Ions Emittance Measurements in the LHC

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Many thanks to R. Versteegen and J. Jowett

MSWG

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Outline

- Measurement devices and availability.
- Run overview.
- Measurements at injection and simulations.
- Measurements in collisions.

Emittance Measurement in LHC

Devices to measure emittance in the LHC

1. Wire Scanner (WS)
2. Beam Synchrotron Light Telescope (BSRT)
3. Beam Gas Monitor (BGI)
4. Schottky Monitors
5. From Luminosity

Acquisition capability for Pb

1. Bunch-by-bunch but only at injection and only maximal for the first 3 trains.
2. At injection: average over all bunches.
   At flat top: bunch-by-bunch, calibrated with WS.
3. Average over all bunches through the whole cycle, calibrated with WS.
4. Not operational yet.
5. Bunch-by-bunch in collisions, but mixture of both beams and planes.

Emittance Measurement in LHC

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Availability for Pb in 2013

1. During commissioning and second half of the run (Pb-p mode) .
   -> One wire broke due to server problem in the front end, no permission to use the device before problem was solved.
2. NO calibration, due to WS failure and leak of WS data at flat top.
   Data of the first week of physics was lost:
   -> Wrong settings in the logging.
3. Data for most of the fills taken, but only B2 functional (i.e. in p-Pb mode) .
   -> Calibration difficult.
4. Only a few measurements taken for commissioning of the device.
5. Difficult to interpret due to unequal beam sizes of the two species, and assumption of round beams.

Average Performance

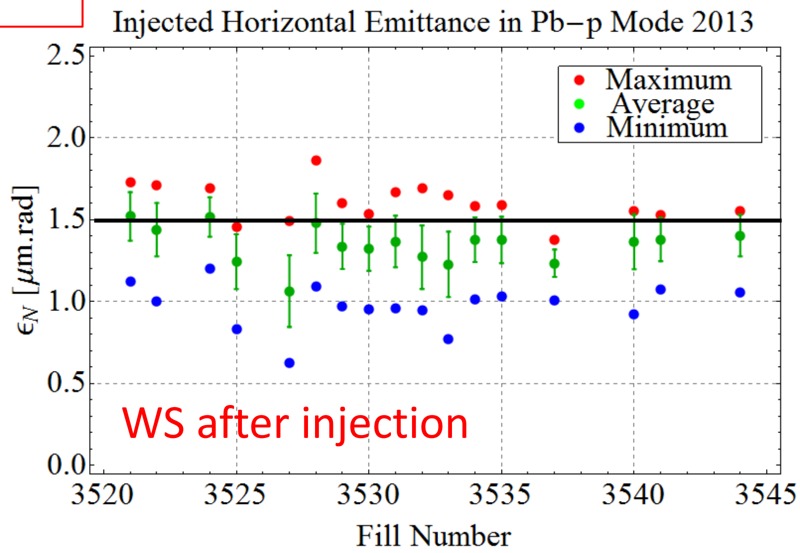
	Design	Injection (2011)	Collision (2011)	Injection (2013)	Collision (2013)
Beam Energy [GeV]	7000 Z	450 Z	3500 Z	450 Z	4000 Z
No. Ions per bunch $[10^8]$	0.7	1.24 ± 0.30	1.20 ± 0.25	1.67 ± 0.29	1.40 ± 0.27
Transv. normalised emittance $[\mu\mathrm{m.rad}]$	**1.5**	**---**	$\mathbf{1.7 \pm 0.2}$	$\mathbf{1.3 \pm 0.2}$	**$\sim$1.5**
RMS bunch length [cm]	7.94	8.1 ± 1.4	9.8 ± 0.7	8.9 ± 0.2	9.8 ± 0.1
Peak Luminosity $[10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	1	---	0.4 ± 0.1	---	p-Pb

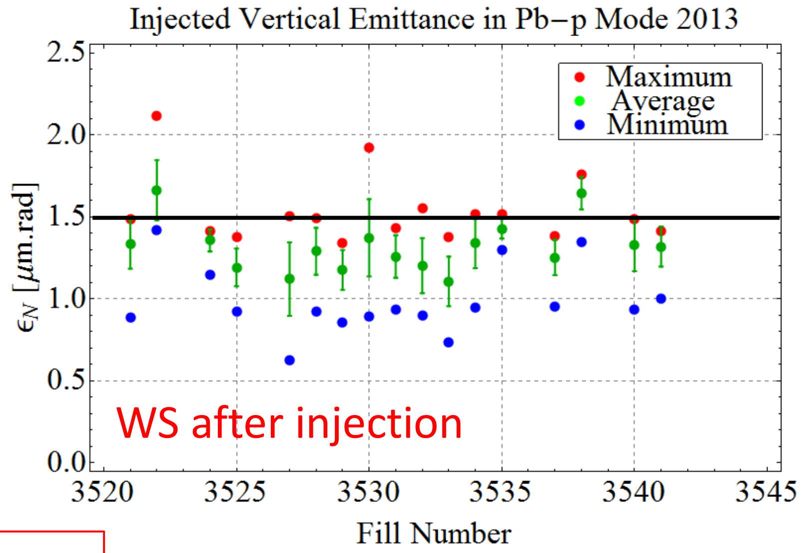
- In 2011 no emittance measurements at injection available, at flat top only BSRT and luminosity.
- 2013 WS at injection, but calibration of devices at flat top is difficult.

- Pb emittances injected into LHC seems to be similar in 2011 and 2013.
- Pb emittances around the design value, however great improvement in intensity.

Run Overview

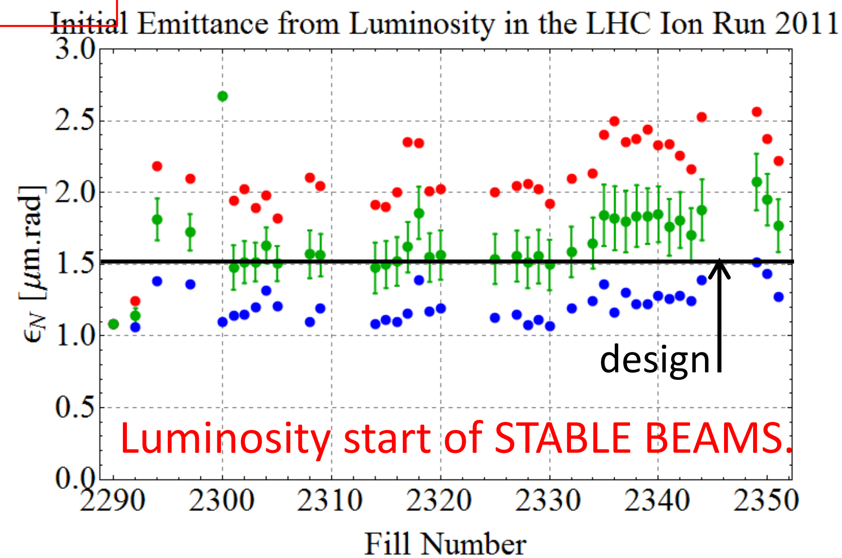
2013





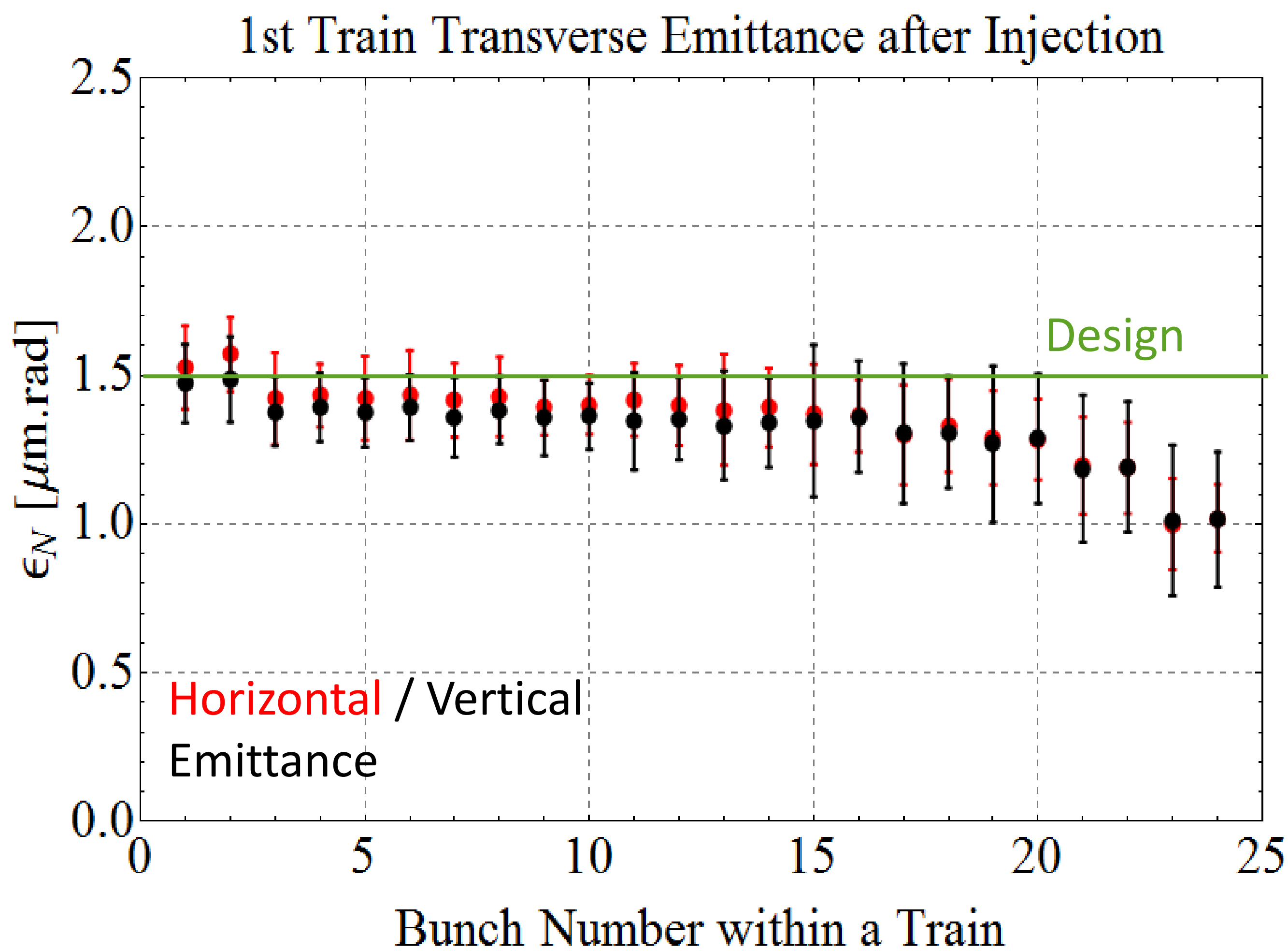
- Red and blue dots indicate bunch with minimum and maximum value.
- Spread arising from IBS at the injection plateau of SPS.
- Average values vary around design value.
- 2013 data taken at injection.
- 2011 data from luminosity at flat top.
- Difference between both years mainly due to blow up during the ramp.

2011



Bunch-by-Bunch Differences after Injection @ 450Z GeV

2013



Wire Scanner data of the first train in Pb-p Mode 2013 (Pb in Beam1)

Data and Simulation Programme

Simulations include:

- IBS
- Burn-off from luminosity production
- Radiation damping and quantum excitation

Collider Time Evolution (CTE) Programme

Simulations require initial beam parameters (from measurements):

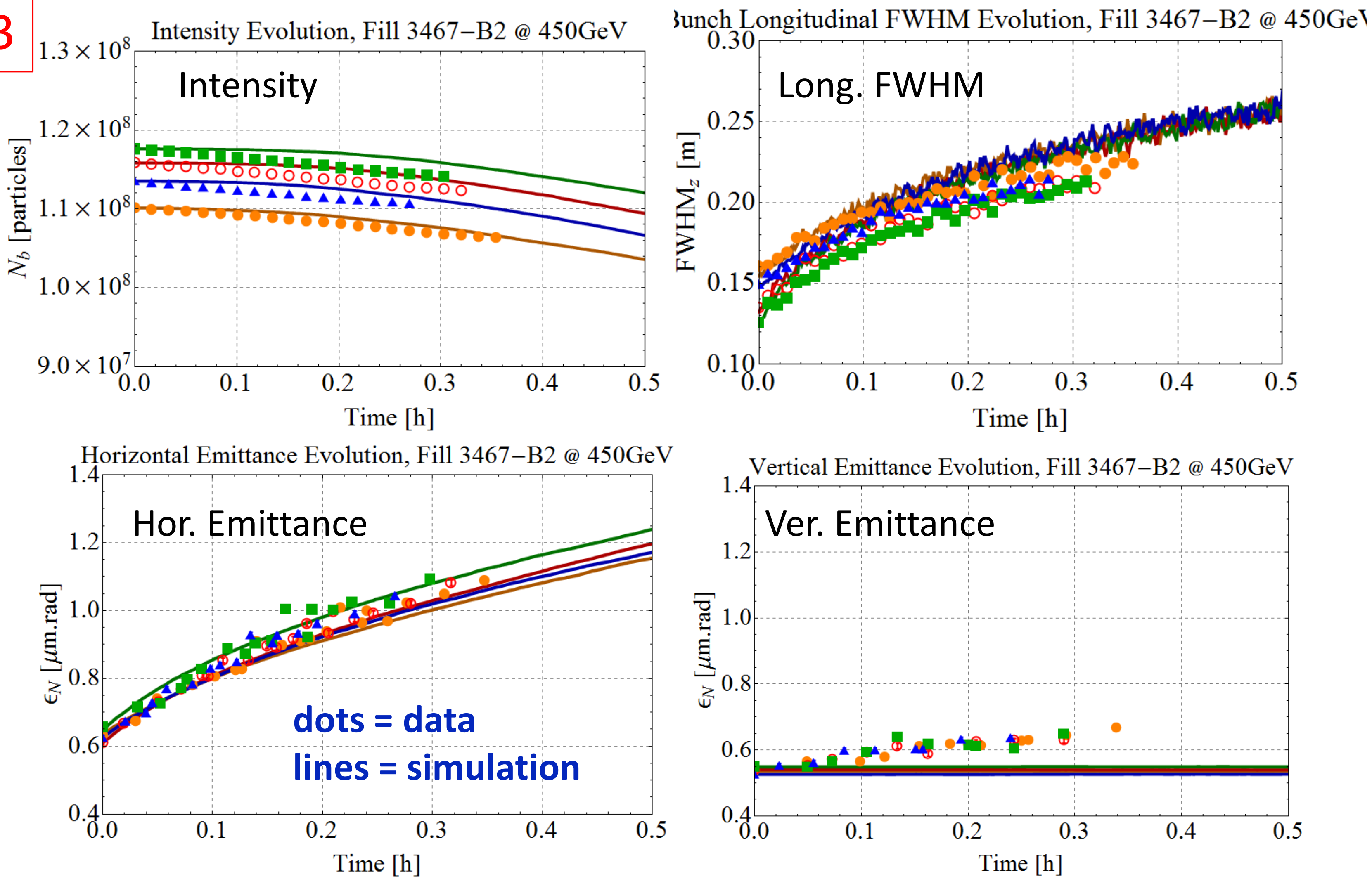
e.g. particle type, particles per bunch, horizontal and vertical emittances, bunch length, RF voltage…

Measurement devices used:

• Intensity:	Fast Beam Current Transformer (FBCT)	Bunch-by-Bunch acquisition
• Emittance:	Wire Scanner (WS), Beam Synchrotron Radiation Telescope (BSRT)	
• Bunch Length:	Beam Quality Monitor (BQM)	
• Luminosity:	ATLAS Experiment	

Beam Evolution & Simulation at 450Z GeV (Injection)

2013

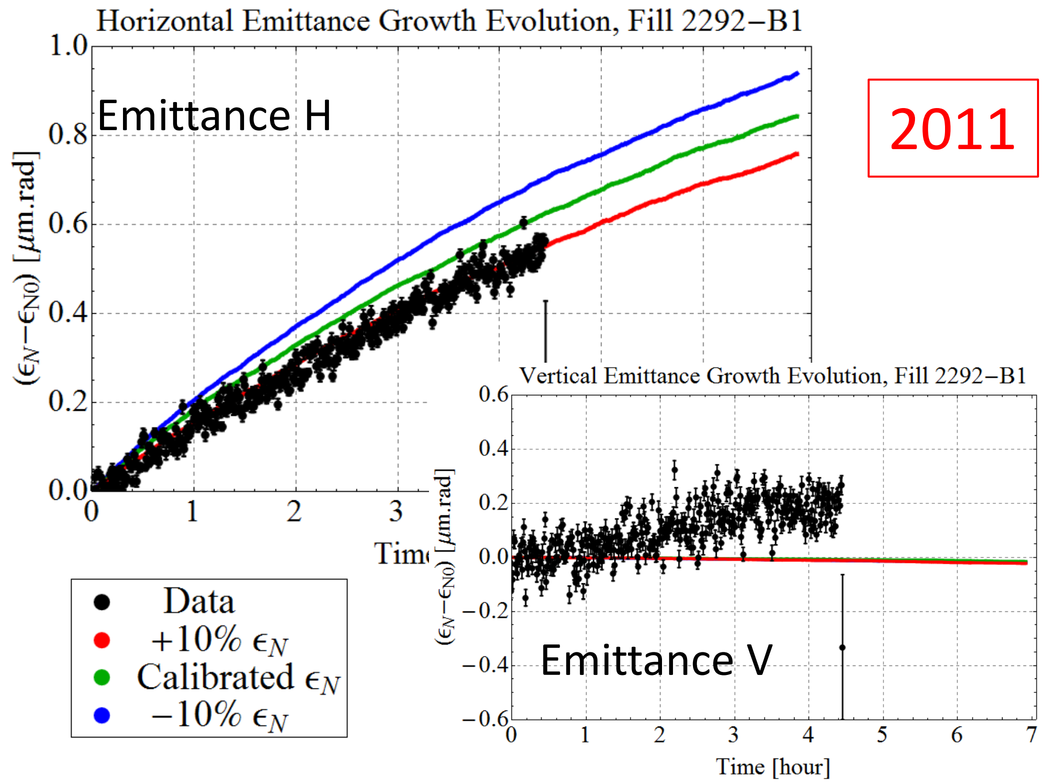


Emittances were measured with the WS during p-Pb.

Simulation and data are in good agreement.

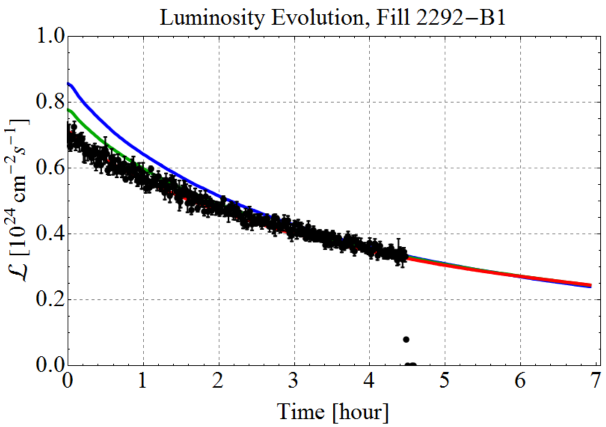
Only vertical emittance shows unpredicted growth – maybe due to coupling.

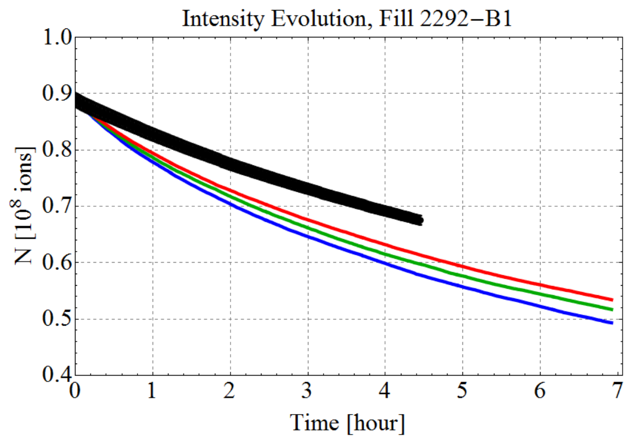
Evolution in Pb-Pb Collisions @ 3.5Z TeV

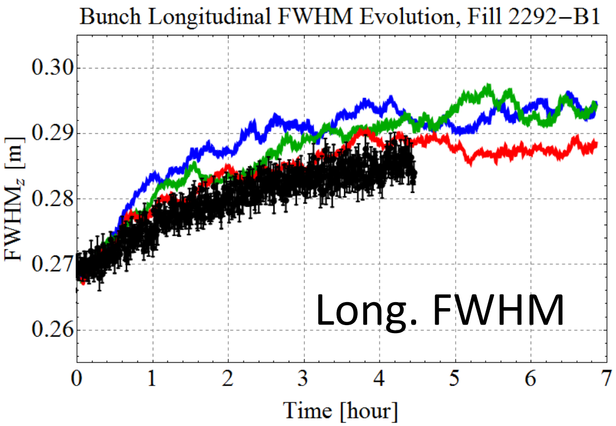


2011

- Emittances measured with the BSRT.
  - Calibration is difficult.
- Good agreement for relative emittance evolution.
- Data shows unpredicted growth in vertical emittance – coupling?
- Simulation overestimates particle losses.
  - Possibly due to non-Gaussian long. distribution.

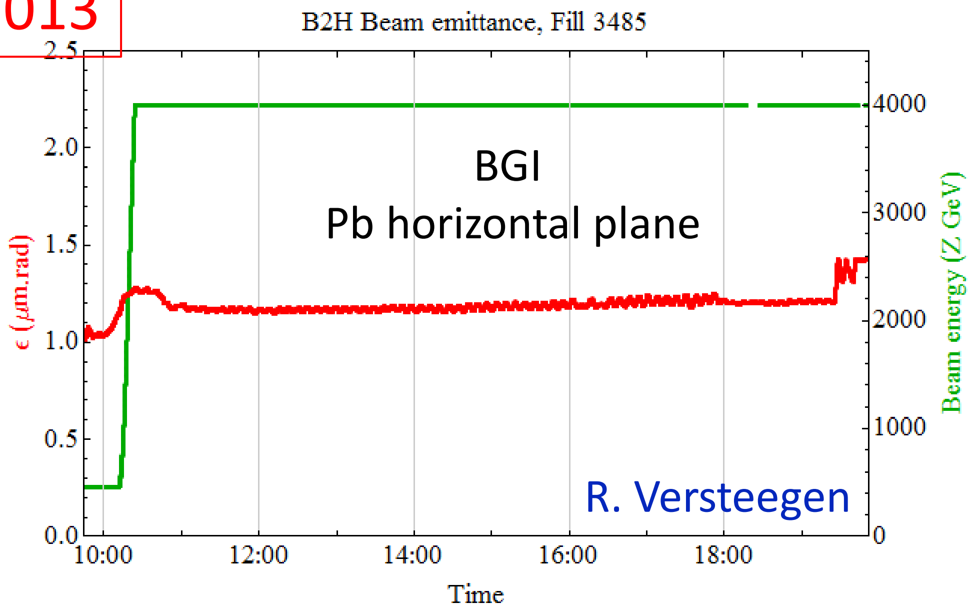






BGI and BSRT at 4Z TeV in 2013

2013



- Data is average over all bunches.
- BGI calibration very uncertain,

 -> under investigation by M. Sapinski.

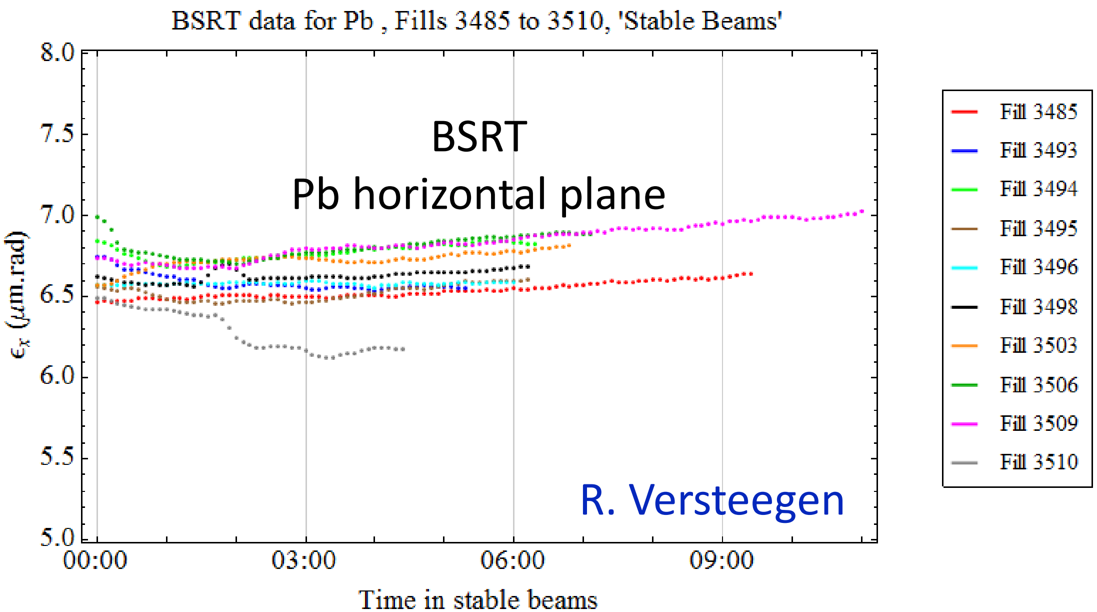
- BSRT NOT calibrated,

 -> requires calibration via

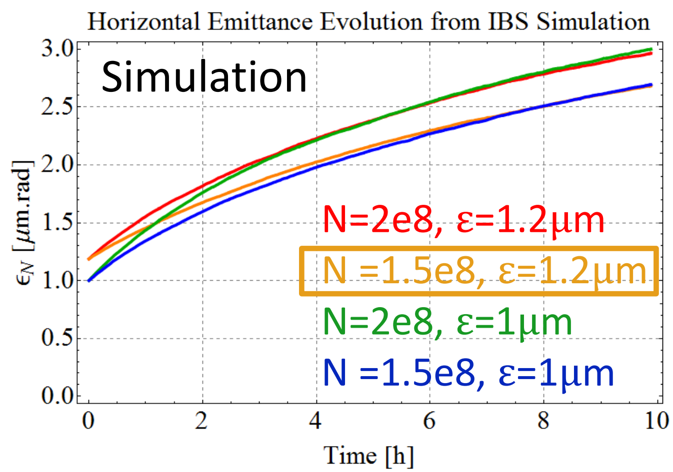
$$\sigma = \sqrt{\sigma_{meas}{}^2 - \sigma_{corr}{}^2}$$

-> σ_{corr} should come from cross-calibration with the WS, but not sufficient data is available at flat top.

-> under investigation by G. Trad.



BSRT shows small growth, while almost no growth visible from BGI.



Summary

- We encountered many problems and failures during the 2013 p-Pb run concerning the measurement of the emittance:
    - WS only available during the commissioning and second half of the run.
    - BSRT and BGI calibration relies on the WS measurement, therefore a reliable calibration is very difficult and only relative values form the BSRT can be used to monitor the evolution.

- Average emittances slightly below the nominal value were injected to LHC.
- The emittance spread within one train is relatively small, but shows the expected pattern arising from IBS at the injection plateau of the SPS.

- Simulations show good agreement with the data at injection and in collisions.

- The BGI and BSRT data show only a very small growth during physics.
    - But IBS is expected to introduce a much faster emittance growth than the one observed.
    - No WS measurements for comparison.
    - Not explained yet.

THANK YOU
FOR YOUR ATTENTION

Particle Tracking – Collider Time Evolution (CTE) Program

- Authors: Mike Blaskiewicz, Roderik Bruce and Tom Mertens
- Program to track 2 bunches of **macro-particles** in time in a collider
  - Subroutines act on the bunches on a **turn-by-turn basis**: one simulation turn can correspond to any chosen number of machine turns.
  - Several other input parameter define the initial beams:
    e.g. particle type, particles per bunch, horizontal and vertical emittances, bunch length, RF voltage…
  - IBS effects are simulated but no Beam-Beam
- Program returns the luminosity, emittance, bunch length, intensity and IBS growth rate evolution as a function of time

Collider Time Evolution (CTE) Program

Processes taken into account:

- COLLISIONS
  - user can choose between 2 collision routines:
    - very slow, integrates interaction probability for every particle by sorting particles in opposing beam in discrete bins. **No assumptions on the shape of the beam distribution**.
    - fast routine, **assumes Gaussian transverse distribution** and calcualtes interaction probability from transverse distribution analytically and uses **global reduction factor** (hourglass and crossing angle) for all particles. **No assumptions on longitudinal distribution**.
- IBS
  - rise time calculated using a standard method and modulated to account for non-Gaussian longitudinal profiles
  - user can choose between the following methods:
    - Nagaitsev full lattice
    - smooth lattice Piwinski
    - full lattice Piwinski
    - full lattice modified Piwinski
    - full lattice Bane *(not good at injection)*
    - interpolation from tabulated risetimes in external file at given points in emittance-space
- BETATRON MOTION
- SYNCHROTRON MOTION (particles outside RF bucket are lost)
- RADIATION DAMPING and QUANTUM EXCITATION
- transverse aperture cut from COLLIMATION

Collider Time Evolution (CTE) Program

- Output on a turn-by-turn basis
  - IBS rise times
  - Intensity
  - Transversal and longitudinal emittances
  - Luminosity

- Not Implemented
  - Beam-Beam effects
  - Betatron noise from feedback
    - emittance blow-up
  - RF noise
  - Elastic and inelastic beam gas scattering
    - particle loss and emittance blow-up