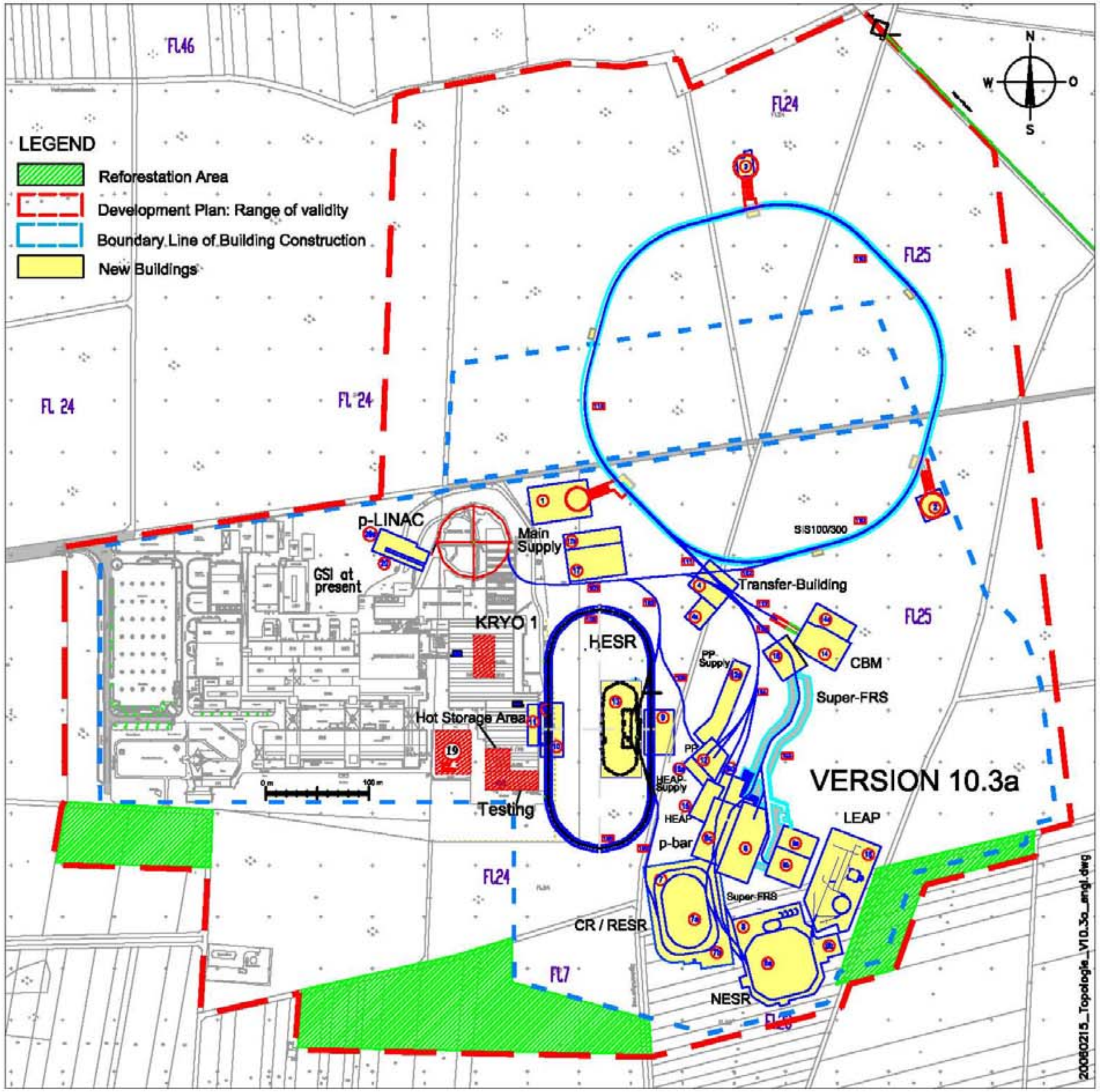
Design Study of HESR and CSR at FAIR

- The FAIR facility
- HESR design criteria
- Future upgrade prospects
- Summary

The FAIR Facility



BUILDINGS

1	Extraction Building
2	Injection Building
3	Emergency Exit
4	Transfer Building
4a	Transfer - Supply
6	Super - FRS
6a	Super - FRS Supply
6b	Super - FRS LE - Branch
6c	p-bar - Target
6d	p-bar - Target Supply
7	CR / RESR
7a	CR / RESR Supply
7b	CR / RESR High Building
8	NESR
8a	NESR Supply
8b	NESR - Preparation
9	HESR PANDA Detector
10	HESR - Cooler
10a	HESR - Cooler Tower
11	HESR Supply
12	PP
12a	PP/HEBT Supply & LASER
13	HESR - COSY
14	NC (CBM)
14a	NC (CBM) Supply
15	HEAP
15a	HEAP Supply
16	LEAP Supply
17	Main Supply Building
17a	Compressor Building
18	Super - FRS Target
19	Office Building
20	p - Linac
20a	p - Linac Supply

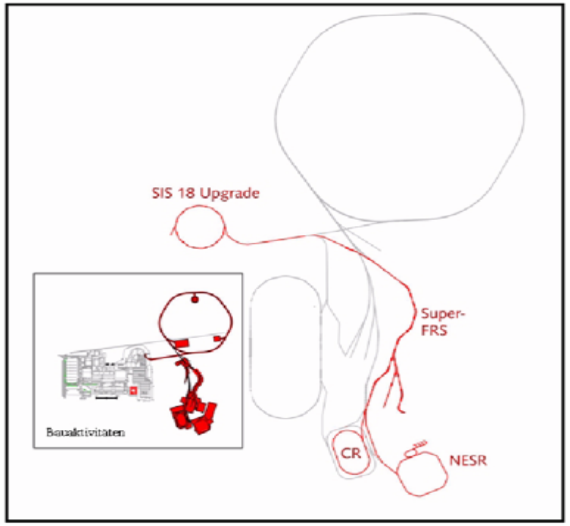
101	SIS18 - Transfer
102	Transfer Injection SIS100
103	Super - FRS
104	Transfer SIS100/300 - Exp.
105	Transfer SIS18 - PP
106	Transfer CR/RESR - HESR
107	HESR - Injection
108	HESR
110	SIS100/300 Tunnel
111	Extraction SIS100/300
112	Transfer CBM-Cave

The Staging Plan for Construction

Political request since early 2003:
"Build FAIR complex in three stages
in order to guarantee physics output at each stage"

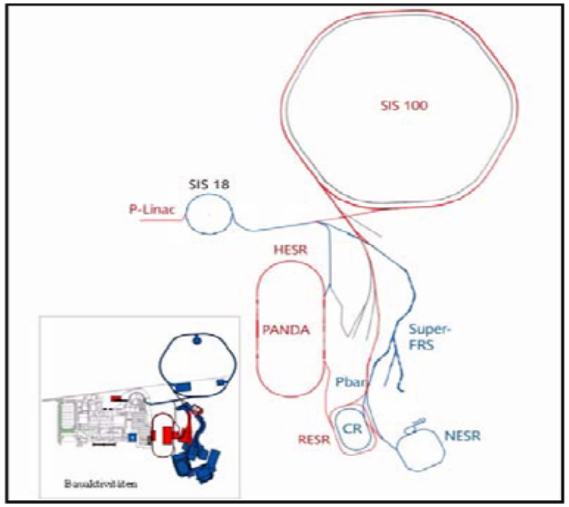
Stage 1

2007 - 2011



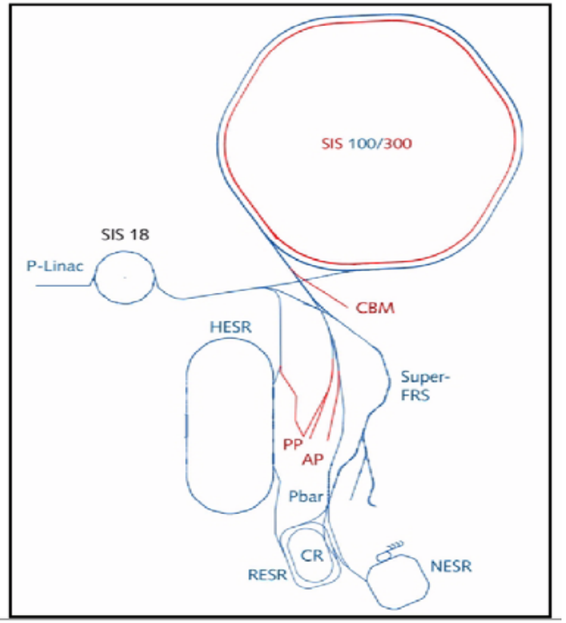
Stage 2

2011 - 2013



Stage 3

2013 - 2015



From a talk by Dieter Krämer, GSI, June 19th, 2006

The Costbook Rev. 3.0

Investment Cost:

• Accelerators w/o sFRS*	592 M€
• Civil Construction	322 M€
• Experiments incl. sFRS	200 M€
Sum	1114 M€
• Manpower	2400 FTE
according to FCI (1 FTE=77k€/y)	185 M€

Project Cost 1299 M€

"The *Costbook* reflects the present status of the estimate. The facility costs are evaluated on a component basis and then aggregated for the sub-systems and finally for the total facility.

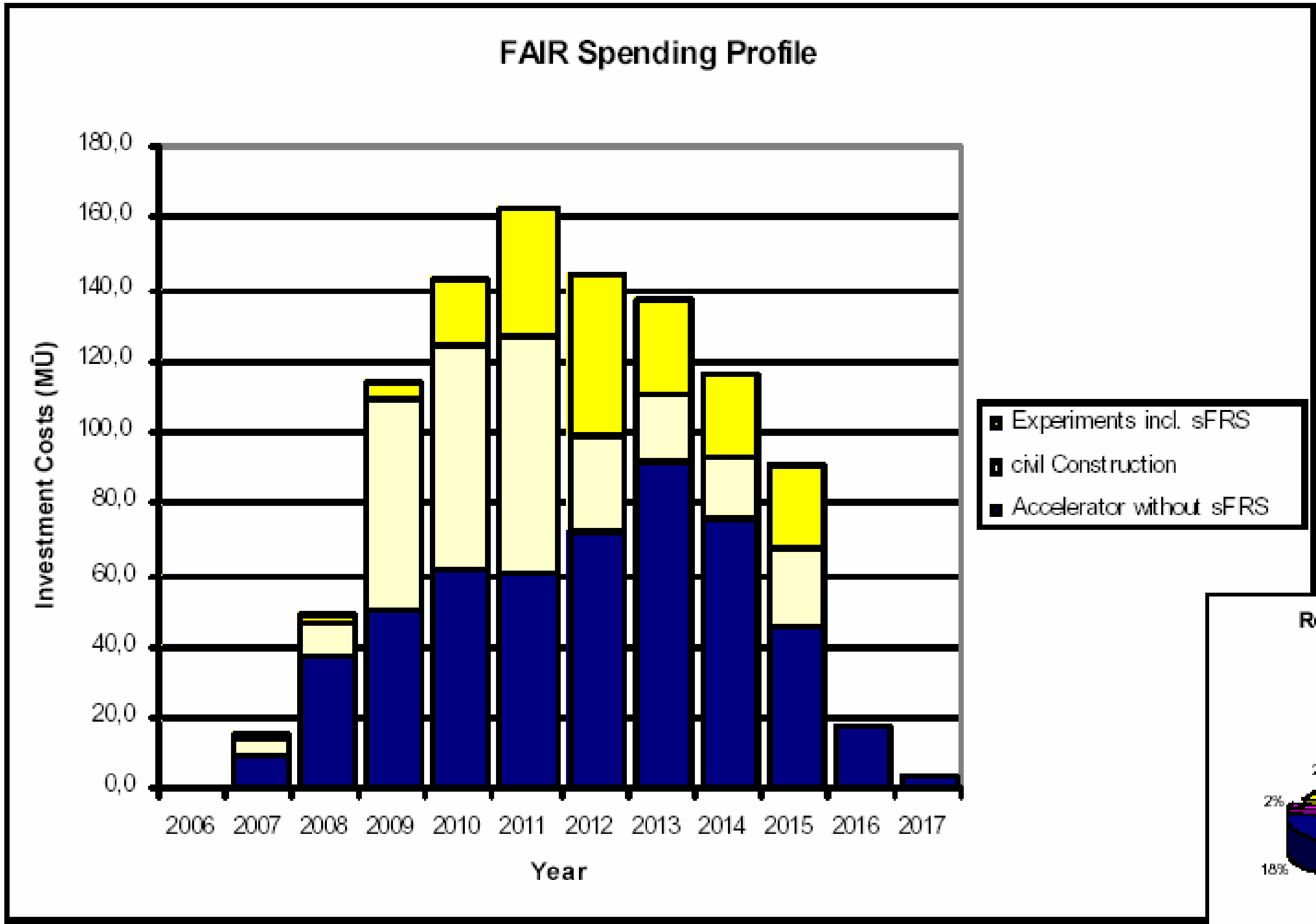
This adds up to a total of 1114 M€ in investment cost."

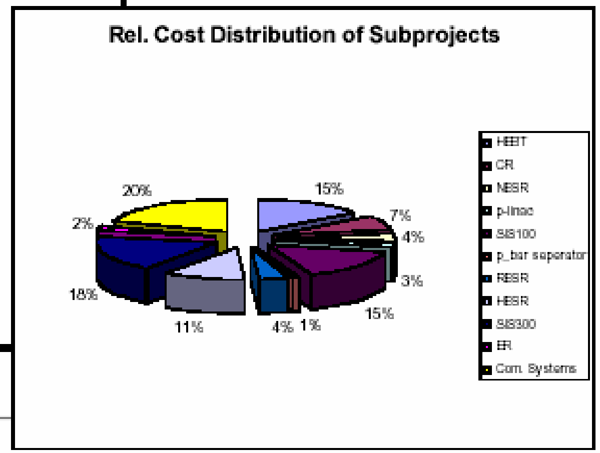
Supplement to FBTR

*sFRS equivalent 81 M€

Costbook Version 2.67

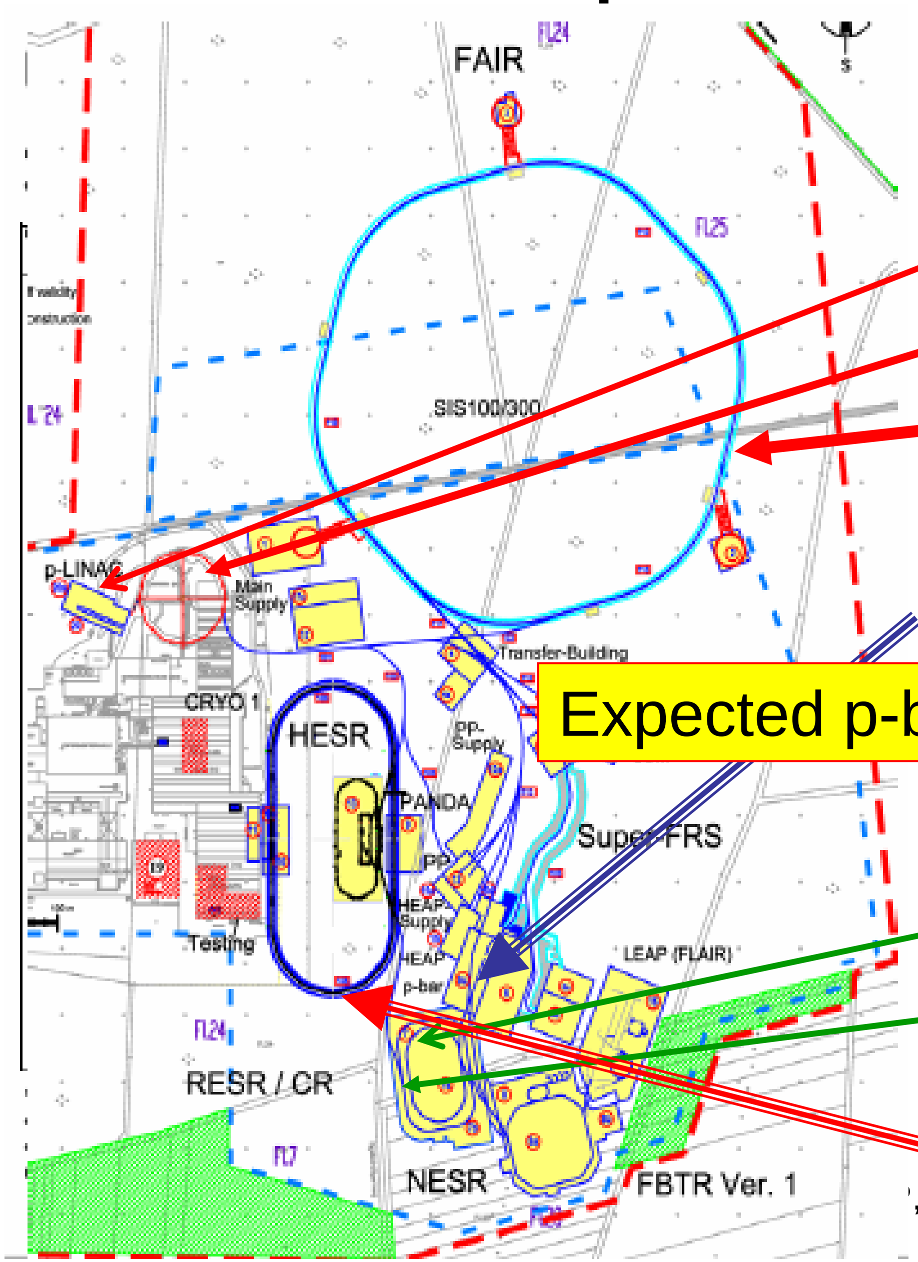
2.11	**HESR**	**65.831**
2.11.1	**System Design**	**0**
2.11.2	**Magnets**	**25.680**
2.11.3	**Power Converter**	**7.257**
2.11.4	**RF Systems**	**2.227**
2.11.5	**Injection/ Extraction**	**156**
2.11.6	**Beam Diagnostics**	**5.336**
2.11.7	**Vacuum**	**1.870**
2.11.8	**Particle Sources**	**0**
2.11.9	**Electron Cooling**	**12.500**
2.11.10	**Stochastic Cooling**	**4.000**
2.11.11	**Special Installations**	**0**
2.11.12	**Cryogenics (local)**	**6.805**





D. Krämer June 19th, 2006

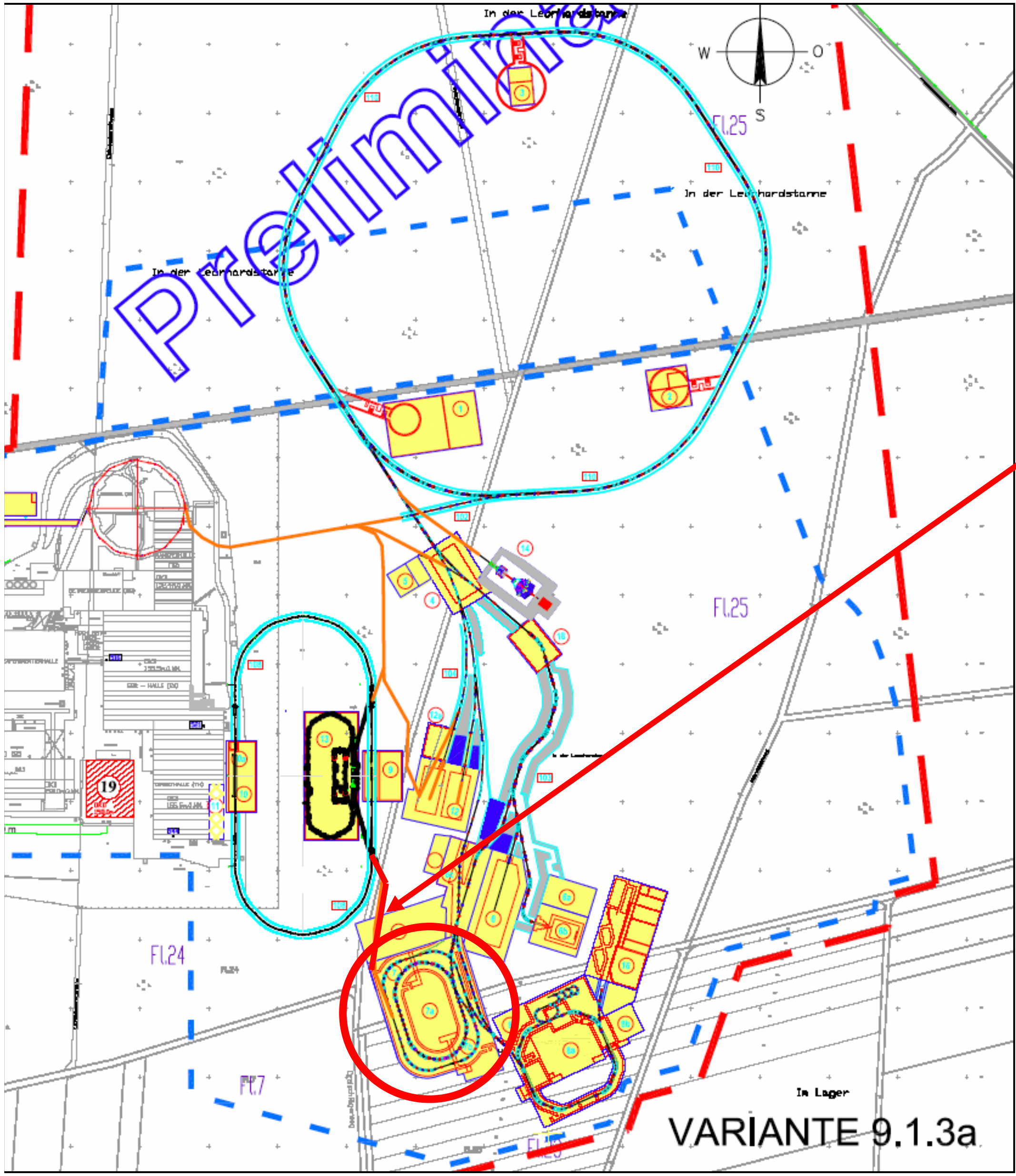
The Antiproton path to HESR



- Protons with 30 GeV:
  - p-LINAC (70 MeV)
  - SIS 18 (6 GeV)
  - SIS 100 (29 GeV)
- P-bar Target

Expected p-bar production rate: $1*10^7\ s^{-1}$

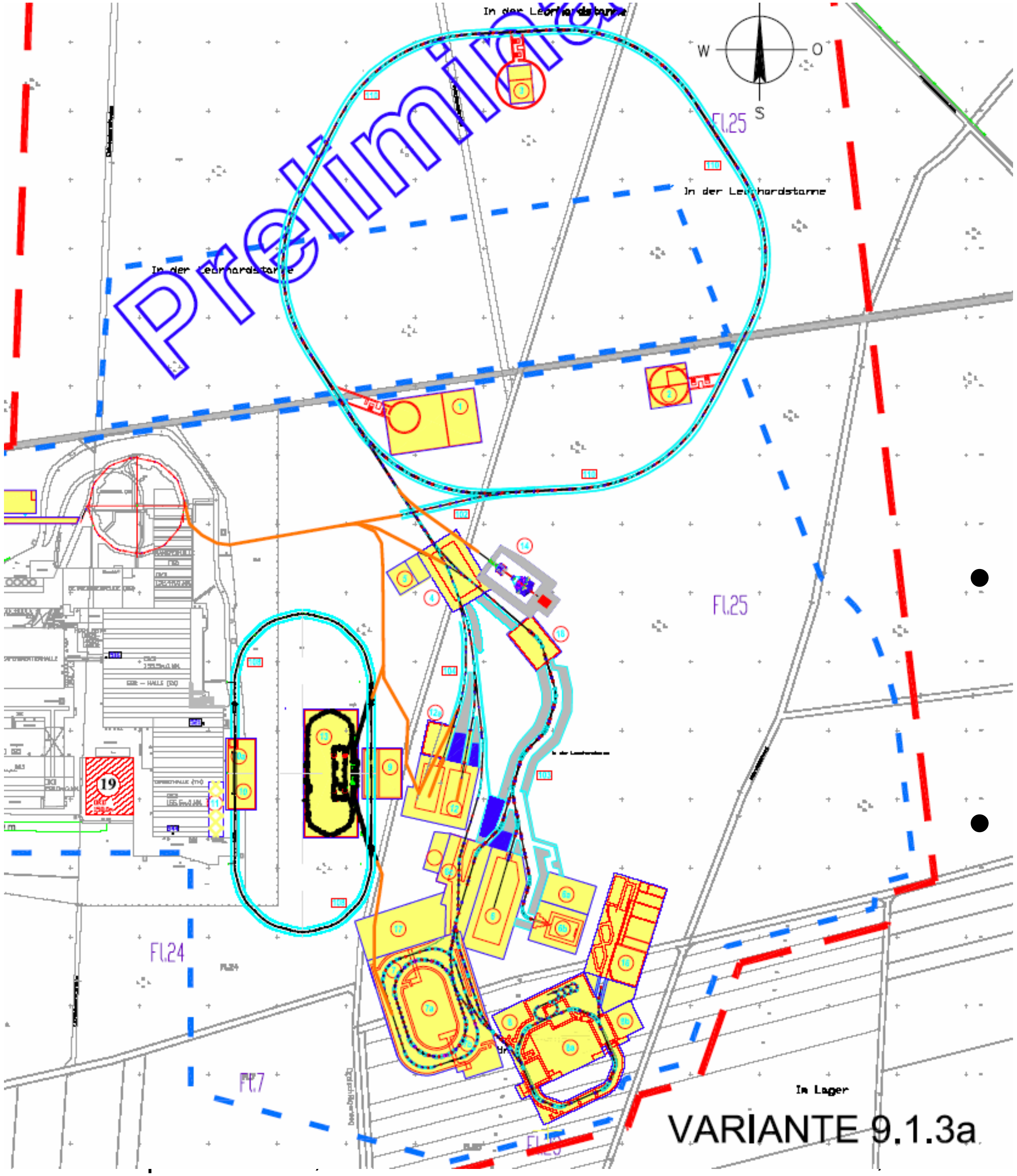
- Accumulation of p-bars:
  - Collector Ring
  - RESR
- HESR



The HESR in the actual Topology

The $\bar{p}$-beam is injected from RESR at 3.8 GeV/c

- Advantage:
  - Low energy beam lines and injection elements
  - Electron cooling at low energy
- Disadvantage:
  - HESR is a synchrotron
  - Reduced duty cycle



For commissioning **protons** can be injected from

- RESR at reversed field polarities
- SIS 18 at 12.7 Tm with same field polarity, but opposite direction

The HESR-Consortium

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

- Leadership in the consortium
- System design
- magnet layout
- Stochastic cooling
- Integration of experiments

UPPSALA UNIVERSITET

High Energy Electron Cooler

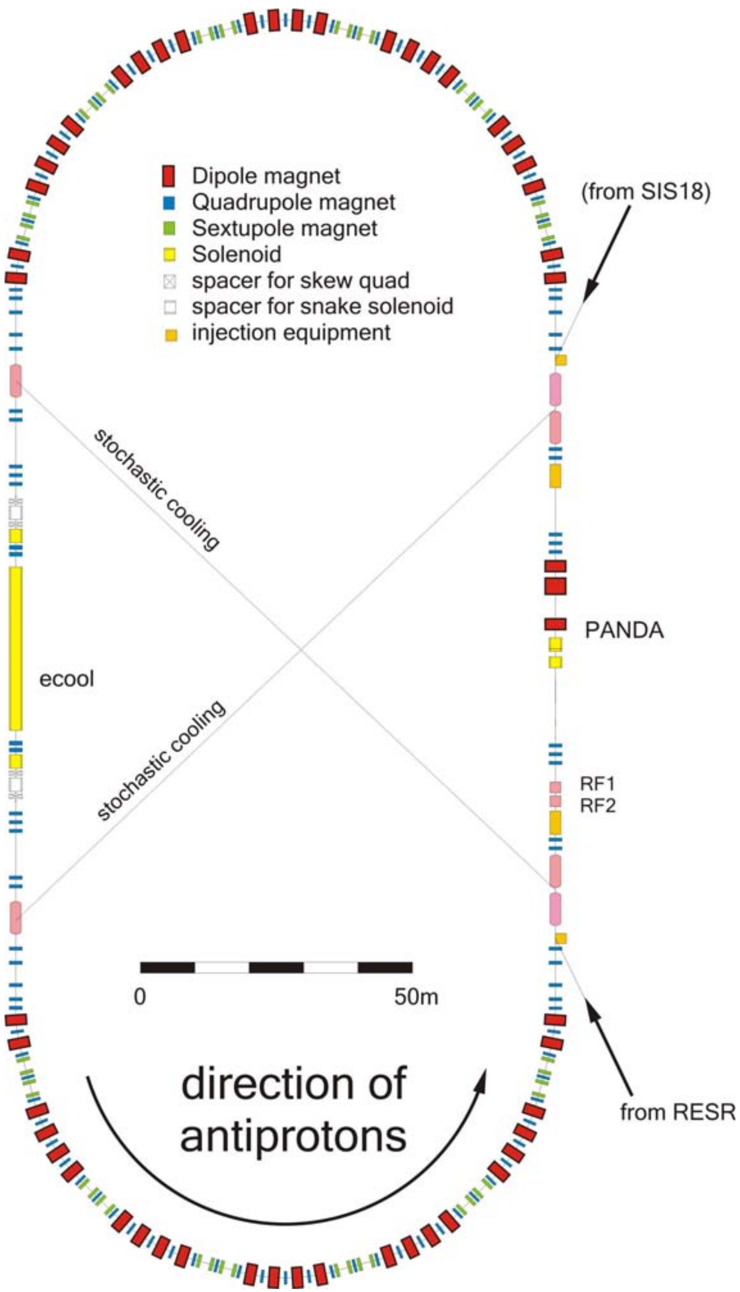
GSI

- Infrastructure
- Building
- System integration

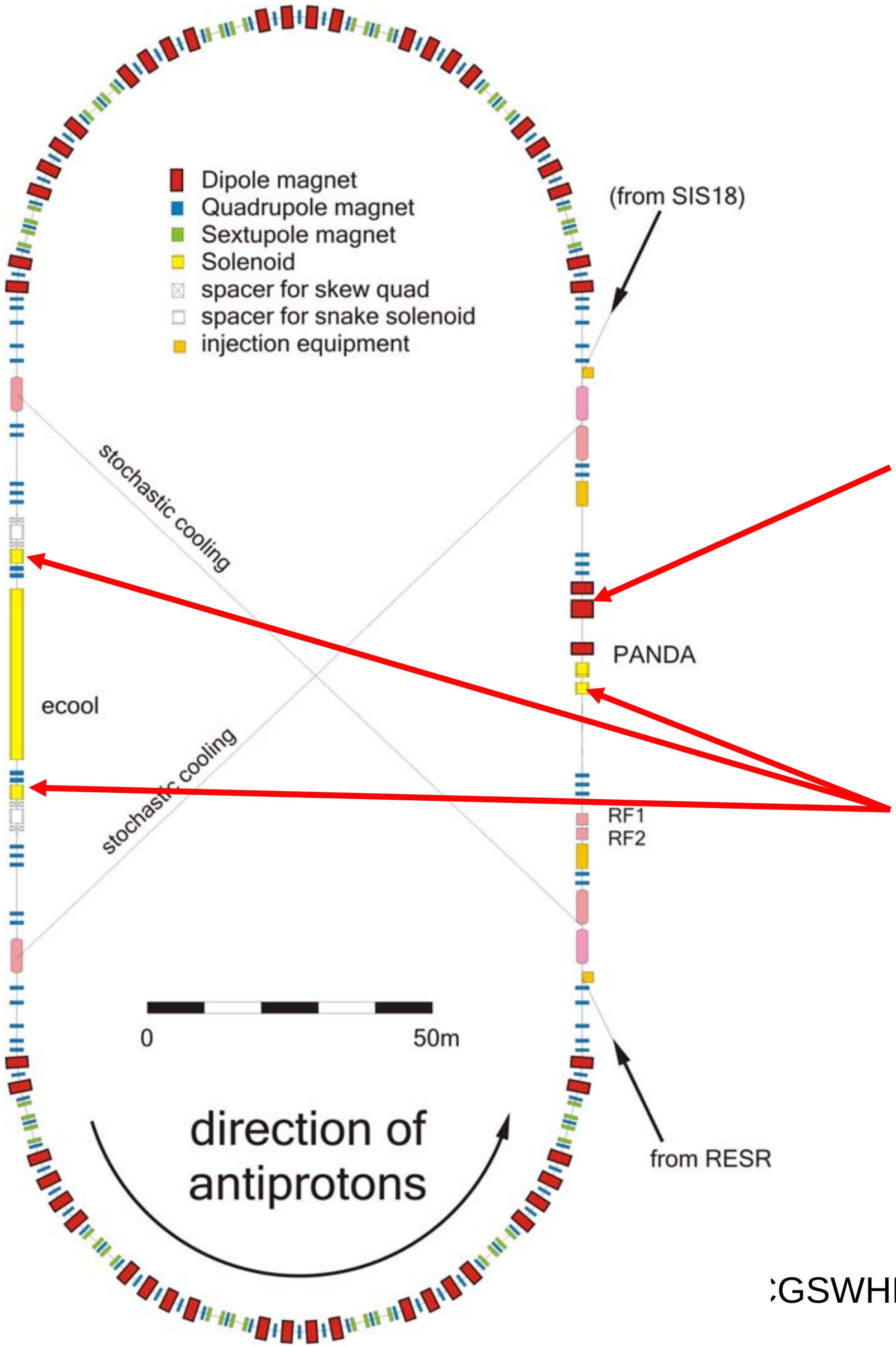
universitätbonn

- Ion Optics
- Injection Beam Lines
- Beam - Target Interaction

Basic Data of HESR



- Circumference 574 m
- Momentum (energy) range
  1.5 to 15 GeV/c (0.8-14.1 GeV)
- Injection of (anti-)protons from RESR at 3.8 GeV/c
- Acceleration rate 0.1 (GeV/c)/s
- Electron cooling up to 8.9 GeV/c (4.5 MeV electron cooler)
- Stochastic cooling above
  3.8 GeV/c

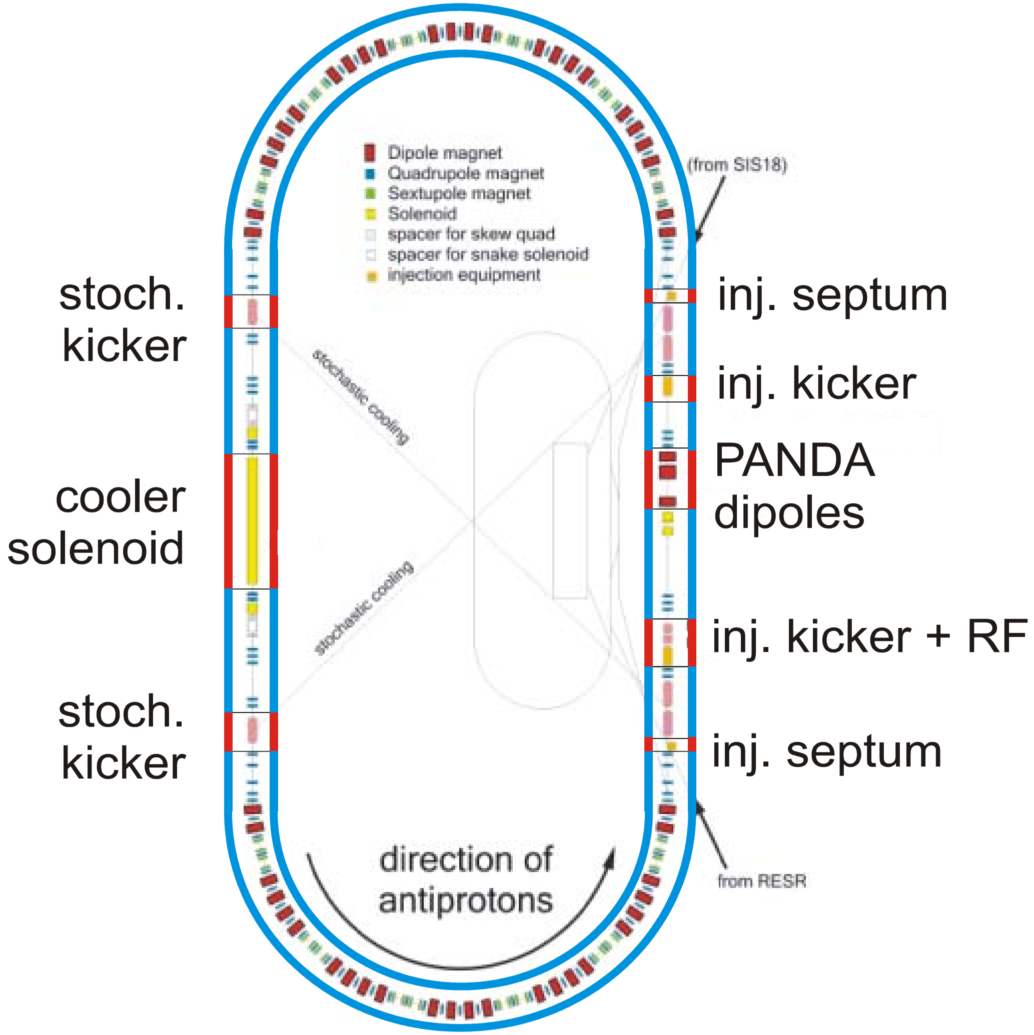


Additional Installations

2 compensation dipoles for the PANDA-chicane

Compensation solenoids for PANDA and the electron cooler

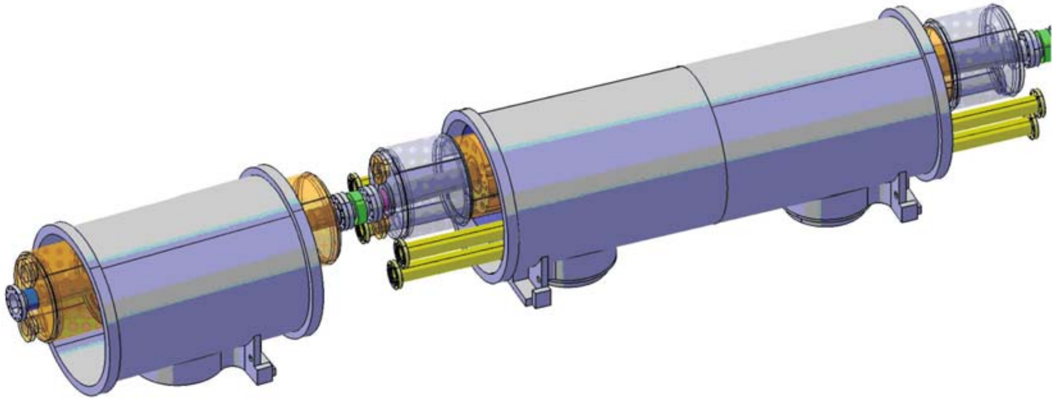
System Design

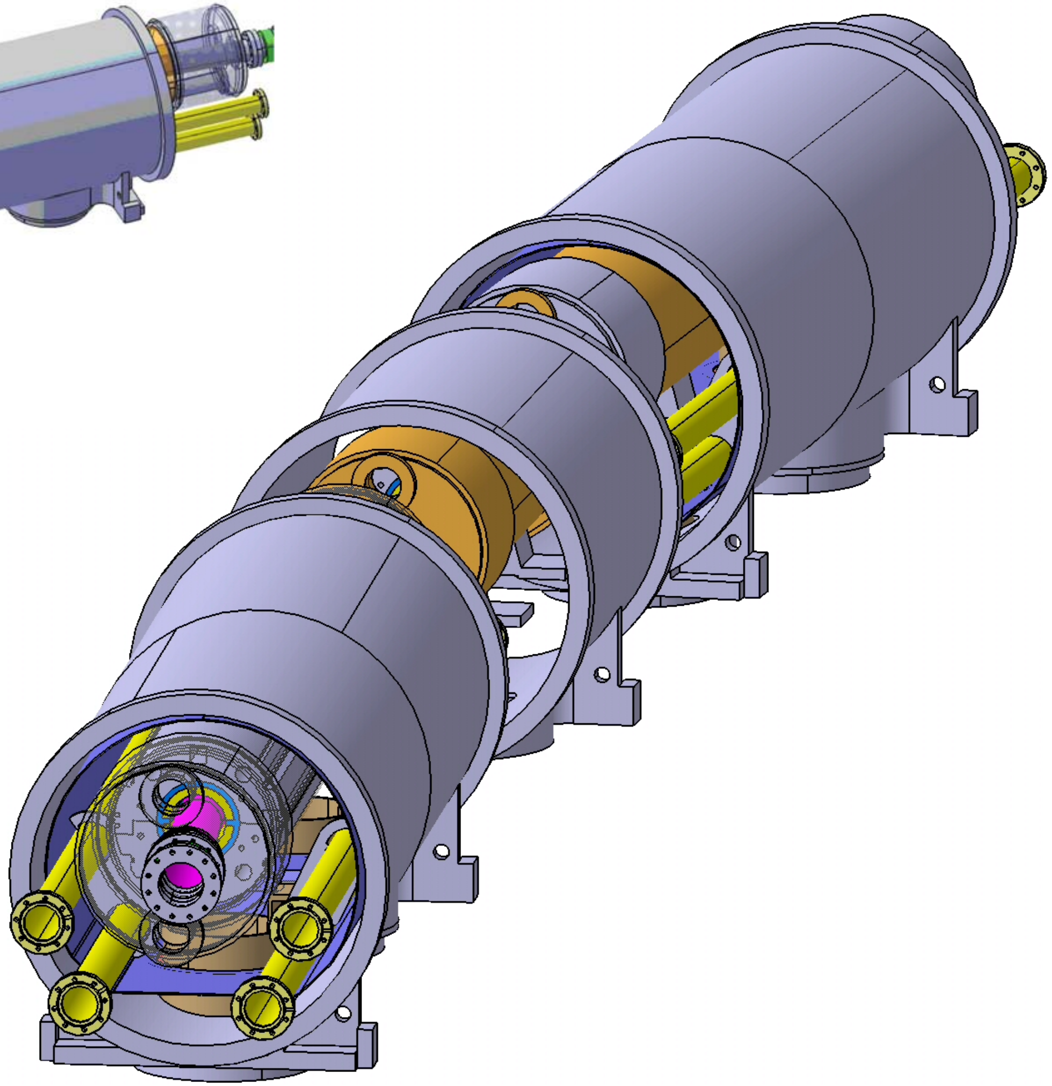


- Ring mainly cold (only short warm insertions)
- 2 Cryogenic subsections, cryogenic bypasses for warm sections

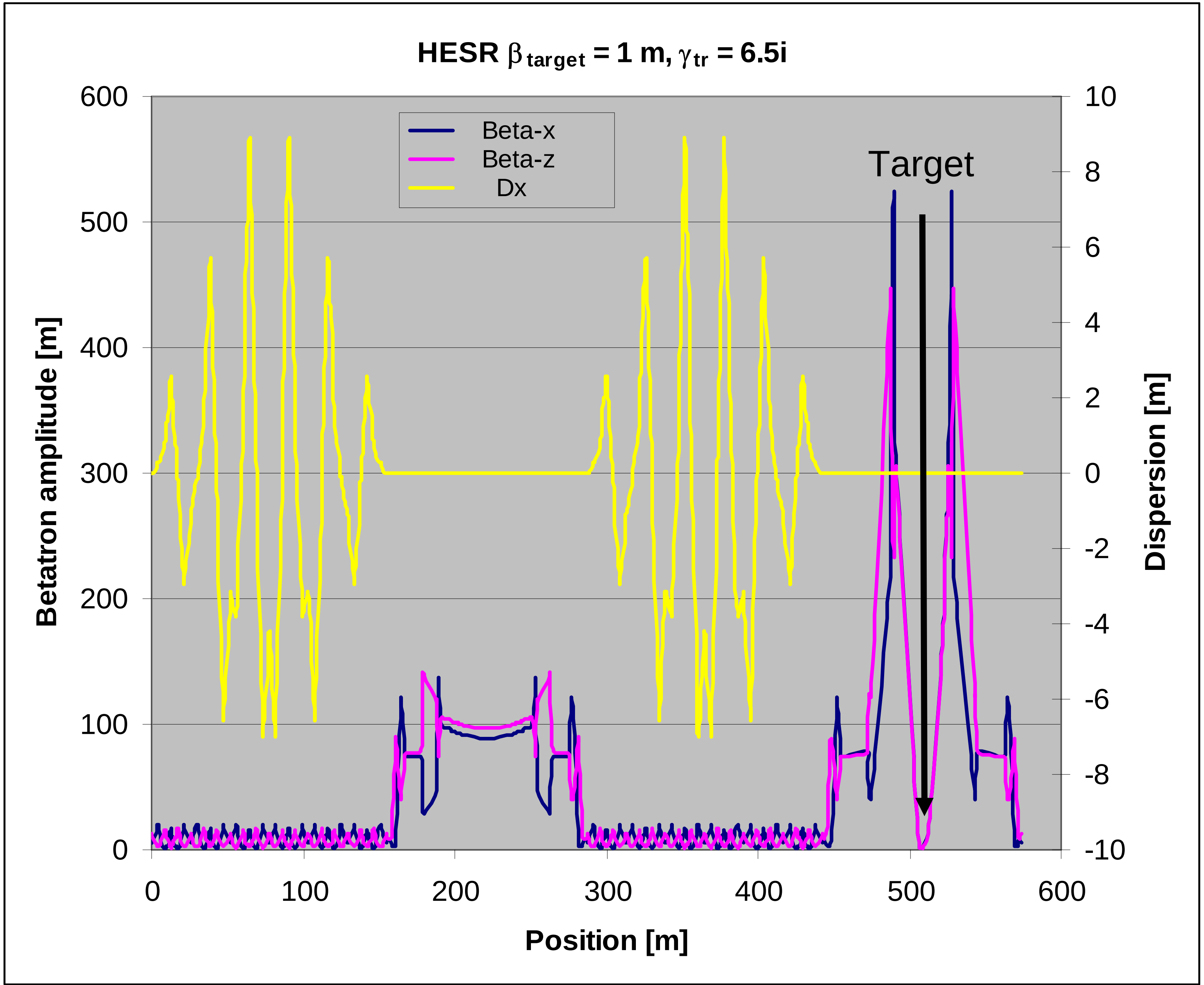
Dipoles	48	3.6 T
Quadrupoles	112	60 T/m
Sextupoles	24	560 T/m^2
Correctors	112	1 mrad

Impression of the segmented 180 degree cryostat





September 24, 2006


HESR β target = 1 m, γ tr = 6.5i
Beta-x
Beta-z
Dx
Target
Betatron amplitude [m]
Dispersion [m]
Position [m]
600
500
400
300
200
100
0
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
100
200
300
400
500
600

Modes of Operation with PANDA

Experiment Mode	High Resolution Mode	High Luminosity Mode
Target	Pellet target with $4 \cdot 10^{15}$ cm^{-2}	
rms-emittance	1 mm mrad	
Momentum range	1.5 – 8.9 GeV/c	1.5 – 15.0 GeV/c
Intensity	$1 \cdot 10^{10}$	$1 \cdot 10^{11}$
Luminosity	$2 \cdot 10^{31}$ cm^{-2} s^{-1}	$2 \cdot 10^{32}$ cm^{-2} s^{-1}
rms-momentum resolution	$1 \cdot 10^{-5}$ … $4 \cdot 10^{-5}$	$1 \cdot 10^{-4}$

Injection Parameters at 3.8 GeV/c for the …

High Resolution Mode ($1*10^{10}$ p)	High Luminosity Mode ($1*10^{11}$ p)
▪ $\varepsilon_{rms,\ geom.}$ = 0.1 mm mrad	▪ $\varepsilon_{rms,\ geom.}$ = 0.6 mm mrad
▪ $\Delta p/p_{rms}$ = $1.5*10^{-4}$	▪ $\Delta p/p_{rms}$ = $3.8*10^{-4}$

High Resolution Mode

between 1.5 and 8.9 GeV/c

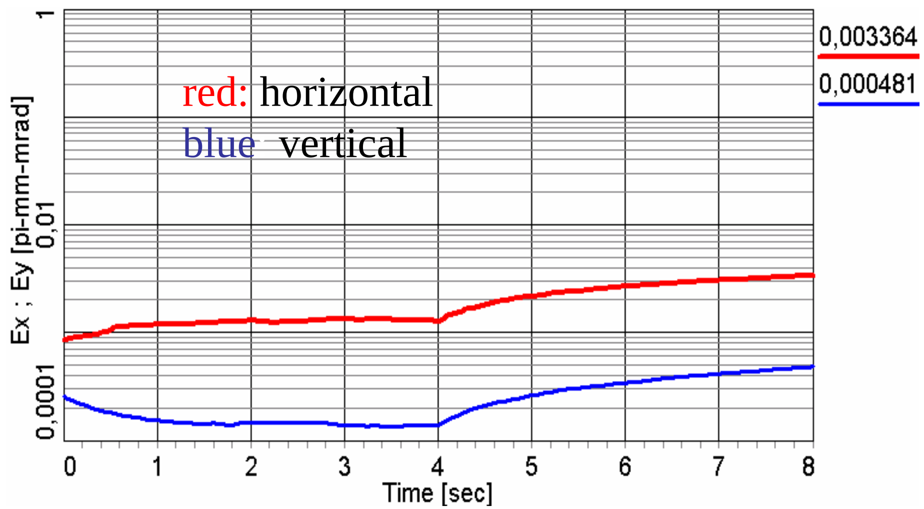
- Injection at 3.8 GeV/c
  - N $= 10^{10}\ \bar{p}$
  - ε_{rms} = 0.1 mm mrad
  - $\Delta p/p_{rms}$ $= 1.5 \cdot 10^{-4}$

- Acceleration/Deceleration to required momentum (up to 60 s)

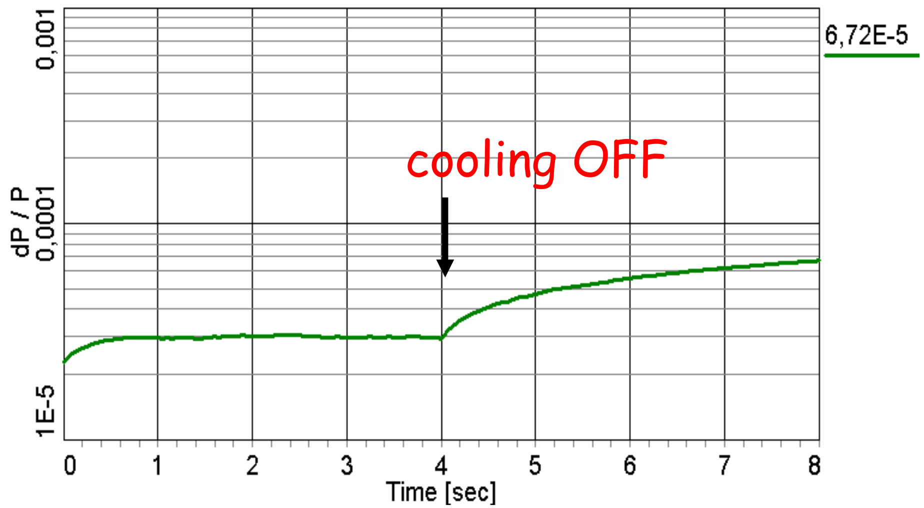
- Experiment with electron cooling

Electron Cooling : HR-Mode @ p = 8.9 GeV/c

Number of antiprotons:	10^{10}	
Initial rms emittance (H):	0.000861	mm mrad
Initial rms emittance (V):	0.000258	mm mrad
Initial rms relative momentum spread:	$2.28 \cdot 10^{-5}$	
Rms-beam radius at cooler (H):	0.3	mm
Rms-beam radius at cooler (V):	0.2	mm
Revolution frequency:	519.40	kHz
Kinematic beta:	0.994	
Kinematic gamma:	9.526	
Frequency slip factor:	0.035	
Luminosity:	$2 \cdot 10^{31}$	$cm^{-2}\ s^{-1}$



- Electron cooling and target ON



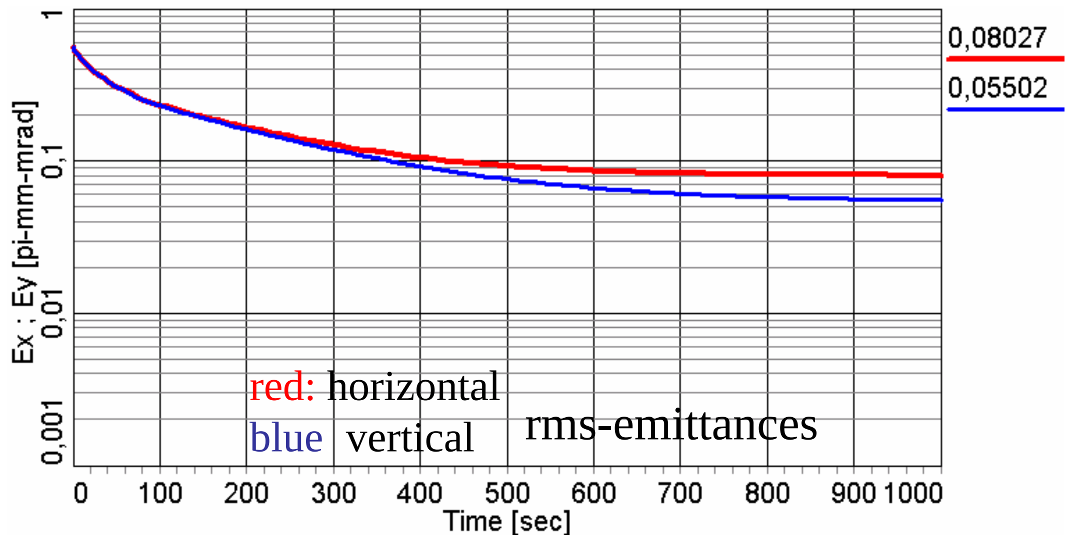
- Equilibrium dominated by IBS

Final rms-momentum spread with target and IBS :

3.0×10^{-5}

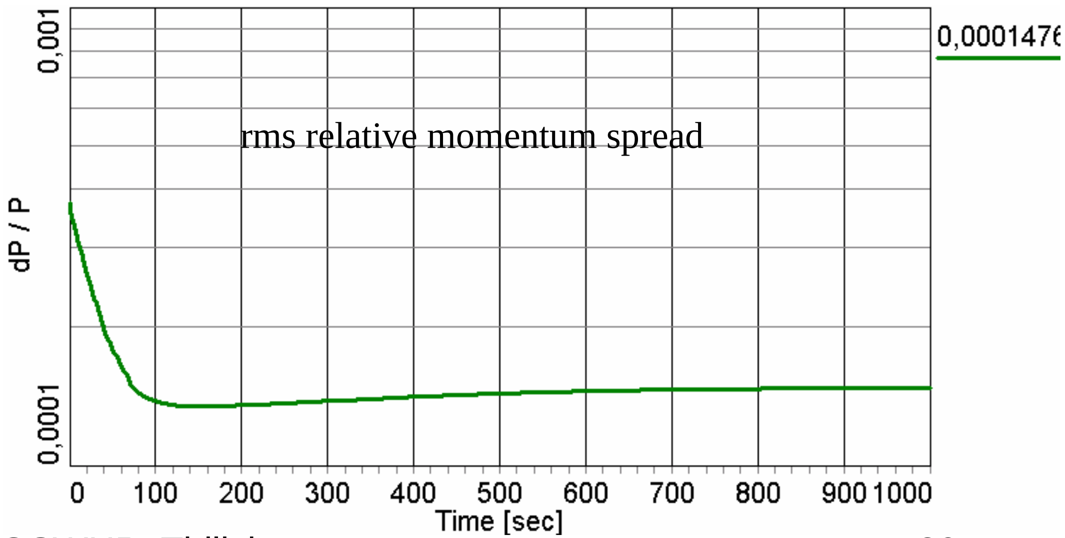
Stochastic Cooling: HL-Mode @ p = 3.8 GeV/c

Transverse and longitudinal stochastic cooling



Including IBS+Target

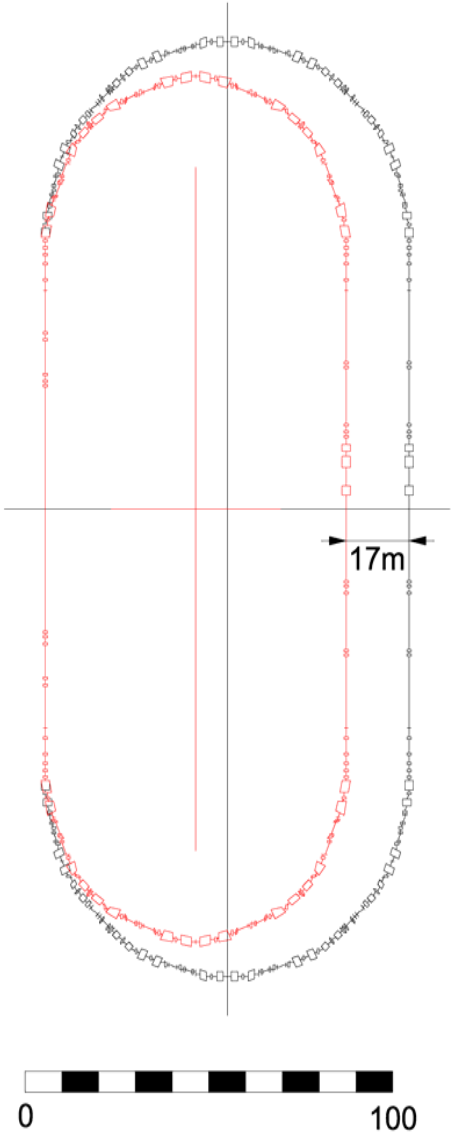
Final rms-momentum spread:
$\approx 1.5 \times 10^{-4}$



- The present layout is based on 48 straight dipole magnets in the arcs

- Still under investigation: Costs for curved dipole magnets
  - Increase of momentum acceptance
  - Reduction to 32 longer magnets
  - Reduction of ring circumference
  - Extension in east-west direction reduced by 17 m

Comparison of the HESR lattice with straight or curved dipole magnets

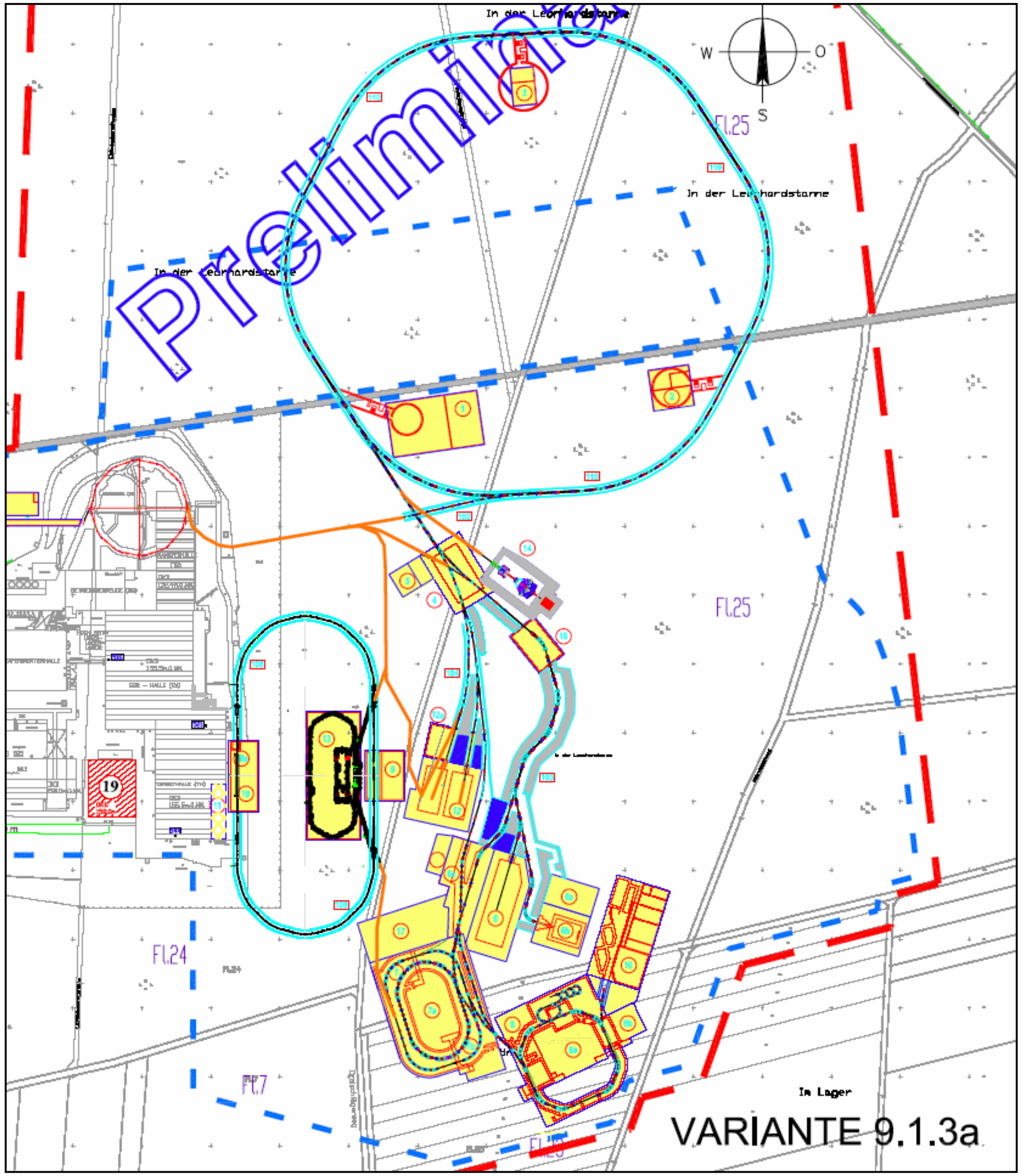


HESR 6fold symmetry
circumference 574 m
area 99m x 231m

HESR 4fold symmetry
circumference 518m (-10%)
area 82m x 214m

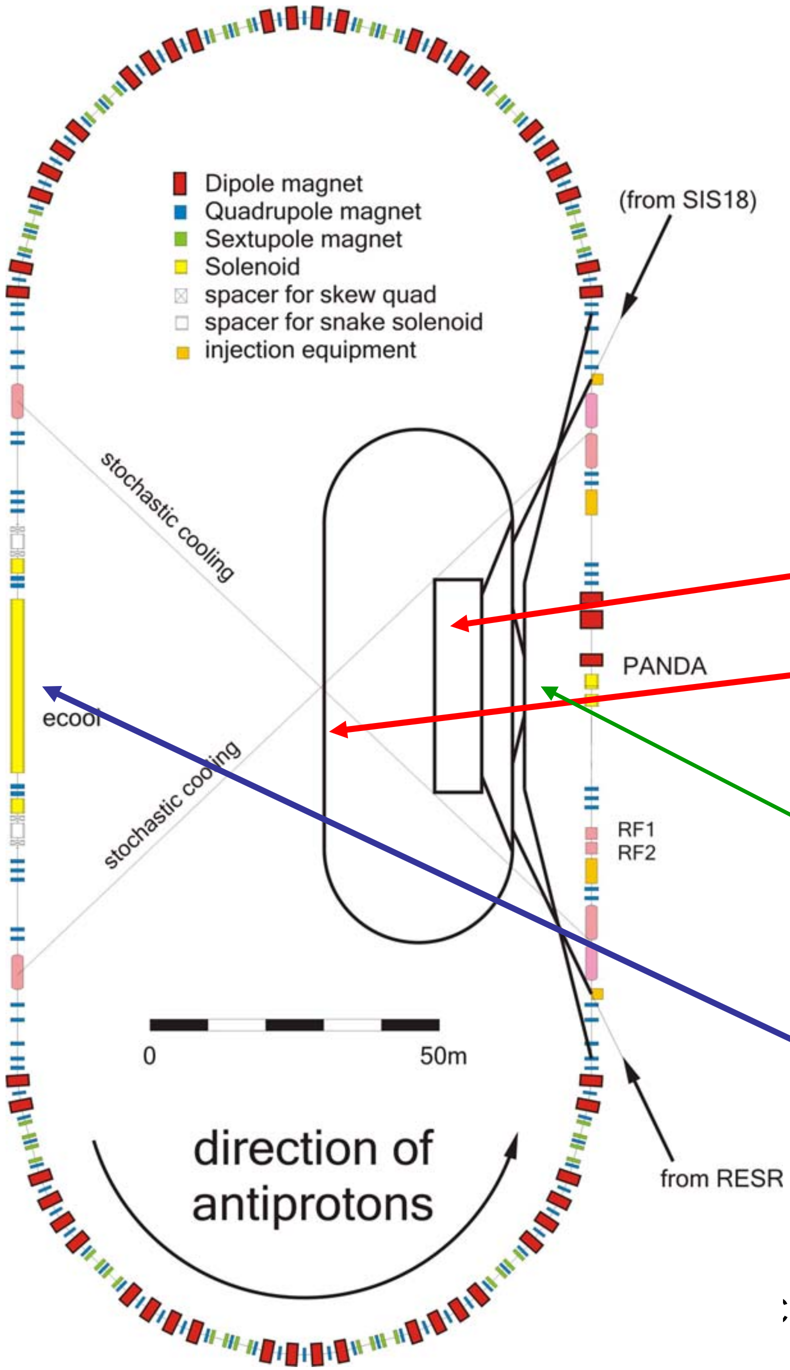
- Straight dipoles:
  - 48 dipoles with 1.8 m length
  - Sagitta of 38 mm
  - High order field components for the off-center beam

- Curved dipoles:
  - 32 dipoles with 2.7 m length
  - No sagitta
  - Beam is centered in the dipole



Advantage of the curved dipole lattice:

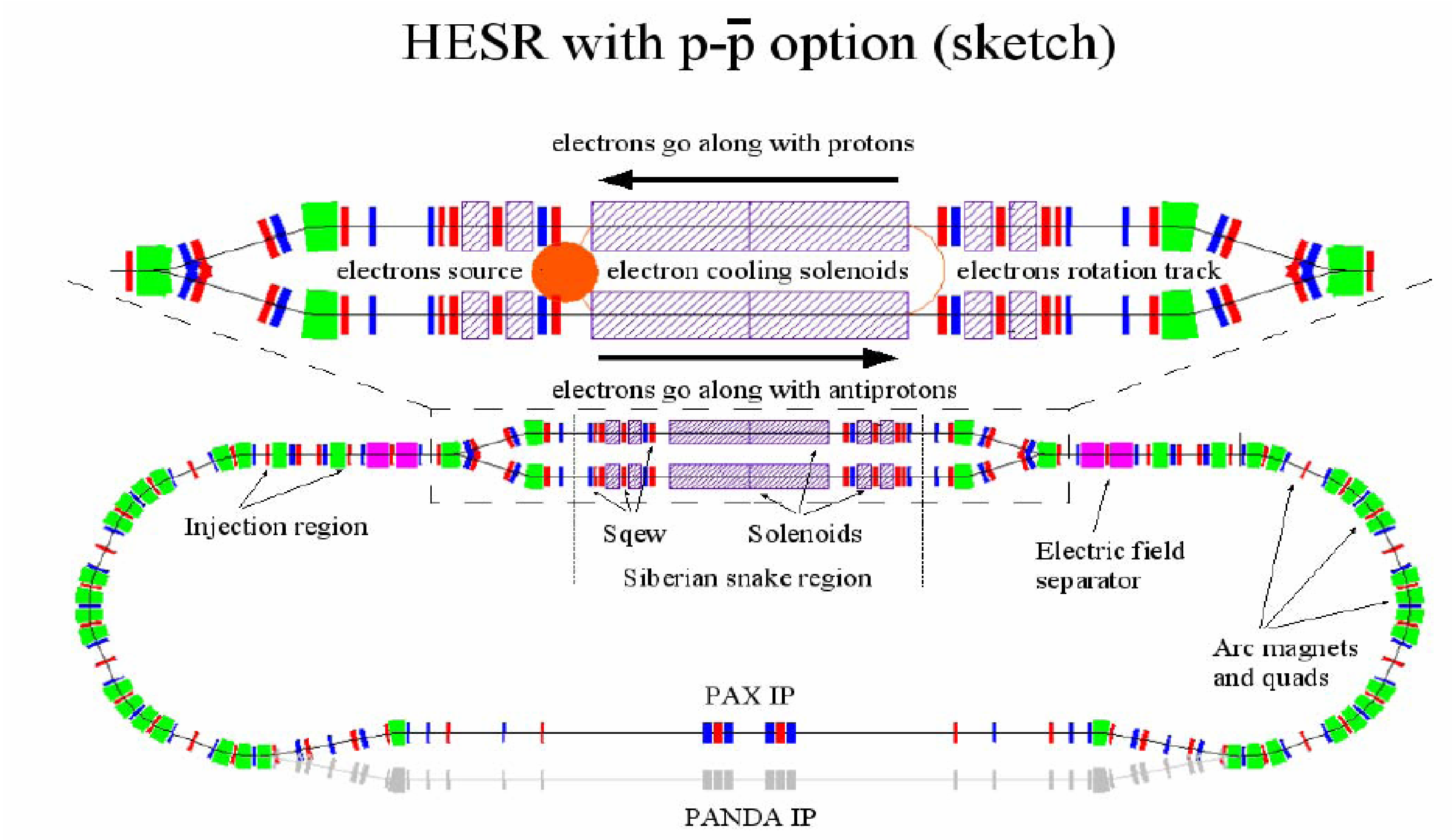
More space between PANDA-hall and Plasma Physics Cave



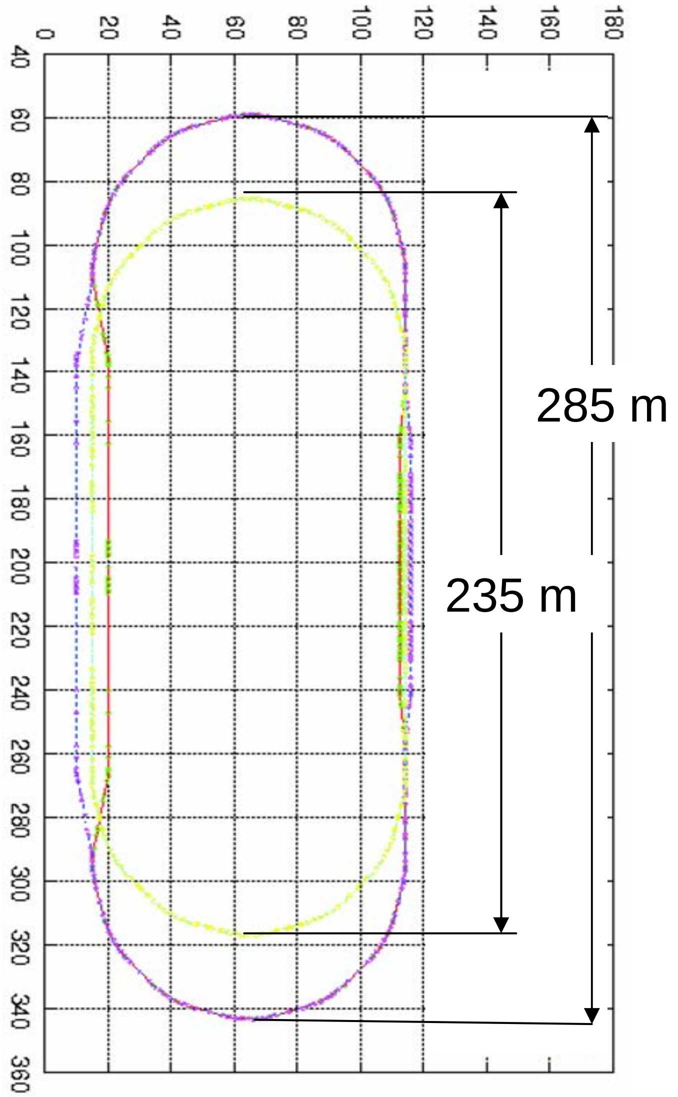
Steps in View of Future Experiments

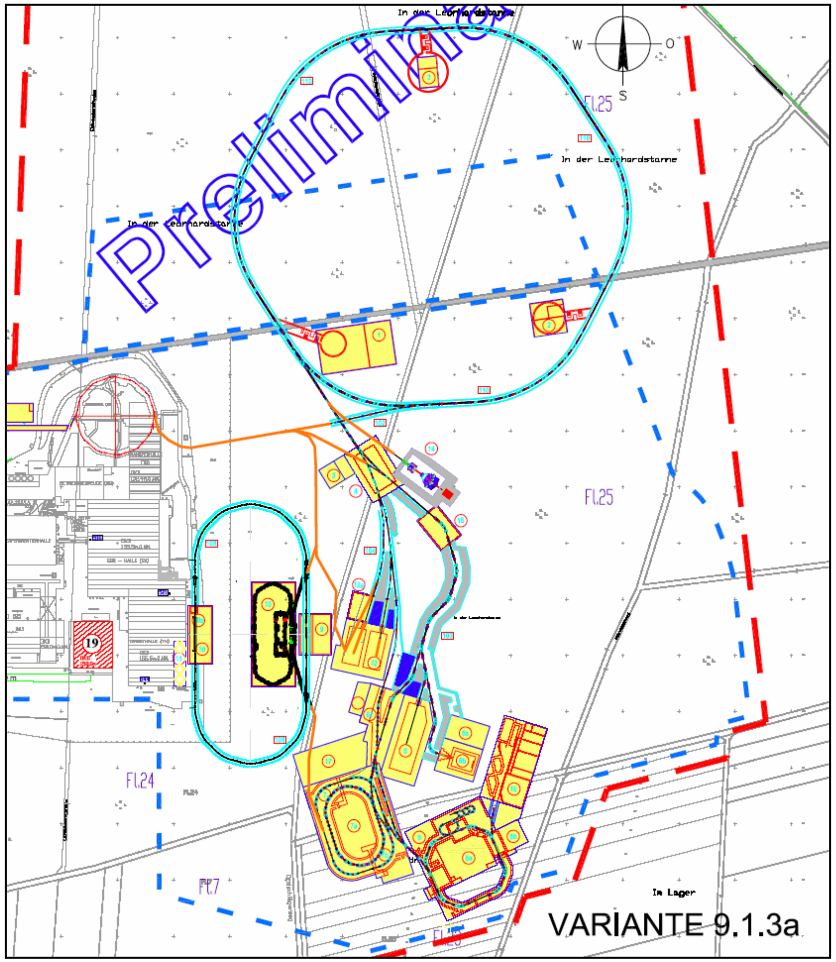
1. for production of polarized antiprotons:
   APR and
   CSR
2. For PAX in its optimum stage:
   "asymmetric" collider
3. Upgrade of the electron cooler to 8 MeV

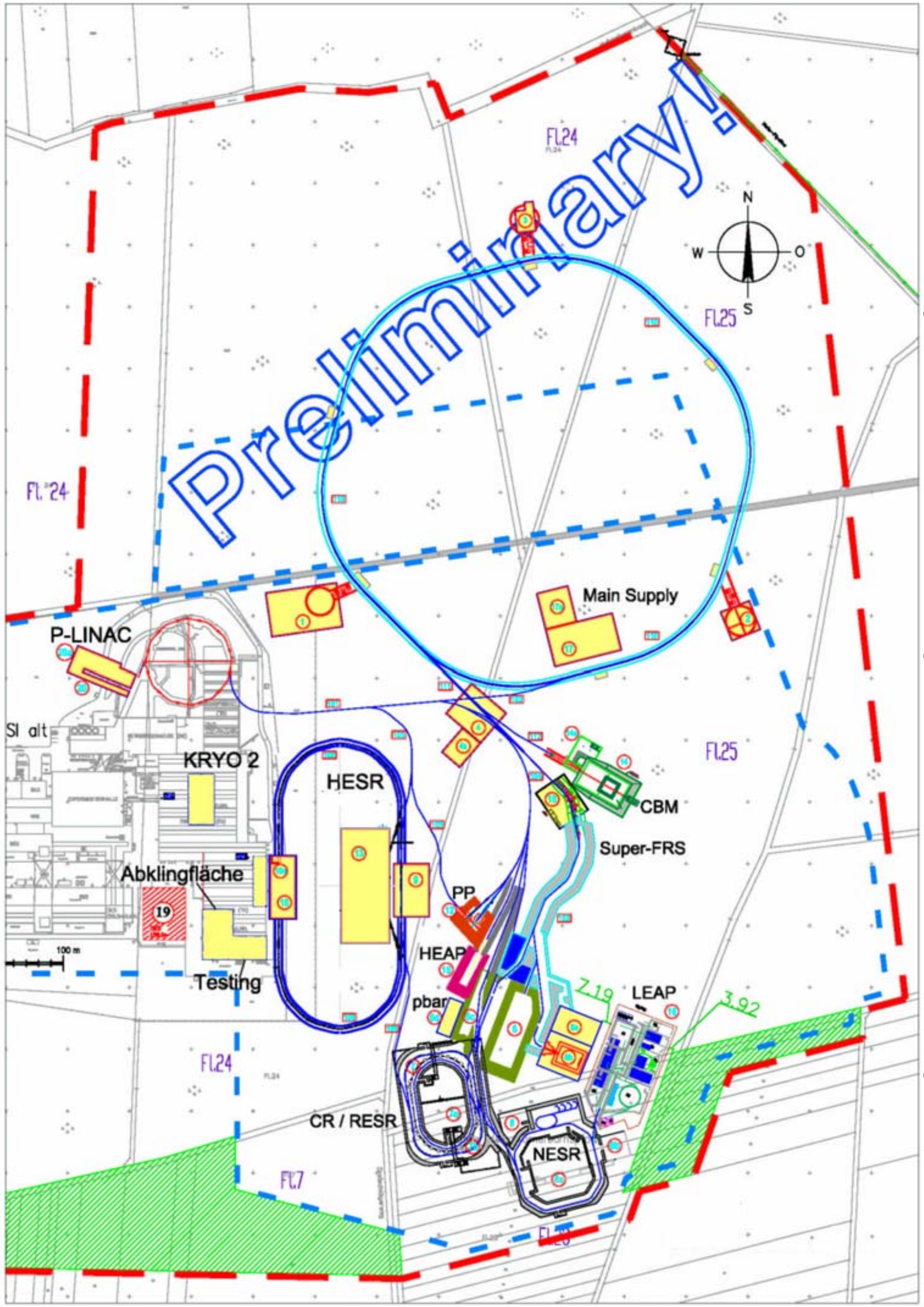
The “symmetric collider” scheme worked out by Yuri Shatunov



Problems connected to the symmetric collider lattice







Preparations in view of the symmetric collider:

- We continue the design of the HESR as planned now
- It is checked if the position of HESR can be moved by 30 m to the South
- This gives space for the future extension in North – South direction

Summary

or:

My Personnel View of the HESR tasks

- PANDA is part of the CORE program
  - The layout of HESR to meet the PANDA experimental requirements is finalized

- PAX is a 2nd generation experiment:
  - Buildings and infrastructure for PAX and the additional rings are foreseen
  - An upgrade to the asymmetric collider is taken into account in the planning
  - Electron cooling can be upgraded to maximum HESR energy

- The symmetric collider is a project of the far future
  - The topology of FAIR will foresee space “not to exclude” a later re-arrangement of the HESR

Technical Challenges for HESR

- Design of curved dipole magnets (ρ=13 m)
- High bandwidth stochastic cooling system (4 to 8 GHz)
- High energy electron cooler

  (4.5 MeV $\rightarrow$8 MeV)

- Beam dynamic issues for high phase space density beams