Vertex reconstruction and tracking performance of the STS detector with the mCBM setup at SIS18

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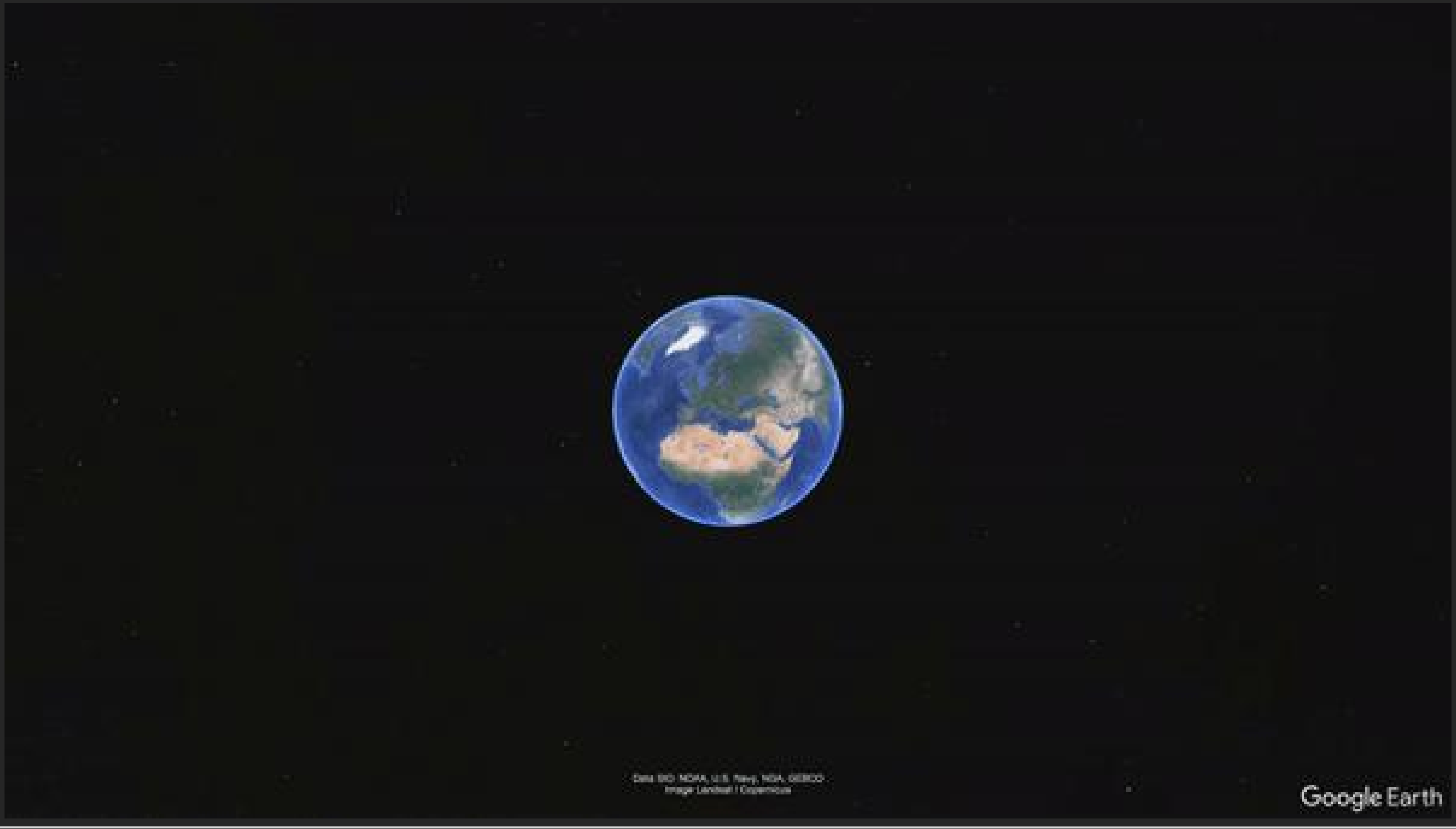
Goethe University Frankfurt - GSI

(CBM collaboration)

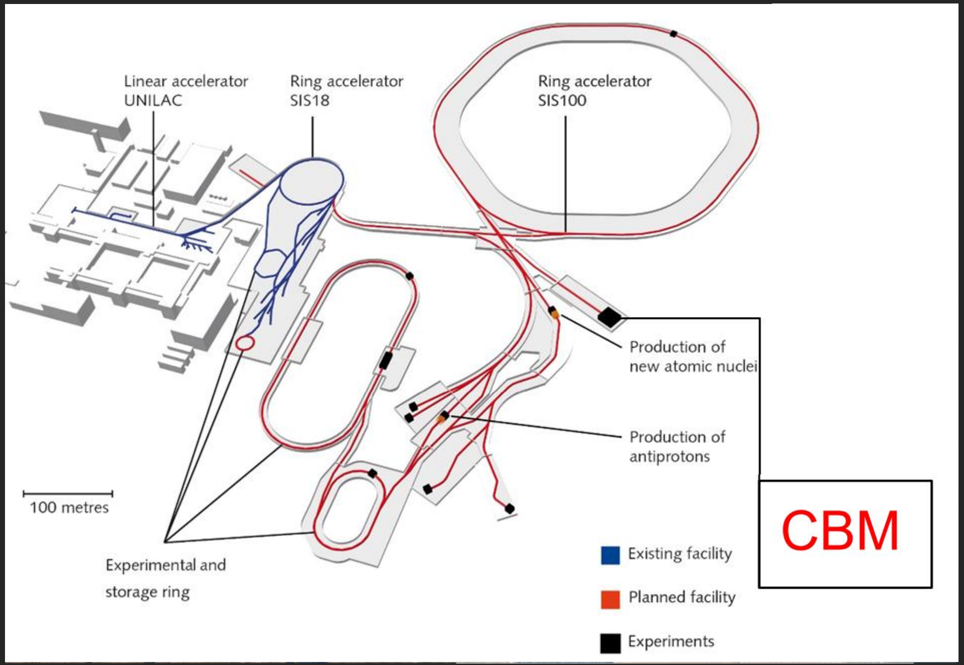
GSI - Facility for Antiproton and Ion Research (FAIR) - location

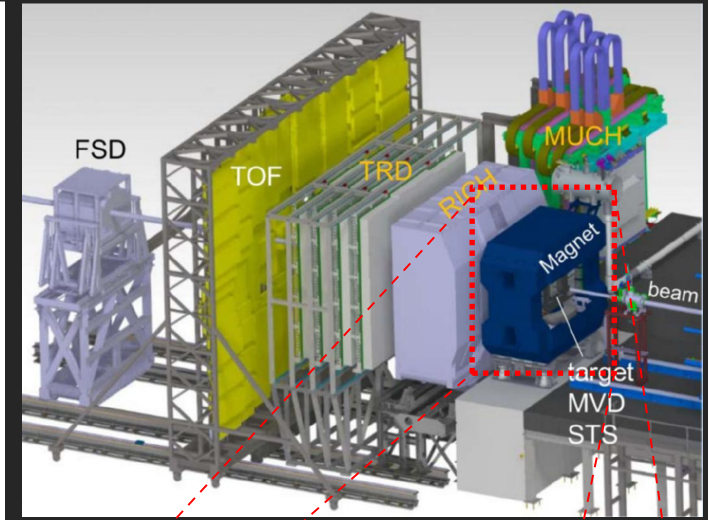


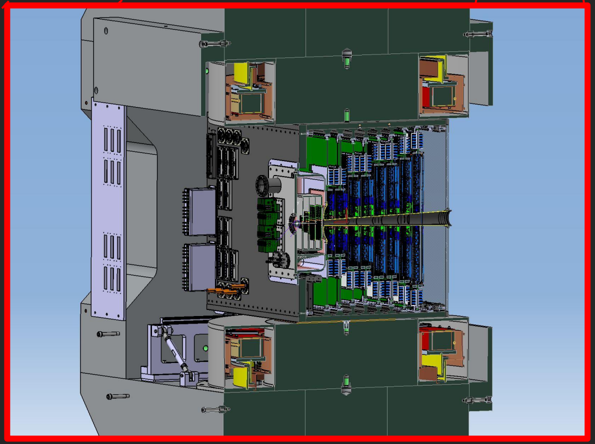
Facility for Antiproton and Ion Research (FAIR) - Construction site

https://www.youtube.com/watch?v=x0RTwgaRock

Facility for Antiproton and Ion Research - Compressed Baryonic Matter







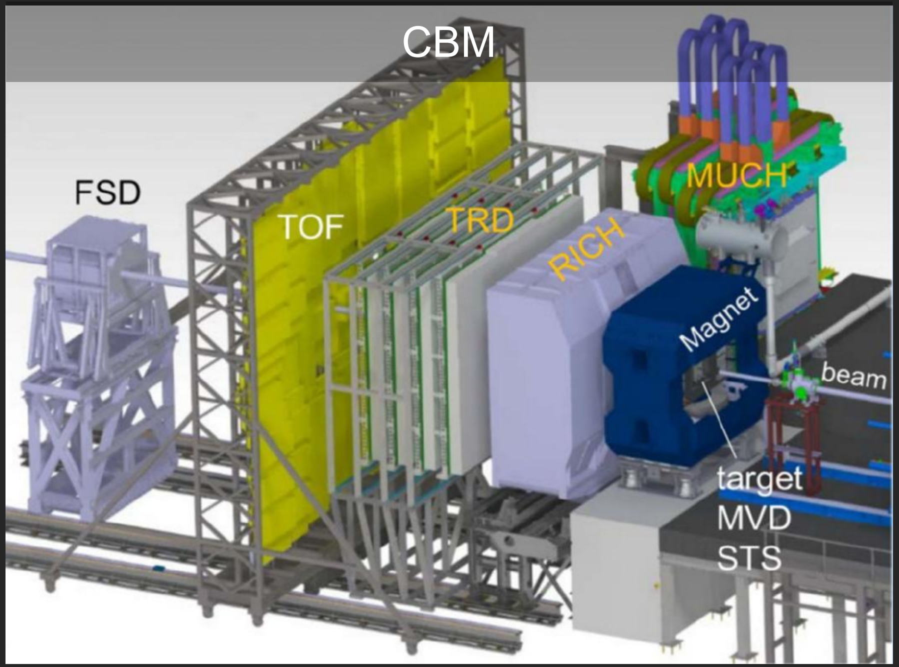
CBM

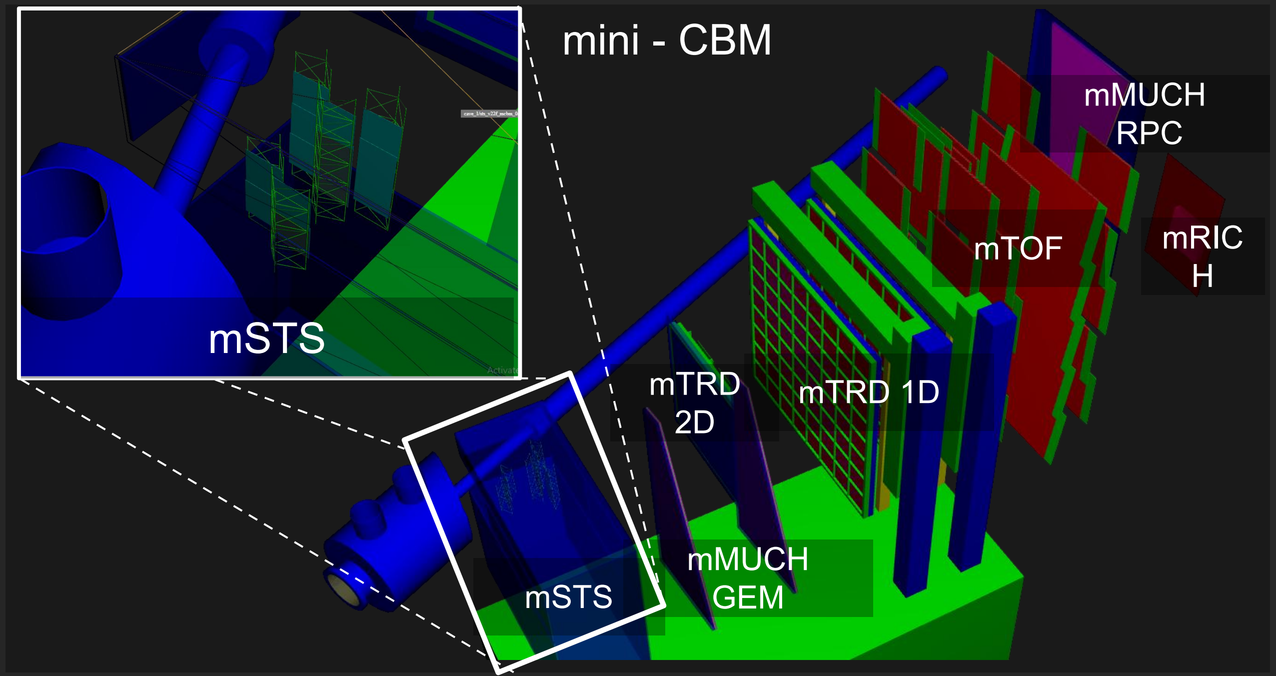
- Fix target experiment
- Heavy ion collisions
- 700 particles/events Au+Au 12 AGeV/c
- High interaction rates: 10 MHz
- 2.5^0 - 25^0 polar angle coverage
- Free-streaming data (software trigger)
- Online track reconstruction

Silicon Tracking System:

- 8 Stations - 900 modules - 1.8M channels

CBM - Small scale prototypes : mini-CBM (mCBM)





mCBM@SIS18 goals:

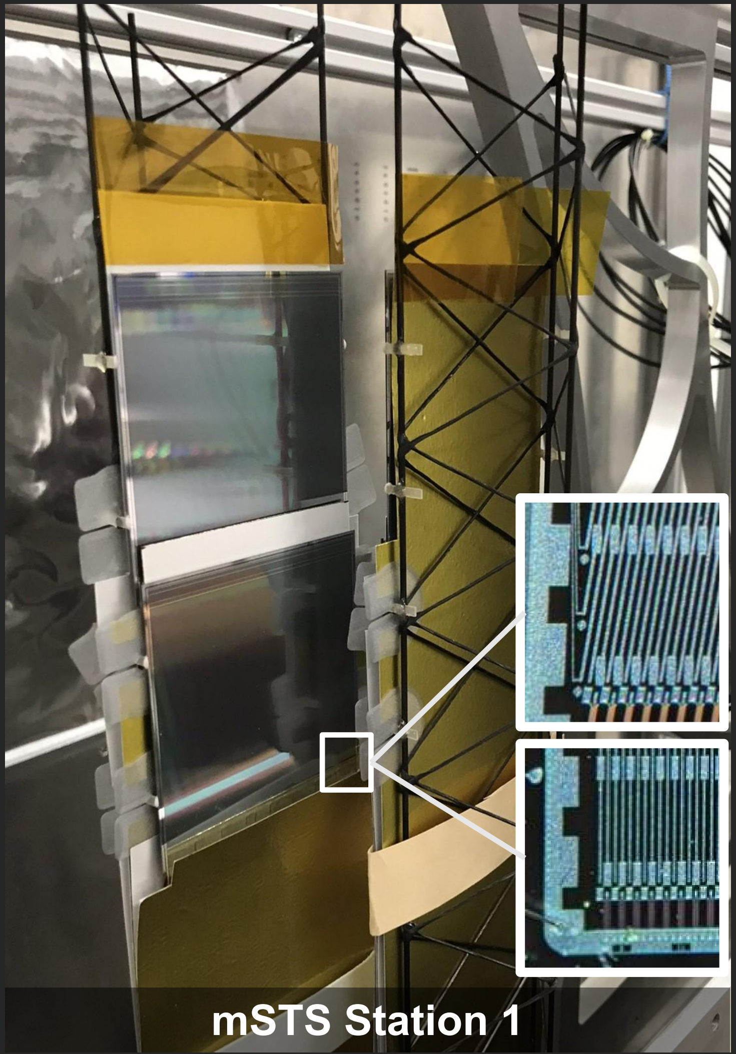
- ... test and optimize the operation of the full system (...) under realistic experiment conditions.
- ... the free-streaming data acquisition system ...
- ... the online track and event reconstruction ...
- ... the offline data analysis and the detector control system ...

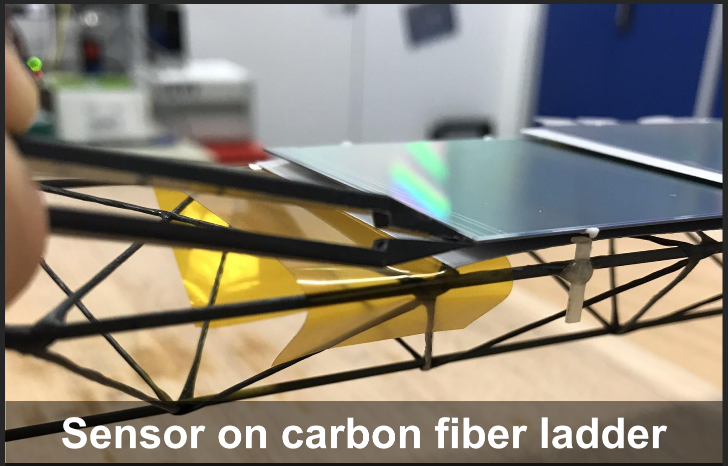
- First beam-time 2019
- Full setup during 2021-2022 data taking campaign

mini-STS(mSTS) Setup

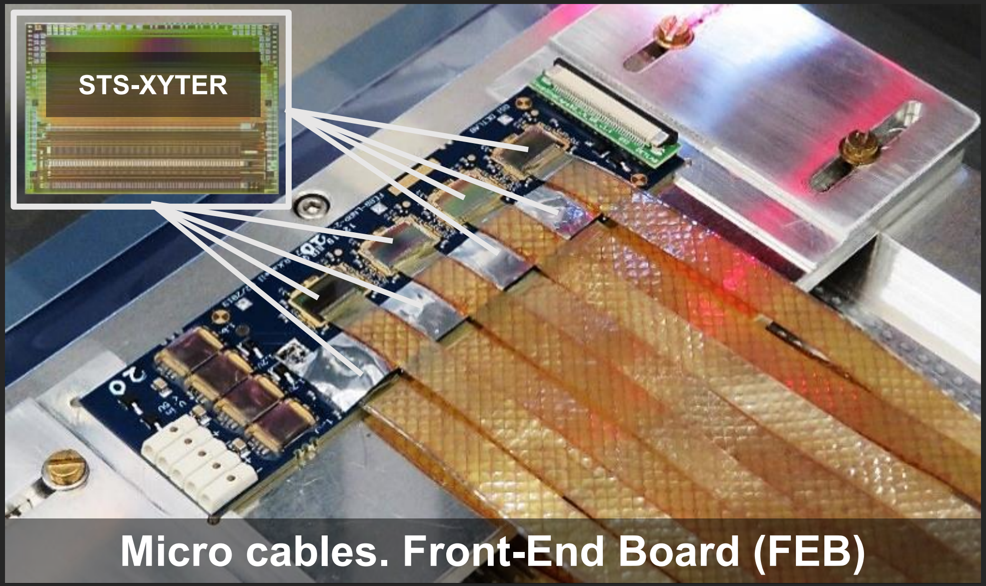
M. Teklishyn et al. TWEPP2023
https://indico.cern.ch/event/1255624/contributions/5444008/

- 2 tracking stations
- 11 modules (~1% full STS): double-sided double-metal micro-strip silicon sensors


mSTS Station 1


Sensor on carbon fiber ladder

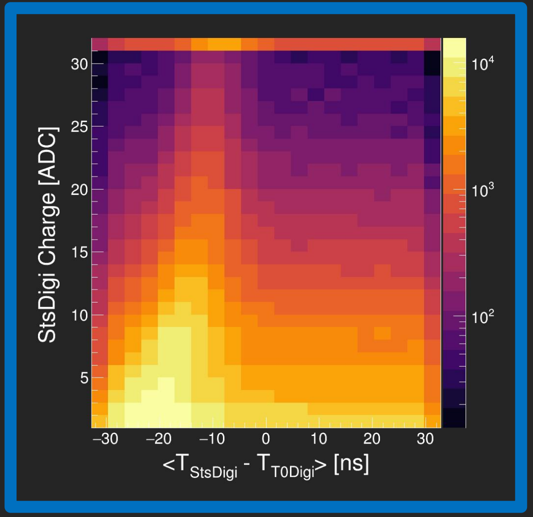

Open mSts box

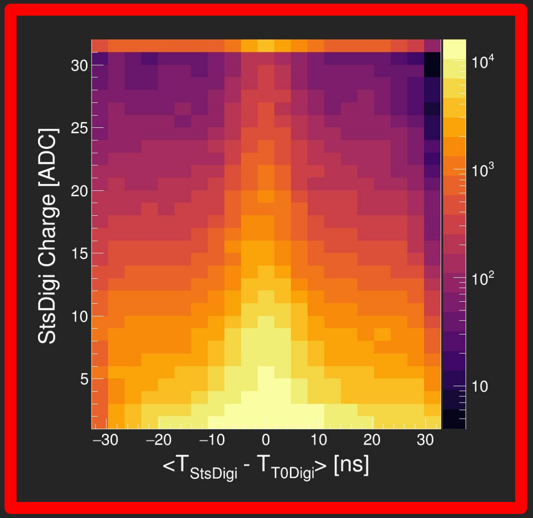


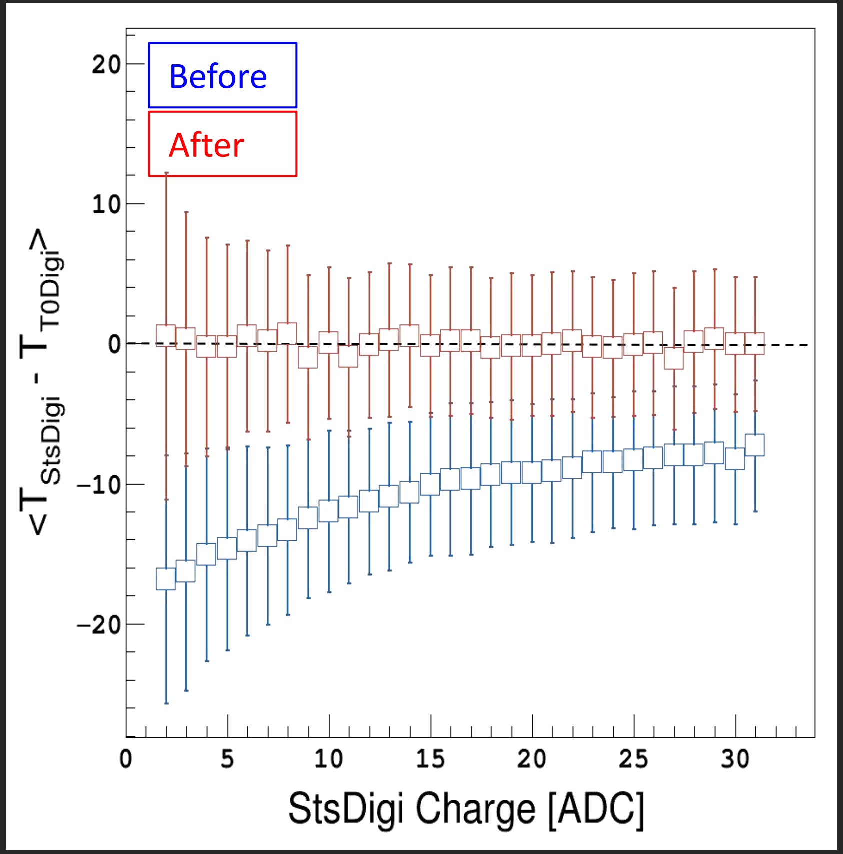
Micro cables. Front-End Board (FEB)

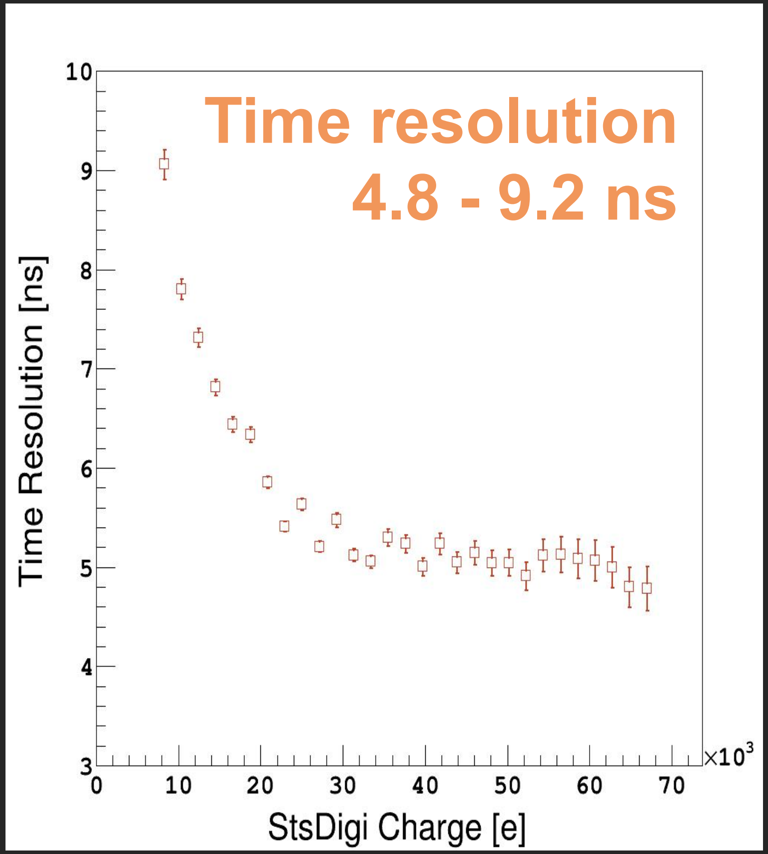
… time calibration …

mSTS Time calibration - Time Resolution



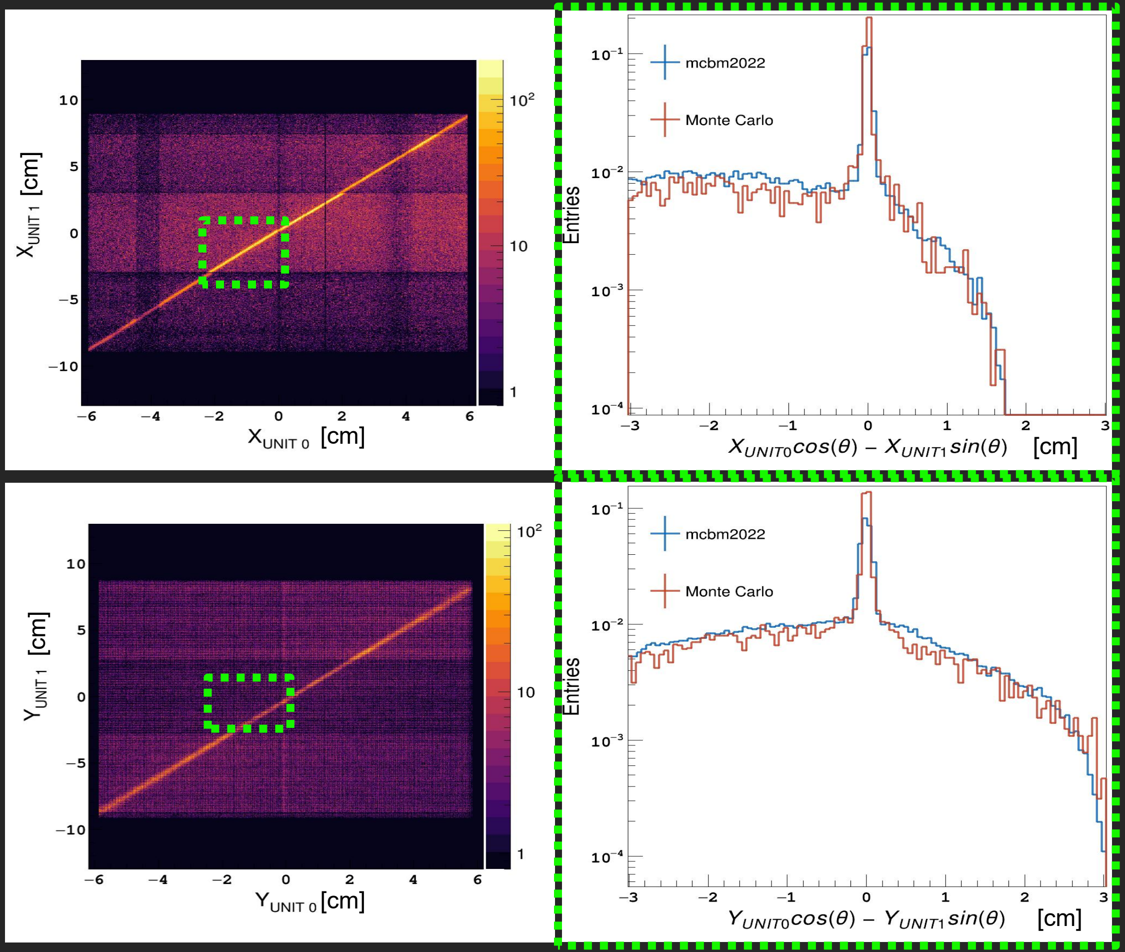






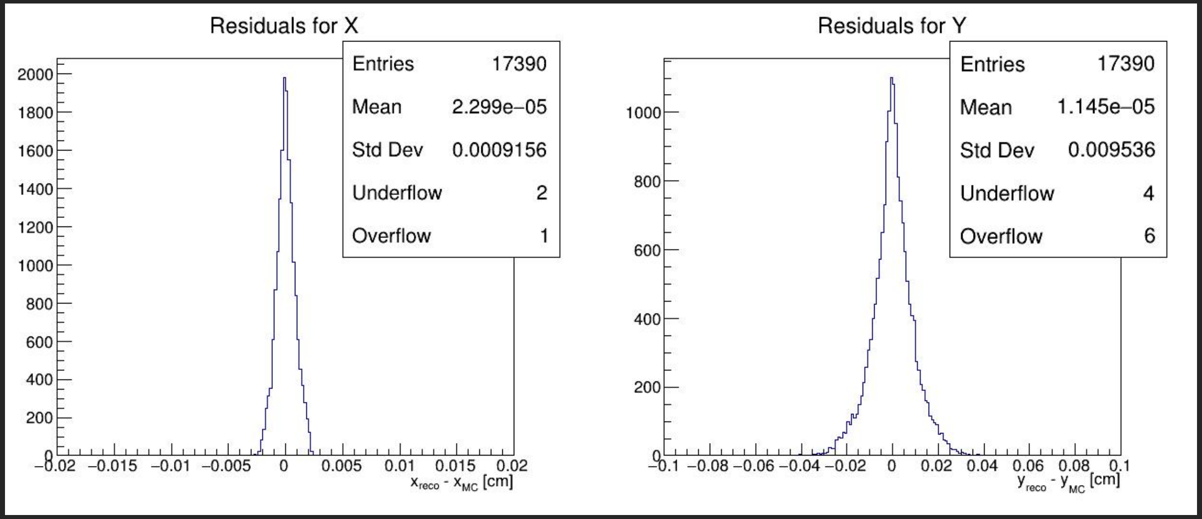
… we got time, what about space …

STS Space Resolution



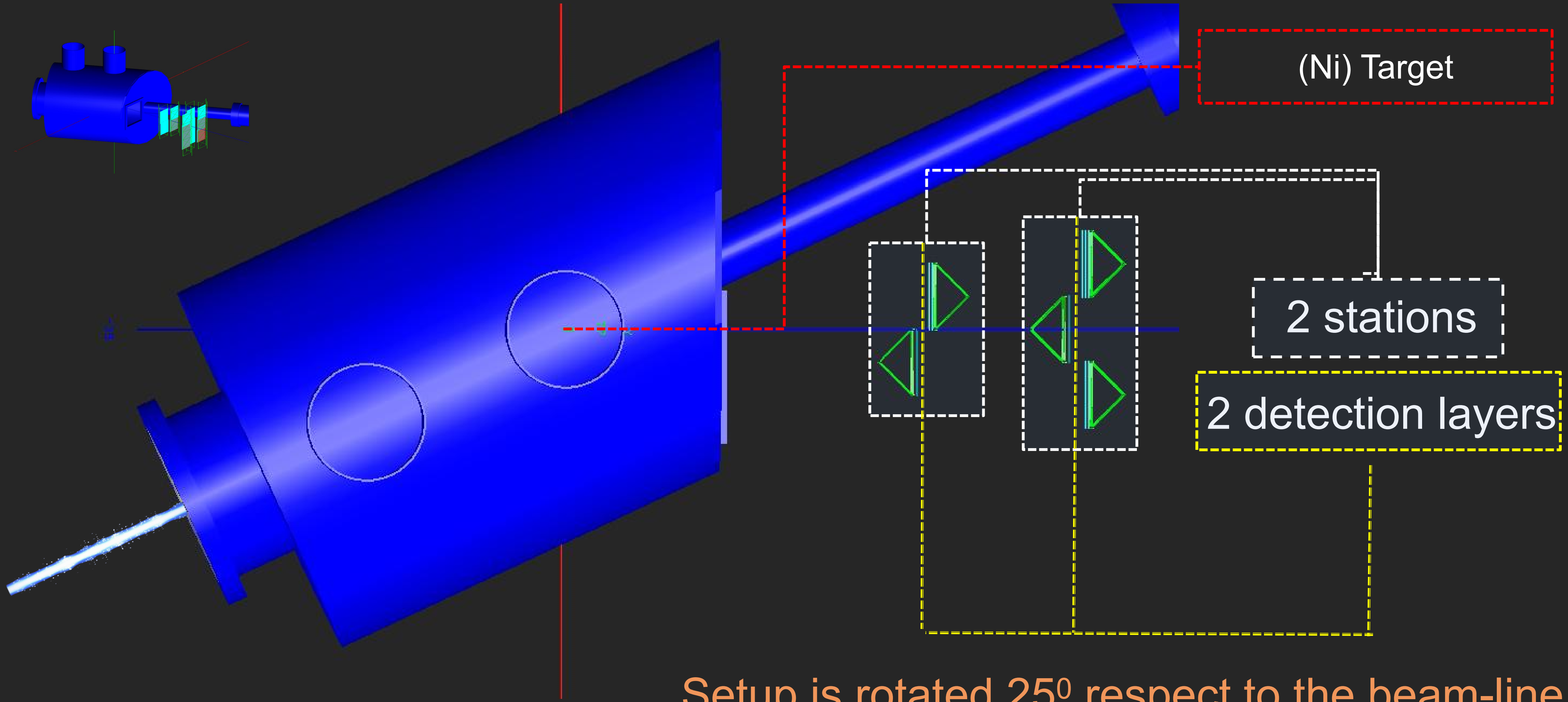
XY Hit correlation inline with Monte Carlo expectations

Space resolution 9 um



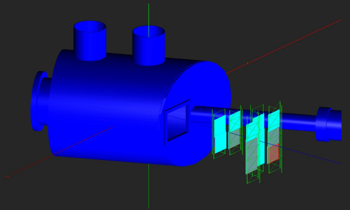
… track-lets, beam spot …

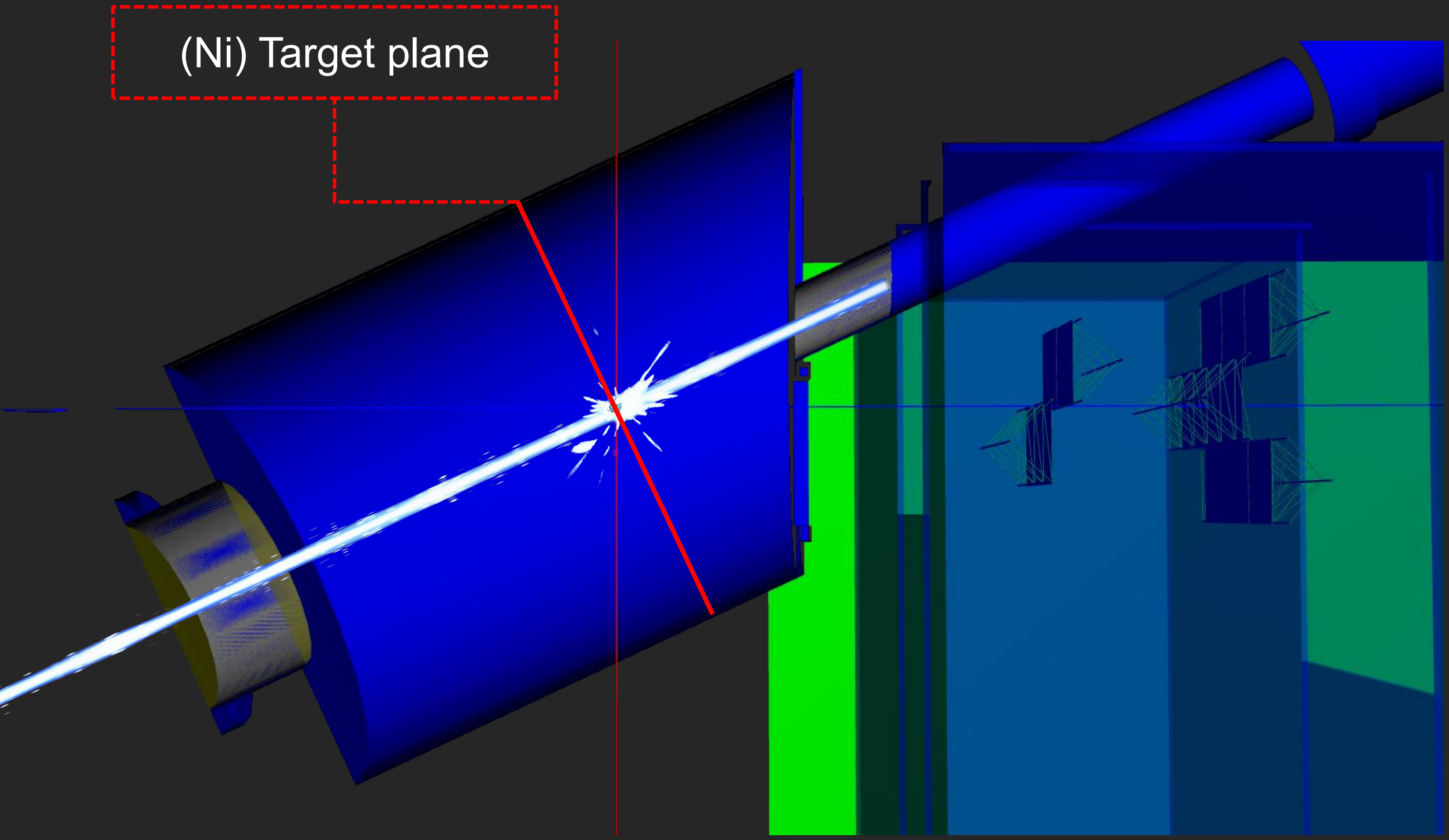
mSTS Vertex Reconstruction (beam spot) - Setup: Top view



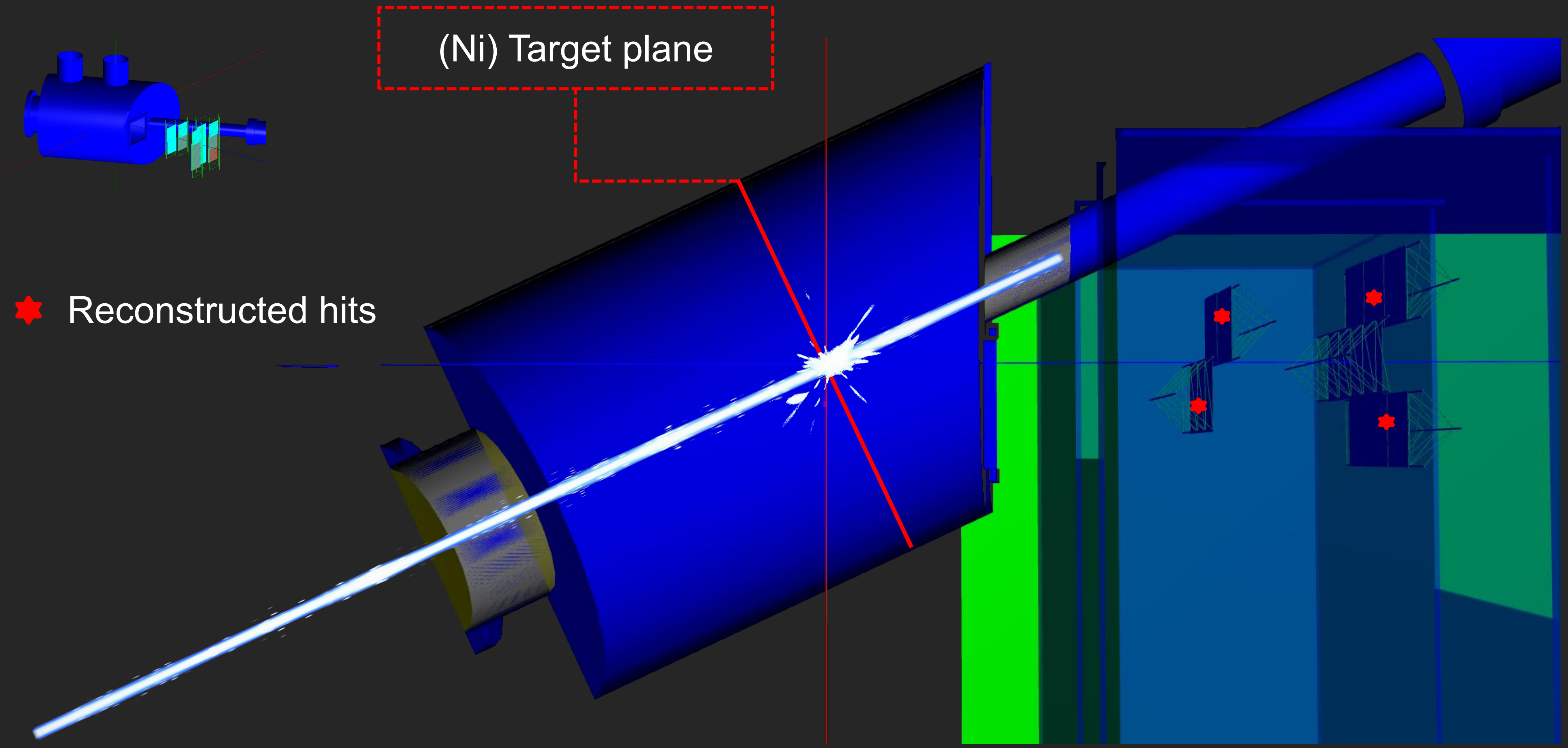
Setup is rotated 25^0 respect to the beam-line

mSTS Vertex Reconstruction (beam spot) - Setup: Top view

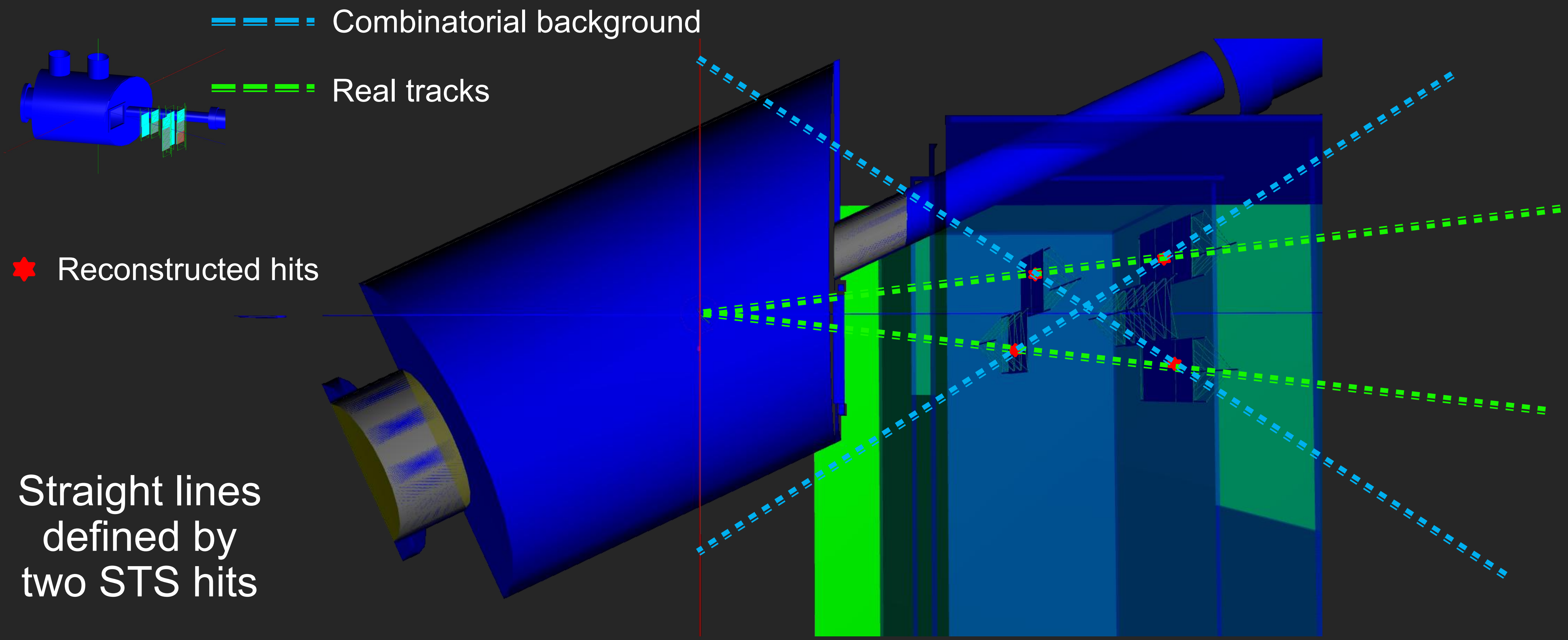




mSTS Vertex Reconstruction (beam spot) - Setup: Top view

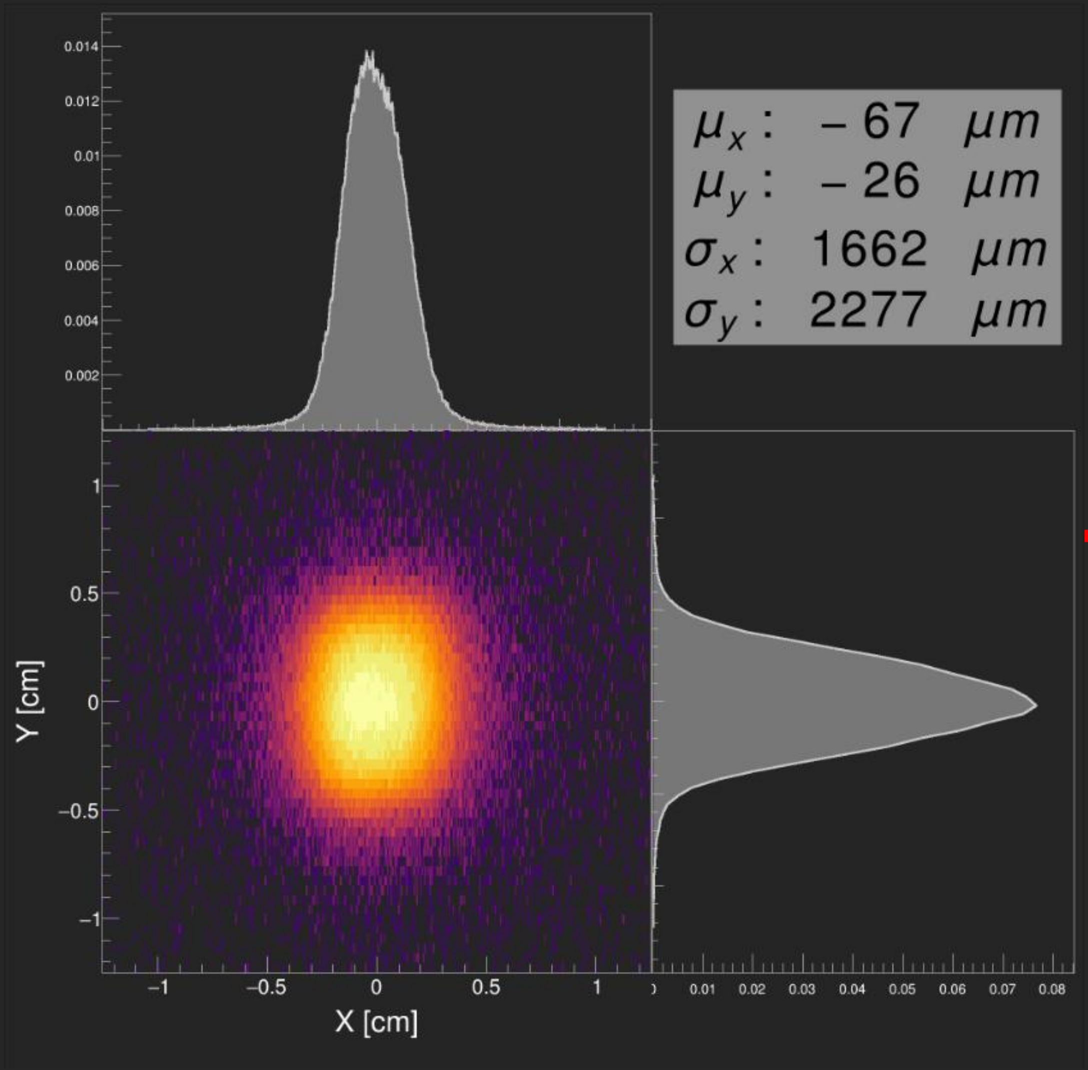


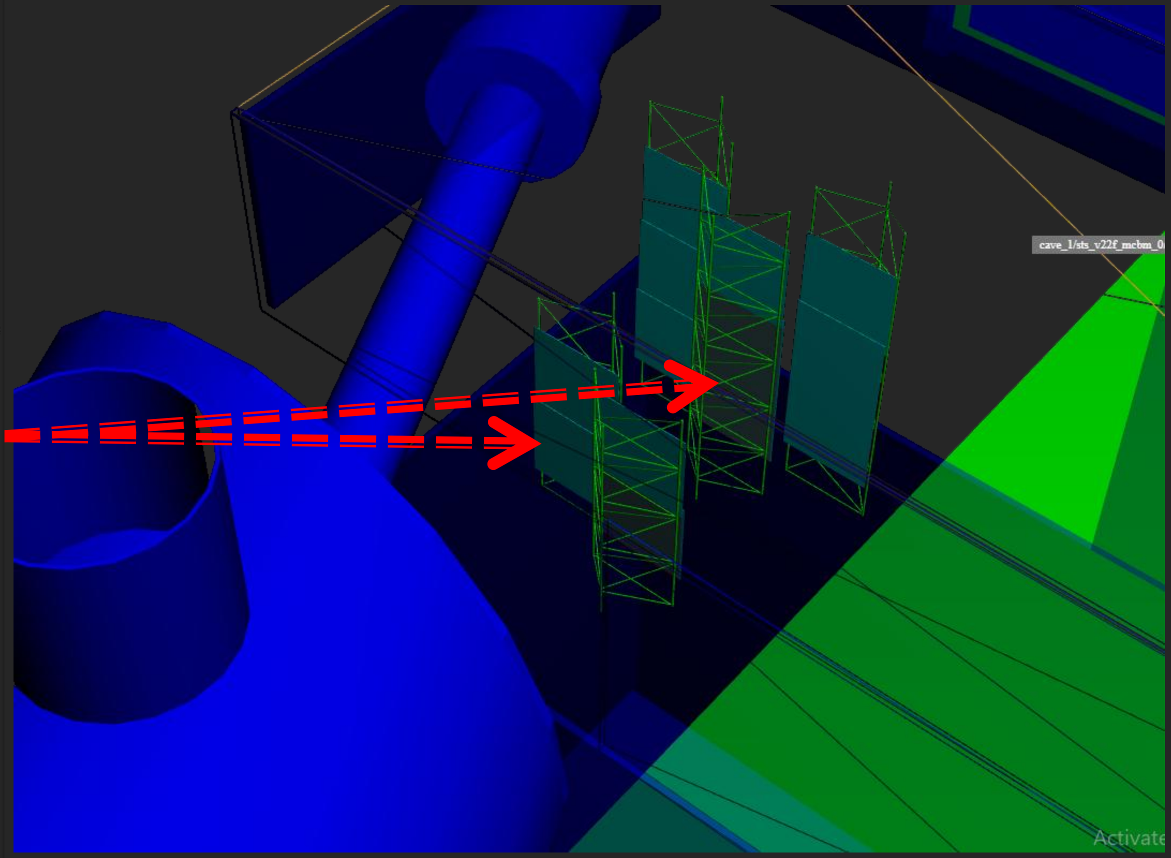
mSTS Vertex Reconstruction (beam spot) - Setup: Top view



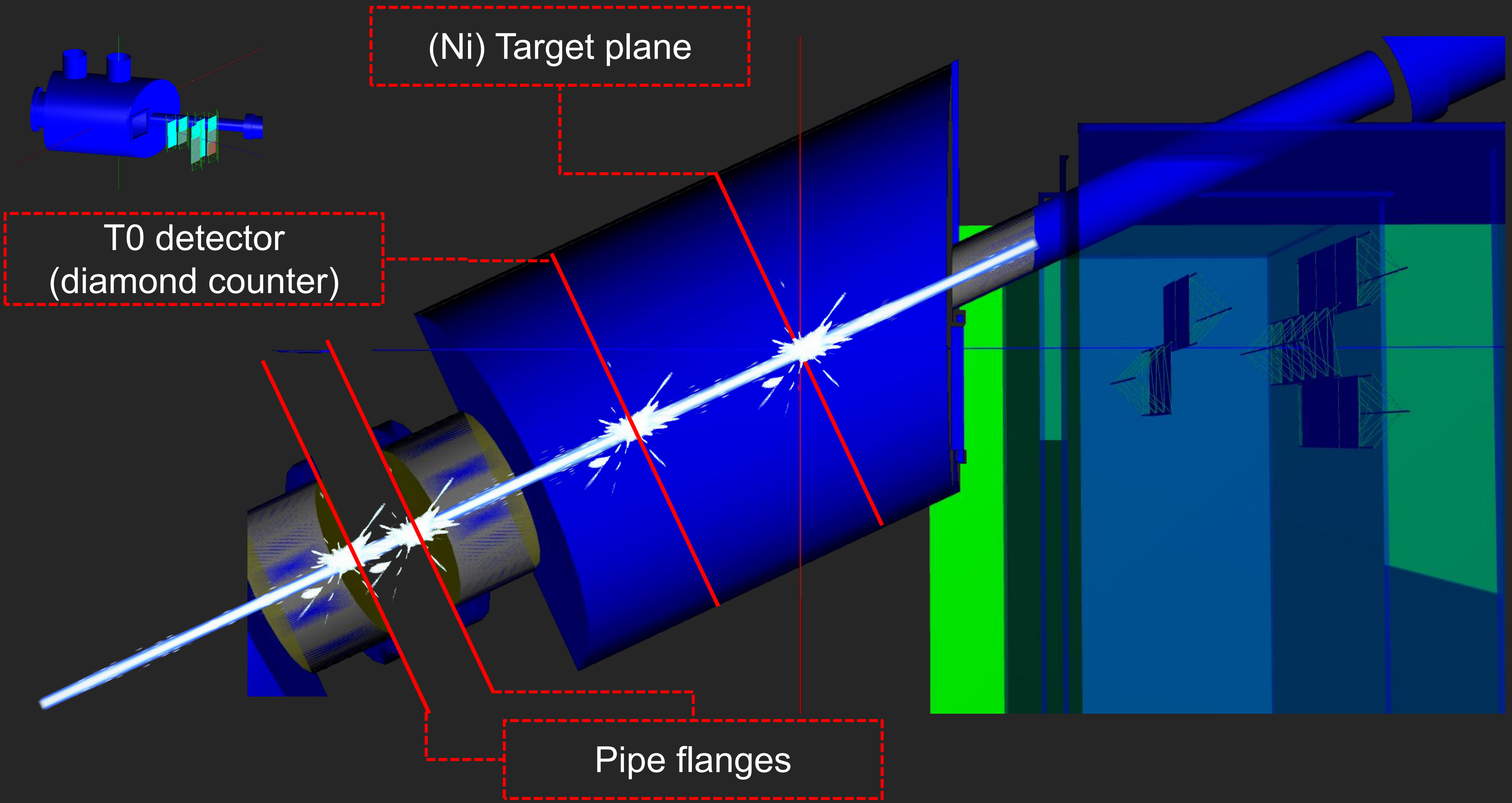
Straight lines defined by two STS hits

mSTS Vertex Reconstruction : beam spot at target plane

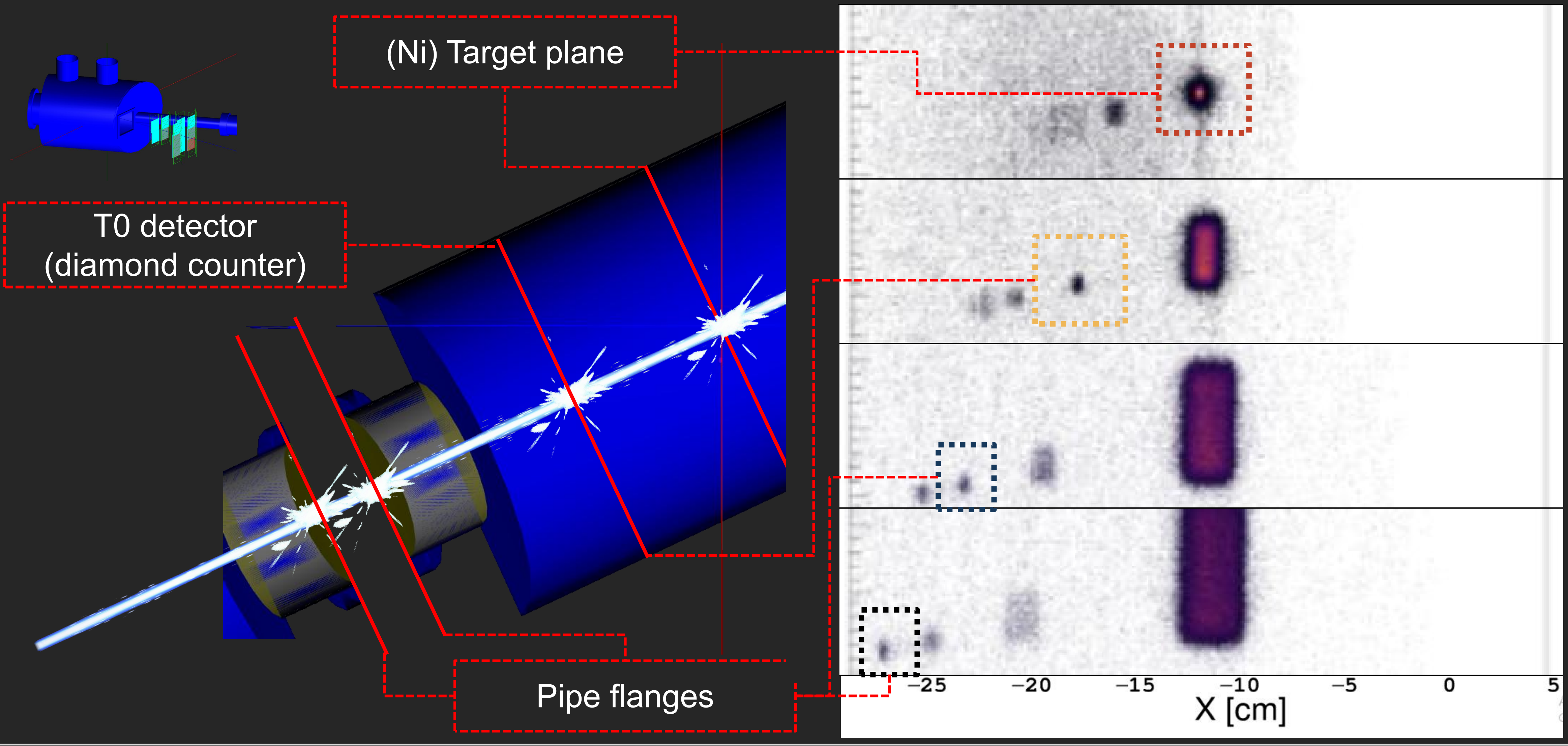




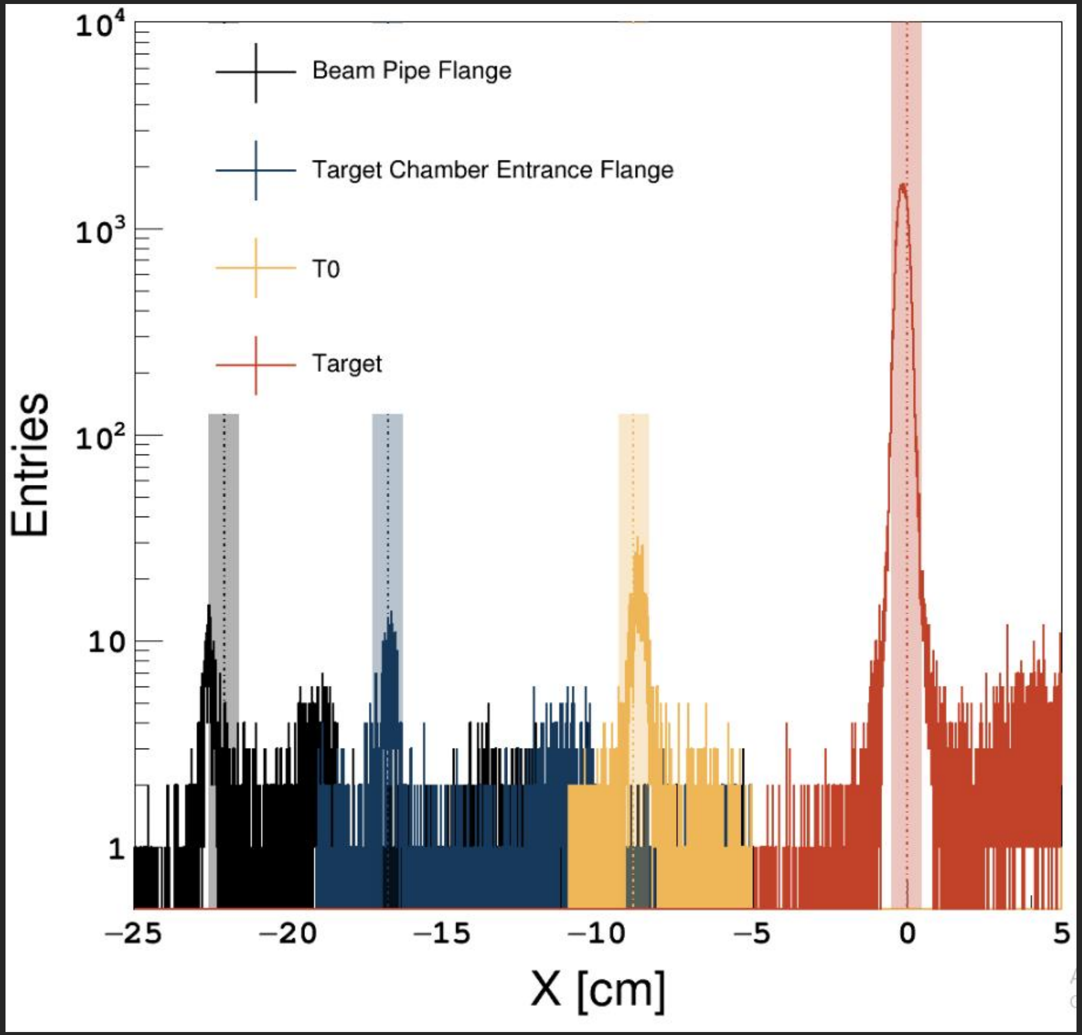
mSTS Vertex Reconstruction : secondary targets

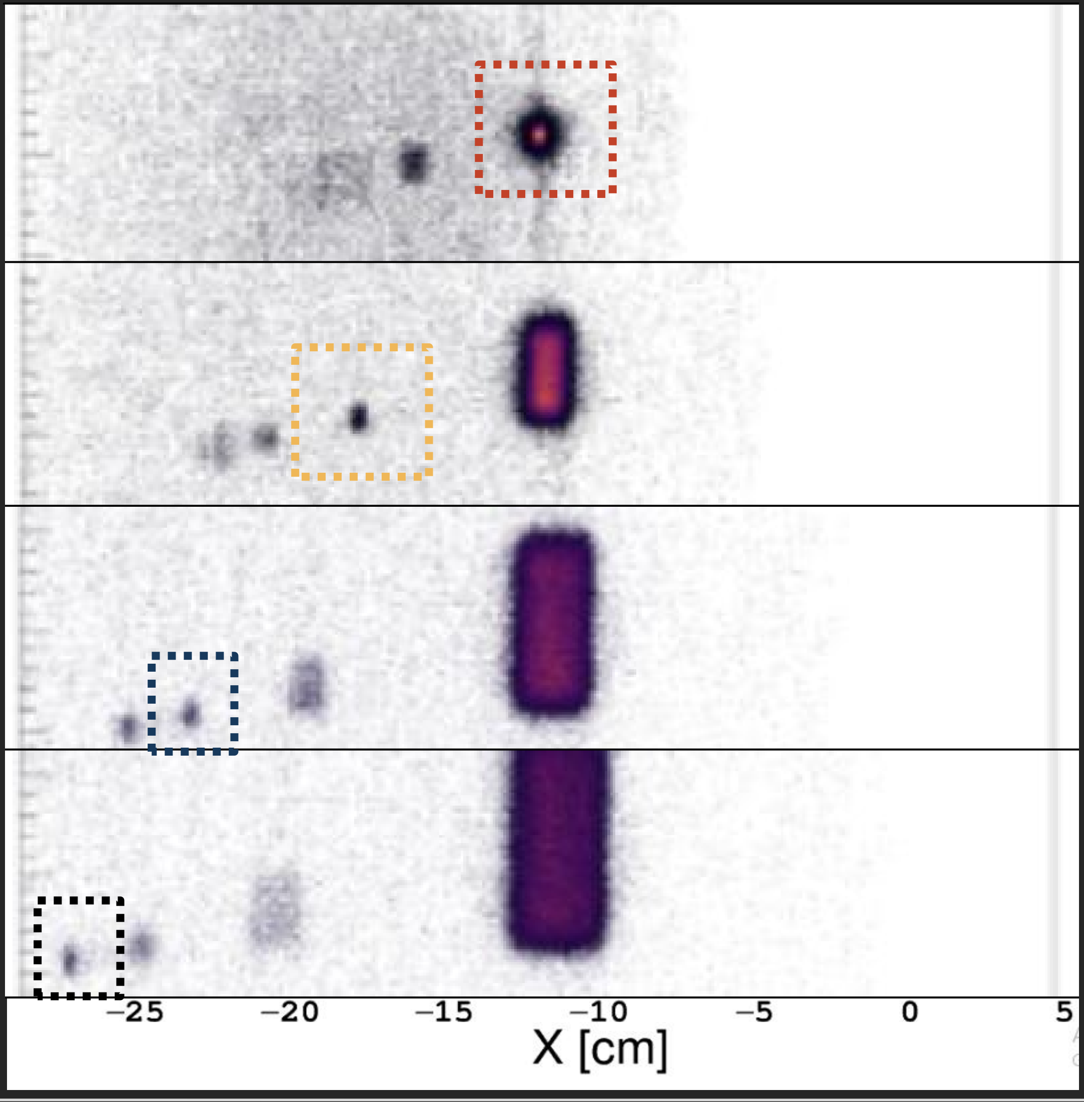


mSTS Secondary targets - Cave "tomography"



mSTS Secondary targets - Cave "tomography"

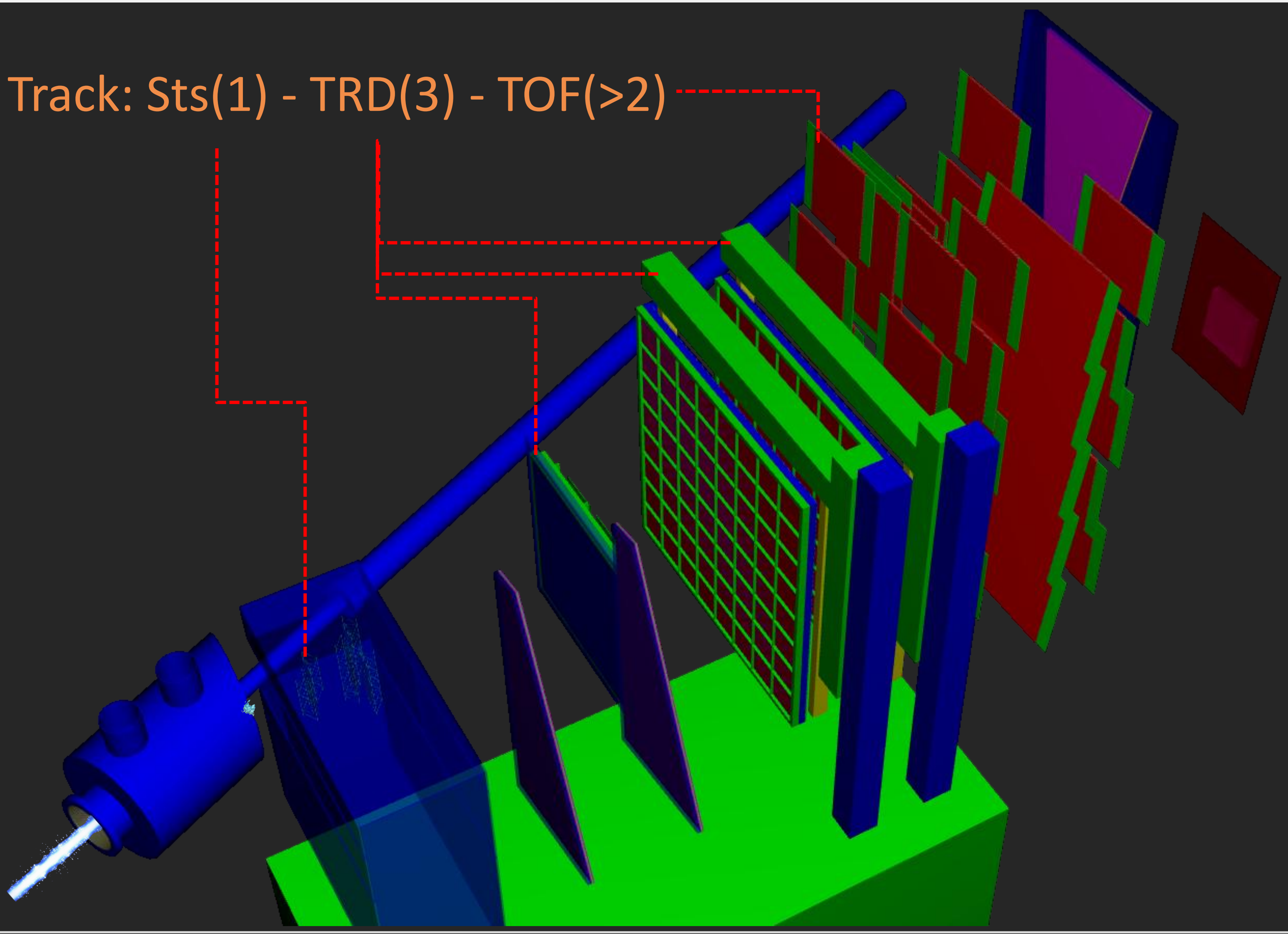




… hit reconstruction efficiency …

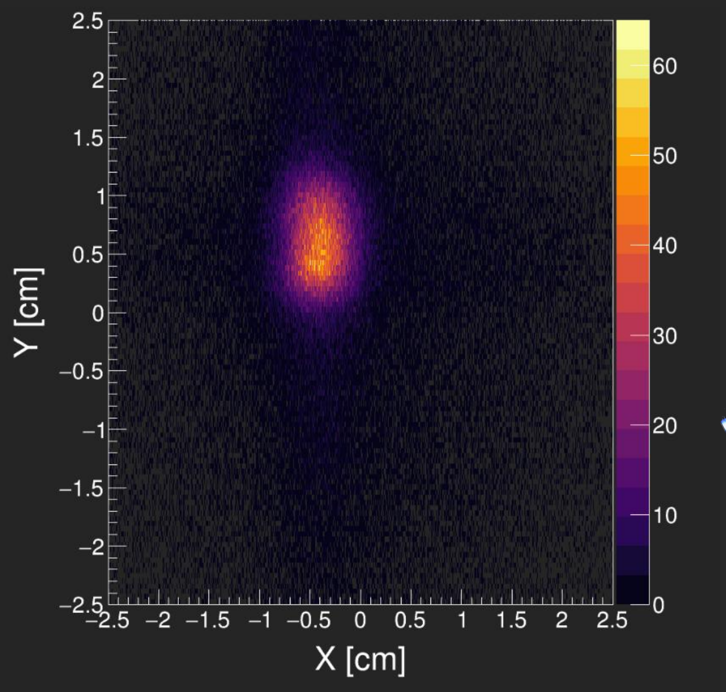
mSTS - Hit Reconstruction Efficiency

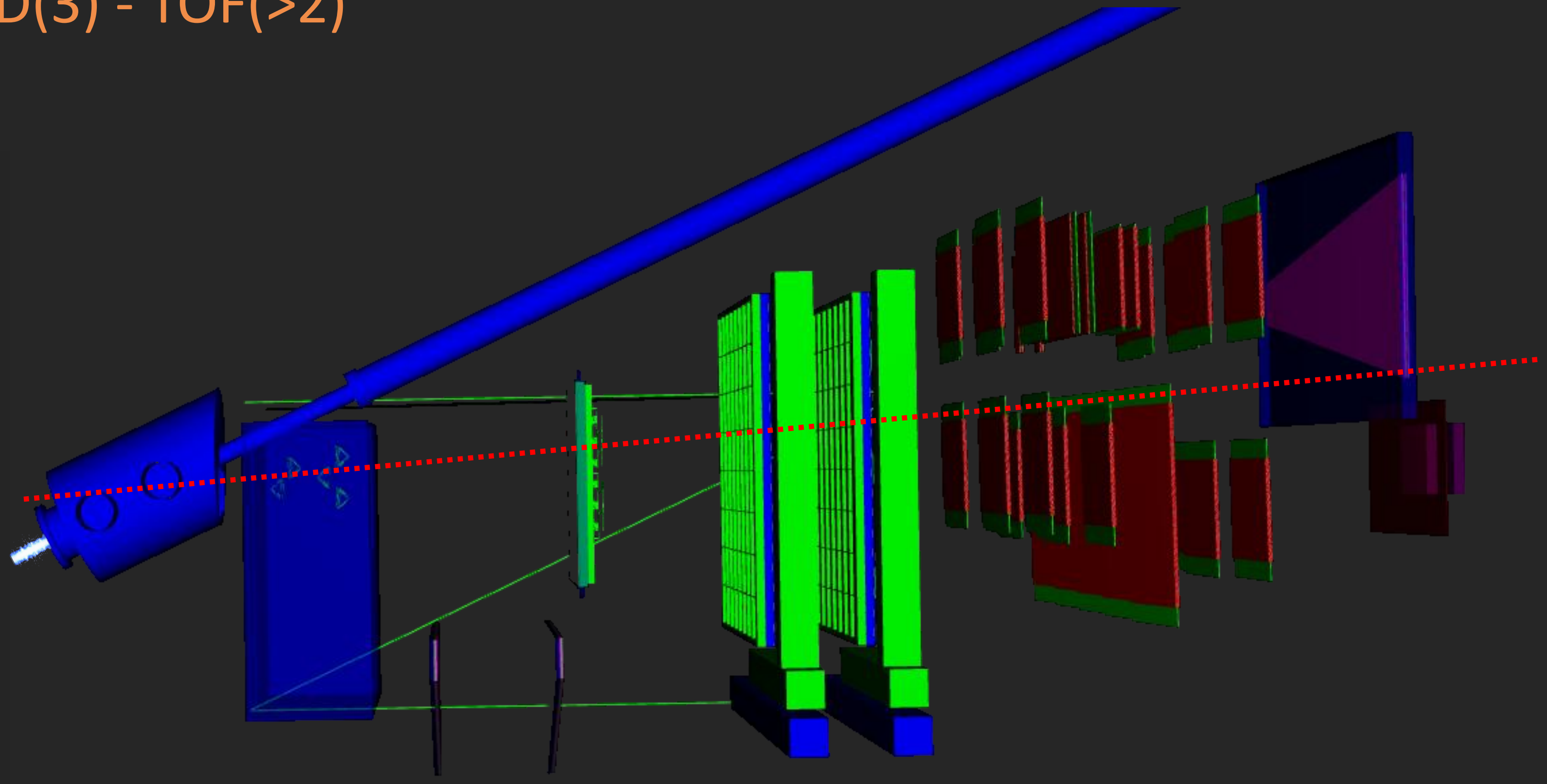
Global Track: Sts(1) - TRD(3) - TOF(>2)



mSTS - Hit Reconstruction Efficiency

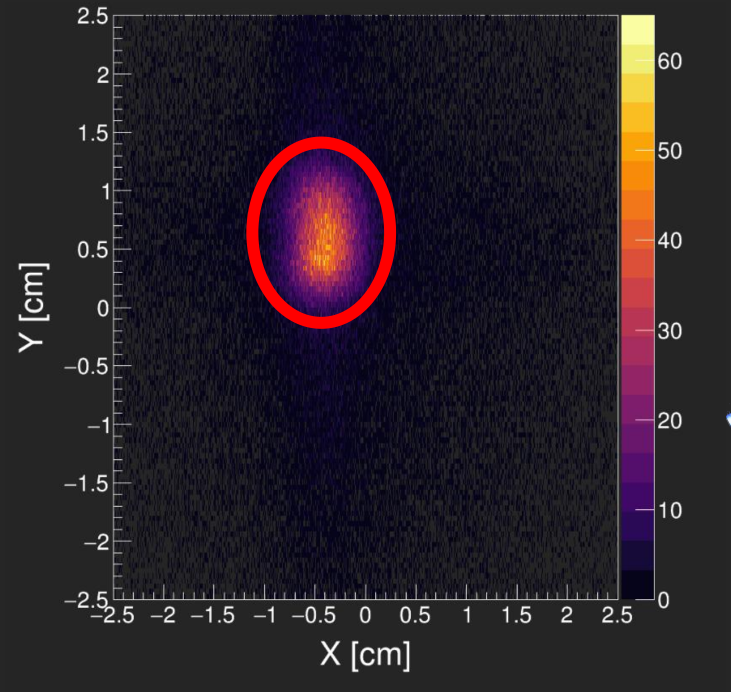
GlobalTrack: Sts(1) - TRD(3) - TOF(>2)

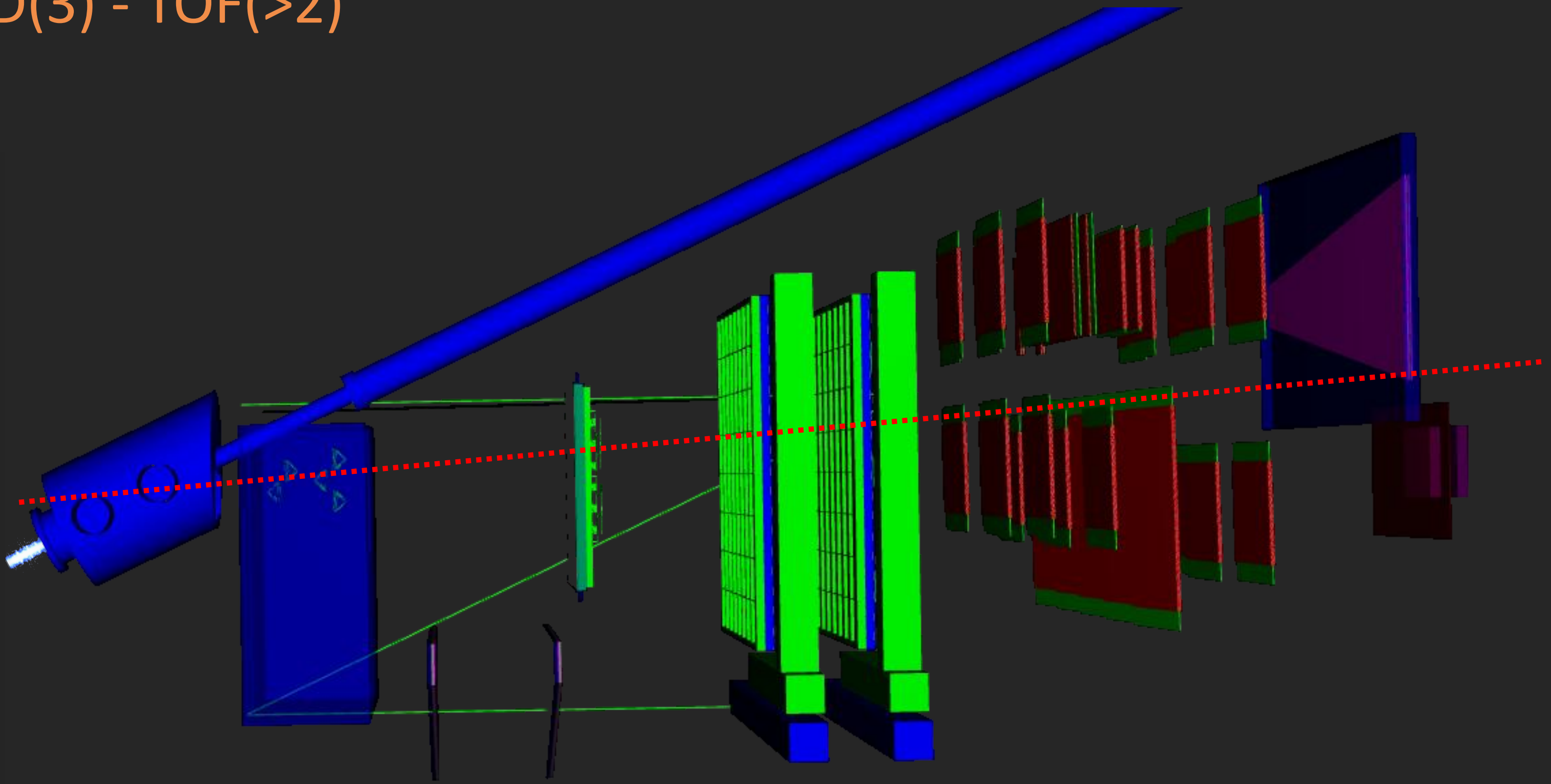




mSTS - Hit Reconstruction Efficiency

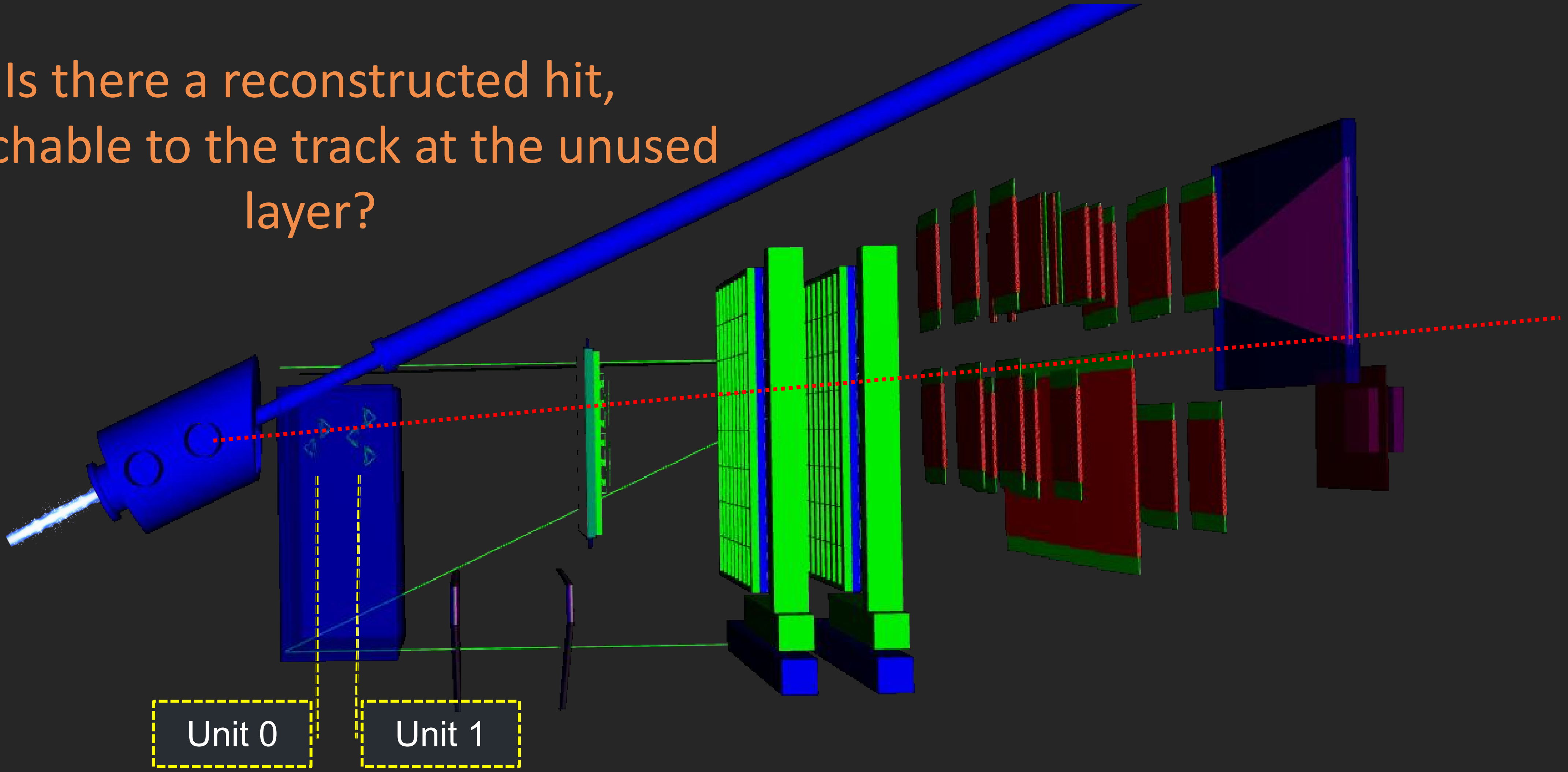
GlobalTrack: Sts(1) - TRD(3) - TOF(>2)





mSTS - Hit Reconstruction Efficiency

Is there a reconstructed hit, attachable to the track at the unused layer?



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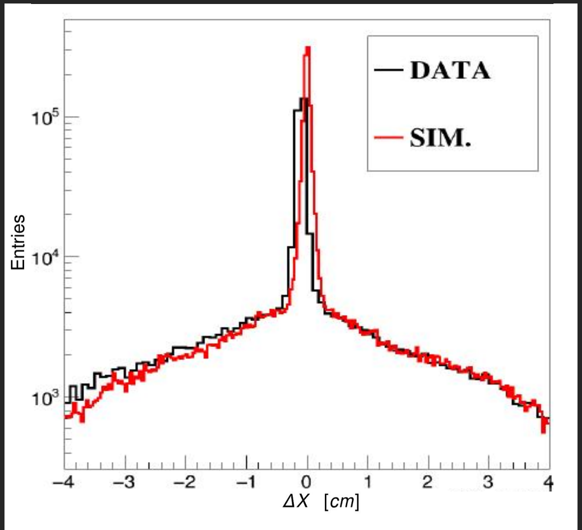
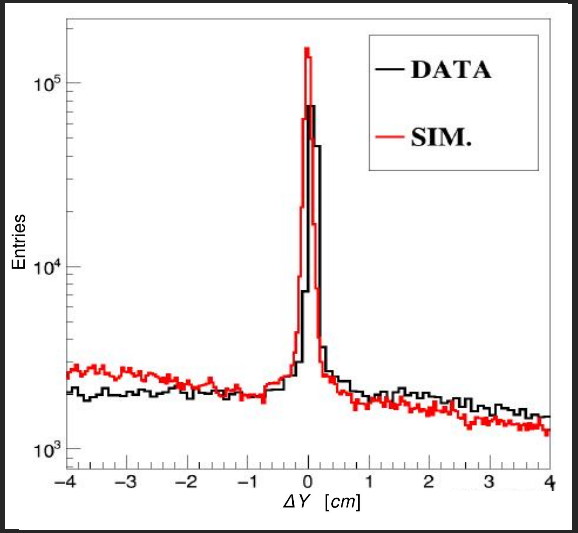
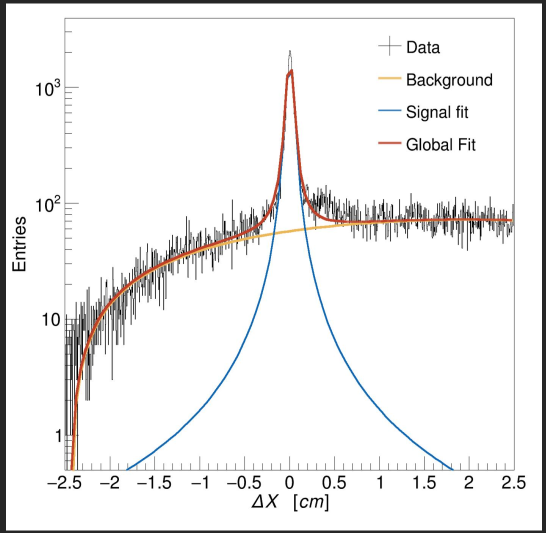
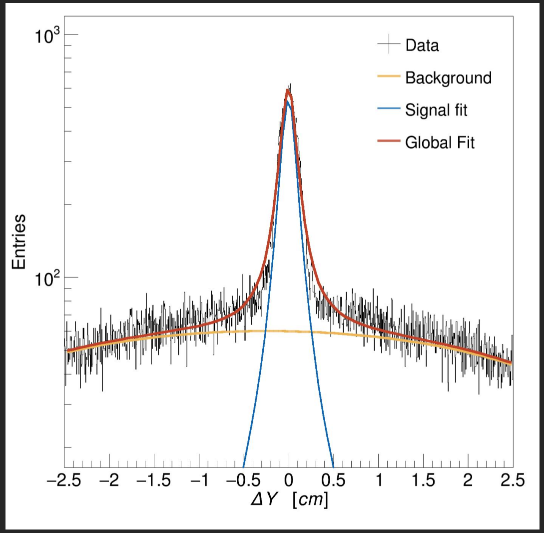








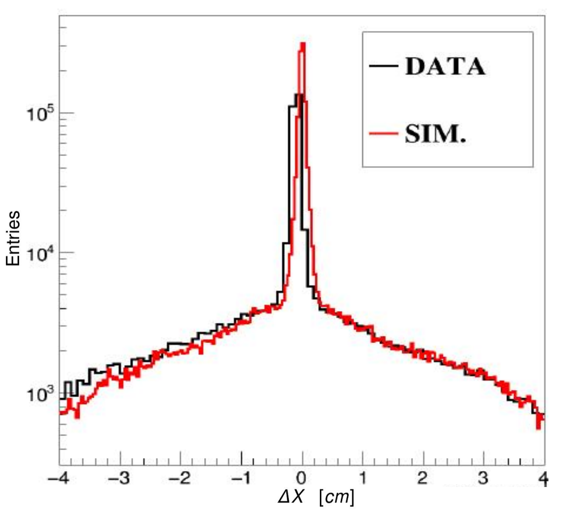
mCBM2021
Track-lets: Sts(1) - TOF(1)

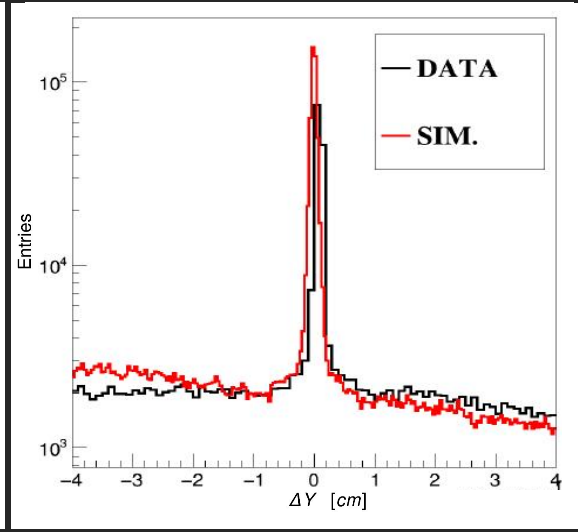
mCBM2022
Global Tracks: Sts(1) - Trd(3)

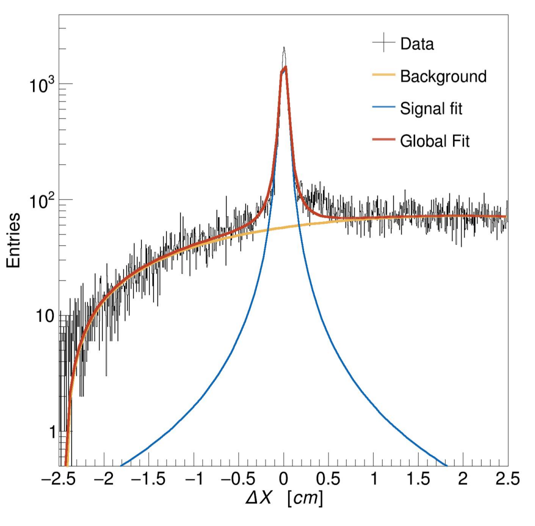
mSTS - Hit Reconstruction Efficiency

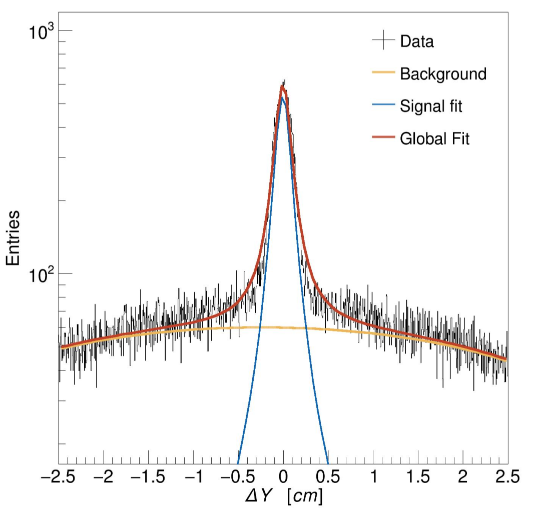
Is there a reconstructed hit, attachable to the track at the unused layer?

$$||(\vec{r}_{trk} - \vec{r}_{StsHit_i} - \vec{r}_{res})|| \leq 3\sigma_{res}$$









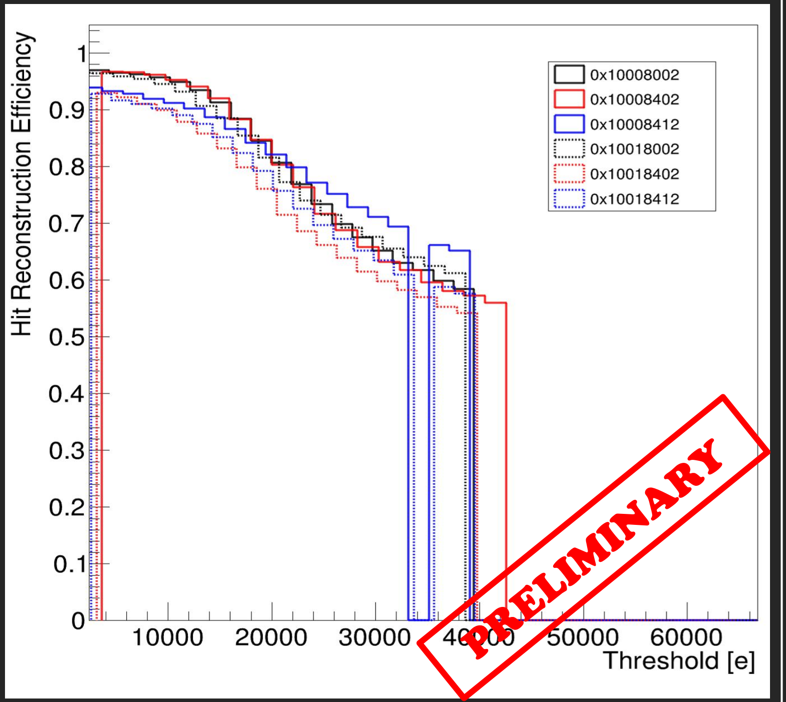
mCBM2021
Track-lets: Sts(1) - TOF(1)

mCBM2022
Global Tracks: Sts(1) - Trd(3)

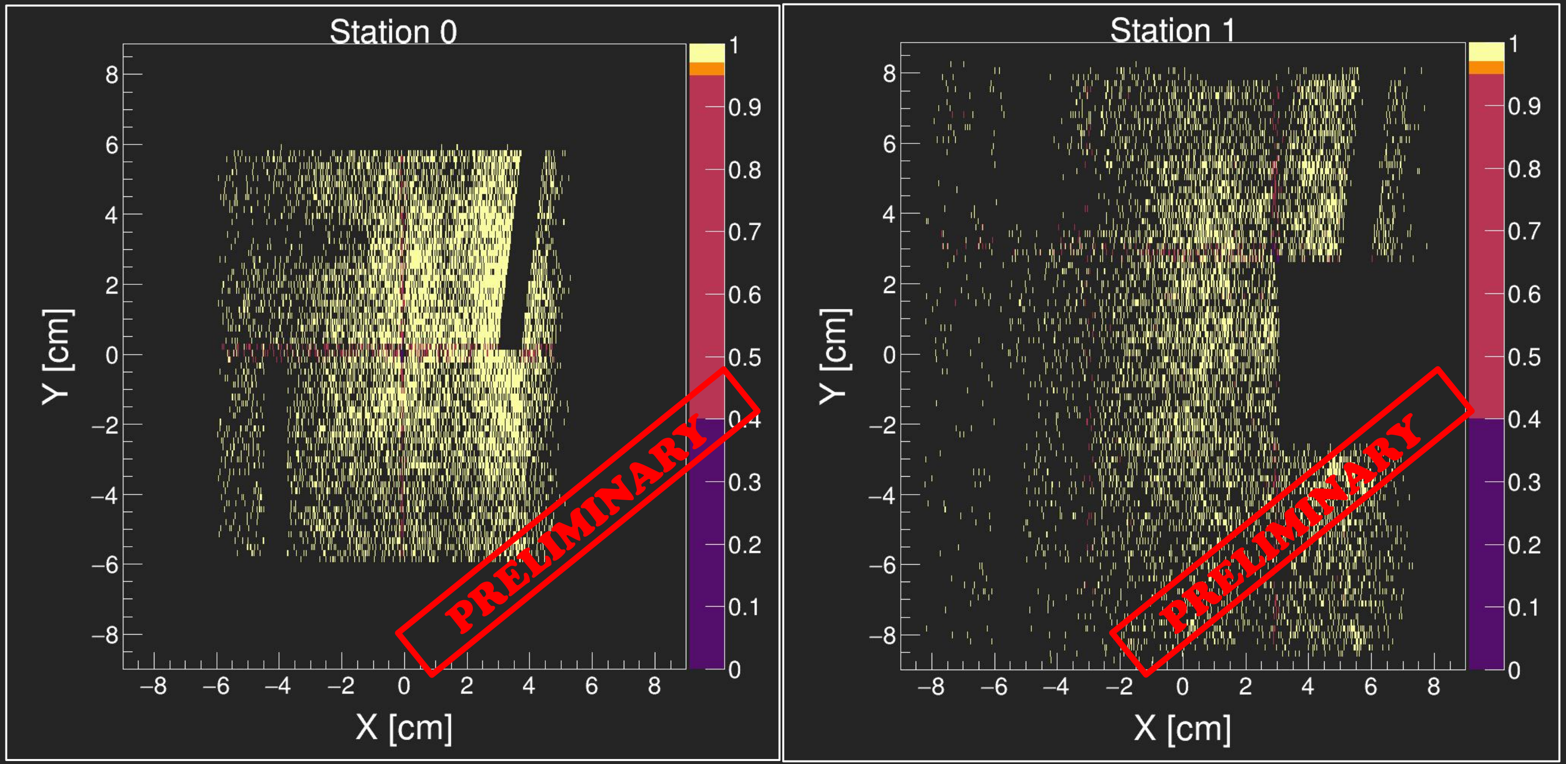
Good agreement with Monte Carlo expectations
First tests of 4D tracking capabilities with data

mSTS - Hit Reconstruction Efficiency

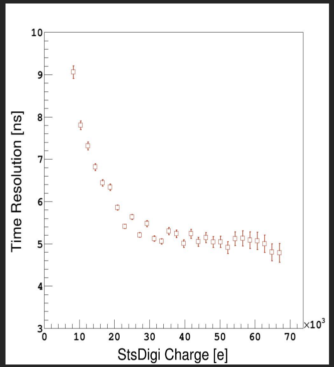
HRE > 97%
Excluding inactive areas



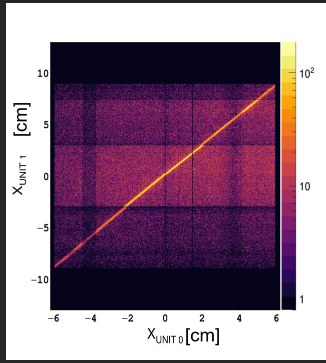
HRE > 97%
Excluding inactive areas and sensor edges



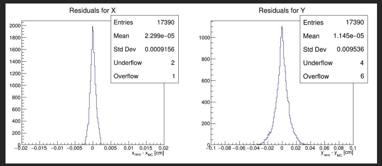
Summary

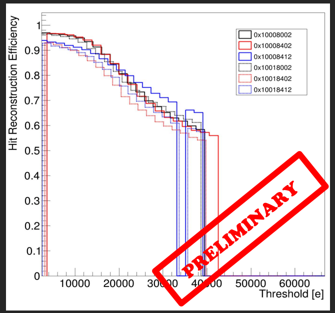


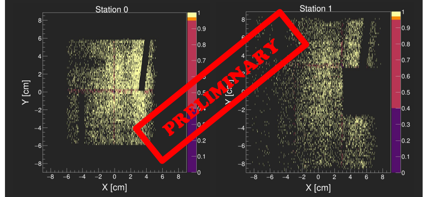
Robust time resolution procedure: 4.8 - 9.2 ns (6k-67k e)



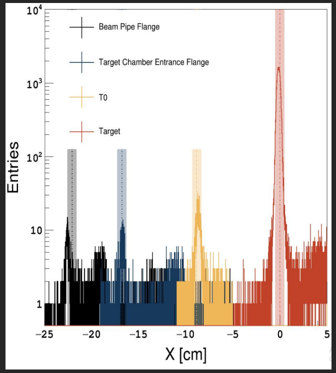
Position measurement inline with MC expectations 9 um





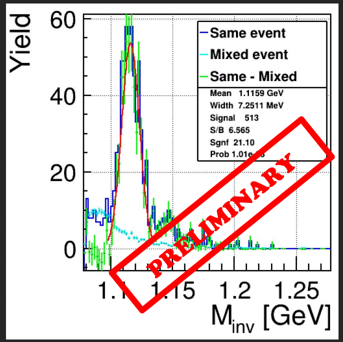


Hit reconstruction efficiency above 97%



Self-alignment capabilities Consistent secondary targets reconstruction

Benchmark Lambda reconstruction



Good performance for vertexing and tracking

Deep dive

M.Teklishyn From 3D to 5D tracking: SMX ASIC-based Double-Sided Micro-Strip detectors for comprehensive space, time, and energy measurements
TWEPP 2023 https://indico.cern.ch/event/1255624/contributions/5444008/attachments/2728888/4743371/smx_5d_tracking_teklishyn_06OCT2023.pdf

A. Rodriguez Rodriguez et al., Functional characterization of modules for the Silicon Tracking System of the CBM experiment
accepted by NIM

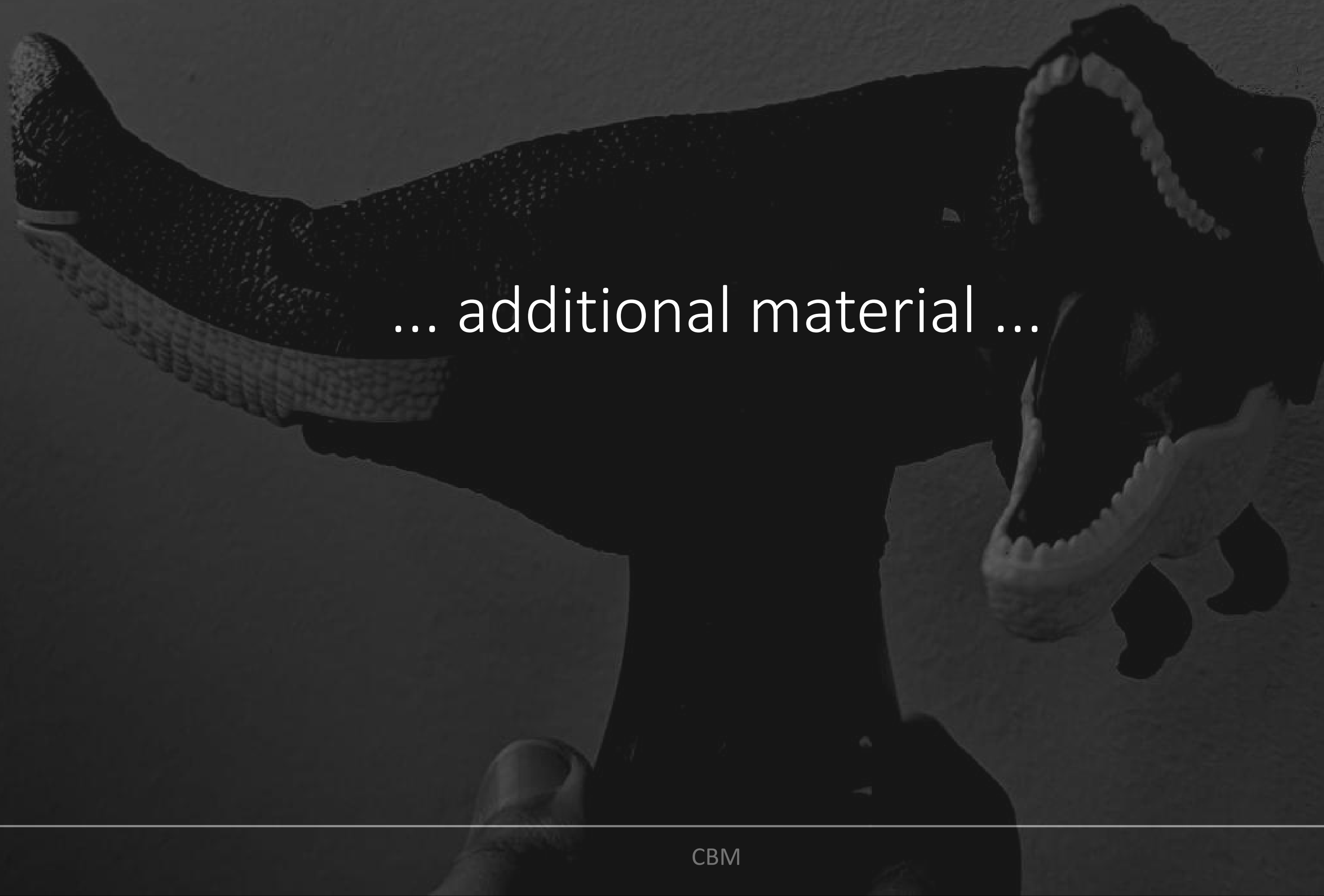
K. Agarwal, Thermal Management of the CBM-FAIR's Silicon Tracking System (STS) – Concept and Demonstrators
Forum on Tracking Detector Mechanics 2023
https://indico.cern.ch/event/1228295/contributions/5390887/attachments/2656554/4600811/20230531_Agarwal_FTDMT%C3%BCbingen.pdf

S. Mehta, Impact of air cooling on mechanical stability of silicon sensors in CBM-STS
Forum on Tracking Detector Mechanics 2023
https://indico.cern.ch/event/1228295/contributions/5390888/attachments/2656536/4600775/Vib_Tracking_forum_Mehta_1.pdf

I. Elizarov, Sustainable cooling supply for the STS detector electronics
Forum on Tracking Detector Mechanics 2023
https://indico.cern.ch/event/1228295/contributions/5401384/attachments/2656351/4600422/Elizarov-Pilot%20Cooling%20Supply%20for%20the%20CBM%20Silicon%20Tracking%20System%20Detector%20Electronics.pdf

L.M. Collazo, Temperature calibration and thermal stress tests of the Front-End Electronics of the CBM Silicon Tracking System
Forum on Tracking Detector Mechanics 2023
https://indico.cern.ch/event/1228295/contributions/5394879/attachments/2656948/4601561/FTDM2023_Poster_Lady_Maryann.pdf

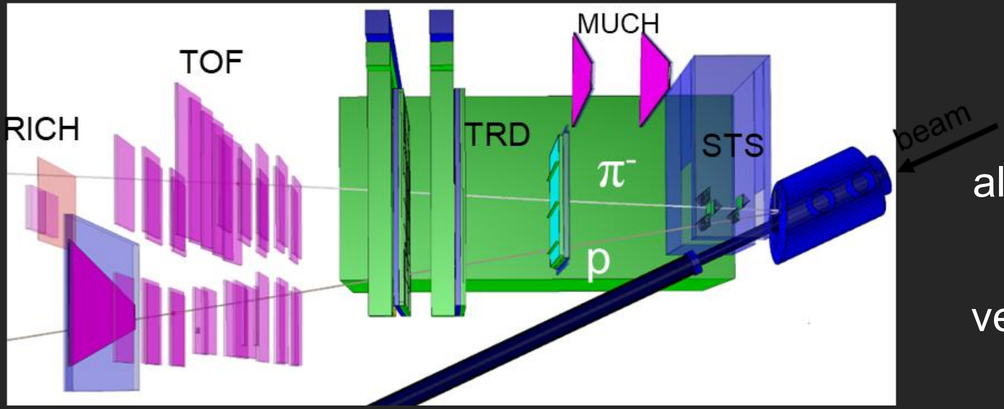
M. Teklishyn Detectors and Electronics for the CBM experiment at FAIR
ICPADGP 2023 https://events.vecc.gov.in/event/19/contributions/1009/attachments/198/411/teklishyn_cbm_detectorselectronics_07feb2023.pdf



... additional material ...

mCBM Benchmark Lambda reconstruction

Rare signal reconstructed: $\Lambda \rightarrow p\,\pi^-$

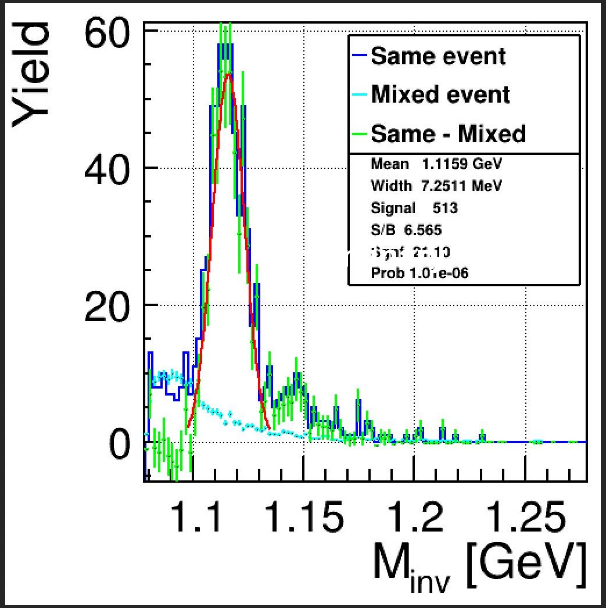


Ni+Ni 1.93 AGeV
run 2391 (May '22):
10^9 collisions, 1:57h
400 kHz av. coll. rate

all detector systems involved

secondary vertex

velocity windows for p and π^- candidate

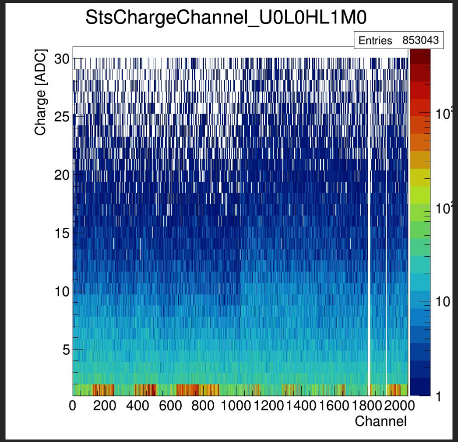


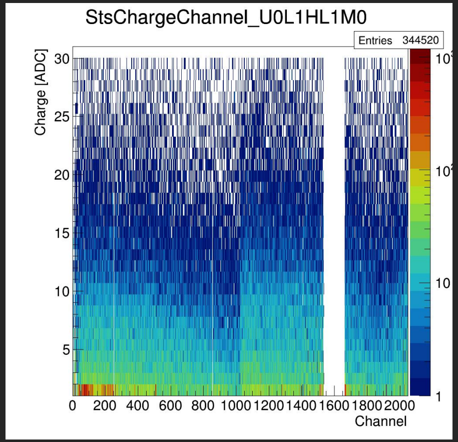
mSTS Signal Analysis - Charge vs Channel

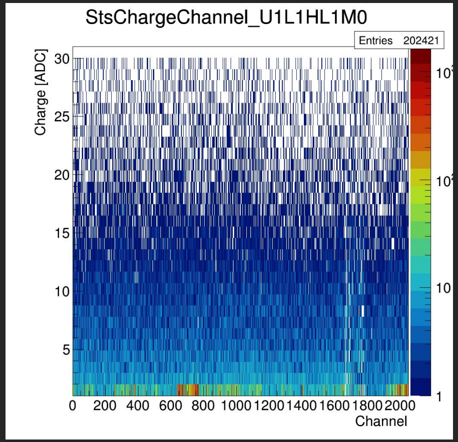
Station 1 | **Station 2**

ladder 0 | **ladder 1** | **ladder 1**

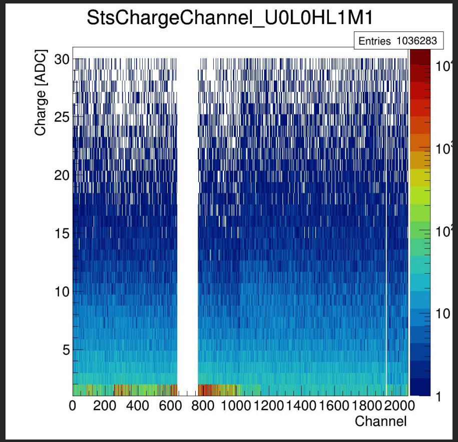
module 0

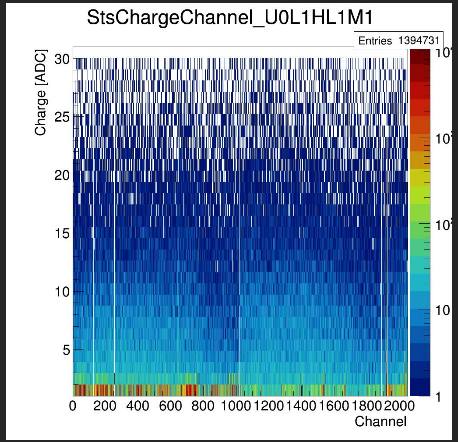


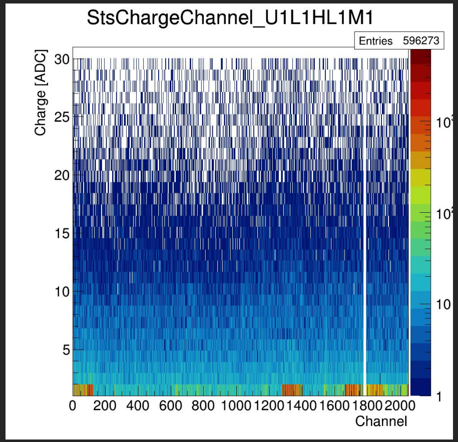




module 1

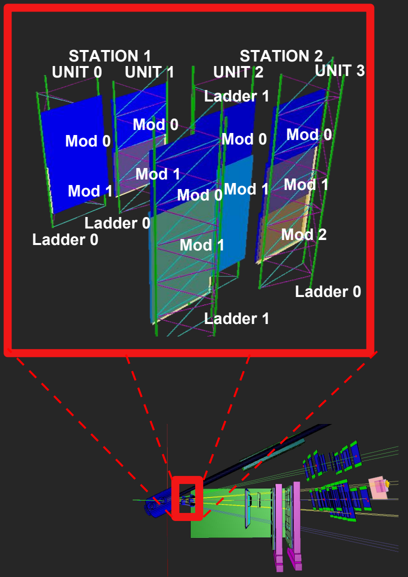






2 non functional ASICs

few dead channels



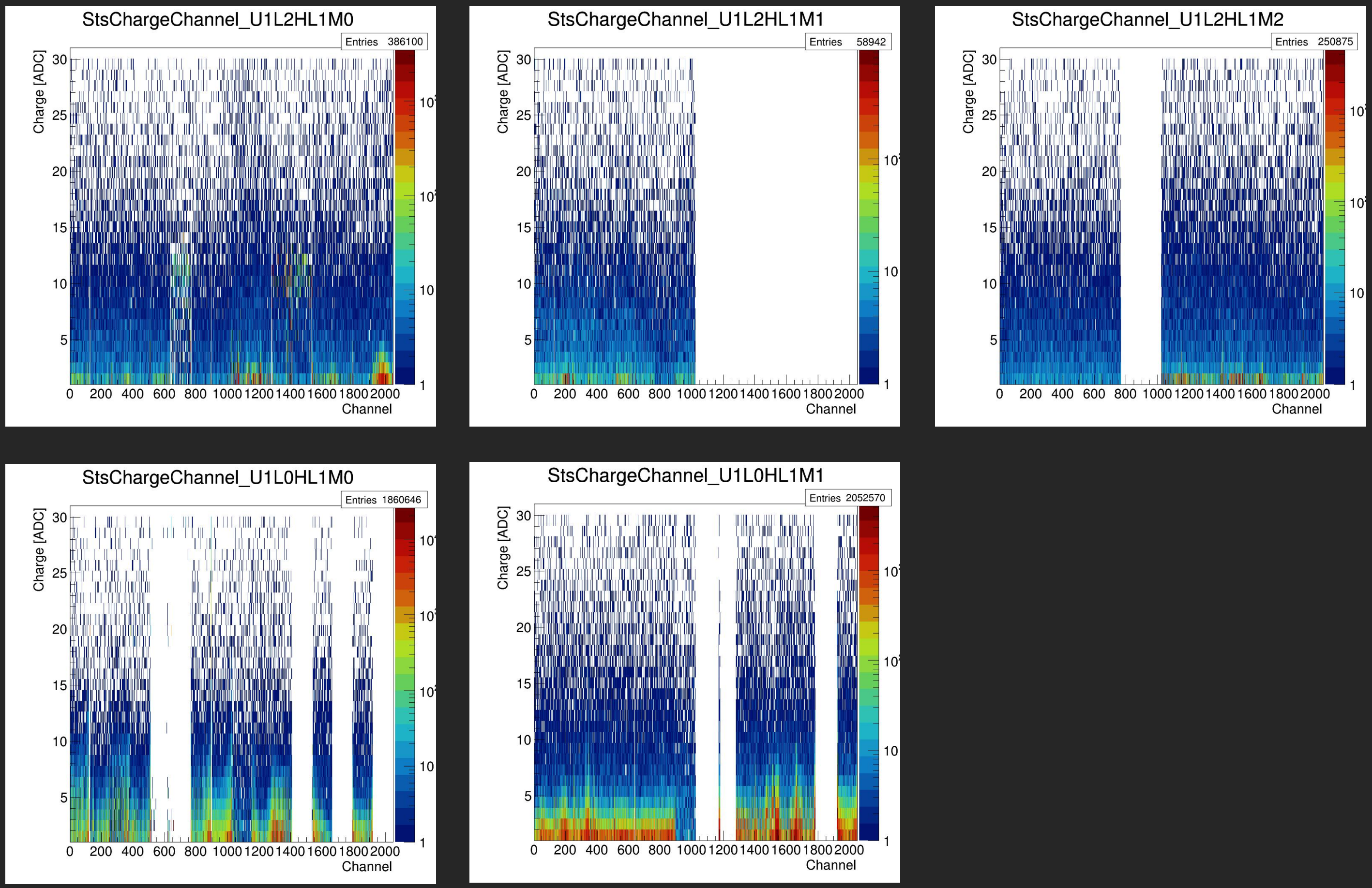
mSTS Signal Analysis - Charge vs Channel

Station 2

module 0 **module 1** **module 2**

ladder 0

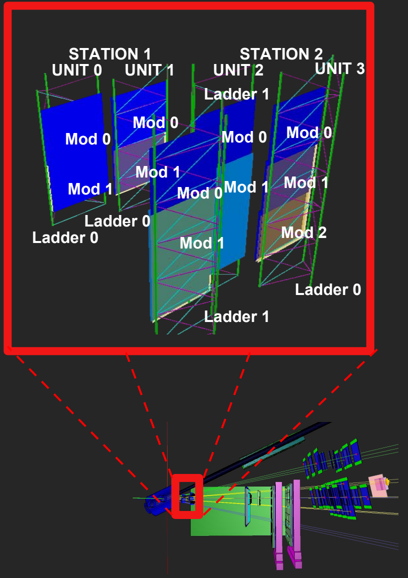
ladder 2



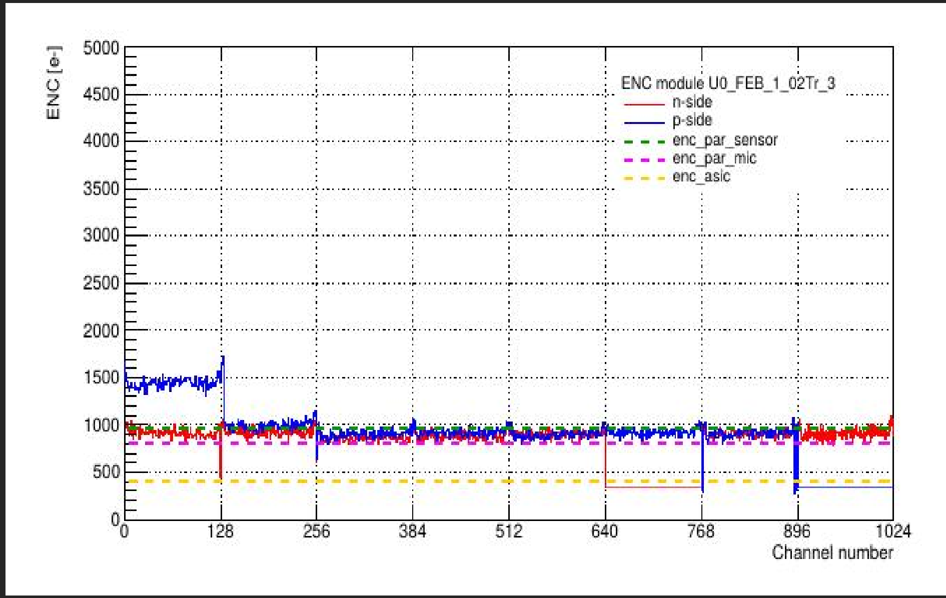
1 non functional FEB

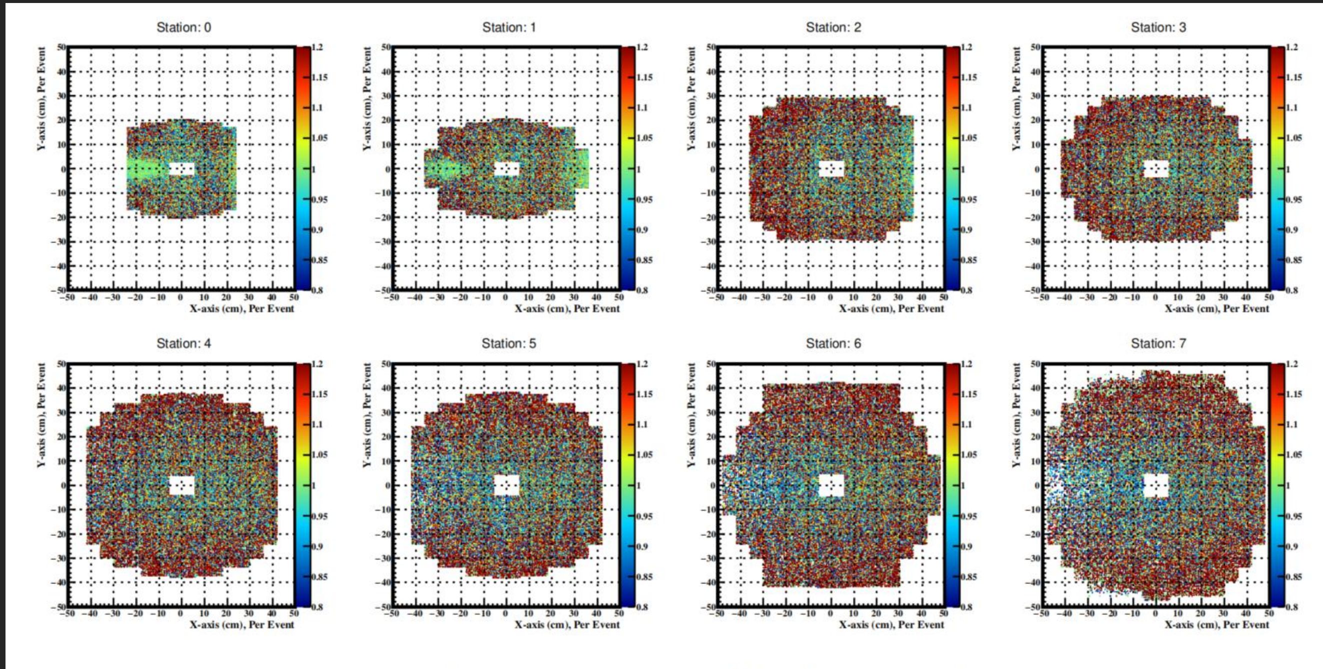
8 non functional ASICs

Calibration issues



STS Noise



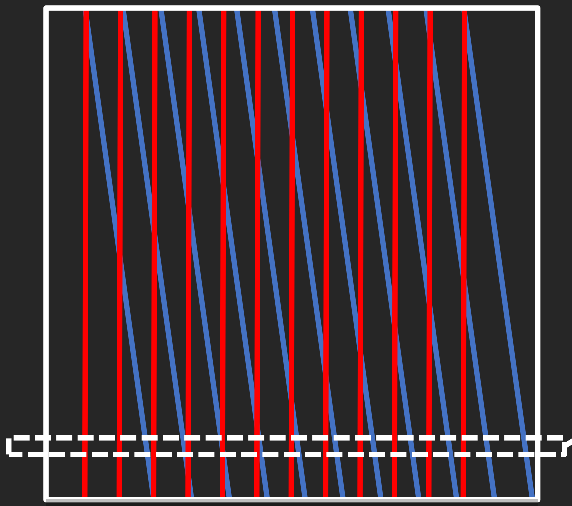


2D ratio histogram of all particles at ENC 1500 for 12 AGeV/c.

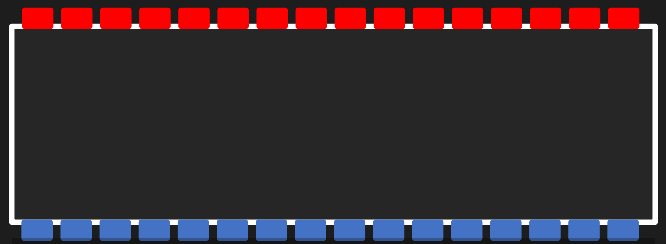
… from hardware to software …

STS sensors strips

p-side strips tilted by 7.5^0



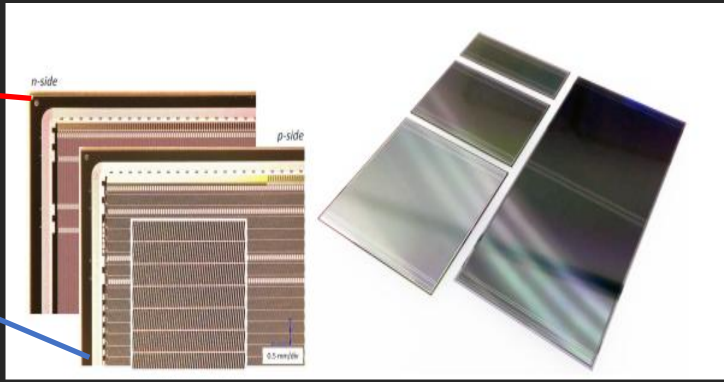
Front view

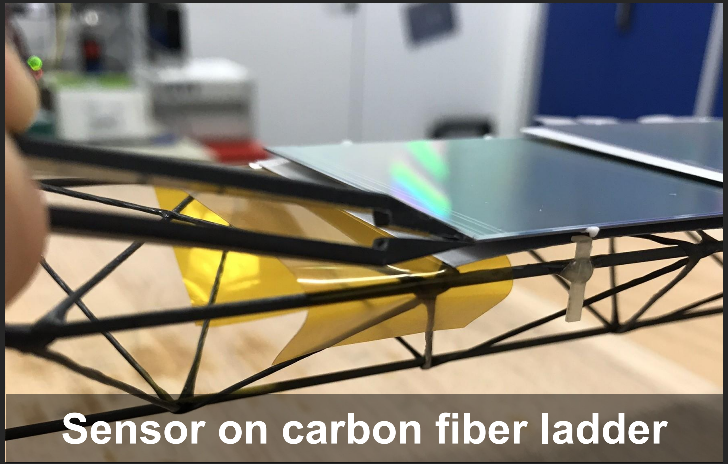


Cross-section view

n-side strips

p-side strips



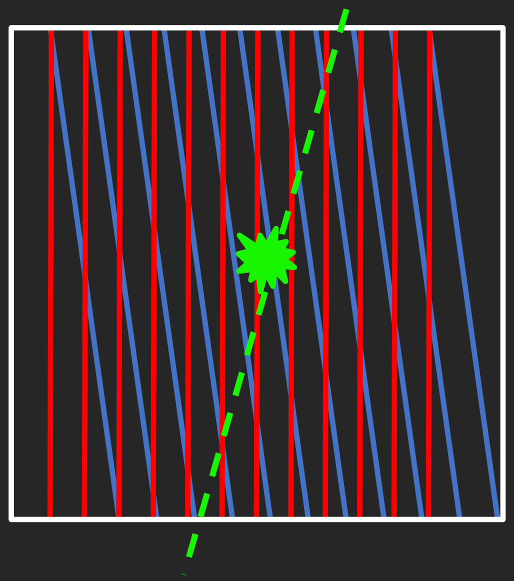


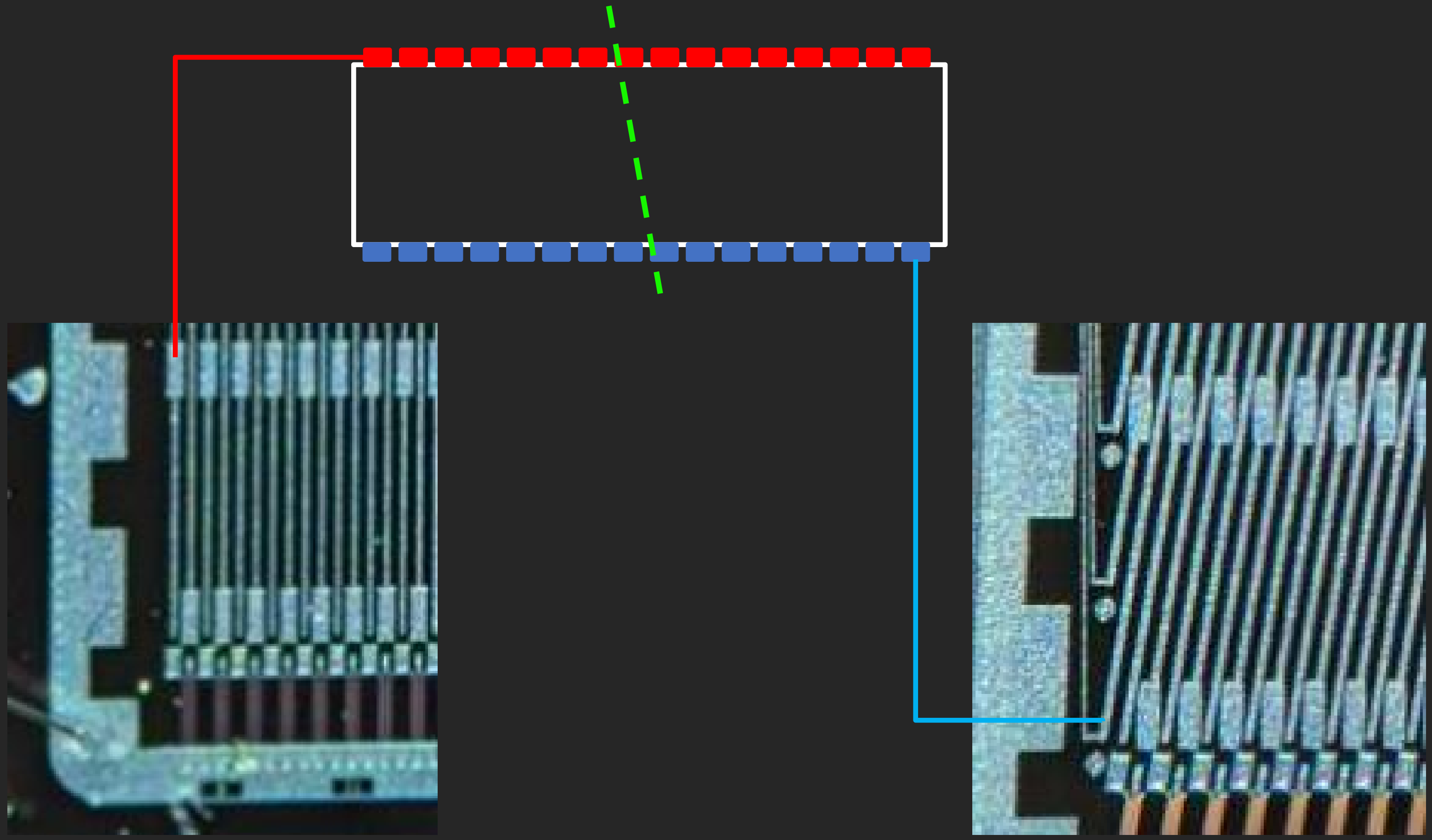
Sensor on carbon fiber ladder

STS sensors strips

n-side strips

p-side strips

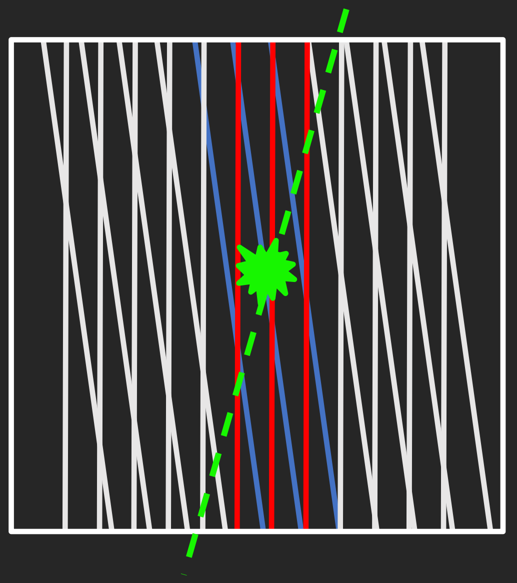


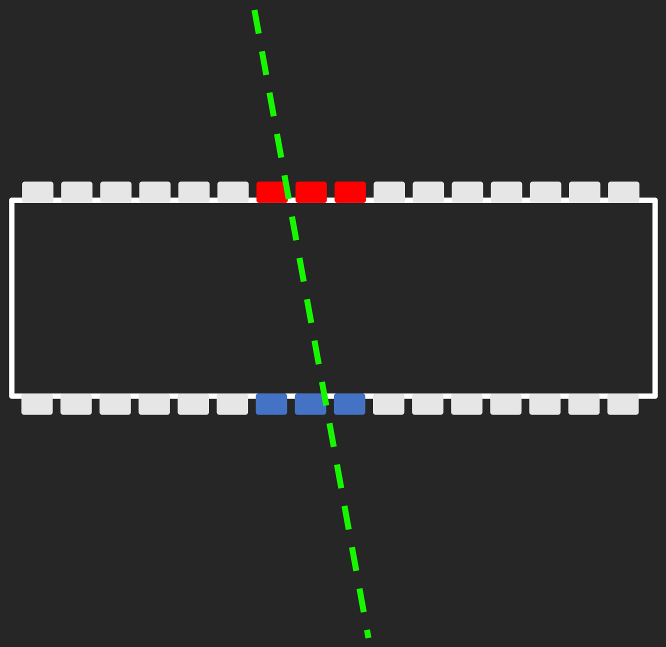


STS sensors fired strips

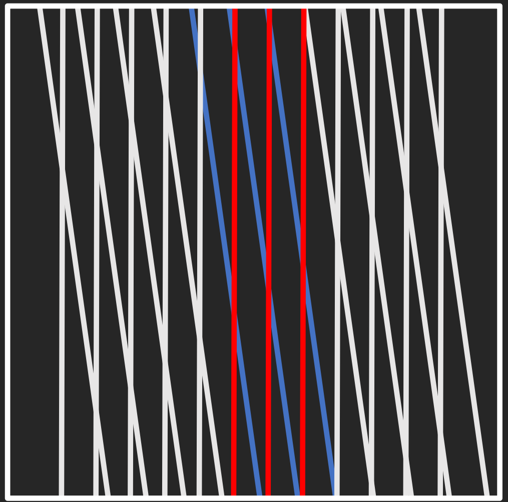
n-side fired strips

p-side fired strips



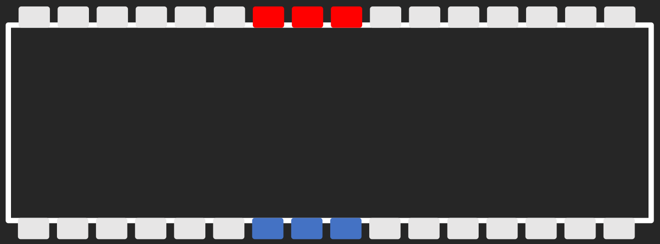


STS sensors strips

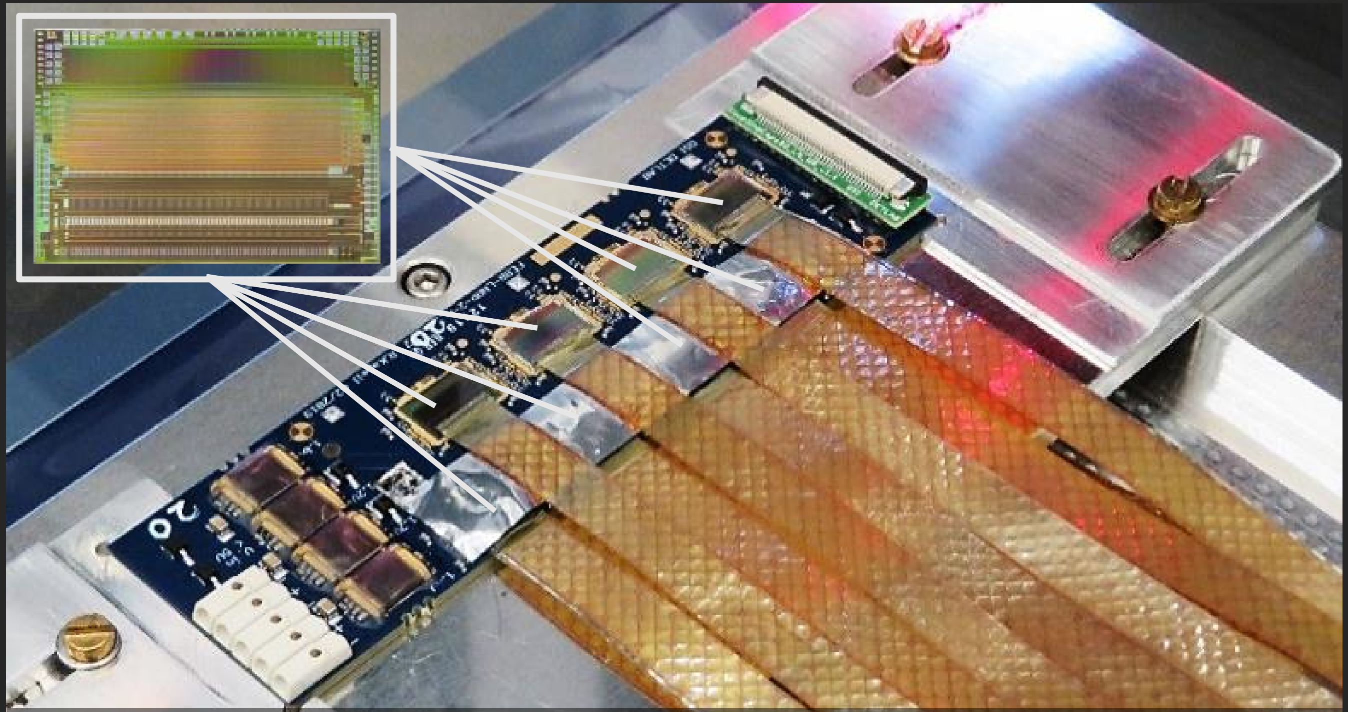


n-side fired strips

p-side fired strips



1 channel per strip
128 channels per ASIC
8 ASIC per side

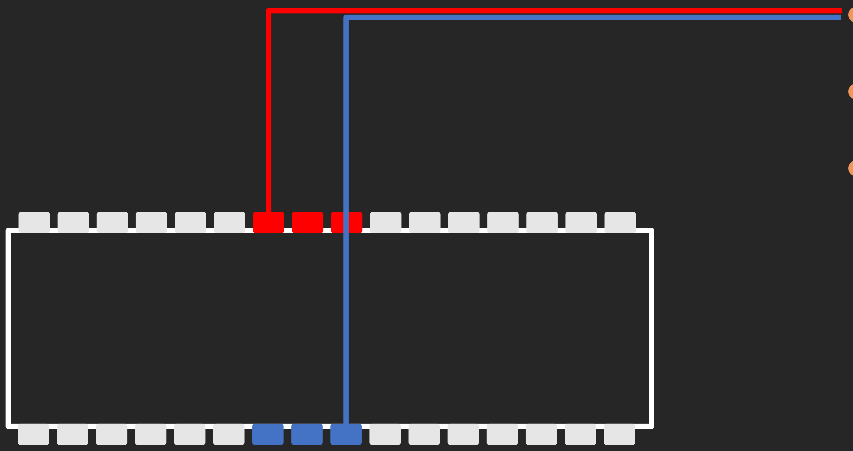


Micro cables. Front-End Board (FEB)

Software objects: STS

n-side fired strips

p-side fired strips



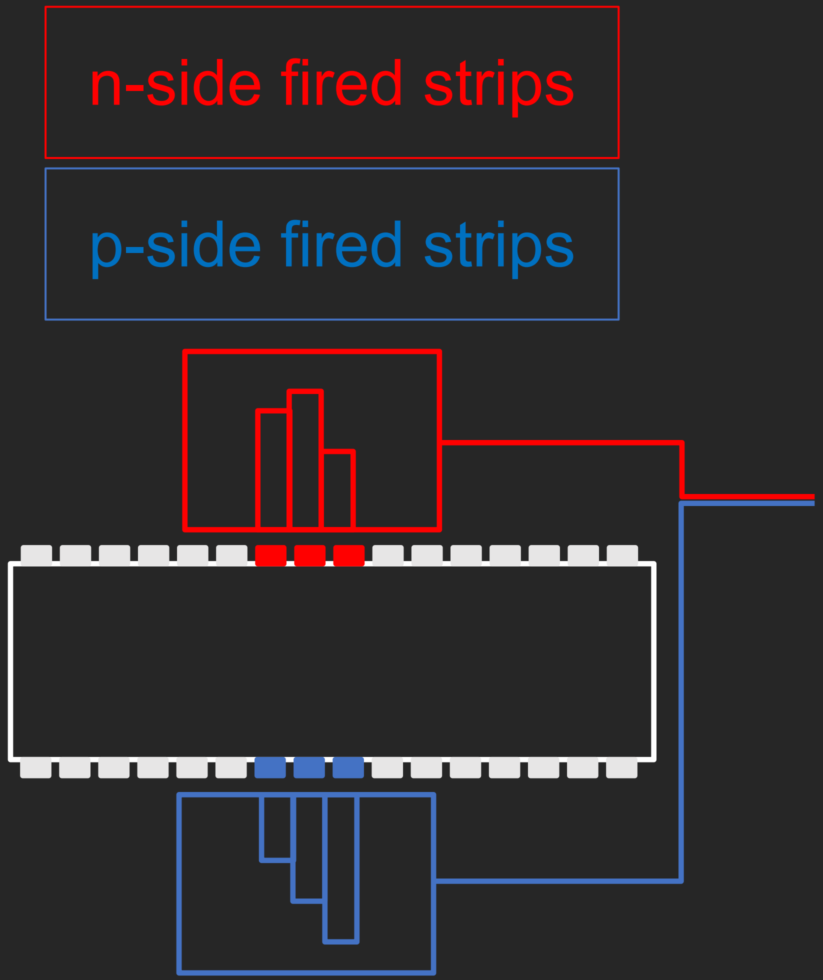
StsDigi

- Address (position of the sensor)
- Channel (position relative to the sensor)
- Time
- Charge (1-31 ADC)

StsCluster

StsHit

Software objects: STS



StsDigi

StsCluster

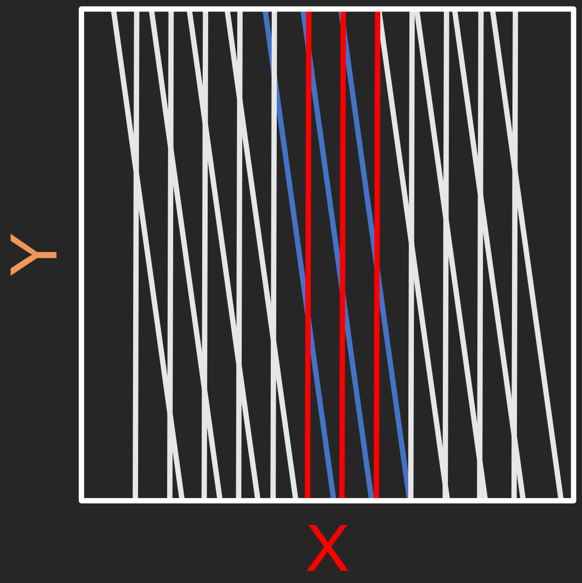
- Charge (1 - cluster size * 31)
- Position

StsHit

Software objects: STS

n-side fired strips

p-side fired strips



StsDigi

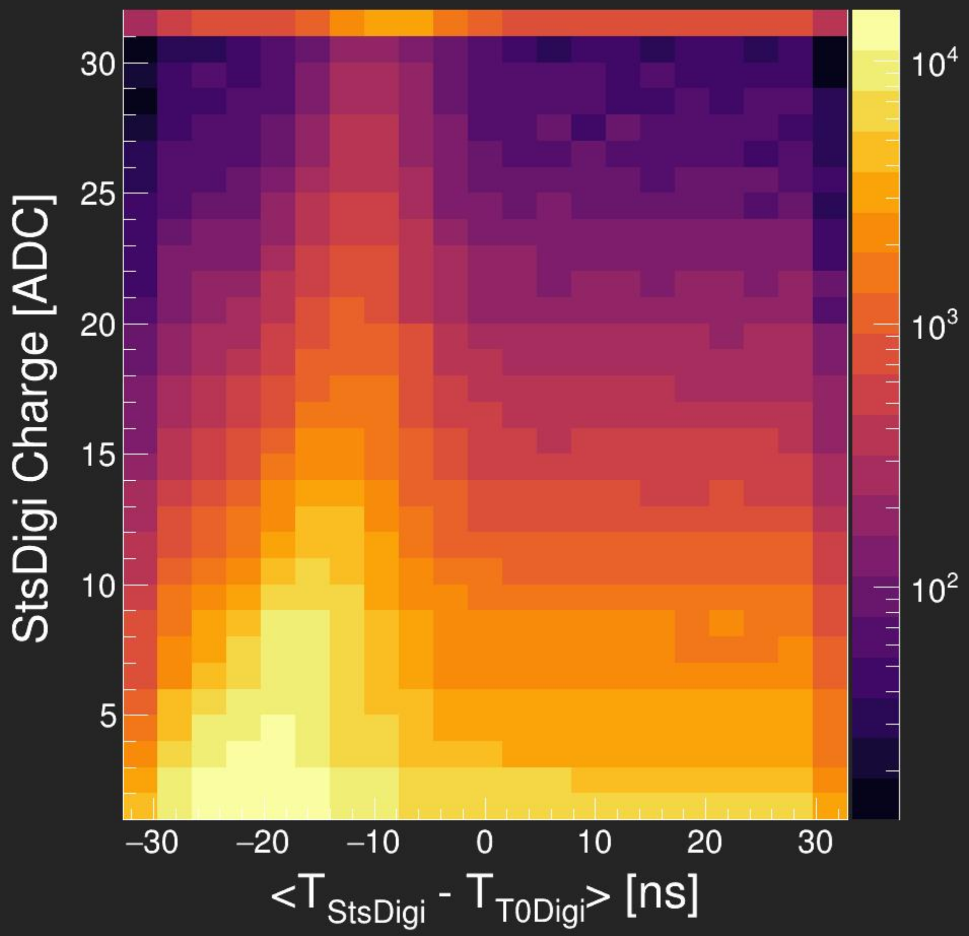
StsCluster

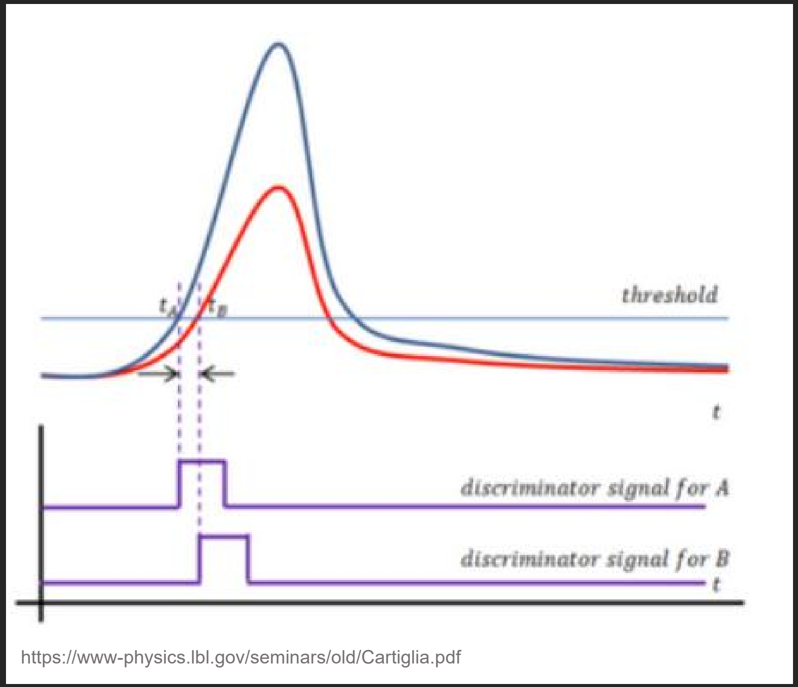
StsHit

- X, Y - cluster position
- Z - sensor position
- Time
- Charge

… time distributions …

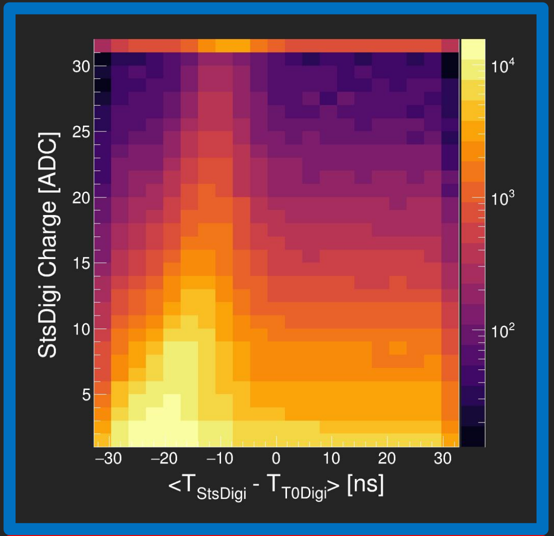
STS Time Calibration (Time Walk correction)

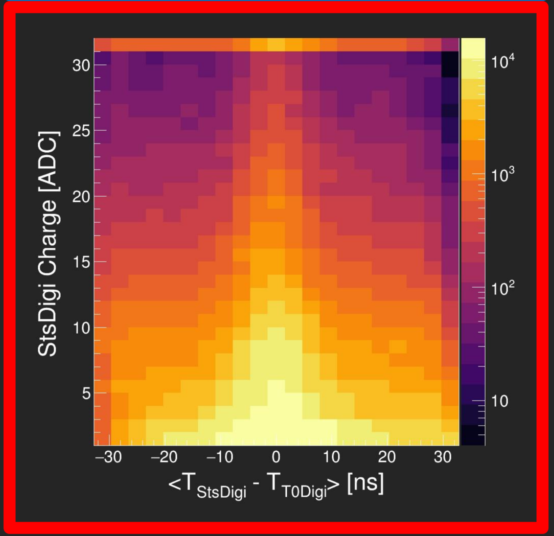


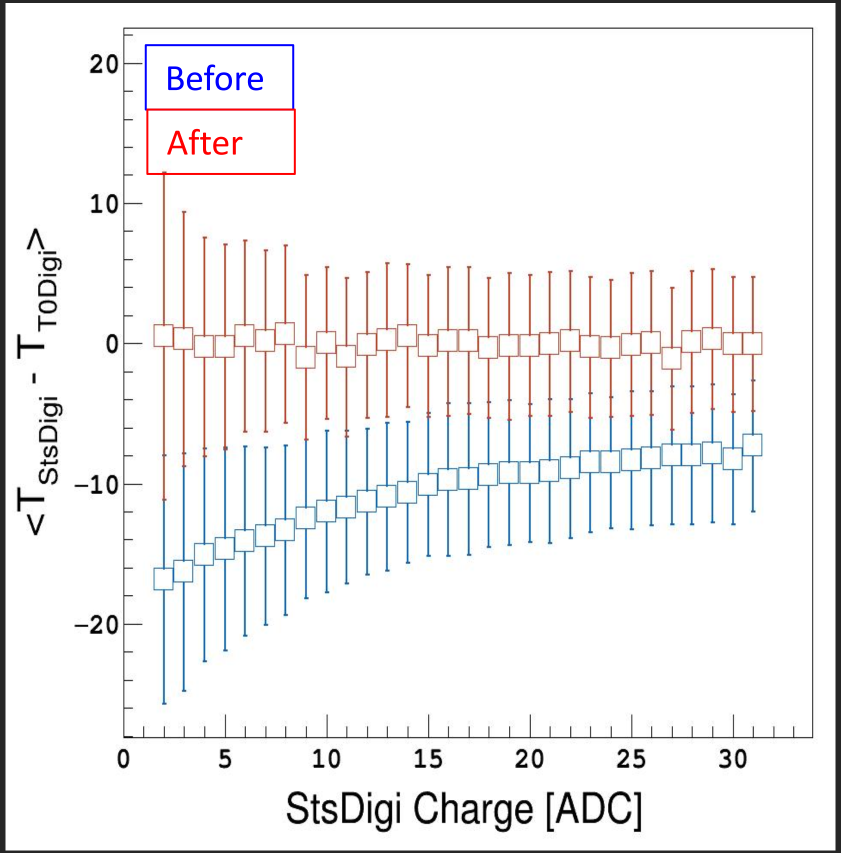


Signal of different amplitudes are timed differently

STS Time Calibration (Time Walk correction)

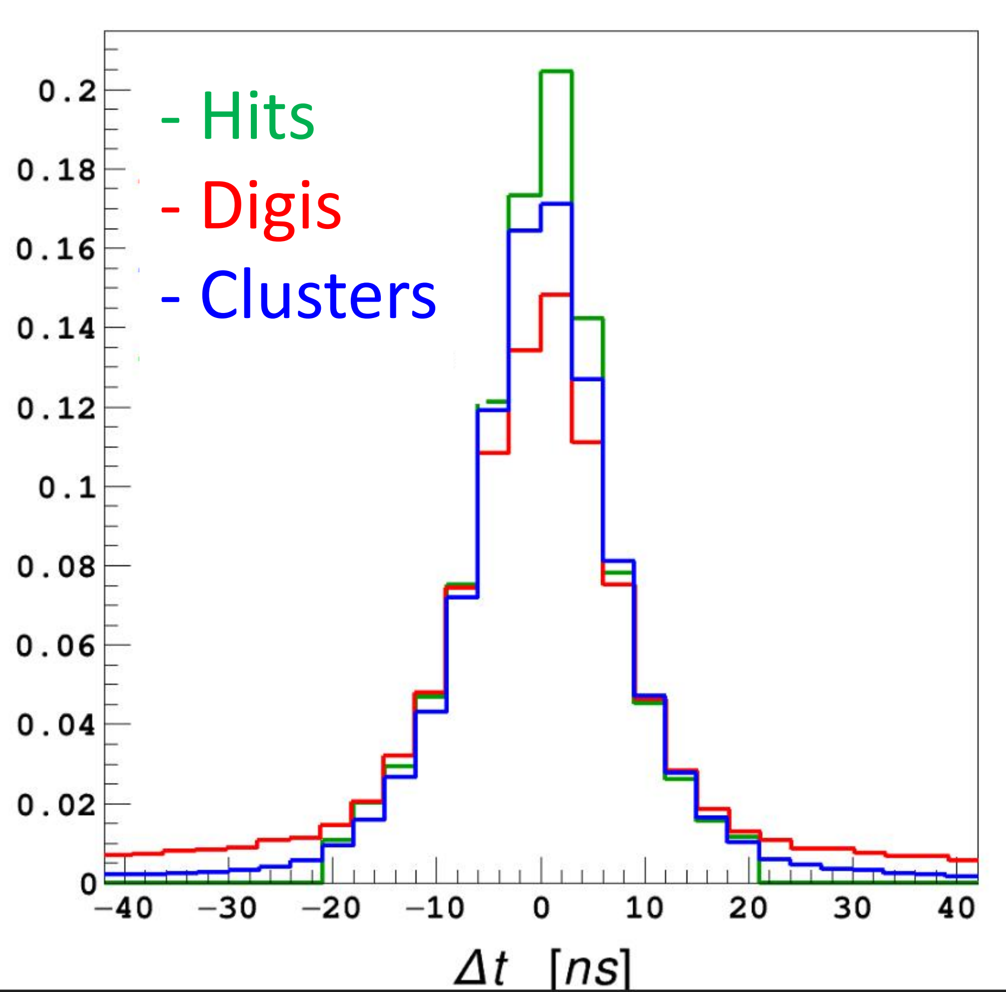






Correction is ASIC dependent

mSTS Time Resolution



Consistent time calibration across ASICs, Modules & Stations

Removal of combinatorial

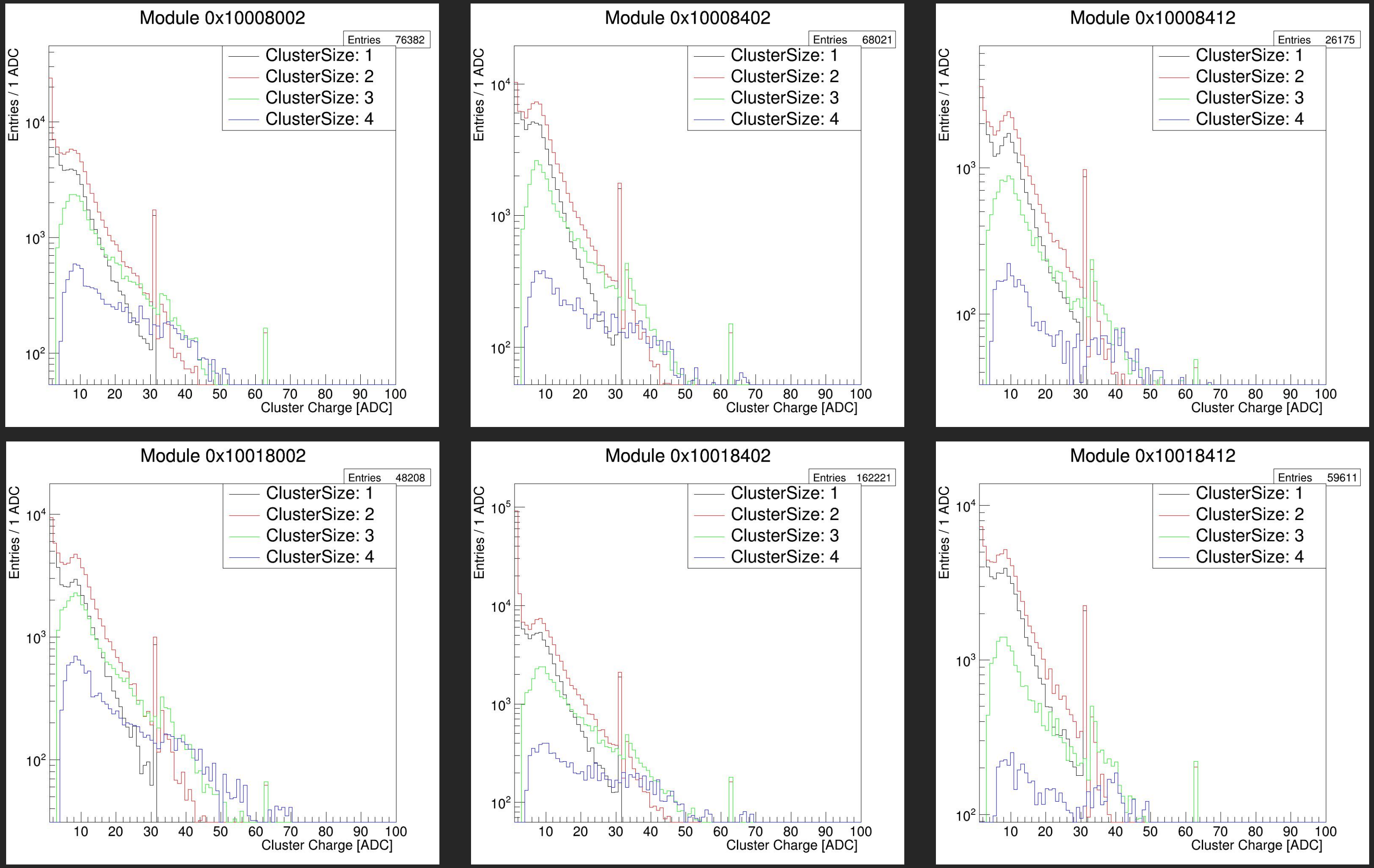
… cluster distributions…

mSTS Signal Analysis - Cluster charge distribution

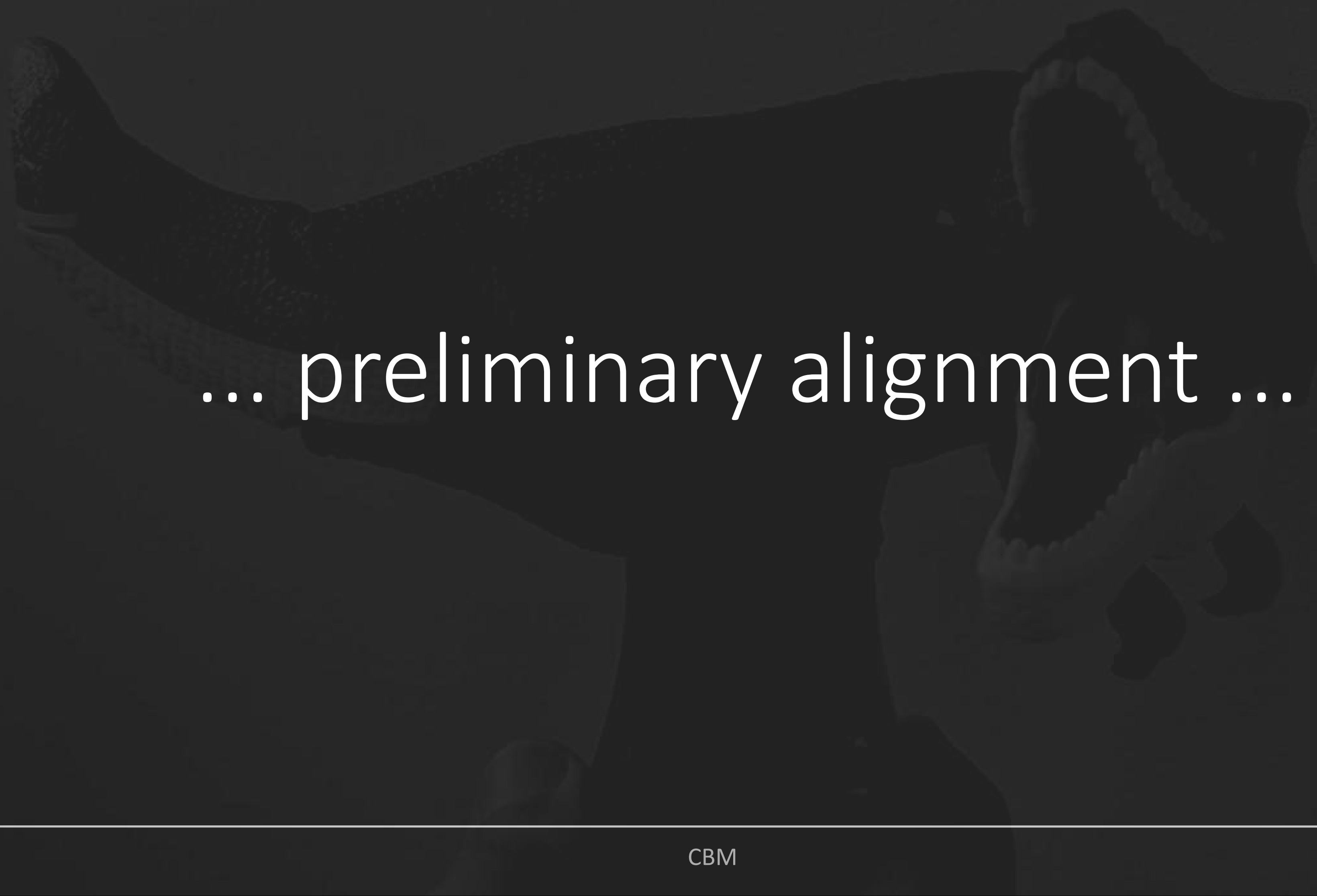
UNIT 0 **UNIT 1** **UNIT 2**

MODULE 0

MODULE 1

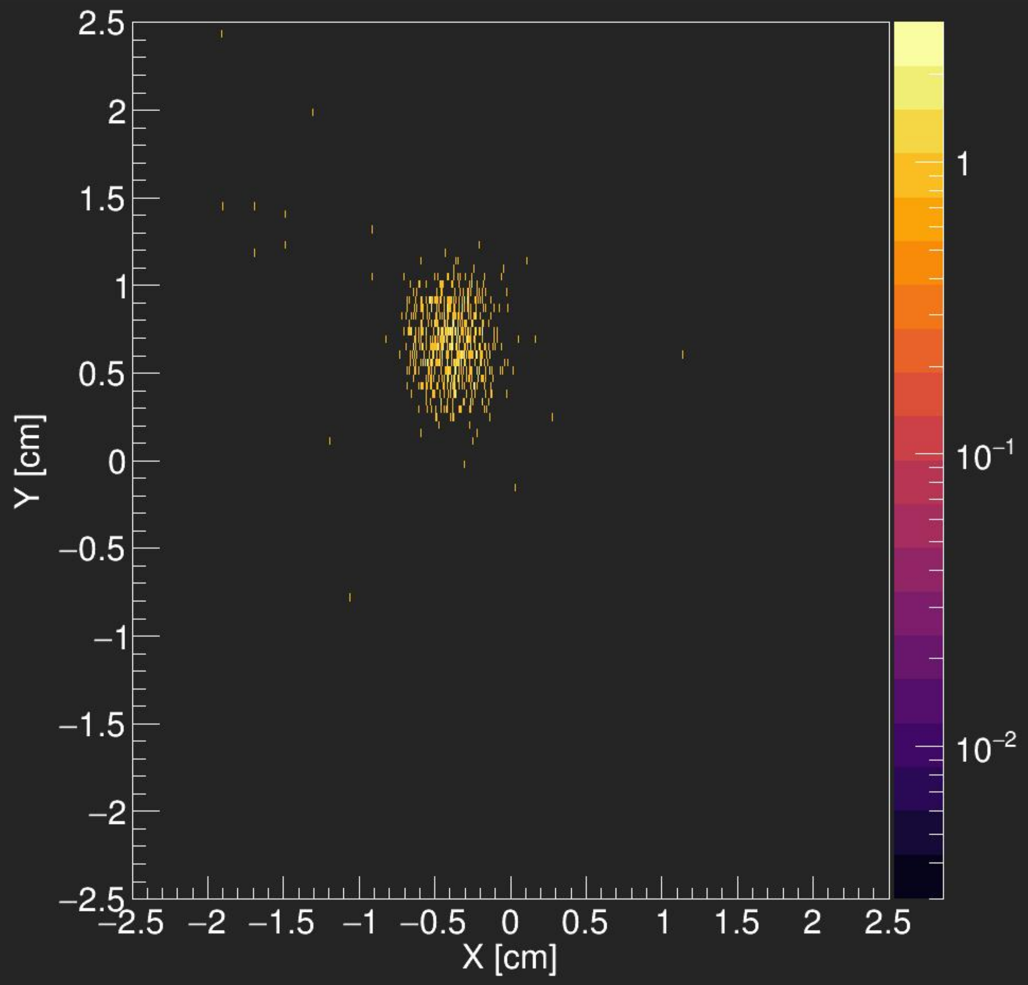


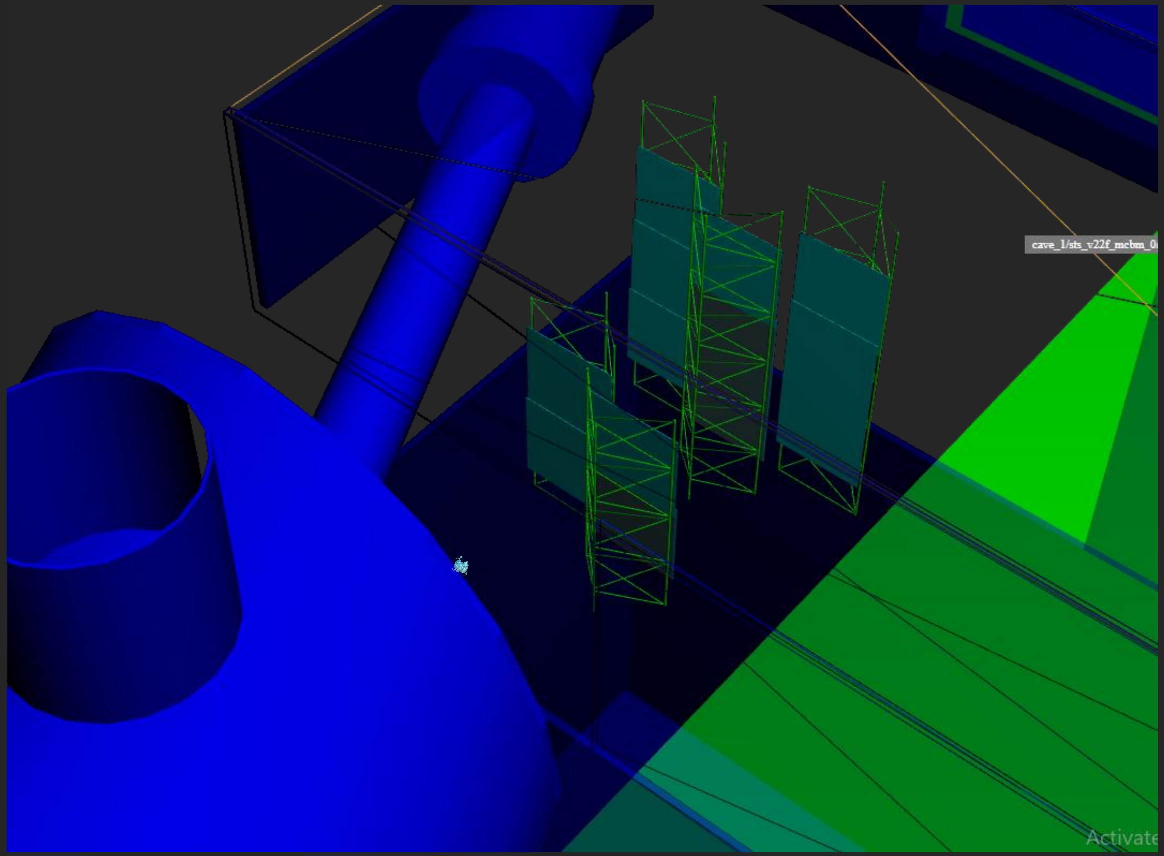
Charge distribution is consistent along different cluster size



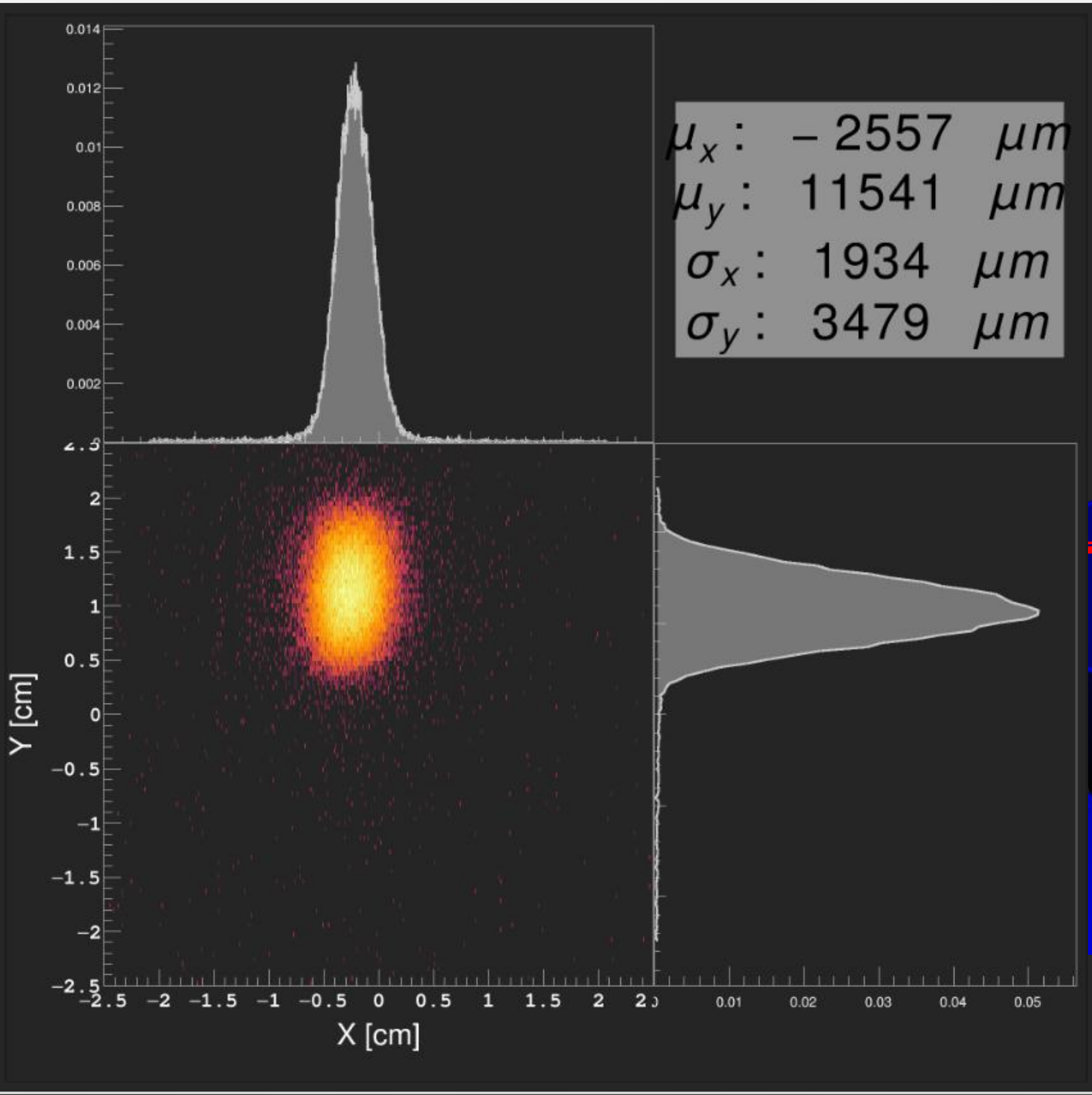
… preliminary alignment …

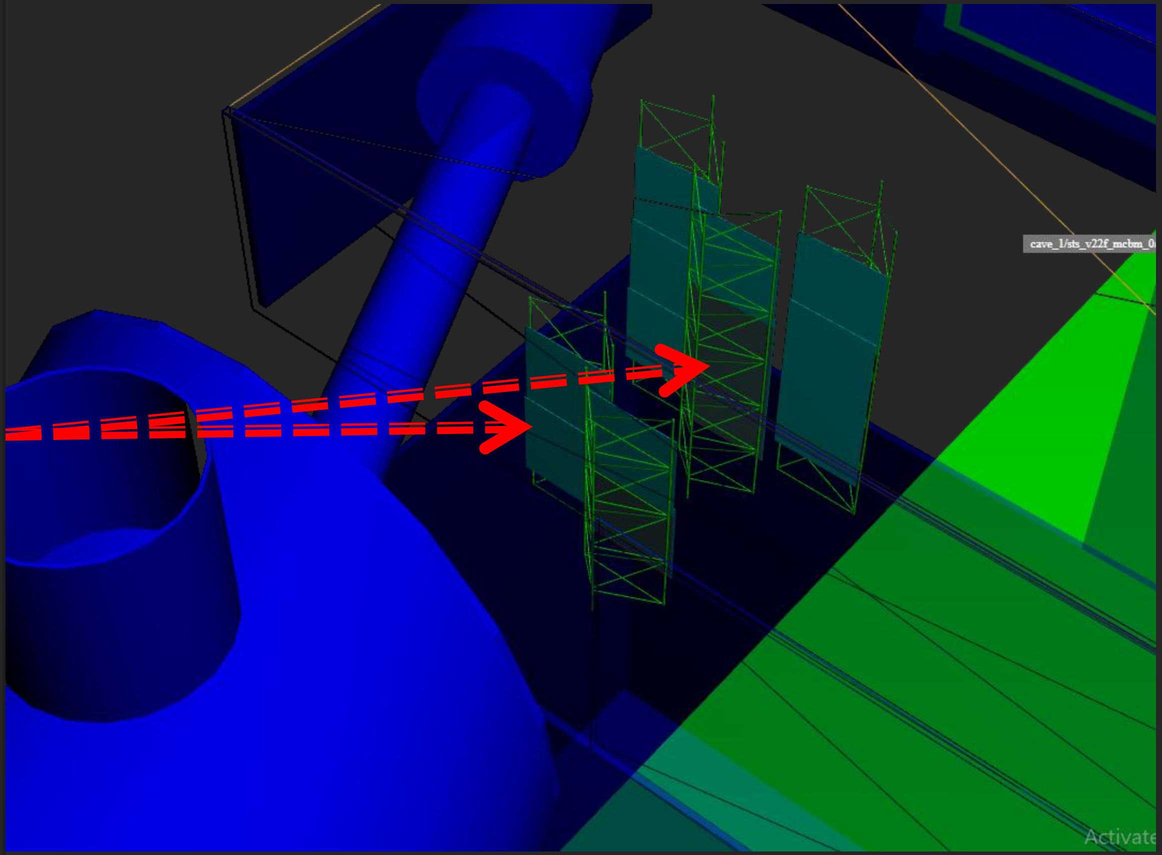
mSTS Vertex Reconstruction - Setup: Top view



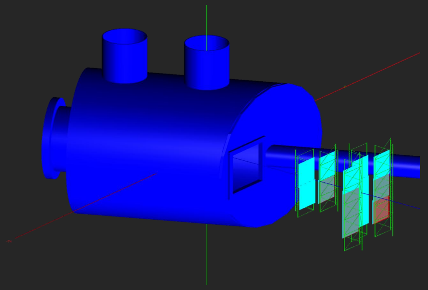


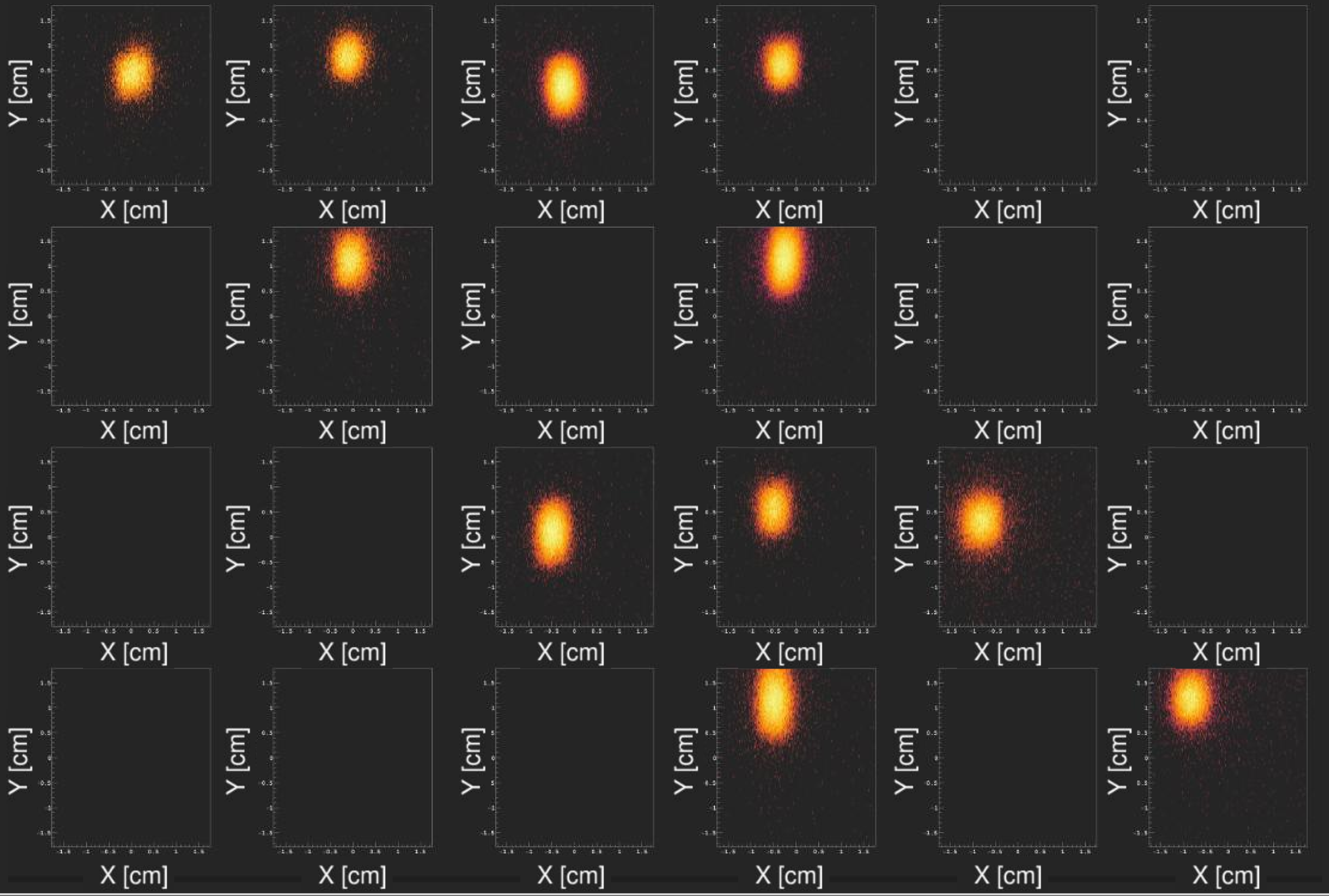
mSTS Vertex Reconstruction - Setup: Top view



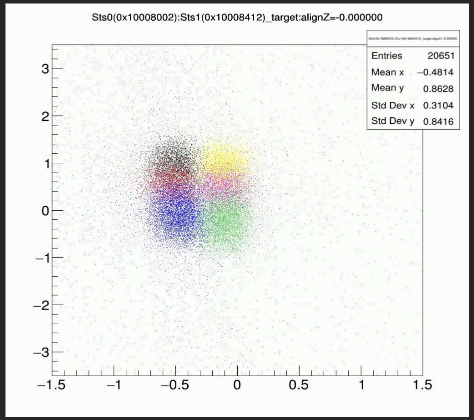


mSTS Vertex Reconstruction - Splitting contributions



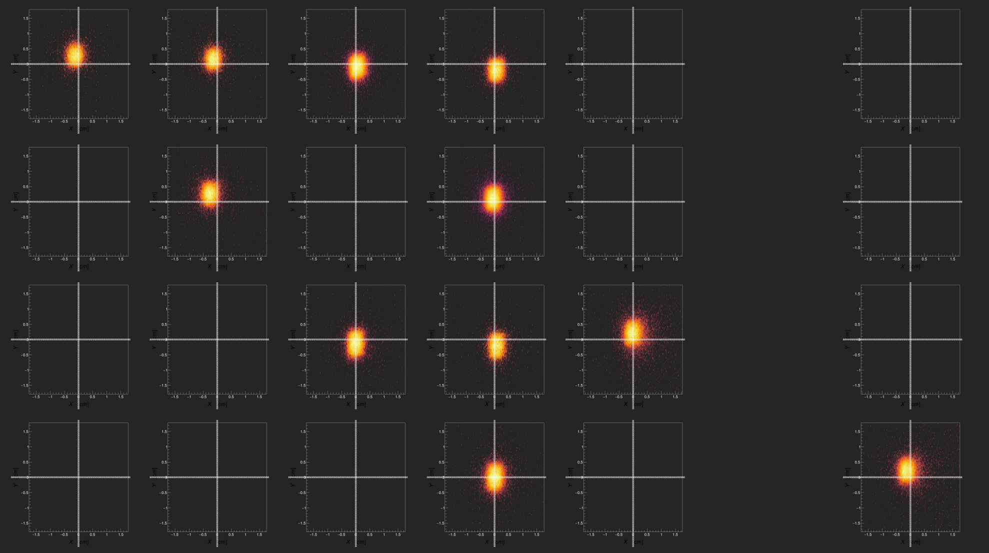


mSTS Self alignment



Run minimization: Vertex Spread

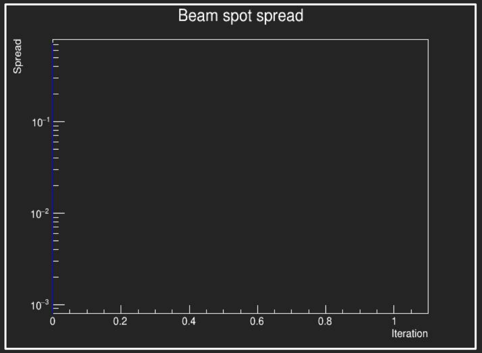
$$S = \sqrt{\frac{\sum_{ij}(v_{ij} - \bar{v})^2}{N_{pairs}}}$$

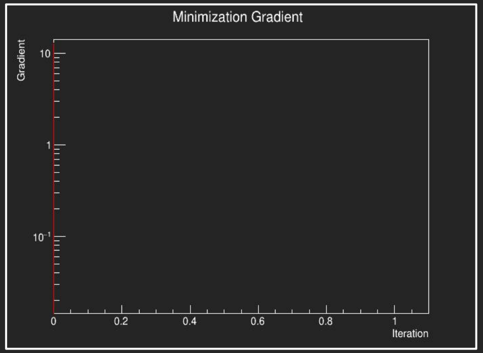


Minimization: Gradient decedent

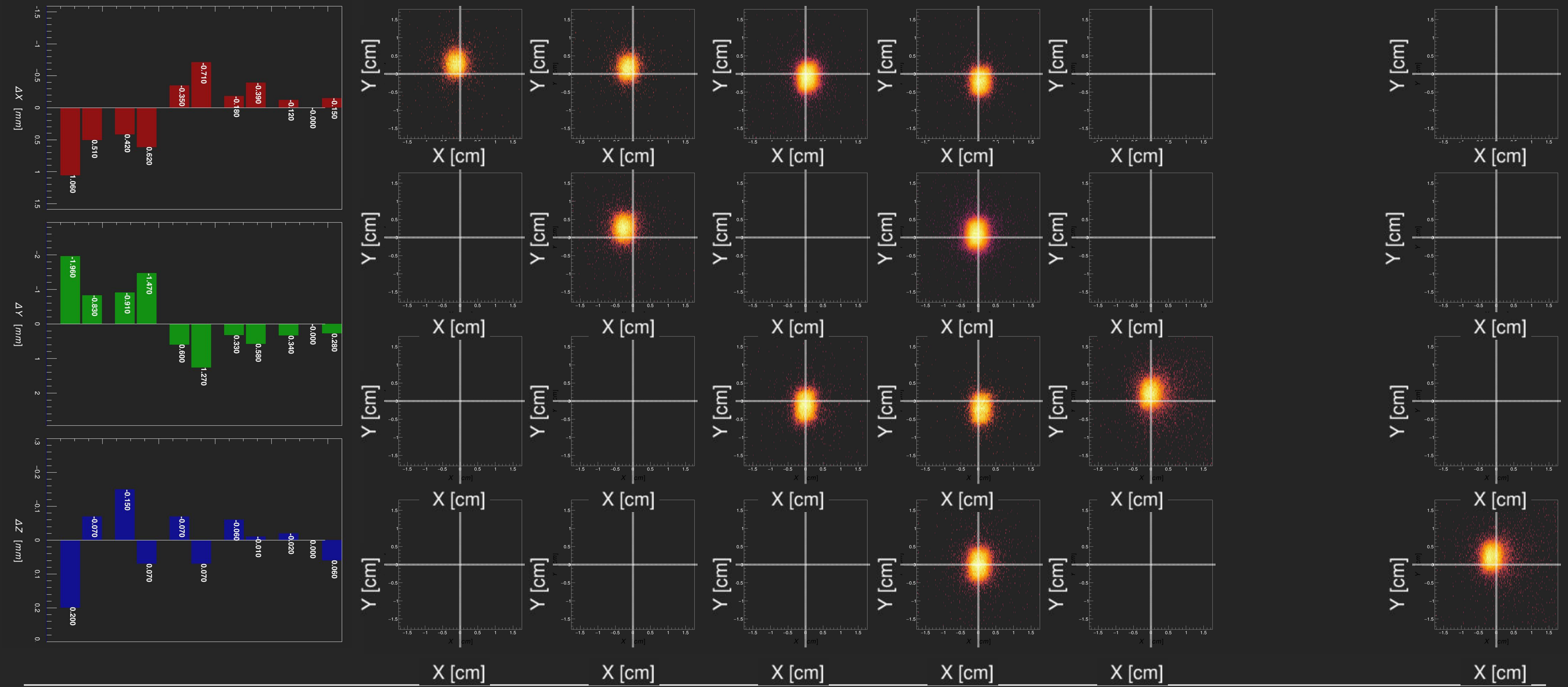
v_{ij} : vertex position for sensor_i, sensor_j

(currently, only translations - easily extended)



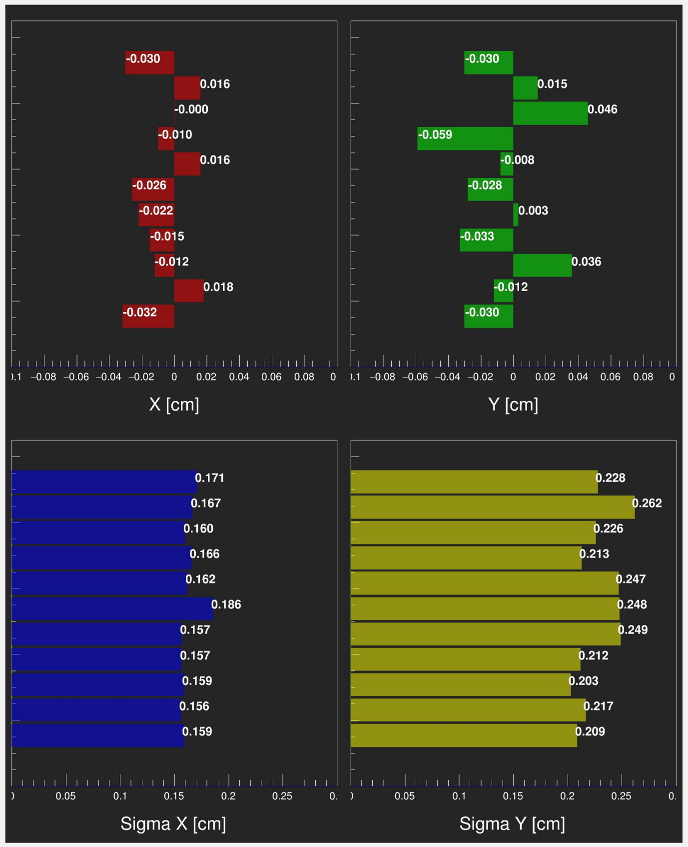


mSTS Vertex Reconstruction - Splitting contributions

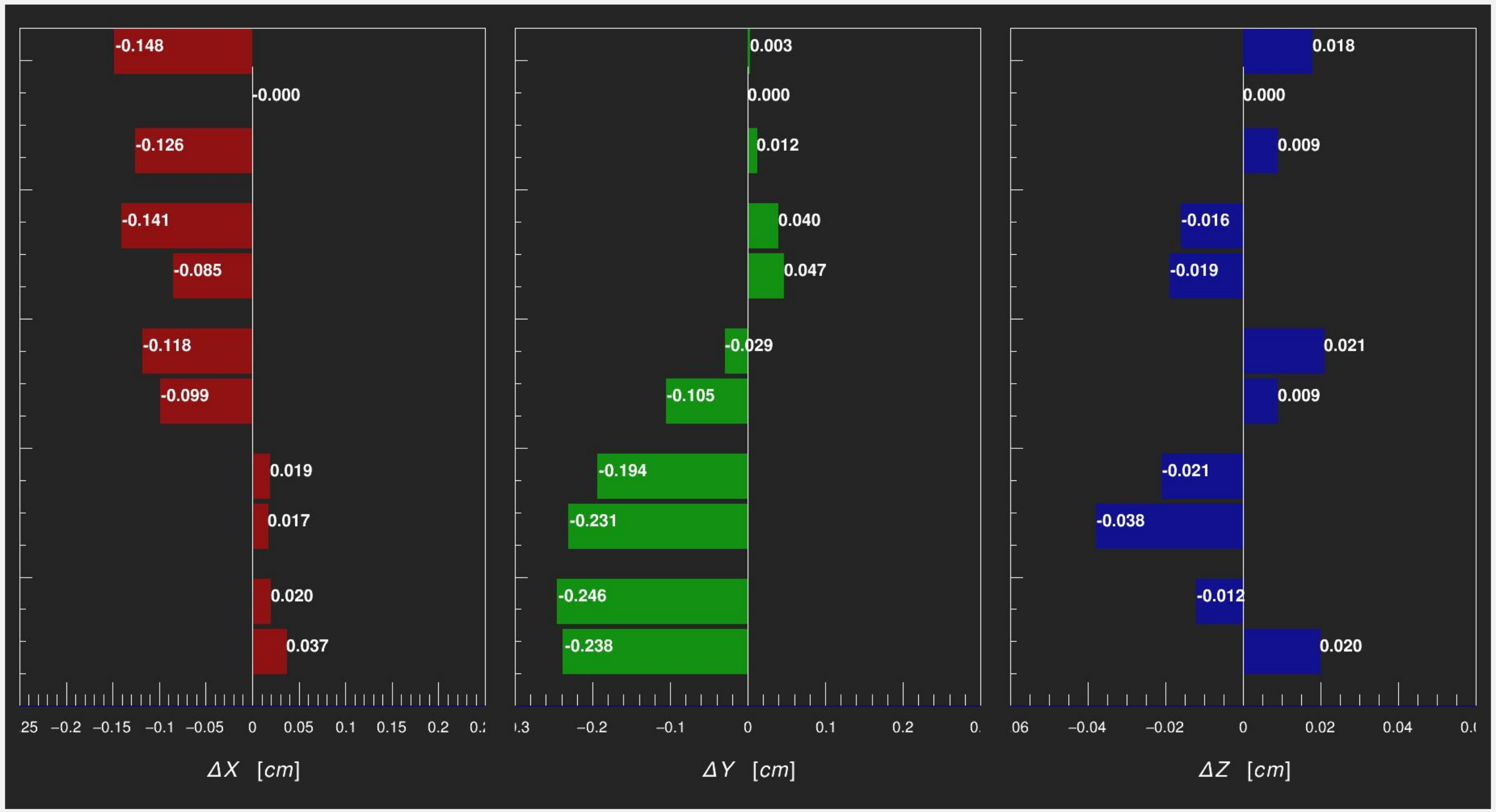


mSTS Vertex Reconstruction

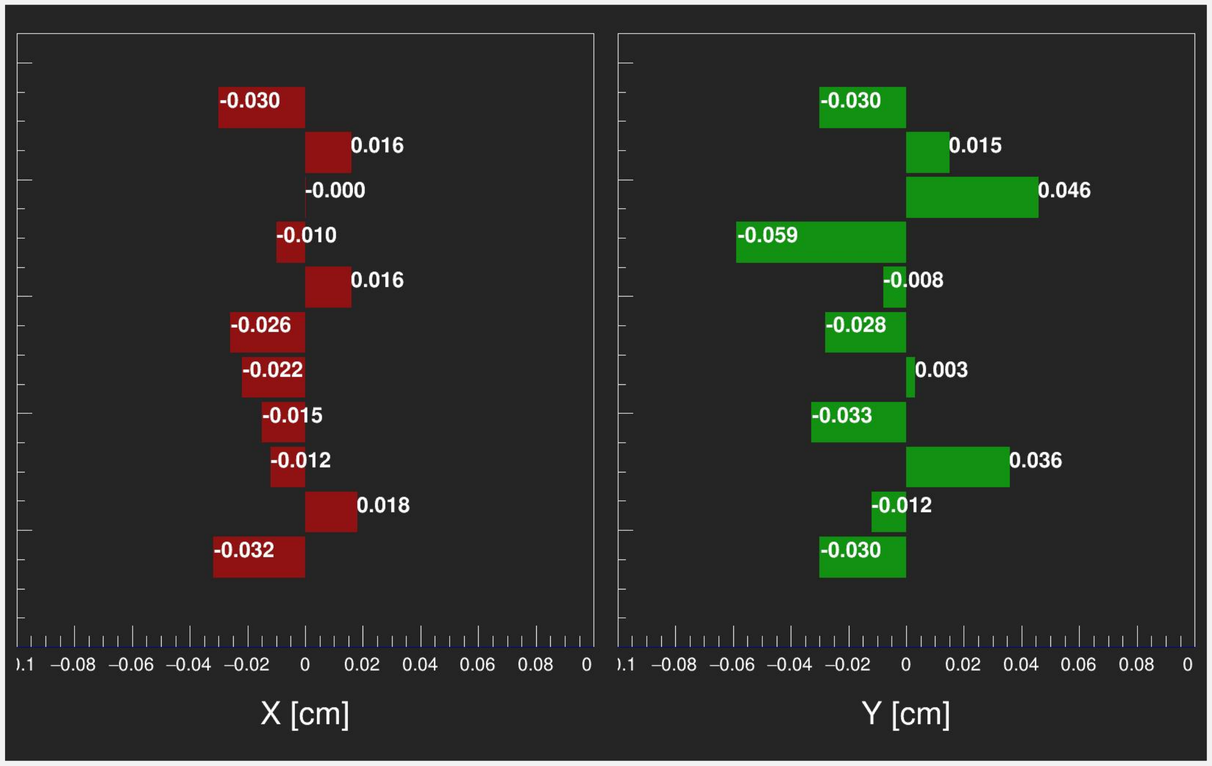
Aligned vertex



Sensor alignment parameters

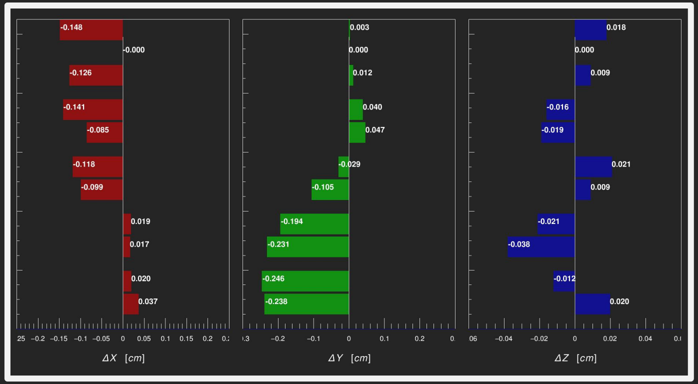


mSTS Vertex Reconstruction

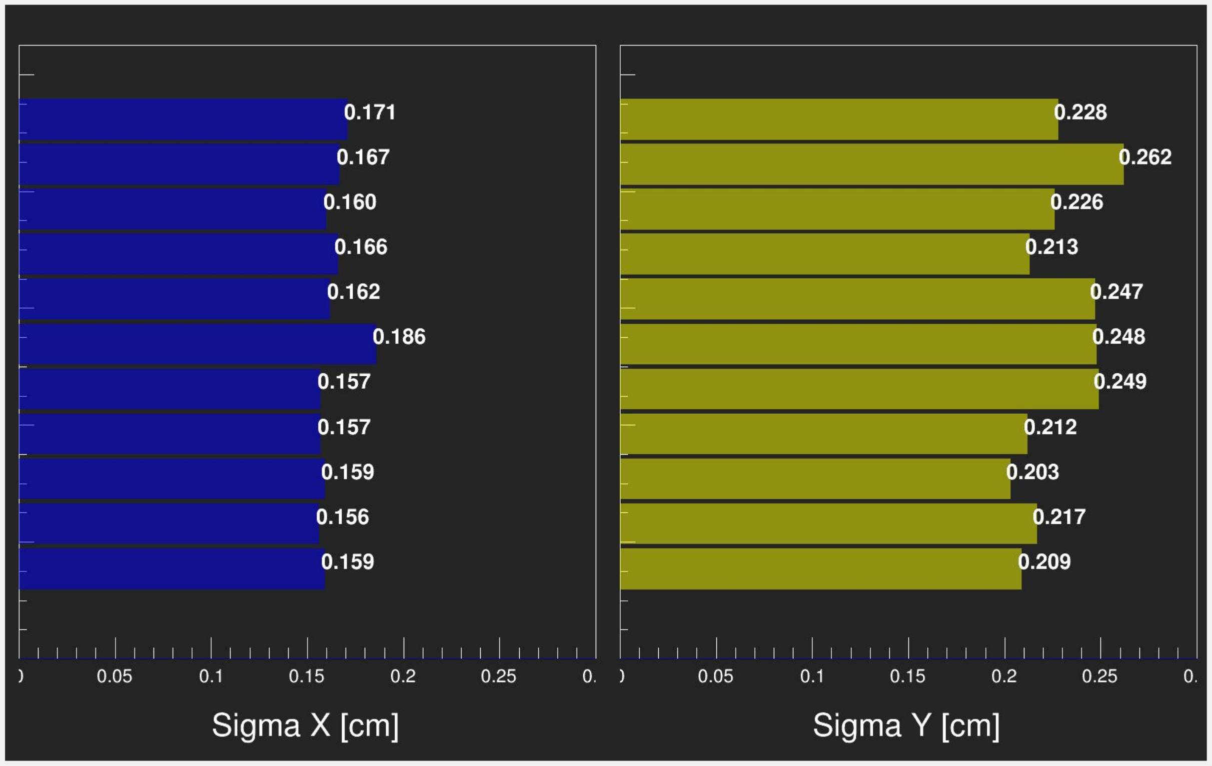


Different sensor pairs reconstruct beam spot at the same position

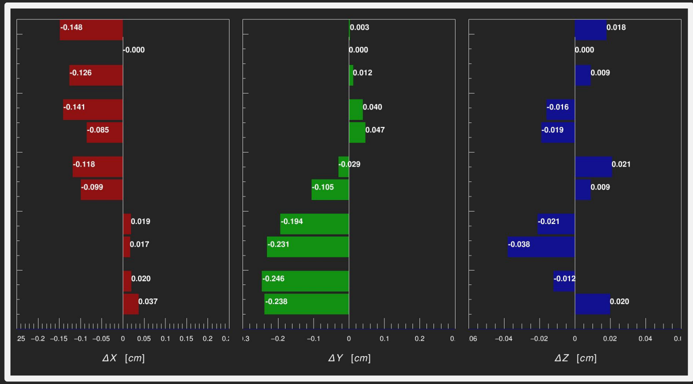
$$S = \sqrt{\frac{\sum_{ij} (v_{ij} - \bar{v})^2}{N_{pairs}}} = 300\ \mu m : 8\ iterations$$



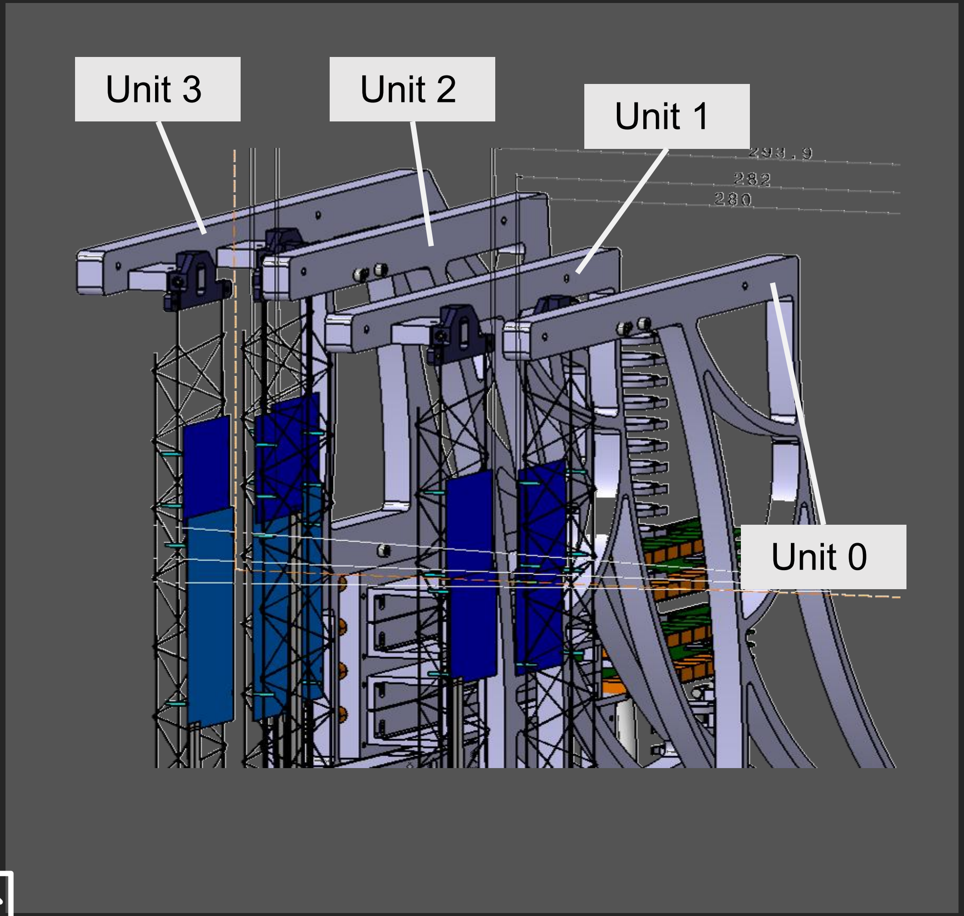
mSTS Vertex Reconstruction



Consistent vertex shape for different sensor pairs!

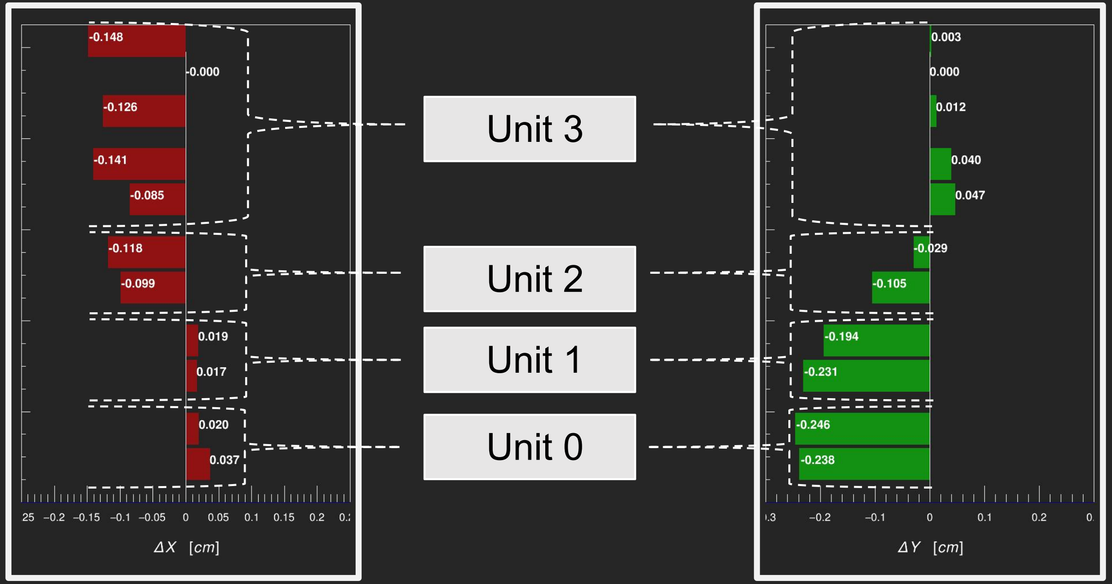


mSTS Vertex Reconstruction

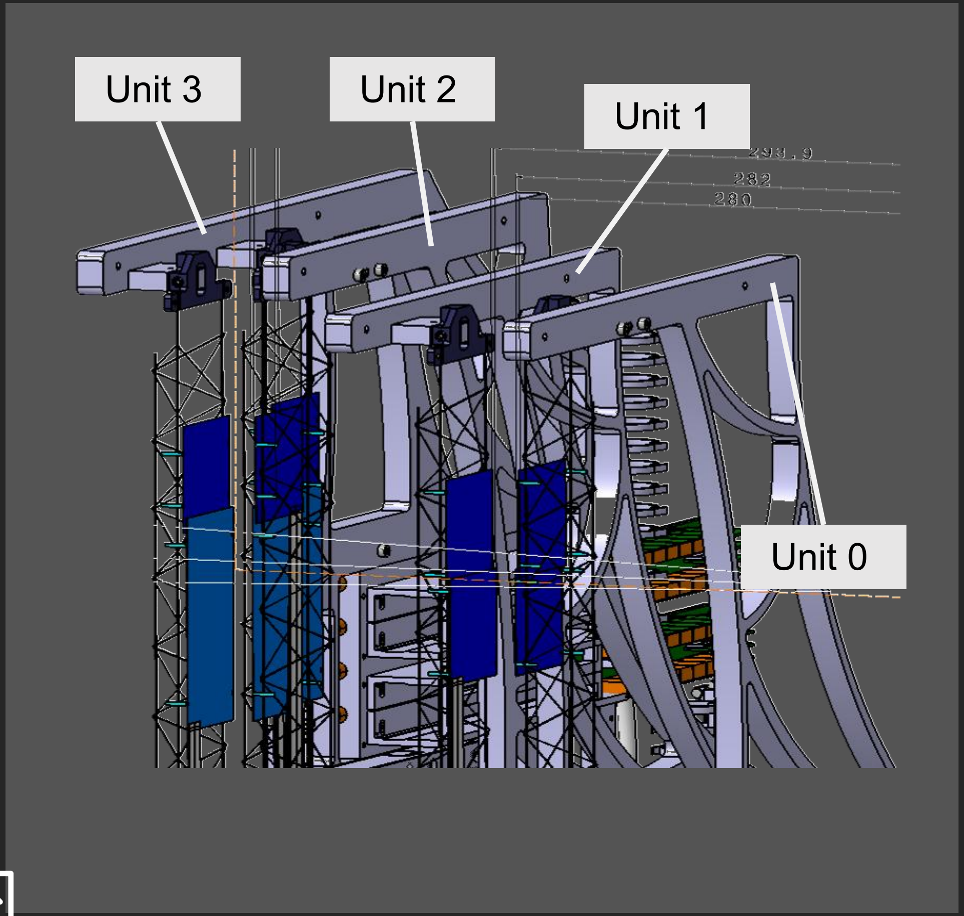


Sensor in the same mechanical structure move on the same direction

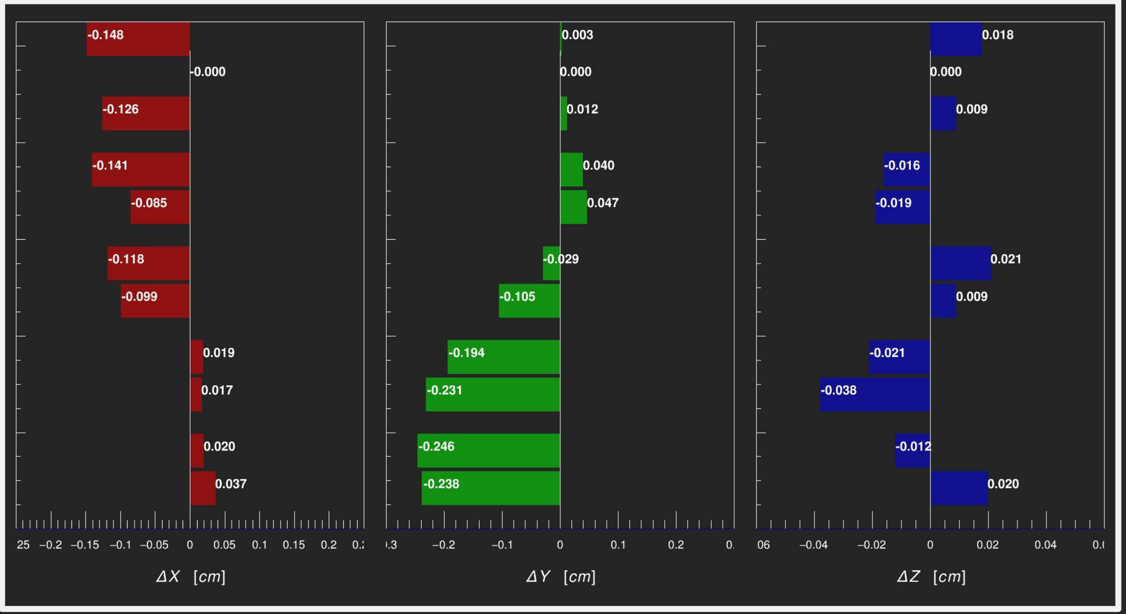
Rotations still need to be considered

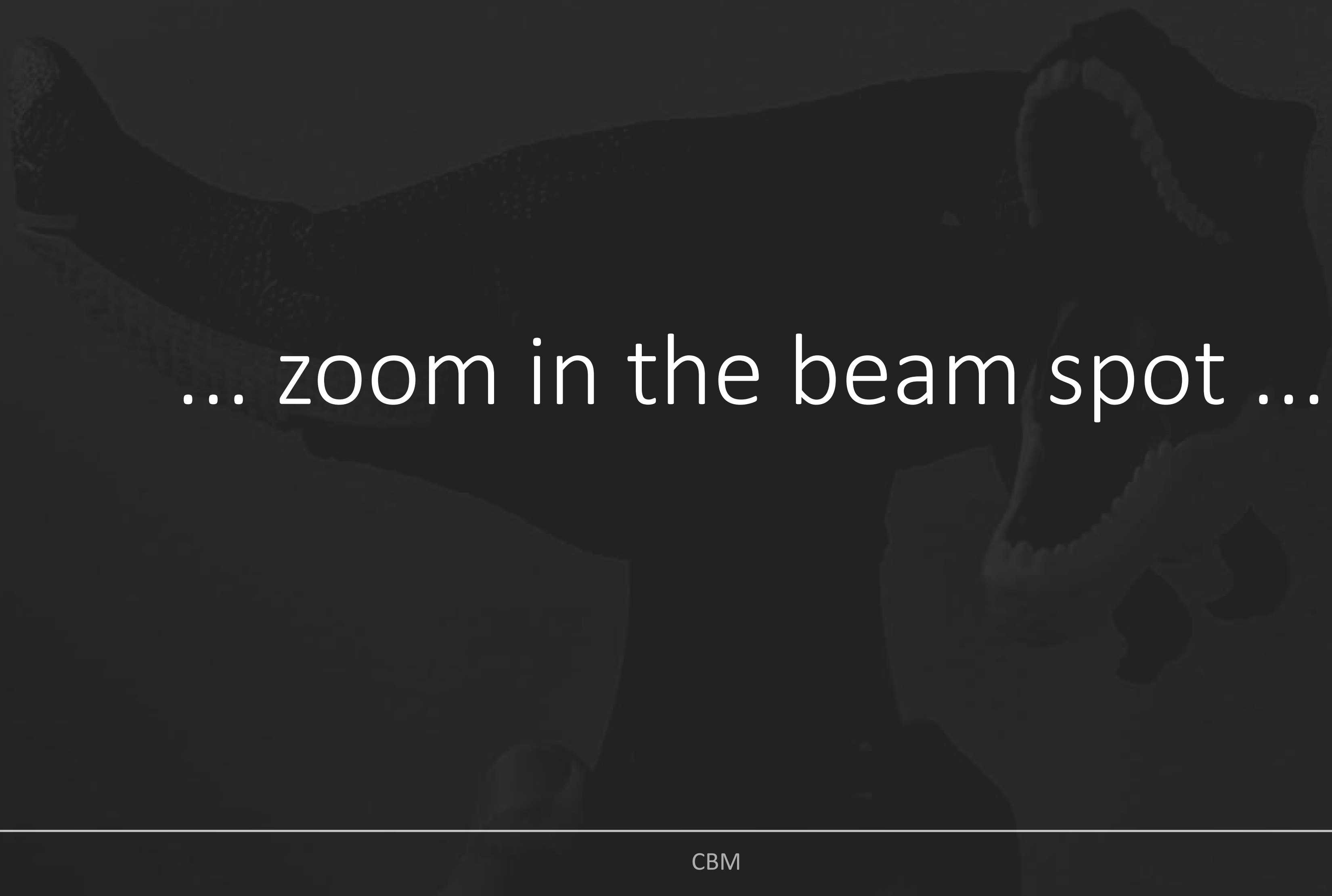


mSTS Vertex Reconstruction



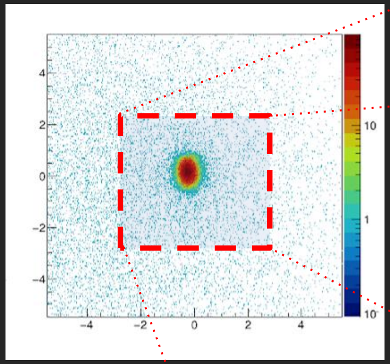
Sensor alignment translations are consistent with the mechanical assembly!

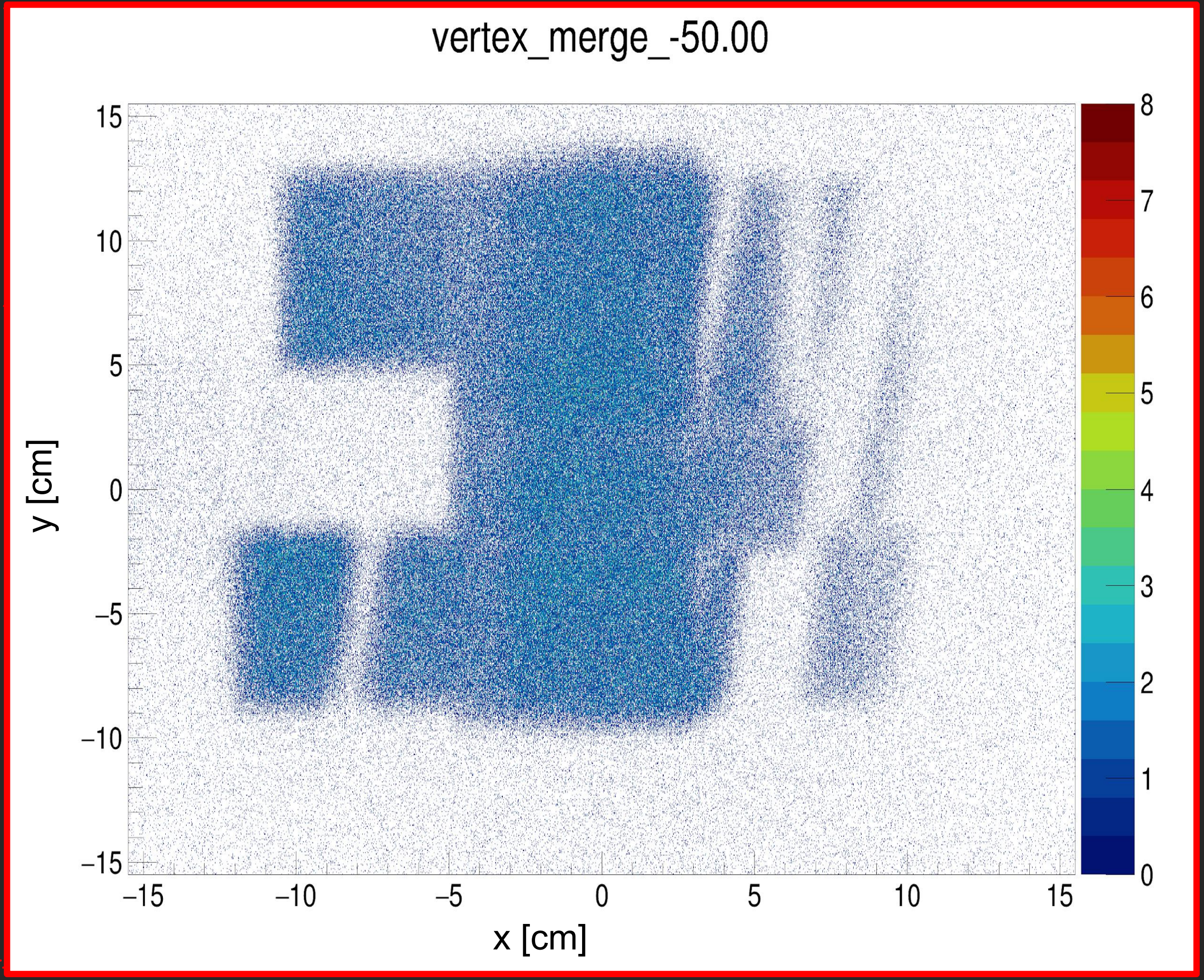




... zoom in the beam spot ...

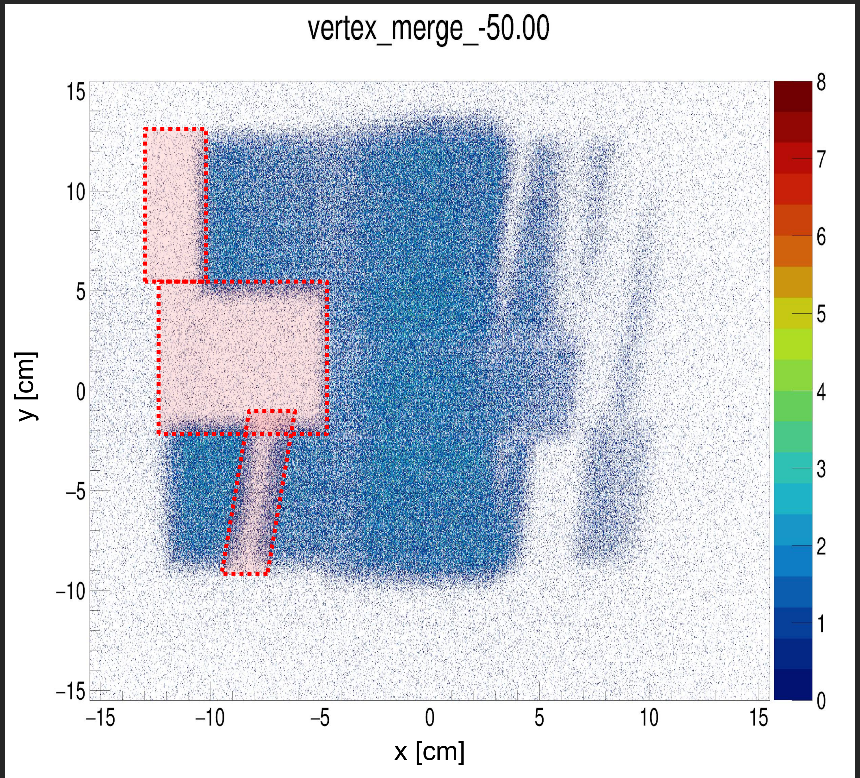
mSTS Vertex Reconstruction - Zooming the vertex

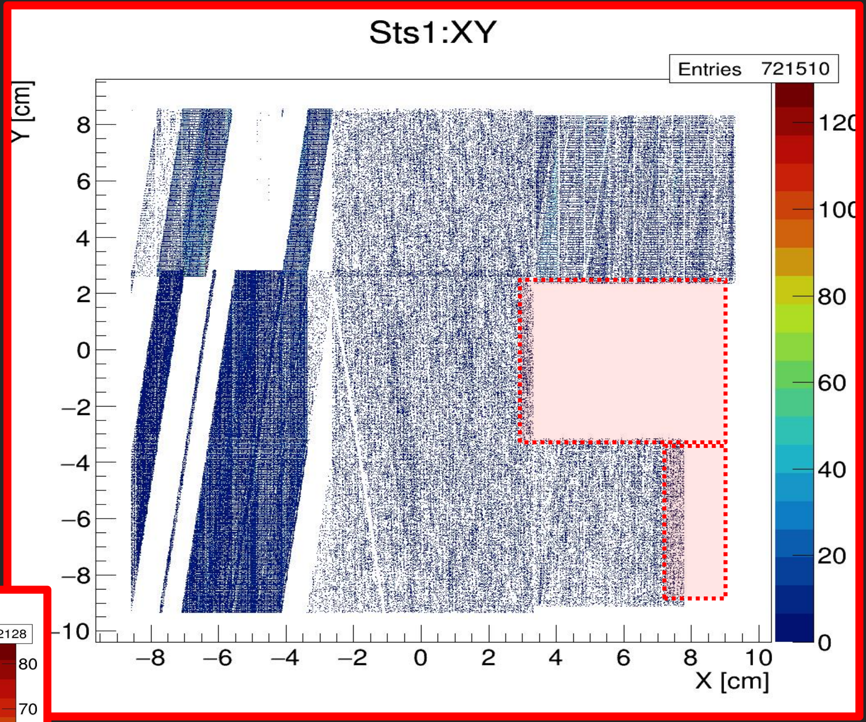


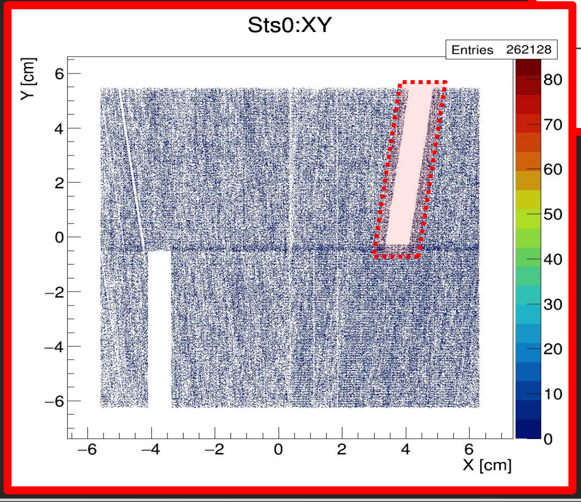


Extrapolating to large distance, detector structure shows up

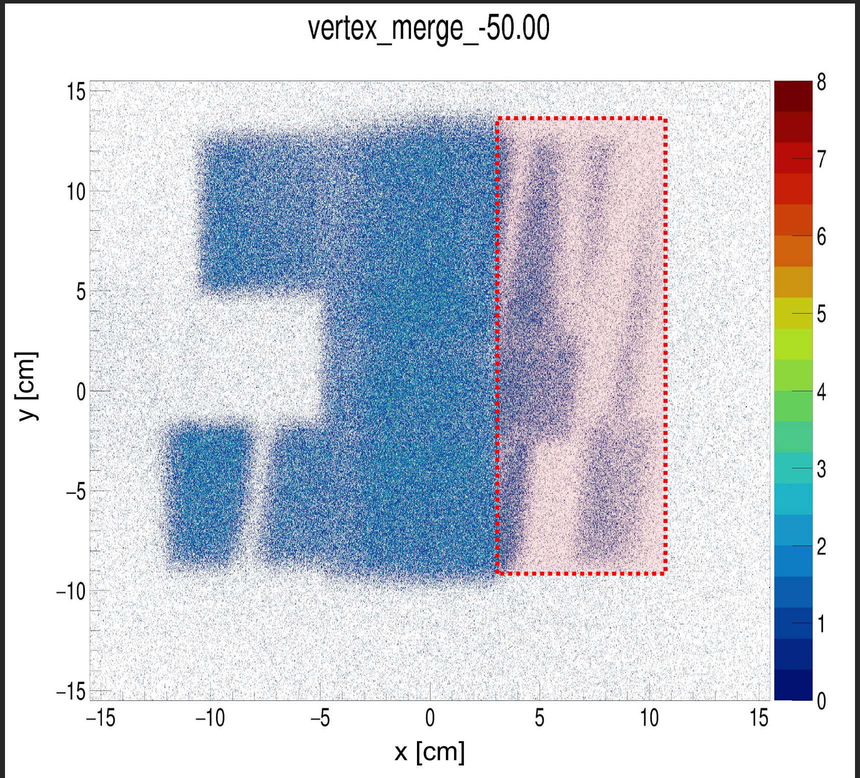
mSTS Vertex Reconstruction - Vertex structures

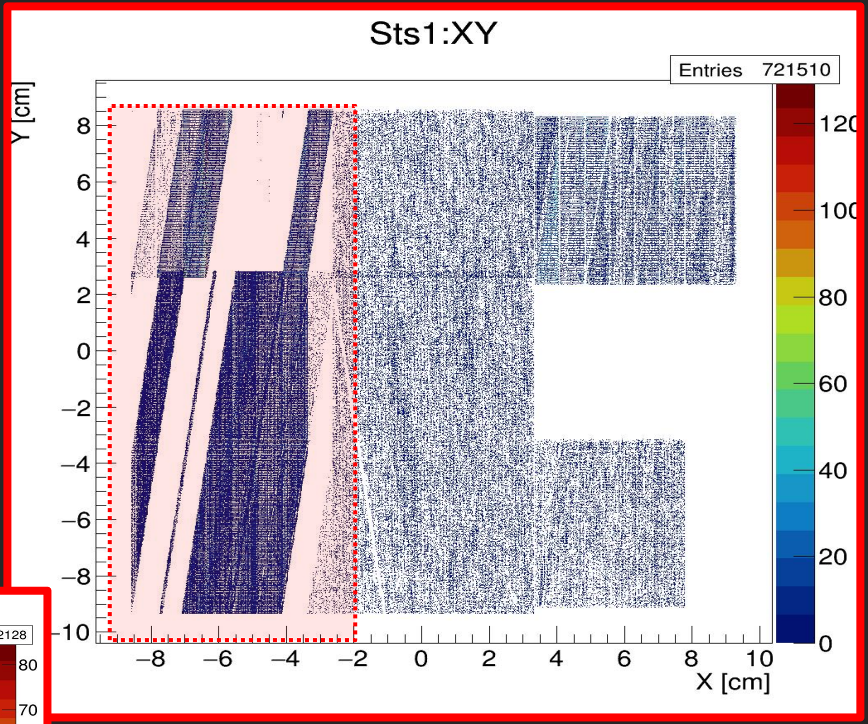


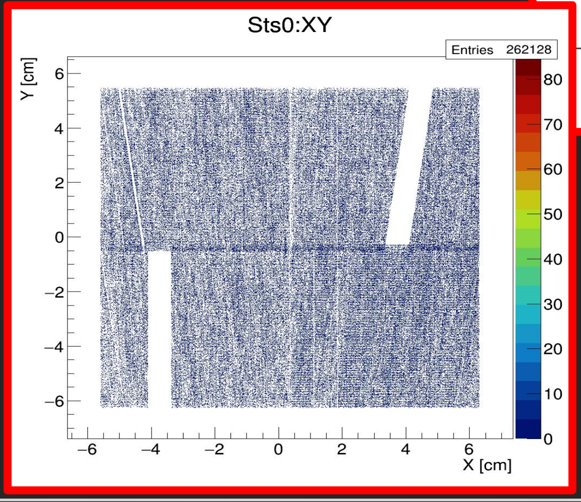


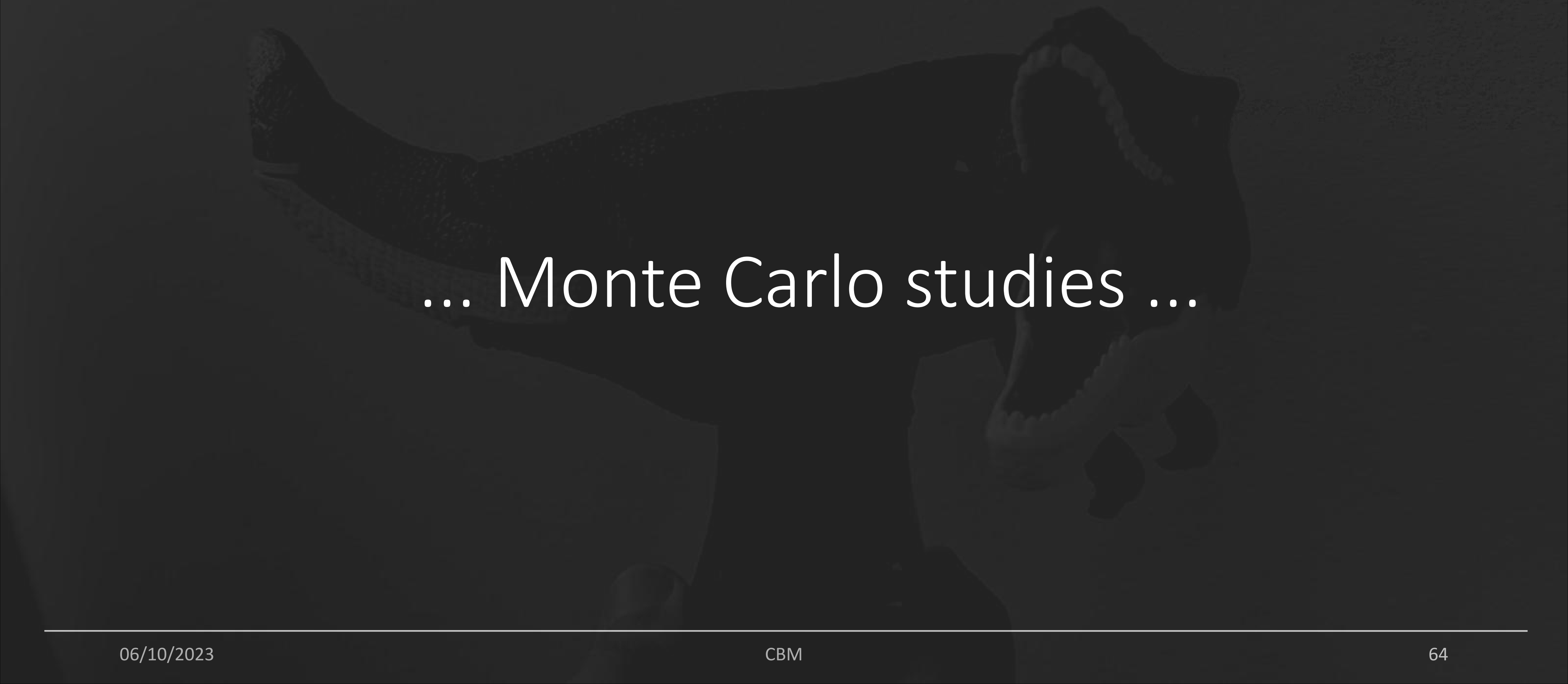


mSTS Vertex Reconstruction - Vertex structures



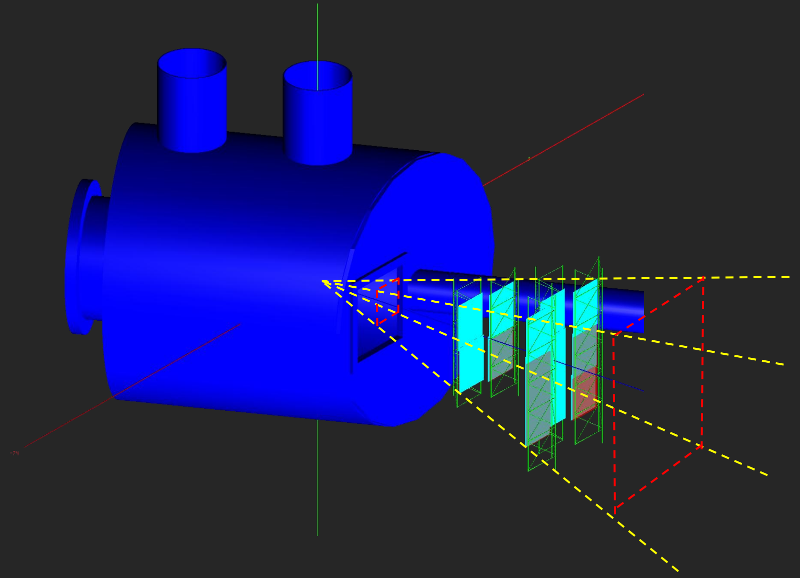






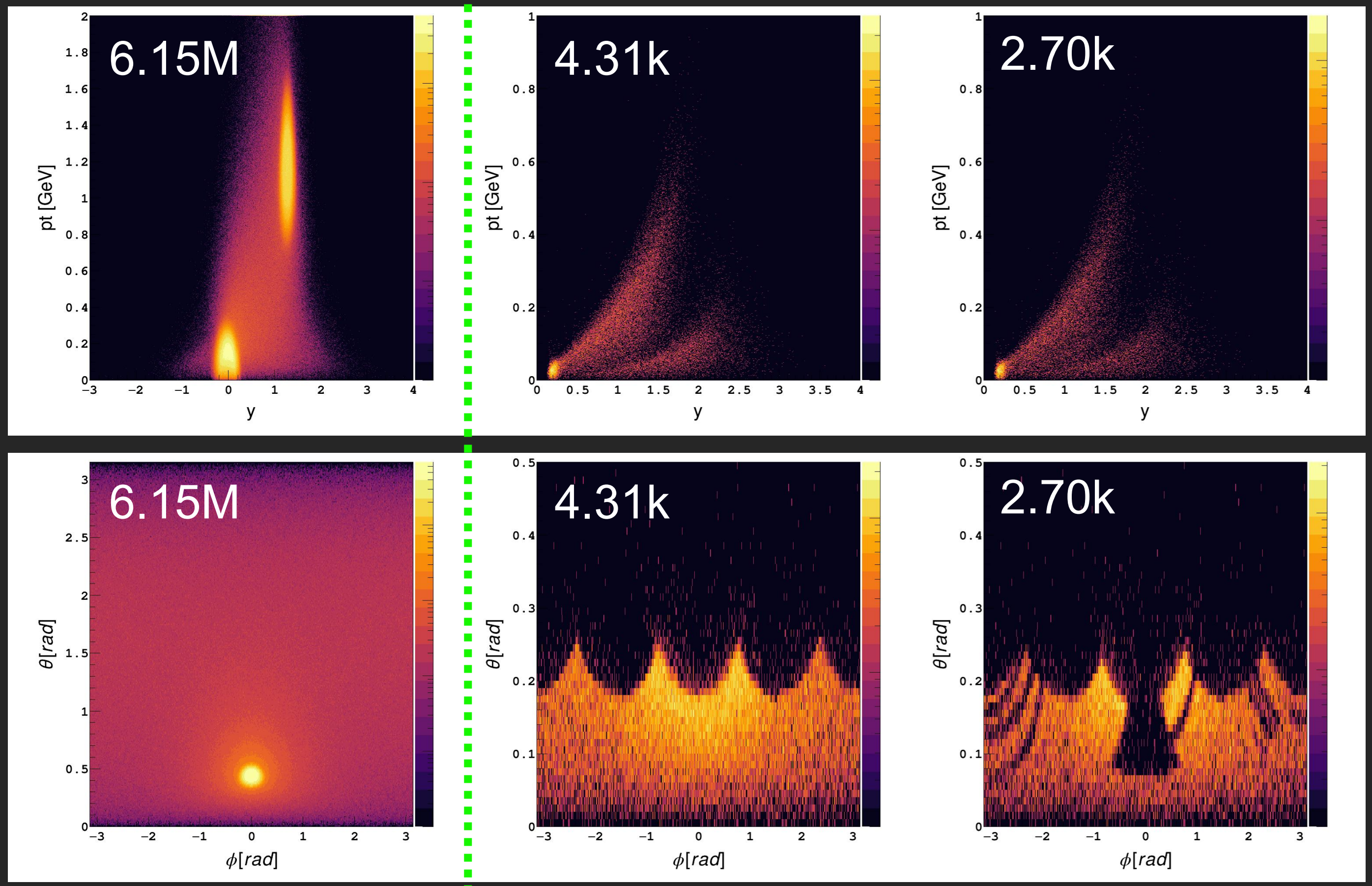
… Monte Carlo studies …

mSTS Acceptance - MCTrack

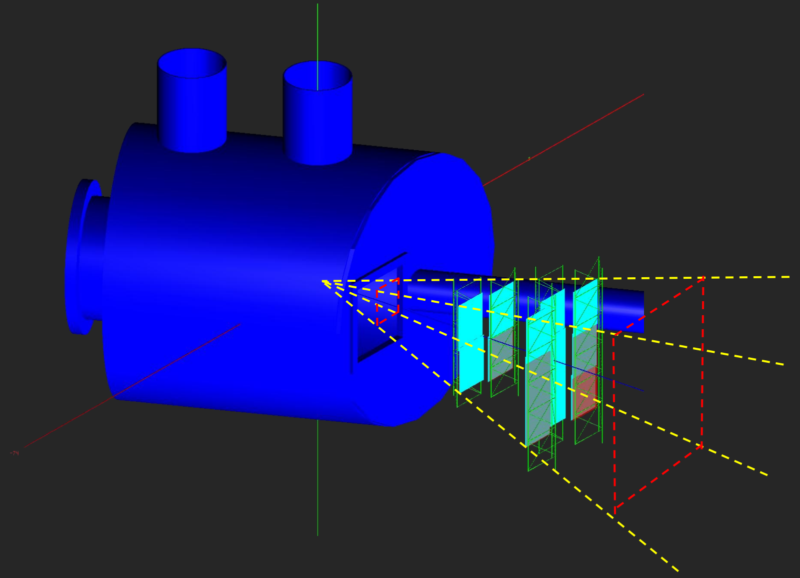


6.15M primary tracks

All tracks | Hitting 2 Sts layers | 2 Reconstructed layers



mSTS Acceptance - MCTrack

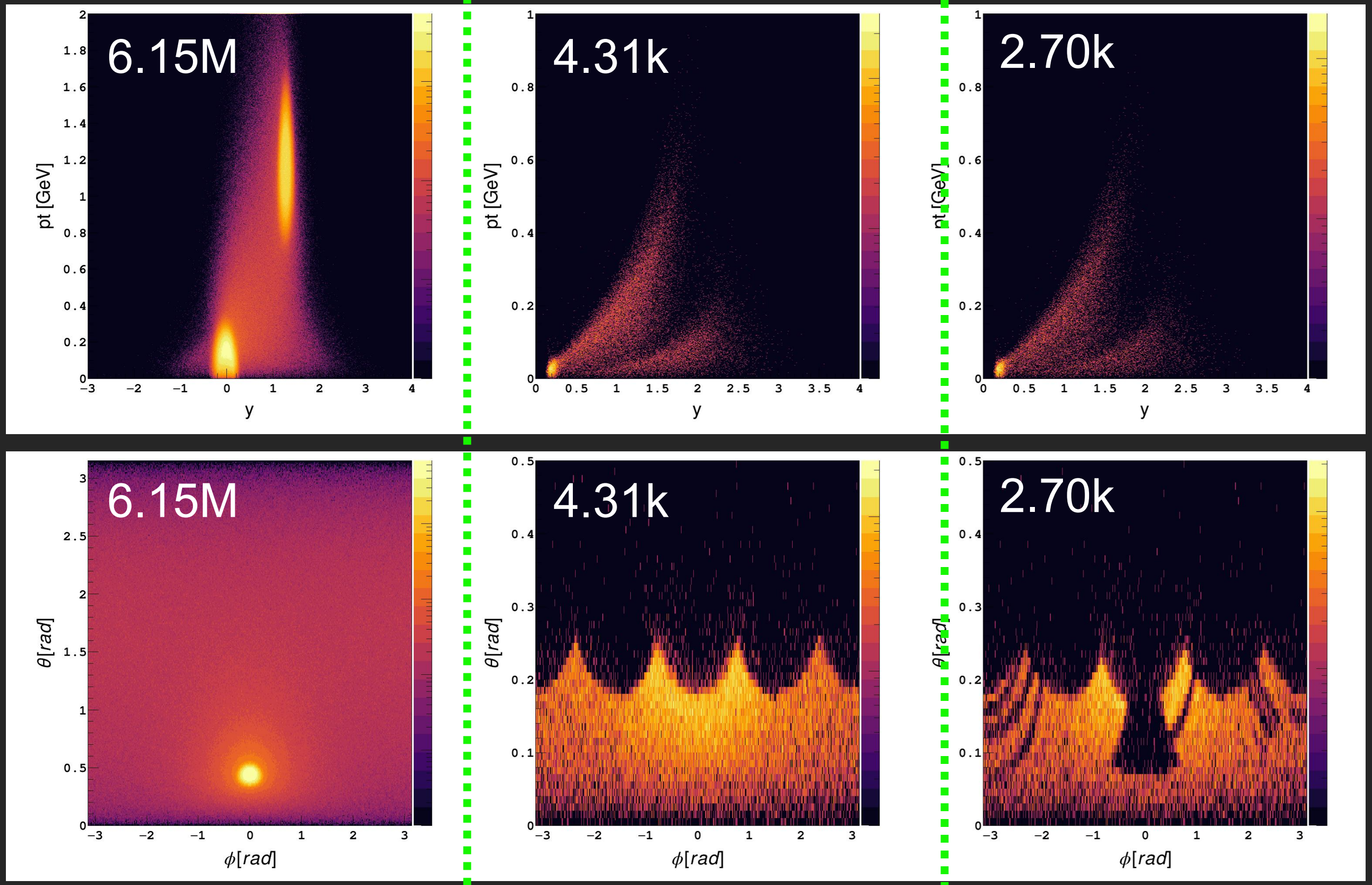


ACCEPTED / ALL: 7.00 %
RECO / ALL : 4.39 %
RECO / ACCEPTED: 62.64 %

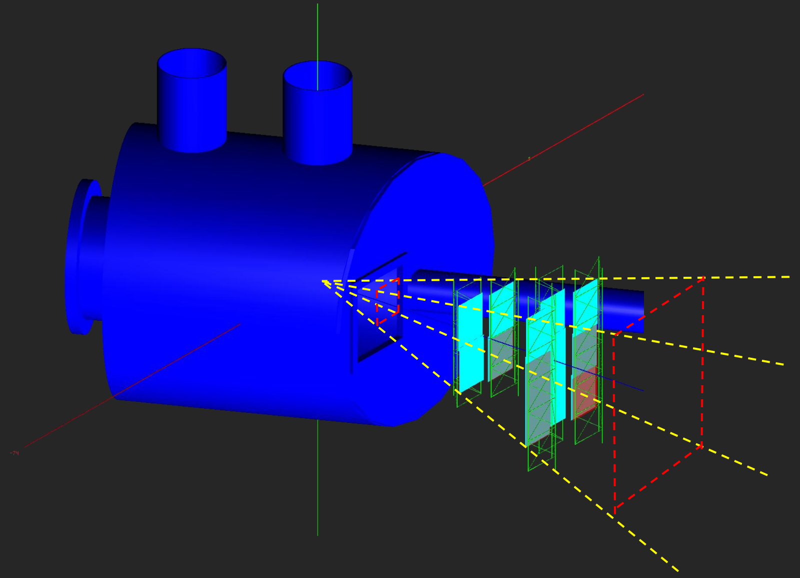
All tracks

Hitting 2 Sts layers

2 Reconstructed layers



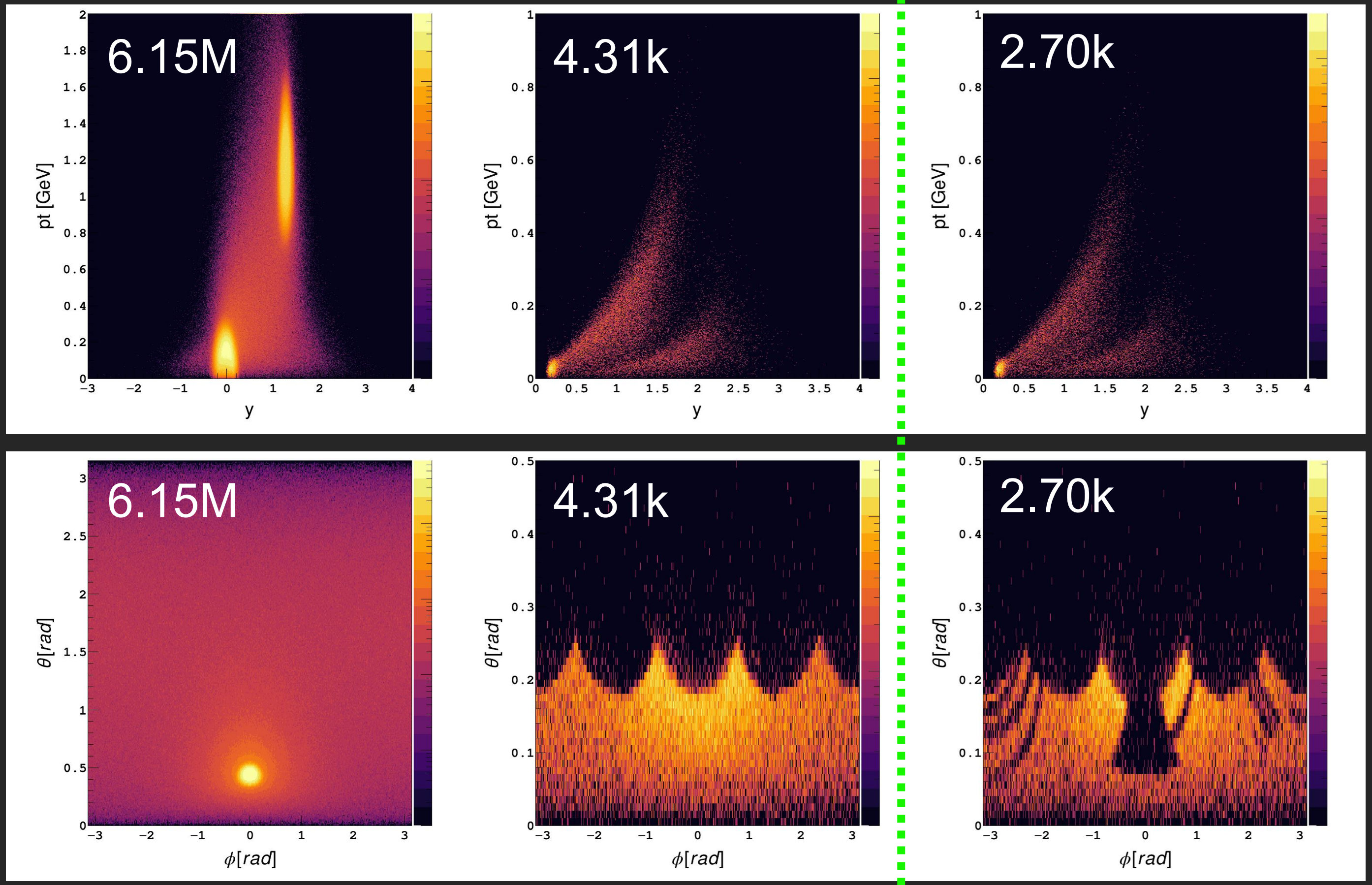
mSTS Acceptance - MCTrack



All tracks

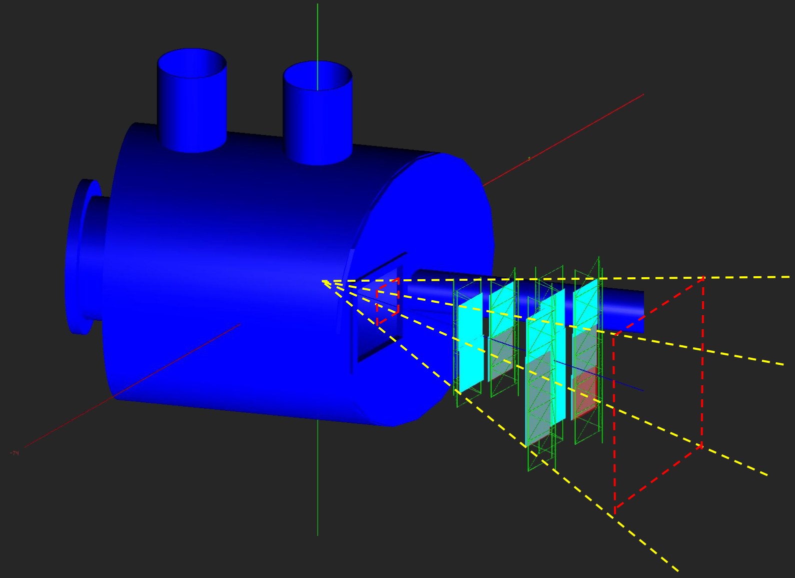
Hitting 2 Sts layers

2 Reconstructed layers



ACCEPTED / ALL: 7.00 %
RECO / ALL : 4.39 %
RECO / ACCEPTED: 62.64 %

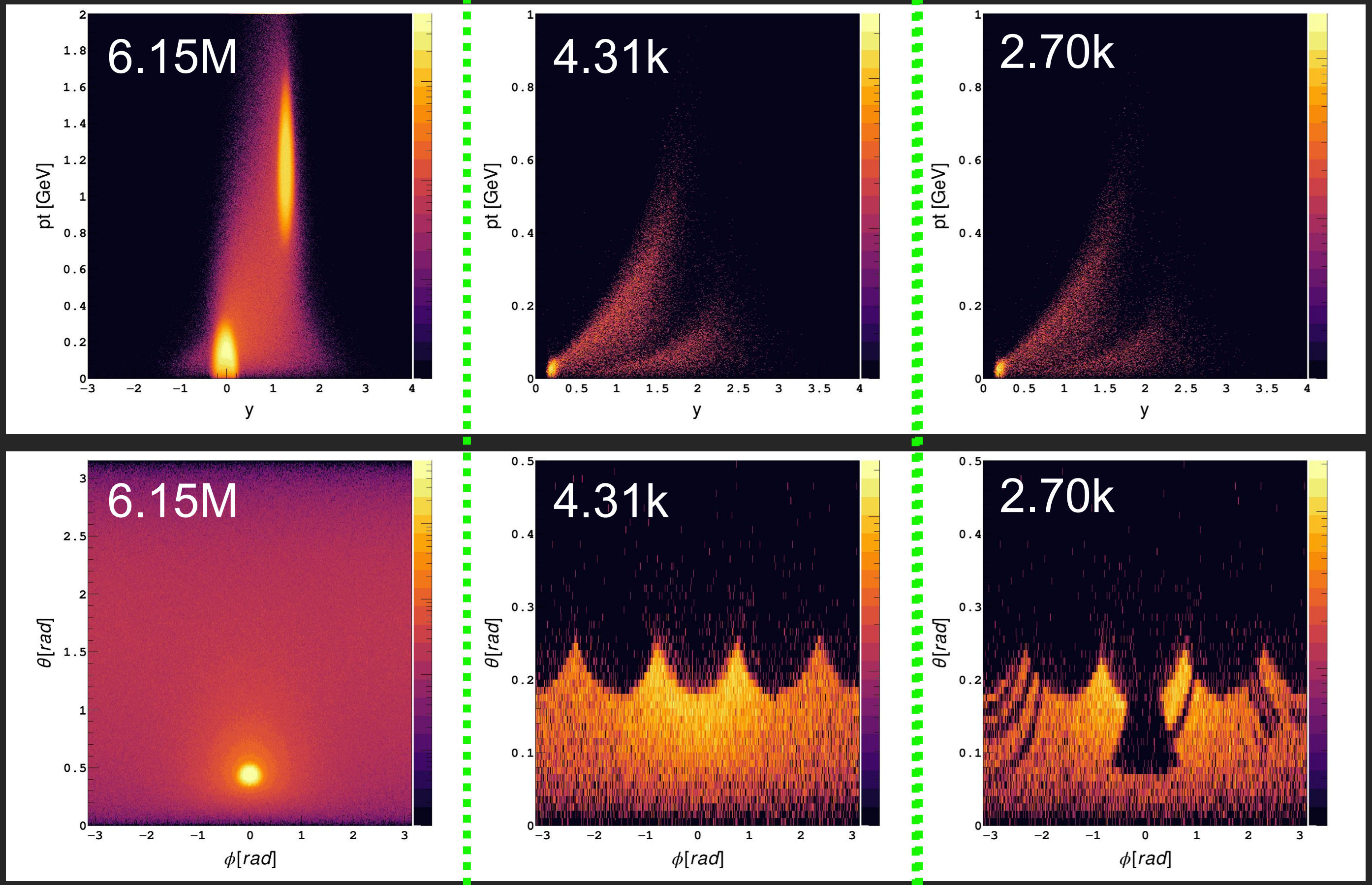
mSTS Acceptance - MCTrack



All tracks

Hitting 2 Sts layers

2 Reconstructed layers

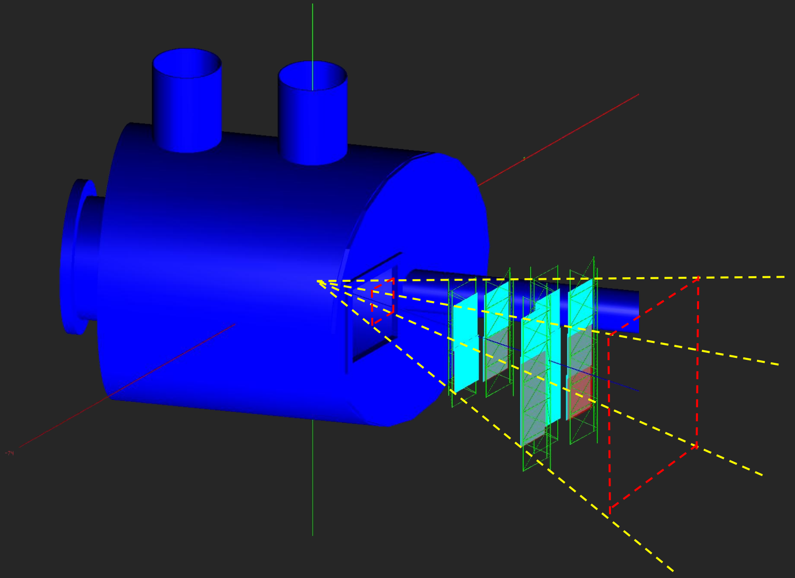


ACCEPTED / ALL: 7.00 %

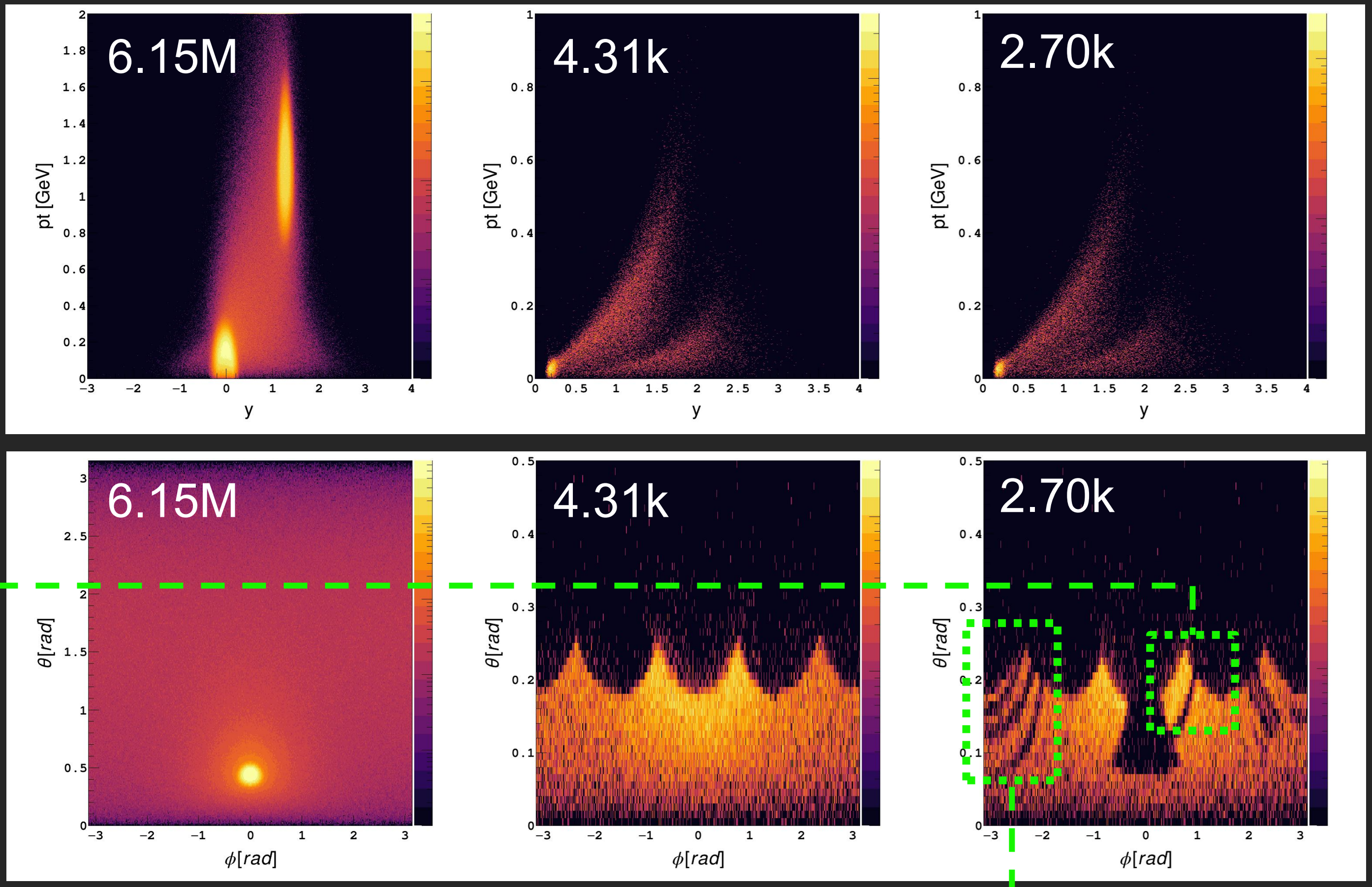
RECO / ALL : 4.39 %

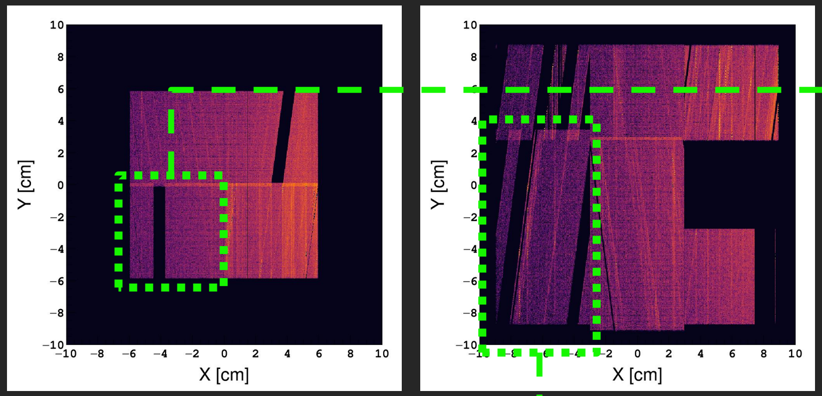
RECO / ACCEPTED: 62.64 %

mSTS Acceptance - MCTrack

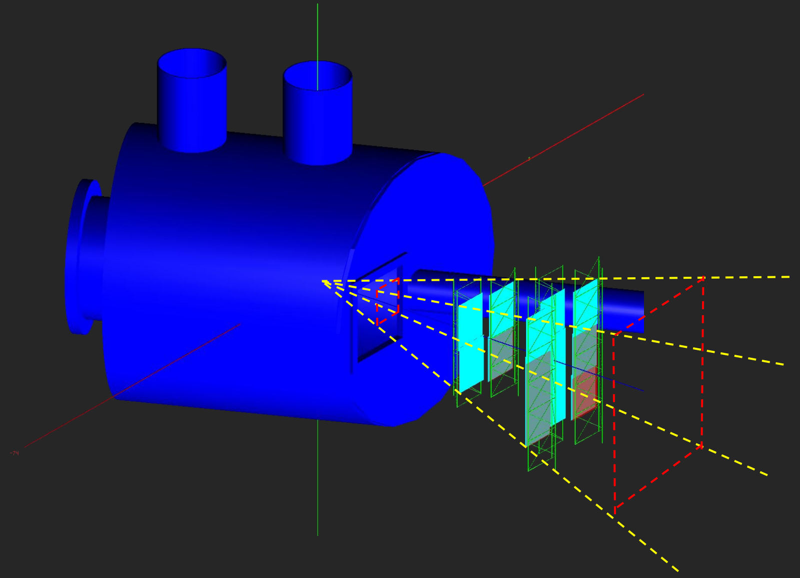


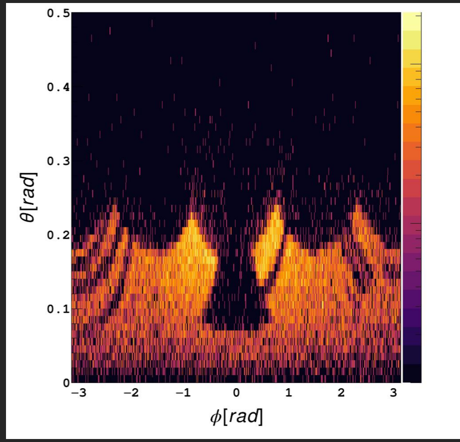
All tracks | Hitting 2 Sts layers | 2 Reconstructed layers



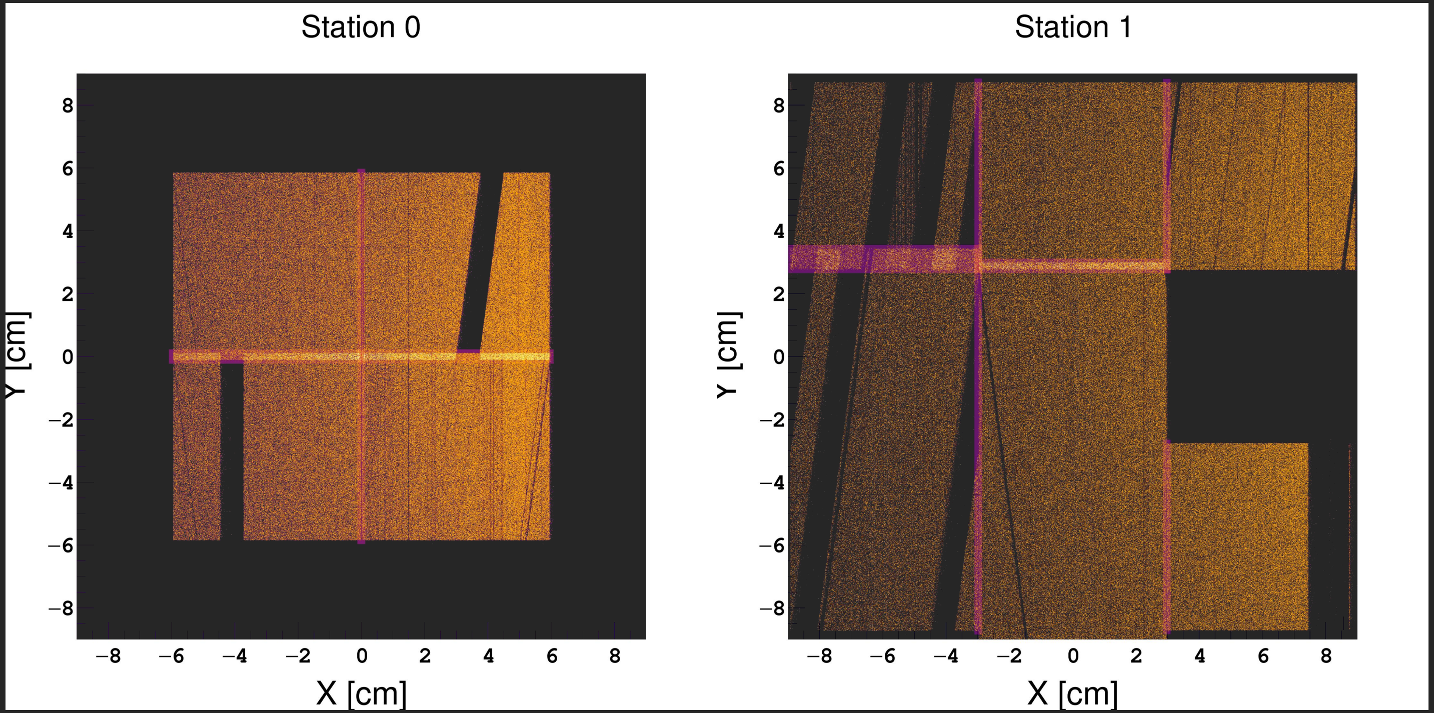


mSTS Acceptance - MC - Hit Reconstruction Efficiency





MC HRE >99.98%
Excluding inactive areas



mSTS Rates

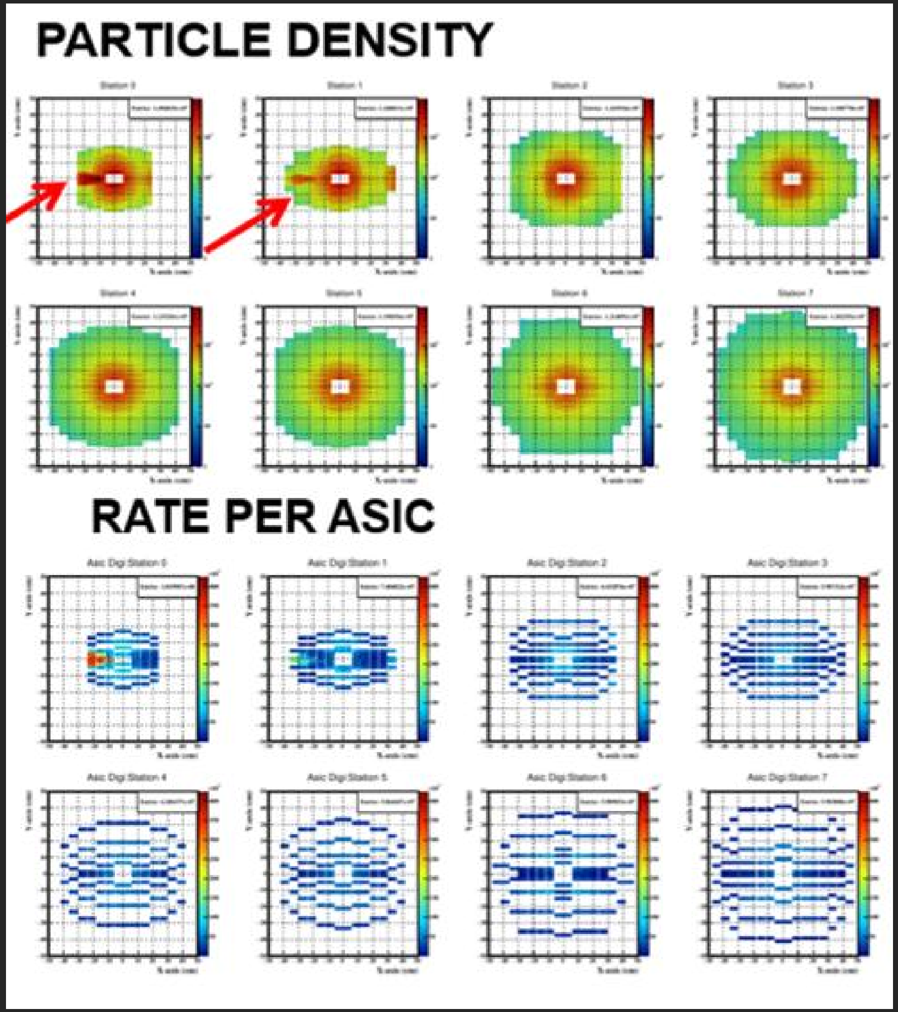
Expected rates STS - Worst Scenario - Monte Carlo

Au+Au - 12AGeV/c - 10MHz
Au-beam target interaction at 10^9 ions/s -> delta e
UrQMD Au+Au at 10^7 collisions/s

Delta e - low pT - B-field (1T): bent out or absorbed
The two first STS stations suffer the most

Digitization:
ENC = 1000 e,
Threshold: 4000 e

Max rate per channel: $150 \cdot 10^3$ digis /ch / s
few exceptions: $250 - 300 \cdot 10^3$ digis /ch / s

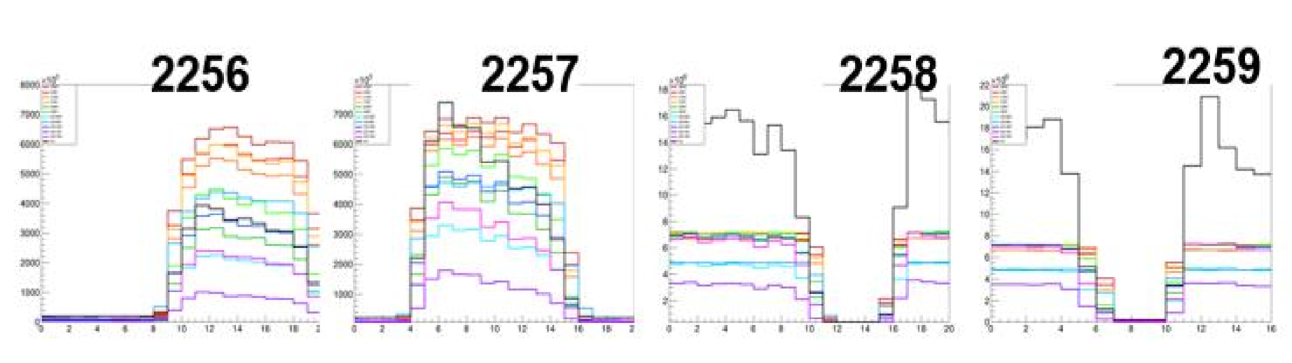


Observed rates mSTS

- Beam Intensity scan: U+Au
- micro-spill structures up to 1:10

STS can sustain rates up to:
27×10^3 digi/channel/sec

Run Number	Beam intensity (ions/spill)	Rate (digi/ch/s)
2256	$5 \cdot 10^7$	$25 \cdot 10^3$
2257	$1 \cdot 10^8$	$27 \cdot 10^3$
2258	$5 \cdot 10^8$	$28 \cdot 10^3$
2259	$1 \cdot 10^9$	$28 \cdot 10^3$



Observed rates mSTS

- Beam Intensity scan: U+Au
- micro-spill structures up to 1:10

STS can sustain rates up to:
28×10^3 digi/channel/sec

In mCBM saturation is reached ~ $5 \cdot 10^8$ ions/spill

Run Number	Beam intensity (ions/spill)	Rate (digi/ch/s)
2256	$5 \cdot 10^7$	$25 \cdot 10^3$
2257	$1 \cdot 10^8$	$27 \cdot 10^3$
2258	$5 \cdot 10^8$	$28 \cdot 10^3$
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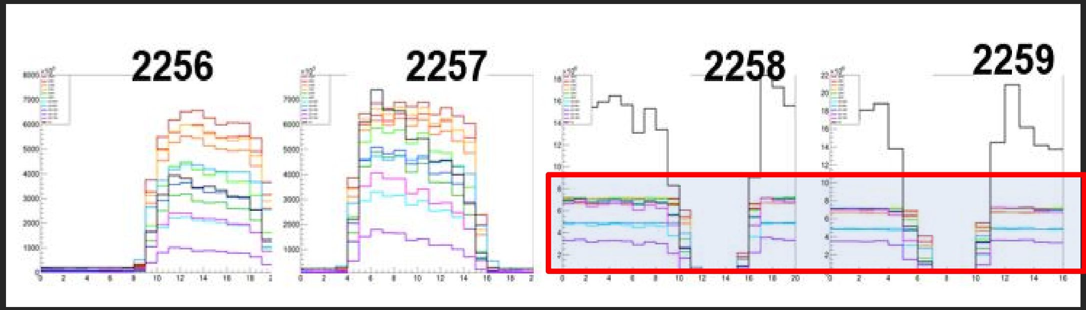
Saturated mSTS



Observed rates mSTS

Scaling bandwidth (to be tested!!!)
x5 FEB8_1 → FEB8_5:
$140 \cdot 10^3$ digi/ch/s

mSTS hardware update is coming to proof the linear scaling!

New module!!!
FEB8_5