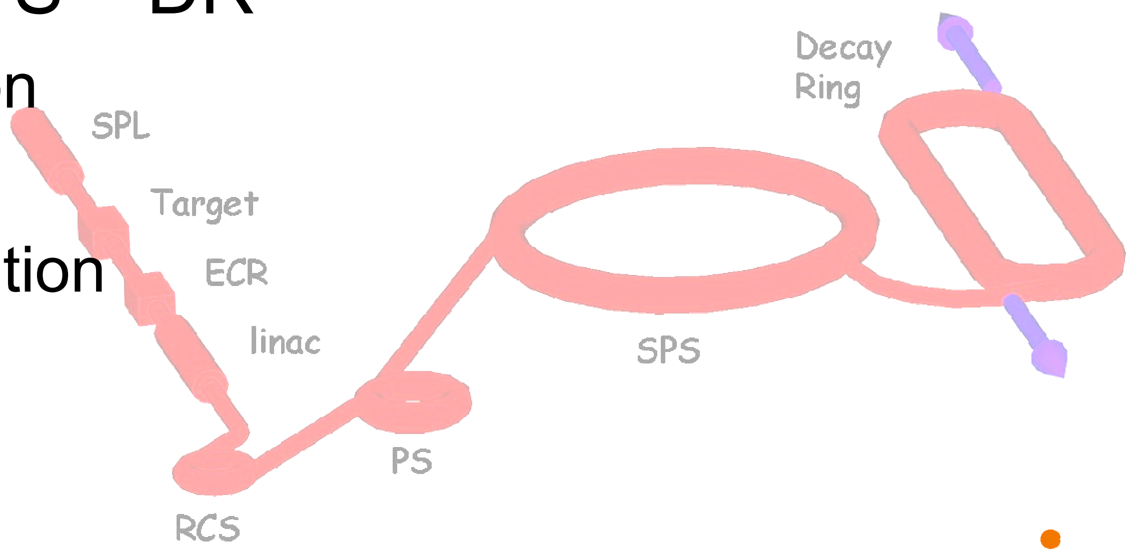
Beam loss distribution and Dynamic Vacuum simulations for RCS, PS, SPS and DR

Lars Bozyk
P. Spiller, M. Kirk, J. Stadlmann,
P. Puppel, (C. Omet)
accelerator development group
GSI Darmstadt

Beta Beam 9th Task Meeting
27th March 2009

Outline

- Loss mechanisms
  - Description
  - Cross Sections
  - Ion stimulated Desorption
- Overview about the StrahlSim code
- RCS – PS – SPS – DR
  - Loss distribution
  - Intensities
  - Pressure evolution
- Summary



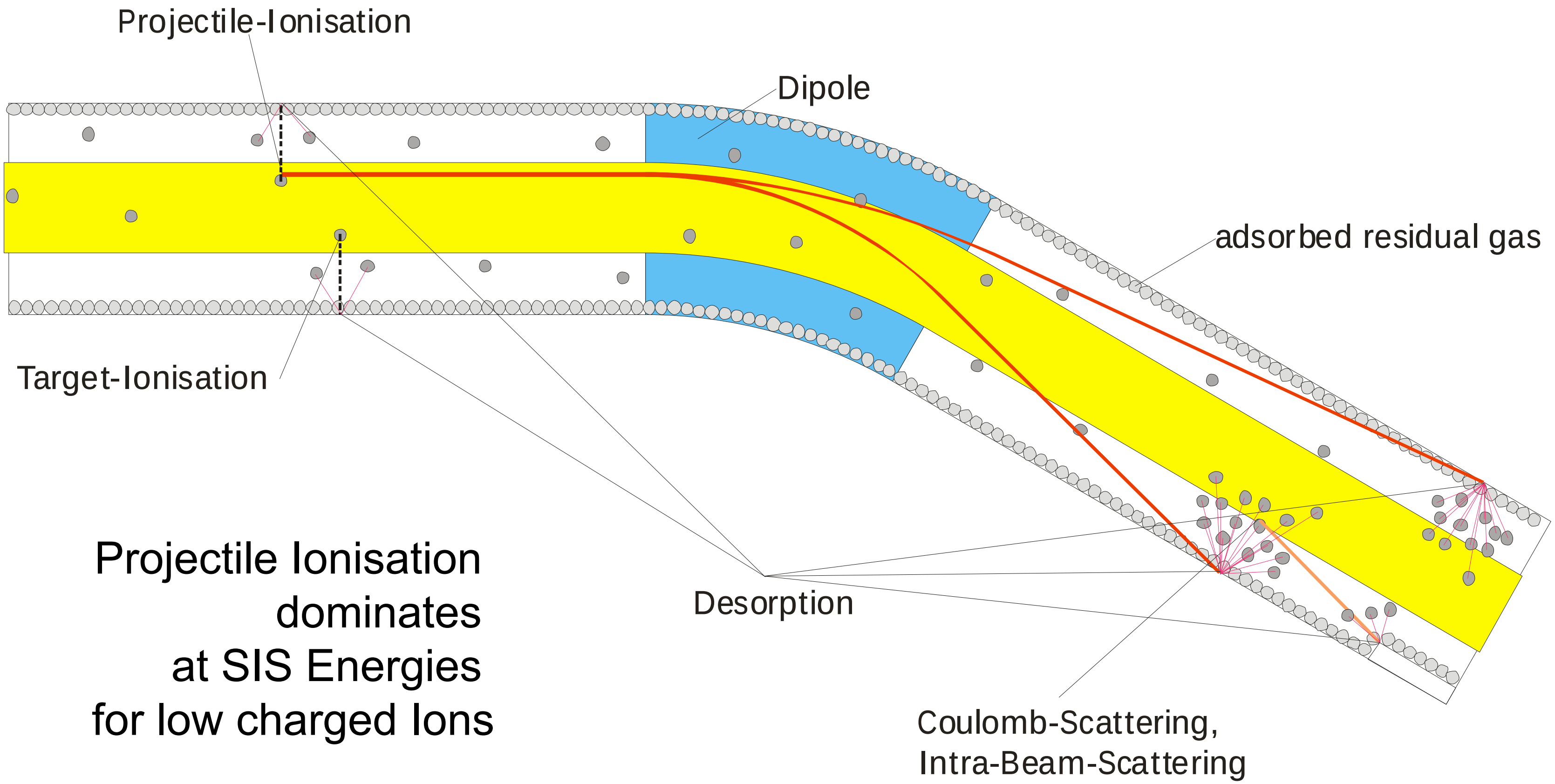
Loss Mechanisms

- Systematic Losses
  - Injection: Multi-Turn-Injection
  - HF-Capture: Frequency not properly adjusted
  - ...
  - ➢ Can be minimized by careful machine adjustment
- Charge Exchange induced Losses
  - Projectile Ionisation and recombination
  - Target Ionisation
  - Beta decay

➢ **All** losses lead to a pressure bump

➢ Avalanches up to complete Beam Loss possible for heavy Ions...

Charge Exchange Loss Mechanisms



Projectile Ionisation
dominates
at SIS Energies
for low charged Ions

Projectile Ionisation

1) Beam Ion encounters residual gas atom and looses or catches electron(s)
2) Ion's charge differs from reference ion
   - Gets separated from beam in dispersive elements (dipole)
   - Hits the wall
3) At the point of impact:
   - Via ionstimulated desorption adsorbed gas molecules are released (Desorption rate $\eta \geq 10^4$)
   - Local pressure increase
4) If there is still beam, Goto 1)
   - Avalanche-like pressure increase and beam losses (for heavy ions)

Cross Sections

- Electron Caputre is possible in β-Beams
  - Cross sections are described by an empirical forumla by Schlachter
  - Validated up to energies of 8.5 MeV/u
- Electon Loss not possible for totally stipped ions
  - Cross sections are usually higher and less certain
  - No empirical formula
  - Doesn't matter here....

Electron Capture

$$\tilde{\sigma} = \frac{1{,}1 \cdot 10^{-8}}{\tilde{E}^{4{,}8}} \left[1 - \exp\left(-0{,}037 \cdot \tilde{E}^{2{,}2}\right)\right] \cdot \left[1 - \exp\left(-2{,}44 \cdot 10^{-5} \cdot \tilde{E}^{2{,}6}\right)\right],$$

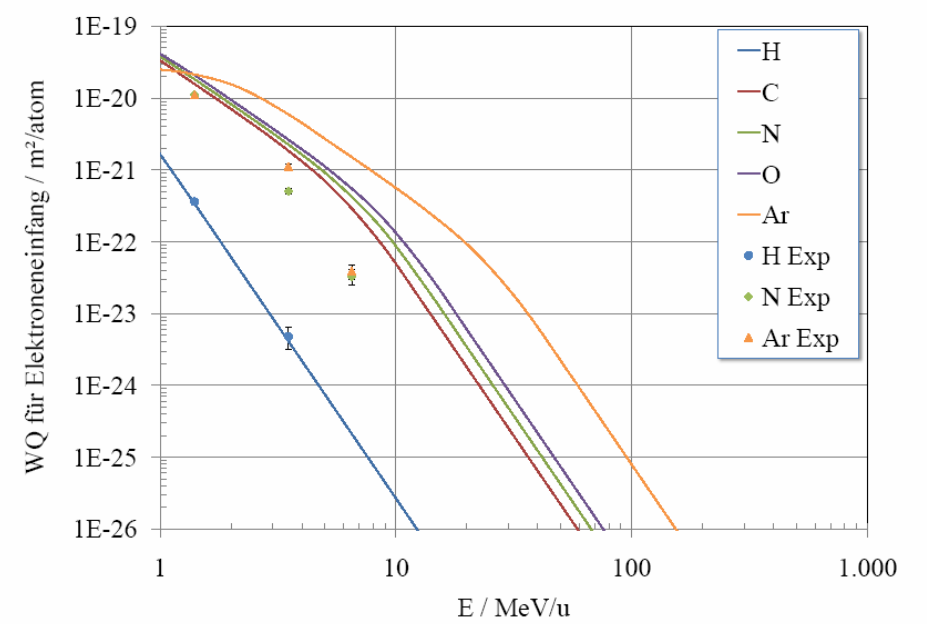
$$\tilde{\sigma} = \sigma \frac{Z_t^{1{,}8}}{q^{0{,}5}}, \tilde{E} = \frac{E}{Z_t^{1{,}25} \cdot q^{0{,}7}}$$

σ: Cross Section in cm²/Atom

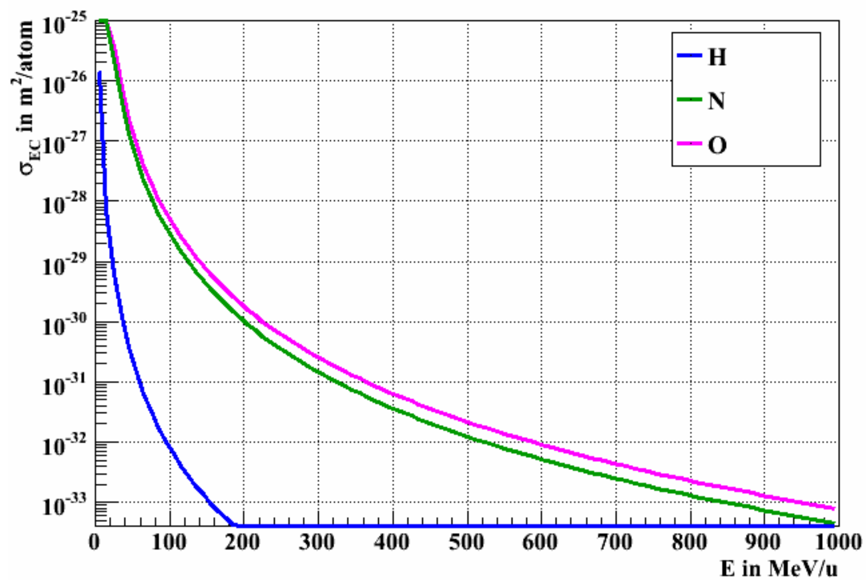
Z_t: Target's charge

E: Projectile's energy in KeV/u

q: Projectile's charge



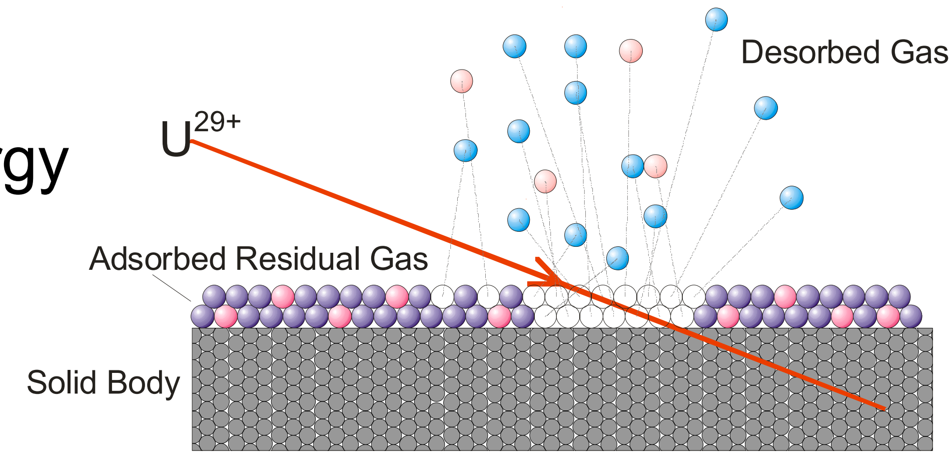
U^{28+} → Residual Gas



Ne^{10+} → Residual Gas

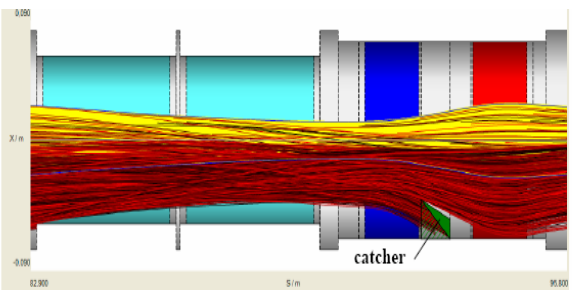
Ion Stimulated Desorption

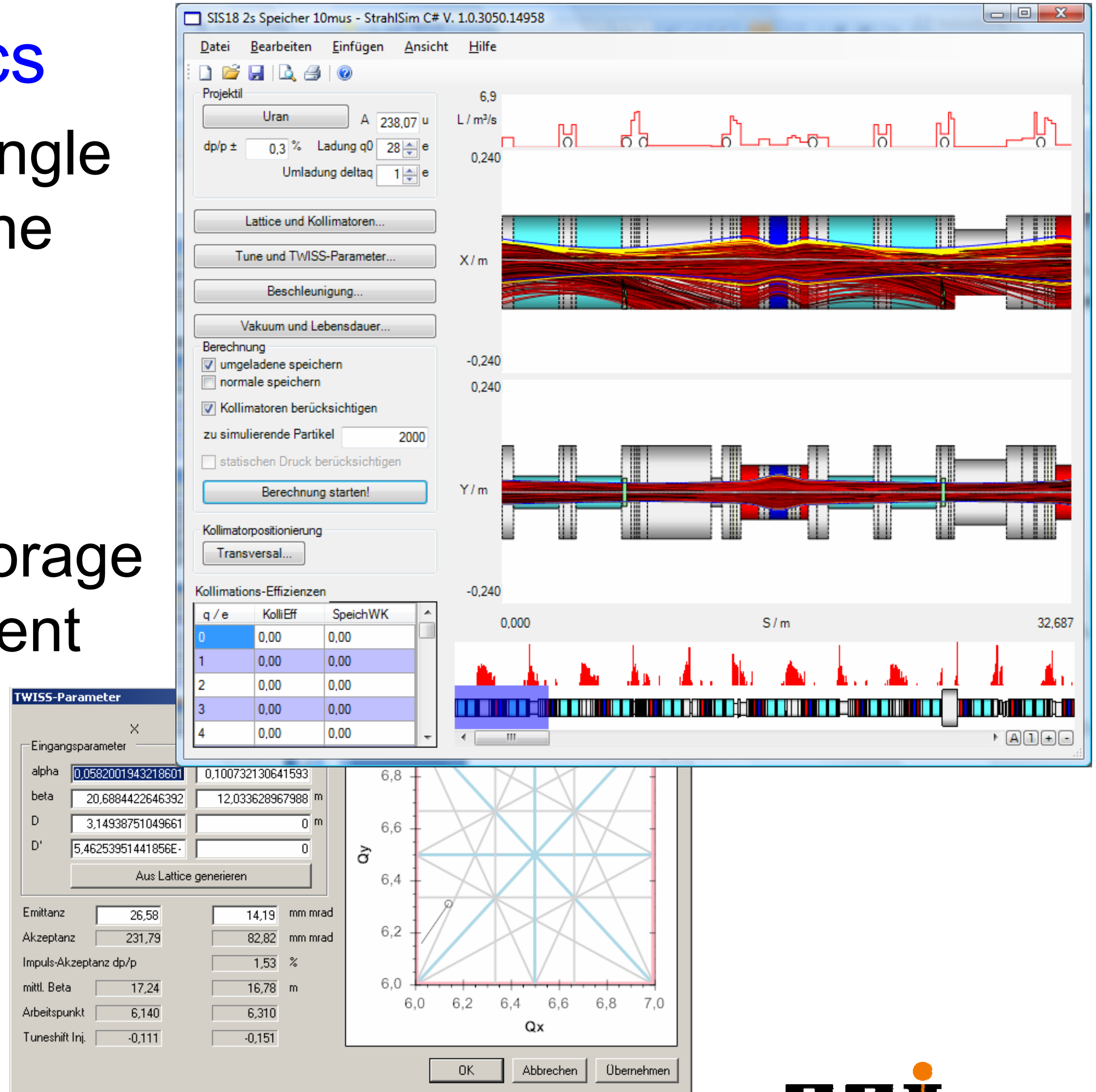
- On vacuum surfaces residual gas molecules get adsorbed
  - Binding Energy few eV
  - Can be released by ion bombardment
- Desorption Rate η
  - Scales with specific energy loss $(dE/dx)^2$ (Max. at ~12 MeV/u)
  - Depends on angle of incidence
    - $\eta_\perp$ ~ 100 molecules/Ion
    - $\eta_\angle$ ~ $3...20 \cdot 10^4$ molecules/Ion, not measured at energies >~200 MeV/u
  - Perpendicular incidence → Low desorption



Simulation with StrahlSim

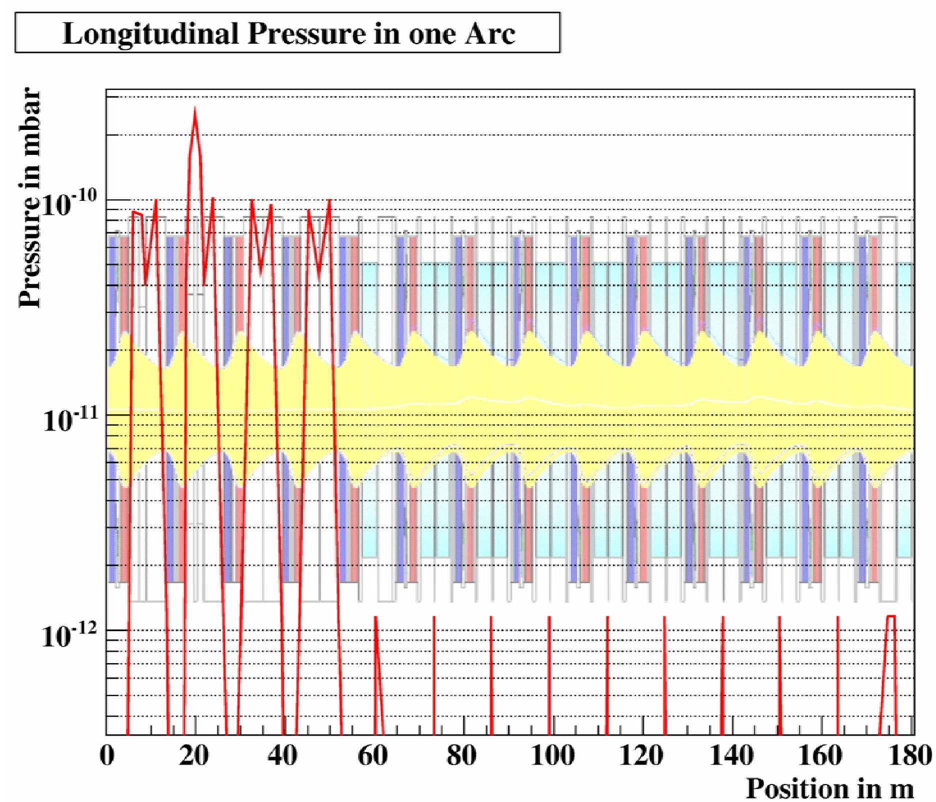
- Linear Beam Optics
  - The code tracks single particles through the given lattice
  - Longitudinal loss distributions
  - Collimation and storage efficiency for different charge states





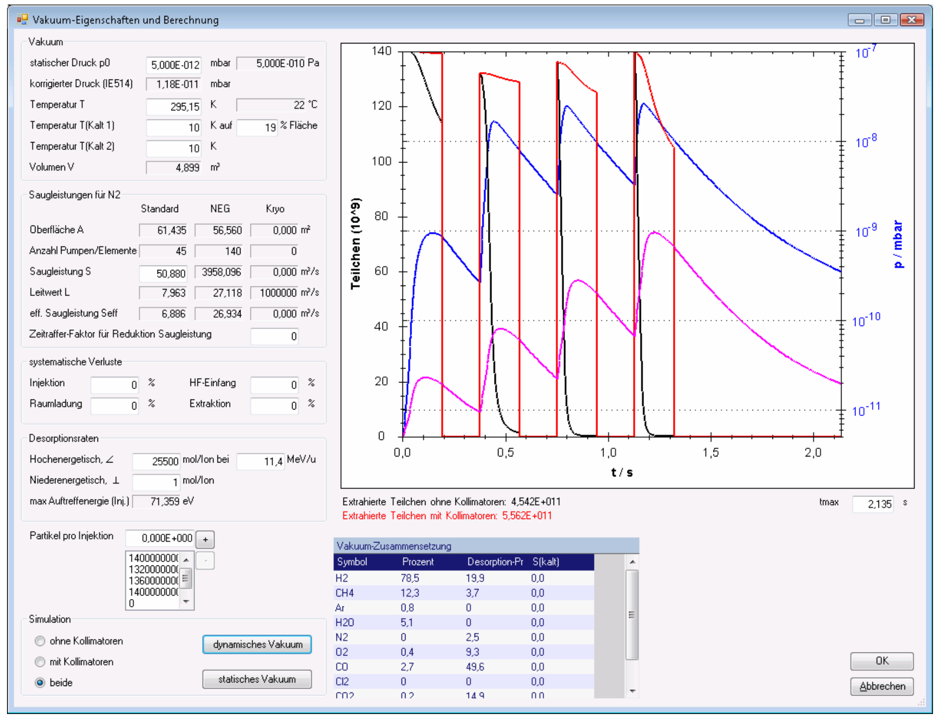
Simulation with StrahlSim

- Static Vacuum
  - Molecular Raytraycer to get longitudinal pressure distribution, vacuum conductance, ...
  - NEG, cryogenic surfaces, normal pumps
  - Different partial pressures of residual gas components



Simulation with StrahlSim

- Dynamic Vacuum
  - Synchrotron-cycle with systematic losses
  - Projectile Ionisation and Target Ionisation
  - Ion stimulated desorption (Desorption rate scaled with $(dE/dx)^2$)
  - Couples beam losses to pressure rises
  - Residual gas composition

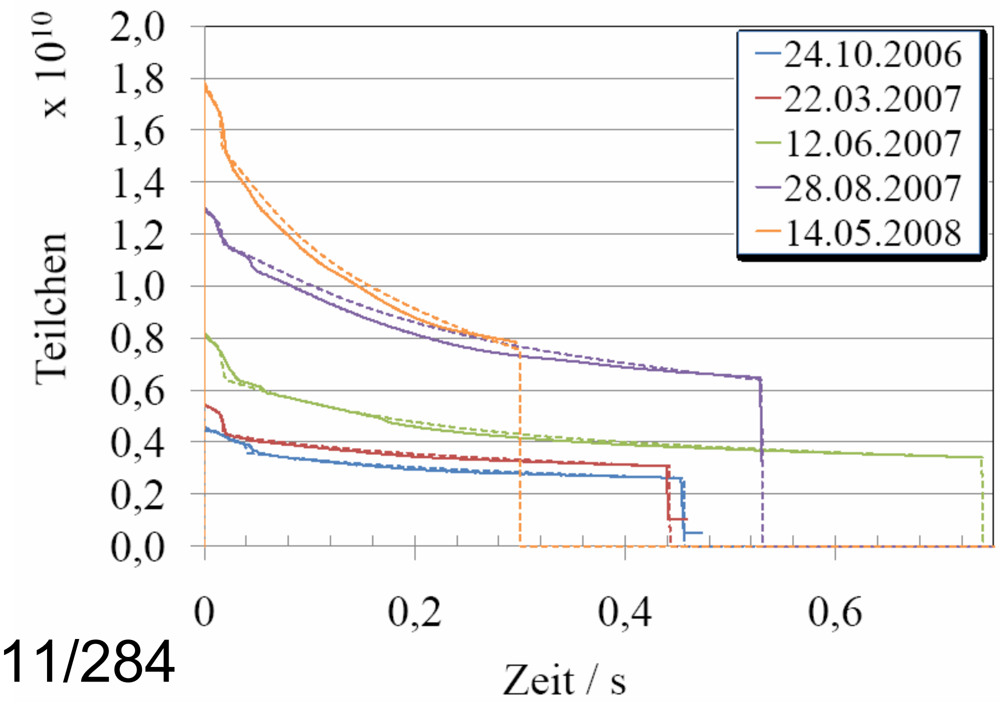


Simulation with StrahlSim

- Simulation has been compared and benchmarked with many machine experiments in SIS18

- Application at GSI, CERN (beta beams) and BNL (AGS Booster)

- Publication: Charge change-induced beam losses under dynamic vacuum conditions in ring accelerators, C.Omet et al 2006 *New J. Phys.* 8 284 doi:10.1088/1367-2630/8/11/284



Simulation

Base for all following simulations is the report

"The EURISOL Beta-beam Facility Parameter and Intensity Values"

from the

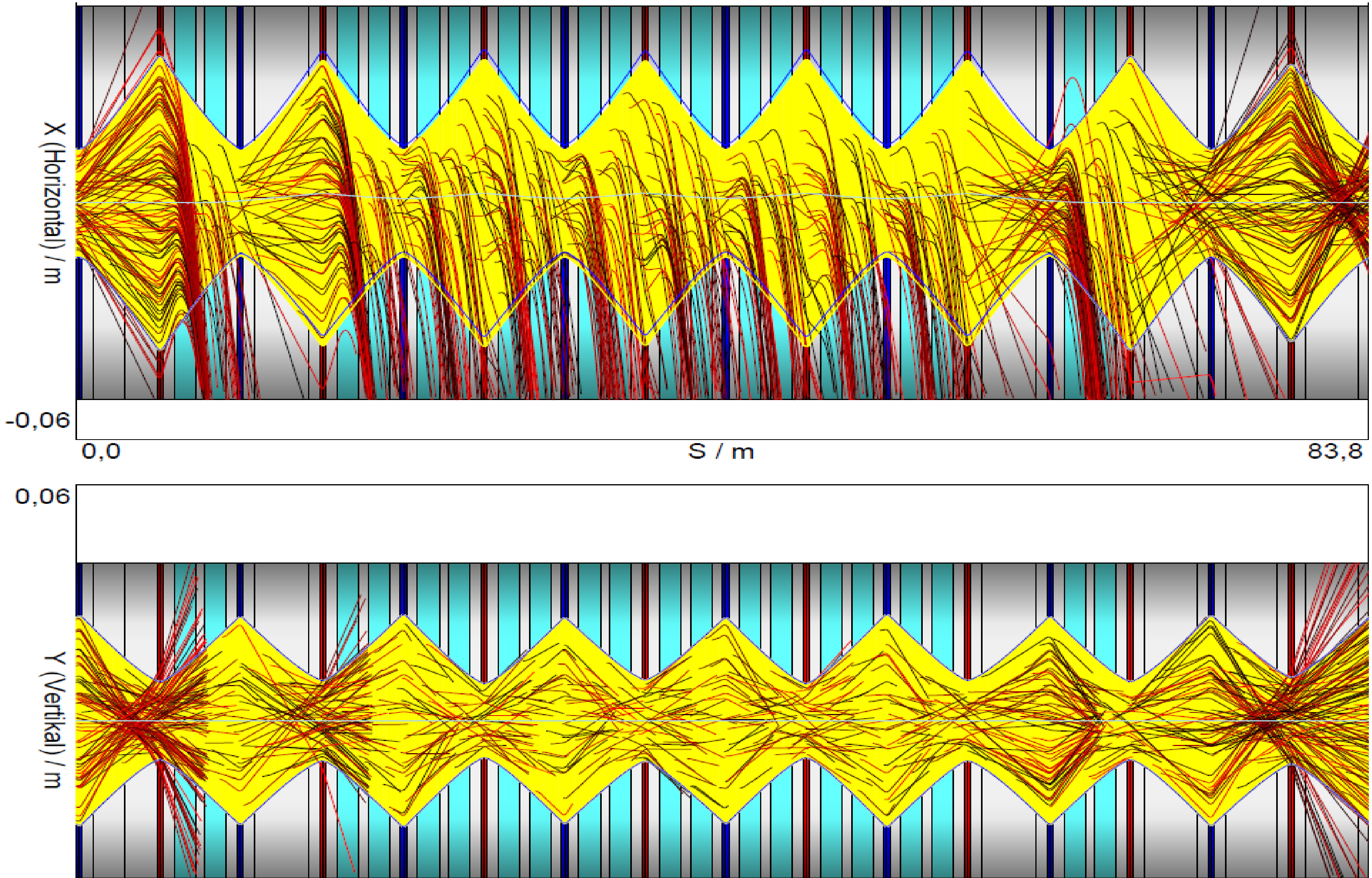
β-beam Oracle database

from 12.03.2009

RCS – Design Parameters

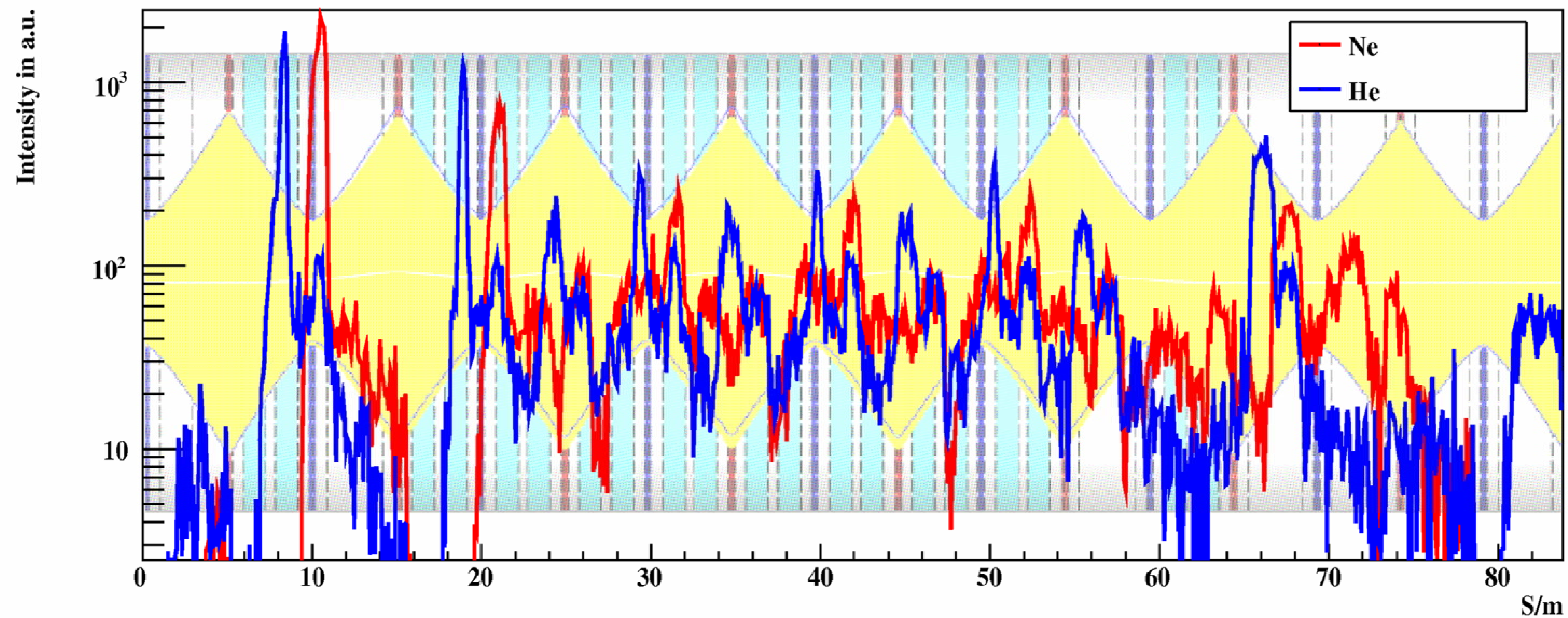
	$^{6}He^{2+}$	$^{18}Ne^{10+}$
Circumference	251,3 m	
dB/dT_{max}	24 T/s	
Volume	1.5 m³	
Total pump speed	2 m³/s	
Bas residual gas pressure	10^{-9} mbar (10^{-6} mbar)	
Vacuum composition	38% H_2, 54.4% H_20, 7.6% N_2	
Energy at injection	100 MeV/u	100 MeV/u
Energy at extraction	787 MeV/u	1650 MeV/u
Ions per Cycle injected	8.53E11	2.62E11
Ions per Cycle extracted	8.29E11	2.59E11
Cycle time	2 s	2 s

RCS – He-Daughter-Trajectories



RCS

- Loss Distribution for He and Ne decay
- Losses more or less equally distributed
- No prominent loss locations for collimators

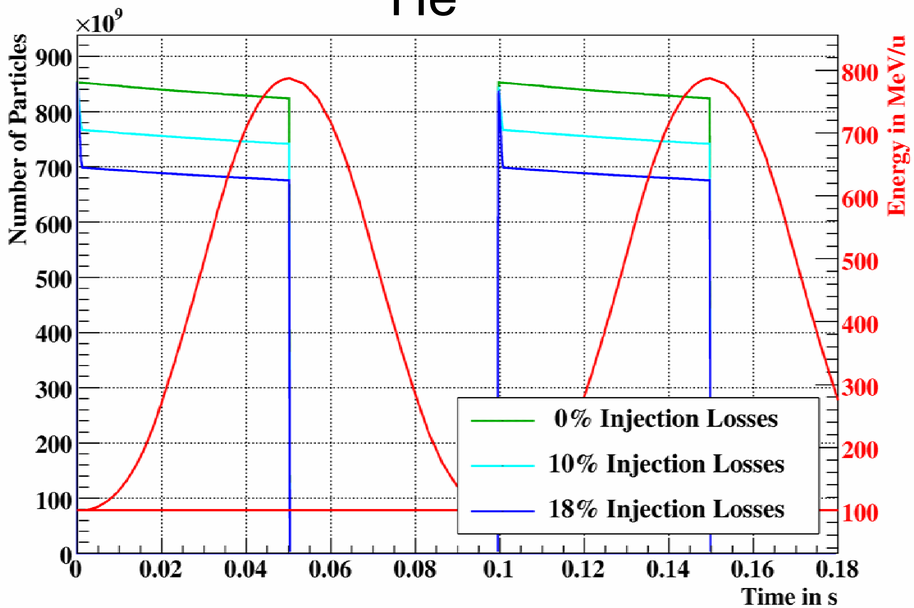


RCS Cycle

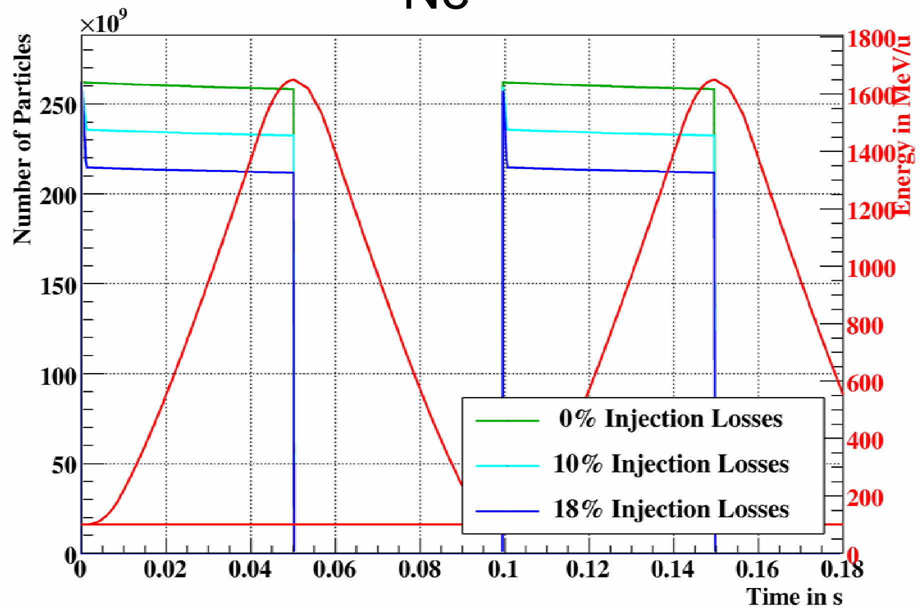
- Cycle was approximated to cos(20·π·t) shape
- Different Injection losses were assumed:

Realistic (18%), optimistic (10%) and ideal (0%)

He



Ne

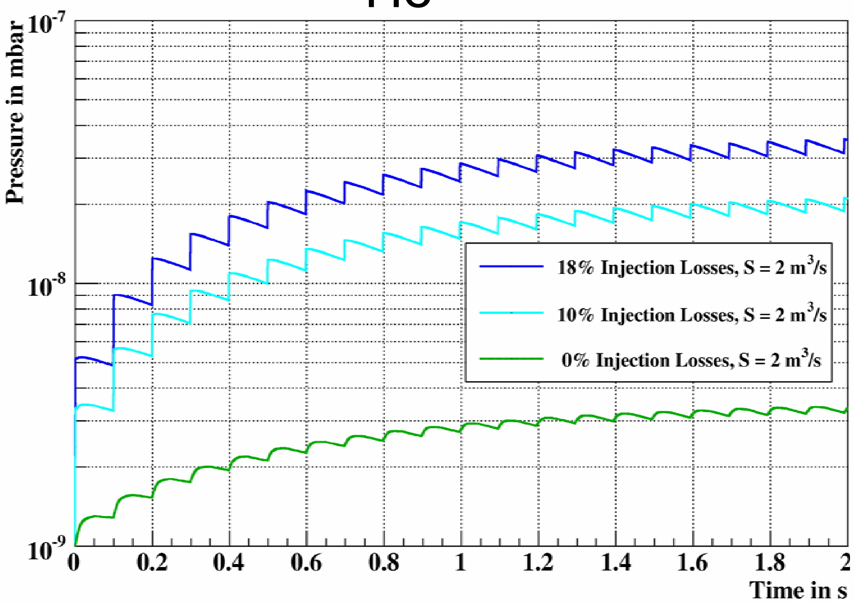


RCS Pressure

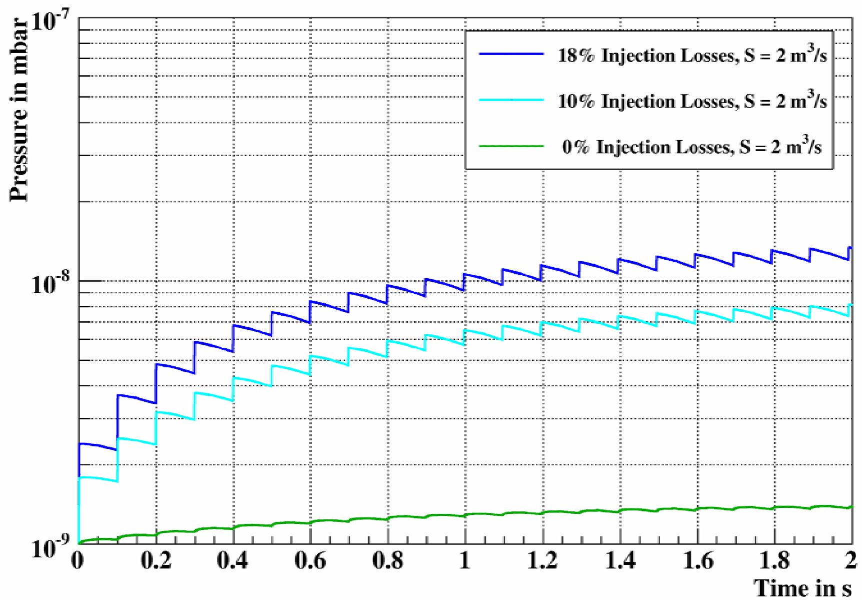
- P0 = 10^{-9} mbar and S = 2 m³/s (design values)

- Pressure converges...

He



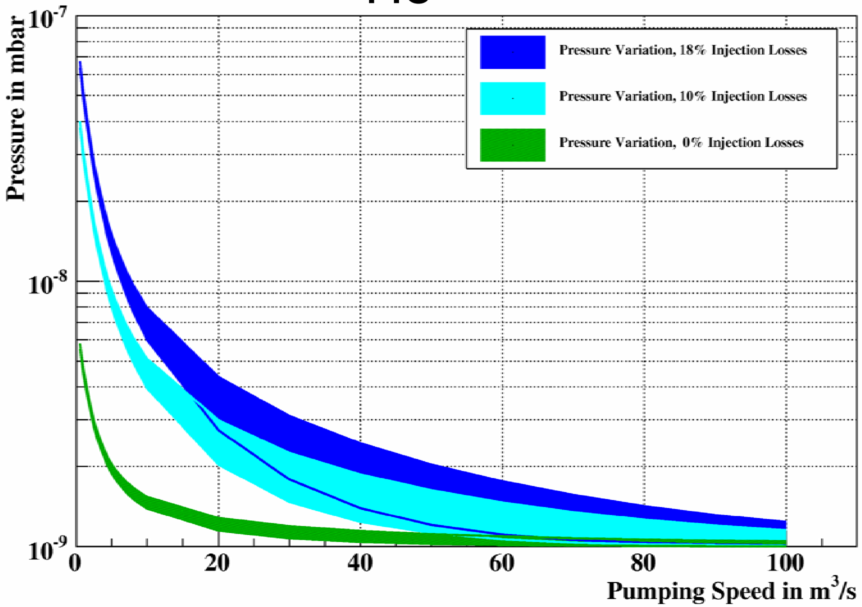
Ne



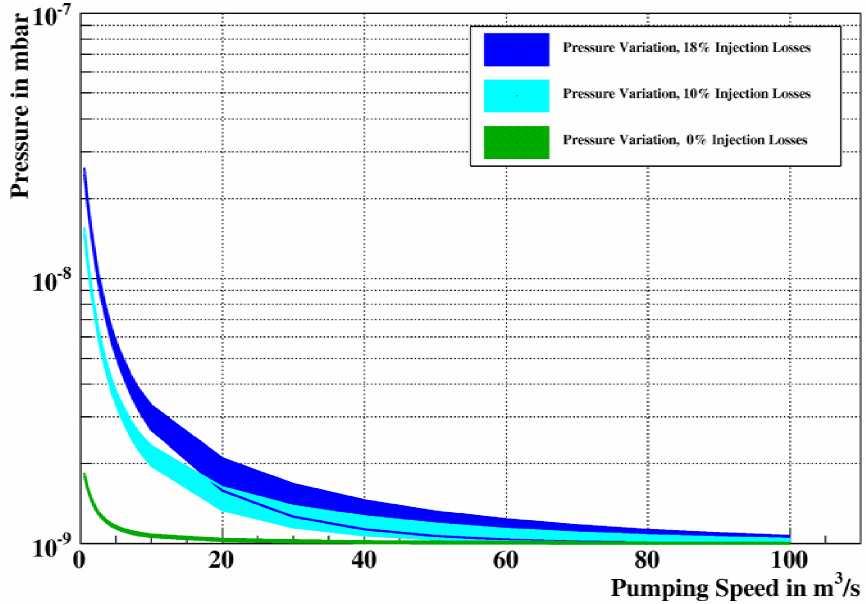
RCS Pumping Speed

- The last of 20 cycles was taken for each Pumping speed
  - Pressure after injection-losses (upper limitation)
  - Pressure at extraction (lower limitation)

He



Ne



RCS –Intensities

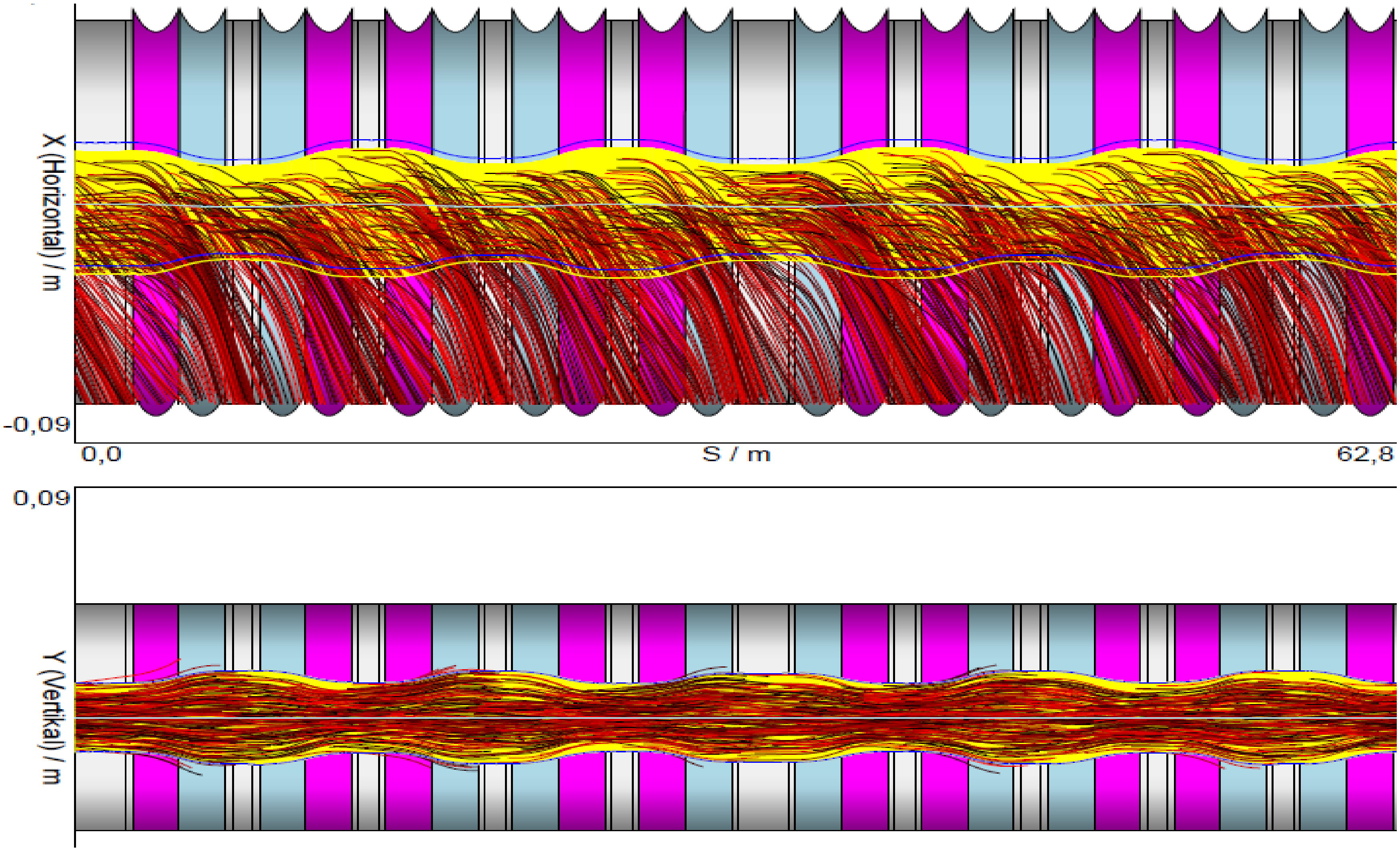
Intensities (Ions per Cycle extracted):

	Design	0% Inj.losses	10% Inj.losses	18% Inj.losses
He	8.29E11	8.25E11	7.42E11	6.77E11
Ne	2.59E11	2.59E11	2.33E11	2.12E11

PS – Design Parameters

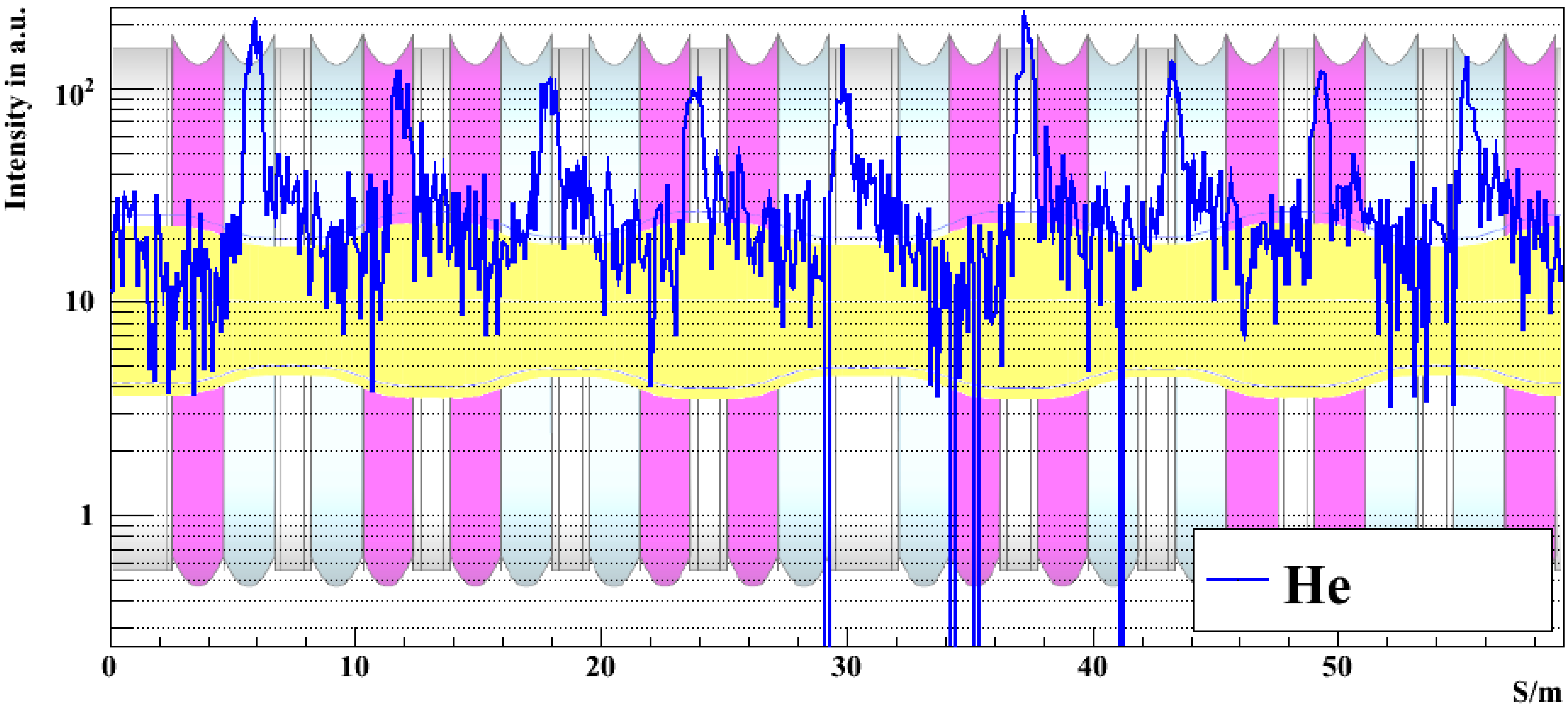
	$^{6}He^{2+}$	$^{18}Ne^{10+}$
Circumference	628.3 m	
dB/dT_{max}	1.6 T/s	
Volume	6.0 m^3	
Total pump speed	37.65 m^3/s	
Bas residual gas pressure	10^{-9} mbar (10^{-6} mbar)	
Vacuum composition	38% H_2, 54.4% H_20, 7.6% N_2	
Energy at injection	787 MeV/u	1650 MeV/u
Energy at extraction	7780 MeV/u	13500 MeV/u
Ions per Cycle injected	11E12	4.51E12
Ions per Cycle extracted	9.53E12	4.31E12
Cycle time	3.6 s	3.6 s

PS – He-Daughter-Trajectories



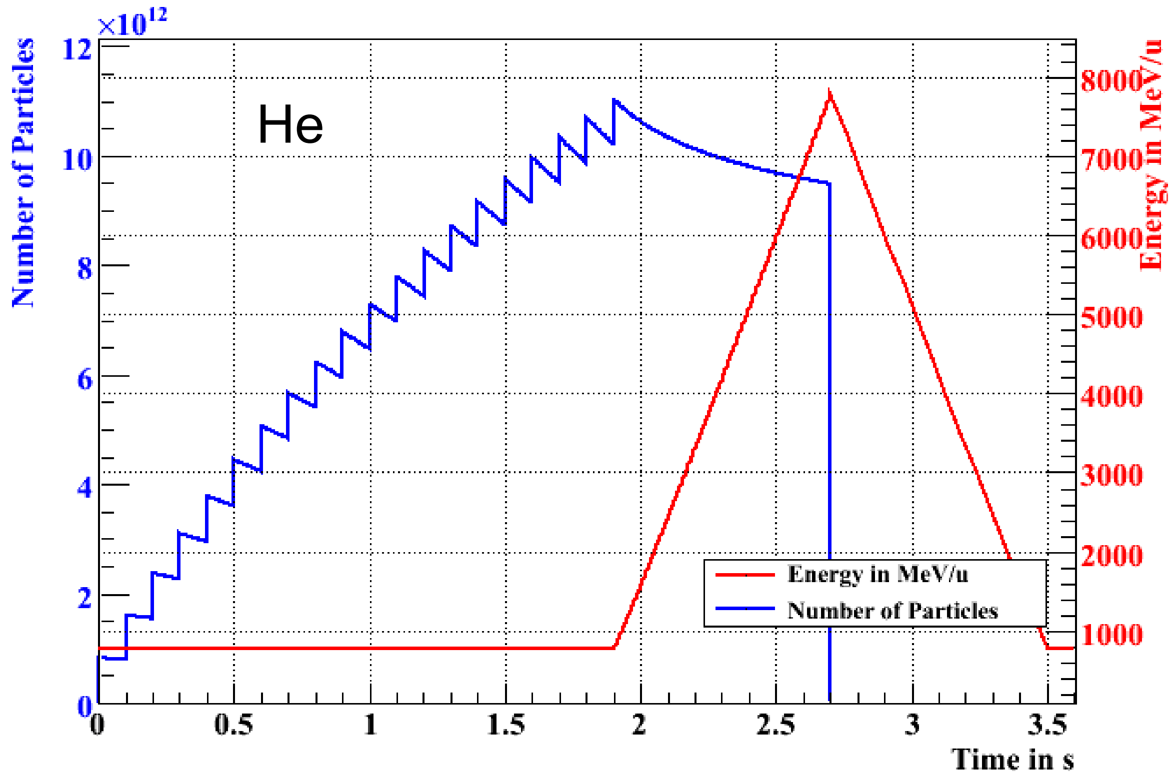
PS – Loss Distribution

- Loss Distribution for $He^{2+} \rightarrow Li^{3+}$
  (Simulation for Ne^{10+} is not yet operably)



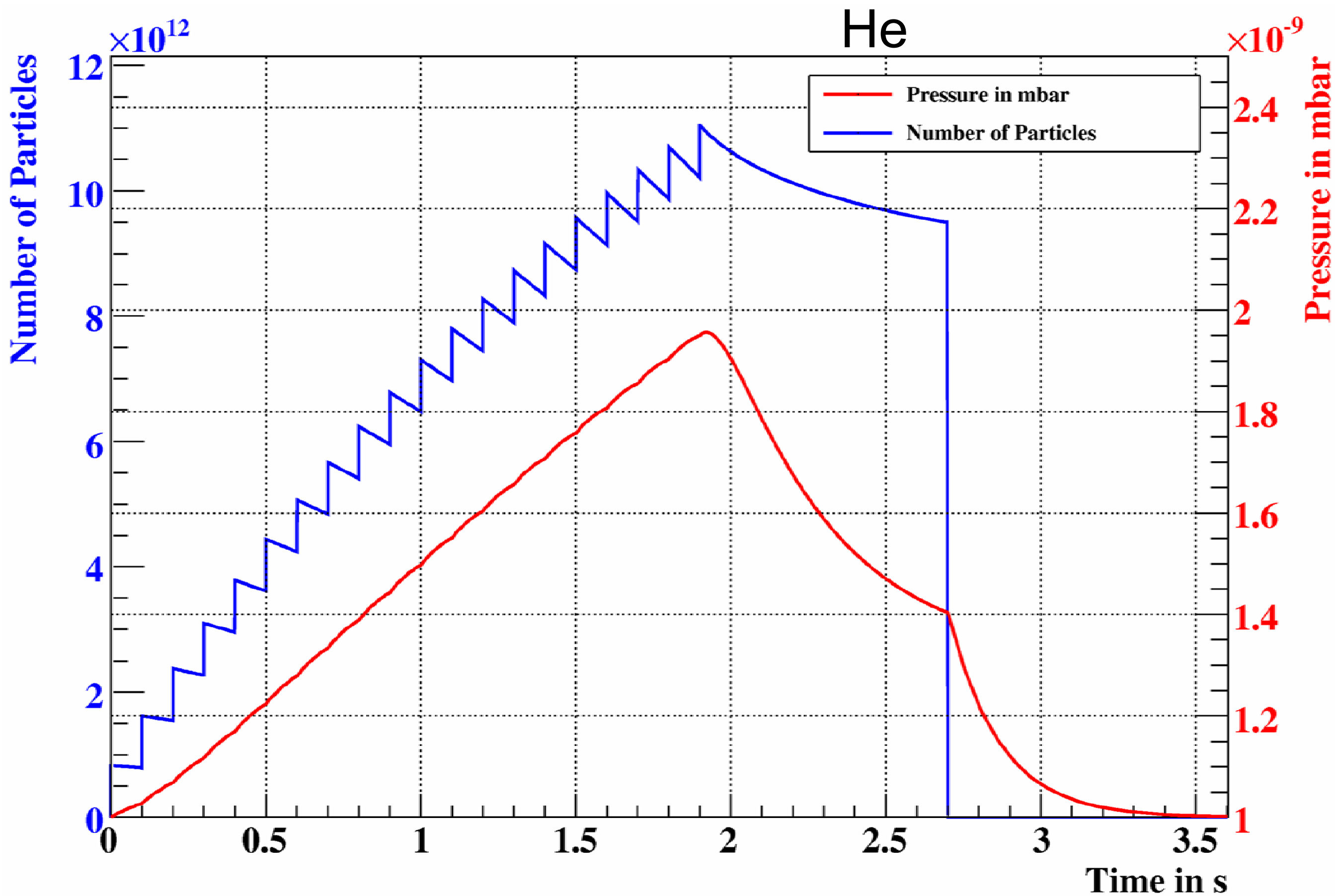
PS Cycle

- 20 injections from RCS
  - β-decay during accumulation
  - No Intra Beam Scattering considered
    (To much losses - model to simple? → to be checked)



PS – Pressure and Particles

- Pressure is relatively stable and converges



PS – Summary

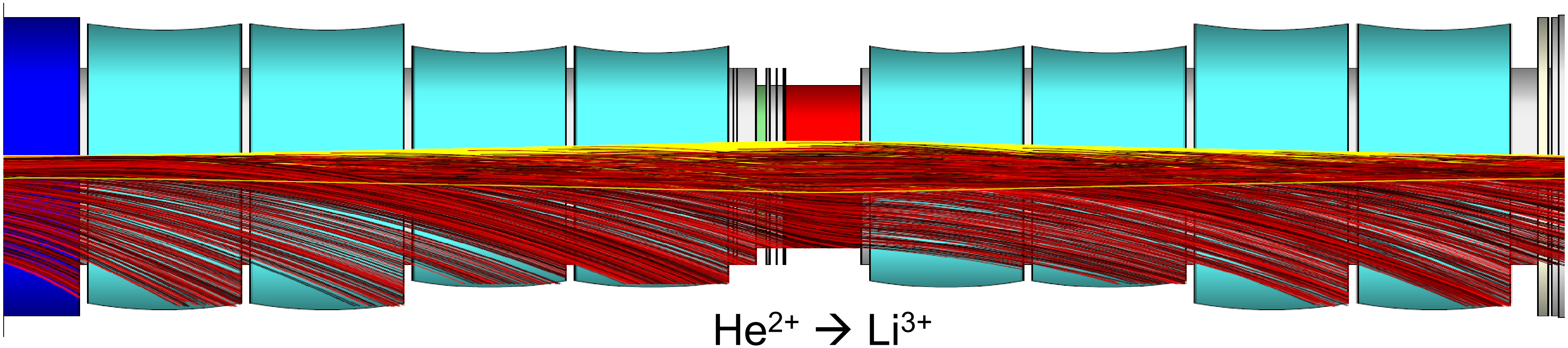
- Simulation for He looks promising, no problems expected
  - Pressure looks stable
  - He Ions per Cycle extracted 9.49E12
  - He Ions per Cycle extracted (Design) 9.53E12

- Simulation for Ne not yet operably

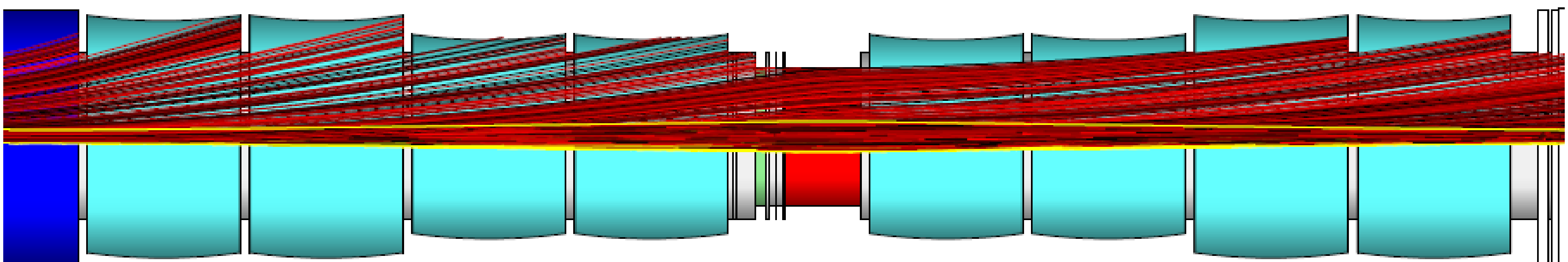
SPS – Design Parameters

	$^{6}He^{2+}$	$^{18}Ne^{10+}$
Circumference	6911.5 m	
dB/dT_{max}	not specified	
Volume	50 m³	
Total pump speed	2.28 m³/s	
Bas residual gas pressure	10^{-9} mbar	
Vacuum composition	38% H_2, 54.4% H_20, 7.6% N_2	
Energy at injection	7.78 GeV/u	13.5 GeV/u
Energy at extraction	92.5 GeV/u	92.2 GeV/u
Ions per Cycle injected	9.53E12	4.31E12
Ions per Cycle extracted	9.00E12	4.26E12
Cycle time	6.0 s	3.6 s

SPS – Daughter Trajectories



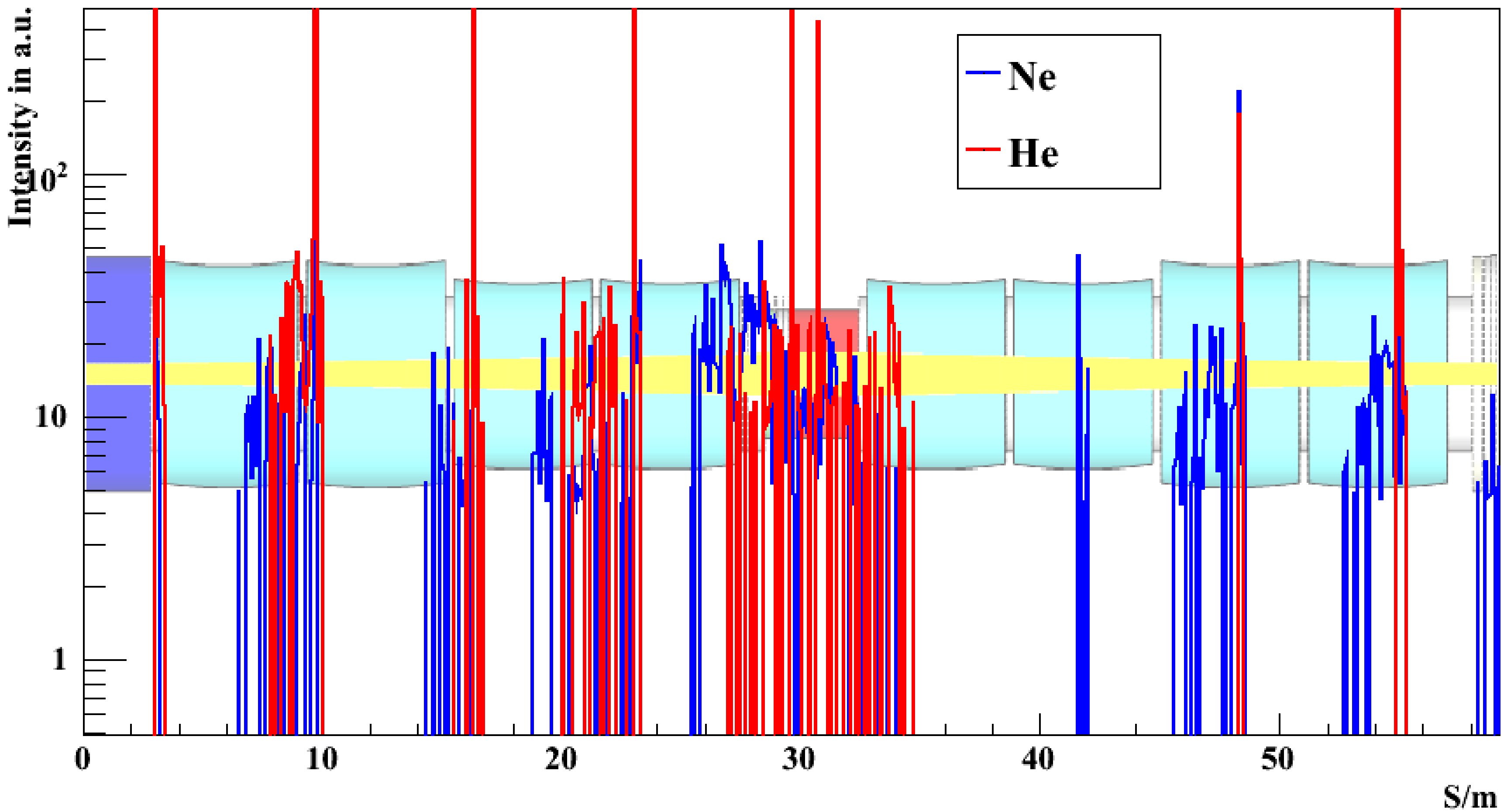
$He^{2+} \rightarrow Li^{3+}$



$Ne^{10+} \rightarrow F^{9+}$

SPS - Loss Distribution

- Loss Distribution along a FODO-cell



SPS – Summary

- Losses in FODO lattices occur mostly inside of the optical elements
  - No prominent loss locations for collimators
  - Overall not much space for additional installations

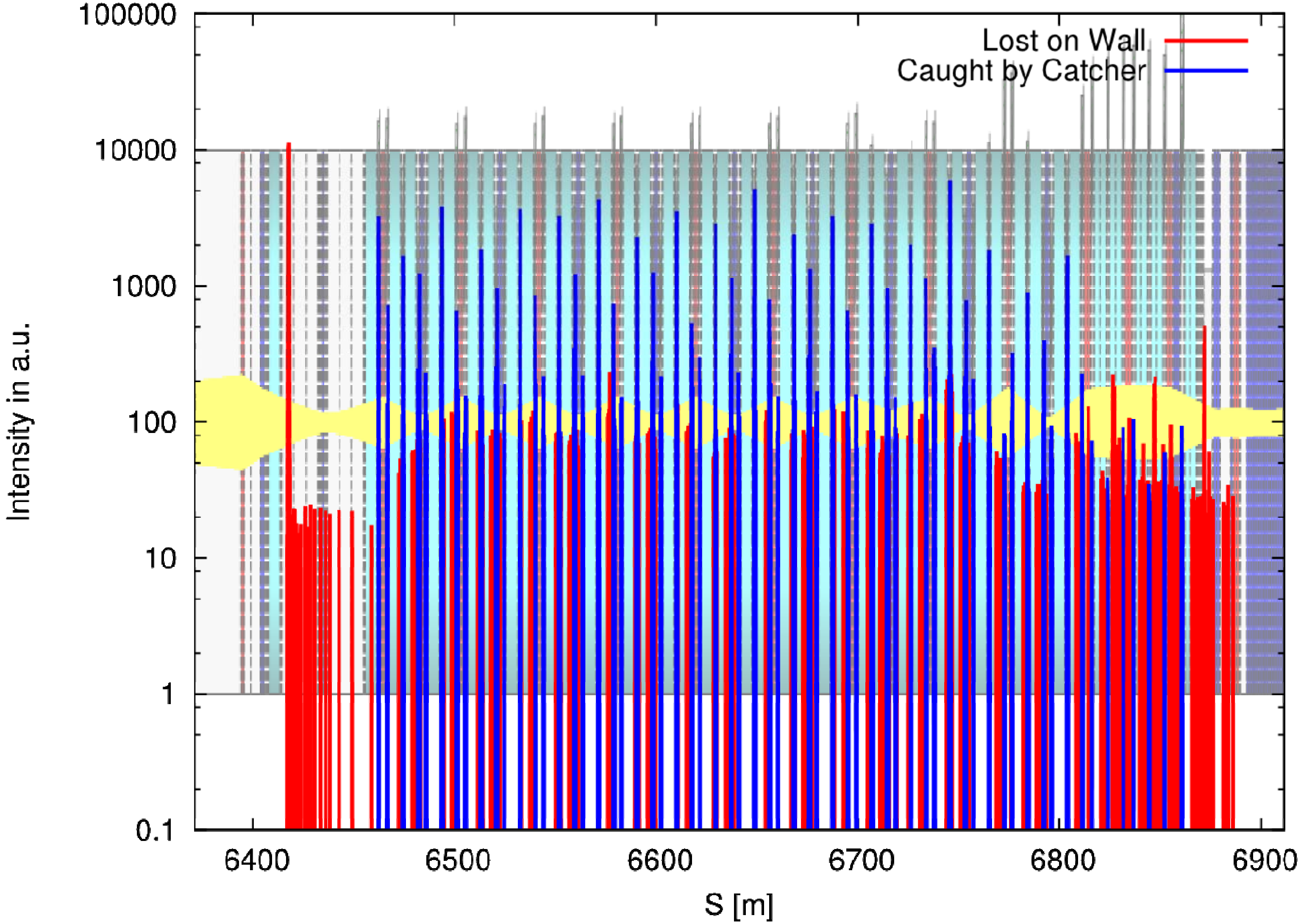
- Simulation not yet fully operable

- Also parameter mismatch:
  - Given volume: 50 m^3
  - Given typical aperture: 28.4 x 6.9 cm^2 would result in a volume of ~106 m^3

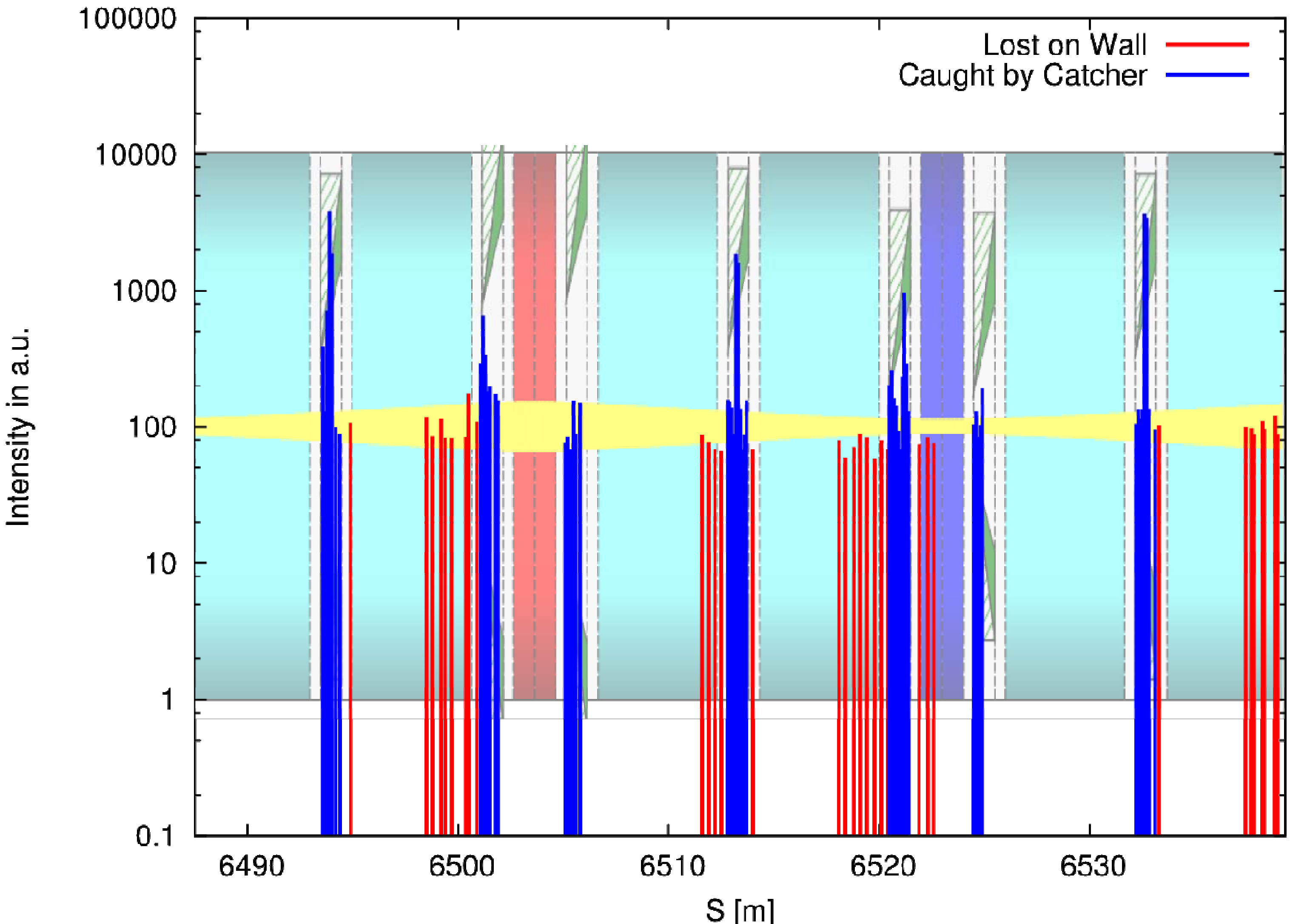
Decay Ring – Design Parameters

	$^{6}He^{2+}$	$^{18}Ne^{10+}$
Circumference	6911.3	
dB/dT_{max}	0 T/s	
Volume	not specified	
Total pump speed	not specified	
Bas residual gas pressure	10^{-9} mbar (10^{-6} mbar)	
Vacuum composition	38% H_2, 54.4% H_20, 7.6% N_2	
Energy at injection	92.5 GeV/u	92.2 GeV/u
Energy at extraction	---	---
Ions per Cylcle injected	9.66E13 (?)	684 (?)
Ions per Cycle extracted	---	---
Cycle time	6.0 s	3.6 s

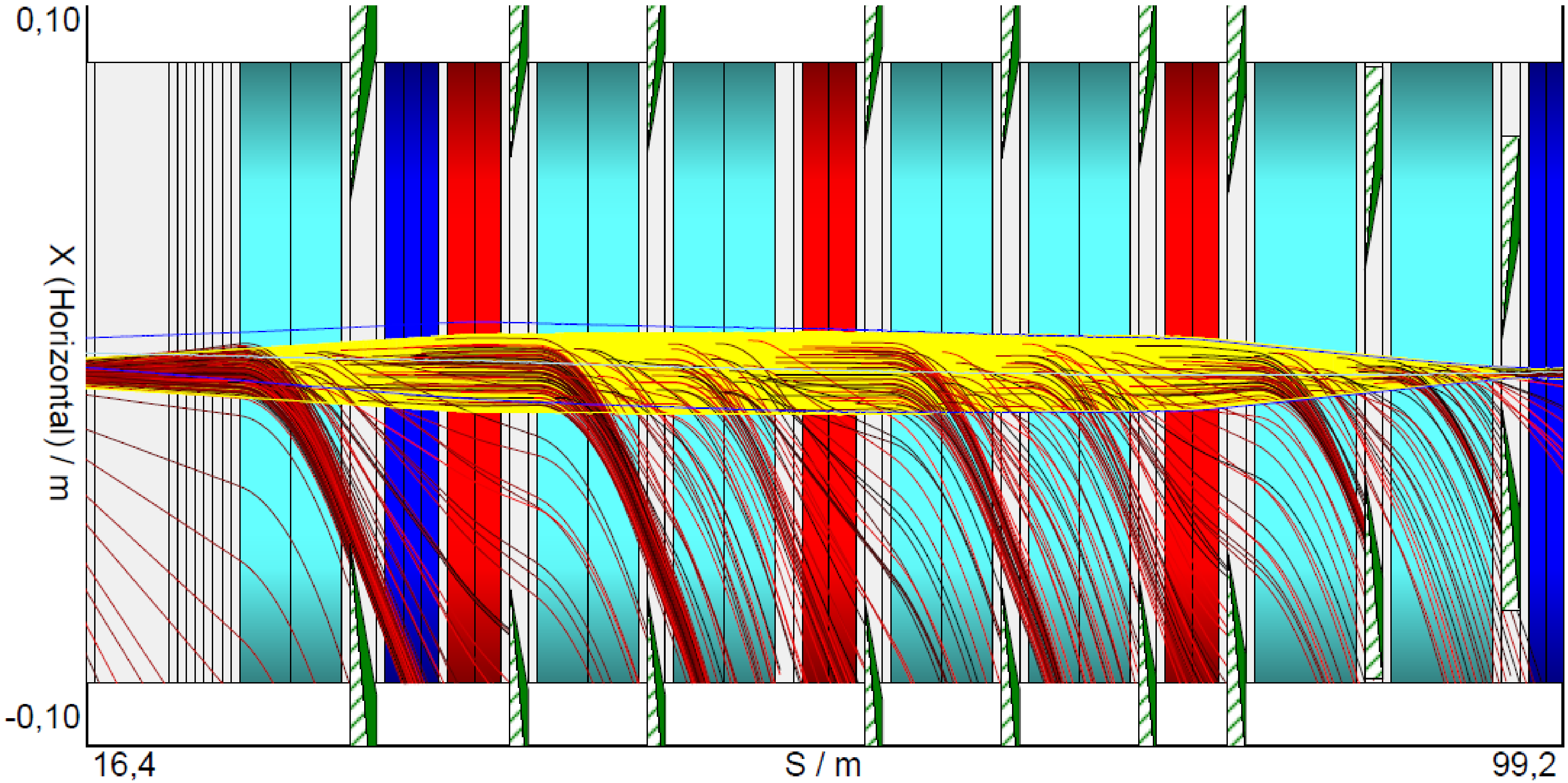
Decay Ring – He Loss Distribution



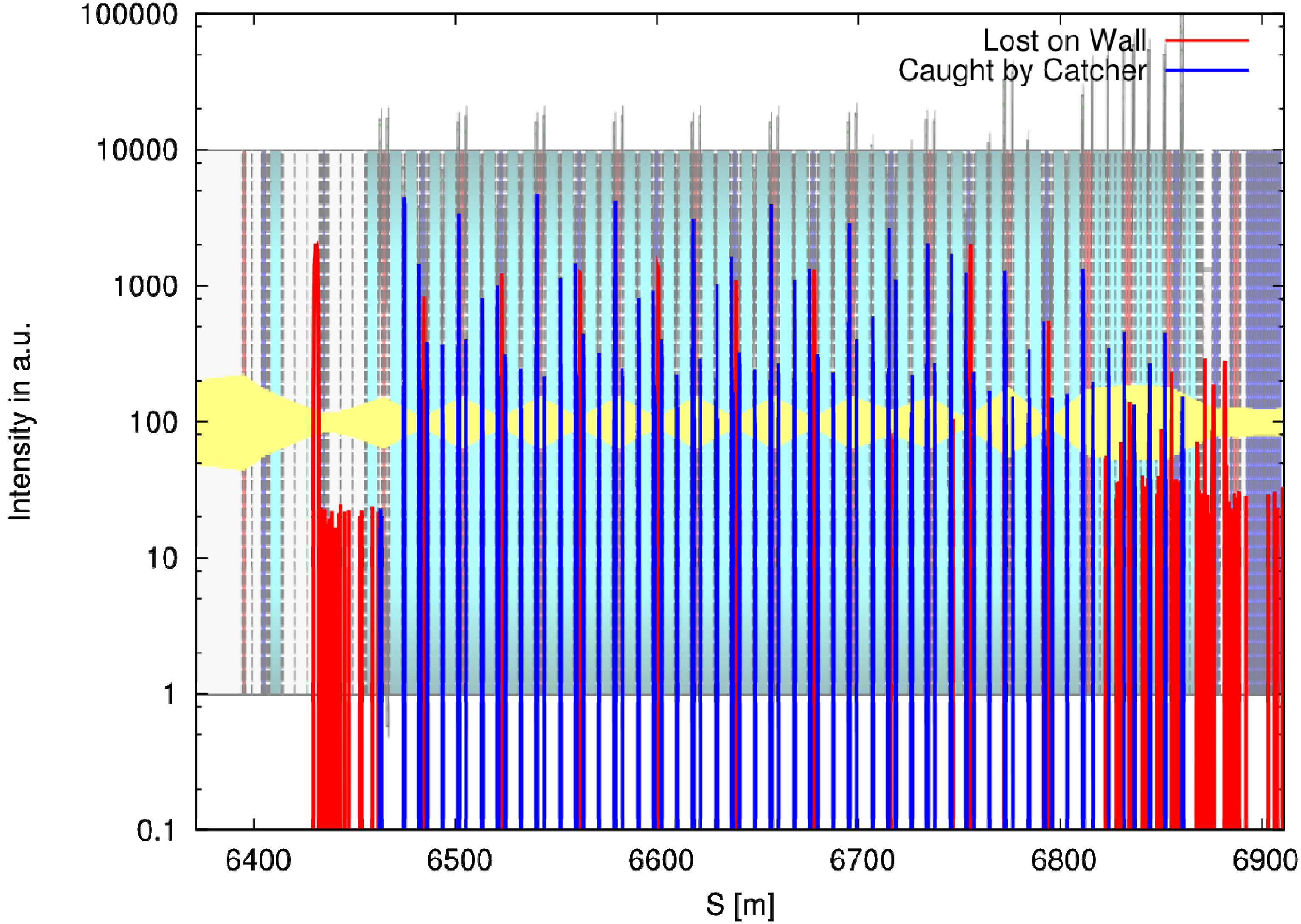
Decay Ring – He Loss Distribution



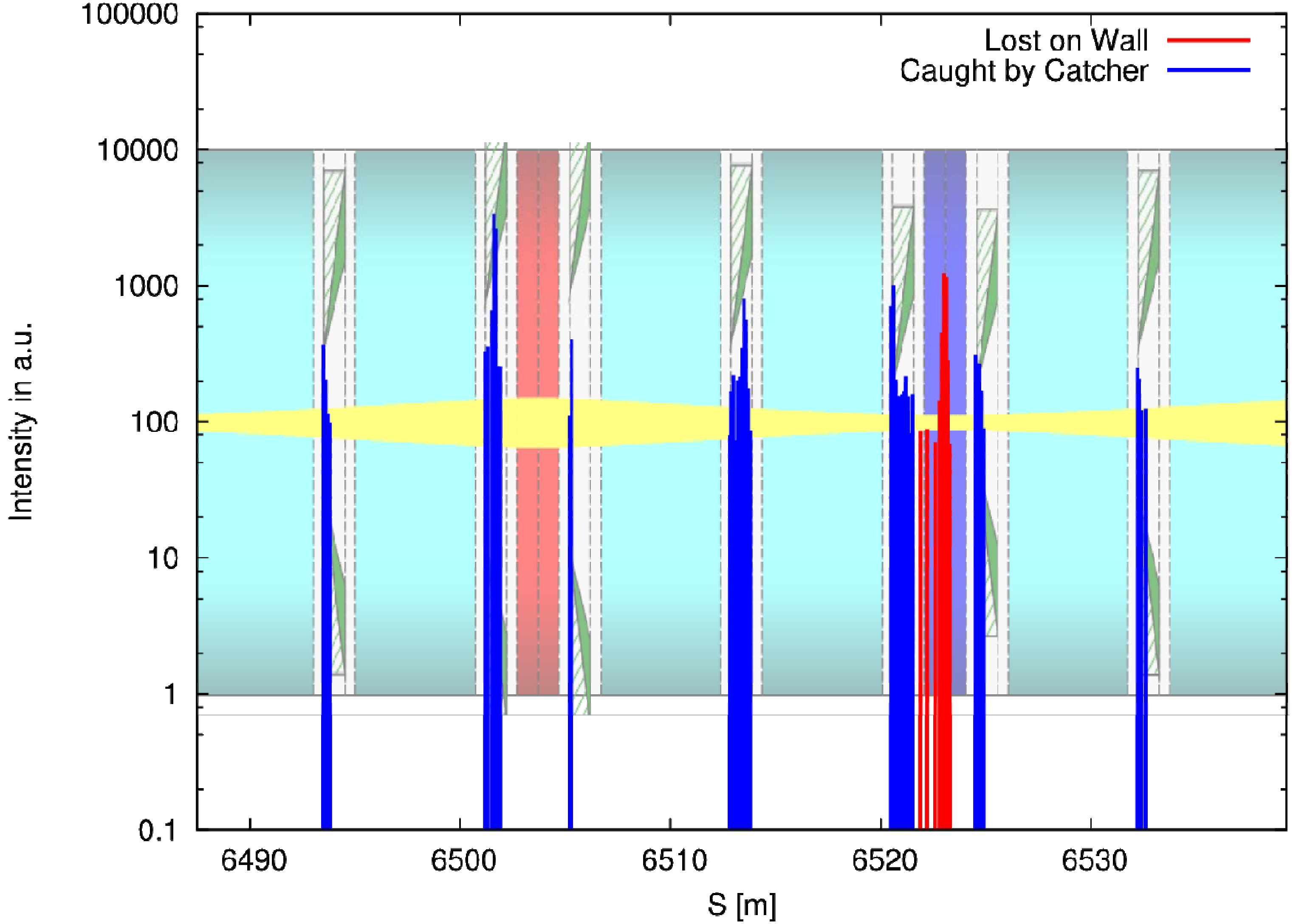
Decay Ring – He daughters



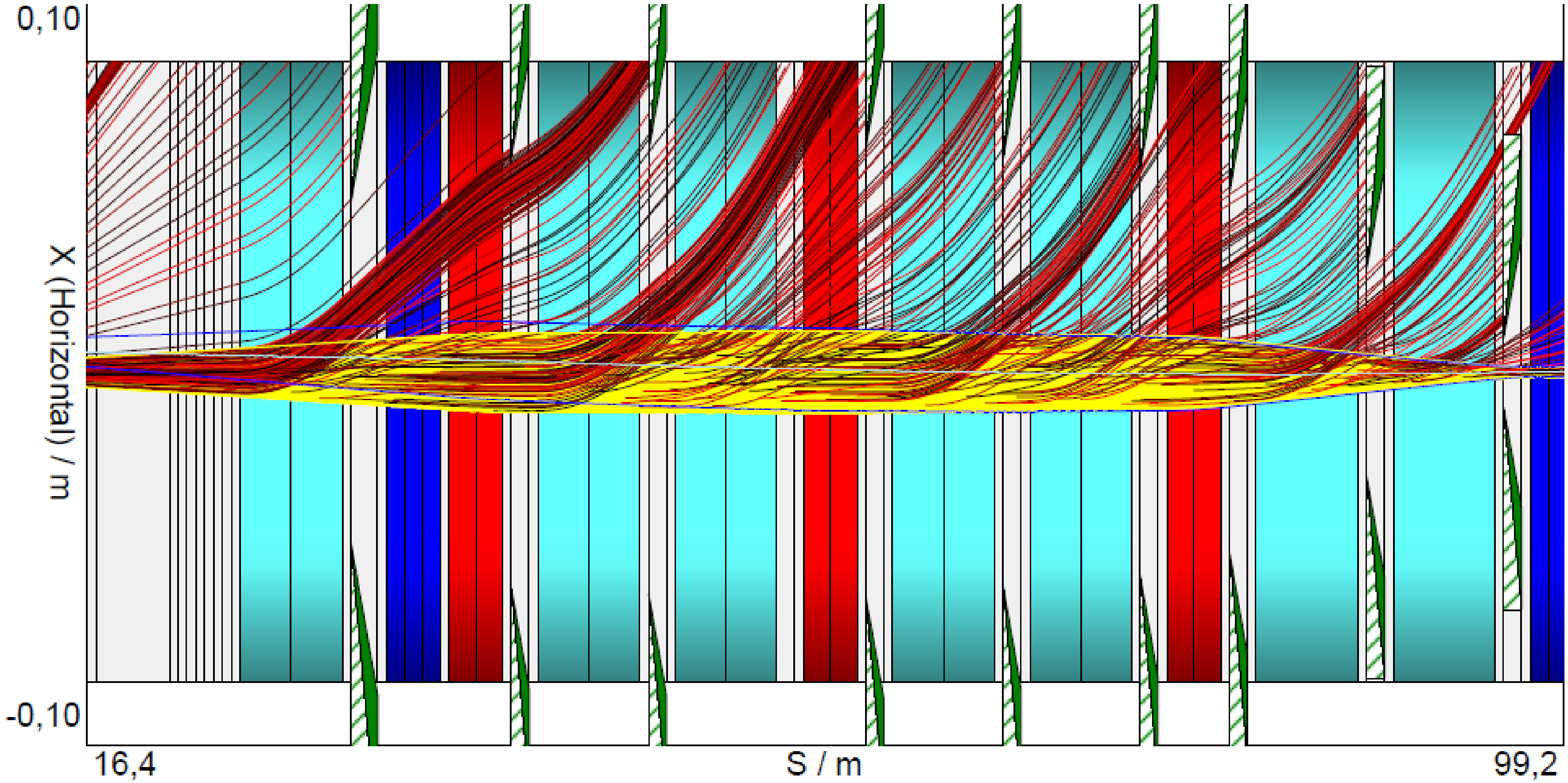
Decay Ring – Ne Loss Distribution



Decay Ring – Ne Loss Distribution



Decay Ring – Ne daughters



Decay Ring – Summary

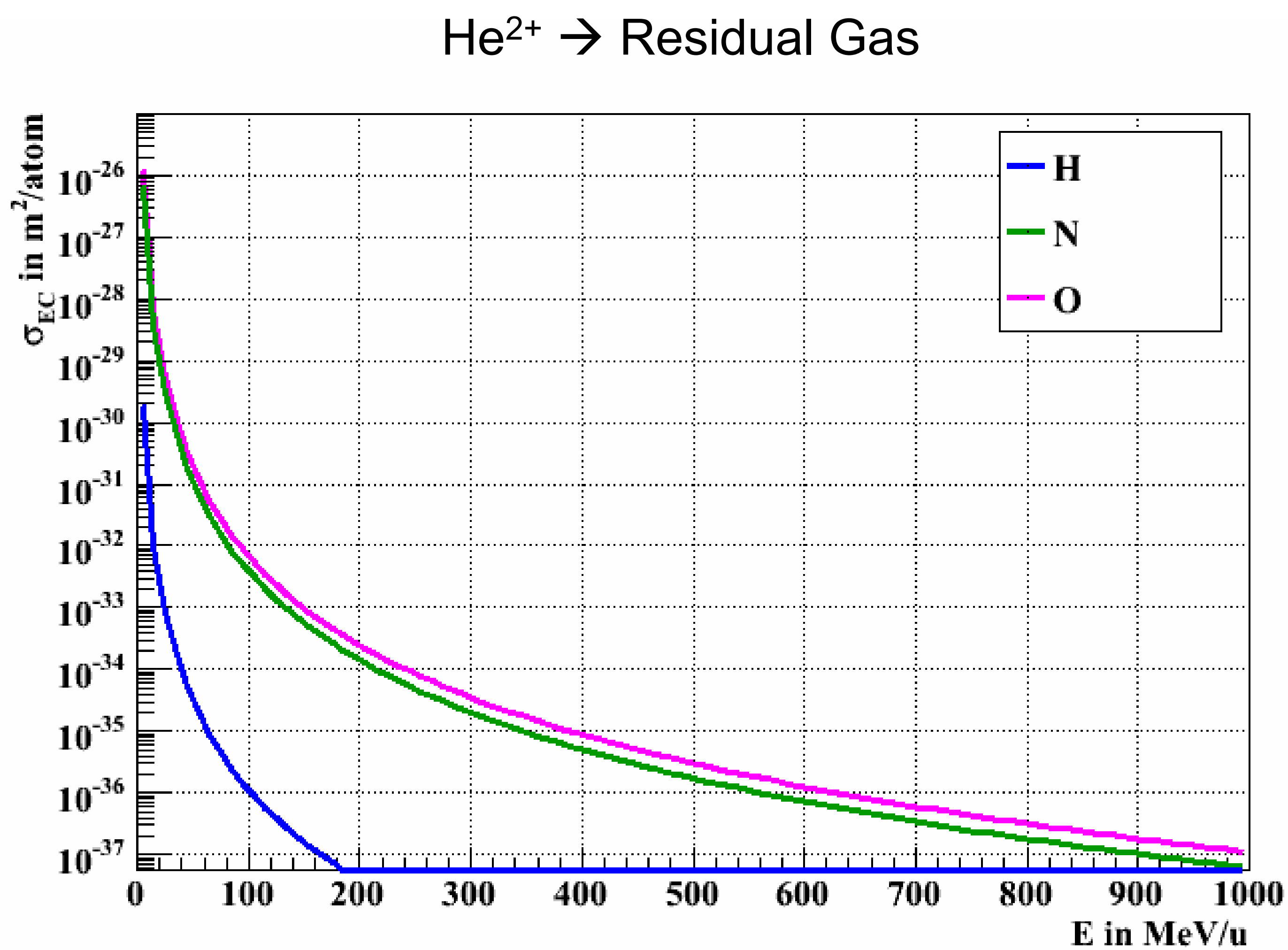
- Simulation not yet fully operable
- Preliminary Catching efficiency:
  - Li^{3+}: ~51.63% (He decay)
  - F^{9+}: ~48.83% (Ne decay)
- Pump Speed and Volume not yet specified

Summary and Outlook

- RCS
  - Pumping speed of RCS needs attention
  - Simulation gives no further concerns
- PS
  - Simulation looks promising
  - No further concerns expected
- SPS and DecayRing
  - StrahlSim-Files need to be ported to latest version

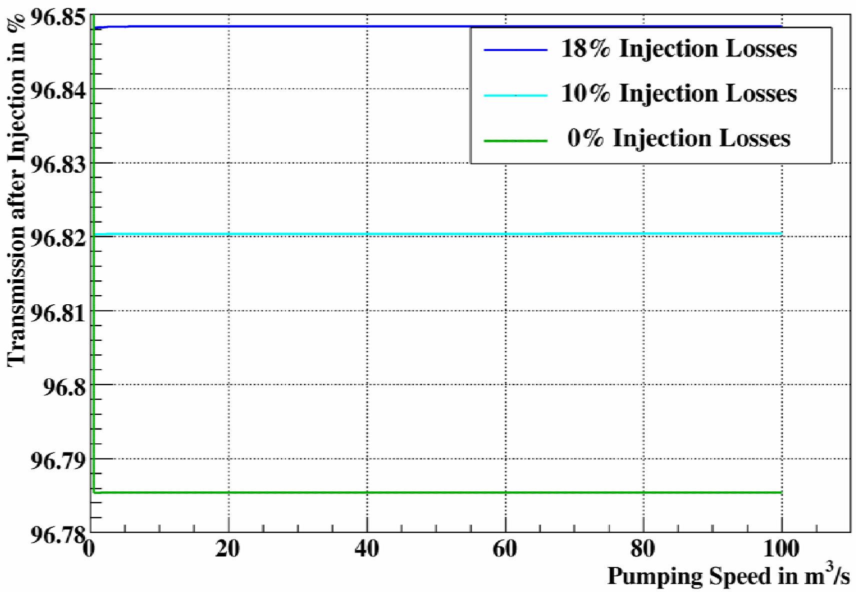
Backup Slides

Electron Caputre

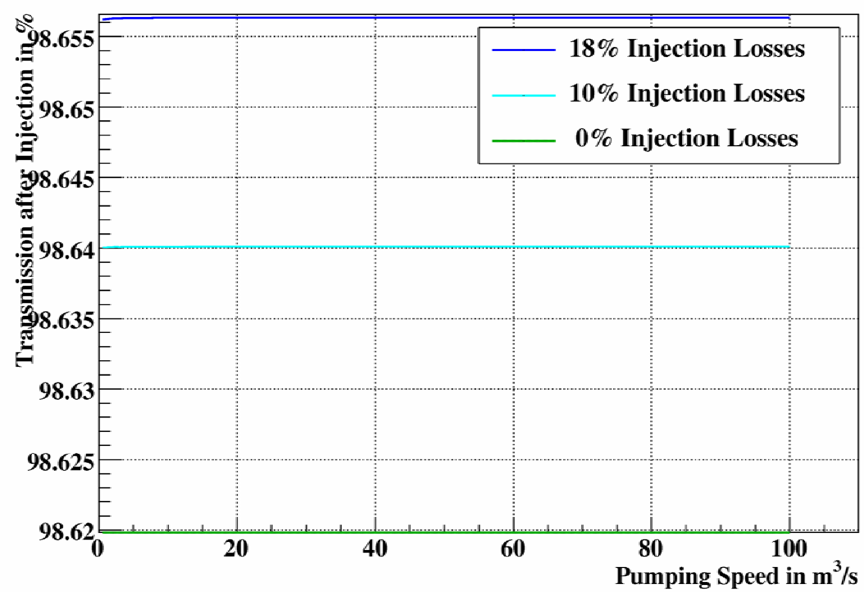


RCS - Transmission

- Transmission after injection losses
  - Independet of Pumping speed
  - Dominated by ß-decay
  - Other Charge Exchange induced effects (projectile recombination) can be neglected

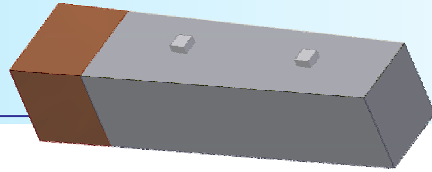


He



Ne

Ion Catching



- Cryo-Ion-Catcher
  - By choosing an appropriate temperature, on the catcher less gas is adsorbed than on the surrounding cold chamber walls
  - Most lost ions get caught by the catcher
  - This leads to a significant reduction of gas desorption and such improves the dynamic vacuum, which in turn reduces the losses induced by charge exchange
  - The surrounding magnets get less activated by lost ions
  - Is part of the EuCARD WP8: ColMat
- Research is ongoing