UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

XXXII DOTTORATO DI RICERCA IN FISICA

Activity report on the I year

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Bari, 13 Nov 2017

Overview

- **First year research activities:**
  1. **Longevity study of the CMS-RPC present system**
  2. **R&D RPC system extension and study of the expected background at HL-LHC in RE3/1 and RE4/1 regions**

- **Activity during next two years**
- **Conferences, schools, workshops and seminaries**
- **PhD courses**

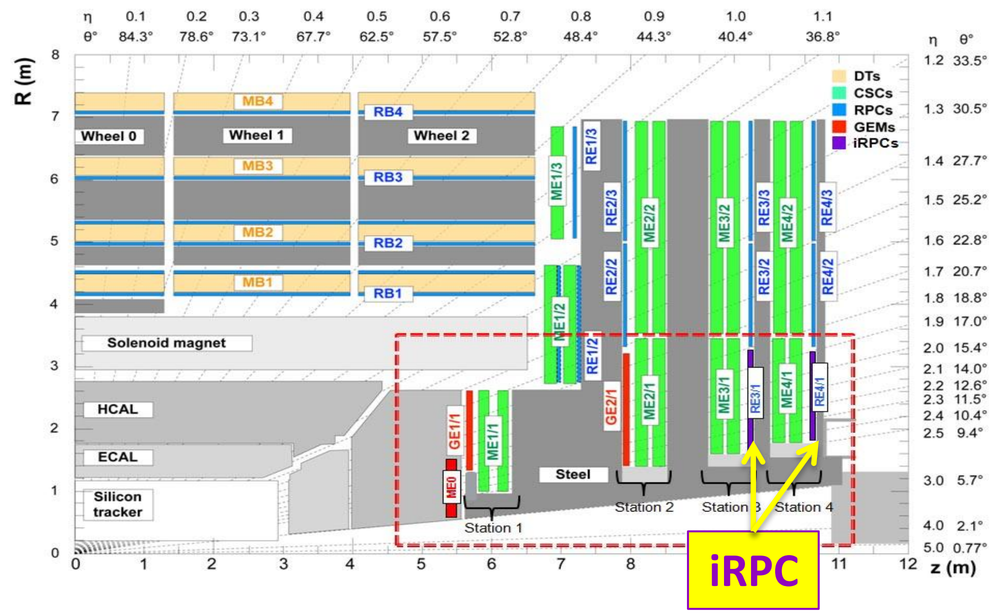
The CMS RPC system at HL-LHC

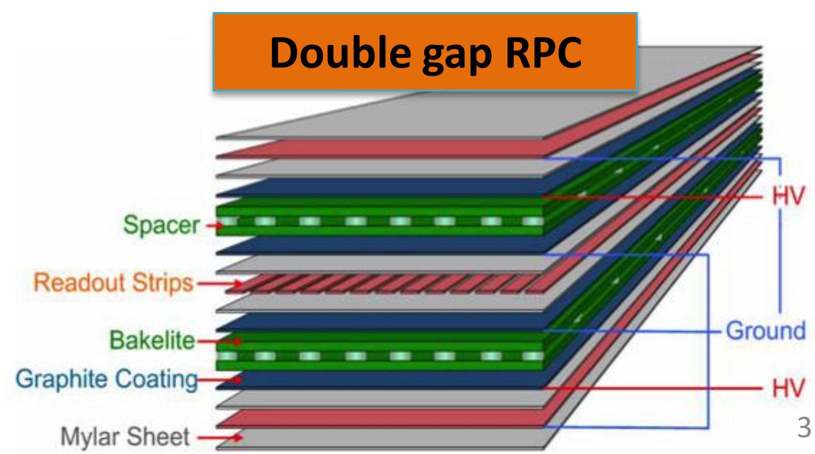
The Resistive Plate Chamber (RPC) system of Compact Muon Solenoid (CMS) experiment *covers both Barrel and Endcap regions.*

At High Luminosity phase of the Large Hadron Collider (HL-LHC) the instantaneous luminosity will increase up to $5 \cdot 10^{34}$ $cm^{-2}s^{-1}$ and the expected integrated luminosity, will be 3000 fb^{-1}.
In view of the ***HL-LHC*** *two upgrades are planned on the RPC system:*

1. CONSOLIDATION of present system

2. EXTENSION at high eta region



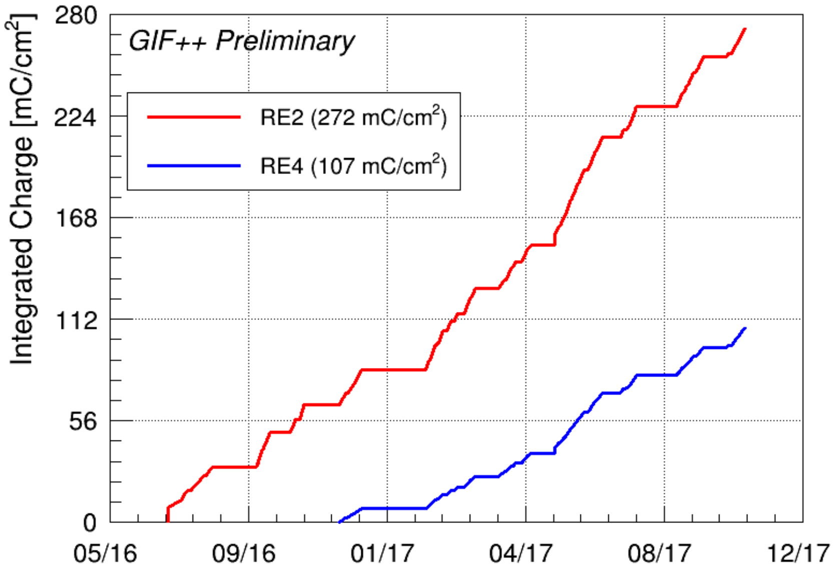


1. CONSOLIDATION: Irradiation Test at GIF++

*The RPC system has been certified for 10 years of LHC. In view of the HL-LHC it has to be certified: ≈ **600 Hz/cm²** and ≈ **840 mC/cm²** (safety factor of 3 included)*

A dedicated irradiation test is ongoing at the Gamma irradiation Facility (GIF++) at CERN, since last year, with four RPC chambers:

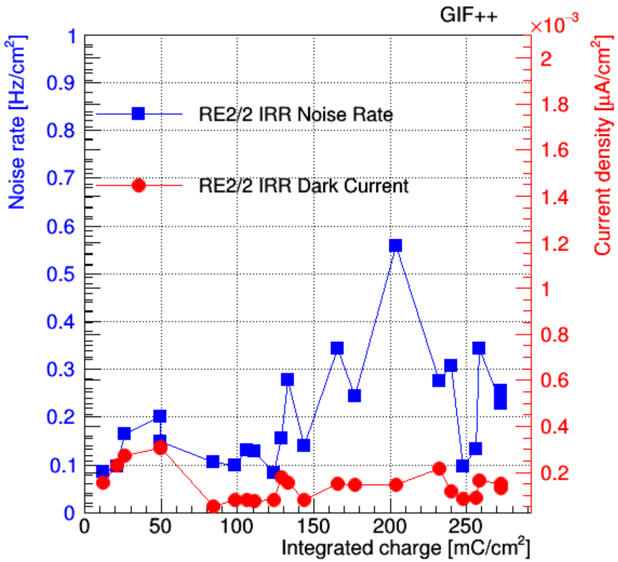
1. *One RE4 and one RE2 always at HV on: "irradiated"*
2. *One RE4 and one RE2 always off: "reference"*

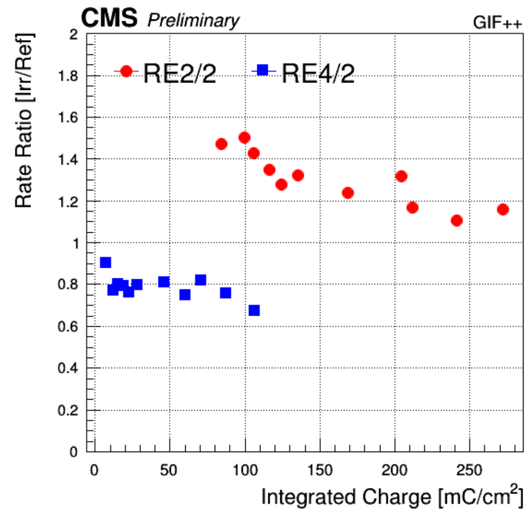


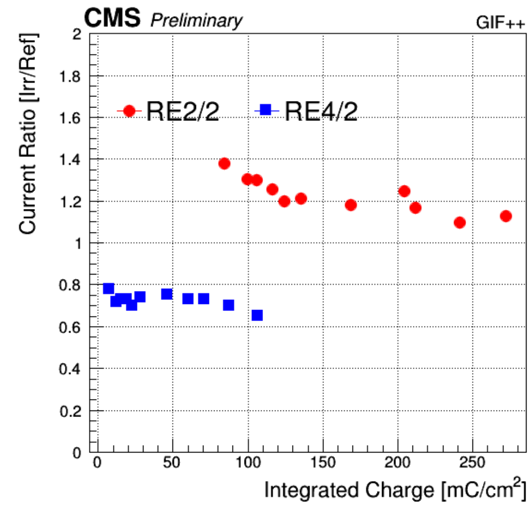
***RE2 irradiation started** on July 3, 2016*
→Since then, integrated charge:
272 mC/cm² (32%)

***RE4 irradiation** started on Nov. 25, 2016*
→ Since then, integrated charge:
107 mC/cm² (12%)

Rate and Currents monitoring



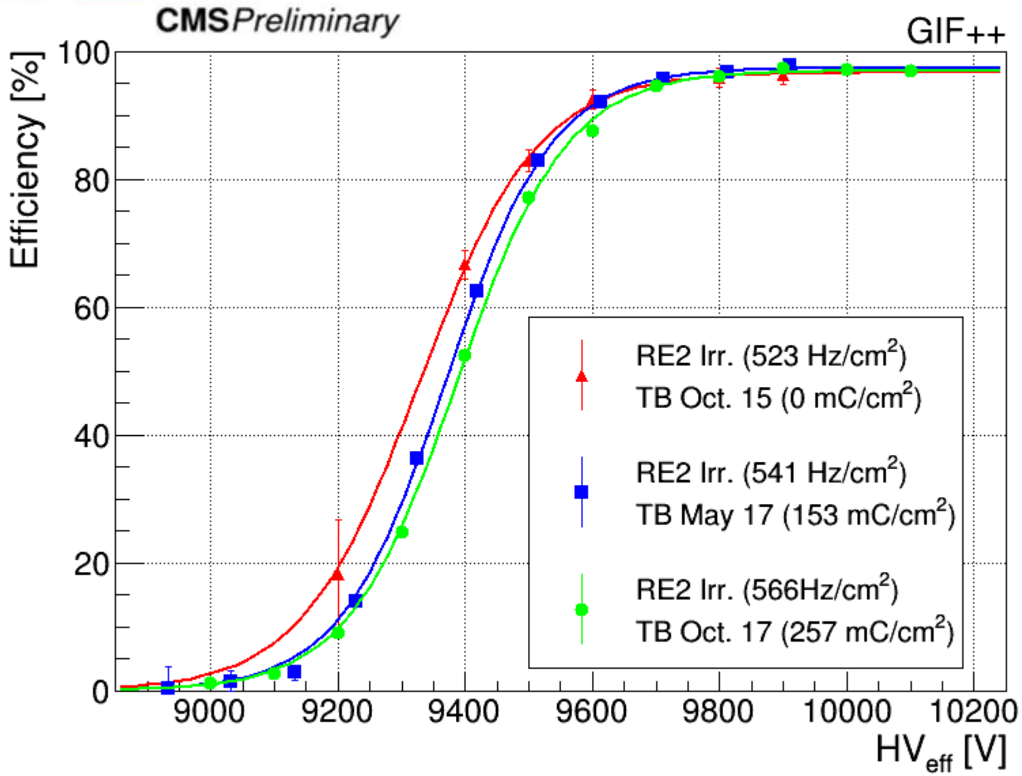




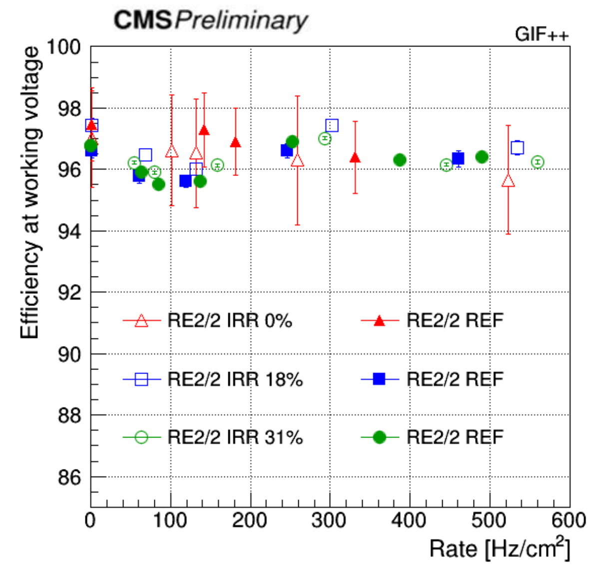
*The **noise rate** and **dark current** at WP (without background) are periodically monitored in order to spot variation of the quality of the electrode surface and resistivity: **stable so far.***

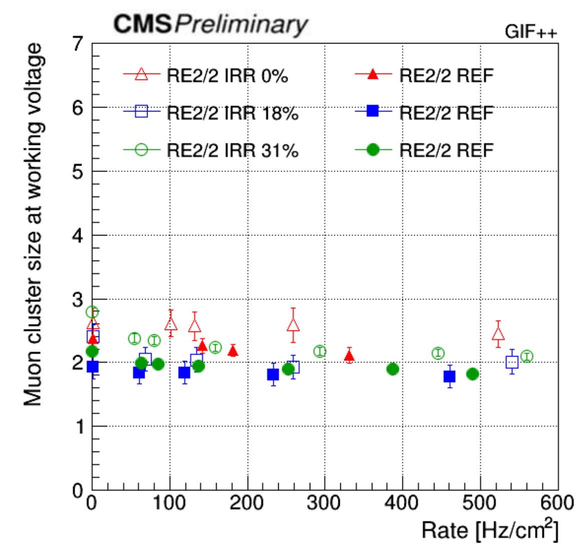
*The relative **current (left)** and **rate (right)** of the **irradiated chamber** with respect to the **reference chambers** are stable.*

RPC performance



WP





The present system:

1. ***performance stable** up to 32 % of the expected HL-LHC integrated charge.* ✔
2. *can sustain the maximum expected rate capability: **600 Hz/cm^2*** ✔

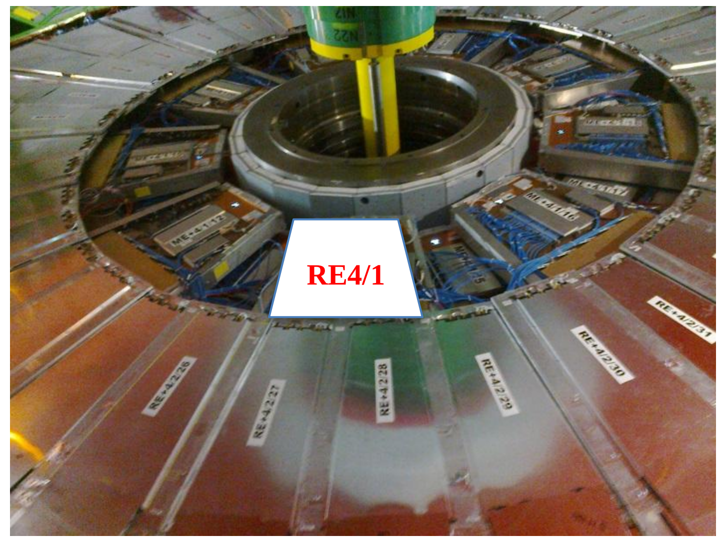
2. RPC system extension

Improved RPC will complete the coverage in the RE3/1 and RE4/1 Endcap stations,
$1.8 < |\eta| < 2.4$ ***18 chambers per disk (20º) → 72 in total***

❑ *Main motivation:*

- *Complement existing ME3-4/1 and increase muon system redundancy extending the contribution of RPCs for both muon tracking and triggering in the forward region*

❑ *Main requirements*

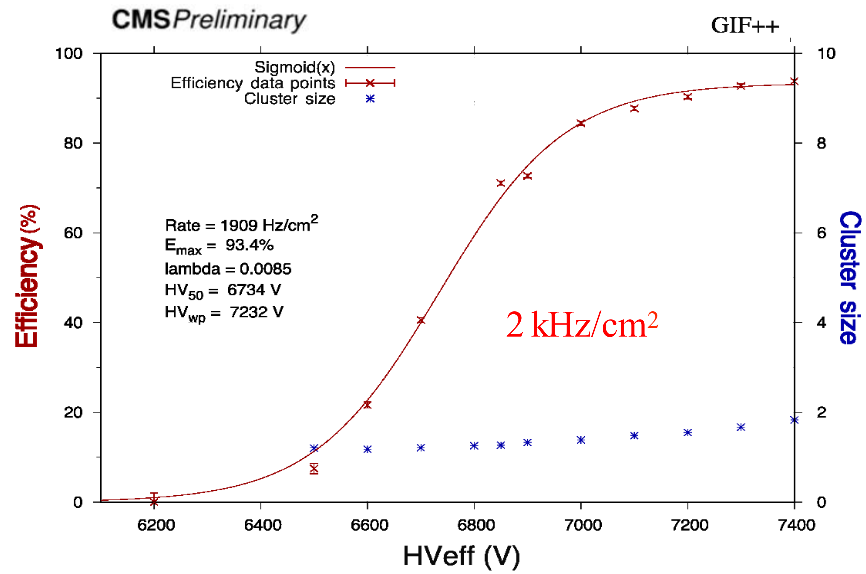


- *Rate capability* ***2 kHz/cm²*** *[1]*
- *Efficiency* ***> 90%***
- *Sufficient aging tolerance* ***2C/cm²*** *[1]*
- *Space resolution for tracking* ***1 cm***
- *Time resolution ≈* ***1.5 ns***

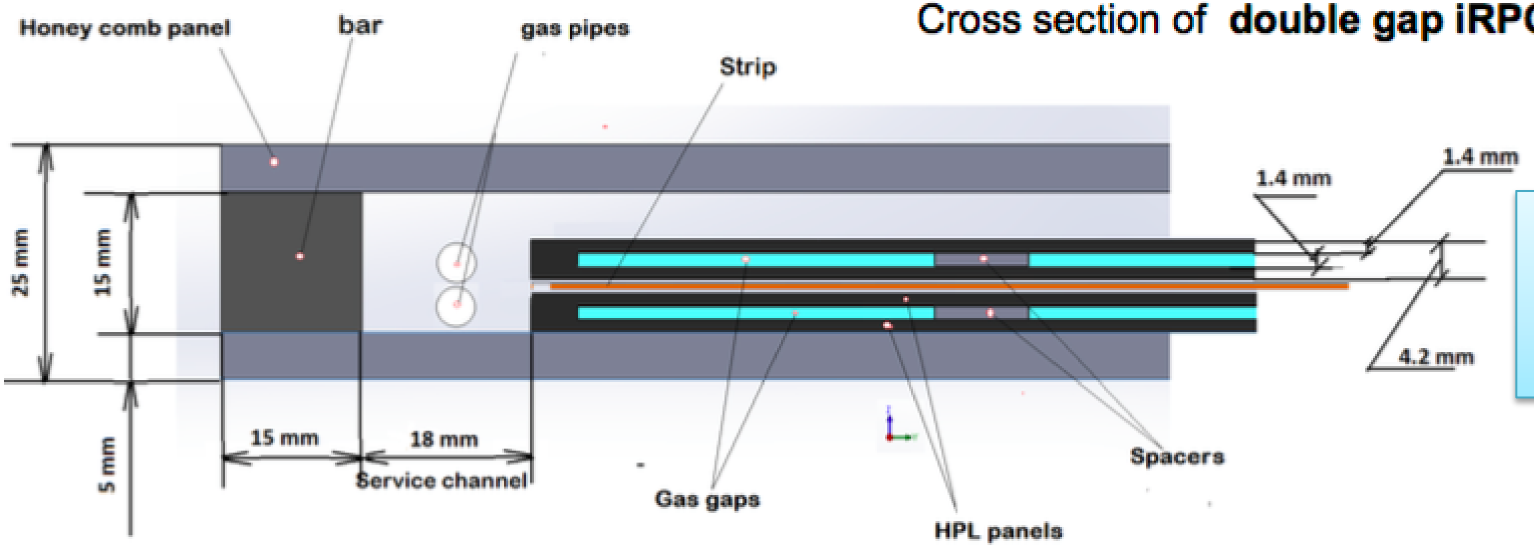
[1] including safety factor 3

iRPC design

During last years, an intense R&D program has been done, and several RPC prototypes have been built using similar technology of the present RPC but having different geometry configurations in order to satisfy the CMS requirements.



Cross section of **double gap iRPC**



iRPC baseline:

- ***gas gaps 1.4mm***
- ***electrodes 1.4mm***

Study of the expected background at HL-LHC in RE3/1 and RE4/1 regions

The goal of this study is to estimate the expected background condition at HL-LHC in the new stations 3/1 and 4/1.

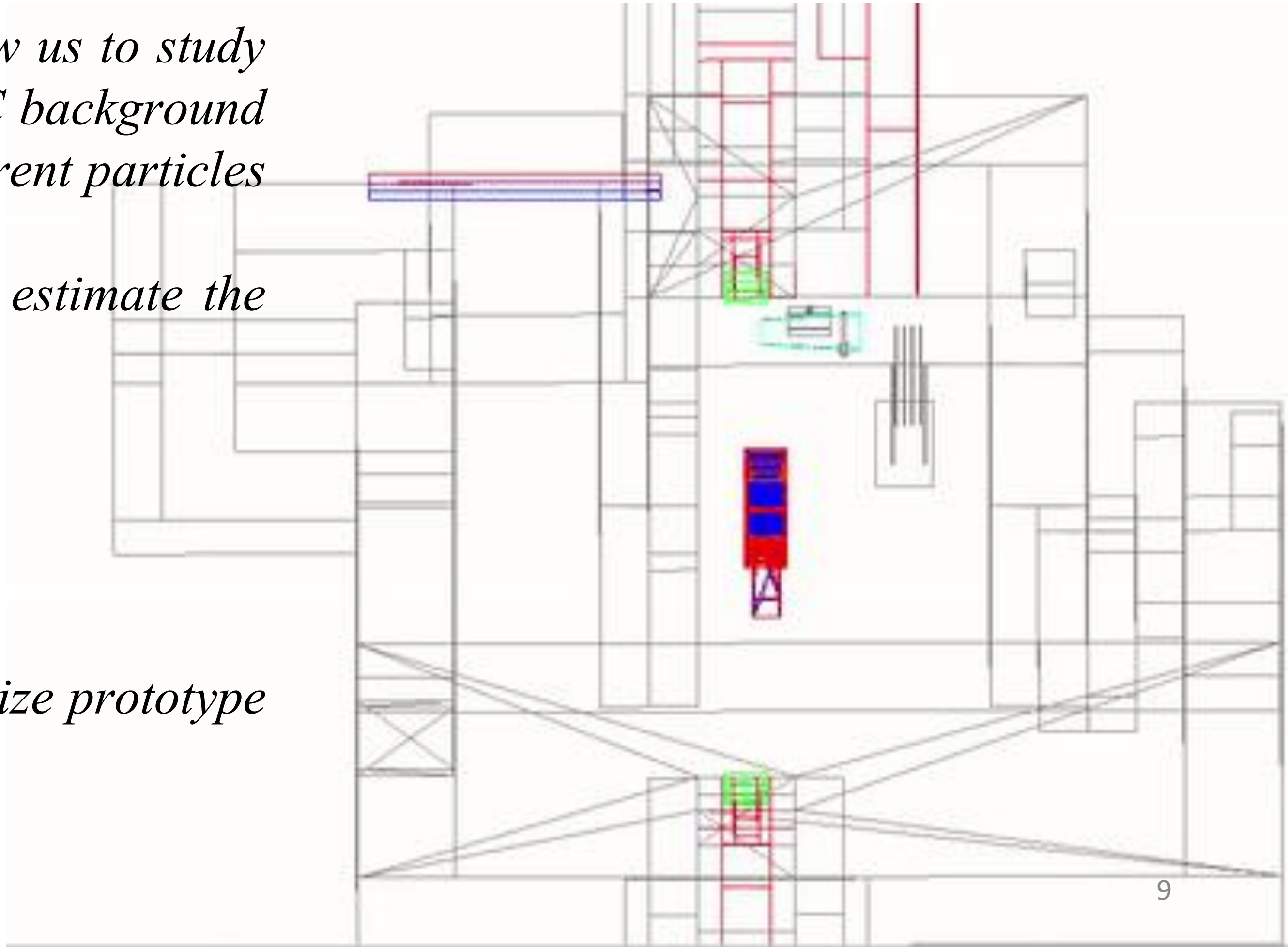
*A Monte Carlo simulation allow us to study the **iRPC sensitivity** at HL-LHC background conditions considering the different particles and energy spectrum.*

This sensitivity will be used to estimate the background hit rate.

$$Hit\ R_{bkg} = Flux(E) \cdot S(E)$$

The sensitivity of the first real size prototype has been studied at GIF++.

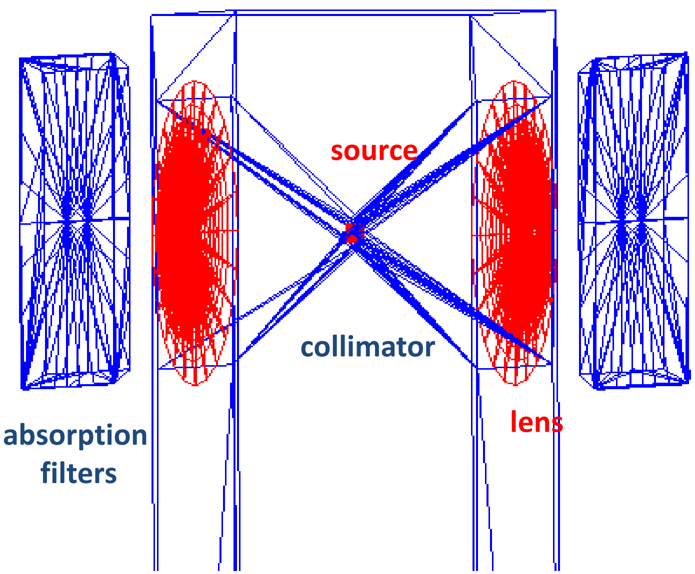
Gamma irradiation Facility (GIF++) Cs-137 source equipped with filters system, 14 TBq

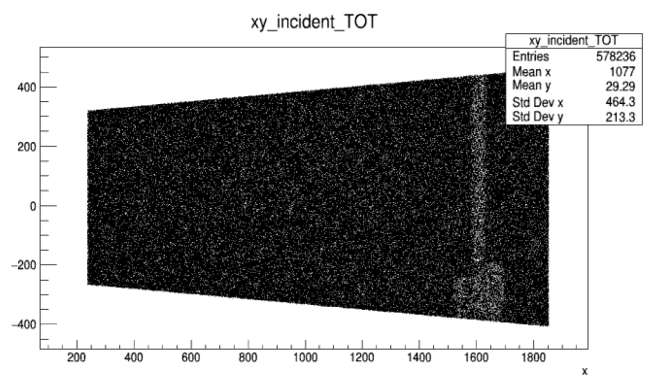


GIF++ source simulation

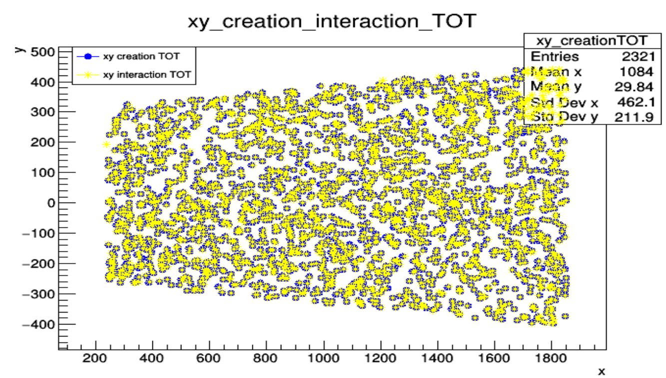
The gamma irradiator source has been described in the simulation including all components: ***source capsule, collimator, lens and filter system****.*
The filter system consist of three convex movable planes, with three filters per plane. The filters positions allow us to change the gamma flux defined by the ***absorption factor (ABS)****.*

The ≤ 37±panoramic collimators and the angular correction lens allow to replace the $1/r^2$ dependence of the photons current by a uniform current in each X-Y plane orthogonal with respect the source.
The simulation confirm the uniform gammas incident distribution on the detector surface is confirmed by the simulation.





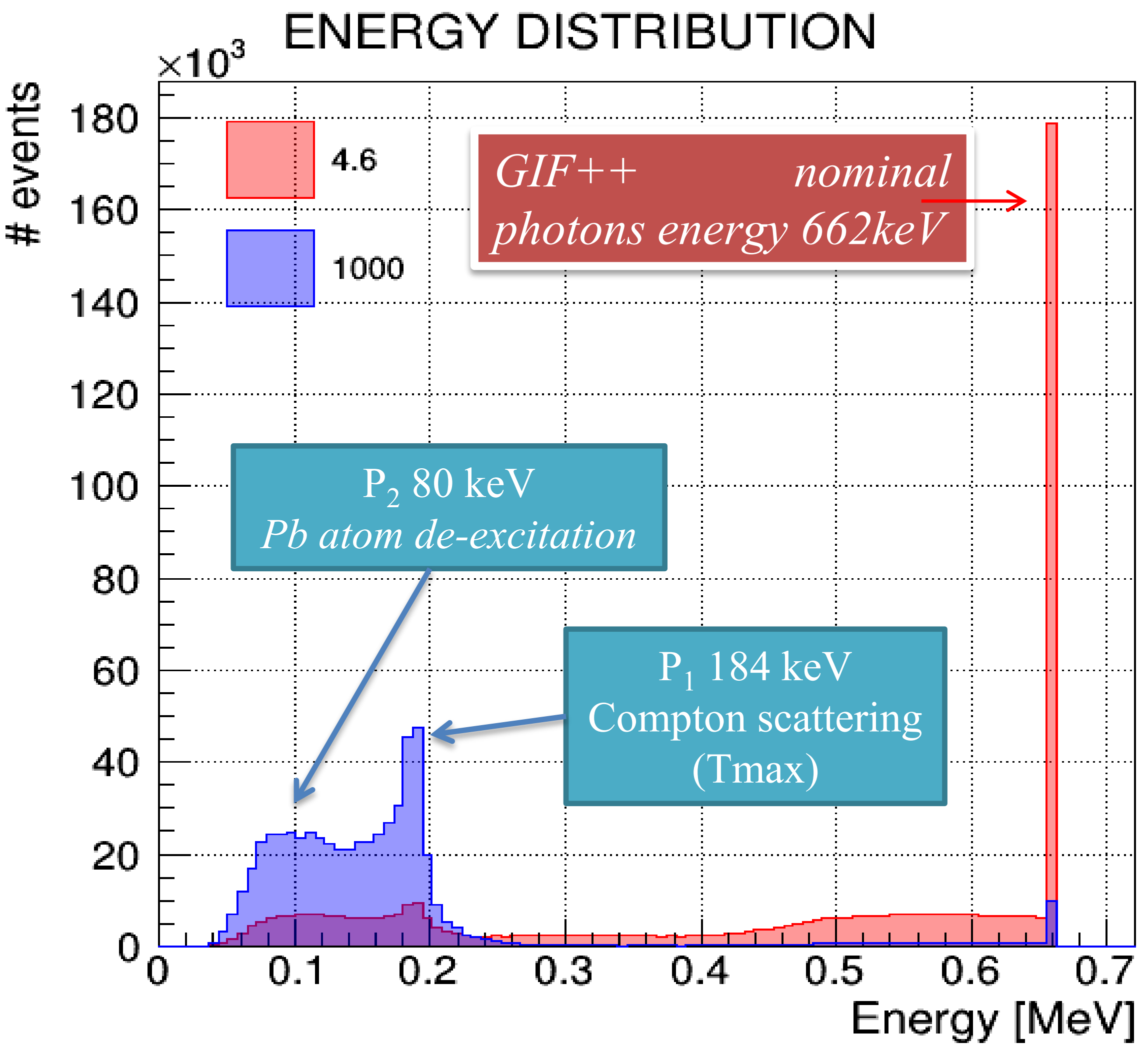
gammas incident distribution



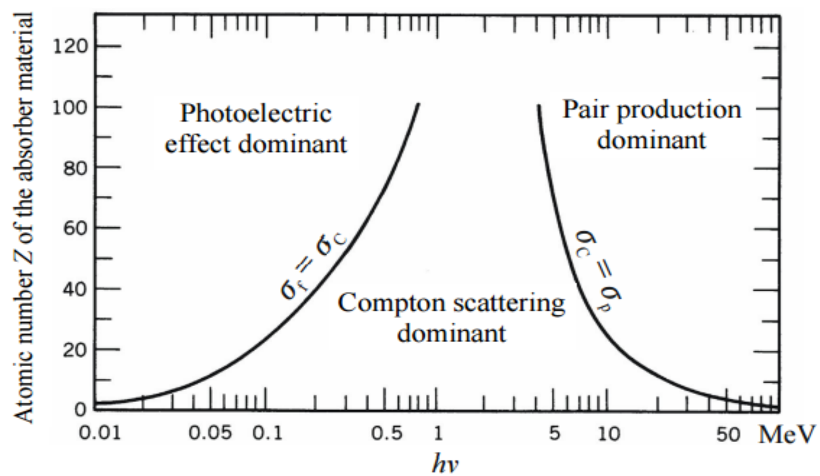
electrons creation and electrons ionization distribution

GIF++ energy distribution

GIF++ photons energy distribution: not monoenergetic!



For γ energies of 662 keV or below, the main processes are Compton scattering and photoelectric Effect.



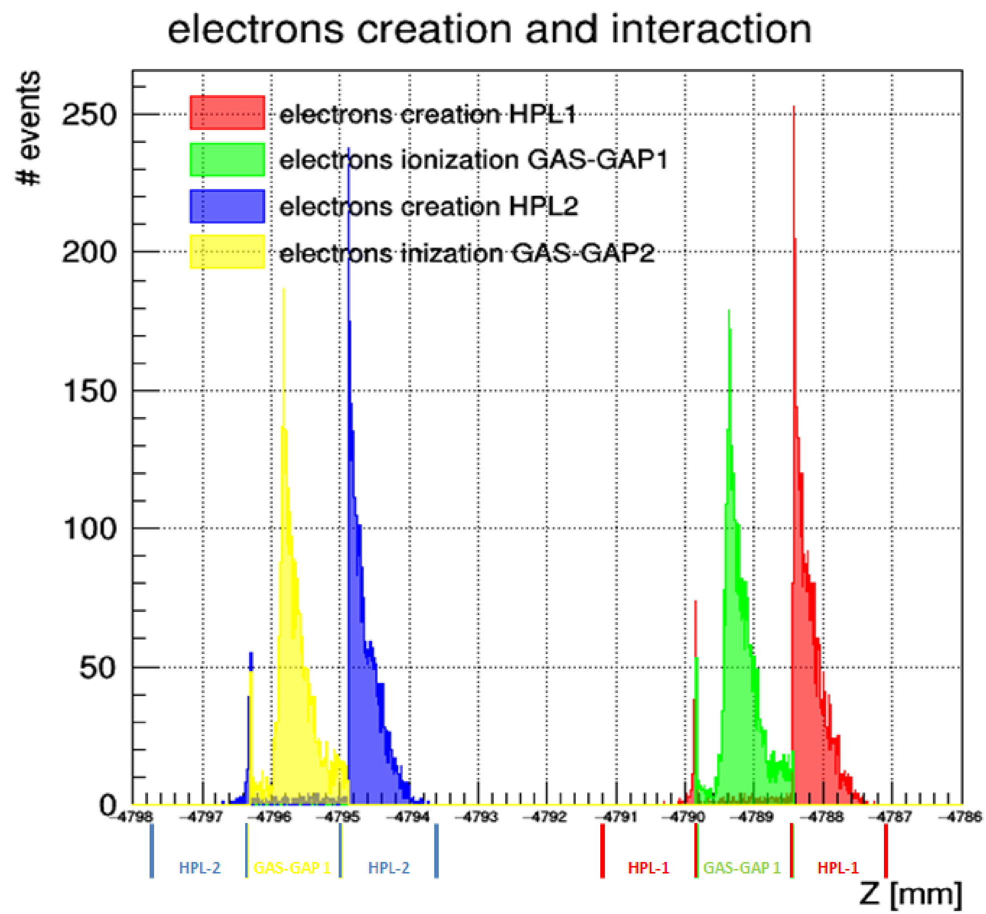
$Z_{Al} = 13$
$Z_{conc} = 11.6$
$Z_{Pb} = 82$

Study of the expected background at HL-LHC in RE3/1 and RE4/1 regions

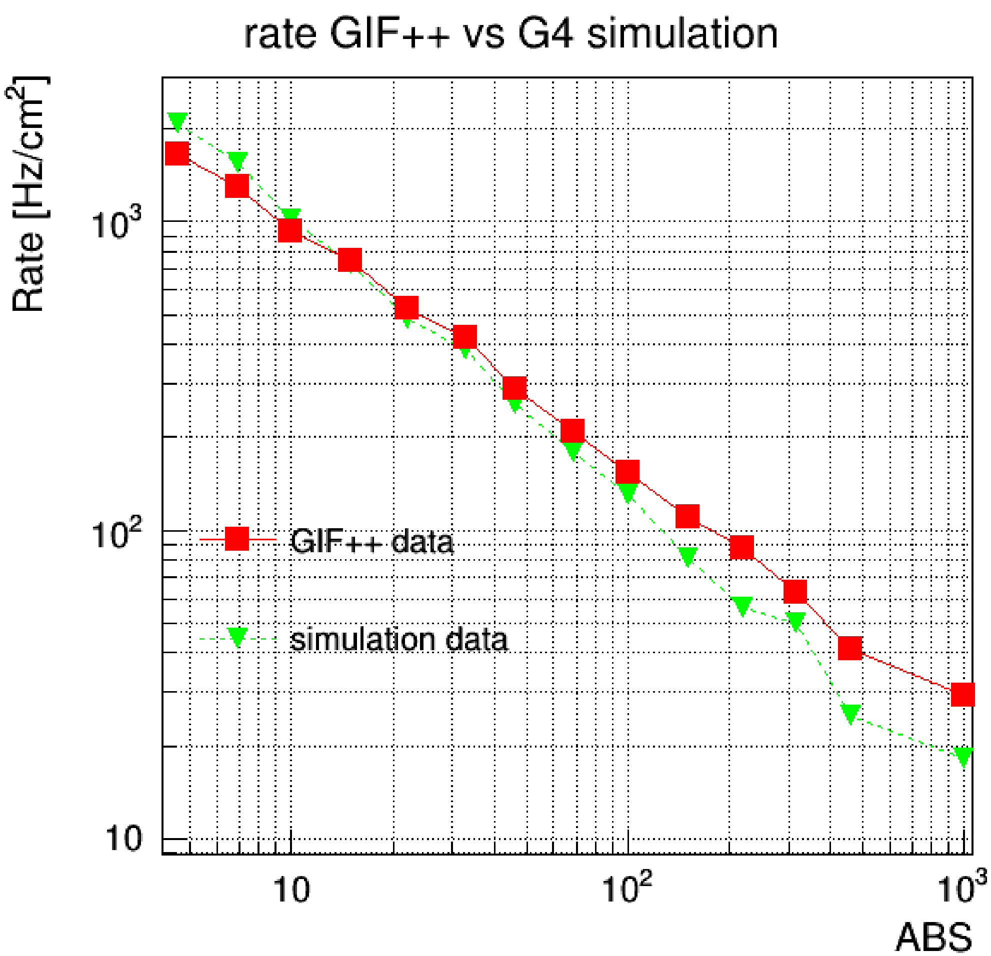
The simulation allowed to study the position where the primary electrons are produced and where they ionize in the gas gaps.
Most of the electrons are produced in the last 200-300 μm of electrode thickness.
For this reason we do not expect a significant difference in the sensitivity of the iRPC with respect the standard CMS-RPC which have 2 mm of electrodes thickness.

Assuming the detector efficiency = 100%
*the **simulated rate** has been defined as:*

$R_{simulated}$ = *N events with an electron that ionizes in one of the two gas gaps or both*



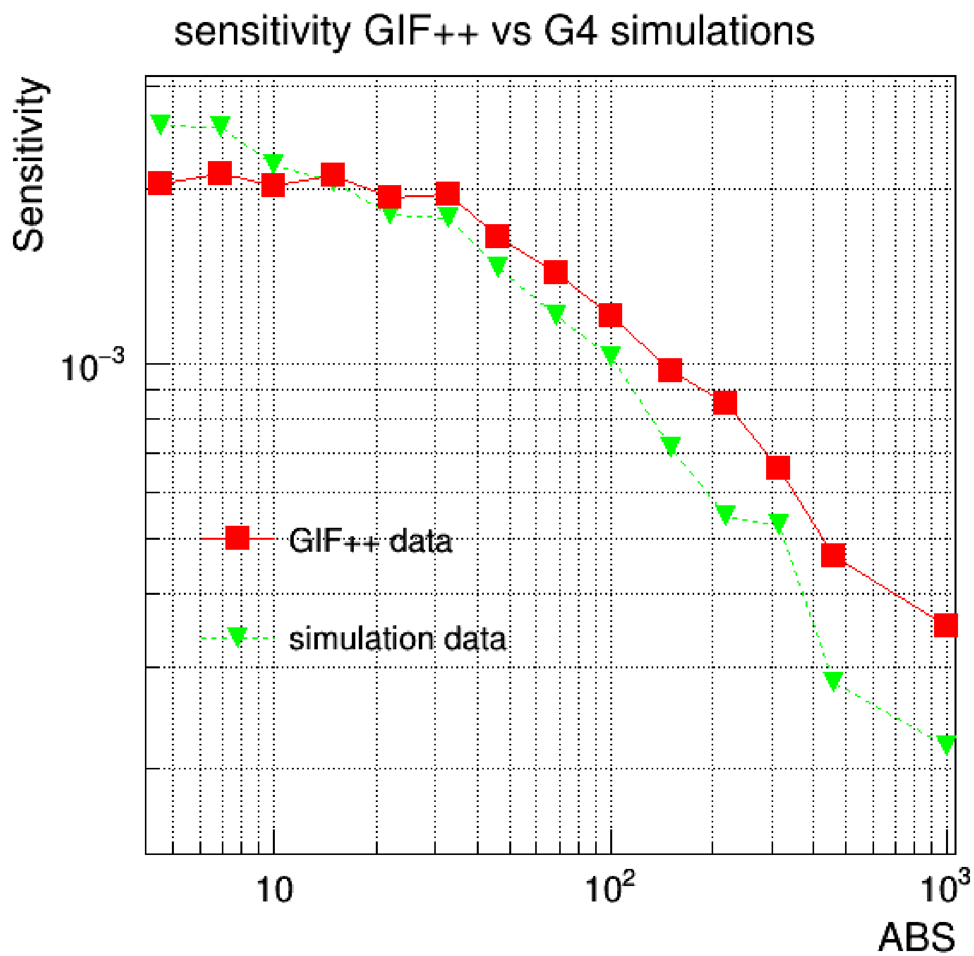
Rate measured and simulated: comparison



On the real size detector, the rate has been measured at different absorption factor (ABS). In order to take into account the cluster size (number of fired strip) and inefficiency (3-4 %) the rate has been corrected as:

$$\boldsymbol{R_{corrected}} = \frac{Hit\ Rate}{Cluster\ size} + Rate_{inefficiency}$$

Sensitivity measured and simulated: comparison



The detector sensitivity measured and simulated have been studied:

$$S_{experimental} = \frac{R_{corrected}}{Background_{simulated}}$$

$$S_{simulated} = \frac{R_{simulated}}{Background_{simulated}}$$

Good agreement between experimental data and simulated data. Maximum difference of factor 1.3 at high ABS.

Activity during next two years

- **Monte Carlo simulation:** the iRPC sensitivity at gammas, neutrons and charged particles with CMS energy spectrum will be performed. This sensitivity will be used to defined the expected background hit rate in CMS at HL-LHC.

- **RPC system longevity study:** the longevity study on spare RPCs will continue in order to validate the system at HL-LHC. Plan to reach the expected integrated charge at HL-LHC in one year.

- **iRPC longevity study:** a new irradiation test will start on the first real size iRPC in order to validate the performance and aging for the entire period running.

- **Ecogas:** the RPC gas mixture is mainly based on C2H2F4 (greenhouse gases). EU regulation in environmental safety policy may lead to banning on the use of GHGs. A test with a new eco-gas will start at GIF++ in order to prove detector performance and confirm longevity.

Conferences, workshops, and seminaries

Conferences:

- ***"Upgrade of the RPC system of the CMS Muon Spectrometer", "SIF2017: 103-esimo congresso nazionale società italiana di fisica", Trento, Italy, September 2017***
- ***"Upgrade of the RPC system of the CMS Muon Spectrometer", "2017 Fall Meeting of the Korean Physical Society", Gyeongju-si, Republic of Korea, October 2017***

Schools:

- ***"XIV Seminar on Software for Nuclear, Subnuclear and Applied Physics"**, Alghero, Italy, June 2017*
- ***"CMS Physics Object School POS"**, Bari, Italy, September 2017, participating as facilitator and giving a lesson about the introduction of "GEANT4" and a short exercise*

Workshops:

- ***"RPC workshop"**, CERN Geneva, Switzerland, November 2016*
- ***"RPC Upgrade workshop"**, CERN Geneva, Switzerland, March 2017*
- ***"Muon phase II Upgrade workshop"**, CERN Geneva, Switzerland, March 2017*
- ***"2nd RPC Upgrade workshop"**, CERN Geneva, Switzerland, May 2017*
- ***"Muon Upgrade workshop"**, CERN Geneva, Switzerland, June 2017*

Seminaries:

- ***"Last results about BSM in the Higgs scalar sector and beyond"**, Bari, Italy, May 2017*
- ***"The big picture of the particle physics"**, Bari, Italy, September 2017*

PhD courses

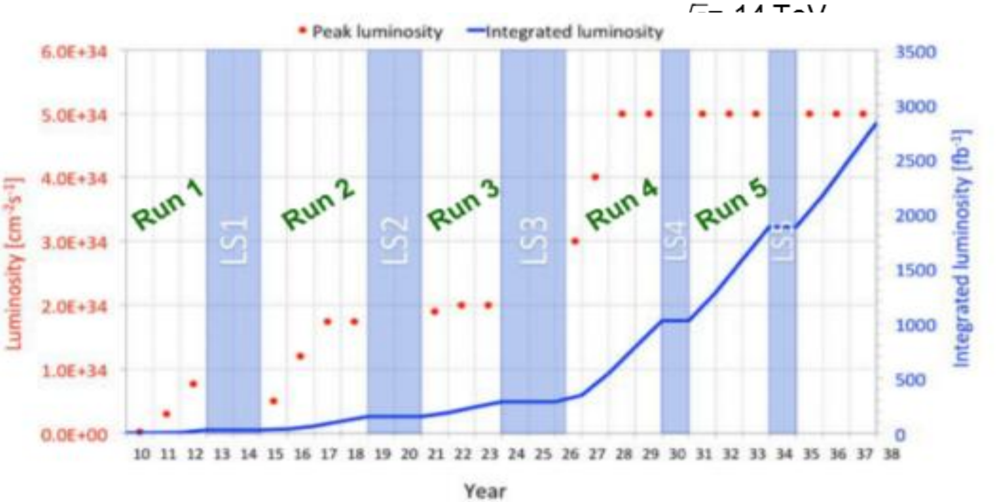
Course	*Credits*	*Status*
LHC phenomenology	*2 CFU*	✓
Gas detectors	*2 CFU*	✓
Interpolation methods and techniques for experimental data analysis	*2 CFU*	✓
LabVIEW introductory course	*2 CFU*	✓
Programming with Python	*2 CFU*	✓
European research model and promotion of research results	*2 CFU*	✓
How to prepare a technical speech in English	*2 CFU*	✓
C++	*2 CFU*	✓

Thanks

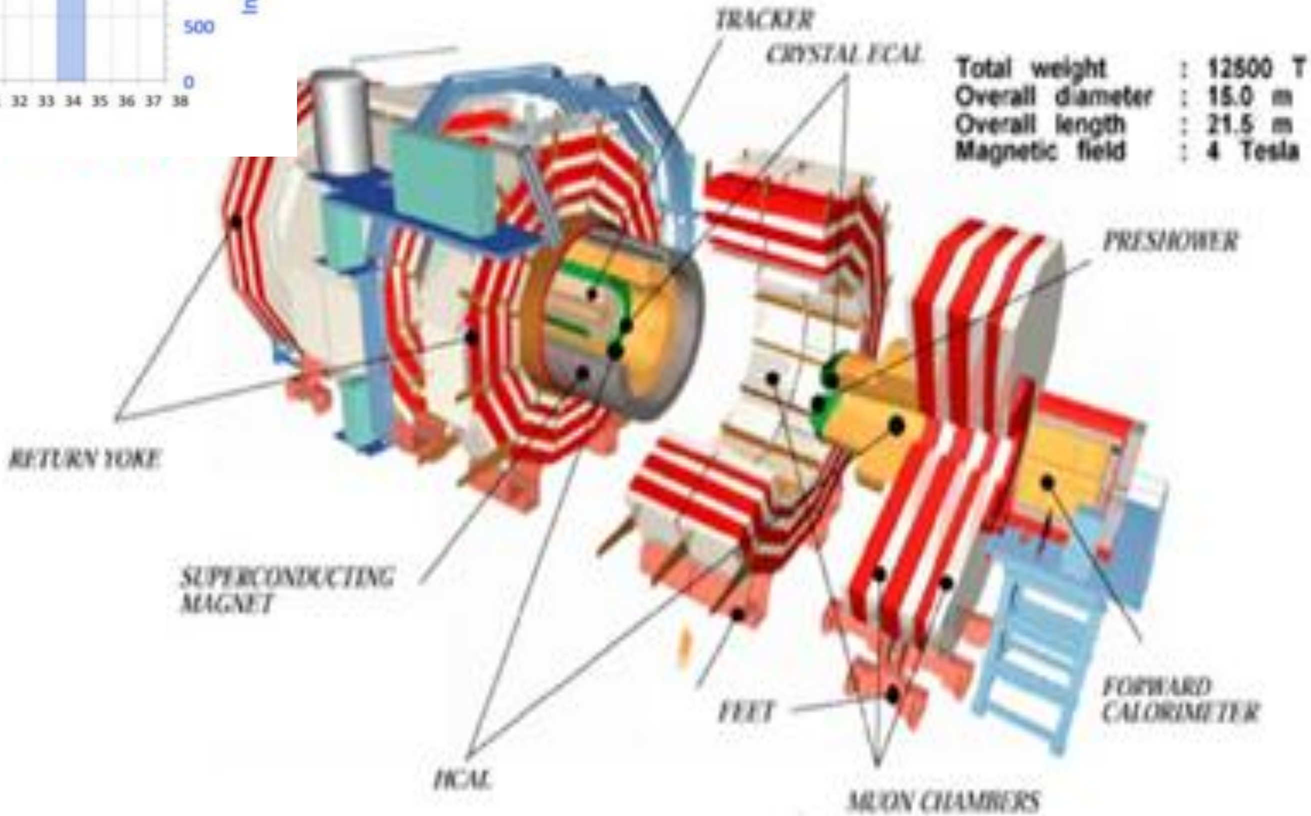
for your attention

Back up

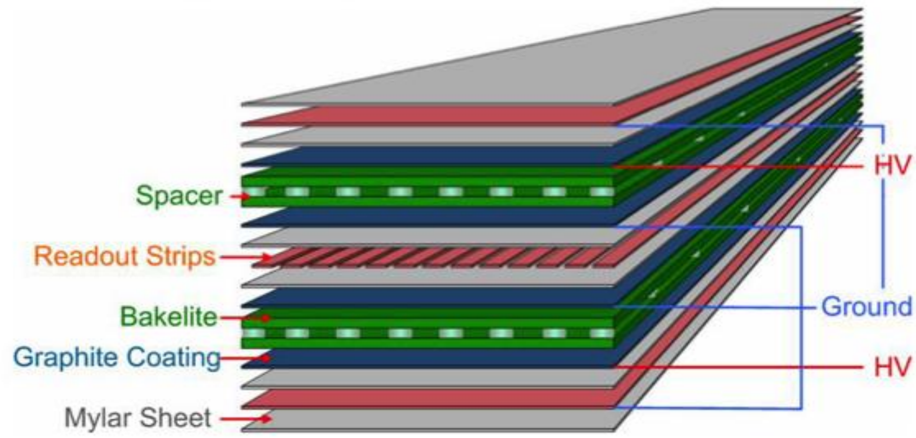
HL-LHC



$$L = \frac{R_{inel}}{\sigma_{inel}}$$



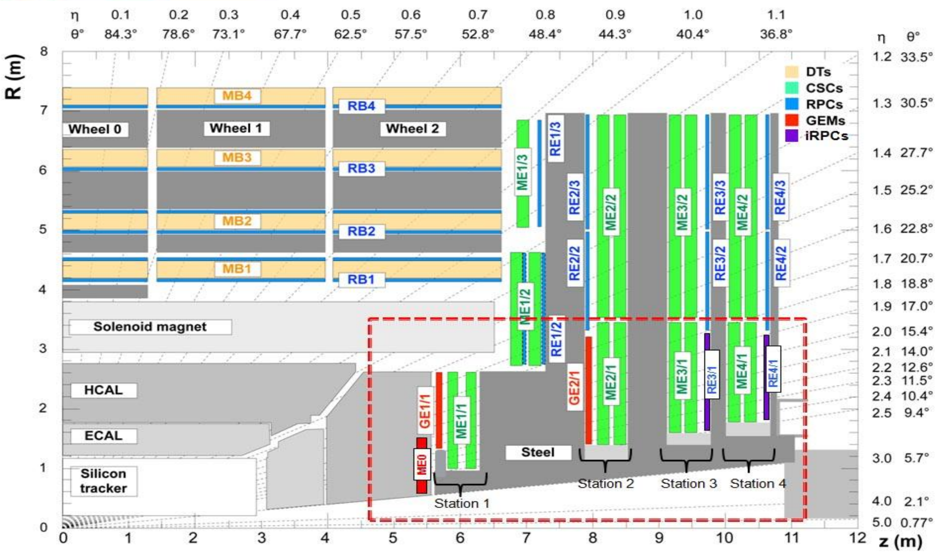
CMS RPC System



- **Covers 0 < |η | < 1.8**
- **1056 chambers** (480 in Barrel and 576 in Endcap)
- 120000 **electronic channels** and 400 m^2 **of active area**
- **Double gaps gas chamber:** 2 mm gas width
- **Electrodes:** High Pressure Laminate
- **HPL** bulk resistivity: $\rho = 1 - 6 \times 10^{10}\ \Omega cm$
- **Humidified Gas mixture:** $C_2H_2F_4$ + isoC_4H_{10} + SF_6 (40% of H)

  95.2% 4.5% 0.3%
- Close loop with 10% -15% of fresh gas
- Operated in **avalanche mode**

1. Consolidation present RPC system



RPC @ LHC

- ***Covers 0 < | η | < 1.8 with 1056 chambers***
- ***Double gap RPC***
- *RPC information used in the Muon Trigger, reconstruction and identification*
- *High and stable RPC performance (efficiency 95 %) with the increasing of luminosity*

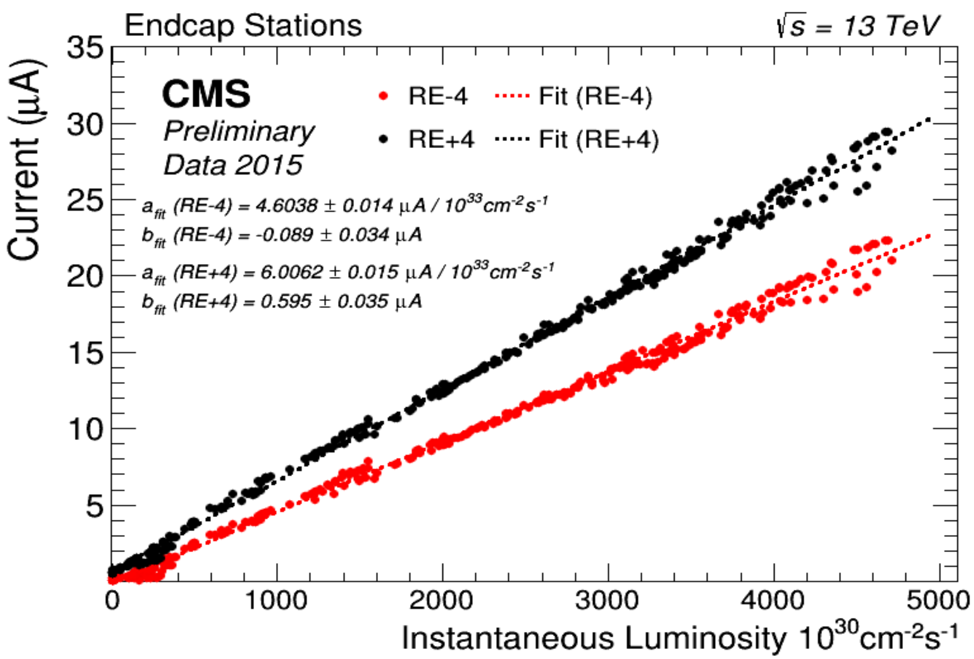
*The RPC system has been certified for 10 years of LHC (at nominal luminosity of 10^{34} cm^{2}s) to maximum rate of **300 Hz/cm^2** and 0.05 C/cm^2*

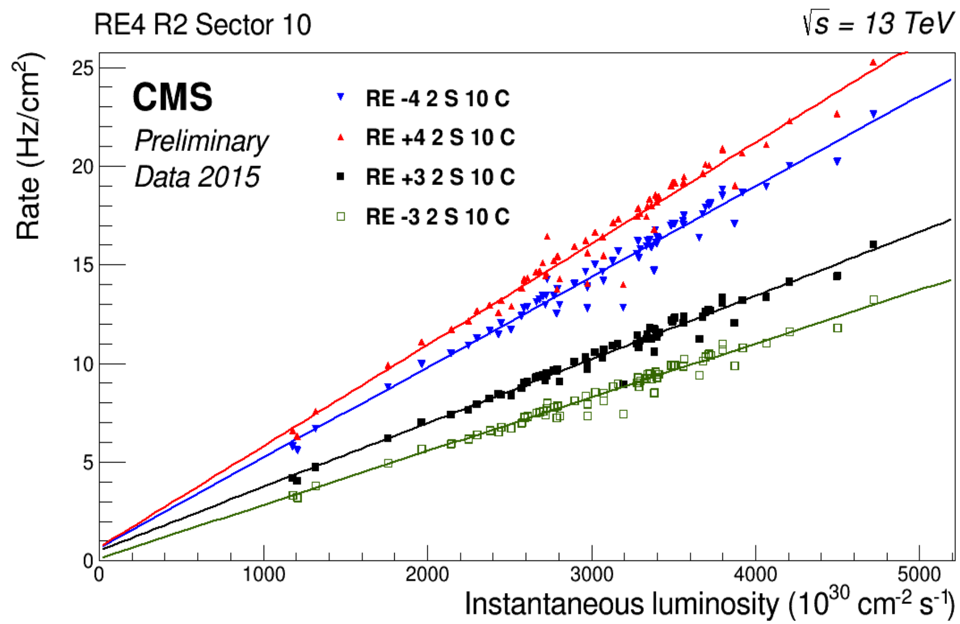
By the end of LS3 the RPCs will be 20 years old and be required to operate beyond the design specification

To maintain high and stable muon performance through ***HL-LHC:***

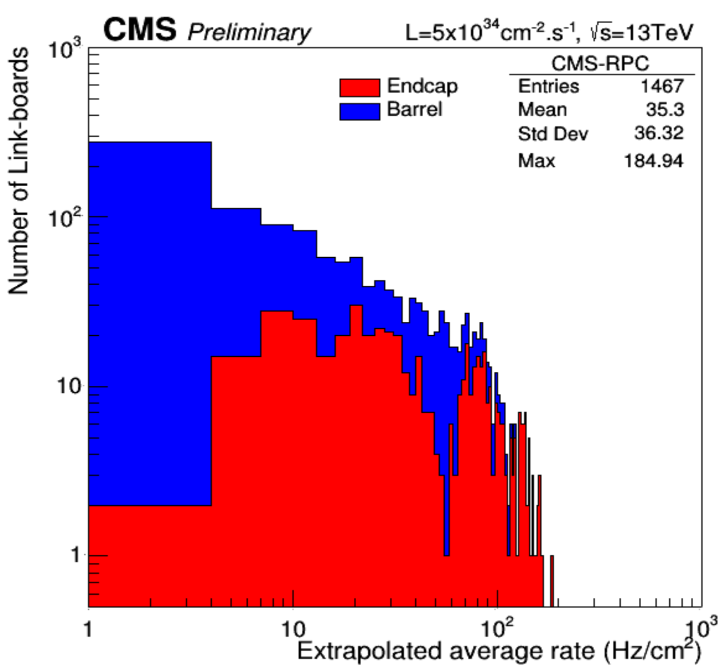
- *LONGEVITY STUDIES: The detector is expected to maintain excellent performance up to 3 times the expected HL-LHC conditions (integrated charge and rates).*

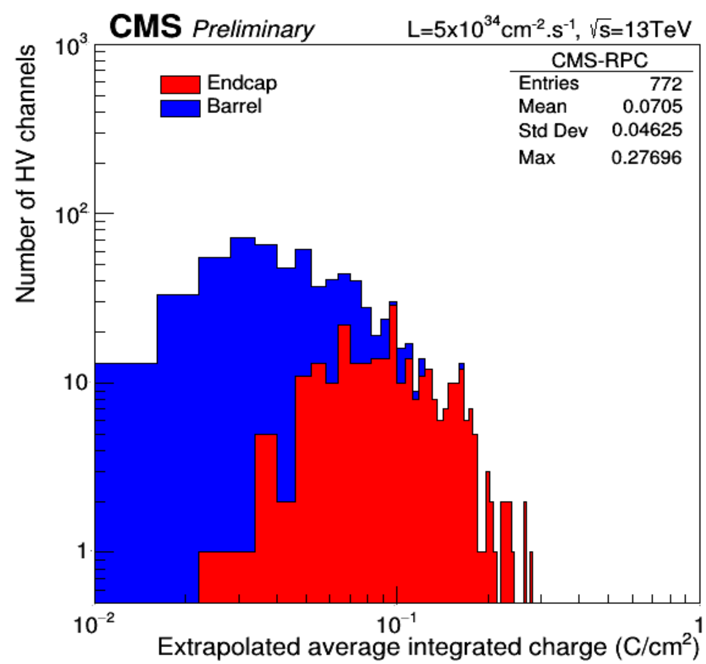
Current and rate vs Luminosity

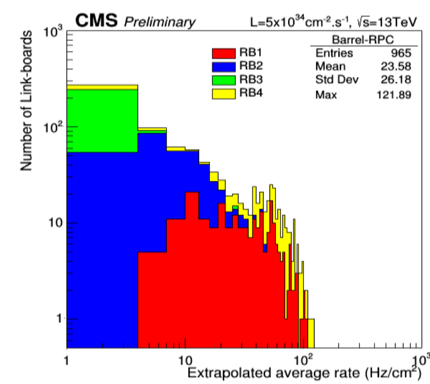


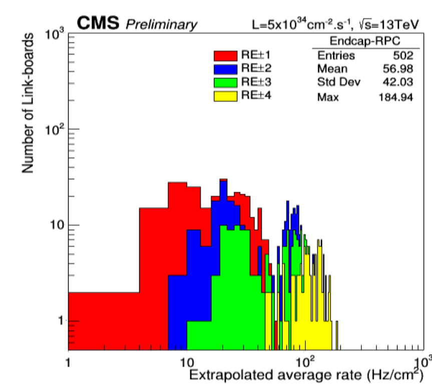


Expected conditions at HL LHC
Background rates and Integrated charge





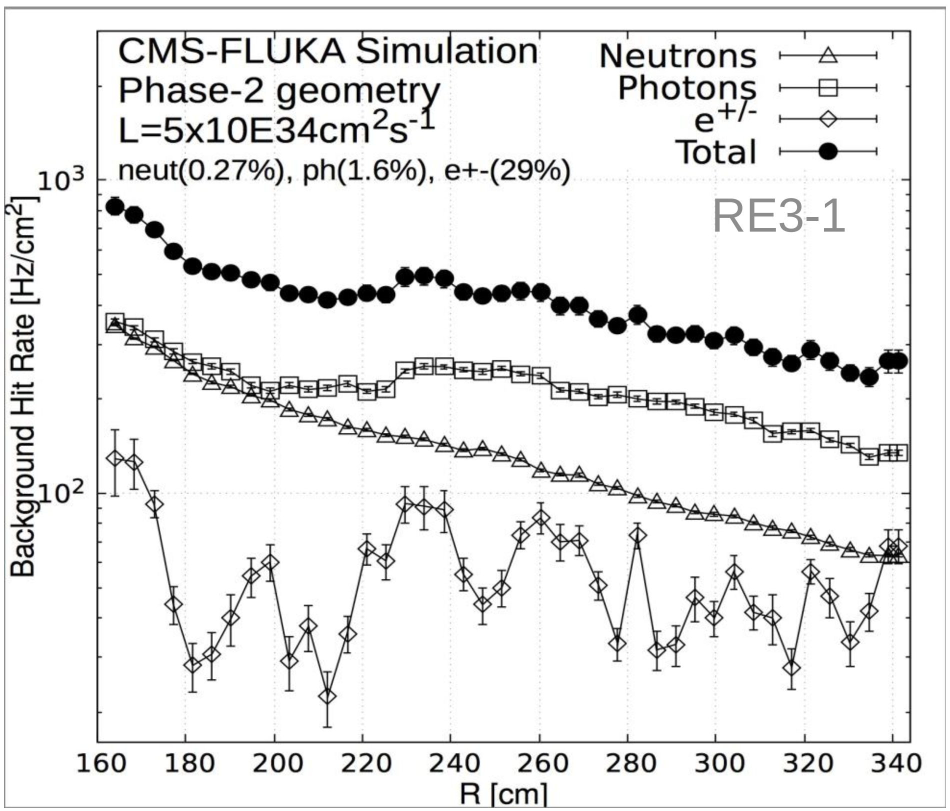


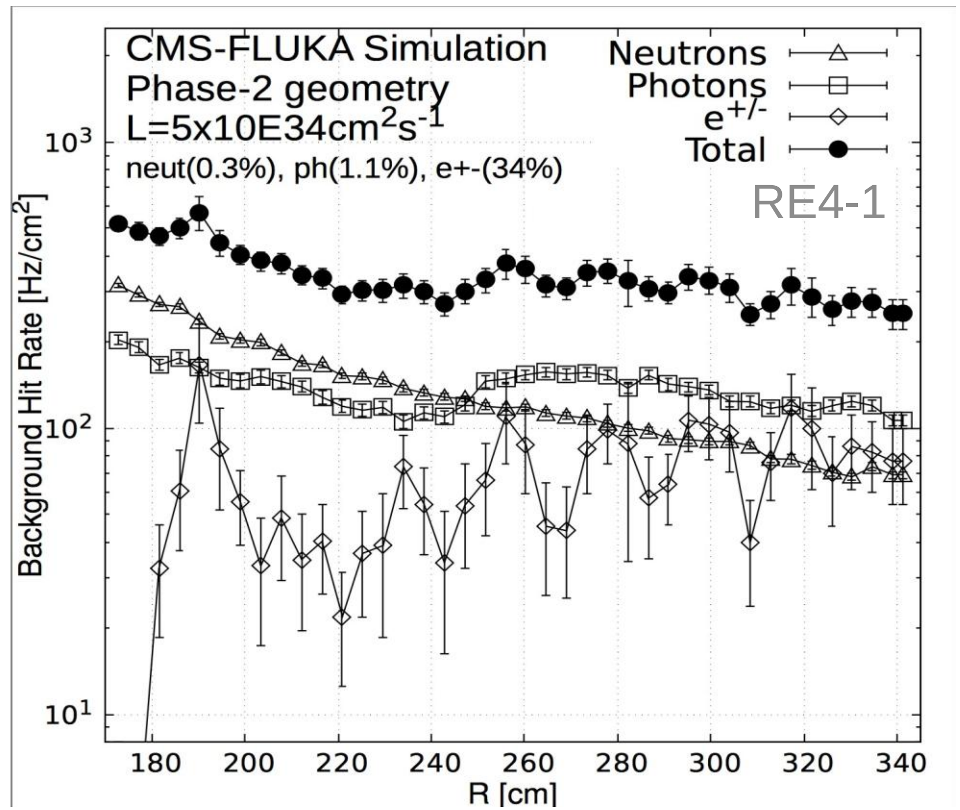


Expected conditions at HL LHC in the forward region

Expected background flux in the RPC forward region at HL-LHC has been simulated

The average expected values:
*RE3/1 – **550 Hz/cm2**;*
*RE4/1 – **430 Hz/cm2***

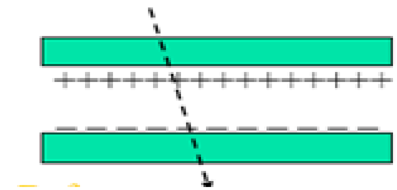




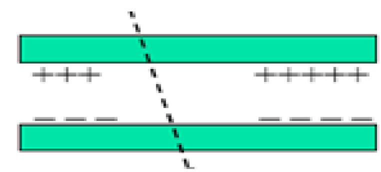
iRPC design

❑ ***Present CMS RPC chambers certified up to 300Hz/cm^2****, irradiated with photons up to an integrated charge of 0.05 C/cm^2 : not suitable for the high forward region.*

❑ ***Rate capability of the RPC is related to the voltage drop in the resistive plate:*** $\Delta V = I\,R = \rho\, d\, q\, \Phi$



Before



After

➢ ***Increase rate capability by reducing***

- *electrode resistivity* ρ*: as low as the RPC principle still stands (> ~10^8-10^9 Ωcm)*
- *electrode thickness* ***d****: depends on electrode material* → *possible with both glass and HPL*
- *produced charge* ***q*** *(+ increasing FE electronics sensitivity): depends on gas mixture, number of gaps, and thickness of gaps* → *beneficial also for chamber aging*

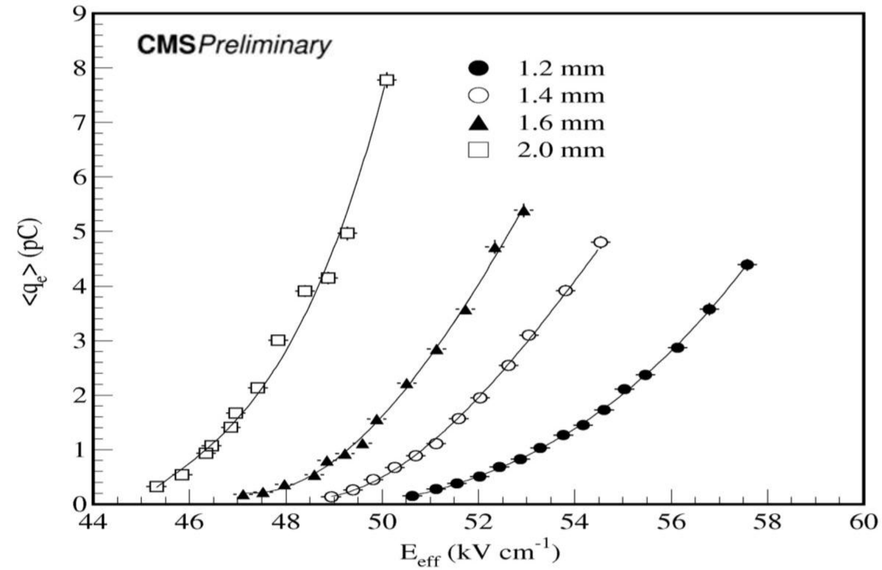
iRPC design

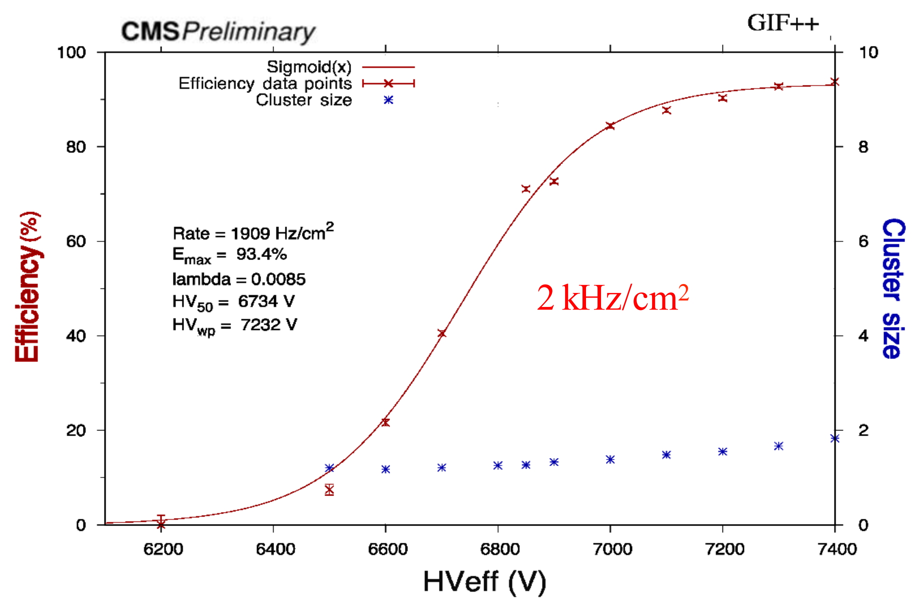
	RPC	iRPC
Gas Gap	2 mm	**1.4 mm**
High Pressure Laminate	2 mm	**1.4 mm**
Resistivity (Ωcm)	1 - 6 x 10^{10}	**0.9 - 3 x 10^{10}**
Strip pitch	2-4 cm	**0.7-1.2 cm**
Electronics Threshold	150 fC	**10 fC**
Chamber dimension	10 degrees	**20 degrees**

*The **thinner gap thicknesses**:*

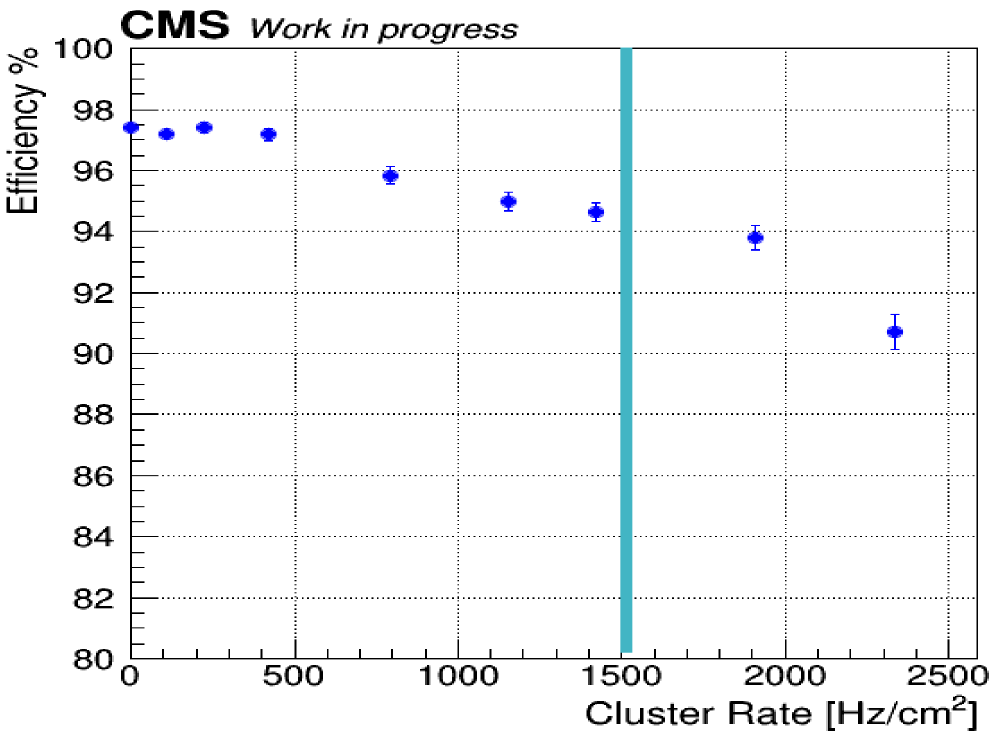
- *retard the fast growth of the pickup charges*
- *reduce aging effects*
- *reduction of the high improving the robustness of the system*

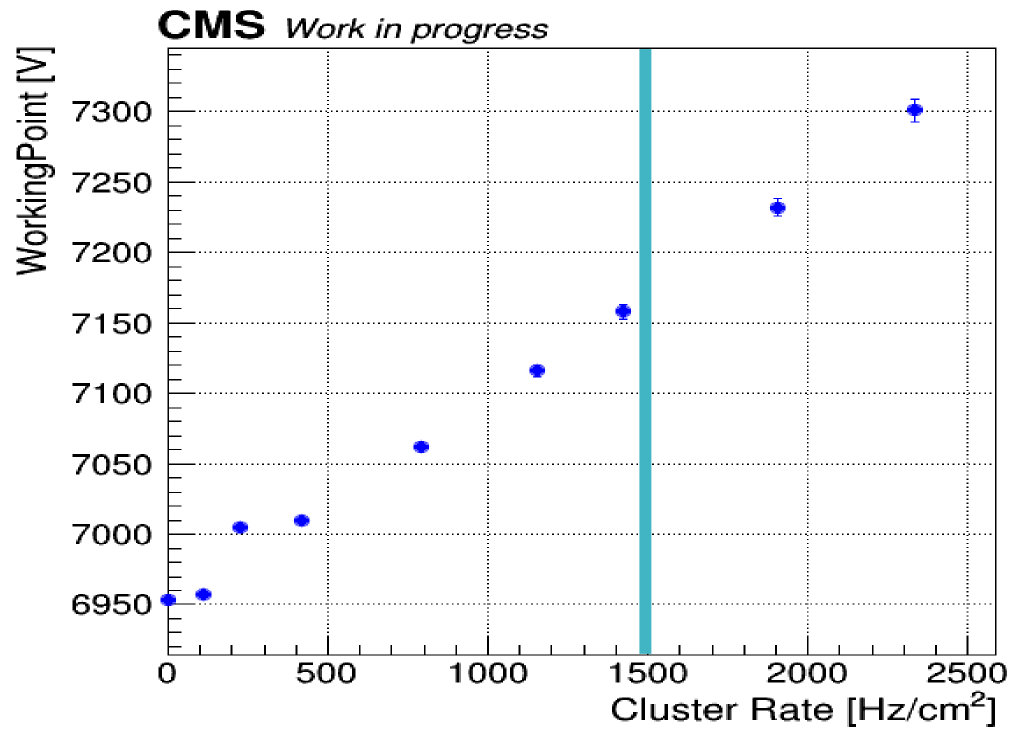
Large-size chamber iRPC 1.4 mm has been tested at Gamma irradiation Facility (GIF++)** at several gamma rate values. Achieved rate capability with more than 94% of efficiency at **2 kHz/cm²





Large-size chamber iRPC 1.4 mm





- *At a background rate of 1.5 kHz/cm^2 the RPC efficiency drop of about 3%;*
- *The shift of the **WP** between no background and at 1.5 kHz/cm^2 is ~200 V (3% in ΔV/V).*

Layer n°	Material	Density [g/cm³]	Thickness [mm]
1	Aluminium	2.69	0.500
2	Aluminium core	0.5	5
3	Aluminium	2.69	0.500
4	C10H8O4 PET	1.37	0.188
1	C6H10O5 cellulose	0.3	1
6	Copper	8.96	0.380
7	C10H8O4 PET	1.37	0.188
8	C10H8O4 PET	1.37	0.188
9	EVA (10%etylene + 90%vinyl acetate)	0.934	0.150
10	Graphite	1.7	0.001
11	HPL	1.4	1.350
12	RPC gas	3.569	1.400
13	HPL	1.4	1.350
14	Graphite	1.7	0.001
15	EVA (10%etylene + 90%vinyl acetate)	0.934	0.150
16	C10H8O4 PET	1.37	0.188
17	C10H8O4 PET	1.37	0.188
18	Copper	8.96	0.380

Honey comb (layers 1–3)

GAP 1 (layers 6–18)

Layer n°	Material	Density [g/cm^3]	Thickness [mm]	
19	C10H8O4 PET	1.37	0.200	strip
20	Copper	8.96	0.170	strip
21	C10H8O4 PET	1.37	0.200	strip
22	Copper	8.96	0.380	GAP 2
23	C10H8O4 PET	1.37	0.188	GAP 2
24	C10H8O4 PET	1.37	0.188	GAP 2
25	EVA (10%etylene + 90%vinyl acetate)	0.934	0.150	GAP 2
26	Graphite	1.7	0.001	GAP 2
27	HPL	1.4	1.350	GAP 2
28	RPC gas	3.569	1.400	GAP 2
29	HPL	1.4	1.350	GAP 2
30	Graphite	1.7	0.001	GAP 2
31	EVA (10%etylene + 90%vinyl acetate)	0.934	0.150	GAP 2
32	C10H8O4 PET	1.37	0.188	GAP 2
33	C10H8O4 PET	1.37	0.188	GAP 2
34	Copper	8.96	0.380	GAP 2

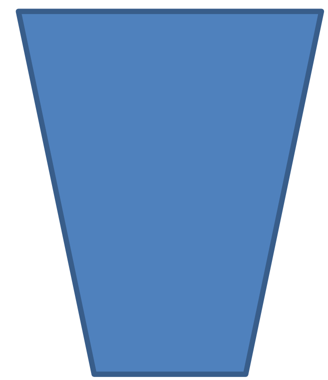
Layer n°	Material	Density [g/cm^3]	Thickness [mm]
35	$C_{10}H_8O_4$ PET	1.37	0.188
36	Bakelite	1.25	2
37	Aluminium	2.69	0.500
38	Aluminium core	0.5	5
39	Aluminium	2.69	0.500

Honey comb (layers 37–39)

TOTAL LAYERS THICKNESS	27.774

TRAPEZOIDAL AREA :

Height = 1613.0 mm
majorBase = 584.1 mm
minorBase = 866.3 mm



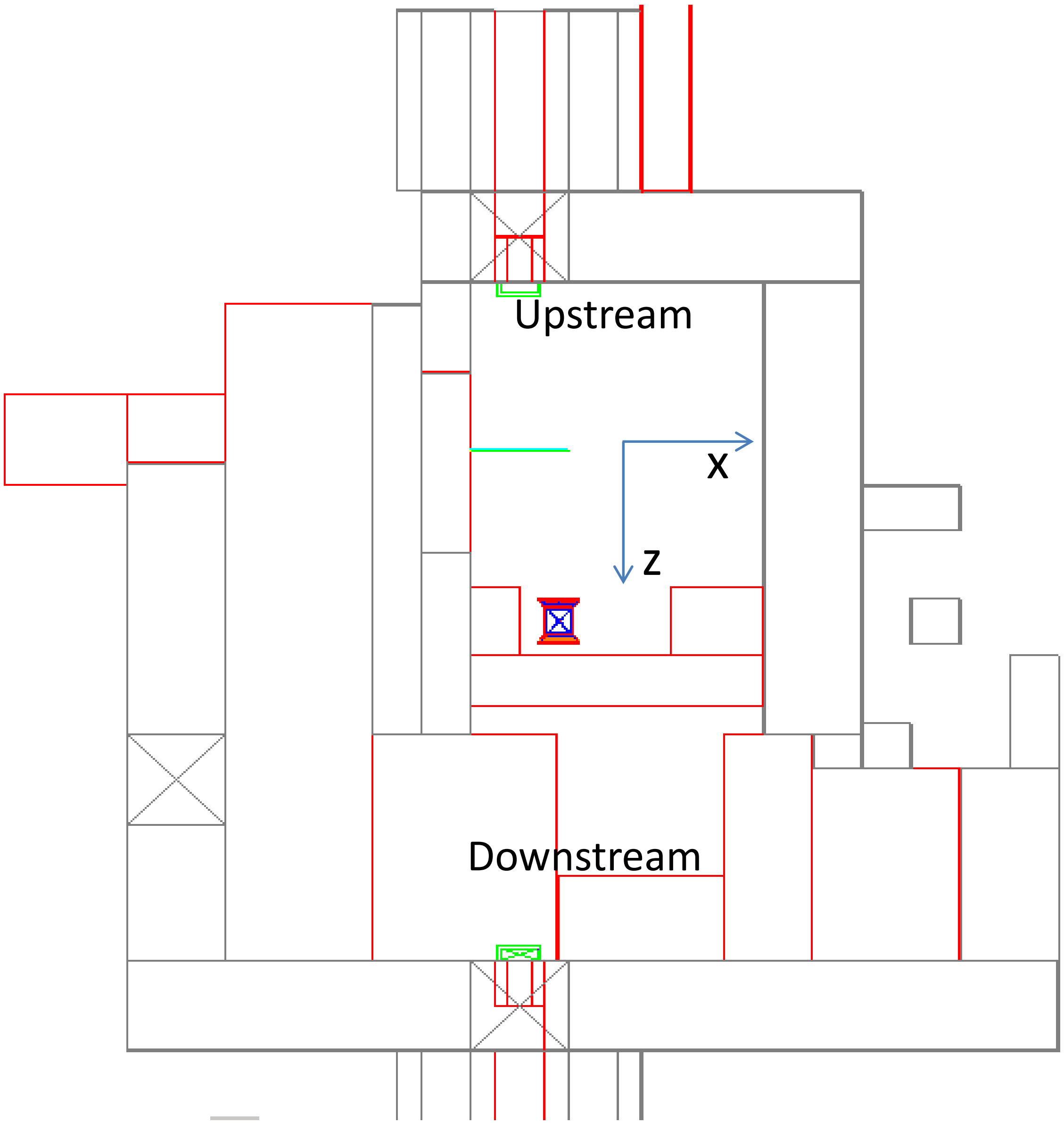
APPROXIMATIONS:

- Same area for all layers
- Electronics not included

KODEL DG 1.4 1.4 in GIF++

No others stup in between the source and the detector.

KODEL DG 1.4 1.4 in GIF++



iRPC

Distance to the source	Z = -4779 mm
Distance to the Saleve wall	X = 1845 mm
High from the floor	h = 1617 mm

Simulated Rate normalization

Number of simulated events: **8*10⁸** → 1 day

To compare the simulated rate with the measured rate, they must be normalized :

Rate simulated * $\left(\frac{real\ events}{simulated\ events}\right)$

Actual source Cs^{137} activity:

$A_0 = 14\,TBq$ (spring 2015)

2 years T= $6.0372 \cdot 10^7$

Cs^{137} half life ⇒ $\tau_{1/2} = 30.19\,years = 9.52 \cdot 10^8 s$

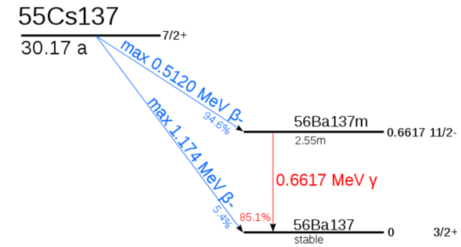
$\tau_{1/2} = 1/\lambda \Rightarrow \lambda = 1/\tau_{1/2} = 1/9.52 \cdot 10^8 = 1.054 * 10^{-9}$

$\boldsymbol{A_{2y} = A_0 \cdot e^{-\lambda T}}$

$$A_{2y} = A_0 \cdot e^{-\lambda T} = 14 \cdot 10^{12} \cdot e^{-1.054*10^{-9} \cdot 6.037 \cdot 10^7}$$
$$= 13.09 * 10^{12} = \mathbf{13.09\,TBq}$$

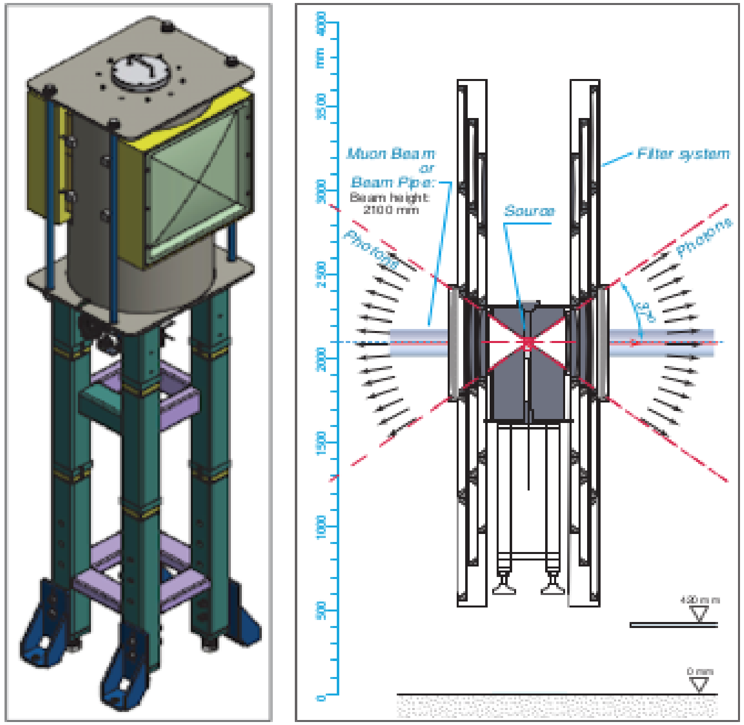
A_{2y}/N simulated = 16250

Rate scans at GIF++



ID scan	ABS upstream
2363	4.6
2361	6.9
2360	10
2364	15
2359	22
2370	33
2356	46
2374	69
2358	100
2371	150
2357	220
2372	316
2362	460
2365	1000

Source Cs^{137}
Nominal energy gammas = 662 keV



(a) Irradiator with angular correction filters

(b) Irradiator with filter system

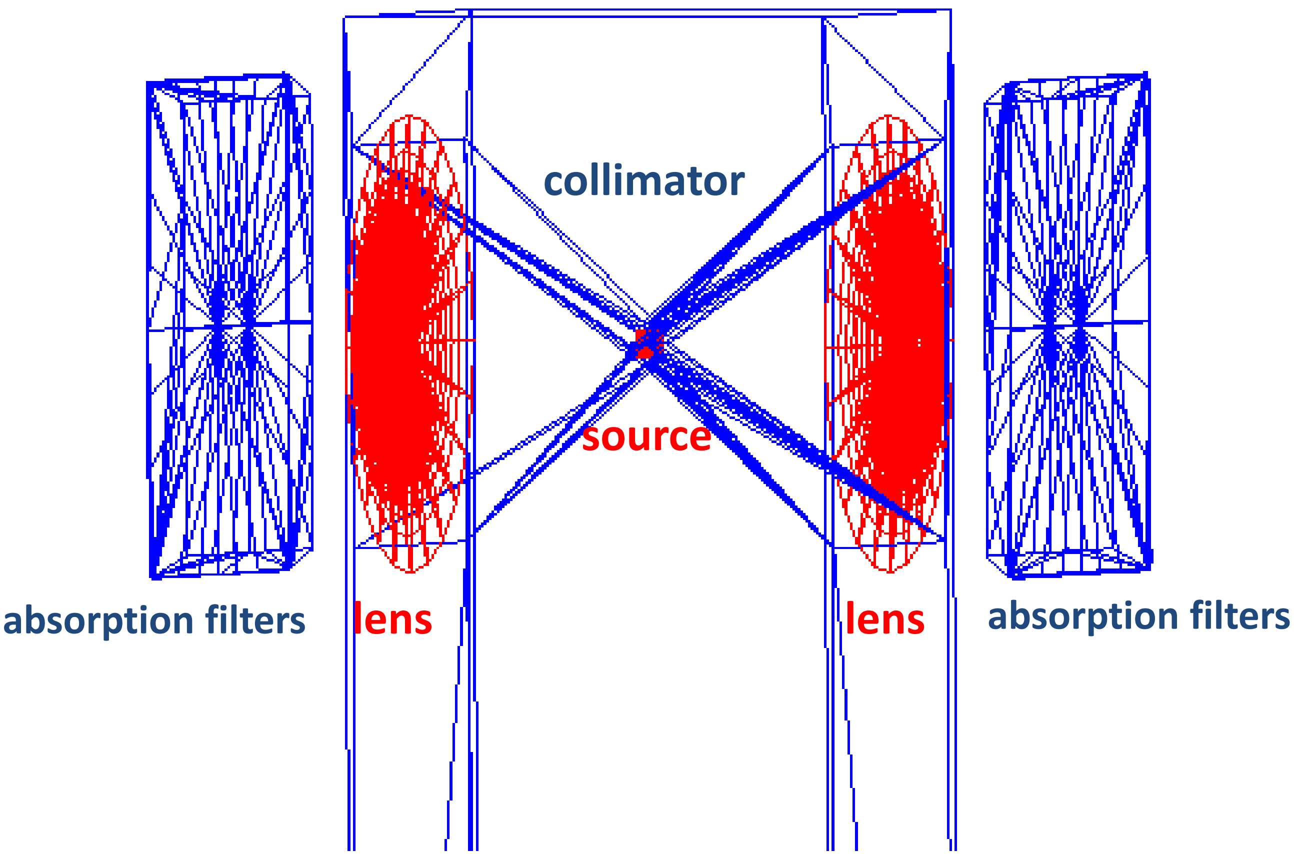
Filter	Material	ABS
A1	Empty	1
A2	Pb	10
A3	Pb	100
B1	Empty	1
B2	Al	1.5
B3	Pb	100
C1	Empty	1
C2	Pb	2.2
C3	Pb	4.6

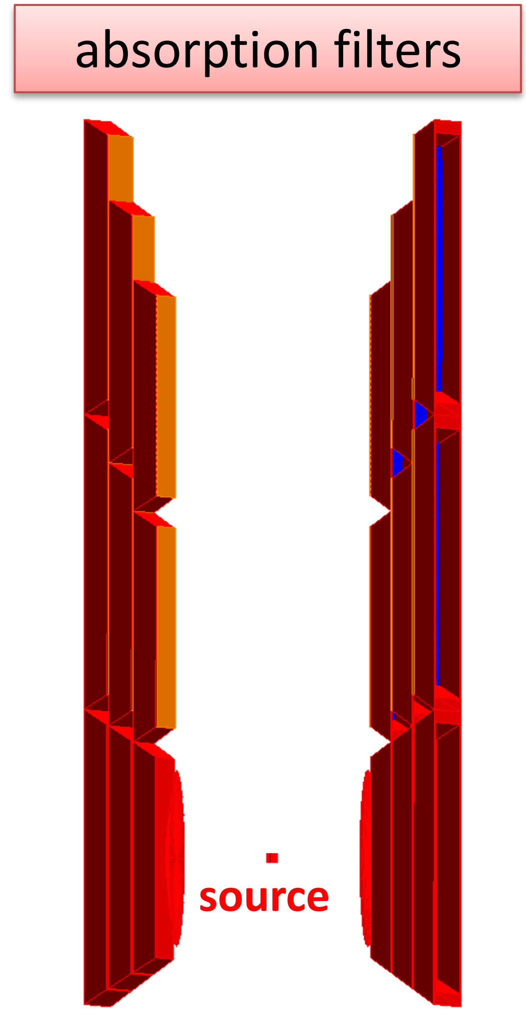
Aluminium support

T = 21 °C P = 965 mbar RH = 40 % Thr = 330 mV = 50 fC gax-mixture = CMS

GIF++ photons energy spectrum

The gammas interact with the materials present in the GIF++:
lead (absorbtion filters, collimators, lense),
steel (absorbtion filters frame, source capsule, floor),
aluminium (absorbtion filters),
concrete (surrounding bunker enclosure).

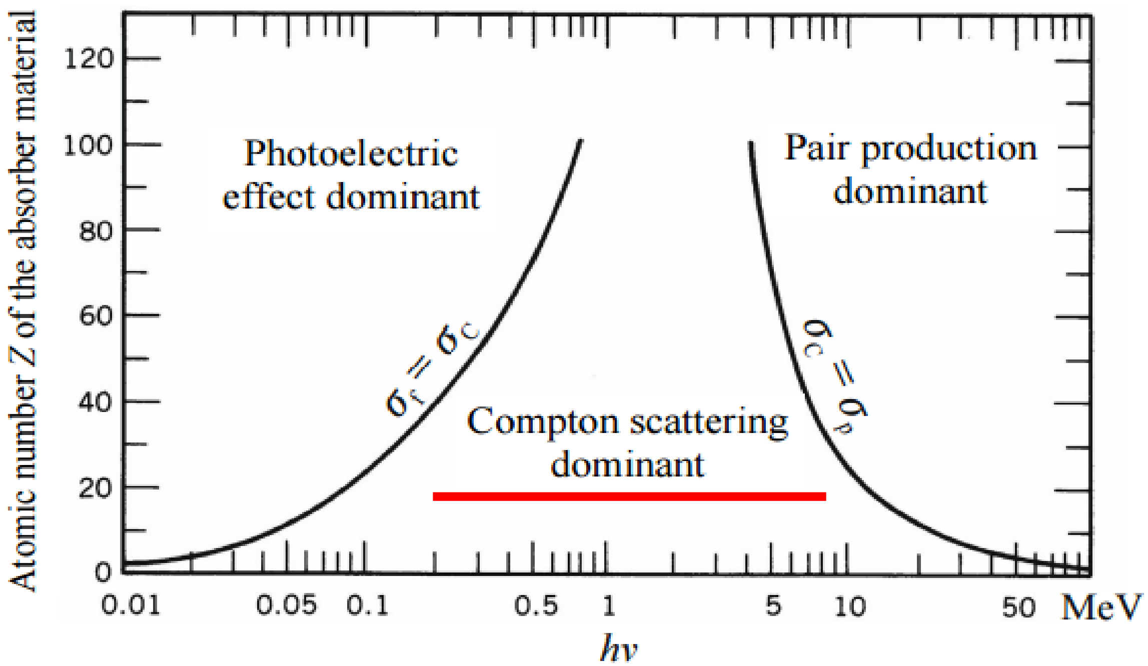




GIF++ photons energy spectrum

For energies of 662 keV or below, the main processes are Compton scattering and photoelectric Effect.

$Z_{Al} = 13$
$Z_{conc} = 11.6$
$Z_{Pb} = 82$

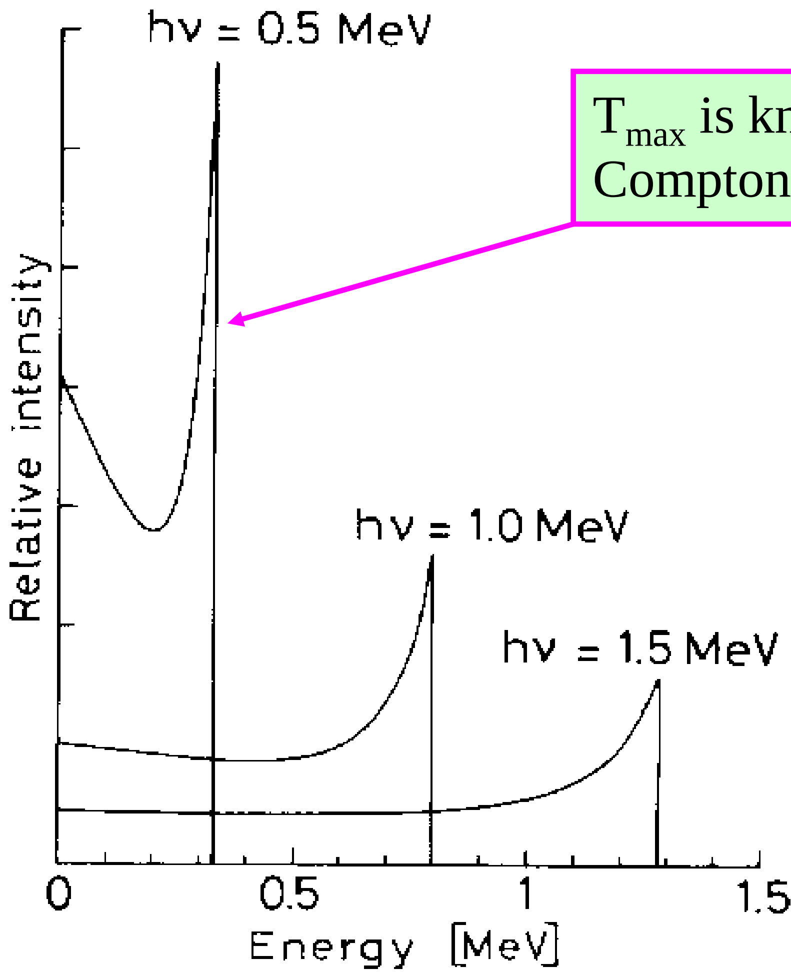


The photons arrive already at the attenuation filters with low energy component, the source capsule and the irradiator collimator already cause an amount of scattering that broadens the spectrum.

GIF++ photons energy spectrum

Why the photons pick (p1) at ~ 200 keV ?

Kinetic energy distribution of Compton scattered electrons



T_{max} is known as the Compton Edge

$$\gamma \equiv E_{\gamma,in} / m_e c^2$$

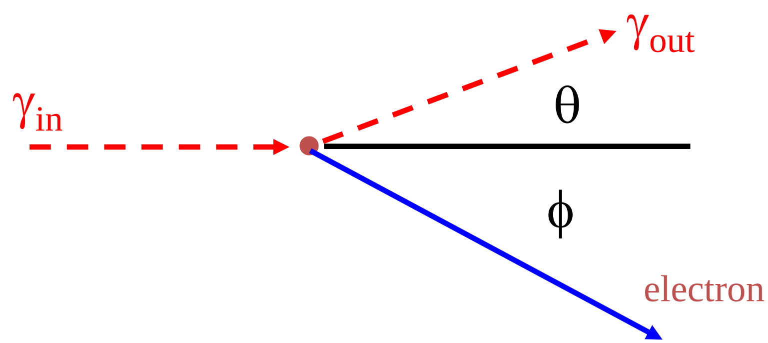
$$T_{max} = E_{\gamma,in} \frac{2\gamma}{1+2\gamma}$$

$$T_{max\ electrons} = 662 \frac{2\times 1.3}{1+2\times 1.3} = 478 keV$$

$$T_{ph} = 662 - 478 = 184 keV$$

Compton scattering

Compton scattering is the interaction of a real γ with an atomic electron.



Solve for energies and angles using conservation of energy and momentum

$$\cos\theta = 1 - \frac{m_e c^2}{E_{\gamma,in}E_{\gamma,out}}(E_{\gamma,in} - E_{\gamma,out})$$

The result of the scattering is a "new" γ with less energy and a different direction.

$$E_{\gamma,out} = \frac{E_{\gamma,in}}{1+\gamma(1-\cos\theta)} \quad with \quad \gamma \equiv E_{\gamma,in}/m_e c^2$$

Not the usual γ!

$$\text{Kinetic Energy of Electron} = T = E_{\gamma,in} - E_{\gamma,out} = E_{\gamma,in}\frac{\gamma(1-\cos\theta)}{1+\gamma(1-\cos\theta)}$$

The result is known as the Klein-Nishima cross section.

$$\frac{d\sigma}{d\Omega} = \frac{r_e^2}{2[1+\gamma(1-\cos\theta]^2}(1+\cos^2\theta + \frac{\gamma^2(1-\cos\theta)^2}{1+\gamma(1-\cos\theta)}) = \frac{r_e^2}{2}(\frac{E_{\gamma,out}}{E_{\gamma,in}})^2(\frac{E_{\gamma,out}}{E_{\gamma,in}} + \frac{E_{\gamma,in}}{E_{\gamma,out}} - \sin^2\theta)$$

At high energies, γ>>1, photons are scattered mostly in the forward direction (θ=0)

At very low energies, γ≈0, K-N reduces to the classical result: $\frac{d\sigma}{d\Omega} = \frac{r_e^2}{2}(1+\cos^2\theta)$

Compton scattering

At high energies the total Compton scattering cross section can be approximated by:

$$\sigma_{comp} \approx (\frac{8}{3}\pi r_e^2)(\frac{3}{8\gamma})(\ln(2\gamma)+1/2)$$

$(8/3)\pi r_e^2$=Thomson cross section
From classical E&M=0.67 barn

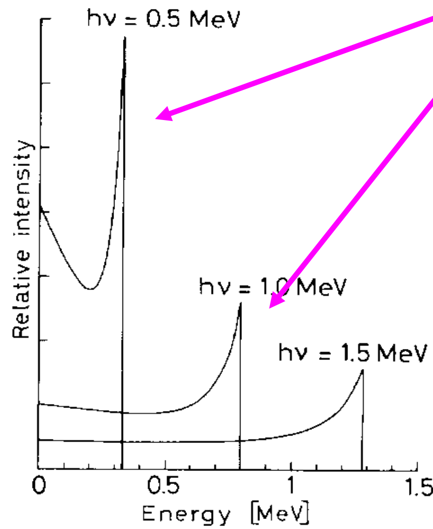
We can also calculate the recoil kinetic energy (T) spectrum of the electron:

$$\frac{d\sigma}{dT} = \frac{\pi r_e^2}{m_e c^2 \gamma^2}\left(2 + \frac{s^2}{\gamma^2(1-s)^2} + \frac{s}{(1-s)}\left(s - \frac{2}{\gamma}\right)\right) \quad \text{with } s = T/E_{\gamma,in}$$

This cross section is strongly peaked around T_{max}:

$$T_{max} = E_{\gamma,in}\frac{2\gamma}{1+2\gamma}$$

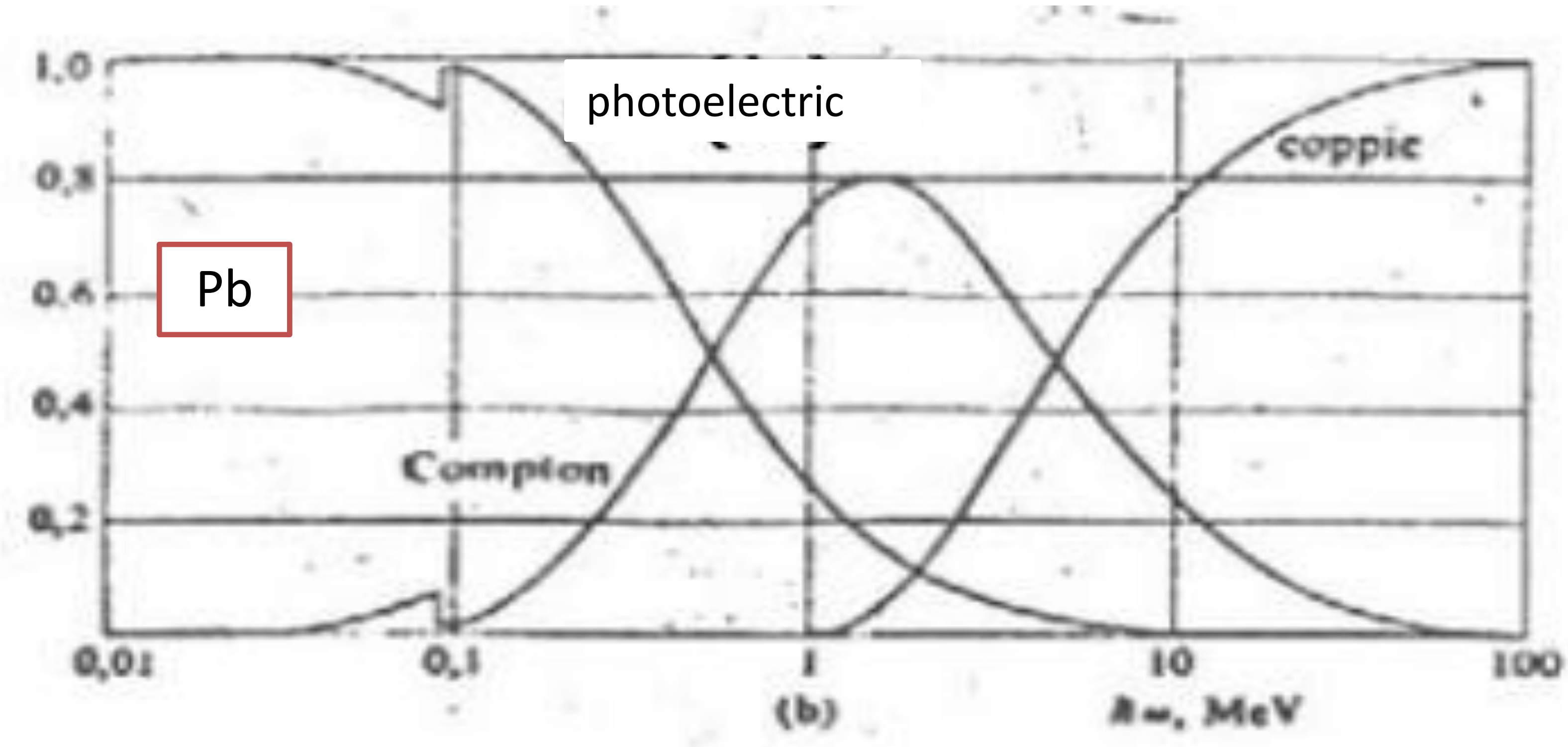
T_{max} is known as the Compton Edge



Kinetic energy distribution of Compton recoil electrons

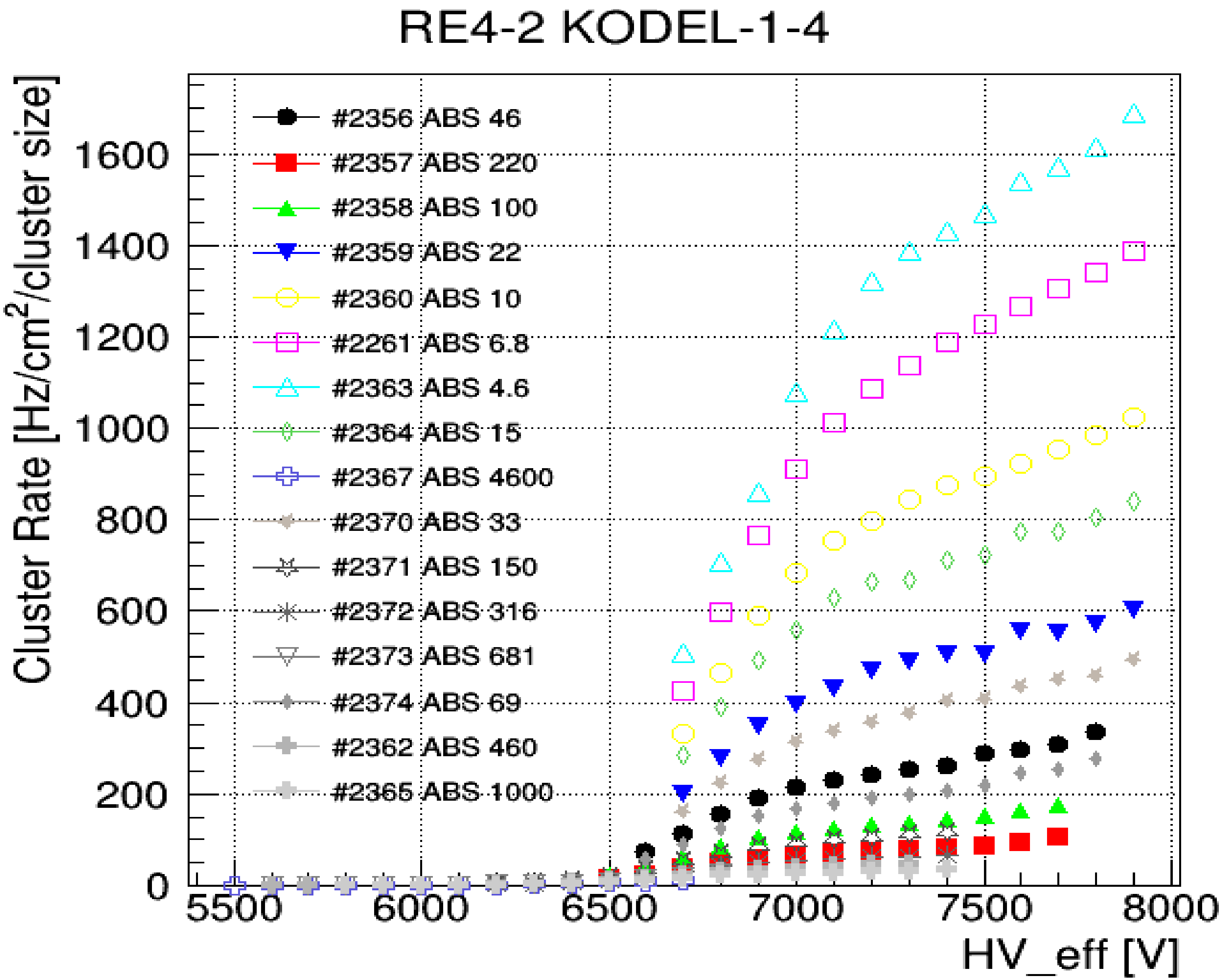
GIF++ photons energy spectrum

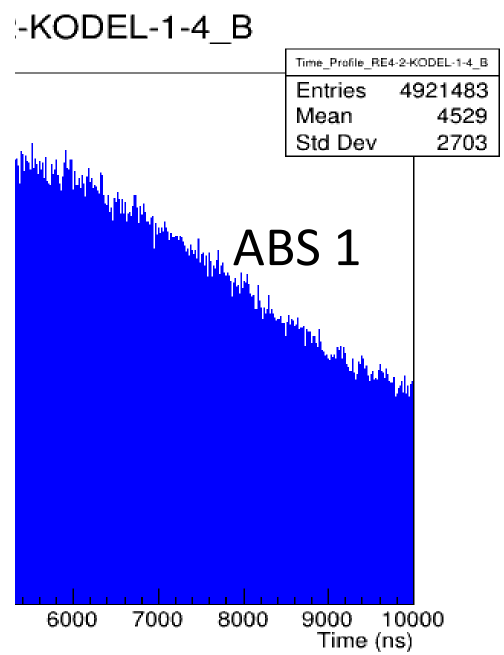
Why the photons pick (p2) at ~ 100 keV ?



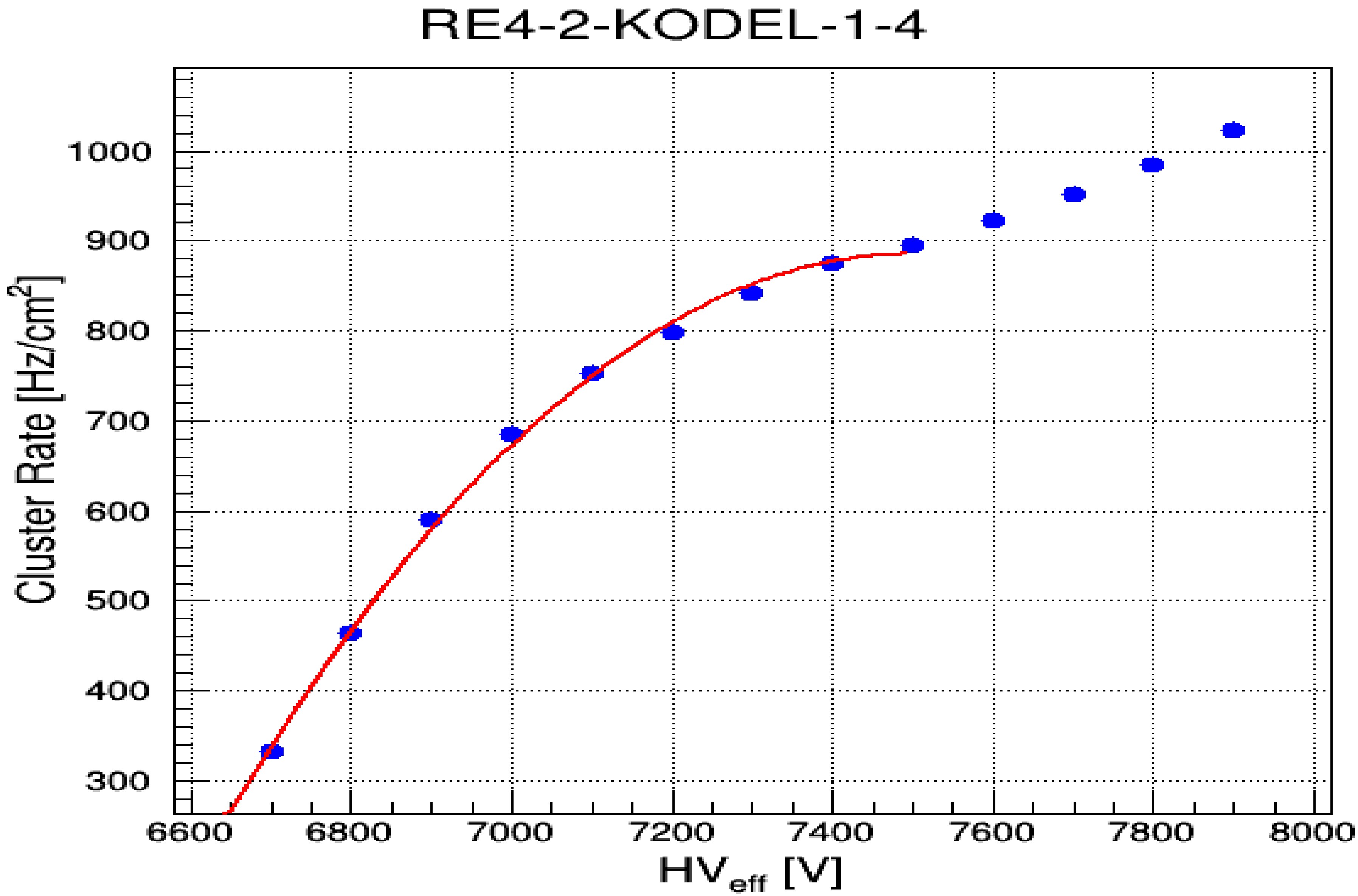
The gammas with energy of 0-300 keV have an high probability to interact by photoelectric effect. The X-rays emitted because of the Pb atom de-excitation from K-shell have an energy around **80 keV**.

Rate scans at GIF++

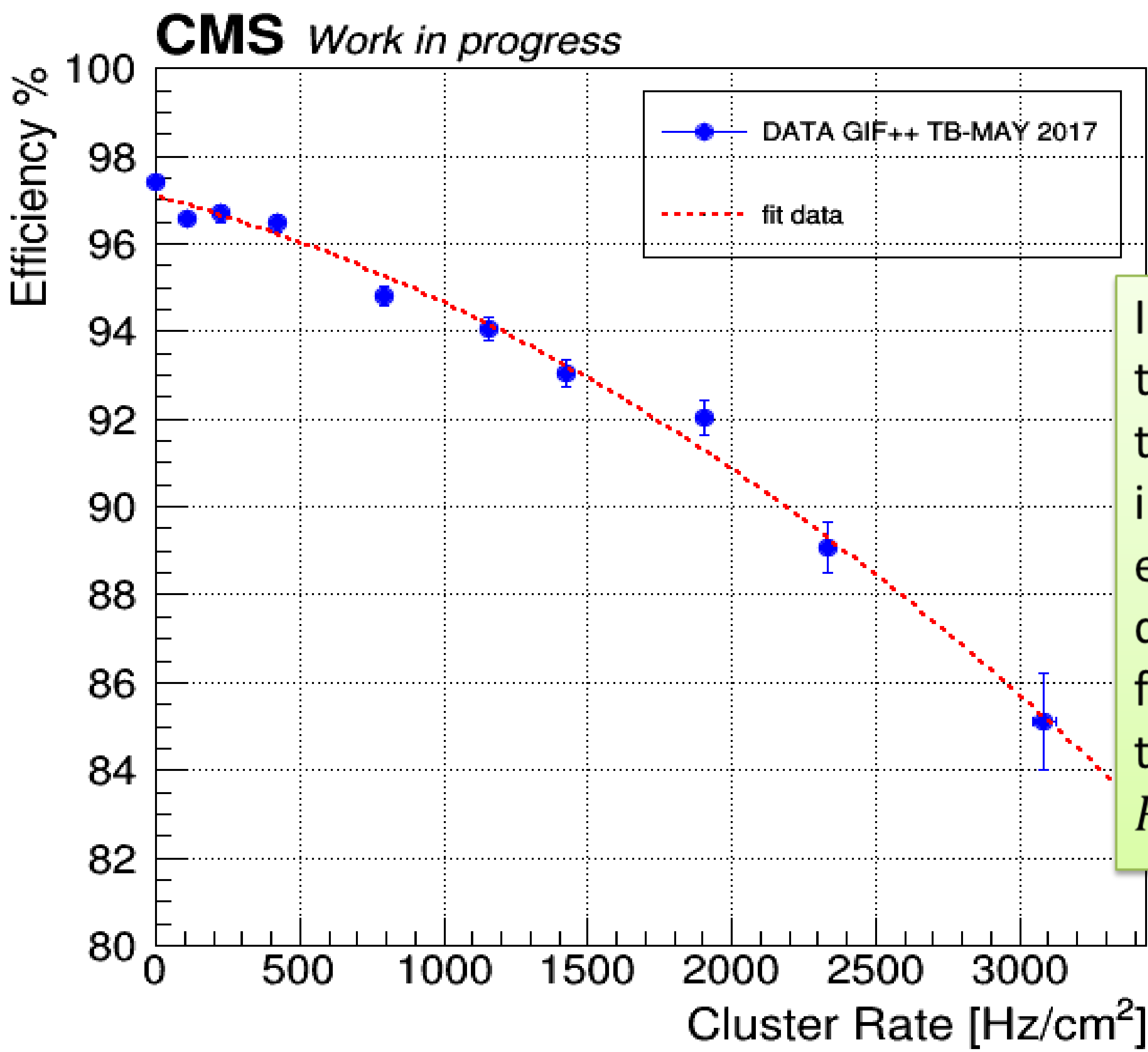




Rate scans at GIF++



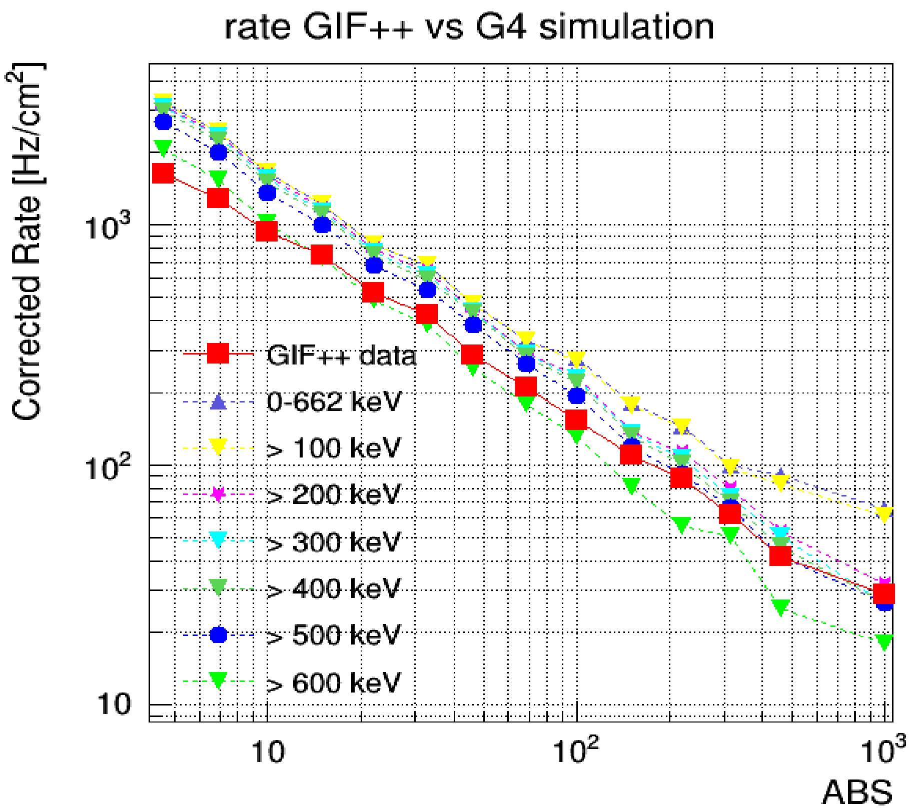
Kodel Efficiency scans May 2017 TB

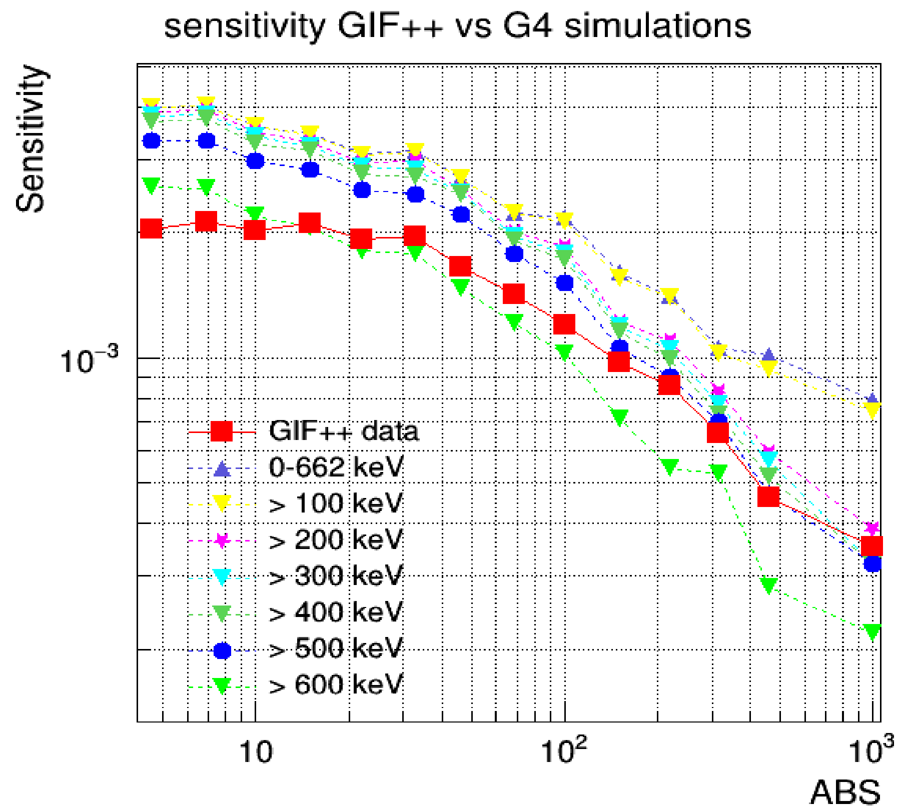


In the simulation we assume the detector ε = 1. In order to take into account the inefficiency, the experimental efficiency at different rates has been fitted, and has been defined the corrected rate:

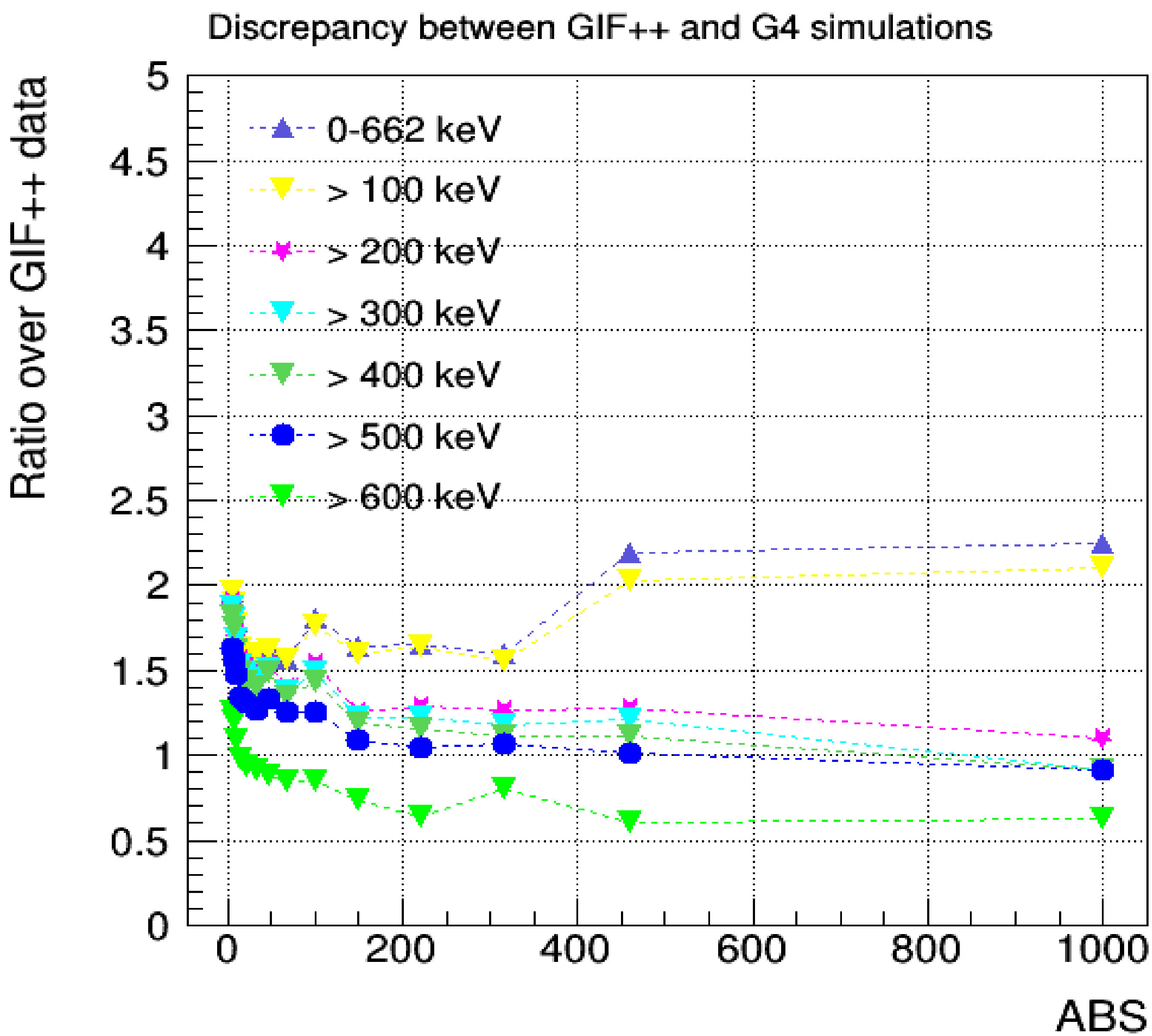
$R_{corr} = R_{\mathrm{ABS}} + R_{ineff}$

Rate GIF++ vs G4 simulation



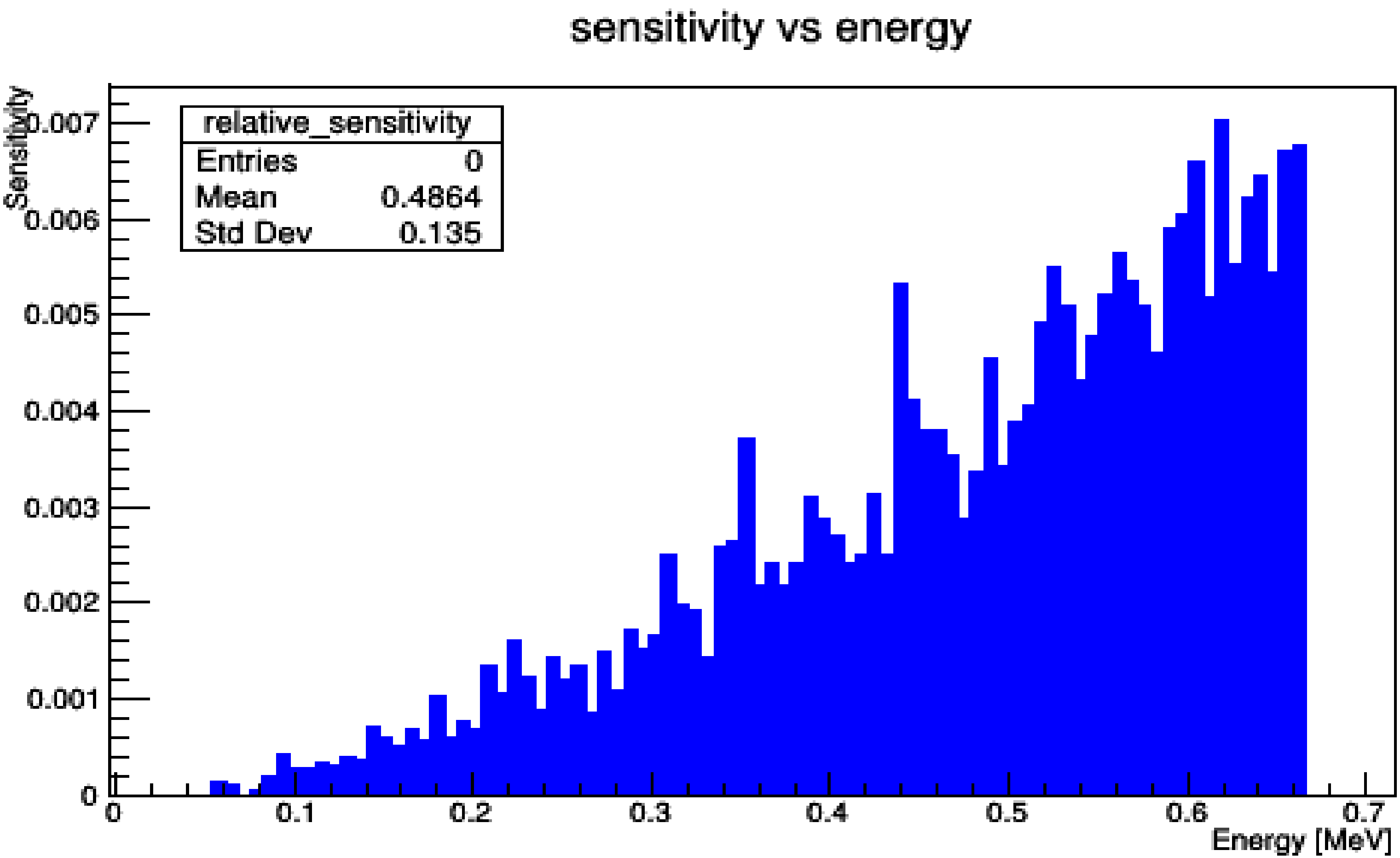


Rate GIF++ vs G4 simulation

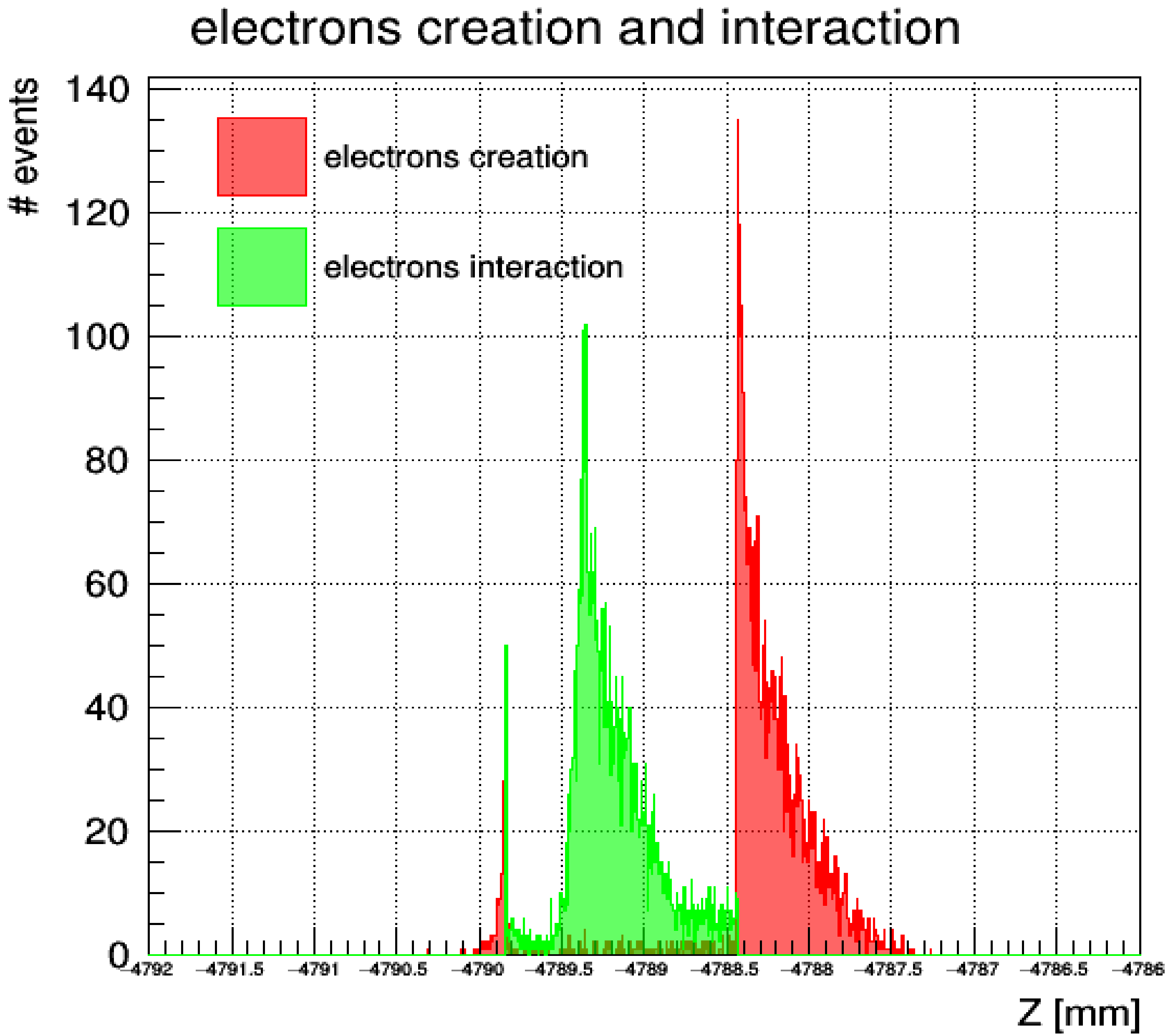


Sensitivity G4 simulation

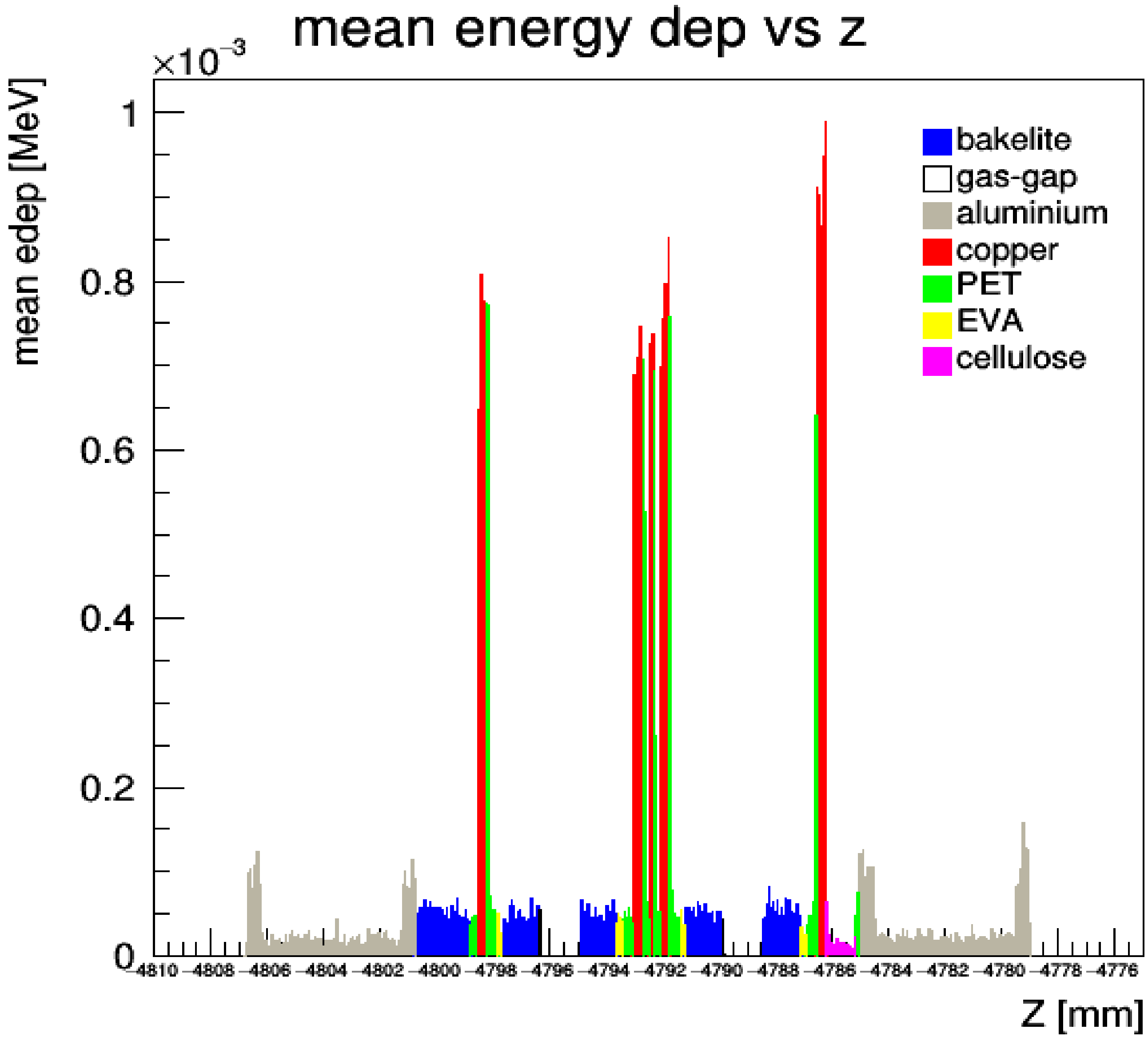
The G4 simulation allow us to know the sensitivity at different energy values, from 0 to 662 keV.



Electrons creation and interaction



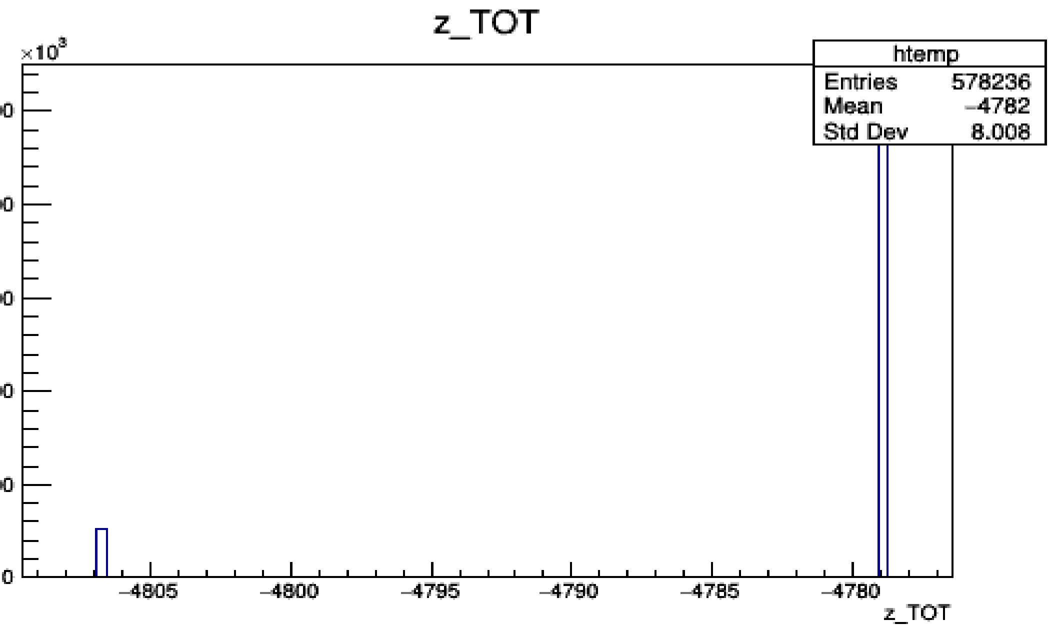
Energy deposited vs z



SIMULATION DETAILS

Incident particles (TOP,BOT, TOTAL):

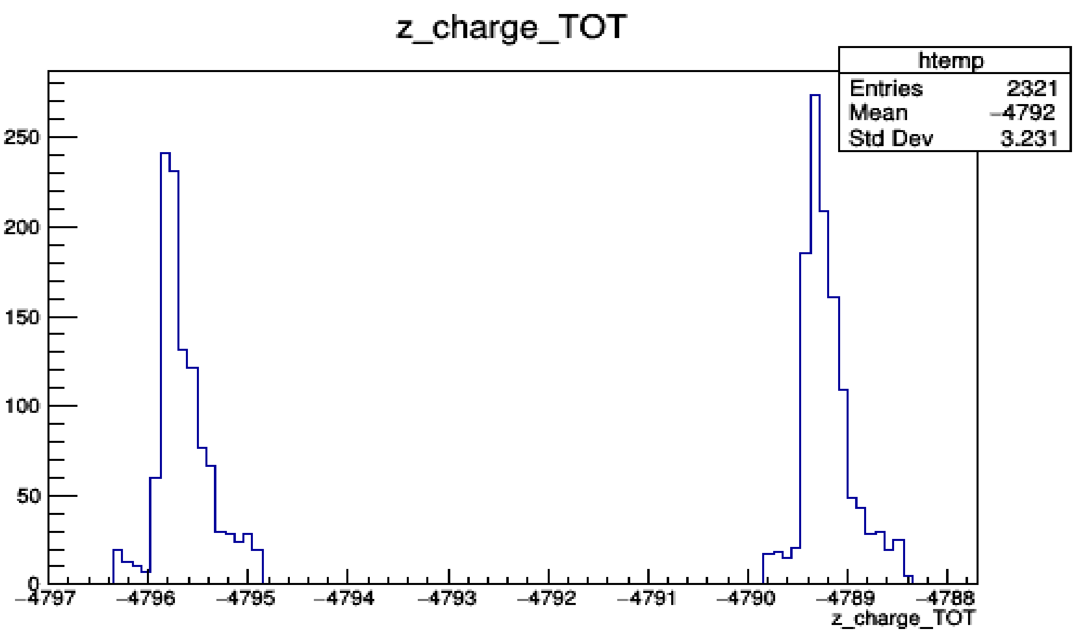
- Number of particles,
- Particle Data Group,
- ID,
- Parent ID,
- Kinetic energy,
- X position,
- Y position,
- X-Y position,
- Z position,



SIMULATION DETAILS

Charged particles (GAP1, GAP2, TOTAL):

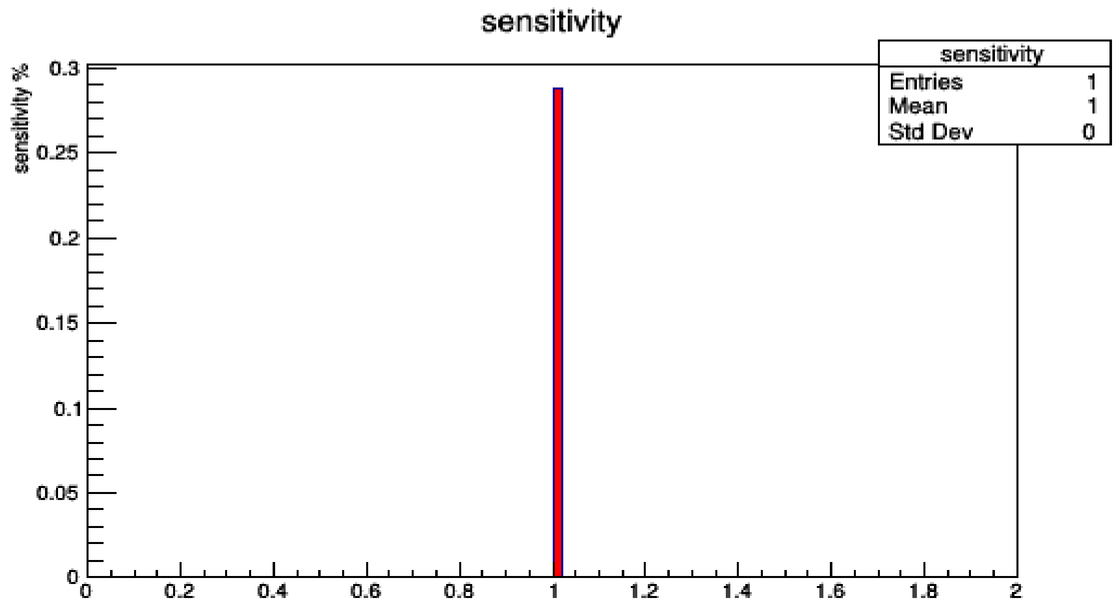
- Number of particles,
- Particle Data Group,
- ID,
- Parent ID,
- Kinetic energy,
- X position creation,
- Y position creation,
- X-Y position creation,
- Z position creation,
- X position interaction,
- Y position interaction,
- X-Y position interaction,
- Z position interaction,



SIMULATION DETAILS

Charged particles (GAP1, GAP2, TOTAL):

- X-Y creation vs interaction,
- Z creation vs interaction,



- Creation Compton vs Photoelectric,
- Interaction mcs vs ion vs eBrem,
- Energy deposited,
- Sensitivity.

RPC gas mixture

In view of a reduction of the Green-House gases emission ***an extended R&D program*** *has been started.*

The CMS RPC gas mixture has a high Global Warming Potential (GWP ~ 1433)

95.2% $C_2H_2F_4$ (tetrafluoroethane): GWP = ***1430*** → ***active gas***

0.3% SF_6 (sulphur hexafluoride): GWP = ***23900*** → ***electronegative gas***

4.5% C_4H_{10} (isobutane): GWP = ***3.3*** → ***quencher gas***

This gas mixture has been optimized to ensure a stable and long term operation of the system at LHC .

Strategy to find a suitable ecogas:

- ✓ *Search for candidates with a low GWP to replace the $C_2H_2F_4$ within the gas used as Freon replacement in the industry.*
- ➢ *Study the detector performance with these new gases (efficiency, time resolution, streamer probability) also in combination to other gases (like the CO_2).*
- ➢ *Study the detector longevity performance in presence of gamma background on few candidate gas mixtures at GIF++.*

RPC gas mixture

New ecogas mixture:
*50% Tetrafluoropropene **HFO**-1234ze ($C_3H_2F_4$): **GWP = 6***
*45.2% **$C0_2$** : **GWP = 1***
*0.3% SF_6 : GWP = **23900***
*4.5% C_4H_{10} : GWP = **3.3***

GWP_{tot} = 73

- ***HFO***: *α coefficient less then $C_2H_2F_4$, working voltage increasing*
- ***CO_2***: *quencher and reduce the working voltage.*

Test with iRPC 1.4 mm:
- ✓ *High efficiency*
- ✓ *HV working point increasing of ~ 1.5 kV, still less than the maximum allowed by CMS 10 kV.*