Status of Incoherent effect of space charge and electron cloud

G. Franchetti GSI

21/11/2008

GSI, Darmstadt

Overview

SC & EC incoherent effects

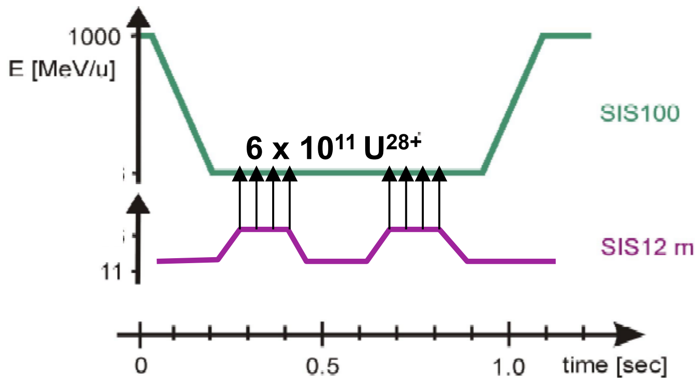
Simulation of Incoherent effects

Experimental verification of
SC-EC incoherent effects

Summary/Conclusion

Motivation @ GSI

SIS100 beam dynamics requirements brought to the attention the mixed area of high intensity effects in presence of lattice nonlinearities



Space charge tunespread

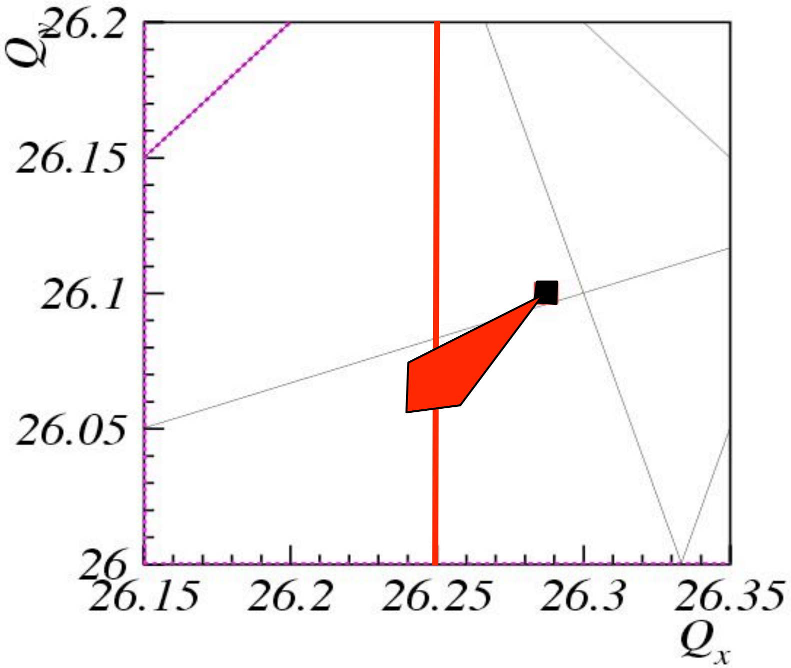
$\Delta Q \sim 0.3$

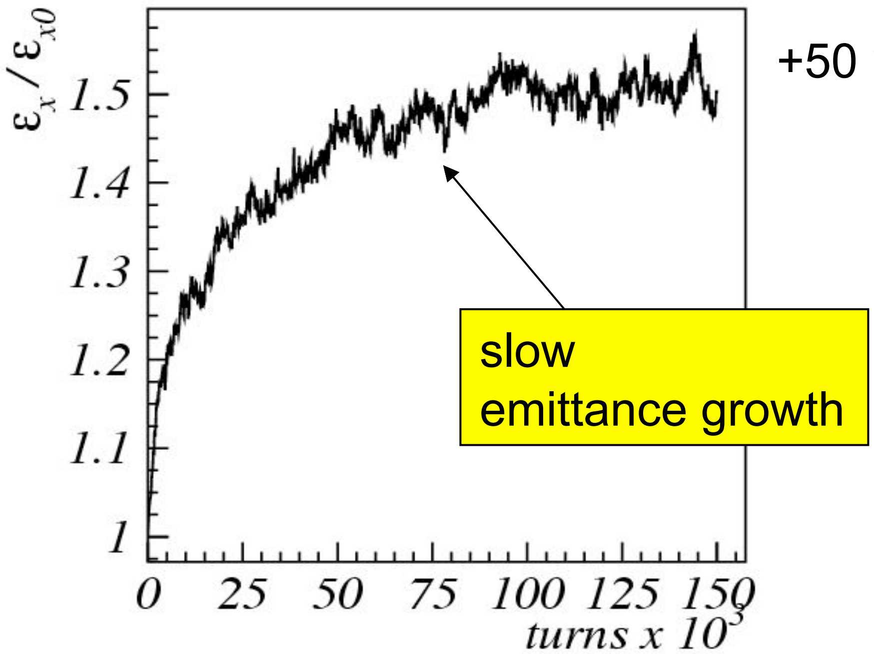
•P. Spiller *et al.*, MOPC100, EPAC 2008
•J. Stadlmann *et al.*, MOPC124, EPAC 2008

Example of space charge incoherent effects

Liner lattice + 1 octupole
Q_{x0} = 26.28 Q_s = 1/300
Q_{y0} = 26.1

High intensity bunched beam:
ΔQ_x = -0.075

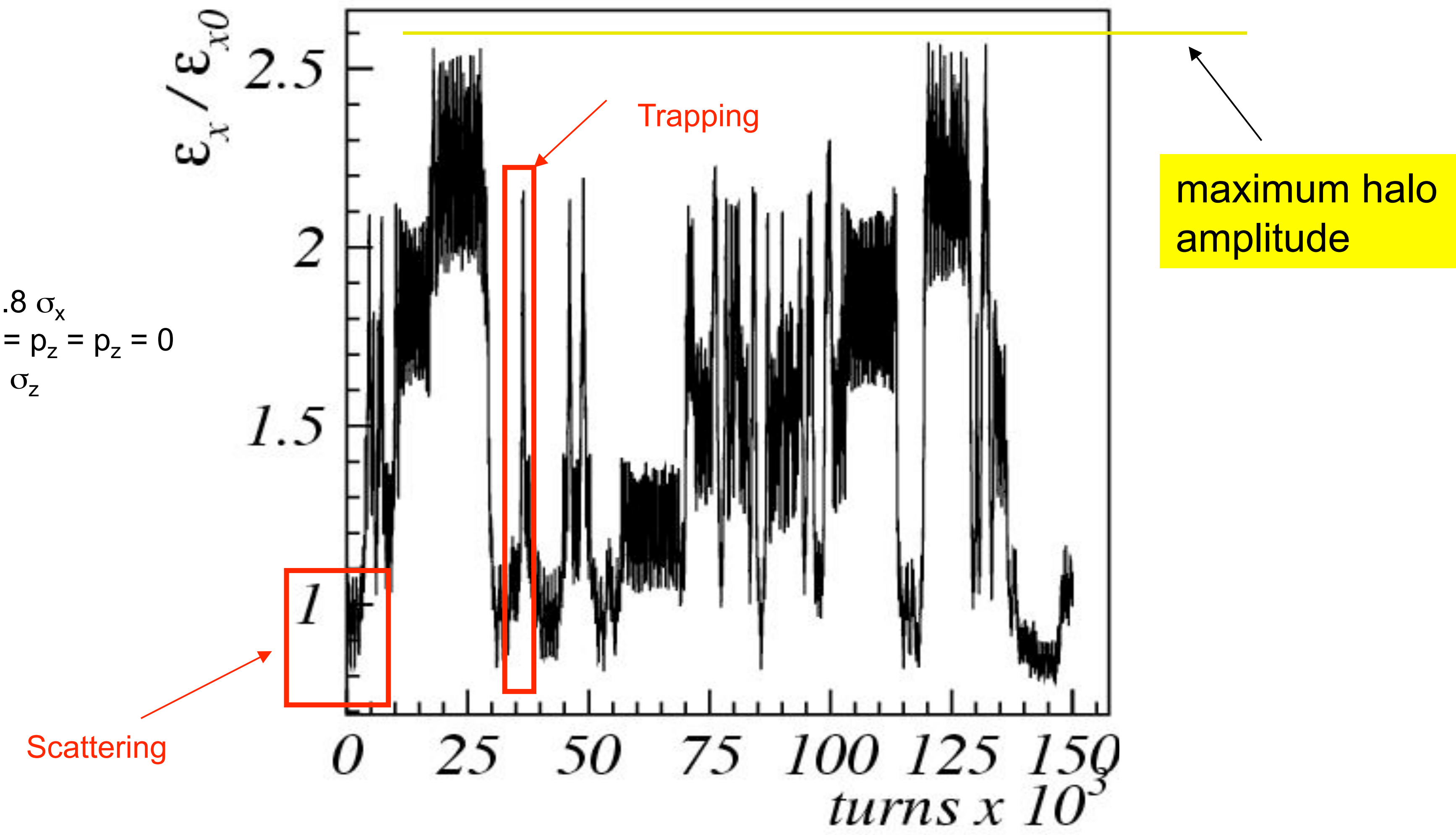




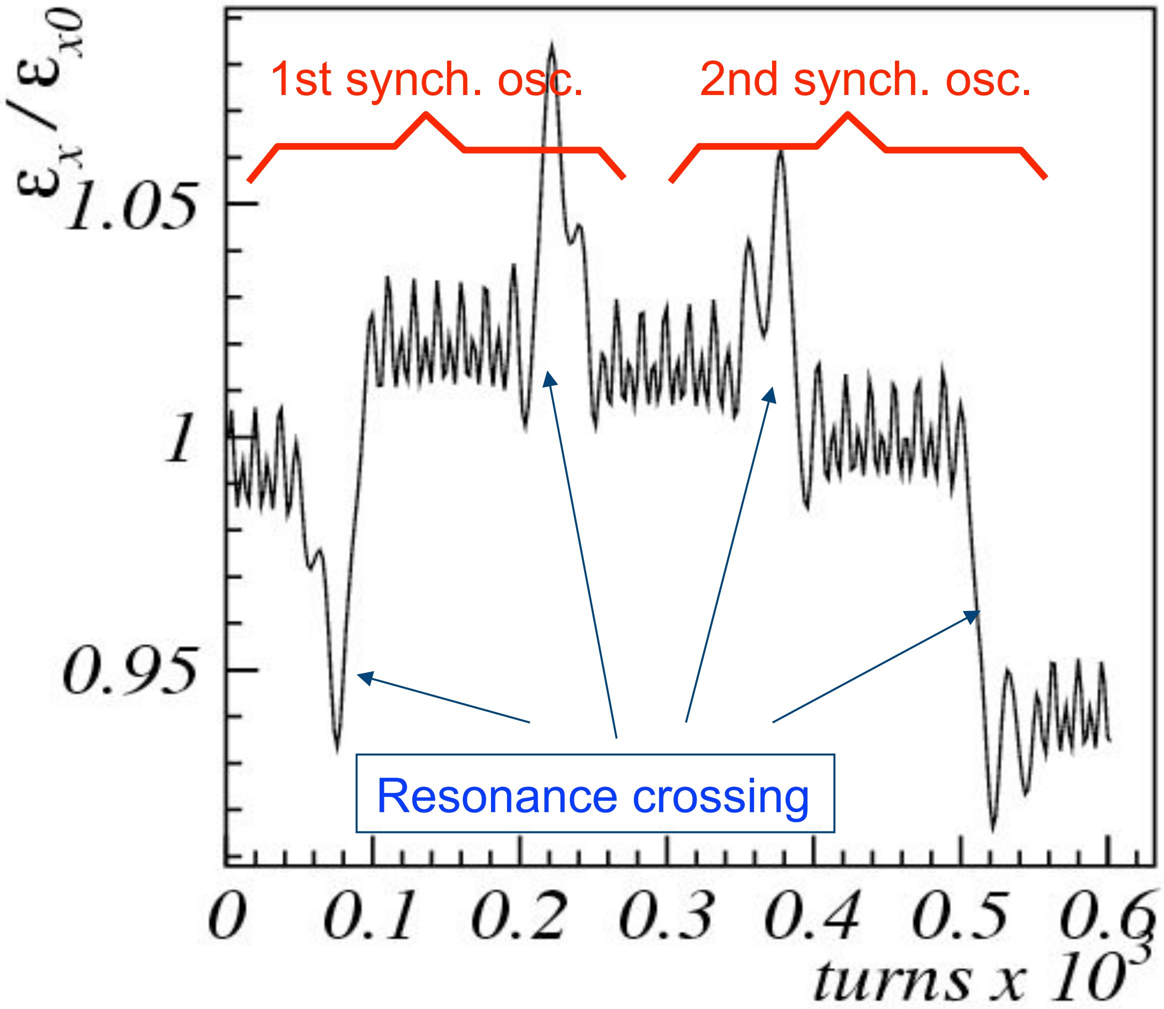
+50 %

One beam particle motion

$x = 1.8\ \sigma_x$
$p_x = y = p_z = p_z = 0$
$z = 3\ \sigma_z$

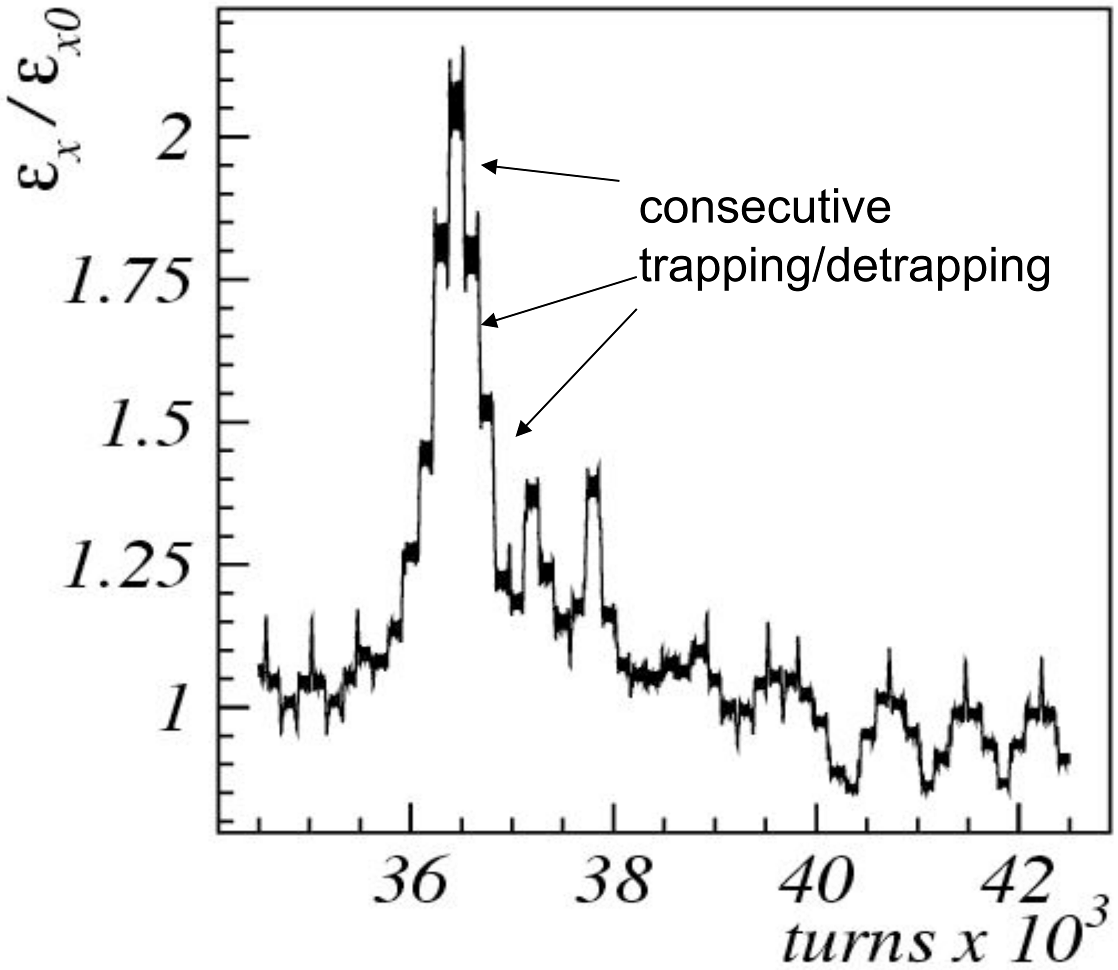


Scattering



- *A.I. Neishtadt, Sov. J. Plasma Phys. 12, 568 (1986)*
- *A.I. Neishtadt, A.A. Vasiliev NIM A **561**, (2006) 158*

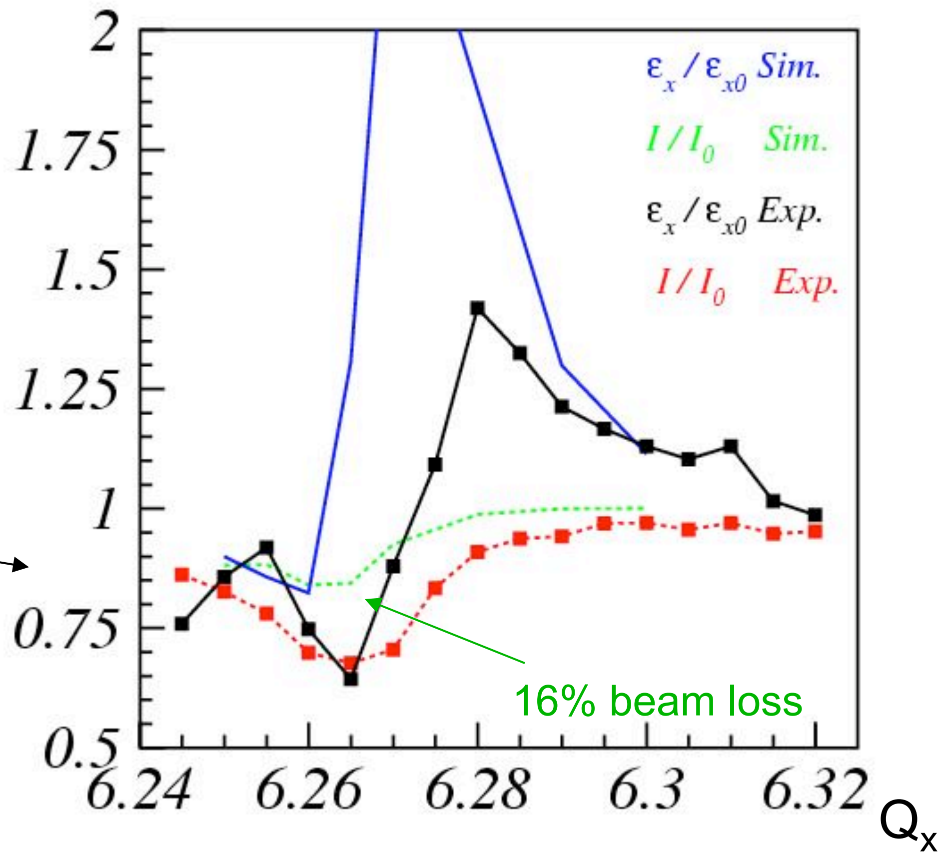
Trapping



- A.W. Chao and Month NIM 121, 129 (1974).
- A. Schoch, CERN Report, CERN 57-23, (1958)
- A.I. Neishtadt, Sov. J. Plasma Phys. 12, 568 (1986)

Benchmarking experiment at CERN-PS

G.Franchetti, I.Hofmann, M Giovannozzi,
E.Metral, M.Martini HHH-CARE Workshop 2004

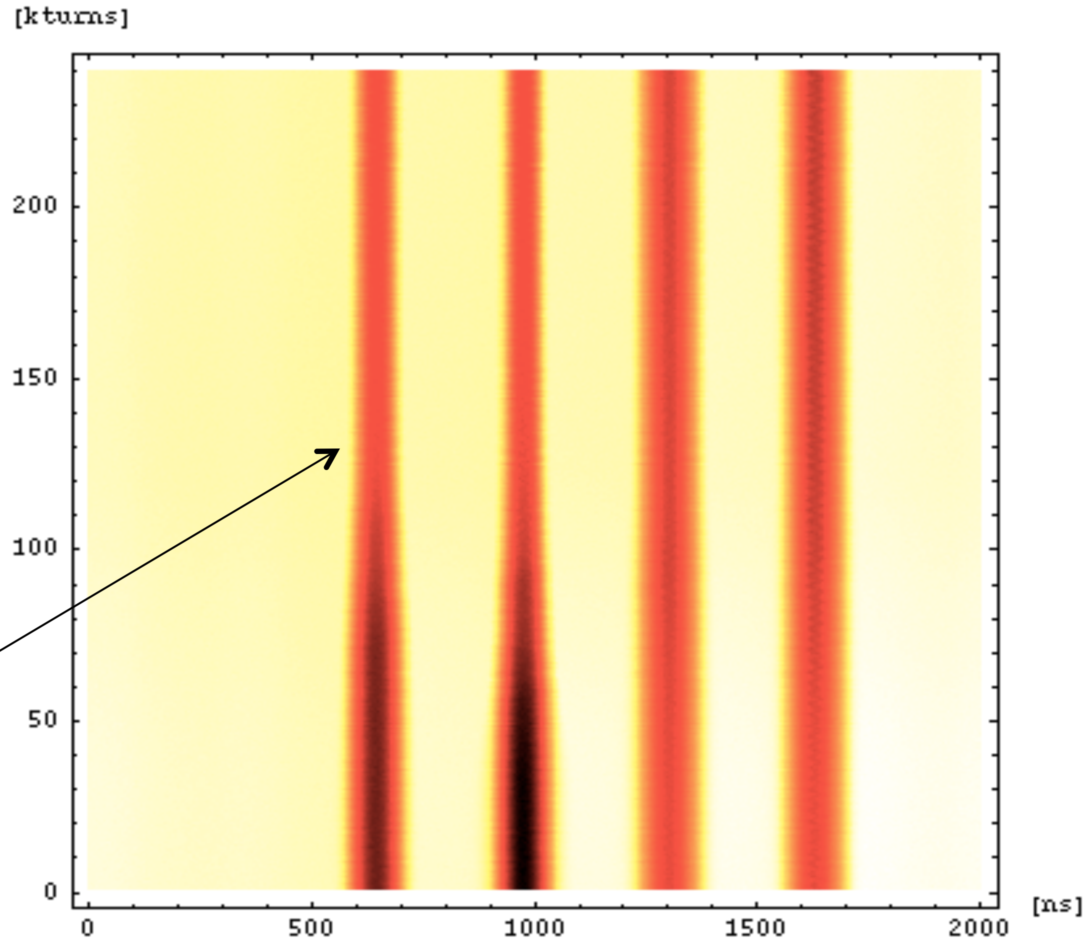


Simulated beam loss predictions have now reached 50% of the measurements

Chromaticity included

G. Franchetti, I. Hofmann, G. Arduini, E. Benedetto, M. Giovannozzi, T. Linnecar, M. Martini, E. Metral, G. Rumolo, E. Shaposhnikova, F. Zimmermann
LHC Lumi 2006, October 16-20 2006, Valencia, Spain

Further evidences of trapping/scattering phenomena @ CERN



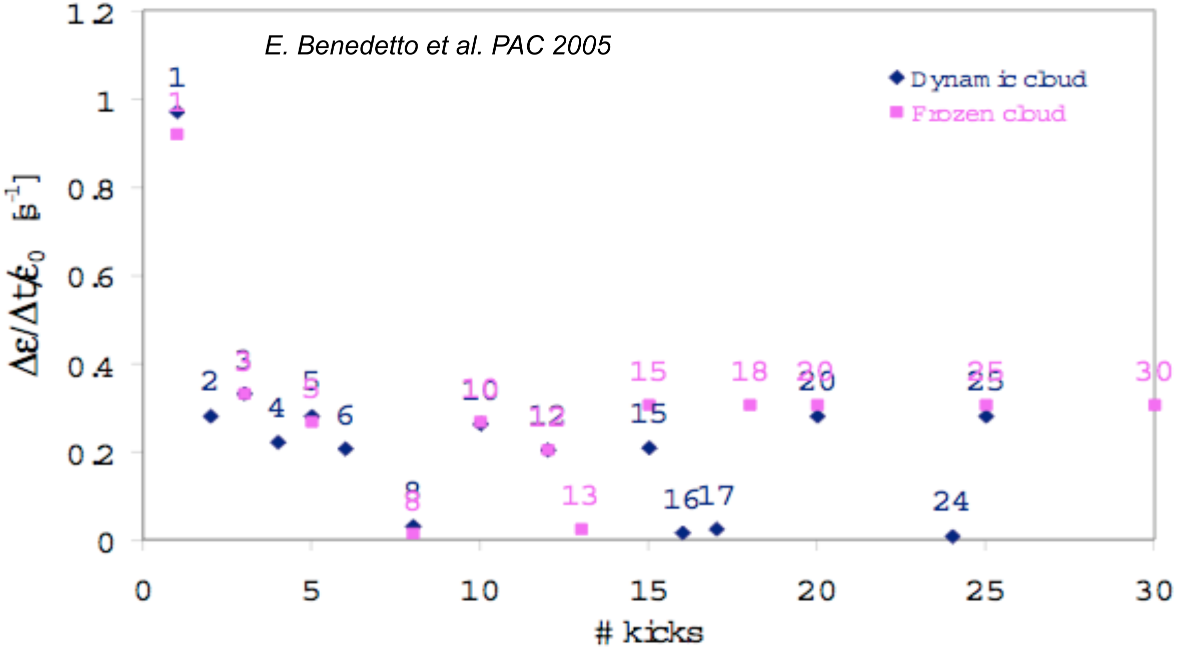
S. Hancock
E. Metral

long term beam loss
and bunch shortening

Electron cloud incoherent effects

Discussions on EC incoherent effects started in the ICFA-HB2004 workshop in relation to the SPS beam lifetime observations and continued in the HHH workshop series
(F. Zimmermann, E. Metral, E. Shaposhnikova, G. Arduini, T. Linnecar)

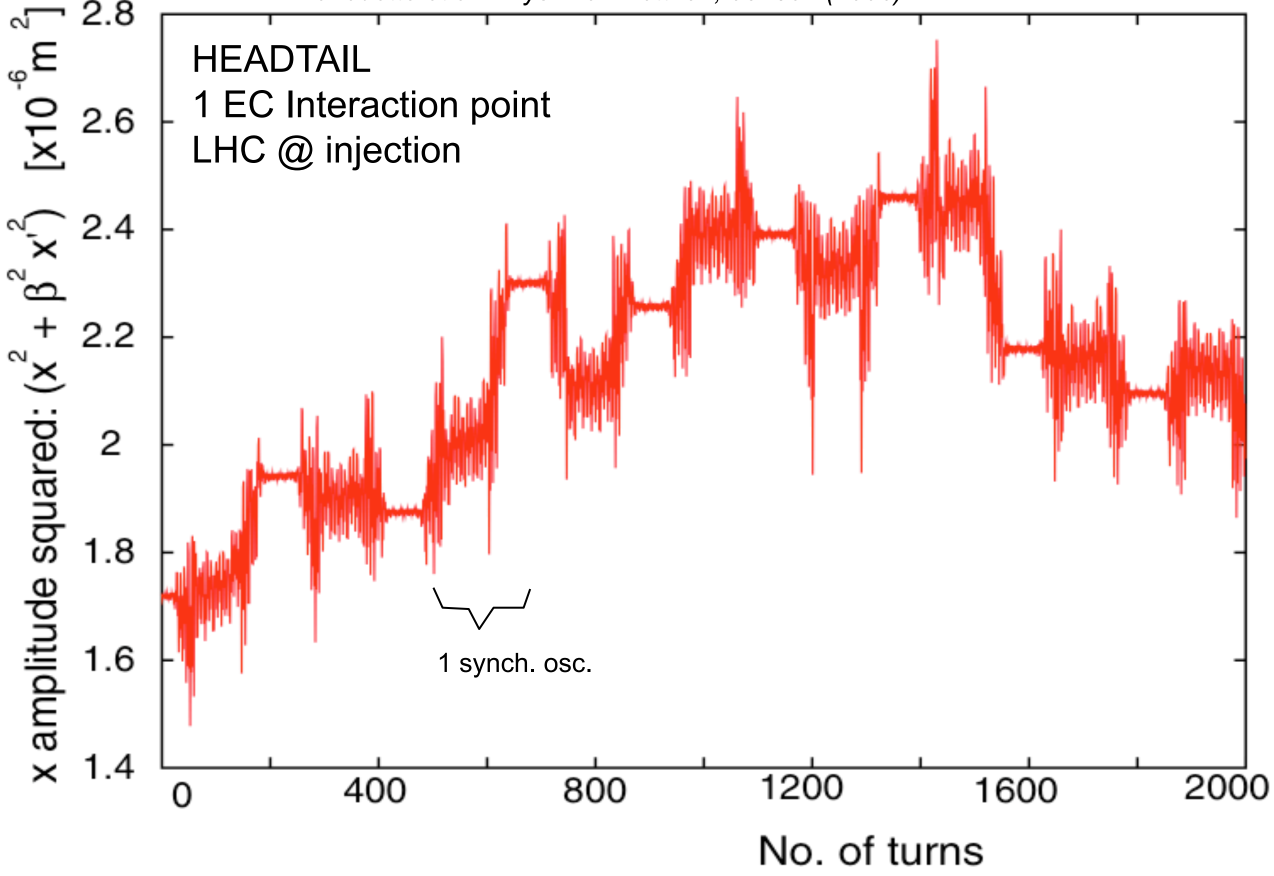
In simulations: unexplained slow emittance growth (noise?)



Average growth rate $\Delta\varepsilon/(\varepsilon\ \Delta t) \sim 0.4$

Evidence of EC induced scattering

E. Benedetto et al. Phys. Rev. Lett. 97, 034801 (2006).

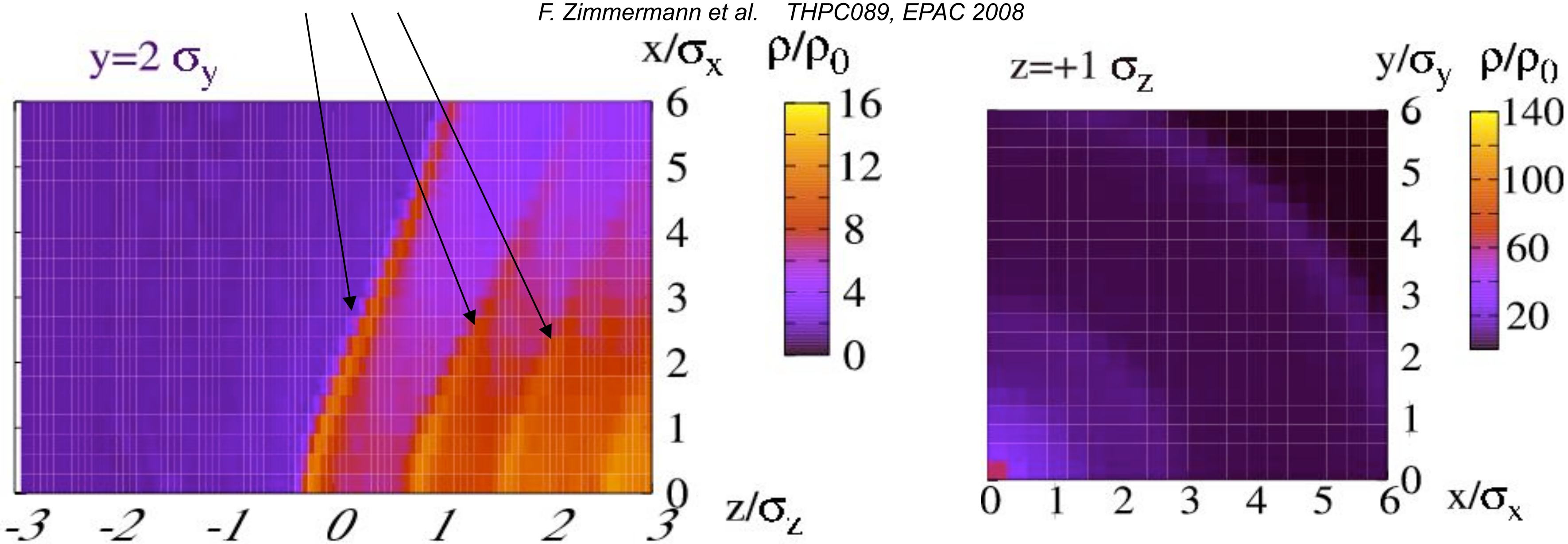


The pinch of the electron cloud

During the bunch passage through an uniform EC,
electrons oscillates in the bunch potential creating a pinch

Electron cloud rings created by a Gaussian bunch in free field region

F. Zimmermann et al. THPC089, EPAC 2008



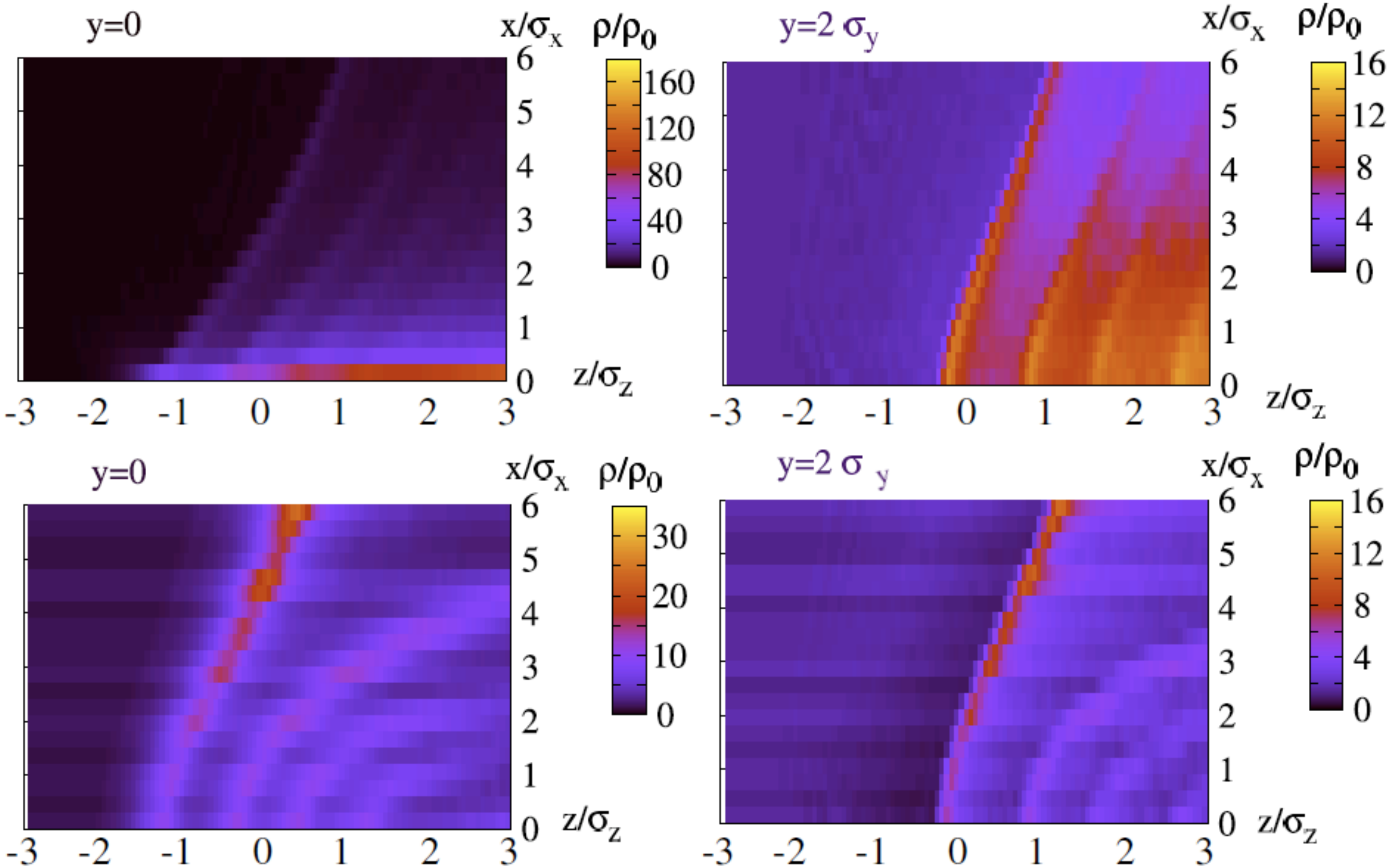
Pinched EC creates nearly circular rings which feed back on the main beams

EC-rings (stripes)

F. Zimmermann et al.   THPC089, EPAC 2008

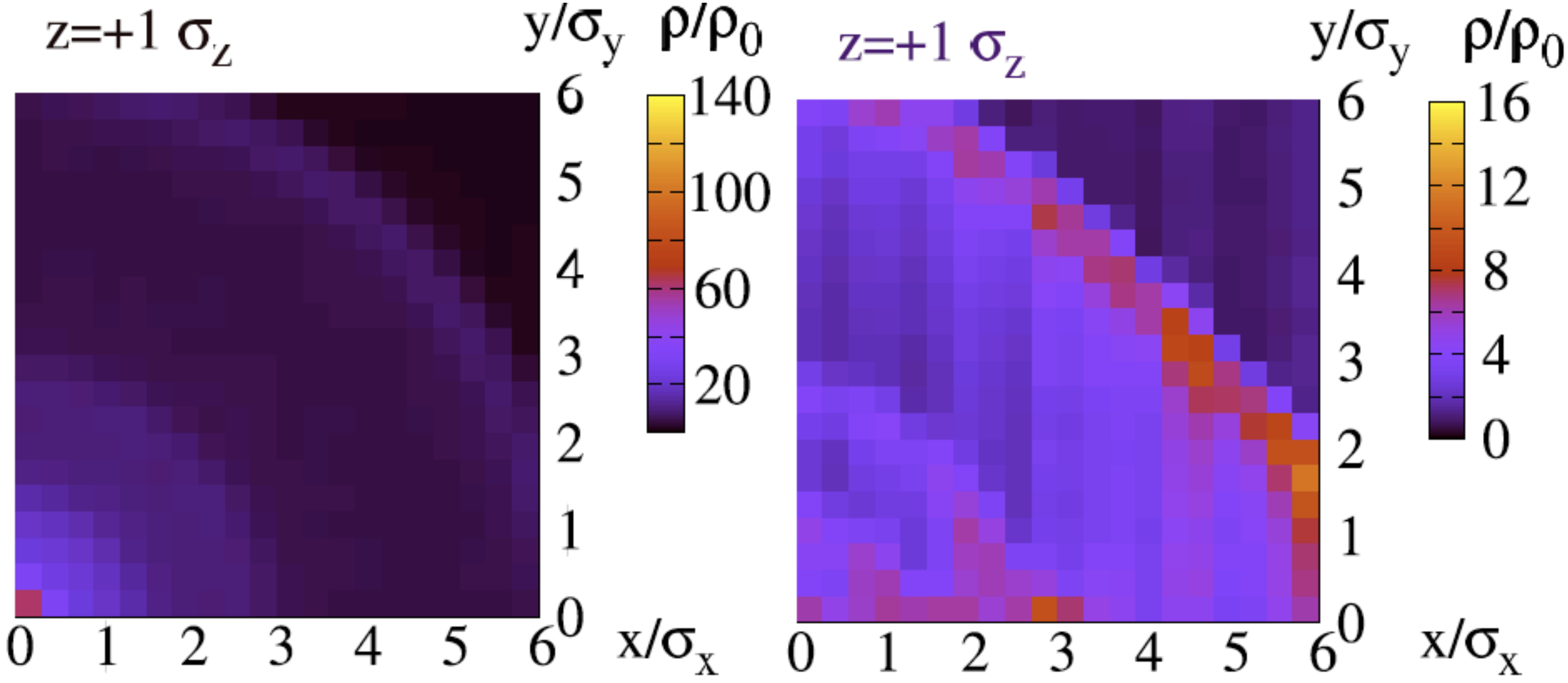
In field free-region

In a dipole



transverse profile => EC rings

F. Zimmermann et al.   THPC089, EPAC 2008



in a field free region

In a dipole

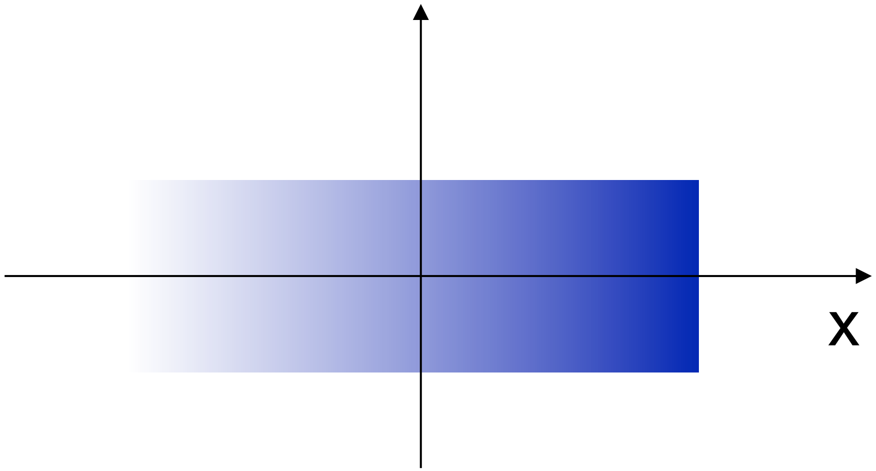
Previous models of pinched EC (frozen)

Varying central density

E. Benedetto et al. Phys. Rev. Lett. 97, 034801 (2006).

Linear varying EC density and varying EC size keeping

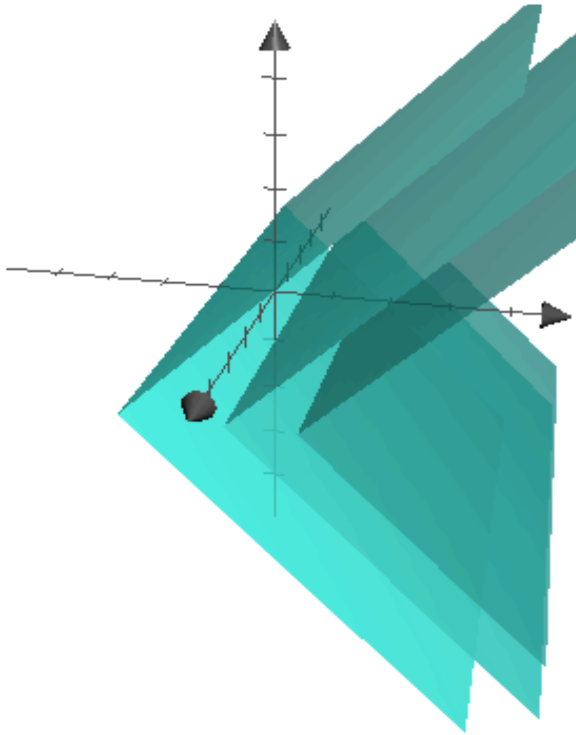
$$\rho_e \sigma_e^2 = \text{const.}$$



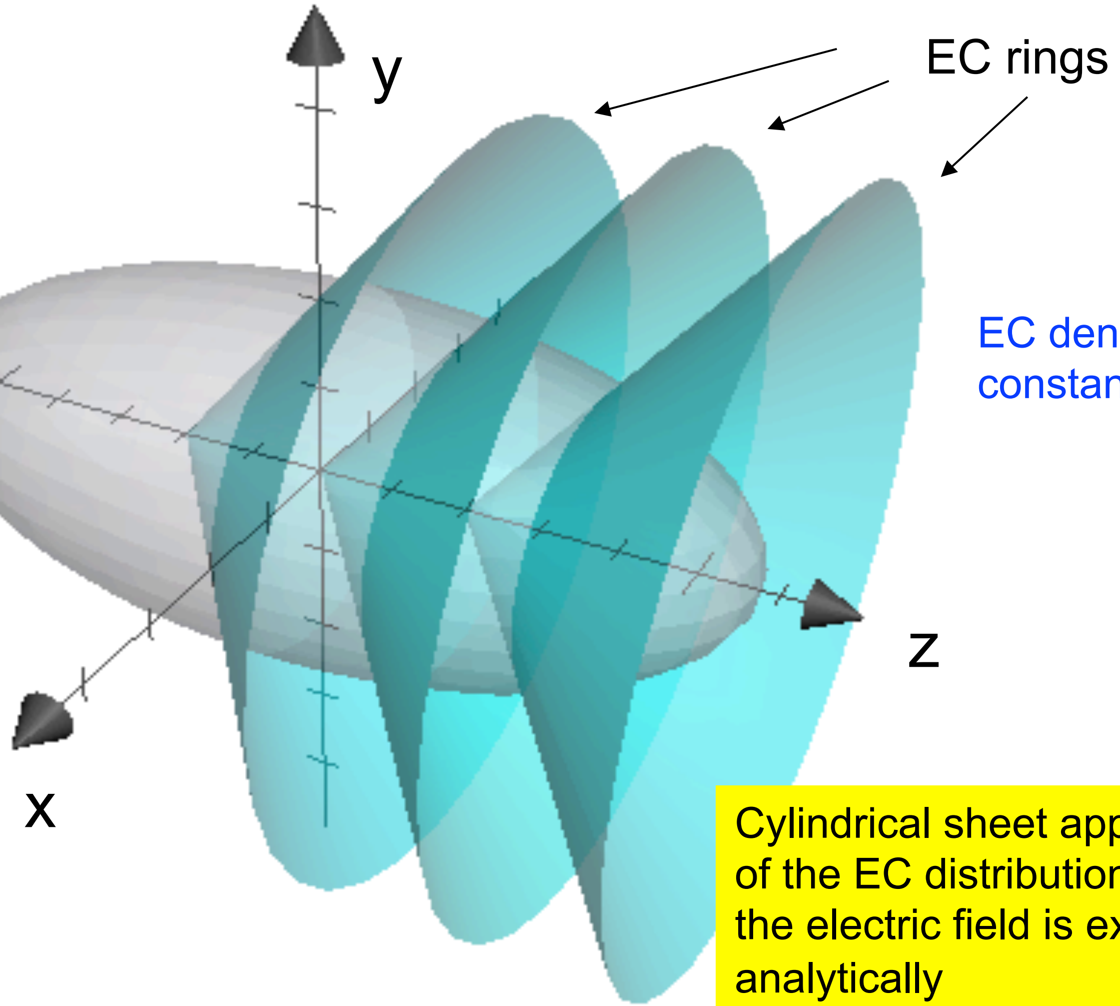
No structured EC pinch modeled

Parallel EC Wall

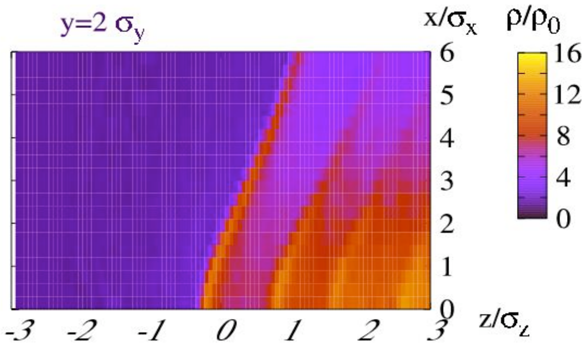
G. Franchetti and F. Zimmermann
Proc. of Beam 07 , Oct. 1-6, 2007



New EC frozen model

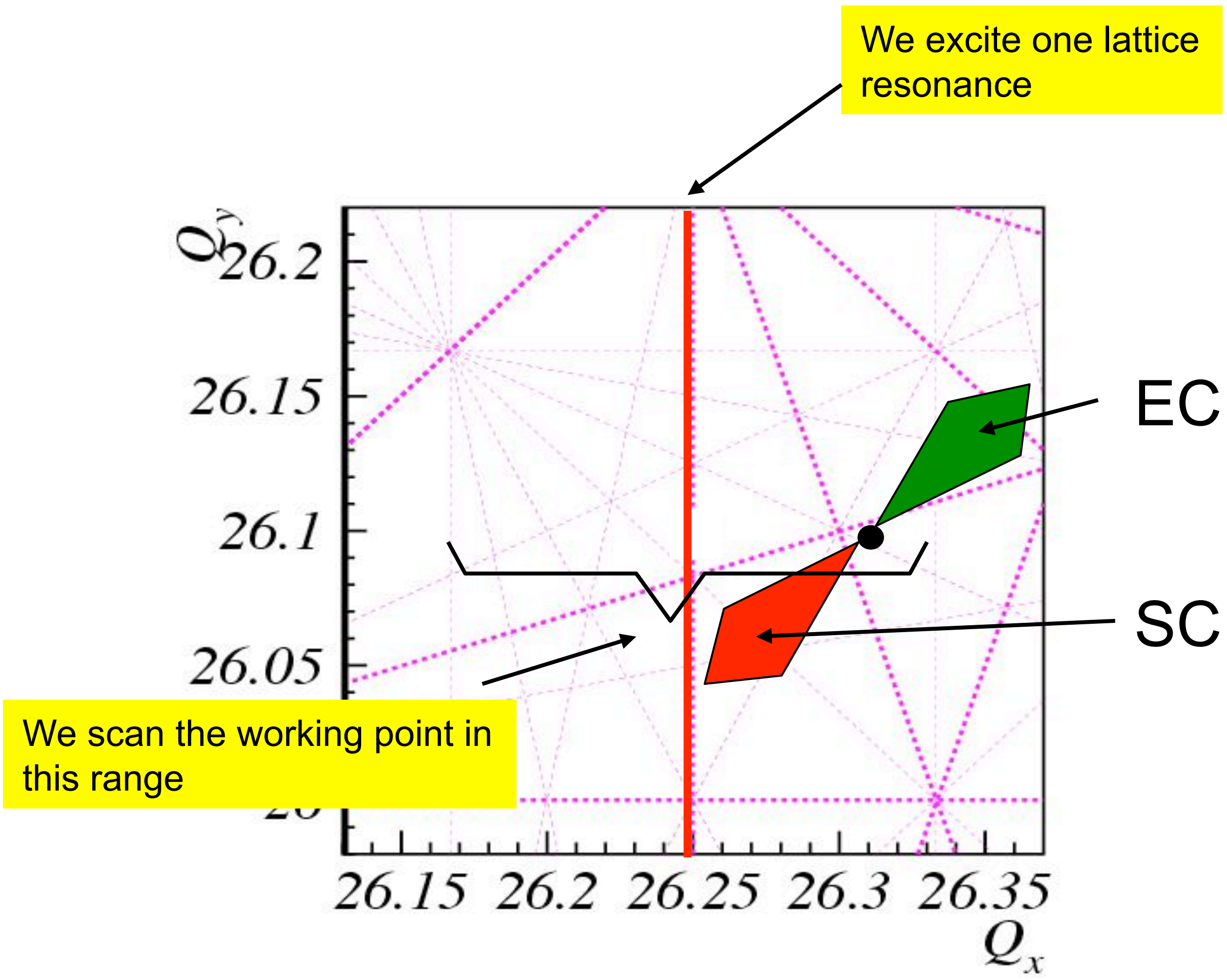


EC density
constant in the rings



Cylindrical sheet approximation of the EC distribution:
the electric field is expressed analytically

Comparison of EC and SC incoherent effects

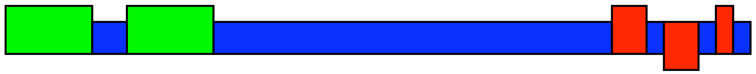


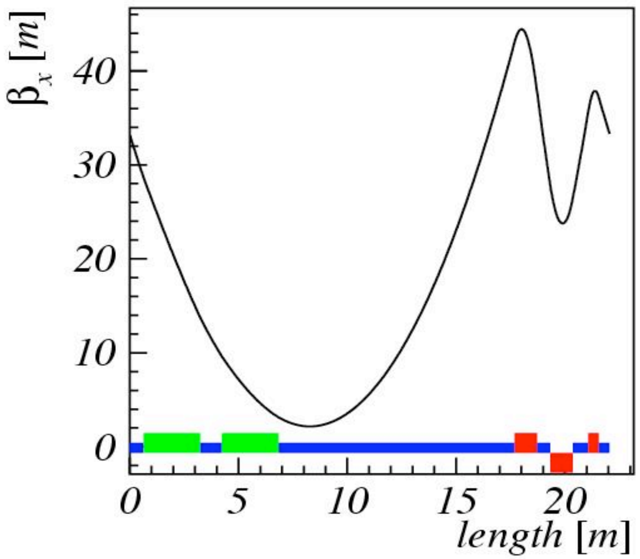
Equal SC and EC detuning

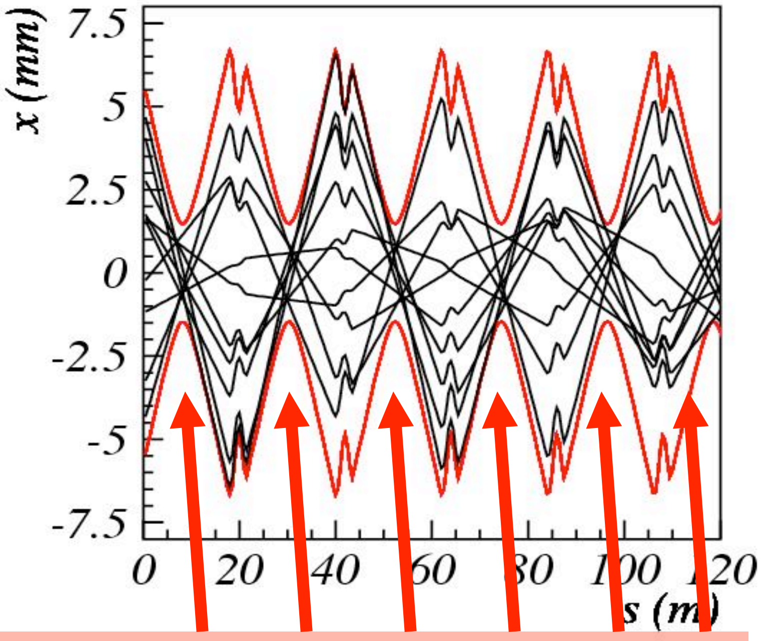
$\Delta Q_{sc} = - \Delta Q_{ec} = -0.075$

Space charge induced structure resonances

Lattice with fodo cell



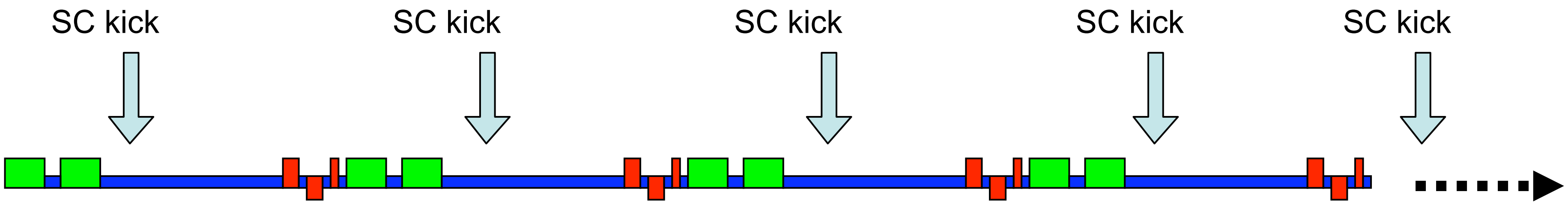




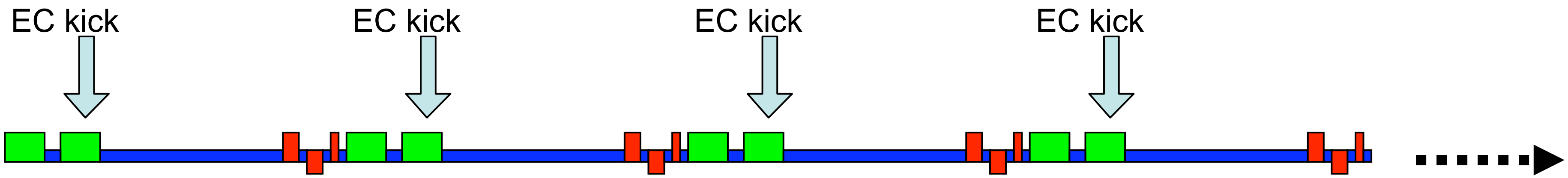
At these positions of minimum transverse size space charge creates strong nonlinear forces which acts like nonlinear errors

Space charge and electron cloud structure resonances

The lattice optics induces a structure of space charge kicks, which excites a resonance



The electron cloud creates also structure resonances as it is strongly localized



Due to the property of Coulomb forces

$$E_x(x) = -E_x(-x)$$

resonances of order 2,4,6,8,.. are excited

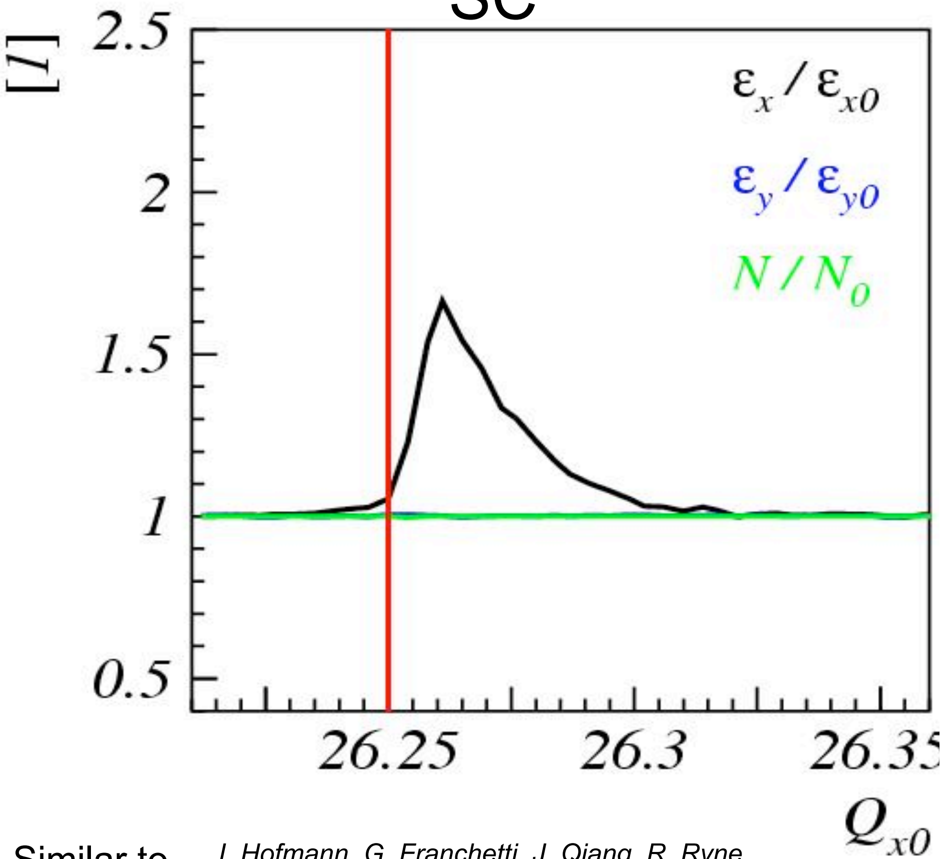
Strength of the resonance is proportional to the Coulomb induced tunespread

Comparison of SC and EC incoherent effects for 2D beams

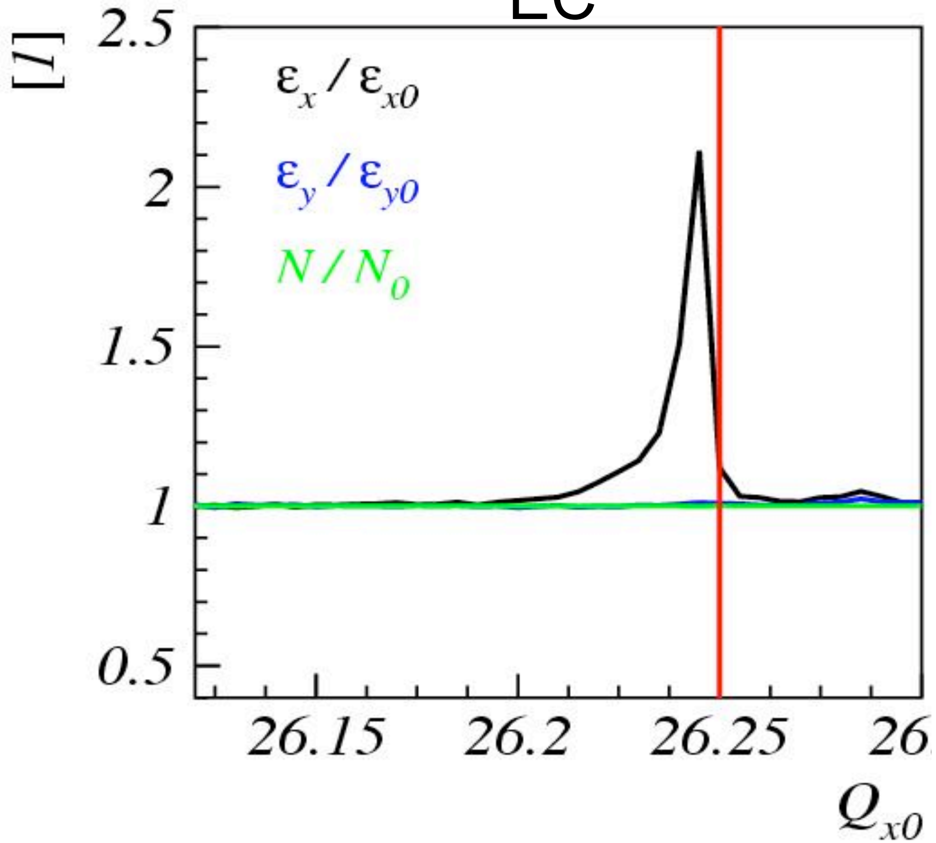
Structure resonance: 105 EC and SC kicks, $\Delta Q_{sc} = - \Delta Q_{ec} = -0.075$

Synchrotron motion is frozen

SC



EC

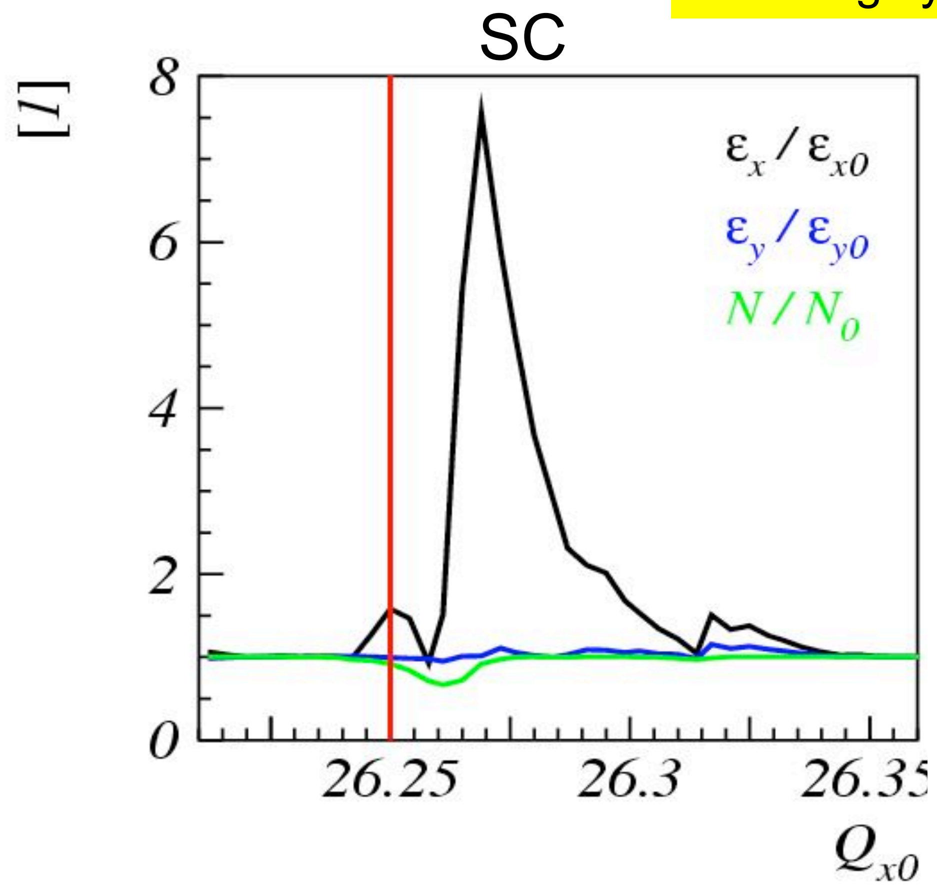


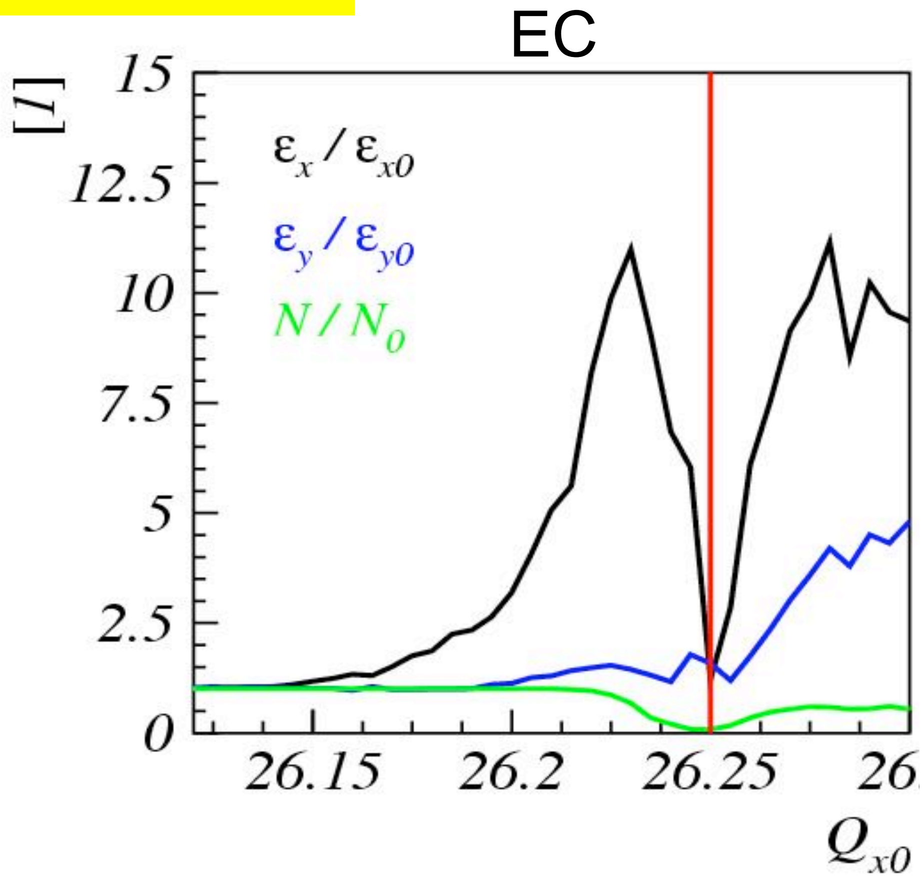
Similar to *I. Hofmann, G. Franchetti, J. Qiang, R. Ryne*
Proc. 29th ICFA Workshop(AIP, New York, 2003), ***693****, 65*

Comparison of SC and EC incoherent effects for bunched beams

Structure resonance: 105 EC and SC kicks, ΔQ_{sc} = - ΔQ_{ec} = -0.075

Including synchrotron motion

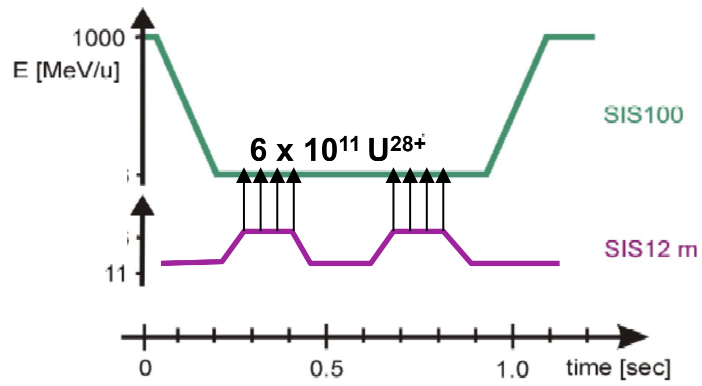




Space charge incoherent effects in FAIR

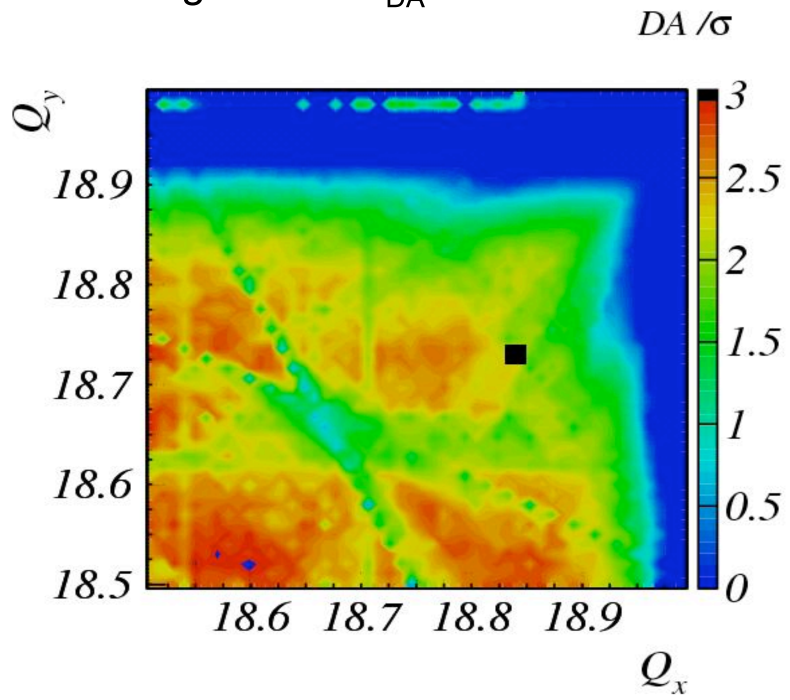
First bunch @ 150 MeV/u

Nominal N_{ions} = 0.75 x 10^{11}/bunch
Beam1: $\varepsilon_{x/y}$ = 35/15 mm-mrad (2σ) $\Delta Q_{x/y}$= -0.31/-047
Beam2: $\varepsilon_{x/y}$ = 50/20 mm-mrad (2σ) $\Delta Q_{x/y}$= -0.21/-0.24
Turns = 1.2 x 10^5 (1 sec.)



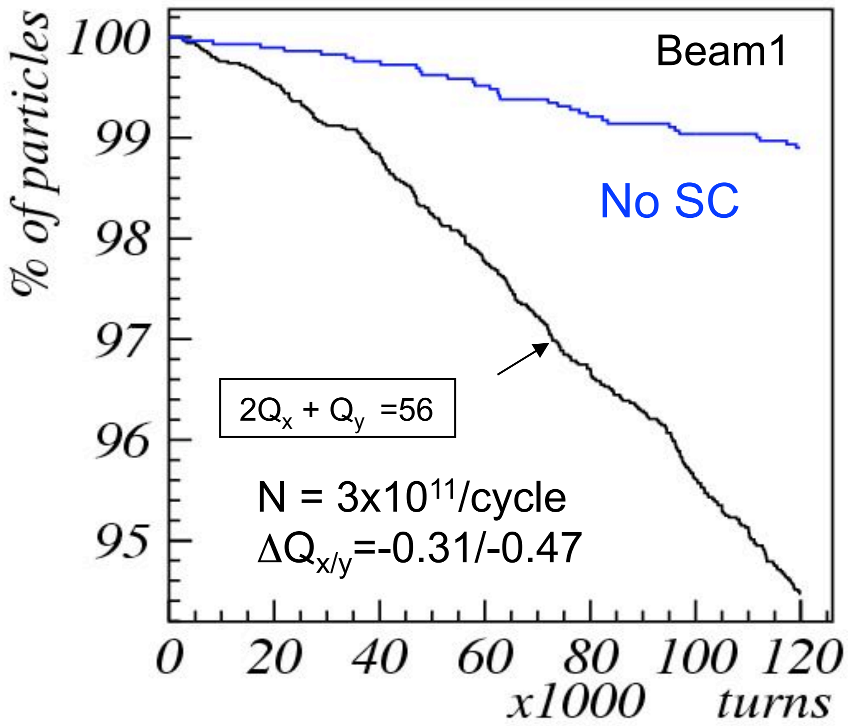
- *P. Spiller et al., MOPC100, EPAC 2008;*
- *J. Stadlmann et al., MOPC124, EPAC 2008;*
- *P. Spiller, C. Omet et al., MOPC099,EPAC 2008;*
- *A. Kovalenko, WEPD017, EPAC 2008;*
- *P. Schnizer et al., TUPP105, WEPD021, EPAC 2008;*
- *E. Mustafin et al., THPP102, EPAC 2008;*
- *O. Malyshev et al., THPP099, EPAC 2008;*
- *A.W. Molvik et al., Phys. Rev. Lett.* ***98*** *054801 (2006).*

Nonlinear errors in bends and quadrupoles + COD with 16 seeds average DA - $3\sigma_{DA}$.

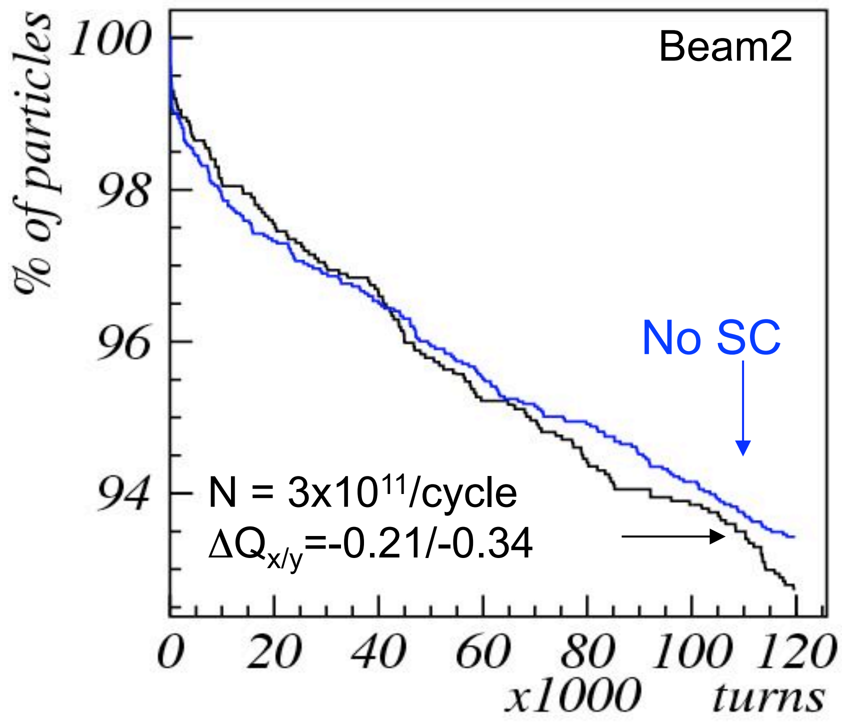


Beam loss estimates

Take one seed (1mm residual COD, 99% beam loss) + $\langle \delta p/p \rangle_{rms}$ = 5 x10^{-4}



Space charge dominates
(incoherent effects)



DA dominates over space charge

Over the full cycle N = 3x10^{11} ~ 3% and for N= 6x10^{11} ~15%

Exploratory discussion of EC incoherent effects in LHC

Approximated lattice: constant focusing between EC kick

1 EC kick per dipole -> 1152 kicks

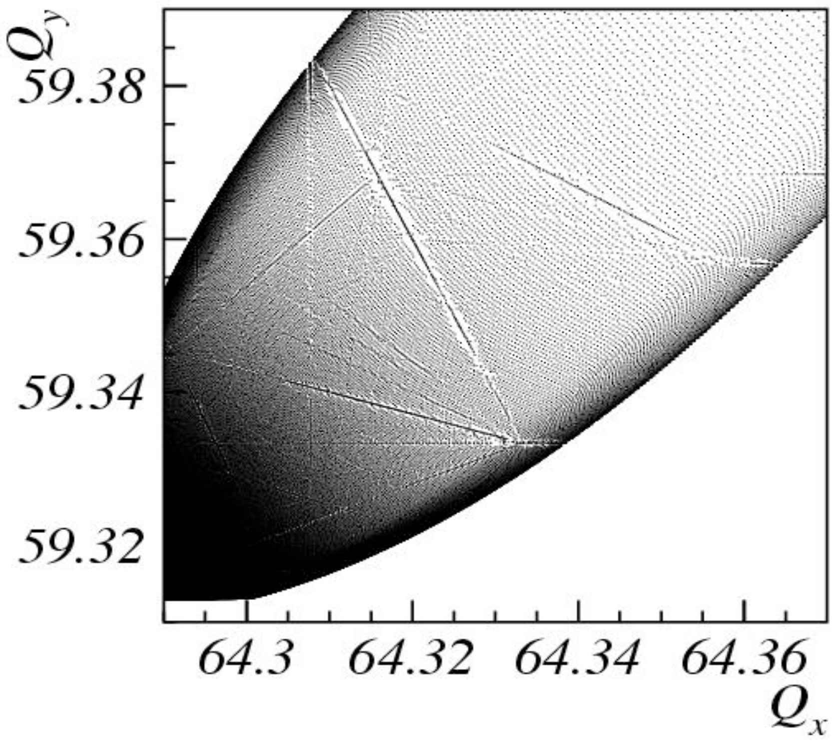
Tunes: Q_x = 64.28 Q_y = 59.31, Q_s = 1/168

Assumptions:

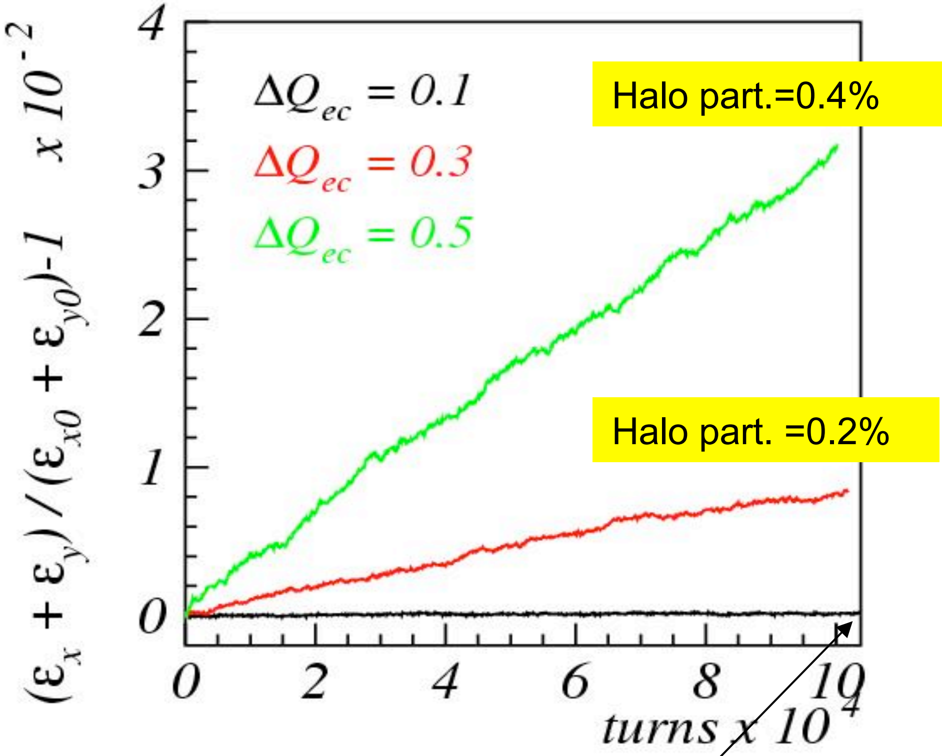
1 all EC kicks are equally strong
2 no lattice change of beta is included
3 no fluctuations of EC included
4 no adjustment of EC rings as function of total integrated detuning

Possible incoherent effects in LHC

$Q_x = 64.28 \;\; Q_y = 59.31$
$\Delta Q_{ec} = 0.18$

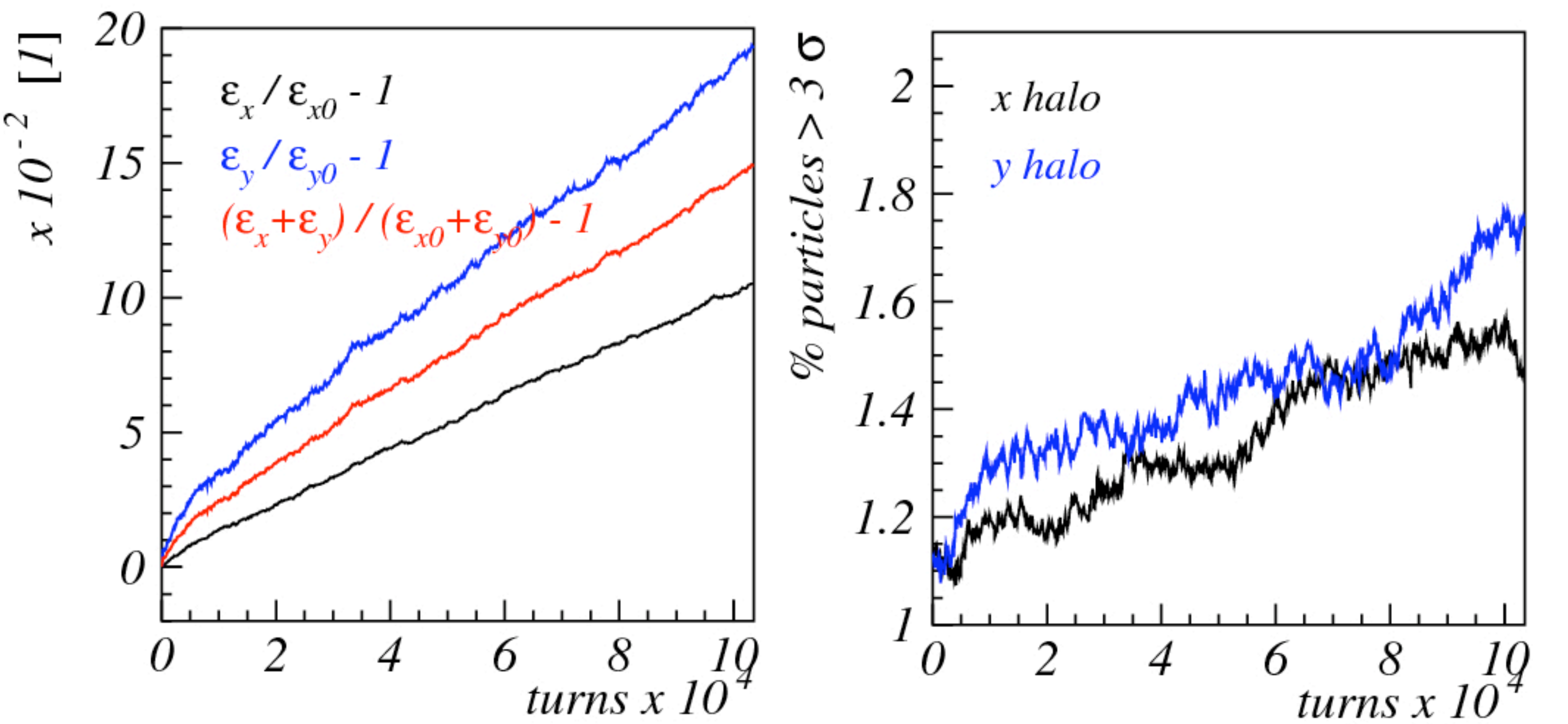


Slow emittance growth

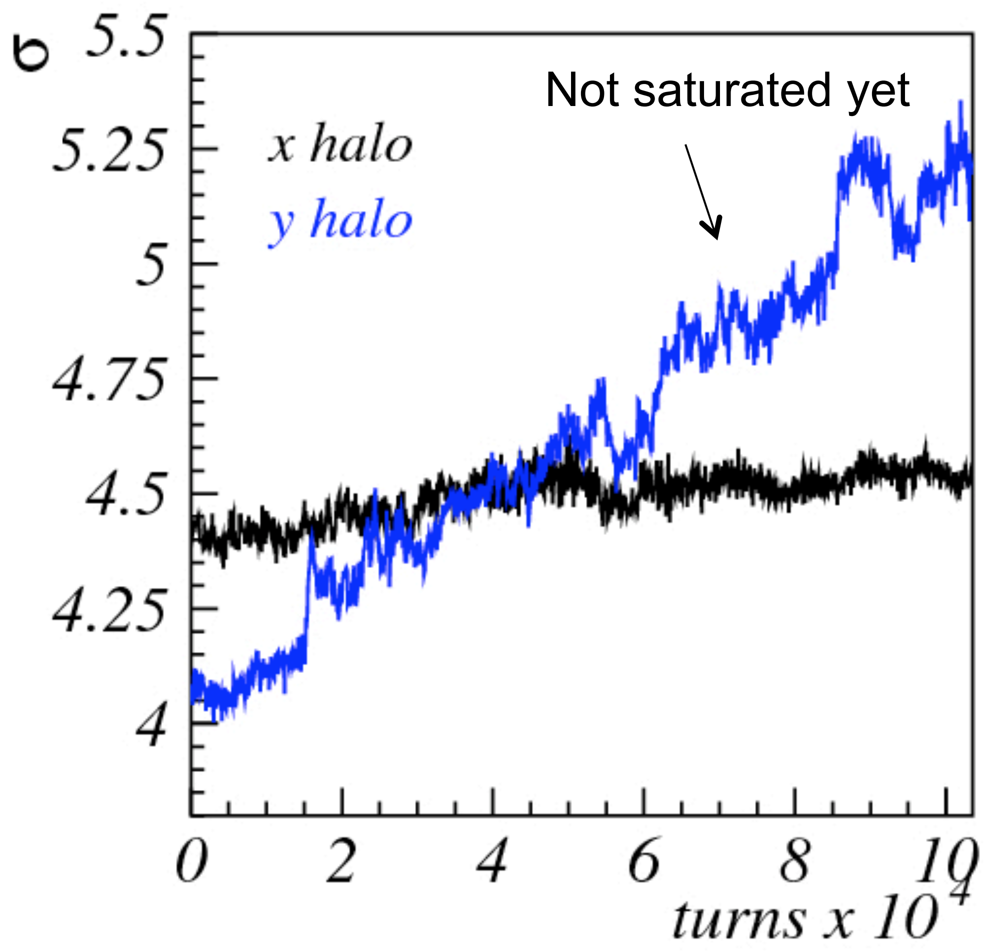


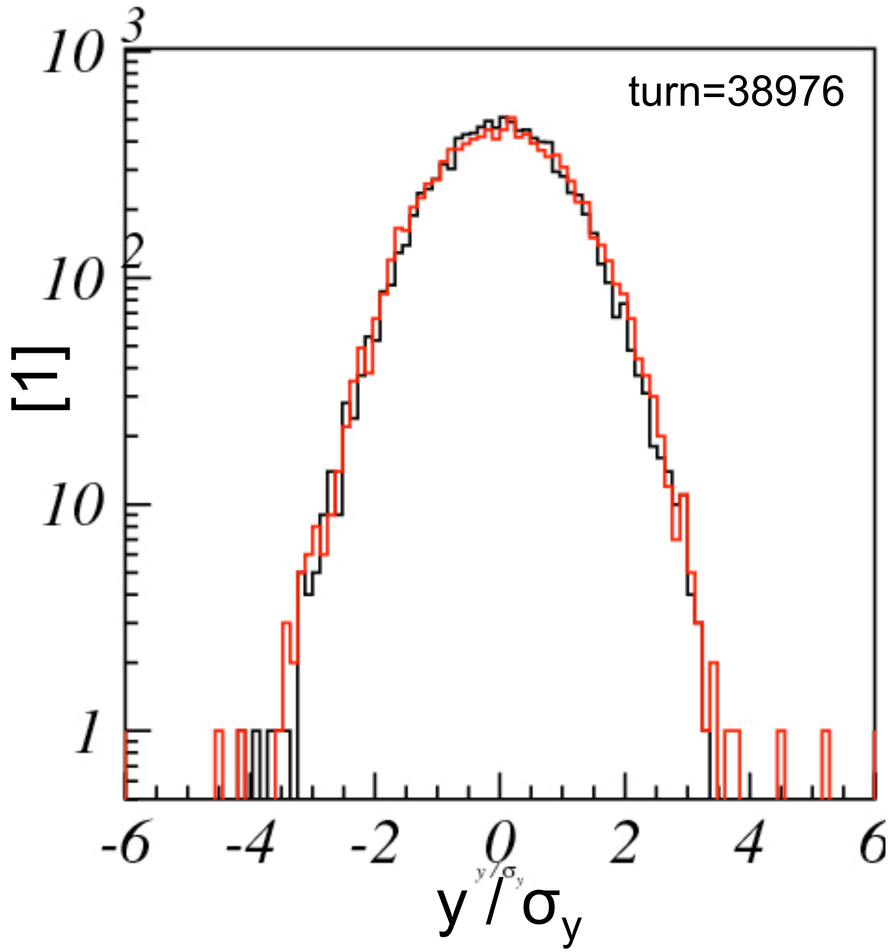
emttance growth of 0.04 %

For $\Delta Q_{ec} = 0.7$



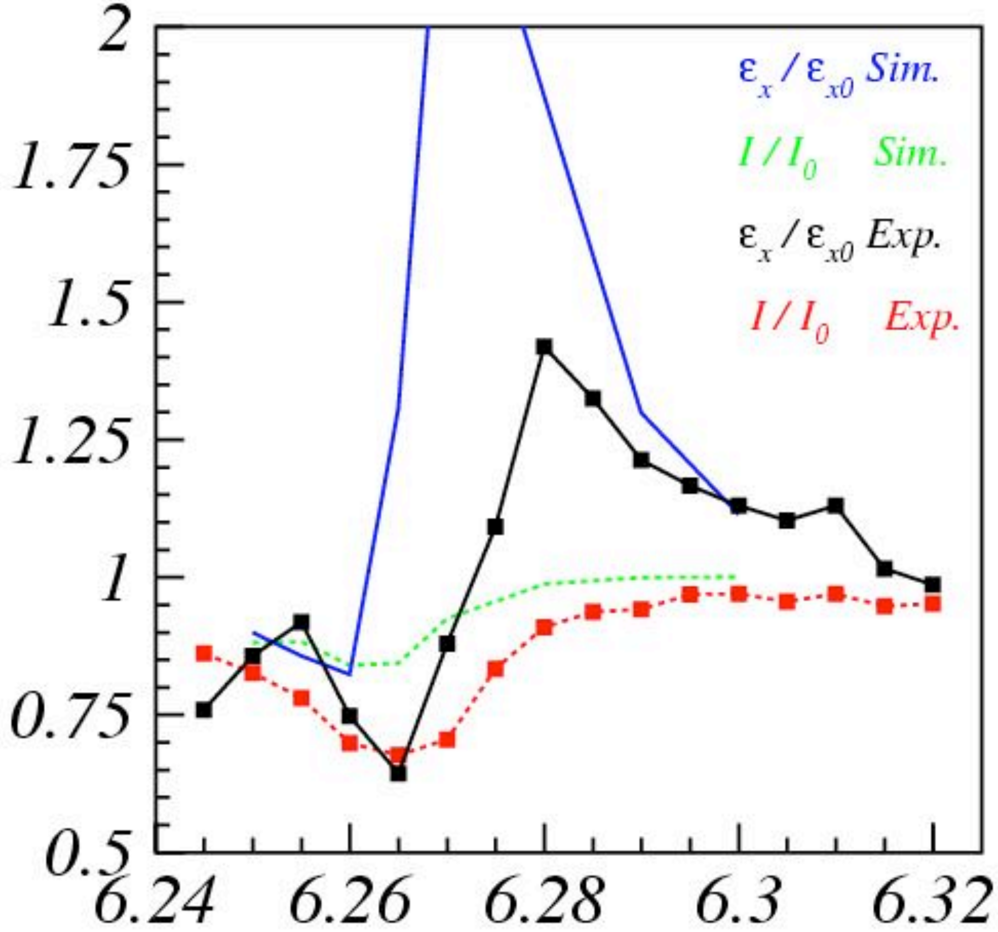
Scattering dominated regime (long term diffusion)

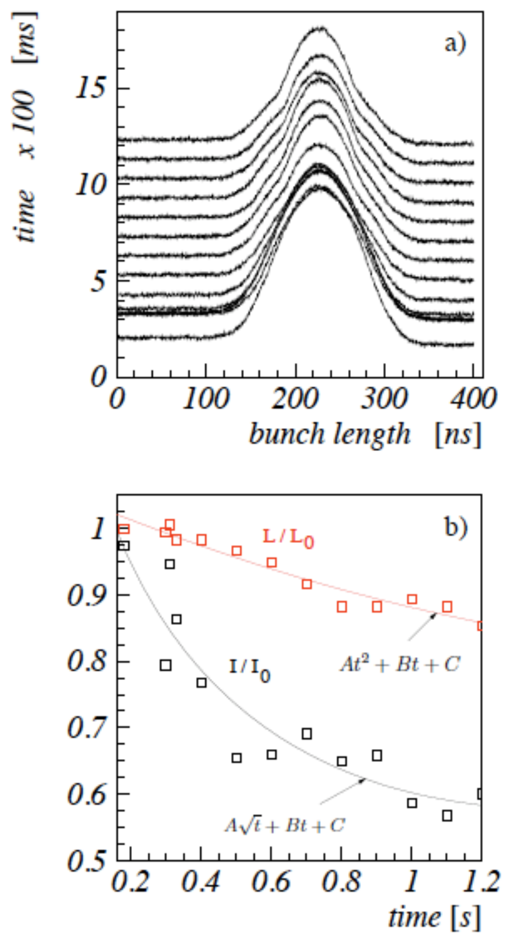




Experimental verification and benchmarking

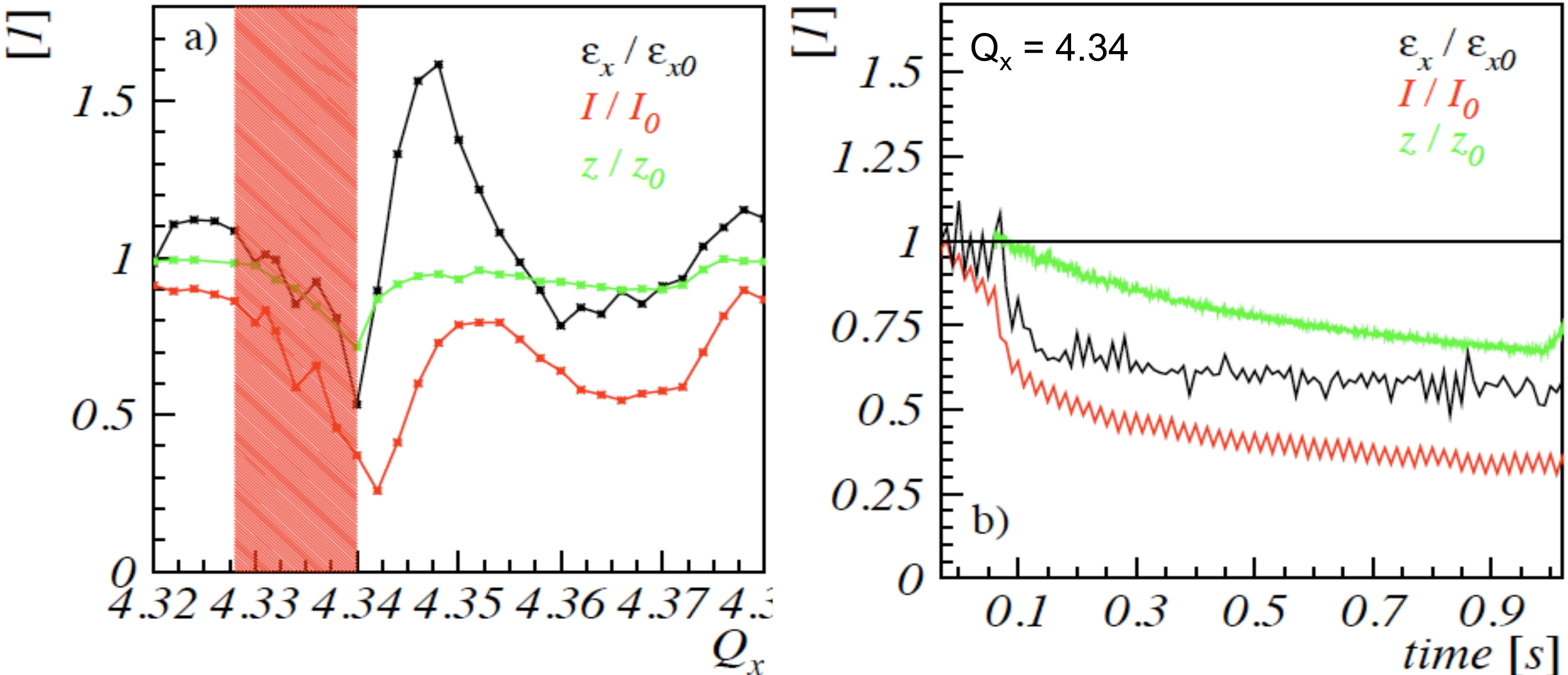
CERN-PS result of 2002-2003





The experimental campaign at GSI (S317 2006-2008)

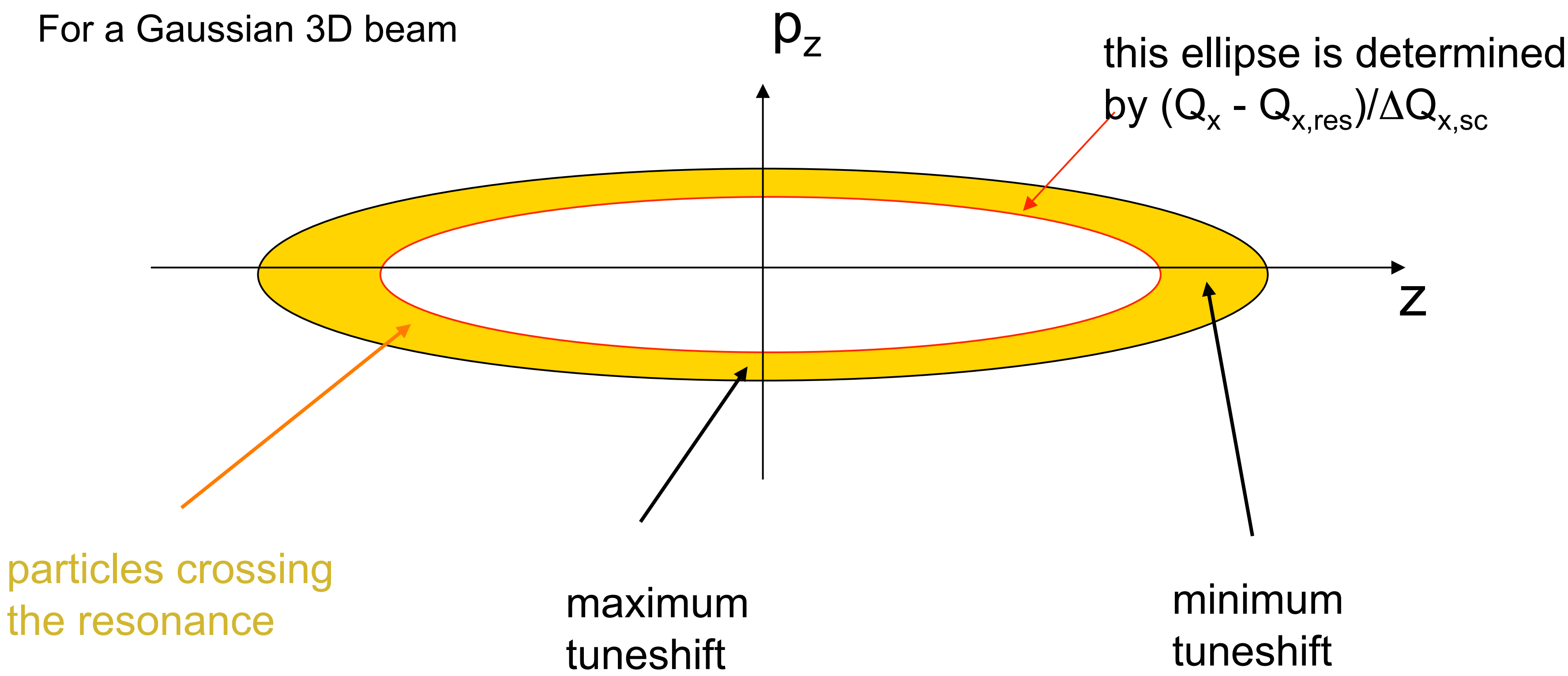
$\Delta Q_x = 0.04$, ε_x=6.5 mm-mrad, ε_y=3.5 mm-mrad



The S317 experiment on high intensity beam loss and emittance growth
G. Franchetti, I. Hofmann, W. Bayer, F. Becker, O. Chorniy, P. Forck, T. Giacomini, M. Kirk,T. Mohite, C. Omet, A. Parfenova,P. Schütt, Proc. Of HB2008 workshop

Asymptotic limits

For a Gaussian 3D beam



$$\Delta N/N \sim (Q_x - Q_{x,res})/\Delta Q_{x,sc}$$

The correlation is function of the longitudinal distribution

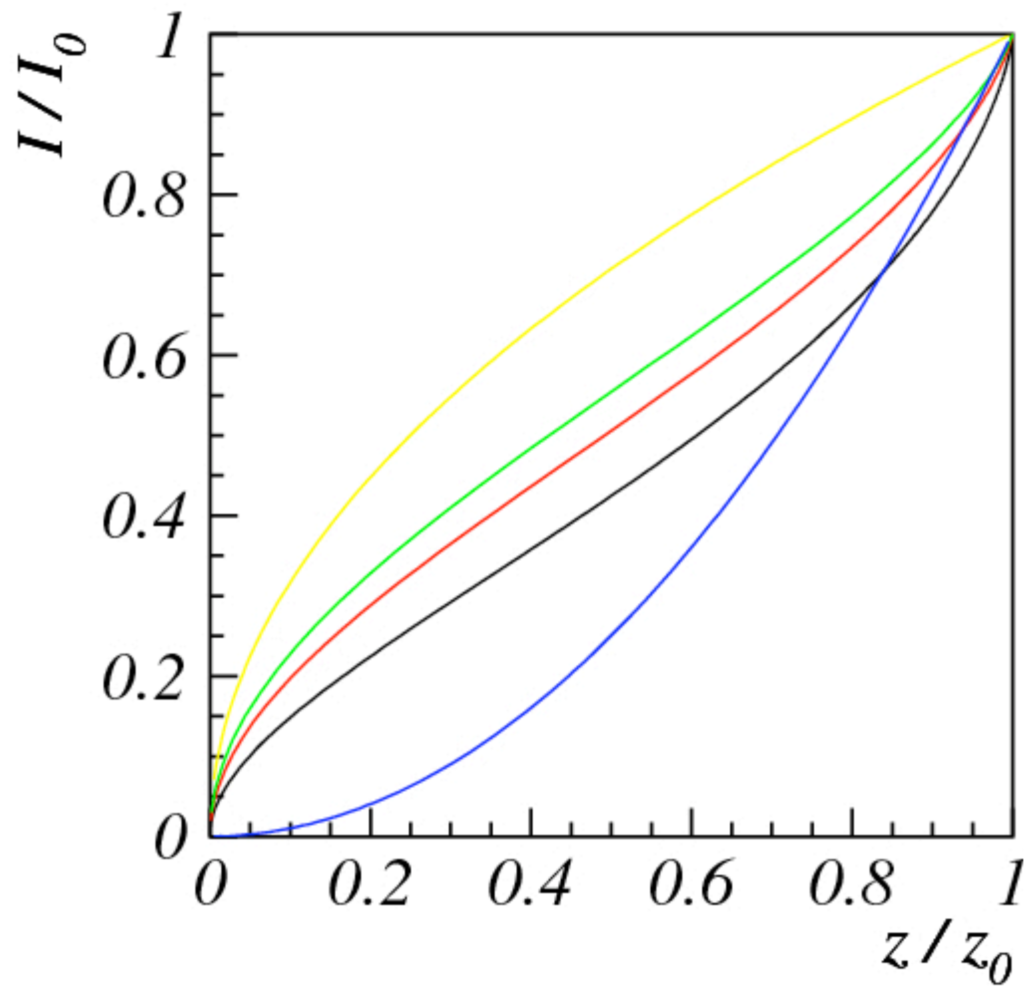
$\rho \propto (\epsilon_z/\epsilon_{z0})^{-3/2}$

$\rho \propto \exp(-0.5\,\epsilon_z/\epsilon_{z0})$

$\rho \propto \exp[-0.5\,(\epsilon_z/\epsilon_{z0})^{1/2}]$

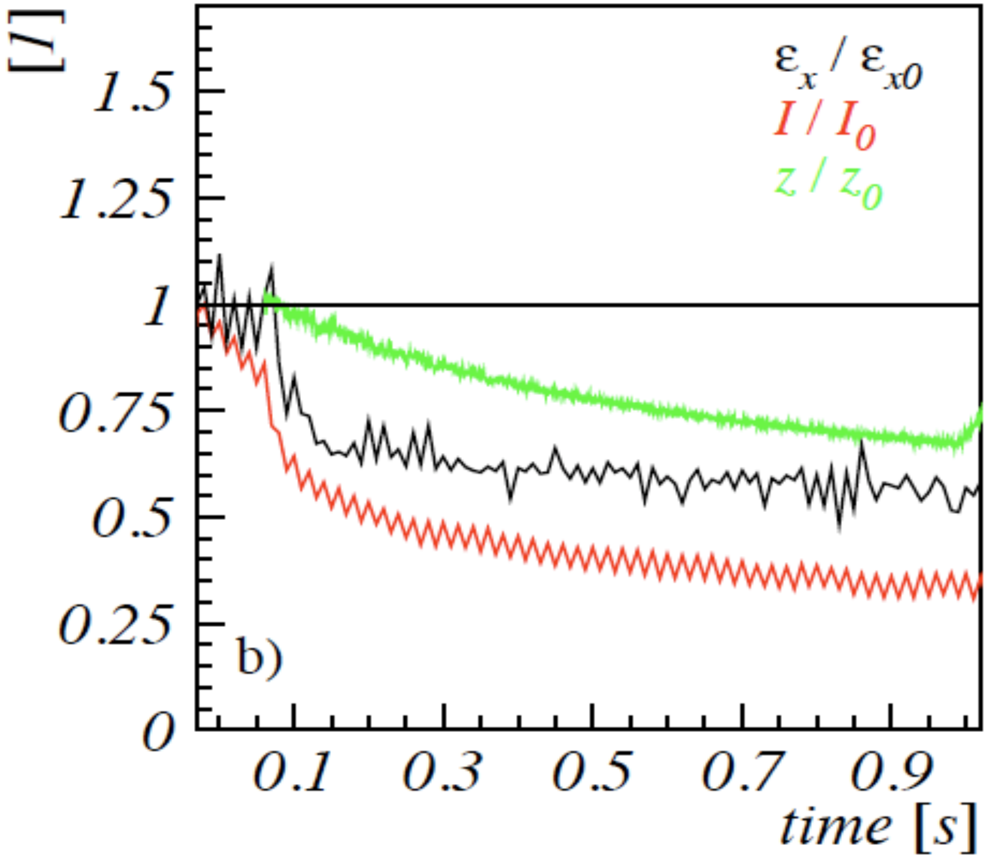
$\rho \propto \exp[-0.5\,(\epsilon_z/\epsilon_{z0})^{1/4}]$

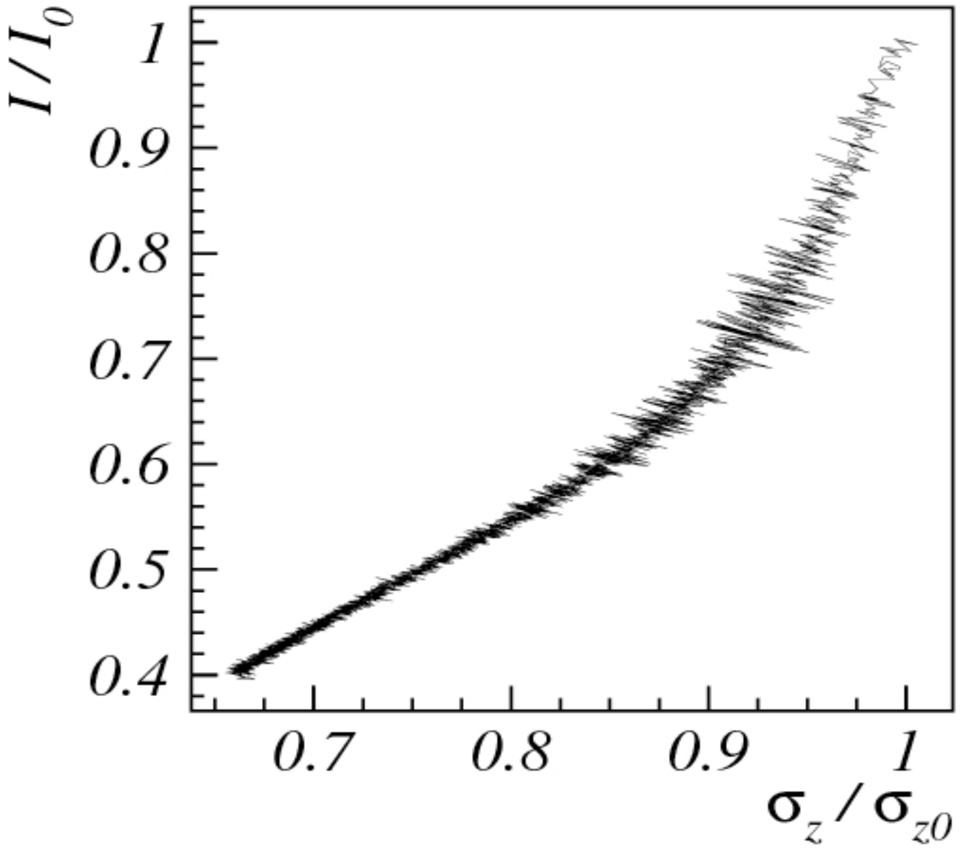
$\rho \propto \Theta(\epsilon_z/\epsilon_{z0})$



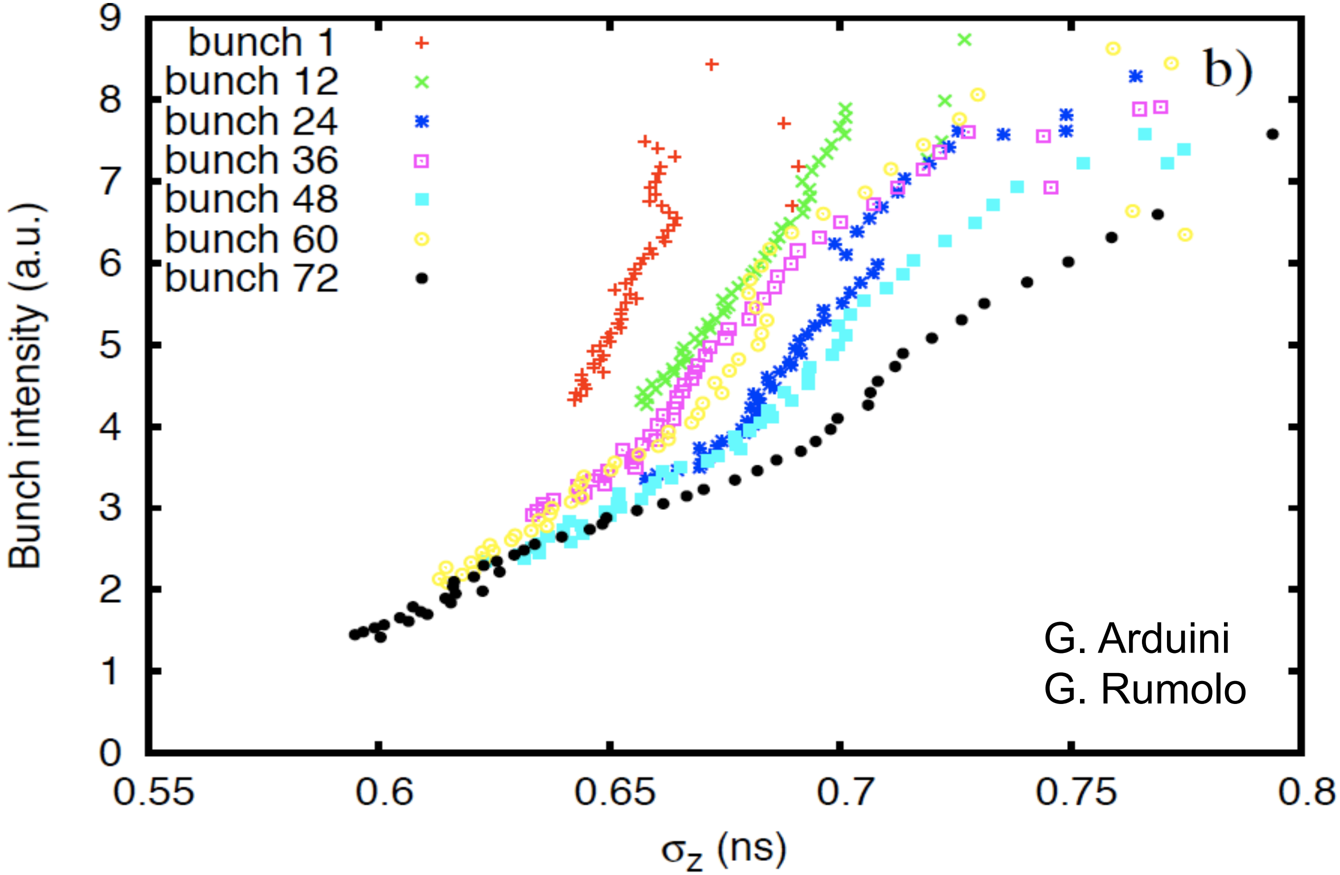
Correlation Beam loss – Particle in bucket

Experimental findings for Q_x = 4.34





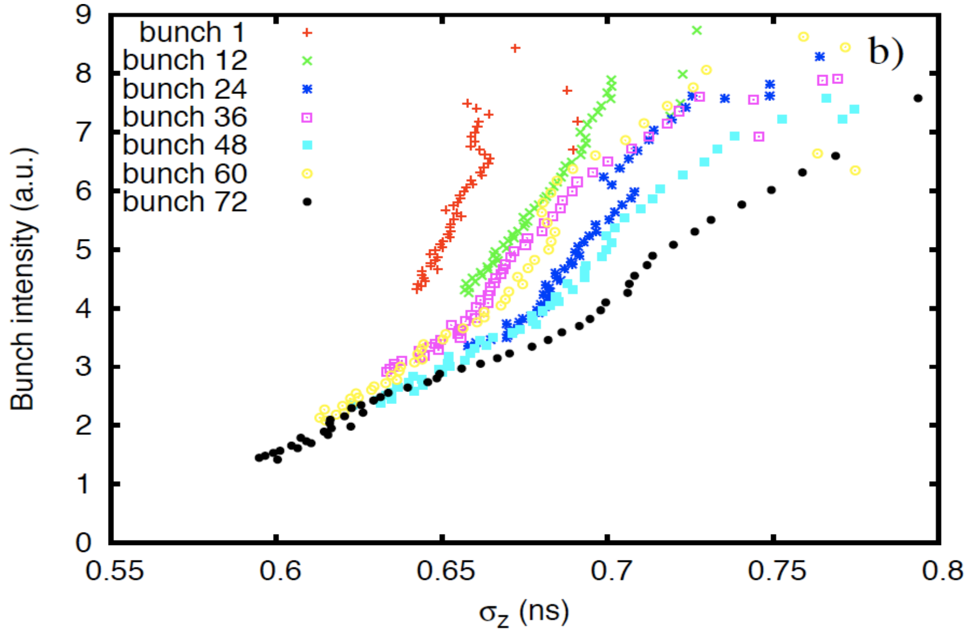
Evidences of EC incoherent effect in SPS



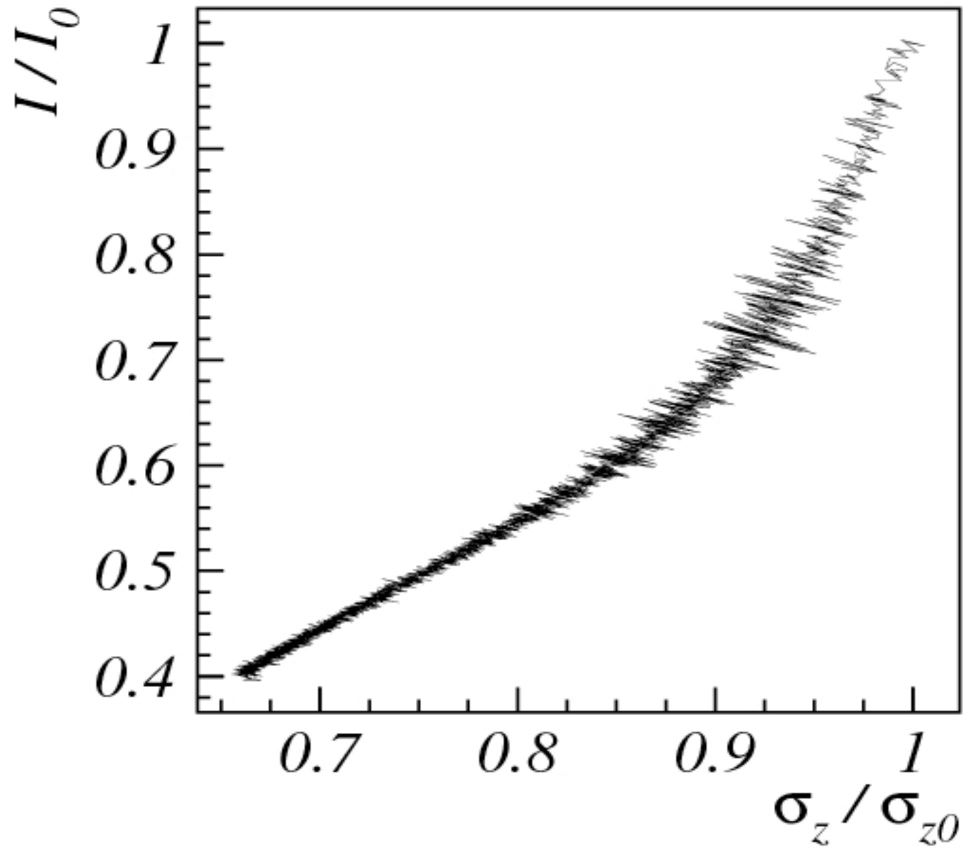
G. Franchetti, I. Hofmann, G. Arduini, E. Benedetto, M. Giovannozzi, T. Linnecar, M. Martini, E. Metral, G. Rumolo, E. Shaposhnikova, F. Zimmermann
LHC Lumi 2006, October 16-20 2006, Valencia, Spain. p. 192.

Comparison SPS bunch train – SIS space charge

Electron Cloud (?)

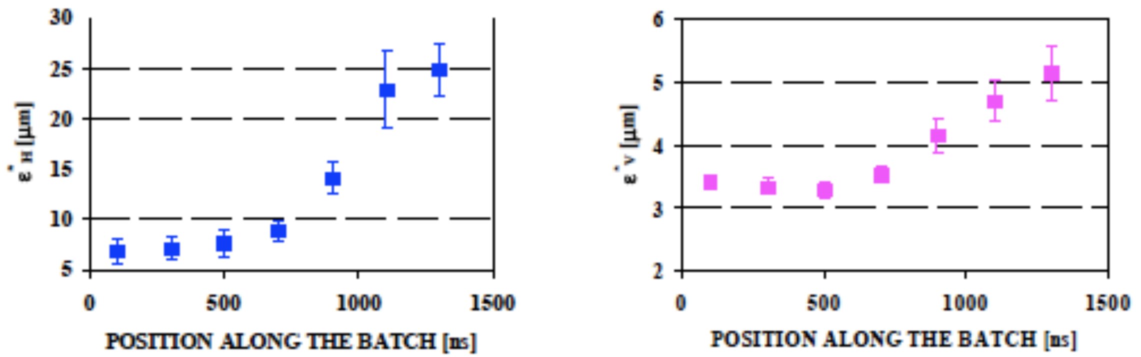


Space charge



An observation on this picture

Observations prior to 2006 (III)

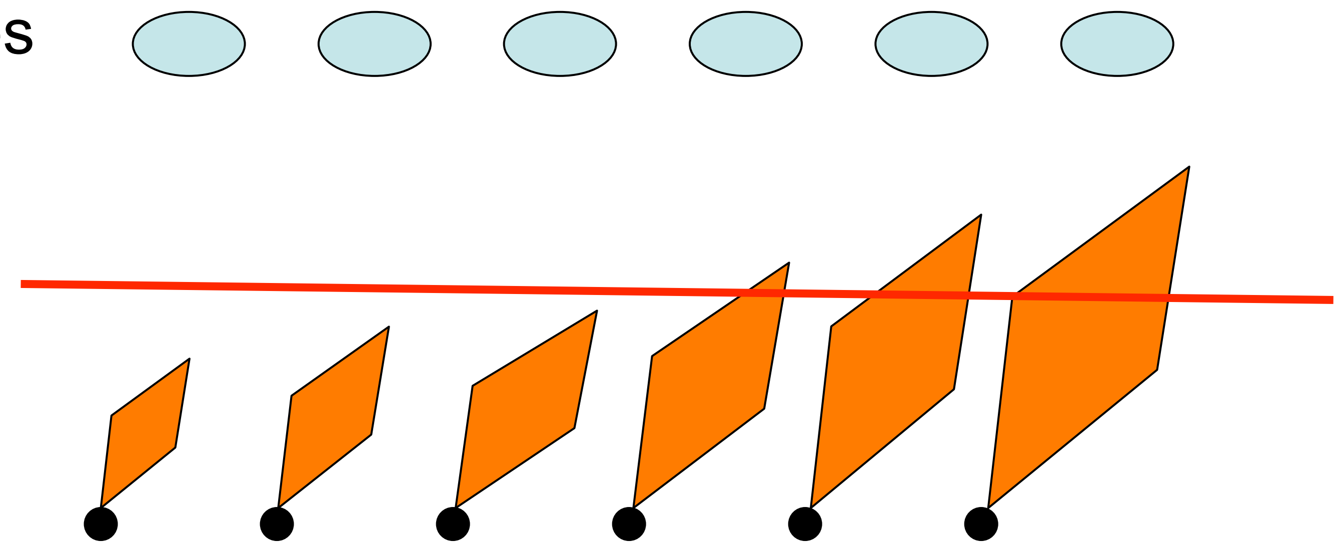


copied from G. Rumolo's talk

- Observation of emittance blow up along the batch
  - ✓ Tail bunches have larger emittances than those at the head of the batch
  - ✓ Both transverse planes affected
  - ✓ Effect seems more pronounced in the horizontal plane
- Coherent or incoherent effect ?

ECM08, CERN, 21.11.2008 Giovanni Rumolo 5

Bunches



No emittance growth

Emittance growth incoherent effects, bunch shortening

Summary and Outlook

Comparison of SC and EC incoherent effect

We compared SC & EC incoherent effects in terms of beam emittance growth for structure resonances. We find that the beam response for EC incoherent effects is understandable in terms of periodic resonance crossing as for SC incoherent effects

High intensity incoherent effects in SIS100

Estimates of long term beam loss for two beams scenario in a lattice with magnet error and a residual 1mm closed orbit distortion are performed. The modeling of full beam intensity needs more realistic ring modeling including residual CO, chromaticity correction, compensation elements and a realistic beam distribution.

Exploratory example of EC incoherent effects in LHC

In LHC a dense EC induced structure resonance web makes large integrated EC tunespread ($\Delta Q_{ec} > 0.5$) undesirable. A more precise pinched EC modeling is required.

Validation and benchmarking

Long term prediction for SC are better understood than EC and experimentally benchmarked.
EC incoherent effects need further studies and dedicated experiments in order to validate models for long term predictions:

Thanks to

GSI	O. Choriny, W. Bayer, O. Boine-Frankenheim, C. Omet, B. Franczak, P. Forck, T. Giacomini, I. Hofmann, M. Kirk, H. Kollmus, T. Mohite, A. Parfenova, P. Schuett, P. Spiller
BNL	W. Fischer
CERN	E. Benedetto, O. Bruening,C. Carli, R. Cappi, M. Giovannozzi, M. Martini, E. Metral, R.R. Steeremberg, G. Rumolo, F. Zimmermann
ITEP	P. Zenkevich, A.Bolshakov, V. Kapin
SRI	A.I. Neishtadt
Univ. Bologna	G. Turchetti, C. Benedetti, A. Bazzani