Experience with Van der Meer scans to measure (absolute) luminosity at RHIC

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- **The Method**
- **Some examples**
- **… it all depends**

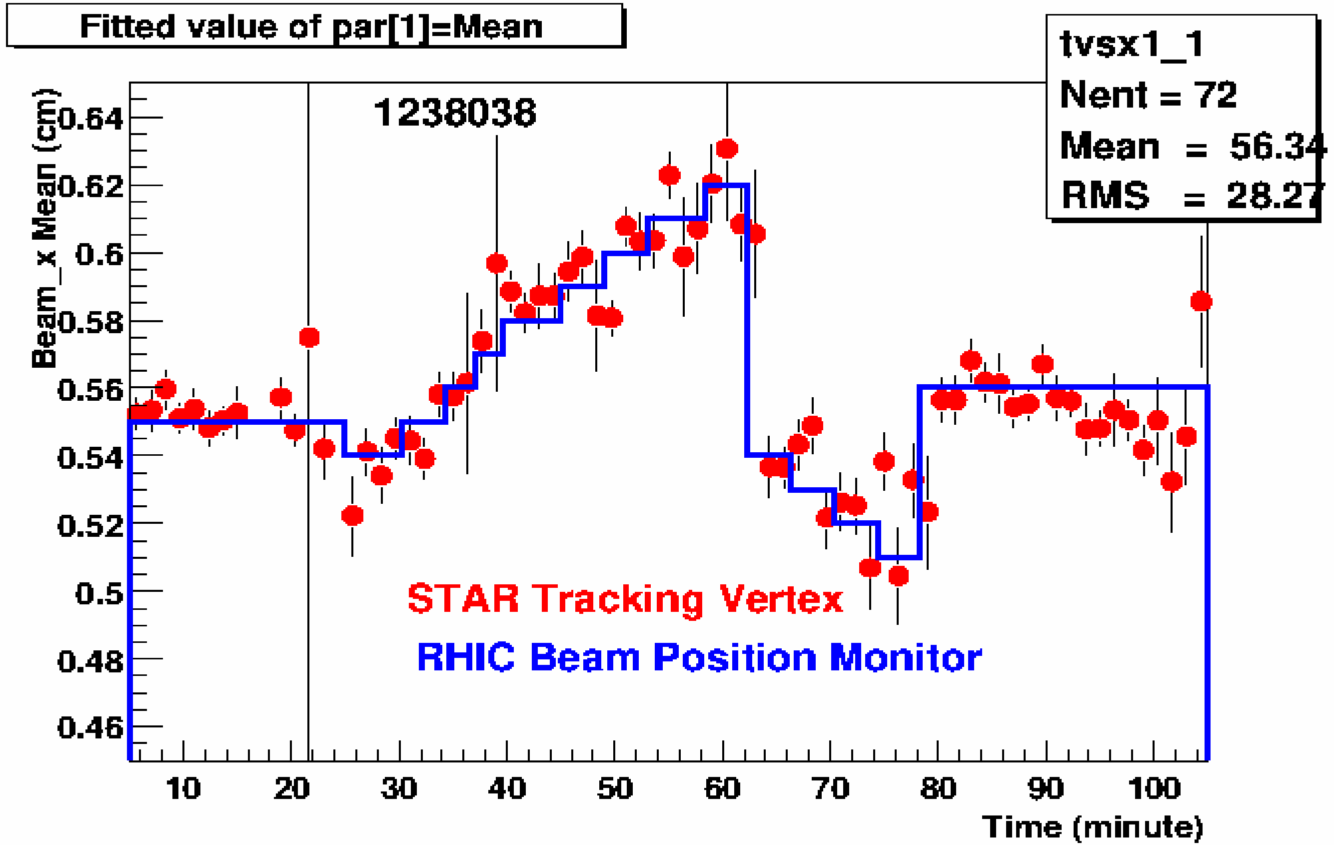
What are Vernier Scans?

Van-der-Meer Scans or Vernier Scans are done by stepwise sweeping one beam across the other while measuring collision rates as a function of beam displacement. This is done in both planes.

Needed basic instrumentation: the ZDCs or other collision monitors (BBC ...) at the various IRs, corrector magnet control to apply 4-bumps at IR, DX Beam Position Monitors (BPM) and beam current measurements from Wall Current Monitor (WCM) or DCCTs.

A Gauss function is fitted to the result yielding the maximum rates (R_x^{max}, R_y^{max}) the location of the maximums (x_{max}, y_{max}) and the effective beam overlap widths (σ_x, σ_y) in both planes.

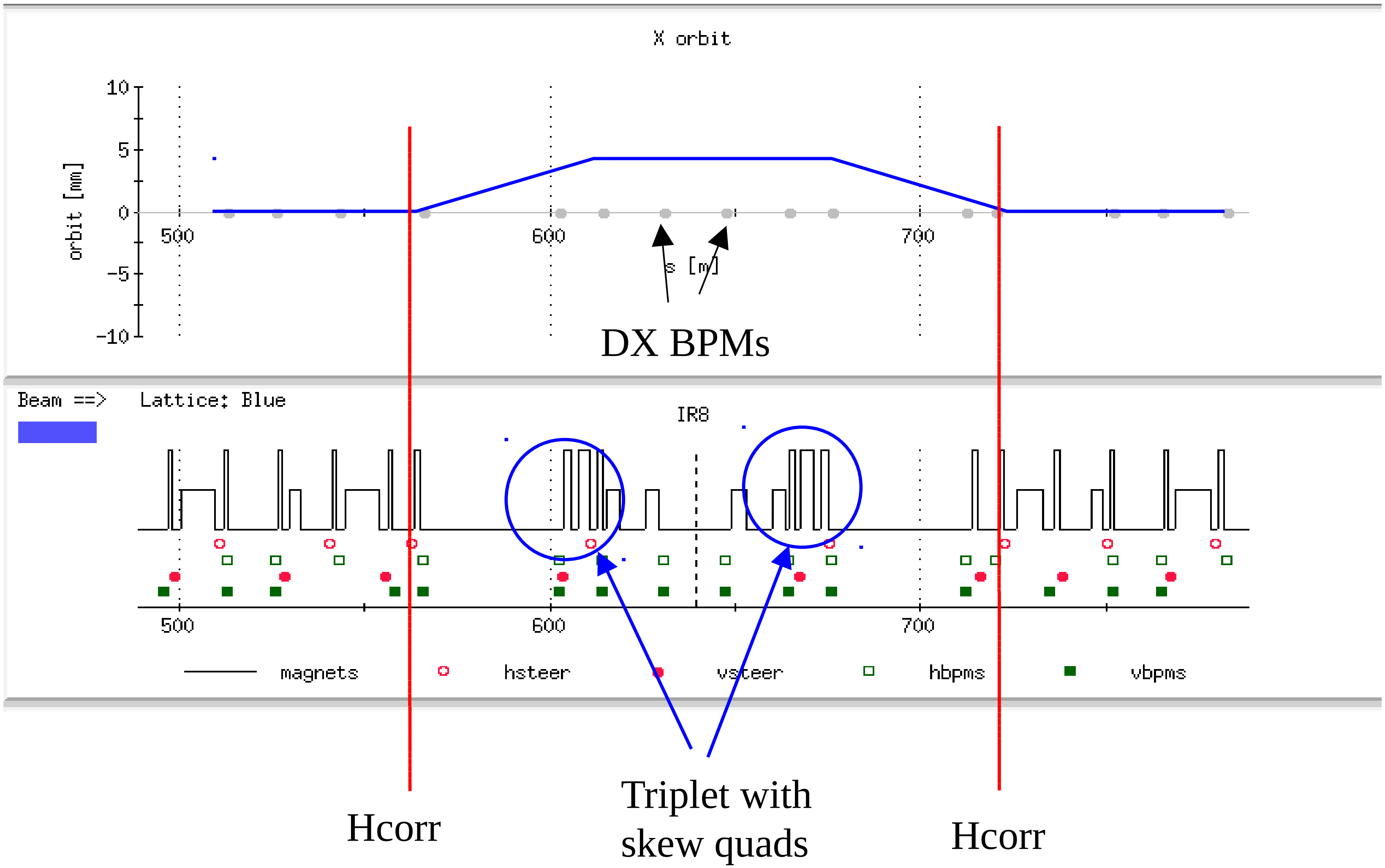
The Method



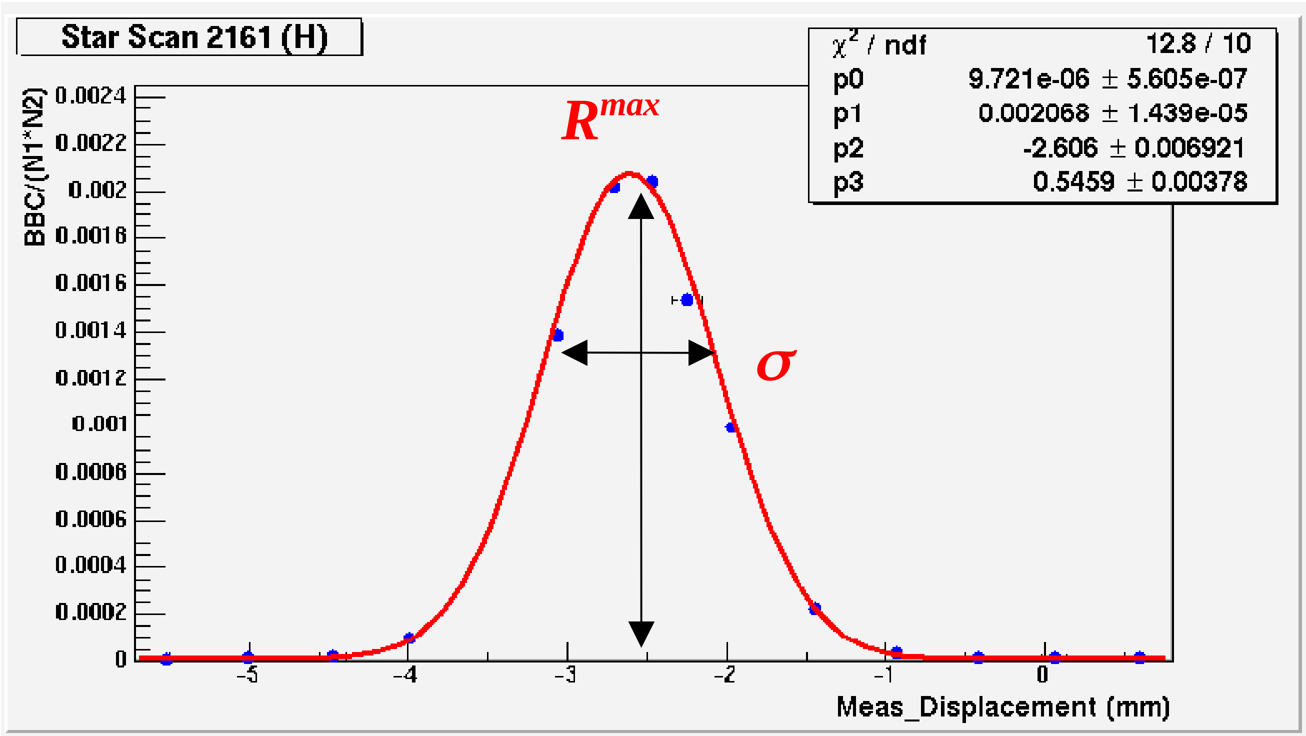
STAR reconstructed vertex during a horizontal scan in 2000 (arbitrary offset added to adjust both data sets).

- Sweeping blue or yellow beam
- Stepsize: 100-500 μm
- approx. 2 min./point
- good agreement with STAR data

Method: IR bumps (in RHIC)



- Vernier (or Van der Meer) scans can cause backgrounds
- Different optics (β*) or energy requires different scan setup.
- Only one beam is moved per scan



- do both planes (varying order)
- approx. 30 min. / scan
- fit Gauss function to data (1st order)
- reasonable χ^2/ndf
- get fit parameters to calculate luminosity and cross section

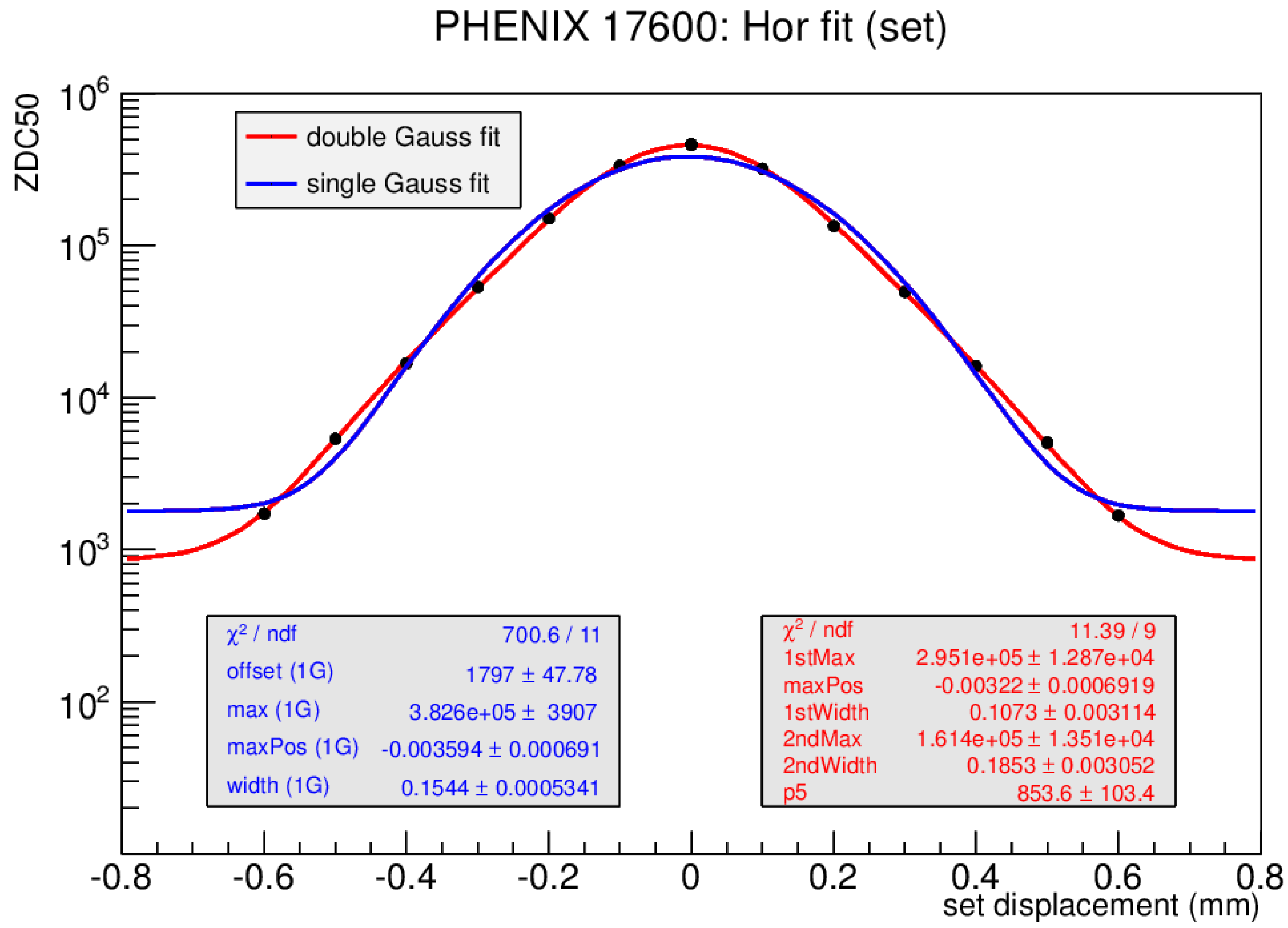
$$\sigma_{(BBC)} = R^{max}\, 2\pi\sigma_x\sigma_y k_b/f_{rev}$$

$\sigma_x\,\sigma_y$: horz./vert. profiles

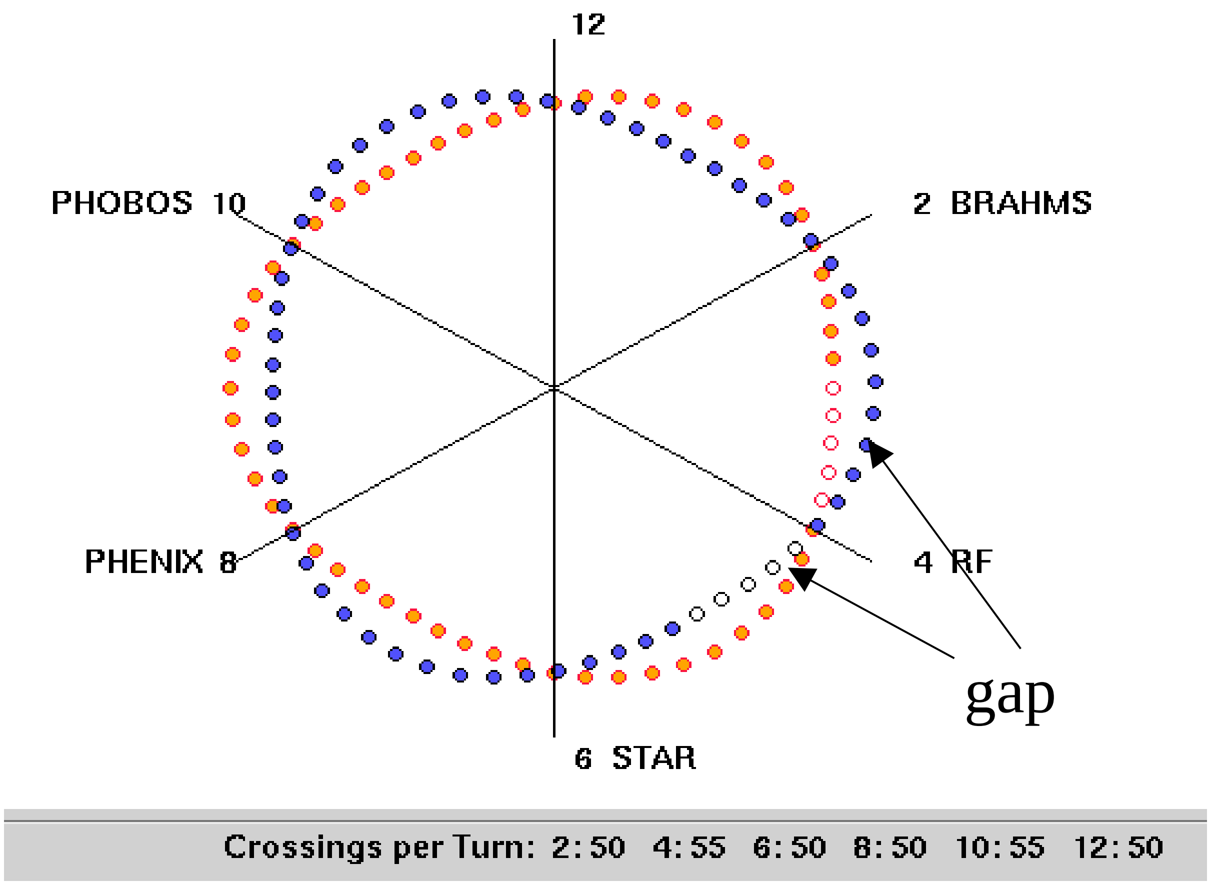
k_b : number of bunches

f_{rev} : revolution frequency

Fit-Function: not necessarily a simple Gauss

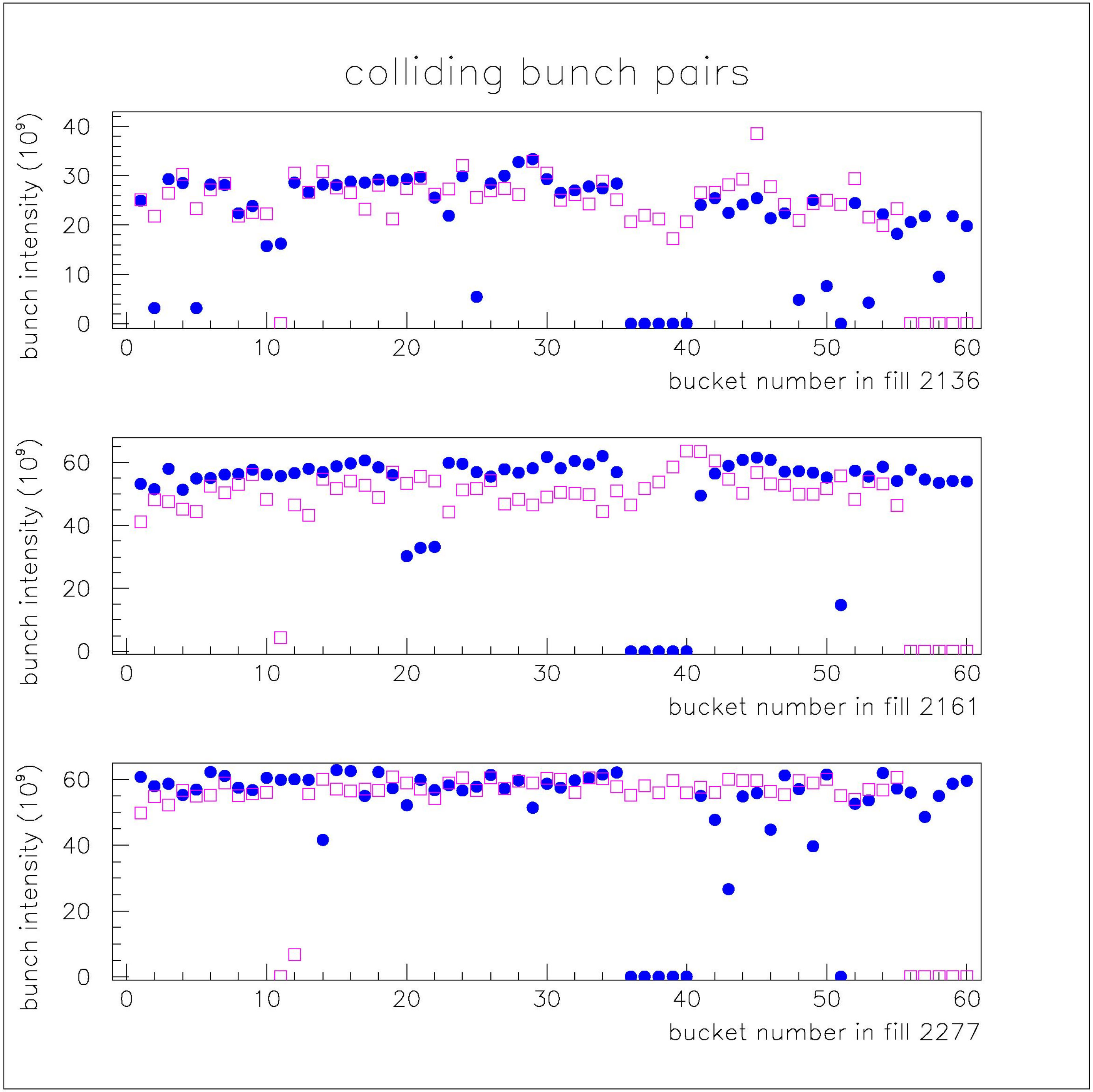


Correction example: Fill Pattern



- Total beam current has to be corrected for actual colliding pairs of bunches at the IRs.

- With 55 bunches (and 60 bunch pattern) this is 9% (5 out of 55) at all IPs except IR8 and IR2 (Au-Au) or IR4 and IR10 (pp). Correction varies from fill to fill slightly.

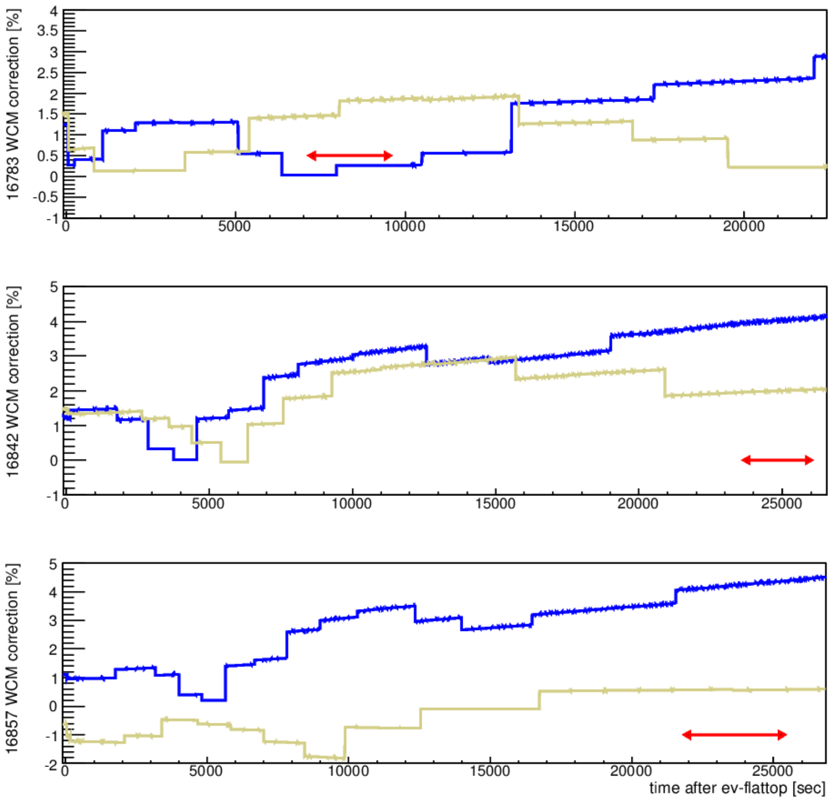


2136
0.97

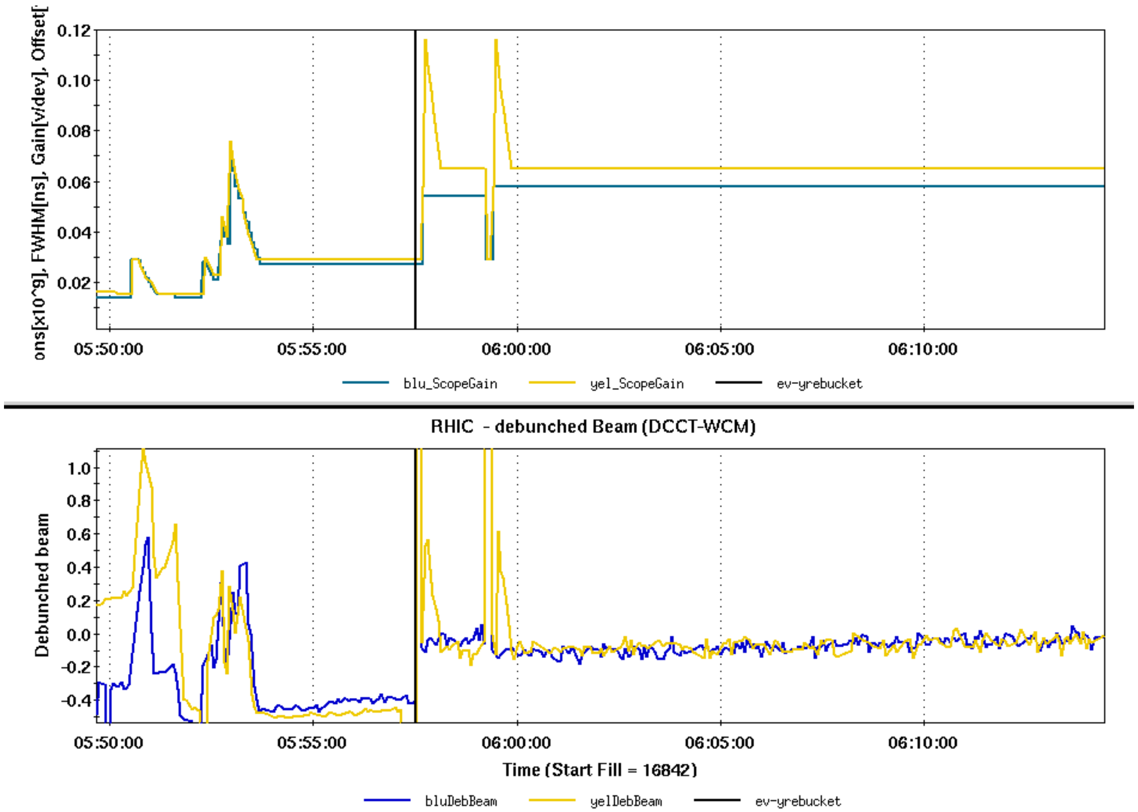
2161
0.90

2277
0.90

HI: bunched vs. debunched beam (UU2012)

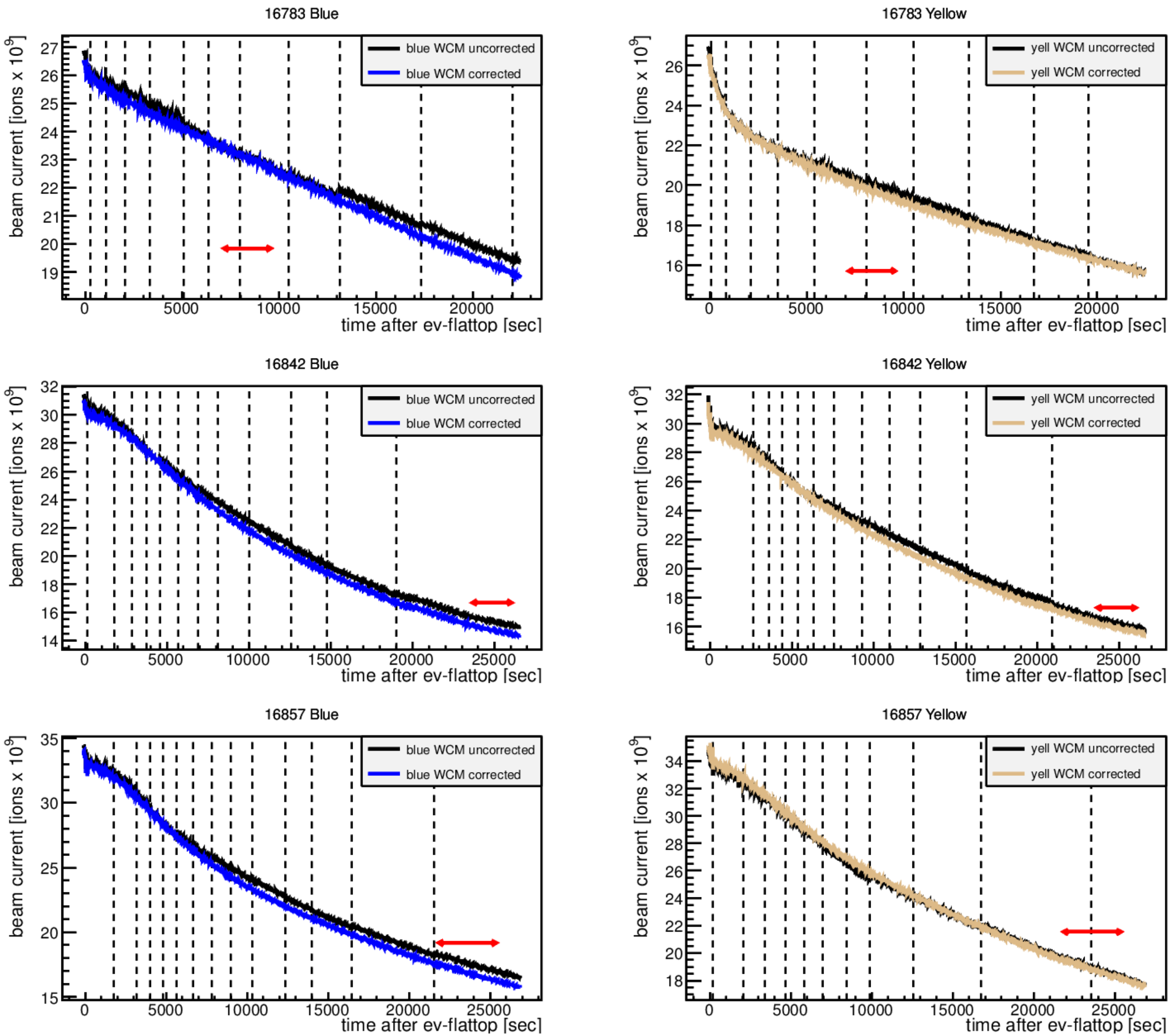


WCM gain changes during stores

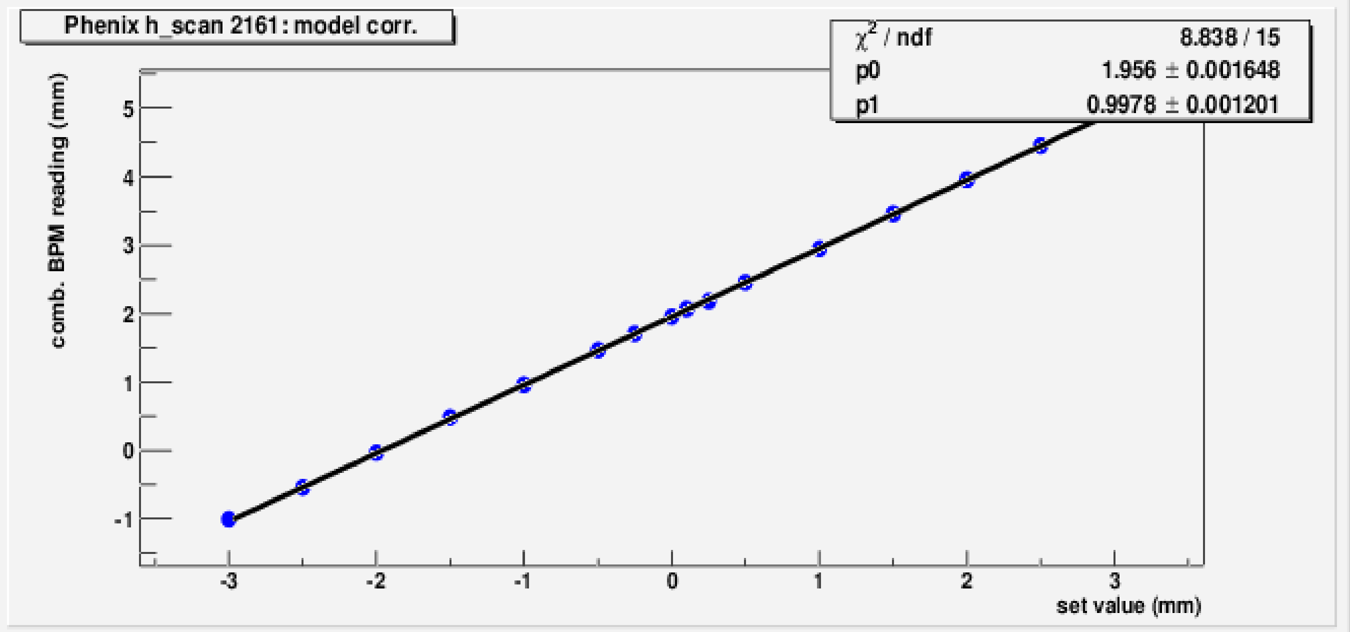


Rebucketing example:
Debunched or just gain change?

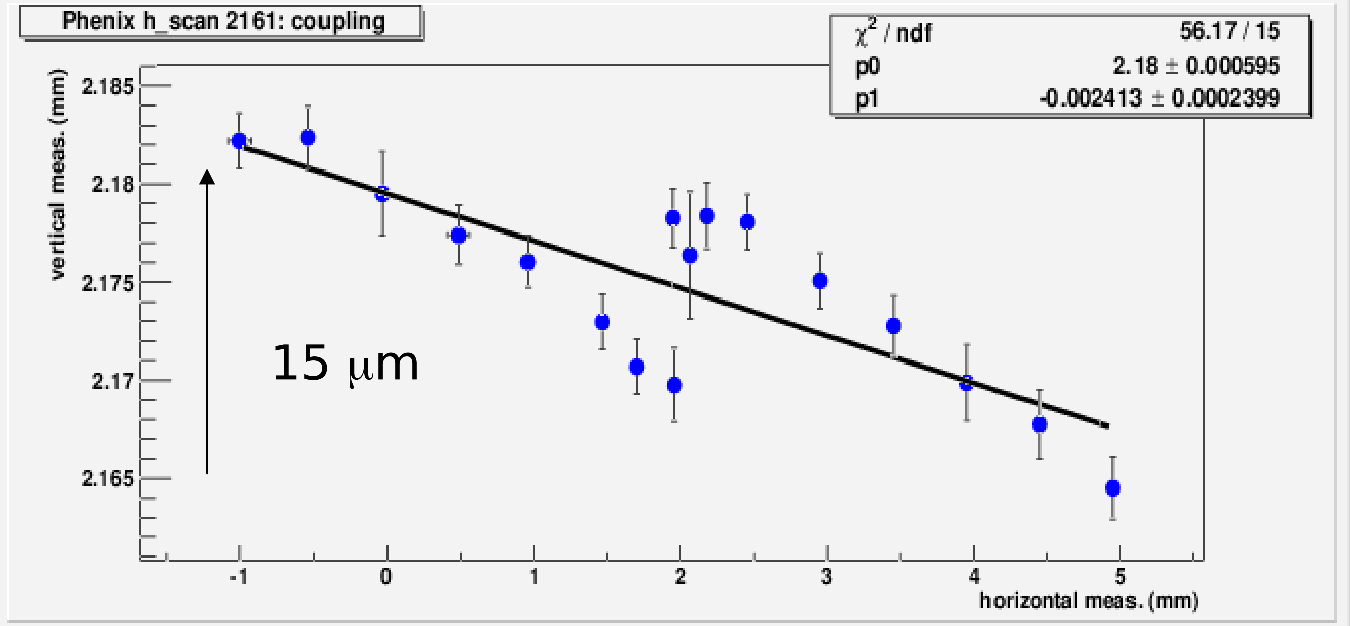
HI: WCM correction for debunched beam and gain changes (dashed lines)



Transverse coupling and Model Corrections



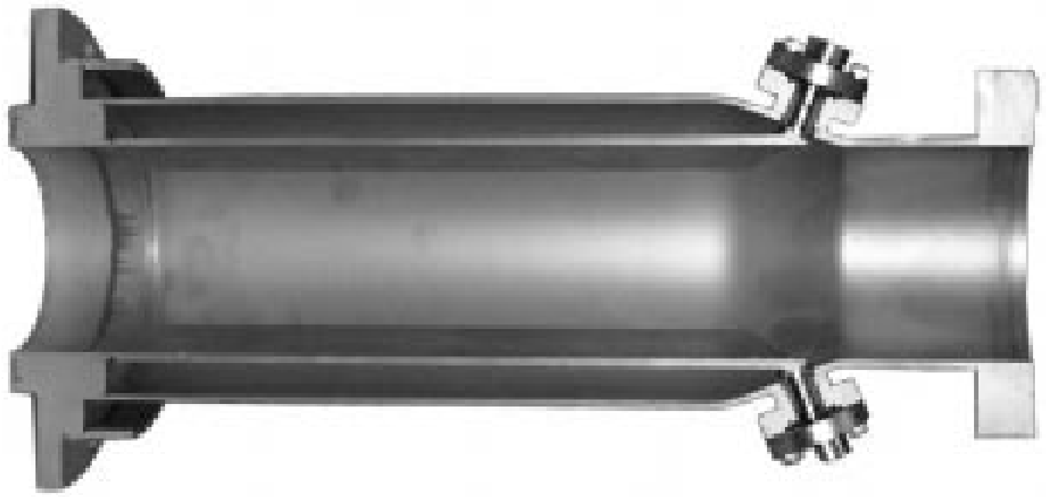
meas. vs. model (set) used for consistency check and systematic error

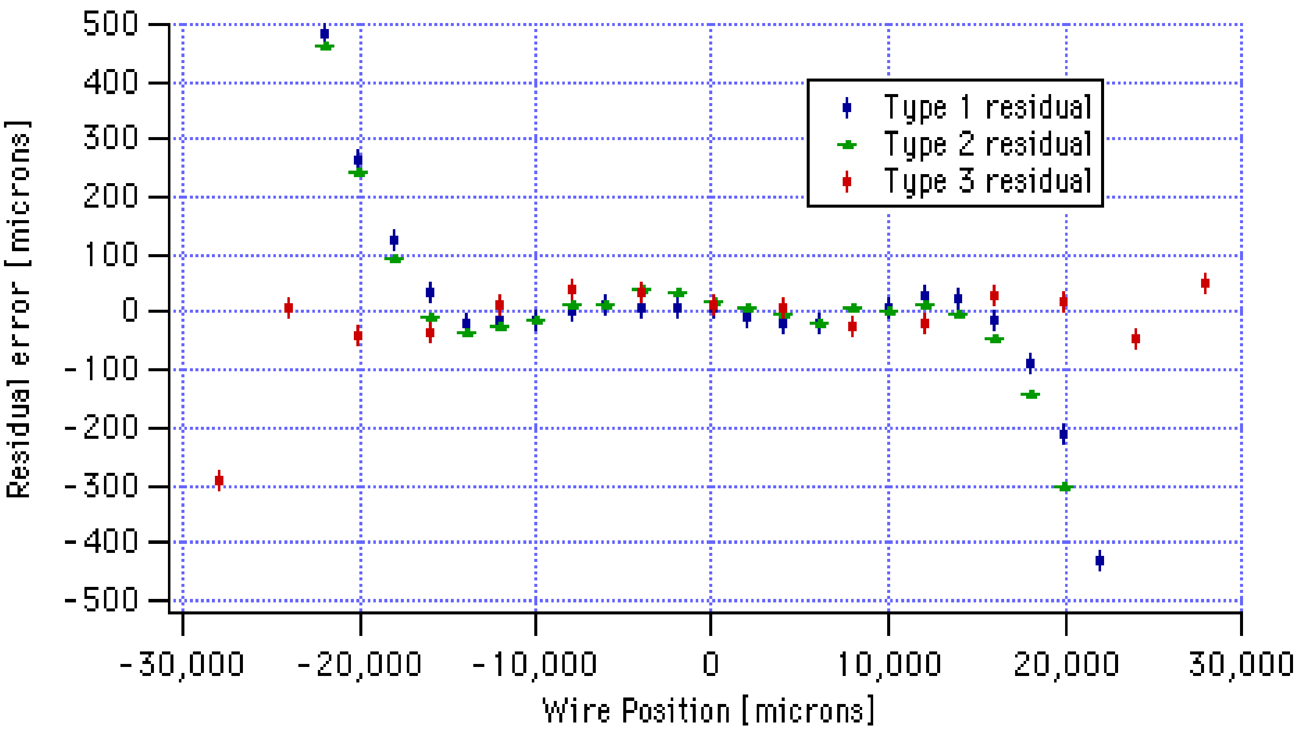


“cross talk”, i.e. movement in v-plane while moving in h-plane, is corrected for

BPM precision/resolution

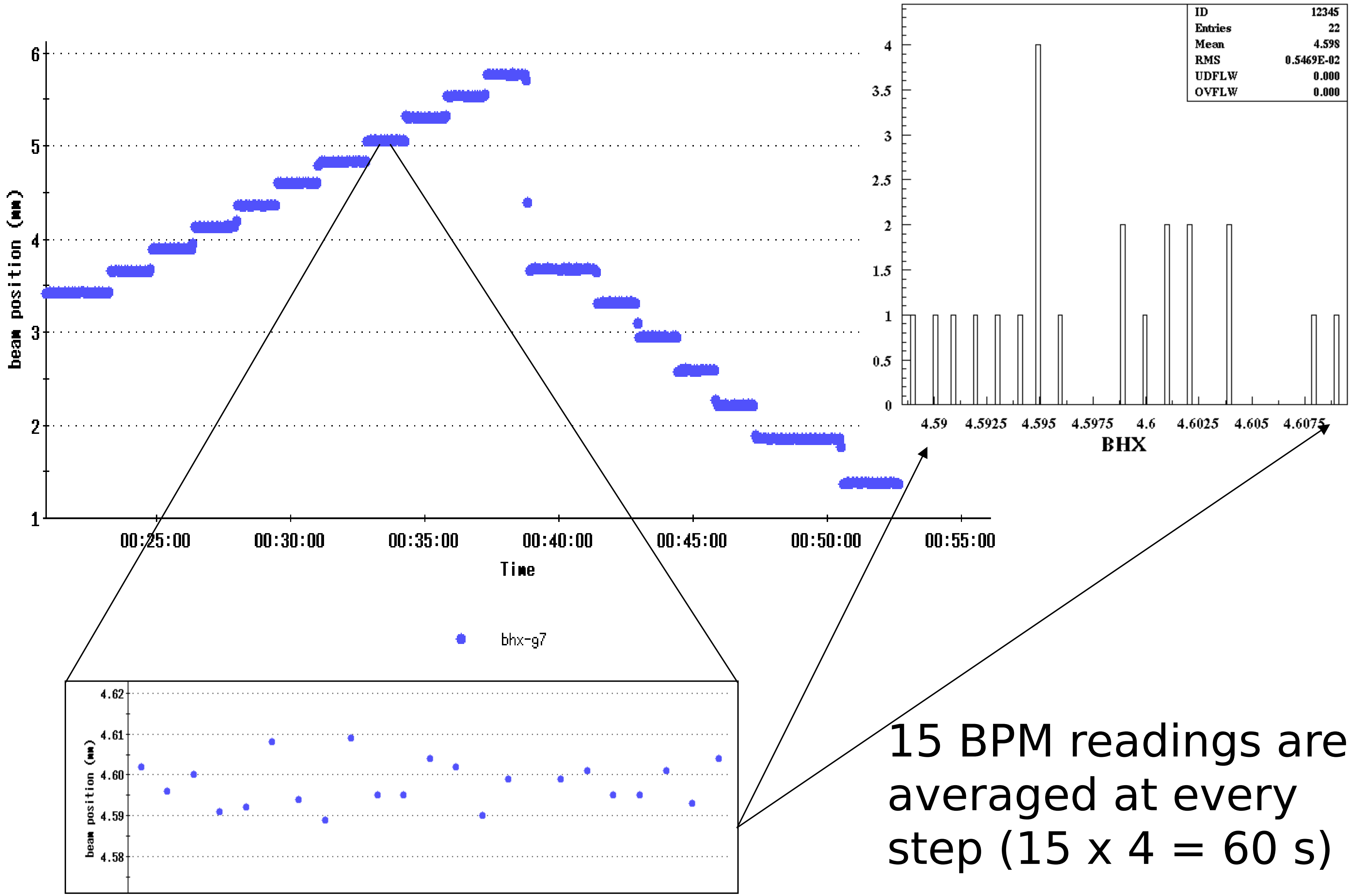
DX BPMS: type2
Dual plane
Small aperture





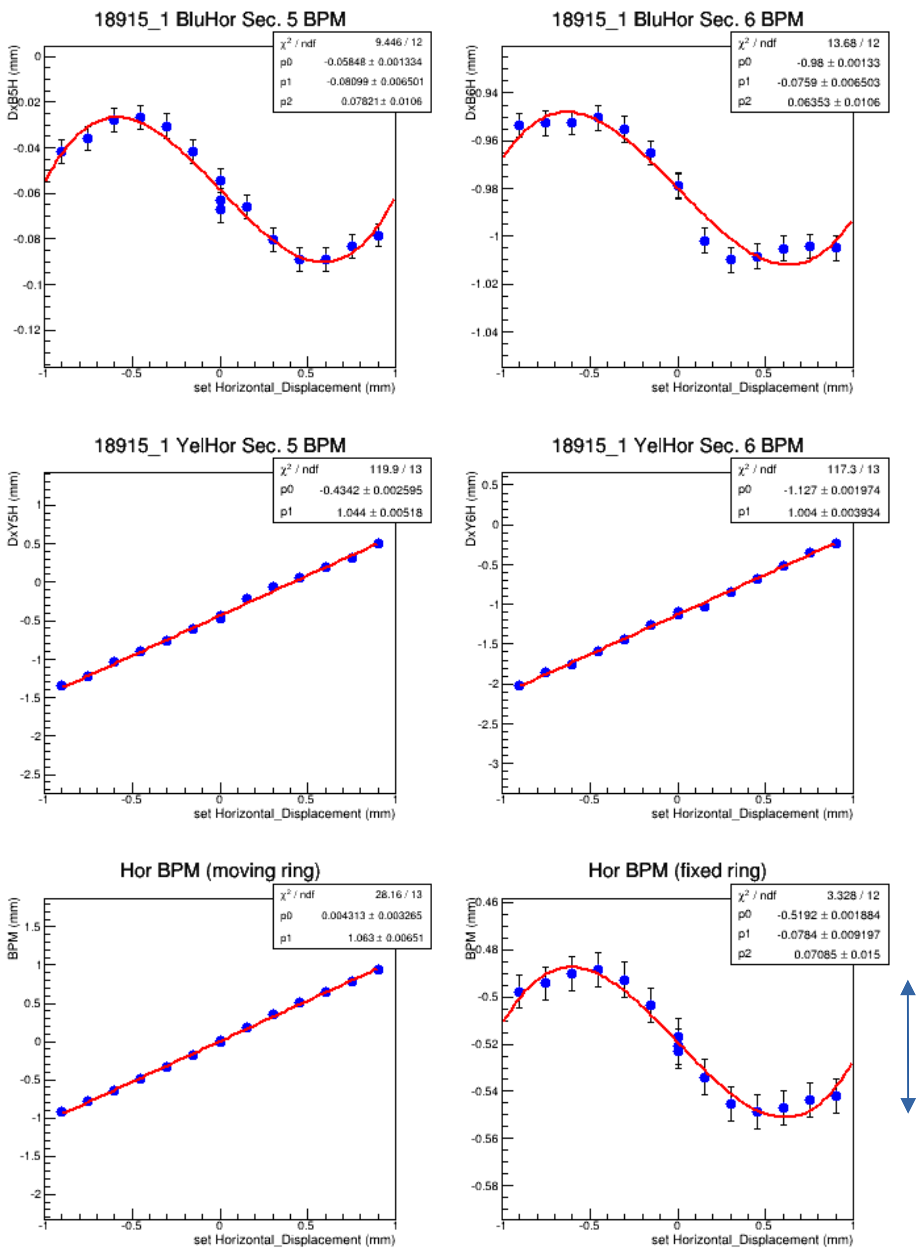
Absolute error
(if needed) depends
On equipment

BPM repeatability



15 BPM readings are averaged at every step (15 x 4 = 60 s)

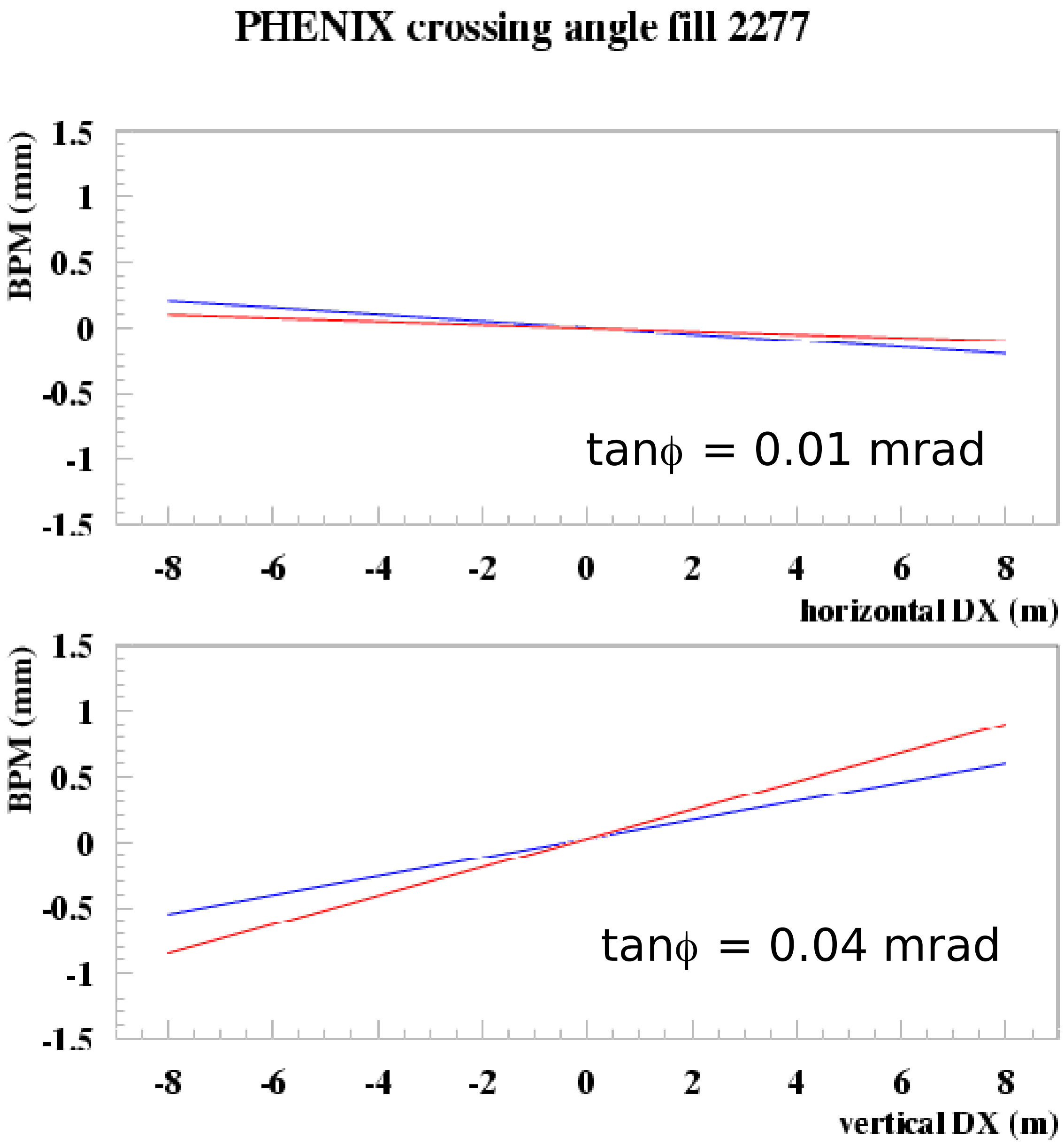
Ring-Ring coupling



Fixed ring

Moving ring: +/- 1 mm

60 μm



Correction for crossing angles:

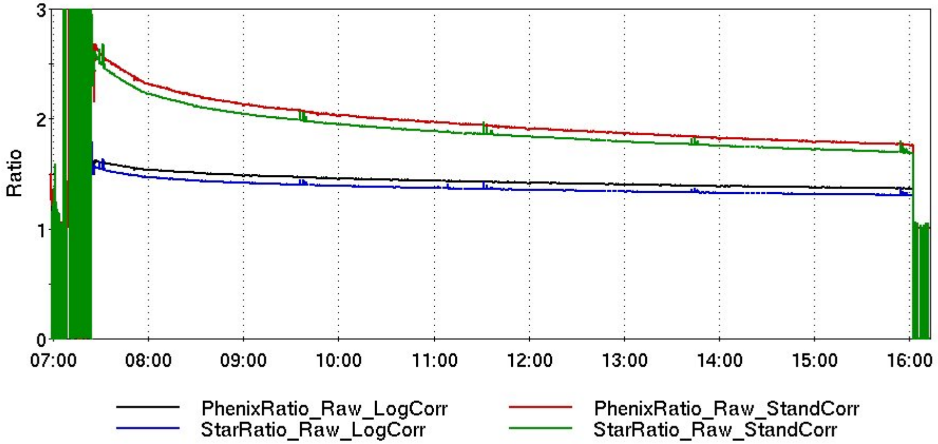
$$R = \sqrt{1 + \left(\frac{\sigma z}{\sigma x} \tan\varphi\right)^2}$$

tanφ : ½ cross. angle
σ_z: long. bunch profile
1m (avg.)
σ_x: horiz. bunch profile
360 μm (avg.)

tanφ = 0.1 mrad R=1.01
tanφ = 0.2 mrad R=1.04
tanφ = 0.5 mrad R=1.20

Data taken after vernier scan (no transv. offsets)
Adjusted by 0.-0.4 mm to cross at 0/0 -> uncertainty of 0.1 mrad

Accidental collision rate correction

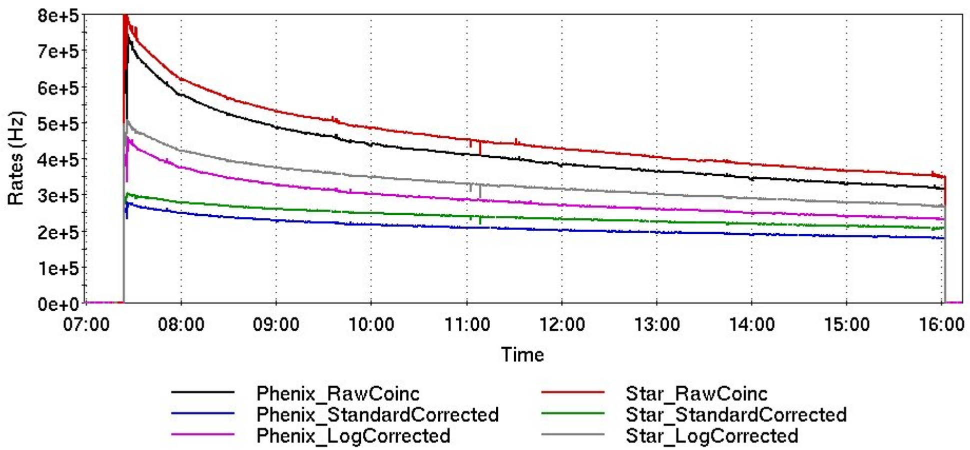


$$\mathrm{ZDC_{BY}} = \frac{\mathrm{ZDC_B\ ZDC_Y\ n_{coll}}}{\mathrm{n_B\ n_Y}\ f_{\mathrm{rev}}} \quad (5)$$

$$\mathrm{ZDC_{corr}} = \mathrm{ZDC_{raw}} - \mathrm{ZDC_{BY}} \quad (6)$$

with the parameters equivalent to Equation 3 and $\mathrm{ZDC_{raw}}$ corresponding to the uncorrected collision rate. This approach overestimates the number of accidental coincidences by hits in the two sides of the ZDC detector that lead to coincidence hits but are not true beam crossing events. The following Equation corrects for multiple hits that are counted as a single hit and contains the correction for accidental hits from above [7]:

$$\mathrm{ZDC_{log.corr}} = \mathrm{n_{coll}}\ f_{\mathrm{rev}} \left(-ln\left(1 - \frac{\mathrm{ZDC_{raw}} - \mathrm{ZDC_{BY}}}{\mathrm{n_{coll}} f_{\mathrm{ref}} + \mathrm{ZDC_{raw}} - \mathrm{ZDC}_B - \mathrm{ZDC}_Y}\right)\right) \quad (7)$$



Accidental collision rate correction depends on species and detector specifics (like dead time)

Example for error analysis

- In short: achievable accuracy depends strongly on specifics such as instrumentation, lattice (beta*, hour-glass), bunch length, bunch size, species (beam-beam), number of scans etc.

5 Summary

Combining the 3 scans the effective cross section for the BBC detector results in:

$$\sigma^{eff}_{BBC} = 23.6 \pm 0.2 \ \textbf{(stat.)} \ \pm 0.6 \ \textbf{(syst.)} \ \textbf{mbarn}$$

Systematic errors for beam current measurements (1%), model vs. measured beam position (1.5%), transverse coupling (1%), ring-to-ring cross-talk (1%) and singles correction (1%) are taken into account. The combined systematic errors add up to a total of 2.5%.

Example: 2013 pp@255GeV

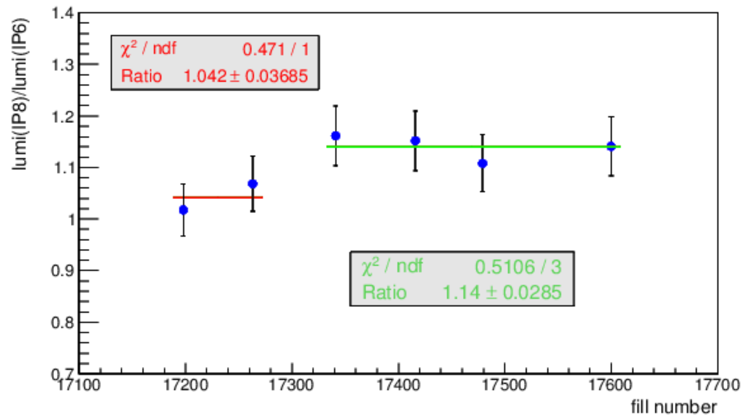


Figure 10: Ratios of measured instantaneous luminosities. Expected values are 0.98 (pp13e-s4) and 1.15 (pp13b-s1). The two lattice periods were fitted separately (pp13e-s4:red and pp13b-s1:green).

The second set of vernier scans, 17341 to 17600, were all done with lattice pp13b-s1. For this lattice the β^*-ratio (measured, see [3]) yields 1.06. Most stores were done with 111/102 pairs of colliding bunches. Both values combined result in an expected ratio for the two experimental and fully corrected luminosities of 1.15. This result is fully consistent with the measurement shown in Figure 10. Note that for this lattice more data samples were available for β^* measurements than for the first one.

Combining the corrections, statistical errors and the systematic errors from above, the resulting effective cross sections for Run-13 are:

IP6 2.73 mbarn ± 2% (stat.) ± 5% (syst.)

IP8 before 04/03/13: 2.55 mbarn ± 3.5% (stat.) ± 5% (syst.)
after 04/03/13: 2.05 mbarn ± 2.5% (stat.) ± 5% (syst.)

We could still gain from an increased number of vernier scans per run.