GEM Simulation for the CMS upgrade

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Bari

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Outline

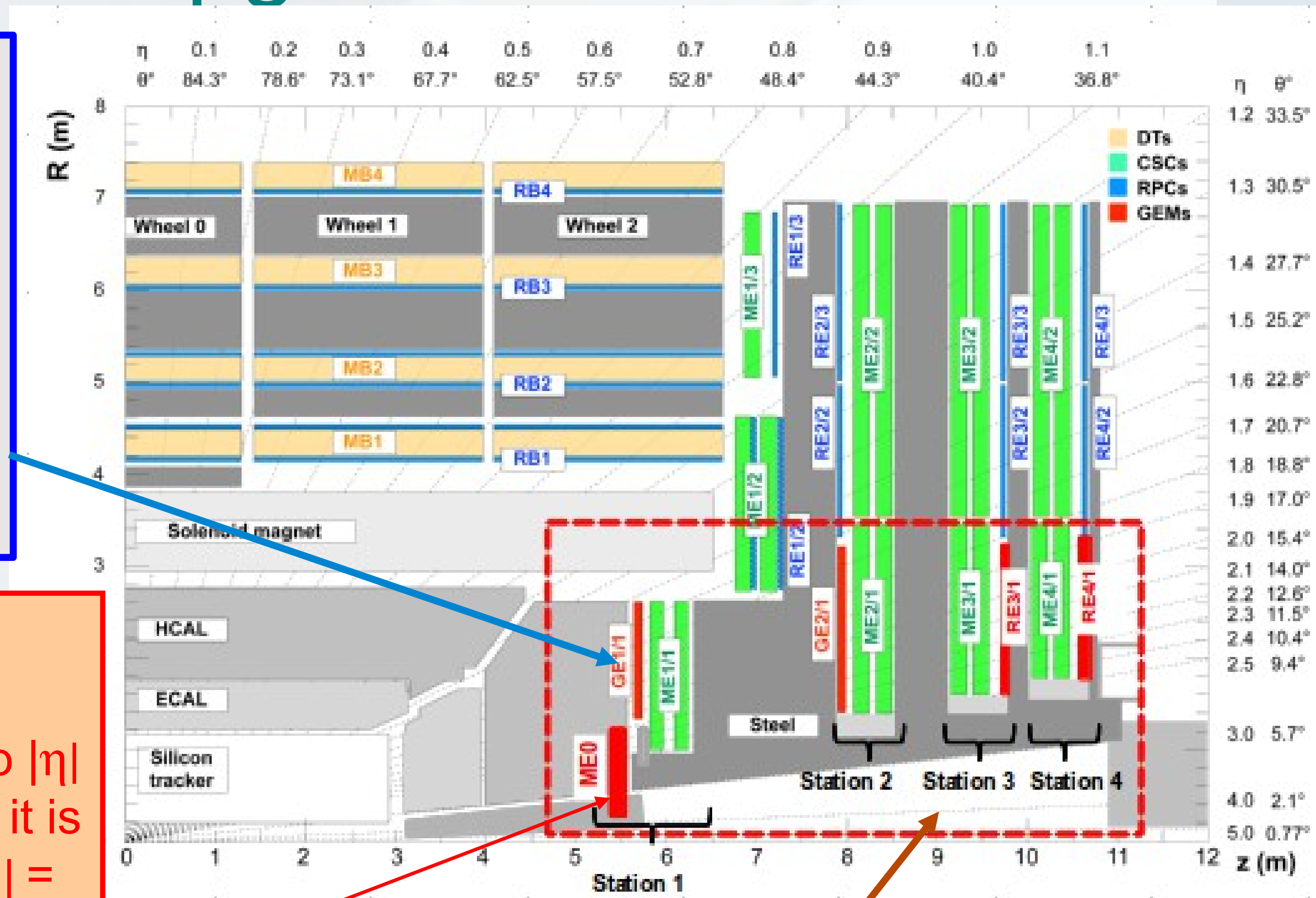
- CMS Muon upgrade scenario
- Status of the simulation for GE1/1, GE2/1 and ME0
  - Geometries
  - Background studies
  - Trigger
  - Realistic Digitization
  - "Local" reconstruction studies
  - "Global" reconstruction studies

Muon Upgrade Scenario

Post LS2:

– **GE1/1** GEM technology Demonstrator in YETS2016 approved

Plan for installation in LS2
TDR by October 2014



Post LS3:

– **ME0** to ensure efficient trigger coverage up to |η| = 2.4 (under studies if it is possible to go up to |η| = 3.5-4)

– **Station GE2/1:** GEM technology

Post LS3:

– **Station RE3-4:**

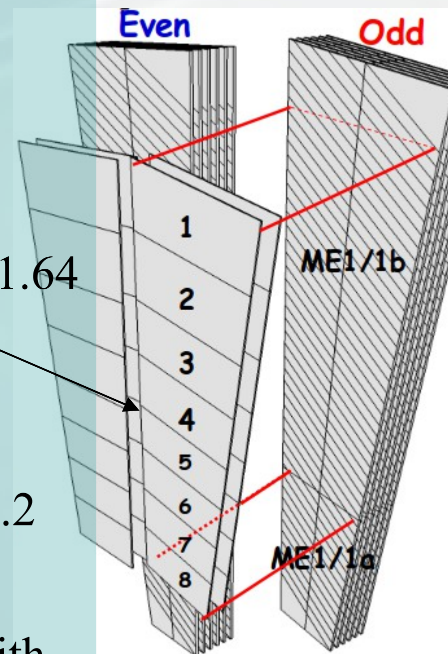
Technologies: advanced-RPC, GEMs

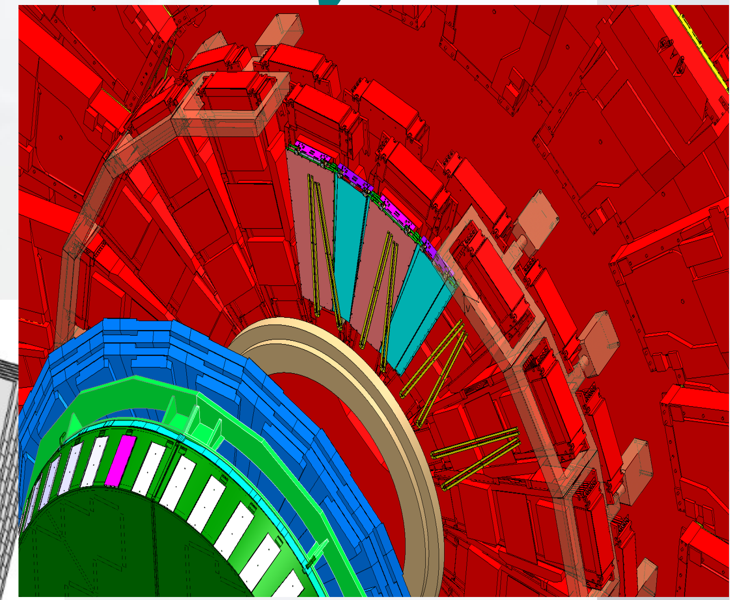
GE1/1

Present and final geometry

LAYOUT

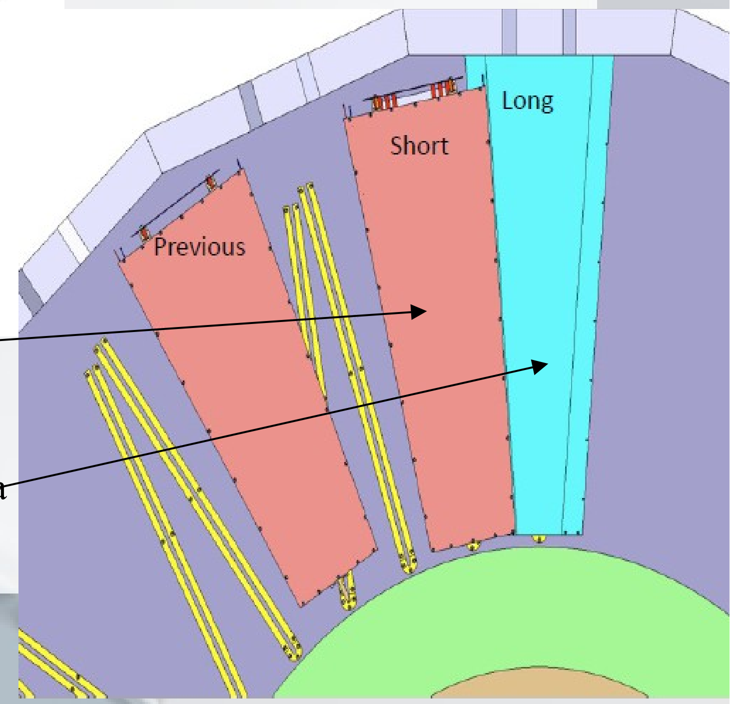
- Two 10° triple-GEM chambers to form a "super-chamber"
- 144 total chambers (36 super chambers in one station per endcap)
- Each chamber is segmented into different columns and η region
- Current geometry: 8 eta partitions covering 1.64 < |η| < 2.12





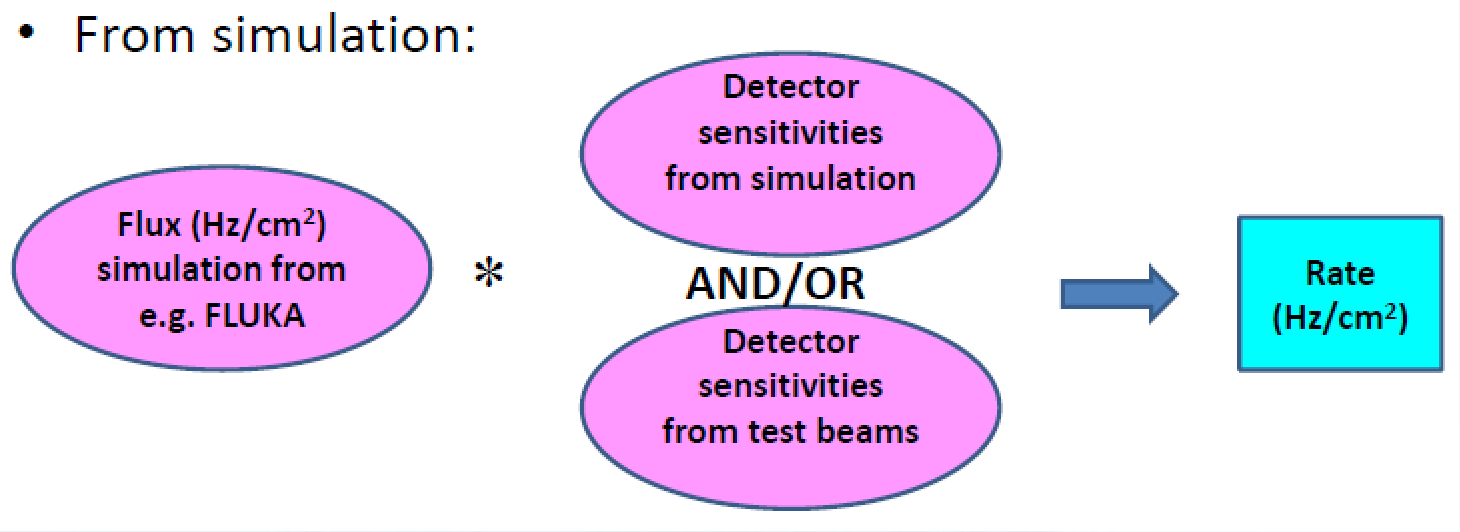
Final geometry:

- Short super chambers extend to 1.6 < |η| < 2.2 (due to the steel brackets):
  - 3 columns and 8 η-partitions with 384 strips per η-partition
- Long super chambers extend to 1.5 < |η| < 2.2:
  - 3 columns and 8-10 η-partitions (under studies) with 384 strips per η-partition



Radiation background in the Muon system

- Expected background rates are an important consideration in the planning of the Muon system upgrade
- Rates vs. detector rate capability determine the choice of the most suited detector technologies
- Can drive the choice of the optimal detector coverage
- Can also allow to determine the necessary shielding in front of the Muon system
- Estimated through simulation or extrapolation



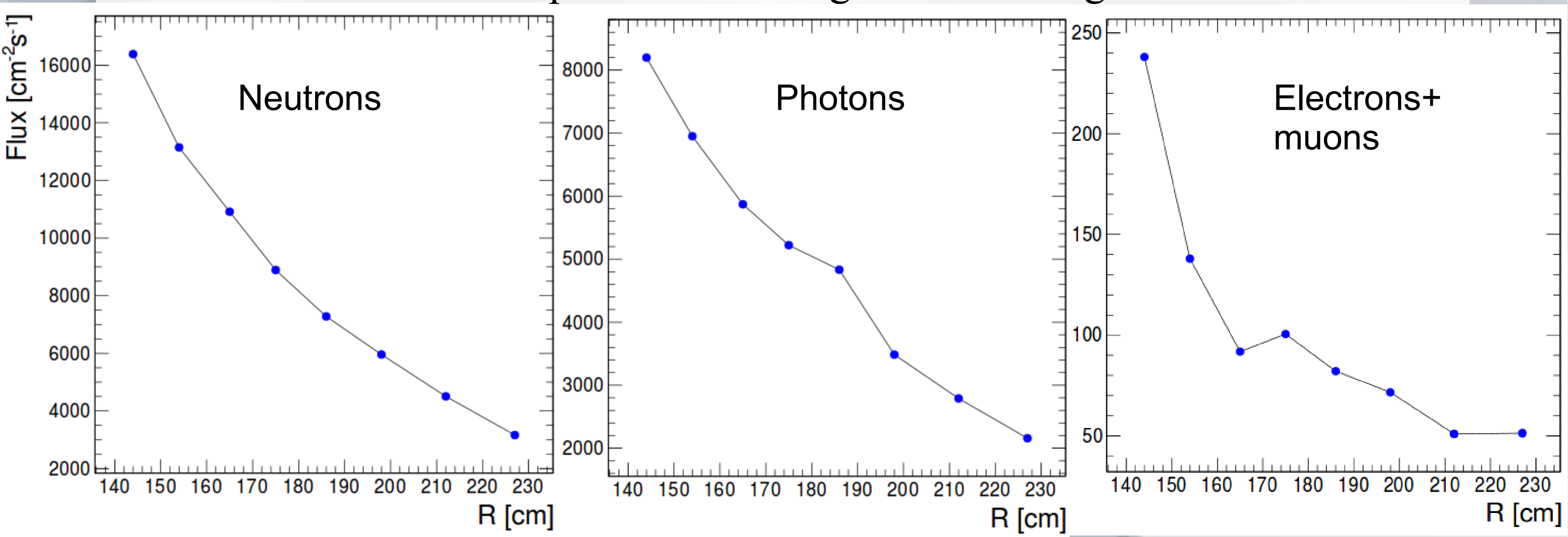
Background simulation

- First step: Particle fluxes
  - Simulation Tool: FLUKA
- CMS geometry:
  - 2019 scenario for GE1/1 - Current geometry, not including any of the upgrade systems (Full study presented)
  - 2023 scenario - including all upgrade systems (ME0, GE1/1, GE2/1, RE3, RE4) Need to have a realistic calorimetry upgrade description
- Second step: Sensitivity
  - Simulation tool: GEANT
  - Precise detector description in GEANT4 for the detector response to the photons and neutrons

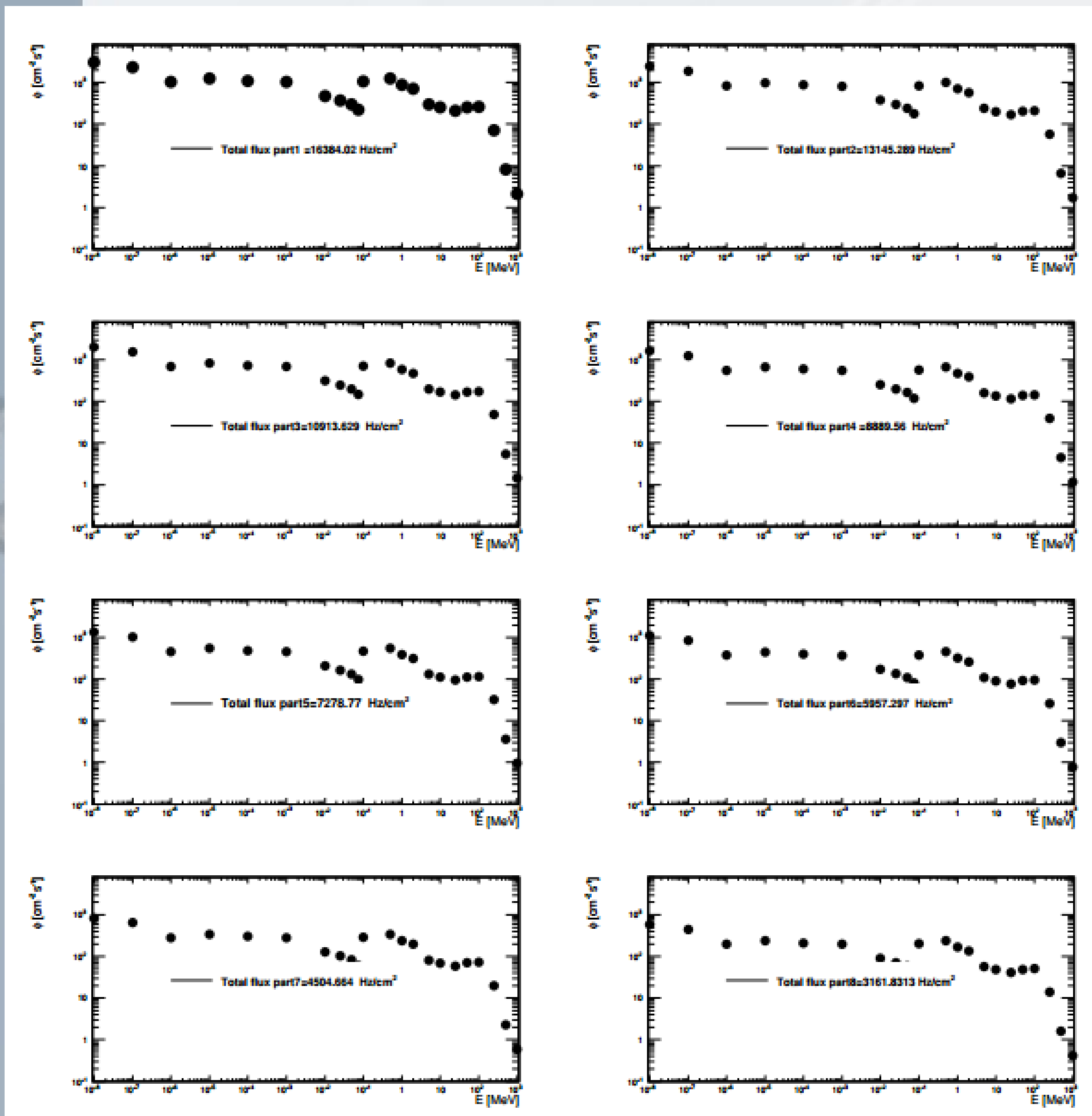
Flux predictions: Fluka

- According to FLUKA after neutrons and photons the next most important contribution coming from electrons and muons in that order (sensitivity ~1)
- Only small percentage of them will generate a signal in the detector
- Since the sensitivities are energy dependent, need fluxes also as a function of energy
- Missing YE4 shielding and endcap calorimeter not simulated: Expected rates could be overestimated

Flux of particles crossing the GE1/1 region



Neutron and photon flux in each eta partition

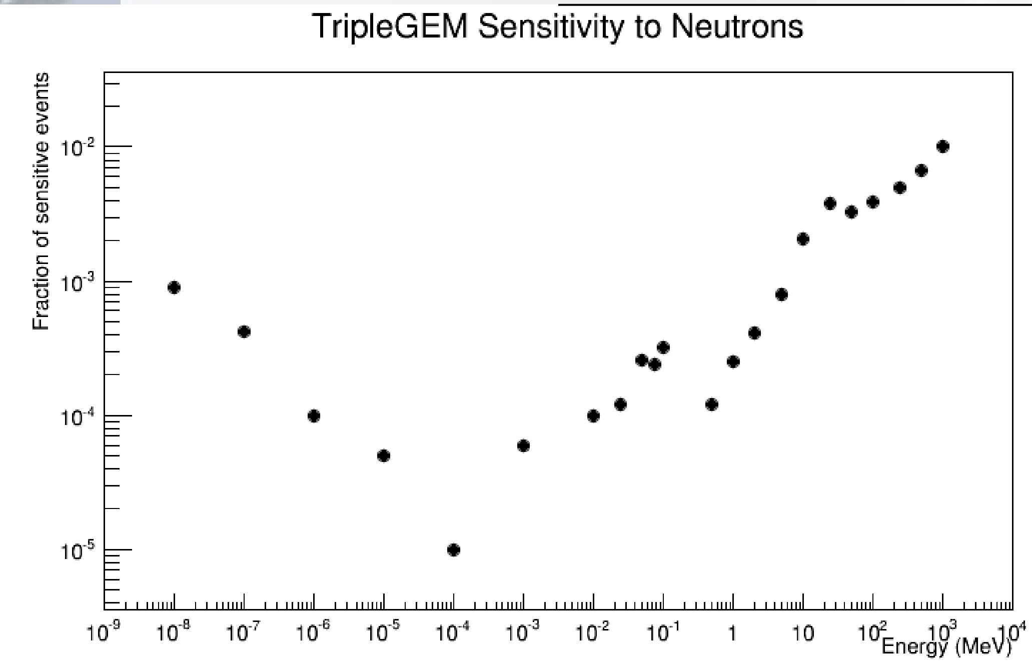


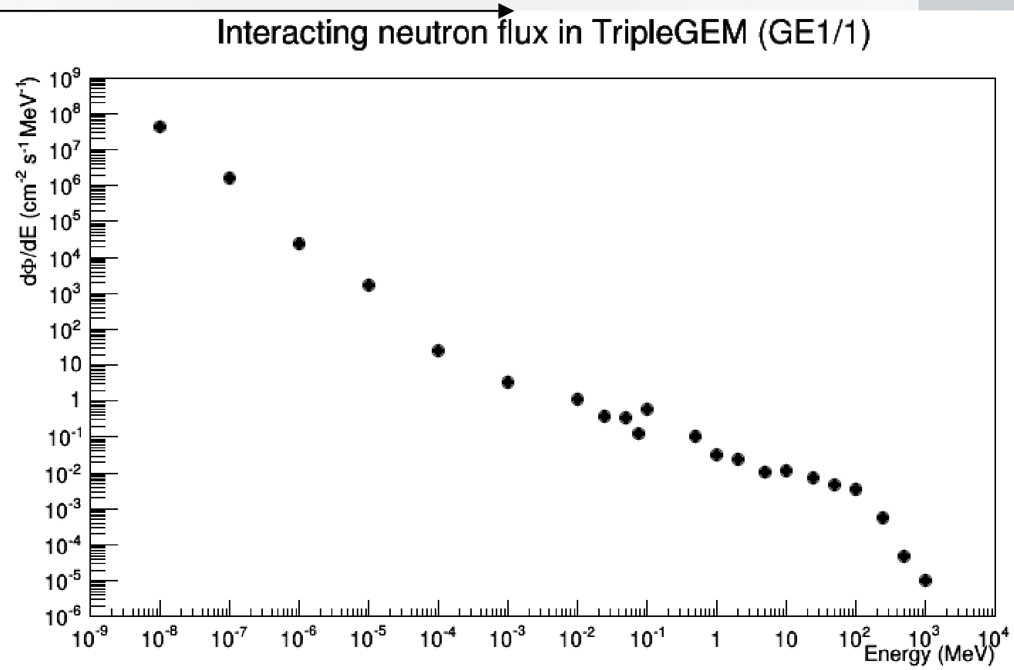
- Flux evaluate in each of the 8 eta-partitions.
- Last step is to combine this results with the sensitivities (as a function of energy) then integrate to get a total "effective" flux for each partition
- Left: example for the neutron flux vs. energy

Sensitivity with Geant4: Neutrons

- Precise, energy-dependent, detector sensitivities to each particle type is needed
- Description of triple-GEM detector and gas mixture in GEANT4
- An event is considered as sensitive if there is a deposition of energy (Drift Gap) of 5 times the average potential (15.54 ev)

Convolution with detector sensitivity





Background rates

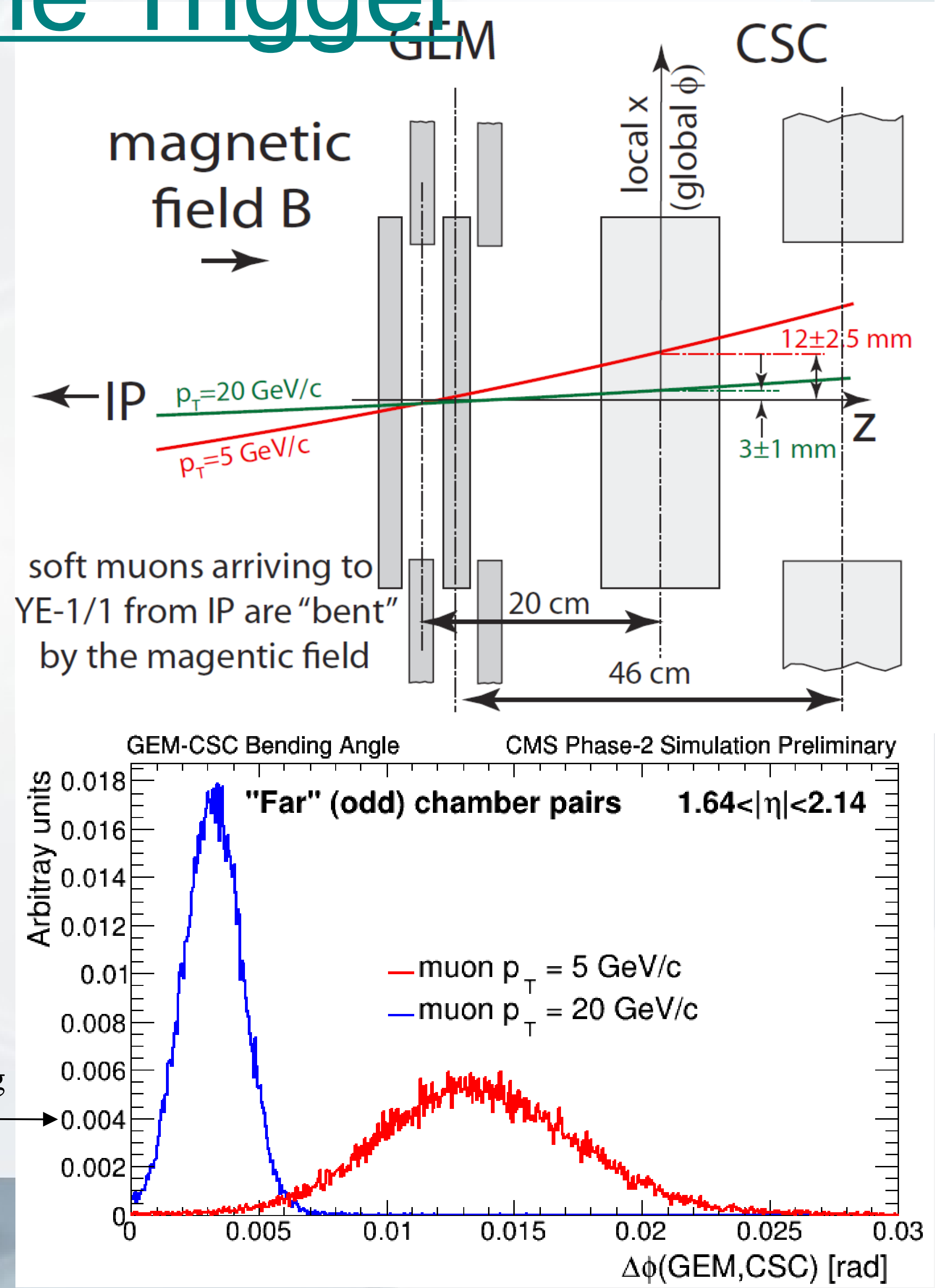
- Background rates for each partition
- Taking a sensitivity of 1 for (electrons+positrons)
- Numbers used in the simulation (digitization)

Partition	n [Hz/cm^2]	γ [Hz/cm^2]	$e^{\pm}$	Combined [Hz/cm^2]
1	39	37	238.1	314.1
2	31	31	137.9	199.1
3	26	26	91.8	143.8
4	21	24	100.5	145.5
5	17	22	82.1	121.1
6	14	16	71.7	101.7
7	11	12	51.0	74.0
8	8	10	51.3	69.3

Impact on the Trigger

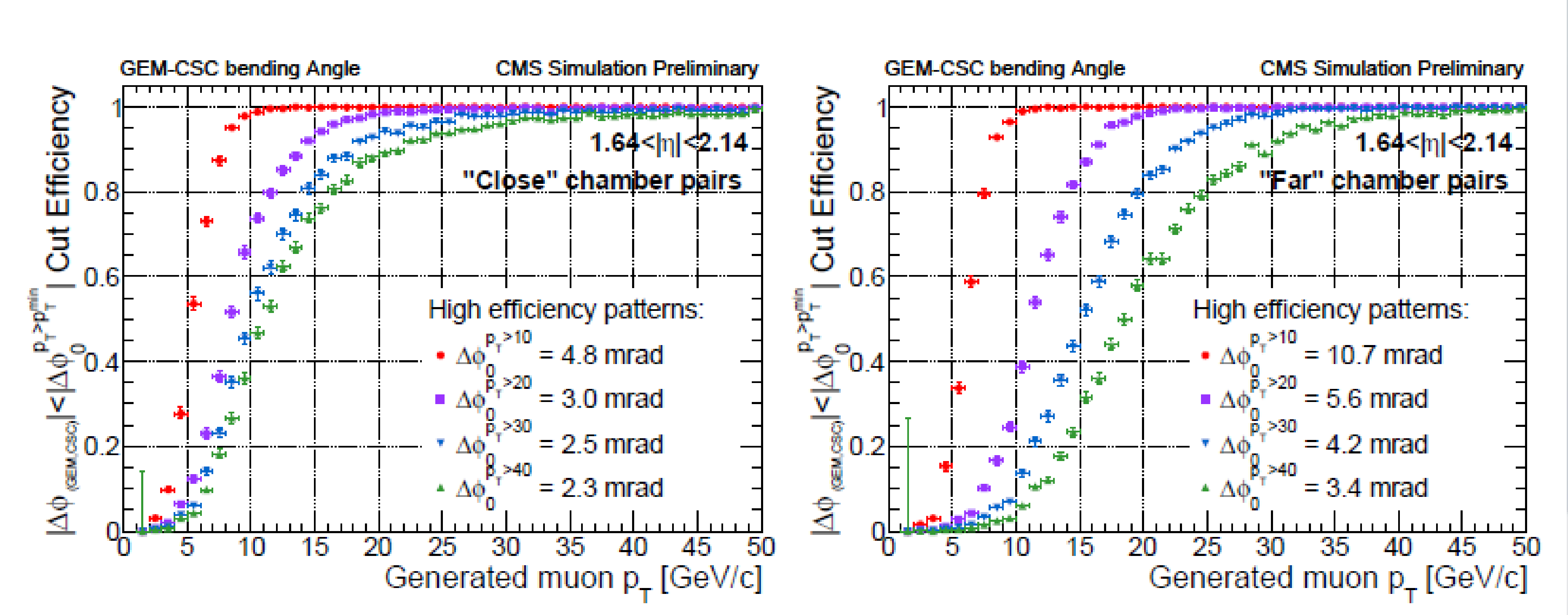
- L1 muon momentum resolution can be improved with a second detector if we can measure the "bending angle"
- GE1/1 in reagion with least scattering, strongest B:
  - Increase "lever arm" (to ~20-46 cm)
  - High point resolution of GEM detector improve over the limited p_T resolution.

- Excellent discrimination power to distinguish soft muons from hard ones
- Larger lever arm for "far" chambers provides even better separation



Muon selection using the bending angle

- Level-1 Muon Track Finder candidate (without requirements on the reconstructed momentum of the candidate) with signal in stations GE1/1 and ME1/1



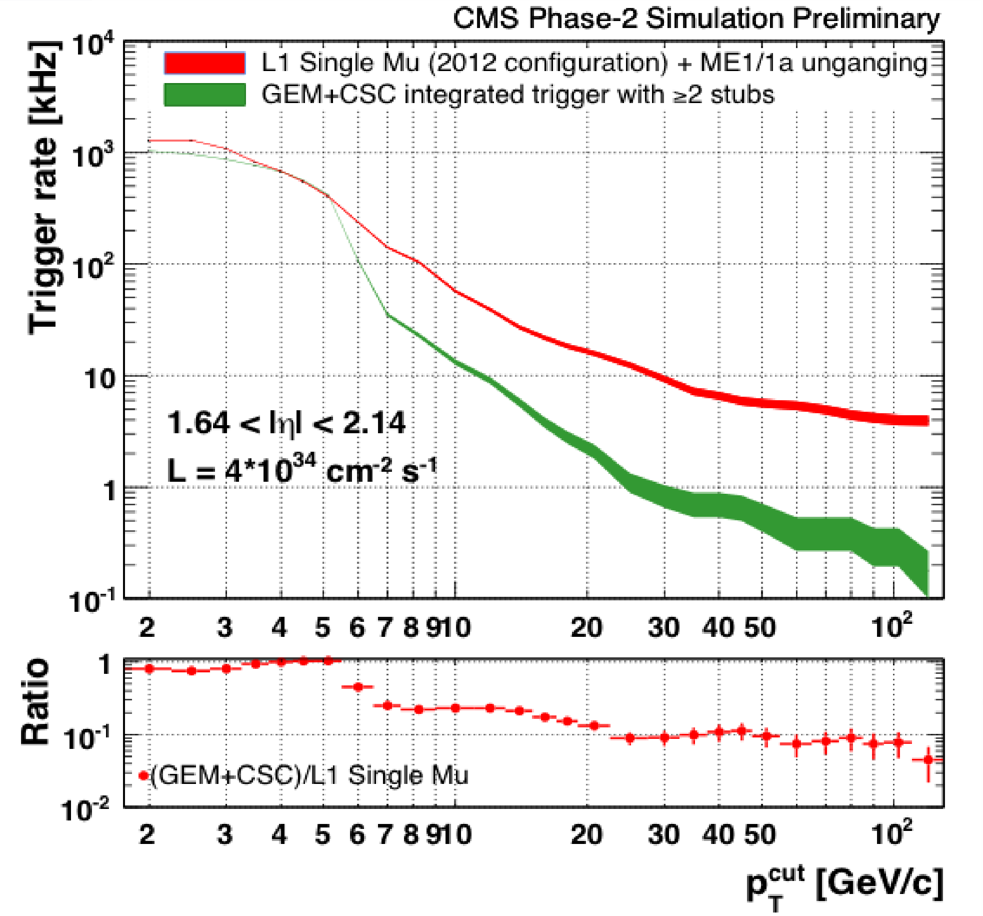
Lowering thresholds with GEM

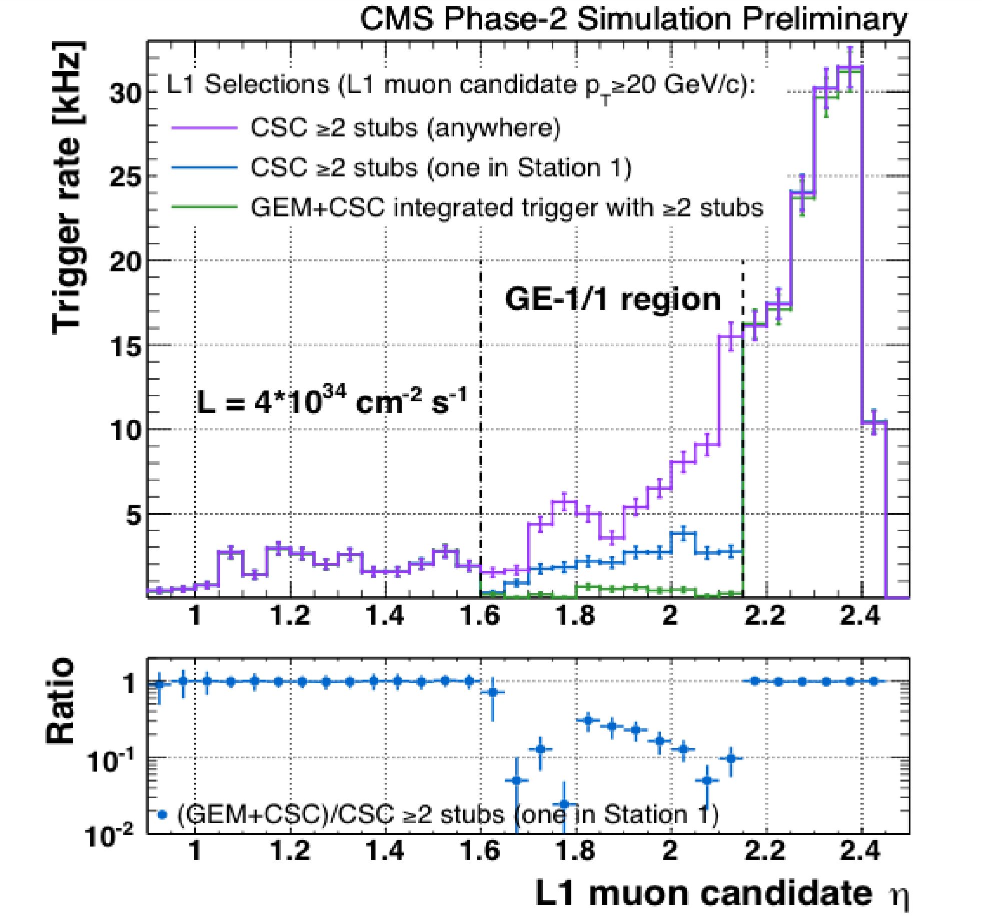
CSC only: at least 2 CSC stations with hits + presence of a track in ME1/1:

- Muon L1 rates increase with |η|, as the momentum resolution decreases.

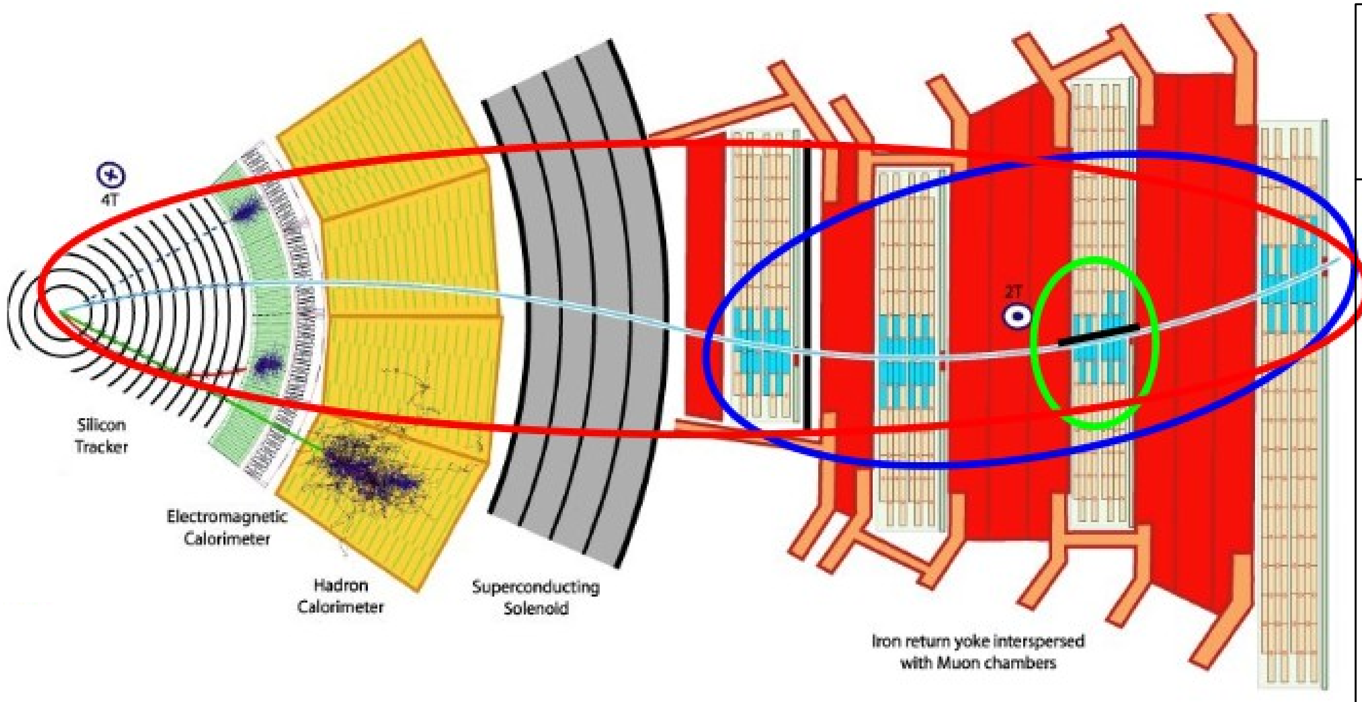
GEM+CSC combined trigger:

- Improve the momentum resolution and reject background without much loss of efficiency





Reconstruction status

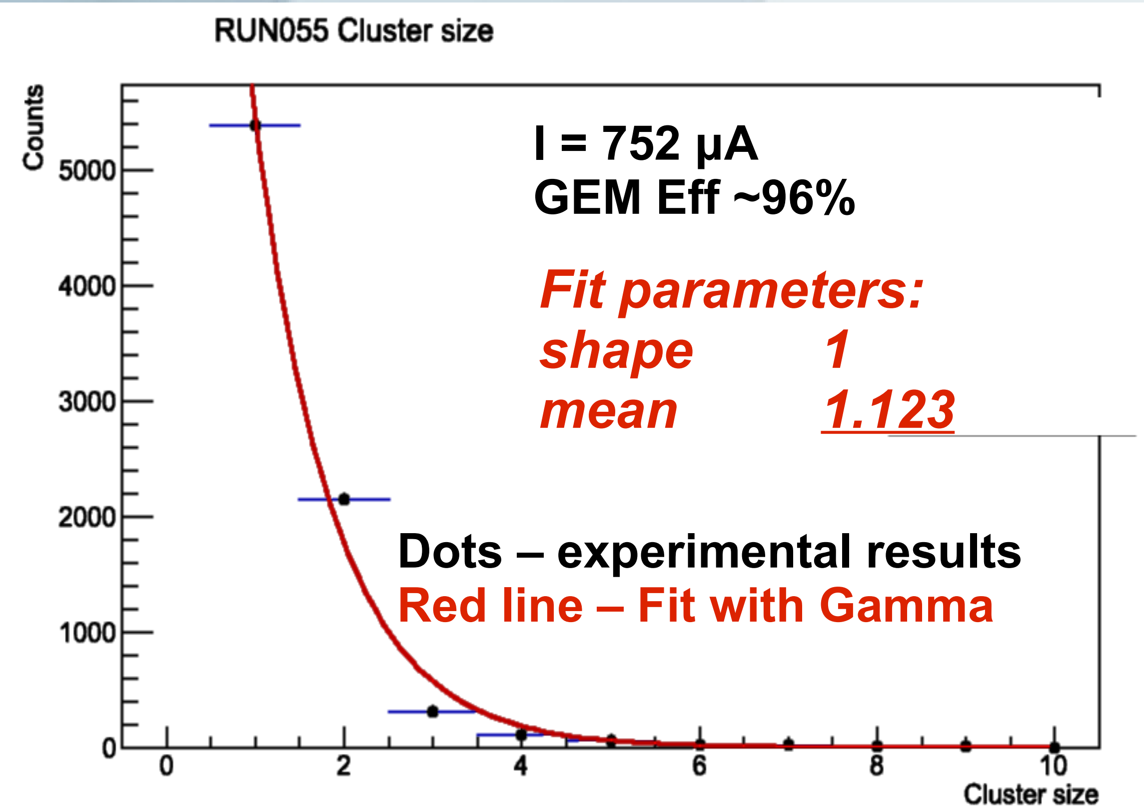


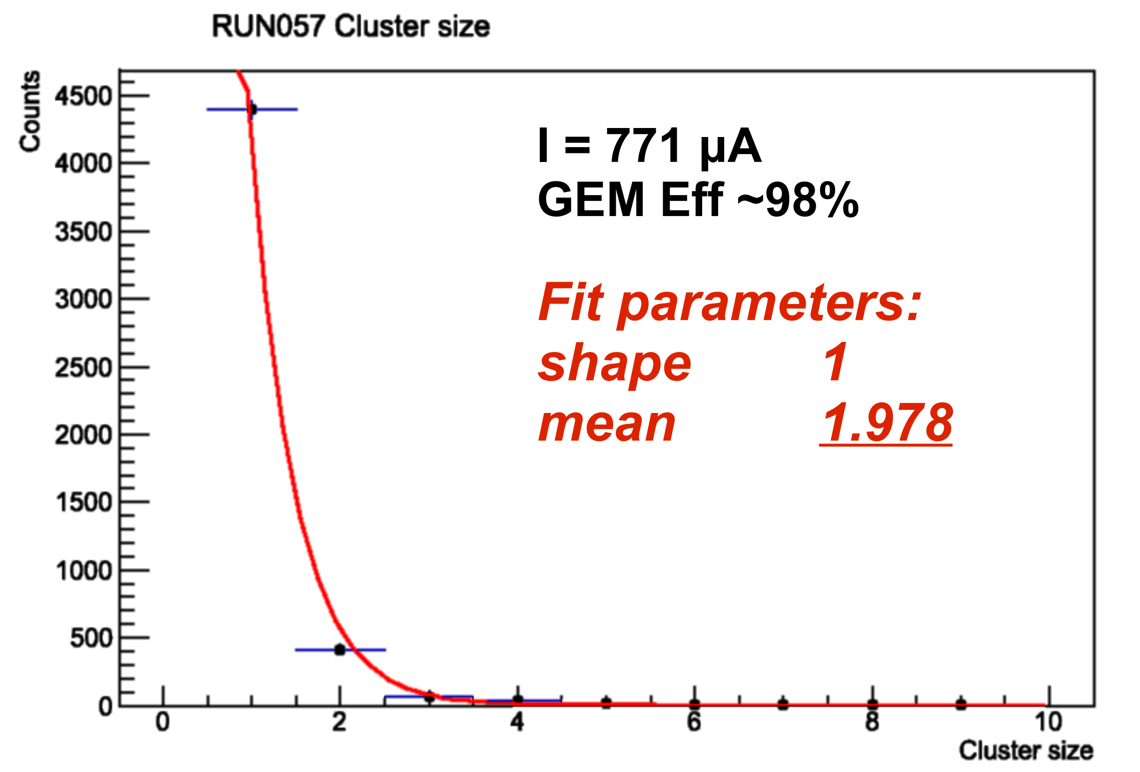
0. Digitization step: DONE with realistic cluster and background description
1. Local reconstruction: Reconstruction of **hits** and **track segments** inside a **chamber** DONE: GEM RecHit implemented for Digital R/O DONE: Correct RecHit uncertainty implemented TO BE DONE: Seeding with GEMs

2. Stand-alone Reconstruction (or Level-2 in HLT) Reconstruction of the **track** inside the **muon system**	DONE: GEM RecHits included in the track fittting
3. Global Reconstruction (or Level-3 in HLT) Reconstruction of the **track** combining the information from **tracker** and **muon system**	DONE: GEMs included in the STA muon, GLB muon comes consequently
Cosmin muon, Tracker and TeV muon	TO BE DONE
Muon ID with GEMs	TO BE DONE

Digitization with Realistic Condition: Cluster Size Model

- The experimental CLS distribution have been fitted using Gamma Distribution
- The average value of the mean parameters obtained from the fit has been chosen for digitization model





Digitization with Realistic Condition: Cluster Size Model

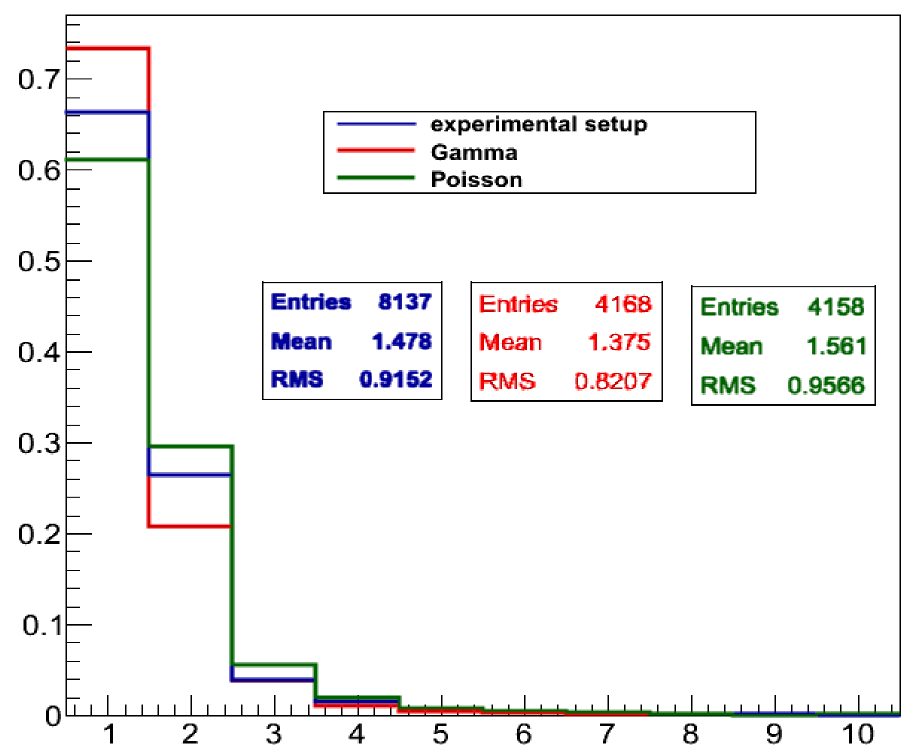
Experimental data vs. MC

Two MC models have been tested:

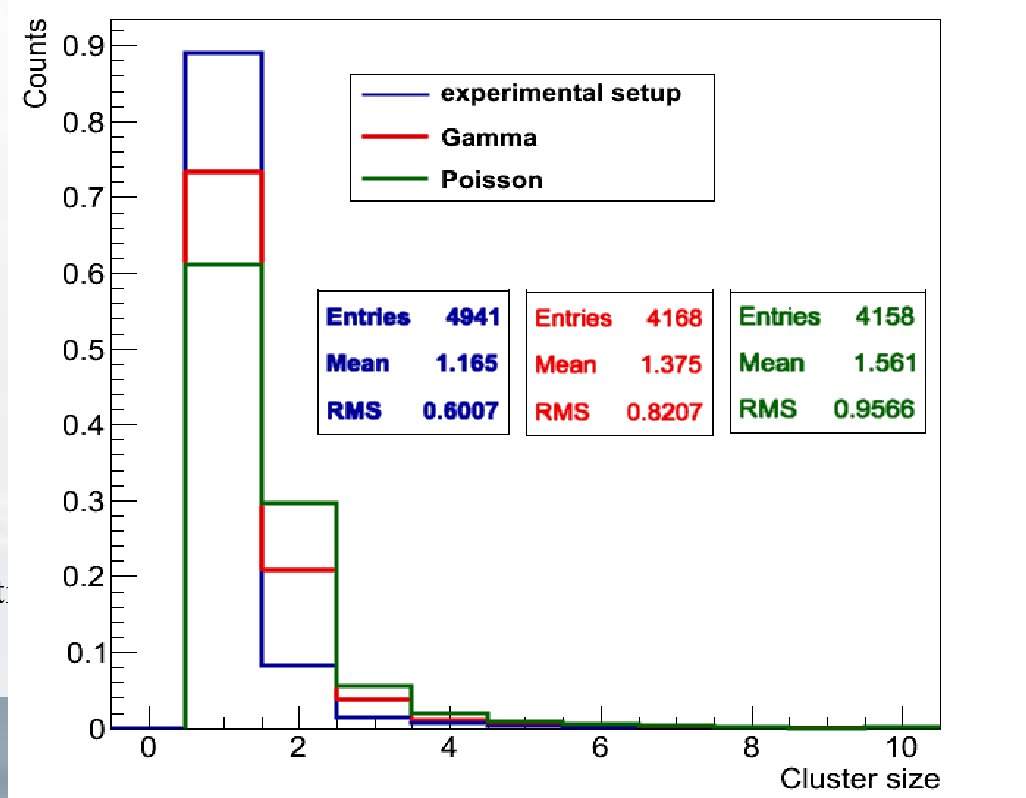
1. The value of CLS is generated using Gamma Distribution pdf

2. The value of CLS is generated using Poisson Distribution pdf

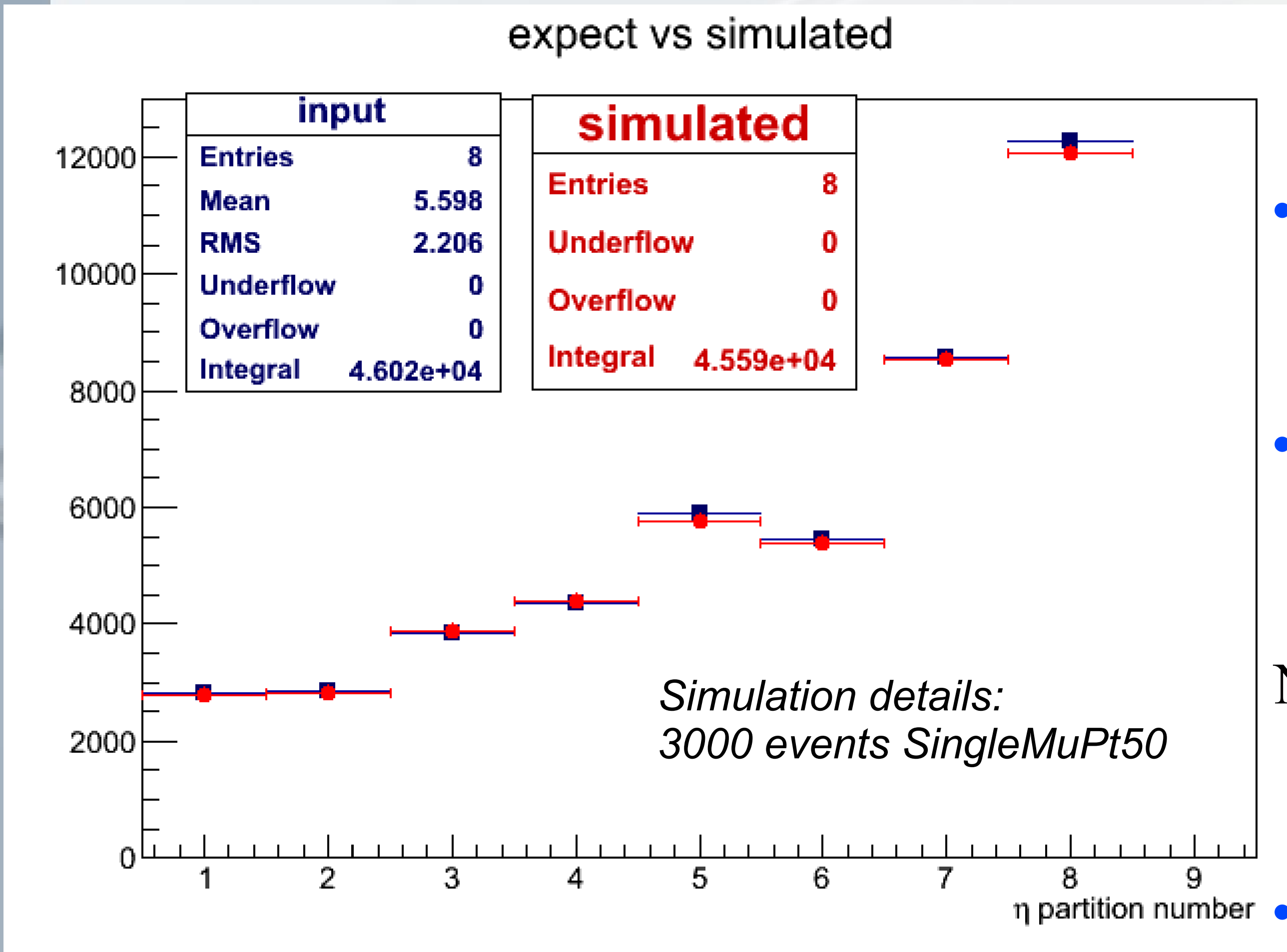
CLS I = 771 μA



CLS I = 752 μA



Digitization with Realistic Condition: Background rate

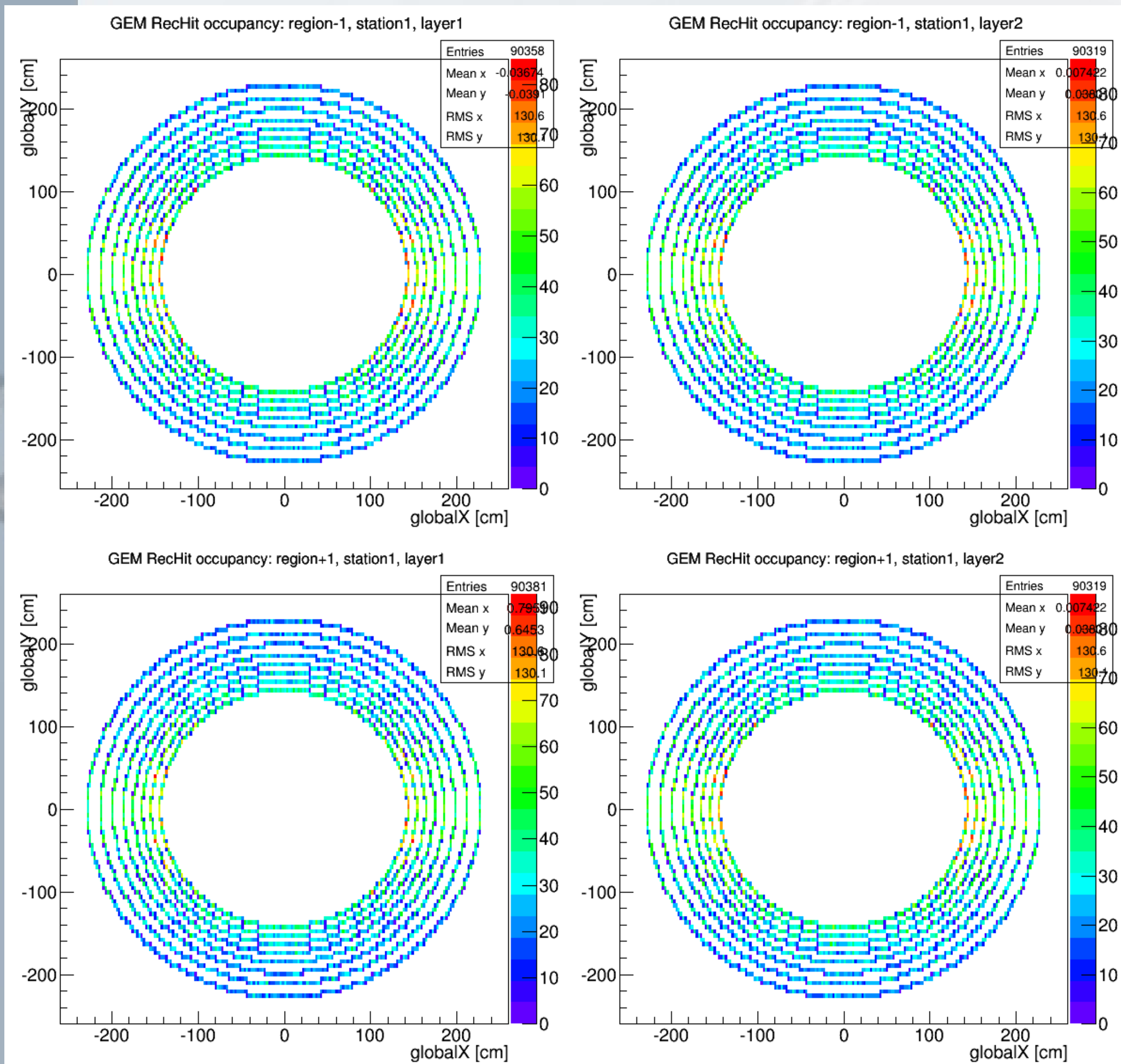


- The results from Fluka simulation have been used as an input parametrization
- Comparison between the number of input noise rate and the simulated
- The input noise rate for a given eta partition is has been calculated as:

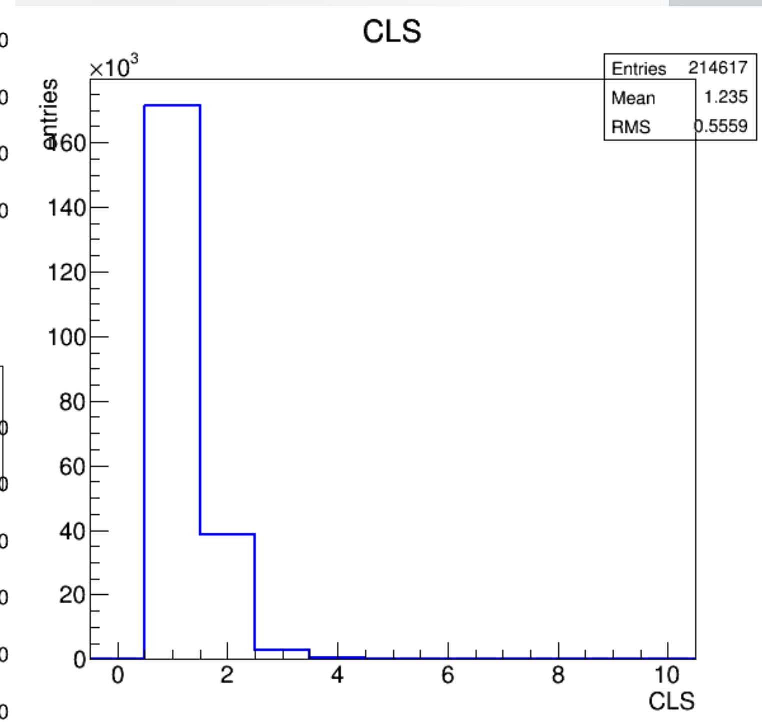
Noise rate = Input value [Hz/cm^2] x partition area [cm^2] x simulated time [s]

- The simulated rate has been taken directly from the simulation

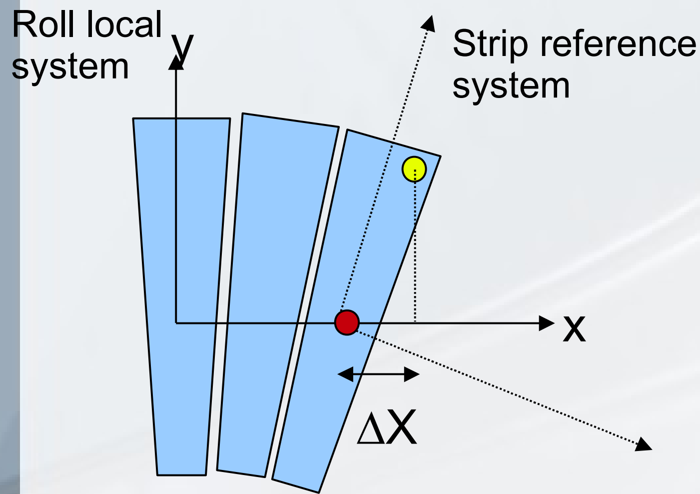
Local reco: X-Y occupancy plots



Only GEM recHits matched to muon GEM simHits (coming from muon simTracks)



Local Reco: recHit local error position



Roll Local reference system:

- SimHit (x_simHit, y_simHit)
- RecHit (x_recHit,0)

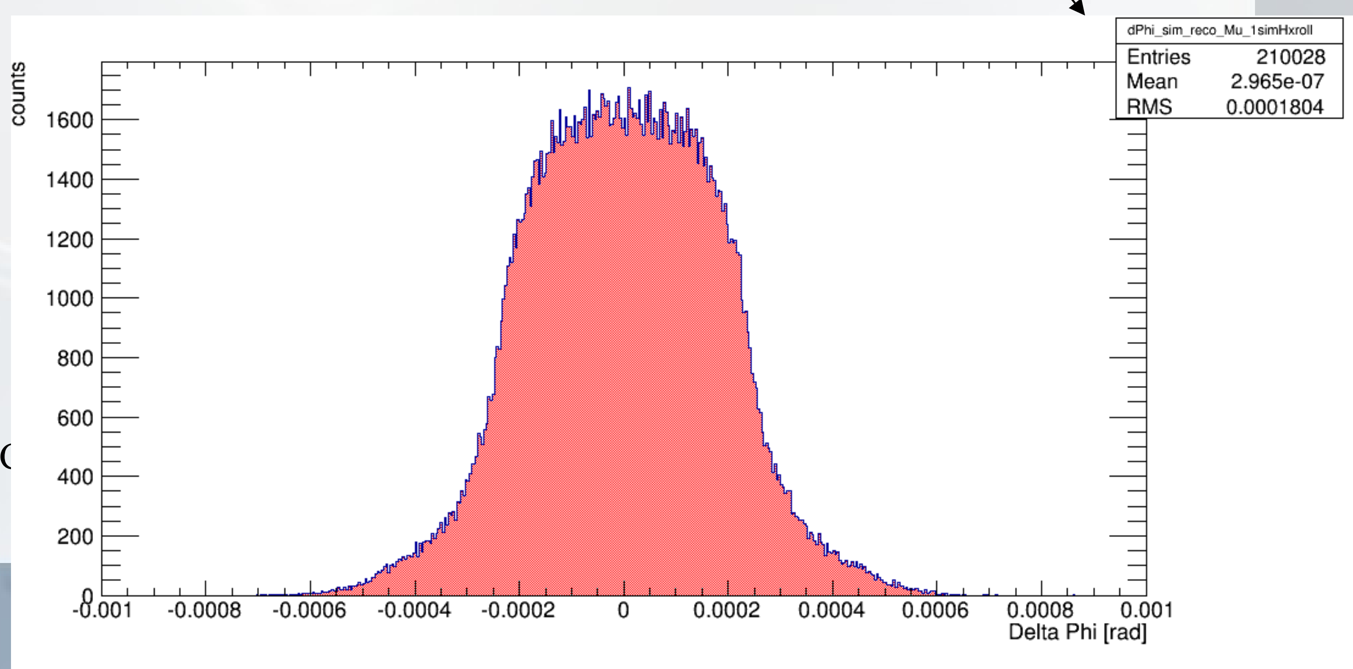
- Maximum ΔX due to orientation of the strips in the local system: ≈ 0.5 cm

- The only solution to evaluate the resolution is to look at $\Delta\Phi$ instead of ΔX

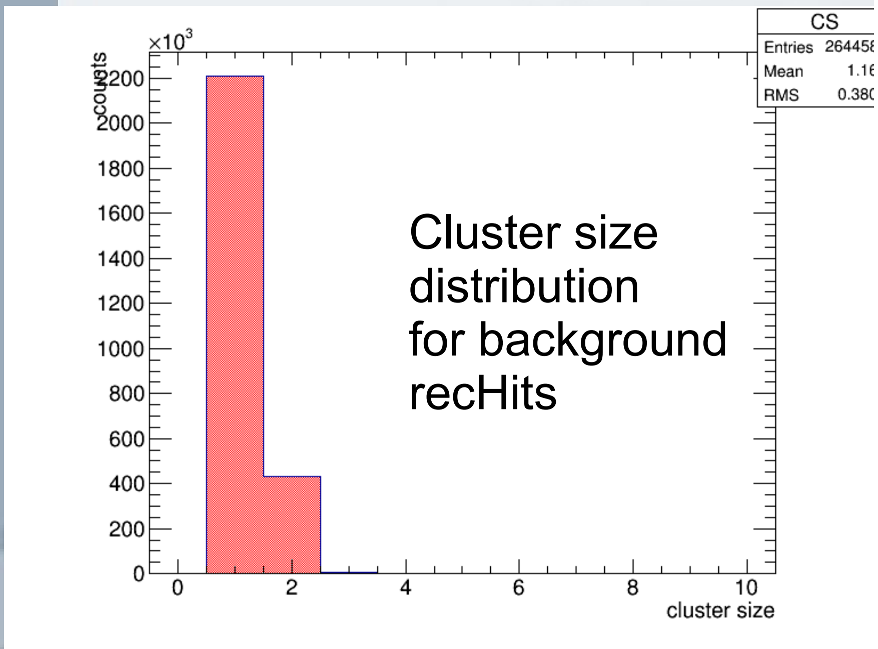
NB: Local error position now depends also on the CLS!

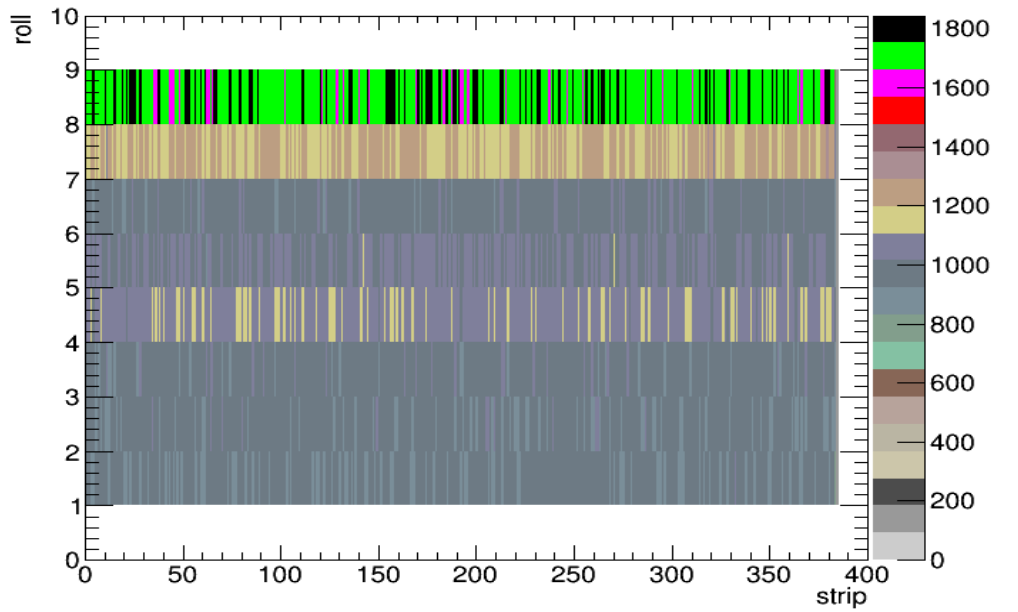
- $\Delta\Phi$ = (simHit_Phi – recHit_Phi) [rad]
- $\Delta\Phi$ 1 roll = 10° = 0,1744 [rad]
- $\Delta\Phi$ 1 strip = 10°/384 = 0.0004427 [rad]

- Expected resolution:
  - $\Delta\Phi/\sqrt{12}$ = 0.000178 [rad] (if CLS size = 1.4 strips)
- Observed resolution: ~0.00018 [rad]



Local reco: Background rate from recHits





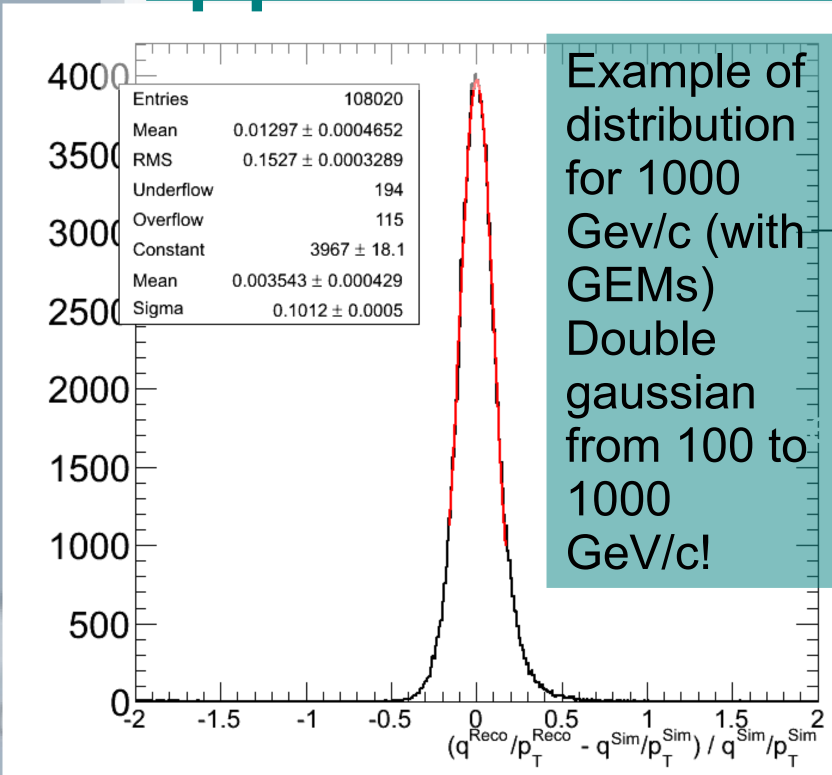
Roll	Pitch [cm]	Striplength [cm]	Area [cm^2]	Expected noise rate [Hz/cm^2] (A.Castaneda)	Observed noise rate [Hz/cm^2]
1	0.10598	15.26	621.024	69.3	69.43 ± 0.28
2	0.0989986	15.26	580.116	74	74.13 ± 0.3
3	0.0926564	12.376	440.339	101.7	101.46 ± 0.42
4	0.0869529	12.376	413.234	121.1	121.29 ± 0.48
5	0.0816915	10.38	325.616	145.5	145.30 ± 0.58
6	0.0768721	10.38	306.406	143.8	143.88 ± 59
7	0.0721121	10.112	280.012	199.1	199.30 ± 0.78
8	0.0674115	10.112	261.759	314.1	313.44 ± 1.13

Number of clusters from background per roll

The expected and observed noise rate are compatible

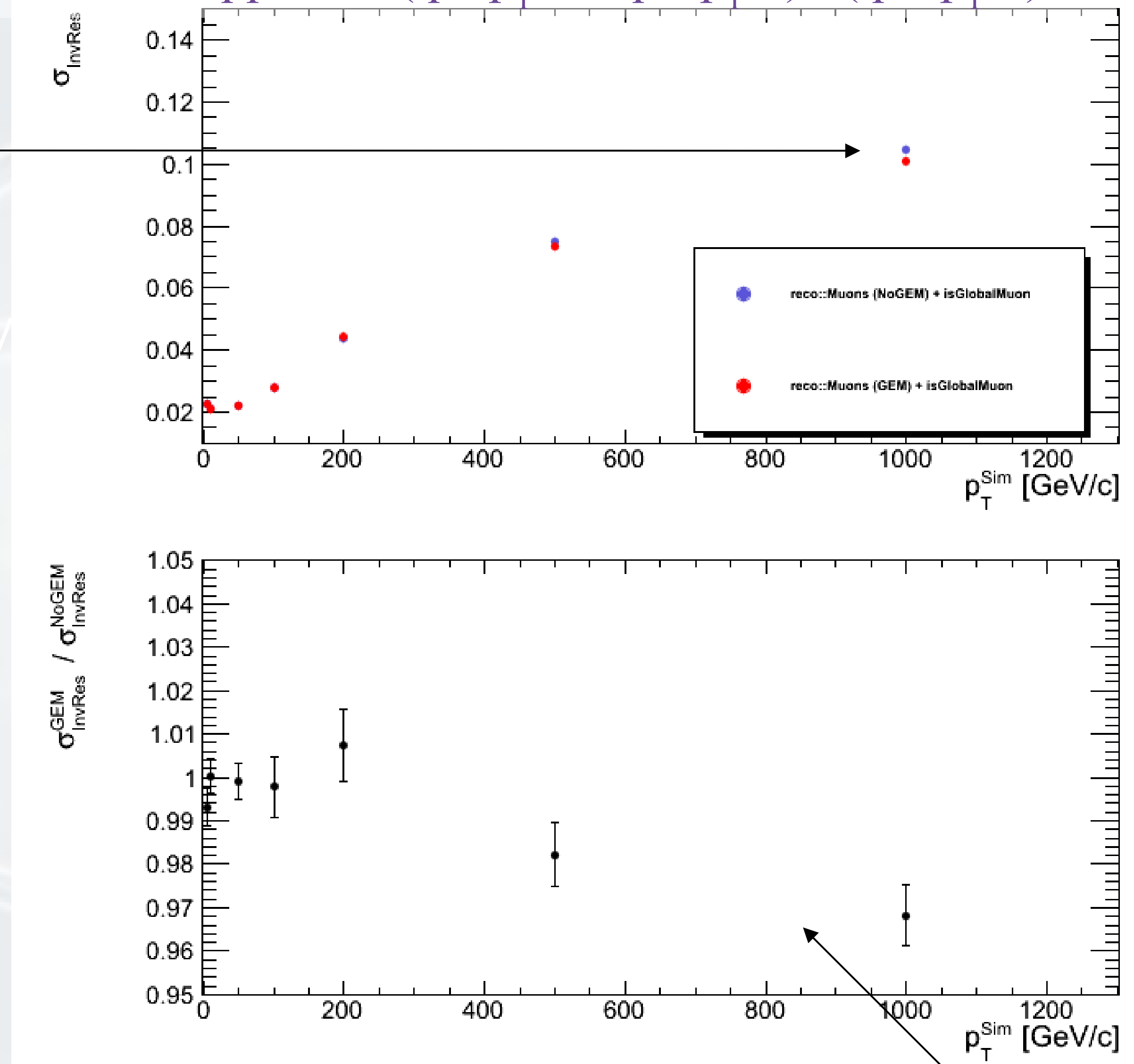
NB: Roll 8 is at higher η!

q/p resolution: core width vs. sim p_T



Example of distribution for 1000 Gev/c (with GEMs) Double gaussian from 100 to 1000 GeV/c!

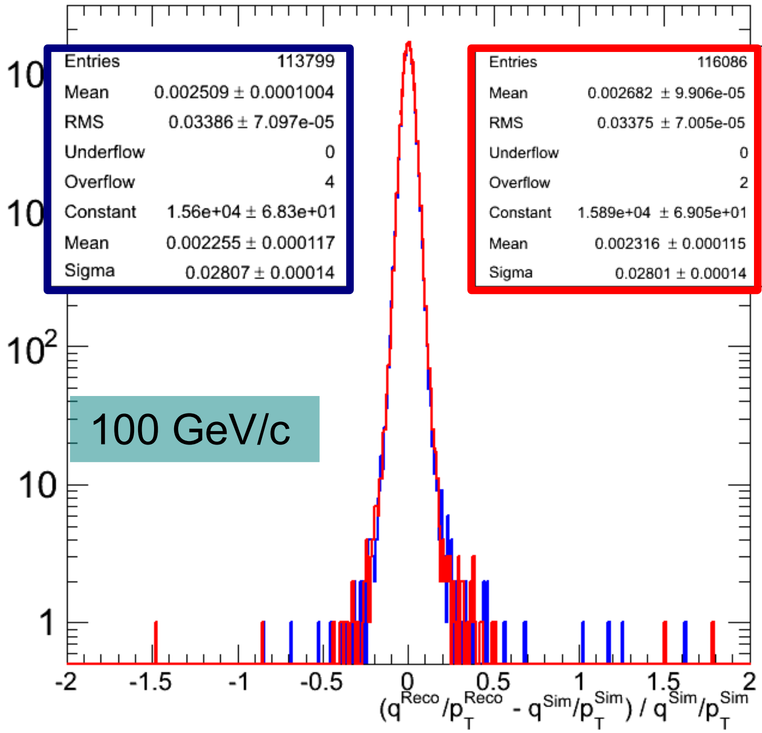
$q/p \text{ res} = (q^{rec}/p_T^{\ rec} - q^{sim}/p_T^{\ sim}) / (q^{sim}/p_T^{\ sim})$

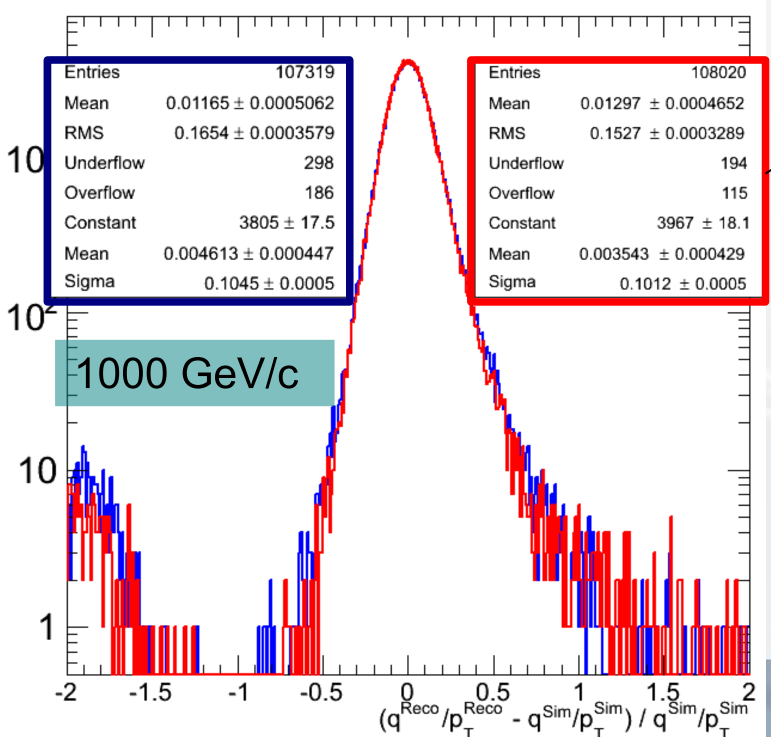


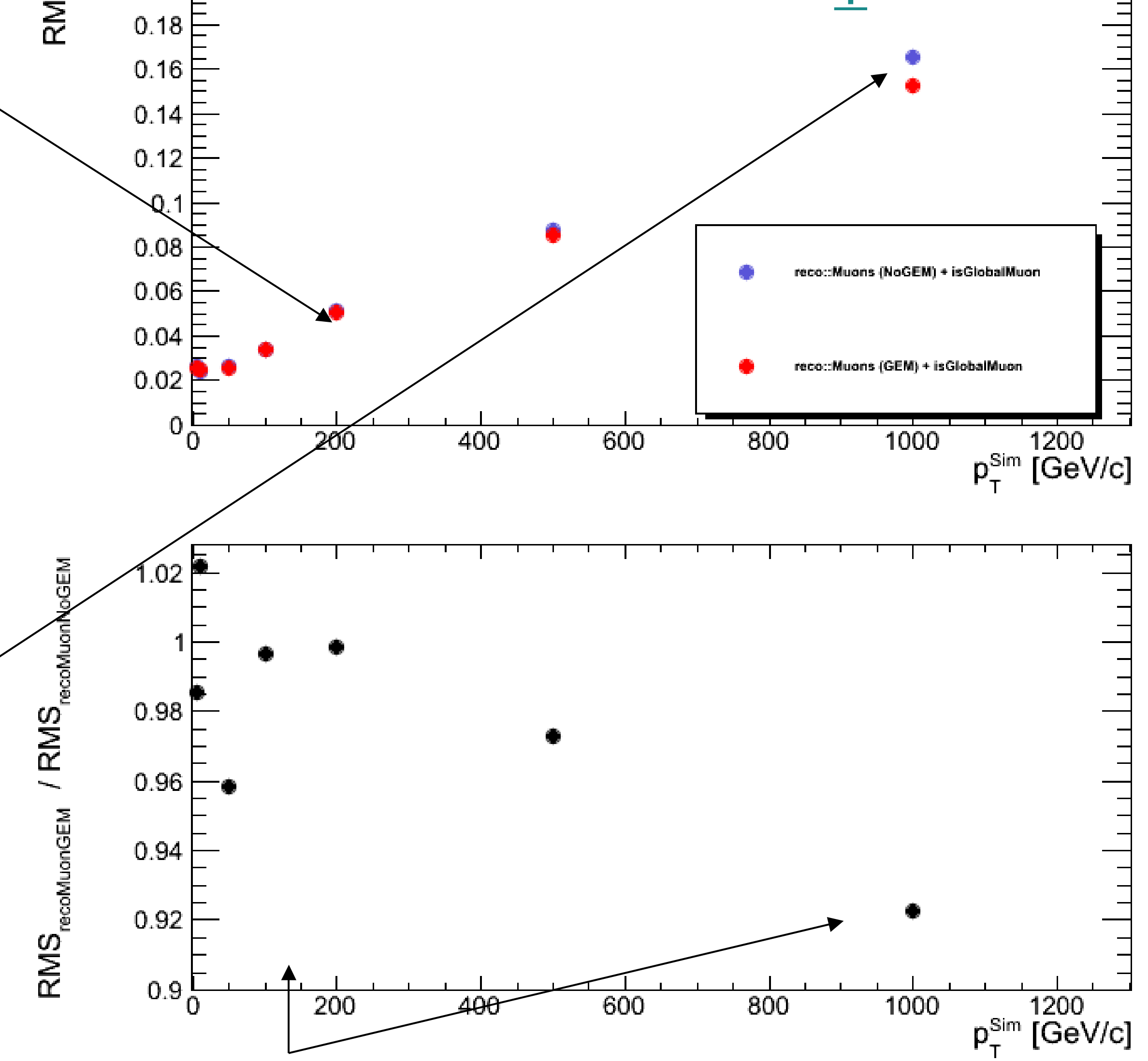
- Inverse p_T resolution obtained fitting the distribution (for each p_T) to a gaussian
- Range used: mean ± 2xRMS (as done in AN2008_097)
- Uncertainty: statistical uncertainty in quadrature with the difference in sigma observed when fitting over the reduced and whole range

- Slight improvement at 500-1000 GeV/c
- Core width is stable

q/p resolution: RMS vs. sim p_T



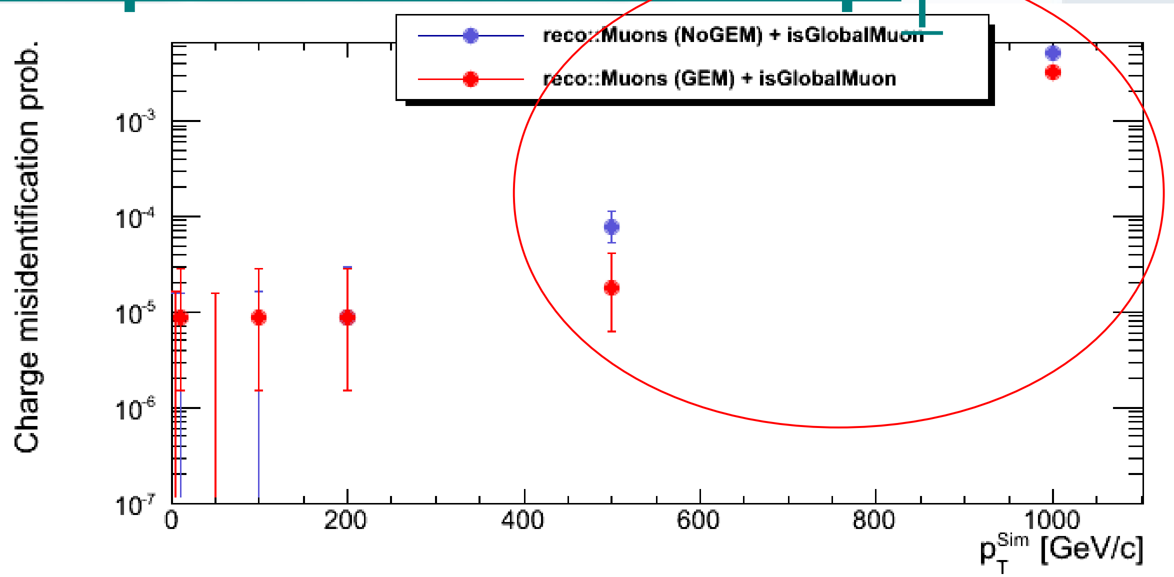


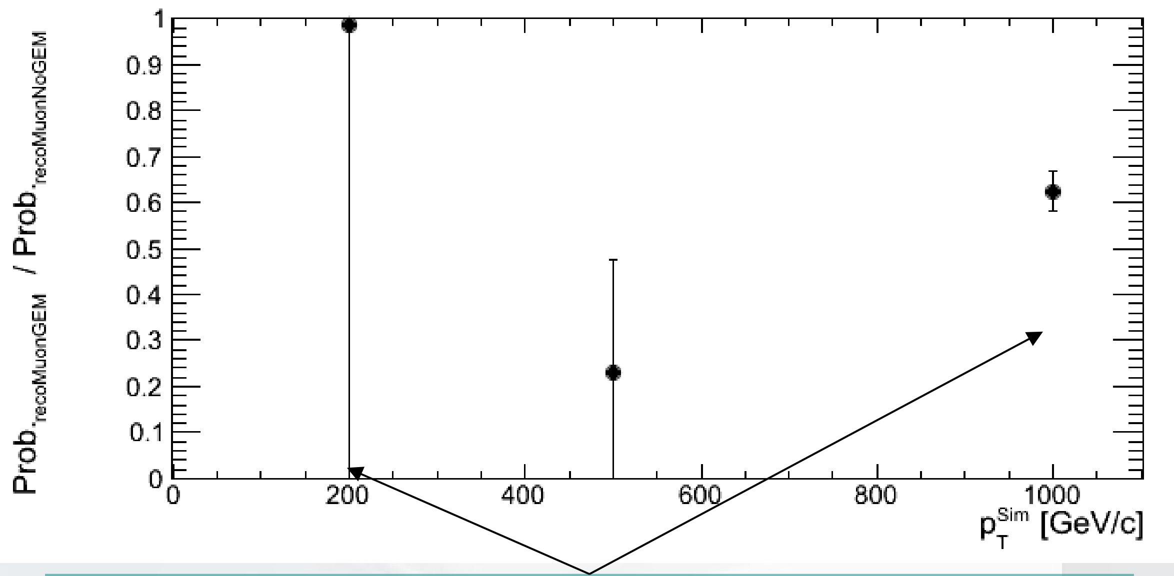


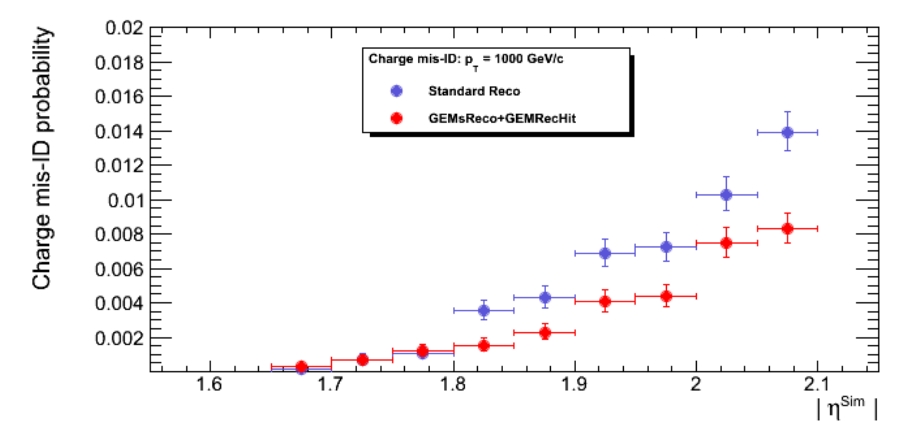
- Improvement in the RMS still present at intermediate and high p_T (up to ~8%)

Charge mis-ID prob. vs. Sim p_T

- Numerator: number of reco muons (matched with gen muon) in the GEM eta region with wrong charge assigment, i.e. (gen charge – reco charge) ≠ 0
- Denominator: total number of reco muons (matched with gen muon) in the GEM eta region
- Comparison of the charge mis-ID probabilities between the standard reco and the reco with GEMs included



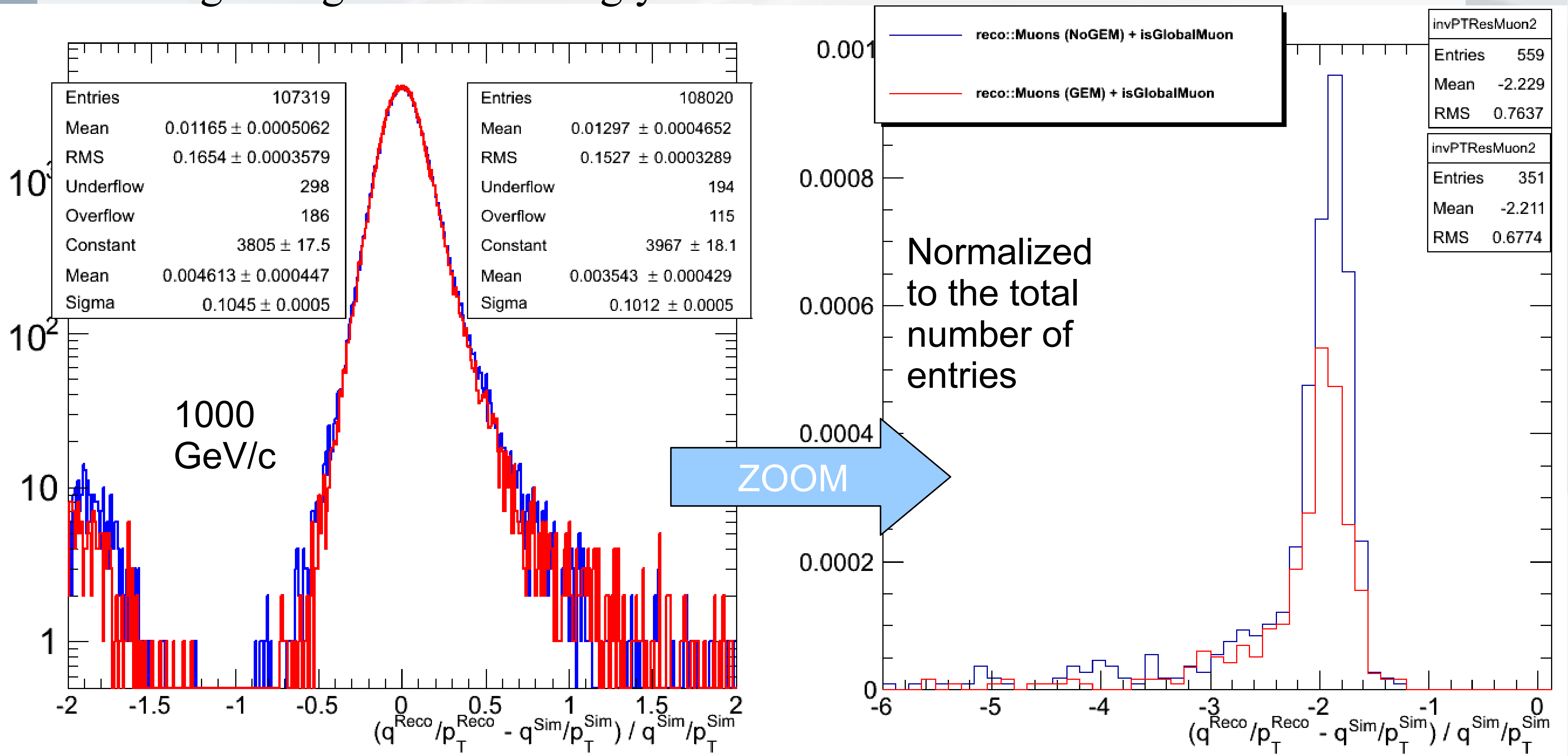




- Improvement still present at hight p_T (up to ~60%)
- At low p_T the charge mis-ID is unchanged or 0

Where is the improvement

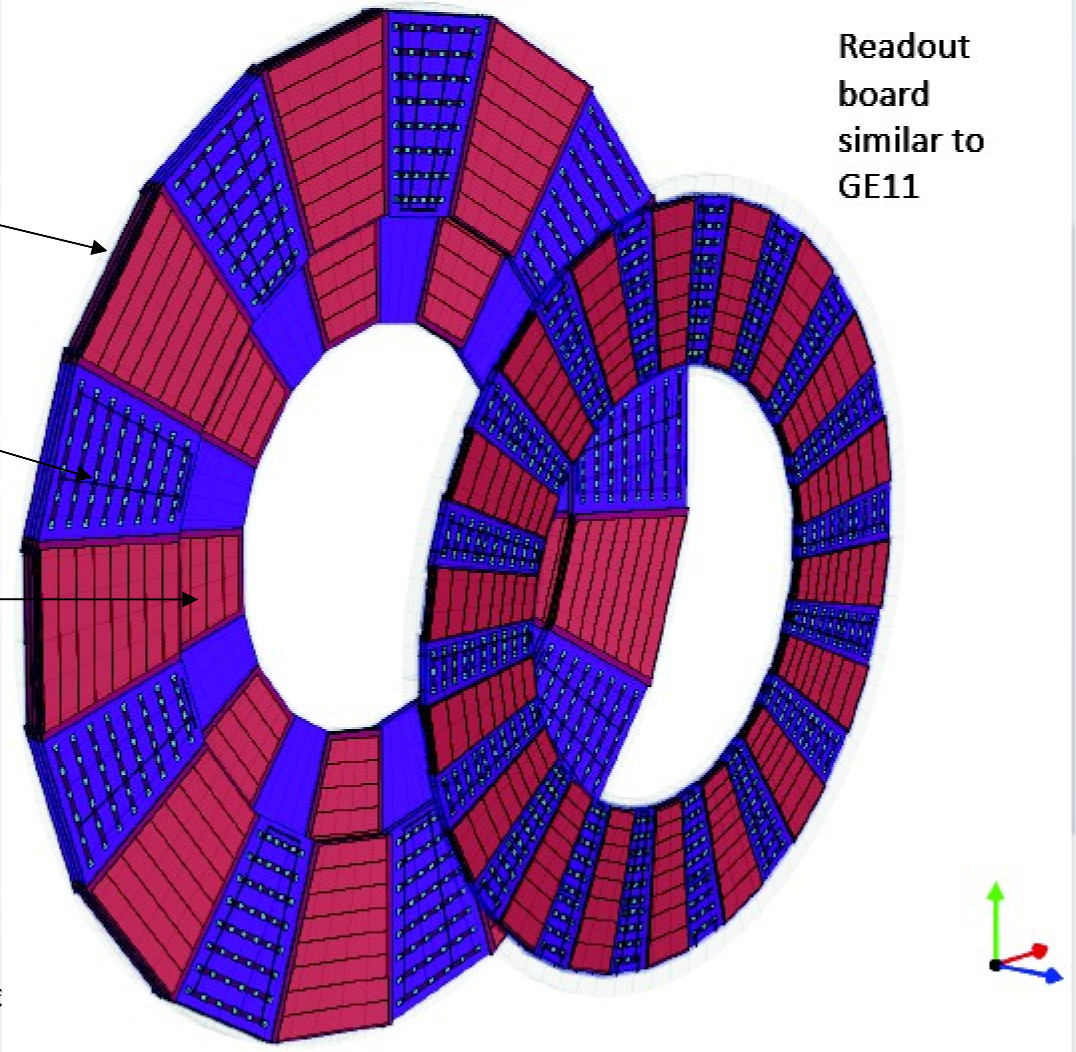
- q/p resolution distribution for p_T = 1000 GeV/c where GEMs bring the major improvement
- Peak at -2 due to muons with a good momentum measurement but wrong charge assignment is strongly reduced



GE2/1

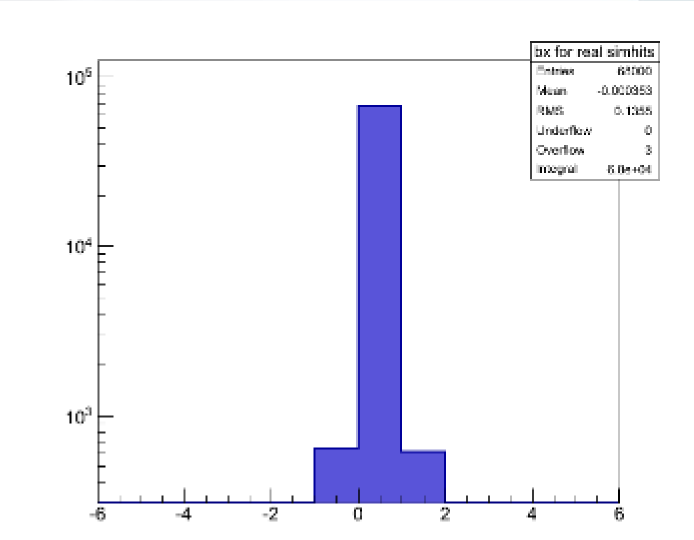
GE2/1 Pilot geometry

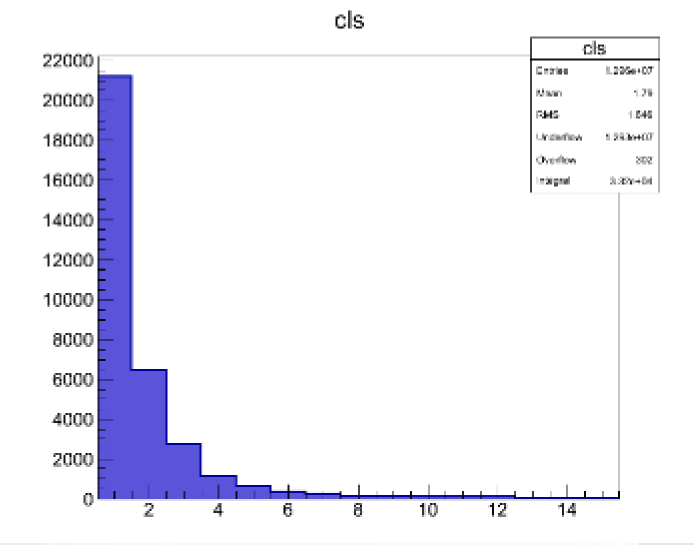
- 20 degree chambers (764 strips)
- 8 rolls up to 2.12 (Short Double super-chamber): station 2
- 12 rolls up to 2.4 (Long super-chamber): station 3.

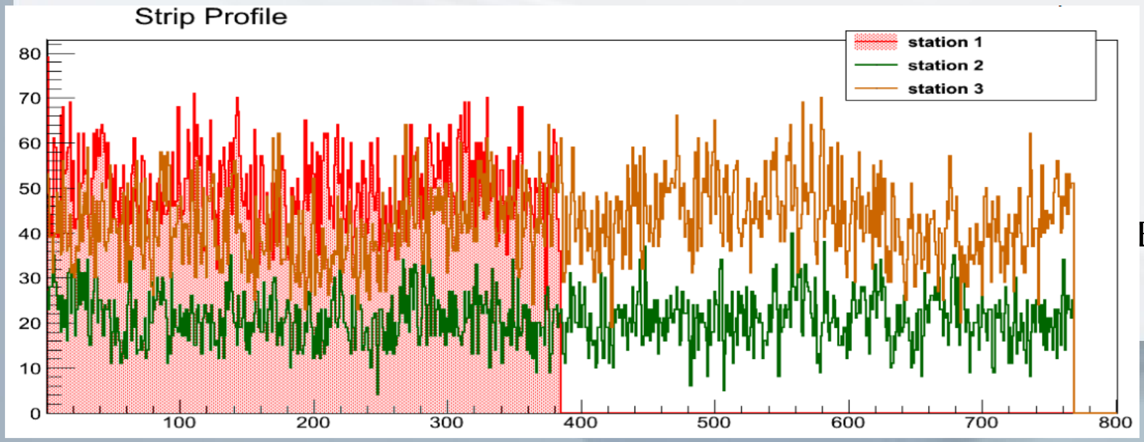


GE2/1 Digitization

- Same GE1/1 digitization code slightly modified to take into account GE2/1:
  - Muon TOF for GE2/1 (it affects BX)
  - Allowed number of rolls up to 12 to include the simulated background
  - Three set of input parameters for the background rates in each station and roll
- ONGOING: Estimation of the simulated background per station and roll (as done for GE1/1)

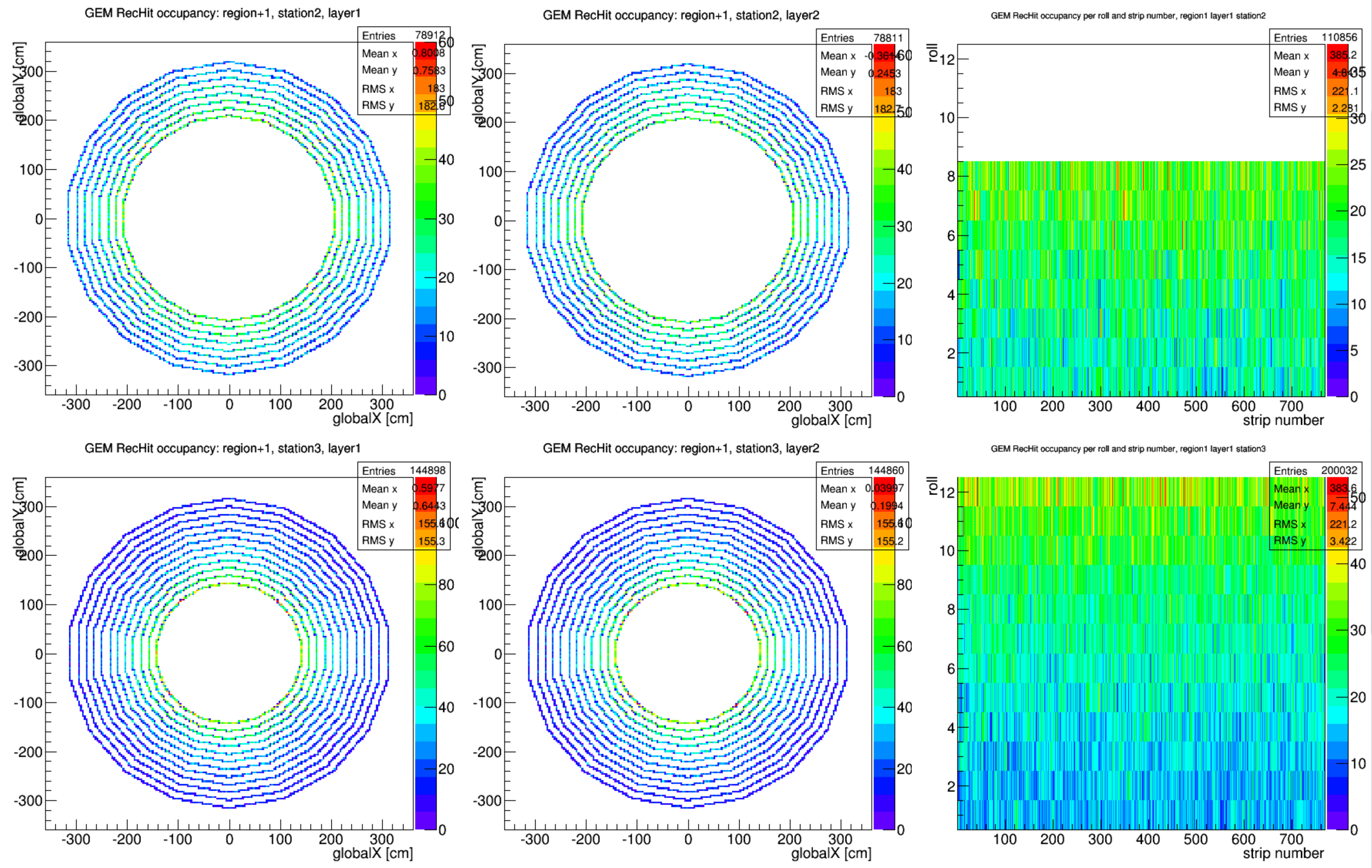






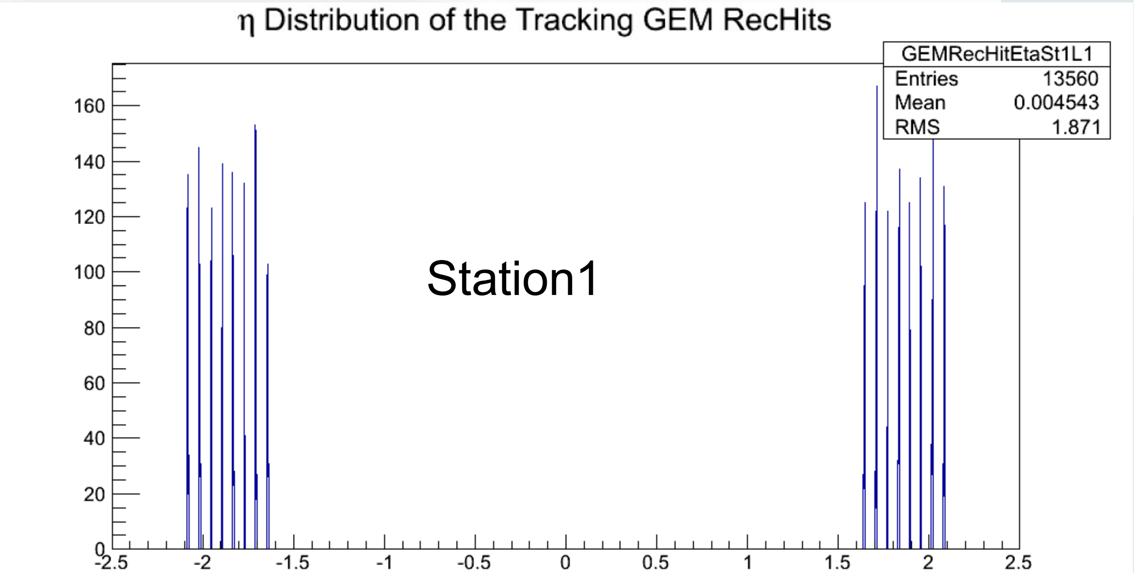
Local Reco in GE2/1

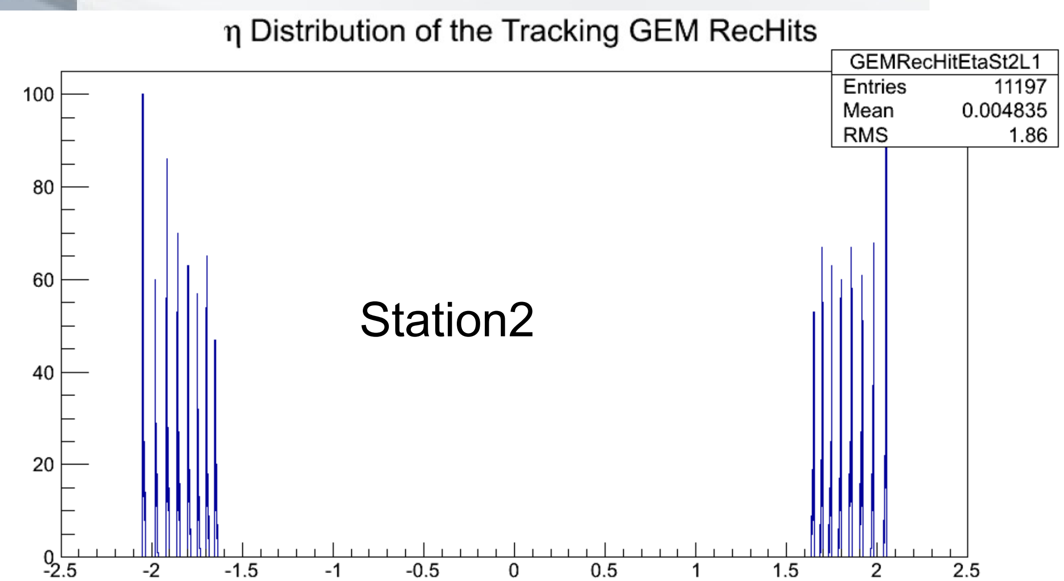
- Local reco from digital R/O implemented for GE1/1 works fine

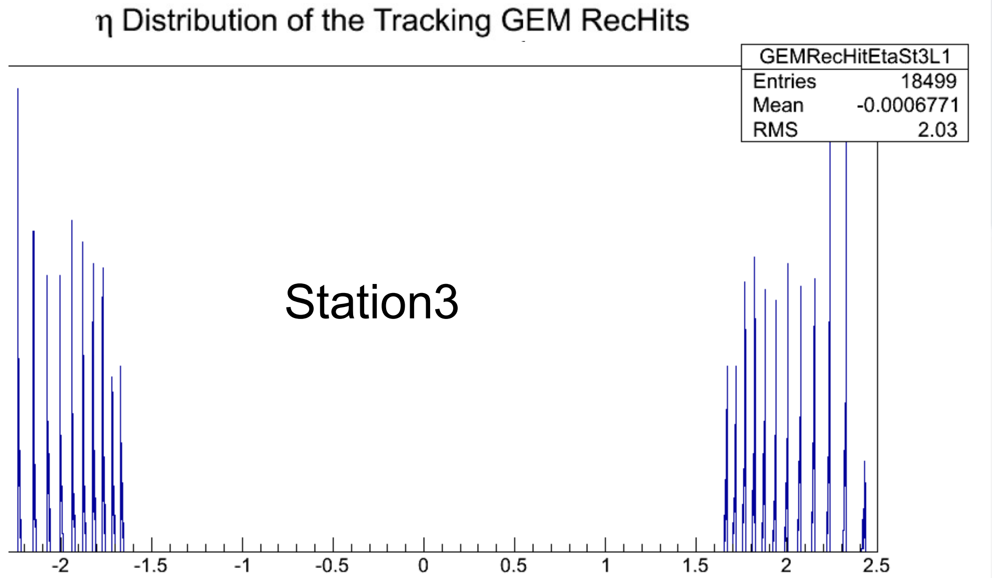


Global Reco with GE1/1 + GE2/1

- The muon reconstruction software is taking without problems also the GEM recHits from GE2/1 to perform the track fitting
- More results will come soon

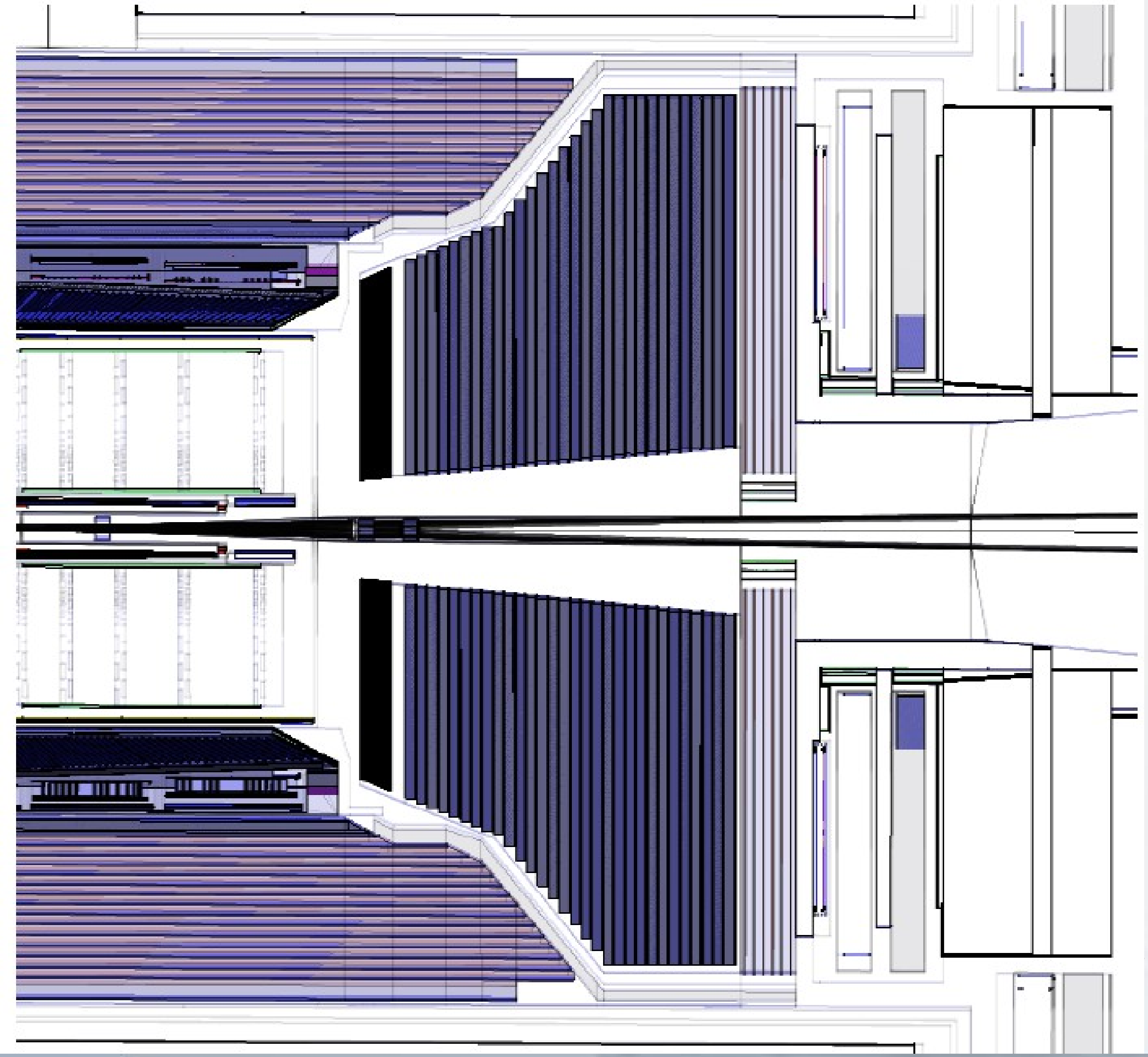






ME0

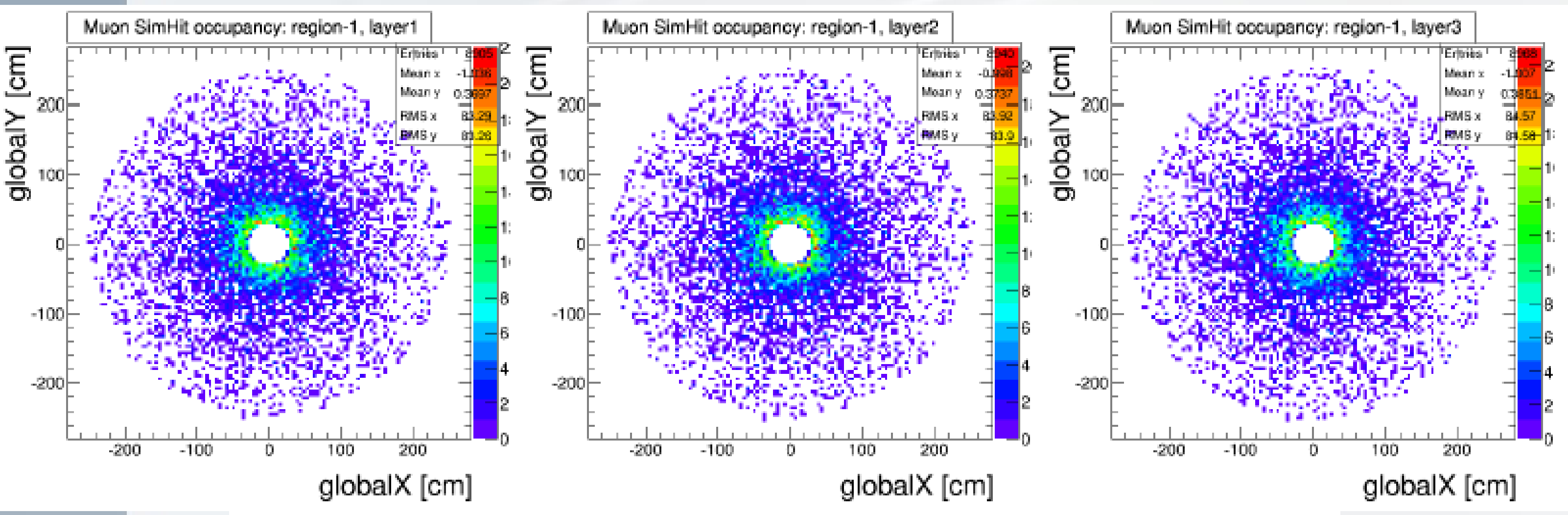
ME0 Pilot geometry

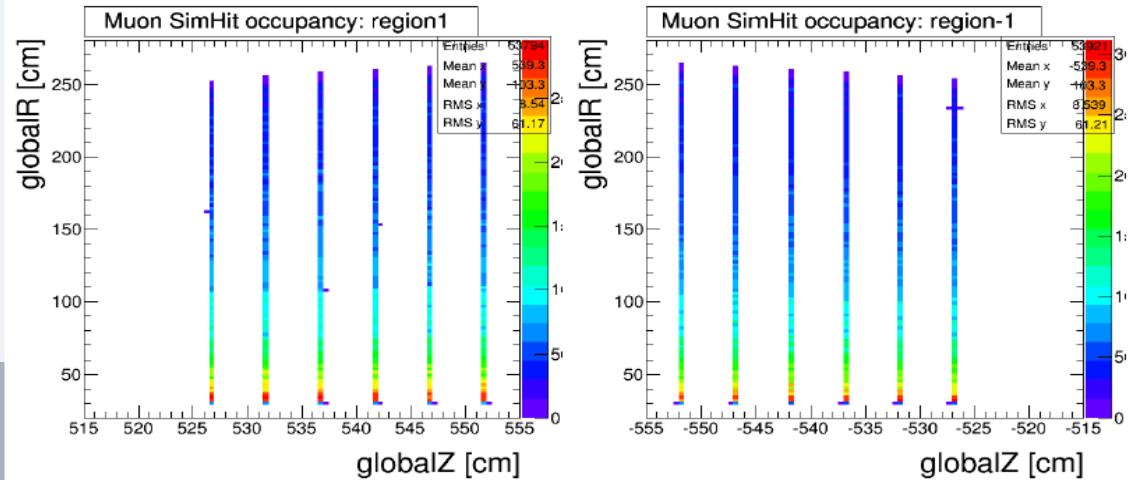


- Total width of 30 cm
- 2x18 chambers
- 6 layers (dZ = 0.3 cm) of GEMs
- r_{Min} = 30.0 cm, hard limit $\eta = 4$
- r_{Max} = 273.0 cm, limited by cables

ME0 Simulation

- First validation with select number of plots looks good.
- Good occupancy of ME0 SimHits over active volume
- Linearly increasing chamber size vs. global z is clearly visible





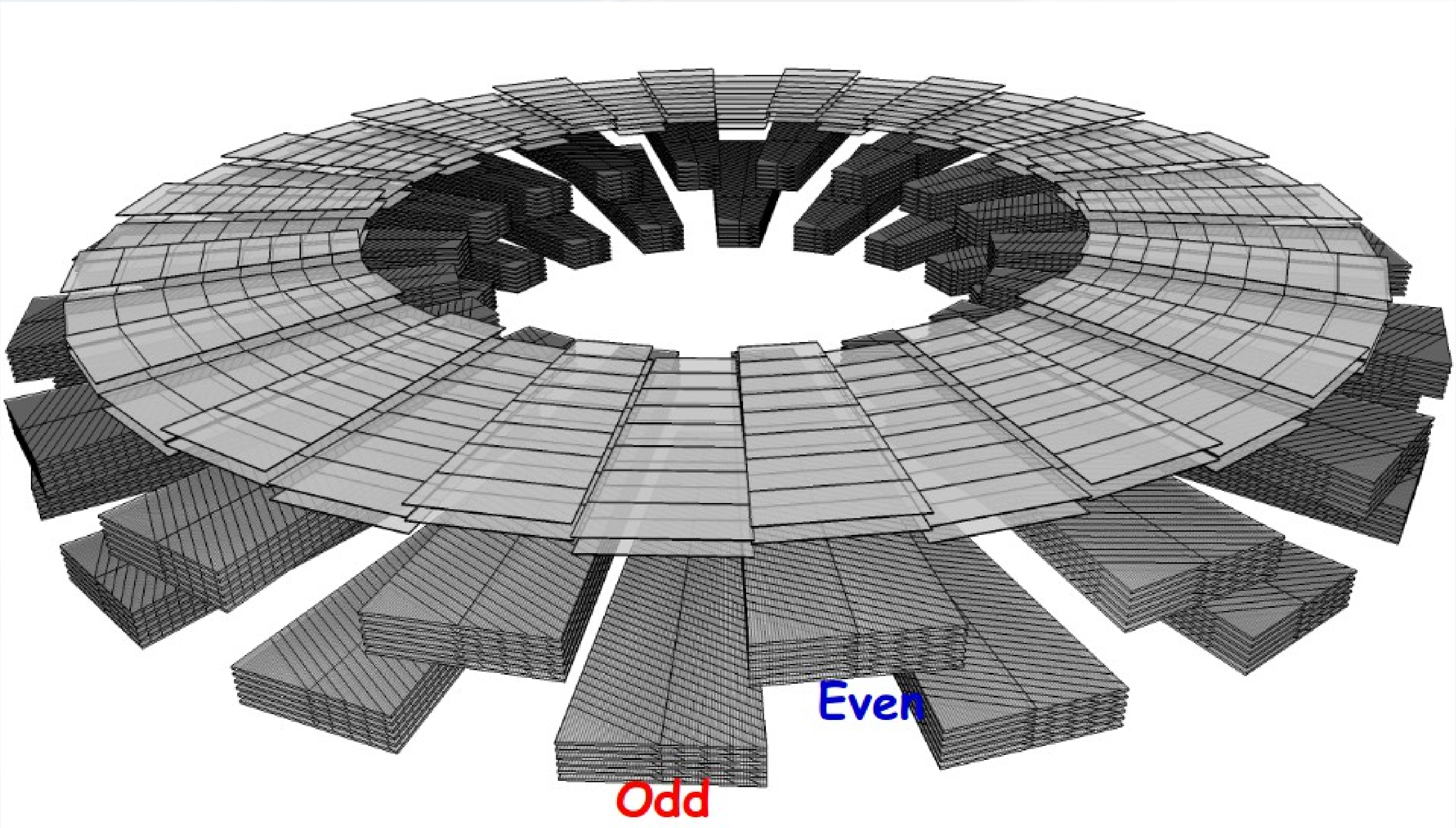
- SimHits will be used in the FastSimulation to simulate the reconstruction in ME0
- No Digitization for the moment, background rates will be included at simHit level

Conclusions

- A lot of progress in all the areas: background studies, geometry, trigger and reconstruction
- Move toward the software integration of all Muon detectors
  - GE1/1 and GE2/1 integrated in full reconstruction path
  - ME0 SimHits already available
- Every aspect of the simulation in GE1/1is validated (simHits, Digis, local and global reco)
- GE2/1 validated up to the local reconstruction
- Muon reconstruction takes advantage from GE1/1, we will see the contibution from GE2/1
- <u>Big contribution from Bari to the GEM simulation</u>

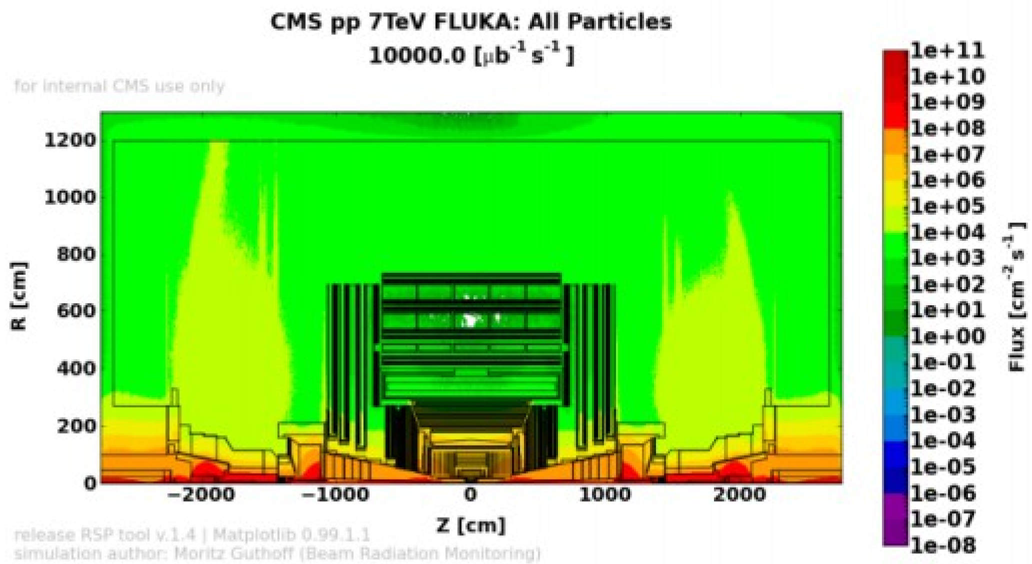
Backup

GE1/1 Geometry



Flux predictions: Fluka

- Mainly neutrons and photons. Contribution also from electrons, positrons, muons (charged particles)
- Post-LS1 geometry to be implemented
- Missing YE4 shielding
- Endcap calorimeter not simulated
- Expected rates could be overestimated



Detector part	R (cm)	Z (cm)	Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{34}\ cm^{-2}\ s^{-1}$	Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{35}\ cm^{-2}\ s^{-1}$	Flux uncert. (%)
GE1/1	150	560	$\sim 1.4 \cdot 10^{4}$	$\sim 1.4 \cdot 10^{5}$	~10%
GE1/1	180	560	$\sim 8.3 \cdot 10^{3}$	$\sim 8.3 \cdot 10^{4}$	~12%
GE1/1	250	560	$\sim 1.4 \cdot 10^{3}$	$\sim 1.4 \cdot 10^{4}$	~22%
GE2/1	180	800	$\sim 1.7 \cdot 10^{4}$	$\sim 1.7 \cdot 10^{5}$	~5%
ME0	120	540	$\sim 6.3 \cdot 10^{4}$	$\sim 6.3 \cdot 10^{5}$	~5%
ME0	20	540	$\sim 7.2 \cdot 10^{7}$	$\sim 7.2 \cdot 10^{8}$	~1%
RE3/1	200	980	$\sim 1.1 \cdot 10^{4}$	$\sim 1.1 \cdot 10^{5}$	~10%

- Neutron flux

Detector part	R (cm)	Z (cm)	Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{34}\ cm^{-2}\ s^{-1}$	Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{35}\ cm^{-2}\ s^{-1}$	Flux uncert. (%)
GE1/1	180	560	~$5.6\cdot10^{3}$	~$5.6\cdot10^{4}$	~12%
GE2/1	180	800	~$1.3\cdot10^{4}$	~$1.3\cdot10^{5}$	~5%
ME0	120	540	~$5.0\cdot10^{4}$	~$5.0\cdot10^{5}$	~6%
ME0	20	540	~$2.8\cdot10^{6}$	~$2.8\cdot10^{7}$	~2%

- Photon flux

Detector part	R (cm)	Z (cm)	Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{34}\ cm^{-2}\ s^{-1}$	Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{35}\ cm^{-2}\ s^{-1}$	Flux uncert. (%)
GE1/1	180	560	~$2.5\cdot10^{3}$	~$2.5\cdot10^{4}$	~20%
GE2/1	180	800	~$3.9\cdot10^{3}$	~$3.9\cdot10^{4}$	~11%
ME0	120	540	~$1.3\cdot10^{4}$	~$1.3\cdot10^{5}$	~8%
ME0	20	540	~$6.0\cdot10^{7}$	~$6.0\cdot10^{8}$	~1%

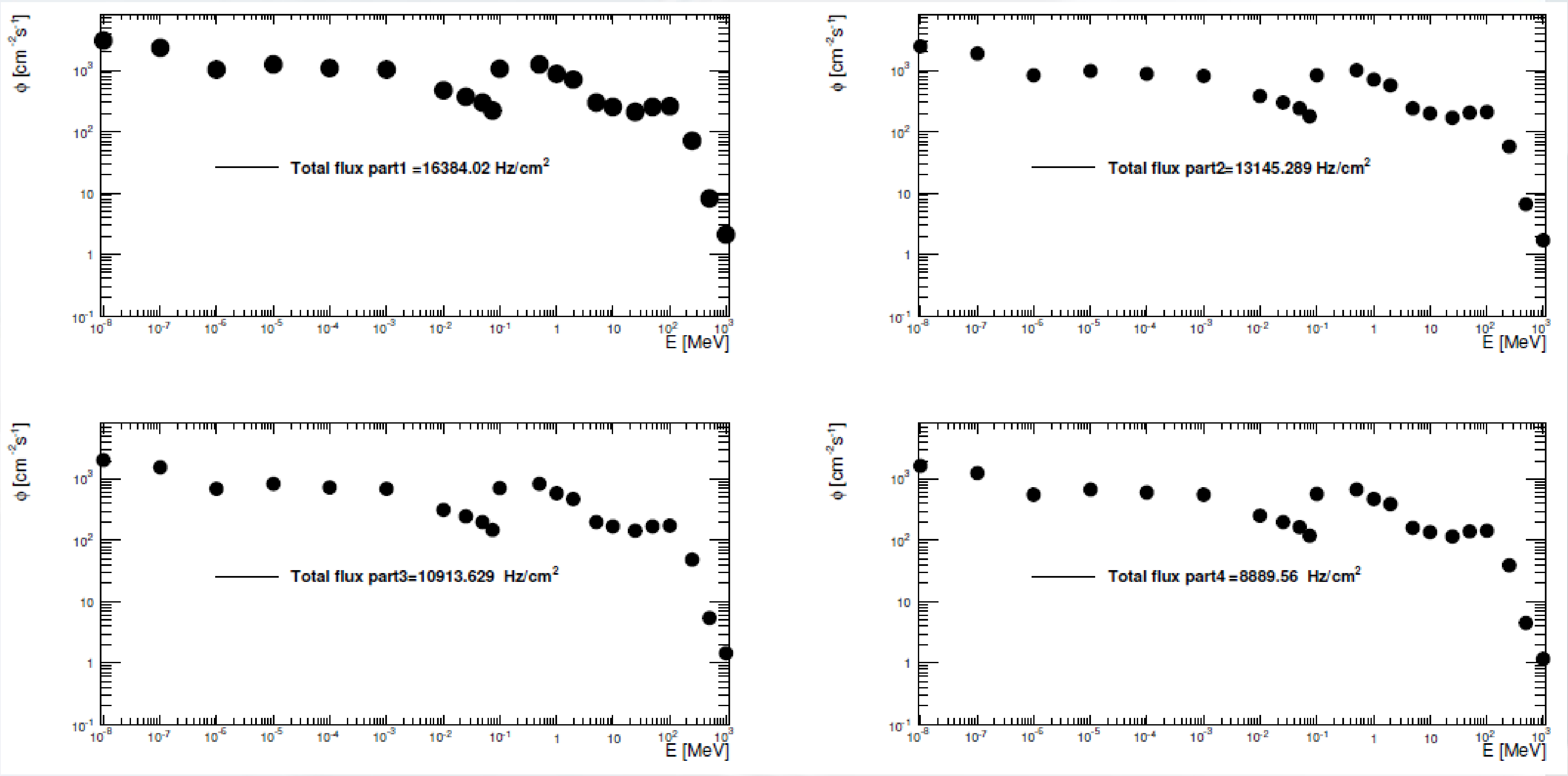
- Electron + positron flux

Detector part	R (cm)	Z (cm)	Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{34}\ cm^{-2}\ s^{-1}$	Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{35}\ cm^{-2}\ s^{-1}$	Flux uncert. (%)
GE1/1	180	560	~$6.5\cdot10^{1}$	~$6.5\cdot10^{2}$	~25%
GE2/1	180	800	~$2.4\cdot10^{1}$	~$2.4\cdot10^{2}$	~100%
ME0	120	540	~$3.2\cdot10^{2}$	~$3.2\cdot10^{3}$	~13%
ME0	20	540	~$5.0\cdot10^{6}$	~$5.0\cdot10^{7}$	~1%
RE3/1	200	980	~$2.3\cdot10^{1}$	~$2.3\cdot10^{2}$	~21%

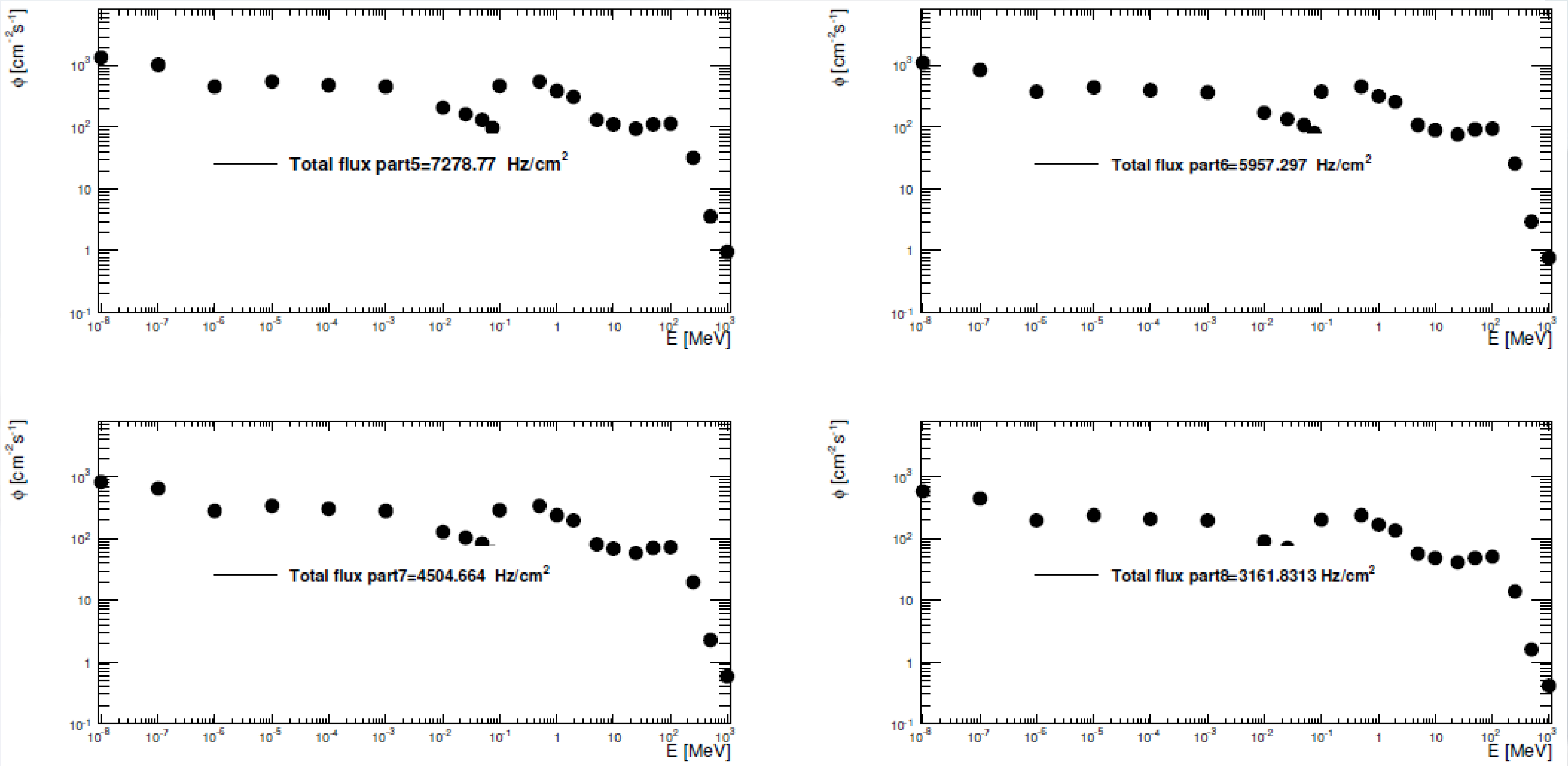
- Muon flux

Detector part	R (cm)	Z (cm)	Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{34}\ cm^{-2}\ s^{-1}$	Flux ($cm^{-2}\ s^{-1}$) for lumi=$10^{35}\ cm^{-2}\ s^{-1}$	Flux uncert. (%)
GE1/1	180	560	~$4.5\cdot10^{1}$	~$4.5\cdot10^{2}$	~25%
GE 2/1	180	800	(~$2.4\cdot10^{1}$) (*)	(~$2.4\cdot10^{2}$)	~100%
ME0	120	540	(~$5.4\cdot10^{1}$) (*)	(~$5.4\cdot10^{2}$)	~100%
ME0	20	540	~$3.8\cdot10^{5}$	~$3.8\cdot10^{6}$	~3%
RE3/1	200	980	(~$2.3\cdot10^{1}$) (*)	(~$2.3\cdot10^{2}$)	~100%

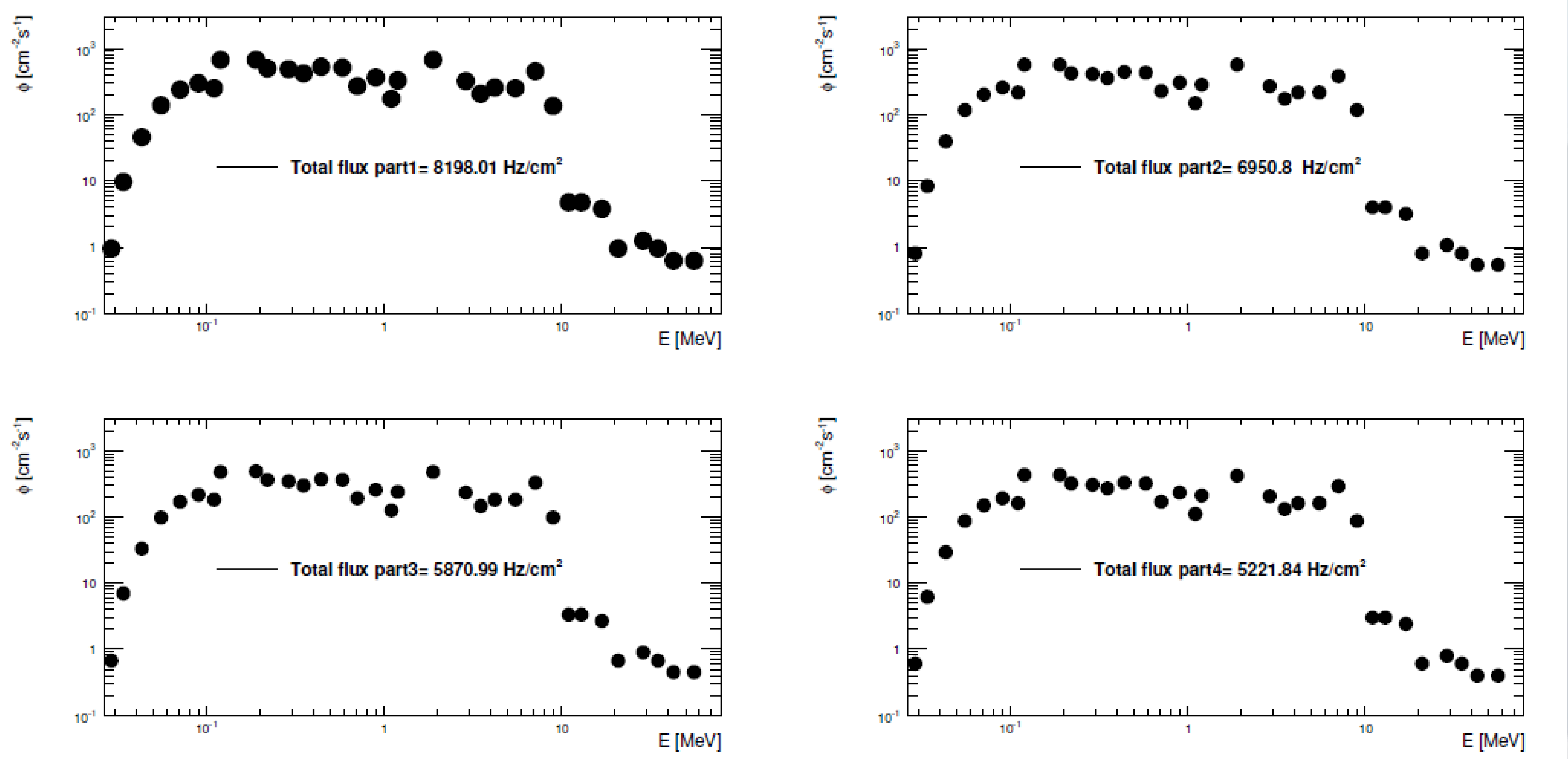
Neutron flux per eta partition



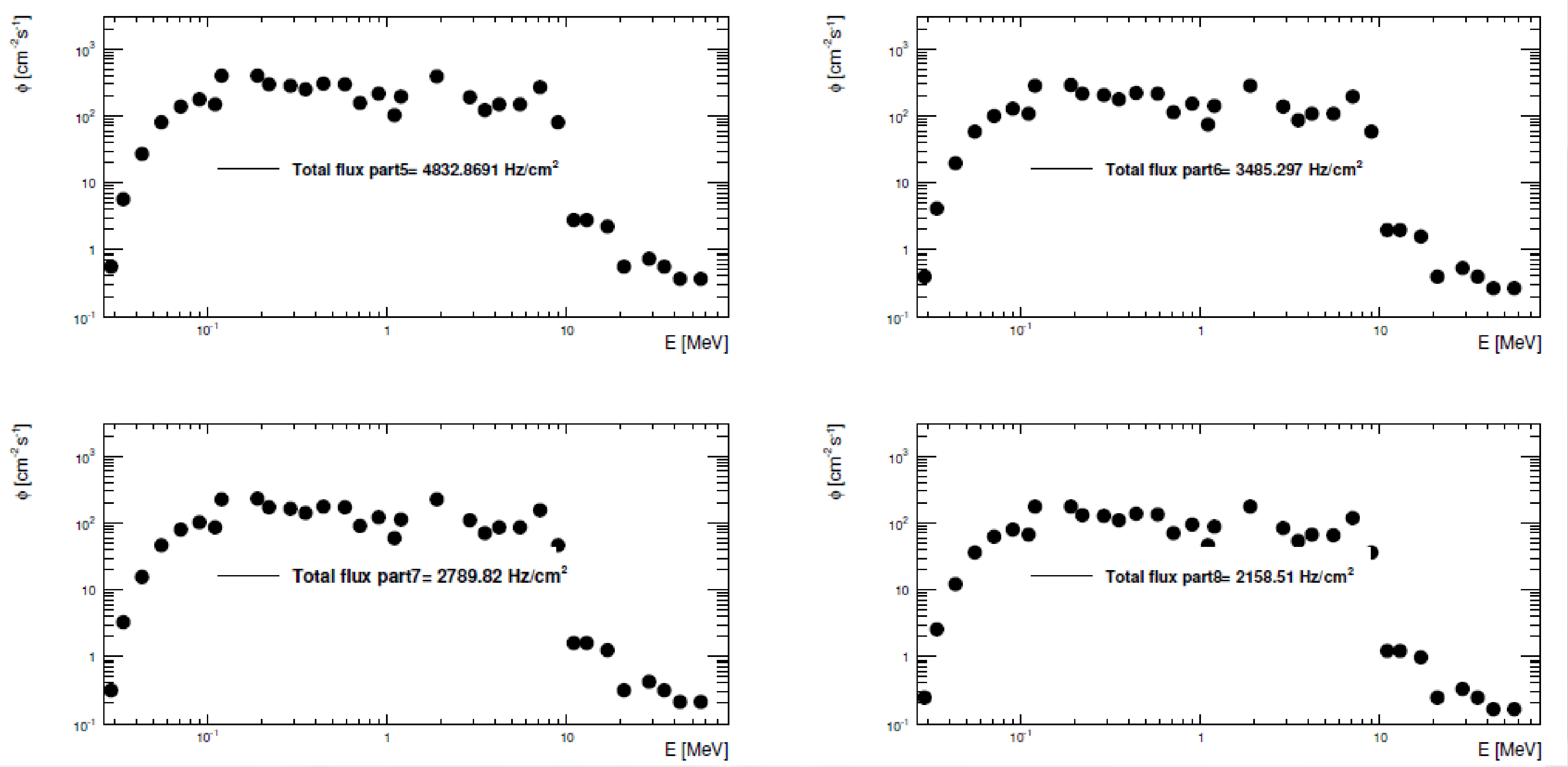
Neutron flux per eta partition



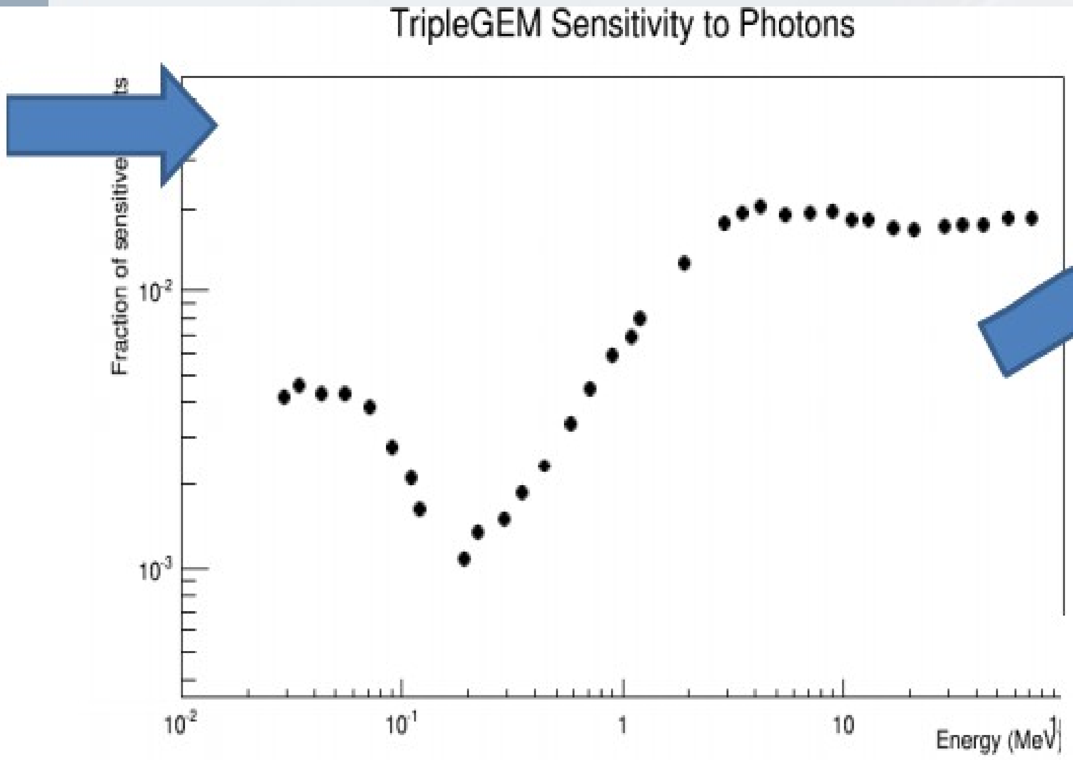
Photon flux per eta partition

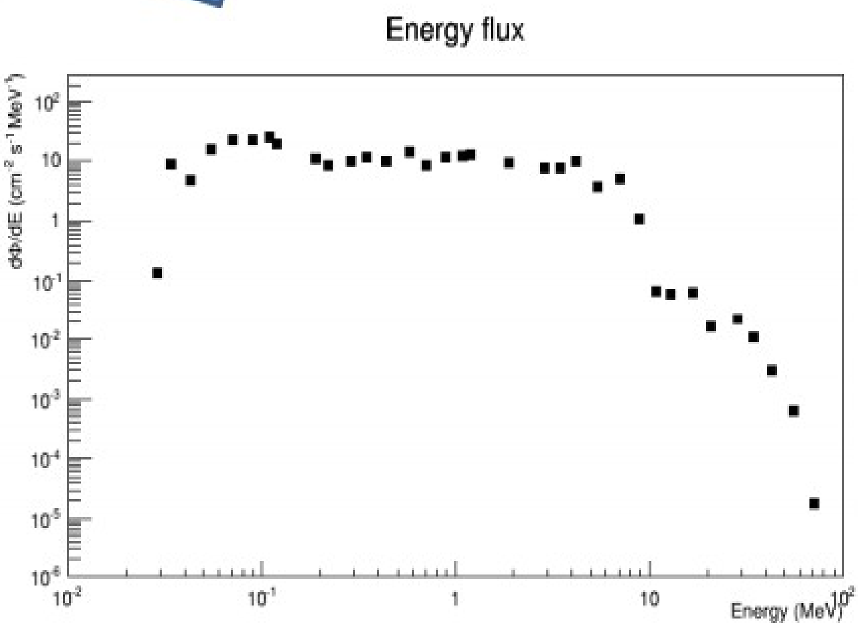


Photon flux per eta partition



Sensitivity with Geant4: Photons





Convolution with detector sensitivity

Selections (Global Reco)

- Reconstruction performed with the standard sequence and making GEMs recHits avalaible for the track fitting procedure
- RecoTracks are matched in ΔR ($\Delta R < 0.1$) to the simTracks in the eta region of interest: $|\eta|$ in [1.64, 2.1]
- Muon simTracks coming from the PV with at least one GEM (muon) simHit associated to the simTrack
- When the tracks are reconstructed including GEMs, the presence of at least one GEM recHit is required

Additional requirement:

- RecoTracks are kept only if the SimTrack-RecoTrack matching is 1 to 1