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

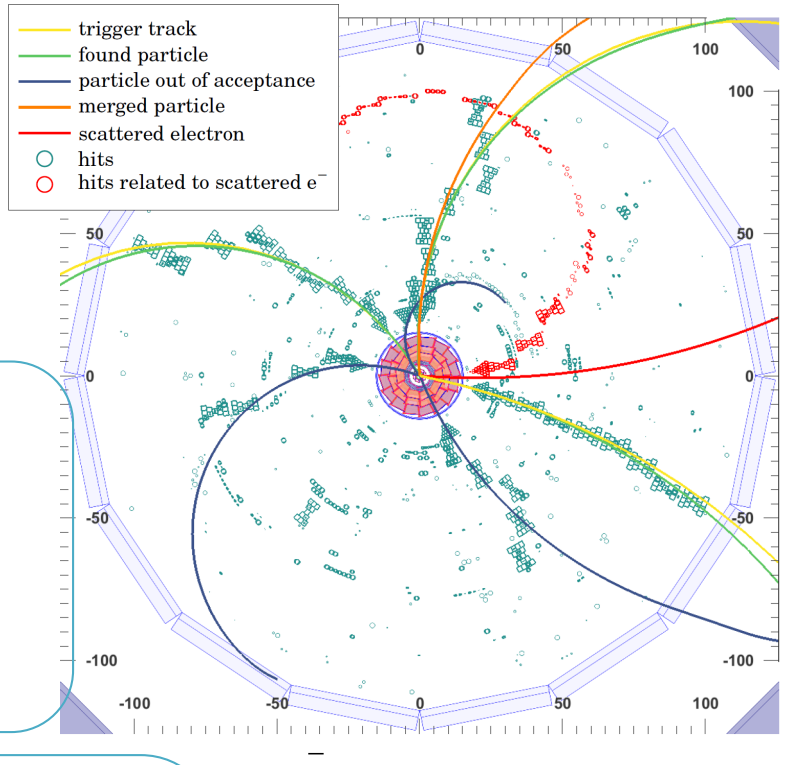
Institut für Experimentelle Teilchenphysik

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

MPI & TUM

MAX-PLANCK-GESELLSCHAFT

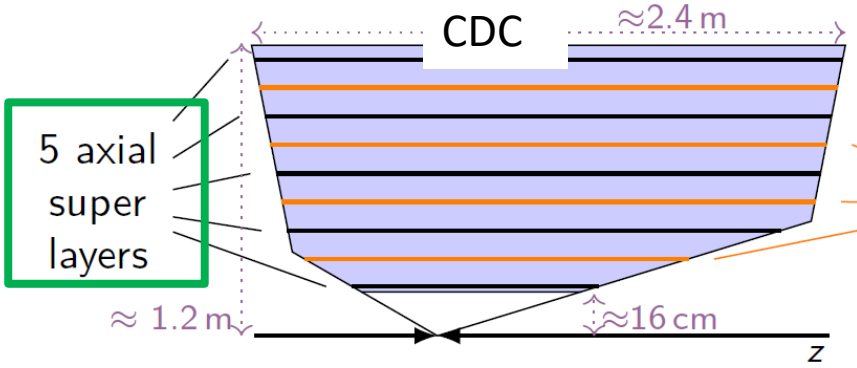
- Felix Meggendorfer
- [Elia Schmidt]
- Simon Hiesl
- Timo Forsthofer
- Christian Kiesling
- Alois Knoll

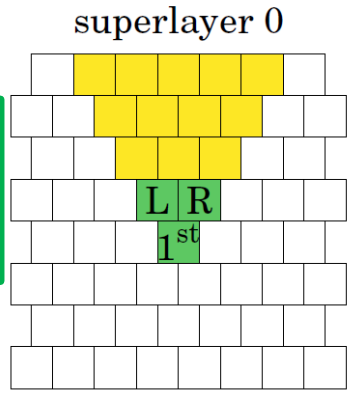


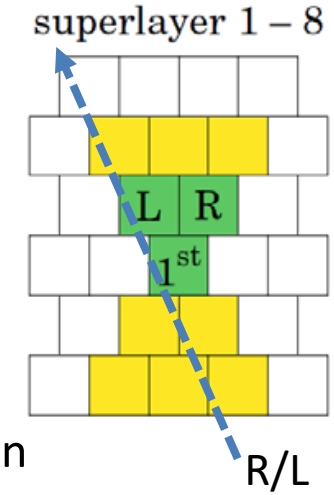
focus of TUM/MPI groups:

Track Triggers

Recap: Elements of the Neural L1 Track Trigger

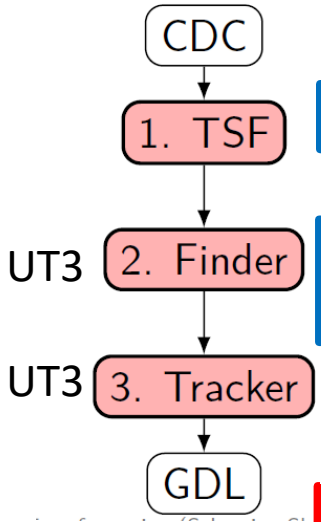






- 56 layers combined to 9 super layers (SL)
- 2336 track segments (TS) in 9 SL

L1 Neuro Trigger pipeline

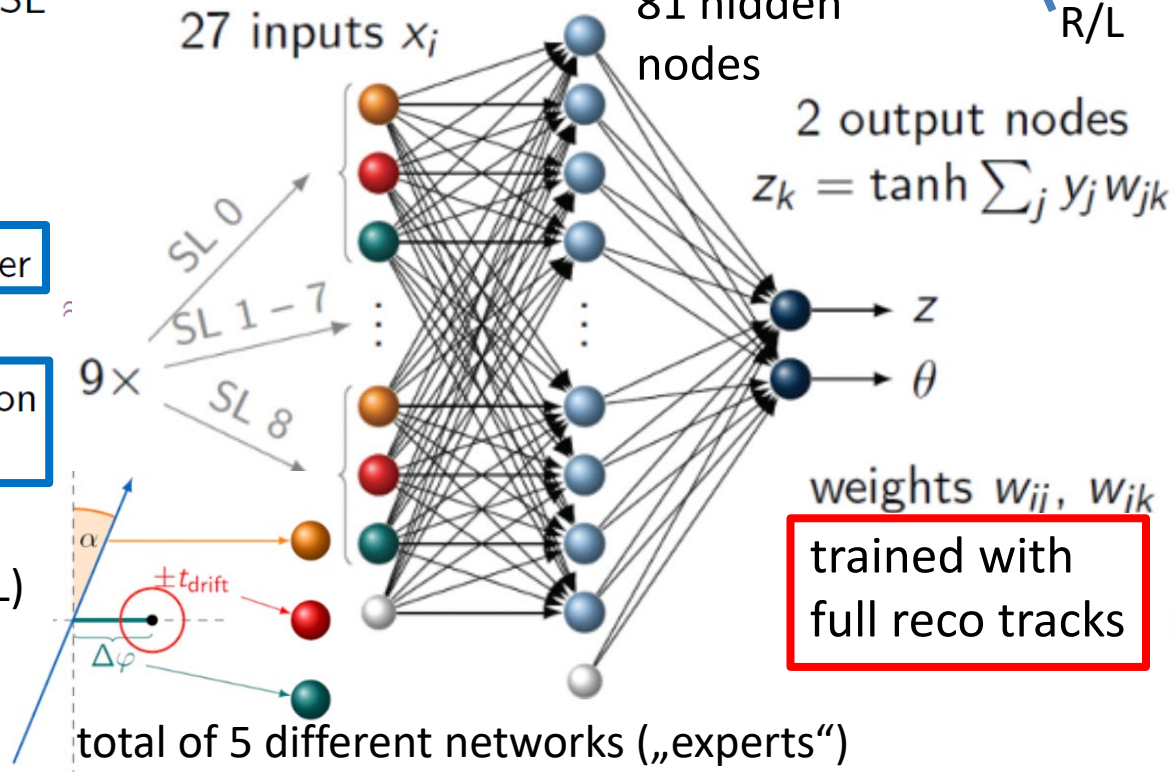


Track Segment Finder
(ATS [2D] and STS)

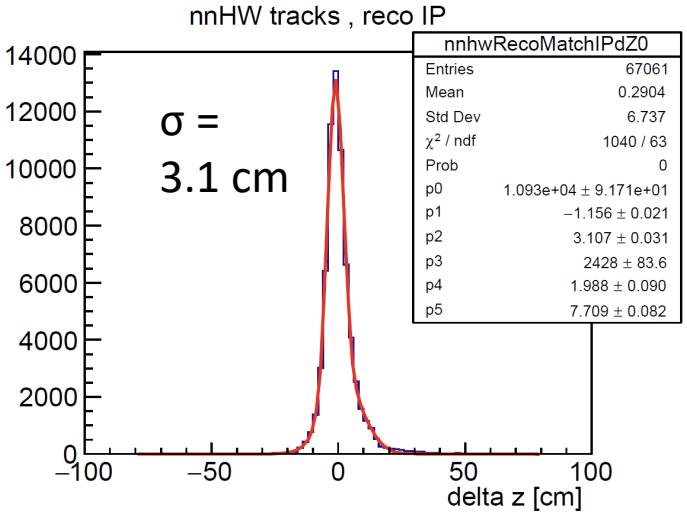
Hough Transformation
2D (std rϕ trig)

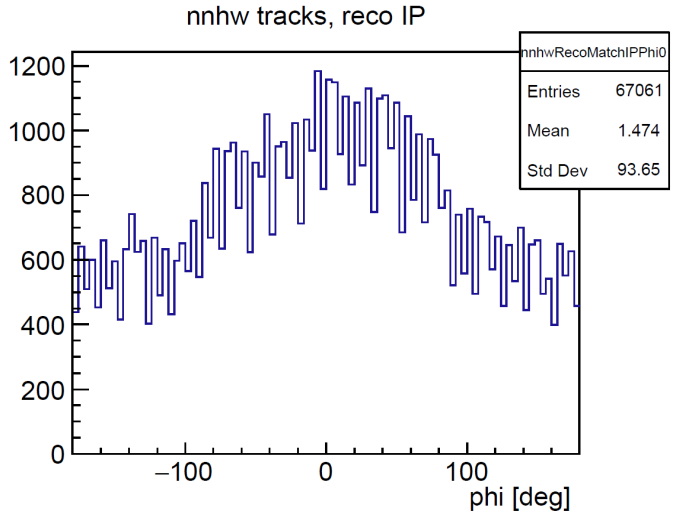
Neural Networks
(add 3 (4) STS + R/L)

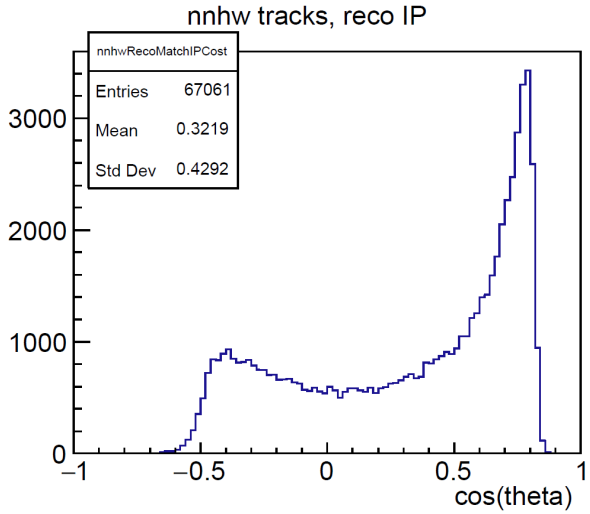
determine
z and Θ



z-Resolution Exp 26 (runs 1700-end)







Exp 26, runs 1700-1968 (end)

Results from high background

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

Central Gauss: σ = 3.1 cm

2nd Gauss: σ = 7.7 cm

z cut for all track triggers („y“ bit): |z| < 15 cm

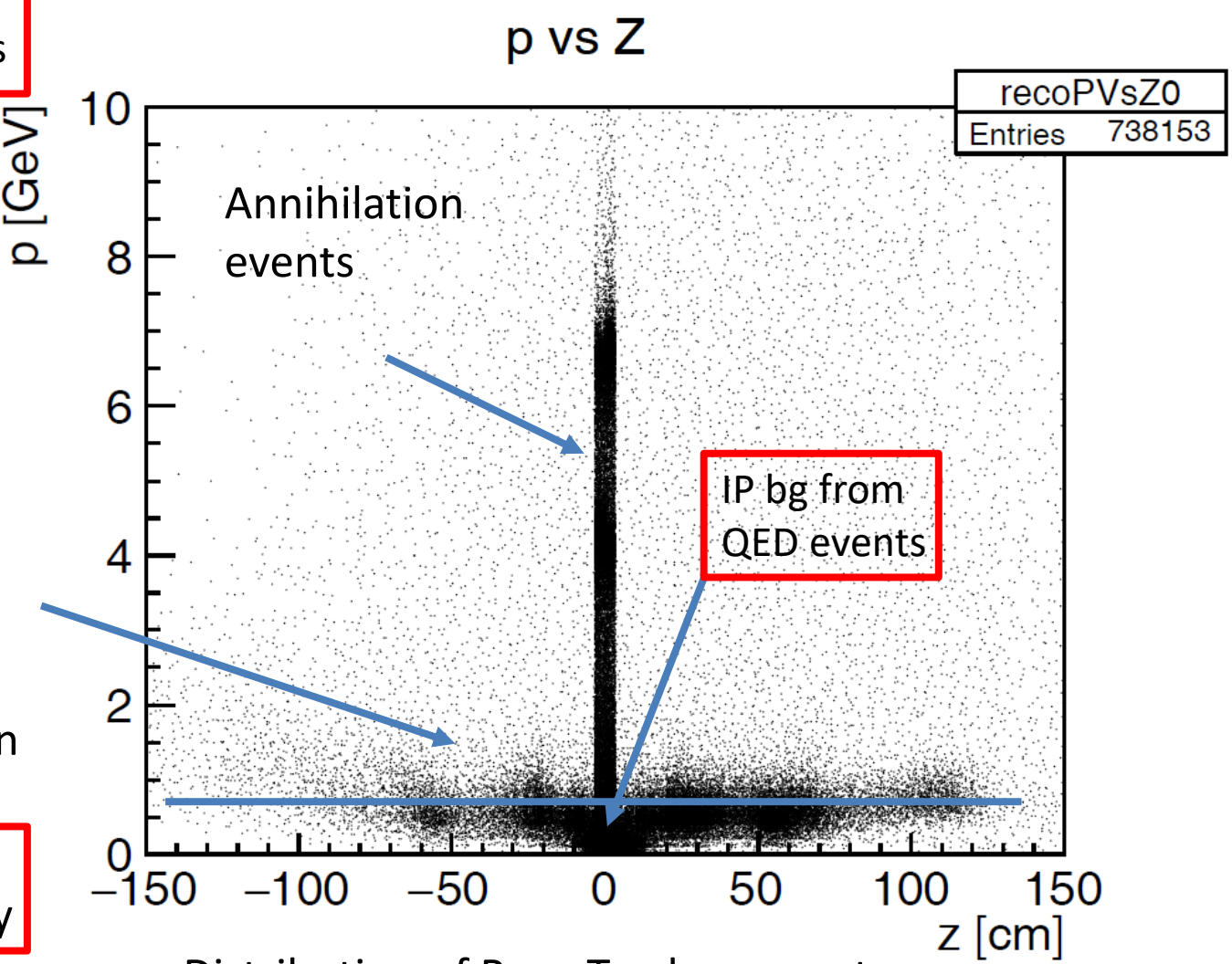
„STT“: a Minimum Bias Single Track Trigger

Rate from z-Trigger high due to QED events

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

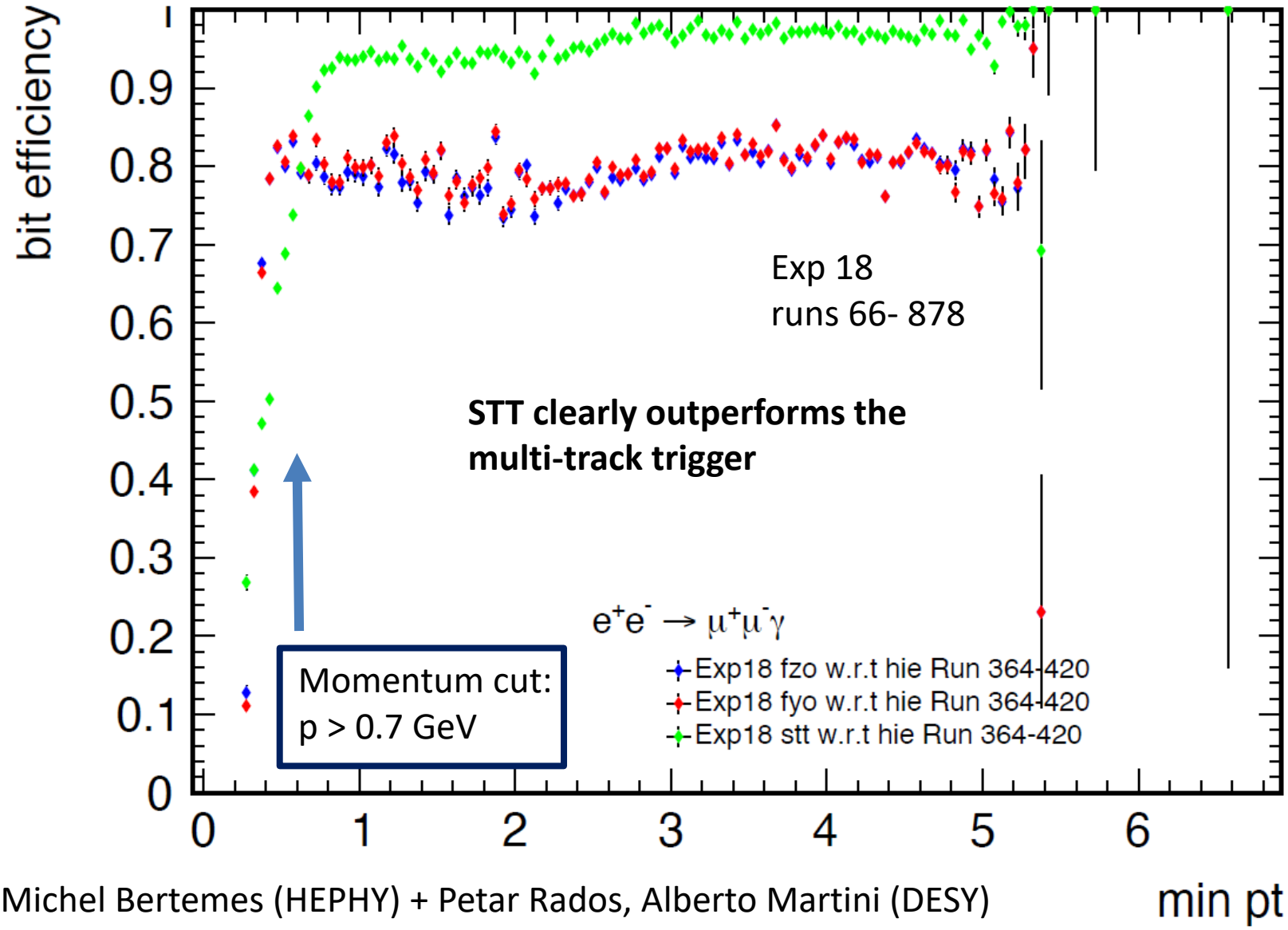
Collisions of electron with elements of the beam guide system, producing protons from nuclear spallation

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



Distribution of Reco Track momentum vs z

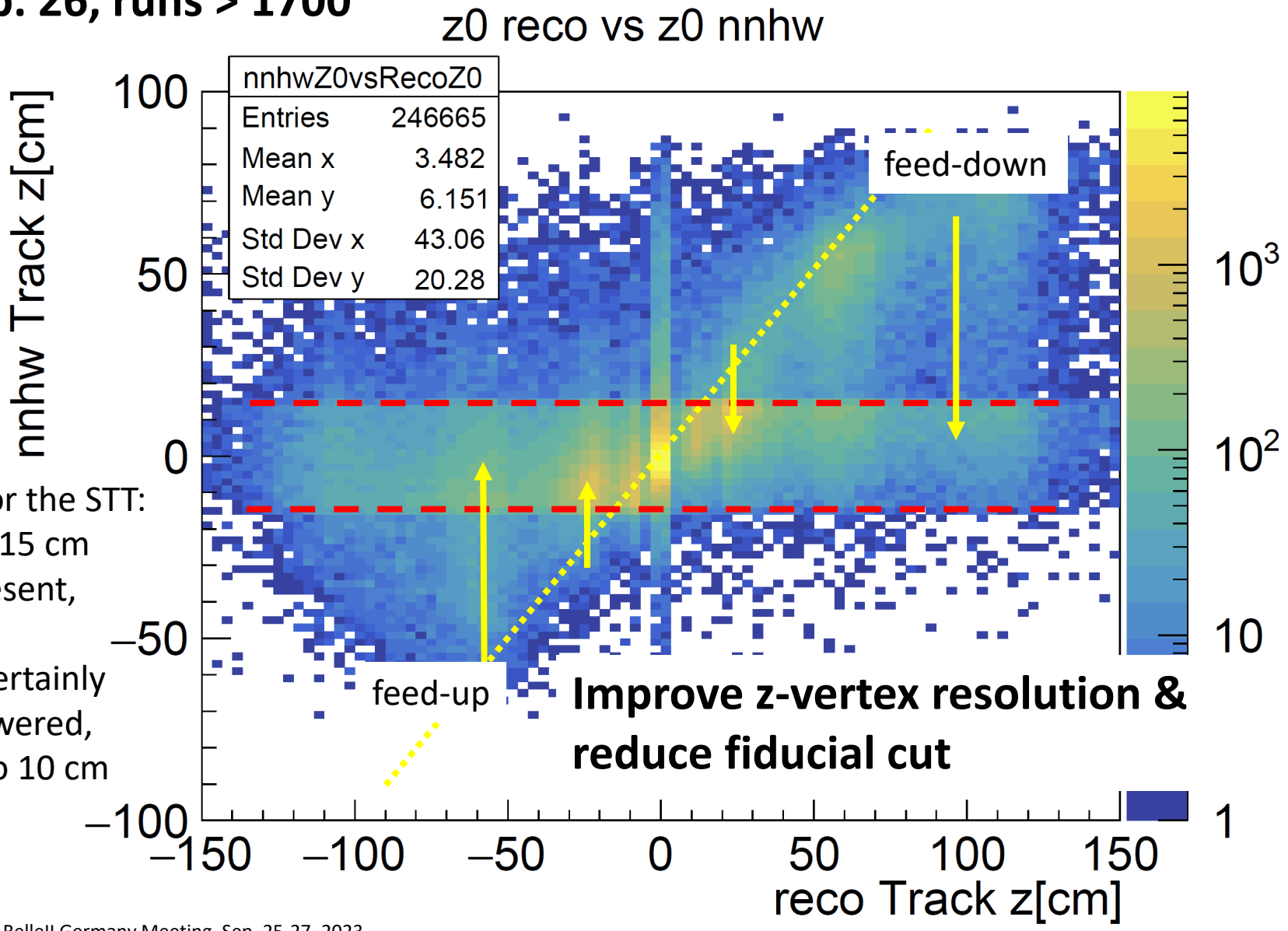
Trigger Efficiencies



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

Problems of the STT (I) : „Feed-Down“

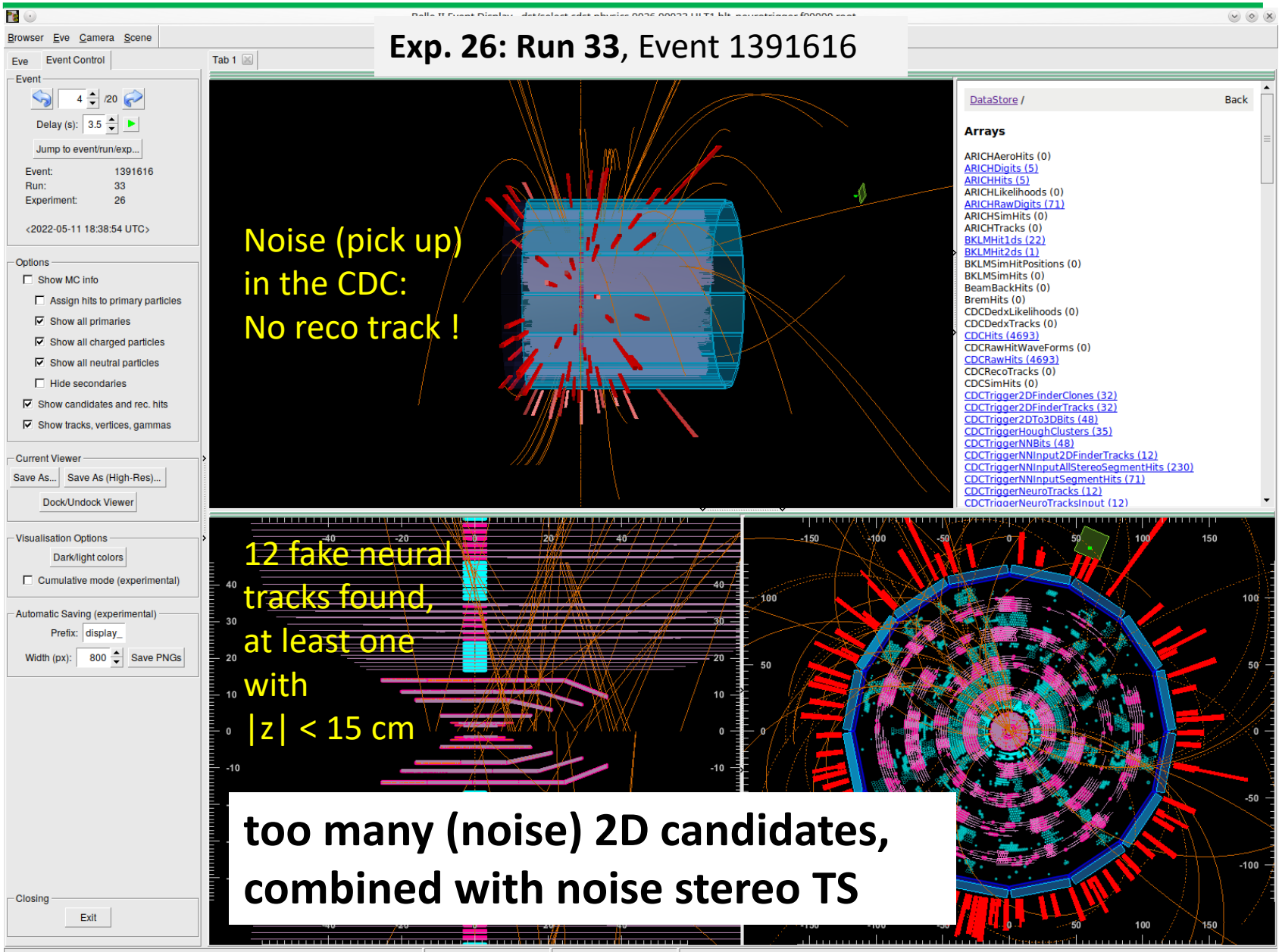
Exp. 26, runs > 1700



Cut for the STT:
|z| < 15 cm
at present,

can certainly
be lowered,
e.g. to 10 cm

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



Core Program, Part 1: STT Optimization

-> 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 vaccum polarization) etc.
- quite generally: determination of lepton ID, tracking and photon efficiencies
- from unbiased track -> **STT is a minimum bias single track trigger**

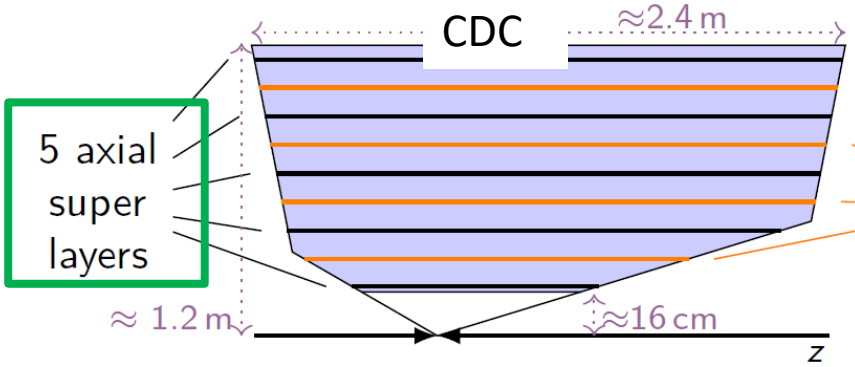
Improved track finding / training algorithms:

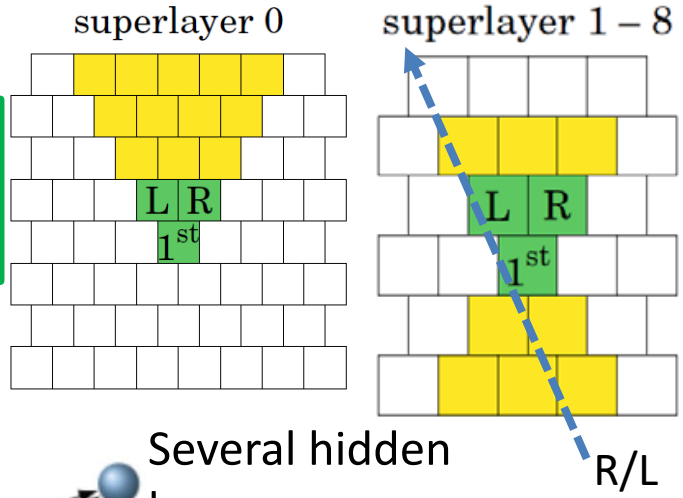
- do track finding in 3D Hough space -> this is really new (S. Skambraks)
- enhance network architecture: „deep-learning“
- -> improve resolutions @ IP and for larger |z|

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

CDC

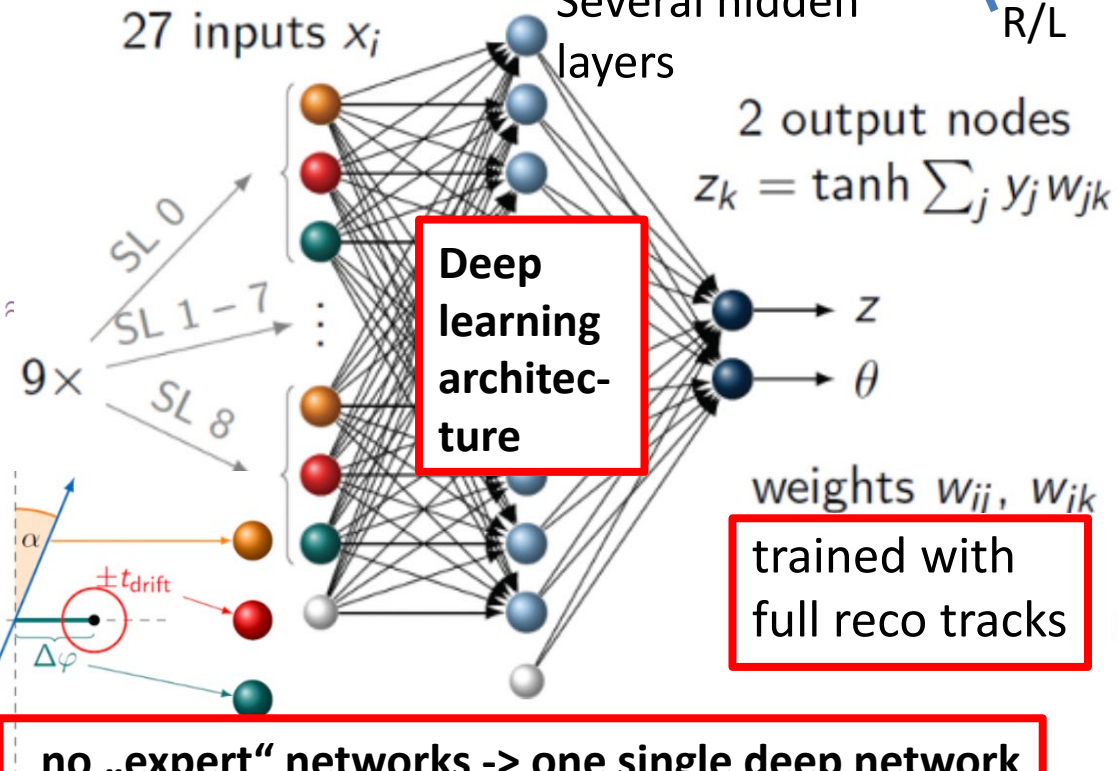
1. TSF — Track Segment Finder (ATS [2D] and STS)

2. 3D Hough Transforms (φ, pT, θ) <- S. Skambraks

3. Tracker — **Neural Networks** (ATS + STS + R/L)

GDL — determine z and Θ

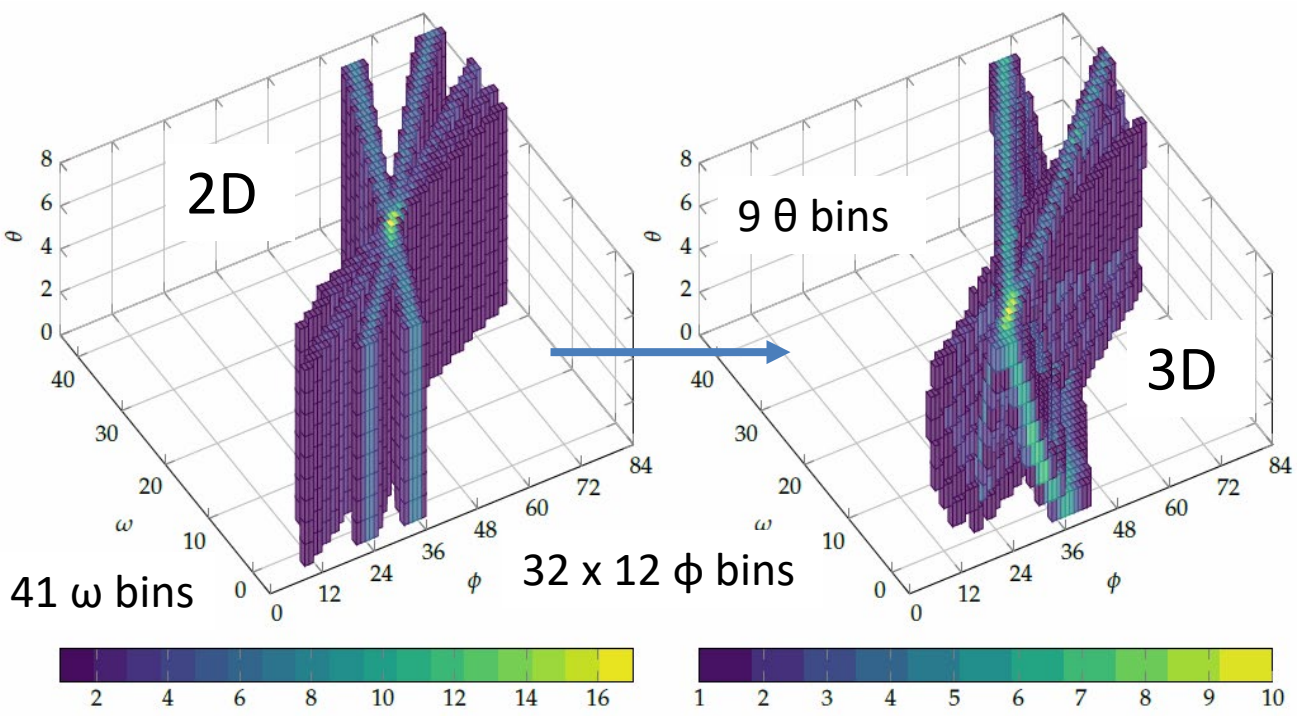
UT4



no „expert“ networks -> one single deep network

3D Hough Track Finding

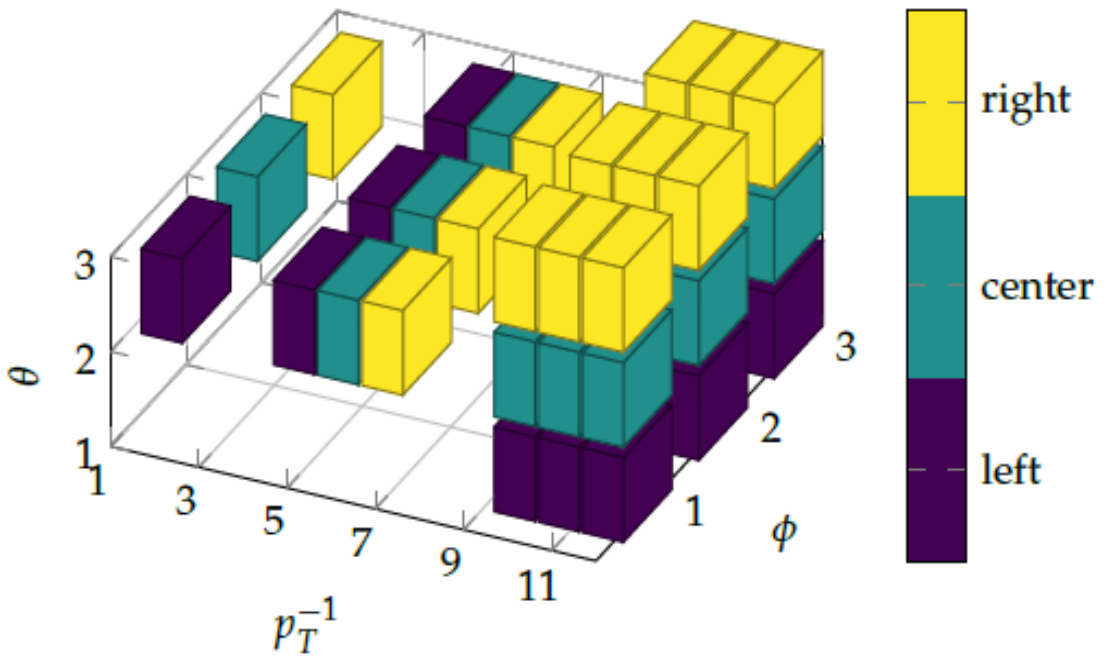
- Extend traditional 2D ($\omega=1/p_T$,ϕ=azimuth angle) Hough space by a third dimension, the (binned) polar angle θ
- For track finding use axial and stereo track segments (->3D)
- Peak finding in 3D Hough space



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 candiates far from IP
- 3D track candidates come with θ estimate,
  -> improve z resolution

Clustering in 3 Dimensions



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

- 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 pT and to
  calculate track momentum for STT

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

Hough parameter space/granularity:

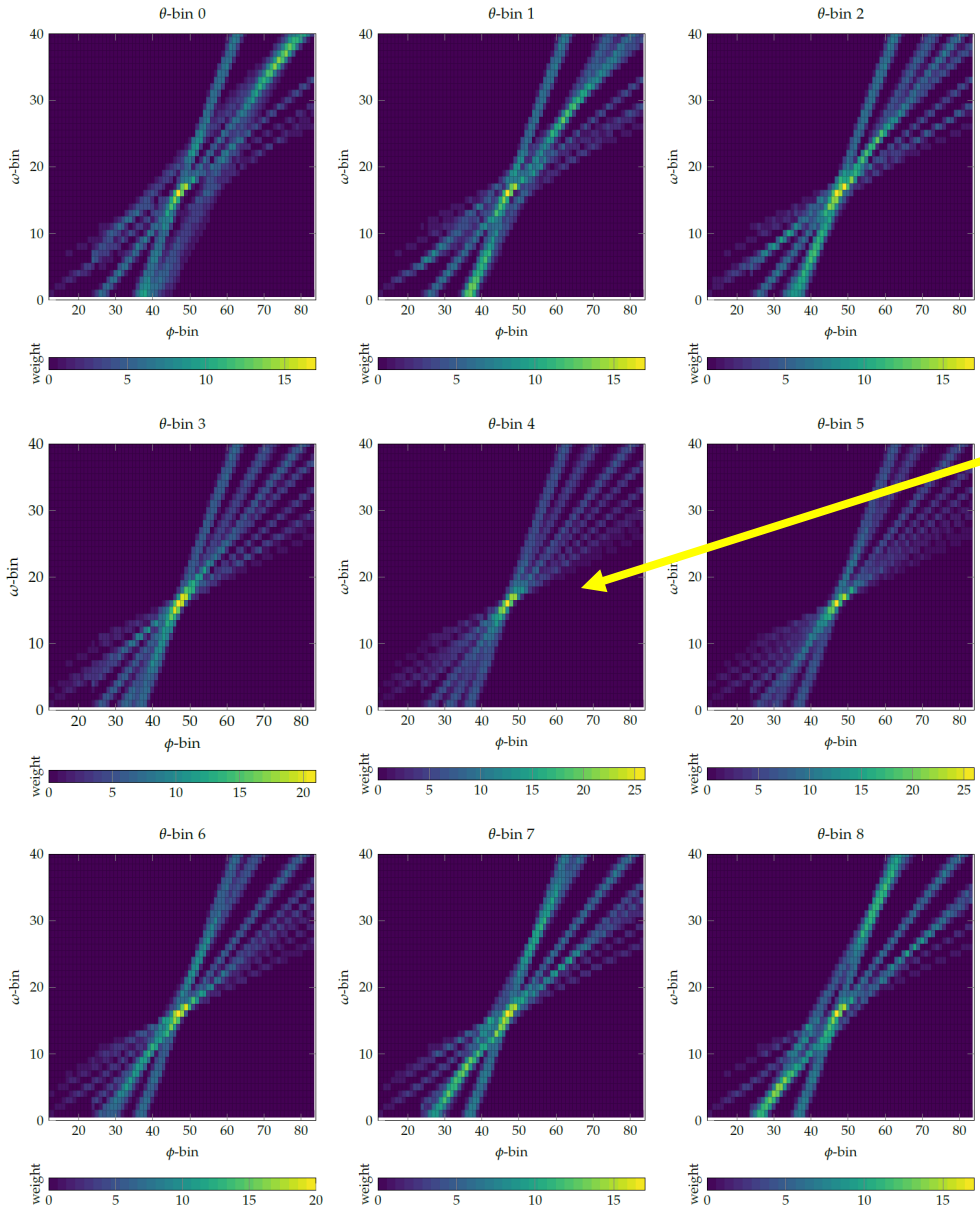
$p_T > 0.2$ GeV	[41]
$\phi \in [0, 360°]$	[384]
$\Theta \in [19°, 140°]$	[9]

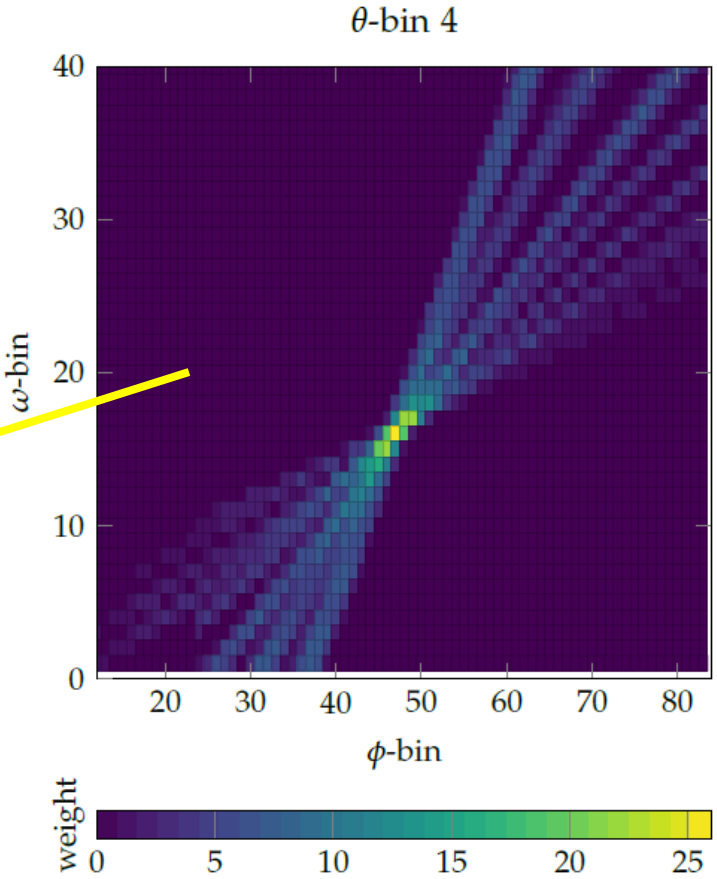
Typical values of cluster-defining parameters:

W_{min}	= 20	(cluster cell)
minPts	= 1	(# neighbors)
minHits	= 4	(# cells in cluster)
thresh	= 0.85 (	

Parameters subject to optimization!!

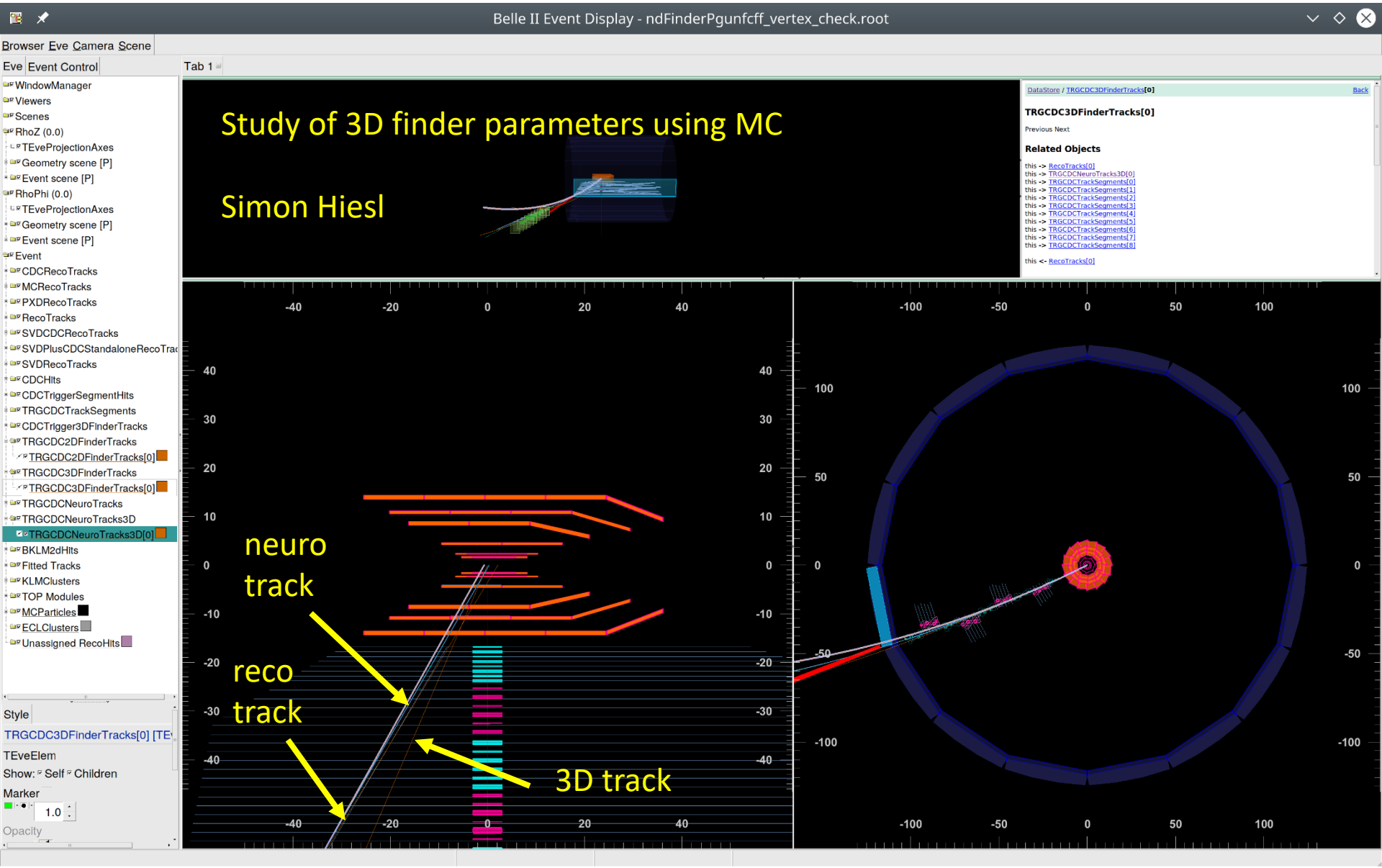
Example of 3D Hough Map





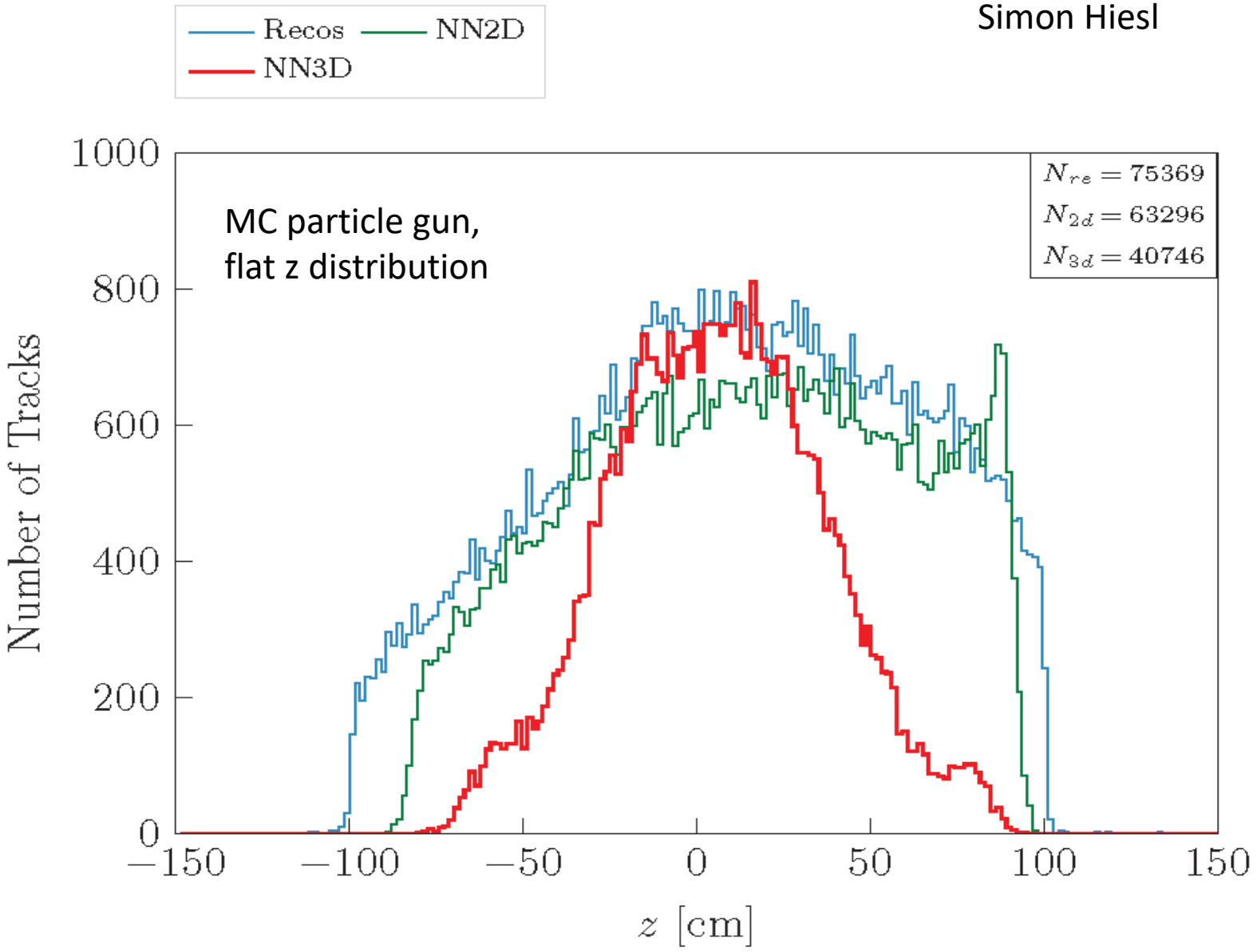
Stacked view for illustration only, cluster finding is done in 3D

Vertex Track via 3D Preprocessing



Suppression of Tracks from Outside IP

Simon Hiesl



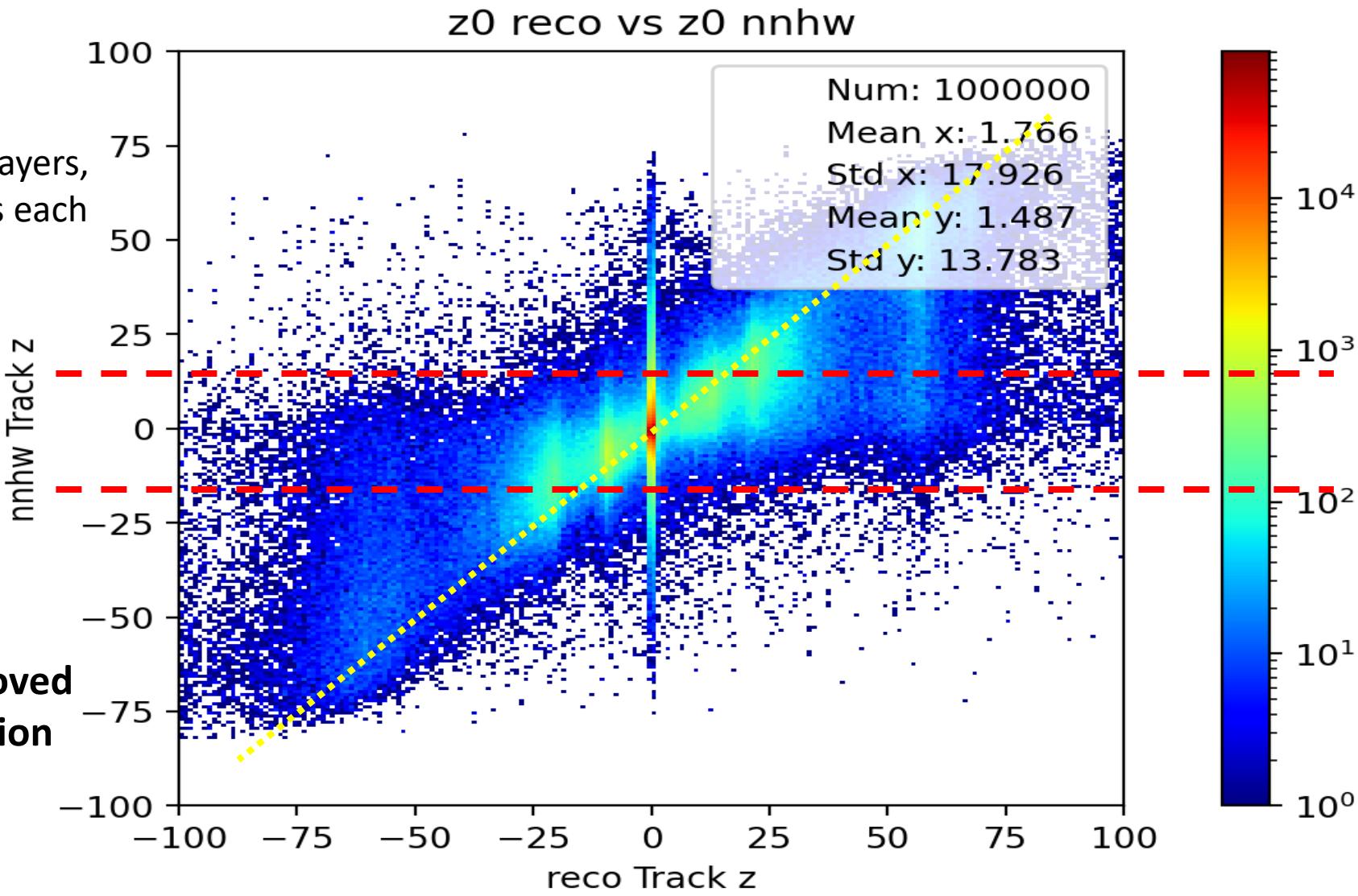
First Studies with Deep-Learning Networks

Timo Forsthofer

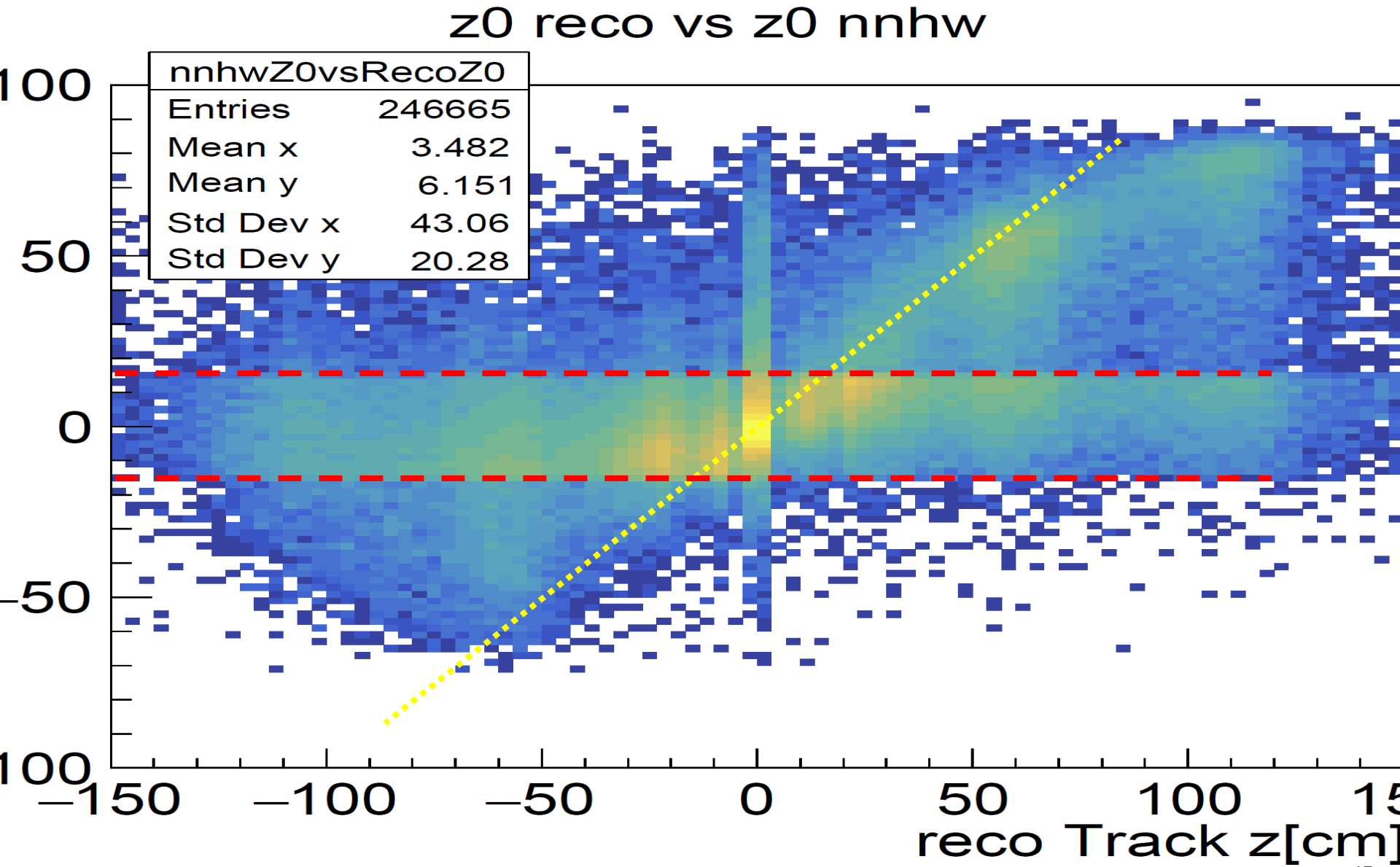
real data
(Exp. 26)

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 learing 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”), inprove z-resolution

  -> add-ons: improve track segment quality by using ADC information increase probability of finding correct L/R relation (“drifttime”)

Status STT Upgrade Program

- 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)

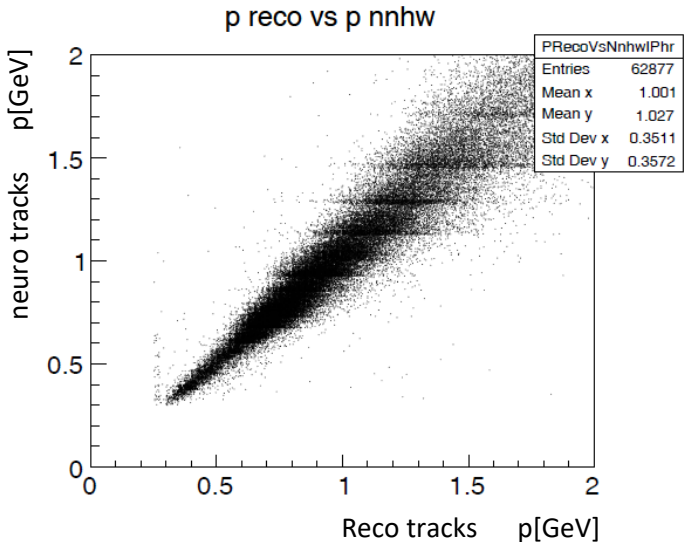
- HW/SW activities are well-defined, full concentration on new UT4 platform

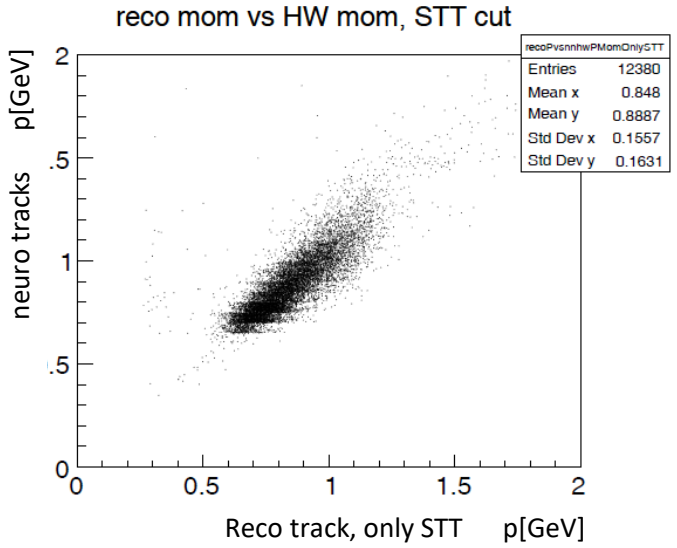
- Schedule for realization has some delay wrt original planning, aim for commissioning by spring 2024.

- New: Displaced Vertex Trigger on the horizon, could realistically be brought online during the next running period (see Elia’s presentation)

Backup

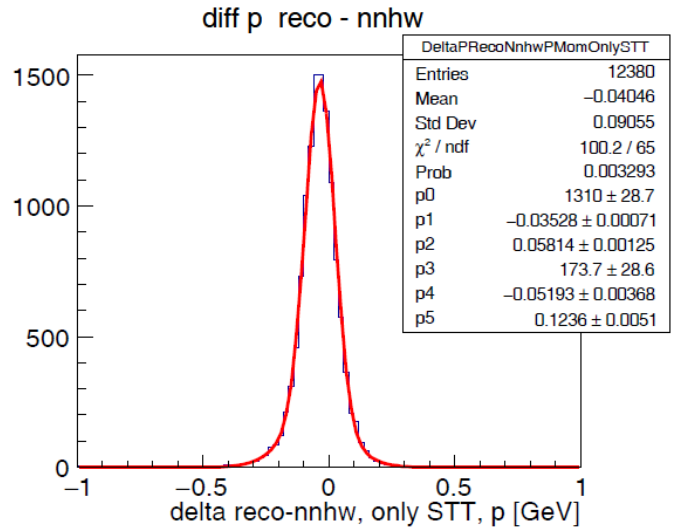
Momentum Resolution of STT





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

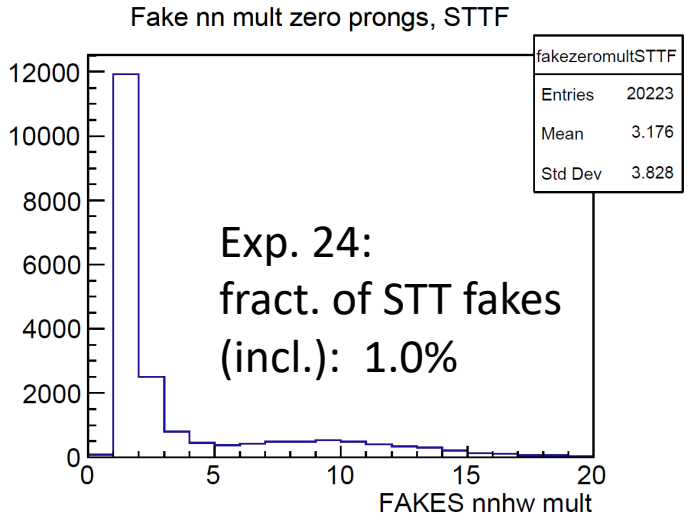
$$p[GeV] = \frac{1}{\left|\omega\right|[1/m]\sin(\theta)} 0.3B[T]$$

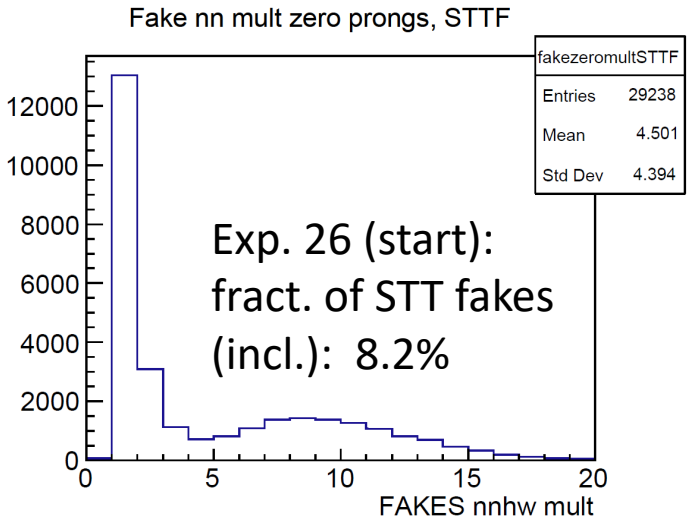


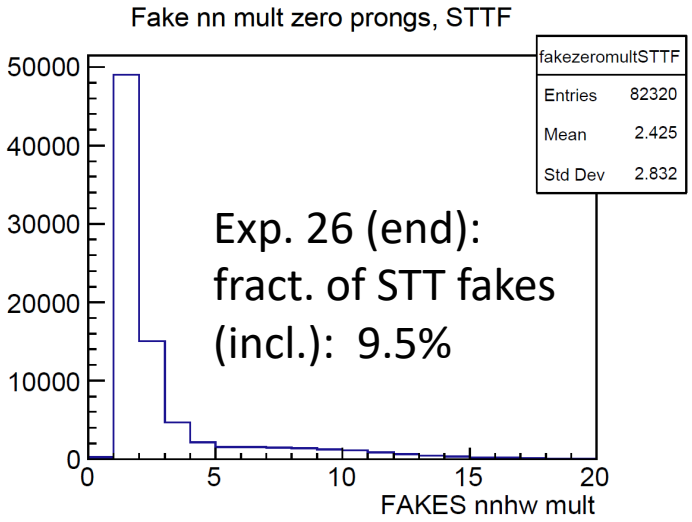
Core Gaussian:
σ = 61.3 MeV
weighted:
σ_p = 81.0 MeV

„STT“ = |z| < 15 cm && p > 0.7 GeV && ¬ Bhabha

Fake Neuro Tracks (Exp 24 -> Exp 26)







More plots see Backup

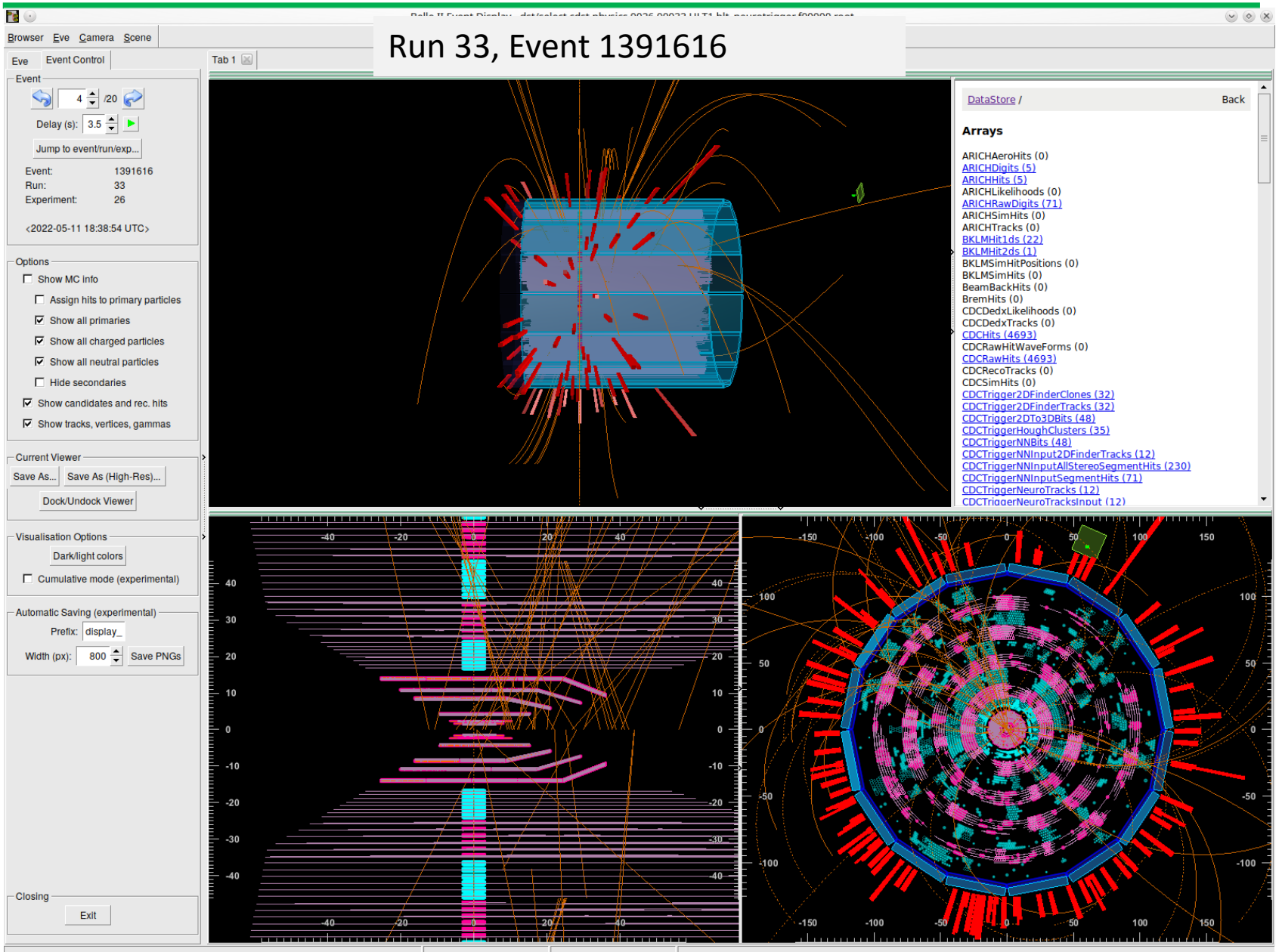
Data: look at events with no reconstructed track &
plot multiplicity of neural tracks

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.)

-> **up to 5% are excl. STT fakes**

No Reco Tracks -> Fake Neuro Tracks



No Reco Tracks -> Fake Neuro Tracks