Mitglied der Helmholtz-Gemeinschaft

JÜLICH FORSCHUNGSZENTRUM

Machine Aspects of Spin-Filtering Experiments

September 29th, 2008 Bernd Lorentz

For COSY-Juelich and the PAX collaboration

Outline

- General remarks about Spin Filtering
  Plan for polarized Antiproton Experiment
- Tests at COSY
  - Requirements:
    - Beam life time
    - Polarization life time
  - First Results
- Conclusion

Spin Filtering Experiments - Why?

• Polarized protons:	ion source
• Antiprotons:	production is unpolarized
• A method to polarize antiprotons:	interaction with a polarized target

Principle of Spin Filter Method

$$\sigma_{tot} = \sigma_0 + \sigma_\perp \cdot \vec{P} \cdot \vec{Q} + \sigma_{||} \cdot (\vec{P} \cdot \vec{k})(\vec{Q} \cdot \vec{k})$$

P beam polarization
Q target polarization
k || beam direction

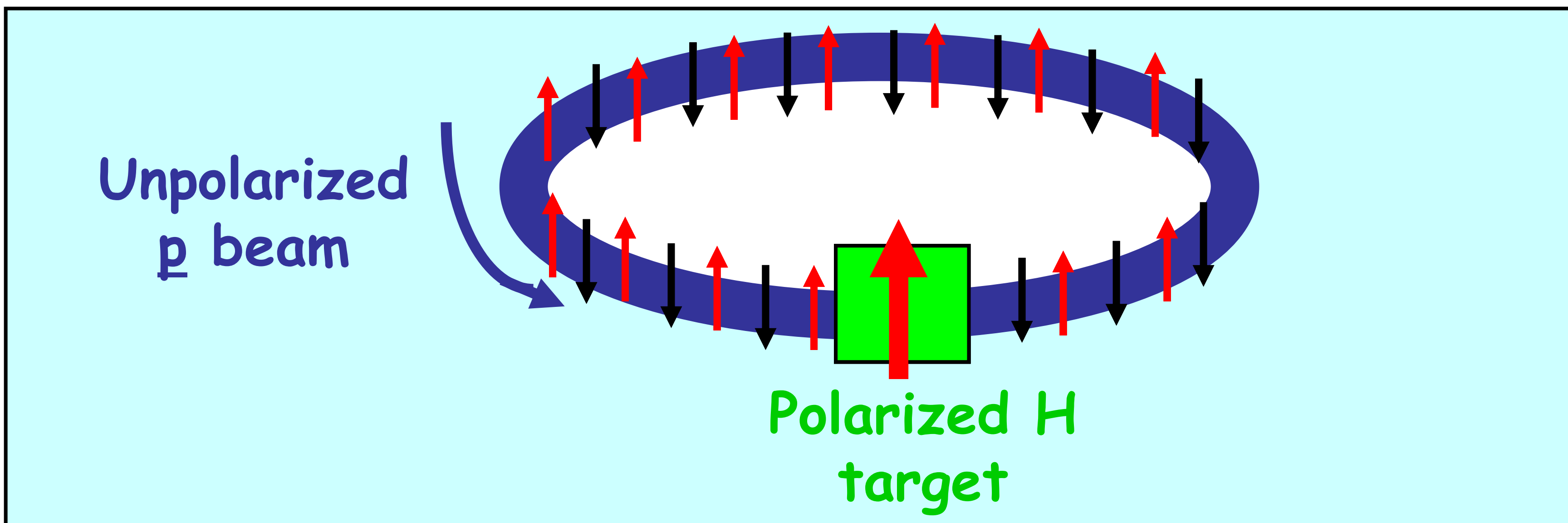
For initially equally populated spin states: ↑ ($m=+\frac{1}{2}$) and ↓ ($m=-\frac{1}{2}$)

transverse case:

$$\sigma_{tot\pm} = \sigma_0 \pm \sigma_\perp \cdot Q$$

longitudinal case:

$$\sigma_{tot\pm} = \sigma_0 \pm (\sigma_\perp + \sigma_{||}) \cdot Q$$



Principle of Spin Filter Method

$$\sigma_{tot} = \sigma_0 + \sigma_\perp \cdot \vec{P} \cdot \vec{Q} + \sigma_{||} \cdot (\vec{P} \cdot \vec{k})(\vec{Q} \cdot \vec{k})$$

P beam polarization
Q target polarization
k || beam direction

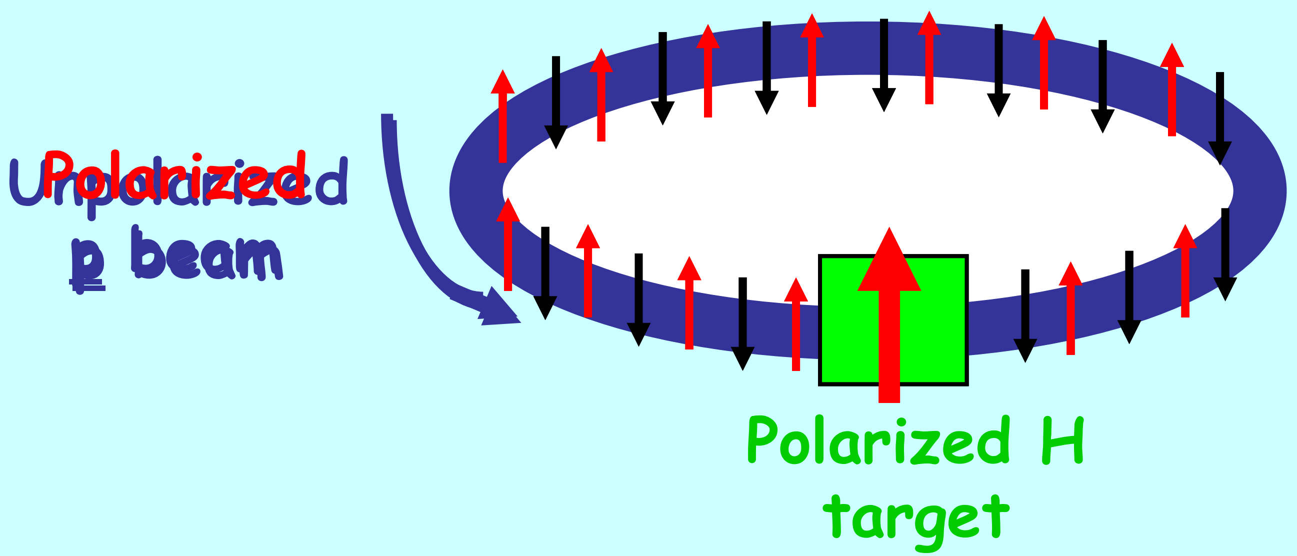
For initially equally populated spin states: ↑ ($m=+\frac{1}{2}$) and ↓ ($m=-\frac{1}{2}$)

transverse case:

$$\sigma_{tot\pm} = \sigma_0 \pm \sigma_\perp \cdot Q$$

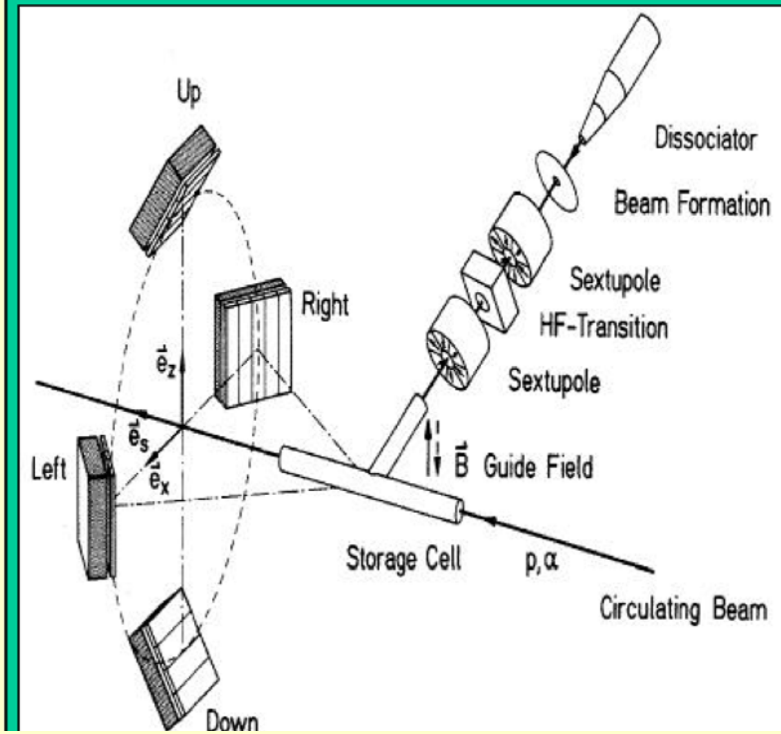
longitudinal case:

$$\sigma_{tot\pm} = \sigma_0 \pm (\sigma_\perp + \sigma_{||}) \cdot Q$$

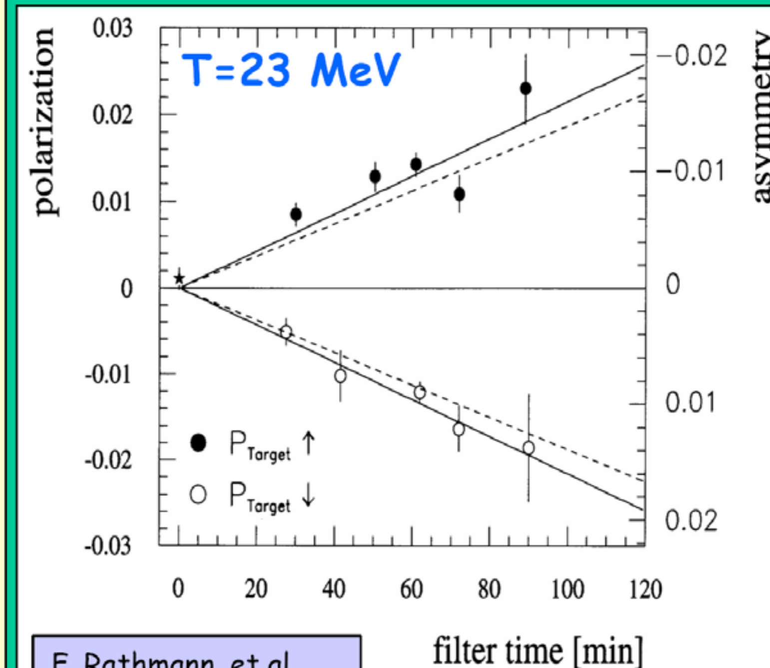


1992 Filter Test at TSR with protons

Experimental Setup



Results



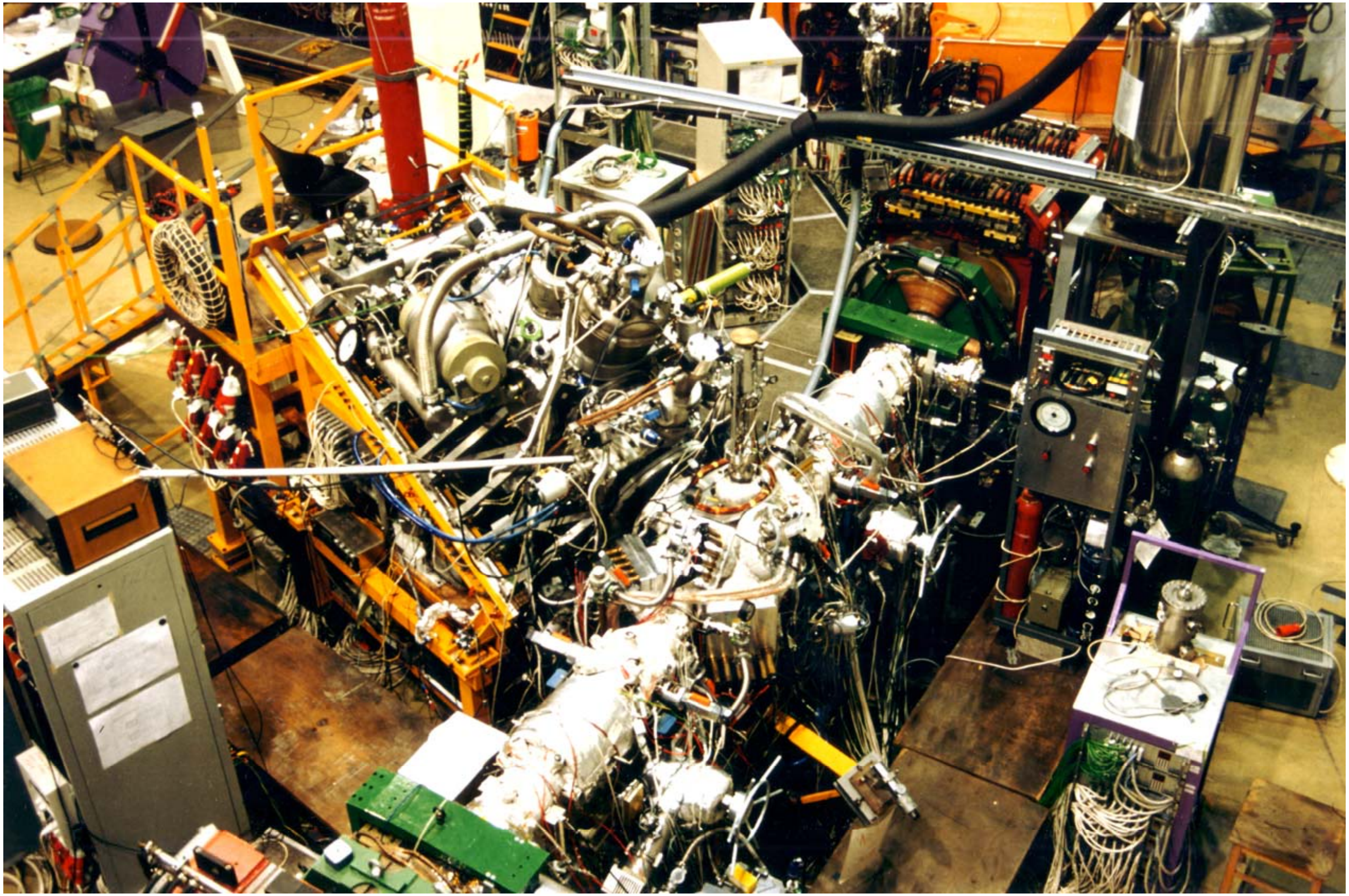
F. Rathmann. et al., PRL 71, 1379 (1993)

Observed polarization build-up: $dP/dt = \pm (1.24 \pm 0.06) \times 10^{-2}\ h^{-1}$

$P(t)=\tanh(t/t_1),\ \ 1/t_1=s_1 Q d_t f$

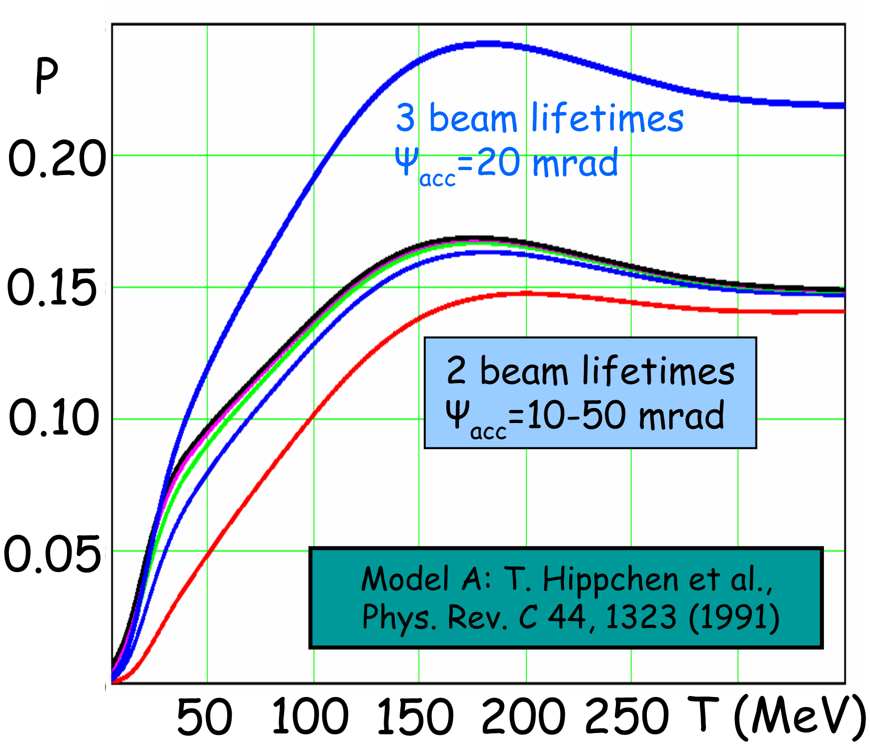
$s_1 = 72.5 \pm 5.8$ mb

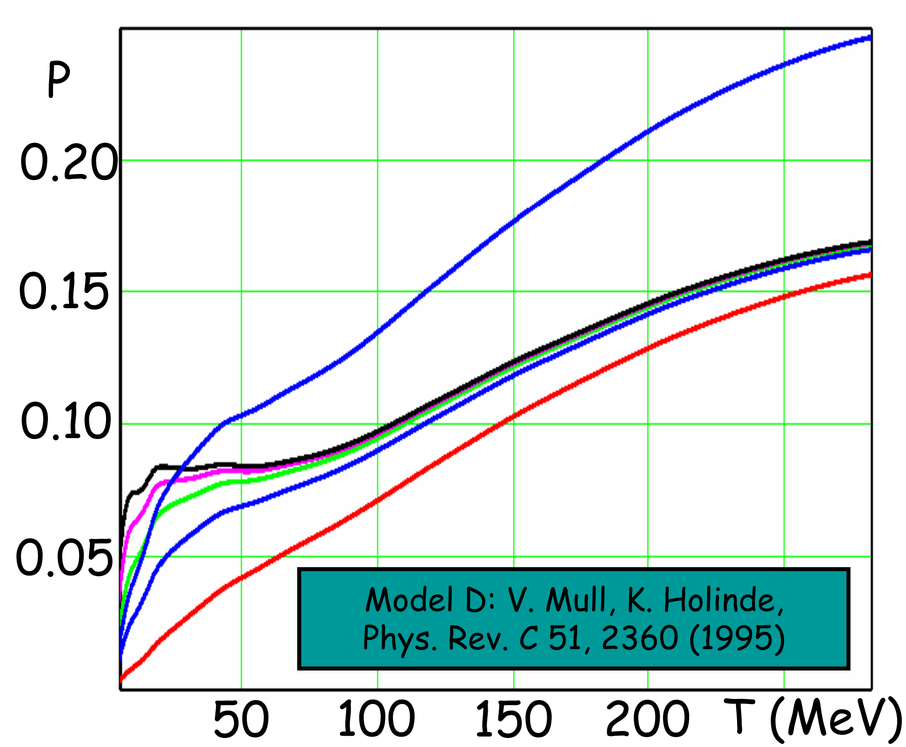
Experimental Setup at TSR (1992)



Beam Polarization

(Hadronic Interaction: Longitudinal Case)





Experimental Tests required:

- **Repetition of Filtex with protons at COSY**
- **Filter test with p at AD of CERN**
- **Final Design of Antiproton Polarizer Ring (APR)**

Final Goal for the PAX Accelerator Setup

Antiproton Polarizer Ring (APR)

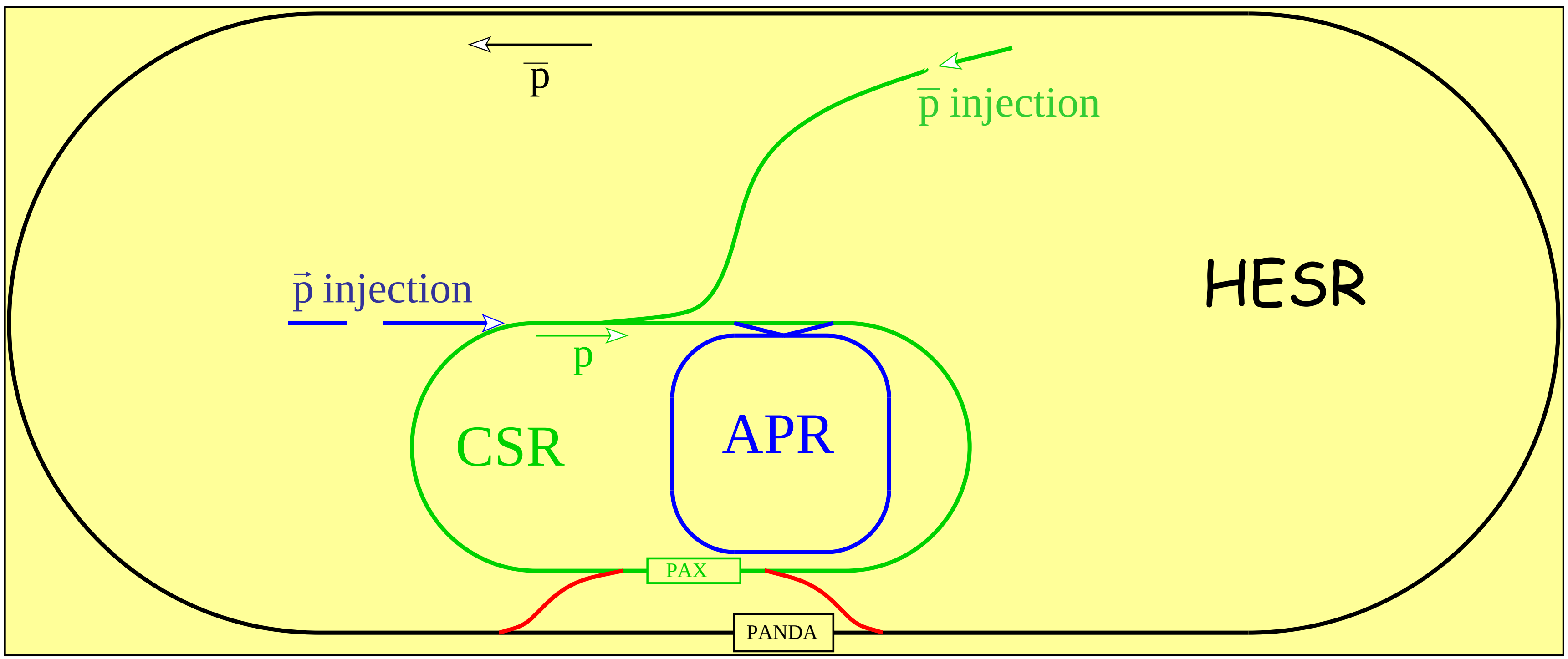
+

Cooler Storage Ring (CSR, COSY-like): 3.5 GeV/c

+

HESR: 15 GeV/c

→ **Asymmetric Double-Polarized Antiproton-Proton Collider**



Timeline

Phase 0: 2005-2012

APR design and construction.

Physics: buildup measurements @ COSY and CERN

Phase I: 2013-2017

APR+CSR @ GSI

Physics: EMFF, p-pbar elastic with fixed target

Phase II: 2018 - …

HESR+CSR asymmetric collider

Physics: h_1

Timeline

Phase 0: 2005-2012

APR design and construction.

Physics: buildup measurements @ COSY and CERN

Phase I: 2013-2017

APR+CSR @ GSI

Physics: EMFF, p-pbar elastic with fixed target

Phase II: 2018 - …

HESR+CSR asymmetric collider

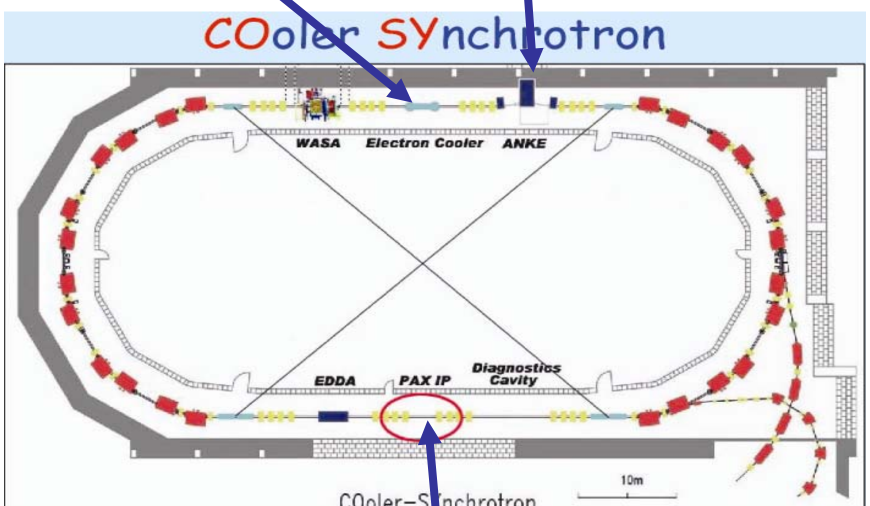
Physics: h_1

Preparations at COSY

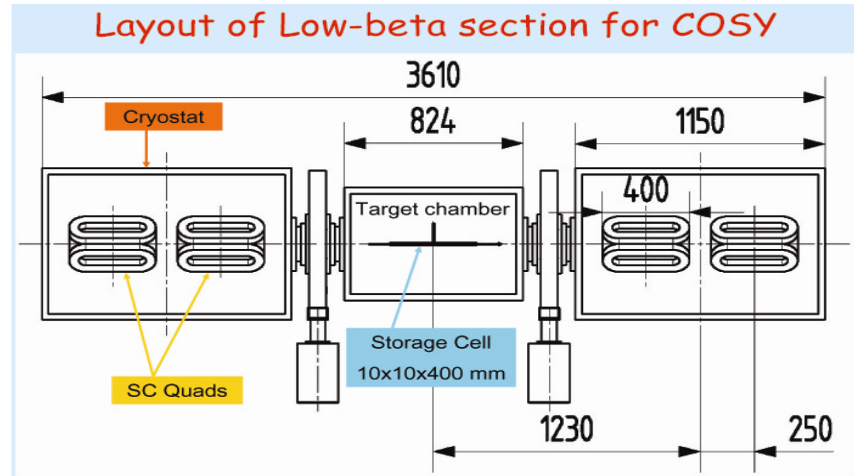
45-2800 MeV p, but experimental program so far mainly at T > 500 MeV

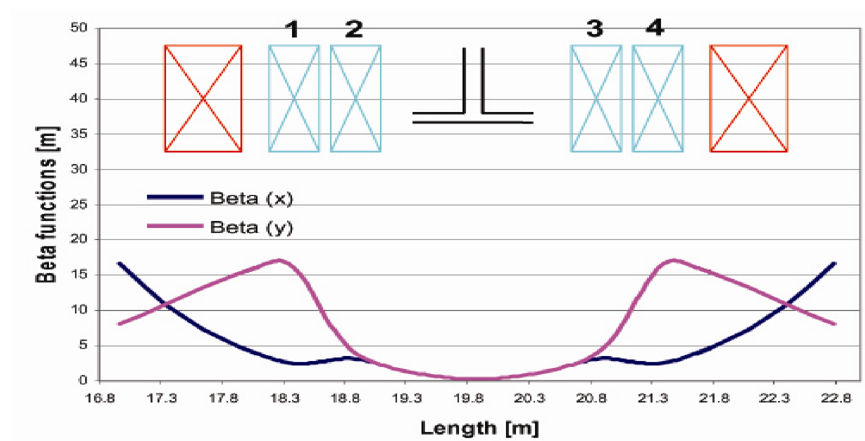
Anke Target: Cluster jet or polarized storage cell target

Electron Cooler



Future low beta target position





Ongoing Investigations at COSY

1st Requirement: Beam Life Time

The beam life time is limited by:

1. Multiple Coulomb scattering
2. Mean energy loss

   $\Rightarrow$ effective beam cooling

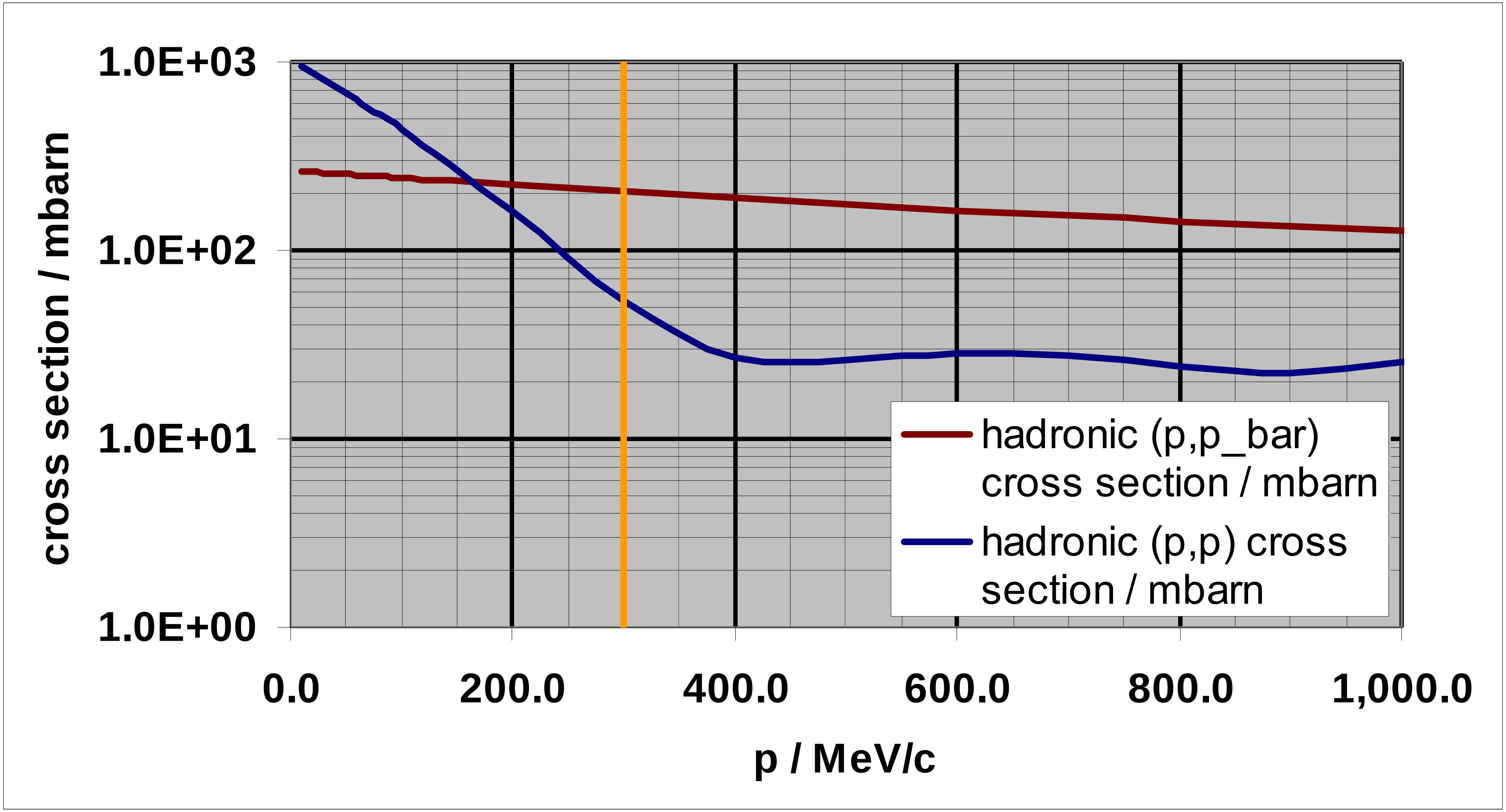
3. Single Coulomb scattering out of the ring acceptance
4. Energy loss out of the momentum acceptance of the ring
5. Hadronic interactions

Mitglied der Helmholtz-Gemeinschaft

JÜLICH FORSCHUNGSZENTRUM

Losses due to hadronic interaction

Total p -- p-bar cross section



Losses due to Single Coulomb Scattering

Single Coulomb scattering out off the ring acceptance

Definition of ring acceptance:

$$acc = \frac{r^2}{\beta_{\max}}$$

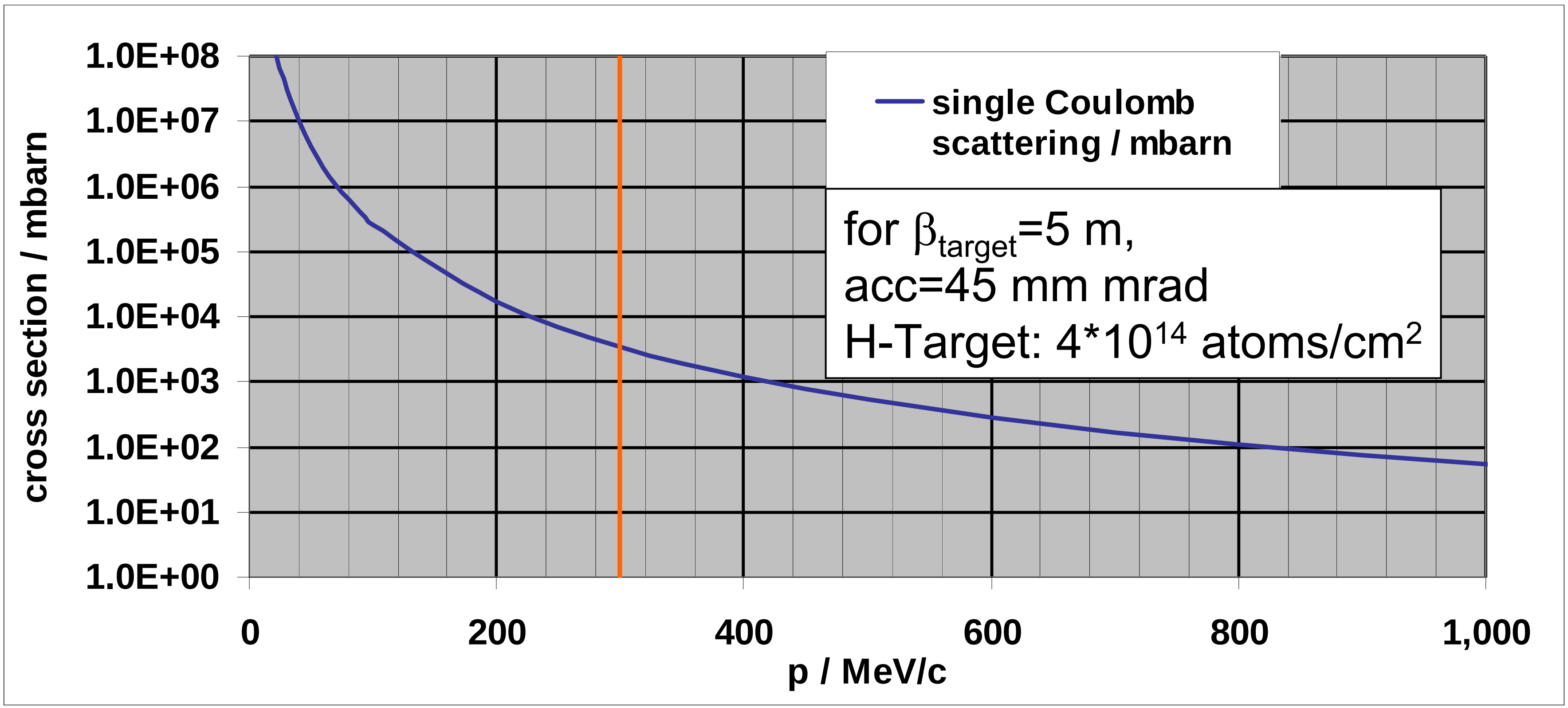
with r=30 mm and β_{max}=20 m
➔ acc = 45 mm mrad

Acceptance angle for target scattering:

$$\theta_{acc} = \sqrt{\frac{acc}{\beta_{target}}} = \frac{r}{\sqrt{\beta_{target} \cdot \beta_{\max}}}$$

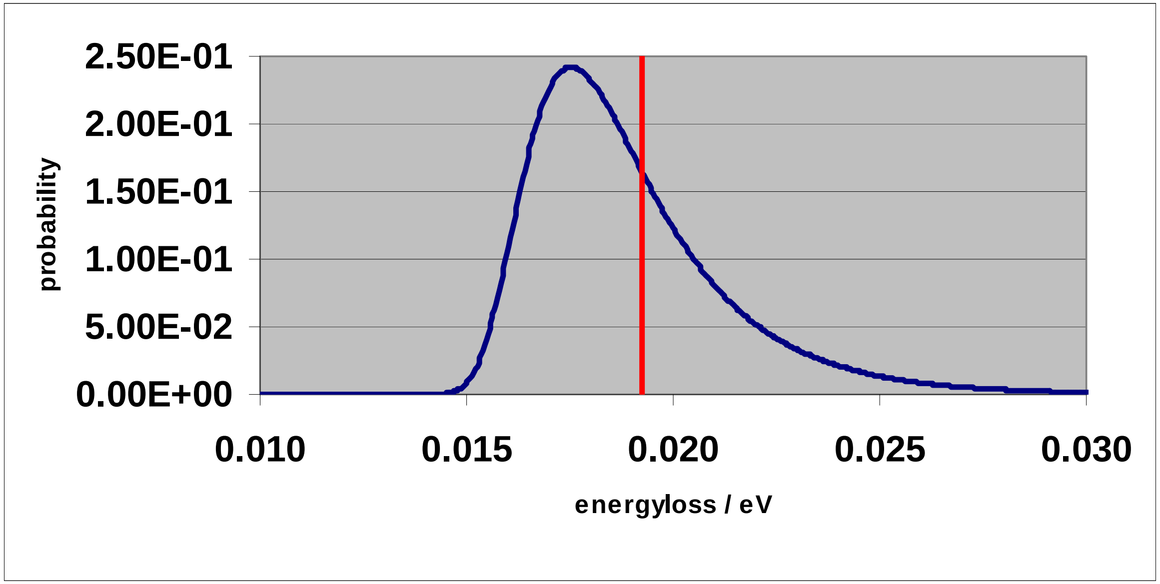
with β_{target}=5 m
➔ θ_{acc} = 3 mrad

Single Coulomb scattering cross section



Losses due to energy loss

Energy loss distribution



Example:

p=300 MeV/c

H-target $4*10^{14}$ /cm^2

Characteristic data:

Mean energy loss	=	0.019 eV
Most probable energy loss	=	0.017 eV
Maximum possible energy loss	=	0.10 MeV (dp/p=$1.1*10^{-3}$)

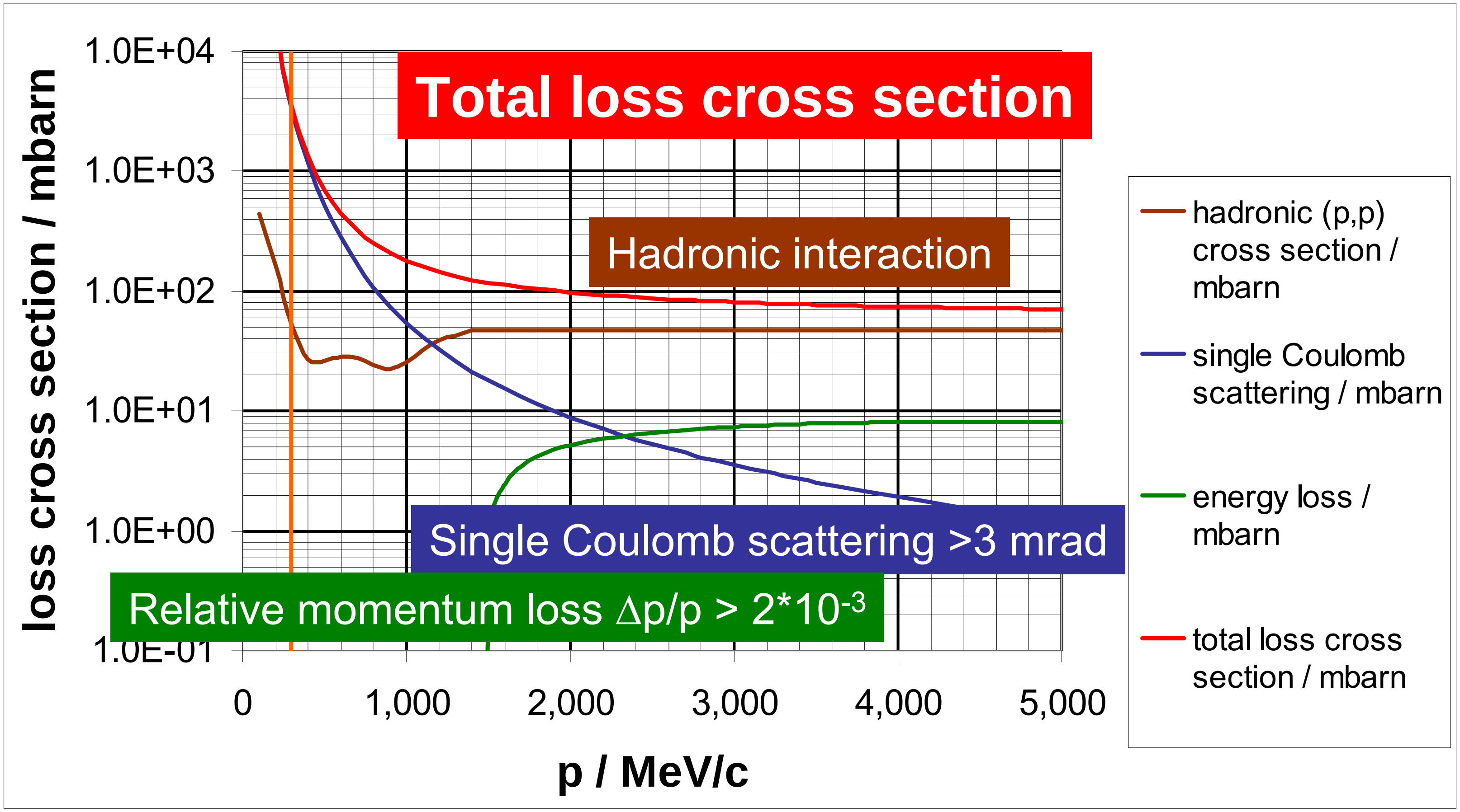
Result:

Dominating loss mechanism **at low momenta** is the Single Coulomb Scattering.

This means for long beam lifetimes:

- Small β-function at the target, large acceptance (low beta target section design)
- Momentum acceptance larger than maximum energy loss
- Efficient Cooling important

Total loss probability for given parameters and a Hydrogen target of $4*10^{14}$ atoms/cm^2



In addition: Ion optics can limit the beam lifetime

For large amplitude particles higher order field errors in the magnetic components increase the resonance strength.

2^{nd} requirement: Polarization lifetime

Spin filtering is a very slow process. Ions have to be stored for a long time:

The polarization has to be conserved!

⇒ All depolarizing resonances (also of higher order) have to be avoided!

⇒ Additional constraints on the machine tune

Tests at COSY

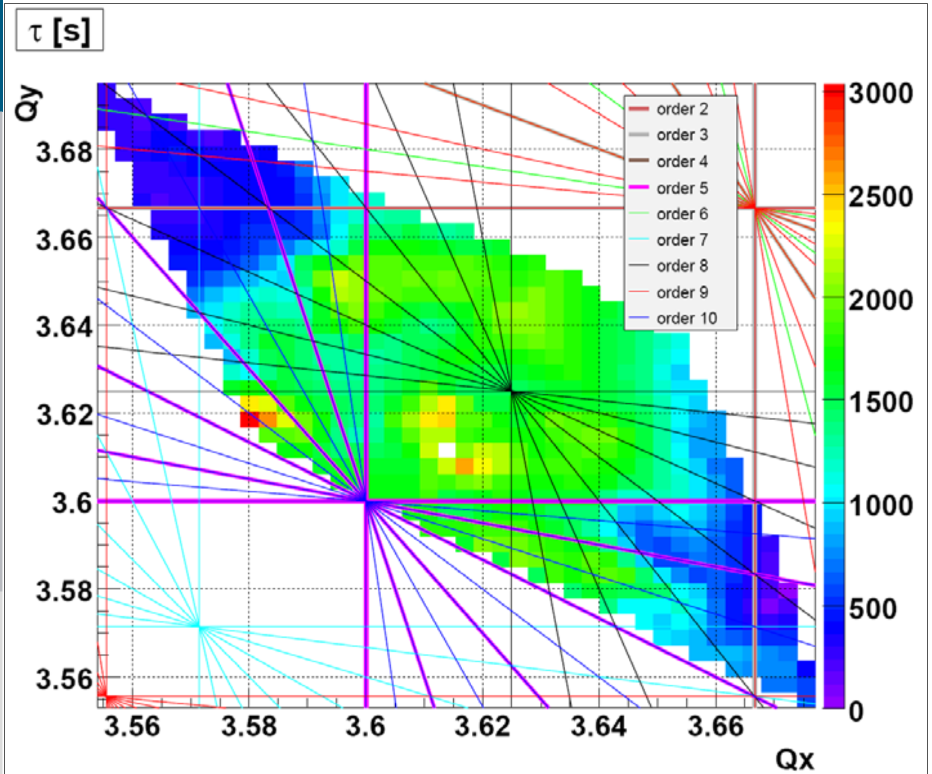
First tests at COSY

Beam lifetime measured as function of

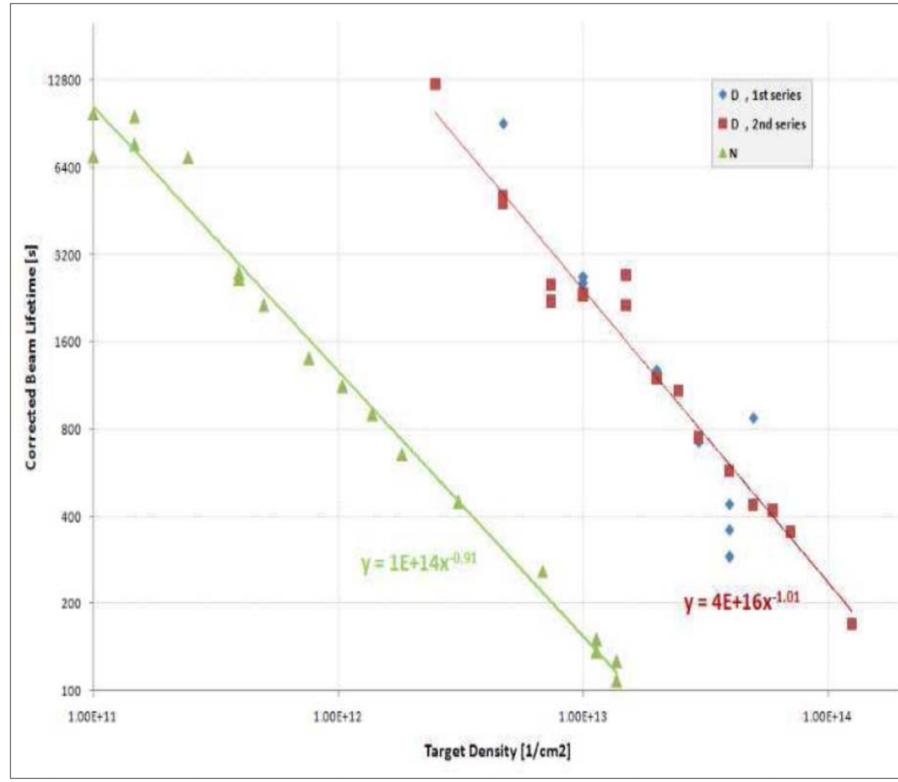
- Tune
- Closed orbit
- Phase space coupling
- Target thickness
- Different target materials
- Efficiency of electron cooling

COSY beam lifetime with electron cooling

Machine tunes

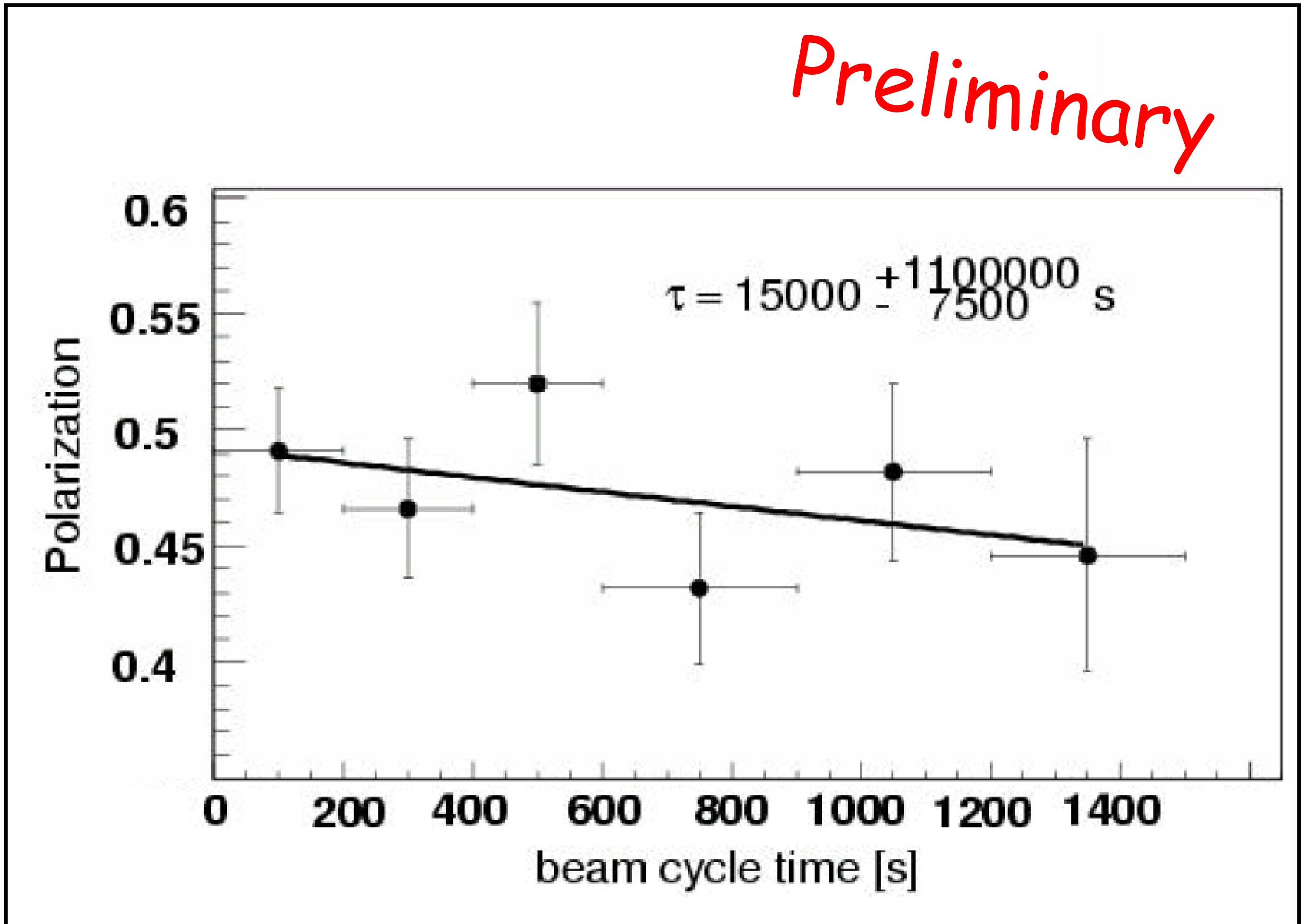


Target material



- Tunes near Q_x=Q_y showed highest beam lifetimes
- Exponential time dependence and scaling with z^2, but τ much too short

First Measurement of polarization lifetime at T_p = 45 MeV (Nov. 2007)



Analysis by S. Barsov & G. Macharashvili

Not yet understood: The beam lifetime

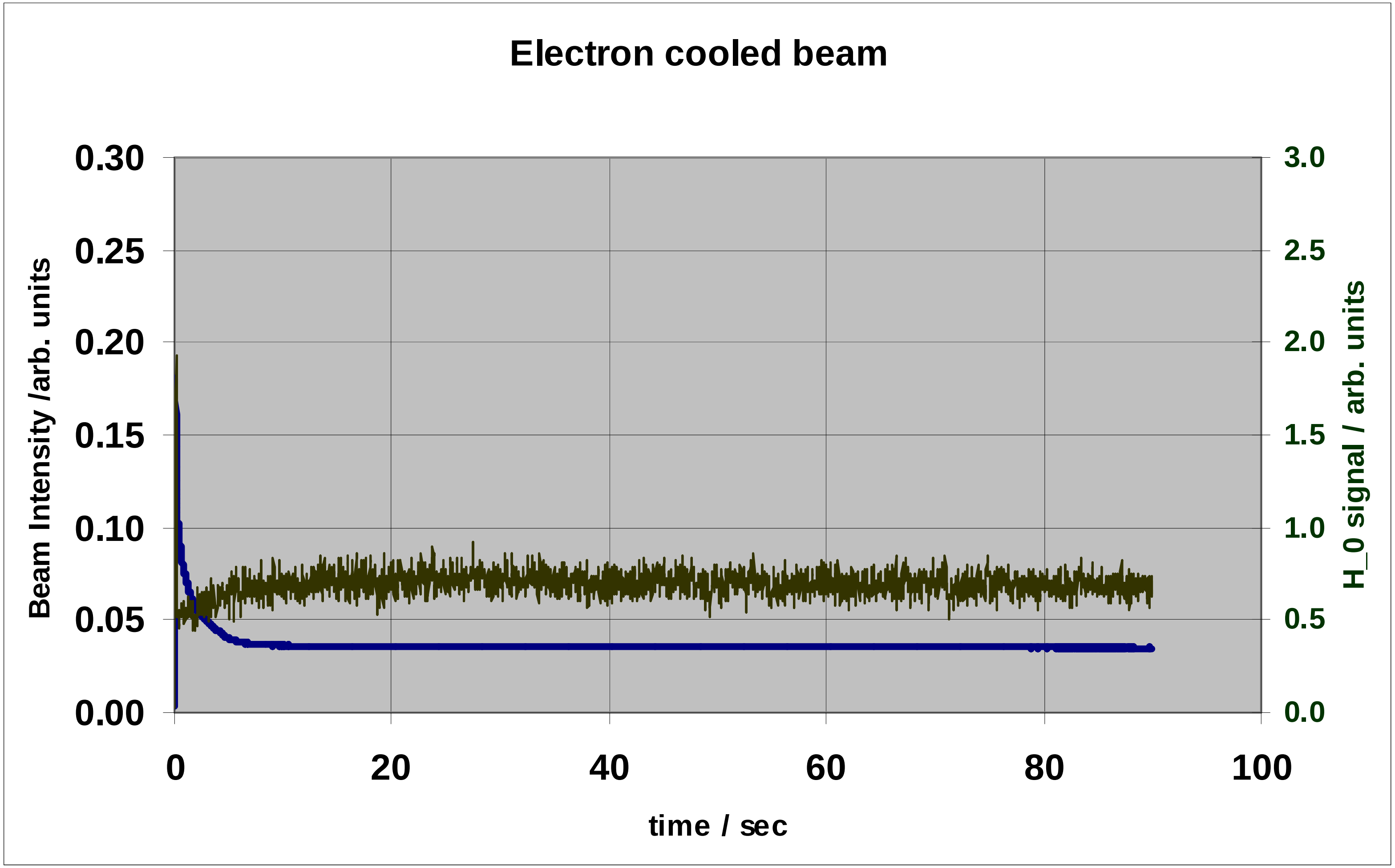
Reasons can be:

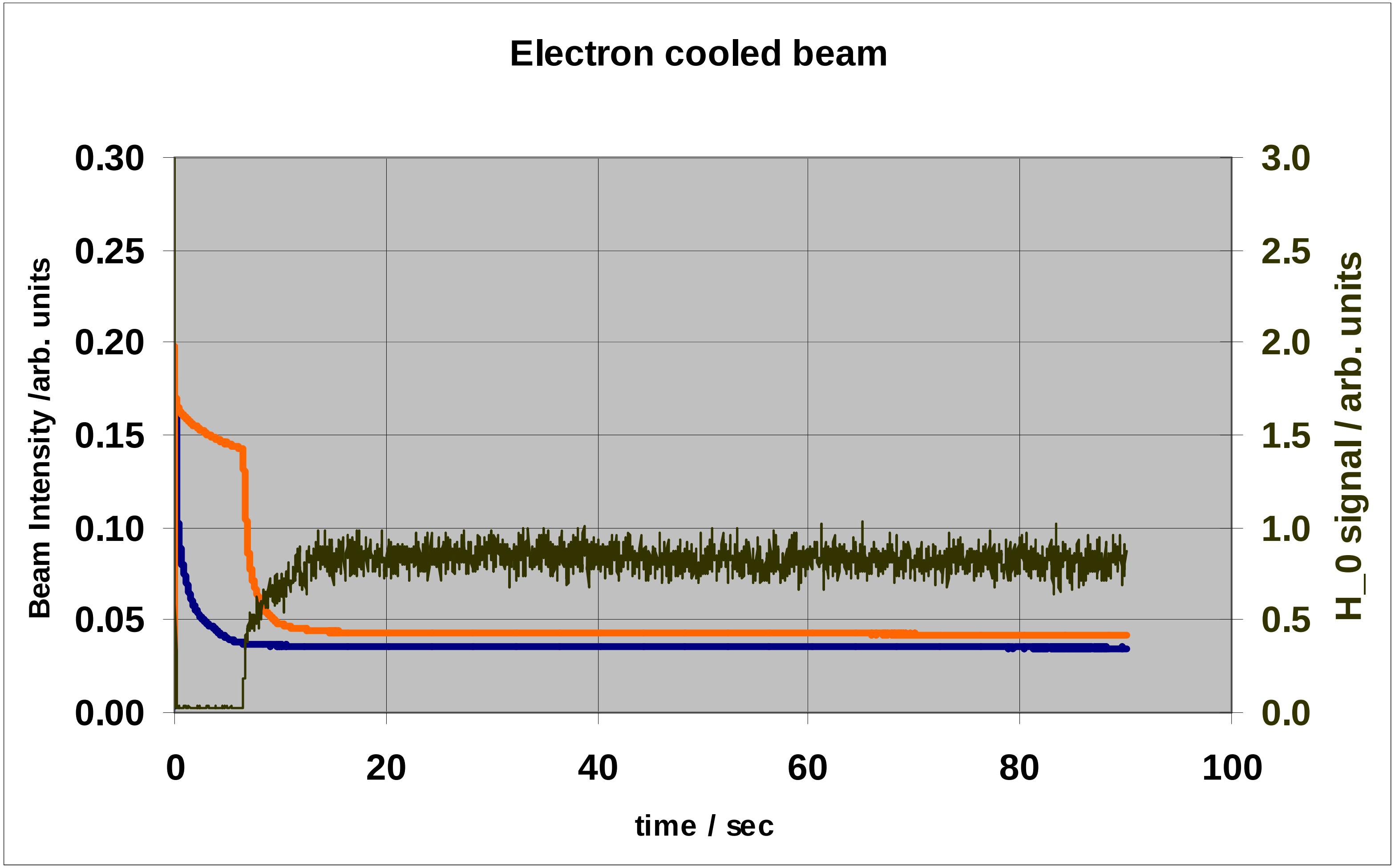
- Non optimum closed orbit, therefore too small acceptance
- Ion optical resonances of higher order
- Too small dynamic aperture
- Inefficient Cooling
- Under-estimation of the rest gas pressure
- Wrong assumptions of rest gas composition

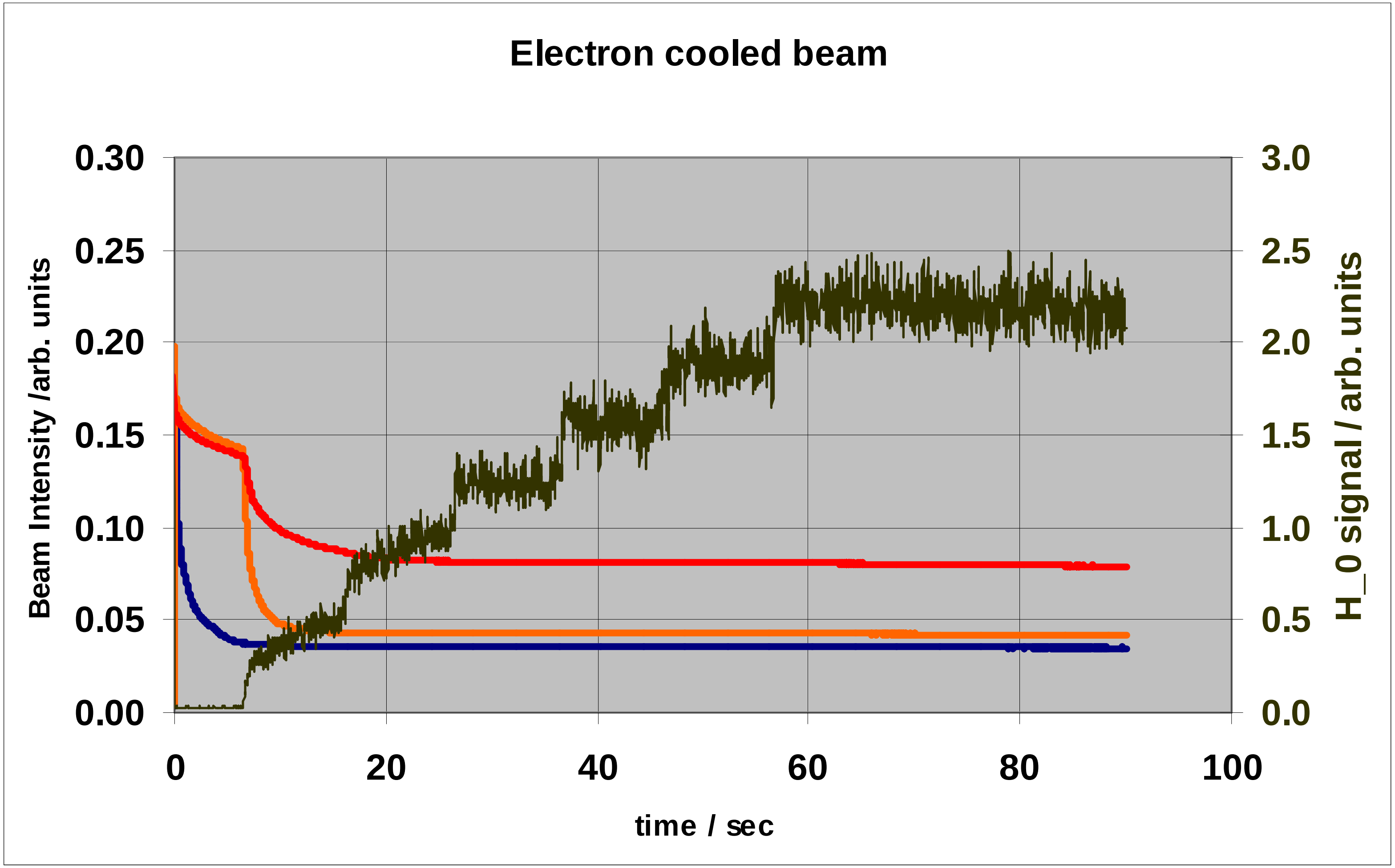
Next steps (already started):

- More detailed study of the rest gas
- Measurement of energy loss without cooling
- Local bumps to understand the “golden orbit” with maximum acceptance
- Further studies of tunes and chromaticity
- Investigations of electron cooling

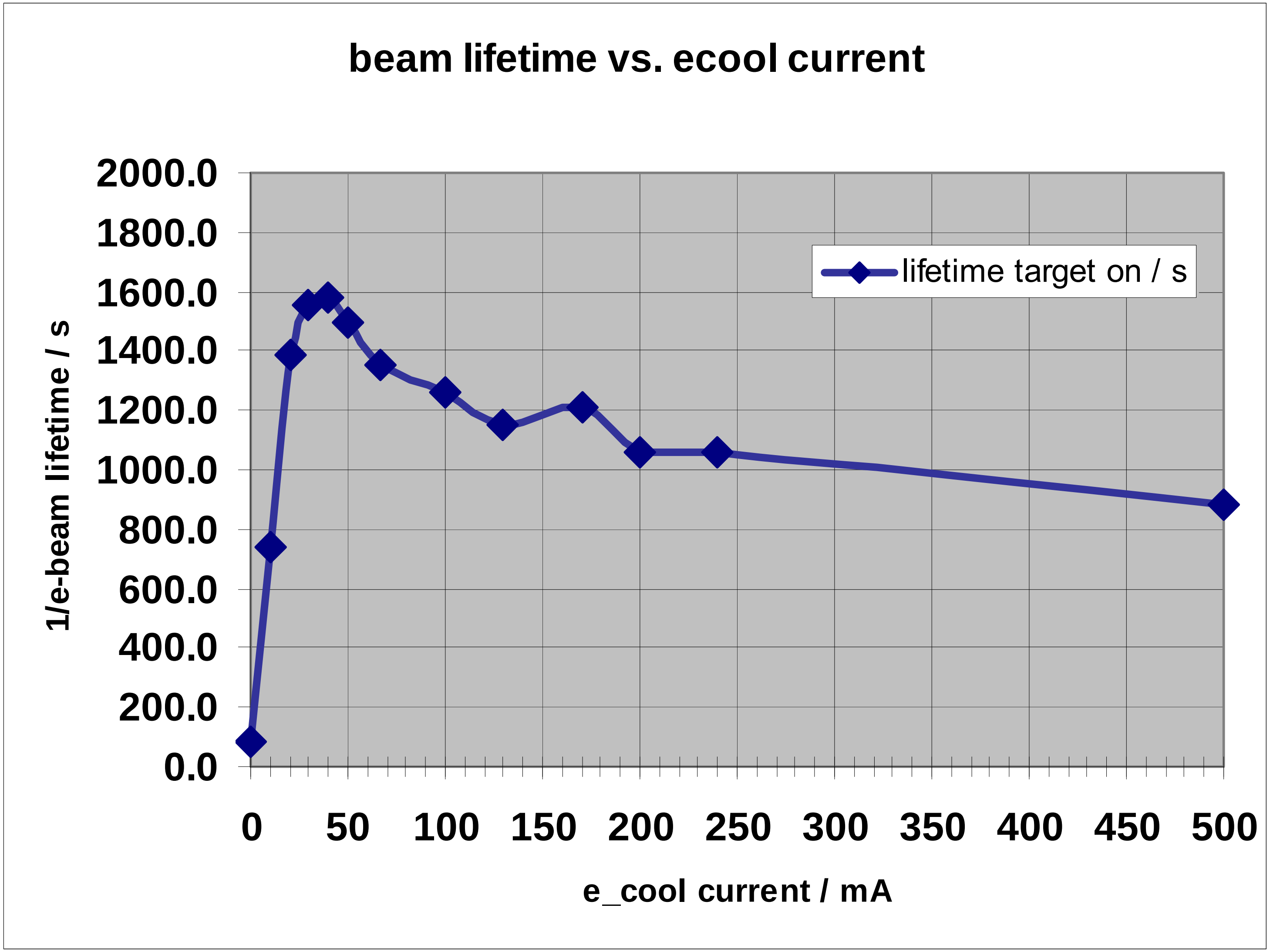
Recent studies to overcome initial losses:




Electron cooled beam
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Beam Intensity /arb. units
3.0
2.5
2.0
1.5
1.0
0.5
0.0
H_0 signal / arb. units
0
20
40
60
80
100
time / sec

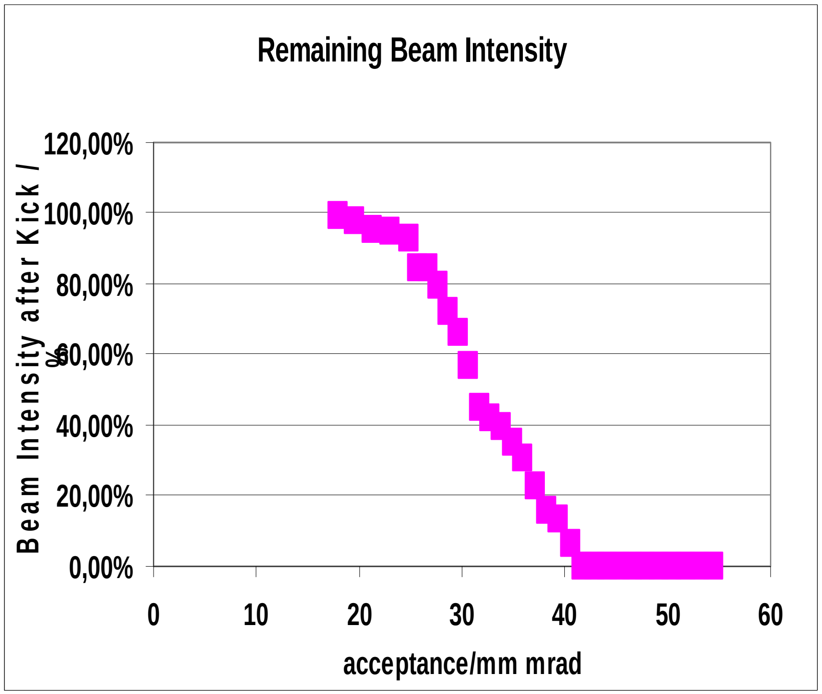

Electron cooled beam
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Beam Intensity /arb. units
3.0
2.5
2.0
1.5
1.0
0.5
0.0
H_0 signal / arb. units
0
20
40
60
80
100
time / sec

Beam life time versus electron current

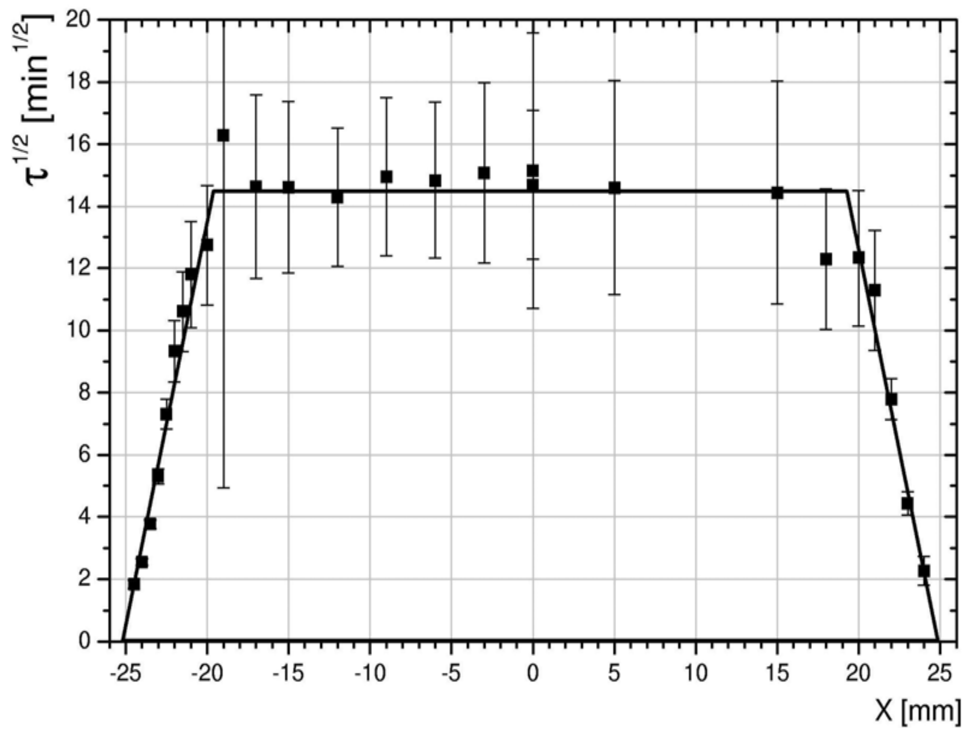


Ring Acceptance

Acceptance measurement with fast kicker magnet:
single turn kick: A=40 mm mrad



Acceptance measurement with scrapers:
Beamlifetime versus scraper position:
approx A=14 mm mrad for cooled beam
(naturaly includes dynamic effects)



Conclusion

- Spin filtering experiments require careful understanding and tuning of the storage ring
- Strong cooling is essential
- Preparations at COSY are underway, dynamic effects need to be studied in detail
- For efficient spin filtering a design of a new low beta target section is in progress
- Tests with antiprotons are needed

- The layout of a storage ring optimized for spin filtering (APR) is a challenging task for the designer

Mitglied der Helmholtz-Gemeinschaft

Additional Transparencies

PAX-System layout

see addendum to the technical report

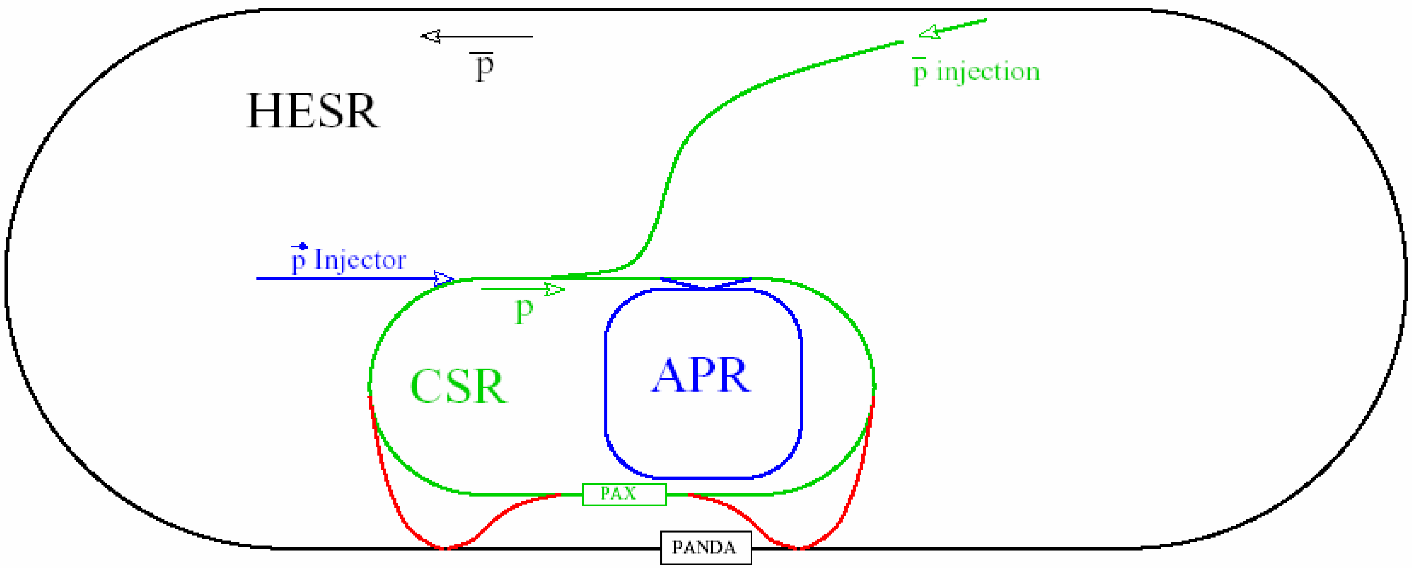
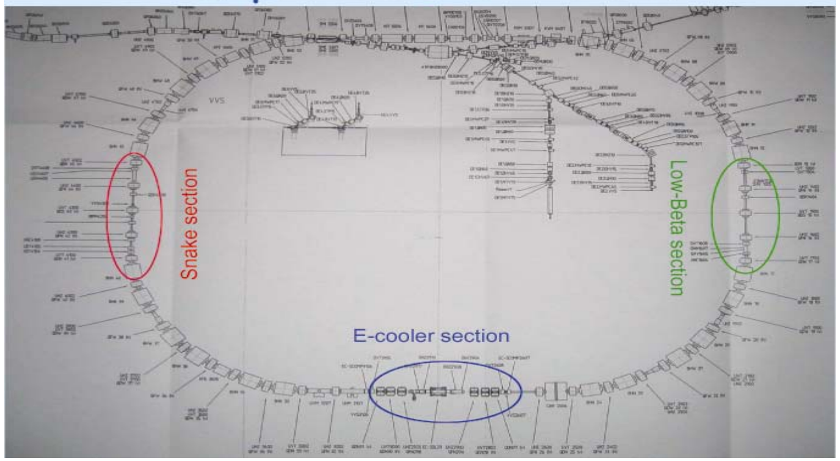
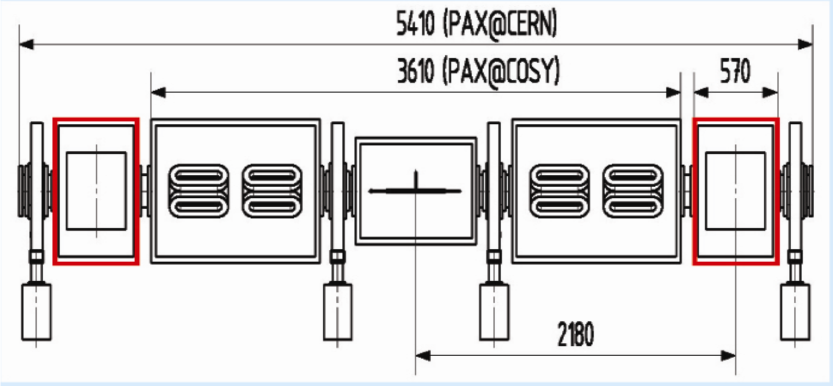


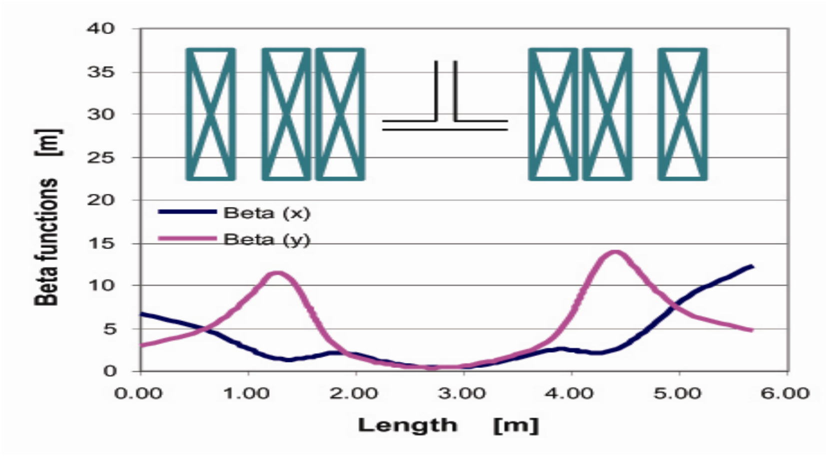
Figure 9: The proposed accelerator set–up at the HESR (black), with the equipment used by the PAX collaboration in Phase–I: CSR (green), APR, beam transfer lines and polarized proton injector (all blue). In Phase–II, by adding two transfer lines (red), an asymmetric collider is set up. It should be noted that, in this phase, also fixed target operation at PAX is possible. (The figure is drawn to scale.)

Antiproton Decelerator

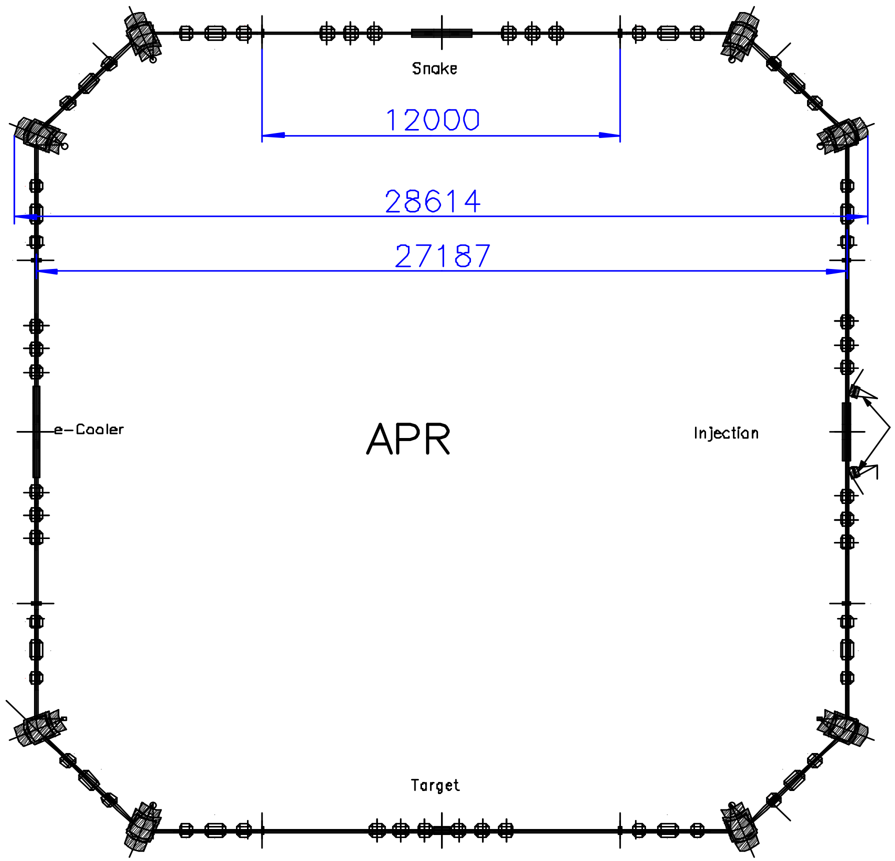


Layout of low-beta section for AD

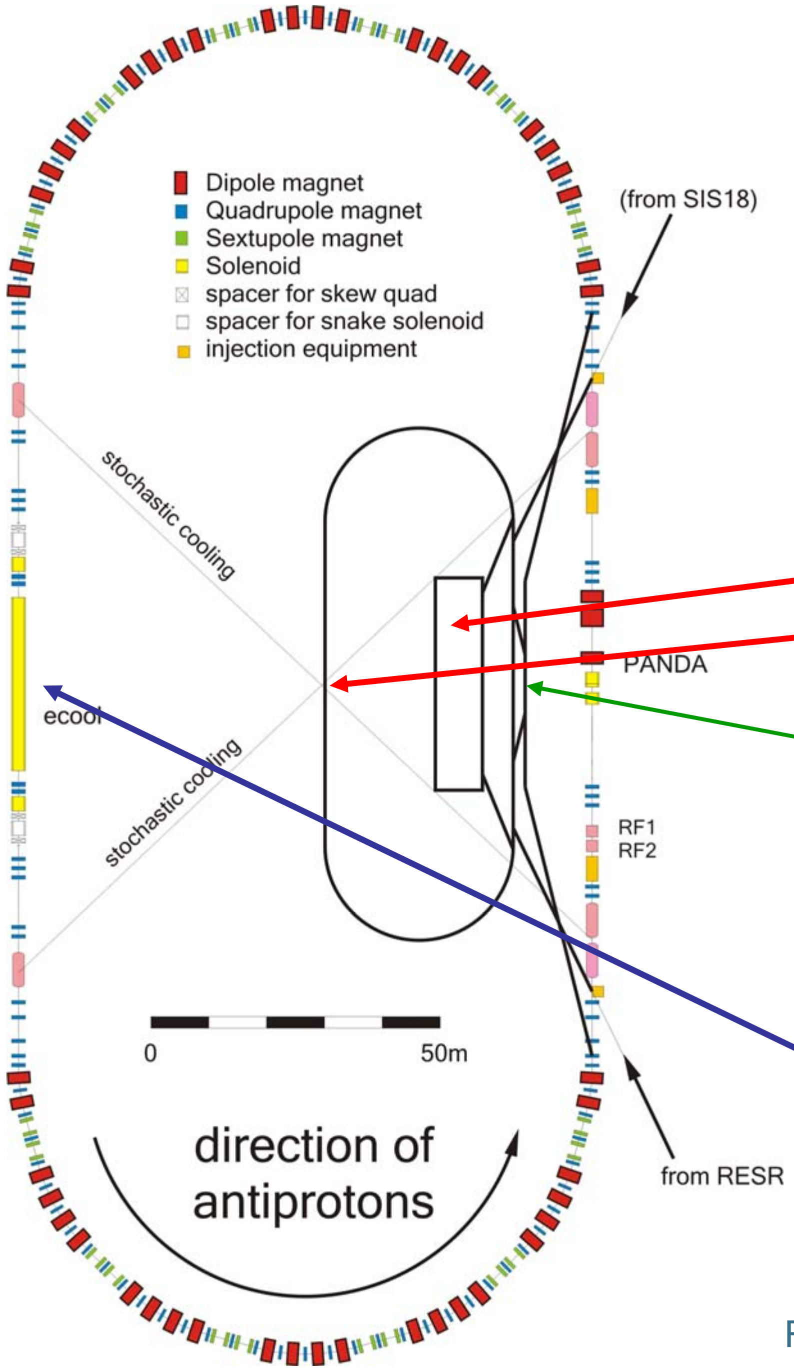




PAX layout



Space for Future Installations



for production of polarized antiprotons:

APR and

CSR

For PAX in its optimum stage:

"asymmetric" collider

The 8 MeV electron cooler

plus snake