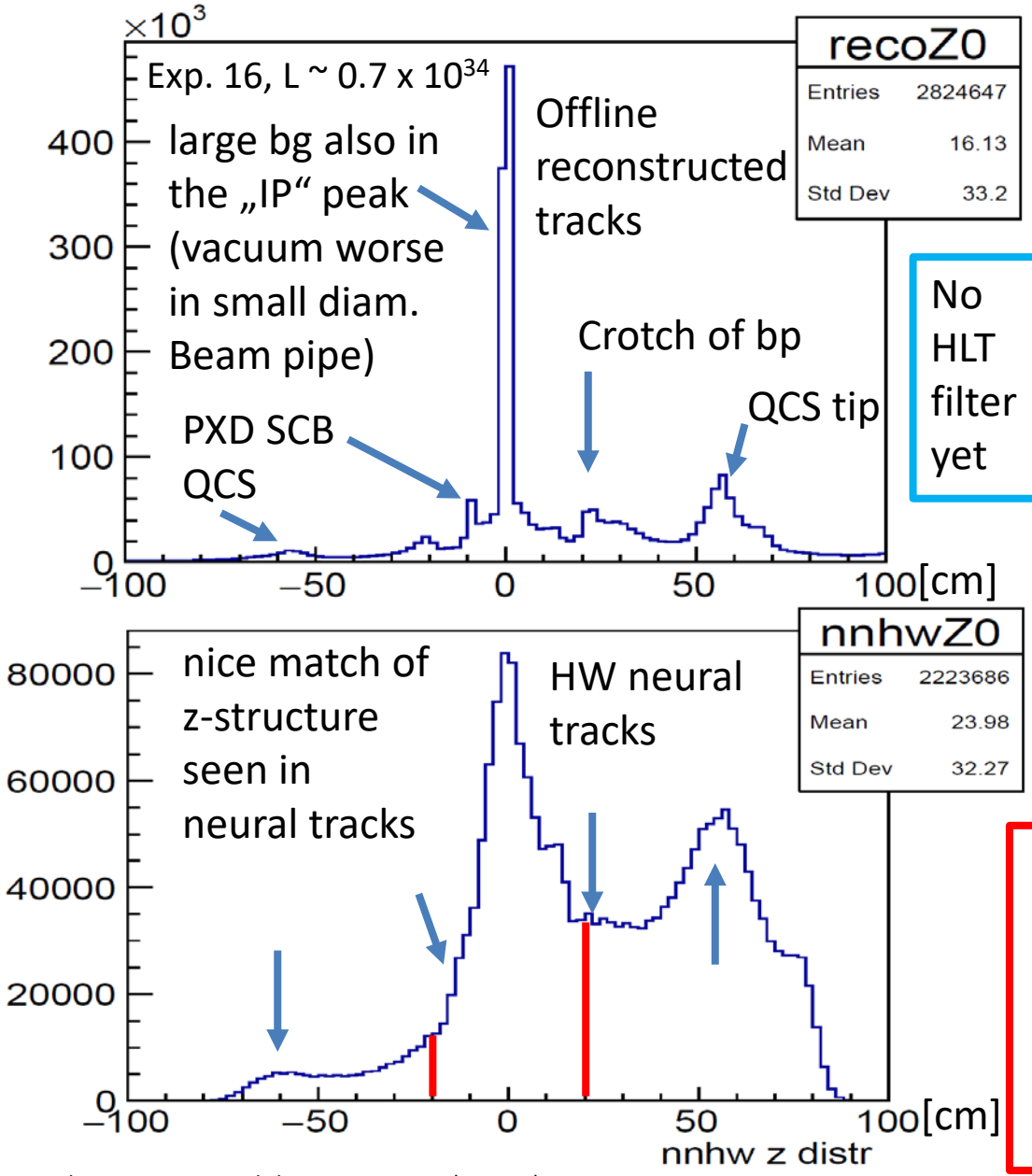
Status of the STT & LS1 Plans + Neuro-Trigger-Activities Beyond

- STT:
  Status and Problems (Feed-down and Fakes) -> data from HLT neuro-skims, look at Exp 24 and 26 (beginning and end)

- Plans for LS1
  Improve z-resolution for |z| > 10 cm (feed-down) -> Felix
  Optimization of new 3D preprocessing & networks -> C.K. + NN
  UT4: Integration of 2D/3D preprocessing + neural networks -> Kai, Marc
  Development of a Displaced Vertex Trigger DVT -> Elia
  Implementation of DVT into UT4 platform -> Kai, Marc

- Future
  Some discussion points for LS2

Launching the Neural z-Trigger in March 2021



No HLT filter yet

Early 2021 running

Reco tracks:
z-distribution after full off-line reconstruction, including VXD space points

Networks trained with the real data from May-June 2020

Large 2D trigger rate in 2021 ->
„y“ bit: ≥ 1 track, $|z| < 20$ [cm],
require ≥ 2 (2D) tracks && y=1

Fundamental change at Belle II wrt Track Triggers:
due to overwhelming BG,
all 2-Track Triggers require at least one neural track: „y=1“

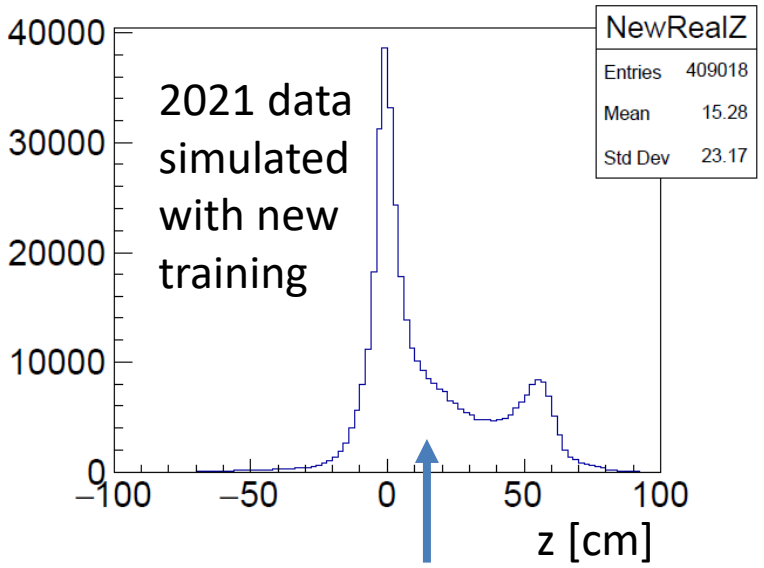
New Training with 2021 High BG Data

- Training data from high background data from the summer of 2021

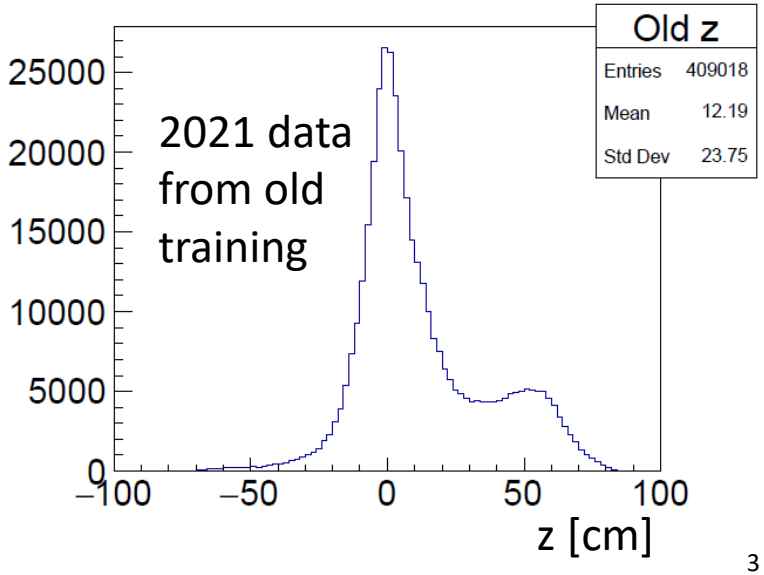
- Better preparation of training data (we had some issues with the data for the expert networks with missing STS)

- State-of-the-art network training frame work used: PyTorch library

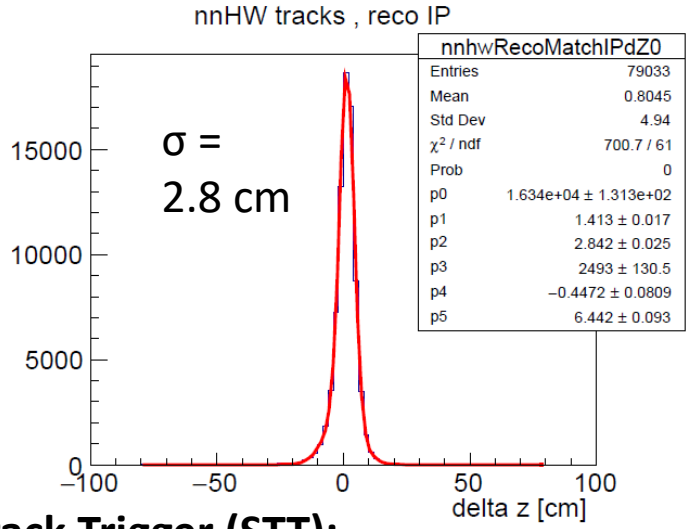
- Main features:
  . loss function with additional term against large weights
  . standardized initialization of network parameters
  . early training stop criteria

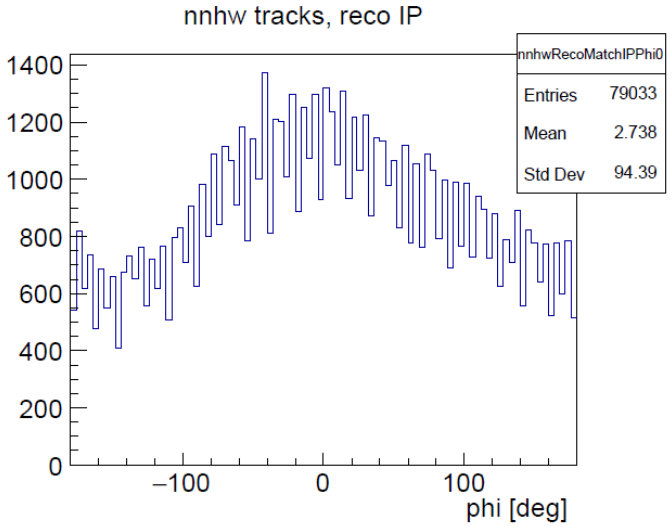


clear improvement seen!



z-Resolution for IP Tracks (Exp 24, 2022.03)

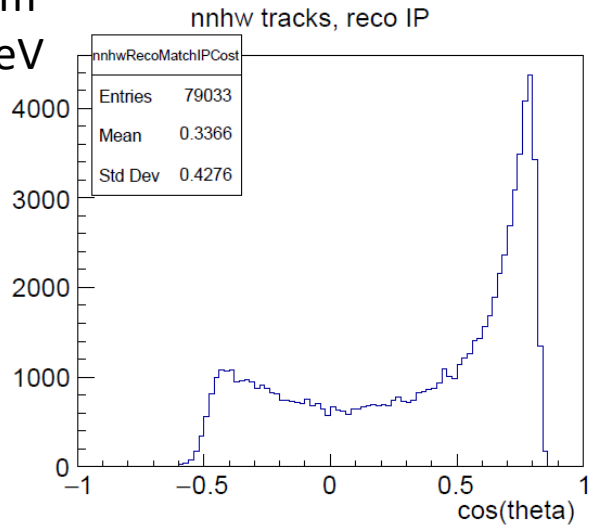




Single Track Trigger (STT):

|z|< 15 cm

P > 0.7 GeV



Exp 24, runs 790 - 890, New FW

Results from improved training

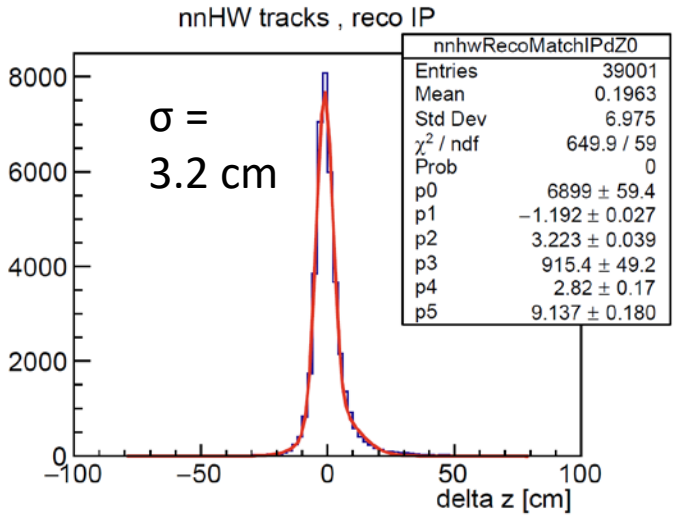
Gaussian fits to neuro tracks associated with reco tracks from IP (|z|<1 cm, d < 1.5cm)

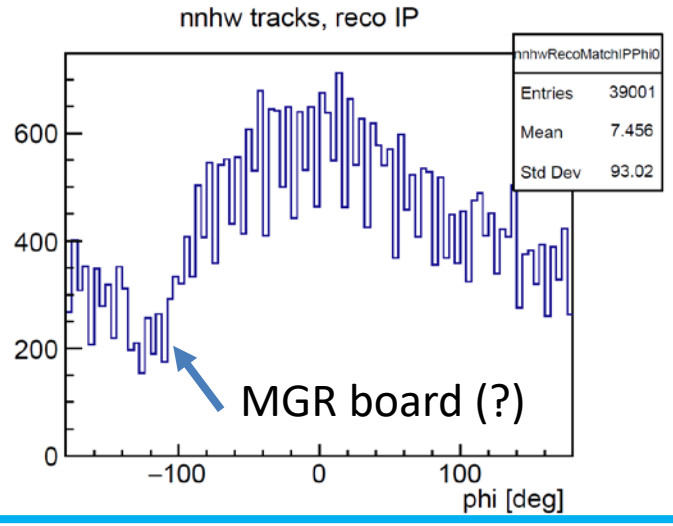
Central Gauss: σ = 2.8 cm

2nd Gauss: σ = 6.4 cm (13.2 %)

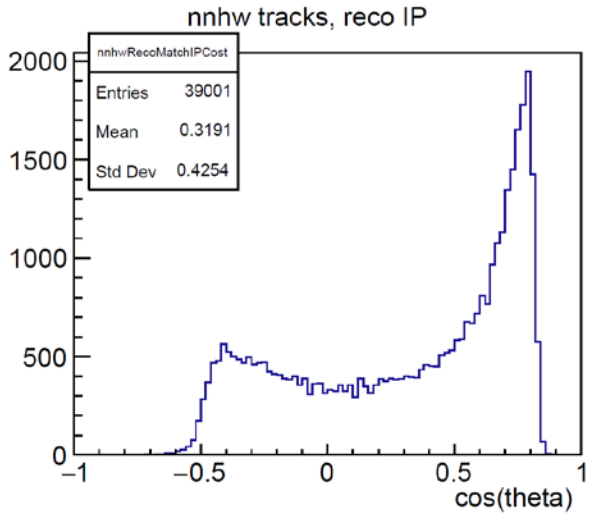
Old training: σ = 5.6 cm: factor 2 improvement

z-Resolution Exp 26 (runs 33-200)





Results from high background



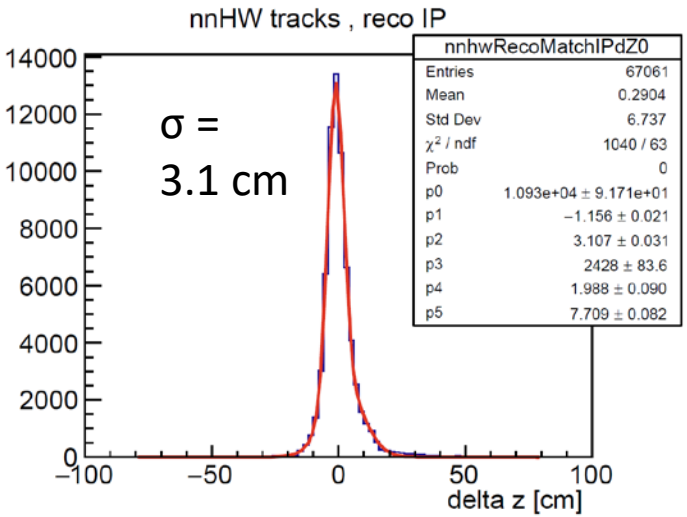
Exp 26, runs 33-200

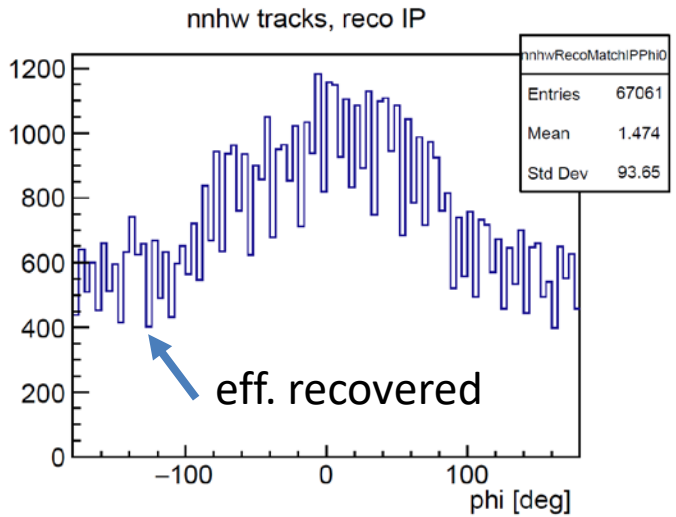
Gaussian fits to neuro tracks associated with reco tracks from IP (|z|<1 cm, d < 1.5cm)

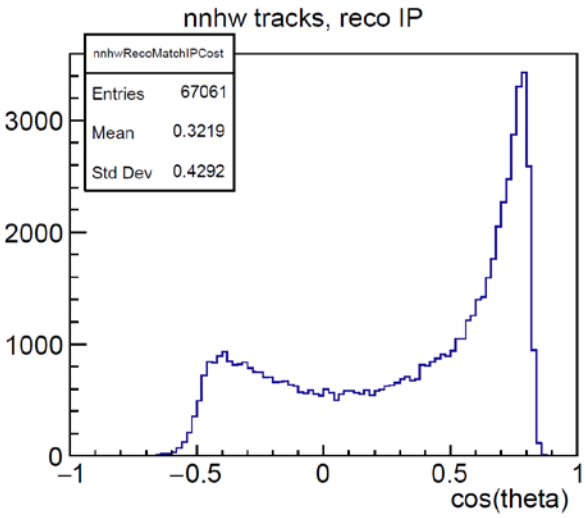
Central Gauss: σ = 3.2 cm

2nd Gauss: σ = 9.1 cm

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)

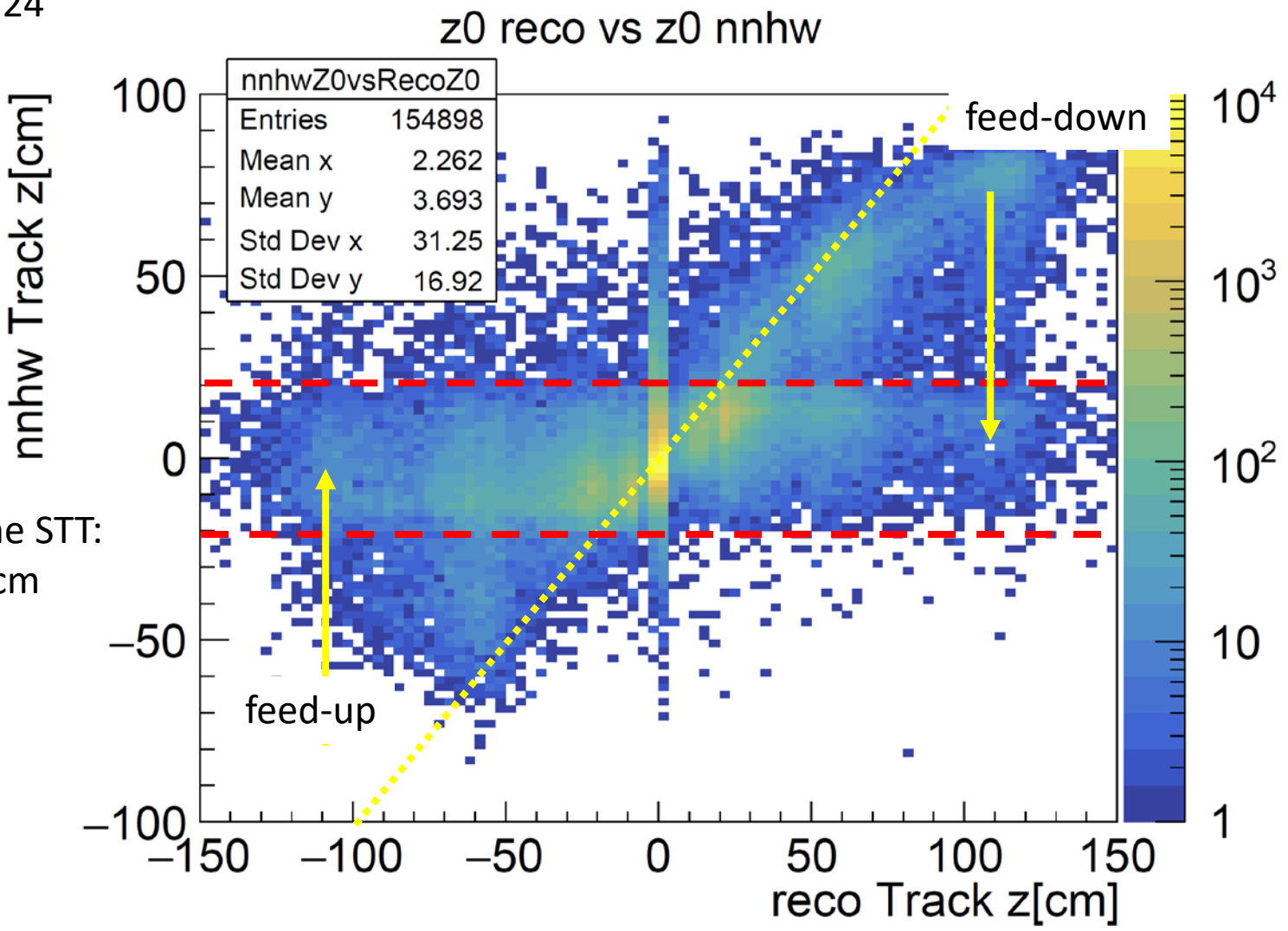
Central Gauss: σ = 3.1 cm

2nd Gauss: σ = 7.7 cm

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

(I): |z| >~20 cm: The „Feed-Down“ Problem

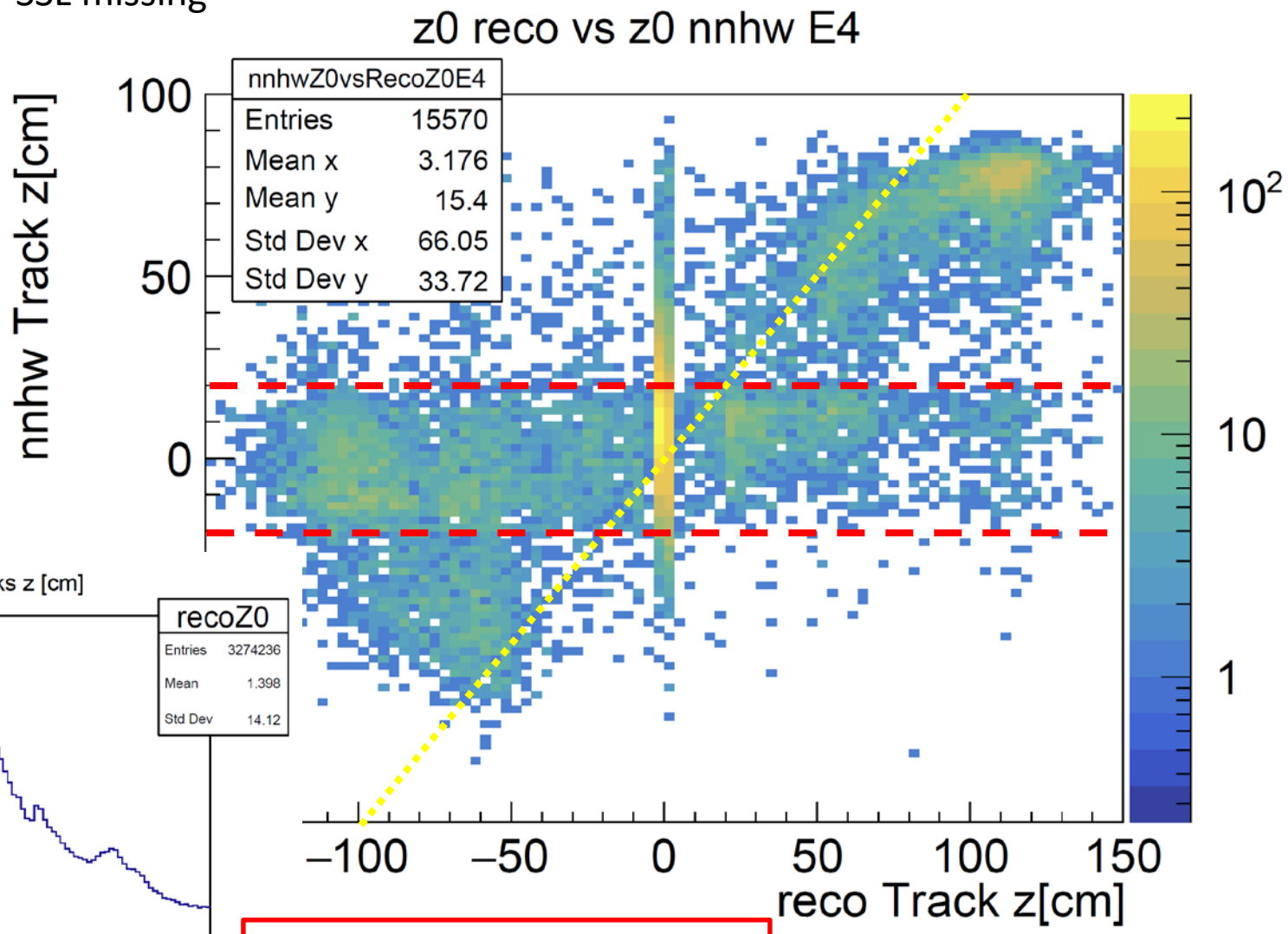
Exp. 24



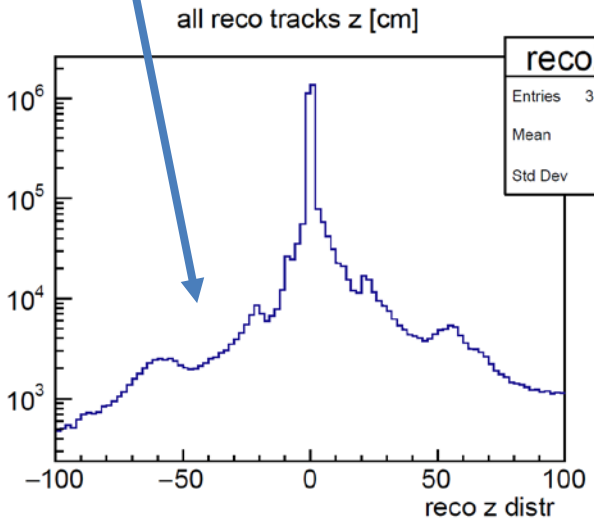
Cut for the STT:
|z| < 20 cm

|z| >~20 cm: The „Feed-Down“ Problem

Expert 4: inner SSL missing

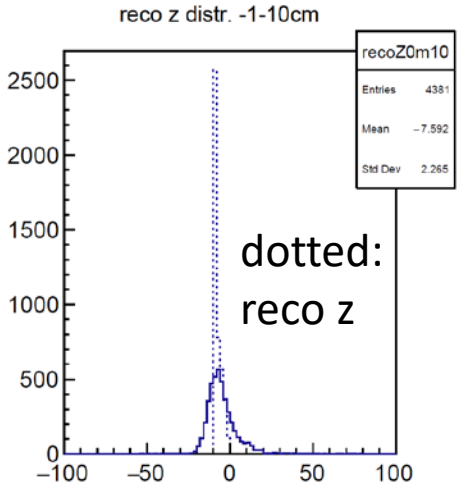


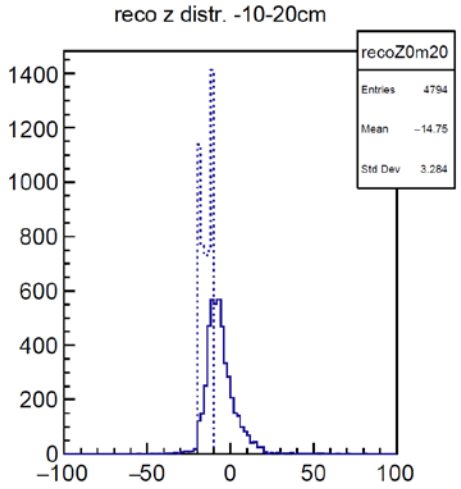
Data for large |z| in permille range only !!

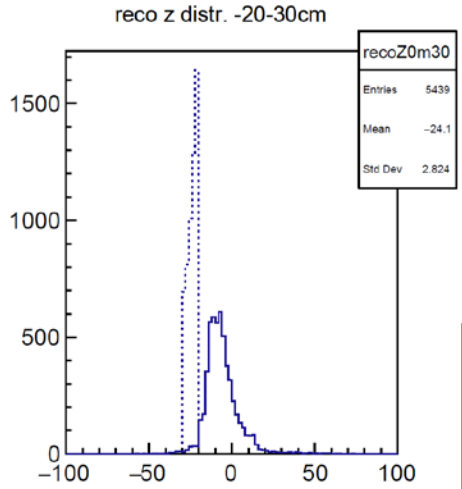


Likely problem: to few data at large |z| for training

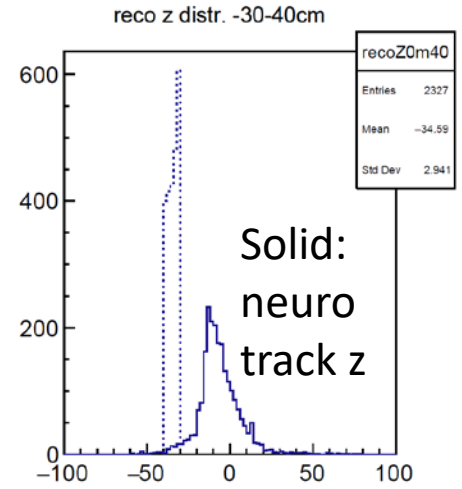
„Feed-Up“ for z < 0, Exp 24

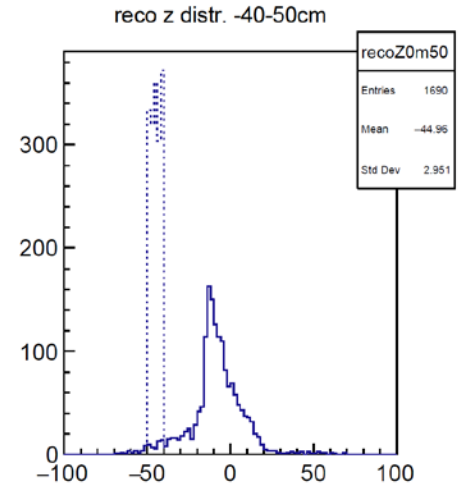


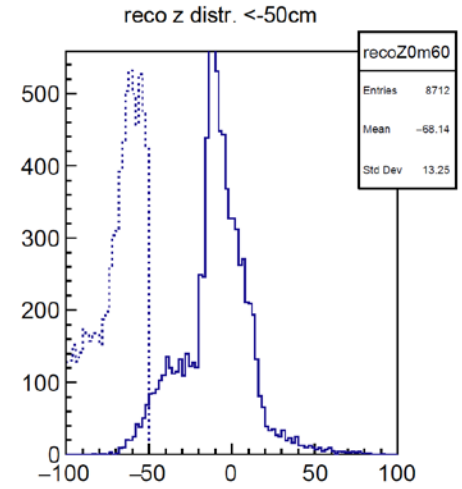




plots for +z and Exp. 26 see backup

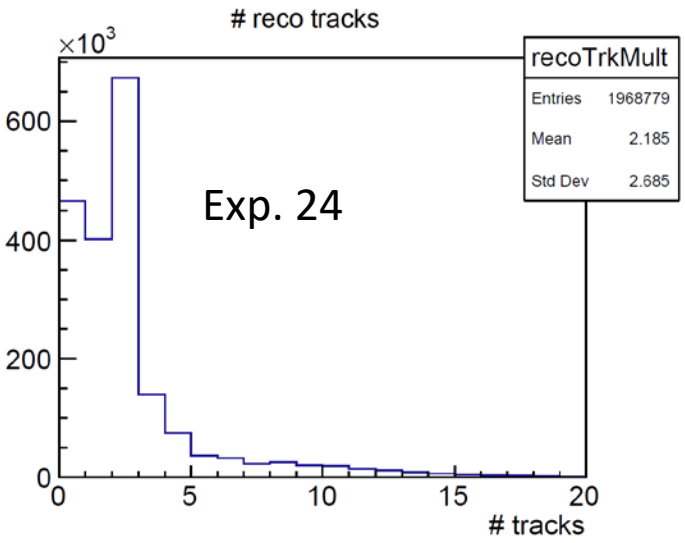


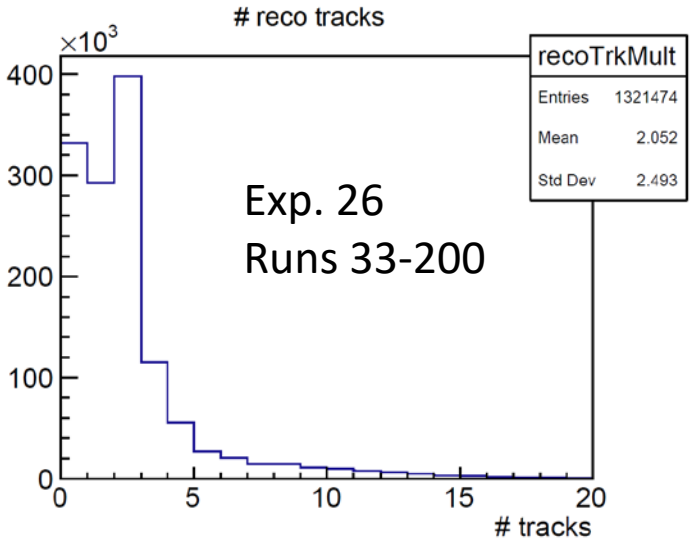


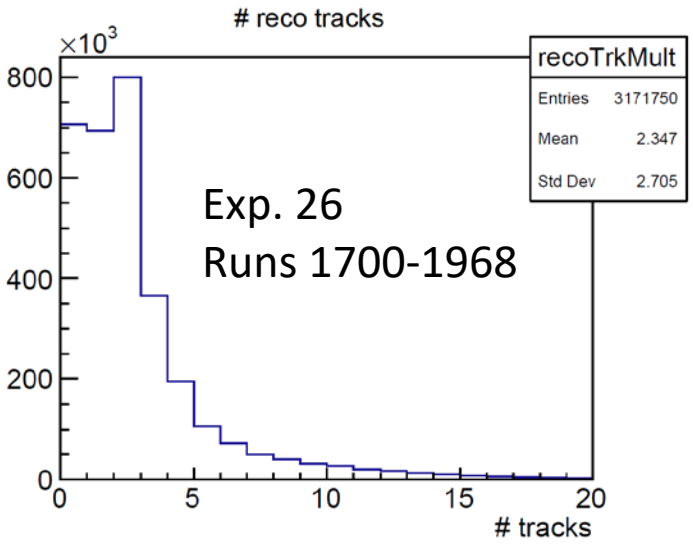


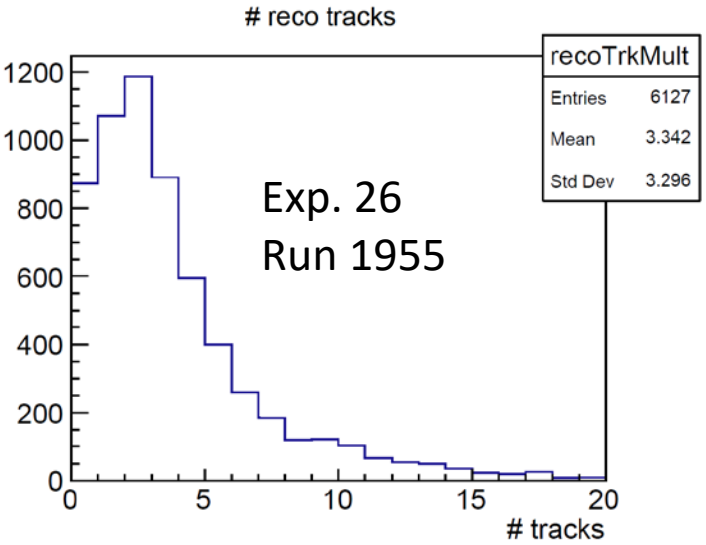
dotted lines: z for reco tracks, solid line: z for matched neuro tracks, in six z-intervals

(II): STT Contribution in Trigger Menu





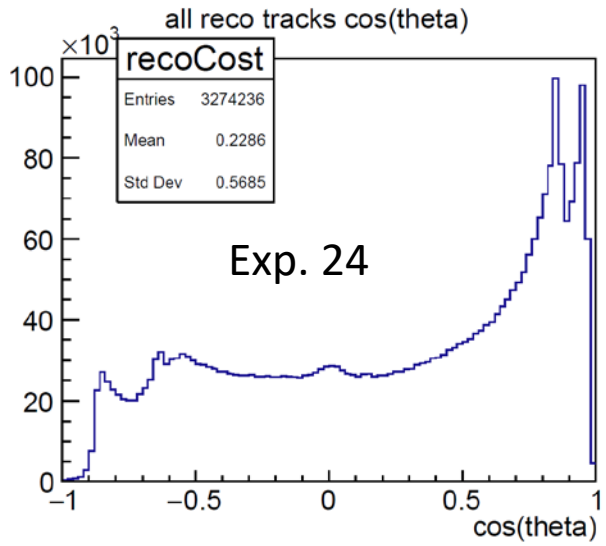


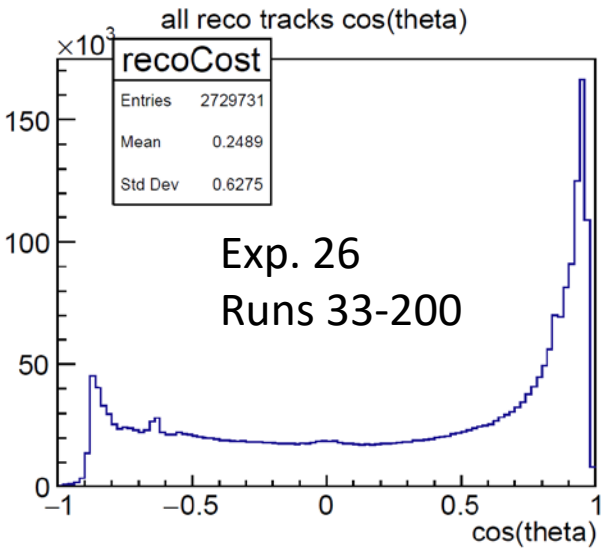


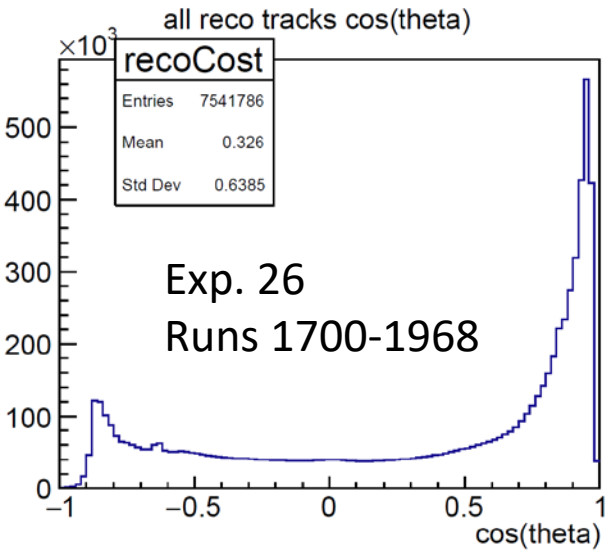
Clear tendency of events with large spread of charge multiplicity during spring/summer running, relative to 2-track events (Bhabhas)

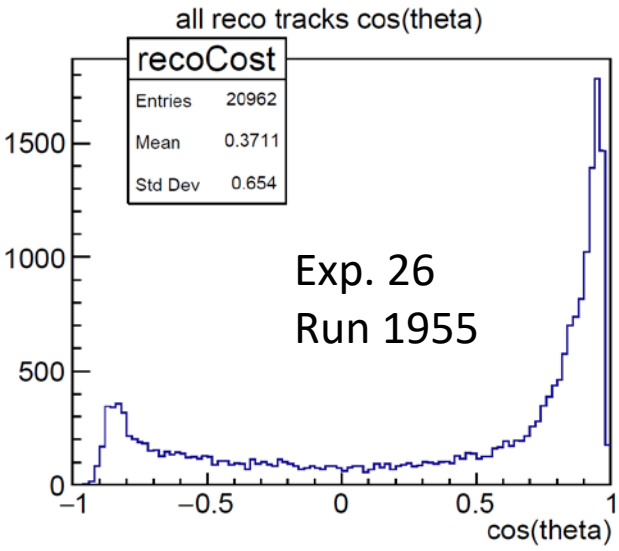
„Background“ ??

Reco Track Scattering Angle





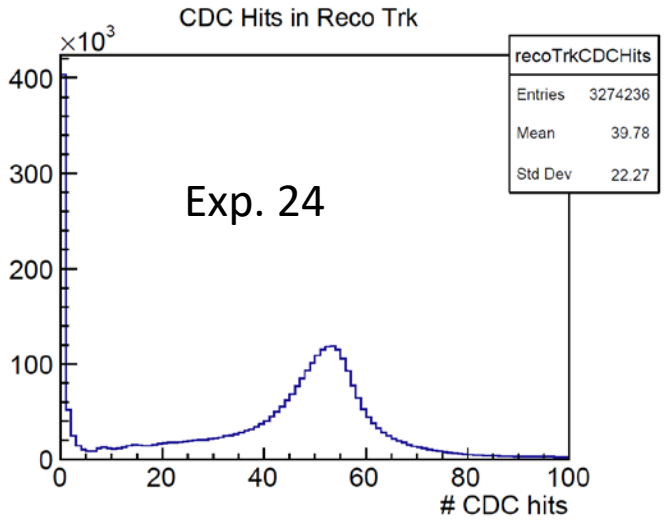


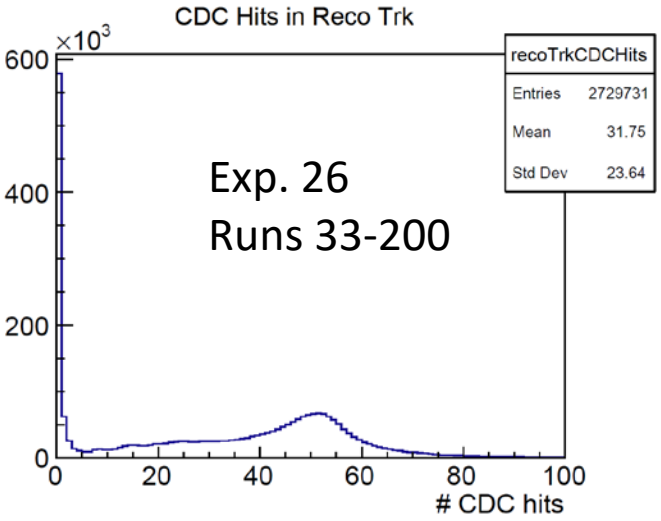


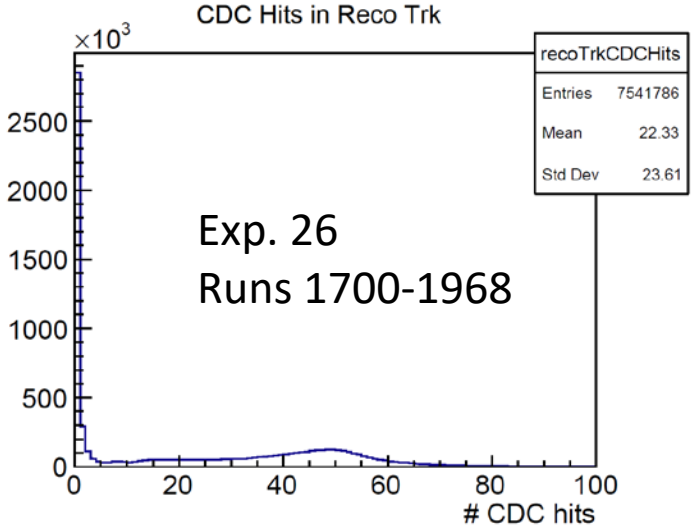
Clear tendency of events with large spread of charge multiplicity during spring/summer running, relative to 2-track events (Bhabhas?), populating the FWD / BWD polar regions

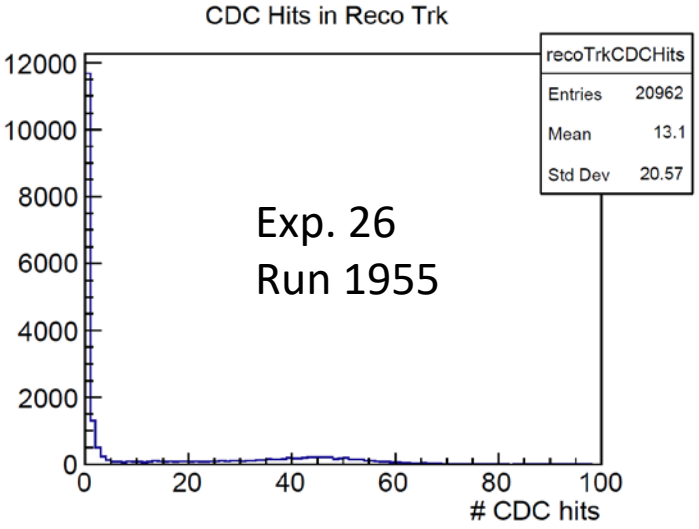
„Background“ ??

CDC Hit Multiplicities for Reco Tracks







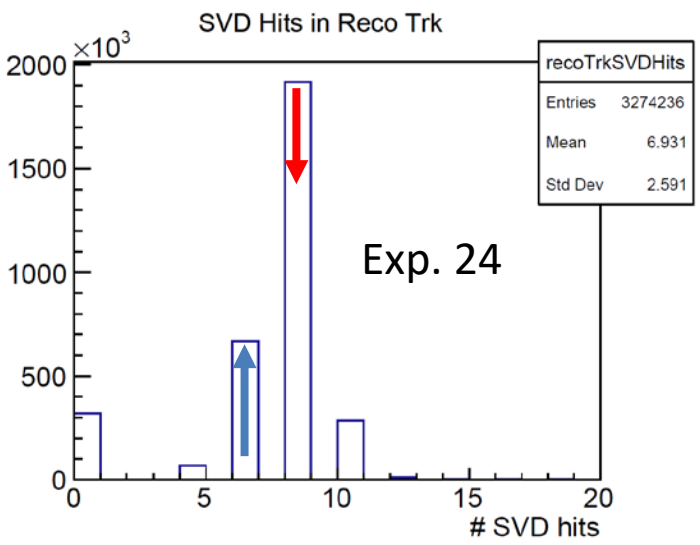


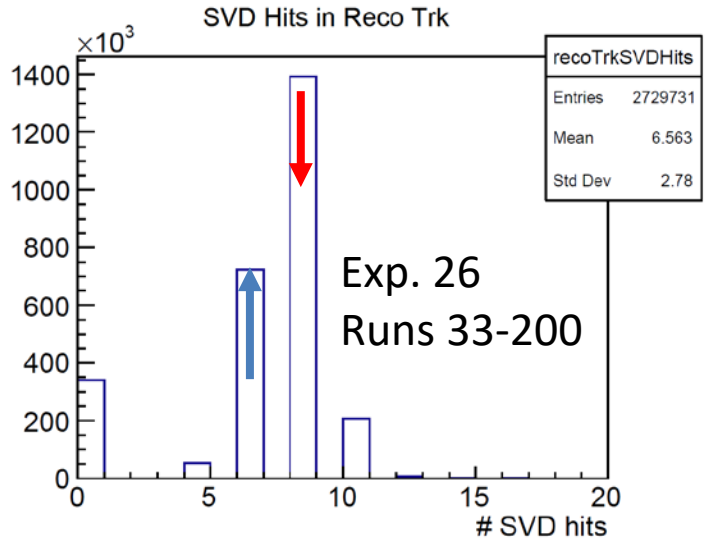
Clear tendency of reduced ADC counts for reco tracks during spring/summer running (inceased cross talk?)

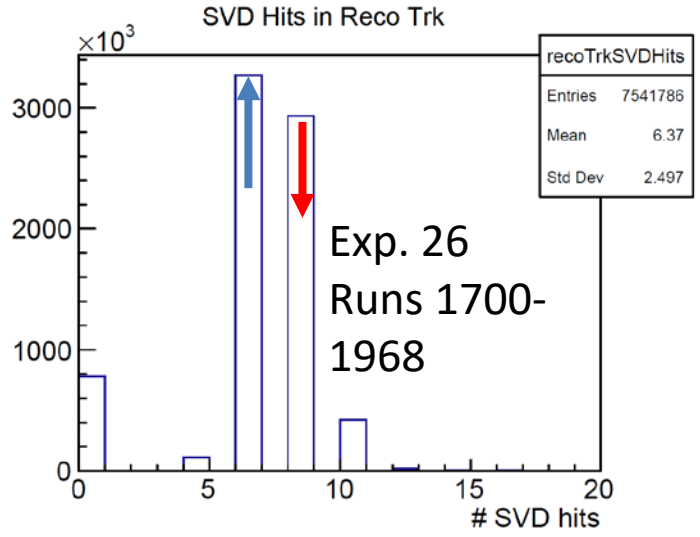
more tracks in FWD / BWD

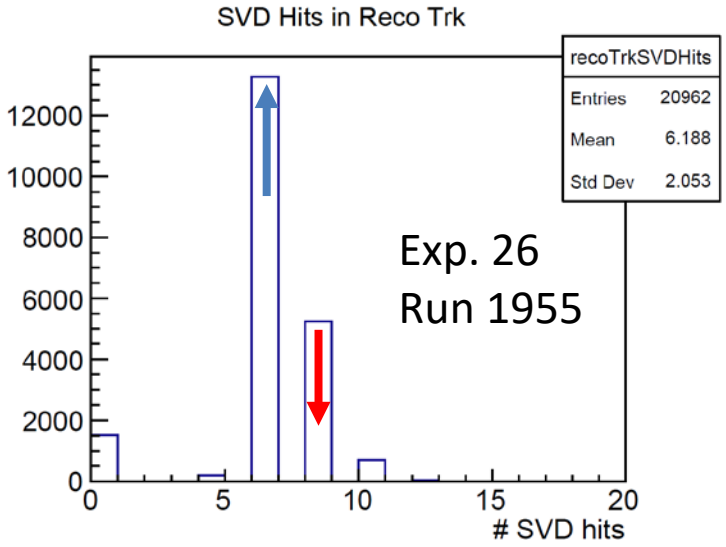
„Background“ ??

SVD Hit Multiplicities for Reco Tracks







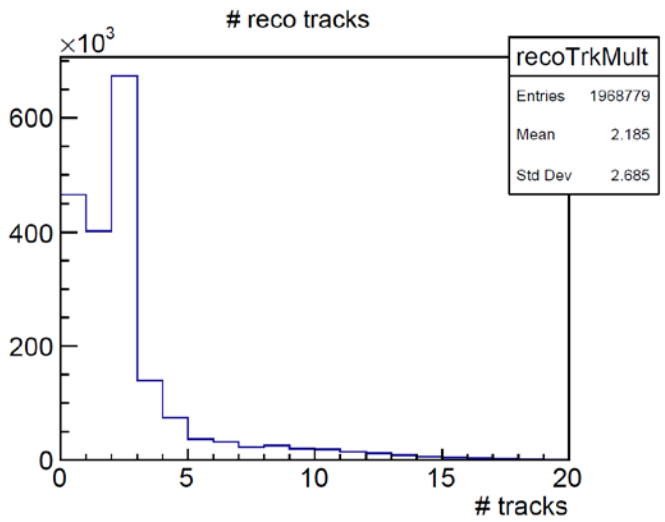


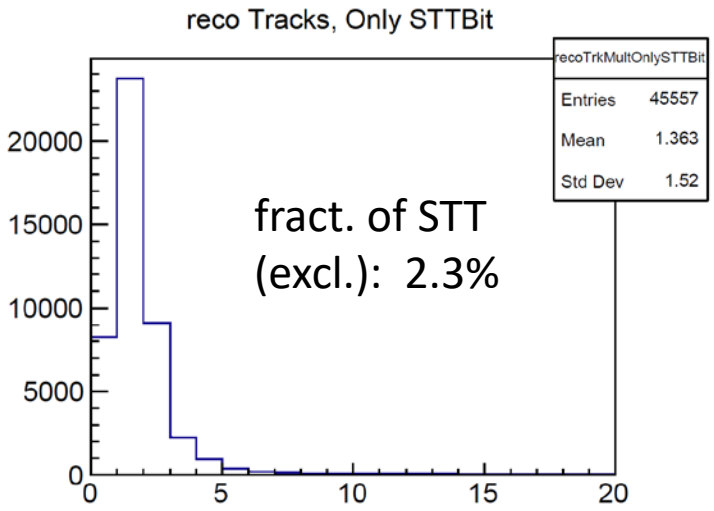
Clear tendency of reduced SVD hits for reco tracks during spring/summer running

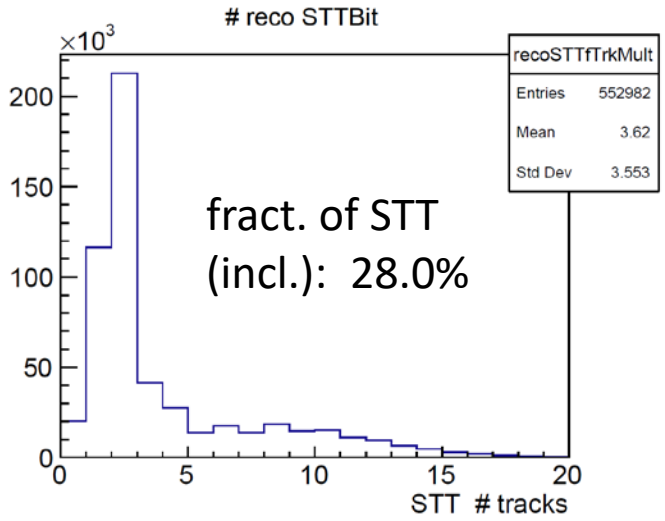
more tracks in FWD / BWD

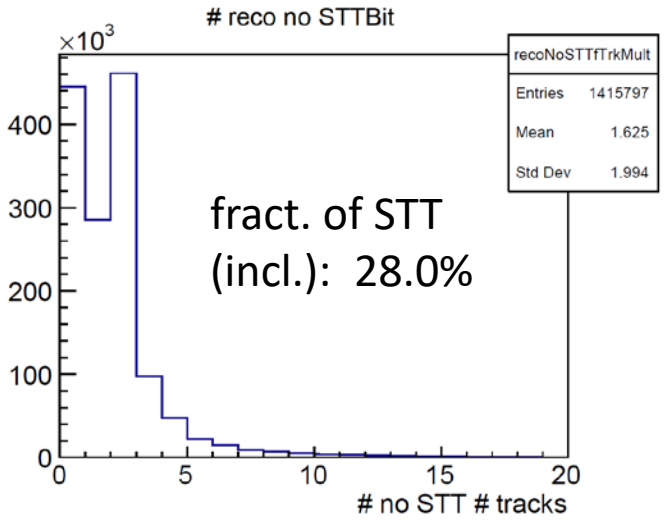
„Background“ ??

Exp. 24: STT Rate



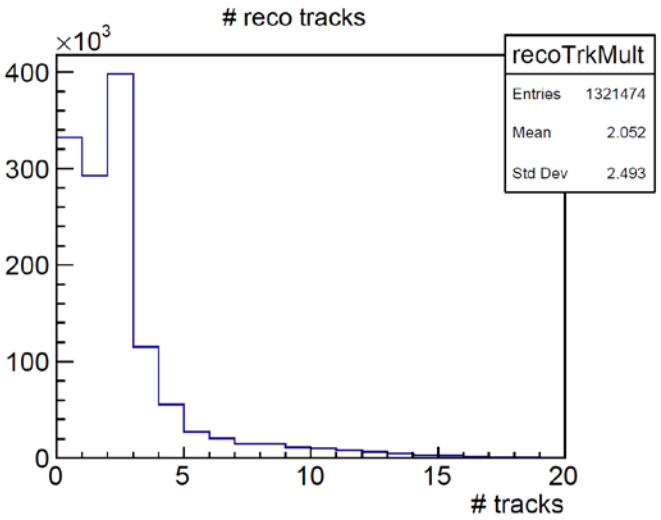


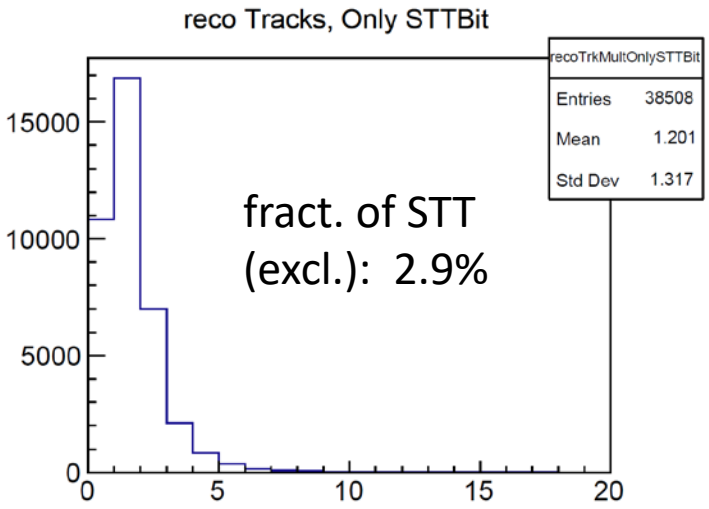


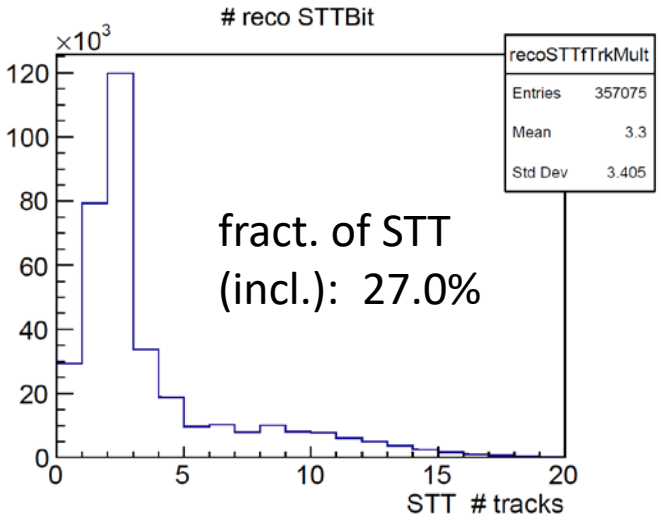


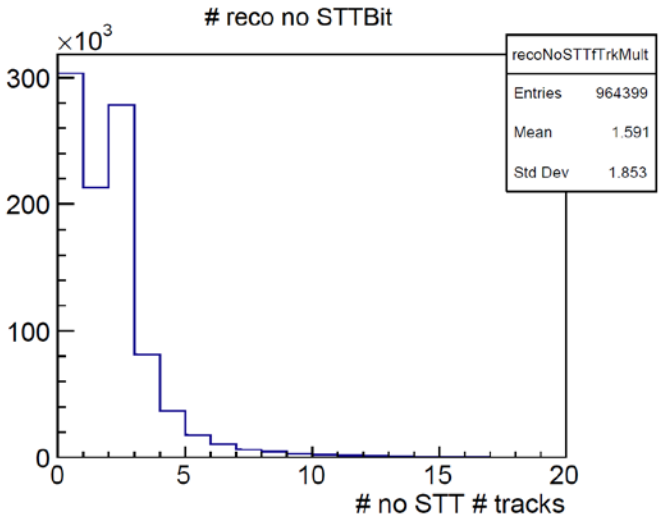
Exp 24, runs 1900-2100 |z| < 20 cm, STTactive 29/11/2022 4

Exp. 26, runs 0-200



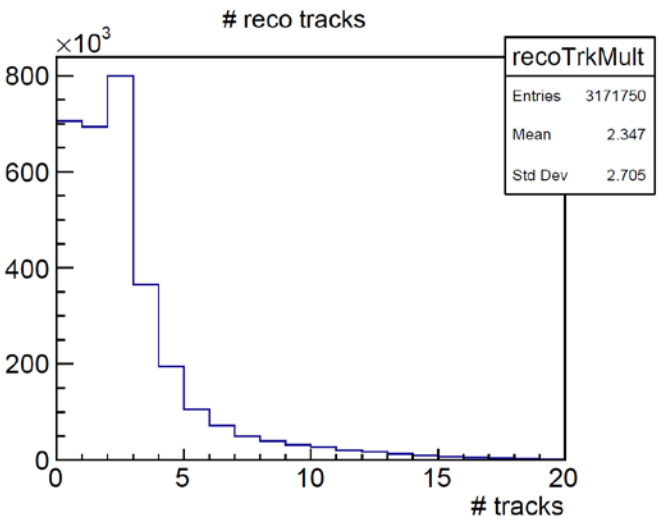


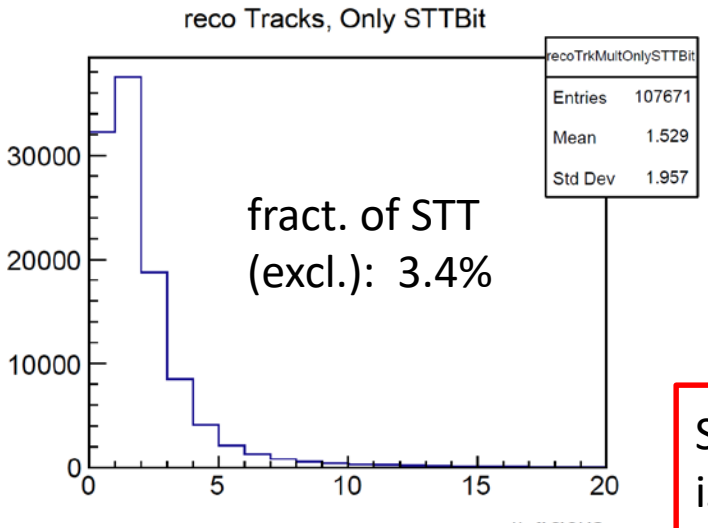




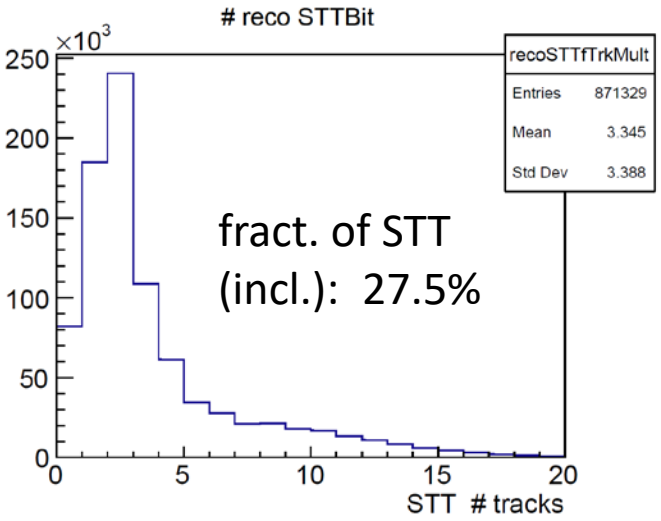
Exp 26, runs 33-200 |z| < 20 cm, STTactive 28/11/2022 4

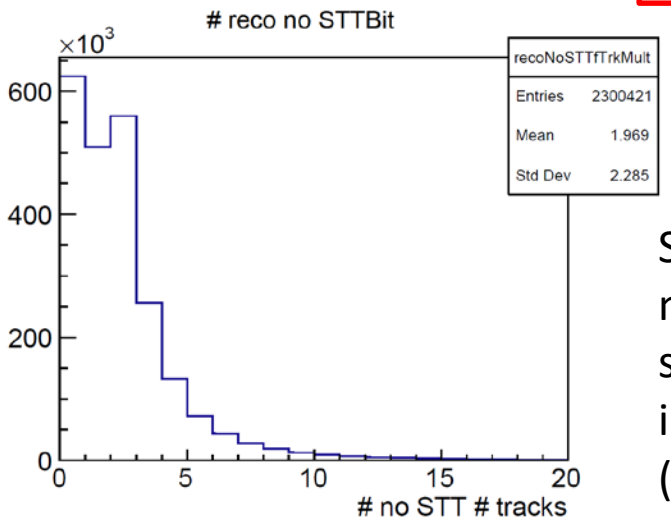
Exp. 26, runs 1700-end





STT rate (incl.) is remarkably stable

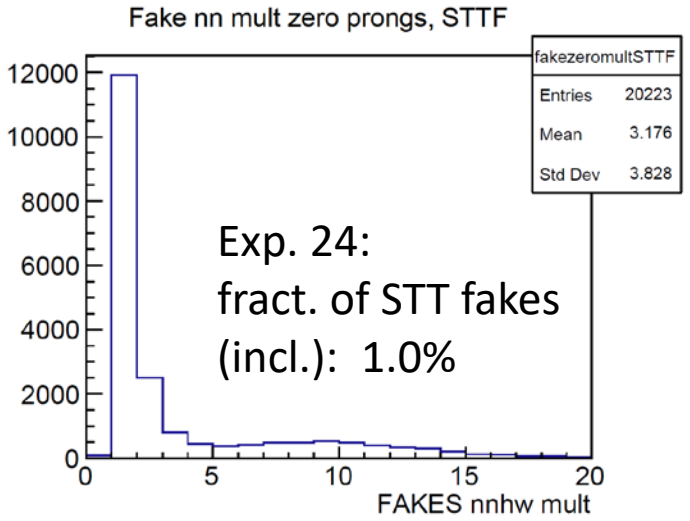


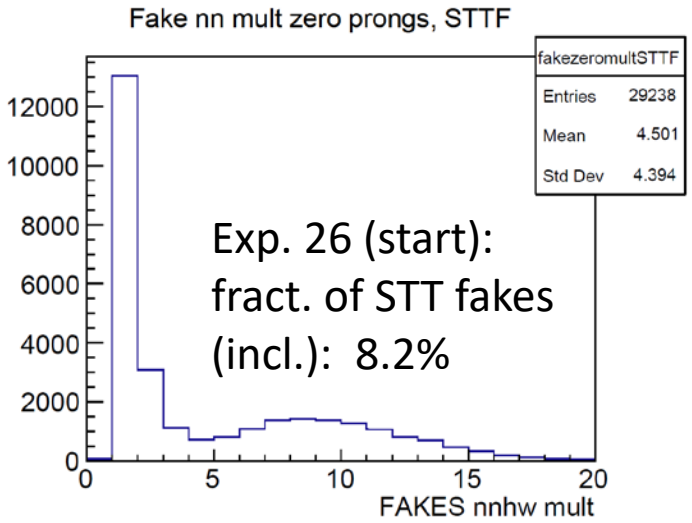


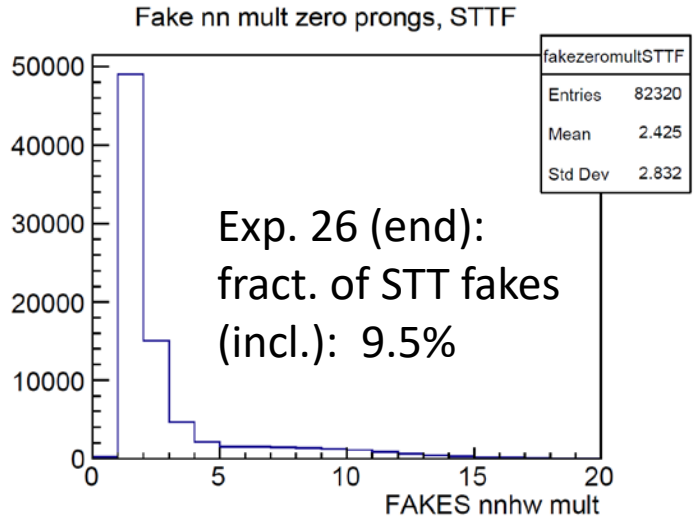
STT rate (excl.) marginal, but shows some increase (2.3% -> 3.4%)

Exp 26, runs 1700-1968 (end) |z| < 15 cm, STTactive 28/11/2022 4

(III): Fake Neuro Tracks (Exp 24 -> Exp 26)







More plots see Backup

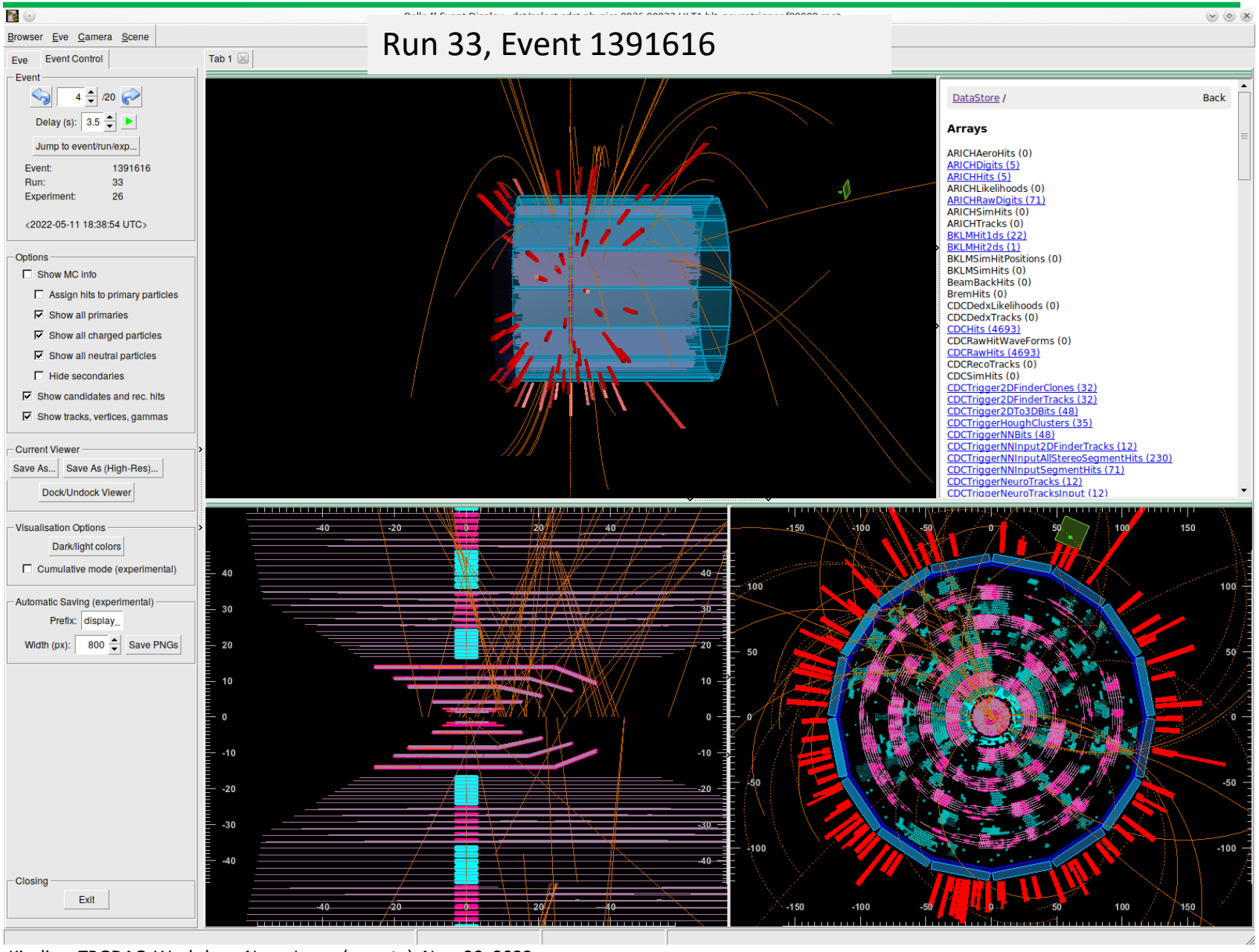
Data: look at events with no reconstructed track &
plot multiplicity of neural tracks

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.)

-> **~ 0.4 – 4% are excl. STT fakes**

No Reco Tracks -> Fake Neuro Tracks



Details for Run 33, Event 1391616

------- Track Output ------ Event 1391616 Run 33 -> this is a FAKE STT event, passed STT

# of reco Tracks : 0

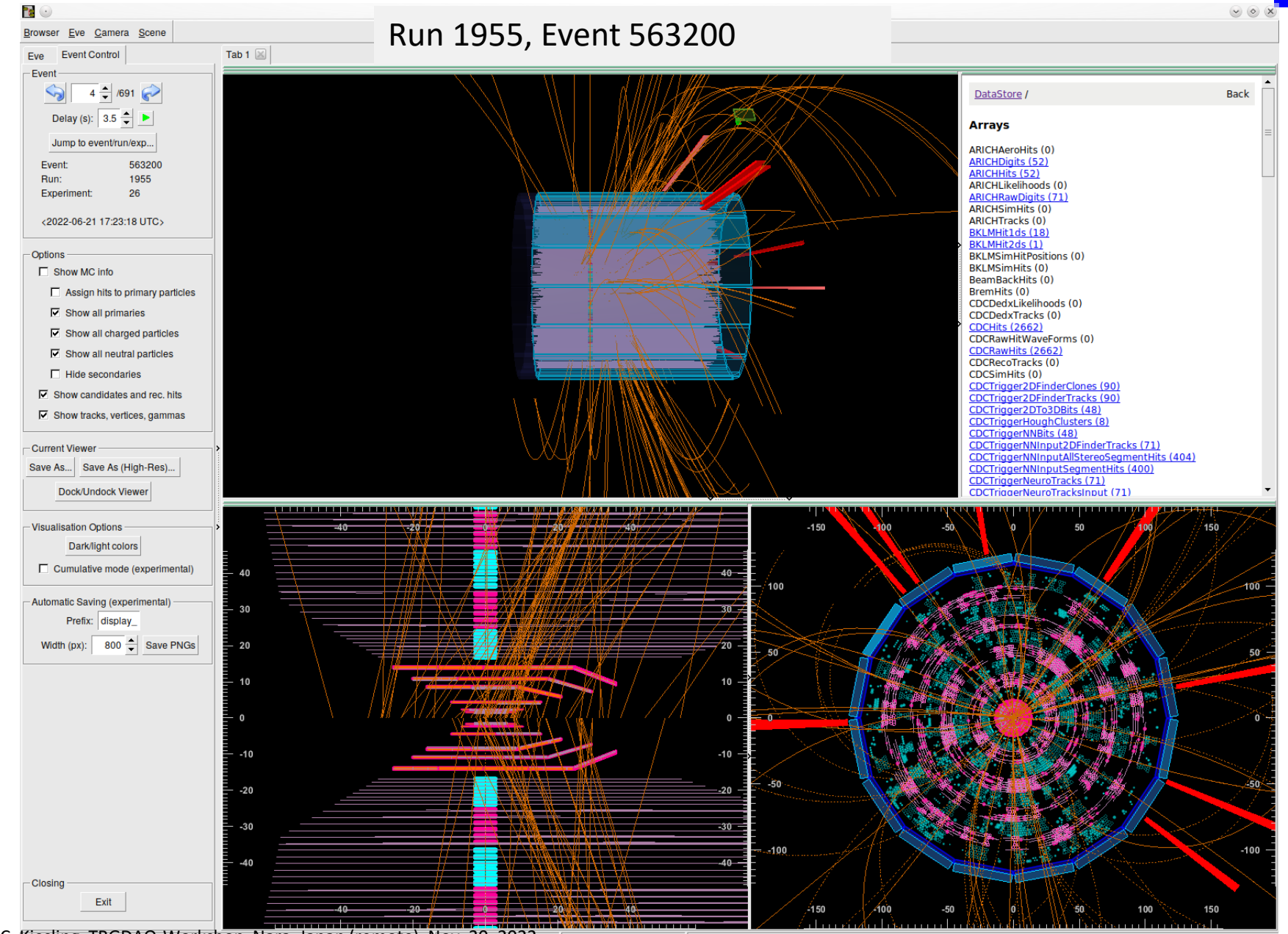
hw Tracks : 3
1 (STT) phi 90, cost 0.42, z0 10.69, DTerr 3, charge -1, p[GeV] 1.02, exp 1, Quad 0
network output (int) : z0 438, theta -1280, th from cos 65
2 (STT) phi 132, cost -0.29, z0 11.08, DTerr 0, charge 1, p[GeV] 10.65, exp 2, Quad 0
network output (int) : z0 454, theta 851, th from cos 106.62
3 phi 139, cost 0.64, z0 26.95, DTerr 2, charge -1, p[GeV] 0.83, exp 3, Quad 1,
network output (int) : z0 1104, theta -2053, th from cos 49.9

Trig Bits for FTDL # f = 1, ff = 1, fff = 1, ffy = 1, fyy = 1, yyy = 0, fy = 1, yyyv = 0, y = 1, yy = 1, fyo = 1

Physics event :0, hw (calc) pass :1, y : 1 STT (Ftdl): 1 STT (Psnm): 1 , Hie : 1 C4 : 1, lml : 0, other triggers : 0

CDC shows a lot of close-by wire hits, almost uniformly distributed -> cross talk??

No Reco Tracks -> Fake Neuro Tracks



Details for Run 1955, Event 563200

------- Track Output ------ Event 563200 Run 1955 -> this is a FAKE STT event, STT only

# of reco Tracks : 0 **Example of Exclusive STT Fake Trigger**

hw Tracks : 7

Final Array of 7 NNhw tracks

1 phi 57, cost 0.61, z0 44.04, DTerr 0, charge 1, p[GeV] 6.45, exp 4, Quad 0,
2 STT phi 139, cost 0.62, z0 3.42, DTerr 0, charge 1, p[GeV] 3.27, exp 0, Quad 1
3 phi 163, cost 0.23, z0 -32.37, DTerr 1, charge 1, p[GeV] inf, exp 4, Quad 1
4 STT phi 150, cost -0.01, z0 0.88, DTerr 1, charge -1, p[GeV] 2.55, exp 4, Quad 1
5 STT phi 173, cost 0.42, z0 -0.59, DTerr 1, charge -1, p[GeV] 5.62, exp 3, Quad 1
6 STT phi -91, cost -0.03, z0 8.08, DTerr 3, charge -1, p[GeV] 3.4, exp 4, Quad 2
7 phi -31, cost 0.23, z0 25.95, DTerr 0, charge 1, p[GeV] 10.5, exp 3, Quad 3

Trig Bits for FTDL # f = 0, ff = 0, fff = 0, ffy = 0, fyy = 0, yyy = 0, fy = 0, yyyv = 0, y = 1, yy = 1, fyo = 0
Physics event :0, hw (calc) pass :1, y : 1 STT (Ftdl): 1 STT (Psnm): 1 , Hie : 0 C4 : 0, lml : 0, other triggers : 0

(IV): Neuro Trigger Plans for LS1

The driving arguments:

- further improve the z-resolution of the STT due to recently observed new backgrounds close to the IP (from presently about 3 cm to below 2cm)
  [machine background has dramatically increased with increasing luminosity during the last months before the shutdown in June 2020]

- Porting track finding (2D/3D Hough) to **UT4** + network operation: provide latency for full exploitation of the CDC information:

  - Include information of the charge deposition (ADC signals) on the wires
    -> more complex neural algorithms for the STT

  - new algorithms sensitive to events with displaced vertices ("Displaced Vertex Trigger" DVT).

Task list to be completed during the Long Shutdown (LS1)
-> person power in the project needs serious consideration

Task List for STT HW Developments

This is short-term time scale development (completion ~ first quarter of 2023)

1. Develop FW for the UT4 (160) boards:

    - mandatory for any extension of the present algorithms.
    - First project: port the existing STT firmware (FW) installed on the UT3 onto the UT4 platform (preprocessing and network algorithms)

    Time scale for realizing the porting of the FW onto the UT4 platform to be discussed

2. Testing and evaluating the newly established FW on the UT4 platform with Cosmics

    - Run without magnetic field (detector open for the installation of the new PXD).
    - Data with both the present UT3 and the new UT4 successively

Task List for STT HW Developments

This is mid-term time scale development (completion ~ second / third quarter of 2023)

3. Major change in the hardware chain of the neural track trigger system

- Replace the 2D input from the standard 2D track trigger with our own implementation on the UT4 board (sample code from 2D may be used and adapted)
- use standard preprocessing and STT networks already developed under point 2.
- Important point: new FW should include a cluster algorithm in the 2D Hough plane (this is a necessary exercise for the DVT in the MPI version)
- At the same time (or earlier) the existing 3D preprocessing can be tested (network algortihms using 3D still to be developed)
- Add Displaced Vertex Trigger
  -> need new set of TS, optimization ongoing (see Marc's presentation)
  ->Algorithms already quite advanced (see Elia's presentation)

Task List for STT HW Developments

4. Implementation of neural algorithms using 3D preprocessing

- The cluster algorithm from the previous step 3 should be extended to 3D, executing on 9 theta bins in parallel (-> optimization ongoing).
- Network training with the new 3D input.
- The input could be simulated with the wire signals from real data, training can then be done with this modified input stream.
- Also here a cosmic test would be essential. The time scale most likely towards the second half of 2023.

  Central questions:
  -> What is the gain in z resolution at small and large z (this might be more important than increasing the polar angular range.
  -> What is the chance to reduce fake tracks?

- Time scale for network optimization with 3D preprocessing realistically not before mid of 2023

Long-Term Plans (-> LS2)

5. For the "ultimate" z-resolution of the STT use the complete wire information from the track segments.

- Using all 11 wires will require more complex networks (more inputs, possibly more hidden layers).
- Information from CDC ADC counts can be used (thresholds on wire signals with the track segments (TS).
- Required additional latency comes from the integration of the 2D/3D preprocessing (see points 1-4) into the UT4 platform, performing also the neural computation.
- The same "win" in latency might also make possible the implementation and execution of GNNs and other involved network architectures on the UT4 platform for the DVT project

Summary and Conclusions

- Analysis of STT shows relatively stable rate budget even under large backgrounds (end of 2022 running)
  However, “Feed-down” and “Fakes” will get attention (-> mainly re-training)

- Major next goal: bring 3D-preprocessing & networks online, possibly with coarse analog thresholds for CDC wire signals (cross-talk, spiraling electrons)

- First DVT (MPI variant) could realistically be brought online for the next running period

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

Development for LS2 (> 2026 ….) , just for completeness

- New UT5 platform being discussed

- During LS2 CDC frontend will be replaced, providing also the digitized charge depositions on all of the CDC wires (full ADC values, not just thresholds).

- Could be very useful for suppressing background hits for advanced DVTs and further “sharpening” of the STT when design luminosity is being approached.

Backup

Groups Involved in Neural Trigger Project

Core Team:

KIT ITIV:

Jürgen Becker (PI), Steffen Bähr*, Marc Neu, Kai Unger (+ students):
FPGA prog. UT3/UT4
Sebastian Skambraks*: 3D track finding, DM (MC) neuro algorithms (basf2 impl.)

TUM (inf):

Alois Knoll (PI), Felix Meggendorfer (+ students): Neuro algorithms, training with real data, DQM (basf2 impl.)

MPP:

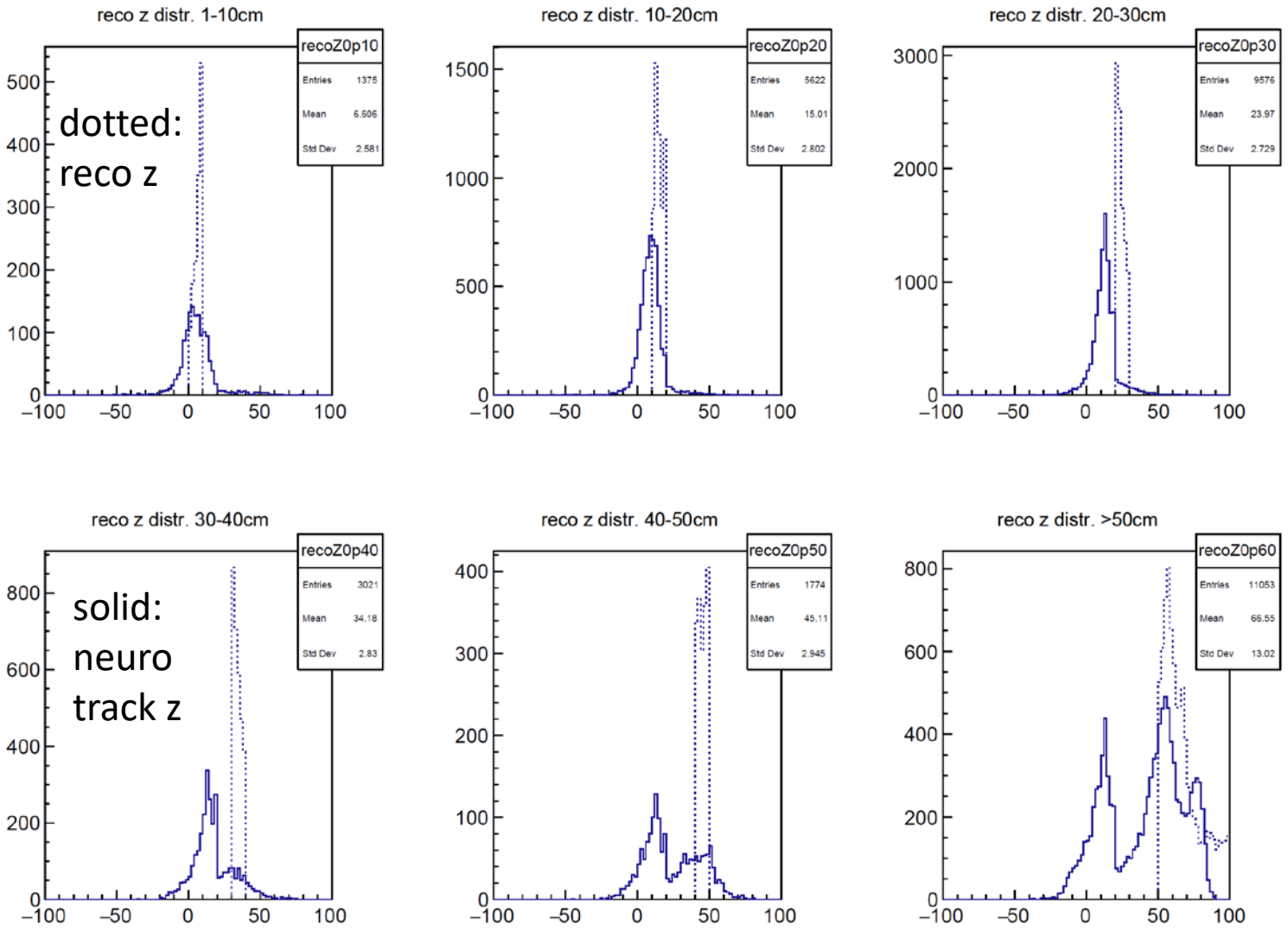
Christian Kiesling (PI), co-supervising TUM/LMU students, Elia Schmidt:
Trigger analysis (basf2) , STT and DVT development

Physics support:

KIT ETP:

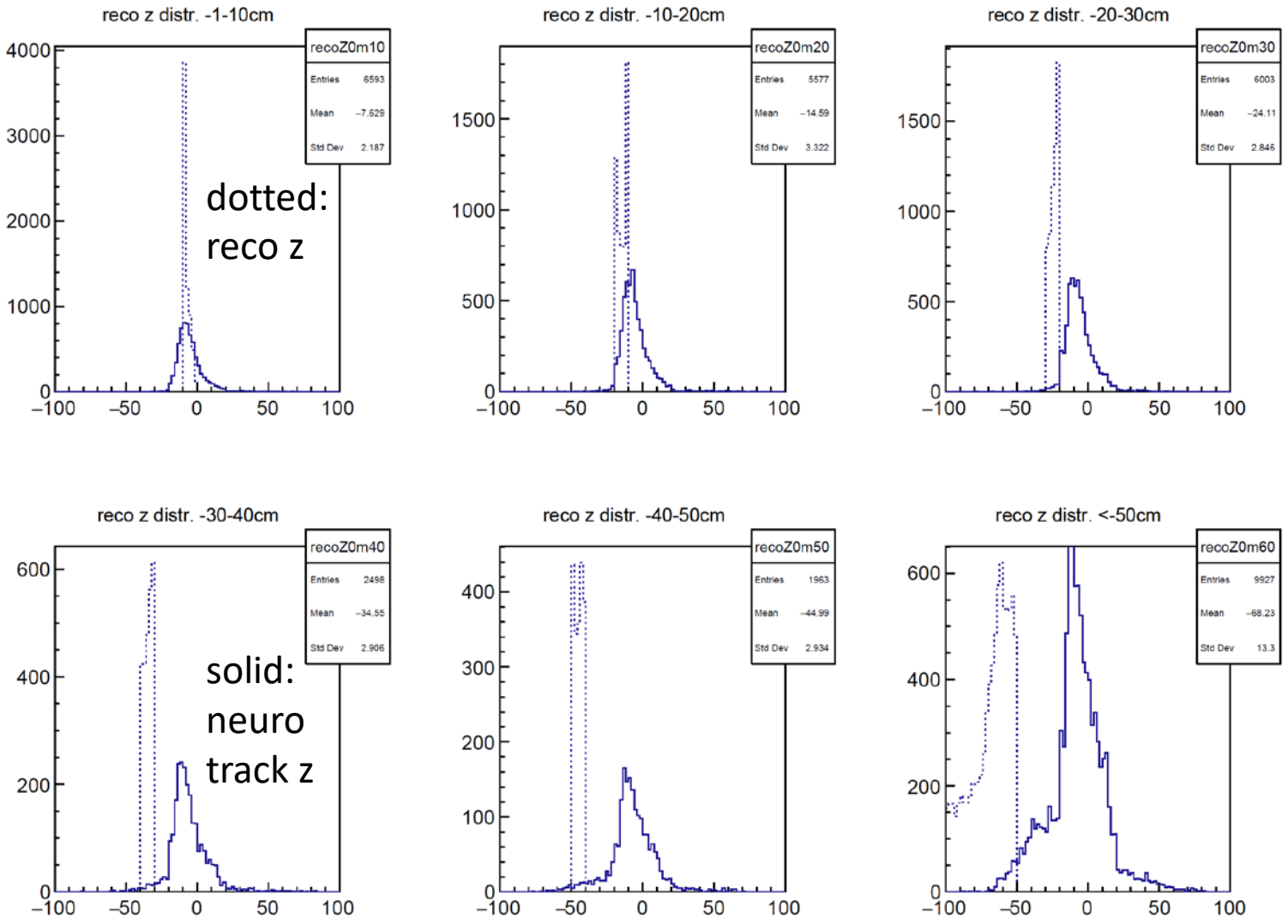
Torben Ferber(PI), Pablo Goldenzweig (+ students): Dark matter generators

„Feed-Up“ for z > 0, Exp 24



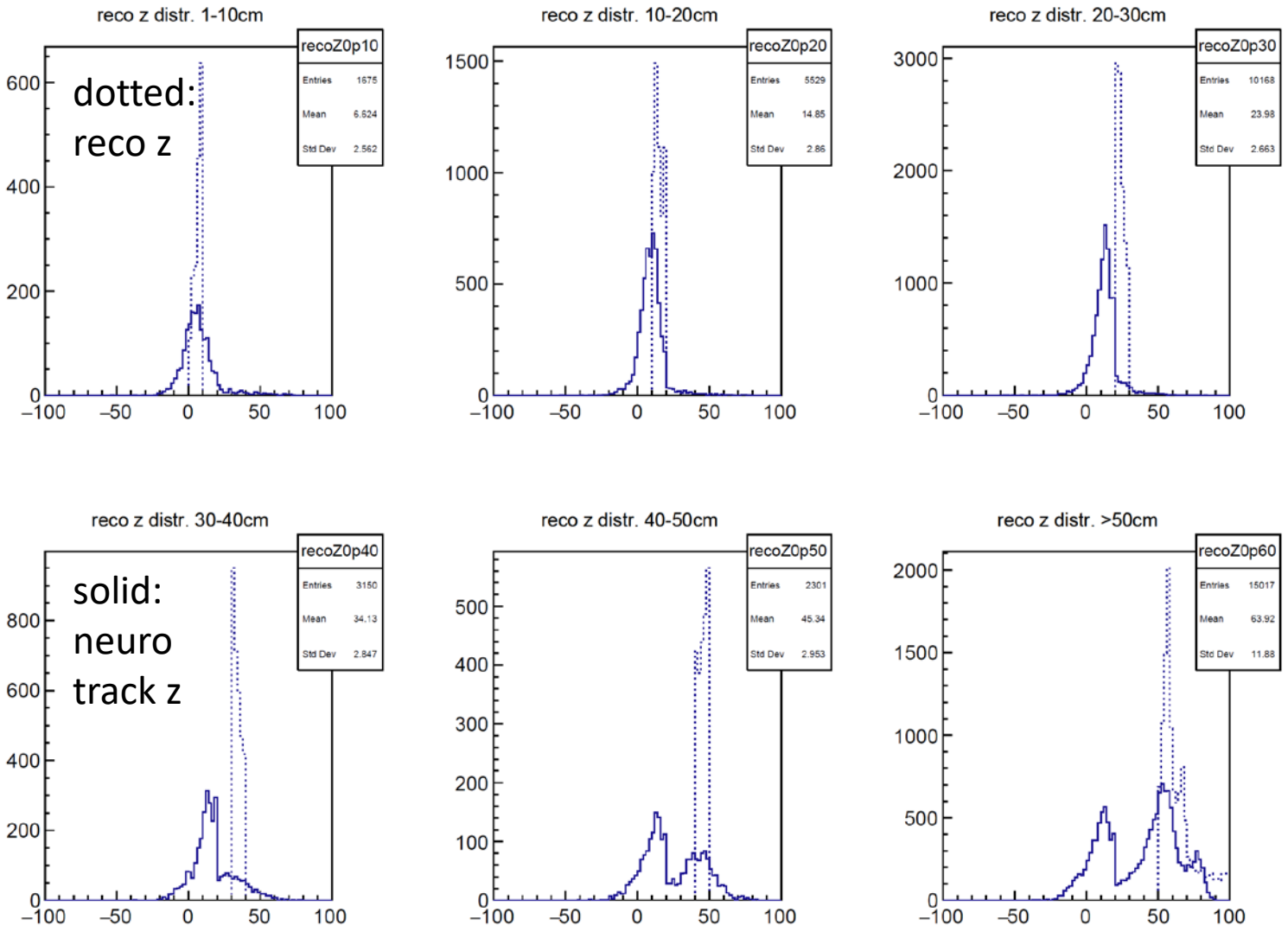
dotted lines: z for reco tracks, solid line: z for matched neuro tracks, in six z-intervals

„Feed-Up“ for z < 0, Exp 26, run 33-200



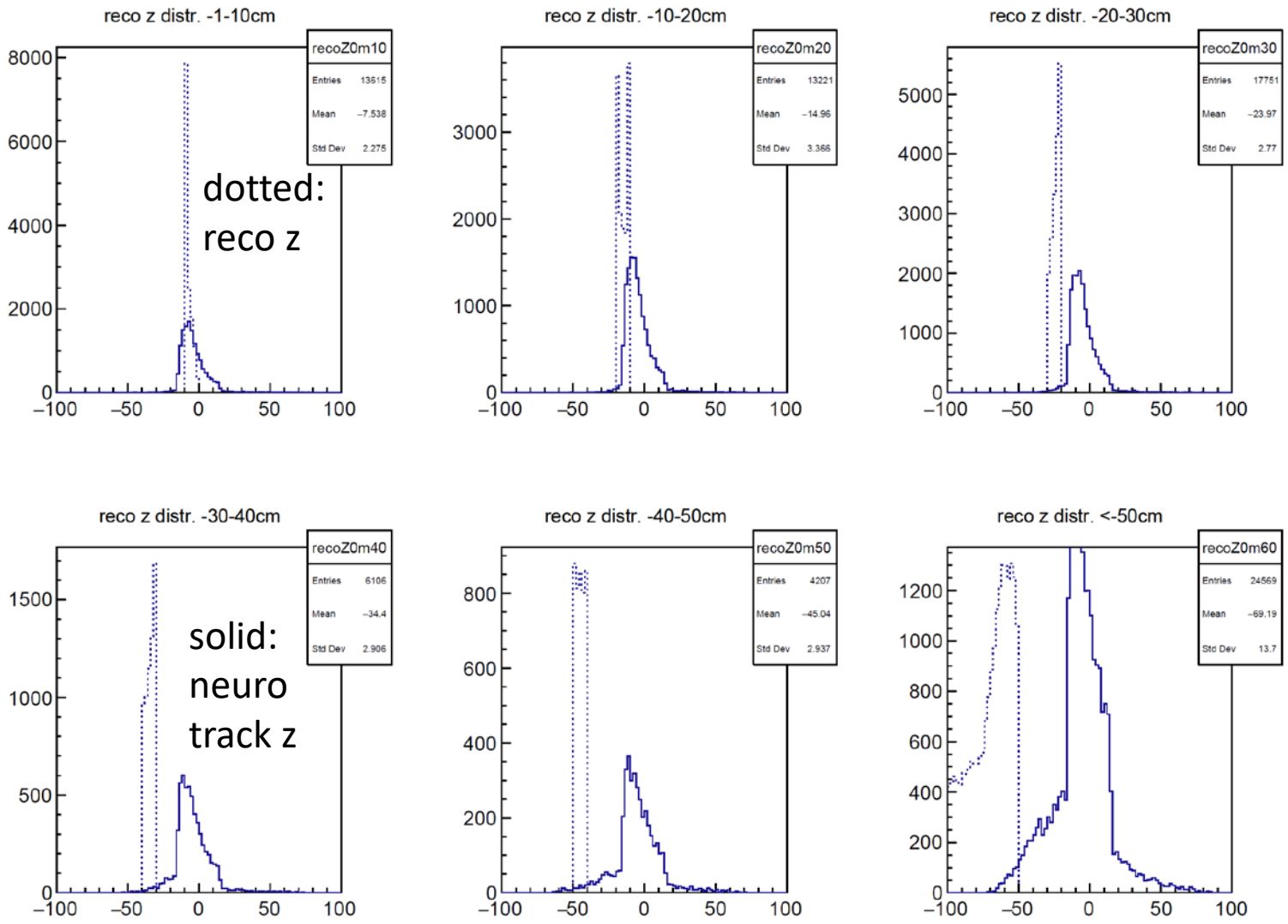
dotted lines: z for reco tracks, solid line: z for matched neuro tracks, in six z-intervals

„Feed-Up“ for z > 0, Exp 26, run 33-200



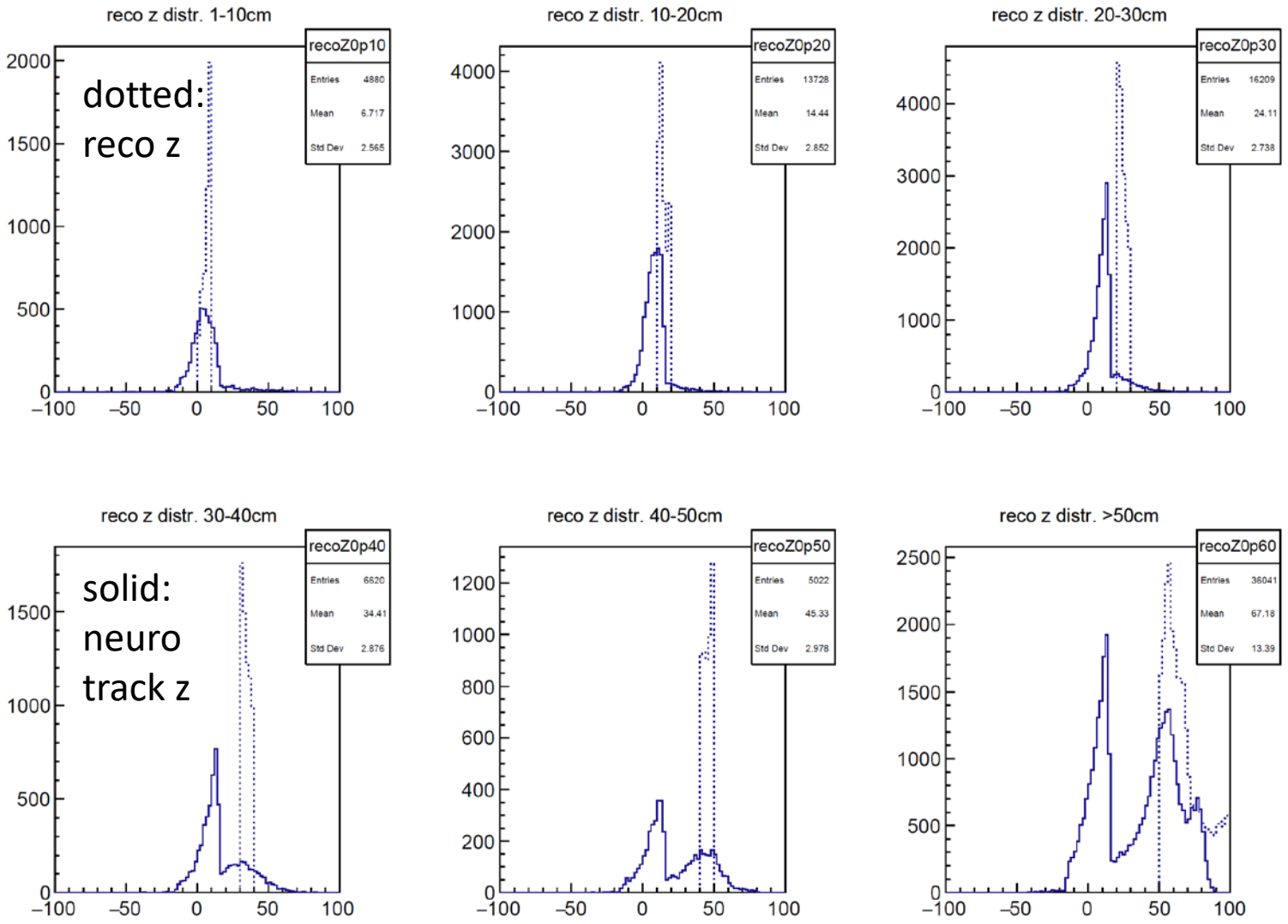
dotted lines: z for reco tracks, solid line: z for matched neuro tracks, in six z-intervals

„Feed-Up“ for z < 0, Exp 26, run 1700-end



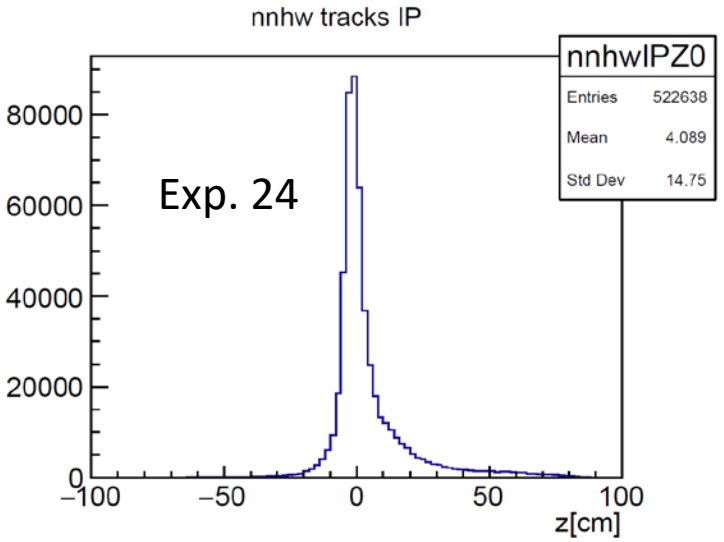
dotted lines: z for reco tracks, solid line: z for matched neuro tracks, in six z-intervals

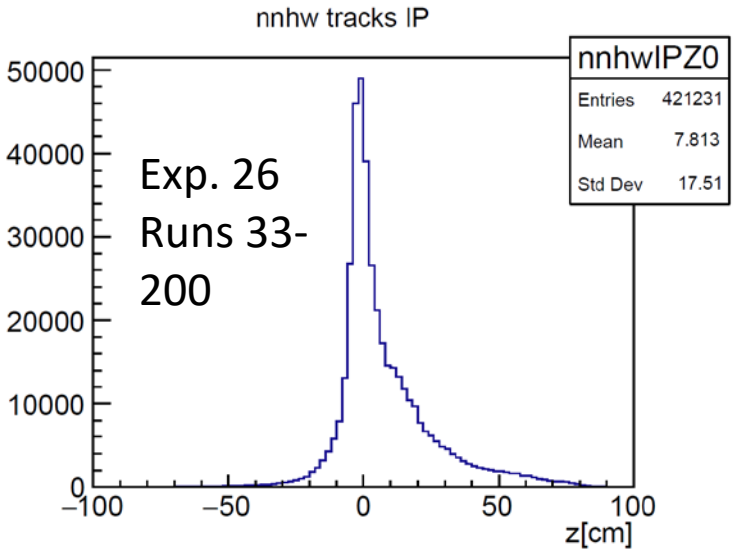
„Feed-Up“ for z > 0, Exp 26, run 1700-end

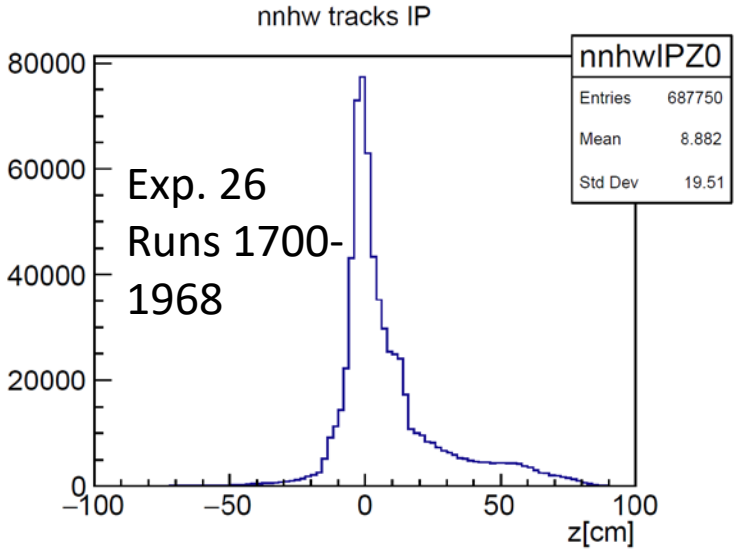


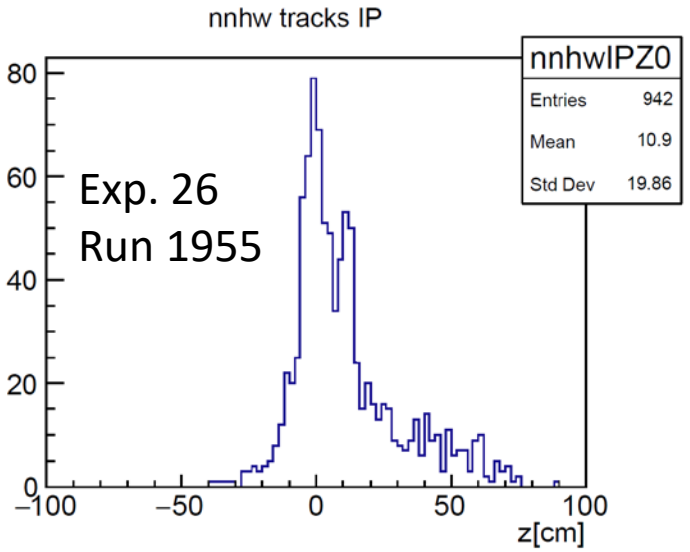
dotted lines: z for reco tracks, solid line: z for matched neuro tracks, in six z-intervals

Neuro-Tracks in IP Events: z-Distribution

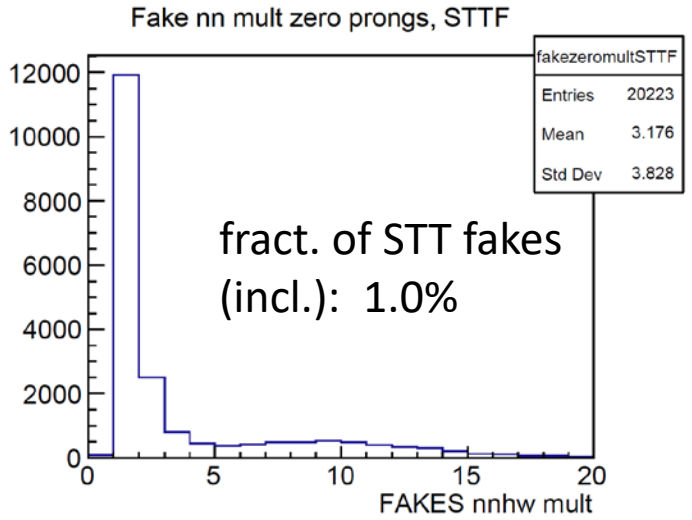


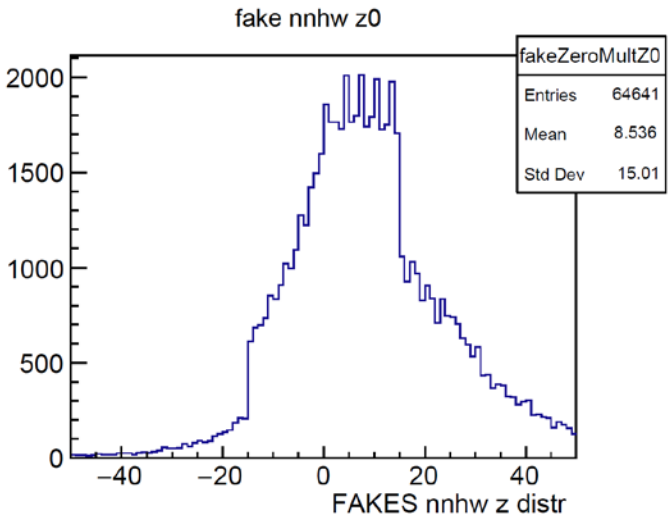


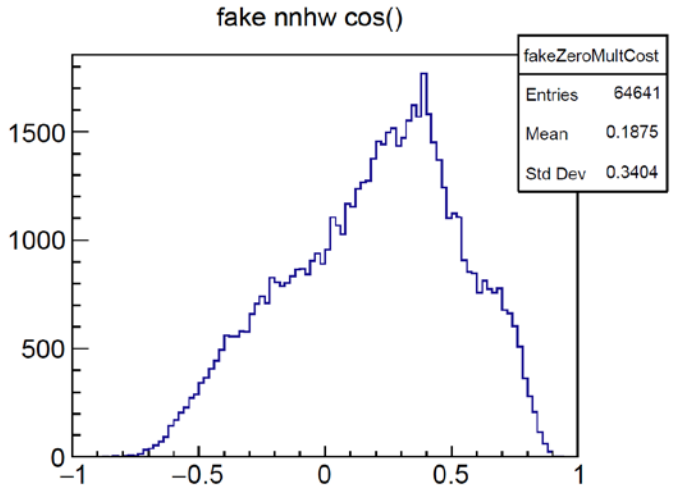


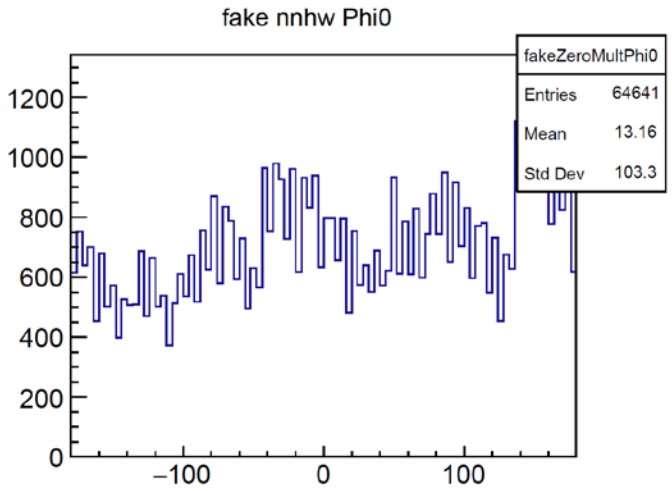


(III): Fake Neuro Tracks (Exp 24)



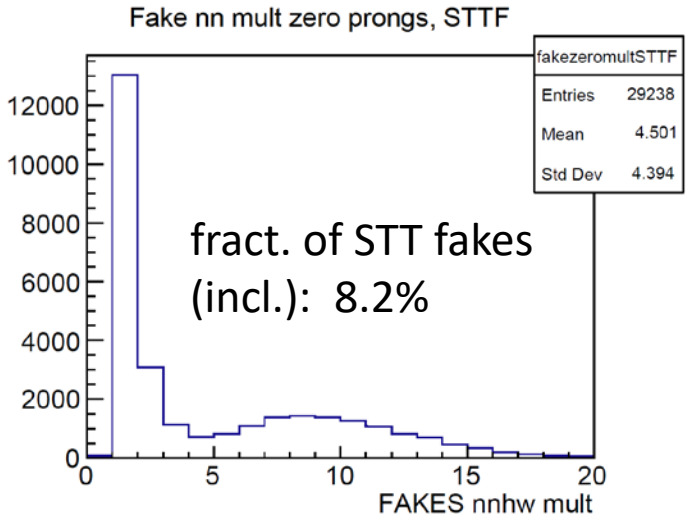


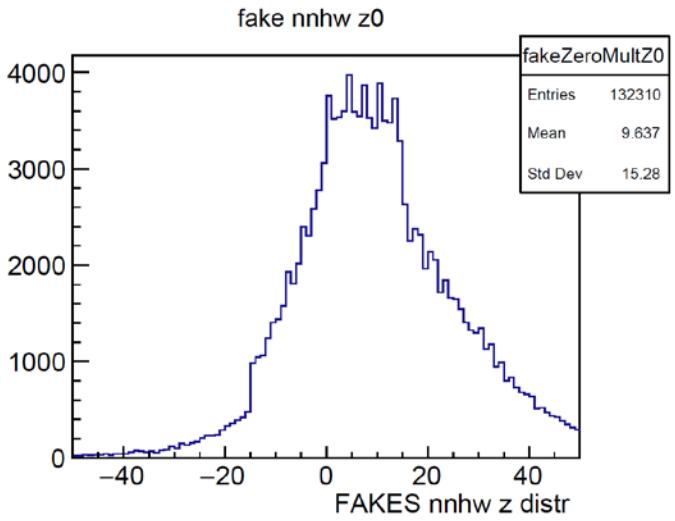


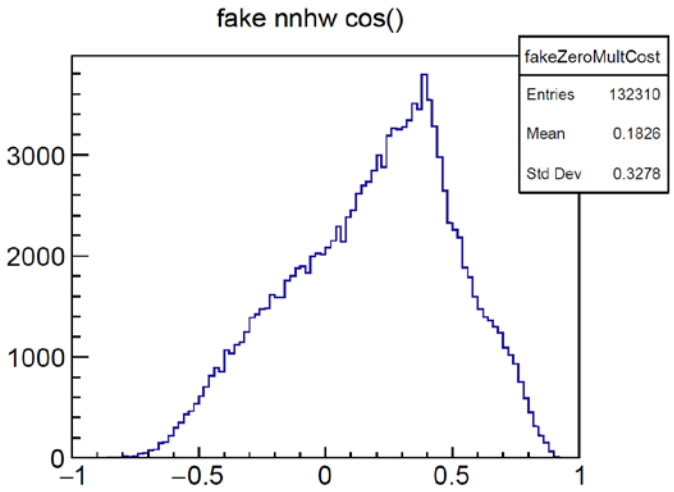


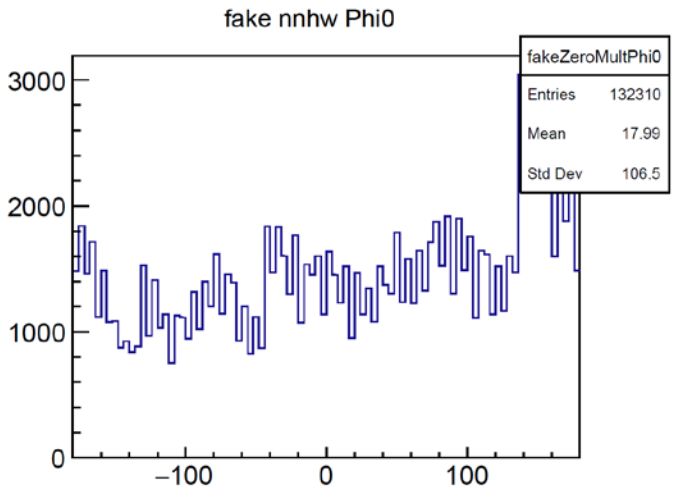
Exp 24, runs 1900-2100 |z| < 20 cm, STTactive 29/11/2022 9

Fake Neuro Tracks (Exp. 26, start)



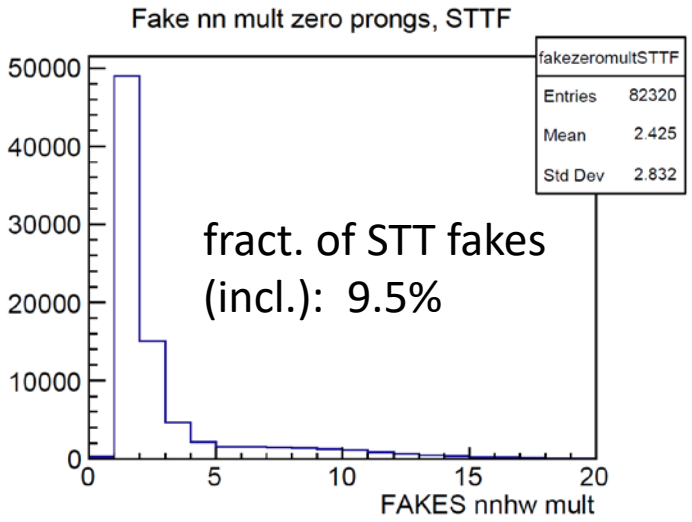


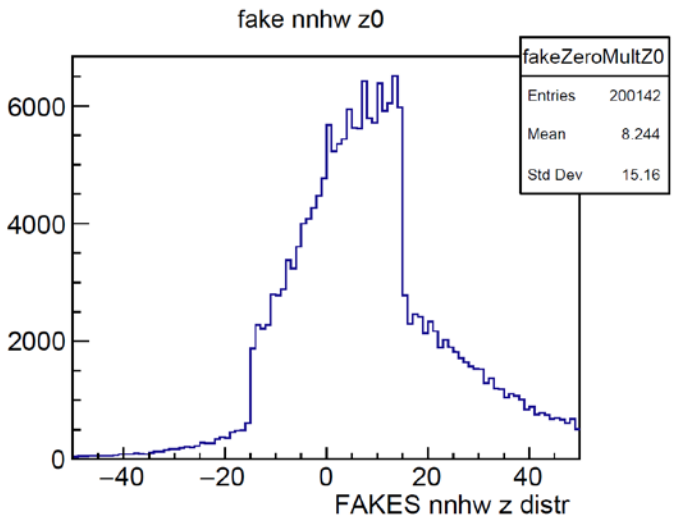


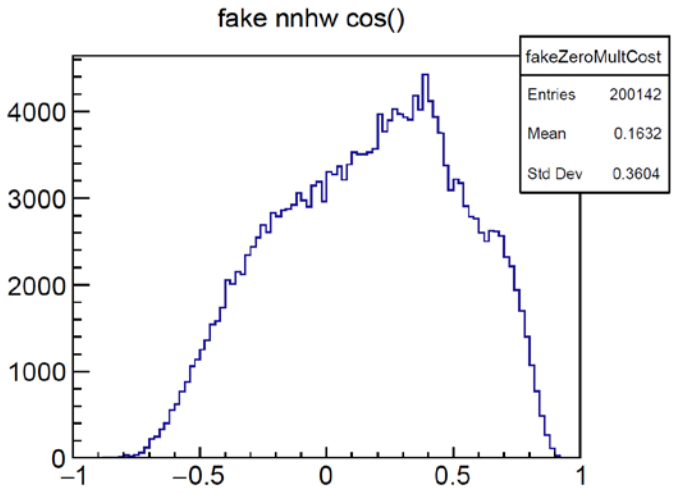


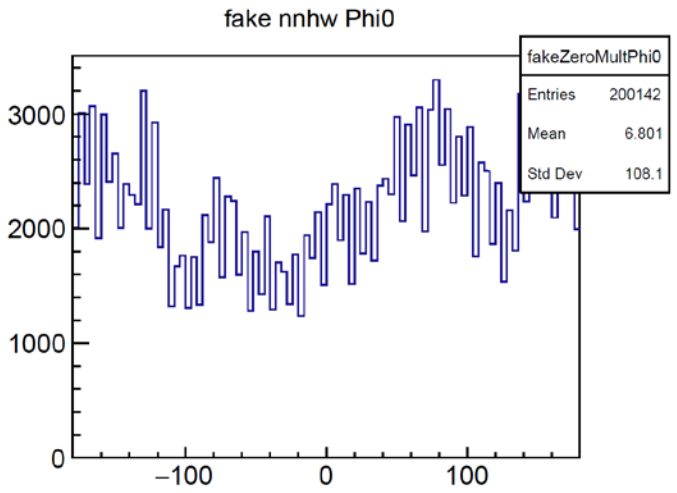
Exp 26, runs 33-200 |z| < 20 cm, STTactive 28/11/2022 9

Fake Neuro Tracks (Exp. 26, end)

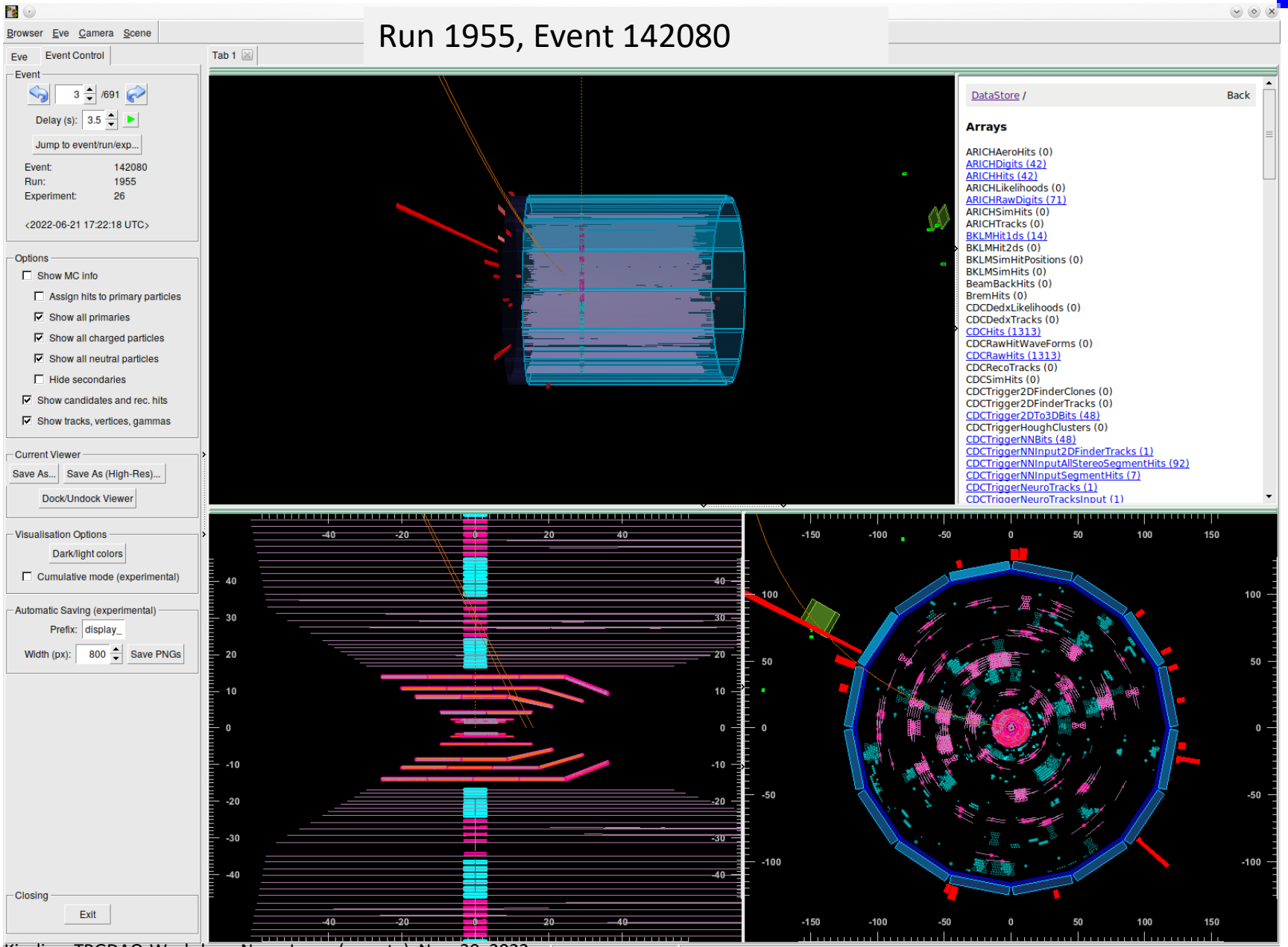








No Reco Tracks -> only STT Bit



Details for Run 1955, Event 142080

------- Track Output ------ Event 142080 Run 1955 -> this is a FAKE STT event, triggered by STT Bit alone

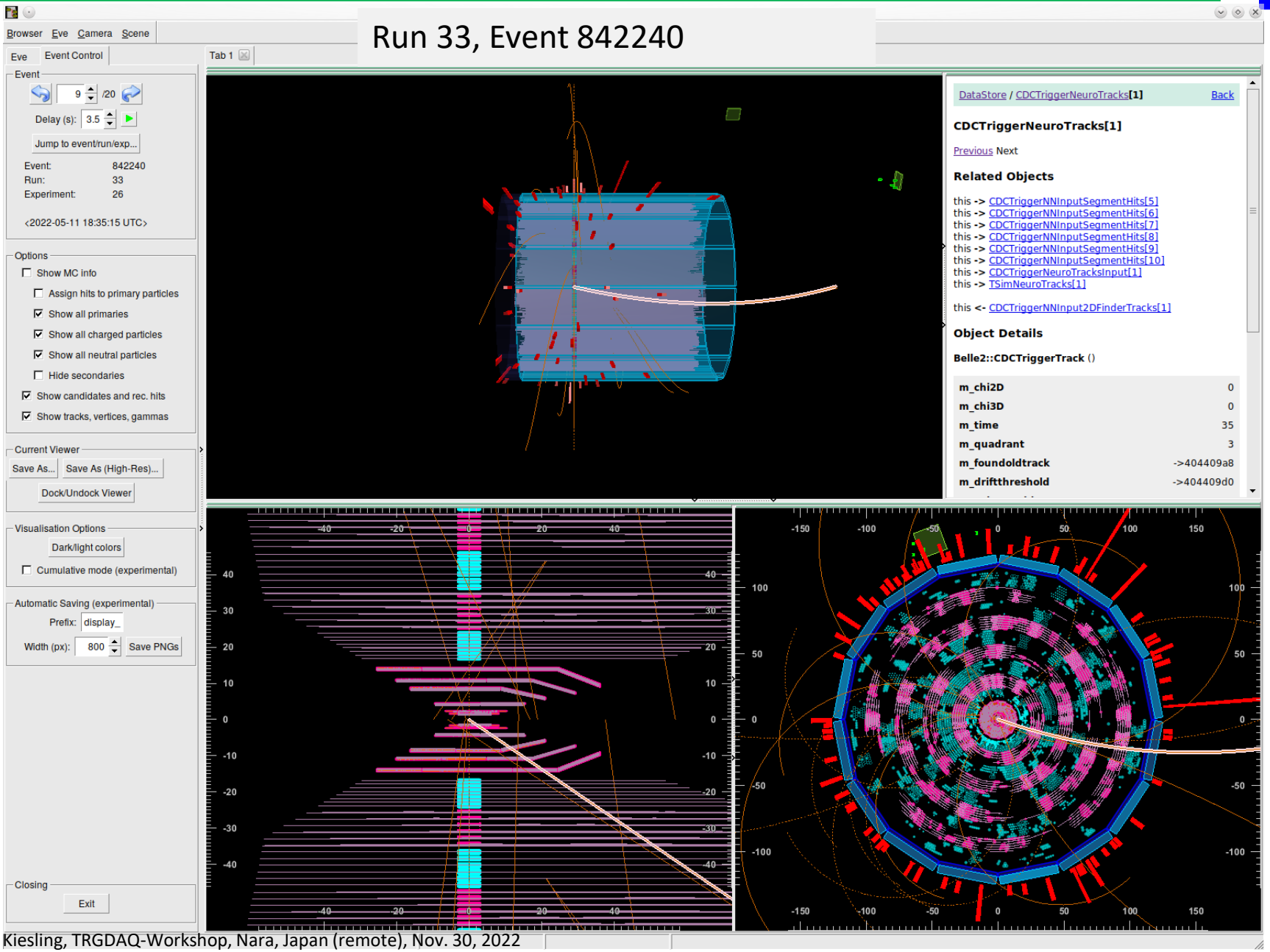
# of reco Tracks : 0

hw Tracks : 1

Final Array of 1 NNhw tracks
1 (STT) phi 173, cost -0.44, z0 13.87, DTerr 0, charge 1, p[GeV] 1.14, exp 1, Quad 1
network output (int) : z0 568, theta 1330, th from cos 115.98

Trig Bits for FTDL # f = 1, ff = 0, fff = 0, ffy = 0, fyy = 0, yyy = 0, fy = 0, yyyv = 0, y = 1, yy = 0, fyo = 0
Physics event :0, hw (calc) pass :1, y : 1 STT (Ftdl): 1 STT (Psnm): 1 , Hie : 0 C4 : 0, lml : 0, other triggers : 0

No Reco Tracks -> Fake Neuro Tracks



Details for Run 33, Event 842240

------- Track Output ------ Event 842240 Run 33 -> this is a FAKE STT event, passed STT

# of reco Tracks : 0

hw Tracks : 1

Final Array of 1 NNhw tracks
1 (STT) phi -19, cost 0.83, z0 -0.1, DTerr 0, charge -1, p[GeV] 3.62, exp 3, Quad 3
network output (int) : z0 -4, theta -2853, th from cos 34.28

Trig Bits for FTDL # f = 1, ff = 1, fff = 0, ffy = 0, fyy = 0, yyy = 0, fy = 1, yyyv = 0, y = 1,
yy = 0, fyo = 1
Physics event :0, hw (calc) pass :1, y : 1 STT (Ftdl): 1 STT (Psnm): 1 , Hie : 1 C4 : 1, lml: 0,
other triggers : 0

CDC shows a lot of close-by wire hits, almost uniformly distributed -> cross talk??