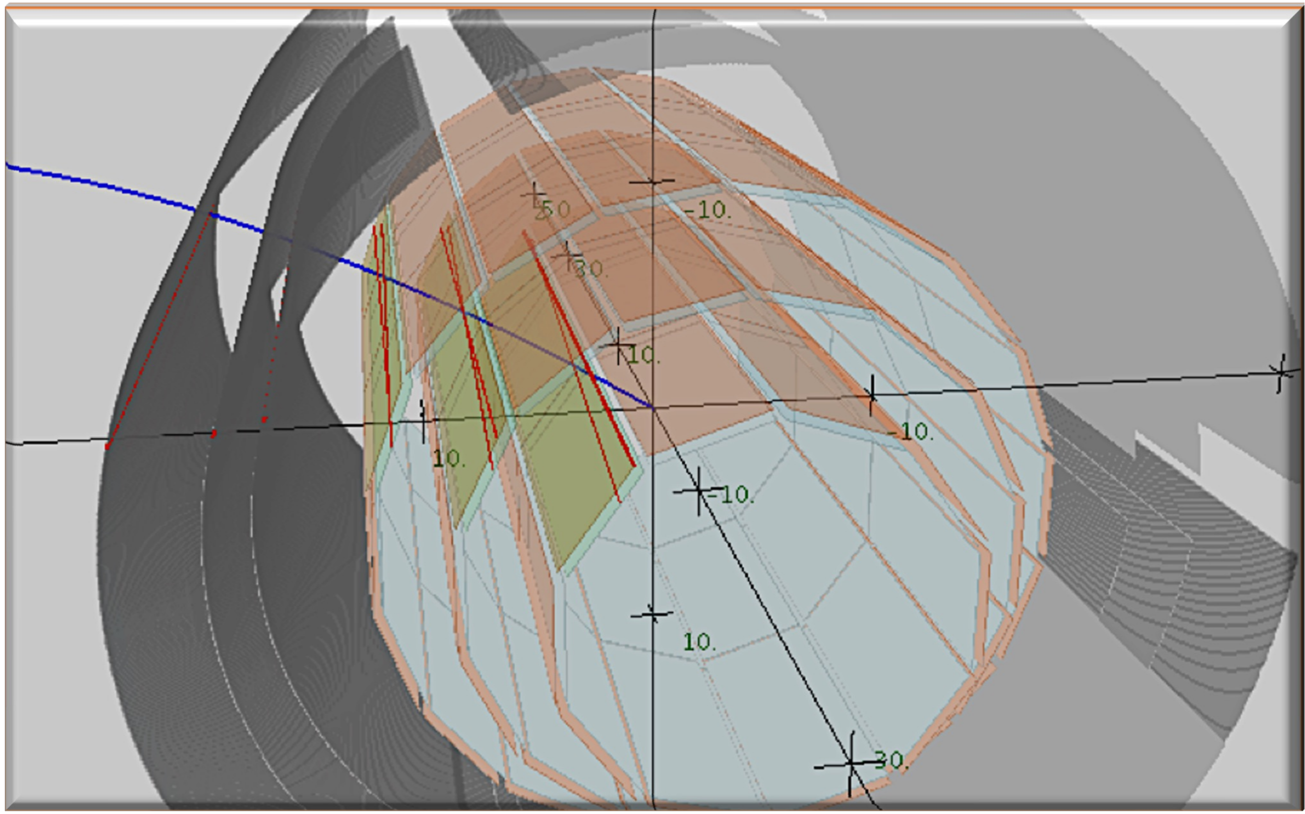
CLAS12 Collaboration Meeting

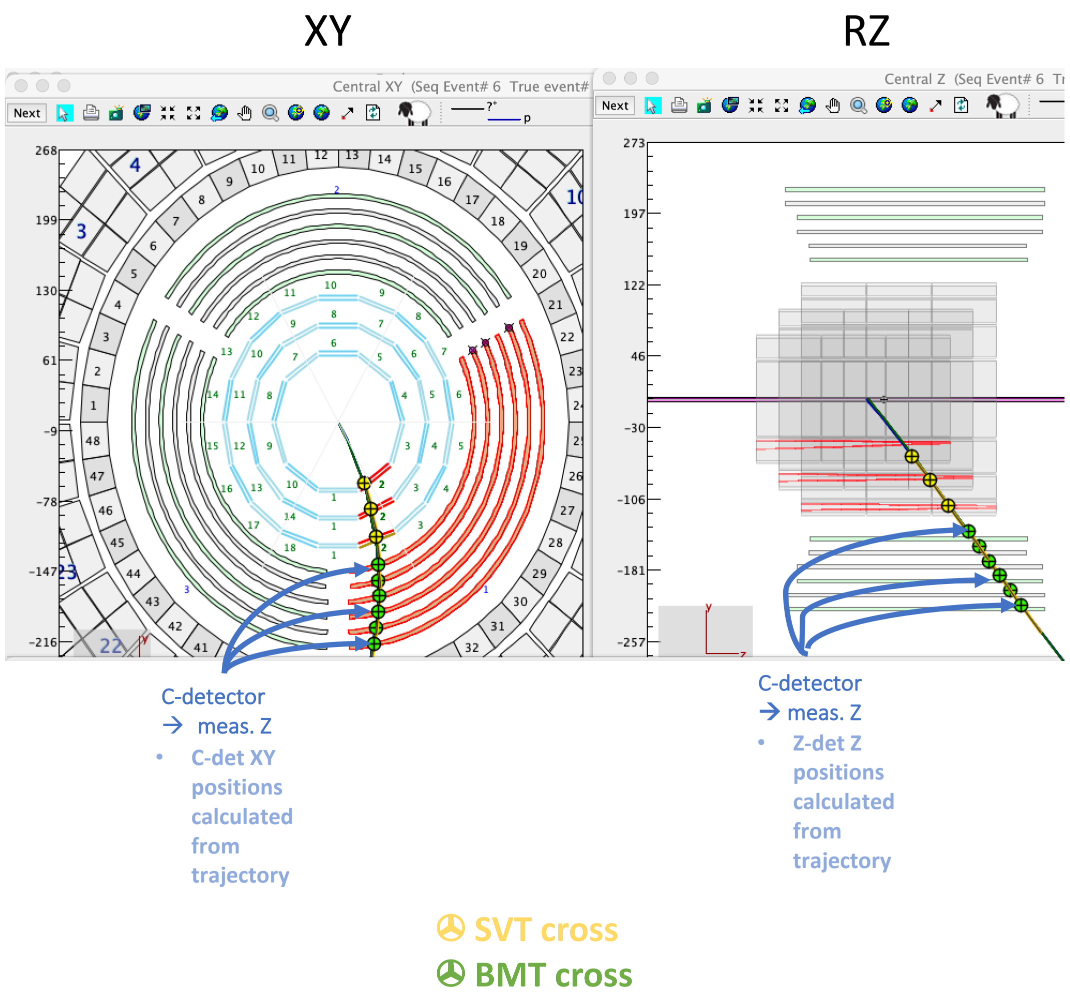
March 22, 2023

CVT Reconstruction Results and Plans

Veronique Ziegler



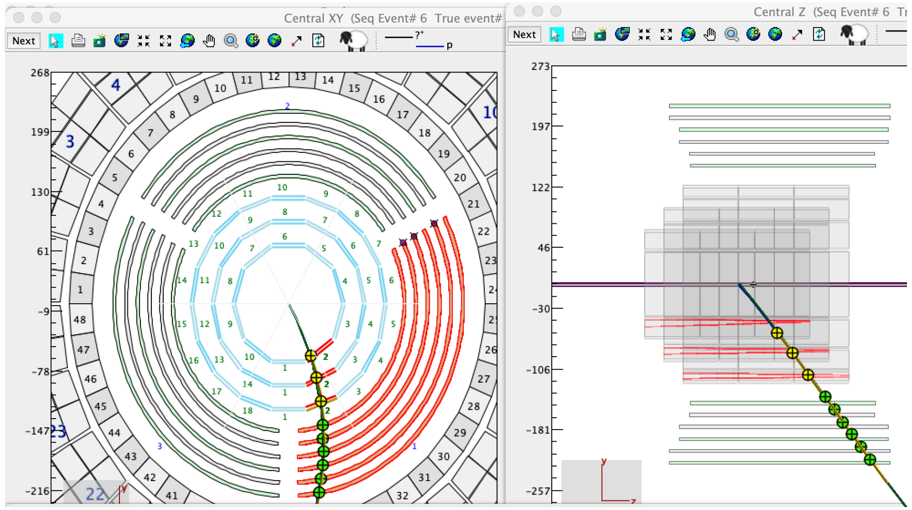
CVT TRACKING ALGORITHMS OVERVIEW



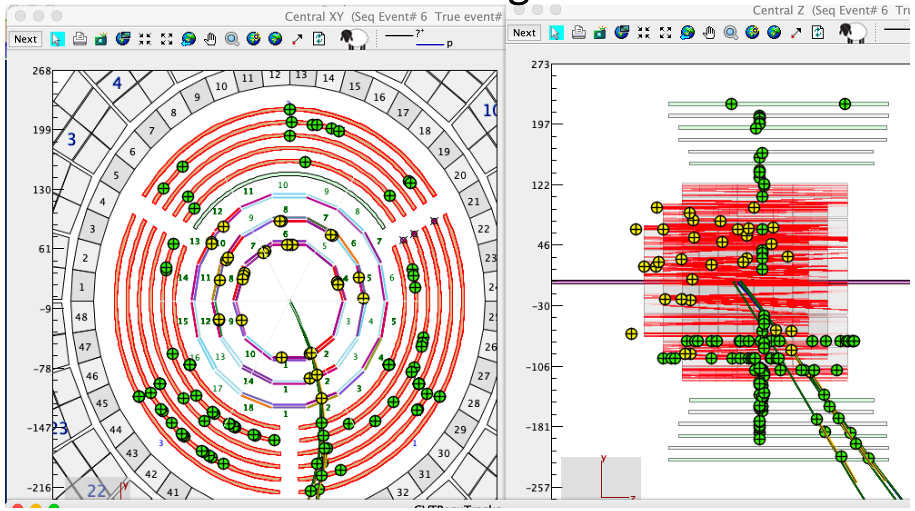
CVT tracking algorithms:

- 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

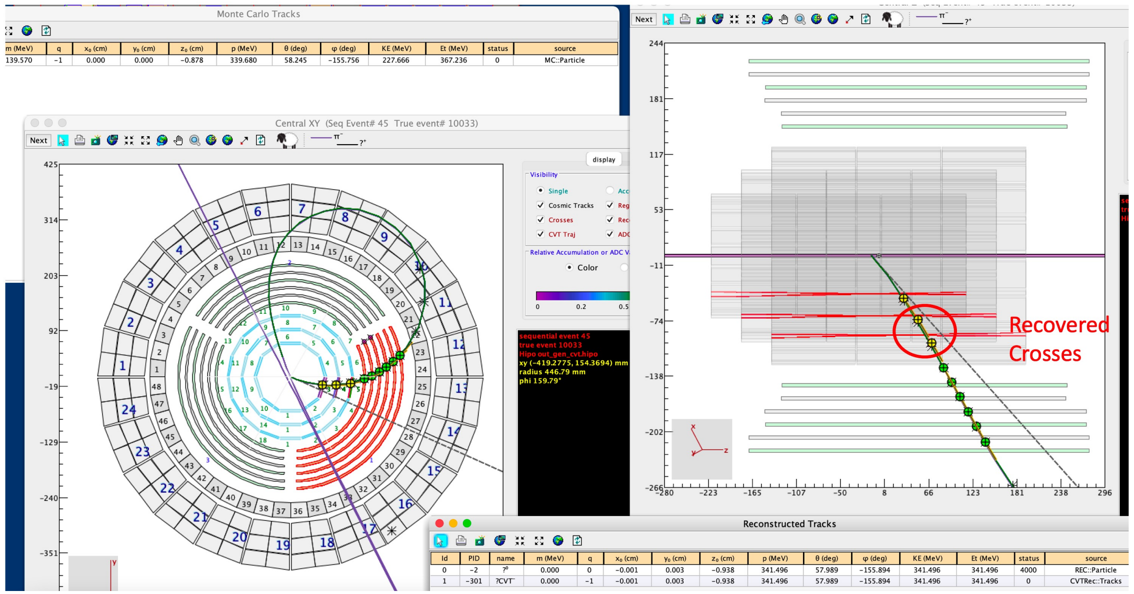
- **SVT Linker Algorithm (SLA, new pass-2 algorithm)**
  - Find line using BMT C detector crosses (RZ Linker)
    - Select BMT C crosses in the same sector to get a RZ seed → fit gives helix dip-angle line
  - Match line to SVT cross cluster lines (XY Linker)
    - Save SVT crosses matched to the line 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

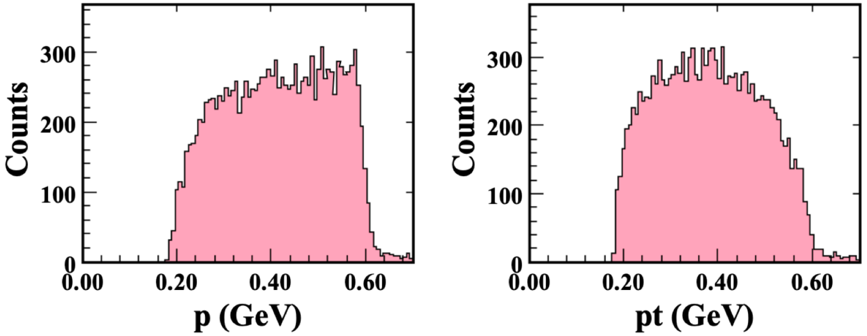
- MC π- single track event generated with 0.1<p<0.6 GeV
- With added clusters on track and redoing Pattern Recognition with the 2 additional crosses, the KF fit is successful



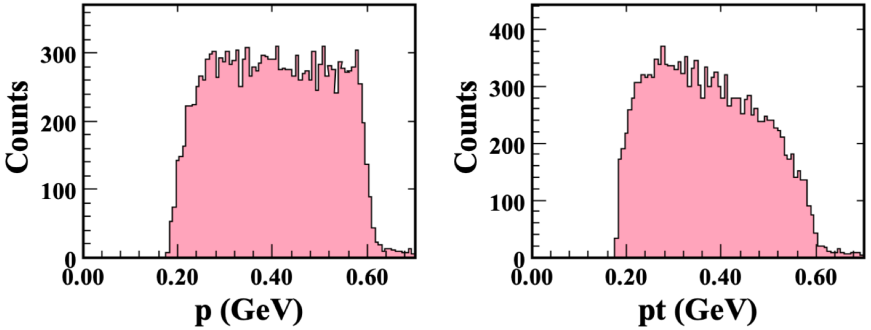
- **Low pt tracks Recovery**
  - Mitigation of track fit failures for low momentum tracks
    - Seed found but tracks fail Kalman fit
    - Due to poorer resolution at low momentum, clusters on track missing or hits rejected in fitting
      - Fit diverges (MS, Eloss)
      - Too many measurements get 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

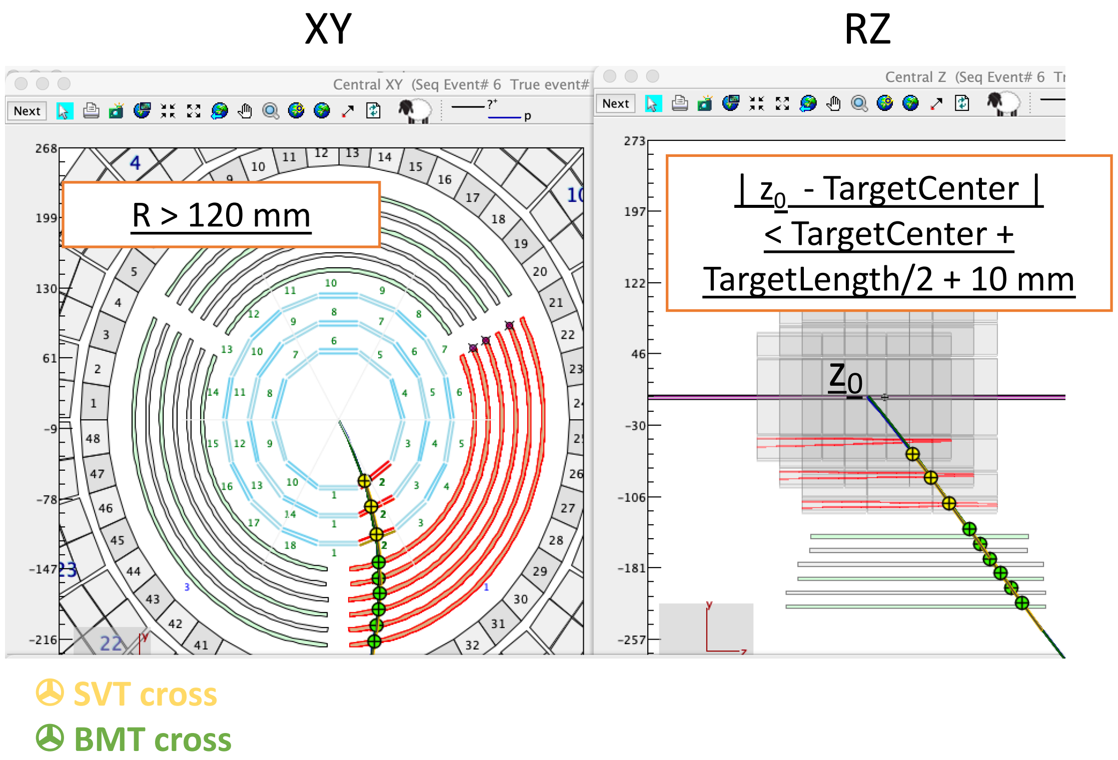
Without track recovery algorithm



With track recovery algorithm



CVT RECONSTRUCTION SELECTION CUTS



CVT tracking algorithms seed selection cuts:

- Helix radius of curvature R >**120 mm** ➔minimum to reach CTOF, corresponds to p_T ~ 180 MeV at full 5-T field
  - 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

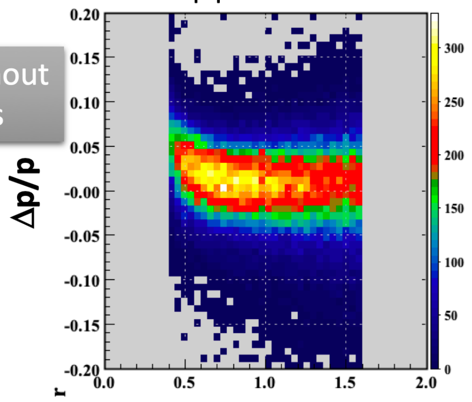
CENTRAL TRACKER RECONSTRUCTION CODE FUNCTIONALITY

- 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

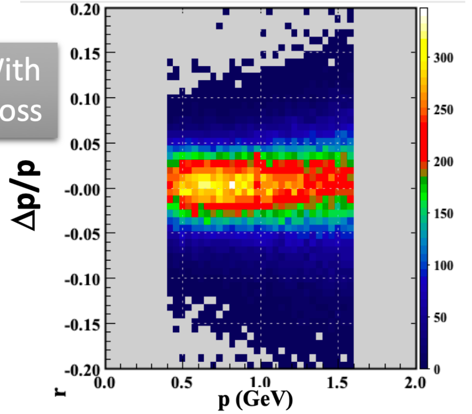
Eloss PID

- Low p protons MC

Without Eloss

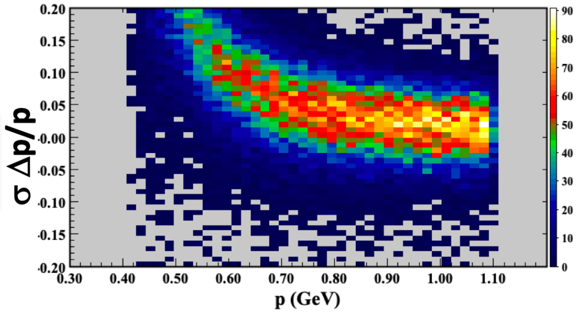


With Eloss

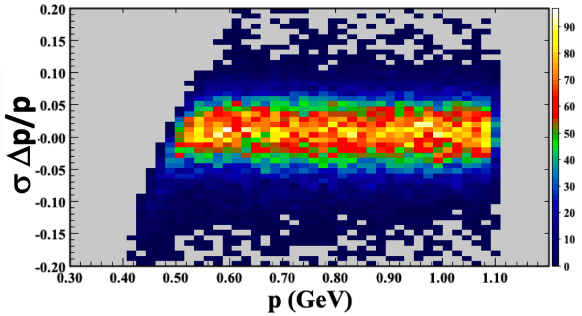


- Deuteron momentum resolution with energy loss correction with pion and deuteron hypothesis

Pion Hypo.



Deuteron Hypo.



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

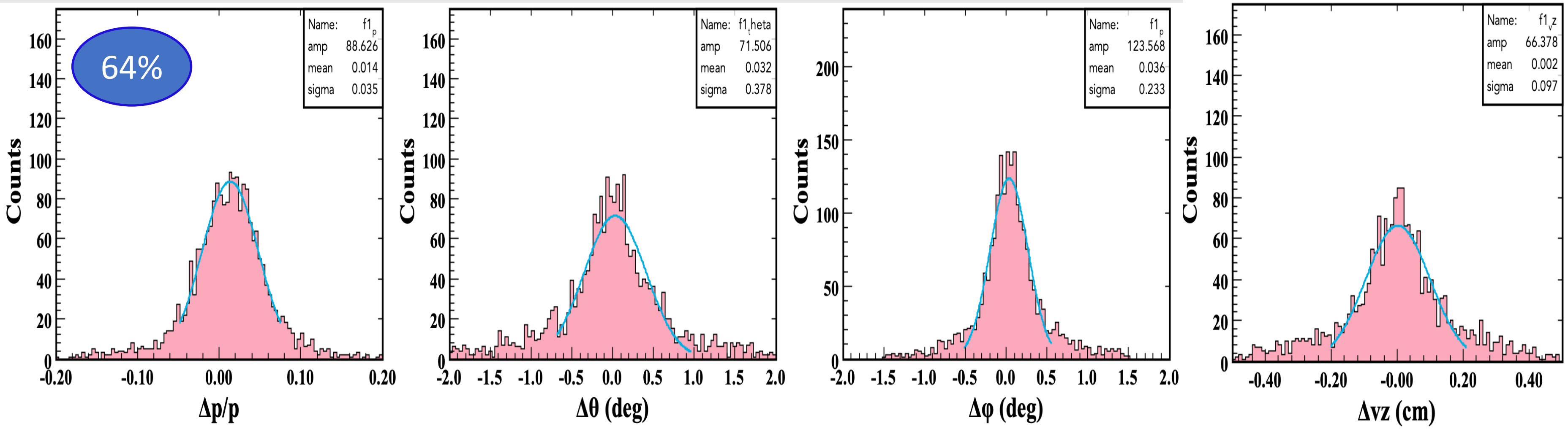
MC + Background Merging Validation Studies

Sample: protons 0.4-1.6 GeV

+ RGB 50 nA merged background

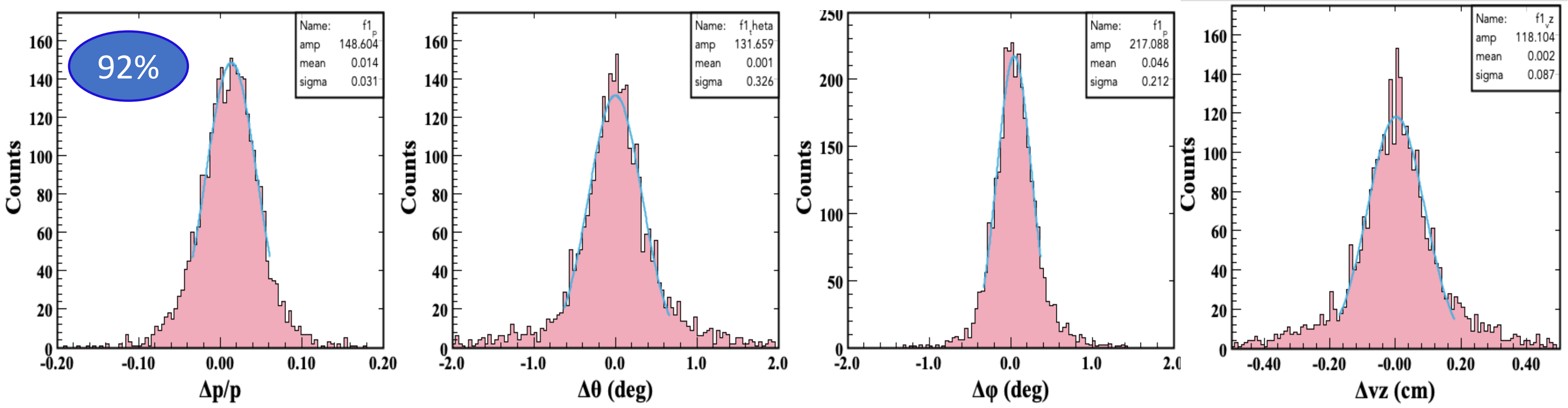
- Improvements in efficiency and resolution
- Next present improvements in data

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

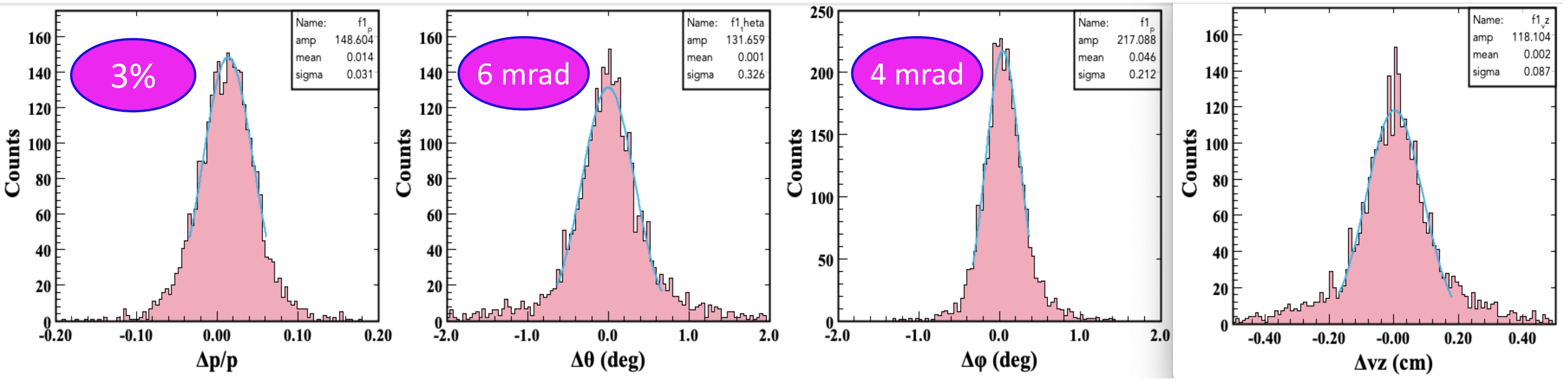
Sample: protons 0.4-1.6 GeV

+ RGB 50 nA merged background

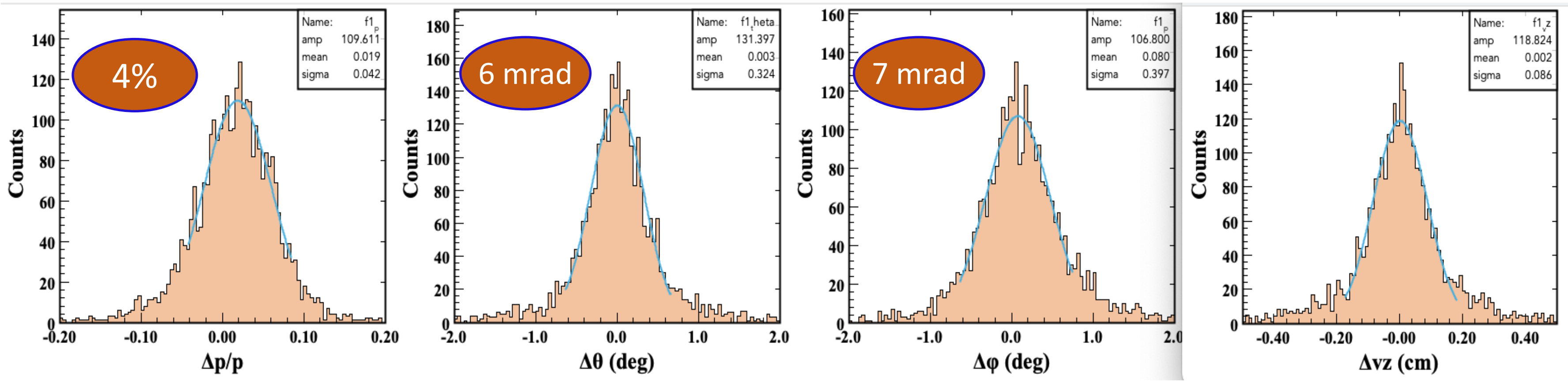
Pass-2 Algorithms

- 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
  - $Z_0 < 10$ mm
  - R>120 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
$e\ p \to e\ p' \pi^+ \pi^-$

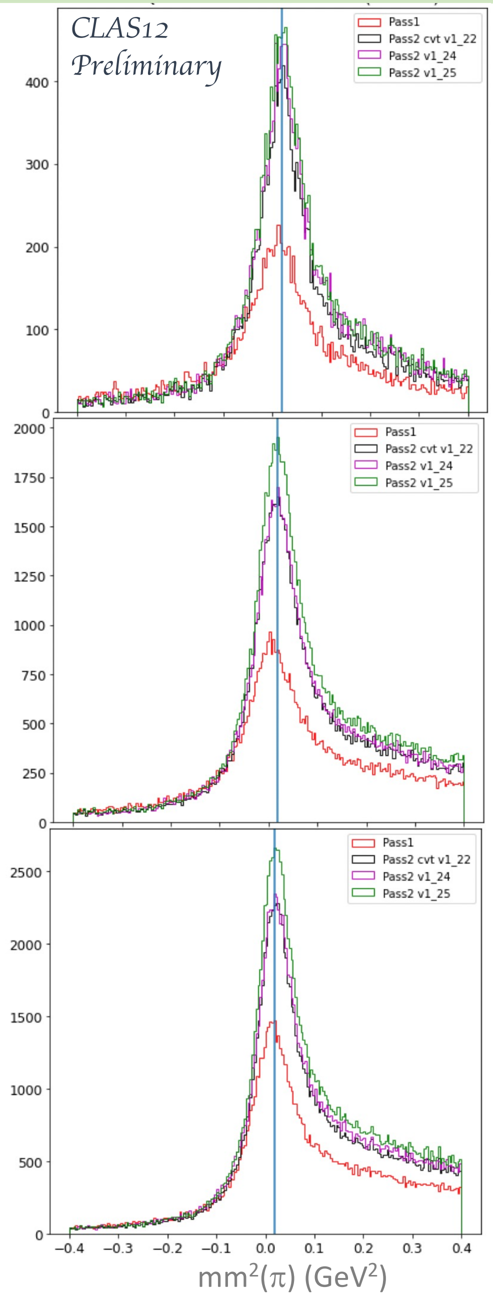
- Missing proton
- Missing π^-
- Missing π^+
- All particles detected

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)

Analysis of TCS final state
γ p -> e^{+-}e p'
- M(e+e-)
- θ_{proton}

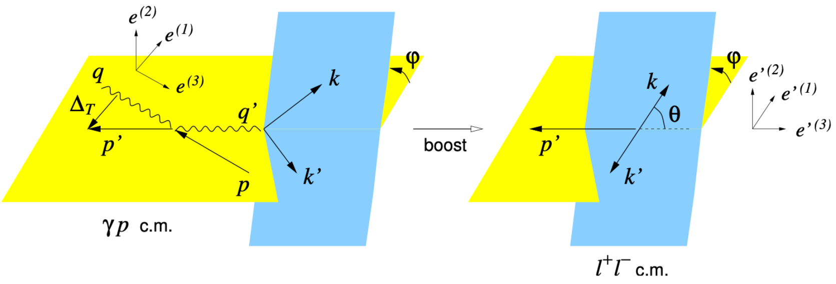
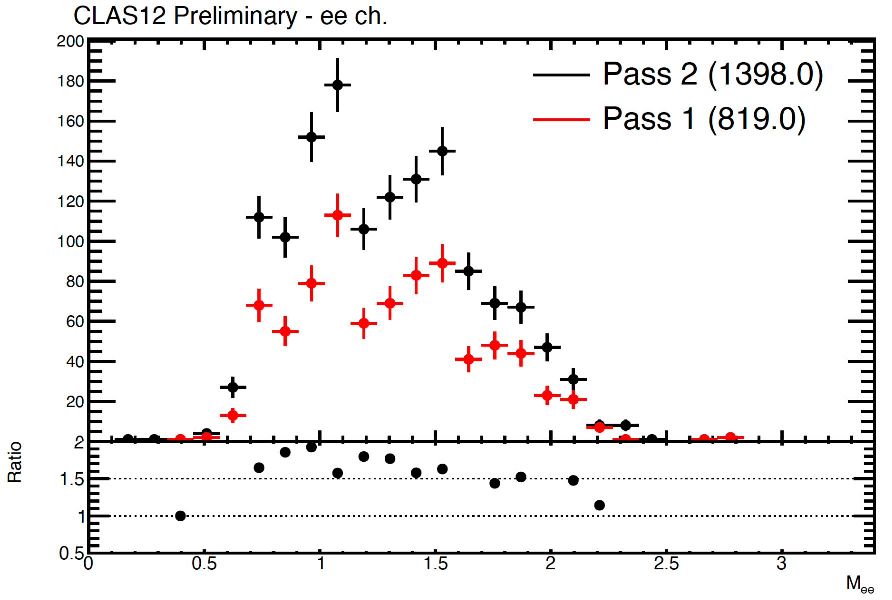
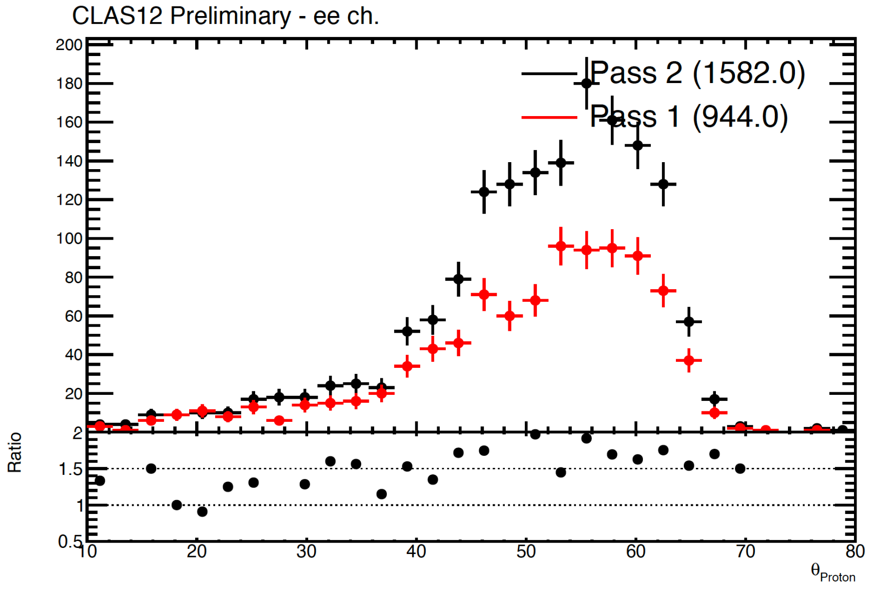


Figure in Berger et al., *EPJ C*, 2002

M(e+e-) Spectra
- proton in Central Detector
- Significant improvement in yield

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

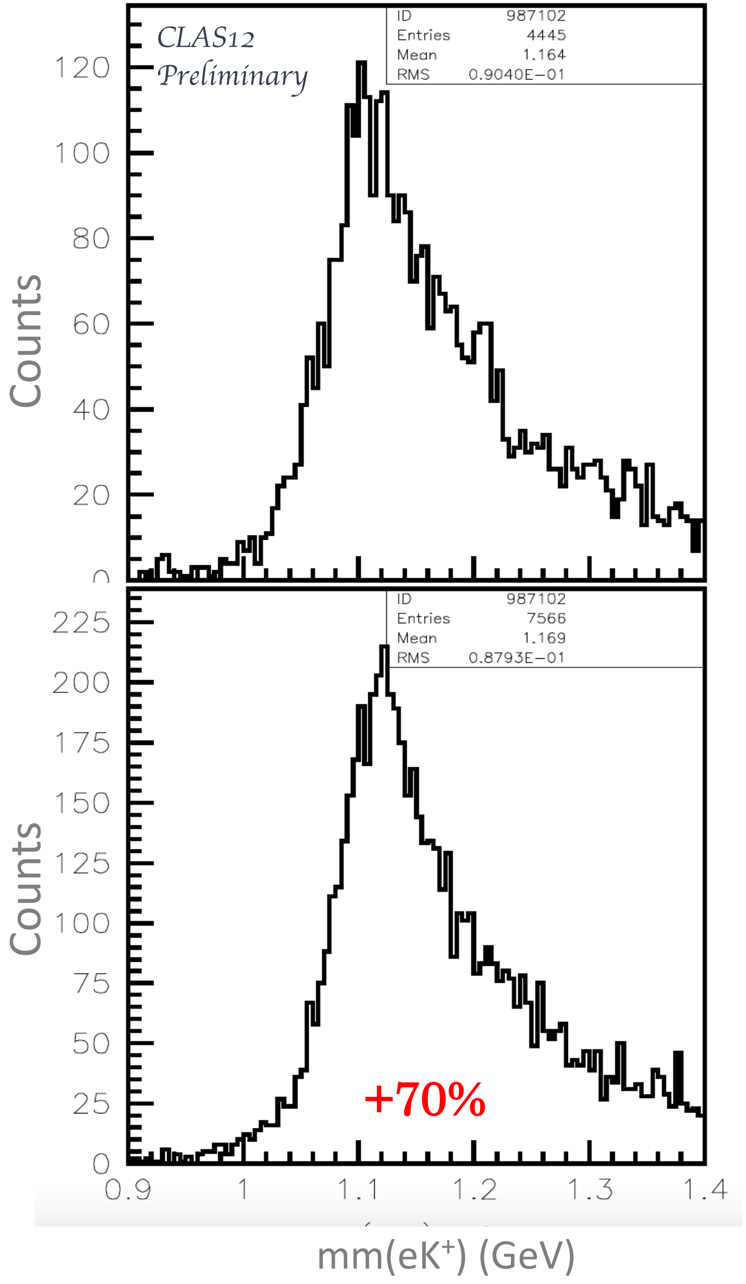
- Analysis **by Dan Carman** (JLAB)
- Comparison of Pass1 and Pass2 cooking with new CVT tracking
- Analysis using 6642, 6670, 6712, 6714, 6716, 6718, 6728, 6769 (50 nA, production runs)

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

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

- 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

- 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 -> e’ K^+ p’ π^-

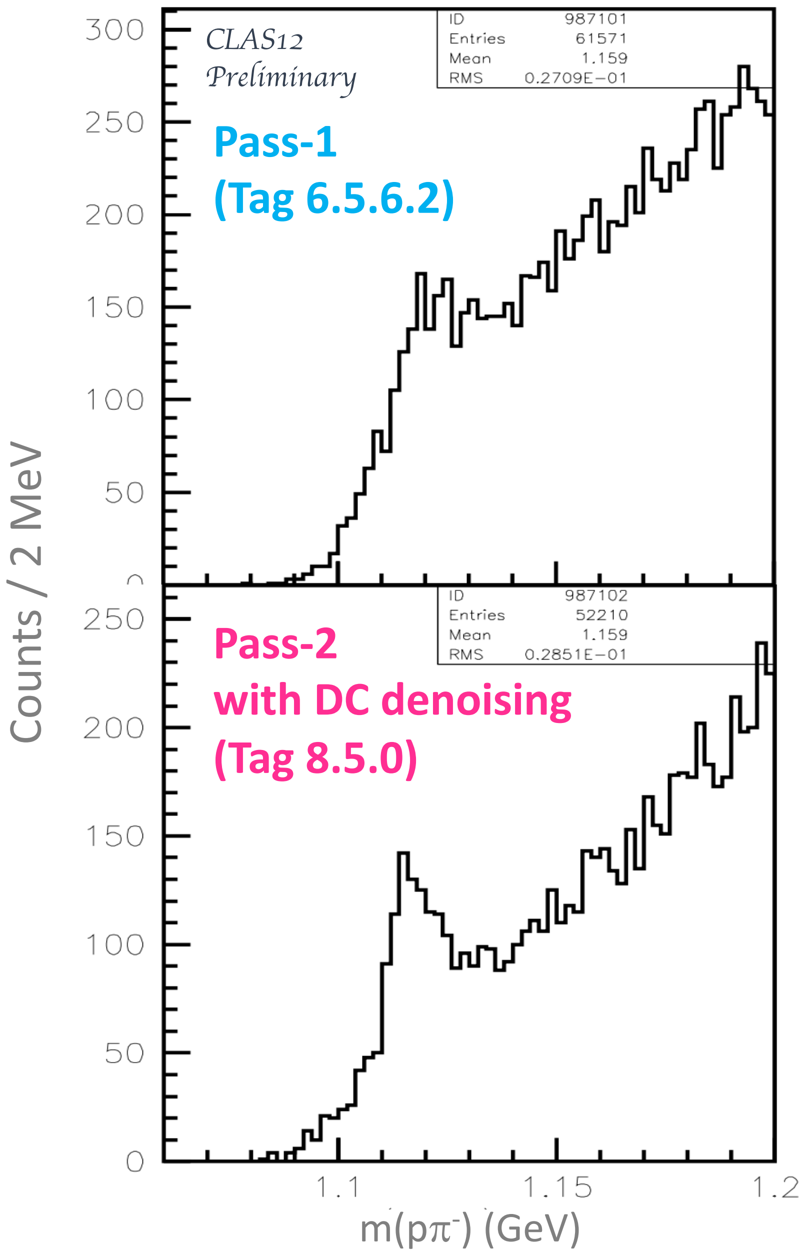
- Using eK+ analysis train
- K^+ & e- from event builder

($p\,\pi-$) 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



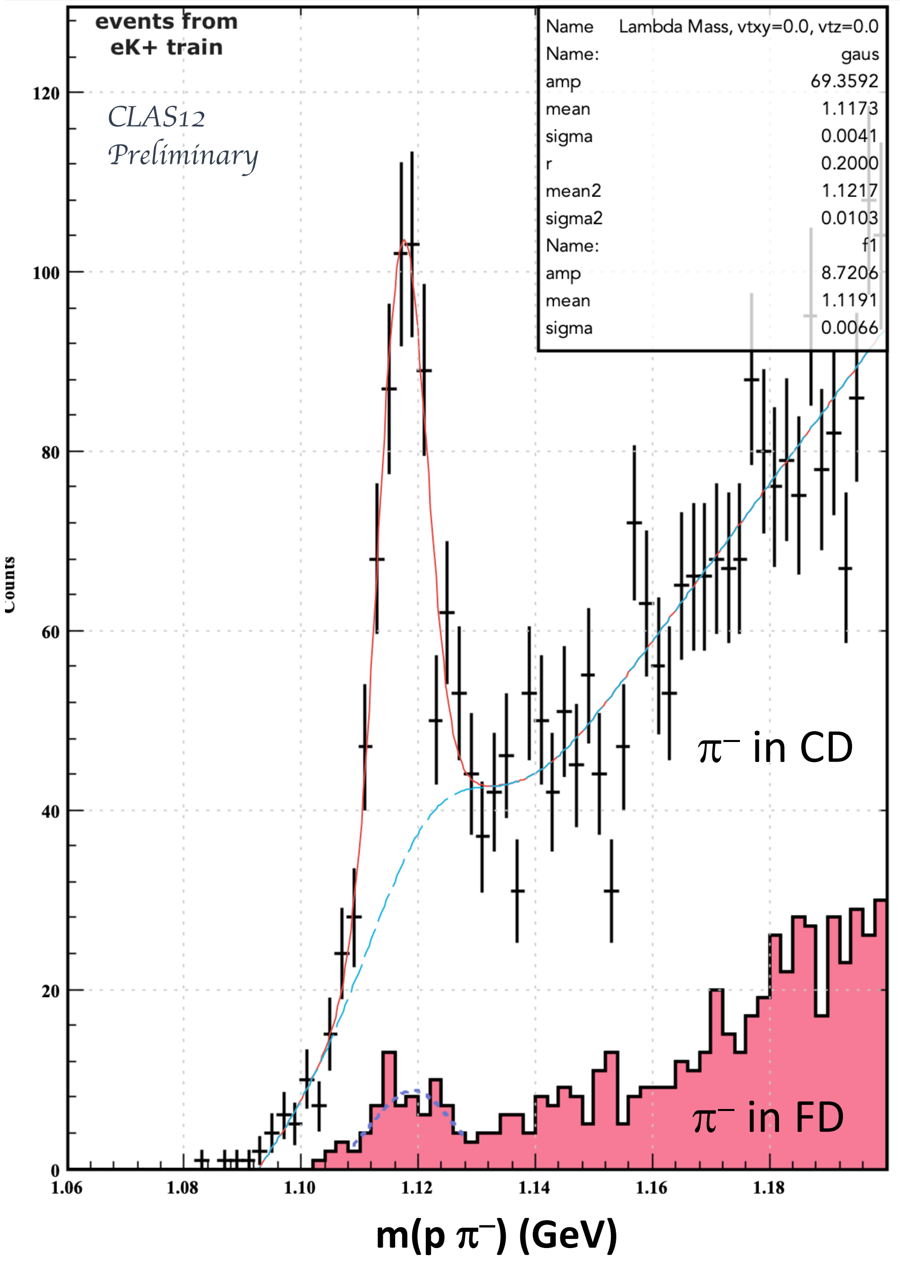
ANALYSES FROM THE RUN GROUPS

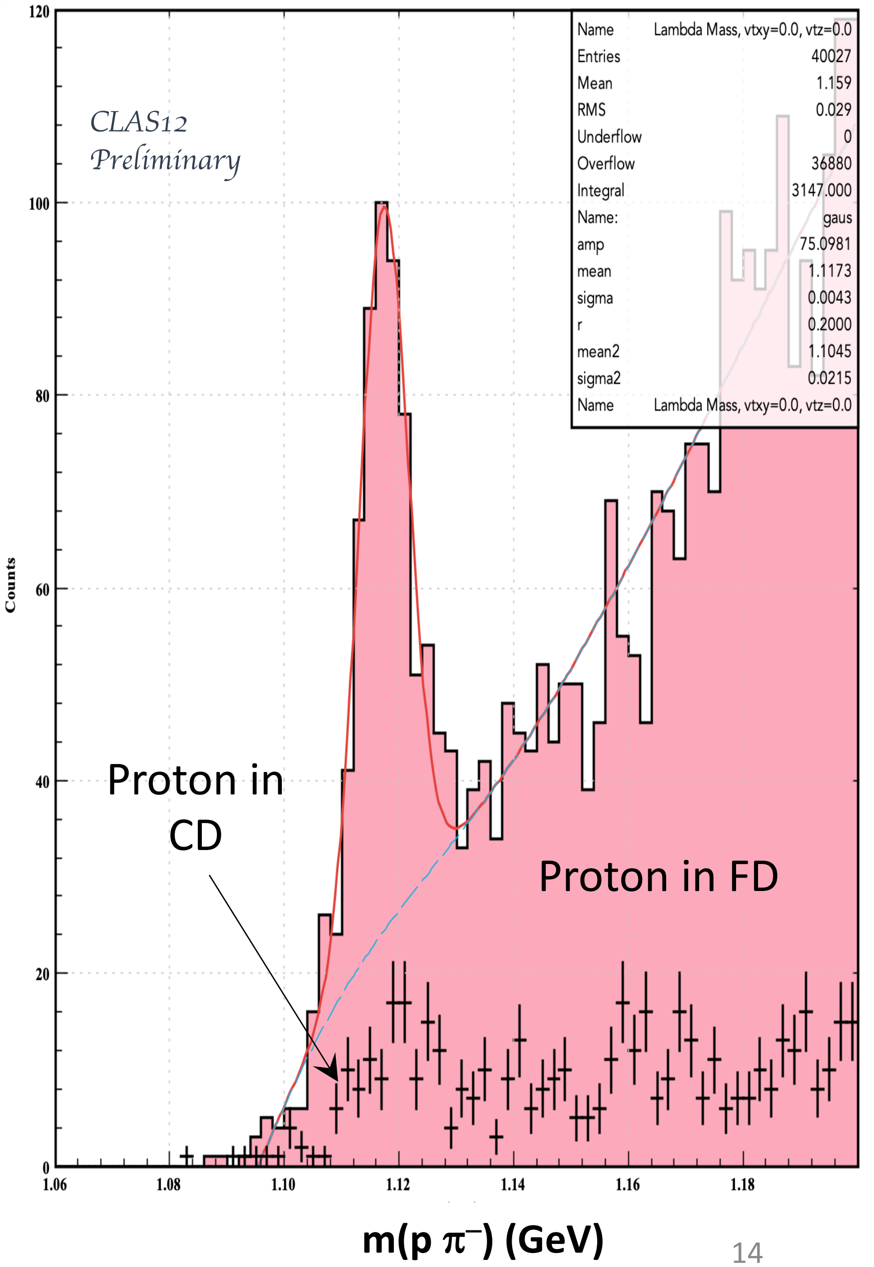
RGA

- 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



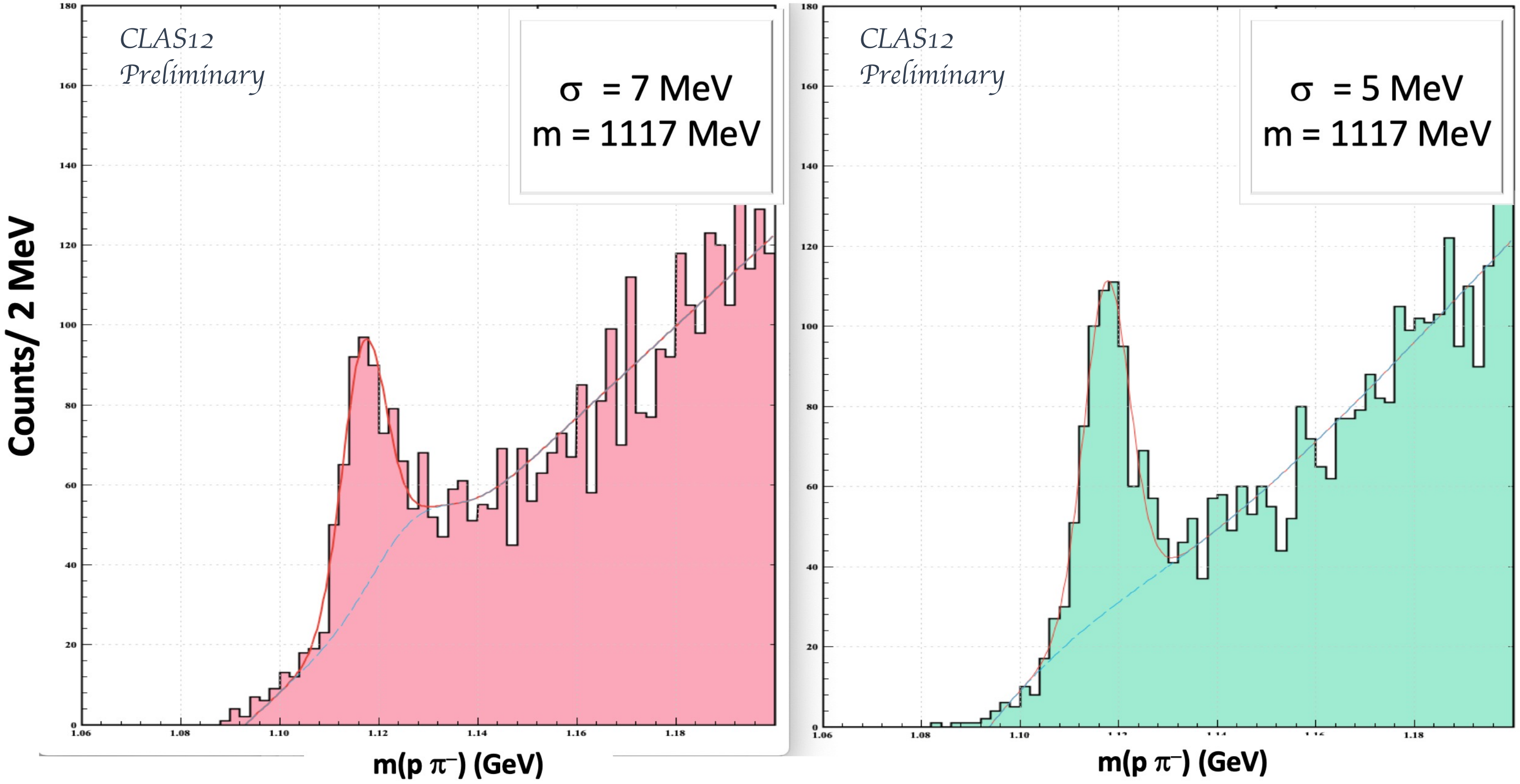


VERTEXING WITH CVT TRACKS

- 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

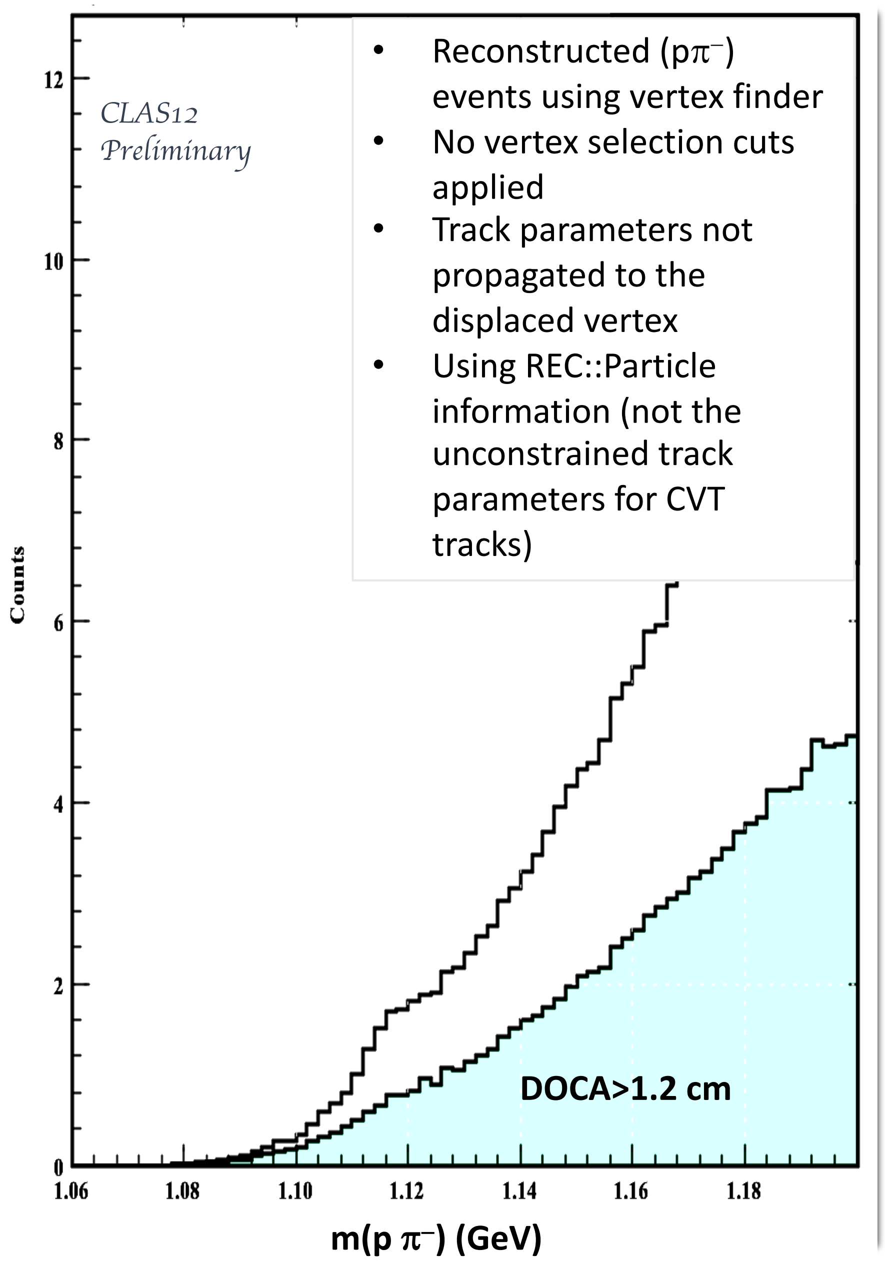
ANALYSES FROM THE RUN GROUPS

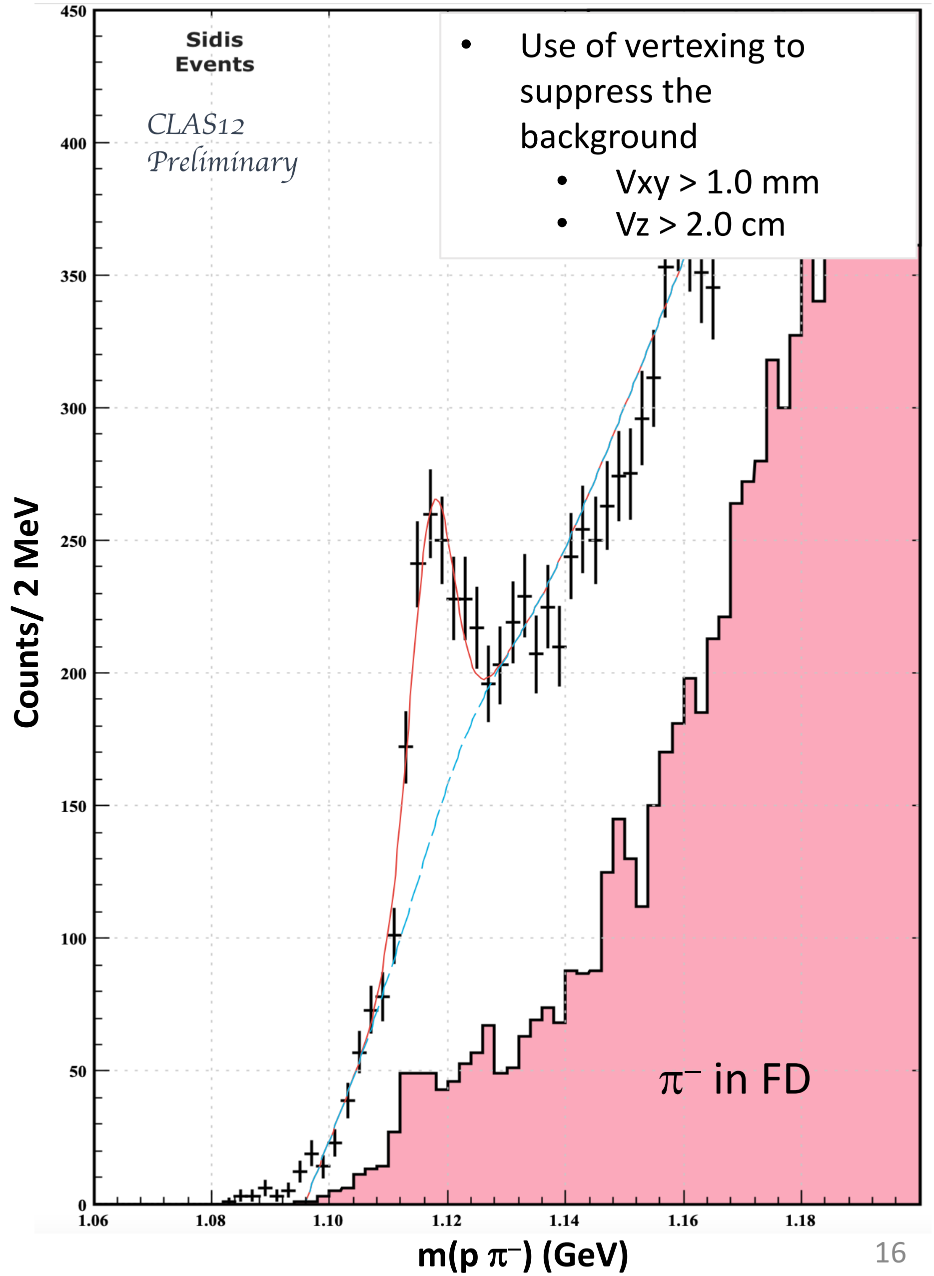
RGA

- Exclusive $\Lambda \rightarrow p\pi^-$ reconstruction (SIDIS evts)
- 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





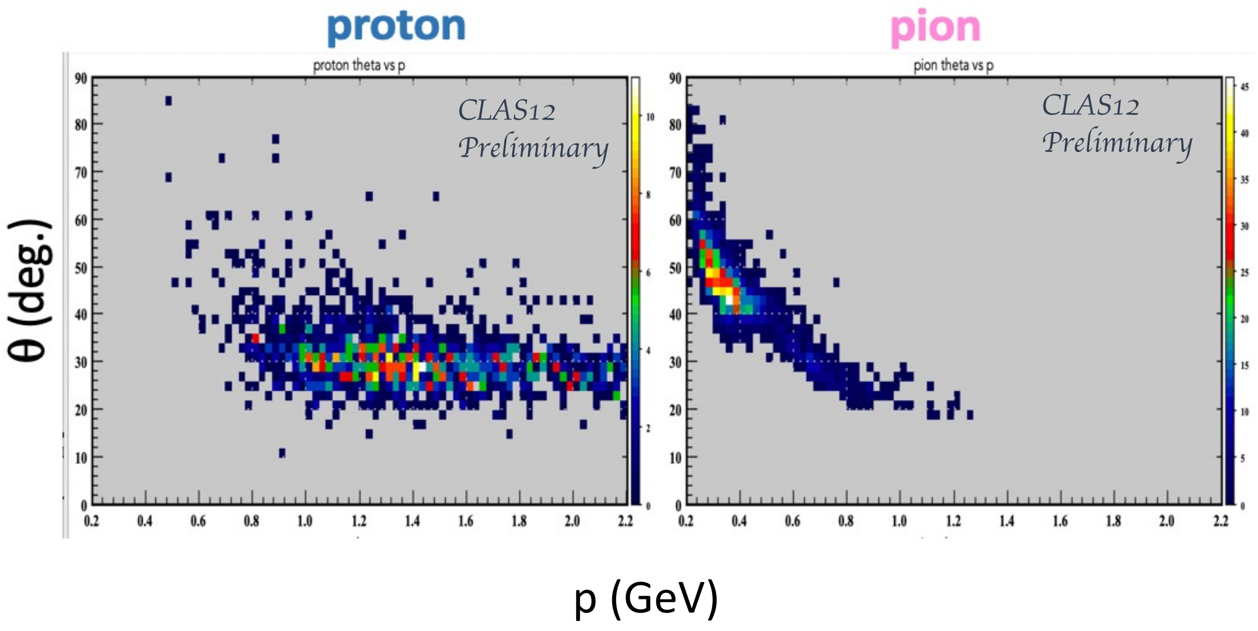
ANALYSES FROM THE RUN GROUPS

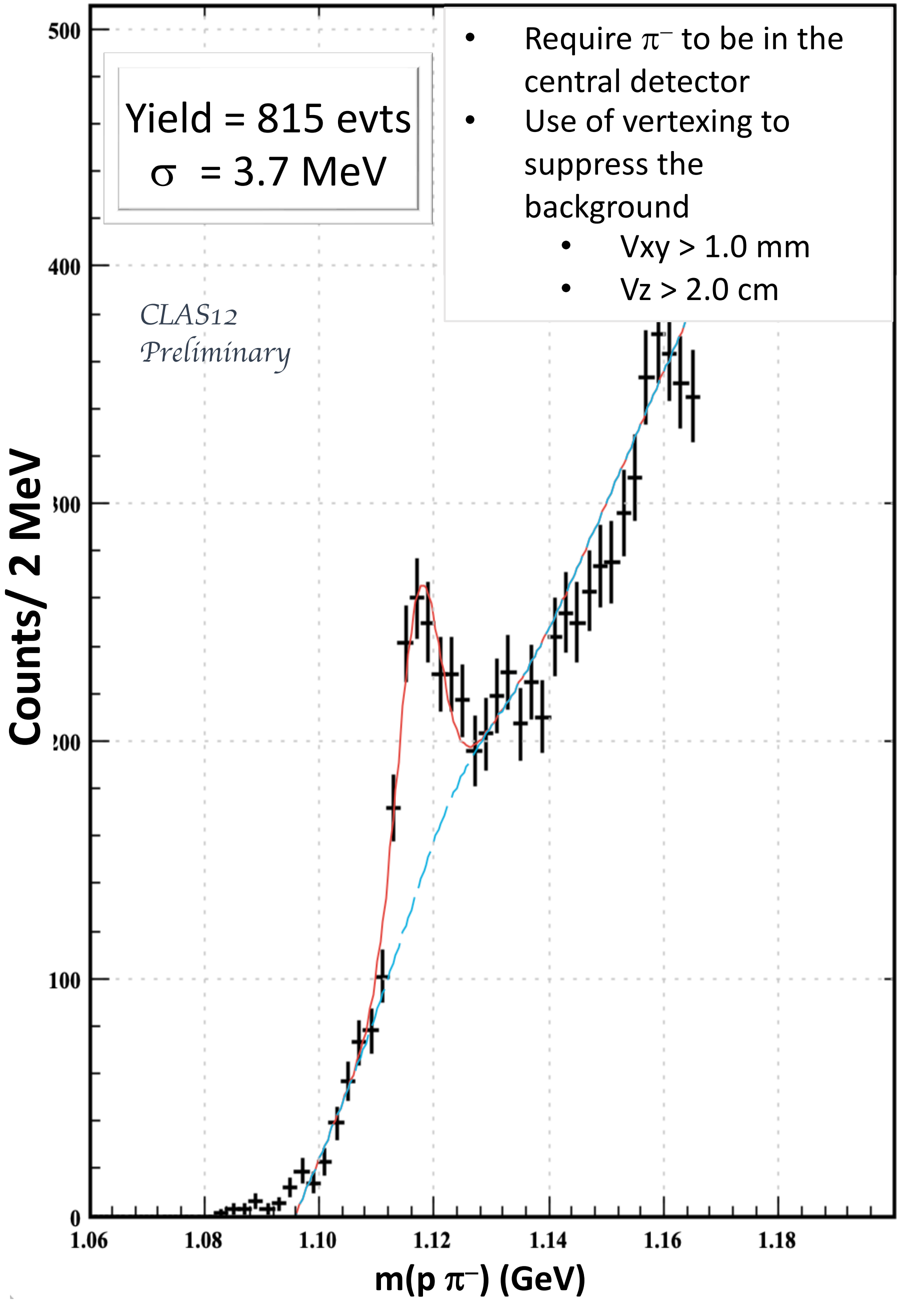
Events from nSidis train

- 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





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

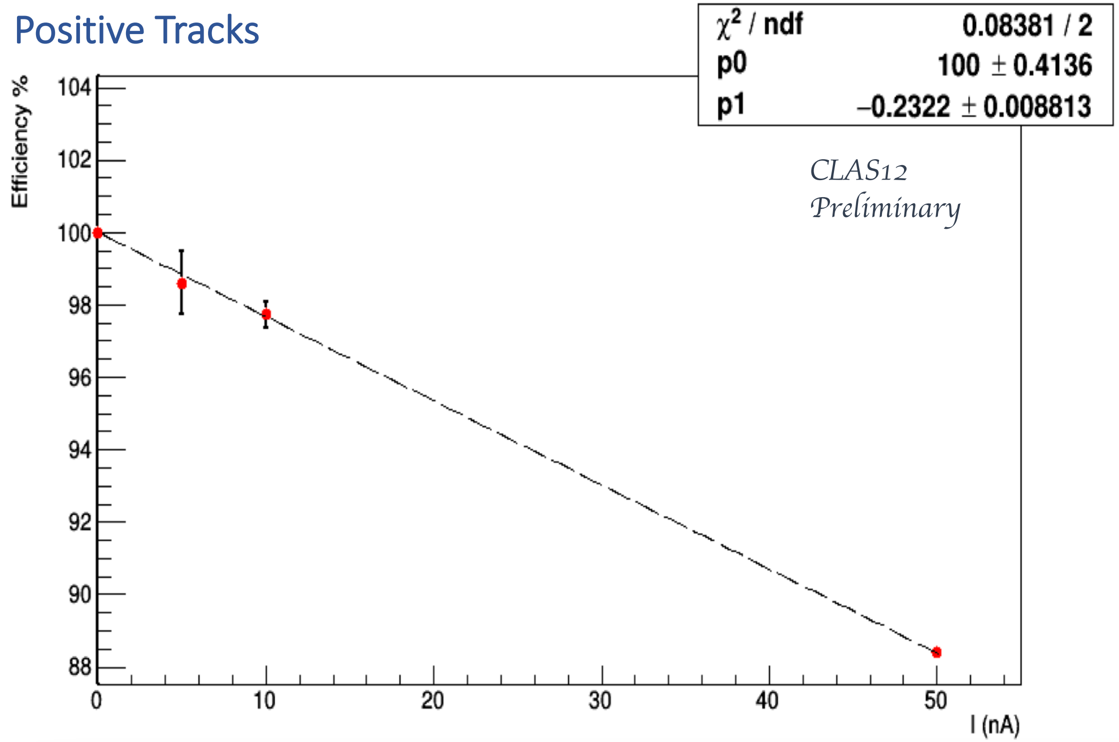
- **Electron**
  - Pid=11
  - P>2 GeV
  - 2000<|status|<4000
- **Positive particle**
  - Pid=211
  - P>0.4 GeV
  - |status|>4000
  - |chi2|<3
- **Negative particle**
  - Pid=-211
  - P>0.4 GeV
  - |status|>4000
  - |chi2|<3

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

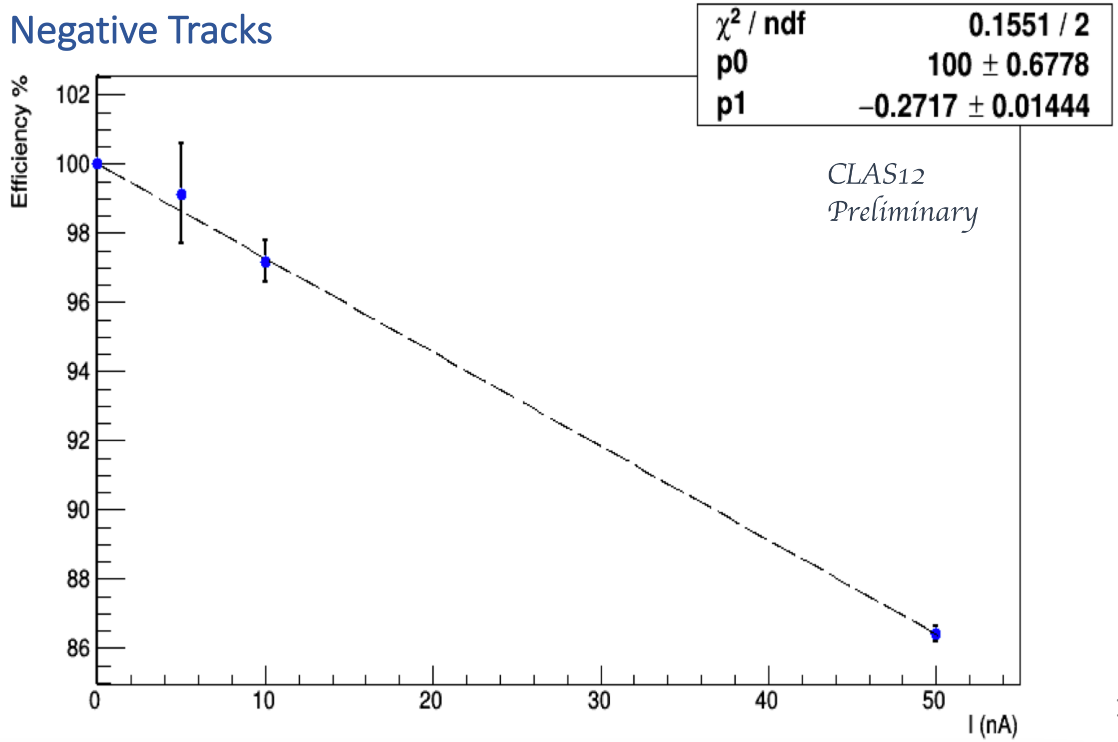
Efficiency loss ~0.3% / nA

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

Positive Tracks

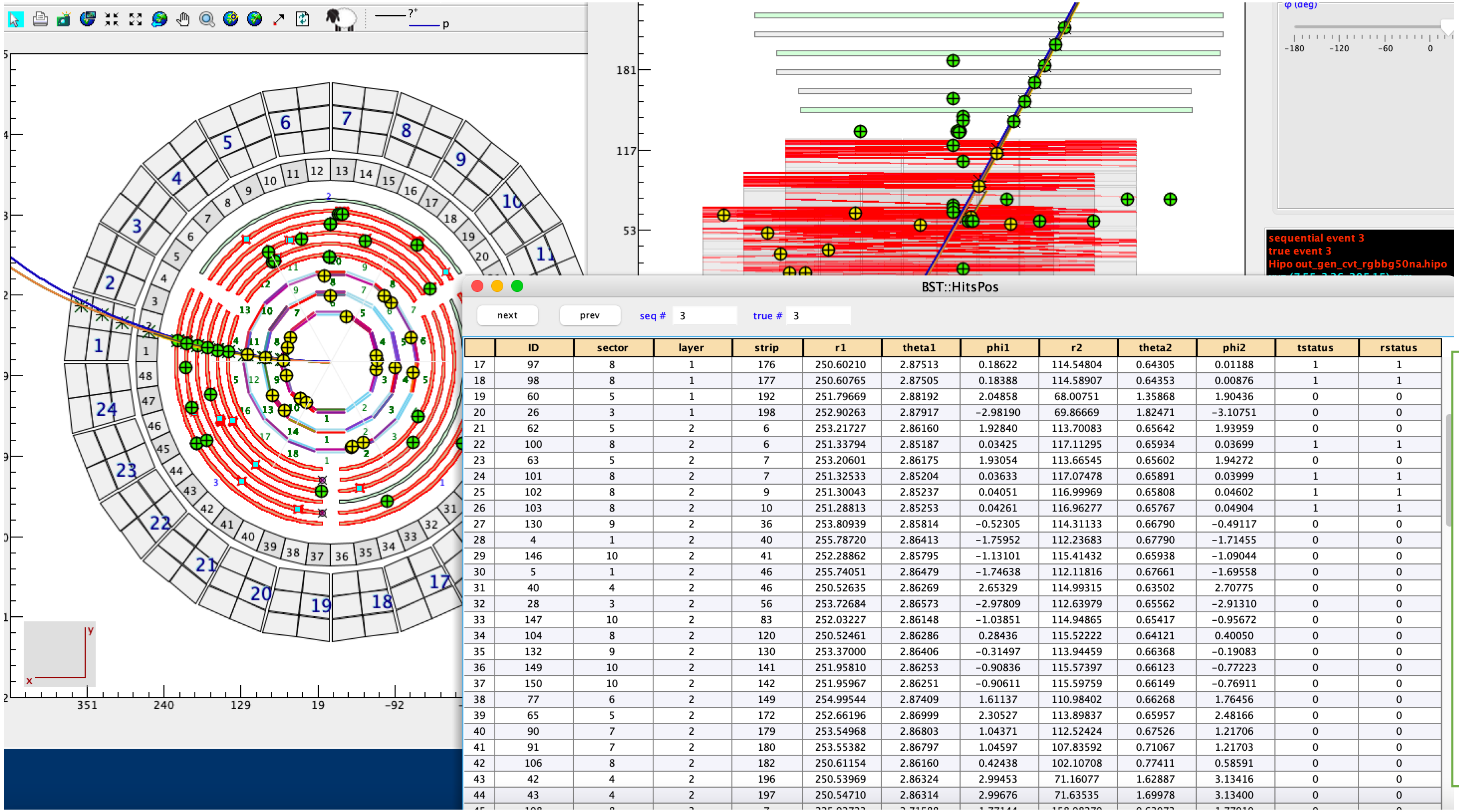


Negative Tracks



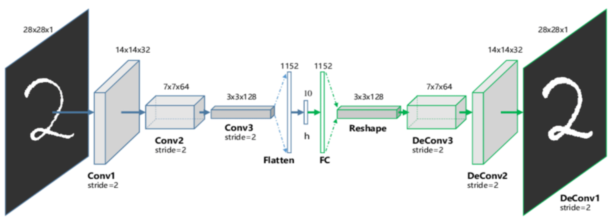
CVT RECONSTRUCTION WITH AI PLANS

- 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

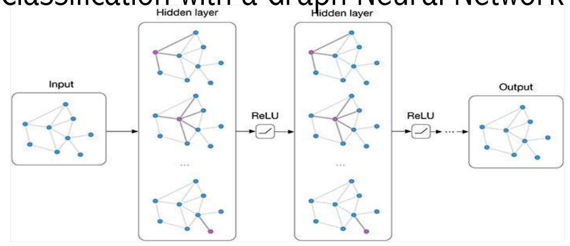


	ID	sector	layer	strip	r1	theta1	phi1	r2	theta2	phi2	tstatus	rstatus
17	97	8	1	176	250.60210	2.87513	0.18622	114.54804	0.64305	0.01188	1	1
18	98	8	1	177	250.60765	2.87505	0.18388	114.58907	0.64353	0.00876	1	1
19	60	5	1	192	251.79669	2.88192	2.04858	68.00751	1.35868	1.90436	0	0
20	26	3	1	198	252.90263	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

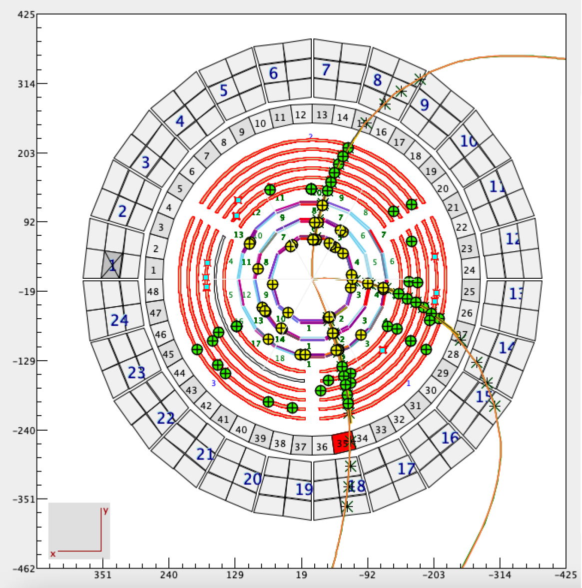


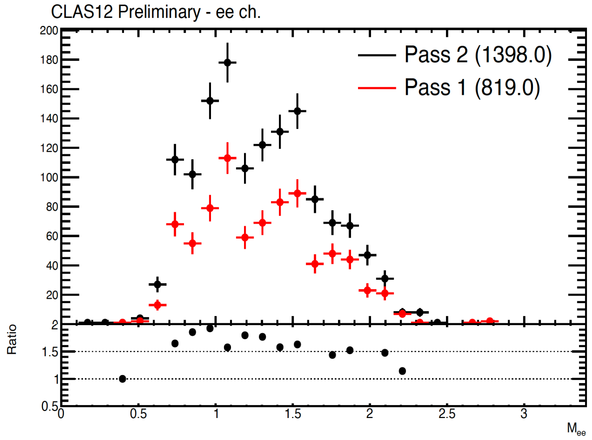
- tstatus (MC truth status)
  - 0: generated hit on track
  - 1: generated hit not on track
- rstatus (reconstruction status)
  - 0: hit not assigned to track by reco algorithm
  - 1: hit assigned to track by reco algorithm

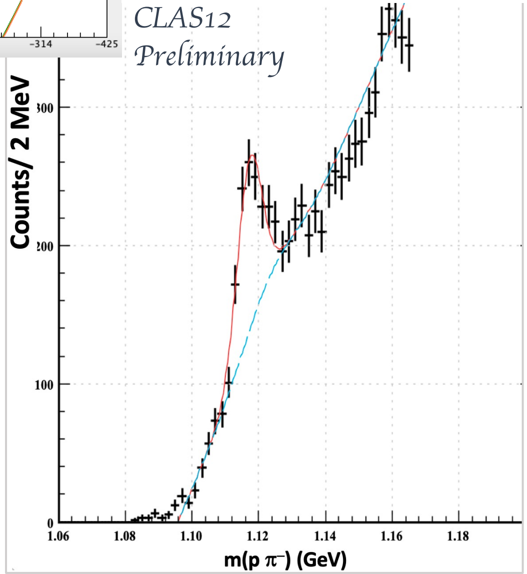
CVT EFFICIENCY CODE DEVELOPMENT: STATUS & PLANS

- **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

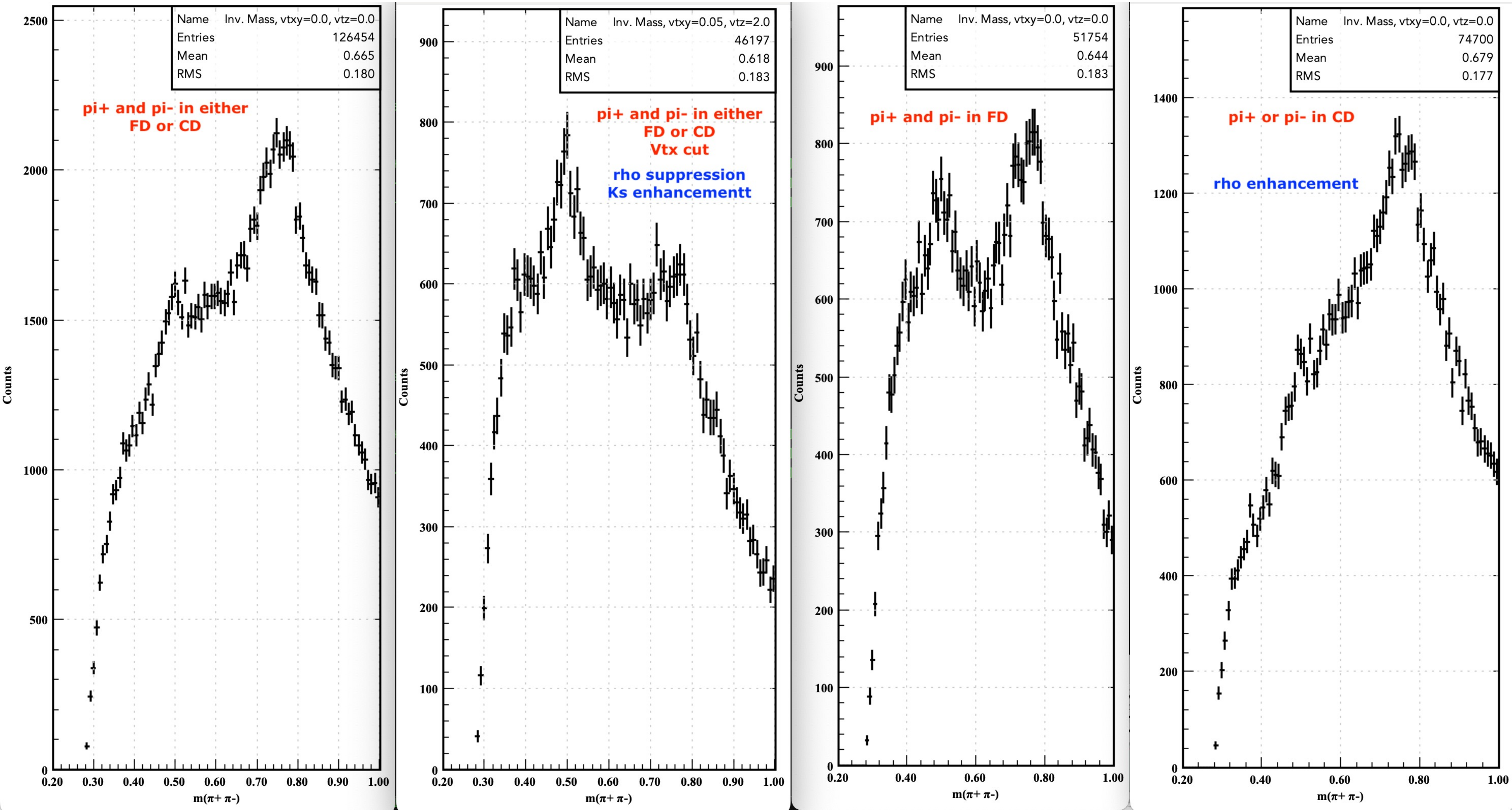
- **Next Steps**
  - Use of AI for further efficiency improvements (Pass-3)







BACK-UP SLIDES

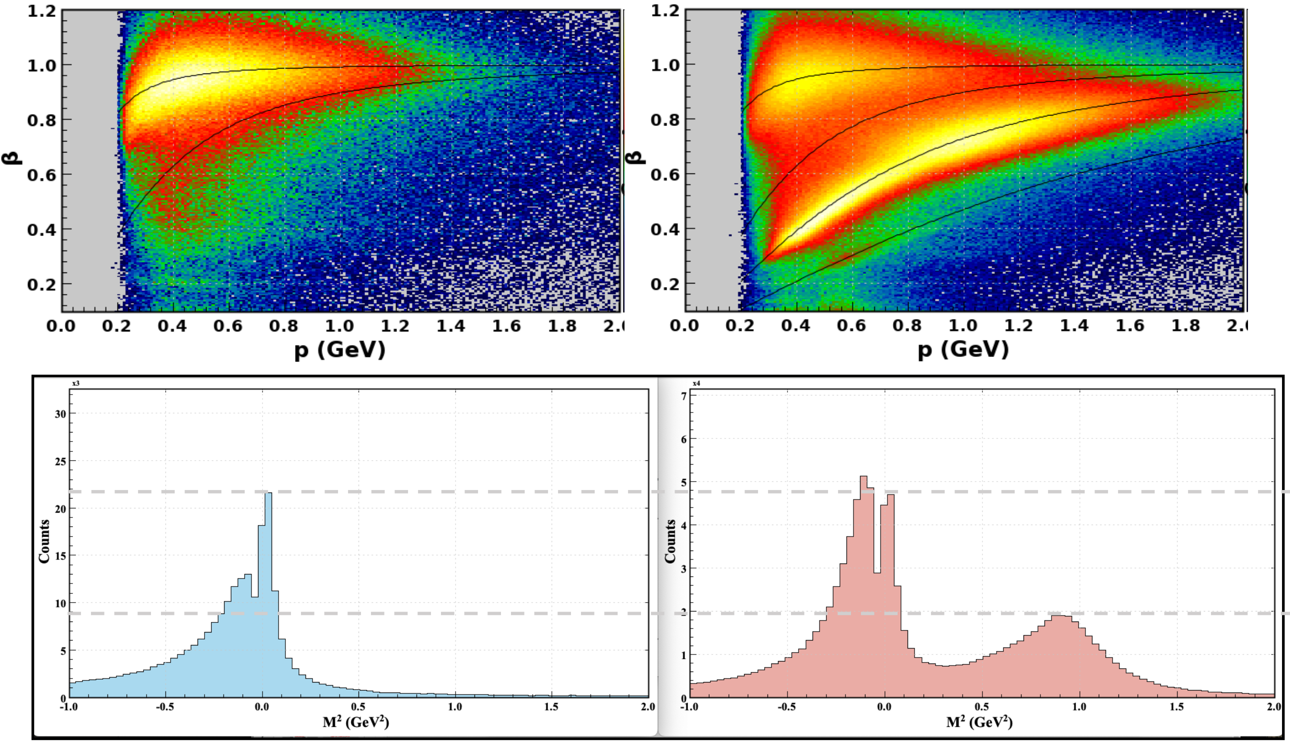

Name Inv. Mass, vtxy=0.0, vtz=0.0
Entries 126454
Mean 0.665
RMS 0.180
pi+ and pi- in either FD or CD
Counts
m(π+ π-)
Name Inv. Mass, vtxy=0.05, vtz=2.0
Entries 46197
Mean 0.618
RMS 0.183
pi+ and pi- in either FD or CD Vtx cut
rho suppression
Ks enhancementt
Counts
m(π+ π-)
Name Inv. Mass, vtxy=0.0, vtz=0.0
Entries 51754
Mean 0.644
RMS 0.183
pi+ and pi- in FD
Counts
m(π+ π-)
Name Inv. Mass, vtxy=0.0, vtz=0.0
Entries 74700
Mean 0.679
RMS 0.177
pi+ or pi- in CD
rho enhancement
Counts
m(π+ π-)

ANALYSES FROM THE RUN GROUPS

RGM
Hydrogen @6 GeV
(Justin Estee, MIT)

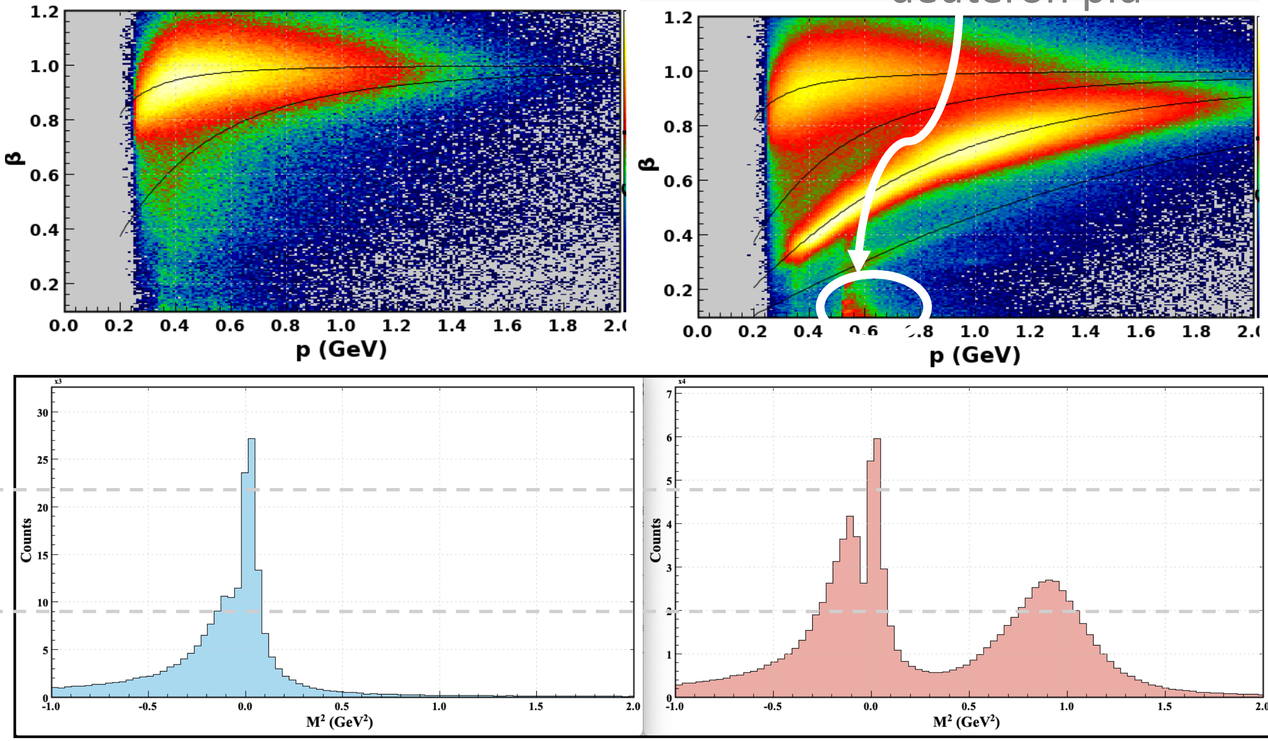
PID

Coatjava 8.3.0



Coatjava 8c.3.2

Fixed: failed tracks assigned deuteron pid



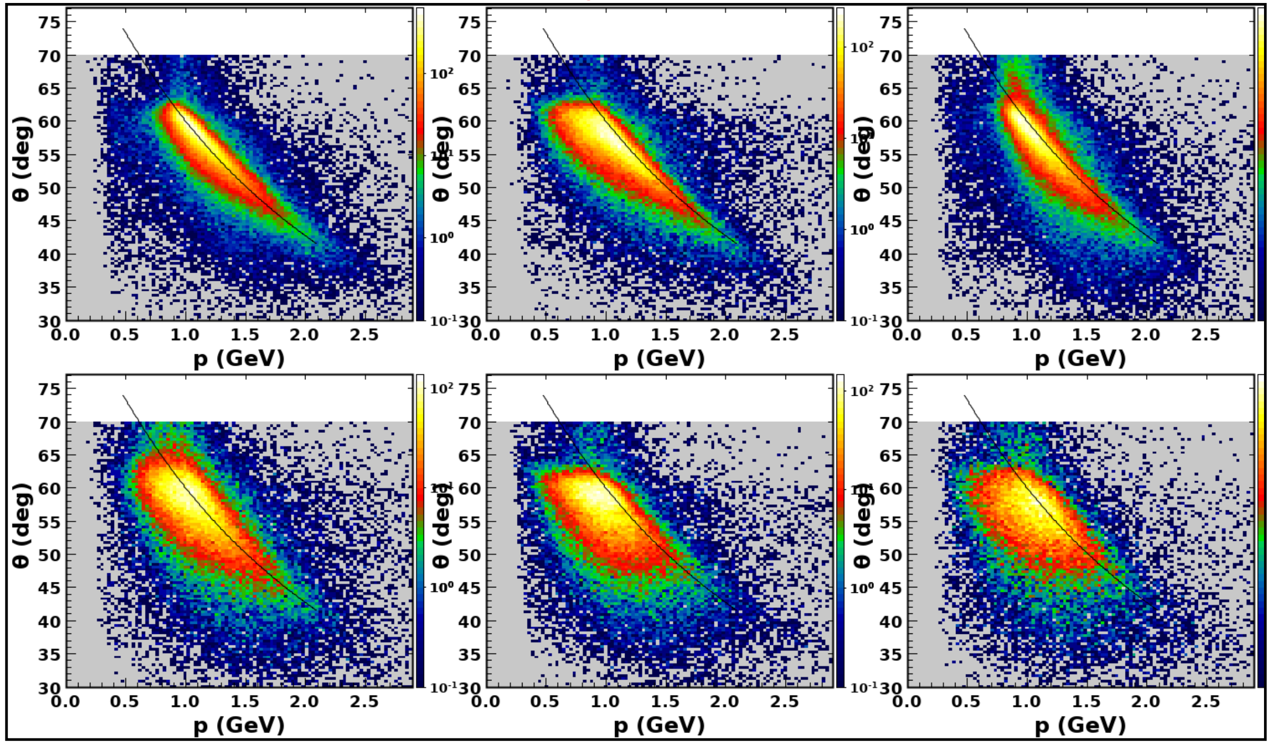
- Improved resolution
- ~1.4 x more protons

ANALYSES FROM THE RUN GROUPS

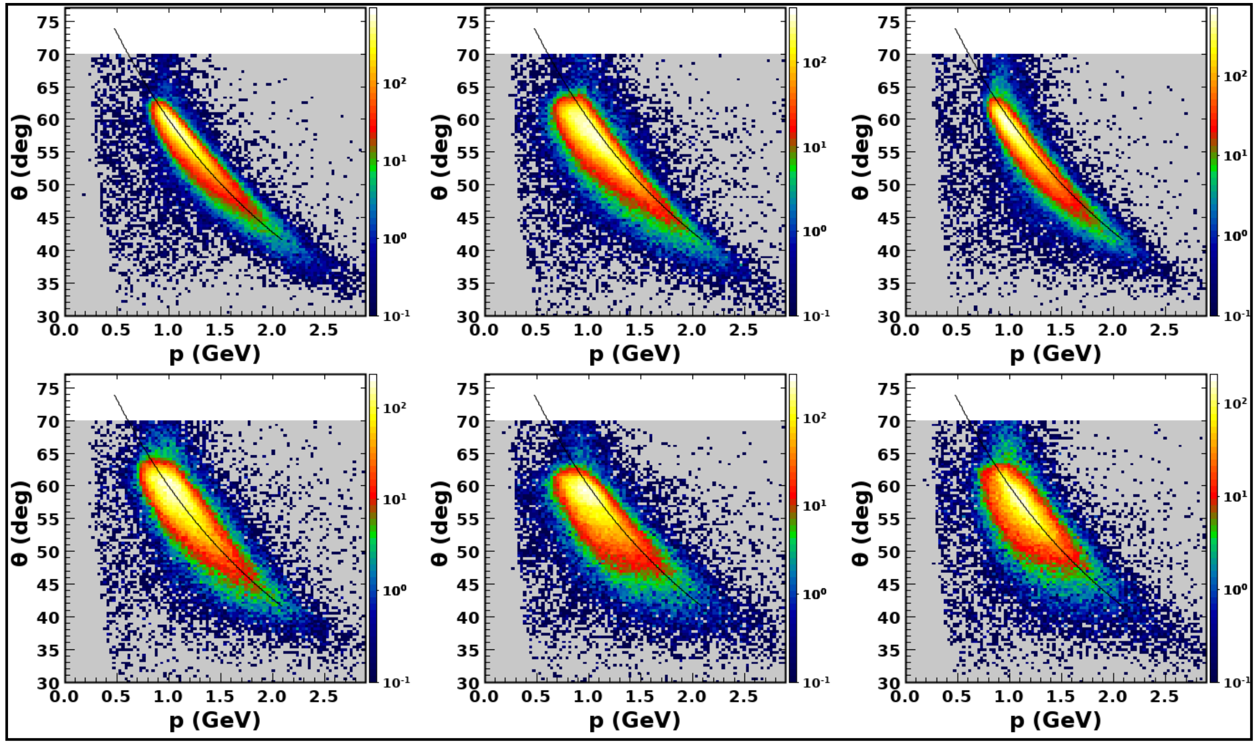
RGM
Hydrogen @6 GeV
(Justin Estee)

Elastics

Coatjava 8.3.0



Coatjava 8c.3.2



- Improved resolution

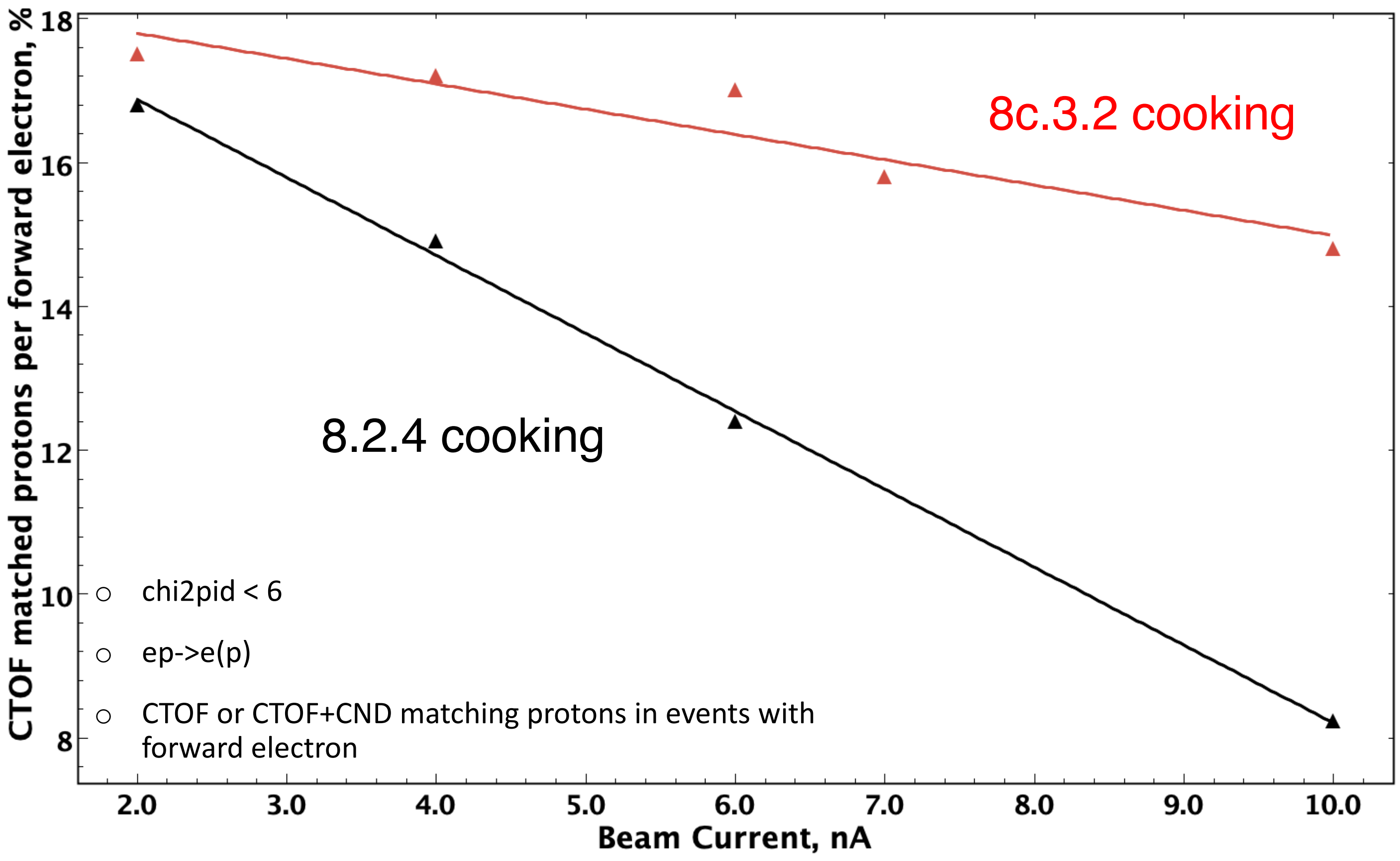
ANALYSES FROM THE RUN GROUPS

RGC
(Dan Carman)

RG-C FTOff
Luminosity Scan
Analysis

- Cooking using official release 8.2.4 & test release 8c.3.2 (done by Mohammad)
- RUNS used in analyses:
- 16850 (2 nA)
- 16852 (6 nA)
- 16947 (7 nA)
- 16882 (10 nA)

CTOF matched proton fractions vs beam current

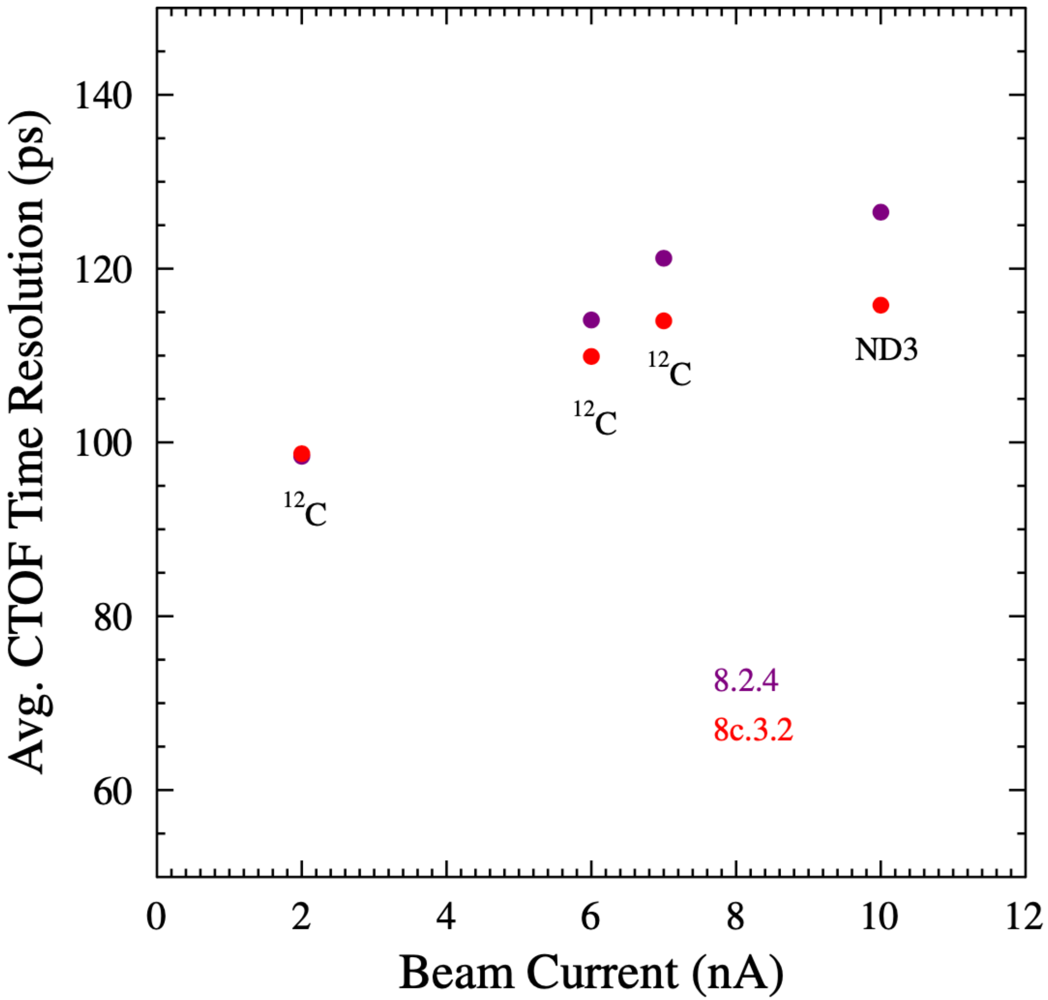


ANALYSES FROM THE RUN GROUPS: CALIBRATIONS

RGC
(Dan Carman)

CTOF performance with FT-Off

- Cooking using official release 8.2.4 & test release 8c.3.2 (done by Mohammad)
- RUNS used in analyses:
- 16850 (2 nA)
- 16852 (6 nA)
- 16947 (7 nA)
- 16882 (10 nA)
- CTOF counter timing resolution for the different runs of the luminosity scan at beam currents of 2, 6, 7, and 10 nA.



8.2.4 cooking

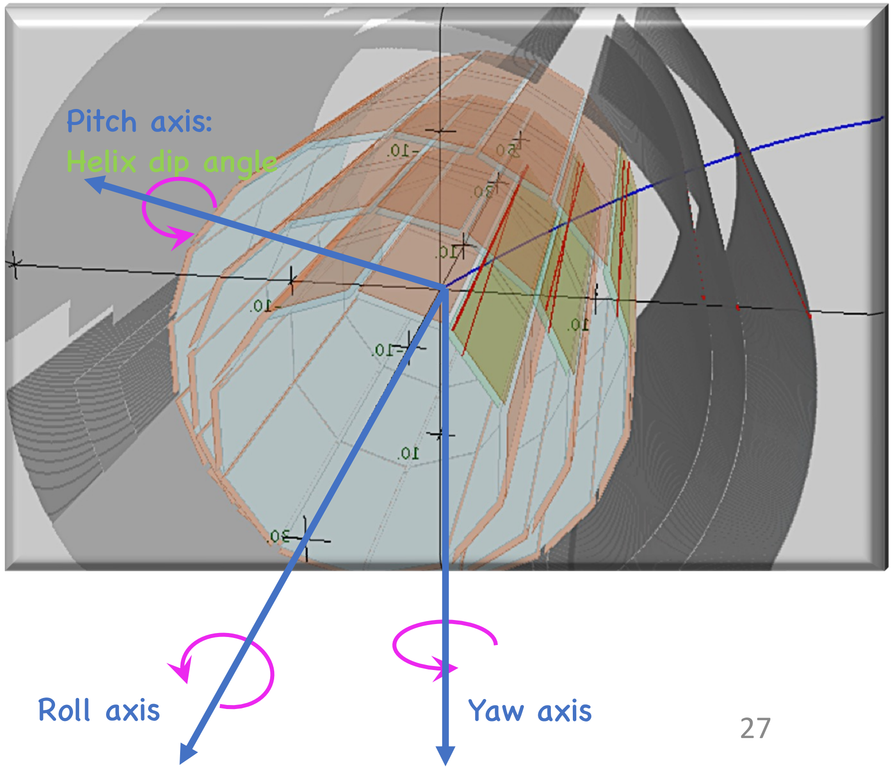
8c.3.2 cooking

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

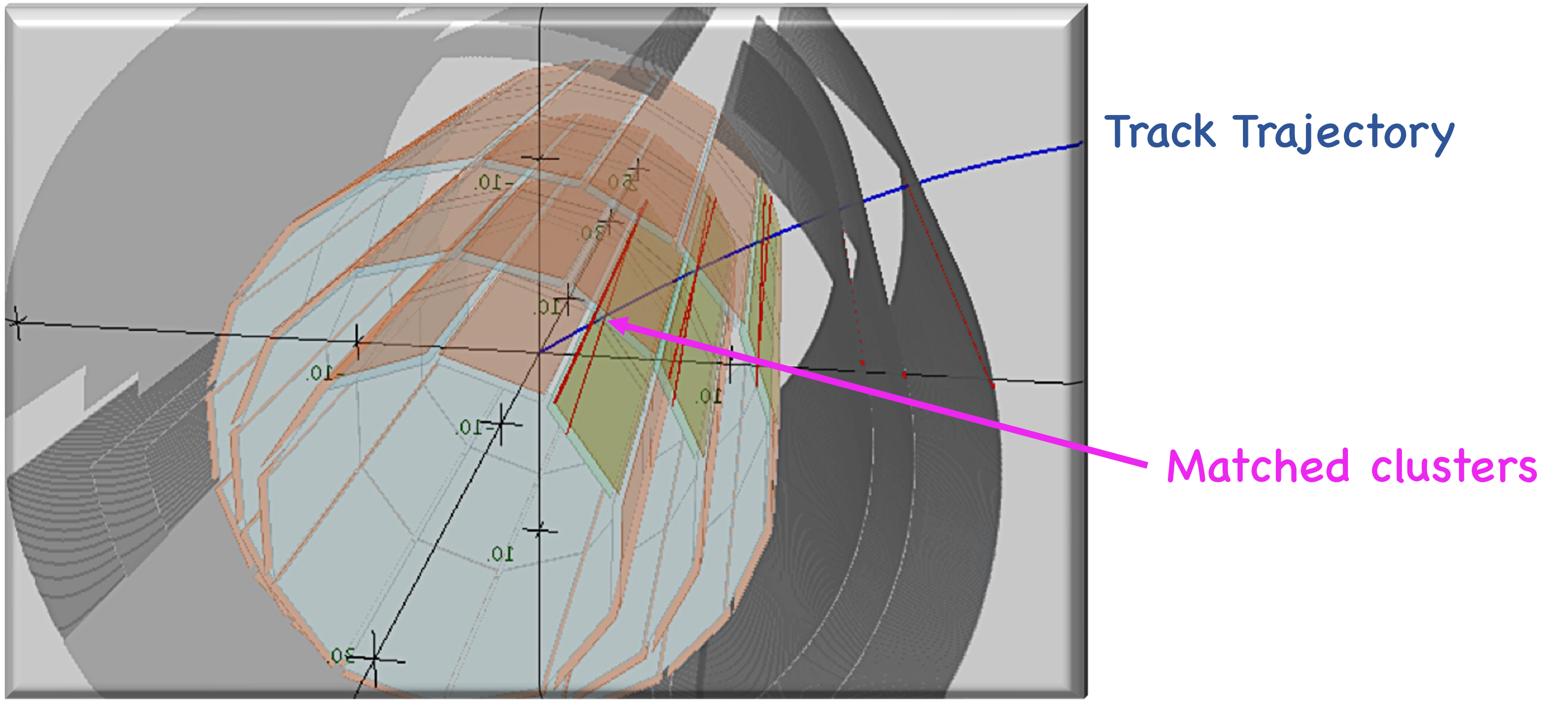


- Simpler, more efficient than CA-based algorithm for CLAS12

NEW CVT TRACKING ALGORITHMS (2)

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

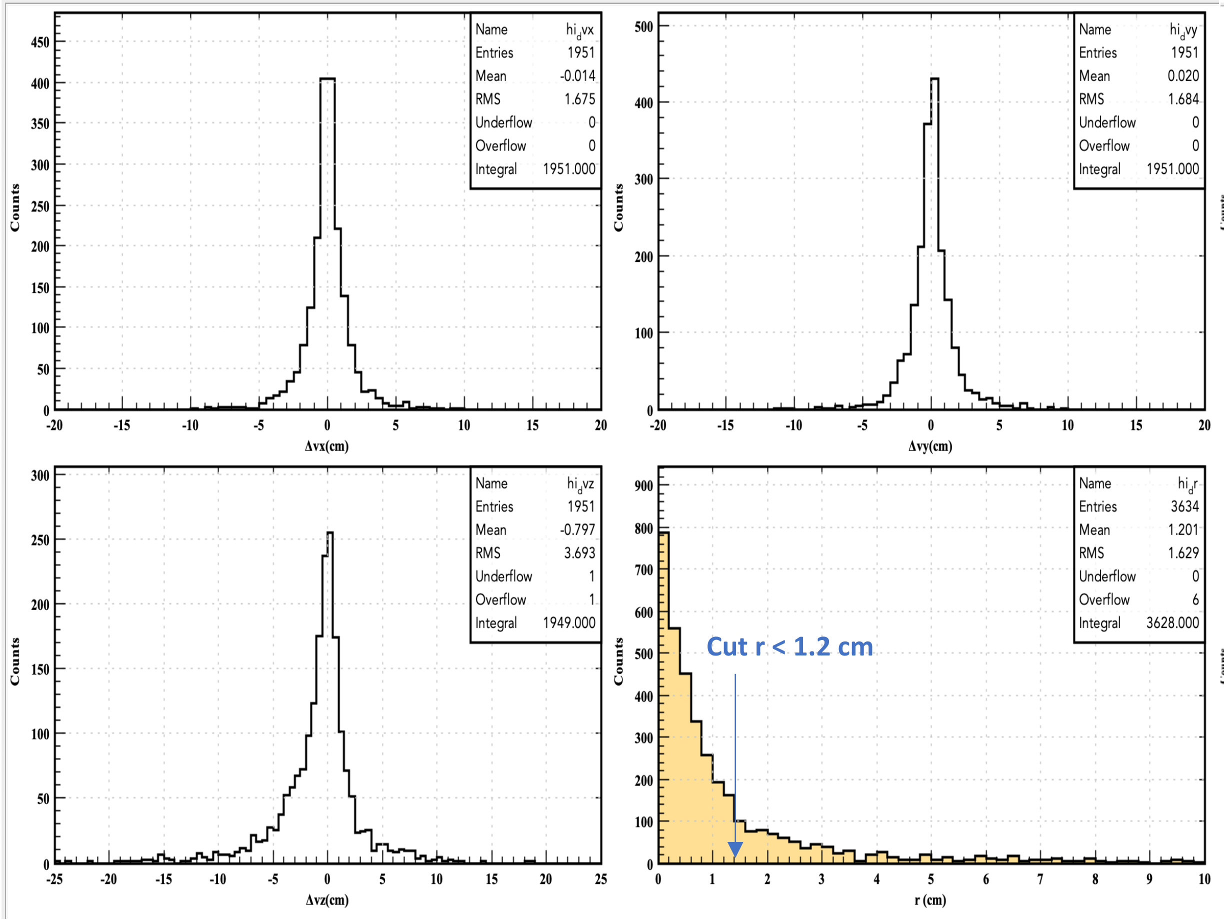
- Uses KF trajectory of fitted seed (i.e. KF track) to search for clusters on track
  - Select best match (doca cut)
  - If two clusters found in a region → create the cross if cross missing or update the cross as on track if it exists.
  - Compensates for clusters missed by SLA (misses due to cuts; 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

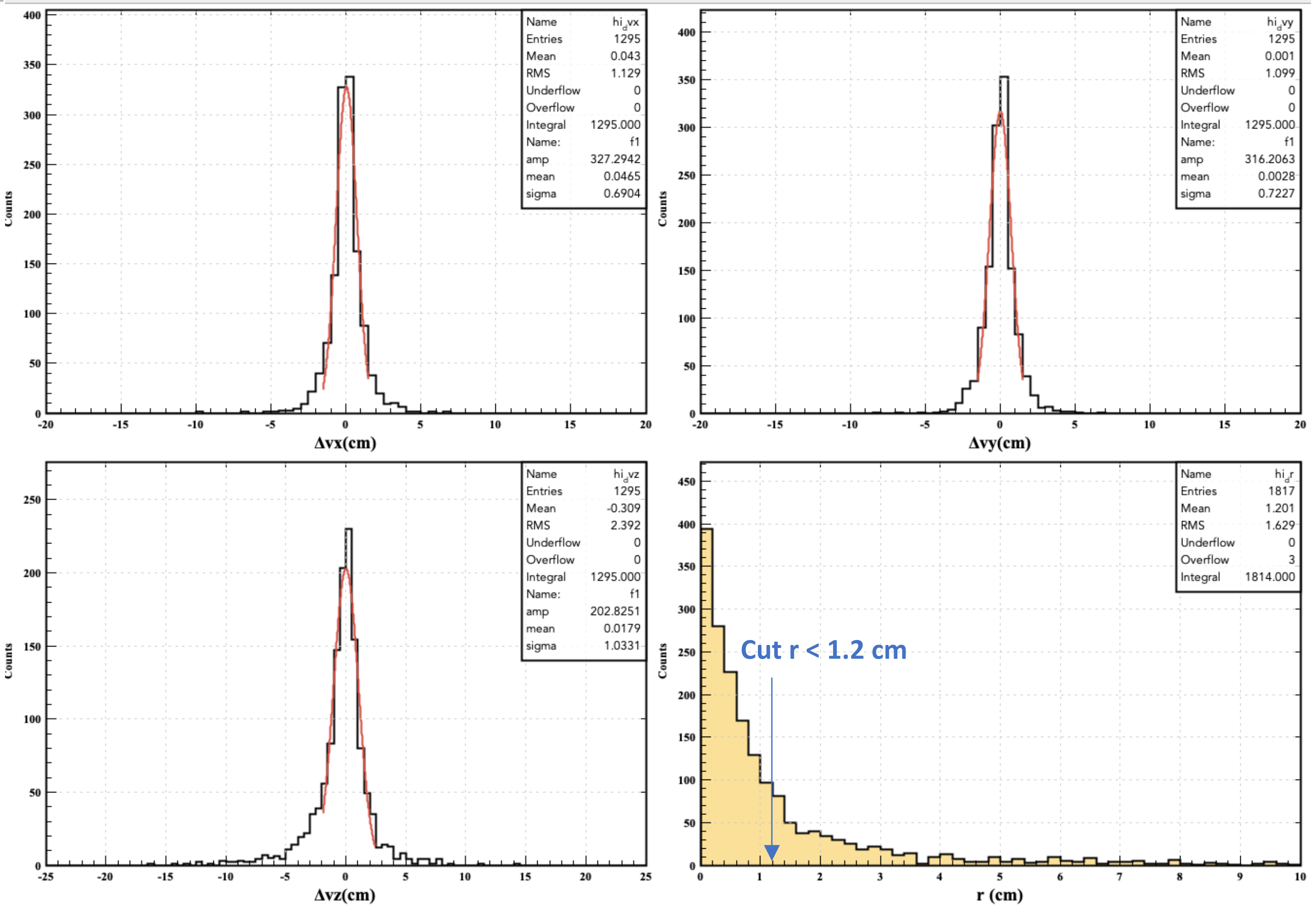
No Background

Entire m(pπ⁻) range



Cut r < 1.2 cm

Signal region
1.11<m(pπ⁻)<1.124 GeV

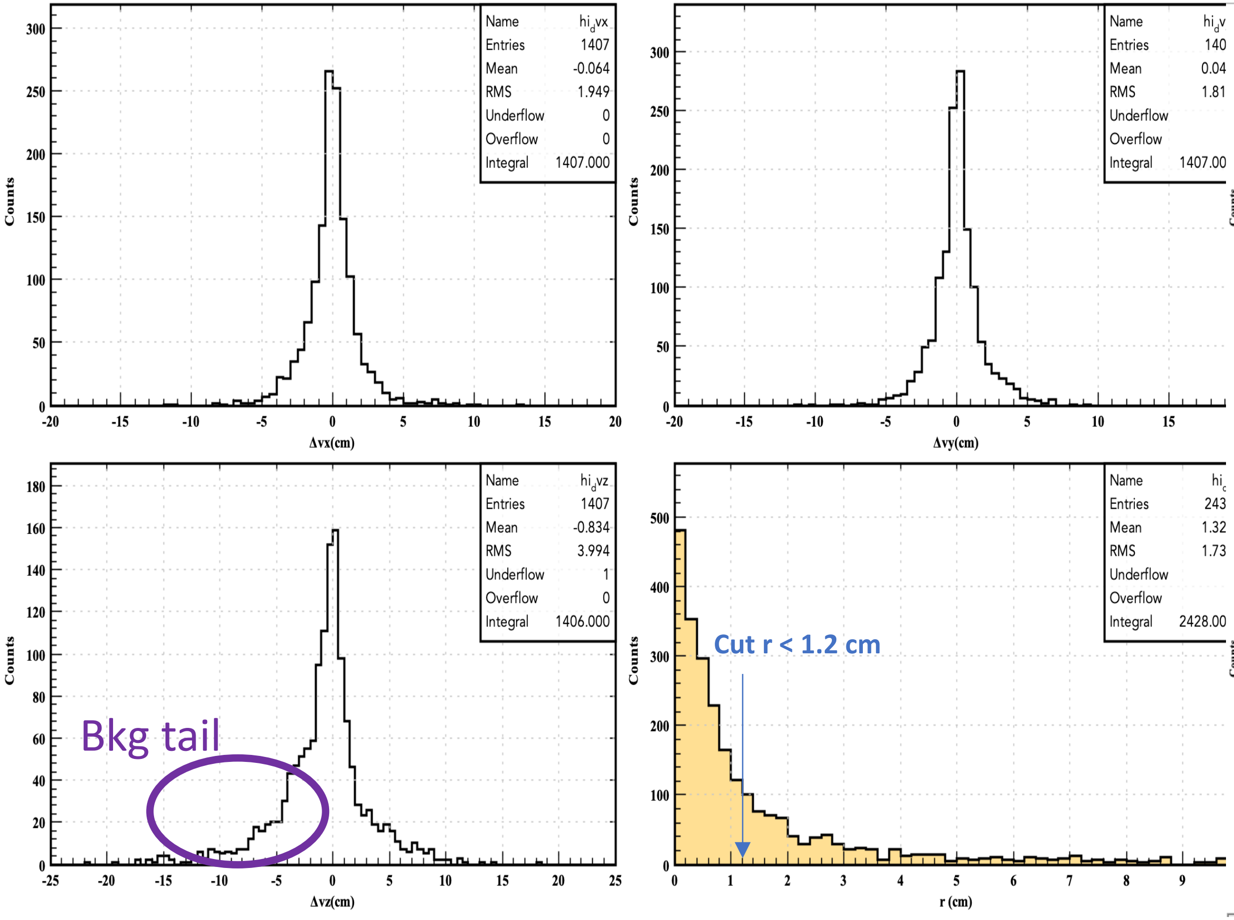


KLambda MC Sample (6.5 GeV) Λ vertex resolution

With 35 nA Background

Cut r < 1.2 cm

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



Signal region

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