Transverse Emittance through the Injector Chain

LHC Beam Quality Working Group:
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and the OP/ABP/BI team participating in the measurements

Outline

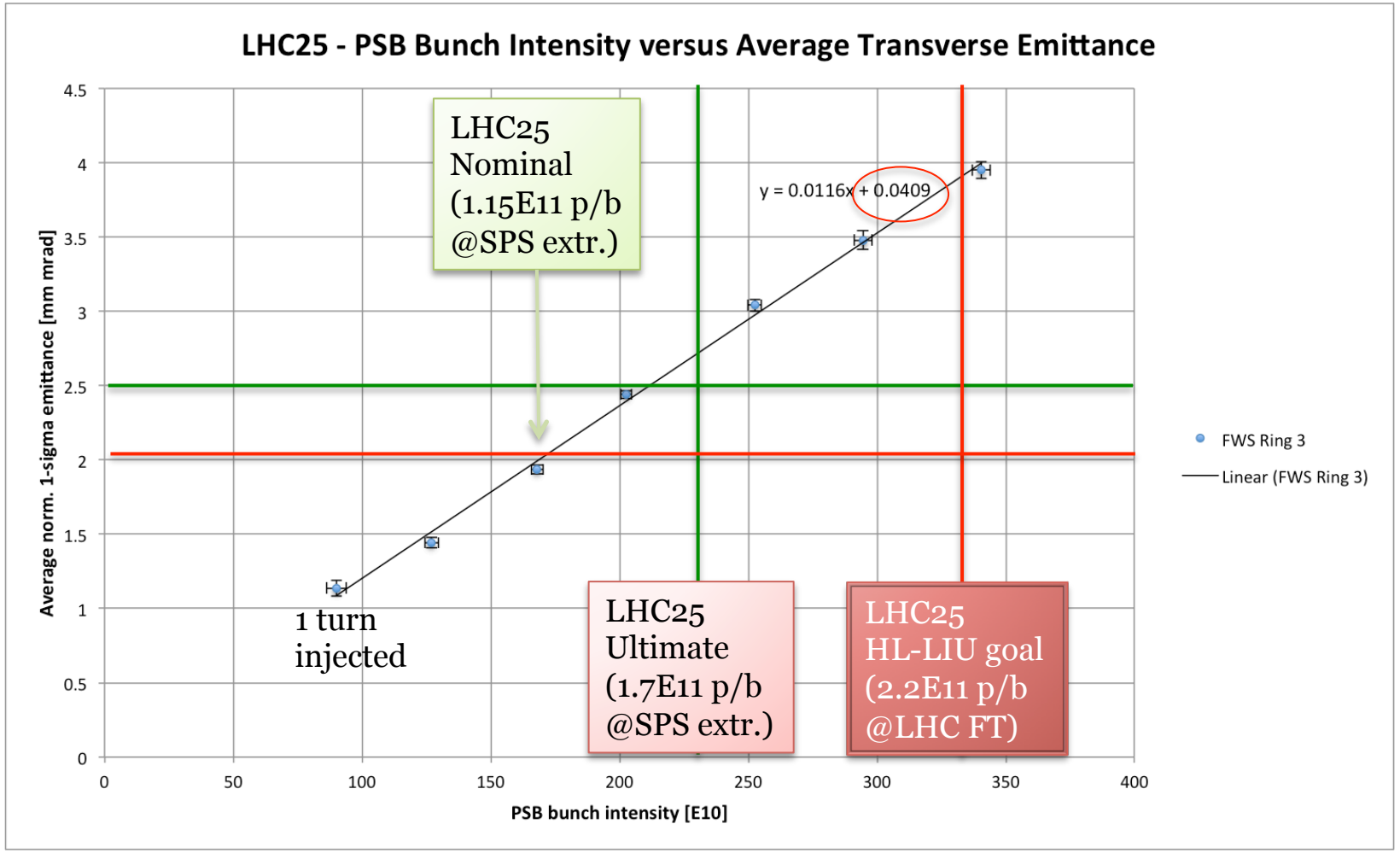
- Transverse emittances in PSB, PS and SPS of the 25ns and 50ns beams
- LHC Beam Quality Working Group
- Conclusions

Remark: Emittances quoted in the presentation correspond to 1-sigma normalised values.

PSB

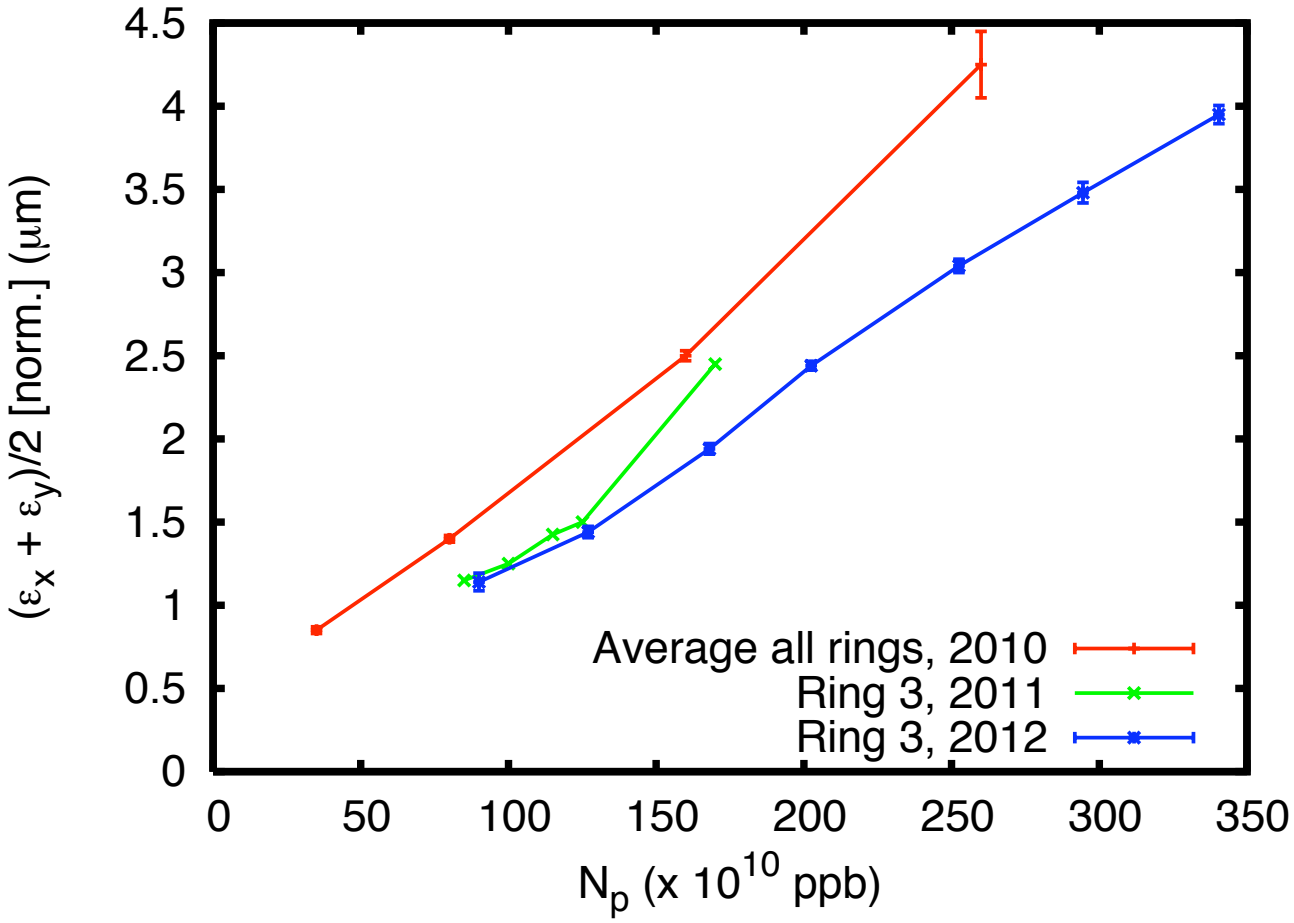
- Main actor in definition of transverse emittances
  - Linac2: provides beam with ~1.1 μm emittance in both planes at PSB entrance
    - Linac4: expected to be ~1/3 lower
  - Transverse emittance increase in PSB is directly proportional to intensity increase due to proton multi-turn injection process
    - Linac4: H^- charge-exchange injection process allows to break this relationship to conserve small emittances; designed to allow halving the emittance for constant intensity

PSB FT – Average Emittance versus Intensity (Ring3)



Remark: Constant bunch length for each measurement point.

PSB – Emittance Evolution of LHC50/25



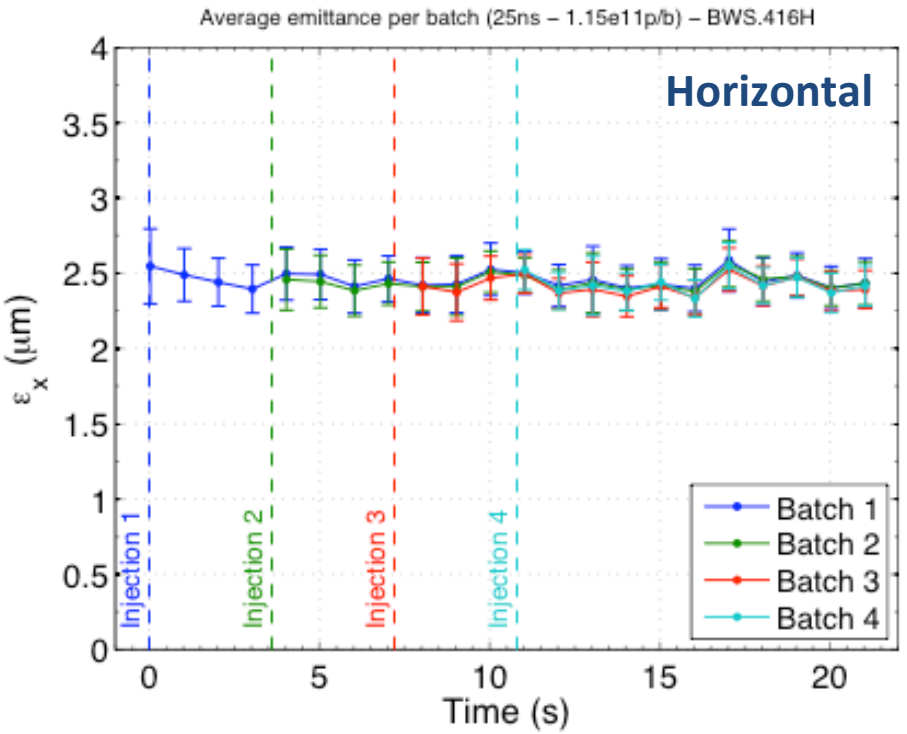
Good beam quality needs constant work and tuning (x4 for PSB)…

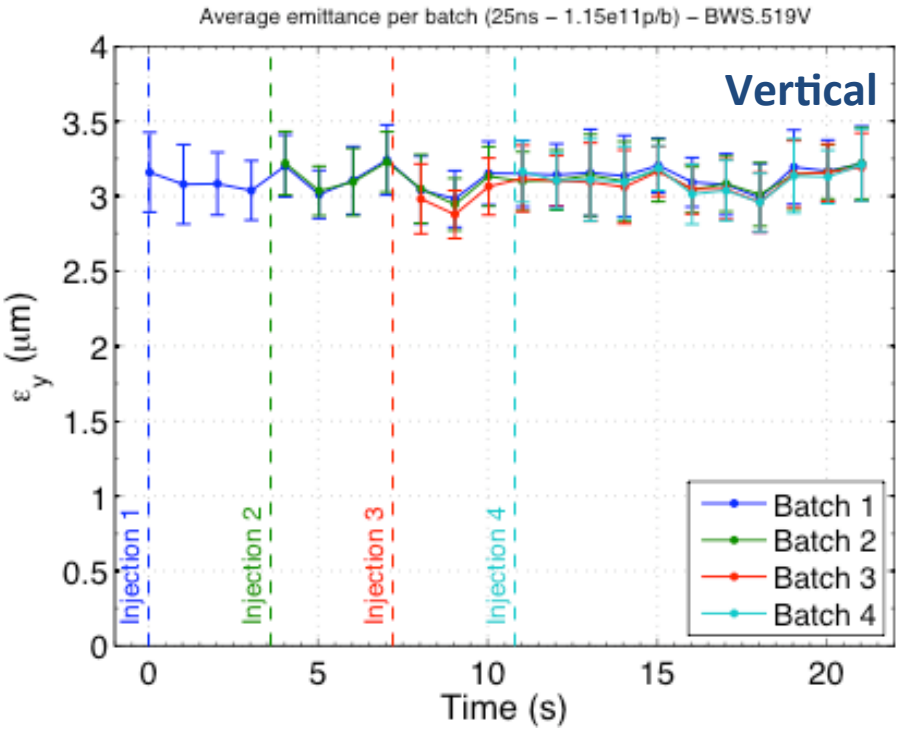
PS

- Main actor in definition of longitudinal parameters; bunch splitting
- LHC 50ns beam: transverse emittance from PSB ~conserved with careful tuning of all parameters (injection steering, working point, transition crossing etc.):
  - ~1.25 μm average emittance measured with wire scanners before extraction
- Operational intensity limit of multi-bunch beams in the PS around **1.7E11 ppb** (coupled-bunch instabilities) for 50ns beam
  - Above this limit, longitudinal beam quality degradation in terms of bunch length spread and bunch-to-bunch intensity spread with increasing bunch intensity (→ triggers SPS BQM)
- Novel schemes aiming to increase beam brightness were implemented this year → presentation of batch compression scheme by H. Damerau

SPS – Emittances of 25ns LHC Beam in 2012

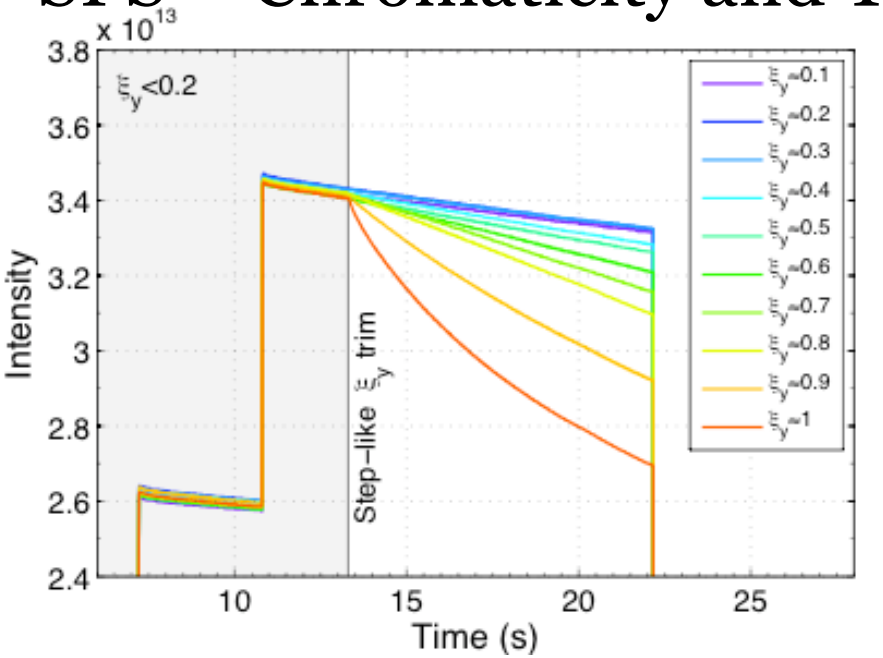
- Average emittance with 4 batches of 1.15 p/b

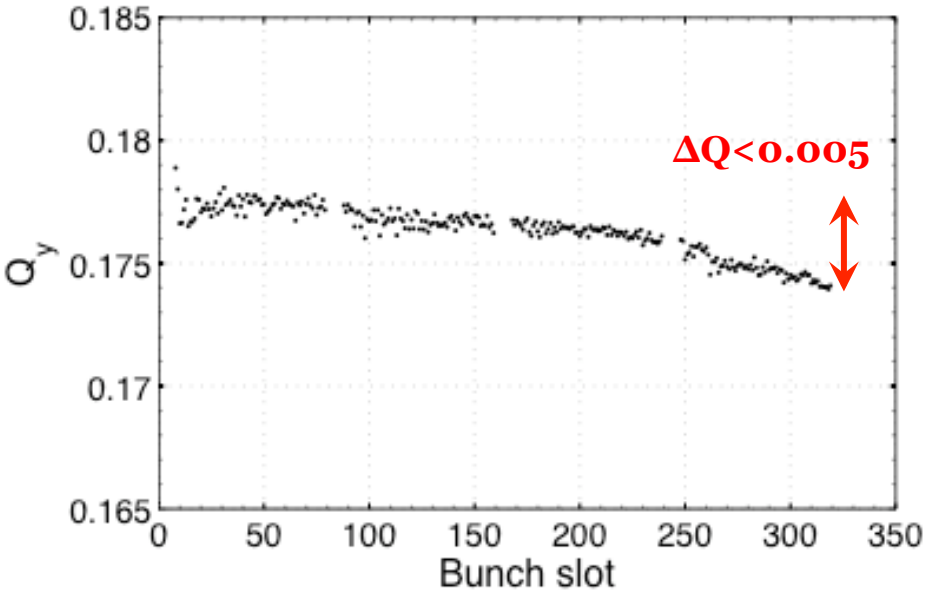




- No measurable emittance growth along 20s flat bottom
- Emittance values within specifications

SPS – Chromaticity and Tune of LHC25 in 2012





No need for large chromaticity in 2012 with 4 batches of 1.15x10¹¹p/b

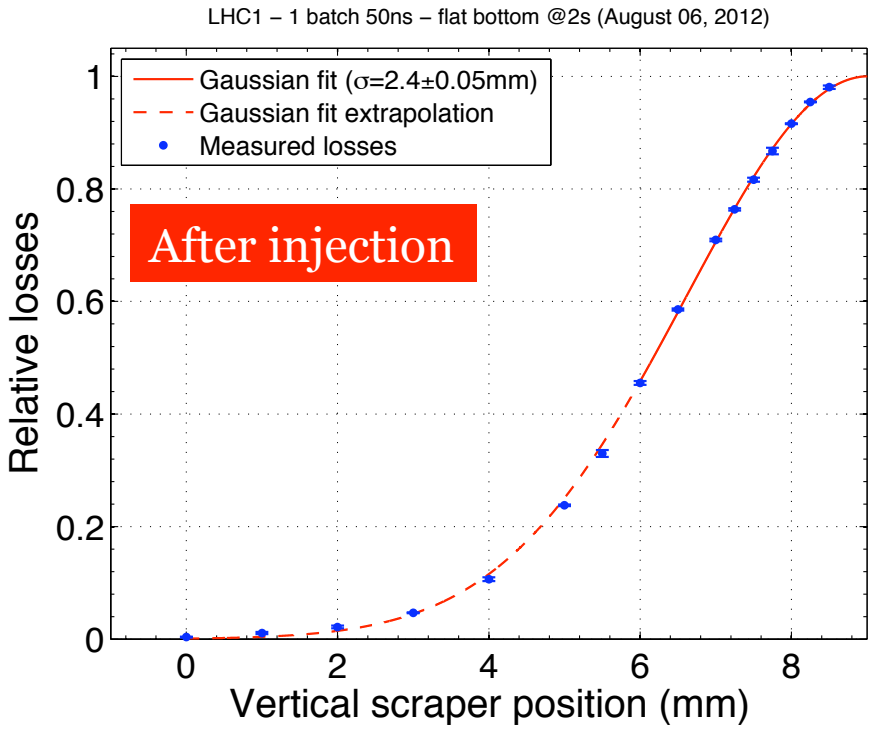
- Best life-time with smallest chromaticity
- No instability or beam degradation with chromaticity around 0.1

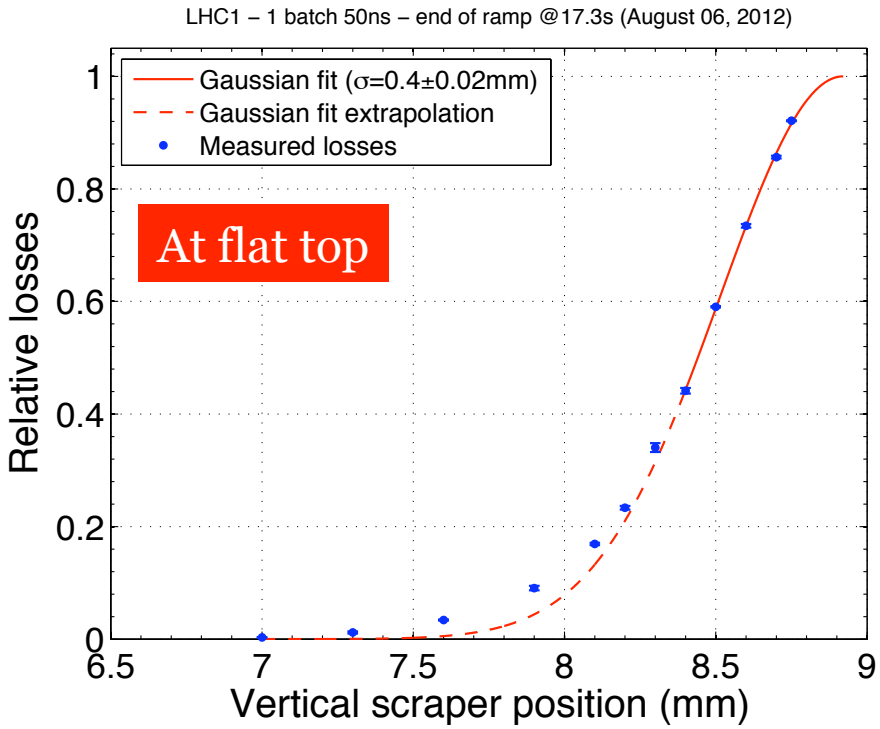
Negative tune shift!

- Dominated by resistive wall impedance?
- E-cloud not anymore dominant compared to 2000 data – scrubbing!

Tails of 50 ns LHC Beam: Scraping in the SPS

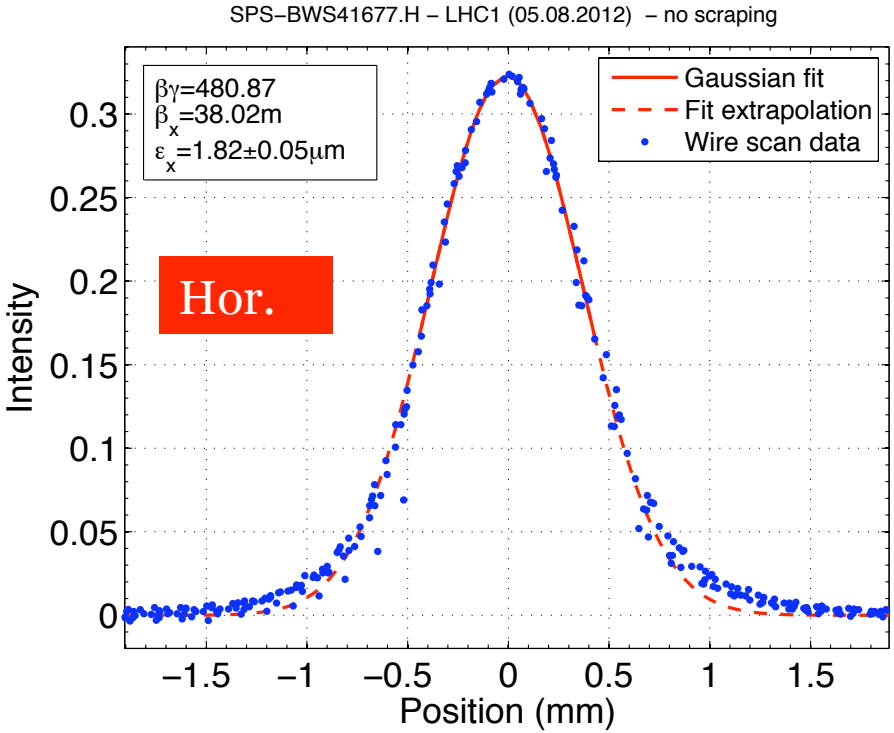
- Important to reduce tails to avoid losses/dumps in the LHC
- Powerful tool to measure tails (but: destructive)
- Measurements taken after the PSB/PS improvements from 4/8/2012
- No tails after injection in the SPS, but some tails at flat top!

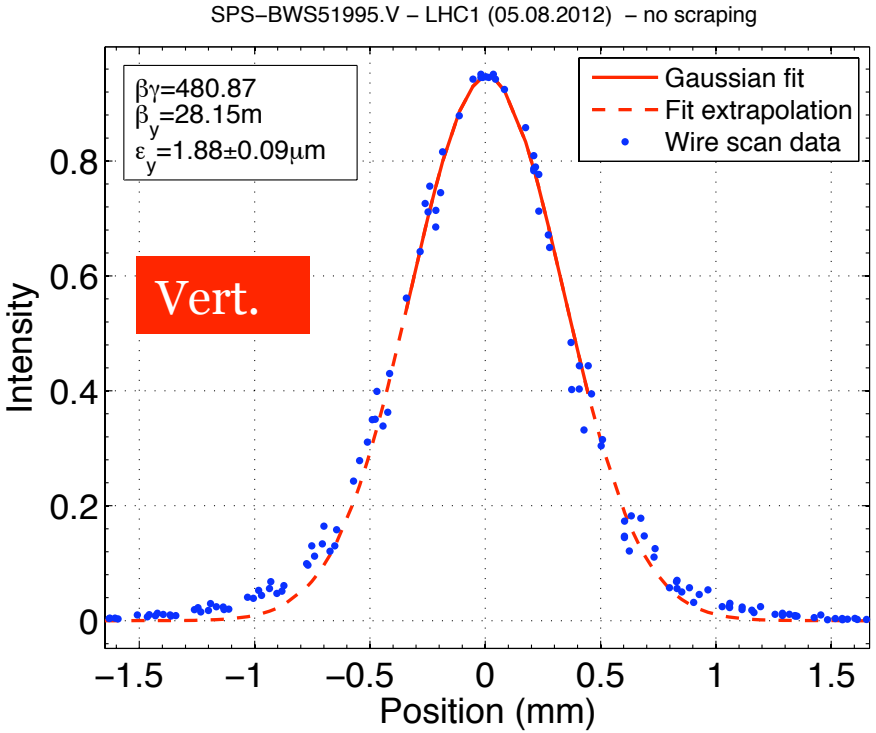




Emittance measurements at SPS FT – no scraping

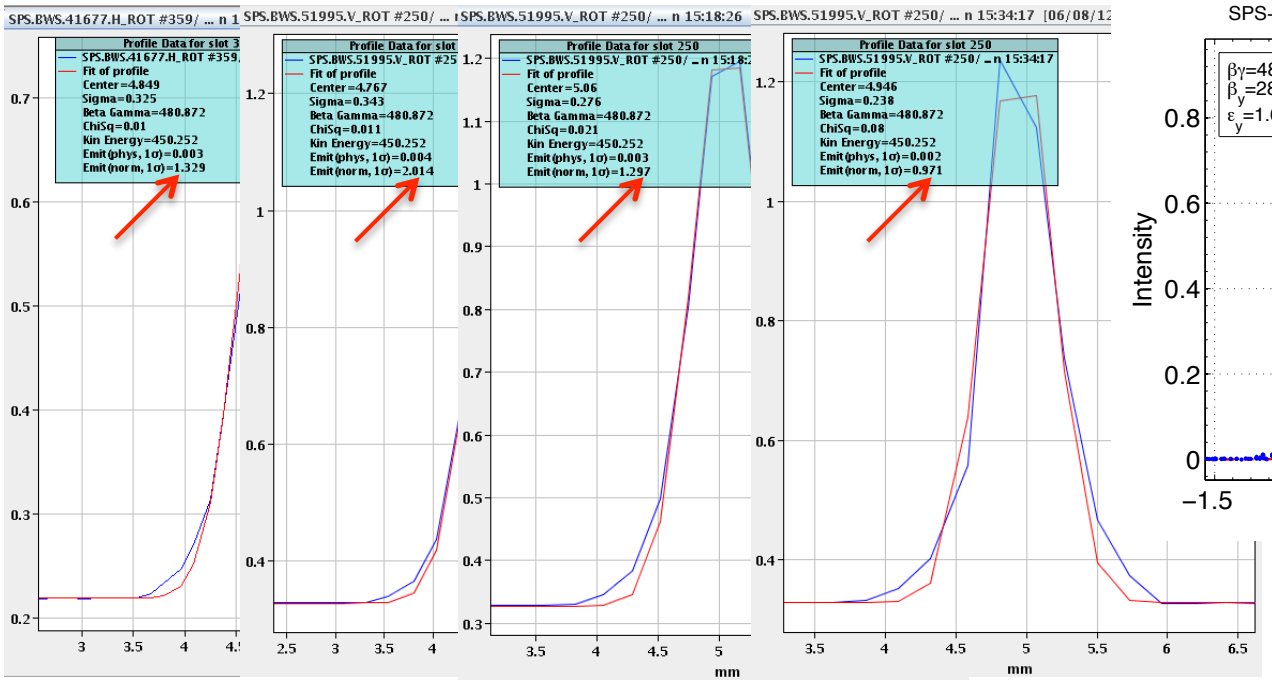
- Small tails of 50ns LHC beam at SPS flat top *without scraping* – resembles the loss profile
- Tails removed with up to 6% scraping
- With scraping: measure emittances between 1.4-1.8 µm in both planes at SPS FT for LHC 50ns production beam
  - This corresponds ~ to results at SPS injection and LHC emittance measurements at injection

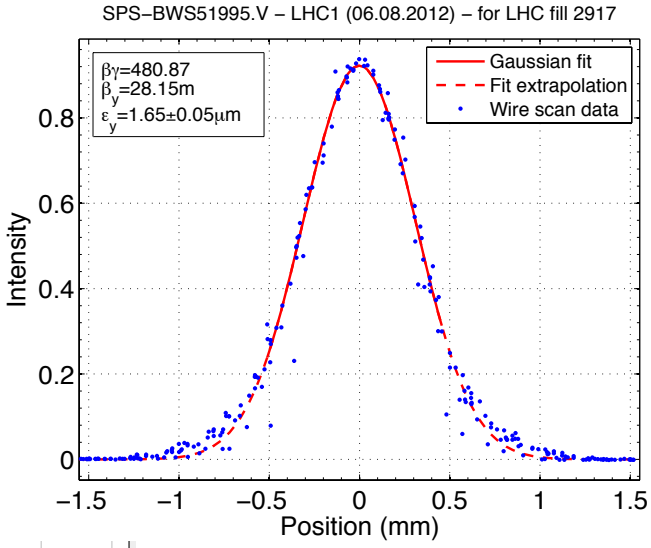




SPS: Improvement of WS Measurement Quality

- H. Bartosik proposes to enhance the measurement quality by averaging measurements over multiple cycles, every time for 4 batches.
- A library is under preparation to be used in the new SPS wire scanner application.





- Data sources from same LHC fill.
- Wire scanners only provide 5 – 6 points per profile @ SPS FT.

LHC Beam Quality Working Group for Injectors (1)

- Working group proposed at LMC134 end of May

Monitoring LHC beam quality from injectors

Following discussions with Malika, Brennan & Roland

Members: Bettina Mikulec, Rende Steerenberg, Verena Kain

- Small working group with the above membership to:
  - ensure systematic measurement every fill of key transverse and longitudinal parameters at established points in the beam's passage through the complex
  - in collaboration with BI ensure well defined parameters for use with measurement devices
  - condense and collate these measurements to provide fill-by-fill data - this could be done by hand with excel or ideally the data would find its way into the supertable
  - track fill-by-fill evolution of parameters and cross-correlate with parameters relating to LHC luminosity performance
  - flag issues/problems/discrepancies with machine coordinators
  - periodic report to LMC

Slide: M. Lamont

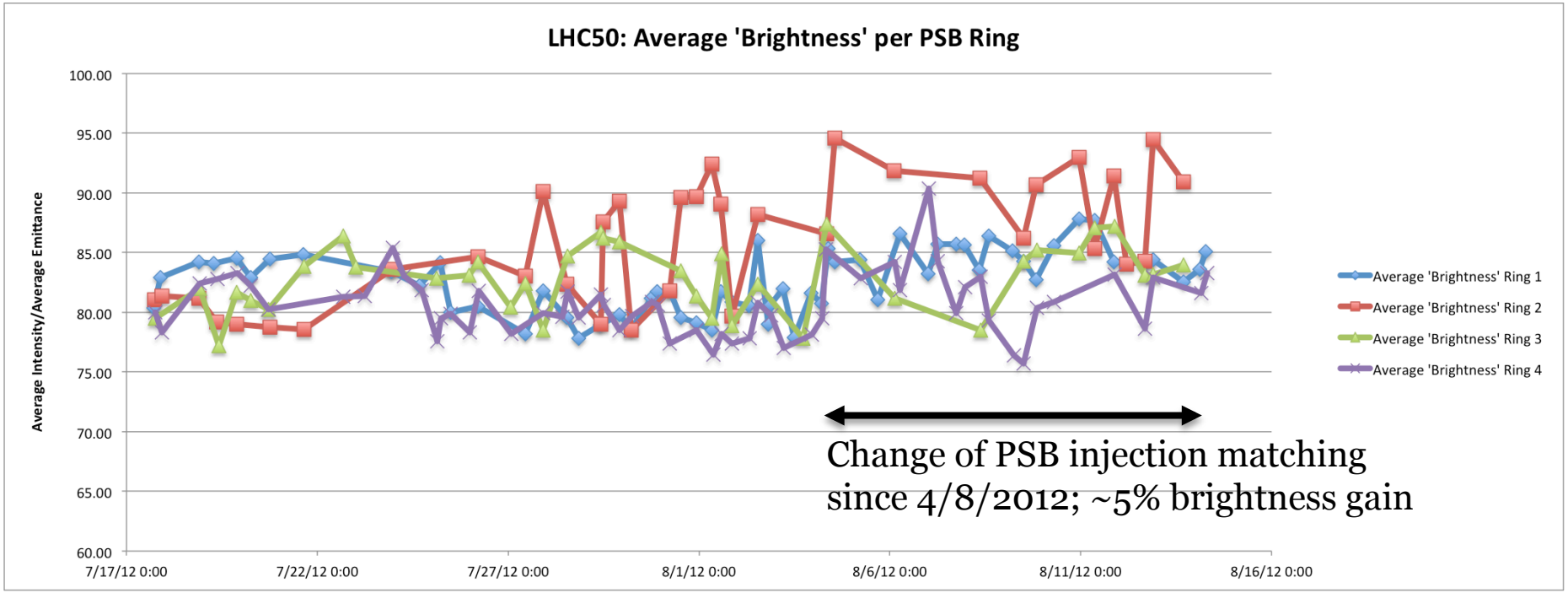
LHC Beam Quality Working Group for Injectors (2)

- Systematic measurements of transverse emittances once per shift started in June in PSB/PS; database logging from wire scanner application since 17/07 in place for PSB/PS.
- In addition to wire scanner profiles log the following parameters:
  - ☑ Avg. H/V emittance, avg. bunch/beam intensity, avg. bunch length, avg. Δp/p
    - Tail information, β/D and TT2 position logging to come…
  - ☑ At PSB extraction (4+2 rings), PS injection, PS flat top
    - Some more work needed to include SPS (injection and FT) and LHC (injection and flat top from luminosity for B1+B2)

LHC Beam Quality Working Group for Injectors (3)

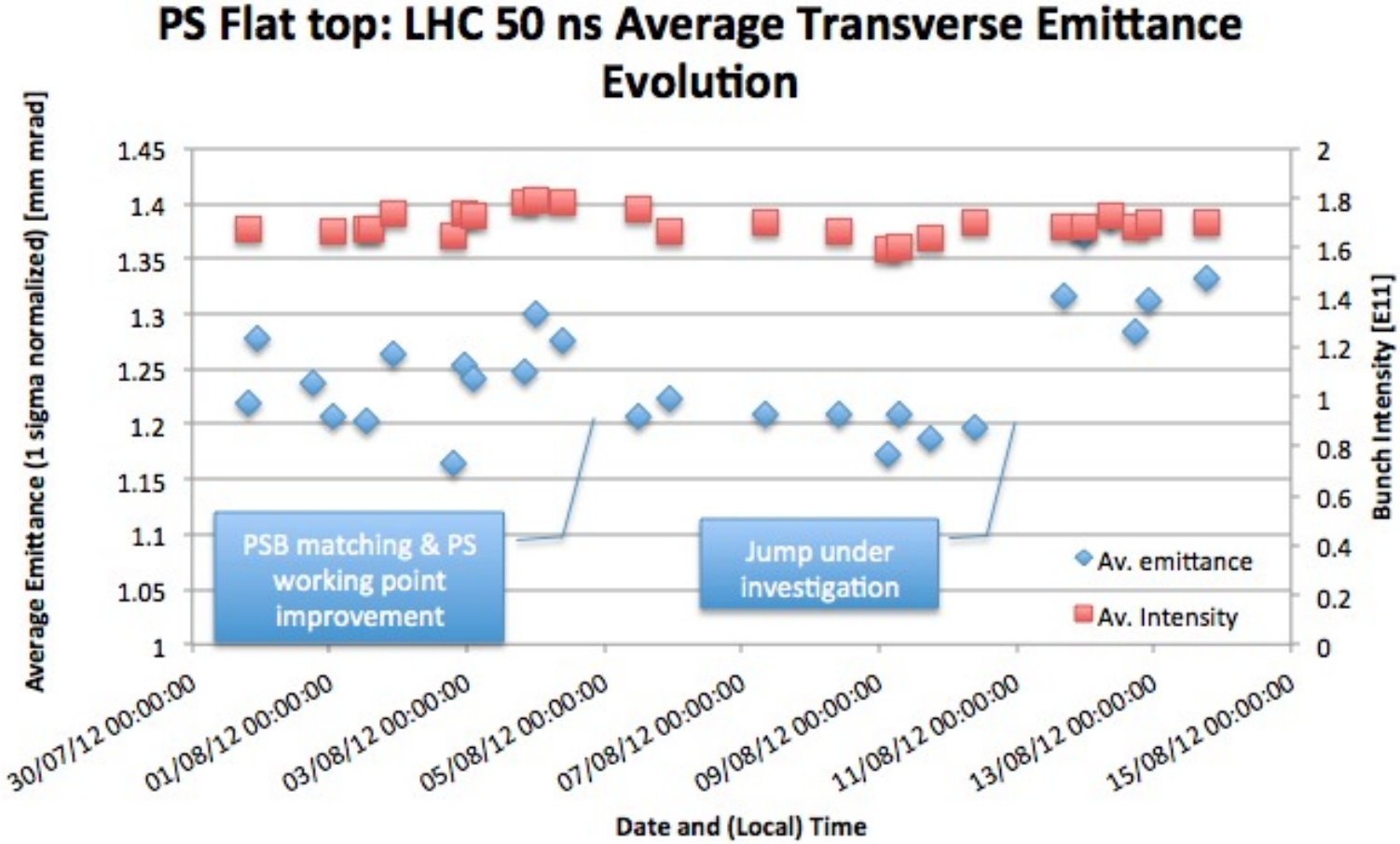
- Goal for this year:
  - Measurements throughout injector chain before each LHC fill; raw data in machine-specific logging database branches
  - Automatic extraction of data linked to an LHC fill number from various branches via a server that fills a database table
  - Graphical representation to view trends
    - Until everything will be in place, extract data manually and produce emittance evolution plots per machine

Examples for Beam Quality Logging – PSB



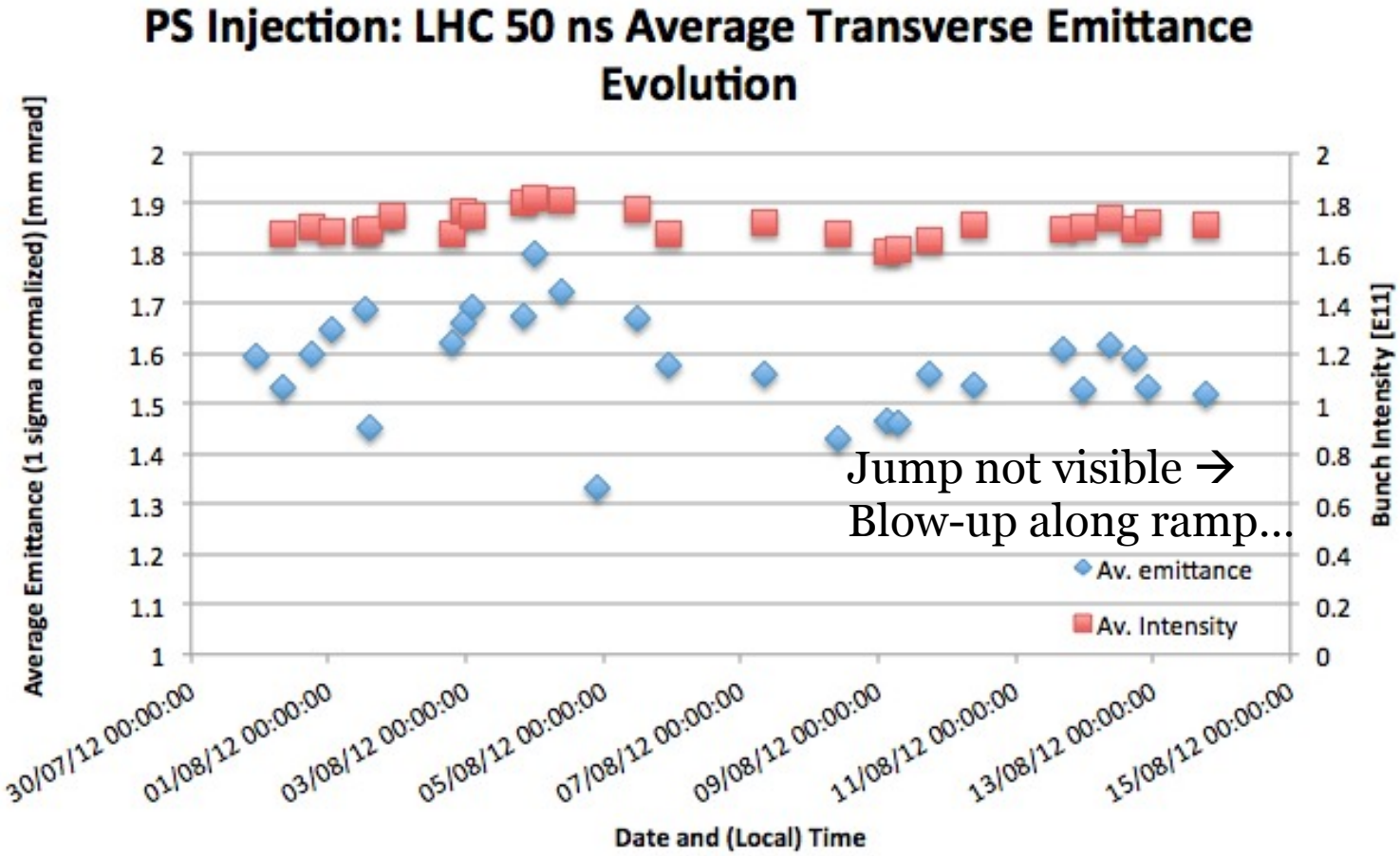
Examples for Emittance Logging – PS (1)

Measurements at flat top:



Examples for Emittance Logging – PS (2)

Measurements at injection:
(absolute emittance values wrong; not corrected for injection optics)



Issues with Transverse Measurements in the Injectors (1)

- PSB:
  - Wire scanners: work fairly well; reproducible when using the same optimised settings; issues to understand results at lower energies
  - SEM grids in BTM: obsolete electronics, but through steady maintenance relatively reliable; limited resolution (small beams)
- PS:
  - Wire scanners: absolute calibration between devices and settings problematic; bunch-by-bunch measurement tests planned after LS1
  - SEM wires in TT2: spacing too coarse and gain not adapted for current intensities
  - OTR screens in TT2: hardware made operational during last weeks; currently being commissioned
  - Ionisation monitors: long-term **aim** for PS ring (emittance evolution along the cycle), but absolute calibration with wire scanner needed

Issues with Transverse Measurements in the Injectors (2)

- SPS:
  - SEM grids in TT10: spacing too coarse for LHC beams
  - OTR screens in TT10: used for transfer line matching
  - Wire scanners: intrinsic problem of measuring small beam size at high energy
    - Wire movement cannot be slowed down much more → limited resolution
    - Only 2 out of 4 wire scanners placed at location with large beta function
    - Very sensitive to systematic errors (beam position, filter/gain settings etc.)
    - New feature in 2012: bunch-by-bunch measurements; especially useful on flat bottom; present configuration of filters not optimal; some issues with cross-talk
  - Ionisation monitors: not operational

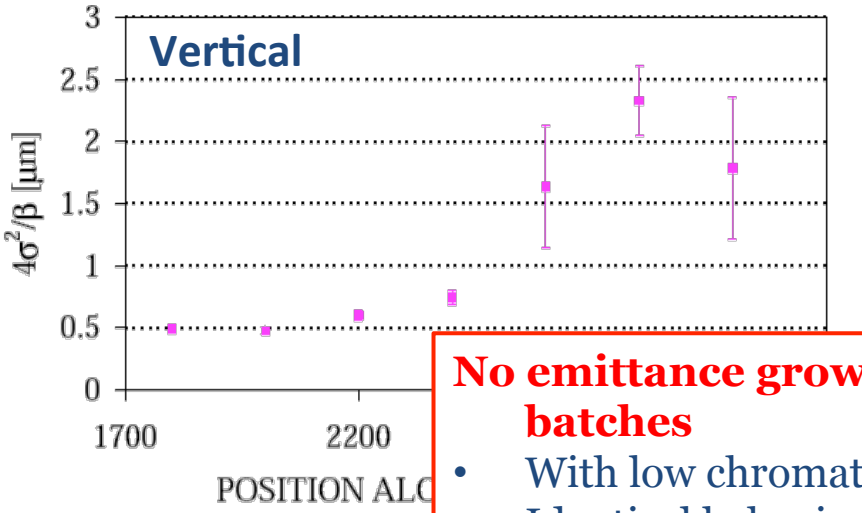
Conclusions and Outlook

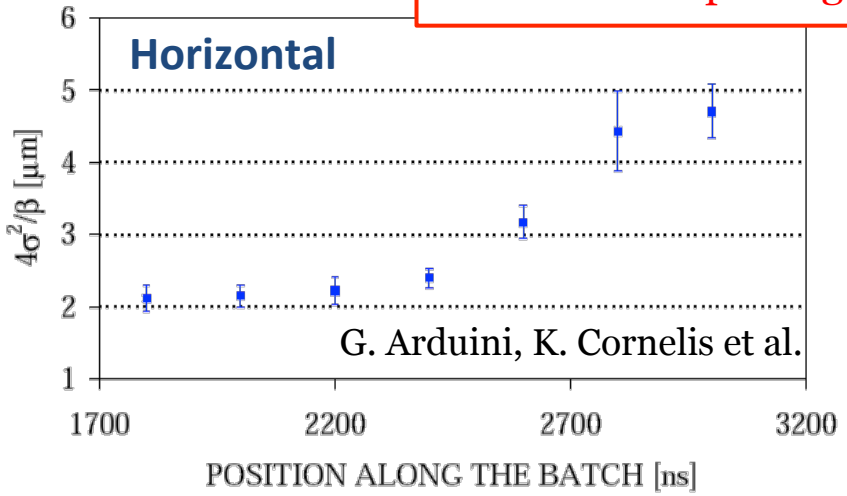
- Difficult to obtain emittance evolution along the injector chain
  - Absolute values from wire scanners can contain quite large errors (~5% on sigma of profile →~10% on emittance, plus errors in optics, delta p/p, beam position dependency etc.)
  - Impossible today to provide precise emittance blow-up values between machines, but very useful for relative changes
  - Continue effort between OP/ABP and BI to improve measurement quality
- Beam quality logging for injectors/LHC has started and shows already first results
  - Automatic data extraction related to LHC fill numbers is under development
- Machine tuning on daily basis essential to maintain high brightness, but little potential left for further improvement in PSB/PS
- Re-iterate optics matching PS extr. – TT2 – TT10 – SPS inj.
- Is there really emittance blow-up between PS extraction and SPS injection flat bottom?
- SPS: Study tail development along the cycle
- LHC 25ns nominal beam seems to be in good shape now, but a scrubbing run in the SPS is certainly needed after LS1 (since part of the machine will be opened)
  - Need to continue studies for ultimate intensities (emittances, pressure rise…)

Spare Slides…

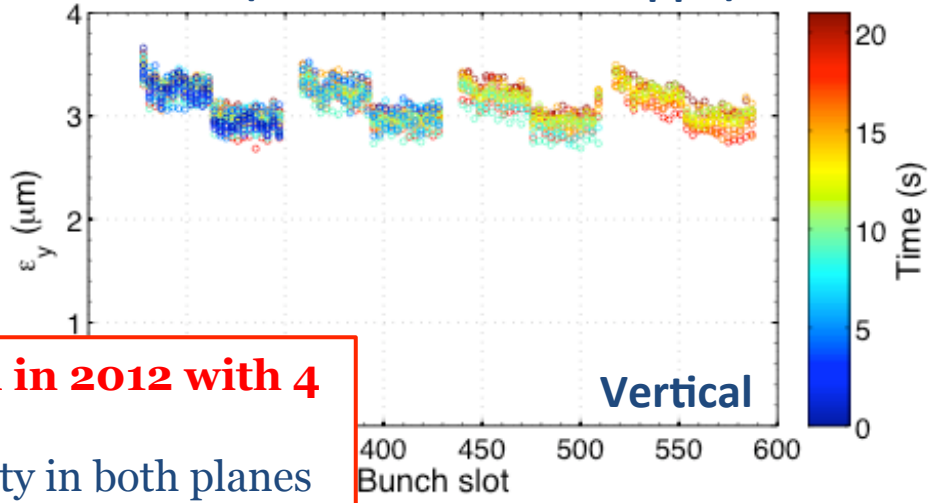
LHC 25ns beam: Emittances

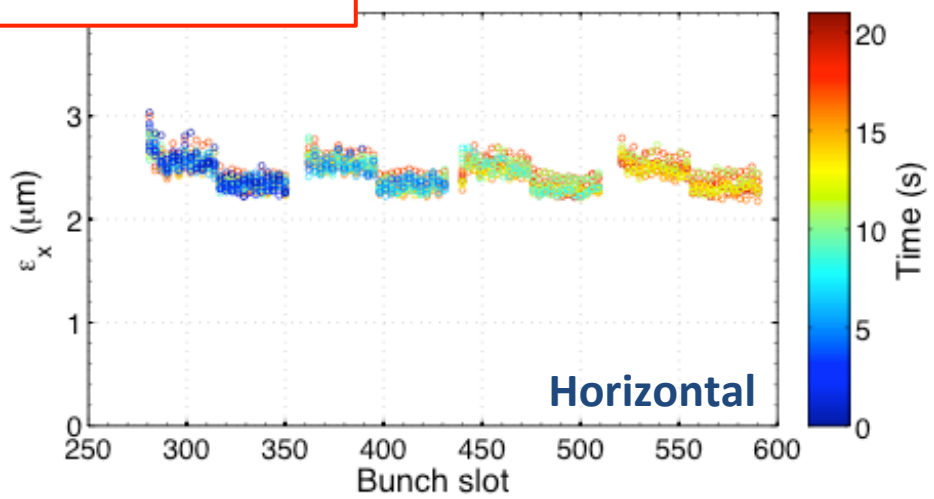
2000 (1 batch 0.8x10^{11}ppb)





2012 (4 batches 1.15x10^{11}ppb)





No emittance growth in 2012 with 4 batches

- With low chromaticity in both planes
- Identical behavior of all 4 batches
- No blow-up along bunch train