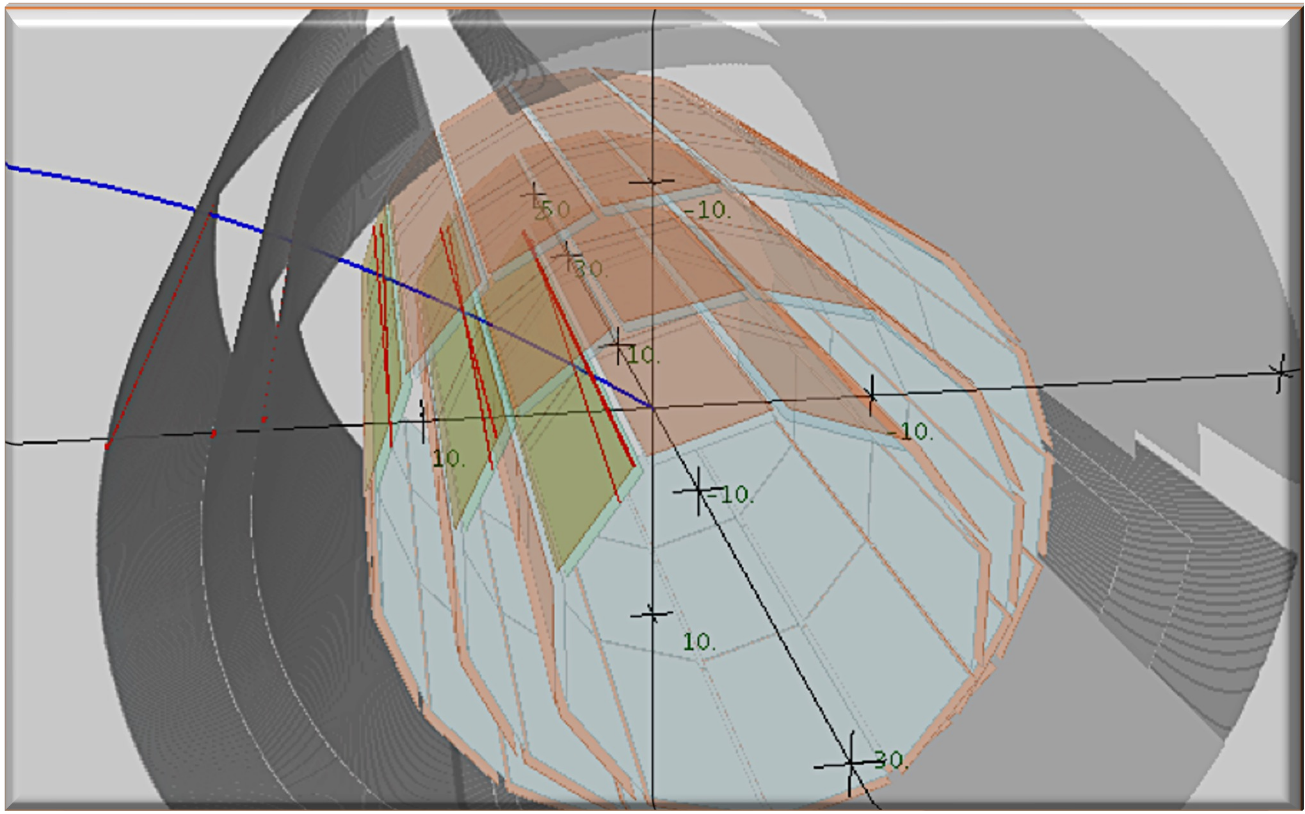
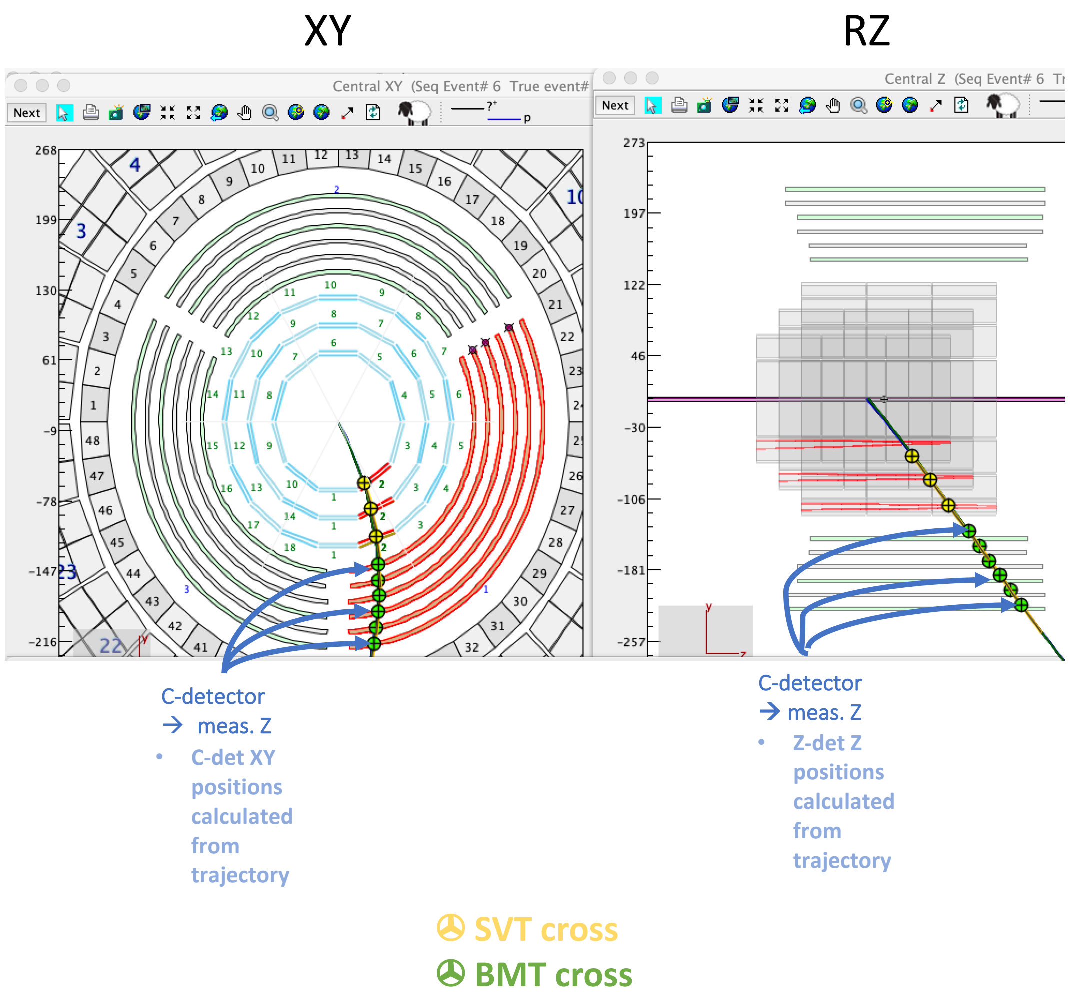


CVT Tracking Results and Plans

Veronique Ziegler

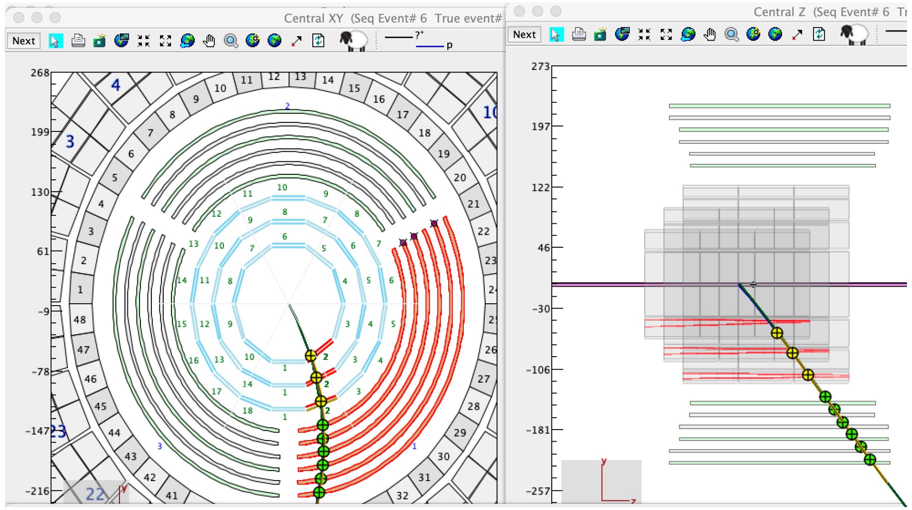
CVT TRACKING ALGORITHMS OVERVIEW



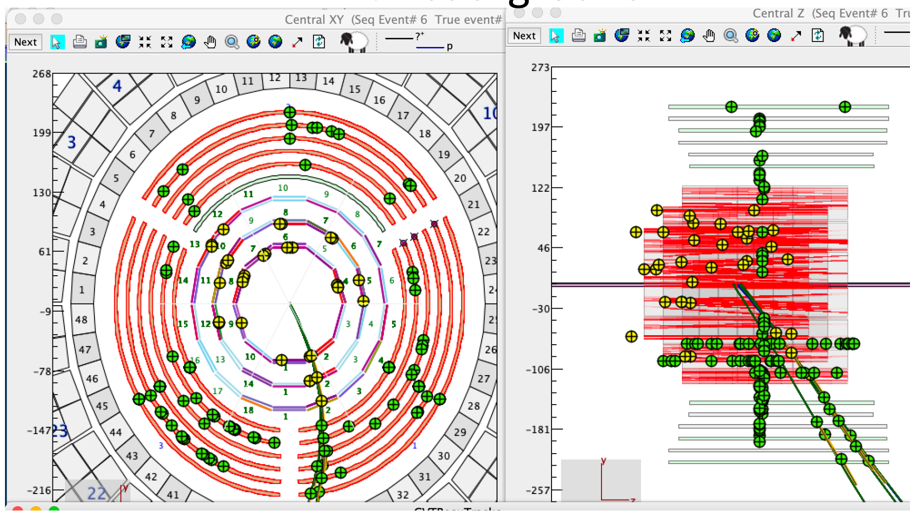
CVT tracking algorithms:

- Lines in RZ
- Arcs in XY
  - Hybrid system → combine 3 types of crosses
    - SVT → XY, Z (poor Z resolution) information
    - BMT-Z (strips along Z axis) → XY information
    - BMT-C → Z information (fairly good resolution)
  - BMT orthogonal coordinates
  - Need a way to connect XY with Z “crosses”
  - Use SVT (→ strips provide 3-D information) to connect XY with RZ components of the helical track candidate

CVT SEEDING with BMT: ALGORITHMS OVERVIEW



With background



SVT cross
BMT cross

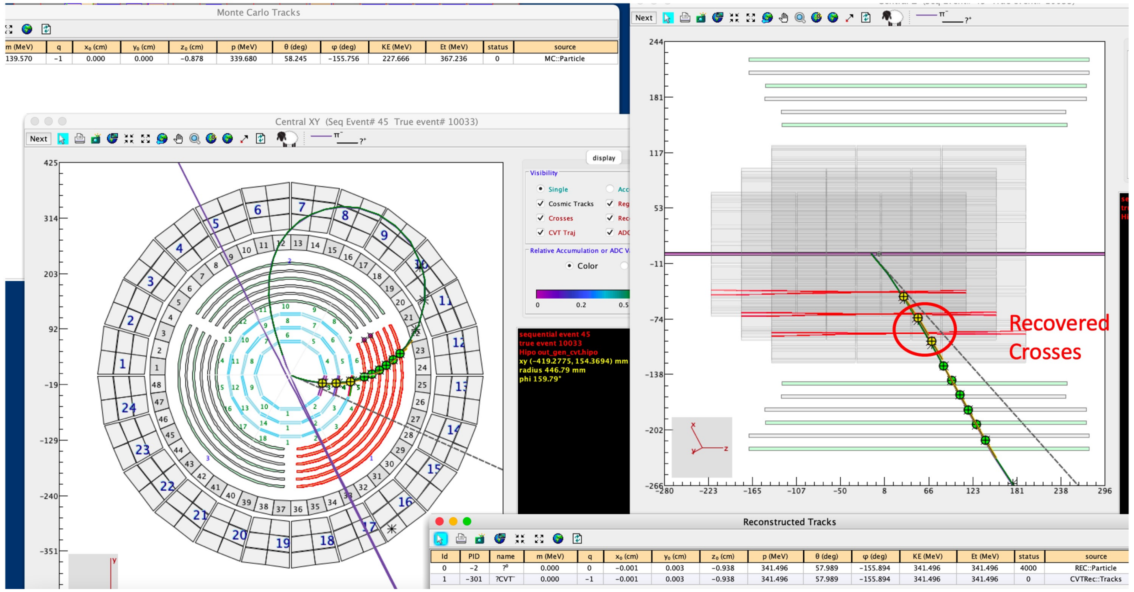
- **SVT Linker Algorithm (SLA, new algorithm running in place of CA)**
  - Find line using BMT C detector crosses (RZ Linker)
    - Select BMT C crosses in the same sector to get a RZ seed → fit gives helix dip-angle line
  - Match line to SVT cross cluster lines (XY Linker)
    - Save SVT crosses matched to the line to start arc seed
    - Employ Arc finding algorithm to match other crosses providing XY information
- **Clusters ON Track Recovery Algorithm (CONTRA)**
  - Find missing clusters on track using KF trajectory and refit the track to improve resolution – necessitates efficient seeding from SLA
- **SVTStandalone algorithm**
  - Works on SVT only crosses or on SVT+BMT tracks that do not have at least 2 BMT-C crosses

- Simple, efficient algorithms that improve resolution and seeding & tracking (after fit) efficiency

CVT SEEDING with SVT: ALGORITHMS OVERVIEW

Recovered track

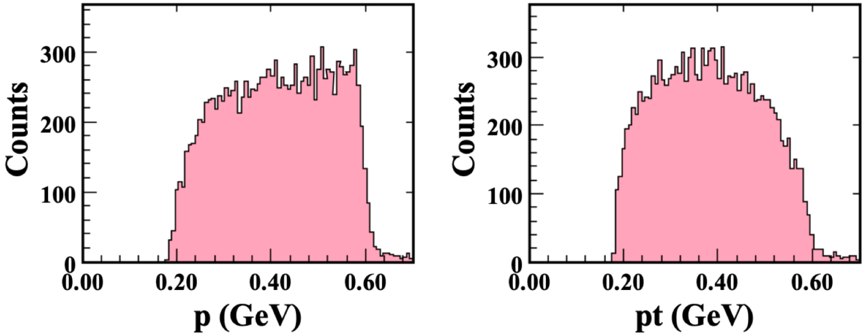
- MC π- single track event generated with 0.1<p<0.6 GeV
- With added clusters on track and redoing Pattern Recognition with the 2 additional crosses, the KF fit is successful



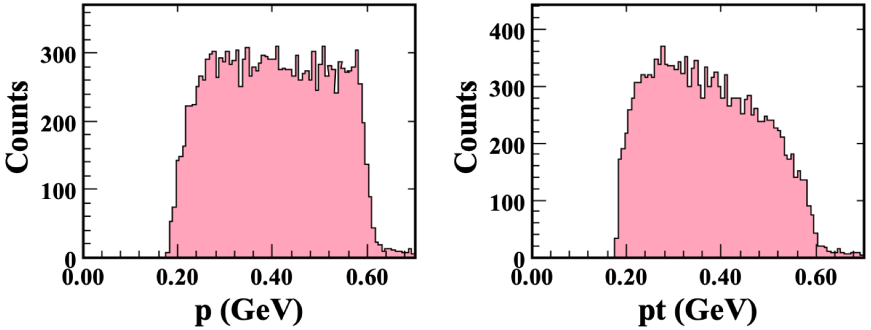
- **Low pt tracks Recovery**
  - Mitigation of track fit failures for low momentum tracks
    - Seed found but tracks fail Kalman fit
    - Due to poorer resolution at low momentum, clusters on track missing or hits rejected in fitting
      - Fit diverges (MS, Eloss)
      - Too many measurements get rejected
- **Recovery Procedure**
  - Find missing clusters on track using KF trajectory obtained without filtering and refit the track
  - If still fails, return seed
  - Failed tracks have negative status word to flag them in analysis

Reconstructed parameters for MC tracks with 0.1<p<0.6 GeV

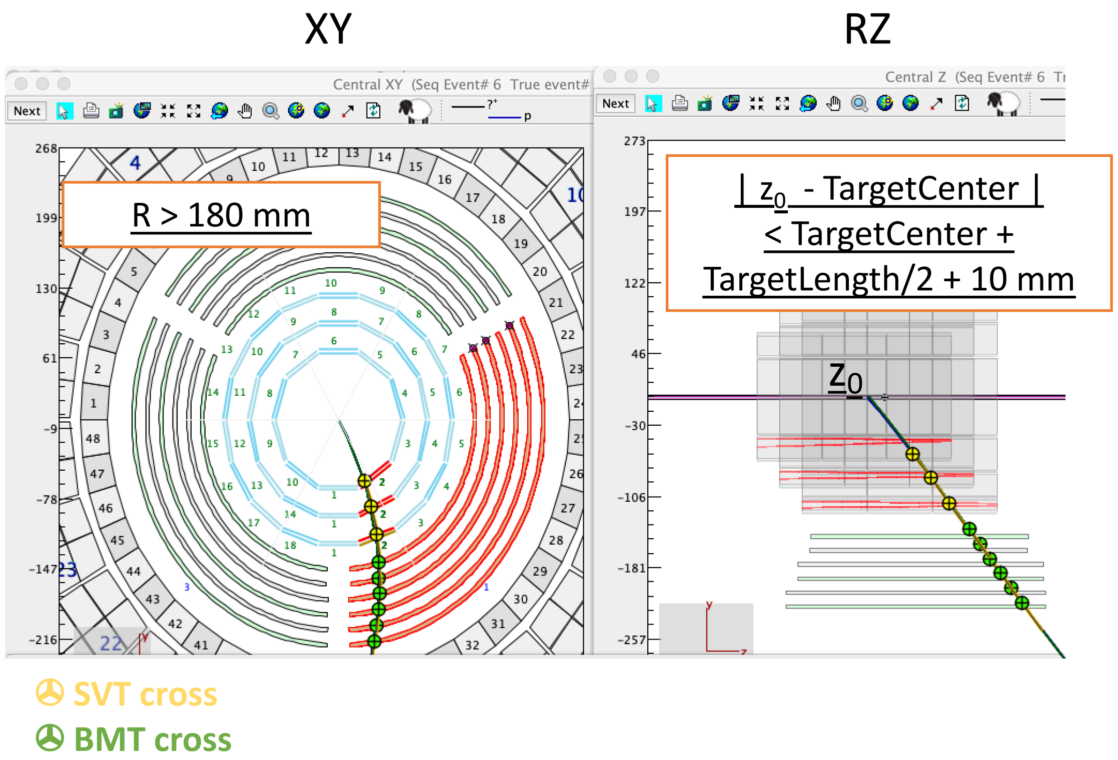
Without track recovery algorithm



With track recovery algorithm



CVT RECONSTRUCTION SELECTION CUTS



CVT tracking algorithms seed selection cuts:

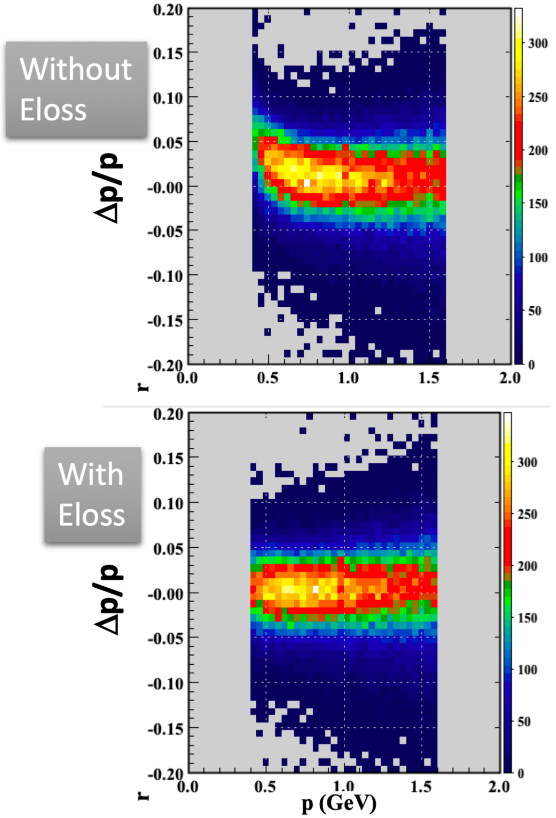
- Helix radius of curvature R >**180 mm** ➔minimum to reach CTOF
  - Mostly rejects low momentum pions for which PID can not be determined
  - Reduces combinatorials at seeding level
- Cut on helix z_0 w/in +/- **10 mm** of target length
  - Reduces combinatorials
  - Most tracks production vertex in that range
  - Minimal impact on exclusive hyperon reconstruction

CENTRAL TRACKER RECONSTRUCTION CODE FUNCTIONALITY

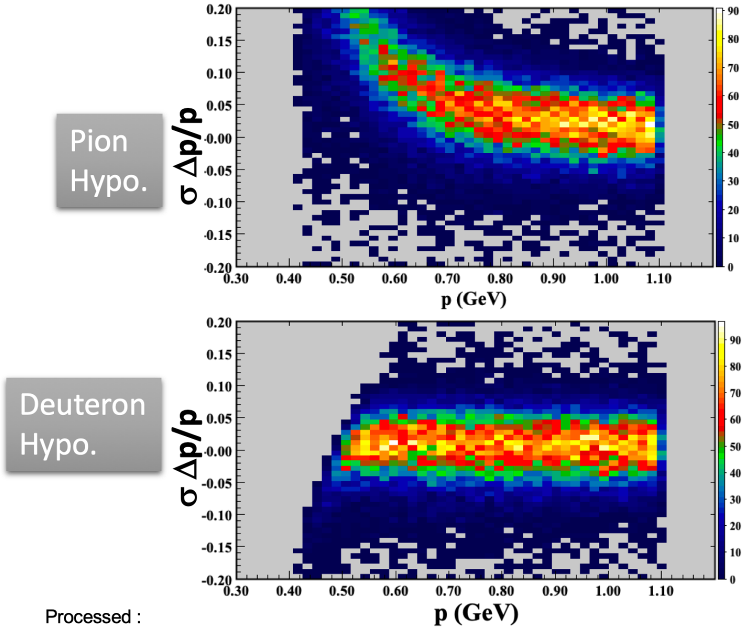
- Handling of detector **misalignments**
- KF **alignment** procedure, functionality for **alignment support, constants extraction and use in reconstruction**
- **Lorentz angle correc**tion for SVT and BMT
- Detector-agnostic library for KF-based tracking in solenoidal field with Kalman smoothing and **energy loss correction**
- Two-pass services for **Eloss PID** and beam spot constraint
  - ✓ 2-pass information for tracking and seeding to output banks
  - ✓ Saving track seeded with and without Beam spot constraint
    - ✓ Relevant for detached vertexes
    - ✓ Constraint improves resolution of tracks close to IP

Eloss PID MC samples

- Low p protons MC



- Deuteron momentum resolution with energy loss correction with pion and deuteron hypothesis



Processed :
- Including energy loss based on EB PID
- With latest CVT internal alignment and relative position of CD-FD based on beam-spot analysis
- Beam spot constraint on

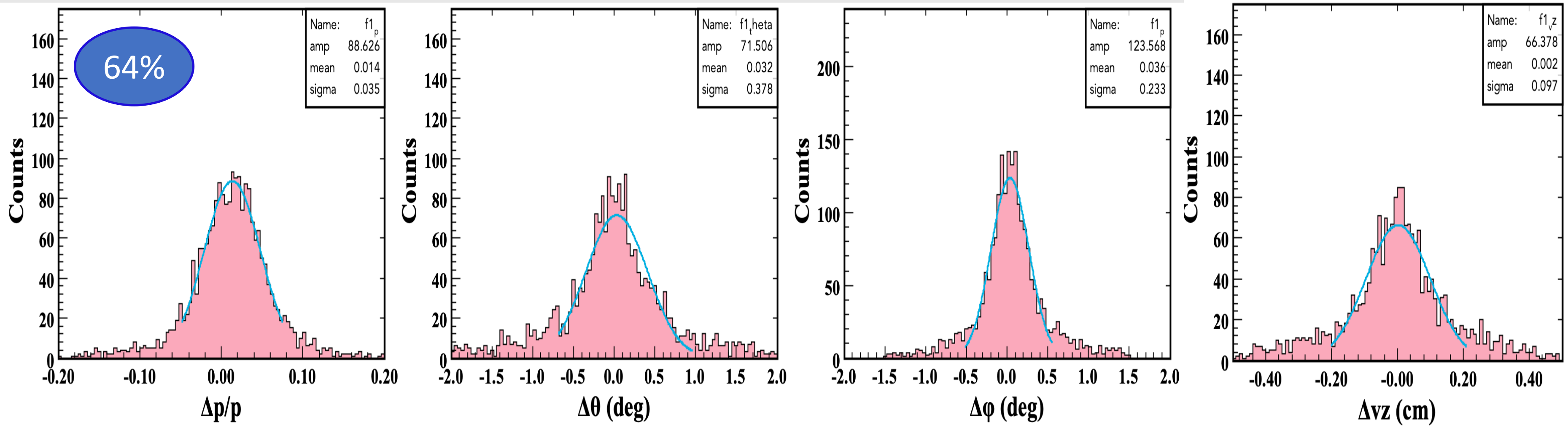
MC + Background Merging Validation Studies

Sample: protons 0.4-1.6 GeV

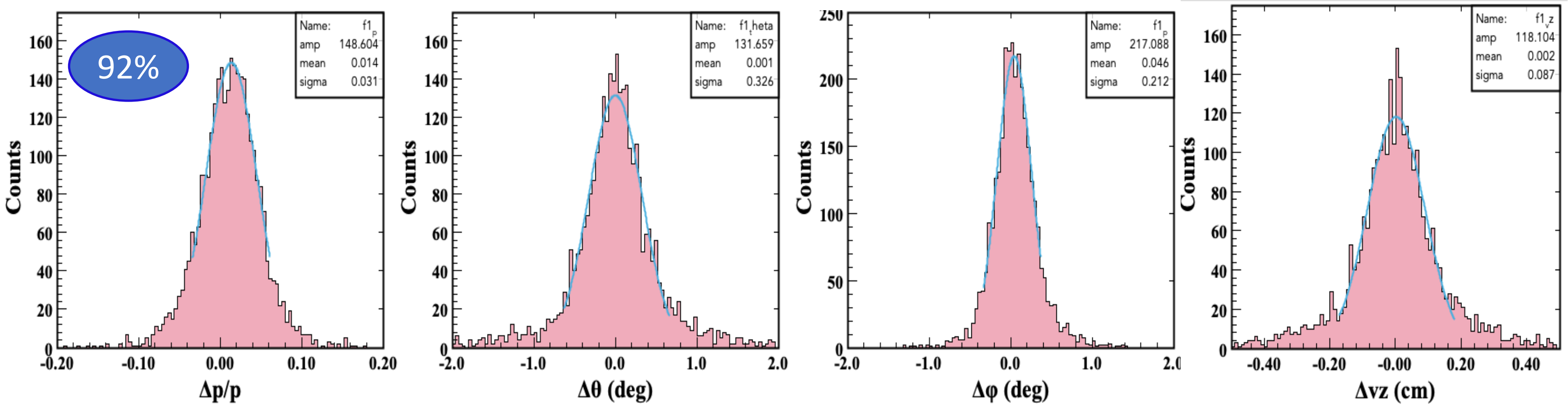
+ RGB 50 nA merged background

- Improvements in efficiency and resolution
- Next present improvements in data

Pass-1 Algorithms



Pass-2 Algorithms



- Reconstruction efficiency **(+28%, 5-σ cut)** & Resolution improvements
  - **11% in p**
  - **14% in θ**
  - **10% in ϕ**
  - **11% in Vz**
- Tails in resolution spectra reduced

MC + Background Merging Validation Studies

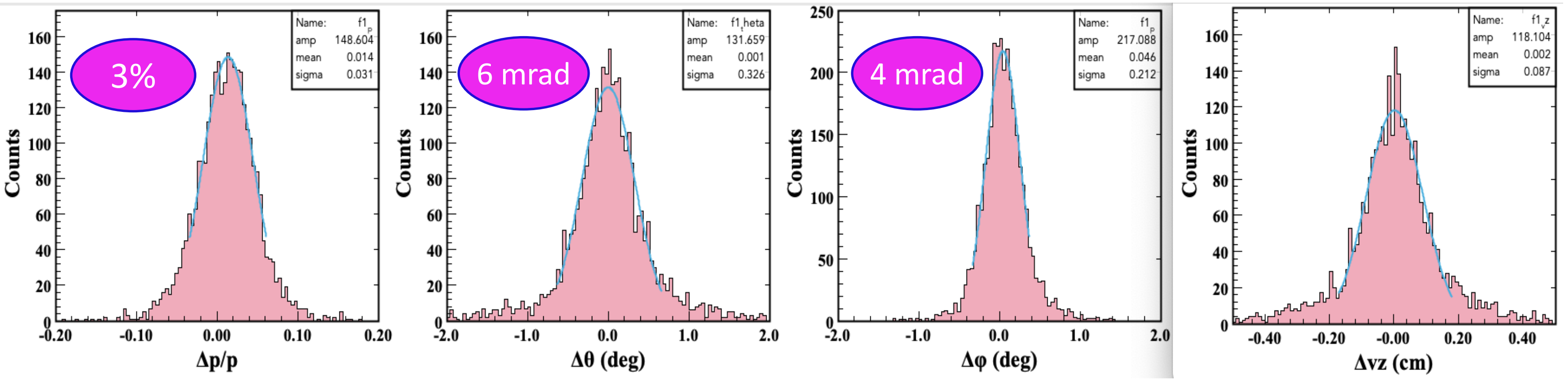
Sample: protons 0.4-1.6 GeV

+ RGB 50 nA merged background

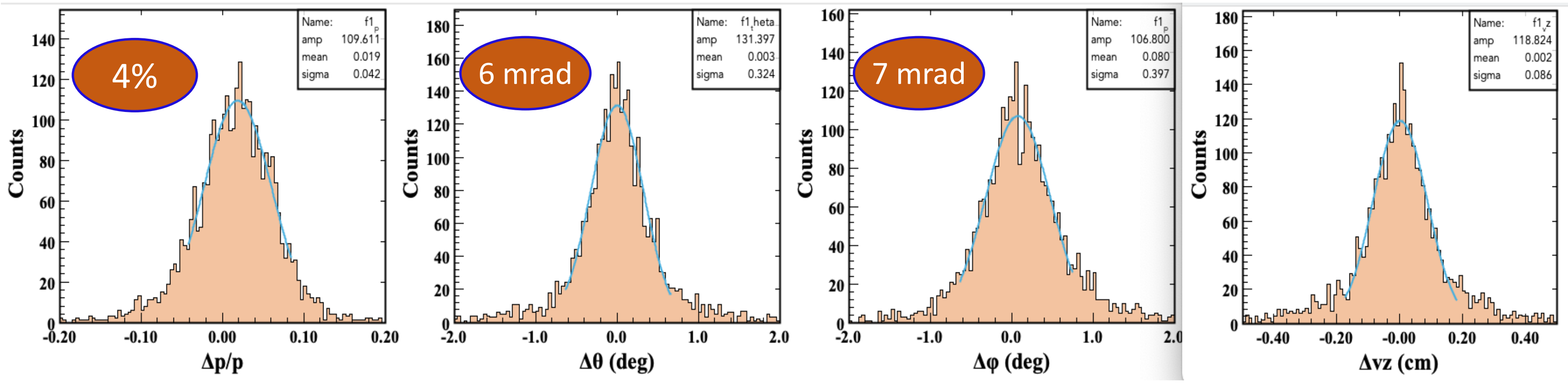
Pass-2 Algorithms

- Removing beam spot constraint from seeding and fitting results in poorer resolution in pt and phi (small level arm)
- However, still well within the CVT specs* for p and θ :
  - $\Delta p/p$: 5%,
  - $\Delta\theta$: 10 mrad,
  - $\Delta\varphi$: 5 mrad
- Ability to do tracking without beam spot constraint essential for the reconstruction of detached vertexes (slides 14-17)

With Beam Spot constraint



Without Beam Spot constraint



* Specs established for SVT 4 regions configuration

VALIDATIONS FROM THE RUN GROUPS

- Tag (8.5.0) produced for cooking data to do these studies
- Processing of the same runs with Pass-1 code and tag 8.5.0 to obtain physics-driven comparisons

- Relevant cuts
  - Z0 < 1 cm
  - R>180 mm

ANALYSES FROM THE RUN GROUPS

RGA

- Analysis **by Krishna Neupane** (UCSC, Columbia)
- Comparison of Pass1 and Pass2 cooking with new CVT tracking
- Analysis using runs 6712,6714,6716,6718,6728 (50 nA, production runs)

Analysis of topologies
$e\ p \rightarrow e\ p' \pi^+ \pi^-$

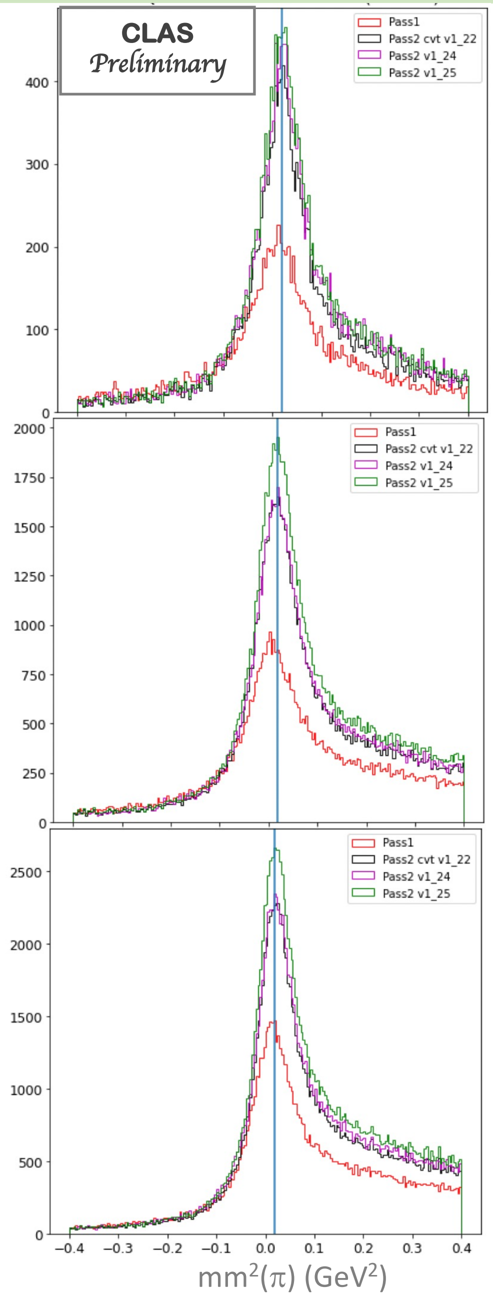
- Missing proton
- Missing π^-
- Missing π^+
- All particles detected

2-π channel, missing pion

- Missing π^-
- proton in Central Detector

- Missing π^-
- π^+ in Central Detector

- Missing π^+
- π^- in Central Detector



Significant improvements in yields in all 3 topologies (green after low momentum track recovery)

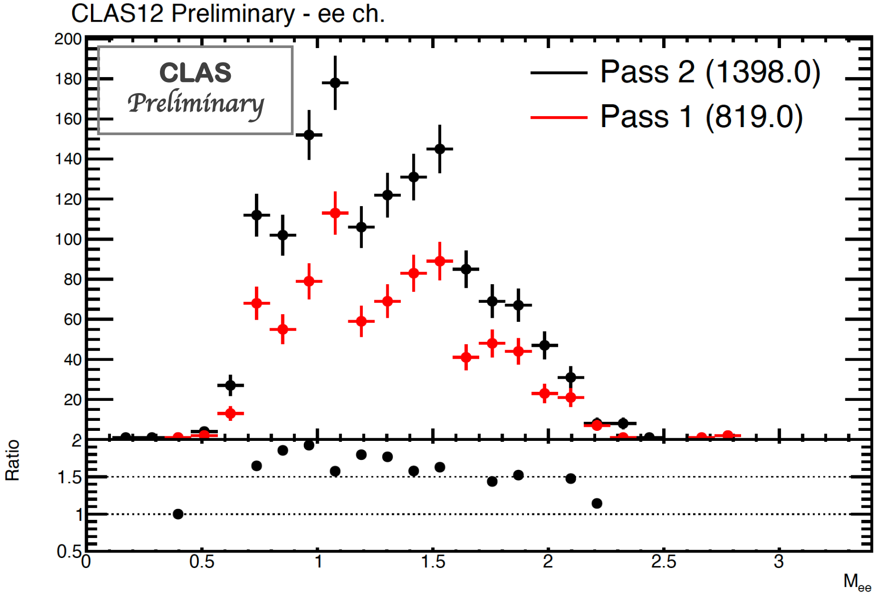
ANALYSES FROM THE RUN GROUPS

RGA

- Analysis **by Pierre Chatagnon** (JLAB)
- Comparison of Pass1 and Pass2 cooking with new CVT tracking
- Analysis using runs 6642, 6670, 6712, 6714, 6716, 6718, 6728, 6769 (50 nA, production runs)

M(e+e-) Spectra

- proton in Central Detector
- Significant improvement in yield



Analysis of TCS final state

$\gamma p \to e^{+-}e\, p'$

- M(e+e-)
- θ_{proton}

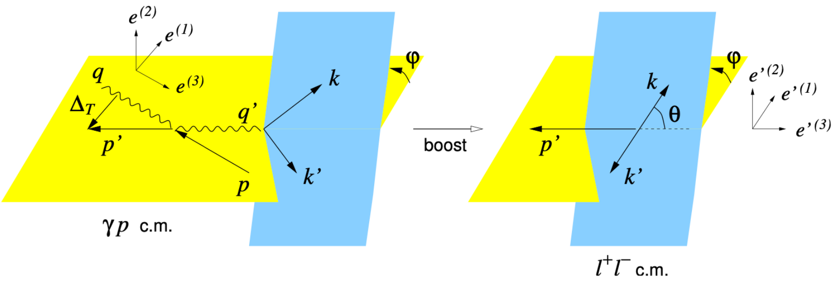
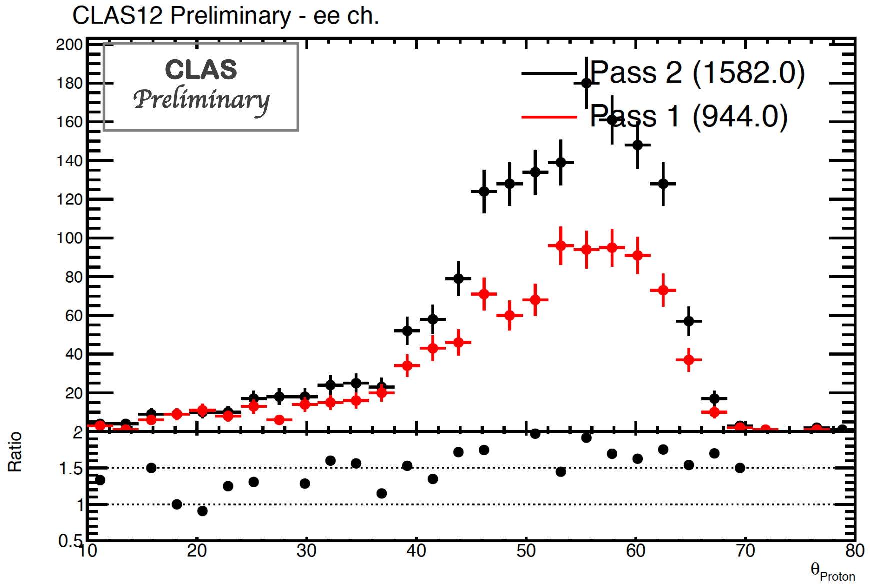


Figure in Berger et al., *EPJ C*, 2002

θ_{proton} Spectra

- visible enhancement in large θ region, corresponding to TCS events



θ_{proton} : angle between p' and e- in the e+e- cm frame

ANALYSES FROM THE RUN GROUPS

RGA

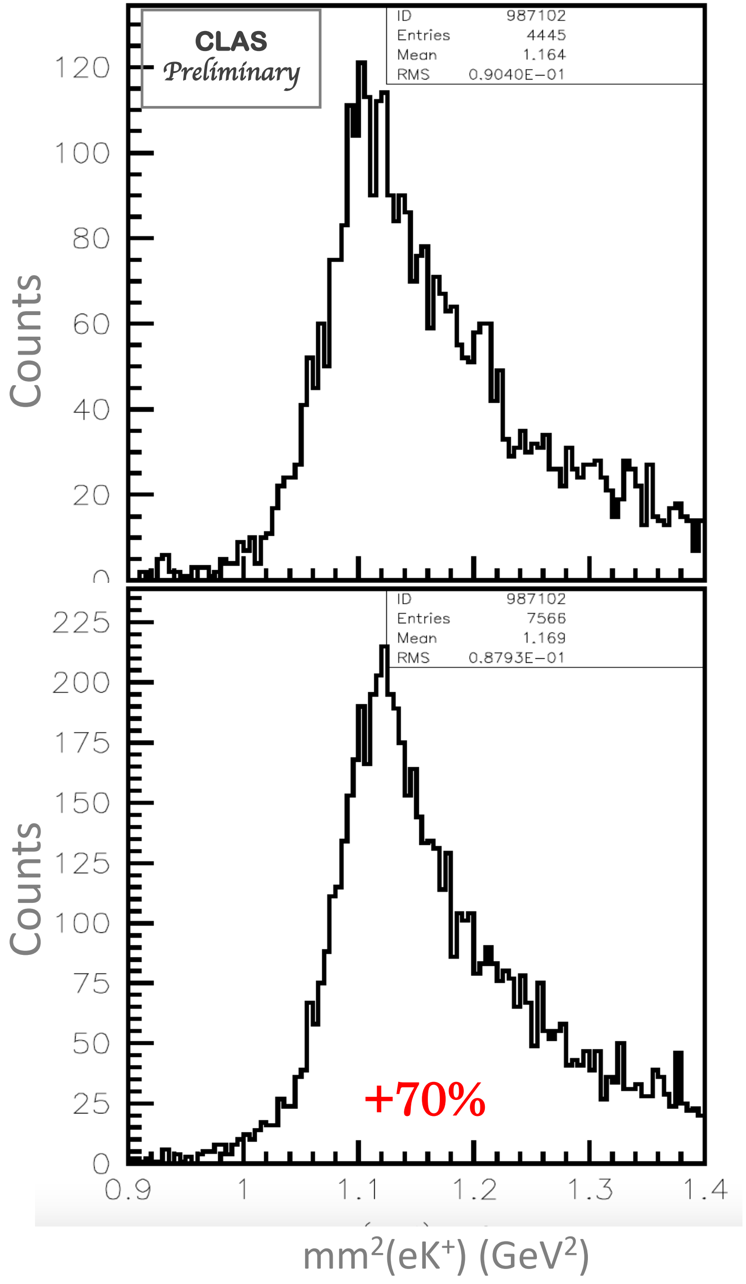
- Analysis **by Dan Carman** (JLAB)
- Comparison of Pass1 and Pass2 cooking with new CVT tracking
- Analysis using runs 6642, 6670, 6712, 6714, 6716, 6718, 6728, 6769 (50 nA, production runs)

- Electron reconstructed in the ECAL and K^+ in the Forward Detector
- Proton reconstructed in the Central Detector
- To obtain $MM^2(e'K^+)$ spectra
  - Cut on the $MM^2(e'K^+p)$ distribution to select the ground state hyperons

<u>Analysis of final state</u>
<u>e p -> e' K^+ p' π^-</u>

- Using eK+ analysis train
- Hyperon reconstruction by missing mass
- Kaon tagging

- Significant improvement in number of reconstructed events



ANALYSES FROM THE RUN GROUPS

RGA

- Analysis **by Dan Carman** (JLAB)
- Comparison of Pass1 and Pass2 cooking with new CVT tracking
- Analysis using runs 6642, 6670, 6712, 6714, 6716, 6718, 6728, 6769 (50 nA, production runs)

Analysis of final state
$e\ p \rightarrow e'\ K^+\ p'\ \pi^-$

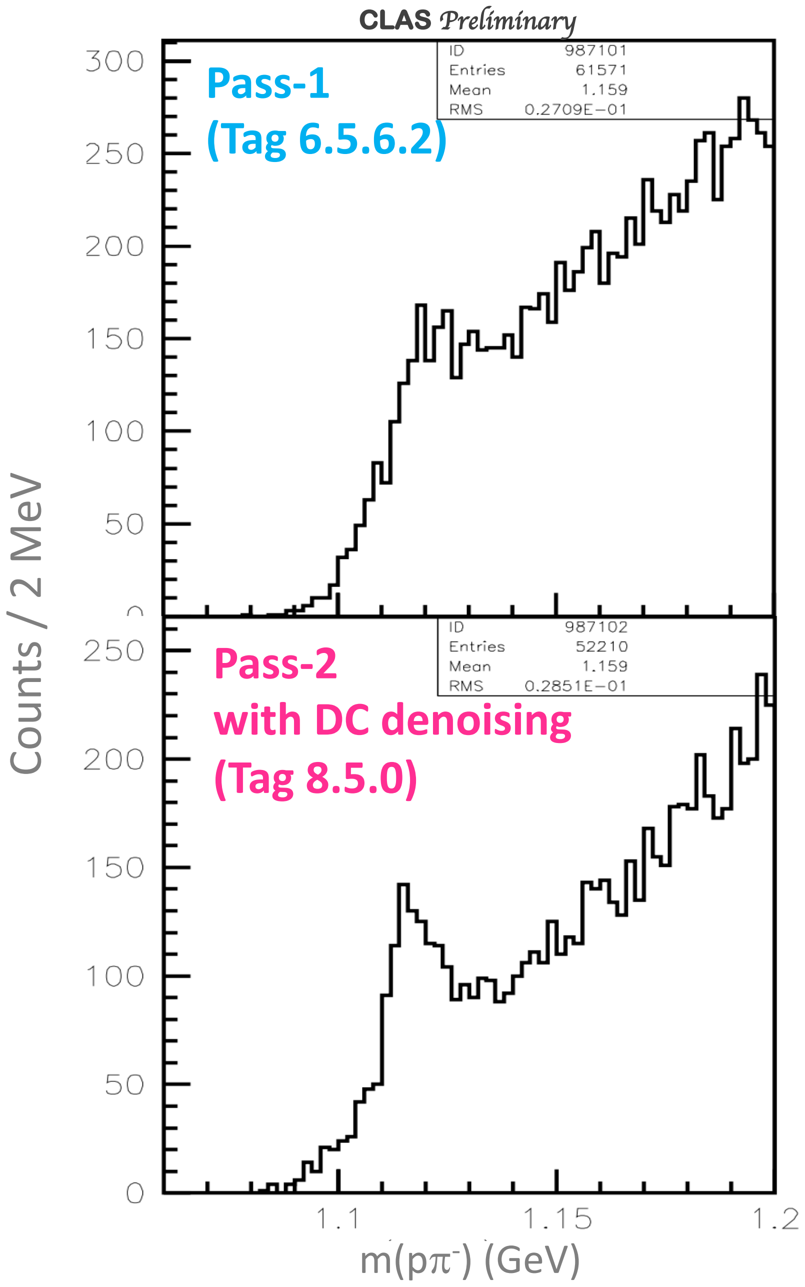
- Using eK+ analysis train
- Kaon tagging

($p\ \pi-$) invariant mass spectra

- p in Forward Detector
- π^- in Central Detector

No vertexing to reconstruct the invariant mass
No correction of the track parameters

- ➢ Significant improvement in number of Λ reconstructed candidates



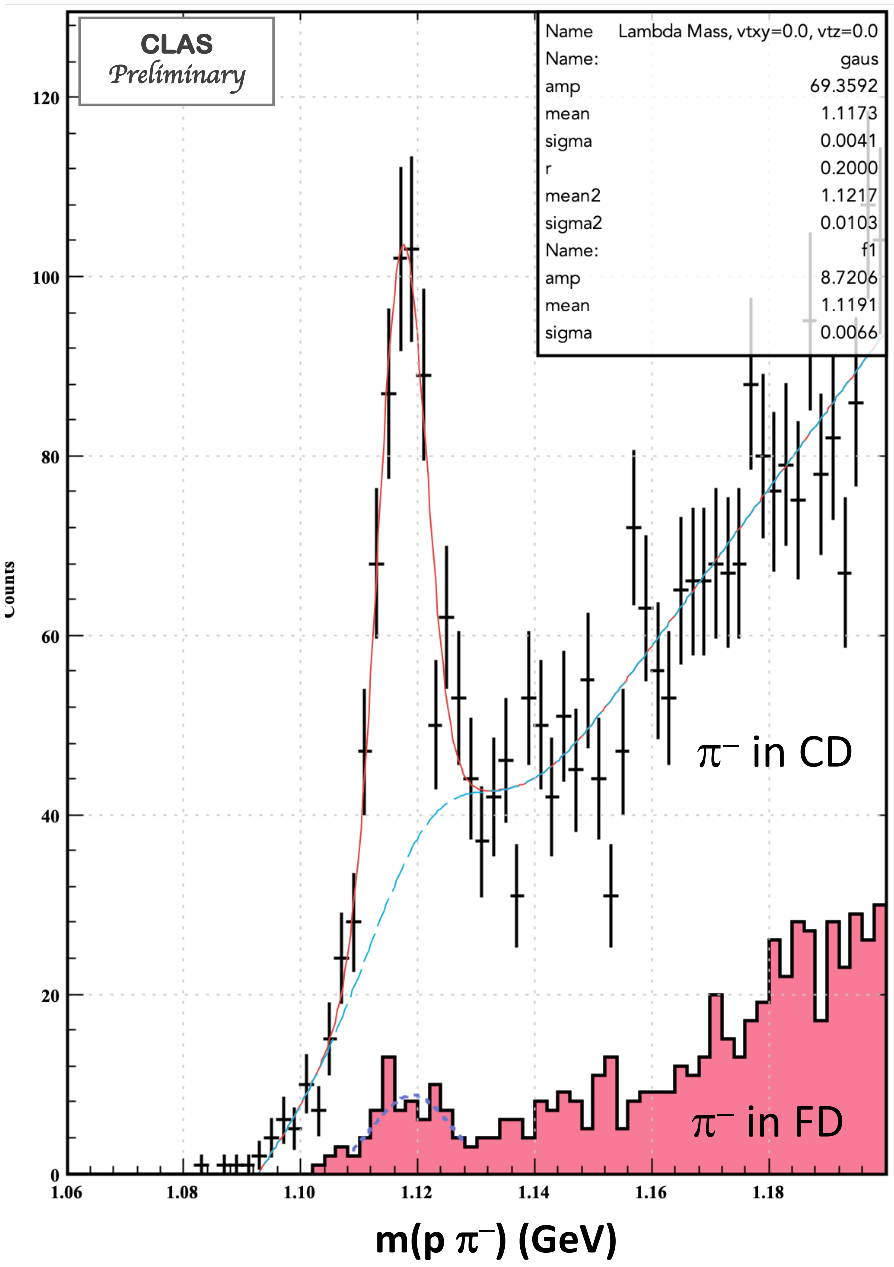
ANALYSES FROM THE RUN GROUPS

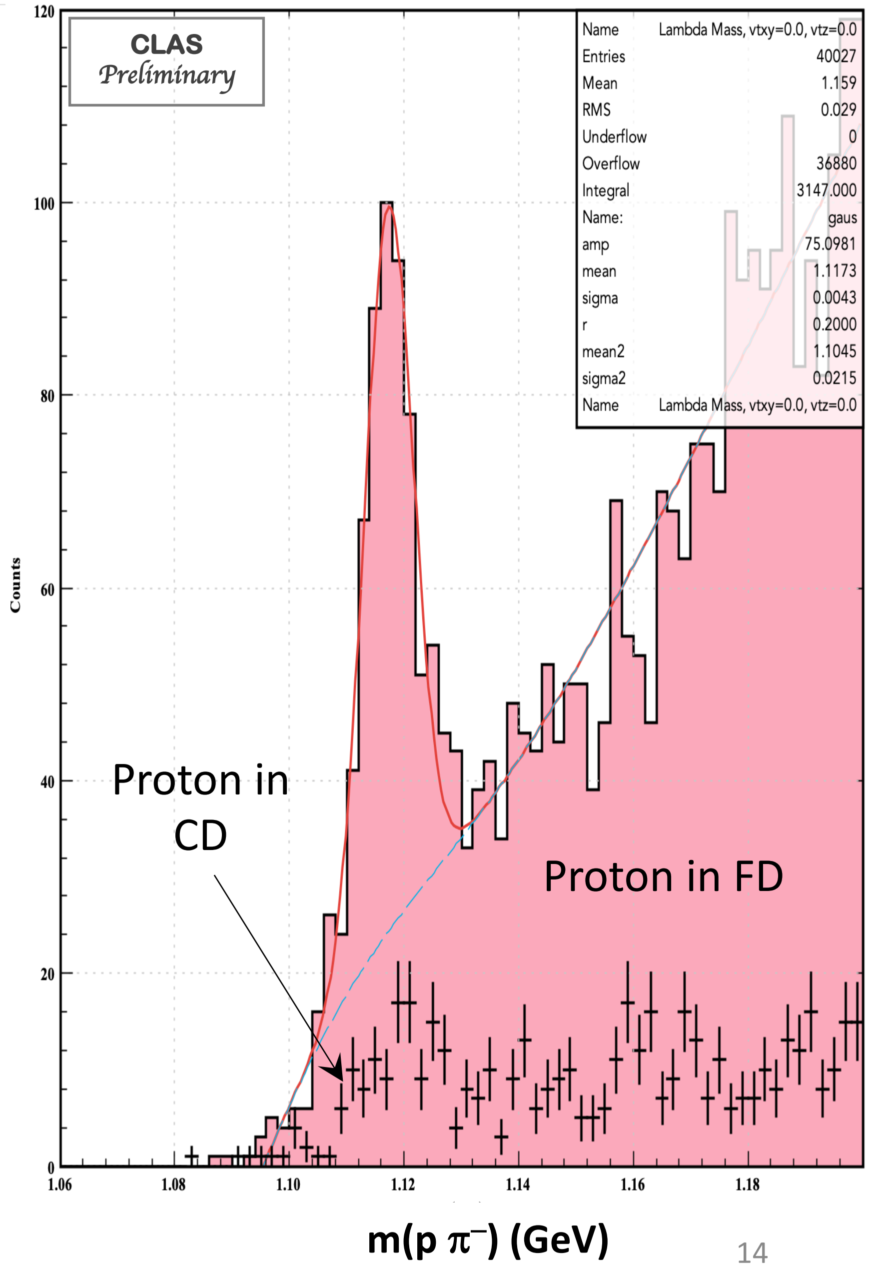
RGA

- Exclusive $\Lambda \rightarrow p\pi^-$ reconstruction
- Analysis using runs 6642, 6670, 6712, 6714, 6716, 6718, 6728, 6769 (50 nA, production runs)
- Events from eK+ analysis train

- Electron reconstructed in the ECAL and K^+ in the Forward or in the Central Detector
- Proton goes mostly in the Forward Detector
- Pion goes mostly in the Central Detector

- Vertexing to select ($p\pi^-$) & propagate track parameters to the displaced vertex
- Require that DOCA between the p and the π^- < 1.2 cm



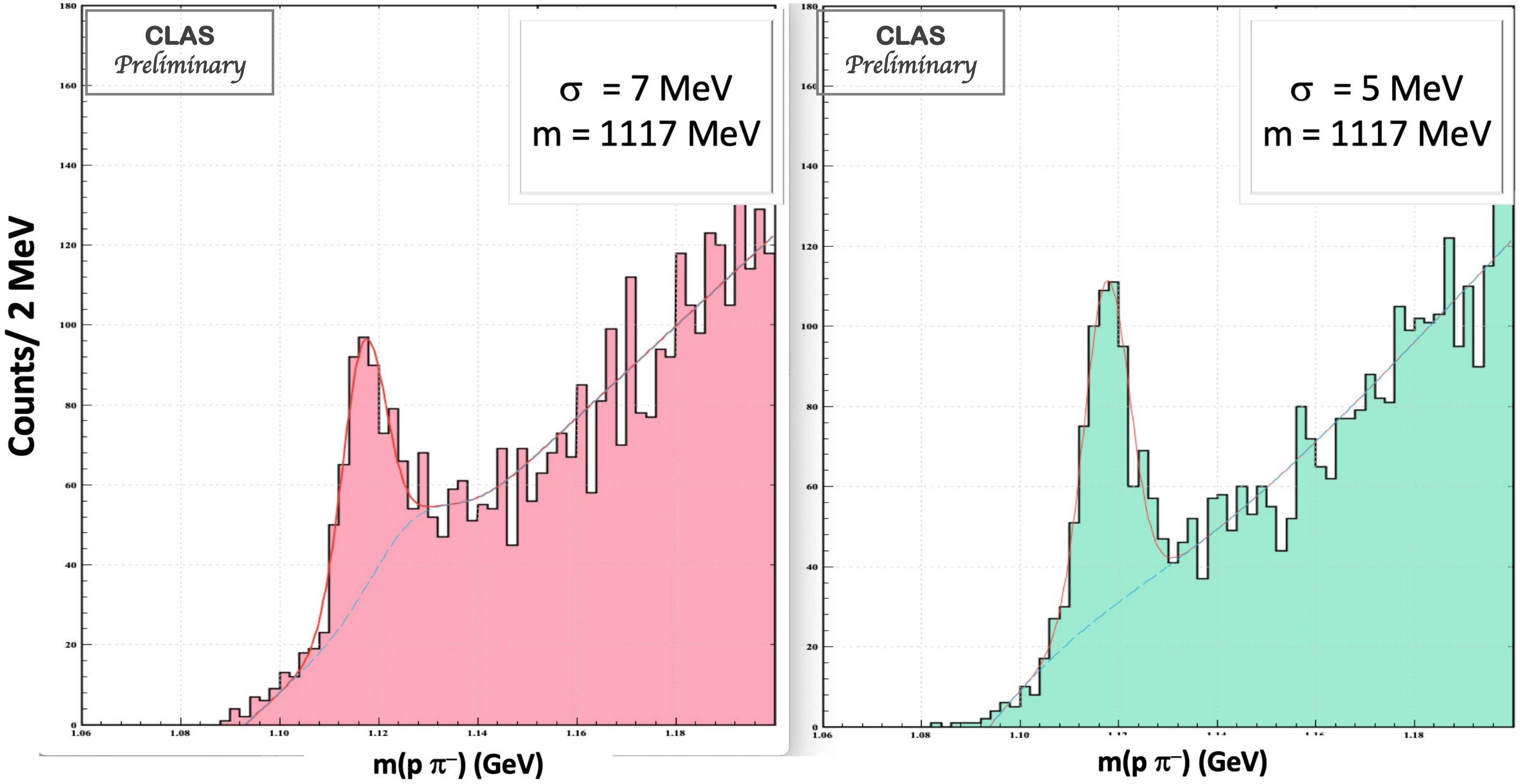


VERTEXING WITH CVT TRACKS

- For $\Lambda \rightarrow p\pi^-$, the vertex is displaced; the parameters of the track in the REC bank are not at the Lambda vertex
  - Biases the distribution even in the case where a peak could be found
- In order to properly compute the Λ invariant mass by 4-momentum addition, it is necessary to get the Λ decay track parameters at the Λ decay vertex
- Use the CVT U-Track information for tracks reconstructed in central detector (no beam constraint in seeding and fitting)
- The detached Λ decay vertex can also provide a powerful handle to reject background candidates

Use track parameters from REC::Particle bank → no propagation of parameters to the reconstructed vertex

Use track parameters at the reconstructed vertex (CVT UTracks)



- Require doca between vertexed tracks <1.2 cm

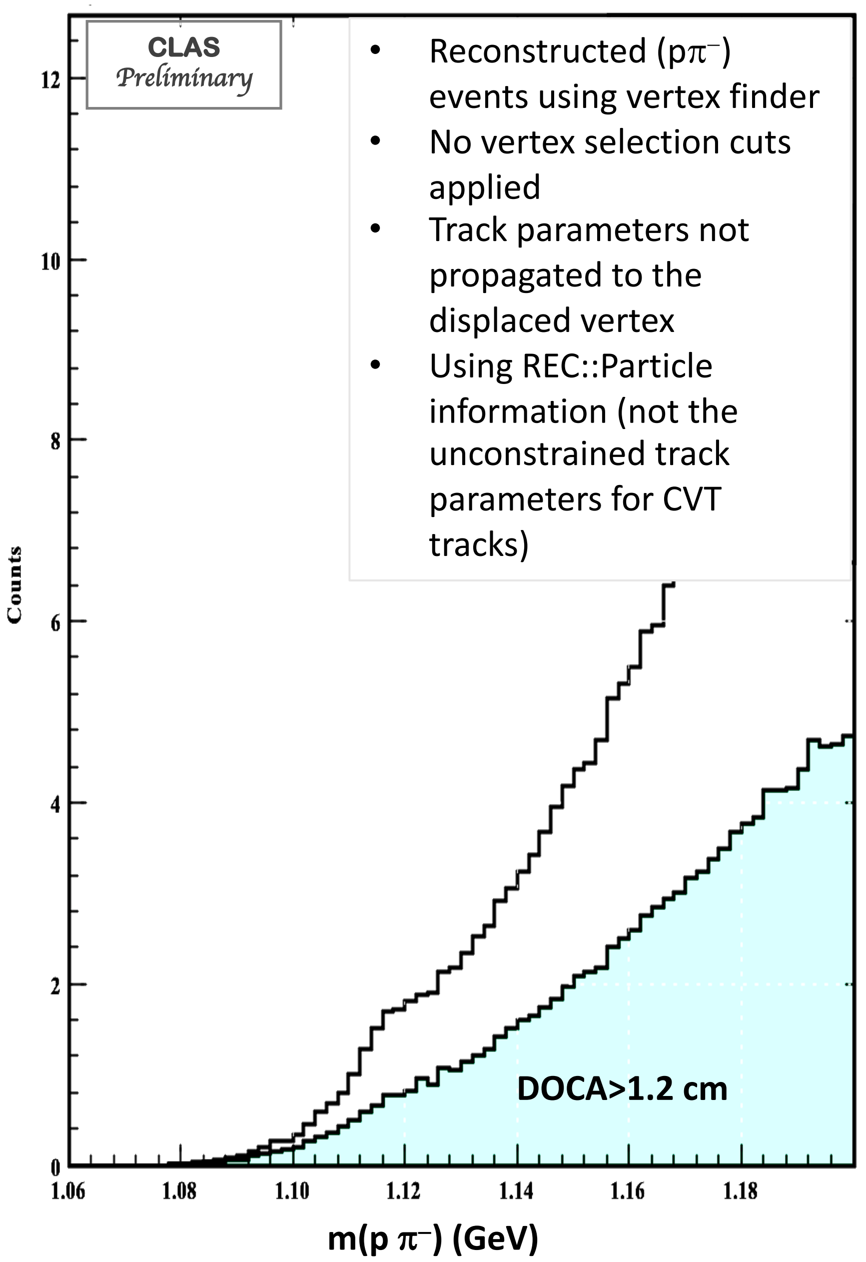
ANALYSES FROM THE RUN GROUPS

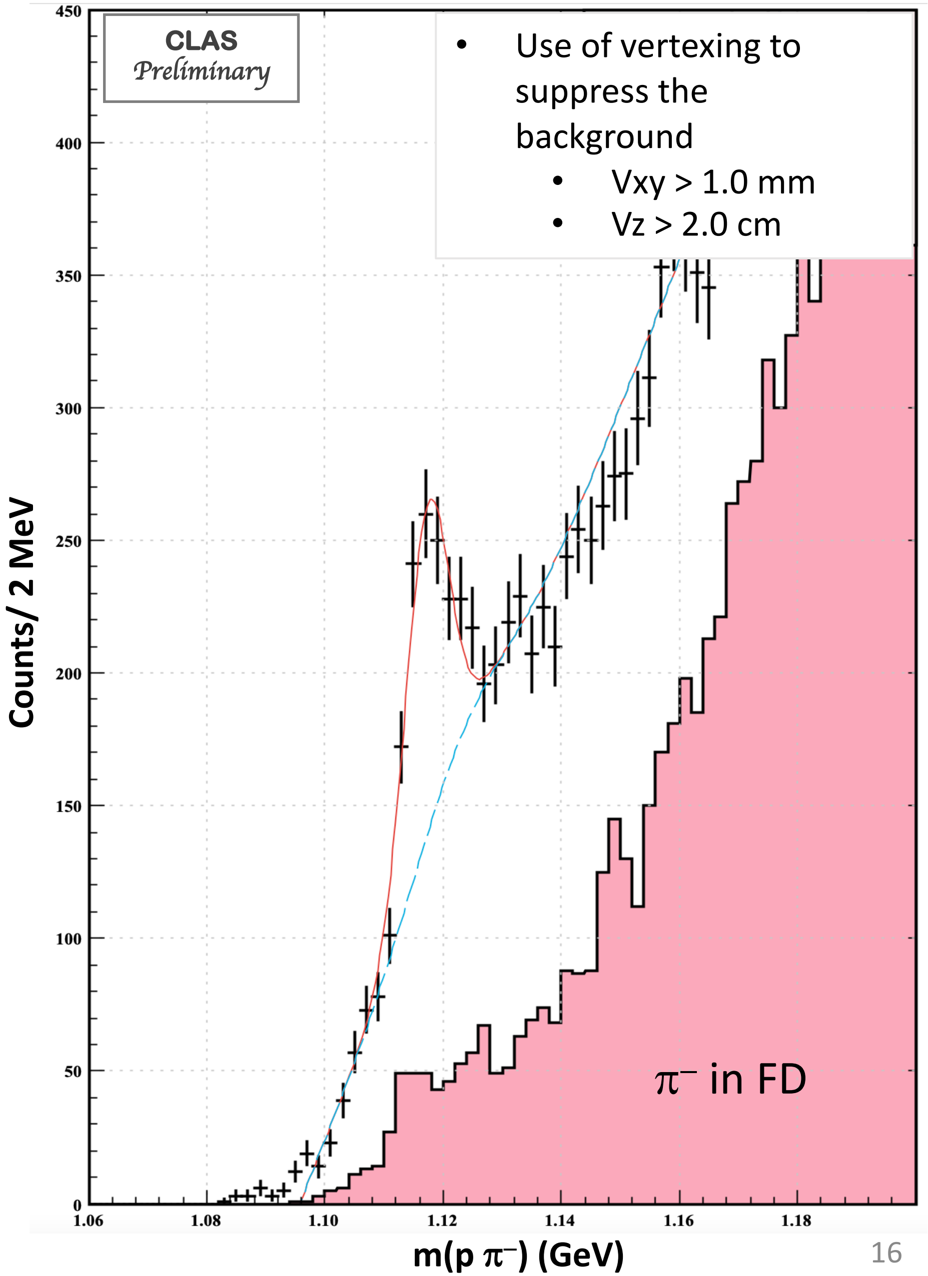
RGA

- Exclusive $\Lambda \rightarrow p\pi^-$ reconstruction (SIDIS events)
- Analysis using runs 6642, 6670, 6712, 6714, 6716, 6718, 6728, 6769 (50 nA, production runs)
- **Events from nSidis train**

- Electron reconstructed in the ECAL
- Proton goes mostly in the Forward Detector
- Pion goes mostly in the Central Detector

- Using vertexing to select $(p\pi^-)$ candidates
- Require that DOCA between the p and the π^- < 1.2 cm
- Cut on displaced vertex





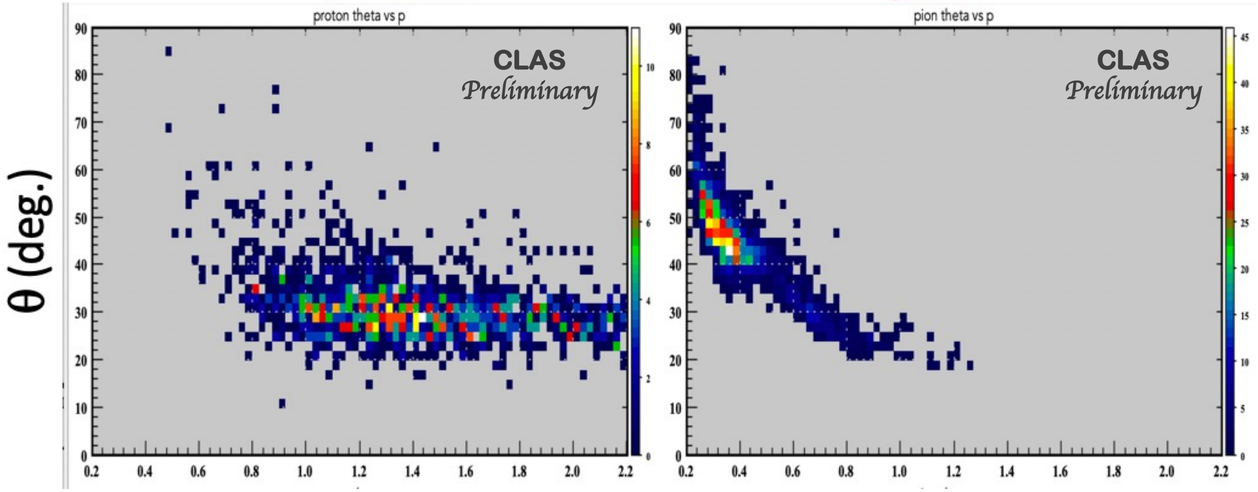
ANALYSES FROM THE RUN GROUPS

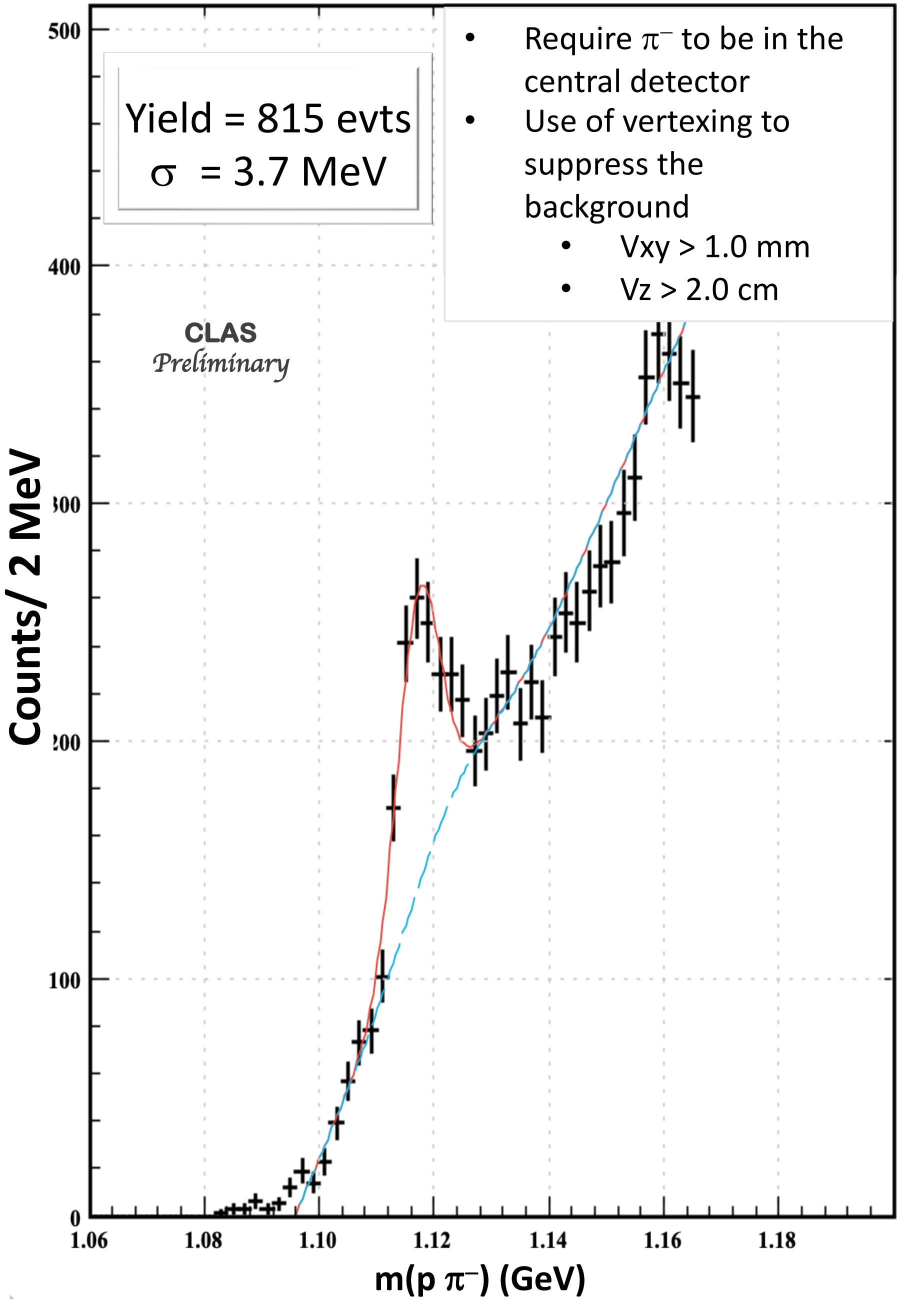
Events from nSidis train

- Since most signal pions go to the Central Detector, the requirement to use CD π^- candidates significantly reduces the Λ signal background
- These pions are low momentum → low momentum tracks reconstruction in the CVT using Track Recovery algorithm

Λ signal region

$1.11 < m(p\pi^-) < 1.124$ GeV





- Require π^- to be in the central detector
- Use of vertexing to suppress the background
  - Vxy > 1.0 mm
  - Vz > 2.0 cm

LUMINOSITY SCAN

- Analysis **by Davit Martiryan** (U. Yerevan)
- Analysis using runs 6616 (5 nA), 6618, 6723 (10 nA), 6642, 6670, 6712, 6714, 6716, 6718, 6728, 6769 (50 nA) production runs

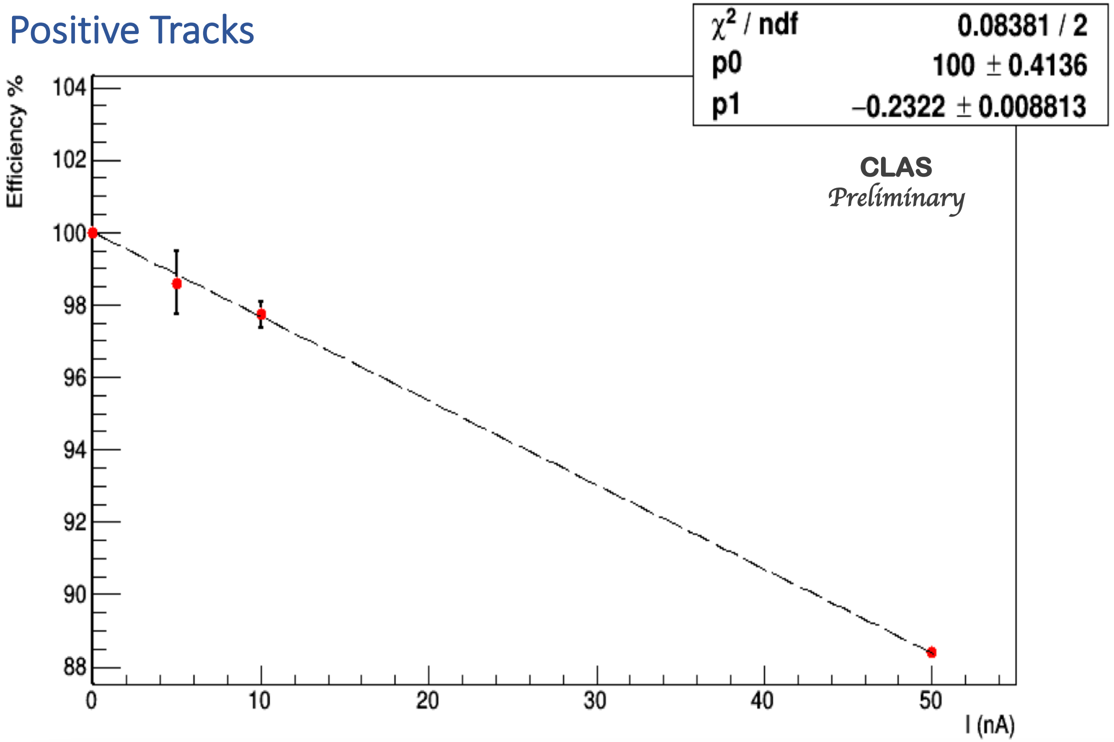
- **Electron**
  - Pid=11
  - P>2 GeV
  - 2000<|status|<4000
- **Positive particle**
  - Pid=211
  - P>0.4 GeV
  - |status|>4000
  - |chi2|<3
- **Negative particle**
  - Pid=-211
  - P>0.4 GeV
  - |status|>4000
  - |chi2|<3

- Selected events: e- in Forward Detector + hadron in Central Detector

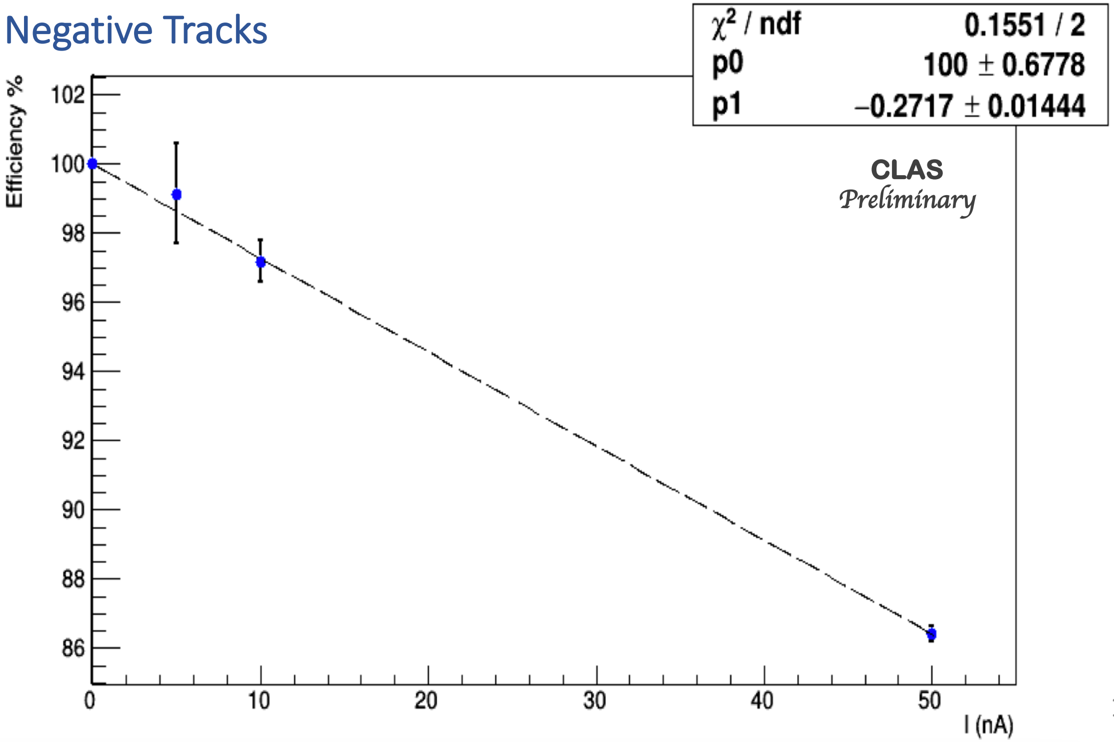
Efficiency loss ~0.3% / nA

- RGB di-hadron analysis → efficiency loss ~0.4% / nA, a factor >2 improvement over pass-1

Positive Tracks

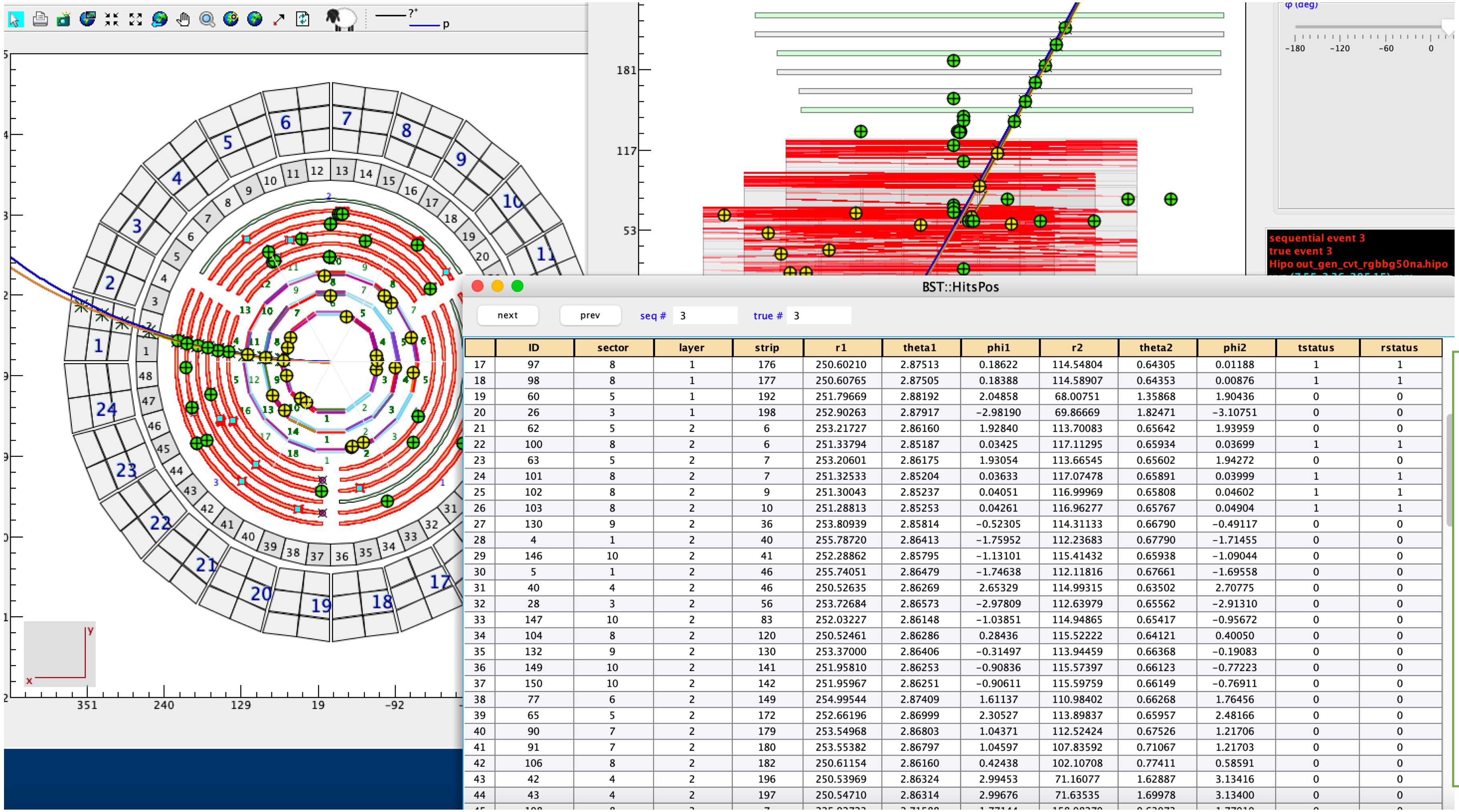


Negative Tracks



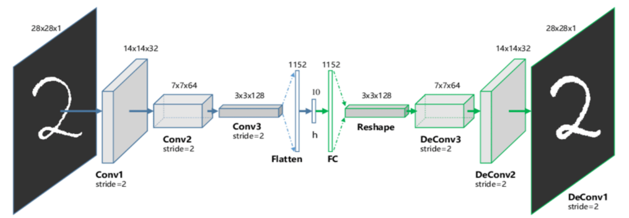
CVT RECONSTRUCTION WITH AI PLANS

- Use of a dedicated bank for training the Network
- Development and validation on MC + merged background samples
- Use existing hit order variable to flag generated hits on track

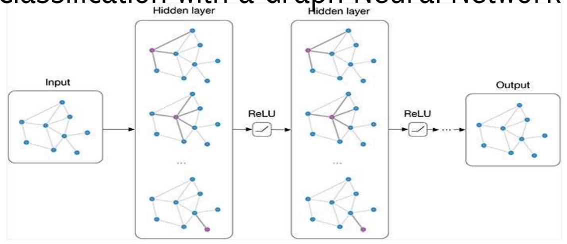


	ID	sector	layer	strip	r1	theta1	phi1	r2	theta2	phi2	tstatus	rstatus
17	97	8	1	176	250.60210	2.87513	0.18622	114.54804	0.64305	0.01188	1	1
18	98	8	1	177	250.60765	2.87505	0.18388	114.58907	0.64353	0.00876	1	1
19	60	5	1	192	251.79669	2.88192	2.04858	68.00751	1.35868	1.90436	0	0
20	26	3	1	198	252.90263	2.87917	−2.98190	69.86669	1.82471	−3.10751	0	0
21	62	5	2	6	253.21727	2.86160	1.92840	113.70083	0.65642	1.93959	0	0
22	100	8	2	6	251.33794	2.85187	0.03425	117.11295	0.65934	0.03699	1	1
23	63	5	2	7	253.20601	2.86175	1.93054	113.66545	0.65602	1.94272	0	0
24	101	8	2	7	251.32533	2.85204	0.03633	117.07478	0.65891	0.03999	1	1
25	102	8	2	9	251.30043	2.85237	0.04051	116.99969	0.65808	0.04602	1	1
26	103	8	2	10	251.28813	2.85253	0.04261	116.96277	0.65767	0.04904	1	1
27	130	9	2	36	253.80939	2.85814	−0.52305	114.31133	0.66790	−0.49117	0	0
28	4	1	2	40	255.78720	2.86413	−1.75952	112.23683	0.67790	−1.71455	0	0
29	146	10	2	41	252.28862	2.85795	−1.13101	115.41432	0.65938	−1.09044	0	0
30	5	1	2	46	255.74051	2.86479	−1.74638	112.11816	0.67661	−1.69558	0	0
31	40	4	2	46	250.52635	2.86269	2.65329	114.99315	0.63502	2.70775	0	0
32	28	3	2	56	253.72684	2.86573	−2.97809	112.63979	0.65562	−2.91310	0	0
33	147	10	2	83	252.03227	2.86148	−1.03851	114.94865	0.65417	−0.95672	0	0
34	104	8	2	120	250.52461	2.86286	0.28436	115.52222	0.64121	0.40050	0	0
35	132	9	2	130	253.37000	2.86406	−0.31497	113.94459	0.66368	−0.19083	0	0
36	149	10	2	141	251.95810	2.86253	−0.90836	115.57397	0.66123	−0.77223	0	0
37	150	10	2	142	251.95967	2.86251	−0.90611	115.59759	0.66149	−0.76911	0	0
38	77	6	2	149	254.99544	2.87409	1.61137	110.98402	0.66268	1.76456	0	0
39	65	5	2	172	252.66196	2.86999	2.30527	113.89837	0.65957	2.48166	0	0
40	90	7	2	179	253.54968	2.86803	1.04371	112.52424	0.67526	1.21706	0	0
41	91	7	2	180	253.55382	2.86797	1.04597	107.83592	0.71067	1.21703	0	0
42	106	8	2	182	250.61154	2.86160	0.42438	102.10708	0.77411	0.58591	0	0
43	42	4	2	196	250.53969	2.86324	2.99453	71.16077	1.62887	3.13416	0	0
44	43	4	2	197	250.54710	2.86314	2.99676	71.63535	1.69978	3.13400	0	0

Denoising with a Convolutional Auto Encoder



Classification with a Graph Neural Network

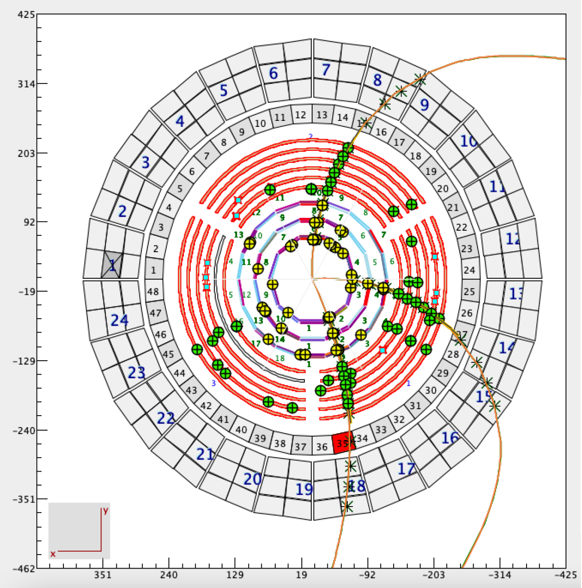


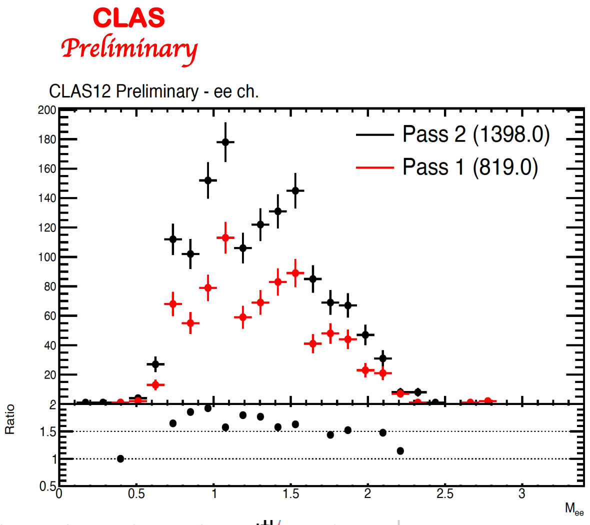
- tstatus (MC truth status)
  - 0: generated hit on track
  - 1: generated hit not on track
- rstatus (reconstruction status)
  - 0: hit not assigned to track by reco algorithm
  - 1: hit assigned to track by reco algorithm

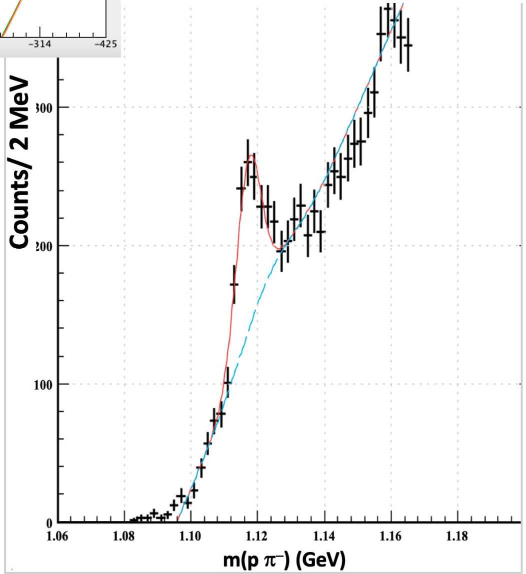
CVT EFFICIENCY CODE DEVELOPMENT: STATUS & PLANS

- **Current Status**
  - Detailed validation studies (MC+Bg, 5nA+RGA(B) events)
    - Significant improvements in efficiency and resolution
    - Physics gain
  - Code stable
  - New CVT code > ~2 x faster
  - In use for Pass-2 cooking

- **Next Steps**
  - Use of AI for further efficiency improvements (Pass-3)







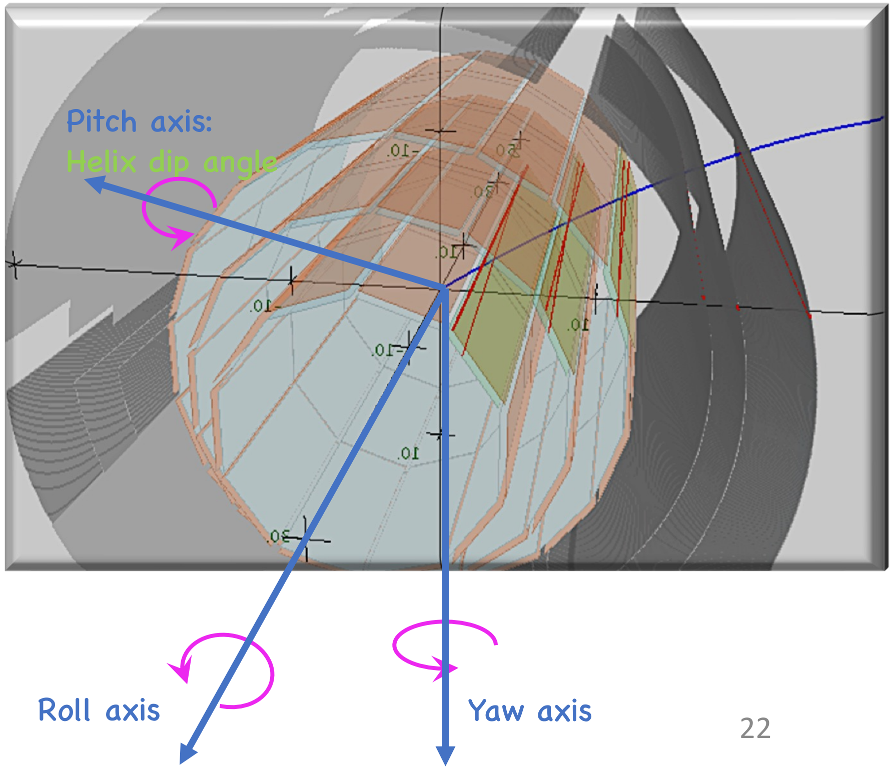
BACK-UP SLIDES

NEW CVT TRACKING ALGORITHMS (1)

New algorithm SVT Linker Algorithm (SLA):

- Find line using BMT C detector crosses (RZ Linker)
  - Select BMT C crosses in the same sector to get a RZ seed → fit gives helix dip-angle line
    - Can have 2 or 3 crosses. If 3 regions have hits in a sector, look for 3-cross line candidates: if 3 crosses well represented by a line, save RZ seed. If only 2 regions have hits, save 2-cross RZ seeds. (Working on handling dead zones in BMT sector).
  - Only search if there are SVT crosses in same angular range (corresponding to BMT sector)
  - Check that the intercept with the beam line is within target length range (target center +/- target length + jitter)

- Match line to SVT cross cluster lines (XY Linker)
  - SVT cross has top and bottom clusters represented by line
  - Roll the dip-angle line so that it's angle in the XY plane coincides with the azimuth angle of cross we are attempting to match. If doca within a selection cut (optimized on MC at this stage), pass the cross as a match. If more than one cross in a layer is a candidate, select the closest one to the strip
  - Repeat for all SVT regions, where there is at least one SVT cross
  - Save SVT crosses matched to the line to start arc seed
  - Employ Arc finding algorithm
    - Phi space search similar to a HT algorithm → fill accumulator array and get crosses belonging to peaks
    - If circle fit is OK, save the seed

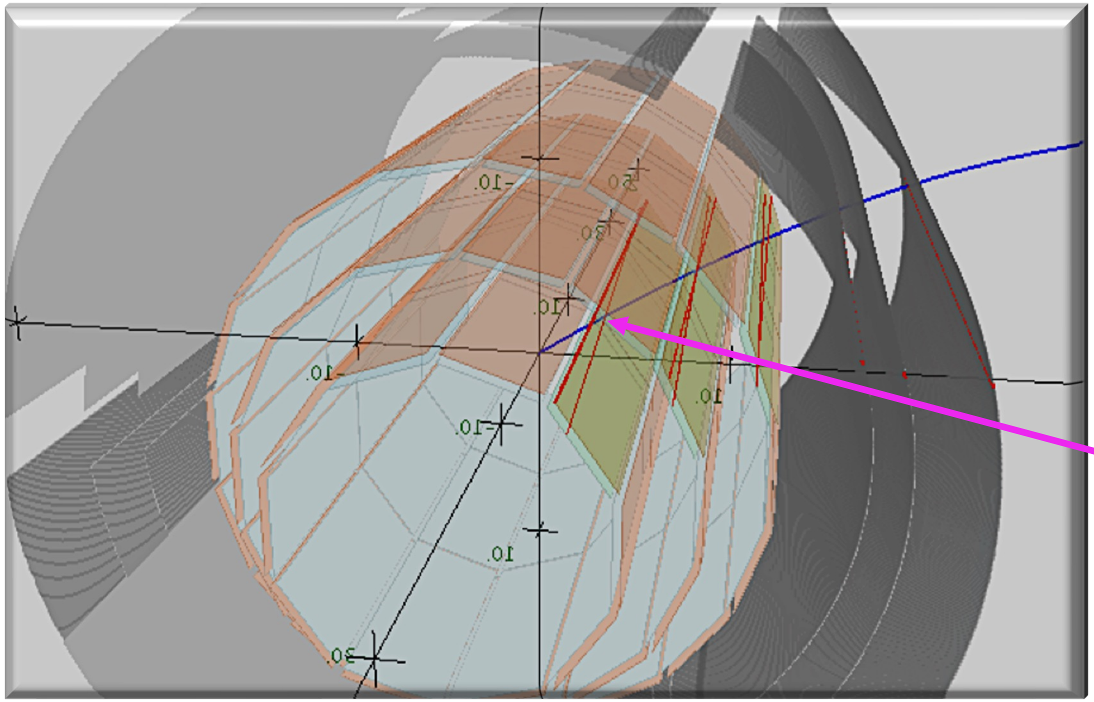


- Simpler, more efficient than CA-based algorithm for CLAS12

NEW CVT TRACKING ALGORITHMS (2)

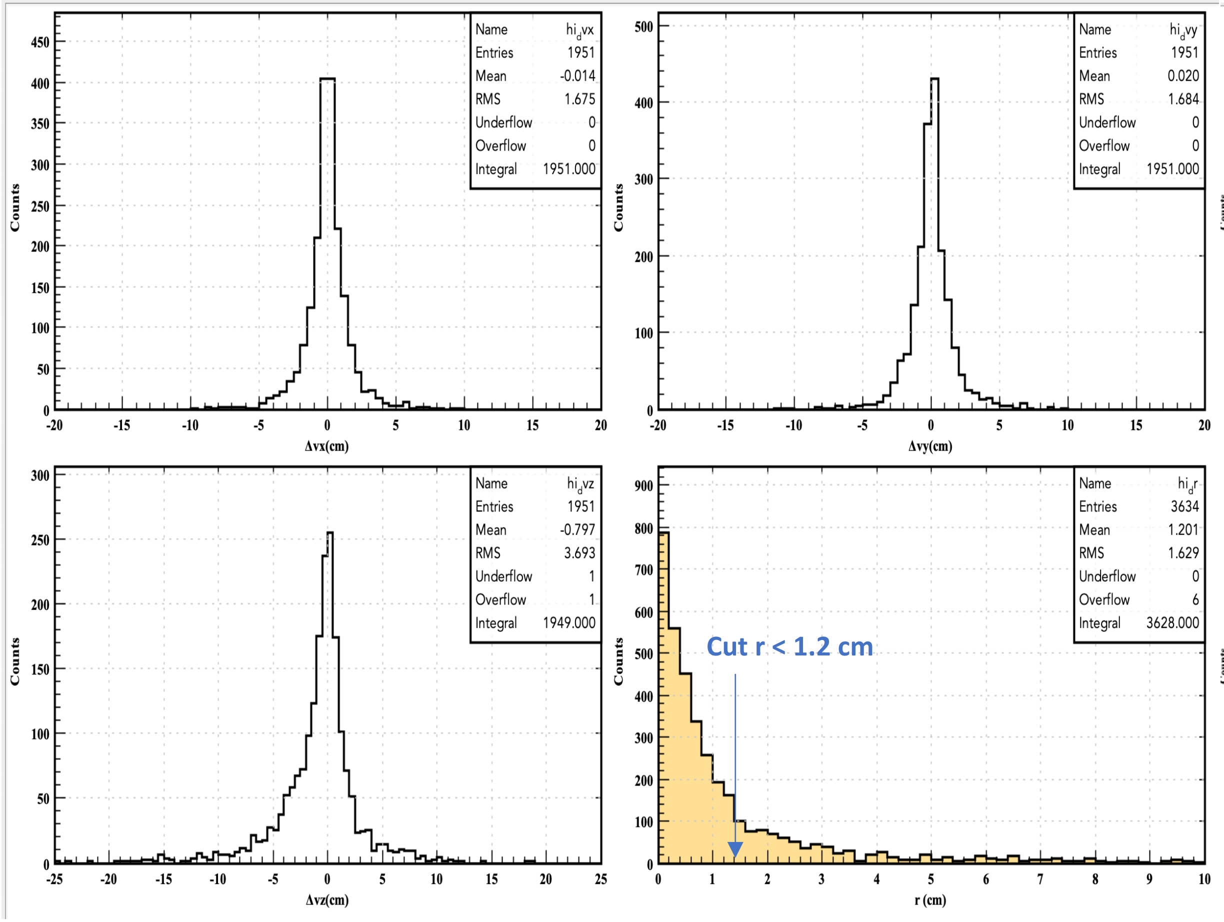
Updated algorithm to find clusters belonging to a track but missed by seeding:
Clusters ON Track Recovery Algorithm (CONTRA)

- Uses KF trajectory of fitted seed (i.e. KF track) to search for clusters on track
  - Select best match (doca cut)
  - If two clusters found in a region → create the cross if cross missing or update the cross as on track if it exists.
  - Compensates for clusters missed by SLA (misses due to cuts; note: cuts optimized for efficiency; loosening cuts increases nb seeds)
  - Improves MC track matching by ~ 20%



KLambda MC Sample (6.5 GeV) Λ vertex resolution

Entire $m(p\pi^-)$ range



Cut r < 1.2 cm

Signal region

$1.11<m(p\pi^-)<1.124$ GeV