Status of the Beam Gas vertex profile monitoring instrument development for HL-LHC

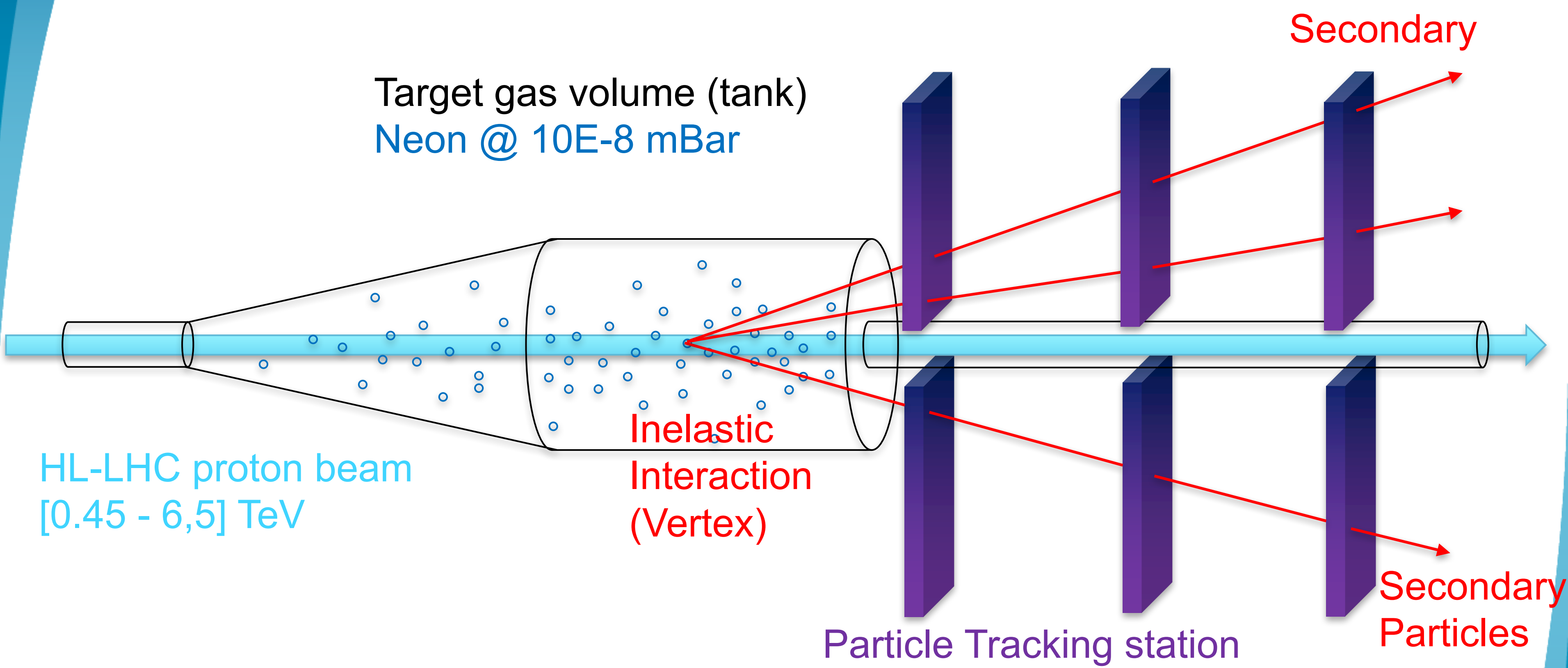
Robert Kieffer BE-BI-BLM, on behalf of the BGV team
rkieffer@cern.ch

For the HL-LHC annual meeting 16th of October 2018

Overview

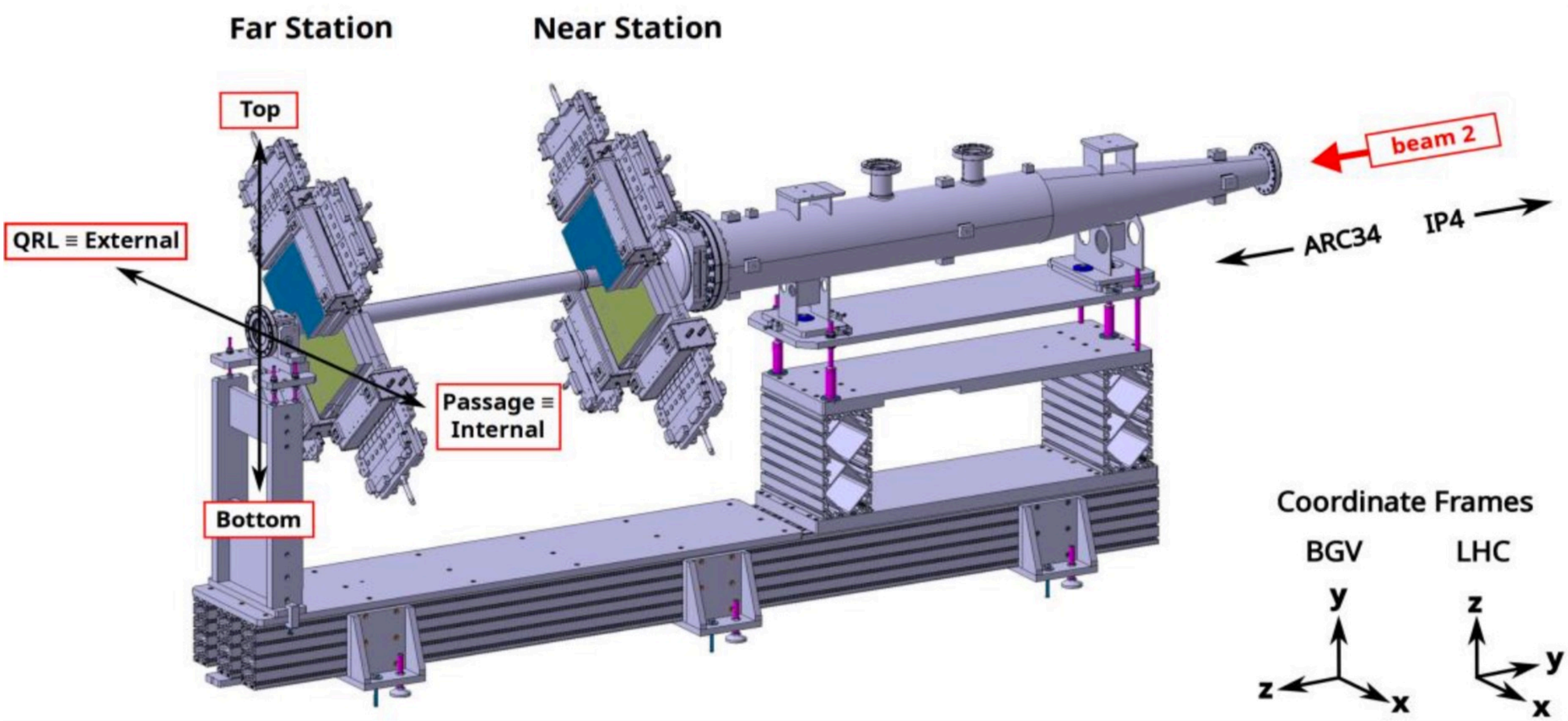
- Intro: Beam Gas Vertex profile measurement.
- The BGV demonstrator in LHC.
- The HL-LHC BGV design.
- Material budget study.
- GEM predesign
- BGV Readout and online processing.

Beam Gas Vertex Profile Monitoring



- A set of few thousands **Beam Gas interaction Vertex events** allows to measure the **HL-LHC beam size** within desired accuracy.
- This is a fully **non-invasive method** with no visible effects on the beam lifetime.

LHC Beam Gas Vertex demonstrator



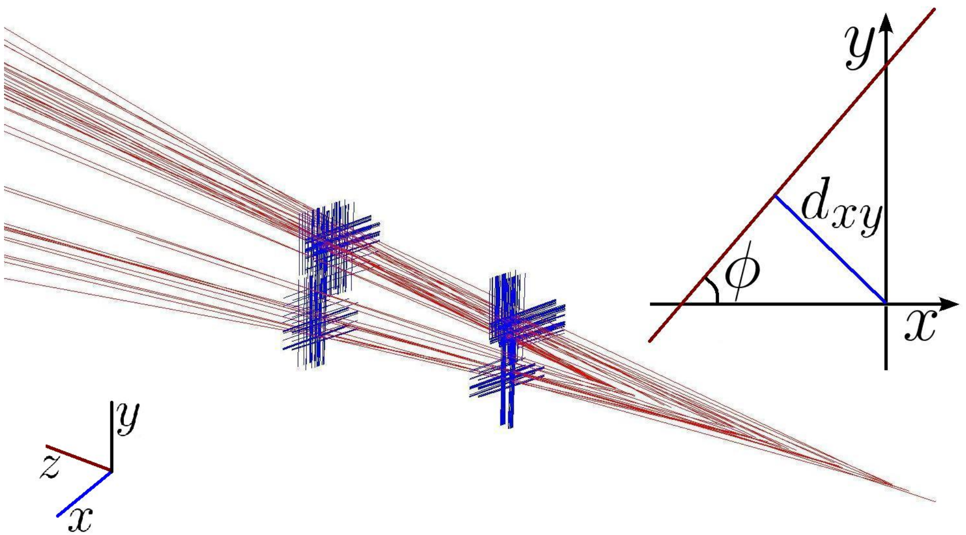
Demonstrator operating in LHC point 4, will be used until the end of this LHC run for full characterization and as a test bench for online processing development.

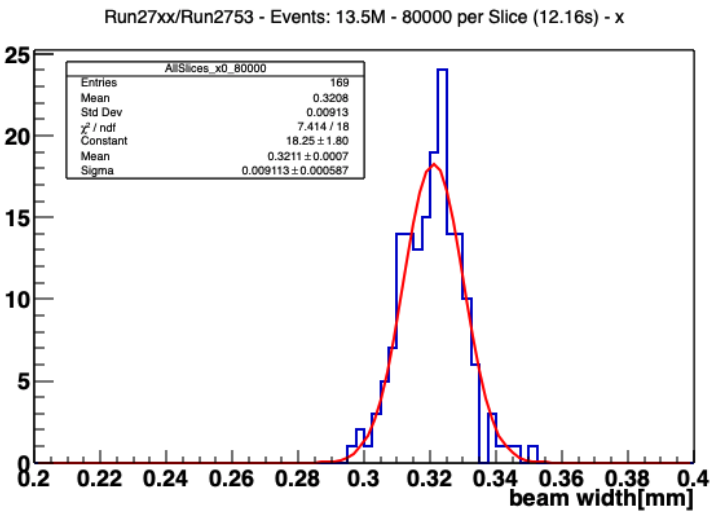
Status of the BGV demonstrator

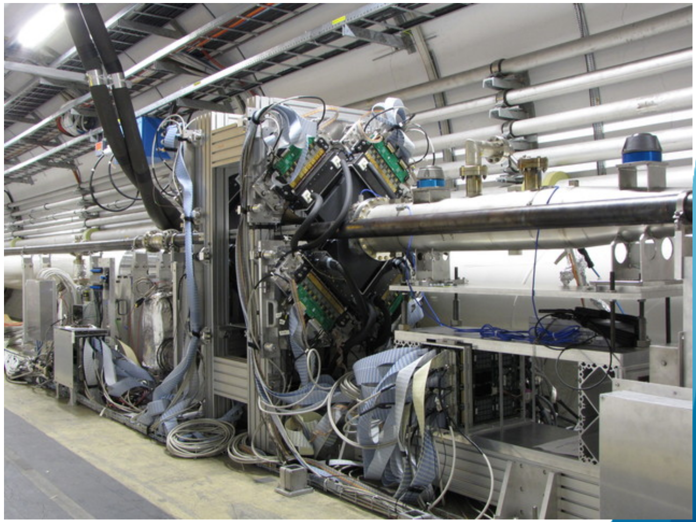
The BGV demonstrator make use of **SciFi** detector technology from the **LHCb** R&D.

It already provided very satisfactory **LHC beam size measurement**.

12 seconds integration
80k events -> 3% stat. error







The most recent BGV demonstrator results (Run2) will be presented tomorrow by Benedikt Würkner in the afternoon session.

HiLumi HL-LHC PROJECT
CERN

Two BGV stations for HL-LHC

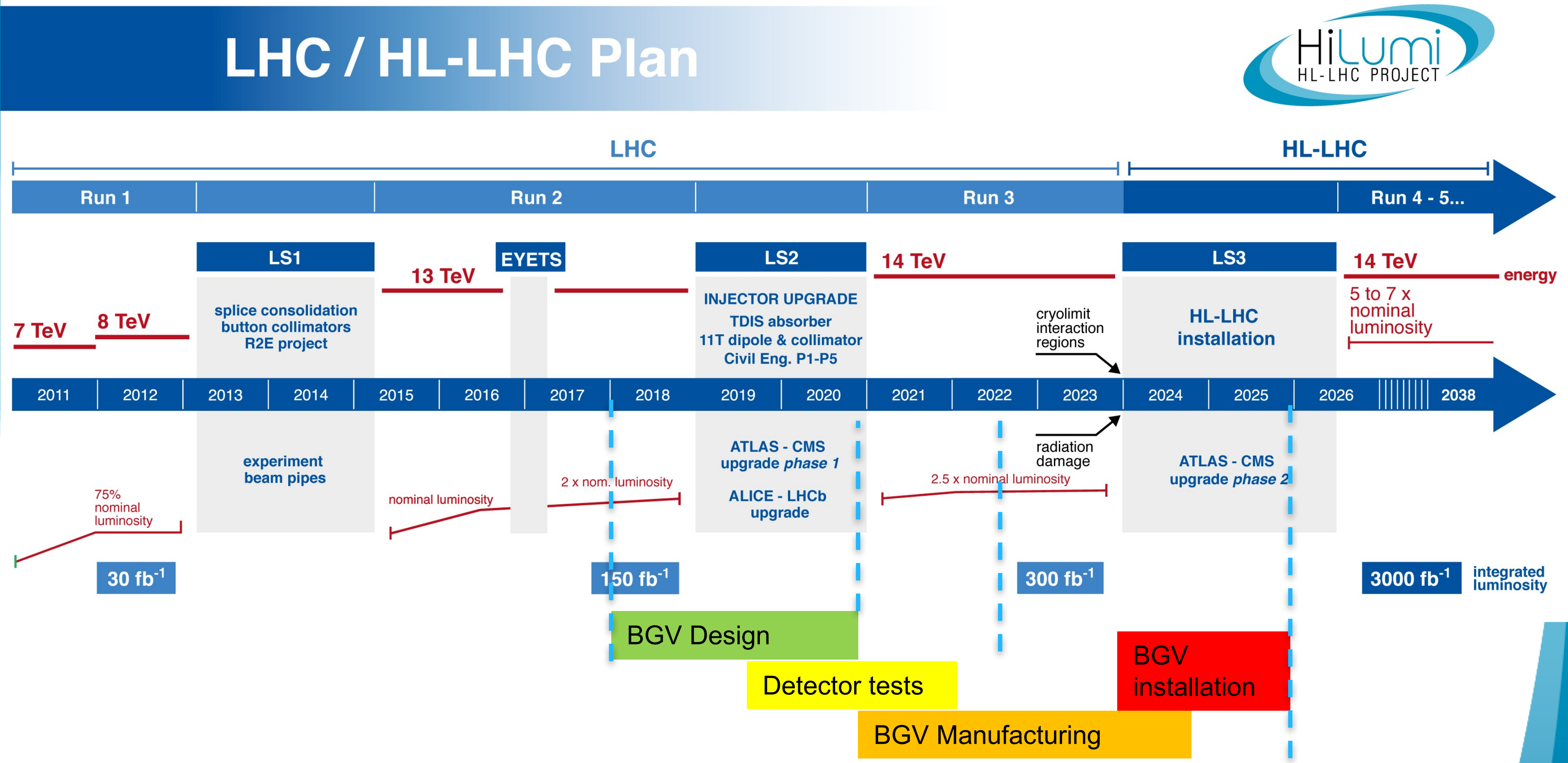
Up to now

- The BGV is currently the **only device able to measure the LHC beam size continuously during the ramp** with full physics beam loading!
- Work is ongoing to demonstrate **online processing** of the data and publication of the beam size measurement to the accelerator database in **real time**.
- We are very close to a **stable automated operation of the BGV**!

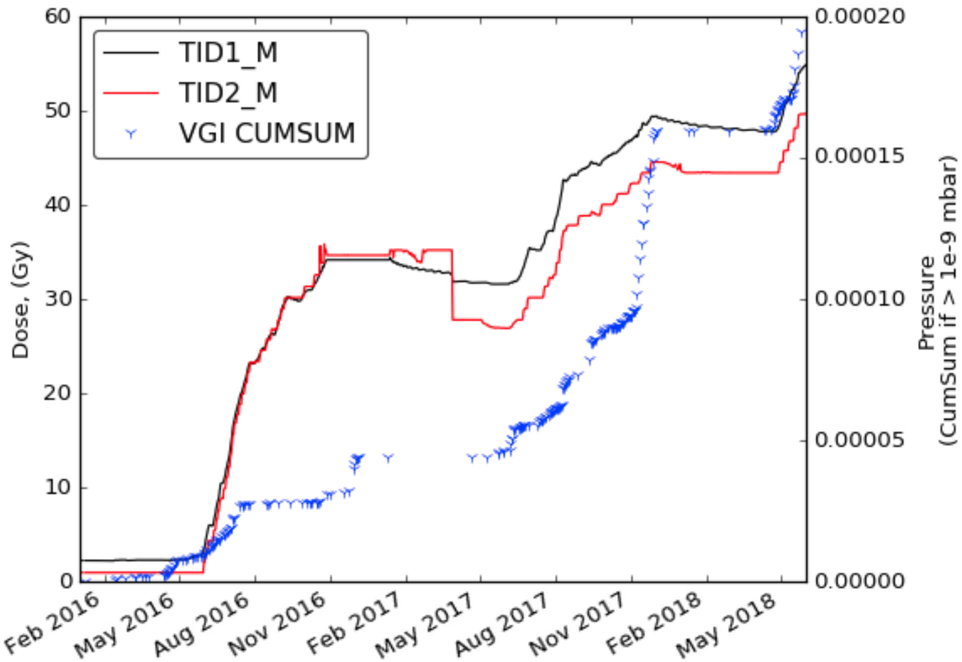
The future…

- From this fruitful preliminary experience, an **optimized BGV is under development** to be installed on both HL-LHC beams in LS3.
- The ultimate BGV goal is **single bunch beam size measurement**, it will need significant improvements in terms of **detector design, acquisition, and processing rate**.

Timeline for HL-LHC BGVs

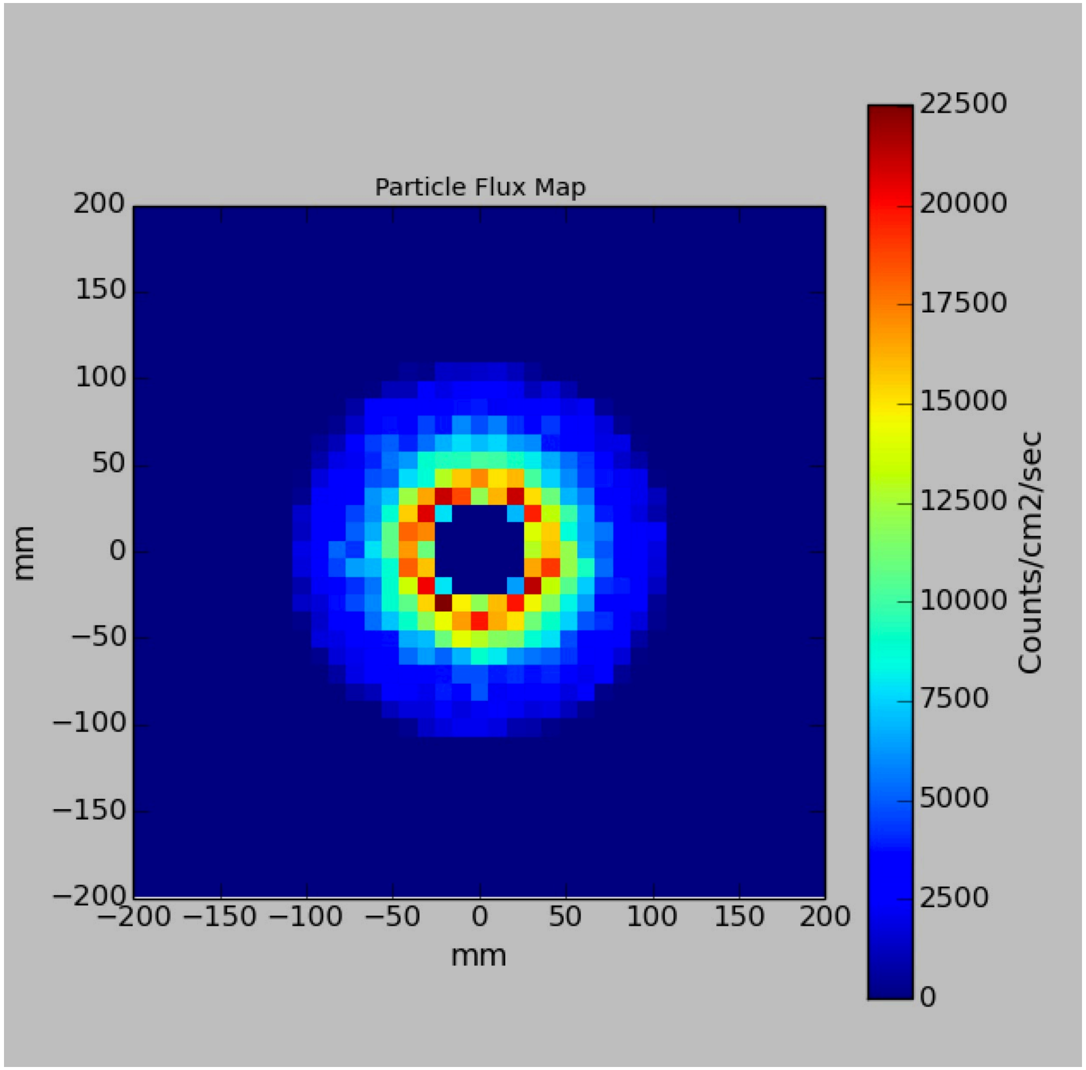


Expected radiation dose



- RadMon located 20 cm from beam axis (location of the readout ASICs)
- Two years of BGV demonstrator operation accumulated a TID of 50 Gy.
- The annual TID is expected to be around 150Gy/year for full time operation.
- The expected TID input from the Fluka team would also be useful.

Expected Rate in the first detector layer

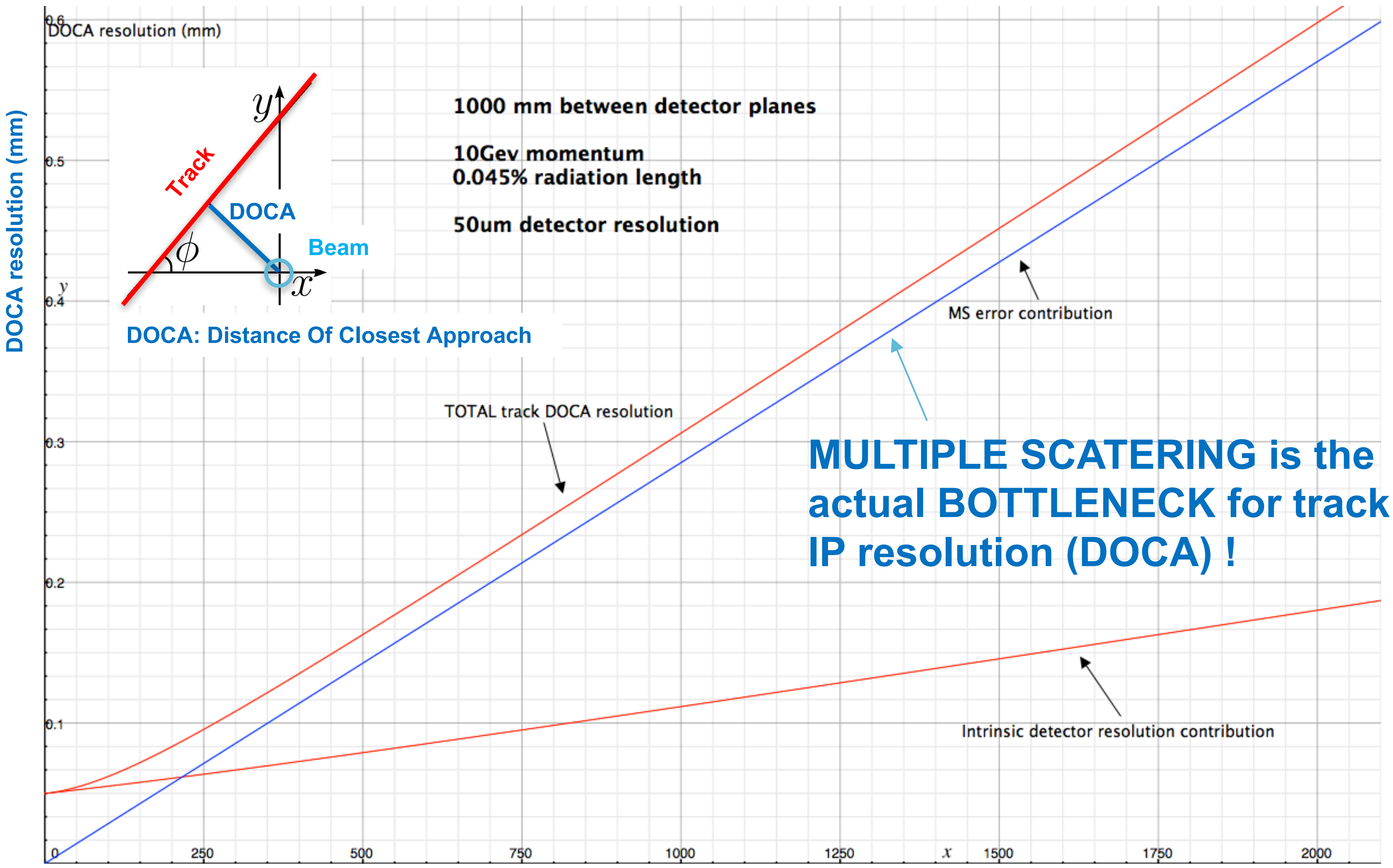


Full LHC train (2808 bunches) produce about 200kHz of beam-gas interactions in the gas target.

Collision rate of 80Hz/bunch

A maximum **secondary rate of 25kHz/cm^2** is expected in the first detector layer.

Impact Parameter (IP) Resolution

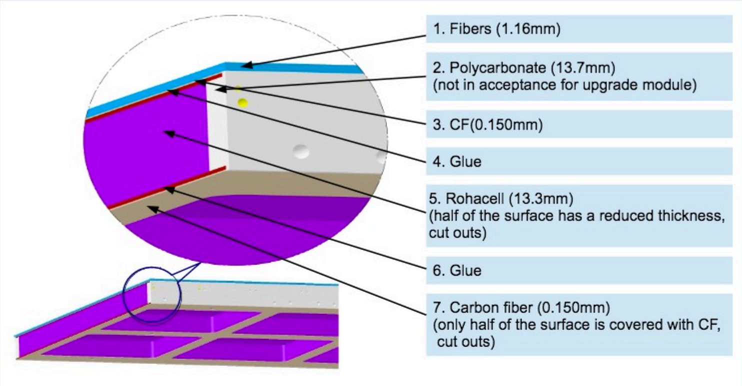


Distance of Primary vertex from 1st detector plane

Looking for a low material budget tracker sensor

The BGV demonstrator SciFi module reference

Material budget



Drawing from a talk of B. Rakotomiaramanana: https://indico.cern.ch/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=235449

#	Material (rad len [mm])	Thickness [mm] Edge	Thickness [mm] Center	Rad len of layer [%] Edge	Rad len of layer [%] Center
P1	Scint. Fibers (400)	1.2		0.3	
P2	Glue (400)	2×0.1	1×0.1	0.05	0.03
P3	Carbon Fiber (237)	2×0.15	1×0.15	0.13	0.06
P4	Rohacell (8160)	1×20	0.3×20	0.25	0.07
SUM	**Single layer**			**0.73**	**0.46**
$2 \times$ SUM	**Module (X–V or Y–U bi-layer)**			**1.46**	**0.92**

3 / 4

In average we have **1.2% of X_0** over the surface for a X-V layer (equivalent to an X-Y)

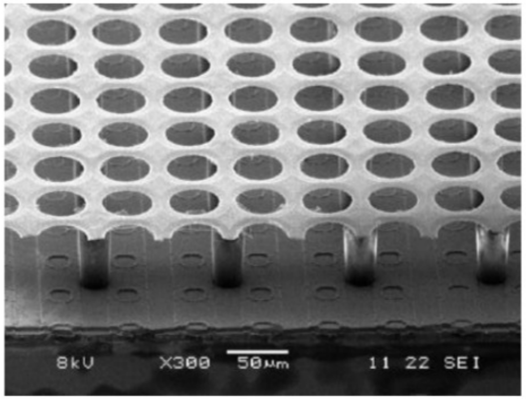
The TOTEM GEM modules for comparison

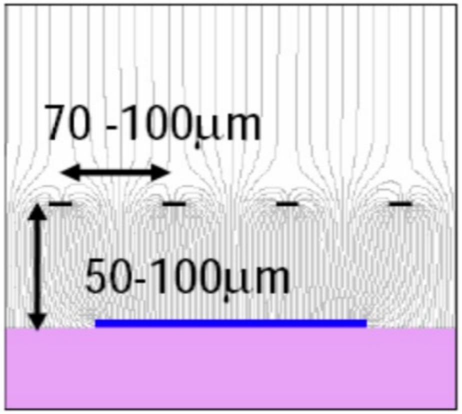
Item	Details	$^o/_{oo}$ of X_o
3 GEMs	6 x 5 μm copper [0.7]	1.68
	3 x 50 μm kapton [0.7]	0.42
	TOTAL:	2.10
1 Drift	5 μm copper	0.35
	50 μm kapton	0.17
	TOTAL:	0.52
3 Grid spacers	3 x 2 mm fiberglass [0.008]	0.25
1 Readout board	80 μm strips: 5 μm copper [0.2]	0.07
	1536 pads: 5 μm copper [0.85]	0.26
	50 μm kapton [0.2]	0.03
	120 μm fiberglass	0.62
	60 μm epoxy	0.30
	TOTAL:	1.28
1 Shielding	10 μm aluminium	0.11
2 Honeycombs	2 x 3 mm Nomex	0.46
4 Fiberglass foils	4 x 120 μm fiberglass	2.47
	TOTAL:	7.19

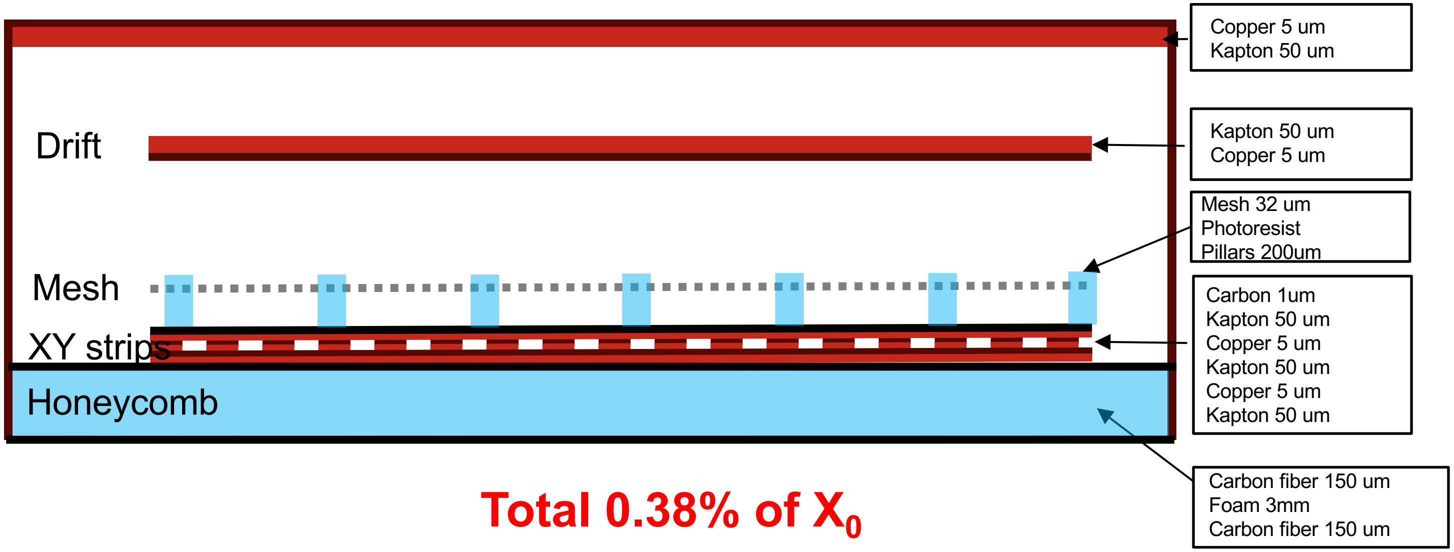
0.719% of X_0

Table 1.1: Material in one GEM detector

Micromegas with XY strip readout

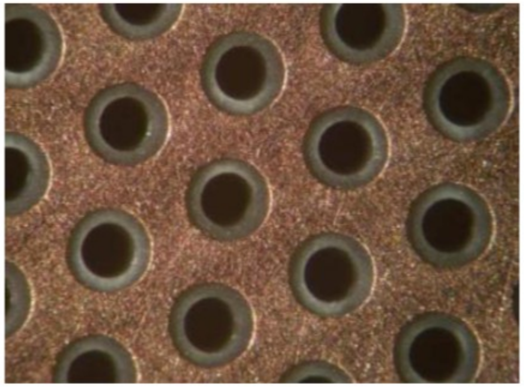


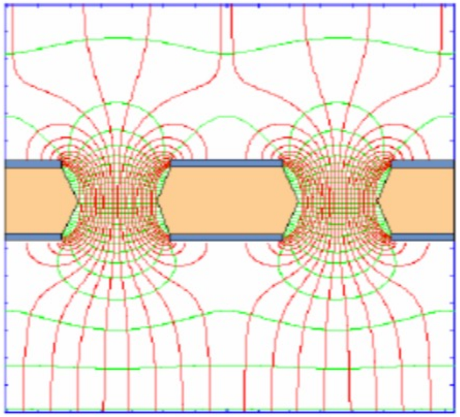


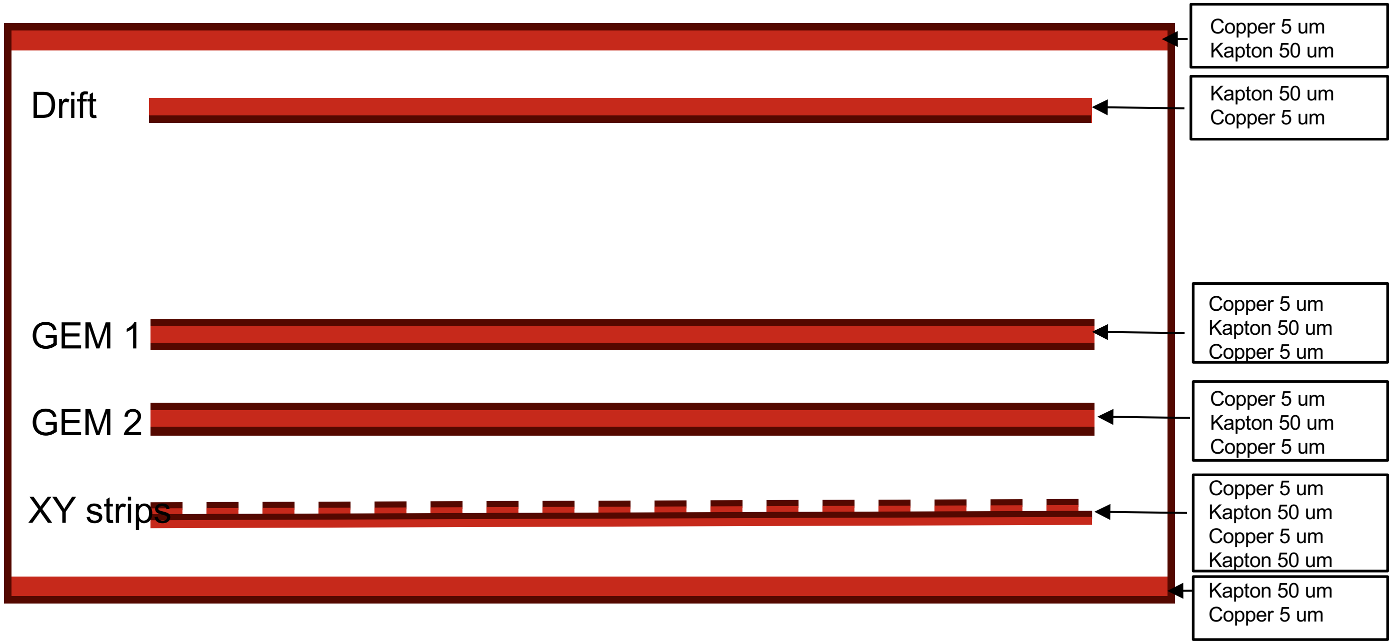


Total 0.38% of X_0

Double GEM structure with XY strip readout







Total 0.34% of X_0

Sensor options for the tracking station

Sensor	GEM	Micromegas	SiFi (Fibers)	Silicon
Spatial resolution	50 um	50 um	75 um	70 um
Material budget	0.34% of X_0	0.38% of X_0	1.2% of X_0	0.15% of X_0
MIP Signal (mean)	50 fC	25 fc	1.8 pC	3.5 fC
Detector capacitance	10-20pF	10-20pF	10 pF	10-15pF
Sensor cost				

Ref: **The gas electron multiplier (GEM): Operating principles and applications** Fabio Sauli, NIMA 805 1 (2016),
Ref: **Micromegas detectors for the muon spectrometer upgrade of the ATLAS experiment** NIMA 824 (2016)
Ref: ***BGV fibre module: Test beam report*** LPHE Note 2016-04
Ref: ***LHCb Inner Tracker Technical Design Report*** CERN/LHCC 2002-029 LHCb TDR 008 November 8, 2002

GEM vs Micromegas in the BGV case

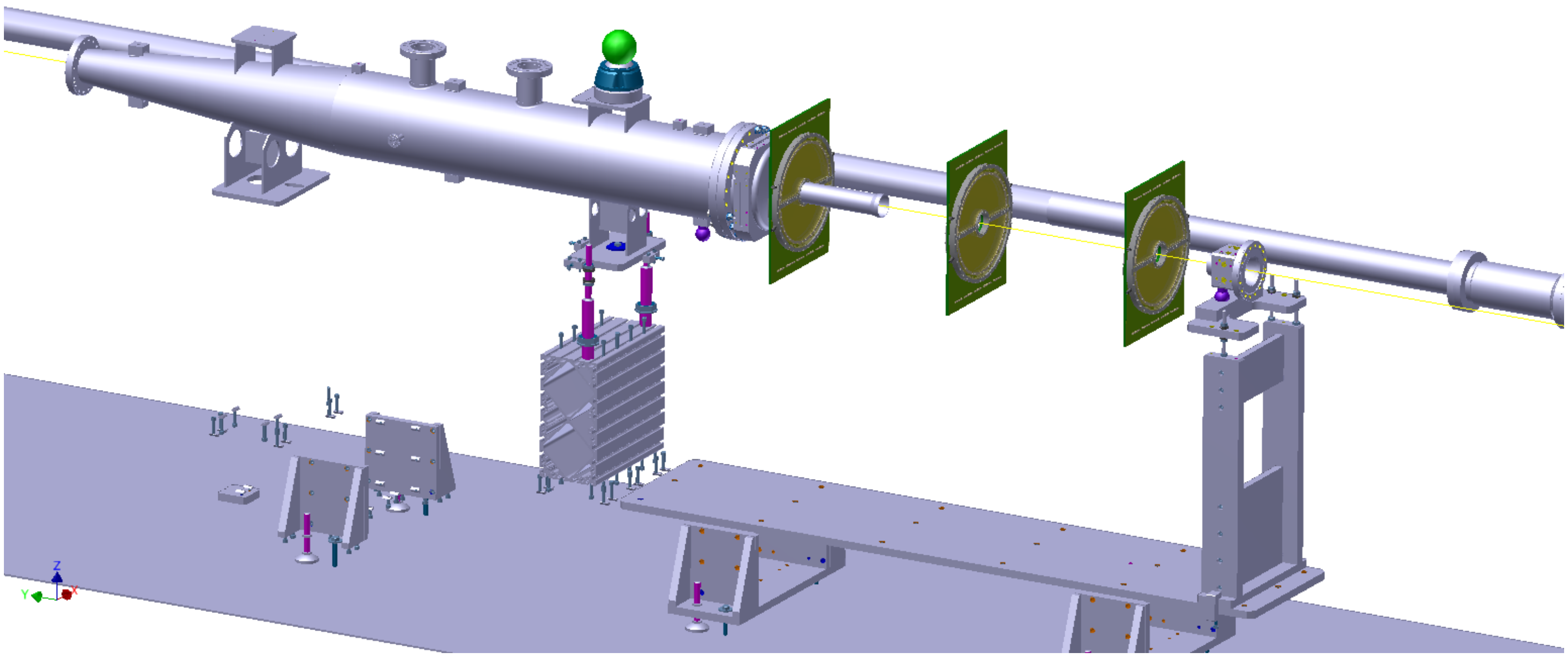
Both **GEM and MM** could eventually be build with similar material budget even though the GEM reach smaller budget**.**

Nevertheless, the GEM have an higher **multiplication gain**, it's always easier to read stronger charges! Specially close to the RF cavities of PT4.

The GEM also seems more adapted to high rates than the MM with a smoother operation due to its **wider HV plateau** region.

The smaller **drift gap** of the GEM (**3**mm) versus MM (**6**mm) is also more adapted since most of the tracks will cross the drift with an angle.

LHC-BGV
preliminary GEM design



Three stations with two consecutive **GEM XY readout planes** tilted by a small angle.

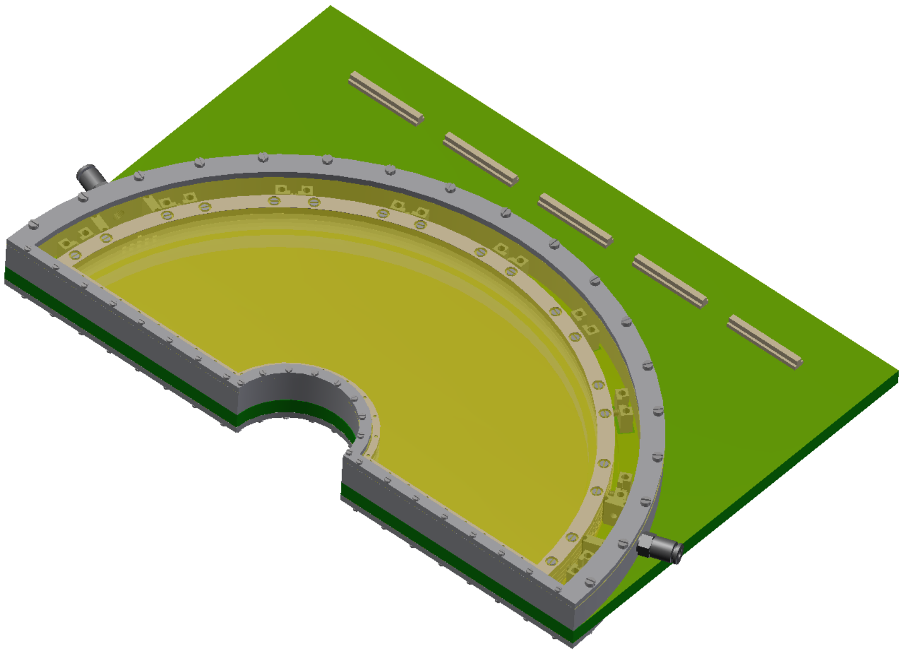
“CMS style” dismountable triple GEM

Three stations with two consecutive **GEM XY readout planes** tilted by a small angle.

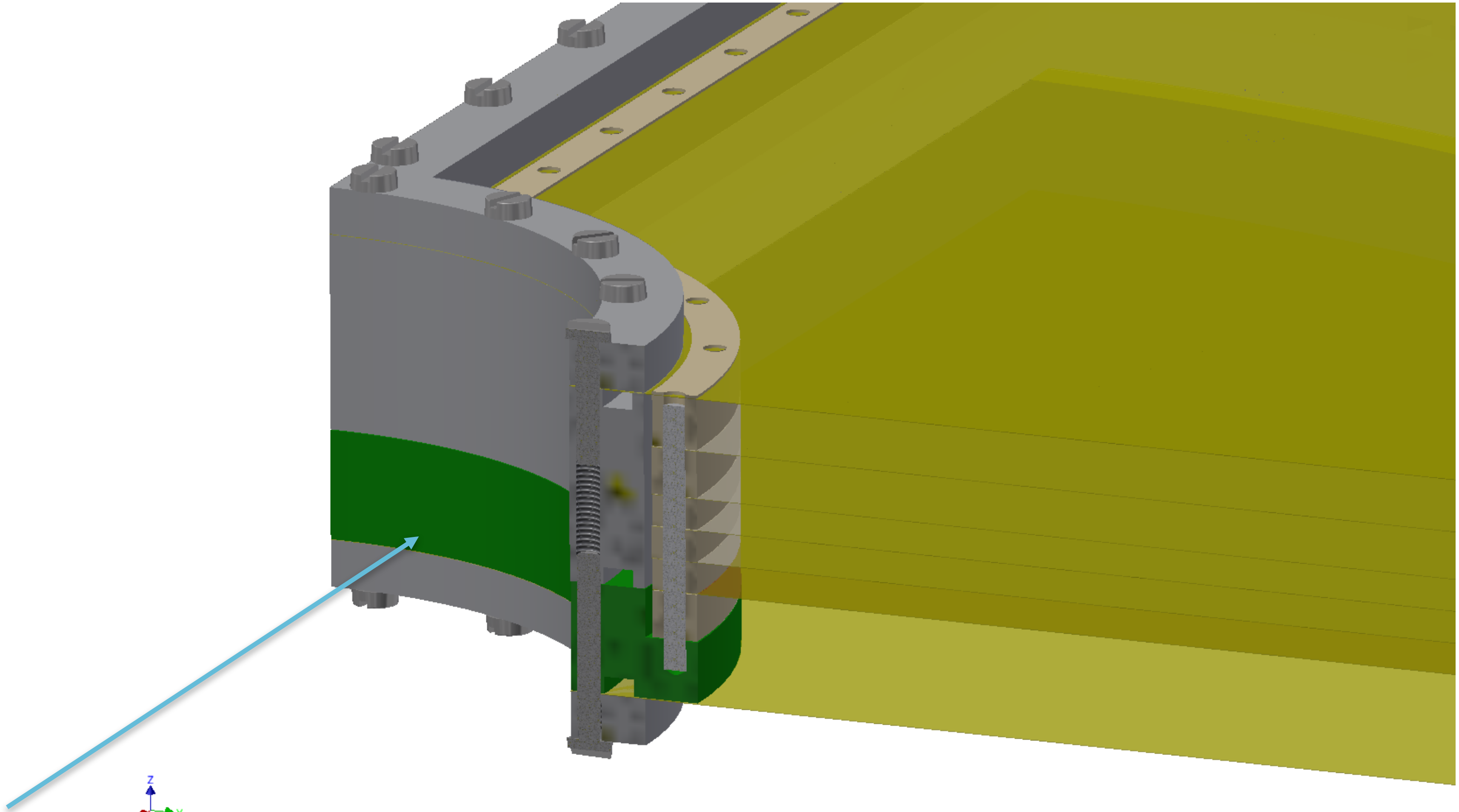
Total of **12 half-moon detectors** for top and bottom (15cm radius).

<u>Detector **Half-moon**</u>

- Double GEM configuration
- Readout strips **stretched (New!)**
- Strip Pitch: 400 um
- Goal: **50um** position resolution
- **1280** Strips XY per detector
- Readout: **20 VMM** ASICs (64 channels)



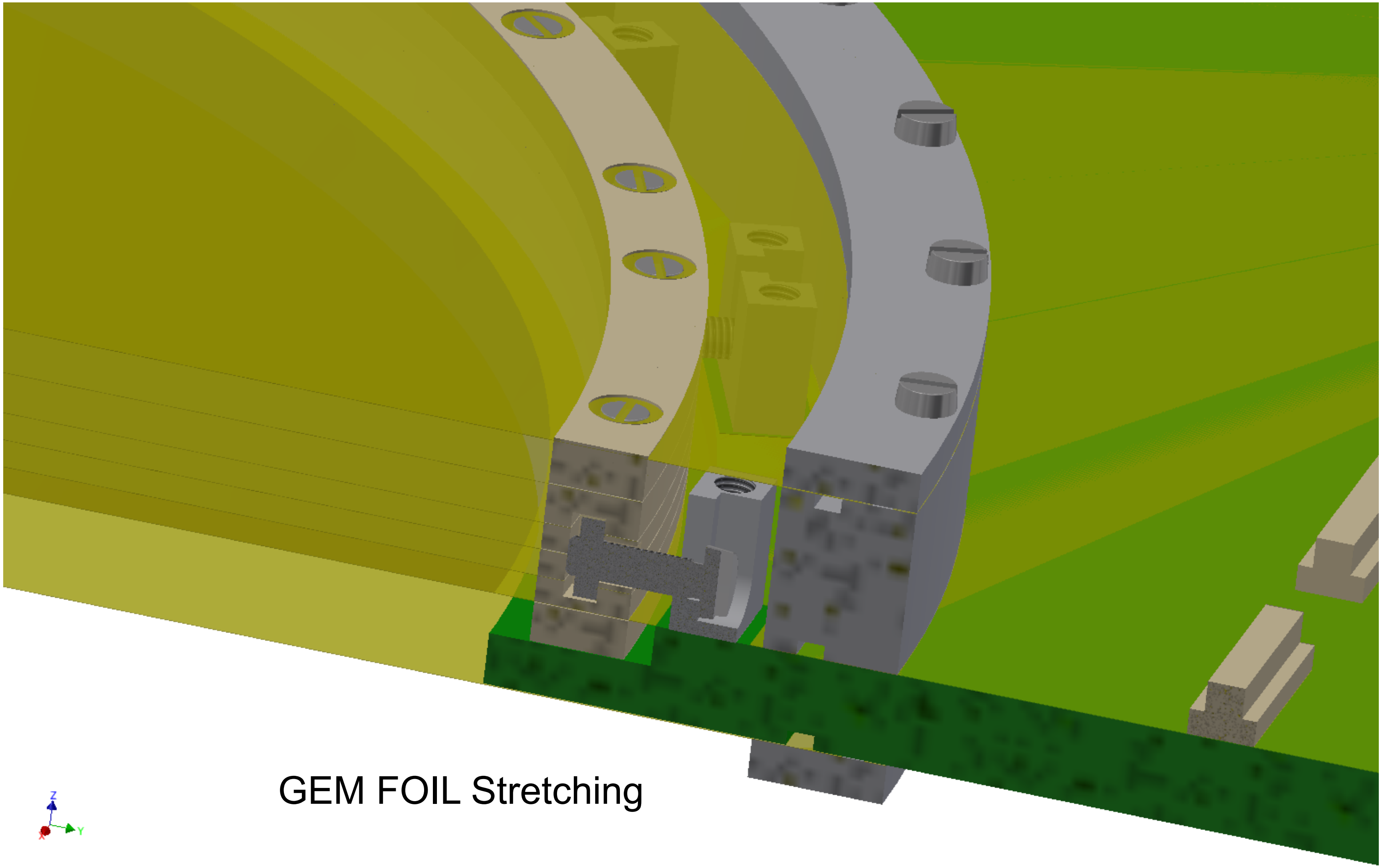
"CMS style" dismountable triple GEM



- The main goal is the reduction of the material used in between the beam pipe and first sensitive area of the GEM
- The objective is to reduce the multiple scattering in dead structural zones.

robert.kieffer@cern.ch

“CMS style” dismountable triple GEM



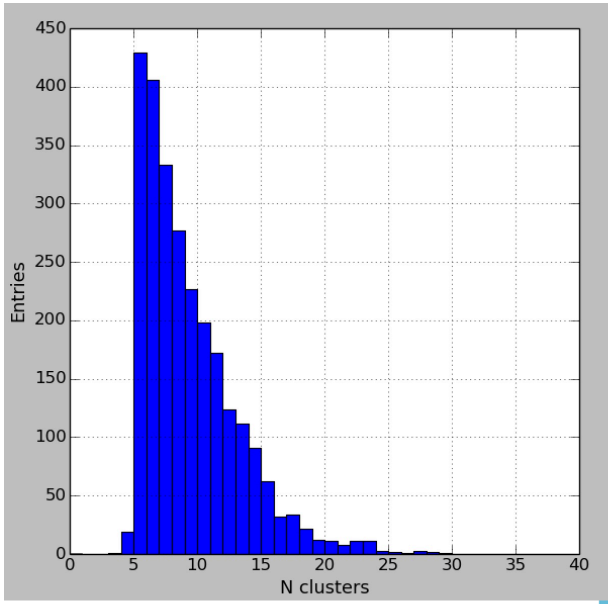
GEM FOIL Stretching

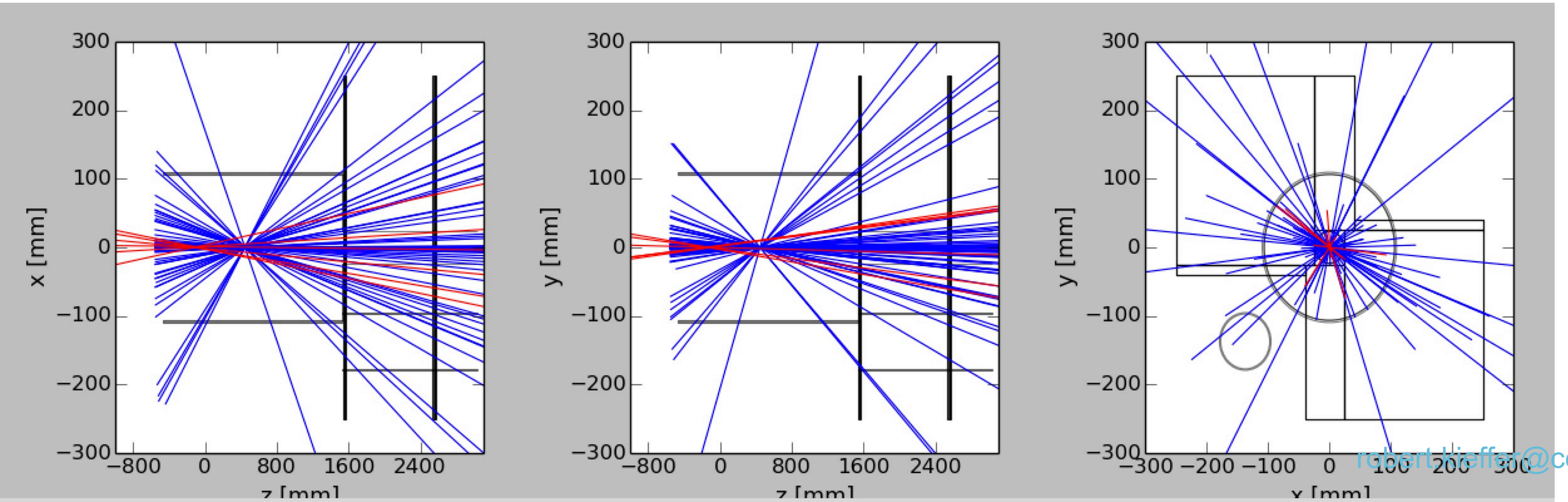
Readout layer Pattern Study

Consideration concerning the event topology

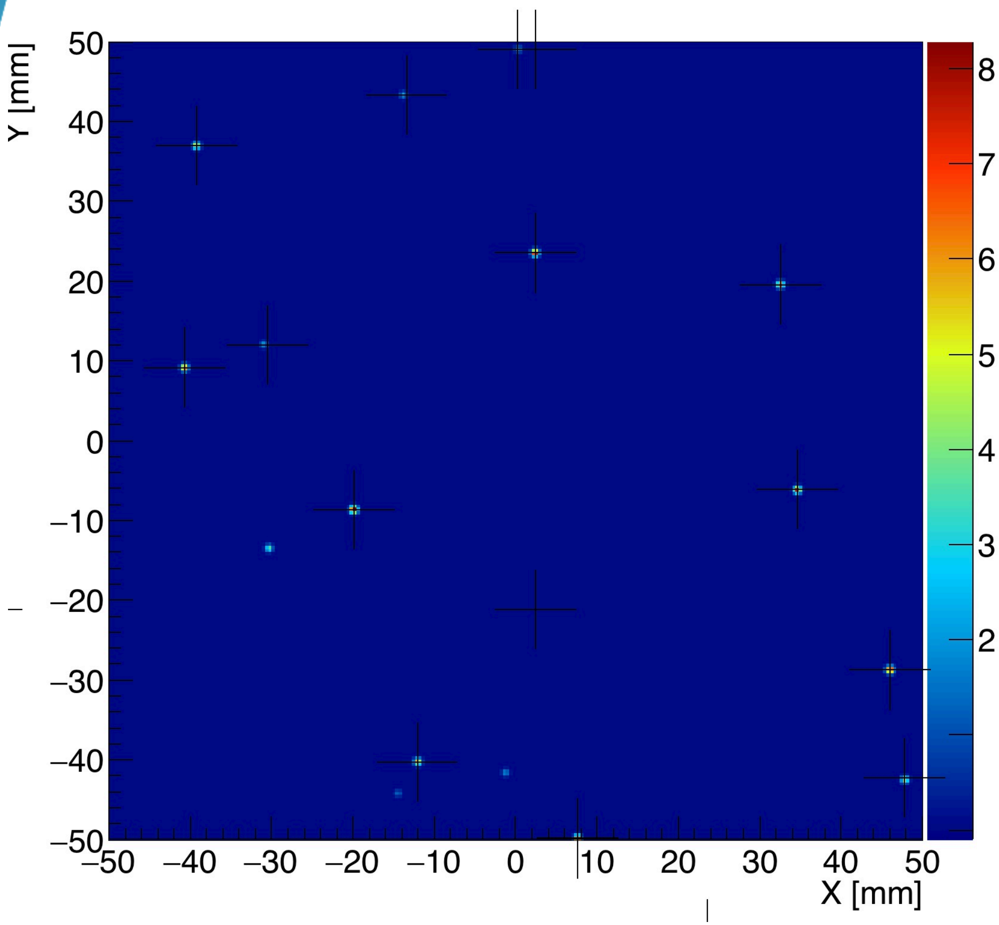
- Up to 25 clusters for a GEM layer in a single event.

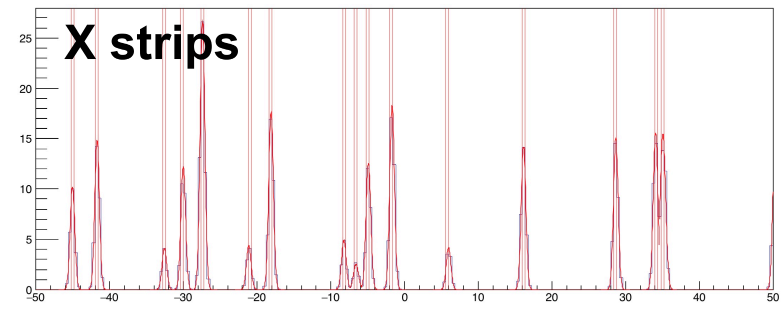
- Use of two consecutive layers to discard Ghost clusters. (XY and X'Y' tilted by few degrees)

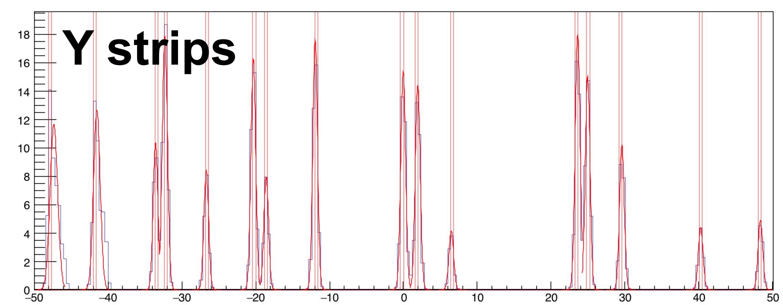


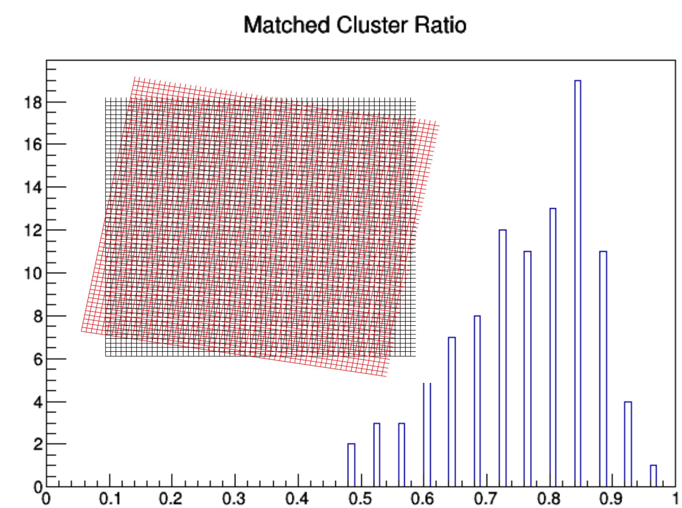


XY strip readout with 25 cluster to be found









Simulation: Two consecutive XY strip detectors tilted by 10 degrees.

1. Mono-dimensional Clustering
2. XY Cluster matching over two layers

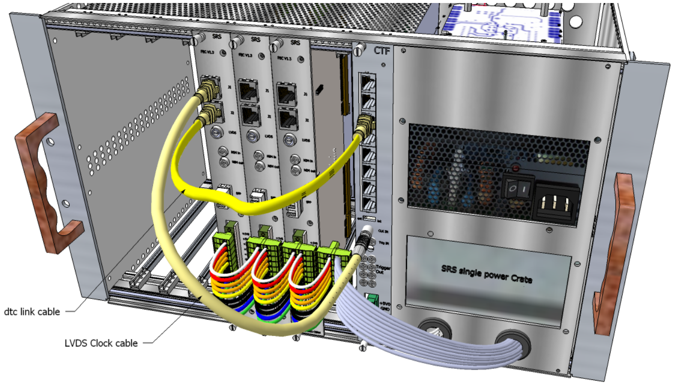
Readout Scheme for the HL-BGV

Readout Scheme for HL-LHC BGV

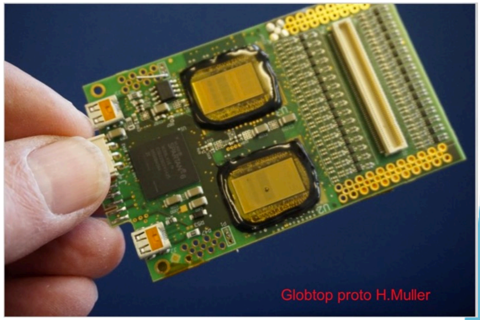
The main ingredients

CPU network

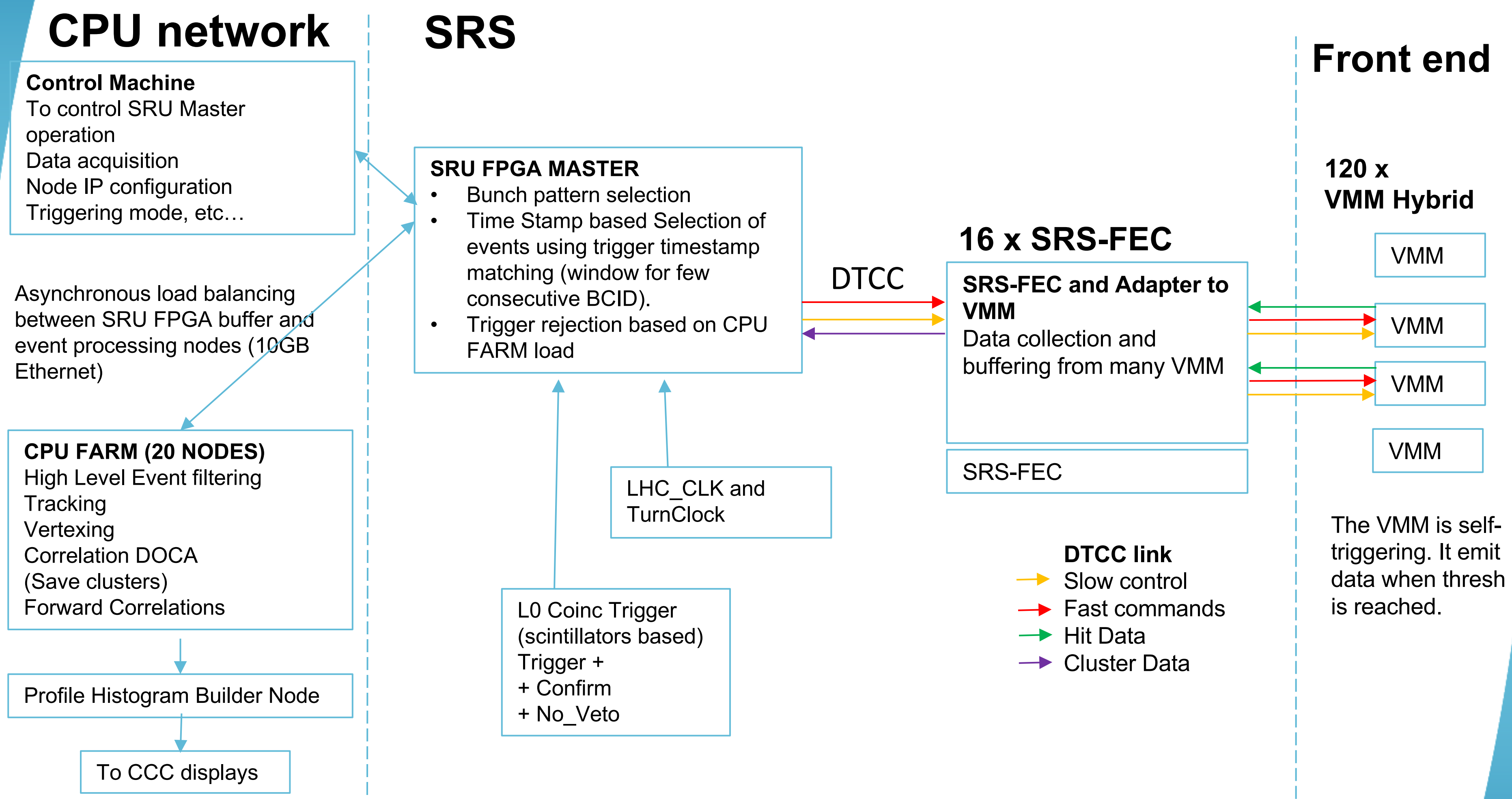
SRS



Front end Hybrid VMM



Readout Scheme for HL-LHC BGV

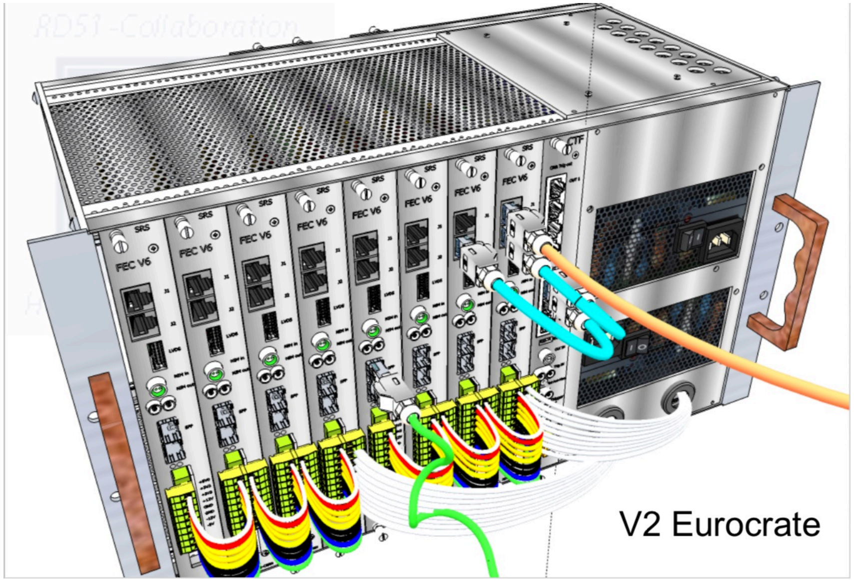


Is there any phase adjustment for the VMM trigger and clock?

Readout system in numbers

For one Half-Moon GEM detector
The current Half-Moon geometry needs 5 VMM hybrid for 640 channels on X and 5 VMM hybrid for 640channels on Y
1280 strips per Half-Moon => **10 Hybrids** needed

For one BGV station
12 Half-Moon detectors => **120** Hybrids to be read-out
Two SRS racks with **15** FEC+adapter
One SRU



TOTAL for two BGV stations

- **240 VMM hybrids.**
- **30 FEC+Adapter**
- **2 SRU**
- **4 CTF cards?**

Open Questions:

- Radiation hardness of the FPGA present on the VMM hybrids?
- Need for GBT optical interface to put the SRS in the technical galleries?
- Event processing on the BI-VFC cards ?

TOTAL 85KCHF for the full DAQ of one BGV station

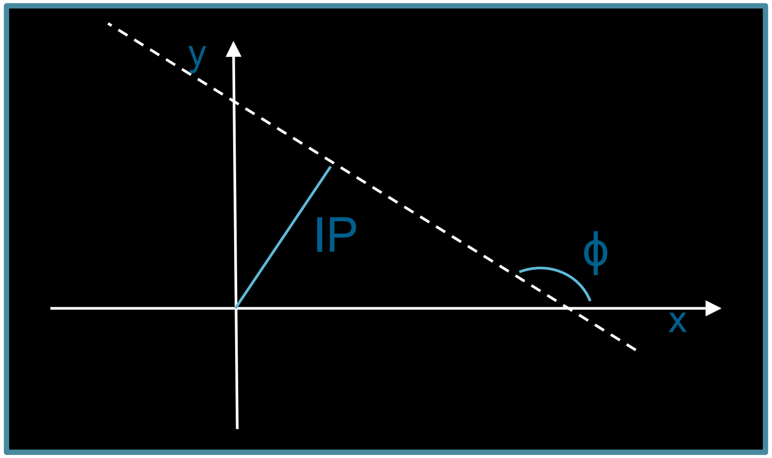
Conclusion

- The **HL-LHC BGV** is still at the **design phase**.
- The **gas target tank** upgrade might be beneficial.
- The **GEM** seems to be the **best option** for the tracking technology.
- The final readout scheme could be an Hybrid solution between **BI-standards (VFC)**, and **SRS scheme** with the **VMM ASIC**.
- The green light for production of both BGV stations should come after the review of all HL-LHC beam size monitoring options next spring.

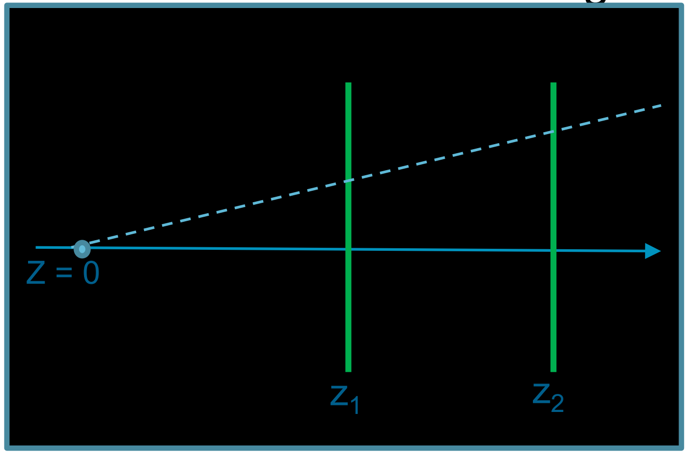
Thanks for your attention!

Any constructive feedback is welcome!

Impact Parameter (IP) Resolution



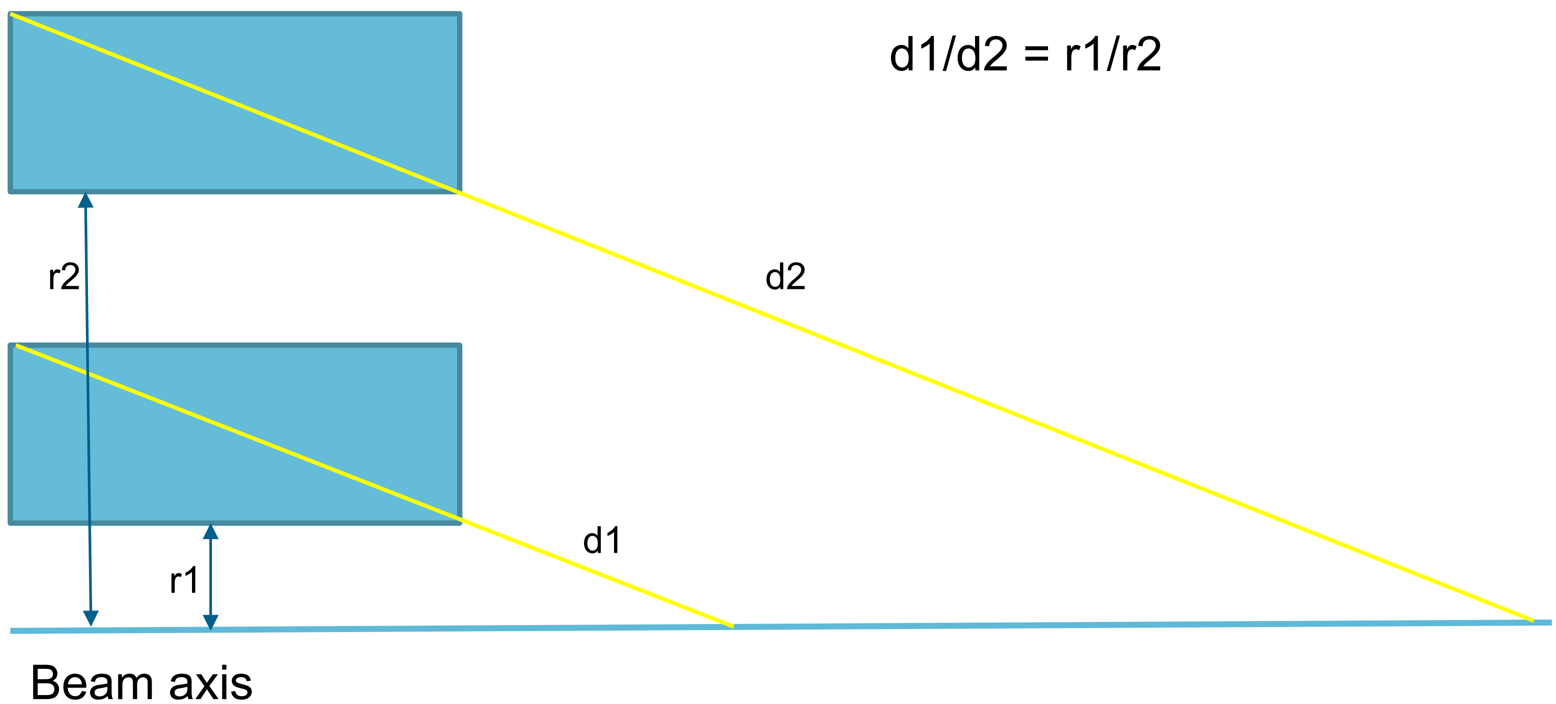
Use two detectors along z



IP resolution depends on **extrapolation** error and **multiple scattering** (at 1st station):

- $\sigma_{IP}^2 = \sigma_{Extrap}^2 + \sigma_{MultScat}^2$
- $\sigma_{Extrap}^2 = \frac{z_1^2 + z_2^2}{(z_2 - z_1)^2}\sigma_{hit}^2$
- $\sigma_{Multscat} = z_1 \frac{13.6\ MeV}{p}\sqrt{\frac{x}{X_0}}$

Detector position and extrapolation error



- The closest to the beam pipe, smaller are extrapolation errors
- Since the **gas target volume is long (2m),** the situation is quite different from LHC experiments with a **few mm long IP center.**