STATUS report

Space charge effects and machine resonances CERN Injectors for LHC (LIU project)

Alexander Molodozhenstev (KEK)

October 29, 2012

CONTENT

→ CURRENT status of the group activity for the period March – October 2012

- Motivation for this activity
- Plans and Current status of the group activity
  - → *Computational tools and hardware …*
  - → *MDs and benchmarking activity …*
  - → *Status of the simulation activity …*
- Next mile-stones in the group activity

CERN Space charge Group (ABP-ICE)

Group manager Frank Schmidt

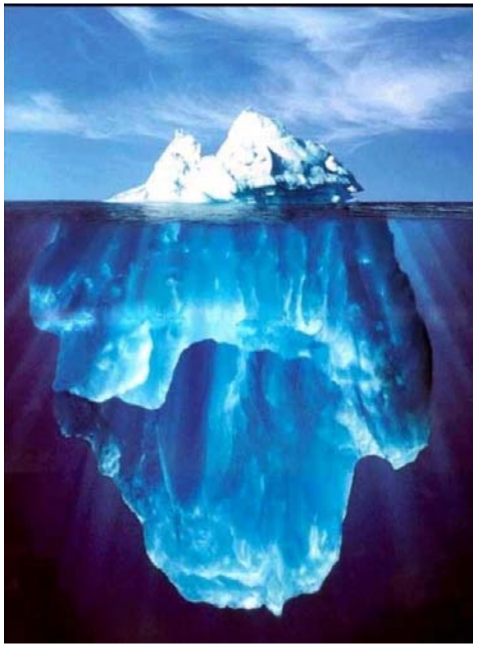
External expert: Alexander Molodozhnetsev (KEK)

PS Booster Vincenzo Forte
Michel Martini
Elena Benedetto
Nicolas Mounet
Christian Carli

PS Raymond Wasef
Cedric Hernalsteens

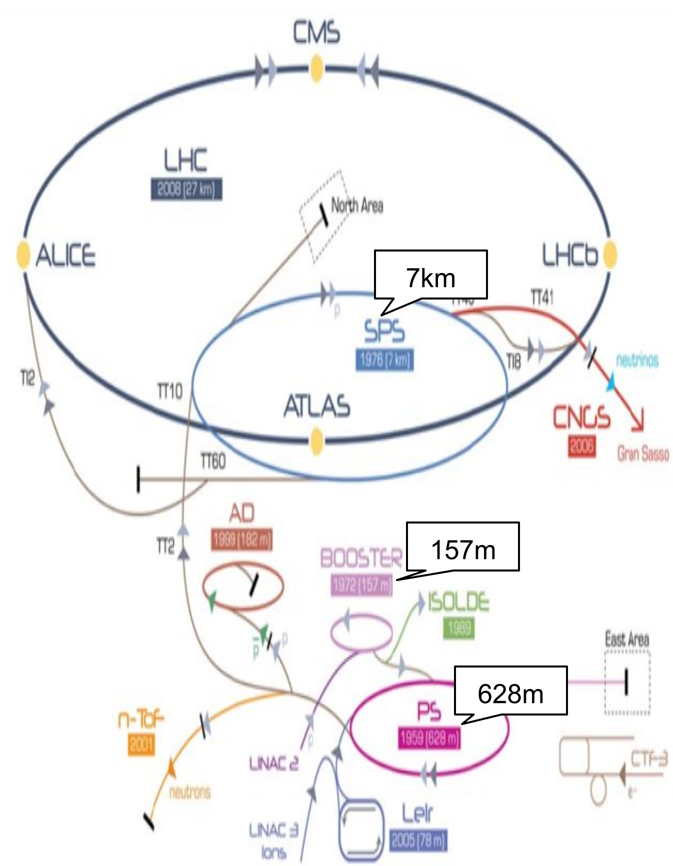
SPS Hannes Bartisik

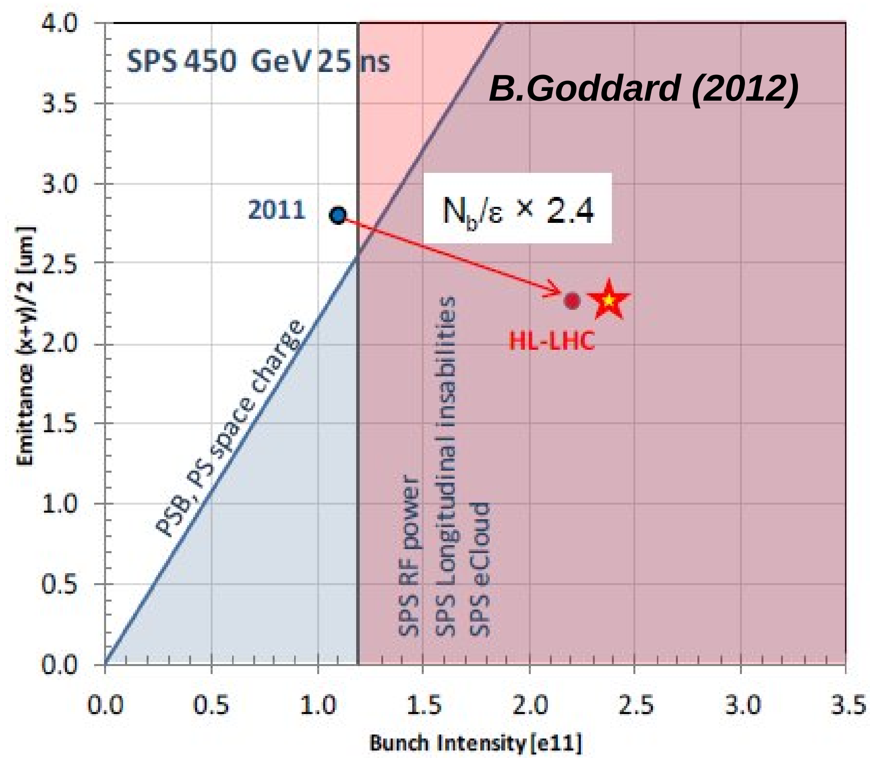
'RCS' design Miriam Fitterer



Thanks everybody for the contributions to this presentation

Motivations … LHC 25 nsec





2011: ~ 1.1e11 with 2.8μm for 25nsec has been extracted from SPS

Post LS2 (2019): → × 2.4 times in brightness for 25nsec

Motivations … key-points

- **LINAC2** (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 $\Delta Q_y \approx -(0.20 \ldots 0.25)$

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

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

Motivation

- Strict limitation of particle losses during injection and acceleration is crucial to avoid radiation damage in a proton machine with high beam power.

- This limitation requires reliable prediction / identification and proper correction the most dangerous lattice resonances, caused by the machine imperfections.

- To avoid significant growth of the emittance of the space charge dominated beam, the self-consistent study of the low-energy beam dynamics should be performed in the synchrotron with realistic representation the sources of the machine resonances.

Motivation

We need a tool to …

- describe the machine, including the high-order field and alignment imperfections
- be able to change the magnet and RF properties dynamically

  → *MT injection & Acceleration*
- analyze the single particle dynamics ('lattice' resonance study including the resonance compensation)
- analyze the multi particle dynamics, including the collective effects … in combination with different resonance compensation schemes
- analyze the beam properties (RMS emittance and the 'halo' formation) and particle losses around the machine

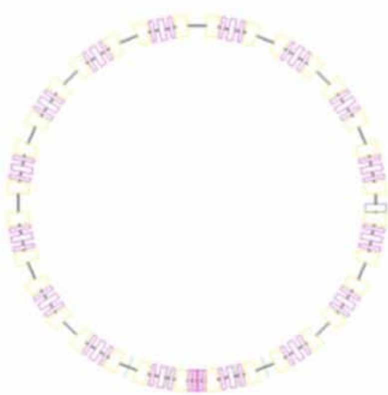
PTC-ORBIT combined code

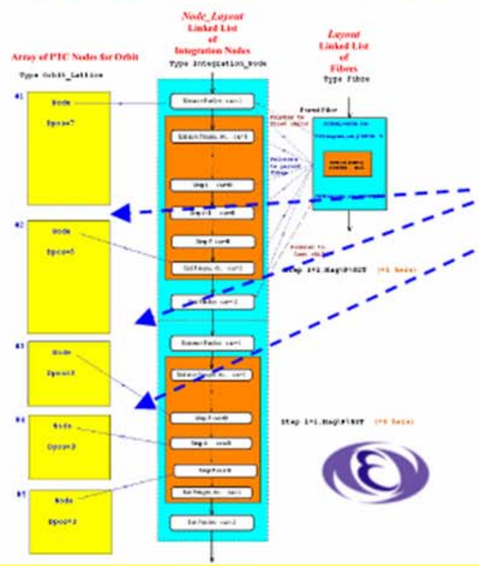
Why PTC-ORBIT ?

Real machine *with field Imperfections and alignment data*

PTC *lattice representation*
*→ **Comprehensive lattice analysis***
*→ **RF cavities (acceleration)***
*→ **NEW !...Time dependent magnets***

ORBIT *node*
PTC *as the tracker (6D integrator)*





'ORBIT' staff:
- *Injection foil.*
- *Space charge model.*
- *Transverse and longitudinal impedance.*
- *Feedback for stabilization.*
- *Aperture and collimation.*
- *Electron cloud model.*

Main feature:
Common environment *for the single particle dynamics (lattice analysis and resonance compensation) and multi particle dynamics (collective effects).*

Polymorphic Tracking Code (PTC)

- **Symplectic Integration and Splitting (E.Forest, KEK)**

  PTC's philosophy for symplectic integration is based on the work of Richard Talman ('drift-kick' model):

  (1) Split the elements in the lattice into integration nodes using one of PTC's integration methods (the 2nd method, the Ruth-Neri-Yoshida 4th order method or the Yoshida 6th order method)

  (2) Fit all the stuff you would normally fit using your matching routines

  (3) Examine the resulting lattice functions and perhaps some 'short-term' dynamic aperture

  → … after oscillating between steps (1) and (3), make up your mind and call that the 'LATTICE'

- ... use MADX-PTC interface to prepare
  the beamline description → **PTC FLAT file**

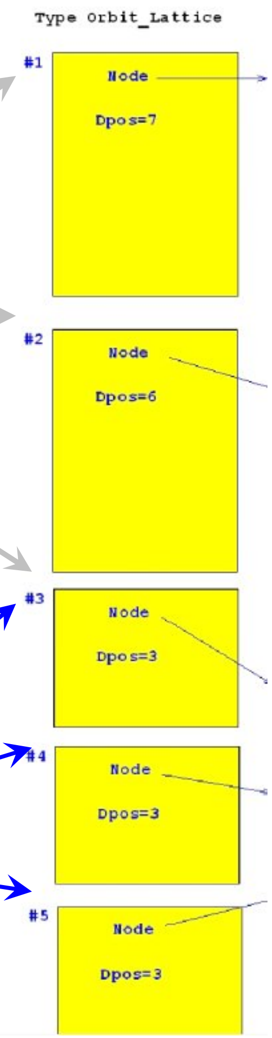
Polymorphic Tracking Code (PTC)

- **'ORBIT' nodes by PTC**

In the **PTC flat file** we can define a quantity 'LMAX' which represents the approximate minimal length between the nodes to introduce the collective effects.

PTC will group the 'integration nodes' of the node layout of PTC into groups whose length does not exceed the 'LMAX' length.

'ORBIT' nodes can be used to introduce the space charge, impedance effects and the diagnostic elements between the 'trackable' PTC blocks …



ORBIT (MPI)

- Developed by SNS to simulate the collective effects (space charge effects, impedance effects, electron clouds effects)
- Object-oriented open-source code (C++)
- Beam diagnostic, FOIL and APERTURE modules
- Parallel implementation
- ORBIT program is a script interpreter of the extended SuperCode program language
- Basic machine (lattice) description by MAD8
- Space charge kick:

  Particle-In-Cell method

  2.5D or 3D model

  Poisson solver → Fixed (with boundary) or Adjustable Grid (without boundary)

Jeff Holmes, jzh@ornl.gov

PTC-ORBIT combined code

- **First discussion with the SNS group → ICFA HB06 workshop**
- **First test of the combined PTC-ORBIT code → 2007**
- **2007 → first version of the code has been compiled for the KEK Super-Computers (Hitachi and IBM)**
- **PTC-ORBIT combined code has been used extensively for beam dynamics study for the J-PARC accelerators at the early stage of the Complex commissioning**
- **… study the different J-PARC Main Ring operation scenario for the case of high-power proton beam (up to 1.5MW at 30GeV)**

- ***This work is supported by the Large Scale Simulation Program (FY2007-2013) of High Energy Accelerator Research Organization (KEK).***

- **2011 → the PTC-ORBIT combine code has been compiled and tested for the CERN lxplus cluster → CERN LIU Project**
- **2012 → … has been compiled and tested for the GSI cluster**

CERN PS Booster

… main steps for 2012

CERN PS Booster study:

- ❑ 'SHORT-dipole' vz 'NORMAL' PSB lattice → emittance growth analysis …
- ❑ Halo formation at the injection energy … losses in realistic Aperture
- ❑ Effect of the double-harmonic RF system
- ❑ Effects of Basic machine imperfections & resonance correction scheme
- ❑ Benchmarking with existing results of the emittance measurements at the injection energy (160MeV)
- ❑ Acceleration process → 'time' scale of the emittance growth …
- ❑ 'Bare' working point optimization during injection and acceleration
- ❑ Multi-turn injection scheme (with FOIL and 'painting' process)
  → dynamic variation of the machine properties during the injection process

LIU: Machine imperfection and Space charge effects

CERN PS Booster *… continue activity '2011'*

… main steps for 2012

Christian plan (07-01-2012) for PS Booster team

- Effects of the short bending magnets in the injection section of PS Booster
- Multi-turn injection process taken into account FOIL and APERTURE (using the same machine parameters as for the ORBIT study … Matthias Scholz PhD thesis … C.Braco simulations)
- Benchmarking the simulations and measurements by using low-order resonances
- Introduction nonlinearities in to the PS Booster description (comments: (1) no data, which could be used to describe the field nonlinearities of the PS Booster; (2) observations of the resonance compensation could be used to provide the required data; (3) the resonance measurements using turn-by-turn data will be possible soon …)

CERN PS

… main steps for 2012

CERN PS study:

- ❑ Emittance growth and Losses
  - → Injection process (with the 'dynamic' chicane variation)
  - → Optimization of the 'bare' working point during the injection and acceleration
- ❑ Effects of machine imperfections and resonance correction
- ❑ Benchmarking with the emittance growth measurements
- ❑ Time scale of the emittance growth due to the combined effects of the machine resonances and the space charge during the injection / acceleration
- ❑ Effects of the longitudinal splitting at the injection energy

LIU: Machine imperfection and Space charge effects

CERN SPS

… main steps for 2012

CERN SPS study:

- ❑ … convergence study should be performed for the 'LHC'-type beam
- ❑ … similar to the PS items #1b → #4…

LIU: Machine imperfection and Space charge effects

Current status of the group activity

Computational tools and hardware

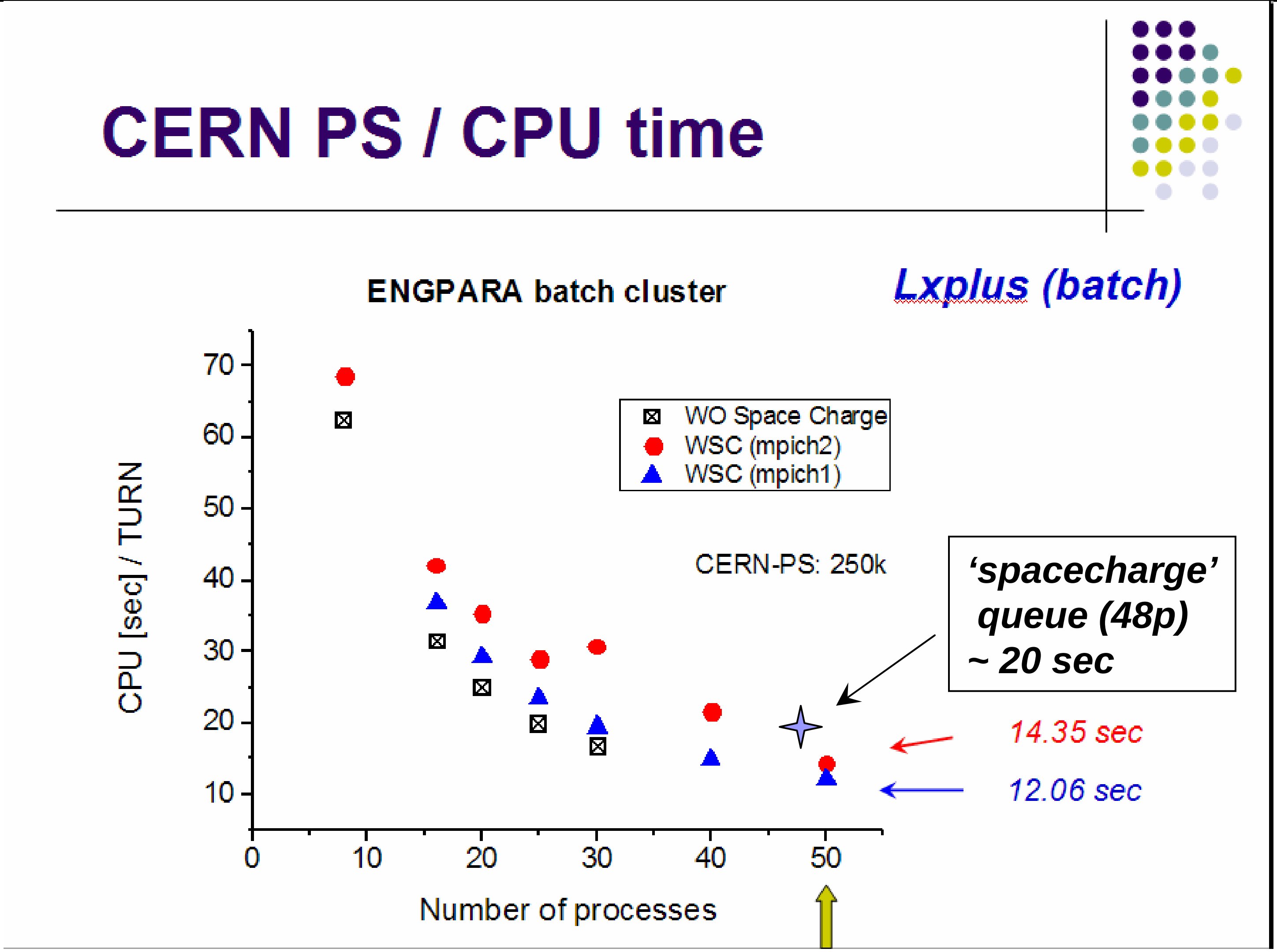
- **PTC-ORBIT(MPI) code has been installed and compiled** for the CERN lxplus cluster
- PTC update **is synchronized** with the MADX update
- **Dedicated 10 multi-core computers** are available for the group from June 2012 (‘space charge’ queue)
- **Basic PTC-ORBIT scripts** have been prepared and uploaded into the Space-charge Group home-page
- **Batch script** has been prepared and tested for the ‘spacecharge’ queue
- **Further code development** (with support from E.Forest) …

→ basic version (v0318) → for the convergence studies

→ v0413 → ‘FOIL’ issue has been solved

→ v1112 → current version of the code (with new implementations)

Dedicated 'spacecharge' queue …



Machine's name

lxbsu2107
lxbsu2207
lxbsu2306
lxbsu2307
lxbsu2406
lxbsu2407
lxbsu2606
lxbsu2607
lxbsu2706
lxbsu2707

Current status of the group activity

Computational tools and hardware

```
echo "*     04-13-2012                                              *"
echo "*     --> PTC TWISS modification ...                          *"
echo "*     --> 'MARKER' at the beginning of the machine layout     *"
echo "*         to introduce the zero-length element for the        *"
echo "*         tracking --> to put FOIL at the beginning           *"
echo "*                                                             *"
echo "*     DEVELOMPENT VERSION:                                    *"
echo "*    ======================                                   *"
echo "*                                                             *"
echo "*     07-03-2012 ... 07-09-2012                               *"
echo "*     --> PTC modification to be able to use                  *"
echo "*         script to generate field-errors in magnets          *"
echo "*     --> NO Teng-Edwards in the PTC-TWISS table              *"
echo "*                                                             *"
echo "*     08-09-2012                                              *"
echo "*     --> PTC bug with FLAT file                              *"
echo "*     --> has been observed with Alexey's lattice             *"
echo "*                                                             *"
echo "*     09-04-2012                                              *"
echo "*     --> Krein collision check is suppresed to avoid         *"
echo "*         observed (v080912) interruption the tracking        *"
echo "*                                                             *"
echo "*     09-07-2012                                              *"
echo "*     --> modification: time unit for the PTC is [sec]        *"
echo "*         internally                                          *"
echo "*         but in Tables one can use any time-units            *"
echo "*         as before                                           *"
echo "*     --> FINIAL_SETTINGS.TXT is changed                      *"
echo "*         NO time-unit                                        *"
echo "*     --> checked for the machine with a few cavities         *"
echo "*         it should work                                      *"
echo "*                                                             *"
echo "*     09-24-2012                                              *"
echo "*     --> some bug in the Normal Form part of PTC             *"
echo "*         used for the 'twiss_ptc' procedure                  *"
echo "*         by PTC-ORBIT is not effected                        *"
echo "*                                                             *"
```

```
echo "*                                                             *"
echo "*     09-26-2012                                              *"
echo "*     --> new ptcinterface.f90 for proton only                *"
echo "*         corrected sq_orbit_ptc.f90                          *"
echo "*                                                             *"
echo "*     10-11-2012                                              *"
echo "*     --> to put some 'ORBIT' elemet (APERTURE, BPMs ...)     *"
echo "*         just before the lattice elements,                   *"
echo "*         defined in pre_orbit_set.txt                        *"
echo "*                                                             *"
echo "* ----------------------------------------------------------- *"
echo "*                                                             *"
echo "* Alexander Molodozhentsev (KEK): molodxx@gmail.com           *"
echo "*                                                             *"
echo "*  compiled:  October 11, 2012                                *"
echo "*                                                             *"
echo "***************************************************************"
```

→… **will be explained in the PTC-ORBIT node (updated version)**

→… **current version of the node:**
PTC-ORBIT-v3.pdf / 04-25-2012

→… **available through Internet:**
/afs/cern.ch/user/a/amolodoz/public/PTC-ORBIT-NODES/

Current status of the group activity

MDs and benchmarking activity …

Motivations (PS Booster, PS and SPS):

Started from May, 2012

- Machine study and collecting measured data for the benchmarking activity:
  - → Effects of the low-order machine resonances
  - → Resonance compensation schemes
  - → Emittance evolution for the combined effects of the machine resonances and the low-energy space charge effects
  - → Losses observations
  - → Better understanding the current machine operation

Current status of the group activity

MDs and benchmarking activity …

PS Booster → 9 parallel MD sessions (160MeV+SpaceCharge)
LHC25 type beam → 180×10[10] ppb

(1) Effects of the Integer resonance $Q_x = 4$ (static tune scan)

(2) Effects of the Montague resonance $2Q_x$-$2Q_y$=0 (static tune scan)

(3) Effects of the LINEAR coupling resonance Q_x-Q_y=0 — Used for BenchM

(4) RF manipulations to provide different bunching factor — Used for BenchM

(5) Static tune scan with $\Delta Q_{INC} \approx -0.37$ — ---

(6) Dynamic tune scan with $\Delta Q_{INC} \approx -0.37$

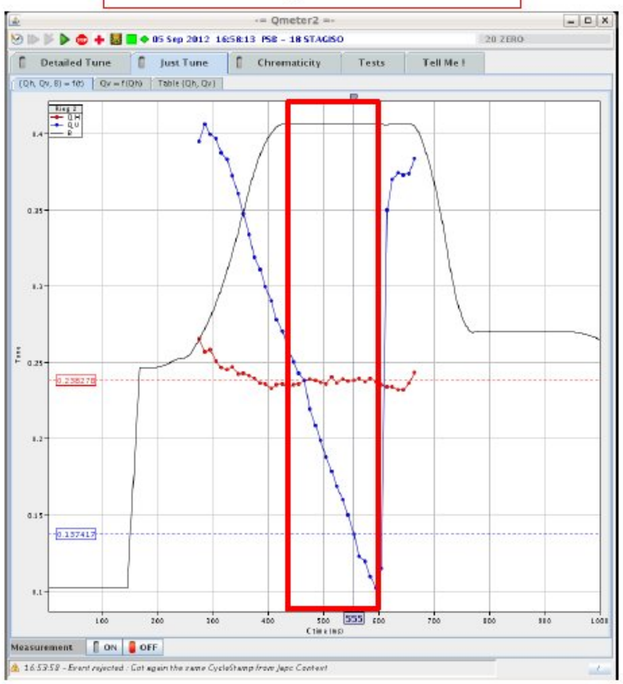
(7) Observation the resonance compensation

Benchmarking status: *Performed* *In progress* *In preparation*

Current status of the group activity

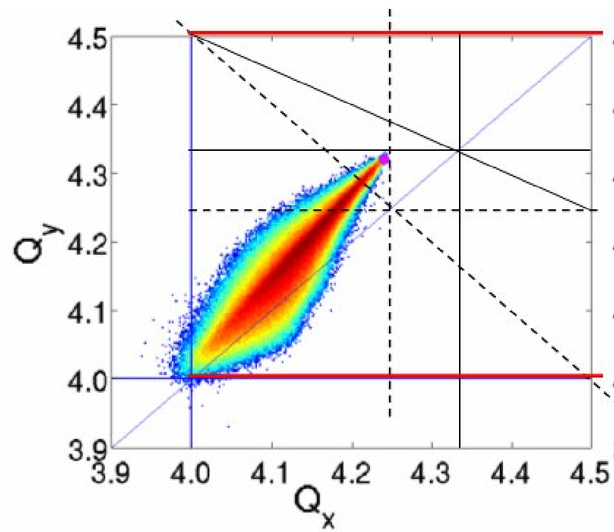
MDs and benchmarking activity → [0,1,4] resonance

Qx=4.23 Qy=4.26 -> 4.10



Time variation of the vertical tune

Dynamic tune-scan



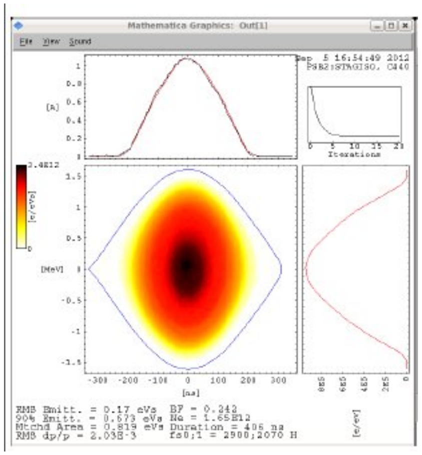
Double harmonic RF: 8+8(in-phase)

B_f ~0.23 → $\Delta Q^V_{INC} \approx -0.37$

Dynamic tune scan with $\Delta Q_{INC} \approx -0.37$

Current status of the group activity

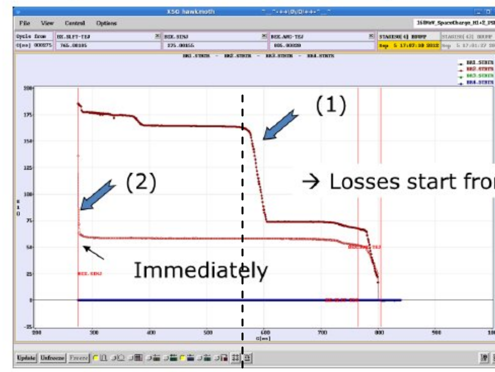
MDs and benchmarking activity → [0,1,4] resonance



Double harmonic RF:
8+8(in-phase)

$B_f \sim 0.24 \rightarrow \Delta Q_{INC} \approx -0.37$

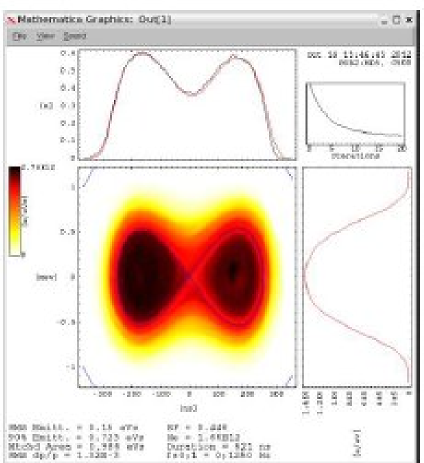
Bf = 0.24



→ Losses start from **$Q_x = 4.137$**

(1) 'down' scan

(2) 'up' scan



Double harmonic RF:
8+8(anti-phase)

$B_f \sim 0.4 \rightarrow \Delta Q_{INC} \approx -0.20$

Bf = 0.4 ('down' scanning)

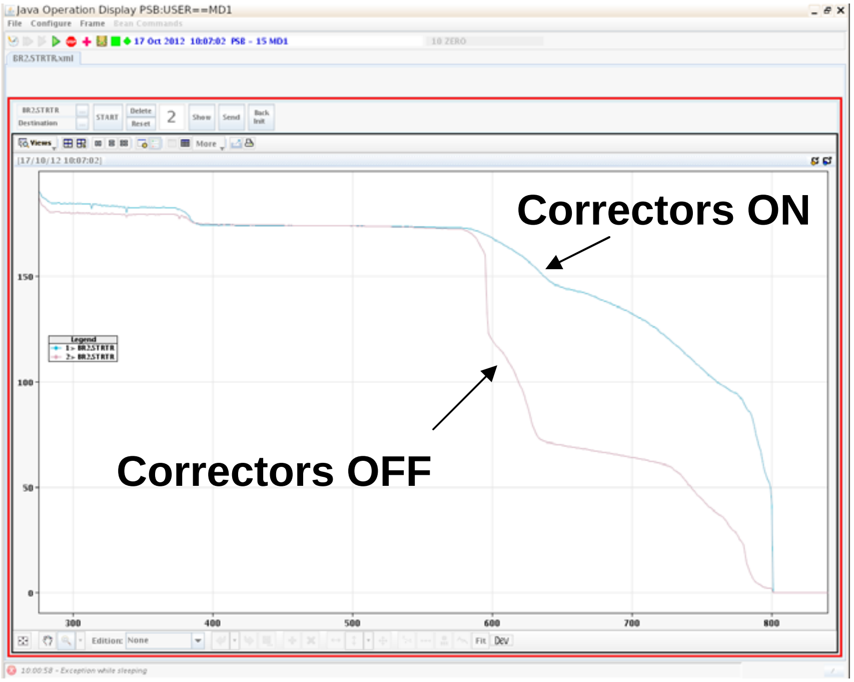
Losses start from **$Q_x \sim 4.10$**

… Q_x moved away from 4.10

Dynamic tune scan with $\Delta Q_{INC} \approx -0.35$

Current status of the group activity

MDs and benchmarking activity → [0,2,9] resonance



→ … *in preparation to make the simulations with APERTURE*

Current status of the group activity

▪ 'Space-charge' convergence study

ORBIT(MPI) is the PIC code
→ in particular, FFT Particle-In-Cell without (adapted grid) or with (fixed grid) the boundary

→ Optimum set of the required parameters for the 'space-charge' model
- *… avoid artificial emittance growth ('core' and 'halo' parts of the beam)*
- *… reasonable CPU time per the '1 turn' tracking*
- *… N_{mesh} (X&Y), N_{mp}, L_{bin}, N_{spch} should be optimized for beams with different parameters (LHC type or CNGS type)*

Machine lattice:

PSB → basic IDEAL lattice without any errors (static lattice)
PS → basic IDEAL lattice → NO any correctors
SPS → basic IDEAL lattice
RCS → basic IDEAL lattice

PTC-ORBIT(MPI)

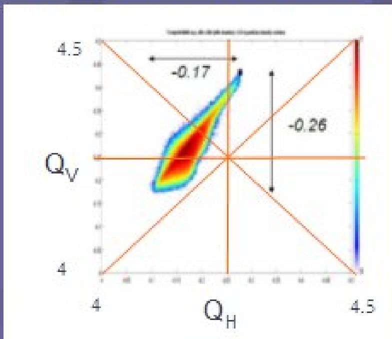
	Method	Lmax / N_{sp}	N_{mesh} (x=y)	N_{macro} × 10^3	L_{bin}
PSB	*Fixed grid*	*1m / 199*	*256*	*1000*	*128*
	Adapted grid	*1m / 199*	*64*	*500*	*128*
PS	*Fixed grid **	*10m / 70*	*1024*	*250*	*128*
SPS	*Adapted grid*	*3.32m / 2688*	*64*	*200*	*128*
RCS	*Adapted grid*	*1m / 157*	*128*	*500*	*128*

** H: ± 73mm / V: ± 35mm*

LHC type beam

	Beam intensity ×10^{12} ppb	Bunching factor	Tunes	Normalized emittances 1σ / π μm	Estimated $\Delta Q^{INC}_{sc,V}$
PSB 160MeV *LHC25*	*2.475 (1.5 nominal) (MTInj-20bl)*	*0.6 (τ_p = 185ns) RF: 2nd harmonic*	*4.26 / 4.43*	*3 / 2* official Excel datasheet	*~ -0.26*
PS 1.4GeV *LHC50*	*0.81* *1.15*	*0.174 (T_p = 90ns)* *0.35 (T_p= 180ns)*	*6.21 / 6.23*	*1.45 / 1.32* *2.0 / 1.7*	*~ -0.26* *~ -0.23*
SPS 26GeV *LHC25*	*0.27*	*0.5 (τ_p = 3 ns)*	*20.15 / 20.23*	*2.1 / 2.1*	*~ -0.16*
RCS 160MeV	*1.2×10^{12} (1/2 nominal)*	*0.3*	*4.29 / 3.38*	*2.5 / 2.5*	*~ -0.15*

Space charge detuning
for CERN PS-Booster (160MeV)



2D histogram
Q_H/Q_V=4.26/4.43

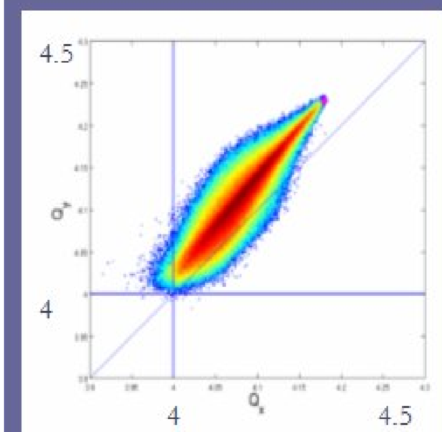
PTC-ORBIT(MPI)

A.Molodozhentsev (KEK), ICFA HB12 workshop
Beijing, China, September 17-21, 2012

Current status of the group activity

*'Simulation' activity (**PS Booster**): **benchmarking***

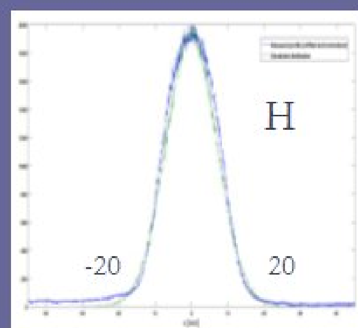
Motivation:
- **reproduce** the measured beam evolution at 160MeV by the PTC-ORBIT tracking

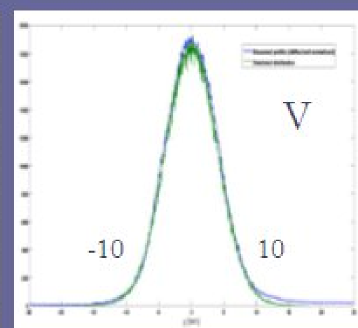


Foot print

Q_H/Q_V=4.18/4.23

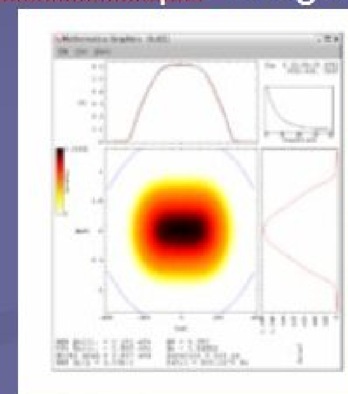
LHC25 beam
B_f ~ 0.4



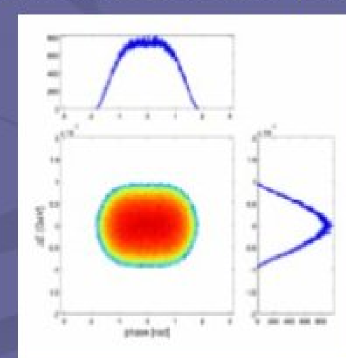


Generated and measured transverse beam profile at the 160MeV energy

Measured beam profile
'Tomoscope' image



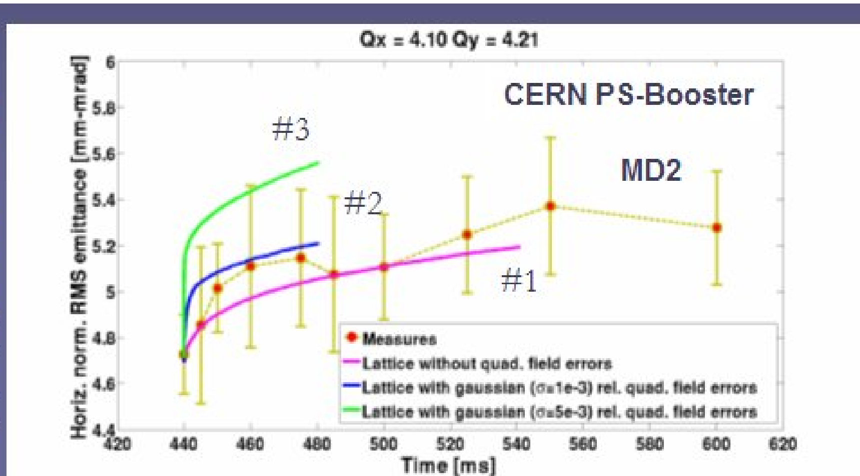
Generated beam profile



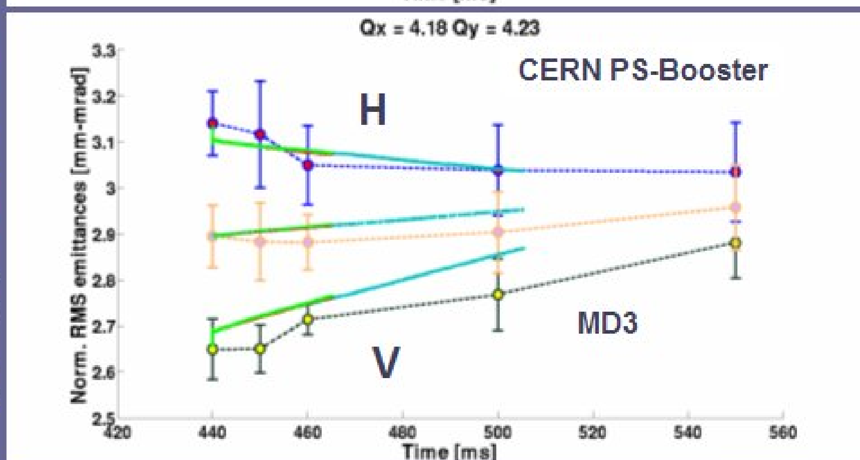
Current status of the group activity

*'Simulation' activity (**PS Booster**): **benchmarking***

[1,0,4] resonance



[2,-2,0] resonance



→… taken into account the random error of the quadrupole strength of the PS Booster magnets

→ lattice with RANDOM errors {δK1}QM

#1: 'ideal' lattice

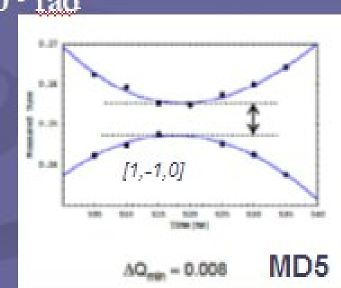
#2 : 1Sigma = 1.0×10^{-3} (relative value)

#3 : 1Sigma = 5.0×10^{-3}

→… including the random TILT of the PS Booster quadrupole magnets

Up to 1Sigma = **4.28×10^{-5}** rad

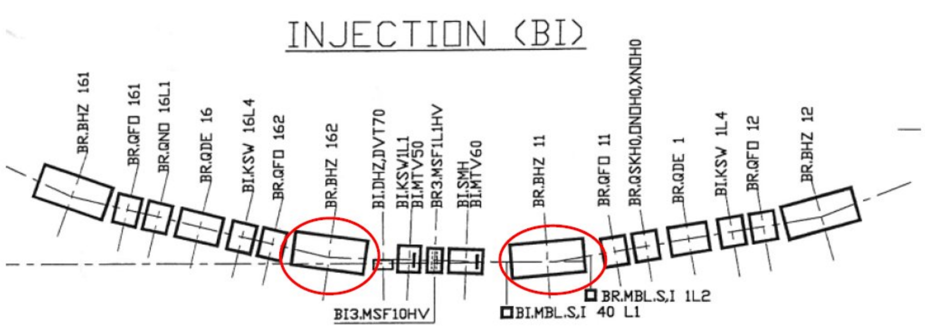
Linear coupling of the PS Booster: $\Delta Q_{MIN} \approx 0.008$



Current status of the group activity

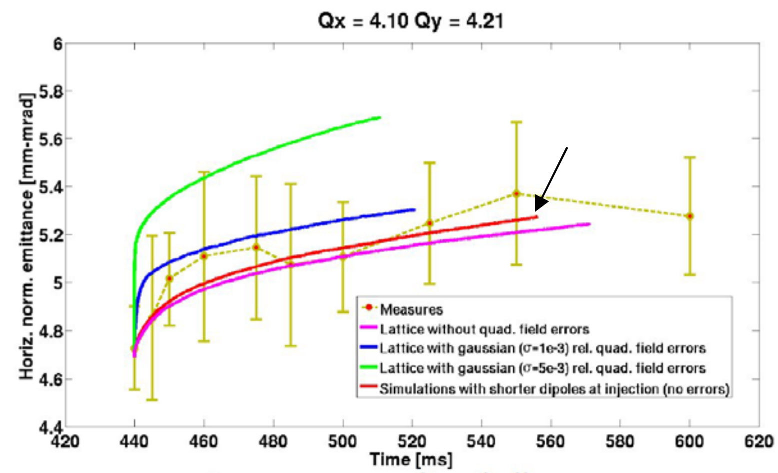
*‘Simulation’ activity (**PS Booster**): **short-bends***

The shorter bending magnets at injection ...

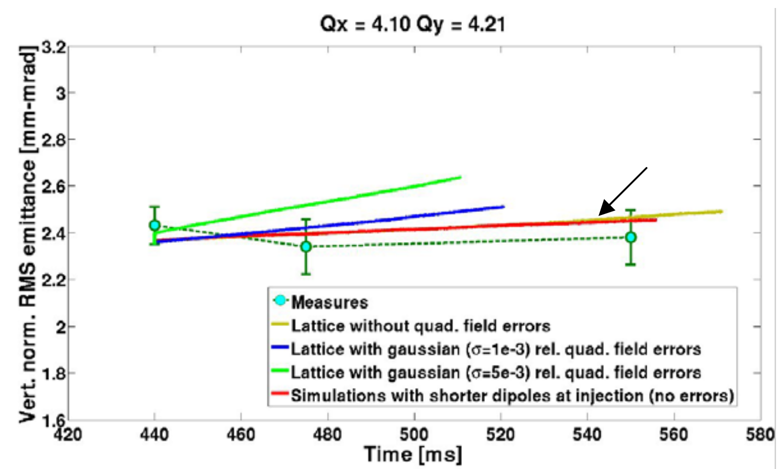


Courtesy V.Forte

→Simulations should be continued to check effects of the [0,2,9] resonance



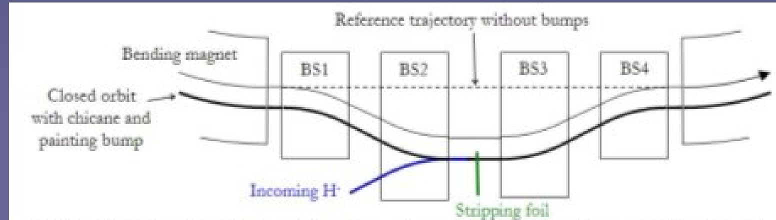
Integer resonance (Qx=4) effect



Current status of the group activity

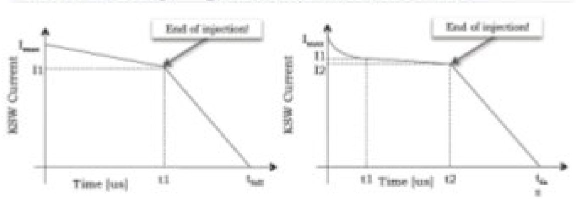
▪ Multi-turn injection for the CERN PS Booster with LINAC4

- ❑ Significant improvement of the efficiency of the MT injection by using the H^- stripping injection in the H-plane
- ❑ Control over both transverse emittances
- ❑ Effects of the edge-focusing of the 'slow' bump-magnets, changing during the chicane reduction



Injection straight at the beginning of the injection (trajectory of incoming H^- coincides with closed orbit)

KSW Decay – possible waveforms



Linear KSW Decay:

✓ Slow linear KSW decay until end of injection.

✓ Fast decay to 0 in order to move the beam away from the stripping foil (15 us)

Exponential-Linear KSW Decay:

✓ Fast exponential decay over first few turns

✓ Slow linear KSW decay until end of injection.

✓ Fast decay to 0 in order to move the beam away from the stripping foil (15 us)

KSW Parameters

	LHC Beam	CNGS Beam
I1	94% I_{max}	71% I_{max}
I2	92% I_{max}	70% I_{max}
t1	7 us	10 us
t2	20 us	49 us
t_{fall}	35 us	64 us

I_{max}: current corresponding to a bump height at the foil of -35 mm

Kicks for a 55 mm bump at the foil:
KSWP16L1: 8.74 mrad ➔ 0.045 T
KSWP1L4: 2.55 mrad ➔ 0.013 T
KSWP2L1: 2.55 mrad ➔ 0.013 T
KSWP16L4: 8.74 mrad ➔ 0.045 T

Functions have to be defined for varying the dI/dt of the KSW during injection.
Different functions for different users ➔ high flexibility is required

Current status of the group activity

Multi-turn injection process for the 'LHC25' type of beam

- **'20 turns' injection**
- **generated distributions for each beamlet**
- **'Matched'** injection process
- **Ideal lattice** of CERN PS Booster (Q_H=4.28, Q_V=4.55)
- **'Time variation' of the injection chicane** by KSW and BSW (realisitic lattice description)
- **RF system:** double harmonic with acceleration at the injection
- **ACTIVE vertical beta-beating compensation** during the chicane reduction
- **FOIL and APERTURE** are taken into consideration (first attempt)
- **Long-term tracking**

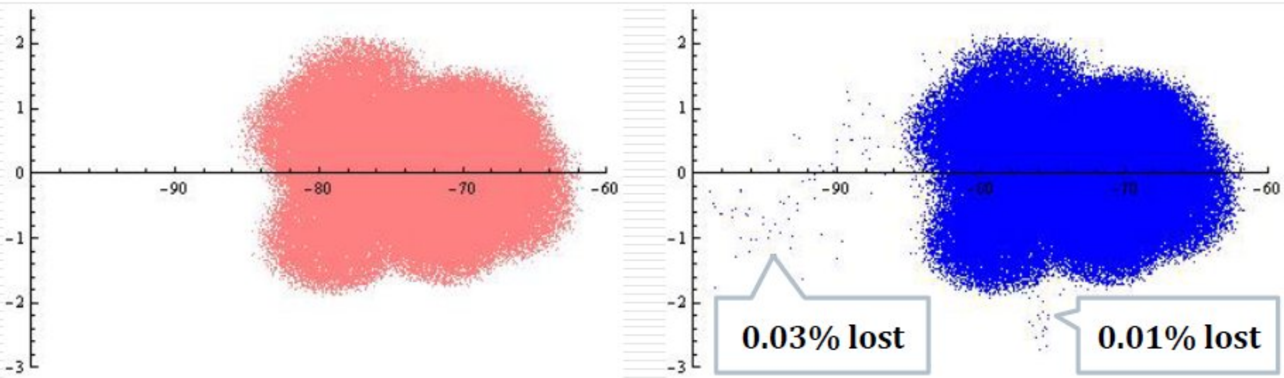
Current status of the group activity

CERN PS Booster: Multi-turn injection from LINAC4

LHC type beam: beamlet injection

Courtesy M.Martini

Horizontal phase-plane (x[mm],x'[mrad])



without foil	with foil
ε_H (rms, norm) ~ 1.319π mm.mrad	ε_H (rms, norm) ~ 1.328π mm.mrad
ε_V (rms, norm) ~ 1.333π mm.mrad	ε_V (rms, norm) ~ 1.336π mm.mrad

Estimations …

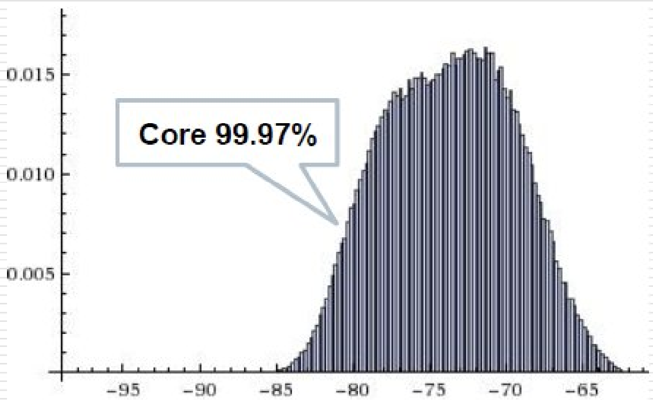
Effect of the stripping foil (no aperture limit implemented)

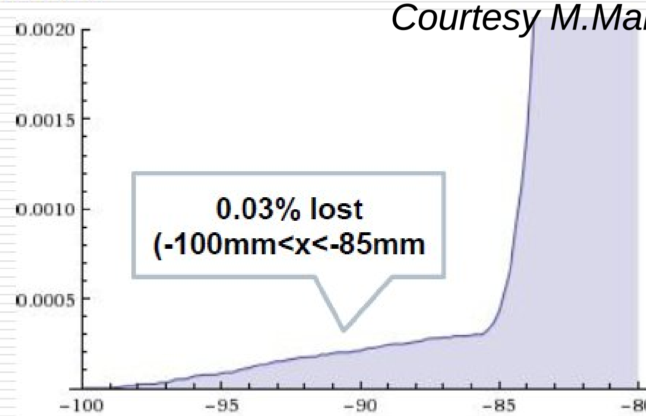
Current status of the group activity

LHC type beam: beamlet injection

Foil and no aperture

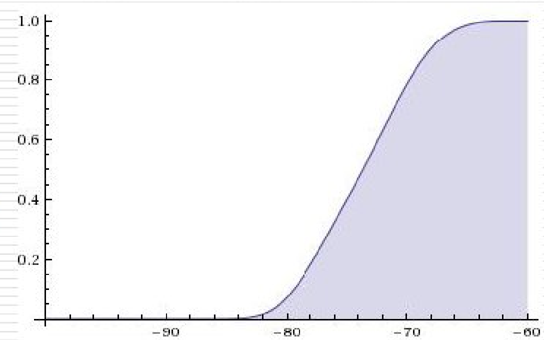
Courtesy M.Martini





Histogramme function(x-axis, mm)
Probability distribution function

Cumulative distribution function (x-axis, mm)



Effect of the stripping foil (no aperture limit implemented)

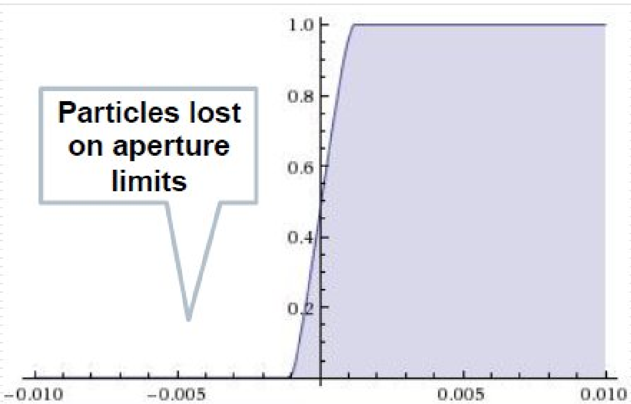
Current status of the group activity

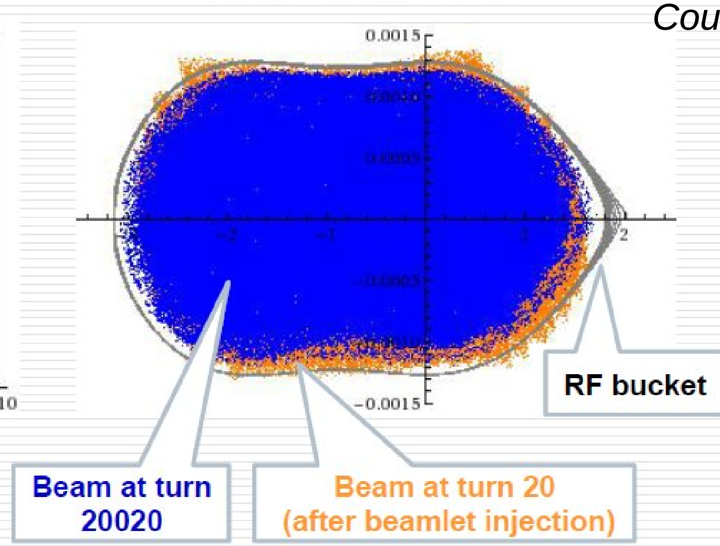
LHC type beam: tracking up to ~ 20msec

Cumulative distribution function (ΔE-axis, GeV)

Longitudinal phase-plane (φ[rad],ΔE[GeV])

Courtesy M.Martini





Beam-scope window

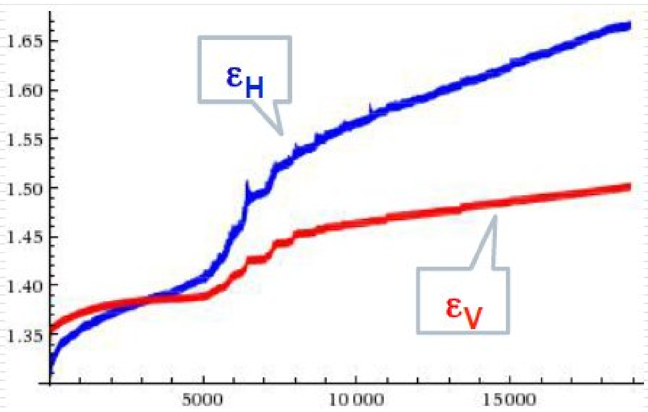
Capture efficiency ~ 98%, B_f ~ 0.6

Aperture limit implemented for tracking after beamlet's injection

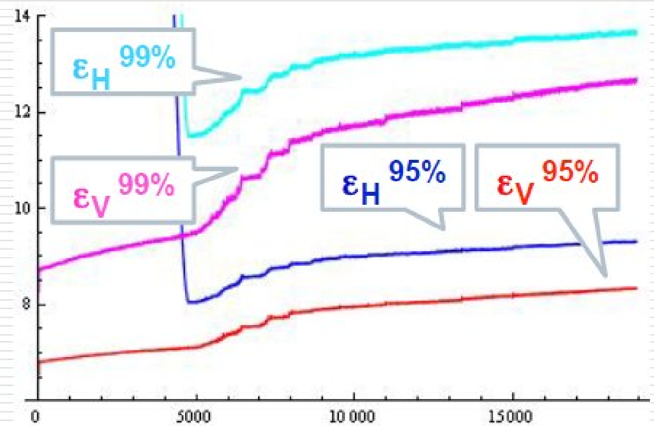
Current status of the group activity

LHC type beam: tracking

Courtesy M.Martini



Normalized transverse rms emittances [mm.mrad] vs time [μs]



Normalized transverse 95% and 99% emittances [mm.mrad] vs time [μs]

Aperture limit implemented for tracking after beamlet's injection

Current status of the group activity

CERN PS

PTC-ORBIT

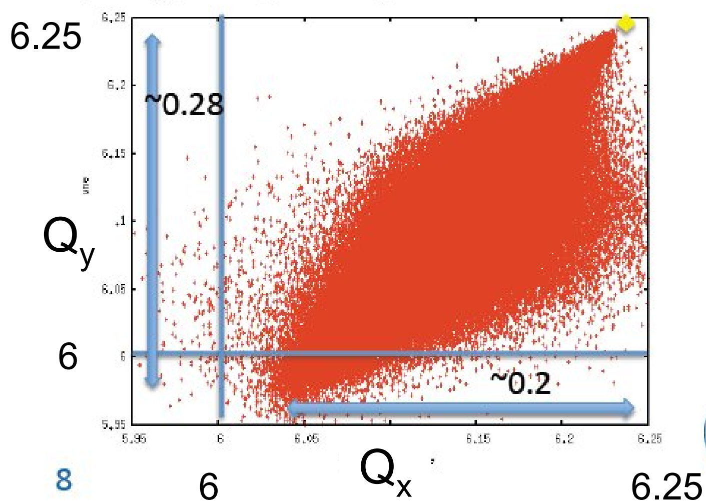
- A convergence study has been done and the simulation parameters have been set for LHC-50 beam and ideal latice.

- Operational LHC-50 (August 2012):
  105E10 p/b ; $\varepsilon_{normalized}$=1.5µm; Δp/p(1σ)= 1.25E-3 ; full bunch length=180ns
  working point (6.235 ; 6.245)

Laslett tune-spread: $\Delta Q_{x,y} = \frac{r_p N_b}{(2\pi)^{3/2}\gamma^3\beta^2\sigma_z}\oint\frac{\beta_{x,y}(s)ds}{\sigma_{x,y}(s)[\sigma_x(s)+\sigma_y(s)]}$ =(0.19 ; 0.28)

➢ From PTC-ORBIT:

➔Very good agreement



Raymond WASEF, LIU Beam Studies Review, 28/08/12, CERN

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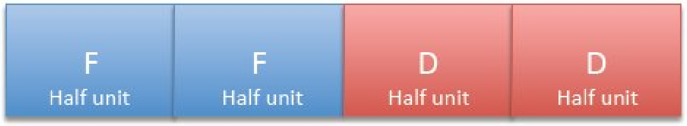
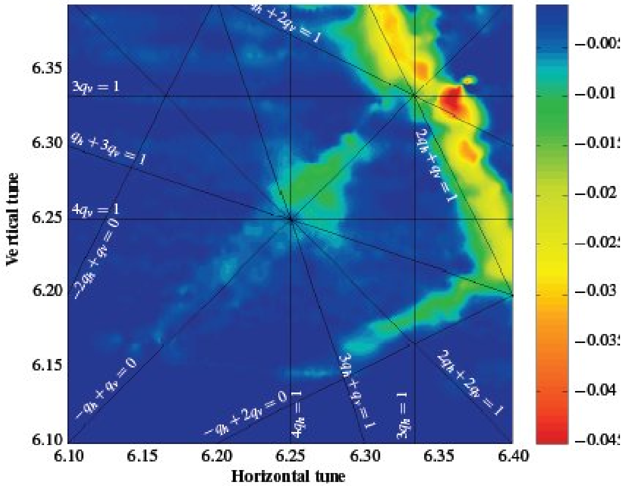
Current status of the group activity

B. I. Including errors in MAD lattice

- Magnetic & alignment errors are essential for Space Charge studies because at low energy (bare machine) they are the main cause of resonance excitation, and cause therefore losses and emittance growth
- PS is implemented in MAD with ideal lattice
- In MAD the main magnets are divided in 4 half units 2D & 2F → 400 elements





- Main magnetic errors have been implemented in MAD. For each half unit one set of multipolar field errors is created, i.e., 400 numbers per multipolar field error have to be generated → … up to octupole component (normal and skew)

- ❑ Skew sextupole coupling resonance
- ❑ Linear coupling resonance
- ❑ Montague resonance
- ❑ $3Q_x$ resonance

Observation by analysing Turn-by-Turn data → **in progress**

CERN PS

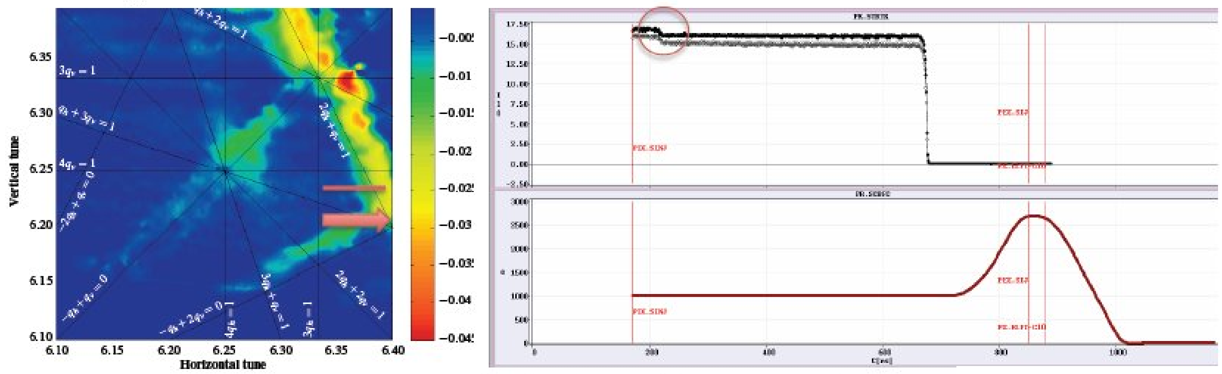
Current status of the group activity

CERN PS

B. II. Verification and calibration

➢ Benchmark between lattice with errors and experimental data:

- Loss due to skew sextupole resonance over 25ms (MD 06/08/2012), Ramp Q_y = 6.24; Q_x = [6.34 : 6.38]



- PTC-ORBIT simulation using the lattice with magnetic errors

Losses in the machine (MADX aperture definition) during the tune-scan process

- Alignment errors have been introduced which gave a realistic closed orbit (Xco=4mm , Yco=1mm) and a simulation of the resonance scan is currently running.

Current status of the group activity

Resonance observation

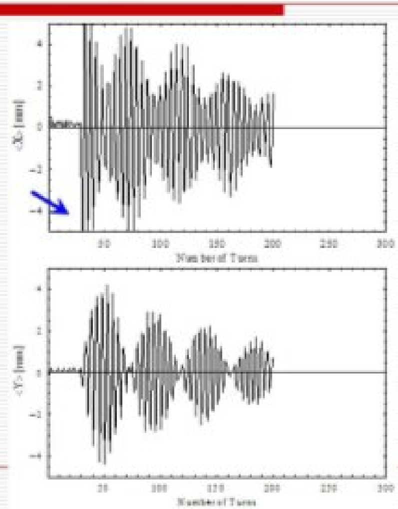
CERN PS

'LHC-INDIV' beam

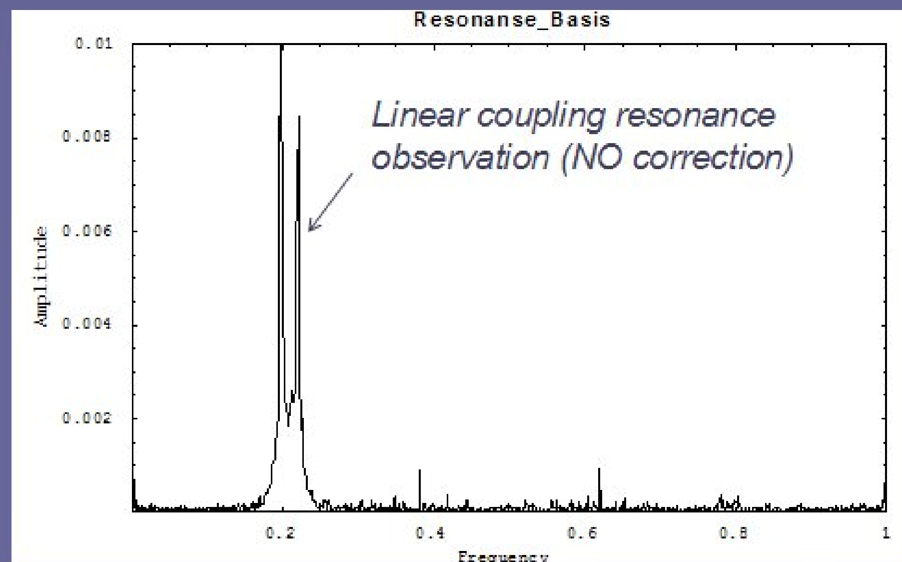
Beam centroid evolution
→ LINEAR coupling → [1,-1,0]

H-kick only

$Q_x = 6.20$
$Q_y = 6.21$



[1,-1,0] resonance observation



Observation of the [1,-1,0] resonance
→ turn-by-turn data acquisition …

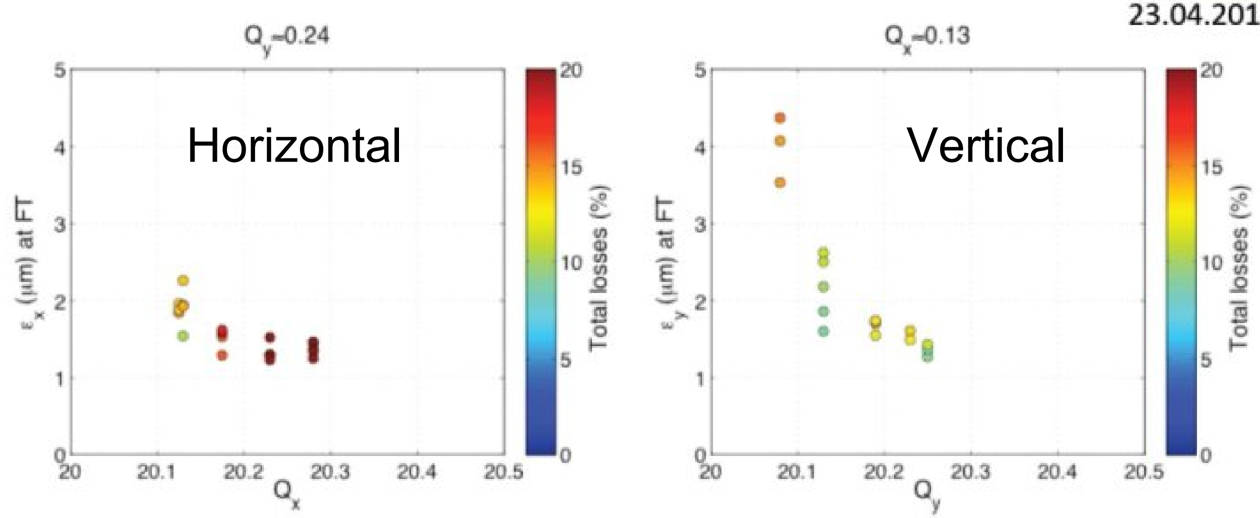
Turn-by-Turn data analysis

Current status of the group activity

SPS MDs for the code's benchmarking

Estimation of space charge tune spread

23.04.2012



'Q20' optics

- **Approaching the integer resonances leads to**
  - Emittance blow up in the respective plane
  - A reduction of losses in the horizontal plane (
  - Increasing losses in vertical plane aperture restriction

Courtesy H.Bartosik

High-intensity beam

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- **For 2.7e11p/b and about $(\varepsilon_x+\varepsilon_y)/2$~1.0-1.2μm injected**

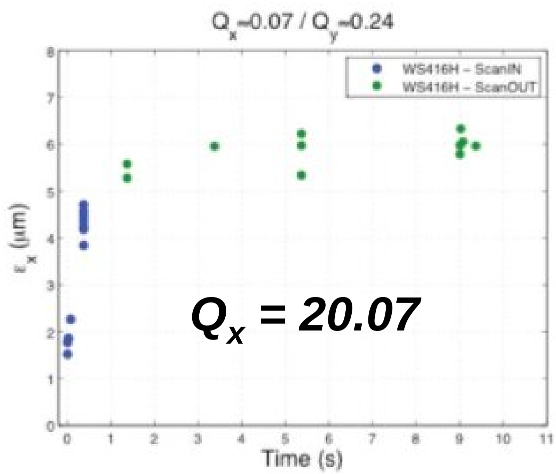
ΔQ_x≈0.15 / ΔQ_y≈0.25

Current status of the group activity

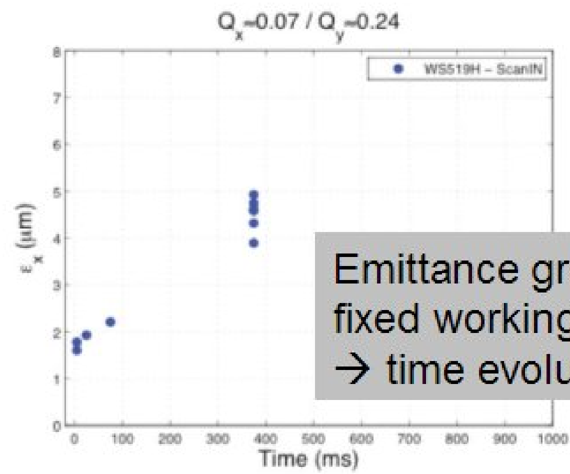
SPS MDs for the code's benchmarking

Emittance growth for Qx close to integer

26.04.2012



$Q_x = 20.07$



'Q20' optics

Emittance growth for the fixed working point → time evolution …

- **Same beam parameters as on 24.05.2012 (see above) initial tune spread is about $\Delta Q_x \approx 0.15$ / $\Delta Q_y \approx 0.25$**
- **(lossless) blow up of the core**
  - εx>2μm after 40ms
  - εx~4-5μm after 400ms

Courtesy H.Bartosik

Current status of the group activity

SPS MDs for the code's benchmarking

Behavior close to integer resonances

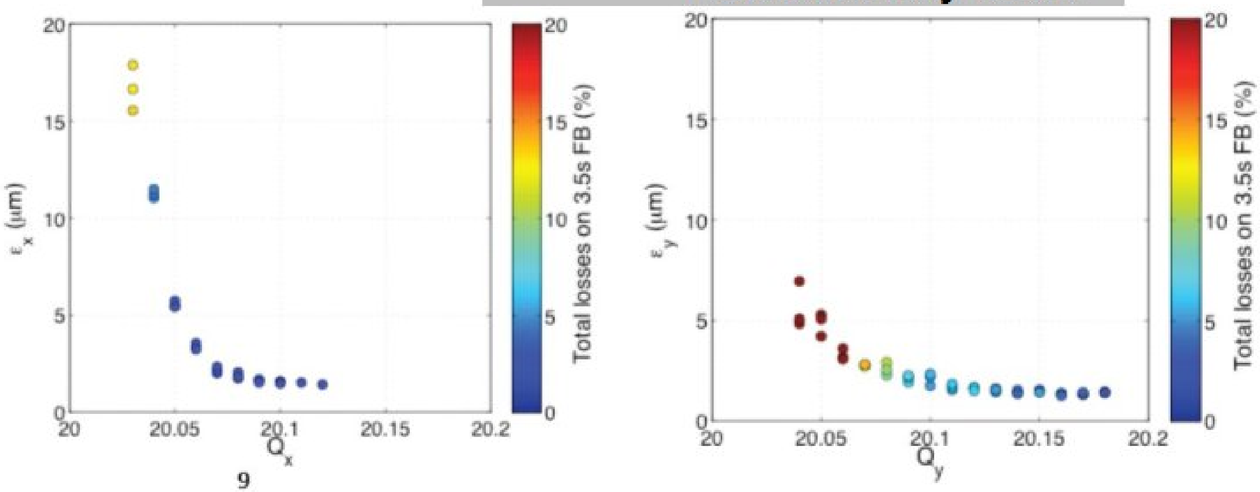
04.05.2012

- Parallel MD short flat bottom cycle
- Standard LHCindiv bunch 1.2e11p/b with $(\varepsilon_x+\varepsilon_y)/2$~1.2μm
  - Expect ΔQ_x~0.07/ΔQ_y~0.11

Courtesy H.Bartosik

Low-intensity beam

'Q20' optics

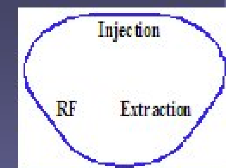


Large aperture in horizontal plane allows for huge emittance blow-up without losses

Aperture limitations in vertical plane lead to increasing losses with vertical beam size

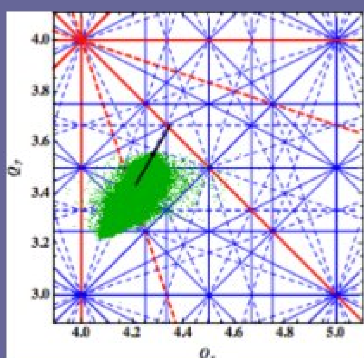
Current status of the group activity

▪ RCS conceptual design



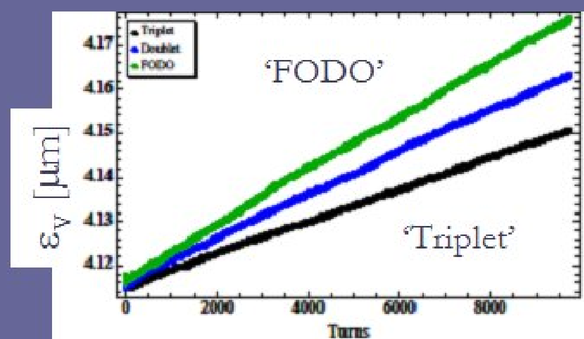
Motivations (including the space charge at injection):
- alternative to the CERN PS Booster upgrade (160MeV-2GeV, 10Hz)
- effect the beam envelope modulations on the emittance growth
- effect of the super-periodicity

Courtesy M.Fitterer

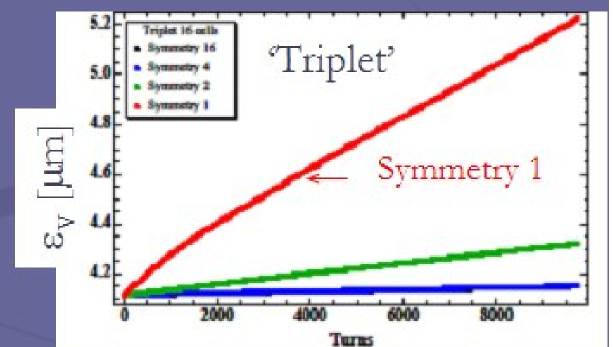


$\Delta Q_y \approx -0.4$

→ Lattice tune above $2Q_y$=7
→ Including the Vertical beta-beating correction …



Variation of the beam size can lead to the emittance growth:
→ the 'TRIPLET' features smallest variation of the transverse emittance compared to the 'DOUBLET' and the 'FODO' cell

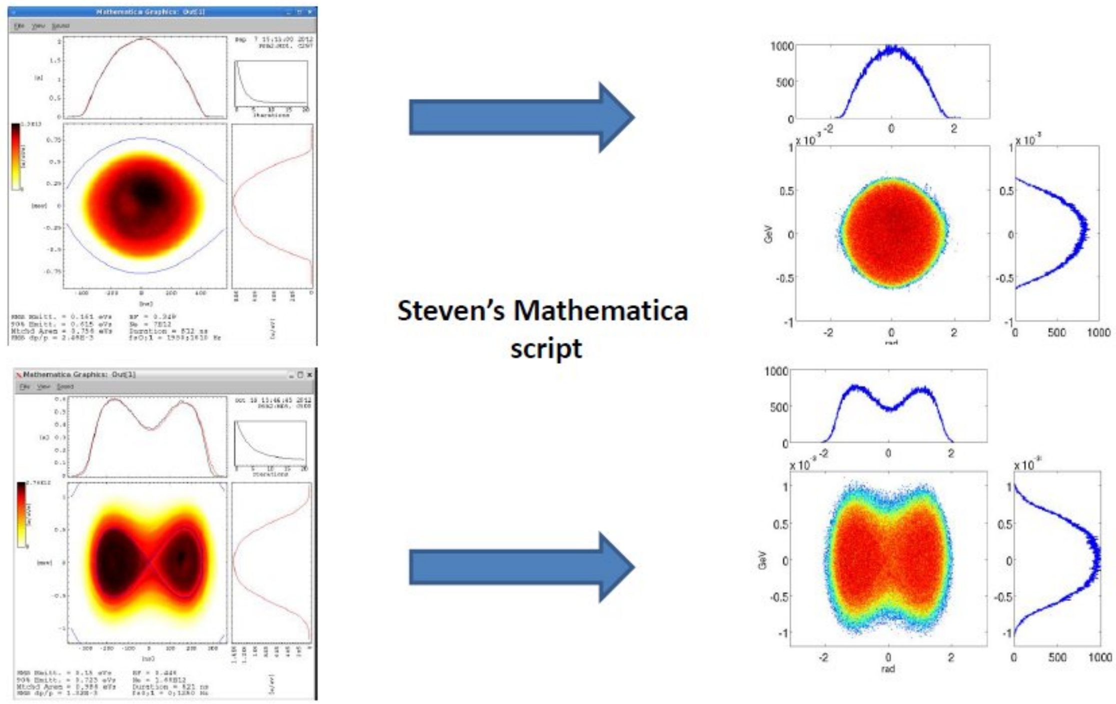


Emittance growth due to excitation of 'systematic' resonances:
→ 'weak' symmetry breaking in one cell with correcting the beat-beat

Current status of the group activity

Measurements to be used for the simulations (to avoid assumptions) …

A new way to match the longitudinal distribution (thanks to S. Hancock)



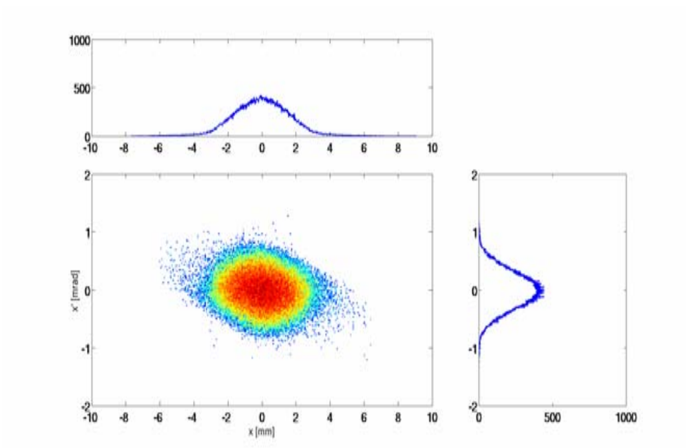
Very useful in case of "particular" longitudinal shapes (filamentation, acceleration,…)

CERN PS Booster

Current status of the group activity

CERN PS Booster

Horizontal plane

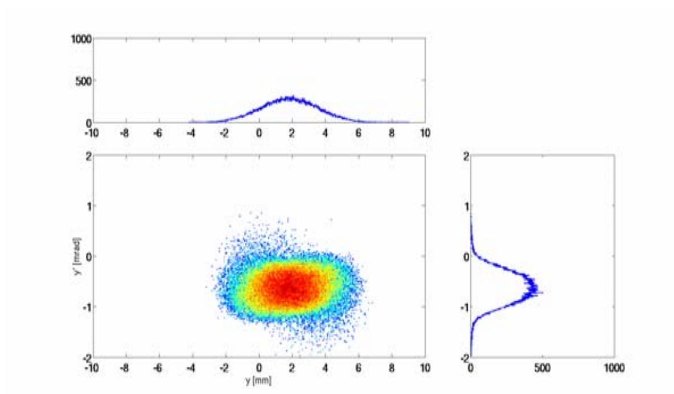


Pre-simulated 6D distribution of the H^- beam from LINAC4 (micro-bunch) at the injection point of PS Booster

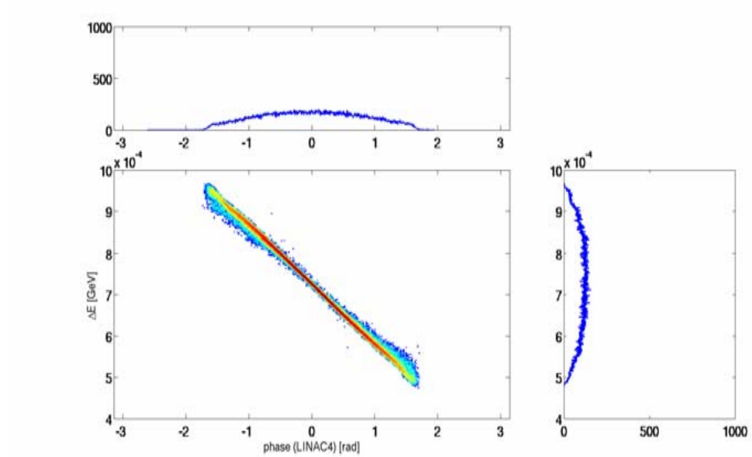
→ … should be used as the 6D distribution to study the multi-turn injection

Courtesy A.Lombardi

Vertical plane



Longitudinal plane



Summary of the LIU Beam Studies Review

CERN-ATS-Note-2012-083 PERF, 25 October 2012

CERN PS Booster

- **To predict the performance of the injectors after LS2, it seems that several questions still need to be answered:**

- Full simulations of the H− injection at 160 MeV into the PSB have to be set up to determine realistic curves of transverse emittance versus intensity and fully justify the usual assumption that the brightness of the beams will be increased by a factor two.

- The PSB machine studies necessary to set up these simulations (i.e., those leading to a benchmarked nonlinear optics model of the PSB at 160 MeV) are still missing, even if an effort has been undertaken to describe the machine at 160 MeV in strong space charge regime.

Next steps in the group activity

CERN PS Booster (1) → with V.Forte, M.Martini, E.Benedetto

- ❑ Check the simulations, performed by Chiara Bracco and Matthias Scholz for multi-turn injection from LINAC4 into PS Booster, taken into account the FOIL and APERTURE effects

- ❑ Multi-turn injection process to provide different beams from PS Booster (from LHC to CNGS beam)

- ❑ Continue study (data accumulation) of the emittance evolution and the particle losses in PS Booster at 160MeV energy for the space-charge dominated beam (LHC type beam)

- ❑ Emittance evolution at different energies for the case of the space-charge dominated beams from LINAC2 (measurements and simulations)

Next steps in the group activity

CERN PS Booster (2) → with V.Forte, M.Martini, E.Benedetto

- ❑ Benchmark the particle losses around the machine for the LHC25 type beam at 160MeV energy

  → Closed Orbit Reconstruction at different energies to reproduce measurements

- ❑ Study the resonance excitation and compensation at different energies

  PS Booster lattice imperfection (based on the measurements of non-linear resonances)

- ❑ Collaboration with the LINAC4 group (A.Lombardi) 'H- beam parameters for the PS Booster multi-turn injection'

  → use the realistic 6D distributions, required for each beam from PS Booster

Next steps in the group activity

CERN PS Booster (3) → with V.Forte, M.Martini, E.Benedetto

- ❑ Mismatching and Injection errors as sources of the emittance growth
  → simulations and measurements (for 50MeV injection)
  → simulations for 160MeV beam

- ❑ Effects of field errors and nonlinear field components on the emittance growth and particle losses
  → eddy current effects in the bump magnets with the 'inconel' chamber

- ❑ Optimization of the 'bare' working point for different beams (LHC → CNGS)

…

Next steps in the group activity

CERN PS (with Raymond Wasef)

- ❑ Resonance study: measurements and simulations
- ❑ Reconstruction the closed orbit distortion
- ❑ Effects of the injection errors: measurements and simulations
- ❑ Improvement the machine description (field nonlinearities and alignment errors)
- ❑ Optimization the 'bare' working point for different beam parameters
- ❑ Particle losses around the machine

Next steps in the group activity

CERN SPS (with Hannes Bartosik)

- ❑ Identify machine resonances (MDs) by the 'probe' beam
- ❑ Develop nonlinear machine model in MADX/PTC
  - closed orbit, nonlinear chromaticity, multipole of main magnets, misalignments …
- ❑ Benchmark machine model with integer resonance (experimental data with space charge dominated beam)
- ❑ Experimental explore the tune diagram with the space-charge dominated beam (with LIU required space charge tune spread)
  - find 'promising' working point region (with minimum emittance blow-up and losses)
  - identify relevant (limiting) resonances
- ❑ Specific studies of relevant resonances
  - measure resonance driving terms
  - study and model beam behavior close to resonances (losses, emittance blow-up, bunch shortening …)
  - study possible compensation schemes using non-linear elements

Thanks for your attention