LHC Injectors Upgrade

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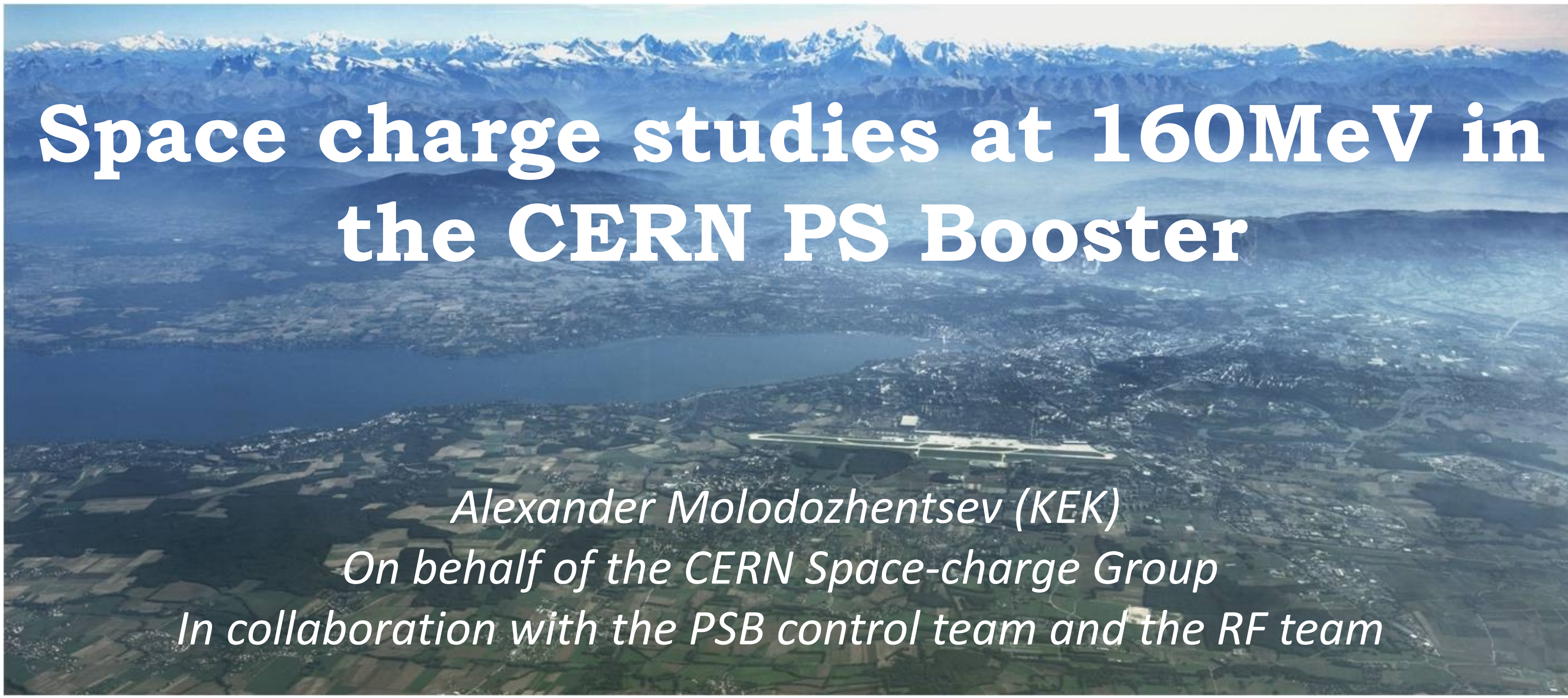

Space charge studies at 160MeV in the CERN PS Booster

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On behalf of the CERN Space-charge Group
In collaboration with the PSB control team and the RF team

CERN Space Charge Group

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‘RCS’ design	Miriam Fitterer Christian Carli

Outline

- **Motivations for PSB MD at 160MeV**
- **PS Booster MD for the PTC-ORBIT code benchmarking**
  - *Computational tools → PTC-ORBIT code*
  - *Resonance observations for PSB at 160MeV*
  - *PTC-ORBIT benchmarking results*
  - Extreme space-charge detuning (first attempt)
- **Basic plan for nearest Mds**
- **Summary**

Motivations for PSB MD at 160MeV

- **LINAC**2 (p^+ 50MeV) → LINAC4 (h^- 160MeV)
- **PS Booster** → W_{inj} = 160 MeV

… **very confident** to run with $\Delta Q_y \approx -0.3$ (and **reasonable hope** for $\Delta Q_y \approx -0.36$)

- **PS** → W_{inj} = 2 GeV

… **very confident** to run with $\Delta Q_y \approx -0.26$ (with **reasonable hope** for $\Delta Q_y \approx -0.30$ with 180nsec long bunches)

- **SPS** (Q20 lattice)

… present **assumption** is to run with $\Delta Q_y \approx -0.15$

… need to increase $\Delta Q_y \approx -(0.20 \dots 0.25)$

GOAL

25 ns	PSB inj	PSB extr/PS inj	PS extr/SPS inj	SPS extr/LHC inj	LHC top
Energy GeV	0.16	2	26	450	7000
Nb	1	1	72	288	2808
Ib [e11 p+]	35.2	33.5	2.7	2.4	2.2
Ib in LHC [e11 p+]	2.9	2.8	2.7	2.4	2.2
Exyn [mm.mrad]	1.9	2.0	2.1	2.3	2.5

$B_f = 0.4 \rightarrow \Delta Q_y \approx -0.25$
$B_f = 0.3 \rightarrow \Delta Q_y \approx -0.37$

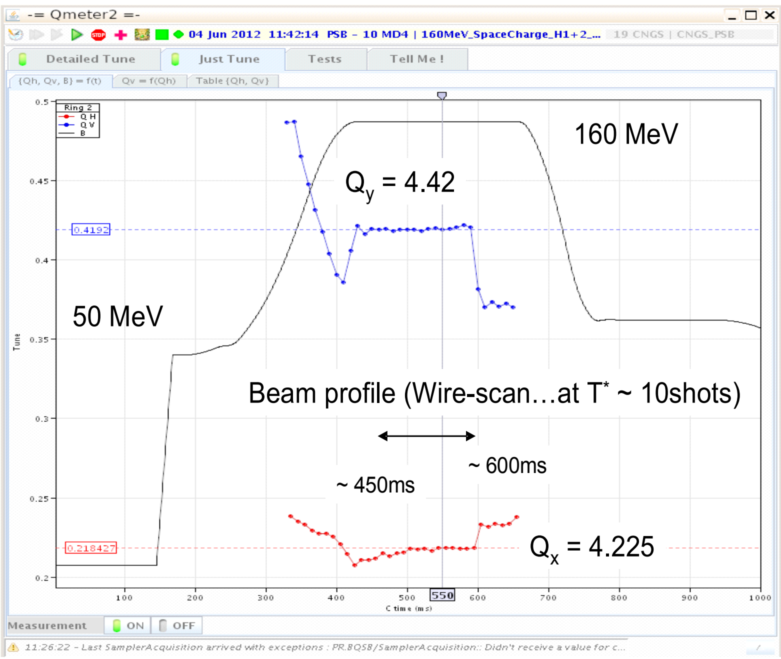
Motivations for PSB MD at 160MeV

LHC25 beam

- Moderate space-charge detuning ***($\Delta Q_y \approx -0.25$)***
  → check the estimated space-charge detuning
  → observation the INTEGER and MONTAGUE resonances
  → benchmarking the measured and simulated emittance evolution
  → effect of the linear coupling resonance [1,-1,0]

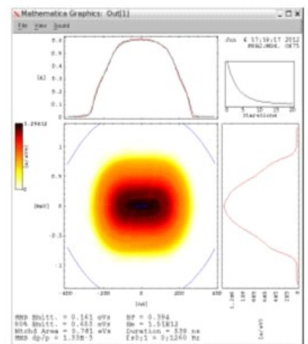
- Extreme space-charge detuning ***($\Delta Q_y \approx -0.40$)***
  → LOW-loss operation at the energy 160MeV

PS Booster: MD for the code benchmarking



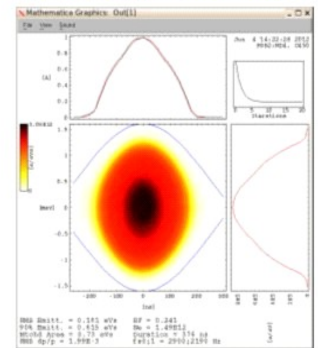
'LONG' bunch … h=1, 'ANTI' phase (8kV+4kV)

B_f = 0.40, N_b ~ (150÷170)×10[10]



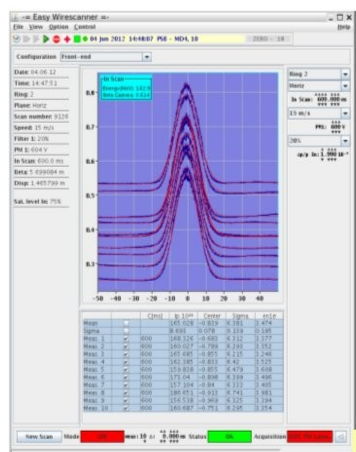
'SHORT' bunch … h=1, 'IN' phase (8kV+8kV)

B_f = 0.241, N_b ~ (150÷170)×10[10]



… with Steven Hancock

→ Taken into account the space charge effect in the longitudinal plane



~ 2.8 turns MT injection

Horizontal profile: 'IN' scan
Vertical profile: 'IN' scan

Single bunch intensity
→ ~ 165×10[10] ppb

Normalized 1σ Emittance
H → ~ 3.4π mm.mrad
V → ~ 1.8π mm.mrad

Q_x = 4.23 Q_y = 4.42

Estimation: *B_f = 0.25 → ΔQ_y (Laslett) ~ -0.4*

Computational tools

PTC(MADX)-ORBIT code, developed in collaboration of KEK and SNS.

Main features of the code:

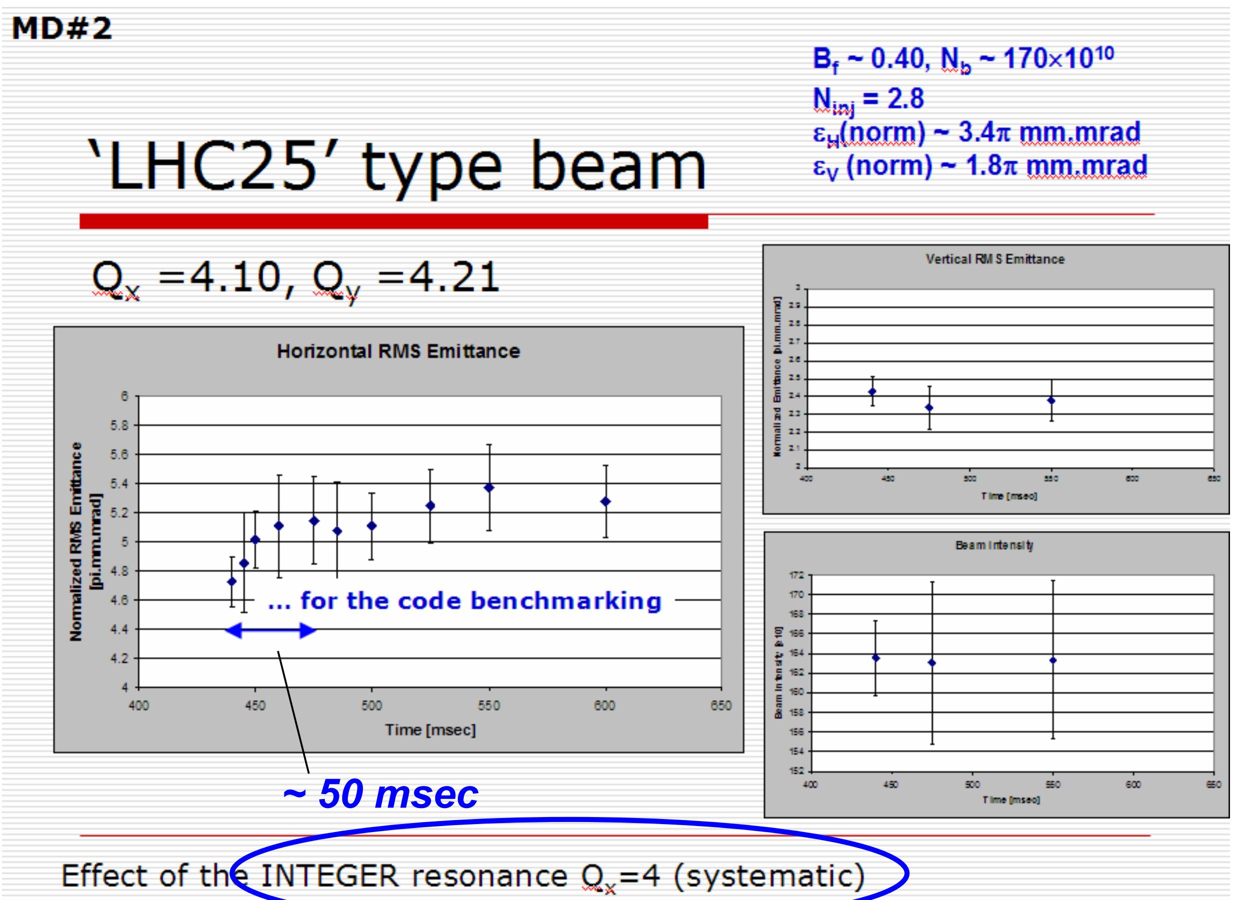
- common environment for the single particle and multi particle dynamics, including the collective effects (space-charge, impedance and e-clodes);

- dynamic variation of the machine elements (magnets and RF systems).

The code has been compiled for the CERN lxplus cluster.

Convergence study has been performed for the LHC type beam to define the optimum set of the basic parameters for the space-charge model (2.5D), implemented into the ORBIT(MPI) code.

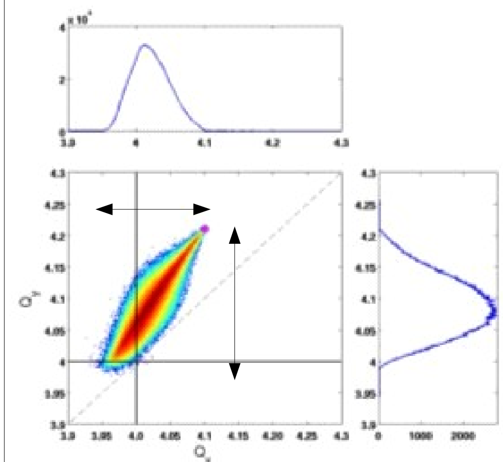
PSB MD: resonance observations at 160MeV



LHC25 type beam (B_f=0.40)

Q_x = 4.10, Q_y = 4.21

Footprint after 1000 turns

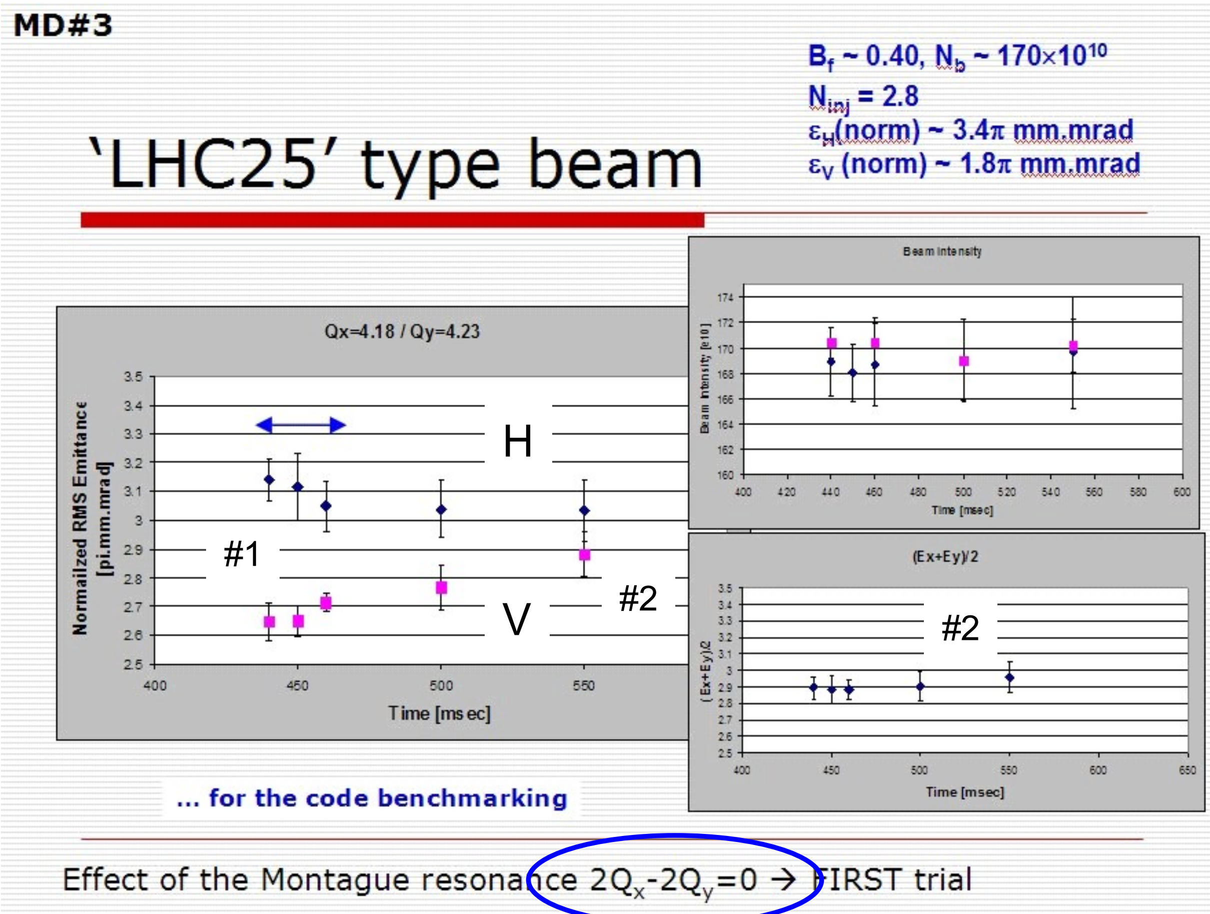


Q_x =4

PTC-ORBIT

Maximum detunning:
ΔQ_H = - 0.16
ΔQ_V = - 0.24

PSB MD: resonance observations at 160MeV



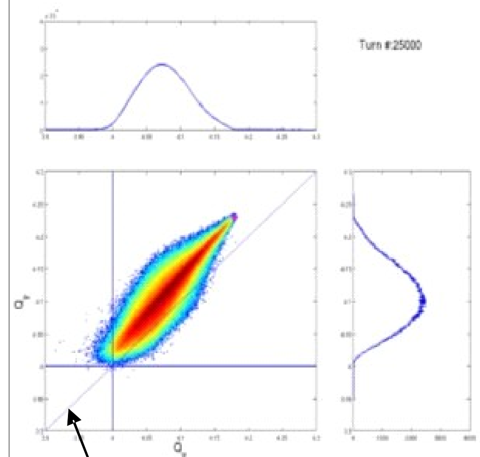
#1 → exchange of the H & V emittances
#2 → increasing the V emittance

W_{kin} = 160MeV

LHC25 beam

$B_f \sim 0.4$

$Q_x = 4.18$ / $Q_y = 4.23$



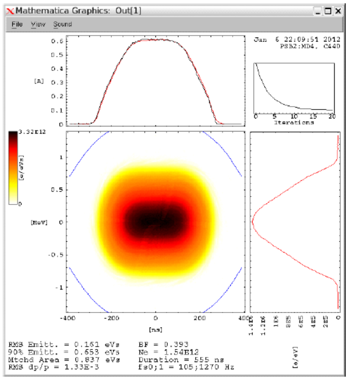
$2Q_x-2Q_y=0$

PTC-ORBIT

PTC-ORBIT benchmarking results

MD - Beam characteristics – longitudinal

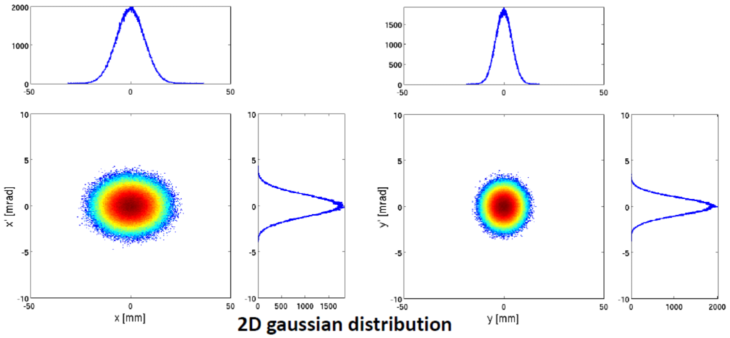
- h=1 - double harmonic RF +8kV & +4kV in antiphase
- Long bunch – B.f. ~0.39
- RMS emittance = 0.161 eVs
- RMS $\Delta p/p$ = 1.33e-3



Simulations - Beam characteristics – transverse

	αx	βx	αy	βy	Dx
Lattice (PTC)	-0.1889E-14	5.8138	-0.22351e-3	4.2509	-1.5215
500e3 (Matlab post p.)	-5.7985e-4	5.805	-7.7873e-4	4.2485	-1.5238

- εx (1 sigma – normalized) ~ **4.7235** mm-mrad
- εy (1 sigma – geometrical) ~ **2.3392** mm-mrad
- BetaGamma = 0.614

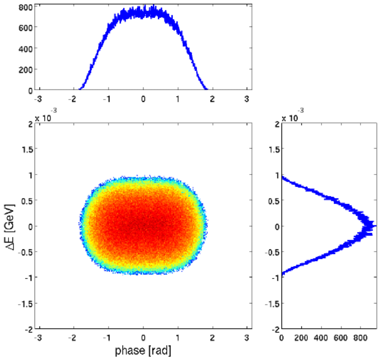


2D gaussian distribution

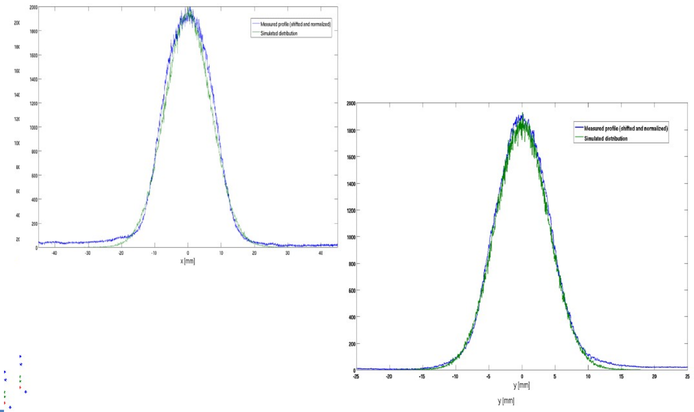
Simulations - Beam characteristics – longitudinal

- 500e3 m.particles
- Long bunch – B.f. ~0.39
- RMS emittance ~ 0.16 eVs
- RMS $\Delta p/p$ ~ 1.33e-3

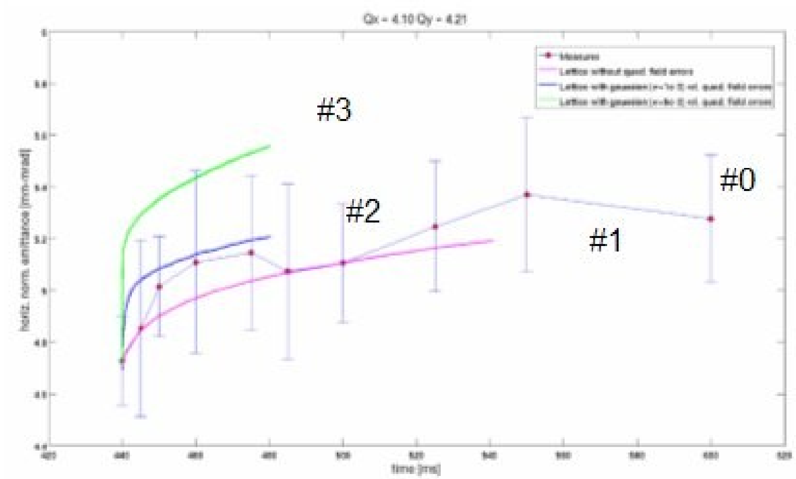
Thanks to Alexander for the longitudinal distribution

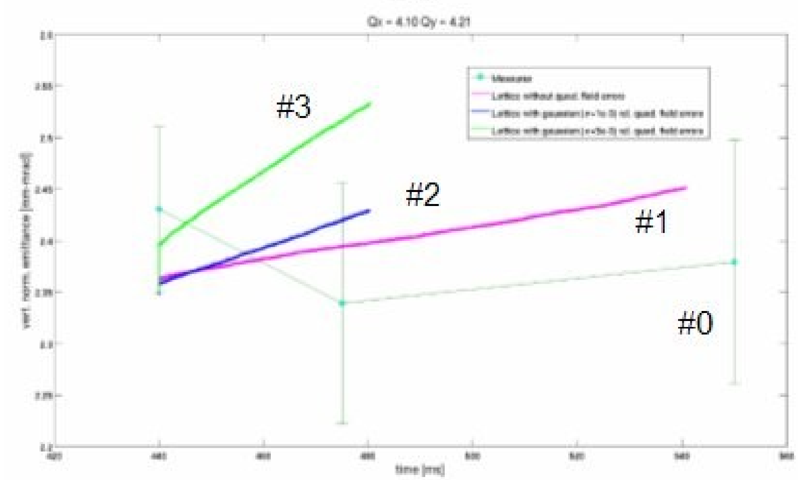


Profiles comparison – measured and simulated



PTC-ORBIT benchmarking results





Effect of [1,0,4] resonance

W_{kin} = ***160MeV***

LHC25 beam
B_f ~ ***0.4***
$Q_x = 4.10 / Q_y = 4.21$

#0 → measurements
#1 → ideal lattice

#2, #3 → lattice with RANDOM errors $\{\delta K1\}_{QM}$
#2 : 1Sigma = 1.0×10^{-3} (relative value)
#3 : 1Sigma = 5.0×10^{-3}
Gaussian generator (no cut)

Courtesy V.Forte

Acceptable agreement between experimental data and simulation results (LHC25 beam)

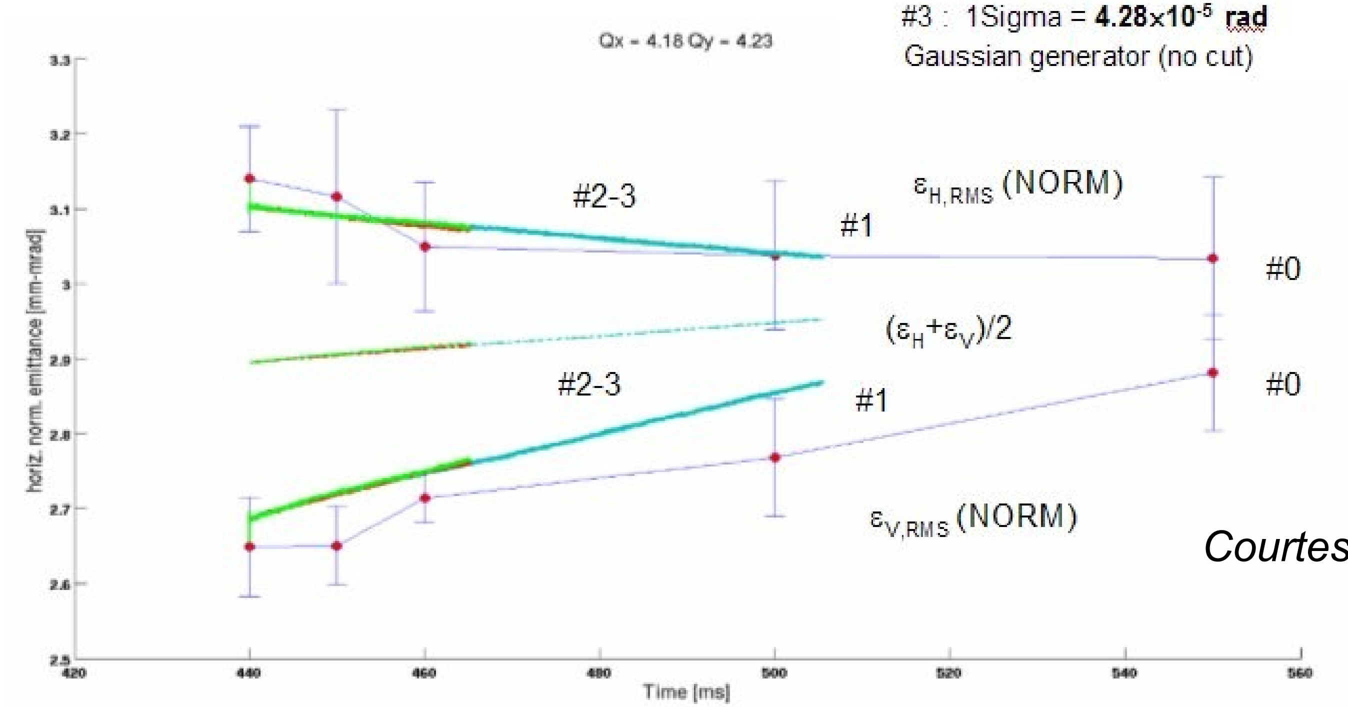
Maximum random error of the PSB quadrupole magnets ~ 1.0×10^{-3} (1σ)

PTC-ORBIT benchmarking results

Effect of the Montague resonance [2,-2,0]

#0 → measurements
#1 → ideal lattice

#2, #3 → lattice with RANDOM TILT of {QM}
#2 : 1Sigma = **2.17×10^{-5} rad**
#3 : 1Sigma = **4.28×10^{-5} rad**
Gaussian generator (no cut)

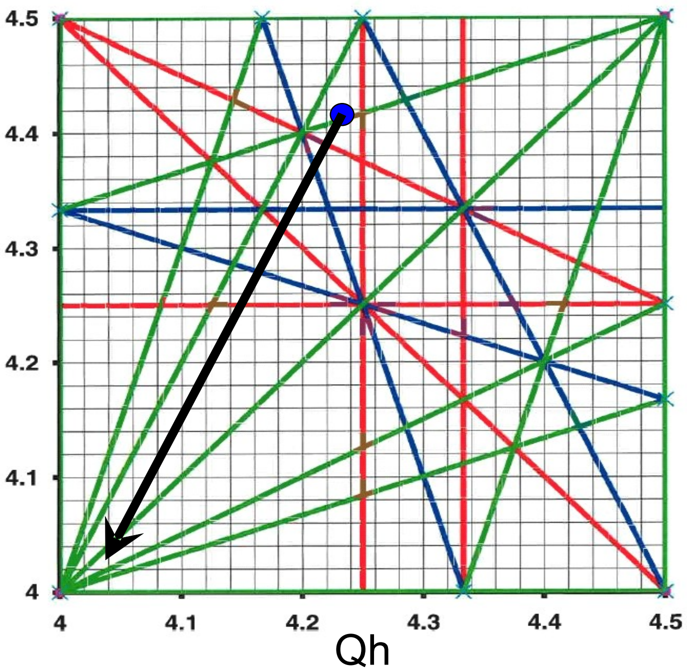


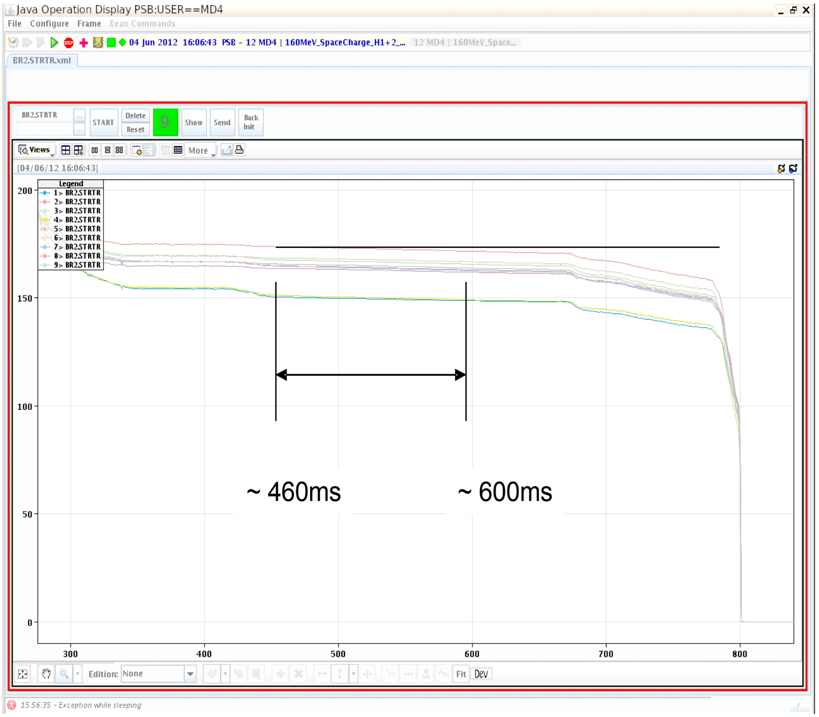
Courtesy V.Forte

PSB MD: resonance observations at 160MeV

MD: extreme space-charge detuning
ΔQy ≈ -0.4 (LHC25 beam)

WITH resonance compensation





Q_x = 4.23

Q_y = 4.42

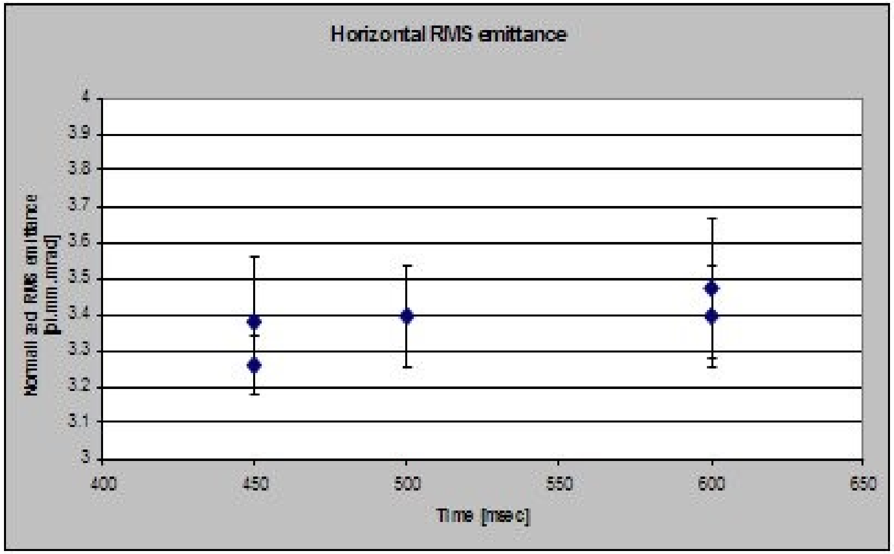
Estimated incoherent space-charge detuning

→ **Observation at 160MeV: losses < 1%**

PSB MD: resonance observations at 160MeV

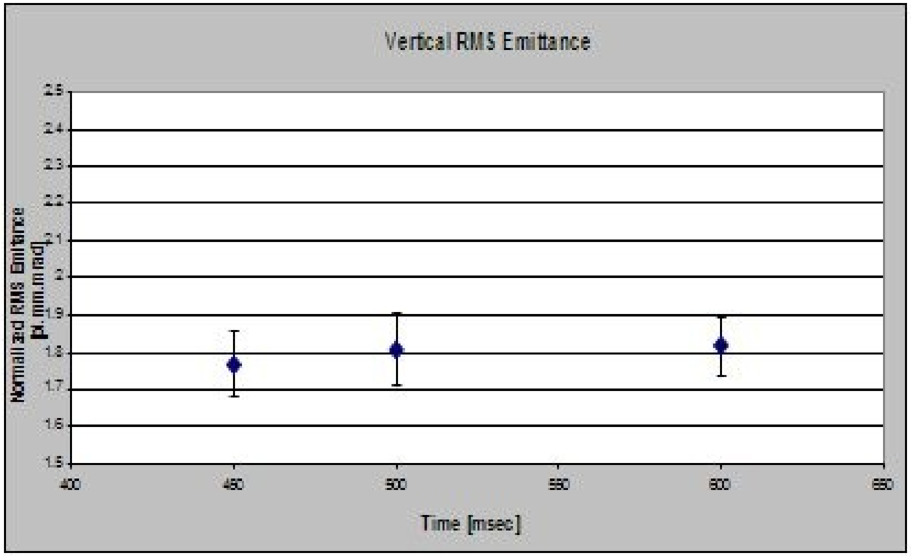
MD: extreme space-charge detuning
ΔQy ≈ -0.4 (LHC25 beam)

$B_f = 0.241, N_b = 149\times10^{10}$



WITH resonance compensations, used for the PSB operation ...

$B_f = 0.241, N_b = 149\times10^{10}$



→ ***observations should be reproduced by the simulations …***

Basic plan for nearest PSB MDs

- Tune scan at 160MeV for different space charge detuning by using the LHC25 type beam …
- Observation of the emittance evolution at the 50MeV energy including existing schemes of the resonance compensation to collect information for further simulations...

Summary

- Effects of INTEGER and Montague resonances at the 160MeV energy has been investigated experimentally to collect data for benchmarking the PTC-ORBIT code.

- Benchmarking the PTC-ORBIT code demonstrates acceptable agreement with the beam observations for the moderate space-charge detuning (V: -0.25).

- The first attempt to use the 'extreme' space charge detuning at the 160MeV energy indicates some promising possibility to reach the space charge detuning of (V: -0.4) with limited emittance blow-up and acceptable particle losses.

LHC Injectors Upgrade

THANK YOU FOR YOUR ATTENTION!