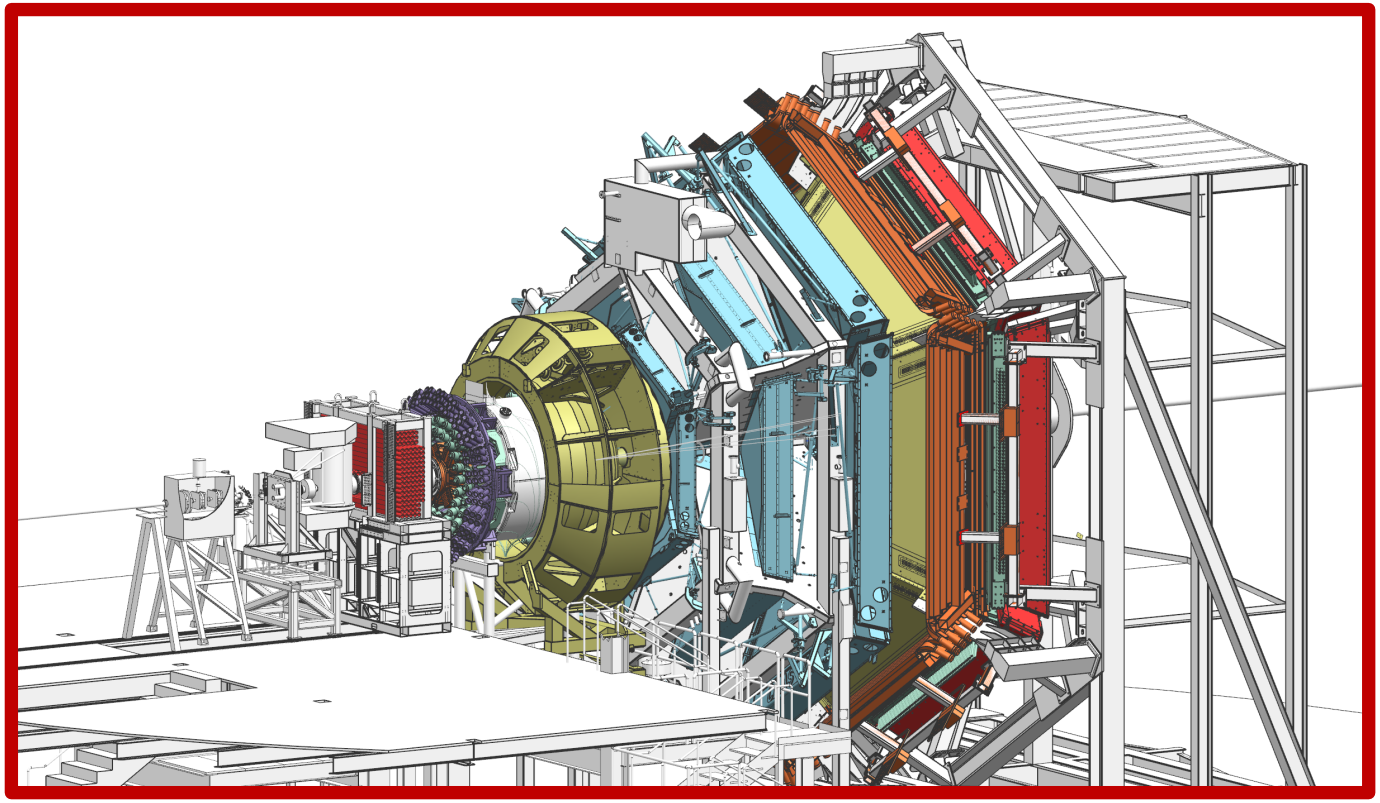
CLAS12 Detector Calibration Status



Daniel S. Carman, June 19, 2019

CLAS12 Run Periods

Run Group A

1) Feb. – May 2018
2) Sep. - Nov. 2018
3) Mar. – Apr. 2019

- 2.2, 6.4, 10.2, 10.6 GeV
- Torus +/- polarity; different settings
- FMT in/out
- LTCC 2/4 boxes (different gas levels)
- Different Central Detector geom.
- Different DC efficiencies (gas gain)

Run Group K

Nov. – Dec. 2018

- 6.5, 7.5 GeV
- FT on/off
- Different luminosities/backgrounds
- LTCC 2 boxes (different gas levels)

Run Group B

Feb. – Mar. 2019

- 10.2, 10.6 GeV
- LTCC 4 boxes
- LD2 target – different backgrounds

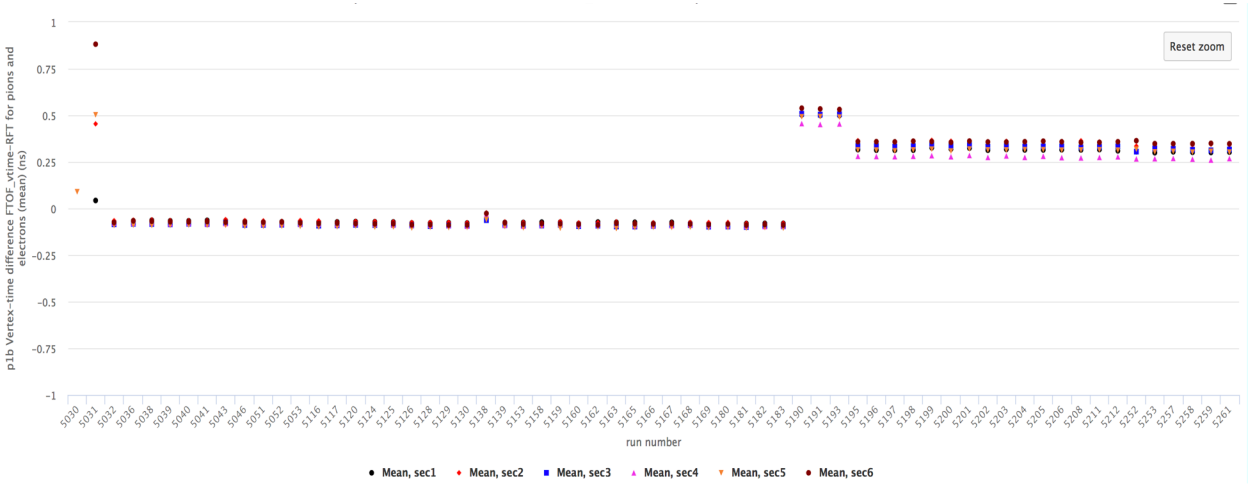
CLAS12 Initial Calibrations

#	Run	Run Group	Torus	Sol	<i> (nA)	E_b (GeV)	Tag	Date
1	3222	A (Spr 18)	+100%	-100%	25	10.6	5.7.4	2/15/18
2	3355	A (Spr 18)	-100%	-100%	35	10.6	5.7.4	2/20/18
3	4013	A (Spr 18)	-100%	-100%	50	10.6	5b.7.1	4/18/18
4	5038	A (Fall 18)	-100%	-100%	45	10.6	6b.2.0	5/31/19
5	5664	A (Fall 18)	+100%	-100%	50	10.6	5.7.4	11/26/18
6	5700	K (Win 18)	+100%	-100%	30	7.5	5b.7.1	11/30/18
7	6164	B (Spr 19)	-100%	-100%	35	10.6	5b.7.7	2/10/19
8	6233	B (Spr 19)	-100%	-100%	35	10.6	5b.7.7	2/25/19
9	6489	B (Spr 19)	-100%	-100%	50	10.6	5b.7.8	3/26/19

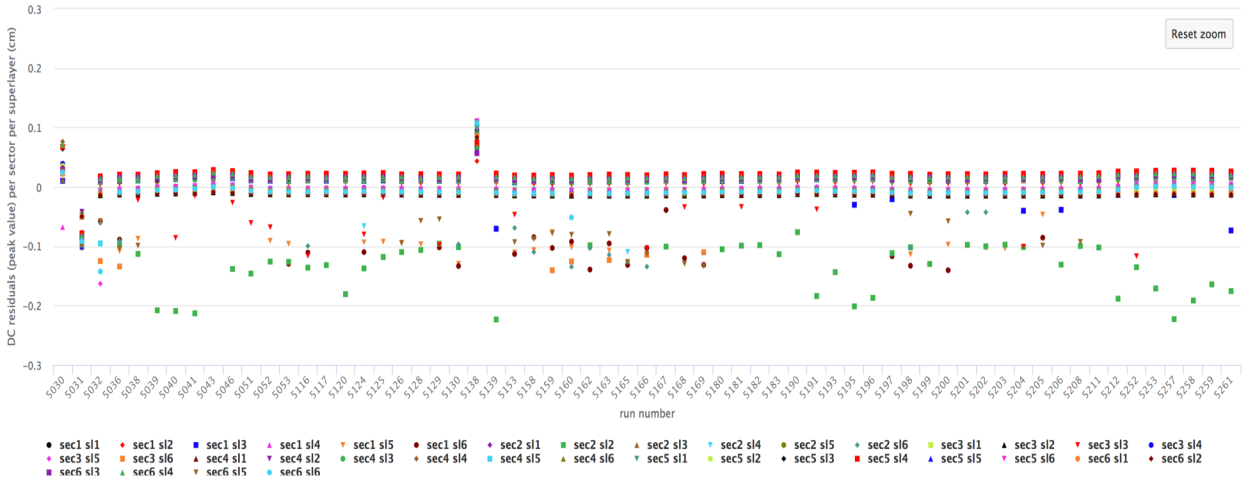
Initial calibrations for all systems for pass-0 cooking

Pass-0 Monitoring

FTOF Vertex Time (ns)



DC Residuals (cm)



https://clas12mon.jlab.org/rga/pass0/v7/tlsummary/

subsystem	variables	link
RF	• $n^{+/-}$ RFtime1 per sector • Electron RFtime1 per sector • Average RFtime difference	timelines
TRIGGER	• Electrons/Protons per trigger per sector • Positives/Negatives/Neutrals per trigger per sector • Muons per trigger per sector • $n^{+/-}$ per trigger per sector • $K^{+/-}$ per trigger per sector	timelines
LTCC	• LTCC Number of Photoelectrons	timelines
HTCC	• Average Number of Photoelectrons per sector • HTCC Number of Photoelectrons	timelines
FTOF	• energy deposit at p1a/p1b for electron/pion • energy deposit at p2 • $mass^2$ at p1a/p1b for $n^{-/+}$/proton (mean/sigma) • time for all (mean/sigma) • time at p1a/p1b for electron/pion (mean/sigma) • time at p2 (mean/sigma)	timelines
FT	• FTH MIPS time, neutral • FTH MIPS energy per layer (Mean) • FTC time - start time, neutrals/charged • FTC pi0 mass	timelines
FORWARD	• VZ (peak value) per sector, positives/negatives/electrons • Average Forward Reconstruction chi2, positives/negatives/electrons	timelines
EC	• $n^{+/-}$ time • $M_{\gamma\gamma}$ • sampling fraction	timelines
DC	• t max per sector per superlayer • DC resuduals (peak value) per sector per superlayer • DC residuals (peak value) per sector	timelines
CVT	• Average vz, positives/negatives • CVT Track Multiplicity • CVT positive/negative track multiplicity • CVT positive/negative track multiplicity per trigger • CVT ndf • CVT chi2/ndf • CVT momentum • CVT transverse momentum • CVT pathlength • Average CVT chi2, positives/negatives/electrons	timelines
CTOF	• energy deposit for n^- • $mass^2$ for $n^{-/+}$ (mean/sigma) • time for neg/pos (mean/sigma) • time_n^- (mean/sigma)	timelines
CND	• CVT z - CND z per layer • CND time per layer • MIPS dE/dz	timelines
CENTRAL	• Protons per trigger • $n^{+/-}$ per trigger • $K^{+/-}$ per trigger	timelines
BMTBST	• BST/BMT layers per track • BST/BMT Occupancy	timelines

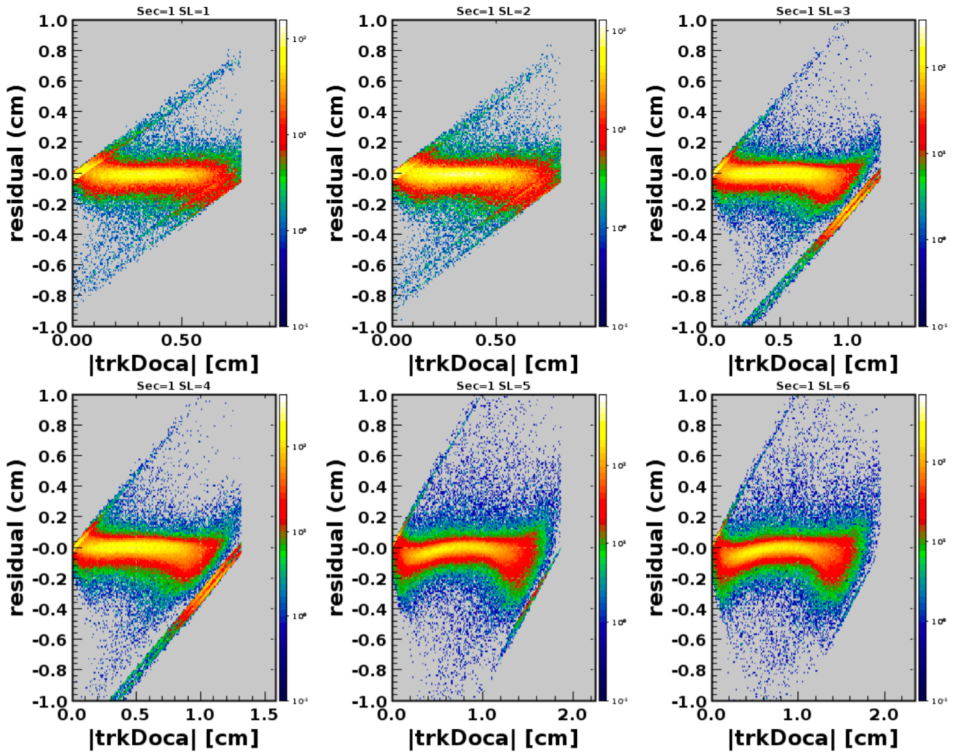
Calibration Improvements

1. Geometry:
   - DC alignment from B=0 data
   - z-shifts: Central Detector (-2 → -3 cm), Forward Carriage (5.5 cm)
2. Data Format:
   - HIPO3 → HIPO4 *(significant speed increase & smaller file size)*
   - Bank variable name changes
3. Reconstruction Code Updates:

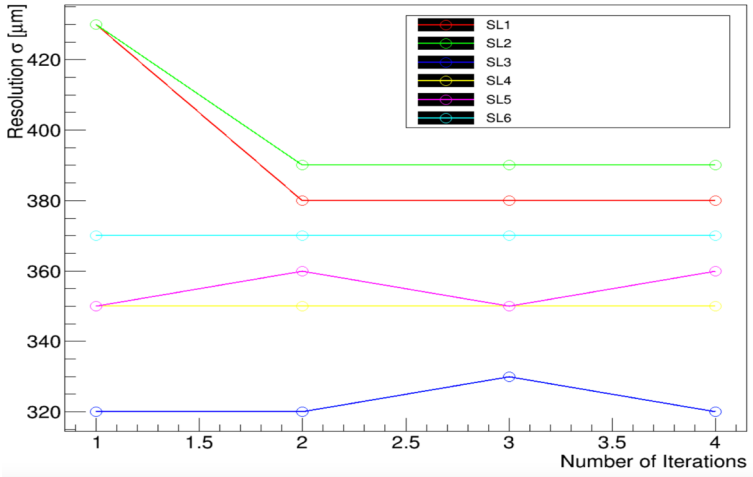
*Updates since 3/19 CLAS meeting

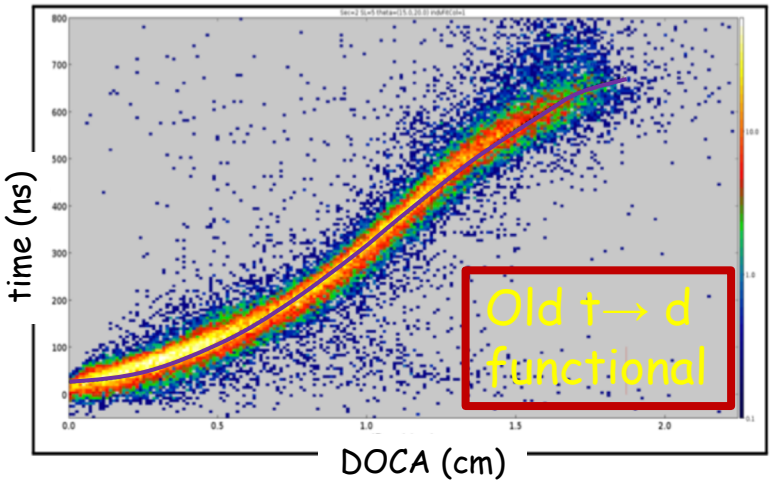
- DC:
  - fix wire sag
  - add complete t→d interpolation tables
  - improve traceback to target and (x,y) beamline
  - improve tracking resolution
- ECAL:
  - improve cluster definition and moments calculation
- FT:
  - add FT-based start time (e in FT, h in FD)
  - FT-Cal TW correction
- TOF:
  - improve FTOF/CTOF track-hit matching algorithm
  - add FTOF TWPOS and CTOF HPOS corrections
  - optimize FTOF hit point definition *(CTOF still to be done)*
  - add FTOF TDC/FADC time matching

DC Calibration Status



"drooping dog-bone"



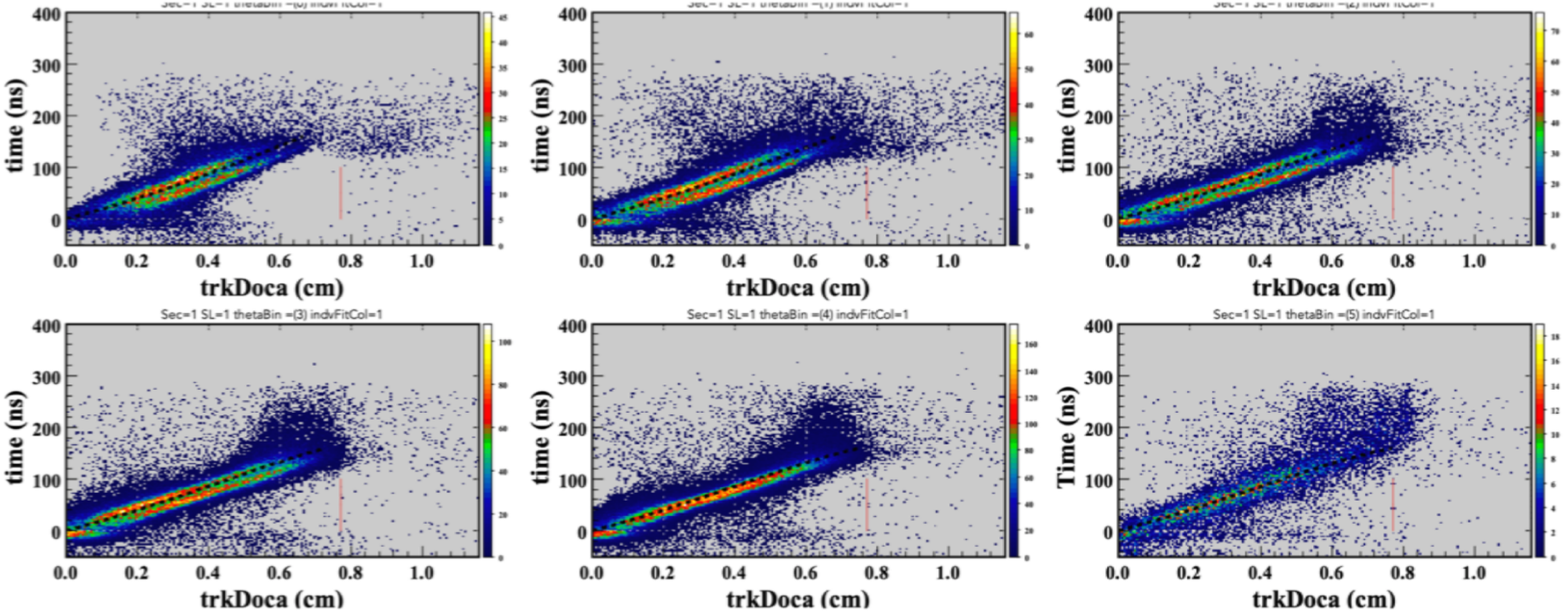


Status and Plans:

- Position resolutions 350-500 μm *(typical)*
- Implement different t→d functional form to better describe data; work in progress
- Understand parameter correlations/limits
- Develop status table for reconstruction and MC matching
- Alignment *(done … for now)*
- Recalibration monitoring metrics defined

DC Calibration Issues

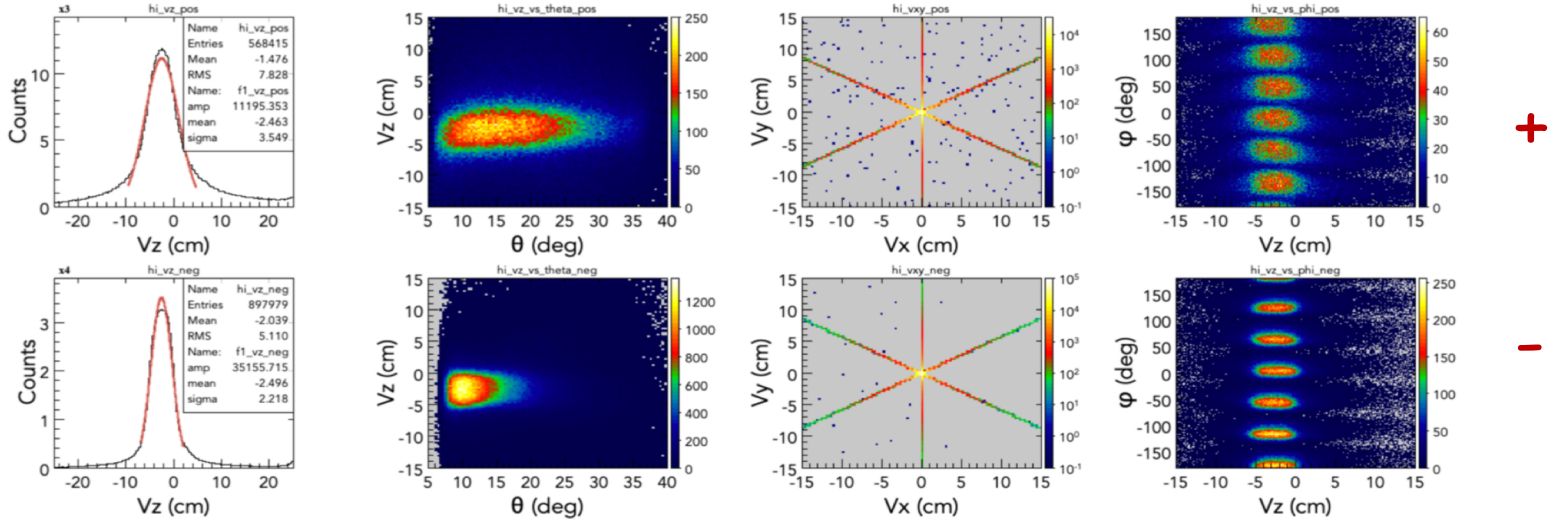
R1 (SL1) drift time vs. track DOCA for different bins in track local angle



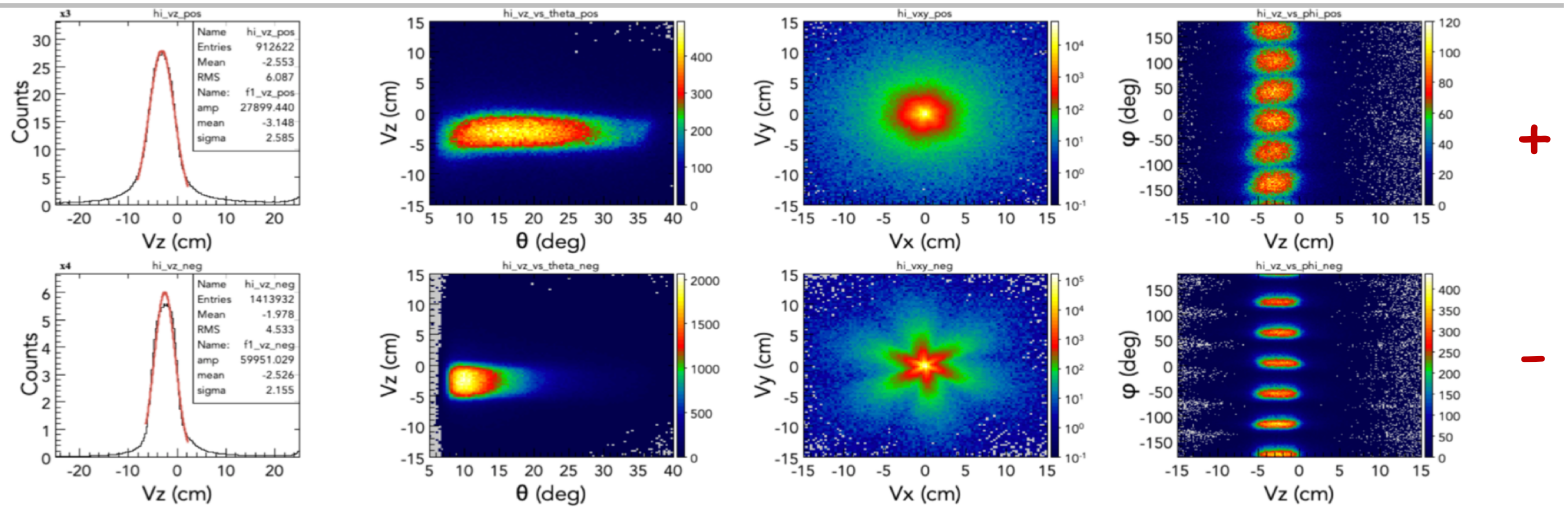
- This effect severely limits the position resolution.
- The effect is biggest in R1 but is also seen at a smaller level in R2.
- This problem has recently been identified and a work-around has been developed to allow the splitting to be removed, but the exact cause(s) are still being investigated.

Forward Tracking Improvements

6b.1.1

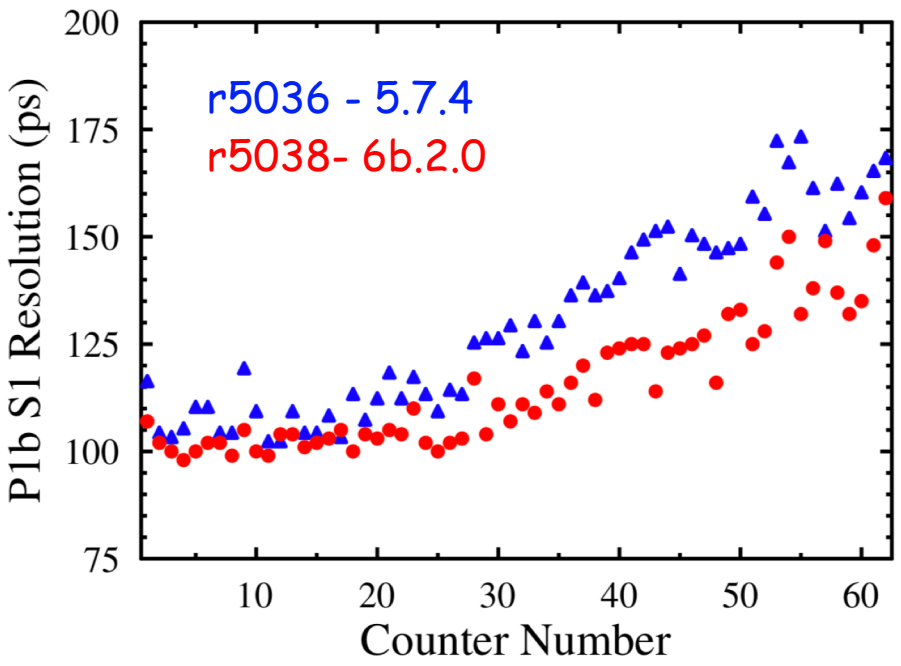


6b.2.0



Improved vertex resolution critical for optimal path length and timing determinations

FTOF Calibration Status



cooked with 5.7.4 – Feb. 2019

cooked with 6b.2.0 – May 2019

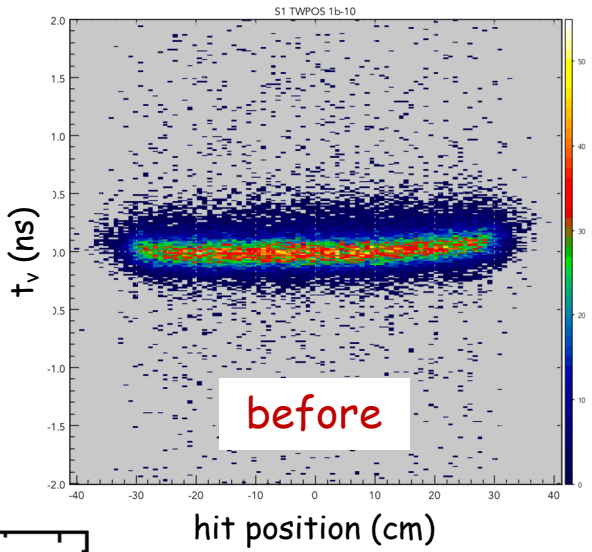
The FTOF timing calibrations have improved since the March 2019 CLAS Collaboration meeting:

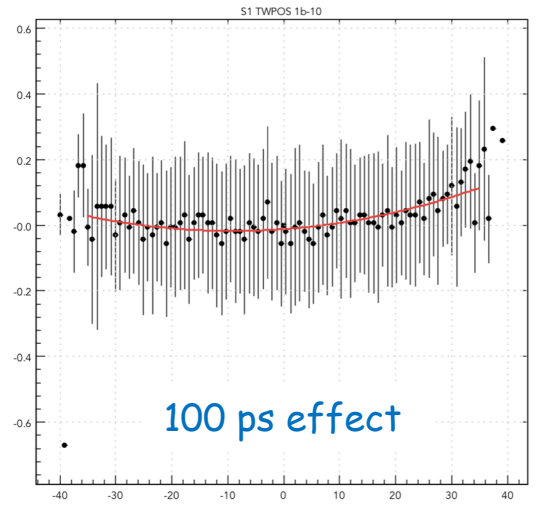
1. Geometry Updates:
   - Included z-offset of Forward Carriage
   - Included z-offset of Central Detector
2. Reconstruction Updates:
   - Improved Kalman Filter to swim back to target
   - Improved algorithm for swimming back to event vertex
   - Included (x,y) offset of beam axis
3. Calibration Suite Updates:
   - Position-dependent time-walk/veff correction

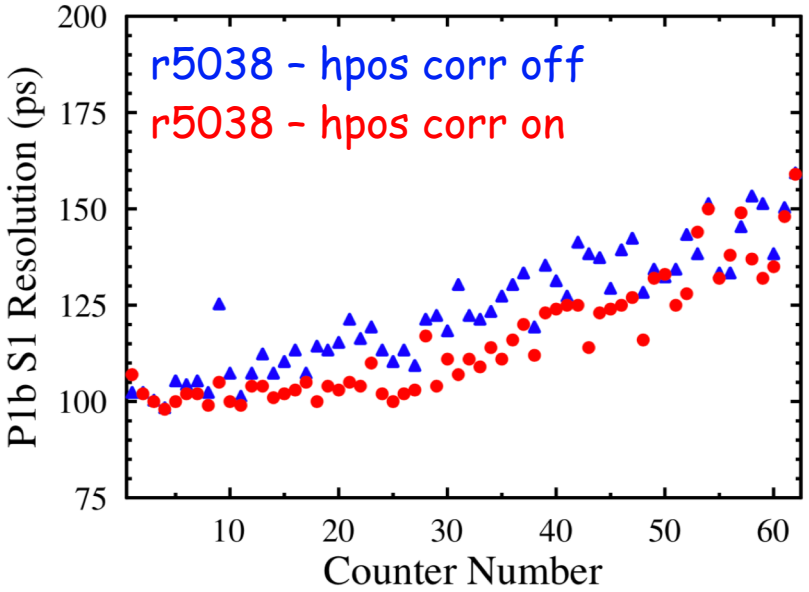
FTOF Calibration Improvements

Calibrations have assumed time walk and veff constants are hit position independent to date.

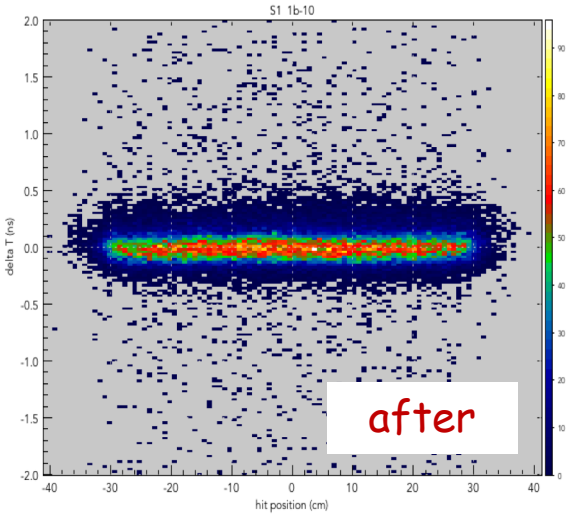
However, they vary and have to be corrected for to optimize timing response.



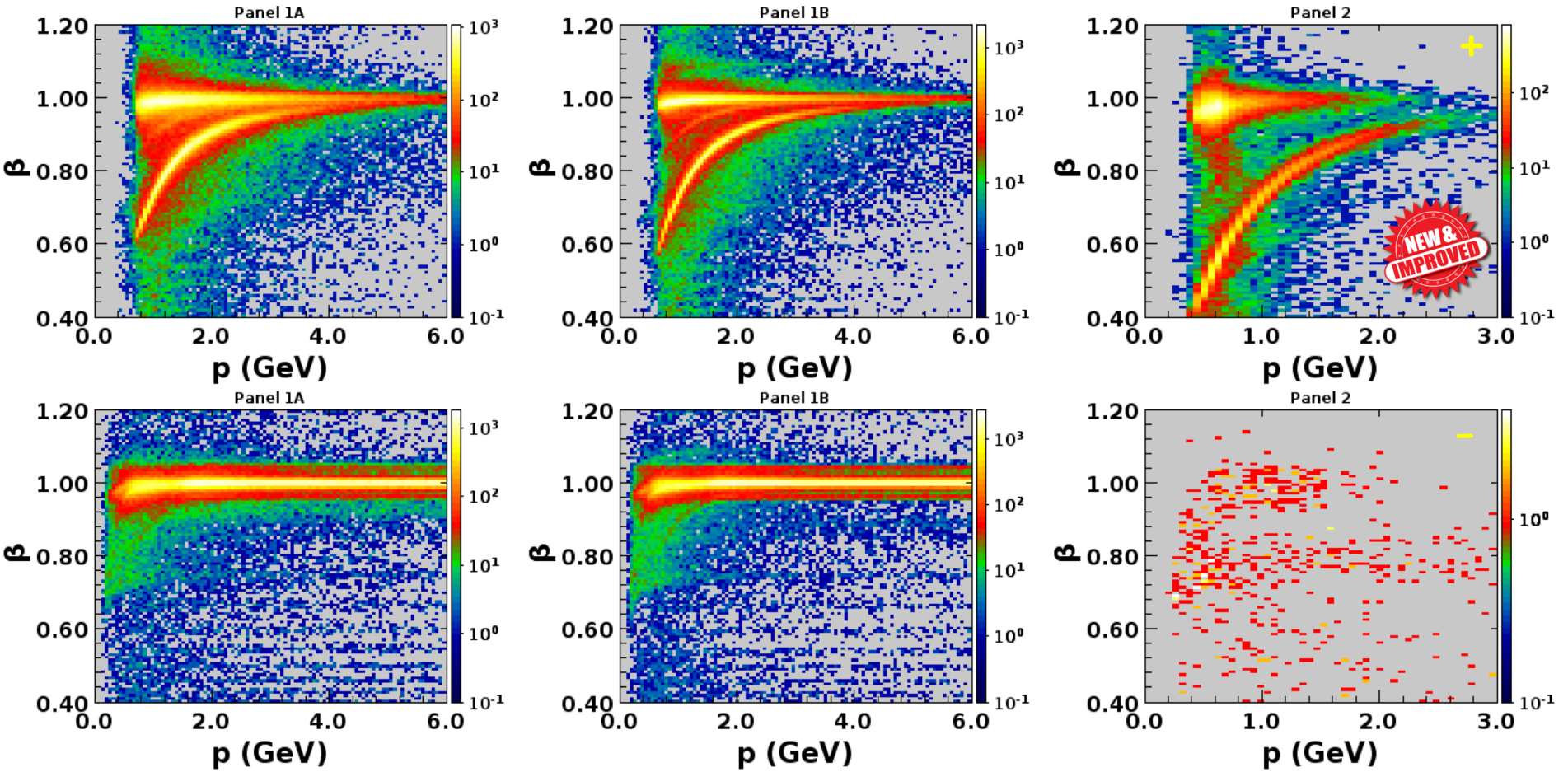




Cooked with 6b.2.0 – May 2019

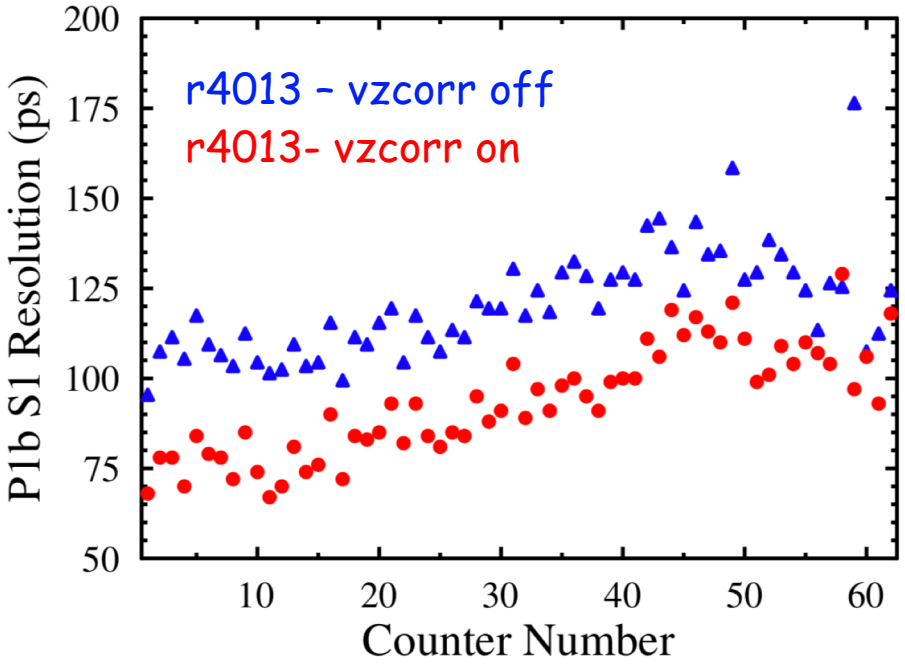


Forward Detector PID



run 5038 cooked with 6b.2.0 – June 2019

FTOF Calibration – What's Left?



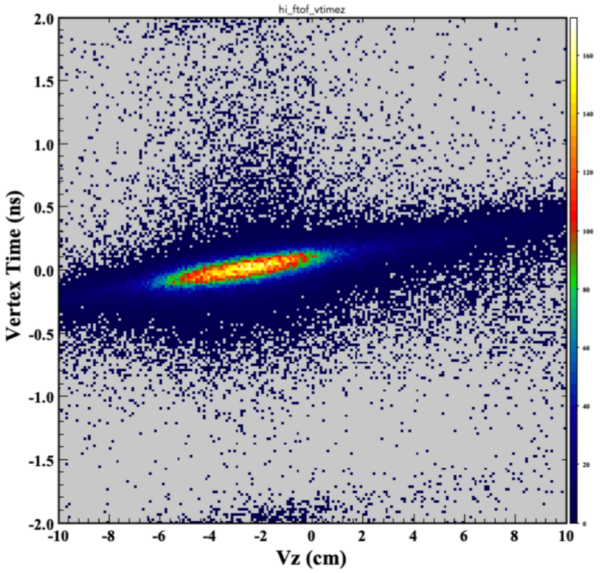
cooked with 5b.5.1 – July 2018

The last major improvement for FTOF timing calibrations to include the vertex correction to the event start time.

- The event ST used for FTOF is given by the time of the RF bucket closest to the trigger particle vertex time
- The RF time is calibrated to give the time of the beam bunch at z=0; Better resolution can be achieved by correcting for the event vertex
- Traditionally this was done using the trigger particle vertex
- This was not possible to consider before recent geometry and forward tracking updates in the current reconstruction release

FTOF PID Status

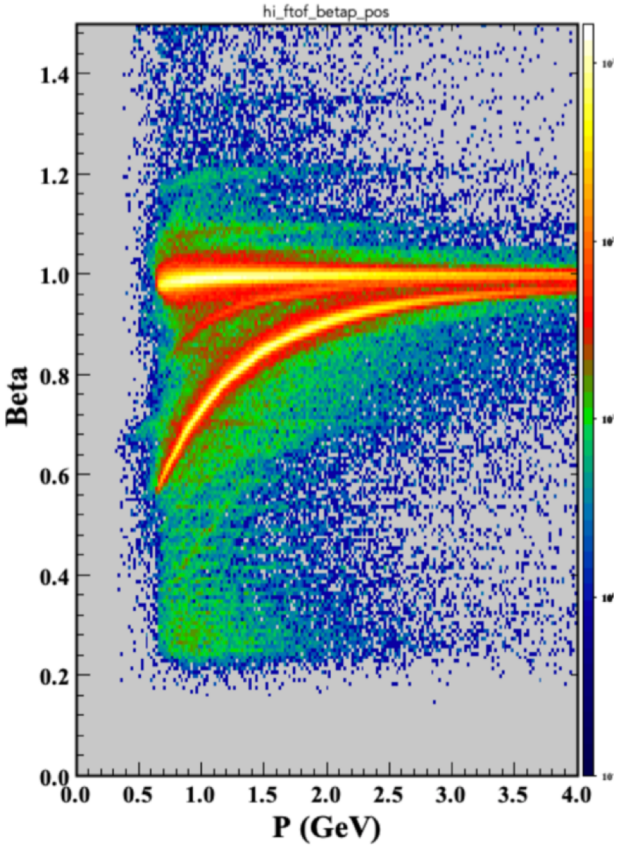
π^- vertex time with no correction



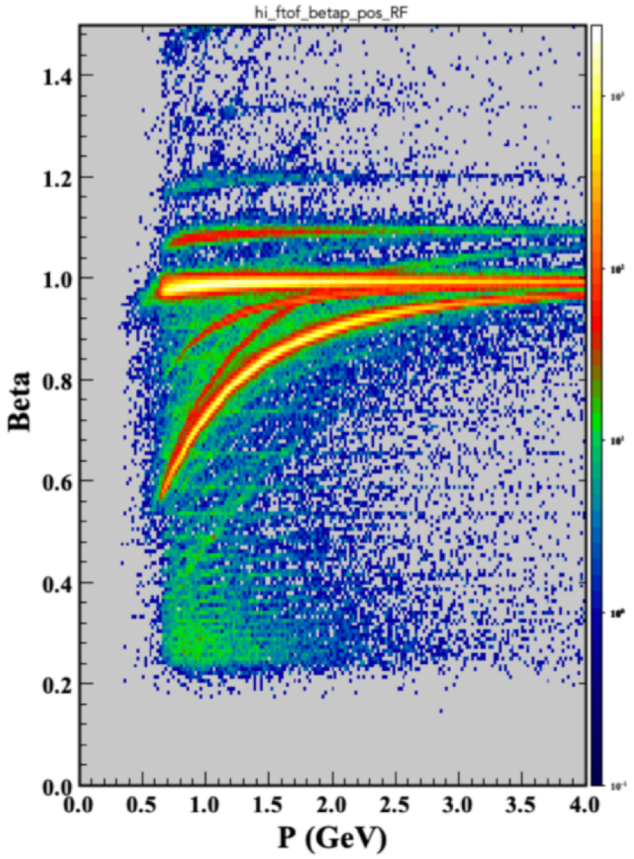
Validation is in progress

This will be updated in the reconstruction and EB soon

no correction

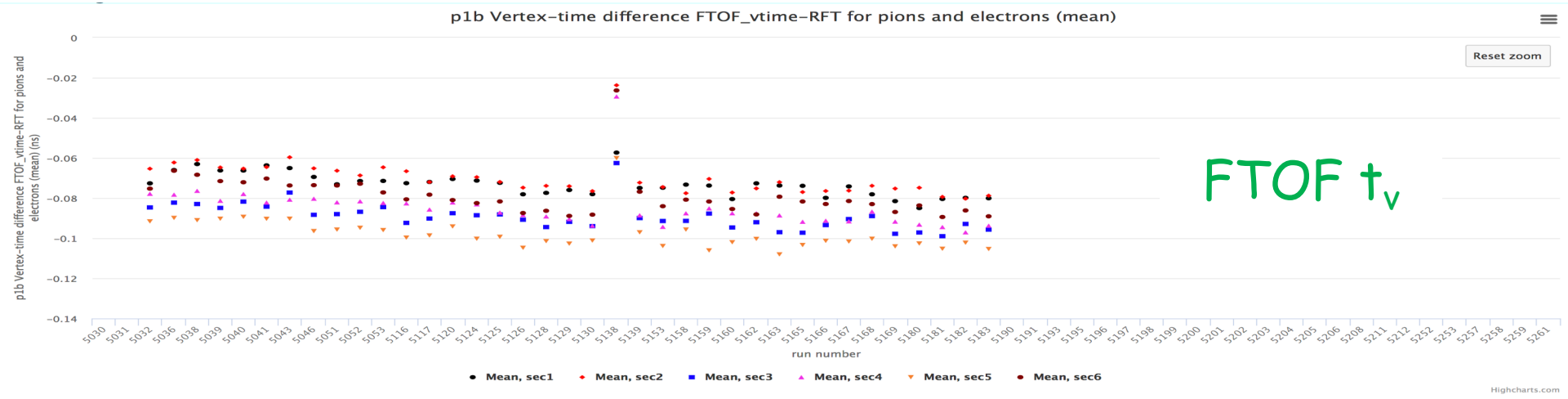


with correction

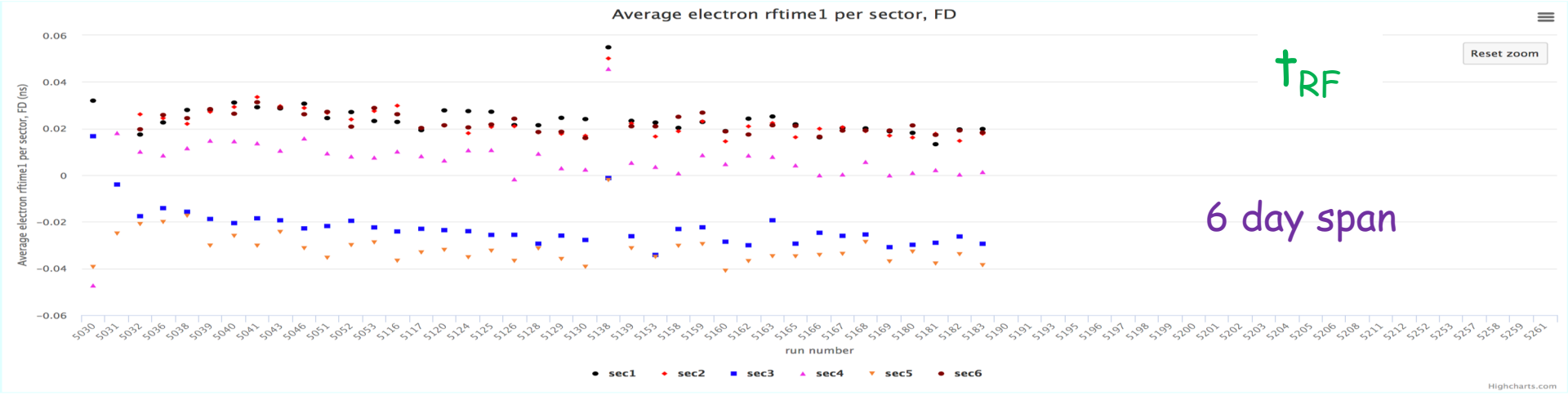


Using a single event vertex to correct the ST for each track gives only marginal improvement; improvement comes only with doing track-by-track corrections

RF Calibrations



FTOF t_v

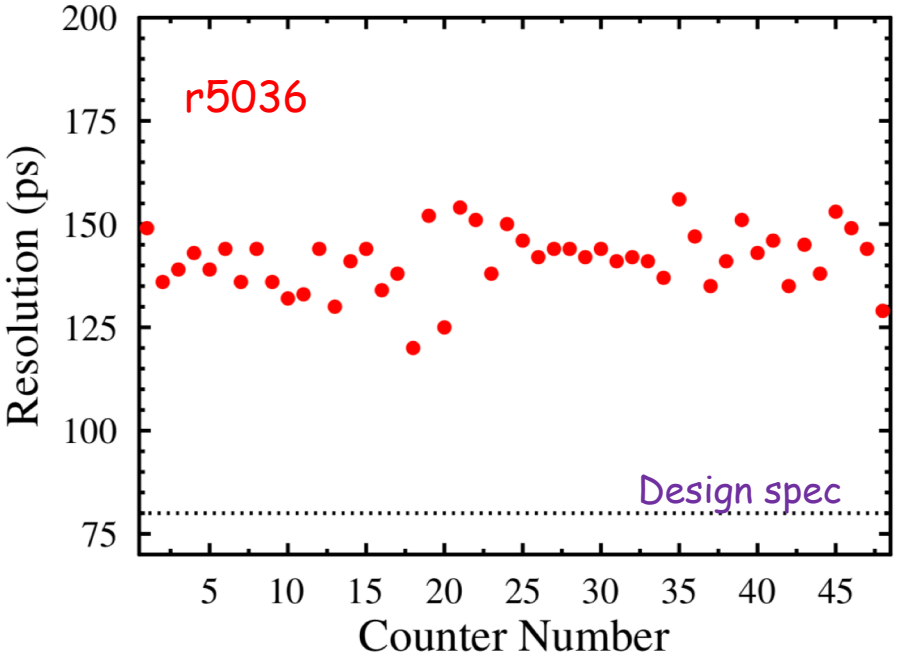


t_{RF}

6 day span

Run-by-run RF calibrations will be required due to slow drift with time

CTOF Calibration Status



Cooked with 5.7.4 – Feb. 2019

The issues have largely been resolved, but work is still ongoing to further optimize

CTOF calibration has consistently resulted in average timing resolutions per counter of $\langle \delta t \rangle$ = 140 ps

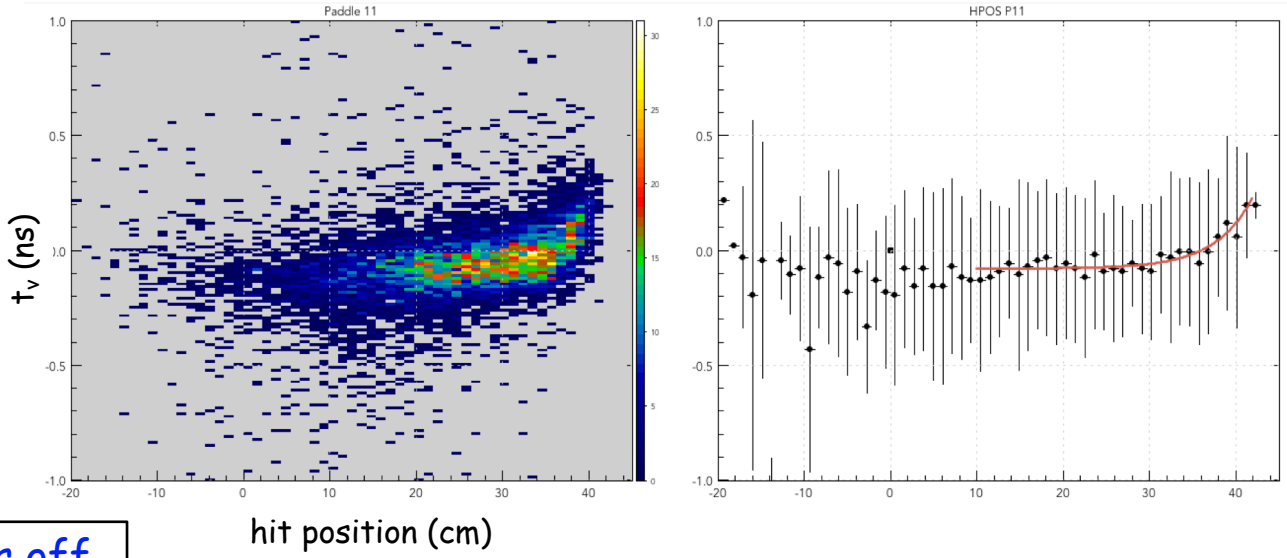
→ significantly worse than design spec!
What is going on??

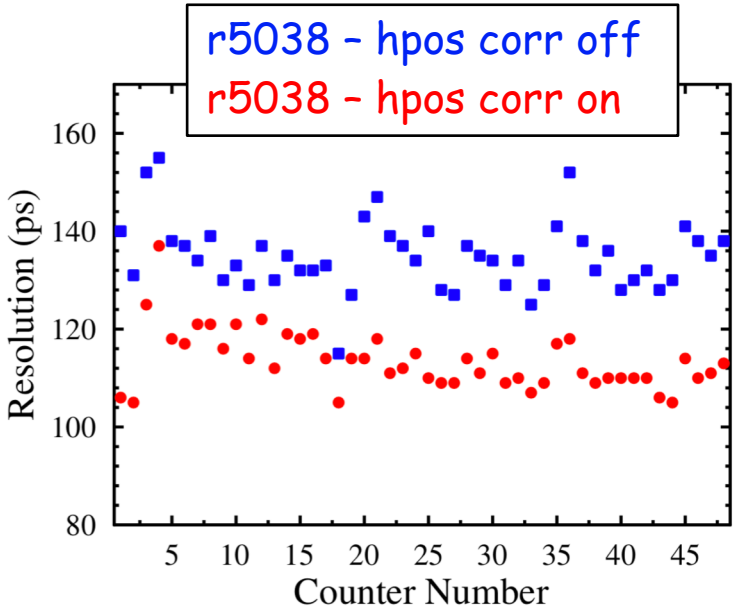
The curved ends of the counters

1. Reconstruction not handling shape of counters properly
2. Imprecise definition of hit end point
3. Response at downstream end of bar not well calibrated
4. Lack of vertex correction (àla FTOF)

CTOF Calibration Improvements

CTOF vertex time vs. hit position along the bar

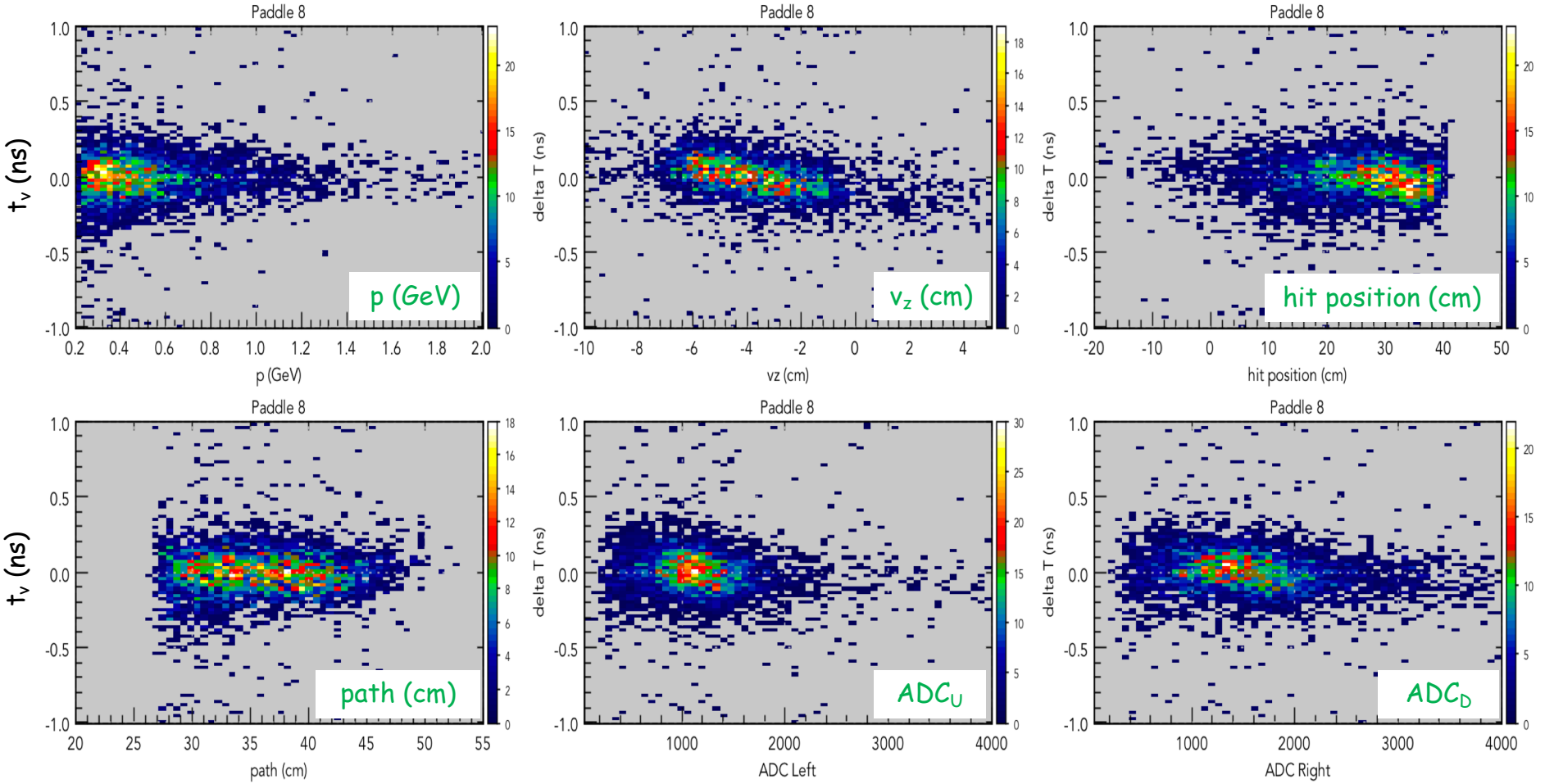




Cooked with 6b.1.1 – May 2019

- Tracks at the downstream end of the bar can also go into the Acrylic light guides and generate Cherenkov light that causes problems with veff calibration
- Incorporate a position-dependent fit to remove this calibration effect

CTOF Calibration Status

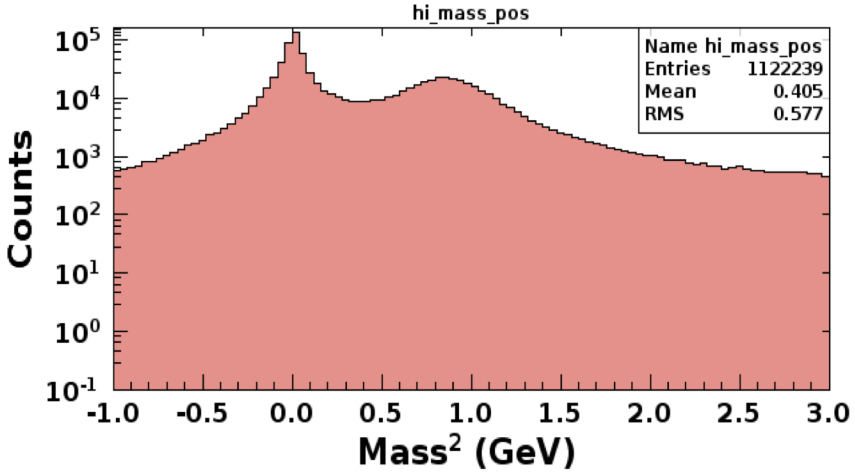


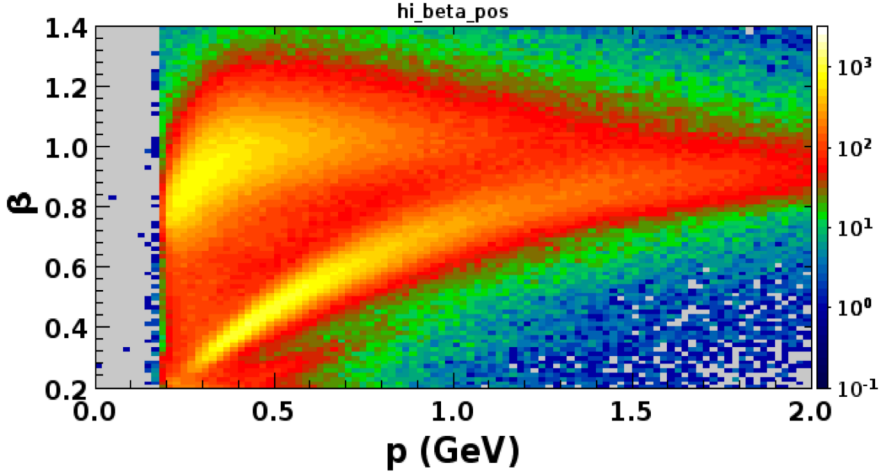
Remaining correction is correlation with vertex position as ST is not yet corrected for the reaction vertex

6b.2.0
run 5038

Central Detector PID

+





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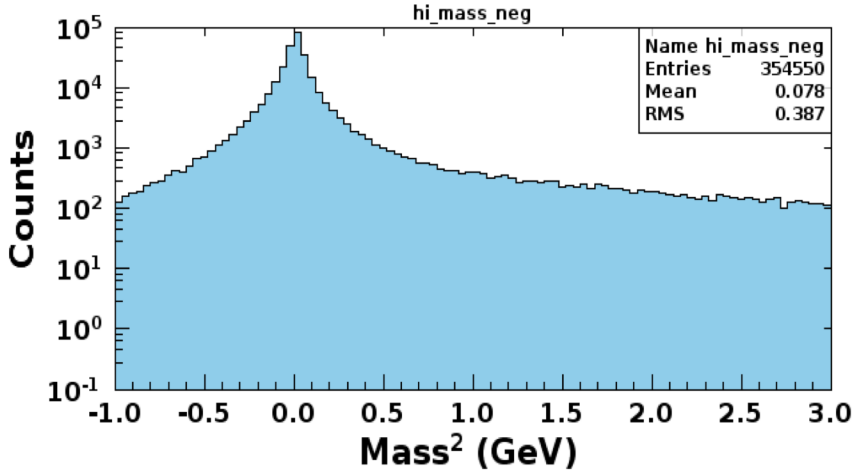
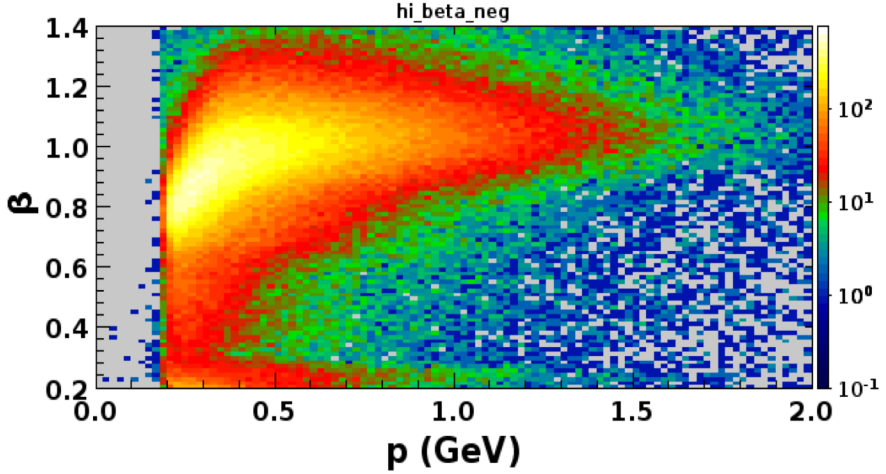
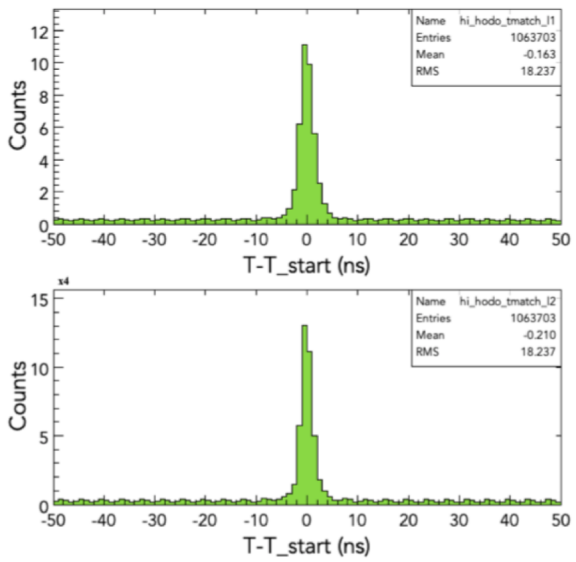


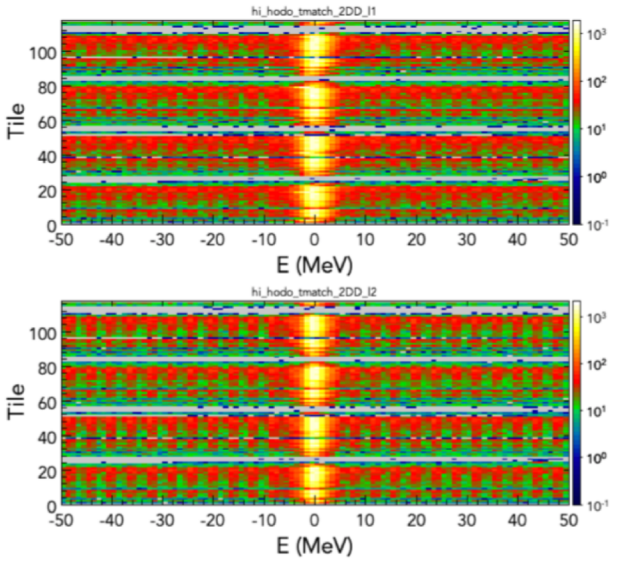


run 5038 cooked with 6b.2.0 – June 2019

FT Calibration Status

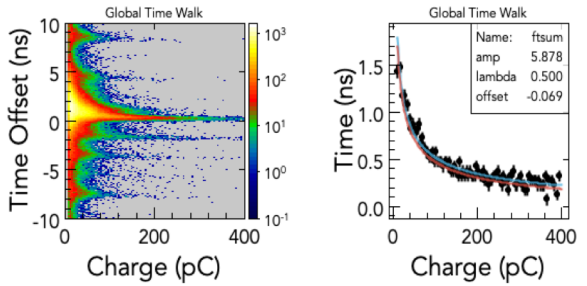
- FT-Hodo:
  - energy and timing within specs

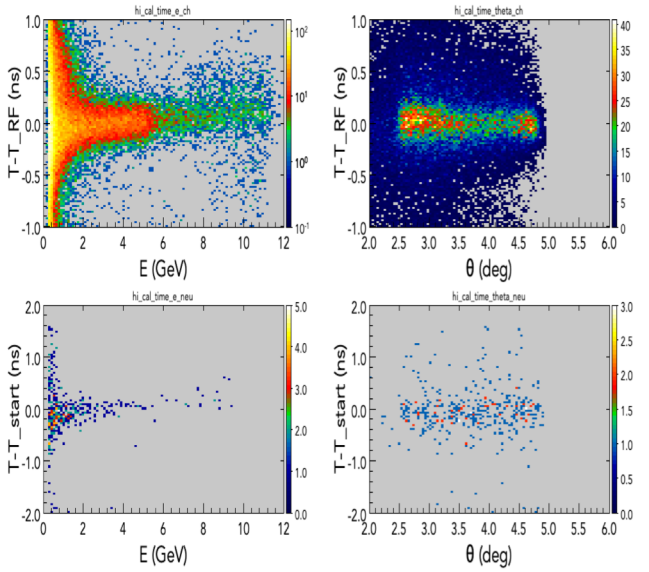




- FT-Cal:
  - timing now includes TW correction
  - tuning of energy calibration in progress

run 5038

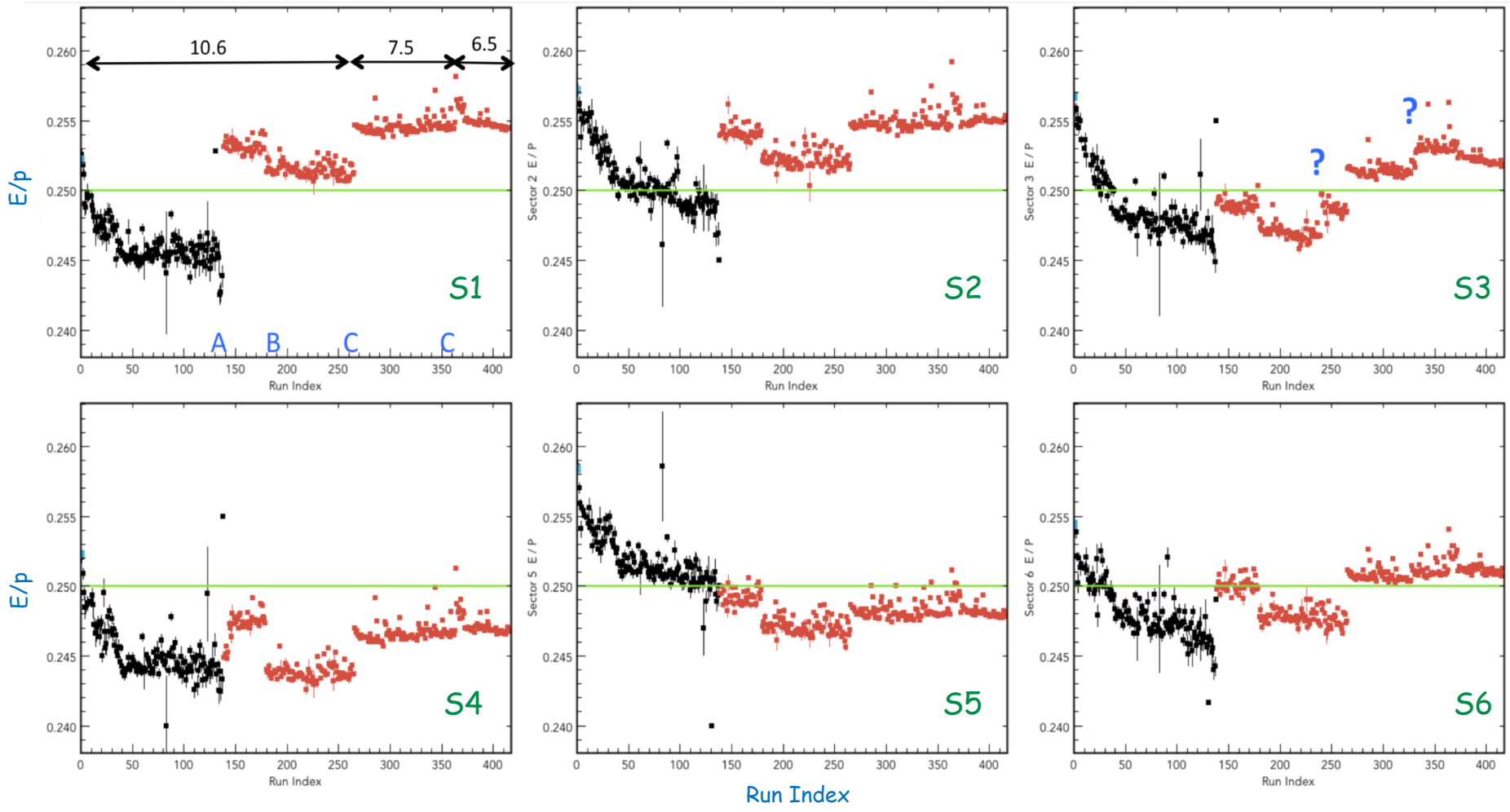




ECAL Calibration Timeline

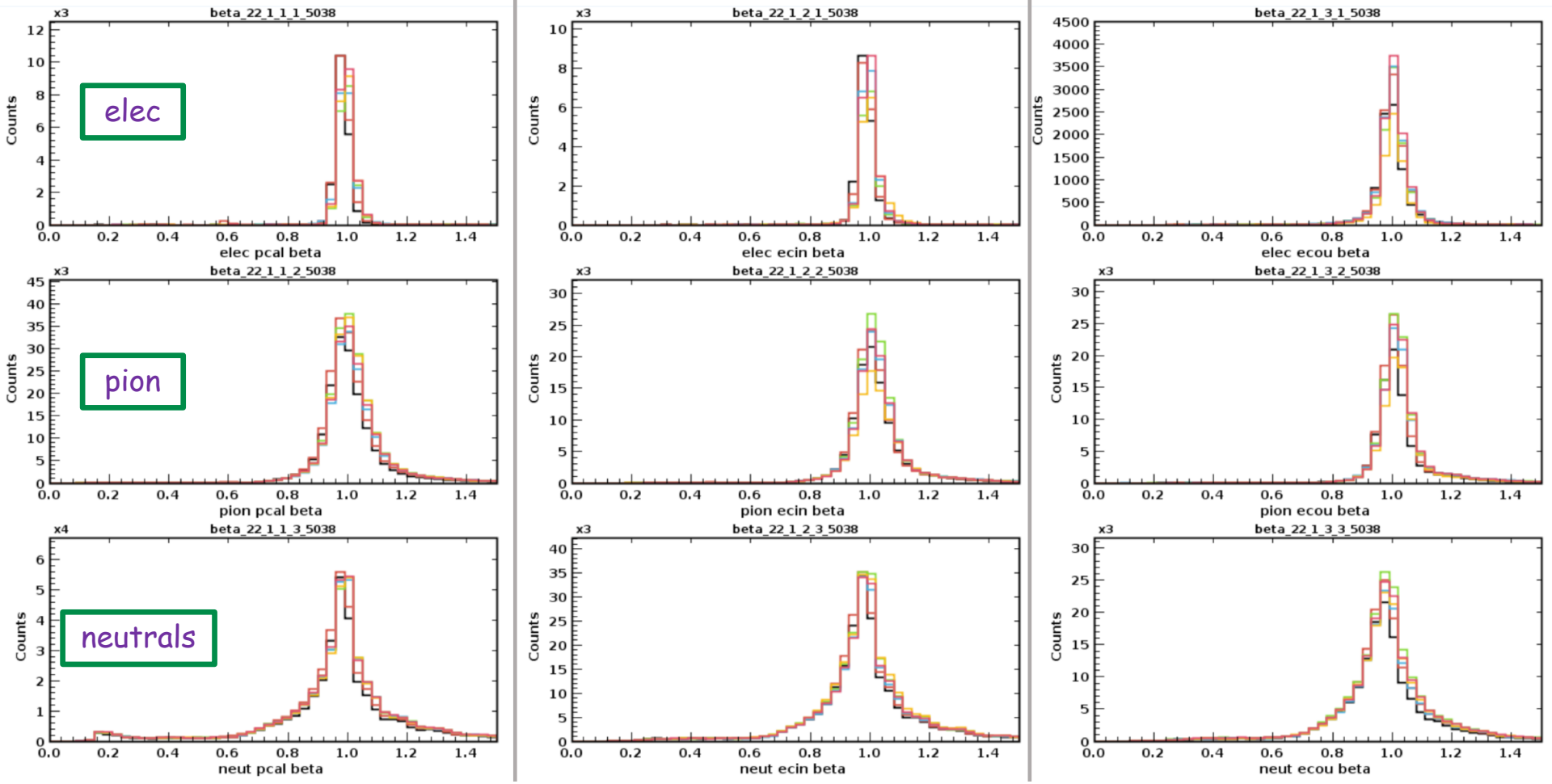
A: torus polarity change
B: Halo reduction effort
C: Beam energy change

RG-A fall 2018 sampling fraction timeline



ECAL Calibration Status

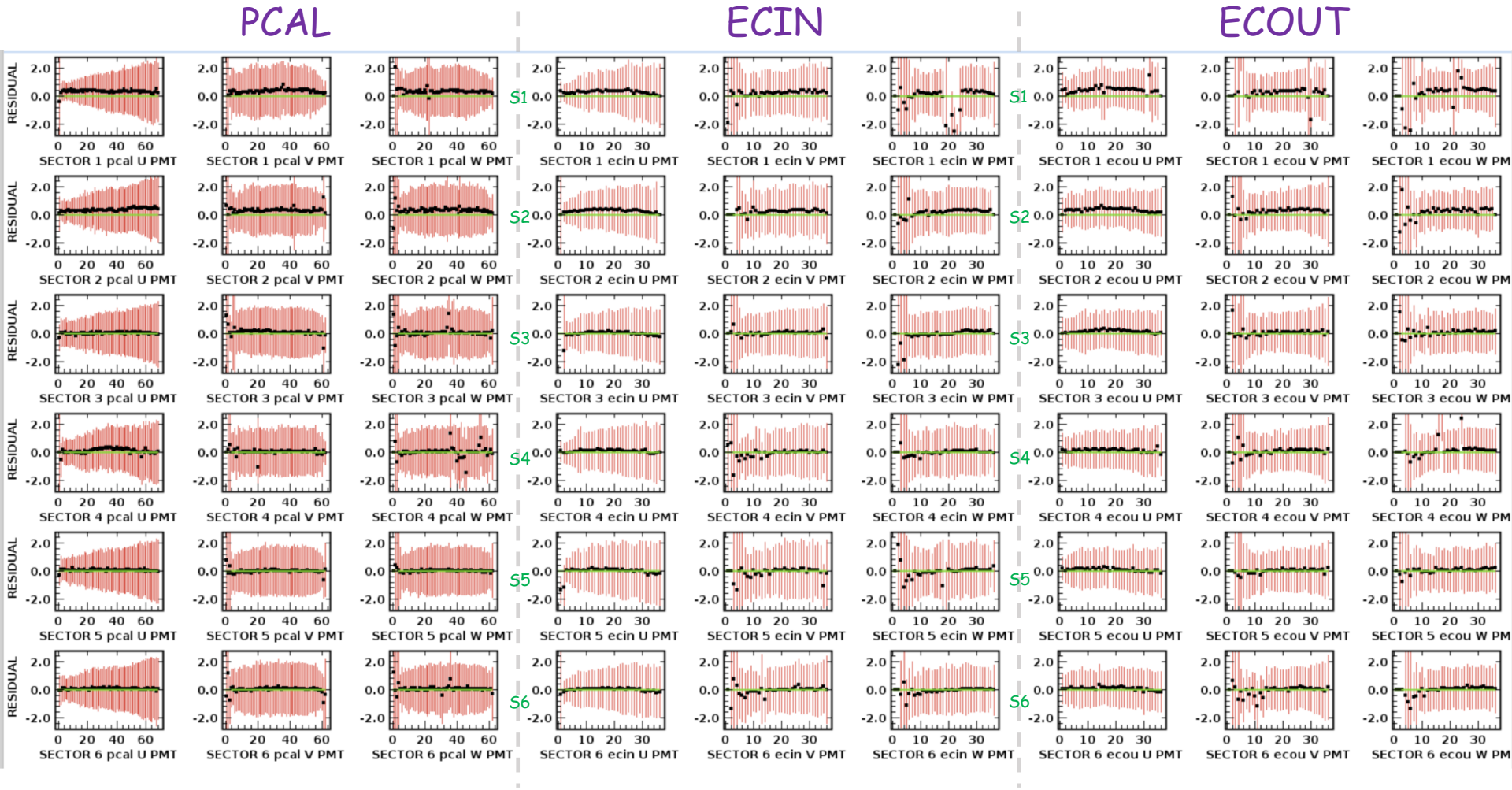
β distributions seem relatively immune to sampling fraction changes



run 5038

ECAL Calibration Status

Tracking timing calibration through timing residuals



run 5038

Remaining Calibration Work

Short term
Longer term

- DC:
  - Change to new t → d function to improve flexibility
  - Complete fix to split time bands
- ECAL:
  - Complete studies of long-term energy calibration drift
  - Understand systematics in MIP peak position (e.g. vs. torus polarity)
  - Develop PMT gain corrections to account for loss with time
  - Develop new timing calibration scheme and implement into calibrations
  - Understand systematics in timing vs. PID, path length, geom
- FTOF:
  - Include vertex correction to ST time
  - Understand systematics in MIP peak position (e.g. vs. torus polarity)
- CTOF:
  - Include vertex correction to ST (using optimal vertex)
  - Correct counter hit point definition

Remaining Calibration Work

Short term
Longer term

- FT:
  - CAL: Refine fitting procedure for energy calibration
  - HODO: Address small bias in fits to ΔE
  - TRK: Reconstruction code development underway
- CVT:
  - Complete alignment work

See today's update

- CND:
  - Complete neutron detection efficiency studies
  - Finalize charged particle veto scheme
- BAND:
  - Complete neutron detection efficiency studies

} See tomorrow's updates

- RICH:
  - Complete development of PID scheme and implement in Event Builder
  - Complete alignment work

See yesterday's update

- LTCC:
  - No timing calibration – need code development

See today's update

Performance Status

System	Spec	Achieved	Spec	Achieved
BAND	$\langle eff_n \rangle$ = 35%	TBD	δt < 300 ps	TBD
CND	$\langle eff_n \rangle$ = 10%	9%	δt = 150 ps	150 ps
CTOF	δt = 65 ps	110 ps		
DC	δx = 250 – 400 μm	350 – 500 μm		
ECAL	$\sigma_E/E = 10\%/\sqrt{E}$	$10\%/\sqrt{E}$	δt < 500 ps	< 600 ps
FT	$\sigma_E/E < 2\%/\sqrt{E} + 1\%$	$3.3\%/\sqrt{E}$	δt < 300 ps	< 150 ps
FTOF	60 – 100 ps (p1b)	100 – 150 ps (p1b)	90 – 160 ps (p1a)	110 – 250 ps (p1a)
HTCC	eff_π < 1%	< 1%	$\langle nphe \rangle$ = 16	16
LTCC	eff = 90%	TBD	δt = 1 ns	TBD
RICH	δt < 1 ns	0.7 ns	π/K rej > 500	TBD
SVT	S/N > 10	~15	δx = 50 – 65 μm	~75 μm

**Entries highlighted in red have not yet met spec's*

Concluding Remarks

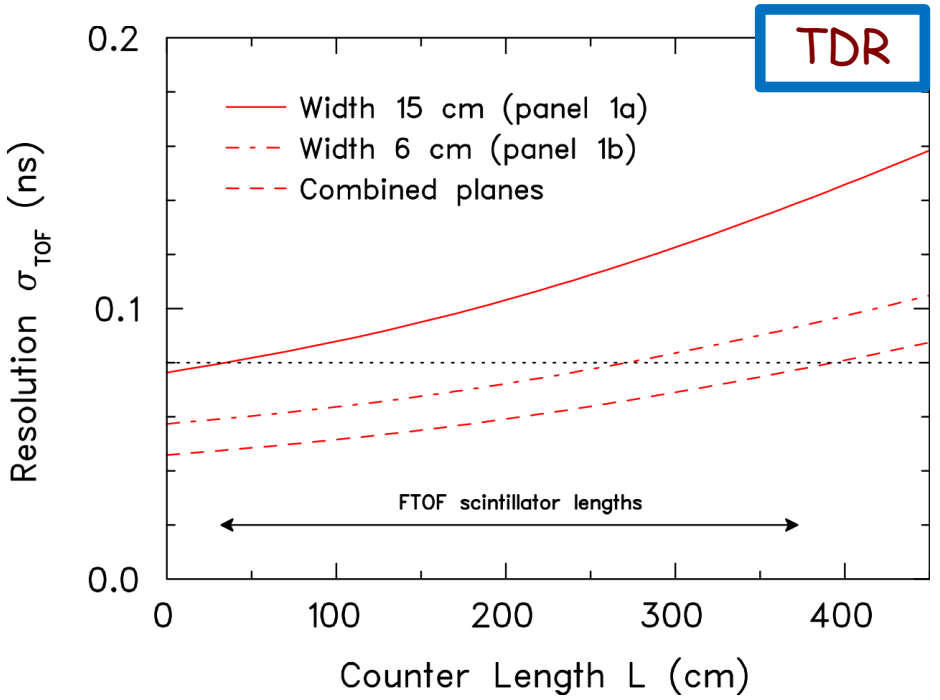
- This presentation has focused on the main systems for charged particle identification as these are most critical for data processing.
  - Updates on BAND, CND, CVT, LTCC, and RICH reconstruction, calibrations, and progress are reported in other presentations at this meeting
- The calibration suites for all subsystems are well advanced
  - Development work continues (optimization and fine-tuning in most cases)
- Initial calibrations have been completed for all subsystems
  - Pass-0 studies are in progress and are being used with the available monitoring tools to determine when calibrations need to be redone
  - Subsystems have developed recalibration metrics that will be used to determine when to recalibrate
- Limitations of calibrations toward achieving design specs being investigated
  - Most issues understood and work plans to overcome them in progress
  - Issue with selection of RF period (2.004 ns vs. 4.008 ns) an issue
  - Working closely with Software Coordinator, Software Group, and the RG-A, RG-B, and RG-K Analysis Coordinators to make progress

BACKUP SLIDES

Optimizing FTOF Time Resolution

Combine the measured times from the FTOF panel-1a and panel-1b to optimize the resolution

$$t_{corr} = \frac{\dfrac{t_{1b}^{cluster}}{\delta_{1b}} + \dfrac{(t_{1a}^{cluster} - \Delta r/\beta)}{\delta_{1a}}}{\left(\dfrac{1}{\delta_{1b}} + \dfrac{1}{\delta_{1a}}\right)}$$



Algorithms for cluster > 1:

- *use hit with t_{min}*
- *use hit with E_{max}*
- *use weighted average*

Upgrade to future EB PID

GEMC Studies with cluster=1

(20% gain)	e	p	π^+	π^-
FTOF 1a	152 ps	164 ps	160 ps	151 ps
FTOF 1b	62 ps	67 ps	65 ps	61 ps
FTOF 1a+1b	49 ps	54 ps	54 ps	51 ps

CLAS12 Calibration Sequence

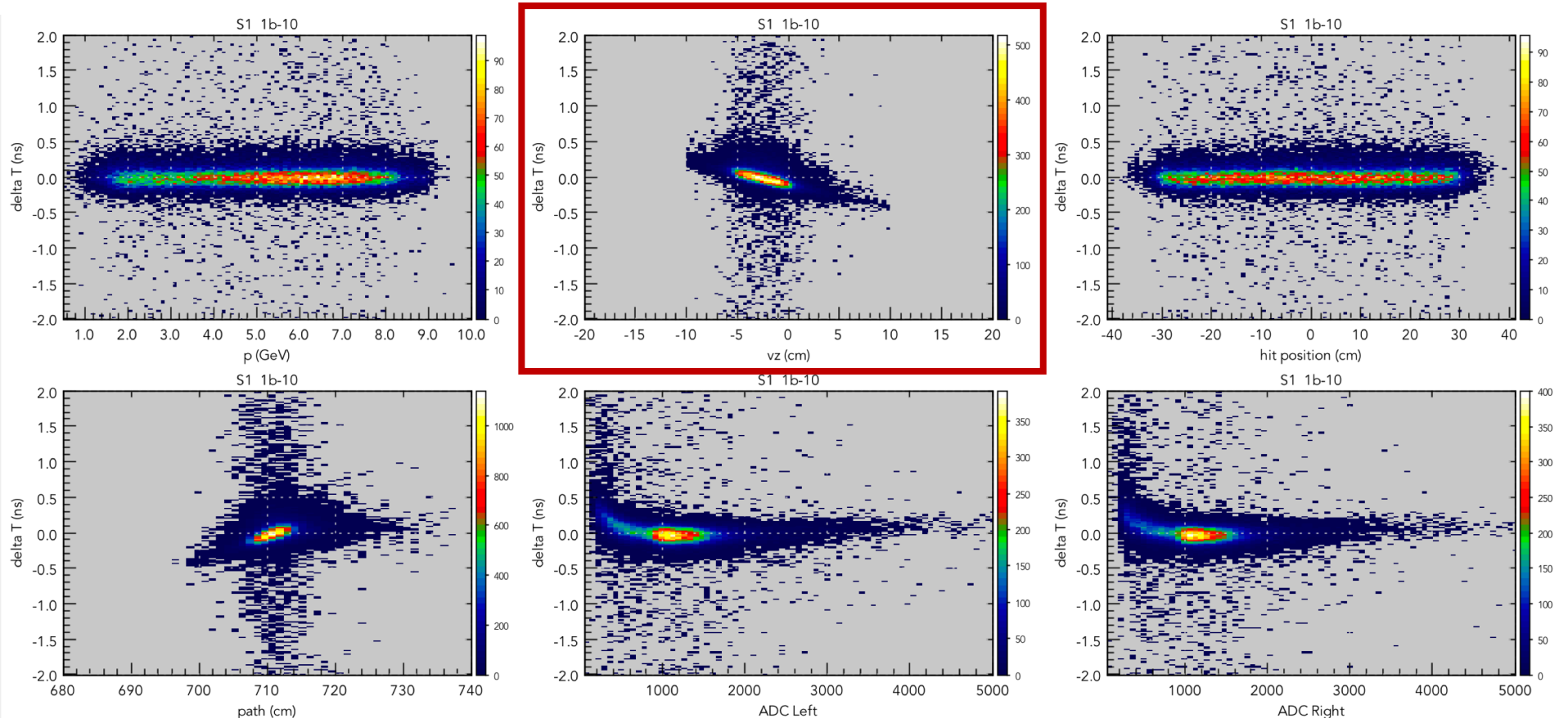
1) DC (+ FTOF Time Matching) Calibration:
   - time → distance calibration
     - relies on at least crude ST calibration from FTOF (few ns level)
     - calibrate offset between FTOF FADC and TDC time

2) FTOF (+ CTOF Time Matching) Calibration:
   - energy calibration
     - can be done before DC calibration using even crude DC calibration parameters for path length corrections
   - timing calibration
     - calibrate FTOF timing; employs PID from EB (requires initial FTOF calib)
     - defines event ST using electron in ECAL (1st option), positron in ECAL (2nd option), high momentum pion in DC/FTOF (3rd option)
     - calibrate offset between CTOF FADC and TDC time

3) CLAS12 Subsystem Calibration:
   - CND, CTOF, ECAL, FT (Hodo, Cal), HTCC, LTCC, RICH calibrations
     - timing calibration employs event ST from FTOF; employs PID from EB (requires initial CTOF calib)
     - energy calibration employs PID from EB

4) RF Calibration:
   - Capture overall RF timing shifts run-by-run

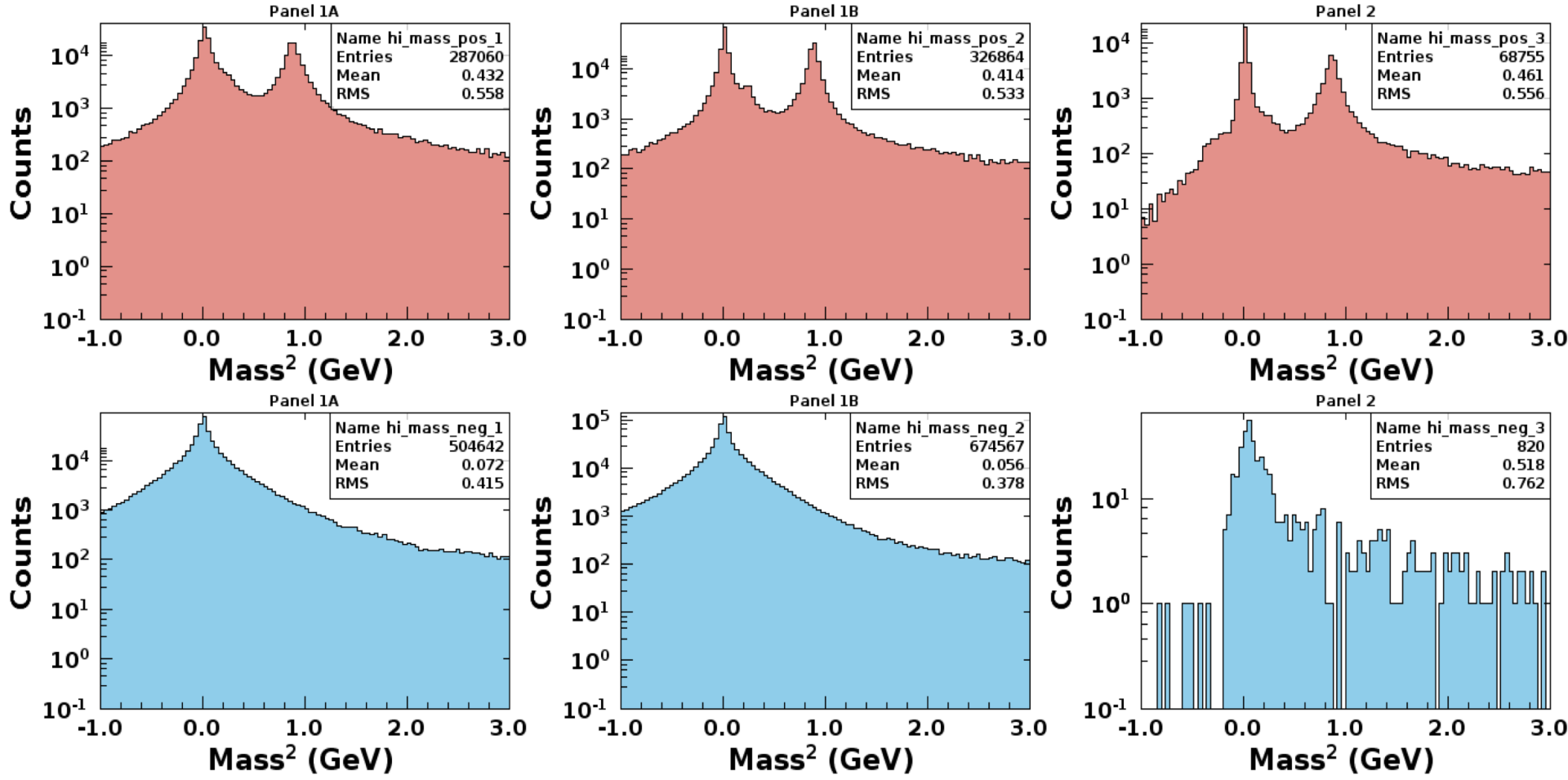
FTOF Calibration Status



run 5038

Remaining correlation with vertex position as ST is not yet corrected for the reaction vertex

Forward Detector PID



run 5038 cooked with 6b.2.0 – June 2019

Subsystem Recalibration Criteria

Subsystem	Recalibration Criteria
CND	Timing: $\langle\Delta t\rangle$ > 165 ps
	Gains: <gain shift> > 10%
DC	T_{max} > ±5 ns / ±20 ns (partial /full)
ECAL	Timing: var(δt) > 300 ps
	Gain: <gain shift> > 5%, var(G) < 5%
FT	CAL energy: $\sigma(\pi^0$ mass) > 20% or 2-3 MeV shift
	CAL timing: <resolution> worsens by 10%
	HODO energy: MIP peak position shifts by > 0.2 MeV
	HODO timing: <resolution> worsens by 10%
TOF	Gains: <gain shift> > 10%
	Timing: $\langle\Delta t\rangle$ > 170 ps (p1a), > 90 ps (p1b), > 88 ps (CTOF)

IN PROGRESS

1) recalibrations required after readout or HV changes
2) RF calibrated run-by-run
3) HTCC, LTCC, RICH : TBD

Run Group A/K – Calibration Team

Subsystem	Group Leader	RG-A/K Calibrator(s)
BAND	Larry Weinstein	Florian Hauenstein, Efrain Segarra, Reynier Cruz Torres
CND	Silvia Niccolai	Pierre Chatagnon
CTOF	Daniel S. Carman	Chan Kim
DC	Mac Mestayer	Dilini Bulumulla, Taya Chetry, Shirsendu Nanda
ECAL	Cole Smith	Cole Smith/Joshua Artem Tan
FT	Raffaella De Vita	Raffaella De Vita, Nick Zachariou
FTOF	Daniel S. Carman	Christopher McLauchlin
HTCC	Youri Sharabian	Nick Markov, Will Phelps
LTCC	Maurizio Ungaro	Maurizio Ungaro
MVT	Maxime Defurne	Maxime Defurne, Guillaume Christiaens
RF	Raffaella De Vita	Jose Carvajal
RICH	Marco Contalbrigo	Marco Contalbrigo, Andrey Kim
SVT	Yuri Gotra	Yuri Gotra

Run Group B – Calibration Team

Subsystem	Group Leader	Calibrator(s)
BAND	Larry Weinstein	Florian Hauenstein, Efrain Segarra, Reynier Cruz Torres
CND	Silvia Niccolai	Paul Naidoo
CTOF	Daniel S. Carman	Achyut Khanal
DC	Mac Mestayer	Dilini Bulumulla, Taya Chetry, Shirsendu Nanda
ECAL	Cole Smith	Cole Smith, Susan Schadmand
FT	Raffaella De Vita	Raffaella De Vita, Nick Zachariou, Susan Schadmand, Alessandra Filippi
FTOF	Daniel S. Carman	Jose Carvajal
HTCC	Youri Sharabian	Isabella Illari
LTCC	Maurizio Ungaro	Maurizio Ungaro
MVT	Maxime Defurne	Maxime Defurne, Gerry Gilfoyle
RF	Raffaella De Vita	Jose Carvajal
RICH	Marco Contalbrigo	Hyon-Suk Jo
SVT	Yuri Gotra	Yuri Gotra