Challenges of Future Storage Rings

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Design of an Accumulator, Storage Ring (and Synchrotron)

- Experiment (Steffen):
  - high beam quality
  - internal experiments
  - large energy range
- State of the Art Technology
  - phase space cooling
  - internal targets - polarized
  - design tools

Experimental Requests to APR

- Energy   injection   50 MeV
  maximum   350 MeV
- Internal experiments
  bright beam ~ 10 mm * 250 mrad
  phase space cooling
  long life time ~ 10 h (10 min)
  polarisation
- Extraction - injection
  precise extraction - low losses

Internal vs. External Experiments

- Internal
- All particles in the ring hitting the target every turn
- Target heating corrected by cooling
- Each particle is used for the experiment

- External
- One particle out of ~ 10^6 is used for the experiment

Internal Experiments

- Gas-, cluster -, fiber -, foil - targets
- Requested space 5 * 2 * 2 m^3
- Matching of beam to target
- Maximise luminosity
- Definition of dispersion

High Beam Quality

- Beam diameter < 10 mm
- Flux 10^8,..., 10^{11} ppb
- Flux variation in time < 10 %
- Momentum spread ~ 10^{-3}
- Adjustable optics at experiment

Event rate = Luminosity * cross section
accelerator ⊗ physics

- Luminosity =
  particles per second * atoms per cm^2

COSY

$$L = \frac{dN}{dt} \bullet \frac{atoms}{area} \bullet o_{verlapp}$$ $2.4 \cdot 10^{30}$

$$\frac{dN}{dt} = N_0 \bullet f_{rev} \bullet \text{duty cycle}$$ $5 \cdot 10^{16}$

$$\frac{atoms}{area} = \frac{L_{oschmidt}}{Mol} \bullet \rho \bullet th$$ $\geq 10^{14}$

$$o_{verlapp} = \frac{area(beam) \wedge area(target)}{area(beam)}$$ 0.5

Maximize luminosity

$$L = \frac{dN/dt}{area(beam)} \bullet \frac{atoms}{area(target)} \bullet area(target) \wedge area(beam)$$

o - adjust beam well centered to the target

$\frac{atoms}{area}$ - target thickness limited because of particle losses

$$\frac{dN/dt}{area(beam)} = \frac{I/e}{\langle x \rangle \cdot \langle y \rangle} = \frac{I/e}{\sqrt{\varepsilon_x \cdot \beta_x} \cdot \sqrt{\varepsilon_y \cdot \beta_y}} = \frac{I}{\bar{\varepsilon}} \bullet \frac{1}{\bar{\beta}} \bullet \frac{1}{e}$$

→ maximize brilliance $= \frac{I}{\varepsilon}$ - minimize β - function

Maximum luminosity by maximum brilliance

- Ion source defines final brilliance
- Charge exchange injection multiplies brilliance (COSY 800) by increase of the phase space density
- Phase space cooling rises brilliance by reducing area (beam)

F.O.M. = $P^2 * I$ - Filter method

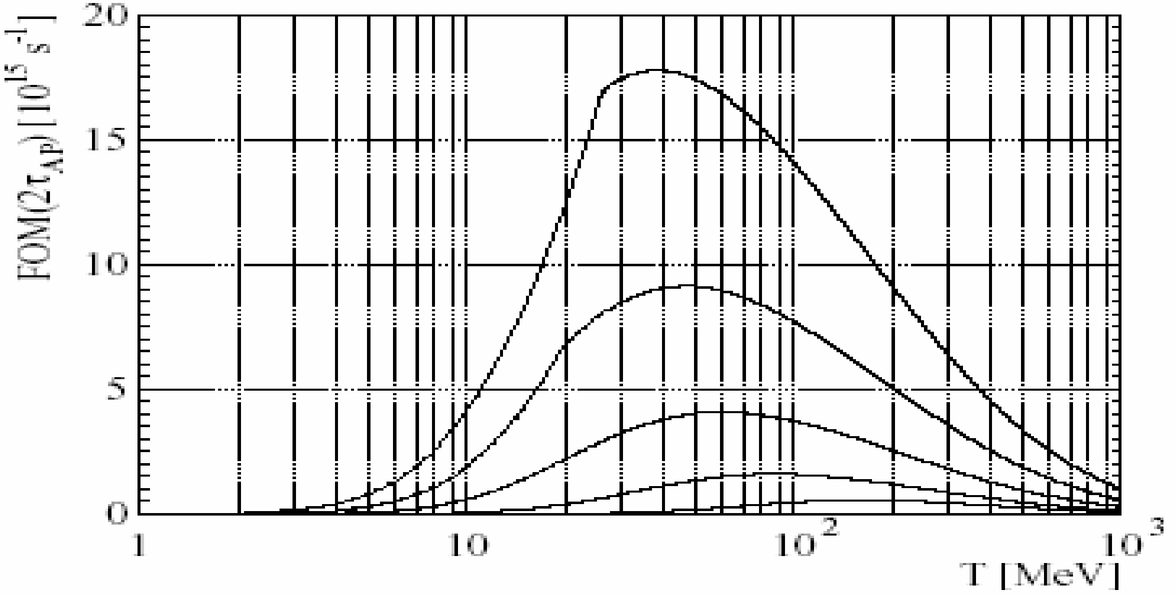


Figure 15: Figure of Merit for the polarized antiproton beam for filtering times $t = 2 \cdot \tau_{APR}$ as function of beam energy. The parameters associated with the maxima are summarized in Table 3. (Lines are organized as in Fig. 12.)

Design tools - optics

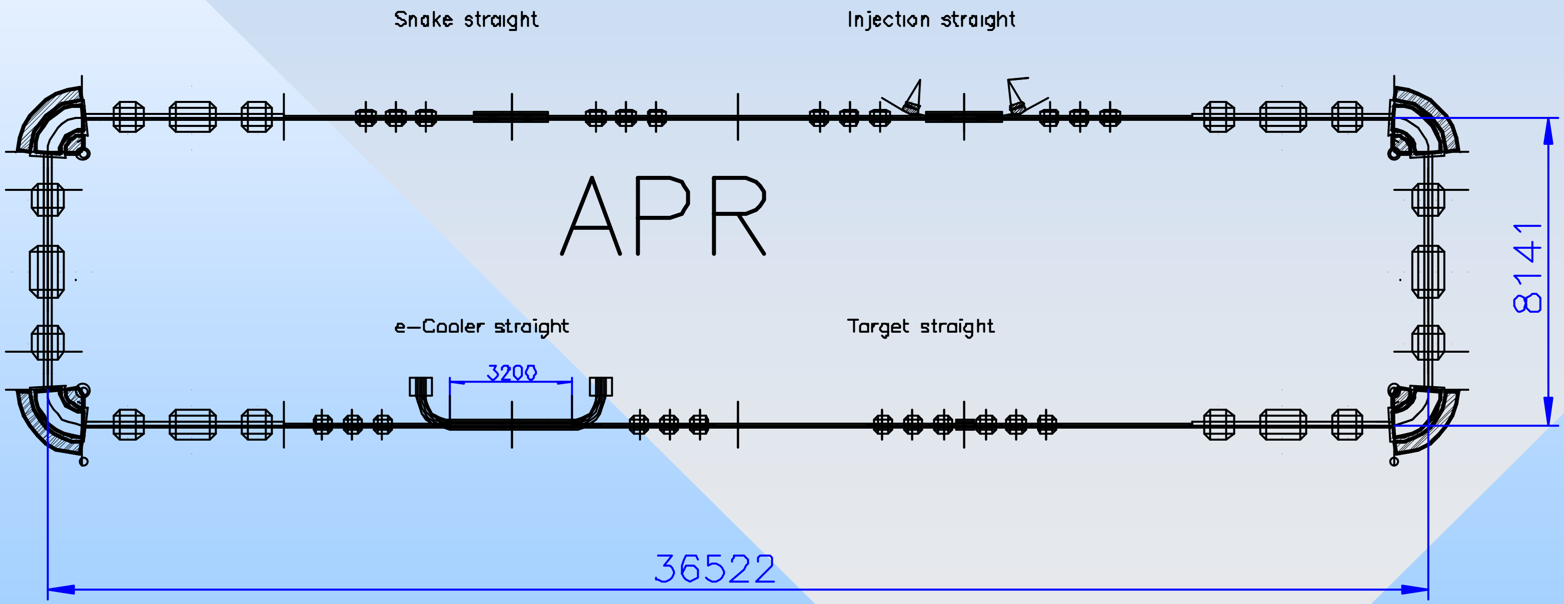
- Separated function lattice
  bending separated from focusing
- Injection by charge exchange and stacking
- Extraction on resonance (ultra slow, COSY)
  or by kicker-septum
- cost optimized design

Lattice - separated functions

- F-D-D-F
  D-F-F-D
- Elliptic beam
  more economic
  less power
- Adjustable optics

- F-D FODO
  Triplet
- Circular beam
  higher operation cost
  lower complexity
- Simple operation

APR lattice


Snake straight
Injection straight
APR
e—Cooler straight
Target straight
3200
8141
36522

Design tools - space charge problems

- Emittance shrinks by cooling
- Optics optimised for cooling

Design tools - space charge tune shift

$$\Delta Q = -\frac{N \cdot r_0}{16\pi^3 \cdot \varepsilon \cdot \beta^2 \gamma^3} = -\frac{N \cdot r_0}{16\pi^3 \cdot E \cdot \beta \cdot \gamma^2}$$

$$\Delta Q = -\frac{N \cdot r_0 \cdot \beta_x}{16\pi^3 \cdot a^2 \cdot \beta^2 \gamma^3}$$

Design tools - extraction

- Single turn extraction (APR, CSR, HESR)
  fast kicker magnet + dc septum magnet

- Ultra slow extraction (COSY)
  - excite resonance by 6-poles (3. order)
  - move beam by noise to resonance
  - unstable particles get little kick ~2mrad
    in the electrostatic septum (ES)
  - extracted finally by dc septum magnet

Extraction - electrostatic septum

- Maximum kick ϑ_{ES} ~ 3 mrad

- Length ~ 1 m

$$\vartheta_{ES} \approx \frac{E \cdot l}{p \cdot \beta} \left[\frac{MV}{MeV/c} \right]$$

- Reliable E-field ~ 10 MV/m

Extraction - magnetic septum (MS)

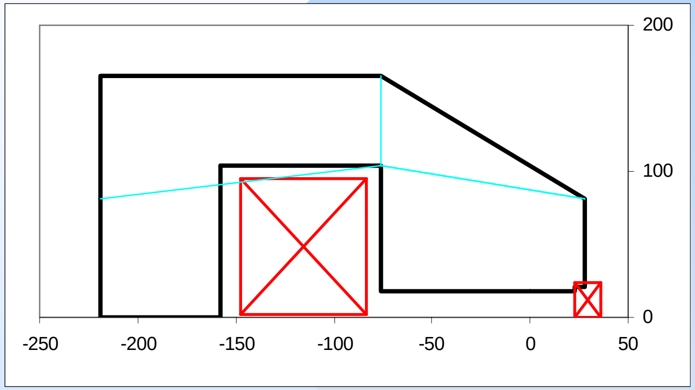
- Separation in radial direction

$\Delta x \sim 30$ mm

$$\Delta x = \sqrt{\beta_{ES} \cdot \beta_{MS}} \cdot \sin(\psi)$$

- Minimum fringe field seen by the circulating beam in MS

Septum data



Gapheight mm	34.7	
Beam radius max mm	20	
B-field max (gap)	0.636	T
B-field max (yoke)	1.5	T
good field region	20	m
Field quality dB/B	0.001	
Magnet strength	2.224	Tm
Effective field length	3.500	m
Length of steel body	3.471	m
Length total	3.841	m
Horizontal size total	0.247	m
Vertical size total	0.331	m
Total weight	2.017	t

Number of coils	2		
B-field ramp rate	0.031	T/s	
B-field rise time	20	s	
Pulse rep. rate0.1	Hz		
Resistance per magnet	0.0115	Ohm @ 20deg	
Current (max)	1435	A	
Voltage per dipole	16.5	V	
Driving voltage	121	V	
Inductivity	2.76	mH	
Power per magnet	24	kVA	
Copper conductor specs			
Current density return coil		2	A/mm^1
Current density knife	18	A/mm^2	
Copper layers hor.	2		
Copper layers vert.	3		
Insulation thickness	0.5	mm	
thicknes ground insulation		1	mm

Cost optimized design (Chris)

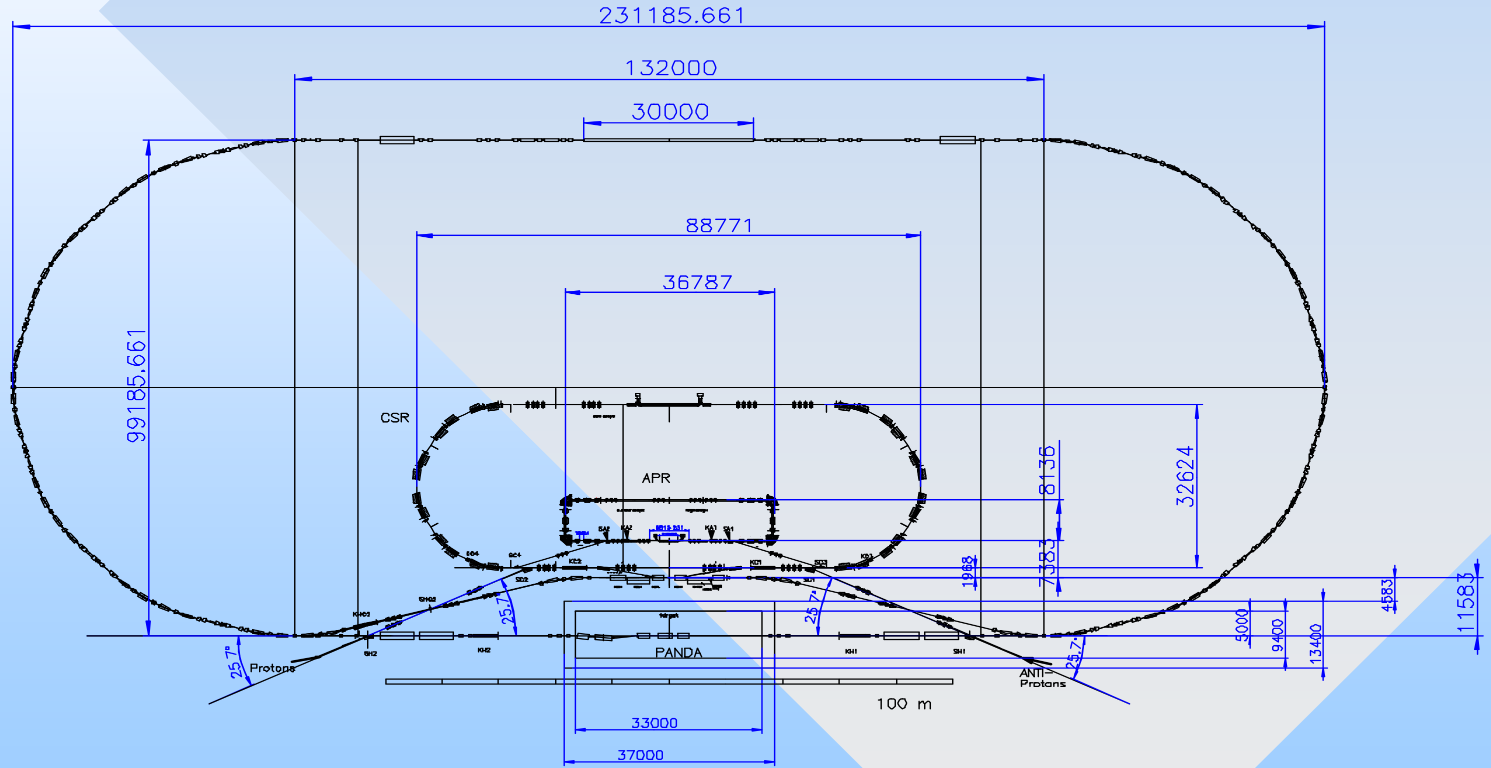
- Design optics:
  - small gap in dipole magnets
    power ~ gap^2
  - keep maximum field low: B~1T
    Vol. iron ~ length * area
    ~ 1/B * B^2
    ~ B

lower field-> lower cost-> larger accel. !

Challenges of future storage rings

- Phase space cooling
- Large acceptance e. g. APR
- Beam life time
- Reliability, availability
- Losses
- Cost optimisation
- Investment and operation

The Challenge: PAX and HESR



Questions to be answered in the proposal

- Feasibility
- Qualify state of the art
- Qualify R&D
- Costs
- Reliability, availability
- Man power
- Operation