Polarized Antiproton EXperiments

http://www.fz-juelich.de/ikp/pax

Towards polarized antiprotons at FAIR

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Ferrara, October 16th 2007

Motivation

Nucleon structure: polarized reactions

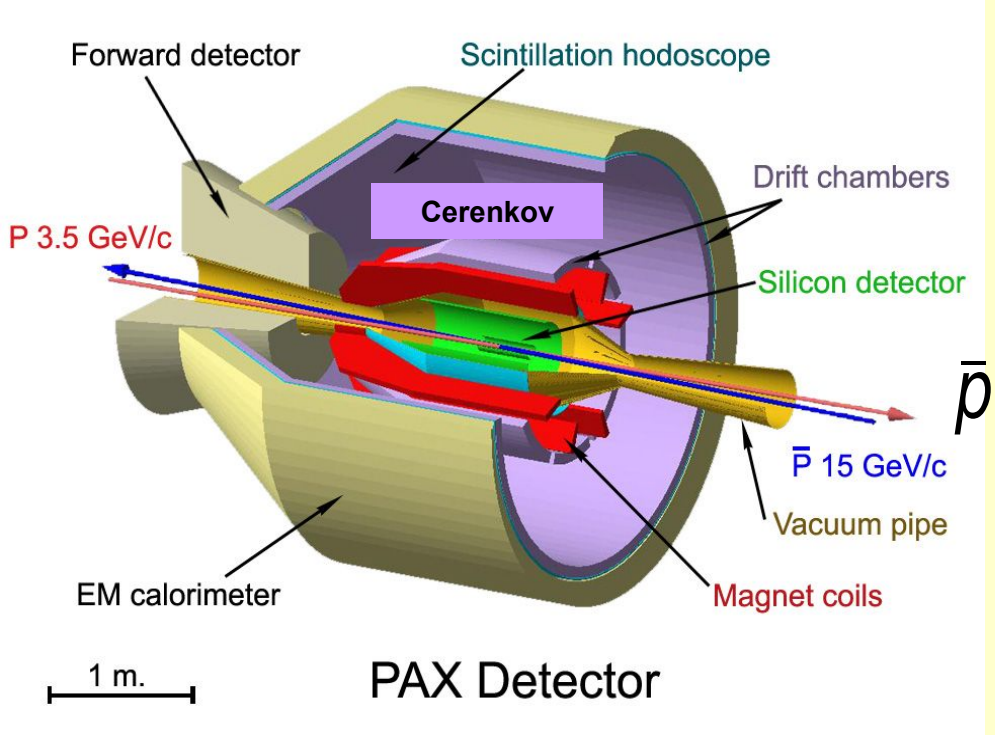
Parton distribution: transversity

pbar-p elastic

$$p^{\uparrow}\bar{p}^{\uparrow} \to p\bar{p}$$

Proton EFFs

$$p^{\uparrow}\bar{p}^{\uparrow} \to e^{+}e^{-}$$



Drell-Yan

$$p^{\uparrow}\bar{p}^{\uparrow} \to e^{+}e^{-}X$$

SSA

$$\bar{p}p^{\uparrow} \to DX, l^{+}l^{-}X$$

Charmonium

$$p^{\uparrow}\bar{p}^{\uparrow} \to J/\psi X$$

Fixed target experiment ($\sqrt{s}$<2 GeV):
pol./unpol. pbar beam (p<4 GeV/c)
internal H polarized target

Asymmetric collider ($\sqrt{s}$=15 GeV):
polarized antiprotons in HESR (p=15 GeV/c)
polarized protons in CSR (p=3.5 GeV/c)

PAX Collaboration

180 physicists
35 institutions (15 EU, 20 NON-EU)

TIMELINE

Jan. 04	Letter of Intent for FAIR
Jan. 05	Technical Report for FAIR
Nov. 05	LoI to CERN-SPSC to perform spin-filtering experiments with antiprotons at the AD ring
Apr. 06	LoI to COSY-PAC for spin filtering experiments with protons at COSY
Sep. 06	LoI to COSY-PAC for beam-depolarization studies
Jun. 07	2 weeks beam-lifetimes studies at COSY
Nov. 07	2 weeks polarization lifetime studies at COSY

Evaluation by QCD-PAC (March 2005)

… the PAC would like to stress again the uniqueness of the program with polarized anti-protons and polarized protons that could become available at GSI.

Recommendation of the STI of FAIR (Sept. 2005)

The STI requests R&D work to be continued on the proposed asymmetric collider experiment with both polarized anti-protons and protons:

-to demonstrate that the required luminosity for decisive measurements can be reached

- to demonstrate that a high degree of anti-proton polarisation can be reached

The STI believes that PAX should become part of the FAIR core research program based on its strong scientific merit once the open problems are convincingly solved.

Polarized antiprotons

Long story! 1st workshop in Bodega Bay (1985)

Workshop on Polarized Antiprotons: Daresbury (UK) 29.08-31.08.07

Intense beam of polarized pbar never produced:

- Synchrotron radiation ~ $\mu(\gamma^4/R)$ -> τ_{pol} ~10^7 y in 20 TeV pbar ring
- Conventional methods (ABS) not applicable
- Polarized pbar from antilambda decay
  - I< $1.5 \cdot 10^5$ s^{-1} (P ≈ 0.35)
- Pbar scattering off liquid H_2 target
  - I< $2 \cdot 10^3$ s^{-1} (P ≈ 0.2)

Spin-filtering is the only succesfully tested technique

- Th. Walcher et al.:
  - 05.2006: "An effective method for polarizing antiprotons"
    - Use of a polarized electron beam (withdrawn)
  - 06.2007 "A surprising method for polarizing antiprotons"
    - Use of a polarized positron beam (withdrawn but…)

Principle of spin-filtering

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

P beam polarization
Q target polarization
k || beam direction

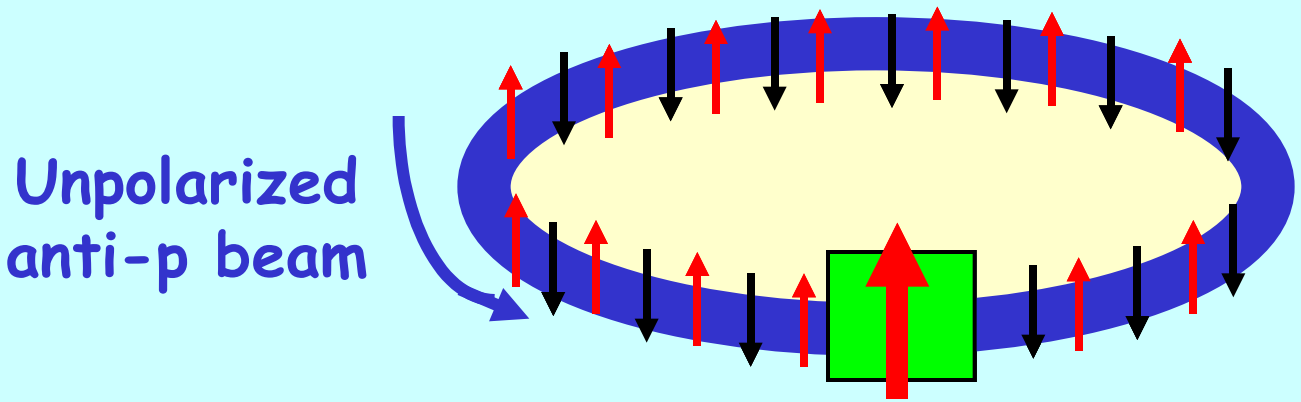
For initially equally populated spin states: ↑ ($m=+\frac{1}{2}$) and ↓ ($m=-\frac{1}{2}$)

transverse case:

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

longitudinal case:

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



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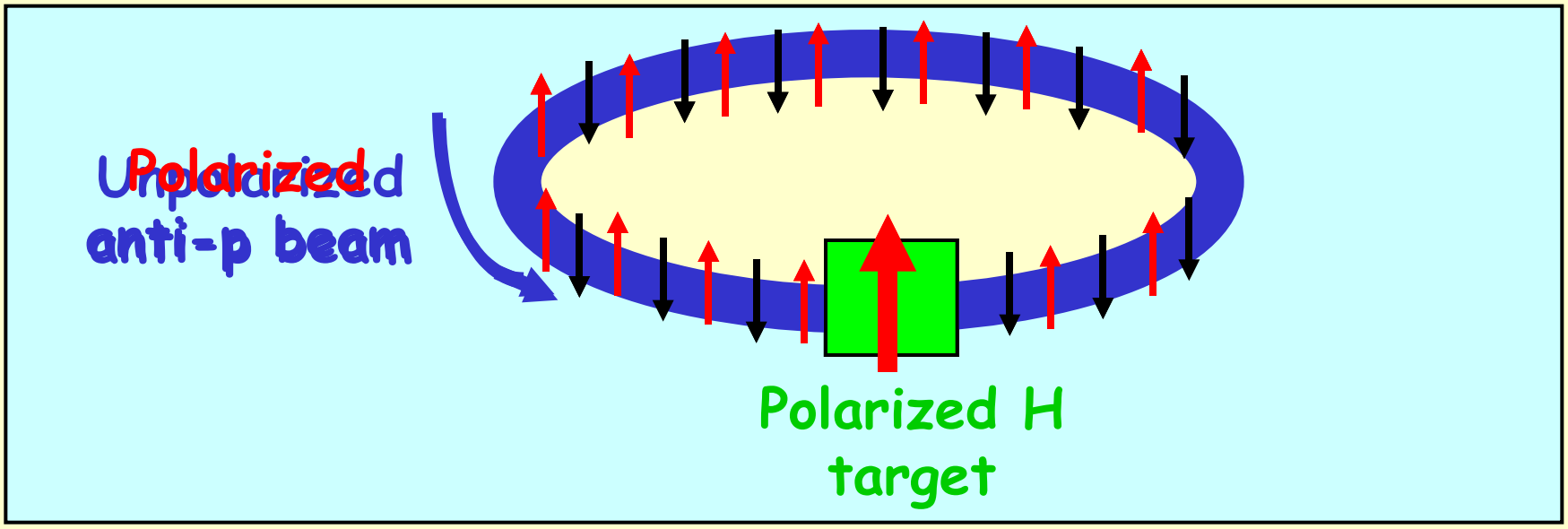
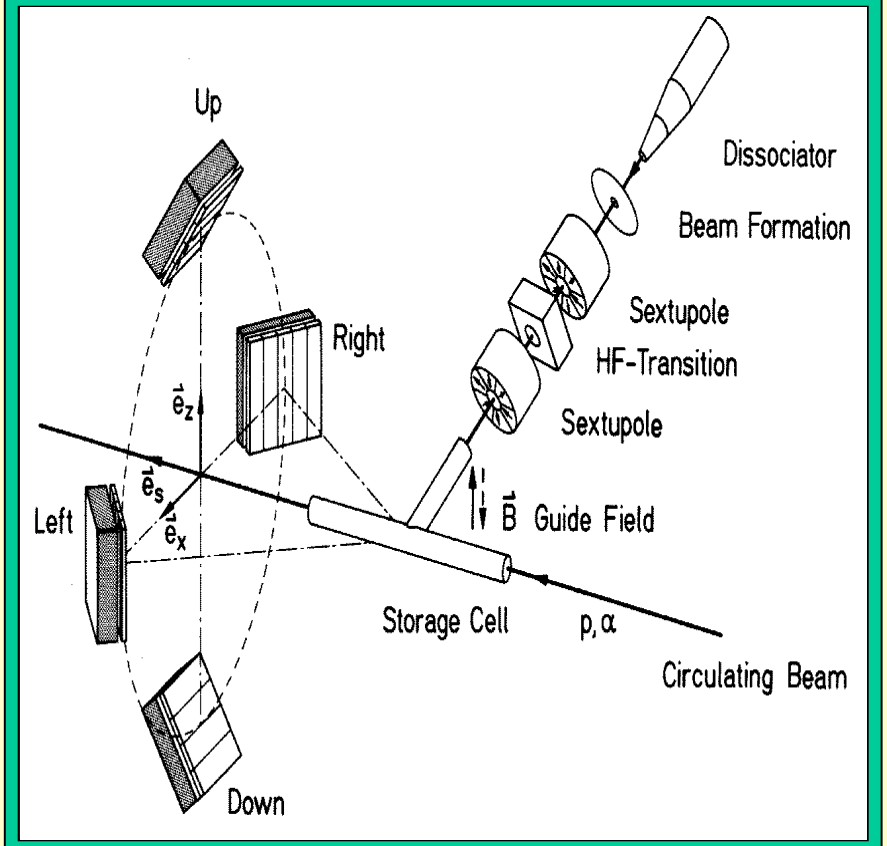
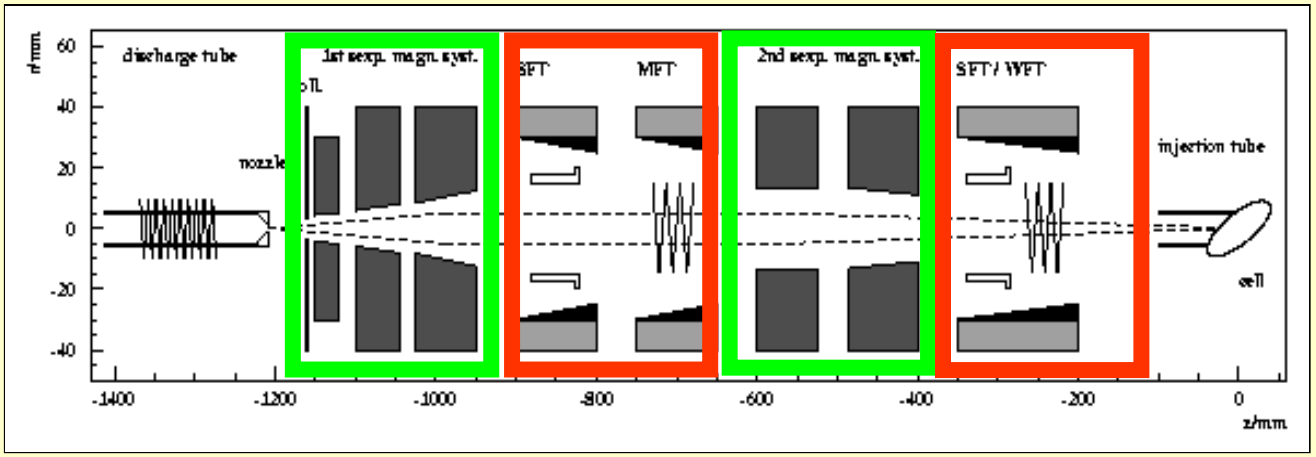


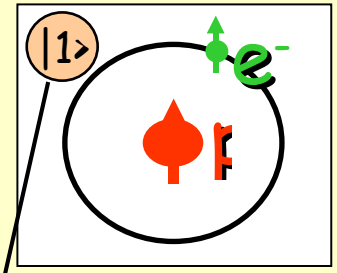
1992 Filter Test at TSR with protons

Experimental Setup



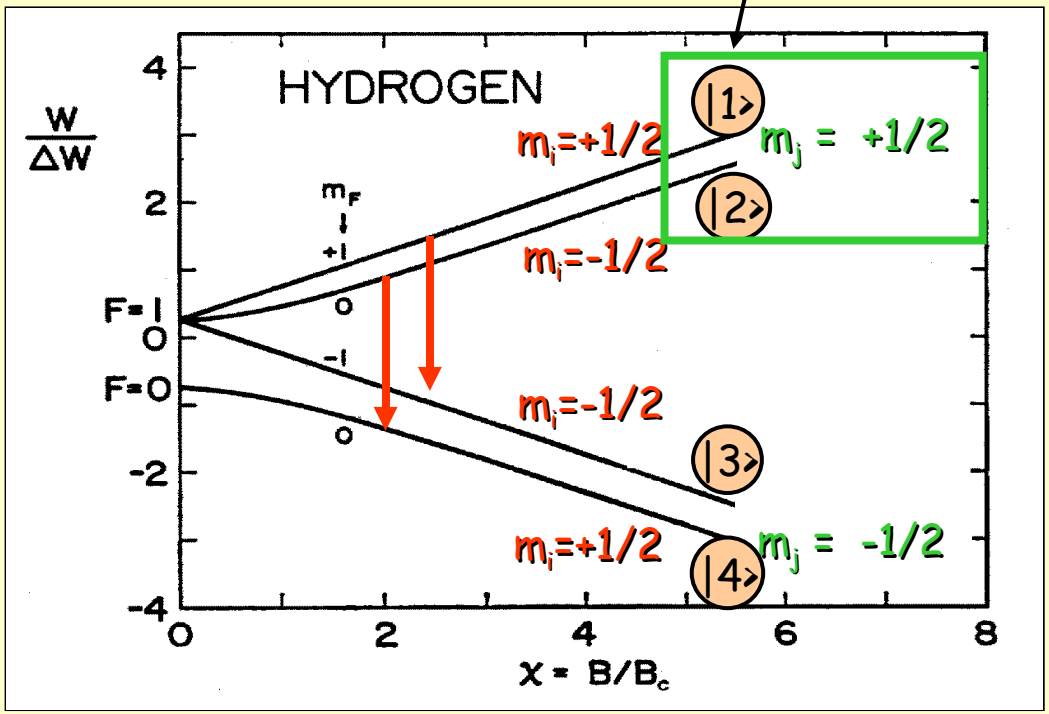
Polarized atomic beam source





Atoms with $m_j=+\frac{1}{2}$ focused in sextupole magnets.

RF transitions select HFS.



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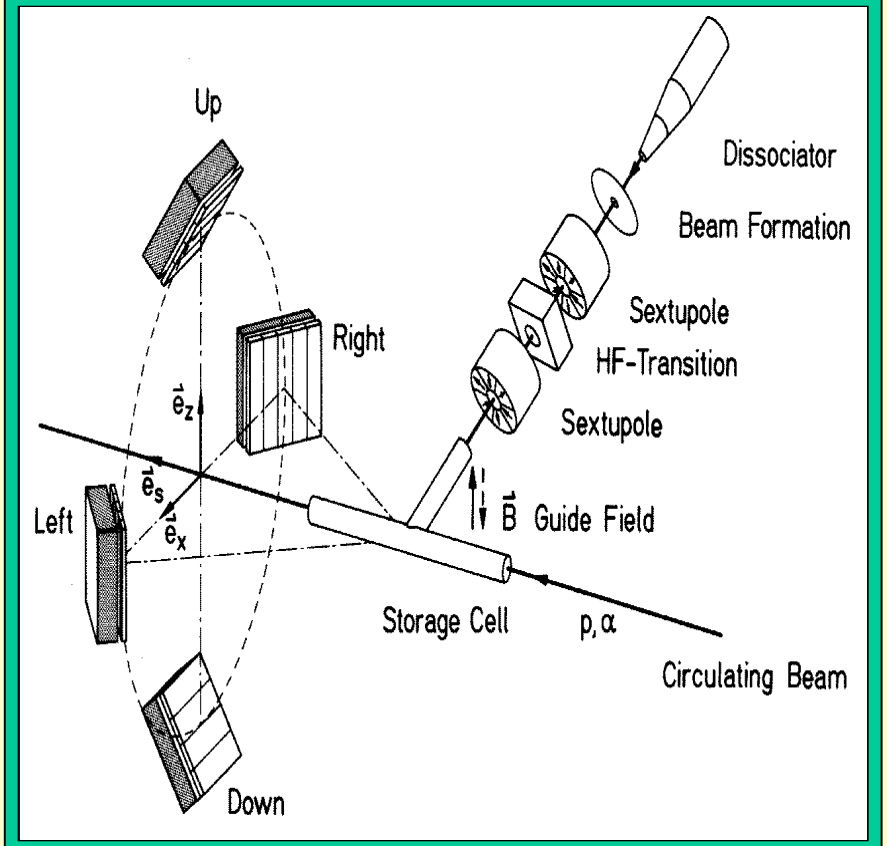
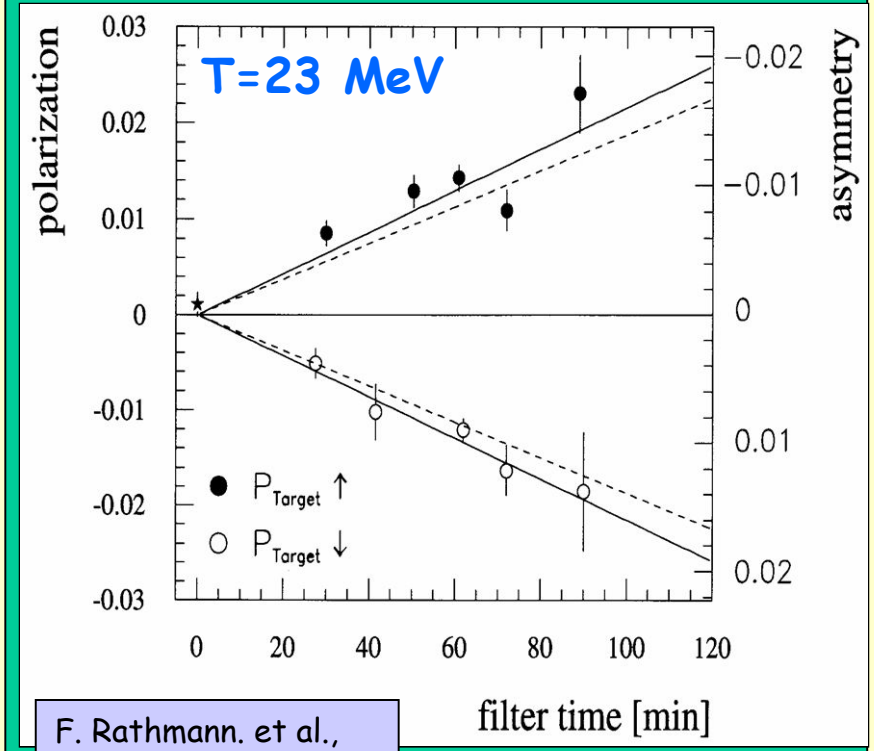


Results



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

Two interpretations of FILTEX result

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

$P(t)=\tanh(t/\tau_1)$, $1/\tau_1=\sigma_1 Q d_t f$

$\sigma_1 = 72.5 \pm 5.8$ mb

Spin-filtering works! But how?

1994. Meyer and Horowitz: three distinct effects

1. Selective removal through scattering beyond θ_{acc}=4.4 mrad ($\sigma_{R\perp}$=83 mb)
2. Small angle scattering of target prot. into ring acceptance ($\sigma_{S\perp}$=52 mb)
3. Spin-transfer from pol. el. of target atoms to stored prot. ($\sigma_{E\perp}$=-70 mb)

$\sigma_1 = \sigma_{R\perp} + \sigma_{S\perp} + \sigma_{E\perp} = 65$ mb

2005. Milstein & Strakhovenko + Nikolaev & Pavlov: only one effect

Only p-p scattering contributes to polarization buildup ($\sigma_{R\perp}$=85.6 mb)

No contribution from polarized electrons

Note: Walcher's proposals regarded spin-transfer

Spin-filtering: Present situation

Spin filtering works, but:

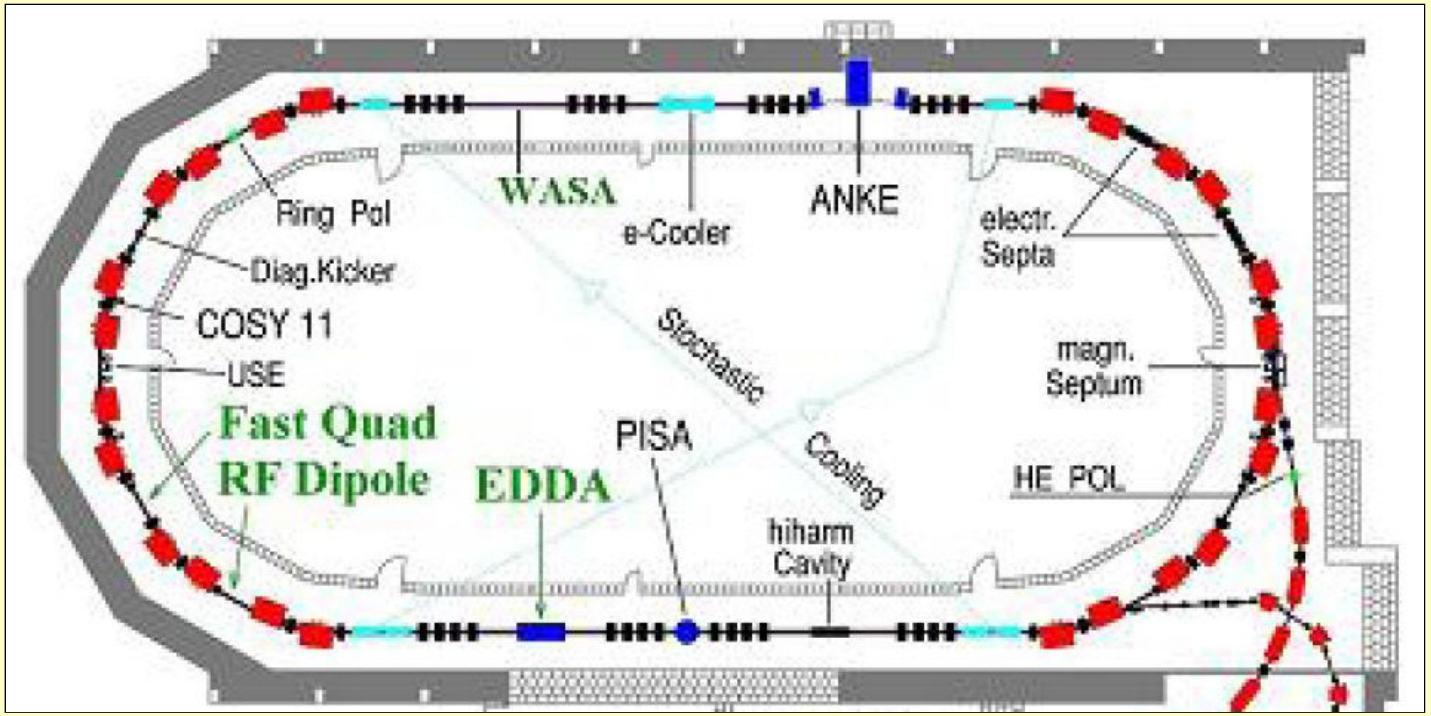
1. Controversial interpretations of FILTEX experiment
   - Further experimental tests necessary
   - How does spin-filtering works?
   - Which role do electrons play?

   → Tests with protons at COSY

2. No data to predict polarization from fitering with antiprotons.

   → Measurements with antiprotons at AD/CERN

Spin-filtering studies with protons (COSY-FZJ)



Objective:

- Understanding of spin-filtering mechanism:
- Disentangle electromagnetic and hadronic contributions to the polarizing cross section

How to disentangle hadronic and electromagnetic contributions to σ_{eff} ?

Method 1: Polarization build-up experiments

Injection of different combinations of hyperfine states

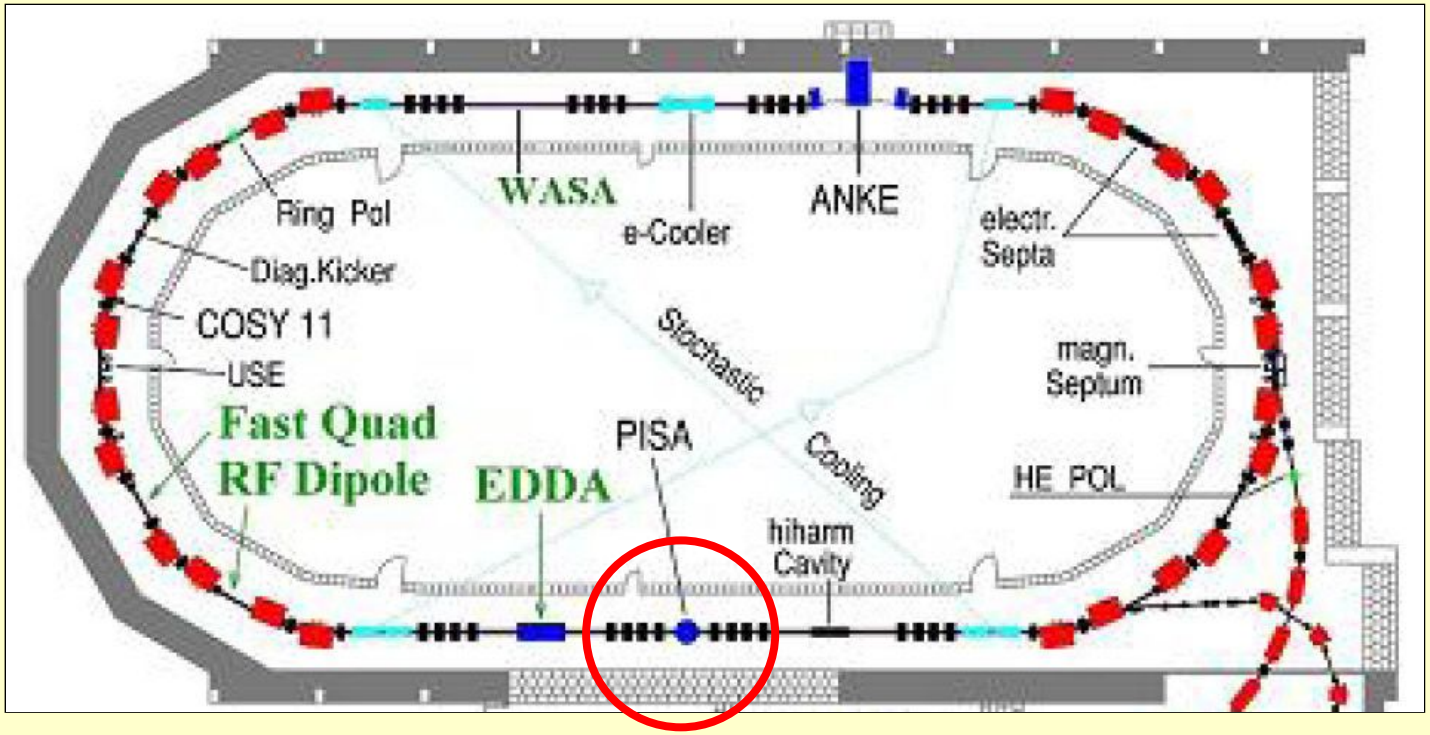
- Null experiments possible:
  - Pure electron polarized target ($P_z = 0$), and
  - Pure nuclear polarized target ($P_e = 0$)

Inj. states	P_e	P_z	Interaction	Holding field	
|1>	+1	+1	Elm. + had.	transv. + longit.	weak (20 G)
|1> + |4>	0	+1	only had.	longitudinal	strong (3kG)
|1> + |2>	+1	0	only elm.		

Strong fields can be applied only longitudinally (minimal beam interference)

- Snake necessary

Experimental setup

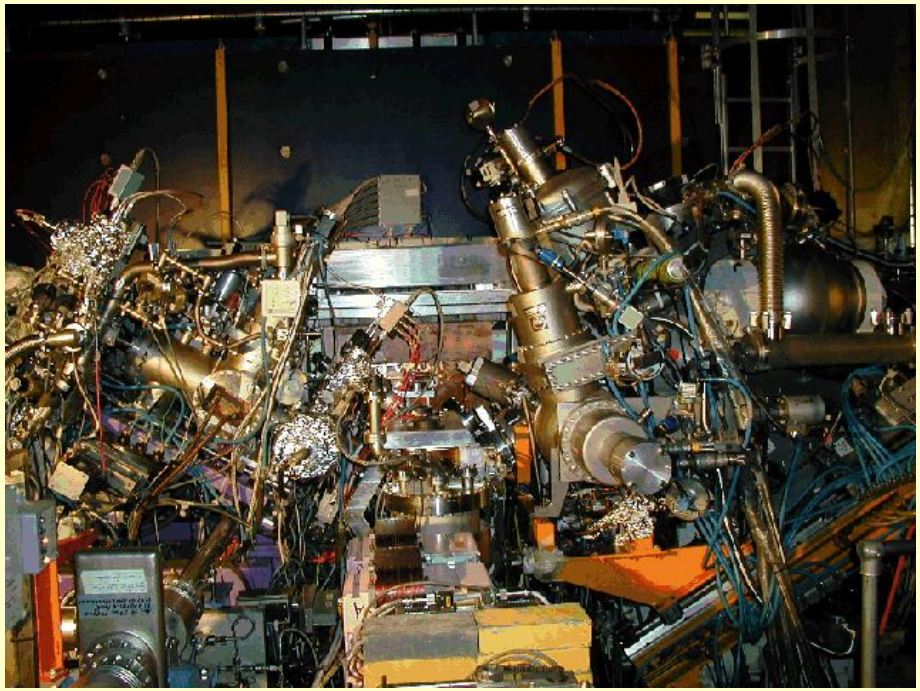


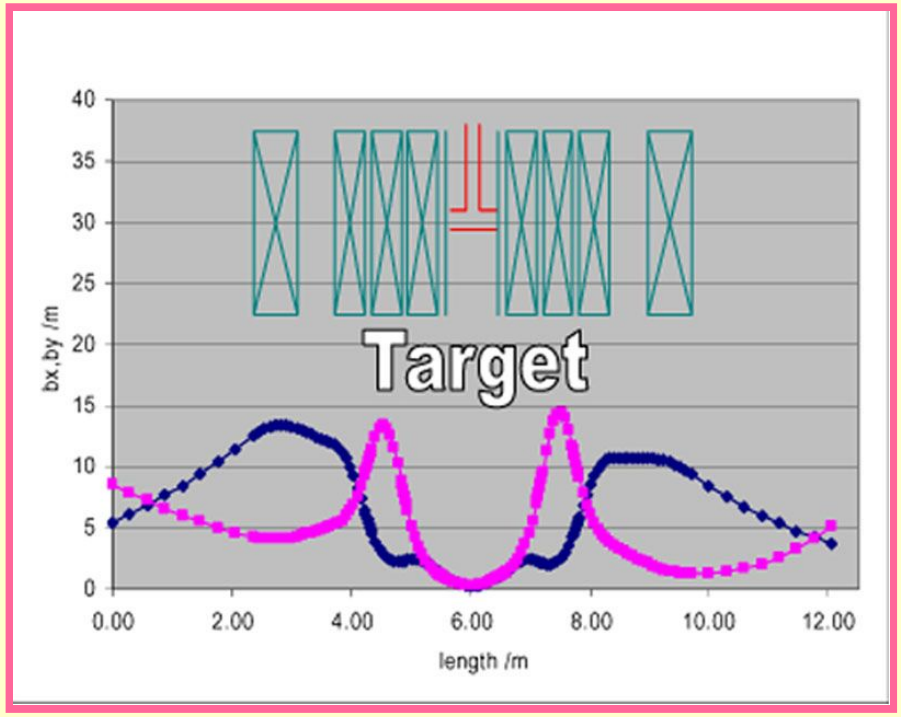
- Low-beta section
- Polarized target (former HERMES target)
- Detector
- Snake
- Commissioning of AD setup

Low beta section

$\beta_{x,y}^{new}$ = 0.3 m -> increase in density with respect to ANKE: factor 30

- Lower buildup time, higher rates
- Larger polarization buildup rate due to higher acceptance
- Use of former HERMES target



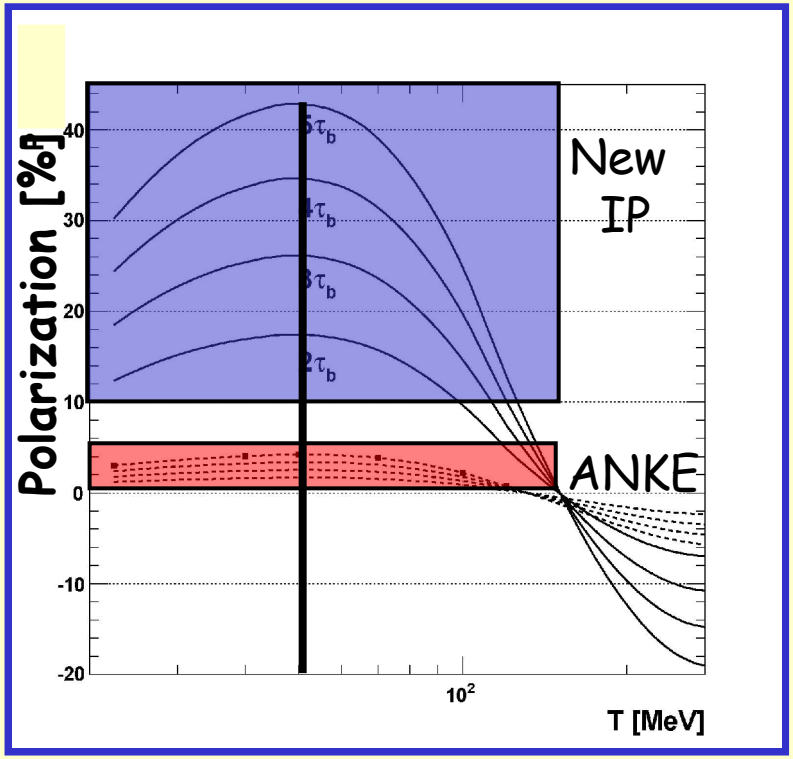


Superconducting quadrupoles necessary

ANKE vs new IP: Polarization

Expectations based on Budker-Jülich for:

- T = 40 MeV
- N_{inj}=1.5x10^{10} protons



PIT	Filter. time	Polar.	Total rate	Meas. Time ($\Delta P/P=10\%$)
ANKE	2τ = 16 h	1.2 %	7.5x10^2 s^{-1}	44 min
	5τ = 42 h	3.5 %	5x10 s^{-1}	26 min
New IP	2τ = 5 h	16 %	2.2x10^4 s^{-1}	1 s
	5τ = 13 h	42 %	1.5x10^3 s^{-1}	< 1 s

Method 2: Depolarization studies

Meyer: "If polarized electrons polarize an initially unpolarized beam, then, unpolarized electrons should depolarize an initially polarized beam!"

Aim: test of the electromagnetic contribution

Electrons in ^{4}He storage cell or D cluster-jet target.

Both electron target and polarimeter:

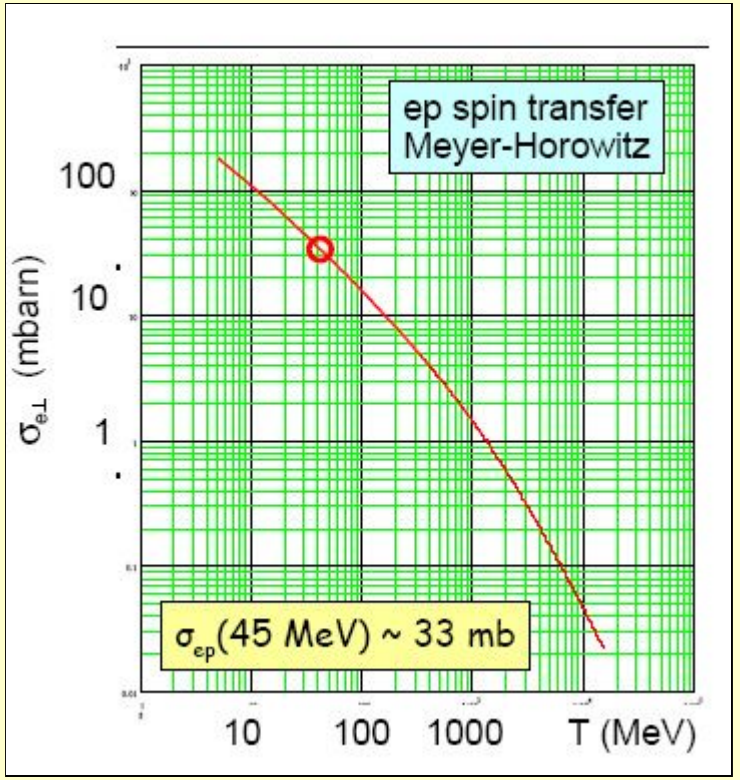
- Large analyzing power
- Large counting rate

Distinguish electron effect from depol. in COSY.

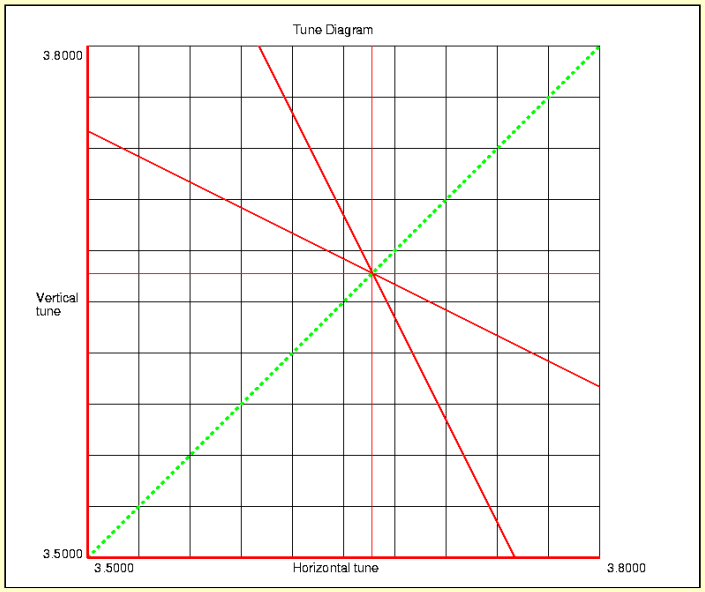
Prerequisites:

- Large beam lifetime

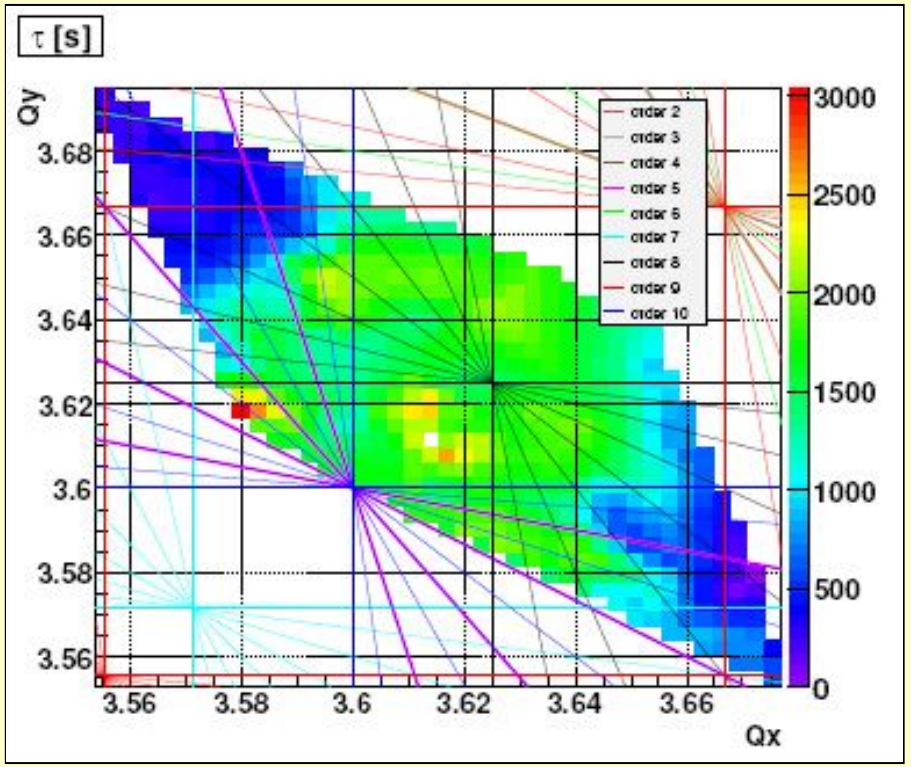
2 weeks of machine studies in June 07

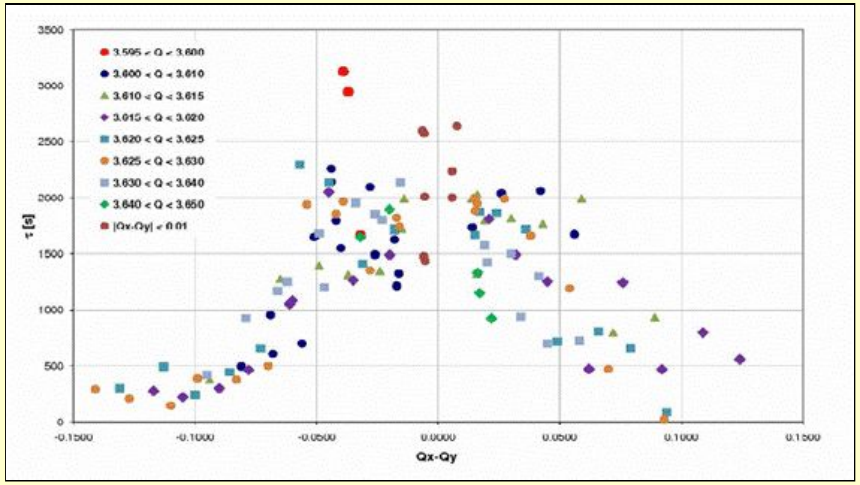


Beam-lifetime studies at COSY (june '07)



Up to third order





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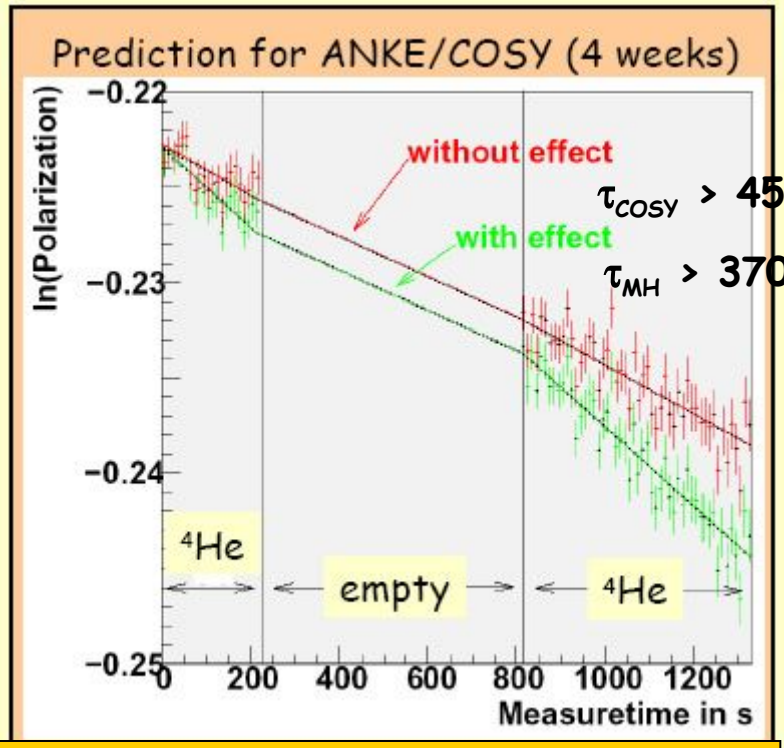
- Large polarization lifetime

  2 weeks of machine studies in Nov. 07

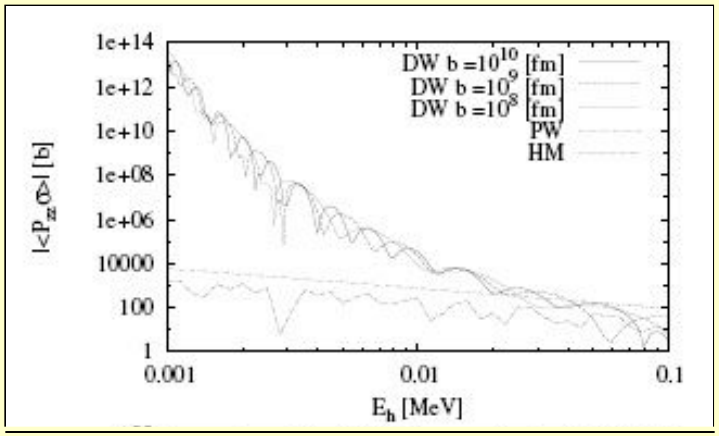


4-5 σ effect target effect in 4 weeks of data taking

Depolarization Studies using unpolarized Electrons

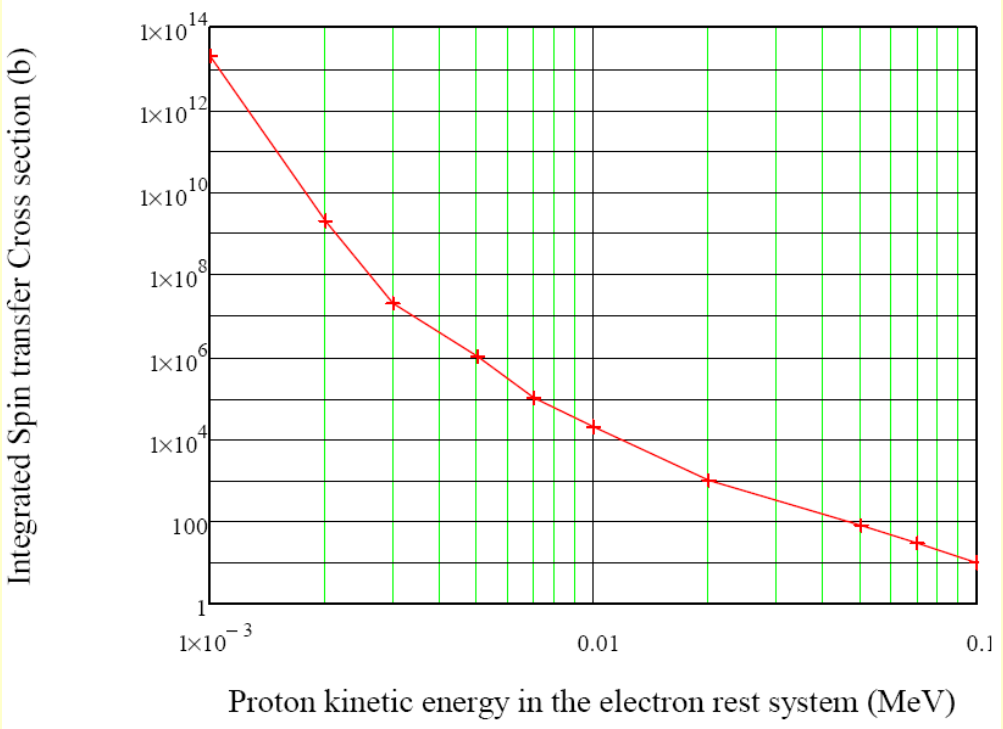
- Use electrons in ecooler instead of target electrons to observe depolarization

Motivation: Walcher-Arenhövel estimation of σ_{ep} spin transfer at low-relative energy

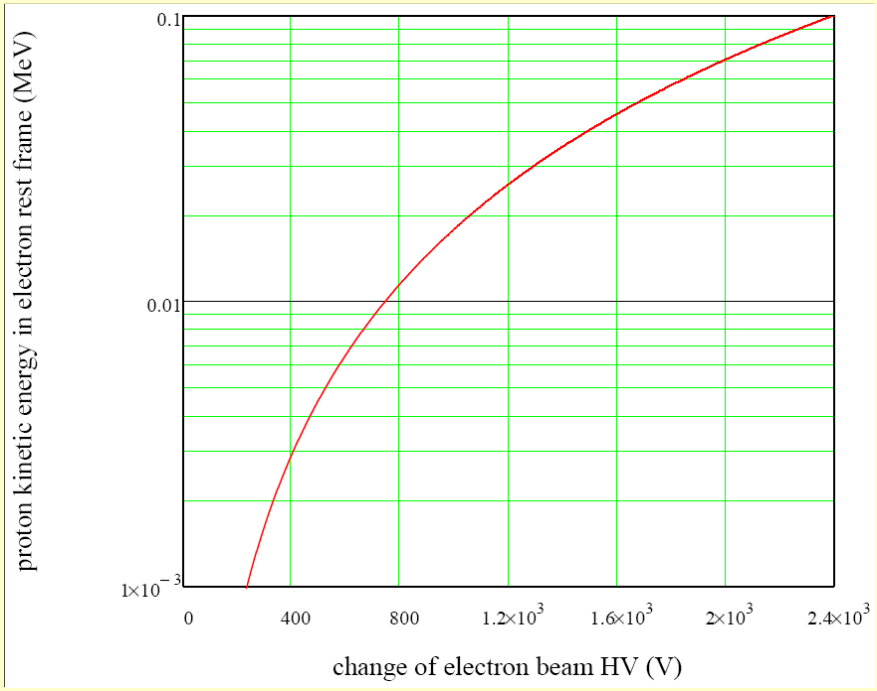


Th. Walcher, H. Aarenhövel et al.
arXiv:0706.3765

Withdrawn but new calculation in progress…



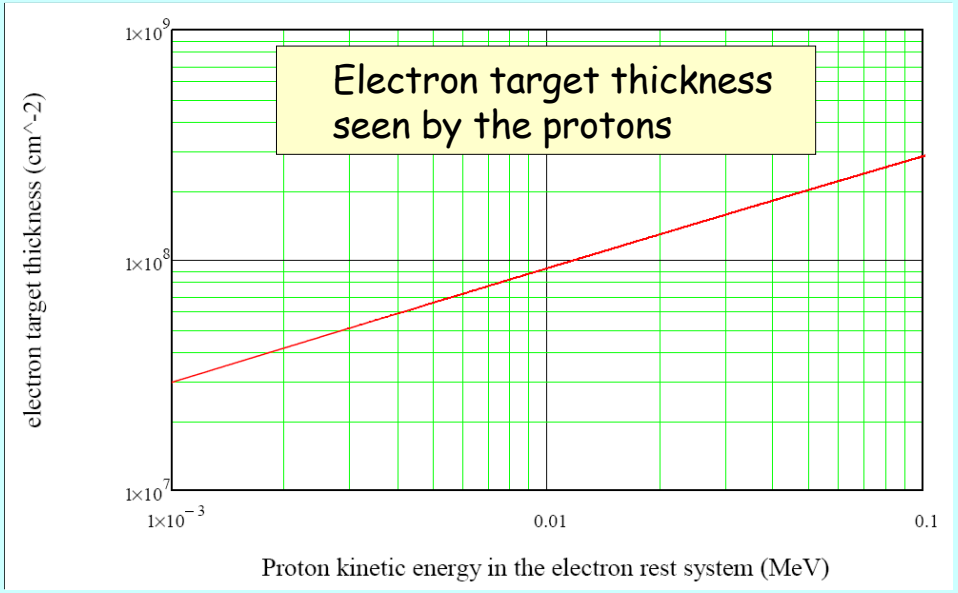
Ecooler Settings for T_p=45 MeV



Typical parameters of COSY Cooler

- Electron Current 240 mA
- Cross section 5 cm²
- Length 2 m
- Nominal Voltage 24.5 kV

$$d_t(T_p, T_e) := \frac{I_e}{q_e} \cdot \frac{l_{cooler}}{\beta_{lab}(T_e, m_e) \cdot c_{light} \cdot A_{cooler}} \cdot \frac{(\beta_{lab}(T_e, m_e) - \beta_{lab}(T_p, m_p))}{\beta_{lab}(T_p, m_p)}$$

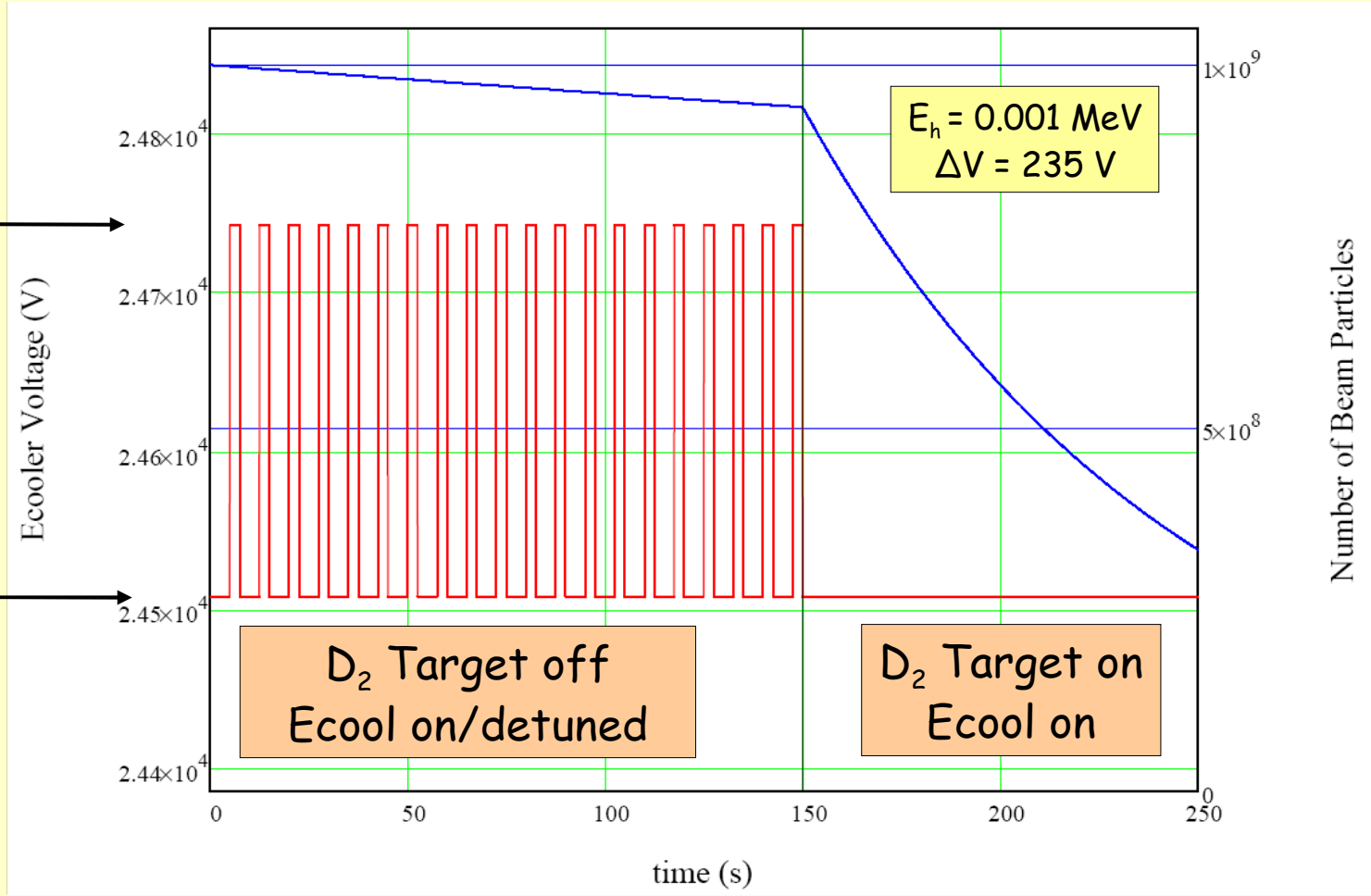


Cycle for Depolarization Study

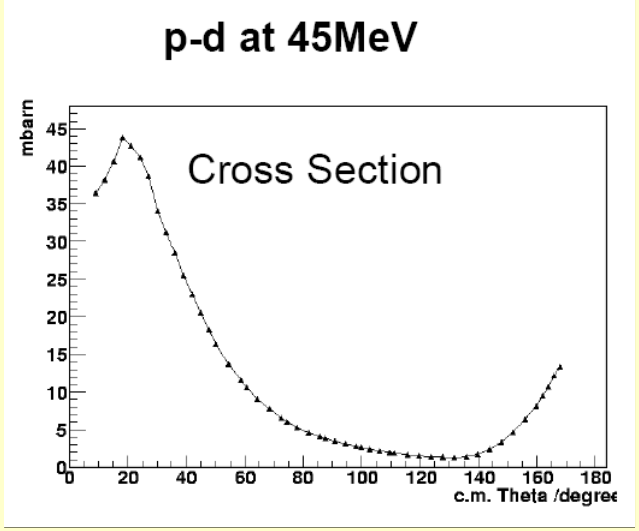
Detuned Cooler Voltage
$T_{detuned}$= 50 s

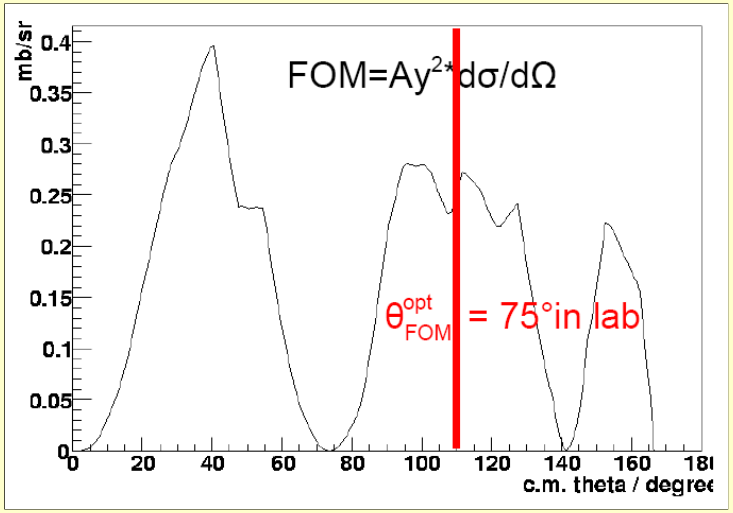
Nominal Cooler Voltage
$T_{nominal}$ = 100 s

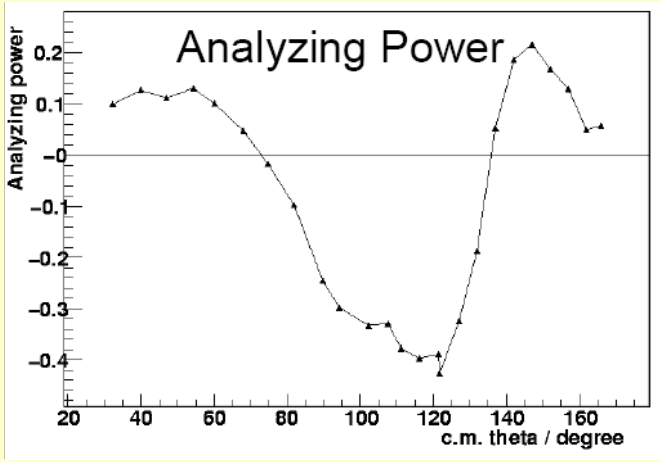
$$\frac{T_{nominal}}{T_{detuned}} = 2$$

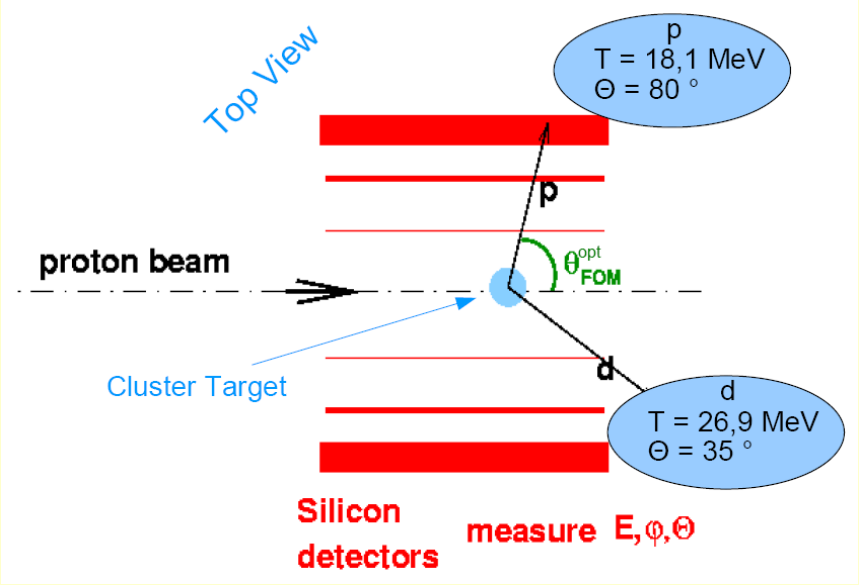


Polarimetry

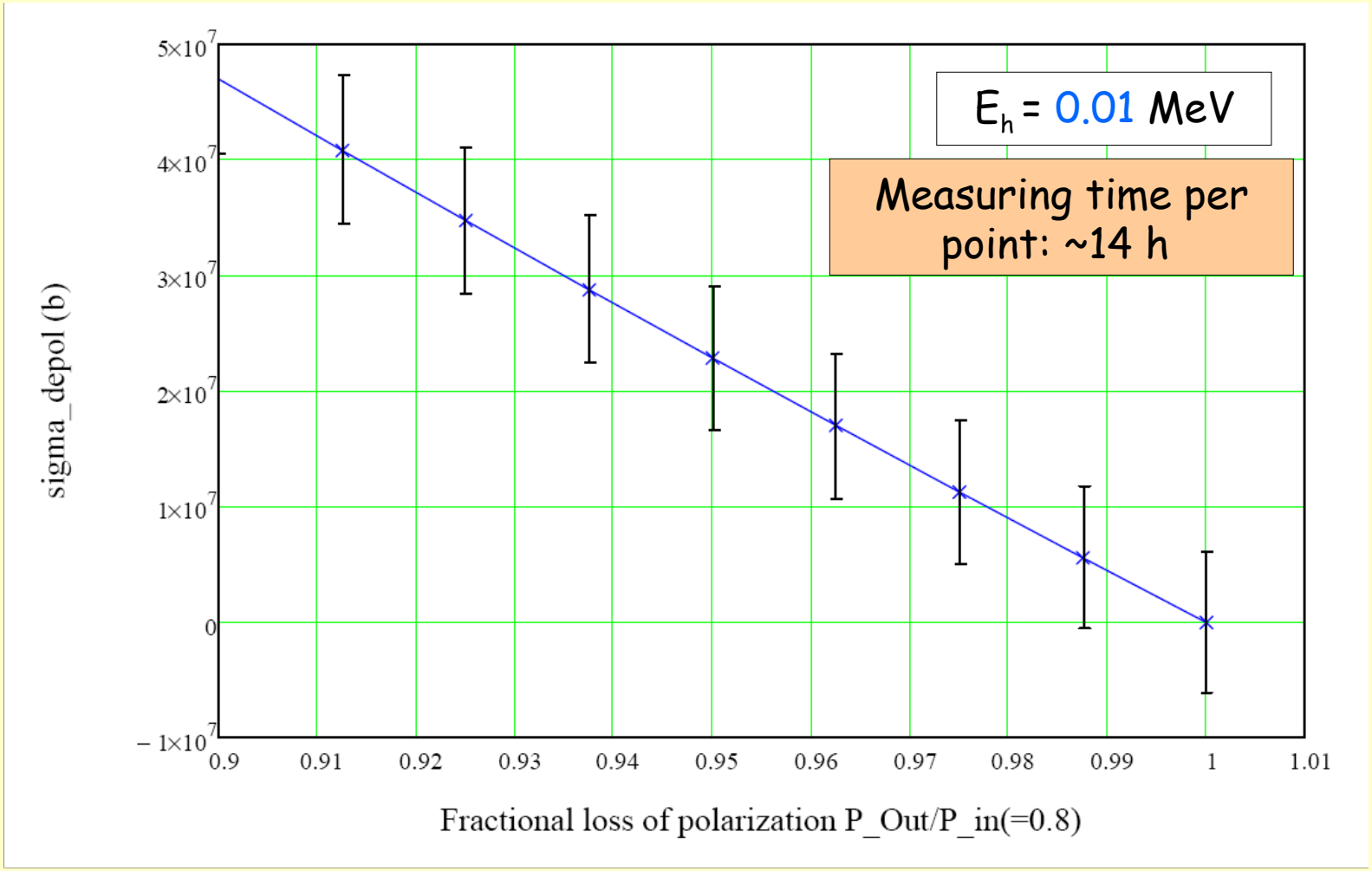






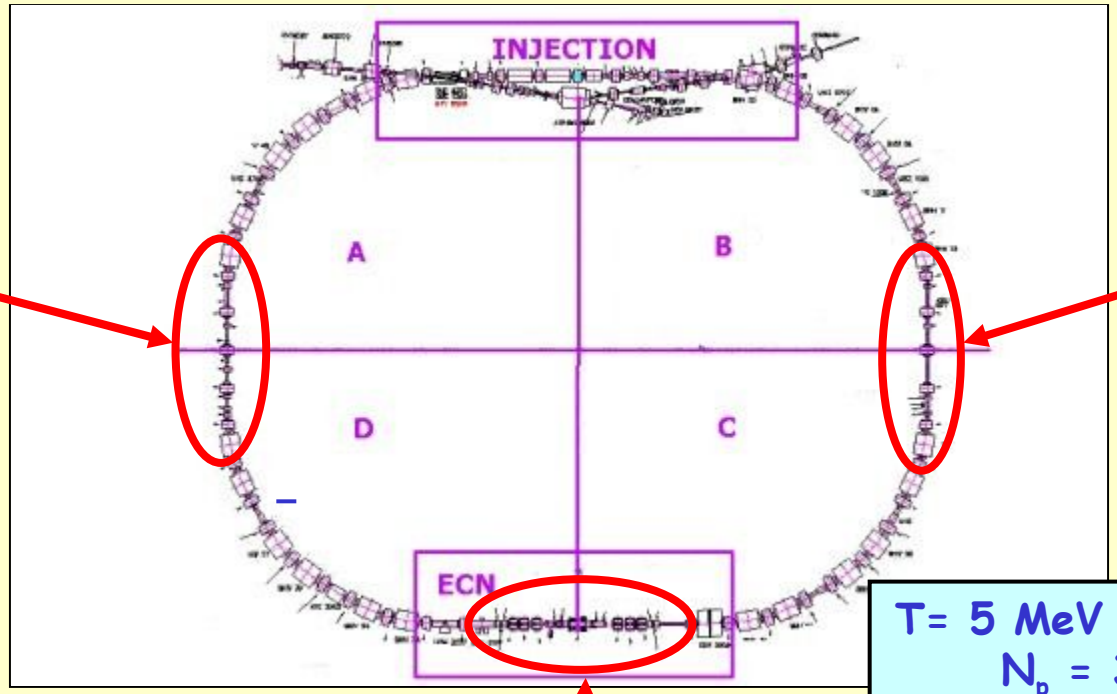


Upper limit for depolarization cross section



AD ring at CERN

Study of spin filtering in pbar-p (pbar-d) scattering



Target

Snake

E-cooler

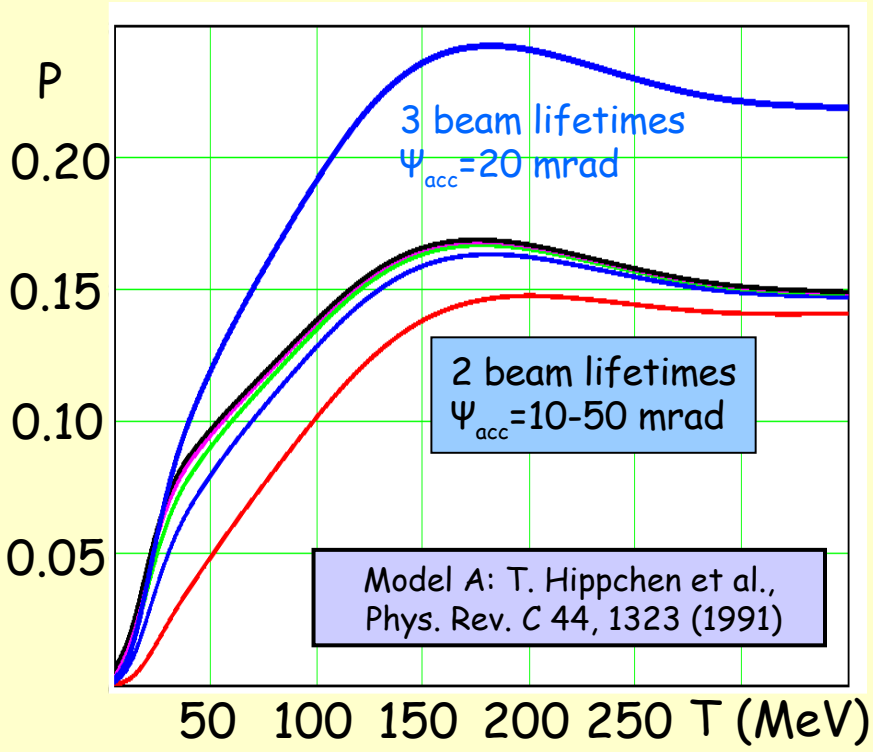
T= 5 MeV - 2.8 GeV
$N_p = 3 \cdot 10^7$

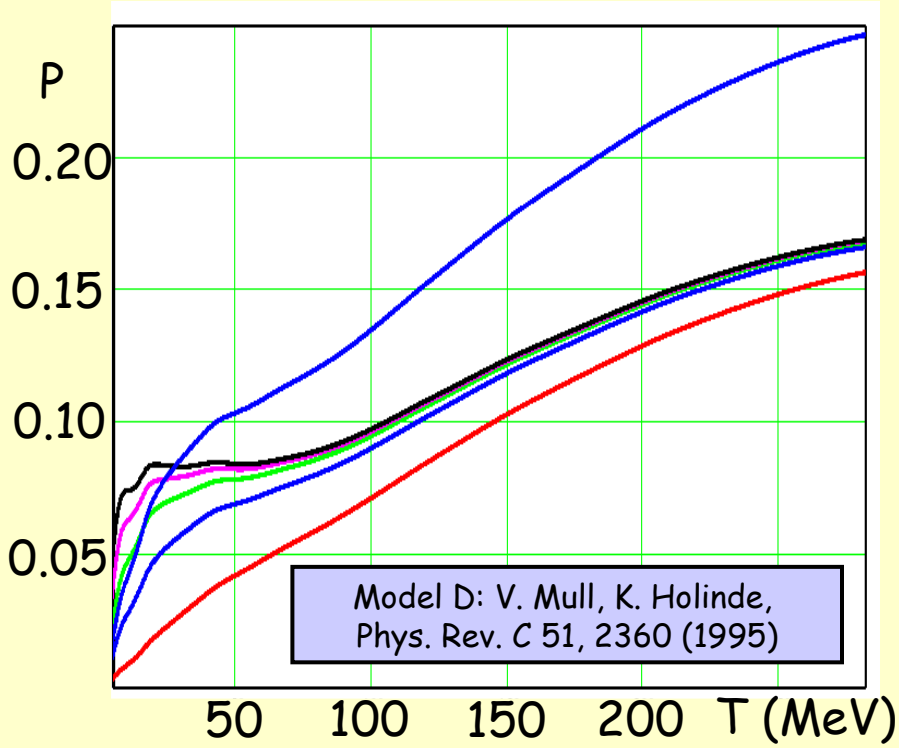
Measurement of effective polarization buildup cross-section

- Both transverse and longitudinal
- Variable acceptance at target
- Test also polarized D target

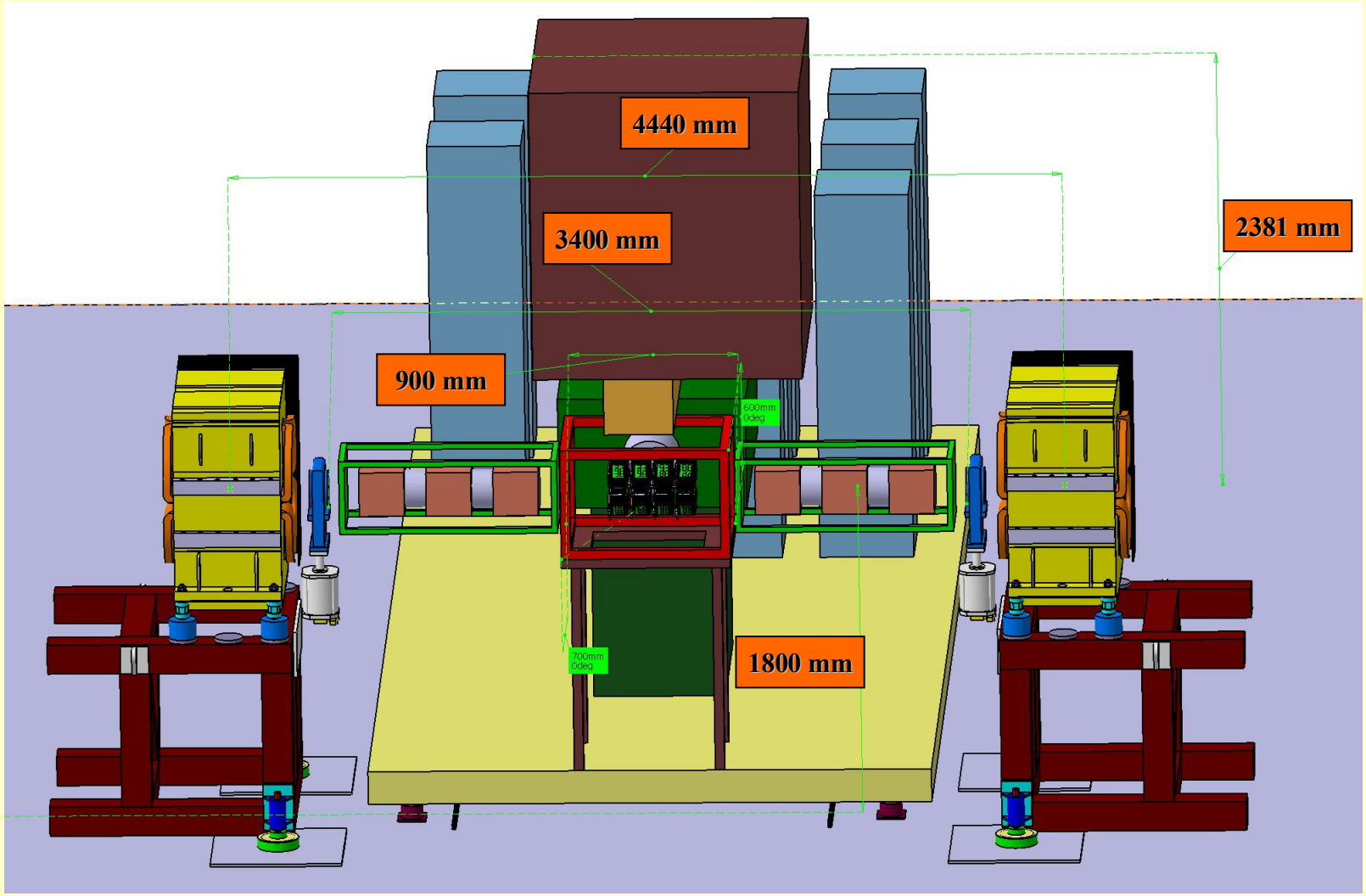
First ever measurement for spin correlations in pbar-p (and pbar-D)

Theoretical estimate of Antiproton Beam Polarization (Hadronic Interaction: Longitudinal Spin Filtering)

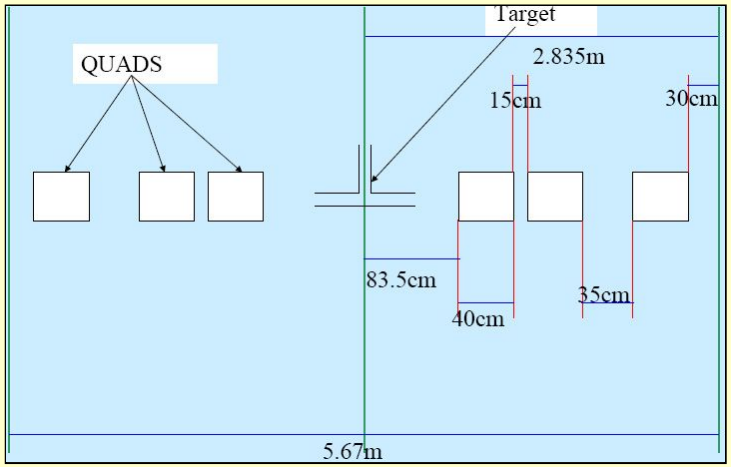


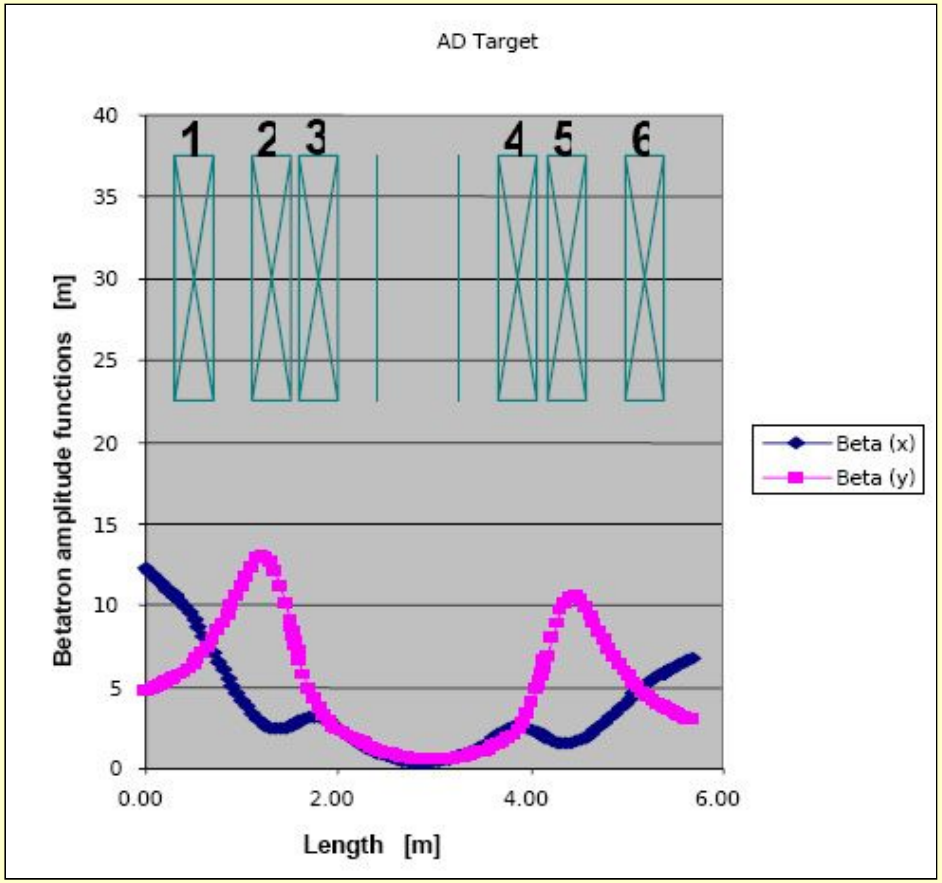


Interaction region for spin-filtering studies



Low beta section

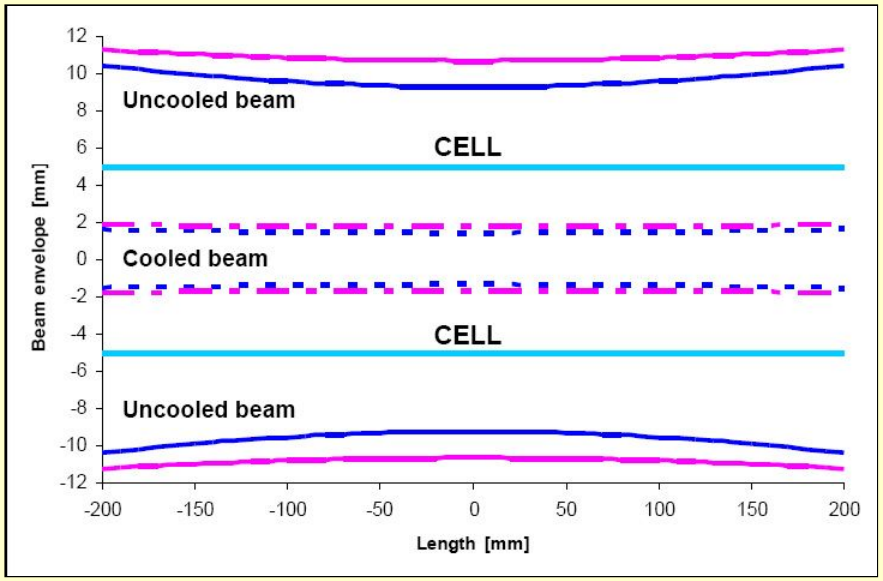


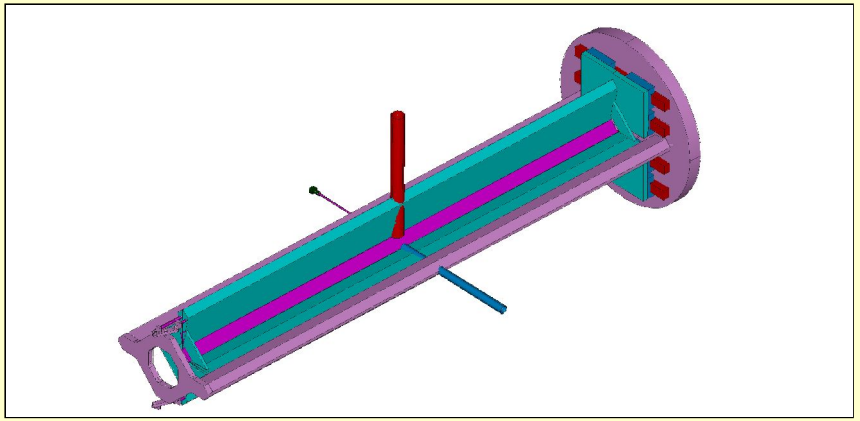


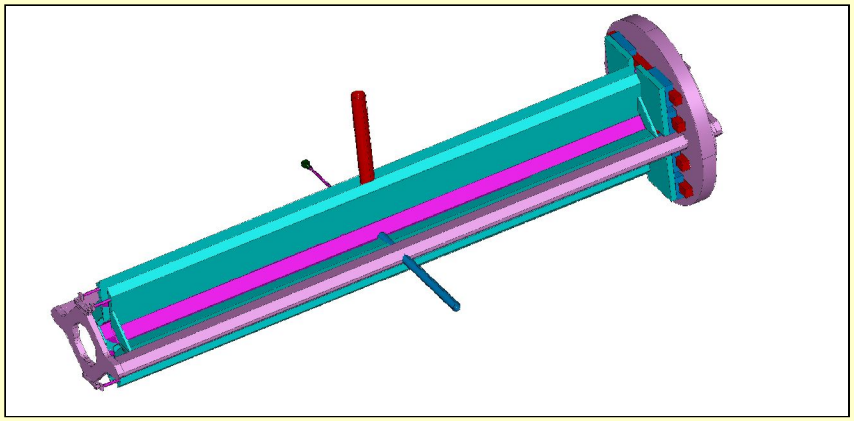
Superconducting quadrupoles necessary

Storage cell design

Pbar beam at AD:

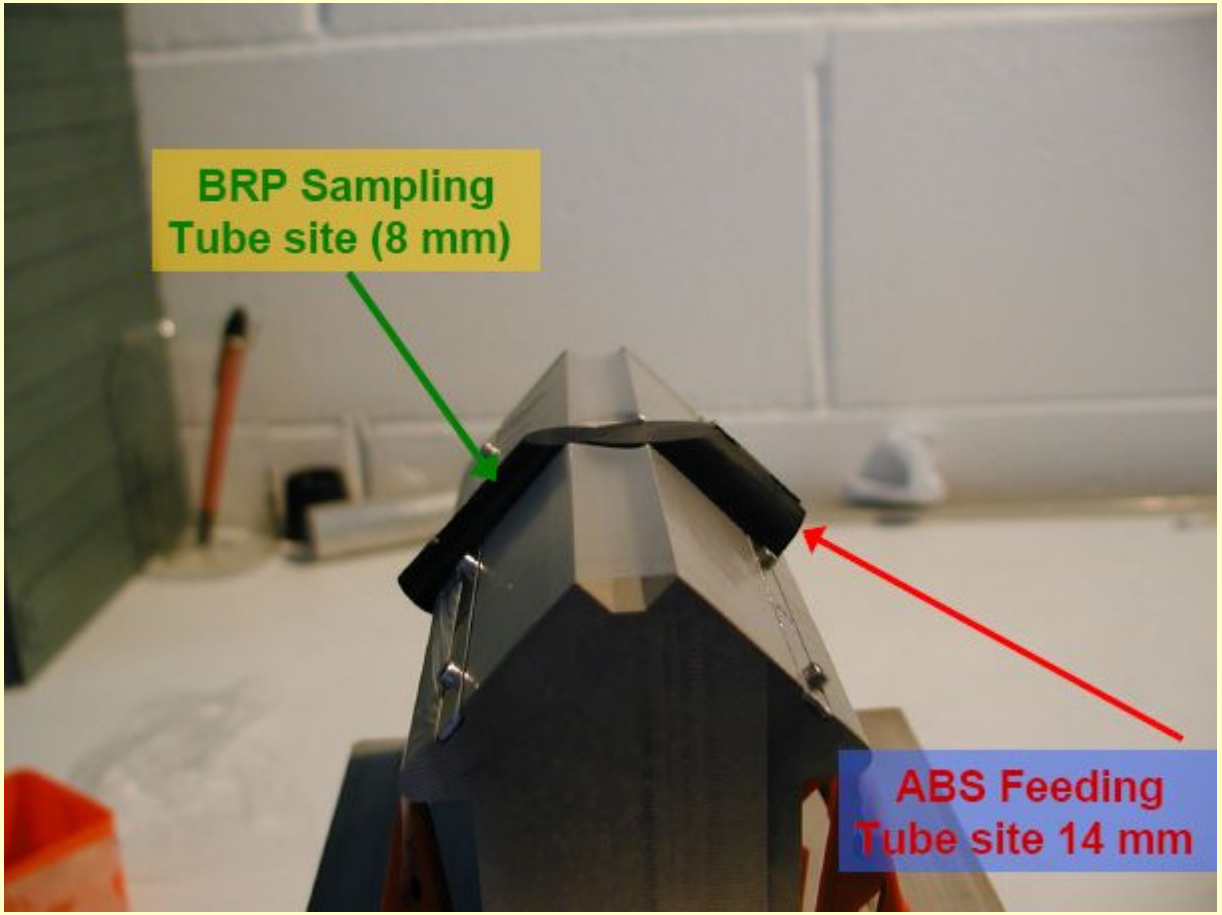






Openable storage cell required

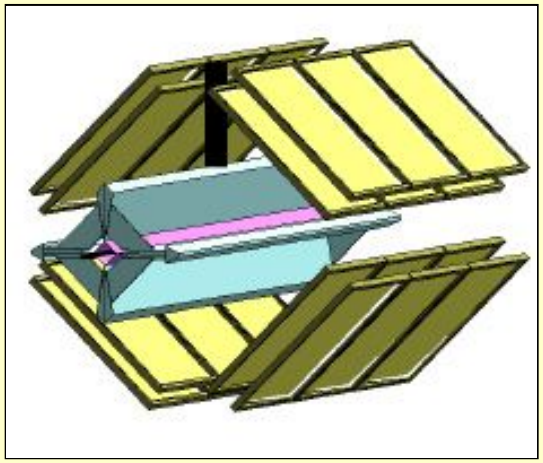
Storage cell design



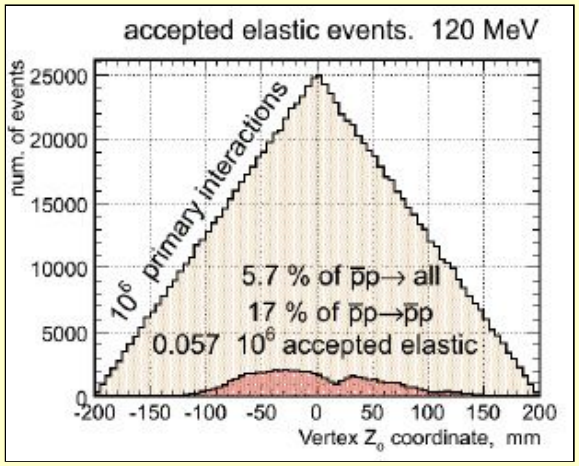
5 μm Teflon foil (T_{rec}<8MeV)

Detector concept

- Will measure beam polarization by using the (measured) analysing power of:
  - pbar-p elastic



- Modular structure
- 10 cm x 10 cm silicon wafers
- 300 μm thick
- Open cell without moving det.
- Re-use of HERMES recoil



beam energy:	43 MeV	120 MeV	220 MeV
total number of primary events:	1 M	1 M	1 M
Primary antiproton-proton elastic:	0.33 M	0.33 M	0.33 M
accepted: elastic	48 k	57 k	40 k
	14.5 %	17.0 %	12.0 %
total 'run' time:	4000 sec	5700 sec	6898 sec
good (reconstructed) event rate:	12 evt/sec	10 evt/sec	5.8 evt/sec

(after spin-filtering)

Timeline

Fall 2007/ Spring 2008	Technical proposal to COSY-PAC for spin filtering
	Technical proposal to SPSC for spin filtering at AD
2007-2008	Design and construction phase
2009	Spin-filtering studies at COSY
	Commissioning of AD experiment
2010	Installation at AD
2010-2011	Spin-filtering studies at AD

June 23-25, 2008 WE Heraeus Seminar at Bad-Honnef

"Polarized Antiprotons"

(chair: P. Lenisa and F. Rathmann)