TRANSVERSE EMITTANCE PRESERVATION STUDIES FOR THE CERN PS BOOSTER UPGRADE

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Circumference: 157m
Super-periodicity: 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 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

- 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
  - \((\beta \gamma^2)^{160\text{MeV}}/(\beta \gamma^2)^{50\text{MeV}} = 2.04\)
  - Keeping the same Space-Charge \(\Delta Q\) means:
    - Increase of intensity by \(x2\)
    - OR Reduction of emittances by \(x2\)
- The slope of the emittance vs. intensity curve should scale by \(x1/2^*\)

\* Dispersion is not included in the 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)

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

Emittance reached at the end of the chicane bump is \(~\)“independent” of the starting value

Initial and final longitudinal distribution
Space-Charge simulations (PTC-Orbit)

- H and V Tune spread
- Initial $\Delta Q_x$ extending below the integer $\rightarrow$ blow-up

**Red**: initial 350e10 ppb, 1µm
**Blue**: final (after 7ms) for the same beam.
**Green**: initial 350e10 ppb, 1.7 µm.
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 jitters

After injection, if beam not removed from the foil

During injection

- Graphite foil
  200 µg/cm²
**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)

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![Graph showing emittance changes over time](image)

- **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)

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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 ($\Delta Q > 0.5$)
- **Brightness curve scales by 2** (same $\Delta Q$) @ 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.