# The Central Neutron Detector
# Jefferson Lab

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# Outline

- Background
- Status of CND work
  → Overview
  → Geometry
  → Calibration
- Cosmic Tests
- Future plans

# Experimental Site

- Hall B: CEBAF Large Acceptance Spectrometer (CLAS)
- CLAS → CLAS12: 11GeV beam physics program
- Upgrade baseline, and introduce non-baseline equipment
- New systems:

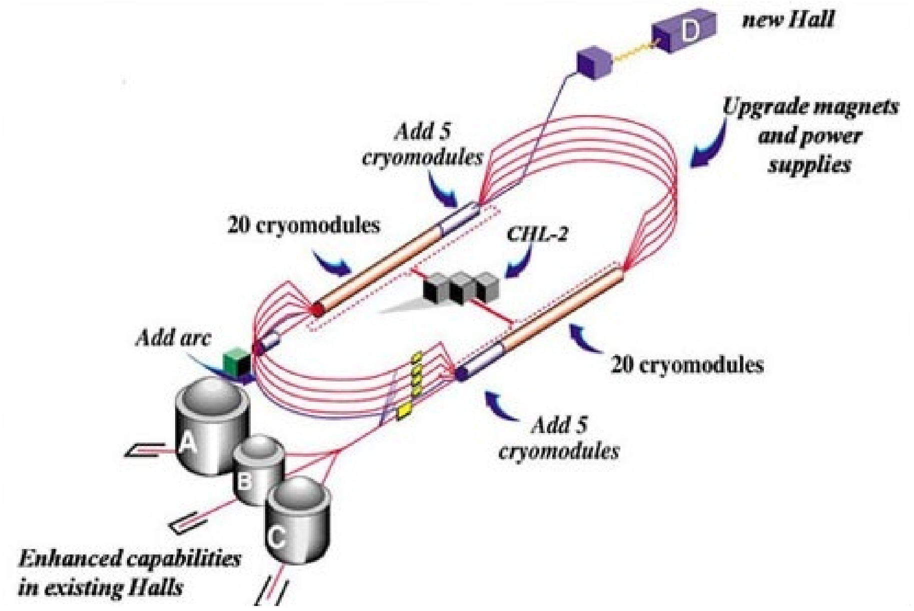
→RICH: Ring-Imaging Cherenkov Detector

→MM: Micromegas Tracker

→FT: Forward Tagger

→**CND: Central Neutron Detector (2009)**

UPGRADED CEBAF




[https://www.jlab.org/sites/default/files/styles/jlab_2-col_page_image/public/12-gev-3.jpg]

# Central Neutron Detector

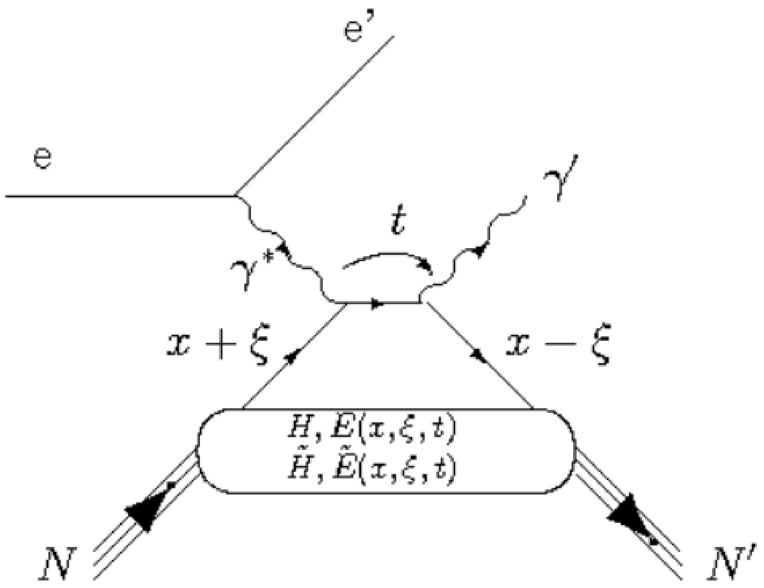
- CND – detect and measure properties of recoil neutrons
- Experiment - electron beam on deuterium target:

$$ed \rightarrow e'n\gamma(p)$$

- Deeply Virtual Compton Scattering (DVCS) experiments
- Scattering by a virtual photon

  →Bjorken limit: E and p of $\gamma^* \rightarrow \infty$

- Beam spin asymmetry studies




[https://www.jlab.org/exp_prog/proposals/11/PR12-11-003.pdf]

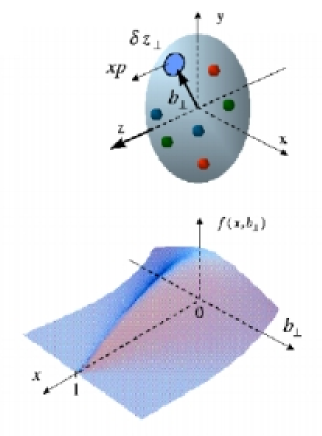
# GPDs

- Phase space images of hadron constituents
- General Parton Distributions (GPDs) independent but related

  → Measurements in n-DVCS are complementary to p-DVCS
- Necessary for flavour separation of quarks (Ji's sum rule)
- Requires knowledge of 4 structure functions, but some are supressed in p-DVCS

  → Need n-DVCS

  → CLAS12 is ideal for this



(GPDs)
fully-correlated quark distribution in both coordinate and momentum space

$$\sum_q \int_{-1}^{+1} dx\, x[H^q(x,\xi,t=0) + E^q(x,\xi,t=0)] = 2\, J_{quarks}$$

[https://userweb.jlab.org/~silvia/nd3_extension.pdf]

# CND Requirements

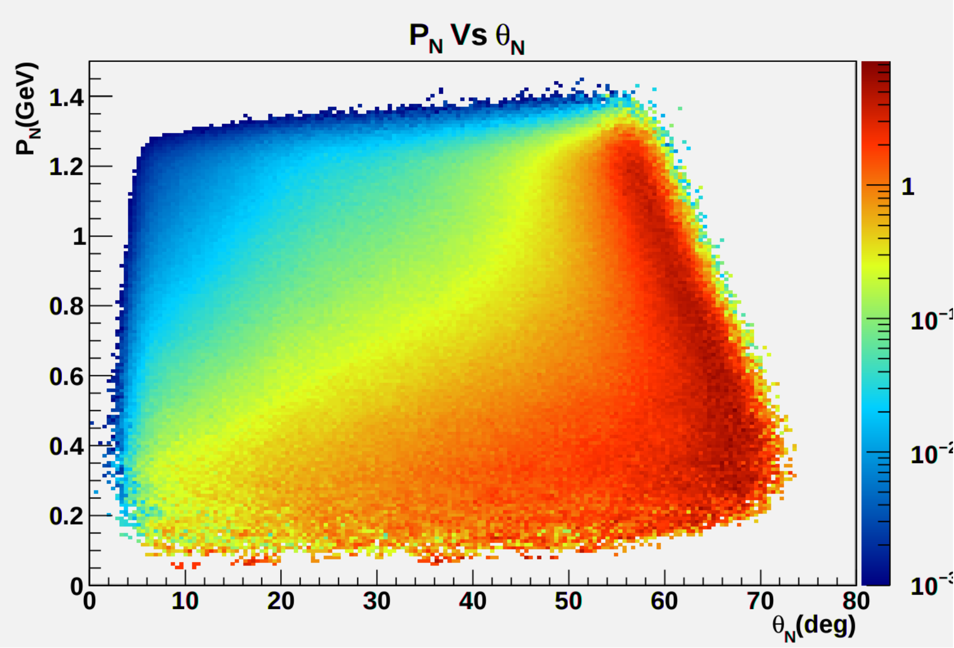
- Requires good neutron timing and momentum resolutions:

  ~150ps and 10%

- Kinematic range of interest:

$$0.2 < p_n < 1.2\,\mathrm{GeV/c} \text{ and } 40^\circ < \theta_n < 80^\circ$$

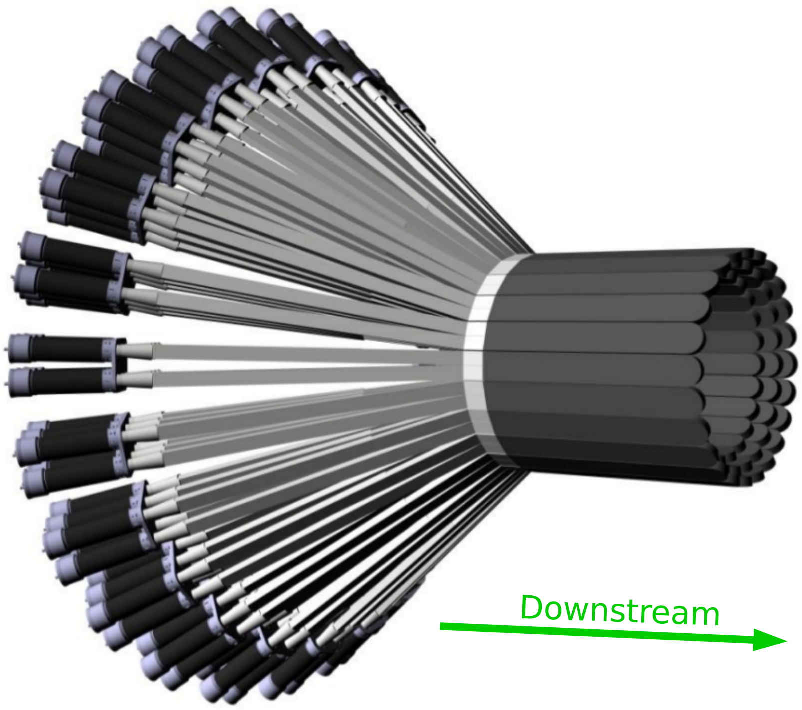
Neutrons emitted at Θ>40° for ~80% of simulated events, with an average momentum of 0.4 GeV/c

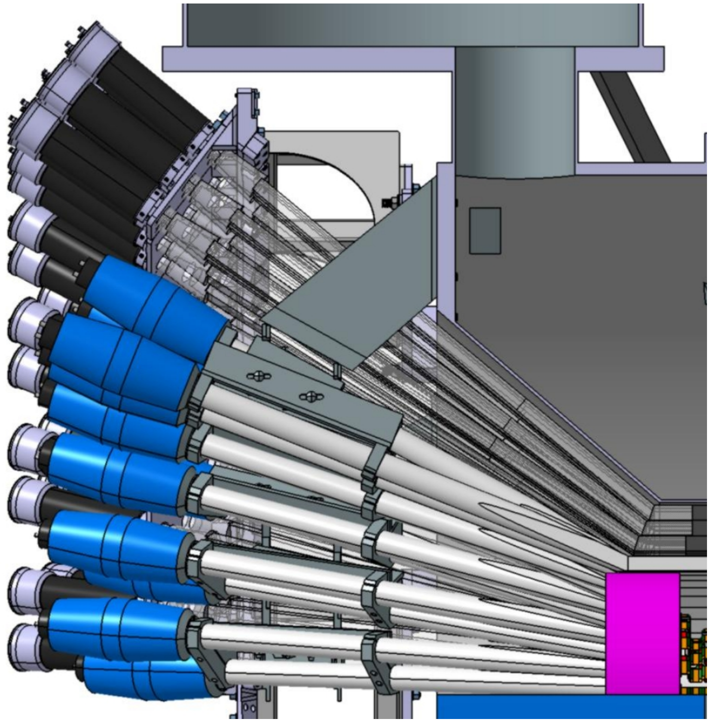



[https://www.jlab.org/exp_prog/proposals/11/PR12-11-003.pdf]

# CND design

- Inside solenoid magnet, outside of the CTOF
- Barrel with 24 blocks, 3 layers of paired scintillators per block connected via light guide u-turn at downstream end
- 2 PMT upstream readout per pair (in low B field)



[Technical drawings: Julien Bettane, IPN]

# CND Overview

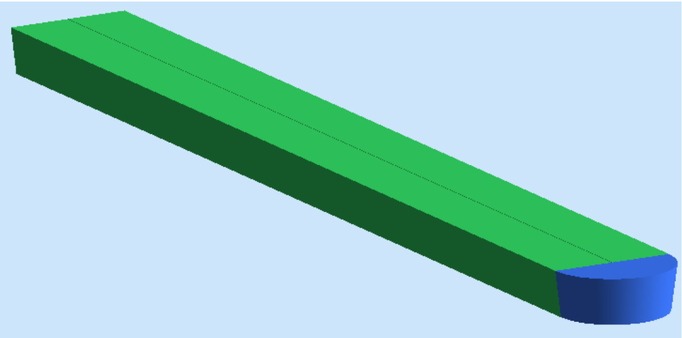
- Geant4 simulations
- Calibrations with real cosmic data
- CLAS12 Java programming framework:

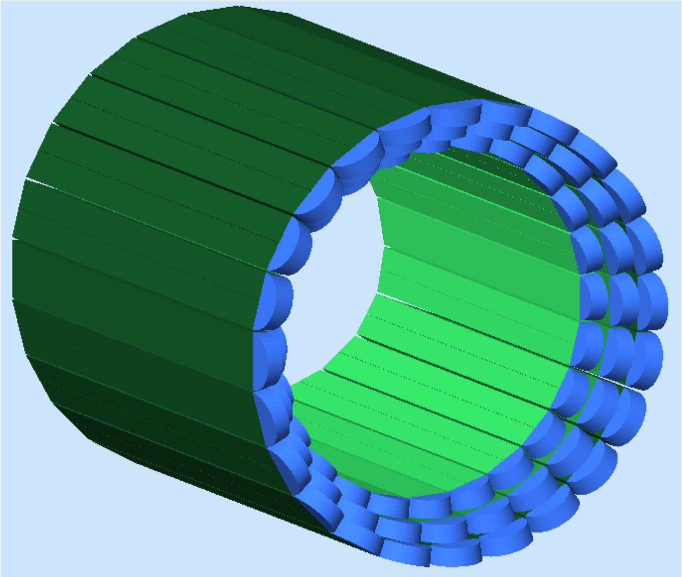
  → Calibration

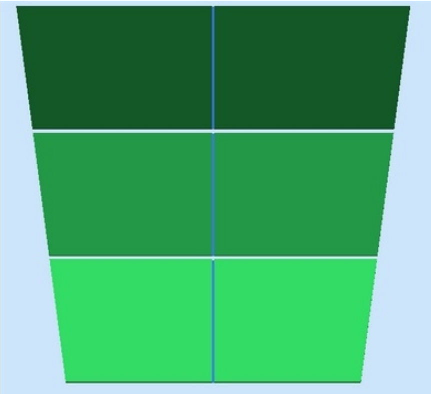
  → Online monitoring

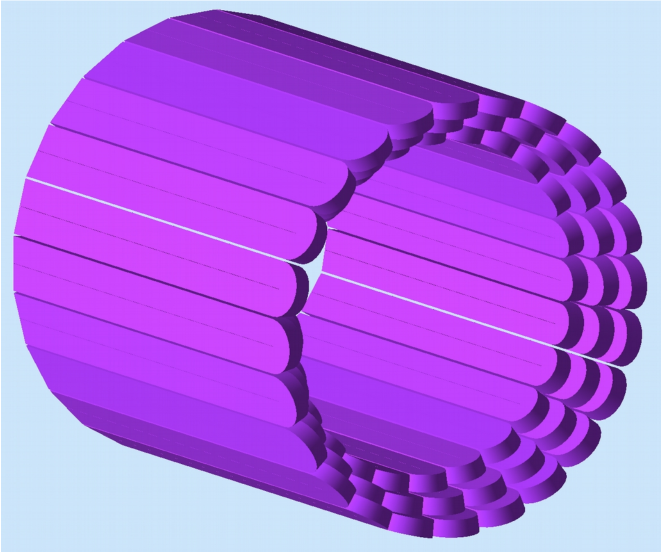
# CND Geometry Work

- Fully implemented in CLAS12 simulation software (utilising Geant4) - reconstruction code to be written

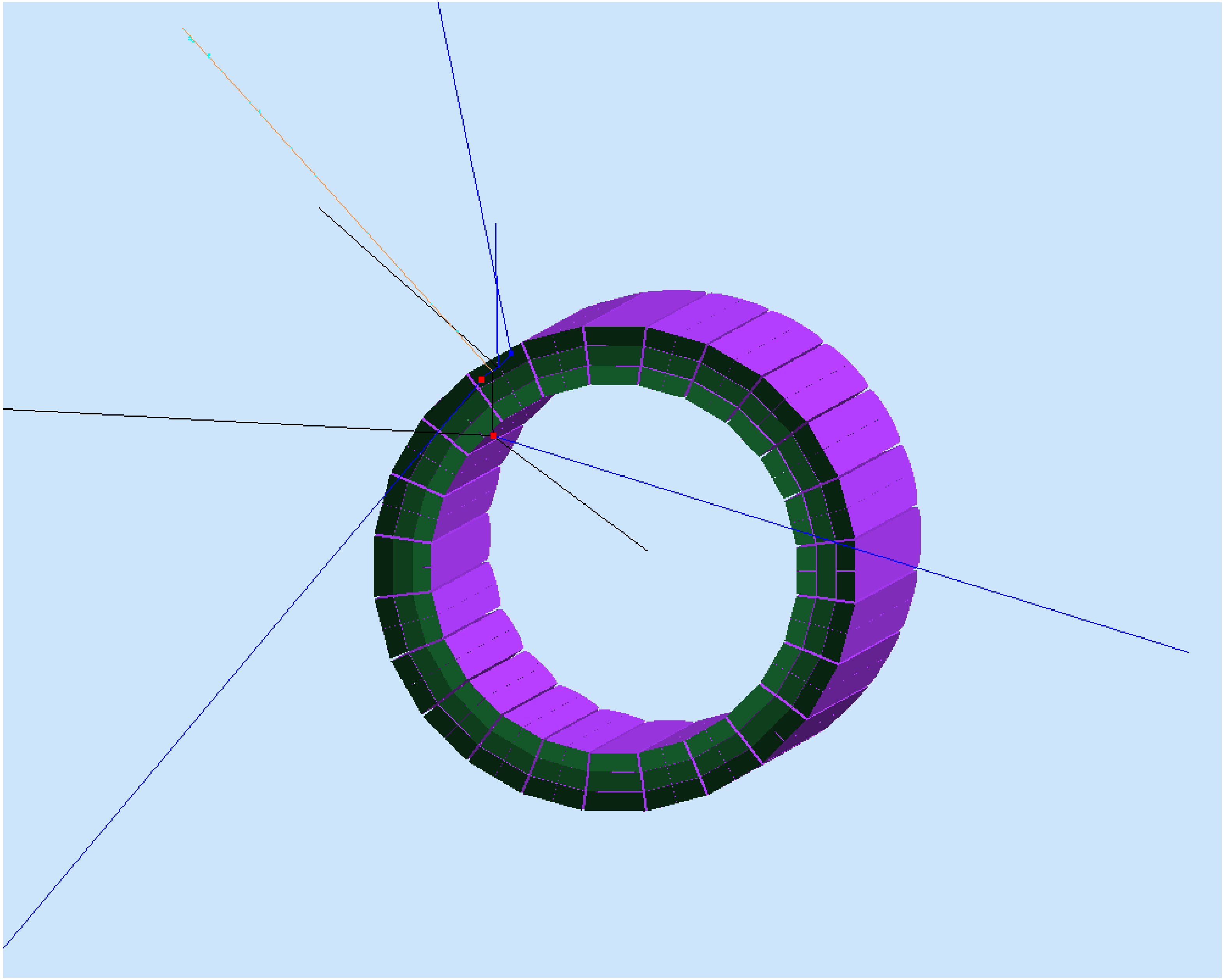








# CND Geometry



# CND Calibration Work

- Cosmic tests were carried out at Institut de Physique Nucléaire d'Orsay, France in 2014.  Real data to analyse.
- Calibration work required:

→ Timing offset corrections

→ Effective velocity

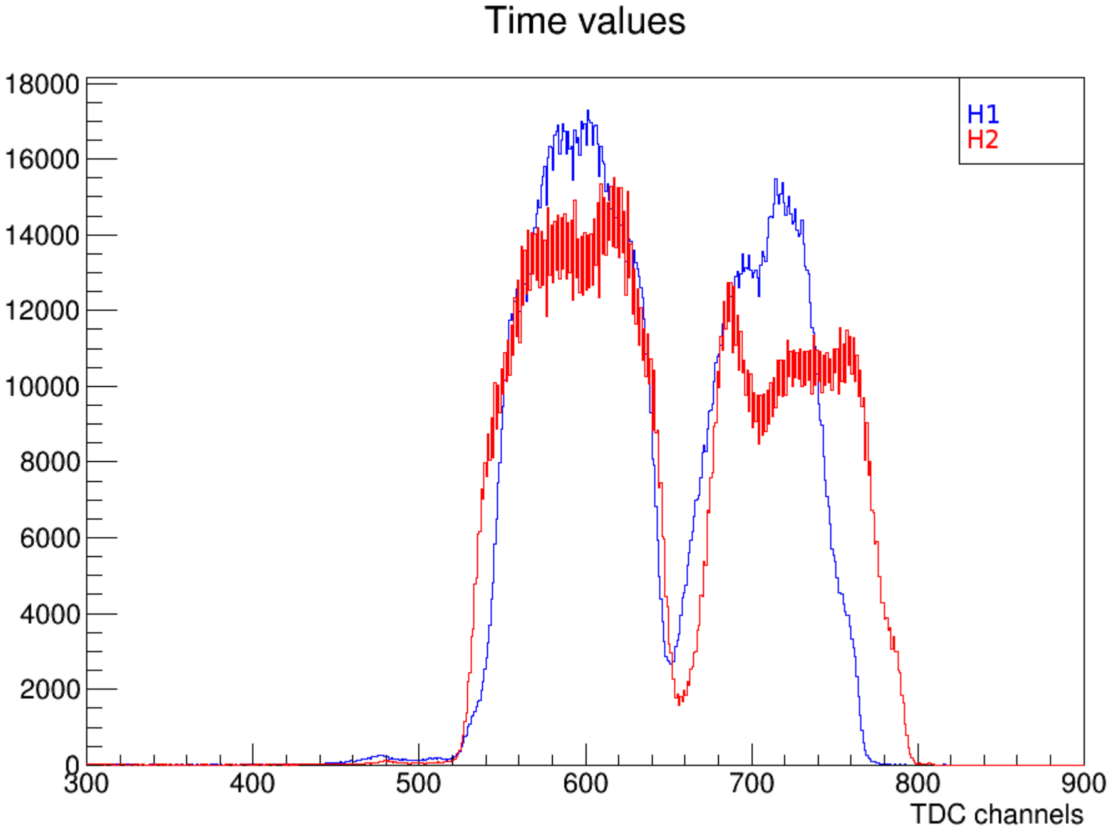
→ Light attenuation

→ Time Walk correction

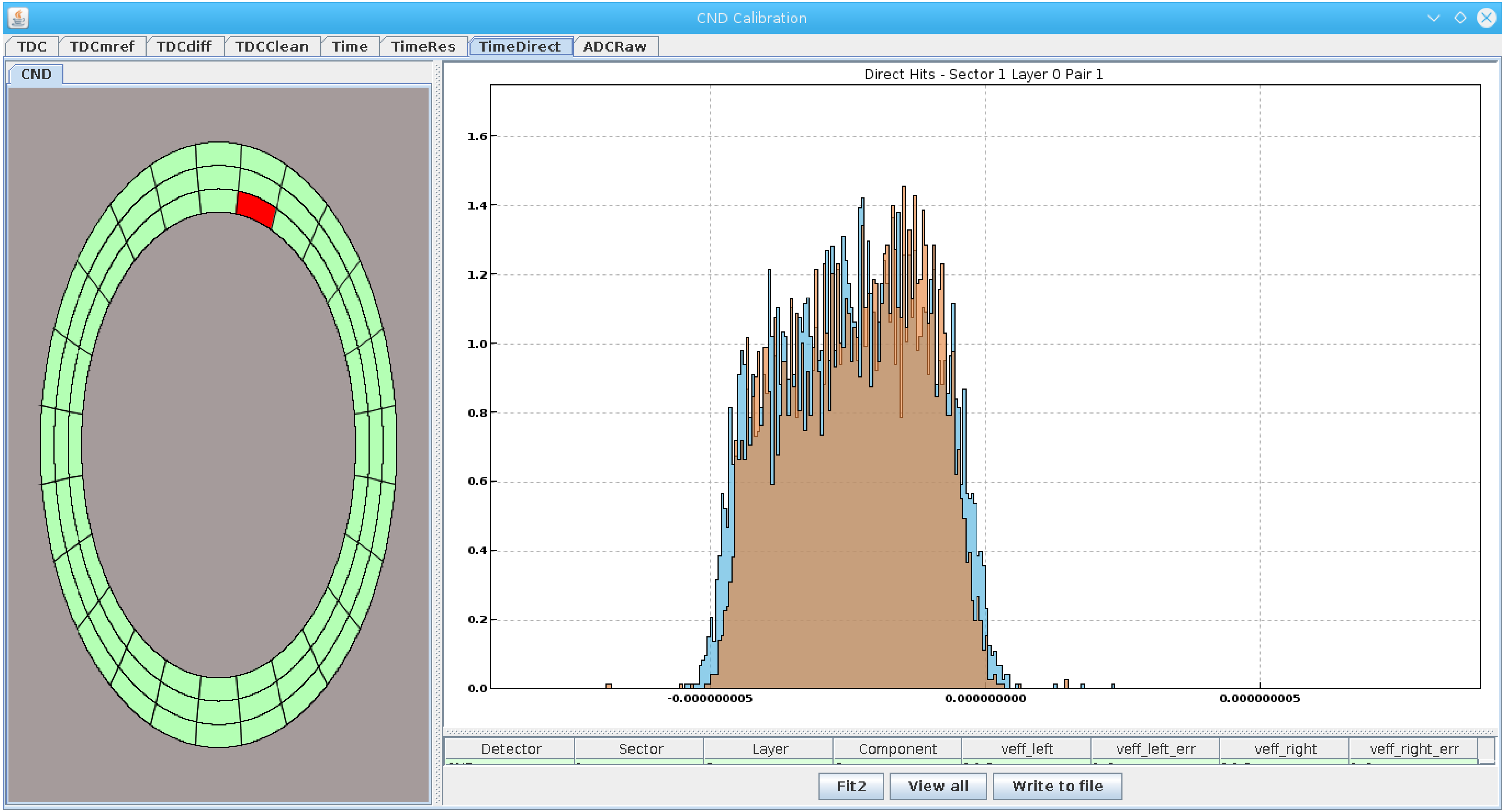
# Effective Velocity

- The velocity light travels at in the scintillator
- Example hit in scint.

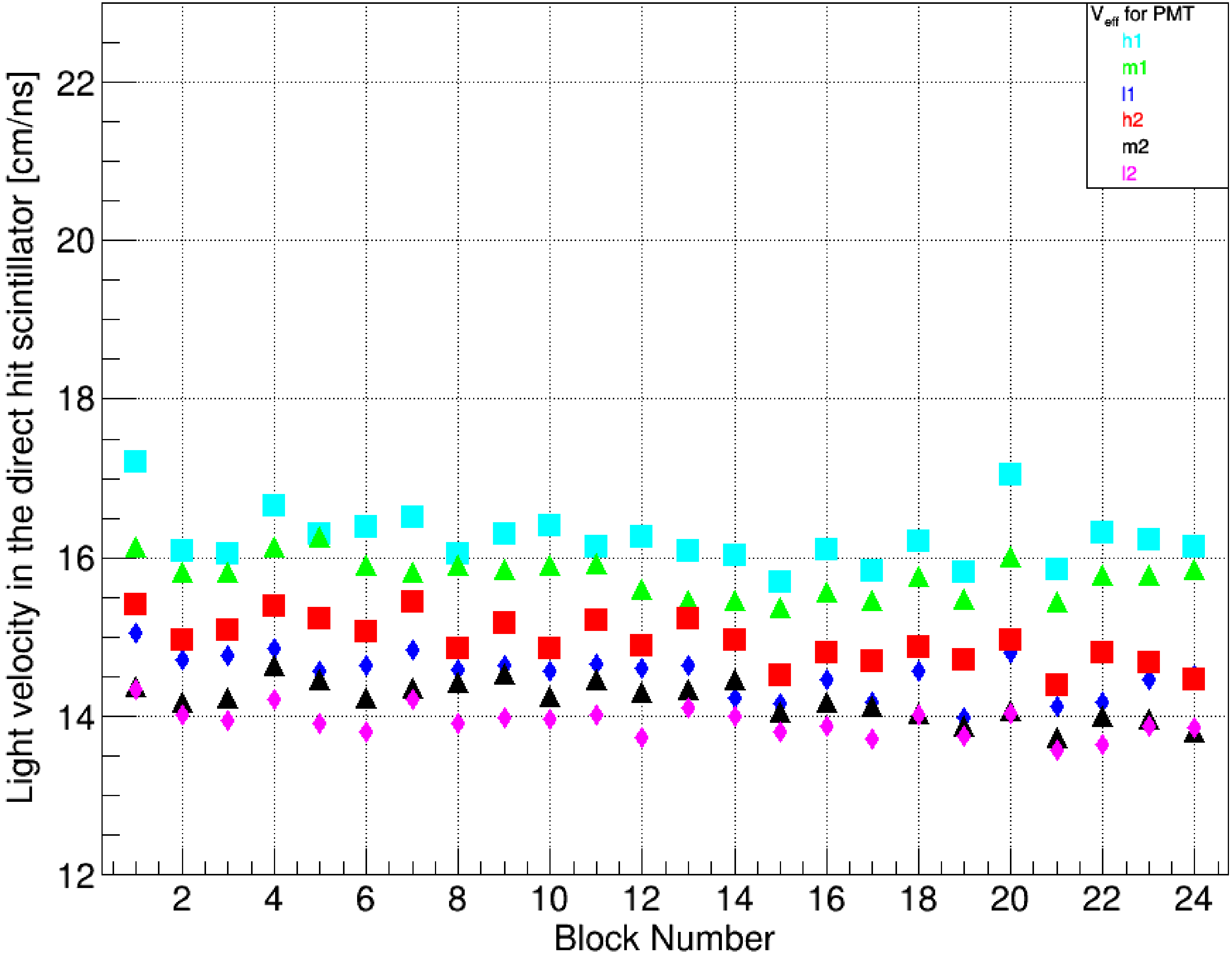

- Raw TDC output highlights the u-turn dip



# CND Calibration Work



# Effective Velocity



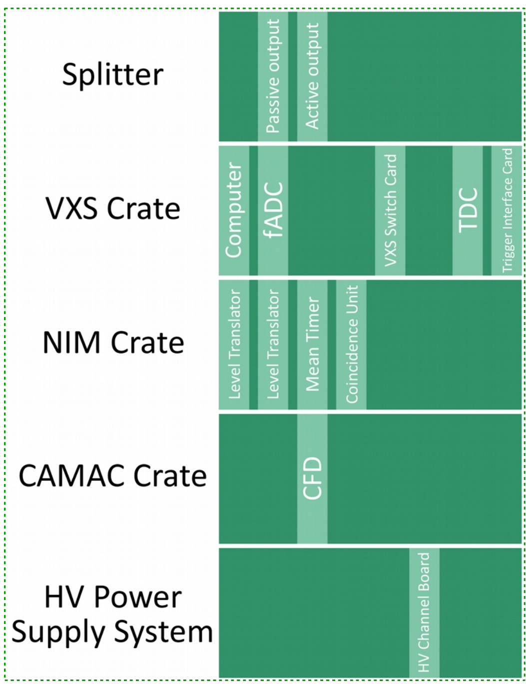
# JLab Cosmic Tests (March-April 2016)

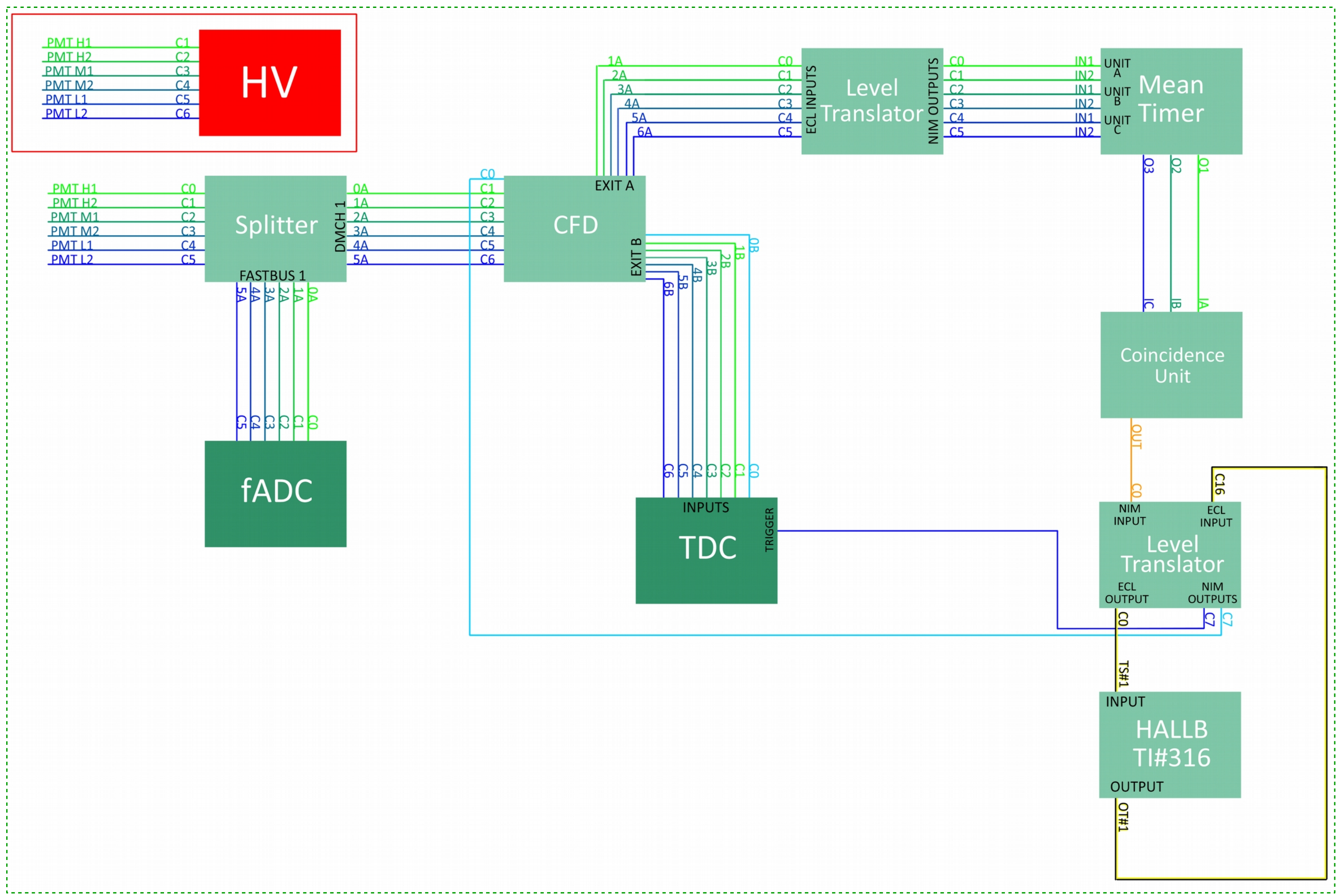
- Cosmic tests carried out for 6 of the 24 CND blocks at JLab

- Aims:
  - → Obtain data with final hardware (TDCs, fADCs)
  - → Calculate time resolution

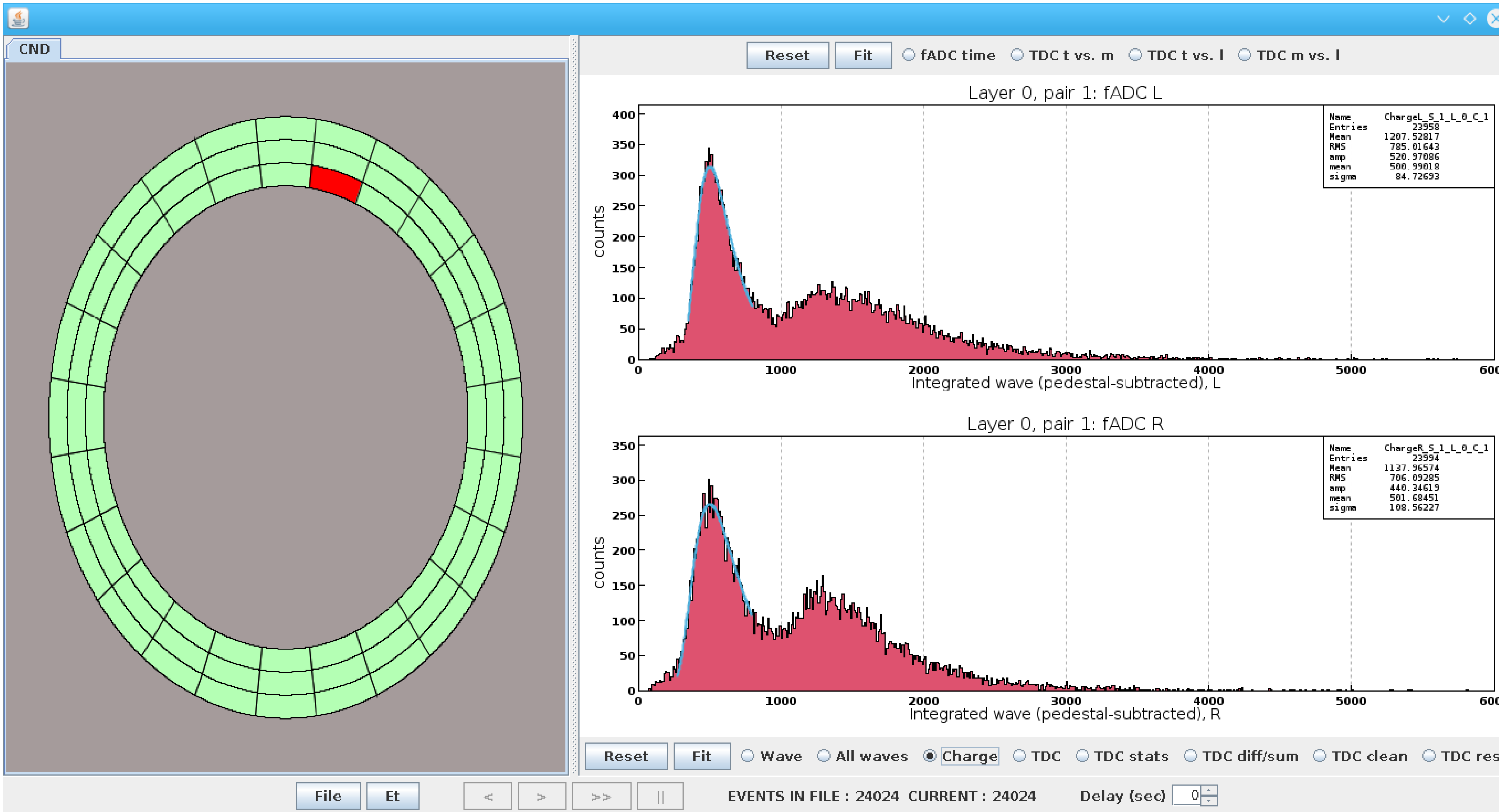
# Read Out

- Self triggering on hit coincidence in all three layers



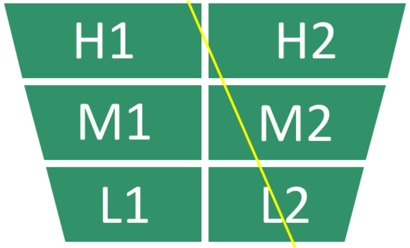



# Monitoring GUI



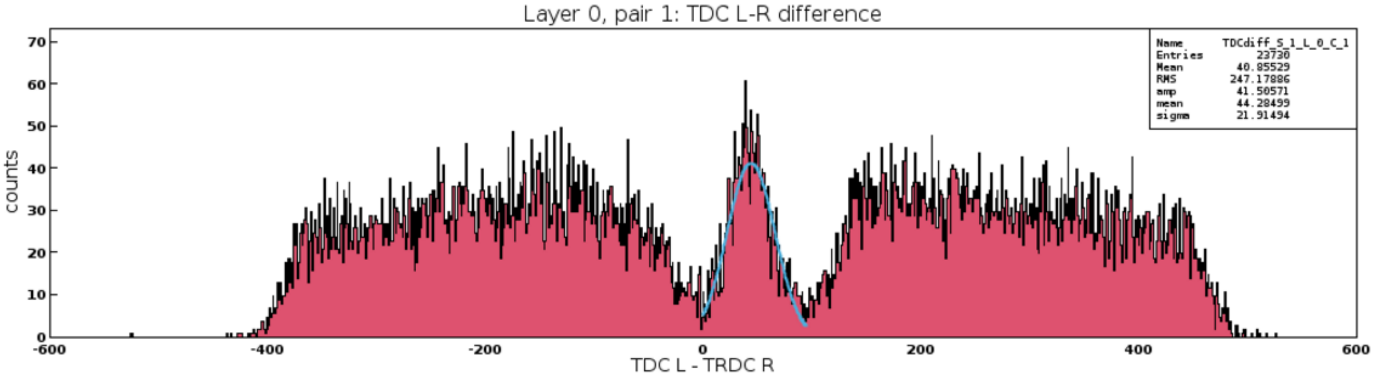
# TDC Offset and Spike Cut

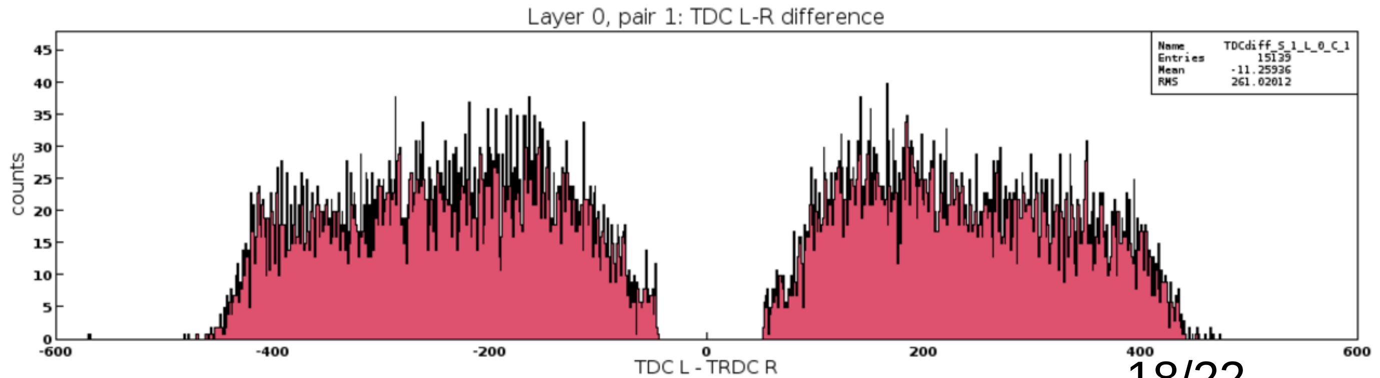
- Determine timing offset from TDC left-right difference
- Spike corresponds to diagonal hits ($cos^2\Theta$ trajectory)
- ~36% entries are in the spike region




- Fit Gaussian to the spike
- Shift spike to be centred on zero
- Hard cut on the spike values

→ Investigating best method



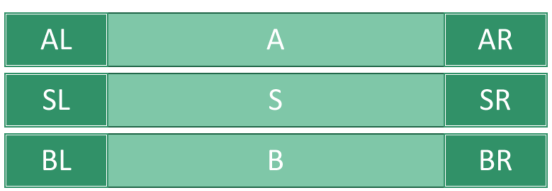
# Time Resolution

- Two different methods are used in time resolution calculations for comparison:

  → E. Smith

  → V. Baturin

- Both using three layer read out arrangement:




$$T_{Ref} = T_A - T_B = \frac{T_{AL} + T_{AR}}{2} - \frac{T_{BL} + T_{BR}}{2} = \frac{T_{AL} + T_{AR} - T_{BL} - T_{BR}}{2}$$

$$T_{Cosmic} = \frac{T_A + T_B}{2} - T_S = \frac{T_{AL} + T_{AR} + T_{BL} + T_{BR}}{4} - T_S$$

$$\sigma_S = \sqrt{\sigma^2_{Cosmic} - \left(\frac{\sigma_{Ref}}{2}\right)^2}$$

$$\rightarrow \sigma_S = \frac{1}{\sqrt{2}}\sigma_{PMT} \rightarrow \sigma_{PMT} = \sqrt{2}\sigma_S = \sigma_{TOF}$$

[E.S. Smith et al. NIMA 432 (1999) 265-298]

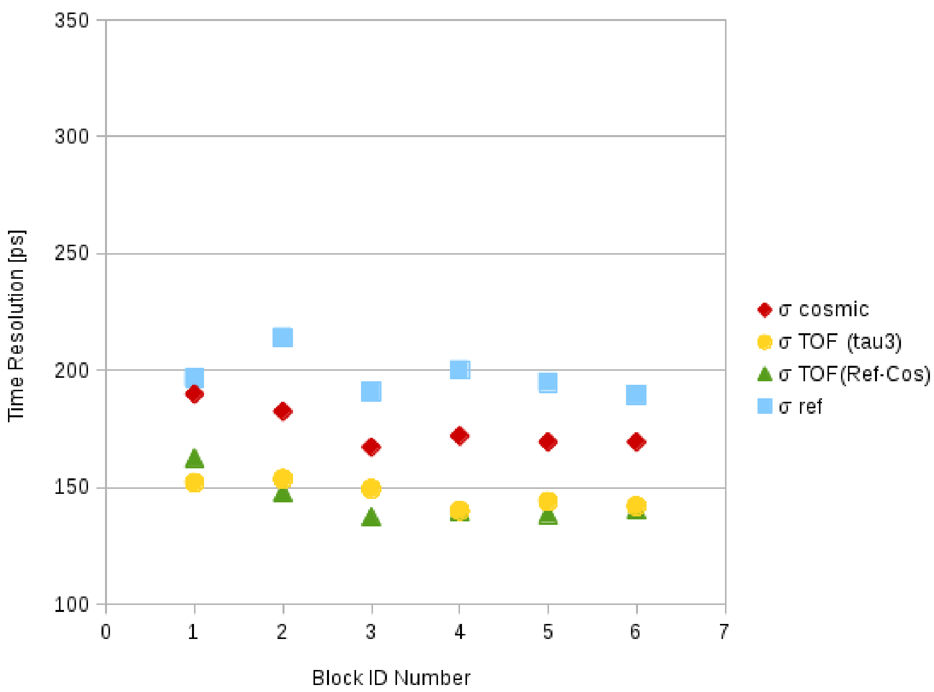
$$\tau_3 = T_A + T_S + T_B$$

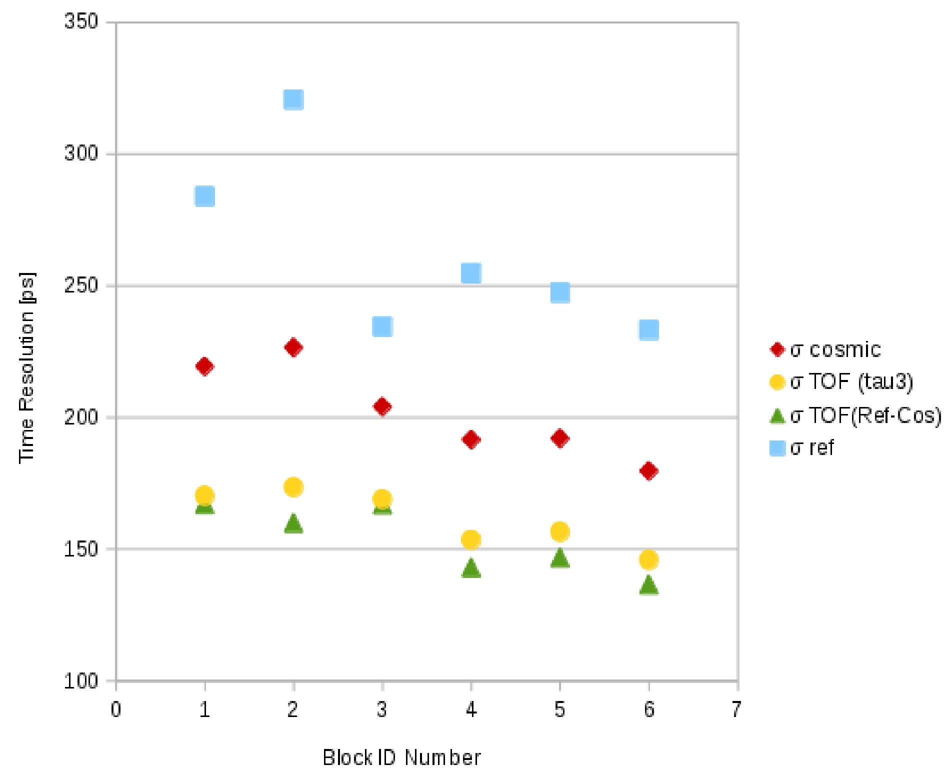
$$\sigma_{\tau_3} = \sqrt{12}\sigma_{PMT} = \sigma_{TOF}$$

[V. Baturin – CLAS-NOTE 2009-001]

# Time Resolution

- Left: time res for Orsay data (2014)
- Right: time res for JLab data (2016)




[Left graph – CND time res 2014: Giulia Hull]

# Plans

- Improve on background subtraction for new cosmic data
- Finalise monitoring and calibration GUIs
- Translate ROOT calibration methods to CLAS12 Reconstruction and Analysis (CLARA) Java framework
- Further develop calibrations, using new data

# Questions