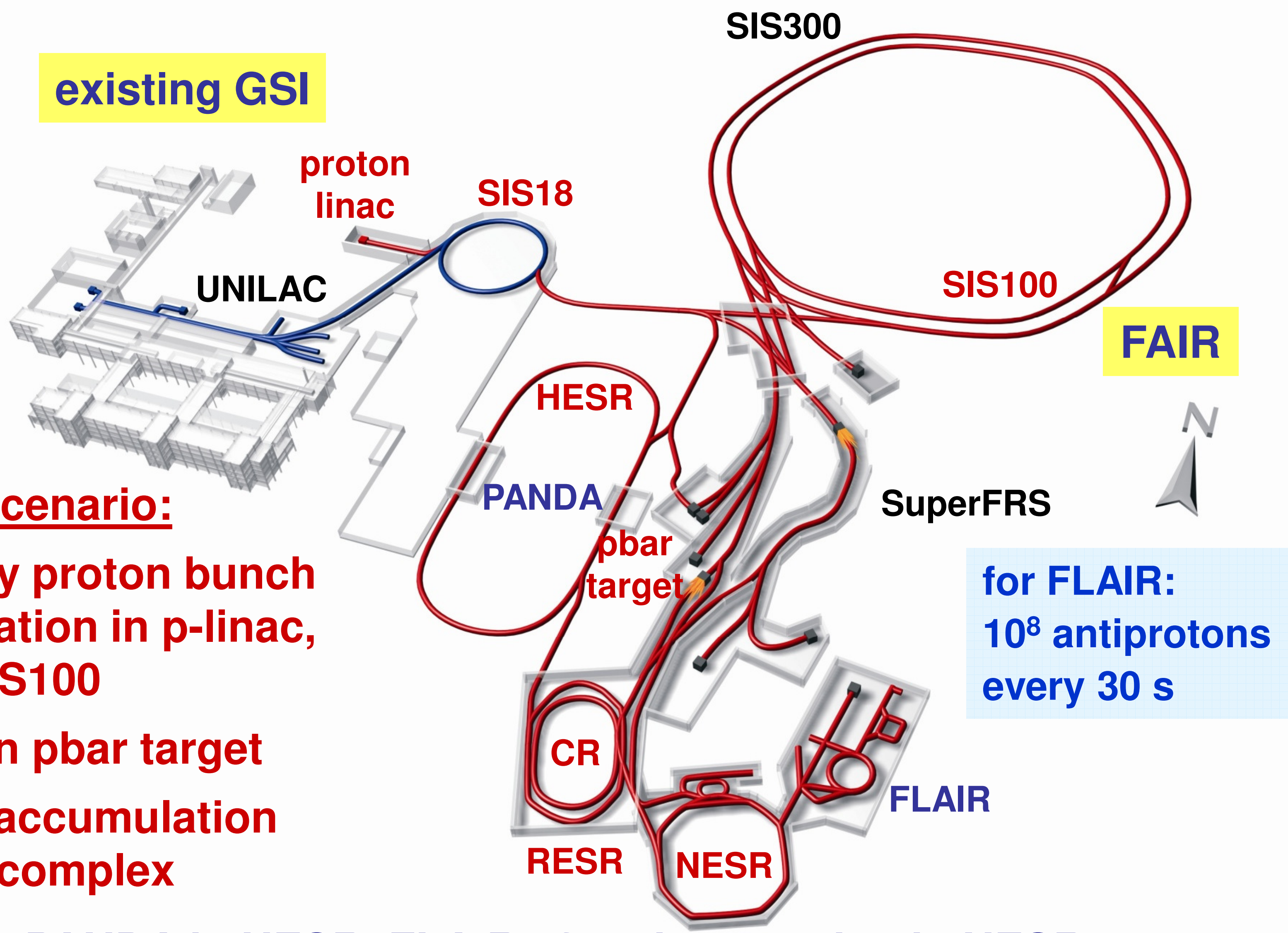
Deceleration of Antiprotons in the Modularized Start Version of FAIR Employing the ESR Storage Ring

M. Steck

F. Herfurth, M. Lestinsky, Y. Litvinov, T. Stöhlker (GSI),

R. Maier, D. Prasuhn (FZJ), T. Katayama (Nihon University)

FAIR Accelerator Facility – Full Version



Antiproton Scenario:

high intensity proton bunch after acceleration in p-linac, SIS18 and SIS100

conversion in pbar target

cooling and accumulation in CR/RESR complex

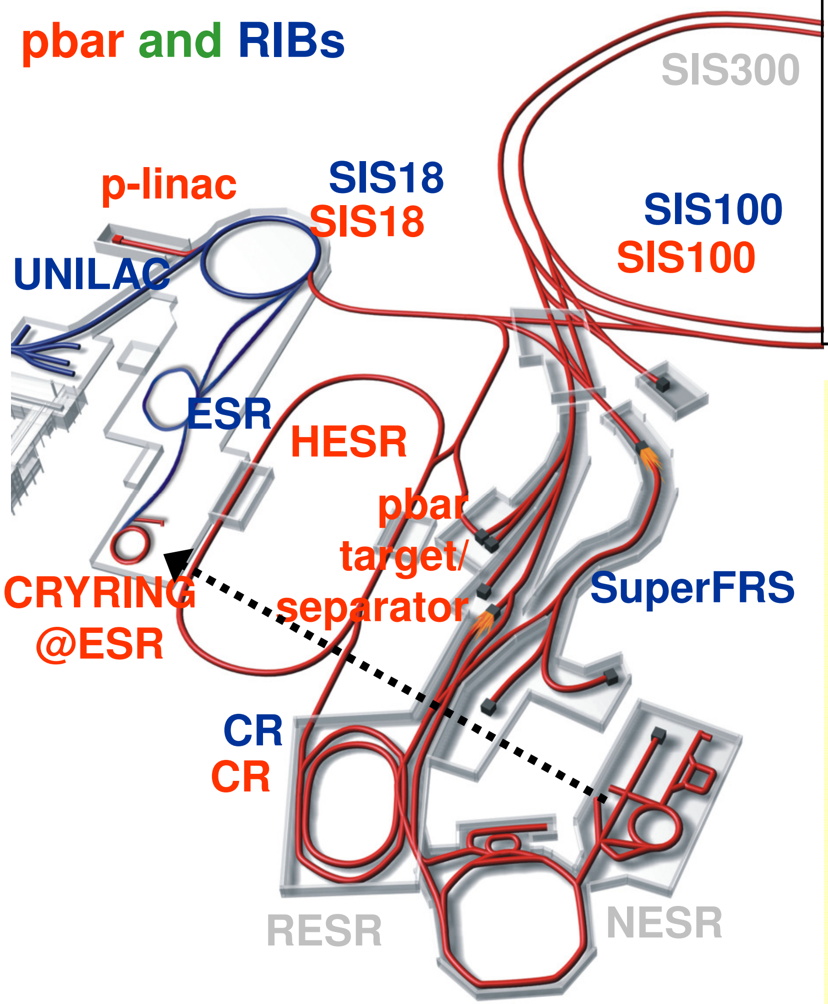
for FLAIR:
10^8 antiprotons every 30 s

Experiments: PANDA in HESR, FLAIR after deceleration in NESR

FAIR - Modularized Start Version (MSV)

Modularized Start Version MSV

pbar and RIBs



not included in MSV:

(can be added later depending on funding)

SIS300 high energy 300 Tm synchrotron

RESR accumulator ring for antiprotons

NESR storage ring for experiments and deceleration of ions an pbars

FLAIR low energy antiprotons

part of MSV:

SIS100 heavy ion and proton synchrotron

SuperFRS and pbar target

CR pre-cooling of pbars (RIBs)

isochronous mass measurements of RIBs

HESR accumulation of pbars and ions

experiments with stored pbars and ions

ESR ion operation will be continued

CRYRING@ESR installation after the ESR

Concept for Antiprotons in the MSV

Proton acceleration in Proton Linac, SIS18, and SIS 100 to 29 GeV

Single short bunch (50 ns) of 2×10^{13} protons is directed to the antiproton production target

Theoretical production rate (2×10^{-5} pbar /p) in useful phase space volume (acceptance of separator and Collector Ring CR) should reliably give 1×10^{8} antiprotons per pulse every 10 s (limited by cooling time in CR)

After bunch rotation and stochastic cooling the cooled antiprotons will be transferred to the HESR

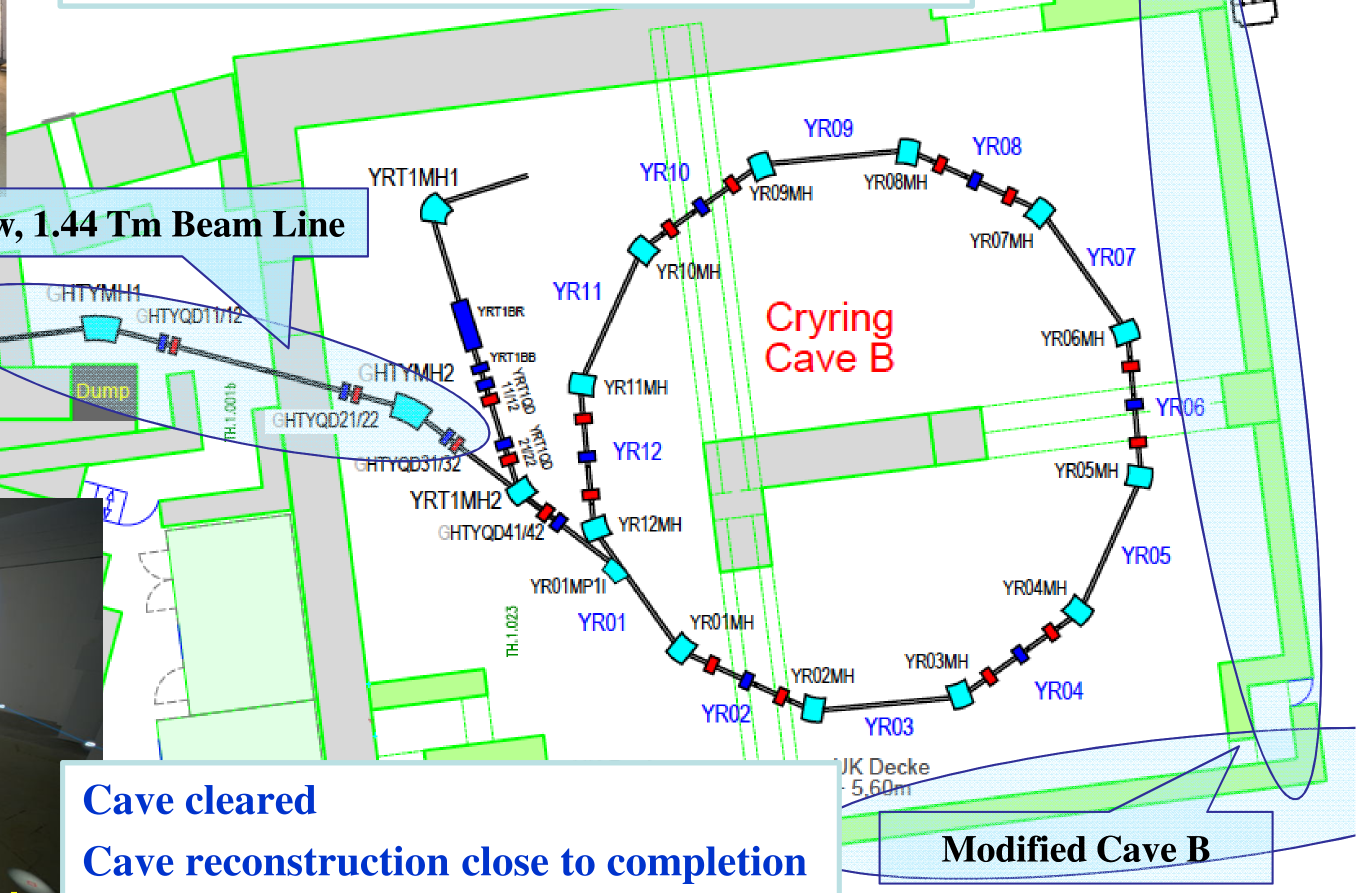
Beam accumulation by combination of barrier buckets and stochastic cooling in the HESR will allow accumulation of stacks of 1×10^{10} pbar

Acceleration/deceleration to energies 0.8 – 14 GeV in the HESR

Stored antiprotons in the HESR:
Internal target and cooling (stochastic and electron) of antiprotons

CRYRING@ESR Status

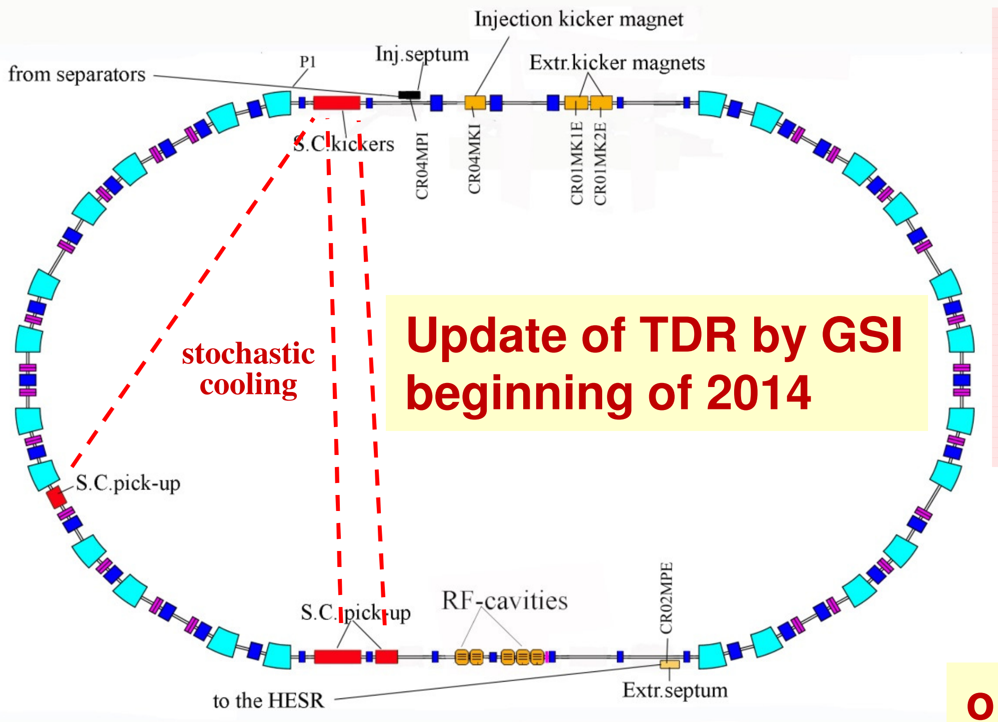
A collaboration of FAIR@GSI, AP@GSI, GA@GSI, HI-Jena, Stockholm Univ., KVI Groningen, *Krakow*, and the SPARC Collaboration



Cave cleared
Cave reconstruction close to completion
Component preparation ongoing

The Collector Ring CR (version 71)

GSI version CR71 contains small changes of lattice (supersymmetry 1)



fast stochastic cooling (1-2 GHz) of antiprotons (10 s) and rare isotope beams (1.5 s)

fast bunch rotation at h=1 (U_{rf} =200 kV)
adiabatic debunching
optimized ring lattice (slip factor)
for proper mixing
large acceptance magnet system

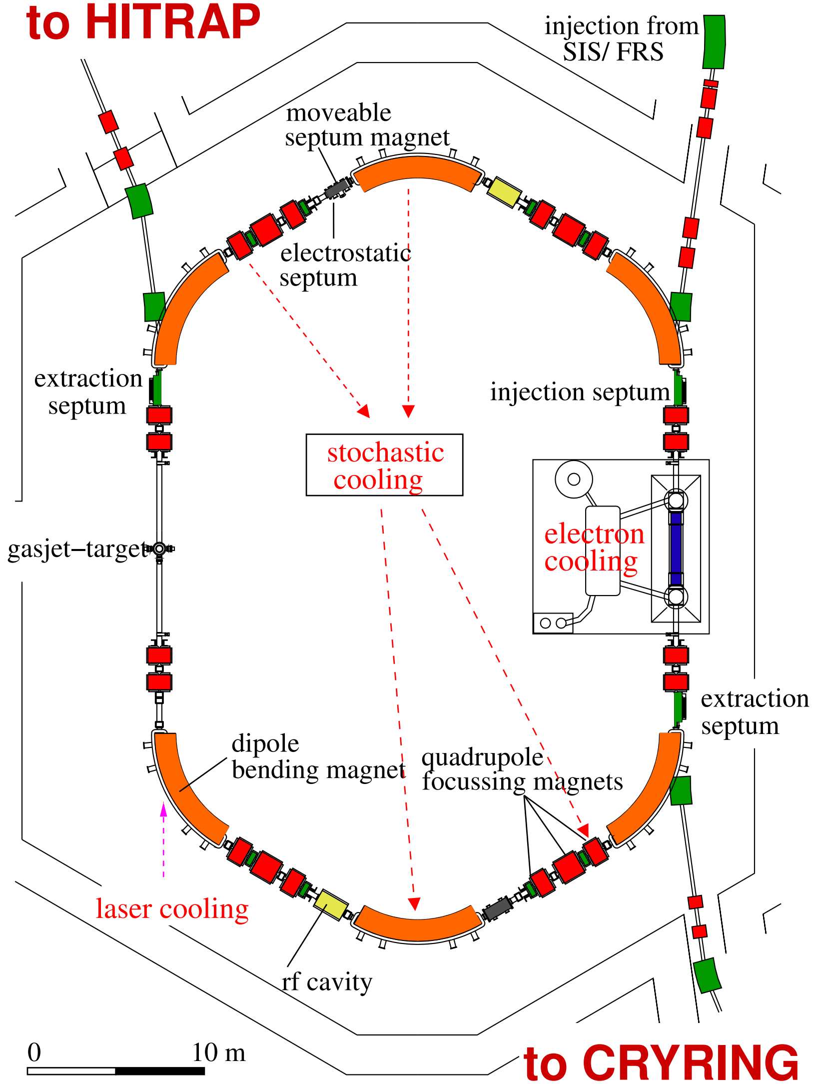
additional option:
isochronous operation with RIBs

circumference	**221.5 m**
magnetic bending power	**13 Tm**
large acceptance	
$\varepsilon_{x,y}$ = 240 (200) mm mrad	
$\Delta p/p = \pm$ 3.0 (1.5) %	

ongoing negotiations with Budker Institute, Novosibirsk, Russia to take full responsibility for concept, design and construction of CR (Russian InKind contribution to FAIR)

The Existing ESR

to HITRAP

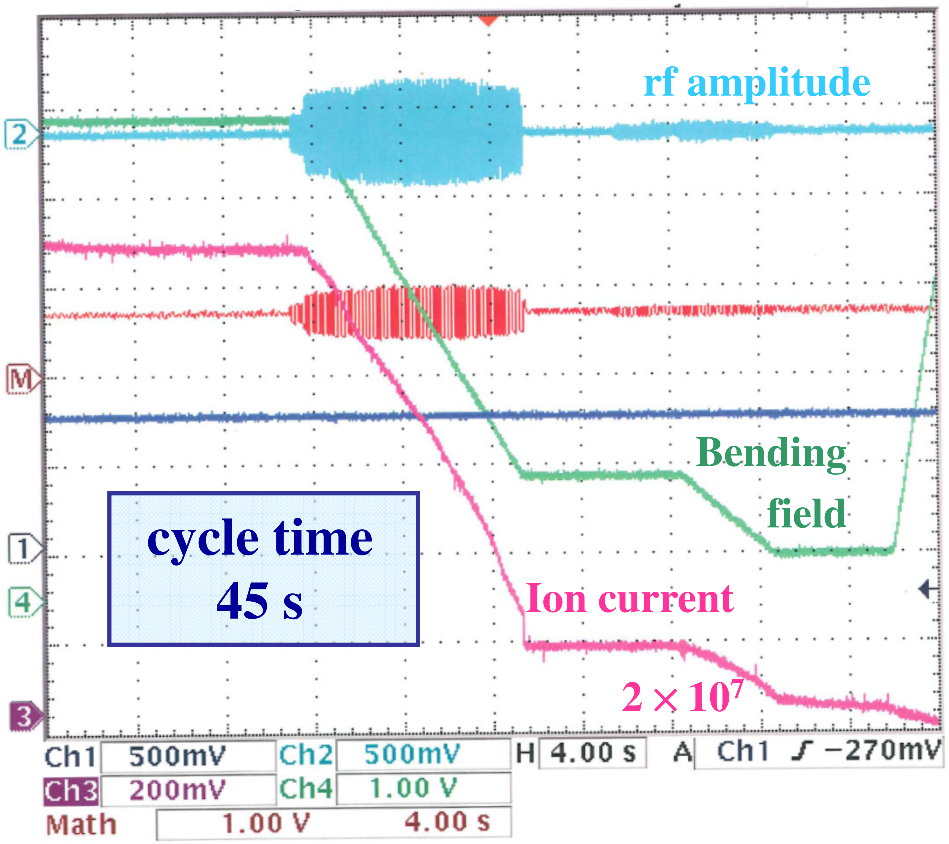


to CRYRING

- Fast injection (stable ions / RIBs)
- Stochastic cooling (≥ 400 MeV/u)
- Electron cooling (3 - 430 MeV/u)
- Internal gas jet target
- Acceleration/deceleration (down to 3 MeV/u)
- Fast extraction (for HITRAP at 4 MeV/u)
- Beam accumulation
- Multi charge state operation
- Schottky mass spectrometry
- Isochronous mode (TOF detector)
- Slow (resonant) extraction
- Ultraslow extraction (charge change)

Fast extraction at present only to the north !
Kicker in the northern arc would allow fast extraction to the south (RIBs to HESR and antiprotons to CRYRING)

Deceleration to 4 MeV/u for HITRAP



Ni^{28+} 400 → 30 → 4 MeV/u

1100 μA → 180 μA → 25 μA

45% 37 %

(incl. Recombination)

beam half life (vacuum dominated):

30 MeV/u: $T_{1/2} \approx 480$ s

4 MeV/u: $T_{1/2} \approx 2$ s

Short beam lifetime is due to radiative electron capture in the residual gas (pressure: 2-3×10^{-11} mbar).

Beam lifetime should not be an issue for antiprotons.

but: uncontrolled beam losses during ramping must be reduced and faster ramping should be developed.

Space Charge Limit

Space charge limit due to incoherent tune shift

$$\Delta Q = r_p N / 2\pi\beta^2\gamma^2\varepsilon \ \ (g/B)$$

antiprotons at 30 MeV

for ΔQ_x=0.1 and ε_x = 1 mm mrad:

$$N \leq 7 \ \times 10^9 \ \ (B/g)$$

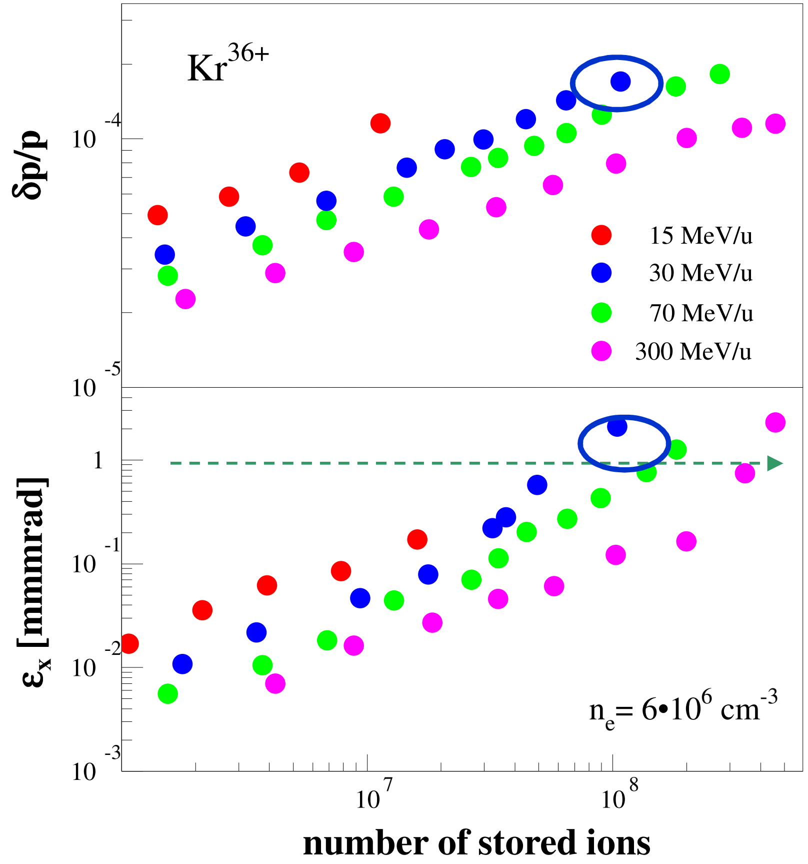
antiprotons at 300 keV

for ΔQ_x=0.1 and ε_x = 1 mm mrad:

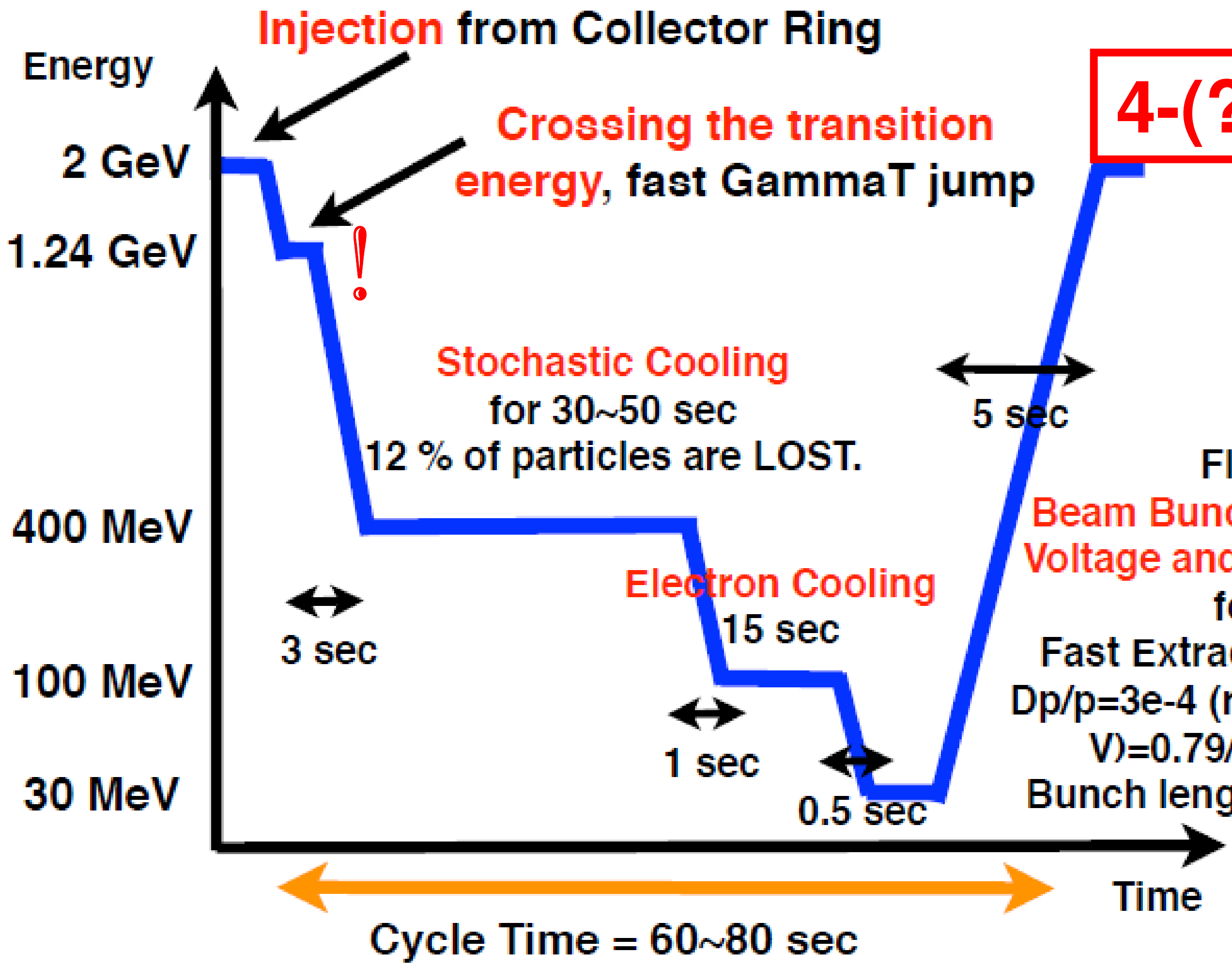
$$N \leq 6 \ \times 10^7 \ \ (B/g)$$

space charge is not relevant for antiprotons in the ESR, but will be significant after deceleration in CRYRING

measurement at ESR of momentum spread and transverse emittance



ESR Antiproton Deceleration Cycle
2 GeV Injection Energy from CR



4-(?)×10⁷ every 80 s

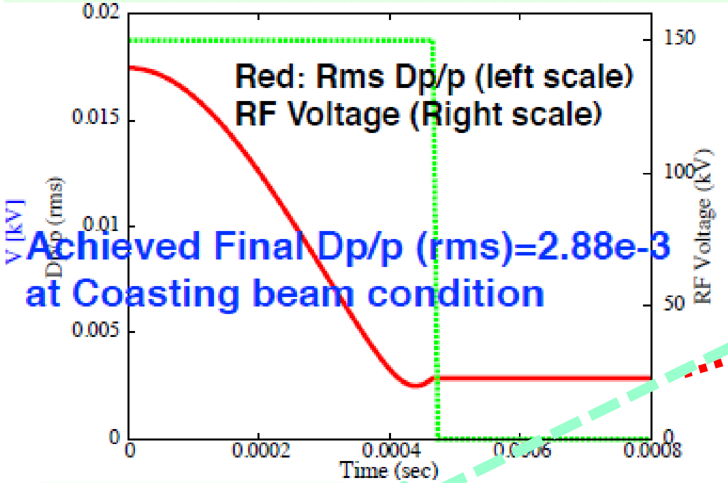
Flat Base:
Beam Bunching with Barrier Voltage and Electron Cooling
for 5 sec
Fast Extraction to CRYRING
Dp/p=3e-4 (rms), Emittance (H/V)=0.79/0.87 mm.mrad
Bunch length= 500~600 nsec

benefits from availability of stochastic and electron cooling in the ESR

Simulation of 2 GeV Antiprotons in the CR

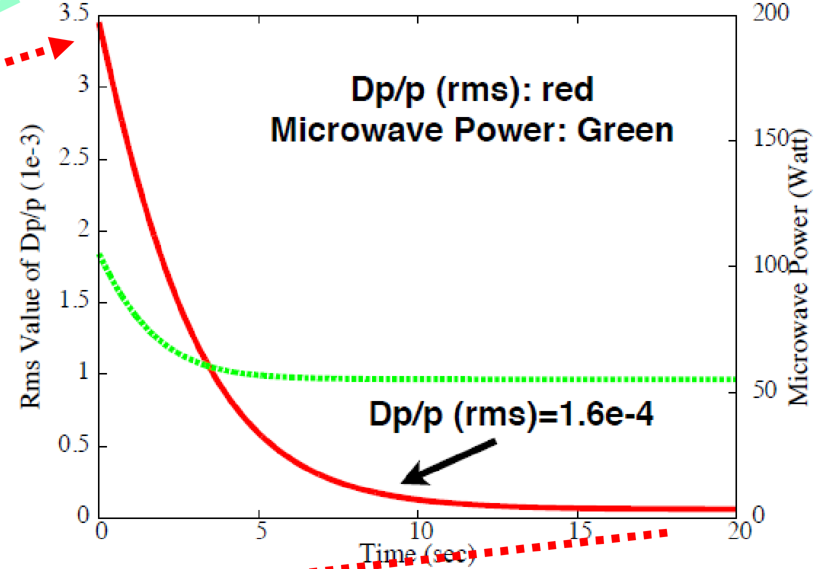
bunch rotation and debunching

simulations by T. Katayama (poster)

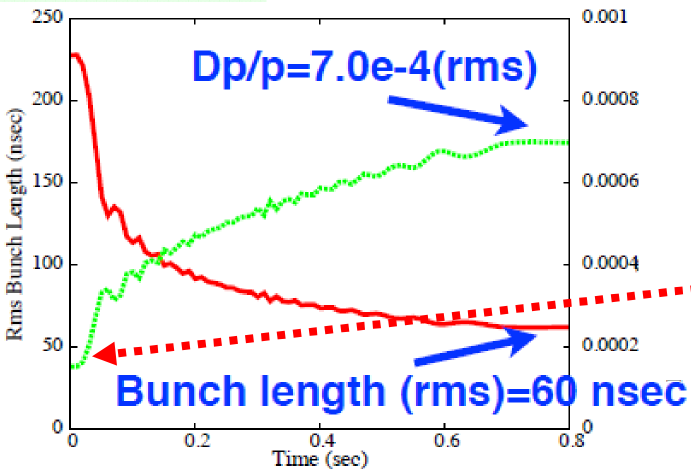


momentum slip factor η=0.0275

stochastic cooling



rebunching



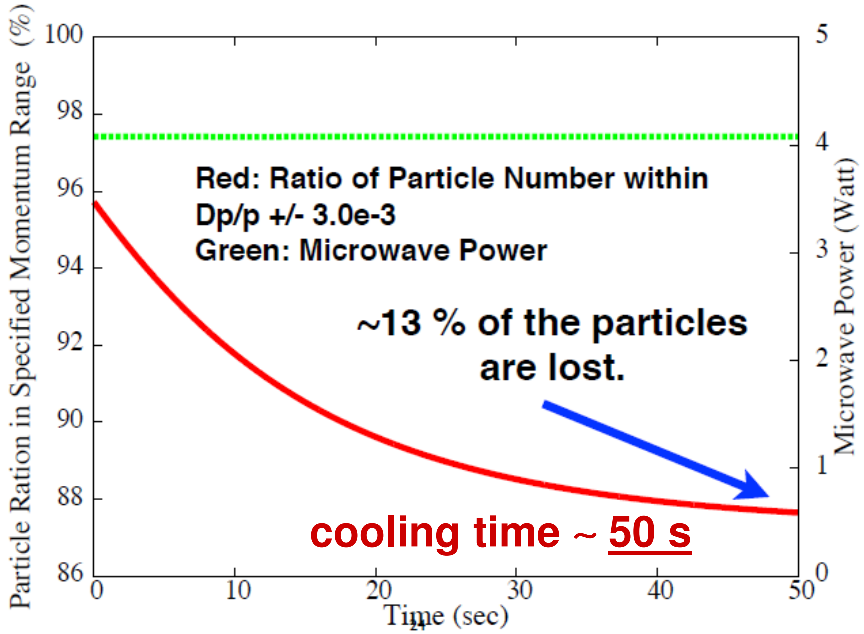
preparation of short bunch (60 ns length) with momentum spread $\delta p/p = 7\times10^{-4}$ for transfer to ESR

HELMHOLTZ GEMEINSCHAFT GSI FAIR

Cooling in the ESR
at the intermediate energy of 400 MeV

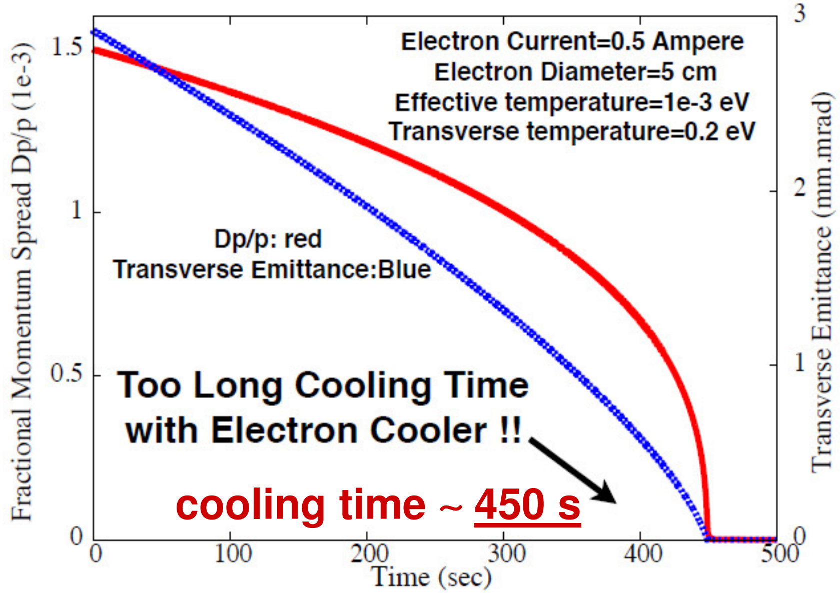
stochastic cooling

Evolution of Fraction of Particle Number in the Dp/p window less than +/- 3.0e-3 and Microwave Power during the stochastic cooling



electron cooling

If we use the Electron Cooling for 400 MeV, Emittance (Initial)= 2.92 Pi mm.mrad Dp/p(initial, rms)=1.5e-3



stochastic cooling is much better suited for antiproton beam parameters

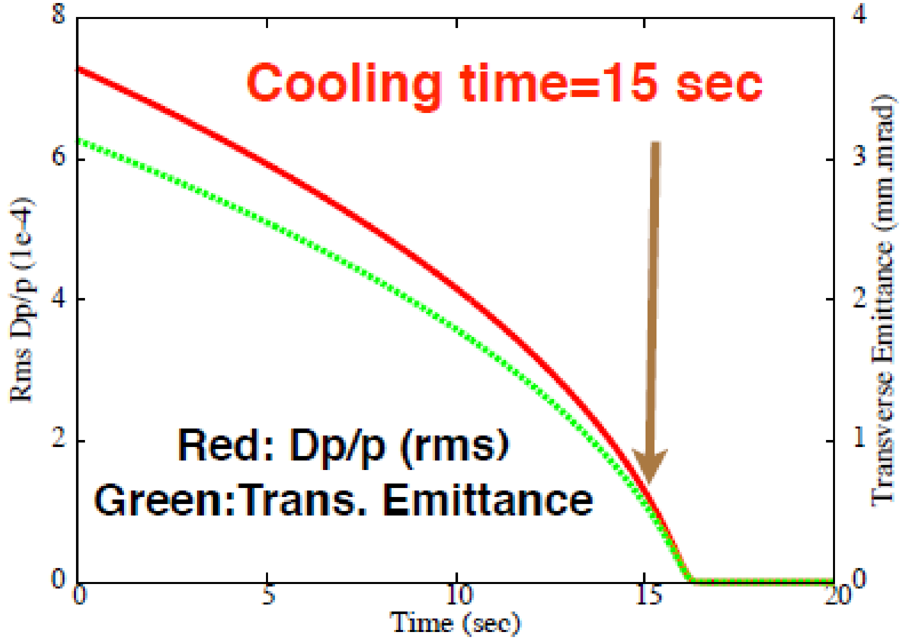
M. Steck, FLAIR Workshop, MPI Heidelberg, May 15-16 2014.

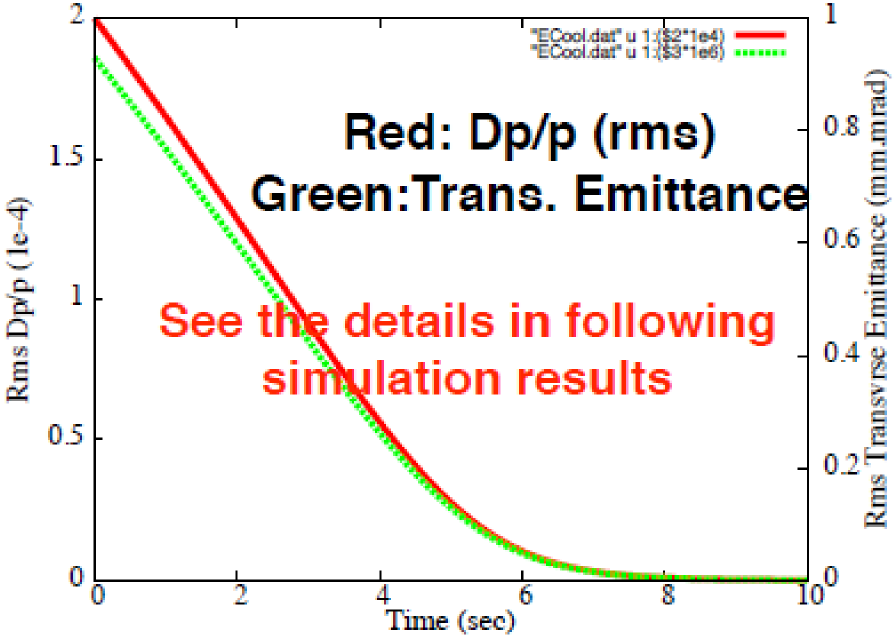
Cooling in the ESR

electron cooling at lower energies

T=100 MeV
Initial Dp/p=7.30e-4
Initial Transverse emittance=3.14 Pi mm.mrad
Diameter of electron beam=5.0 cm
Current of electron=1.0 A

T=30 MeV
Initial Dp/p=2.0e-4
Initial Transverse emittance=0.93 Pi mm.mrad
Diameter of electron beam=5 cm
Current of electron=0.05 A



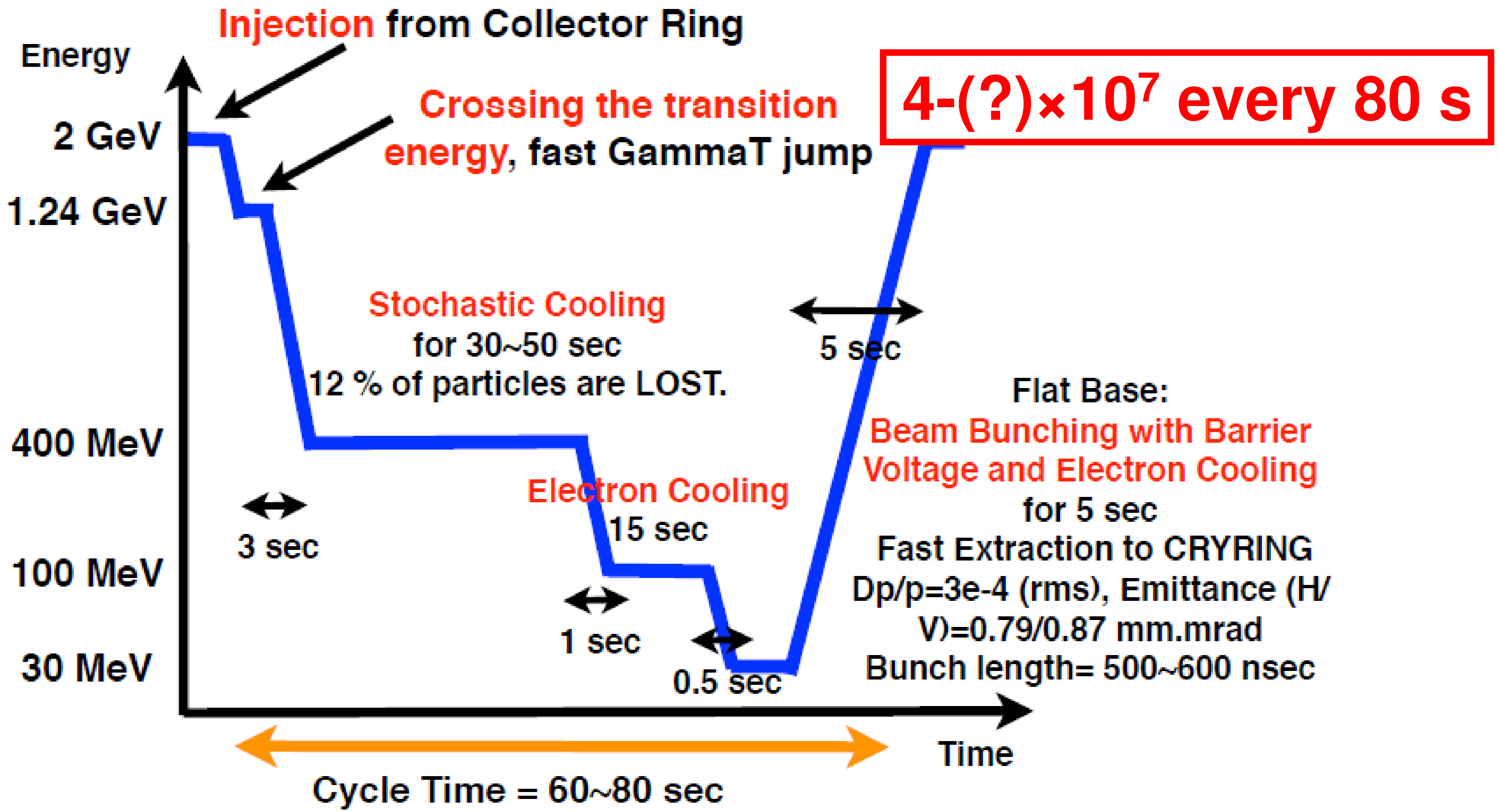


Antiproton Cooling Parameters

Energy (MeV)	Transverse Emittance before Cooling (Pi mm.mrad)	Transverse Emittance after Cooling (Pi mm.mrad)	Dp/p before Cooling	Dp/p after Cooling	Cooling Time (sec)	Ring
2000	45	1	2.9e-3 (After bunch rotation)	1.60E-04	10	Collector Ring (Stochastic Cooling)
400	2.92	1.46 (pessimistic assumption)	1.50E-03	5.10E-04	50	ESR (Stochastic Cooling)
100	3.15	0.5	7.30E-04	1.00E-04	15	ESR (Electron Cooling)
30	0.94	0.8	2.00E-04	3.0e-4 (After Bunching)	5	ESR (Electron Cooling)

(rms values of coasting beam)

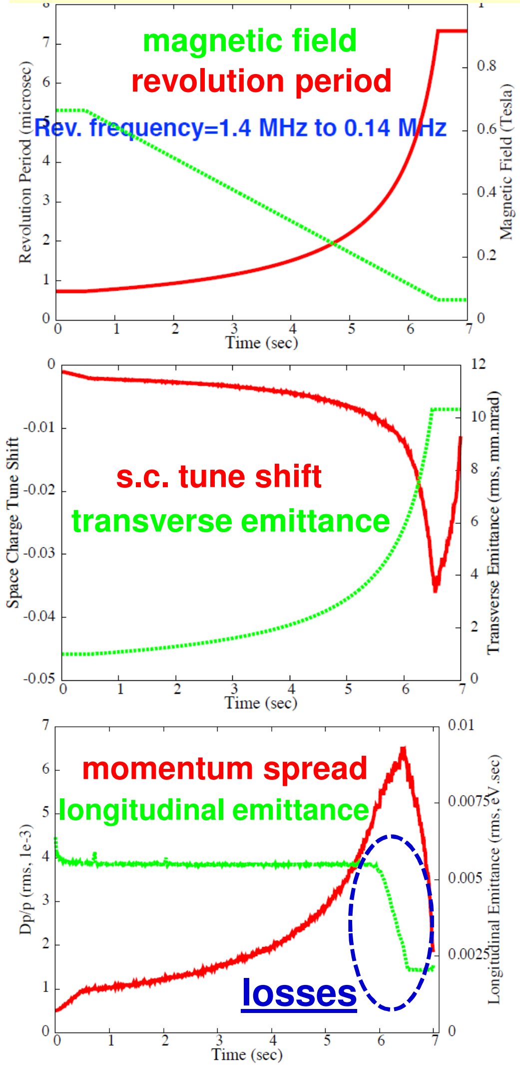
ESR Antiproton Deceleration Cycle
2 GeV Injection Energy from CR



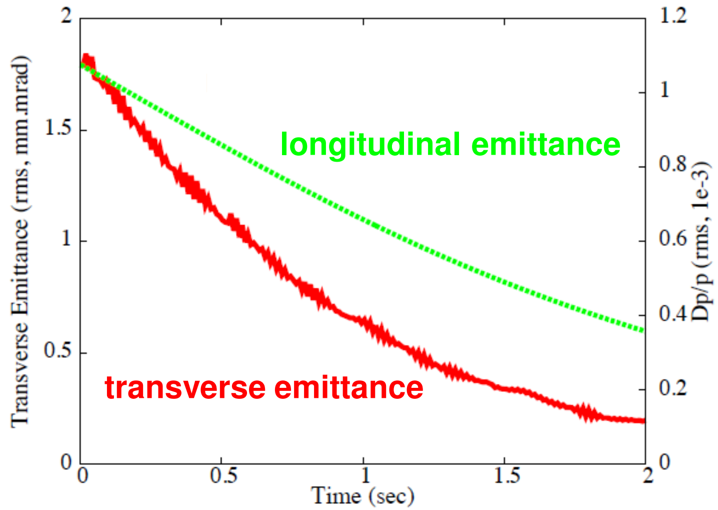
benefits from availability of stochastic and electron cooling in the ESR

Deceleration in CRYRING

from 30 MeV to 0.3 MeV

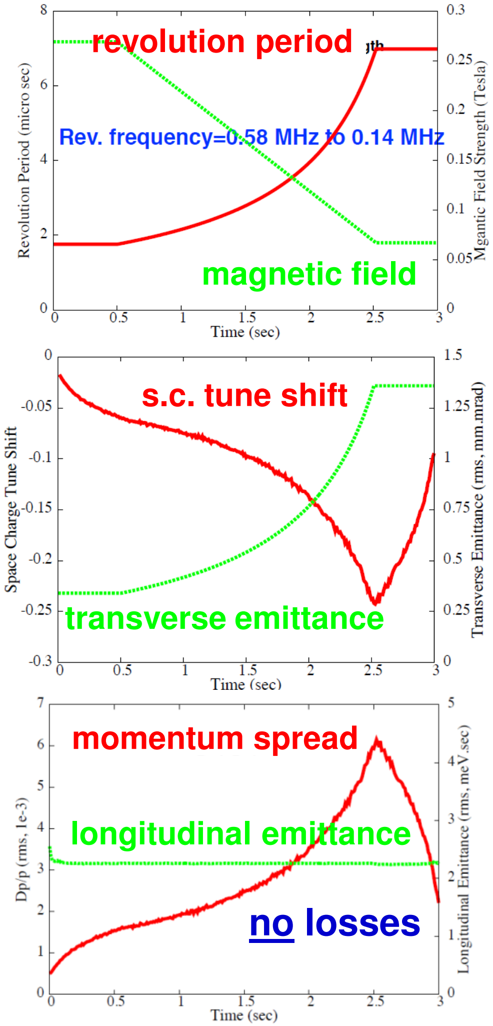


solution to loss problem
electron cooling at 5 MeV
with electron current 0.1 A
over a time of 2 seconds

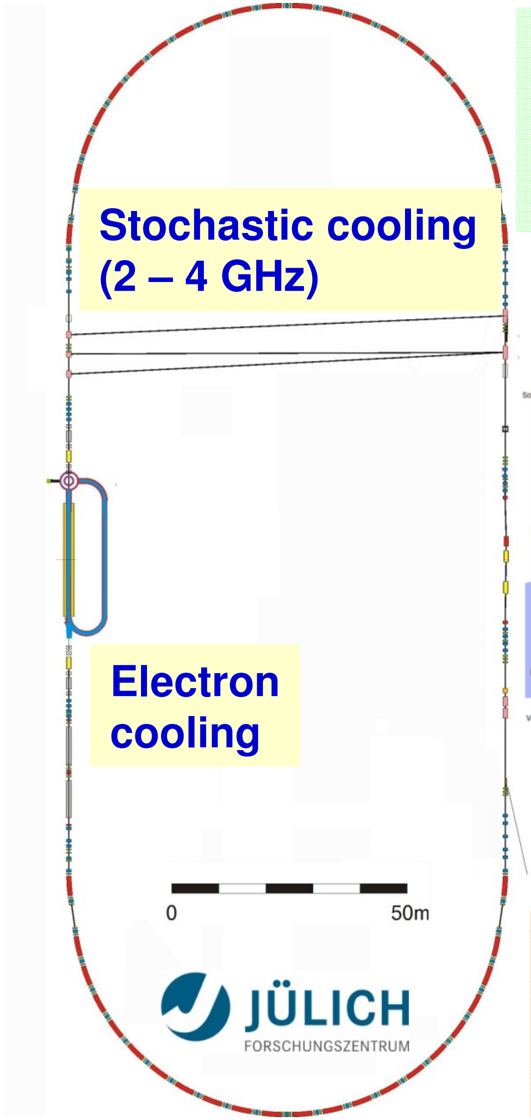


careful investigation of space charge is necessary
control of transverse emittance

from 5 MeV to 0.3 MeV



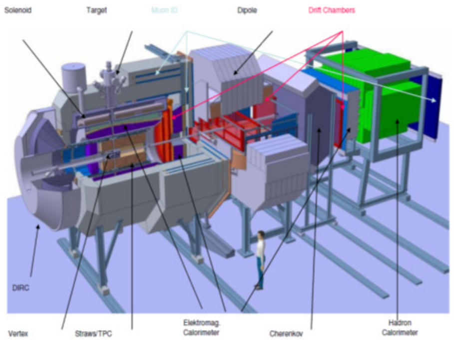
The High Energy Storage Ring HESR



responsibility of FZ Jülich (German in-kind contribution)

Main task: Storage of Antiprotons
New proposal (TDR) : Storage of Ions

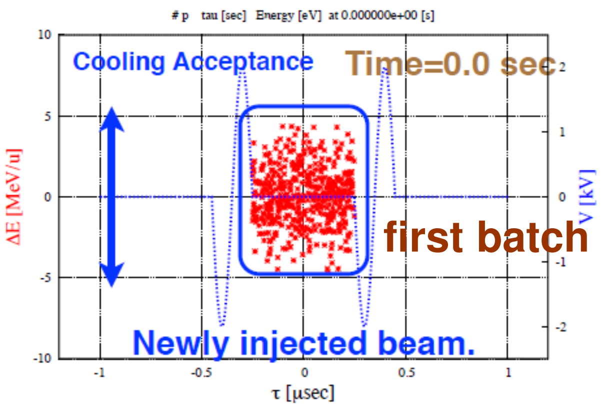
circumference 574 m
momentum (energy) range
1.5 to 15 GeV/c (0.8-14.1 GeV)
injection of antiprotons from CR
accumulation with barrier bucket
and stochastic cooling
maximum dipole field: 1.7 T
dipole field at injection: 0.4 T
dipole field ramp: 0.025 T/s
acceleration rate 0.2 (GeV/c)/s
electron cooling up to 3 GeV
stochastic cooling above 1 GeV

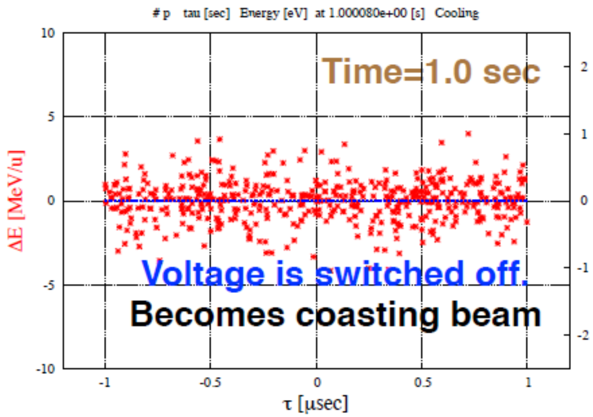


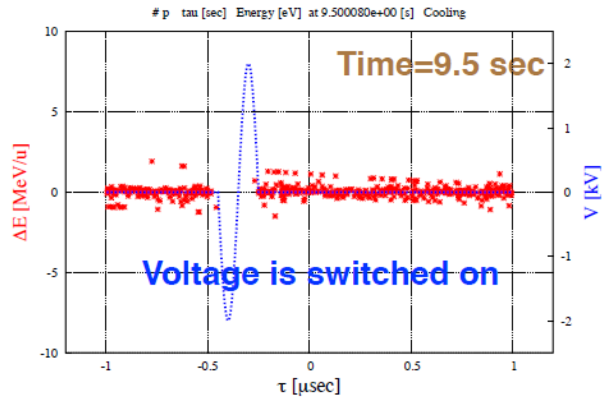
PANDA experiment

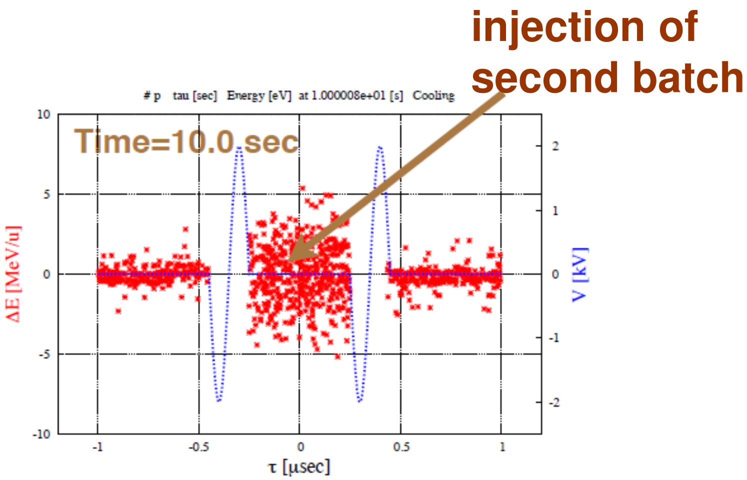
availability of cooling will allow the use of the HESR
for accumulation and deceleration (minimum 0.8 GeV)
missing: beam extraction system (space is available)

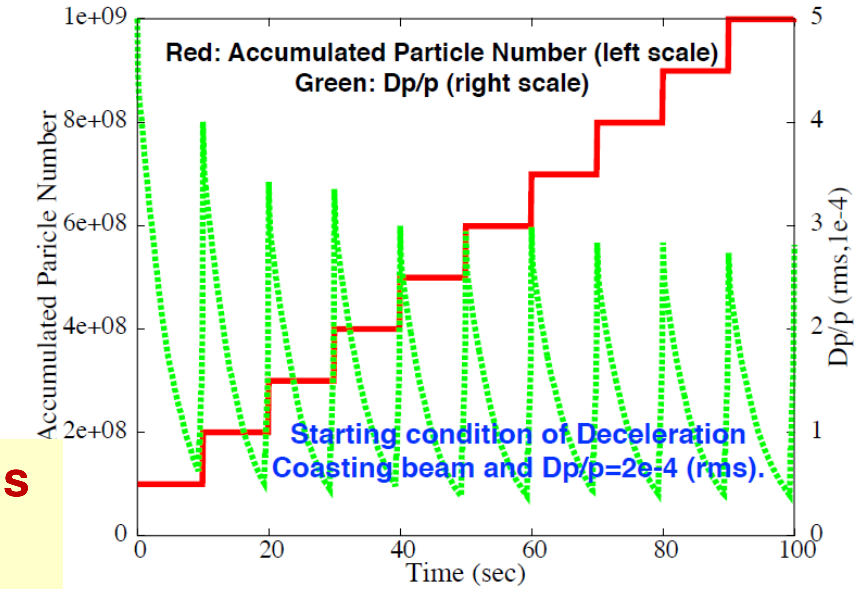
Barrier Bucket Accumulation in the HESR







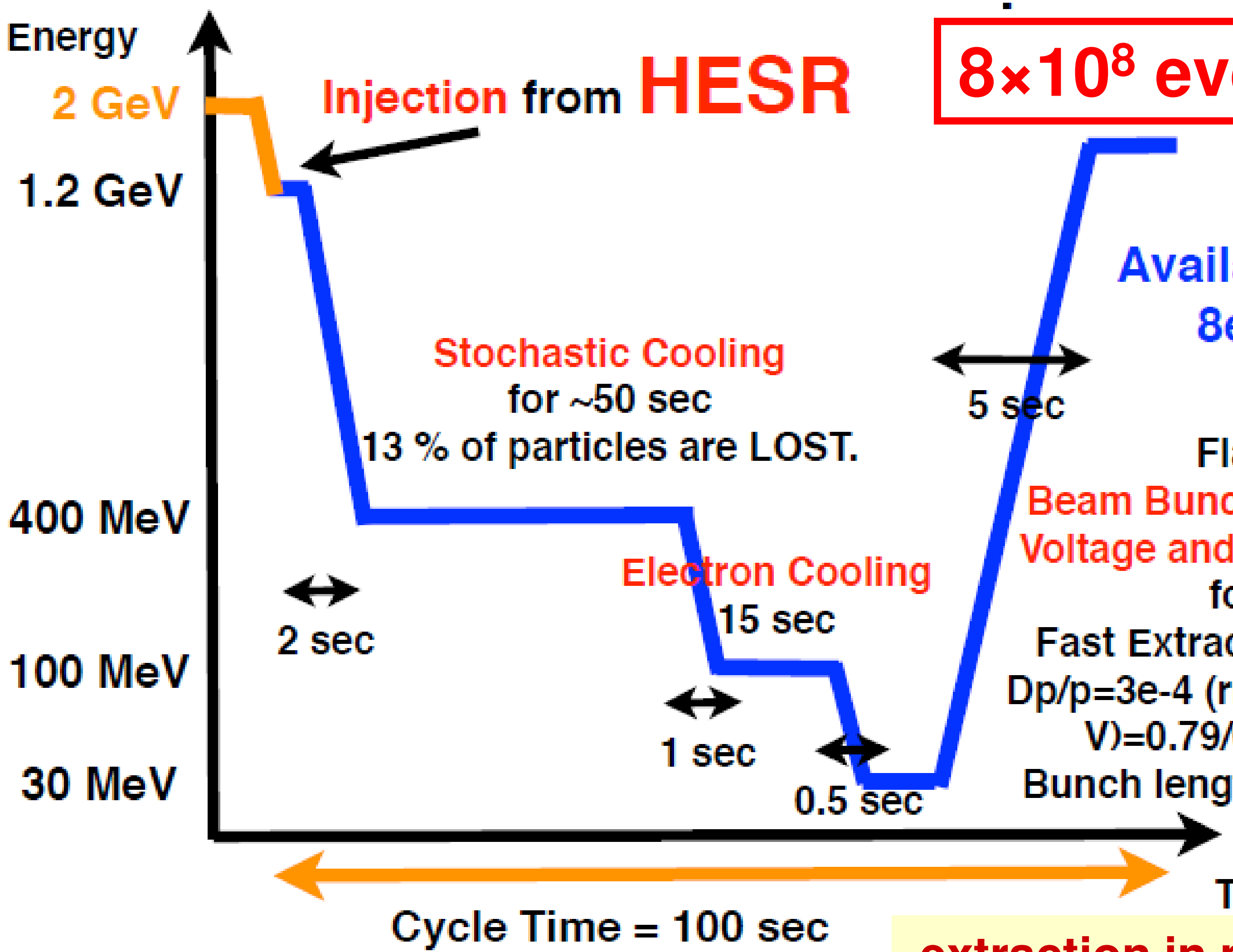




accumulation (in 100 s) of 1 × 10^9 antiprotons in parallel to deceleration in the ESR

same scheme is used for PANDA experiments

ESR Antiproton Deceleration Cycle
1 GeV Injection Energy from HESR



$8{\times}10^8$ every 100 s

Available Pbar Bear
8e8 at 30 MeV
/ 100 sec

Flat Base:
Beam Bunching with Barrier Voltage and Electron Cooling
for 5 sec
Fast Extraction to CRYRING
Dp/p=3e-4 (rms), Emittance (H/V)=0.79/0.87 mm.mrad
Bunch length= 500~600 nsec

requires exclusive HESR operation

extraction in portions is feasible

Consequences of Antiproton Operation of the ESR

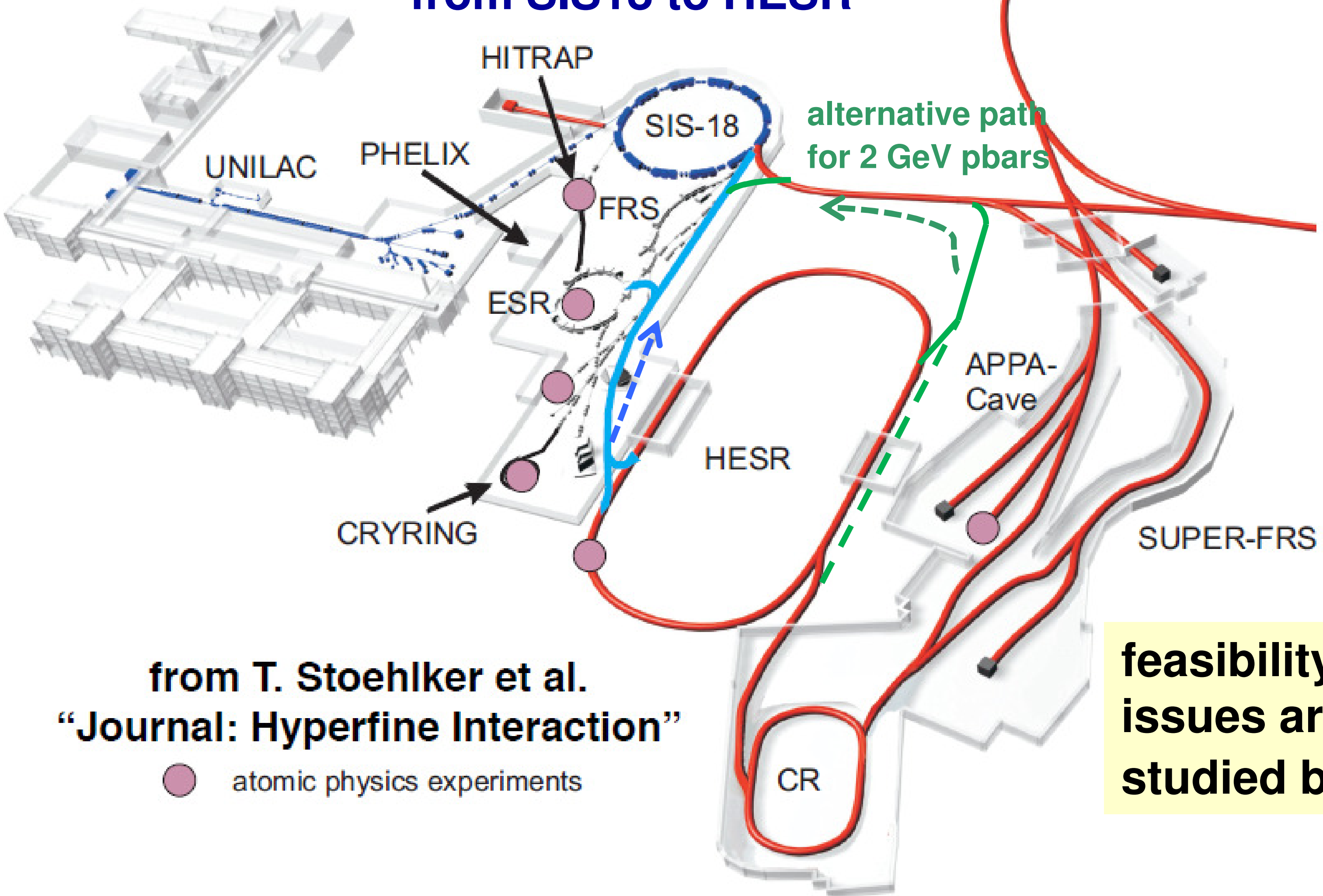
Various components will be operated within their present specifications:
fast ramping power converters, rf system, stochastic cooling system, electron cooling, ultrahigh vacuum system
(minor upgrades could be considered)

some beam diagnostics components will be close to their sensitivity limit
e.g. beam position monitors, destructive devices
but: even single ion detection has been demonstrated in the ESR due to high sensitivity of special beam diagnostics

change of polarity
necessary for all magnetic components
- **probably also for electron cooler $\Rightarrow$ operation with antiparallel field**
- **modification of fast kicker hardware**
- **addition of fast extraction kicker (for extraction towards the South)**

Connecting ESR and HESR

synergy with ion transport from SIS18 to HESR



from T. Stoehlker et al. "Journal: Hyperfine Interaction"

feasibility and cost issues are presently studied by ´Task Force´

Options for Deceleration of Antiprotons in the ESR

injection to CR at 2 GeV
bunch rotation and stochastic cooling
transfer to ESR
    either through direct beam line
    or via HESR ring section
deceleration in ESR to 30 MeV
    with stochastic cooling at 400 MeV
    and electron cooling at 100/30 MeV
transfer to CRYRING

issues:
reduced production rate at 2 GeV
stochastic cooling in CR at 2 GeV
beamline CR to ESR (10 Tm)
deceleration in ESR crossing γ_t
ESR fast extraction system

injection into CR at 3 GeV
bunch rotation and stochastic cooling
transfer to HESR
deceleration in HESR to about 1 GeV
stochastic cooling in HESR
transfer to ESR and
deceleration in ESR to 30 MeV
    with electron cooling at 100/30 MeV
transfer to CRYRING

issues:
option of accumulation in HESR
cooling in HESR at 1 GeV
fast extraction from HESR
beamline HESR to ESR (5 to 10 Tm ?)
    combination with ion injection to HESR
ESR fast extraction system

common: no sharing of antiprotons between HESR and FLAIR

Present Activities

Decelerated antiprotons after the ESR are not part of the Modularized Start Version and therefore not in the scope of the FAIR project.

Recently GSI management established a Task Force, consisting of N. Angert, B. Franzke, R. Maier (FZJ), Y. Litvinov, F. Nolden, D. Prasuhn (FZJ), M. Steck, T. Stöhlker to investigate the feasibility of different approaches.

Conceptual and financial aspects will also be considered.

Experiments of proton stochastic cooling and extraction towards CRYRING will be performed at the ESR this year.

Goal is a report towards the end of 2014.