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

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16th June 2021 - Muon Collider Joint Tracker and Calorimeter Meeting

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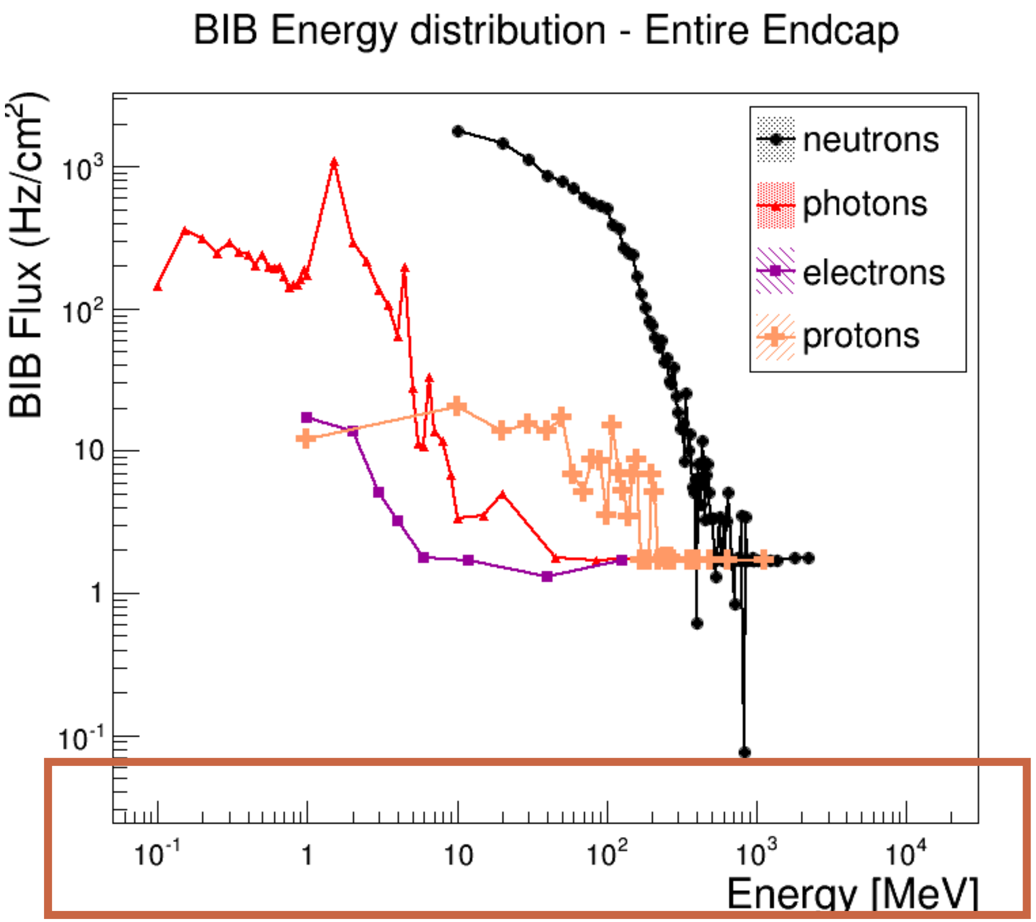
Intro

Goal: evaluate the expected hit rate due to BIB in the muon chambers

What do we need for this? ***Detector sensitivity to BIB particles***

Sensitivity is the probability for a background particle (neutron or photon) to produce a visible signal in the detector.

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



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

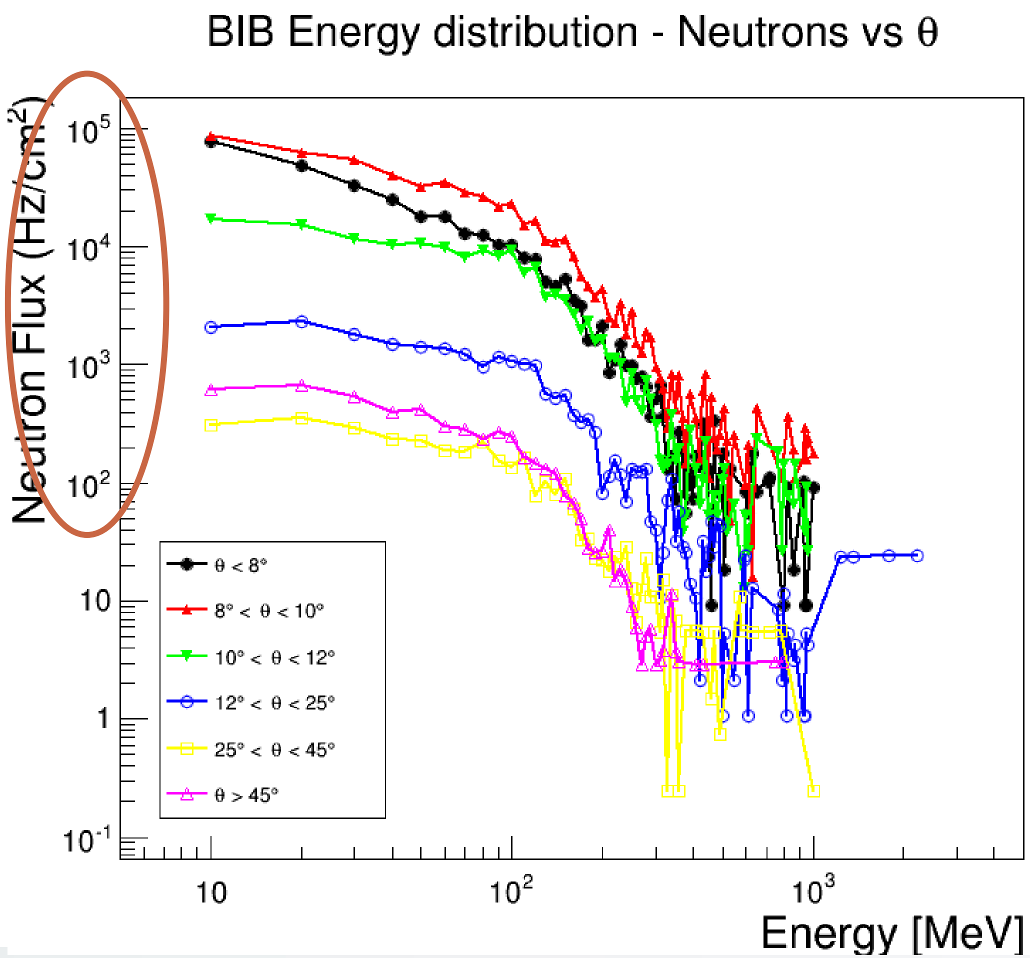
where

- $p(E)$ = 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

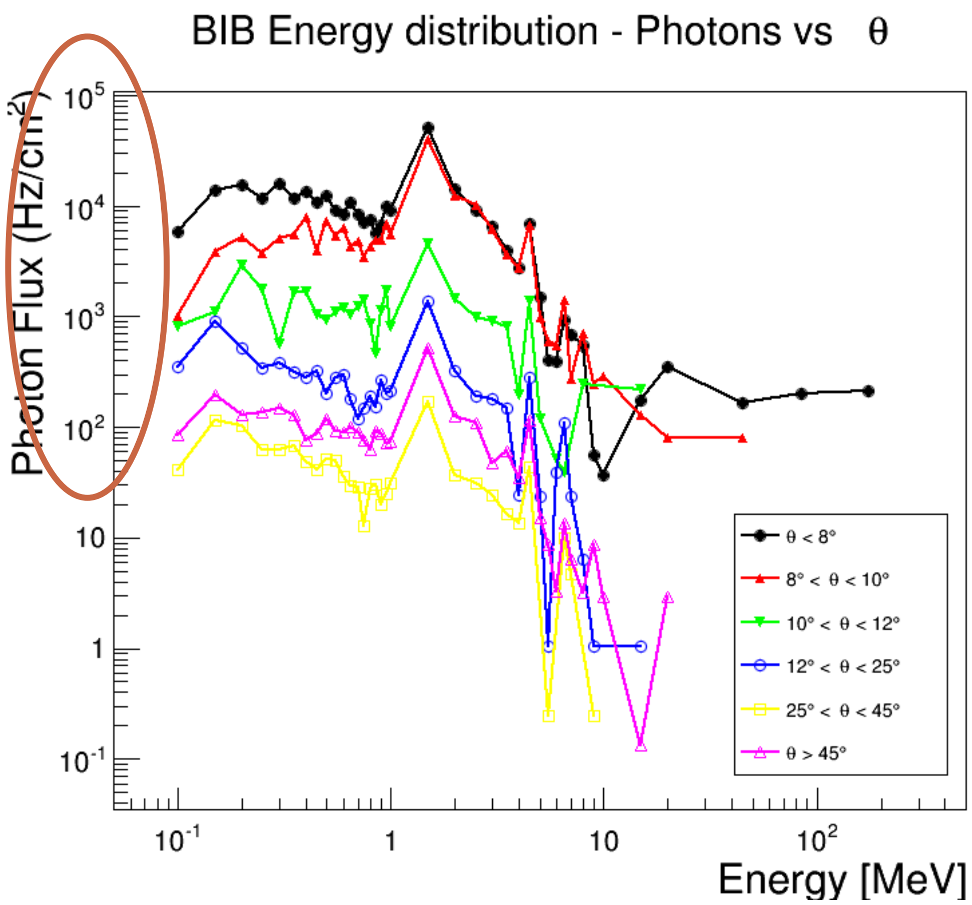
Neutrons



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

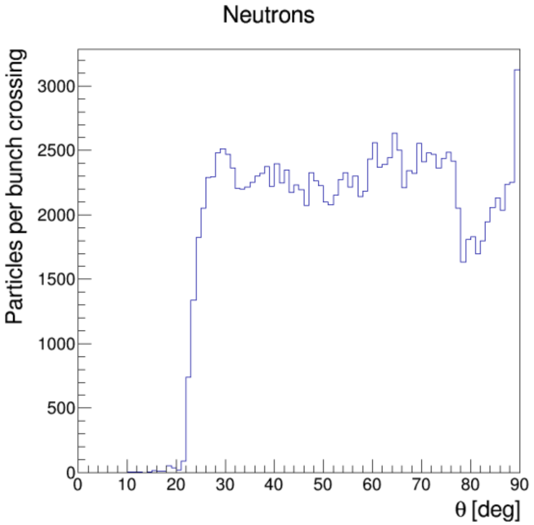
Step 1 – BIB in the muon system @ 1.5 TeV
Photons

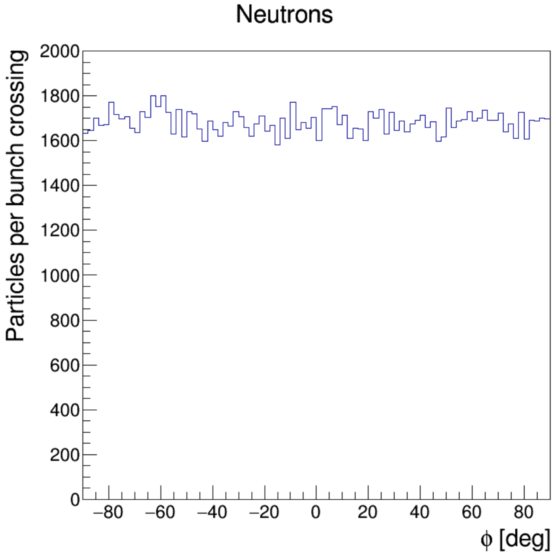


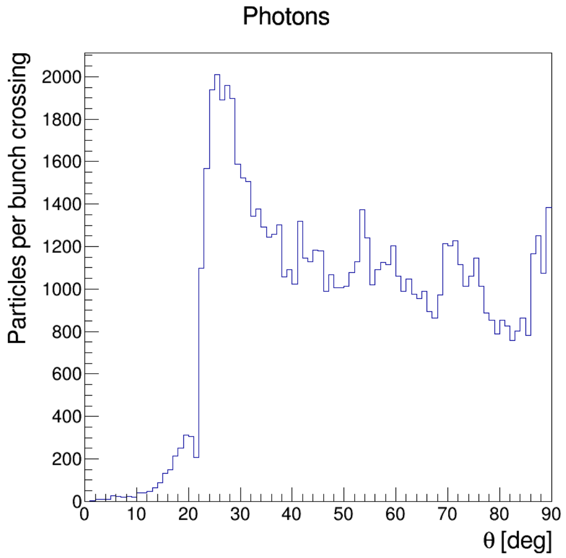
We have divided the endcap region in six sub-regions based on θ (or r):

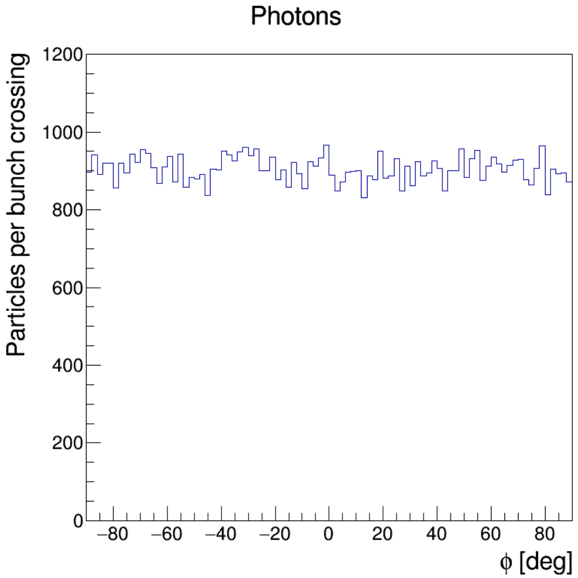
- In the inner regions, the photon flux is almost 3 orders of magnitude higher than in the outer regions
- The energy goes from 100 keV up to 200 MeV → *is there any cut on the lower energies?*
- The highest fluxes are for energies below 10 MeV

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

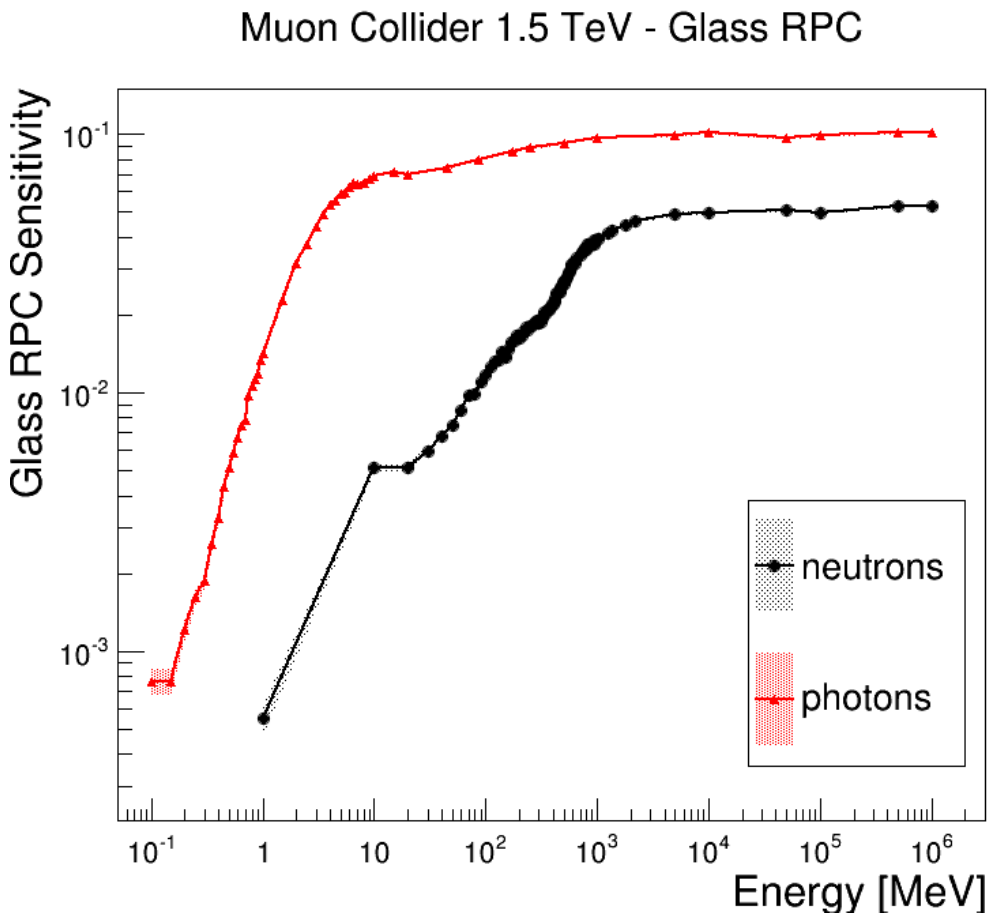
In each run 10^5 particles were generated with:

- 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

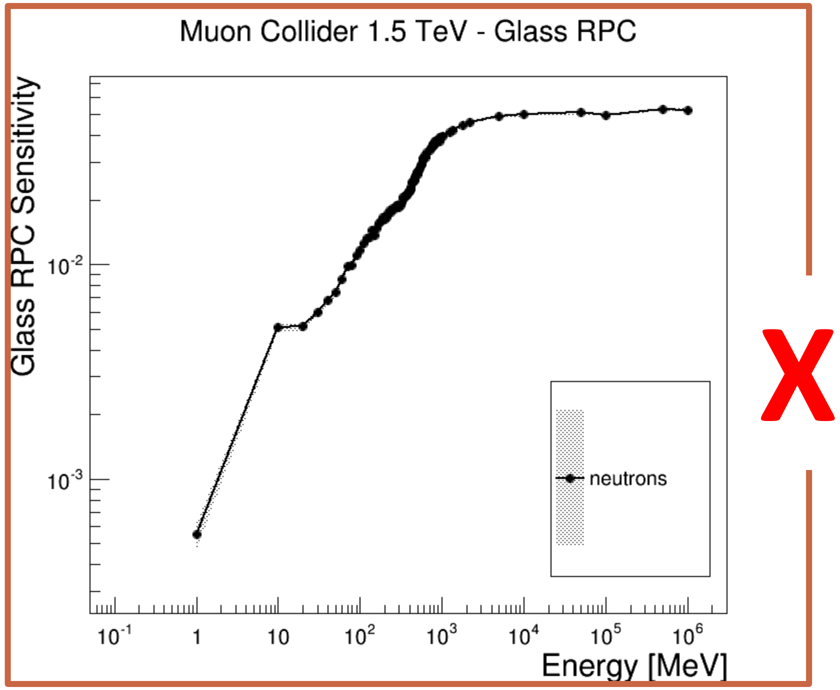
Step 2 - Sensitivity
Glass RPC



Detector geometry simulated with as much detail as possible (see backup for details)

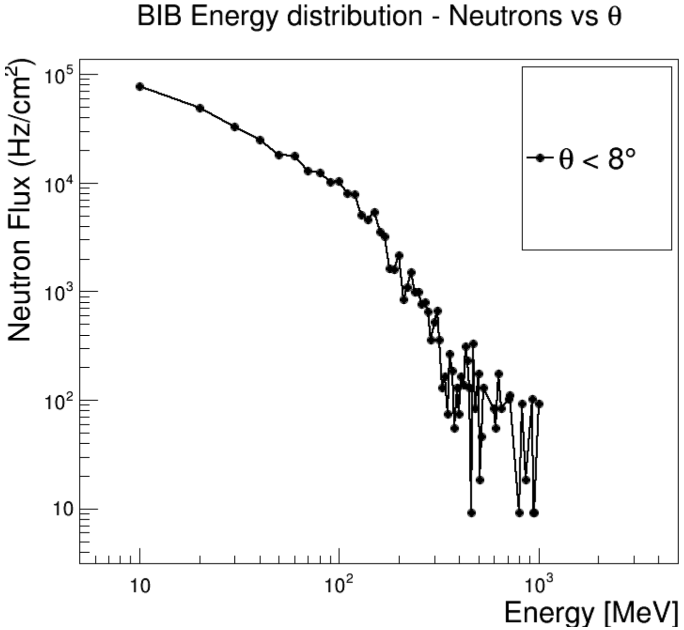
Glass RPC used as reference as this is the technology currently implemented in the MuCollv1 software.

Step 3 – Hit rate
In each θ region…



X

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



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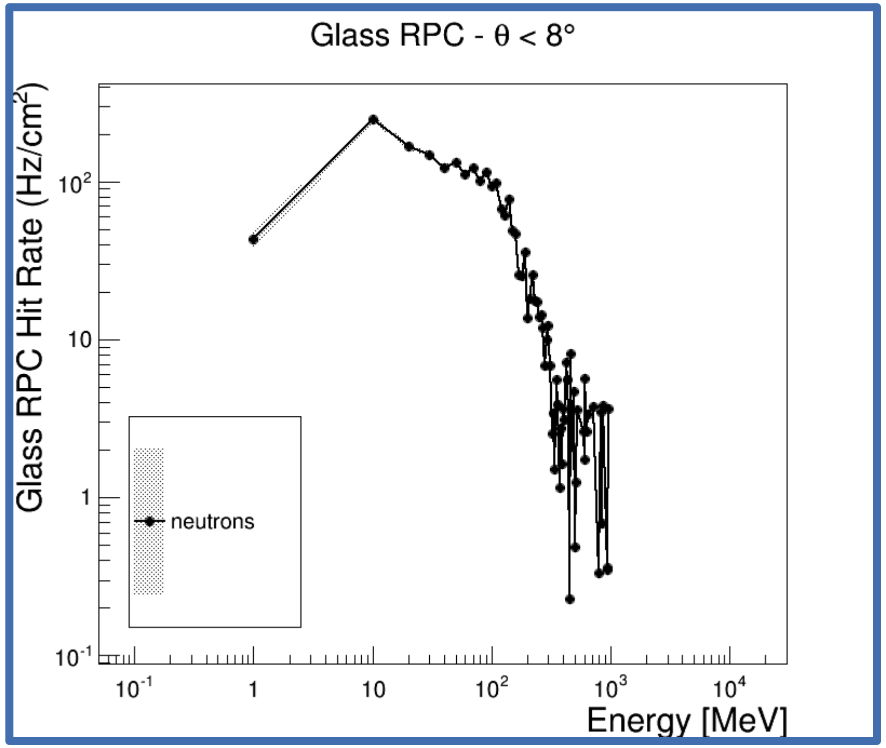
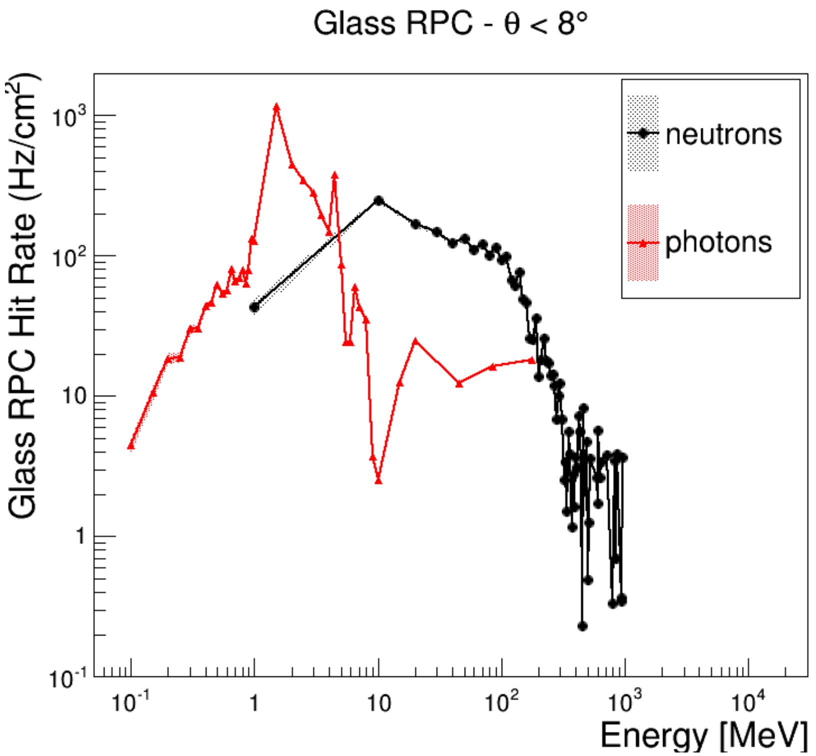


Region $\theta < 8°$ used as example

Step 4 – Total Hit rate

In each θ region…

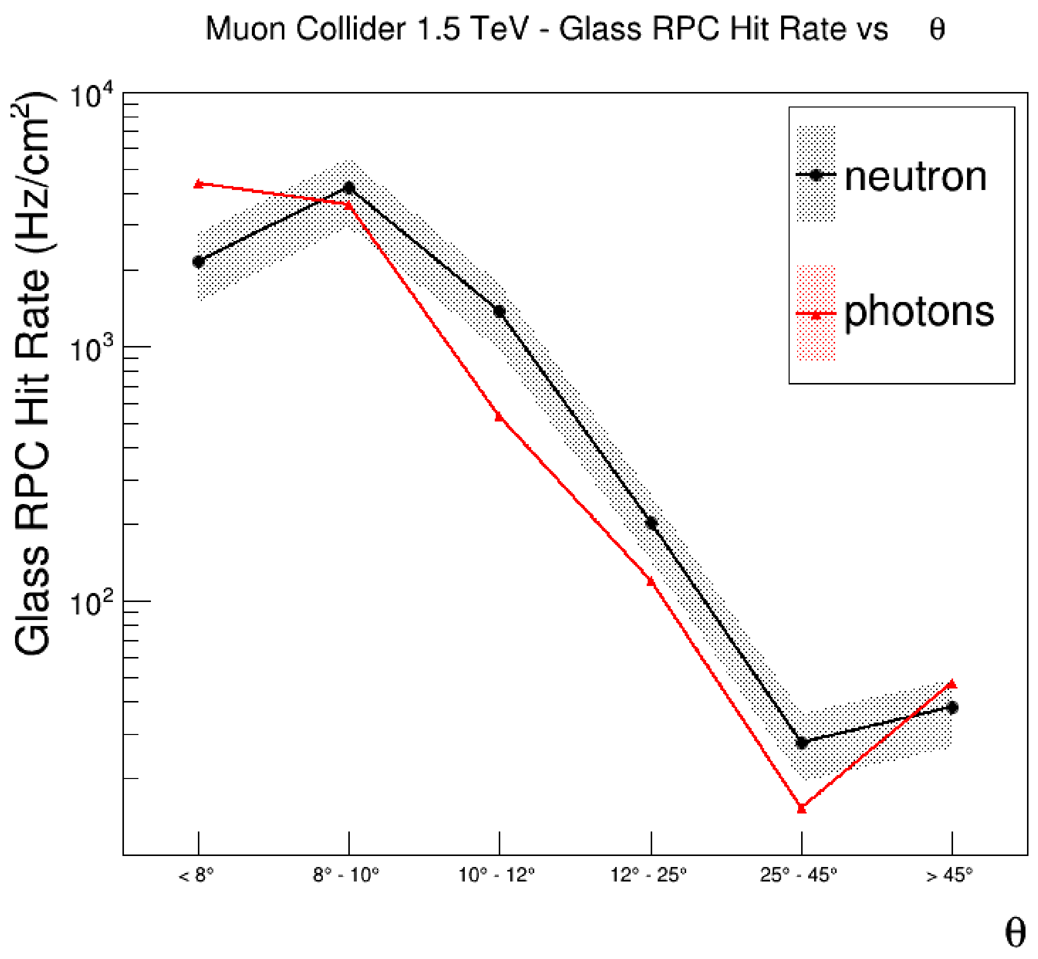


$$Total\ Hit\ Rate = \sum_E Hit\ Rate\ (E)$$

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

Step 5 – Total Hit rate vs θ



Repeating the same procedure on all the θ regions:

- With GRPC both neutron and photon hit rates reaches $\sim 5\ kHz/cm^2$
- Hit rate decreases with θ as expected

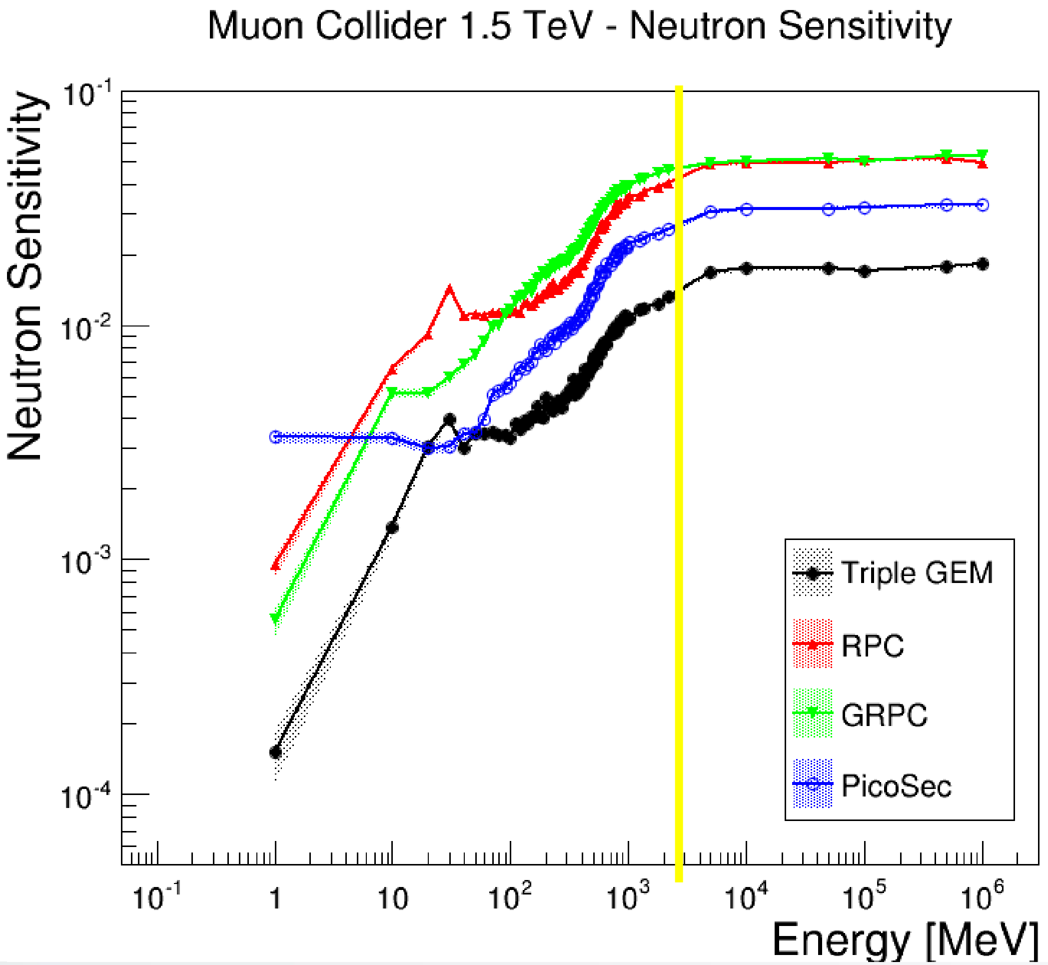
Which detectors?

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.

Neutron sensitivity results

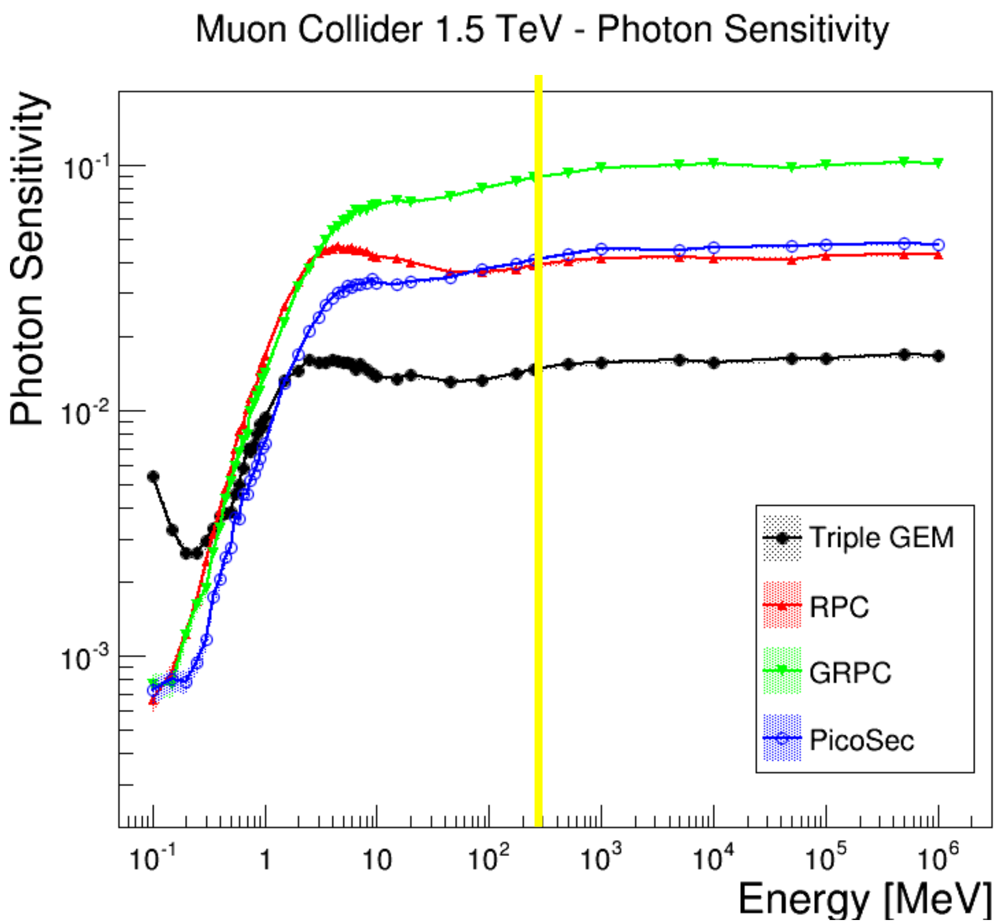


Different technologies = different materials → different sensitivities

- Triple GEM has the lowest neutron sensitivity → less material budget w.r.t. the other technologies
  - GRPC and RPC contains different layers of aluminum and glass
  - PicoSec has a 3mm cherenkov converter on top
- Additional differences between the technologies will be analyzed studying the interaction processes (next step)

The yellow line marks the maximum energy of neutrons from BIB @ 1.5 TeV

Photon sensitivity results

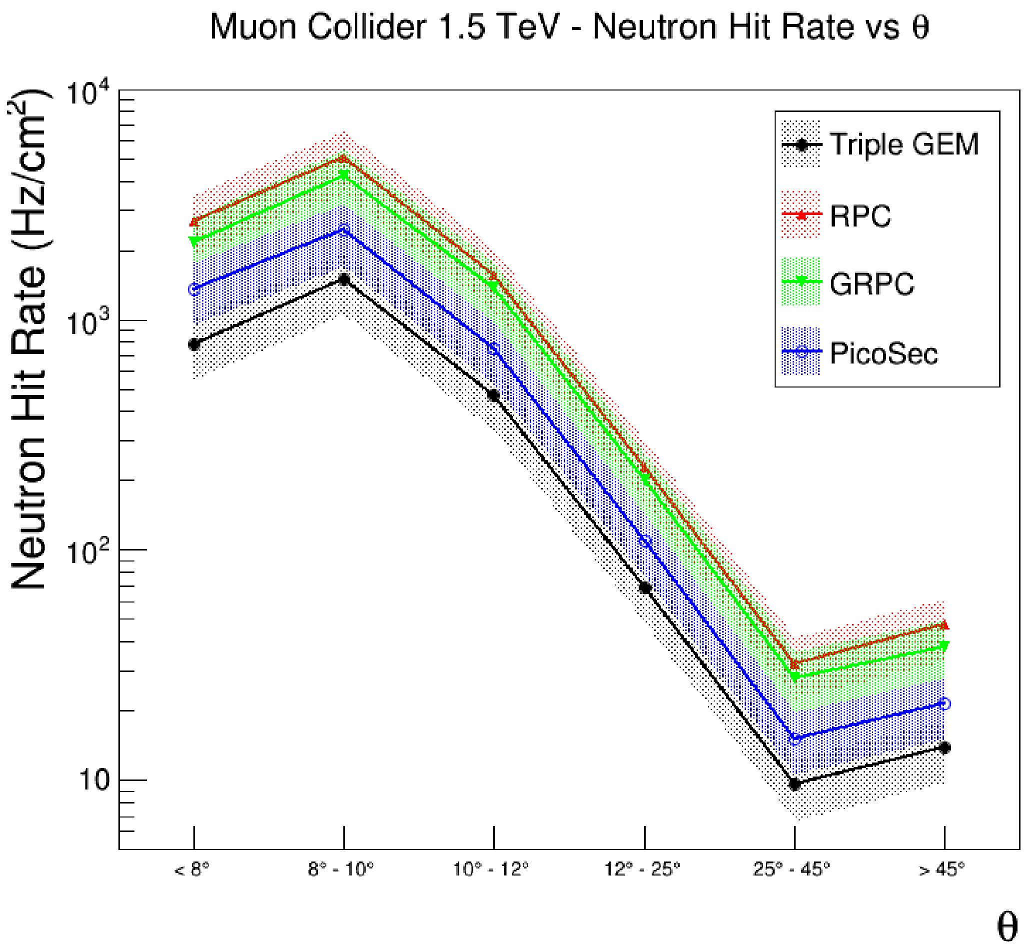


Different technologies = different materials → different sensitivities

- Triple GEM has also the lowest photon sensitivity → less material budget w.r.t. the other technologies
  - GRPC and RPC contains different layers of aluminum and glass
  - PicoSec has a 3mm cherenkov converter on top
- Additional differences between the technologies will be analyzed studying the interaction processes (next step)

The yellow line marks the maximum energy of photons from BIB @ 1.5 TeV

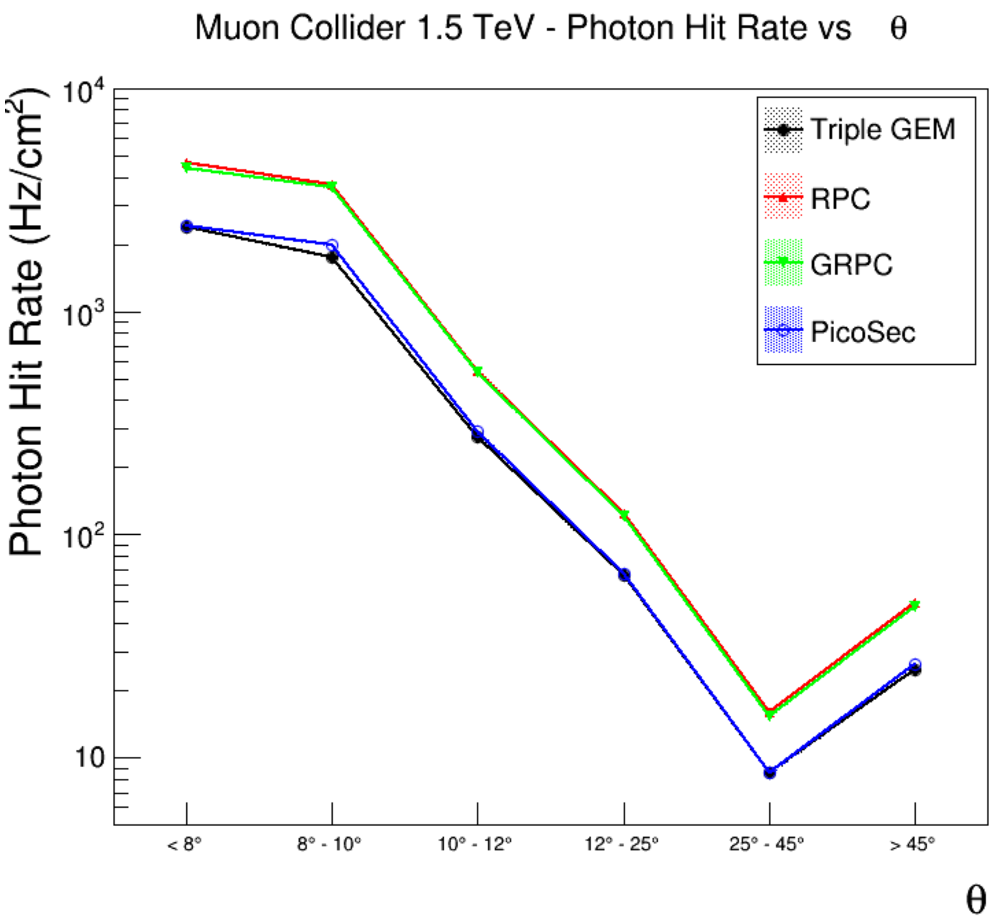
Hit rate - Neutrons



Different sensitivities = different hit rate

- Triple GEM has the lowest sensitivity → lower estimated hit rate
- GRPC and RPC in the inner regions are already at the limit of their current rate capability

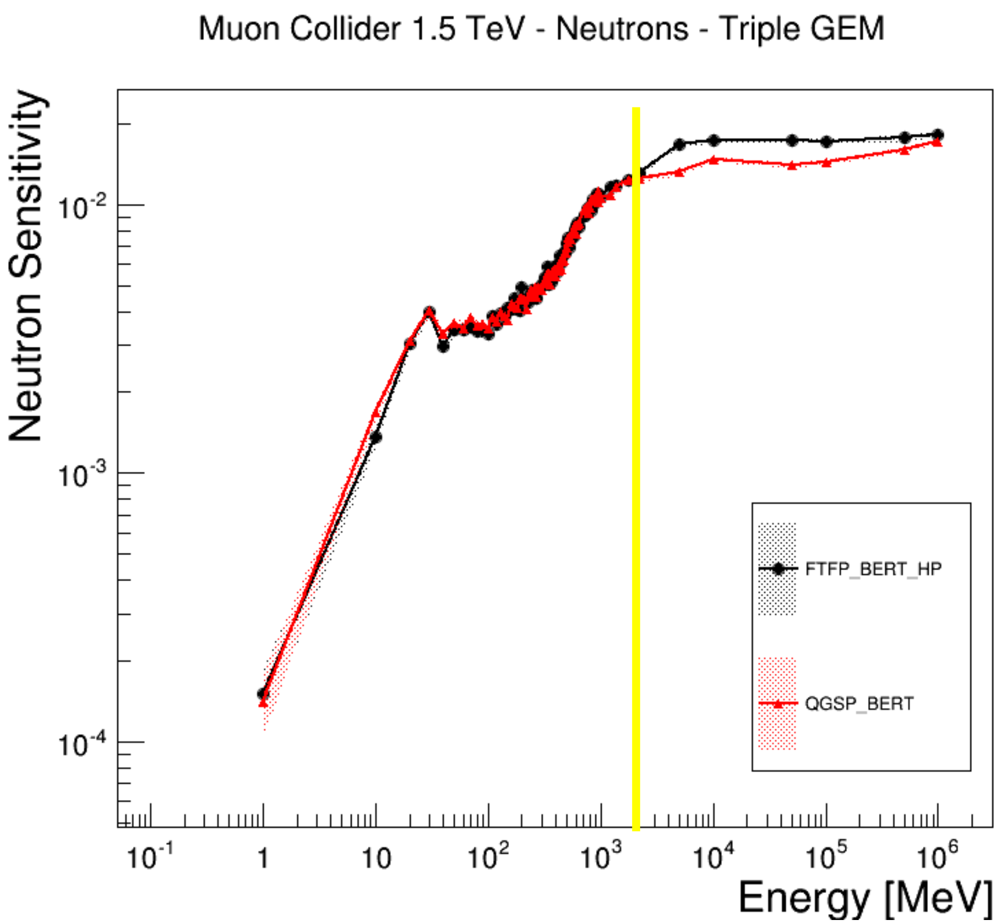
Hit rate - Photons



Different sensitivities = different hit rate

- Triple GEM has the lowest sensitivity → lower estimated hit rate
- GRPC and RPC in the inner regions are already at the limit of their current rate capability
- Estimated hit rates for Triple GEM and PicoSec are almost identical because the photon sensitivity for these two technologies is very similar in the energy range 0.5-5 MeV, where the flux is maximum. Same consideration applies for GRPC-RPC.

Physics List comparison - Neutrons



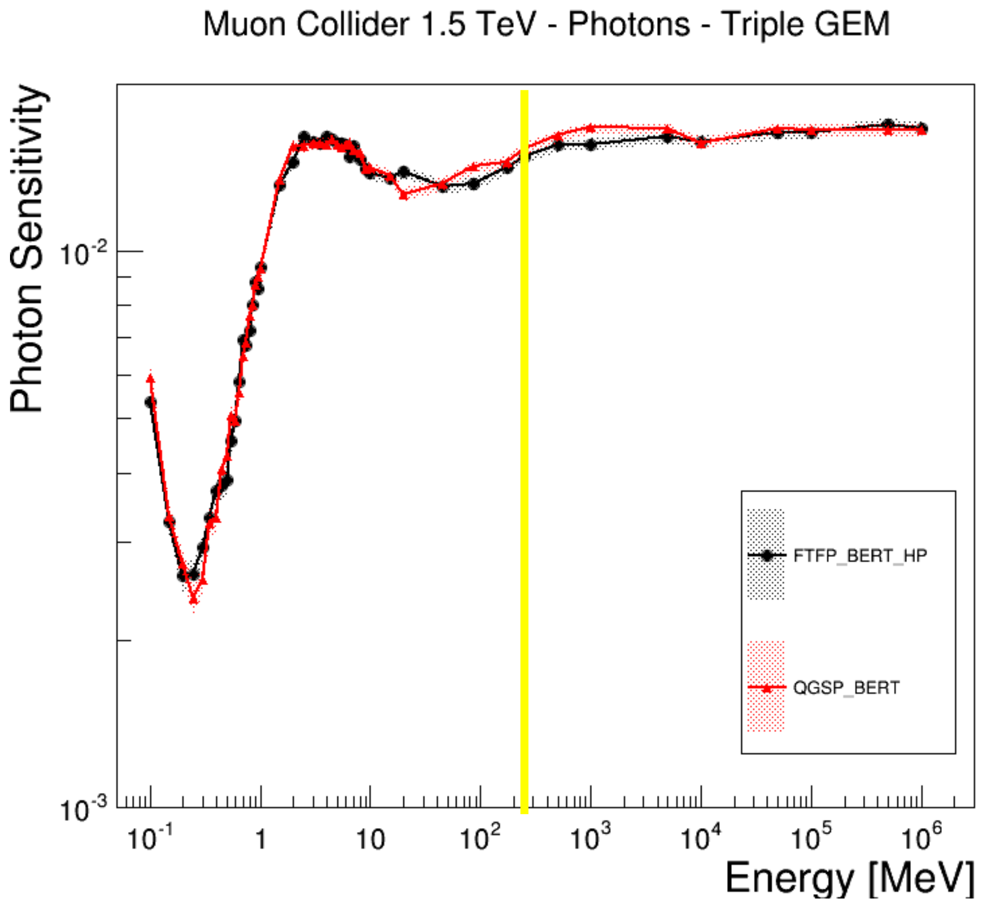
Physics Lists:

- FTFP_BERT_HP: commonly used for sensitivity studies; good for high energy neutrons
- QGSP_BERT: used in the MuCollv1 simulation

- Results comparable in the energy range of BIB @ 1.5 TeV (up to the yellow line)
- For higher energies QGSP_BERT returns a lower sensitivity w.r.t. FTFP_BERT_HP

→ *To be investigated*

Physics List comparison - Photons



Physics Lists:

- FTFP_BERT_HP: commonly used for sensitivity studies; good for high energy neutrons
- QGSP_BERT: used in the MuCollv1 simulation

- Results comparable in the whole energy range considered

Summary & Next steps

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

+

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

- Repeat the study with the new BIB simulations

Backup

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%)