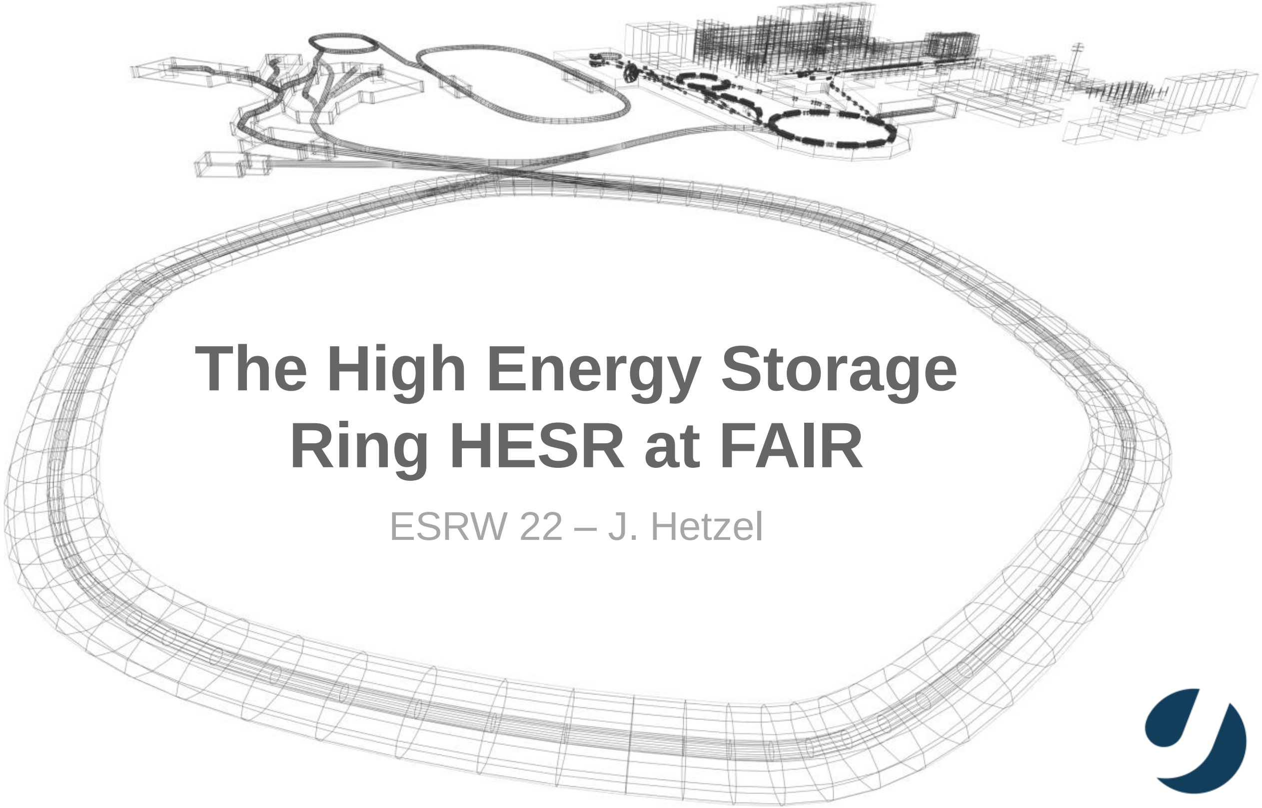


The High Energy Storage Ring HESR at FAIR

ESRW 22 – J. Hetzel

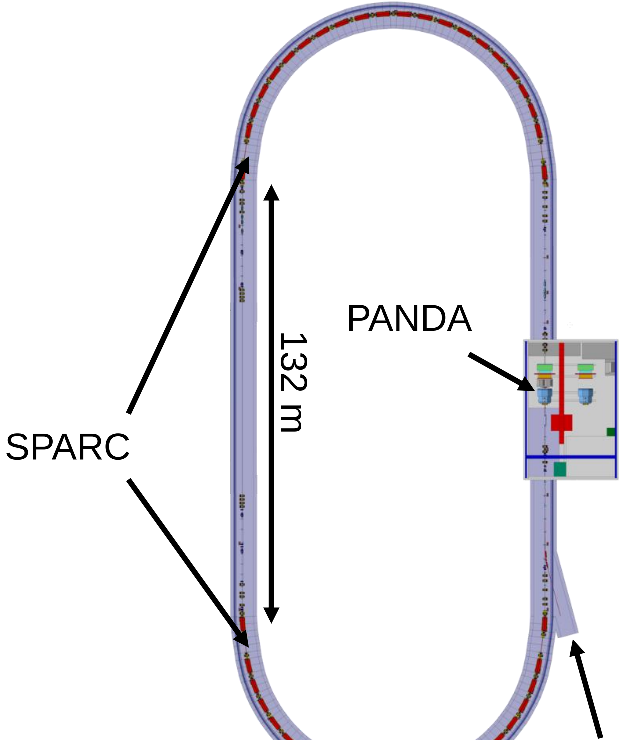
FAIR

artists view, source: http://www.fair-center.de

FAIR

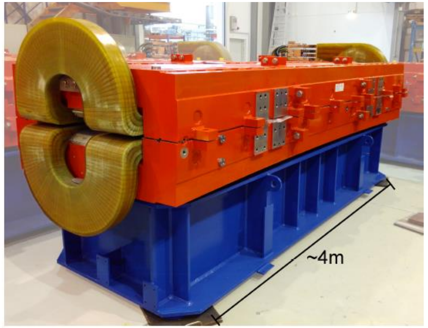
artists view, source: http://www.fair-center.de

The HESR – Key Properties



Length	574 m	
Particle	Antiproton	HI
Experiment	PANDA	SPARC
Rigidity Range	5 – 50 Tm (injection at 12 Tm)	
Kinetic Energy Range	0.8 – 14 GeV	0.17 – 5 GeV/a
Injection Energy	2.78 GeV	0.74 GeV/a

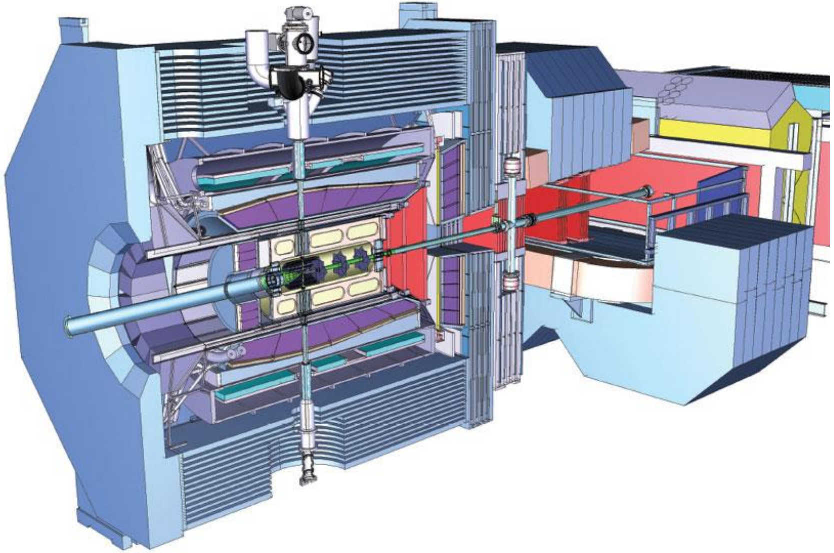
stochastic cooling



44 sector dipoles - normal conducting

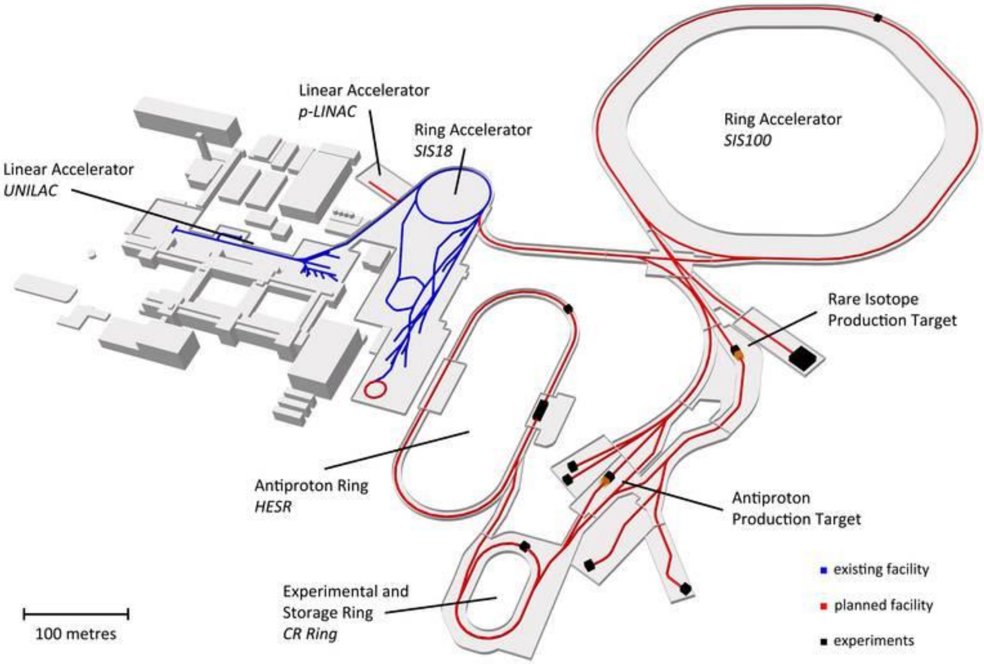
84 quadrupoles - normal conducting

$\overline{\text{P}}$ANDA – Antiproton Annihilation at Darmstadt



- internal hadron physics experiment with **antiprotons** to create **charm** states
- **requirements closely related to performance limits** of the HESR
  - energy range: 0.8 – 14 GeV
  - high momentum resolution: $\frac{\Delta p}{p} = 5\ 10^{-5}$
  - luminosity: $\mathcal{L} \sim 10^{31} \text{cm}^{-2} \text{s}^{-1}$

The HESR Injection Chain - Antiprotons



- preacellerated protons from p-LINAC, via SIS18, SIS100
- antiprotons created at Antiproton Production Target via

$$p + A \rightarrow \bar{p} + p + X$$

- collection and pre-cooling of $10^8\ \bar{p}$ in CR
  - accumulation in HESR
  - extraction conditions have to match **injection** of HESR

Highlights and Challenges of the HESR

- stochastic cooling
- injection
  - longitudinal stacking
  - injection lattice
- dipole magnets
  - have to support momentum range
  - operation modes with antiprotons and heavy ions → different polarity
- COSY as testfacility

requirements

- high momentum resolution
- high luminosity
- wide momentum range
- accumulation in the HESR
- high reproducibility
- antiproton and heavy ion operation

Highlights and Challenges of the HESR

- **stochastic cooling**
- injection
  - longitudinal stacking
  - injection lattice
- dipole magnets
  - have to support momentum range
  - operation modes with antiprotons and heavy ions → different polarity
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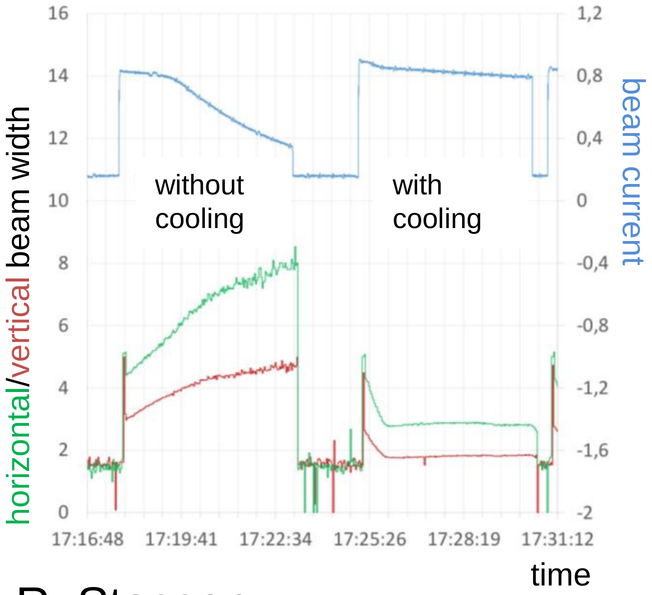
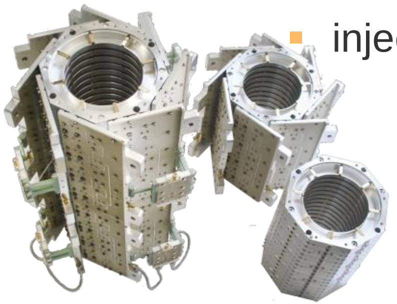
Stochastic Cooling



R. Stassen

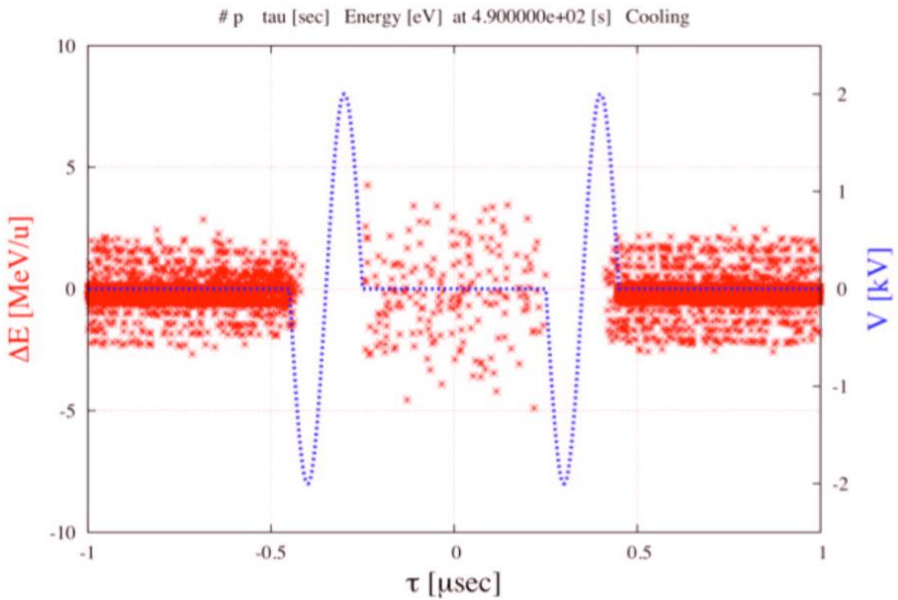
- cooling structures desigend for the HESR
- transverse and longitudinal cooling
- system successfully tested with PANDA cluster target at COSY
- cooling for $\beta \geq 0.84$:
  - lowest momentum for $\bar{p}$
  - injection momentum for HI



Highlights and Challenges of the HESR

- stochastic cooling
- **injection**
  - **longitudinal stacking**
  - **injection lattice**
- dipole magnets
  - have to support momentum range
  - operation modes with antiprotons and heavy ions → different polarity
- COSY as testfacility

Injection – Longitudinal Stacking

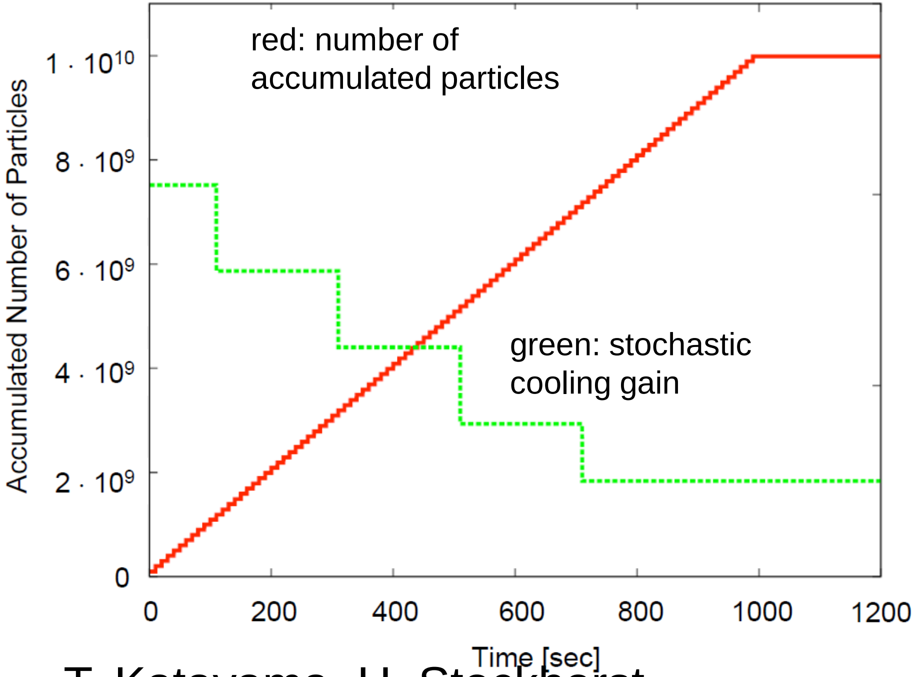


T. Katayama, H. Stockhorst

- 10^8 particles from the CR every 10 s
- accumulation of 10^{10} particles in the HESR
- alternated application of barrier bucket and longitudinal cooling
- equilibrium momentum spread with cooling at 10^{10} $\bar{p}$:

$$\frac{\Delta p}{p} = 5\;10^{-5}$$

Injection – Longitudinal Stacking



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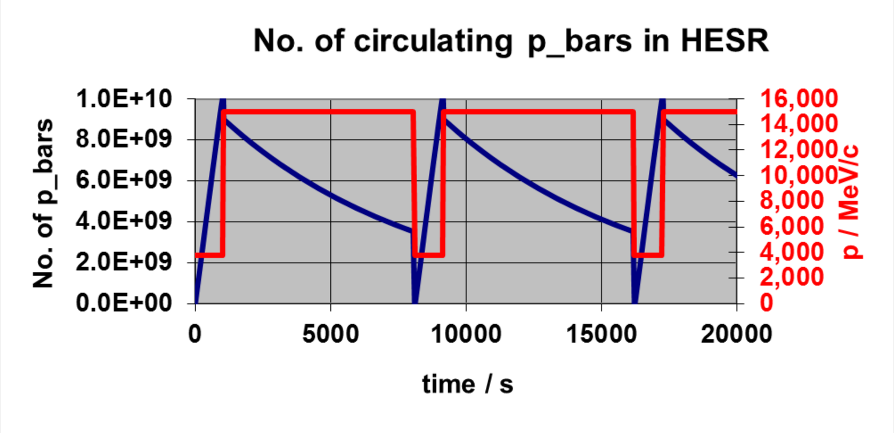
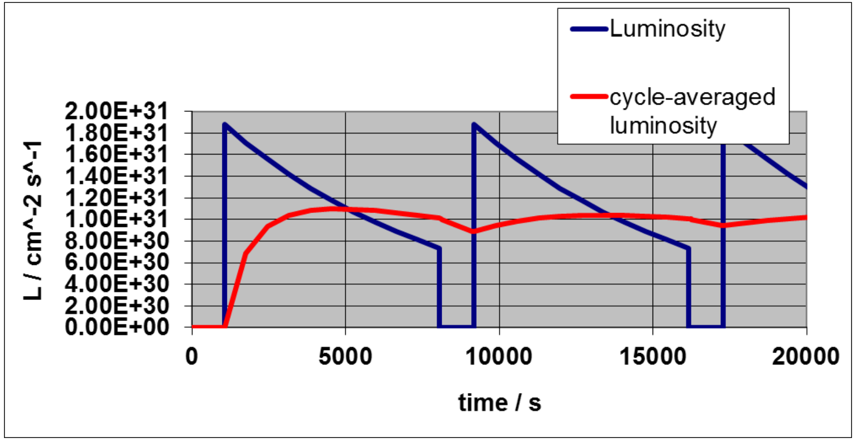
Luminosity for Antiprotons

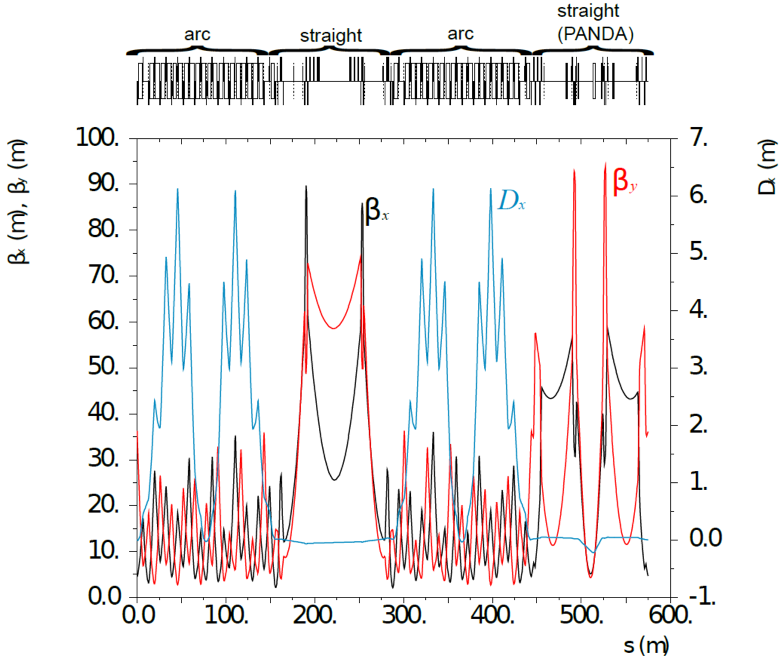
- averaged luminosity



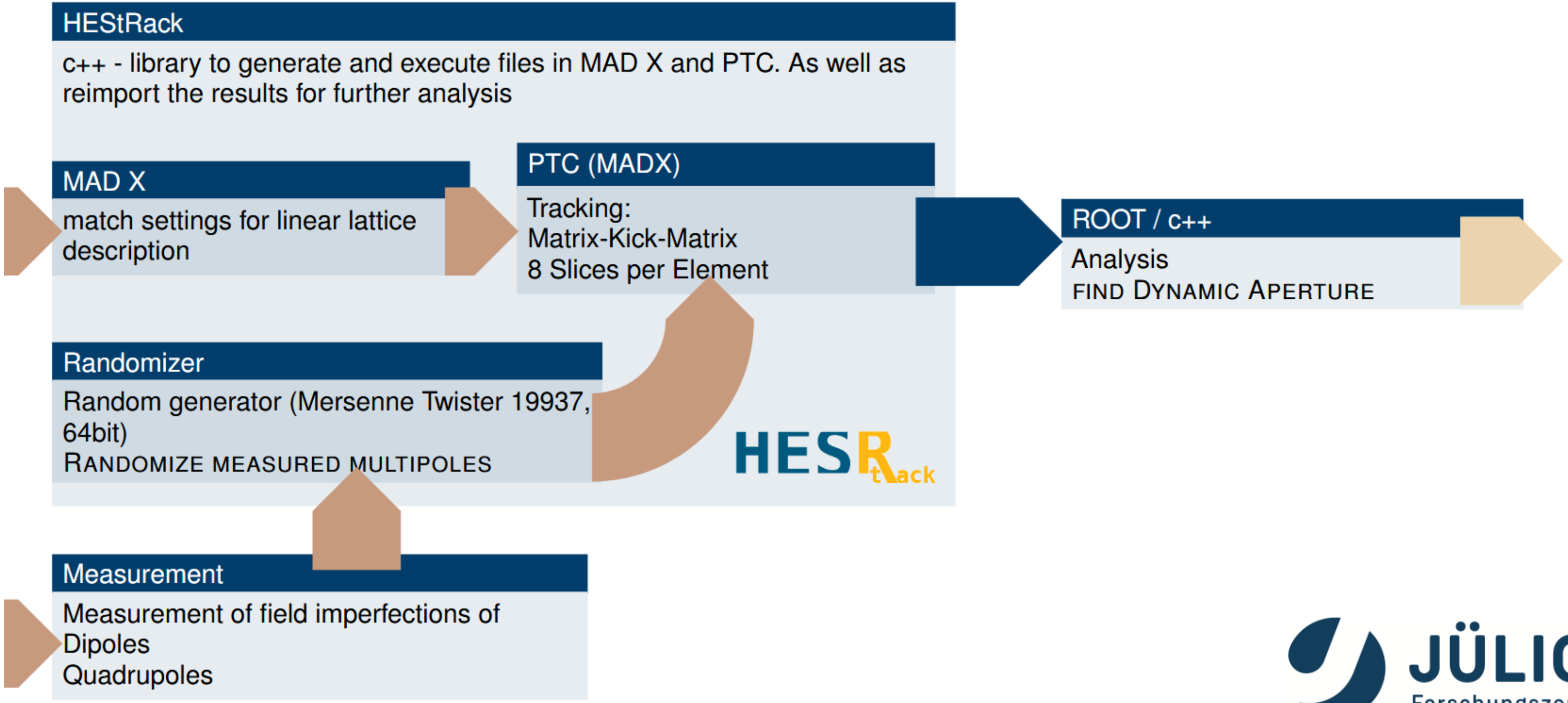


Injection – Lattice (Antiprotons)

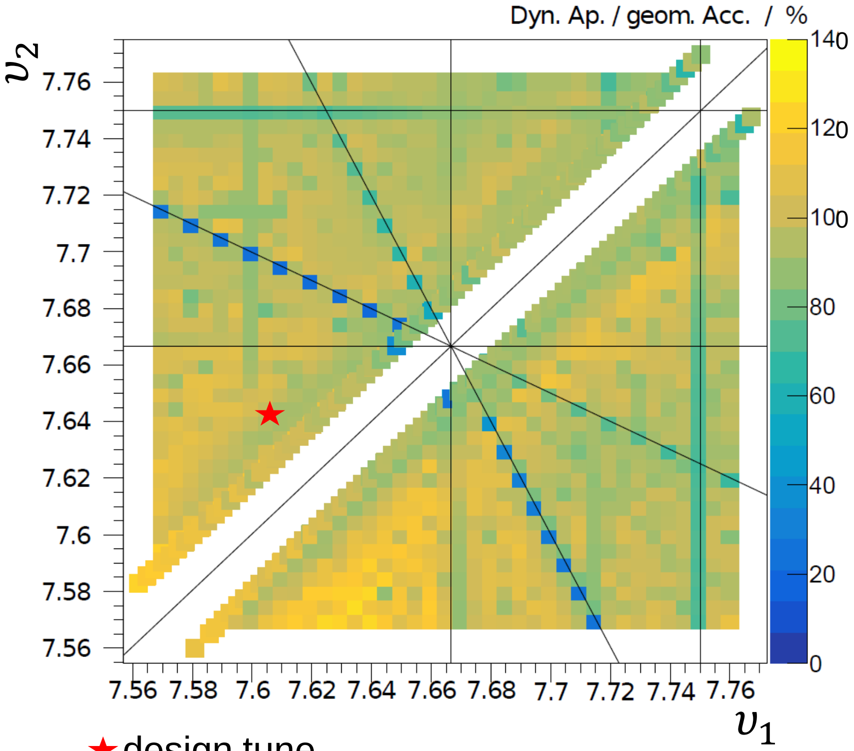
- momentum p=3.825 GeV/c (T=2.78 GeV)
- transition energy $\gamma_{tr} = 6.2$
- dispersion $D_{\mathrm{straight}} = 0$
- chromaticity $\xi_{x,y} = 0$
- tune $\nu_{x,y} \approx 7.6$



Tracking Studies



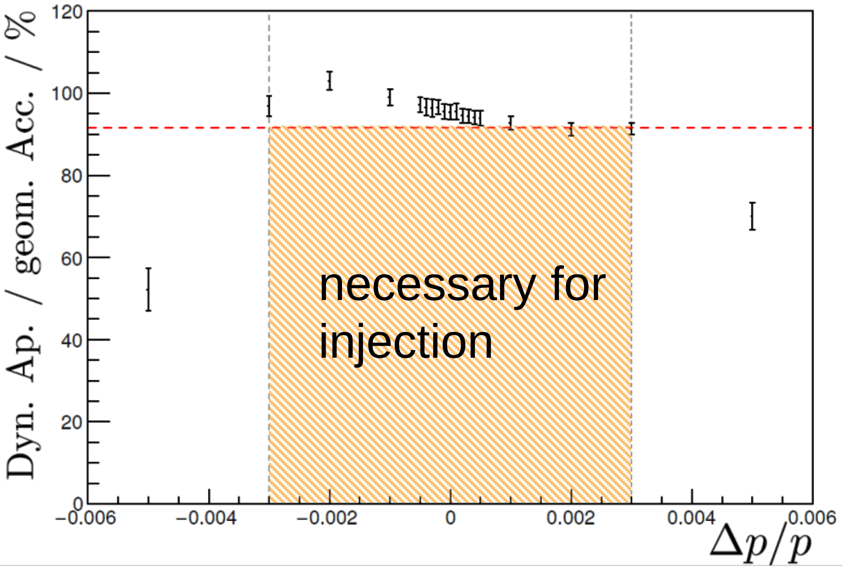
Injection - Dynamic Aperture Calculations



★ design tune

- Dynamic Aperture calculated for different tunes for injection lattice
- visible reduction of geometric acceptance at tune resonances
- areas with stable conditions observed in simulation

Momentum Acceptance at Injection

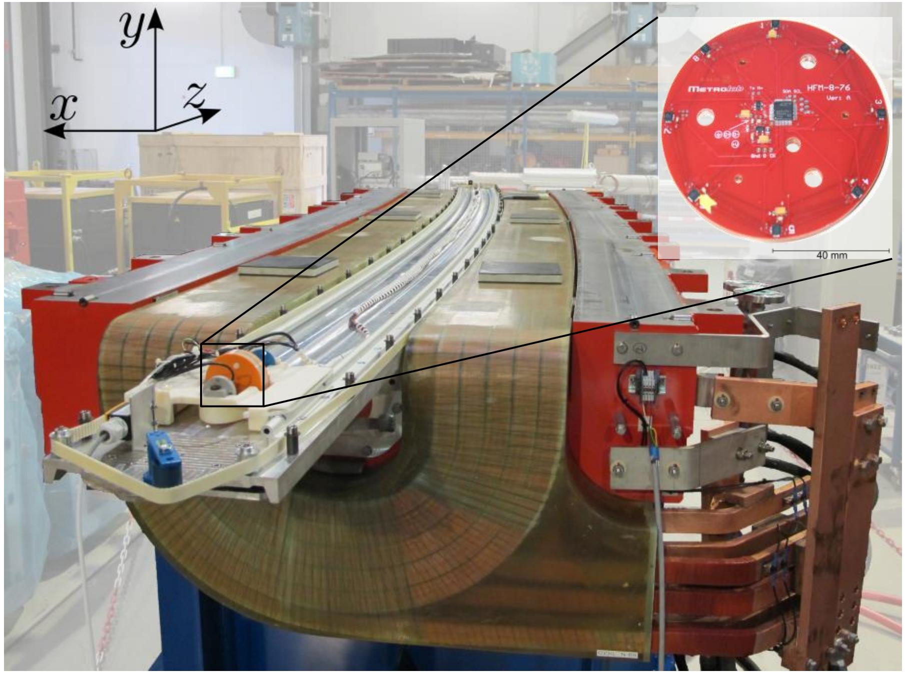


- the application of stochastic cooling for accumulation limits the acceptable momentum spread
- momentum acceptance from linear considerations
- no reduction (below expected limit) by dynamic aperture observed in simulations

Highlights and Challenges of the HESR

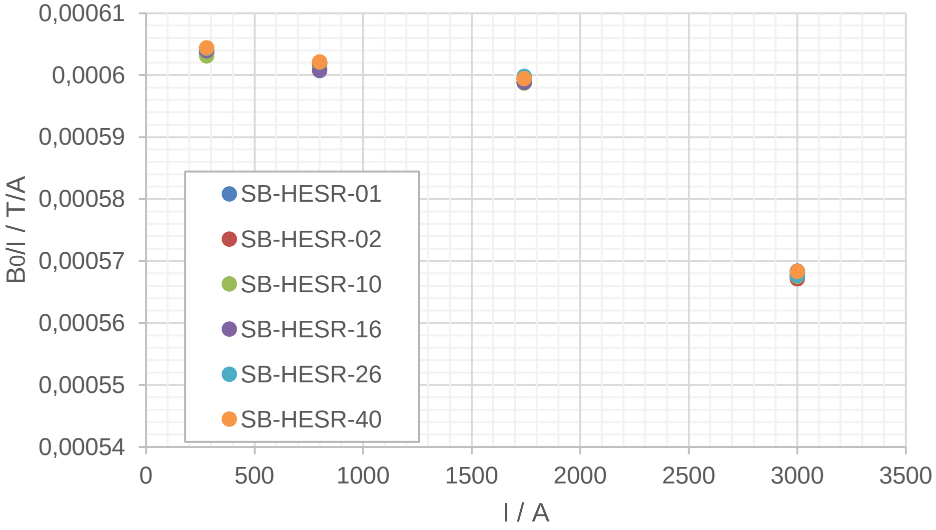
- stochastic cooling
- injection
  - longitudinal stacking
  - injection lattice
- **dipole magnets**
  - **have to support momentum range**
  - **operation modes with antiprotons and heavy ions → different polarity**
- COSY as testfacility

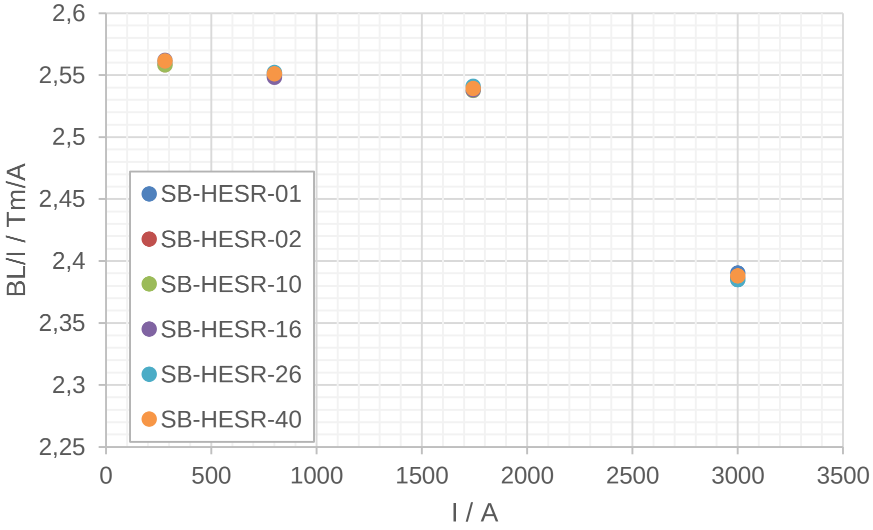
Dipole Measurement System (HEDi)



- designed to measure harmonic content of dipoles
- 8 3D-Hall effect probes
- free movent along central trajectory
- free rotation around central axis
- integral measurement and measurement at dedicated positions
- → determination of $B_0(I)$, $\int BdL\,(I)$, L_{eff} possible

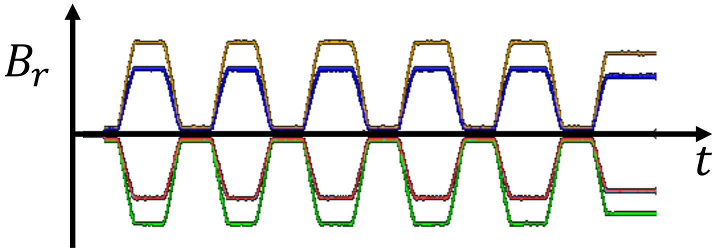
Dipole Measurements





⇒ control sample of measured dipoles shows good conformity of $B_0(I), \int B dL\,(I)$ **over whole range**

Inversion of Polarity



measured at 1743 A	pos. polarity	neg. polarity
$\left\|\int BdL\right\|$	4421 Tm	4424 Tm
$\|B_0\|$	1.044 T	1.044 T
L_{eff}	4236.4 mm	4236.5 mm

- cycle several times to maximum field (for each polarity)
- measurement of B_0,$\int BdL$, L_{eff} comparable for both polarities
- harmonic content comparable as well
- ⇒ HESR dipoles can be operated at both polarities ($\bar{p}$ and HI)

Highlights and Challenges of the HESR

- stochastic cooling
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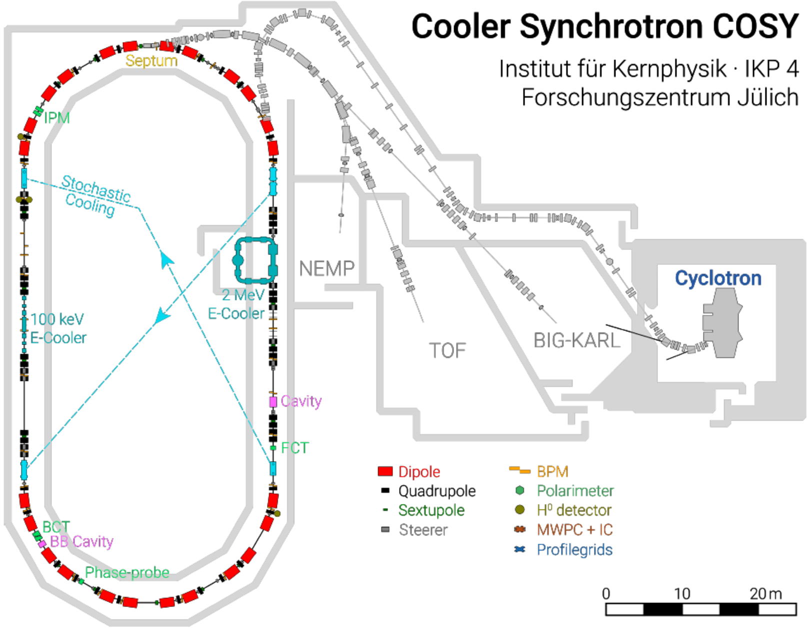
- **COSY as testfacility**

COSY as Testfacility for the HESR



length	184 m
particle	p, D
momentum range	0.3 – 3.7 GeV/c

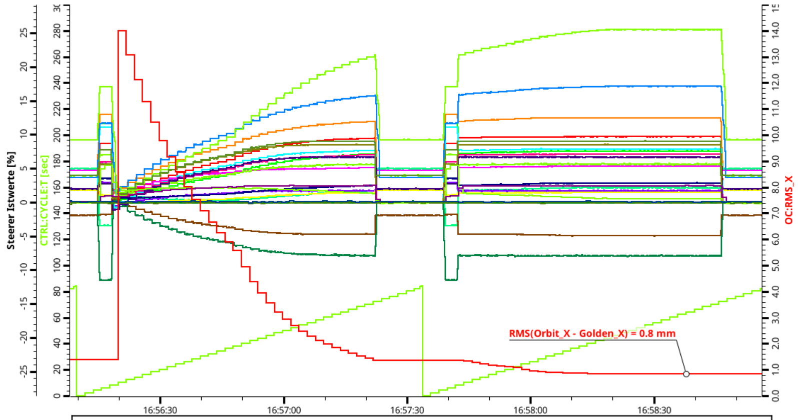
Tests of e.g.

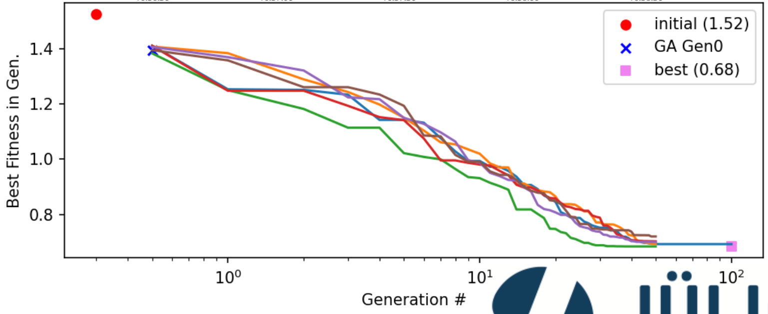
- barrier bucket cavity
- stochastic cooling
- *studies of algorithms and methods*

Studies of Algorithmic Control of COSY

- established: automated orbit correction
- tests with genetic optimisation of machine model
- bayesian optimisation of injection beamline settings
- envisoned: reinforcement learning for injection

➔ methods will be applied at HESR



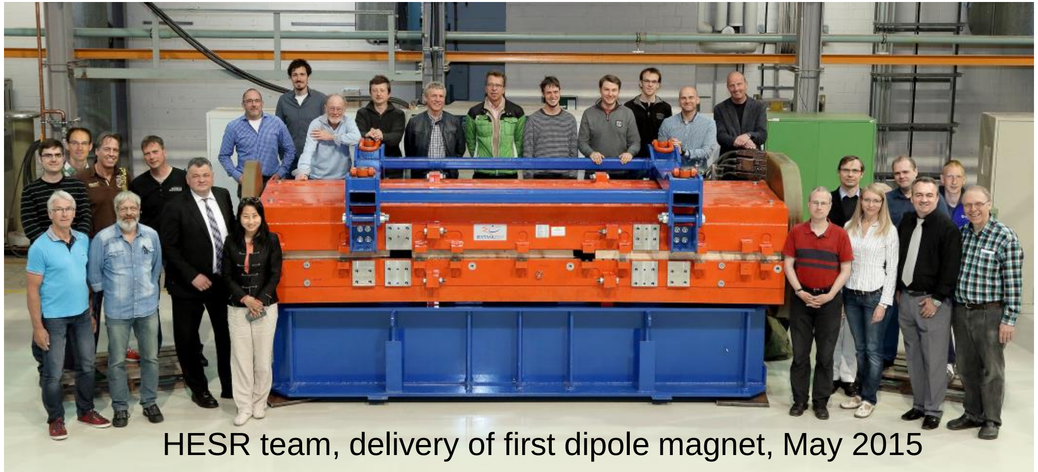


Summary

- high momentum resolution $\frac{\Delta p}{p} = 5\ 10^{-5}$
- accumulation in the HESR via longitudinal stacking
- high luminosity $\mathcal{L} \sim 10^{31} \mathrm{cm}^{-2} \mathrm{s}^{-1}$
- magnets allow for high reproducibility of fields
- componets and concepts tested at COSY in Jülich
- HESR ready for antiproton and heavy ion operation

➔ exciting times ahead

Thank you!



HESR team, delivery of first dipole magnet, May 2015

HESR consortium

(i) Forschungszentrum Jülich,

(ii) INCDIE ICPE-CA Bucharest,

(iii) ISYST Slovenia,

(iv) GSI Darmstadt.