Measuring beam size with the BGV

results from the demonstrator in Run2

Benedikt Würkner on behalf of the BGV Team

Beam Gas Vertex Detector
Non destructive beam size measurement for HL-LHC
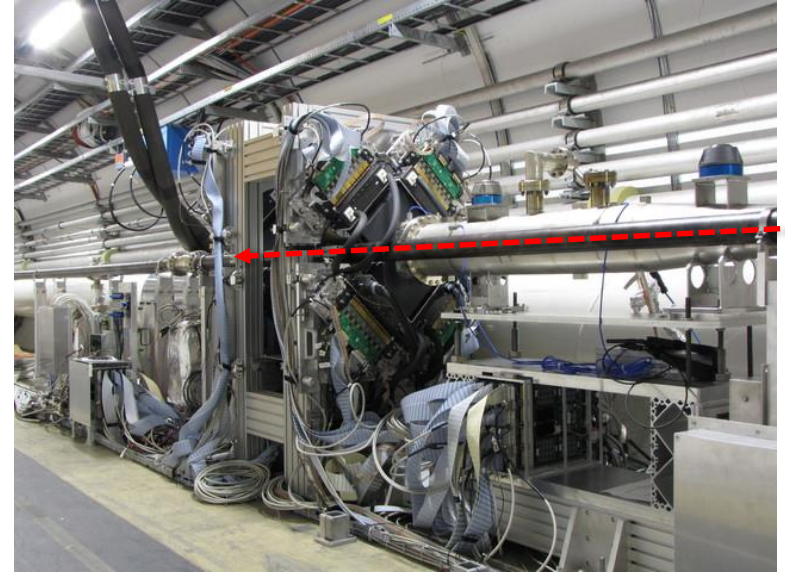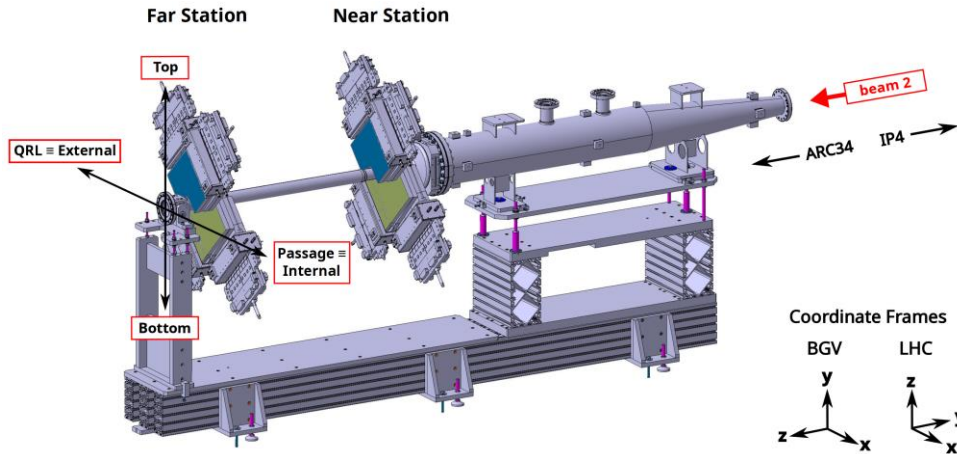## not limited by accelerator luminosity

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

Far Station   **Near Station**

Top

QRL ≡ External

Passage ≡ Internal

Bottom

beam 2

ARC34   IP4

Coordinate Frames
BGV   LHC

Demonstrator fully commissioned
Data acquisition working as expected
Parameter optimization ongoing

Benedikt Würkner

Gas interaction volume

- Almost 2m long gas tank with an exit window made from thinned aluminum
- Gas injection system allows to inject Neon to increase the local pressure up to 4e-8 mbar N2 equivalent
- Increases interaction rate by ~16x
- Doesn't noticeable influence the beam quality
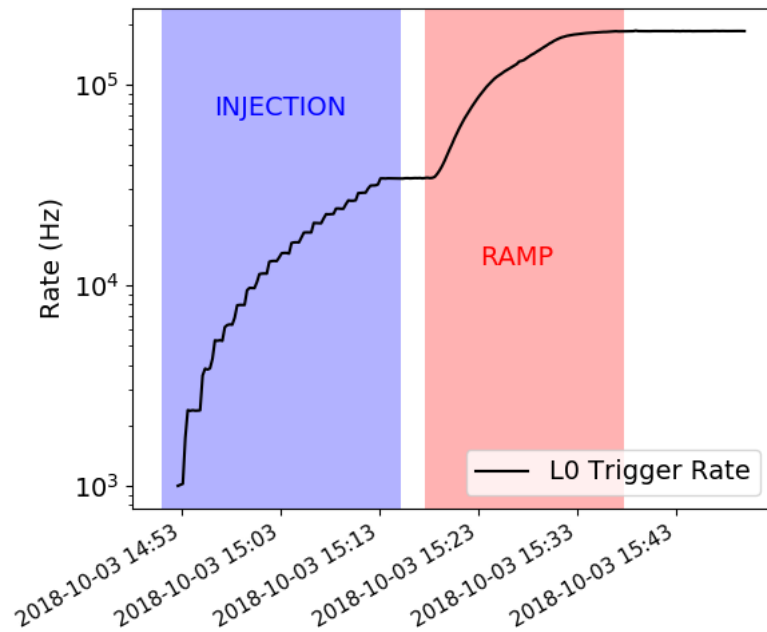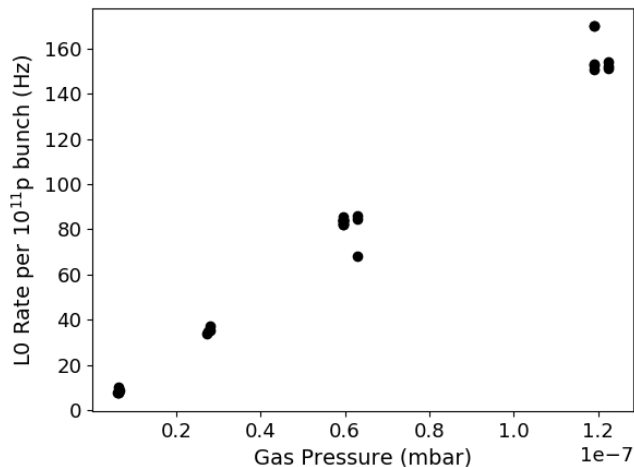
Gas interaction volume

- The pressure distribution can be approximated with the distribution of the z coordinate of the POCA (green line)
- This in mimicked by the vertex z-distribution (blue line)
- The quality of recorded events increases significantly when injecting gas due to the higher percentage of interactions with Neon

Vertex z

Trigger system

- Trigger scintillators | Tracking Detector (SciFi) | Gas Target chamber
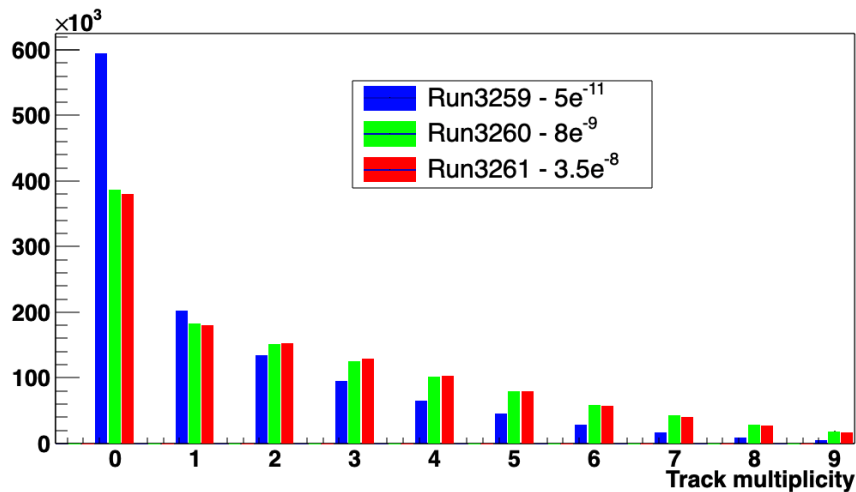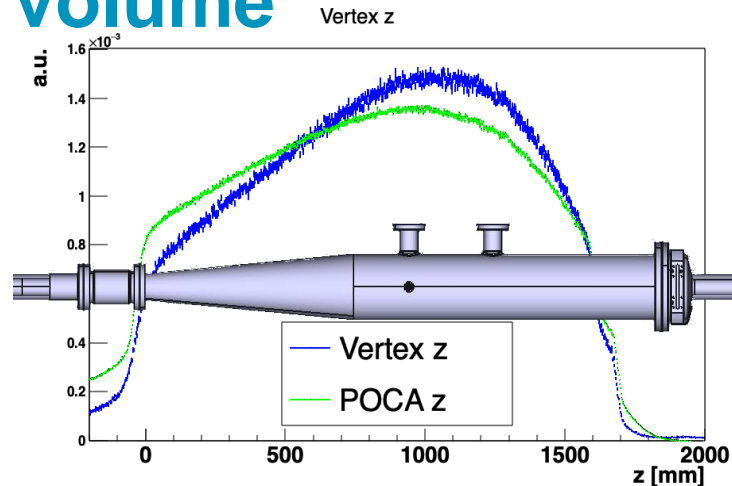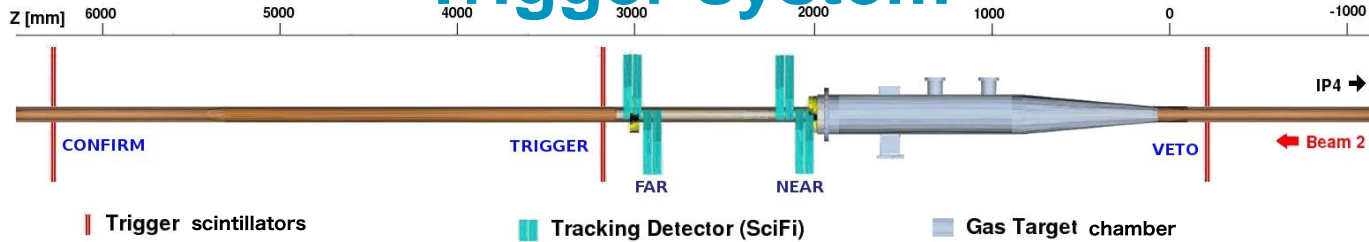
- Hardware trigger system based on scintillating fiber panels
- Requires coincidence between "Trigger" and "Confirm" planes and no "Veto"
- Trigger pulse is shaped using a constant fraction discriminator
- The coincidence signal is handed to the Readout supervisor "ODIN"
- ODIN synchronizes the signal with the Filling scheme
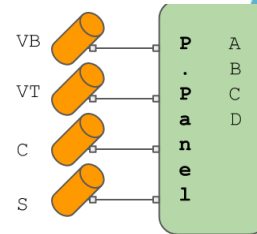
Data acquisition and processing

- Analog readout by Tell1 Digitization board
- Zero suppression in Tell1 -> Clusters
- Transmission of Clusters to HLT node
- Filtering of event based on cluster cut
- Filtering of event based on clusters/module
- Track reconstruction is performed for remaining events
- Discarding Events with less than 2 tracks
- Storage of remaining events (~6kHz)

Data analysis and treatment

- Dedicated pattern recognition algorithm
  - Written to take advantage of all geometric properties
  - Very efficient with regards to processing time
  - Requires a very precisely aligned detector to keep the search windows small
- Overall pattern recognition efficiency of the algorithm >60% for the relevant range of 2 to 7 Tracks/Event
- About 30-40% of tracks with wrong clusters in them
- This influences the results and therefore needs a very robust vertexing algorithm
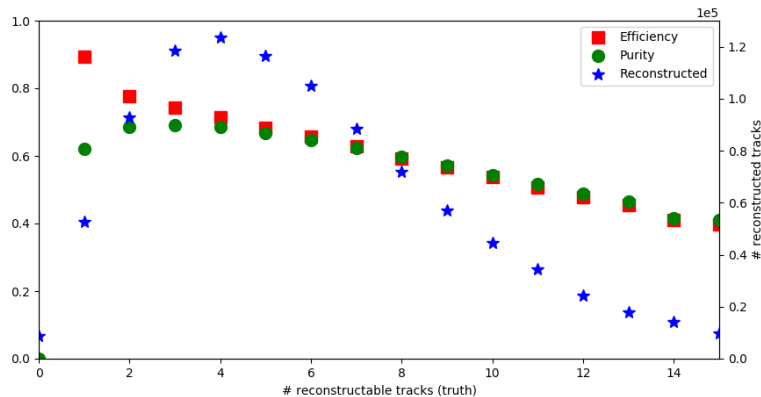
Alignment

- A detailed survey of the setup was performed
- Study of the data revealed, that the detector was not perfectly aligned around the center
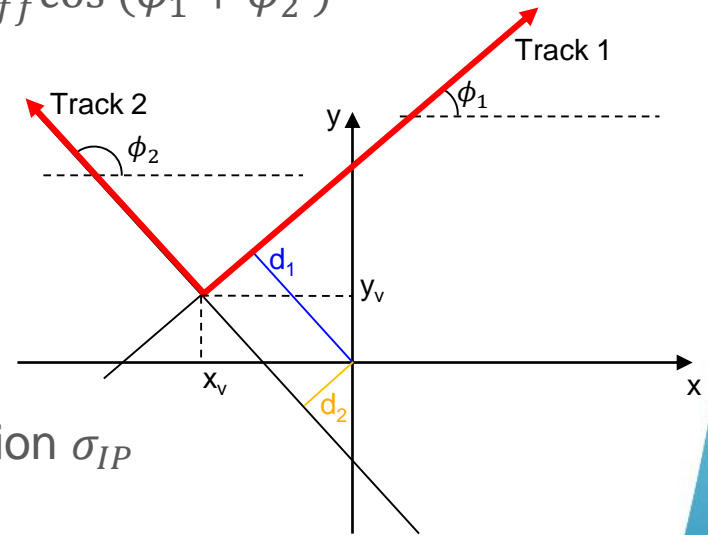- After performing an alignment procedure the detector is now aligned.
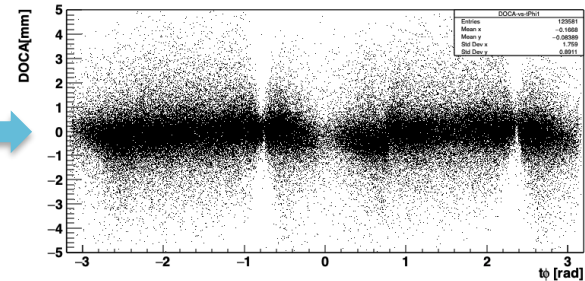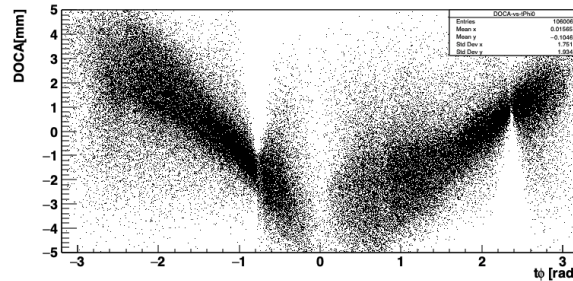
Beam width measurement

IP and φ (1,2) of particles from the same primary vertex are correlated:

$$\langle IP_1\, IP_2 \rangle = \sigma_{sum}^2 \cos(\phi_1 - \phi_2) + \sigma_{diff}^2 \cos(\phi_1 + \phi_2)$$

$$\sigma_{sum}^2 = \frac{\sigma_x^2 + \sigma_y^2}{2}, \quad \sigma_{diff}^2 = \frac{\sigma_y^2 - \sigma_x^2}{2}$$

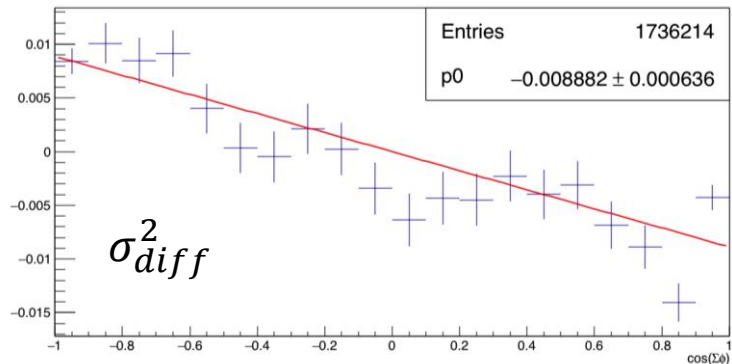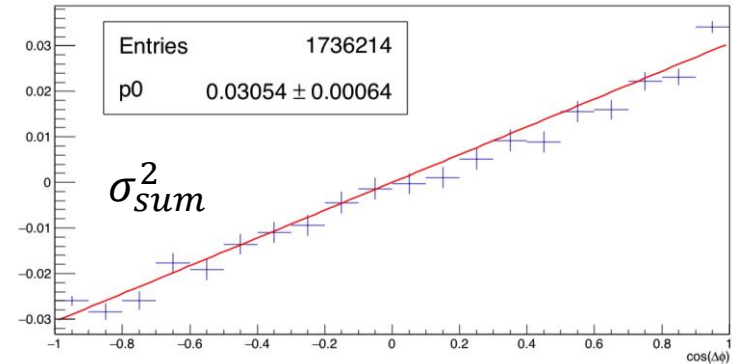σ_x^2 (σ_y^2) being the beam spot width along x (y)

Correlation independent of measurement resolution σ_{IP}

IP correlation → σ_{beam}

Assuming uncorrelated $\phi_1 - \phi_2$ and $\phi_1 + \phi_2$ the parameters σ_{sum}^2 and σ_{diff}^2 can be fit individually:

$$\sigma_x^2 = \sigma_{sum}^2 - \sigma_{diff}^2$$
$$\sigma_y^2 = \sigma_{sum}^2 + \sigma_{diff}^2$$

# Comparison to Simulation

simulated	σ_x	σ_y
0.200	0.211	0.159
0.300	0.293	0.222
0.400	0.383	0.289
0.500	0.467	0.352
0.600	0.541	0.414
0.700	0.617	0.472
0.800	0.687	0.518
1.000	0.802	0.605
1.200	0.891	0.675

- Simulating round beam with defined sigma using Hijing
- Result is not equal to simulated due to
  - Detector geometry
  - clusters from secondary tracks and noise
- Fitting polynomial of second order to these results gives correction factors for both axis independently

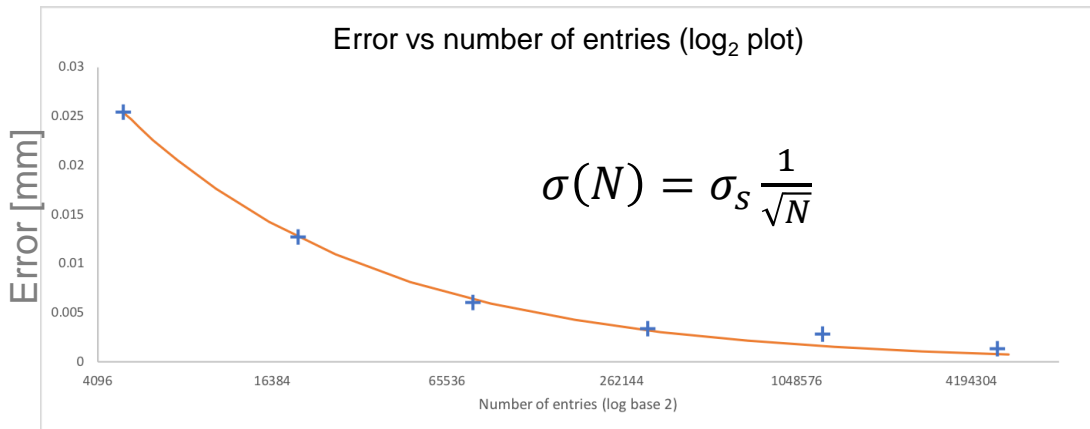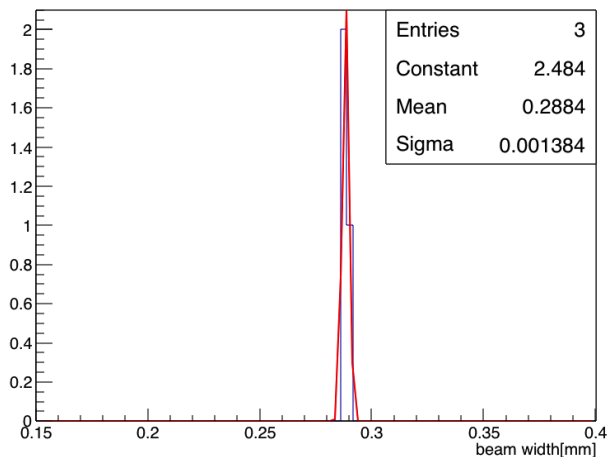$$\sigma_x^{(corr)} = 0.81\sigma_x^2 + 0.53\sigma_x + 0.07$$

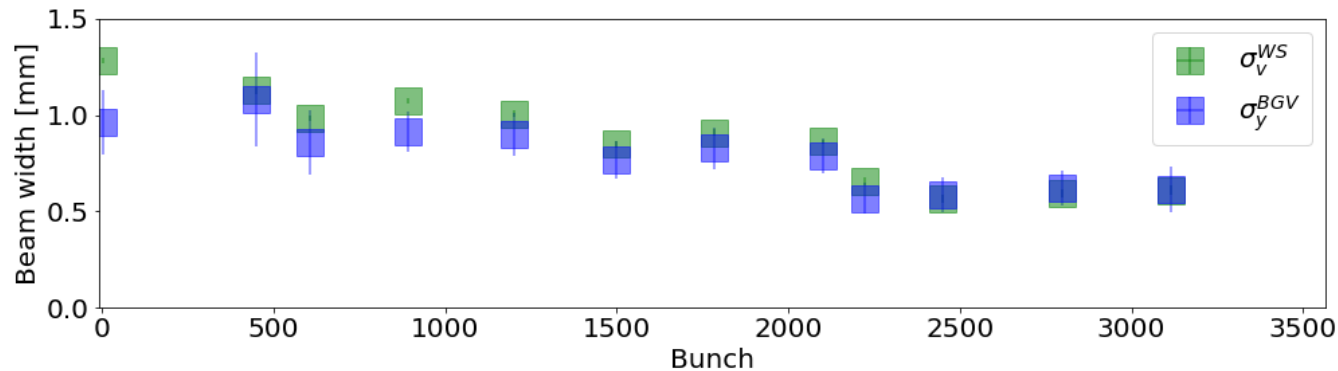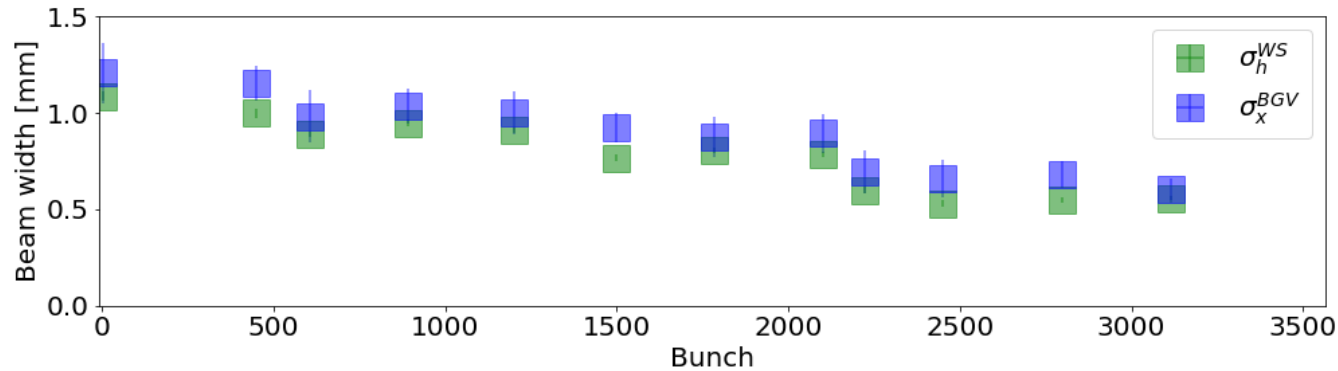$$\sigma_y^{(corr)} = 1.39\sigma_y^2 + 0.72\sigma_y + 0.06$$
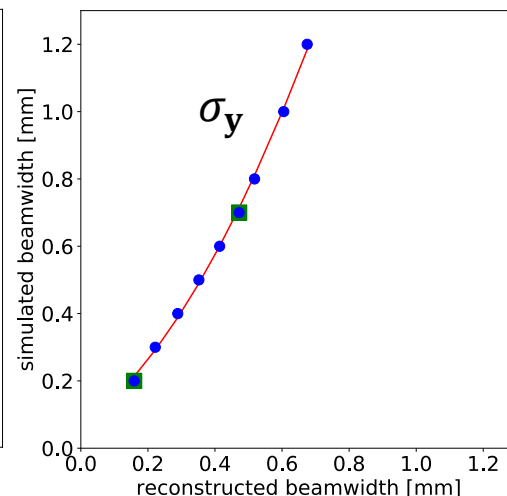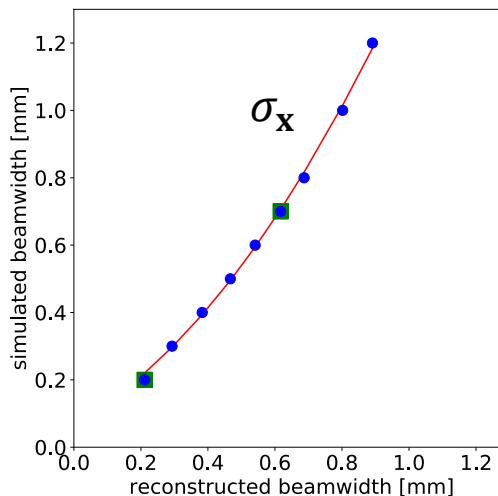
Resolution vs integration time

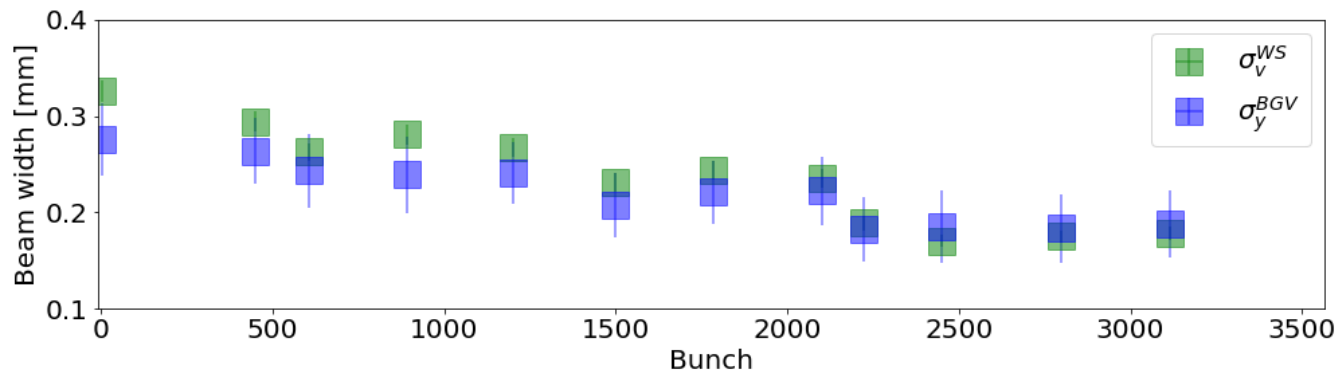- The longer the integration time the higher the precision (until ~5µm)

Run2753 - Events: 13.5M - 5120000 per Slice (778.01s)

Entries	3
Constant	2.484
Mean	0.2884
Sigma	0.001384

Error vs number of entries ($\log_2$ plot)

$$\sigma(N) = \sigma_s \frac{1}{\sqrt{N}}$$

BGV vs Wirescanner (450GeV)
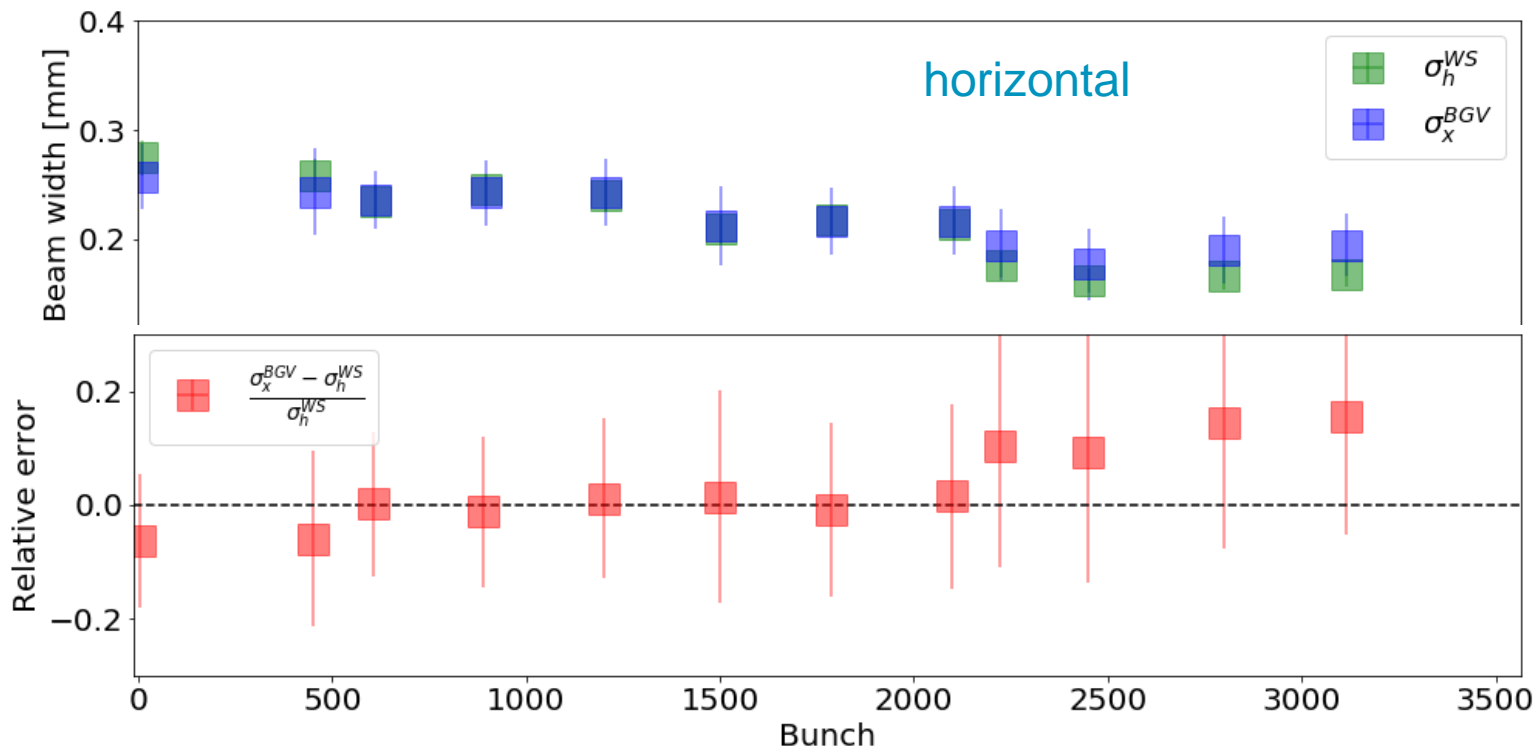

Fill 7220, BSRT calibration fill on 2018-09-25

BGV vs Wirescanner (6.5TeV)
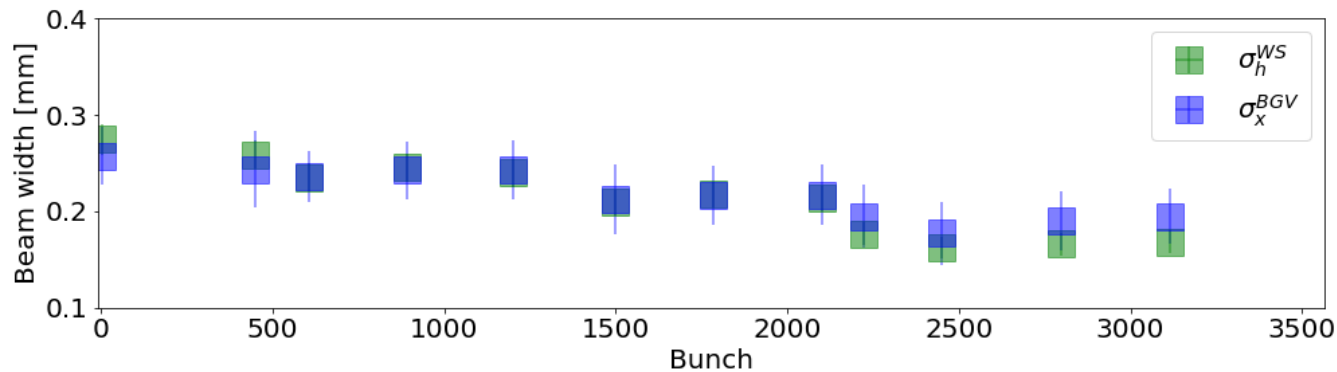
Fill 7220, BSRT calibration fill on 2018-09-25

BGV vs WS relative error – horizontal (6.5TeV)

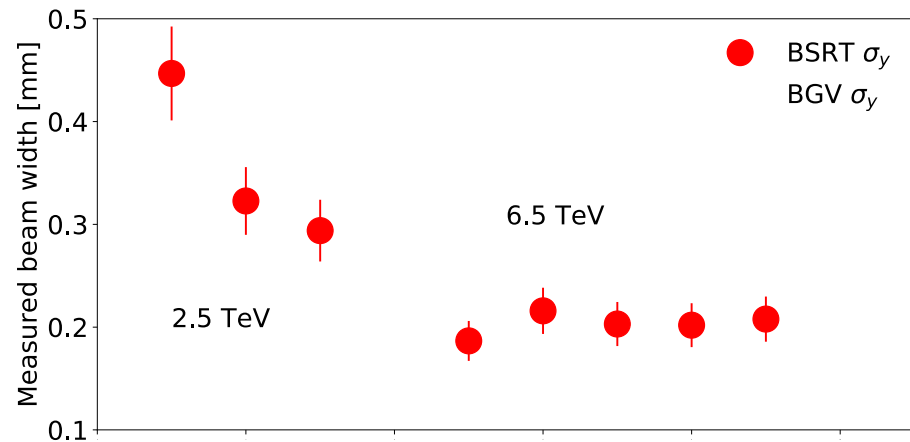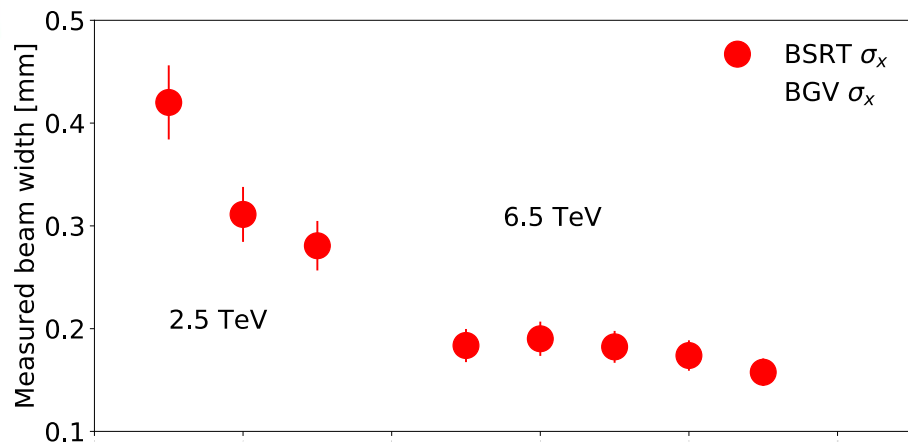Fill 7220, BSRT calibration fill on 2018-09-25

BGV vs WS relative error - vertical (6.5TeV)
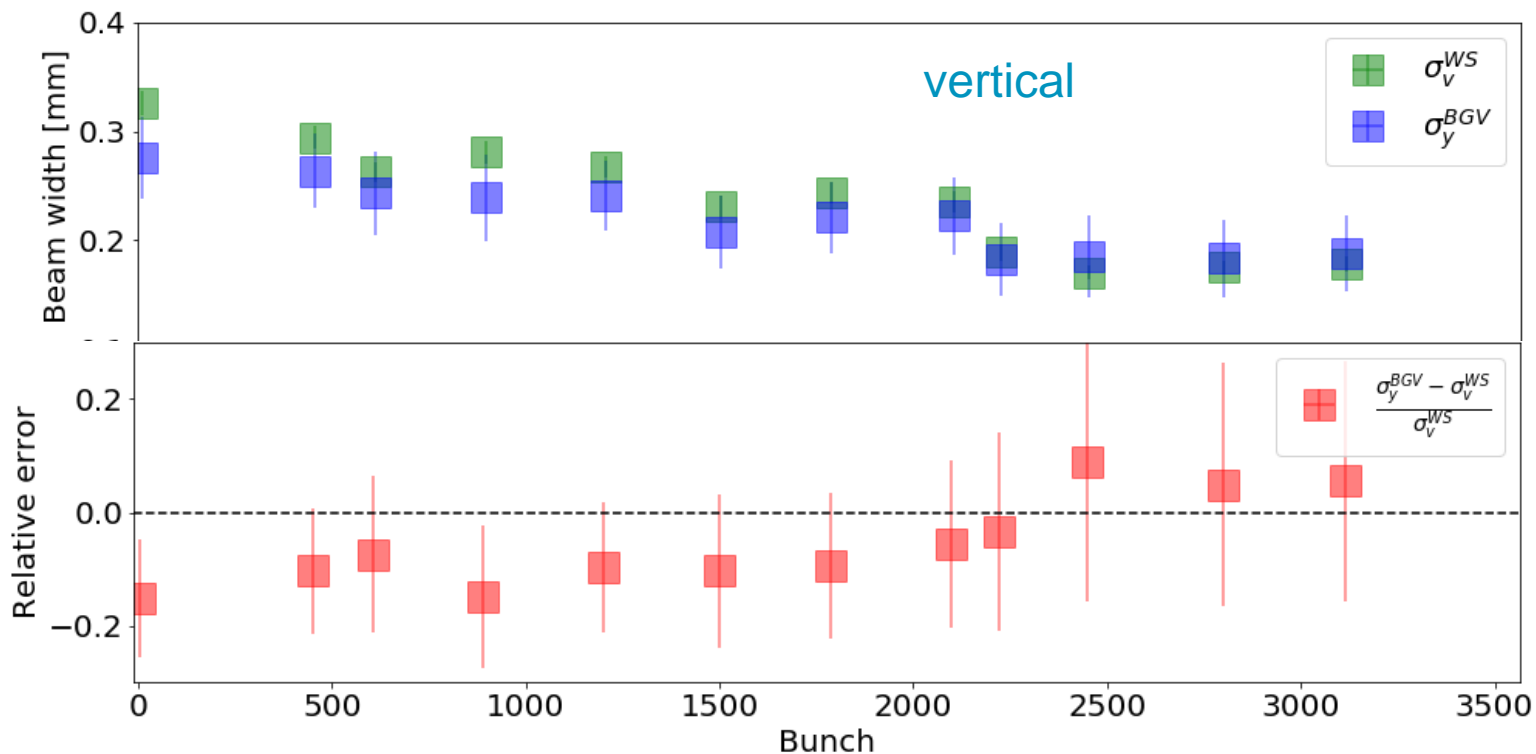
Fill 7220, BSRT calibration fill on 2018-09-25

Average beam profile measurement

fill numbers - 6.5TeV
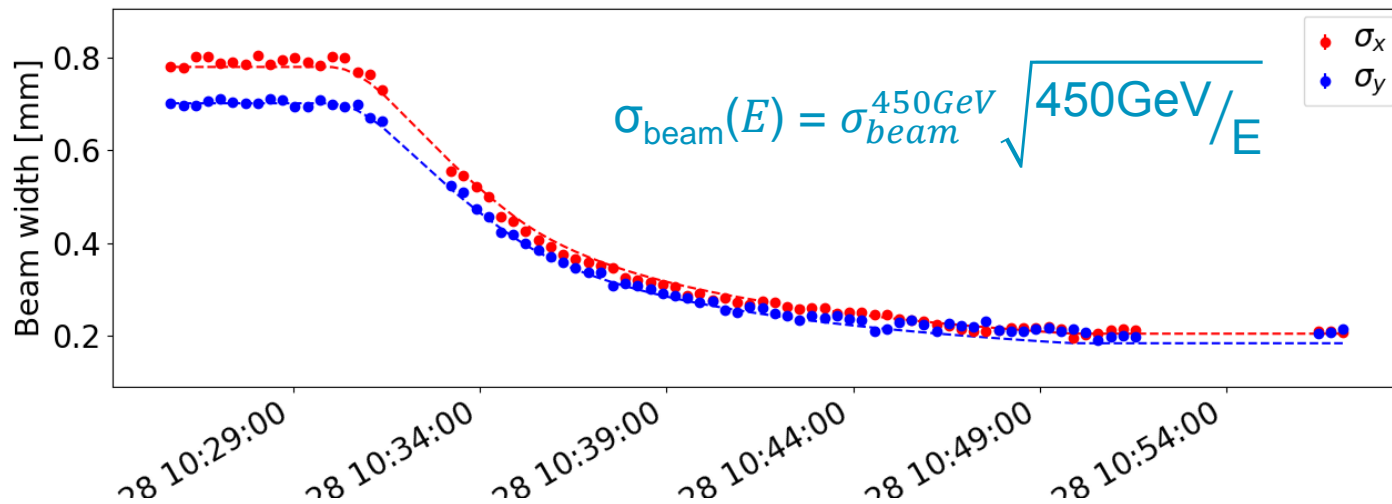6358   November 2017
6371   November 2017
7127   September 2018
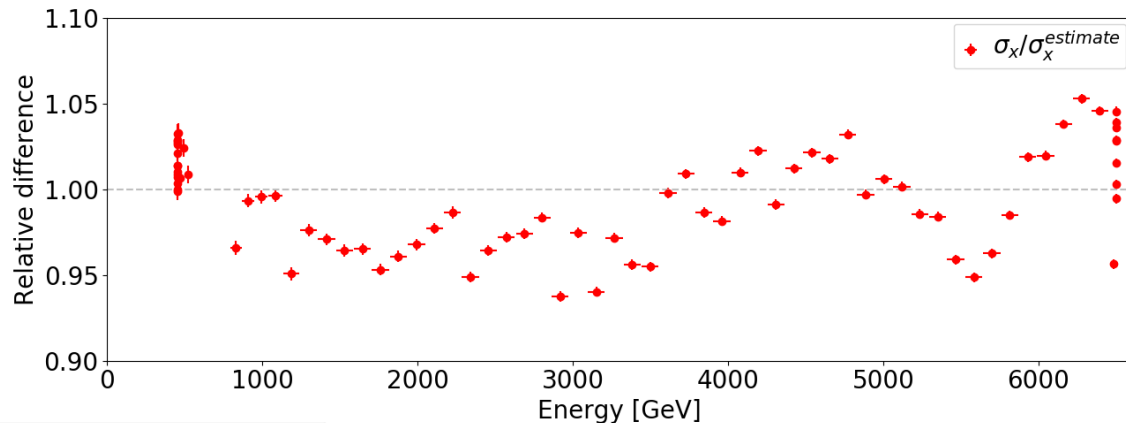7145   September 2018
7232   September 2018
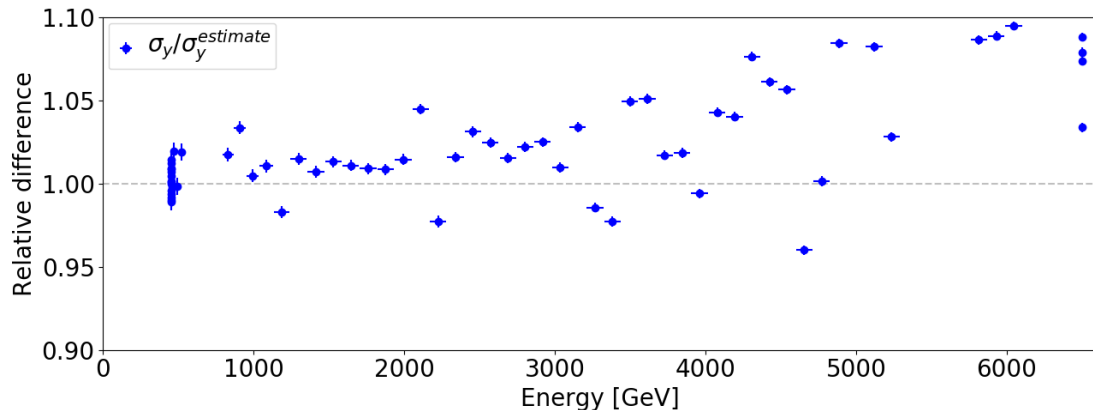
Beam size measurement during ramp

$$\sigma_{\text{beam}}(E) = \sigma_{beam}^{450GeV} \sqrt{450\text{GeV}/E}$$

Integration time: 20s

Fill 7232, 2556 nominal bunches on 2018-09-28

Beam size measurement during ramp

$$\sigma_{\text{beam}}(E) = \sigma_{beam}^{450GeV} \sqrt{450\text{GeV}/E}$$

Integration time: 20s

Fill 7232, 2556 nominal bunches on 2018-09-28

Summary

- BGV is fully working
- Multiple measurements were taken during
  - BSRT calibration
  - Energy ramp
  - Stable beams
- Nice agreement with Wirescanner measurement
- Plans for the future
  - Quantification of systematic errors
  - Online publishing of results

Thanks for the attention

Backup

Full BGV Trigger layout