Sensitivity and hit rate estimation for different gaseous detectors @ muon collider - 2

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30th June 2021 - Muon Collider Joint Tracker and Calorimeter Meeting

Summary & Next steps

From previous talk

A first study of BIB-induced hit rate at Muon Collider has been performed with a standalone Geant4 simulation.

GRPC – currently implemented in the muon collider simulation – have been compared to Triple GEM, classical RPC and PicoSec prototypes.

Generally, MPGDs turn out to have lower sensitivities to BIB and then lower expected hit rate.

What's next?

- Analyze the interaction processes happening in the detectors
- Implement other possible technologies?
- Evaluate the angular distribution in the different endcap region and understand the effect on sensitivity

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- Update the simulation code to a newer Geant4 version
- Investigate which is the proper physics list to be used
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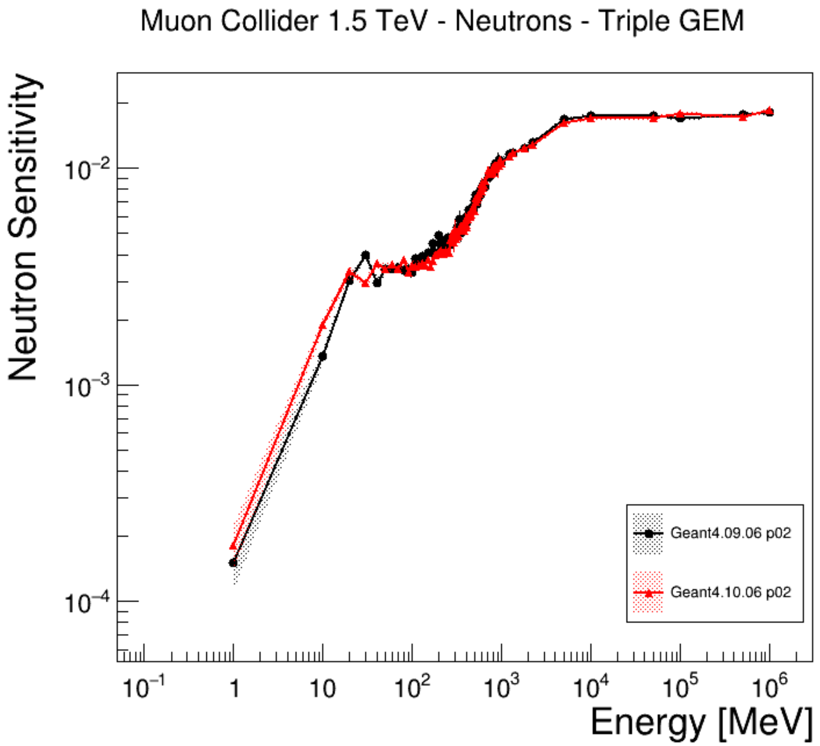
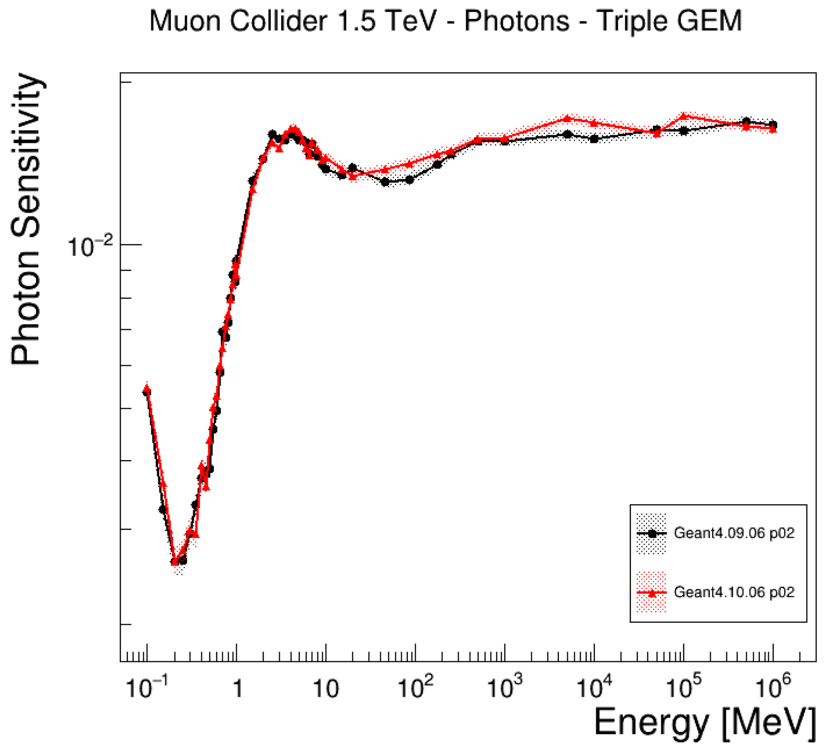
Update the code to a newer Geant4 version

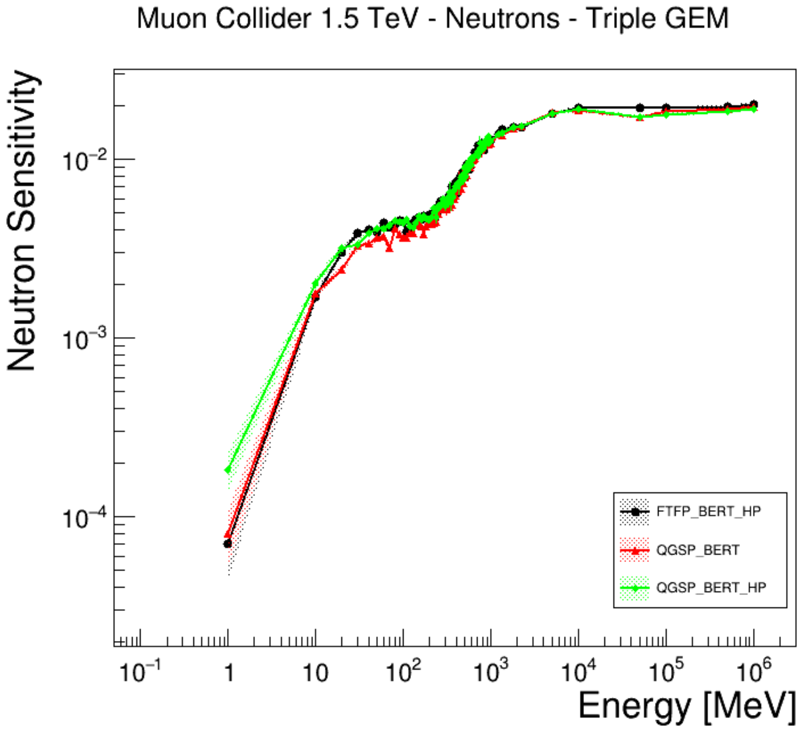
Sensitivity code updated from Geant4.09.06 p02 to Geant4.10.06 p02 → **OK**
Results presented in next slides obtained with Geant4.10.06 p02

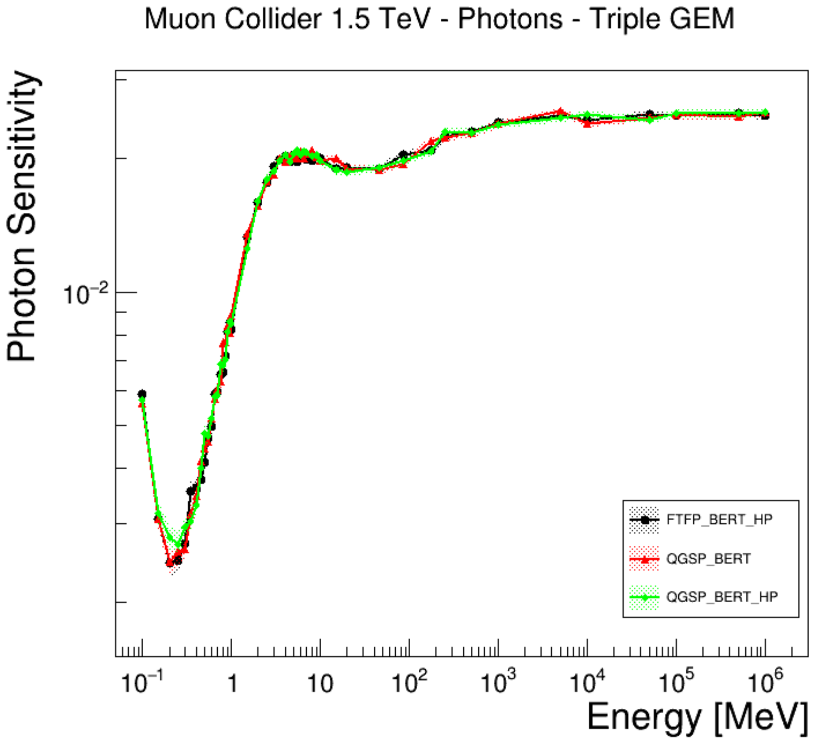




Comparison between physics lists

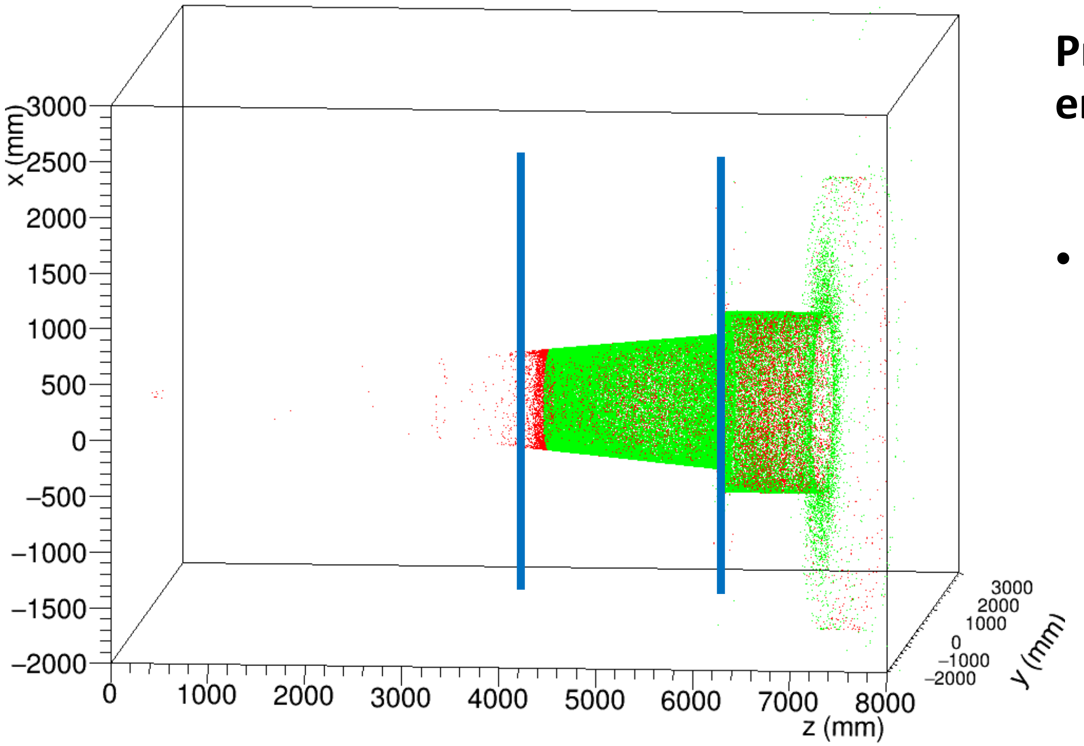
In Geant4.10.06 p02 there is a **better agreement** between FTFP and QGSP physics lists than with previous Geant4 versions → results presented in next slides obtained with FTFP_BERT_HP





New angular distributions

The results presented in the previous meeting were obtained assuming that all the particles arriving in the muon system were coming from the front of the endcap, i.e. from the interaction point..but..



Production vertex of BIB particles arriving in the muon endcap region:

- The endcap region is delimited by the **blue** vertical lines

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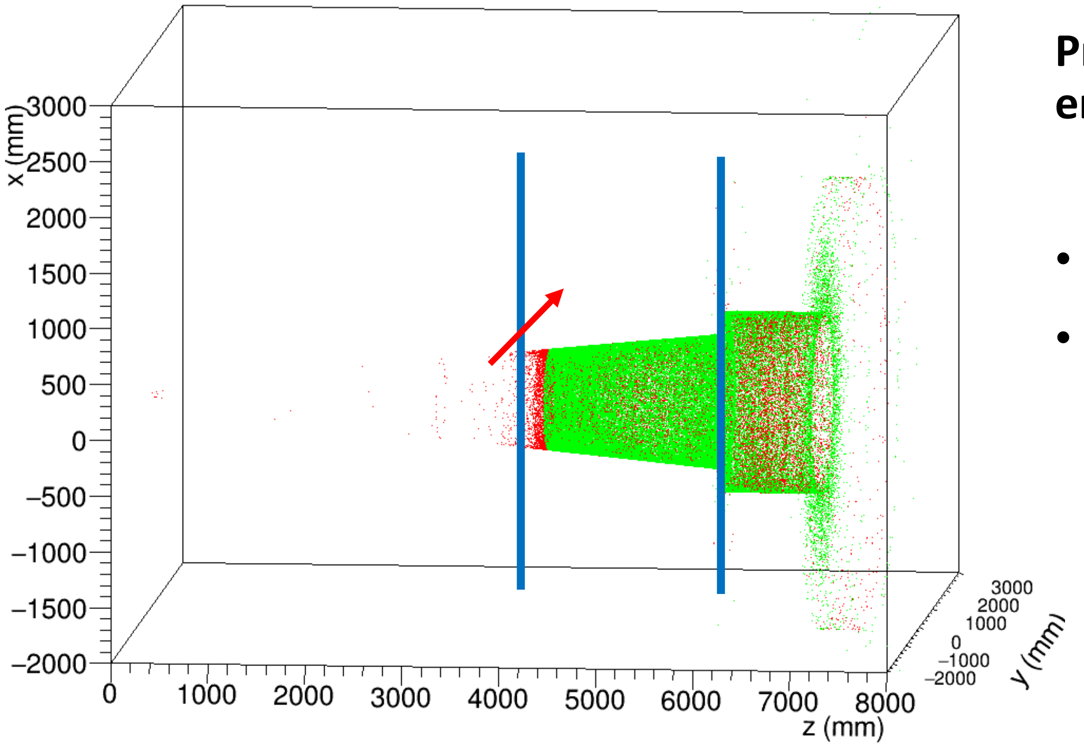

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- Some of the BIB particles travel forward → they cross the detector entering from **the front**

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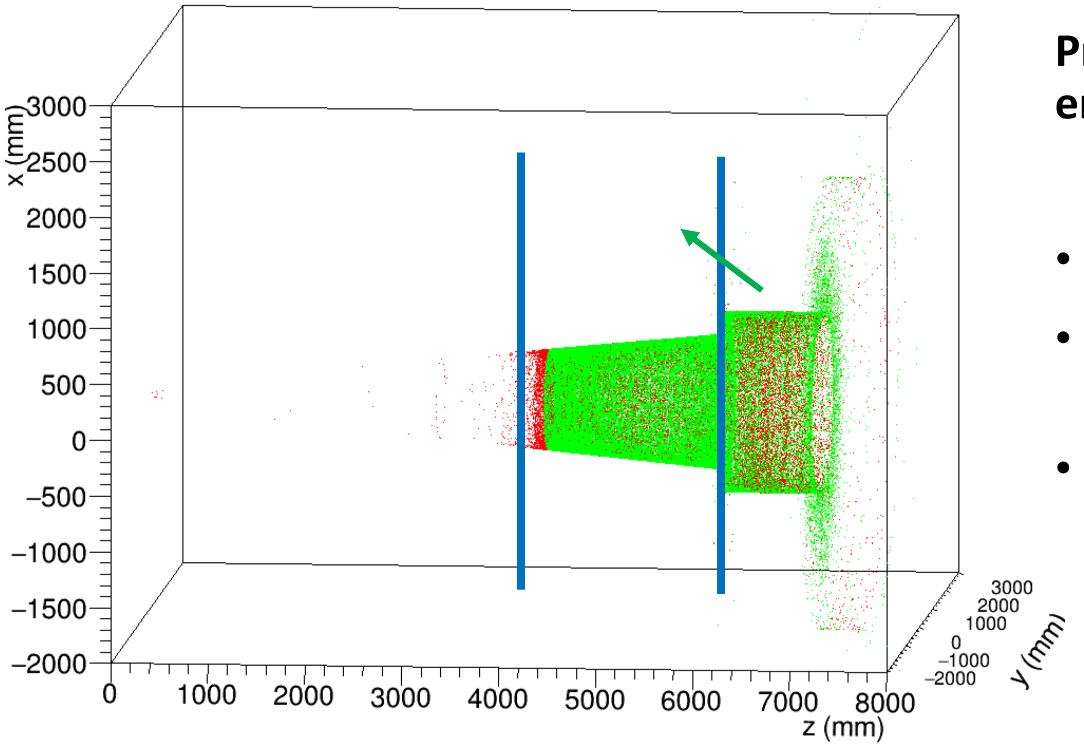
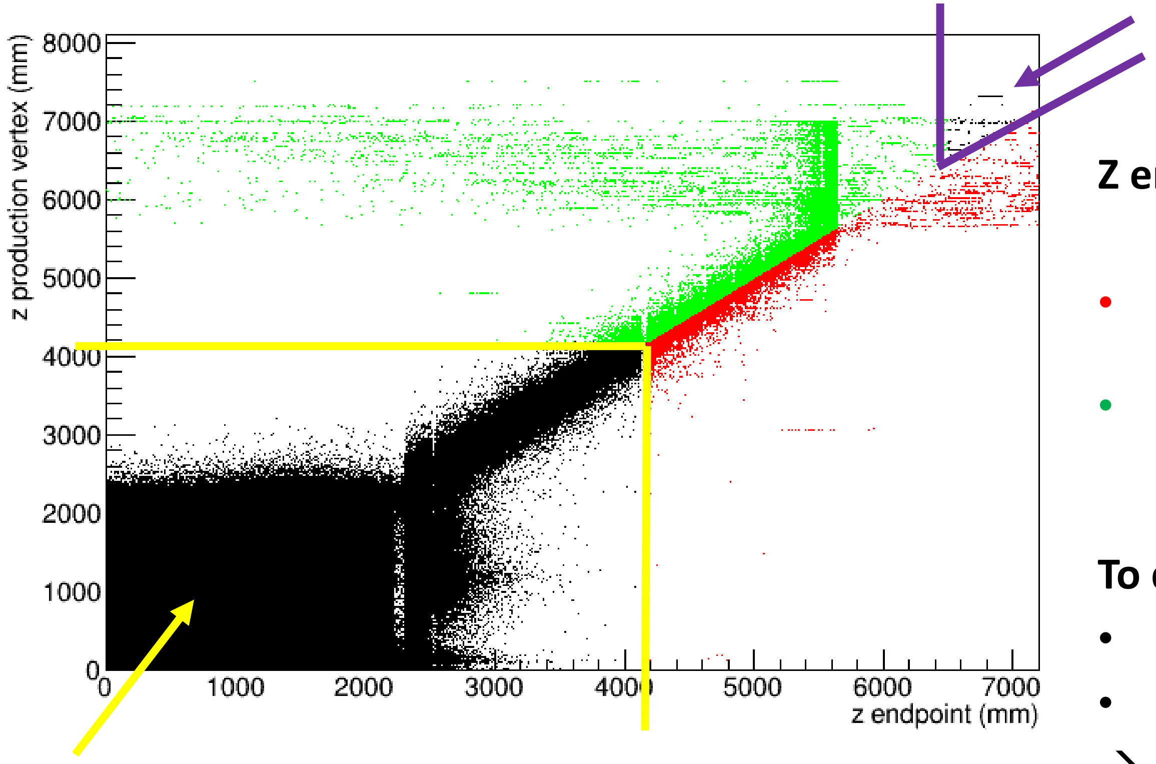


Production vertex of BIB particles arriving in the muon endcap region:

- The endcap region is delimited by the **blue** vertical lines
- Some of the BIB particles travel forward → they cross the detector entering from **the front**
- Some of the BIB particles travel backward → they cross the detector entering from **the back**

New angular distributions

Particles generated and dead after the muon system



Particles generated and dead in the tracker and in the calorimeters

Z endpoint vs Z production vertex

- **In red**: Z endpoint > Z production vertex, i.e. particles travelling forward
- In green: Z endpoint < Z production vertex, i.e particles travelling backward

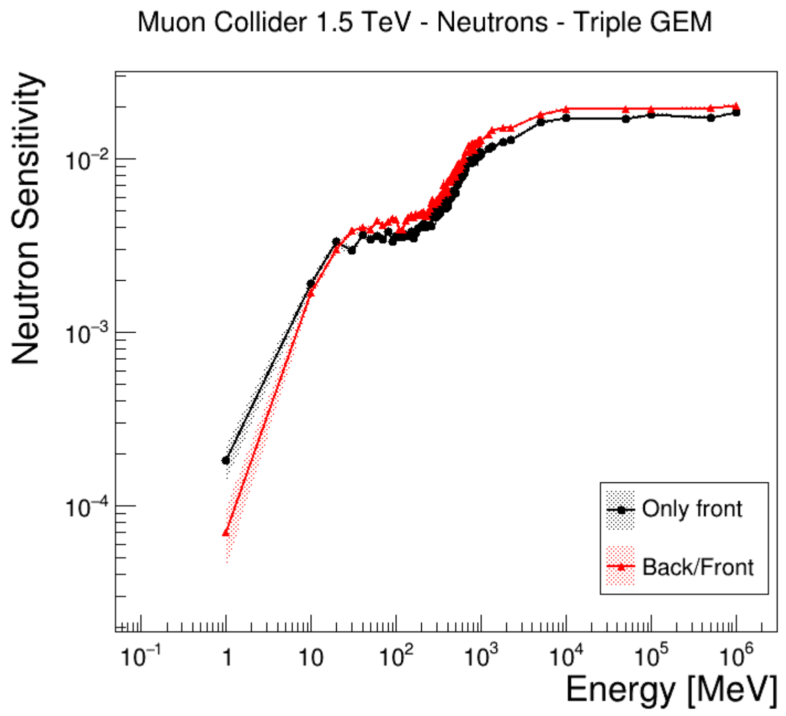
To quantify:

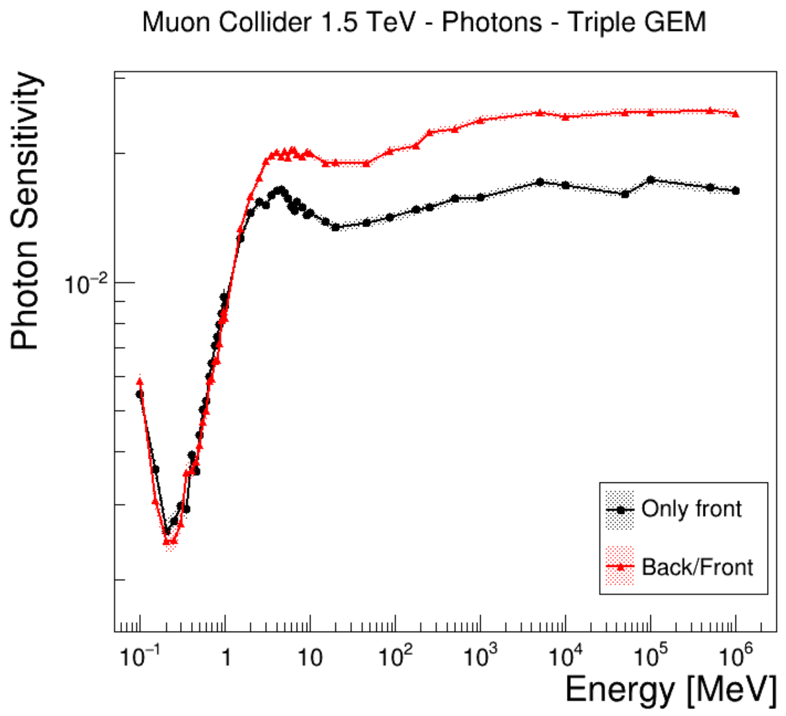
- 57.6 % of the neutrons enter the muon endcap from the back
- 51.5 % of the photons enter the muon endcap from the back

→ *Angular distribution modified accordingly*

Is this modification relevant?

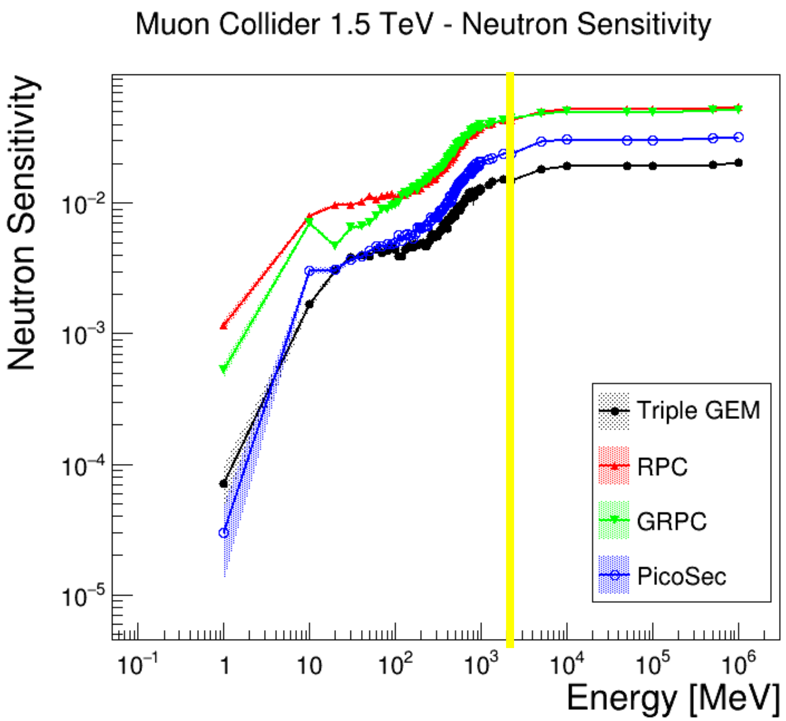
Yes, it is, specially for photons and for not-symmetrical detectors (like Triple-GEM)

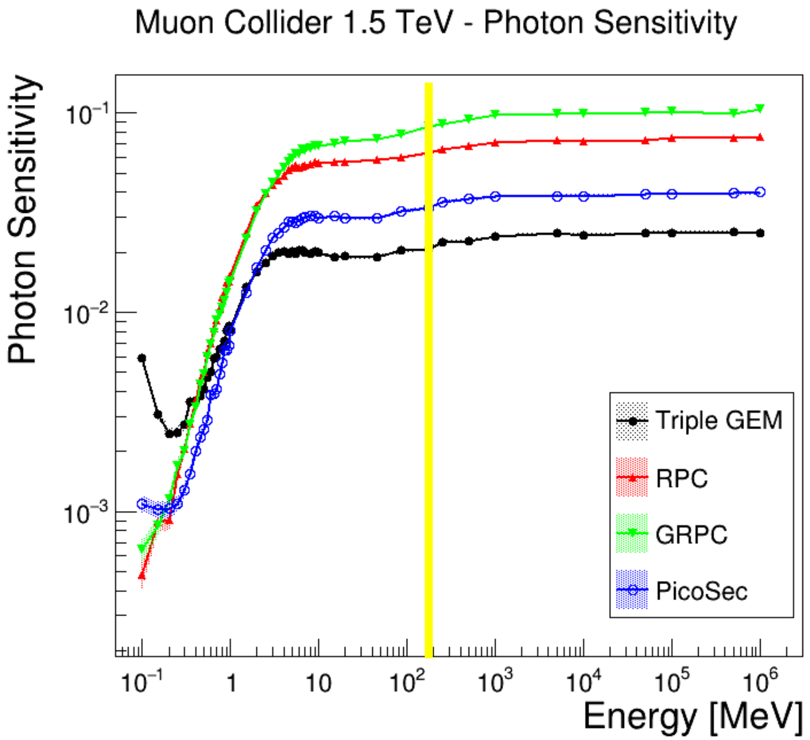




Updated sensitivities

For all the technologies considered we have:



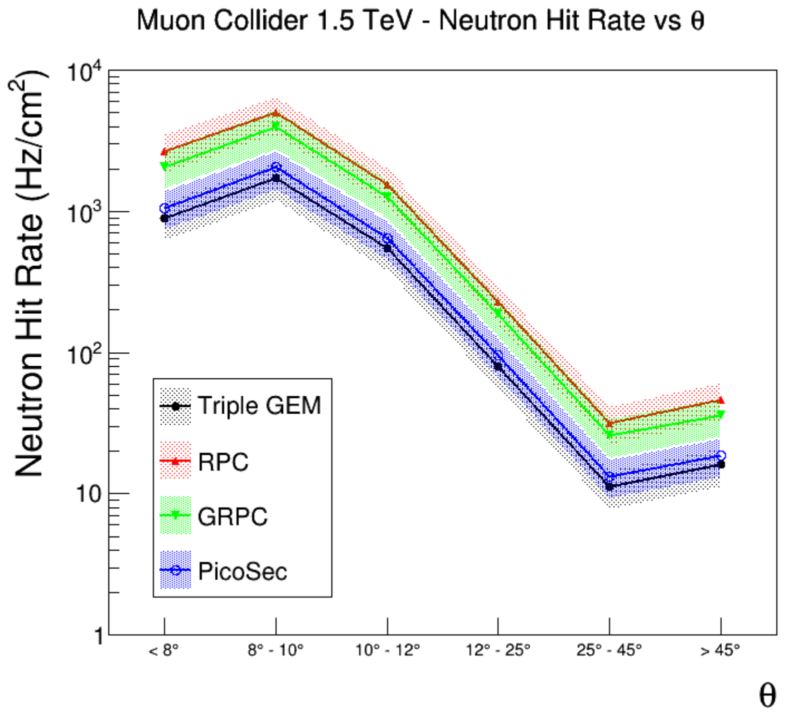


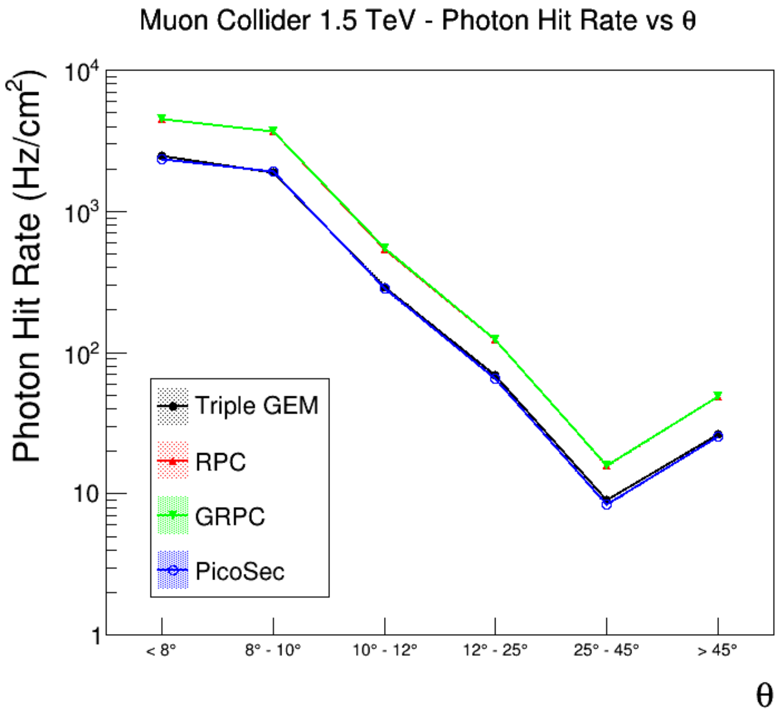
Sensitivity of MPGDs in general lower than RPCs ones (both for neutrons and photons) due to the lower material budget.

The yellow vertical line shows the energy limit of BIB @ 1.5 TeV

Updated hit rates

For all the technologies considered we have:

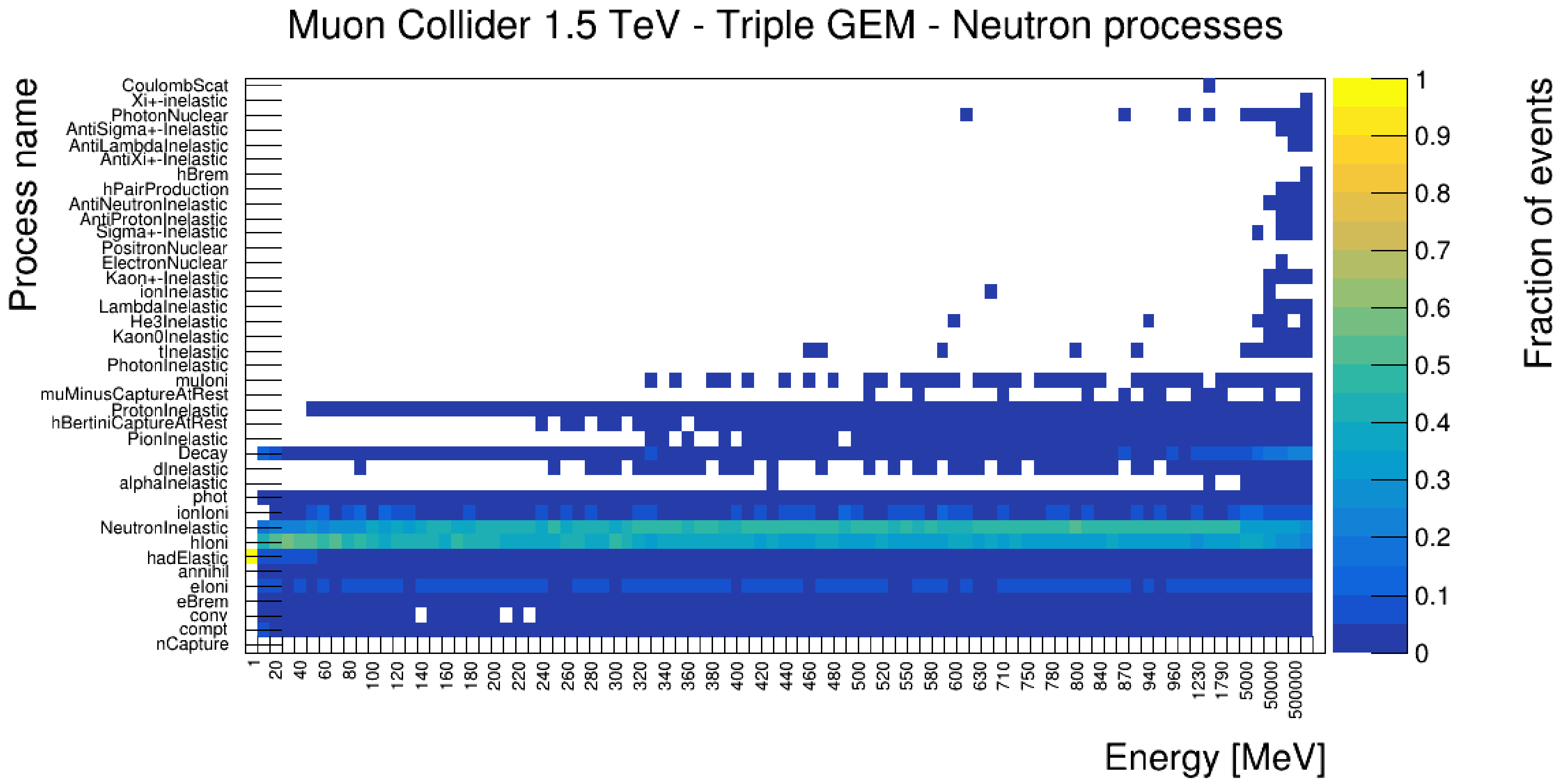




As a consequence the hit rate expected with MPGDs is lower than the one from RPCs.

RPCs and GRPCs in the inner region are at the limit of the standard rate capability.

Interaction processes - Neutrons



In the energy range considered, the dominant process for neutrons is the inelastic scattering, with the production of secondary heavy ions.

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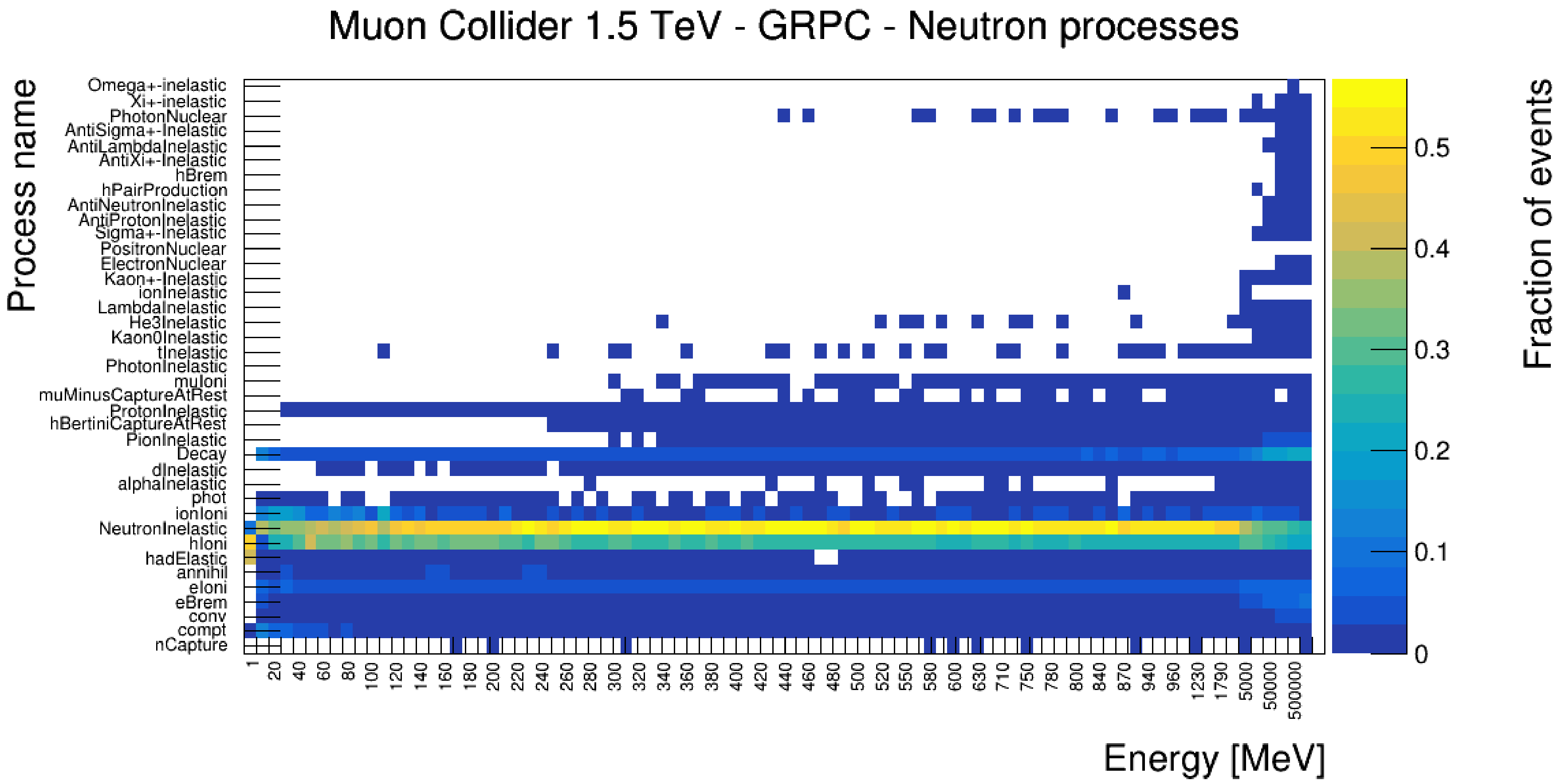
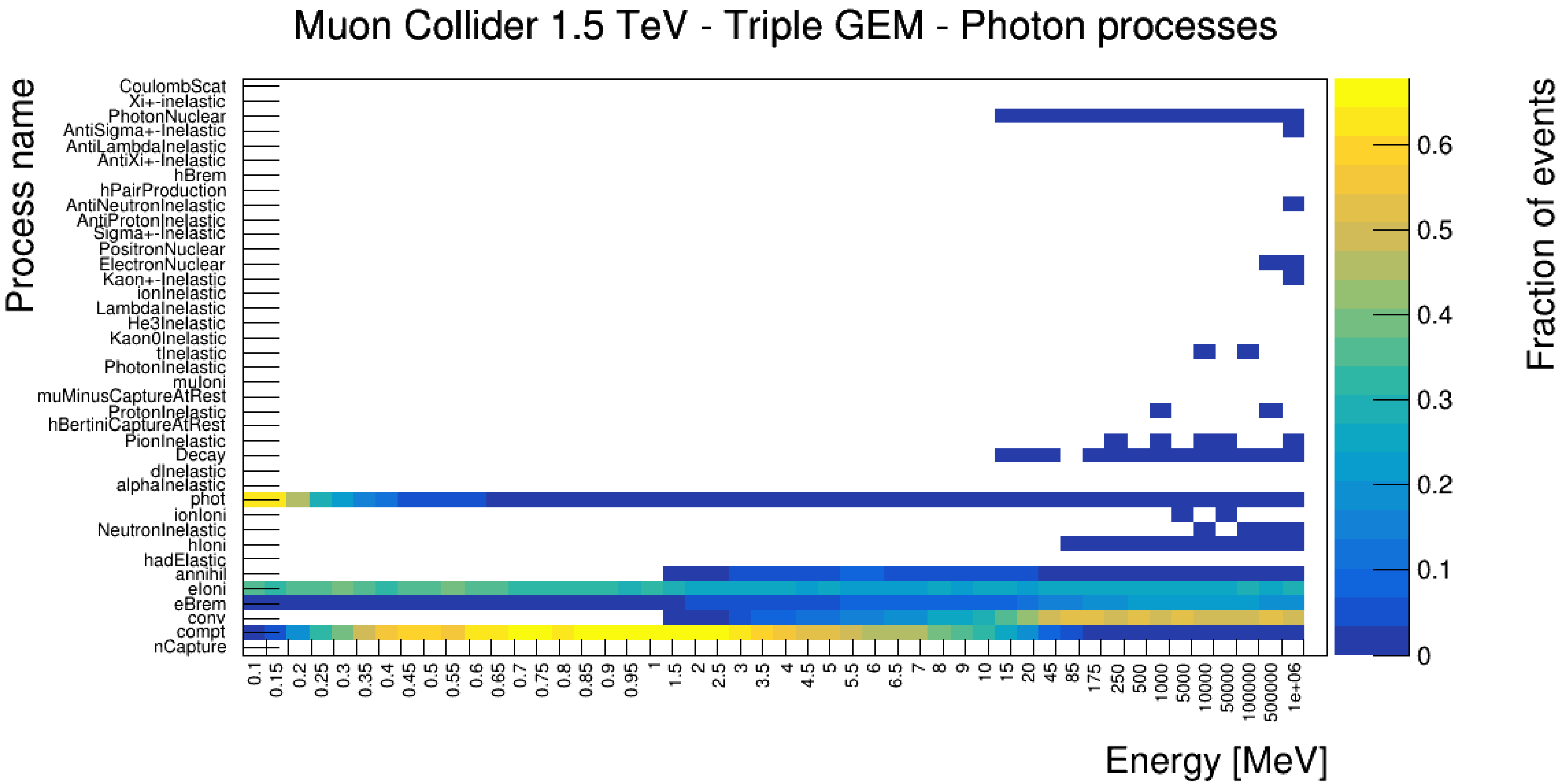


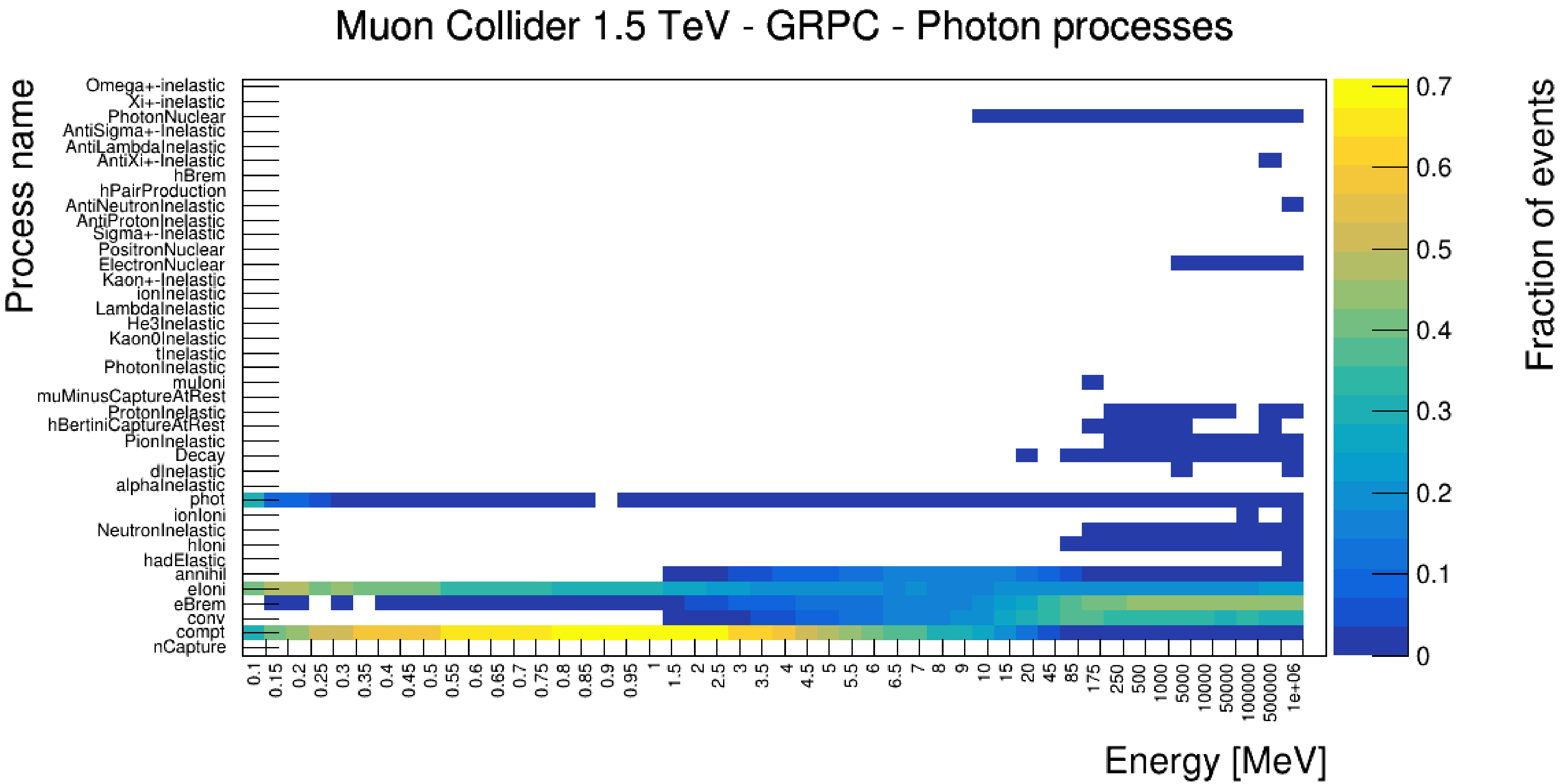
Interaction processes - Photons



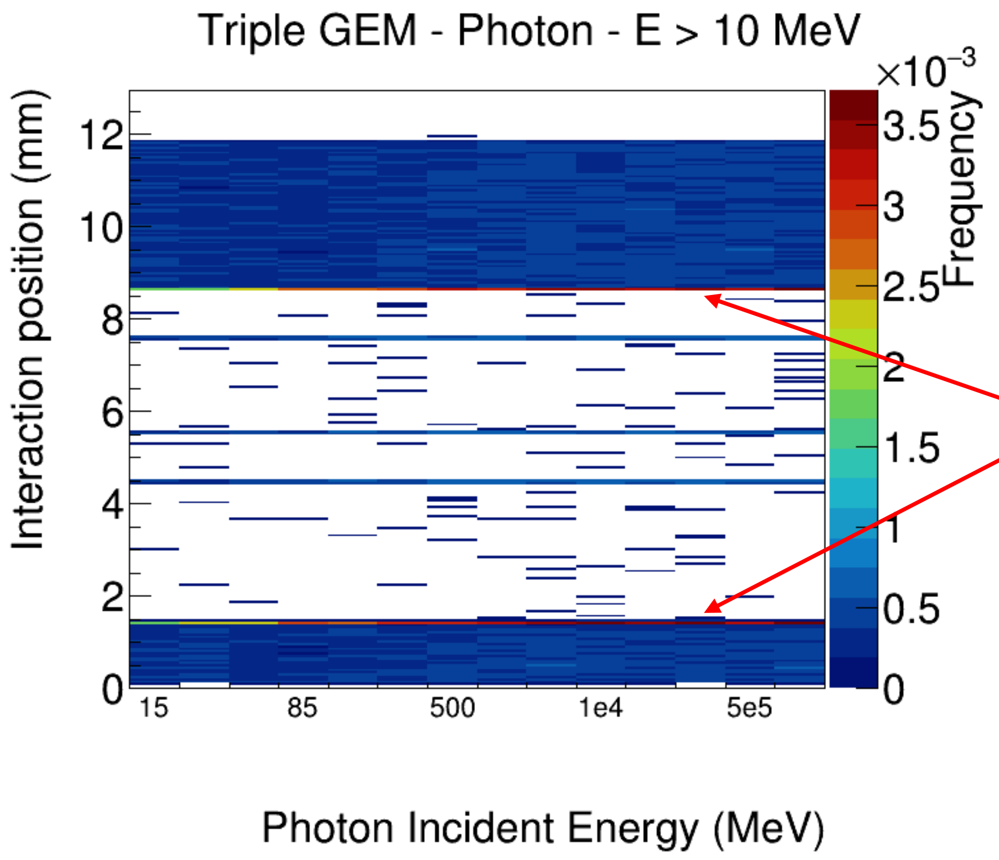
For Triple-GEM, the three main photon processes can be identified clearly. No Al is present, while the Cu (Z=29) contribution is relevant.

Interaction processes - Photons

For GRPCs, photoelectric effect is suppressed, while Compton scattering is dominant, due to the presence of Al (Z=13)



Interaction position in the detector – Triple GEM

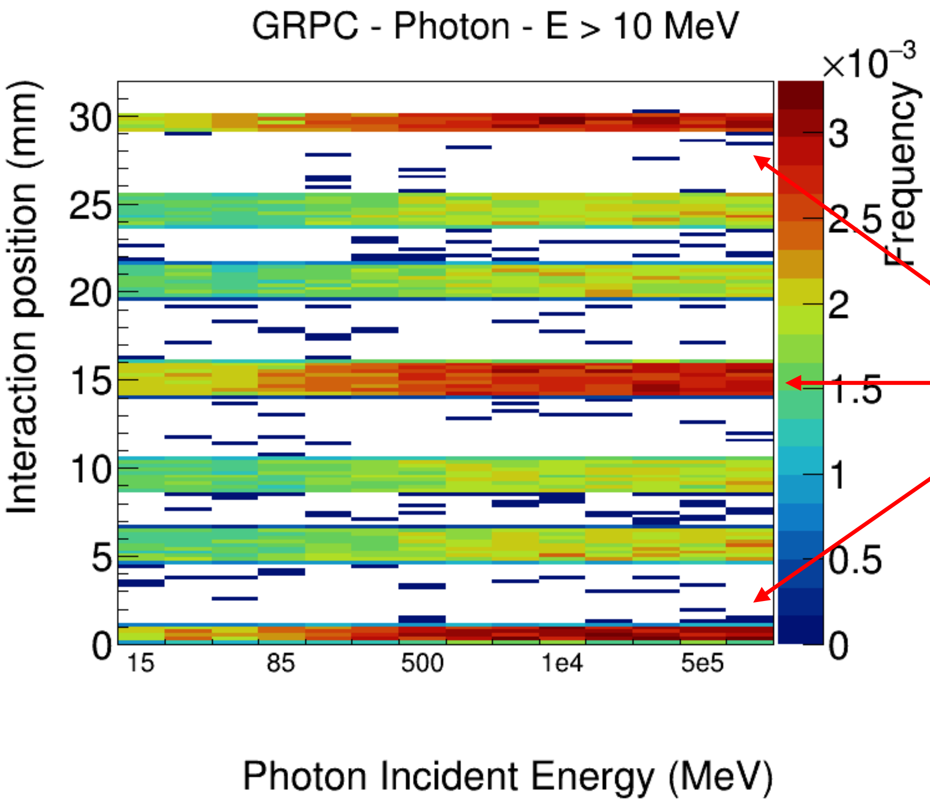


- Z = 0 → front of the detector
- Z = 12 mm → back of the detector

The majority of the interaction happens in the 35 um of Cu of the drift and readout boards

```
"PCB",
"KaptonFoil",
"DriftKapton","DriftCopper2",
"GasGap1",
"Gem1Copper1","Gem1","Gem1Copper2",
"GasGap2",
"Gem2Copper1","Gem2","Gem2Copper2",
"GasGap3",
"Gem3Copper1","Gem3","Gem3Copper2",
"GasGap4",
"ReadCopper1","ReadoutBoard",
```

Interaction position in the detector – GRPC



- Z = 0 → front of the detector
- Z = 30 mm → back of the detector

The majority of the interaction happens in the 1 mm Al plates.

```
"AluminumT1","AirT1",
"PyrexGlassT1",
"GasGap1",
"PyrexGlassB1",
"AirB1","AluminumB1",
"AluminumT2","AirT2",
"PyrexGlassT2",
"GasGap2",
"PyrexGlassB2",
"AirB2","AluminumB2",
```

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What's next?

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- Update the simulation code to a newer Geant4 version ✓
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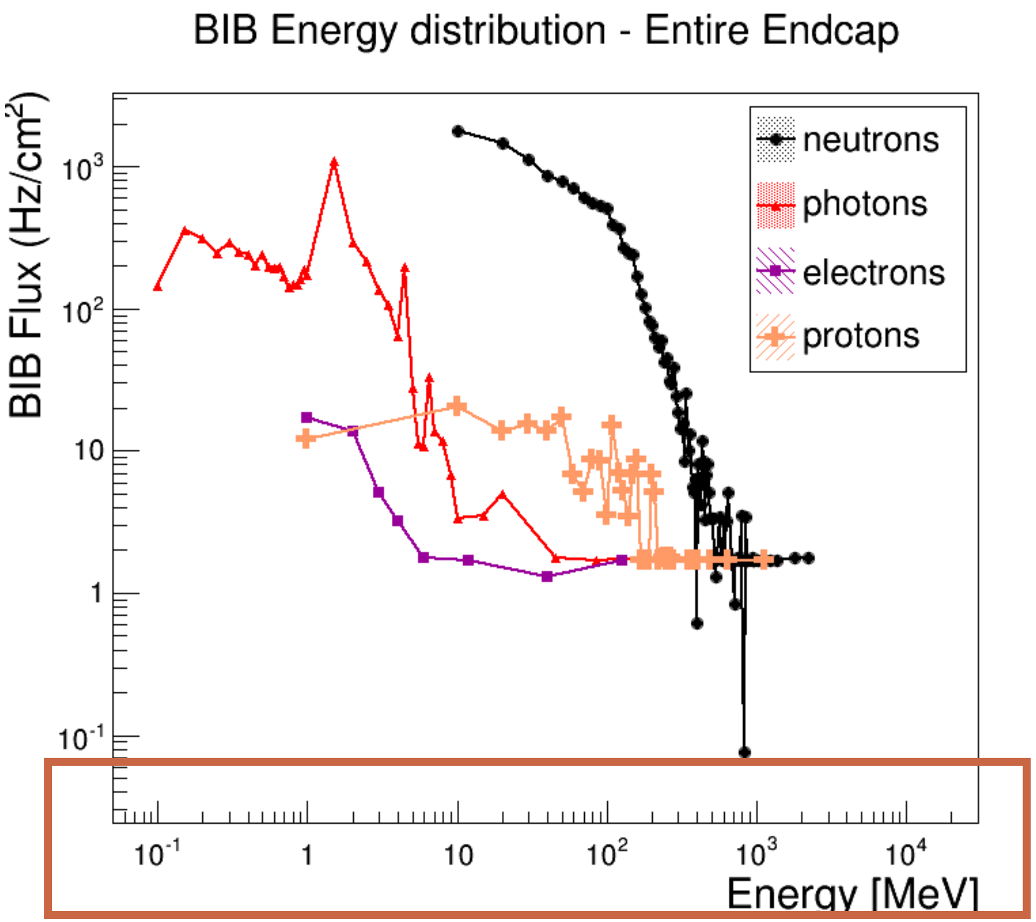
Backup

Step 1 – BIB in the muon system @ 1.5 TeV
Which particles



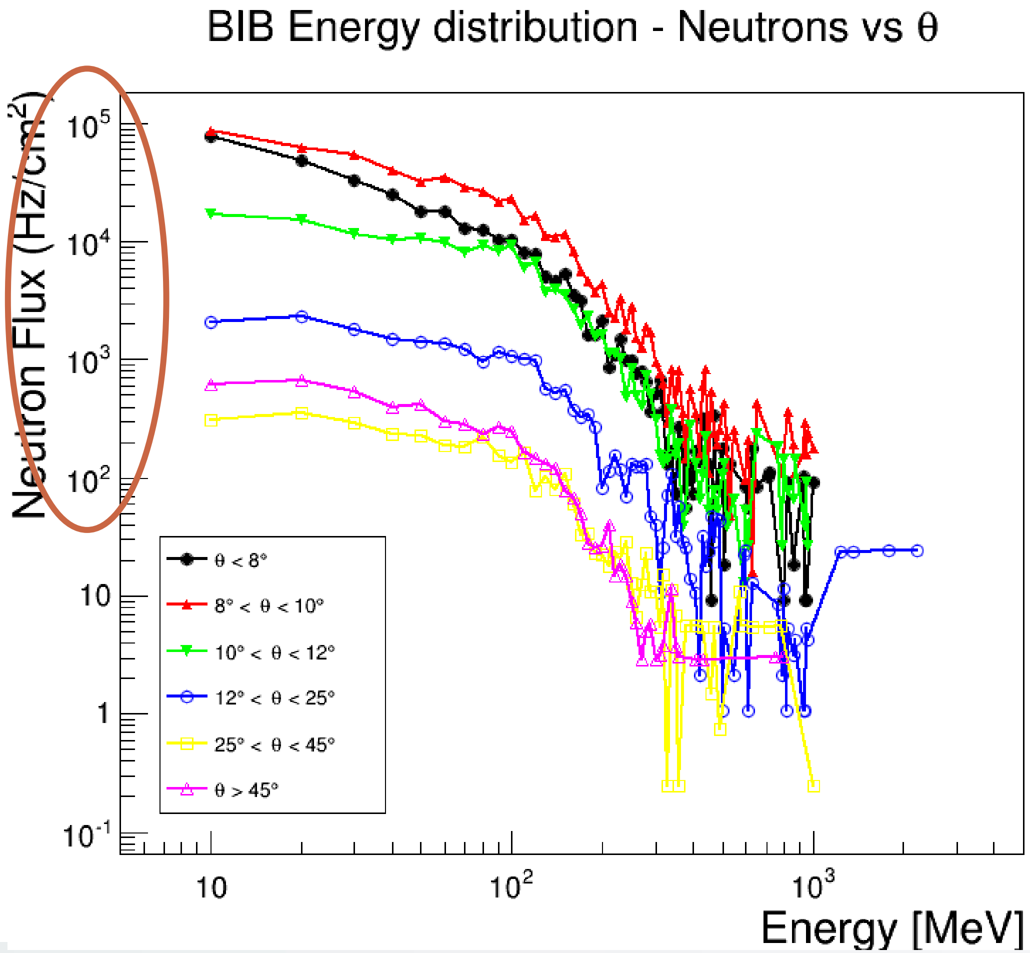
$$f(E) = \frac{p(E) \times BX^{-1}}{A}$$

where

- $p(E)$ = number of particles of a given type and energy reaching the muon system in a BX
- BX^{-1} = number of BX/s (10^5)
- A = considered area

This plot shows the flux on the entire endcap – not to be used to evaluate the actual fluxes on the detectors – but it gives us an overview of particle types and energy ranges.

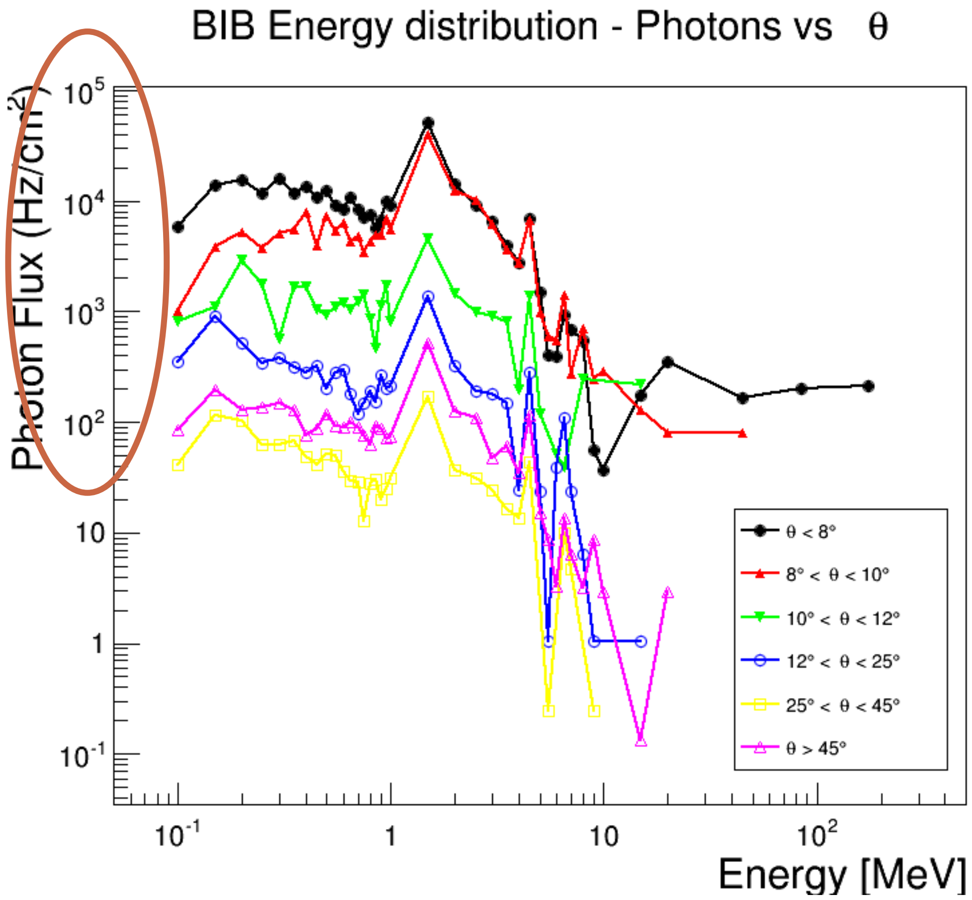
Step 1 – BIB in the muon system @ 1.5 TeV
Neutrons



We have divided the endcap region in six sub-regions based on θ (or r):

- In the inner regions, the neutron flux is almost 3 orders of magnitude higher than in the outer regions
- The energy goes from few MeV up to 2.5 GeV → *is there any cut on the lower energies?*
- The highest fluxes are for energies below 100 MeV

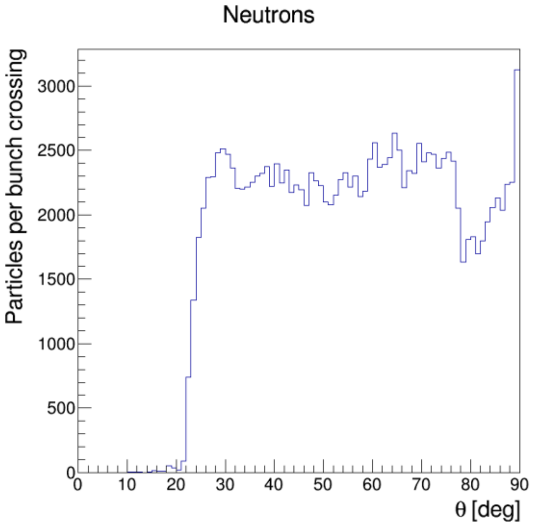
Step 1 – BIB in the muon system @ 1.5 TeV
Photons

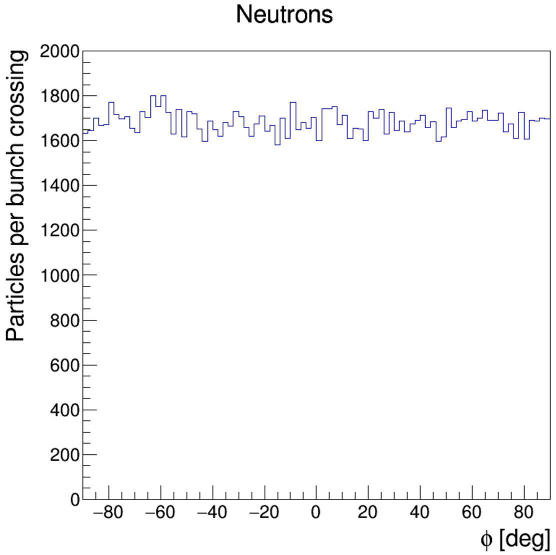


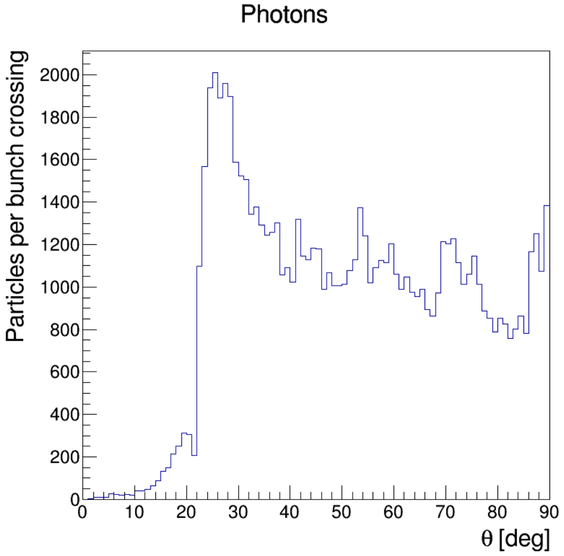
We have divided the endcap region in six sub-regions based on θ (or r):

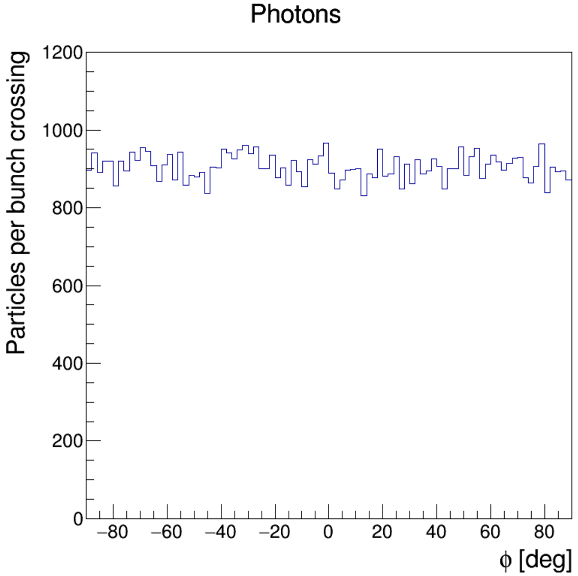
- In the inner regions, the photon flux is almost 3 orders of magnitude higher than in the outer regions
- The energy goes from 100 keV up to 200 MeV → *is there any cut on the lower energies?*
- The highest fluxes are for energies below 10 MeV

Step 1 – BIB in the muon system @ 1.5 TeV
Angular distributions









θ and ϕ defined as the incident impact angles w.r.t. the local detector coordinates system.

Step 2 - Sensitivity

Sensitivity

$$s = \frac{N}{M}$$

- N = number of events in which at least one charged particle reaches a sensitive gap
- M = number of incident particles (counted with a fake layer of air on top of the detector)

Simulation details

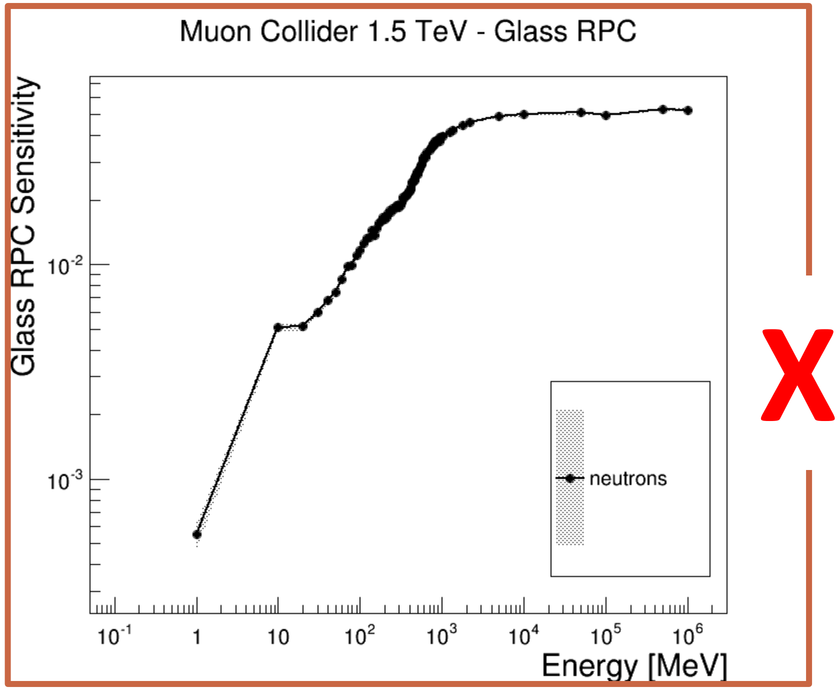
In each run 10^5 particles were generated with:

- Fixed energy → values selected from energy distributions
    - 88 values for neutrons
    - 48 values for photons
- Direction randomly generated from angular distribution

Physics List: FTFP_BERT_HP (and comparison with QGSP_HP)

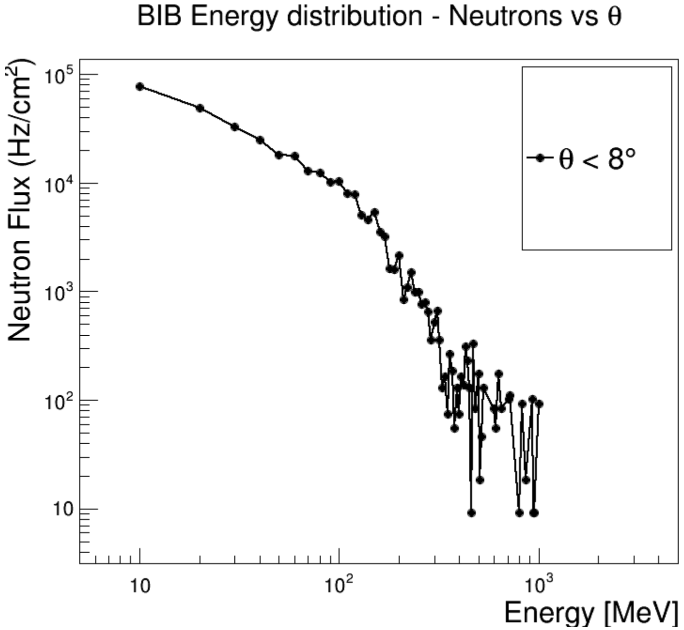
Geant4.9.6.p02

Step 3 – Hit rate
In each θ region…



X

$$Hit\ rate = s \times flux$$



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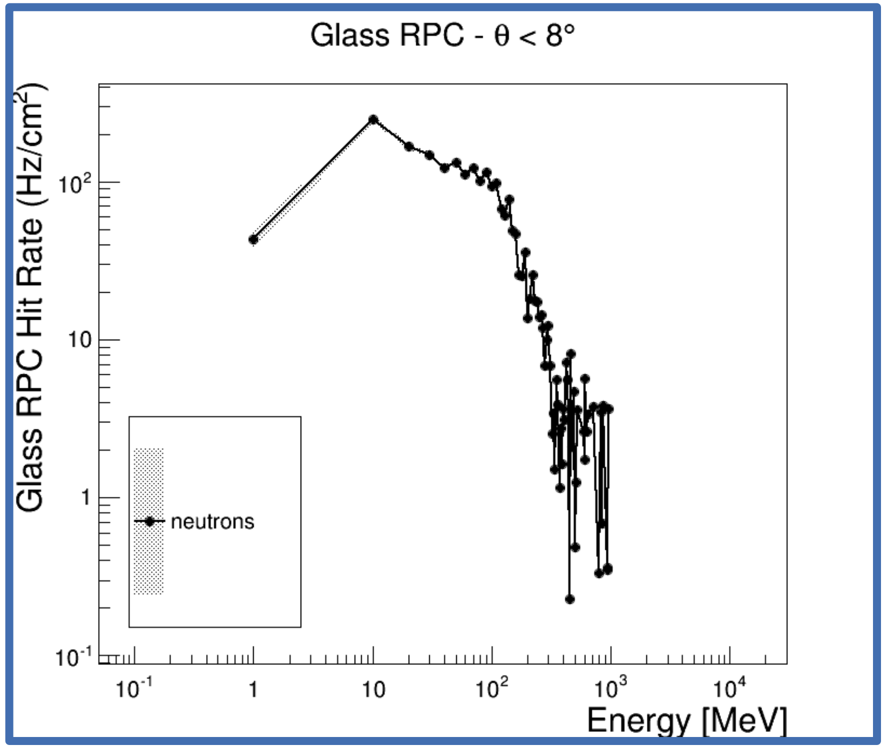
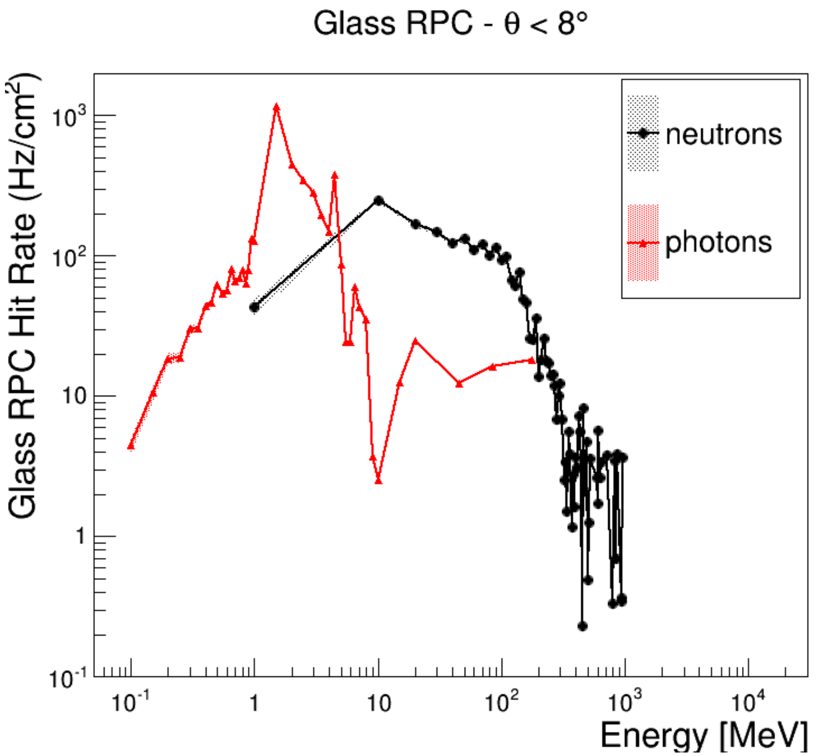


Region $\theta < 8°$ used as example

Step 4 – Total Hit rate
In each θ region…



$$Total\ Hit\ Rate = \sum_{E} Hit\ Rate\ (E)$$

Particle	Total Hit Rate (Hz/cm²)
Neutrons	$(2.16 \pm 0.65) \times 10^3$
Photons	$(4.40 \pm 0.05) \times 10^3$

Region $\theta < 8°$ used as example

Which detectors?

Details of geometries and materials in backup

1. ***Double-gap Glass RPC***
    a) Currently implemented in the MuCollv1 simulation
2. ***Double-gap HPL RPC***
    a) Classical version of the detector
3. ***Triple-GEM***
    a) Micropattern gaseous detector with better space resolution w.r.t. RPC
4. ***PicoSec***
    a) New generation MPGD with improved time resolution

All the detectors were simulated with a «basic» geometry; no electronics, cooling, shielding, etc.. were implemented.

GRPC Geometry

```
"AluminumT1","AirT1",
"PyrexGlassT1",
"GasGap1",
"PyrexGlassB1",
"AirB1","AluminumB1",
"AluminumT2","AirT2",
"PyrexGlassT2",
"GasGap2",
"PyrexGlassB2",
"AirB2","AluminumB2",
```

```
1*mm,3.5*mm,        //Aluminum + Air
2*mm,               //Pirex Glass
2*mm,               //GasGap1
2*mm,               //Pirex Glass
3.5*mm,1*mm,        //Aluminum + Air
1*mm,3.5*mm,        //Aluminum + Air
2*mm,               //PirexGlass
2*mm,               //GasGap2
2*mm,               //PirexGlass
3.5*mm,1*mm,        //Aluminum + Air
```

- Geometry as it is currently implemented in MuCollv1
- Dominant materials are:
  - Aluminum
  - Pyrex Glass = SiO_2 (80.6%) + B_2O_3 (13%) + Na_2O (4%) + Al_2O_3 (2.3%)
- Gas: isobutane (4.5%) + $C_2H_2F_4$ (95.2%) + SF_6 (0.3%)

Double Gap RPC Geometry

```
"MylarElecIns1","totMylarHV1","CopperGND1",          0.2*mm,0.4*mm,0.038*mm,              //Insulator
"HPL1",                                              2*mm,                                //HPL
"GasGap1",                                           2*mm,                                //GasGap1
"HPL2",                                              2*mm,                                //HPL
"totMylarGND1","CuStrips","FR4Strips","totMylarGND2", 0.2*mm,0.017*mm,0.4*mm,0.2*mm,      //Strips
"HPL3",                                              2*mm,                                //HPL
"GasGap2",                                           2*mm,                                //GasGap2
"HPL4",                                              2*mm,                                //HPL
"CopperGND2","totMylarHV2","MylarElecIns2",          0.038*mm,0.4*mm,0.2*mm,              //Readout Board
"AlPanel",                                           5*mm,                                //Aluminum Panel
```

- CMS geometry
- Dominant materials are:
  - HPL (High Pressure Laminate) = H (5.74%) + C (77.46%) + O (16.8%)
  - Mylar ([Geant4 Material DB])
  - Aluminum
- Gas: isobutane (4.5%) + $C_2H_2F_4$ (95.2%) + SF_6 (0.3%)

Triple GEM Geometry

"PCB",	1.2*mm,	//PCB on top
"KaptonFoil",	50*um,	//Kapton window
"DriftKapton","DriftCopper2",	50*um,35.*um,	//Drift Foil
"GasGap1",	3.*mm,	//Drift Gap
"Gem1Copper1","Gem1","Gem1Copper2",	5.*um,50*um,5.*um,	//gem1
"GasGap2",	1.*mm,	//Transfer I Gap
"Gem2Copper1","Gem2","Gem2Copper2",	5.*um,50*um,5.*um,	//gem2
"GasGap3",	2.*mm,	//Transfer II Gap
"Gem3Copper1","Gem3","Gem3Copper2",	5.*um,50.*um,5.*um,	//gem3
"GasGap4",	1.*mm,	//Induction Gap
"ReadCopper1","ReadoutBoard",	35.*um,3.2*mm,	//Readout Board

- Simple Triple-GEM geometry
- Dominant materials are:
  - Kapton
  - Copper
  - PCB (FR4)
- Gas: Ar (70%) + CO_2 (30%)

```
G4Material* SiO2 =  new G4Material("quartz",density= 2.200*g/cm3, numel=2);
SiO2->AddElement(elSi, natoms=1);
SiO2->AddElement(elO , natoms=2);

//from http://www.physi.uni-heidelberg.de/~adler/TRD/TRDunterlagen/RadiatonLength/tgc2.htm
//Epoxy (for FR4 )
density = 1.2*g/cm3;
G4Material* Epoxy = new G4Material("Epoxy" , density, numel=2);
Epoxy->AddElement(elH, natoms=2);
Epoxy->AddElement(elC, natoms=2);

//FR4 (Glass + Epoxy)
density = 1.86*g/cm3;
G4Material* FR4 = new G4Material("FR4"  , density, numel=2);
FR4->AddMaterial(Epoxy, fractionMass=0.472);
FR4->AddMaterial(SiO2, fractionMass=0.528);
fFR4Mat = FR4;
```

PicoSec Geometry

https://arxiv.org/pdf/1901.03355.pdf

```
"Radiator",                            3*mm,              //Cherenkov radiator
"Photocathode",                        20*nm,             //Photocathode
"PCSupport",                           10*nm,             //PC Support
"GasGap1",                             200.*um,           //Drift Gap
"Mesh",                                8.*um,             //Mesh
"GasGap2",                             128*um,            //Transfer I Gap
"ReadCopper1","ReadoutBoard"           35.*um,3.2*mm,     //Readout Board
```

- Prototype geometry
- Dominant materials are:
    - Cherenkov Radiator =MgF_2
    - Need to understand from interaction position study which are the more relevant material (photocathode is CsI, PC support is Cr, Mesh is Al…)
- Gas: Ne (80%) + C_2H_6 (10%) + CF_4 (10%)