Electron Cloud Studies for SIS-18 and for the FAIR Synchrotrons

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Outline

- Why we study electron clouds for FAIR?
- Electron clouds around the world
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  - IPAC10 Electron Cloud Comunity
- Description of Model
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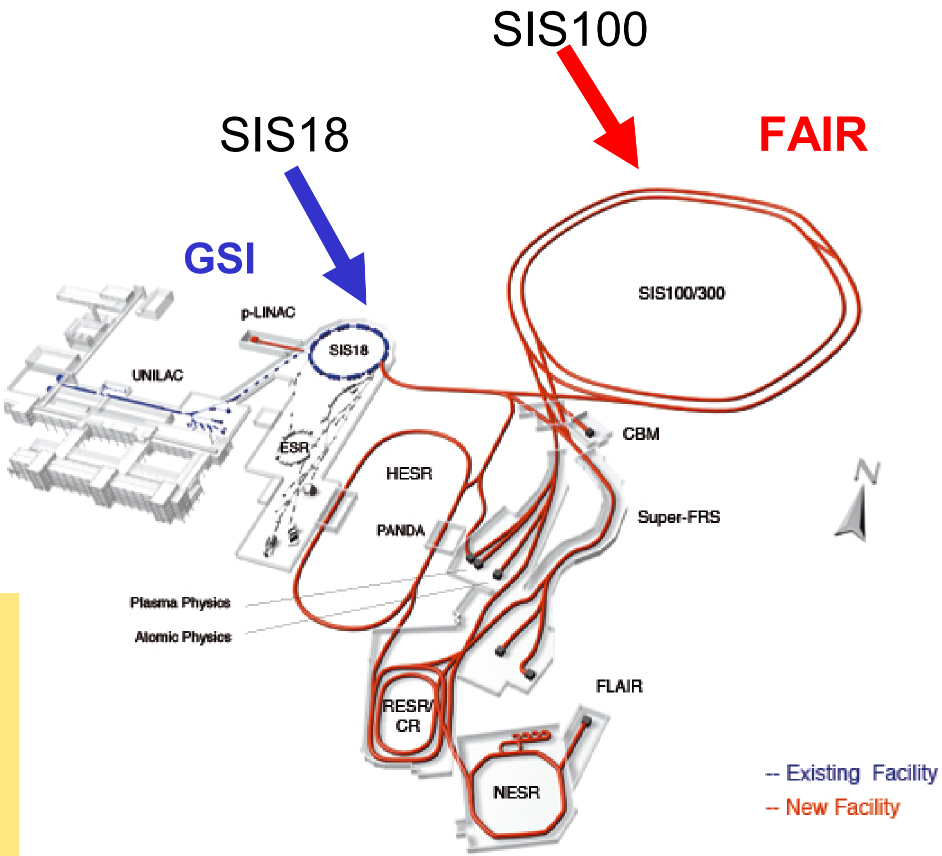
Introduction. Why Do We Study Electron Clouds for FAIR ?

Electron cloud (EC) – electrons produced in SIS-18/100 due to different mechanisms could survive for many cycles.

EC effects:

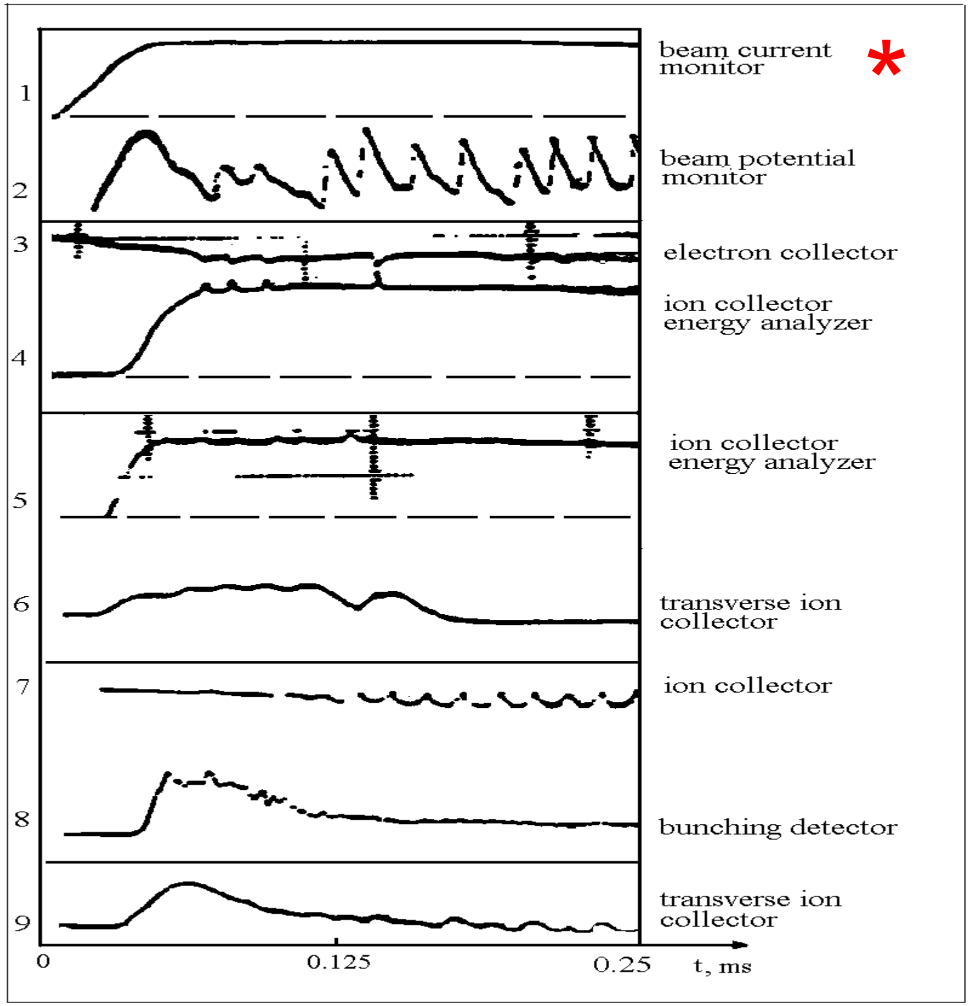
- were observed and studied in various accelerator complexes
- instabilities and possible limiting factor for high intensity machines



FAIR will work with short proton bunches and intense coasting beams during slow extraction.
There was no detailed study of the EC problem for the low to medium energy heavy ions beams in SIS18 and SIS100

**F. Zimmerman, Phys. Rev. Special Topics – Accelerators and Beams, 7, 124801,(2004)*

First Observations



Small proton machine.
At injection:
Coasting beam,R = 42 cm,
E = 1 MeV and, I = 0.1 mA

First published observations in Budker Institute in Novosibirsk in 1965-1967 for bunched and coasting beams.

After threshold intensity dipole oscillations observed

**Vadim Dudnikov, IPAC10 discussion*

Further Observations Around the World

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With increasing currents and intensities EC studies become important for all major accelerator facilities around the world aspeccially operating with positively charged species.

Most of the studies till now were performed for bunched beams where main source of electron production is secondary emission from the wall

There are much less studies of EC problem in application to coasting beams due to their specific use.

IPAC10 showed that it is still so.

IPAC10 Electron Cloud Comunity

CERN SPS, CeSR-TA, RHIC, SuperKEKB

(no works about coasting beam)

De Santis "*TE WAVE MEASUREMENTS OF THE ELECTRON CLOUD IN THE CESR-TA RING*"

Billing "*TECHNIQUES FOR OBSERVATION OF BEAM DYNAMICS IN THE PRESENCE OF AN ELECTRON CLOUD*"

Dudnikov information about observations in Novosibirsk

TE Wave Measurements of Electron Clouds

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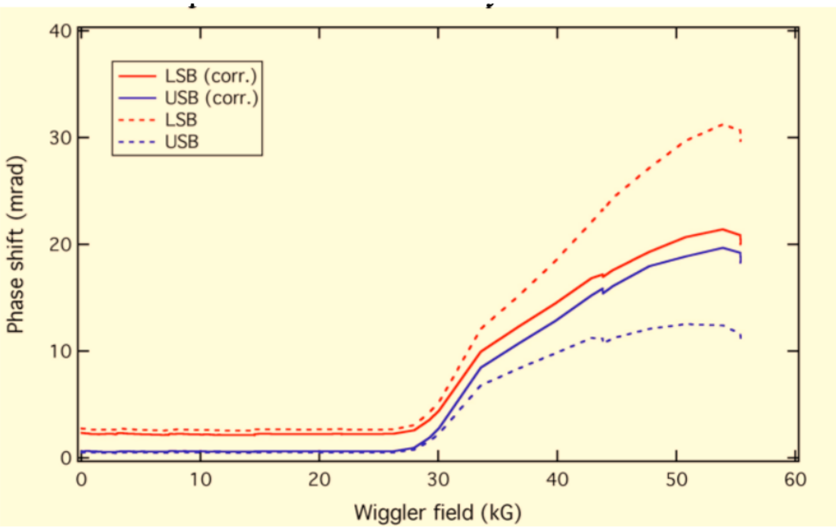
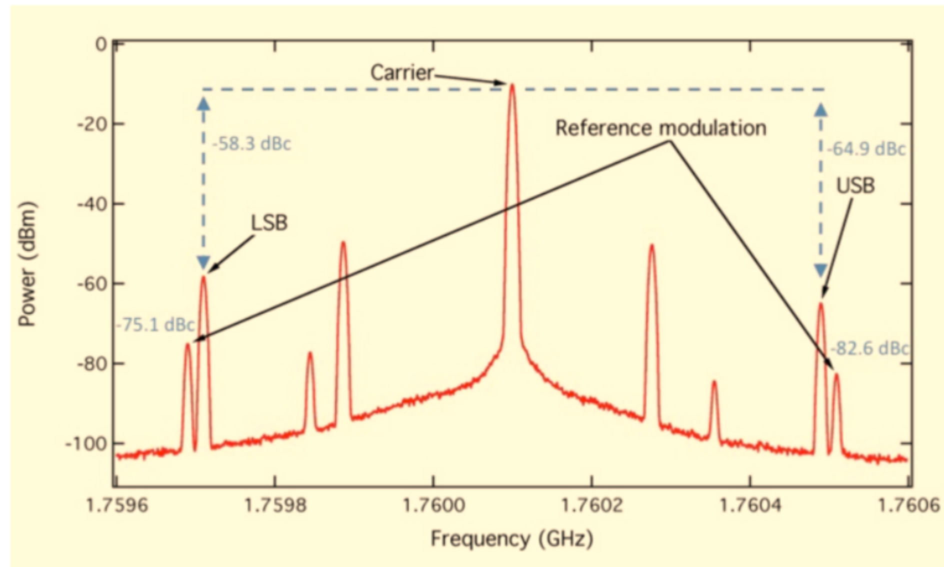
De Santis TE wave measurements in CeSR-TA



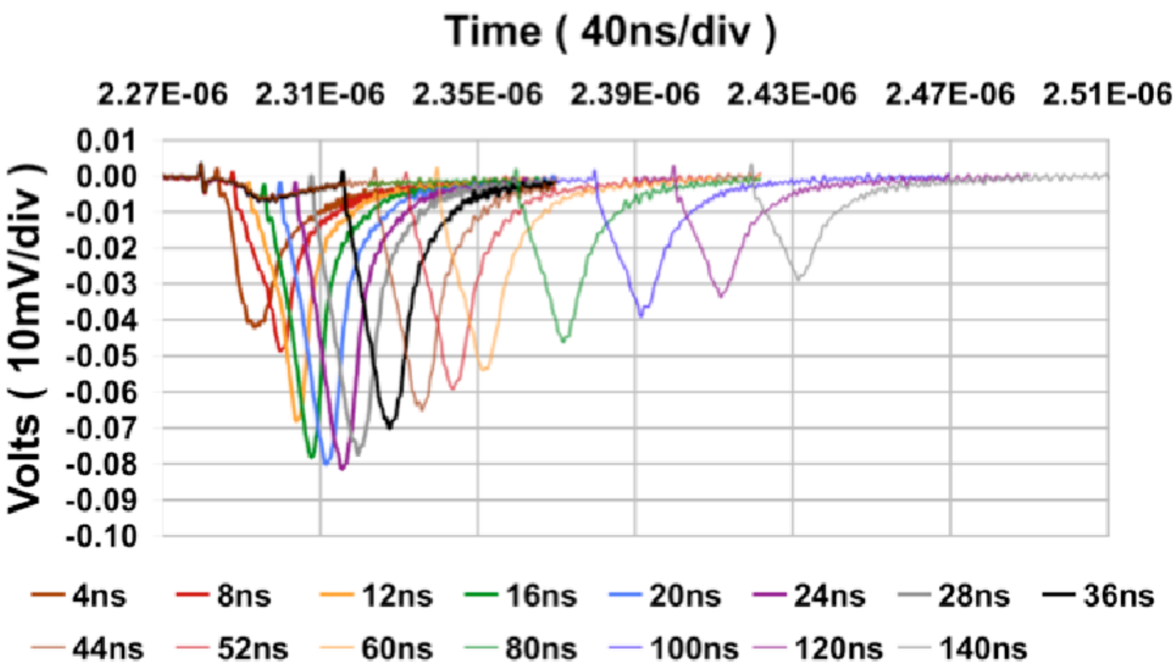


In cold machine heat load from synchrotron radiation can change the attenuation leading to sidebands deformation. Cure is to add reference modulation and compare the intensity of the bands.

***MOPE088 IPAC10 De Santis**

Button Pick-up Usage for EC Measurements

Billing "*TECHNIQUES FOR OBSERVATION OF BEAM DYNAMICS IN THE PRESENCE OF AN ELECTRON CLOUD*"

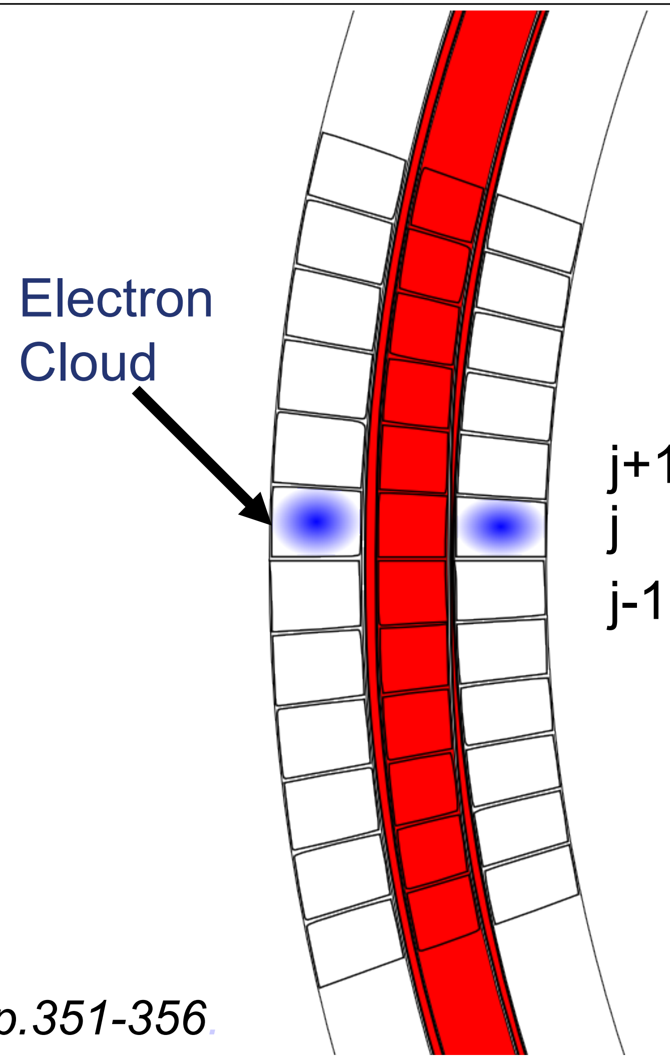


Using button pick-up one can sample with high time resolution the evolution of electron density by changing the spacing between bunches.

Our Numerical Model

Model used by Ohmi* et al for the interaction of a coasting beam with an electron cloud:

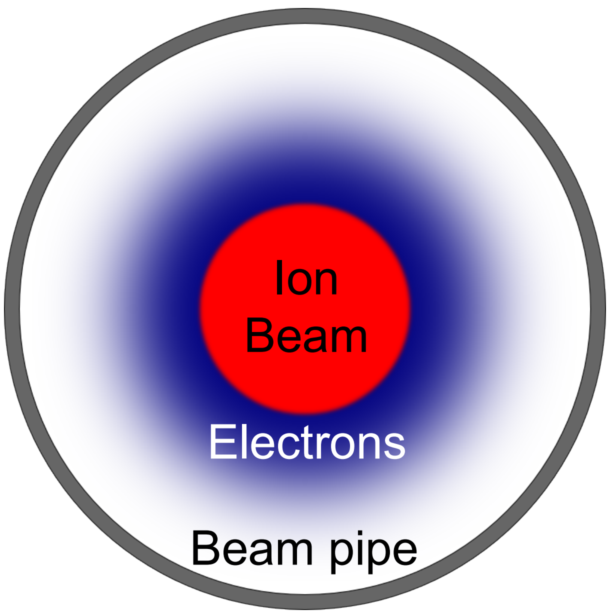
- Ion beam: Only transverse rigid dipole oscillations
- Longitudinal slicing of the ion beam.
- Slices are tracked trough the ring lattice.
- EC localized in one interaction point.
- Landau damping is included in a simple way



*Ohmi et al, Workshop on Electron-Cloud Effects "ECLOUD'04" , Napa, CA, USA, 19 - 23 Apr 2004, pp.351-356.

Transverse Plane

Factors affecting electron cloud build-up in model:



Geometry Scheme

- Residual gas ionization
- Electron secondary emission yield
- Ion secondary emission yield
- Electron refraction from the wall
- Coulomb scattering
- Bunch form and ion energy

Cross Sections

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- Kaganovich fit for ionization cross sections

$$\sigma(v, I_{nl}, Z_i) = \pi a^2 \frac{Z_i}{(1+Z_i/Z_T)} N_{nl} \frac{E_0^2}{I_{nl}^2} G_{new}\left(\frac{v}{v_{nl}\sqrt{1+Z_i/Z_T}}\right)$$

$$G_{new}(x) = \frac{\exp(-1/x^2)}{x^2}\left[1.26 + 0.283\ln(2x^2+25)\right]$$

- Agreement with strict quantum mechanics calculation and experimental values

* *Kaganovich et al, New Journal of Physics 8 (2006) 278*

Analytical Model for Electron Accumulation in Coasting Beam

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Assumptions:

- Cylindrical geometry
- Stable beam
- Electron production due to the gas ionization
- Coulomb scattering
- Heated electrons are lost on the wall

Average potential barrier

$$U_{lim} \approx \frac{U_{wall}}{2}$$

Neutralization degree

$$\eta(t) = \frac{n_e(t)}{Z_i \cdot N_i}$$

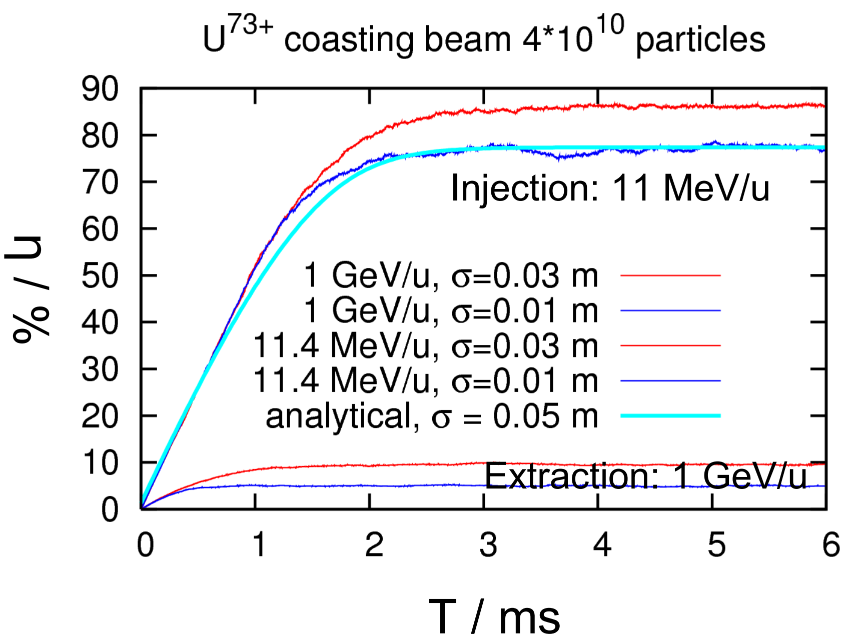
Electron balance equation

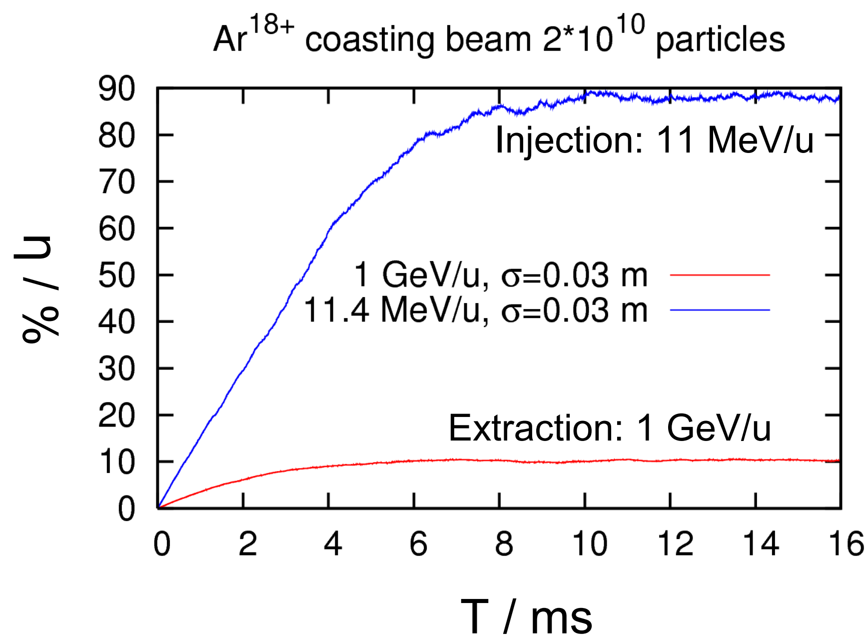
$$n_e' = V_i - \frac{V_{heat}}{U_{lim}(1-\eta)} n_e$$

P. Zenkevich, N. Mustafin, O. Boine-Frankenheim, Proceedings of Ecloud 2002

Fixed Coasting Beam in SIS-18

Slices were fixed in the middle of cylindrical pipe



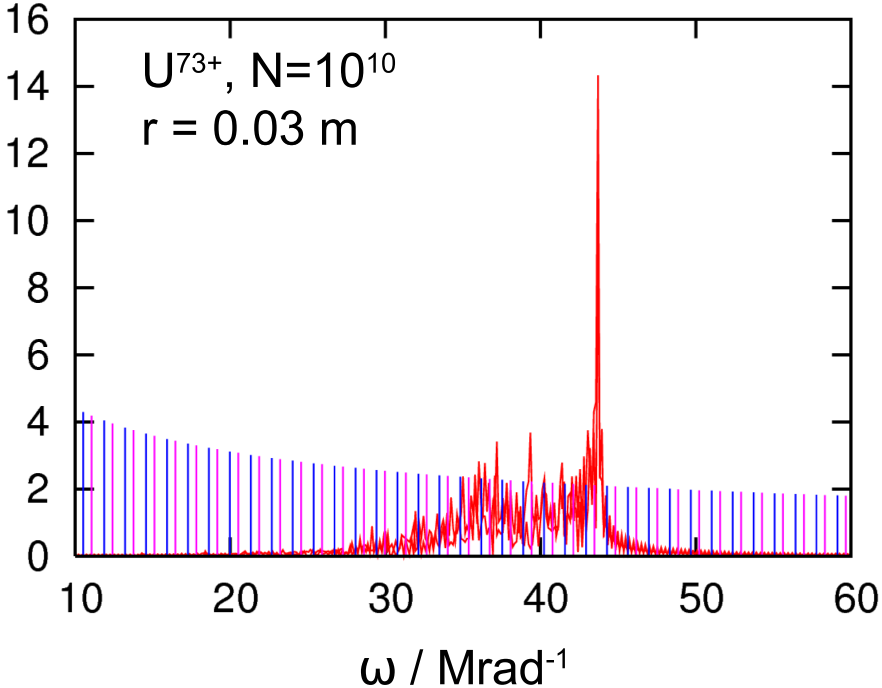


Overestimated values of η if the electron cloud does not affect beam particles position

U^{73+} and Ar^{18+} have different saturation times but similar saturated η values.

Electron Spectra and Schottky Noise

Question: can the natural Schottky fluctuations of the beam potential lead to loss of the trapped electron ?



Side bands position:

$$\omega_{n,\pm} = (n \pm q) \cdot \omega_0$$

Side band width:

$$d\omega_{n,\pm} = (n \pm q) \cdot \omega_0 \cdot \frac{\delta p}{p} \cdot \eta$$

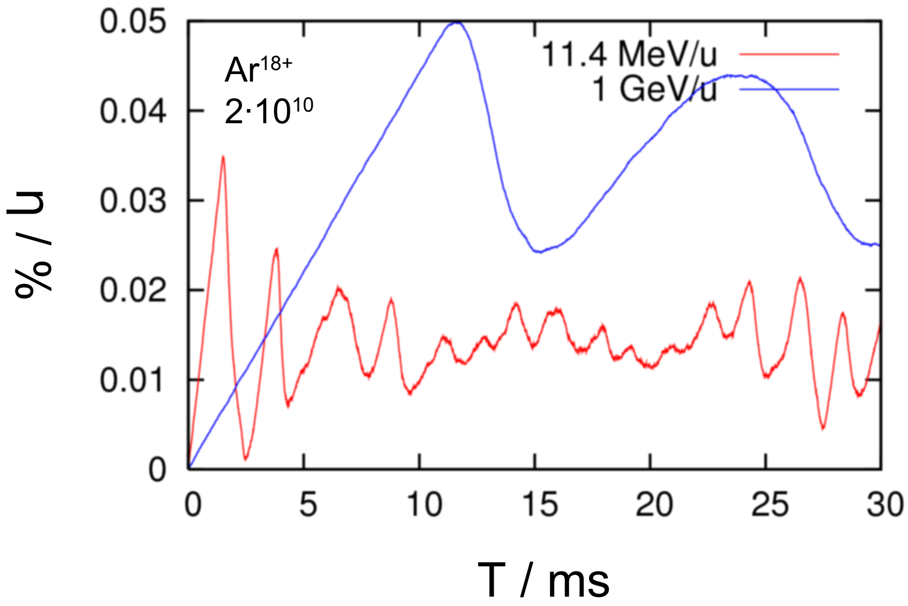
Schottky noise rms amplitude:

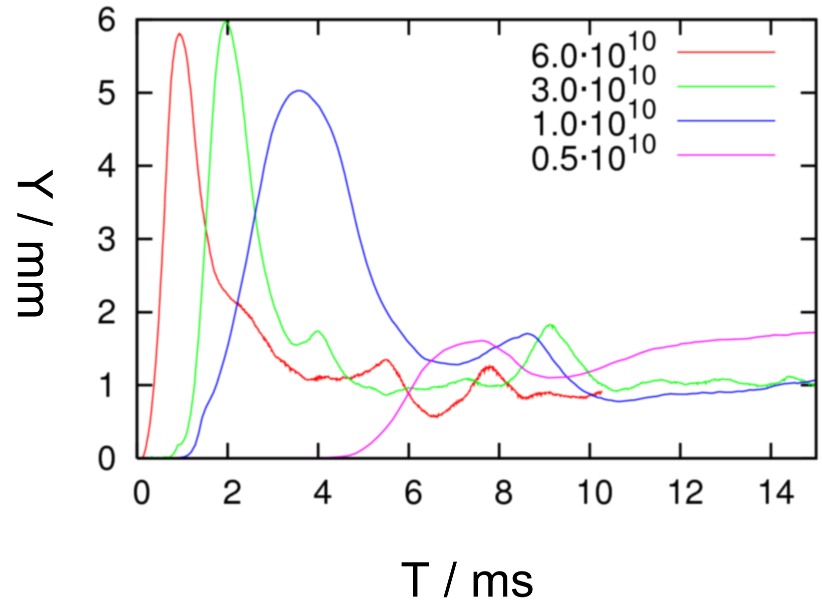
$$a_{rms} = \frac{\sigma_{rms}}{\sqrt{N_{beam}}}$$

No visible effect on neutralization degree for realistic a_{rms}

Chattopadhyay, AIP Proceedings,v.127,p.467,1985

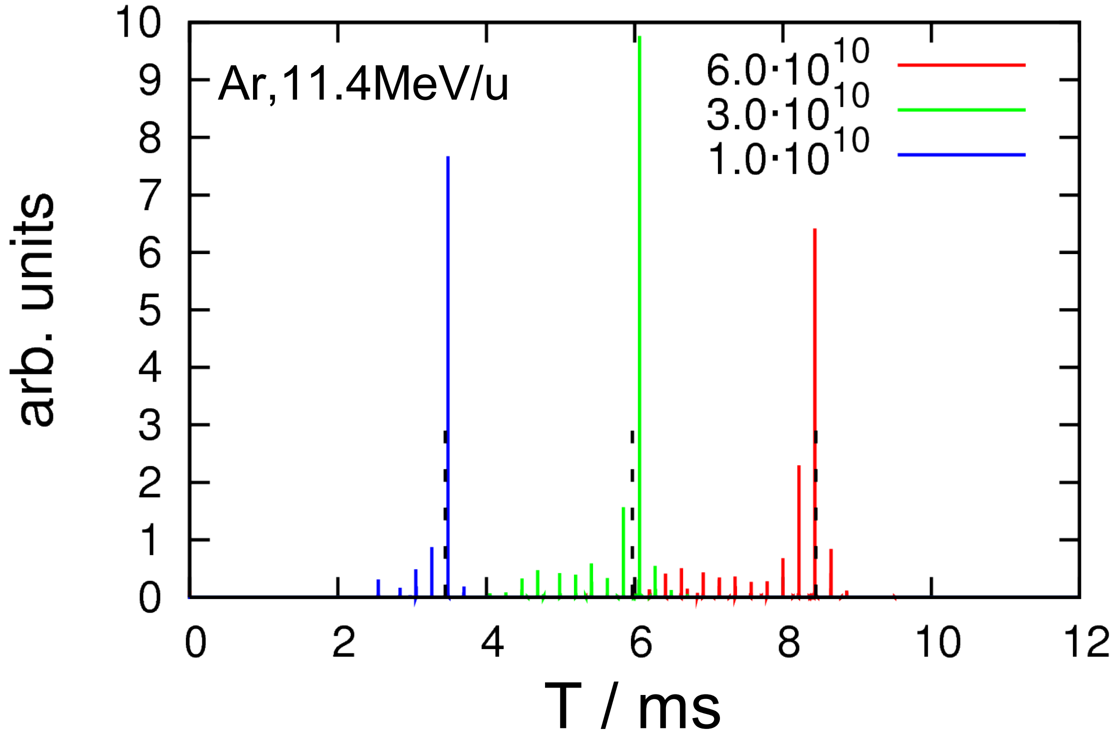
Two-Stream Instability in Case of Beam-Electron interaction





1. For 1GeV/u neutralization degree is higher
2. There are enough electrons to lead to an observable oscillations

Centroid Oscillations Spectra



The harmonic with maximal amplitude is close to the electron bounce frequency

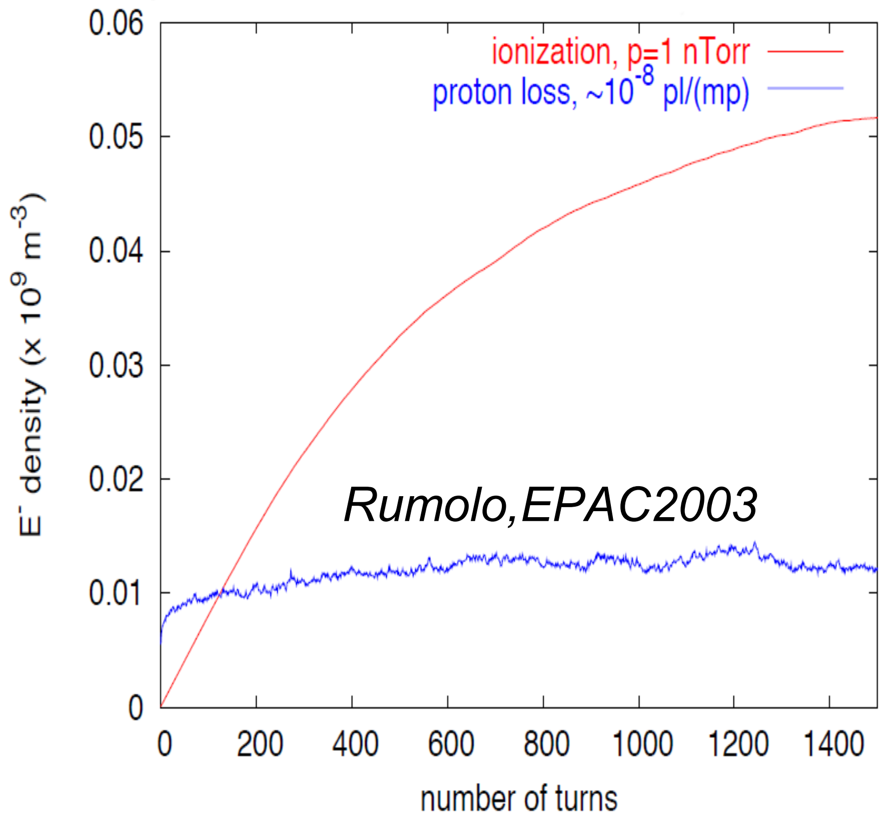
This could be a guide for beam based EC measurements using RGM, Schottky pick-up

HEADTAIL

G. Rumolo in 2004 using modified HEADTAIL performed calculations for SIS18 U^{28+} coasting beam at energy 11.4 MeV/u.

HEADTAIL is a versatile PIC-code for electron-ion beam interaction simulations. Originally suited for modeling interaction with pre-calculated EC from ECLOUD.
In 2004 it was modified to model coasting beams and electron cloud build-up simultaneously.

Rumolo simulations in 2004 showed <u>no dipole oscillations but linear emittance growth</u>. Although he have used underestimated cross sections his pressure was overestimated.



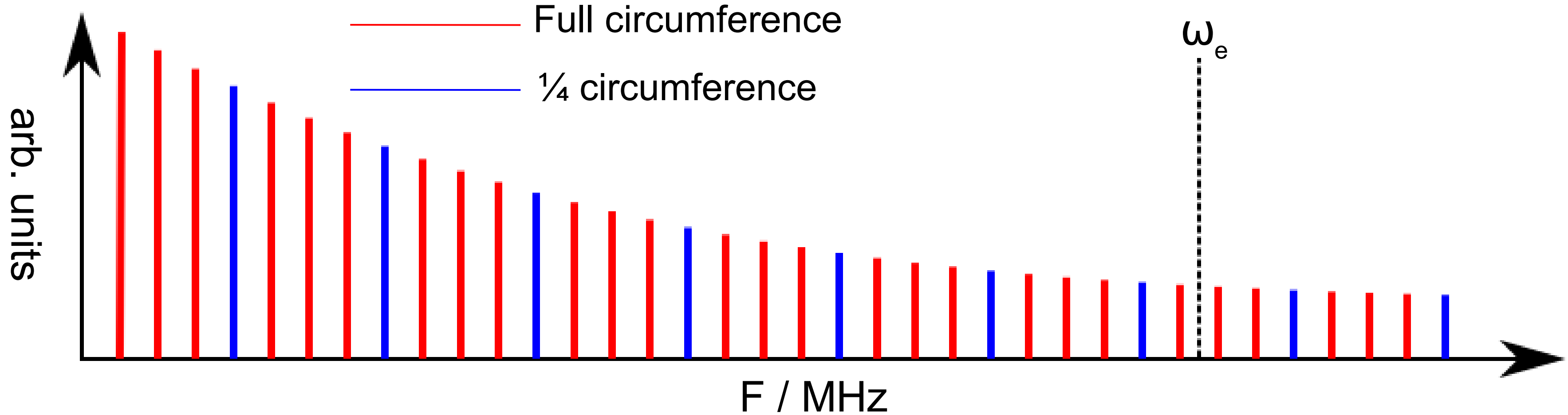
HEADTAIL Discussion and Problems

Till now I didn't achieve the agreement with Rumolo results using HEADTAIL and the same parameters. However, no huge dipole oscillations.

Possible problems of complete PIC modeling:

1. At each interaction point EC interacts with small fraction of beam particles contained in the slice => big artificial noise $\sim\sigma/(N_{macro})^{-1/2}$

2. Modeling the fraction of the ring leads to the removal of many of harmonics responsible for beam loss



Planned Experiments

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Beam-based

·Measuring beam response in the spectral region of electron bounce frequency using Schottky pick-up, RGM etc

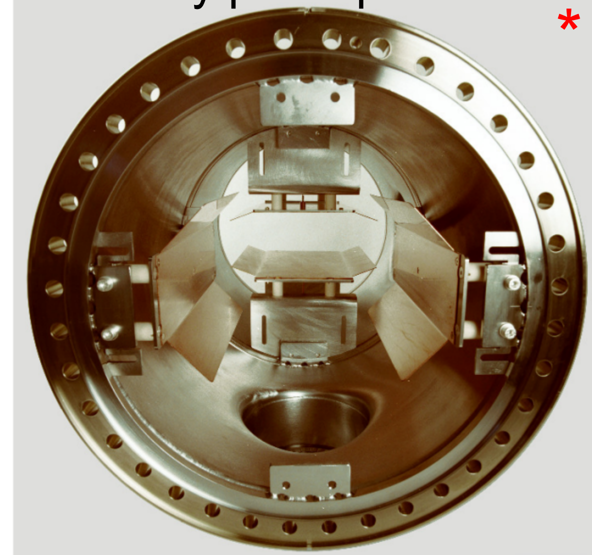
Direct

·Retarding field analyzers, Button pick-up

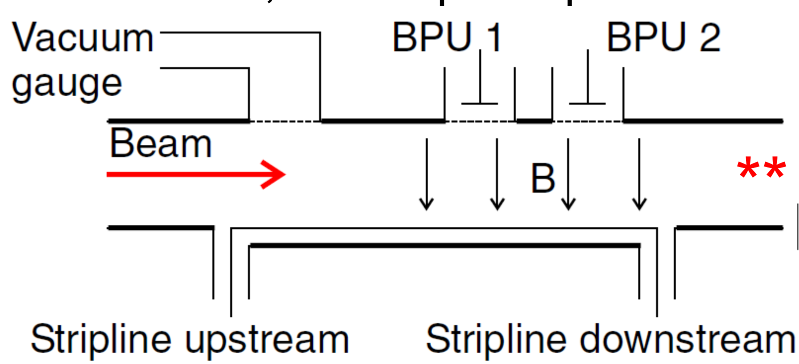
** S.Paret, Ph.D. thesis*

*** E.Mahner, Phys.Rev.ST AP 2008*

Schottky pick-up in SIS18



CERN PS, button pick-up scheme



Conclusion

- Two-dimensional code with rigid beam slices is developed
- Simulations show that beam centroid can oscillate with significant amplitude even for very small neutralization factors
- Preliminary HEADTAIL simulations do not show significant beam centroid and η oscillations.
- This could be either due to the insufficient number of macroparticles and slices or due to the more realistic Landau damping

Outlook

- Further convergence studies are necessary for HEADTAIL simulations
- Beam-based experiments should be performed to investigate whether or not beam exhibits oscillations in the region expected
- The installation of button pick-ups in SIS18 is planned for October-November 2010 which will allow to measure electron presence dirrectly

THANK YOU FOR YOUR ATTENTION

QUESTIONS AND SUGGESTIONS ARE WELCOME