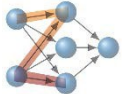


Status and Plans for the Neural Track Trigger Projects

- Reminder: Performance and Problems of Present Neuro-Track-Trigger
- z-Trigger / Single Track Trigger („STT“) Upgrade:
New 3D preprocessing & deep learning networks -> C.K. + Simon Hiesl
UT4: Integration of 3D preprocessing + neural networks -> Kai, Jan-Felix
- [Development of a Displaced Vertex Trigger DVT
Algorithms by Elia (see his presentation)
new student to continue: Timo Forsthofer
Hardware implementation on UT4 platform -> Kai, Marc]



AI Trigger Group at Belle II



KIT ITIV

- Marc Neu
- Kai Unger
- Jürgen Becker



KIT ETP

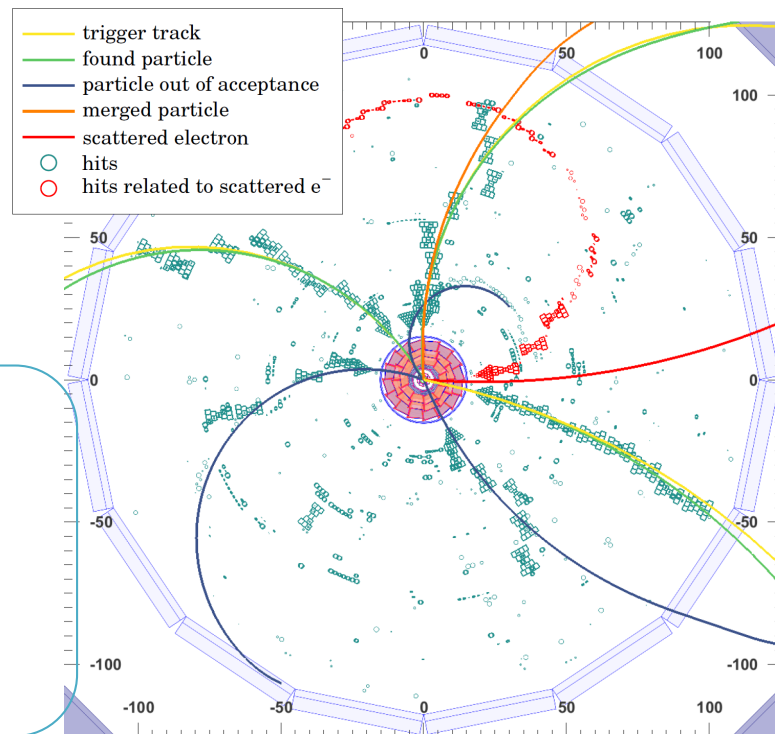
- Lea Reuter
- Greta Heine
- Slavomira Stefkova
- Torben Ferber



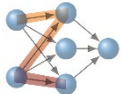
MAX-PLANCK-GESELLSCHAFT

MPI & TUM

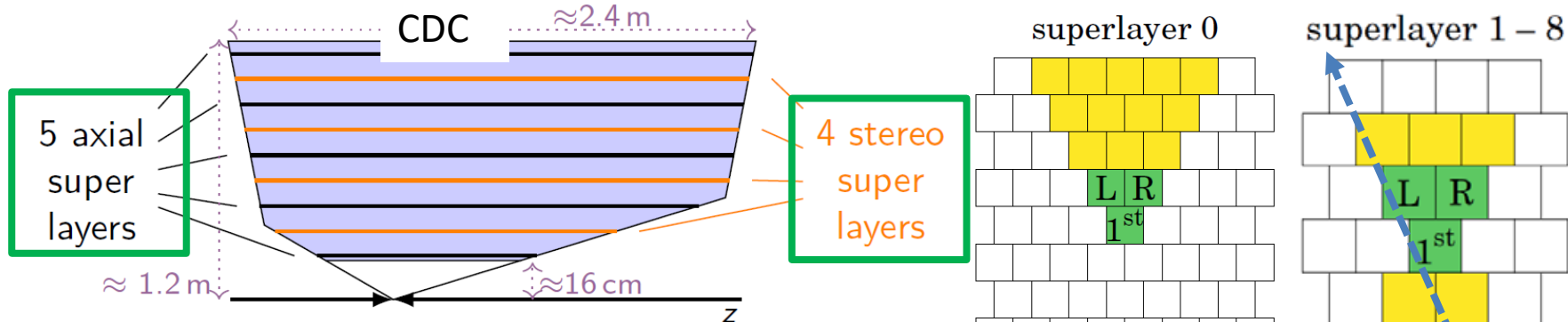
- Felix Meggendorfer
- [Elia Schmidt]
- Simon Hiesl
- Timo Forsthofer
- Christian Kiesling
- Alois Knoll



focus of
TUM/MPI groups:
Track Triggers

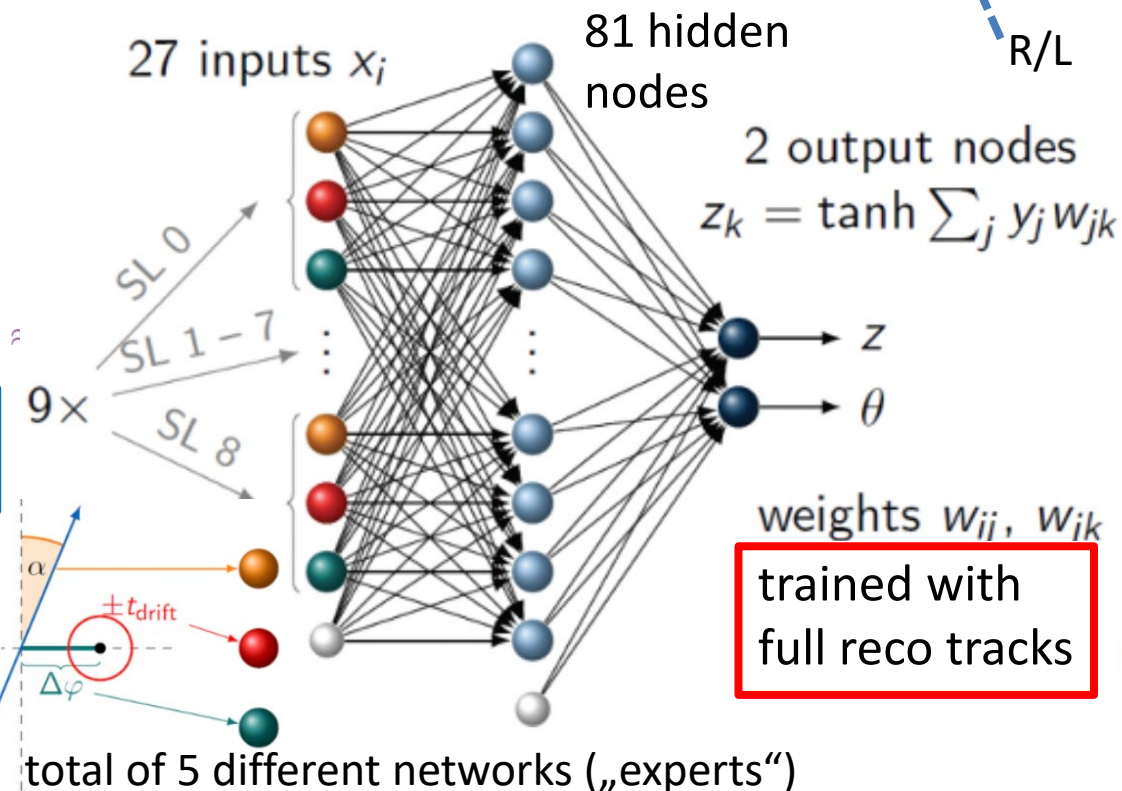
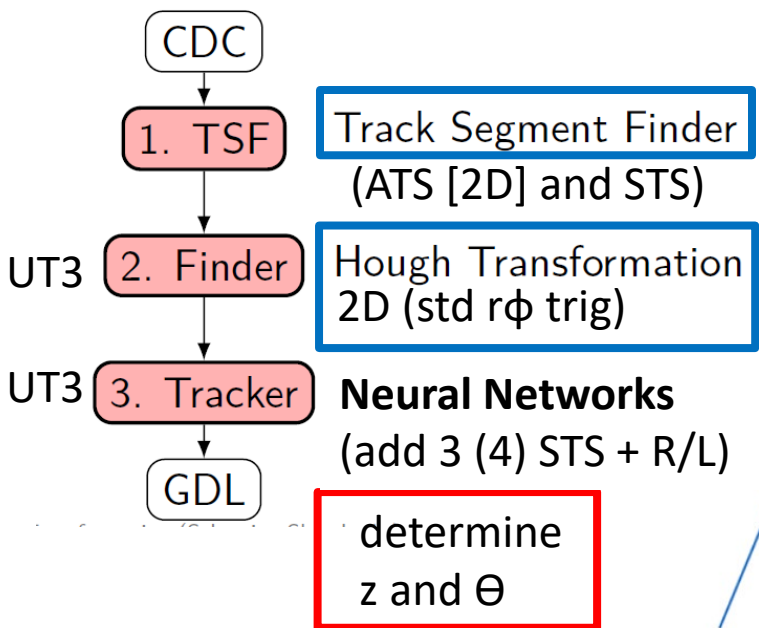


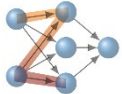
Recap: Elements of the Neural L1 Track Trigger



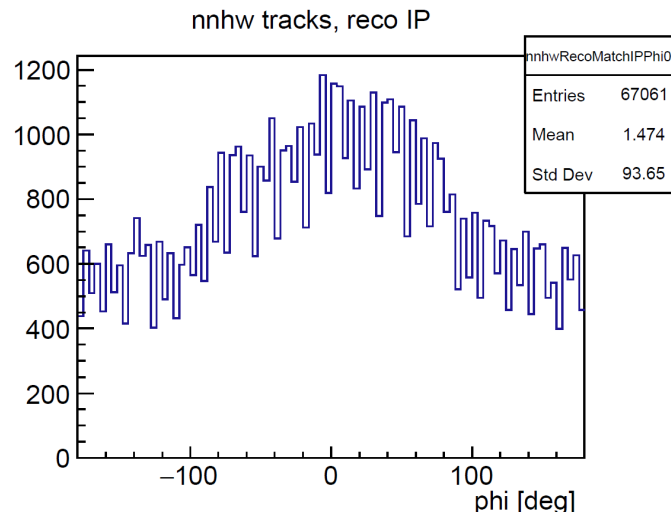
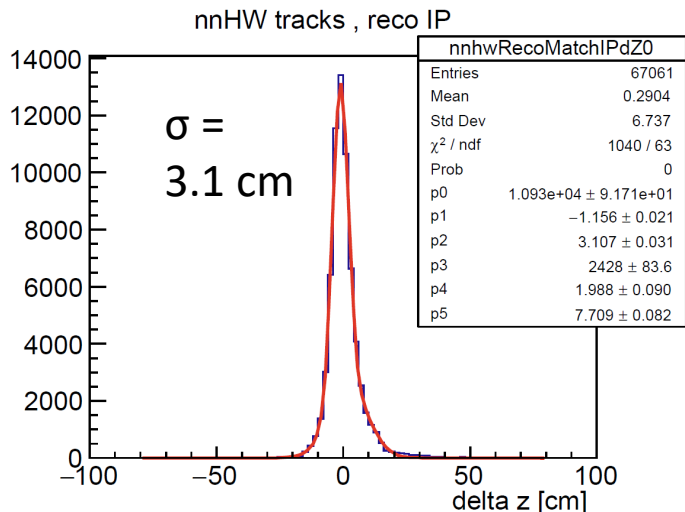
- ▶ 56 layers combined to 9 super layers (SL)
- ▶ 2336 track segments (TS) in 9 SL

L1 Neuro Trigger pipeline

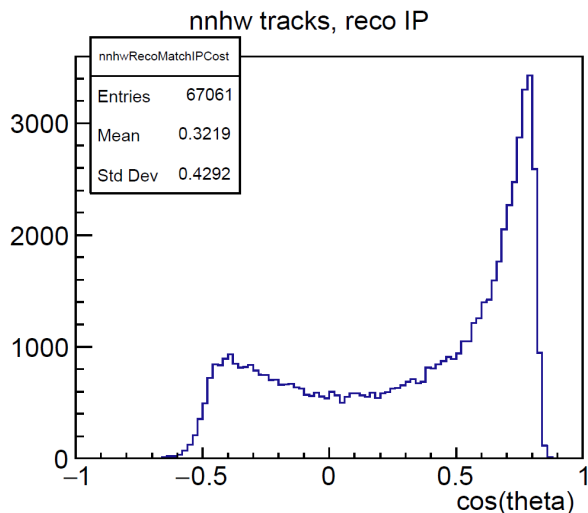




z-Resolution Exp 26 (runs 1700-end)



Results from high background

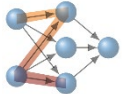


Gaussian fits to neuro tracks associated with reco tracks from IP ($|z| < 1 \text{ cm}$, $d < 1.5 \text{ cm}$)

Central Gauss: $\sigma = 3.1 \text{ cm}$

2nd Gauss: $\sigma = 7.7 \text{ cm}$

z cut for all track triggers („y“ bit): $|z| < 15 \text{ cm}$



„STT“: a Minimum Bias Single Track Trigger

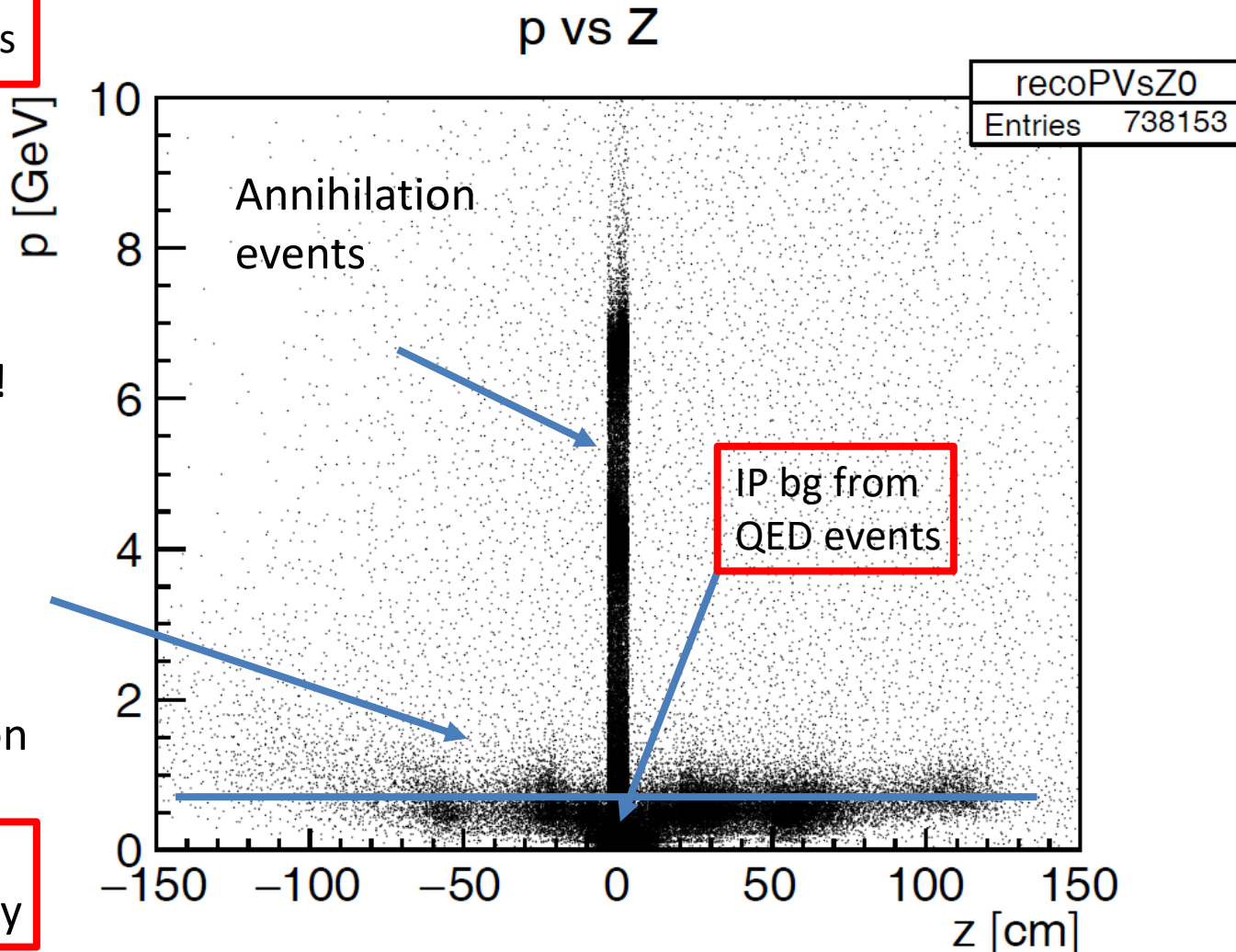


Rate from z-Trigger
high due to QED events

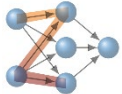
Momentum of
particles outside of IP
mostly below 1 GeV !!

Collisions of electron
with elements of the
beam guide system,
producing protons
from nuclear spallation

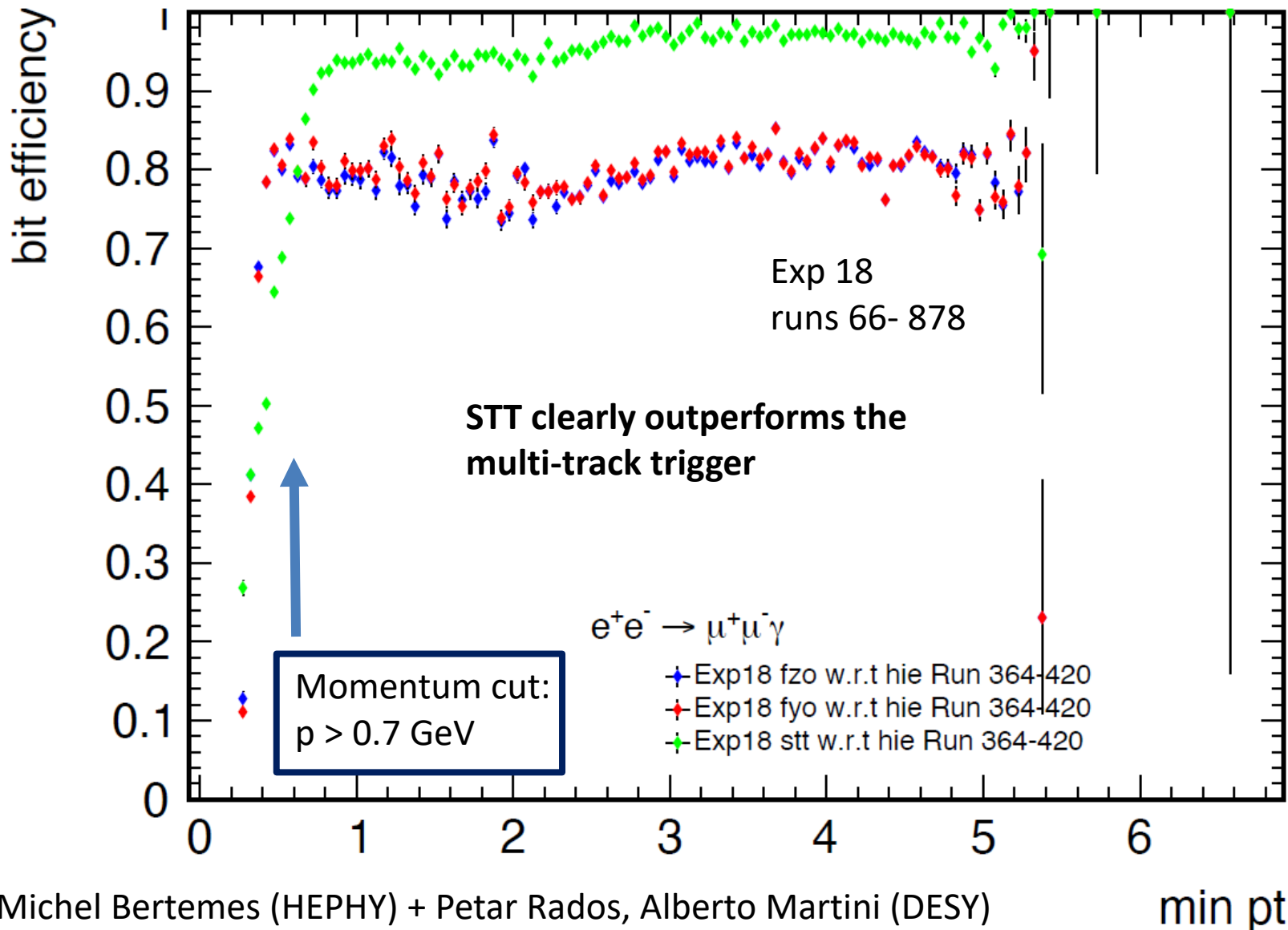
cut at $p > 0.7$ GeV
seems OK for a first try



Distribution of Reco Track momentum vs z

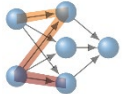


Trigger Efficiencies



Michel Bertemes (HEPHY) + Petar Rados, Alberto Martini (DESY)

min pt

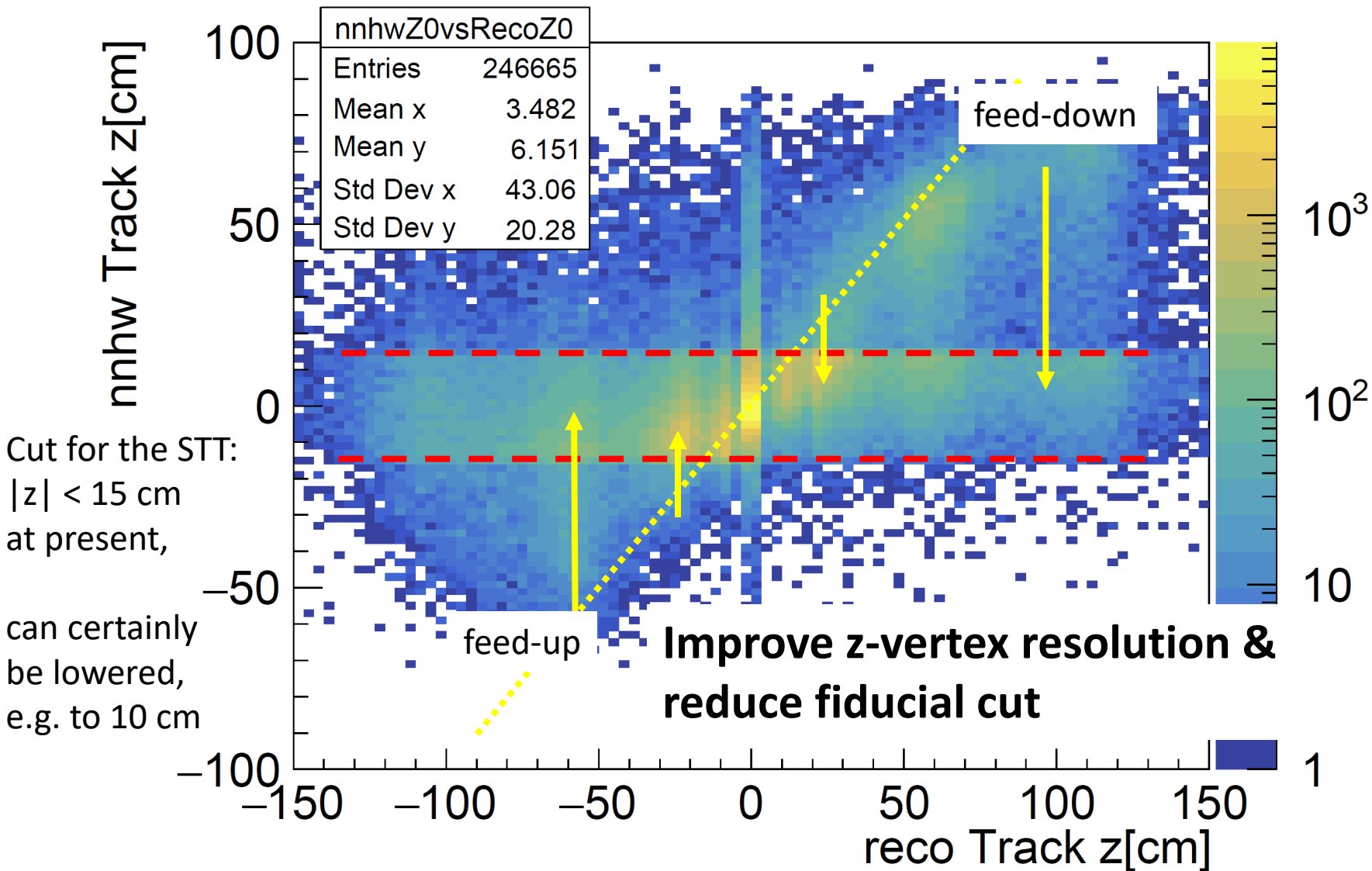


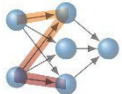
Problems of the STT (I) : „Feed-Down“



Exp. 26, runs > 1700

z0 reco vs z0 nnhw





Problems of the STT (II) : „Fake Tracks“



Exp. 26: Run 33, Event 1391616

Event: 1391616
Run: 33
Experiment: 26

2022-05-11 18:38:54 UTC

Options

- Show MC info
- Assign hits to primary particles
- Show all primaries
- Show all charged particles
- Show all neutral particles
- Hide secondaries
- Show candidates and rec. hits
- Show tracks, vertices, gammas

Current Viewer

Save As... Save As (High-Res)...

Dock/Undock Viewer

Visualisation Options

Dark/light colors

Cumulative mode (experimental)

Automatic Saving (experimental)

Prefix: display_

Width (px): 800 Save PNGs

Closing

Exit

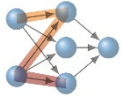
Arrays

- ARICHAeroHits (0)
- ARICHDigits (5)
- ARICHHits (5)
- ARICHLikelihoods (0)
- ARICHRawDigits (71)
- ARICHSimHits (0)
- ARICHTracks (0)
- BKLMHit1ds (22)
- BKLMHit2ds (1)
- BKLMSimHitPositions (0)
- BKLMSimHits (0)
- BeamBackHits (0)
- BremHits (0)
- CDCDedxLikelihoods (0)
- CDCDedxTracks (0)
- CDCHits (4693)
- CDCRawHitWaveForms (0)
- CDCRawHits (4693)
- CDCRecoTracks (0)
- CDCSimHits (0)
- CDCTrigger2DFinderClones (32)
- CDCTrigger2DFinderTracks (32)
- CDCTrigger2DTo3DBits (48)
- CDCTriggerHoughClusters (35)
- CDCTriggerNNBits (48)
- CDCTriggerNNInput2DFinderTracks (12)
- CDCTriggerNNInputAllStereoSegmentHits (230)
- CDCTriggerNNInputSegmentHits (71)
- CDCTriggerNeuroTracks (12)
- CDCTriggerNeuroTracksInbnt (12)

Noise (pick up) in the CDC:
No reco track !

12 fake neural tracks found, at least one with $|z| < 15$ cm

too many (noise) 2D candidates, combined with noise stereo TS



-> keep efficiency & low trigger rate with rising luminosity (BG)

Physics goals: low charged multiplicity, e.g. τ 1-prong decays (- > τ EDM, LFV),

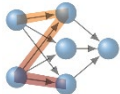
- $e^+e^- \rightarrow \pi^+\pi^-(\gamma)$ for g-2 (hadronic vacuum polarization) etc.
- quite generally: determination of lepton ID, tracking and photon efficiencies
- from unbiased track -> **STT is a minimum bias single track trigger**

Improved track finding / training algorithms:

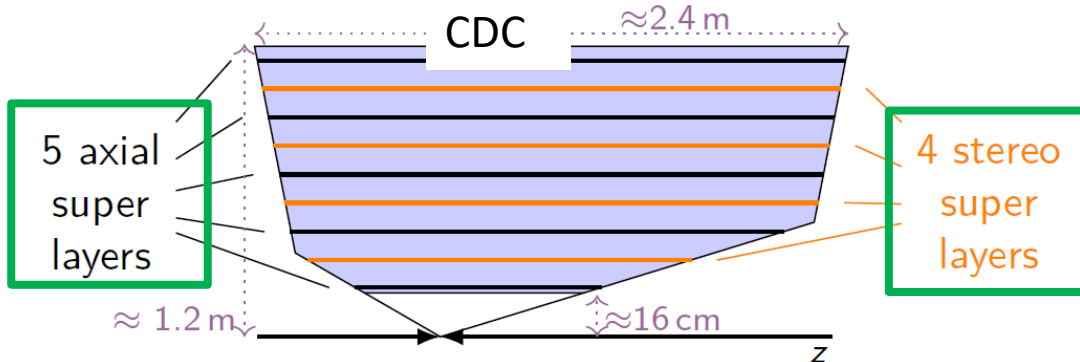
- do track finding in 3D Hough space -> this is really new (S. Skambraks)
- enhance network architecture: „deep-learning“
- -> improve resolutions @ IP and for larger $|z|$

FPGA Implementation:

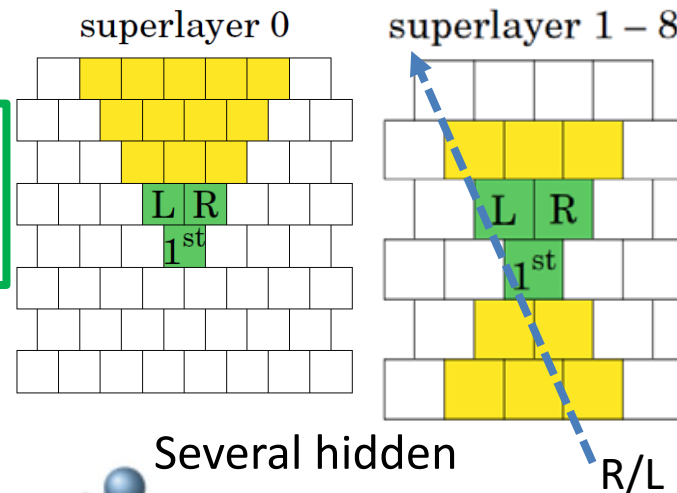
- implement the new algorithms on new UT4-Trigger-Modules
- optimize latency: e.g. move STT decision from GRL to NN



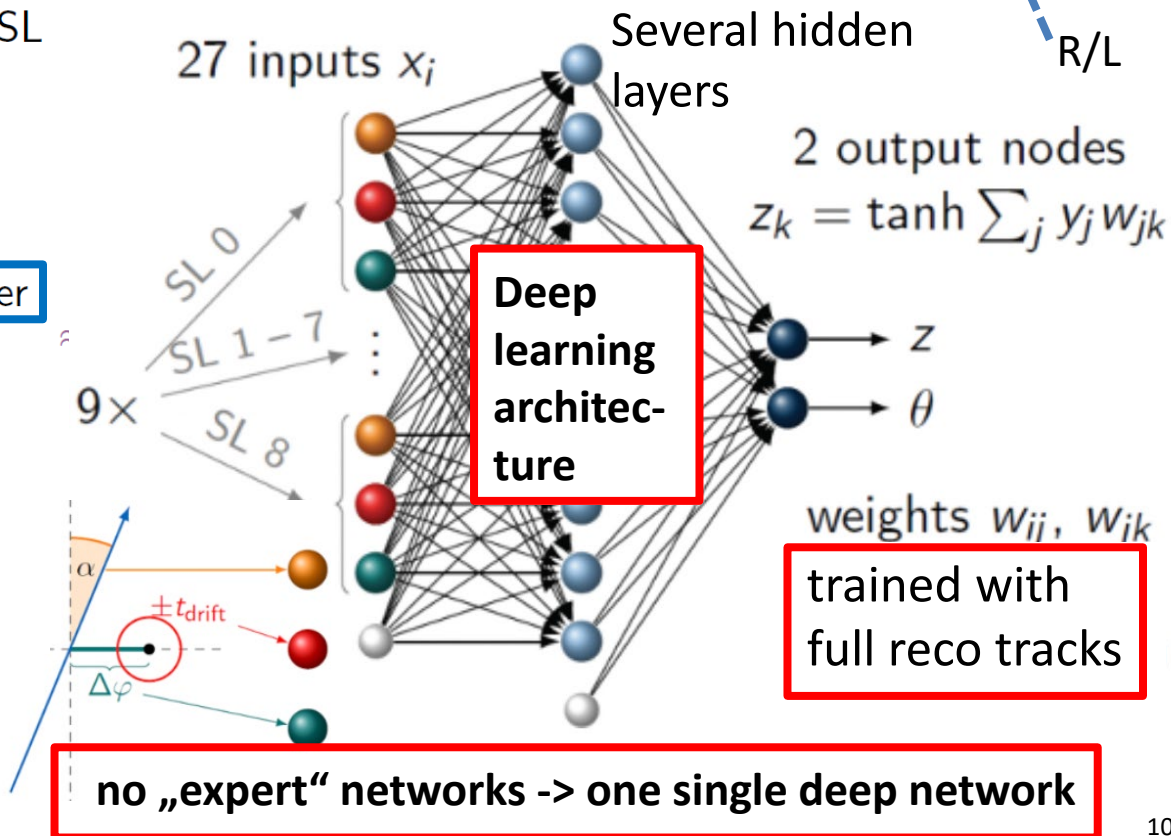
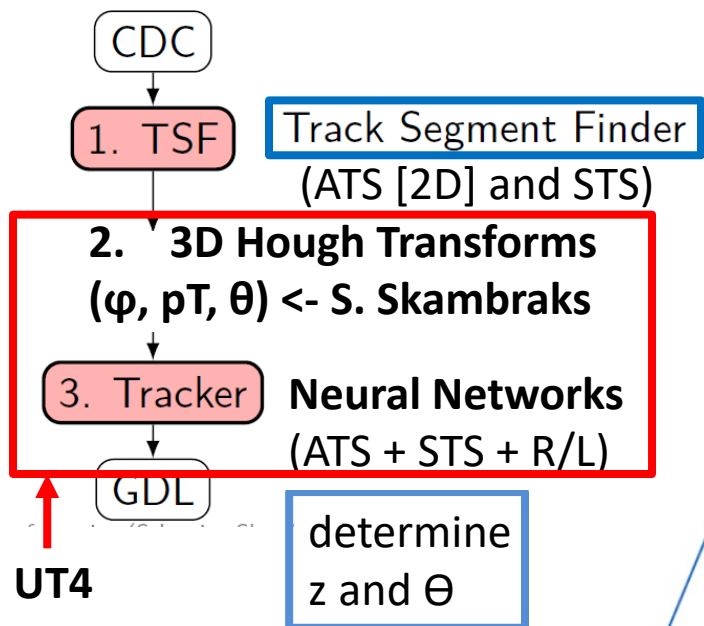
Upgrade of the Neural Trigger: 3D track finding

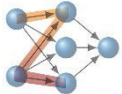


- ▶ 56 layers combined to 9 super layers (SL)
- ▶ 2336 track segments (TS) in 9 SL



L1 Neuro Trigger pipeline





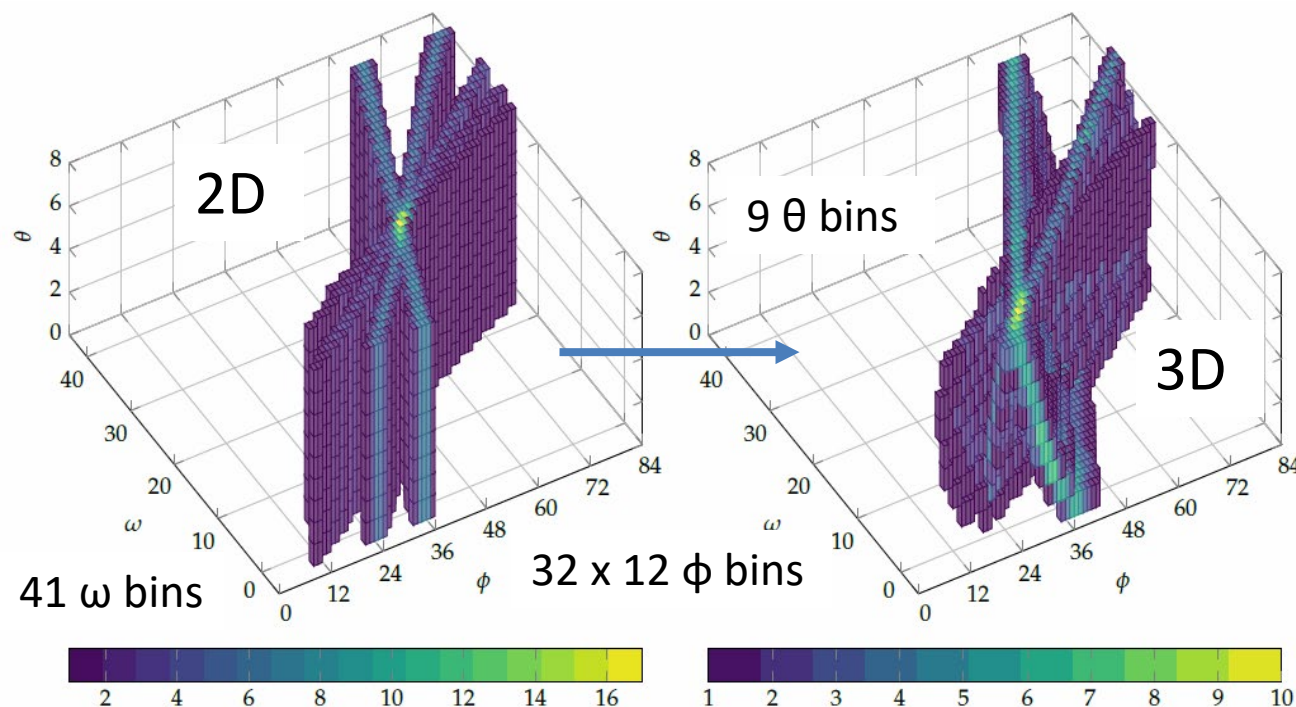
3D Hough Track Finding

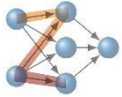


- Extend traditional 2D ($\omega=1/p_T, \phi=\text{azimuth angle}$) Hough space by a third dimension, the (binned) polar angle θ
- For track finding use axial and stereo track segments (->3D)
- Peak finding in 3D Hough space

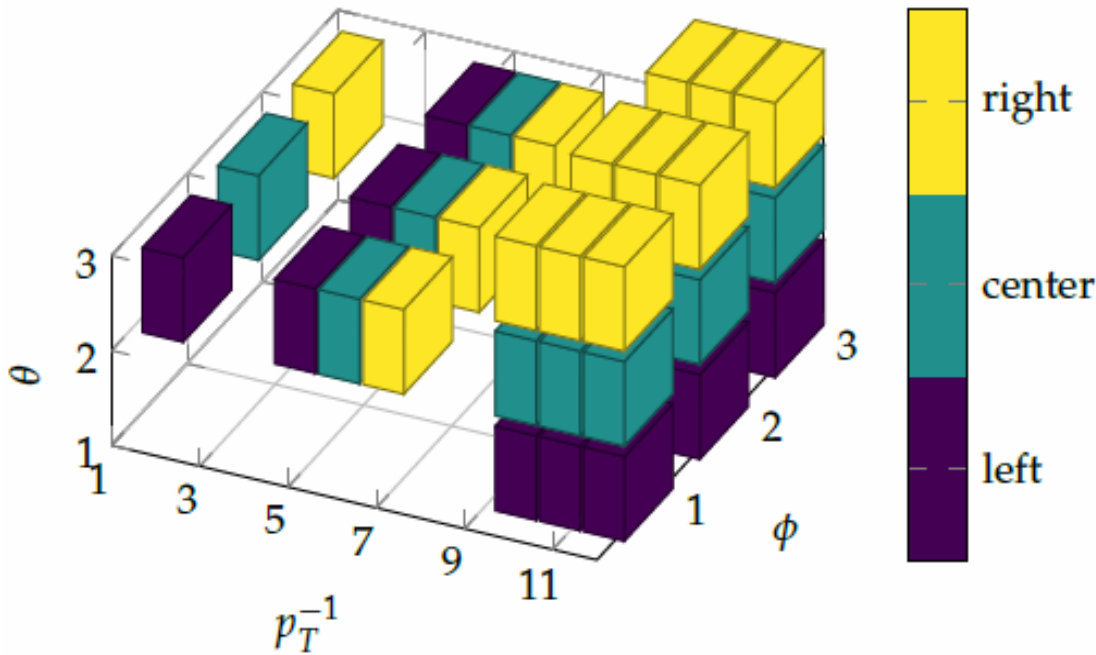
Main advantages:

- more TS (9 vs 5)
-> suppress fakes
- No need to choose STS by min drift time
-> find „correct“ STS
- Force track model to originate from IP
-> suppress candidates far from IP
- 3D track candidates come with θ estimate,
-> improve z resolution





Clustering in 3 Dimensions



Cluster building by checking nearest neighbors according to modified DBSCAN algorithm (density-based spatial clustering):

Hough parameter space/granularity:

$p_T > 0.2$ GeV [41]

$\phi \in [0, 360^\circ]$ [384]

$\theta \in [19^\circ, 140^\circ]$ [9]

Typical values of cluster-defining parameters:

$W_{\min} = 20$ (cluster cell)

$\minPts = 1$ (# neighbors)

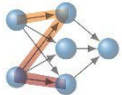
$\minHits = 4$ (# cells in cluster)

$\text{thresh} = 0.85$ (

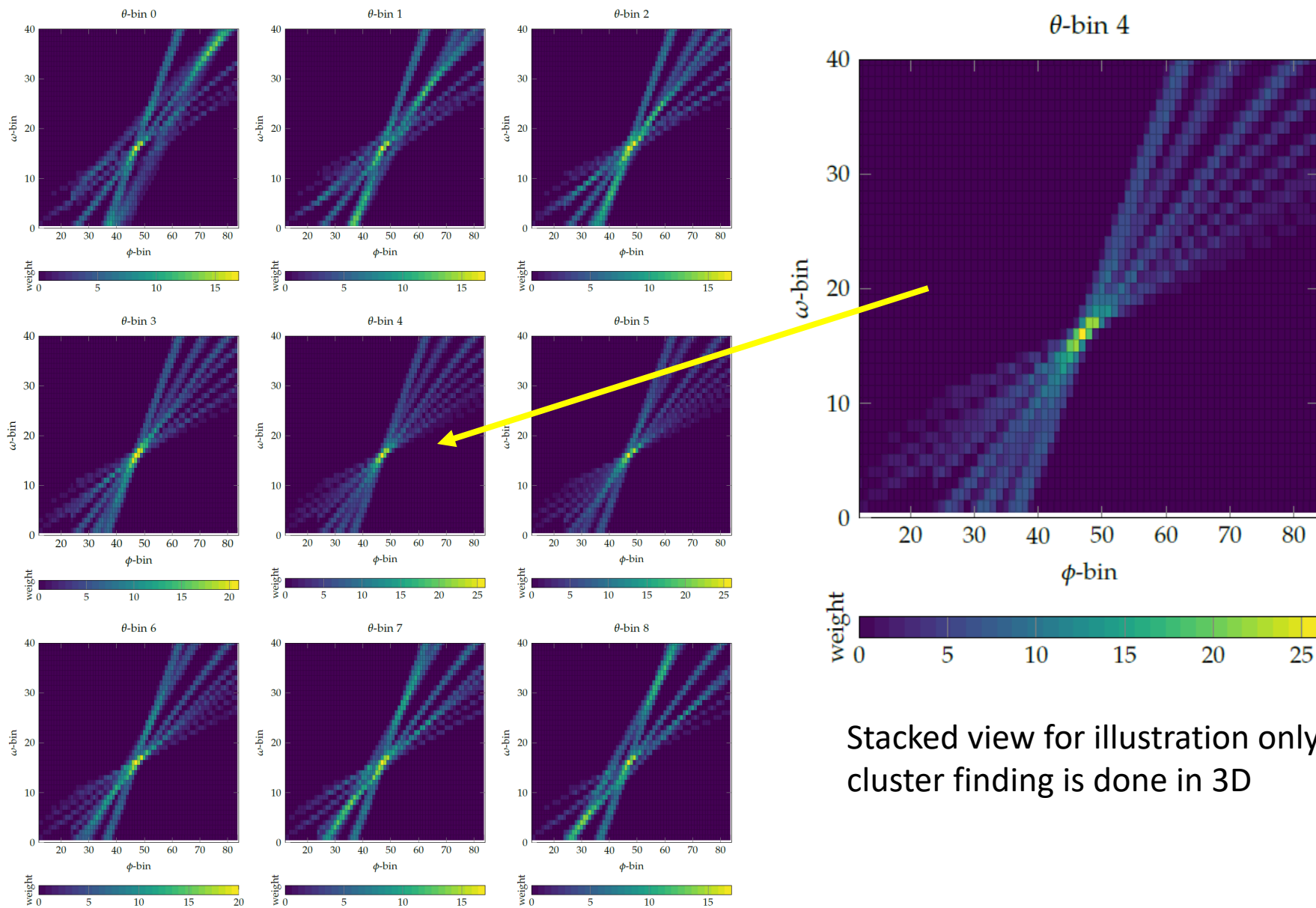
Parameters subject to optimization!!

Alternative algorithm under study (more favorable for HW implementation):

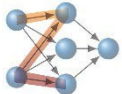
- Look for maximum cell weight in 3D-Hough space
- Define an environment („shell“) around maximum „shell“ can have arbitrary (constant) shape
- Calculate center-of-gravity for Hough center (precision needed to determine p_T and to calculate track momentum for STT)



Example of 3D Hough Map



Stacked view for illustration only,
cluster finding is done in 3D



Vertex Track via 3D Preprocessing



Belle II Event Display - ndFinderPgunfcff_vertex_check.root

Browser Eve Camera Scene

Event Control

- WindowManager
- Viewers
- Scenes
 - RhoZ (0.0)
 - TEveProjectionAxes
 - Geometry scene [P]
 - Event scene [P]
 - RhoPhi (0.0)
 - TEveProjectionAxes
 - Geometry scene [P]
 - Event scene [P]
- Event
 - CDCRecoTracks
 - MCRRecoTracks
 - PXDRecoTracks
 - RecoTracks
 - SVDCDCRecoTracks
 - SVDPlusCDCStandaloneRecoTrac
 - SVDRecoTracks
 - CDCHits
 - CDCTriggerSegmentHits
 - TRGDCDTrackSegments
 - CDCTrigger3DFinderTracks
 - TRGDCD2DFinderTracks
 - TRGDCD2DFinderTracks[0]
 - TRGDCD3DFinderTracks
 - TRGDCD3DFinderTracks[0]
 - TRGDCDNeuroTracks
 - TRGDCDNeuroTracks3D
 - TRGDCDNeuroTracks3D[0]
 - BKLM2dHits
 - Fitted Tracks
 - KLMClusters
 - TOP Modules
 - MCPParticles
 - ECLClusters
 - Unassigned RecoHits

Style

TRGDCD3DFinderTracks[0] [TE

TEveElem

Show: Self Children

Marker

1.0

Opacity

Study of 3D finder parameters using MC

Simon Hiesl

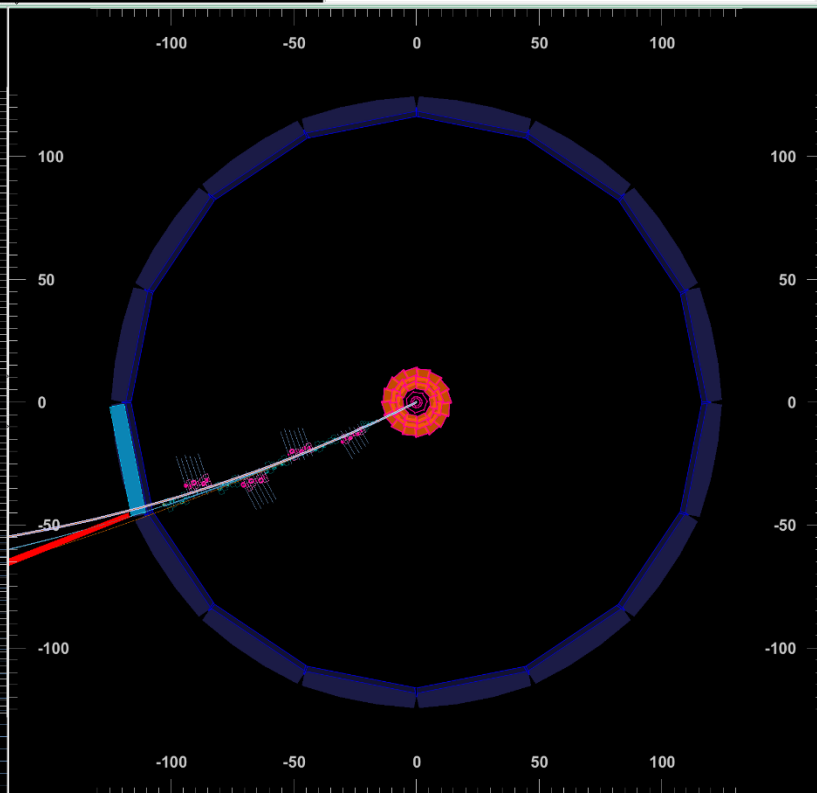
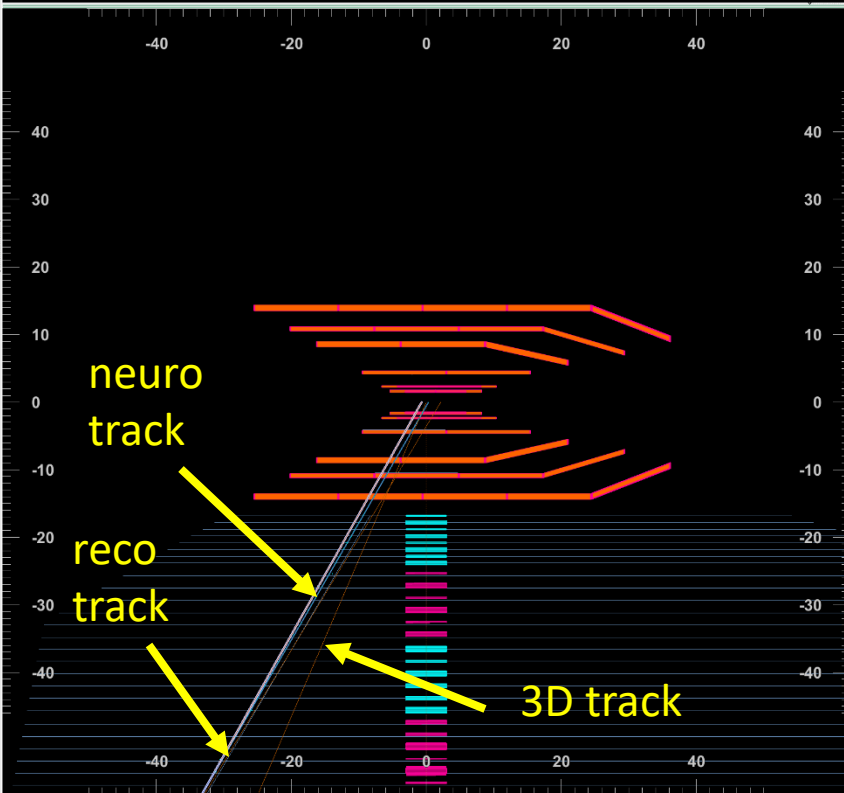
DataStore / TRGDCD3DFinderTracks[0]

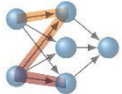
TRGDCD3DFinderTracks[0]

Previous Next

Related Objects

- this -> RecoTracks[0]
- this -> TRGDCDNeuroTracks3D[0]
- this -> TRGDCDTrackSegments[0]
- this -> TRGDCDTrackSegments[1]
- this -> TRGDCDTrackSegments[2]
- this -> TRGDCDTrackSegments[3]
- this -> TRGDCDTrackSegments[4]
- this -> TRGDCDTrackSegments[5]
- this -> TRGDCDTrackSegments[6]
- this -> TRGDCDTrackSegments[7]
- this -> TRGDCDTrackSegments[8]
- this -< RecoTracks[0]

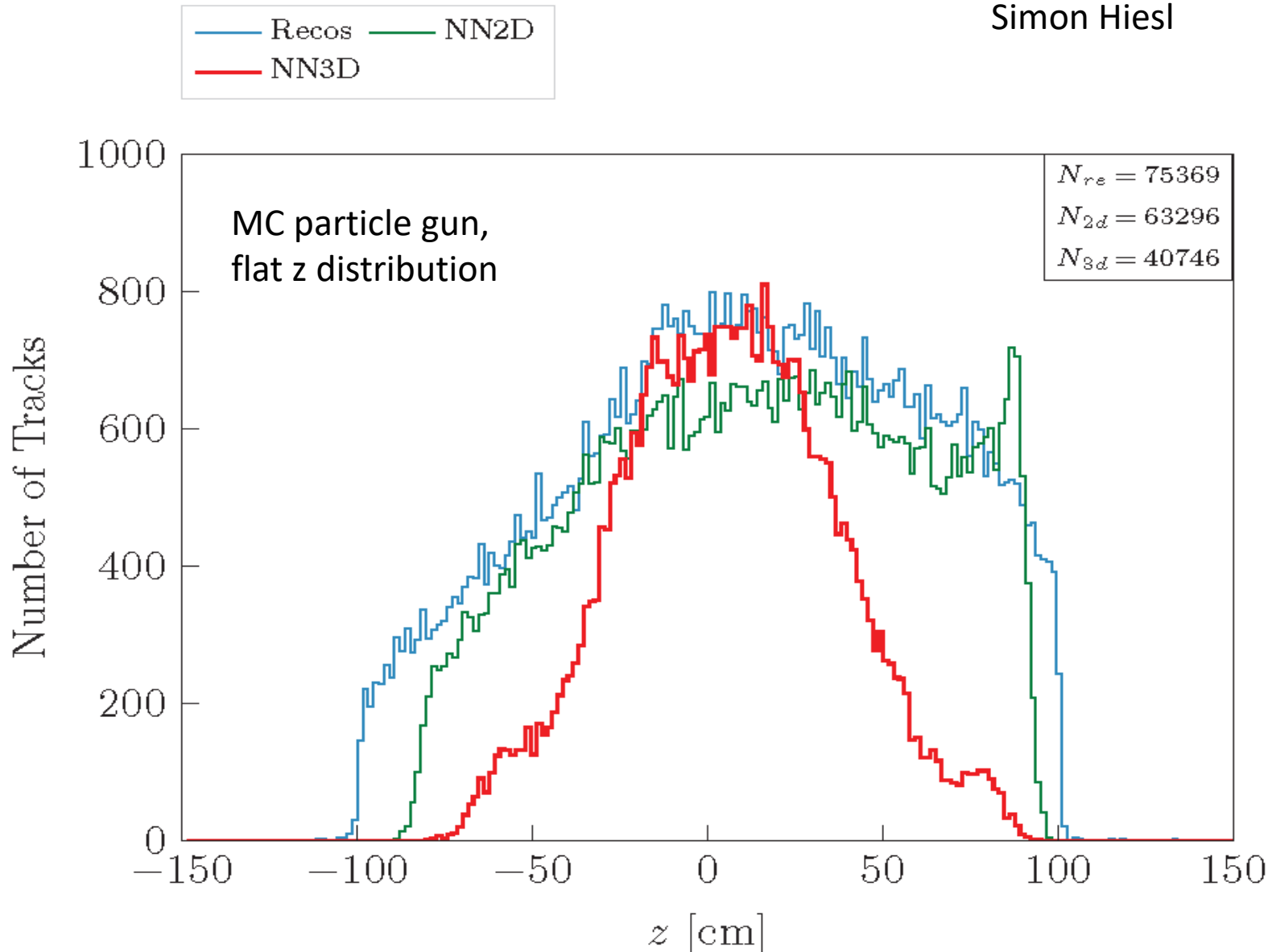


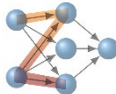


Suppression of Tracks from Outside IP



Simon Hiesl



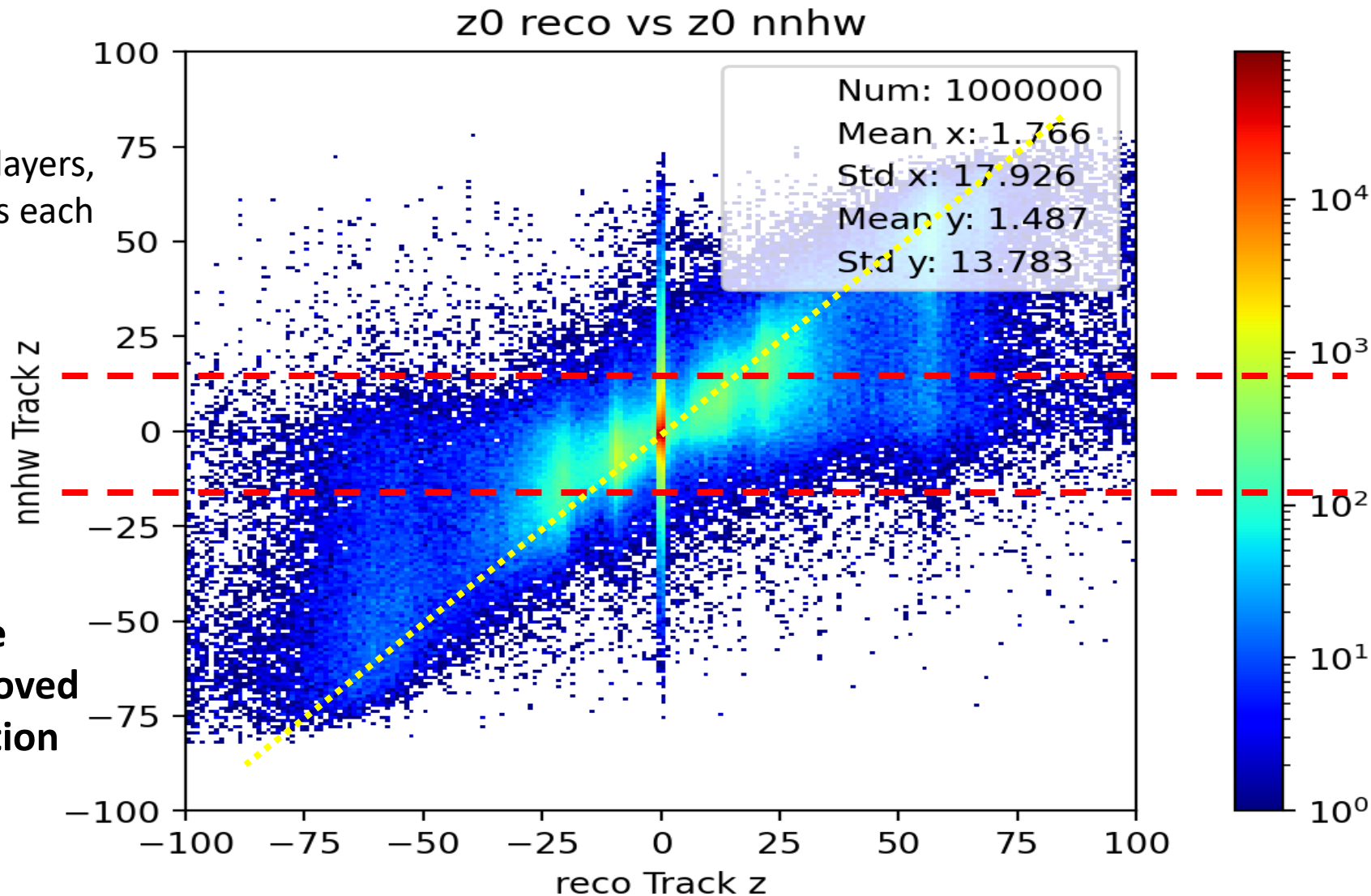


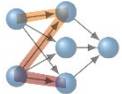
Timo Forsthofer

real data
(Exp. 26)

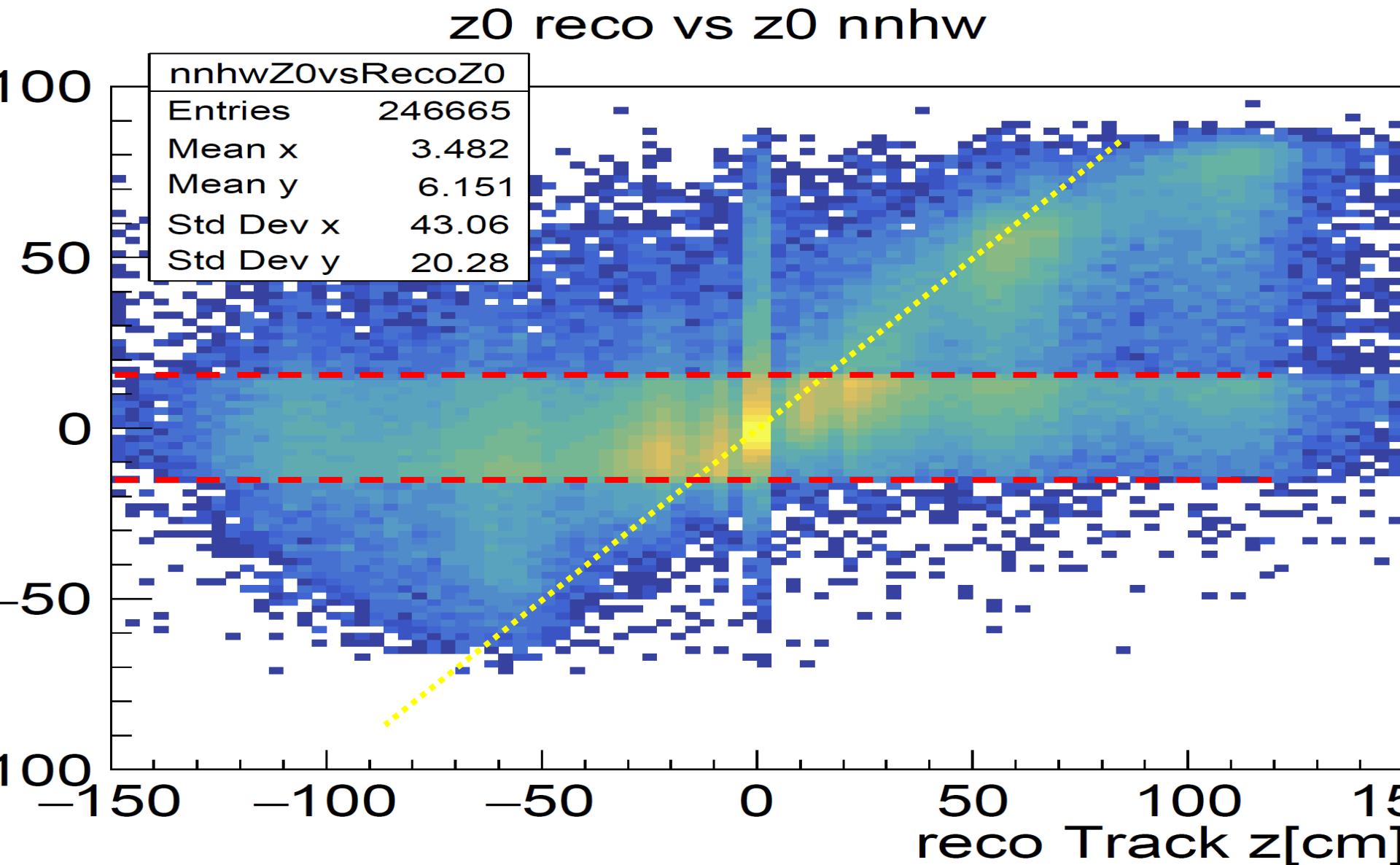
3 hidden layers,
100 nodes each

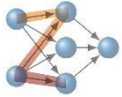
evidence
for improved
z-resolution





Problems of the STT (I) : „Feed-Down“

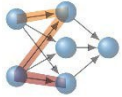




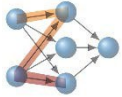
Neuro Trigger Upgrade Program



- Main Goal: keep STT unprescaled and stand-alone (no coincidence with ECAL), i.e. need to improve the z-resolution and fight feed-down and fake tracks
 - Present limitation of the neural hardware (UT3, 300 ns latency):
27 inputs, one hidden layer with 81 nodes
 - Significant gain of latency by switching to UT4(160)
-> move track finding (3D-Hough) and preprocessing of network inputs into UT4 , free latency for deep learning networks + calculation of momentum for STT
- TSF 3D + NN GLR
- Areas of study:
 - > optimize track finding / fake reduction (3D Hough parameters)
 - > increase number of hidden layers and nodes (“deep learning”), improve z-resolution
 - > add-ons: improve track segment quality by using ADC information
increase probability of finding correct L/R relation (“drifttime”)



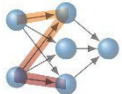
- Ongoing studies of 3D parameters with MC single tracks (vertex tracks, no BG)
-> optimize for efficiency
 - Extend studies to large z interval [-100, +100] cm
-> optimize for suppression of non-IP tracks
 - Apply and test (reoptimize) with real data (Exp. 26)
- Simon Hiesl,
End of March 24
- In parallel: compare results of cluster algo with HW implementation (ongoing)
 - recent proposal due to possible HW limitations
-> no cluster search, only use maxima in Hough space
-> precise point within Hough maximum bin: use weights in (2) neighboring shells or arbitrarily defined (constant shape in Hough space)
 - In parallel: train deep network with 3D track candidates (after optimization)
implementation in basf2 and UT4 to be done (good models exist)
[first test launch expected in spring 2024]



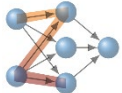
Summary and Conclusions



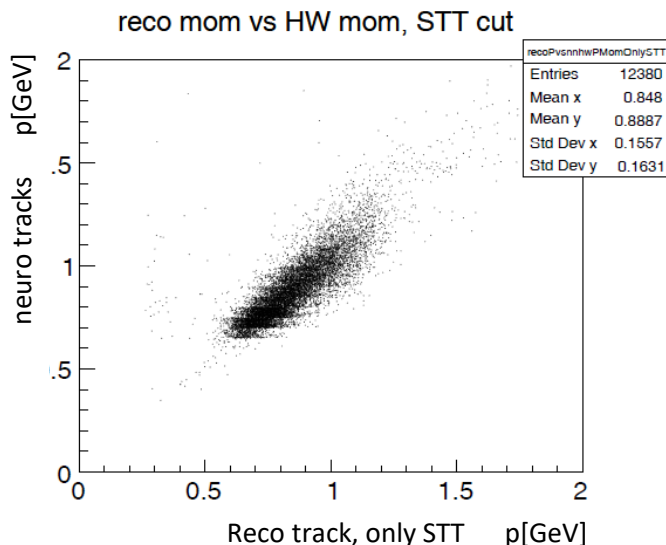
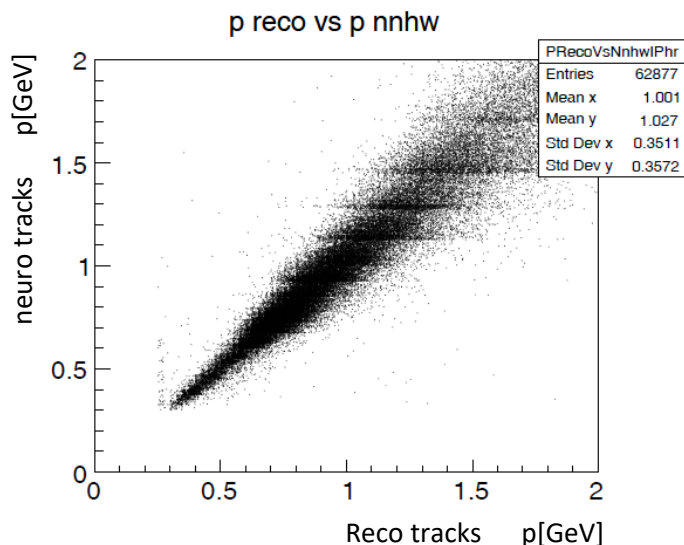
- Analysis of STT shows good performance even under large backgrounds (end of 2022 running)
However, “Feed-down” and “Fakes” needs attention
reasons identified -> fundamental upgrade program ongoing
- Upgrade: track finding via 3D Hough cluster algorithm & deep learning networks possibly with coarse analog thresholds for CDC wire signals to suppress background (e.g. low cut to remove cross talk signals)
- HW/SW activities are well-defined, full concentration on new UT4 platform
- Schedule for realization has some delay wrt original planning, aim for commissioning by spring 2024.
- New: Displaced Vertex Trigger on the horizon, could realistically be brought online during the next running period (see Elia’s presentation)



Backup

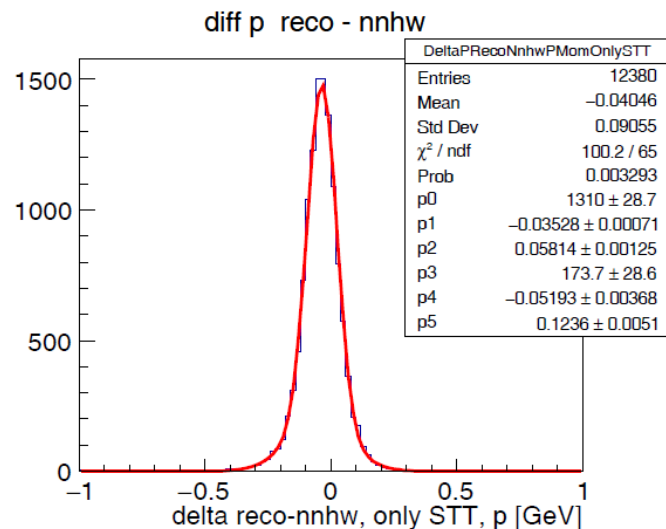


Momentum Resolution of STT



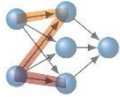
Track momentum at L1 can be calculated via the 2D curvature ω and the polar θ angle from the neuro track

$$p[GeV] = \frac{1}{|\omega| [1/m] \sin(\theta)} 0.3B[T]$$

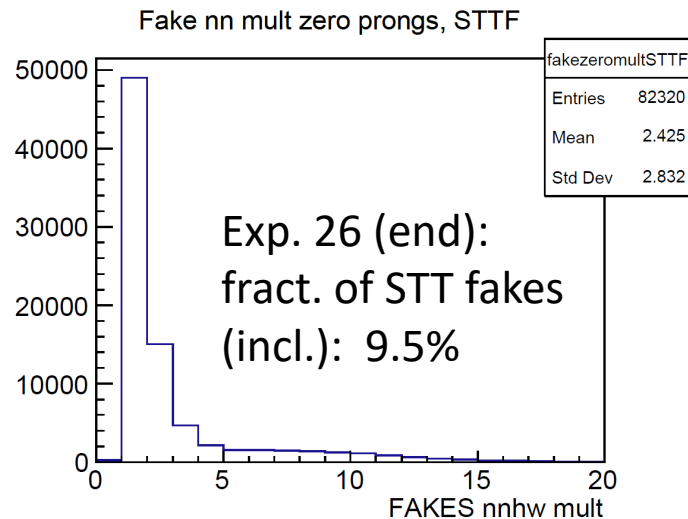
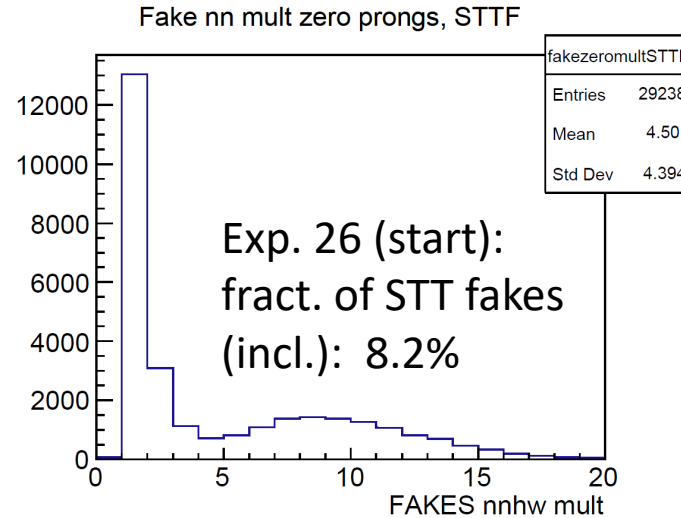
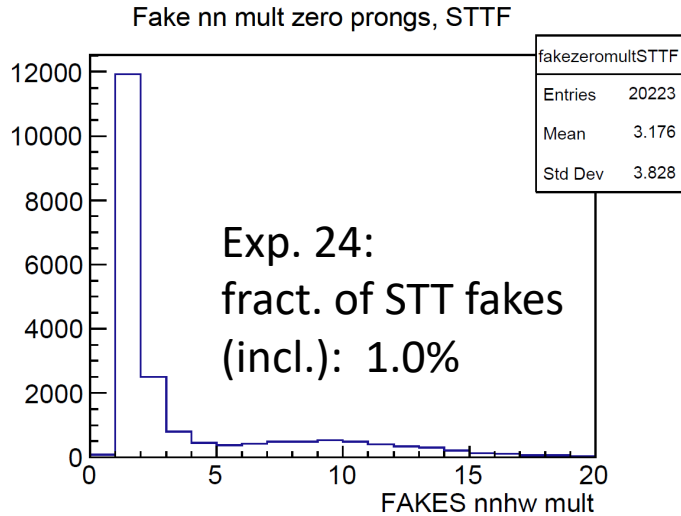


Core Gaussian:
 $\sigma = 61.3 \text{ MeV}$
 weighted:
 $\sigma_p = 81.0 \text{ MeV}$

„STT“ = $|z| < 15 \text{ cm} \ \&\& \ p > 0.7 \text{ GeV} \ \&\& \ \neg \text{Bhabha}$



Fake Neuro Tracks (Exp 24 -> Exp 26)



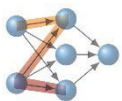
Data: look at events with no reconstructed track & plot multiplicity of neural tracks

events triggered by STT

During 2022 running (spring -> summer) a clear increase of „fake“ neural tracks was observed: 1.0% -> 9.5% (about 40% excl.)

More plots see Backup

-> up to 5% are excl. STT fakes



No Reco Tracks -> Fake Neuro Tracks



Run 33, Event 1391616

Event: 1391616
Run: 33
Experiment: 26
<2022-05-11 18:38:54 UTC>

Options

- Show MC info
- Assign hits to primary particles
- Show all primaries
- Show all charged particles
- Show all neutral particles
- Hide secondaries
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Current Viewer

Save As... Save As (High-Res)...

Dock/Undock Viewer

Visualisation Options

Dark/light colors

Cumulative mode (experimental)

Automatic Saving (experimental)

Prefix: display_

Width (px): 800 Save PNGs

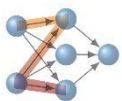
Closing

Exit

DataStore / Back

Arrays

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- ARICHDigits (5)
- ARICHHits (5)
- ARICHLikelihoods (0)
- ARICHRawDigits (71)
- ARICHSimHits (0)
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- BKLSimHits (0)
- BeamBackHits (0)
- BremHits (0)
- CDCDedxLikelihoods (0)
- CDCDedxTracks (0)
- CDCHits (4693)
- CDCRawHitWaveForms (0)
- CDCRawHits (4693)
- CDCRecoTracks (0)
- CDCSimHits (0)
- CDCTrigger2DFinderClones (32)
- CDCTrigger2DFinderTracks (32)
- CDCTrigger2DTo3DBits (48)
- CDCTriggerHoughClusters (35)
- CDCTriggerNNBits (48)
- CDCTriggerNNInput2DFinderTracks (12)
- CDCTriggerNNInputAllStereoSegmentHits (230)
- CDCTriggerNNInputSegmentHits (71)
- CDCTriggerNeuroTracks (12)
- CDCTriggerNeuroTracksInbnt (12)



No Reco Tracks -> Fake Neuro Tracks



Run 1955, Event 563200

Browser Eve Camera Scene

Event Control

Event: 4 / 691

Delay (s): 3.5

Jump to event/run/exp...

Event: 563200
Run: 1955
Experiment: 26
<2022-06-21 17:23:18 UTC>

Options

- Show MC info
- Assign hits to primary particles
- Show all primaries
- Show all charged particles
- Show all neutral particles
- Hide secondaries
- Show candidates and rec. hits
- Show tracks, vertices, gammas

Current Viewer

Save As... Save As (High-Res)...

Dock/Undock Viewer

Visualisation Options

Dark/light colors

Cumulative mode (experimental)

Automatic Saving (experimental)

Prefix: display_

Width (px): 800 Save PNGs

Closing

Exit

DataStore / Back

Arrays

- ARICHAeroHits (0)
- [ARICHDigits \(52\)](#)
- [ARICHHits \(52\)](#)
- ARICHLikelihoods (0)
- [ARICHRawDigits \(71\)](#)
- ARICHSimHits (0)
- ARICHTracks (0)
- [BKLMHit1ds \(18\)](#)
- [BKLMHit2ds \(1\)](#)
- BKLMSimHitPositions (0)
- BKLMSimHits (0)
- BeamBackHits (0)
- BremHits (0)
- CDCDedxLikelihoods (0)
- CDCDedxTracks (0)
- [CDCHits \(2662\)](#)
- CDCRawHitWaveForms (0)
- [CDCRawHits \(2662\)](#)
- CDCRecoTracks (0)
- CDCSimHits (0)
- [CDCTrigger2DFinderClones \(90\)](#)
- [CDCTrigger2DFinderTracks \(90\)](#)
- [CDCTrigger2DTo3DBits \(48\)](#)
- [CDCTriggerHoughClusters \(8\)](#)
- [CDCTriggerNNbits \(48\)](#)
- [CDCTriggerNNInput2DFinderTracks \(71\)](#)
- [CDCTriggerNNInputAllStereoSegmentHits \(404\)](#)
- [CDCTriggerNNInputSegmentHits \(400\)](#)
- [CDCTriggerNeuroTracks \(71\)](#)
- [CDCTriggerNeuroTracksInput \(71\)](#)