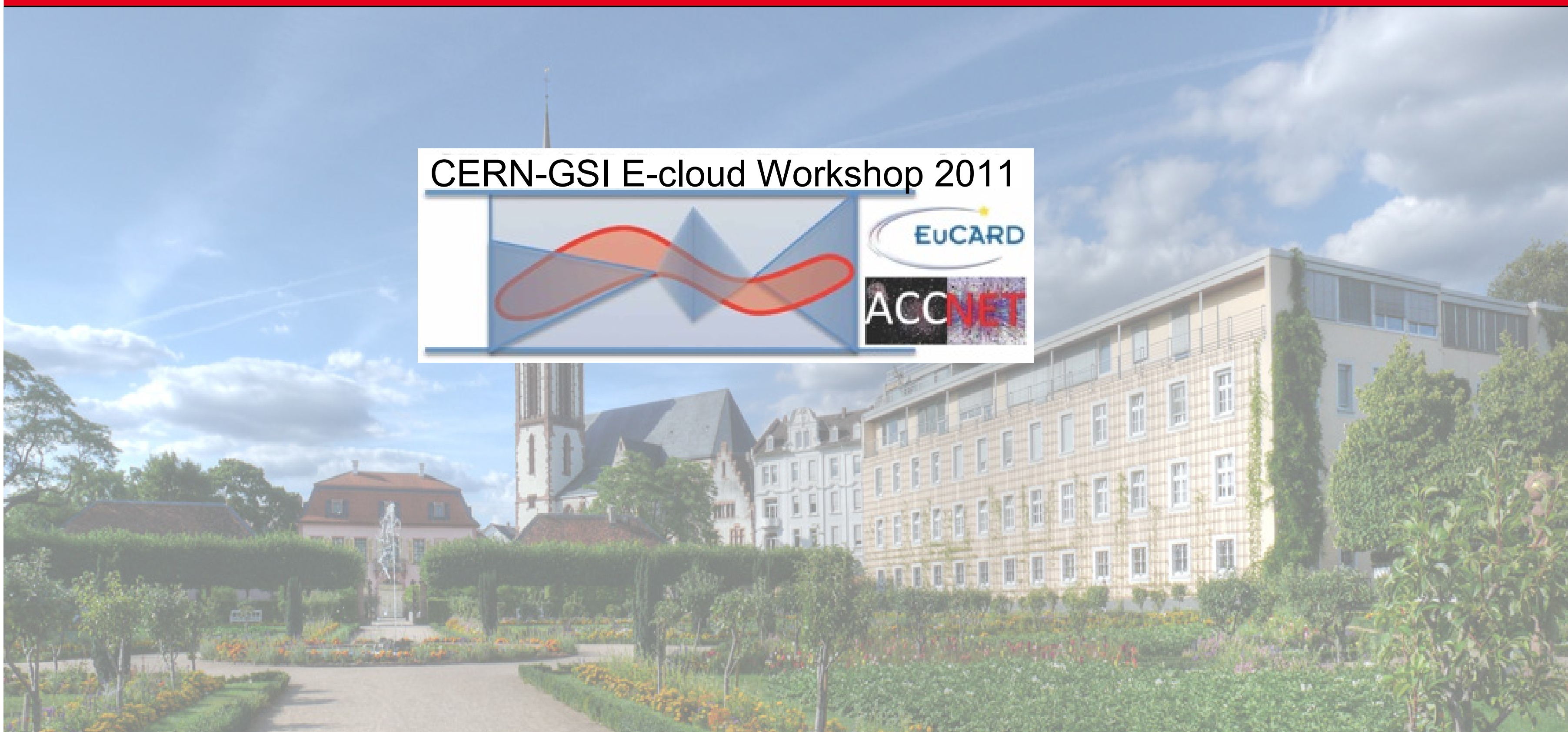
Electron Cloud Studies for FAIR

Fedor Petrov, Prof. Oliver Boine-Frankenheim
Prof. Thomas Weiland



Outline

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Introduction
Tools used for simulations
SIS18
- Electron accumulation studies
- Instabilities

SIS100
- Electron accumulation studies

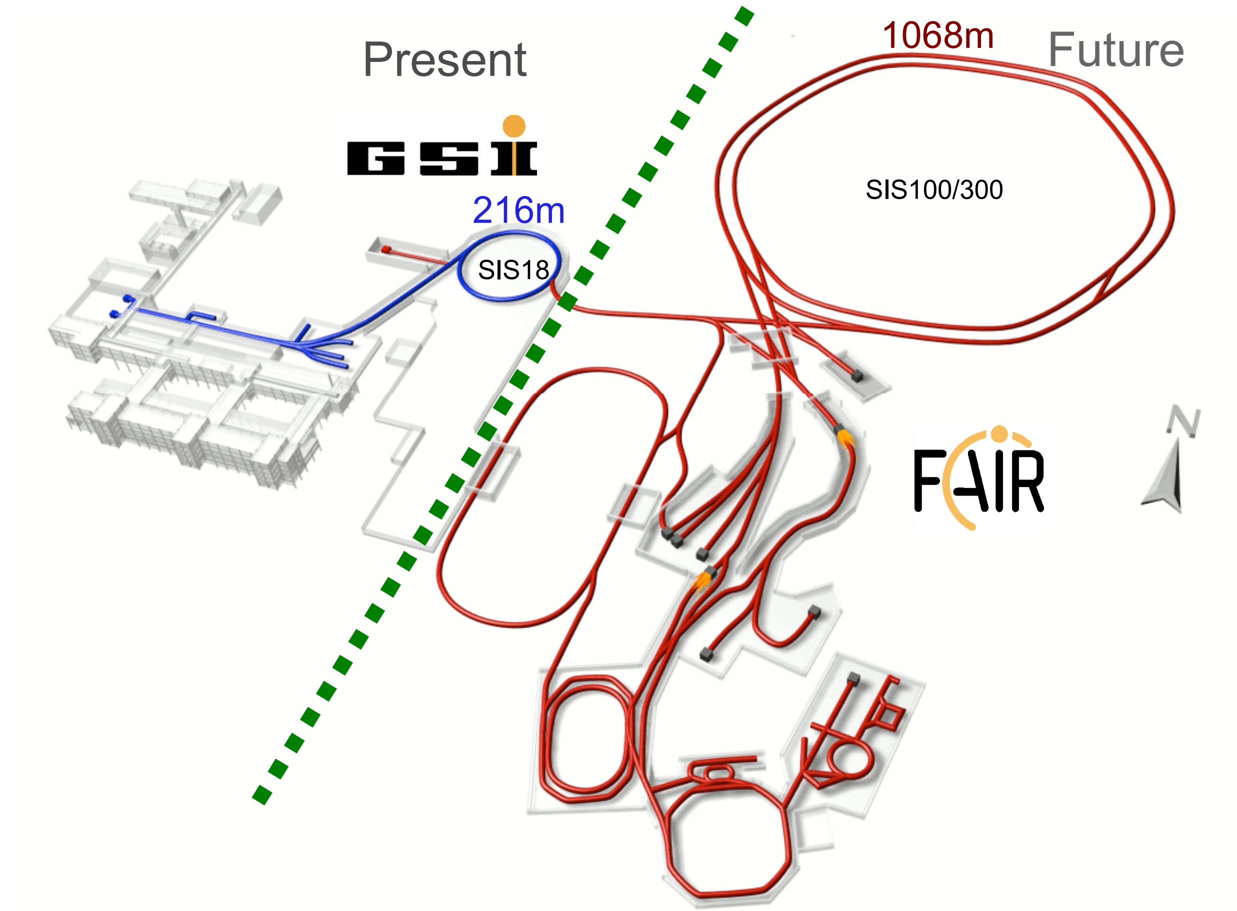
Experimental plans
Conclusions

Introduction: GSI and FAIR

GSI is evolving to FAIR

Upcoming FAIR facility will operate with heavy ion beams at increased intensities.

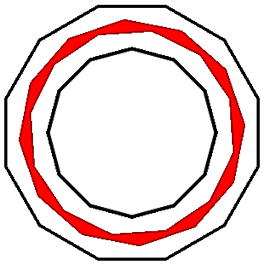
The problem of electron clouds may be important for the upgraded SIS18 and for the projected SIS100.



Coasting and Bunched Beams

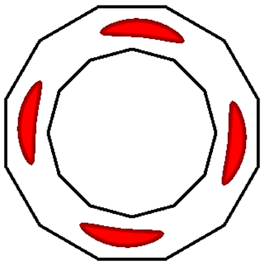
E.cloud problems are studied for two operation modes

Coasting beam



Will be used in experiment and during slow extraction of intense beams from SIS18 and SIS100

Bunches



During SIS100 accumulation and acceleration.

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- **Simulation model**
- **Analytical accumulation model**

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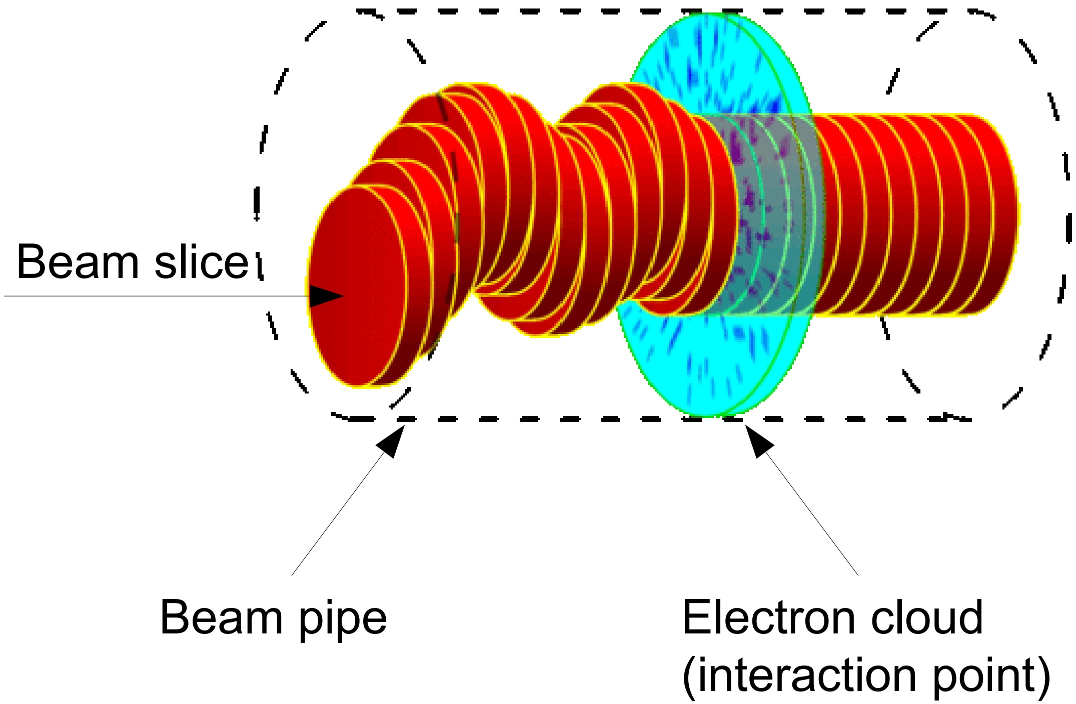
Simulation Model

The idea is taken from
Ohmi et al, "ECLOUD'04"

1. Beam is made of rigid slices
2. Only dipole beam motion
3. Slices are transferred through the focusing lattice
4. Cloud is localized in one point
5. Landau damping for coasting beam is treated in a simple way



$$x_j = (1-\alpha)\, x_j \quad \text{where} \quad \alpha = \frac{\eta}{\sqrt{3}} \frac{\omega_e}{\omega_0} \frac{\delta p}{p}$$

Electrons Production Mechanisms

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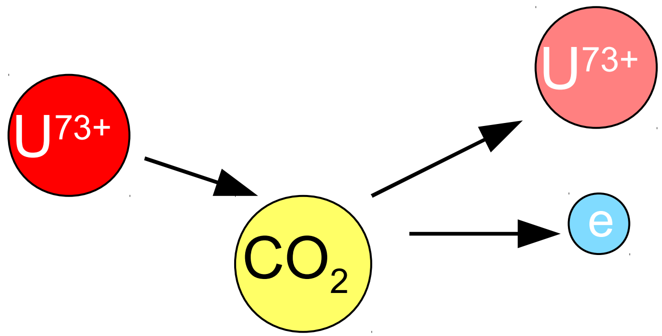
Residual gas ionization



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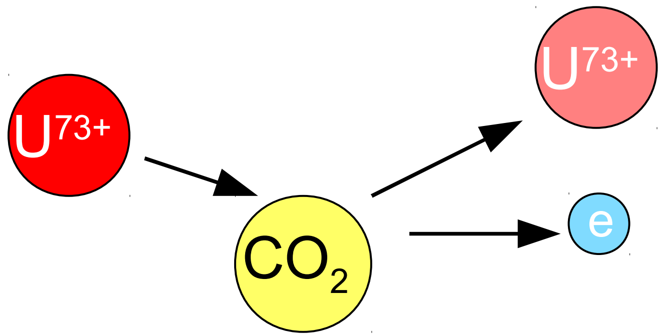
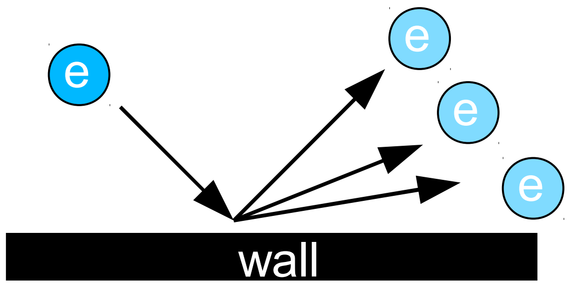


Electron secondary emission



Electrons Production Mechanisms

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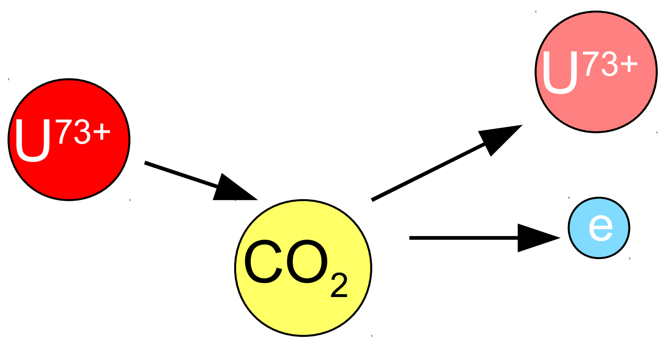

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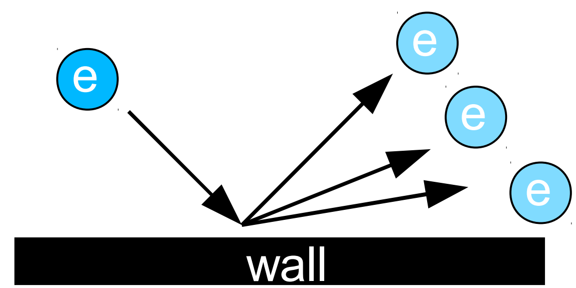
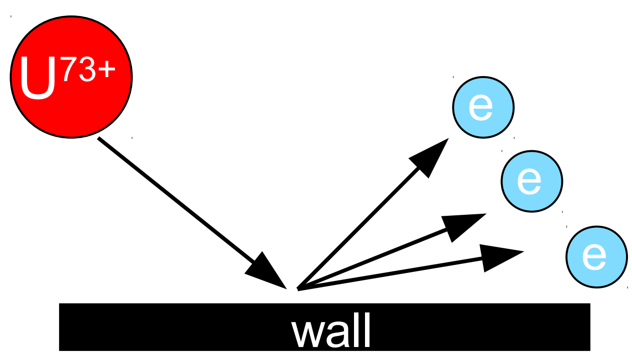


Ion induced secondary emission



Electrons Production Mechanisms

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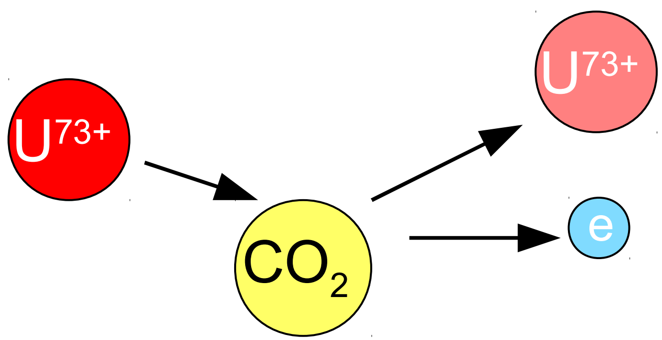

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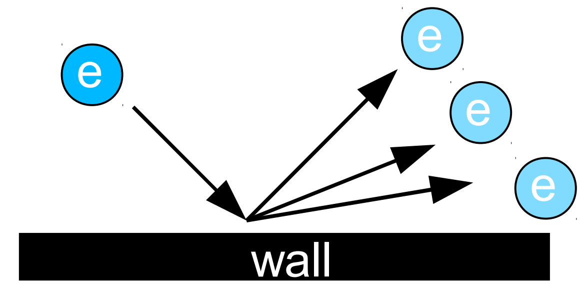
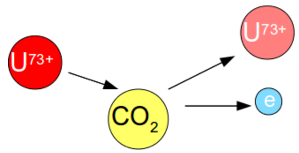


Taken into account in simulations

Electron Processes in the Model



1. Ionization cross sections were calculated based on analytical formula from [1]. For heavy ions ionization may be by 3 orders more effective

[1] Igor D Kaganovich et al 2006 New J. Phys. 8 278
[2] H. Seiler, J. Appl. Phys. 54, 11 (1983).
[3] Cimino et al,, Phys. Rev. Lett. 93, 014801 (2004)

Electron Processes in the Model

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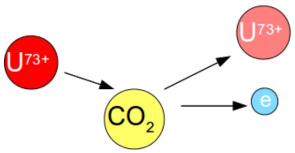

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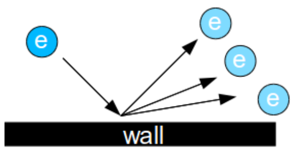

2. Analytical expression for secondary emission yield[2]:

$$\delta_{SEY}(E)=\delta_{E_{max}}\cdot 1.11\cdot\left(\frac{E}{E_{max}}\right)^{-0.35}\cdot\left(1-e^{-2.3\cdot\left(\frac{E}{E_{max}}\right)^{1.35}}\right)\cdot e^{0.5\cdot(1-\cos(\theta))}$$

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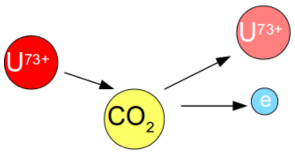

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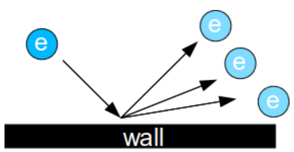

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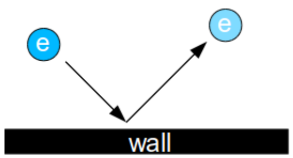

3. Reflection coefficient as a function of kinetic energy [3]:

$$\delta_{ref}=\frac{\left(\sqrt{E}-\sqrt{E-E_0}\right)^2}{\left(\sqrt{E}+\sqrt{E+E_0}\right)^2}$$

[1] Igor D Kaganovich et al 2006 New J. Phys. 8 278
[2] H. Seiler, J. Appl. Phys. 54, 11 (1983).
[3] Cimino et al,, Phys. Rev. Lett. 93, 014801 (2004)

Simple Analytic Electron Accumulation Model (for coasting beam)

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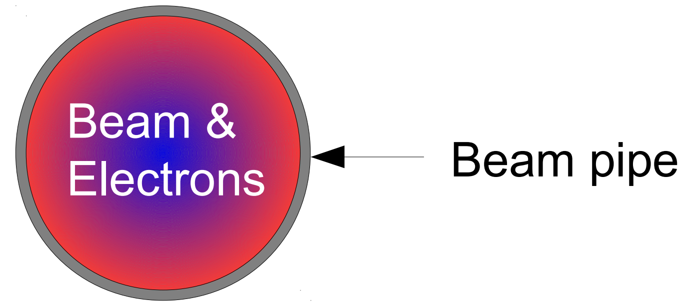
Simple electron balance equation:

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



- Electrons produced by residual gas ionization (V_i [1/s])
- Initially trapped in the potential well of beam (U_{lim} [eV])
- Reach the wall because of Coulomb heating (V_{heat} [eV/s]) (by the heavy-ion beam)

$$V_i = c\beta\sigma_i N_{beam}\rho_{gas}$$

$$V_{heat} = E_0 \frac{4\pi c \rho_i r_e^2 Z_i^2}{\beta} L_{Coul}$$

* *Zenkevich, Mustafin, Boine-Frankenheim, Proceedings of Ecloud 2002*

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Results for Electron Accumulation in Frozen coasting Beam (benchmarking)

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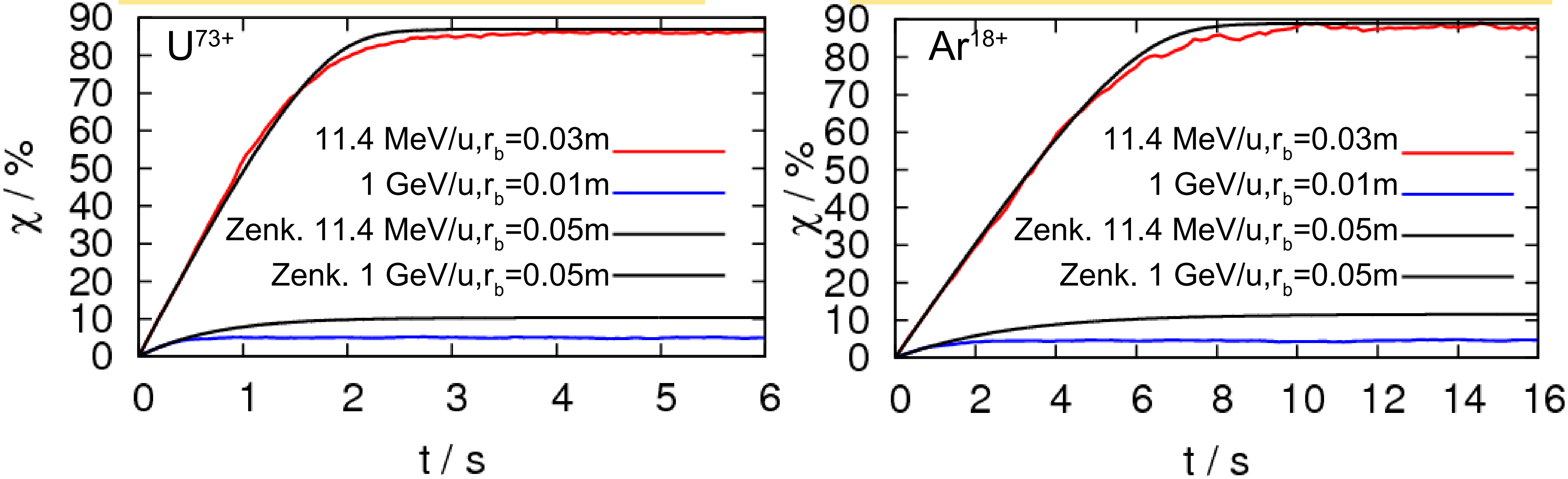
11.4 MeV/u – injection energy;
1 GeV/u – extraction energy

In analytical model beam radius stays constant for different energies



Black curve is solution of

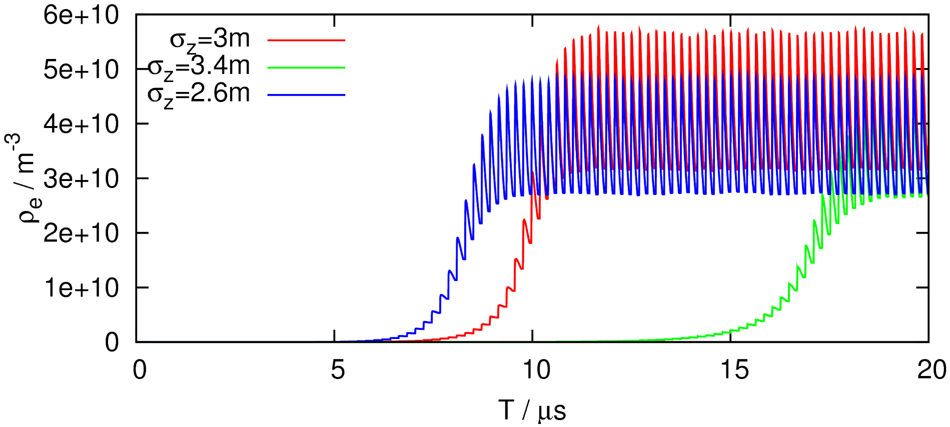
$$n_e' = V_i - \frac{V_{heat}}{U_{lim}(1-\eta)} n_e$$

Results identical for both species.

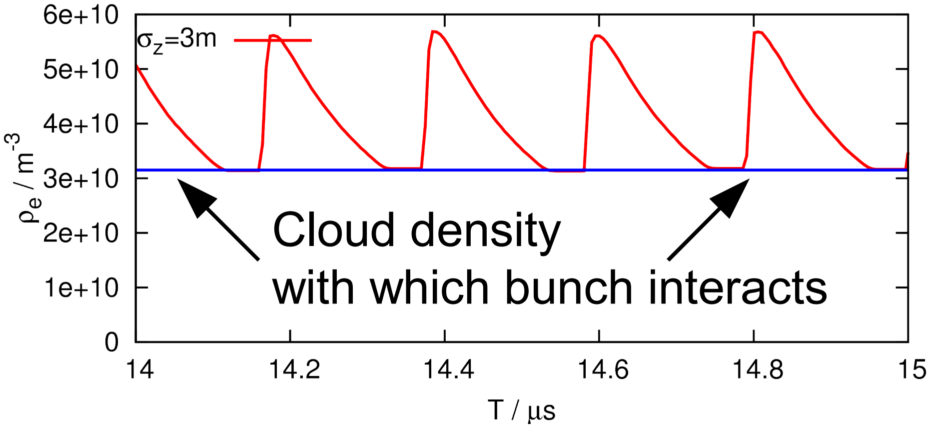
Small radius → big heating → big losses

Example of Electron Cloud Build-up in SIS18 for Bunched Beams

U^{73+},4·10^{10},1 GeV/u, 4 bunches, R_p=17cm



U^{73+},4·10^{10},1 GeV/u, 4 bunches, R_p=17cm



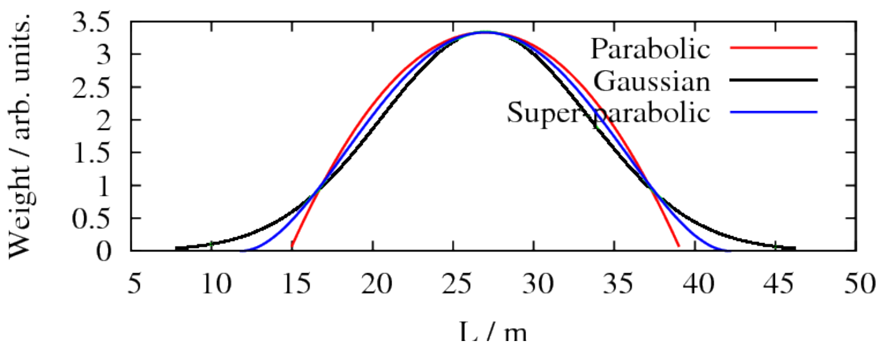
If the build-up takes place(no at injection energy):

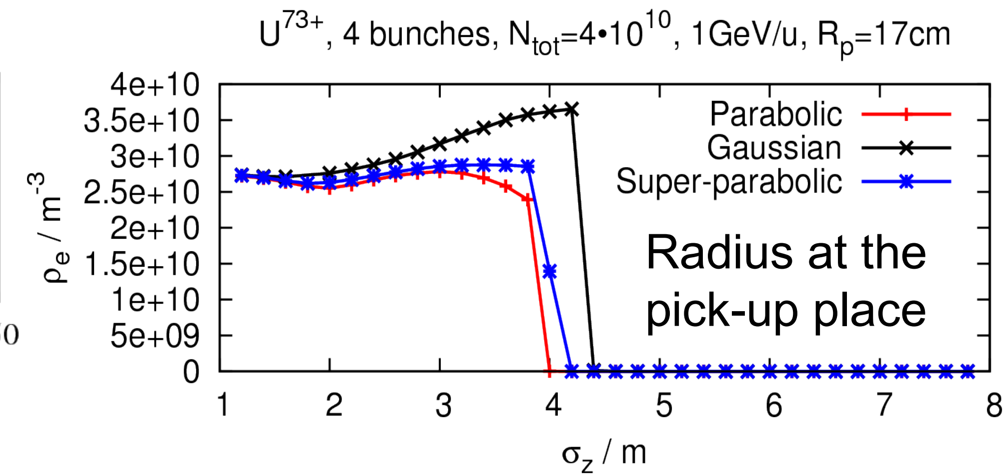
1. Production of electrons happens at the tail of a bunch
2. Next bunch interacts with the decayed cloud density

The following slide shows this cloud density as a function of **bunch length** and **bunch shape** for **two geometries**

Dependence on Bunch Length at Extraction Energy in SIS18 for h=4

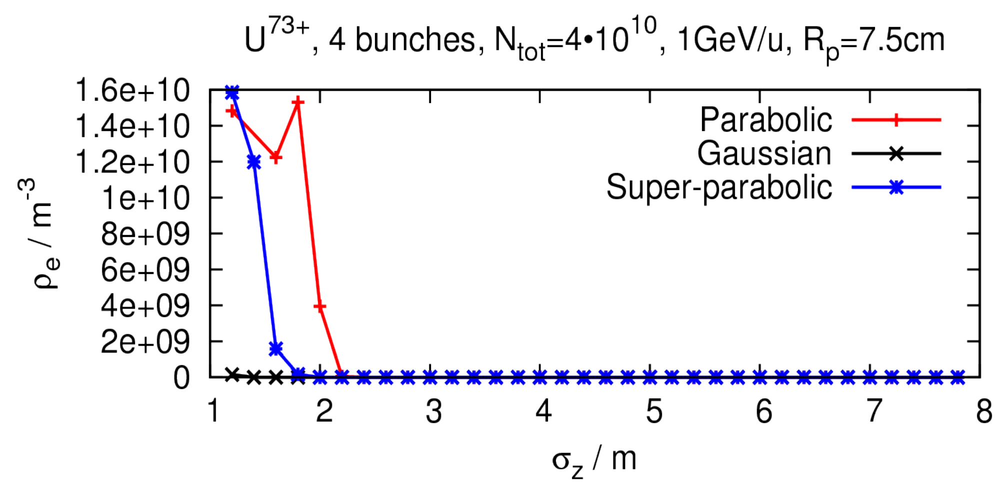
Huge effect of pipe radius on build-up





For h=4 numerical model predicts:

1. No build-up in dipole section
2. Build-up for realistic bunch length at the place of button pick-up
3. Smaller build-up for short bunches in the drift section



Dependence on Bunch Length at Extraction Energy in SIS18 for h=2

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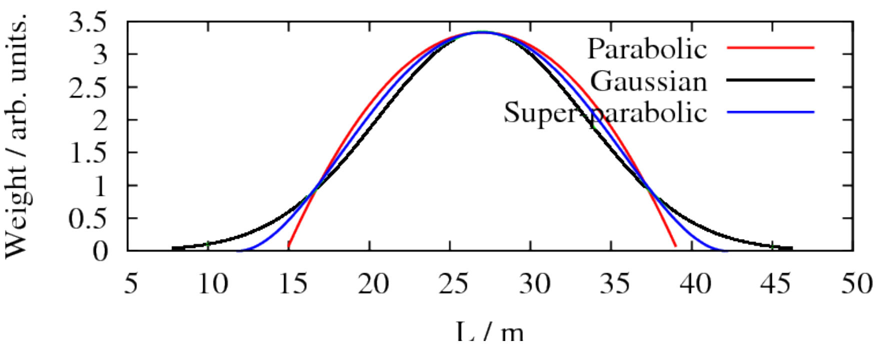
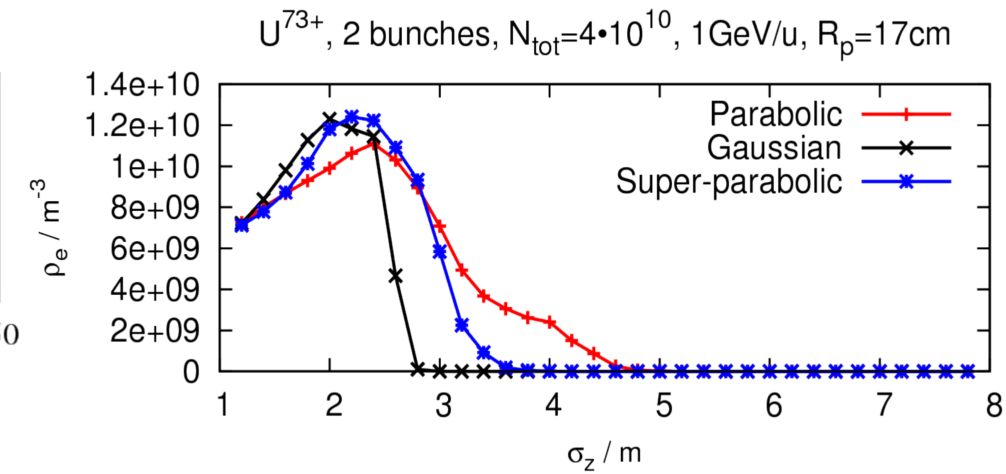
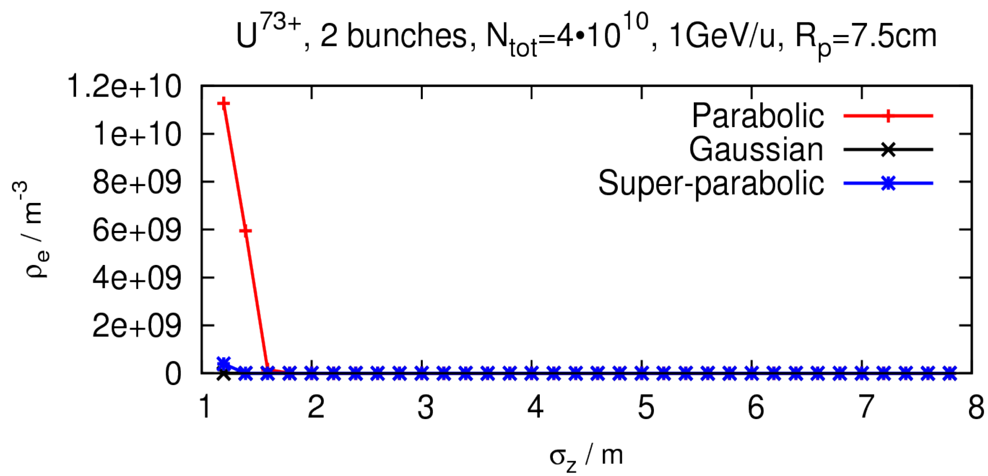
Decreasing cloud density with increased spacing





For h=2 numerical model predicts:

1. No build-up in dipole section
2. Lower for realistic bunch length at the place of button pick-up
3. Smaller build-up for short bunches in the drift section



Why Radius is so Important?

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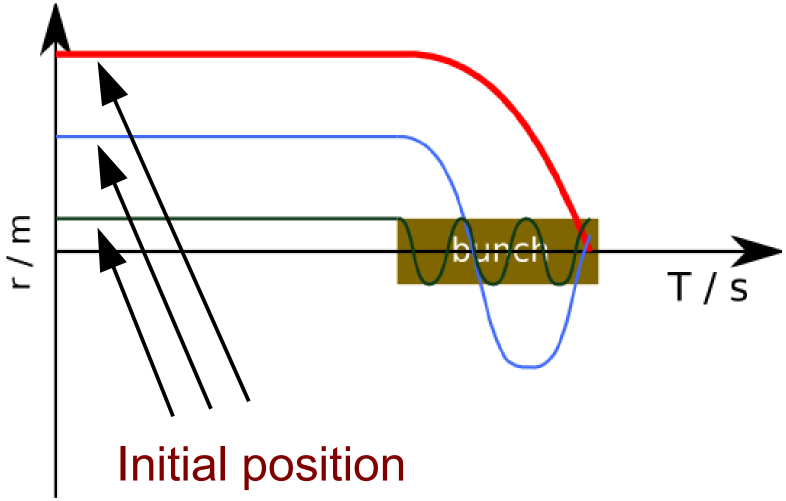
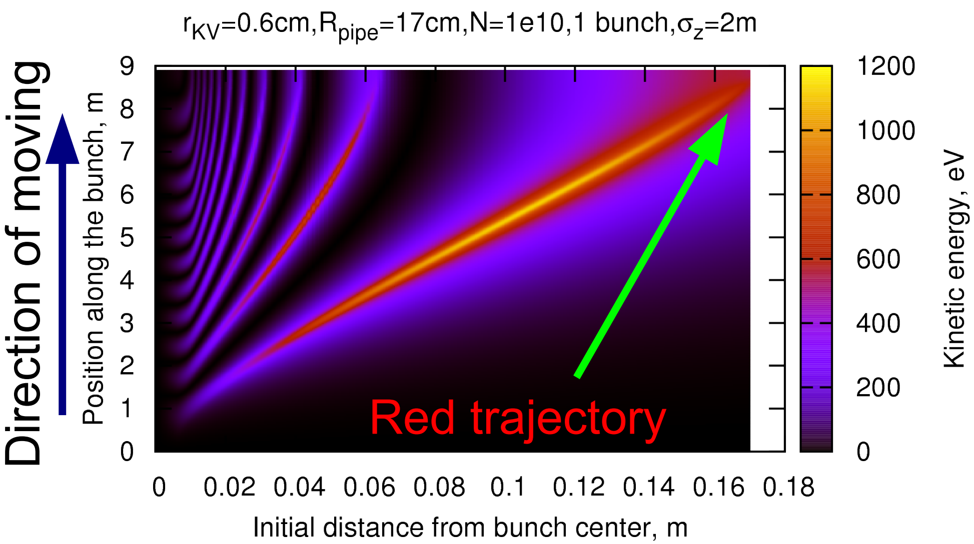
1. Bunches are long enough to accelerate the electrons far away from bunch center
2. For some parameters we have extreme case when electrons near the wall have only pure gain of energy





Pictures show the evolution of kinetic energy of electrons initially situated at different distances from the bunch center.

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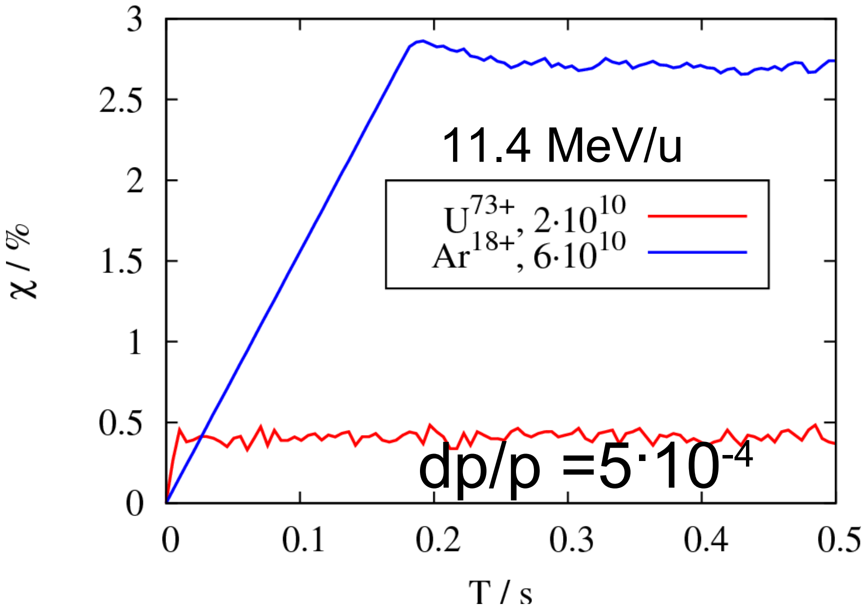
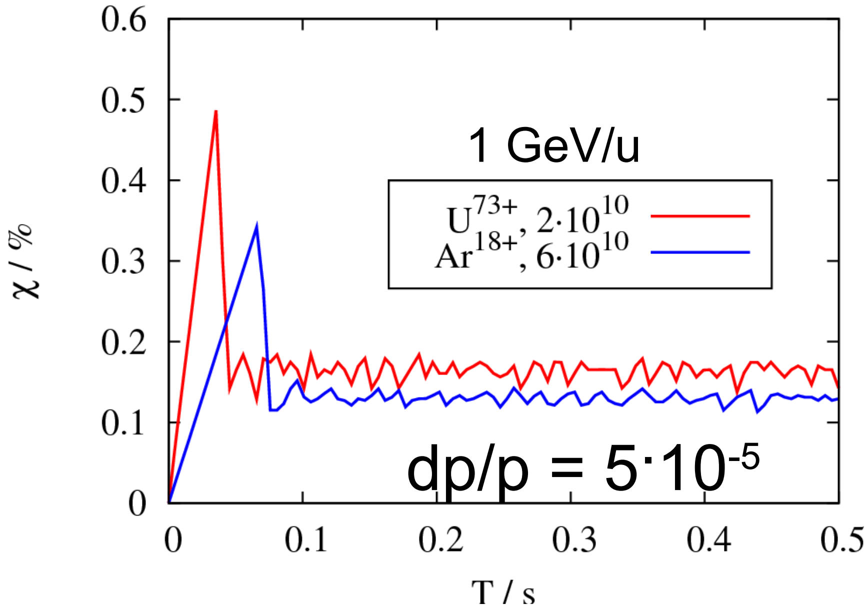
Back to Coasting beam: Beam Interaction With Cloud is ON

Electron cloud density dramatically drops down



From 90% to 3%

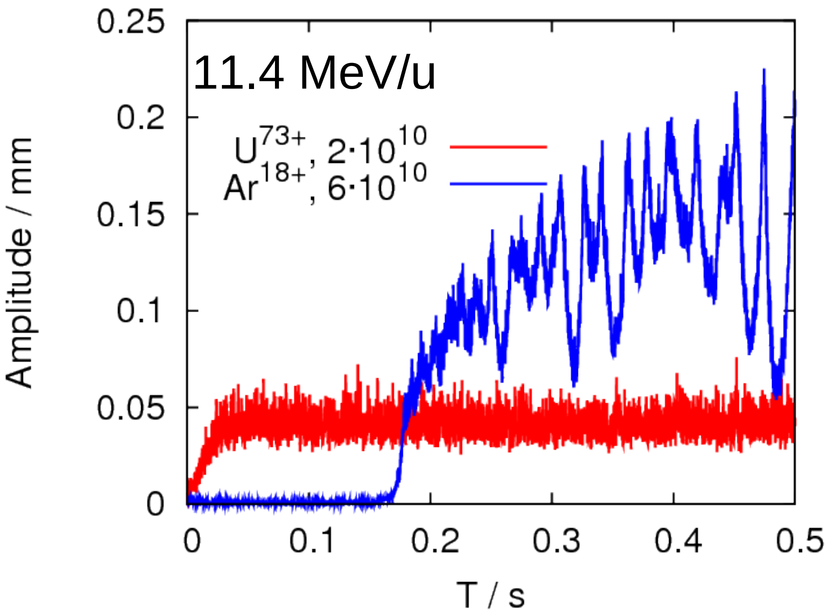


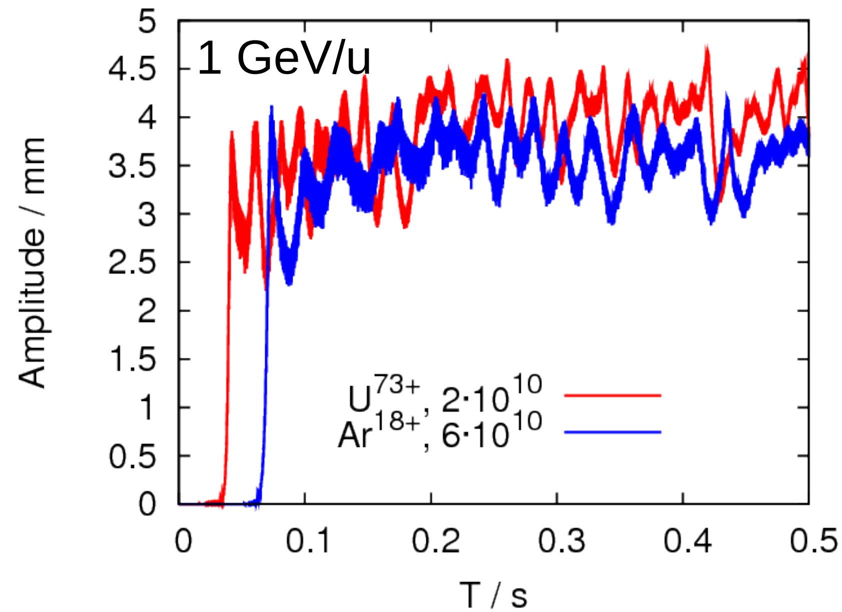
From 10% to 0.1%

Reason: Two-stream instability shakes the electrons off to the wall

Coasting beam: Two-Stream Instability

Oscillation amplitude of the coasting beam at injection and extraction





Oscillations are bigger for extraction energies

Potential danger for slow extraction

Coasting Beam: Oscillation Spectra of Beam Centroid Ar^{18+}

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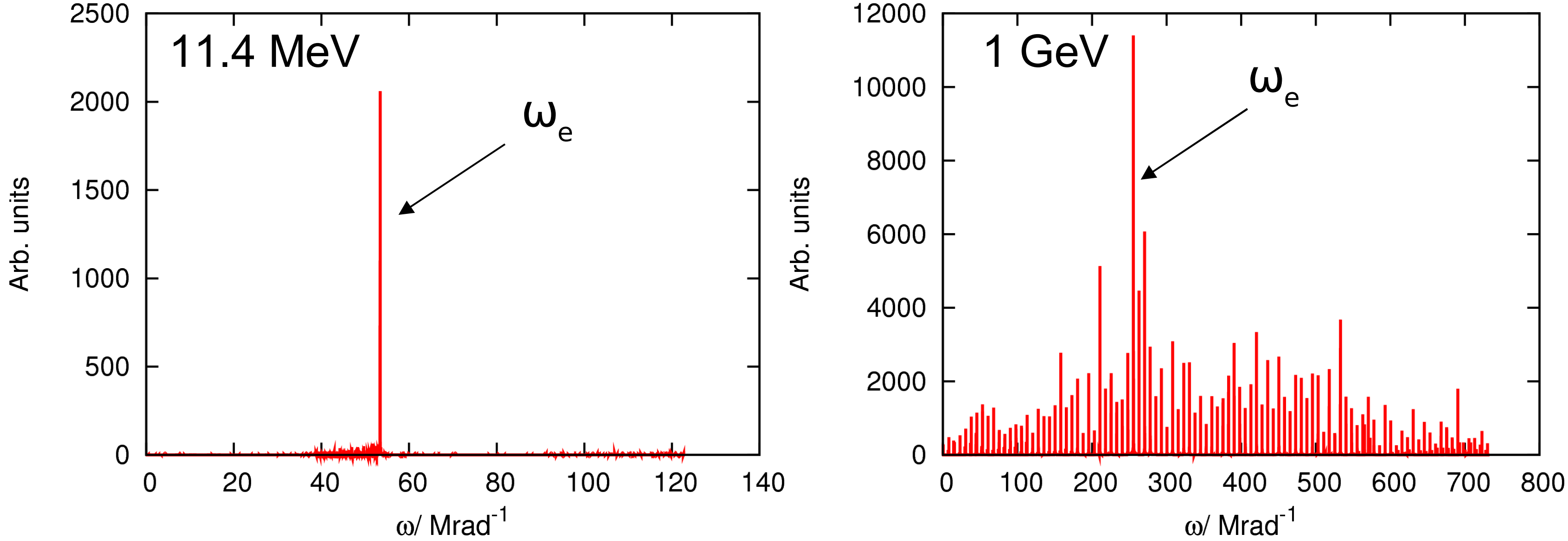
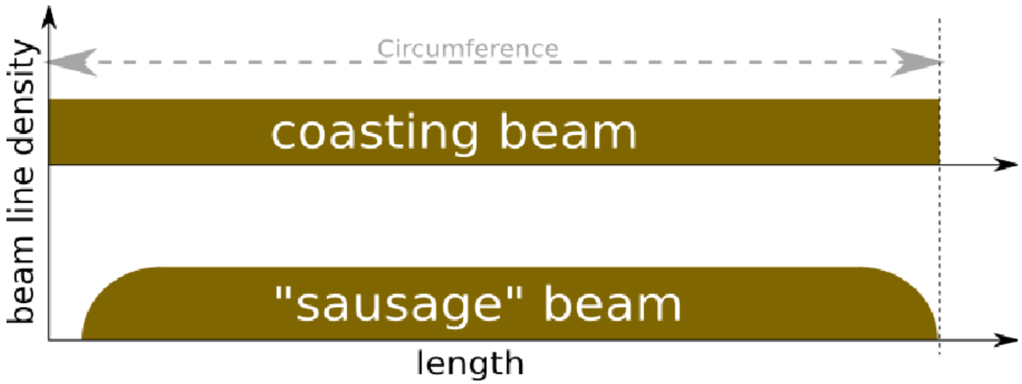


For low energy one line is dominant

For high energy big non-linearity of transverse field leads to wide spectrum

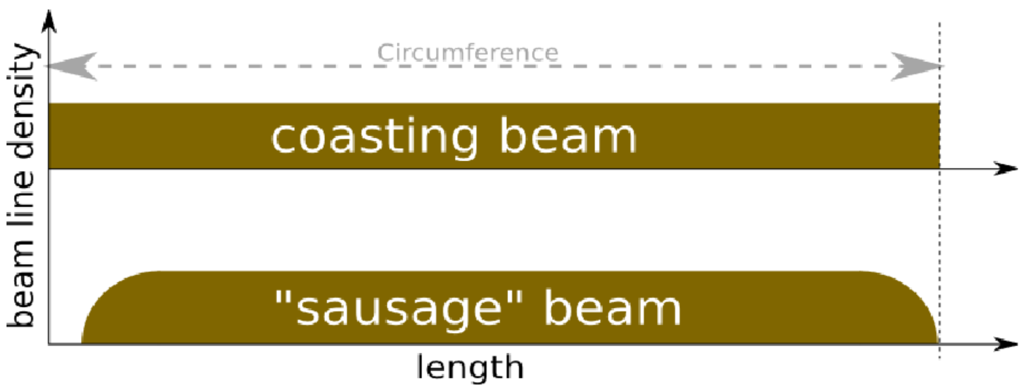
We will experimentally search for these lines in SIS

Build-up Can Be Suppressed by Gap



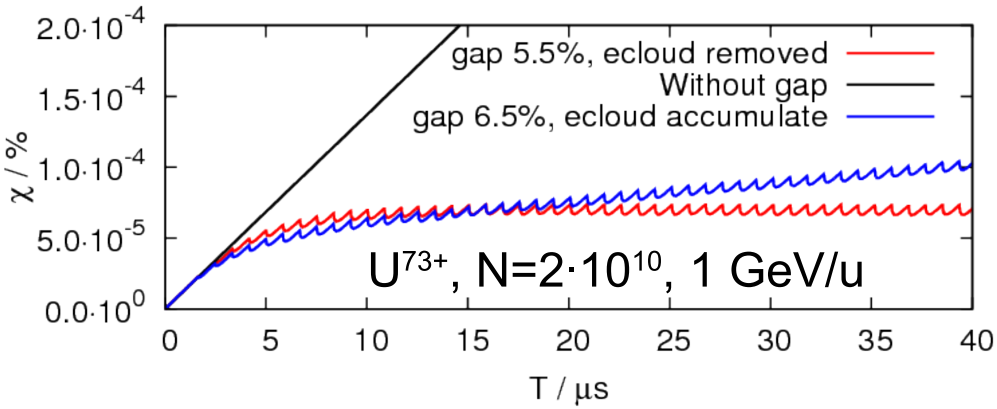
Using barrier bucket one can decouple electron and beam motion and suppress the cloud

Build-up Can Be Suppressed by Gap



Using barrier bucket one can decouple electron and beam motion and suppress the cloud

Cloud density evolution example



Build-up Can Be Suppressed by Gap

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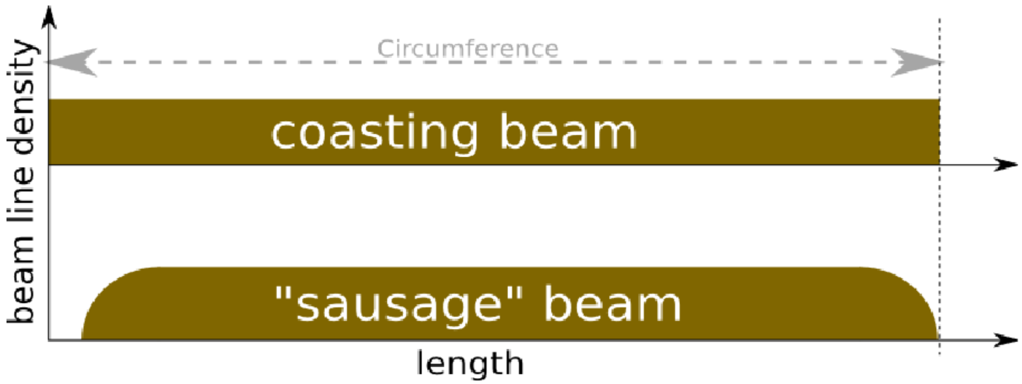

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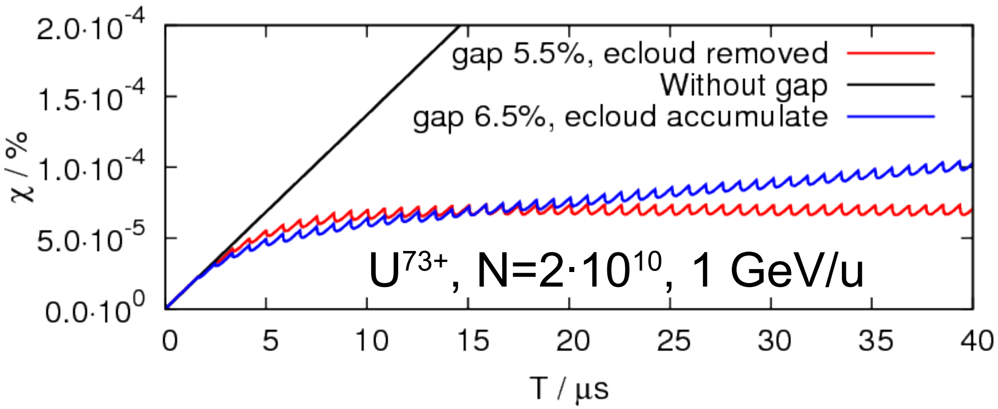
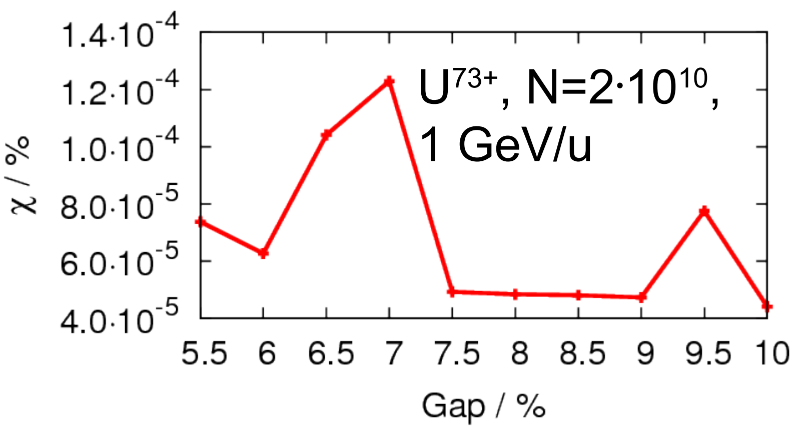
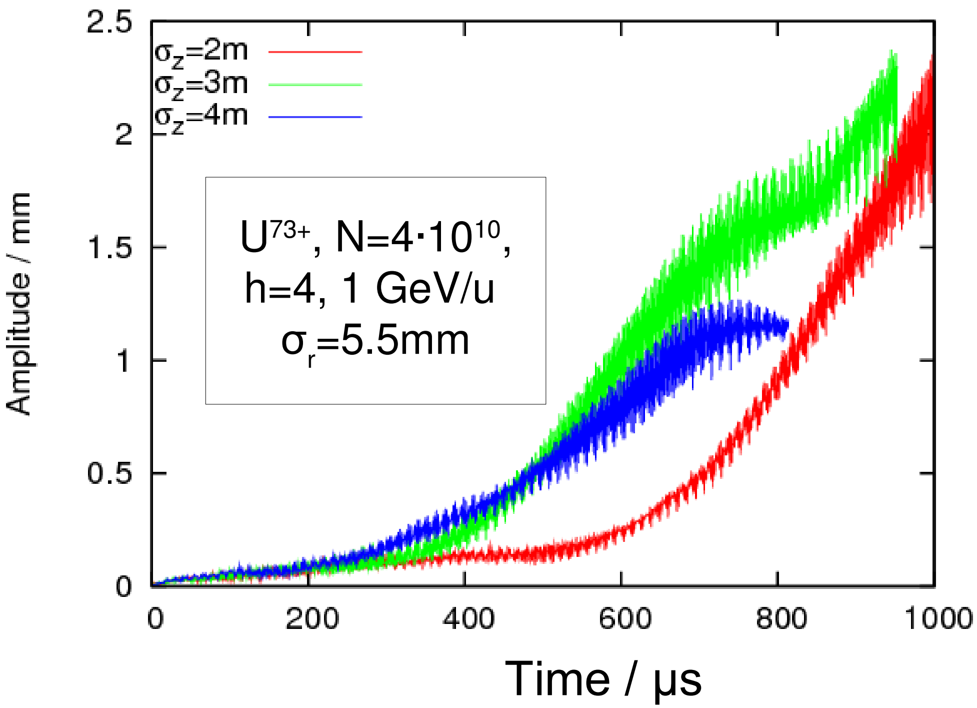


Gap length dependence



Instability in Cold Bunched Beams



Numerical simulations show

1. Dipole oscillations for the densities obtained in build-up studies reach amplitudes of 1 mm after 500 μs
2. Probably the introduction of momentum spread to bunches will add a higher threshold for stability
3. Wide sections are very short and average cloud concentration around the ring stays very small. In reality no instability.

Space charge tune shift for U^{73+} at 1 GeV/u and average $\rho_e=3\cdot 10^{10}$ m^{-3} and $\rho_{peak}=12\cdot 10^{10}$

$$\Delta\nu=\frac{Ze^2}{8\pi\epsilon_0 m_i c^2\gamma}<\beta>\rho_{peak}L\approx 4\cdot 10^{-5}$$

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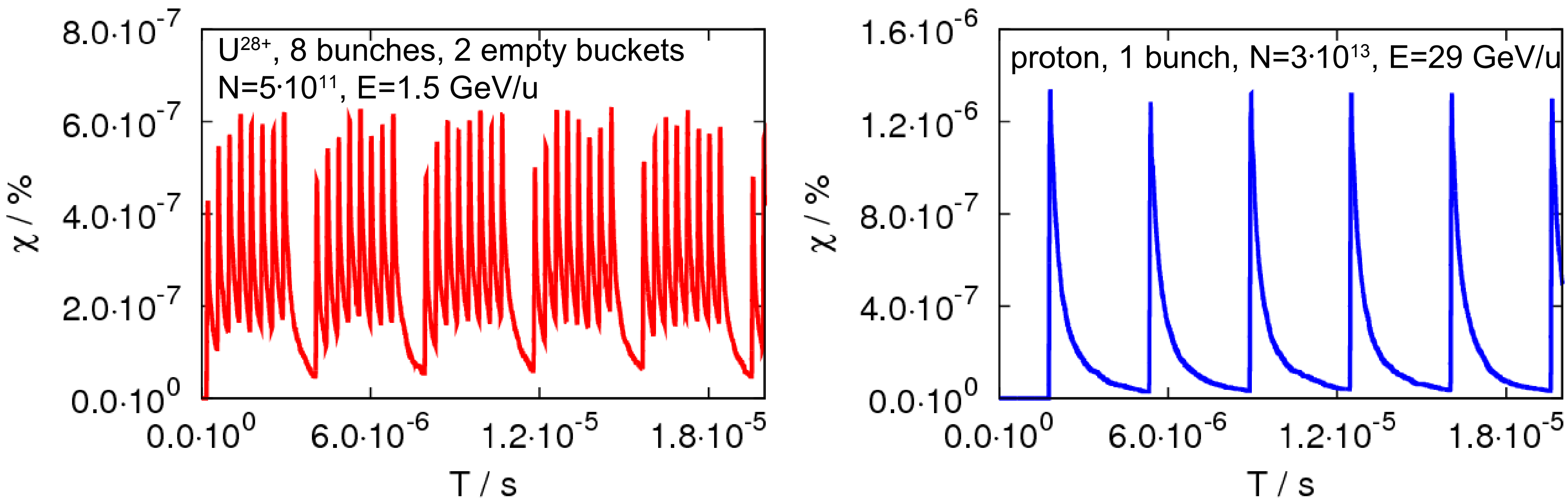
SIS100 Results for Bunched Beams

Coating of vacuum chambers was not foreseen for SIS100.



However simulations using my code revealed no build-up of electron cloud in this synchrotron for one intense proton bunch and 8 ion bunches.

Problems expected for coasting beam but no simulations yet.

Outline

Scheduled Experiments on 1-7 of April, 2011

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Beam-based

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

Direct

- Retarding field analyzers, Button pick-up

Schottky pick-up in SIS18 *

* *Courtesy A. Zschau*

Button Pick-up Close-up

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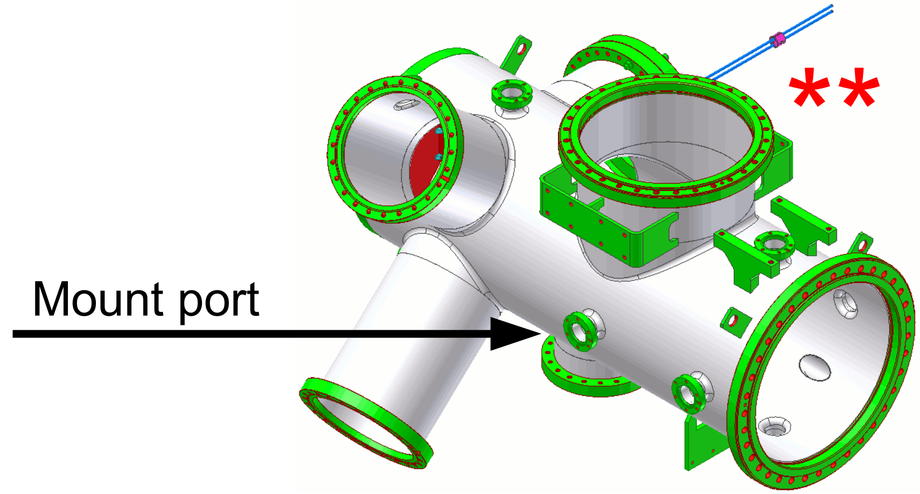

Pick-up is the analogue to the one in SPS

It collects electrons passing through the grid and we should see signal on the ammeter

*Holger Kollmus
** Lars Bozyk

Conclusions

- Simulation using rigid slice code shows significant coasting beam oscillations at extraction energy for Ar and U beams in SIS18
- Introducing a gap may cure the situation
- Build-up of electron cloud predicted below a threshold bunch length at extraction energy in SIS18
- However, average electron densities in SIS18 are not enough to trigger the instability for cold bunches
- In SIS18 we are in the regime when smaller piperadius suppress the electron cloud formation
- No build-up is foreseen in SIS100 for bunched beams

Outlook

- Full PIC simulations
- Results should be compared with HEADTAIL and ECLOUD for buildup
- Electron cloud build-up should be modeled in quadrupole sections
- SIS Experiments in April

Thank you for your attention

Thank you for your attention.