BEAM PROFILE AND EMITTANCE MEASUREMENTS WITH THE BEAM GAS VERTEX SYSTEM

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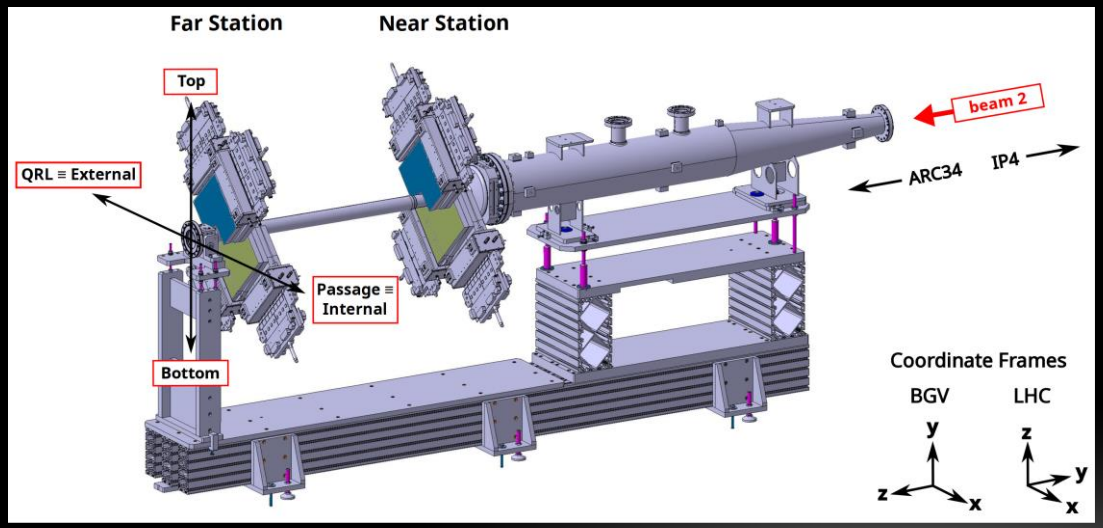
For the BGV collaboration

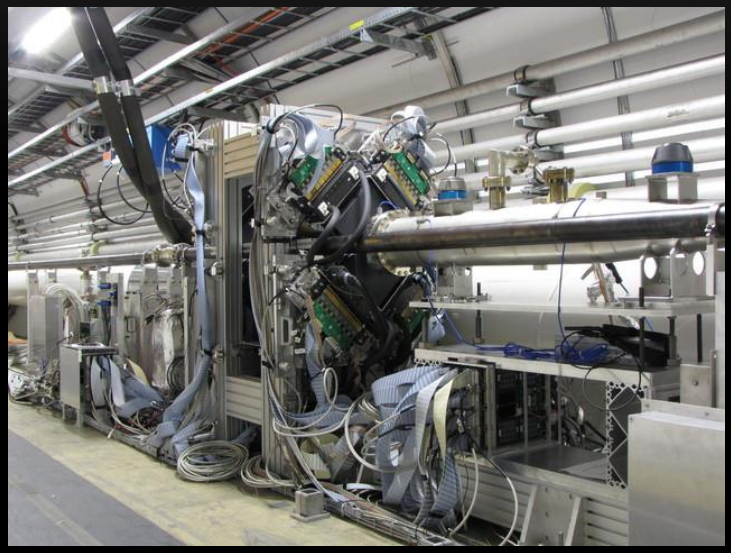
BEAM GAS VERTEX DETECTOR
NON DESTRUCTIVE BEAM SIZE MEASUREMENT FOR HL-LHC NOT LIMITED BY ACCELERATOR LUMINOSITY

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

Ultimate Goals, measurement precision:
Absolute beam width : 2% in 1 min for 10^11 p/bunch
Relative bunch width : 5% in 5 minutes

Should allow ε measurements with similar precision

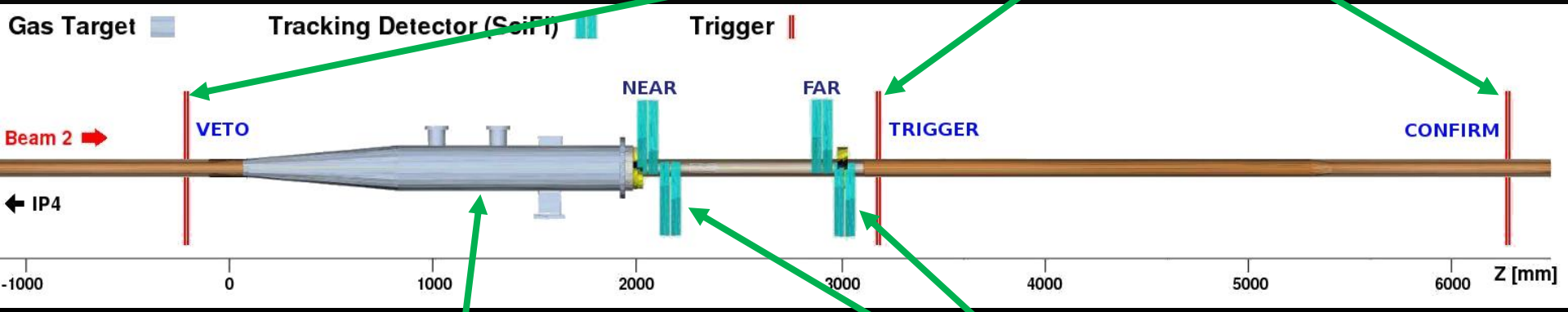




Demonstrator fully commissioned,
Data analysis ongoing

THE BGV detector parts

The trigger system



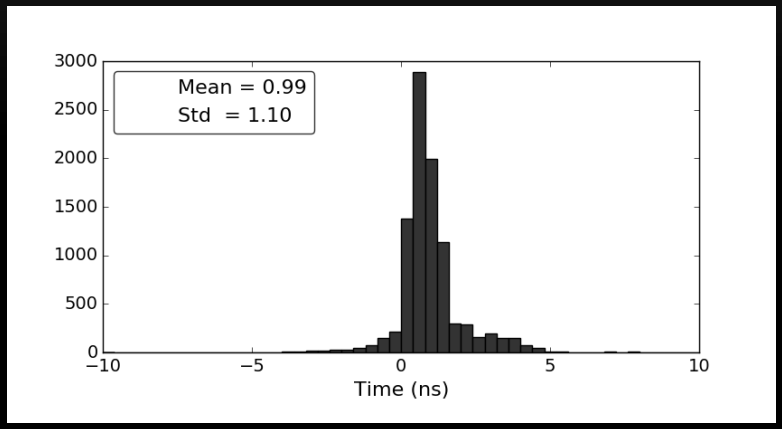
The gas target

The precision tracker

https://twiki.cern.ch/twiki/bin/view/BGV

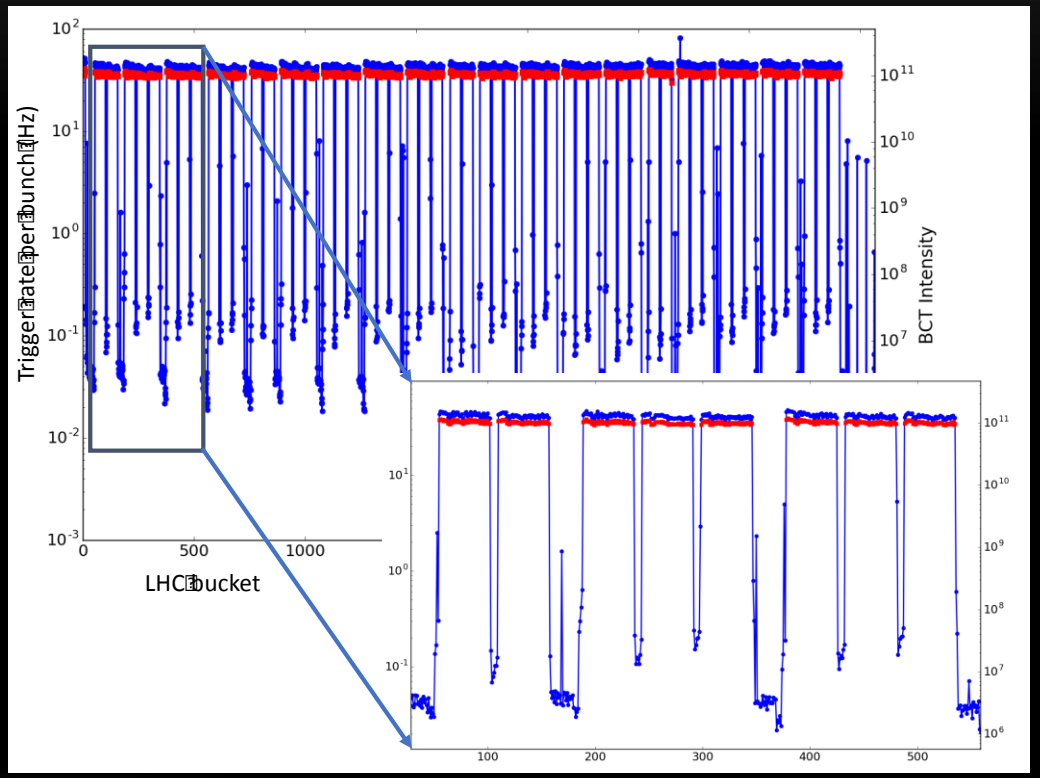
TRIGGER DETECTOR PERFORMANCE

- 1 ns resolution – easy beam bunch identification, beam structure and timing
- Background contamination < 10^{-4}



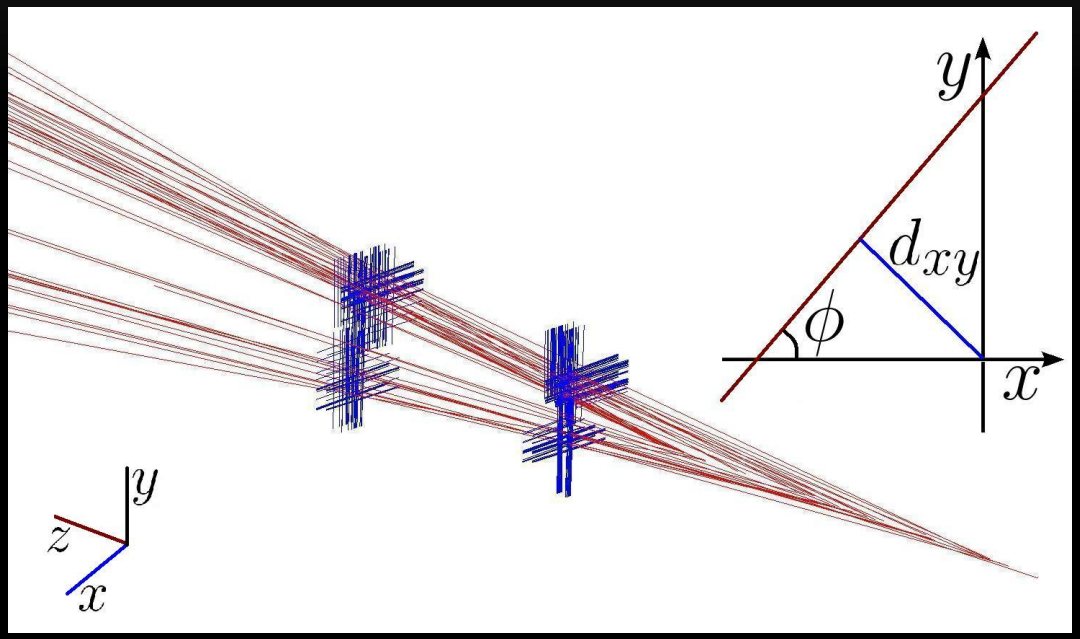
Adjusted time difference between SIGNAL and CONFIRM planes

LHC bunch structure as seen by BGV Trigger



Standalone measurement:
Ghost charge fraction = 0.29% ± 0.03%

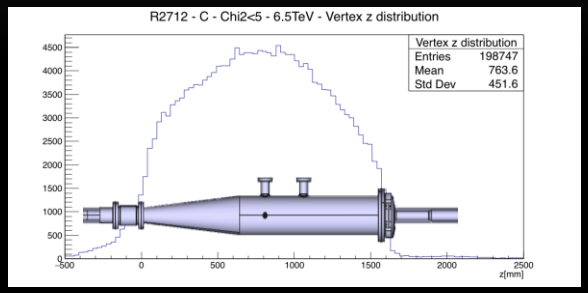
FIRST LOOK AT BGV REAL DATA



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

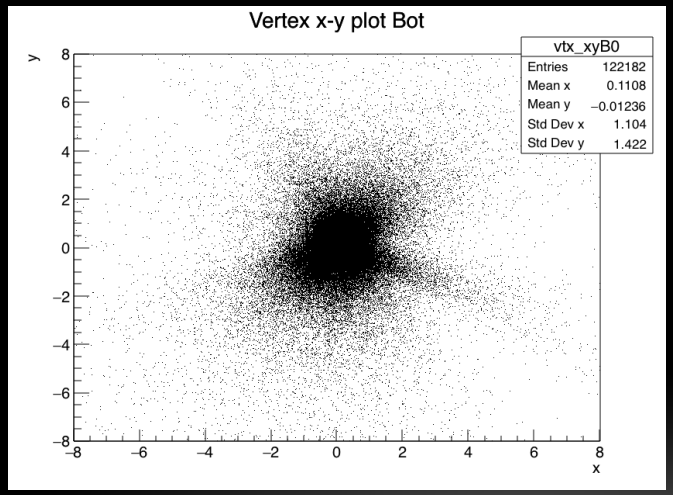
VERTEX DISTRIBUTION IN THE BGV GAS VOLUME

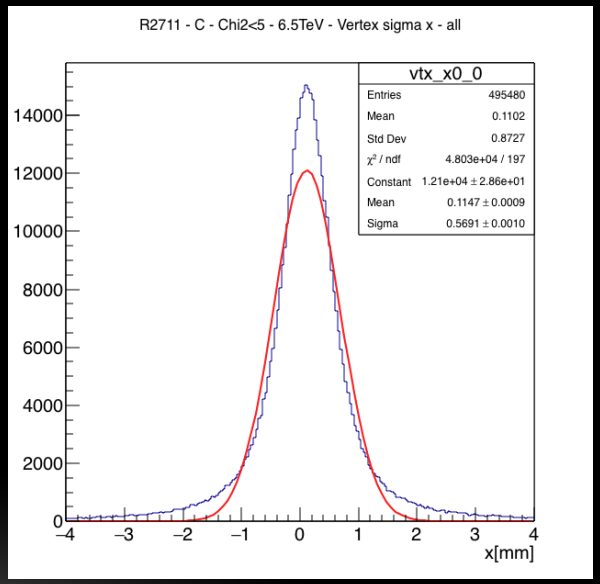
Vertex reconstruction



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

- Convolution of beam width and σ_{vertex}
- σ_{vertex} depends heavily on z

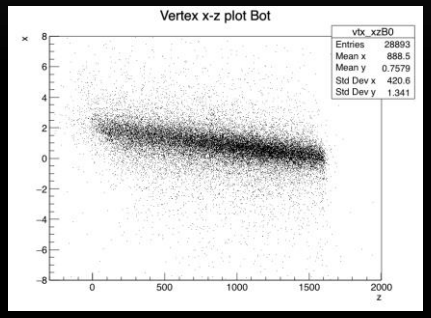


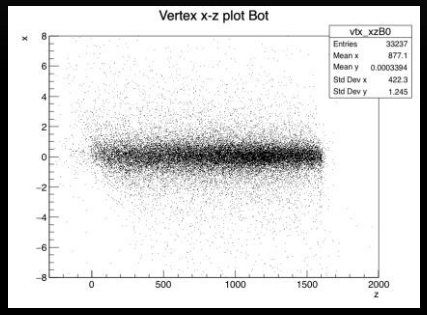


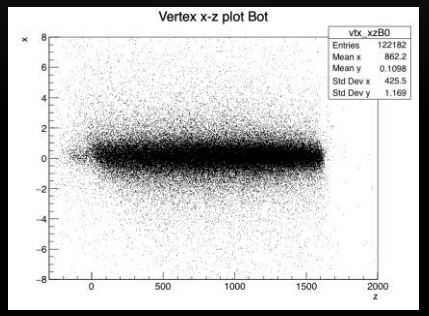
VERTEX RECONSTRUCTION, FOCUS ALONG BEAM DIRECTION

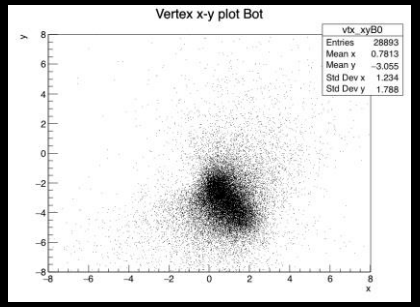
Raw data

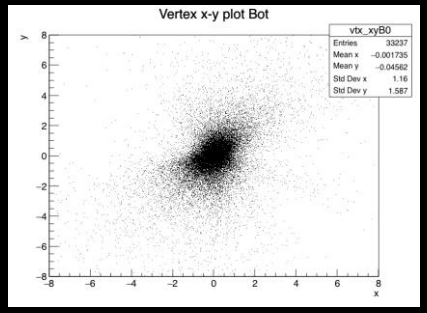
After relative alignment

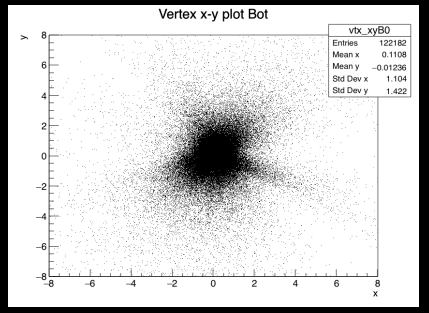








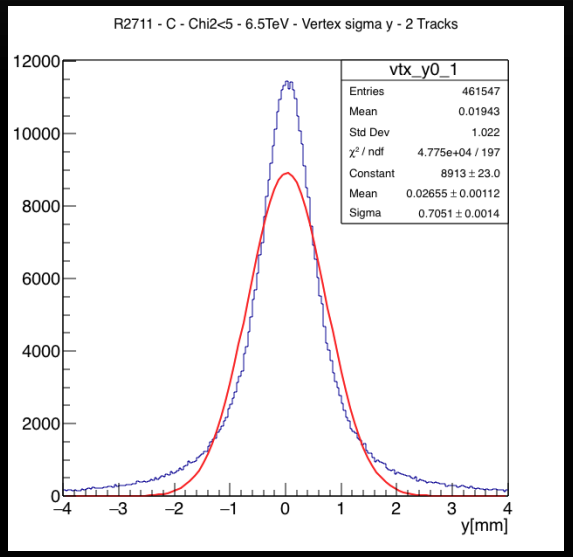


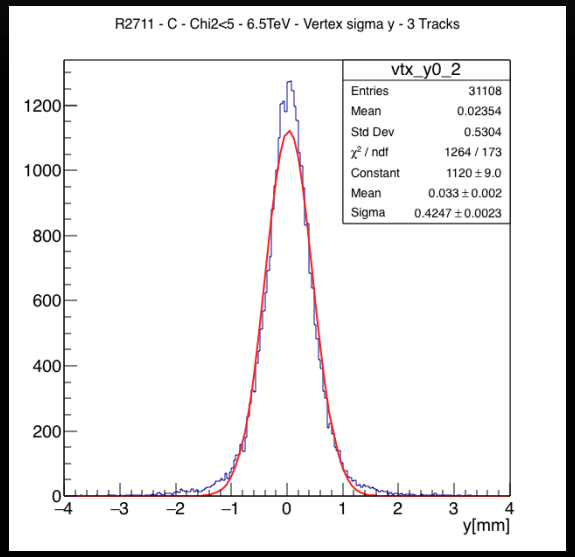


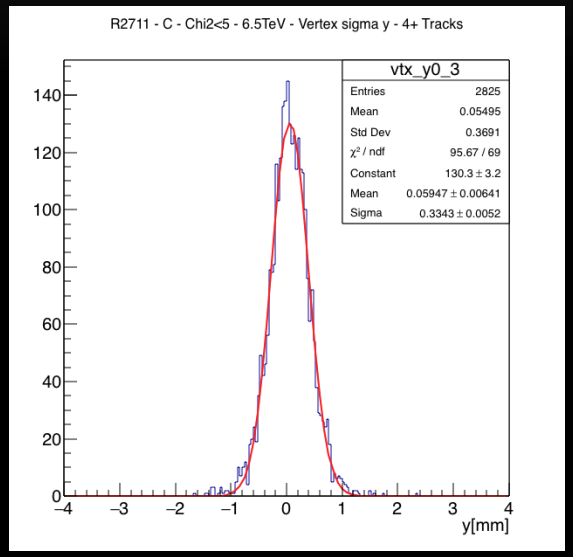
Run 2626,
used to estimate corrections

Run 2712,
same corrections used

X-PROJECTION OF VERTEX DISTRIBUTION







2-prong vertices

3-prong vertices

4-prong vertices

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

High prong vertices allow also better event selection

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) is given by:

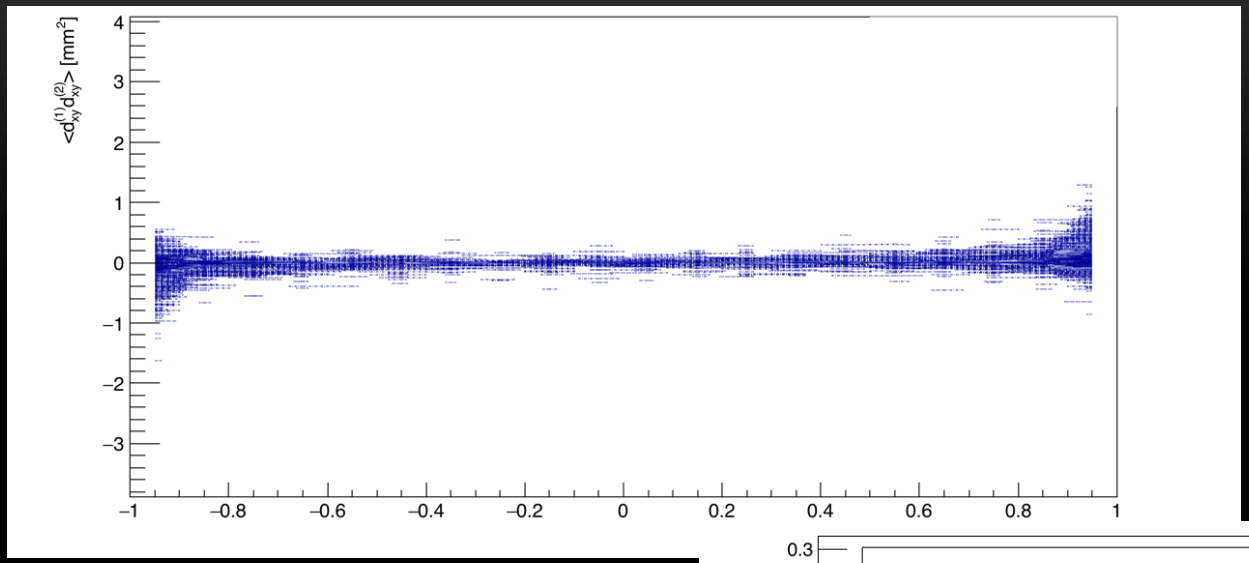
$$\langle IP_1\, IP_2 \rangle = \frac{\sigma_x^2 + \sigma_y^2}{2} \cos(\phi_1 - \phi_2) + \frac{\sigma_y^2 - \sigma_x^2}{2} \cos(\phi_1 + \phi_2)$$

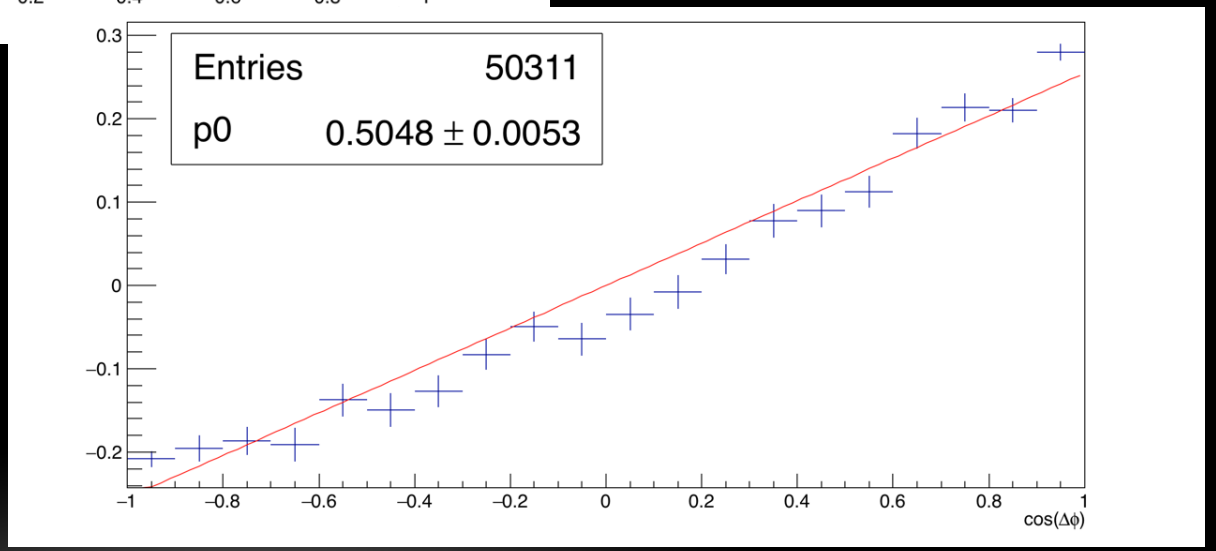
σ_x^2 (σ_y^2) being the beam spot variance along x (y)

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 → σ_{beam}





BEAM WIDTH MONTE-CARLO CORRECTION

Systematic underestimation of beam width due to

- Detector geometry
- Tracking performance and combinatorics

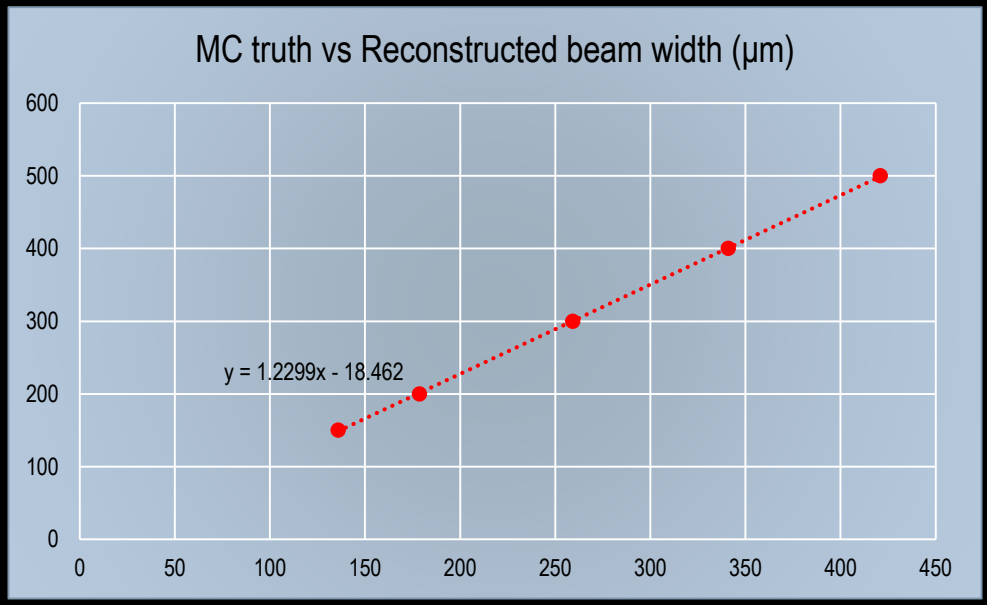
Correction factor derived from

Monte-Carlo simulation

(correction error properly taken into

account in what follows,

Fit parameters: 1.23±0.005, 18.5±1.6)

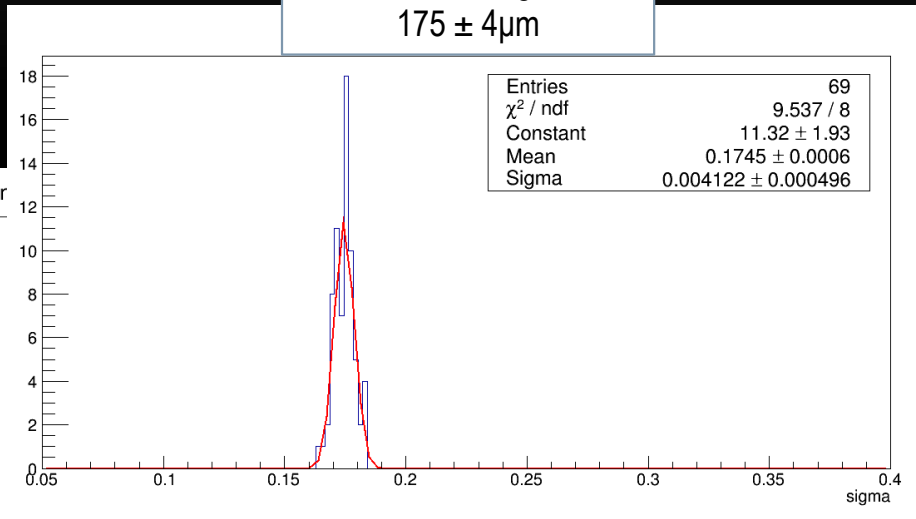


RESOLUTION VS INTEGRATION TIME

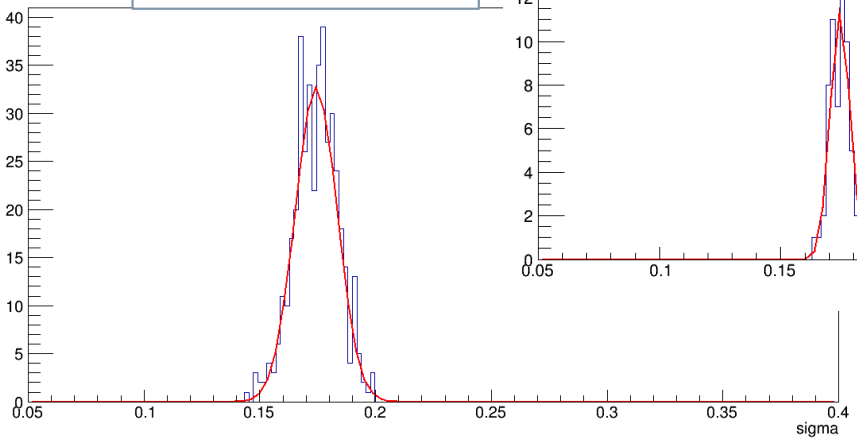
The longer the integration Time the higher the precision

(until a certain limit)

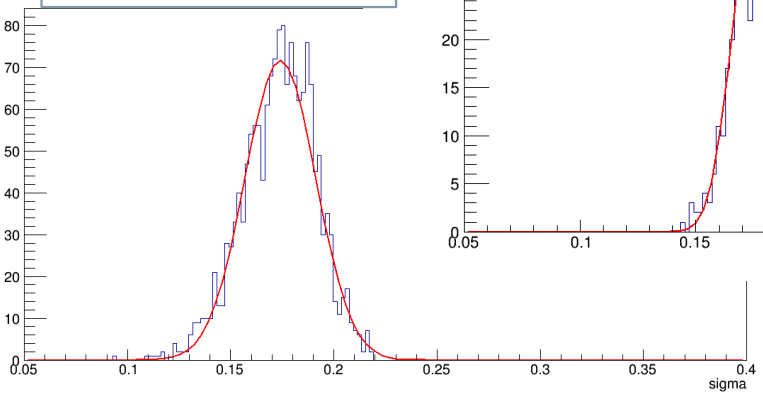
60 seconds integration
175 ± 4μm



10 seconds integration
174 ± 9μm



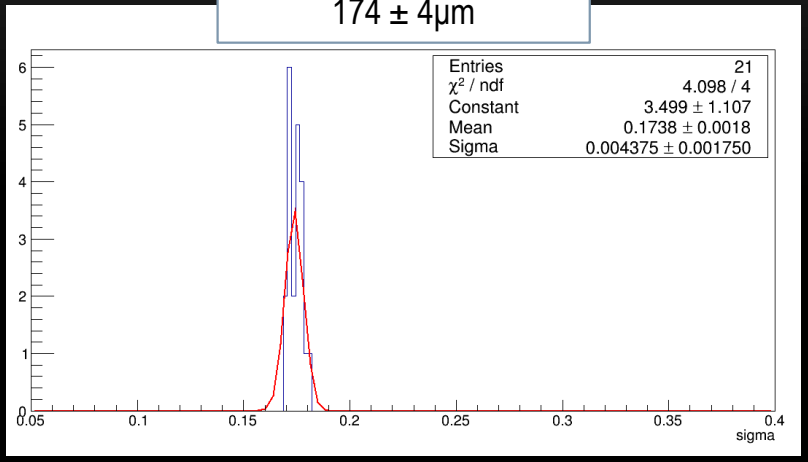
2.5 seconds integration
173 ± 17μm

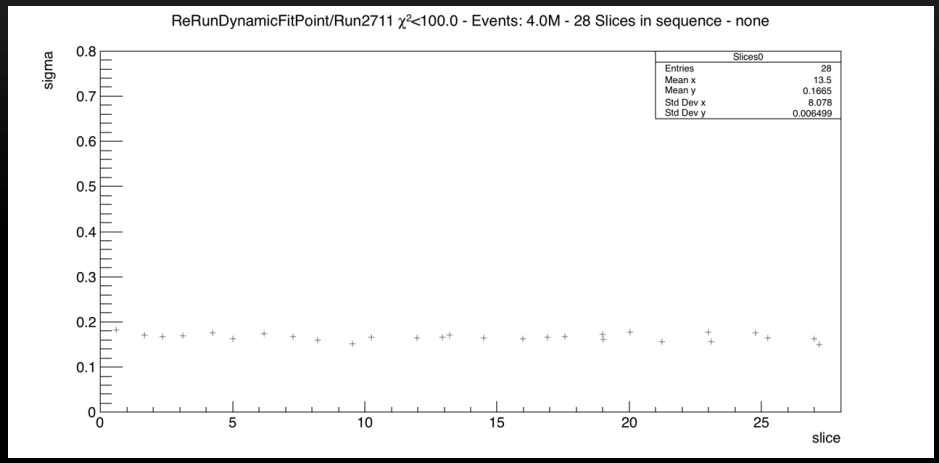


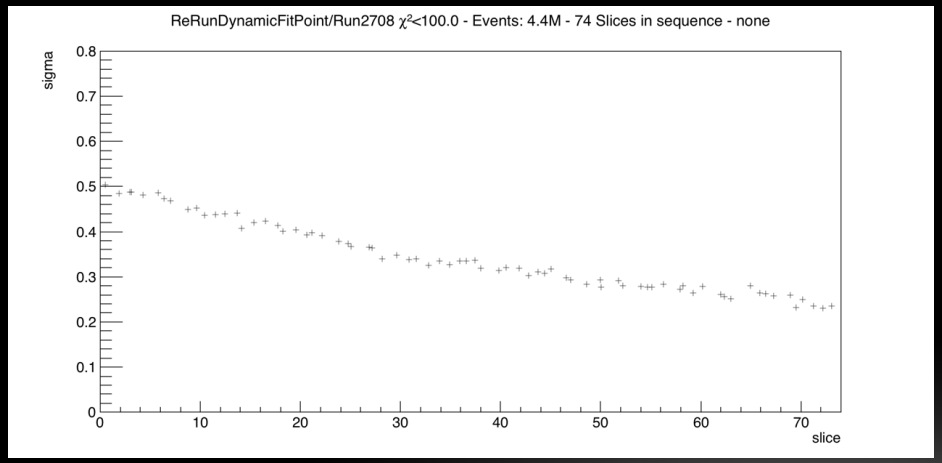
Raw BGV values @ 6.5 TeV

BGV BEAM WIDTH MEASUREMENTS

200 seconds integration
174 ± 4μm





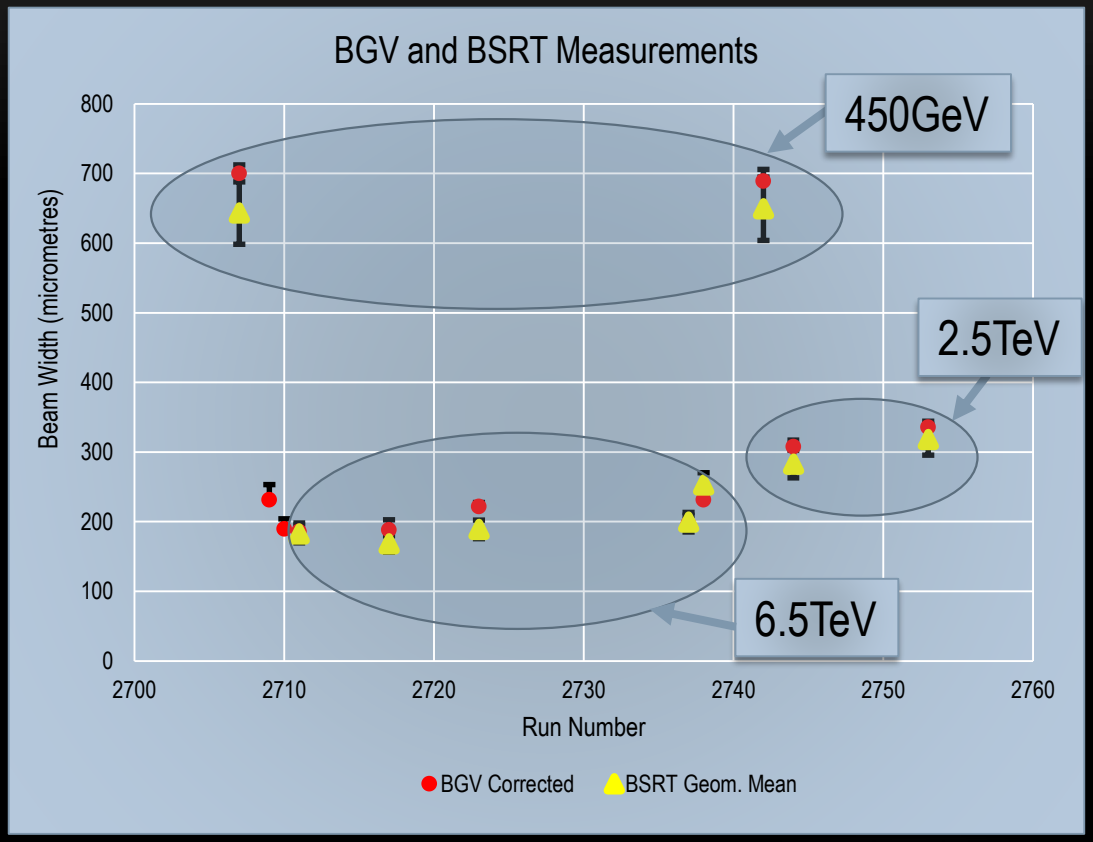


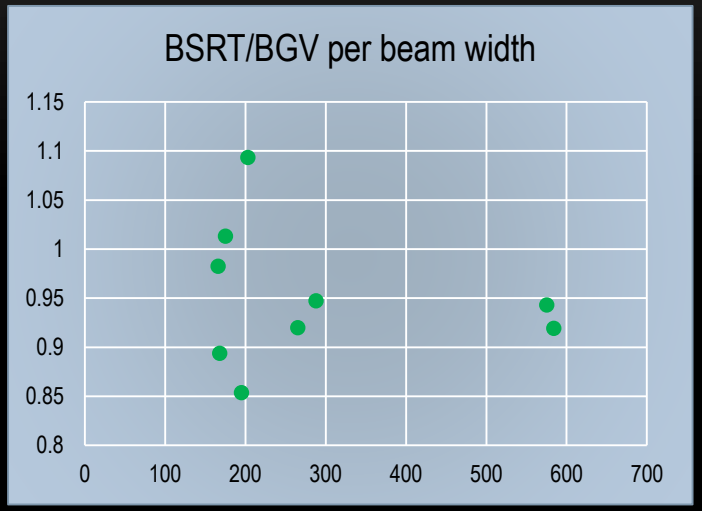
During a ramp

TYPICAL BGV MEASUREMENTS

Fill #	Integration time (sec)	Beam width (μm)	Error (μm)	Rel. Error
6371 (6.5TeV)	2.5	173	17	9.8%
	10.0	174	9	5.2%
	60.0	175	4	2.3%
6358 (450GeV)	2.5	700	30	4.3%
	10.0	698	16	2.3%
6386 (2.5TeV)	10.0	307	10	3.3%

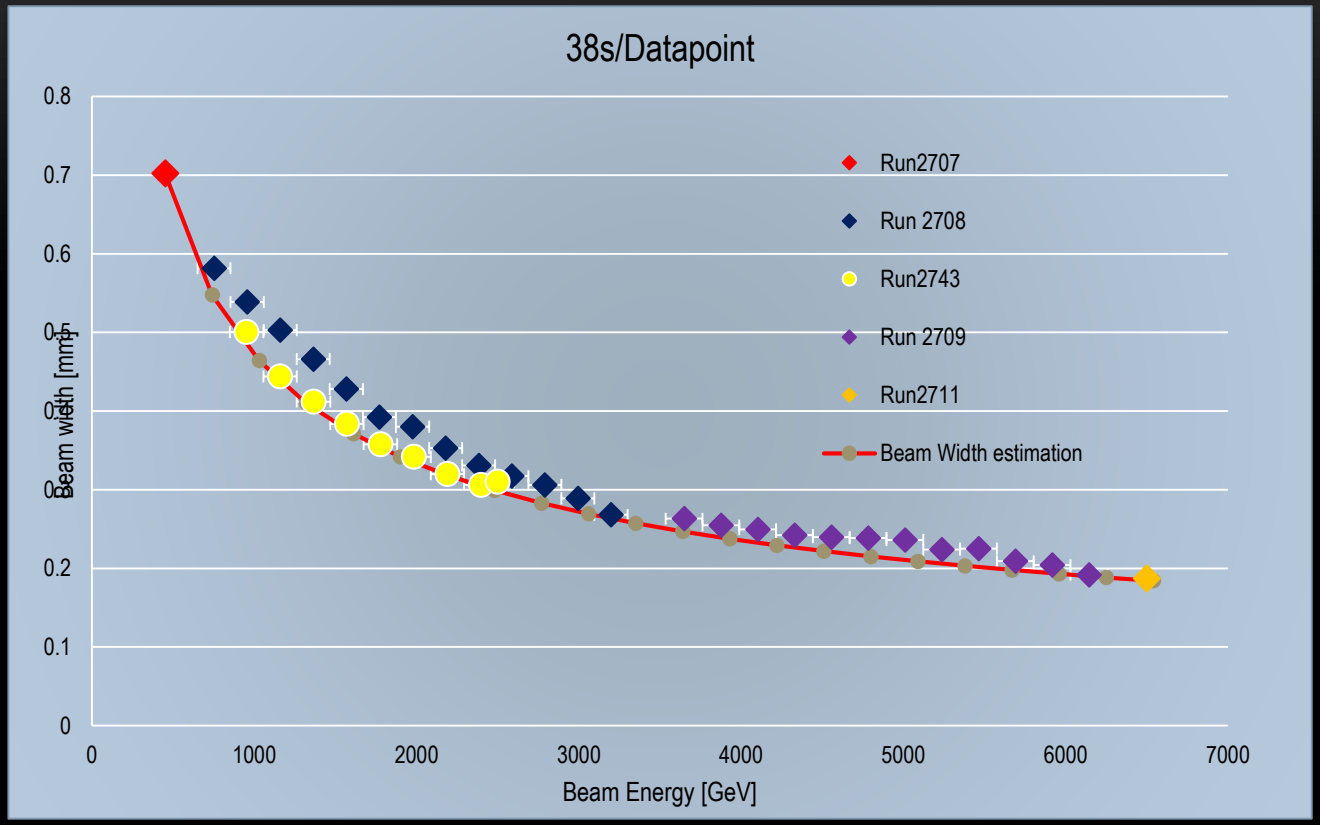
BEAM WIDTH: BGV VS BSRT MEASUREMENTS





- BGV points with 10sec integration time
- Using 7% BSRT error

BEAM WIDTH DURING RAMP



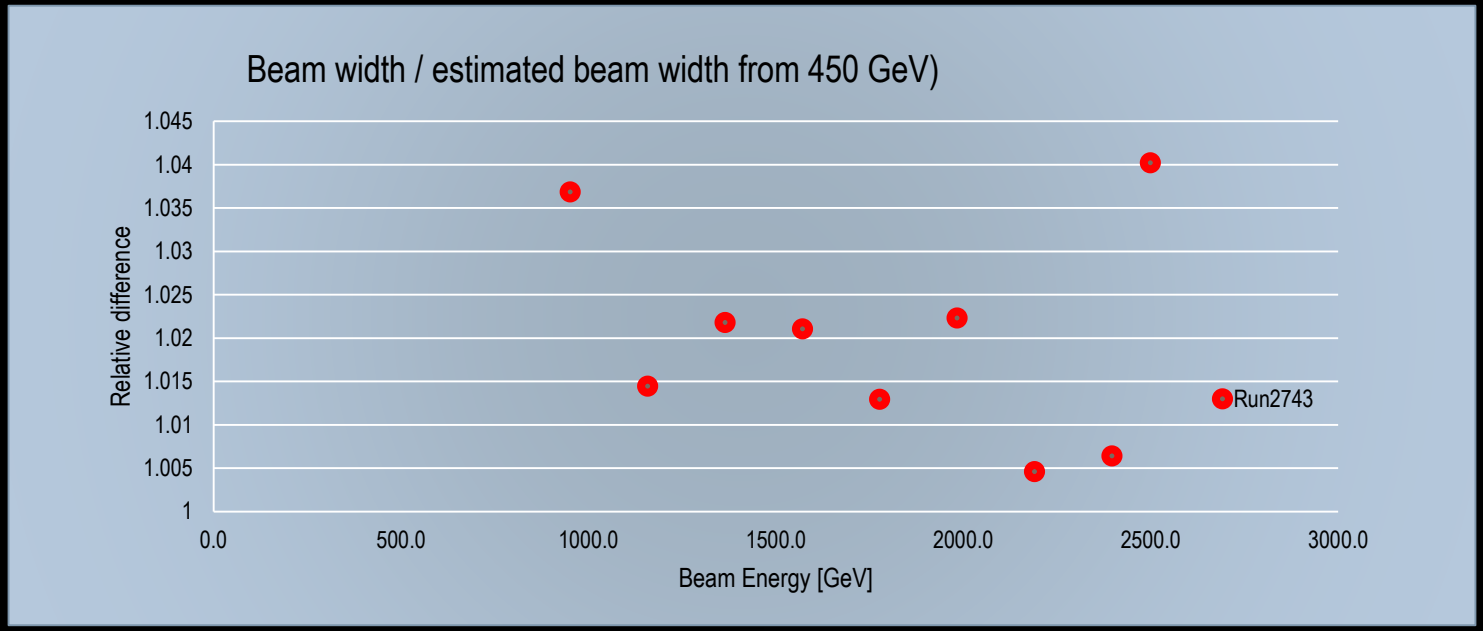
Beam width during ramp estimated from 450GeV value:

$$\sigma_{beam}(E) = \sigma_{beam}(E_0) * \sqrt{E_0 / E}$$

… assuming constant beta function ...

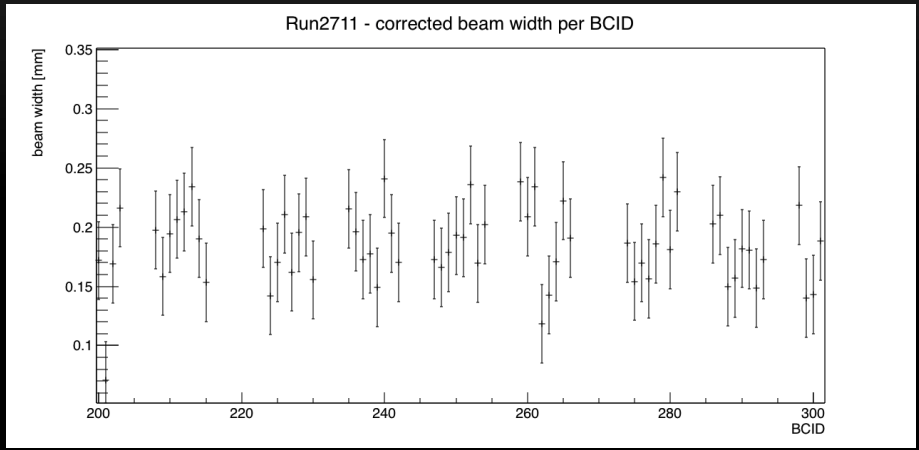
Ratio of measured values to estimation is an estimator of emittance variation during ramp.

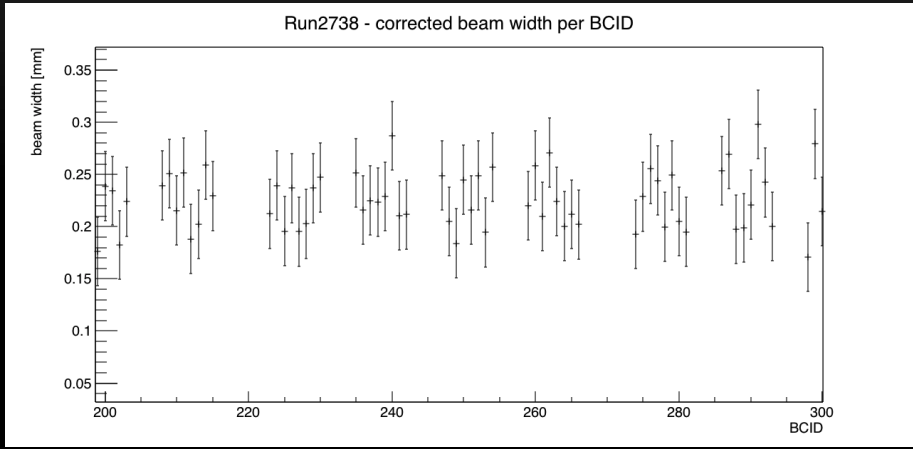
$\sigma_{measured}(E) = \sigma_{estimated}(E,\varepsilon_0) * \sqrt{\varepsilon/\varepsilon_0}$

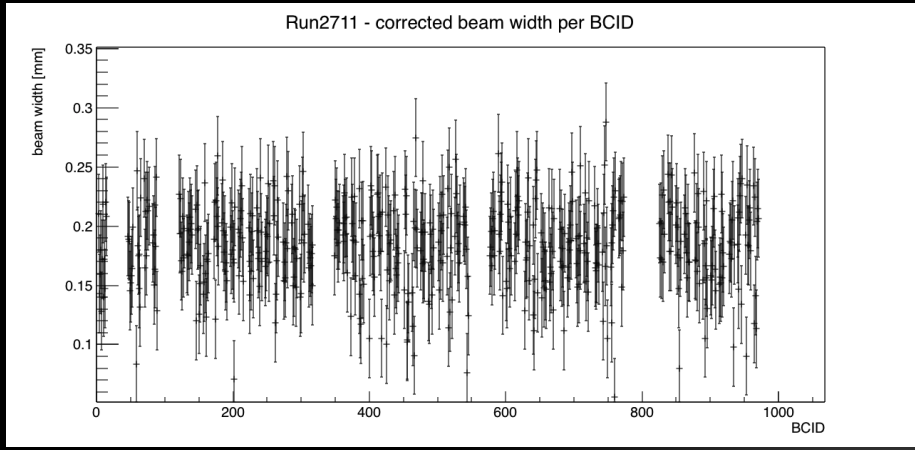


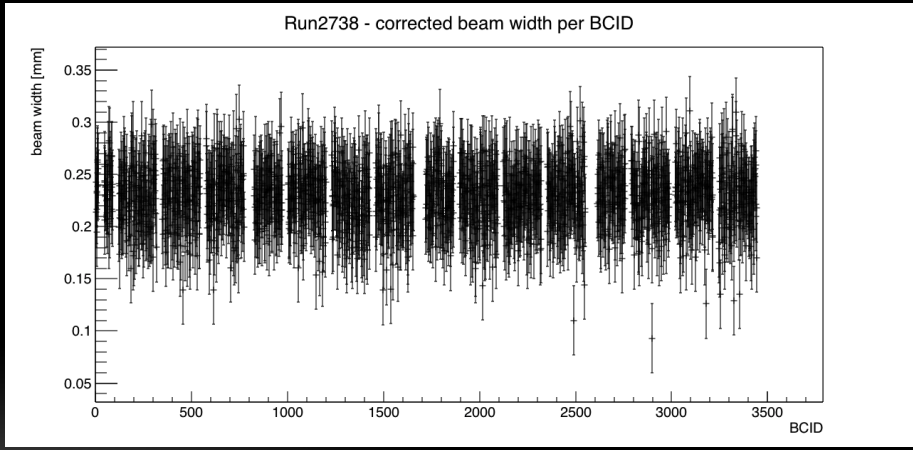
2018 data taking sessions will provide valuable data for such measurements

BEAM WIDTH VS BCID









RATE EXPECTED PER BUNCH ETC

- Available DAQ bandwidth to read-out ~ 200 BCs with maximum statistics
- Improved read-out system will increase the number of BCs to be followed

- Beam width Error per bunch for 9min integration time : ~ 15%
- Improvements in trigger and off-line algorithms should reduce error to less than 10%

NEXT STEPS

- Improve tracking and off-line analysis
- Increase read-out rate

- Disentangle x and y profile

- Refine bunch-by-bunch measurements

- More statistics during ramp(s)

- Ion Run studies

- Comparison with other methods (?) (dedicated MD ? … need ‘intense’ beams)

QUESTIONS TO BE-OP

- Precision needed
  - Mean-value per beam
  - Bunch per bunch
  - $(\sigma_x, \sigma_y)\ or\ \sigma_{beam}$
- Specific bunches of interest
- Feed-back time

BGV STATUS SUMMARY

- BGV Demonstrator fully commissioned and operational

- 2017 campain: absolute stand-alone beam profiles (2% error, 1 min integration time, similar to final design values), ghost charge etc precise measurements
- Bunch-by-bunch measurements show encouraging results, expect 10% relative error with 5 minutes integration time

- HL-LHC equipment should have even better performance

BACKUP

GAS TARGET OPERATING CONDITIONS

Expected beam-gas interaction rate:

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

- 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)

→ **$R = 80\ Hz$ per bunch**

BGV LOCATION

- Single beam demonstrator @ LHC, point 4, beam 2 ring

- at ~ -220m , beam 2 has $\beta_x \cong \beta_y \cong 150$ m
- at 7TeV and $\varepsilon_N \cong 2.5\mu m$, $\sigma_{beam} \cong 0.22$ mm

- $\beta_x \cong \beta_y$ allows beam pipe diameter reduction