Polarized Antiproton EXperiments

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

PAX
Status Report

P. Lenisa - Università di Ferrara and INFN

CSN III – Trieste, 19.09.06

Part I: The PAX proposal at FAIR

Part II: Spin-filtering studies at COSY and AD

PAX Collaboration

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

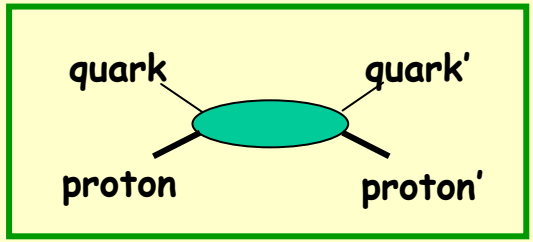
TIMELINE

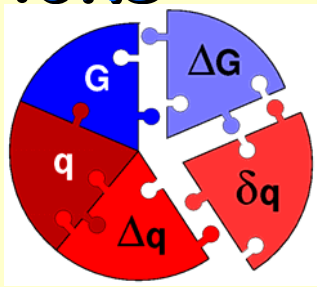
Jan. 04	Letter of Intent for FAIR
May 04	QCD-PAC meeting at GSI
Aug. 04	Workshop on polarized antiprotons at GSI
Jan. 05	Technical Proposal for FAIR
Mar. 05	QCD-PAC meeting at GSI
Nov. 05	LoI to CERN-SPSC to perform spin-filtering experiments with antiprotons at the AD ring
Apr. 06	LoI to COSY-PAC for spin filtering experiments with protons at COSY

Physics Motivations

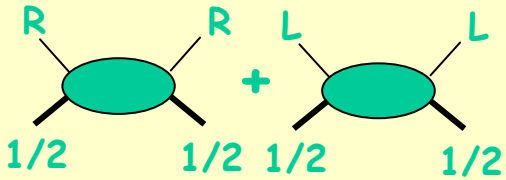
Leading Twist Distribution Functions

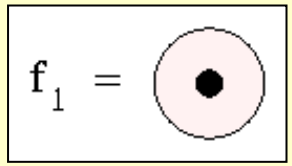
Probabilistic interpretation in helicity base:





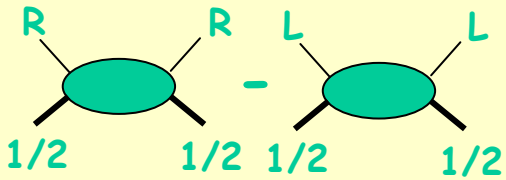
$f_1(x)$

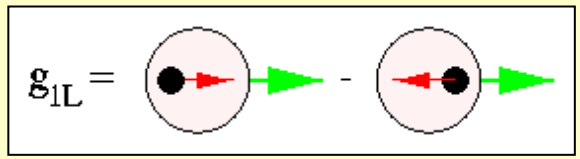




q(x) spin averaged **(well known)**

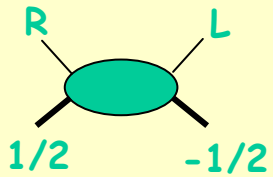
$g_1(x)$





Δq(x) helicity diff. **(known)**

$h_1(x)$

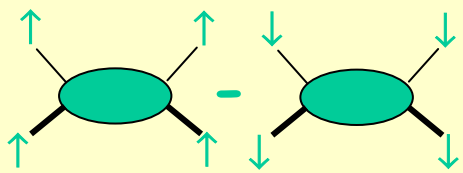


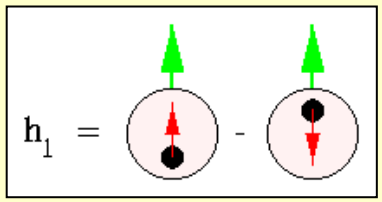
No probabilistic interpretation in the helicity base (off diagonal)

Transversity base

$u_\uparrow = 1/\sqrt{2}(u_R + u_L)$

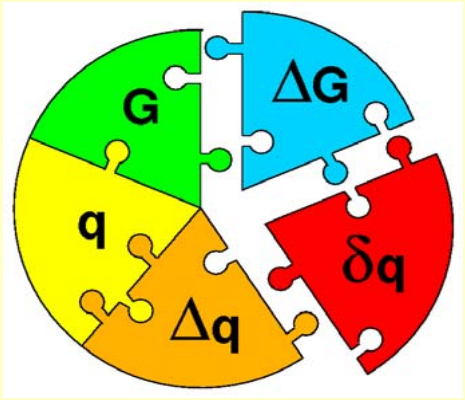
$u_\downarrow = 1/\sqrt{2}(u_R - u_L)$





δq(x) helicity flip **(unknown)**

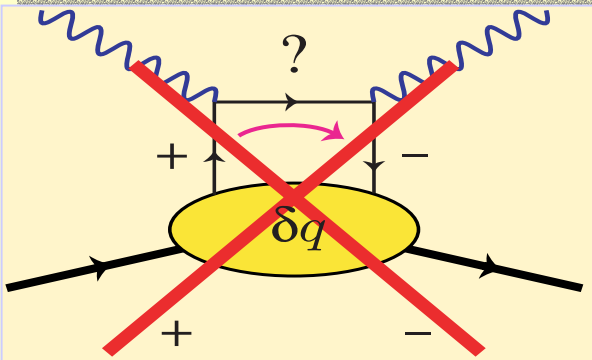
Transversity



Properties:

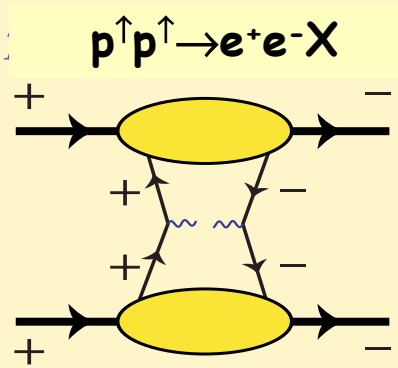
- Probes relativistic nature of quarks
- No gluon analog for spin-1/2 nucleon
- Different Q^2 evolution than Δq
- Sensitive to valence quark polarization

Chiral-odd: requires another chiral-odd partner



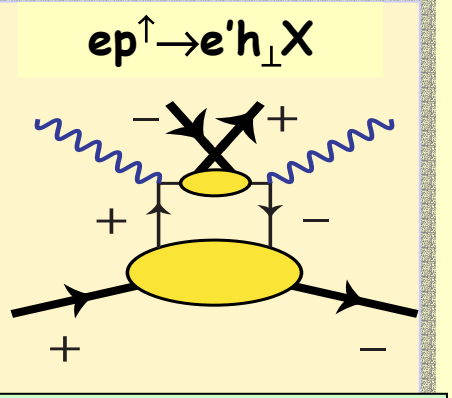
Impossible in DIS

h_1 must couple to another chiral-odd function



Direct Measurement

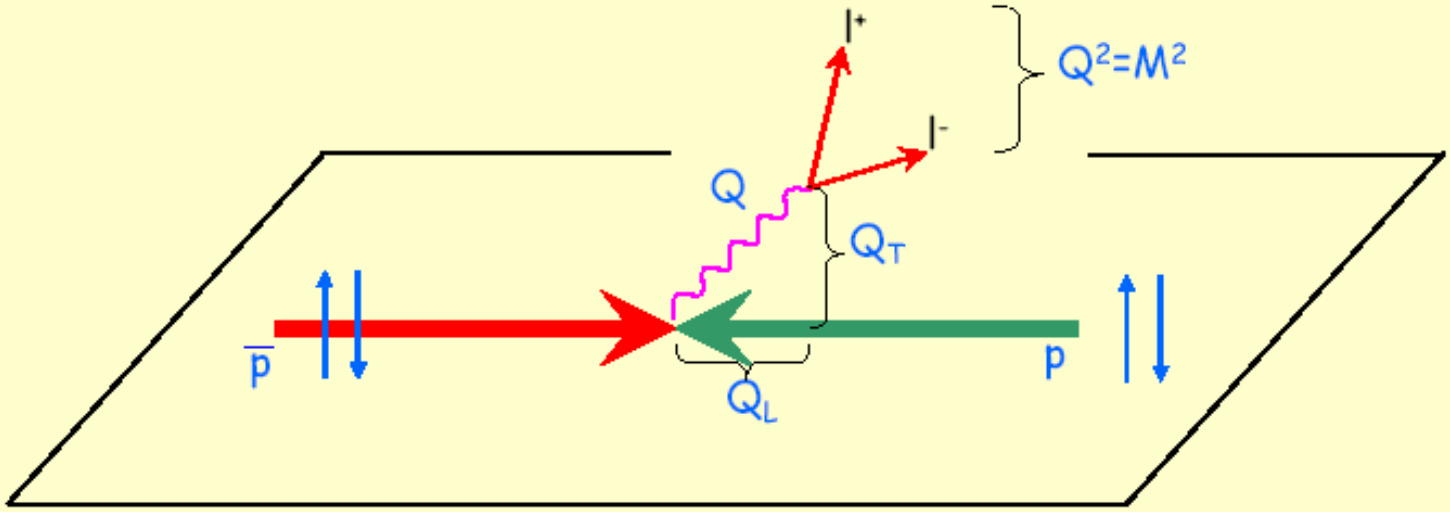
$h_1 \times h_1$



Indirect Measurement: Convolution of with unknown fragment. fct.

$h_1 \times$ Collins function

Drell-Yan process



Elementary LO interaction: $q\bar{q} \rightarrow \gamma^* \rightarrow l^+ l^-$

$$\frac{d^2\sigma}{dM^2 dx_F} = \frac{4\pi\alpha^2}{9 M^2 s} \frac{1}{x_1 + x_2} \sum_q e_q^2 \left[q(x_1)\,\bar{q}(x_2) + \bar{q}(x_1)\,q(x_2) \right]$$

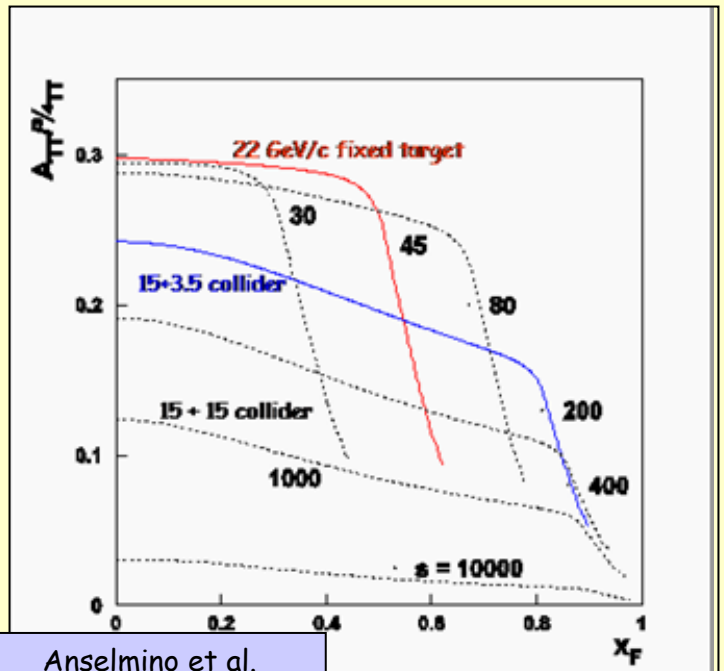
$q = u, \bar{u}, d, \bar{d}, \ldots$

M invariant Mass of lepton pair

$$x_F = x_1 - x_2 \qquad x_1 x_2 = M^2 / s \equiv \tau \qquad x_F = 2Q_L / \sqrt{s}$$

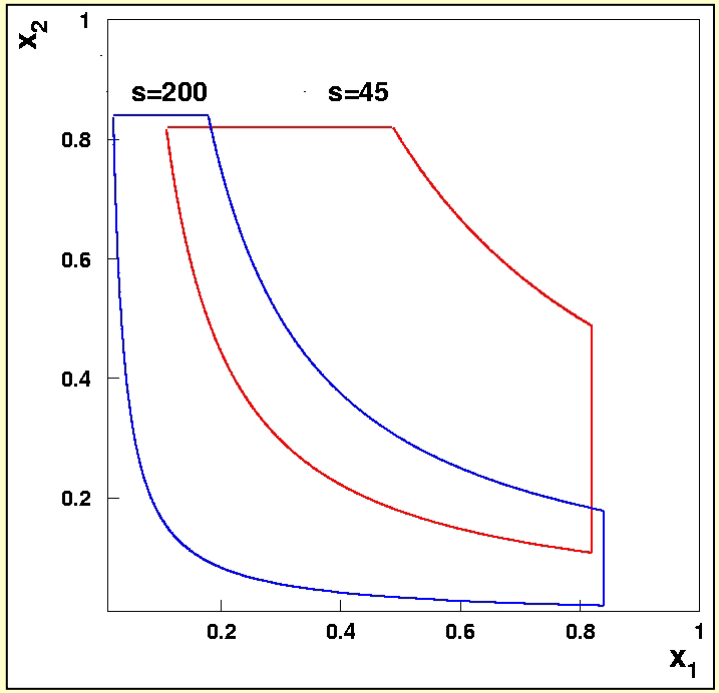
h_1 from pbar-p Drell-Yan at GSI

$$A_{TT} = \hat{a}_{TT} \frac{\sum_q e_q^2 \left[h_{1q}(x_1) h_{1q}(x_2) + h_{1\bar{q}}(x_1) h_{1\bar{q}}(x_2) \right]}{\sum_q e_q^2 \left[q(x_1) q(x_2) + \bar{q}(x_1) \bar{q}(x_2) \right]} \approx \hat{a}_{TT} \frac{h_{1u}(x_1) h_{1u}(x_2)}{u(x_1) u(x_2)}$$



Anselmino et al.
PLB 594,97 (2004)

Similar predictions by Efremov et al.,
Eur. Phys. J. C35, 207 (2004)



PAX : $M^2/s = x_1 x_2 \sim 0.1\text{-}0.3$ → valence quarks (A_{TT} large ~ 0.2-0.4)

What about p-p?

$$A_{TT} = \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 \left[h_{1q}(x_1) h_{1\bar{q}}(x_2) + h_{1\bar{q}}(x_1) h_{1q}(x_2) \right]}{\sum_q e_q^2 \left[q(x_1) \bar{q}(x_2) + \bar{q}(x_1) q(x_2) \right]}$$

➡ $h_{1\bar{q}}(x, Q^2)$ ≠ $h_{1q}(x, Q^2)$

➡ $h_{1q}(x, Q^2)$ small and with much slower evolution than $\Delta q(x, Q^2)$ and $q(x, Q^2)$ at small x

Barone, Calarco, Drago

Martin, Schäfer, Stratmann, Vogelsang

RHIC: $\tau = x_1 x_2 \sim 10^{-3}$ → sea quarks ($A_{TT} \sim 0.01$)

JPARC/U70: $\tau = x_1 x_2 \sim 10^{-1}$ → valence and sea ($A_{TT} \sim 0.1$)

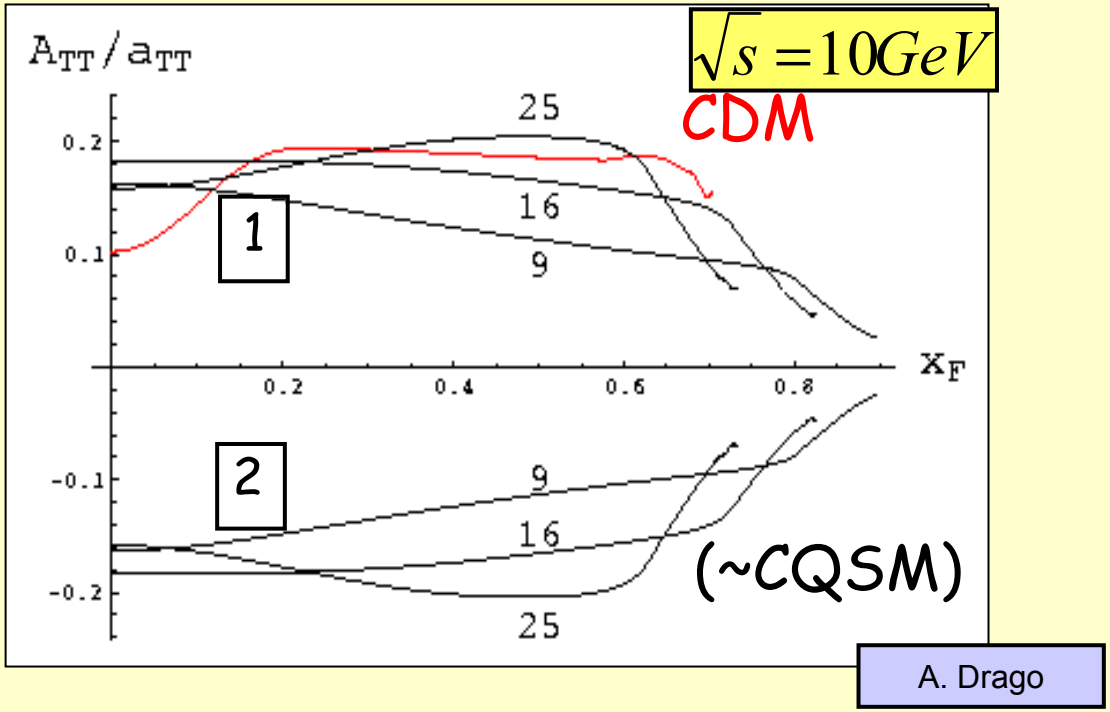
PAX: $\tau = x_1 x_2 \sim 10^{-1}$ → valence and sea ($A_{TT} \sim 0.1$)

DY in p-p: A_{TT}

Asymmetries evoluted from the assumptions:

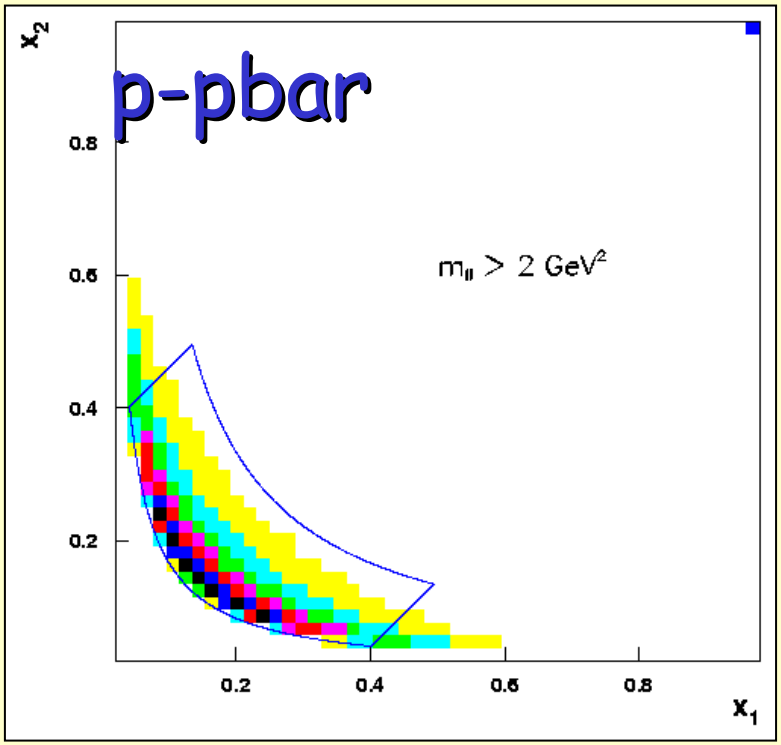
1 $h_{1\bar{q}}(x, Q_0^2) = \Delta\bar{q}(x, Q_0^2)$

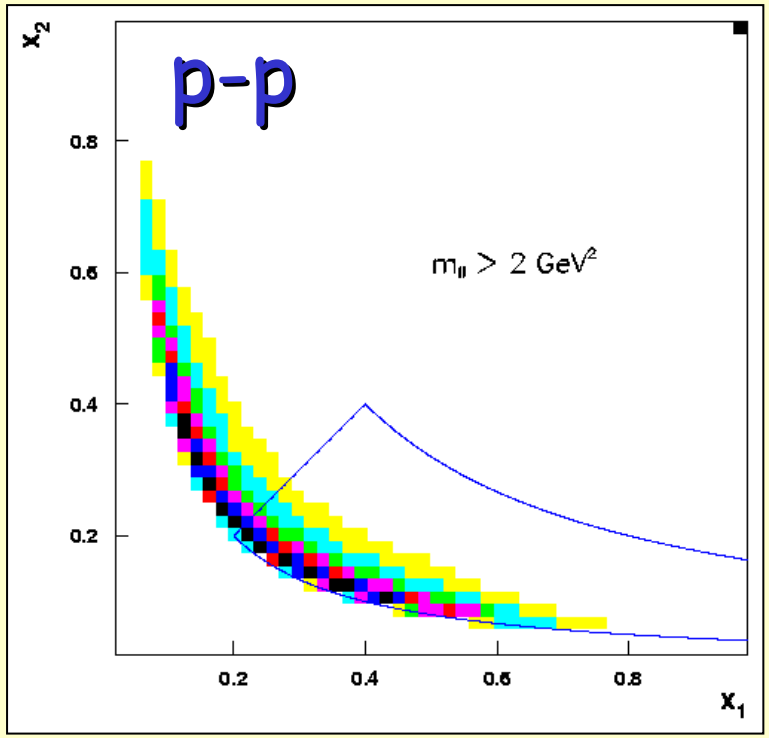
2 $h_{1\bar{q}}(x, Q_0^2) = -\Delta\bar{q}(x, Q_0^2)$



- Aymmetry is large at PAX energy (> 0.1)
- Sign of the asymmetry will distinguish between the two models.
- It will give indications about calculation of sea distributions.

DY events distribution ($\sqrt{s}$~15 GeV)





$M^2/s = x_1 x_2 \sim 0.01\text{-}0.3$

$x_1 = x_2 \rightarrow A_{TT} \sim h_{1u}^2$

Direct measurement of h_{1u} for $0.15 < x < 0.5$

→ Extraction of $h_{1\bar{u}}$ for $x > 0.2$

p-pbar +p-p -> complete map of transversity

Other physics issues for PAX

Transversity via Drell-Yan processes

A_{TT} ➡ direct access to transversity

High Energy

Transverse Single Spin Asymmetries

A_N ➡ QCD "theorem": $(\text{Sivers})_{\text{D-Y}} = -(\text{Sivers})_{\text{DIS}}$

Elastic processes

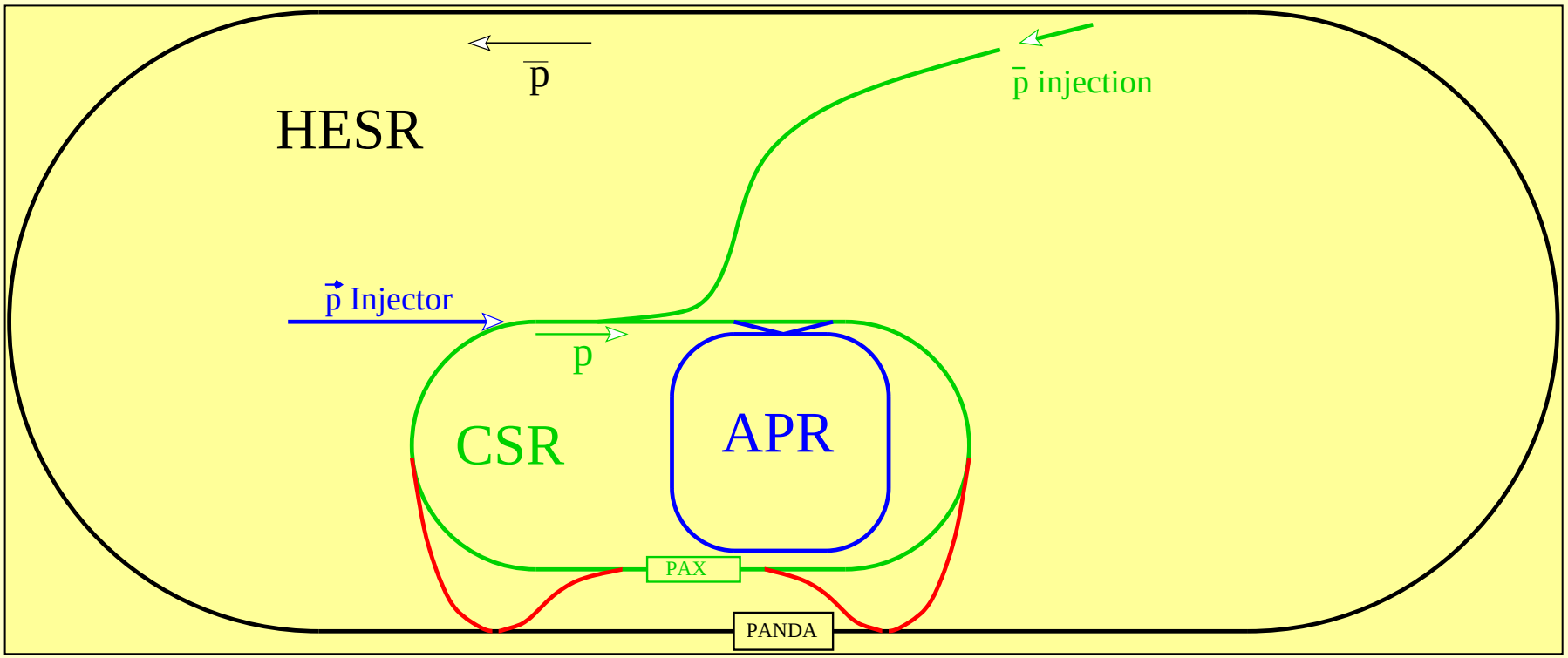
A_N, A_{NN}, A_{LL}, A_{SS}, A_{SL} ➡ spin mysteries like in *pp* ?

Time-like e.l.m. form factors

$p\bar{p} \rightarrow l^+ l^-$ ➡ form factors

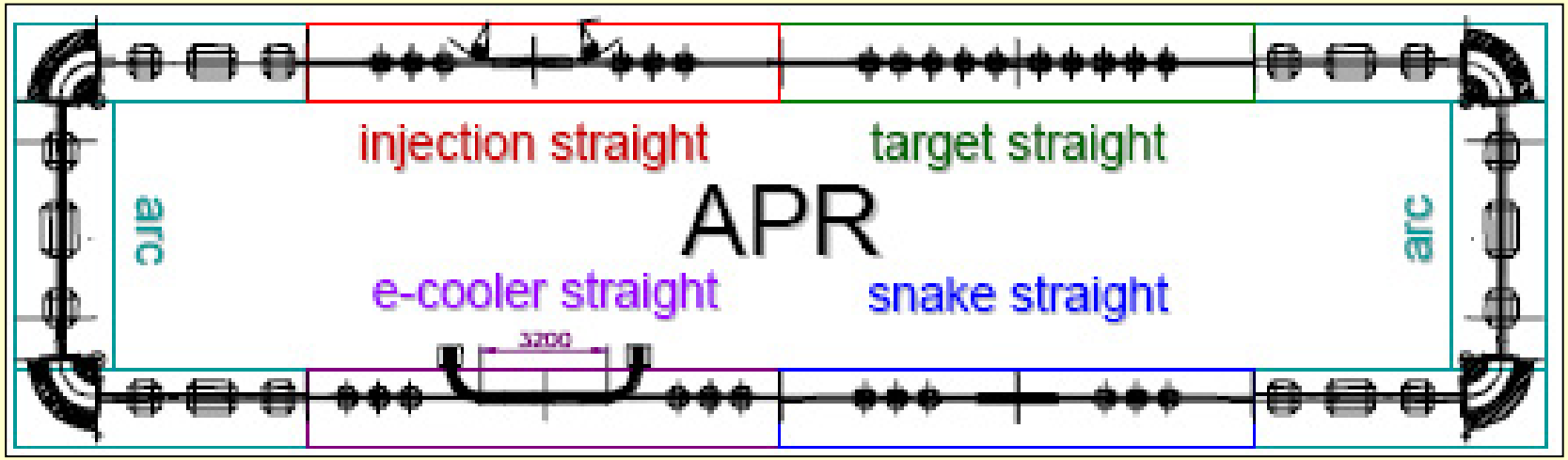
Low Energy

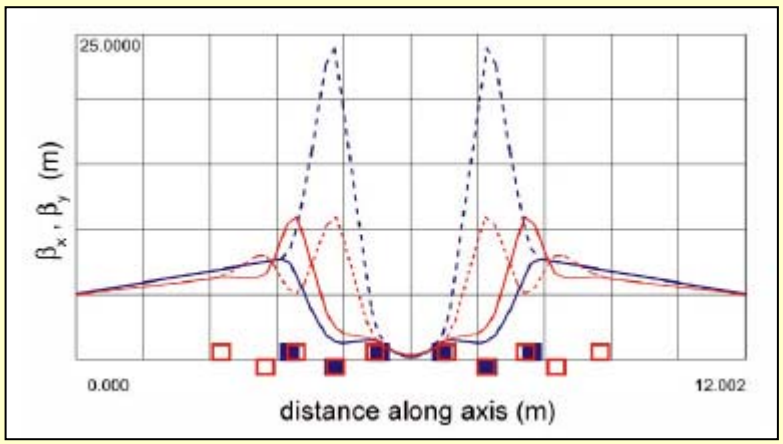
PAX Accelerator Setup



- Antiproton Polarizer Ring (APR)
- Asymmetric Antiproton-Proton Collider (CSR)
- High Energy Synchrotron Ring (HESR)

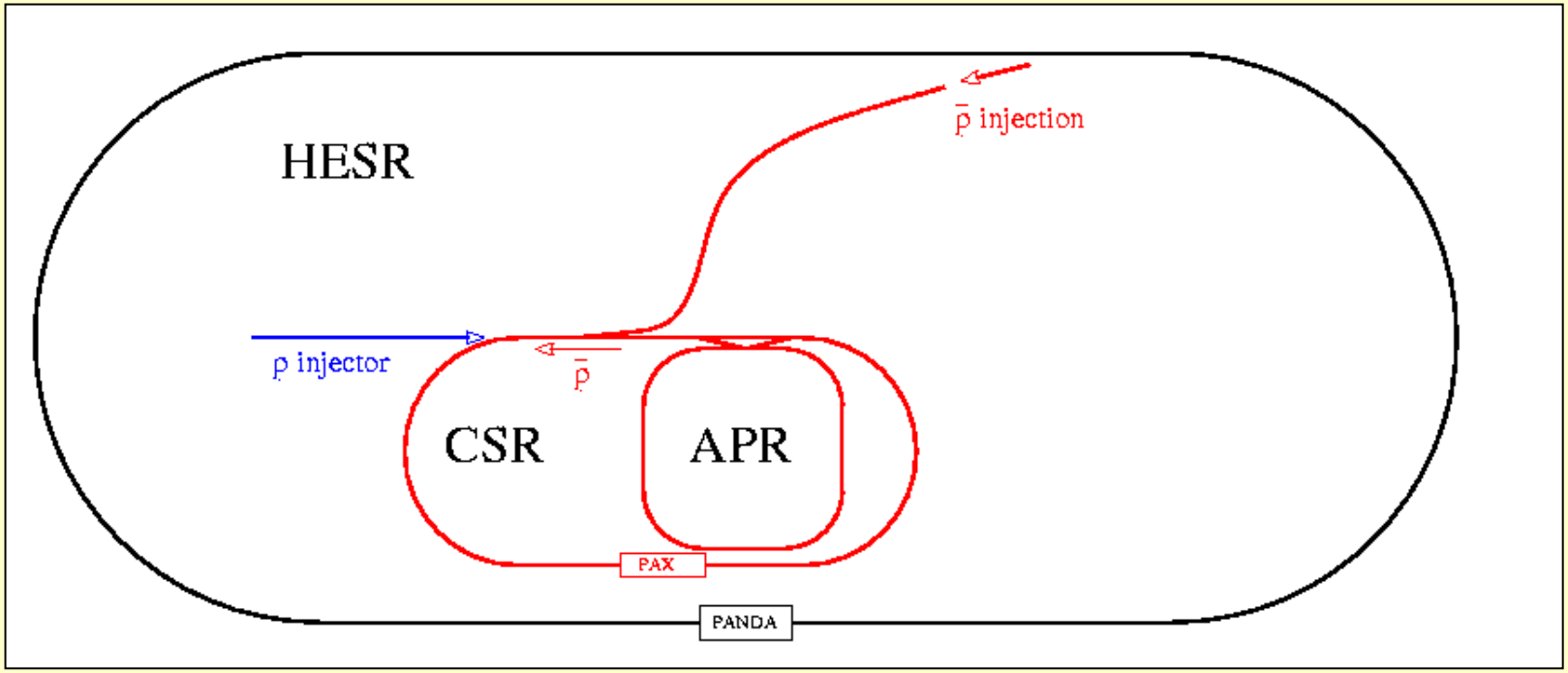
Antiproton Polarizer Ring





Energy	250 MeV
ε	250 mm mrad
Circumf.	86 m

Staging: Phase I (PAX@CSR)

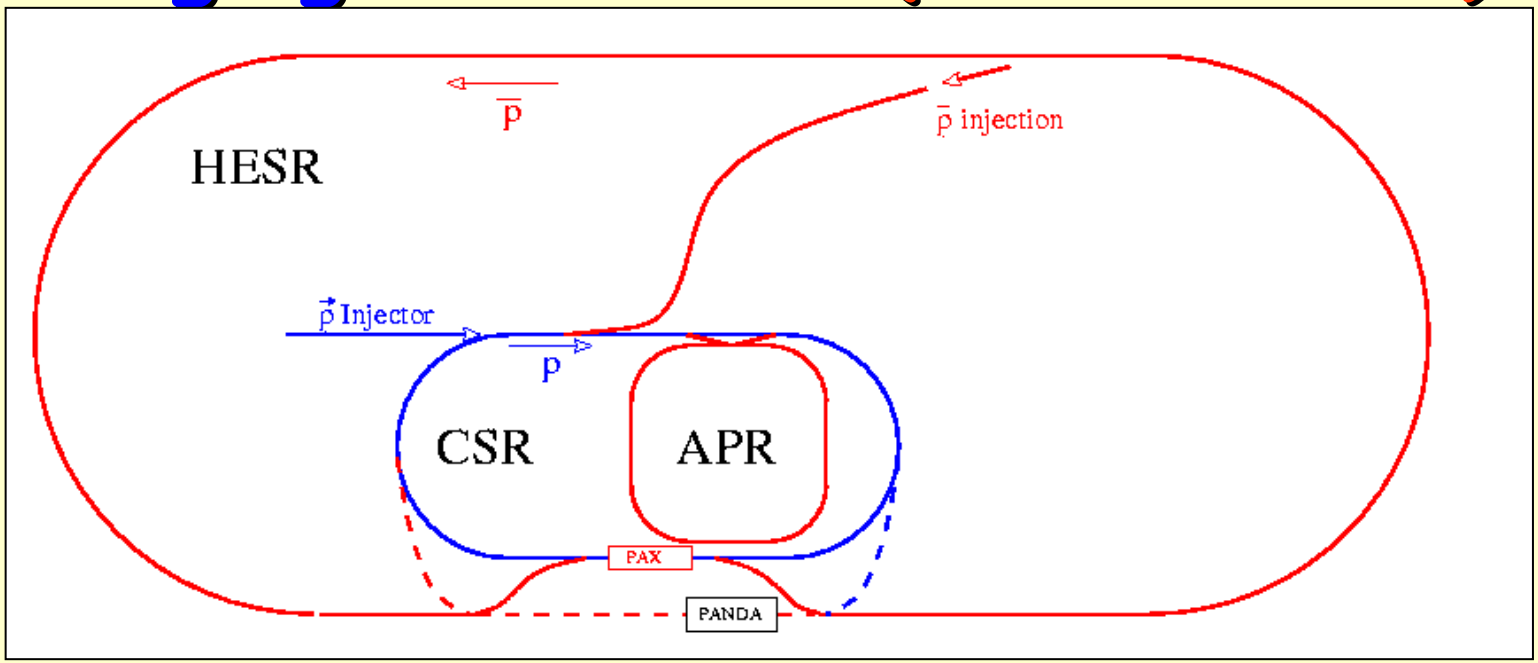


Physics: EMFF
pbar-p elastic

Experiment: pol./unpol. pbar on internal polarized target

Independent from HESR running

Staging: Phase II (PAX@HESR)



Physics: Transversity

EXPERIMENT:

Asymmetric collider:

polarized antiprotons in HESR (p=15 GeV/c)

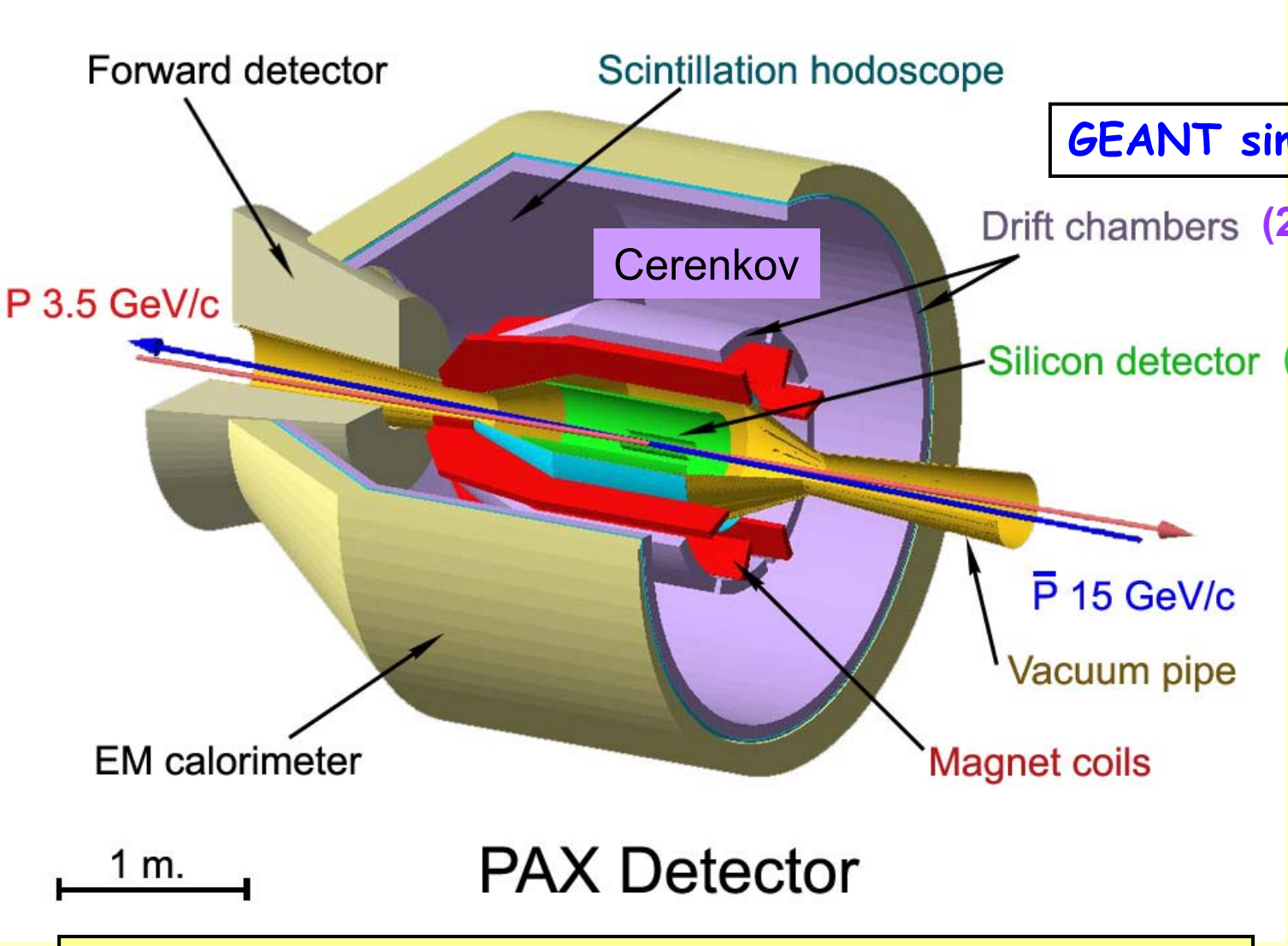
polarized protons in CSR (p=3.5 GeV/c)

Second IP with minor interference with PANDA

Towards higher luminosity

Parameter	Bunched		Coasting	
	CSR	HESR	CSR	HESR
Particles	pbar	p	pbar	p
Circum. [m]	183	574	183	574
P_{max} [GeV/c]	3.65	15	3.65	15
s_{max} [GeV^2]	~ 200		~ 200	
No. bunches	10	30	-	-
No. particles	5×10^{11}	2.4×10^{12}	5×10^{11}	1×10^{13}
Lifetime [hs]	~1500	~300	~1500	~300
Lum. [cm^{-2}s^{-1}]	5×10^{30}		1.2×10^{31}	
Polar.	↑↑, →→		↑↑, →→	
p-p	yes		yes	

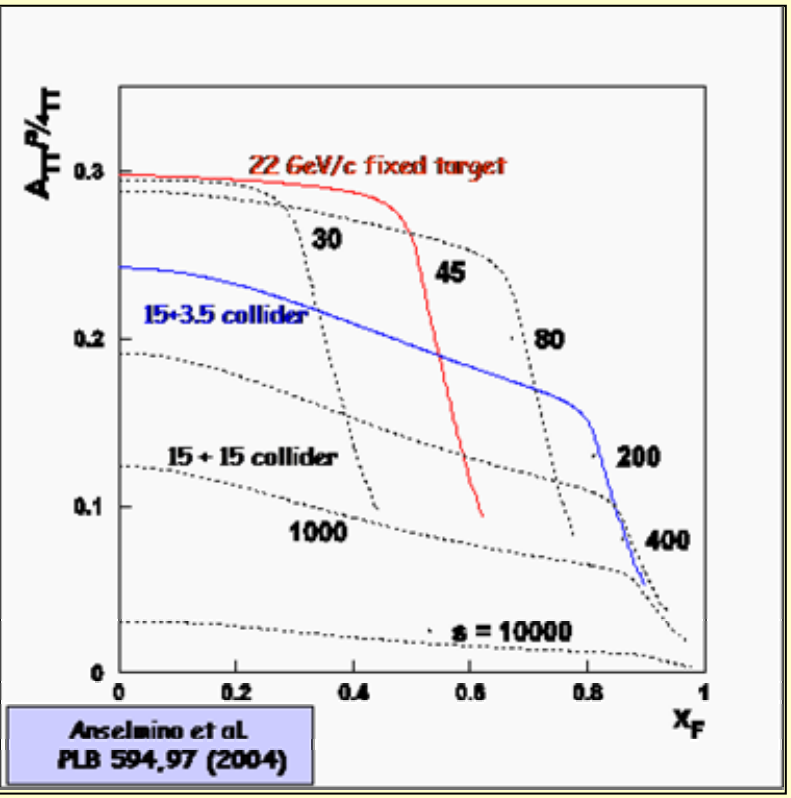
PAX Detector Concept

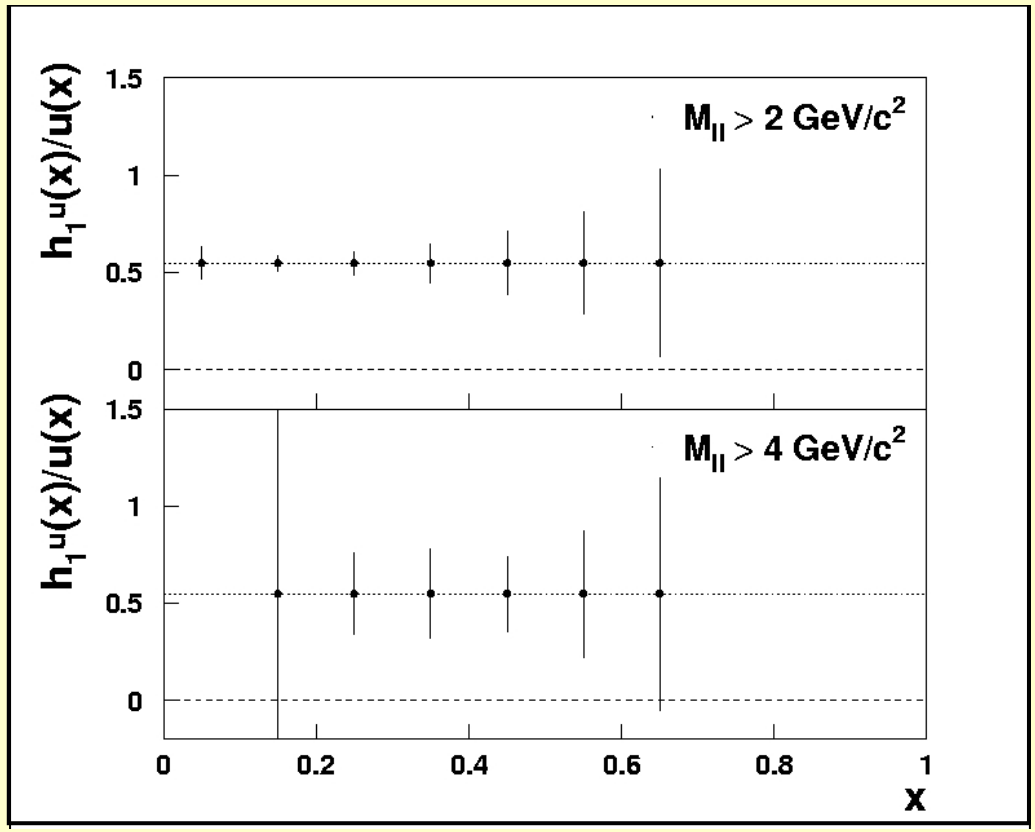


Designed for Collider but compatible with fixed target

Precision in h_1 measurement

1 year of data taking at 15+3.5 GeV collider $L = 2 \cdot 10^{30}$ cm^{-2}s^{-1}





10 % precision on the h_1^u (x) in the valence region

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 (-> practically solved thanks to Y. Shatunov & A. Smirnov)

- 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.

Part I: The PAX proposal at FAIR

Part II: Spin-filtering studies at COSY and AD

Polarized antiprotons

Intense beam of polarized pbar never produced:

- Conventional methods (ABS) not appliable

- 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)

- Stern-Gerlach separation of a stored beam (never tested and withdrawn?)

- 05.2006 (Th. Walcher et al) polarized electron beam (withdrawn)

Spin-filtering is the only succesfully tested technique

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

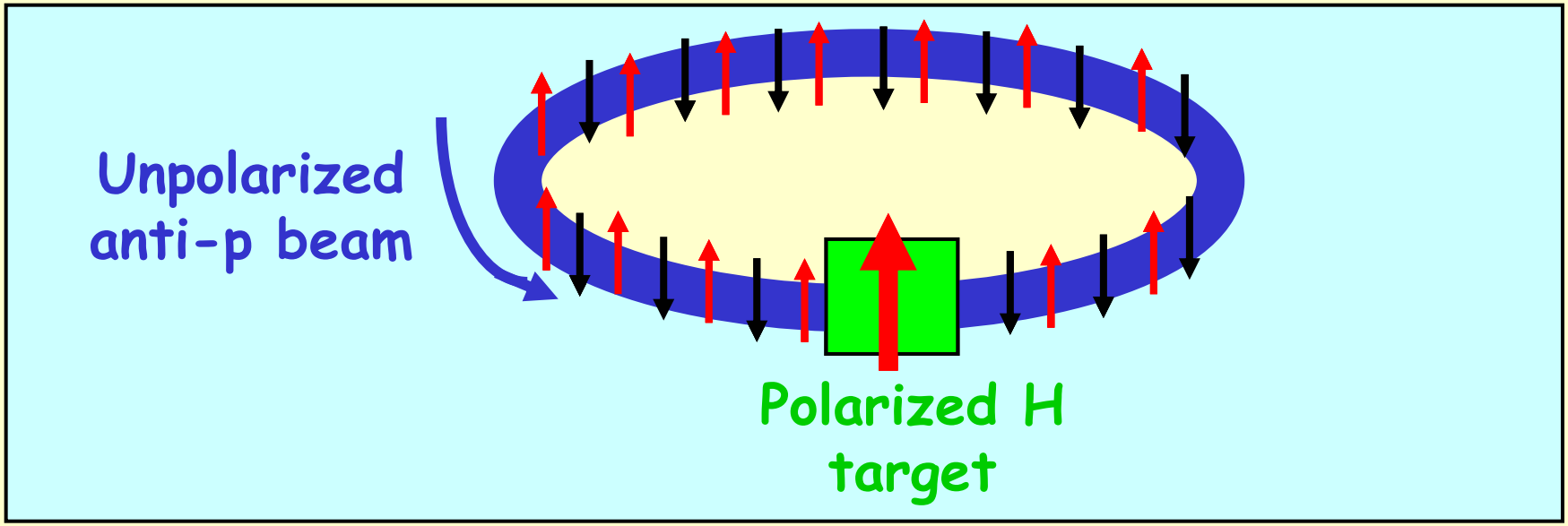
For initially equally populated spin states: ↑ ($m=+\frac{1}{2}$) and ↓ ($m=-\frac{1}{2}$)

transverse case:

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

longitudinal case:

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



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

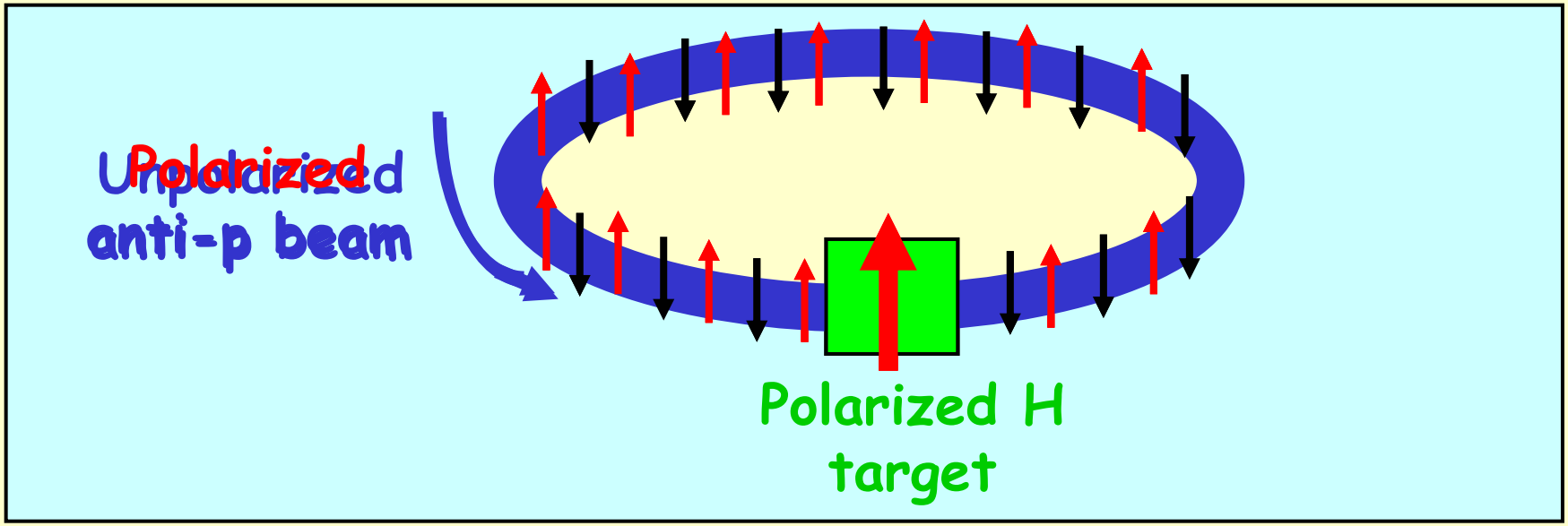
For initially equally populated spin states: ↑ ($m=+\frac{1}{2}$) and ↓ ($m=-\frac{1}{2}$)

transverse case:

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

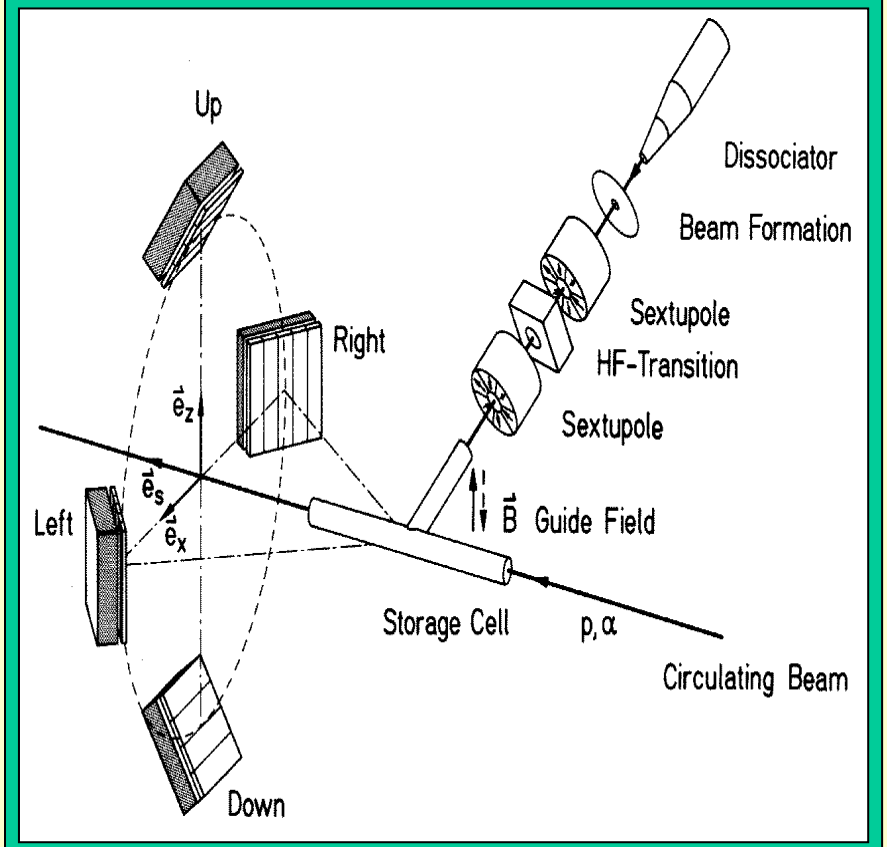
longitudinal case:

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

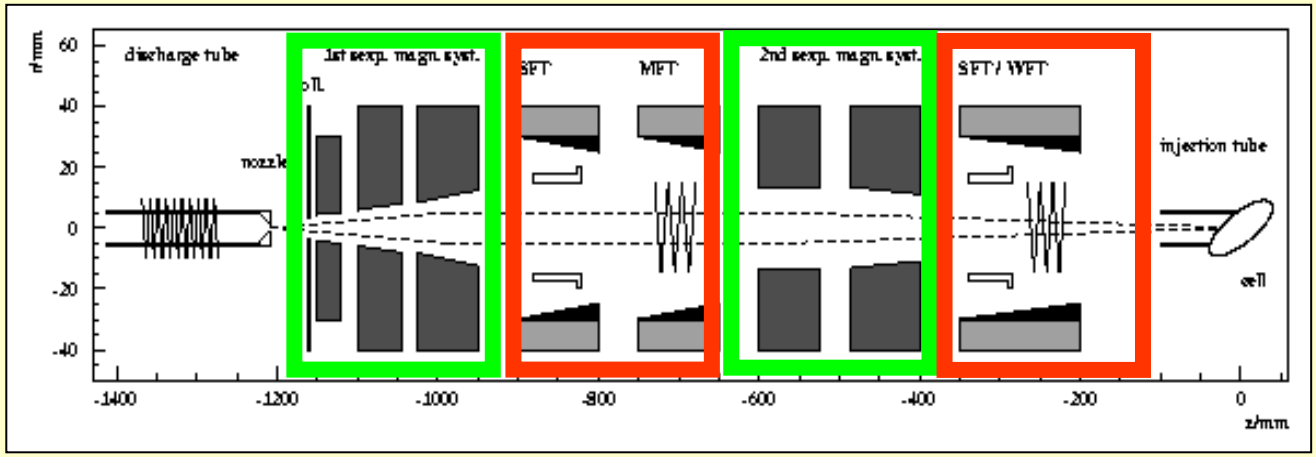


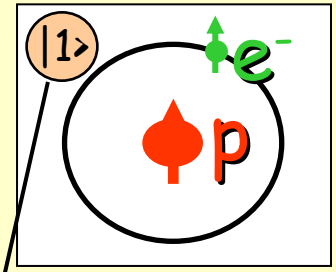
1992 Filter Test at TSR with protons

Experimental Setup



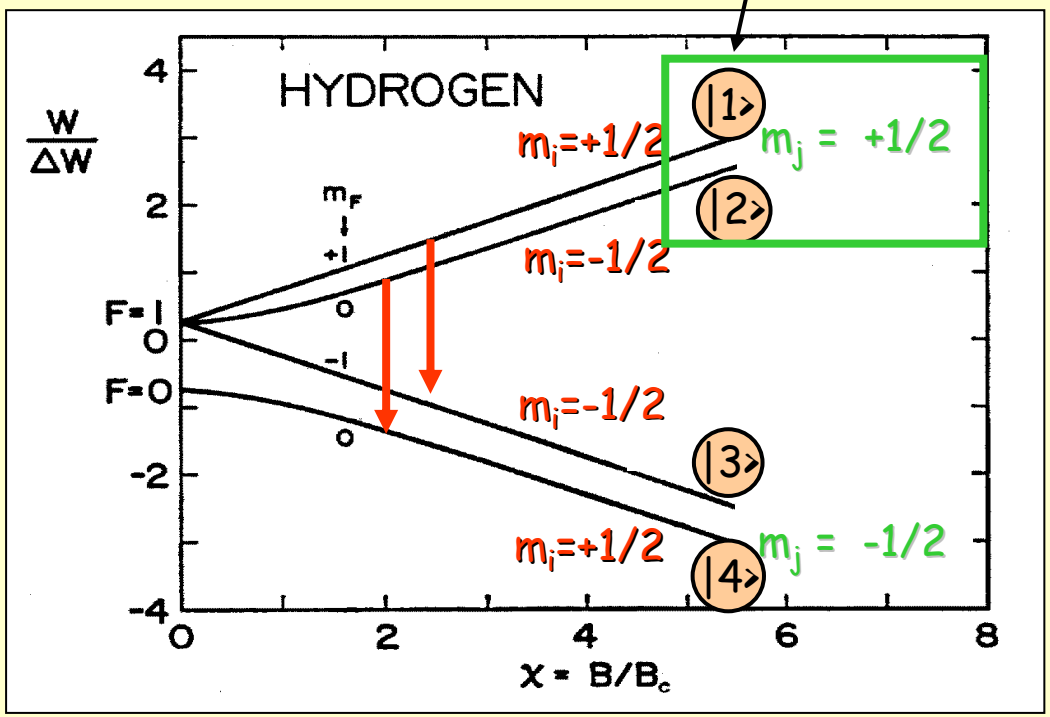
Polarized atomic beam source





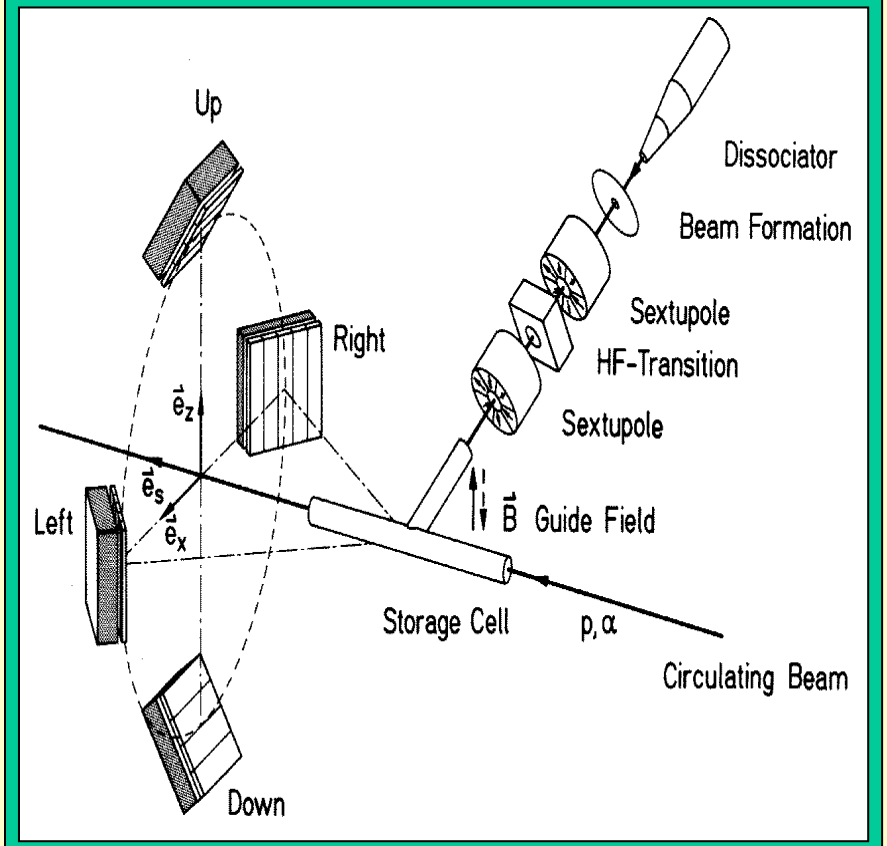
Atoms with $m_j=+\frac{1}{2}$ focused in sextupole magnets.

RF transitions select HFS.

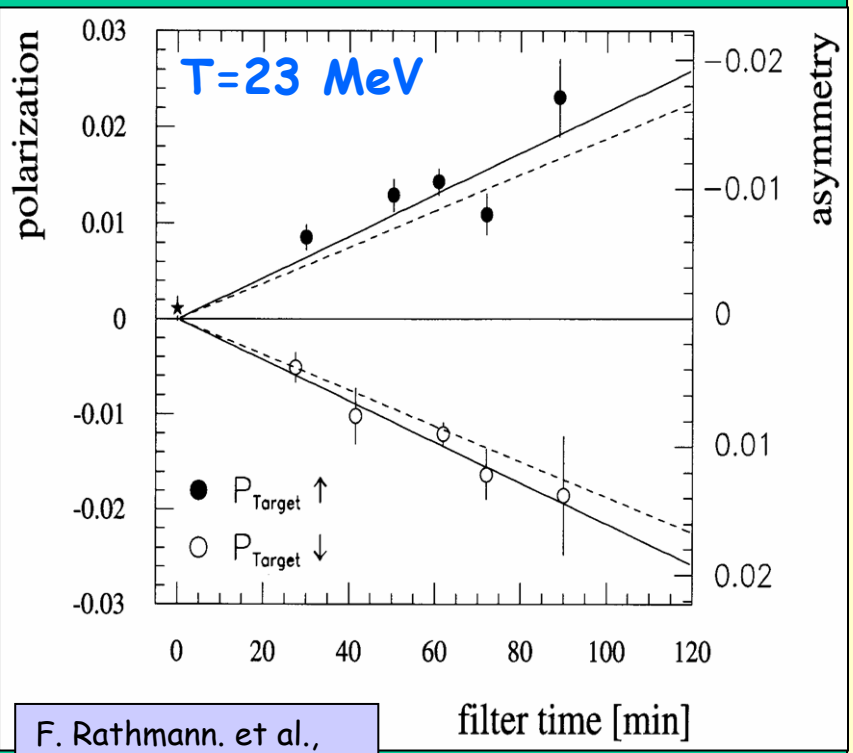


1992 Filter Test at TSR with protons

Experimental Setup



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

1. Selective removal through scattering beyond θ_{acc}=4.4 mrad ($\sigma_{R\perp}$=85.6 mb)

No contribution from other two effects

(cancellation between scattering and transmission)

$\sigma_1 = 85.6$ mb

Spin-filtering: Present situation

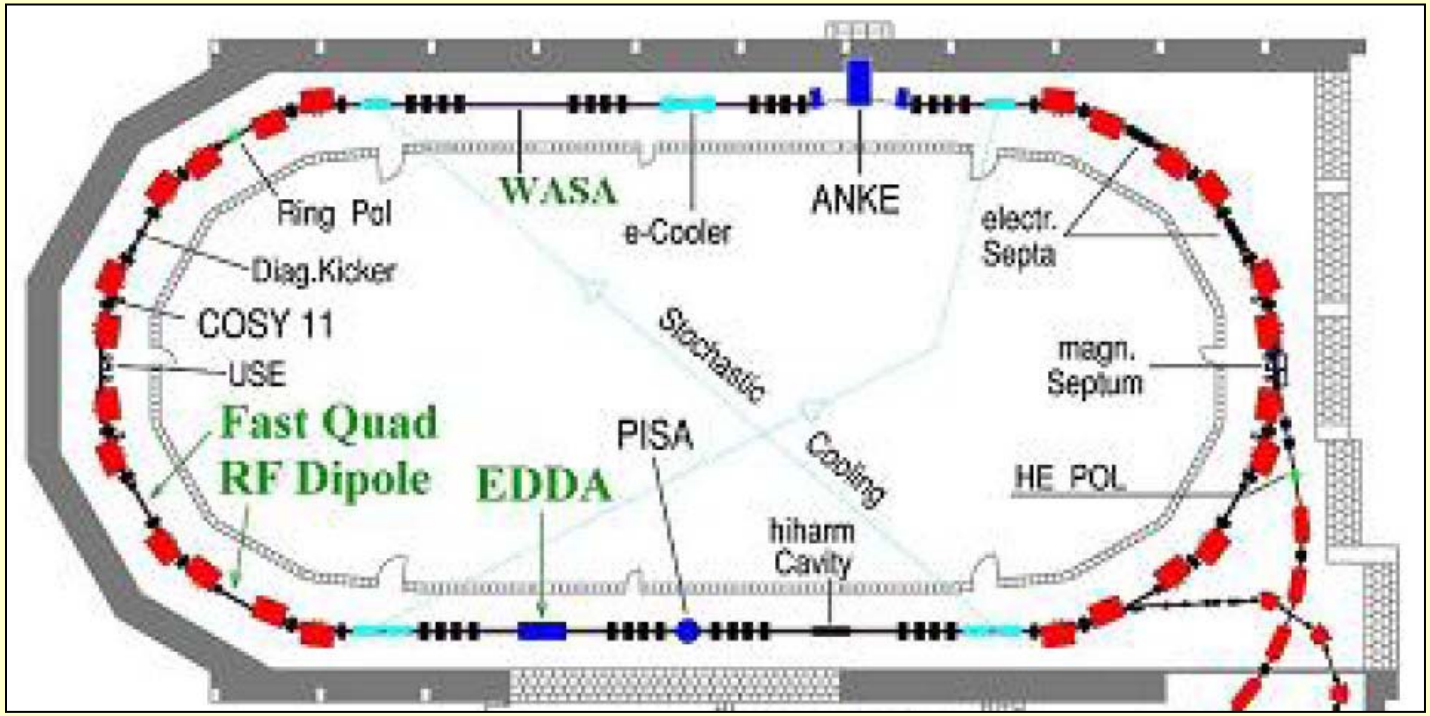
Spin filtering works, but:

1. Controversial interpretations of only experiment with protons
2. No experimental basis for antiprotons

Experimental tests needed with:

1. Protons at COSY
2. Antiprotons at AD

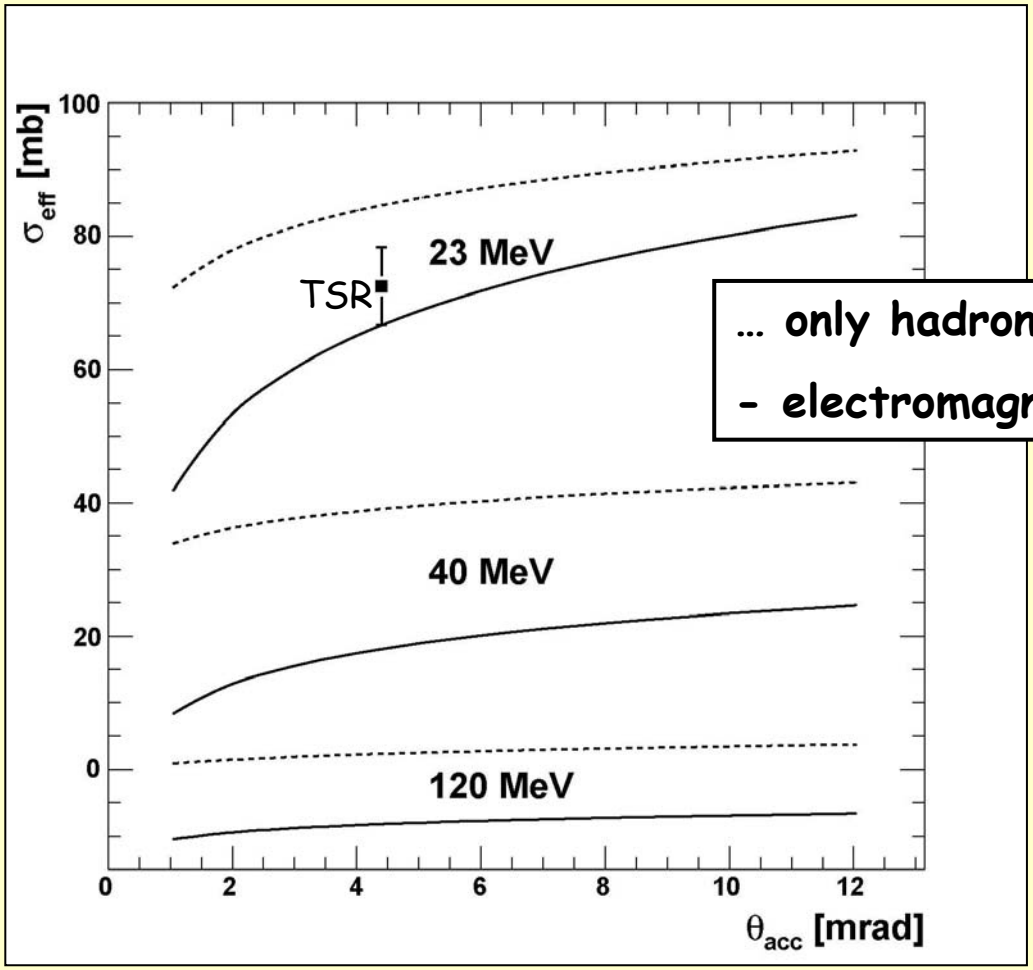
Spin-filtering studies at COSY



Objective:

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

Polarizing cross sections from the two models



… only hadronic

- electromagnetic + hadronic

A measurement of σ_{eff} to 10% precision requires polarization measurement with $\Delta P/P$ = 10%.

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

(Polarization build-up experiments)

Injection of different combinations of hyperfine states

- Different electron and nuclear polarizations
- 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

AD Experiments require both transverse and longitudinal (weak)fields.

AD Experiments will be performed also with D target.

Target polarimetry requires BRP for pure electron and D polarization.

Preliminary test: do unpolarized electrons affect the polarization of a proton beam?

(Polarization "build-down" experiment)

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

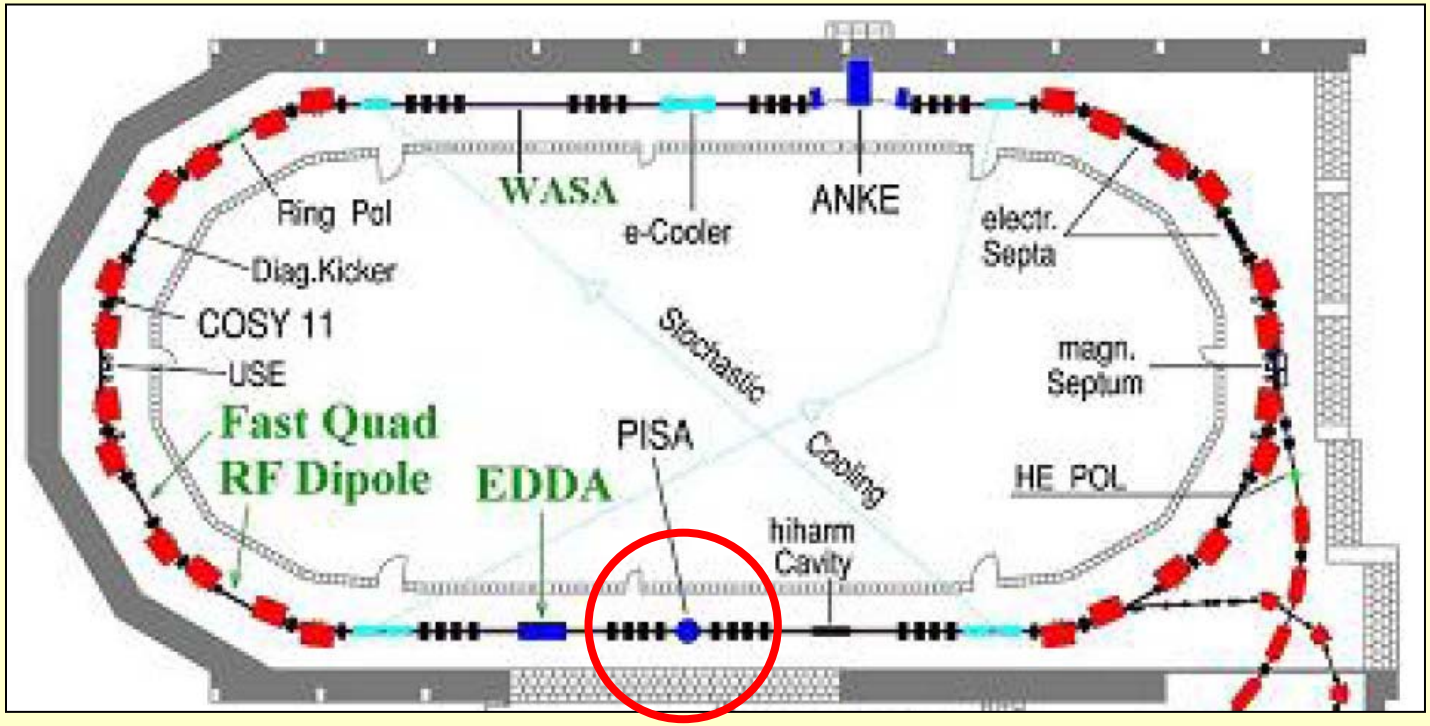
Test with unpolarized ^{4}He target (no hadronic effects):

Measure of depolarization of a polarized proton beam.

Will allow to test the electromagnetic contribution (and Walcher's proposal)

- Use of ANKE interaction point
- Beam lifetime studies
- Measurements spring 2007

Experimental setup

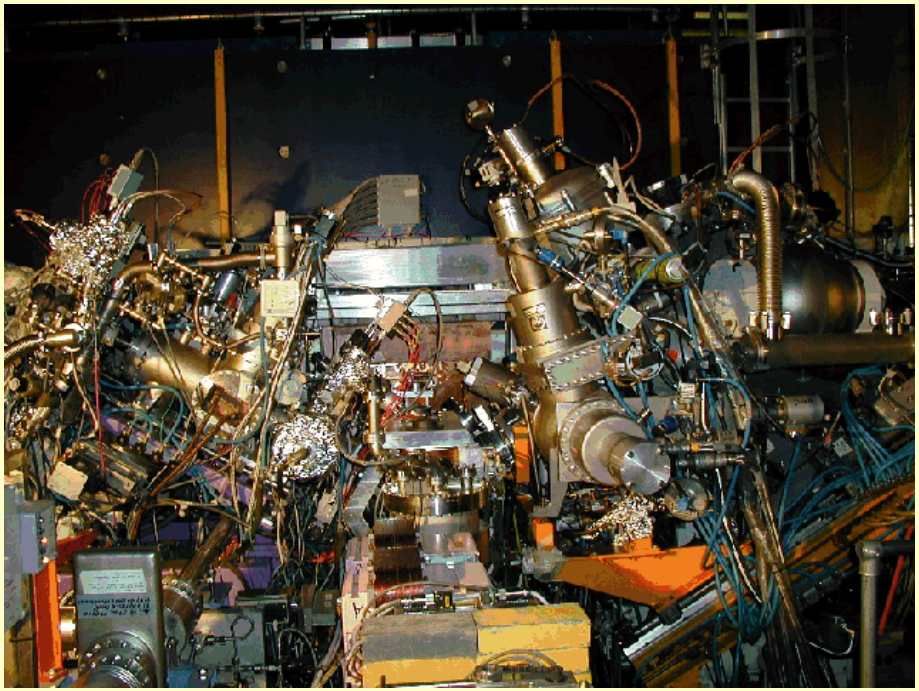


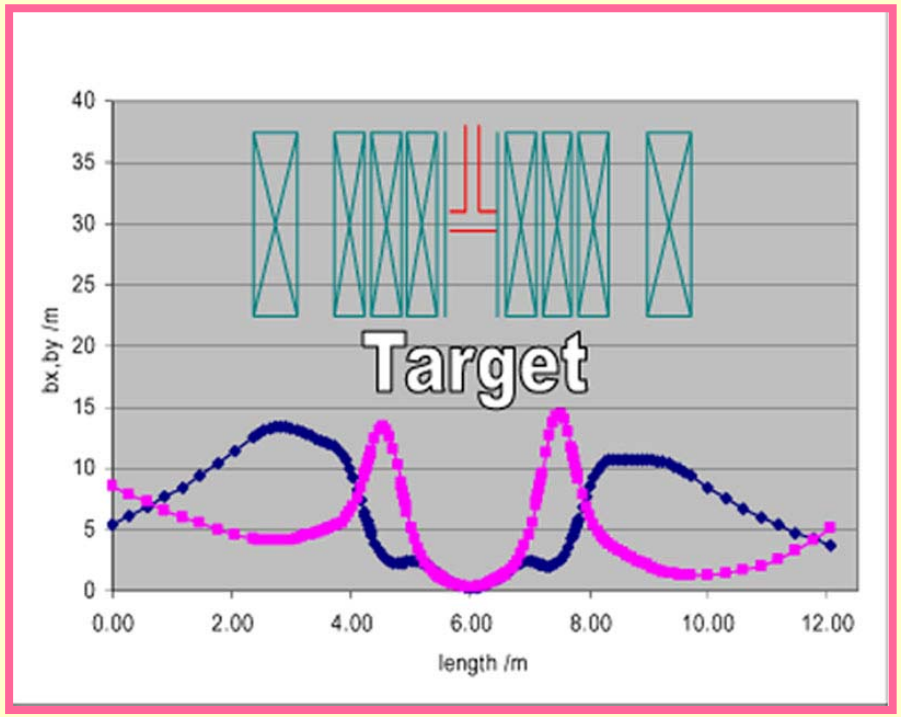
- Low-beta section
- Polarized target (former HERMES target)
- Detector
- Snake
- Commissioning of AD setup

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



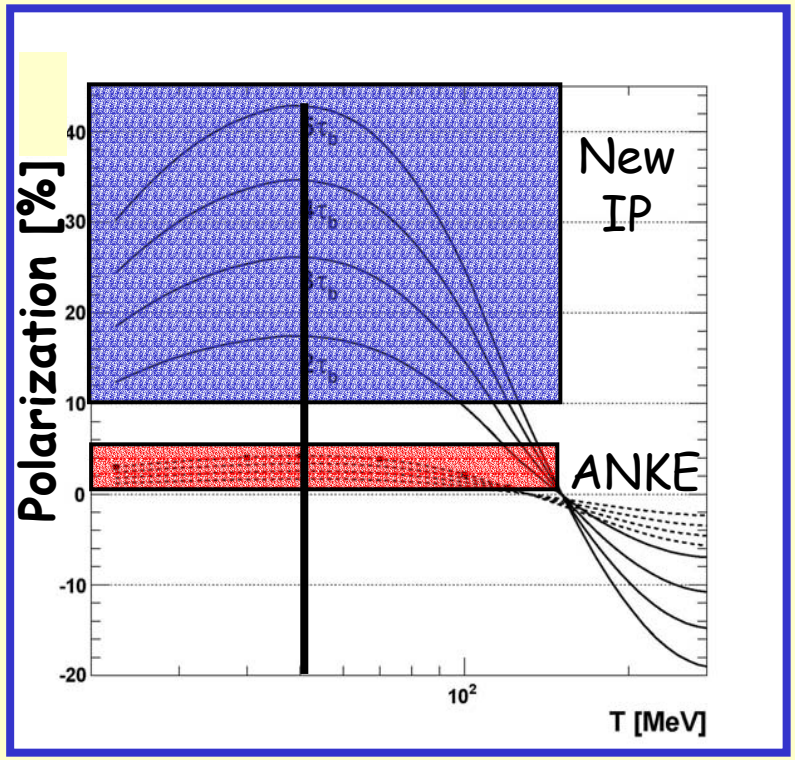


S.C. quadrupole development applicable to AD experiment

ANKE vs new IP: Polarization

Expectations based on Budker-Jülich for:

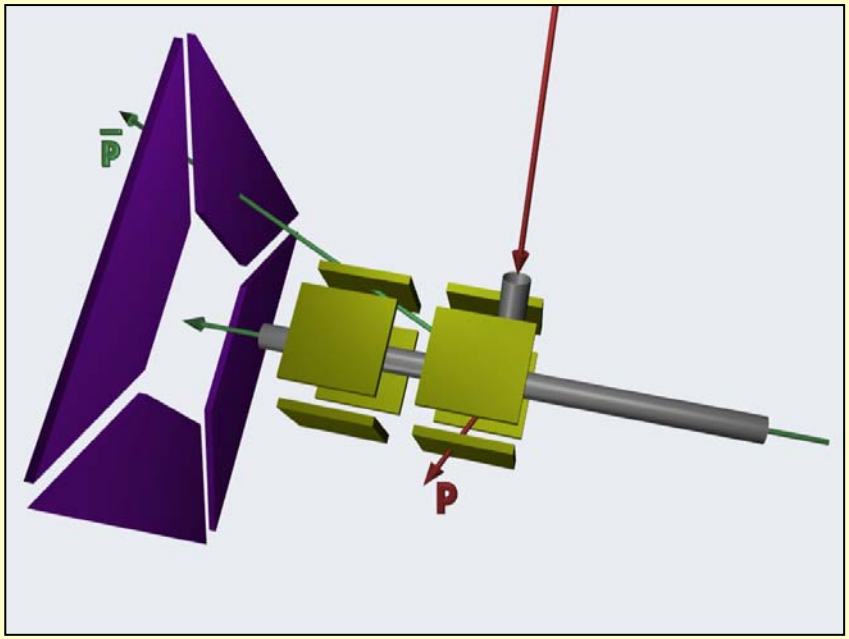
- T = 40 MeV
- N_{inj}=1.5x10^{10} protons

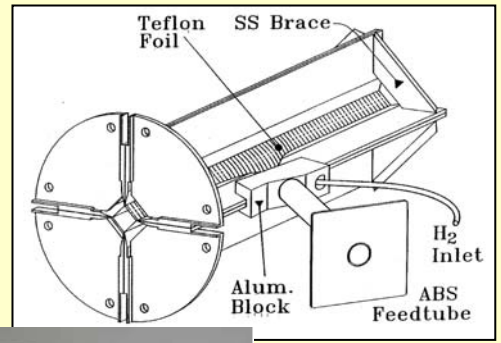


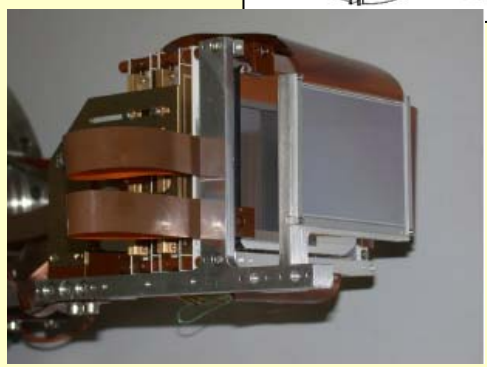
PIT	Filter. time	Polar.	Total rate	Meas. Time ($\Delta P/P$=10%)
ANKE	2τ = 16 h	1.2 %	7.5x10^2 s^{-1}	44 min
	5τ = 42 h	3.5 %	5x10 s^{-1}	26 min
New IP	2τ = 5 h	16 %	2.2x10^4 s^{-1}	1 s
	5τ = 13 h	42 %	1.5x10^3 s^{-1}	< 1 s

Detector concept

- Will measure beam polarization by using the analysing power of:
  - p-p elastic (COSY)
  - pbar-p elastic (AD)
- Good azimuthal resolution (up/down asymmetries)
- Low energy recoil (<8 MeV)
  - Silicon telescopes
  - Thin 5μm Teflon cell needed
- Angular resolution for the forward particle for p-pbar at AD
- AD experiment will require an openable cell

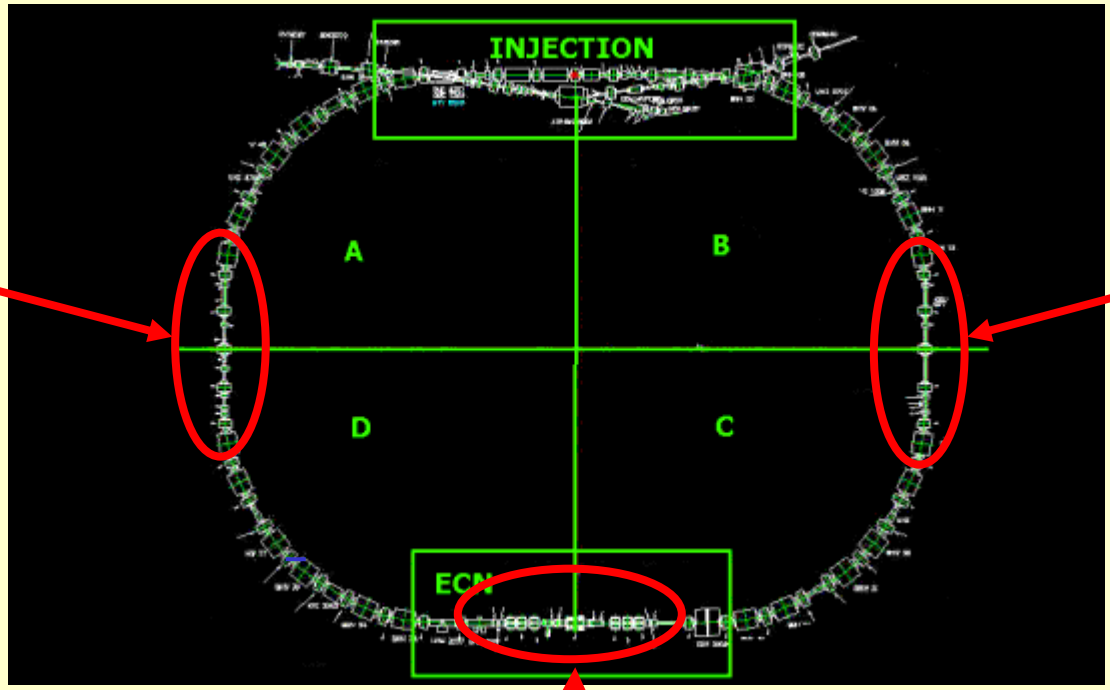






AD ring at CERN

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 cross-section.

Both transverse and longitudinal.

Variable acceptance at target

Polarized D target

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

Timeline

Fall 2006	Submission of proposal to COSY-PAC
	Beam depolarization studies
	(Beam lifetime studies)
Spring 2007	Submission of FP 7 application
Fall 2007	Technical proposal to COSY-PAC for spin filtering
	Technical proposal to SPSC for spin filtering at AD
2006-2007	Design and construction phase
2008-2009	Spin-filtering studies at COSY
	Commissioning of AD experiment
2009	Installation at AD
2009-2010	Spin-filtering studies at AD

Institutional Responsibilities

	Institution		Coordination	Target & BRP	Slow Control	Accelerator & Magnets	DAQ	Detector	Simulations & Data Analysis	Theory
1	Bari				•					
2	Brookhaven					•				
3	Dublin									•
4	Dubna					•	•		•	•
5	Erlangen			•						
6	Ferrara		•	•				•		•
7	Jülich	IKP	•			•		•		•
		ZAT		•		•		•		
		ZEL			•		•	•		
8	Gatchina					•			•	
9	Novosibirsk					•				
10	Tbilisi								•	•
11	Torino									•
12	Uppsala								•	
13	Madison (?)			•						

Italian participation

2006:

- Ferrara:
  - Coordination
  - HERMES target at FZJ
  - cell for ANKE
  - ion-deflector for Lamb-shift polarimeter
- Bari expressed interest
- Ex Roma Sanità expressed interest

Future:

- Ferrara:
  - Coordination
  - Target polarimeter
  - Cell
  - Detector
- Bari (?):
  - Slow control

Previsione di spesa (solo Ferrara)

	2006	2007	2008	2009	2010
FTE	3.5	6.3	8.5	~10	~10
MI	-	10	20	20	20
ME	55	150	200	220	220
Cons. + trsp	30	30	50	70	50
Inv. + App.	-	112	140	30	10
Totale	85	302	410	340	300

(Assegnati)

Richiesti

Previsione di spesa (solo Ferrara)

	2006	2007	2008	2009	2010
FTE	3.5	6.3	8.5	~10	~10
MI	-	10	20	20	20
ME	55	150	200	220	220
Cons. + trsp	30	30	50	70	50
Inv. + App.	-	112	140	30	10
Totale	85	302	410	340	300

(Assegnati)

Richiesti

Richieste 2007 (keuro)

Richieste				Referee	
				Ass.	S.J.
Missioni	Interno	10		6	
	Estero	150 (23 m.u.)	- Coordinazione 3 mesi/uomo - Bersaglio 9 mesi/uomo - Rivelatore 6 mesi/uomo - Misure 4 mesi/uomo	74 (16 m.u.)	
Consumo		30	- Sviluppo e test cell - Consumi bersaglio e polarimetro - Cavetteria rivelatori - Consumi camera pulita	16	
Inv+App		112	- Rivelatori silicio (5 moduli) - Elettronica - Camera tests	15	35
Totale		302		111	35

Funding (besides INFN)

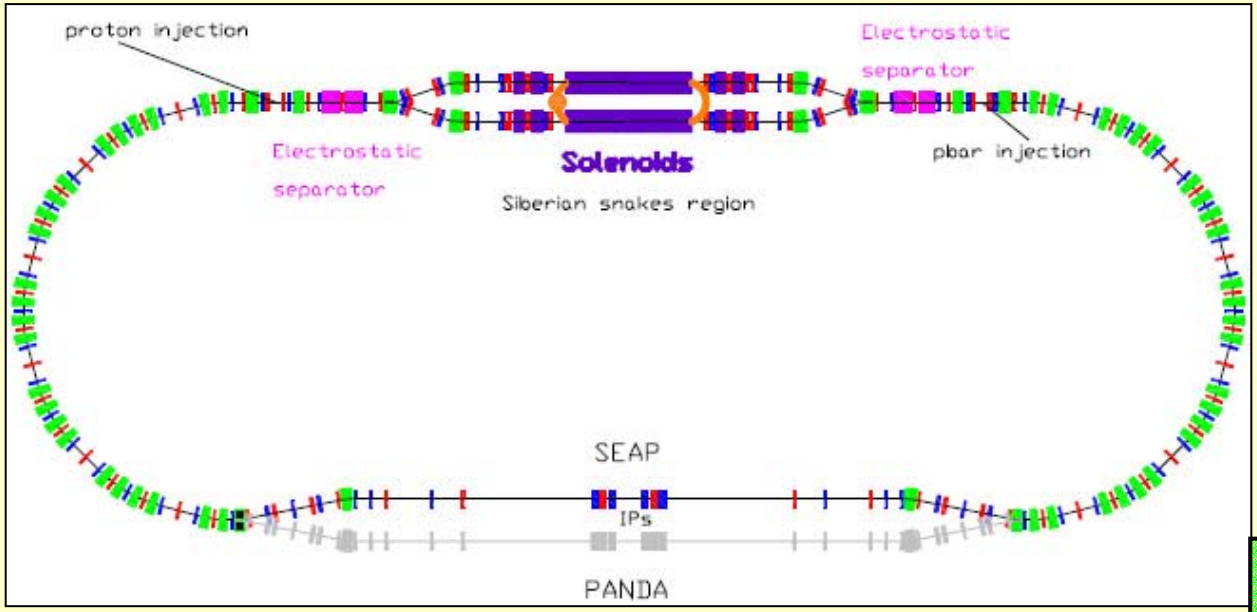
BMBF financed application by prof E. Steffens (U. Erlangen)

Application to FZJ innovation fund

SC quads for low-beta section

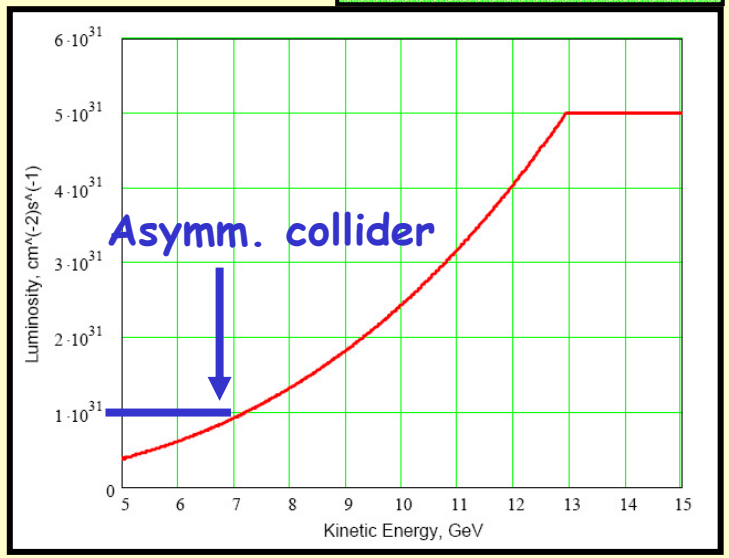
Application to FP7 for spin-filtering studies

Symmetric collider

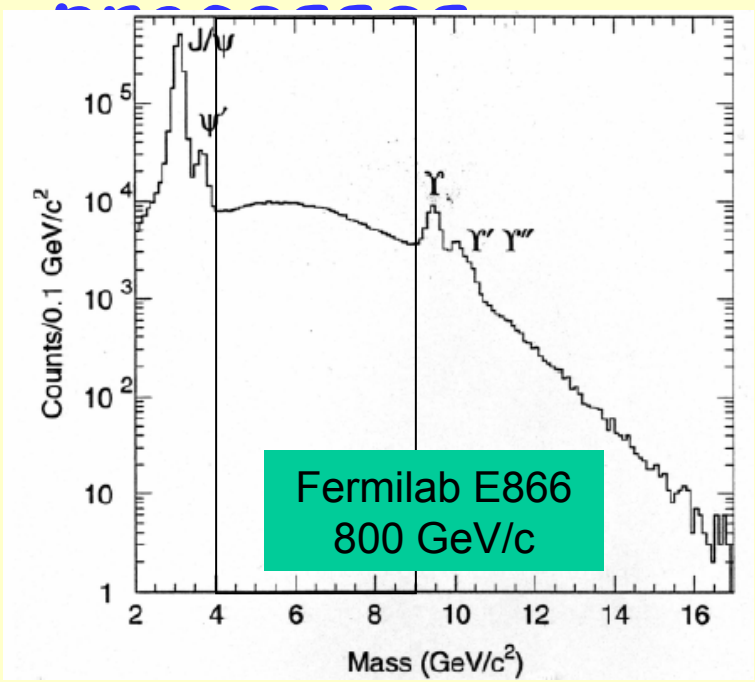


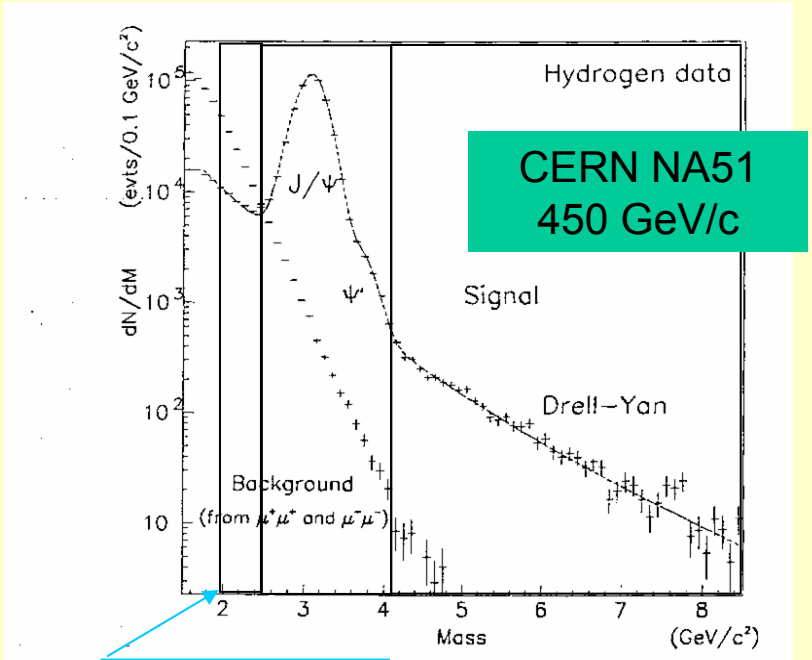
Circum.[m]	681
No. Bunches	10
No. p	$1x10^{12}$
No pbar	$1x10^{12}$
S_{max} [GeV^2]	~900
Polar.	✸✸,99
p-p	no

Luminosity



Kinematics for Drell-Yan





$$M \geq M_{J/\Psi}$$

Usually taken as "safe region"

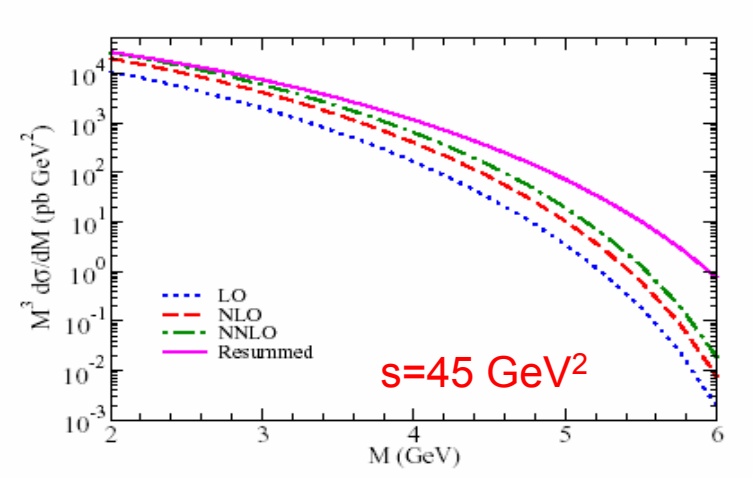
$$\tau \geq \frac{M^2_{J/\Psi}}{s}$$

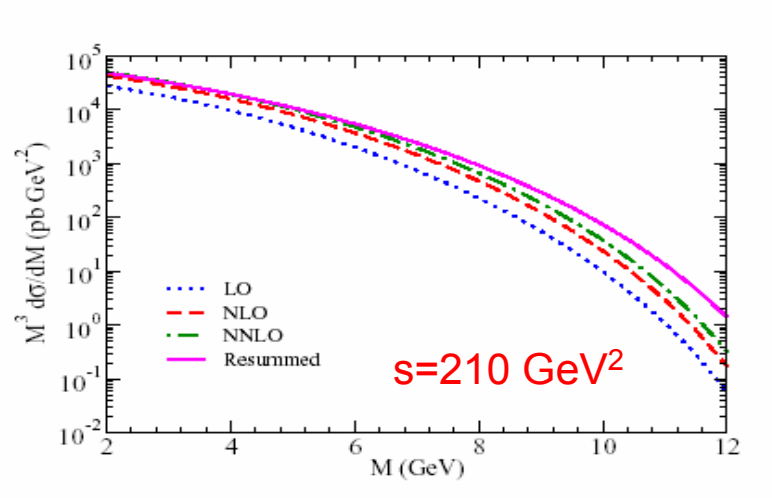
QCD corrections might be very large at smaller values of M, for cross-sections, not for A_{TT}: K-factor almost spin-independent

H. Shimizu, G. Sterman, W. Vogelsang and H. Yokoya, hep-ph/0503270

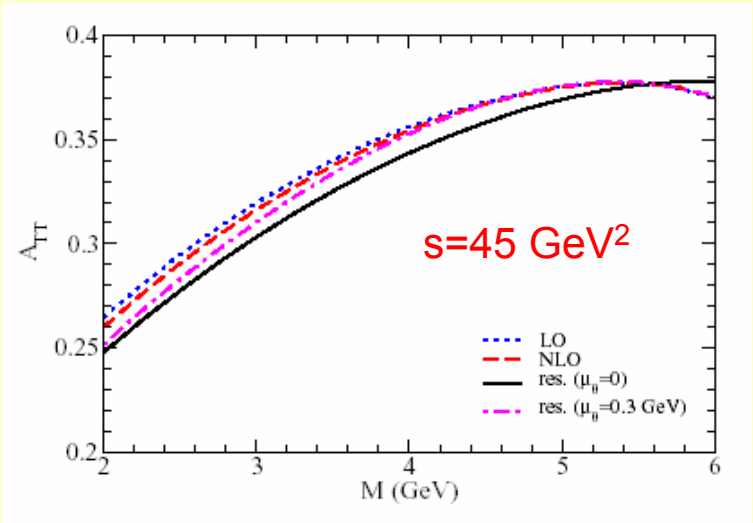
V. Barone et al.,

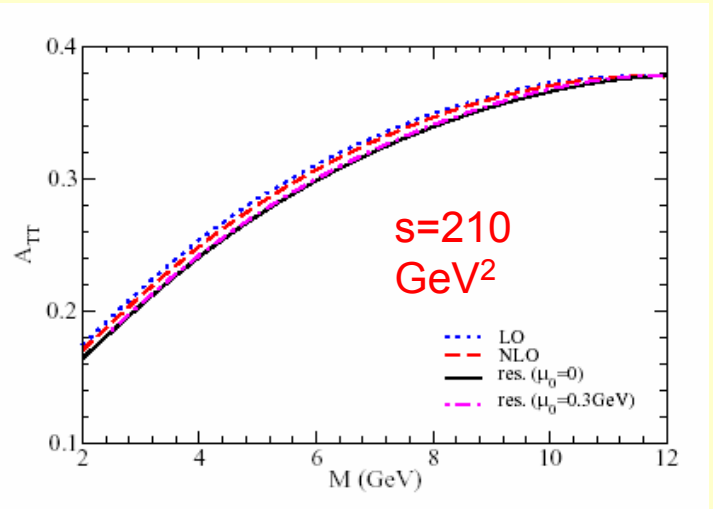
Cross-section



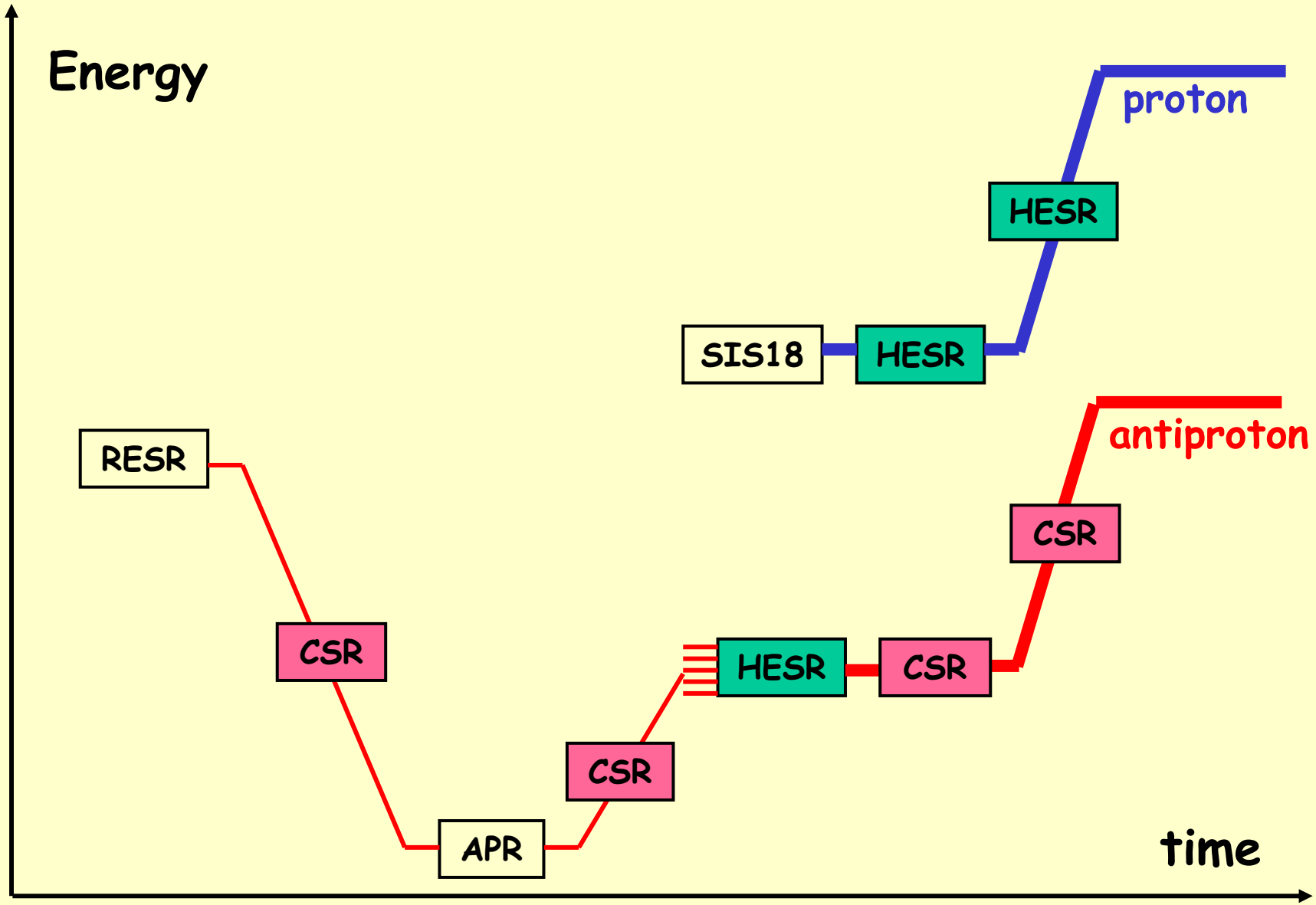


Asymmetry





Antiproton and Proton accelerators' scheme



Italian participation

PAX Coordination board

	Spokespersons: P. Lenisa and F. Rathmann					
	Technical Coordinator: P. Lenisa and F. Rathmann (until Technical Coordinator is named)					
Target + BRP	**Detector**	**Slow Control**	**DAQ**	**Simulation and Data Analysis**	**Accelerator**	**Theory**
Coordinator A. Nass	Coordinator R. Schleichert	Coordinator H. Kleines	Coordinator S. Trusov	Coordinator M. Nekipelov	Coordinator B. Lorentz	Coordinator K. Nikolaev
Deputy M. Capiluppi	Deputy M. Contalbrigo	Deputy G. Tagliente	Deputy P. Wüstner	Deputy G. Macharashvili	Deputy A. Lehrach	Deputy J. Haidenbauer[a]
Local Contact A. Nass	Local Contact R. Schleichert	Local Contact H. Kleines	Local Contact P. Wüstner	Local Contact M. Nekipelov	Local Contact B. Lorentz	Local Contact J. Haidenbauer

Antiproton Beam Polarization (Hadronic Interaction: Longitudinal Case)