TRANSVERSE EMITTANCE PRESERVATION STUDIES FOR THE CERN PS BOOSTER UPGRADE

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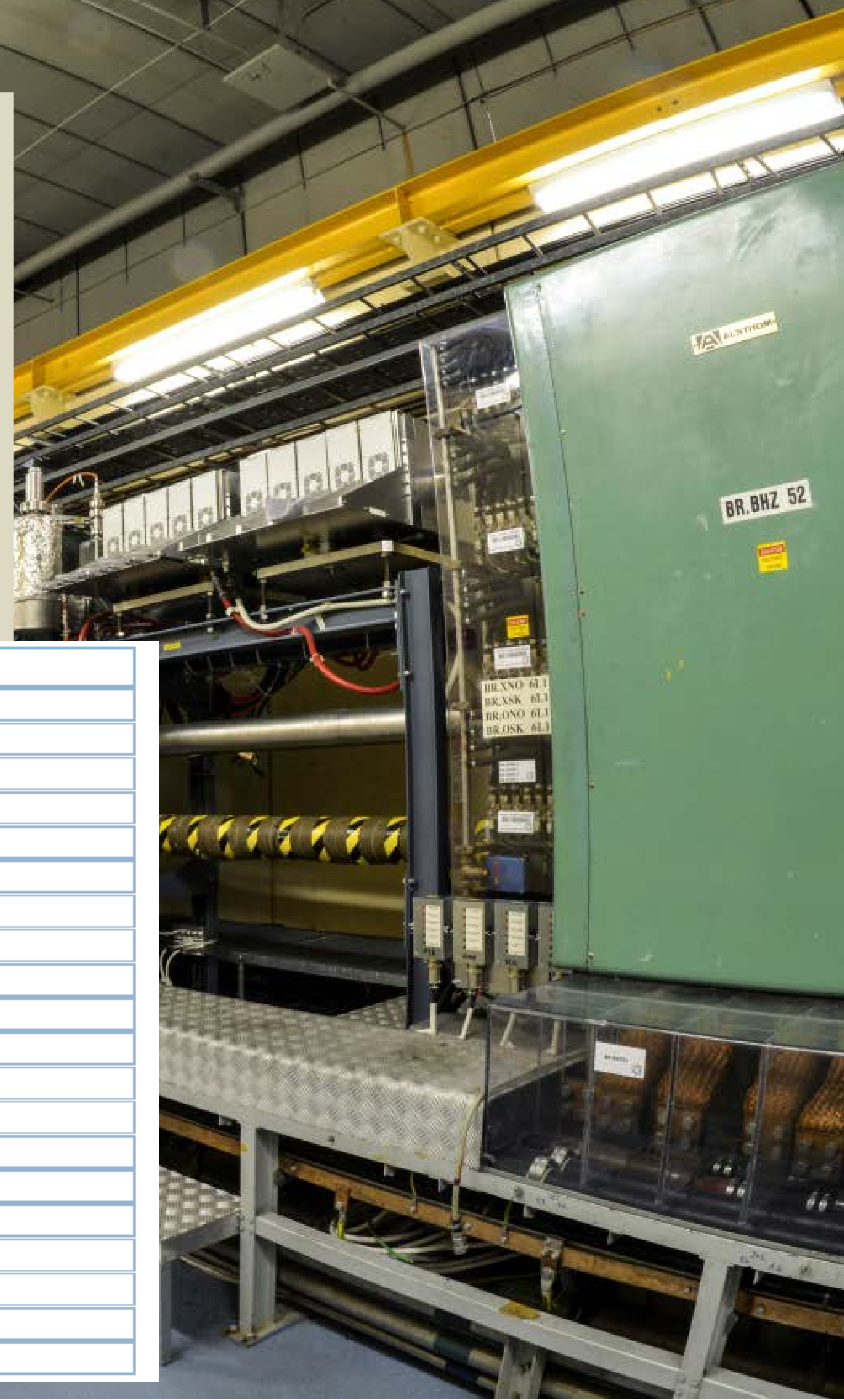
Circumference: 157m
Super-periodiciy: 16
Injection: Multi-Turn p+ → **H-**
Injection energy: 50 MeV → **160 MeV**
Extraction energy: 1.4 GeV → **2 GeV**
Cycle length: 1.2s
bunches: 1 x 4 Rings
RF cavities: h=1+2, h=16
Tunes at injection: ~ 4.3, 4.5, 1e-3
Rev. freq. (160 MeV): 1MHz
protons/bunch: 1e11 to 1e13
H. emittance: 1 to 15 um
V. emittance: 1 to 9 um
L. emittance: 0.8 to 1.8 eVs

Space Charge ΔQ > 0.5 @ inj

PSB
AD
CNGS
EASTA
EASTB
EASTC
LHCINDIV
LHCPROBE
LHC 100ns SB
LHC 25ns DB A
LHC 25ns DB B
LHC 25ns H9 A & B
LHC 50ns DB A & B
LHC 50ns SB
LHC 75ns SB
MTE
NORMGPS-HRS
SFTPRO
STAGISO 1.4Gev
STAGISO 1Gev
TOF



PSB is the first ring in the LHC p+ chain …where transverse emittance is defined

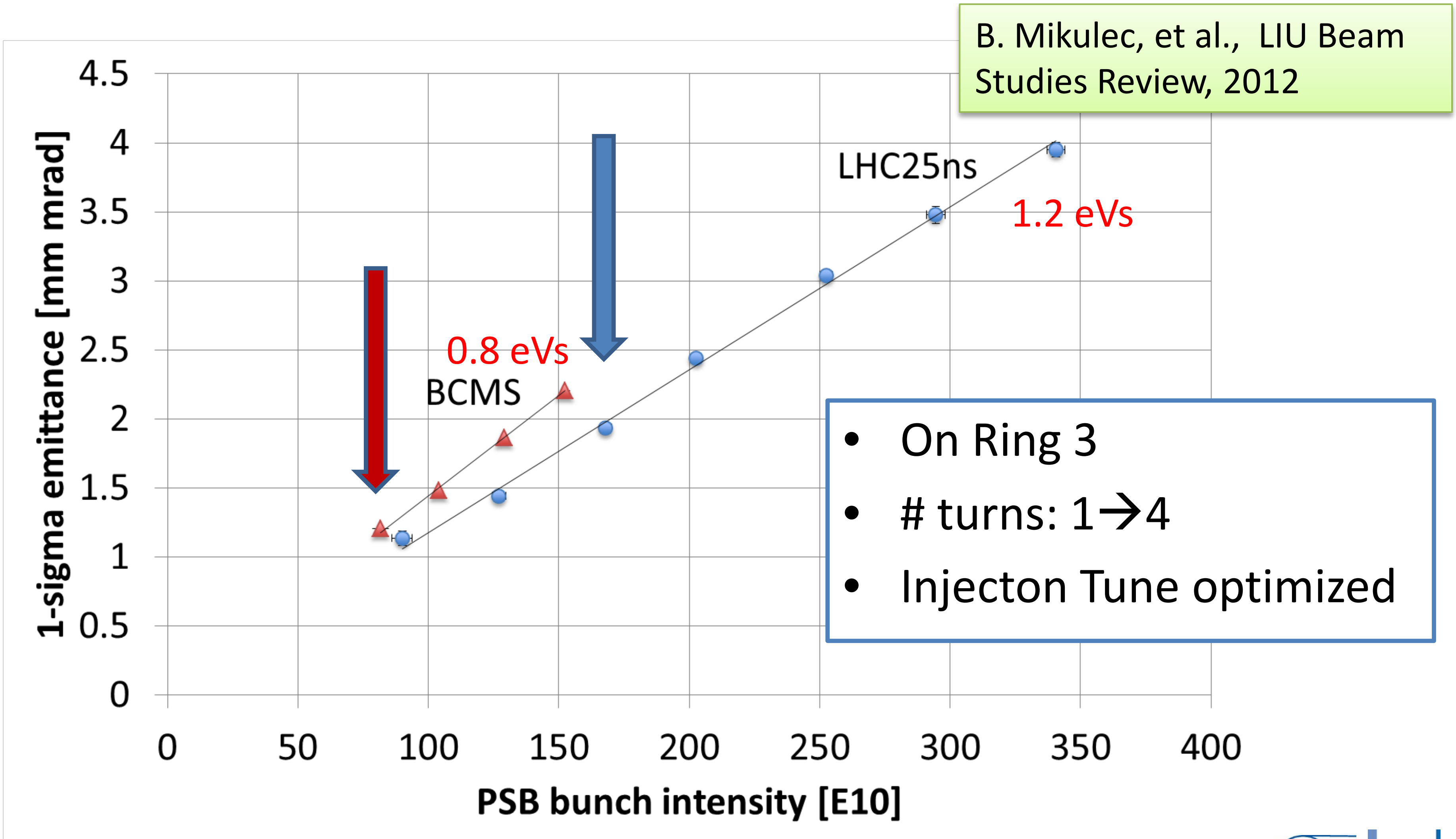
For LHC beams: emittance preservation (vs. losses)

Outline:

- Measurements Emittance vs. Intensity curve
- Space-Charge Simulations ($\Delta Q > 0.5$)
- Blow-up during the H- injection process
- Conclusions

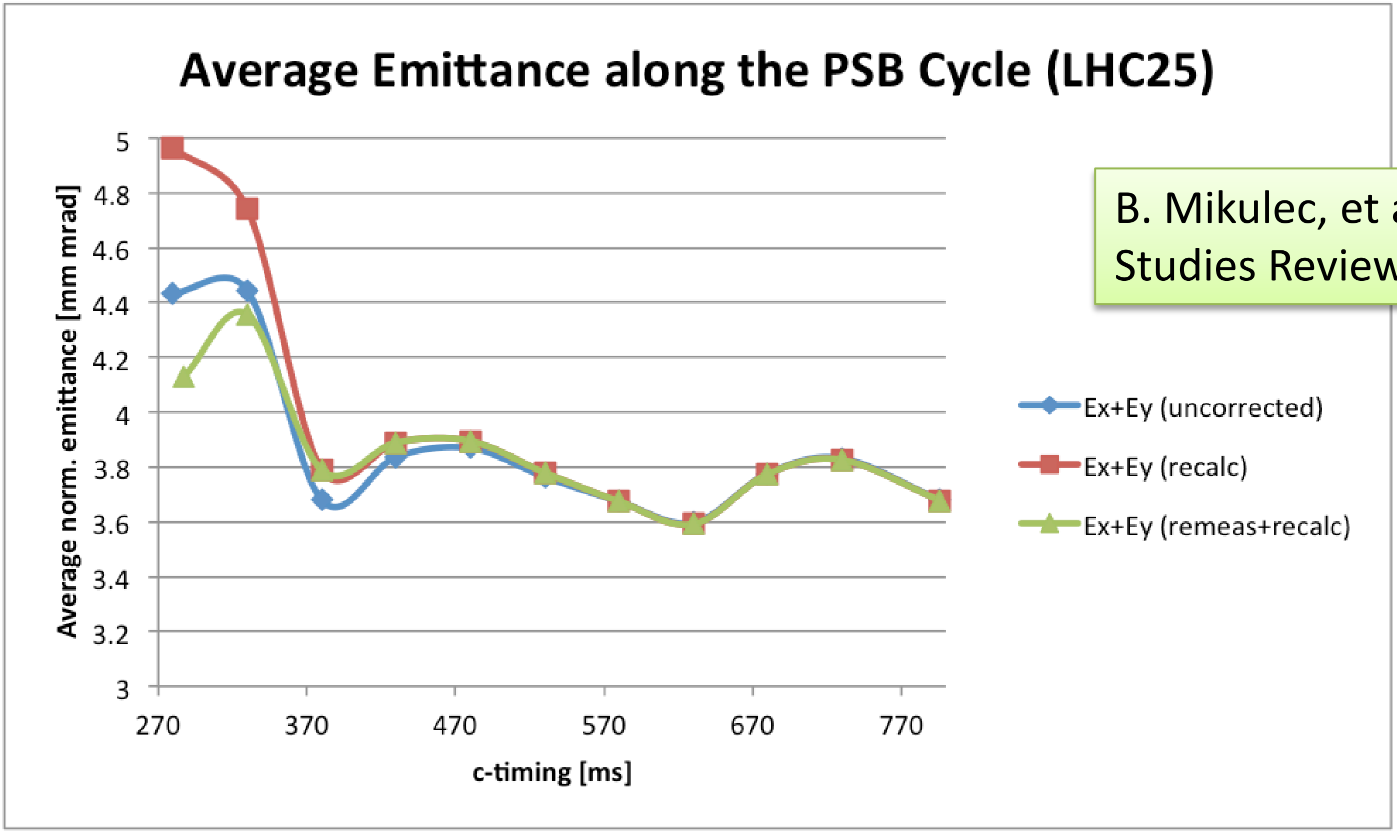
Lot of work behind: code benchmark, simulations of operational beams, studies of best injection (transverse & longitudinal), machine model with new hardware

Emittance vs. Intensity curve



- On Ring 3
- # turns: 1→4
- Injecton Tune optimized

Emittance vs. Intensity curve



B. Mikulec, et al., LIU Beam Studies Review, 2012

- Emittance is preserved along acceleration
- Low energy points not understood (scattering at the wire scanners, calibration, uncertainties in dp/p,…)

Scaling for Linac4 (160 MeV)

- Emittance vs. intensity determined by space-charge (and multi-turn injection process)
- Increase in injection energy: 50 to 160 MeV
  - $(\beta\gamma^2)^{160MeV}/(\beta\gamma^2)^{50MeV}$ =2.04
  - Keeping the same Space-Charge ΔQ means:
    - Increase of intensity by x2
    - OR Reduction of emittaces by x2
- The slope of the emittance vs. intensity curve should scale by x1/2*

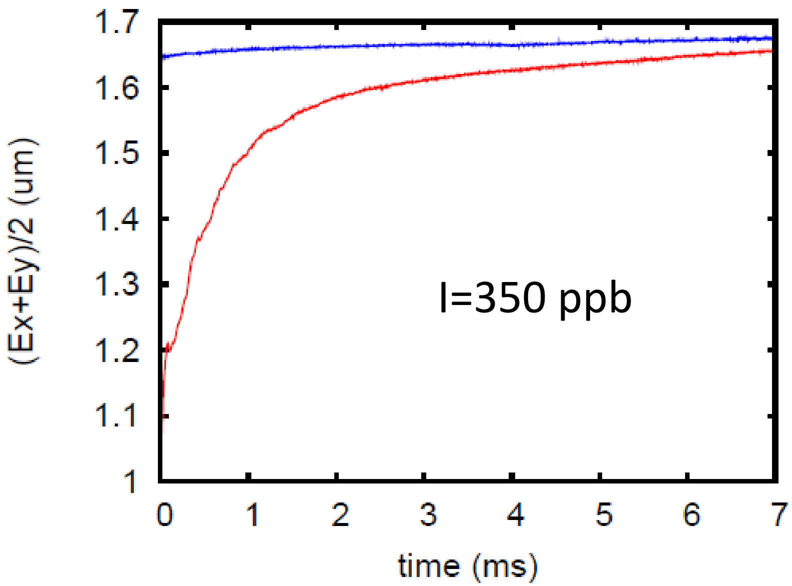
* Dispersion is not included inthe scaling

Space-Charge simulations (PTC-Orbit)

- Transversely MATCHED distribution (Gaussian) (*)
  - With a given emittance
  - Scan on the Intensity
- Let it evolve for ~7ms, during fall of the chicane bump
- Quadrupolar errors at the chicane magnets + Eddy currents + Compensation QDE3, QDE14 (time varying)
  - Beta-beating (mostly in vertical) corrected
  - Excitation of half-integer corrected
  - Excitation of the integer line

(*) In longitudinal (for the time being): I let a "rectangular" distribution evolve in an accelerating bucket, h1+h2. NOT YET optimized…

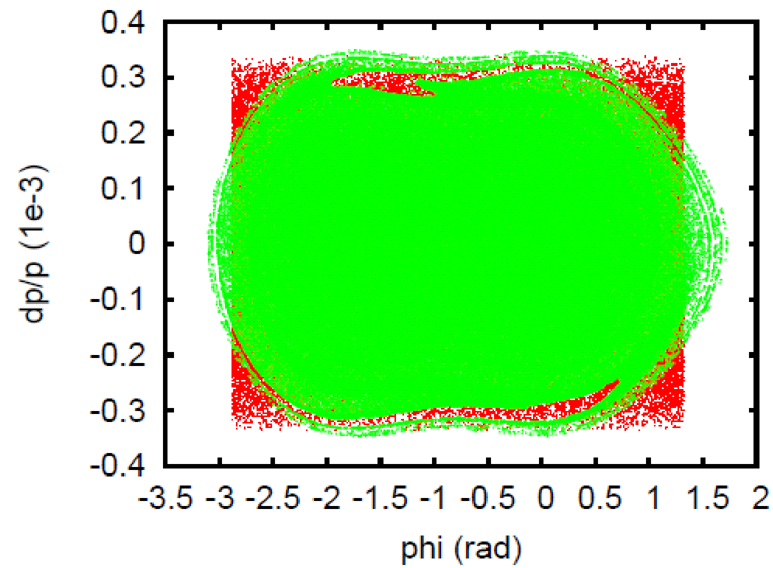
Space-Charge simulations (PTC-Orbit)



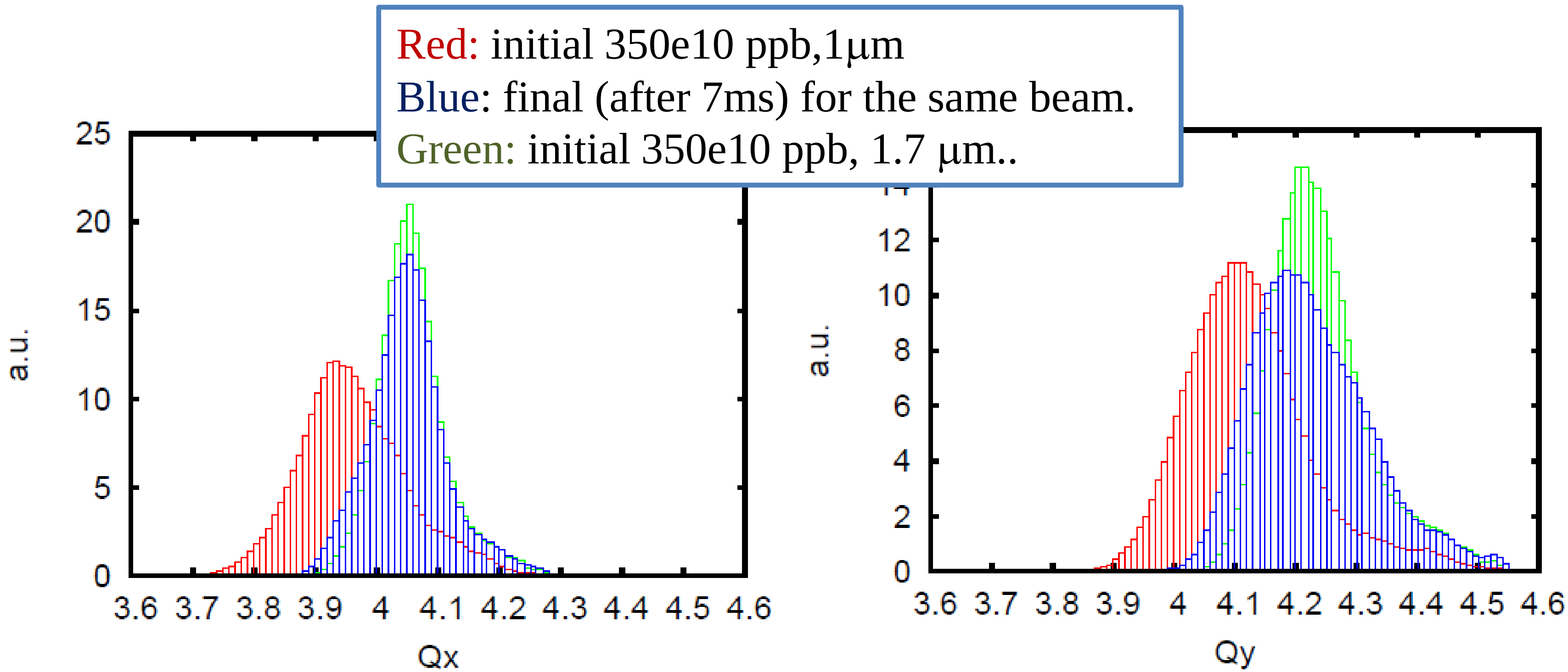
- Emittance reached at the end of the chicane bump is ~“independent” of the starting value

- 200 SC nodes
- 2.5 Direct SC module
- 128x128x128
- 250k macroparticles

Initial and final longitudinal distribution

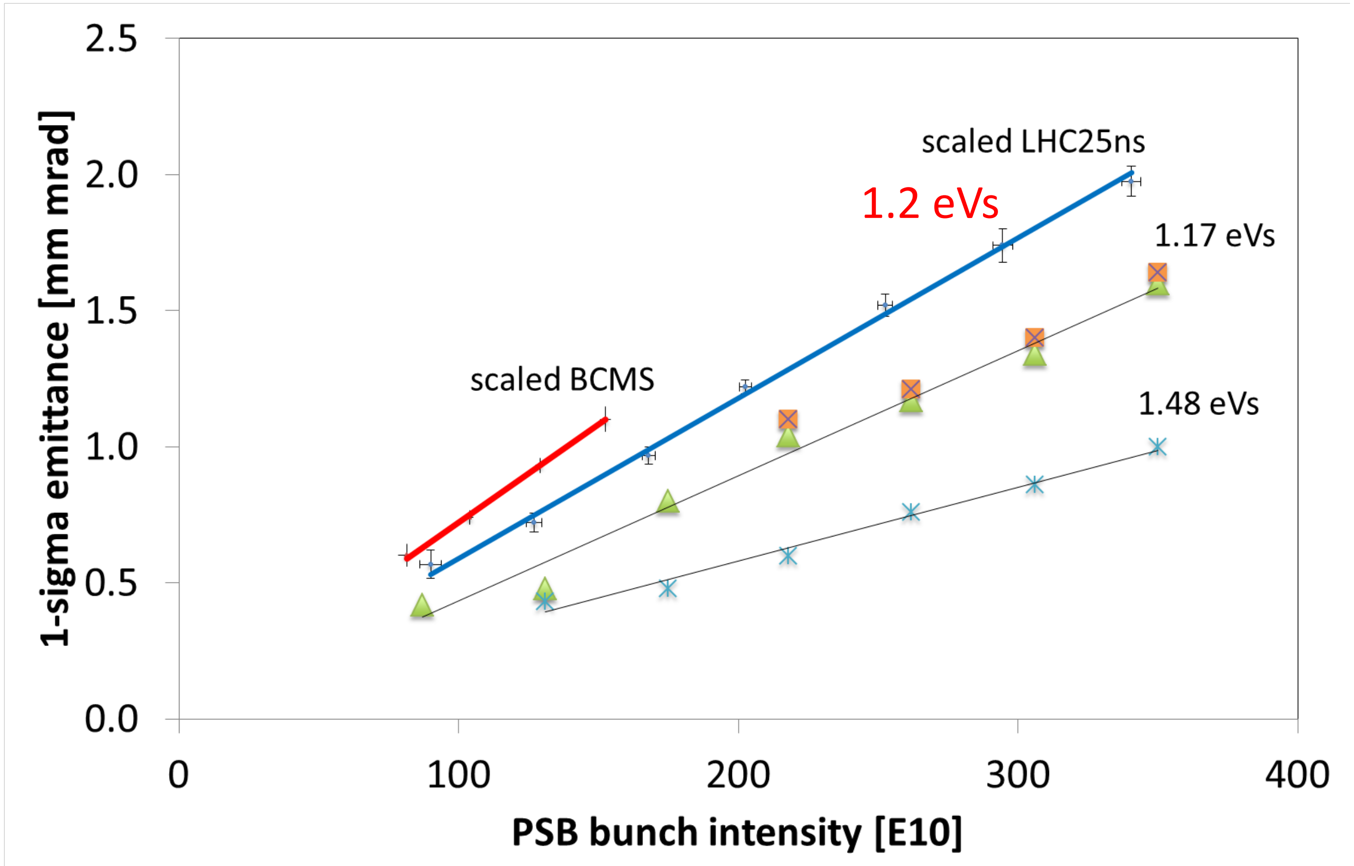


Space-Charge simulations (PTC-Orbit)



- H and V Tune spread
- Initial ΔQx extending below the integer → blow-up

Simulations with PTC-Orbit



- On a straight line & depends on longitudinal emittance
- BUT: the slope for 1.20eVs is a factor 25% lower

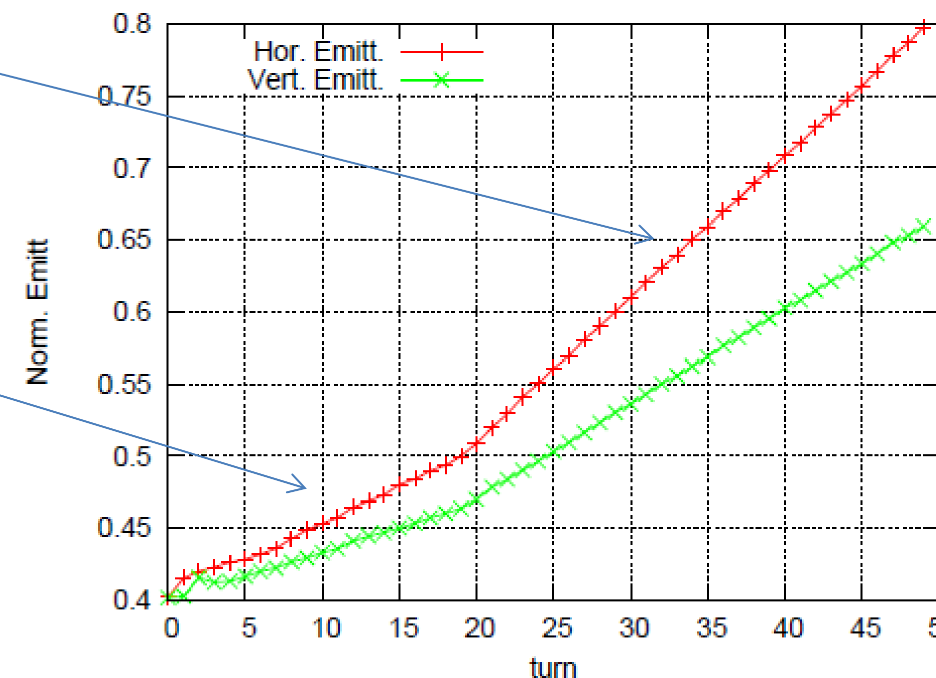
Blow-up during injection process

- Multipole Coulomb Scattering
- Injection mismatch
- Ripples or jtters

After injection, if beam not removed from the foil

During injection

- Graphite foil 200 μg/cm^2



Blow-up during injection process

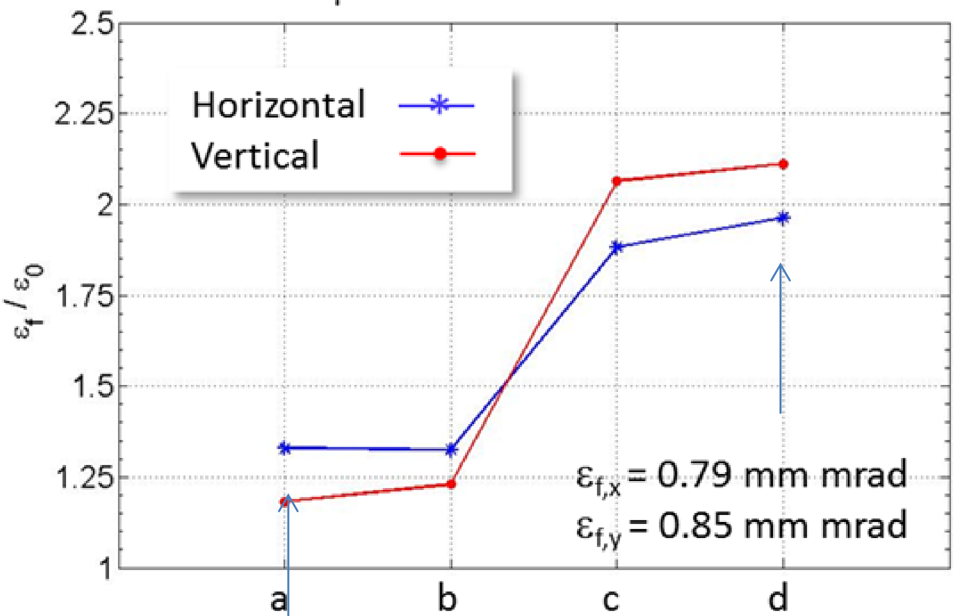
Target (BCMS): 165e10 protons , emittance ≤ 1μm

No longitudinal nor transverse painting

Ideally matched optics

7 turns injected (40 mA from Linac4, in 0.4 μm)

After 100 μs



$\varepsilon_{f,x}$= 0.52 mm mrad

$\varepsilon_{f,y}$= 0.48 mm mrad

a) Ideal optics

b) 25% mismatch

c) Mismatch as in (b) + 2 mm offset (steering, orbit,…)

d) (b) + (c) + 20 mA from Linac4 (=14 turns inj)

C. Bracco, et al., LIU day 2014

Conclusions: Emittance preservation in the CERN PSB

- LHC beams: 165 e10 in 2μm (will be 350 e10 with the Upgrade)
- Emittance vs. intensity measurements:
  - Points on a straight line + no blow-up during acceleration
  - Emittance defined by injection process + space-charge (ΔQ>0.5)
- Brightness curve scales by 2 (same ΔQ) @ 160 MeV
  - Simulations agree qualitatively:
    - Straight line, dependence on longitudinal emittance
  - 25% difference in slope: Missing something? Uncertainties in longitudinal distributions? Scaling is rough?
- Blow-up during H- injection should not prevent 1μm emittances:
  - Foil scattering (<20 turns injection), mismatch, offsets, ripples
- Next: benchmark with measurements will continue, optimization H- injection parameters and scan of different tunes.