



Beam Gas Vertex status and upgrade plans

Sotiris Vlachos for the BGV collaboration



HL-LHC Collaboration meeting, Madrid 14 Nov. 2017

Beam Gas Vertex Detector

Non destructive beam size measurement for HL-LHC not limited by accelerator luminosity

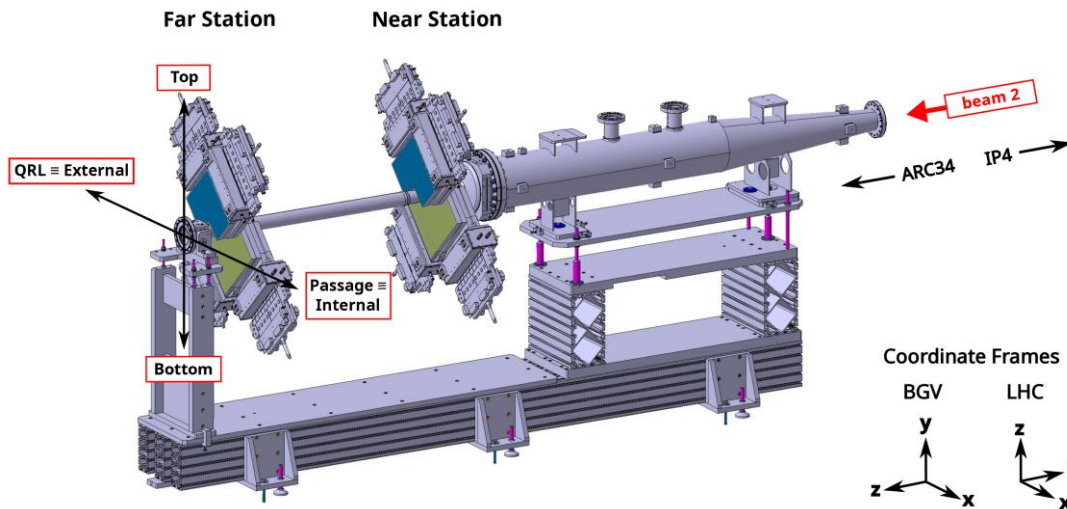
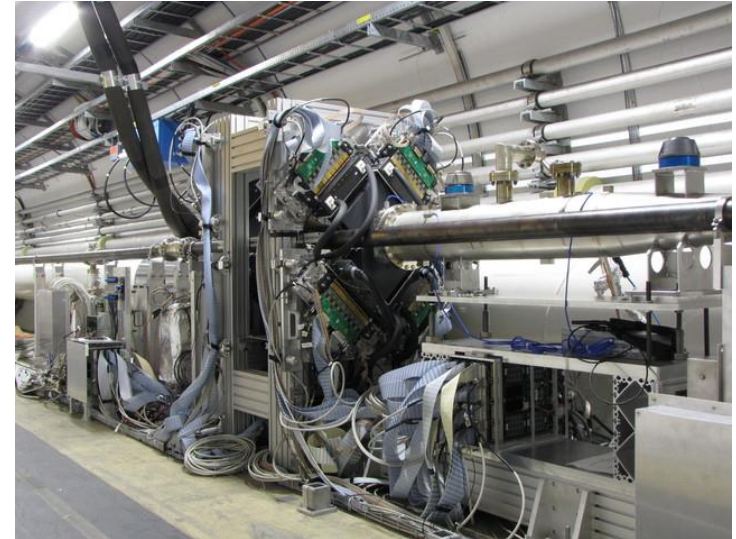
Tracks from beam-gas interactions to reconstruct beam spot
Ne @ 10^{-8} mbar injected at interaction volume

Goals:

statistical uncertainty: 5% in 3 min for 10^{11} p/bunch

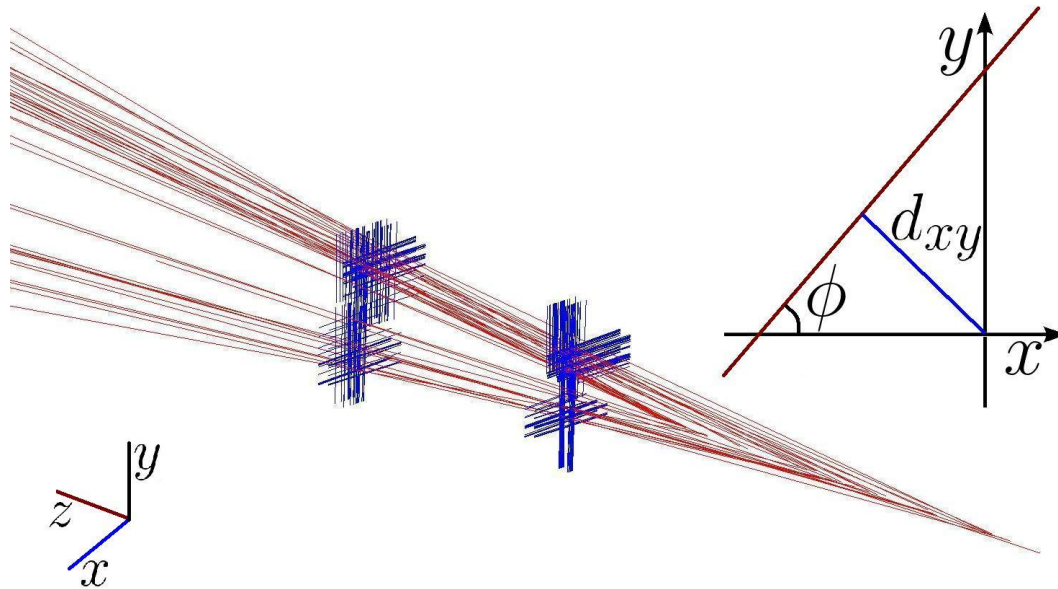
systematic uncertainty (vertex resolution): 5%

Should allow ϵ measurements with similar precision



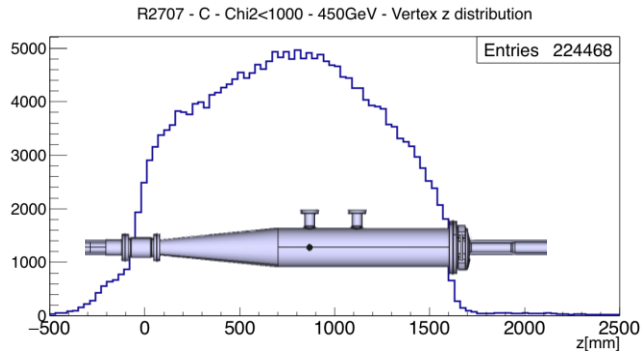
Demonstrator fully commissioned,
Data analysis ongoing

First look at BGV real data



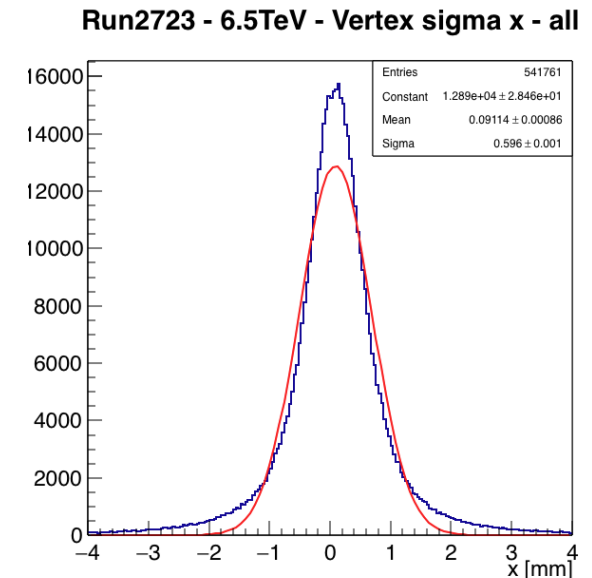
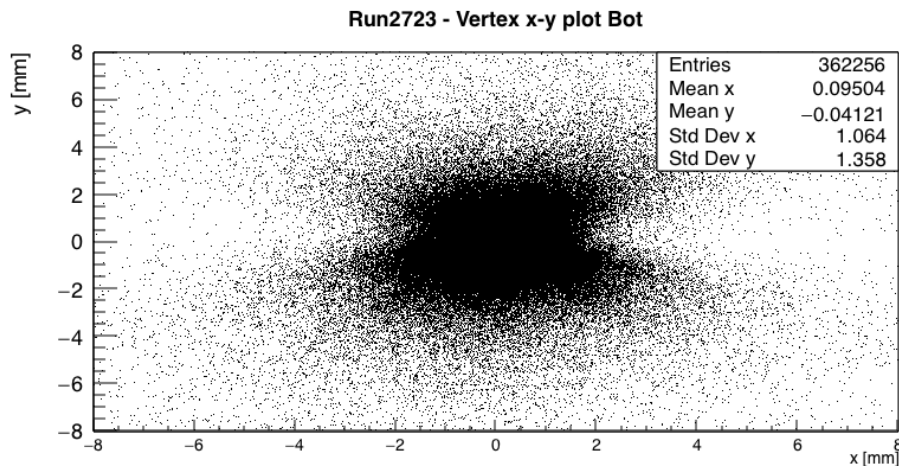
A typical BGV event,
Blue lines : SciFi strips with significant energy deposit
Red lines : reconstructed tracks

Vertex distribution in the BGV gas volume



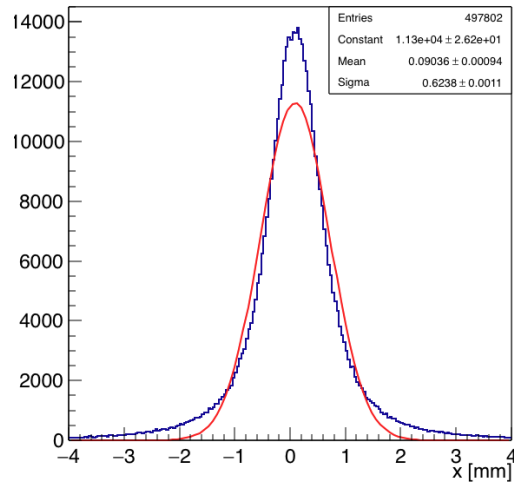
Vertex x-y distribution cannot be used directly for beam profile:

- Convolution of beam width and σ_{vertex}
- σ_{vertex} depends heavily on z (long extrapolation ~ 1 metre)



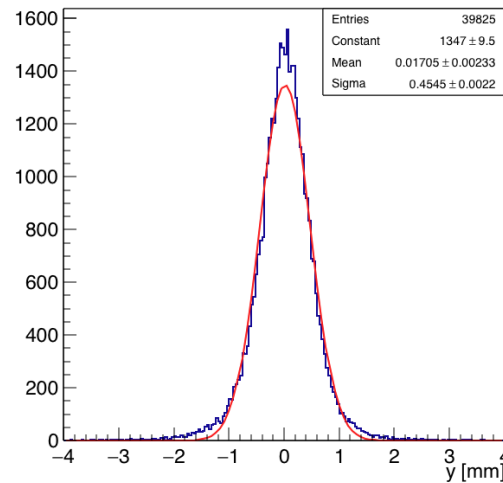
X-projection of vertex distribution

Run2723 - 6.5TeV - Vertex sigma x - 2 Tracks



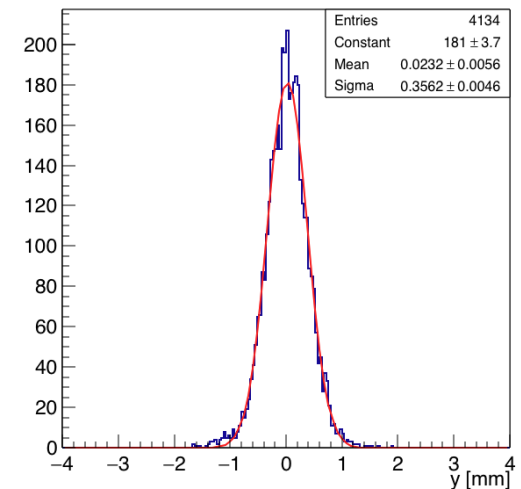
2-prong vertices

Run2723 - 6.5TeV - Vertex sigma y - 3 Tracks



3-prong vertices

Run2723 - 6.5TeV - Vertex sigma y - 4+ Tracks



4-prong vertices

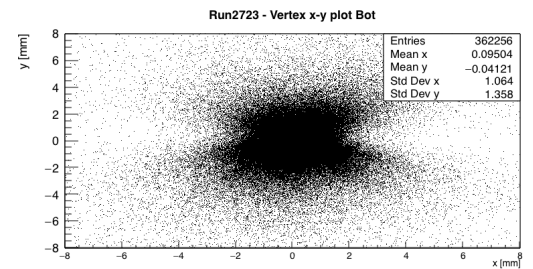
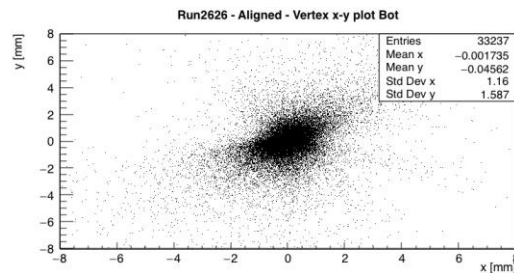
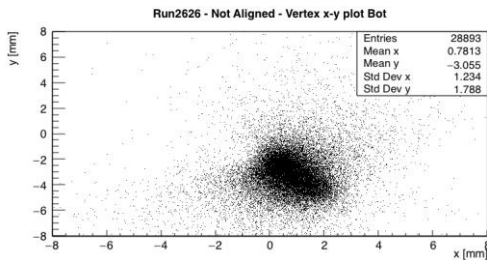
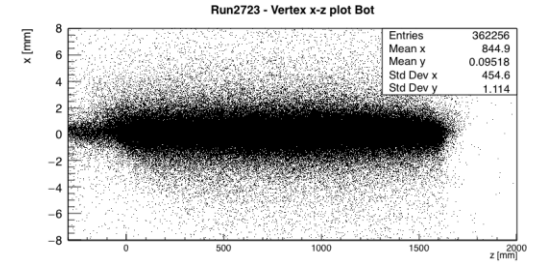
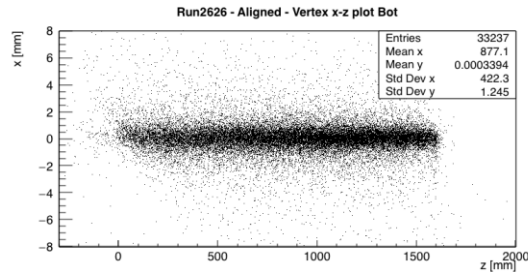
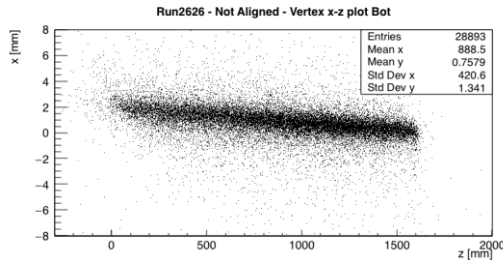
$$\sigma_{vertex} \propto \sqrt{\text{Number of tracks}} \sigma_{IP}$$

High prong vertices allow also better event selection, gaussian position distribution

Vertex reconstruction, Focus along beam direction

Raw data

After relative plane
alignment $O(1\text{mm})$



Run 2626,
used to estimate corrections

Run 2723,
High statistics,
same corrections used

Beam width measurement

IP and ϕ of particles from the same primary vertex are correlated. This correlation for pairs of tracks (1,2 from the same event, with angles ϕ_1 and ϕ_2) is given by:

$$\langle IP_1 IP_2 \rangle = \frac{\sigma_x^2 + \sigma_y^2}{2} \cos(\phi_1 - \phi_2) + \frac{\sigma_y^2 - \sigma_x^2}{2} \cos(\phi_1 + \phi_2 - 2\alpha)$$

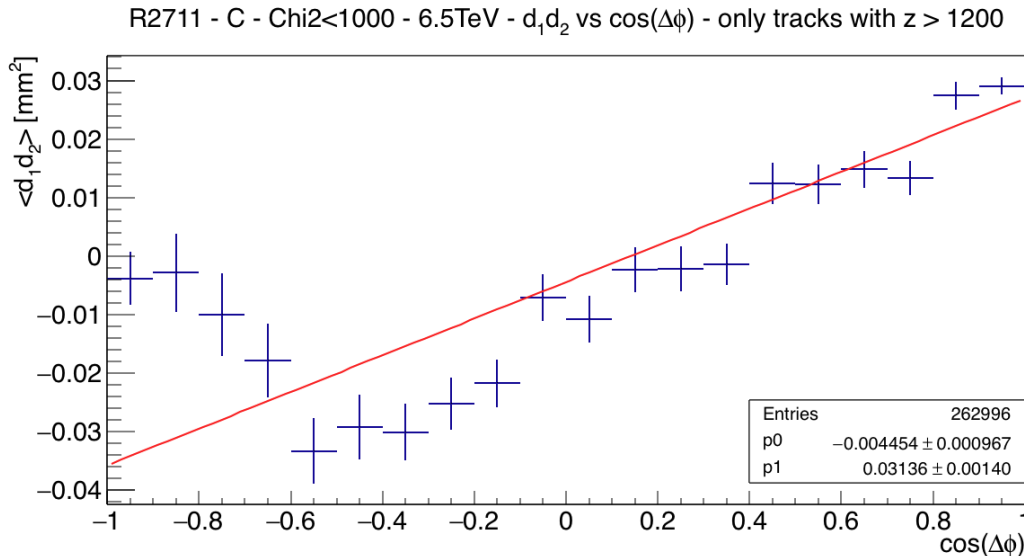
σ_x^2 (σ_y^2) being the beam spot variance along x (y) and α the angle of the beam spot ellipse

If $\sigma_x^2 = \sigma_y^2 = \sigma_{beam}^2 \rightarrow \langle IP_1 IP_2 \rangle = \sigma_{beam}^2 \cos(\phi_1 - \phi_2)$

This correlation does not depend on σ_{IP}

IP correlation $\rightarrow \sigma_{beam}$ @ 6.5 TeV

Fill #6358, BGV run duration 500 sec



$$\sigma_{beam} = 177 \pm 37 \text{ (stat)} \mu\text{m}$$

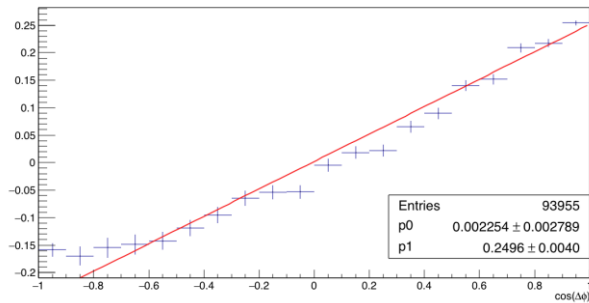
For comparison, BSRT values:
 $\sigma_x = 178 \mu\text{m}$, $\sigma_y = 186 \mu\text{m}$

Preliminary results, no systematic errors, no calibration

Fill #6358: Physics pp run, 6.5 TeV, 1868 bunches, $2.28e14$ p

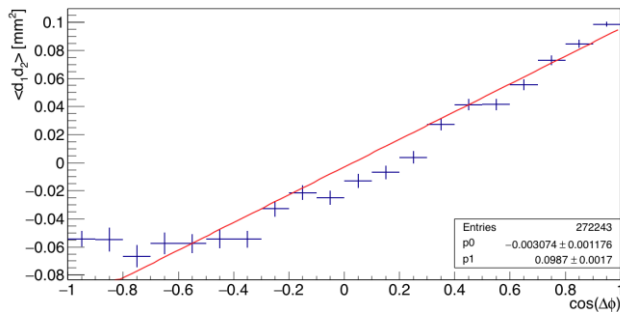
Beam energy dependence of σ_{beam}

R2707 - C - Chi2<1000 - 450GeV - d_1, d_2 vs $\cos(\Delta\phi)$ - only tracks with $z > 1200$



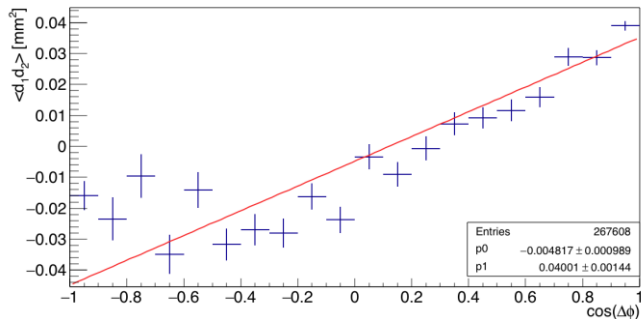
$$450 \text{ GeV} \rightarrow \sigma_{beam} = 500 \pm 63 \mu\text{m}$$

R2708 - C - Chi2<1000 - 450GeV to 3.1TeV - d_1, d_2 vs $\cos(\Delta\phi)$ - only tracks with $z > 1200$



$$450 \text{ GeV} - 3 \text{ TeV} \rightarrow \sigma_{beam} = 314 \pm 41 \mu\text{m}$$

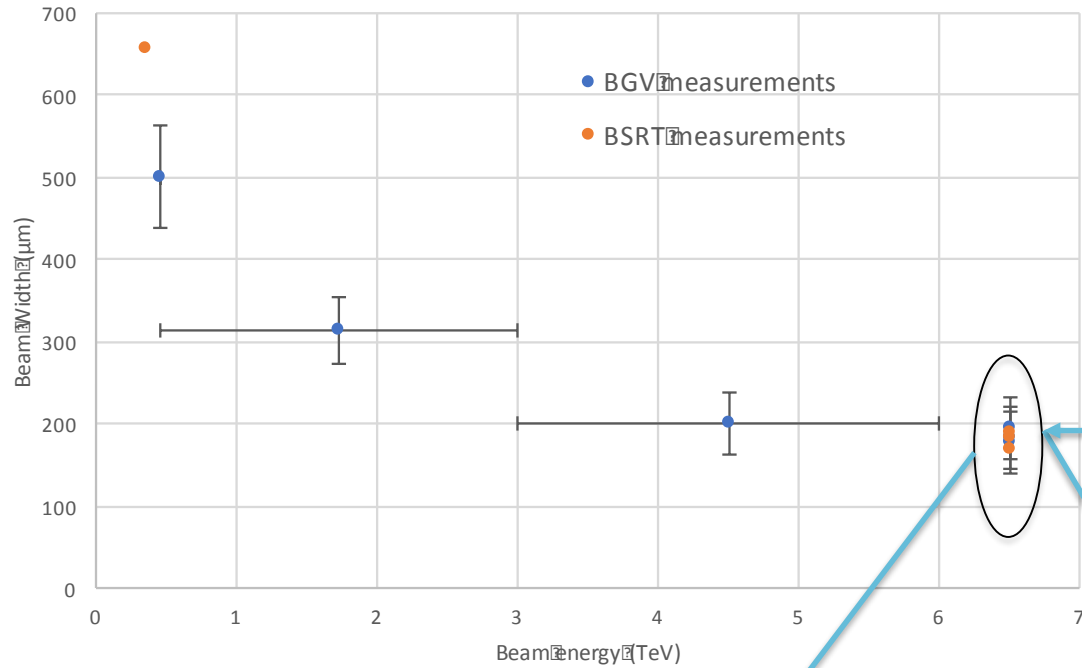
R2709 - C - Chi2<1000 - 3.1TeV to 6.2TeV - d_1, d_2 vs $\cos(\Delta\phi)$ - only tracks with $z > 1200$



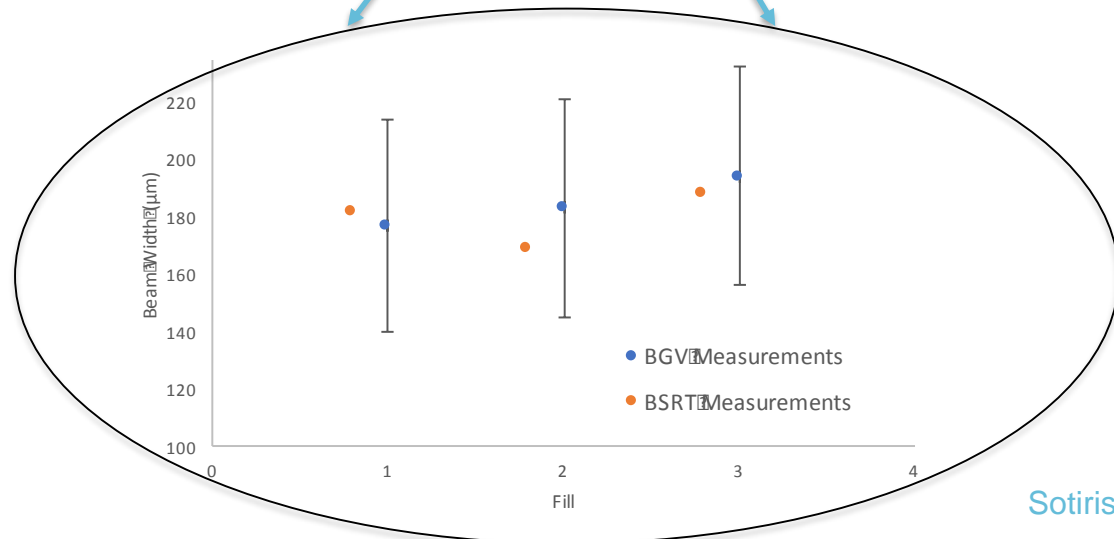
$$3 \text{ TeV} - 6 \text{ TeV} \rightarrow \sigma_{beam} = 200 \pm 38 \mu\text{m}$$

BGV beam width measurements

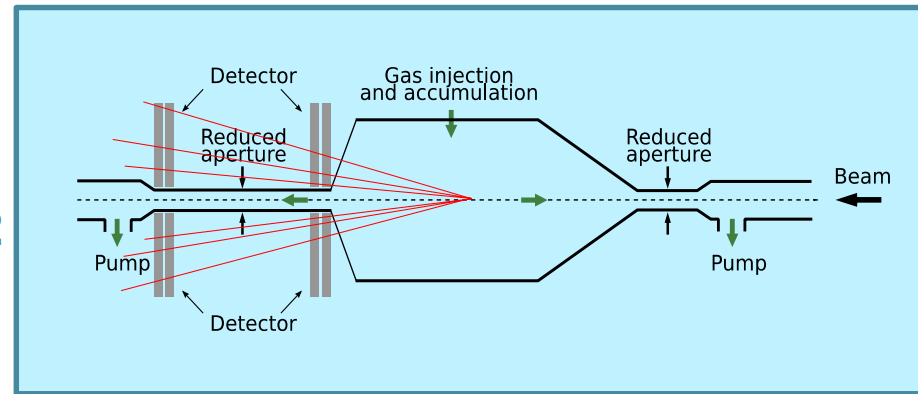
Beam Width vs Energy



Three 6.5 TeV runs at fills:
 #6358 (2.28e14 p, 1868 b)
 #6358 (2.09e14 p, 1868 b)
 #6364 (1.38e14 p, 1868 b)



BGV for HL-LHC == BGV₂



BGV₂ = Optimized BGV design for best vertex resolution

Two important detector design considerations for best IP and vertex resolution:

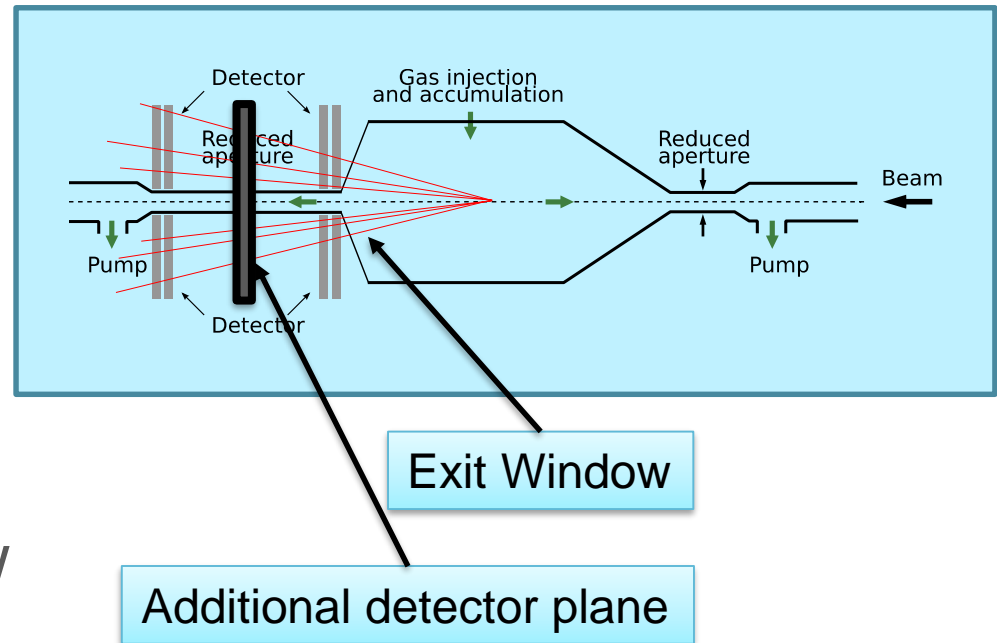
- Good spatial resolution at each detector plane ($\leq 100 \mu\text{m}$)
- Thin detectors in radiation lengths to minimize multiple scattering effects

In addition

- Choice of BGV₂ placement in LHC (optimal beam width to be measured wrt vertex resolution)
- Min. possible reduced beam pipe diameter (currently 54 mm) to reduce extrapolation error

BGV₂ detector design considerations

- Detector technology and thickness
 - Si-Strips
 - MSGS (Micro-Megas)
- Gas volume exit window
 - Be
 - Thin Al
- Number of detectors along z



BGV₂ detector options

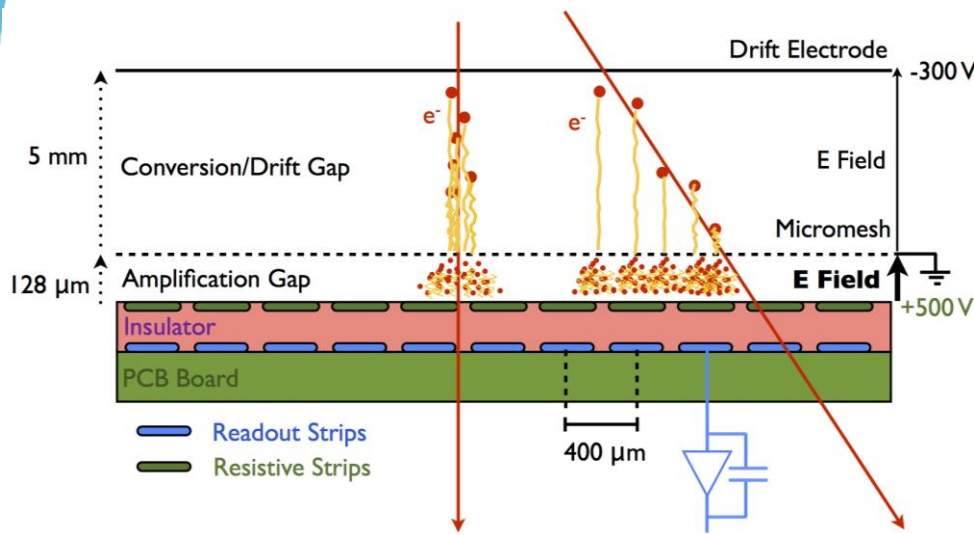
Thin, high precision detectors:

- Si-Strip detectors: 'industry standard' 300 μm thick, 200 μm pitch
→ $\sigma \sim 60 \mu\text{m}$, max. sensor size 10x10 cm^2
- MicroMegas (micro pattern gas detector): 150 μm thick, 400 μm pitch
→ $\sigma \sim 70 \mu\text{m}$, sensor size 30x30 cm^2

Both can be built in x-y configurations

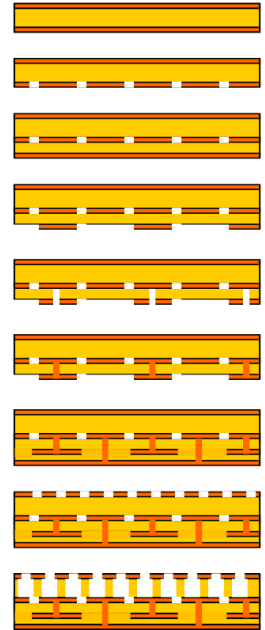
Alternatively SciFi based detectors can also be considered

MicroBulk MM



Building a Microbulk

- Kapton foil (50 μm), both side Cu-coated (5 μm)
- Construction of readout strips/pads (photolithography)
- Attachment of a single-side Cu-coated kapton foil (25/5 μm)
- Construction of readout lines
- Etching of kapton
- Vias construction
- 2nd Layer of Cu-coated kapton
- Photochemical production of mesh holes
- Kapton etching
- Cleaning



To be used in high rate environments, with a resistive strip plane (BGV ~ 1KHz/cm²)

Technology comparison

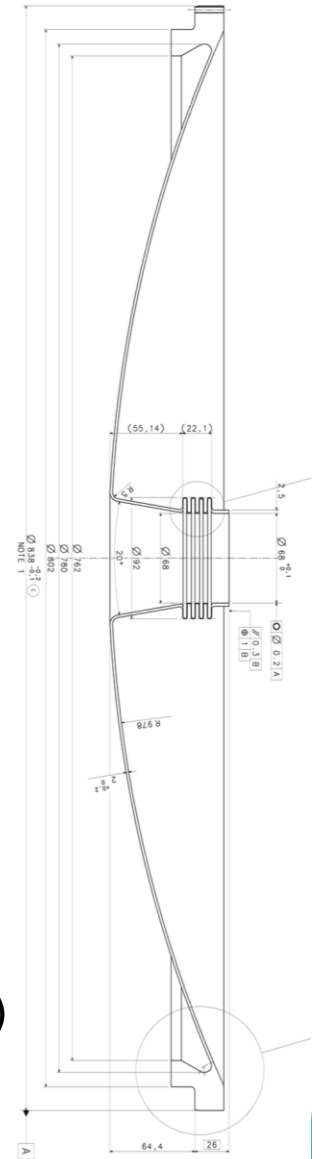
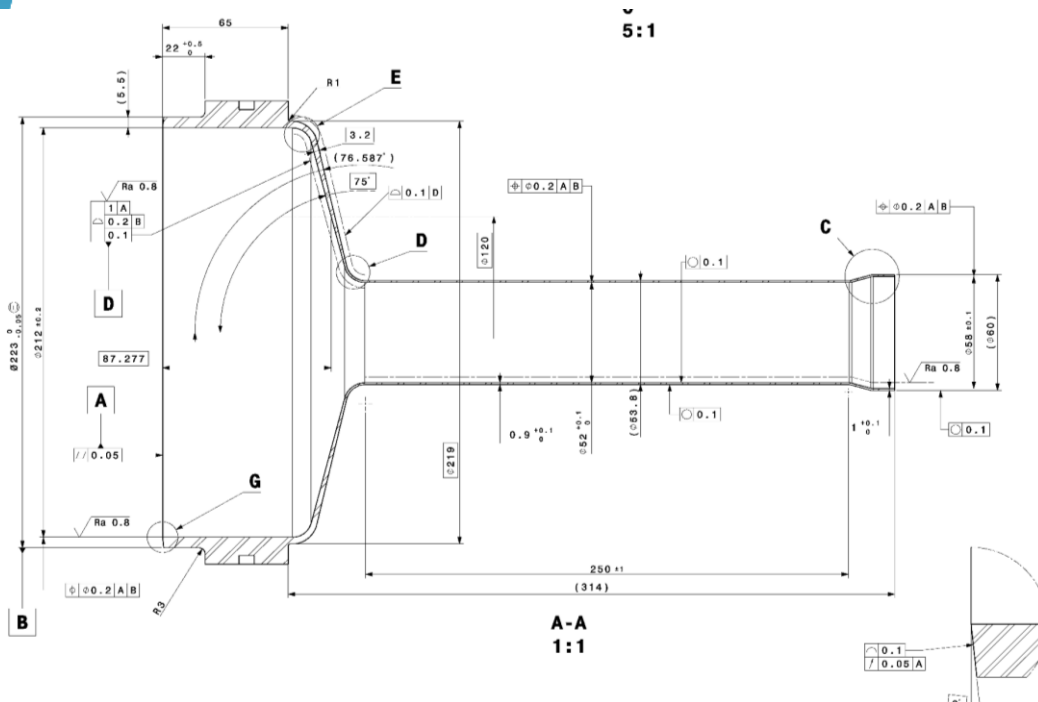
Silicon Strip sensors

- 300 μm thick planes
- 200 μm strip pitch
- Industry-made sensors
- Available analog R/O F/E chip, digital chip under development
- 'Commercial' DAQ and control system
- Required interconnections between sensors
- ~40% more expensive

MicroMegas detector

- 150 μm thick planes
- 400 μm strip pitch
- Joint CERN-Saclay development
- Digital R/O F/E chip under development
- Data transmission using GBT chip
- Some R/D needed for final design
- $\frac{1}{2}$ radiation length due to material
- X-Y option offers an additional $\frac{1}{2}$ in X_0

Gas volume exit window



Current window thickness 0.9 – 3.2 mm

New window thickness 0.9 mm(?)

Or Be window with current design (similar improvement in resolution)



BGV Demonstrator

Very encouraging first results

Final BGV₂ design

Optimization ongoing

Installation schedule compatible with LS3

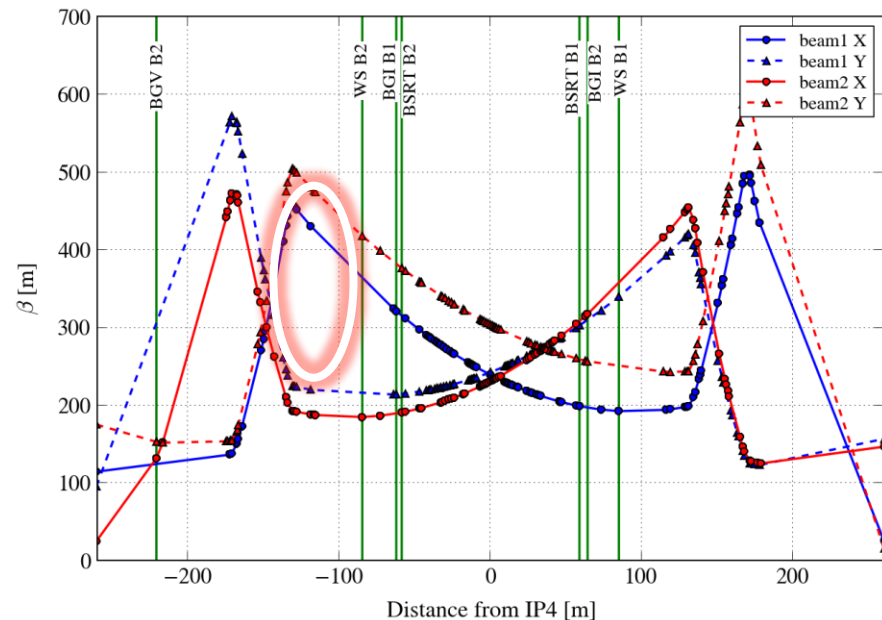


Backup Slides

- BGV Location
- Alignment corrections introduced in analysis
- Material Budget
- Gas target system
- Trigger system
- Precision tracker
- MM read-out scheme

BGV location

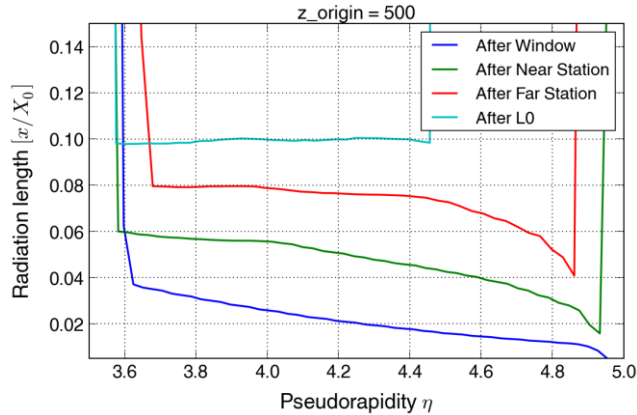
- Single beam demonstrator @ LHC, point 4, beam 2 ring
- at $\sim -220\text{m}$, beam 2 has $\beta_x \cong \beta_y \cong 150\text{ m}$
- at 7TeV and $\varepsilon_N \cong 2.5\mu\text{m}$, $\sigma_{\text{beam}} \cong 0.22\text{ mm}$
- $\beta_x \cong \beta_y$ allows beam pipe diameter reduction



BGV module shifts due to alignment procedure



BGV Material budget



Exit window $\sim 3\% X_0$
 One detector plane $\sim 3\% X_0$

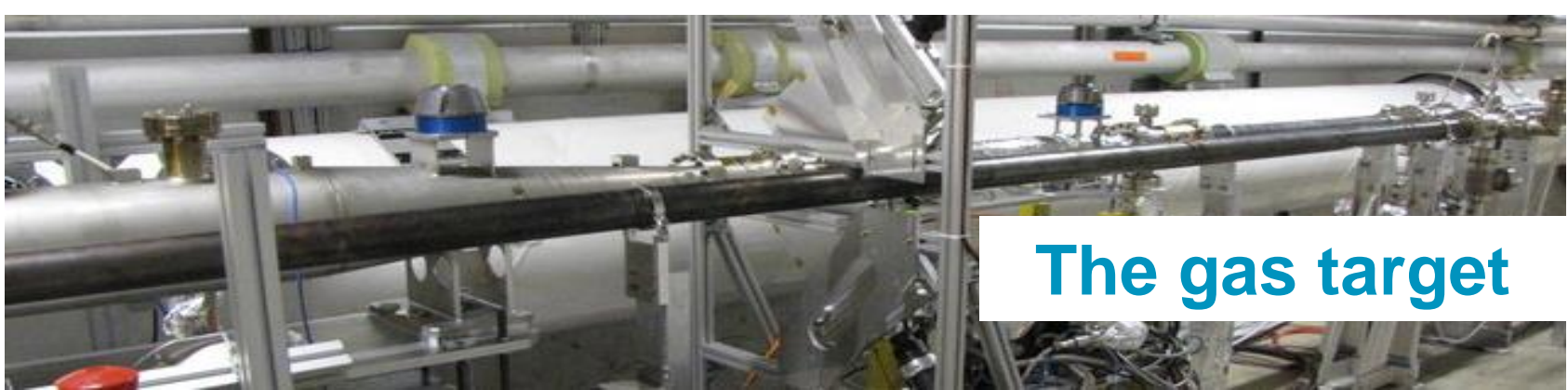
Material	E (GPa)	X_0 (m)	$X_0 E^{1/3}$
Be	290	0.353	2.34
CFC	200	0.271	1.58
Be-Al	193	0.253	1.46
Al	70	0.089	0.37
Ti	110	0.036	0.17
Fe	210	0.0018	0.11

$$\sigma_{MS} \propto \sqrt{X_0}$$

Be instead of Al $\rightarrow \frac{1}{2} \sigma_{MS}$ due to exit window

Table from R. Veness et al., Proceedings of IPAC2011

1mm SciFi \sim 1mm Kapton \sim 0.5mm Si in X_0



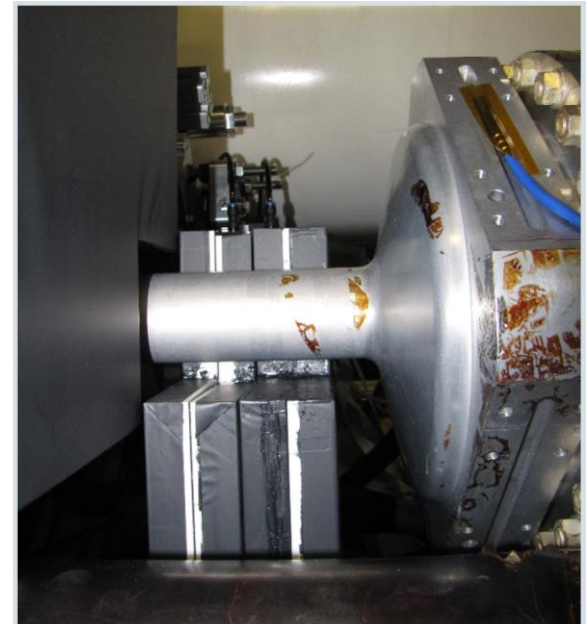
The gas target

2m long gas volume:

- 0.75m conical tube (minimal beam impedance)
- 1.25m long cylinder (main interaction region)
- Thin (1 – 3 mm) exit window to reduce multiple scattering

Narrow beam pipe around BGV (52 – 58 mm instead of nominal 80mm):

- Detector close to beam-gas interactions
 - Max. acceptance
 - Min extrapolation error
- Gas flow restriction : Increased gas pressure in target



Gas target operating conditions

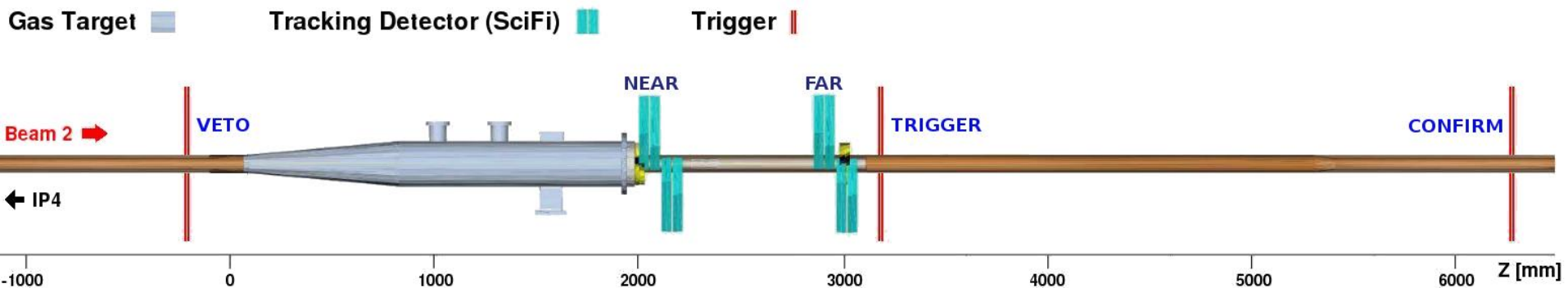
Expected beam-gas interaction rate:

$$R(\text{Hz}) = 2.5 \cdot 10^{-11} p(\text{mbar}) \Delta z(\text{cm}) \sigma_{pA} N f_{rev}(\text{Hz})$$

- p the gas pressure (10^{-7} mbar)
- σ_{pA} the proton nucleus cross-section (295 mb for 7 TeV p on Ne target)
- N the number of protons per bunch (10^{11})
- f_{rev} the bunch revolution frequency (11.245 kHz)
- Δz the gas volume length along the beam axis (100 cm)



$R = 81 \text{ Hz per bunch}$



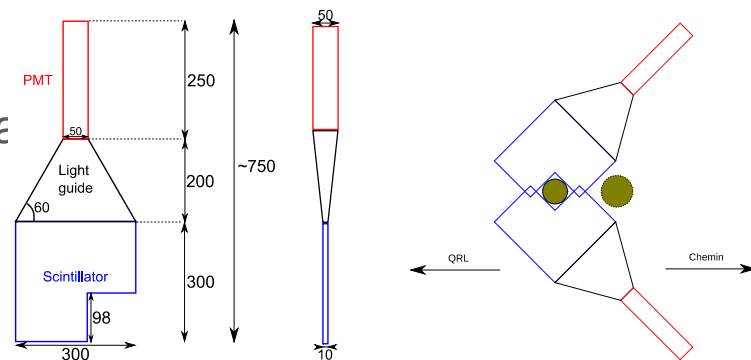
The trigger system

Set of three scintillator planes (30x30 cm above and below beam line), not in particles' path between beam-gas collision and tracking measurements:

- VETO (upstream, before precision tracker)
- SIGNAL and CONFIRM (downstream, after tracking)

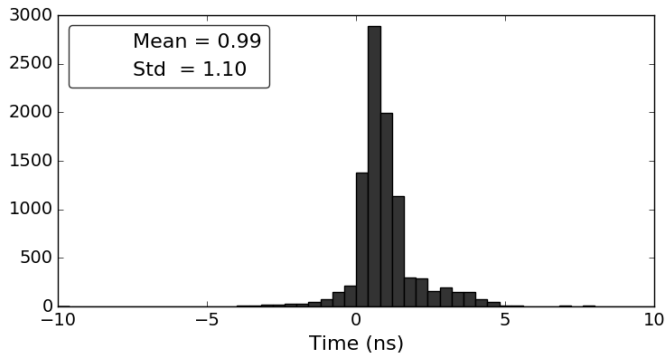
$$\text{TRIGGER} = \text{SIGNAL} \cdot \text{CONFIRM} \cdot \overline{\text{VETO}}$$

Trigger rate \approx 300 Hz per LHC bunch



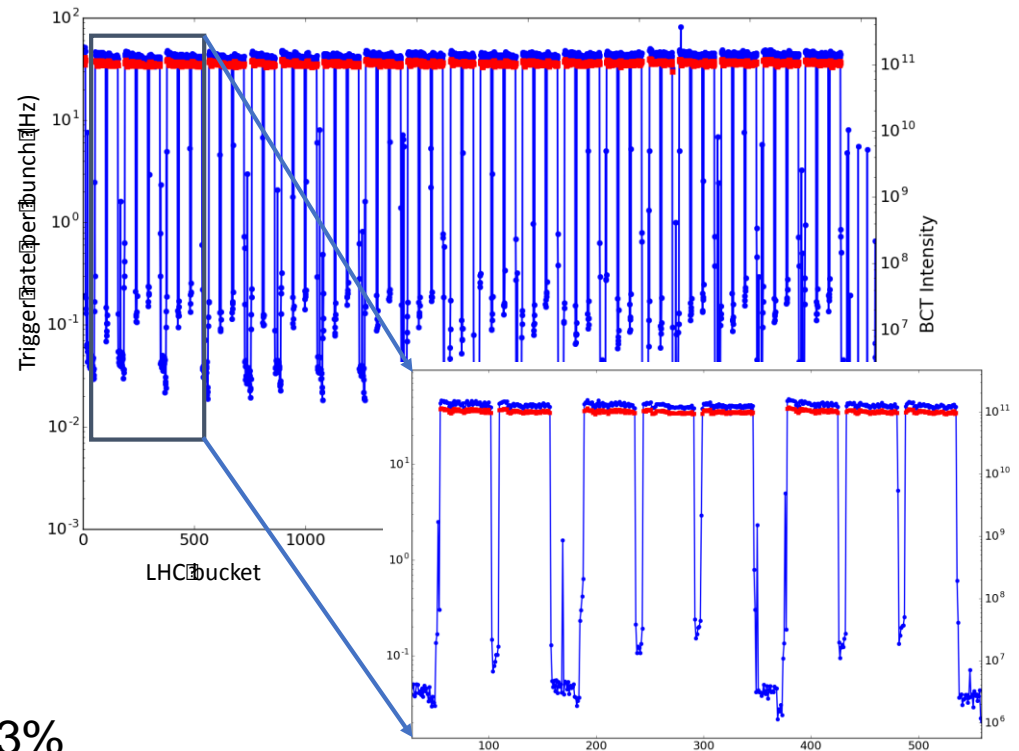
Trigger detector performance

- 1 ns resolution – easy beam bunch identification
- Background contamination $< 10^{-4}$



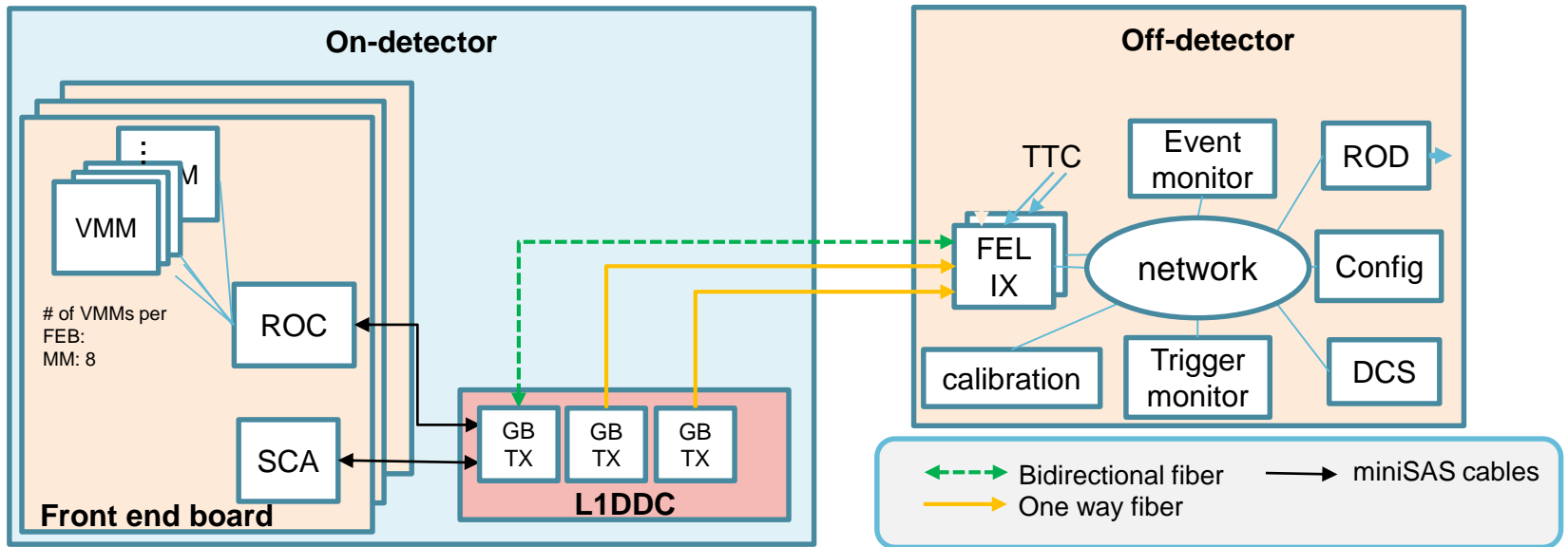
Adjusted time difference between SIGNAL and CONFIRM planes

LHC bunch structure as seen by BGV Trigger

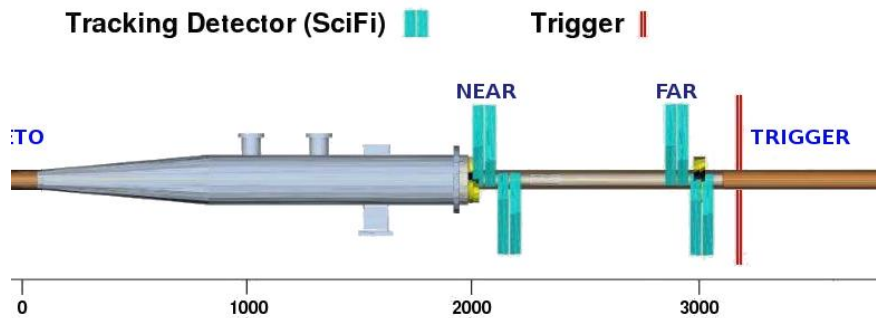


Standalone measurement:
Ghost charge fraction = $0.29\% \pm 0.03\%$

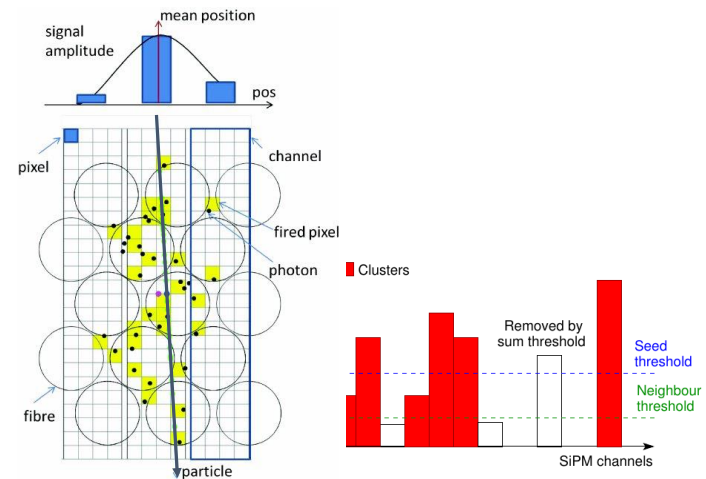
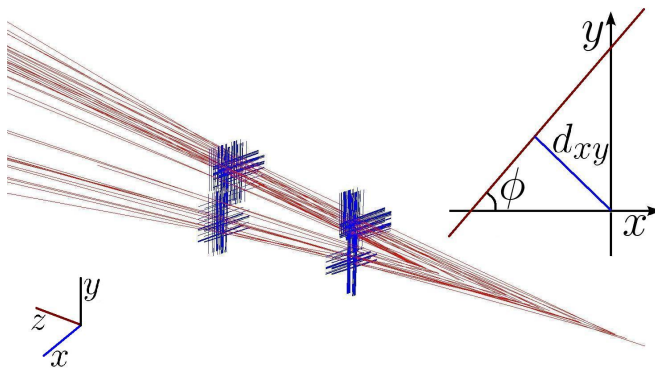
Micromegas readout scheme



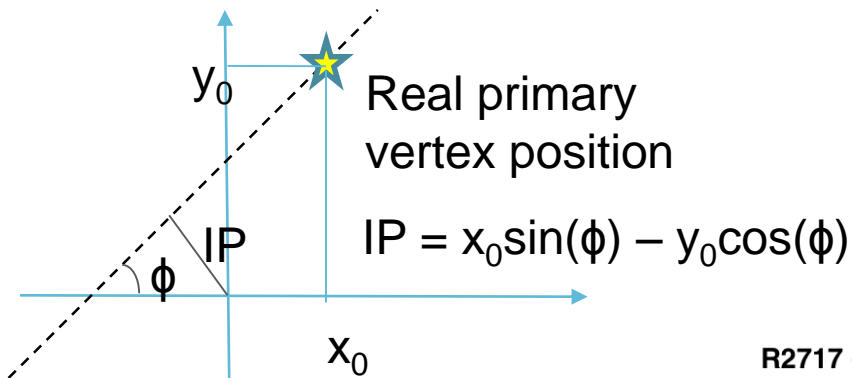
The precision tracker



- 4 Scintillating fibre (SciFi) (250 μm) modules (x, x', y, y') per (NEAR/FAR) station
- 4 (NEAR), 5 (FAR) SciFi planes per module
- $\Delta z = 1 \text{ m}$
- $\sigma_{cluster} \approx 50 \mu\text{m}$



Alternative Beam position measurement



beam 2 positioned at (0,0)
of the BGV reference frame

