Measuring beam size with the BGV

results from the demonstrator in Run2

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8th HL-LHC Collaboration Meeting – 2018-10-18

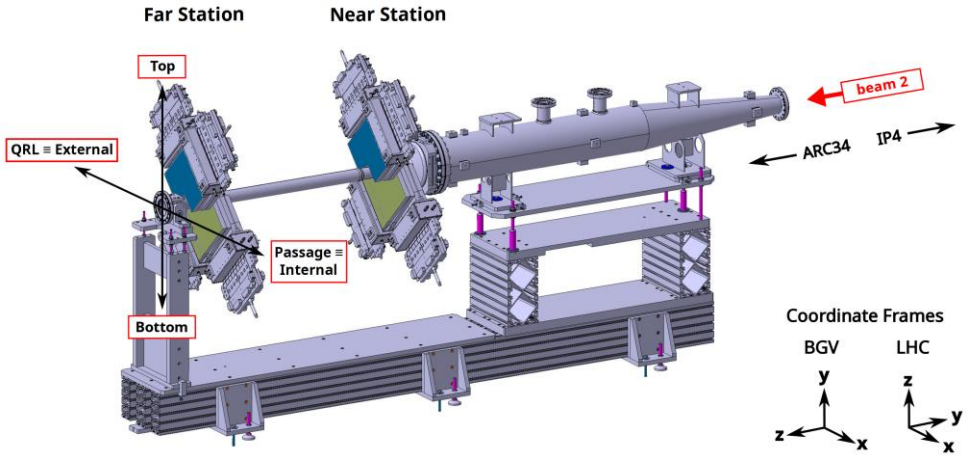
Beam Gas Vertex Detector

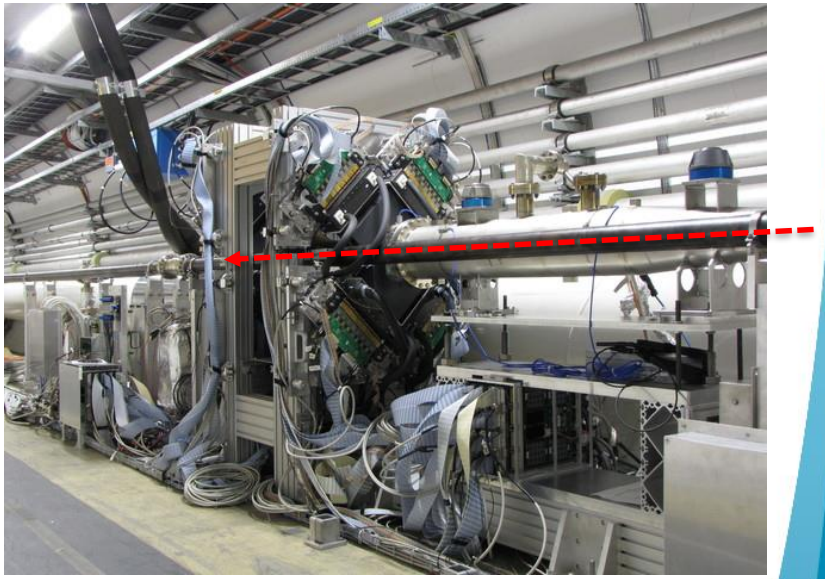
Non destructive beam size measurement for HL-LHC not limited by accelerator luminosity

Tracks from beam-gas interactions to reconstruct beam spot
Ne @ 10^{-7} mbar injected at interaction volume

Goals:
Measurement error: 2% in less than 1 min for beam of 2556 x 10^11 p/bunch

Should allow ε measurements with similar precision

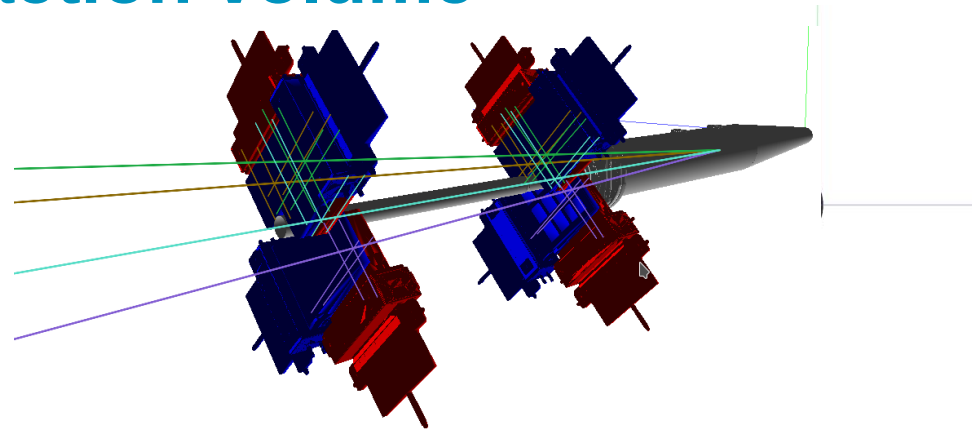




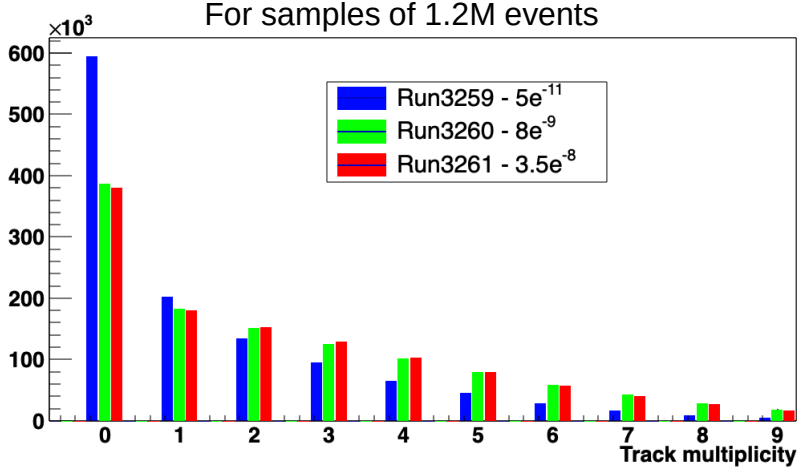
Demonstrator fully commissioned
Data acquisition working as expected
Analysis ongoing

Gas interaction volume

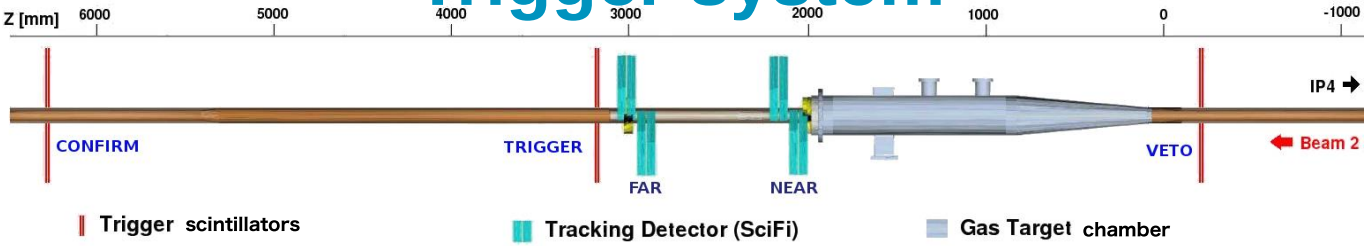
- Almost 2m long gas tank with a thin aluminum exit window
- Gas injection system allows to inject Neon to increase the local pressure up to 1e-7 mbar
- Increases interaction rate by ~16x
- No influence on the beam quality
- The quality of recorded events increases significantly (50% vs 66%) when injecting gas due to the higher percentage of interactions with Neon



For samples of 1.2M events



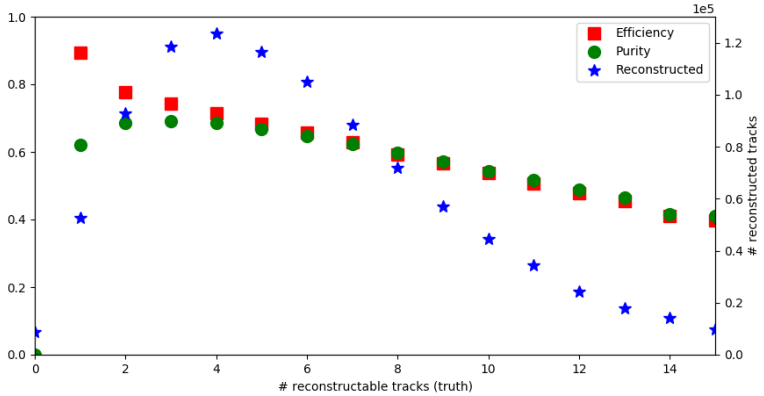
Trigger system



- Hardware trigger system based on scintillating fiber panels
- Requires coincidence between “Trigger” and “Confirm” planes and no “Veto”
- The coincidence signal is handed to the Readout supervisor “ODIN”
- ODIN synchronizes the signal with the Filling scheme and triggers acquisition of an event
- Higher level Trigger system **selects events online** based on number of clusters and tracks for storage

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



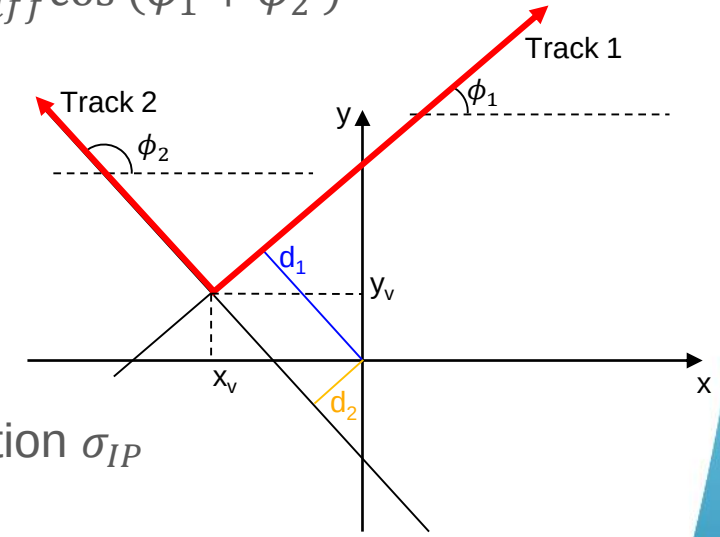
Beam width measurement

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

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

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

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

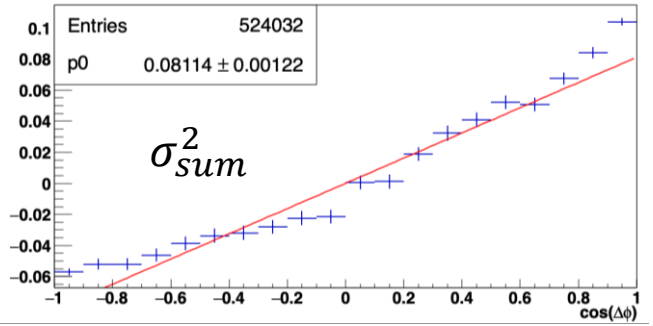


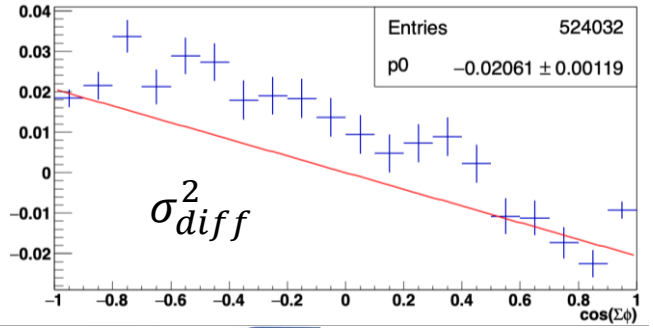
Correlation independent of measurement resolution σ_{IP}

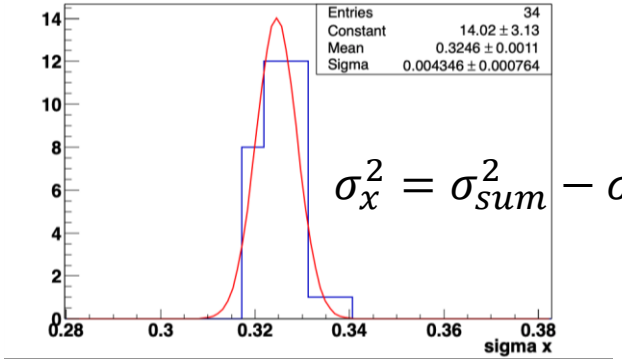
Increased statistics diminish influence of random errors

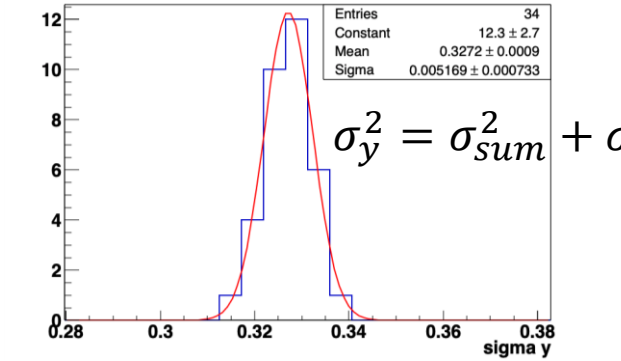
IP correlation → σ_{beam}

Assuming uncorrelated $\phi_1 - \phi_2$ and $\phi_1 + \phi_2$ the parameters σ^2_{sum} and σ^2_{diff} can be fit independently





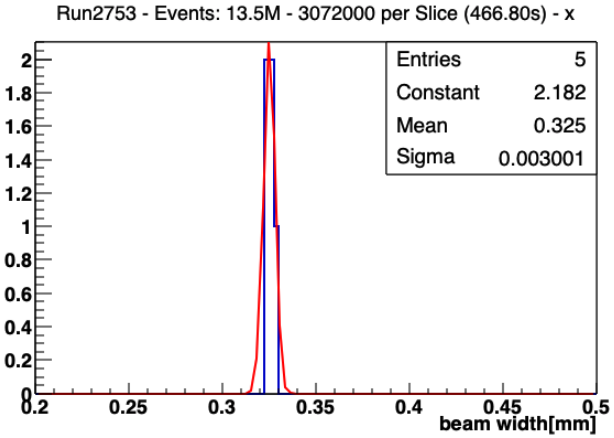


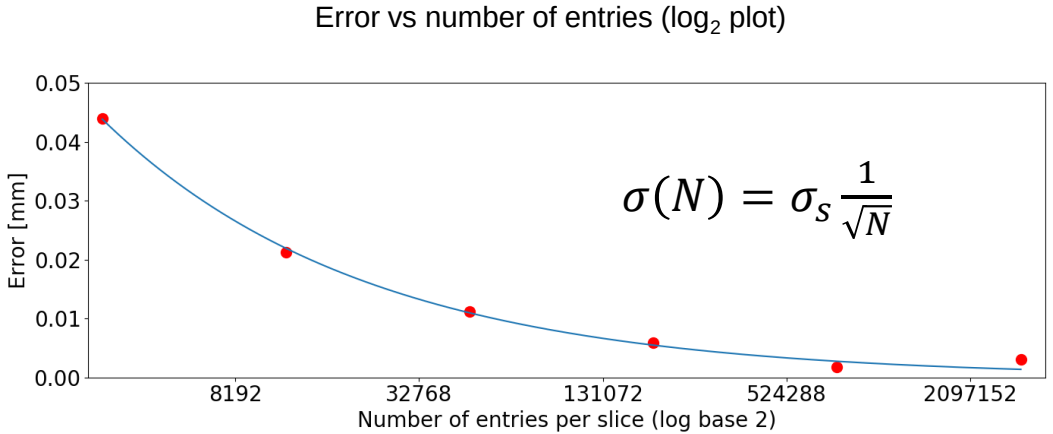


A more detailed explanation can be found at [2018-05-07_-_WP13_-_BGV_update]

Resolution vs integration time

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





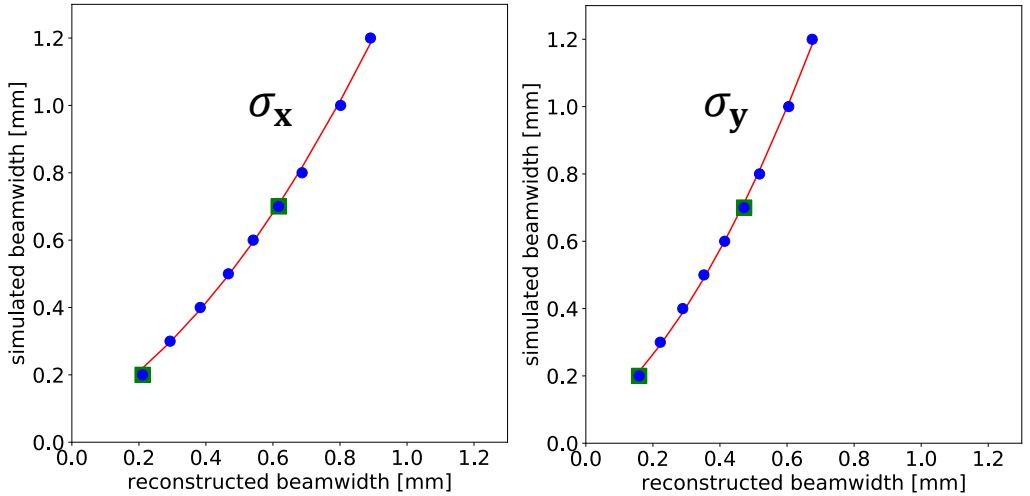
Comparison to Simulation

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

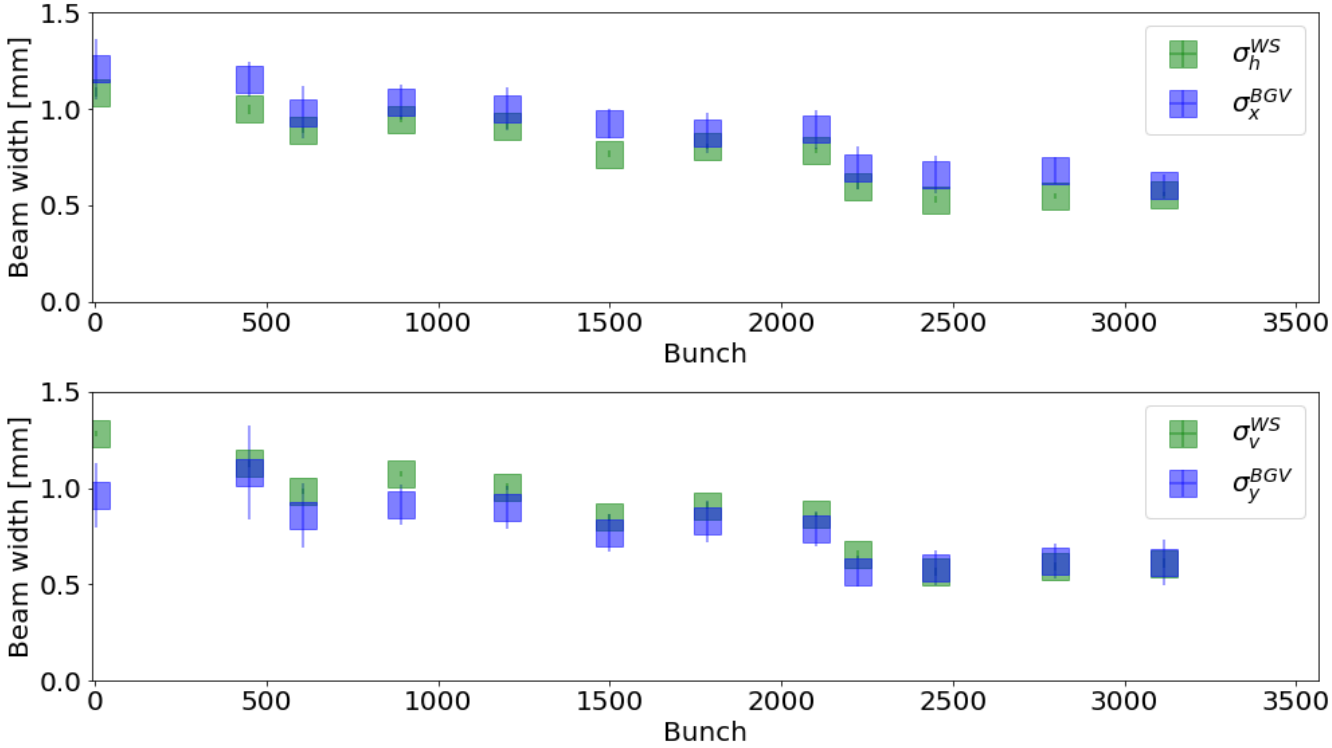
- Simulating round beam with defined sigma using Hijing
- Reconstructed size is not equal to simulated size due to
  - Detector geometry
  - clusters from secondary tracks and noise
- Fitting polynomial of second order to these results gives correction factors for both axis independently

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

$$\sigma_y^{(corr)} = 1.39\sigma_y^2 + 0.72\sigma_y + 0.06$$

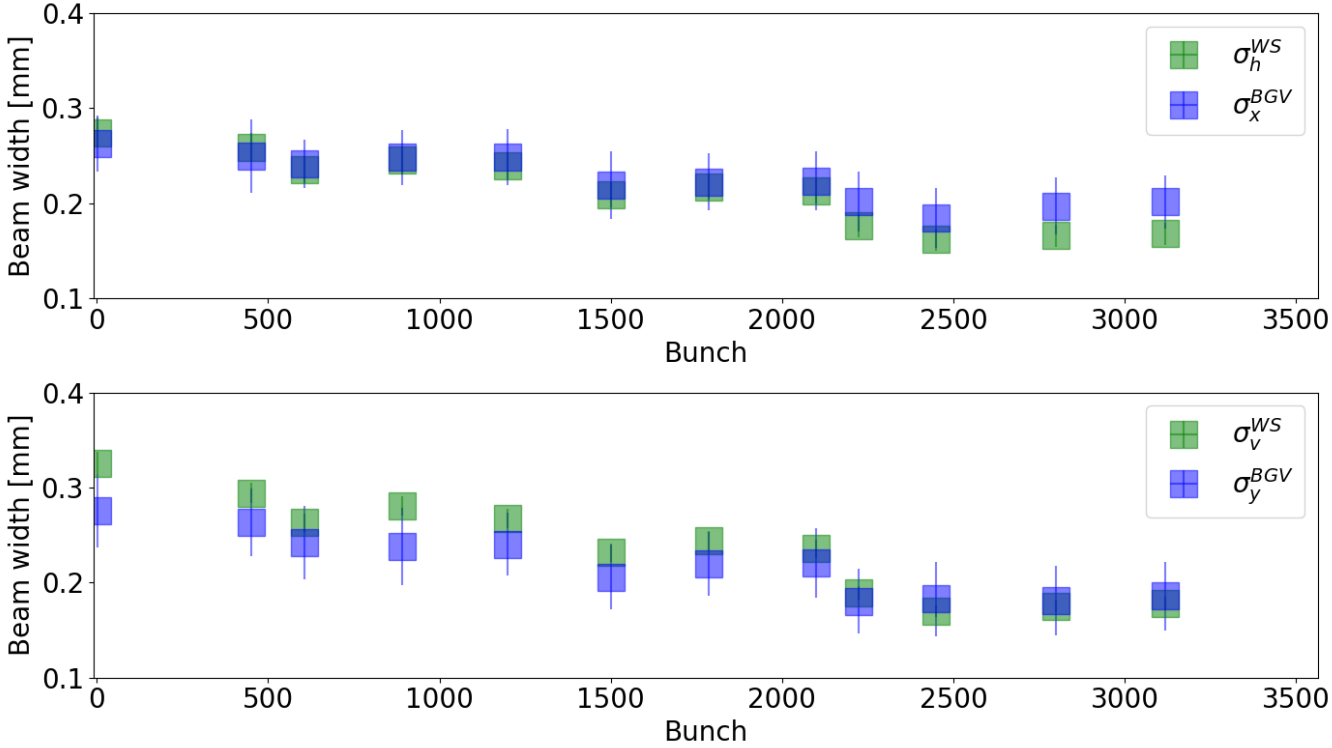


BGV vs Wirescanner (450GeV)



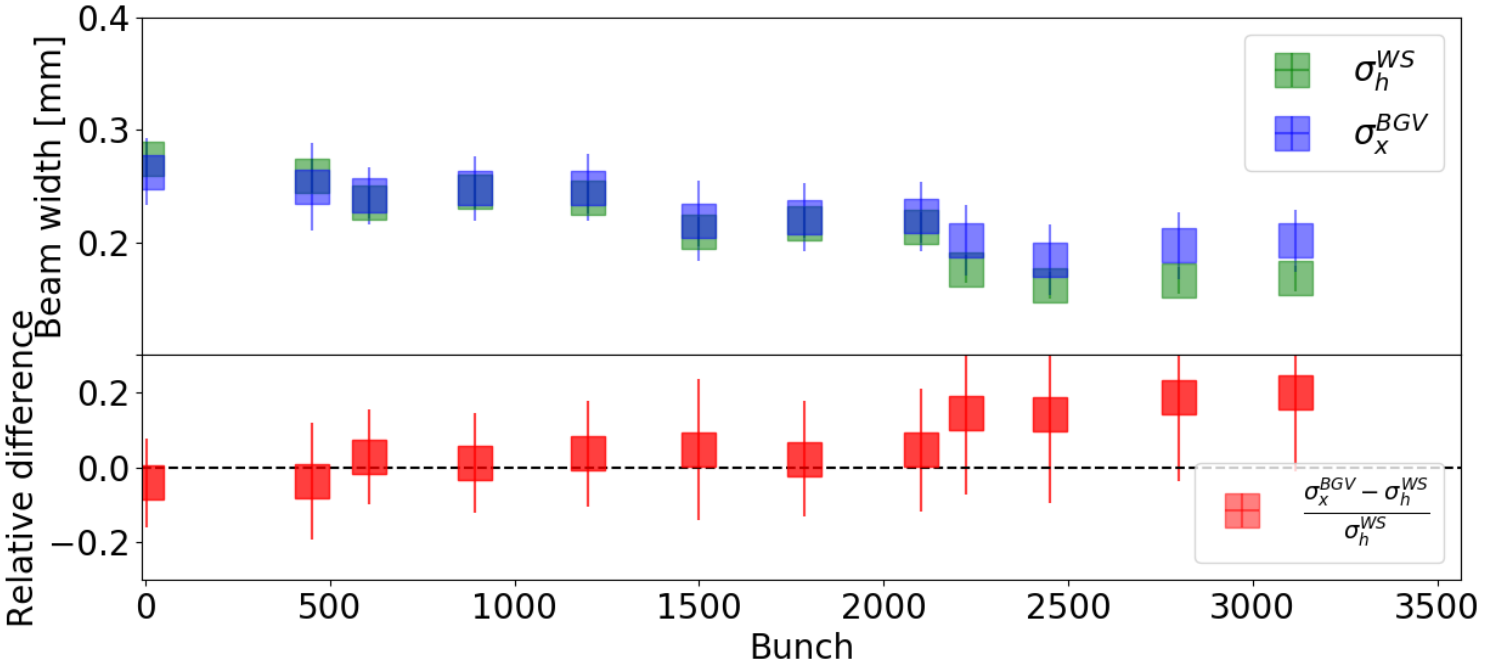
Fill 7220, BSRT calibration fill on 2018-09-25

BGV vs Wirescanner (6.5TeV)



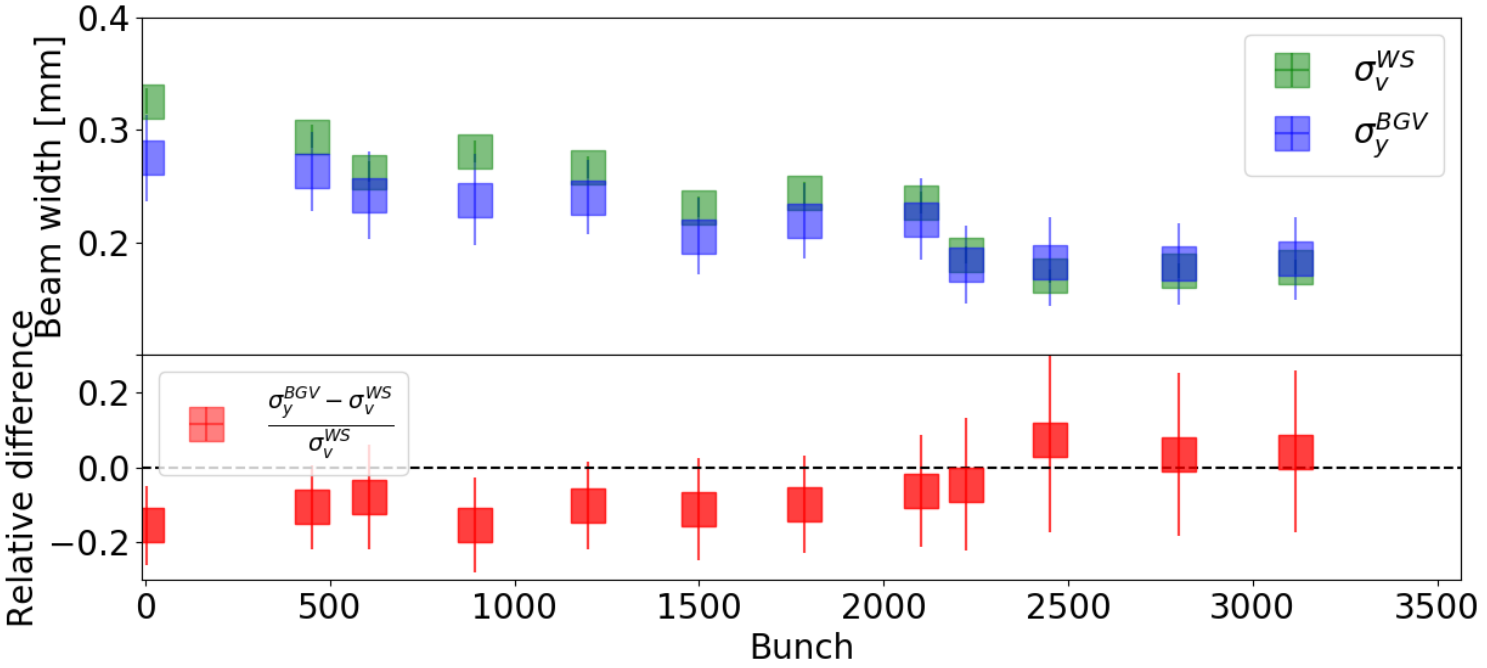
Fill 7220, BSRT calibration fill on 2018-09-25

BGV vs WS relative error – horizontal (6.5TeV)



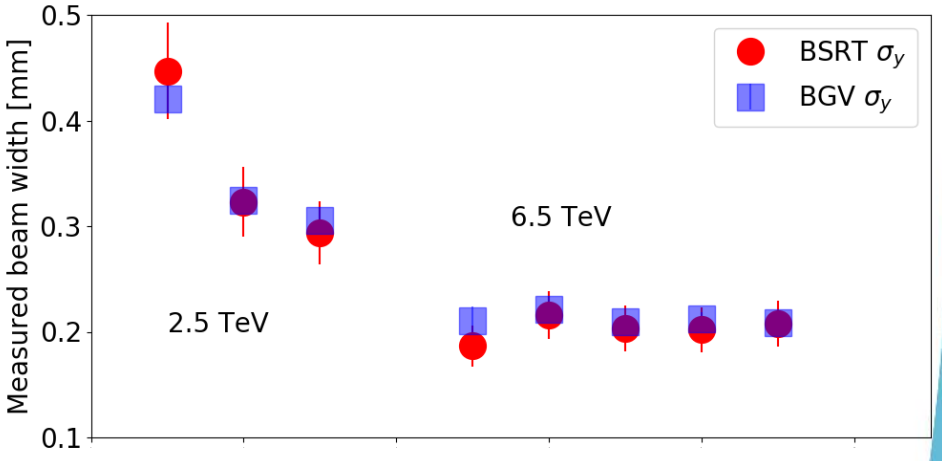
Fill 7220, BSRT calibration fill on 2018-09-25

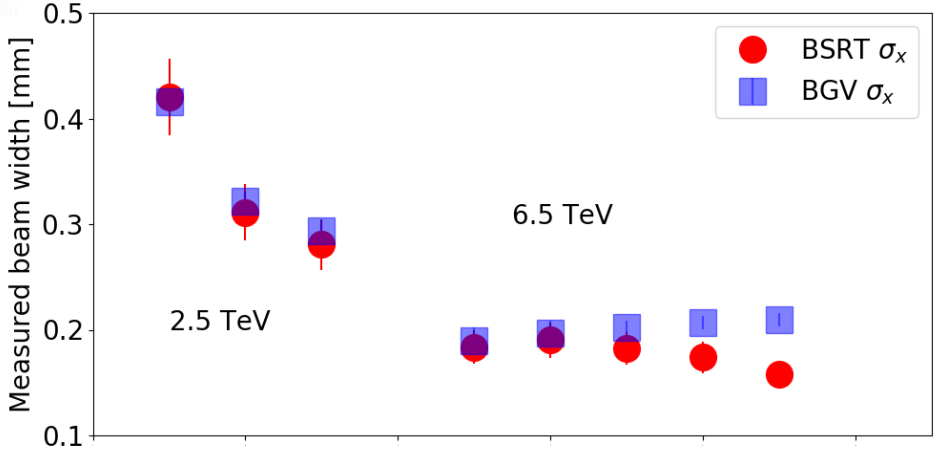
BGV vs WS relative error - vertical (6.5TeV)



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

Average beam profile measurement

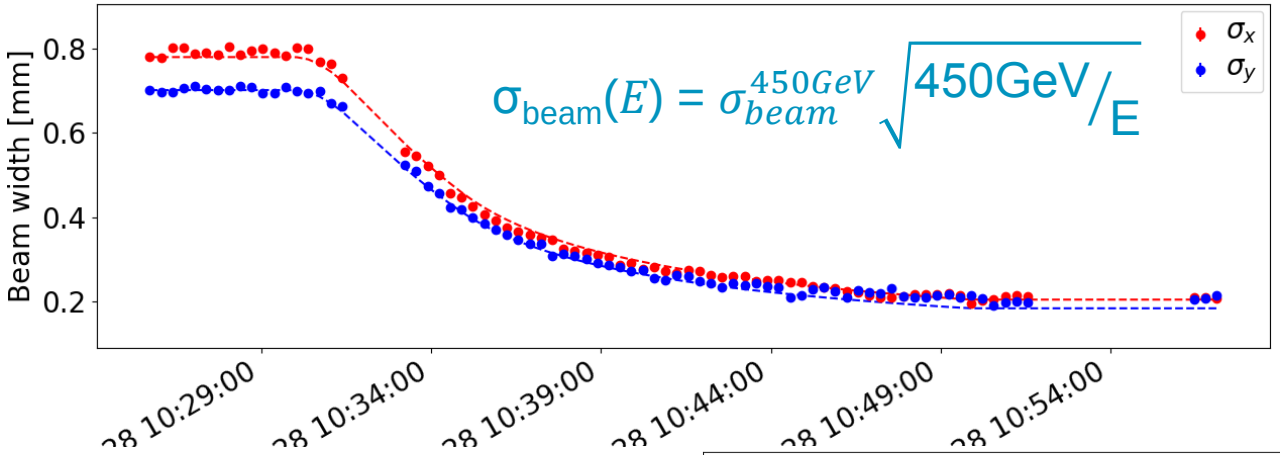




fill numbers - 6.5TeV

6358	November 2017
6371	November 2017
7127	September 2018
7145	September 2018
7232	September 2018

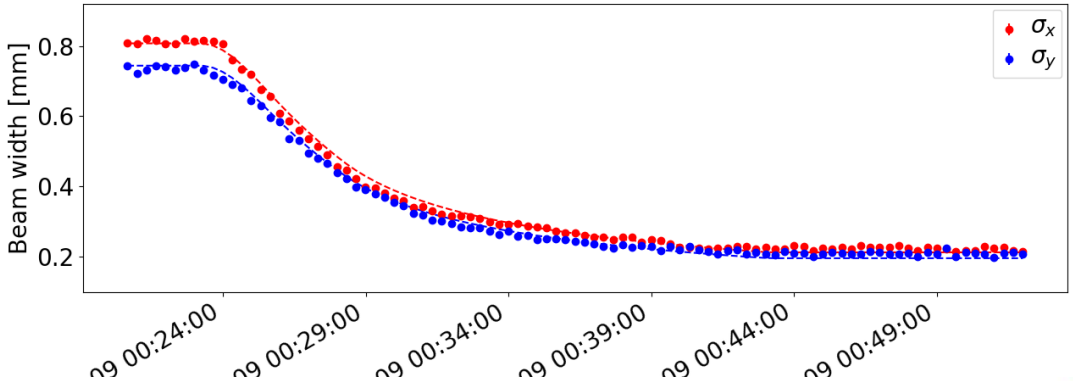
Beam size measurement during ramp



Integration time per data point: 20s

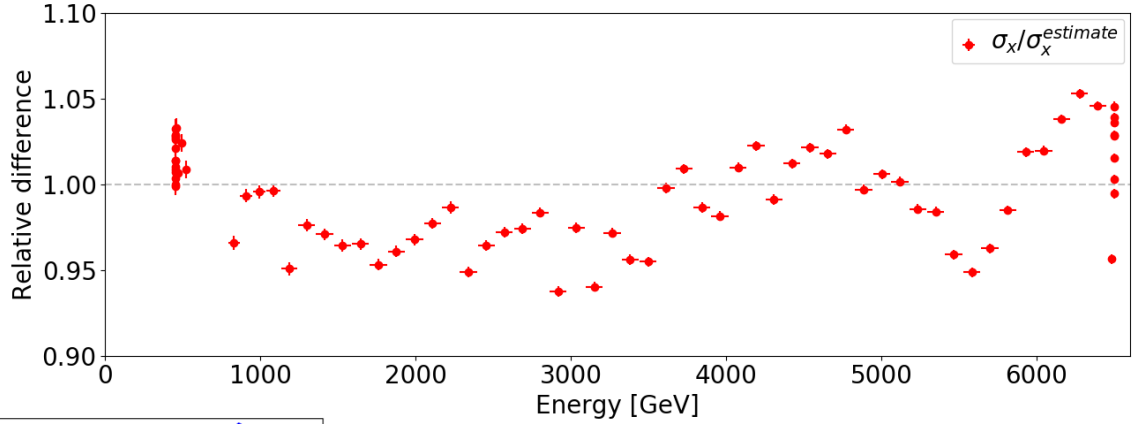
Fill 7232,
2556 nominal bunches
on 2018-09-28

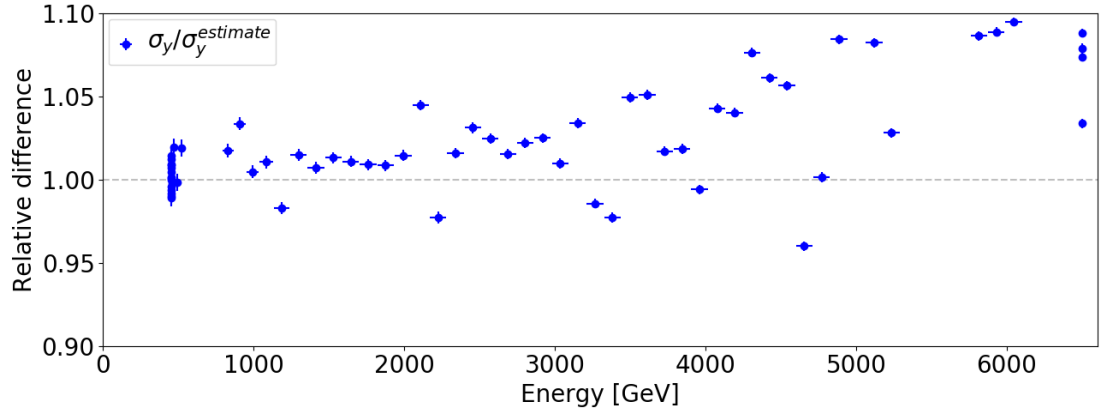
Fill 7270,
2556 nominal bunches
on 2018-10-09



Beam size measurement during ramp

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



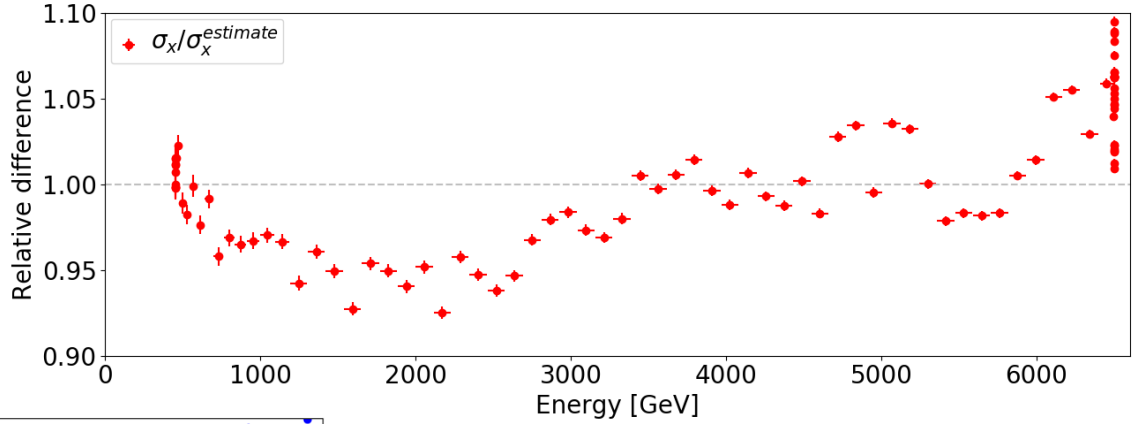


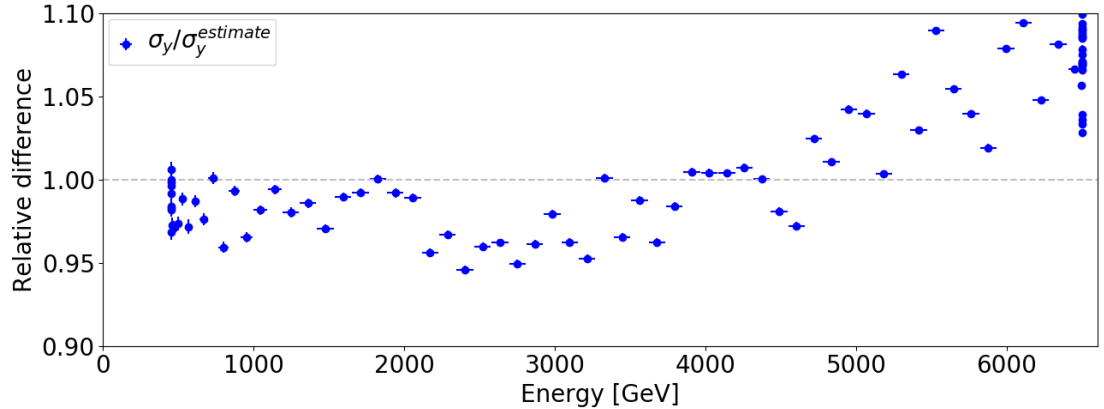
Integration time per data point: 20s

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

Beam size measurement during ramp

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





Integration time per data point: 20s

Fill 7270, 2556 nominal bunches on 2018-10-09

Summary

- The BGV has demonstrated that it can non-invasively measure beam size including measurements during ramp
- The BGV Demonstrator already fulfills the design specifications for the final system
  - Average beam size measurement with a precision of better than 5µm in 30s for 6.5TeV
  - Bunch by bunch measurement with a precision of better than 20µm in 60s for 6.5TeV
- Multiple measurements were taken during
  - BSRT calibration
  - Energy ramp
  - Stable beams
- Relative average difference to Wirescanner of ~8%
- Plans for the Analysis
  - Quantification of systematic errors
  - Online publishing of results
- BGV in Run 3?
  - Not yet clear if the system can be maintained post LS2
- Considerations for future developments are already ongoing and were presented on Tuesday by Robert Kieffer

Error of measurements:
beam average: 2.2% within 30s
for one bunch: ~10% within 60s

Performance adequate for HL-LHC operation!

HiLumi HL-LHC PROJECT

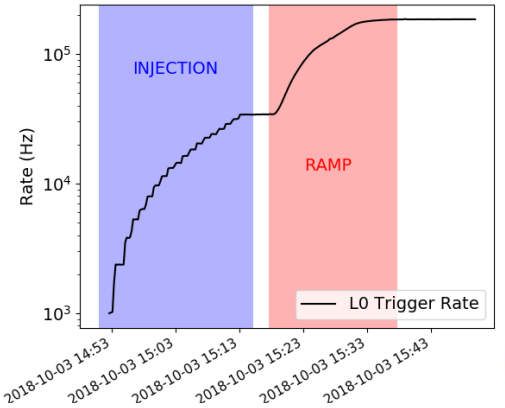
Thank you for your attention

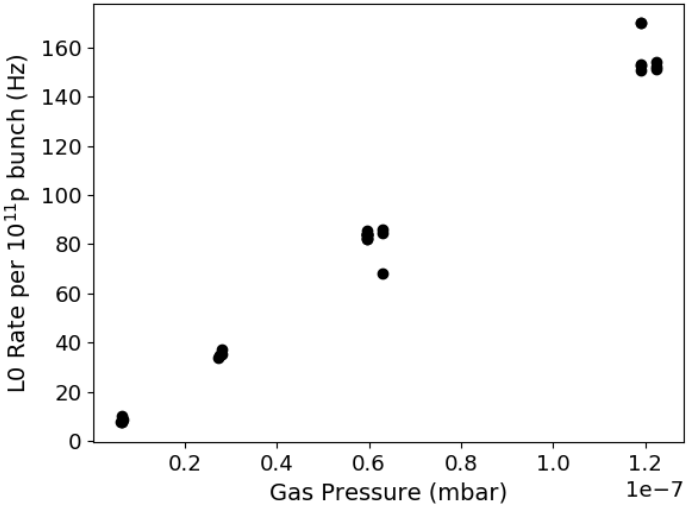
CERN

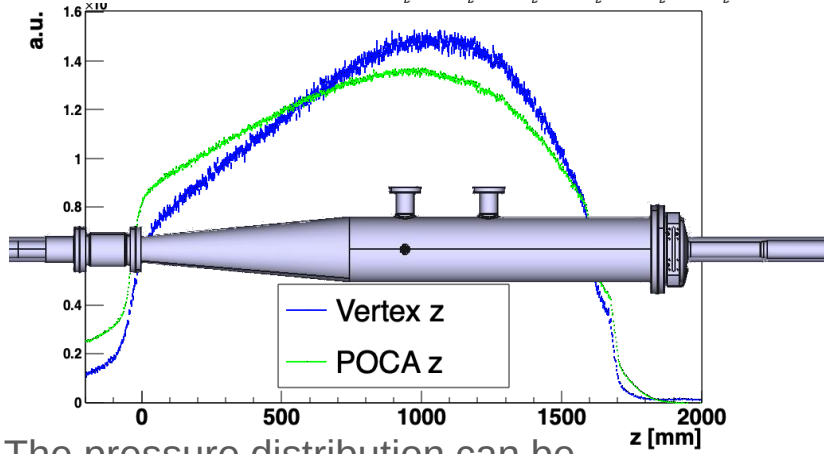
Backup

Gas interaction volume

- Almost 2m long gas tank with an exit window made from thin aluminum
- Gas injection system allows to inject Neon to increase the local pressure up to 1e-7 mbar
- Increases interaction rate by ~16x
- Doesn't influence the beam quality



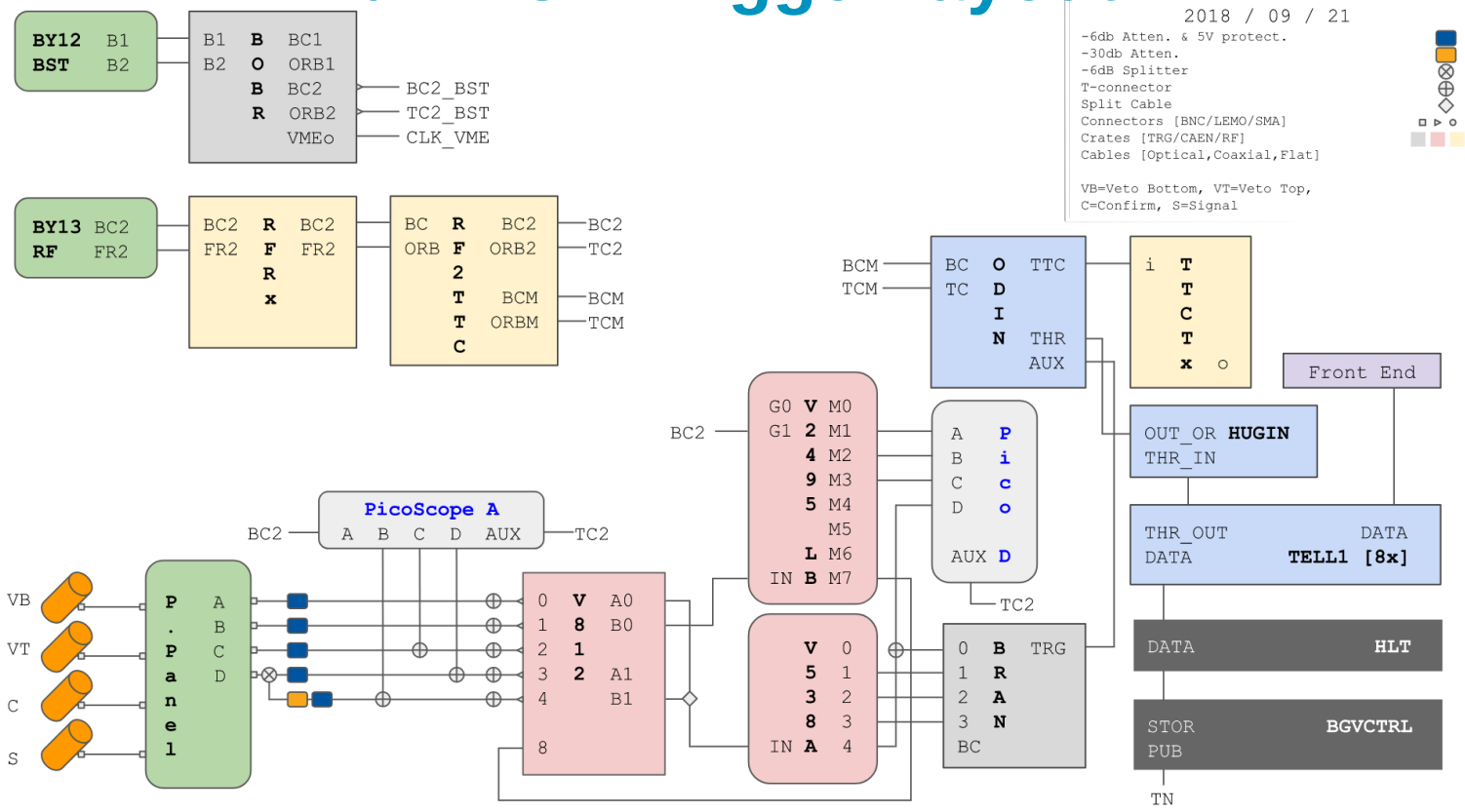




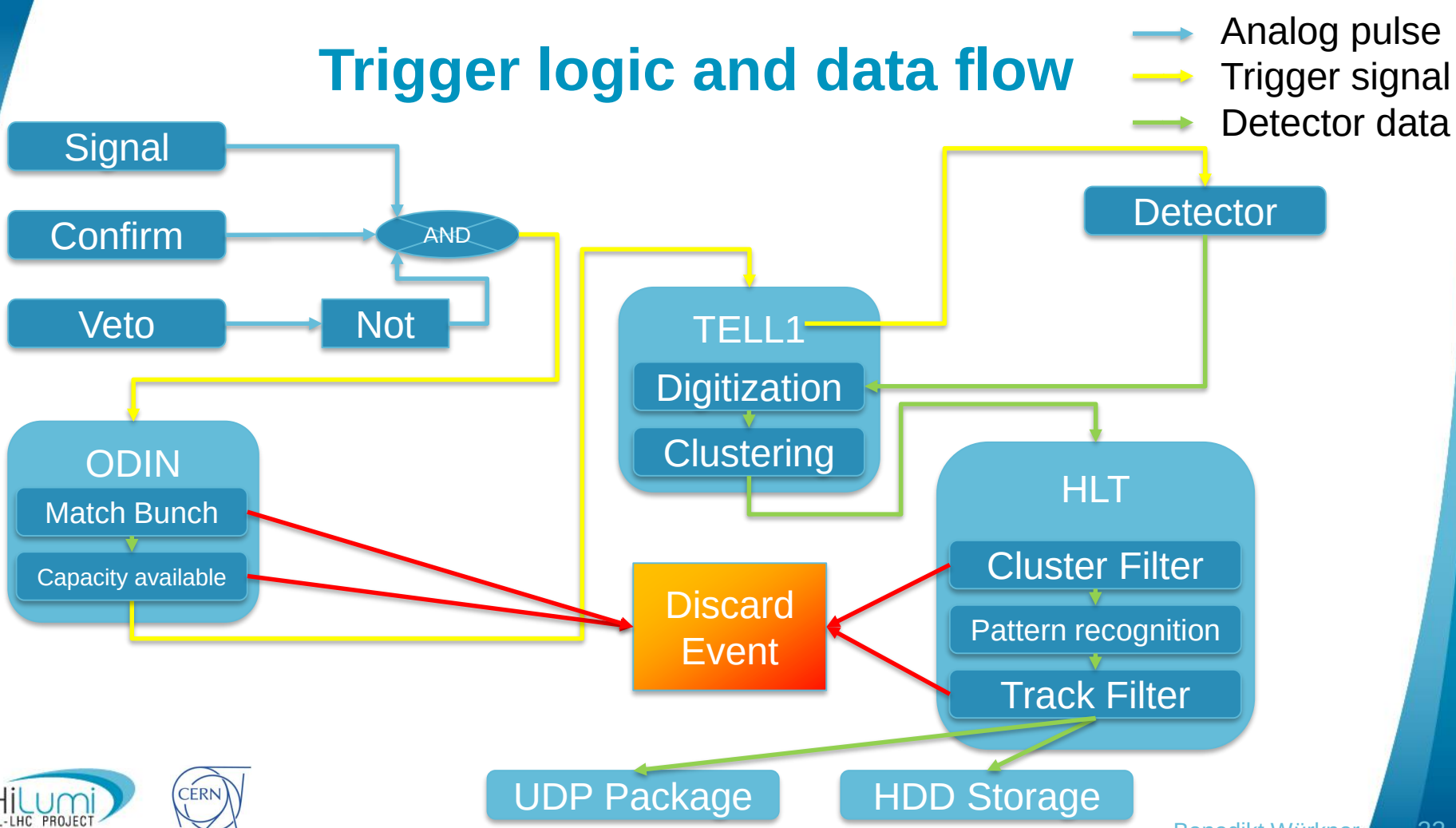
The pressure distribution can be approximated with the distribution of the z-coordinate of the POCA (green line)

This in mimicked by the vertex z-distribution (blue line)

Full BGV Trigger layout



Trigger logic and data flow



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)

Alignment

- A detailed survey of the setup was performed during installation
- The detector was not perfectly aligned around the center hence a precise (order of micrometers) alignment procedure had to be developed