CLAS12 Reconstruction Status

V.Ziegler

CLAS12 Collaboration meeting

March 24, 2020

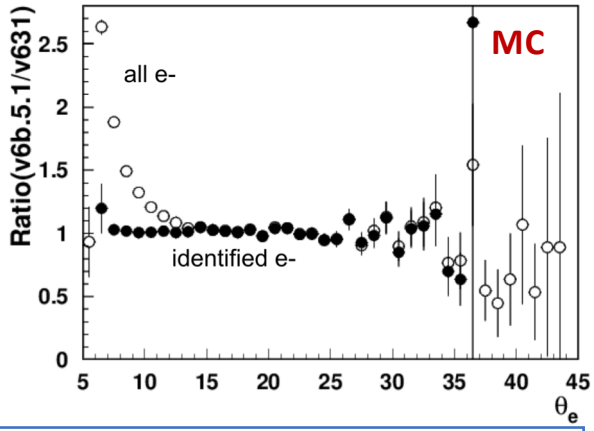
Reconstruction Development Highlights since DNP Cooking

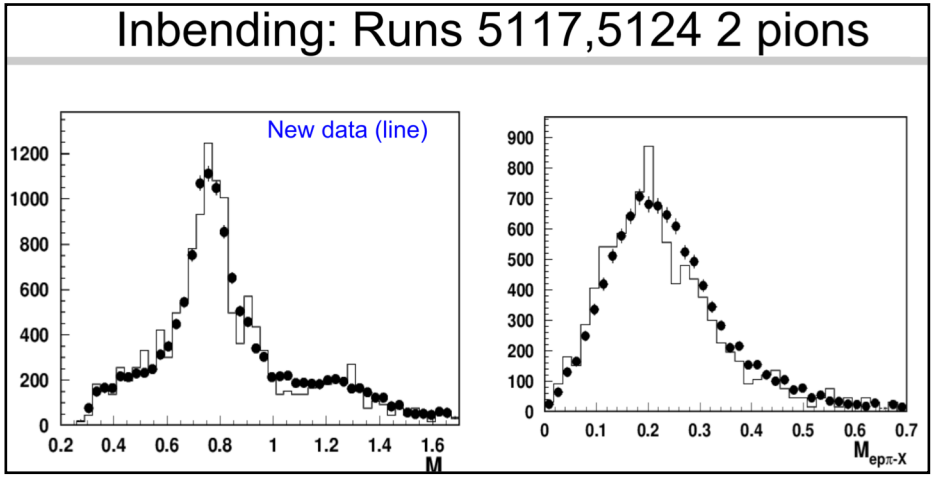
- Central Tracking
  - Addressing the review recommendations (fixes & geometry package)
  - BMT hit multiplicity cut, use beam spot in fit, updated trajectory for CND & CTOF, track status word output
- Forward Tracking
  - New tracking using Doca measurements, improved seeding and segment finding
  - Dropped un-used trajectory surfaces to reduce file size ~40% smaller size for REC::Traj bank, 15-20% for DST; trajectory pathlength fix.
  - Time offset correction to shift TDC spectra allowing coincidence of the peak position in data and MC (for background merging) [Background merger package updated to merge MC with data]
  - Chi2 calculation fix
  - Updated beta cuts for TBT hit selector
  - Removed failed tracks with diverging parameters from output list written to bank
  - Rejection of tracks with unphysical production vertex
- ECAL
  - PCAL projection yielding non-centered residuals resolved
- CND
  - Bug fix in pathlength calculation and interlayer unit
- RICH
  - Ray tracing resolution matching, fixes in par. reading & bank variables ourput (Marco Contalbrigo, INFN)
- FT
  - Bug fix in overlapping clusters. Thresholds from ccdb.
  - Improvements in hodoscope/calorimeter matching
- TOF
  - Clustering algorithm updated to allow for CTOF/CND veto
  - TOF: new TW correction→ better Vtx time resolution
  - CTOF: Use trajectory information for track intersection and path length; timing correction bug fix
- ALERT
  - Geometry development (Viktoriya Sergeyeva, Orsay)
- BAND
  - Updated reconstruction scheme (Florian Hauenstein, ODU)
- RTPC
  - Reconstruction of tracks in BoNUS (David Payette, ODU)
- FVT
  - Reconstruction service available (requires alignment in data).
- EB Updates
  - Vertex-corrected start time, delayed helicity correction improvement
  - Get charged tracks beta from non-TOF outer detectors if TOF info. unavailable
  - Bank updates: REC::Scintillator.dedx and REC::Track.status
  - Switching to trajectory surfaces from POCA, consistency in using pathlength and definitions (layer>=1, chi2pid initialized to -9999 instead of -99)
  - BAND info in EB (tested for RGB)

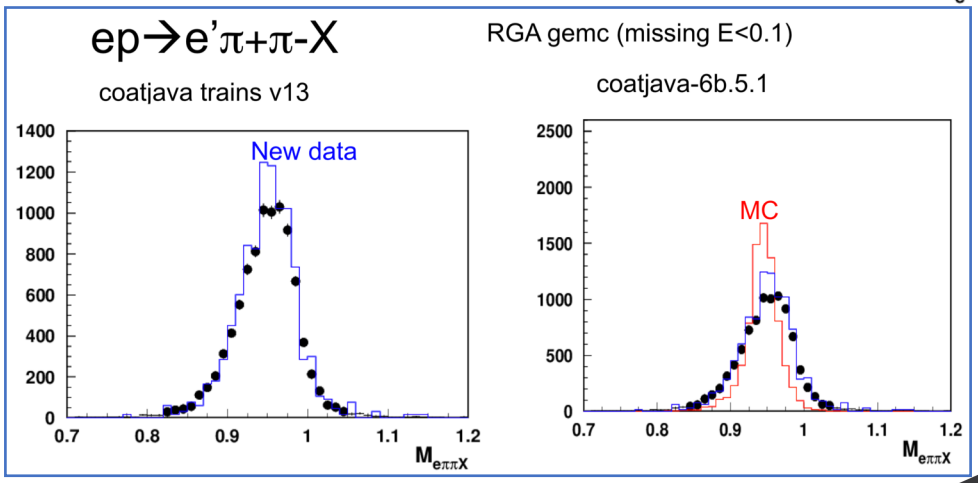
Performance

Harut Avakian

- In MC, more identified tracks at low angles; identified e- ~same
- New tag yields higher number of tracks, and slightly more identified tracks



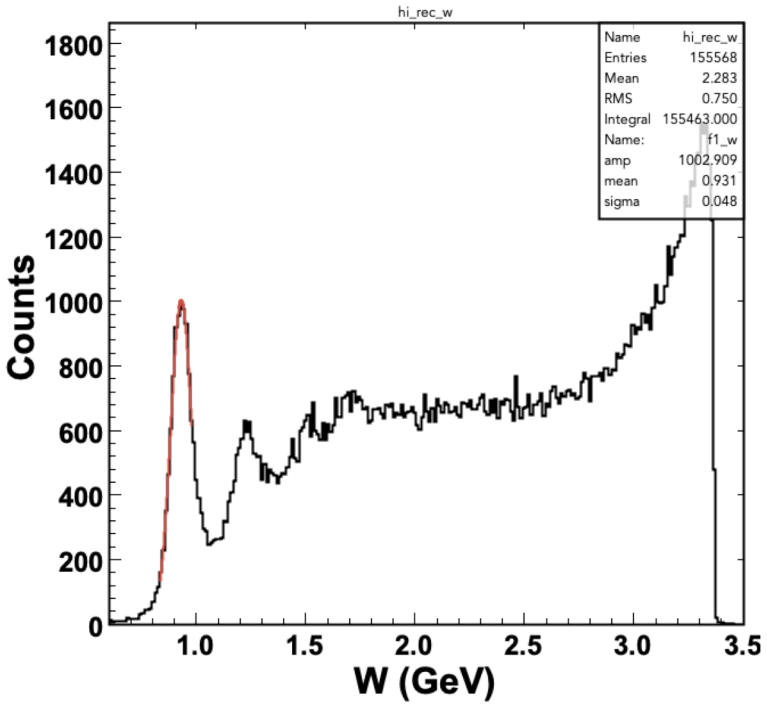




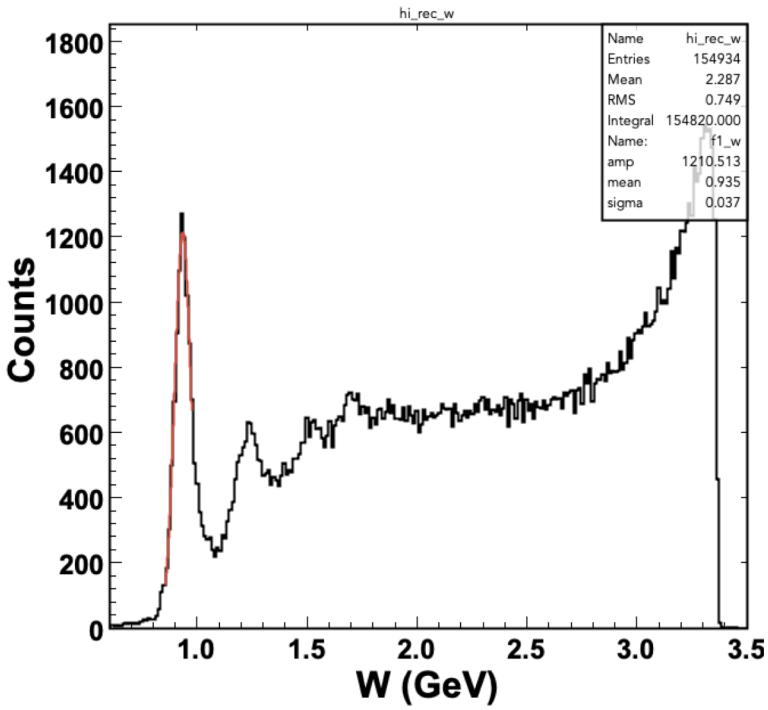
Current Release Improvements: DC

- Tracking improvements well visible in elastic peak resolution (run 5990, 6.5 GeV)

6.3.1

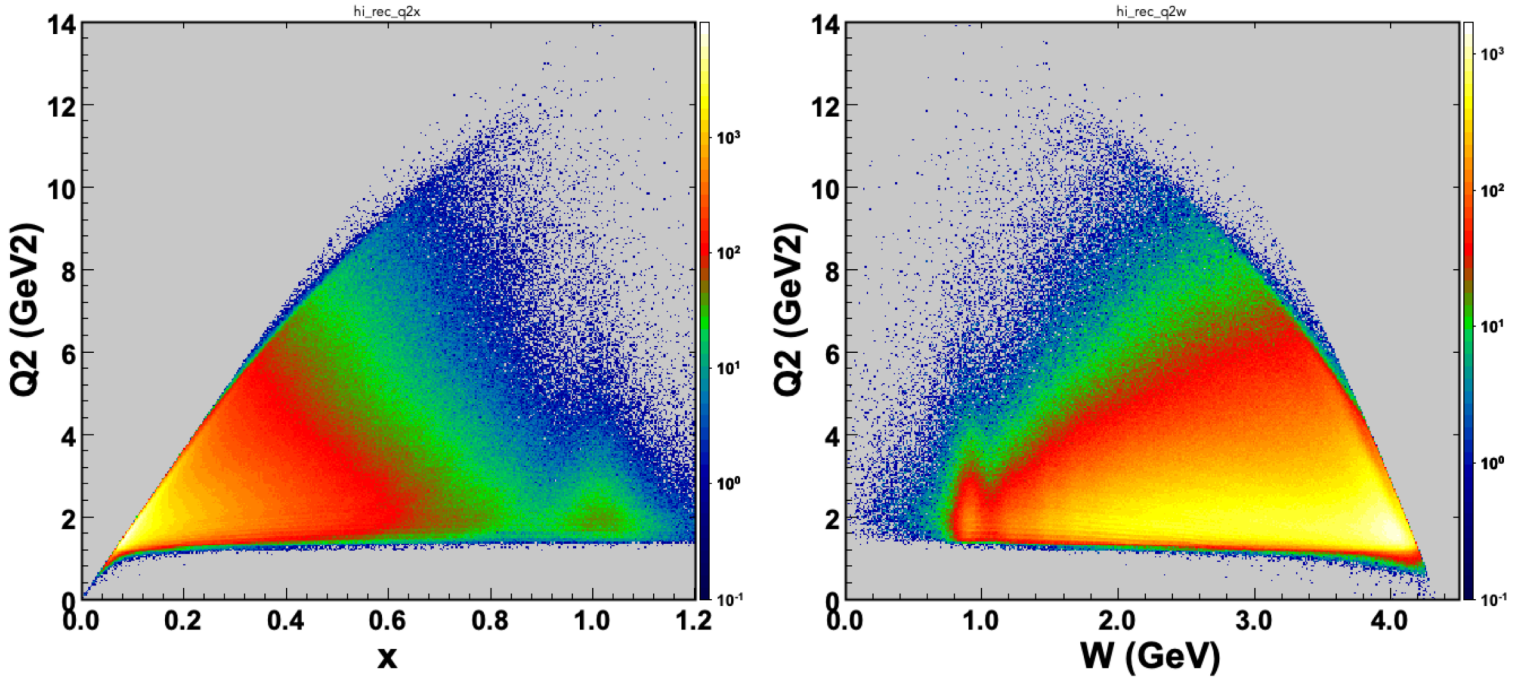


6b.5.1

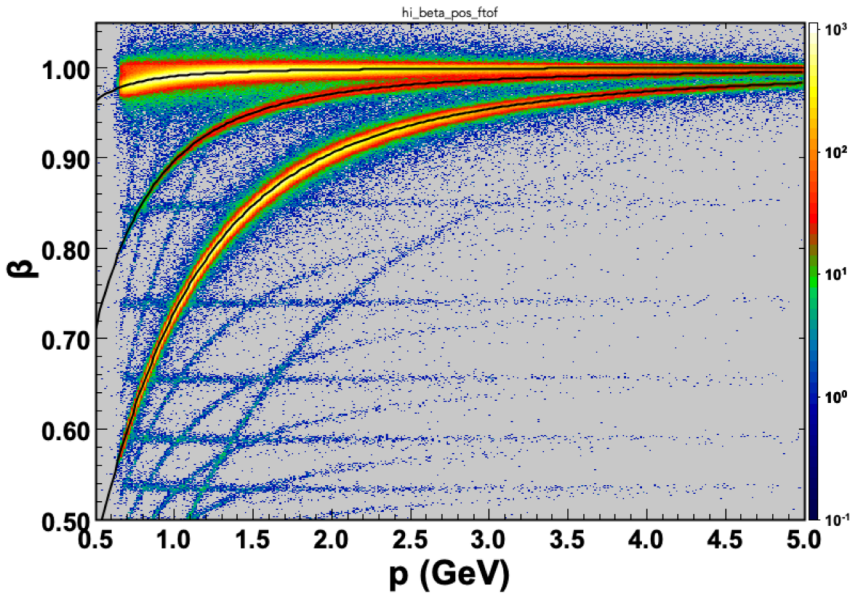


Performance

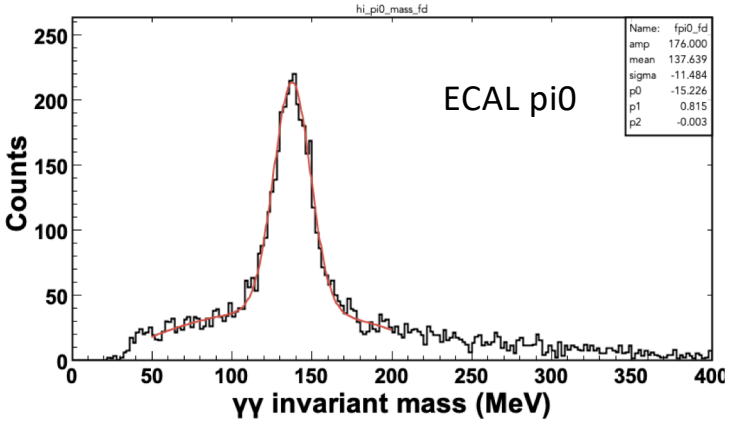
10.6 GeV 6.5.3 kinematics

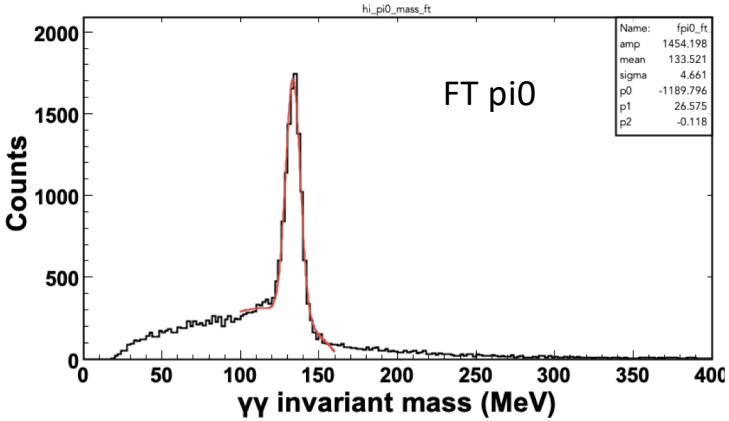


Performance



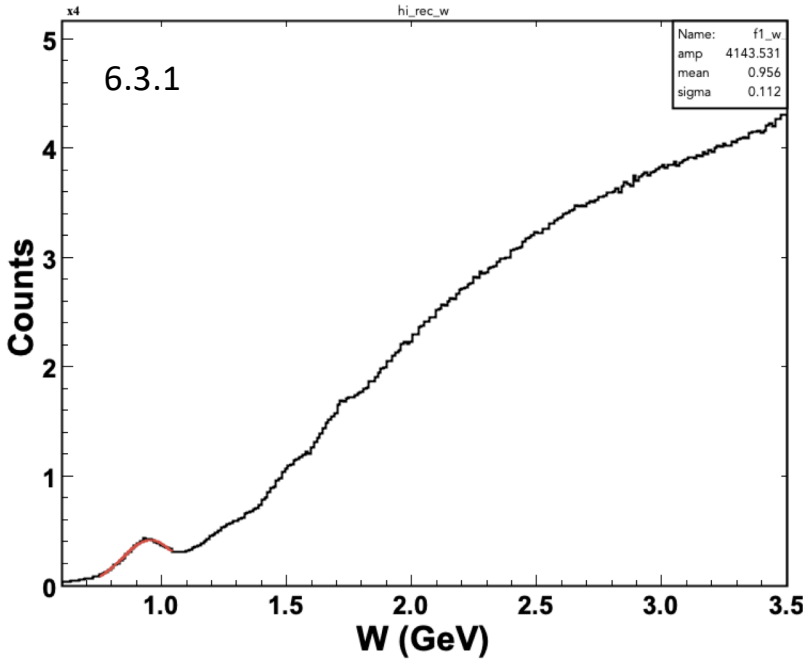
10.6 GeV 6.5.3 performance

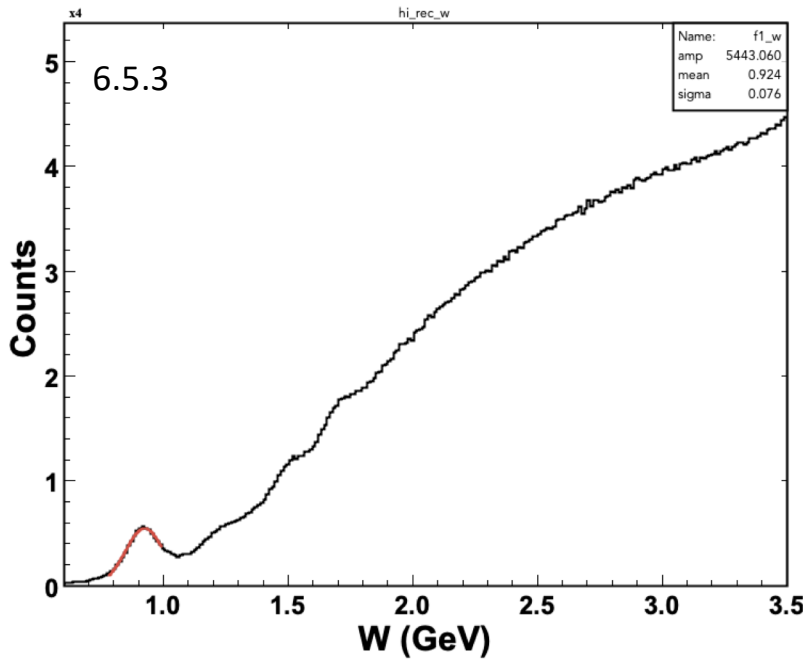




Performance

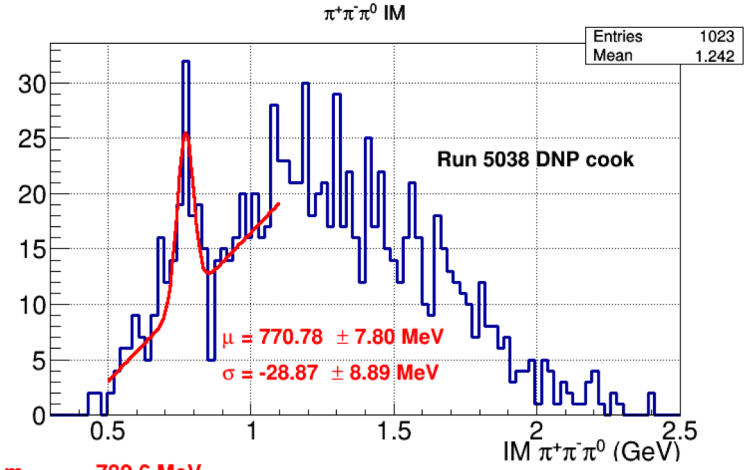
10.6 GeV elastic



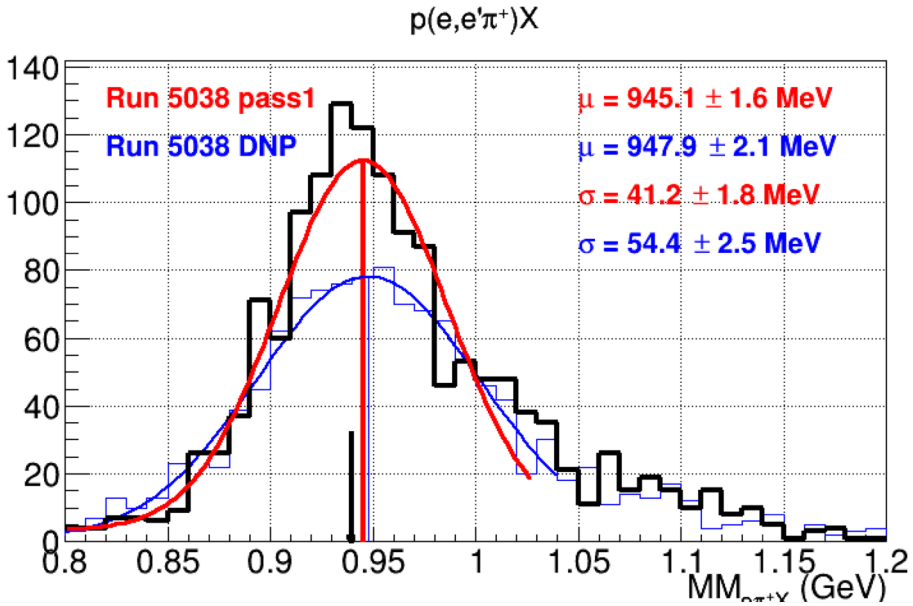


Performance

F-.X. Girod (Uconn)



- Improved ω peak yield
- e π^+ missing neutron mass improved resolution

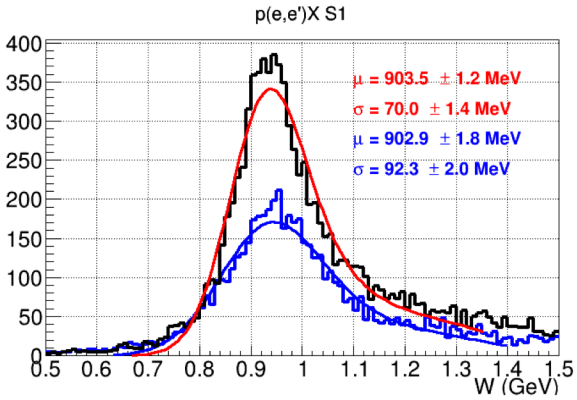


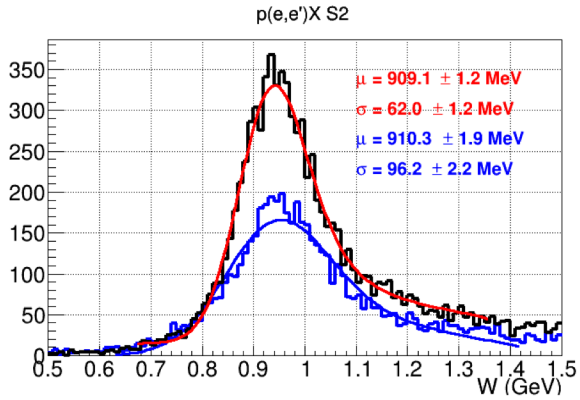
Performance

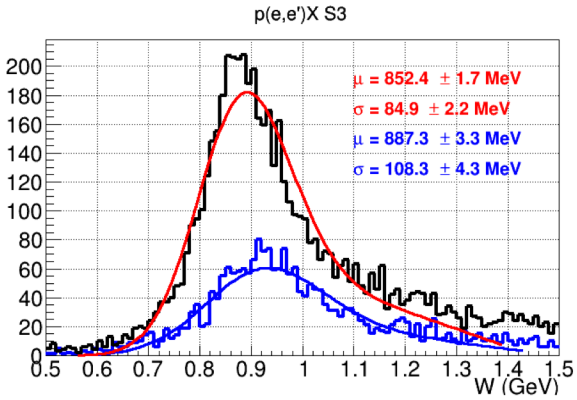
F-.X. Girod (Uconn)

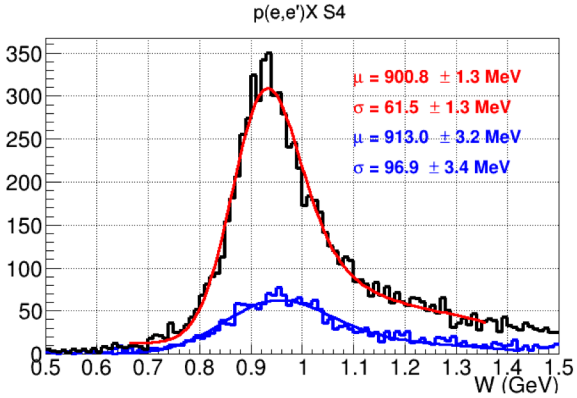
- Elastics per sector, proton in CVT

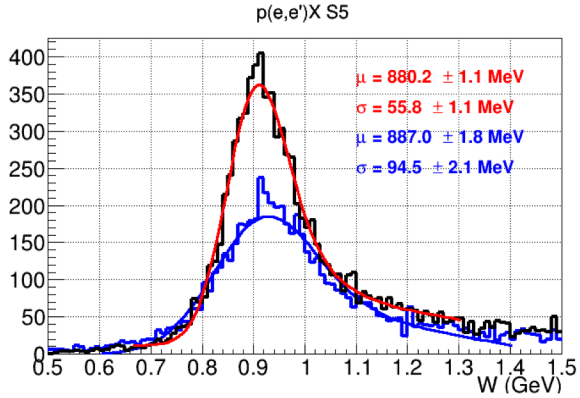
skim4_5038

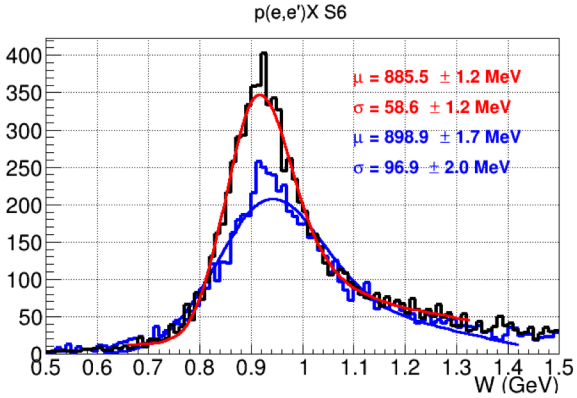










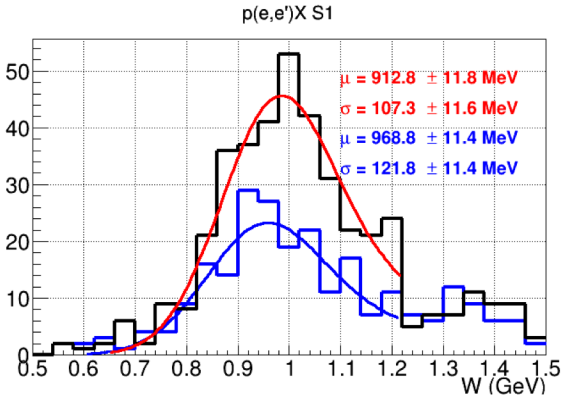


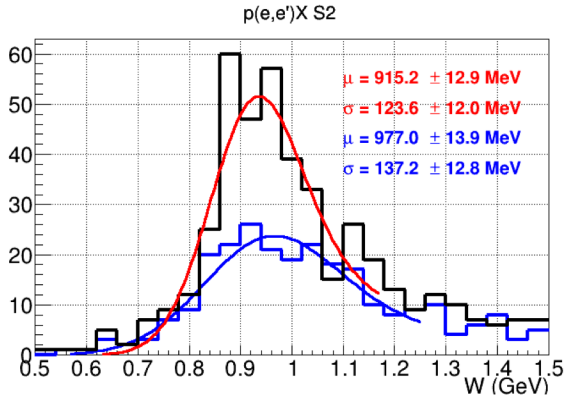
Performance

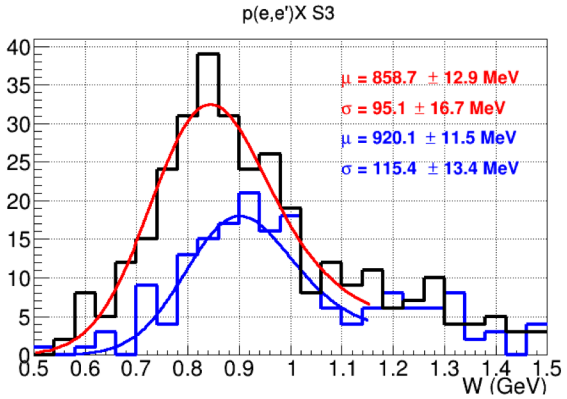
F-.X. Girod (Uconn)

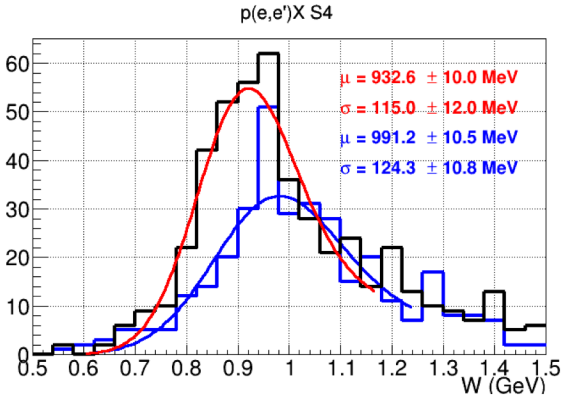
- Elastics per sector, proton in FD

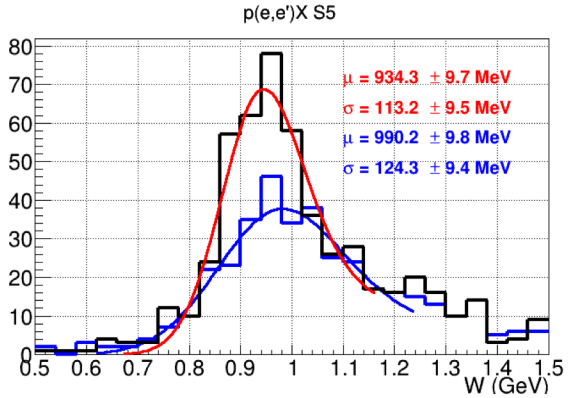
skim4_5038

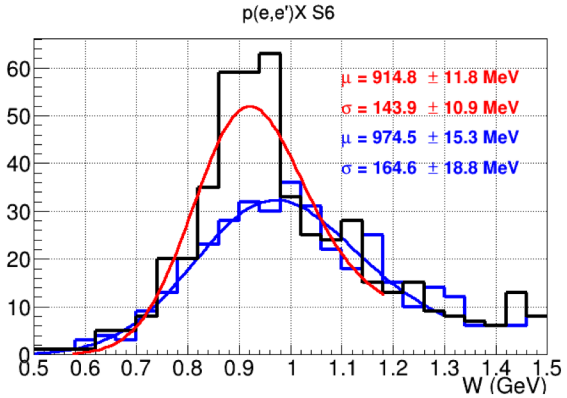








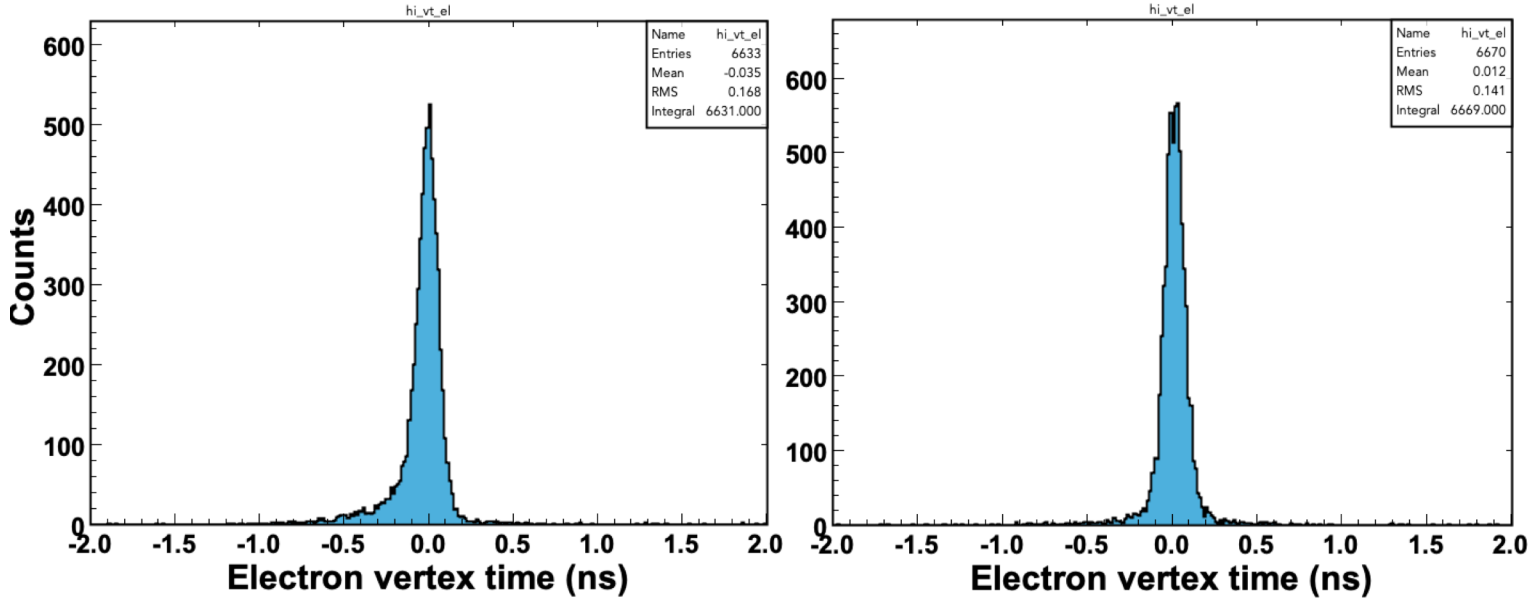




Current Release Improvements: FTOF

- Improved resolution due to new TW correction

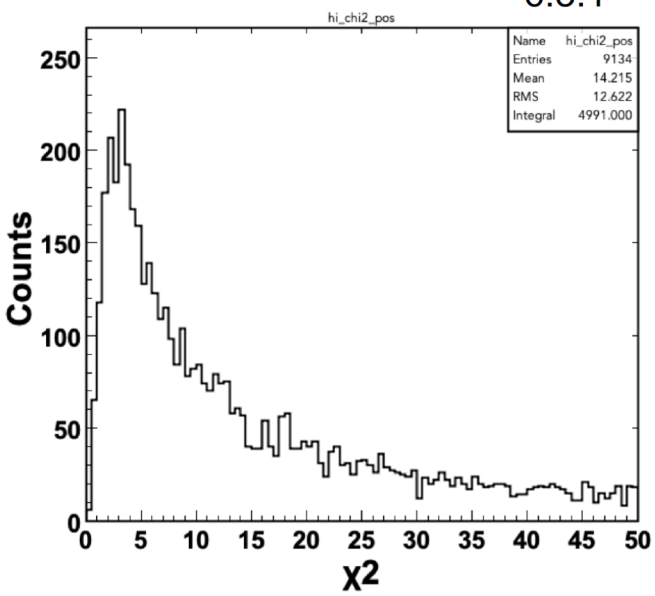
6.3.1 6b.5.1



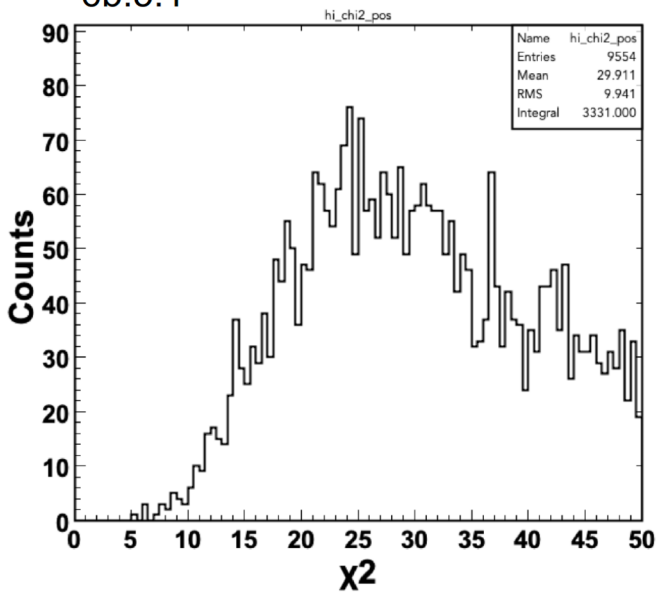
Fixes: DC

- Fix to Chi2 calculation: now Chi2 in simulations is. Consistent with NDF

6.3.1

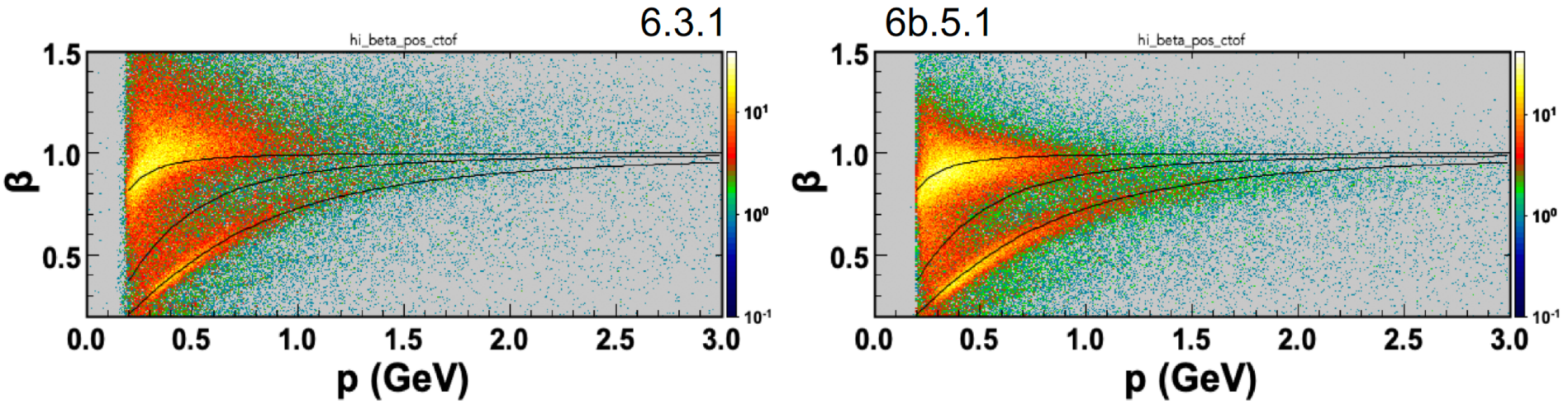


6b.5.1



Fixes: CTOF

- Fixed bug in one of timing correction

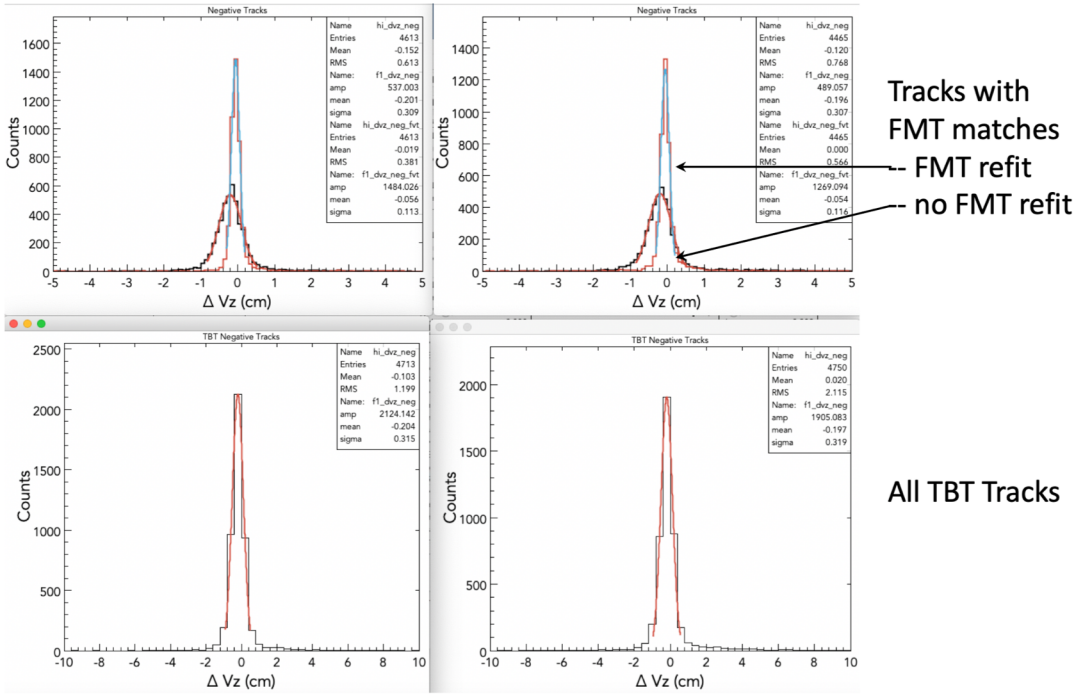


FVT Tracking Developement

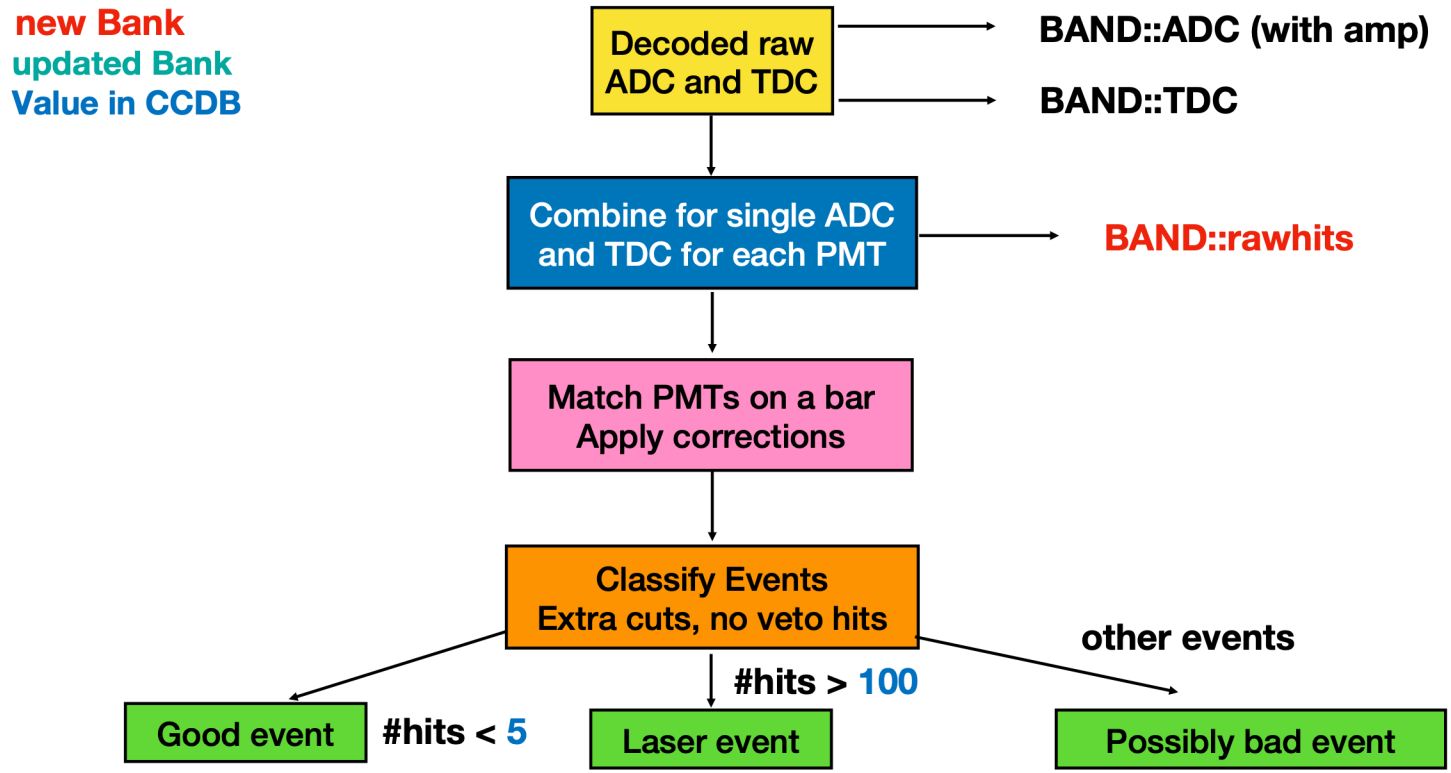
- FMT reconstruction
  - Geometry for planes and strips. Geometry constants & material budget read from ccdb.
    - Updated to rgf_spring2020 geometry (reco. & simulation (Maxime)).
  - Hit reconstruction
  - Clustering (clusters used in fit)
  - Cross reconstruction for displaying in CED
  - Stand-alone service → run after TB tracking to refit the track using FMT clusters

MC Results

- No background
- 10^{34} cm^{-2} s^{-1} luminosity background



Updated BAND Reconstruction Scheme (Florian Hauenstein, ODU)



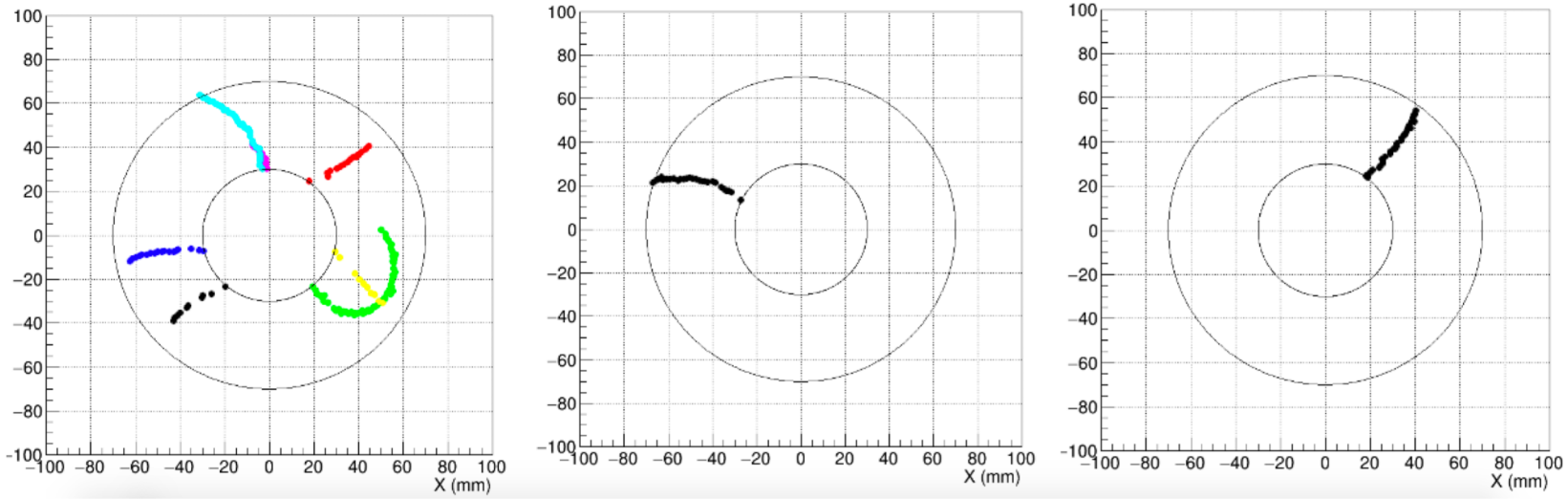
Summary Reconstruction Update (Florian Hauenstein, ODU

- Updated selection criteria for good hits, use of CCDB values
- Updated calibration algorithm i.e. ADC amplitude for time walk
- Changes to BAND::hits bank
  - „**status**“ of BAND::hits as selection criterion for EB
  - Pointers to lower-level banks
  - Updated naming schemes
- New bank BAND::laser for laser hits only
- New bank BAND::rawhits for single PMT hits (before matching to bars), includes veto

RTPC Reconstruction (David Payette, ODU)

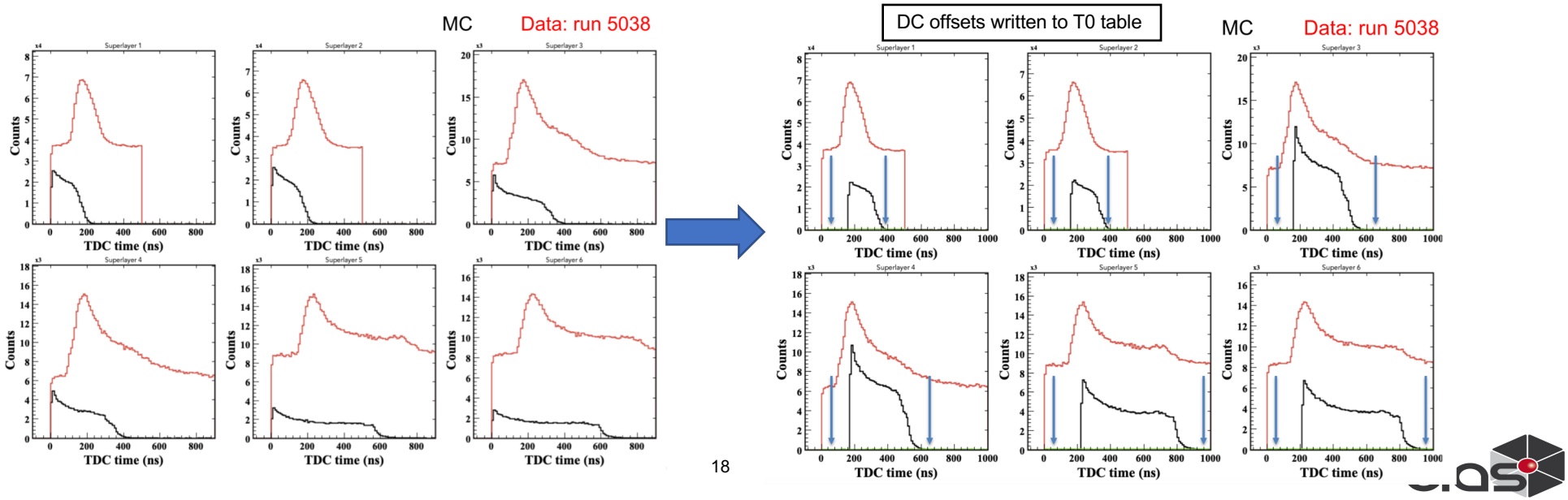
RTPC Reconstruction Status

- Reconstruction is working well for cooking purposes.
- We are currently testing many different reconstruction parameters as well as new strategies for the kinds of tracks we are seeing from RG-F data.
- Currently a new RTPC is being installed so we will see many new results soon.



Tools: Background Merging: DC

- Package in common tools to merge decoded hits (ADC&TDC) coming from 2 hipo files. Previously used to merge low and high lumi. data samples → extend to merge MC and data requires readjusting of the TDC spectra in MC.
- Obtain timing shifts to be applied to simulation by comparing “peak” position between simulation and data (**Raffaella deVita, INFN**)
  - Using single “T0” offset for DC, average ADC&TDC shift for FTOF
- Shifts “undone” in reconstruction (starting from 6b.5.2)

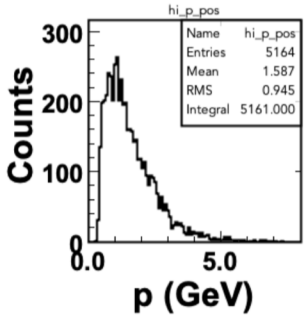


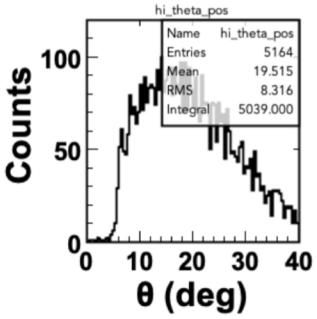
Validations: Signal MC + Random Trigger Data

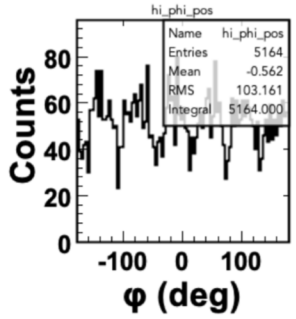
Raffaella deVita, INFN

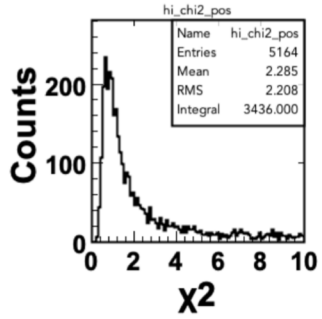
Positive tracks

Without BG

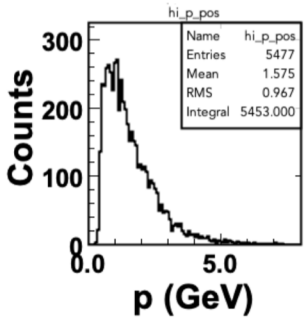


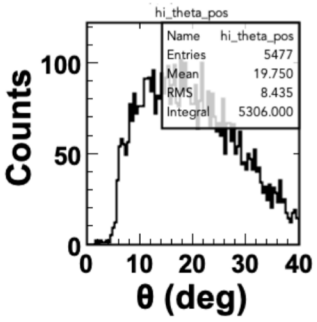


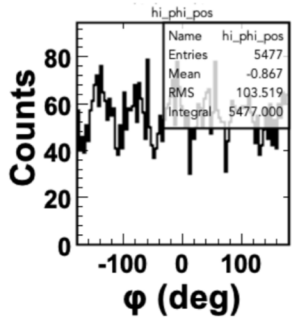


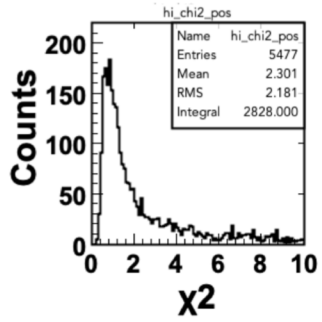


With BG









EB particles

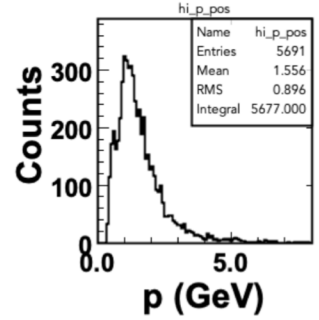
- 10% fewer electrons
- 10% fewer negative
- FD hadrons
- 15% fewer positives
- FD hadrons

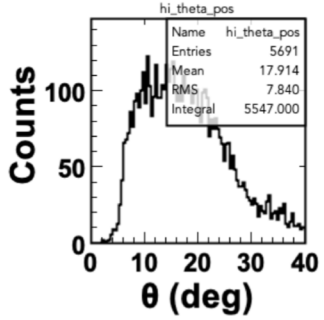
Validations: 2 nA (run 5418) + Random Trigger Data

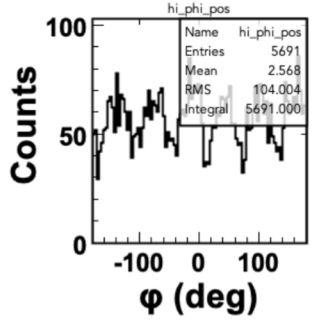
Raffaella deVita, INFN

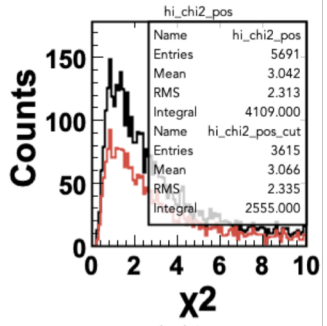
Positive tracks

Without BG

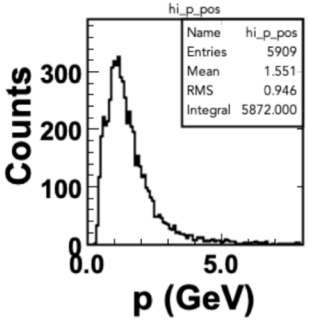


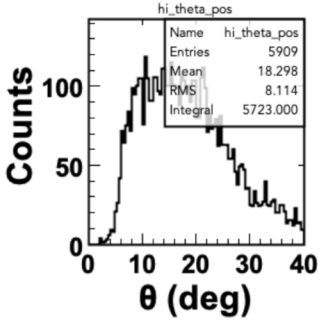


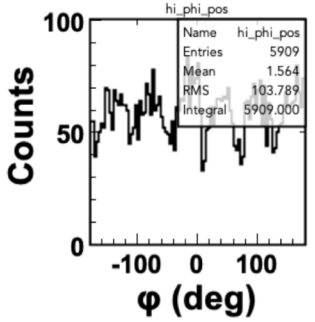


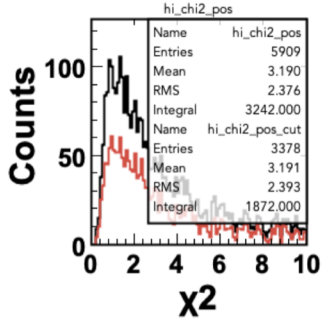


With BG









EB particles

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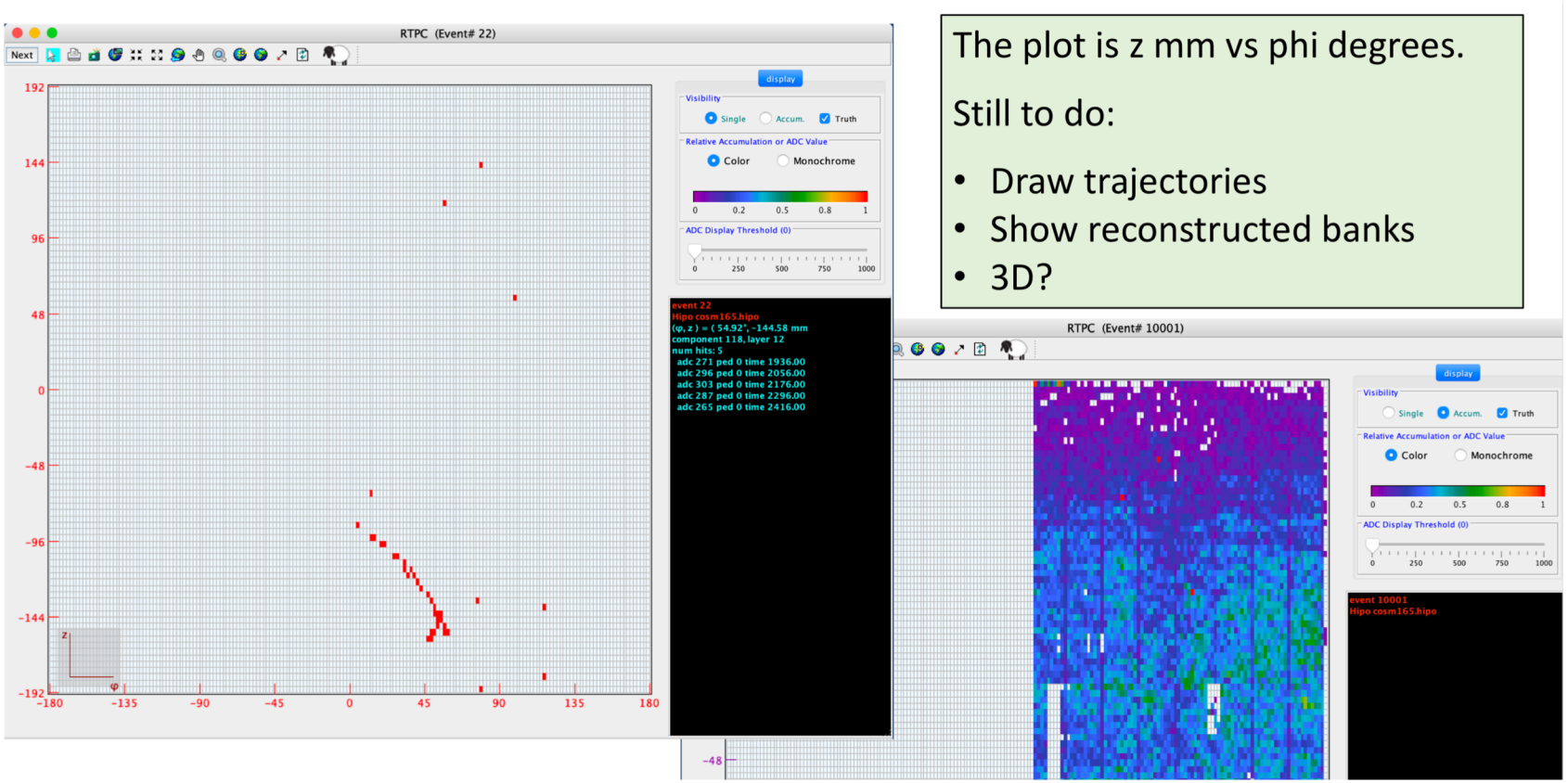
- FD hadrons
- 15% fewer positives
- FD hadrons

CED Updates: Basic RTPC 2D Display (Dave Heddle, CNU)



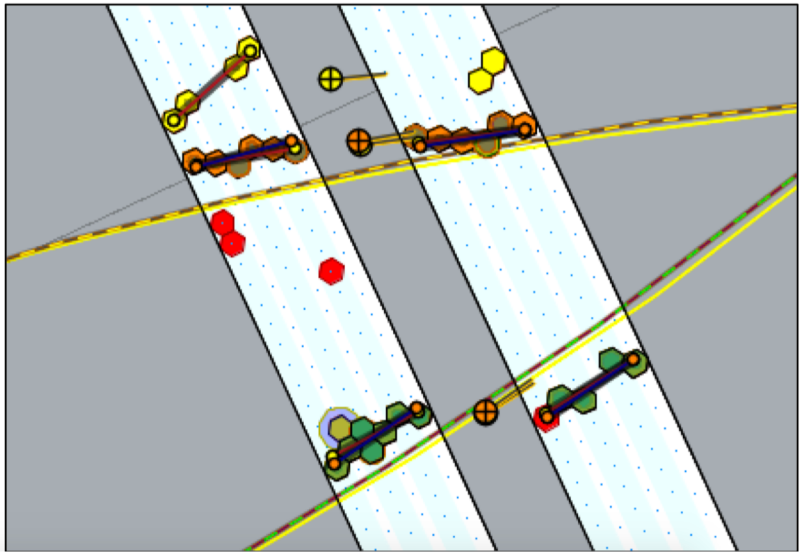
The plot is z mm vs phi degrees.

Still to do:

- Draw trajectories
- Show reconstructed banks
- 3D?

CED Updates: AI Display

Overlays hits (in greenish color) used by the neural net trackfinder. Still to do: draw the nn tracks.



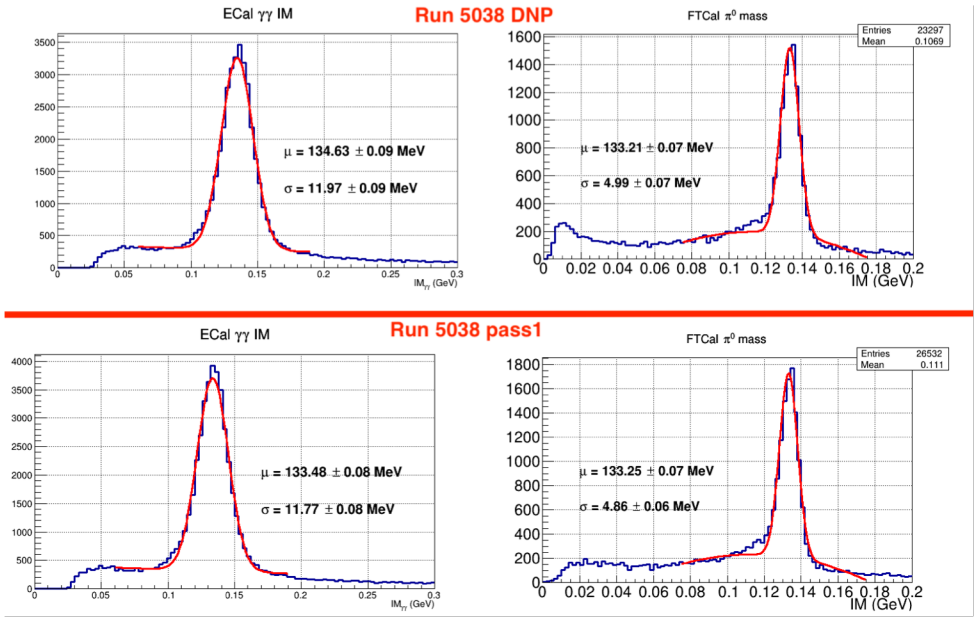
Current Status & Ongoing Tasks

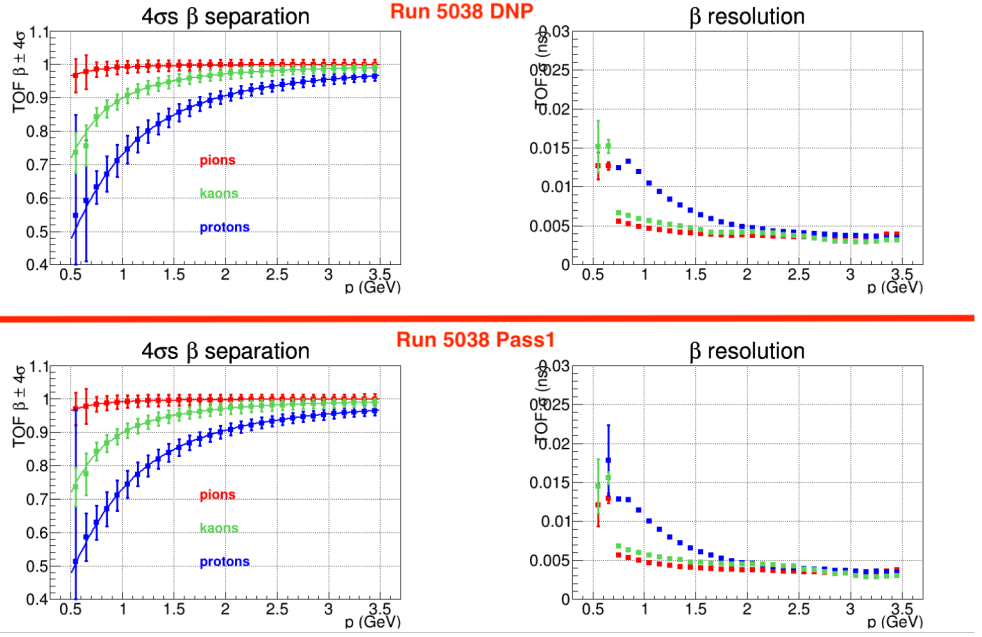
- **Current release validated for data processing**
  - COATJAVA release 6.5.3
  - Compatible with GEMC 4.3.2

- **Ongoing tasks**
  - CVT tracking (next talks)
  - TOF clustering validation
  - CND/CTOF veto
  - BAND information used in EB (tested in dedicated branch)
  - Covariance matrix
    - Transformation of covariance matrix in lab frame
  - Background merging
  - Packages restructuring for AI
    - C.f. Gagik's talk
  - Geometry package restructuring
  - Good track selection

BACK-UP SLIDES

Performance





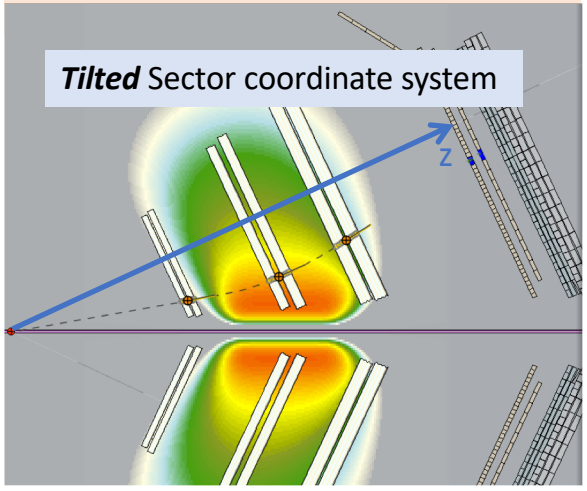
DC TRACKING: Reconstruction Improvements

- Reinitialize the track from last Hit-Based state vector in KF → avoid frame transformation.
- Use of custom 5-d matrix used in KF: faster matrix operation compared to JAMA (matrix library used in development). [Implemented by Gagik in jnp package].
- More efficient track segment overlap finder.
- More efficient code to recompose clusters at Time-Based level using Hit-Based H.O.T.s.
- AI assisted tracking: potentially ~ 5x faster Hit-Based tracking (see my next talk).

- Outer detector matching using ECAL if no TOF hit matches (see Nathan's talk).
  - Preliminary studies: yields about 8% more tracks in MC → Testing with data ongoing.

Tracking in CLAS12 DC

- Covariance matrix estimated at each DC wire plane in TCS
- Reported at last measurement site used in the fit
- Propagated w/o filtering to reconstructed z-vertex



- **site**: DC layer plane where a fired (k = 1…36);
  - in tilted coordinate system, planes are perpendicular to z, so measurement sites are equidistant

- **state**: 5-parameter track representation

$$\tilde{x}(z) = \begin{pmatrix} x \\ y \\ t_x \\ t_y \\ q \end{pmatrix}, \quad \begin{aligned} t_x &= p_x/p_z \\ t_y &= p_y/p_z \\ q &= Q_e/|\vec{p}| \end{aligned}$$

At each step the covariance matrix had to be propagated along with the state vector, with process noise added after each rotation.

- RungeKutta-4 method to solve the equations of motion and derivatives numerically requires over factor 10 fewer steps → faster

$$\boldsymbol{C}_k^{k-1} = \boldsymbol{F}_{k-1}\boldsymbol{C}_{k-1}\boldsymbol{F}_{k-1}^T + \boldsymbol{Q}_{k-1},$$

Solve Jacobian (F) using **RK4**

$$\begin{aligned}
d/dz(\partial x/\partial t_{x0}) &= \partial t_x/\partial t_{x0}, \\
d/dz(\partial y/\partial t_{x0}) &= \partial t_y/\partial t_{x0}, \\
d/dz(\partial t_x/\partial t_{x0}) &= q_0 \cdot v \cdot [(\partial A_x/\partial t_x)(\partial t_x/\partial t_{x0}) + (\partial A_x/\partial t_y)(\partial t_y/\partial t_{x0})], \\
d/dz(\partial t_y/\partial t_{x0}) &= q_0 \cdot v \cdot [(\partial A_y/\partial t_x)(\partial t_x/\partial t_{x0}) + (\partial A_y/\partial t_y)(\partial t_y/\partial t_{x0})], \\
\partial q/\partial t_{x0} &= 0.
\end{aligned}$$

$$\begin{aligned}
\partial A_x/\partial t_x &= t_x \cdot A_x/(1+t_x^2+t_y^2) + (1+t_x^2+t_y^2)^{\frac{1}{2}} \cdot (t_y \cdot B_x - 2 \cdot t_x \cdot B_y), \\
\partial A_x/\partial t_y &= t_y \cdot A_x/(1+t_x^2+t_y^2) + (1+t_x^2+t_y^2)^{\frac{1}{2}} \cdot (t_x \cdot B_x + B_z), \\
\partial A_y/\partial t_x &= t_x \cdot A_y/(1+t_x^2+t_y^2) + (1+t_x^2+t_y^2)^{\frac{1}{2}} \cdot (-t_y \cdot B_y - B_z), \\
\partial A_y/\partial t_y &= t_y \cdot A_y/(1+t_x^2+t_y^2) + (1+t_x^2+t_y^2)^{\frac{1}{2}} \cdot (-t_x \cdot B_y + 2 \cdot t_y \cdot B_x).
\end{aligned}$$

$$\begin{aligned}
d/dz(\partial x/\partial q_0) &= \partial t_x/\partial q_0, \\
d/dz(\partial y/\partial q_0) &= \partial t_y/\partial q_0, \\
d/dz(\partial t_x/\partial q_0) &= v \cdot A_x + v \cdot q_0 \cdot [(\partial A_x/\partial t_x)(\partial t_x/\partial q_0) + (\partial A_x/\partial t_y)(\partial t_y/\partial q_0)], \\
d/dz(\partial t_y/\partial q_0) &= v \cdot A_y + v \cdot q_0 \cdot [(\partial A_y/\partial t_x)(\partial t_x/\partial q_0) + (\partial A_y/\partial t_y)(\partial t_y/\partial q_0)], \\
\partial q/\partial q_0 &= 1.
\end{aligned}$$

Steps to get the covariance matrix in the lab frame in terms of EB track representation

- Jacobian transformations for the transformation from one representation & frame to the other (x, y, tx, ty, z_fixed in TCS --> x, y, px, py, pz, z_rotated)
- Done by Luca and Mylene ➔ needs to be implemented in code

- David: parametrization of covariance matrix from MC (ongoing)

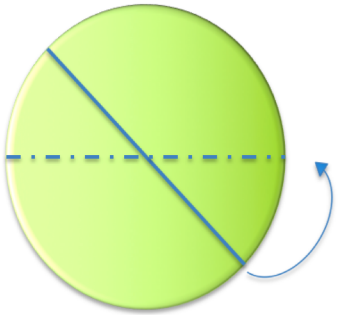
FVT Tracking Development

- Find FMT Matches within ~1 cm of DC track trajectory (resolution at FMT face from MC ~1 cm → 20 strips)
- Use FMT centroid positions as KF Measurements
- Use same KF formalism as for DC except the coordinate system is now the lab frame. Same principle of fixed z measurement planes (FMT disks).

FVT state vector:

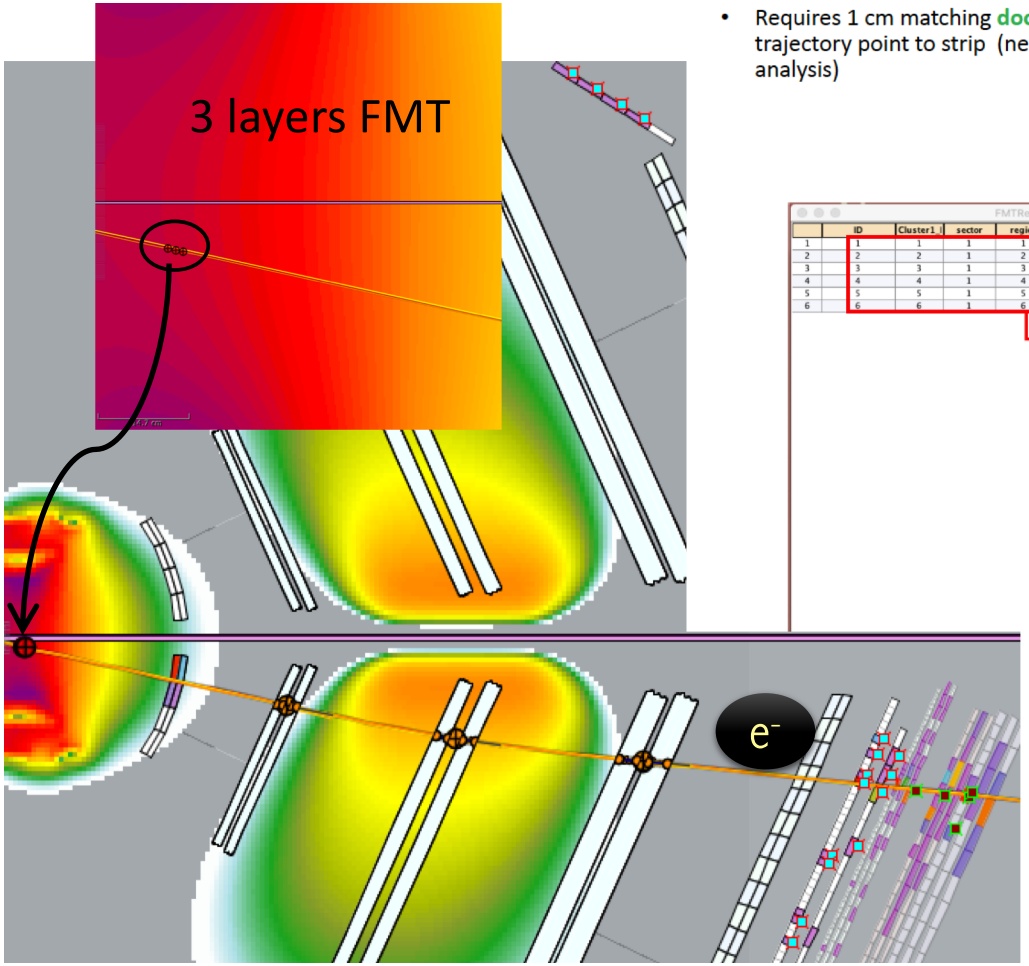
$$\tilde{x}(z) = \begin{pmatrix} x \\ y \\ t_x \\ t_y \\ q \end{pmatrix}, \quad \begin{aligned} t_x &= p_x/p_z \\ t_y &= p_y/p_z \\ q &= Q_e/|\vec{p}| \end{aligned}$$

analysis frame for KF projector



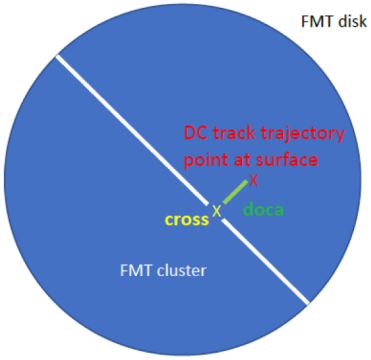
y_loc = y*cos(Alpha[layer-1])- x*sin(.FVT_Alpha[layer-1]);

FMT in ced



New cross definition

- Cluster matched to track using trajectory bank (detector 8)
- Requires 1 cm matching **doca** of trajectory point to strip (needs further analysis)



FMTRec::Crosses

	ID	Cluster1_ID	sector	region	x	y	ux
1	1	1	1	1	2.71218	-4.65996	0.0
2	2	2	1	2	2.78165	-4.83967	0.0
3	3	3	1	3	2.94034	-5.05592	0.0
4	4	4	1	4	3.09415	-5.19660	0.0
5	5	5	1	5	3.19930	-5.36421	0.0
6	6	6	1	6	3.31868	-5.57506	0.0

TimeBasedTrkg::Trajectory

	id	detector	layer	x	y	z
1	1	15	1	18.57695	-24.27033	172.31050
2	1	100	2	0.17980	-0.38287	2.50132
3	1	100	1	-0.01036	0.02458	-5.16208E-4
4	1	8	1	2.71817	-4.67735	30.29550
5	1	8	2	2.84262	-4.85152	31.48720
6	1	8	3	2.96774	-5.02440	32.67529
7	1	8	4	3.09434	-5.19715	33.86780
8	1	8	5	3.22143	-5.36851	35.05588
9	1	8	6	3.34966	-5.53943	36.24594
10	1	6	6	25.91576	-33.66324	239.74167
11	1	6	12	27.12101	-35.22602	250.89462
12	1	6	18	43.54451	-57.51094	367.33524
13	1	6	24	47.90649	-63.46887	386.95242
14	1	6	30	79.14117	-105.93192	497.14178
15	1	6	36	85.34187	-114.41597	517.54712
16	1	12	3	152.59789	-207.22987	739.70172
17	1	12	2	123.57594	-167.31584	644.08997
18	1	12	1	127.96830	-173.35667	658.56042
19	1	16	1	118.71018	-160.62393	628.05988
20	1	7	2	134.28859	-182.04900	679.38239
21	1	7	5	140.13661	-190.09181	698.64844
22	1	7	8	145.15614	-196.99519	715.18512

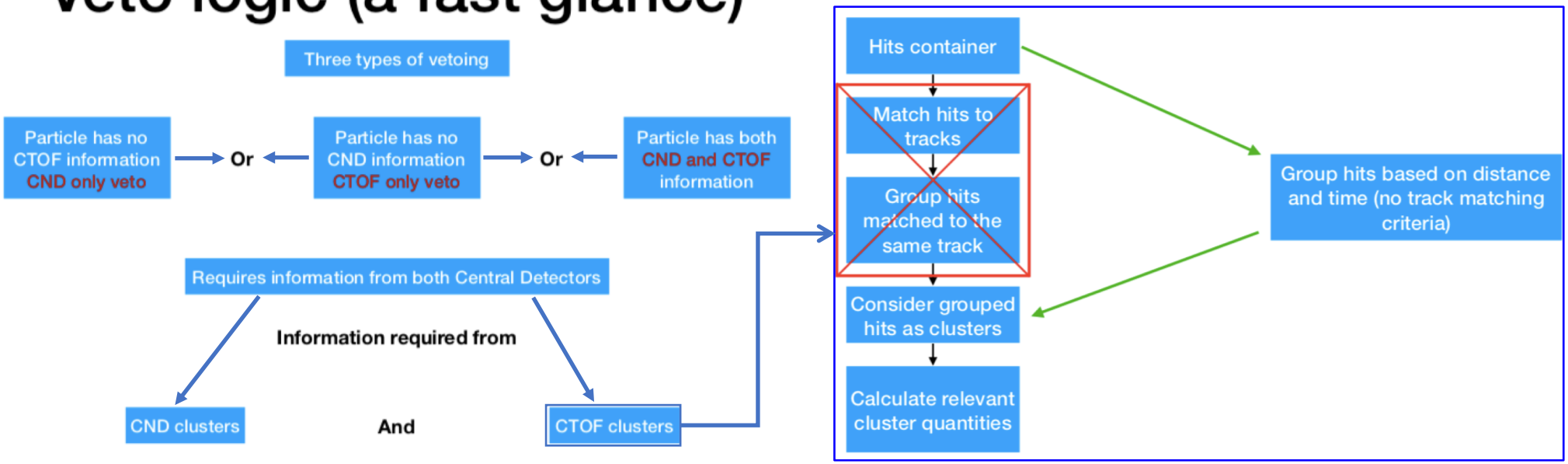
FMTRec::Clusters

	ID	sector	layer	size	ETot	seedE	seedStrip	centroid	centroidRe	seedRe
1	1	1	1	3	45.00000	30.00000	572	-5.28908	0.0	0.0
2	2	1	2	2	20.00000	18.00000	230	-3.65400	0.0	0.0
3	3	1	3	2	16.00000	9.00000	125	1.88672	0.0	0.0
4	4	1	4	2	18.00000	13.00000	48	5.92083	0.0	0.0
5	5	1	5	2	65.00000	53.00000	752	4.16406	0.0	0.0
6	6	1	6	3	29.00000	22.00000	634	-2.03030	0.0	0.0

PID: CND/CTOF Veto

Adam Hobart
(Orsay)

Veto logic (a fast glance)



- For CTOF (and CND) do it in 4 D taking into account detector resolutions

Not a geometric distance ← $d^2 = \frac{\Delta x^2}{\sigma x_1 \sigma x_2} + \frac{\Delta y^2}{\sigma y_1 \sigma y_2} + \frac{\Delta z^2}{\sigma z_1 \sigma z_2} + \frac{\Delta t^2}{\sigma t_1 \sigma t_2}$ < minimum (to be determined)

PCAL Parallax Correction

Cole Smith (UVA)

Z Tracking Planes in PCAL

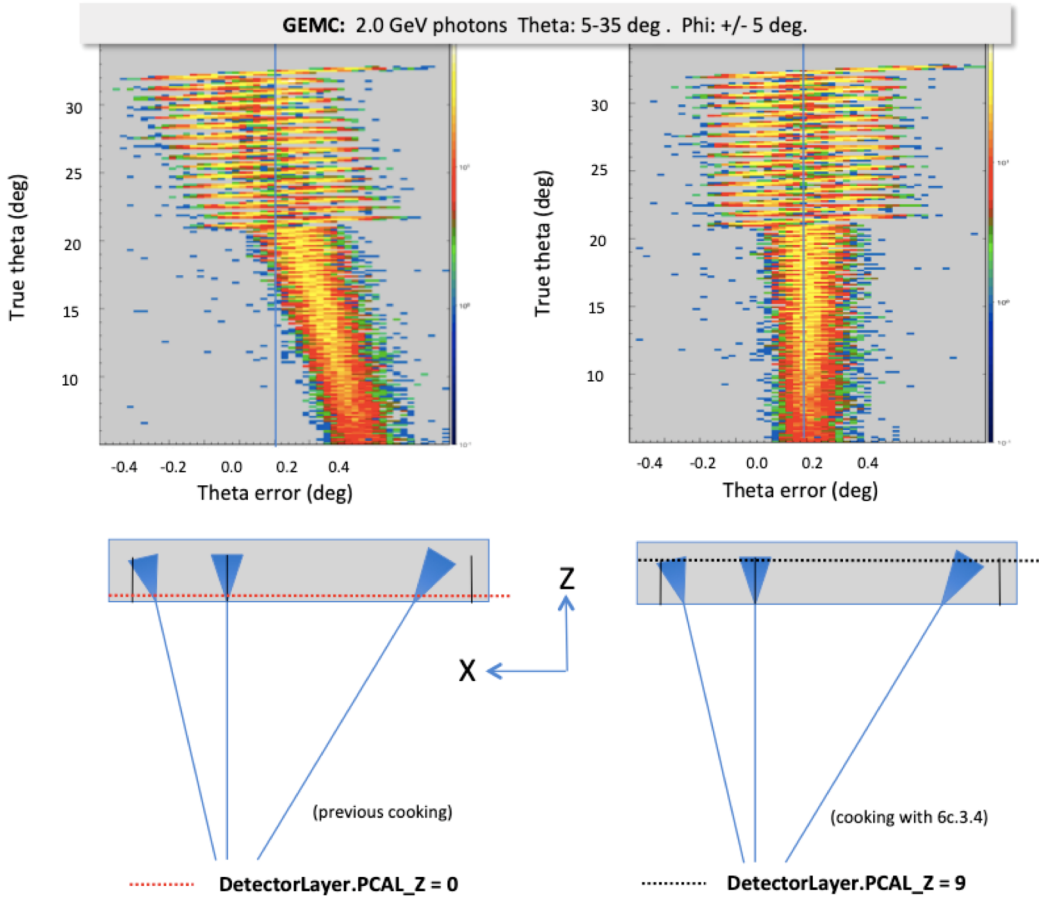
- PCAL and EC reconstruction measures only transverse (x,y) cluster position.
- Cluster z position referenced to user-defined Z tracking plane.
- PCAL Z tracking plane must approximately coincide with depth of shower maximum to avoid parallax errors in theta for off-normal straight tracks (photons,neutrons).
- For EC the scintillator projective geometry compensates for parallax.

Implemented in 6c.3.4

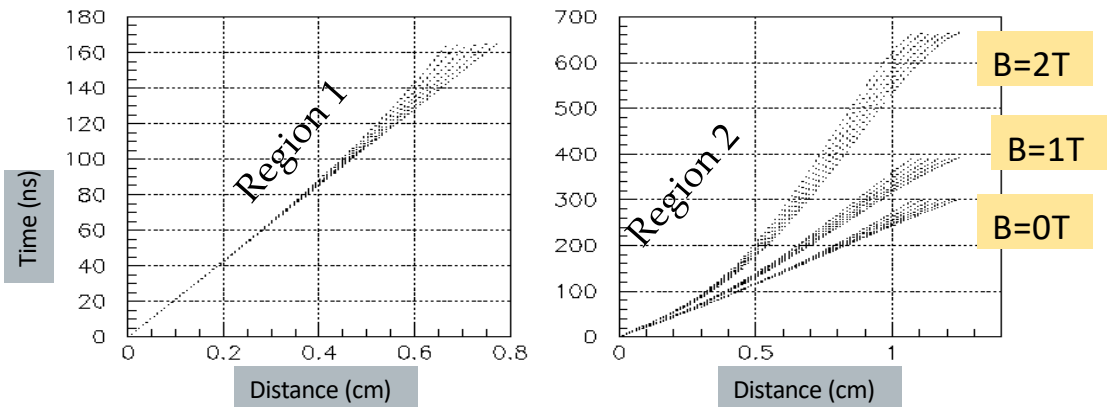
- **ECCommon.java**
- **TrajectorySurfaces.java**
- **DetectorLayer.java**
  - Introduce DetectorLayer.PCAL, EC_INNER, EC_OUTER
  - Set DetectorLayer.PCAL_Z = 9
- **ECFactory.java**
  - Generate scintillator volumes for all ECAL layers

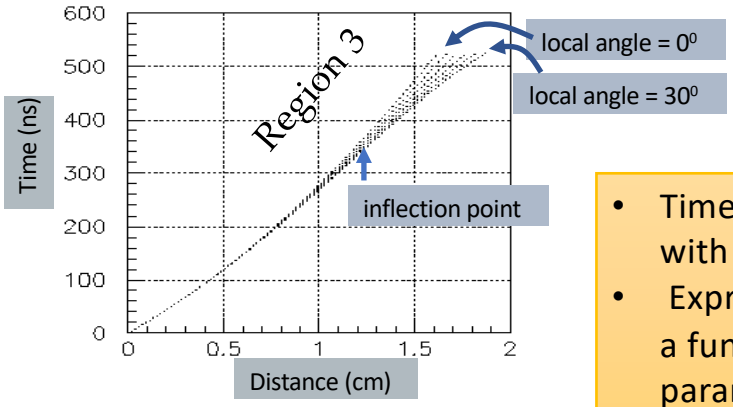
Expected Impact

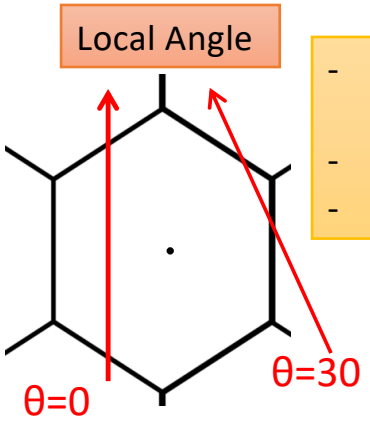
- PCAL-EC cluster matching
- Pathlength for timing calibration
- Neutral meson 4-vector from 2Y decay kinematics
- DC tracking residuals for cluster PID and alignment



DC TRACKING: Time To Distance Calculation







- Calculated from segment fits (superlayer) - fix
- Corrected for B-field
- Reduced to 0—30 deg.

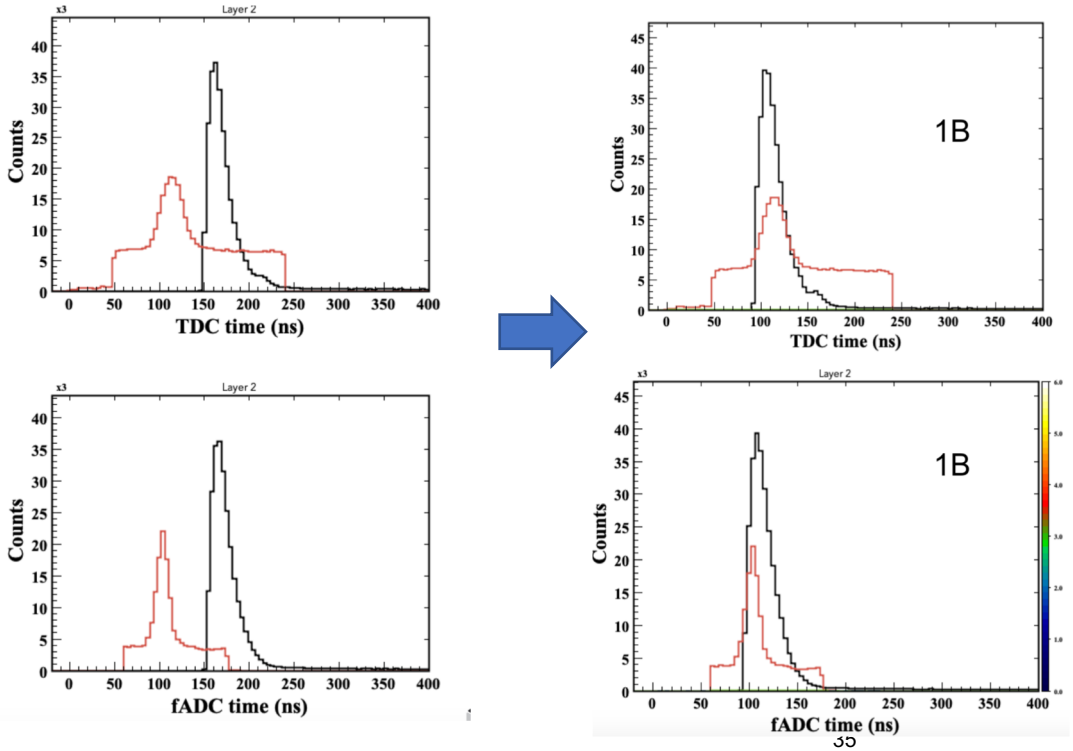
- Time to distance → parametrize with function $t = \Sigma_i a^i d^i$; i=0…4.
- Express polynomial coefficients as a function of calibration parameters.

- **Validated interpolation as a function of <u>local angle</u>, B, time to calculate the DOCAS from Times**

Tools: Background Merging: FTOF

- separate shifts for TDC and ADC; need global offset for each layer.
- GEMC permits only single shift → for now average TDC&ADC

MC Data: run



FTOF offsets (average between TDC and ADC offsets) written to time_offsets table (p2p constants)

•Shifts “undone” in reconstruction (starting from 6b.5.2)