Linear Coupling with Space Charge in SIS18

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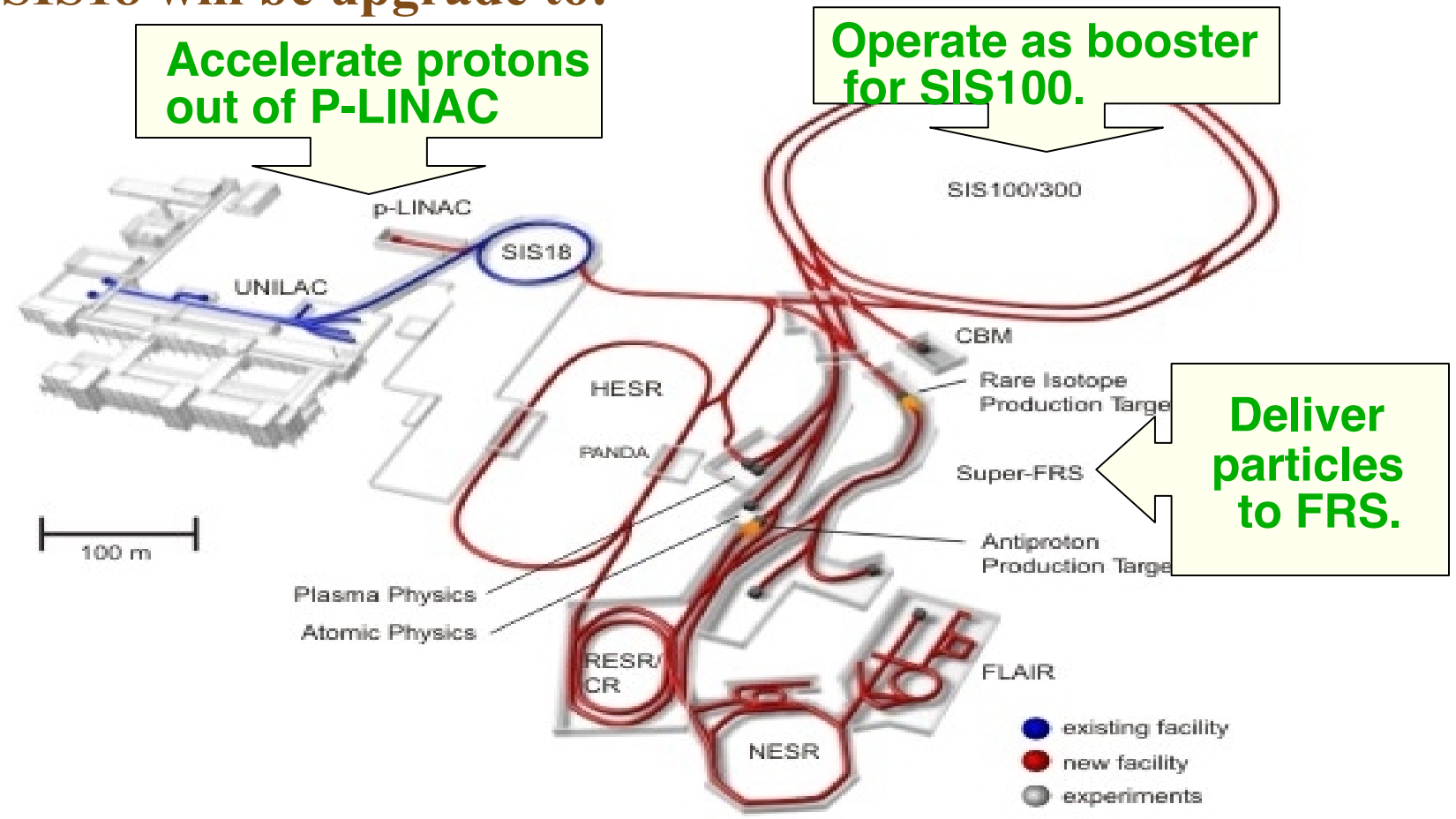
Outline

- Motivation.
- The Coupled Motion.
- Transverse Emittance Exchange.
- Space Charge Effects on the Exchange.
- Application (Multi-Turn Injection).
- Summary.

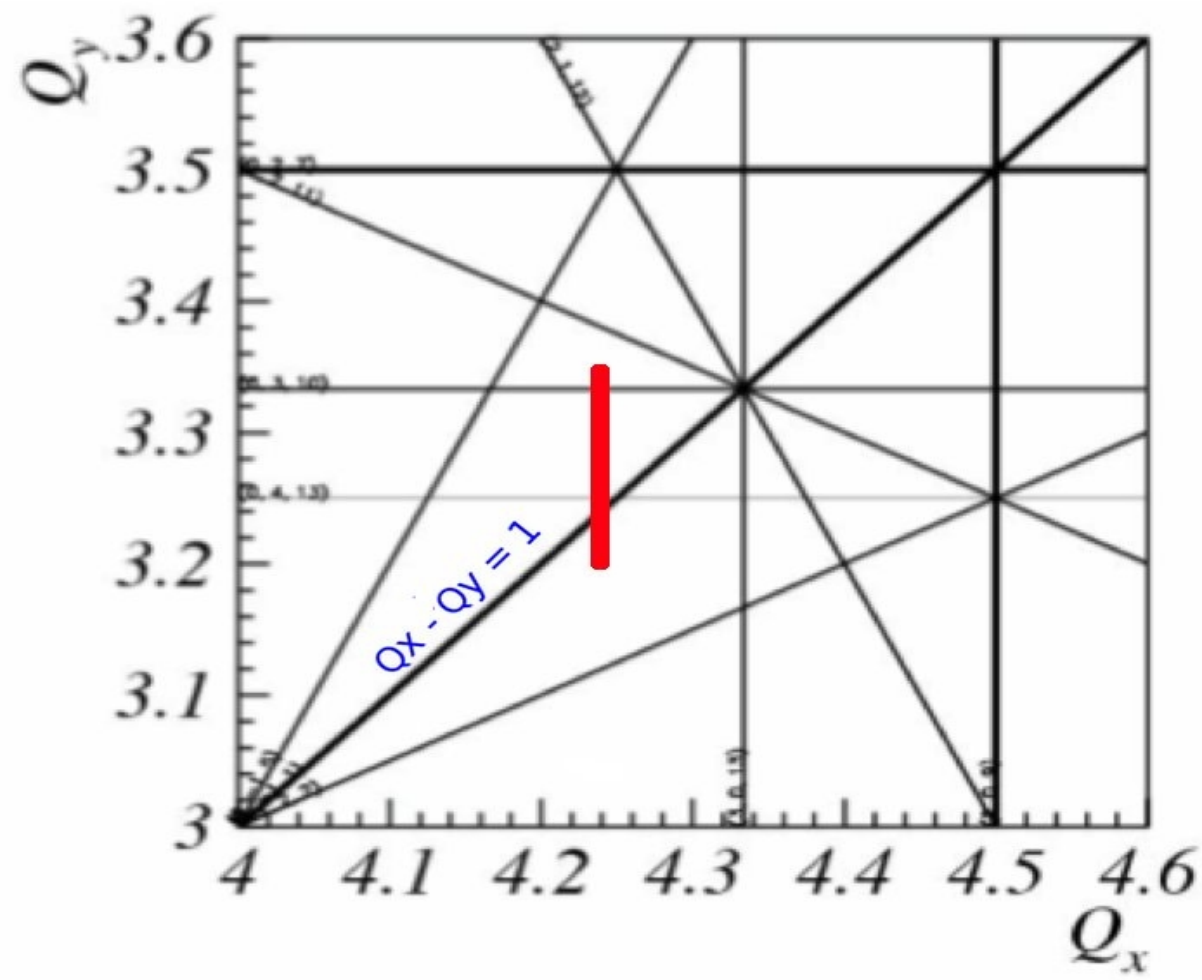
Motivation

SIS18 will be upgrade to:

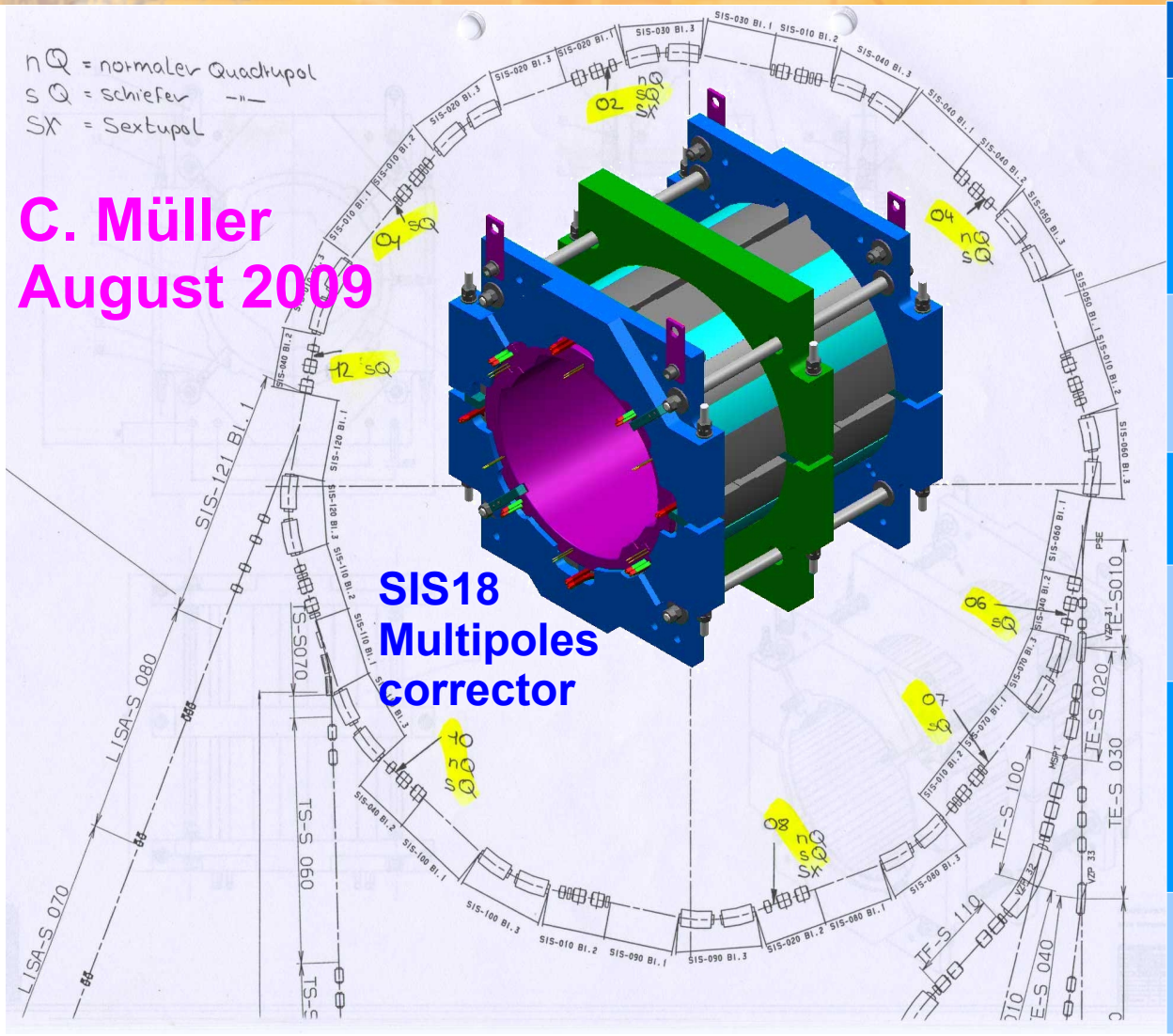


- *Control beam parameters at injection and extraction*

SIS18 Resonance Map



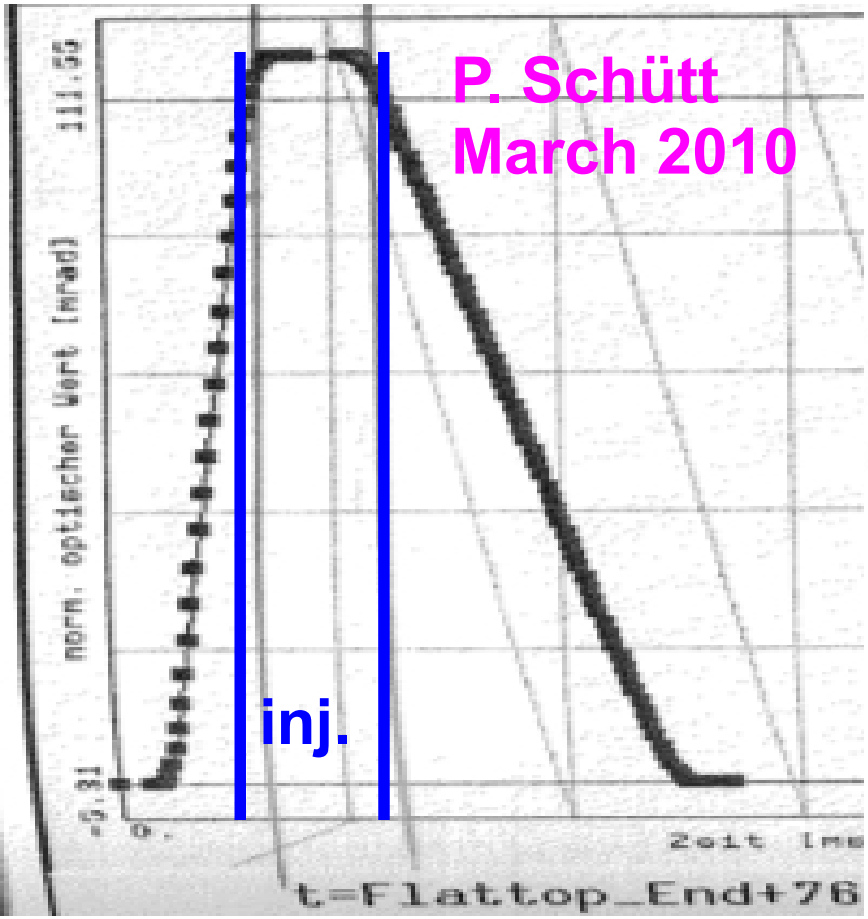
SIS18 Skew Quadrupole Magnets

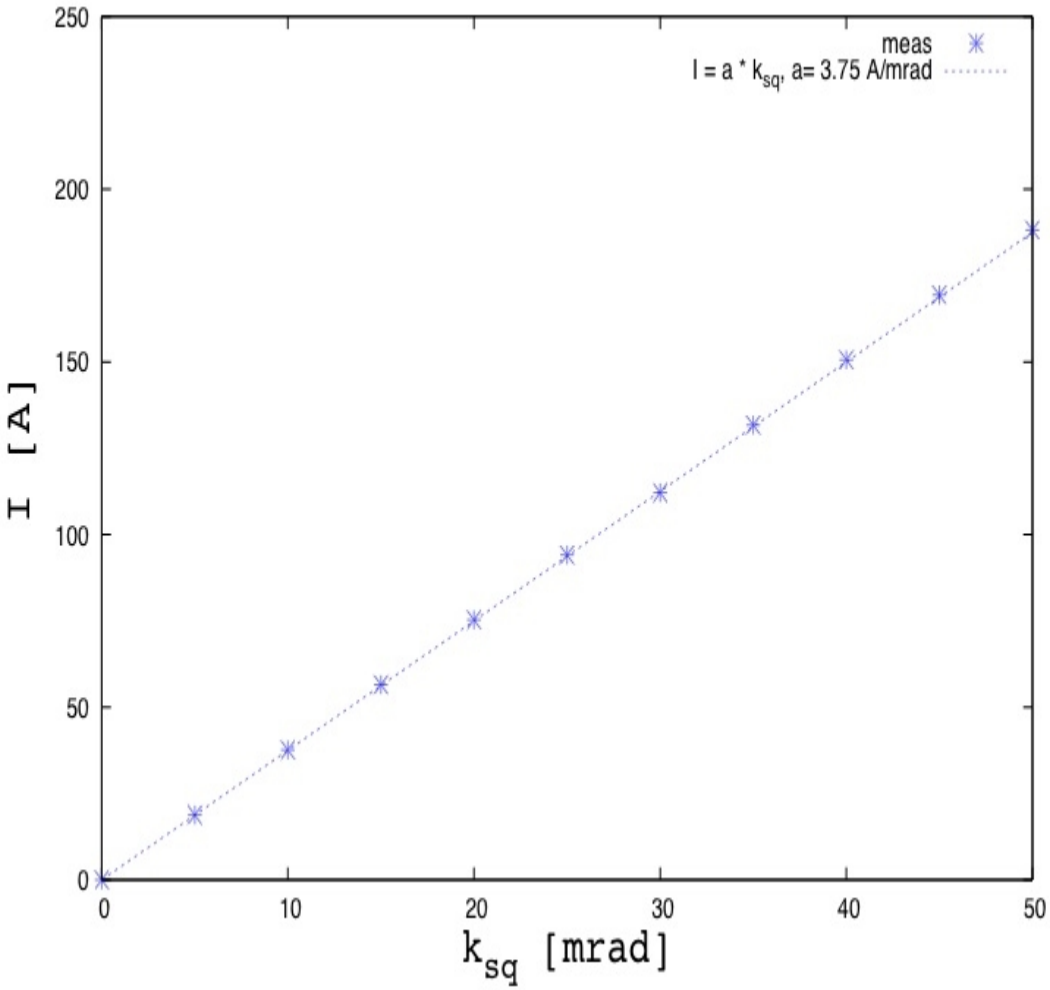


SIS18 Skew-Quadrupole	
g_{max} [T/m]	0.450
l_{eff} [m]	0.371
Total #	8
$\Sigma gl_{sq}/\Sigma gl_{Q}$	0.013
t[ms] 0--->I_{max}	60
I_{max} [A]	400

SIS18 Skew Quadrupole Magnets

Skew Quad S01KM3QS





Skew quadrupole strength is constant during injection.

The Coupled Motion

The coupled tunes can be measured by using Schottky spectrum analysis [S. Van der Meer],

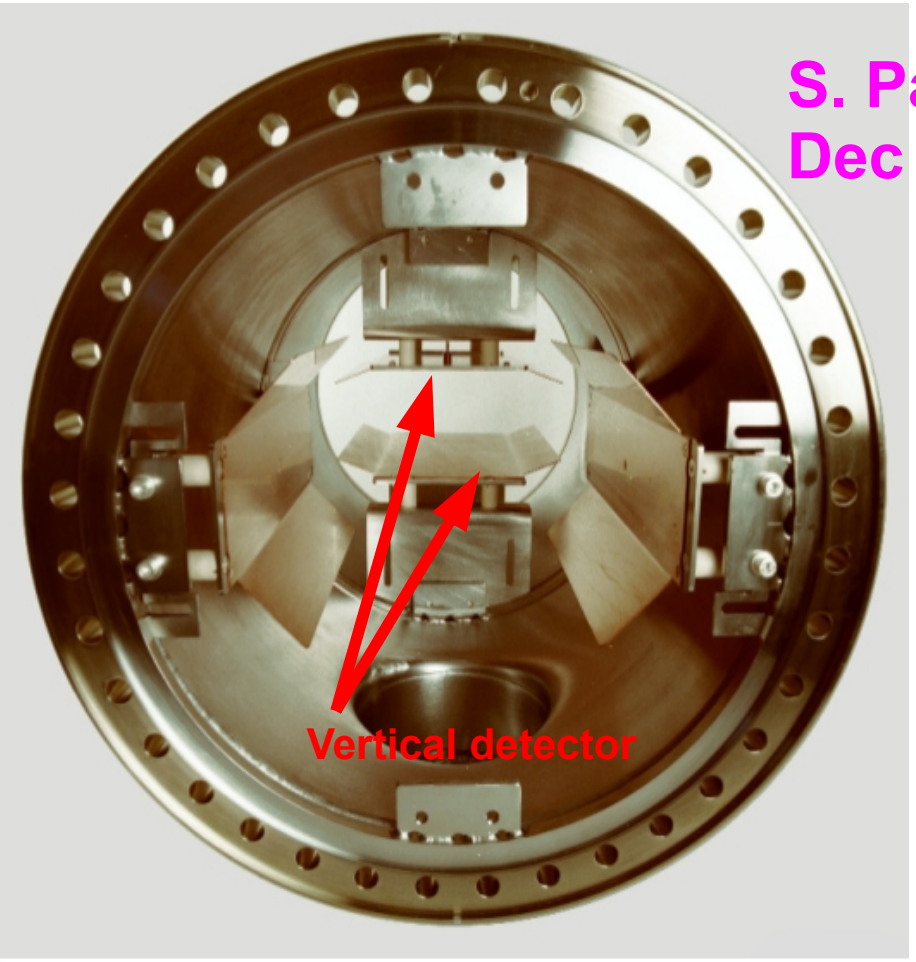
$$f^+ + f^- = 2 f_0 m$$

$$q = m \frac{f^+ - f^-}{f^+ + f^-} \qquad (1)$$

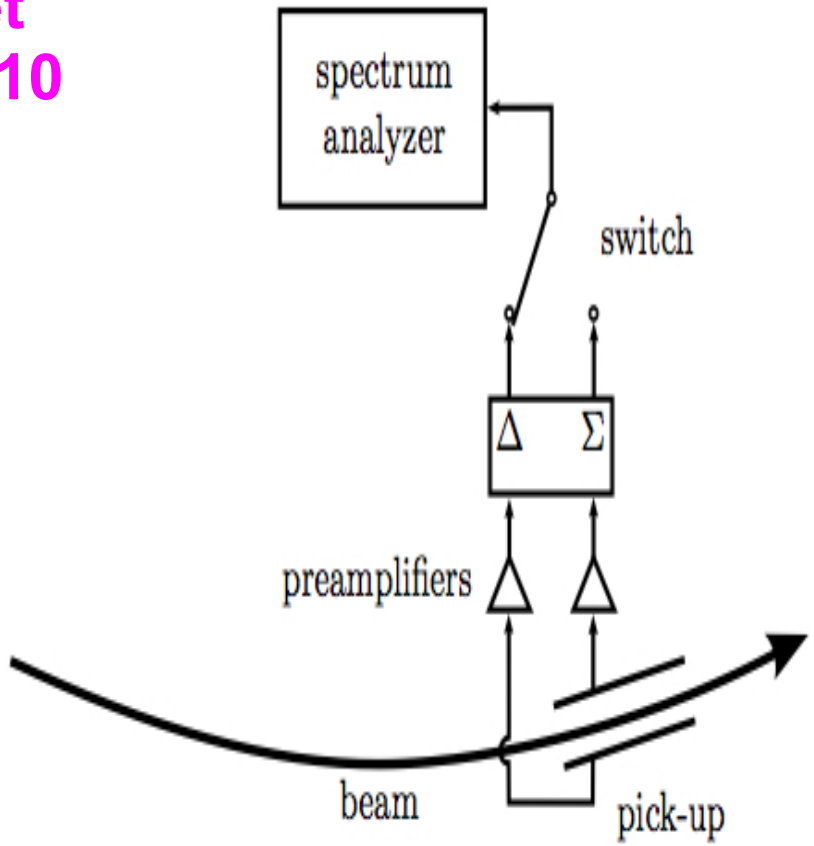
The coupled tunes separation is

$$q_u - q_v = \sqrt{(q_x - q_y)^2 + |C|^2} \qquad (2)$$

Schottky Diagnostics



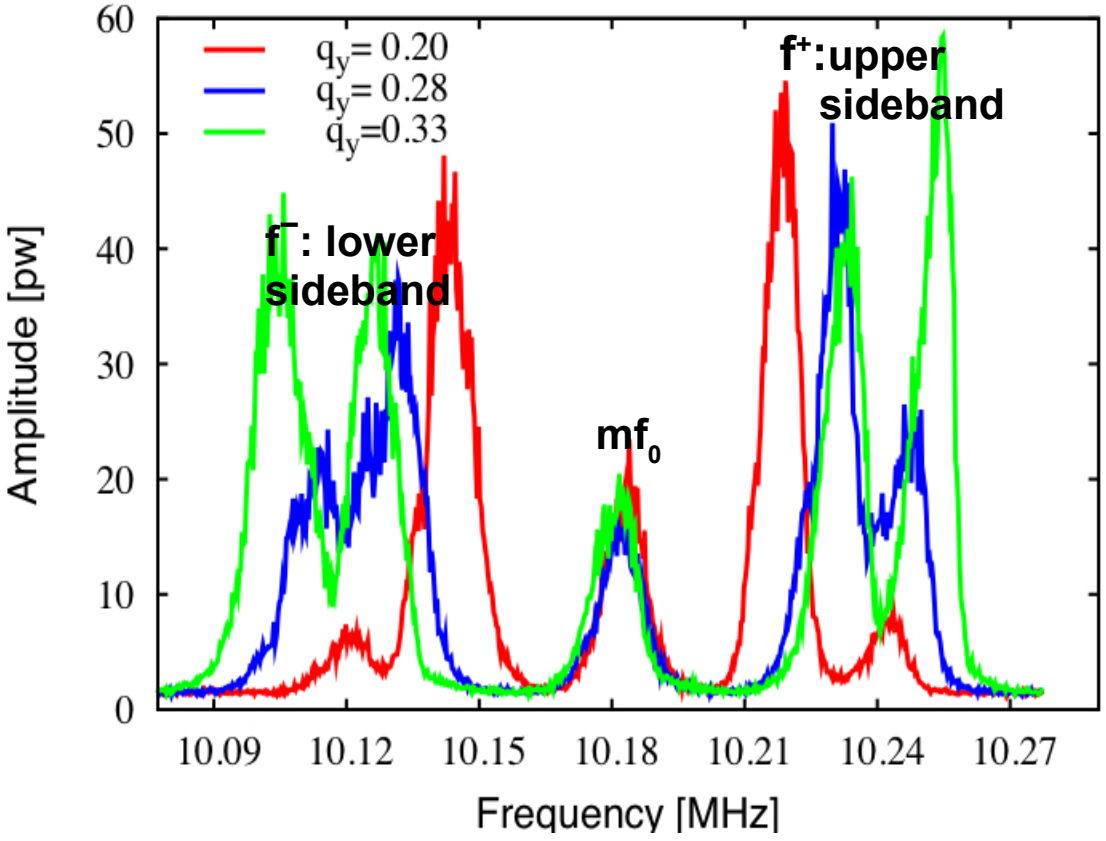
Schottky pick-up



Setup of Schottky measurement

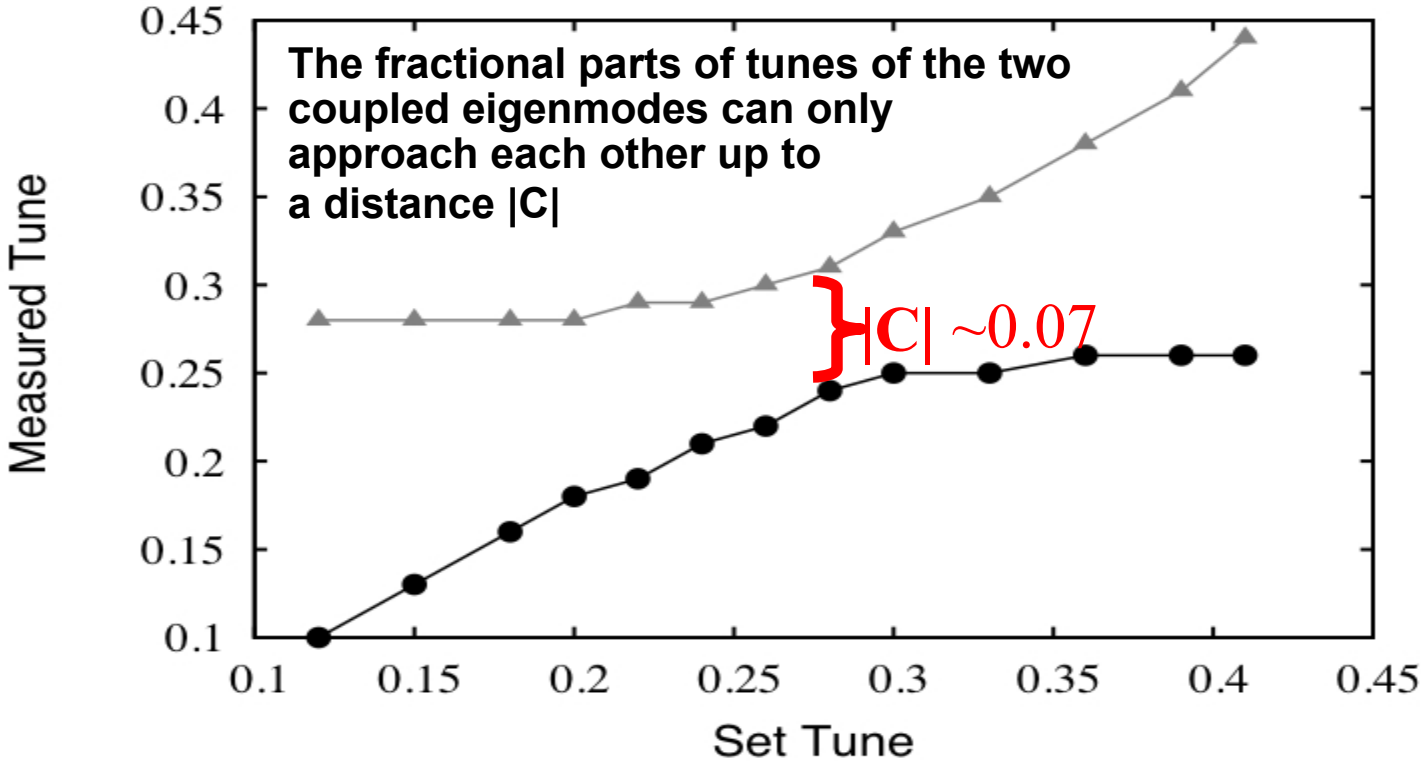
Coupled Tunes Measurement

Schottky vertical spectrum



Beam	$^{181}Ta^{61+}$ (coasting beam)
Beam Intensity	$N_p=10^8$ I= 3 mA
Injection Energy	E=11.14 MeV storage t= 1 s
Transverse tune	Q_x= 4.26 Q_y=3.10-3.39
Incoherent Space charge Tune shift	ΔQ_x=-0.007 ΔQ_y= -0.02
Skew Quad Strength (S01KM3QS)	k_{sq}= 50E-3 m^{-1}

Coupled Tunes Measurement



- *The minimum tune separation gives the coupling strength |C|*

Transverse Emittance Exchange
(Zero Space Chage)

In absence of space charge and close to the difference coupling resonance, the transverse emittance exchange is given by [K. Schindl]

$$\epsilon_{x,y}(N) = \epsilon_{x0,y0} \pm \frac{|C|^2 \sin^2\Theta}{\delta^2 + |C|^2} \frac{(\epsilon_{y0} - \epsilon_{x0})}{2} + \\ + \frac{|C| \sin^2\Theta}{\delta^2 + |C|^2} \delta \sqrt{\epsilon_{x0}\,\epsilon_{y0}} \cos\phi + \\ + \frac{|C| \sin\Theta \cos\Theta}{\delta^2 + |C|^2} \sqrt{\epsilon_{x0}\,\epsilon_{y0}\,(\delta^2 + |C|^2)} \sin\phi \qquad (1)$$

Where,

$$\Theta = \sqrt{\delta^2 + |C|^2}\, 2\pi N \qquad (2)$$

$$|C| = C = \frac{1}{2\pi} k_{sq} \sqrt{\beta_x \beta_y} \qquad (3)$$

Simulation with PARMTRA

PARMTRA is a multi-particles code to simulate the transport of an ion beam through a system of beam optics elements under space charge conditions [J. Struckmeier].

- Source code:FORTRAN, freely available.
- operating system:any,CERN mathlib used.
- Paraxial approximation of particle motion.

I. Input data file

- Lattice elements: 17 Types
- Beam initial ellipse:
  - twiss parameters
  - type of distribution (KV,Gaussian,WB)
  - # of particles generated $<10^7$

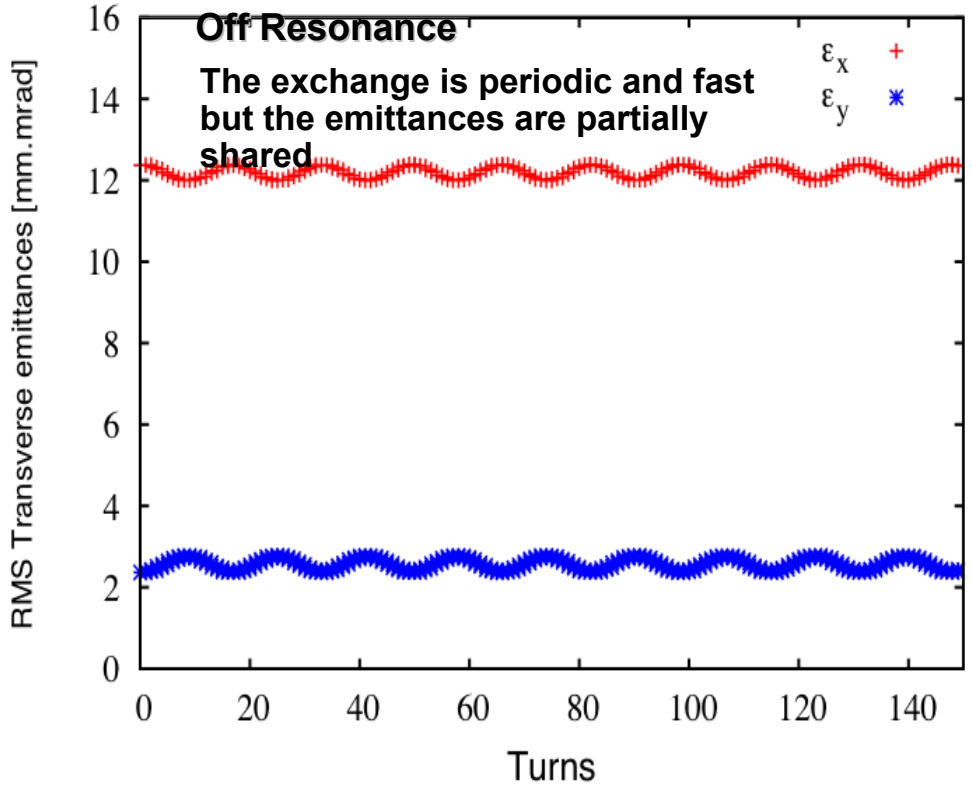
II. Main

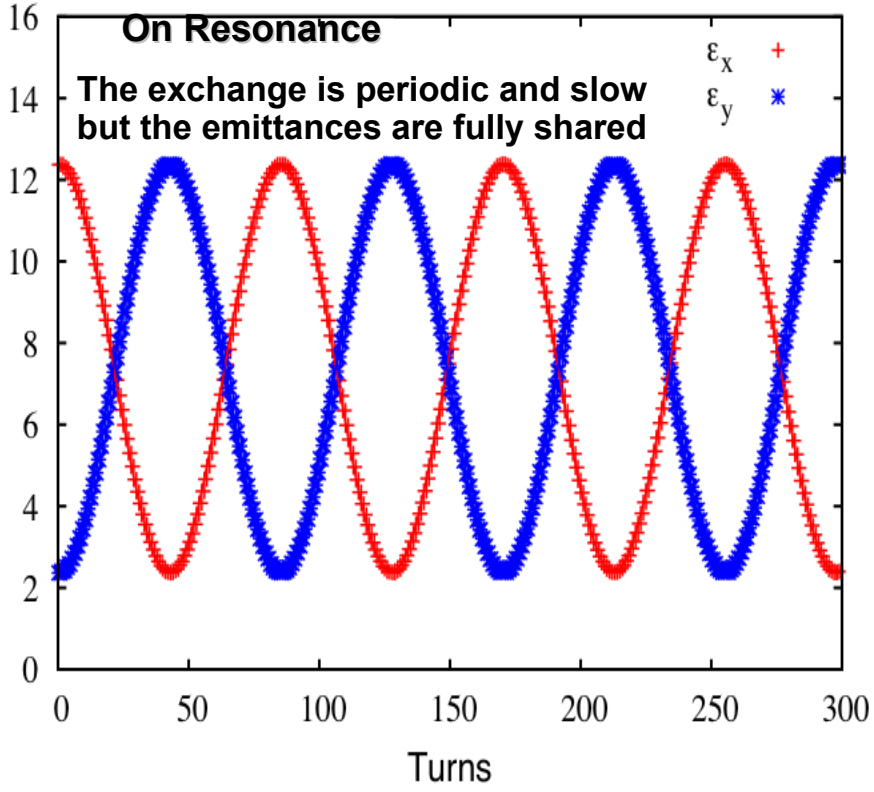
- Matching(Newton-method) with and without space charge
- Tracking & space charge calculation (xy,rz-Poisson solvers)
- Phase advance calculation (least squares method)

III. Output data file

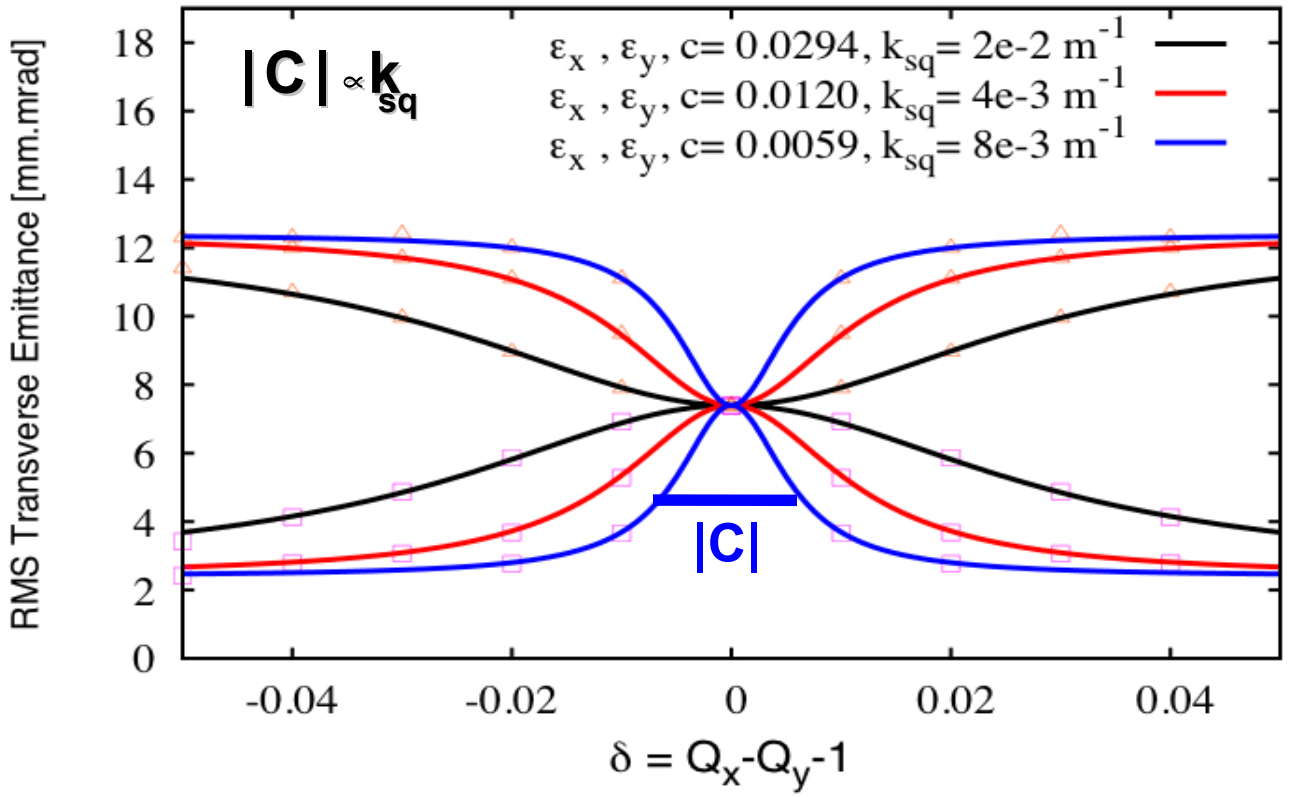
Emittance Exchange Simulation

A) For zero space charge





Emittance Exchange Simulation



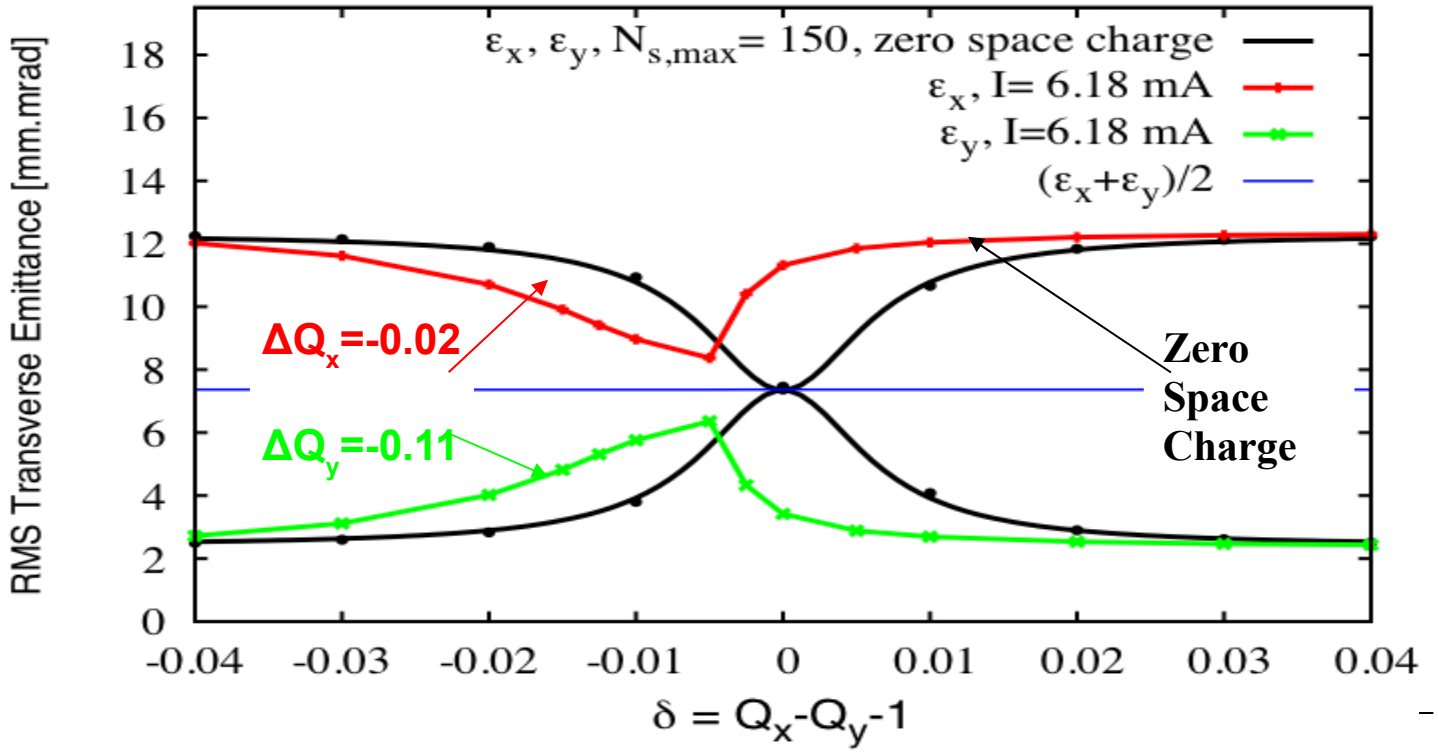
- *The coupling strength is proportional to the skew quad strength*

Space Charge Effect

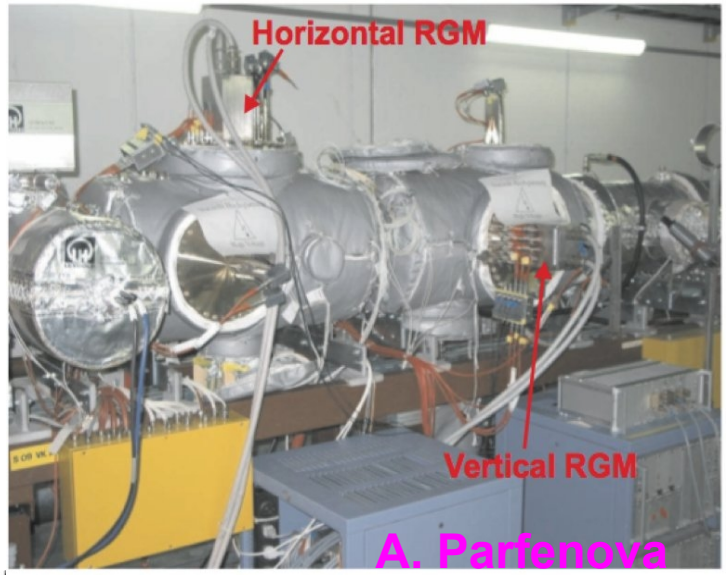
B) Emittance exchange with space charge for coasting beam

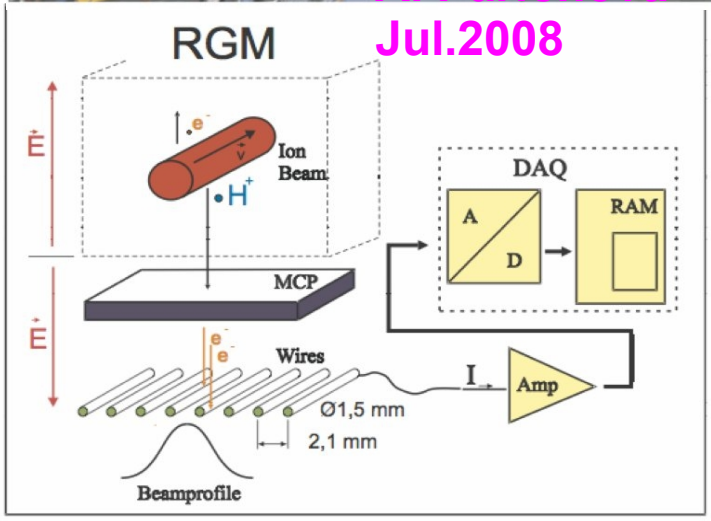
Space charge effects are [I. Hofmann]:

- Shift the resonance center from the single particle resonance.
- Limit the emittance exchange between the transverse planes .
- Broaden the stop band width and modify the exchange curves.



Beam Profiles Measurement





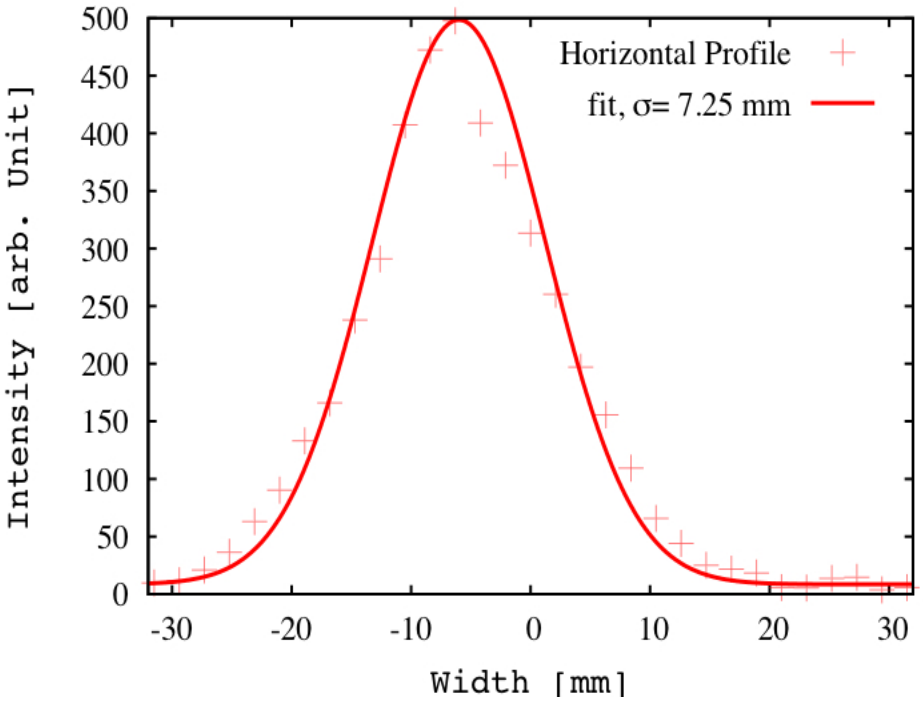
The RGM consist of [T. Gaicomini]:

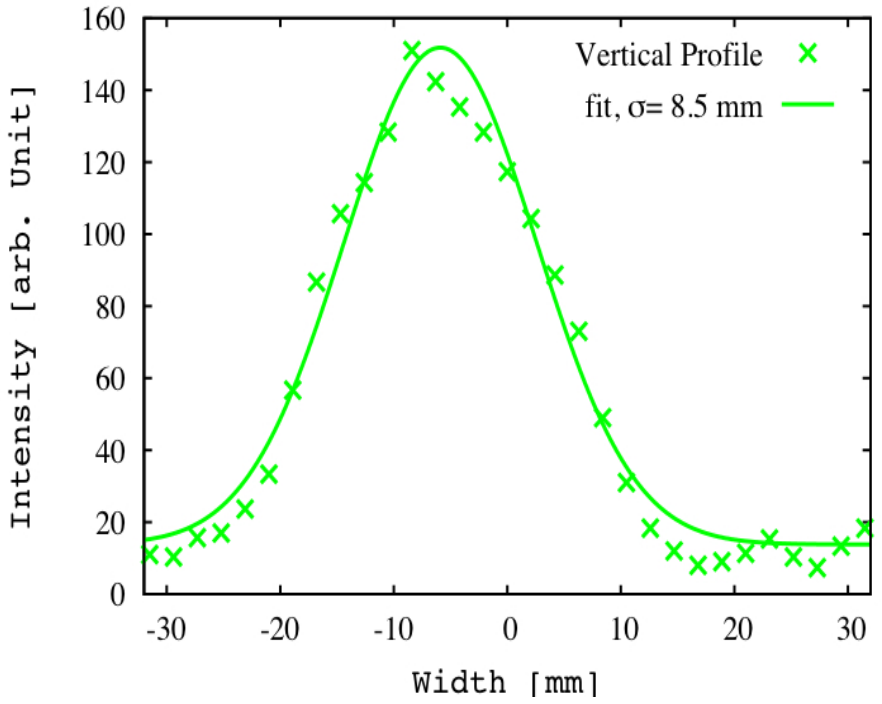
- **Two (100 mm × 30 mm) MCPs.**
- **An array of 64 wires which determines 2.1 mm spatial resolution.**
- **The duration of one measurement is either 0.5 ms or 5 ms and each10 ms a new one starts.**

Beam	$^{40}Ar^{18+}$ (coasting)
Beam Intensity	$N_p=10^{10}$, I=6.18 mA
Injection Energy	E= 11.35 MeV
Transverse Tune	Q_x= 4.26, Q_y=3.20-3.36
Incoherent Tune Shift	ΔQ_x= -0.01, ΔQ_y= -0.1

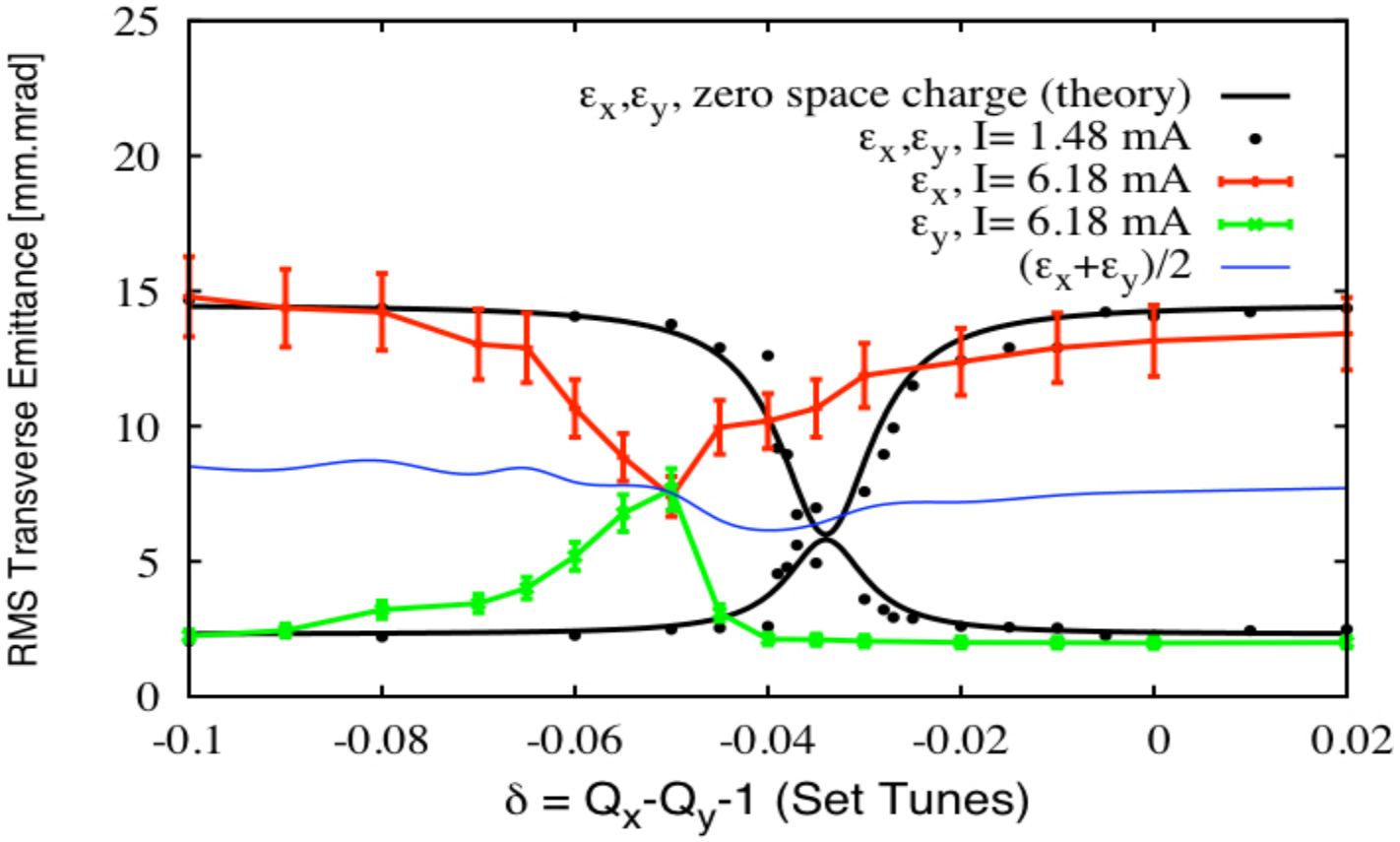
Beam Profiles Measurement

Beam transverse profile on Resonance





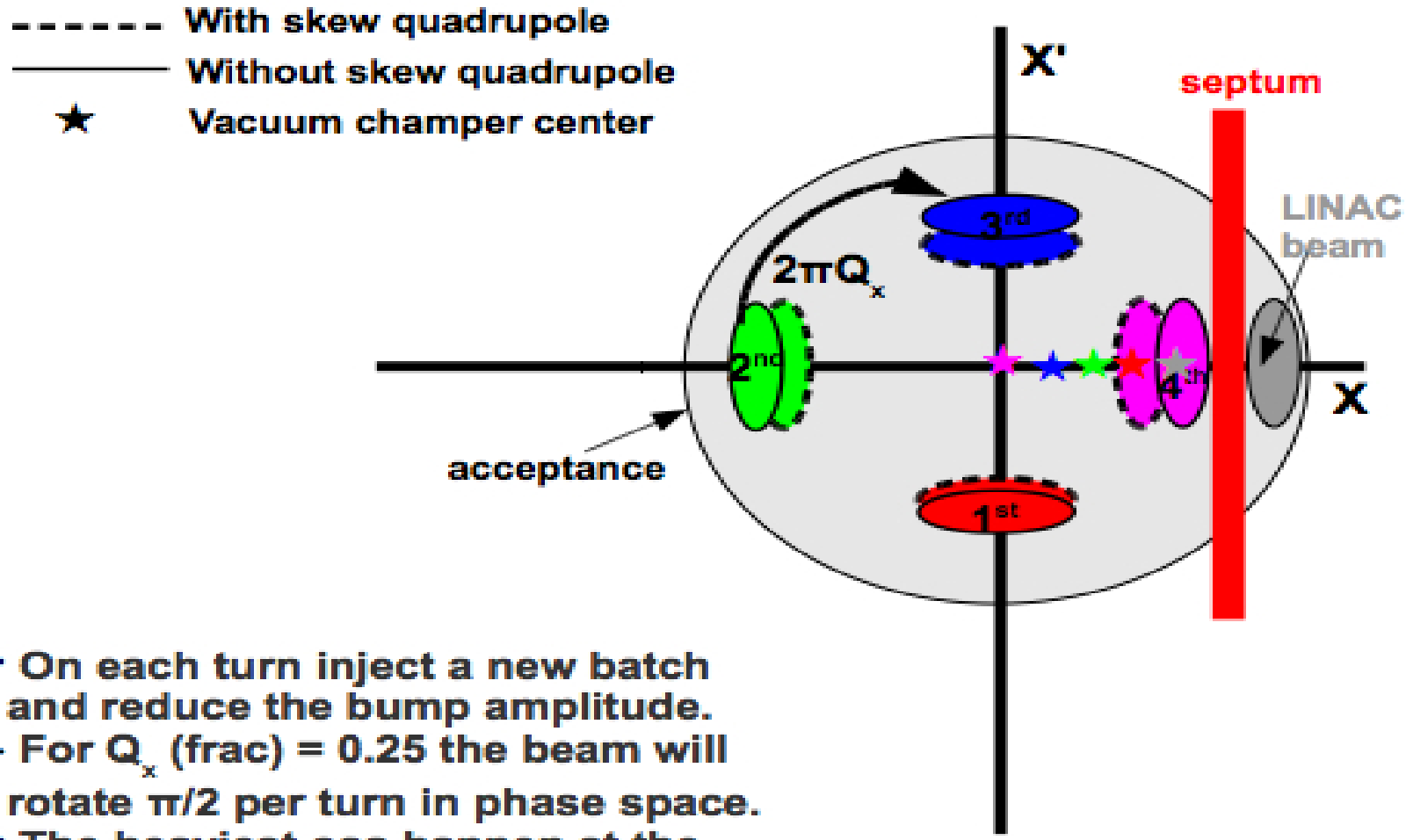
Emittance Exchange Measurement



Space charge effects on emittance exchange were observed in measurement

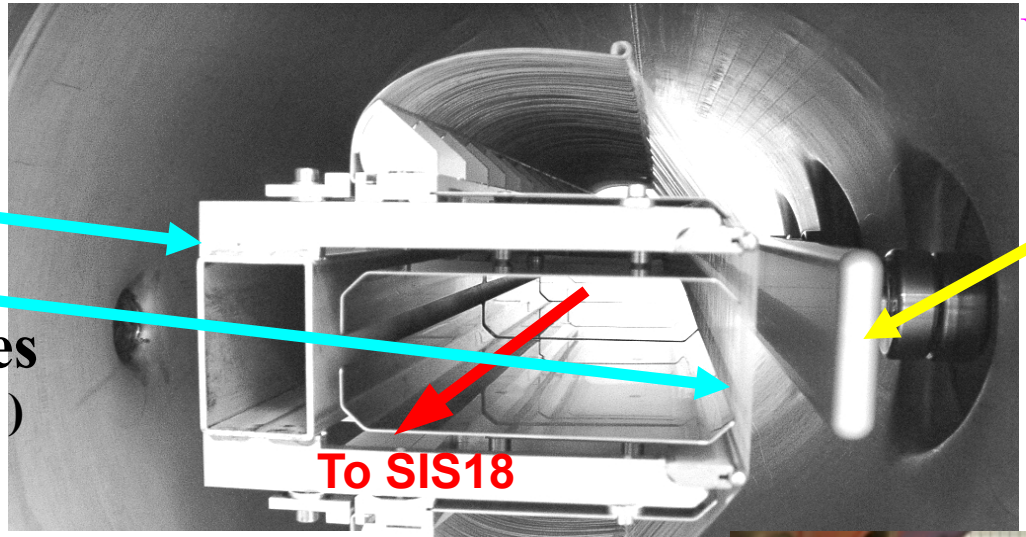
Application: Multi-Turns Injection

i.



- On each turn inject a new batch and reduce the bump amplitude.
- For Q_x (frac) = 0.25 the beam will rotate π/2 per turn in phase space.
- The heaviest oss happen at the septum at N = 4.

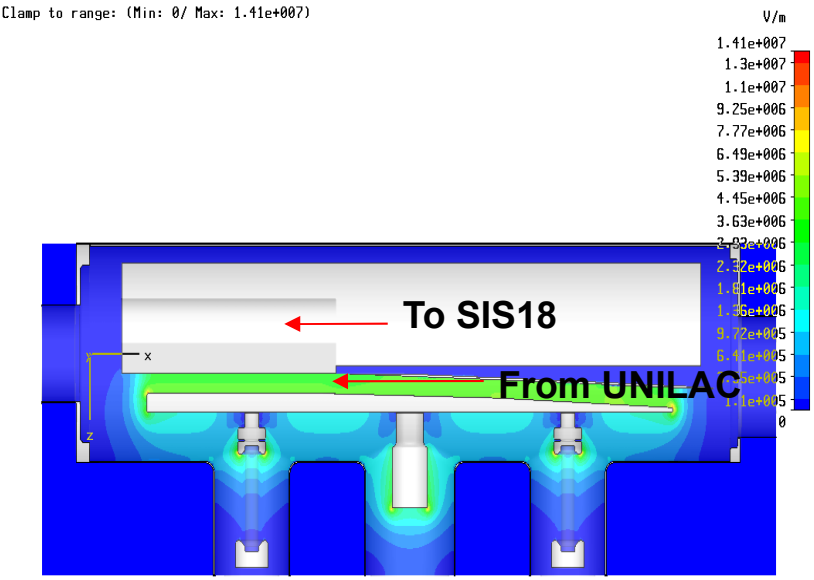
Electrostatic Septum Elements

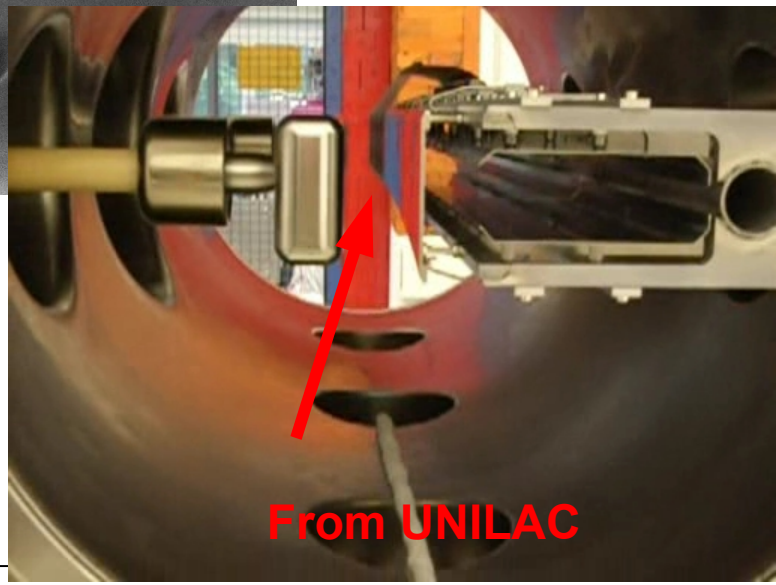


Udo Blell, PAC07

Anode
Tungsten-rhenium wires
(0.1mm diameter)

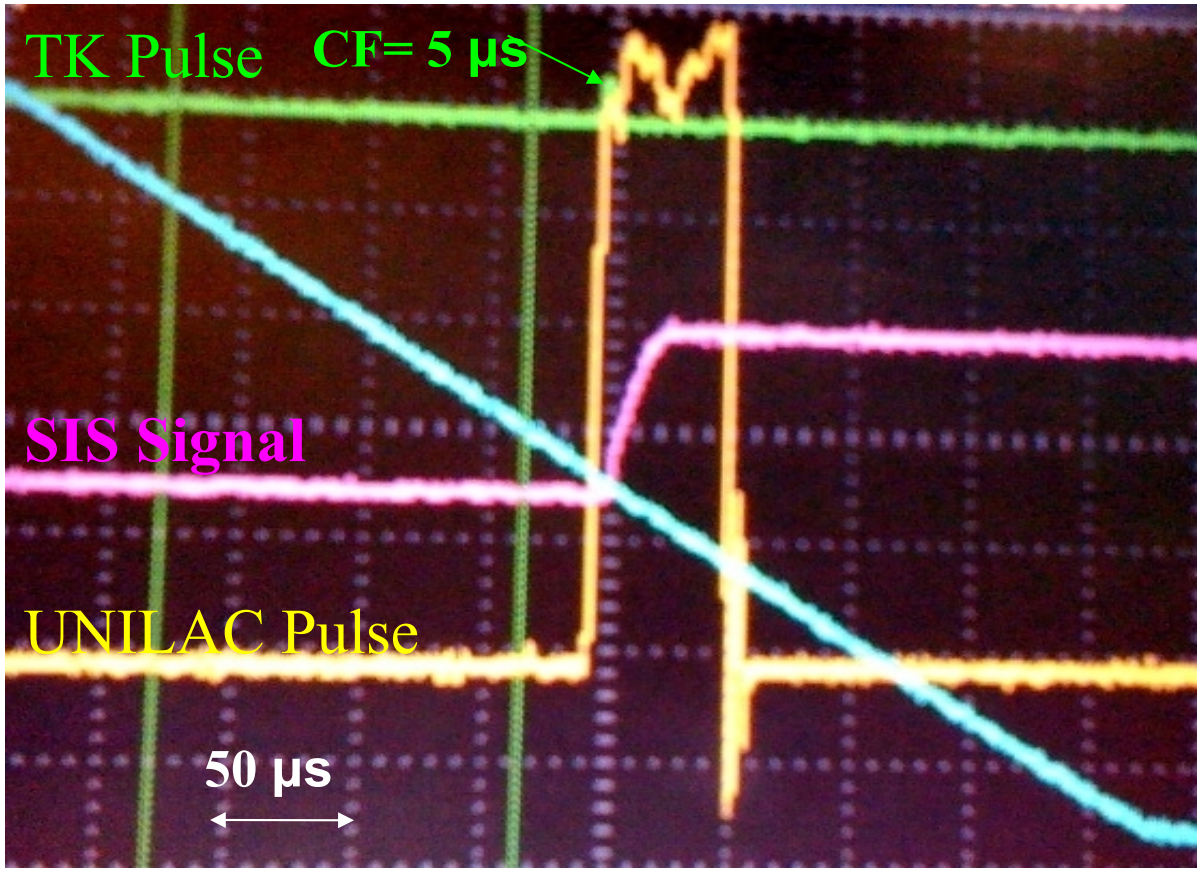
Cathode
(deflection angle 2.5 deg)





Injection Bump Setting

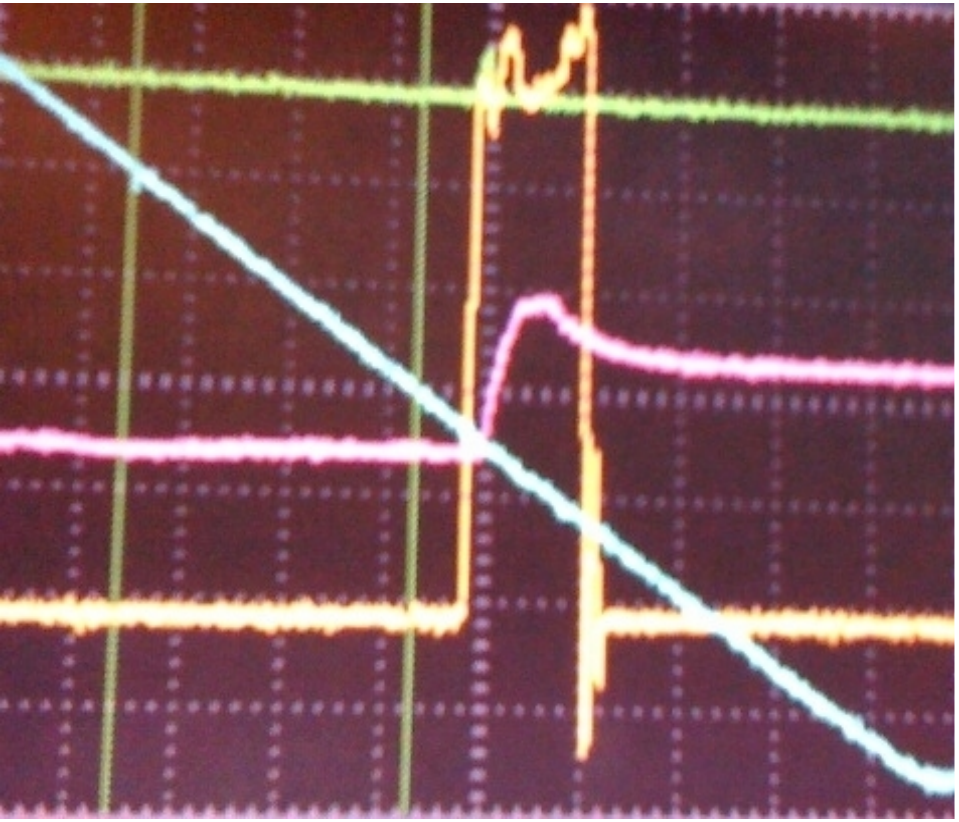
Y. Hayek
Aug.2010



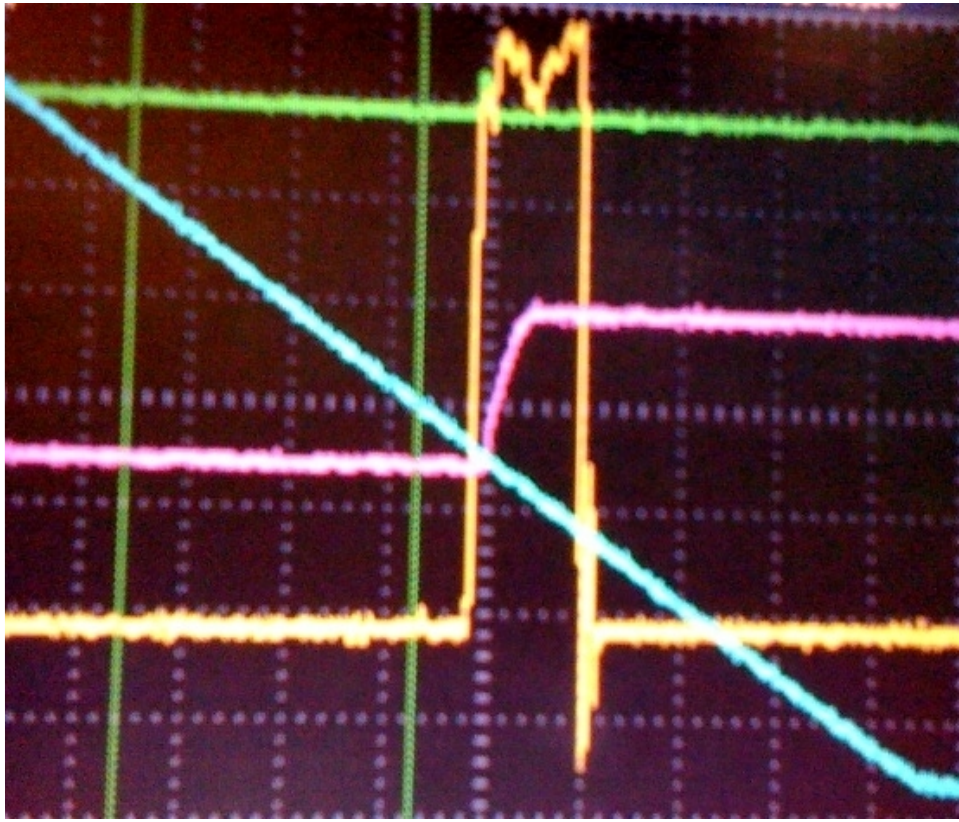
Skew Injection Measurement I

For $^{238}U^{73+}$, $N_p \sim 10^7$, Qx = 4.26 , Qy = 3.35 ,

BA =100 mm, BF = 500µs, BD = 295µs, CF = 5µs



SQ off

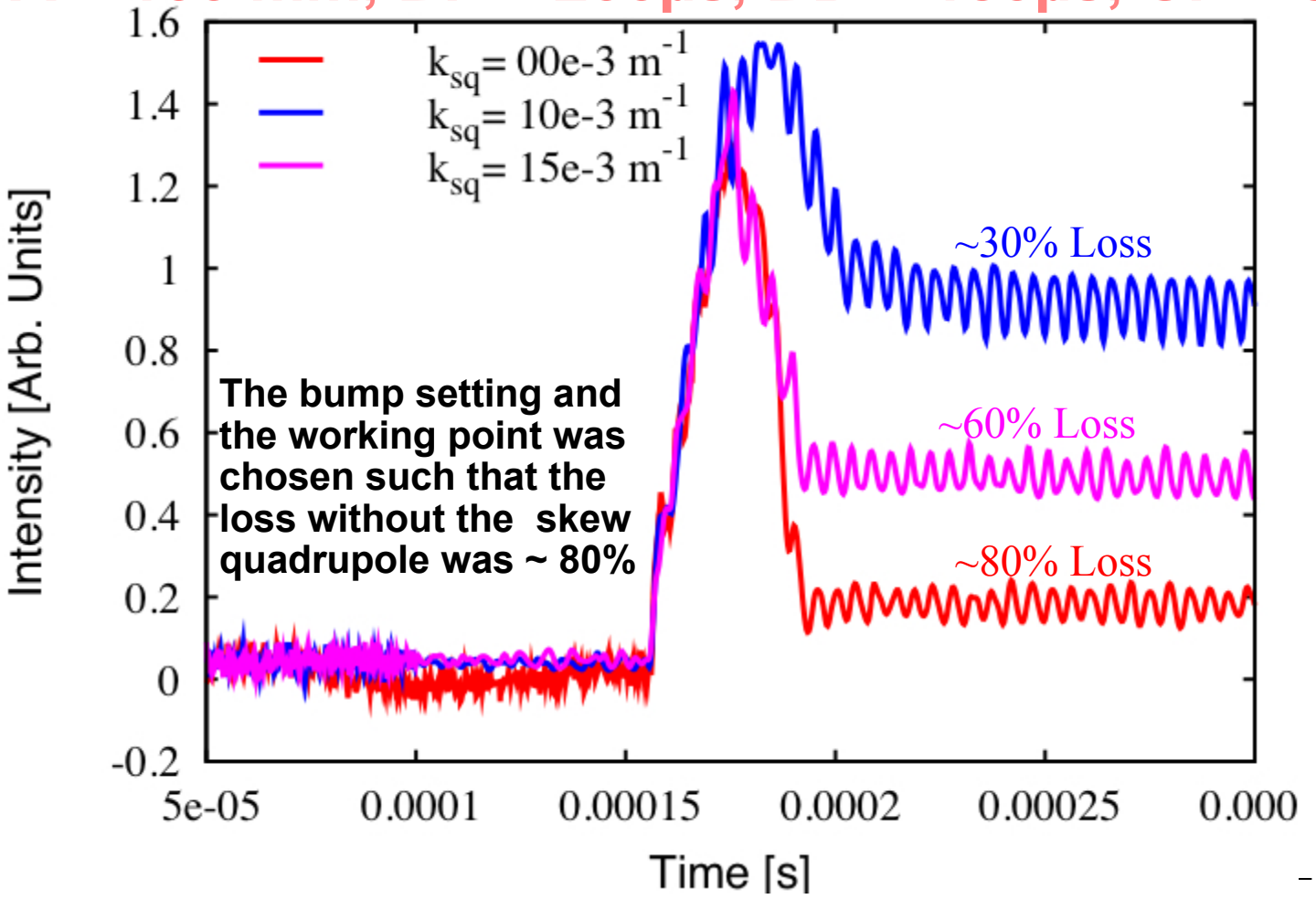


SQ on, k_{sq} = 10e-3 m-1

Skew Injection Measurement II

For $^{40}Ar^{18+}$, $N_p \sim 10^7$, Qx = 4.23, Qy = 3.32

BA = 100 mm, BF = 200µs, BD = 150µs, CF = 30µs



Summary

- The closest tune approach was used to measure the coupling strength in SIS18.
- The transverse emittance exchange due to crossing statically the coupling resonance was simulated with PARMTRA and measured in the SIS18 using the RGM.
- In the absence of space charge, the exchange characteristics were obtained and from the stop band width we estimated the coupling strength.
- The effect of space charge on emittance exchange are confirmed in simulation and measurement. It shifts the resonance center above the zero space charge resonance center and deform the exchange curve.
- Skew quadrupole was used in a preliminary multi-turn injection optimization where the results showed that it can be helpful to improve the injection efficiency.

Results

- The coupling strength due to random skew quadrupole errors in SIS18 was measured to be equal to 0.008 ∓ 0.003.
- A good agreement between the simulation and the measurement results concerning the transverse emittance exchange.
- Space charge effects was confirmed for the first time in measurement in SIS18.
- Injection efficiency was increased up to 70% when we used skew quadrupole magnet with strength 10E-3 [m^{-1}].
- Exact uncoupled tunes measurement is needed.
- Beam time with very stable injection intensity to SIS18 for a realistic multi-turn injection is needed.

References

[1] S. van der Meer, CERNPS88-60(AR).
[2] K. Schindl and P. Van der Stok, CERN/PS/BR76-19(1976).
[3]J. Struckmeier, GSI-ESR-87-03, GSI-Darmstadt.
[4] I. Hofmann and G. Franchetti, Phys. Rev. STAB, 9, 054202(2006).
[5] T. Giacomini, Private communication, 2008.


THANKS