Beam losses, halo generation and collimation

G. Rumolo, in Beam07 -Upgrade of the LHC Injector Complex (05/10/2007)
Summary of Session 3 of Beam07, CERN-GSI Meeting on Collective Fffects

- Most of the presentations (6/8) covered:
  - Collimation and loss localization studies in several machines (PS, SPS, LHC, SIS18, SIS100/300, RHIC)
  - Code benchmark against measurements in running machines (PS, SPS, RHIC)
- Some loss mechanisms were explained (2/8):
  - Resonances induced by the electron cooler
  - Trapping and loss induced by electron cloud

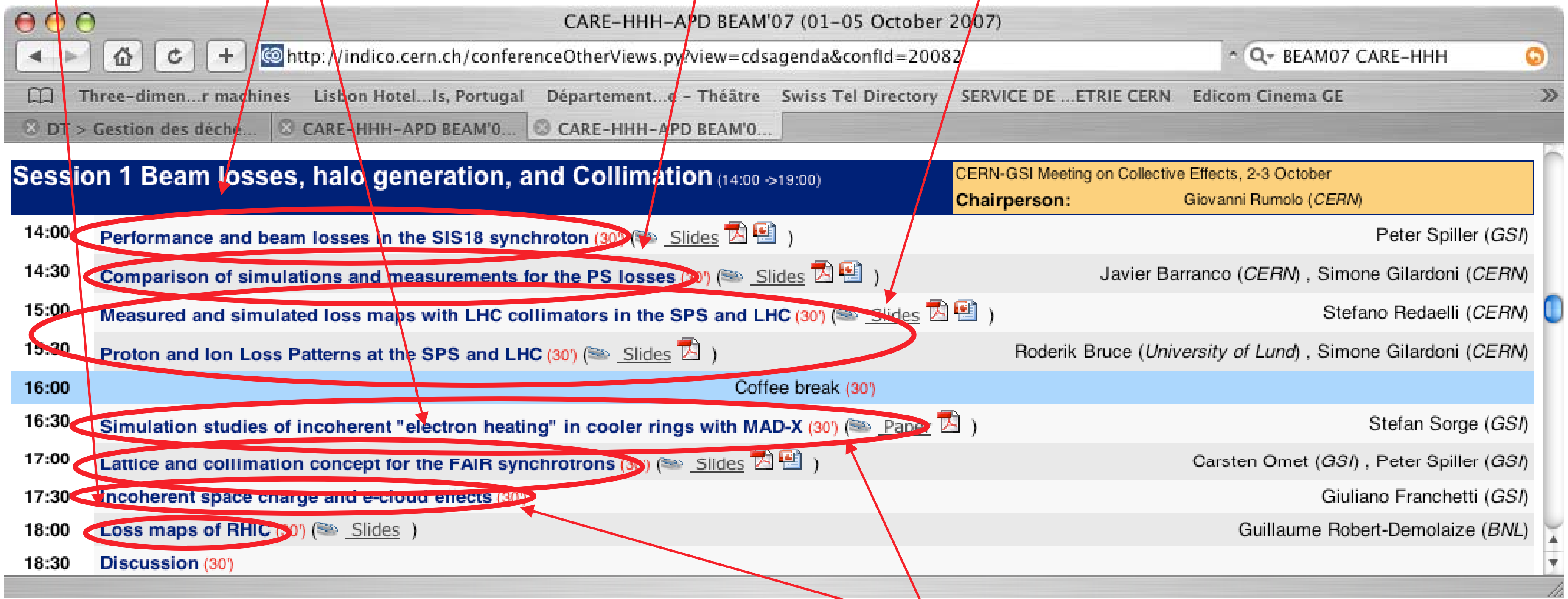
Quick overview on the program of the session

Losses in RHIC (G. Robert-Demolaize)

SPS and LHC loss maps for protons and ions

FAIR related topics, losses in the SIS18 and collimation system (P. Spiller and C. Omet)

Localization of the losses in the CERN-PS (S. Gilardoni)



Losses from e-cooler, e-cloud, space charge (S. Sorge, G. Franchetti)

Several methods to track scattered and secondary particles and study loss distribution were outlined, optimized case by case according to specific needs and requirements:

- **Sixtrack tracking + K2 simulation** for the interaction with matter $\rightarrow$ specific for collimator studies (SPS, LHC, RHIC), adapted for losses in the PS

- Generation of external distribution through **MARS** and tracking with **MAD-X** (PS)

- **ICOSIM** for tracking including ion-matter interaction. It uses **MAD-X optics** and nuclear interaction cross-sections from **RELDIS & ABRATION/ABLATION** routines (ions in the SPS/LHC)

- **STRAHLSIM** (developed at GSI) for full ion tracking including capture/recombination phenomena (cross sections available within 30% at the needed high energies), scattering and desorption (SIS18, SIS100/300)

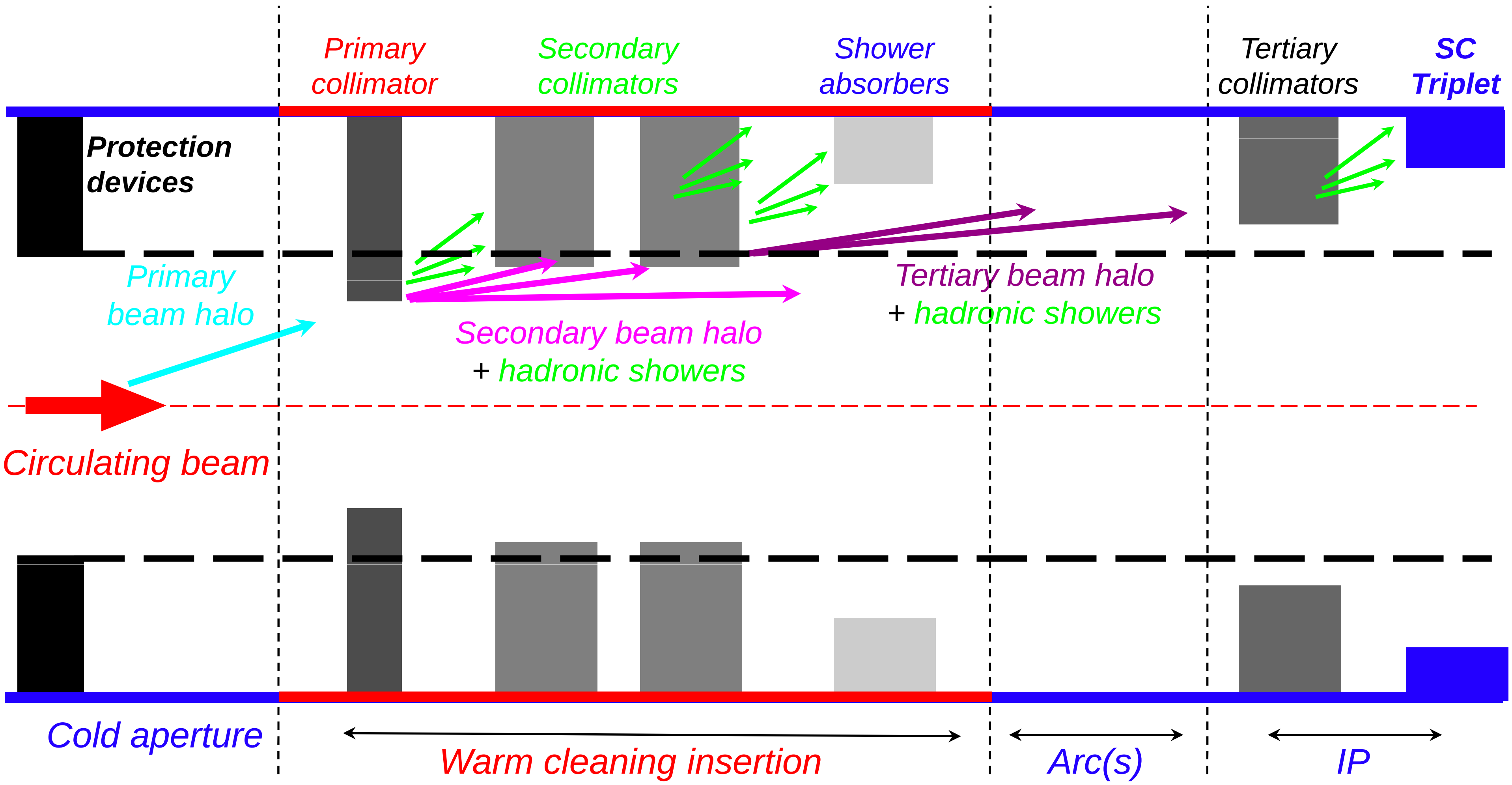
All these methods alsoneed to rely on **a detailed external aperture model** to predict the loss locations and **detailed collimator geometry**, where applicable.

Reasons why it is very important to develop powerful and reliable tools to predict losses around a circular machine:

- **Save surroundings from irradiation** (CT extraction in the PS). If losses can be predicted, they can be also suppressed or relocated in order
  - not to exceed the allowed irradiation doses in critical areas.
  - to increase the transmission efficiency and performance of the machine
- **Guide and determine the design of collimator systems** in new machines (LHC, SIS100, PS2) or new collimator systems necessary for the upgrade of existing machines limited by loss induced vacuum instabilities (SIS18)
- Reliability of these tools can be only assessed through **benchmark with known loss patterns in running machines** (PS, SPS, SIS18, RHIC)
- In the specific case of **LHC, the collimation system is a real challenge** because:
  - ✓ Control losses 1000 time better than the present state-of-the-art!
  - ✓ Collimation needed at all machine states: injection, ramp, squeeze, store
  - ✓ Important role of collimation system for machine protection

Multi-stage collimation at the LHC

(An illustrative scheme, by S. Redaelli)



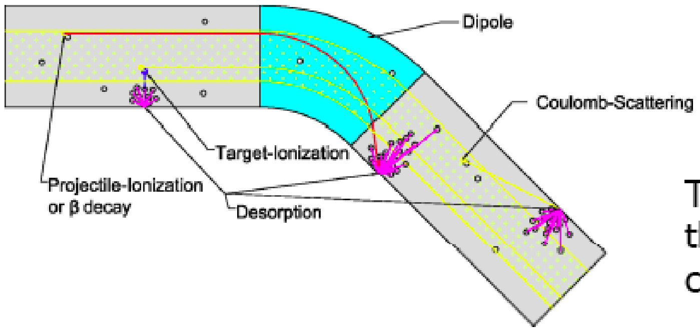
All cleaning + protection devices must be included in simulations!

Collimation needed from injection to collision!

FAIR Facility for Antiproton and Ion Research

Charge change loss mechanism

- A beam ion hits residual gas atoms/molecules and loses one or more electron(s)
- This ion is lost after the next dipole by different magnetic rigidity ($\delta p/p \cong q_0/q - 1$, e.g. for $U^{28+} \rightarrow U^{29+}$ $\delta p/p = -3.45\%$!)
- There, a shower of secondary particles is produced by ion stimulated desorption with a rate of $\eta \geq 10^4$ mol/ion.
- An avalanche process can be initiated!



There are more loss processes, but this one can be controlled with collimators / catchers!

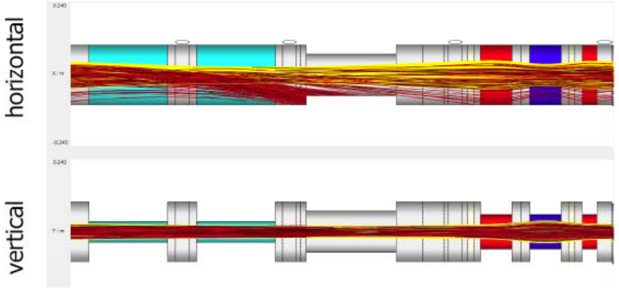
30.09.2007 C. Omet 4

Lattice optimization concepts for the SIS's

Peaked! → Losses concentrated in some sections where scrapers are placed

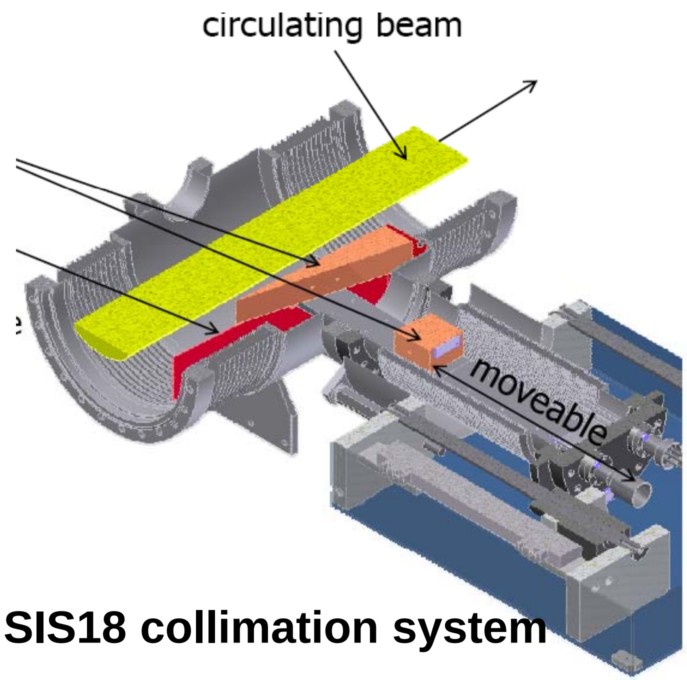
Separated! → Main beam and products of charge exchange processes are well separated in these sections

Acceptance! →
- Scrapers should not reduce the acceptance
- Unwanted ions should reach the location of the next scrapers

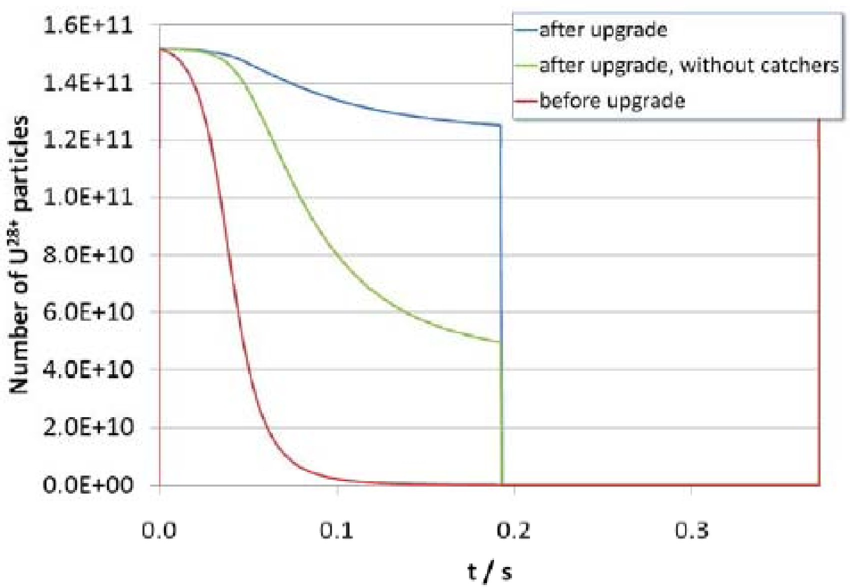


C. Omet, P. Spiller

The performance of SIS18 is expected to increase dramatically (and meet the requirements to become injector for SIS100) with the use of adequately placed absorbers + NEG coating and pumping ports in the vicinity



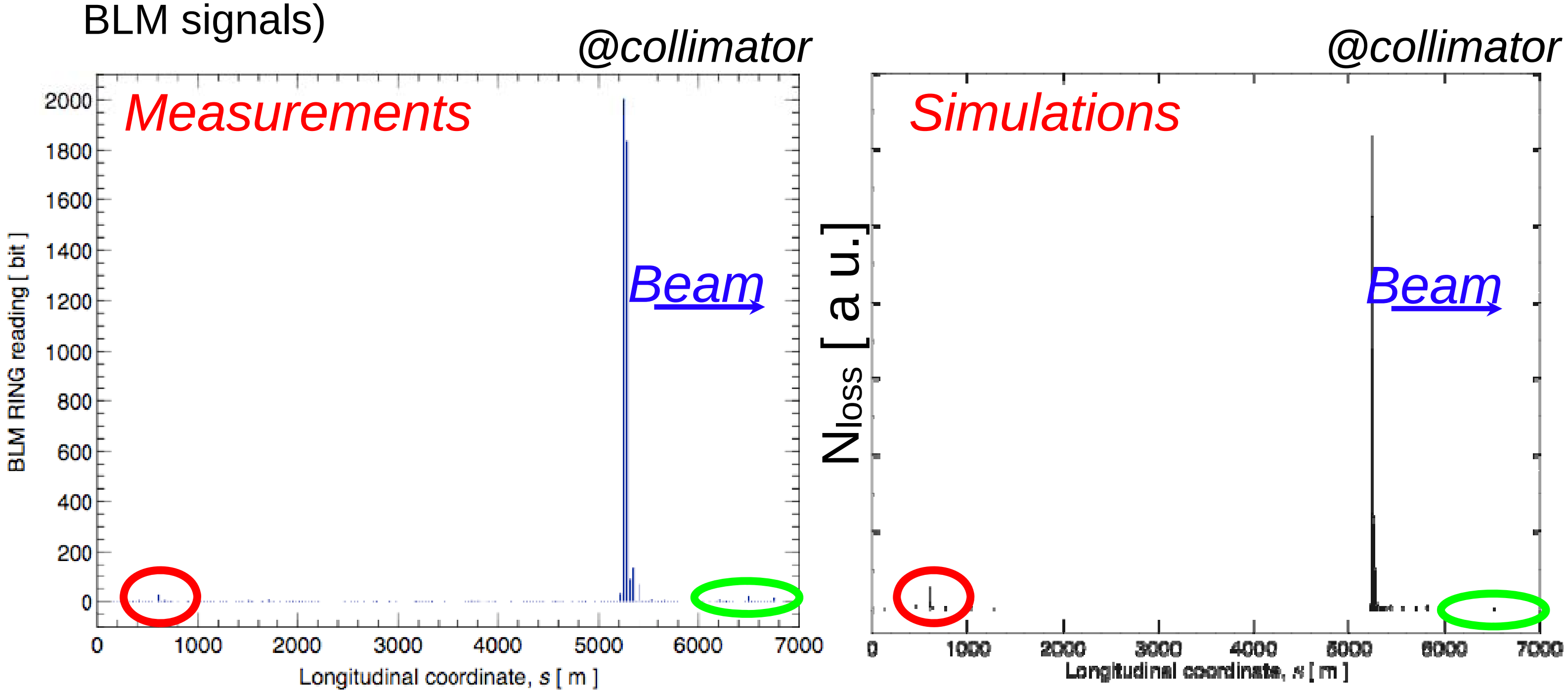
SIS18 collimation system



C. Omet, P. Spiller

Code benchmark with experimental data (I)

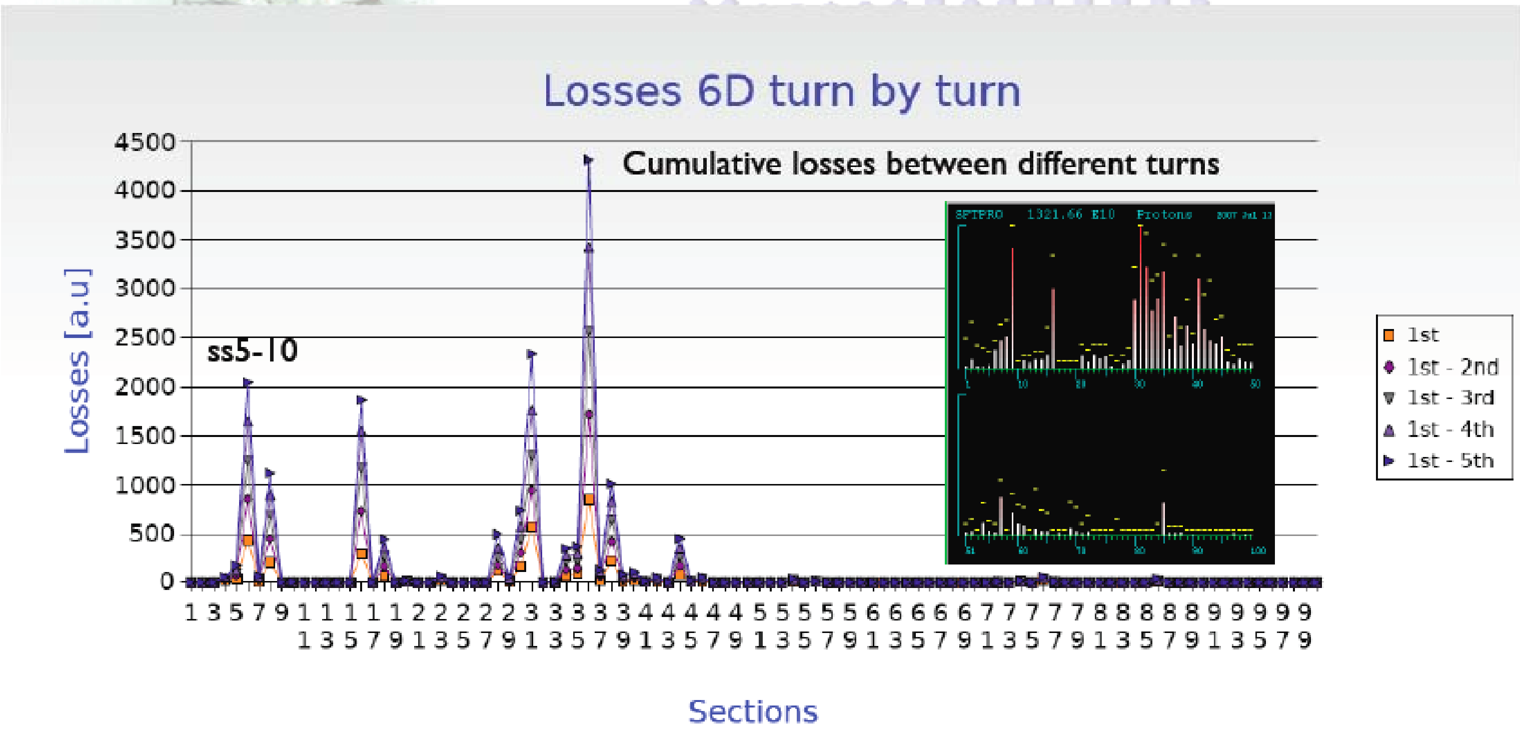
Tools used to design the collimator systems have been successfully benchmarked against existing loss data (simulated loss maps compared with BLM signals)



SPS, S. Redaelli

Code benchmark with experimental data (II)

"LHC style" approach: Sixtrack + K2



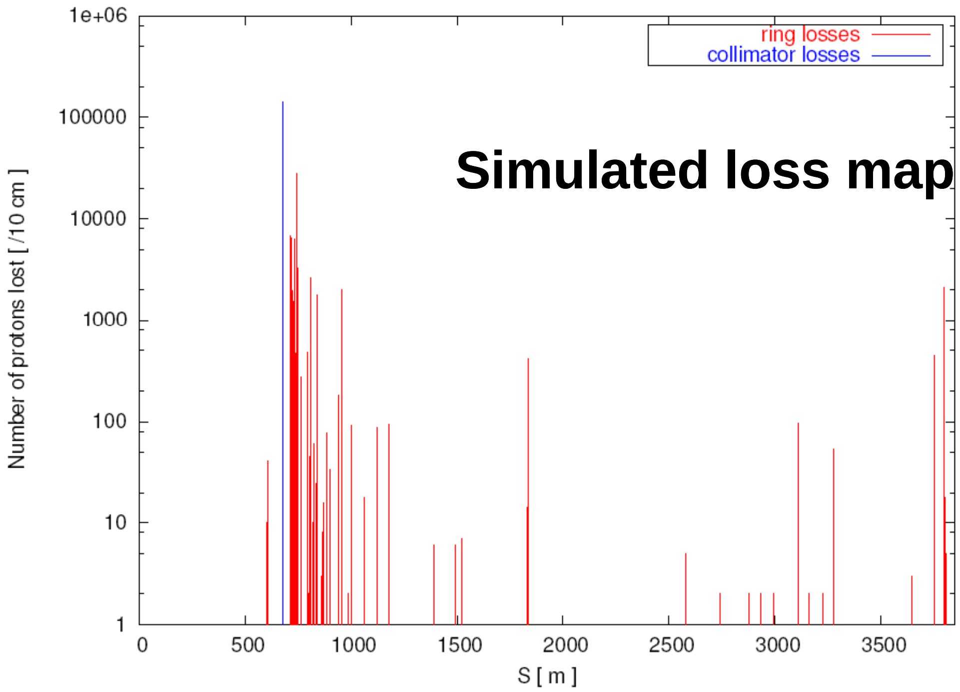
The Sixtrack + K2 tool had to be adapted to this case

- Halo is the scattered particle distribution
- Event cross sections had to adapted to this low energy

PS, S. Gilardoni

Code benchmark with experimental data (III)

- Tracked 240000 particles, impact parameter = 5 µm, 20 turns



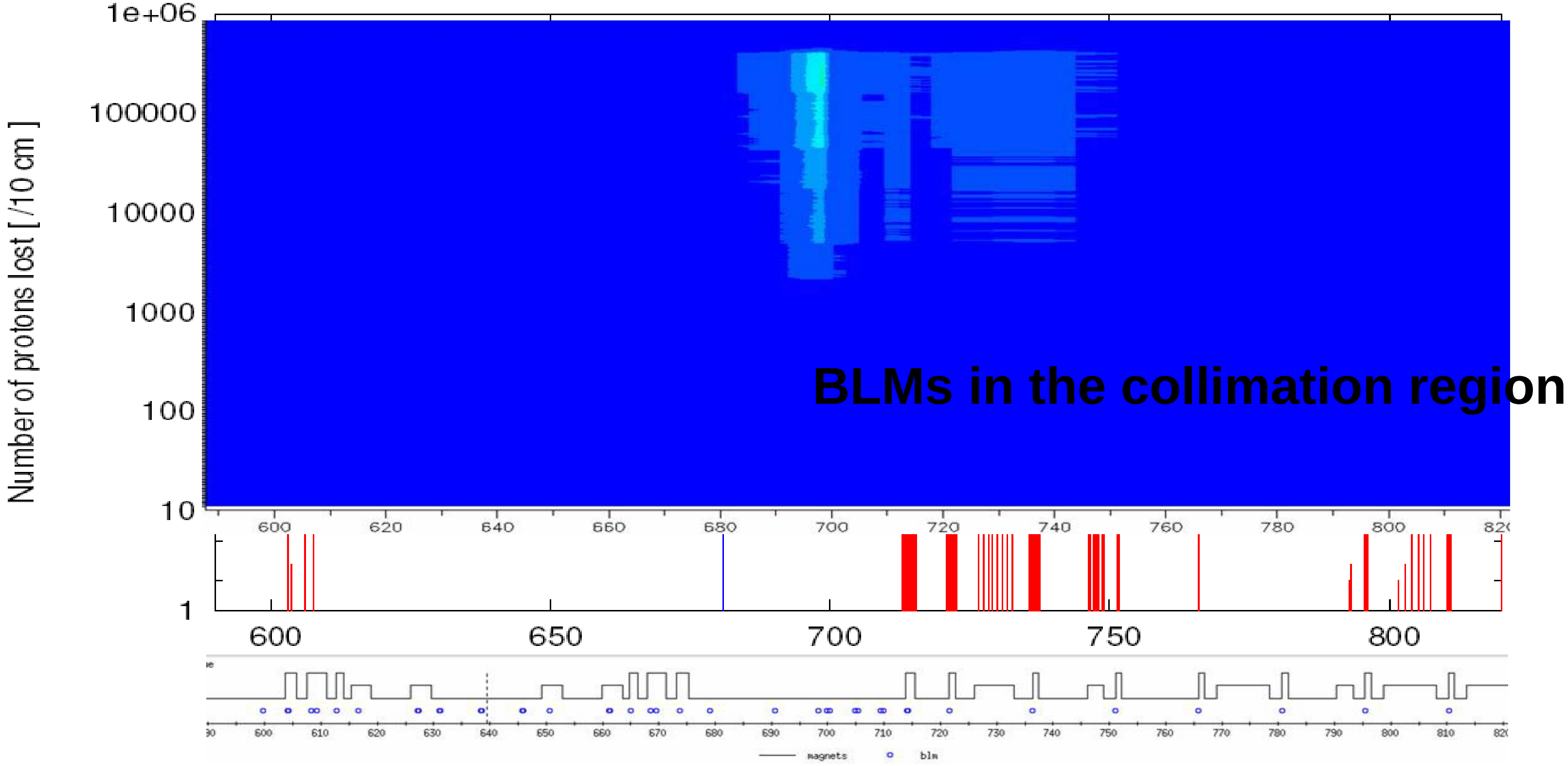
Simulated loss map – horizontal jaw

=> about 59% of impacting protons are absorbed at the collimator (blue spike)

RHIC, G. Robert-Demolaize

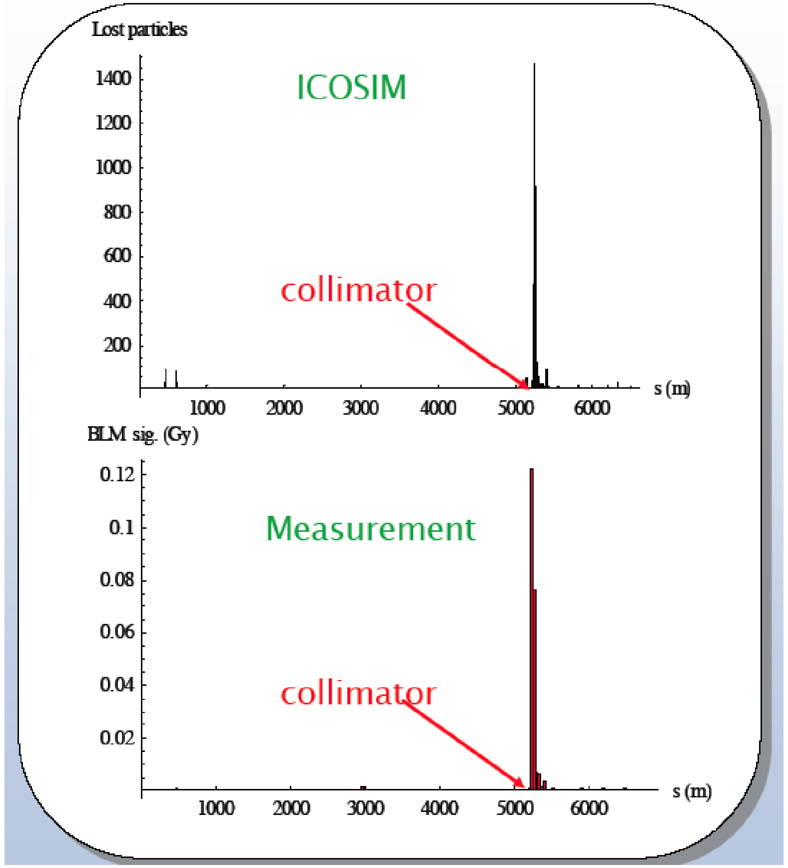
Code benchmark with experimental data (IV)

- Compare loss locations with live measurements:



RHIC, G. Robert-Demolaize

Code benchmark with experimental data (V)



Benchmark of tools used to design the ion collimation system for LHC

→ Due to large probability of fragmentation in primary collimators, there is a high production of isotopes having Z/A such as not to be intercepted by the secondary collimators.

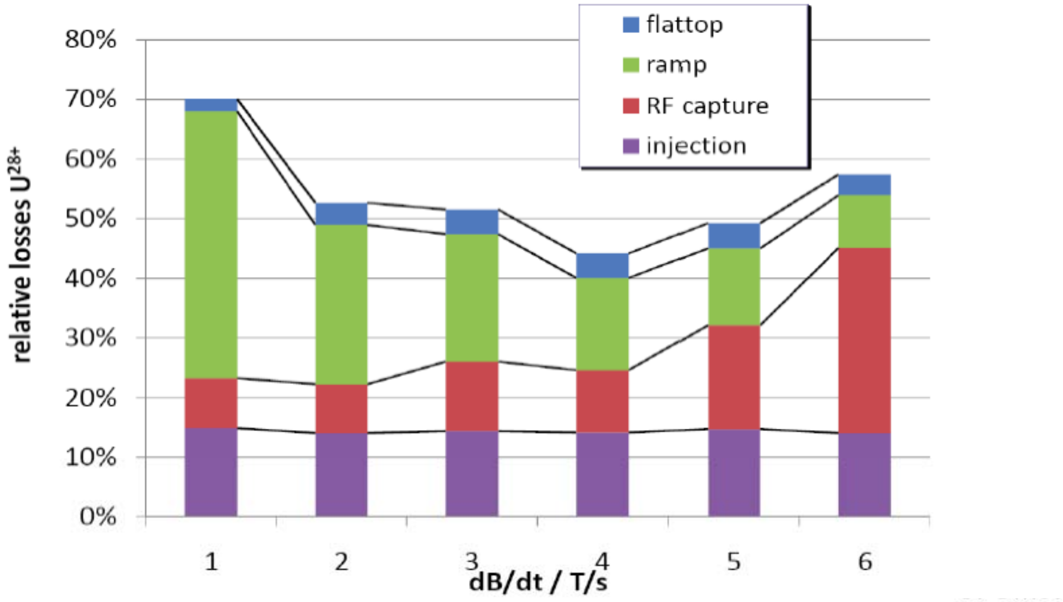
→ Specialized tools for ions need to be used

→ More SPS MDs with coasting ion beams would be desirable to better benchmark this tool

SPS, R. Bruce

Other loss mechanisms (I)

At the SIS18 losses are not only due to charge exchange processes....



Fractional loss of different mechanisms during fast ramping

SIS18, C. Omet, P. Spiller

Improving the SIS18 performance (I)

In the frame of the FAIR project, an SIS18 uppgrade program has been approved to improve all these loss mechanisms. Some important points are:

→ New RF-System, h=2 acceleration cavity and bunch compression system (EU, 2009)

→ Upgrade of the UHV System, with new, NEG coated dipole and quadrupole chambers (EU, 2006-2008). Next year the SIS18 will run with 30% of the chambers coated and a significant improvement in the storage and acceleration of U^{28+} is foreseen.

→ Insertions, Set-up of a „desorption“ collimation system (EU, 2007-2008)

→ Upgrade of the Injection/Extraction Systems, with a new injection septum, power supply and large acceptance extraction channel (EU, 2007)

→ Replacement of Main Dipole Power Supplies, to allow operation with 10 T/s up to 18 Tm (2010)

→ ...

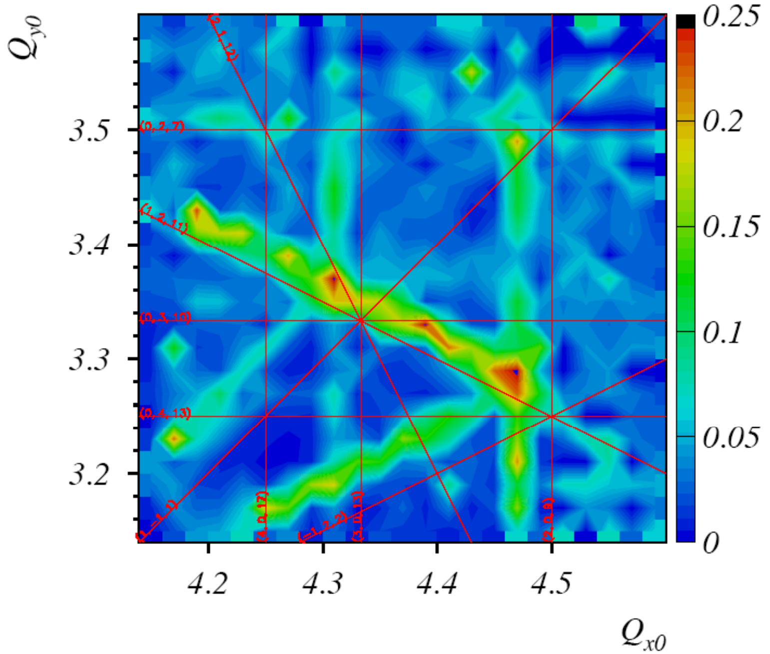
SIS18, P. Spiller

Improving the SIS18 performance (II)

To push the SIS18 performance and fight instabilities and halo formation:

→ Longitudinal and Transverse Feedback Systems for damping of coherent oscillations, coupled bunch modes and phase stabilization

→ Development of High Current Operation, with compensation of resonances, impedance studies, etc. (2007)



Resonances have been measured at the SIS18 through beam loss during a tune scan

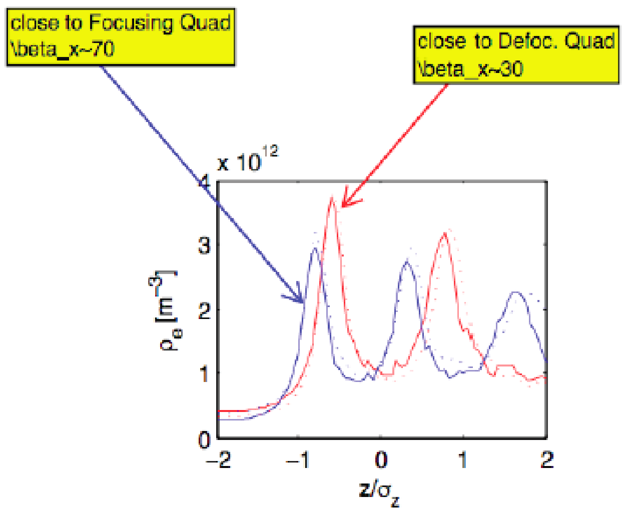
G. Franchetti, A. Franchi, T. Hoffmann, G. Rumolo, P. Schütt, in GSI-Acc-Note-2005-02-001

SIS18, P. Spiller

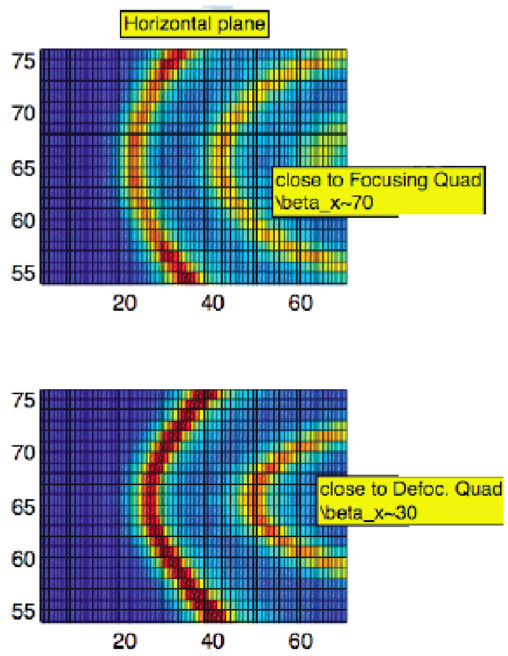
Other loss mechanisms (II)

Space charge and electron clouds are responsible for chaotic behaviour in transverse phase space, eventualy leading to halo formation and emittance growth

In a dipole field the electron pinch from a bunch happens at different times along the horizontal coordinate and the effect on the particle motion has been studied by G. Fr



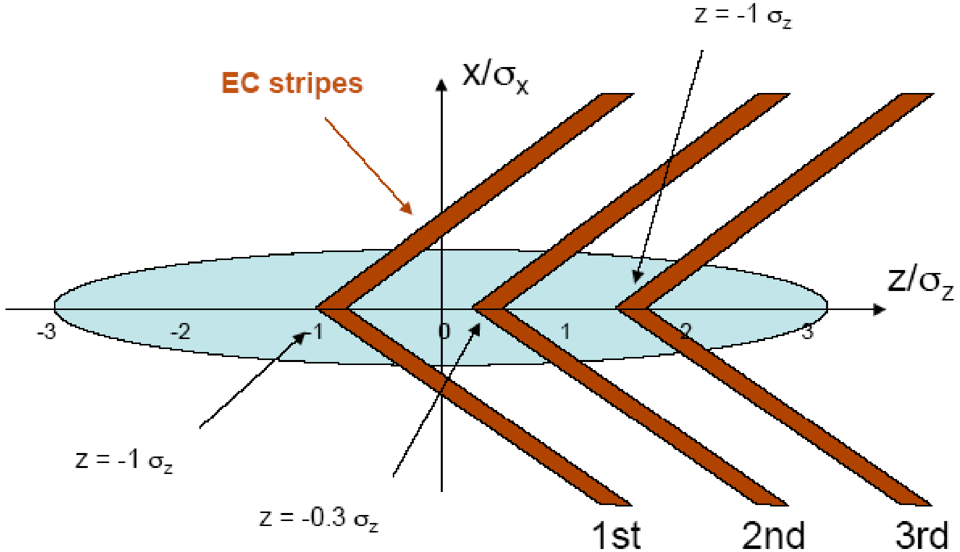
HEADTAIL simulations by
E. Benedetto

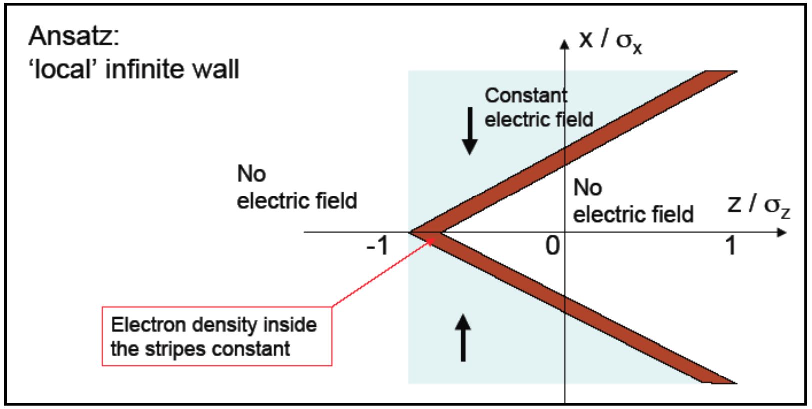


G. Franchetti

Other loss mechanisms (III)

The detuning resulting from such a distribution has been studied semi-analytically by assuming the electrons concentrated in 2 or 3 sets of stripes with constant density



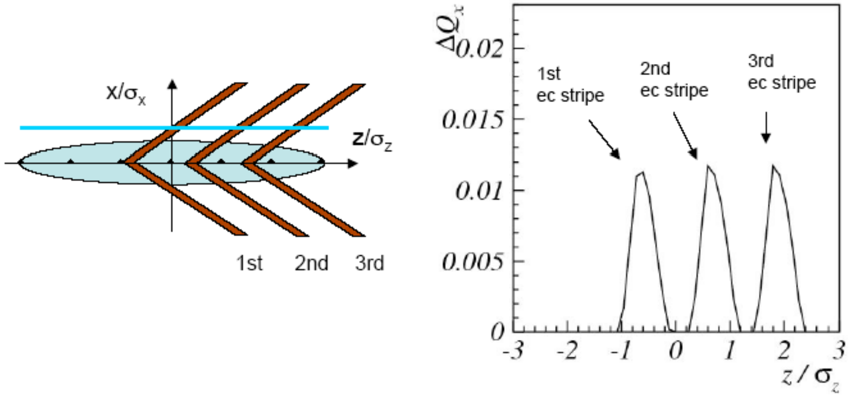


G. Franchetti

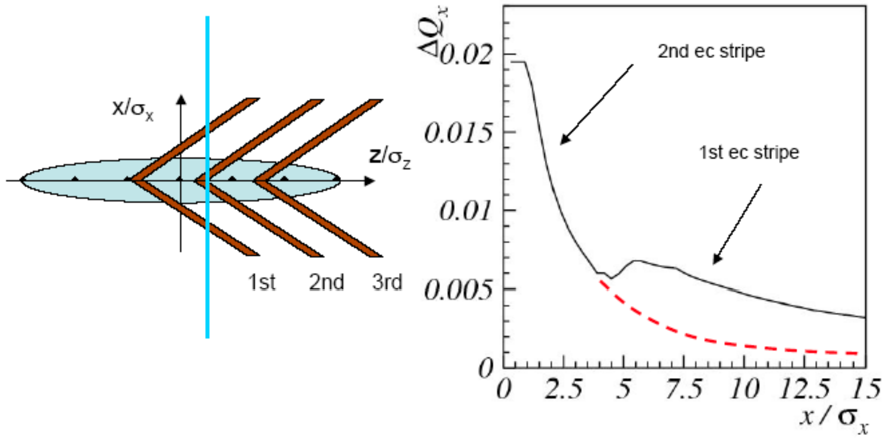
Other loss mechanisms (IV)

From the model, the detuning only appears for a test particle when it crosses the stripe and it depends on x and z!

Test particle with $x_{max} = 2\ \sigma_x$



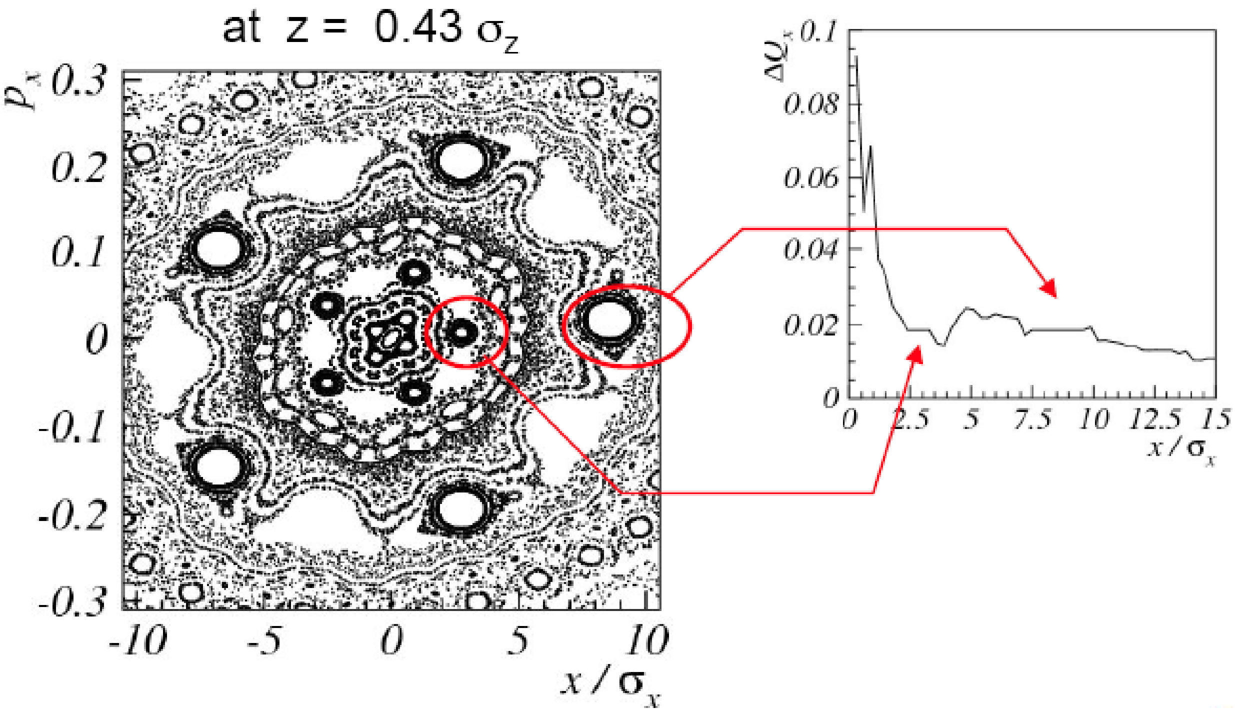
at $z = 0.6\ \sigma_z$



G. Franchetti

Other loss mechanisms (V)

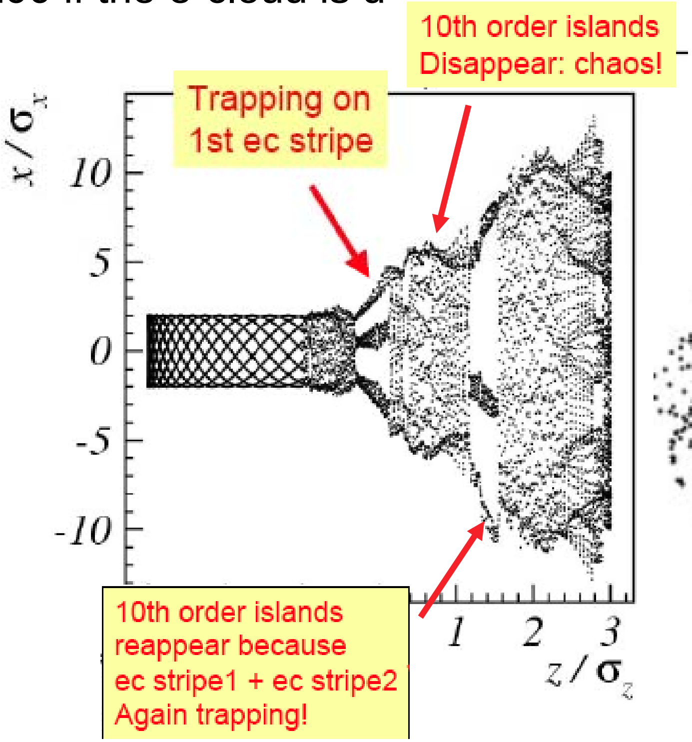
The picture of the particle motion in phase space is very complicated and highlights a 10th order resonance at the amplitudes of the stripe crossing (depends on z)

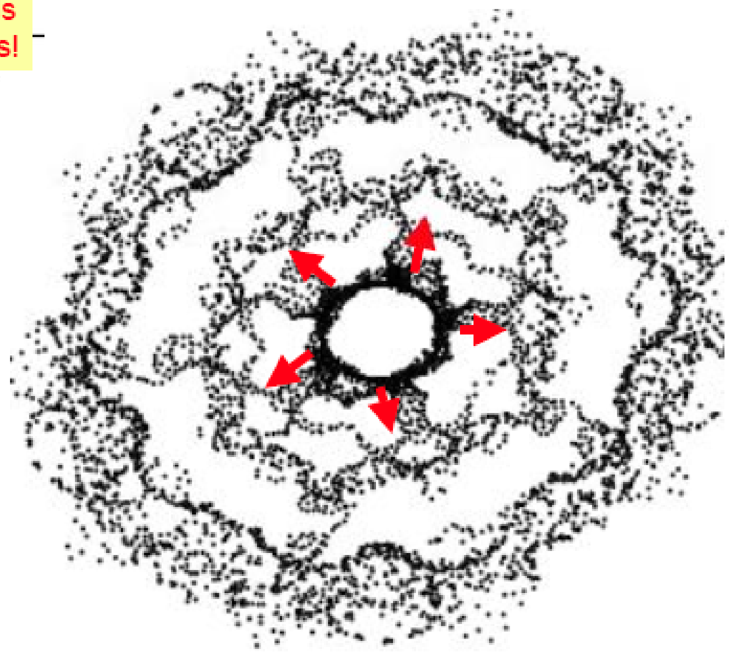


G. Franchetti

Other loss mechanisms (VI)

Trapping in the islands and growth to the large amplitude is possible due to synchrotron motion, it may lead to emittance growth in rings like the SPS and the SIS100 if the e-cloud is dense enough





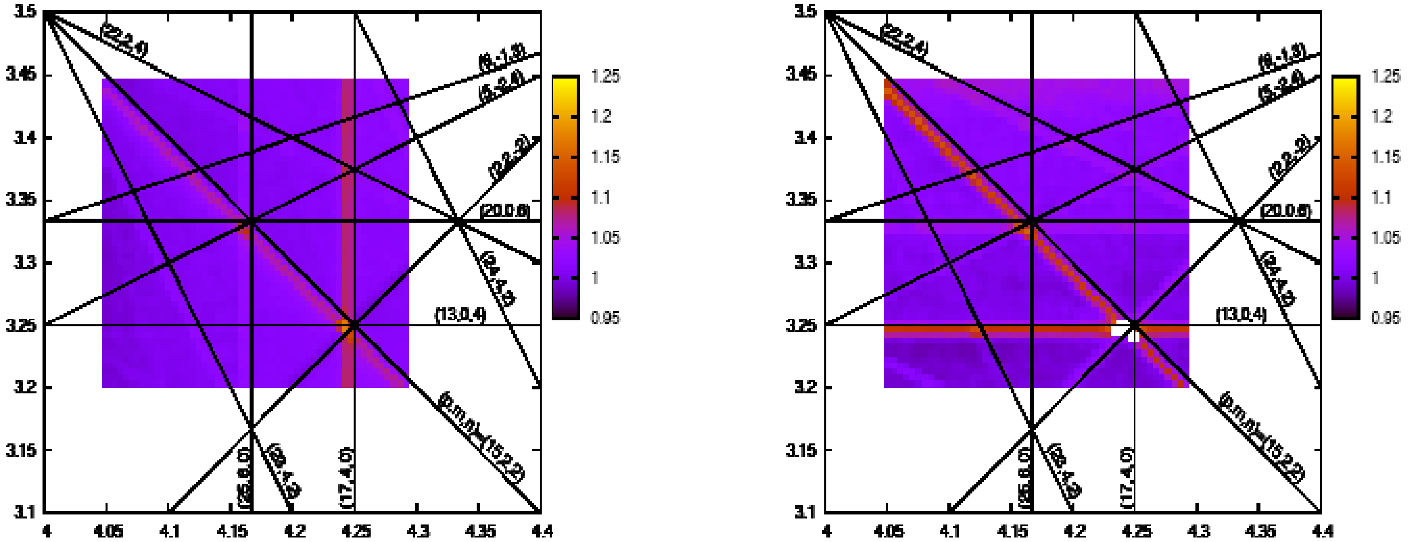
G. Franchetti

Other loss mechanisms (VII)

Resonances due to the electron cooler (important for SIS18) have been identified using MAD-X with a nonlinear kick modeling the electromagnetic interaction of the beam with the electron cooler. Their crossing can lead to emittance growth.

Relative beam width $w_{z,\mathrm{rel}} = \sigma_{f,z}/\sigma_{i,z}$ for variable horizontal and vertical tune

horizontal vertical



S. Sorge

- Many tools have been developed to predict beam loss locations in rings and they have been successfully benchmarked against measurements
- Based on these tools, appropriate collimation systems have been designed for new or upgraded rings
- To understand the losses gives a tool to suppress or re-locate them conveniently
- Electrons in the machine may cause losses...
  - The odd distribution of a uniform electron cloud pinched in a dipole field can give rise to trapping and hence, to emittance growth.
  - The cooler excites resonances up to 6th order