



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

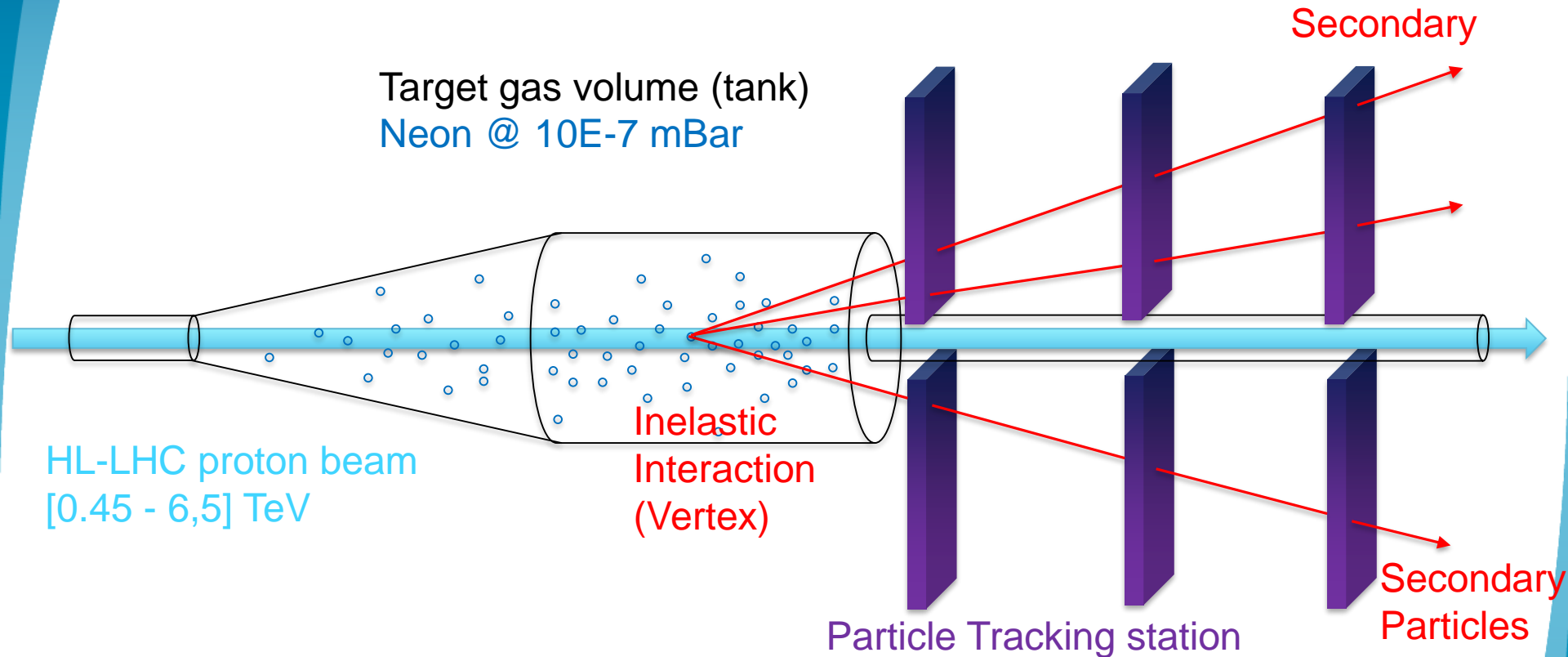


HL-LHC annual meeting 16th of October 2018

Overview

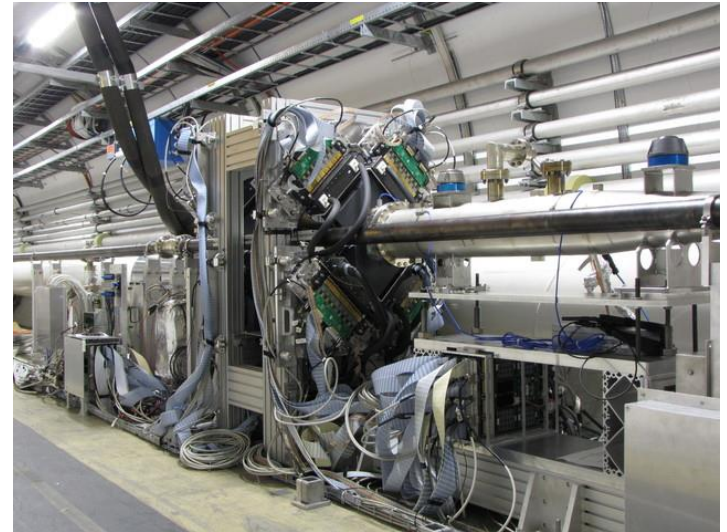
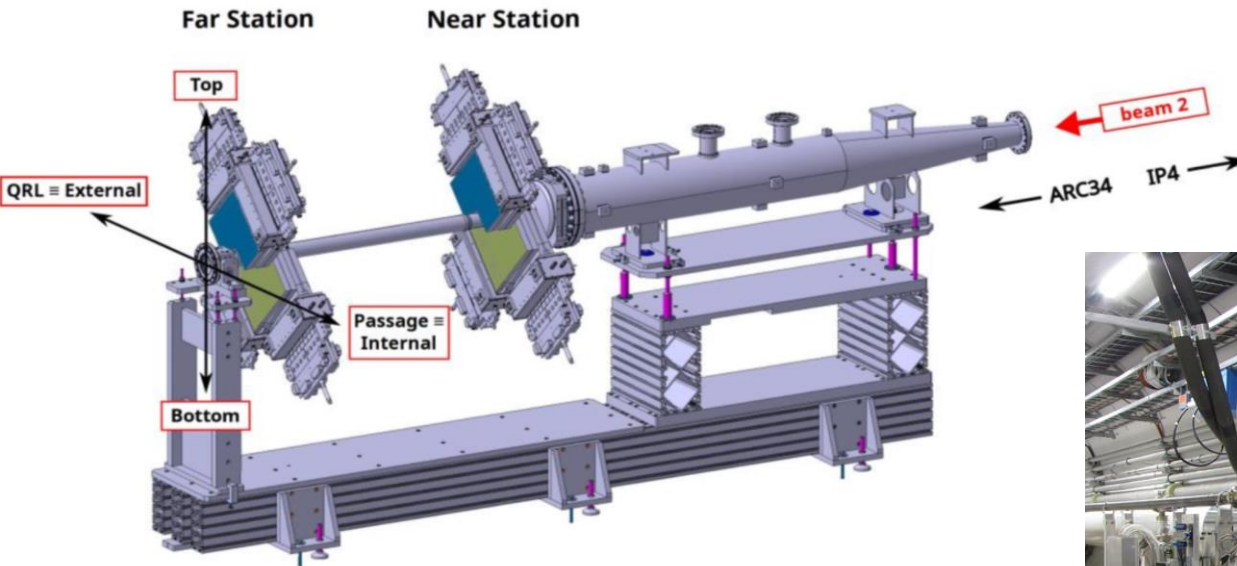
- Intro: Beam Gas Vertex profile measurement.
- The BGV demonstrator in LHC.
- The HL-LHC BGV design.
- Material budget study.
- GEM predesign
- BGV Readout and online processing.

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

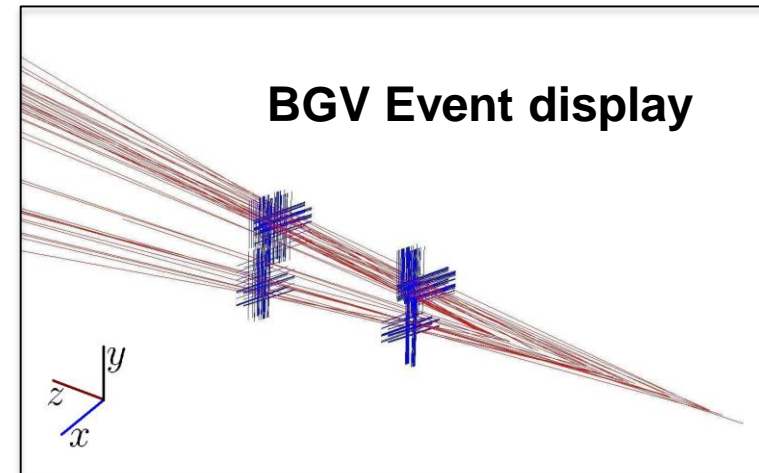


- **BGV Demonstrator** operating in LHC point 4, will be used until the end of this LHC run for full characterization and as a test bench for online processing development.
- Uses **Scintillating Fibers** (SciFi) detector technology from the **LHCb** R&D.

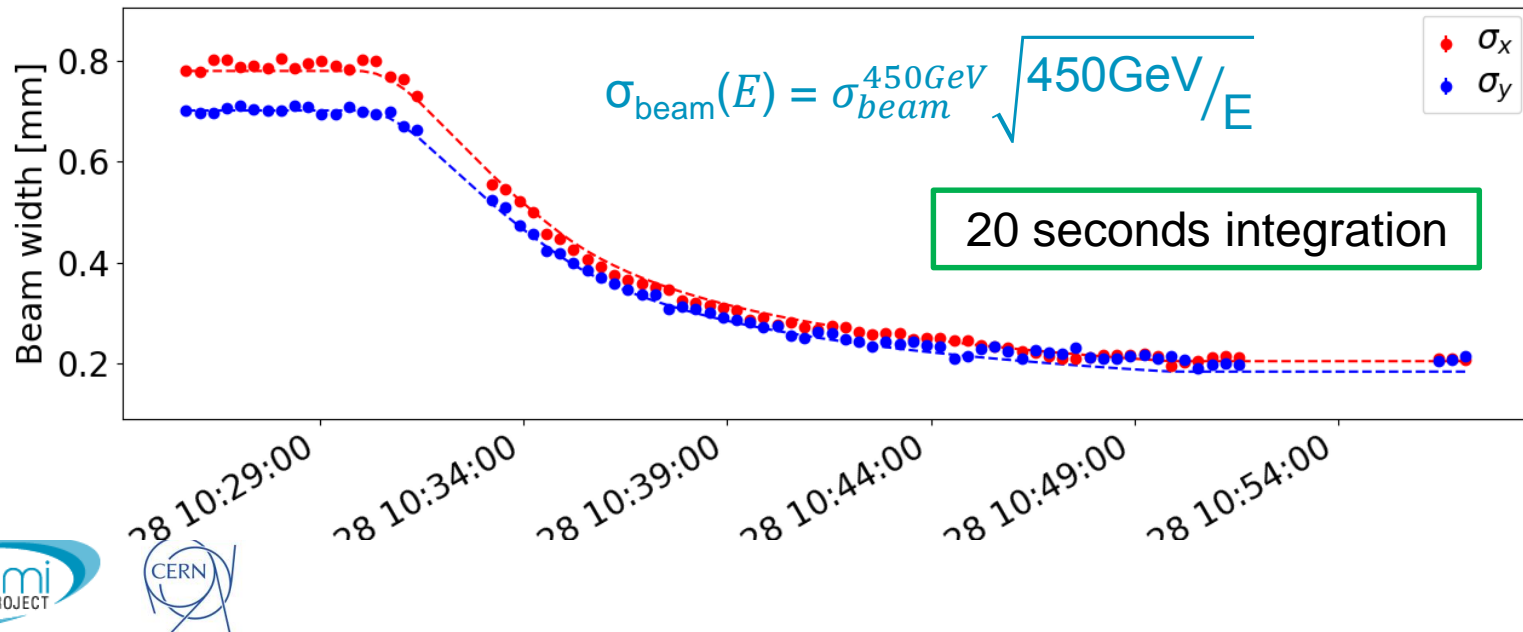
Status of the BGV demonstrator

The BGV demonstrator already provided beam size measurement **in specifications**.

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



Recent Measurement during LHC ramp



Two BGV stations for HL-LHC

Up to now

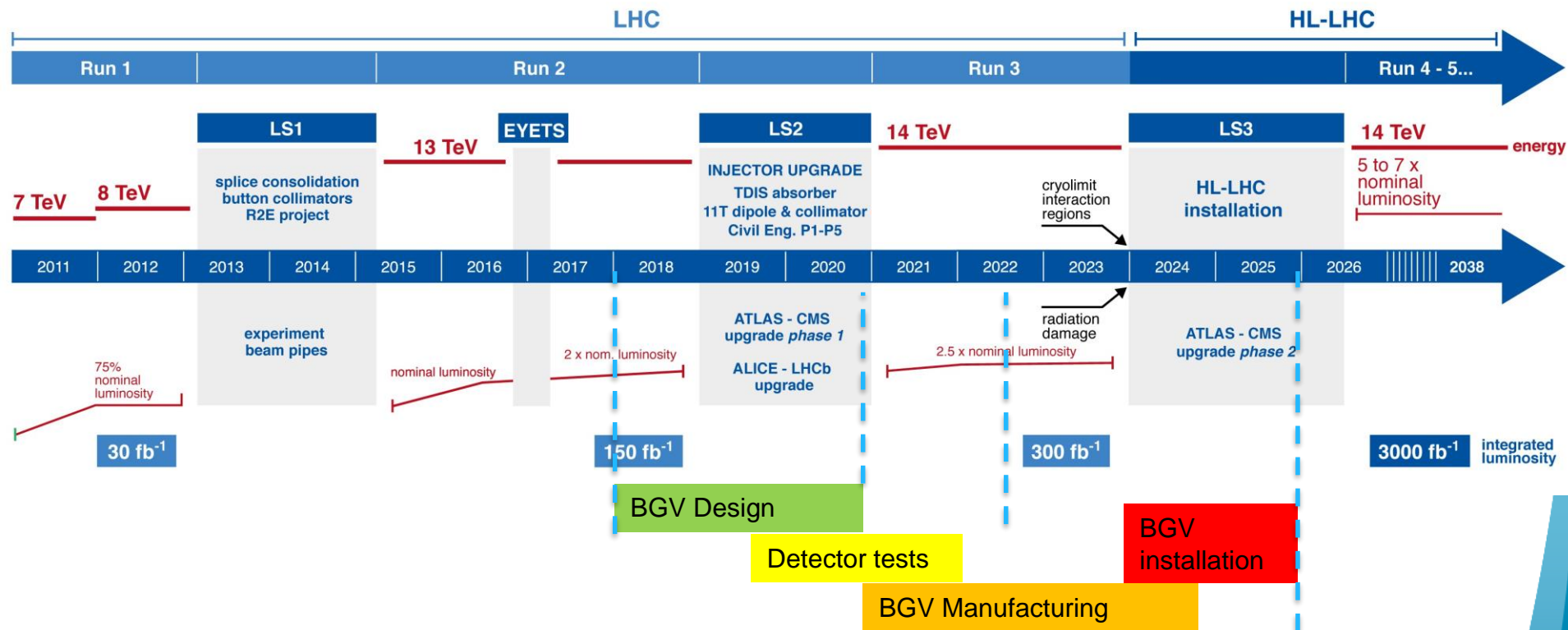
- The BGV is currently the **only device able to measure the LHC beam size continuously during the ramp** with full physics beam loading!
- Work is ongoing to demonstrate **online processing** of the data and publication of the beam size measurement to the accelerator database in **real time**.
- We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

The future...

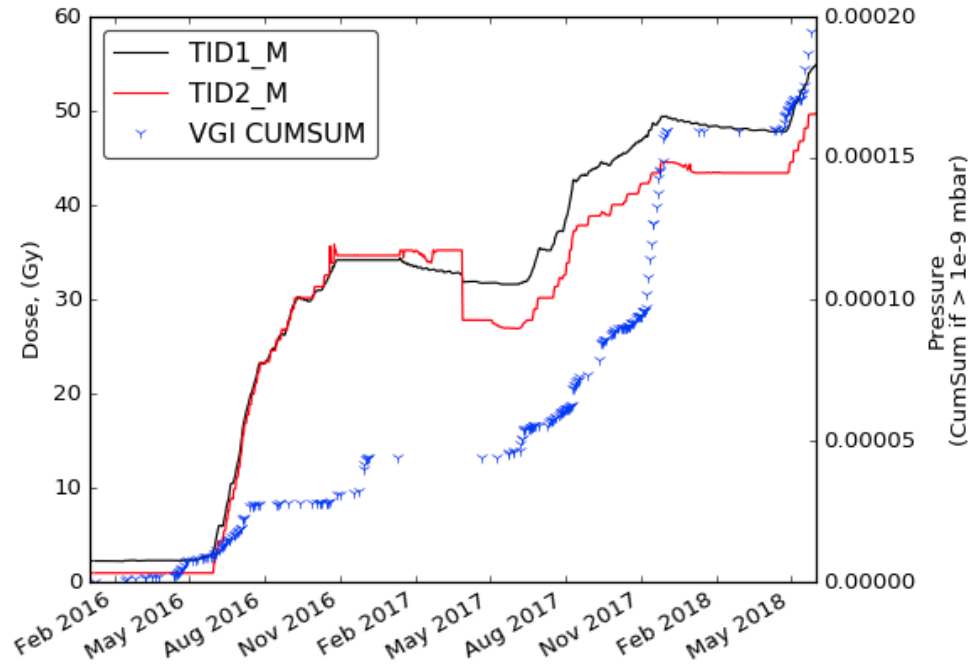
- From this fruitful preliminary experience, an **optimized BGV is under development** to be installed on both HL-LHC beams in LS3.
- The ultimate BGV goal is **single bunch beam size measurement**, it will need significant improvements in terms of **detector design, acquisition, and processing rate**.

Timeline for HL-LHC BGVs

LHC / HL-LHC Plan

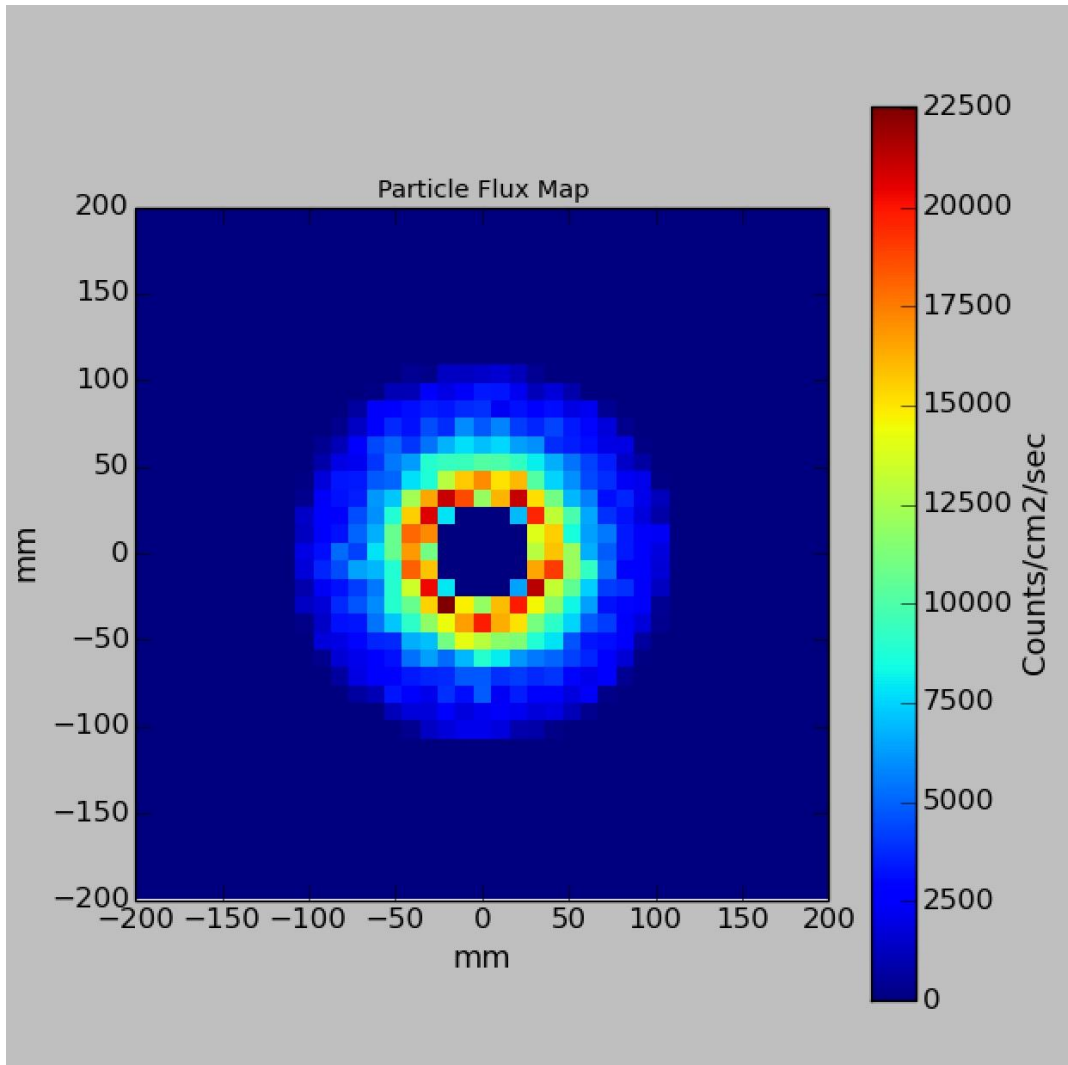


Expected radiation dose



- RadMon located 20 cm from beam axis (downstream from 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.
- 150Gy/year -> need to confirm with the HL-LHC FLUKA model

Expected Rate in the first detector layer

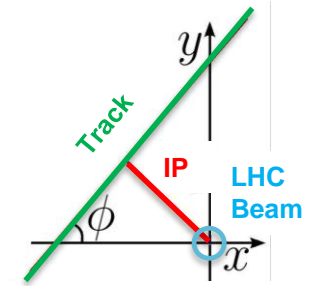
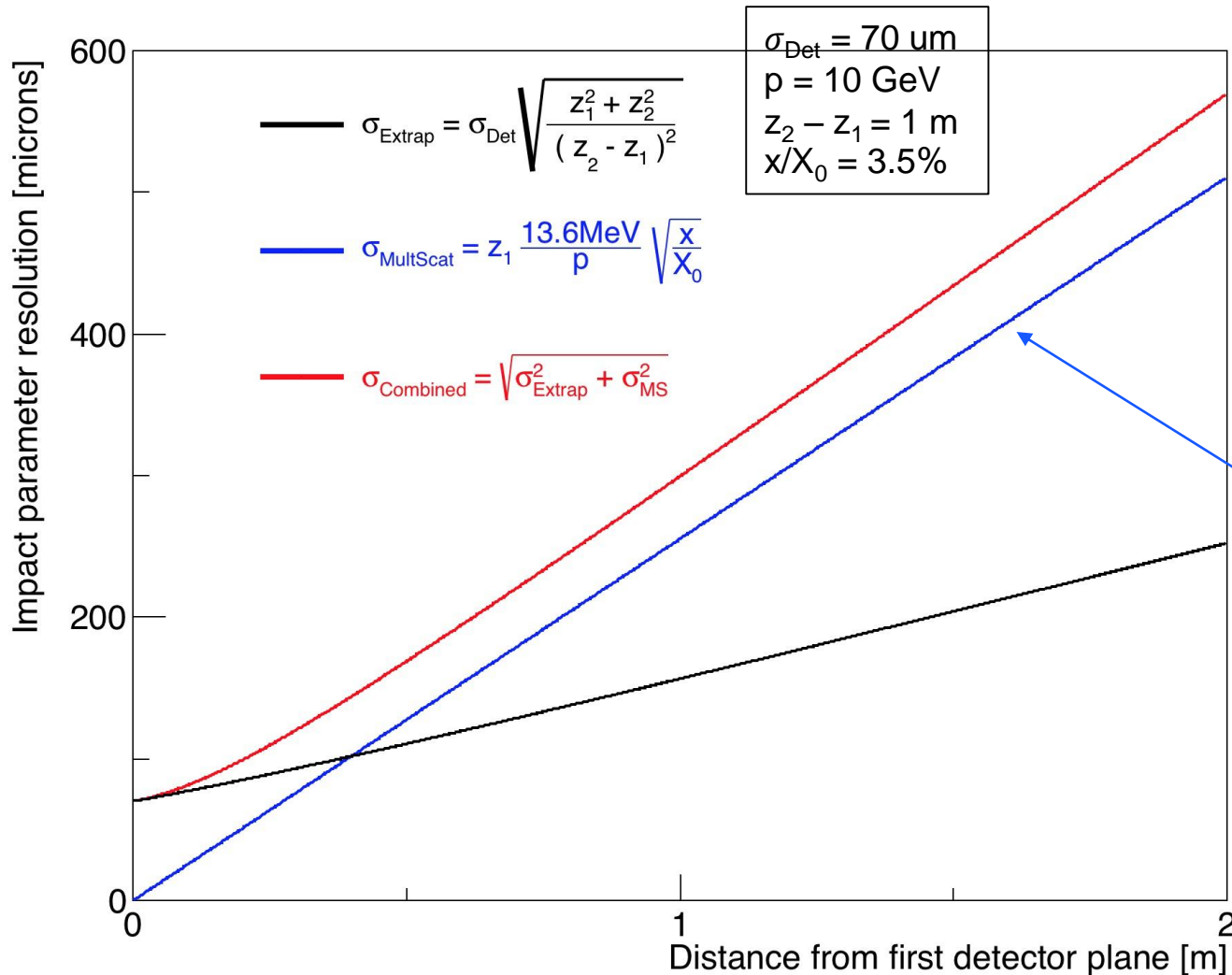


Full LHC train (2808 bunches) produce about 200kHz of beam-gas interactions in the gas target.

Collision rate of 80Hz/bunch

A maximum **secondary rate of 25kHz/cm²** is expected in the first detector layer.

BGV demonstrator Impact Parameter (IP) Resolution



MULTIPLE SCATERING is the BOTTLENECK for track IP resolution !

Designing a low material budget BGV

Material budget contributors

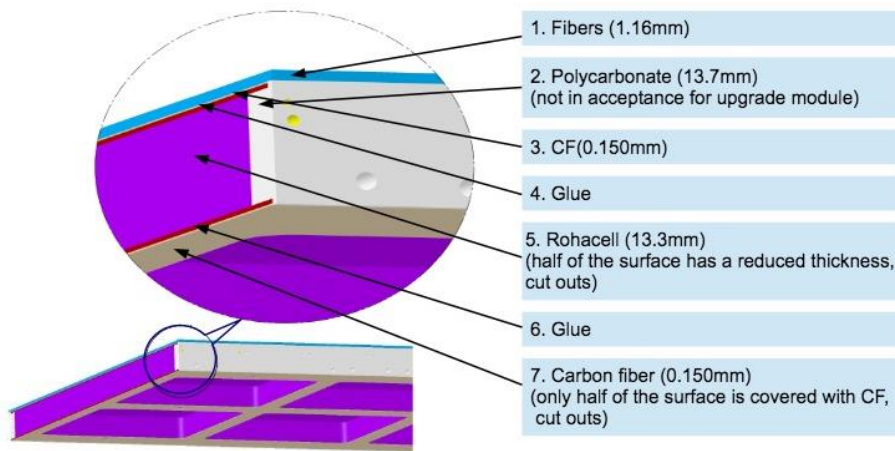
Gas target exit window

- Current BGV demonstrator exit window is **1.124% of X_0**
- A new exit window design might reduce it by **a third**.

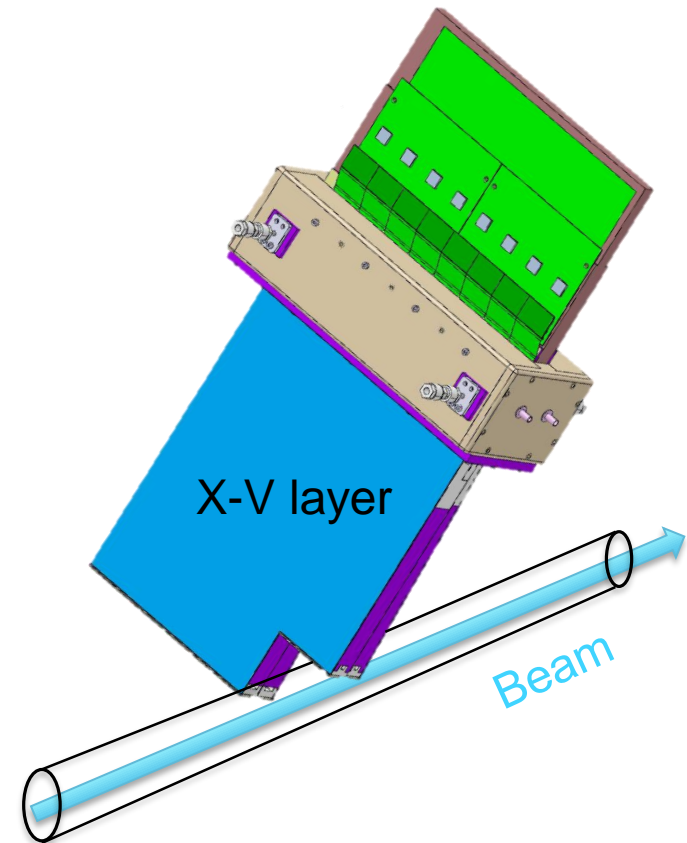
Tracking sensors candidates:

- Multi-pattern gaseous detectors (GEM, Micromegas)
- Silicon strip sensors
- Scintillating Fibers as for the BGV demonstrator

The BGV demonstrator SciFi module reference

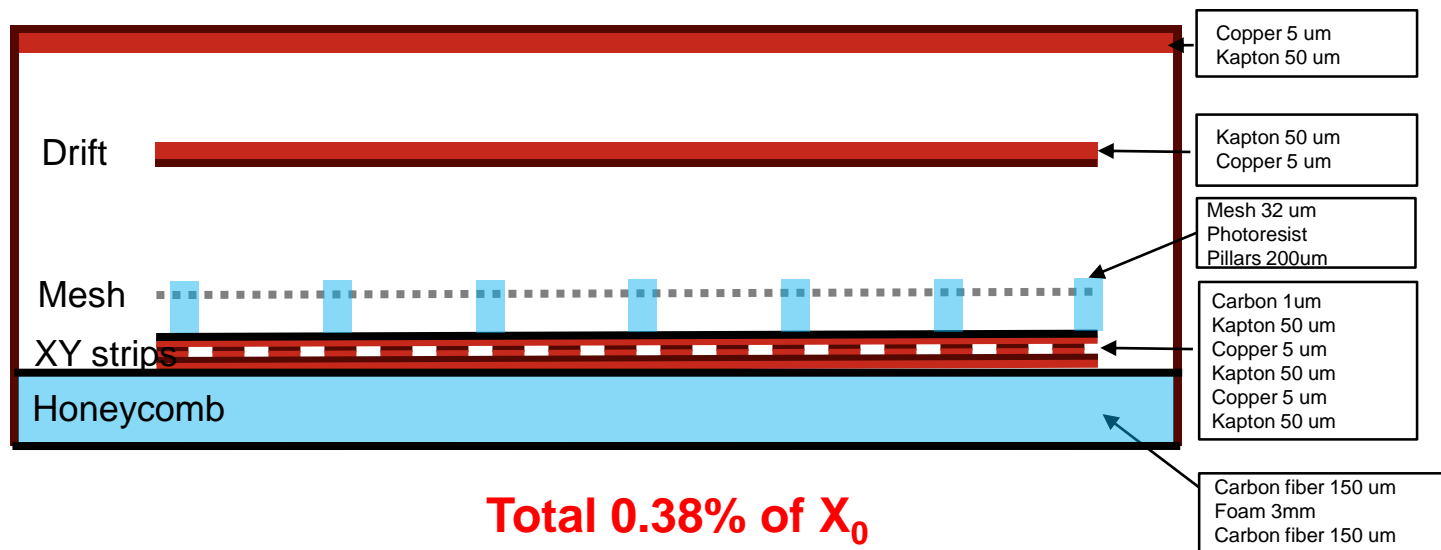
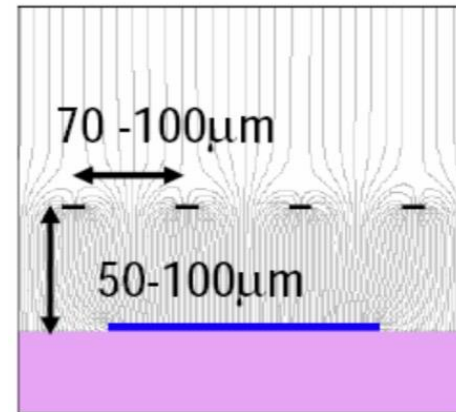
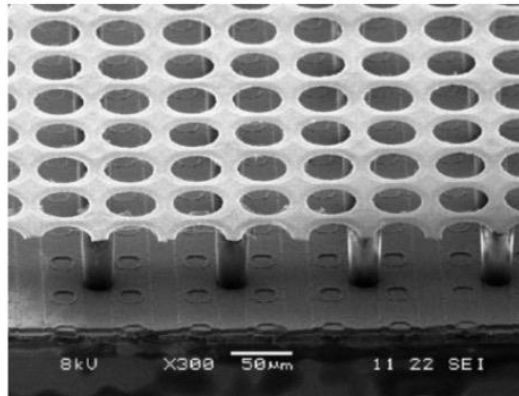


#	Material (rad len [mm])	Thickness [mm]		Rad len of layer [%]	
		Edge	Center	Edge	Center
P1	Scint. Fibers (400)	1.2		0.3	
P2	Glue (400)	2 × 0.1	1 × 0.1	0.05	0.03
P3	Carbon Fiber (237)	2 × 0.15	1 × 0.15	0.13	0.06
P4	Rohacell (8160)	1 × 20	0.3 × 20	0.25	0.07
SUM	Single layer			0.73	0.46
2 × SUM	Module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

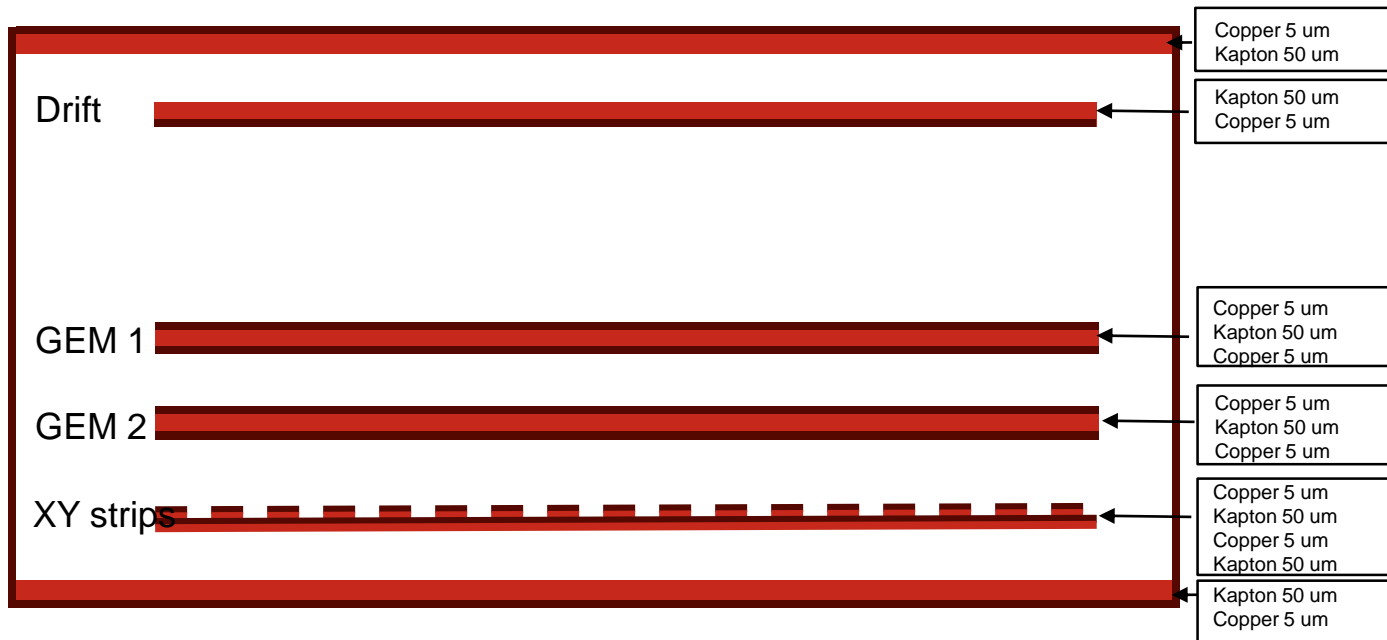
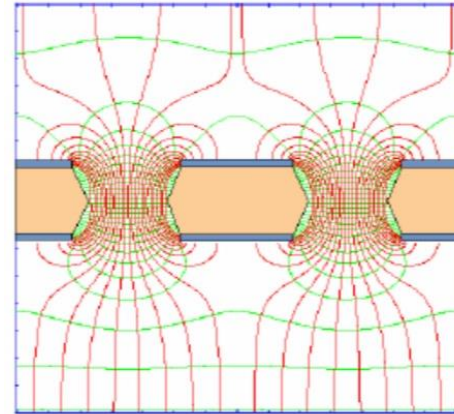
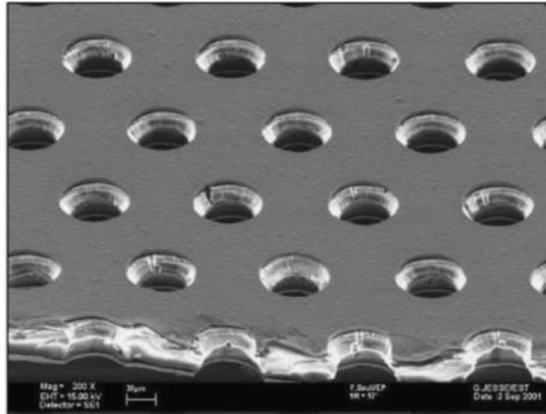


In average we have **1.2% of X_0** over the surface for a X-V layer (equivalent to an X-Y)

Micromegas with XY strip readout

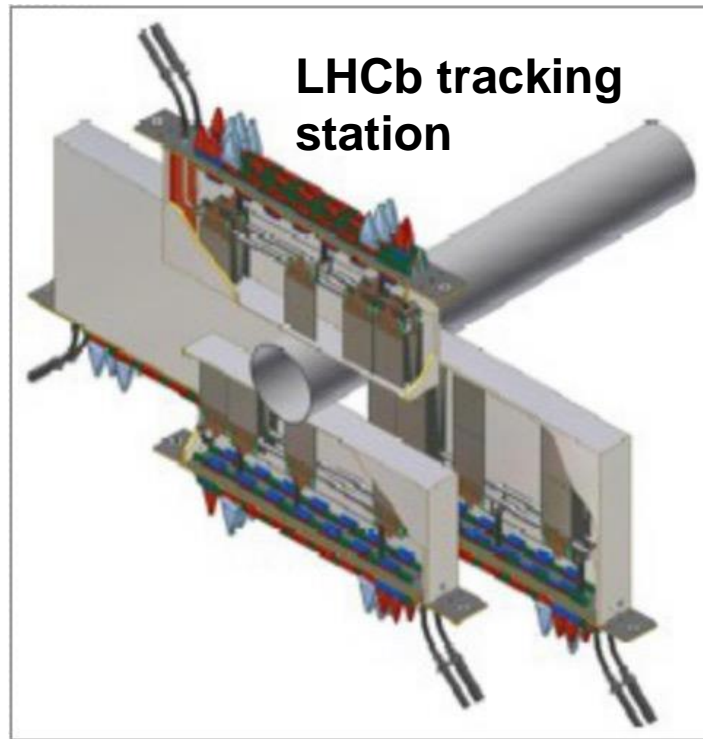


Double GEM structure with XY strip readout

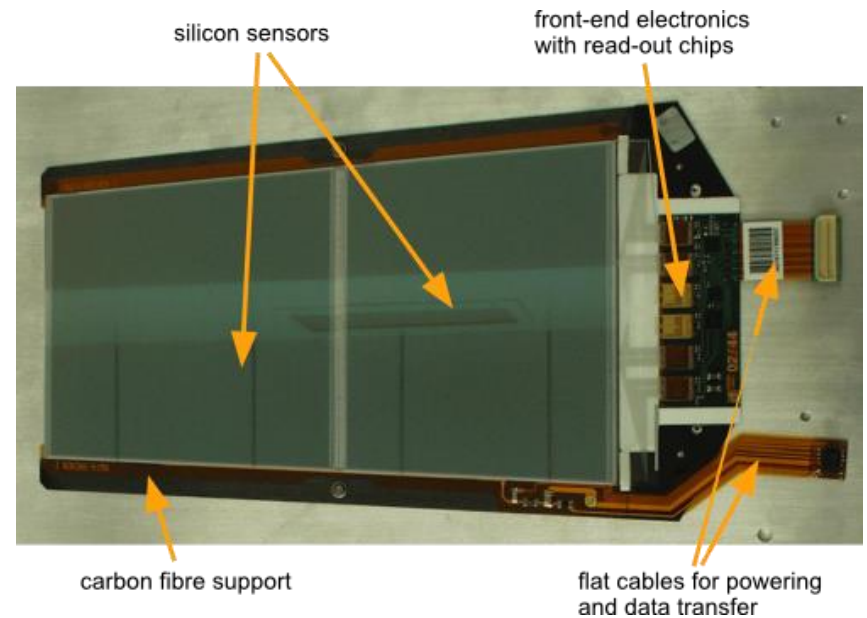


Total 0.34% of X_0

Silicon strip sensors

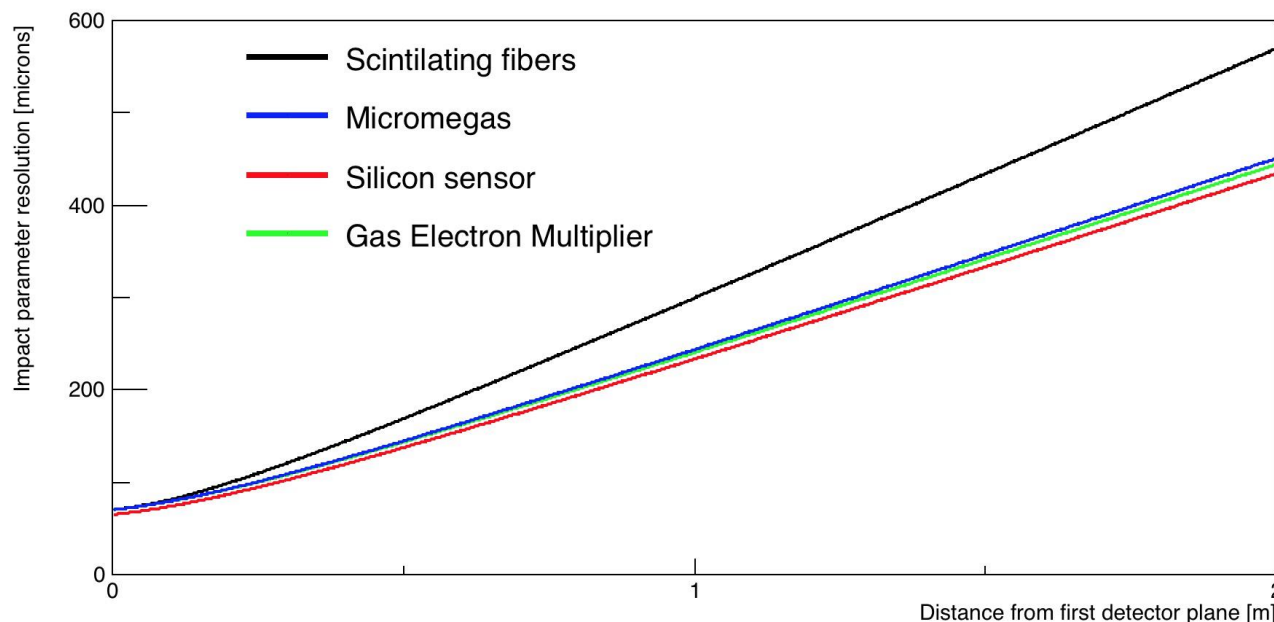


CMS tracker module



Commercially available but quite expensive.
Total 0.34% of X_0 (for 320um silicon thickness)

Example sensor technology comparison

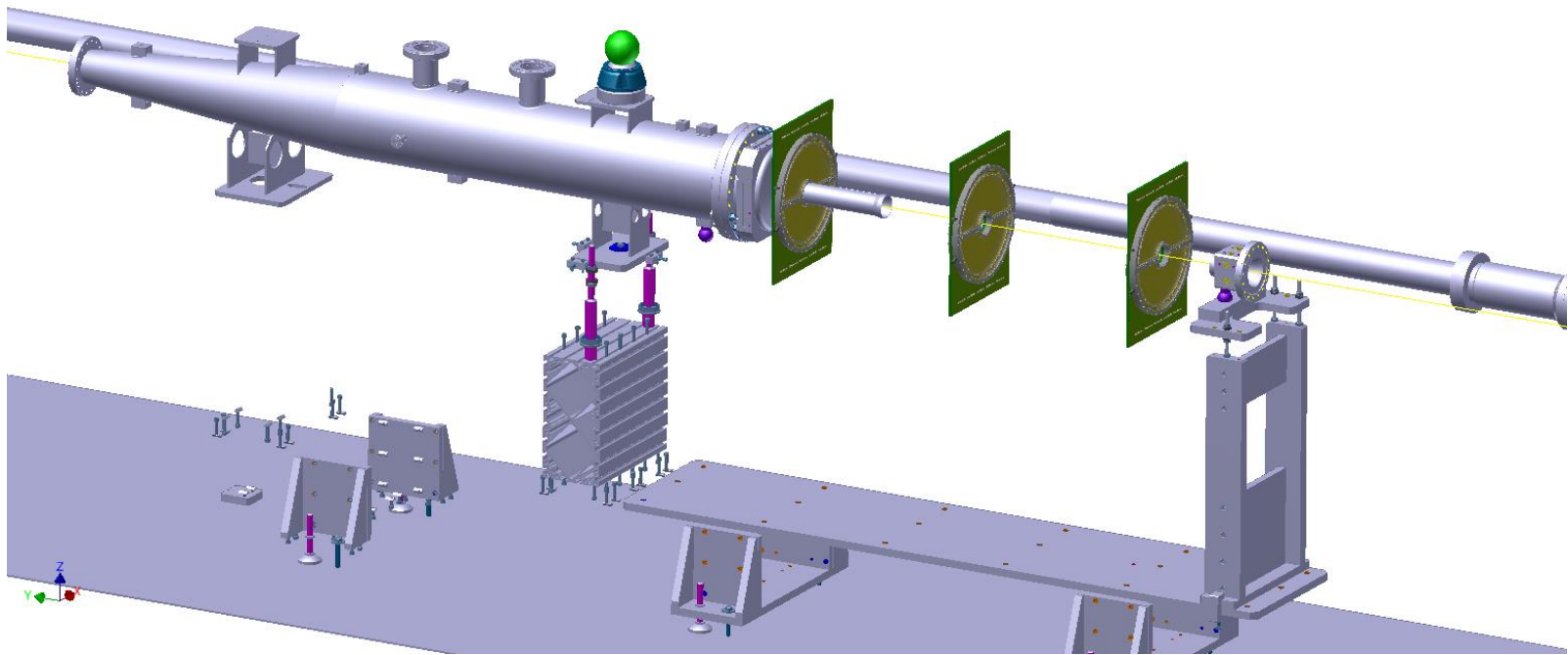


Sensor	Double (triple) GEM	Micromegas	SiFi (Fibers)	Silicon
Spatial resolution [μm]	70	70	70	65
Pitch [μm]	400	400	250	200
Material budget [% of X_0]	0.34 (0.4)	0.38	1.2	0.34
MIP Signal (mean) [fC]	30-50 (Gain: 10^4)	20-25 (Gain: $5 \cdot 10^3$)	1800	5
Sensor cost				

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

robert.kieffer@cern.ch

LHC-BGV preliminary GEM design



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

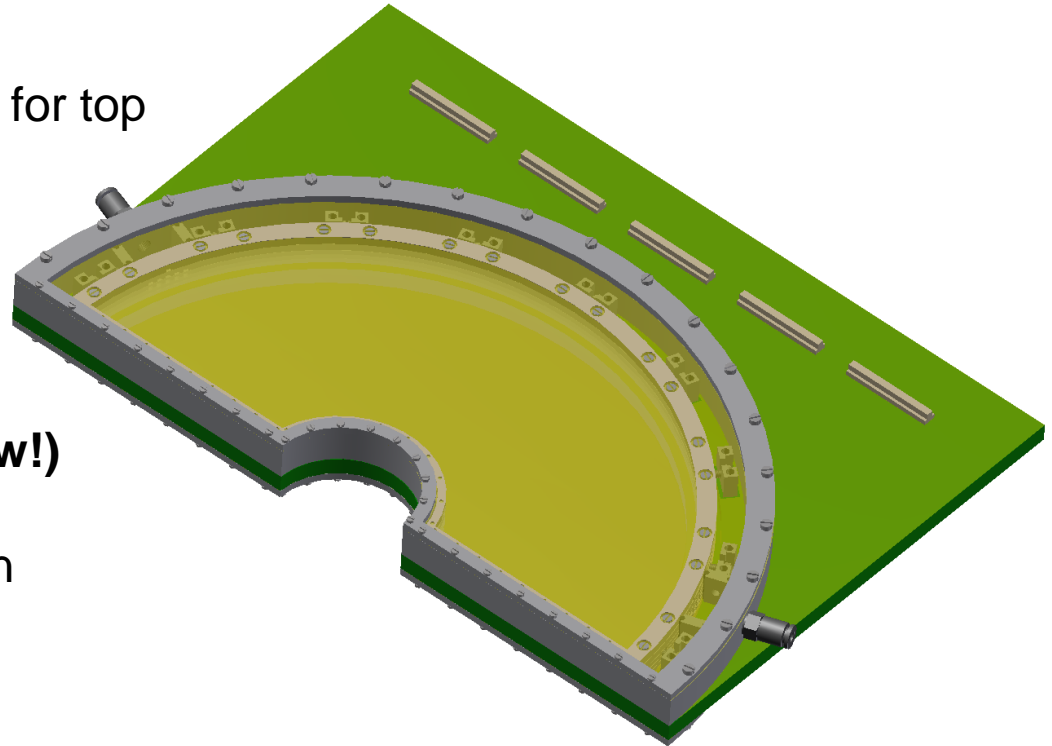
“CMS style” dismountable triple GEM

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

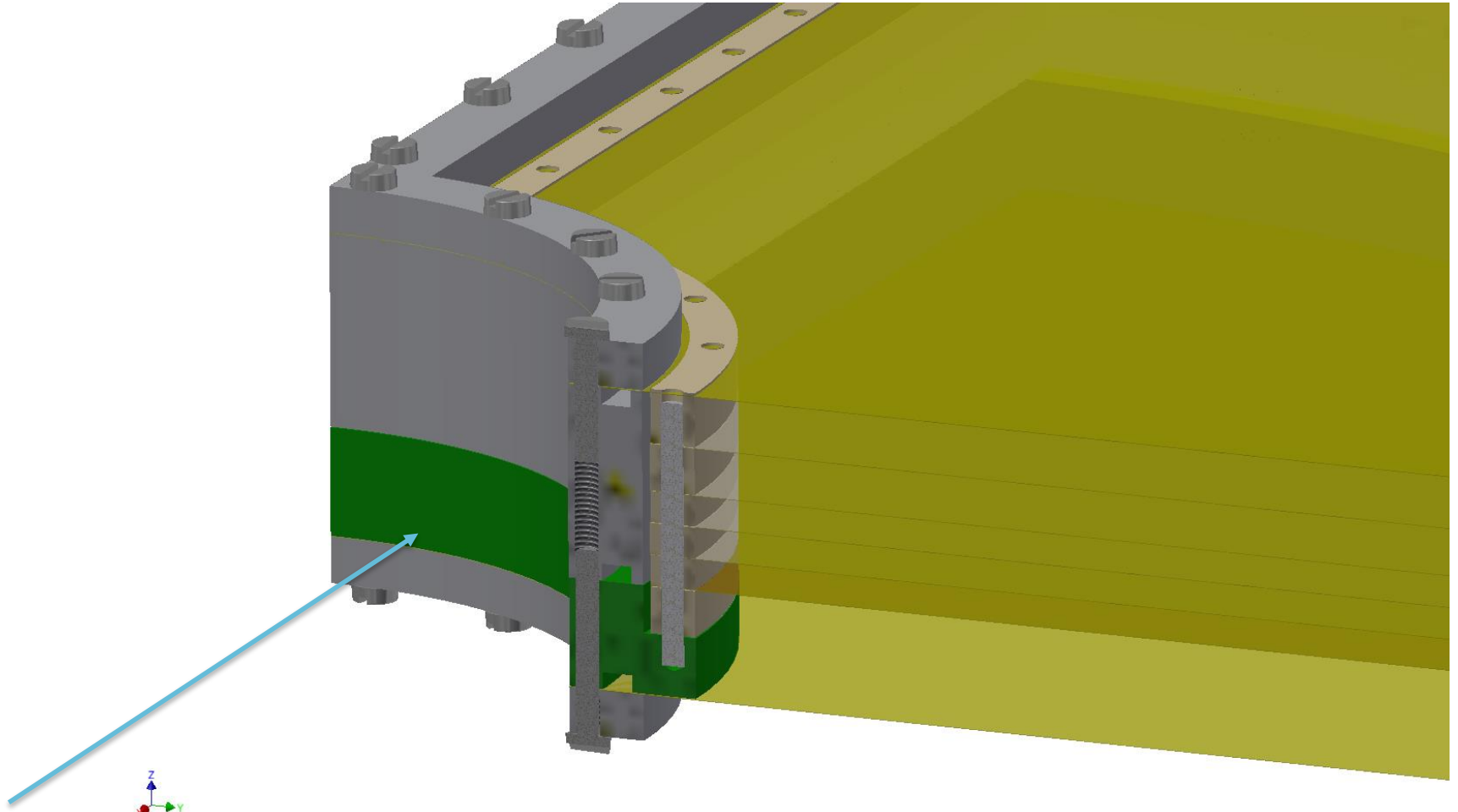
Total of **12 half-moon detectors** for top and bottom (15cm radius).

Detector Half-moon

- Double GEM configuration
- Readout strips **stretched (New!)**
- Strip Pitch: **400 μm**
- Goal: **50 μm** position resolution
- XY Strips: $640 \times 2 = \mathbf{1280 \text{ ch}}$
- Readout: **20 VMM ASICs** (64 channels)



“CMS style” dismountable triple GEM

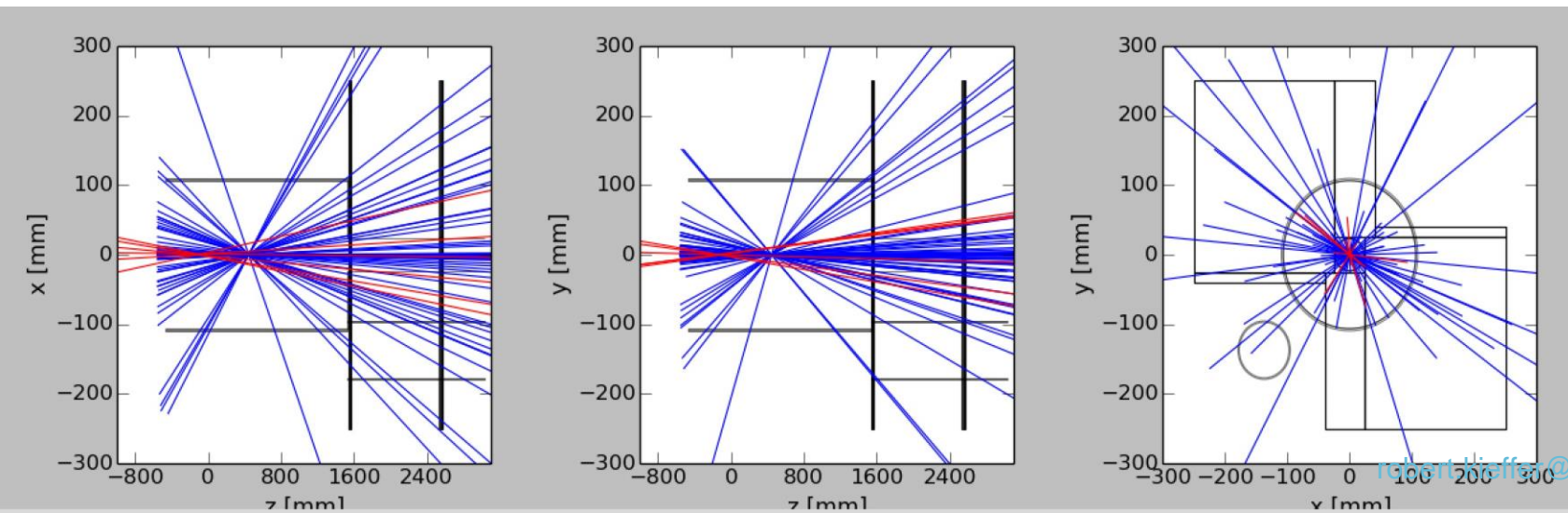
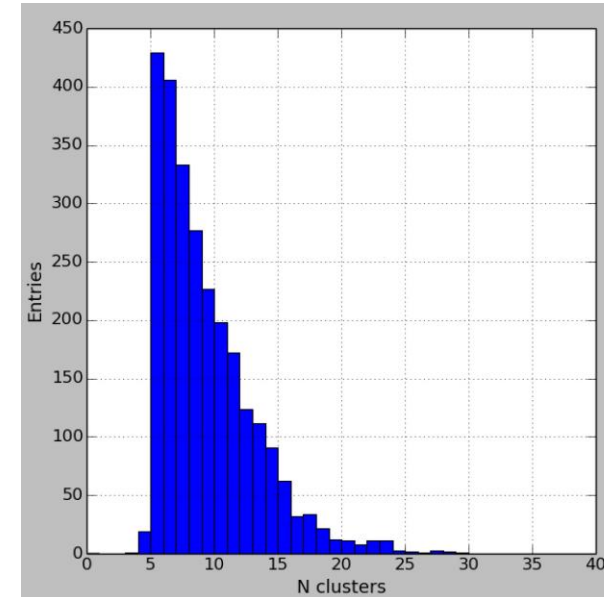


- Minimization of the material used in between the beam pipe and first sensitive area of the GEM.
- The objective is to reduce the **multiple scattering in dead structural zones**.

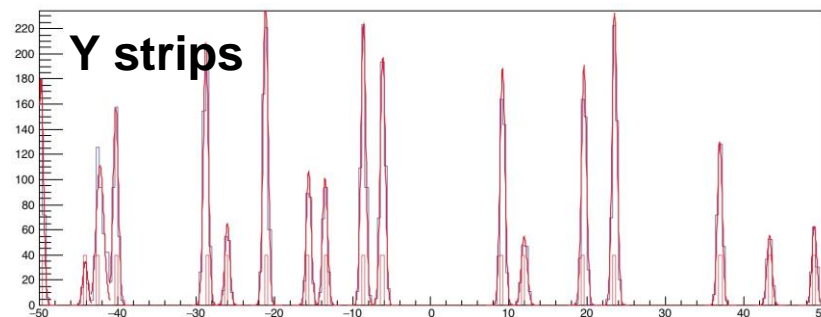
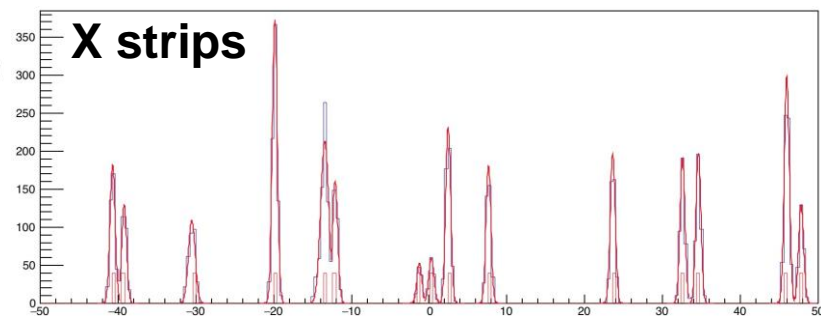
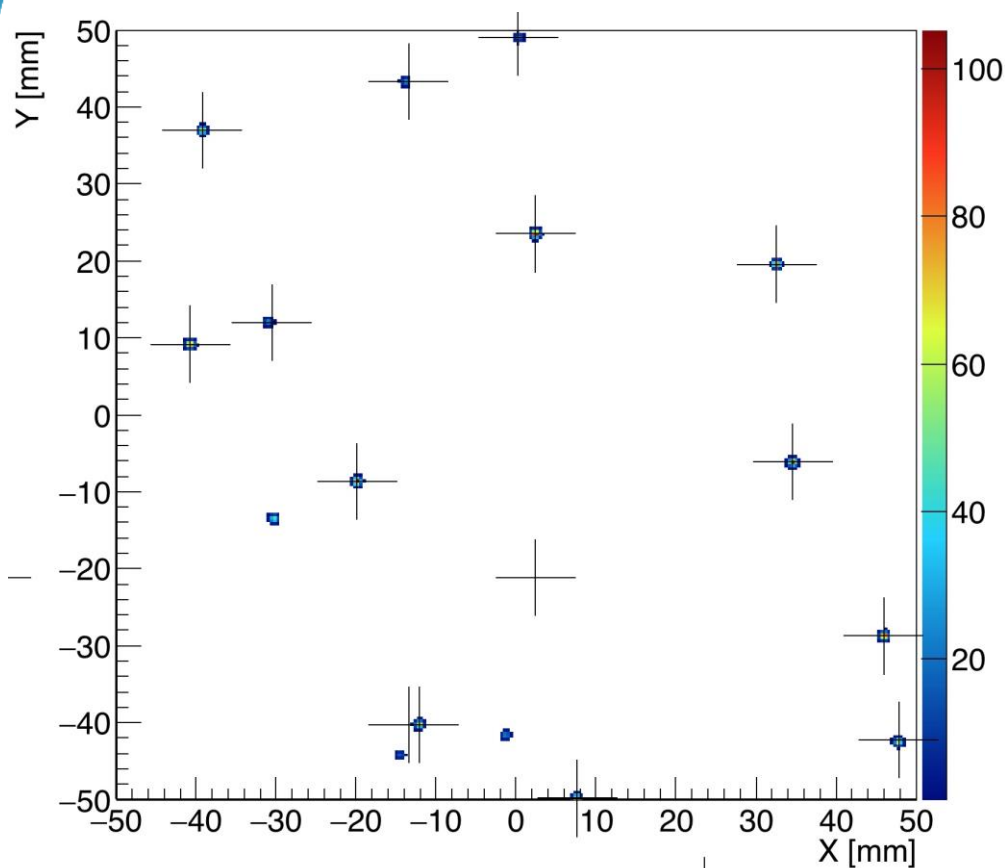
Readout layer Pattern Study

Consideration concerning the event topology

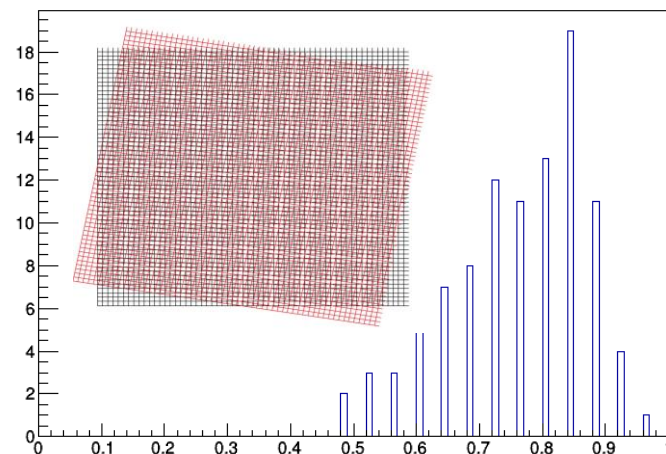
- Up to 25 clusters for a GEM layer in a single event.
- Use of two consecutive layers to discard Ghost clusters. (XY and X'Y' tilted by few degrees)



XY strip readout with 25 cluster to be found



Matched Cluster Ratio



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

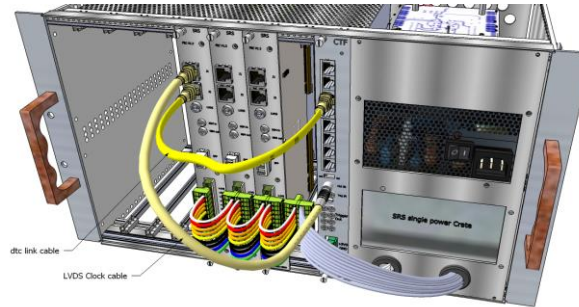
1. Mono-dimensional Clustering
2. XY Cluster matching over two layers

Readout Scheme for HL-LHC BGV

Front end Hybrid VMM



FPGA data concentrator



CPU network



The **VMM3a chip** is a good candidate for our readout scheme, it can read both **MPGD** and **silicon** sensors. Features: [ns] time stamp, 7bit ADC, auto-triggering.

The **FPGA data concentrator** system would be based on the BI standards (VFC) for better integration, and long term maintainability.

The **CPU network** can be scaled up in time to reach **higher online processing rate**. It is currently our limiting factor since we have only 5+1 computing nodes for the BGV demonstrator.

Conclusions and perspectives

- The **HL-LHC BGV** is still at the **design phase**.
- The **gas target tank** upgrade might be beneficial.
- The **GEM** seems to be a **promising option** for the tracking technology (cheap, robust, low MS).
- The final readout scheme intend to use **BI-standards (VFC)** with the **VMM readout chip**.
- **Time** is not the issue but **resources** are low.

Thanks for your attention!

Backup Slides

GEM vs Micromegas in the BGV case

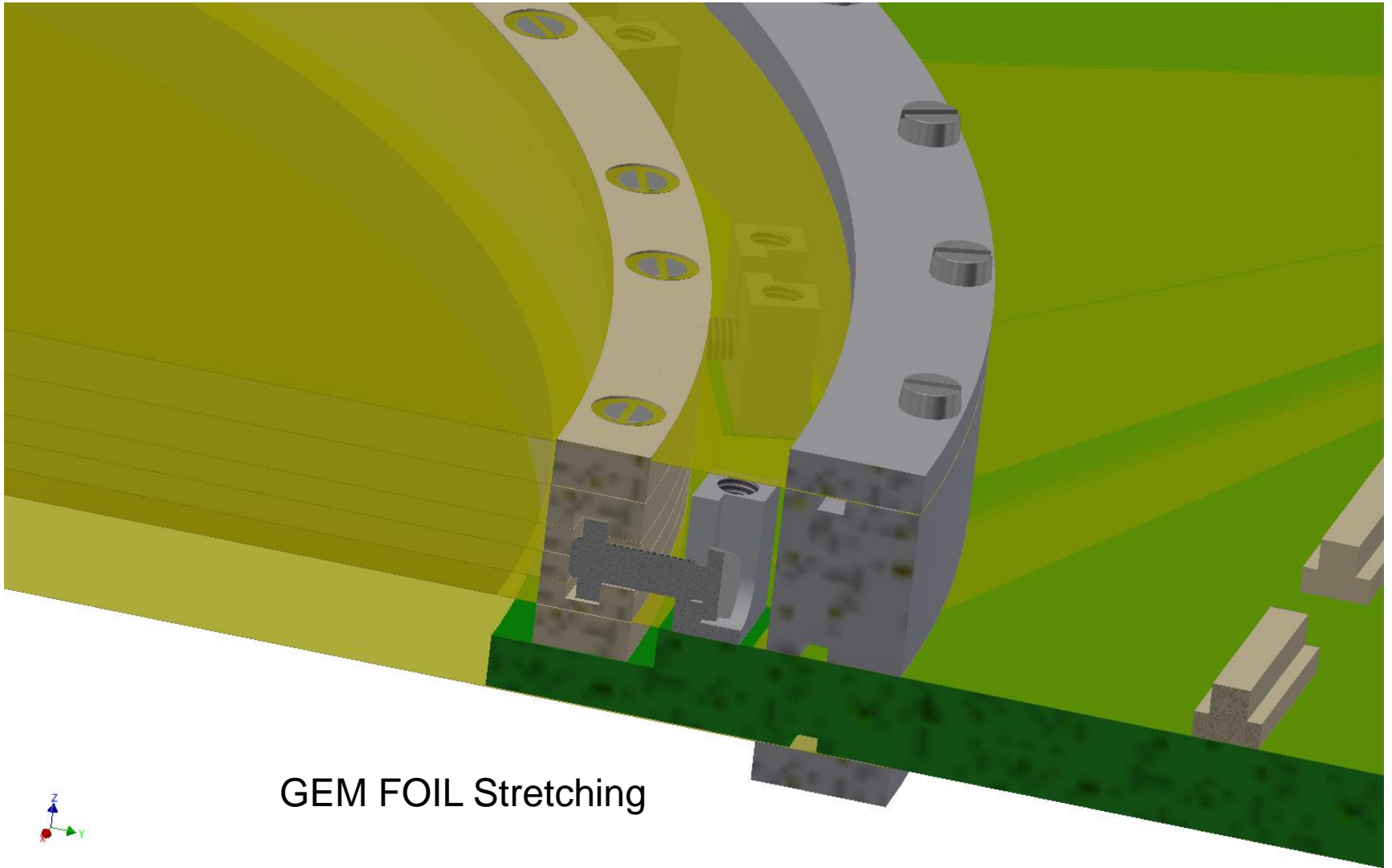
Both **GEM** and **MM** could eventually be build with similar material budget even though the GEM reach smaller budget.

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

“CMS style” dismountable triple GEM



GEM FOIL Stretching



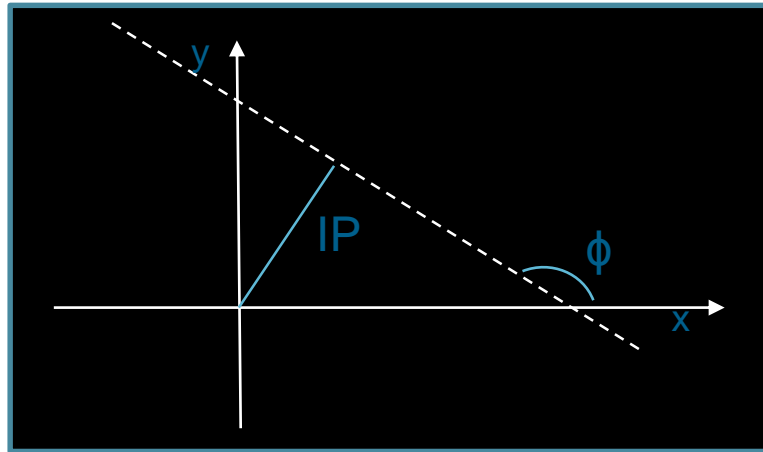
The TOTEM GEM modules for comparison

Item	Details	$^{\circ}/_{oo}$ of X_0
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

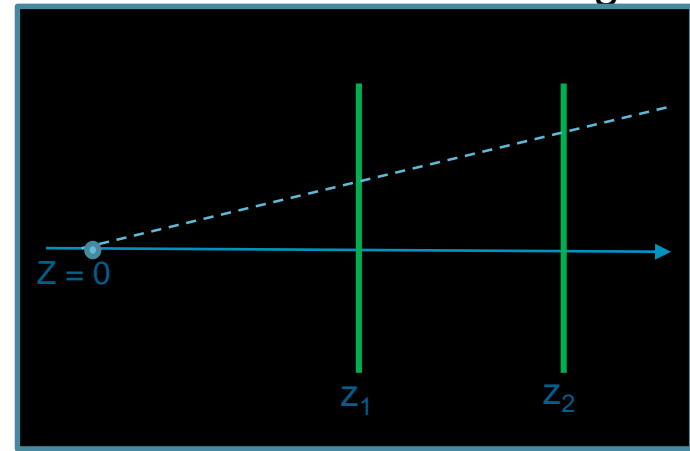
0.719% of X_0

Table 1.1: Material in one GEM detector

Impact Parameter (IP) Resolution



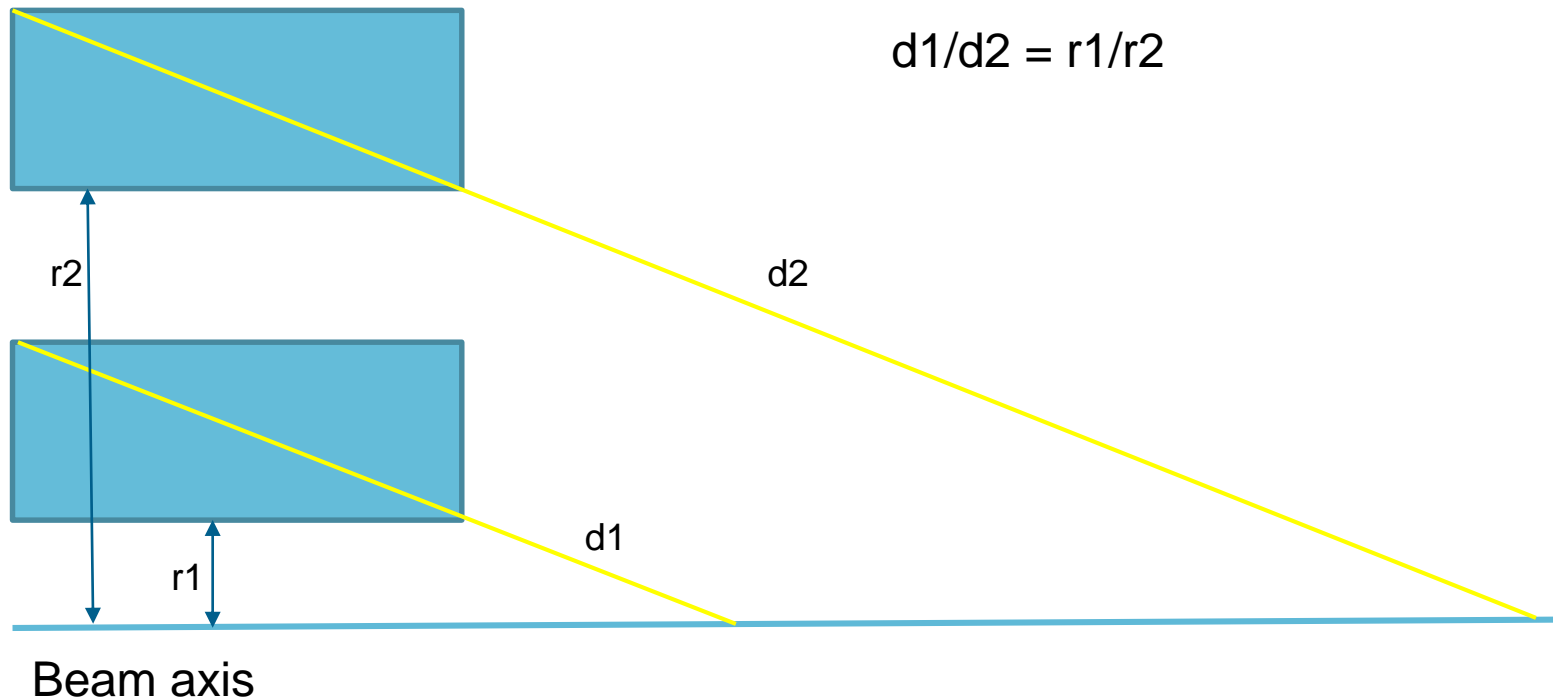
Use two detectors along z



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

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

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**.

Readout Scheme for HL-LHC BGV

CPU network

Control Machine

To control SRU Master operation
Data acquisition
Node IP configuration
Triggering mode, etc...

Asynchronous load balancing between SRU FPGA buffer and event processing nodes (10GB Ethernet)

CPU FARM (20 NODES)

High Level Event filtering
Tracking
Vertexing
Correlation DOCA (Save clusters)
Forward Correlations

Profile Histogram Builder Node

To CCC displays

SRS

SRU FPGA MASTER

- Bunch pattern selection
- Time Stamp based Selection of events using trigger timestamp matching (window for few consecutive BCID).
- Trigger rejection based on CPU FARM load

LHC_CLK and TurnClock

L0 Coinc Trigger (scintillators based)
Trigger +
+ Confirm
+ No_Veto

DTCC

16 x SRS-FEC

SRS-FEC and Adapter to VMM
Data collection and buffering from many VMM

SRS-FEC

DTCC link

- Slow control
- Fast commands
- Hit Data
- Cluster Data

Front end

120 x VMM Hybrid

VMM

VMM

VMM

VMM

The VMM is self-triggering. It emit data when thresh is reached.

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 640 channels on Y

1280 strips per Half-Moon => **10 Hybrids** needed

For one BGV station

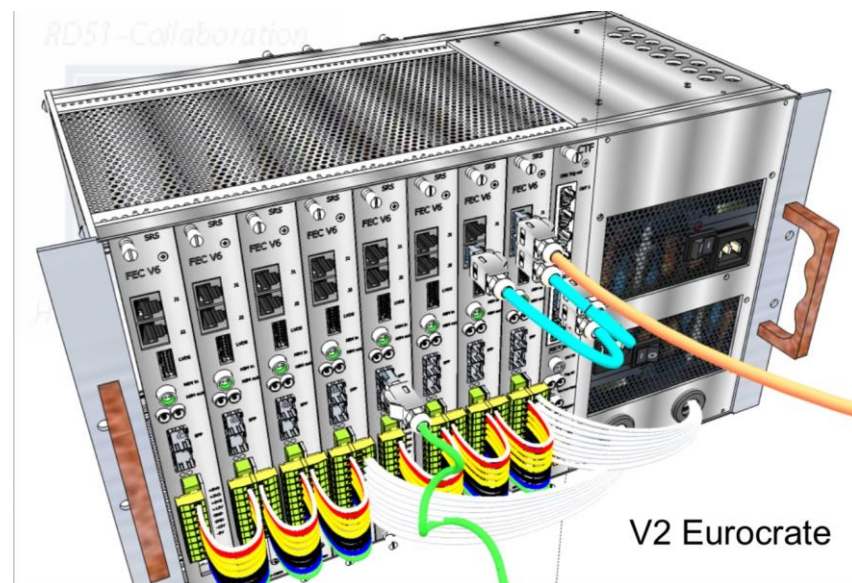
12 Half-Moon detectors => **120** Hybrids to be read-out

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