Polarized Antiproton EXperiments

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

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PAX Collaboration

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PAX Collaboration

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

PAX:

Polarized Antiproton Experiments

Outline

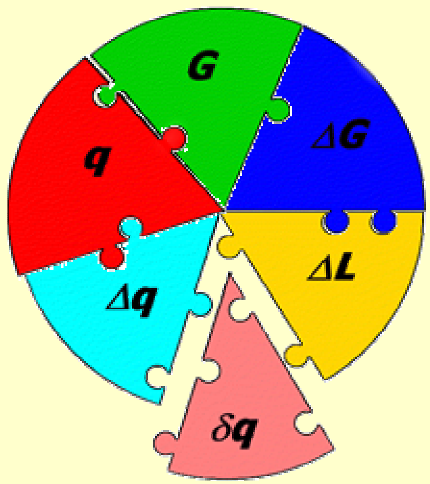
WHY?	Physics Case
HOW?	Polarized Antiprotons
WHAT?	Staging
	Detector and signal estimate
WHERE AND WHEN?	The FAIR project at GSI (D)

Physics Case: Central Physics Issue

Transversity distribution of the nucleon:

- last leading-twist missing piece of the QCD description of the partonic structure of the nucleon
- directly accessible uniquely via the double transverse spin asymmetry A_{TT} in the Drell-Yan production of lepton pairs
- theoretical expectations for A_{TT} in DY > 0.2
  - transversely polarized antiprotons
  - transversely polarized proton target
- definitive observation of $h_1^q(x,Q^2)$ of the proton for the valence quarks

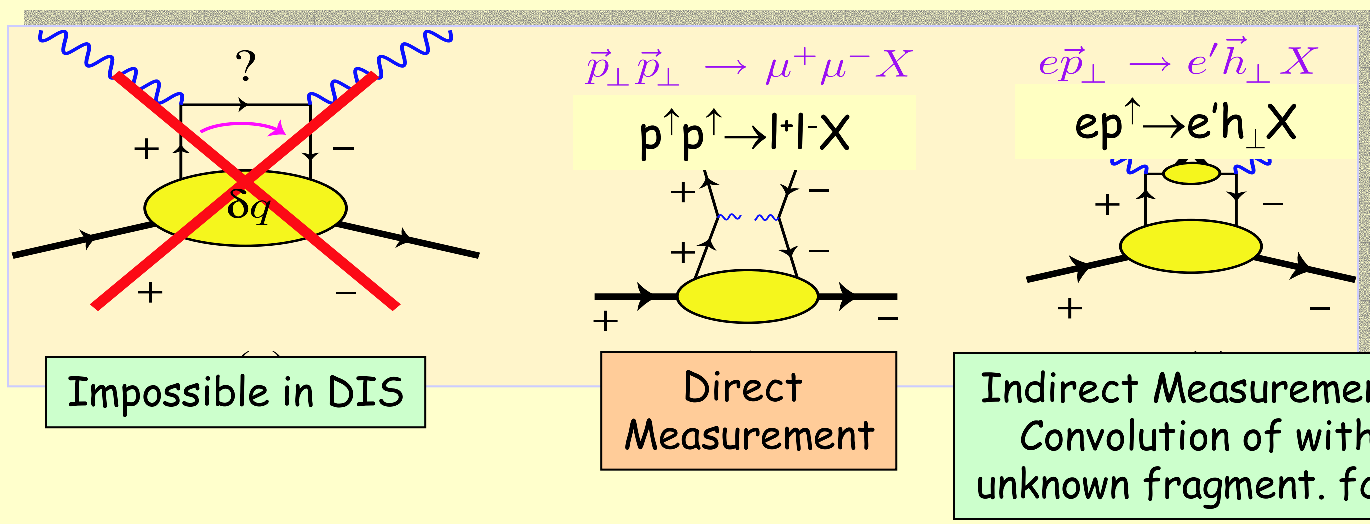
Transversity



Properties:

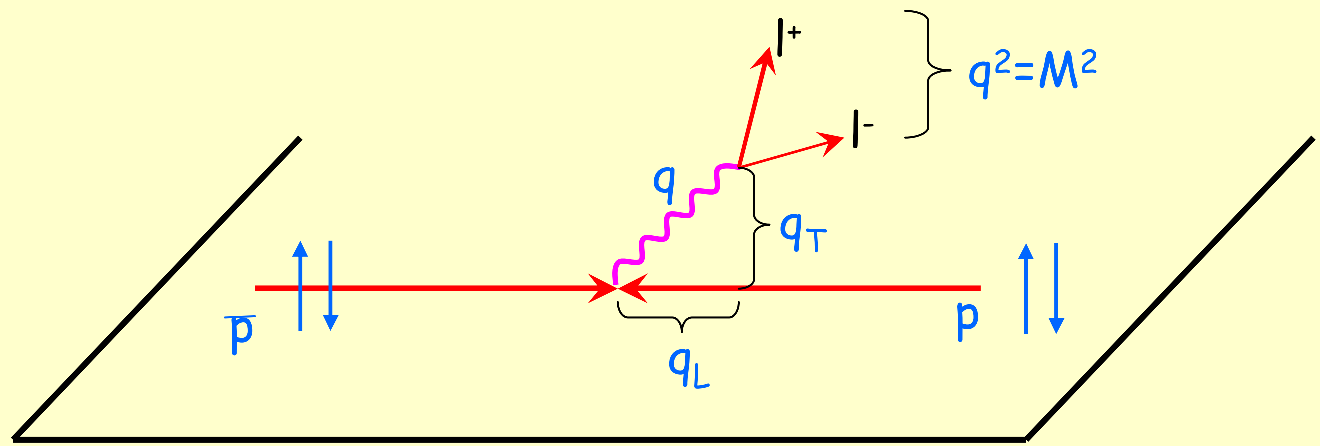
- Probes relativistic nature of quarks
- No gluon analog for spin-1/2 nucleon
- Different Q^2 evolution than Δq
- Sensitive to valence quark polarization

Chiral odd: requires another chiral odd partner



Transversity in Drell-Yan processes

PAX: Polarized antiproton beam → polarized proton target (both transverse)



$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 h_1^q(x_1, M^2) h_1^{\bar{q}}(x_2, M^2)}{\sum_q e_q^2 q(x_1, M^2) \bar{q}(x_2, M^2)}$$

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

M invariant Mass of lepton pair

Other Topics

- Electromagnetic Form Factors
- Hard Scattering Effects
- SSA in DY, origin of Sivers function
- Soft Scattering
  - Low-t Physics
  - Total Cross Section
  - pbar-p interaction

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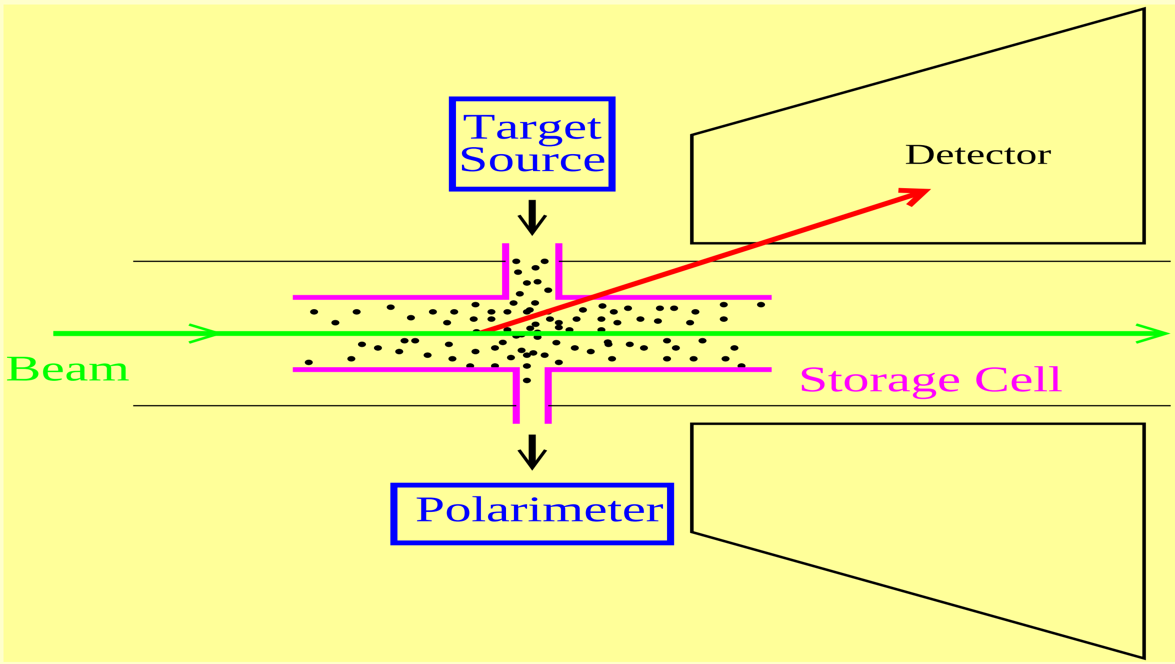
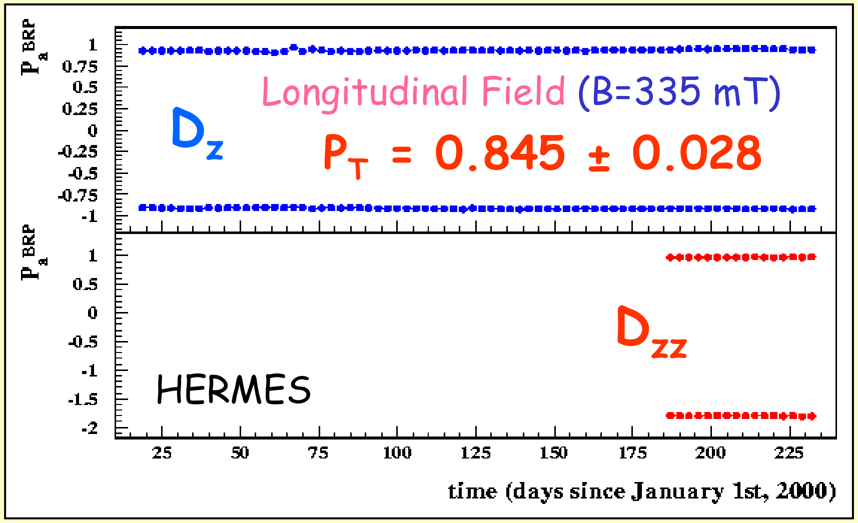
Polarized internal target

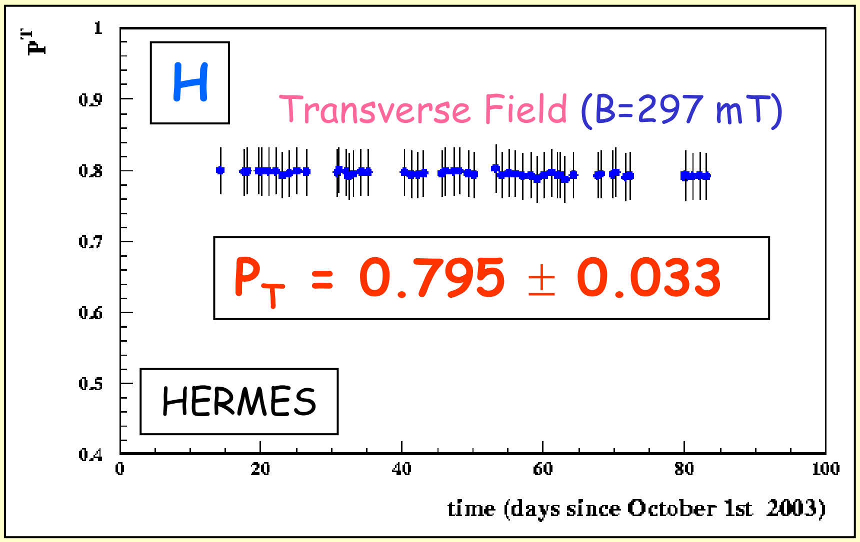


point-like	5-10 mm	free jet	low density	10^{12} cm^{-2}
extended	200-500 mm	storage cell	high density	10^{14} cm^{-2}

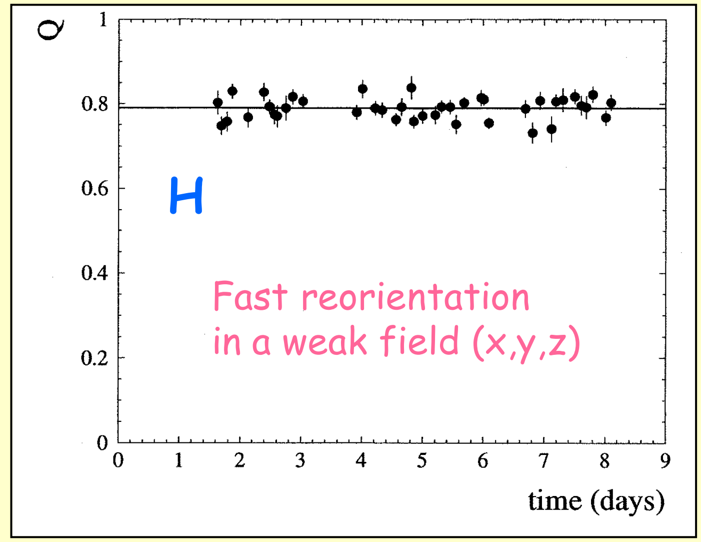
Performance of Polarized Internal Targets

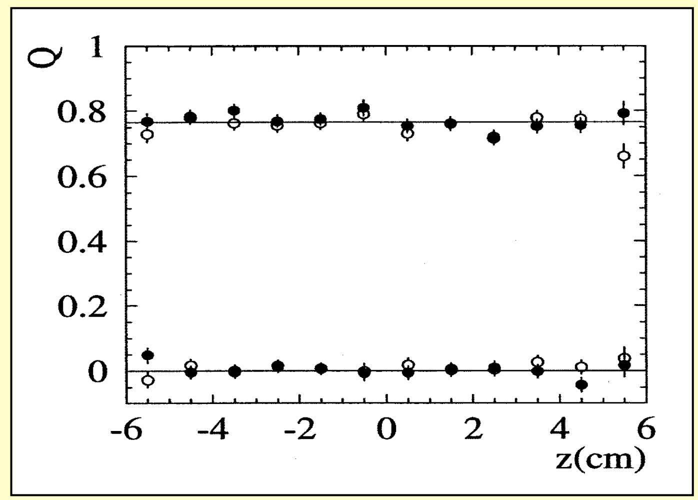
HERMES: Stored Positrons





PINTEX: Stored Protons





Targets work very reliably (months of stable operation)

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

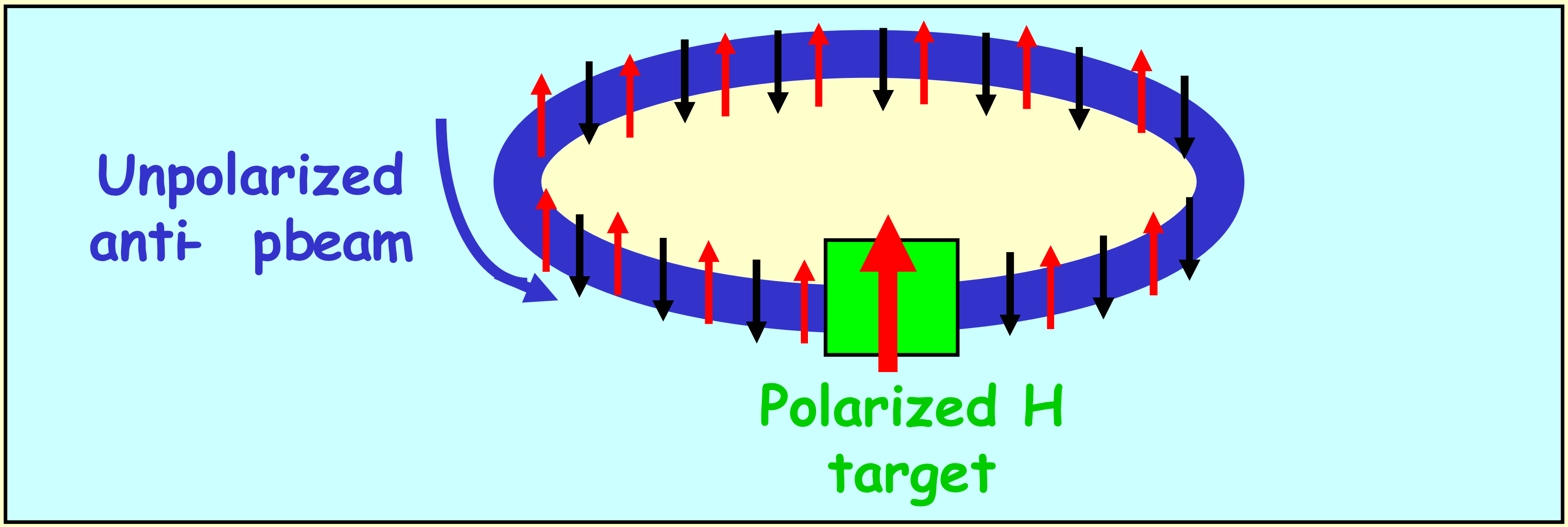
For initially equally populated spin states: ↑ ($m=+\frac{1}{2}$) and ↓ ($m=-\frac{1}{2}$)

transverse case:

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

longitudinal case:

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



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P beam polarization
Q target polarization
k || beam direction

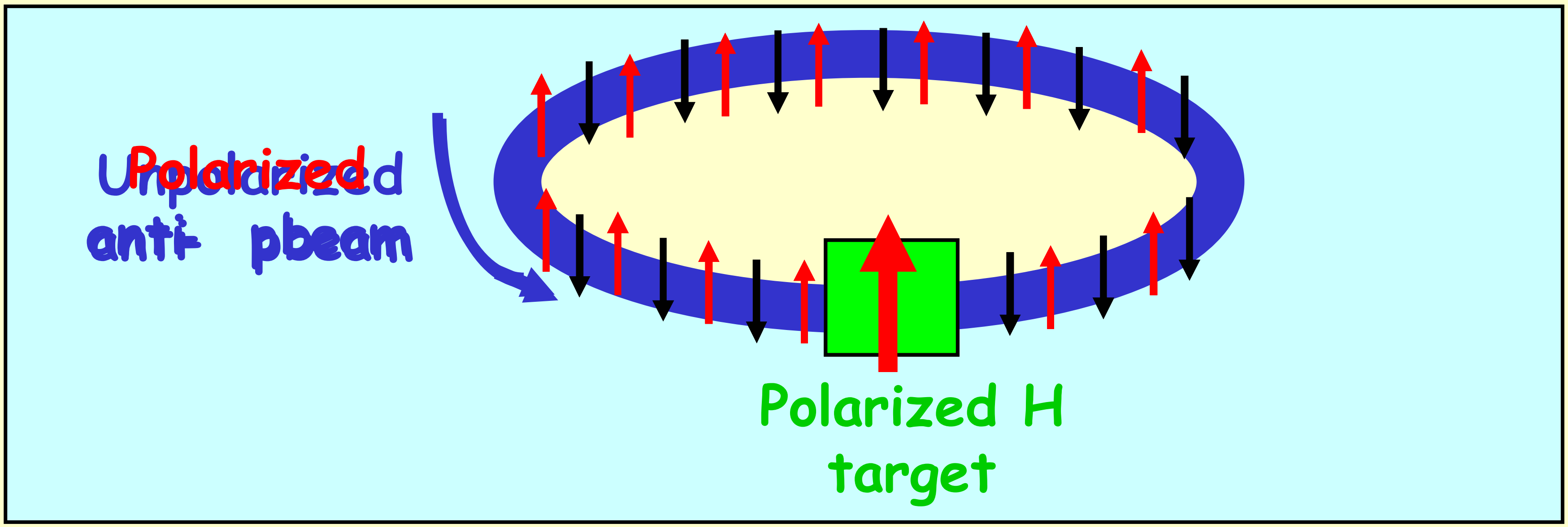
For initially equally populated spin states: ↑ (m=+½) and ↓ (m=-½)

transverse case:

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

longitudinal case:

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



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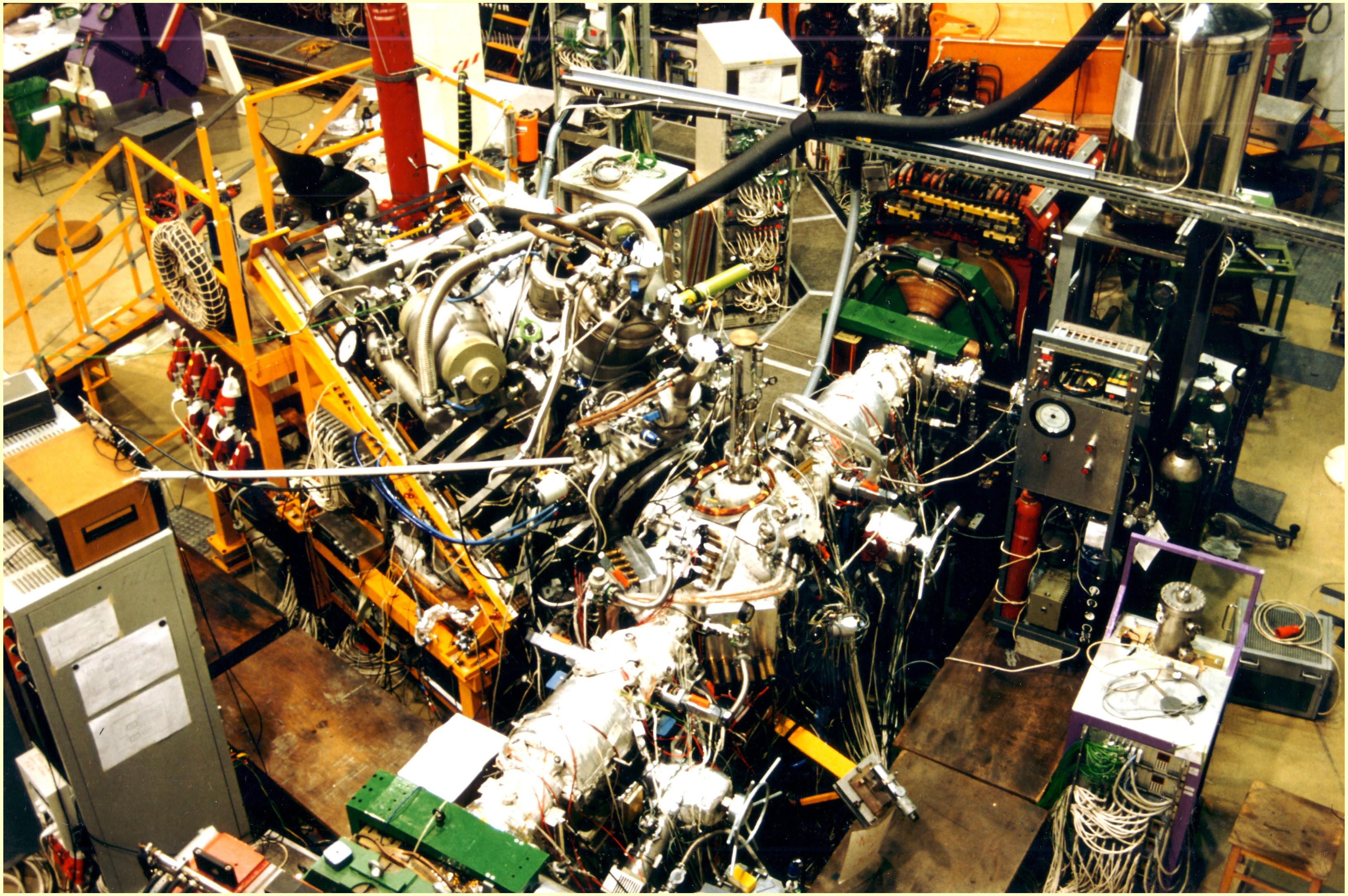
longitudinal case:

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

For low energy pp scattering:
$\sigma_1 < 0 \Rightarrow \sigma_{tot+} < \sigma_{tot-}$

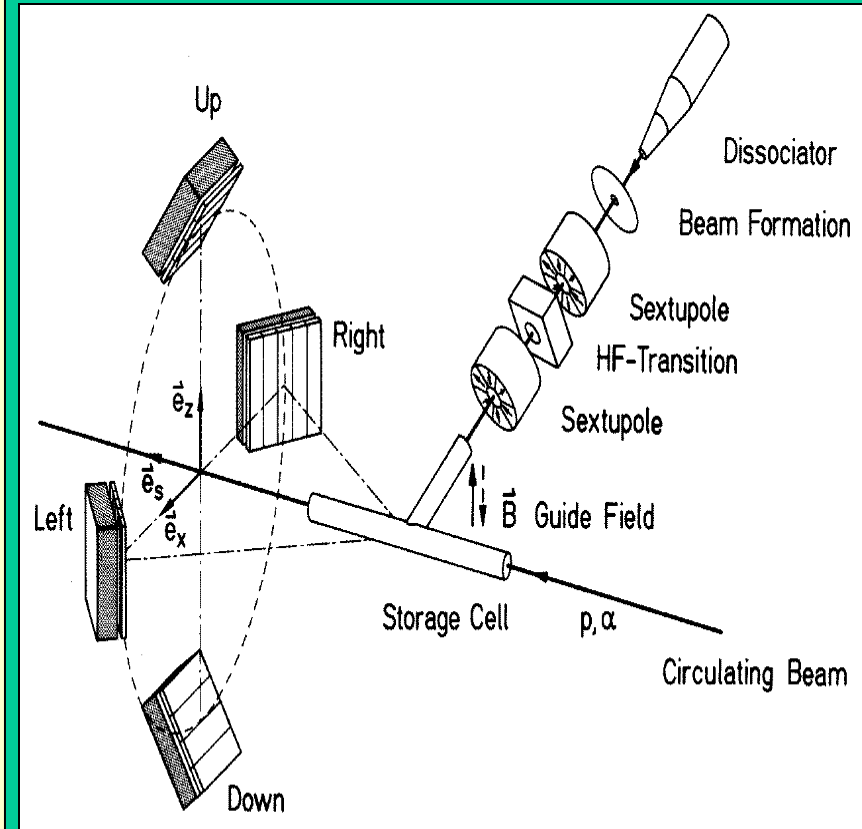
Expectation	
Target	**Beam**
↑	↑
↓	↓

Experimental Setup at TSR (1992)

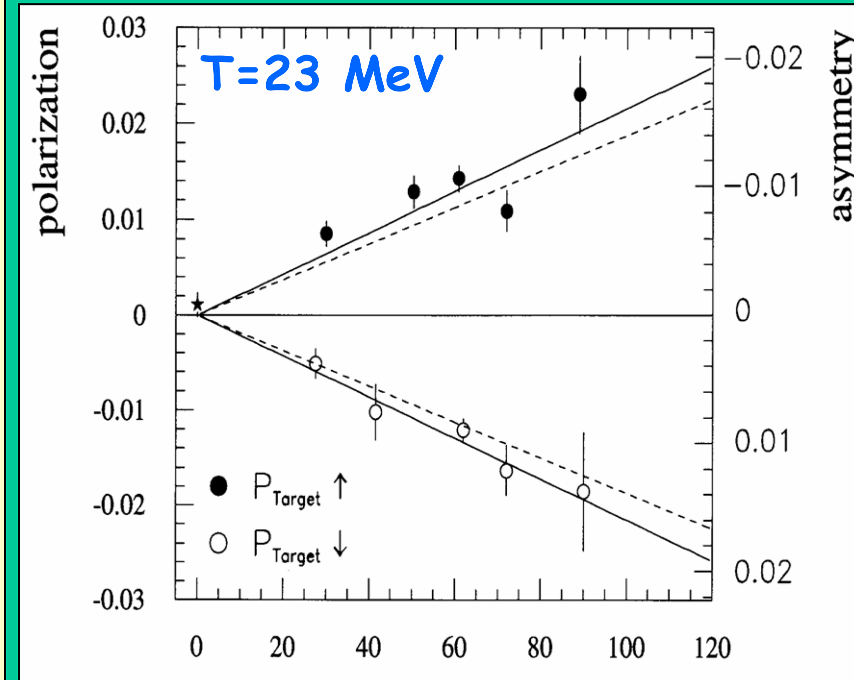


1992 Filter Test at TSR with protons

Experimental Setup



Results



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

Spin transfer from electrons to protons

$$p + \vec{e} \rightarrow \vec{p} + e$$

$$\sigma_{EM\perp} = -\frac{1}{2}\left[\frac{4\pi\alpha^2 (1+\lambda_p) m_e}{p^2 m_p}\right] C_0^2 \left[\frac{\nu}{2\alpha}\right] \times \sin\left[\frac{2\alpha \ln(2pa_0)}{\nu}\right]$$

$$\sigma_{EM\parallel} = 2 \cdot \sigma_{EM\perp}$$

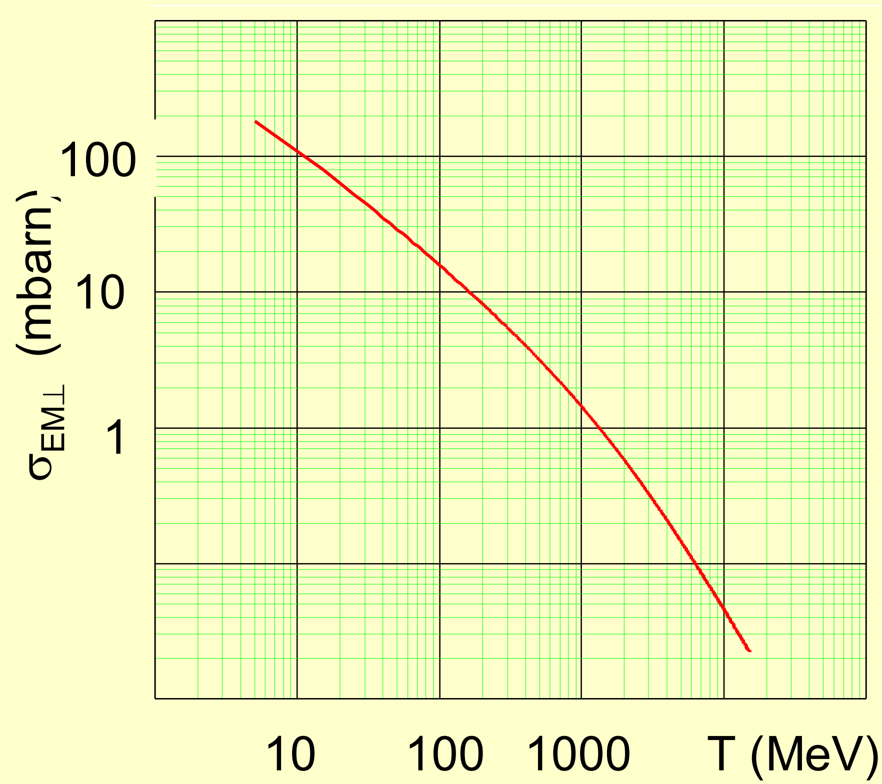
Horowitz & Meyer, PRL 72, 3981 (1994)
H.O. Meyer, PRE 50, 1485 (1994)

α	fine structure constant
$\lambda_p=(g-2)/2=1.793$	anomalous magnetic moment
m_e, m_p	rest masses
p	cm momentum
a_0	Bohr radius
$C_0^2=2\pi\eta/[\exp(2\pi\eta)-1]$	Coulomb wave function
$\eta=z\alpha/v$	Coulomb parameter (negative for antiprotons)
v	relative lab. velocity between p and e
z	beam charge number

PAX will exploit spin-transfer from polarized electrons of the target to antiprotons

Spin Transfer Cross Section

$$p + \vec{e} \rightarrow \vec{p} + e$$



Beam lifetimes in the APR

Beam Lifetime

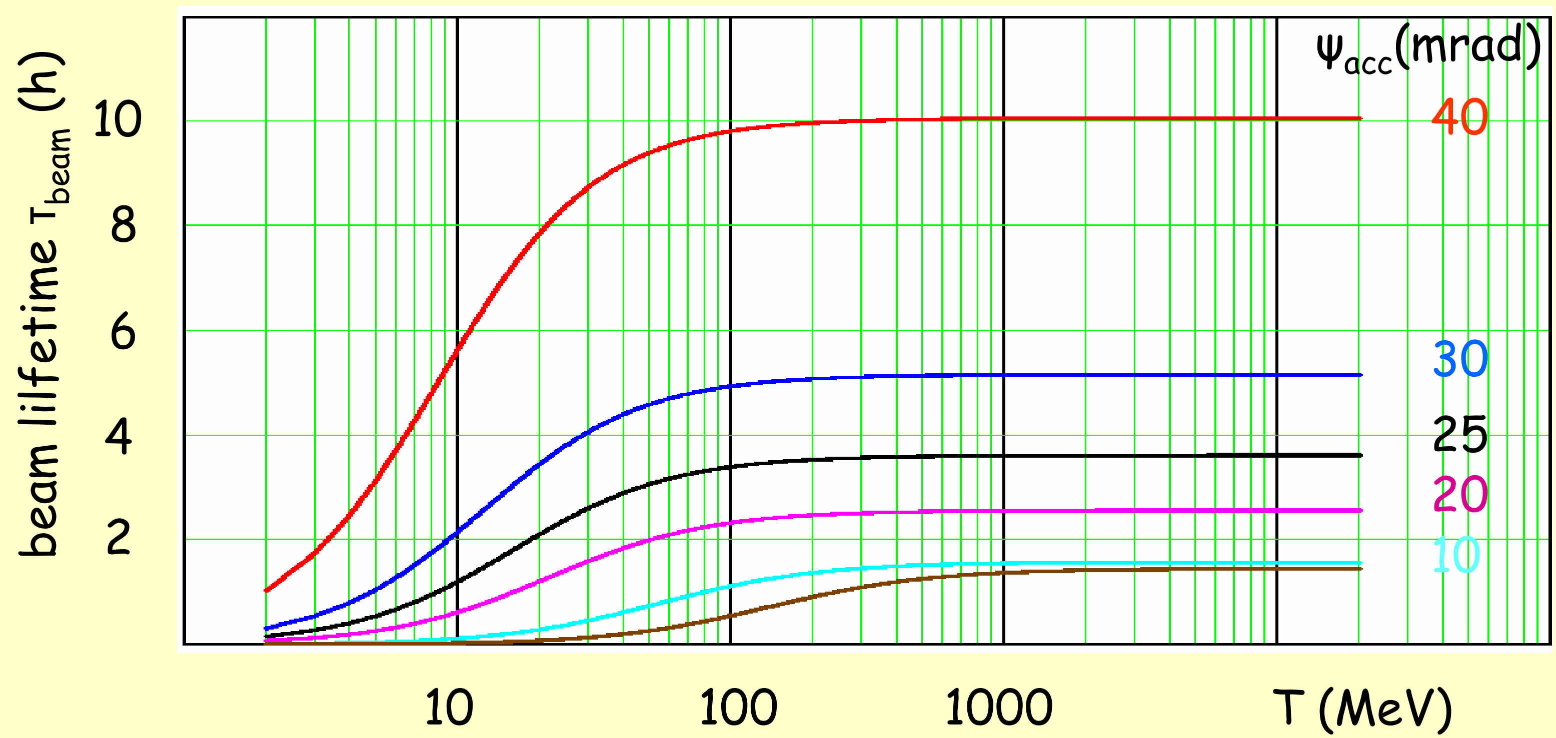
$$\tau_{beam}(T,\Psi_{acc}) = \frac{1}{(\Delta\sigma_C(T,\Psi_{acc}) + \sigma_0(T))\cdot d_t(\Psi_{acc})\cdot f_{rev}(T)}$$

Coulomb Loss

$$\Delta\sigma_C(T,\Psi_{acc}) = \int_{\theta_{min}}^{\theta_{max}} \left(\frac{d\sigma}{d\Omega}\right)_{Ruth.} d\Omega = 4\pi\alpha^2 \frac{(s(T)-2m_p^2)^2 4m_p^2}{s(T)^2(s(T)-4m_p^2)^2}\left(\frac{1}{\psi_{acc}^2} - \frac{s(T)}{4m_p^2}\right)$$

Total Hadronic

$$\sigma_0(T) = \sigma_{tot\,p\bar{p}}(T)$$



Polarization Buildup: optimal polarization time

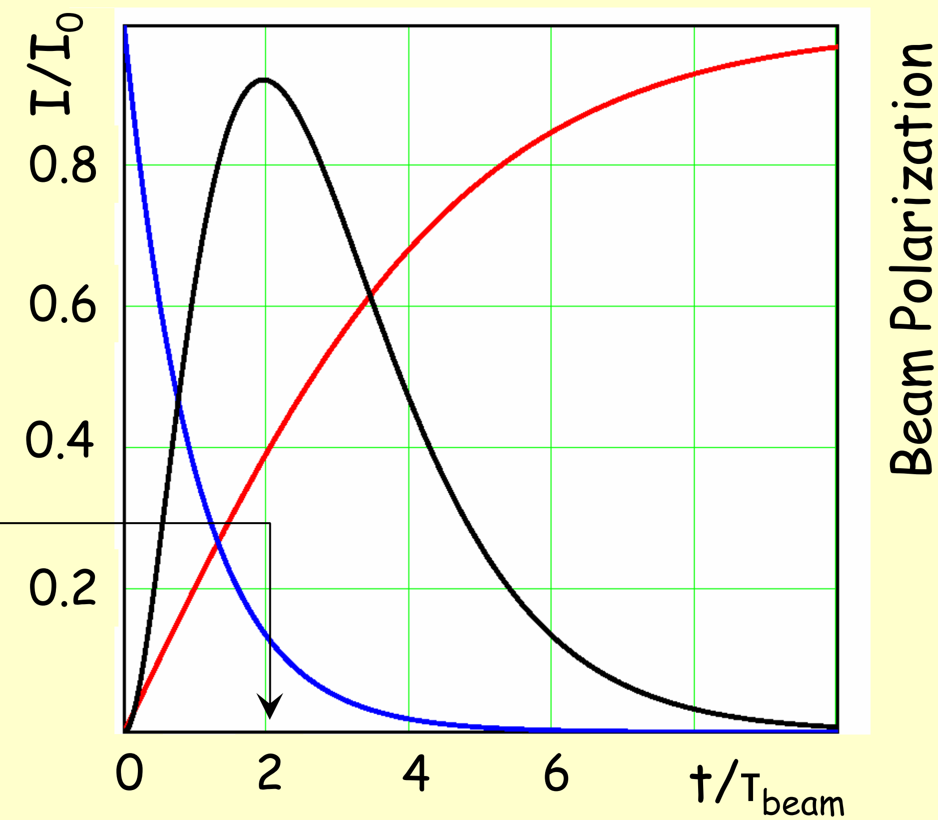
statistical error of a double polarization observable (A_{TT})

$$\delta_{A_{TT}} = \frac{1}{P \cdot Q \cdot \sqrt{N}}$$

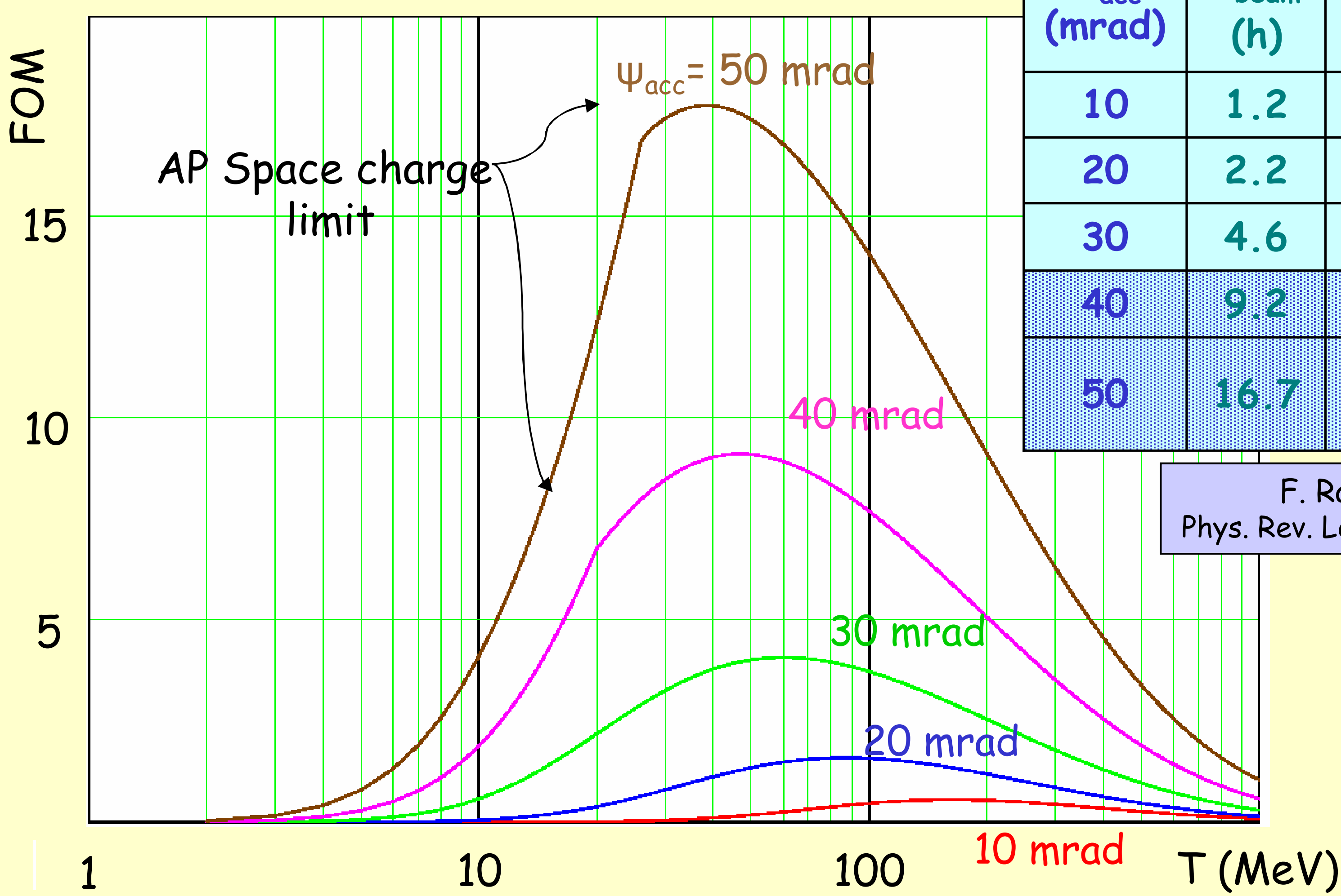
($N \sim I$) →

Measuring time t to achieve a certain error
$\delta_{A_{TT}} \sim \mathrm{FOM} = P^2 \cdot I$

Optimimum time for Polarization Buildup given by maximum of FOM(t)
$t_{filter} = 2 \cdot \tau_{beam}$



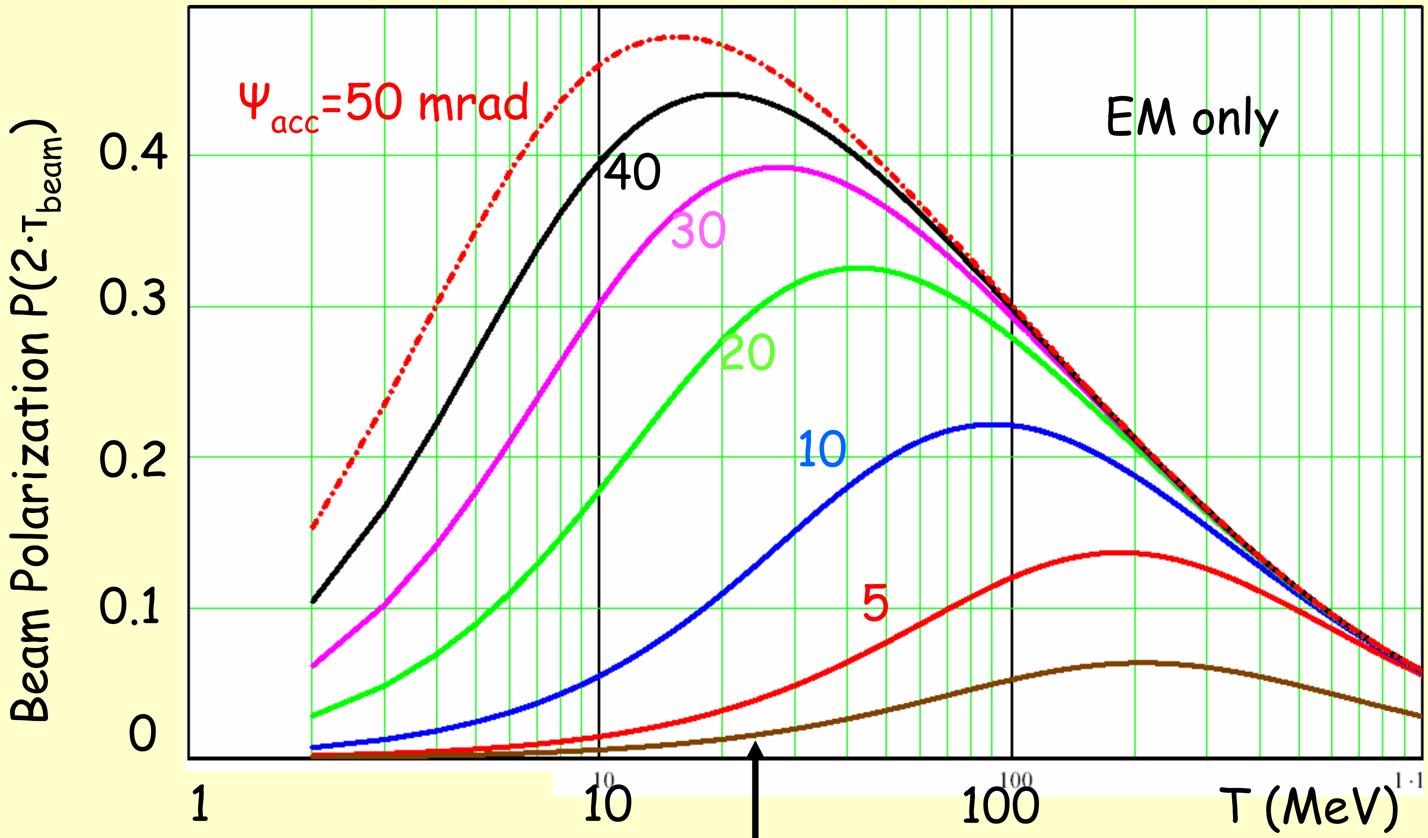
Optimum Beam Energies for Buildup in APR



Maximum FOM			
Ψ_{acc} (mrad)	T_{beam} (h)	$P(2\cdot\tau_{beam})$	T (MeV)
10	1.2	0.19	163
20	2.2	0.29	88
30	4.6	0.35	61
40	9.2	0.39	47
50	16.7	0.42	38

F. Rathmann et al.,
Phys. Rev. Lett. 94, 014801 (2005)

Beam Polarization

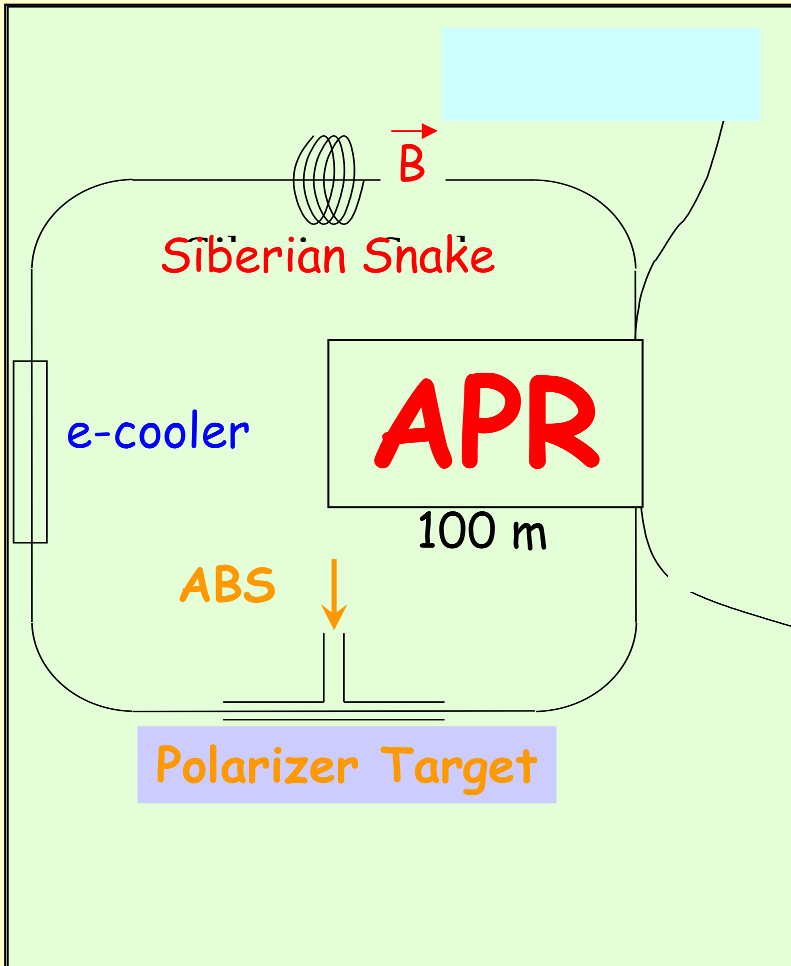


Filter Test: T = 23 MeV
Ψ_{acc}= 4.4 mrad

Antiproton Polarizer Ring (APR)

Mechansim: spin transfer from electrons to protons

$$\bar{p} + \vec{e} \rightarrow \vec{\bar{p}} + e$$



RING PARAMETERS:

Energy:	50 MeV (p~300 MeV/c)
$\varepsilon_{x,y}$:	500 π mm mrad
Circumeference:	100 m
No. Particles:	10^{12}

EQUIPMENT:

Polarized target

Snake

e-cool

Stochastic cooling?

PROJECTION:

P > 30% after 18-20 hrs (10^{11} pbar)

PAX:
Polarized Antiproton Experiments

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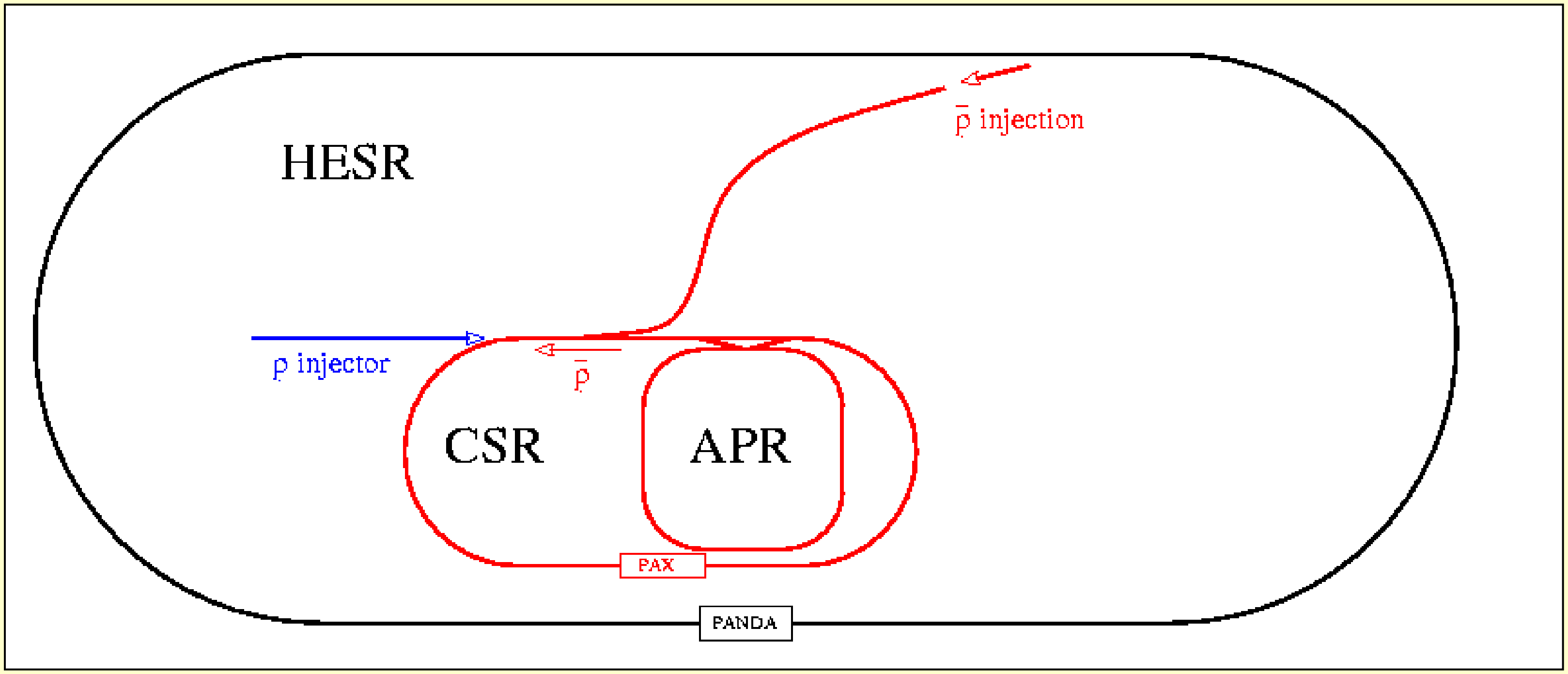
Staging: Phase I (PAX@CSR)

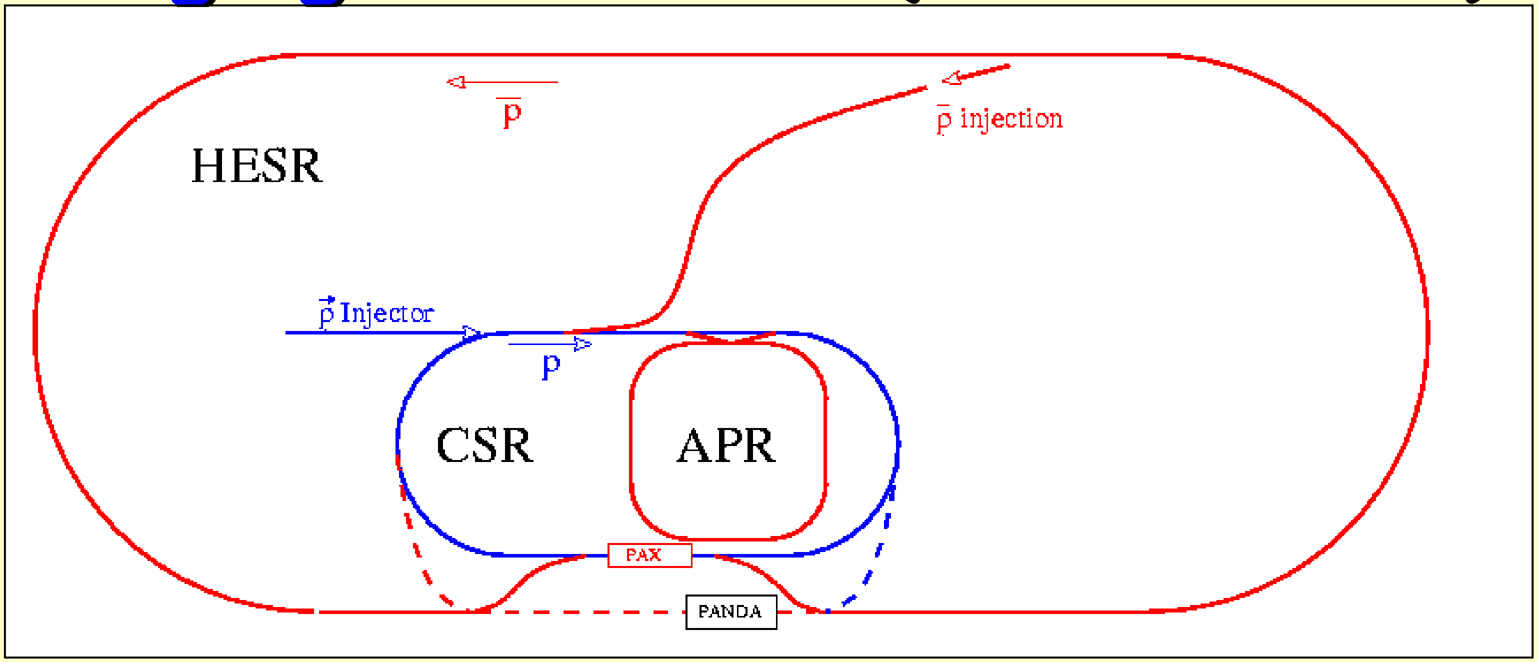


Physics: EMFF
pbar-p elastic

Experiment: pol./unpol. Pbar (3.5 GeV/c) on int. pol. target

Independent from HESR running

Staging: Phase II (PAX@HESR)



Physics: Transversity

EXPERIMENT:

1. Asymmetric collider:
   polarized antiprotons in HESR (p=15 GeV/c)
   polarized protons in CSR (p=3.5 GeV/c)
2. Internal polarized target with 22 GeV/c polarized antiproton beam.

Second IP with minor interference with PANDA

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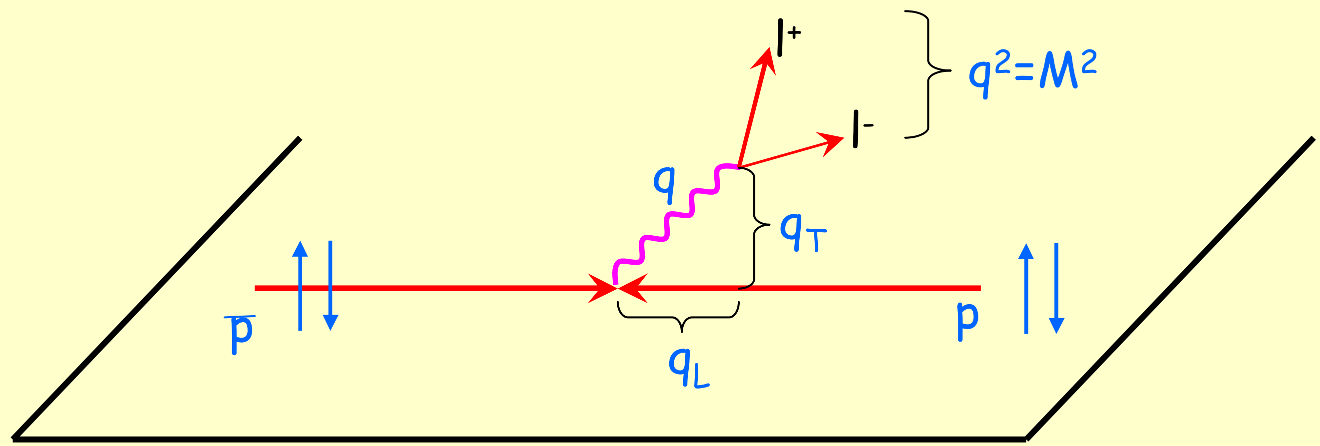
Transversity in Drell-Yan processes

PAX: Polarized antiproton beam → polarized proton target (both transverse)



$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 h_1^q(x_1, M^2) h_1^{\bar{q}}(x_2, M^2)}{\sum_q e_q^2 q(x_1, M^2) \bar{q}(x_2, M^2)}$$

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

M invariant Mass of lepton pair

A_{TT} for PAX kinematic conditions

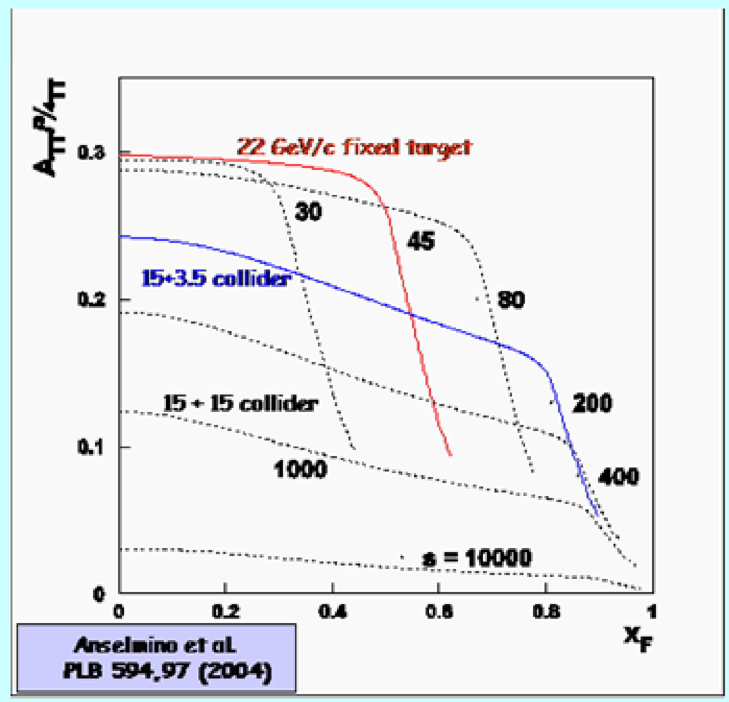
RHIC: $\tau = x_1 x_2 = M^2/s \sim 10^{-3}$
→ Exploration of the sea quark content (polarizations small!)
A_{TT} very small (~ 1 %)

PAX: $M^2 \sim 10\text{-}100\ GeV^2$, $s \sim 45\text{-}200\ GeV^2$, $\tau = x_1 x_2 = M^2/s \sim 0.05\text{-}0.6$
→ Exploration of valence quarks ($h_1^q(x,Q^2)$ large)

$A_{TT}/a_{TT} > 0.2$
Models predict $|h_1^u| >> |h_1^d|$

$$A_{TT} = \hat{a}_{TT} \frac{h_1^u(x_1, M^2) h_1^u(x_1, M^2)}{u(x_1, M^2) u(x_1, M^2)}$$

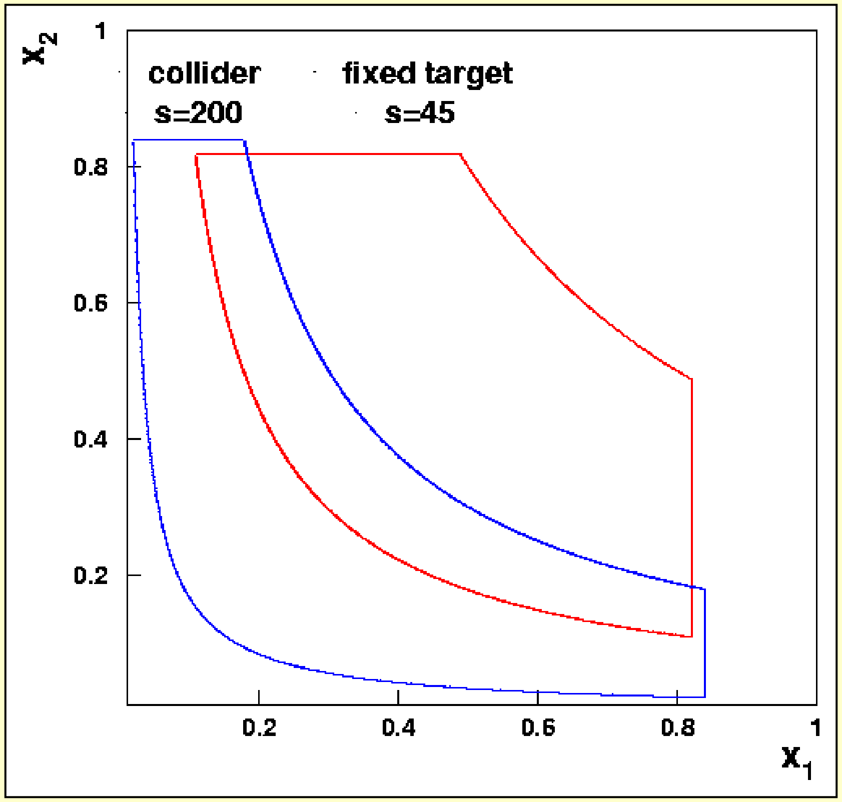
(where $\bar{q}^{\bar{p}} = q^p = q$)

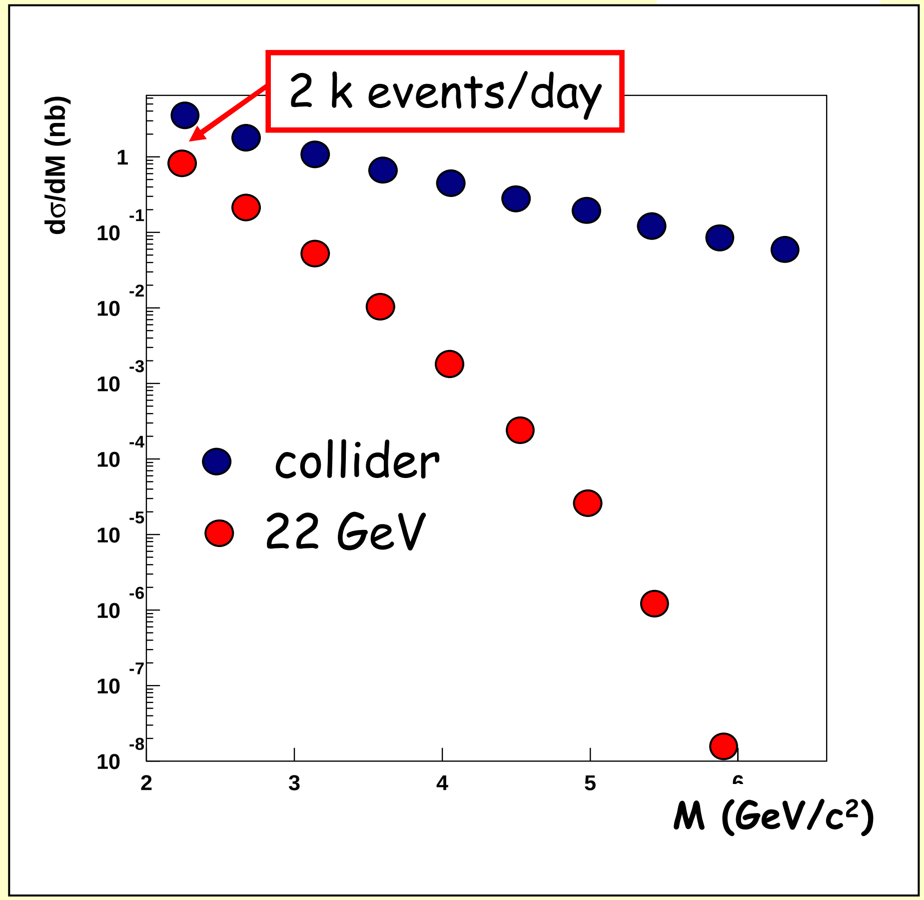


Kinematics and cross section

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

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





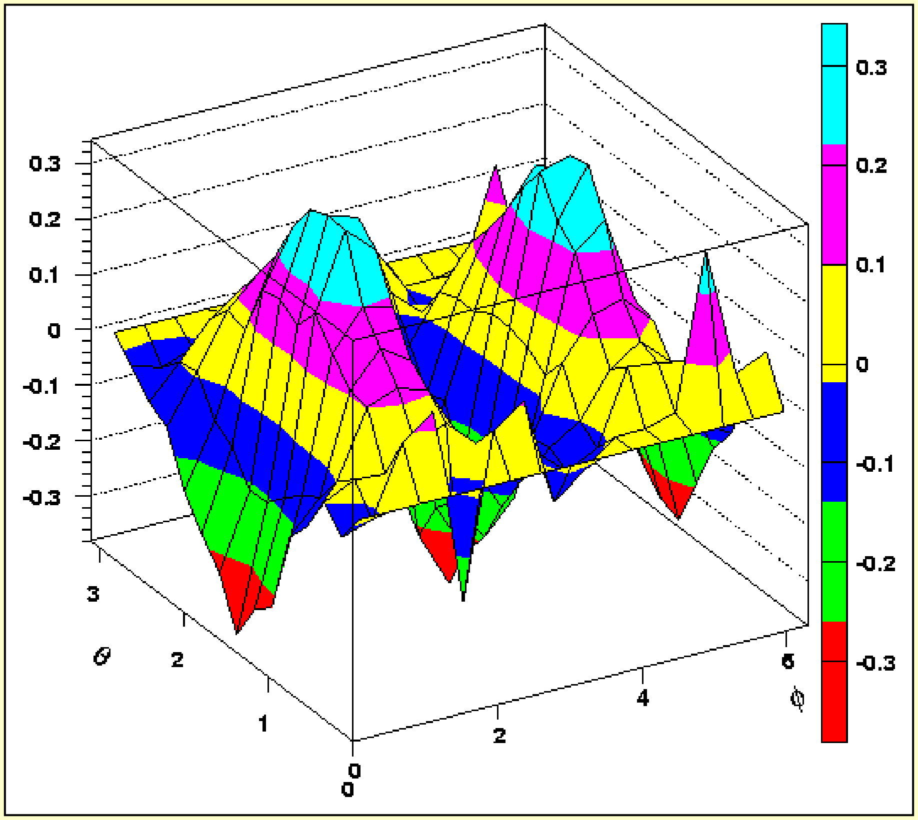
Estimated luminosities:

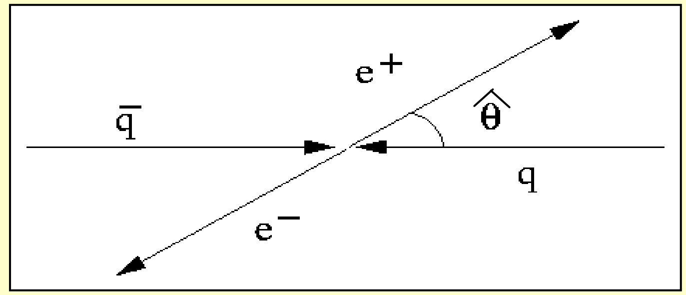
- **Fixed target:** 2.7×10^{31} $cm^{-2}s^{-1}$
- **Collider:** $1\text{-}2 \times 10^{30}$ $cm^{-2}s^{-1}$

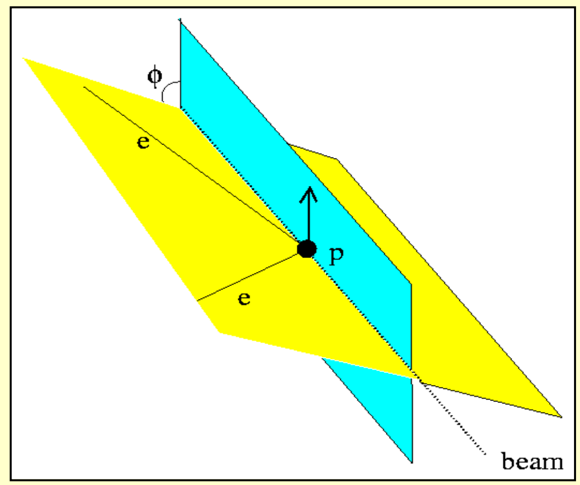
A_{TT} asymmetry: angular distribution

$$A_{TT} = \hat{a}_{TT} \frac{h_1^u(x_1,M^2)h_1^u(x_2,M^2)}{u(x_1,M^2)u(x_2,M^2)}$$

$$\hat{a}_{TT}(\hat{\theta},\phi) = \frac{\sin^2\hat{\theta}}{(1+\cos^2\hat{\theta})} \bullet \cos 2\phi$$



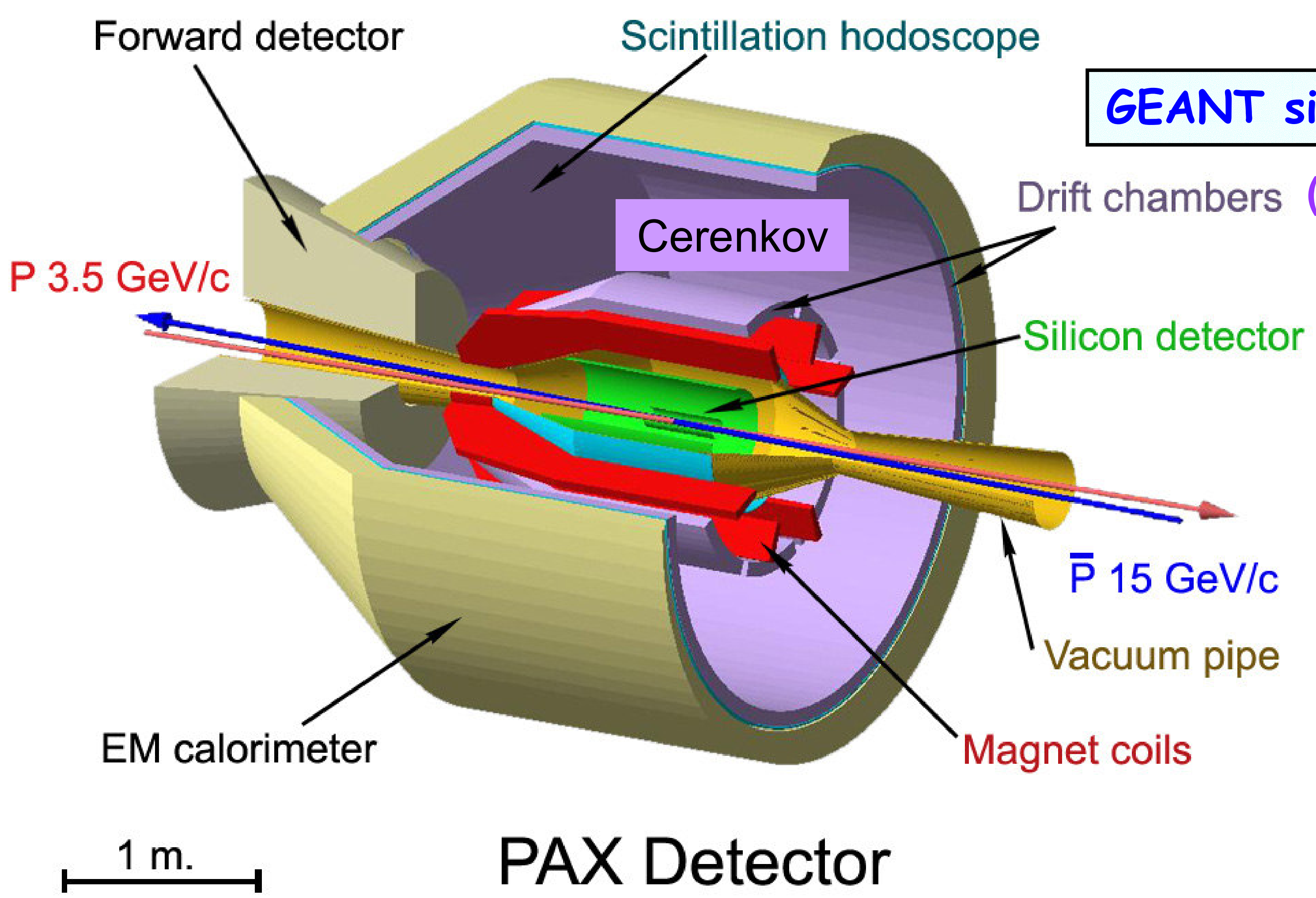




- Asymmetry is largest for angles $\hat{\theta}$ =90°
- Asymmetry varies like cos(2φ).

Needs a large acceptance detector (LAD)

PAX detector concept



GEANT simulation

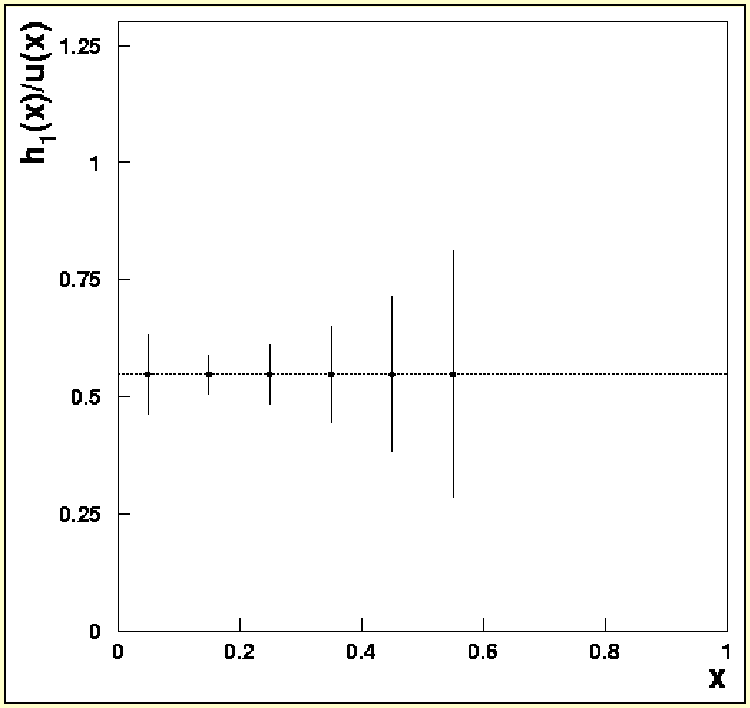
(200 μm)

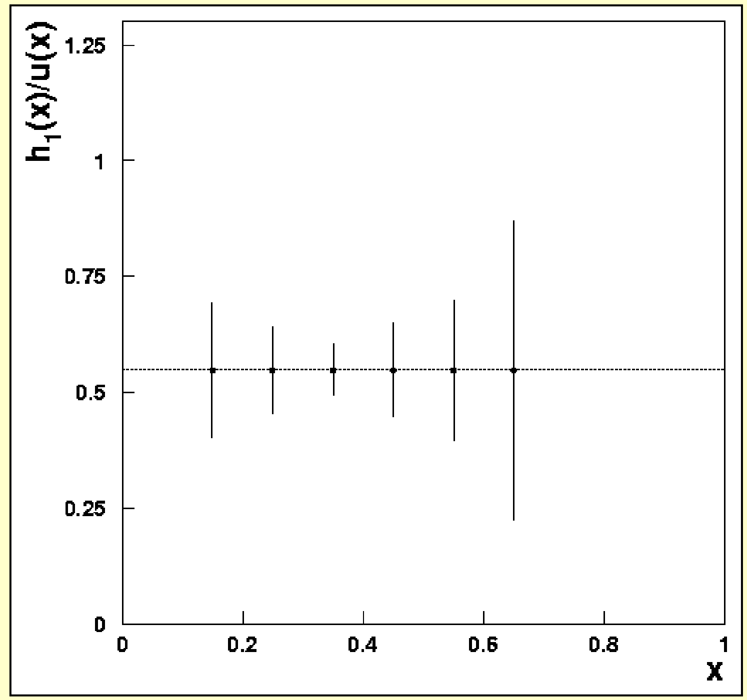
(20 μm)

Designed for Collider but compatible with fixed target

Estimated signal for h_1 (phase II)

1 year of data taking





Collider:

$L=2\times10^{30}\ cm^{-2}s^{-1}$

Fixed target:

$L=2.7\times10^{31}\ cm^{-2}s^{-1}$

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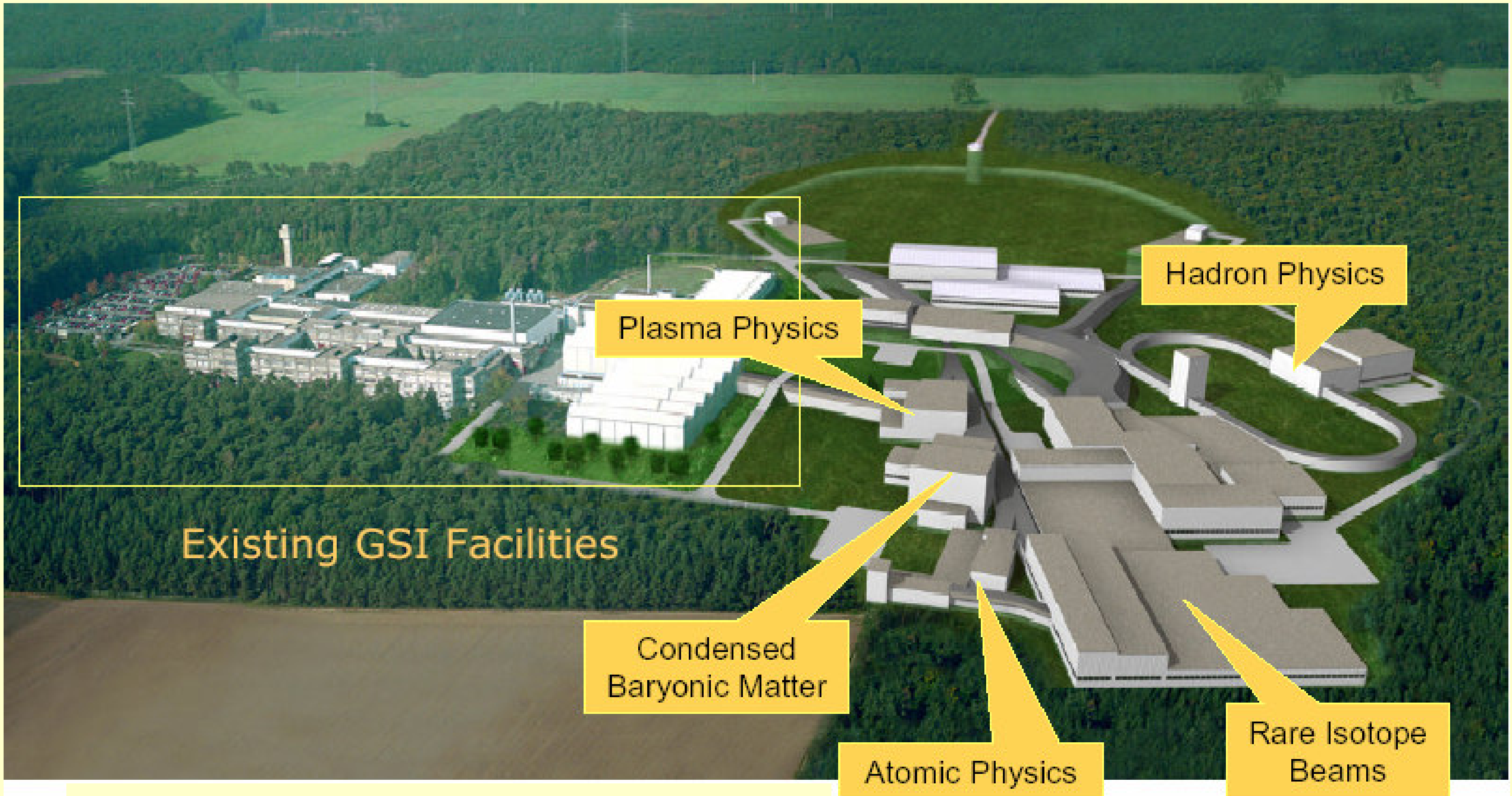
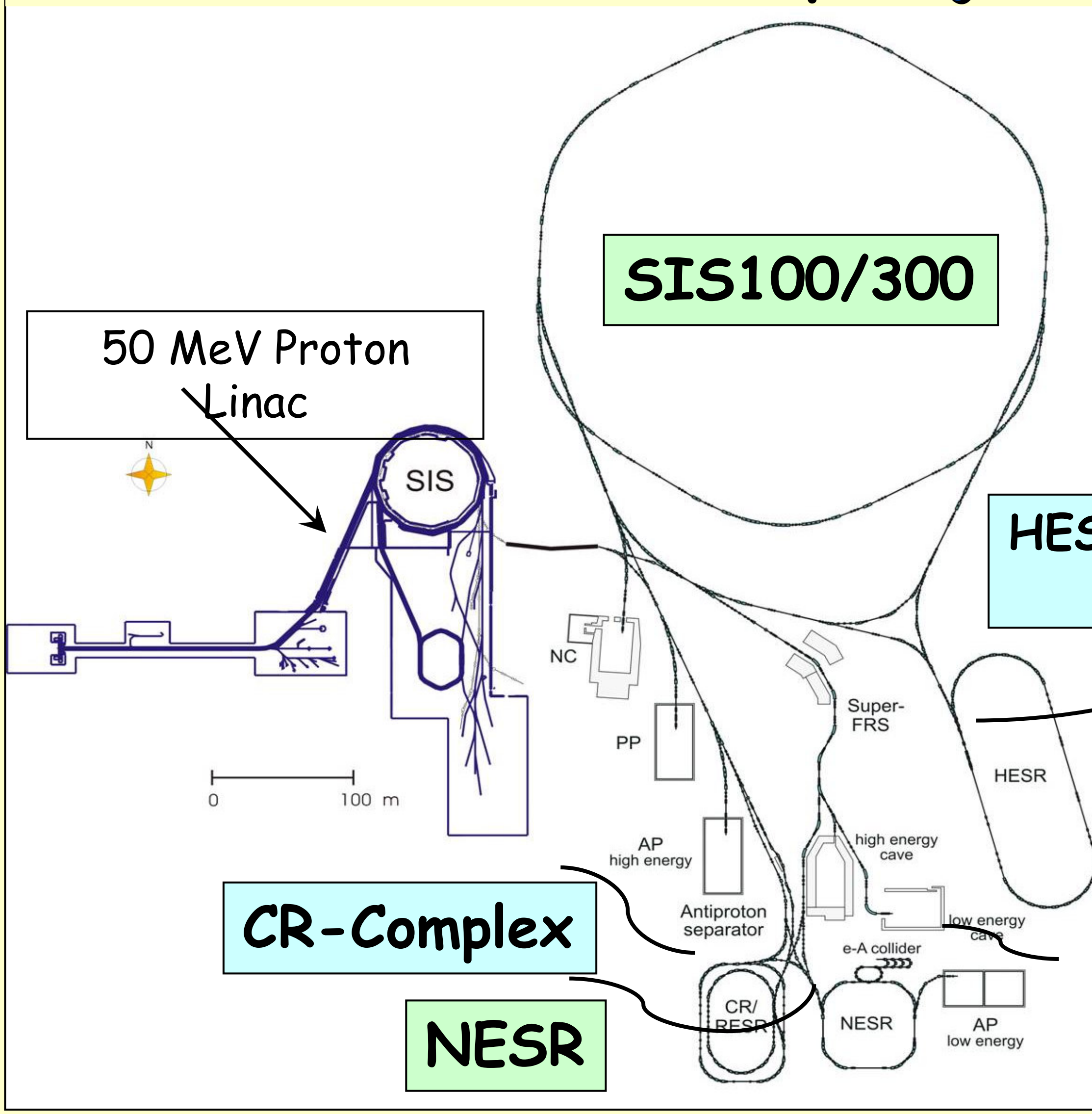
Faciltiy for Antiproton and Ion Research (GSI, Darmstadt, Germany)



-Proton linac (injector)
-2 synchrotons (30 GeV p)
-A number of storage rings
→ Parallel beams operation

The FAIR project at GSI



HESR: High Energy Storage Ring: PANDA and PAX

FLAIR:
(Facility for very Low energy Anti-protons and fully stripped Ions)

Timeline

Phase 0: 2005-2012

- **APR design and construction @ Juelich**

Phase I: 2013-2017

- **APR+CSR @ GSI**
- **Physics: EMFF with fixed target**

Phase II: 2018 - …

- **HESR+CSR asymmetric collider**
- **Physics: h_1**

Conclusions

Challenging opportunities accessible with polarized pbar.

- Unique access to a wealth of new fundamental physics observables
- Central physics issue: $h_1^q(x,Q^2)$ of the proton in DY processes
- Other issues:
  - Electromagnetic Formfactors
  - Polarization effects in Hard and Soft Scattering processes
  - differential cross sections, analyzing powers, spin correlation parameters

Staging approach

Projections for double polarization experiments:

- $P_{beam} > 0.30$
- $L > 1.6 \cdot 10^{30}\ cm^{-2}s^{-1}$ (Collider), $L \approx 2.7 \cdot 10^{31}\ cm^{-2}s^{-1}$(fixed target)

Detector concept:

- Large acceptance detector with a toroidal magnet

Georg Christoph Lichtenberg (1742 1799)

“Man muß etwas Neues machen, um etwas Neues zu sehen.”

**“You have to make something new,
if you want to see something new”**