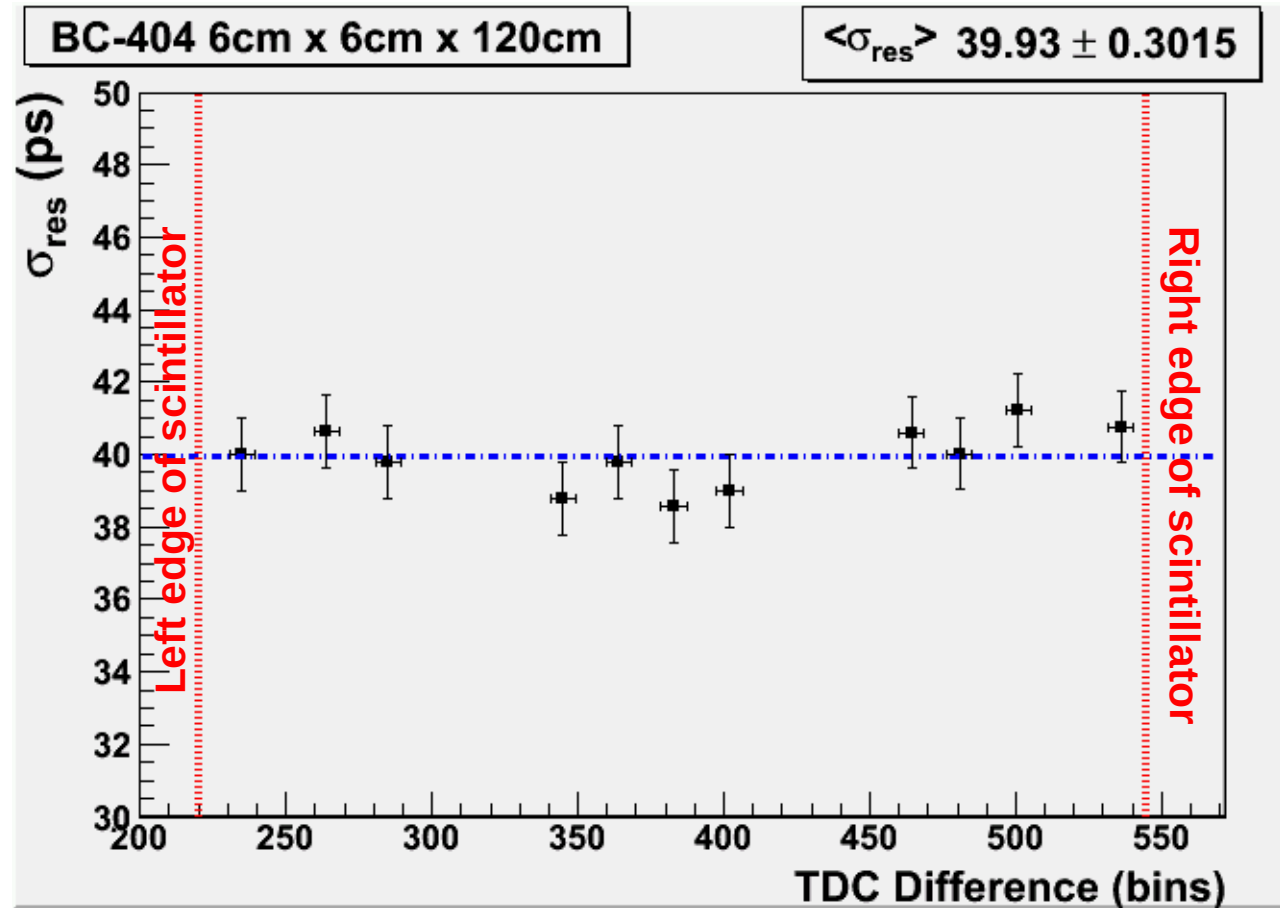
$(\lambda_1, \lambda_3) \approx (1.7, 1.7)$

Position-dependent Resolution

Resolution measurements are consistent, within statistical uncertainties, throughout the counter length.

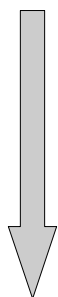The average position-restricted resolution, $<\sigma_{res}>$, Is approximately **40ps**.

Scintillator edges are defined by FWHM of TDC Difference before cuts or TWC.

Position-dependent TW Parameters
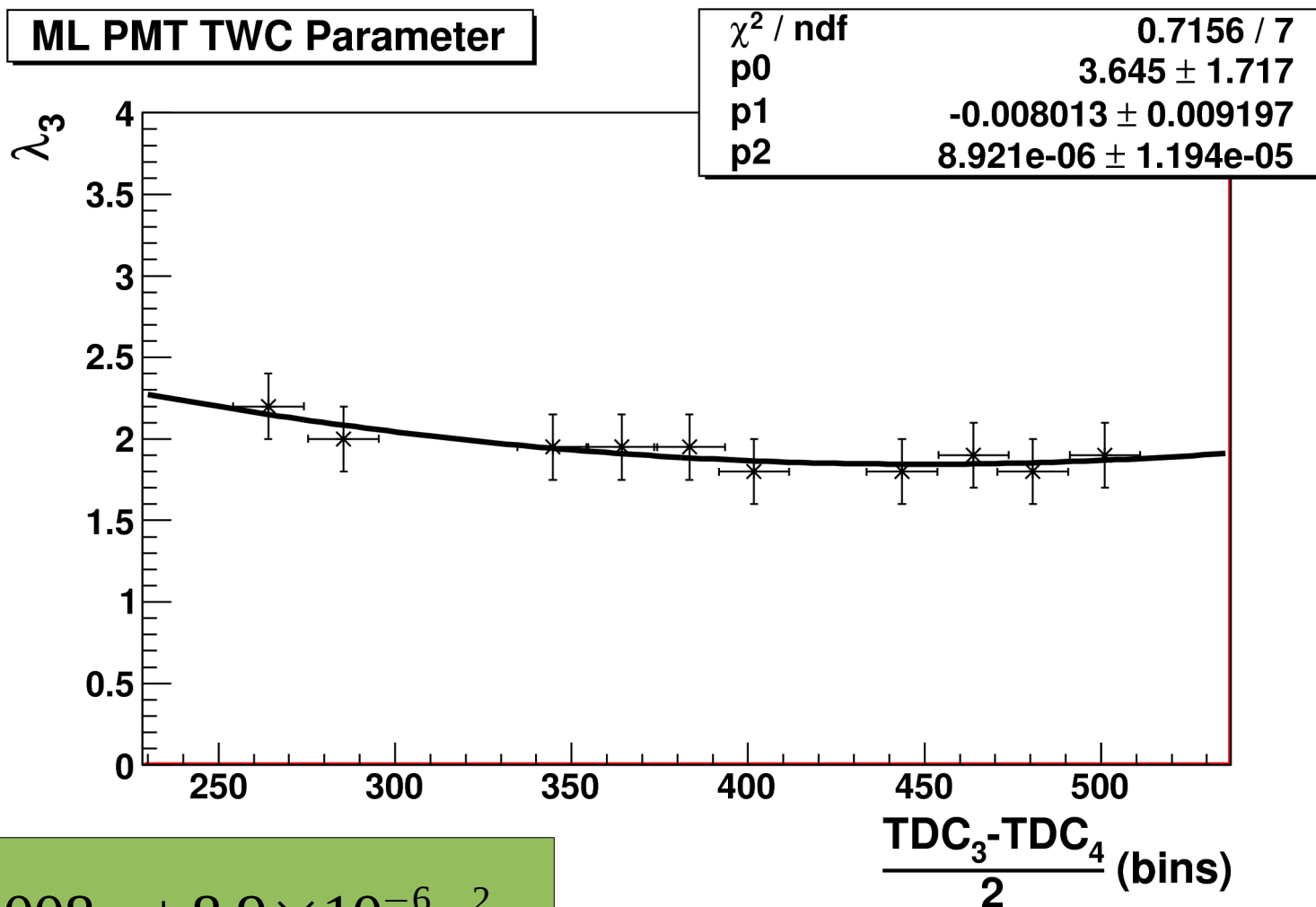
EXAMPLE

Correction function

for the time (t$_3$) of

the middle-left (ML)

PMT

ML PMT TWC Parameter

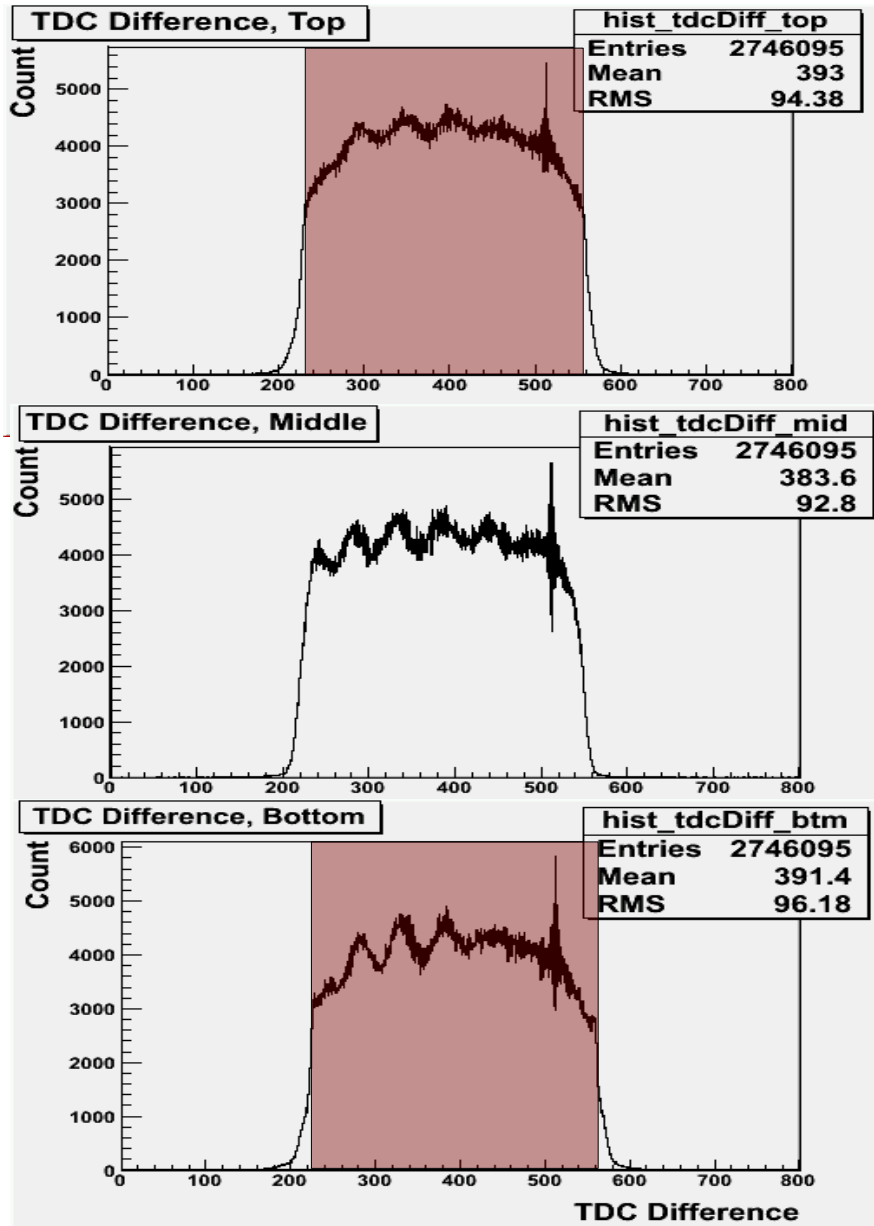| χ^2 / ndf	0.7156 / 7
p0	3.645 $\pm$ 1.717
p1	-0.008013 $\pm$ 0.009197
p2	8.921e-06 $\pm$ 1.194e-05

λ_3

$\dfrac{TDC_3\text{-}TDC_4}{2}$ **(bins)**

$$\lambda_3 = 3.645 - 0.008\,x + 8.9 \times 10^{-6} x^2$$

Full-bar Resolution Event Selection
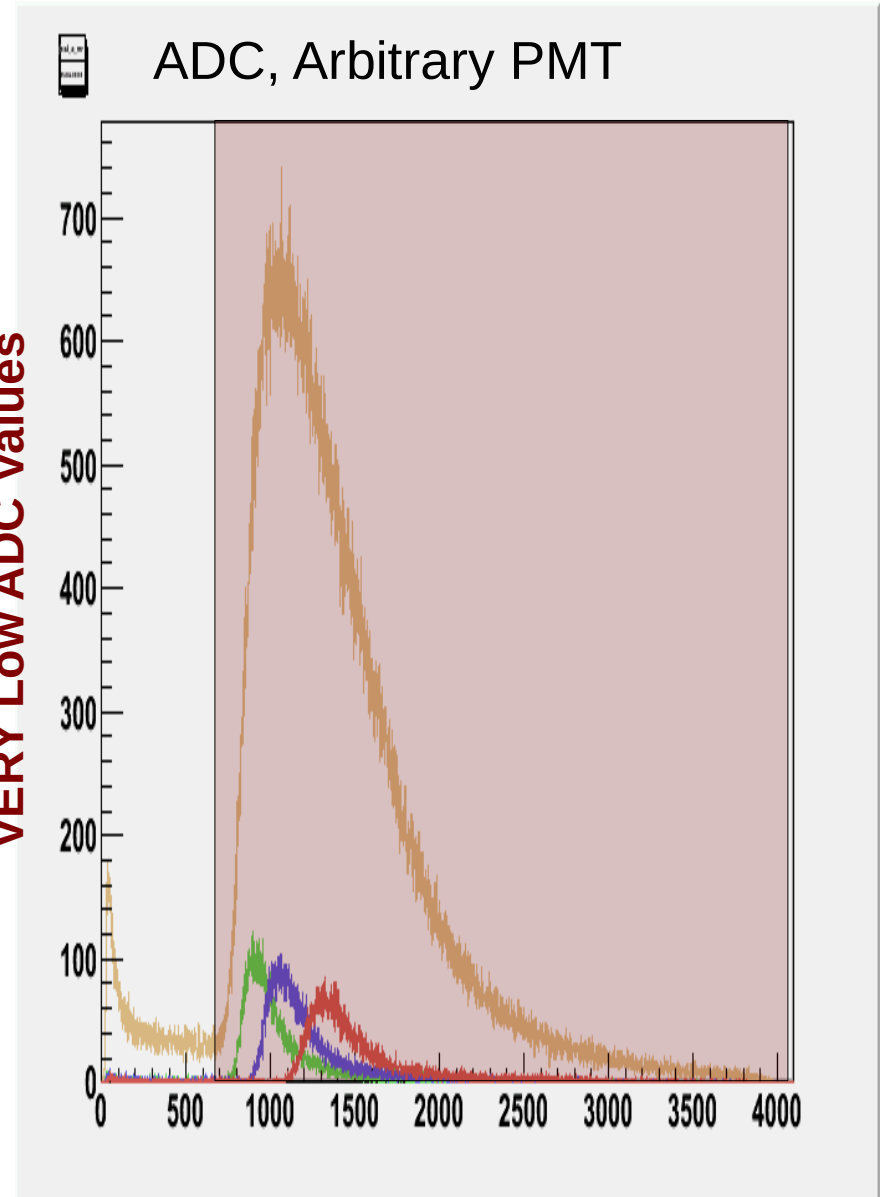
Full-bar Resolution without Vertical Cuts

86.6ps

42.6ps
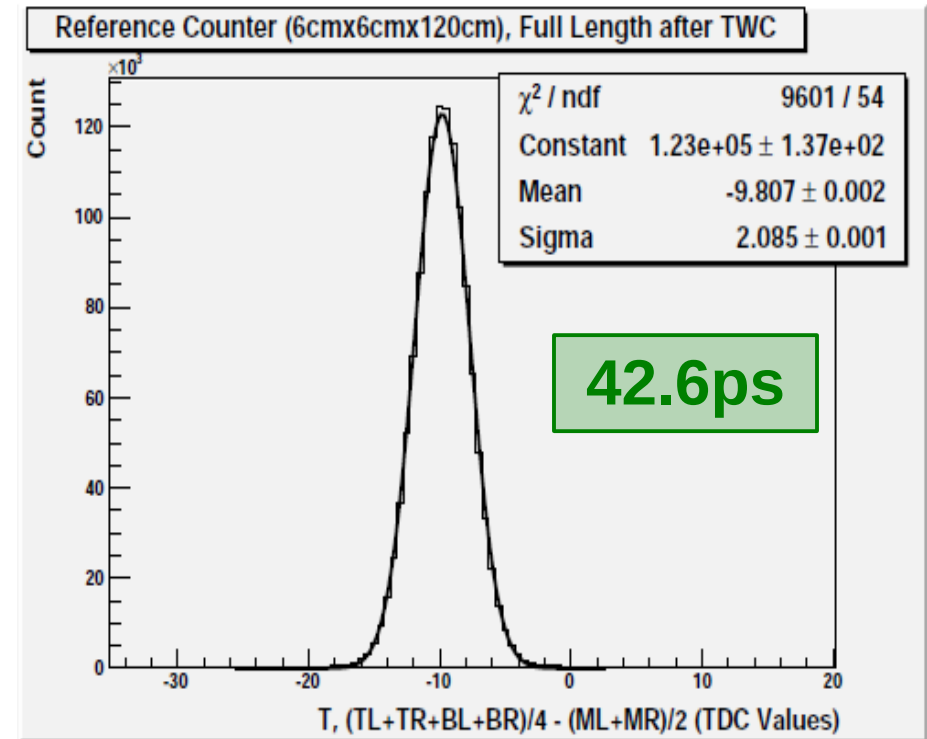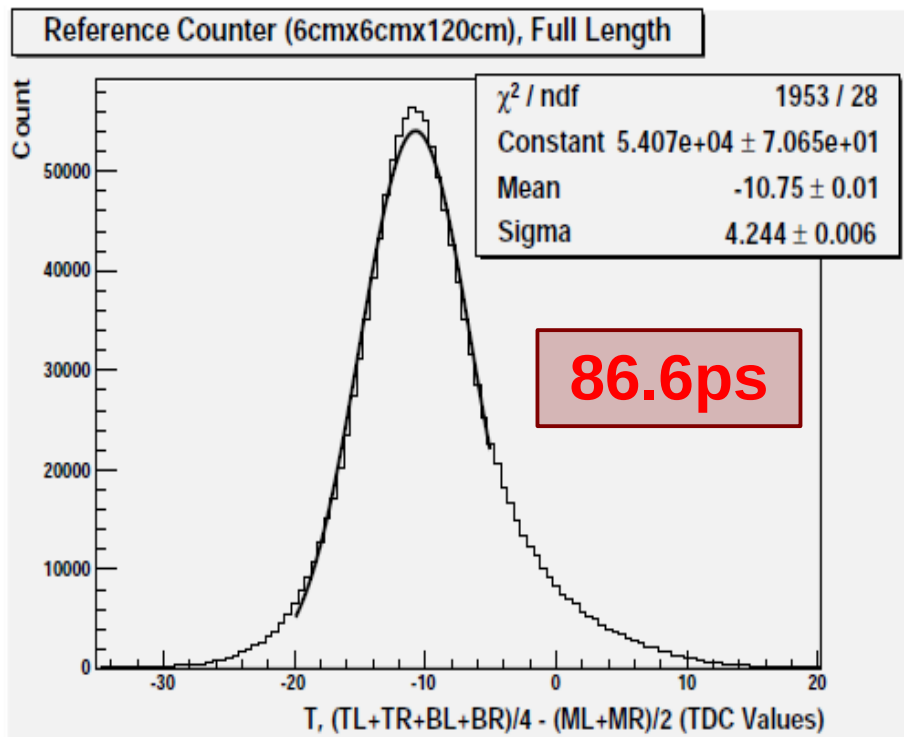
Timewalk
Correction
Functions

Recent Results