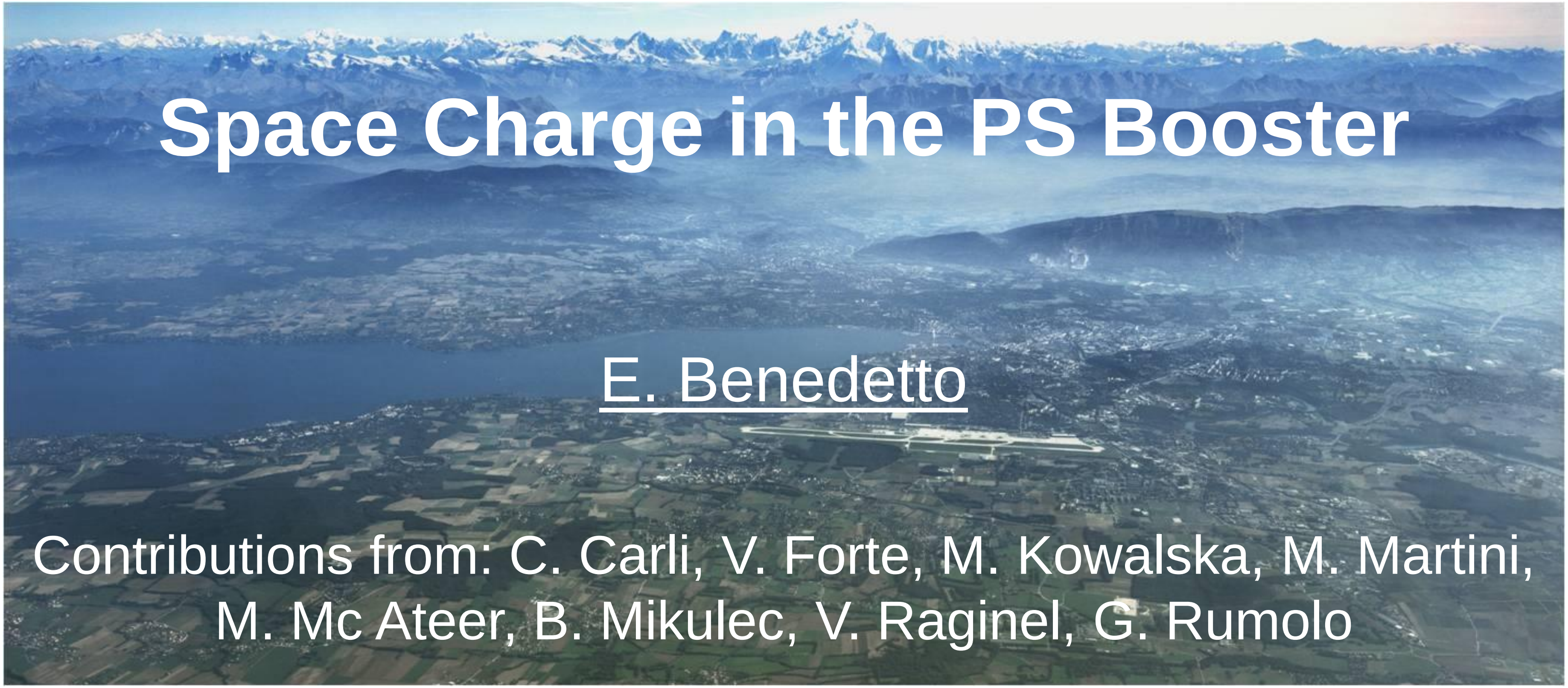
# LHC Injectors Upgrade

LHC Injectors Upgrade



# Space Charge in the PS Booster

E. Benedetto

Contributions from: C. Carli, V. Forte, M. Kowalska, M. Martini, M. Mc Ateer, B. Mikulec, V. Raginel, G. Rumolo



CERN

# Outline

- Intro PS Booster description & Upgrade plan
- Measures against Space Charge
- Space Charge studies for the PS Booster
- Machine modeling
- Computing time

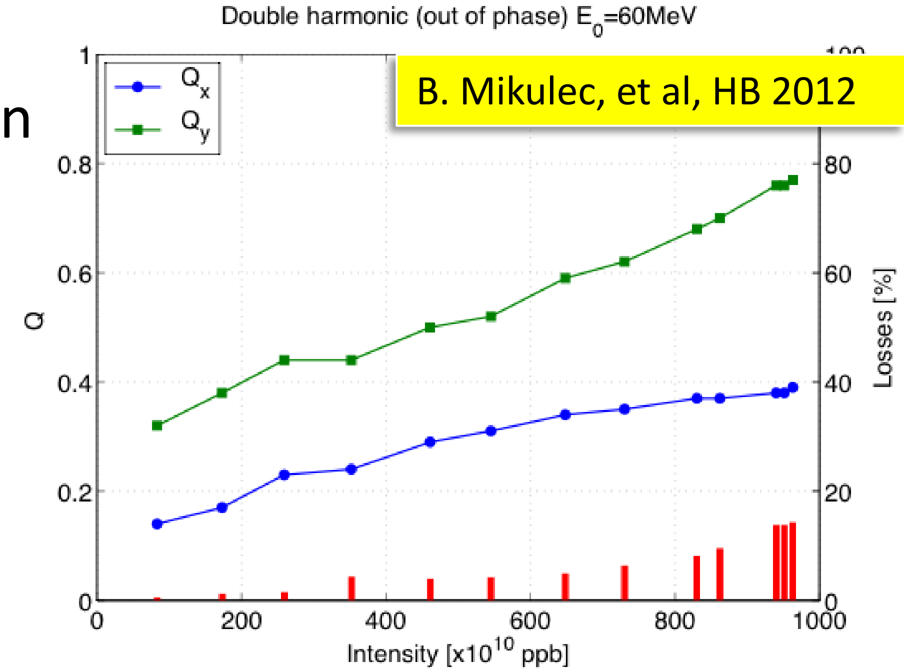
# PSB parameters

| | |
|---|---|
| Circumference: | 157m |
| Super-periodiciy: | 16 |
| Injection: | conventional Multi-Turn → upgrade to H- |
| Injection energy: | 50 MeV → upgrade to 160 MeV |
| Extraction energy: | 1.4 GeV → upgrade to 2 GeV |
| Cycle length: | 1.2s |
| # bunches: | 1 x 4 Rings |
| RF cavities: | h=1+2, h=16 |
| Tunes at injection: | 4.30, 4.45, ~1e-3 |
| Rev. freq. (160 MeV): | ~1MHz |
| # protons/bunch: | 50 → 1000 x 1e10 |
| H. emittance: | 2 →15 um |
| V.l emittance: | 2 → 9 um |
| Longitud. emittance: | 1 → 1.8 eVs |

| 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 |

# Space Charge limitations in the PSB

- Very large tune spread at injection
  - Up to 0.4 for LHC beams
  - > 0.7 for high intensity (with losses)




B. Mikulec, et al, HB 2012

- Injection energy upgrade:
  - From 50 to 160 MeV:
    - 2x intensity (for given emittance)
    - 1/2 x emittance (for the same intensity)
    - Or a combination …

# Measures against Space Charge

- Double harmonic: h1+h2
- Acceleration (no energy flat bottom)
  - H- injection directly on accelerating bucket
  - Today: MT injection in coast, then adiabatic capture + acceleration
- Transverse painting:
  - Horiz. Painting + Vert. Steering
  - Today: injection offset in both planes (V steering and delay of the bump decay wrt injection timing)
- Working point varies with time
- Resonance compensation:
  - Empirical (based on loss reduction and driven by phyiscs considerations)
  - Systematic studies driving terms and response matrix ongoing (M. McAteer)

# Areas of investigation

- Emittance preservation for LHC beams (increased brightness)

  e.g. during fall of H- inj chicane bump

Np=3.4e12 (=2x today)
Ex=1.72 um
Ey=1.72 um
(LIU Parameters, EDMS-1296306)

- Losses control for high intensity beams (increase intensity)

  More activation with increased energy

  → See Magda's talk

Np > 1.e13 (today nominal)
Ex= 15 um
Ey= 9 um

- Multi-Turn injection dynamics (both present and H-)

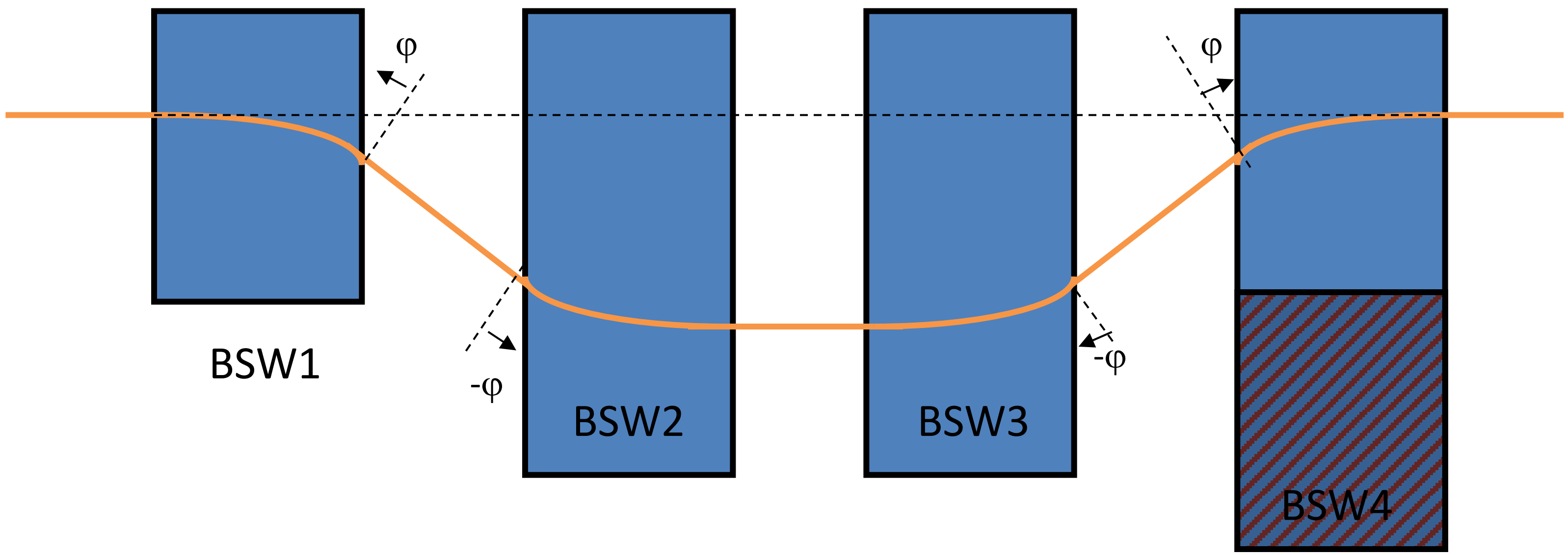
  Must include Space Charge

**Benchmark Simulations w. Measurements & Theory**

→ See Vincenzo's talk

**Optics Model (via response matrix and driving terms)**

# Studies of emittance preservation

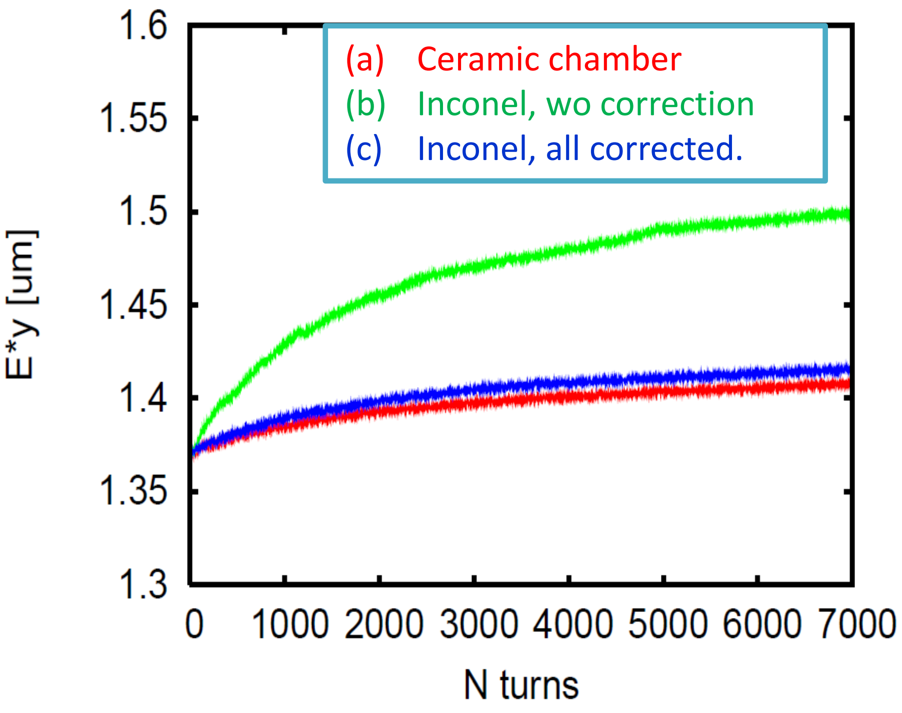



- Perturbation from chicane magnets
- Edge effects (rectangular magnets)
- Corrugated Inconel vacuum chamber new baseline (ceramic in the original design) → induced Eddy currents:
  - Delay of ~50us
  - Higher order field components (sextupolar)
    - Quadrupolar feed-down
    - Excitation 3rd order resonance

3D magnet simulation by B. Balhan, J. Borburgh
Chicane ramp-down shape by D. Aguglia, D. Nisbet

# Studies of emittance preservation

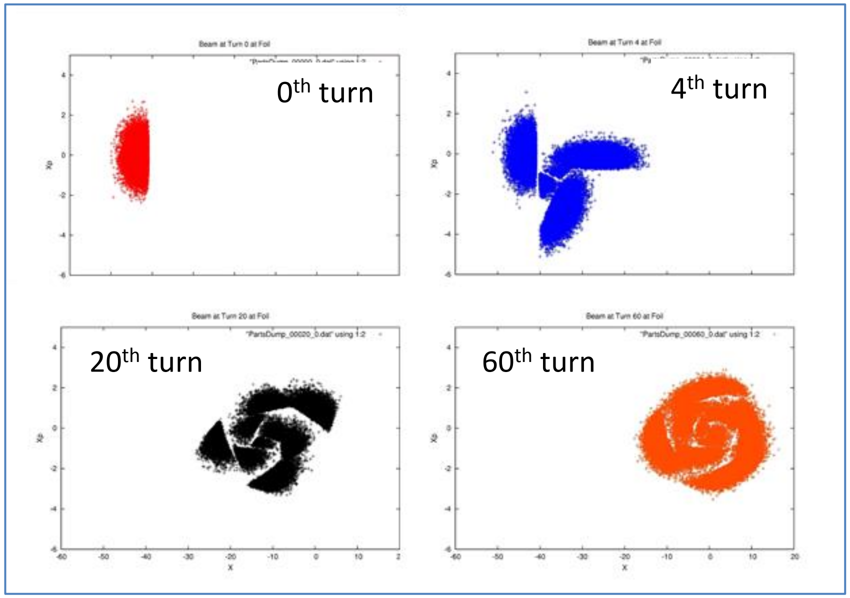
- Simulations with PTC-Orbit:
  - Time varying elements
  - Accelerating bucket
  - Double harmonic
  - Optics model as simple as possible
  - No errors except in BSW magnets
- Results are valid in relative, to discriminate between ceramic and inconel chamber



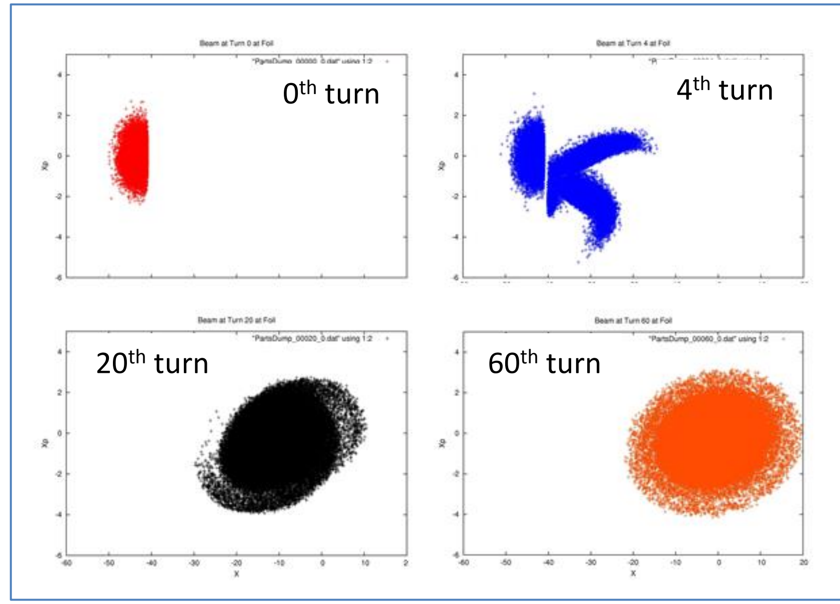

- No showstoppers for inconel chamber found, but compensation is required
  - additional trims on main quads QDE3, QDE14

# Multi Turn injection (present scheme w. septum)

w/o space Charge



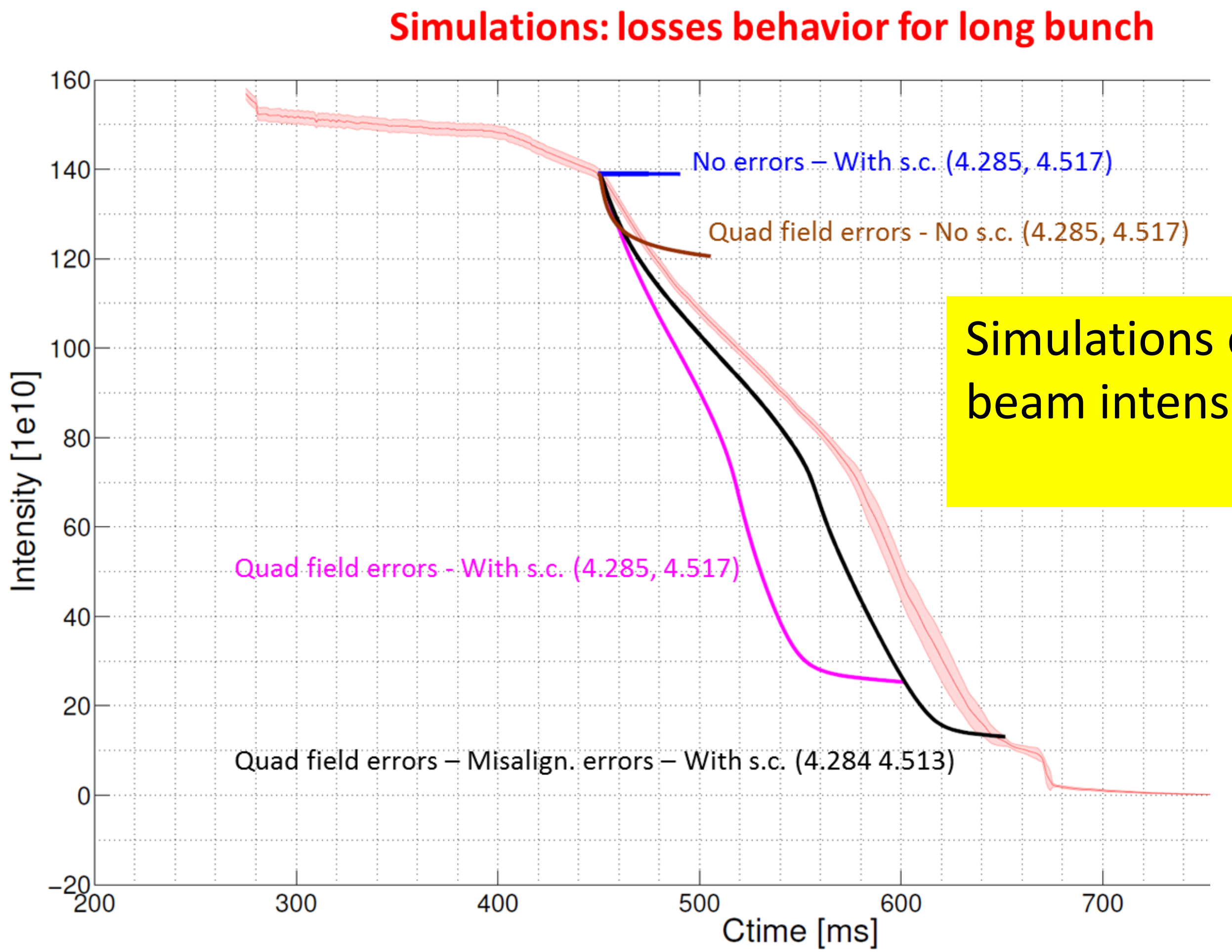

with space Charge




Differences in beam profiles and losses if space charge is (not) included in the simulations

V. Raginel et al. , CERN note 2013 and PAC’13

# Machine modeling and benchmark




Simulations close to the 0.5 line, beam intensity evolution
→ See V. Forte's talk

Very good agreement between measurements & simulations when machine model (misalignments and field errors) is implemented

# Computing time

- Reasonably “short” time scales
- PTC-Orbit (migration to PTC-pyOrbit in summer)
- Time on our CERN cluster:
  - Chicane decay ~7ms=~ 7’000 turns → 8 hours
  - Benchmark with measurements ~200ms → >2 weeks (continuous tracking, i.e. dump & load for restart)
  - High intensity & emittance beams → x2 time (increase # macroparticles)

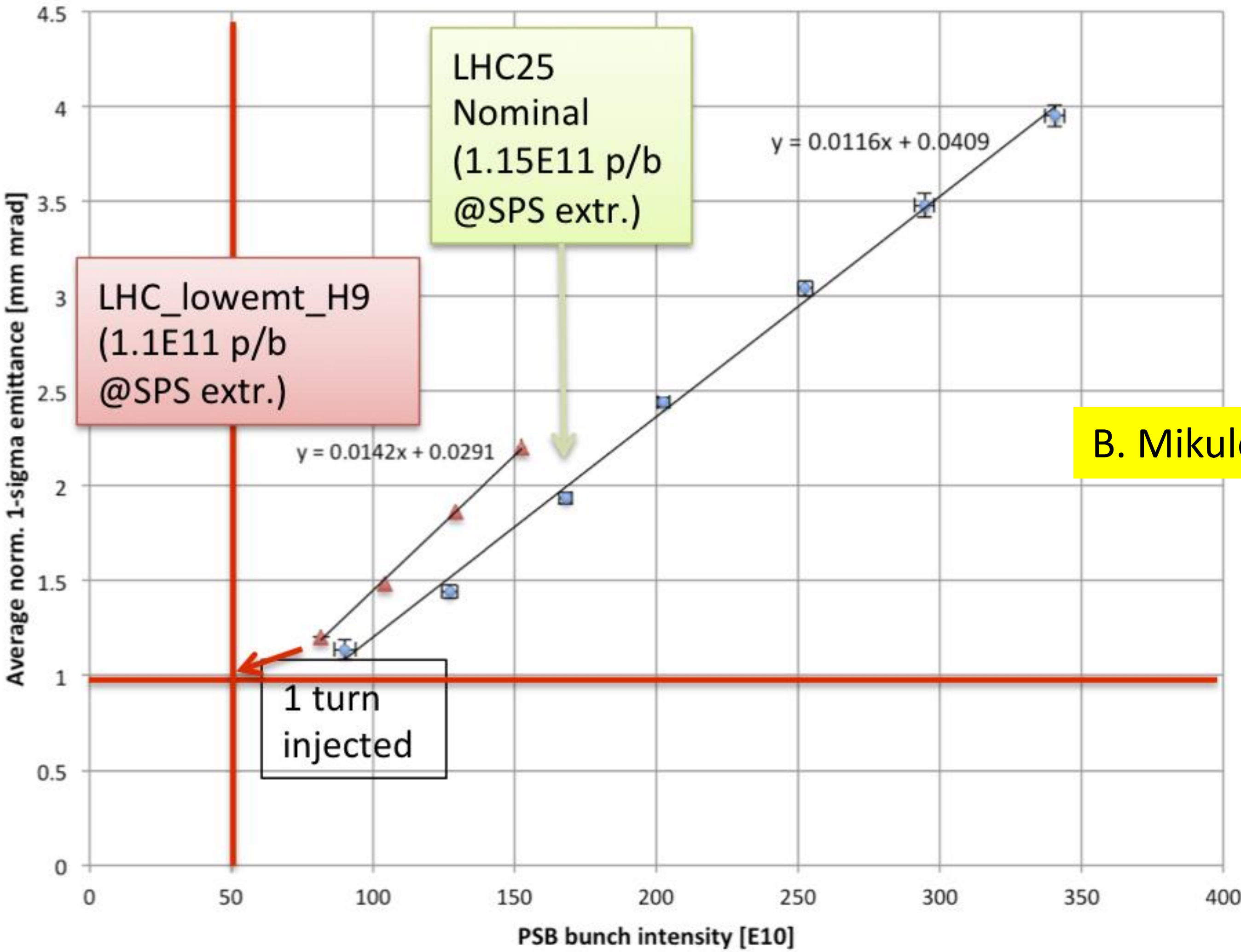
| | |
|---|---|
| # SC nodes: | ~200 |
| # macroparticles: | 250k → 500k |

# Conclusions

- Goal: improve understanding of current Space Charge limits and predict PSB performance with the new H- injection
  - LHC (high brightness) beams → emittance preservation
  - High Intensity beams → losses control
  - Multi-Turn (conventional or H-) process itself
- Benchmark code vs. measurements, was our major effort of MDs in 2012-2013
- Optics model (response matrix and driving terms) studies ongoing in //, the aim is to implement resonance compensation scheme
- Knowledge of optics model fundamental for accurate prediction of Space-Charge induced losses and beam blow-up

CERN

# Curve emittance vs. Intensity




B. Mikulec et al.