Commissioning and Initial Performance of the Belle II iTOP PID Subdetector

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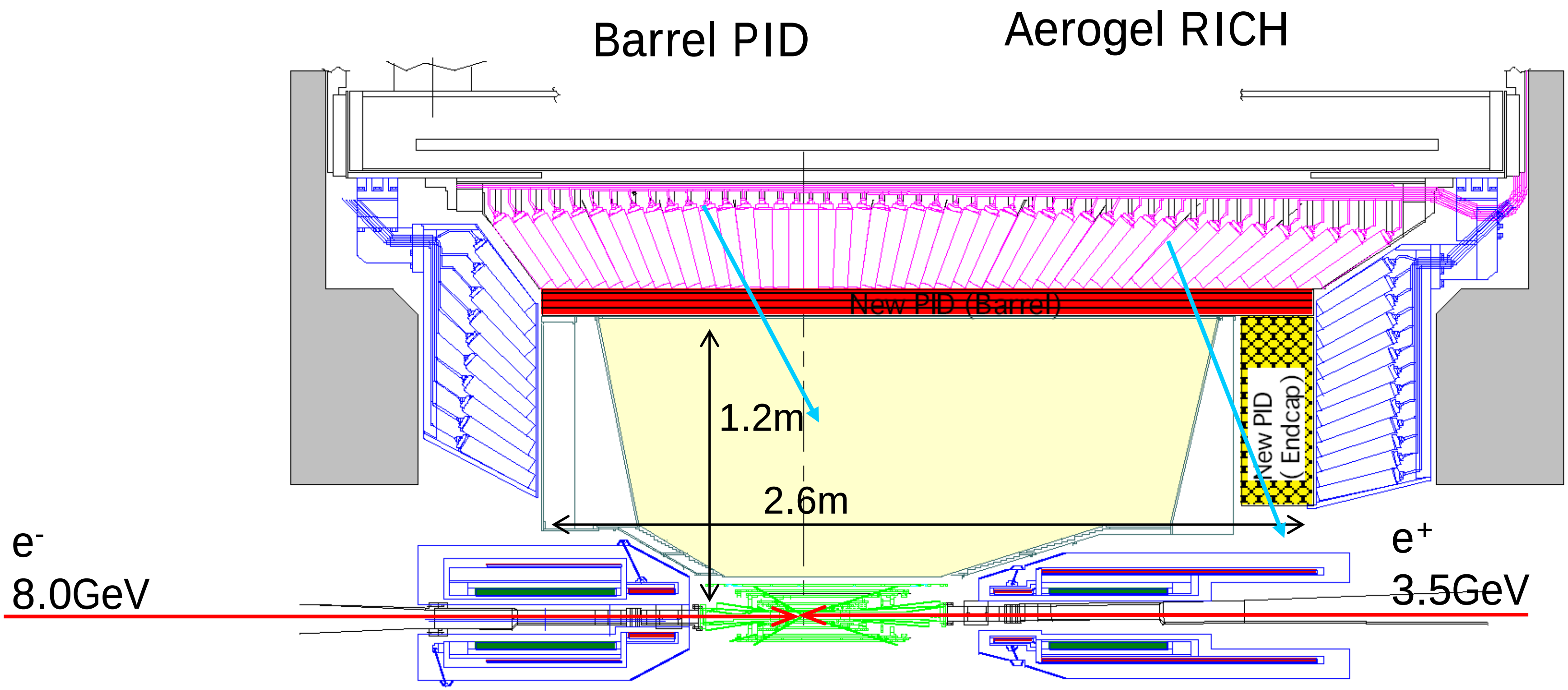
TIPP 2017 Beijing

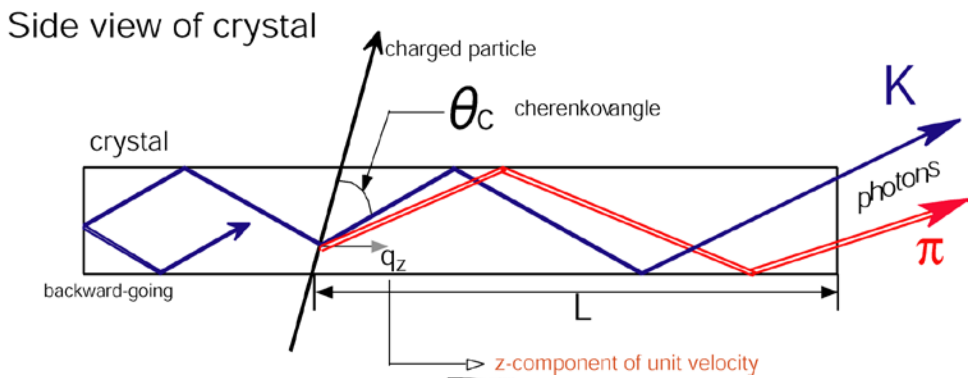
Upgrading PID Performance

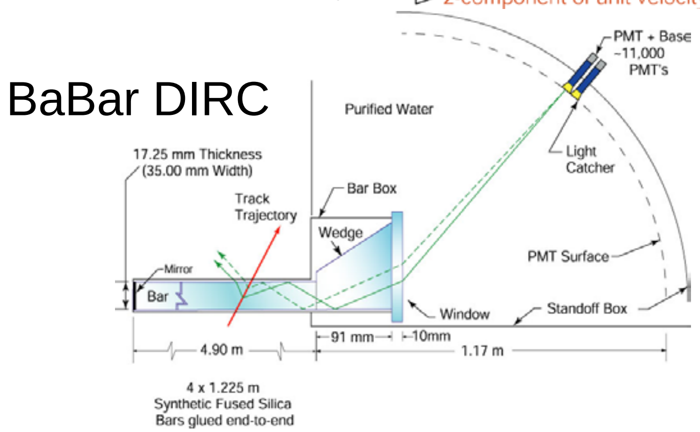
- PID (π/K) detectors
  - Inside current calorimeter
  - Use less material and allow more tracking volume
  - → Available geometry defines form factor
    -



imaging TOP (iTOP)

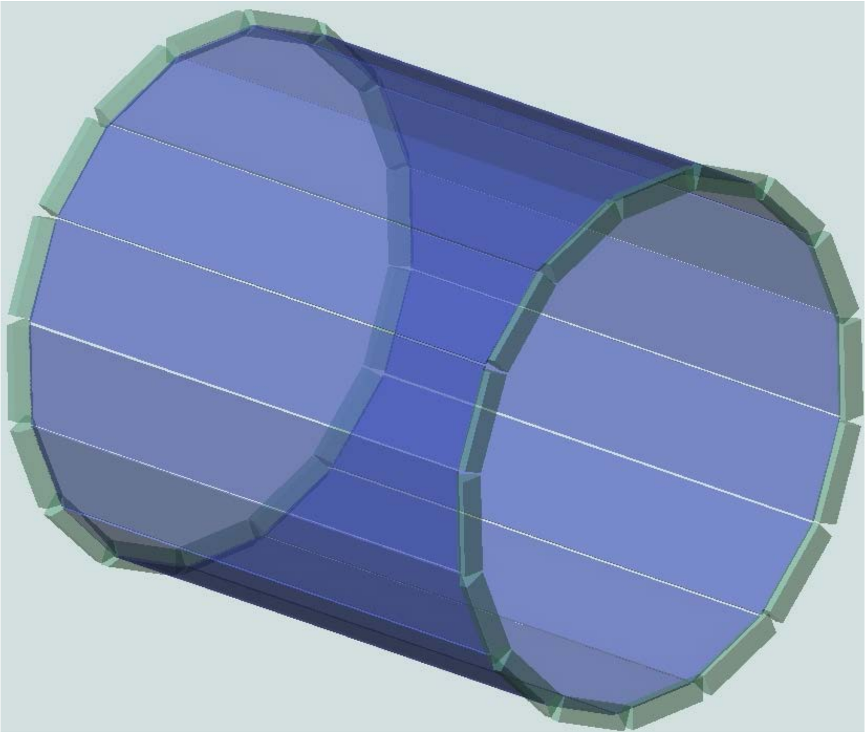
Concept: Use best of both TOP (timing) and DIRC while fit in Belle PID envelope





Use wide bars like proposed TOP counter

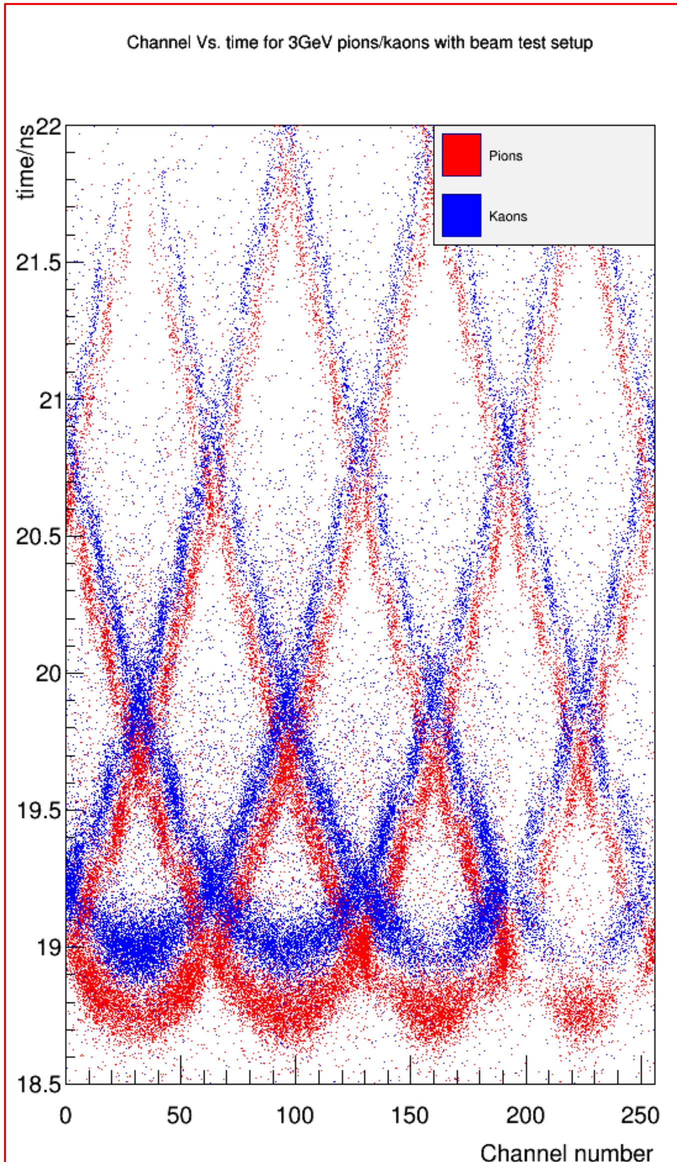
NIM A623 (2010) 297-299.

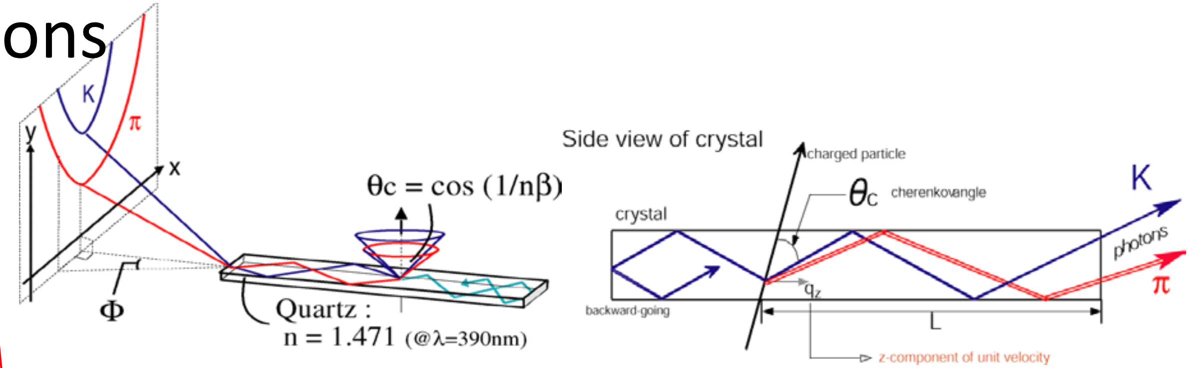


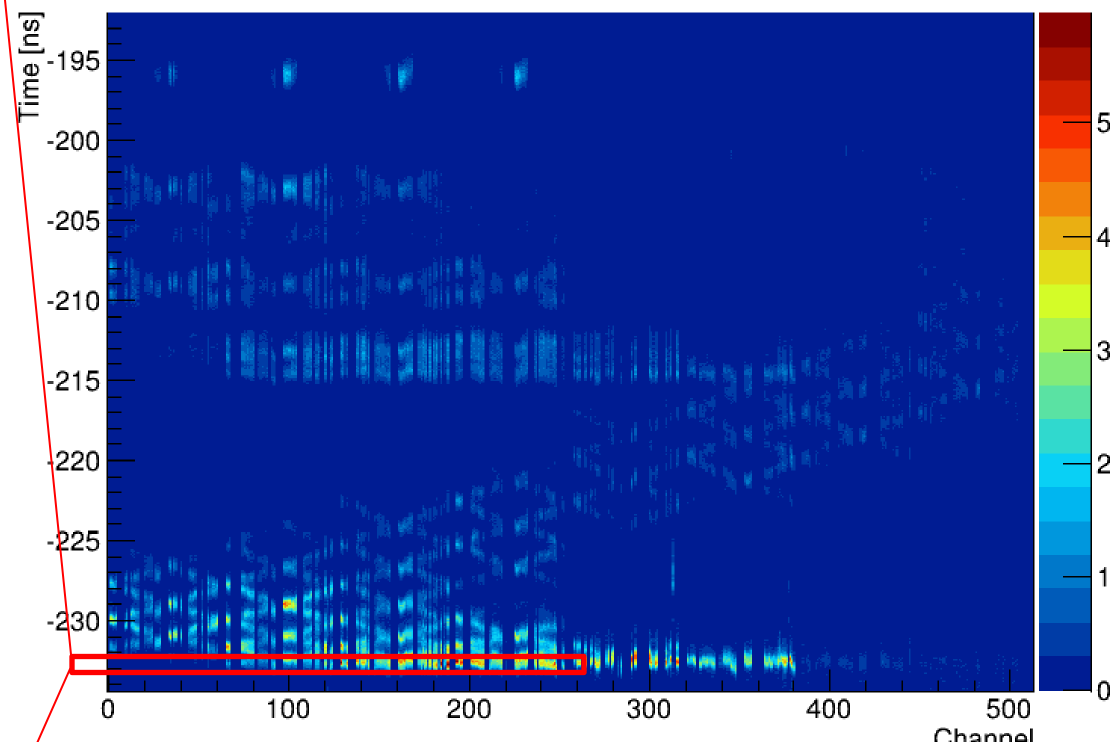
- Use new, high-performance MCP-PMTs for sub-50ps single p.e. TTS
- Use simultaneous T, θ_c [measured-predicted] for maximum K/π separation
- Optimize pixel size

iTOP relativistic velocity

- Space-time correlations





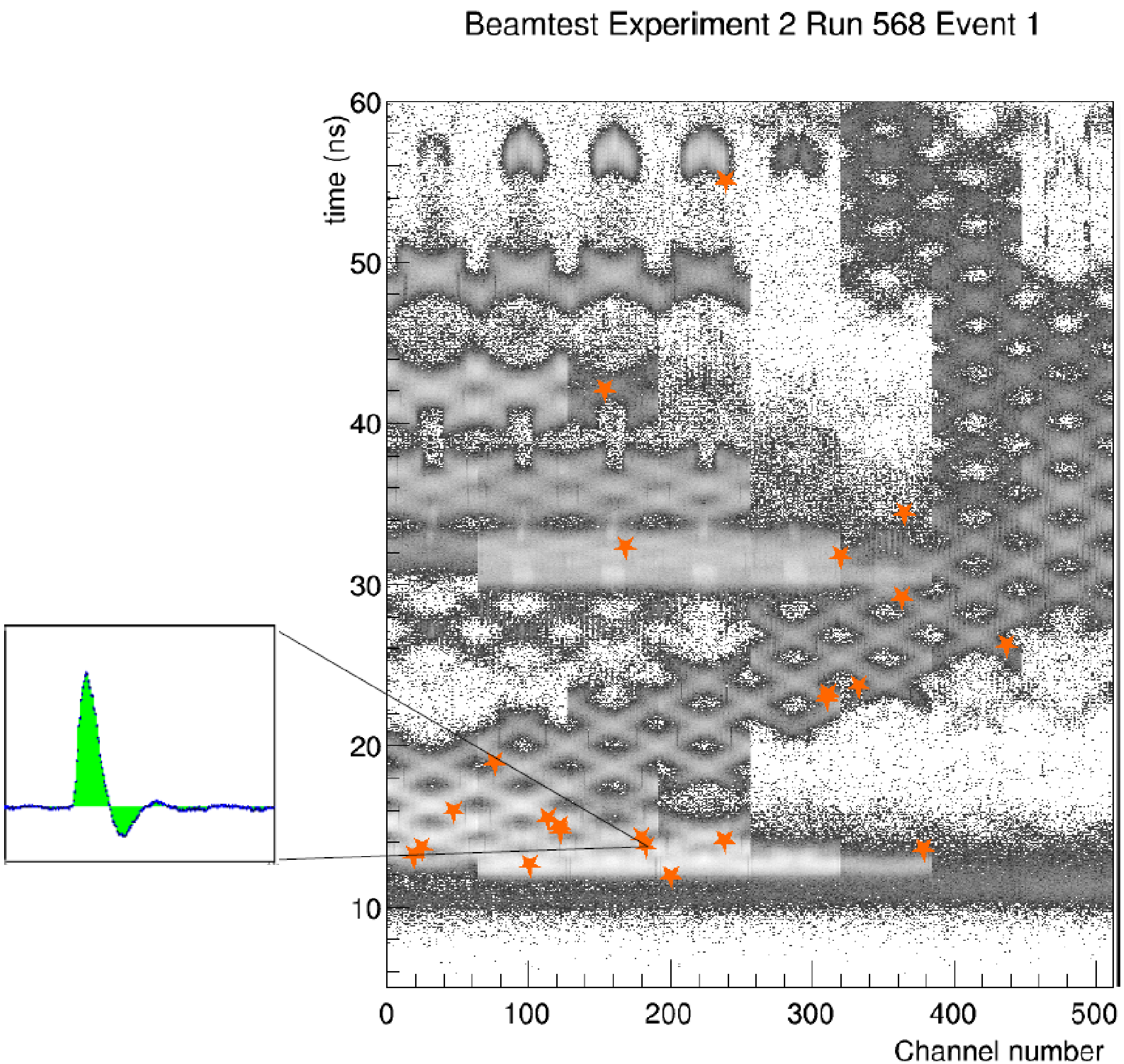


Beam Test Data

These are cumulative distributions

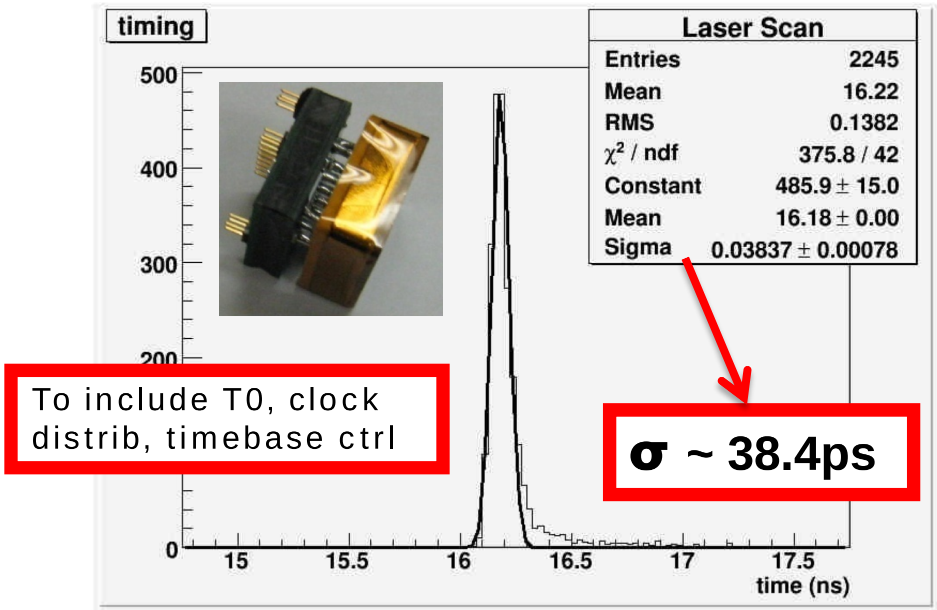
Actual PID is event-by-event

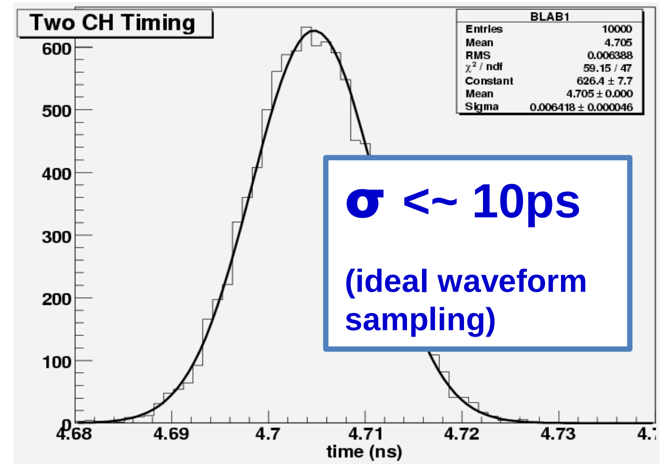
- Test most probable distribution



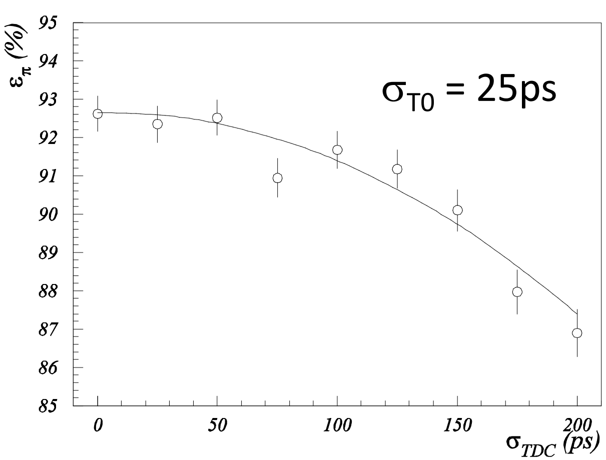
Performance Requirements (TOP)

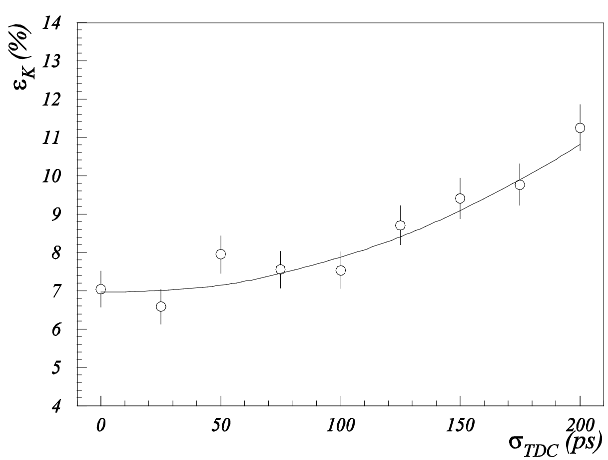
- Single photon timing for MCP-PMTs





NIM **A602** (2009) 438



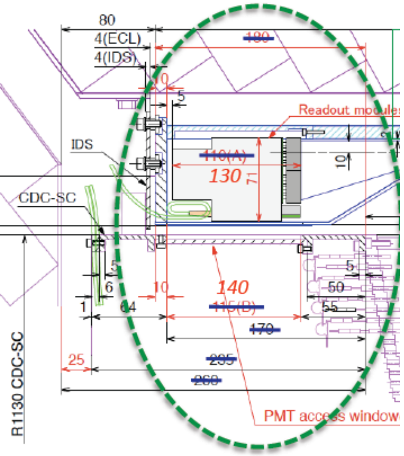


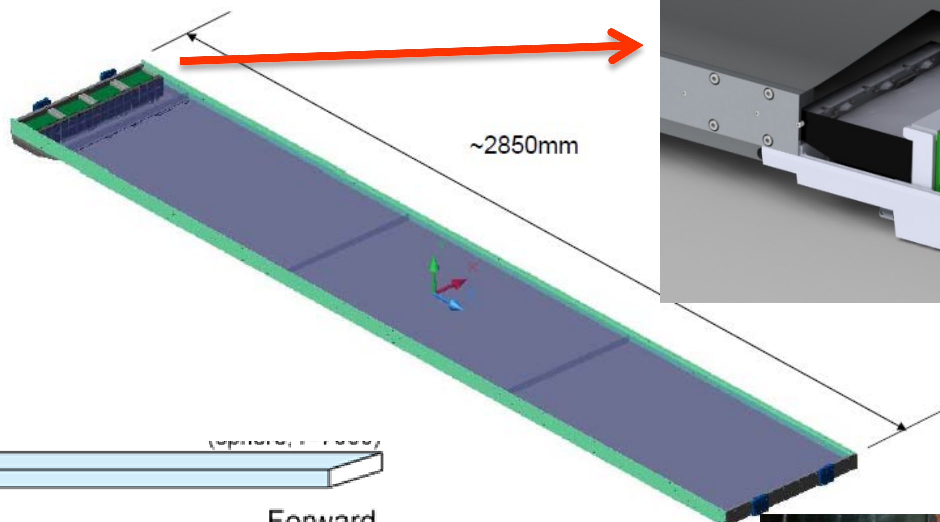
σ <~ 50ps target

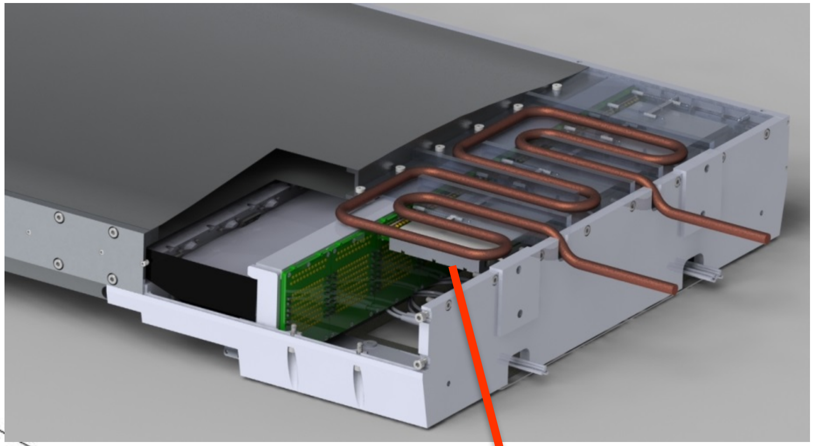
NOTE: this is single-photon timing, **not** event start-time "T_0"

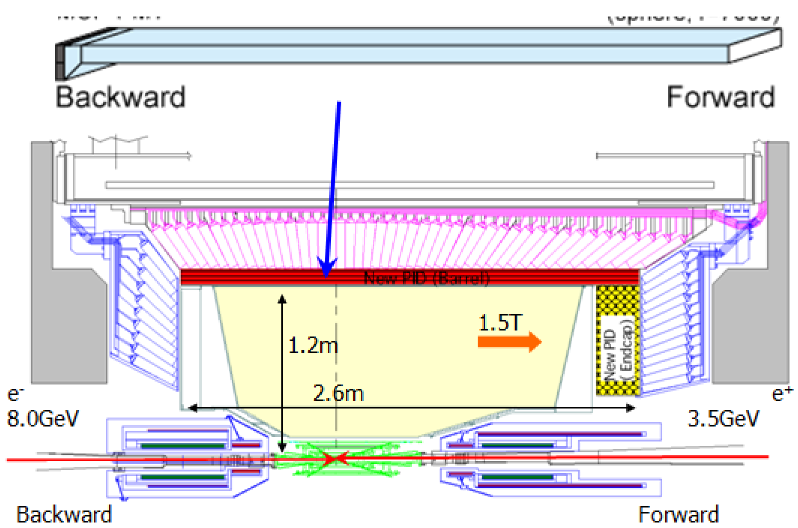
Mechanical constraints

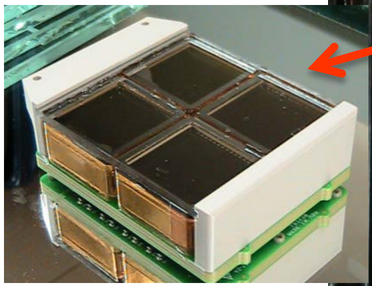
- A highly constrained space

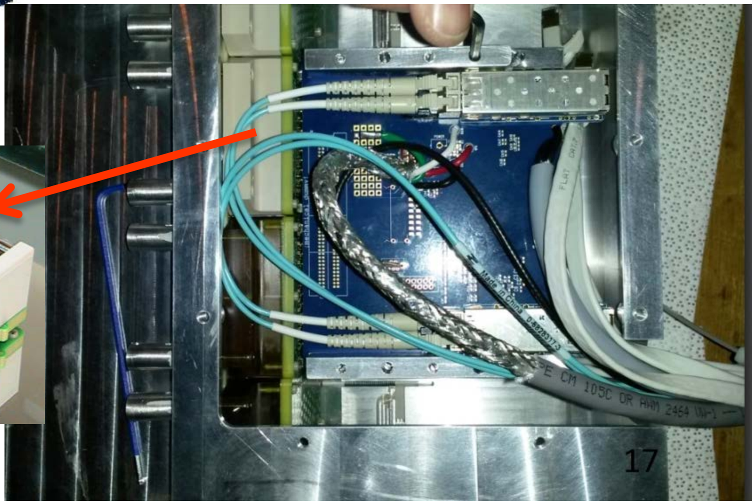










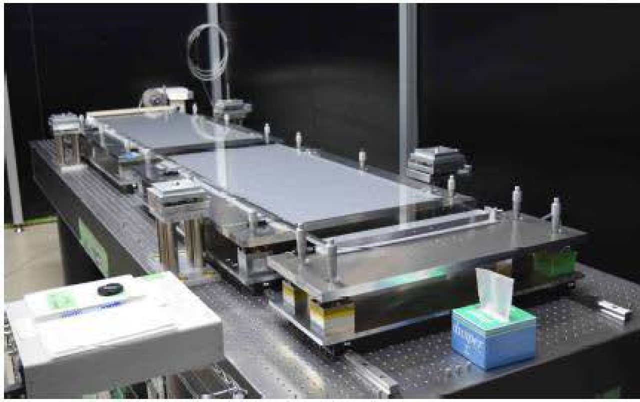


Quartz: procurement, verification

- Bars:
  1250 x 450 x 20 mm^3
  two bars per module
- Mirrors:
  100 x 450 x 20 mm^3
- Prisms:
  100 mm long, 456 x 20 mm^2
  at bar face expanding to
  456 x 50 cm^2 at MCPPMTs
- Material: Corning 7980

- DIN58927 class 0 material has no inclusions (inclusions ≤0.1 mm diameter are disregarded)
- Grade F (or superior) material having index homogeneity of ≤5 ppm over the clear aperture of the blank; verified at 632.8 nm
- Birefringence / Residual strain ≤1 nm/cm

Quartz gluing, Module Assembly



Optics: alignment, gluing, curing and aging (~2 weeks).

Enclosure: gluing CCDs and LEDs, integrating fiber mounts.

QBB: strong back flattening, button & enclosure gluing.

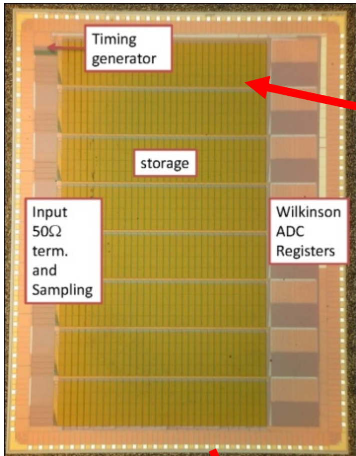
Put on a cart. PMT and front-end integration, performance check.

QBB assembly and gas sealing.

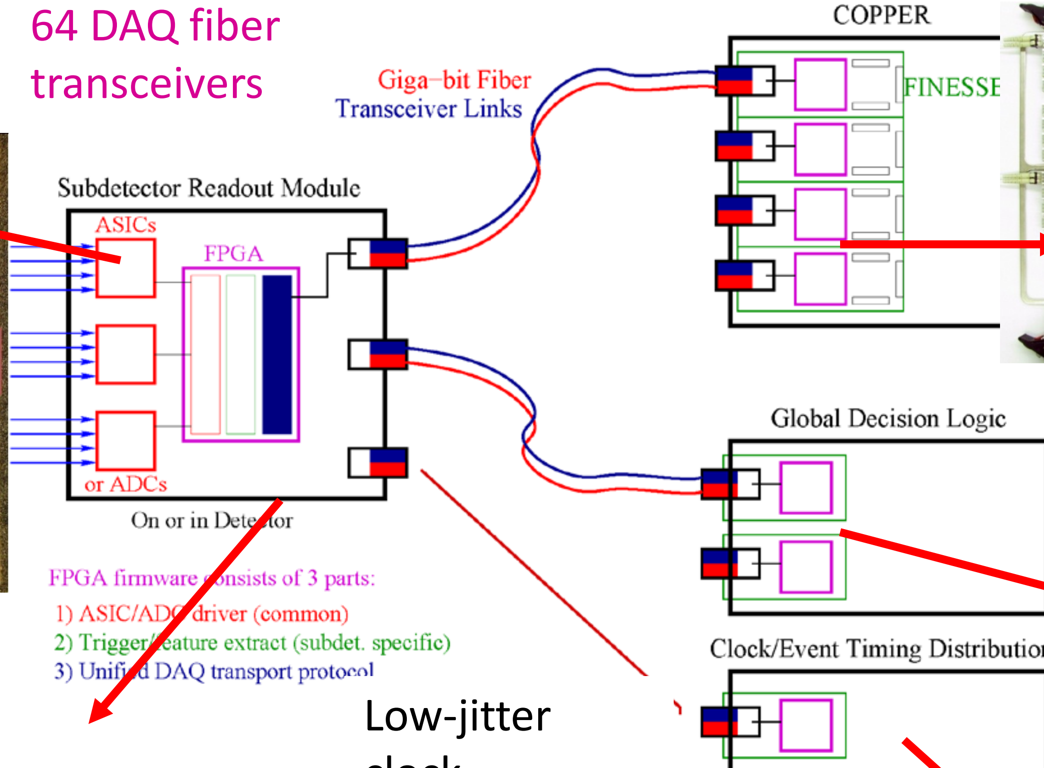
Move optics to QBB using the “lifting jig”.

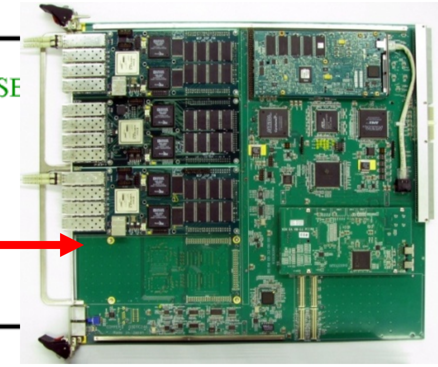
iTOP Readout

Waveform sampling ASIC



64 DAQ fiber transceivers





64 FINESSE

16 COPPER

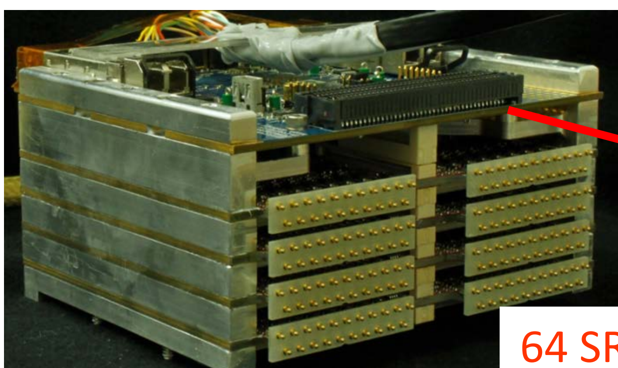
2x UT3 Trigger modules

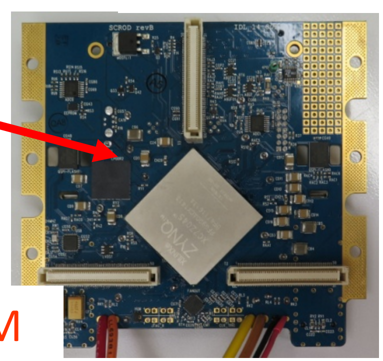
8k channels

1k 8-ch. ASICs

64 "board stacks"

Low-jitter clock



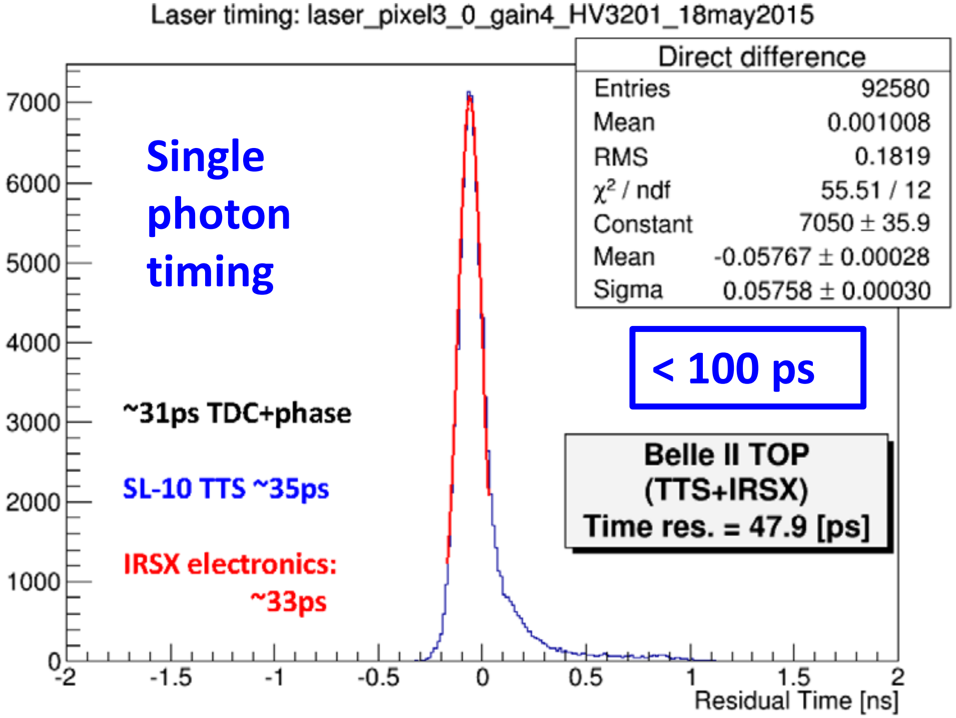


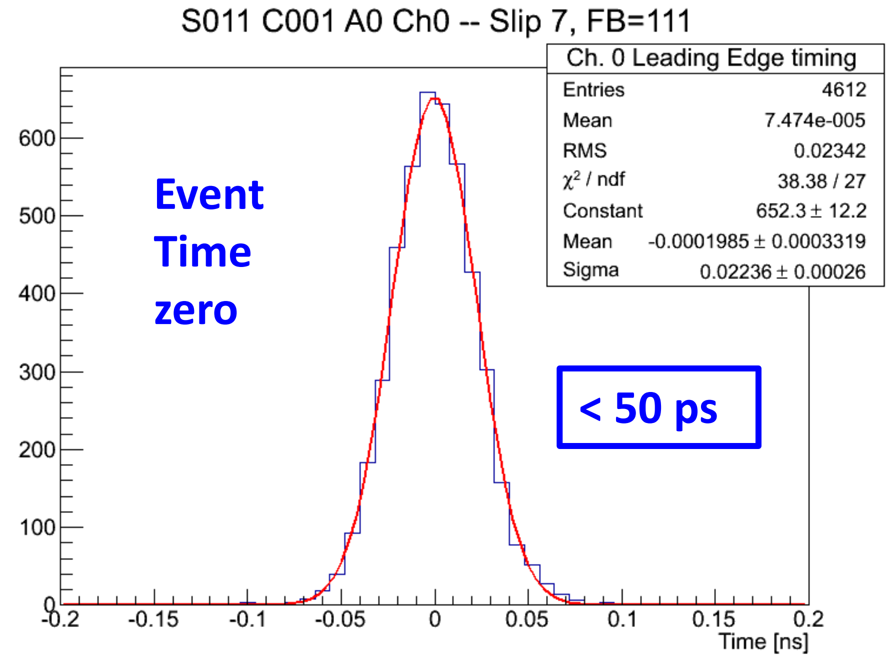
64 SRM

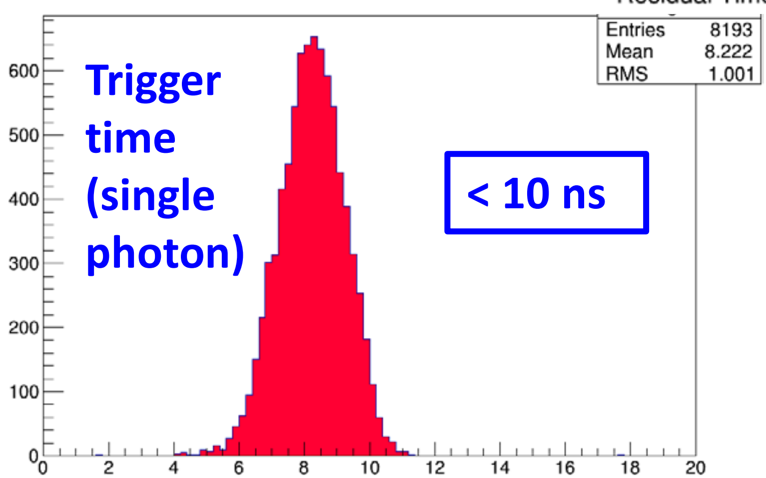
Clock, trigger, programming module (FTSW)

8 FTSW

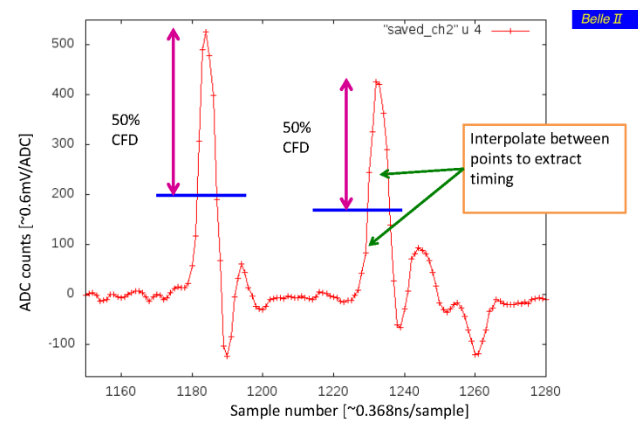
Readout Verification (pre-install, in-situ)





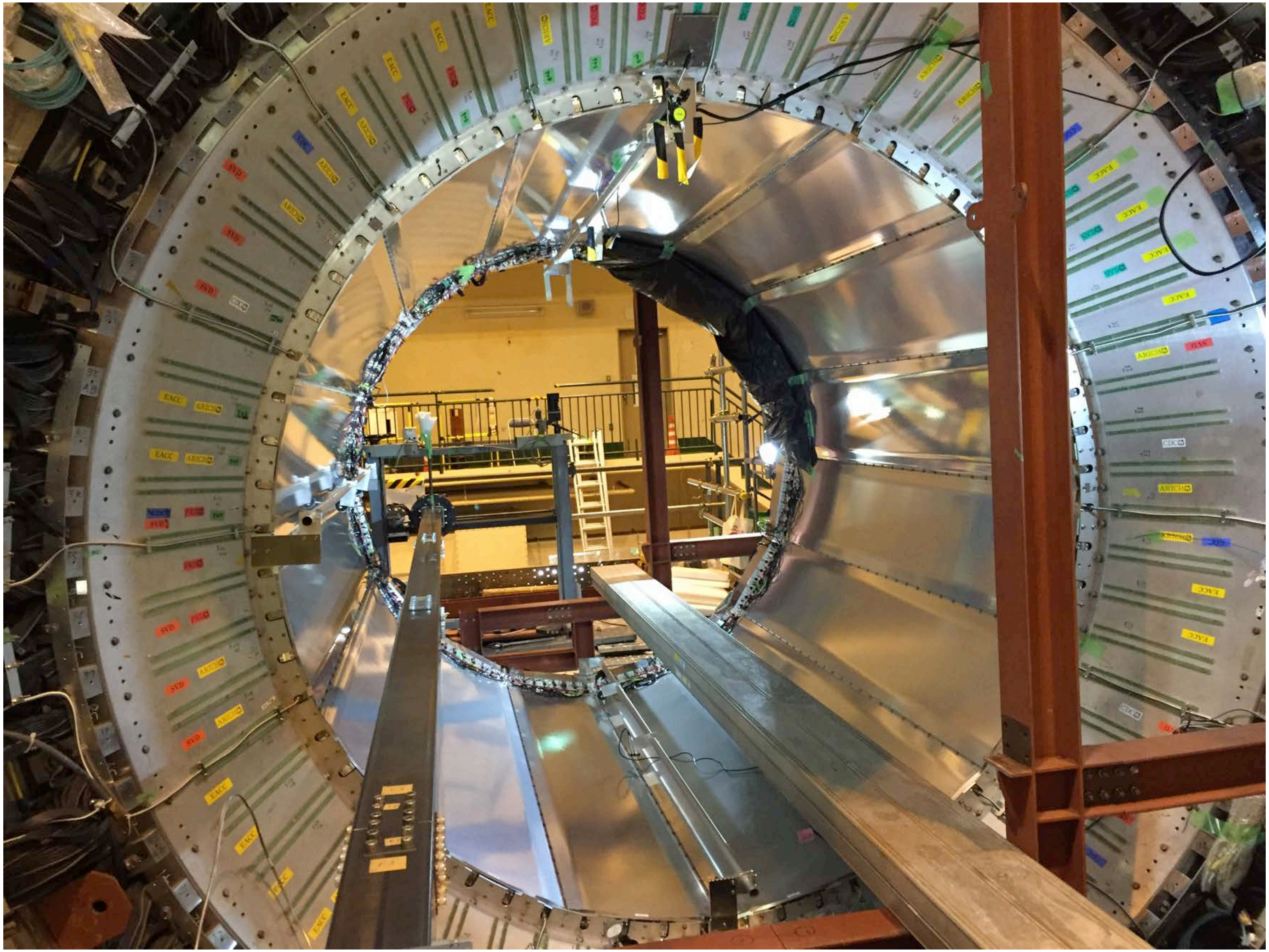


Pulser testing

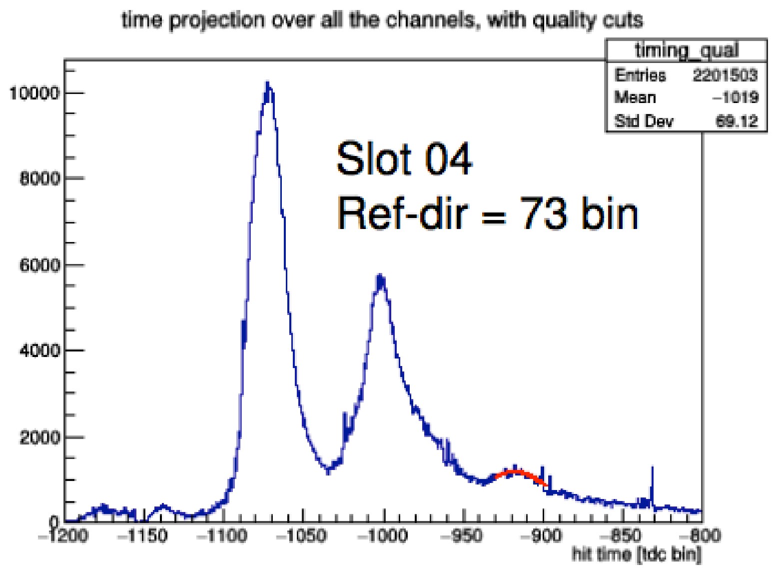


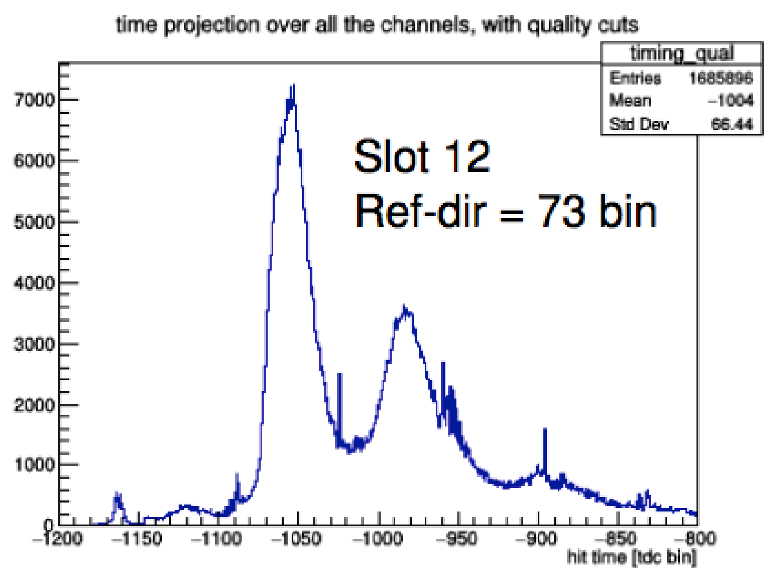
Installation (very tight fit)

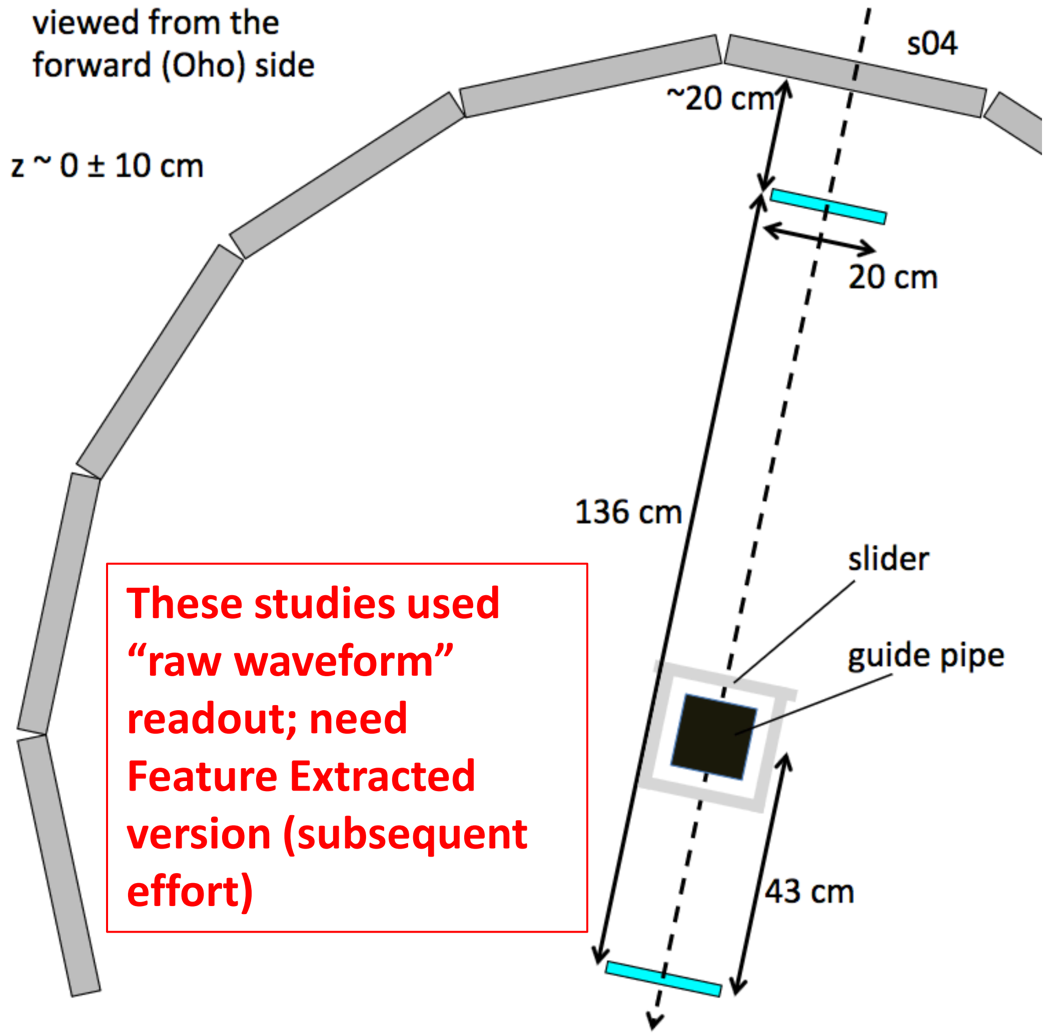
Installation Complete (May 2016)



After installation – continued development





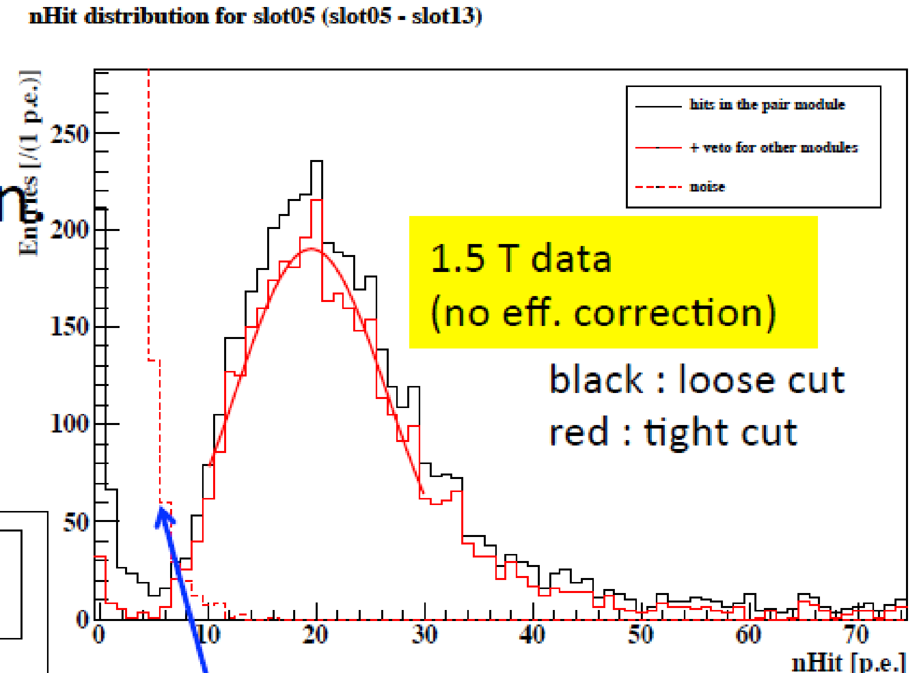


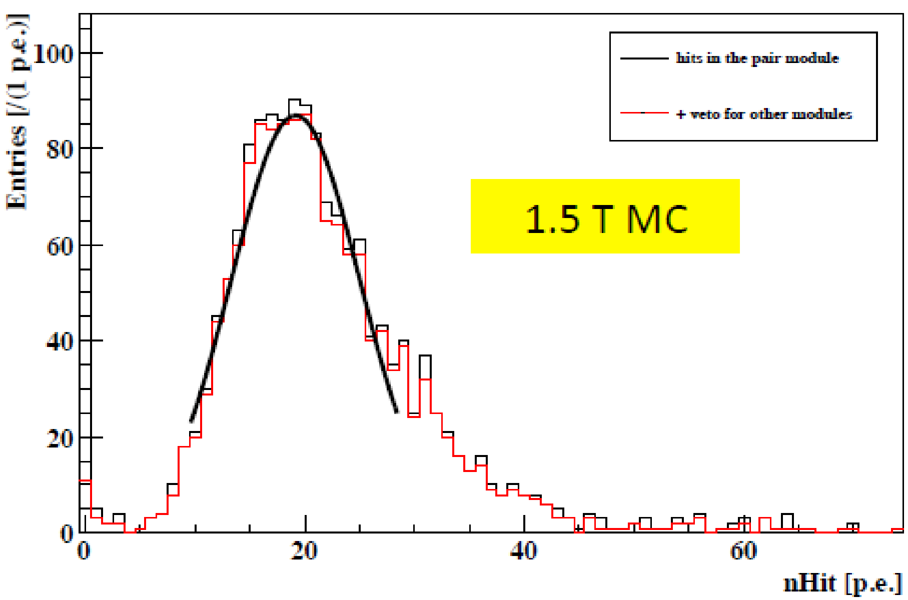
These studies used "raw waveform" readout; need Feature Extracted version (subsequent effort)

0, B-field Cosmic Ray Analysis data/MC nhit distribution

- Gaussian fit mean is used for nhit evaluation (in tight-cut condition)

Efficiency correction, artifact removal is tricky/difficult





Artifact contribution
(Need improved FW)

Further studies were defered for a couple months by PMT motion discovery (outcome of these studies)

PMT Rotation Update (2 rotation issues)

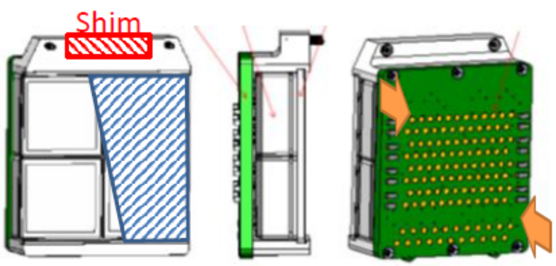
- The PMT tube is made of Kovar and suffers ~1 kgf/PMT in 1.5 T (maximum ~1.4 kgf/PMT in ~1.1 T).

Rotation of PMT module

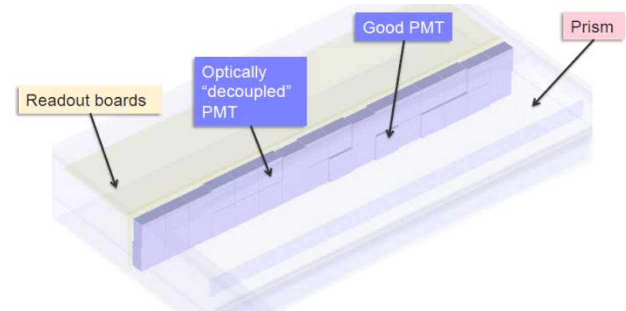
- Large effect on photon transmittance due to bubbles of the optical oil on the Si cookie
- Has been fixed in situ by shimming

Rotation of PMT

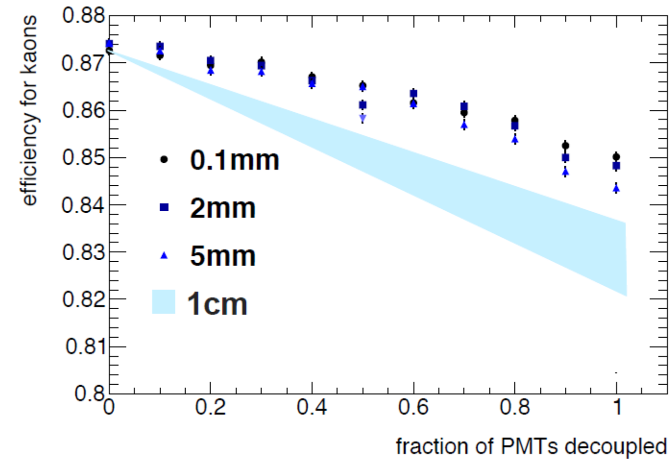
- Effect only for photons of larger incident angles than ~43° if the peel-off surface is clear.
- Wil be fixed if necessary after phase 2



Study of physics impact of decoupled PMTs (Modest effect)

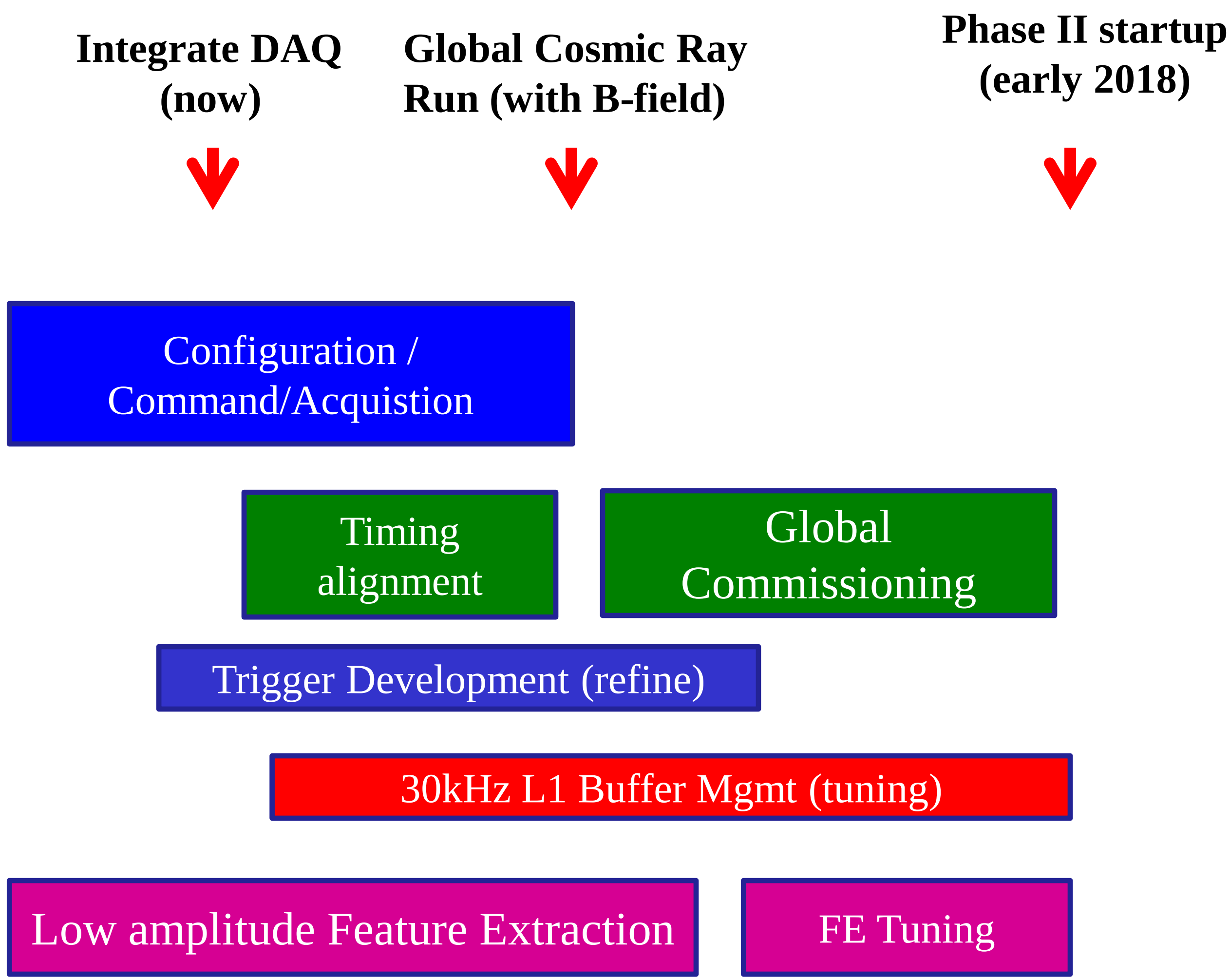


Year	2017				2018				2019				2020		
Month	1	4	7	10	1	4	7	10	1	4	7	10	1	4	7
Global schedule					Phase 2				Physics run			Physics run			
PMT production	Current production														
			Another small production												
							Mass production if necessary								
PMT test															
PMT installation													Assy		Install



Plan in place to replace ~50% of PMTs

Start-up Schedule/Commissioning



Timebase Calibration

- Took a while to get new FW release, SW work continued

/group/belle2/users/wangxl/iTOP/TBC/DB201612b/xval/. The data of run3523 and run3524 are also processed and skimed, and finally saved at **/ghi/fs01/belle2/bdata/group/detector/TOP/Skim-wangxl/2016-12/**.

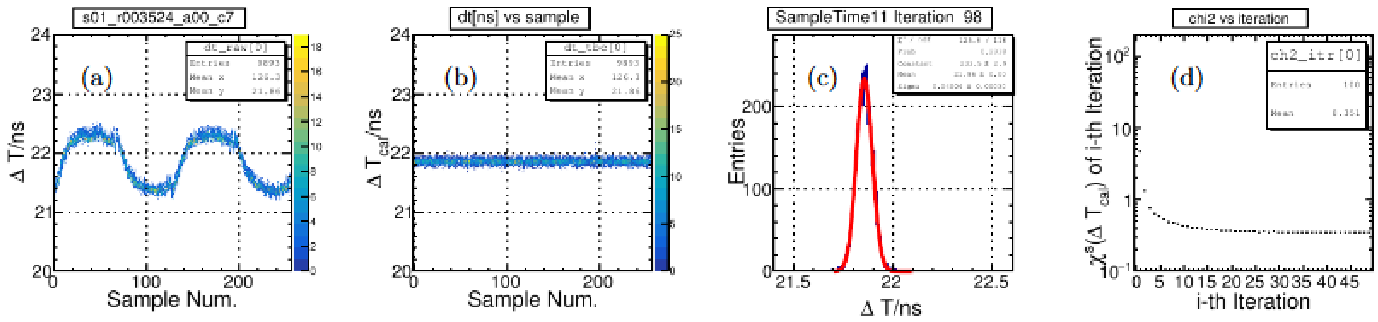


FIG. 1: Example of calculation on Slot_01 ASIC_00. (a) is the shape of time difference (ΔT) of the double pulses in channel_7 from the raw data, (b) is the dime difference after correction, (c) is the project of ΔT after correction and a fit performed to the distribution to show the mean and the resolution of ΔT, (d) shows how the χ^2 values change in the iterations of calculation.

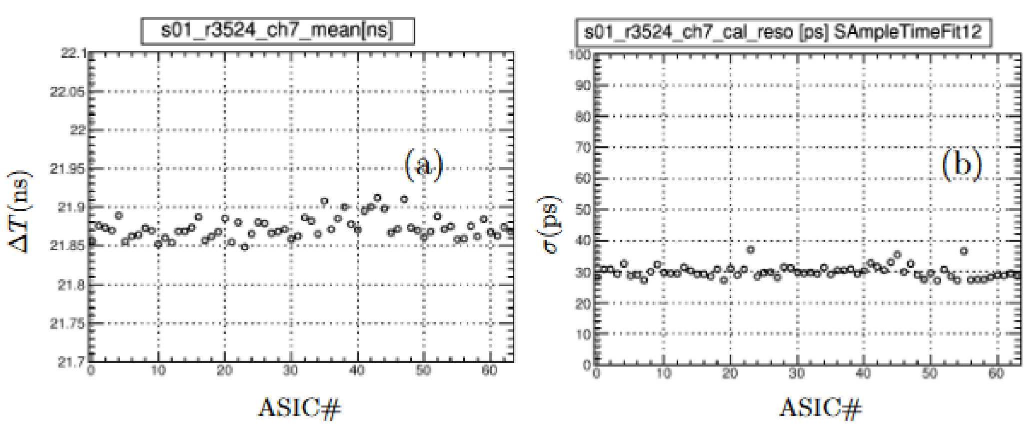


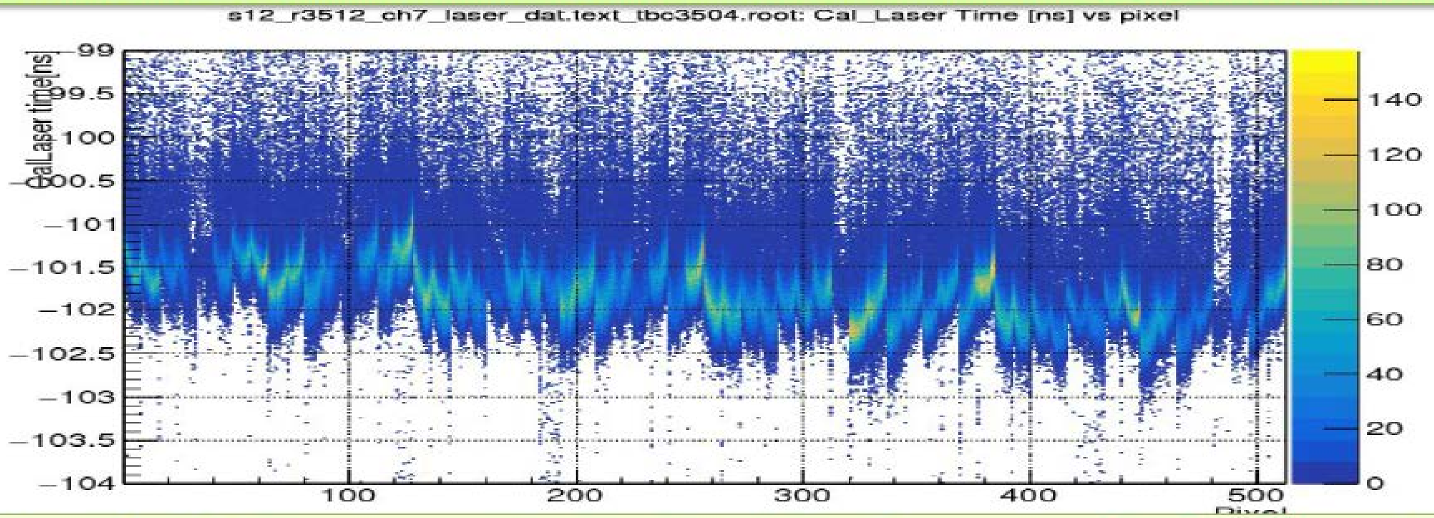
FIG. 2: Summary of calculation results of the 64 ASICs of Slot_01. Plot (a) is means of the time difference of double pulses, and (b) is the time resolution.

Channel-by-channel Timing alignment

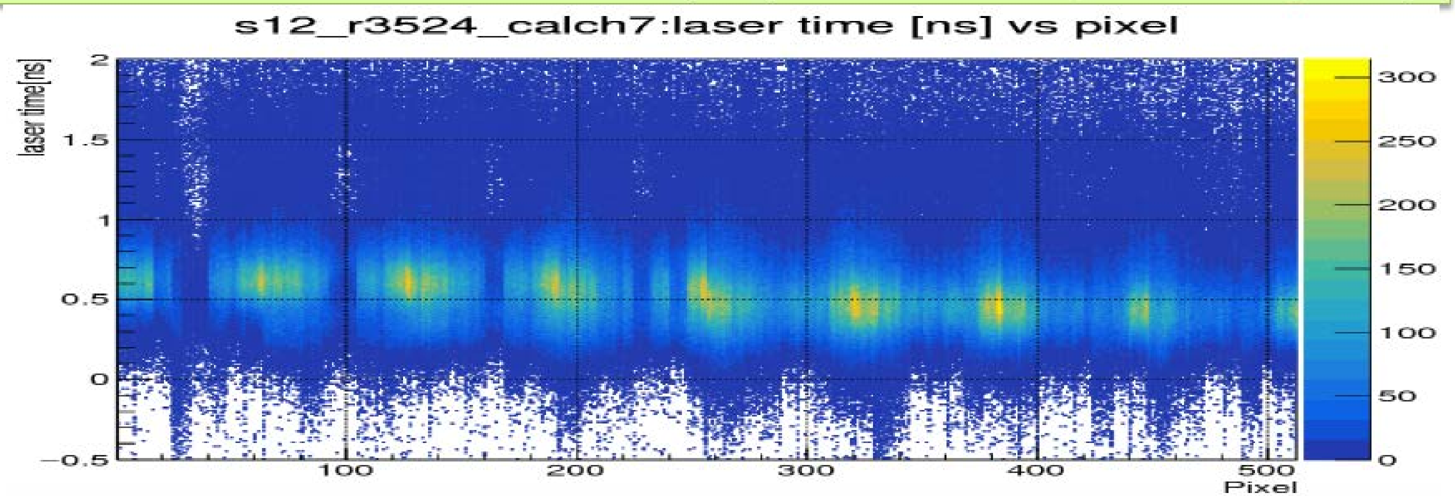
- Global timing alignment – laser studies

NOTE: Different Time Scales!

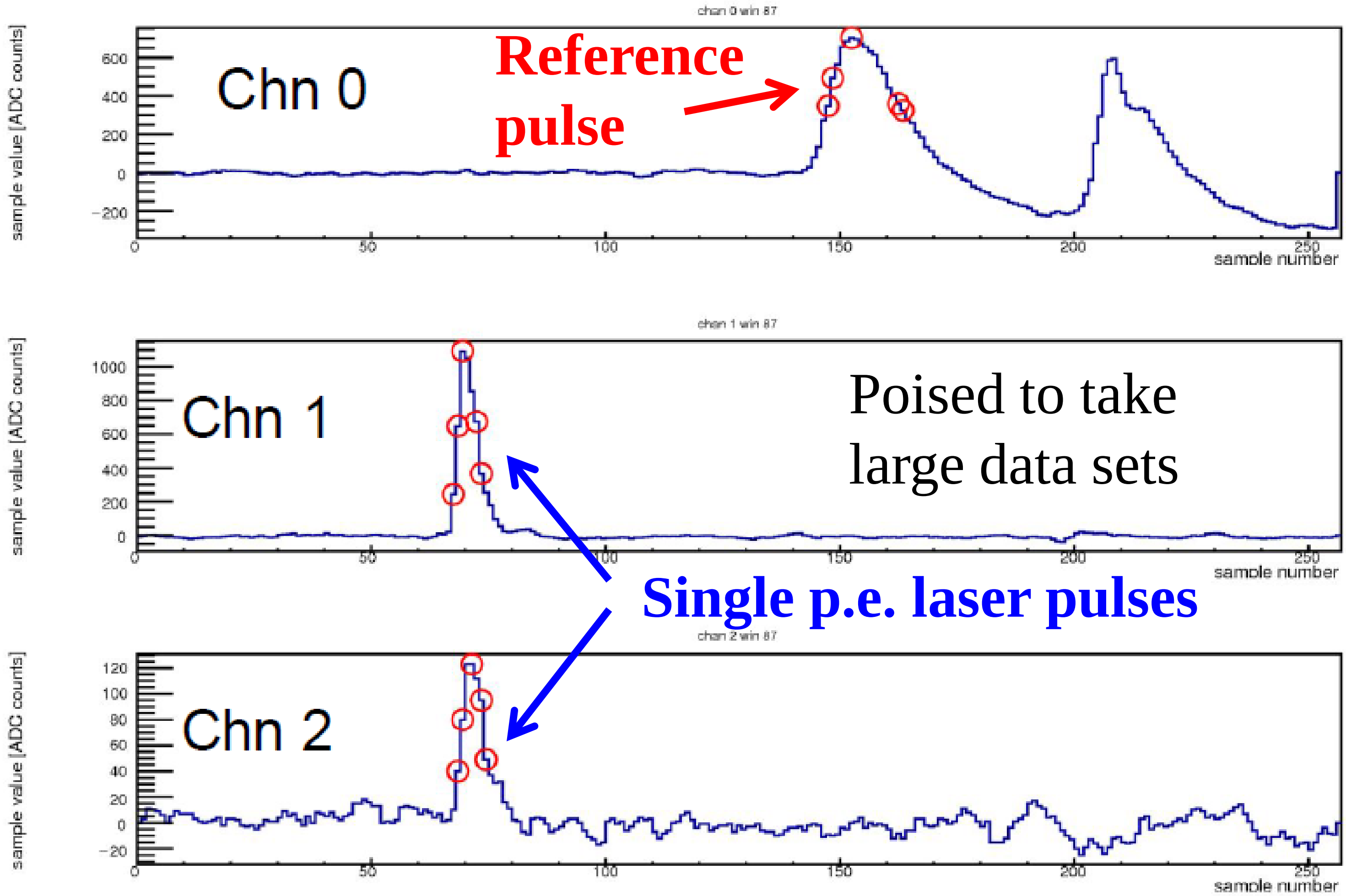
DATA slot12-r3512: Laser time as a function of pixel (after TB correction, before time alignment)



DATA slot12-r3512: Laser time as a function of pixel (after TB correction, after time alignment)



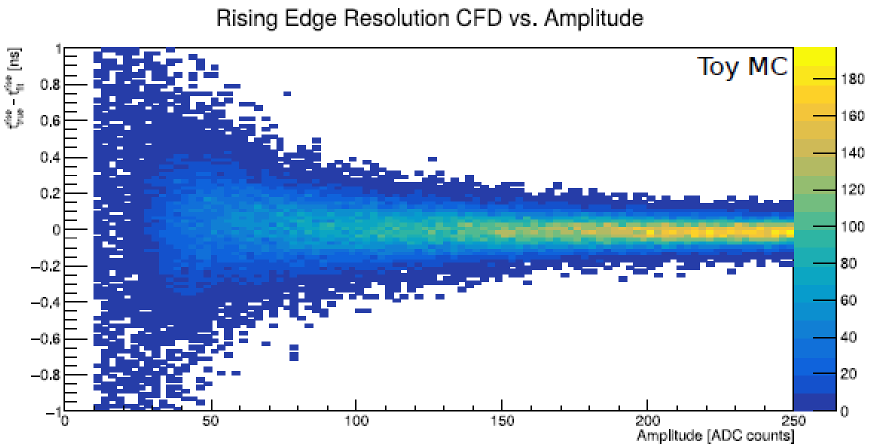
Region Of Interest & Feature Extraction



Standard CFD algorithm works well, though performance degrades at low PMT (mandated to mitigate aging effects)

Low PMT Gain Operation

- current feature extraction uses constant fraction discrimination to extract signal timing
- resolution deteriorates at small signal amplitudes

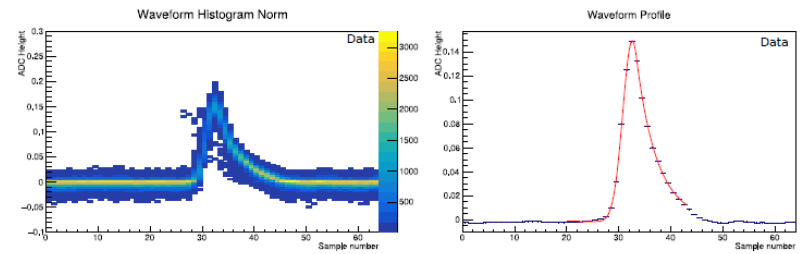


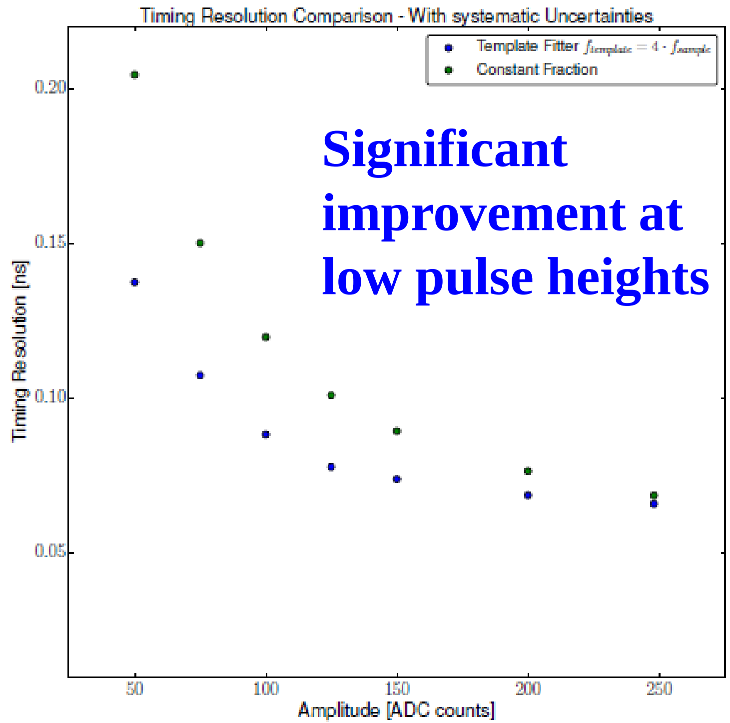
- use template fitter to improve resolution at small amplitudes/high noise

Necessary to maximize MCP lifetime

Studying how best to implement (Zynq: PS is too slow(?), PL option)

- using laser data from Hawaii test setup
- TProfile to get waveform template
- fit with central Gaussian and exponential tail





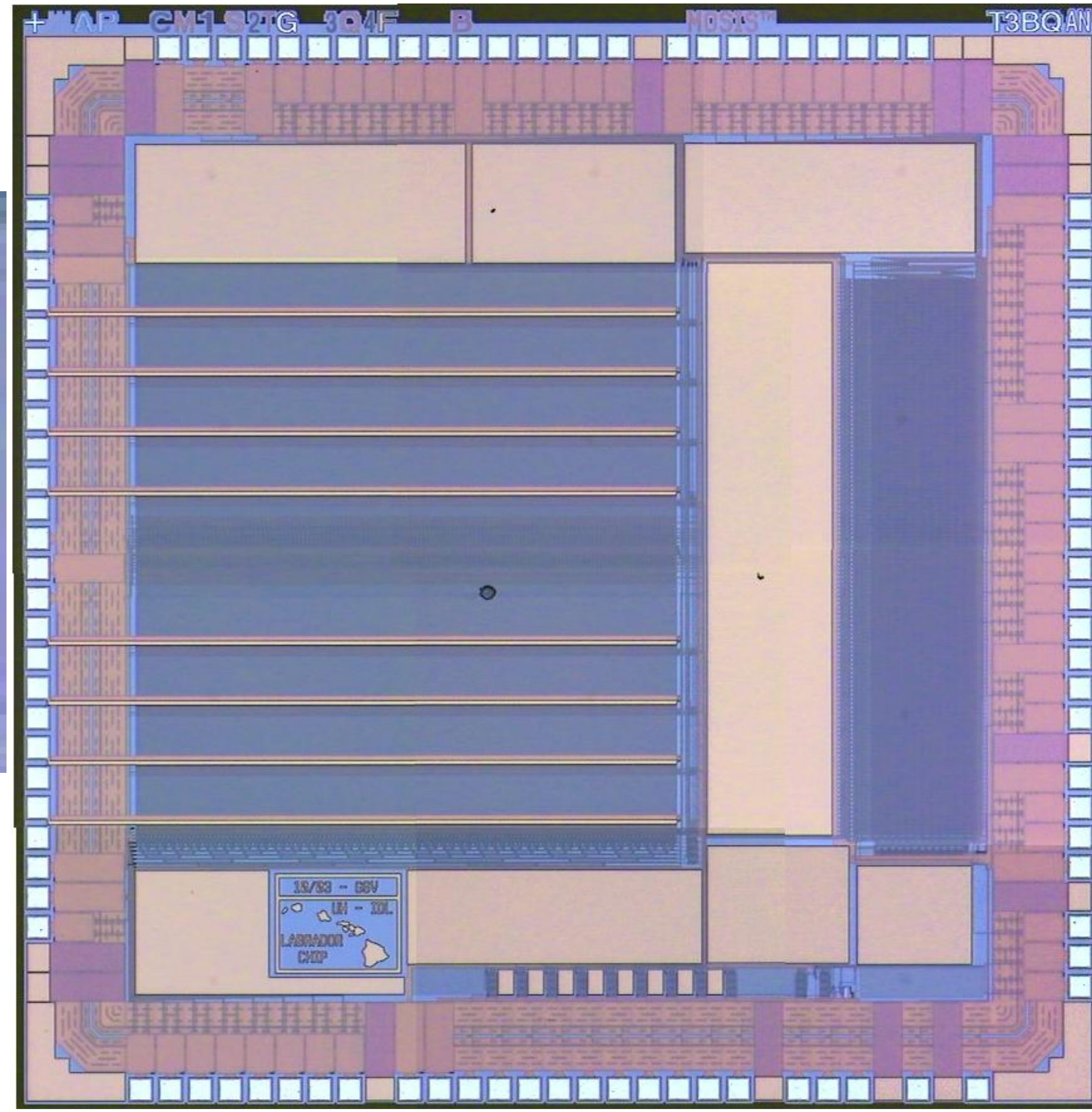
Significant improvement at low pulse heights

Summary

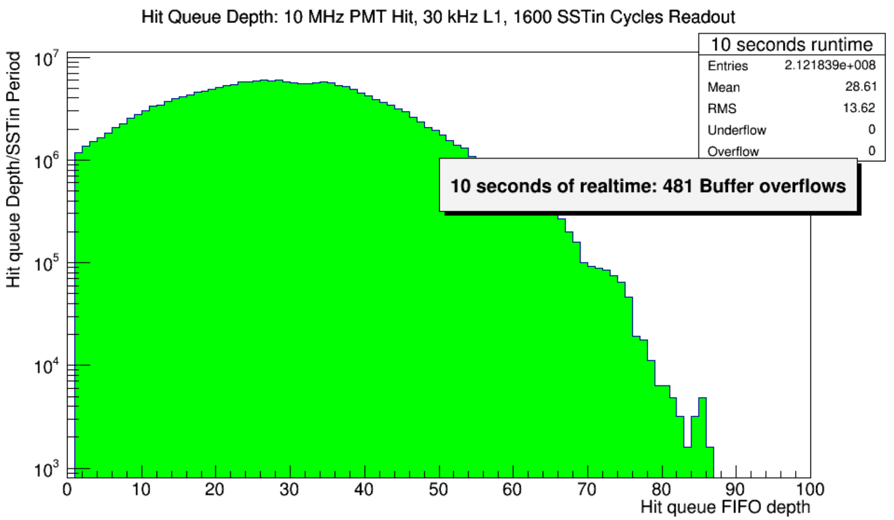
Belle II TOP Detector coming online

- **Present:**
  - **Production Firmware debugging**
  - **DAQ integration and initial timing alignment**
- **Global Cosmic Ray Campaign:**
  - **Detector alignment**
  - **Magnetic field tracking**
- **First collisions (early 2018):**
  - **Verify detector alignment**
  - **Initial PID release**

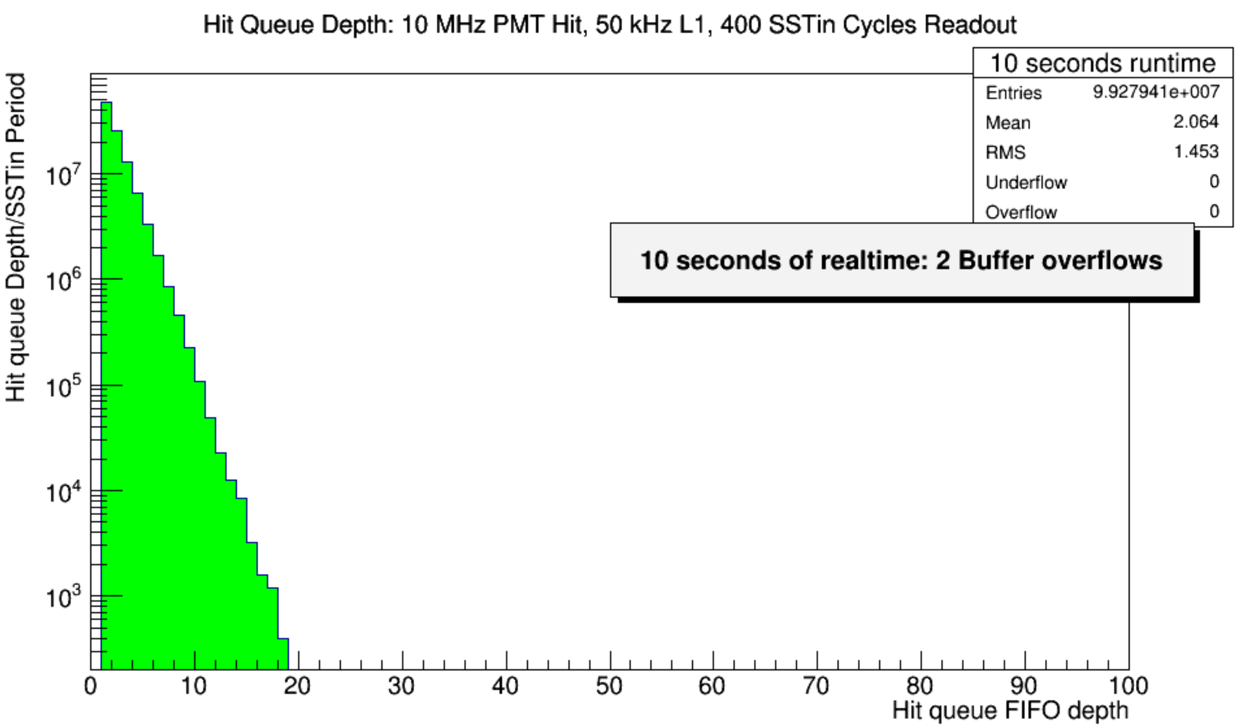
Back-up slides



30kHz L1, high occupancy emulation

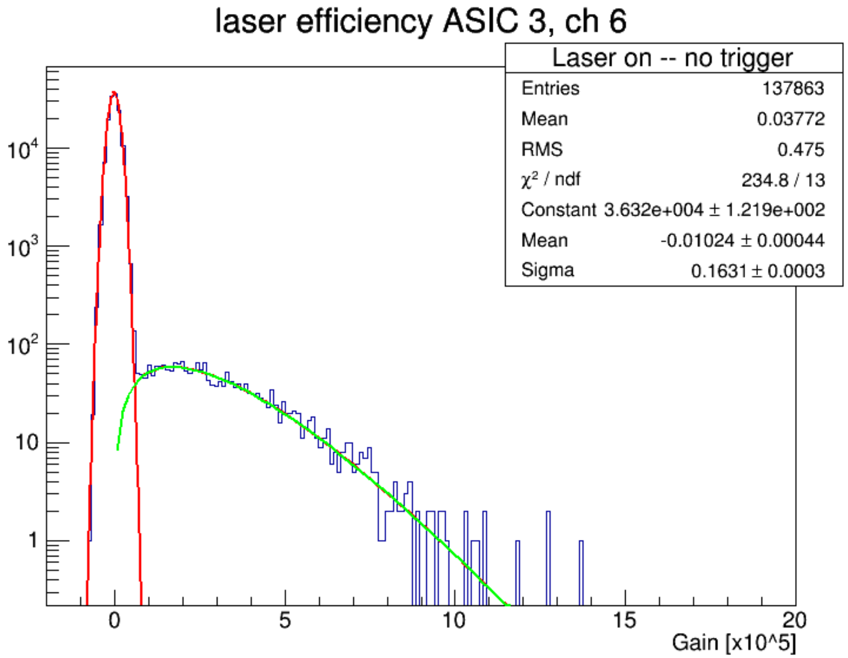


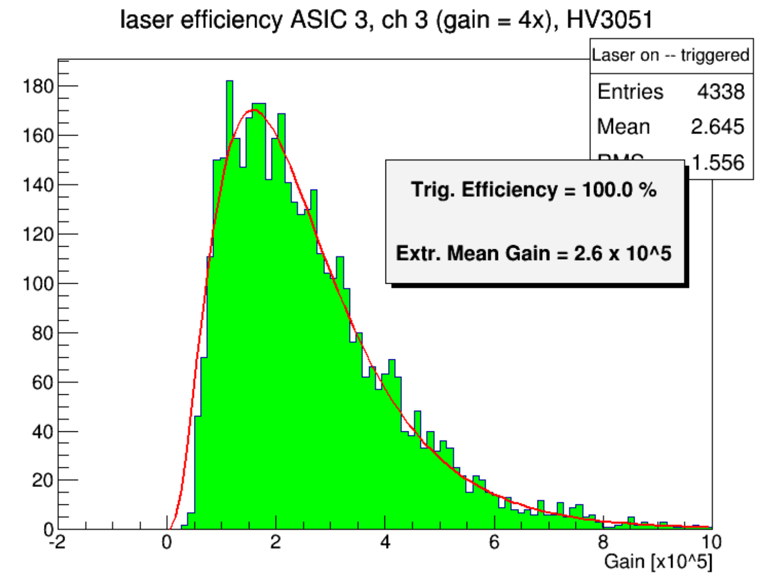
30kHz L1 trigger, 10 MHz background photons/PMT, multi-hit, multi-event buffering

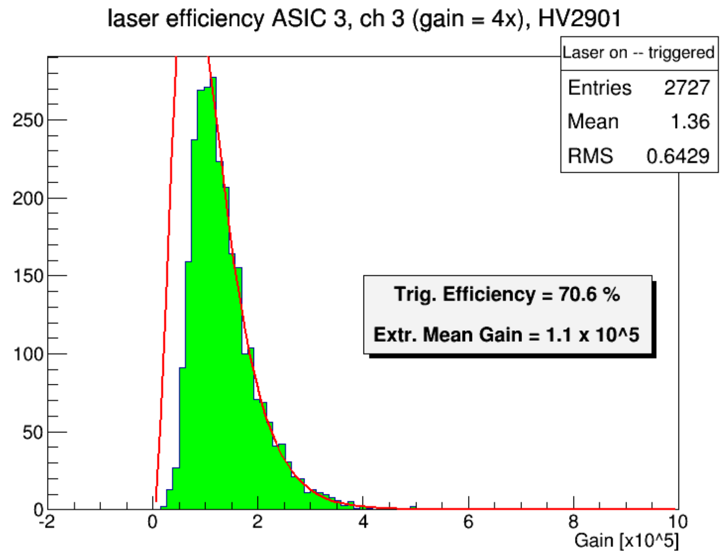


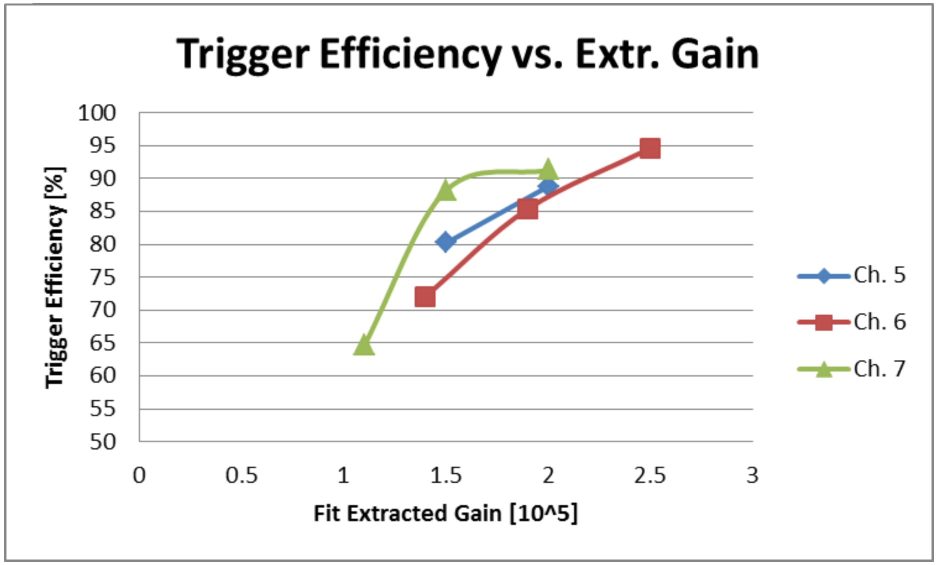
At 400 SSTin Cycles (~19us per single photon hit), can run at 50kHz, so plenty of margin

Gain and Efficiency

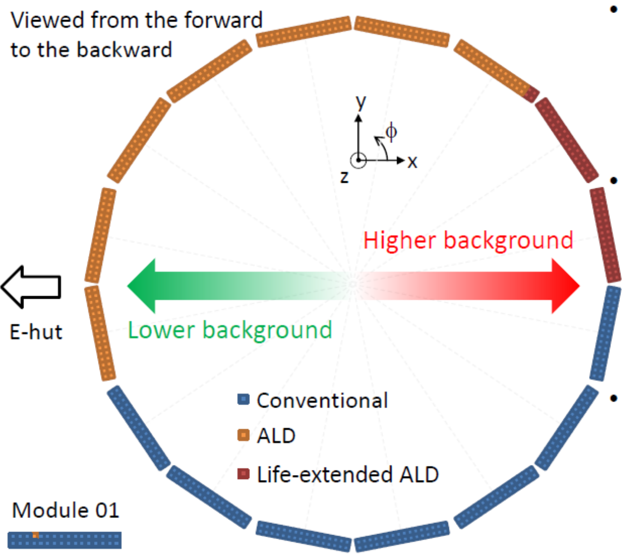








PMT Replacement

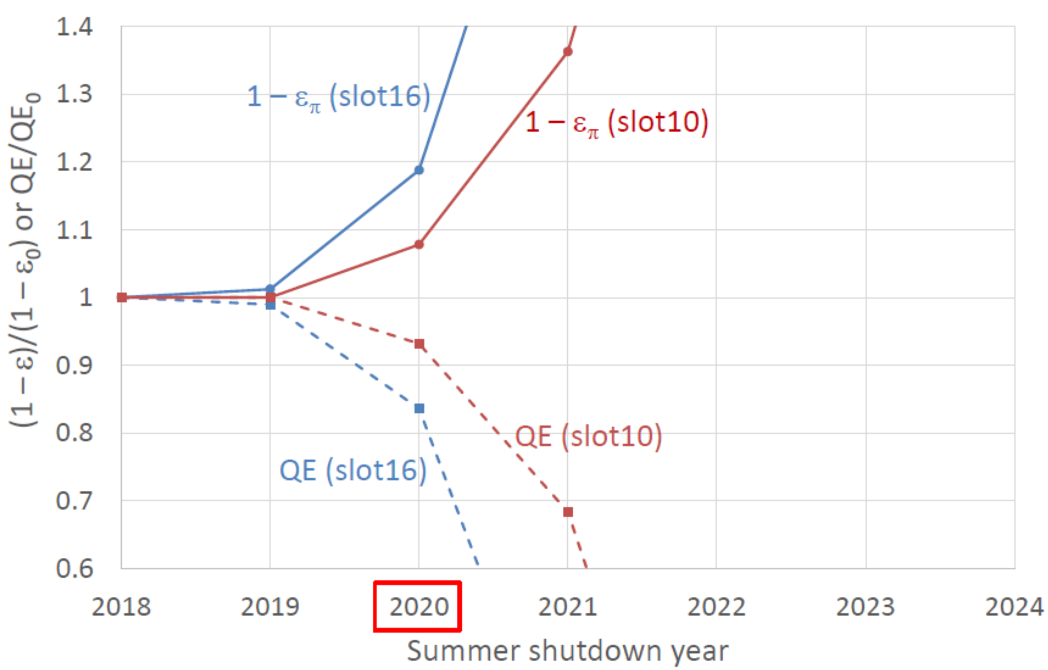


- The 224 conventional MCP-PMTs in the 7 slots have to be replaced due to the QE degradation by the beam background.
- In 2015 the time of the replacement was estimated as the 2020 summer shutdown.

→ Revisit the estimation.

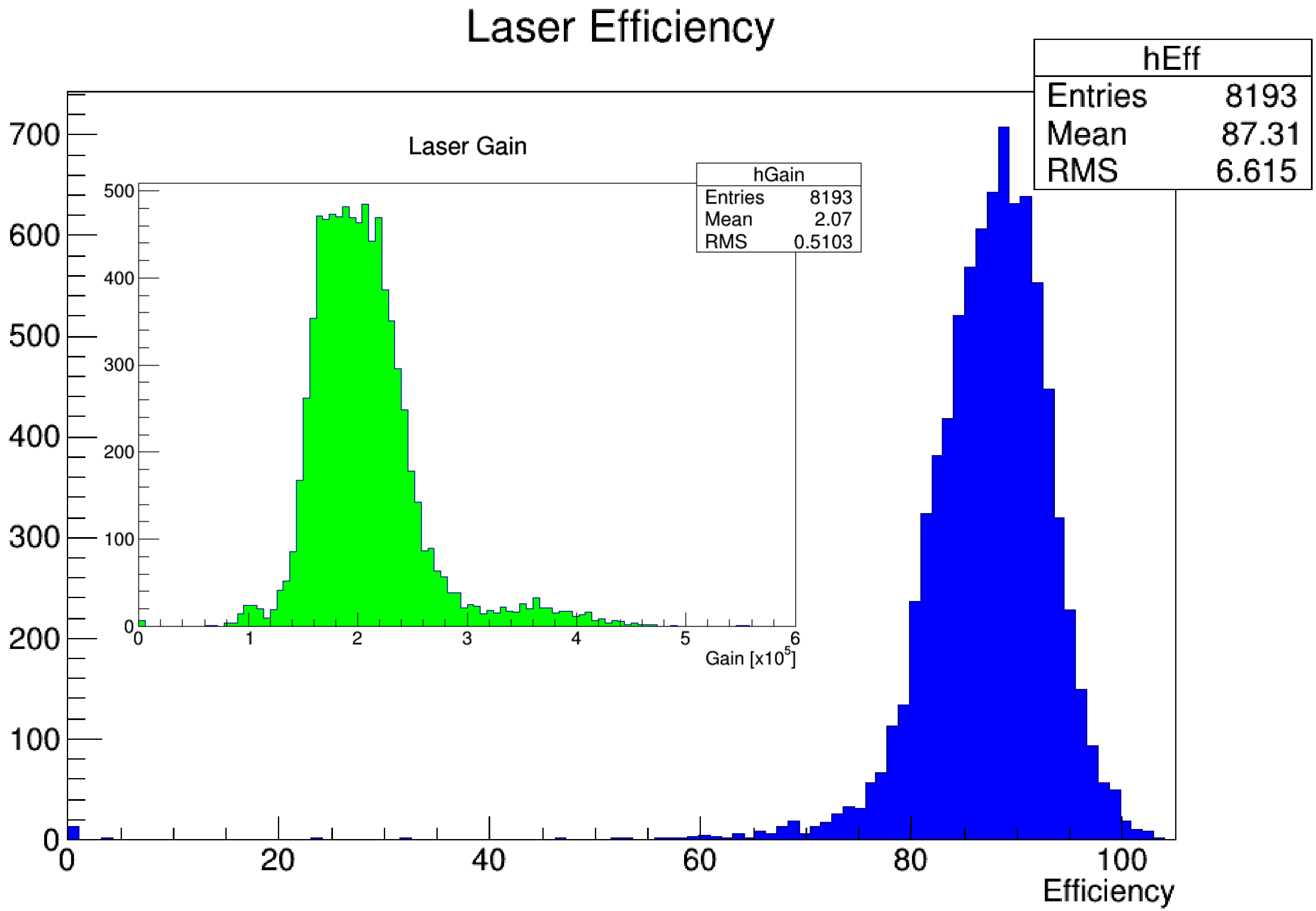
- Need additional mass production of the MCP-PMTs for the replacement.

→ Discuss the production plan.

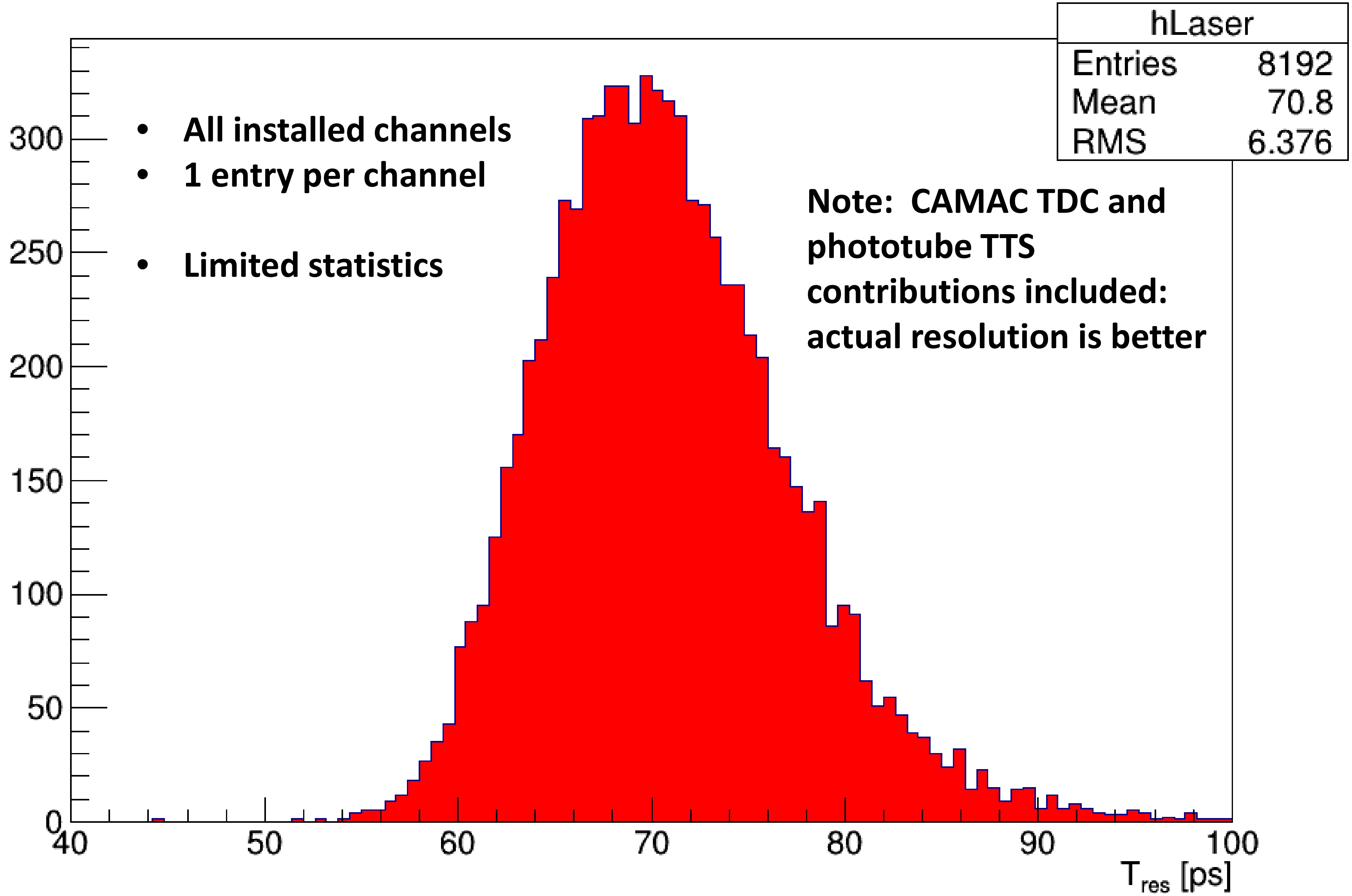


"1x BG"

PERFORMANCE SUMMARIES



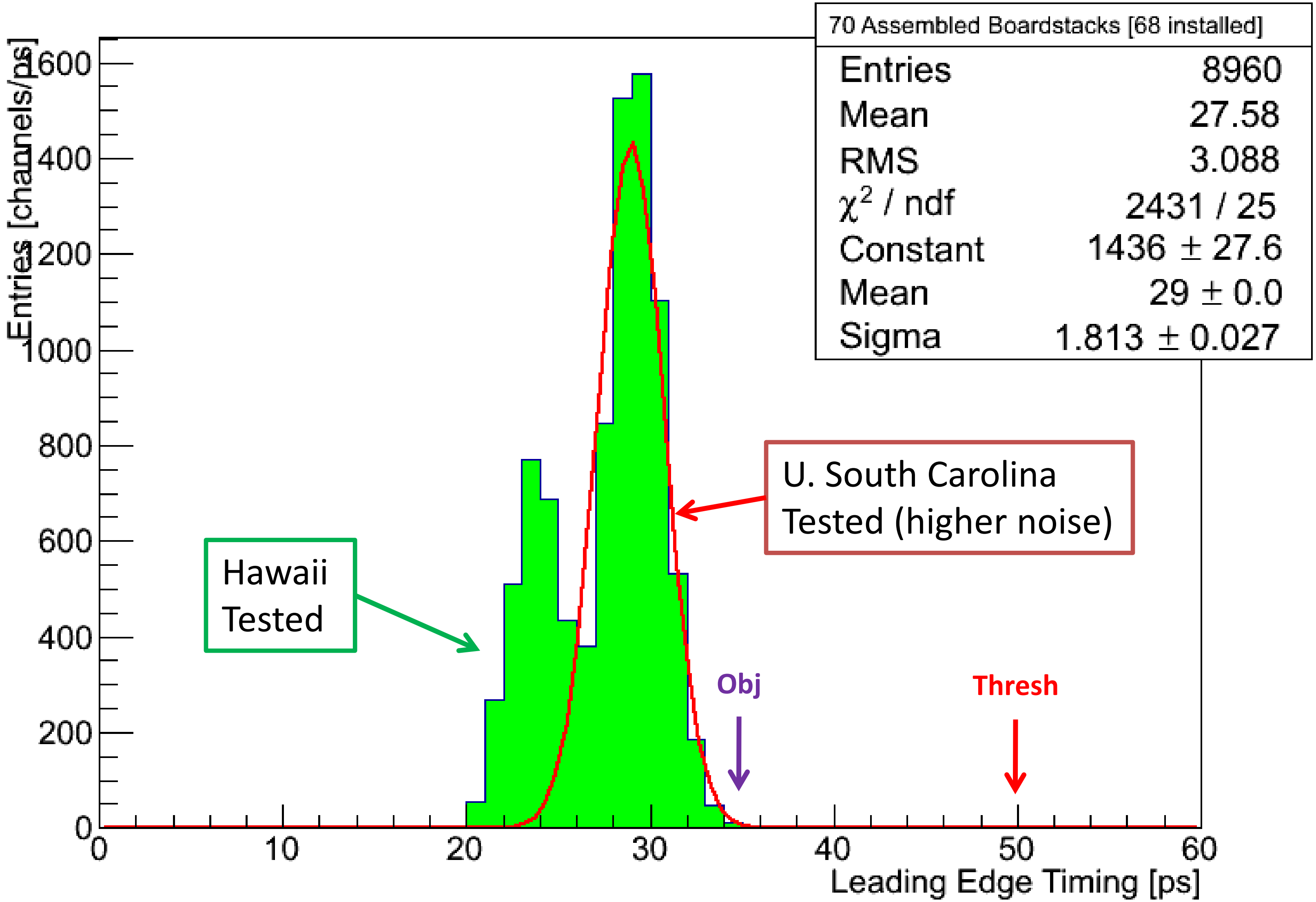
Single photon timing



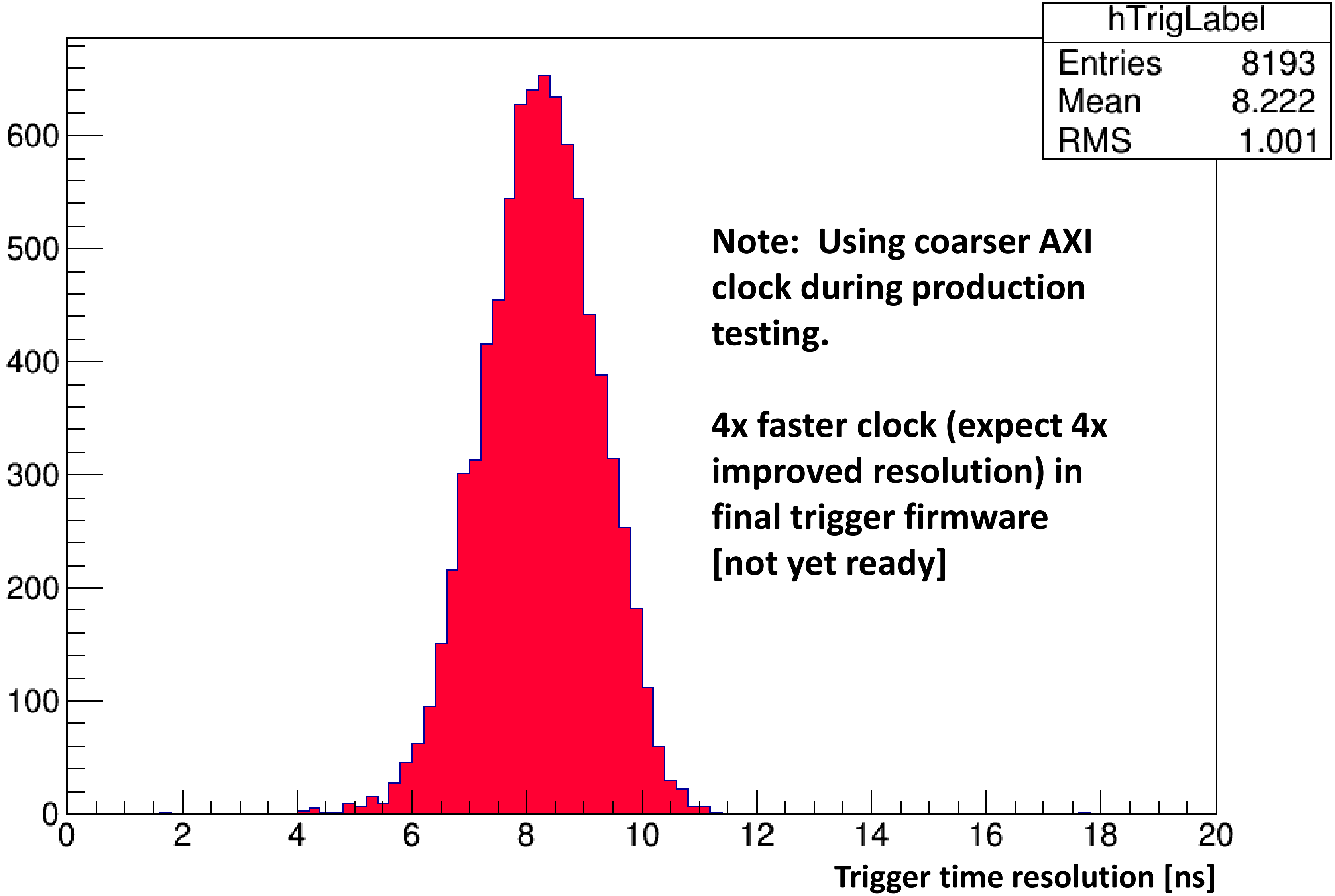
- All installed channels
- 1 entry per channel
- Limited statistics

Note: CAMAC TDC and phototube TTS contributions included: actual resolution is better

Verification: Event Time Zero



Verification: Event Trigger Time

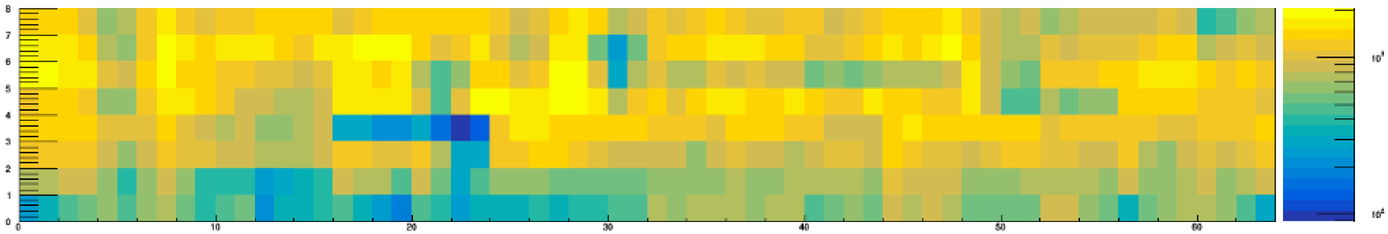


Note: Using coarser AXI clock during production testing.

4x faster clock (expect 4x improved resolution) in final trigger firmware [not yet ready]

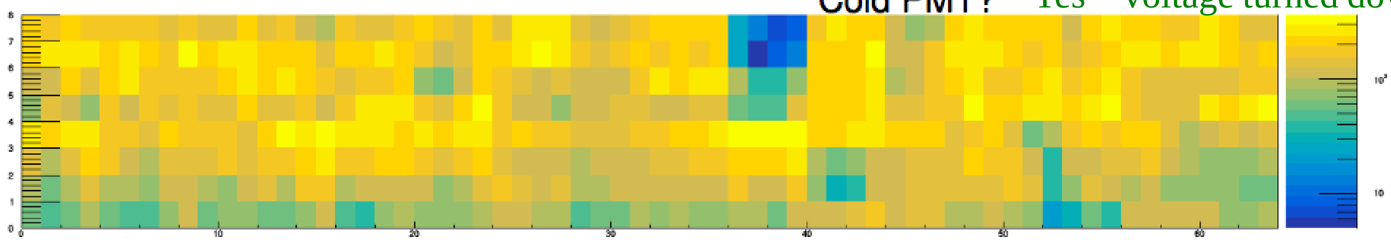
Direct hitmap

S04

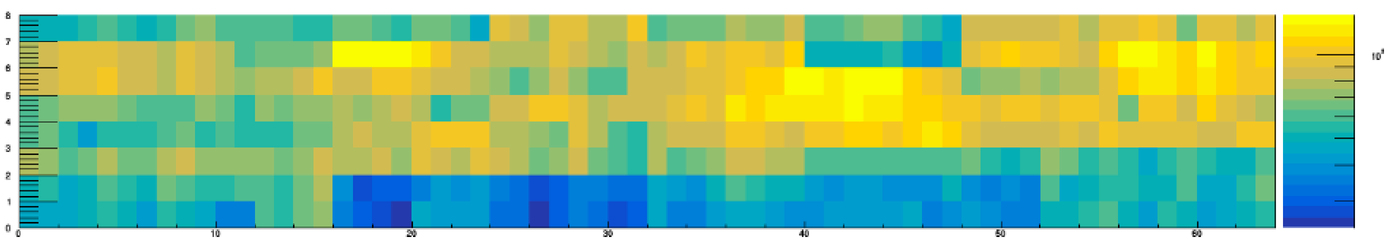


Cold PMT? Yes – voltage turned down

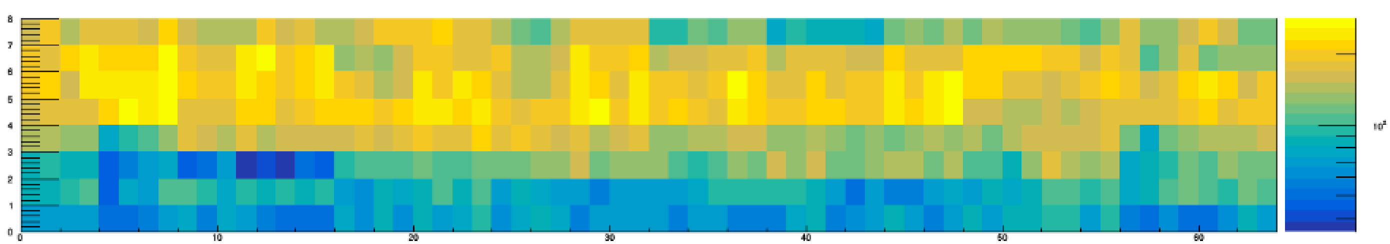
S05



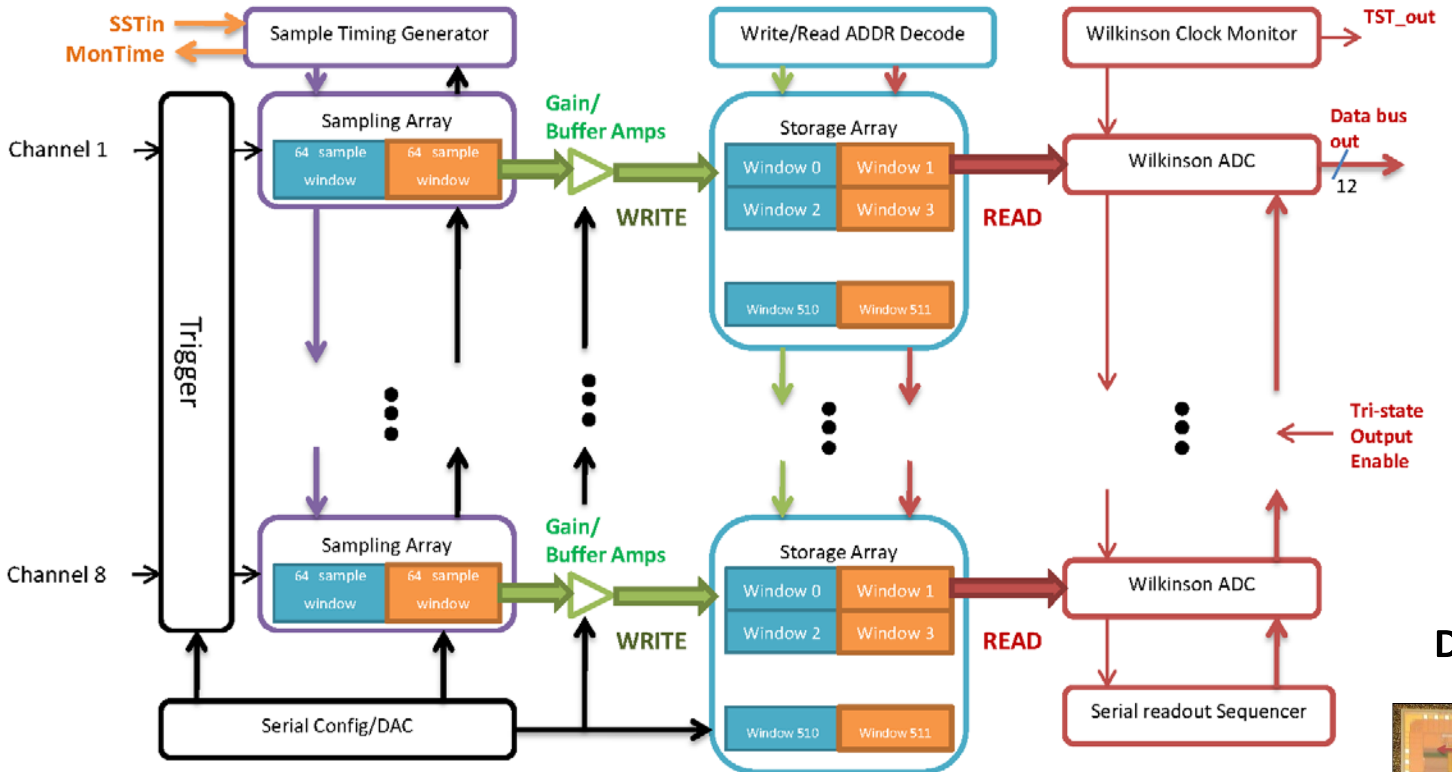
S12



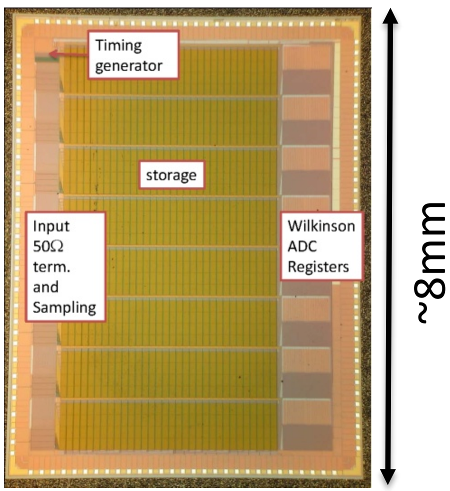
S13



IRSX ASIC Overview



Die Photograph



- **8 channels per chip @ 2.8 GSa/s**
- **Samples stored, 12-bit digitized in groups of 64**
- **32k samples per channel (11.6us at 2.8GSa/s)**
- **Compact ASICs implementation:**
  - **Trigger comparator and thresholding on chip**
  - **On chip ADC**
  - **Multi-hit buffering**

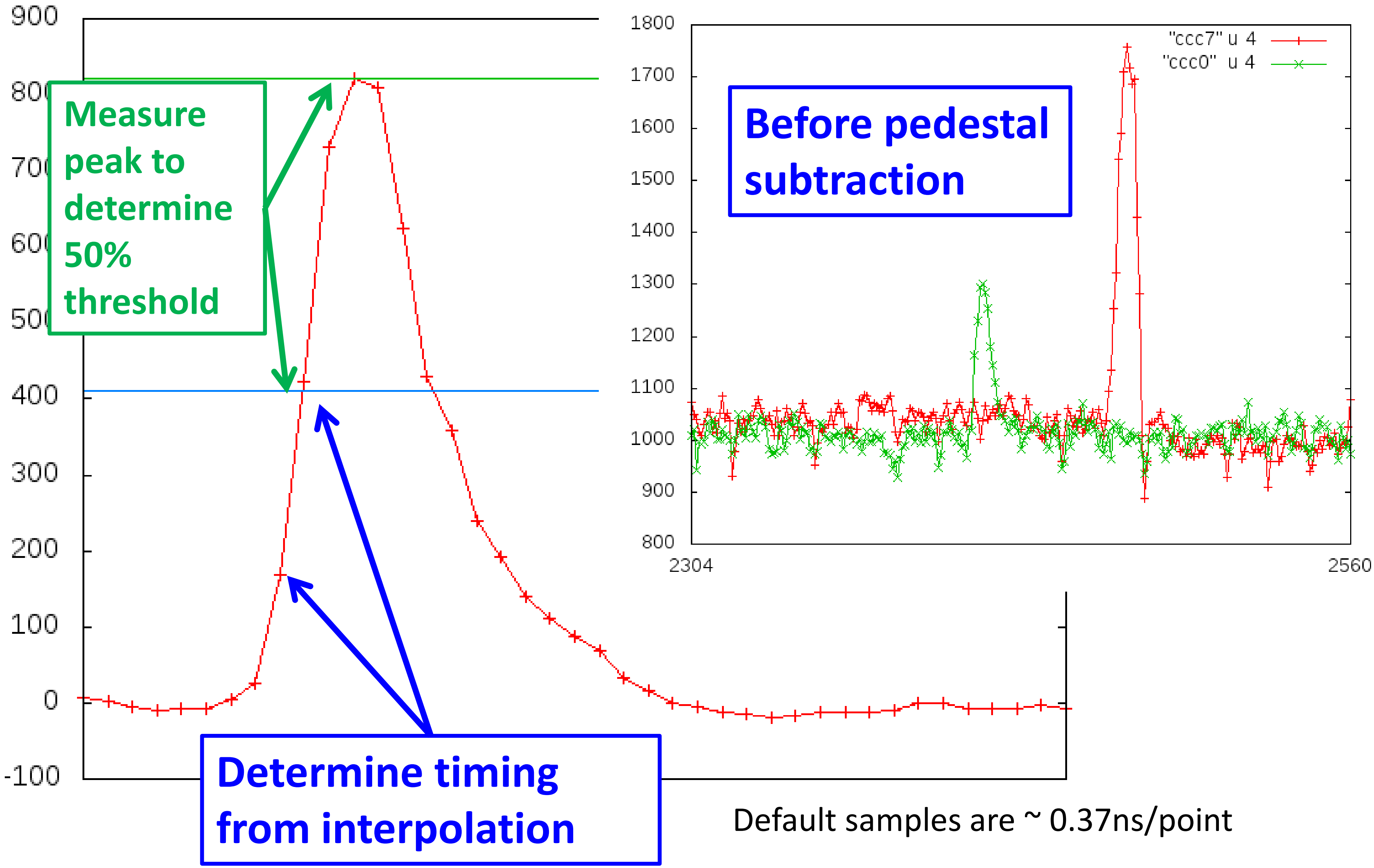
Laser Calibration steps

1. Pedestal subtract
2. Correct Amplitude dependence
3. Run dT Minimizer, obtain results
4. Apply dT values

- **All binned, so easily implemented at Look-up tables on the SCROD FPGA**

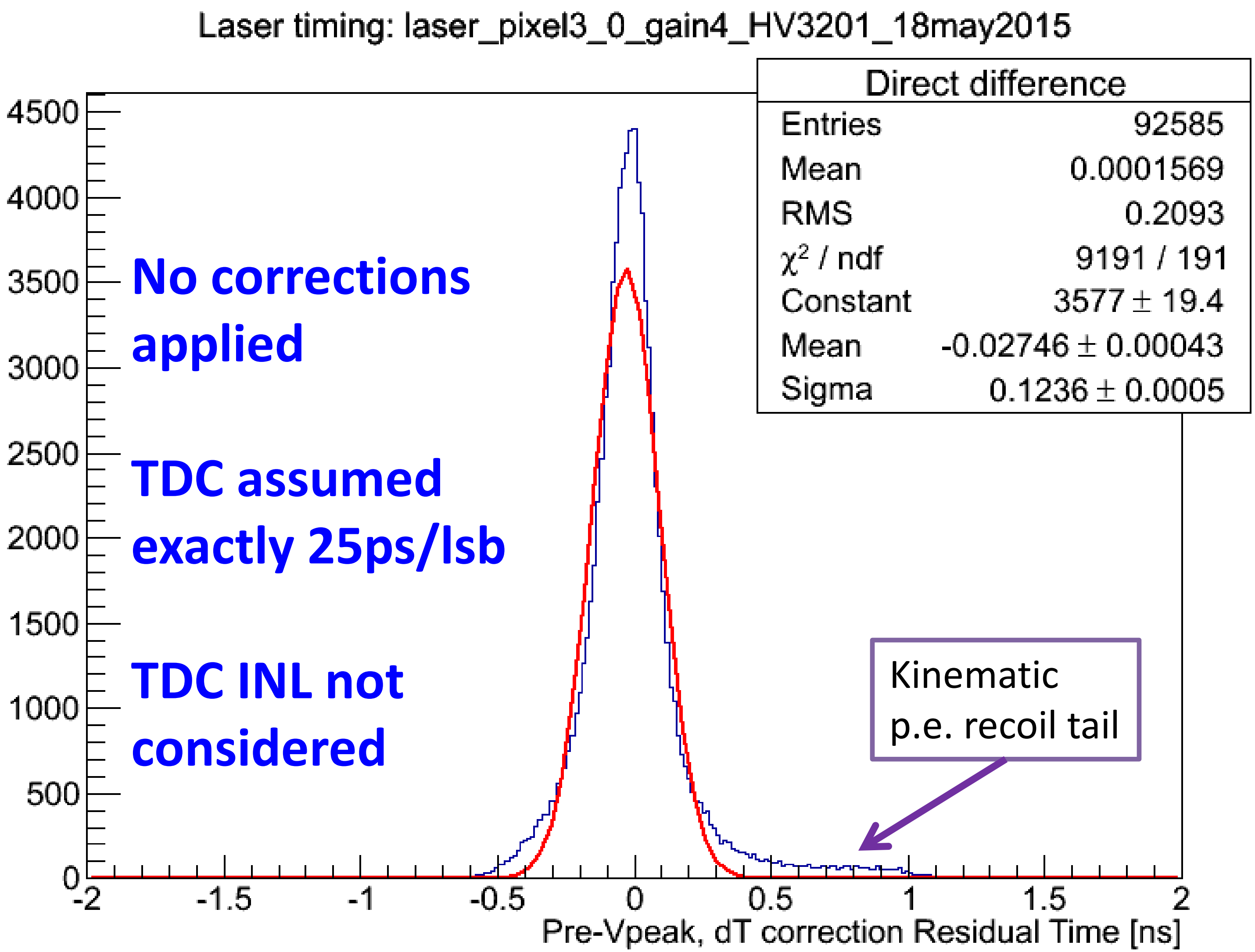
- **Both gain/efficiency and timing data taken at same time**
- **About 8 hours per 128 channel board stack**

1. Ped subtract & 50% CFD



Default samples are ~ 0.37ns/point

1. After 50% CFD algorithm

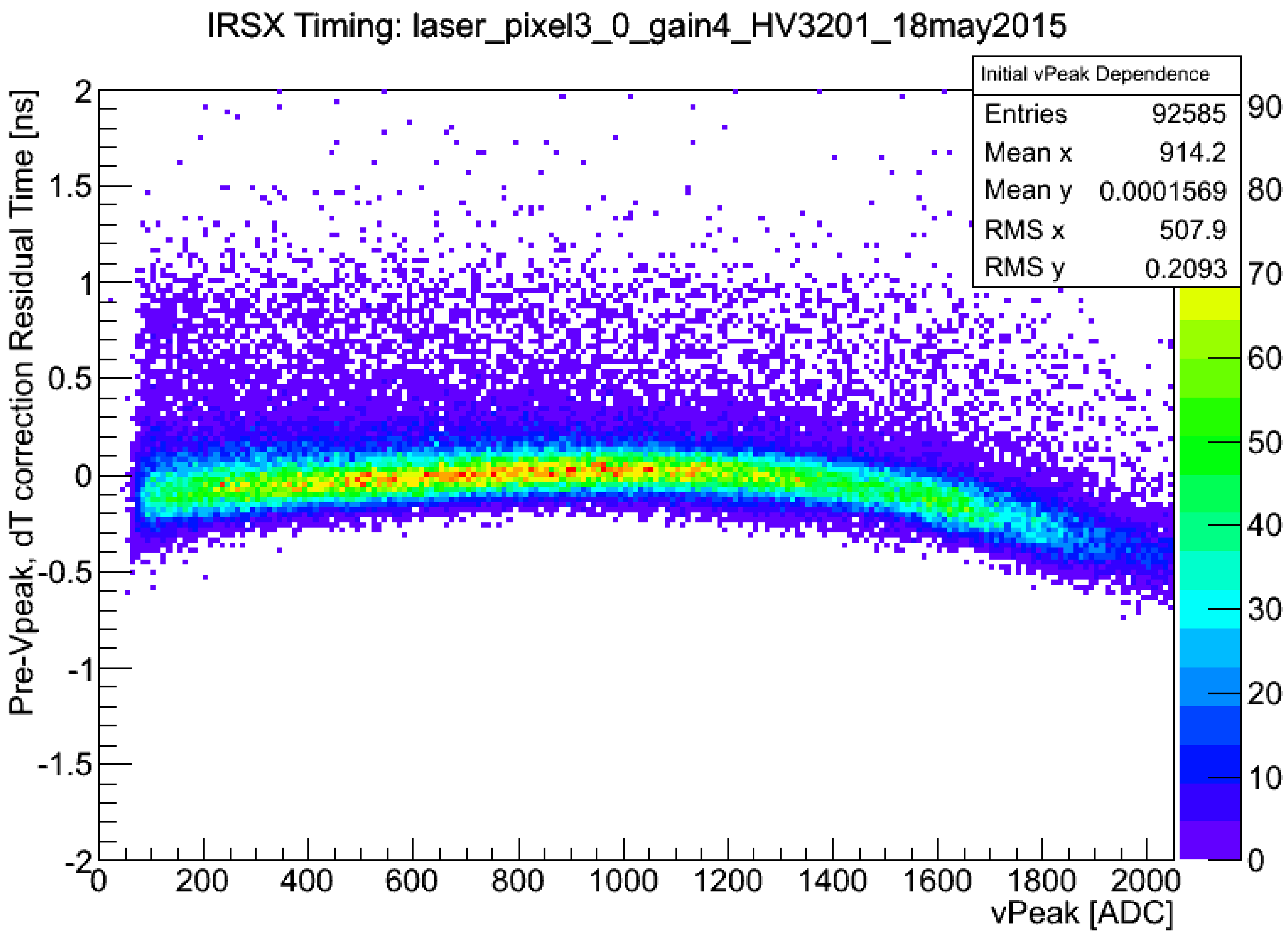


No corrections applied

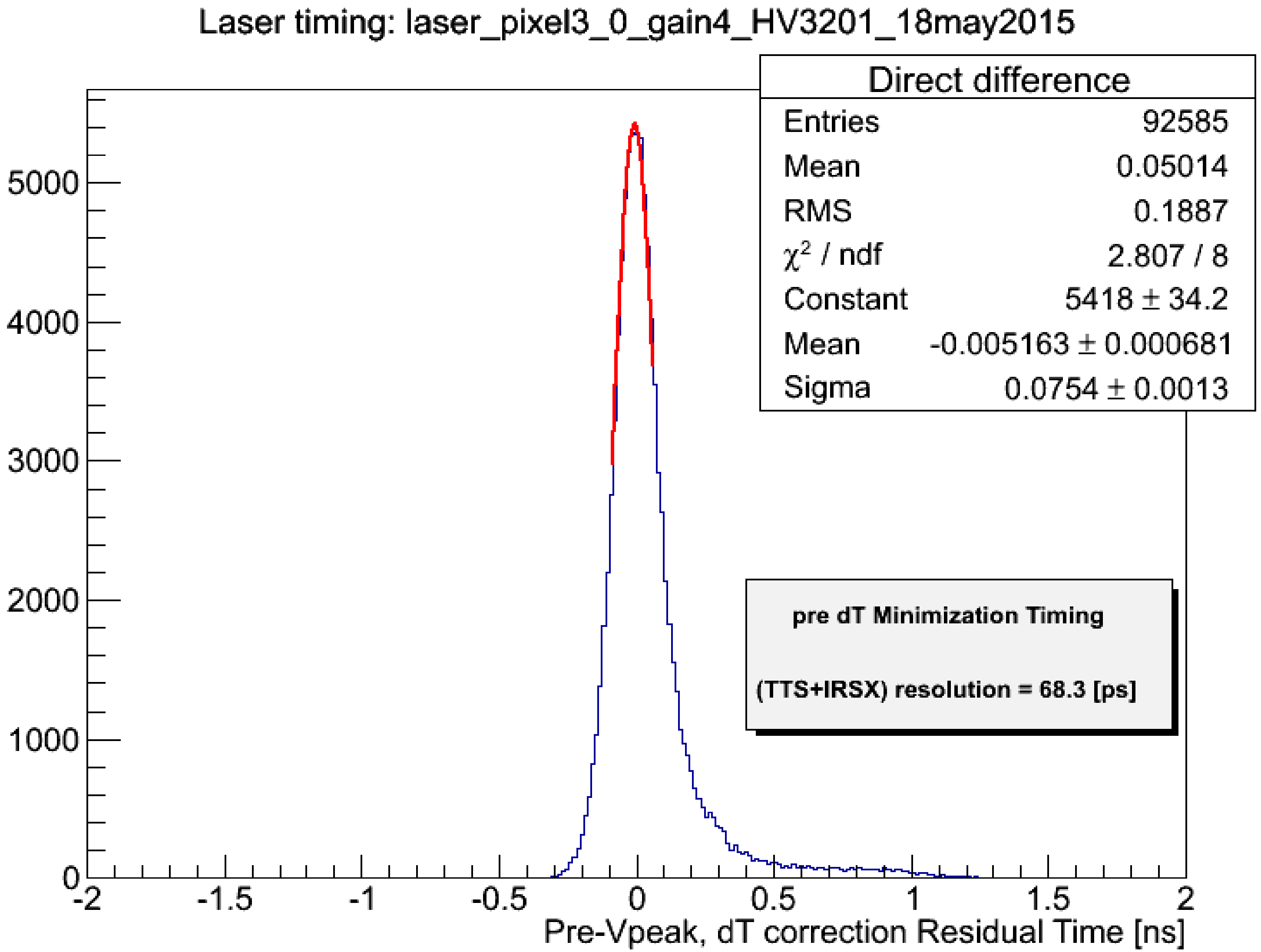
TDC assumed exactly 25ps/lsb

TDC INL not considered

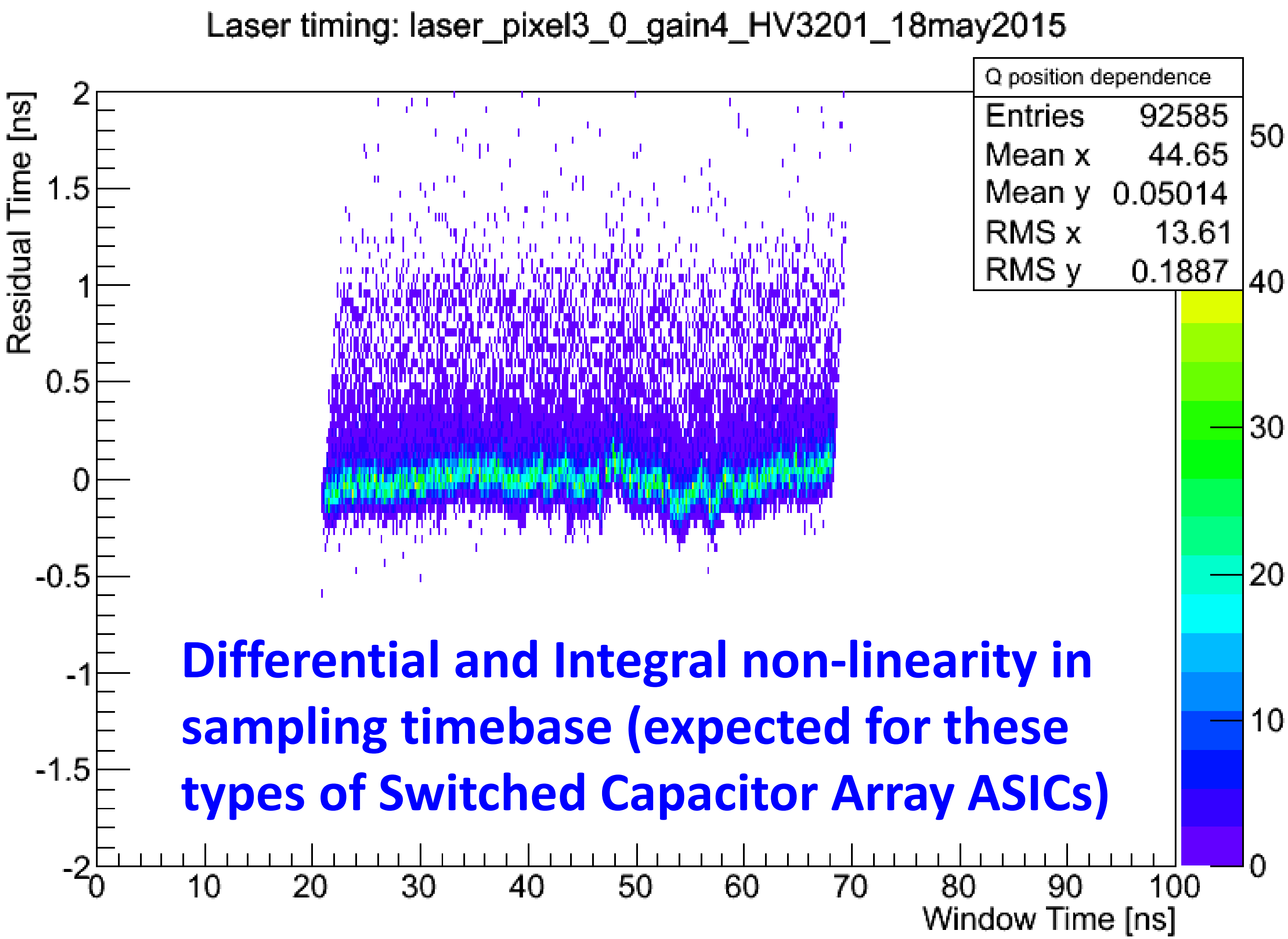
2. Voltage dependence



2. Improved Residual

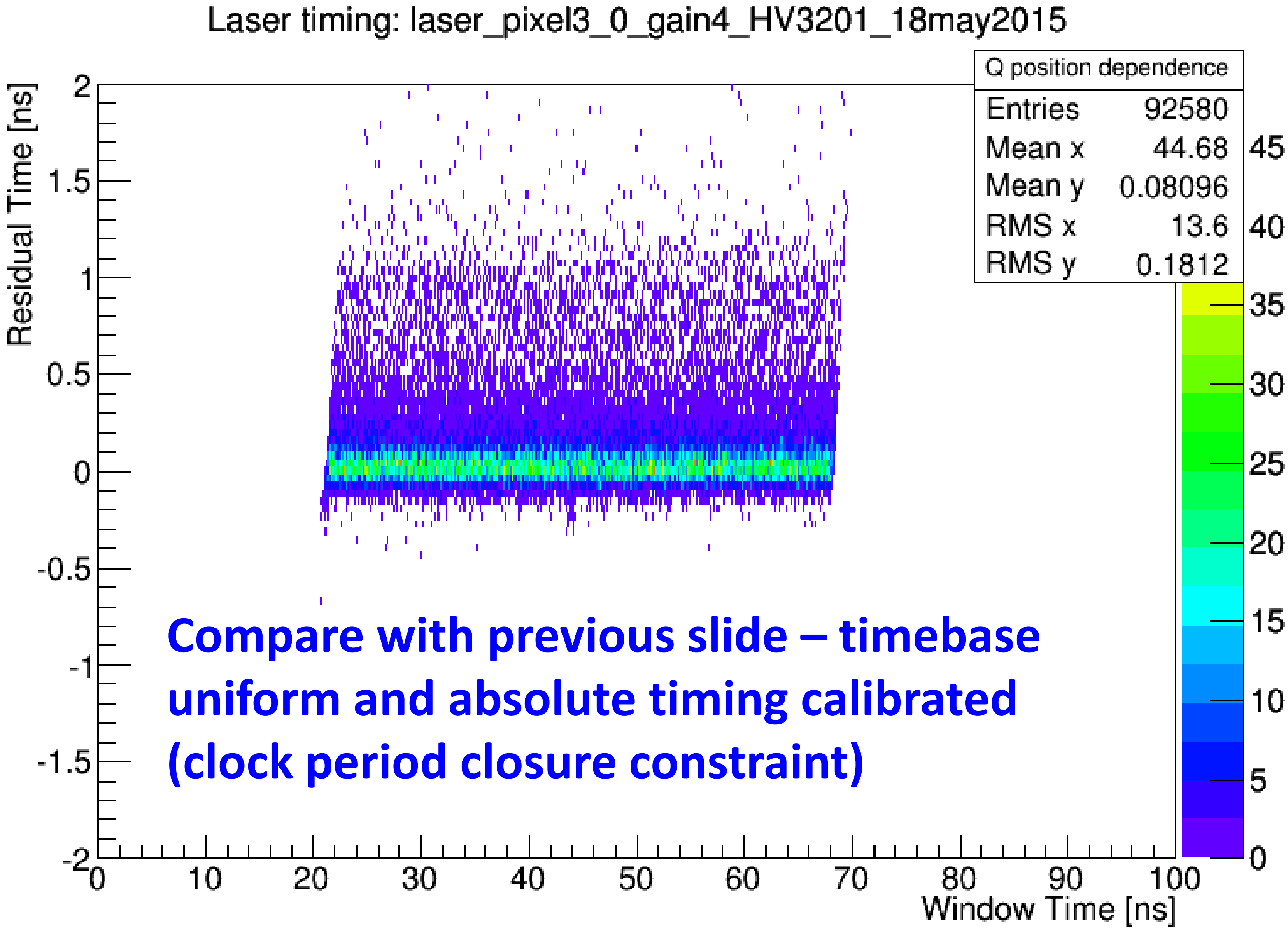


2. TDC resolution residual

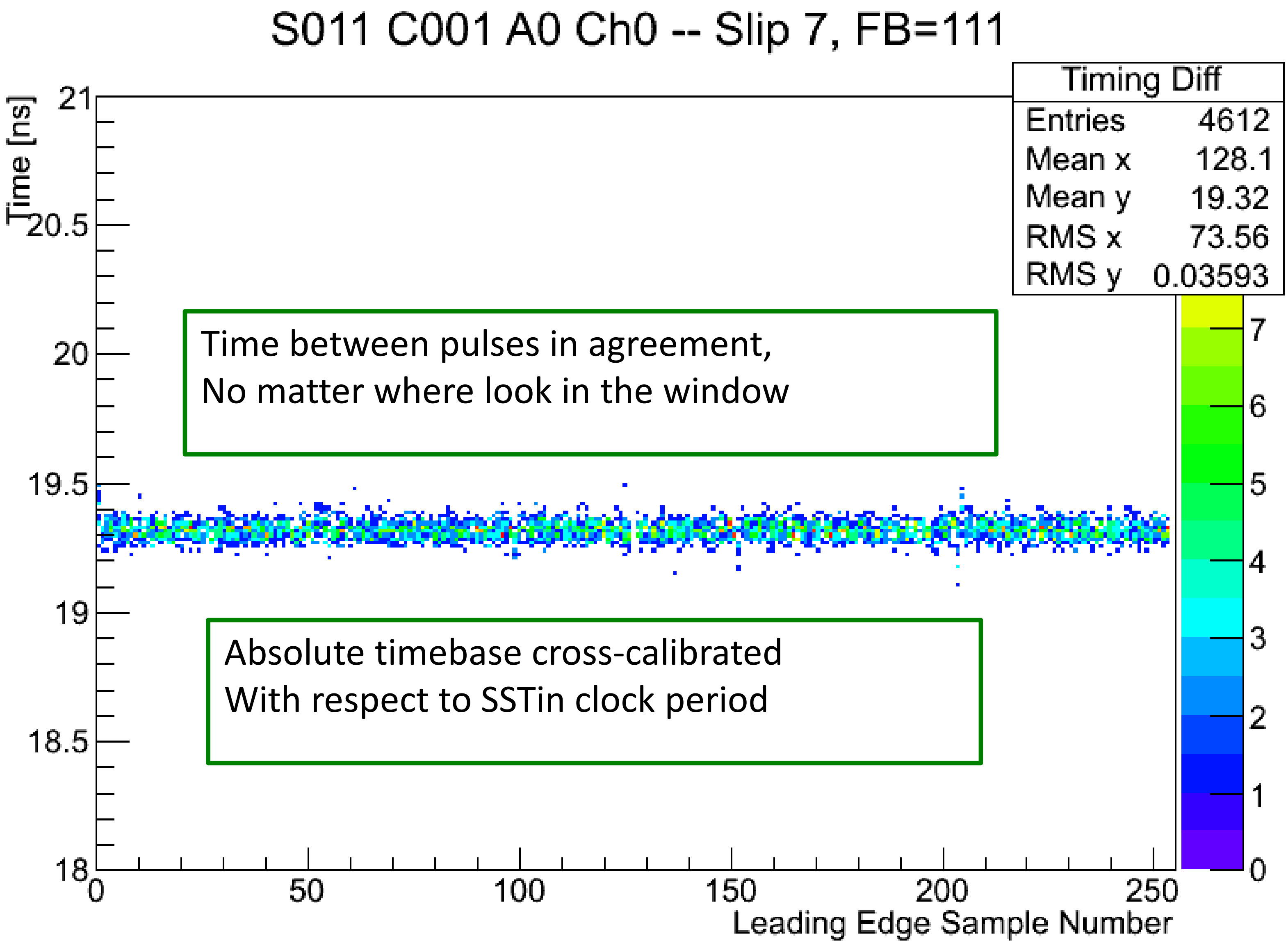


Differential and Integral non-linearity in sampling timebase (expected for these types of Switched Capacitor Array ASICs)

3. After Autocalibration



Output After "dT minimizer" algorithm



Production single photon testing