Charged Particle Trajectory Reconstruction Algorithms for Cathode Strip Chambers of the CMS Experiment

Vladimir Palichik, Nikolay Voytishin
JINR(Dubna)

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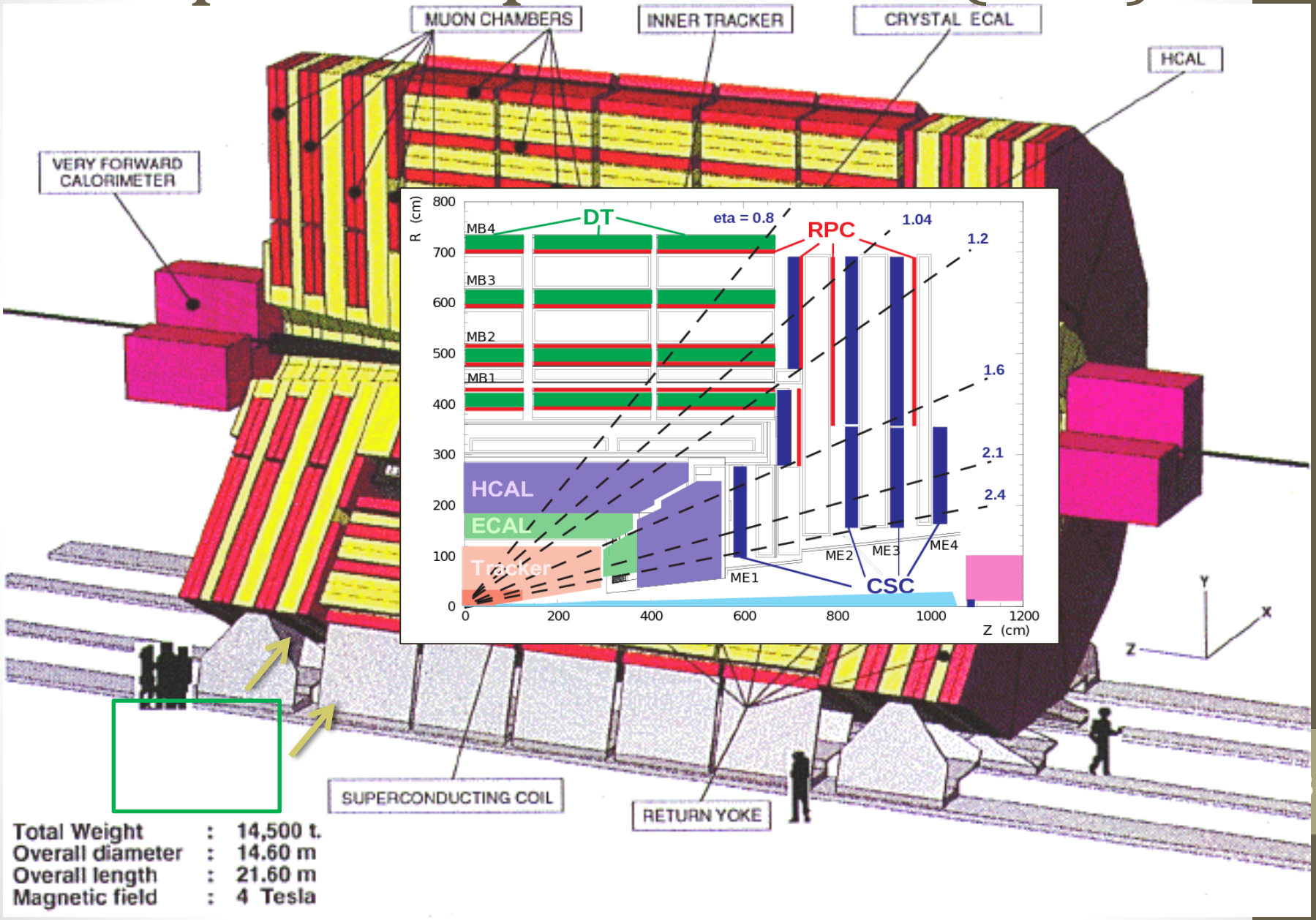
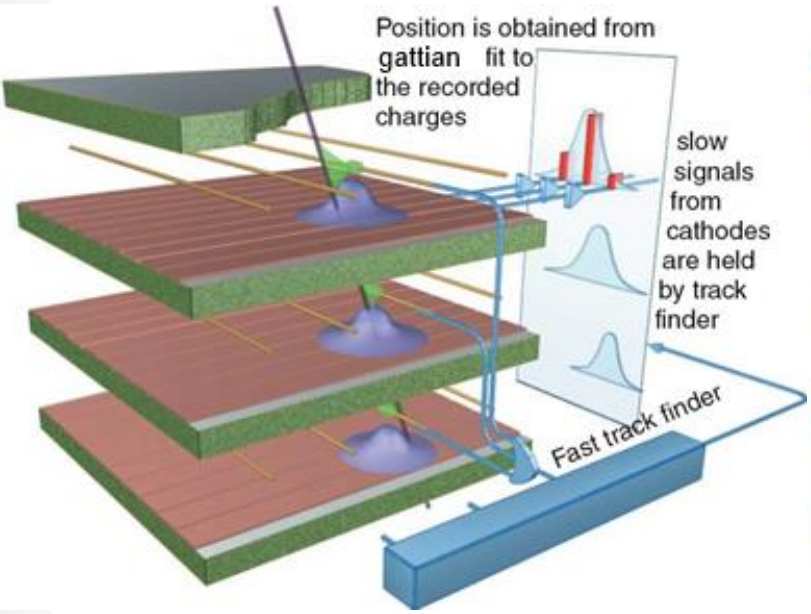
Outline

- Cathode-Strip Chamber (CSC) detector of the CMS experiment;
- Segment reconstruction in CSCs;
- Precise coordinate reconstruction in CSCs:
  - Simple two maxima delimitation;
  - Wavelet-based algorithm for multiple maxima.

Compact Muon Solenoid (CMS) Detector



CSC Local Reconstruction



2D points

- ϕ coordinate measured by charge distribution on strips (fit with the Gatti function)
- R coordinate measured by wires

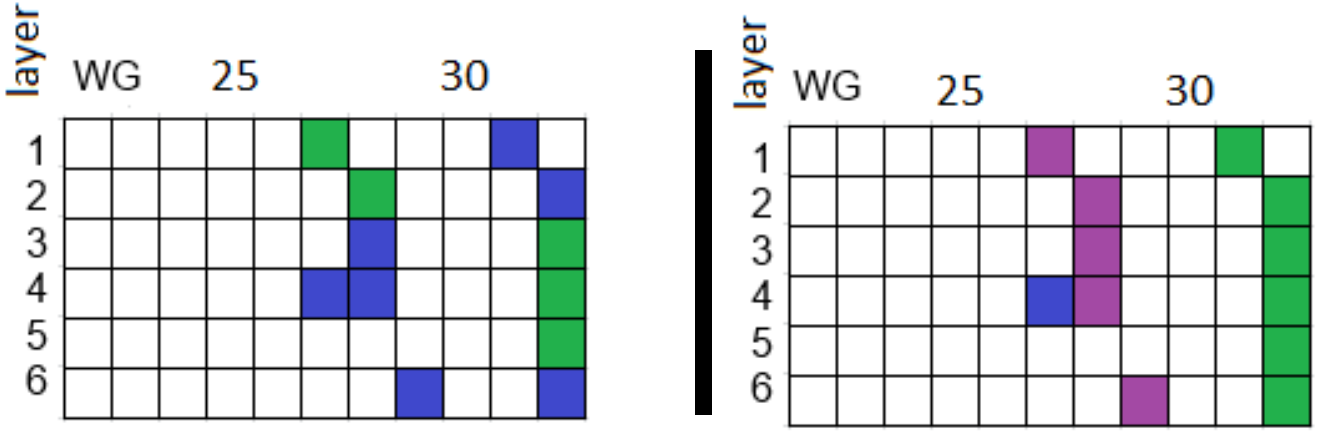
3D segments

Determined by fitting the 2D points from the 6 layers of each chamber

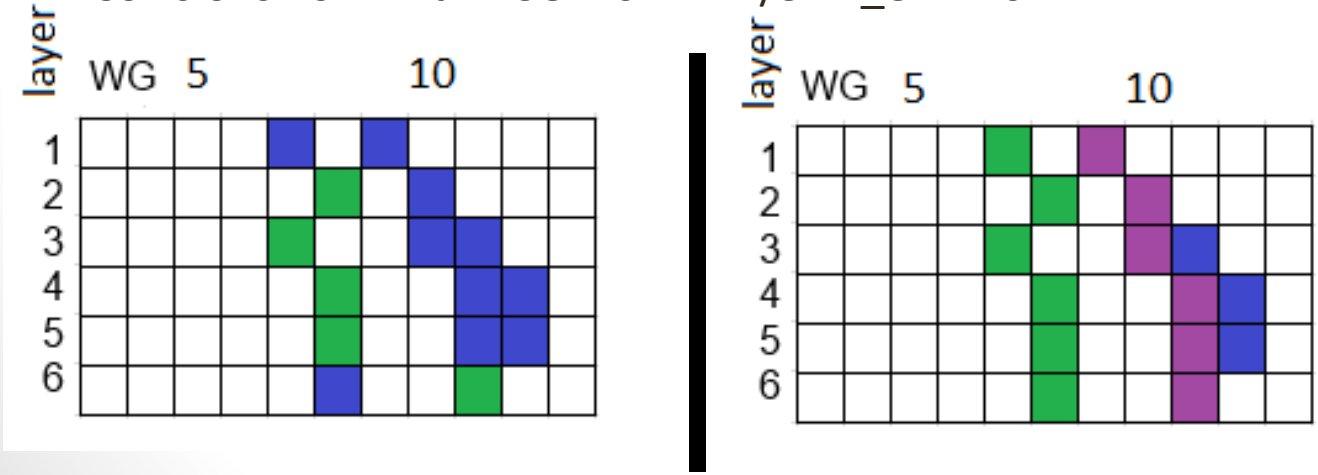
Event Example for wire coordinate segment

ST algo (standard) | Target output

Collisions 2012 Run 198210 ME1/3 n_ev 1543



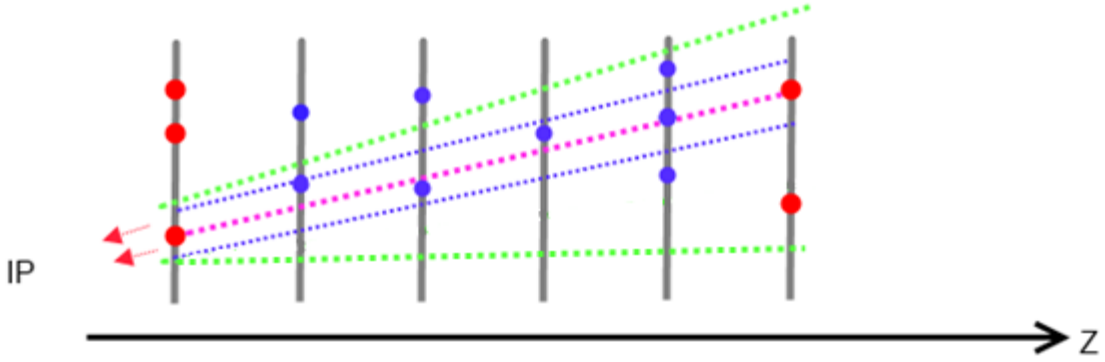
Collisions 2012 Run 198210 ME1/3 n_ev 12044



- muon segment
- segment 2
- BG hit

RU(RoadUsage) Algorithm main ideas

- Taking into account the IP while choosing the base hits in terms of WG for the future segment;
- Base Road for RecHit association:
  - A straight line is traced through the base hits
  - In the road formed along this line new hits from the inner layers are added to the segment

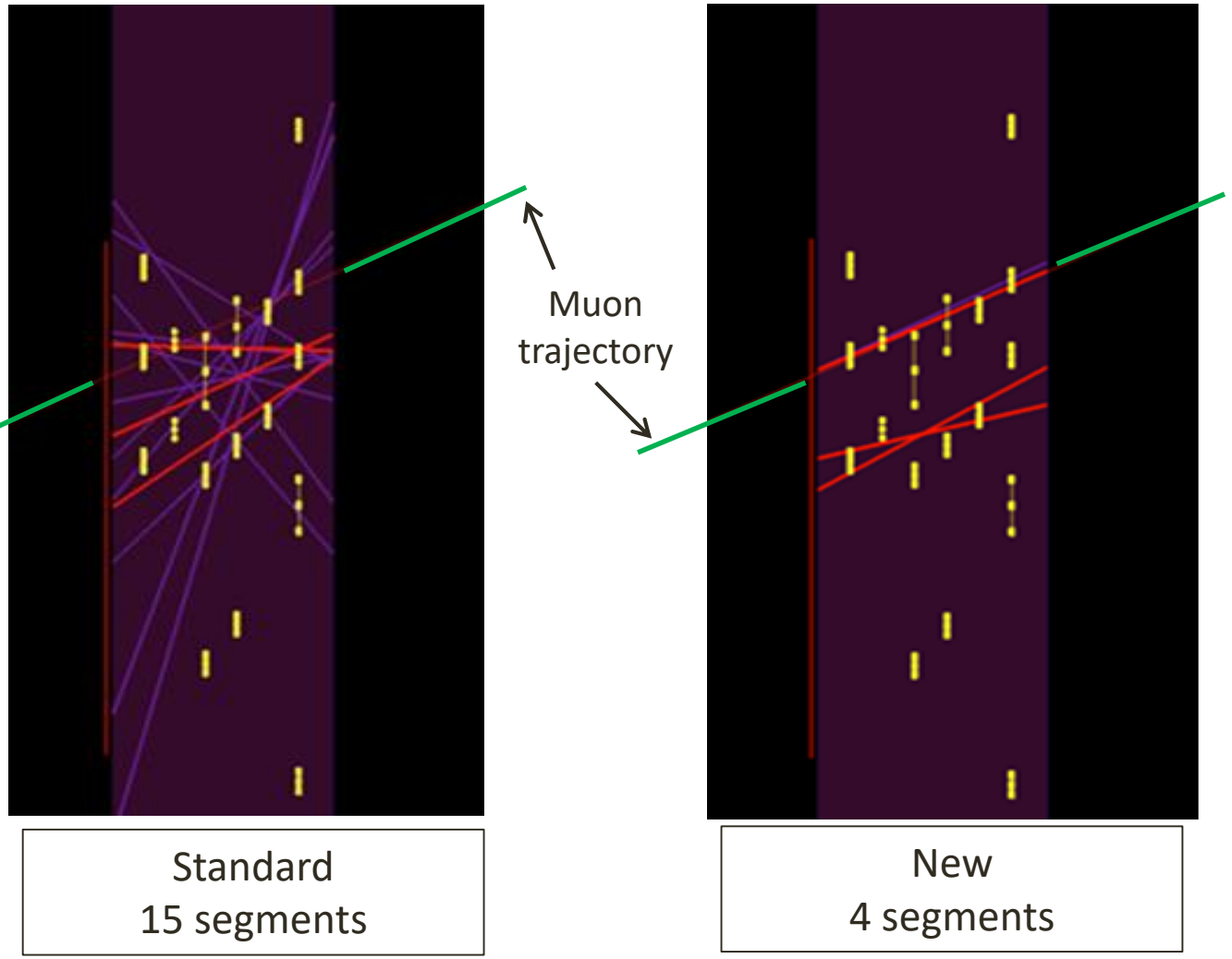


- Phi & χ^2 tuned thresholds for each CSC station;
- If there are enough unused RecHits left the segment reconstruction is run again with the IP check turned off in order to reconstruct segments that correspond to displaced muons.

Implemented into the official CMS software package in July,2016

Starting 2017 it became the DEFAULT algorithm for reconstruction in CSC

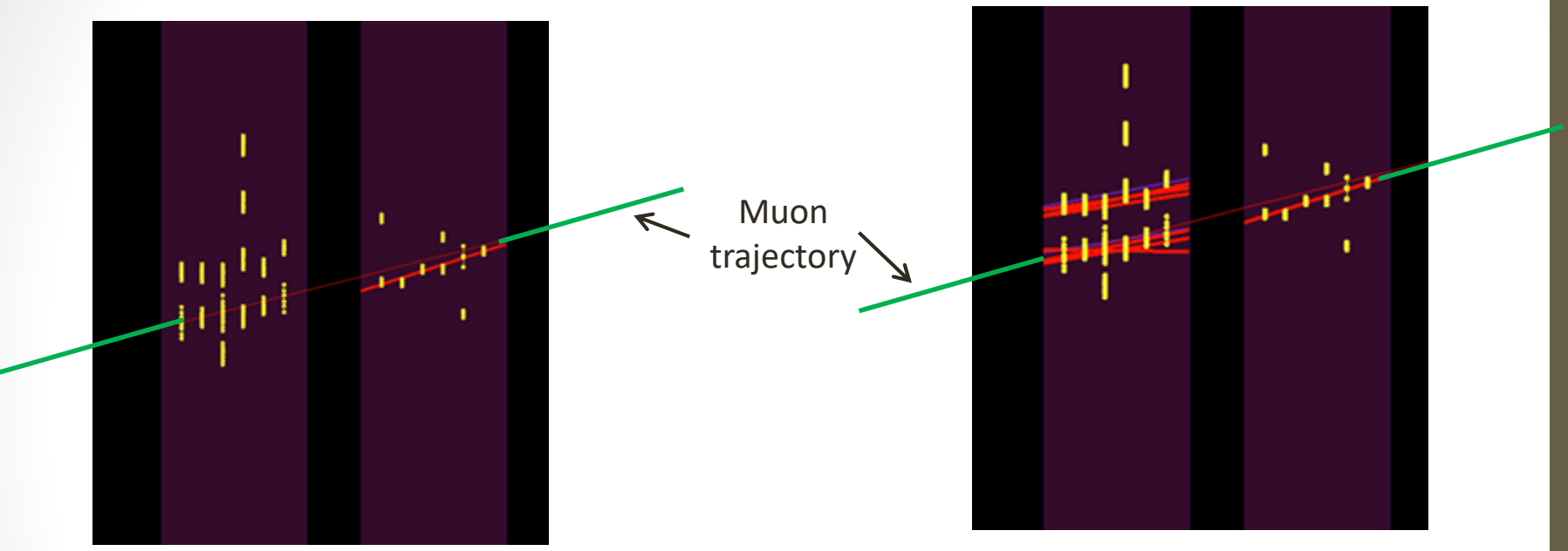
High multiplicity example - 84 RecHits in Chamber



Standard
15 segments

New
4 segments

High multiplicity example - 44 RecHits in ME21

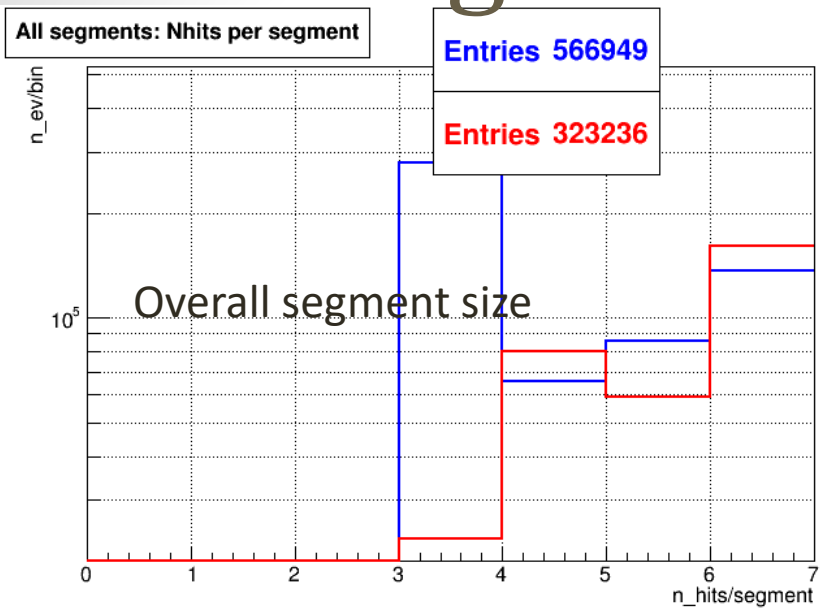


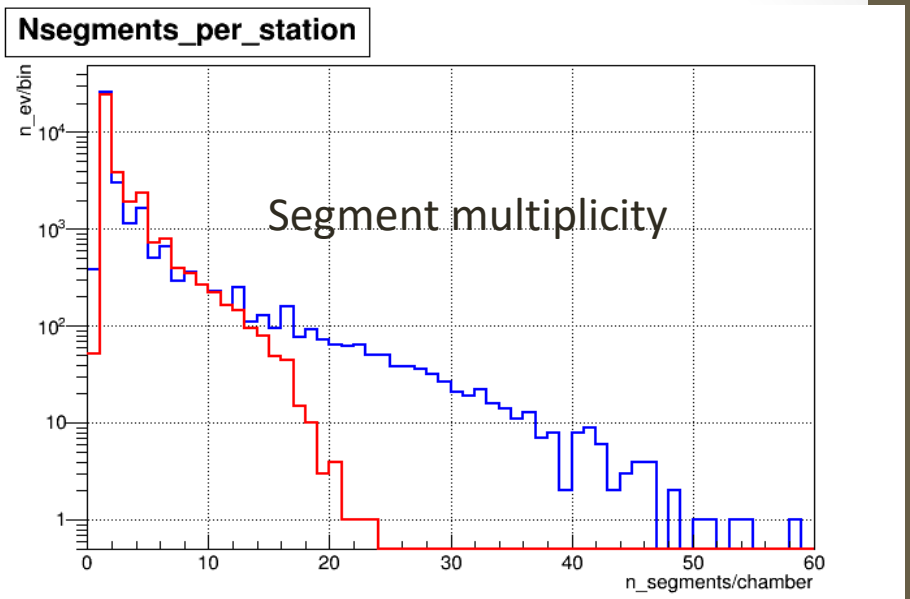
Standard
0 segments

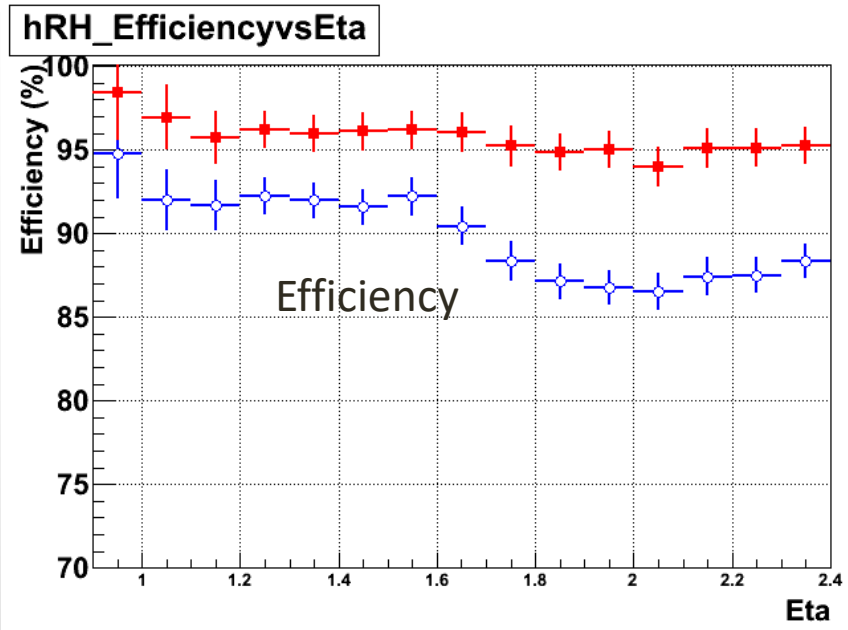
New
8 segments

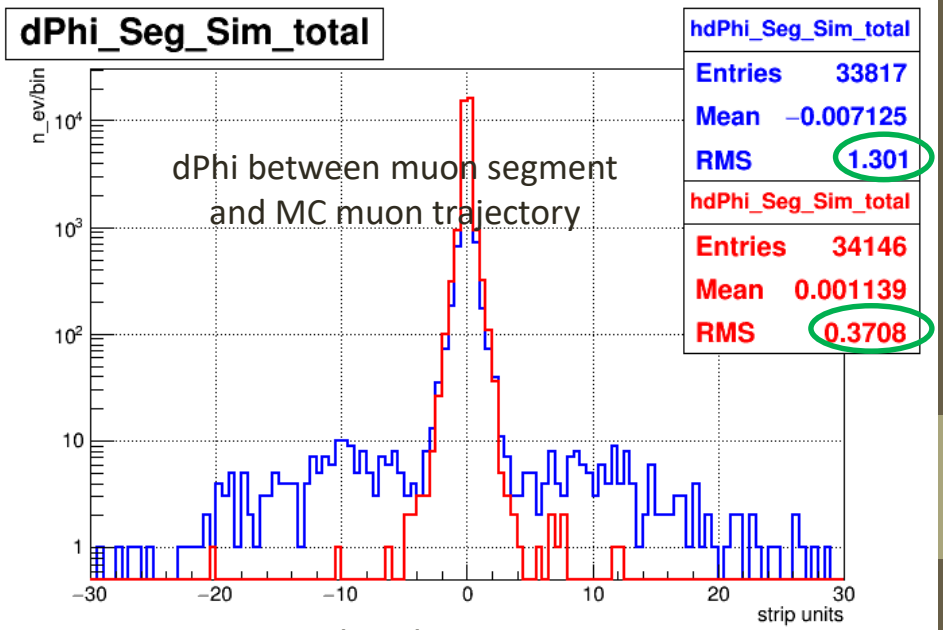
Collisions2015 256630:22:28500814

Two algorithms' comparison





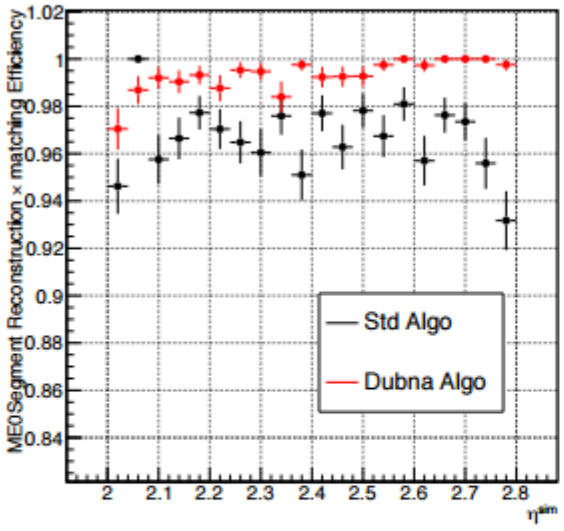


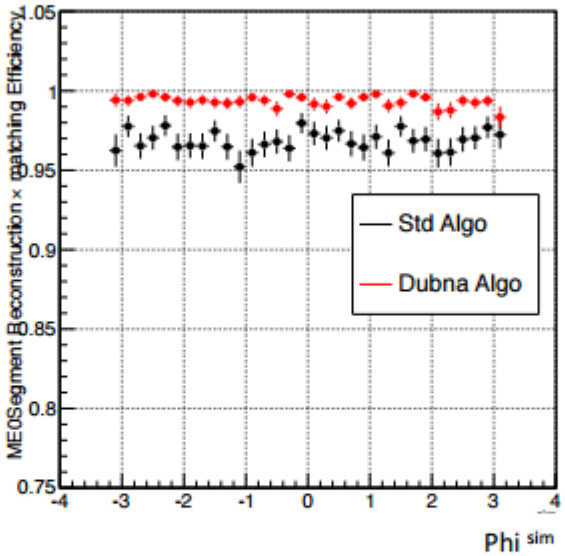


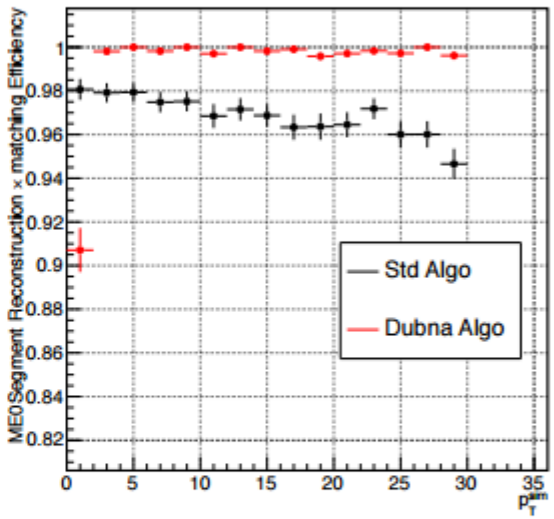
blue – Standard(ST) algorithm; red – NEW(RU) algorithm.

RU algorithm used for GEM detectors in CMS

Example: Std vs Dubna Efficiency







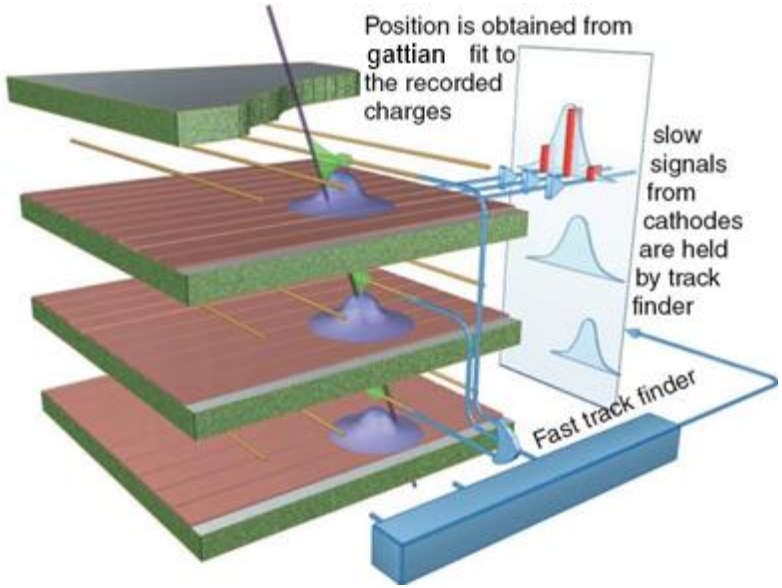
- ✓ Single Mu sample with PU=0, without noise, CMSSW_8_1_0_pre16
- ✓ Flat pT in 0-30 GeV, Flat eta in ME0 acceptance
- ✓ Rechits are Smeared points with perfect spatial resolution (thus, no realistic readout yet)

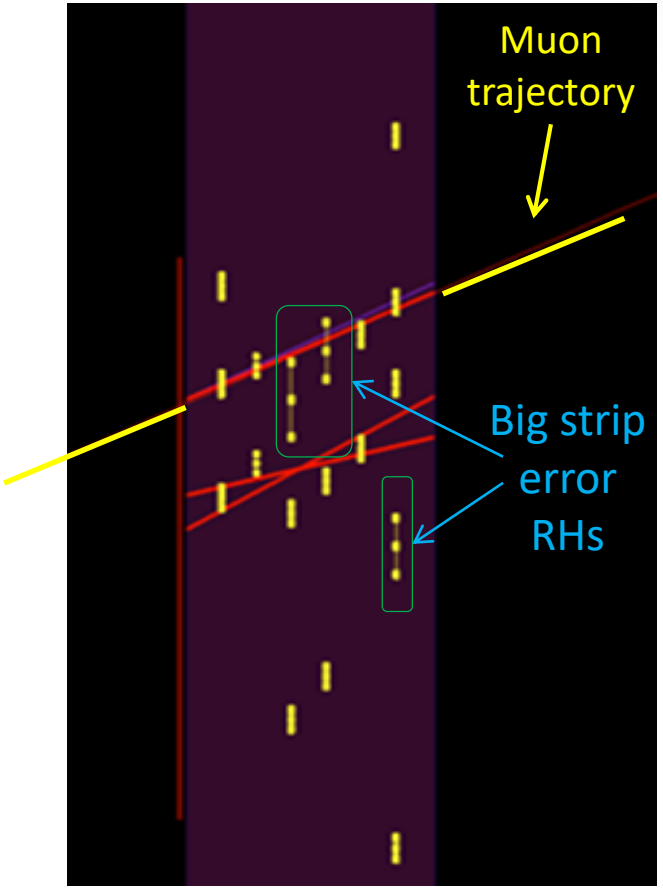
- Overall, the performance of Dubna algo are the better, as expected

Local Segment Reconstruction Summary

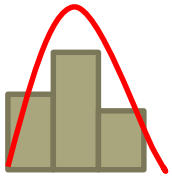
- The new algorithm shows a better performance for all types of CMS data;
- The optimization and bug elimination is continuously ongoing;
- The RU algorithm was implemented in the official CMS software in 2016;
- It was adopted for segment reconstruction in the GEM detectors of the CMS muon system;
- It became the default segment reconstruction algorithm starting with 2017 data-tacking period of the LHC;
- The optimization and code support is a continuously ongoing task for us;

Reconstruction of local coordinate on a particular layer



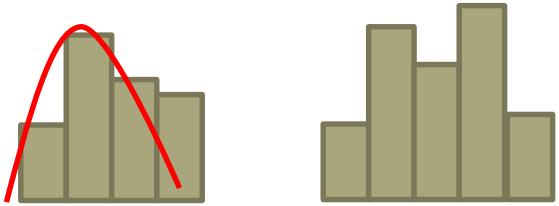


σ_{Gatti_fit} ~ 2% of strip width



Regular strip charge distribution

$\sigma_{strip(RH)}$ > 25% of strip width

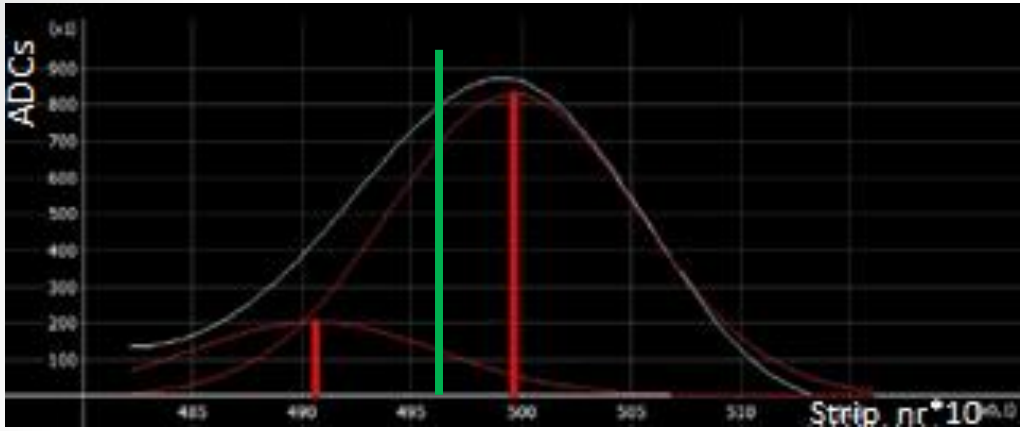


Abnormal strip charge distributions

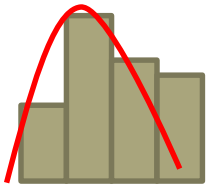
CMS Collisions 2015 event display

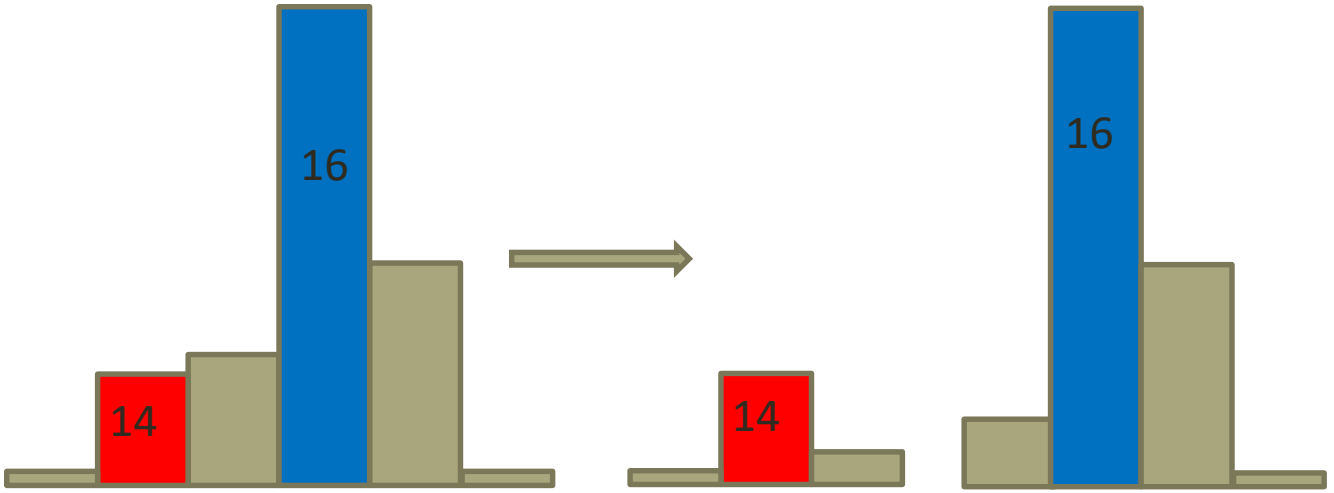
Cases that need improvement

Simple two maxima delimitation



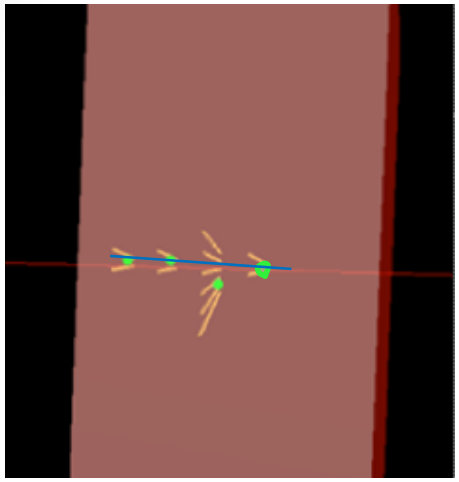
$\sigma_{strip(RH)}$ > 25% of strip width

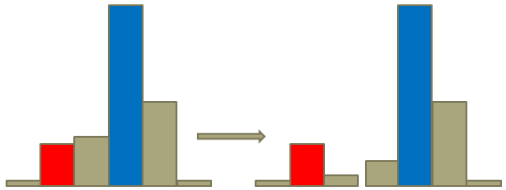


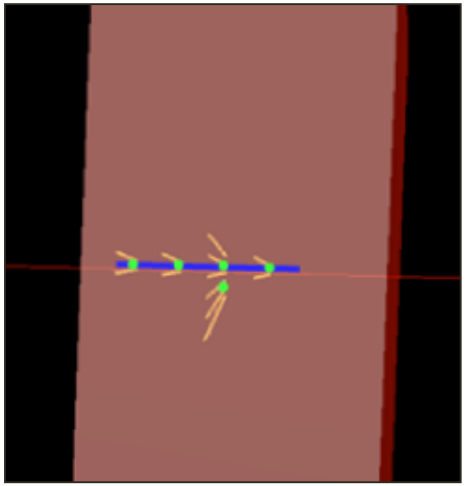


Strip ADC's	10	106	119	374	178	12

Event example with two maxima in layer 3







L1 L2 L3 L4

14.37 14.32 16.20 14.04

χ^2 = 125.7

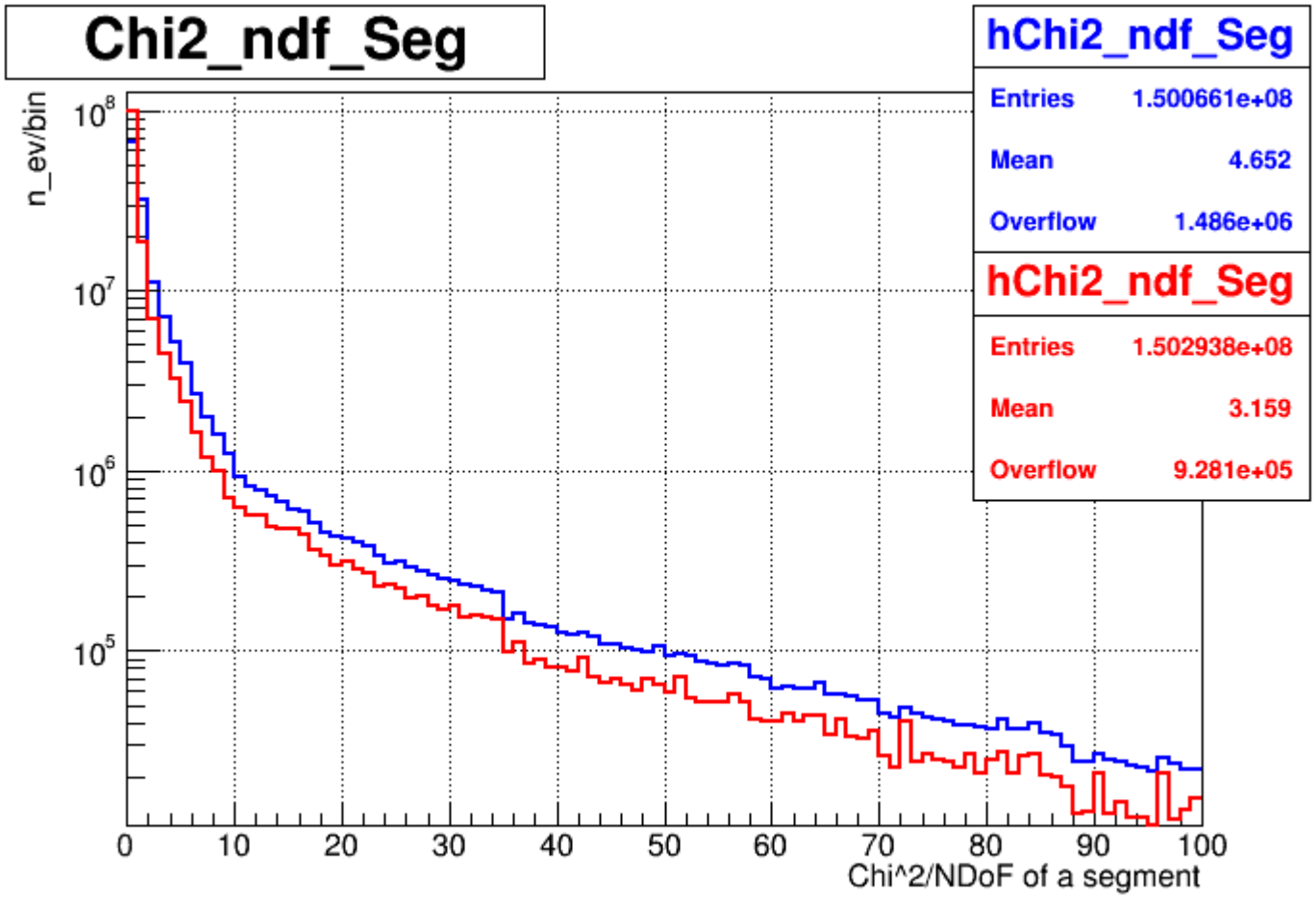
L1 L2 L3 L4

14.37 14.32 14.16 14.04

16.36

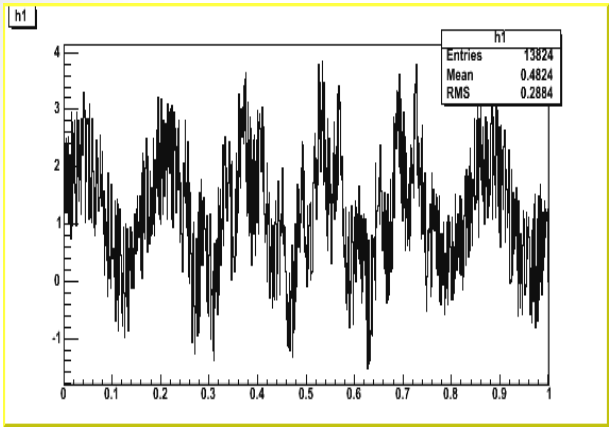
χ^2 = 1.01

χ^2/NDoF of a segment

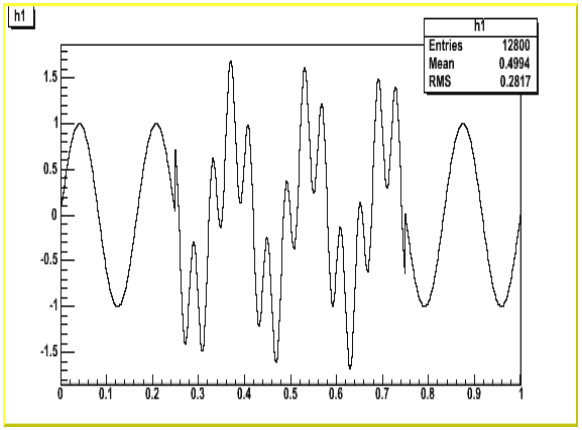


BLUE – standard RH Builder; **RED** – abnormal strip distribution division

Wavelet analysis for overlapped signals



Wavelet filter



$$N(x, A, y) = A exp\left(-\frac{(x-x_0)^2}{2\sigma_x^2} - \frac{(y-y_0)^2}{2\sigma_y^2}\right)$$

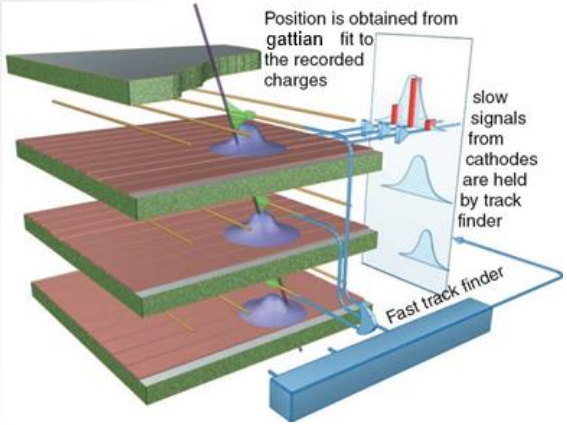
A – Gaussian amplitude, x_0 and y_0 - centers of Gaussian

Usage for overlapped signal separation in HEP experiments

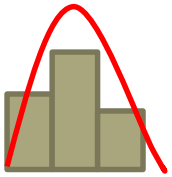
- high precision of extremum recognition;
- scalable number of extrema.

- numerical methods needed;
- slow calculation for > 3 extrema.

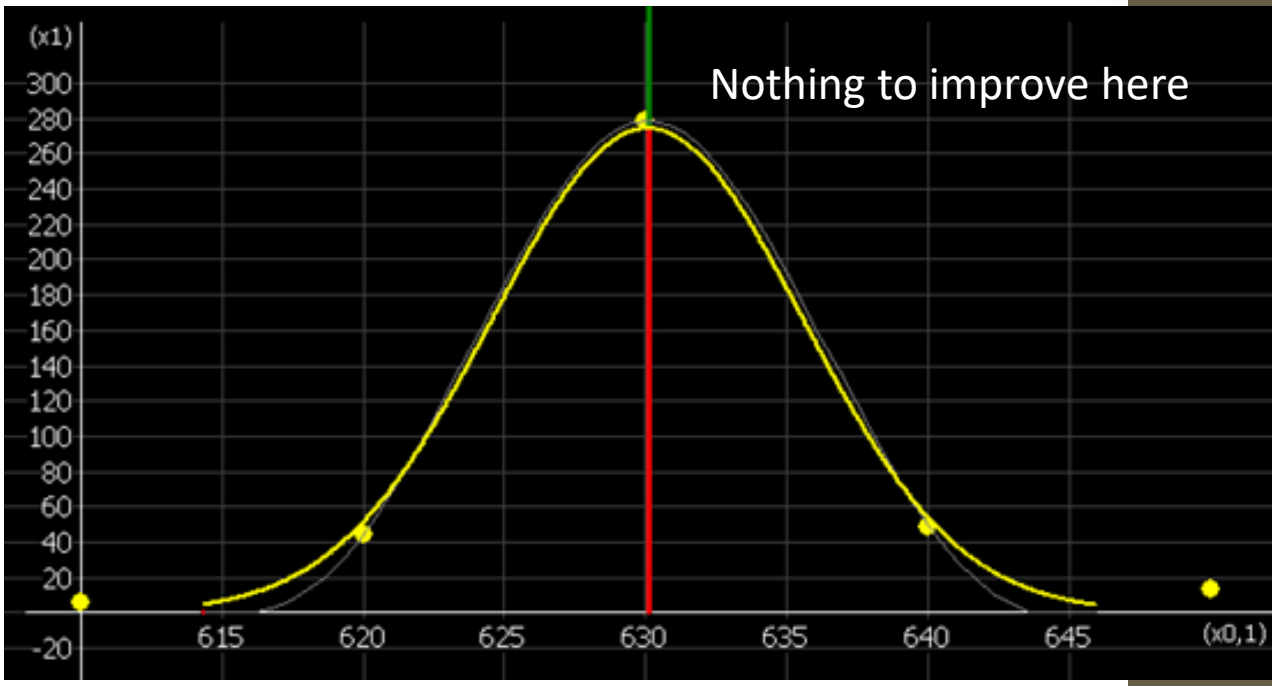
Wavelet-based algorithm for multiple maxima



σ_{Gatti_fit} ~ 2% of strip width

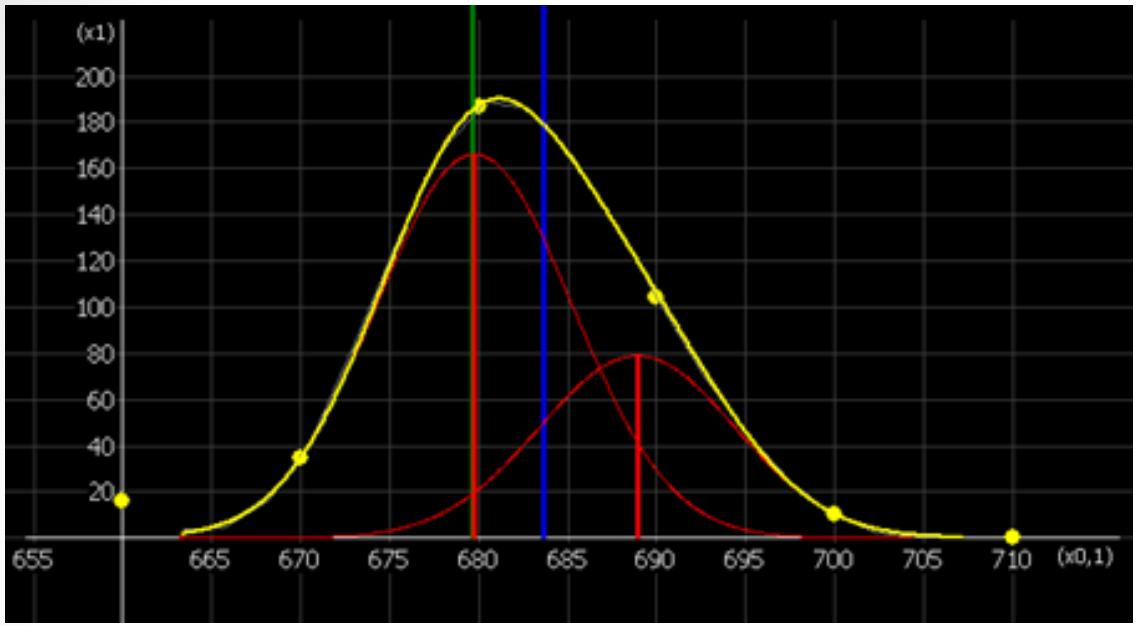


Regular strip charge distribution

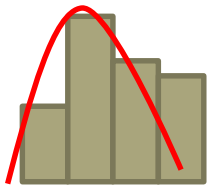


Yellow – initial signal distribution;
Red – coordinate reconstructed by the new algorithm;
Green line – simulated coordinate;
Blue line – coordinate reconstructed by the standard algorithm.

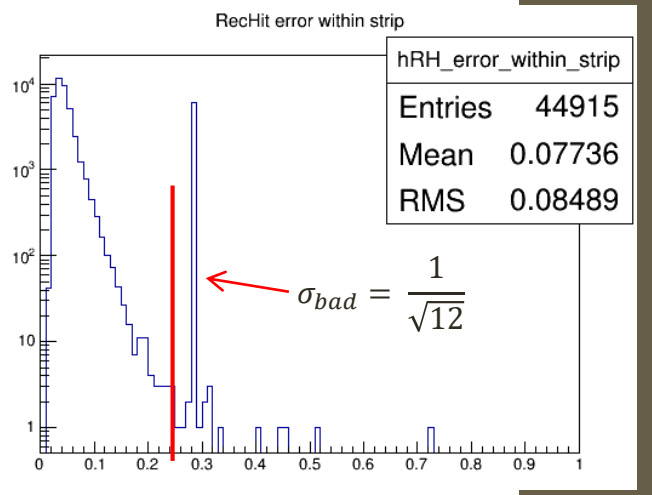
Reconstruction of two overlapping signals



$\sigma_{strip(RH)}$ > 25% of strip width



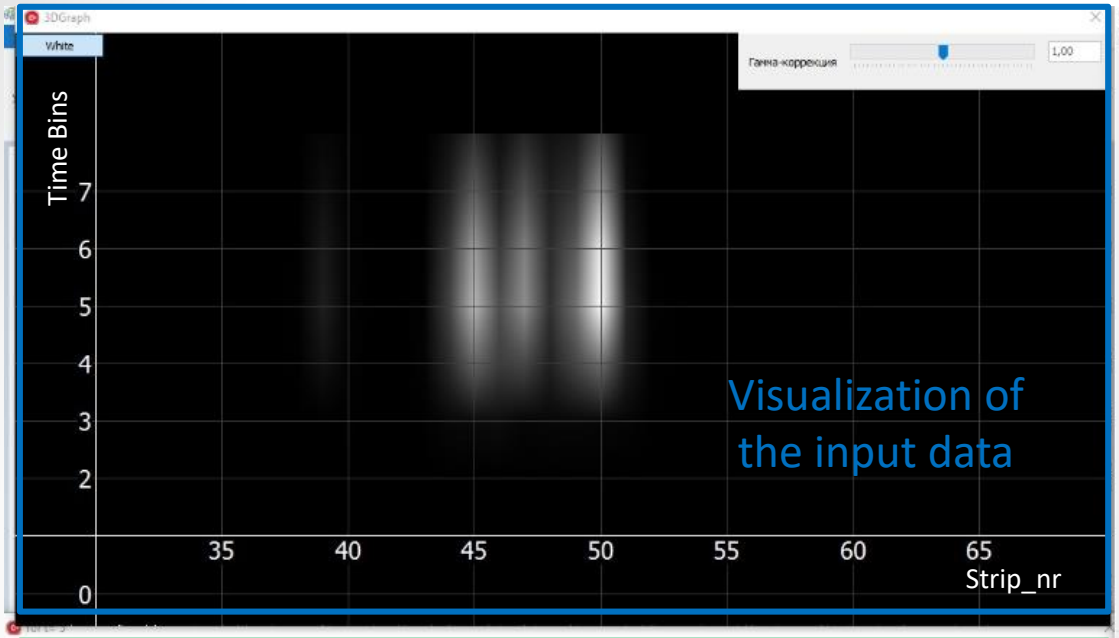
Abnormal strip charge distributions

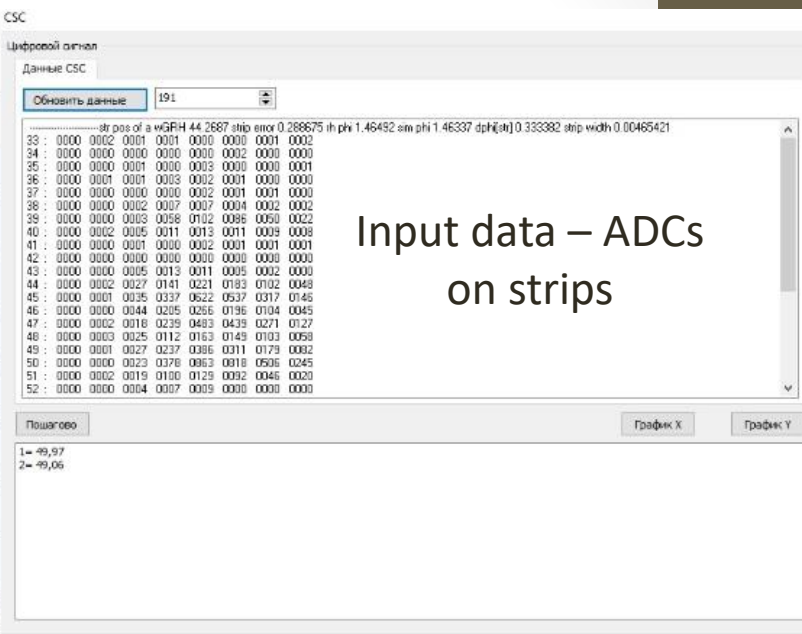


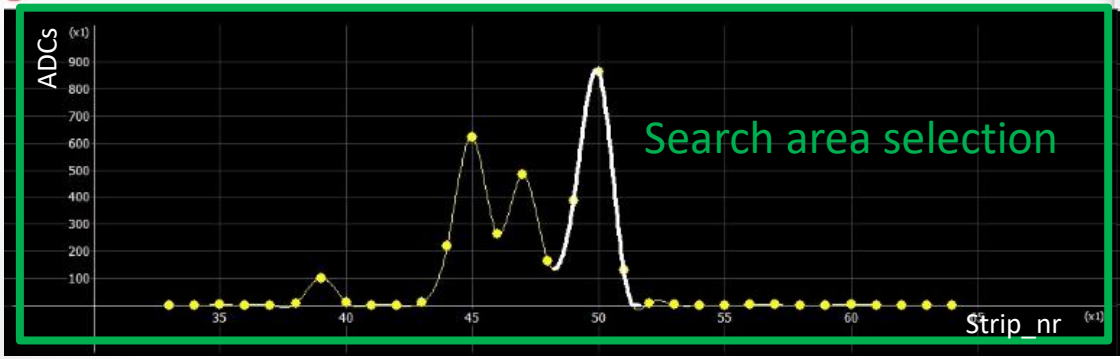
Yellow – initial signal distribution;
Red gaussians and their centers - predicted overlapped coordinates reconstructed by the NEW algorithm;
Green line – simulated coordinate;
Blue line – coordinate reconstructed by the STANDARD algorithm.

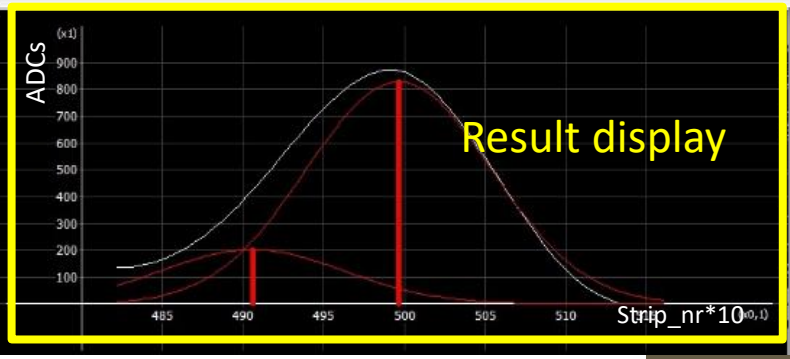
If $\sigma_{Gatti\ fit}$ >25% the coordinate is calculated using Center Of Gravity (COG) algorithm

Universal tool for overlapping signal recognition



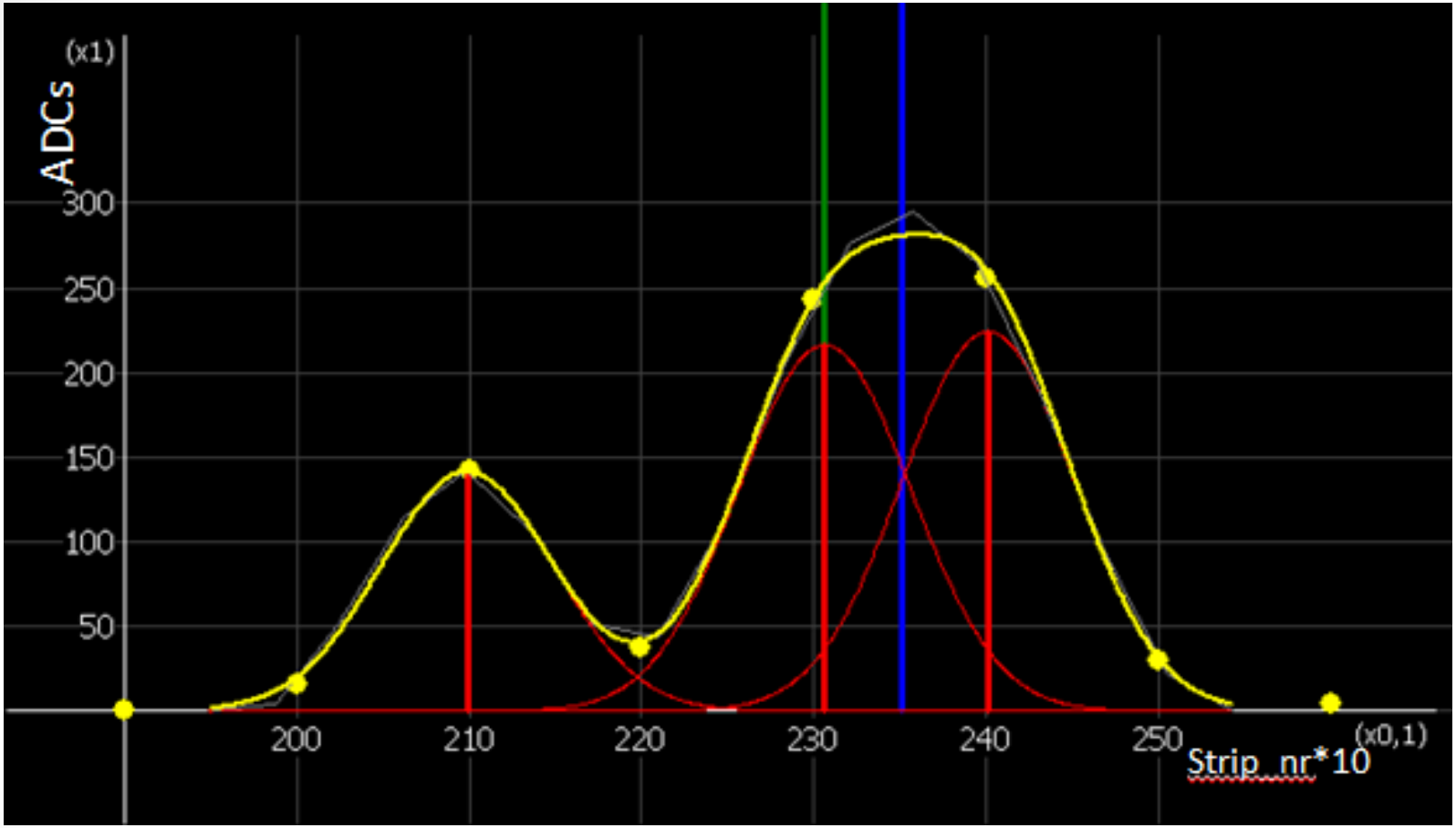






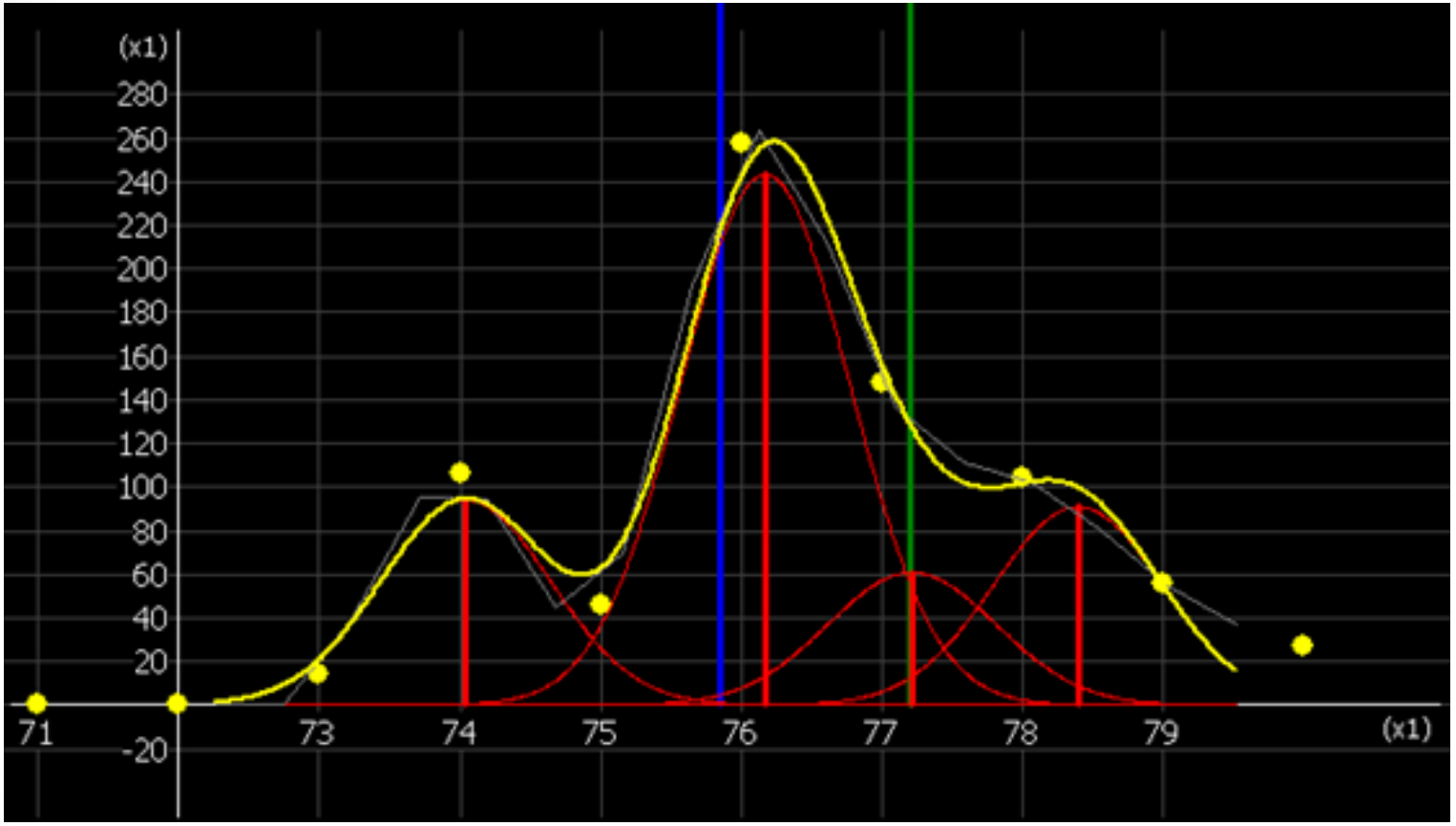
Remark. This tool can be used for visualization and signal delimitation for any detectors that use clustered charge distribution readout.

Three overlapped signals recognition



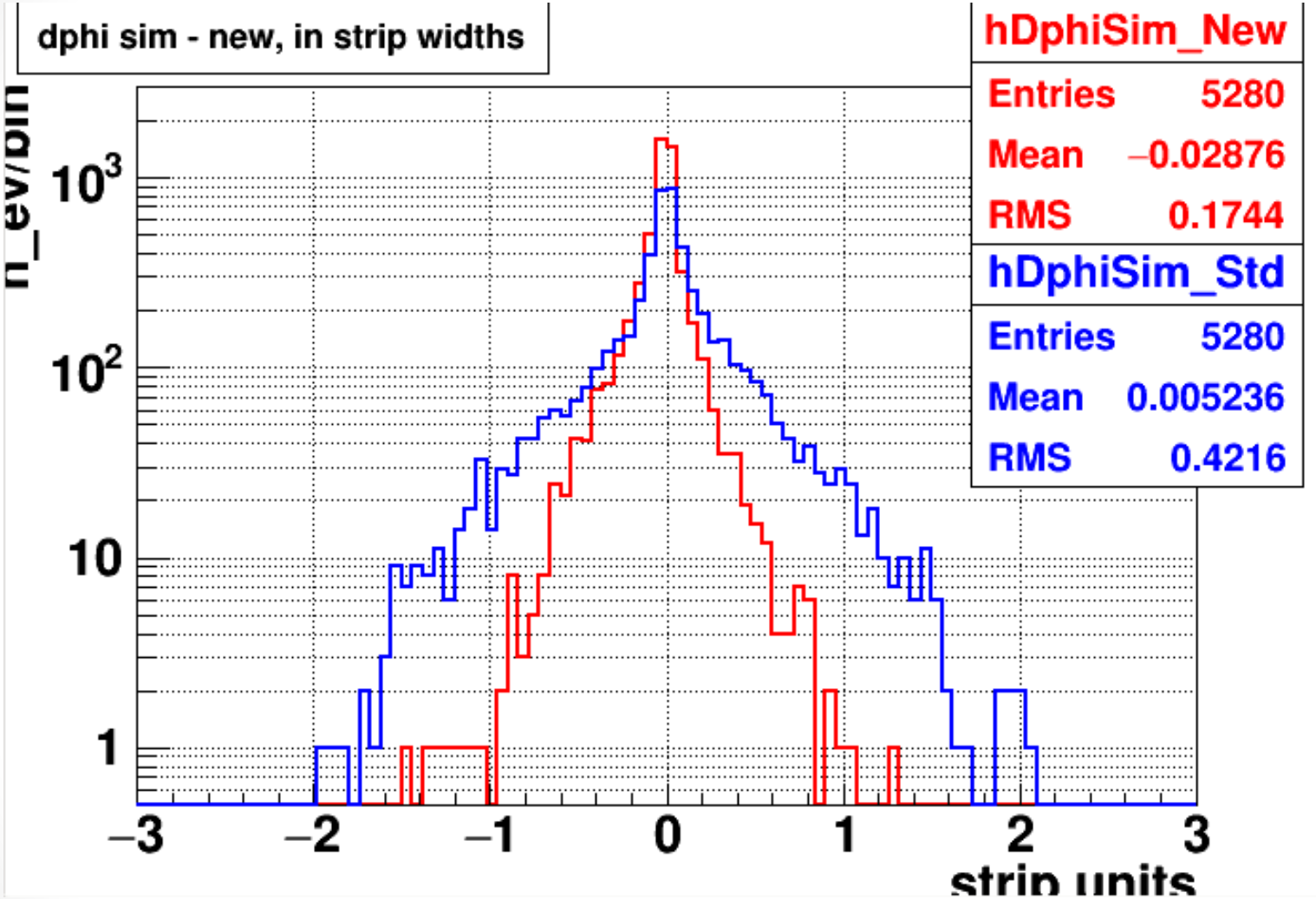
Yellow – initial signal distribution;
Red gaussians and their centers - overlapped coordinates reconstructed by the NEW algorithm;
Green line – simulated coordinate;
Blue line – coordinate reconstructed by the STANDARD algorithm.

Reconstruction of four overlapped signals



Yellow – initial signal distribution;
Red gaussians and their centers - overlapped coordinates reconstructed by the NEW algorithm;
Green line – simulated coordinate;
Blue line – coordinate reconstructed by the STANDARD algorithm.

Two algorithms comparison on higher statistics



BLUE – Standard algorithm; RED – NEW algorithm.

Local Coordinate Reconstruction Status and Plans

Status:

- Simple two maxima delimitation developed;
- It finds “hidden” signal coordinate resulting in a valuable improvement in the quality of segments;
- A more “sophisticated” method based on wavelet method was developed;
- This tool can be used for any detector that works with cluster-shape charge distributions;
- The new approach reconstructs the strip coordinate ~2.5 times closer to the MC muon in comparison with the standard approach;
- It is time consuming, especially for >2 maxima delimitation (tested only on PC);

Plans

- Simple two maxima delimitation implementation into the official CMS software is scheduled for the beginning of next year;
- Run wavelet-based algorithm inside the CMSSW framework to estimate the actual time consumption;
- Apply discrete-wavelets instead of continuous ones in order to decrease the time consumption.

WLCG made all these possible

Filters Users Help Found a bug? REFRESH Disabled CMS dashboard TASK MONITORING

Pattern From Till Time Range Last Month

Submit Reset

Start » [Nikolay Voytishin] » Tasks

Data Charts Show 25 entries *All times are in UTC Search:

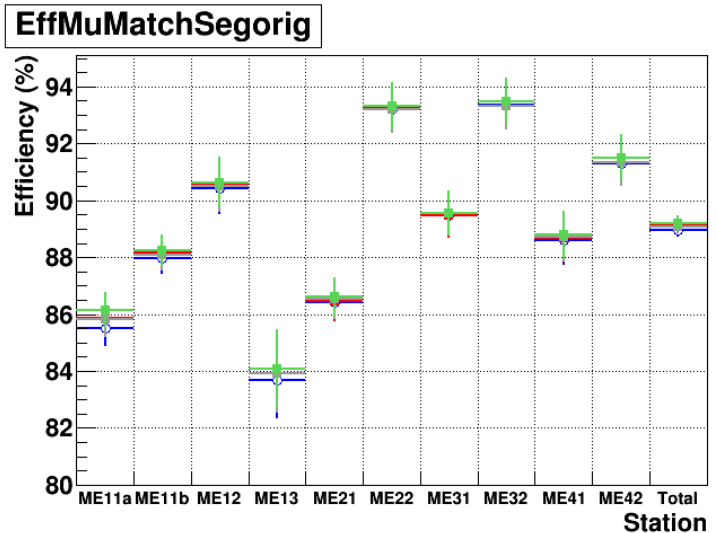
Graphically	TaskName	NJobTotal	Pending	Running	Unknown	Cancelled	Success	Failed	WNPostProc	ToRetry
	181003_065245:nvoytish_crab_ZMu_2018B_v1_ST_0310	655	0	0	0	0	655	0	0	0
	181003_062934:nvoytish_crab_ZMu_2017_v1_ST_0310	396	0	0	0	0	395	1	0	0
	181002_155533:nvoytish_crab_ZMu_2018B_v1_ST	185	0	0	0	0	185	0	0	0
	181001_152247:nvoytish_crab_ZMu_2017F_v1_RU_wide_RH_improwed	396	0	0	0	0	395	1	0	0
	181001_151758:nvoytish_crab_ZMu_2017F_v1_RU_wide	396	0	0	0	0	395	1	0	0
	181001_151520:nvoytish_crab_ZMu_2017F_v1_RUOrig	396	0	0	0	0	395	1	0	0
	181001_144334:nvoytish_crab_ZMu_2017F_v1_ST	396	0	0	0	0	395	1	0	0
Graphically	TaskName	NJobTotal	Pending	Running	Unknown	Cancelled	Success	Failed	WNPostProc	ToRetry

Showing 1 to 7 of 7 entries

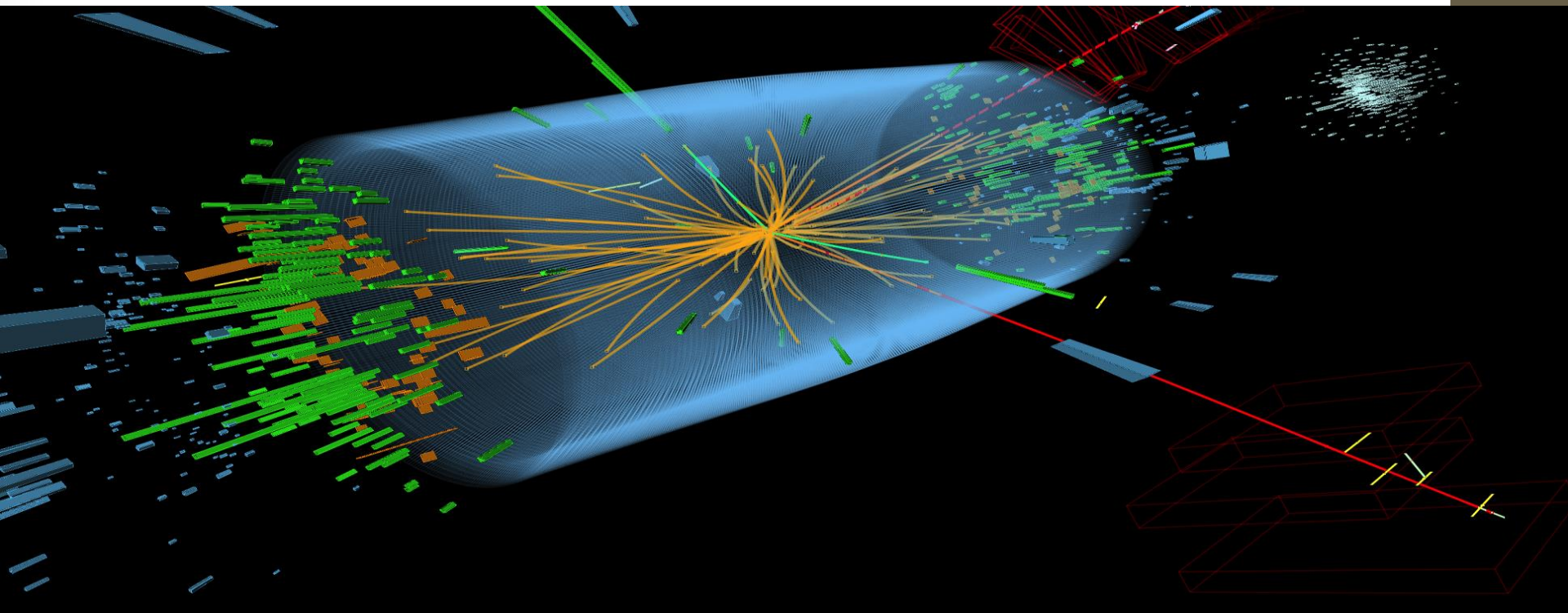
First Previous Page 1 of 1 Next Last

While developing new algorithms and optimizing them:

- > 100 000 jobs were launched;
- ~15 000 000 000 events processed.

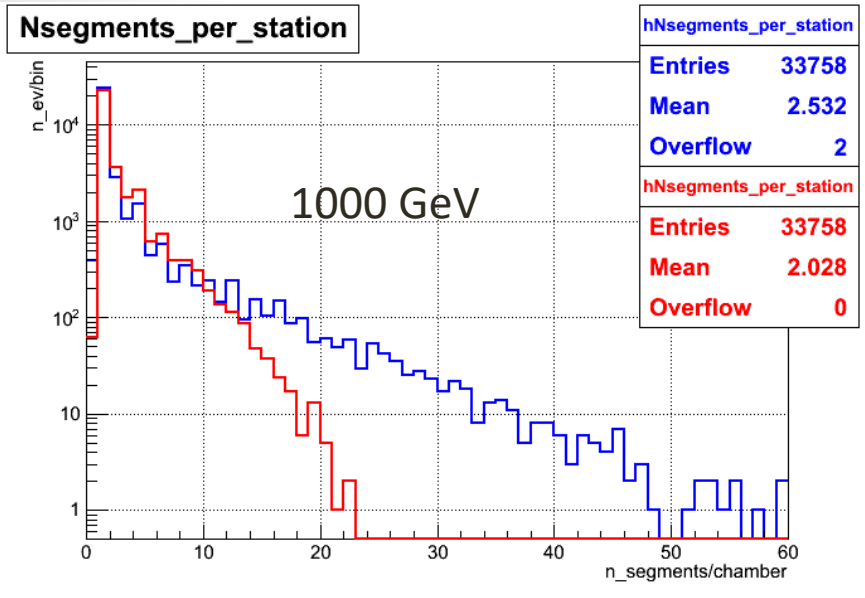


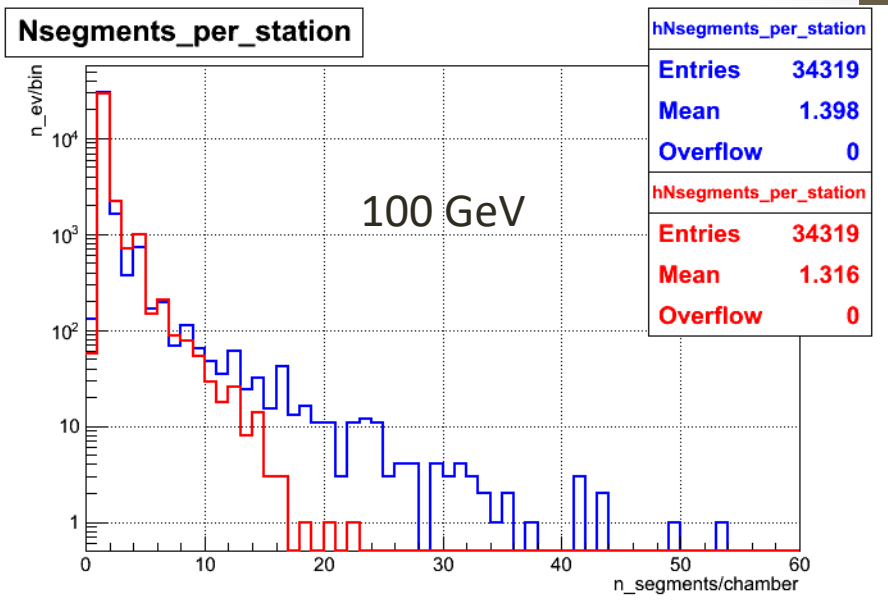
Thank you for your attention!!!

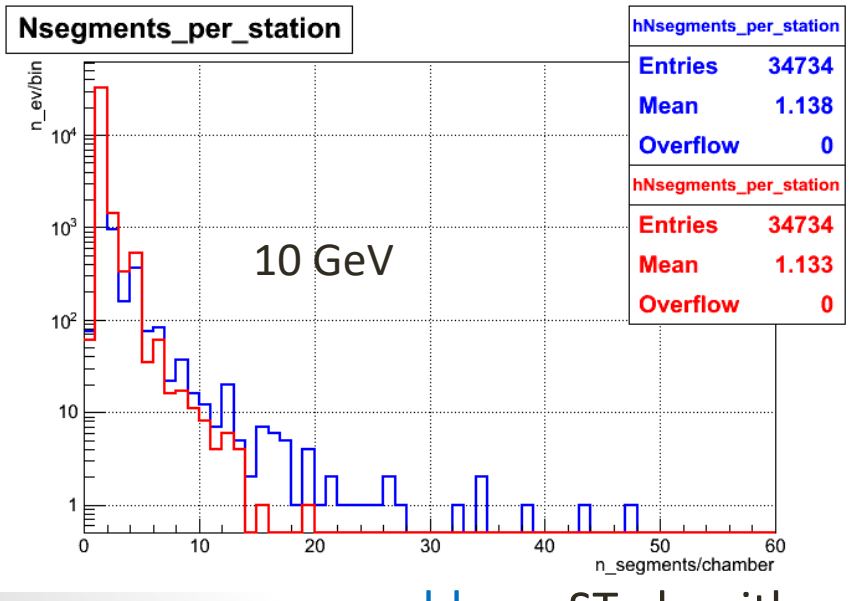


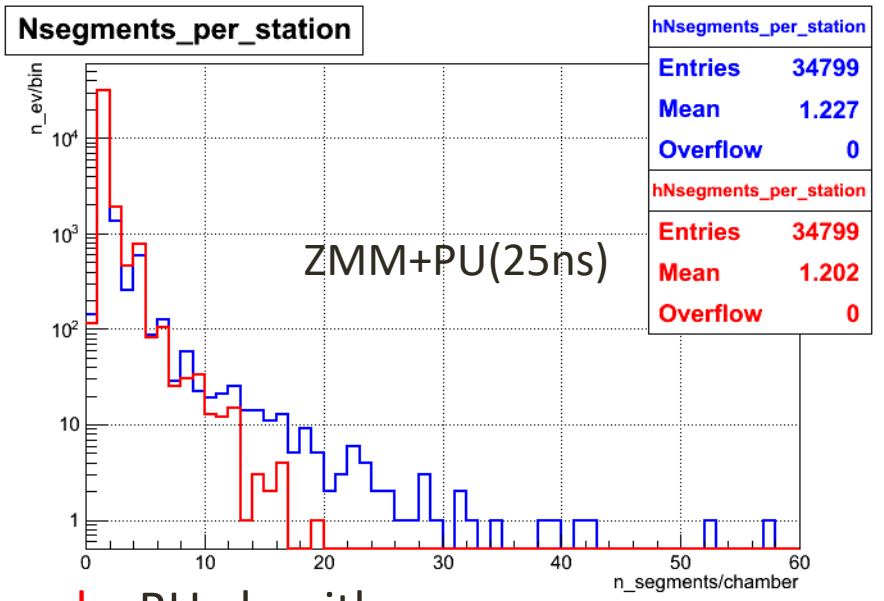
Back up slides

Segment multiplicity per station



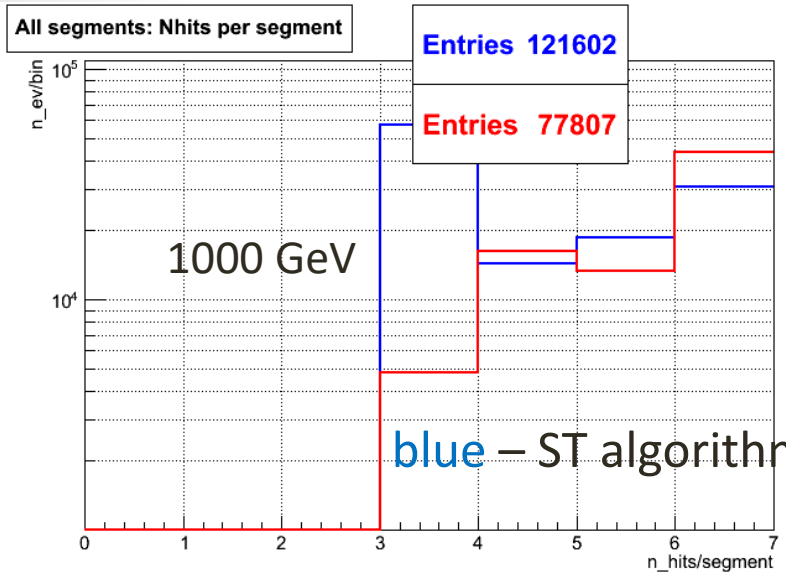


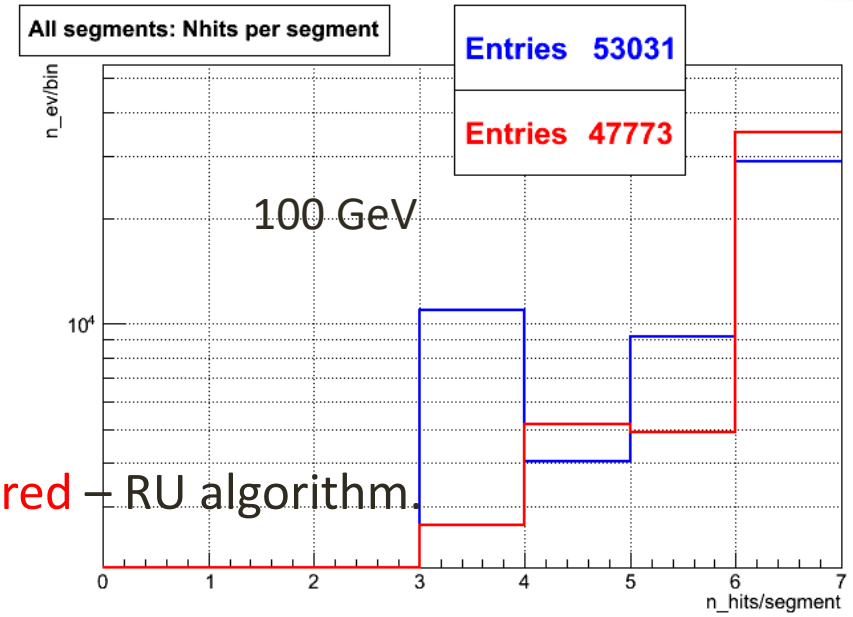




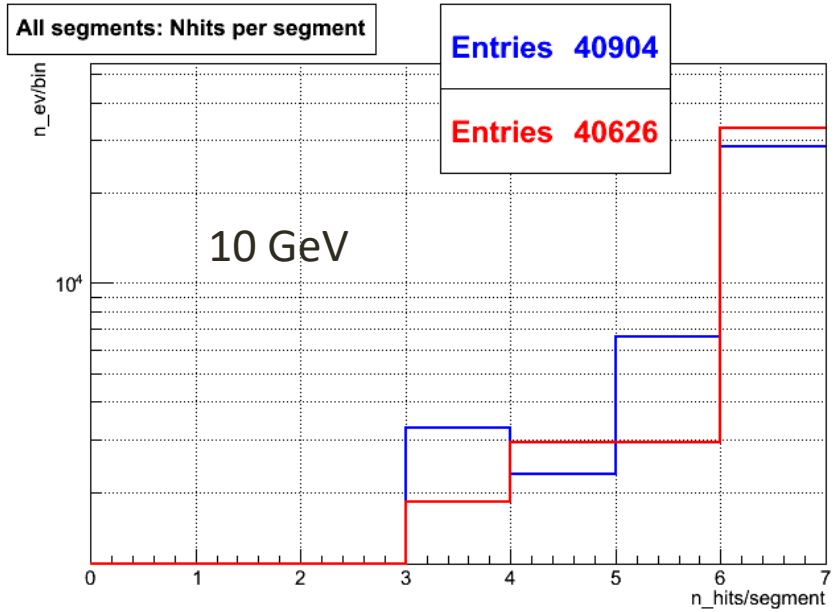
blue – ST algorithm; red – RU algorithm.

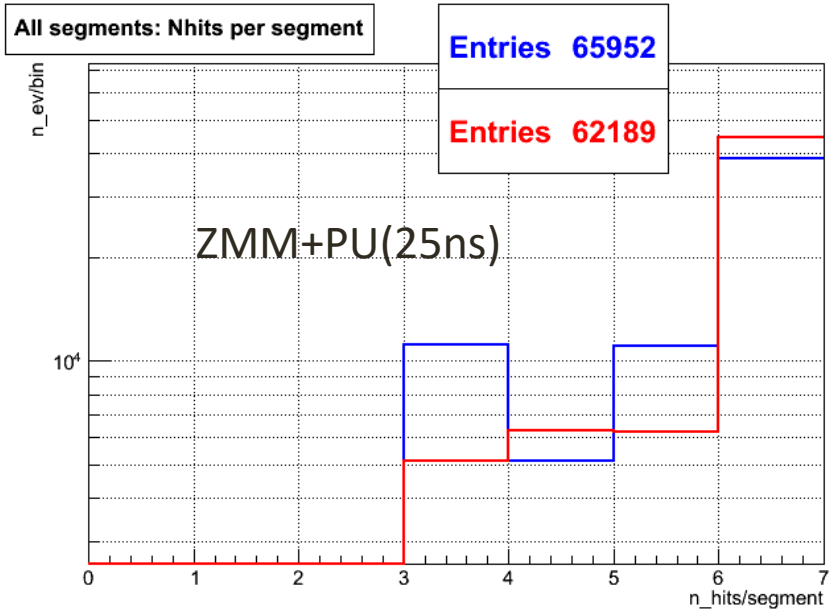
Number of RecHits in all reconstructed segments



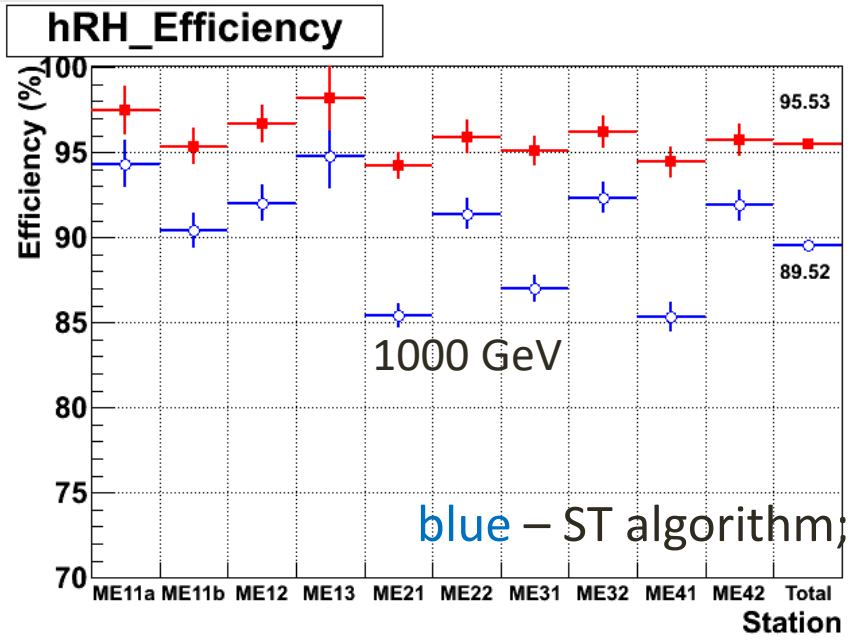


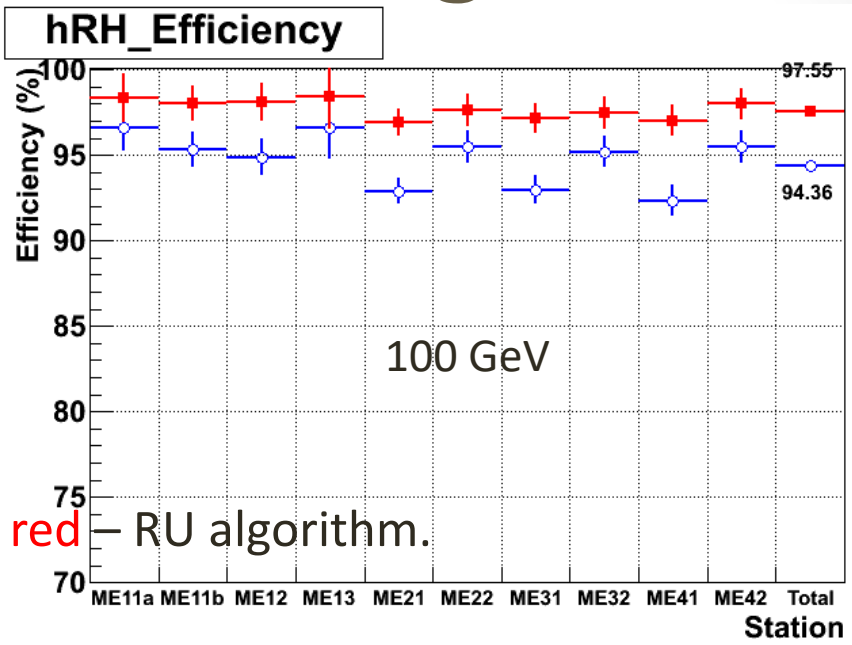
blue – ST algorithm; red – RU algorithm.



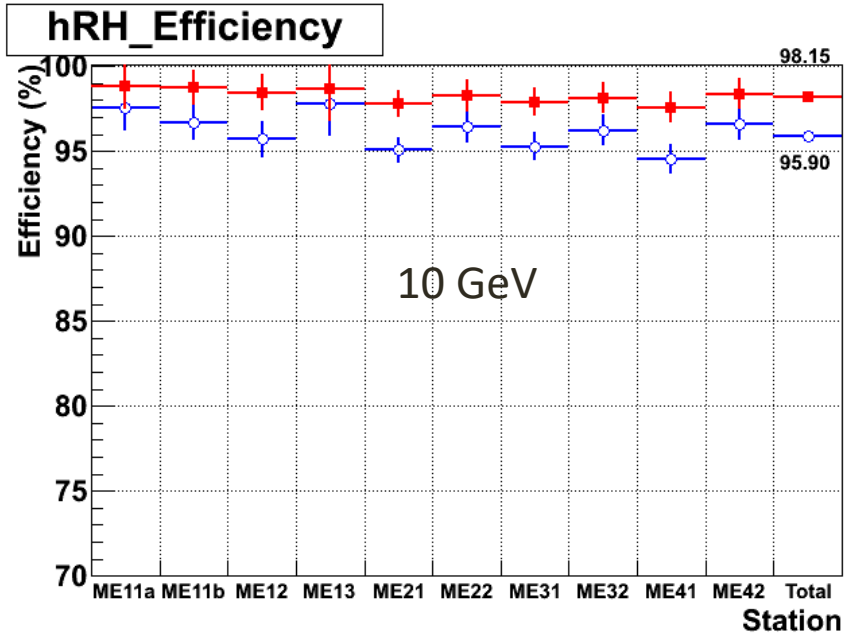


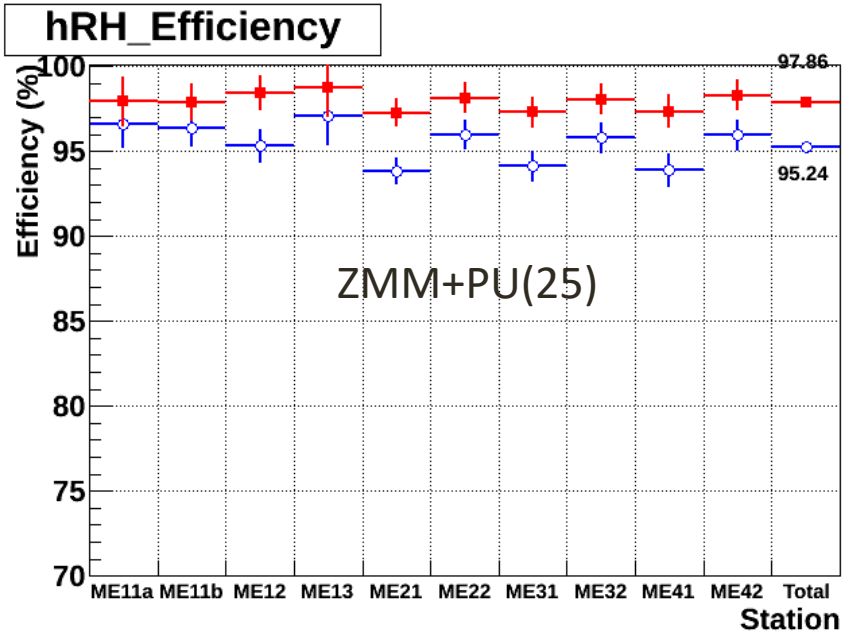
RecHit efficiency for muon segment



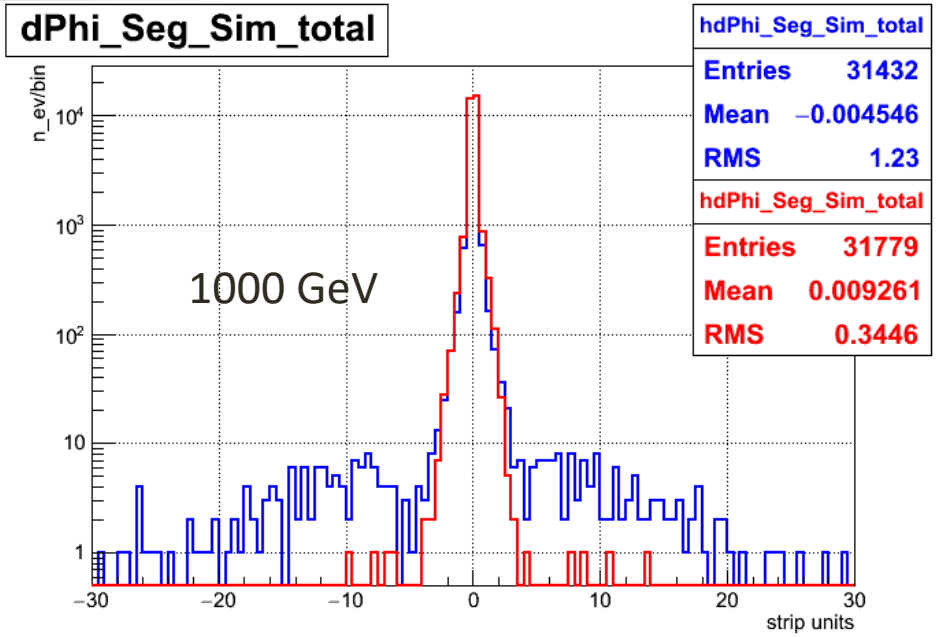


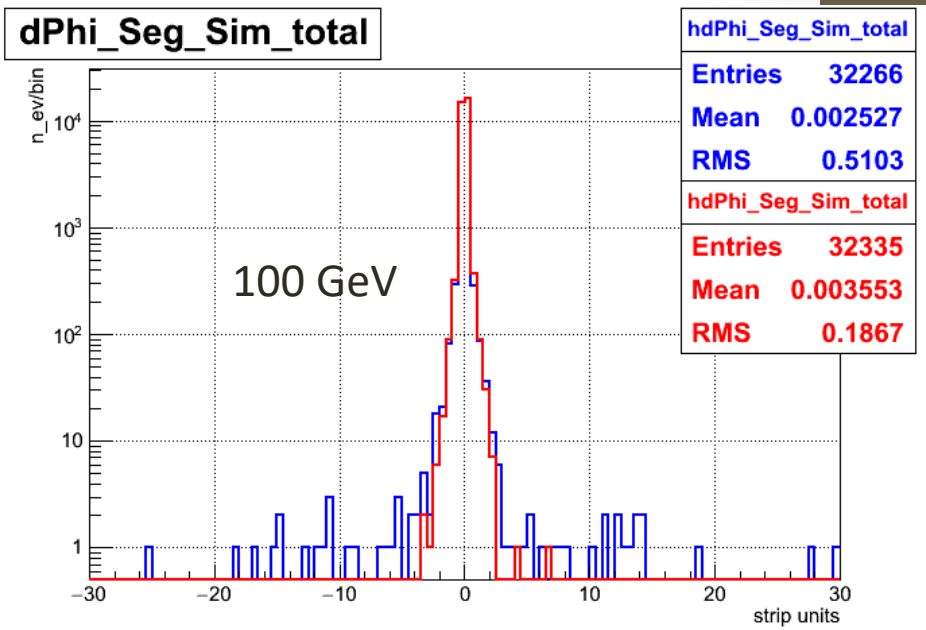
blue – ST algorithm; red – RU algorithm.

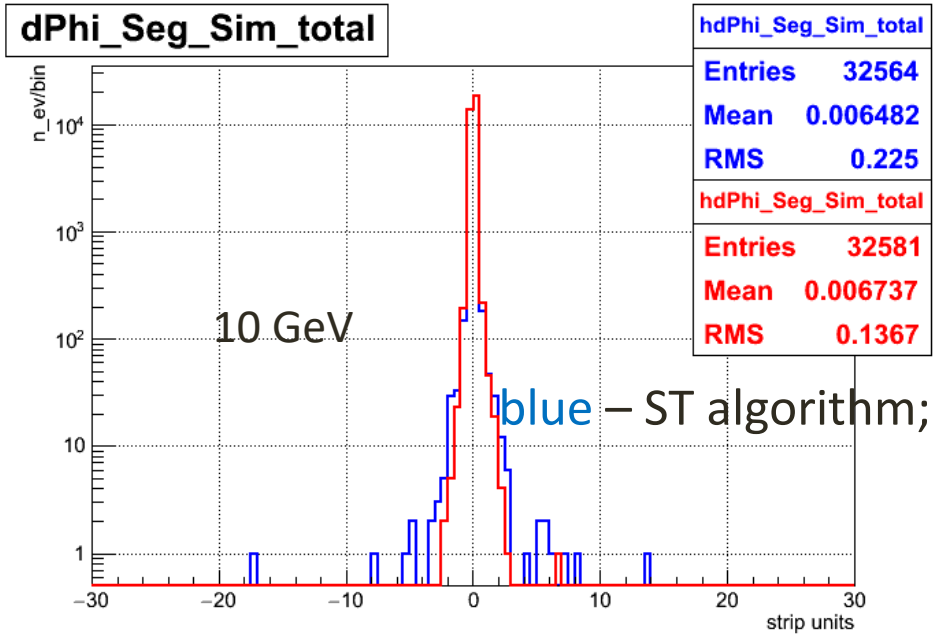


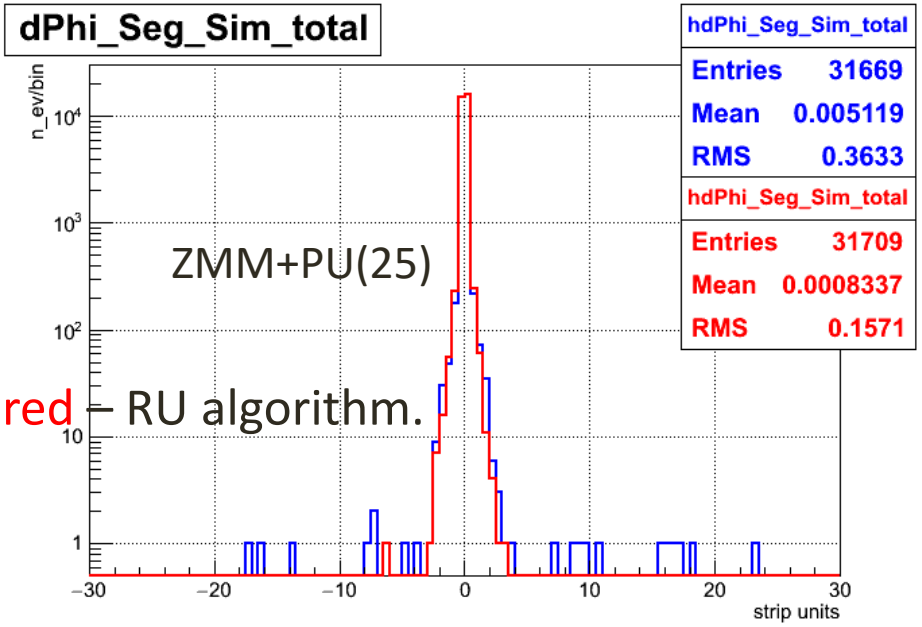


dPhi (RecoSeg - SimSeg)



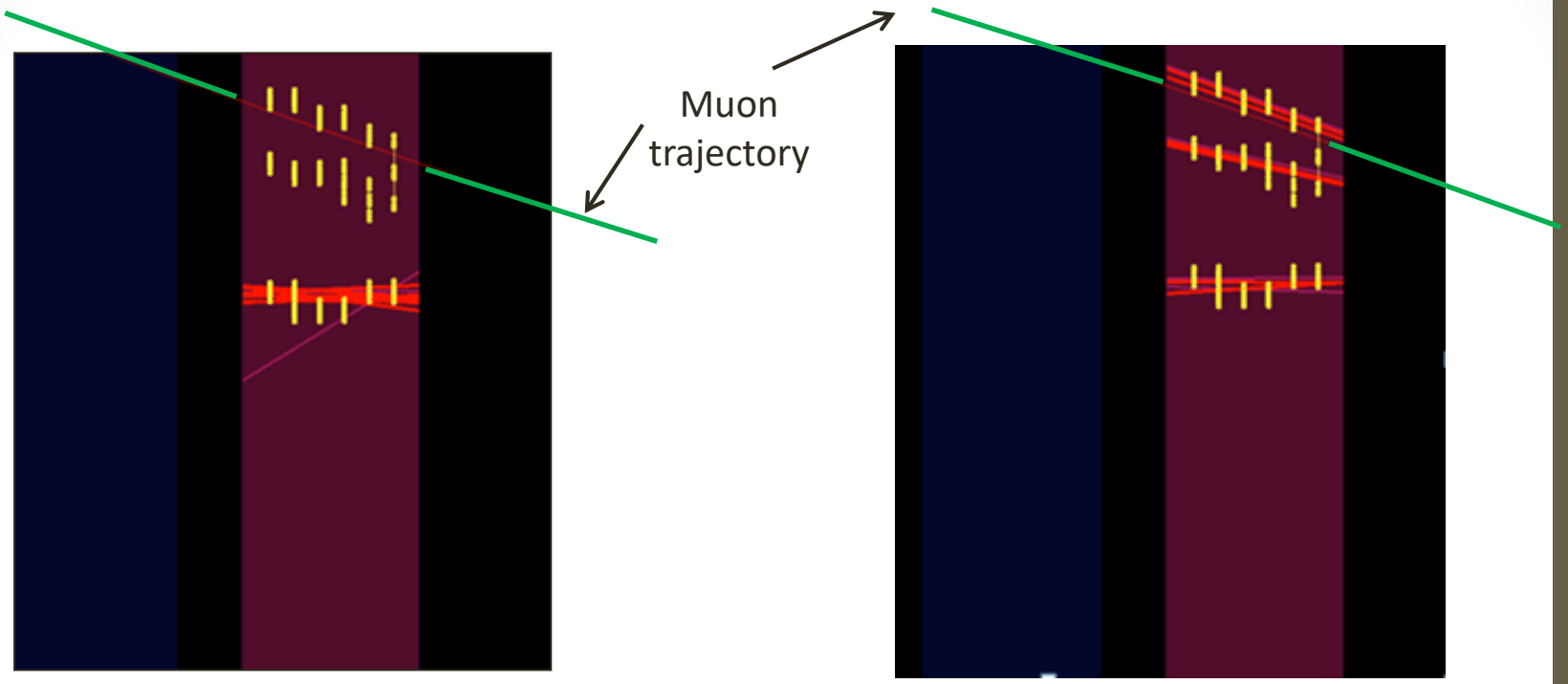






blue – ST algorithm; red – RU algorithm.

High multiplicity example - 72 RecHits in ME21



Standard
10 segments

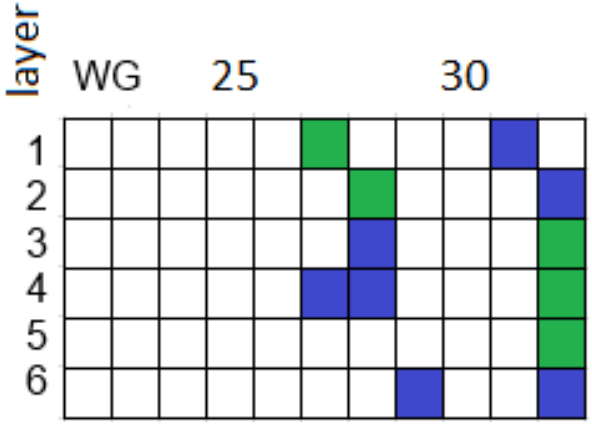
New
11 segments

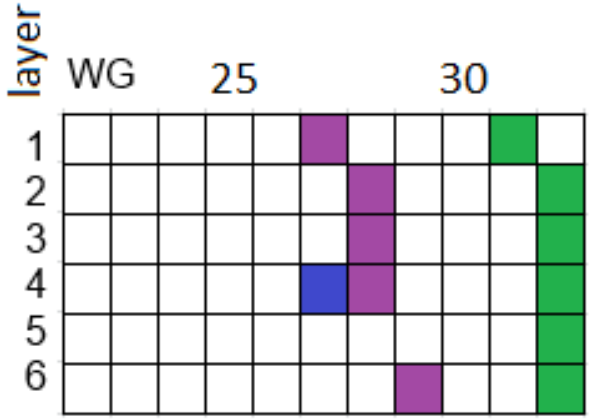
Collisions2015 256630:26:34248876

Event Example for R-coordinate

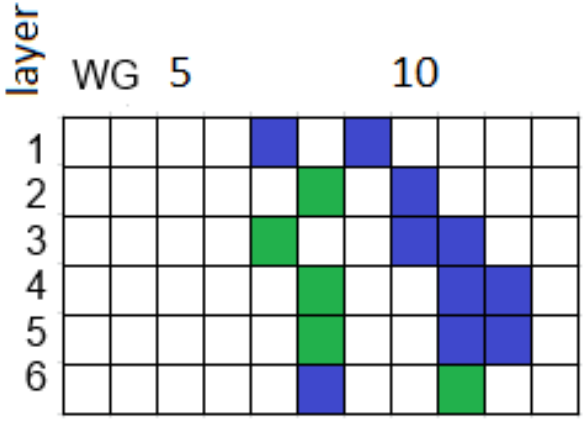
ST segments | Goal segments

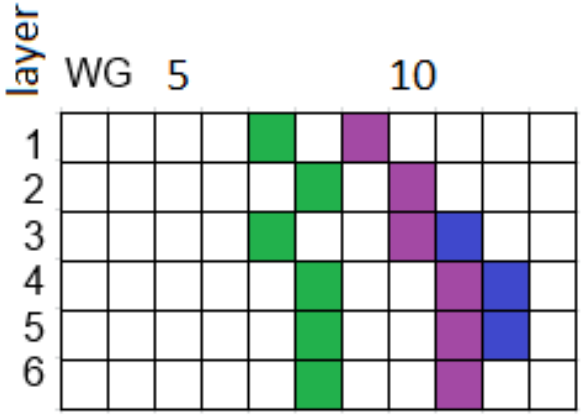
Collisions 2012 Run 198210 ME1/3 n_ev 1543





Collisions 2012 Run 198210 ME1/3 n_ev 12044





- muon segment
- segment 2
- BG hit

ST algo

- Spanning Tree (ST)

(1) $$A = |\theta_{12} - \theta_{23}| + |\theta_{23} - \theta_{34}| + |\theta_{34} - \theta_{45}| + |\theta_{45} - \theta_{56}|$$

(2) $$\theta_{12} \sim \frac{\Delta x_{12}}{d_{12}}$$

(3) $$A = \left|\frac{\Delta x_{12}}{d_{12}} - \frac{\Delta x_{23}}{d_{23}}\right| + \left|\frac{\Delta x_{23}}{d_{23}} - \frac{\Delta x_{34}}{d_{34}}\right| + \left|\frac{\Delta x_{34}}{d_{34}} - \frac{\Delta x_{45}}{d_{45}}\right| + \left|\frac{\Delta x_{45}}{d_{45}} - \frac{\Delta x_{56}}{d_{56}}\right|$$