Status Report on the FAIR project

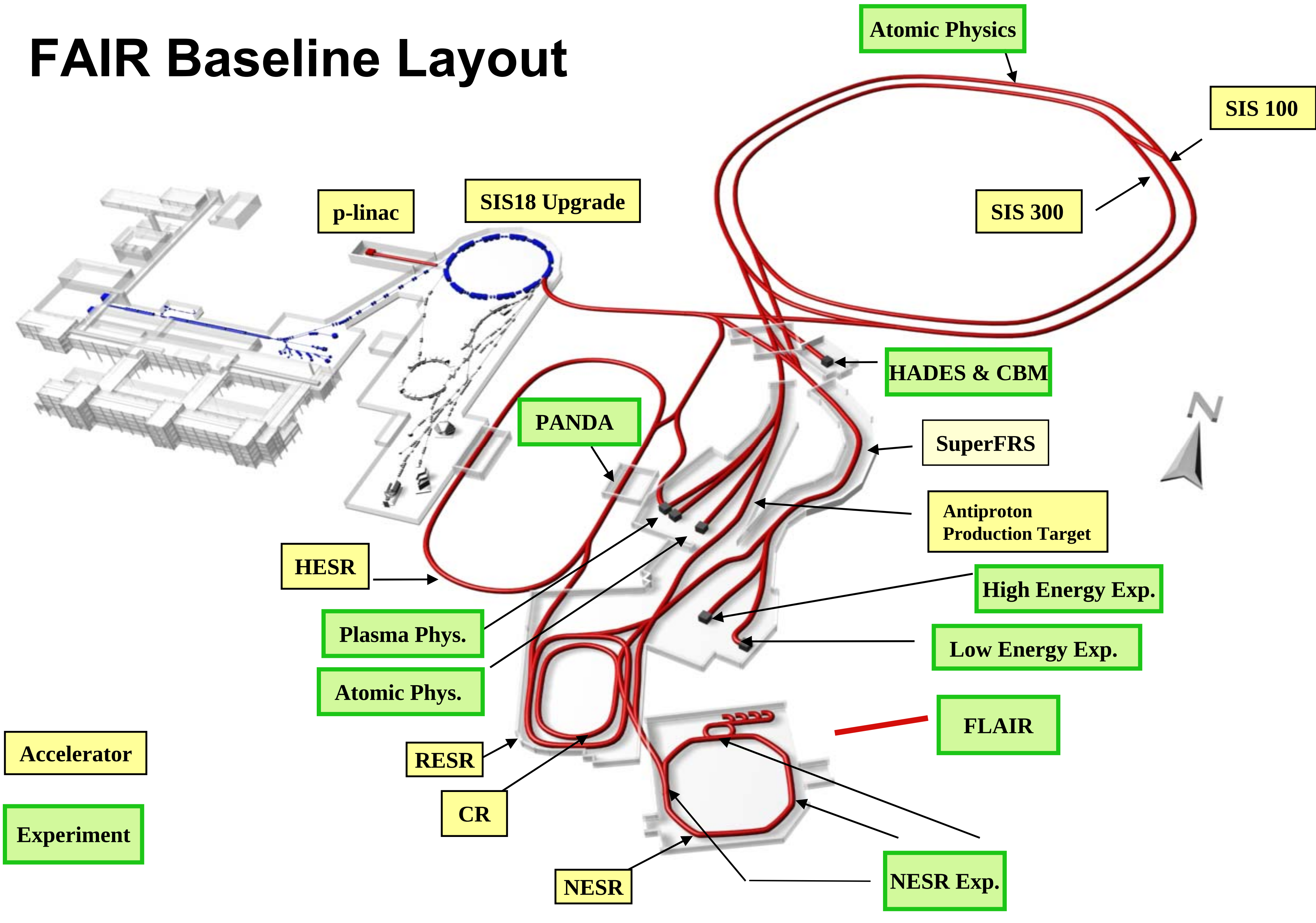
Christina DIMOPOULOU

on behalf of FAIR Technical Division,

GSI Accelerator Division & collaborators ....

RuPAC 2008, 28.09-3.10.08, Zvenigorod, Russia

FAIR Baseline Layout



Great Variety of Experimental Requirements

- **NUSTAR**: 2×10^{11}/pulse U^{28+} @ 200 MeV/u
  bunch compression to 70 ns
  highest gain factors for exotic nuclear beams
- **CBM**: Heavy-ion beam intensities of 10^{10} particles/s
  @ 34 GeV/u for U^{92+}
- **PANDA**: pbar in wide momentum range (1.5 - 15 GeV/c)
  High luminosity and high momentum resolution
- **FLAIR**: Cooled antiprotons in the 20 keV range
- **SPARC**: Cooled and high brilliance beams of rare isotopes
- **Plasma Physics**: High intensity beams, bunch compression to 70 ns

The FAIR Accelerator Complex

Total project: 1300 M€

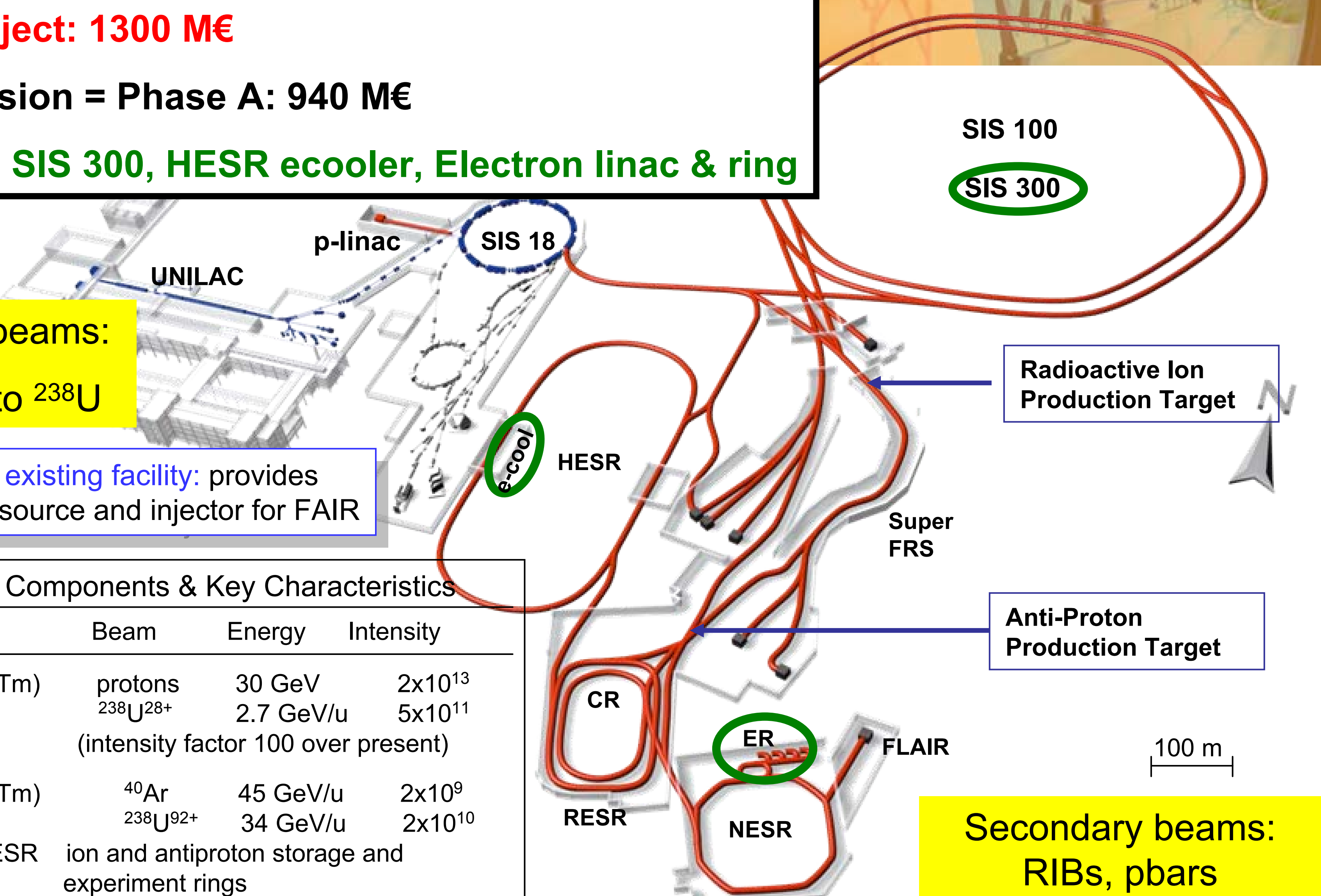
Start Version = Phase A: 940 M€

Phase B: SIS 300, HESR ecooler, Electron linac & ring

Primary beams:

protons to ^{238}U

Upgraded existing facility: provides ion-beam source and injector for FAIR



Accelerator Components & Key Characteristics

Ring/Device	Beam	Energy	Intensity
SIS 100 (100Tm)	protons	30 GeV	$2x10^{13}$
	$^{238}U^{28+}$	2.7 GeV/u	$5x10^{11}$
	(intensity factor 100 over present)		
SIS 300 (300Tm)	^{40}Ar	45 GeV/u	$2x10^{9}$
	$^{238}U^{92+}$	34 GeV/u	$2x10^{10}$
CR/RESR/NESR	ion and antiproton storage and experiment rings		
HESR	antiprotons	14 GeV	$\sim 10^{11}$
Super-FRS	rare isotope beams	1 GeV/u	$<10^{9}$

Secondary beams: RIBs, pbars

New future facility: provides ion and anti-matter beams of highest intensities and up to high energies

FAIR Accelerator Challenges

1. Beam Intensity Frontier:

Highest intensities for energetic heavy ion beams

⇒ 100-1000 times higher primary beam intensities than presently

2. Beam Brightness Frontier:

Highest phase space densities

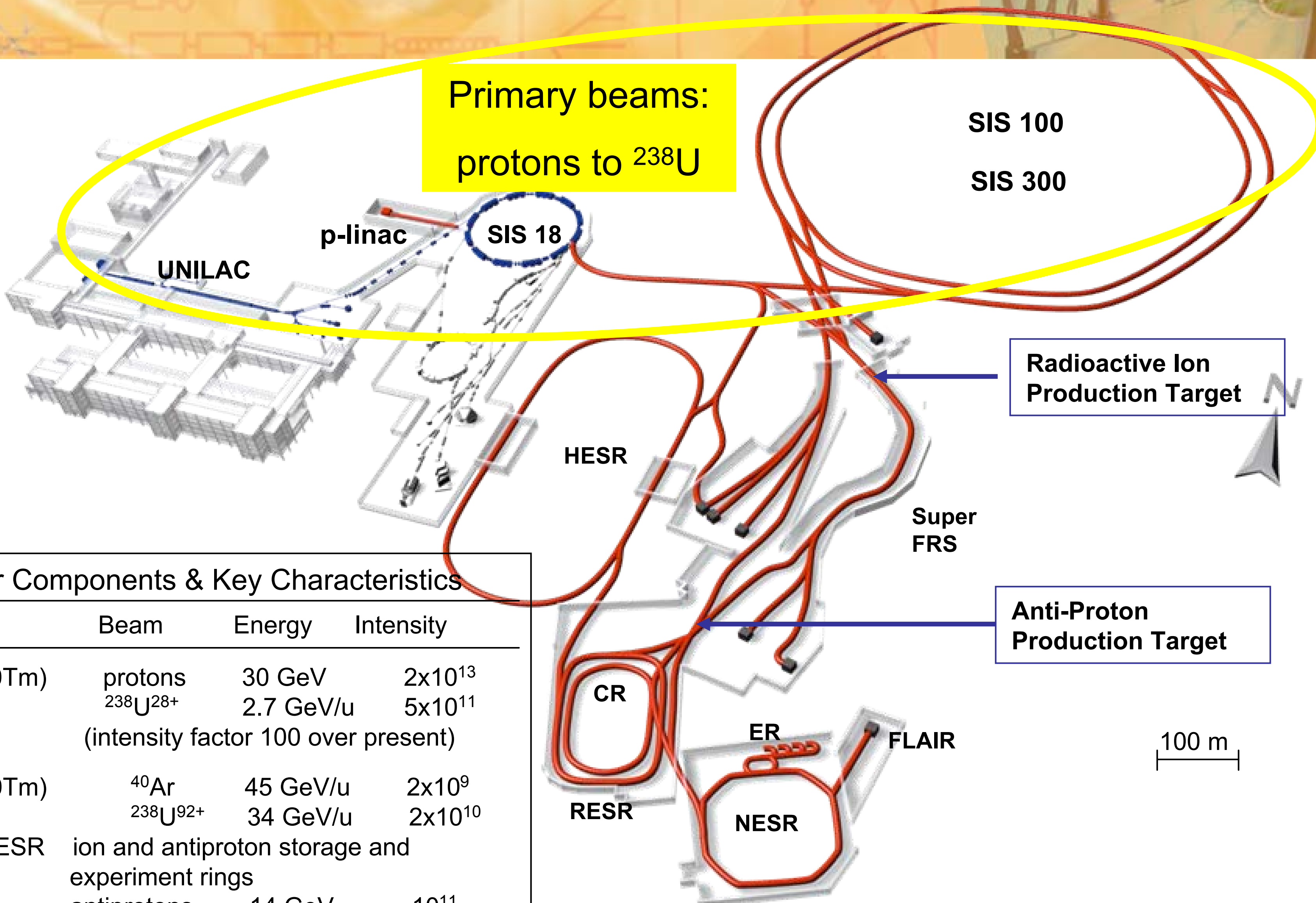
⇒ Compressed and intense primary beams

⇒ Cooled secondary beams: radioactive ions and antiprotons

Related Technical Challenges:

- control of intense, medium charge state heavy ion beams:
  - dynamic vacuum, space charge effects, collective instabilities
- beam cooling at medium/high energies: electron and stochastic cooling
- fast ramping superconducting magnets
- compact rf cavities, complex rf manipulations
- parallel operation of several beam and experiments

The FAIR Accelerator Complex



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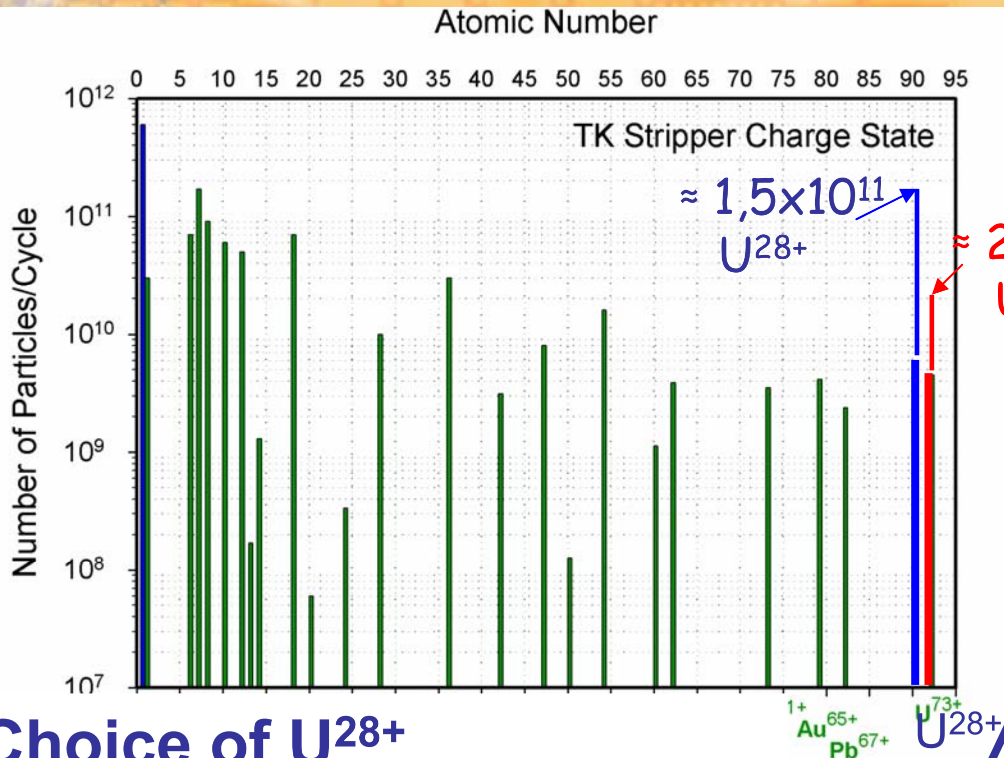
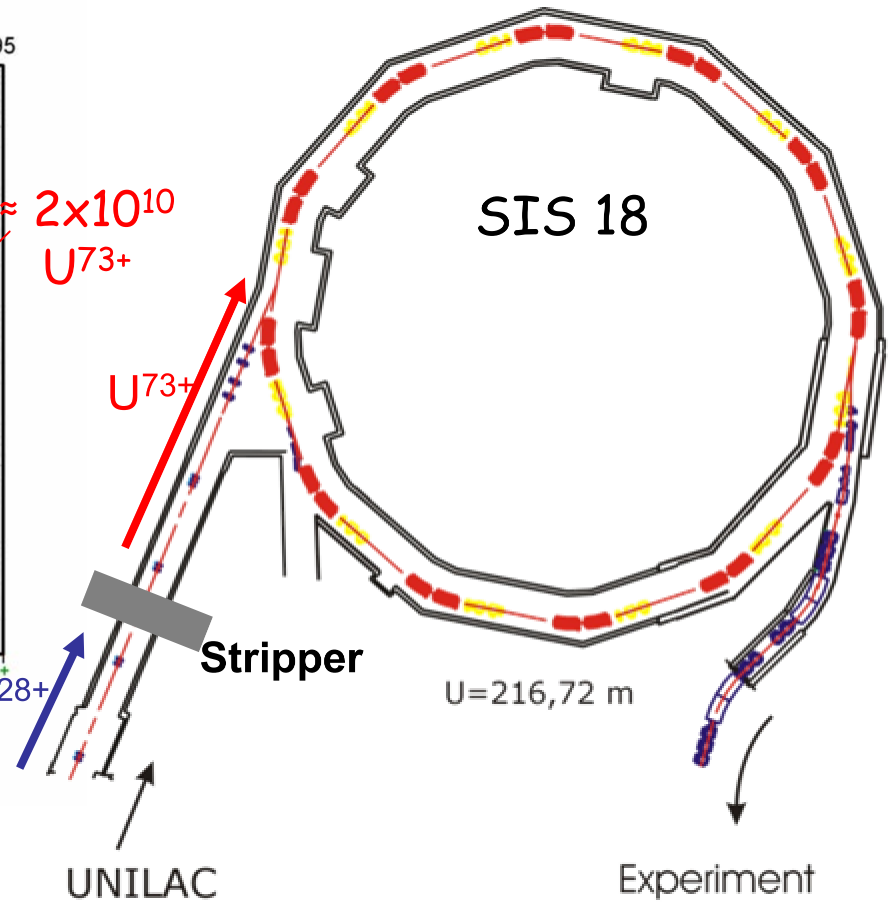
SIS 18 as Injector of SIS 100





Choice of U^{28+}

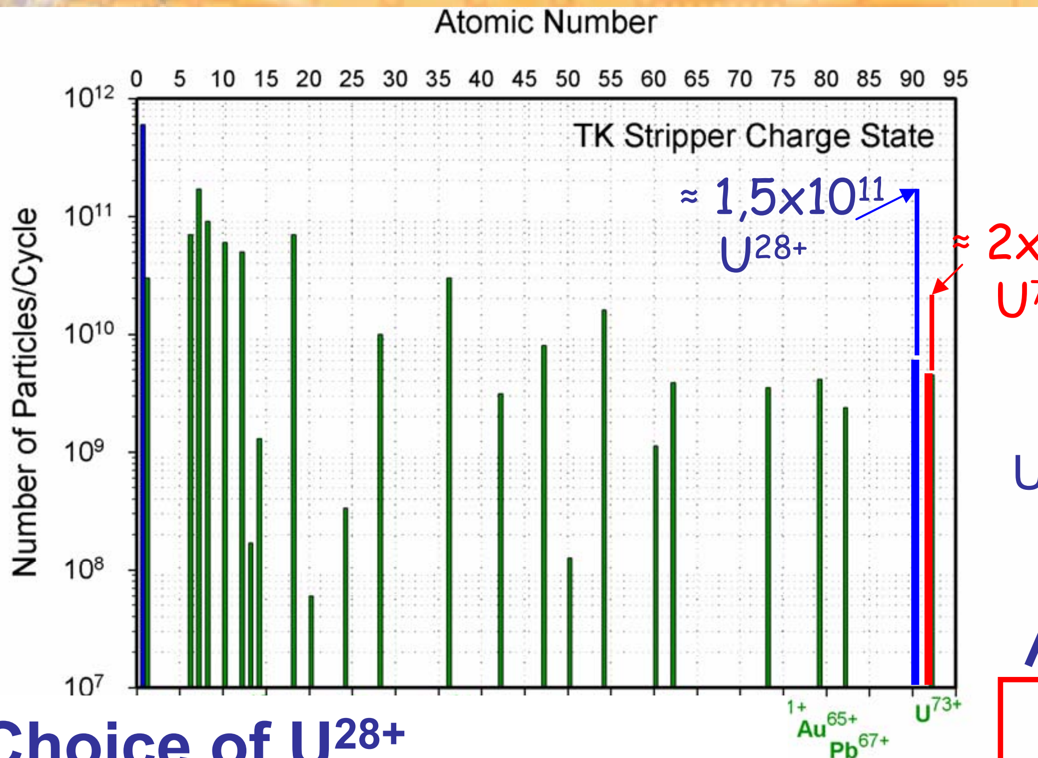
+ Lower space charge

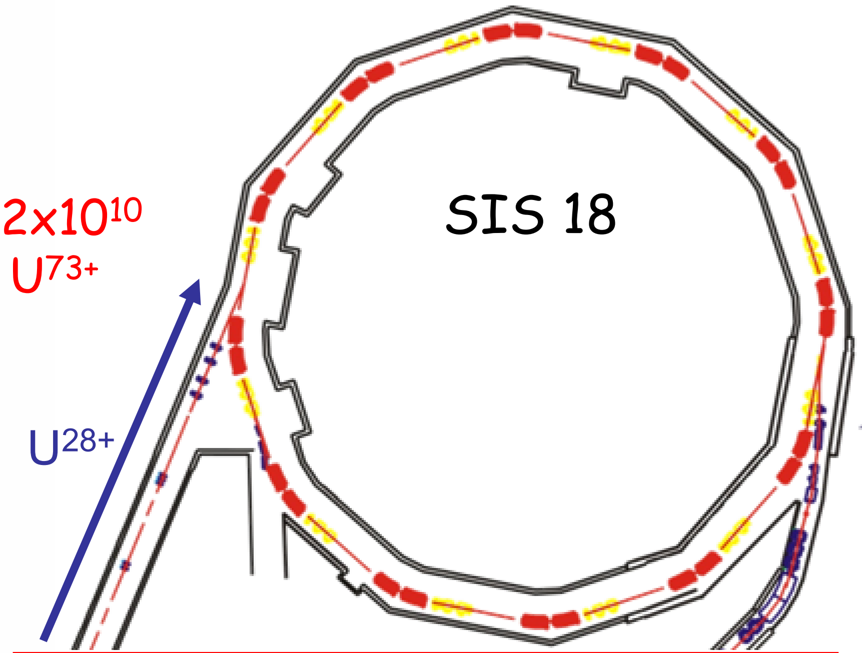
  → higher intensity N_{max}~A/Q^2

+ No stripping losses

- Lower beam lifetime

SIS 18 as Injector of SIS 100





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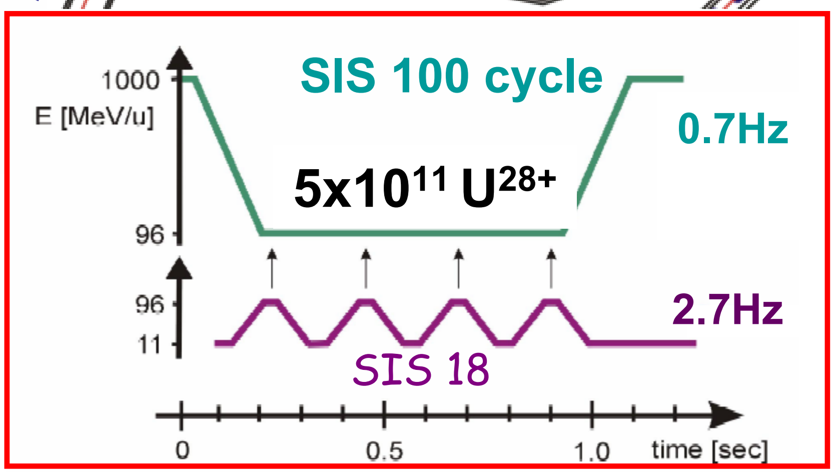

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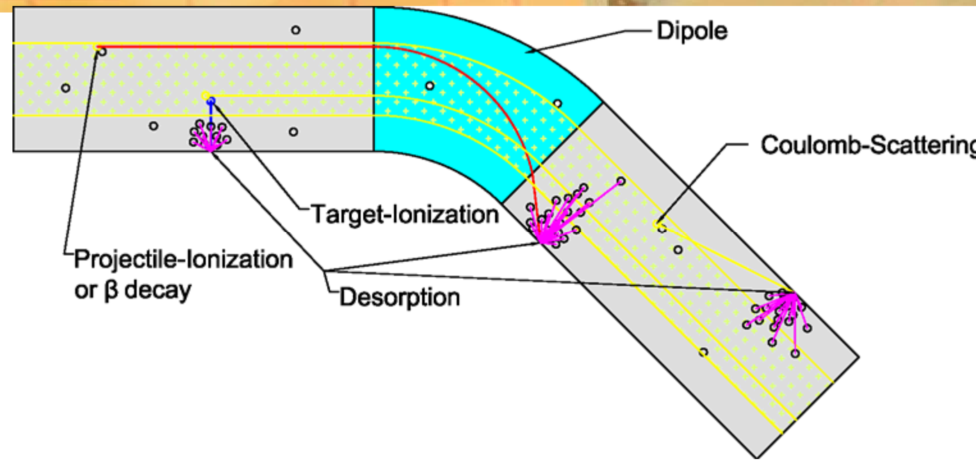
Control of Dynamic Vacuum Pressure in SIS 18

Main beam loss mechanism:
U^{28+} -> U^{29+} (stripping)

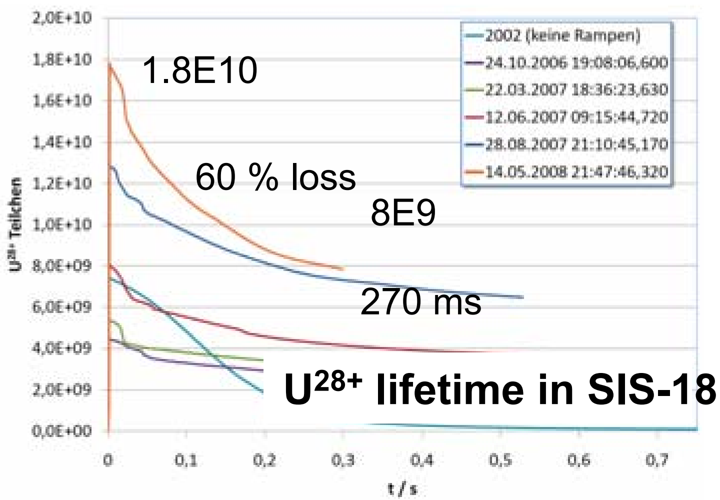


Dynamic pressure:

$$\frac{dP}{dt} = \tau_p^{-1}(P - P_0) + \alpha \eta_{loss} NP$$

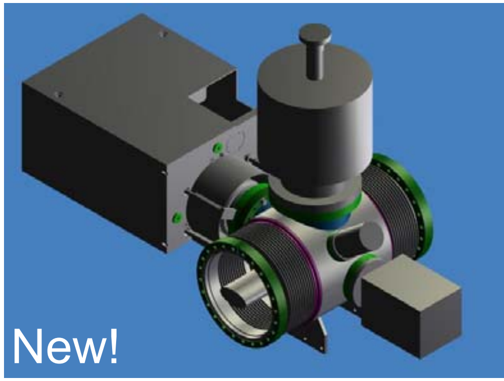
Desorption coefficient:

$$\eta = \frac{\#\ \text{desorbed molecules}}{\#\ \text{incident ions}} \propto \left(\frac{dE}{dx}\right)^2$$

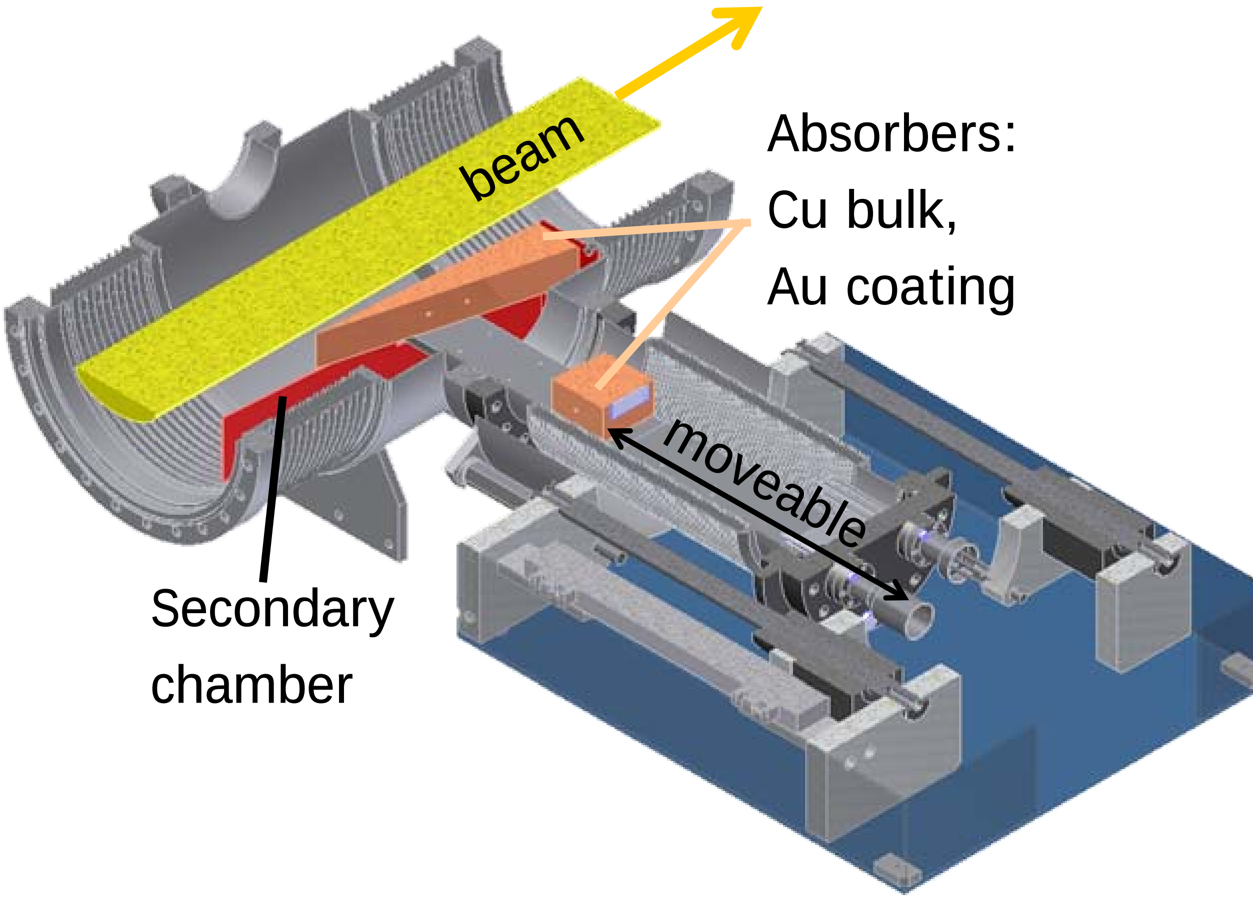


Measures:
-NEG-coated chambers
-Combined pumping/collimation ports behind dipoles

Goals:
- increase pumping speed
- localize beam loss
- minimize desorption
- monitor with diagnostics



Control of Dynamic Vacuum Pressure in SIS 18

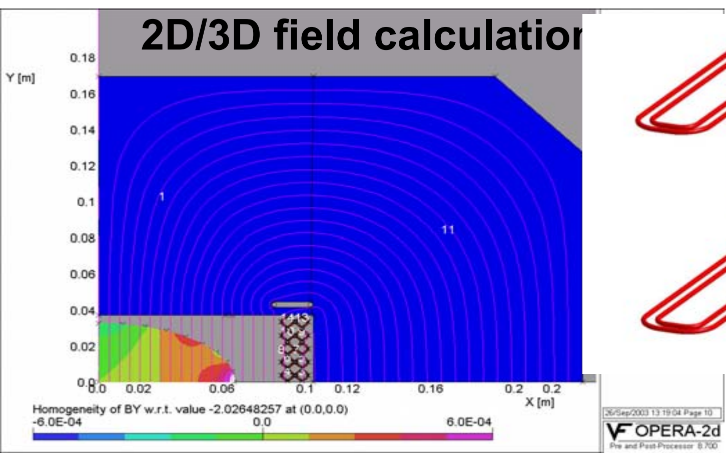


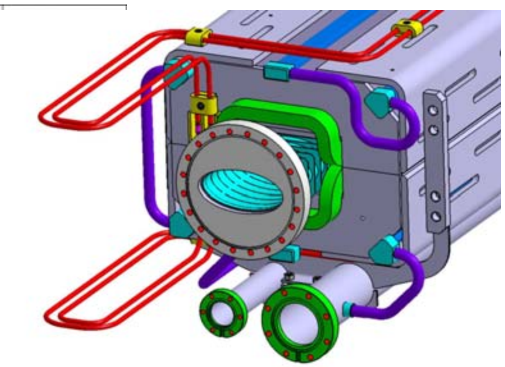
SIS 100
High-Intensity and Compressor Stage

Intermediate charge state ions e.g. U^{28+} ions up to 2.7 GeV/u
Protons up to 29 GeV

- fast-ramped superconducting magnets and
- strong bunch compression system

$B\rho$ = 100 Tm B_{max} = 1.9 T   dB/dt= 4 T/s (curved)





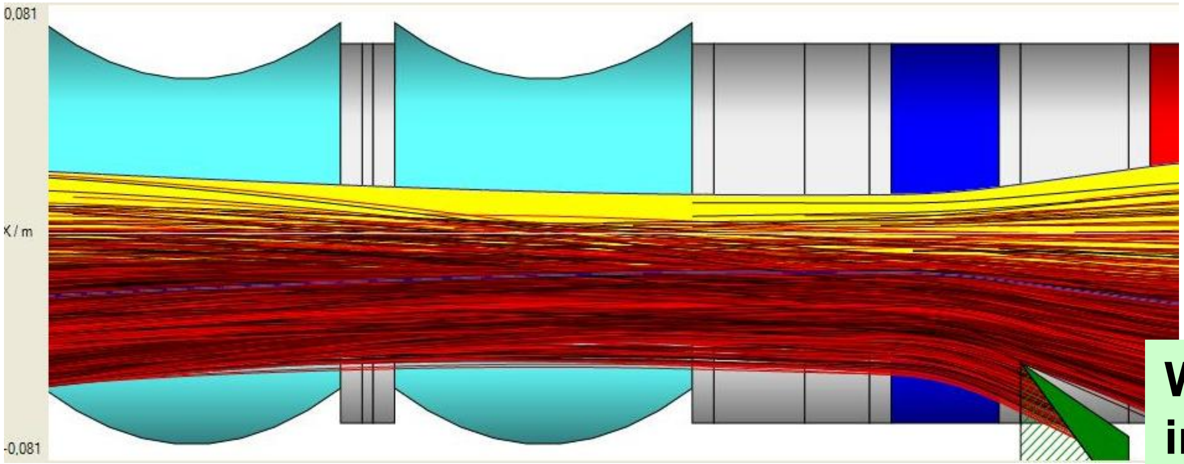
Prototype production also at BINP,JINR

SIS 100 Design Issues

SIS 100 lattice optimized for minimum dynamic vacuum beam

Charge Separator Doublet Lattice with collimators

optimized for catching efficiency close to 100% for U^{29+}



Wedge collimator (at 80 K) in secondary chamber with enhanced pumping, confines most of desorbed gases

Minimum additional load for the UHV and the cryogenic system.

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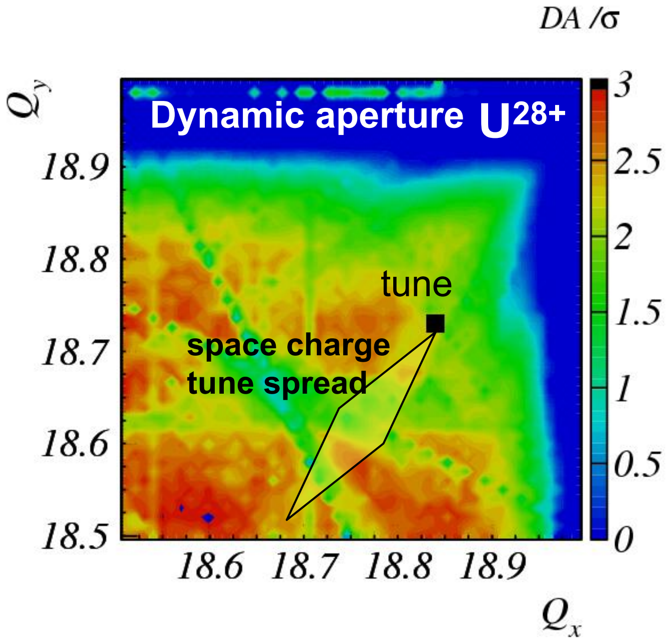
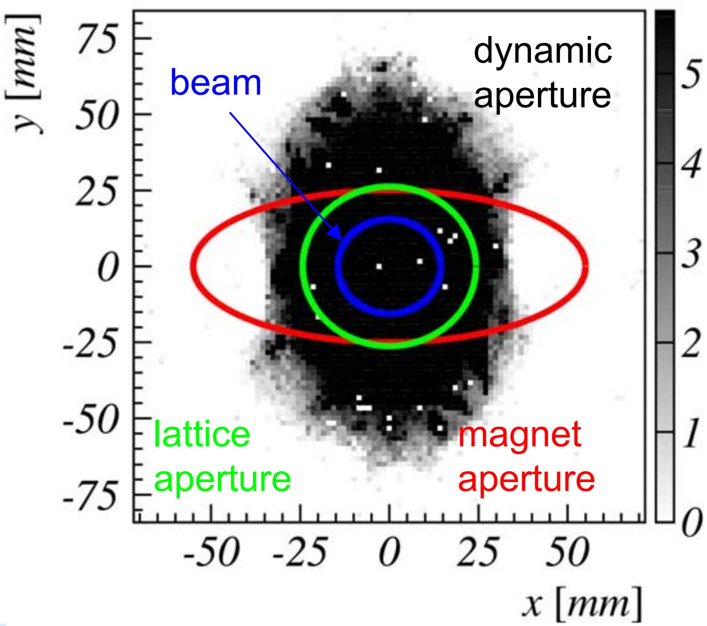
SIS 100 Design Issues

SIS 100 transverse apertures





Long-term (up to 1 s, 10^6 turns) 3D particle tracking with 'frozen' space charge indicates a space charge limit at $3x10^{11}$ U^{28+} (design $5x10^{11}$).

High intensity challenges for SIS 100:

- 2/3 filling factor
- Optimized working point for < 5 % loss

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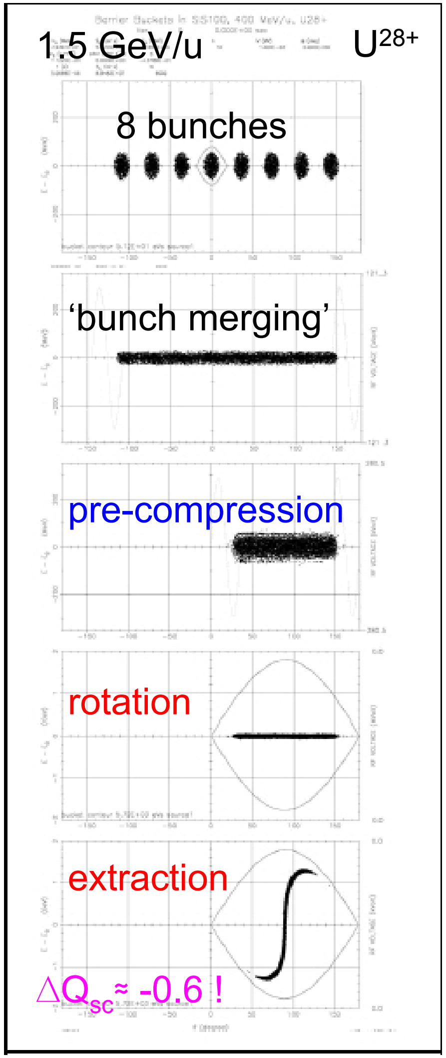
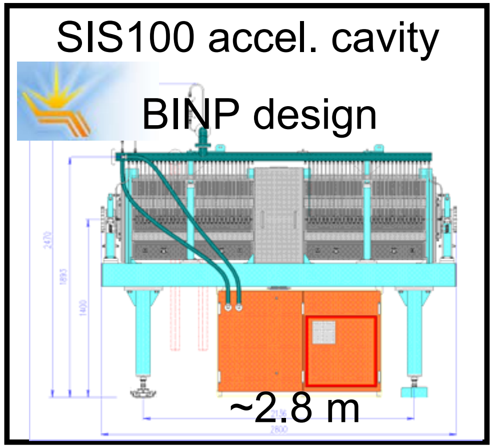
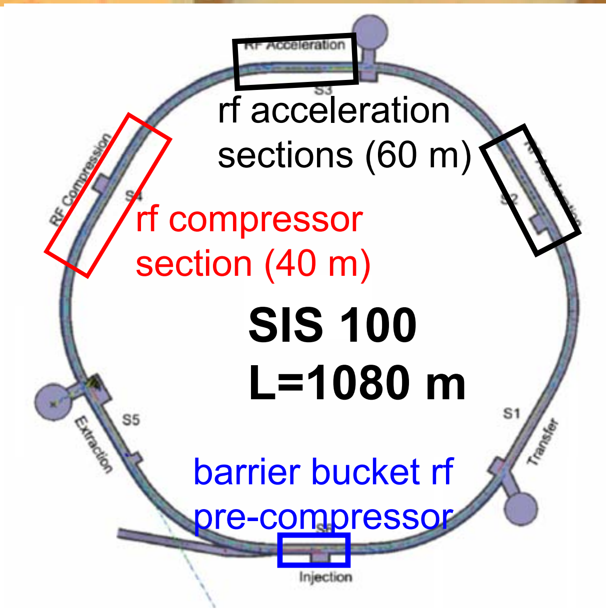
SIS 100 rf Systems & Bunch Compression

Single bunch formation







	#cavities	Voltage [kV]	Frequency [MHz]	Concept
Acceleration	20	400	1.1-2.7 (h=10)	Ferrite

SIS 100 rf Systems & Bunch Compression

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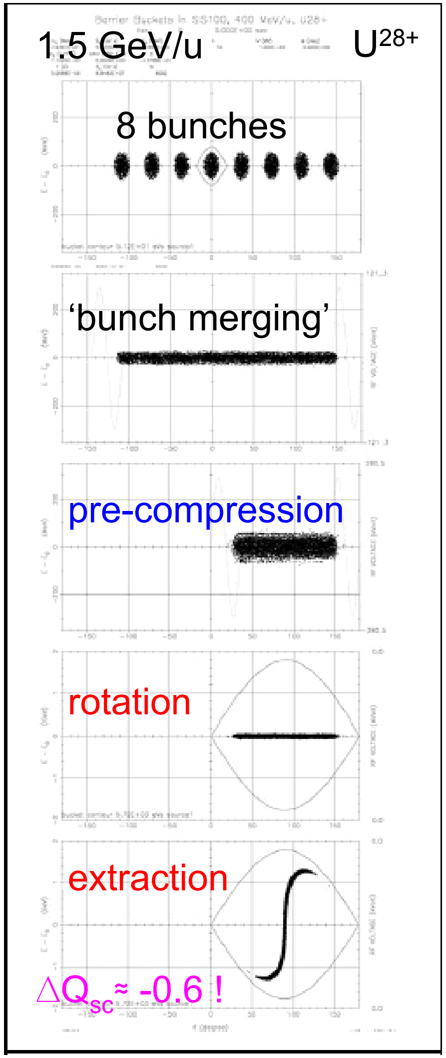
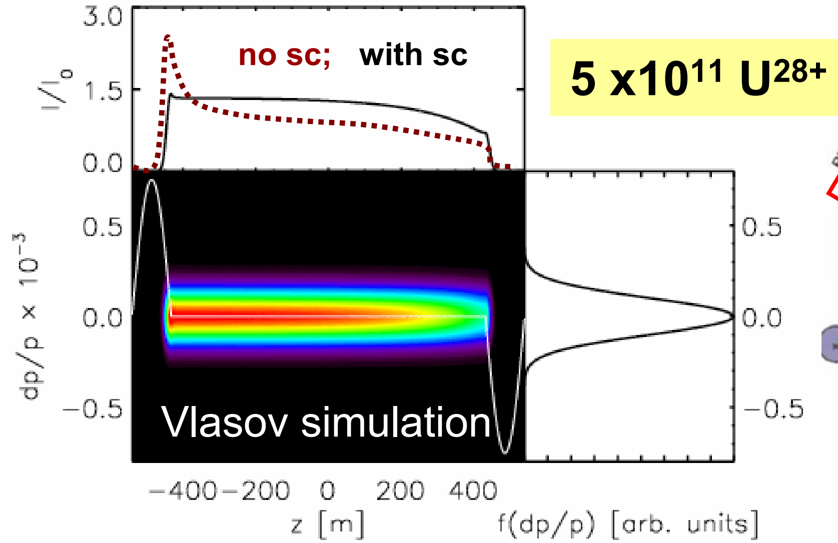
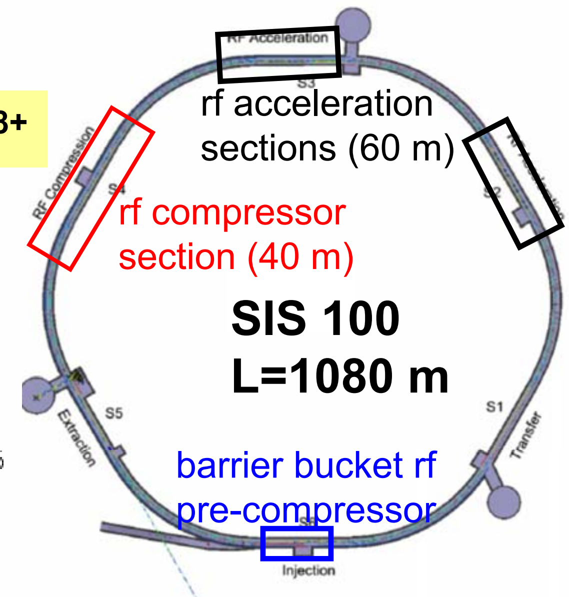


Pre-compression with Barrier bucket rf



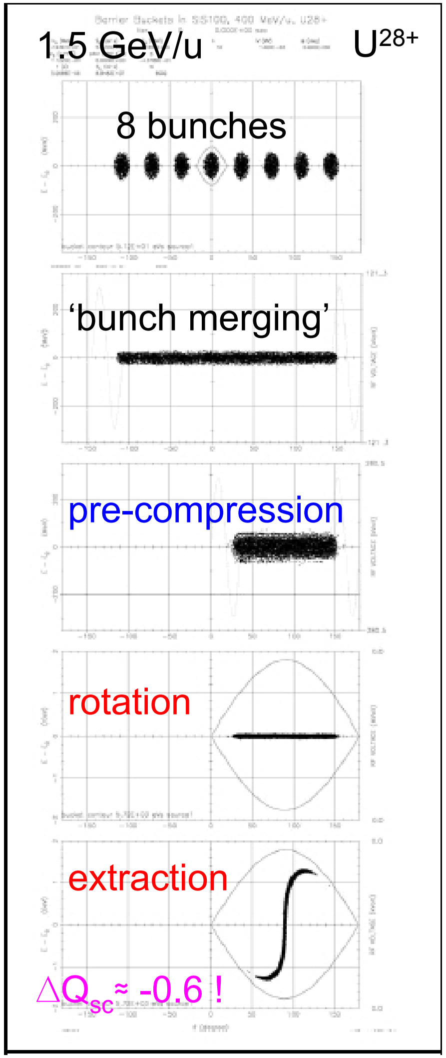
space charge reduces the effect of beam loading

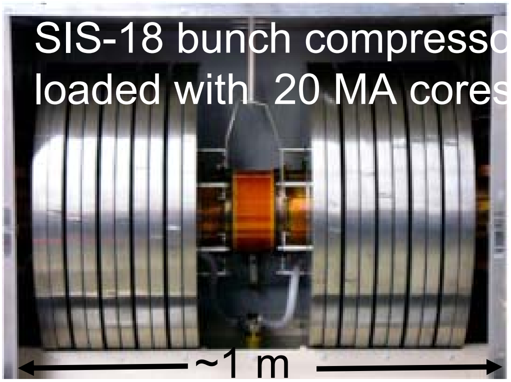


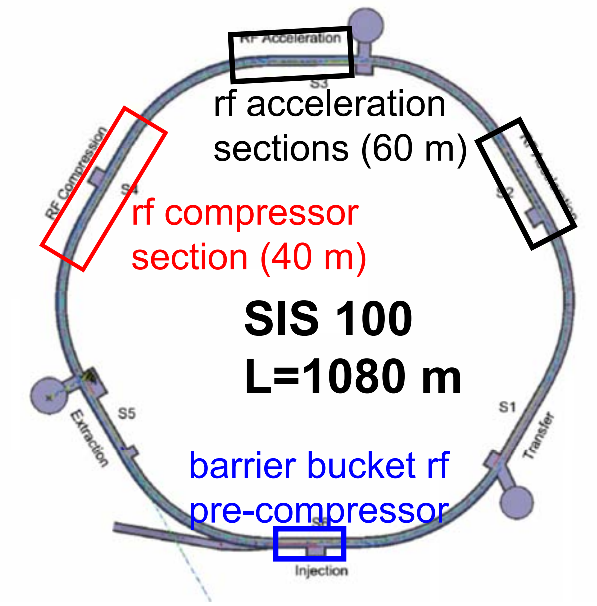
	#cavities	Voltage [kV]	Frequency [MHz]	Concept
Pre-compression	2	15	1.5	MA (low duty cycle)

SIS 100 rf Systems & Bunch Compression

Single bunch formation







	#cavities	Voltage [kV]	Frequency [MHz]	Concept
Compression	16	600	0.4-0.5 (h=2)	MA (low duty cycle)

Final bunch parameters:

	Particles/bunch	bunch length
1.5 GeV/u U^{28+}	5×10^{11}	60 ns
29 GeV protons	2×10^{13}	25 ns

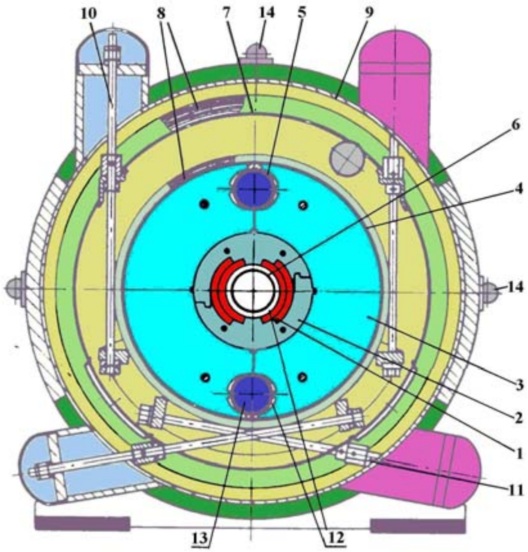
SIS 300
High Energy and Stretcher Stage

Highly charged ions e.g. U^{92+} ions up to 34 GeV/u

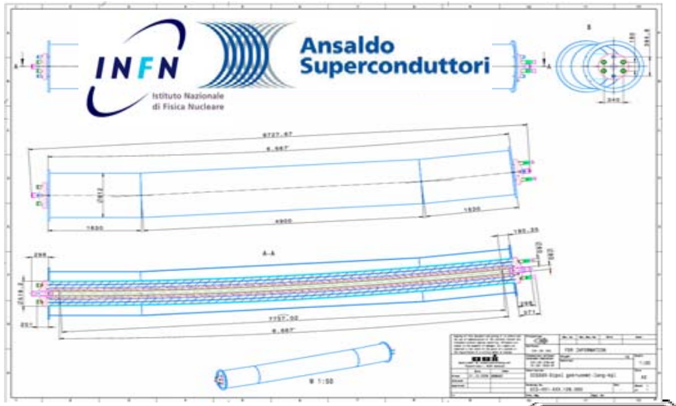
Intermediate charge state e.g. U^{28+} ions at 1.5 to 2.7 GeV/u with 100% duty cycle

- superconducting high-field magnets and
- stretcher function

$B\rho = 300$ Tm $B_{max} = 4.5$ T   dB/dt= 1 T/s (curved)

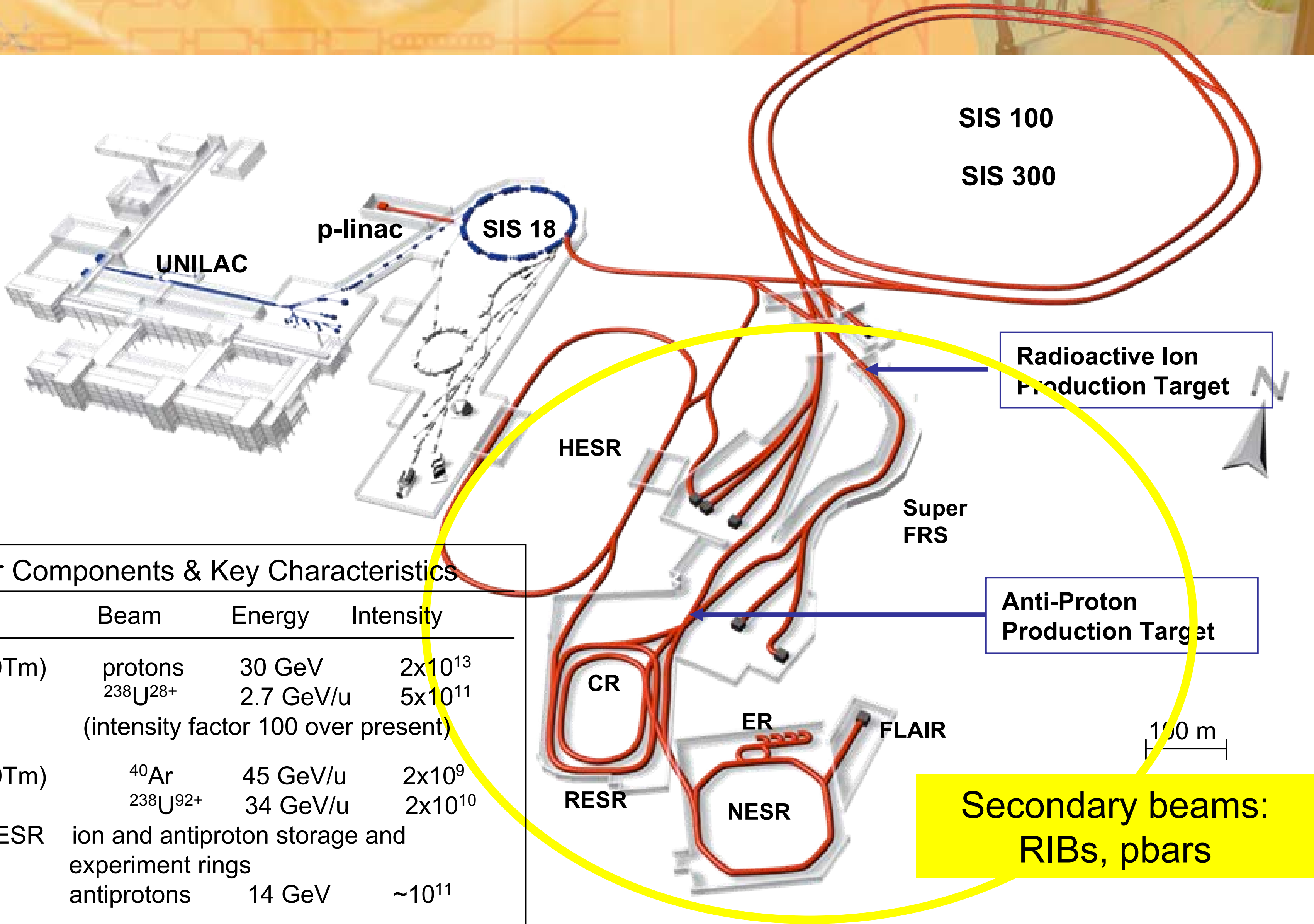


First cycling sc cosθ magnet, BNL 2003



Model under construction

The FAIR Accelerator Complex



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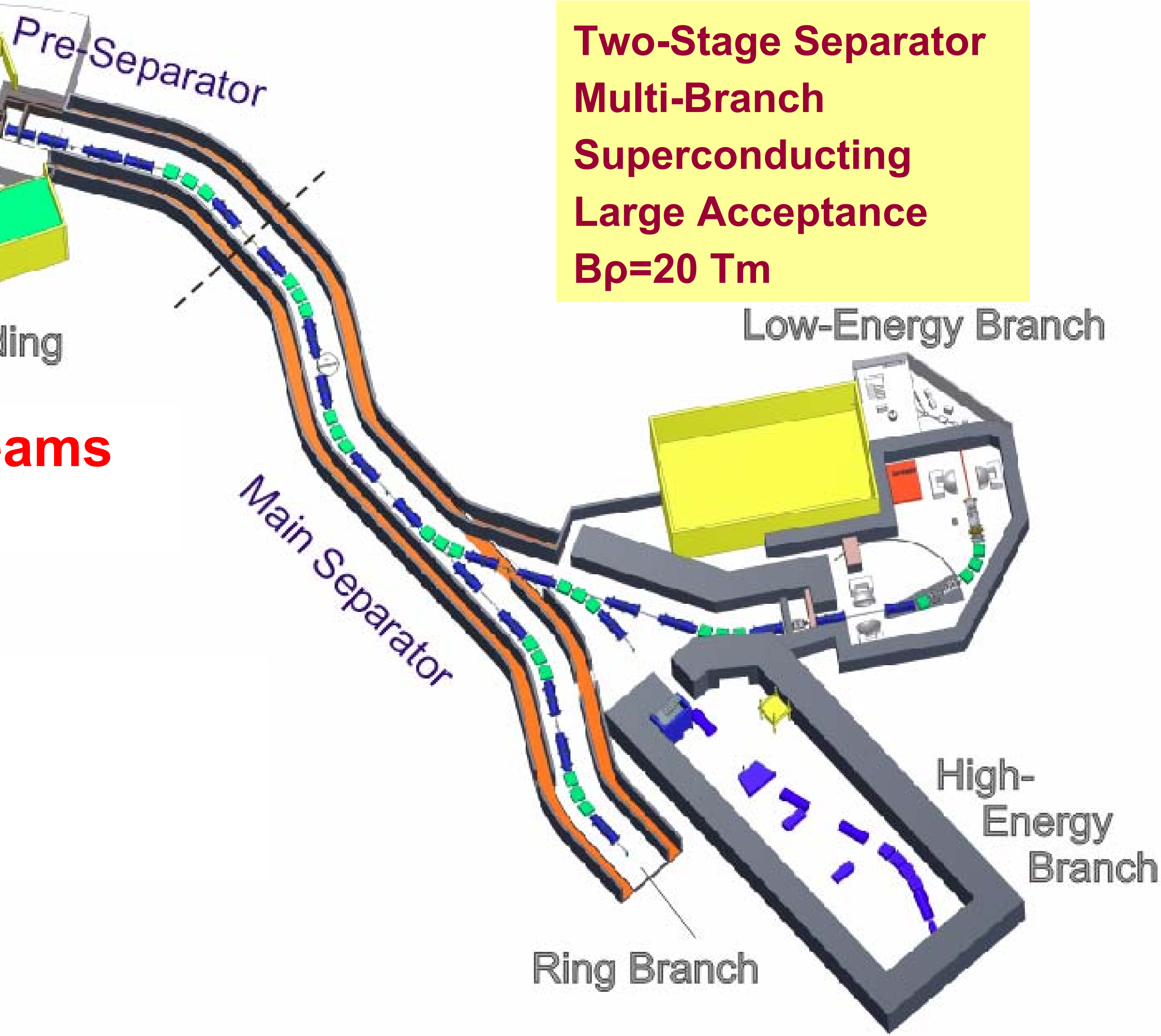
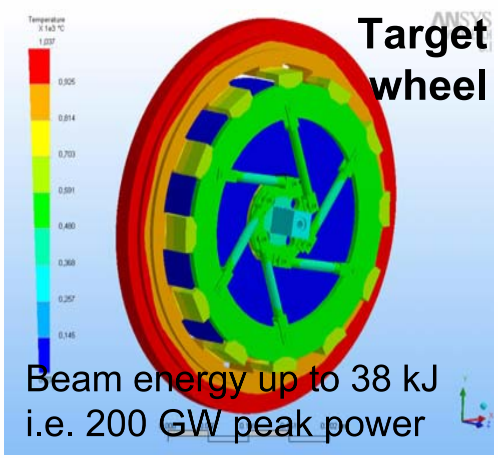
The Rare Ion Beam Separator Super FRS

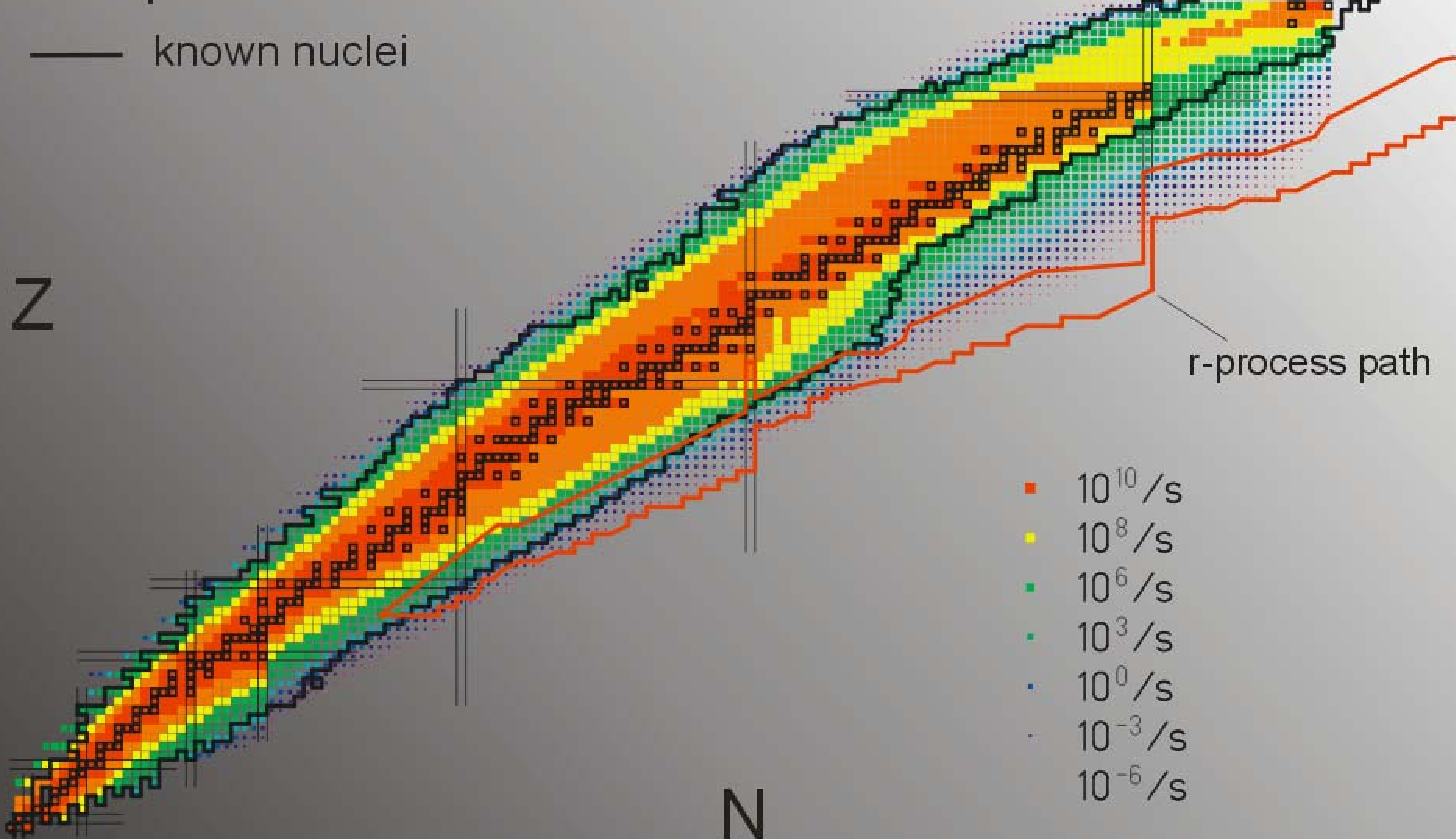
Two-Stage Separator
Multi-Branch
Superconducting
Large Acceptance
Bρ=20 Tm



Primary p to U beams with up to 10^{12}/s



Rate predictions for exotic nuclei

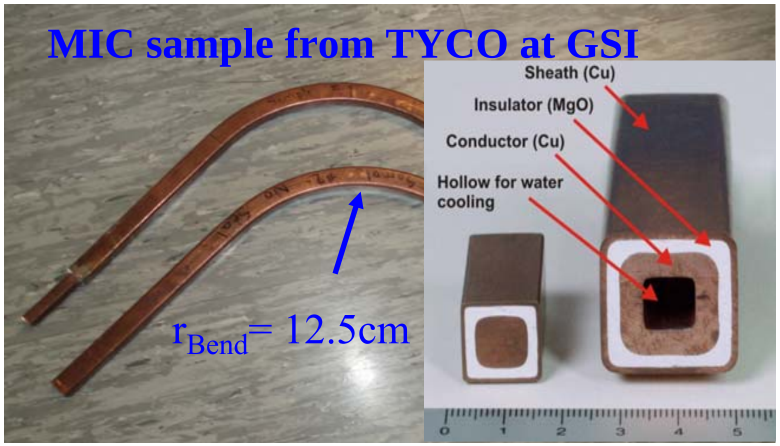


Rate after target for 10^{12}/s primary ions

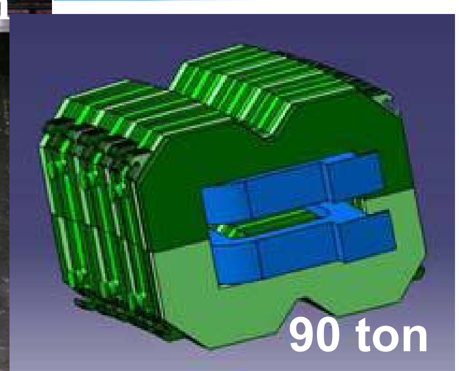
K.H. Schmidt et al.

Super FRS Magnets R&D

Radiation resistant nc dipoles near production target



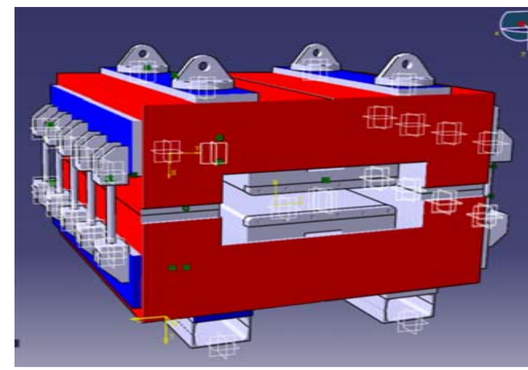
Prototype (BINP)



Large aperture (380 mm) superferric dipole magnets (warm iron, sc coil)

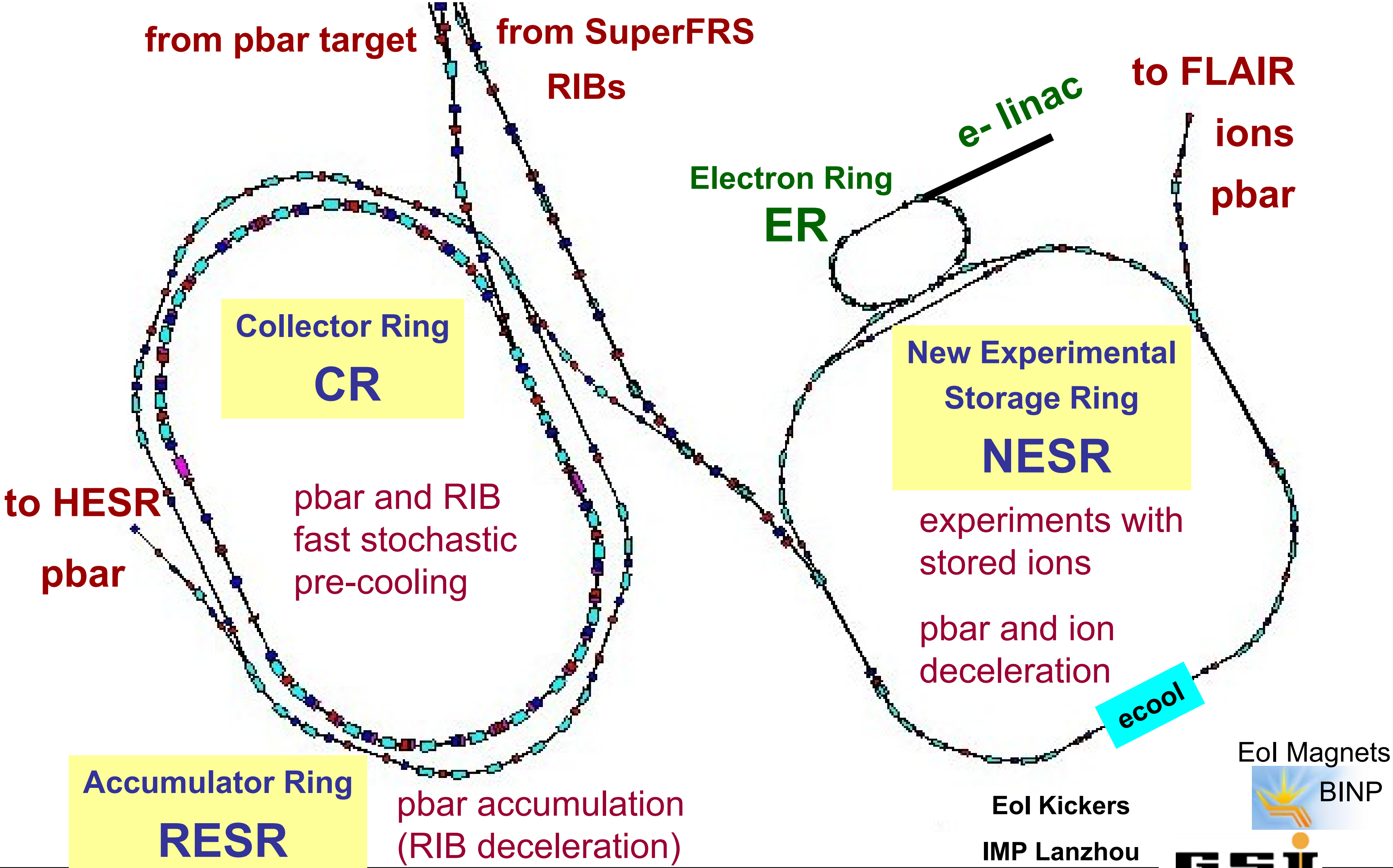
IMP Lanzhou
IPP Hefei
IEE Beijing

Chinese Academy of Science



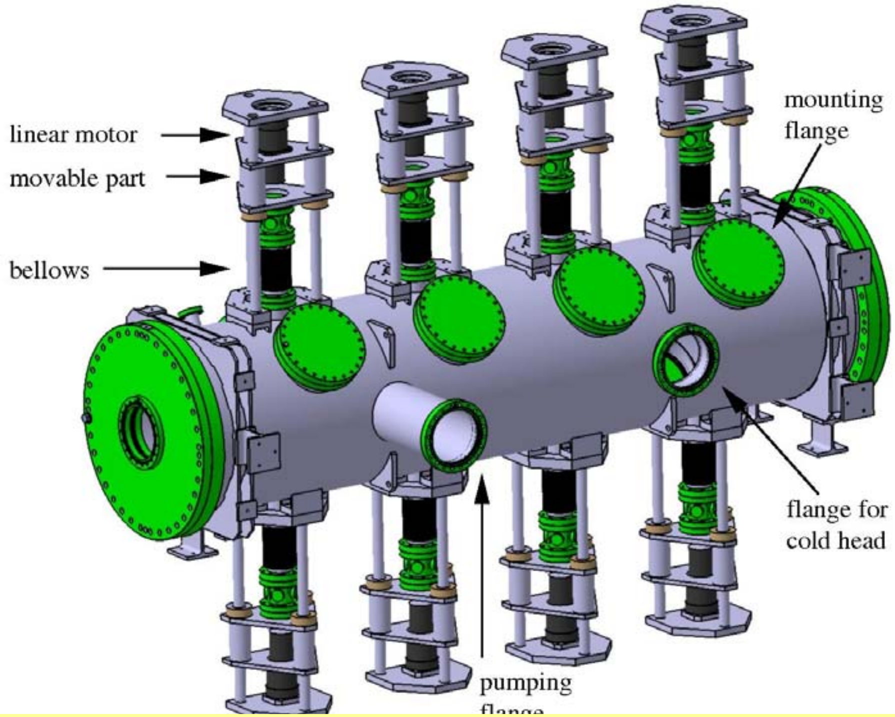
The FAIR 13 Tm Storage Rings

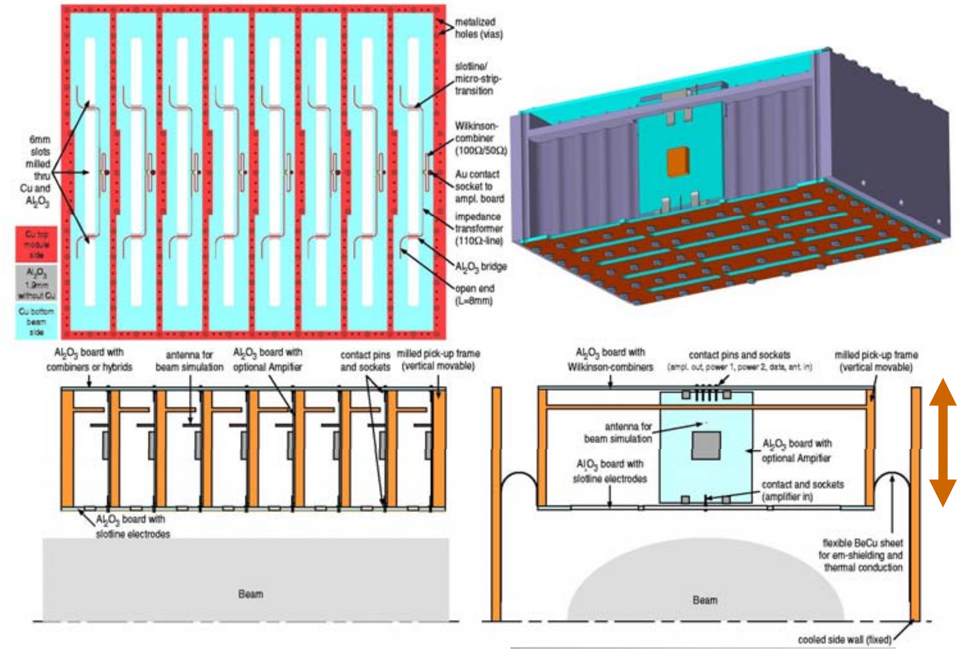
Normal conducting magnets

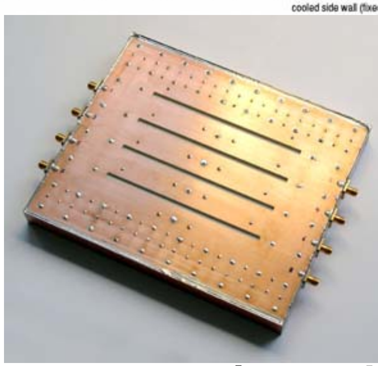


Stochastic Cooling Developments

vacuum tank
with movable electrodes
including cold heads (20 K) and
cooled pre-amplifiers



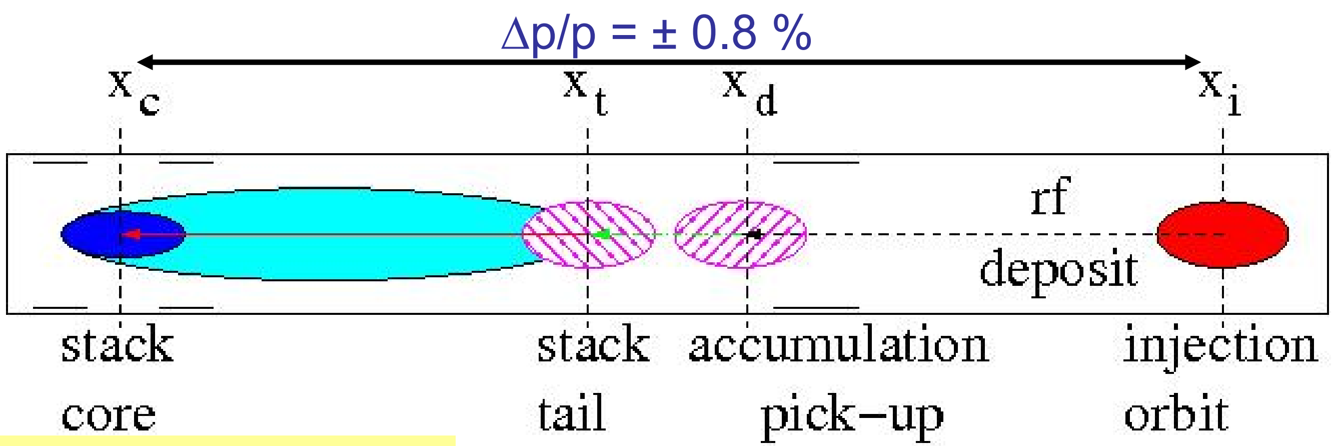




prototype electrode
(ß = 0.83-0.97)

CR: fast stochastic cooling (1-2 GHz) of antiprotons (10 s) and RIBs (1.5 s)

Antiproton Accumulation in RESR
RF Manipulation & Stochastic Cooling



electrodes of Faltin type

core cooling 2-4 GHz

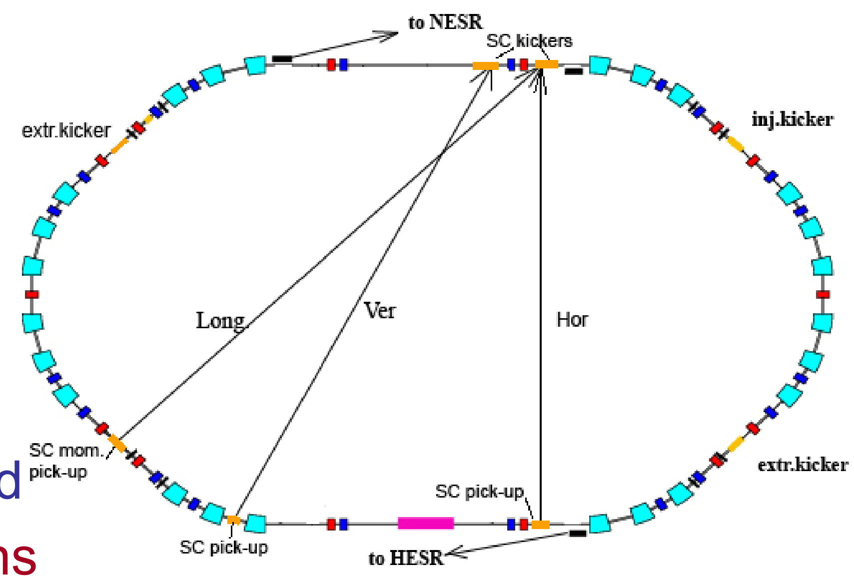
longitudinal,

horizontal,

vertical

tail cooling 1-2 GHz

longitudinal



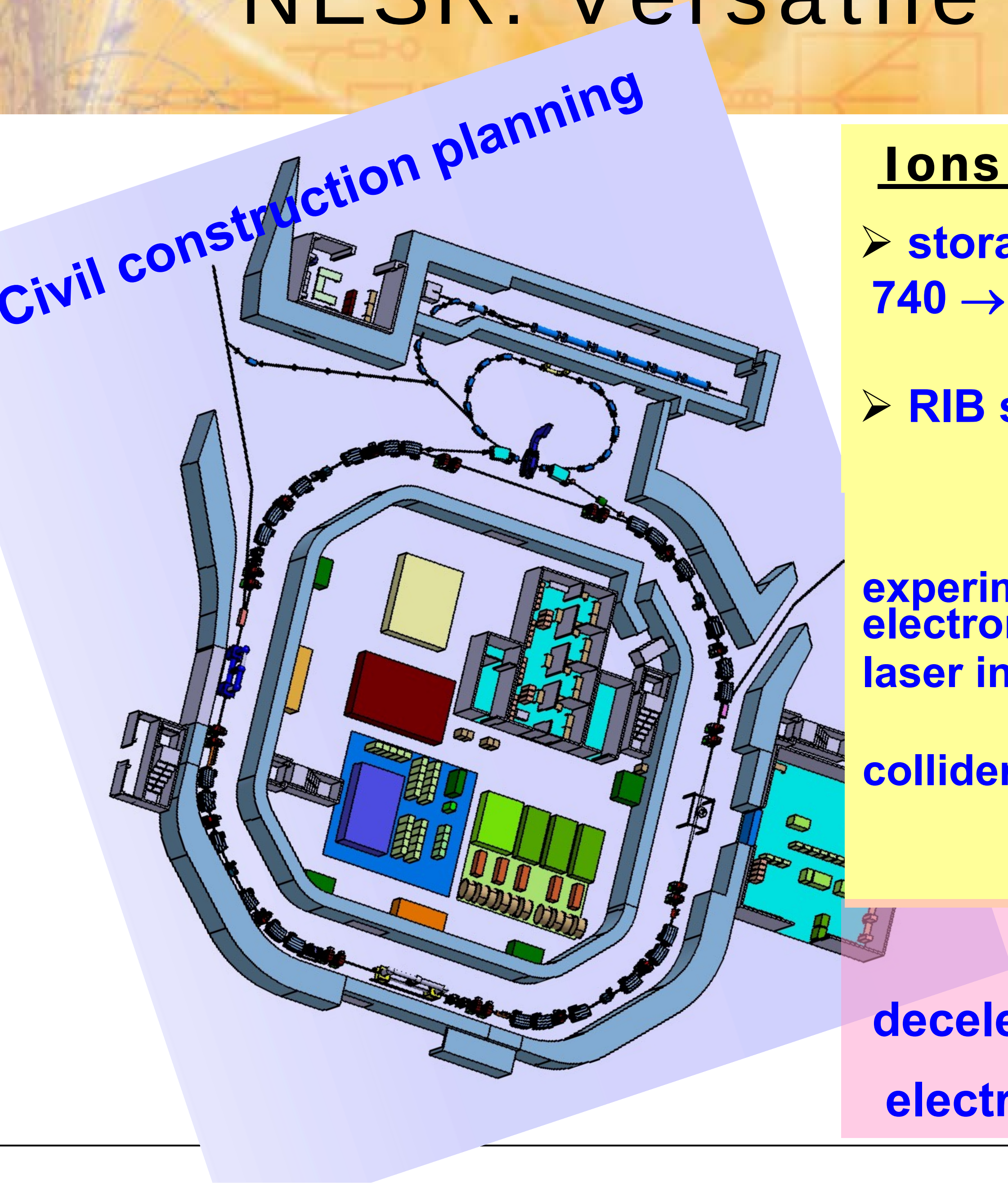
injection of 1×10^{8} antiprotons every 10 s

pre-cooled in CR: $\delta p/p = 10^{-3}, \varepsilon_{x,y} = 5$ mm mrad

maximum stack intensity~ 1×10^{11} antiprotons

max. accumulation rate: 3.5×10^{10}/ h

NESR: Versatile Operation



Ions (Stable & Rare Isotopes)

- storage and e-cooling in the range 740 → 4 MeV/u (decel. rate ≤ 1 T/s)
- RIB stacking assisted by el.cooling

Experiments

experiments with internal target
electron target (2nd electron cooler)
laser interactions (cooling,spectroscopy)

collider mode with e^- / pbar (bypass)

BINP

Antiprotons

deceleration 3000 → 800 → 30 MeV

electron cooling at 800 MeV

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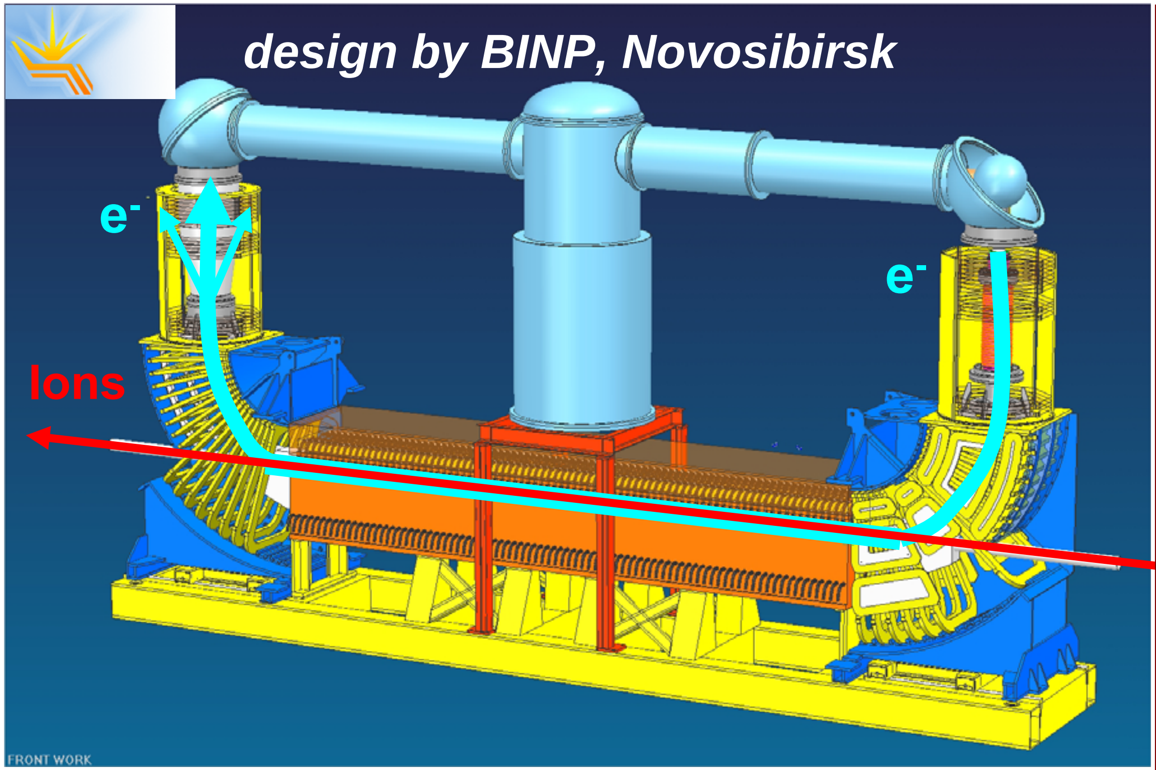
The NESR Electron Cooler



Cooler Parameters

energy	2 - 450 keV
max. current	2 A
cathode radius	1 cm
beam radius	0.5-1.4 cm
hollow cathode option	
magnetic field	
gun	up to 0.4 T
cool. sect.	up to 0.2 T
straightness	$\leq 2\times10^{-5}$
adiabatic expansion option	
cool. section length	5 m
max. power in collector	15 kW
vacuum	$\leq 10^{-11}$ mbar

Issues:

- high voltage up to 500 kV
- fast ramping, up to 250 kV/s
- magnetic field quality

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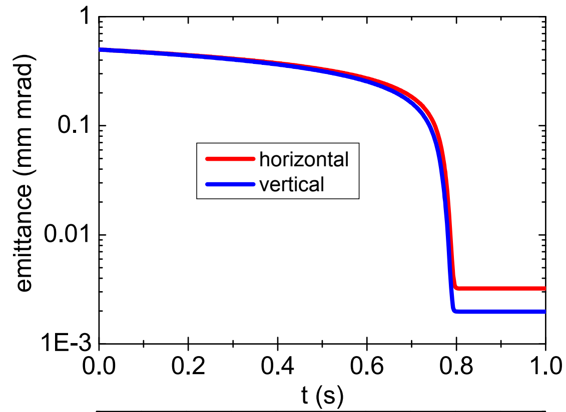
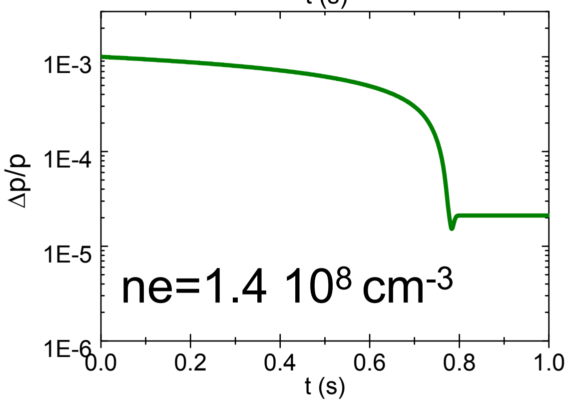
Electron Cooling in the NESR

$^{132}Sn^{50+}$ 740 MeV/u 10^8 ions
Ie=1 A re=0.75 cm B=0.2 T

Antiprotons 800 MeV 10^8 ions
Ie=**2 A!** re=1 cm B=0.2 T

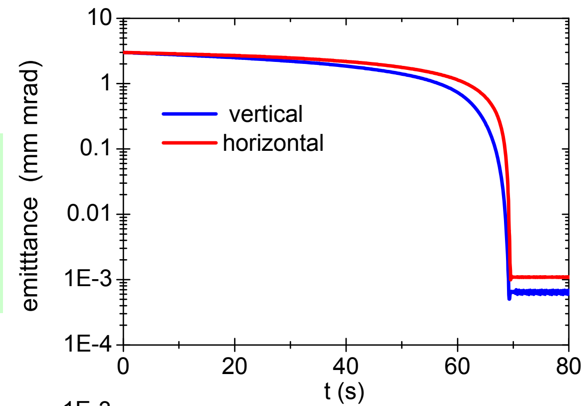


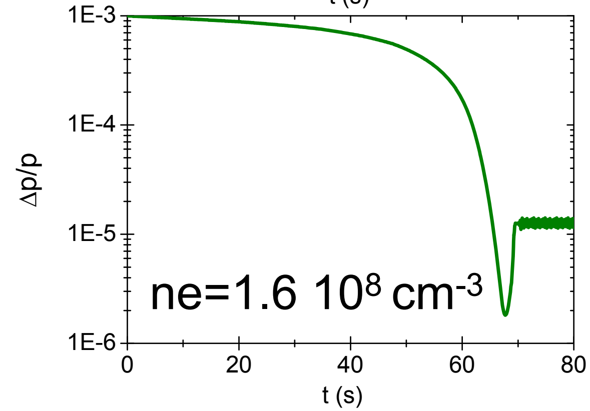


BETACOOL Simulations
Parkhomchuk ecool model ;
Martini IBS model

Initial parameters:
stochastic pre-cooling
in CR (& RESR)

$$\frac{1}{\tau_{cool}} \propto \frac{q^2}{A} \cdot \frac{n_e L_c}{\beta^3 \gamma^5 \theta_{rel}^3}$$





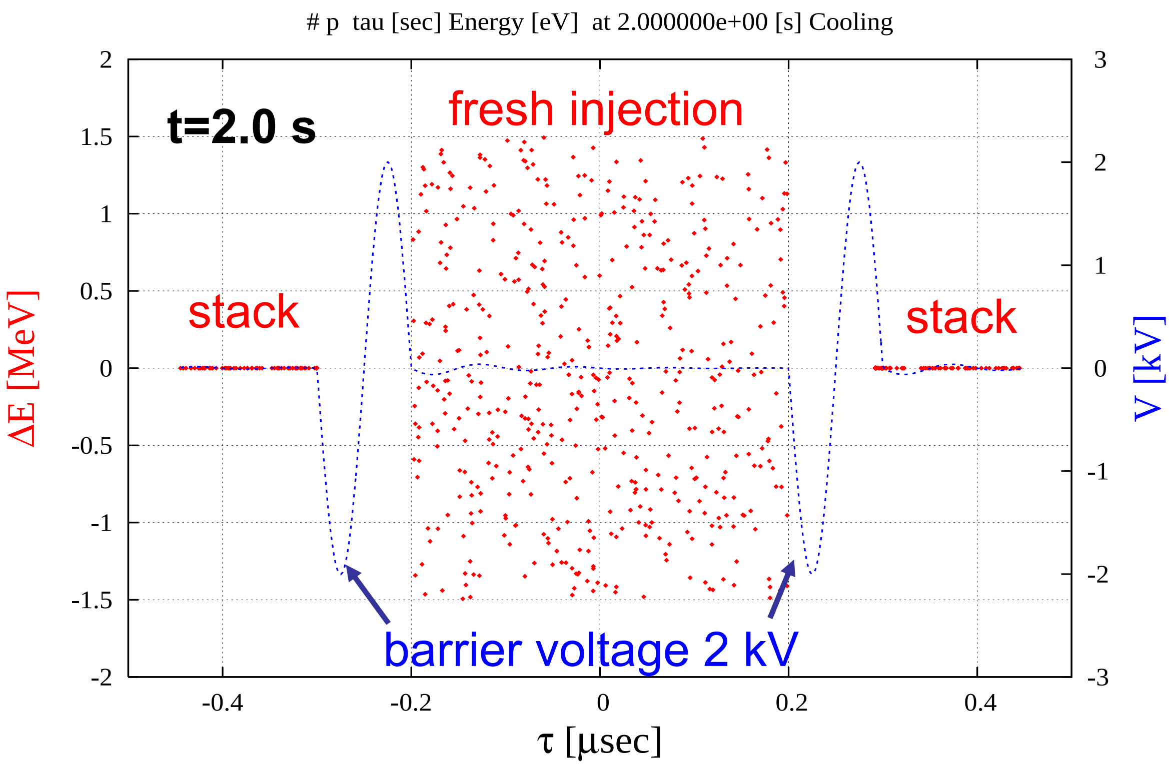
t_{cool} < 1 s
profit of SIS100 cycle !

t_{cool} ~ 1-2 min !

Longitudinal Accumulation of RIBs in NESR
RF Manipulation & electron cooling

Basic idea: confine with RF manipulation the stored beam in a fraction of the circumference, inject into gap & apply strong electron cooling to merge the two beam components

⇒ fast increase of intensity (for low intensity RIBs)



revolution time 0.9 µs

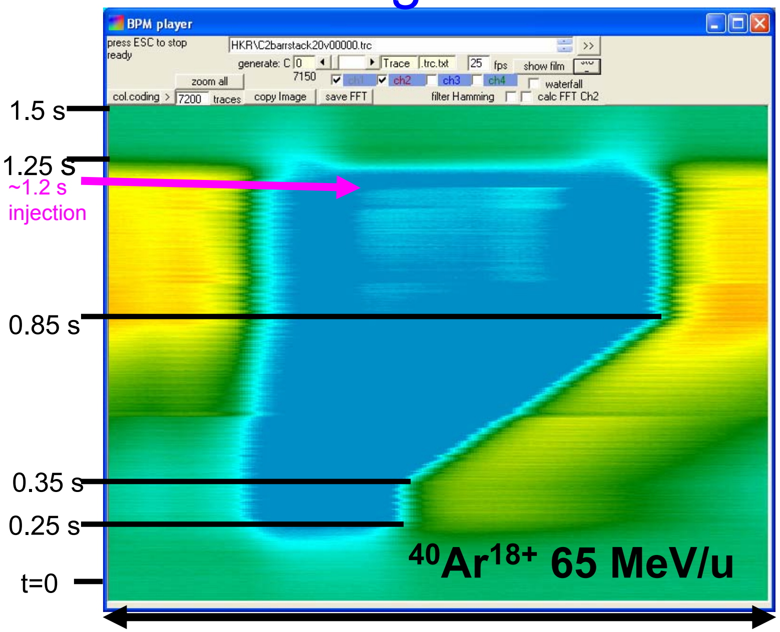
$^{132}Sn^{50+}$

E_k = 740 MeV/u

Longitudinal stacking with Barrier Buckets (simulations by T. Katayama)

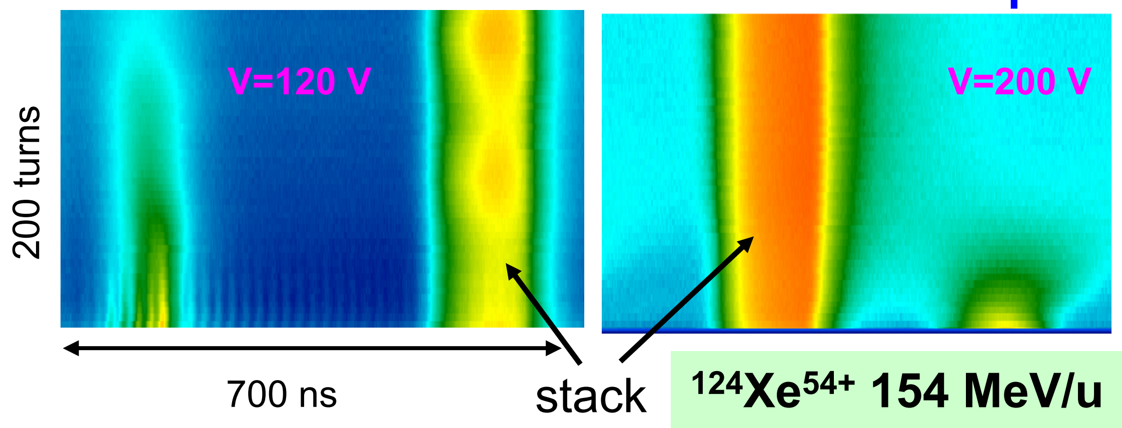
Proof of Principle in the ESR

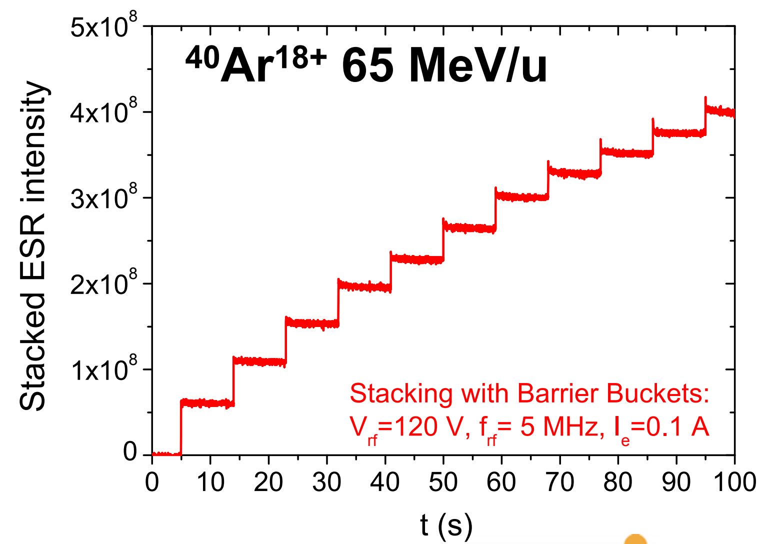
moving barriers



fixed barriers

h=1 unstable fixed point





all three schemes worked well:

cooling times close to expectations

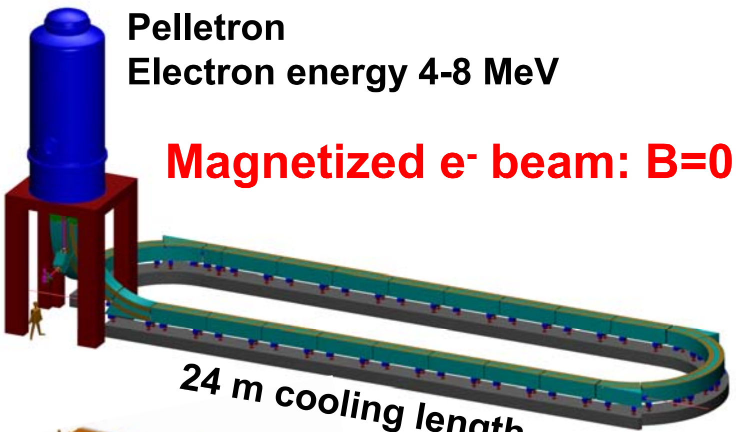
efficient accumulation

high quality timing and kicker pulses required

Intensity limits: RF voltage and instabilities

GSI

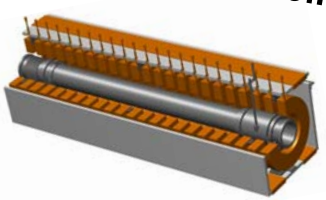
HESR High-energy Electron Cooler



Pelletron
Electron energy 4-8 MeV

Magnetized e^- beam: B=0.07- 0.2T

24 m cooling length



Pancake solenoids

B-straightness =$1x10^{-5}$

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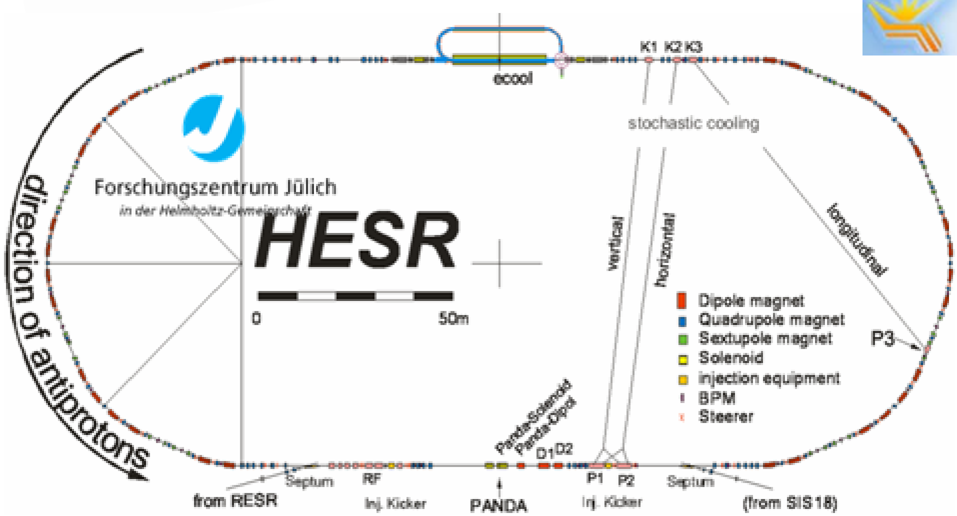
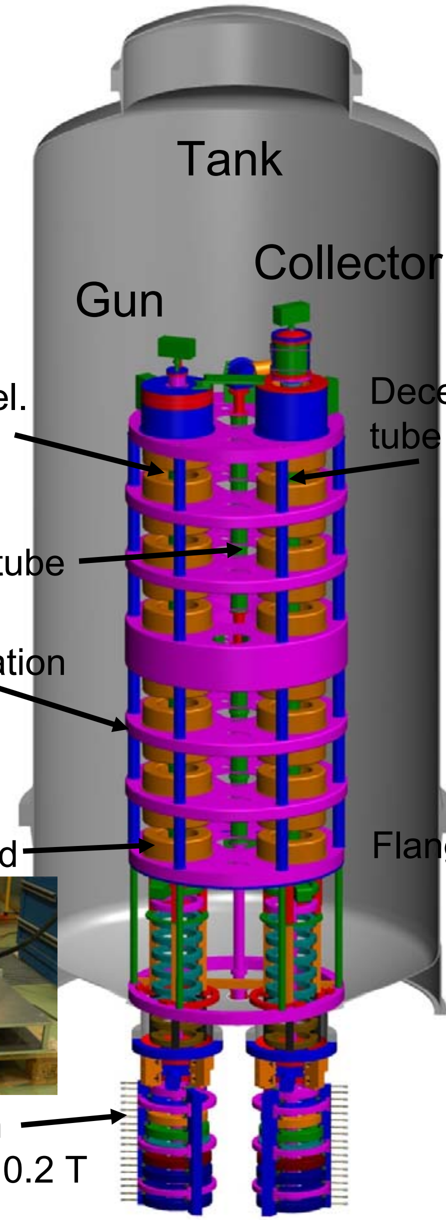
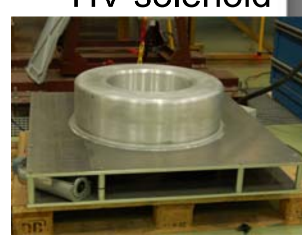
TSL & partners







FAIR Start Event - 7.11.2007
A Success for the Science Communities

1400 international participants

500 international scientists attended the symposium on the Physics of FAIR

FAIR Start Event - 7.11.2007
A Success for the Science Communities

- Towards a world-leading facility for nuclear & hadron research
- Build on the experience of GSI and other labs
- Realize FAIR within an international collaboration at Darmstadt
- Ongoing international negociations on legal framework
- ⟶ Foundation of FAIR GmbH end of 2008

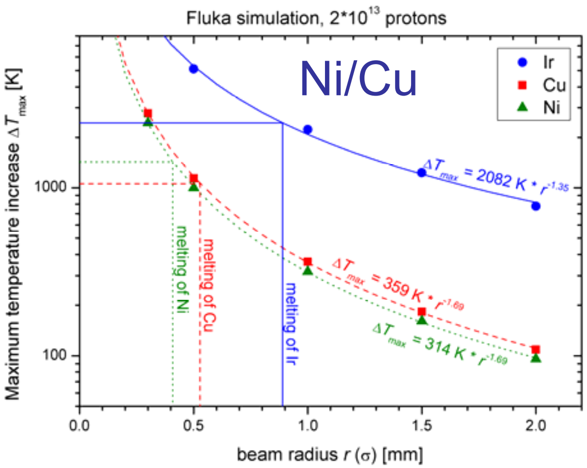
1400 international participants

500 international scientists attended the symposium on the Physics of FAIR

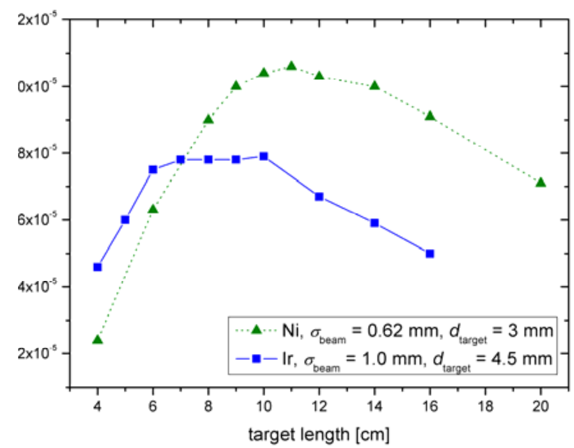

FAIR in 2016
Observers:
Thank you !
Austria
China
Finland
France
Germany
Greece
India
Italy
Poland
Slovenia
Spain
Sweden
Romania
Russia
UK

The Antiproton Target and Separator

target temperature

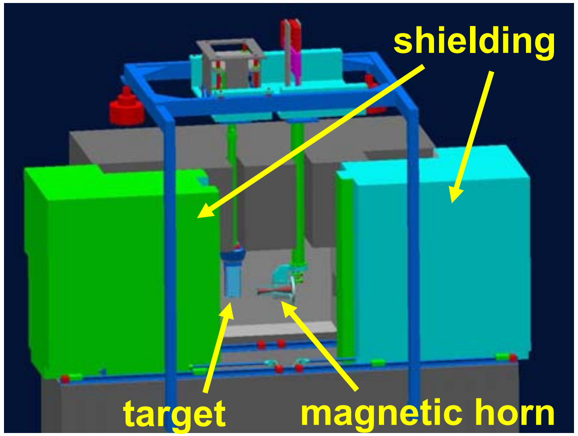


production rate of antiprotons

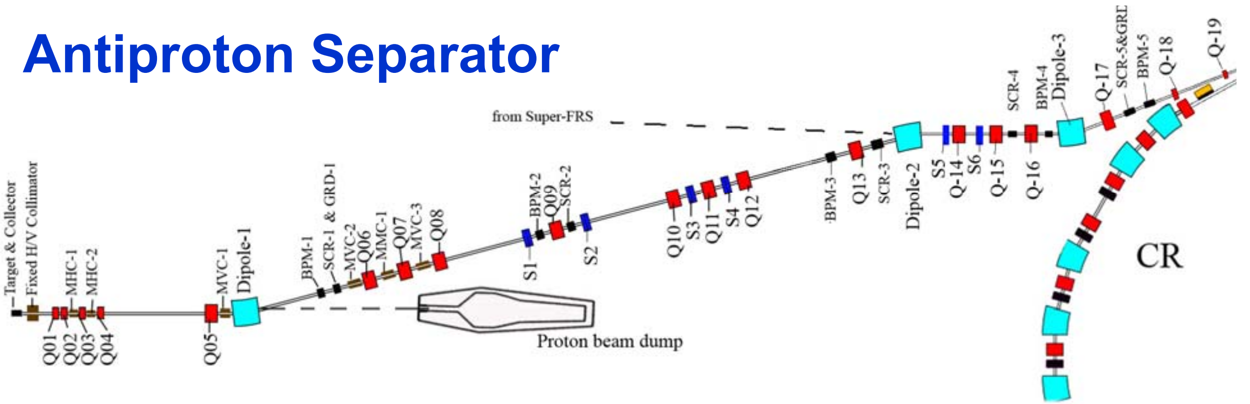


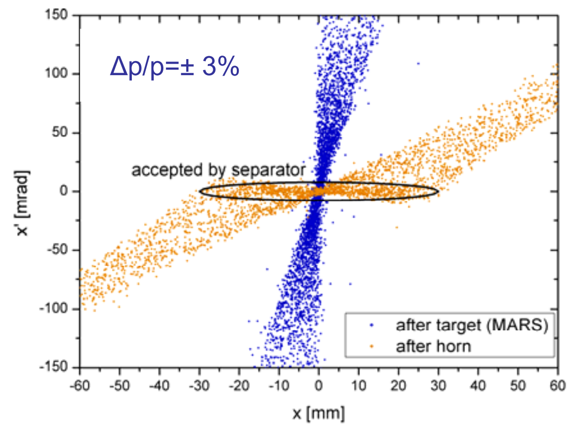
target station

shielding and handling



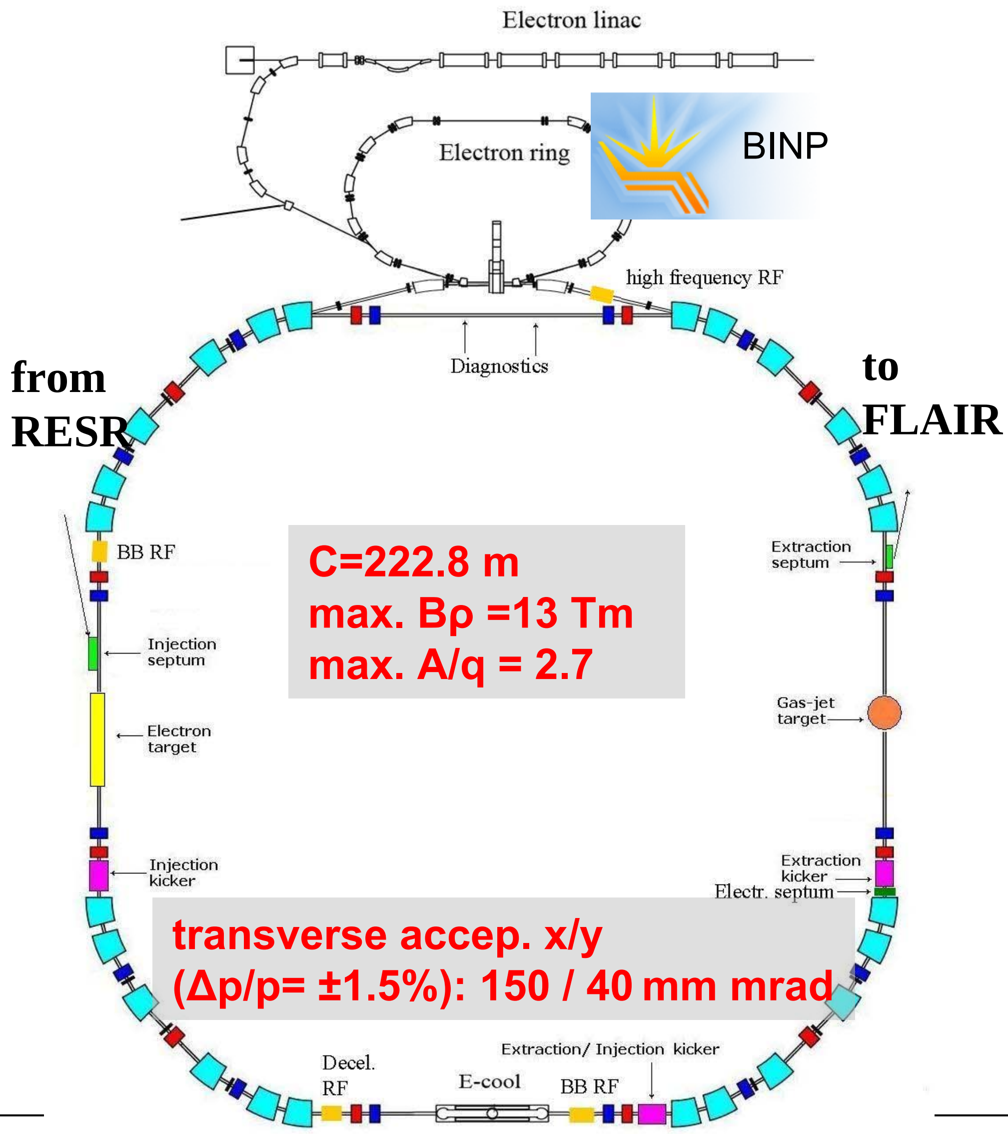
Antiproton Separator





according to tracking calculations about 40 % of the produced antiprotons with Δp/p≤ ± 3% will be stored in the CR

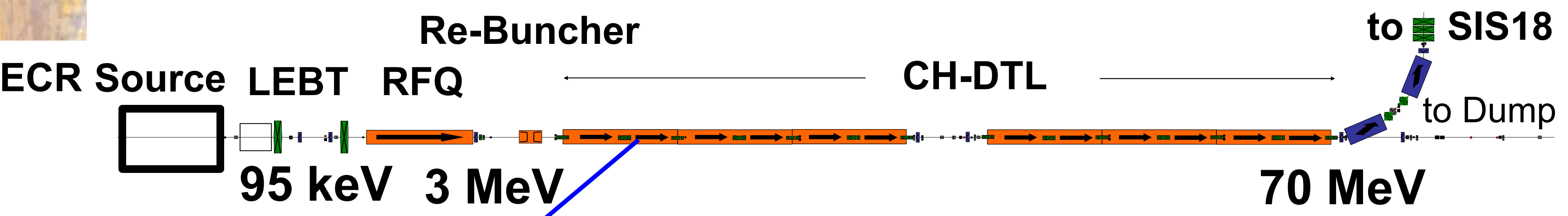
NESR: Versatile Operation



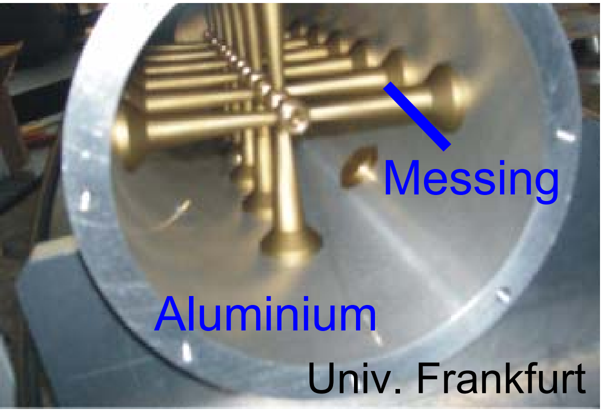
Key components:

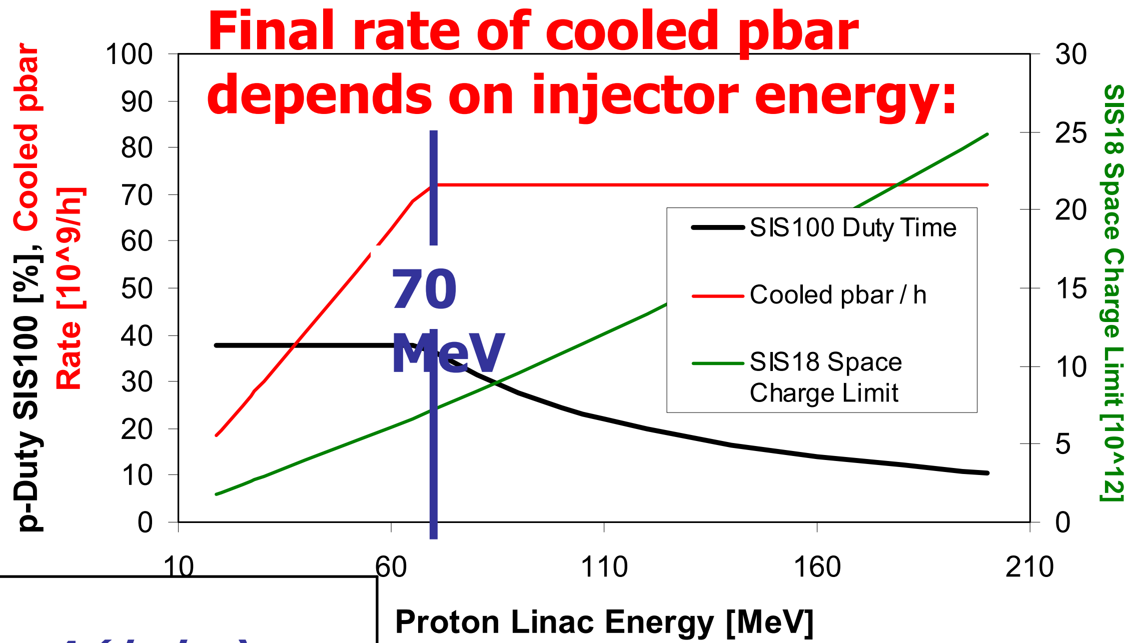
- **Powerful electron cooling**
- **Specific RF systems**
- **UHV: pressure ≲ 10^{-11} mbar**
- **high magnetic field quality within large aperture for large acceptance**

The proton Linac



Crossed-bar H-Cavity (CH)





Linac length	**≈ 35 m**
Beam current	**35 mA; *70 mA (design)***
Beam pulse length	**36 µs**
Rep. rate; rf frequency	**4 Hz ; 325.2 MHz**
Beam power	**5 MW (peak), 710 W (average)**
rf power	**11 MW (peak), 1600 W (average)**
Tot. normal. ε_x; $\delta p/p$	