PAX project at FAIR

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

Marco Contalbrigo – INFN and Università di Ferrara - ITALY

Tbilisi, 5 September 2006

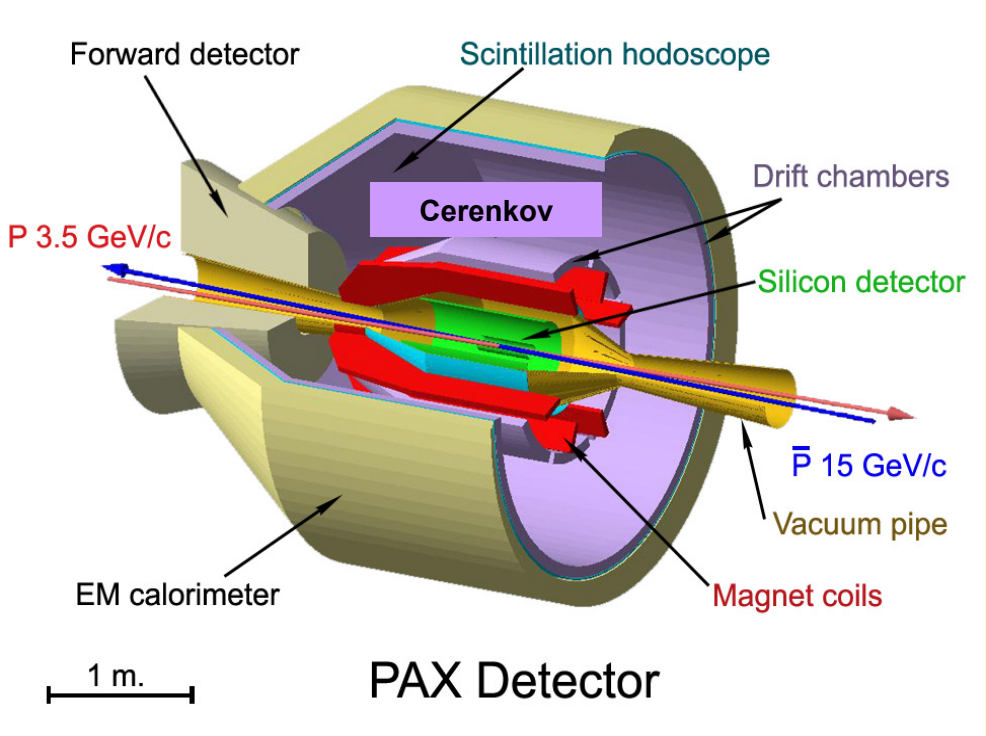
Physics Program

Polarized Antiproton eXperiments

Nucleon structure: polarized reactions

pbar-p elastic

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



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

Elastic Scattering

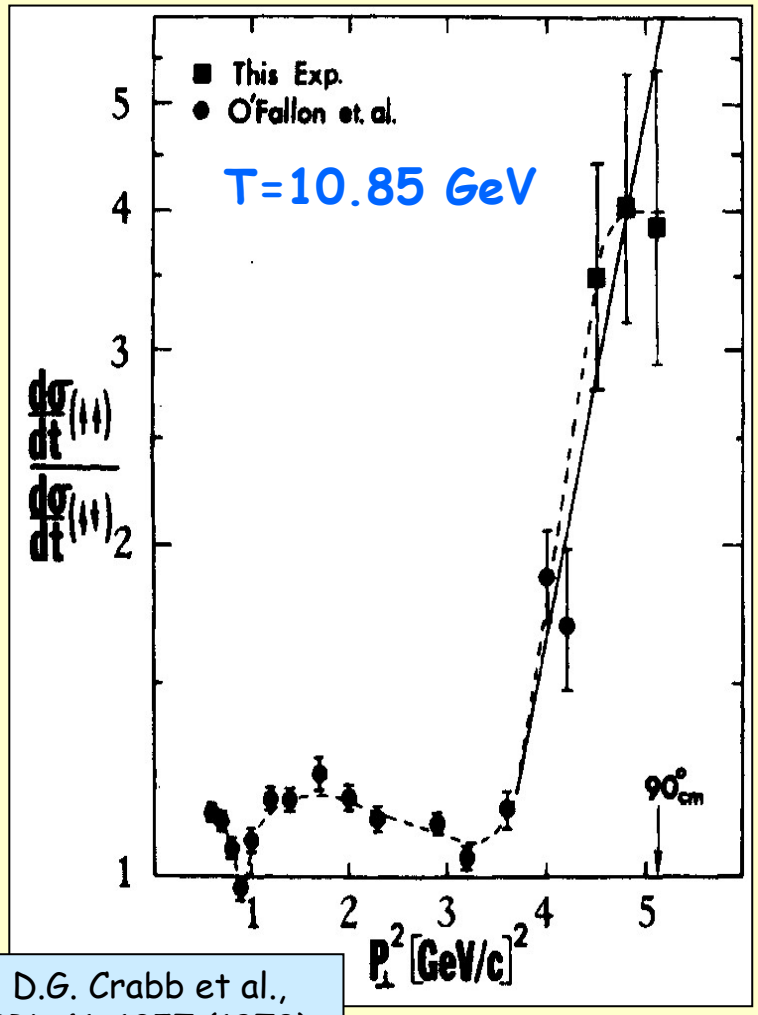
Low-E $\bar{p}p$, $\bar{p}d$ at AD

Polarization build-up studies

High-t pp from ZGS, AGS

Spin-dependence at large-$P_\perp$ ($90°_{cm}$):
Hard scattering takes place only with spins ↑↑.

Similar studies in $\bar{p}p$ elastic scattering



D.G. Crabb et al.,
PRL 41, 1257 (1978)

Polarized Antiproton eXperiments

Nucleon structure: polarized reactions

pbar-p elastic

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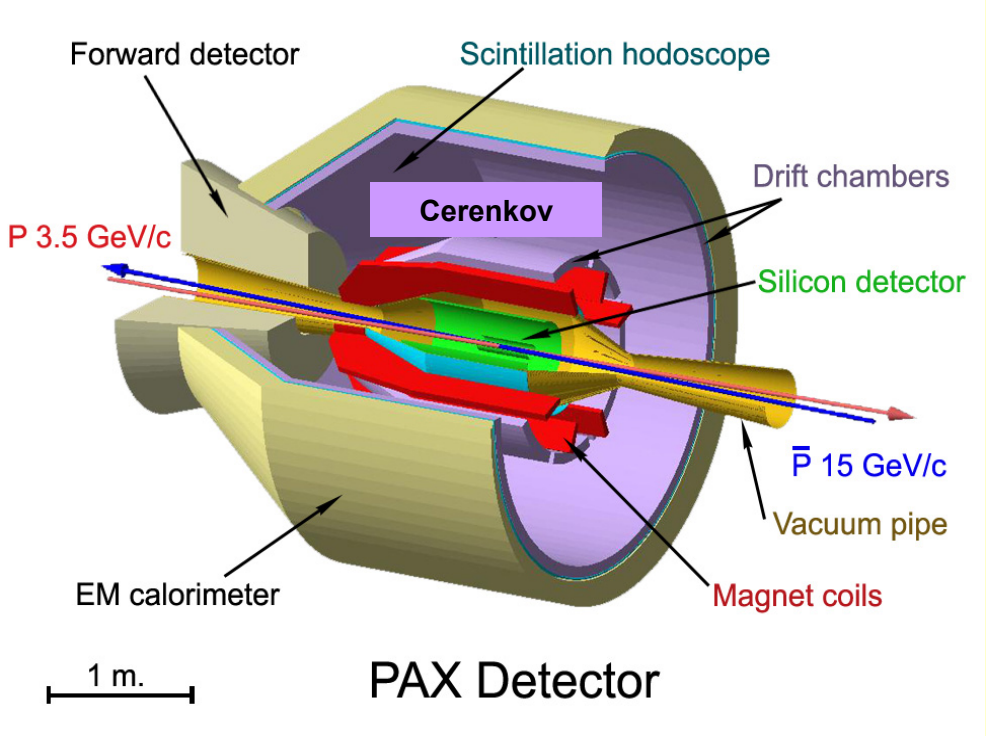
Proton EFFs

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



Fixed target experiment ($\sqrt{s}$<2 GeV):
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Proton Electromagnetic Formfactors

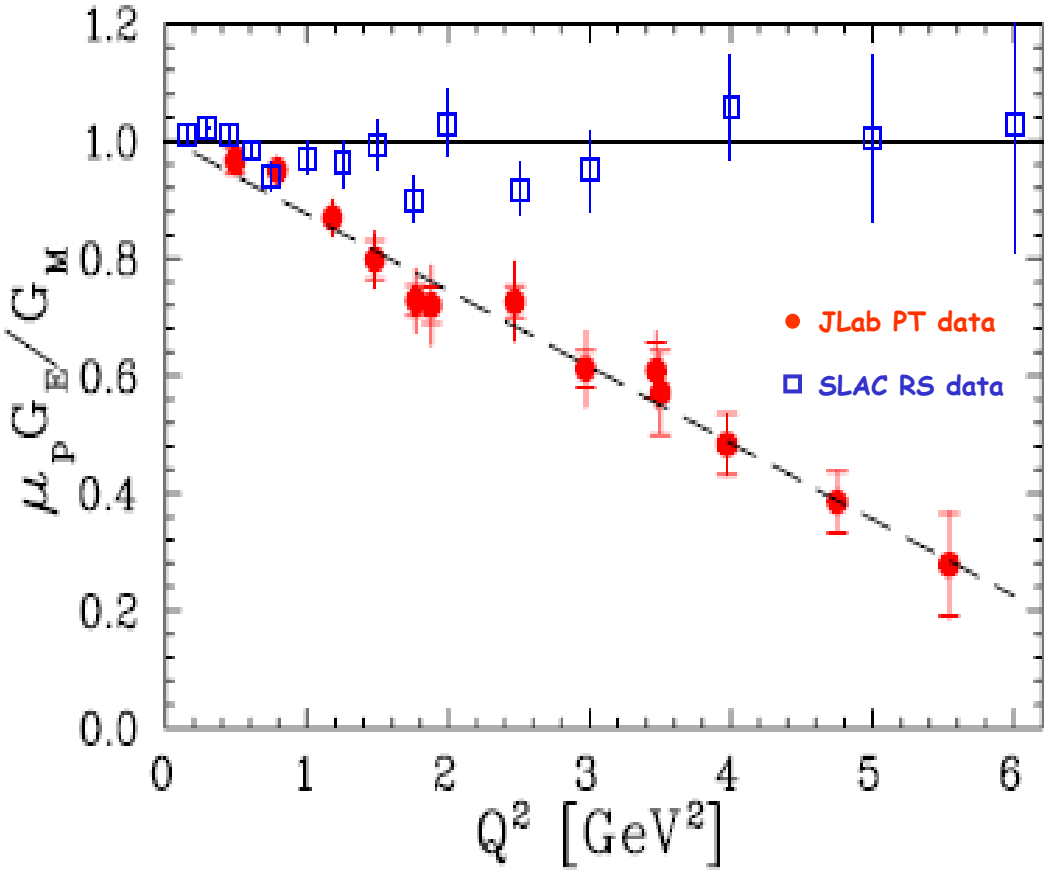


FIG. 1. (Color online) Ratio of electric to magnetic form factor as extracted by Rosenbluth measurements (hollow squares) and from the JLab measurements of recoil polarization (solid circles). The dashed line is the fit to the polarization transfer data.

(Phys. Rev.C 68 (2003) 034325)

COMPARISON BETWEEN ROSENBLUTH SEPARATION AND POLARIZATION TRANSFER TECNIQUES

TWO DIFFERENTS METHODS

TWO DIFFERENTS RESULTS

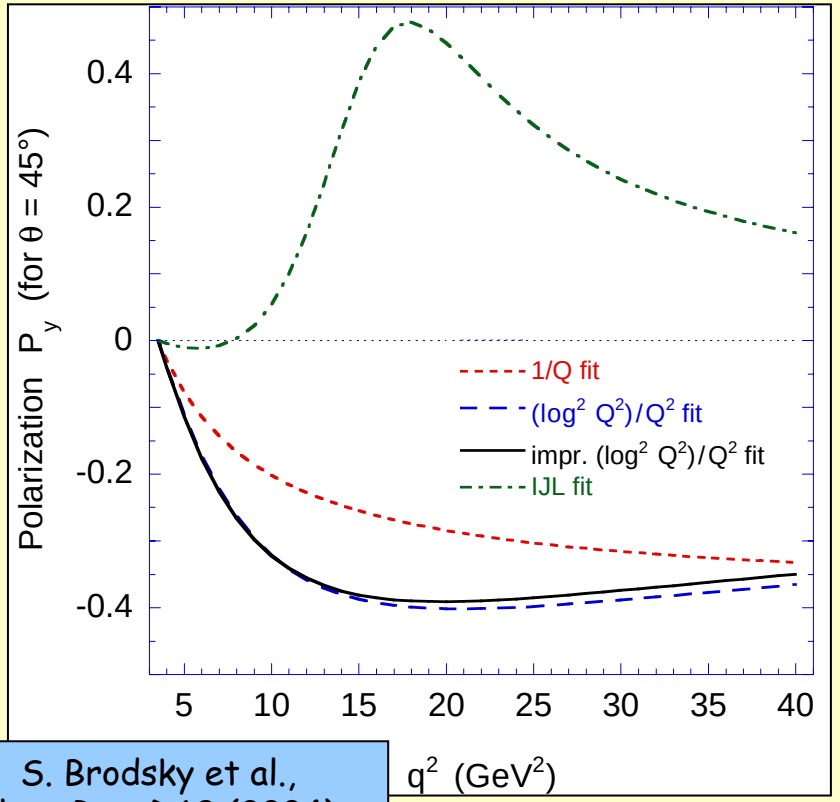
Proton Electromagnetic Formfactors

- Double-spin asymmetry in $\bar{p}p \rightarrow e^+e^-$
  - independent G_E-G_m separation
  - test of Rosenbluth separation in the time-like region

- Single-spin asymmetry in $\bar{p}p \rightarrow e^+e^-$
  - Measurement of relative phases of magnetic and electric FF in the time-like region

$$A_y = \frac{\sin(2\theta)\cdot \mathrm{Im}(G_E^* \cdot G_M)}{\left[\left(1+\cos^2(\theta)\right)|G_M|^2 + \sin^2(\theta)\,|G_E|^2/\tau\right]\sqrt{\tau}}$$

$$\tau = q^2/4m_p^{\,2}$$



S. Brodsky et al., Phys. Rev. D69 (2004)

Polarized Antiproton eXperiments

Nucleon structure: polarized reactions

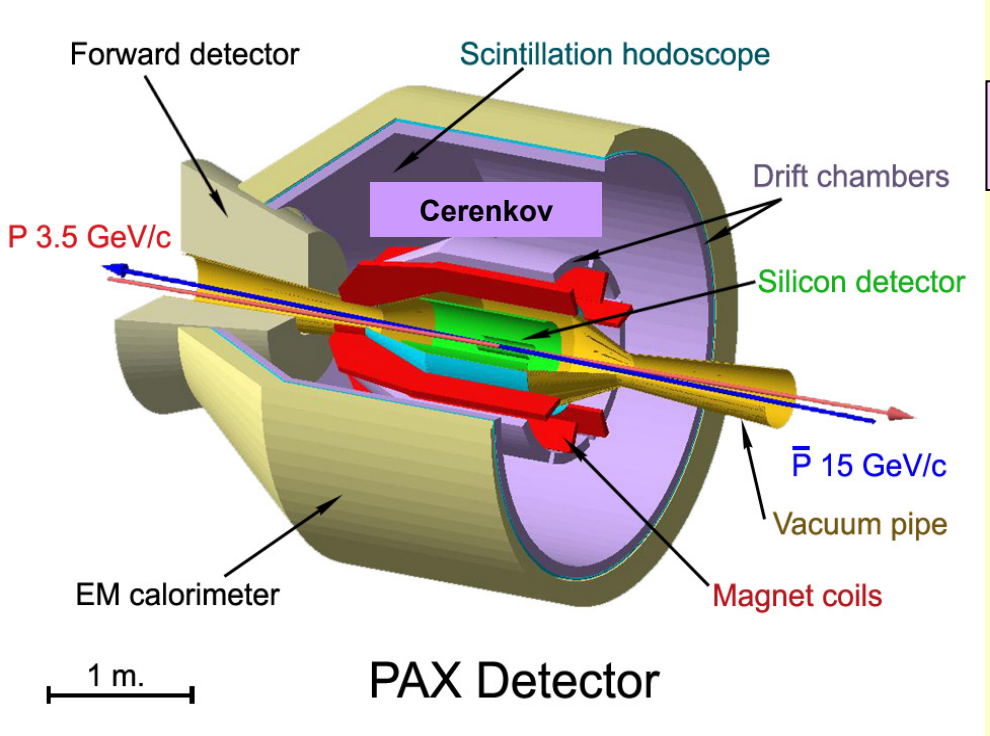
Parton distribution: transversity

pbar-p elastic

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

Proton EFFs

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



Drell-Yan

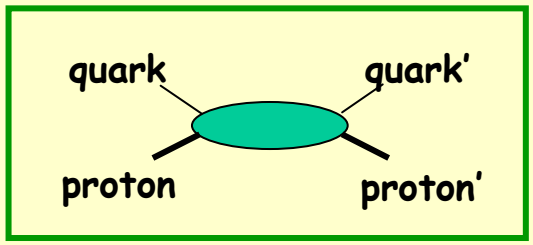
$$p^{\uparrow}\bar{p}^{\uparrow} \rightarrow e^{+}e^{-}X$$

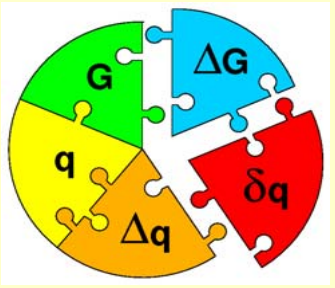
Fixed target experiment ($\sqrt{s}$<2 GeV):
pol./unpol. pbar beam (p<4 GeV/c)
internal H polarized target

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

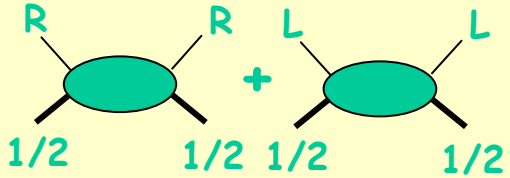
Leading Twist Distribution Functions

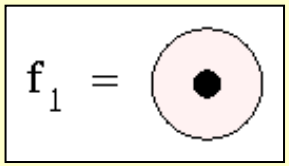
Probabilistic interpretation in helicity base:





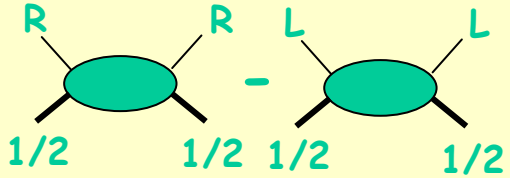
$f_1(x)$

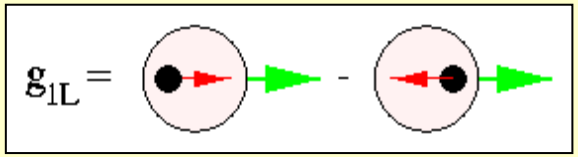




q(x) spin averaged
(well known)

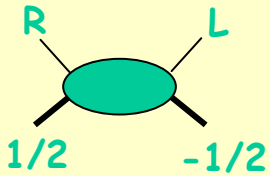
$g_1(x)$





Δq(x) helicity diff.
(known)

$h_1(x)$

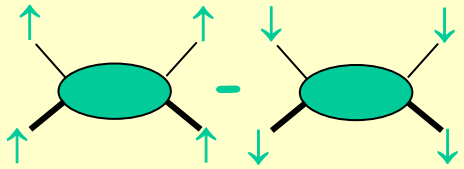


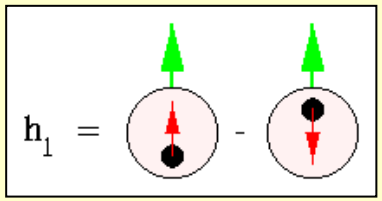
No probabilistic interpretation in the helicity base (off diagonal)

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)

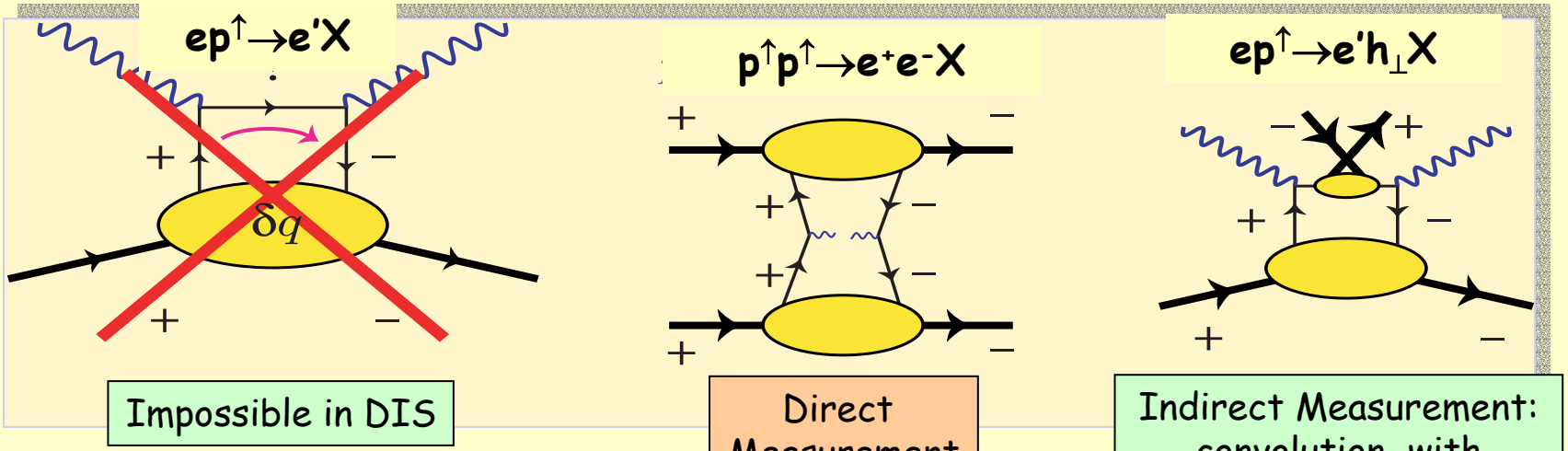
Transversity

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

See talk by M. Anselmino

Chiral-odd: requires another chiral-odd partner



Impossible in DIS

Direct Measurement

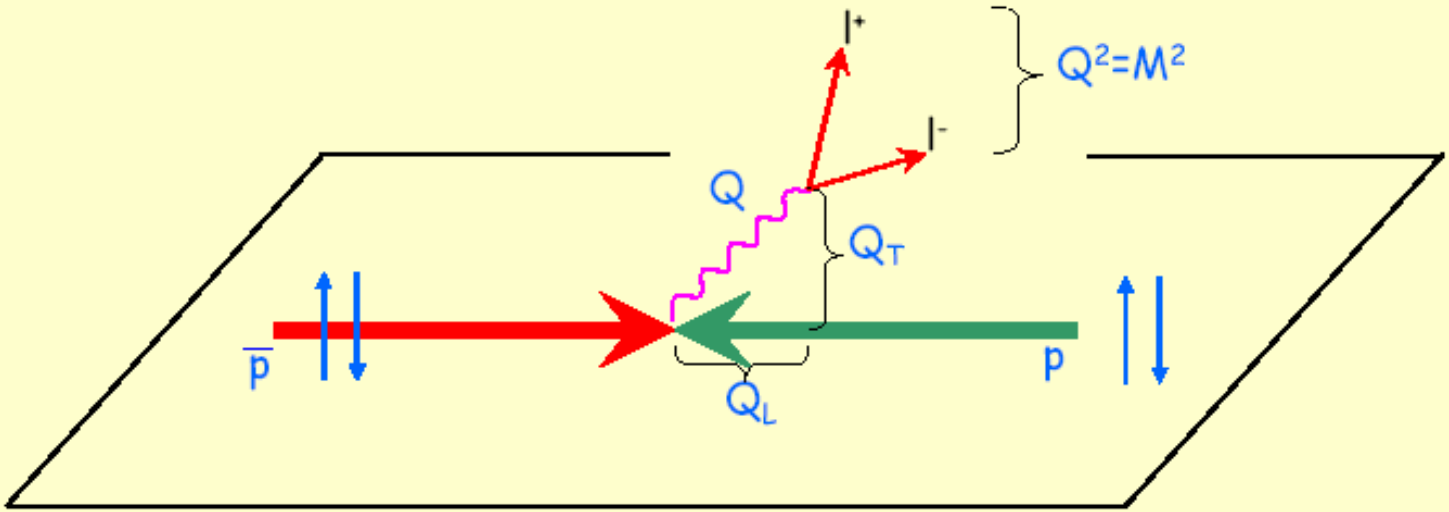
Indirect Measurement: convolution with unknown fragment. fct.

h_1 must couple to another chiral-odd function

$h_1 \times h_1$

$h_1 \times$ Collins function

Drell-Yan process



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

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

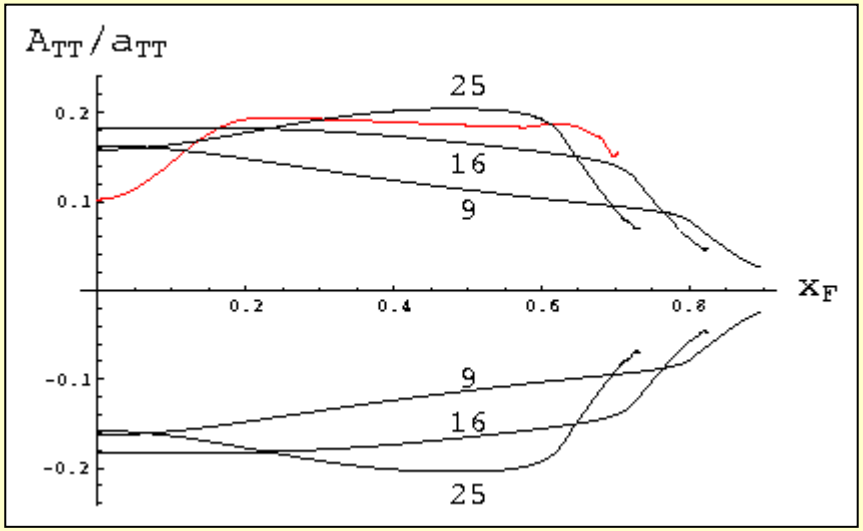
$q = u, \bar{u}, d, \bar{d}, \ldots$

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 p-p Drell-Yan

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



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

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

Barone, Calarco, Drago

Martin, Schäfer, Stratmann, Vogelsang

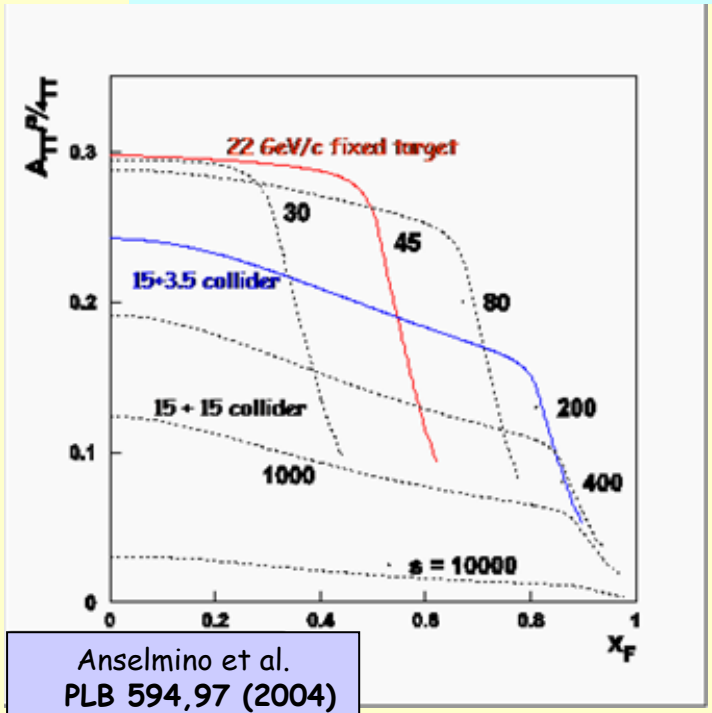
RHIC: $M^2/s = x_1 x_2 \sim 10^{-3}$ → sea quarks (A_{TT} ~ 0.01)

JPARC/U70: $M^2/s = x_1 x_2 \sim 10^{-1}$-$10^{-2}$ → valence and sea (A_{TT} ~ 0.1)

PAX: $M^2/s = x_1 x_2 \sim 10^{-1}$-$10^{-2}$ → valence and sea (A_{TT} ~ 0.1)

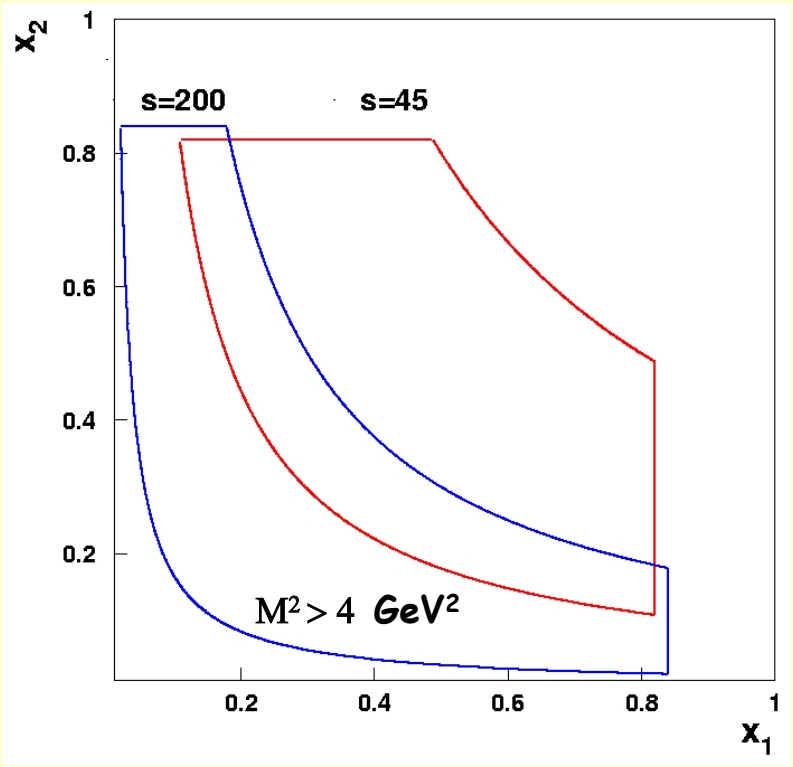
h_1 from pbar-p Drell-Yan

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



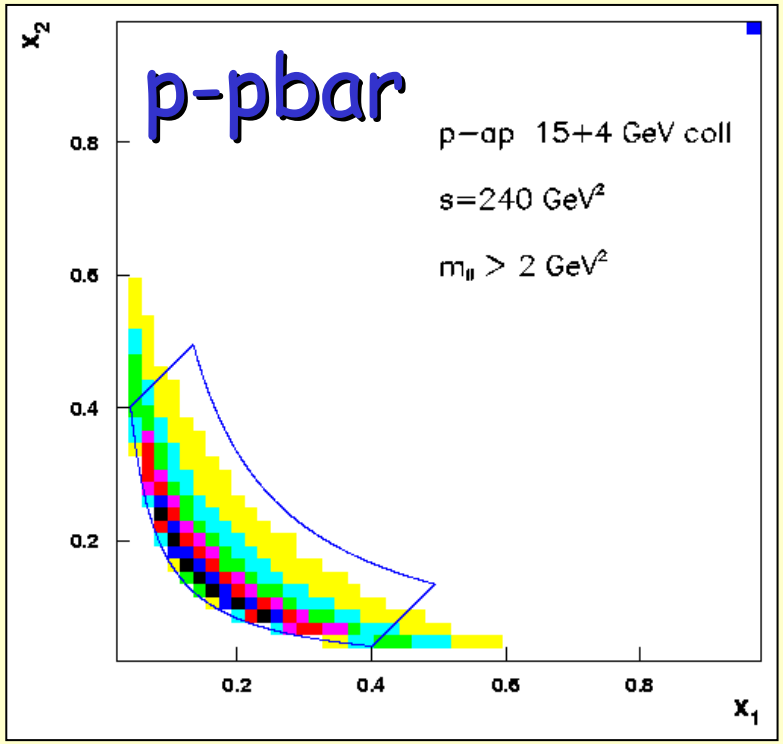
Anselmino et al.
PLB 594,97 (2004)

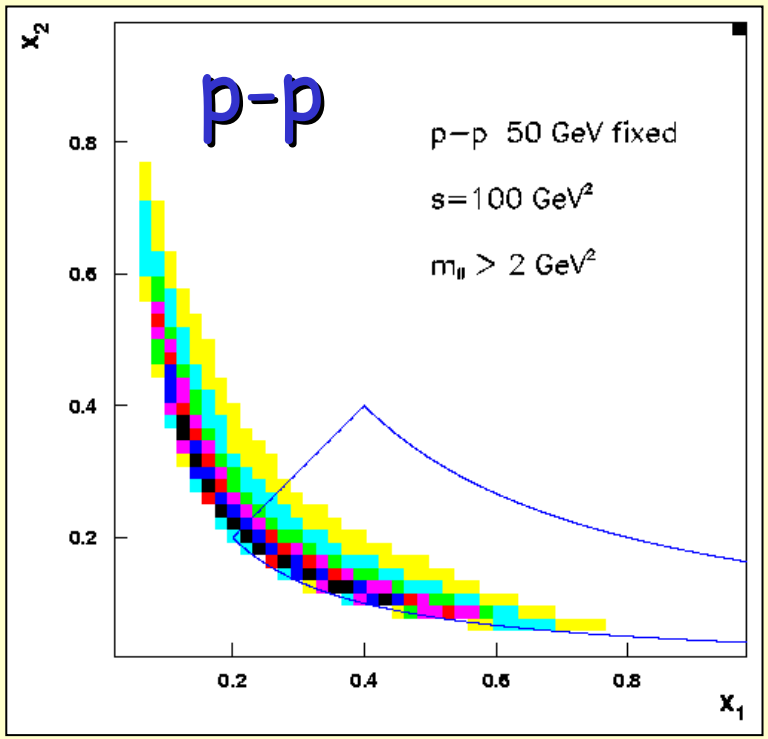
Similar predictions by Efremov et al.,
Eur. Phys. J. C35, 207 (2004)



PAX : $M^2/s = x_1 x_2 \sim 0.02\text{-}0.3$ → valence quarks (A_{TT} large ~ 0.2-0.4)

DY events distribution





$M^2/s = x_1x_2 \sim 0.02\text{-}0.3$

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

Direct measurement of h_{1u} for $0.05<x<0.5$

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

pbarp+pp complete mapping of transversity

Polarized Antiproton eXperiments

Nucleon structure: polarized reactions

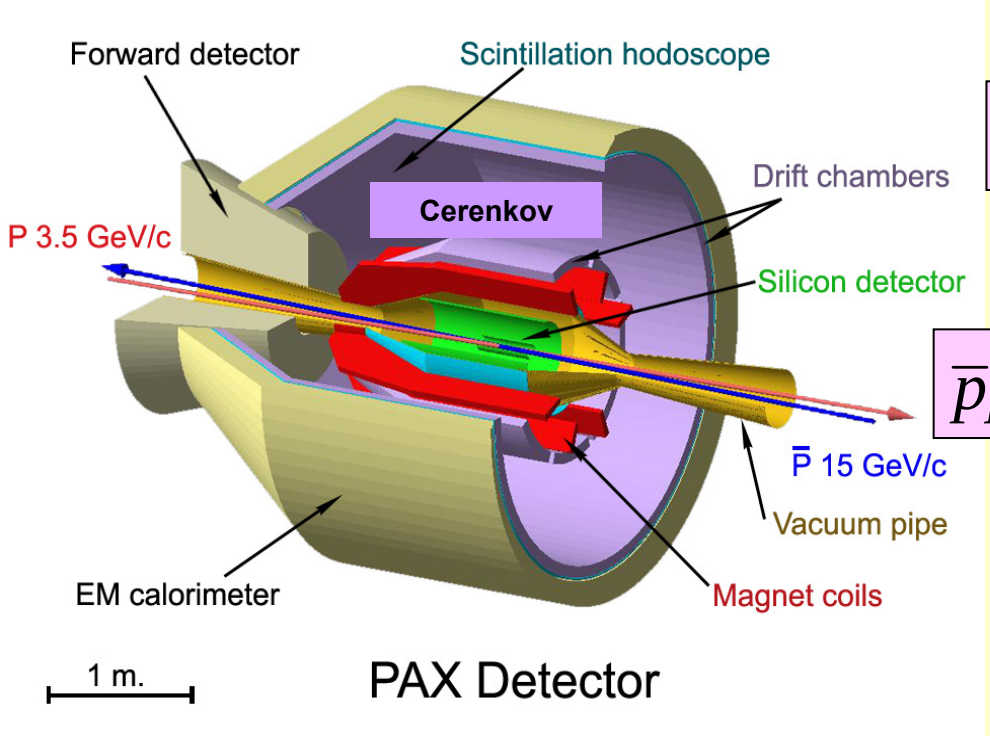
Parton distribution: transversity

pbar-p elastic

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

Proton EFFs

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



Drell-Yan

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

SSA

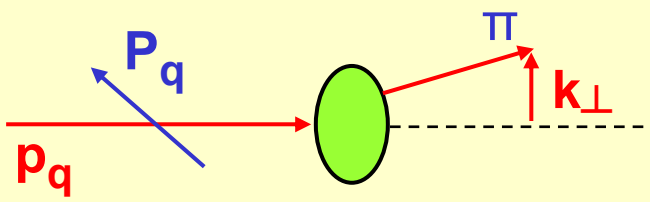
$$\bar{p}p^{\uparrow} \rightarrow DX, l^{+}l^{-}X$$

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

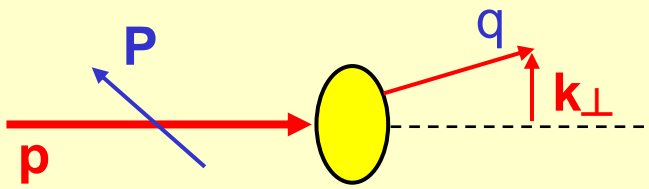
Asymmetric collider ($\sqrt{s}$=15 GeV):
polarized antiprotons in HESR (p=15 GeV/c)
polarized protons in CSR (p=3.5 GeV/c)

Single Spin Asymmetries

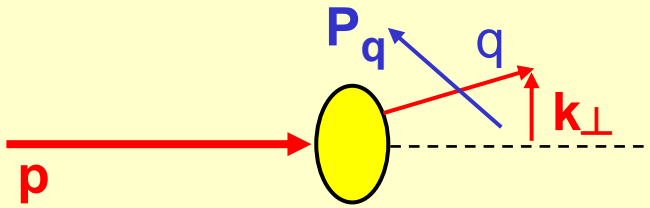
(and their partonic origin)



Collins effect = fragmentation of polarized quark depends on $\mathbf{P_q} \cdot (\mathbf{p_q} \times \mathbf{k_\perp})$



Sivers effect = number of partons in polarized proton depends on $\mathbf{P} \cdot (\mathbf{p} \times \mathbf{k_\perp})$



Boer-Mulders effect = polarization of partons in unpolarized proton depends on $\mathbf{P_q} \cdot (\mathbf{p} \times \mathbf{k_\perp})$

Collins: chiral-odd

Sivers: chiral-even

Boer-Mulders: chiral-odd

These effects may generate SSA

$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

See talk by O. Ivanov, M. Anselmino, O.Shevchenko

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Parton distribution: transversity

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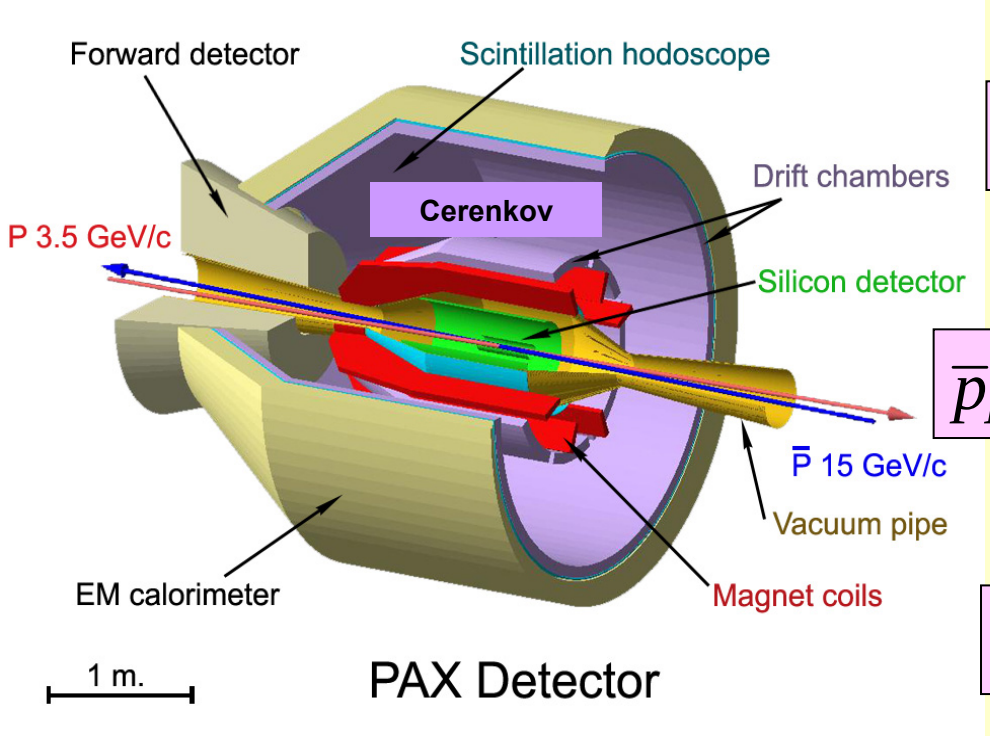

Drell-Yan

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

SSA

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

Charmonium

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

Fixed target experiment ($\sqrt{s}$<2 GeV):
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Asymmetric collider ($\sqrt{s}$=15 GeV):
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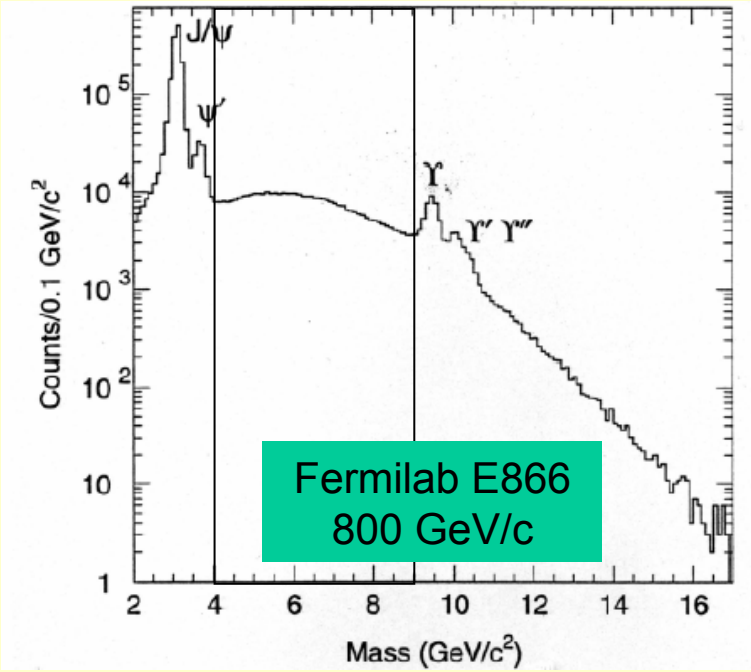
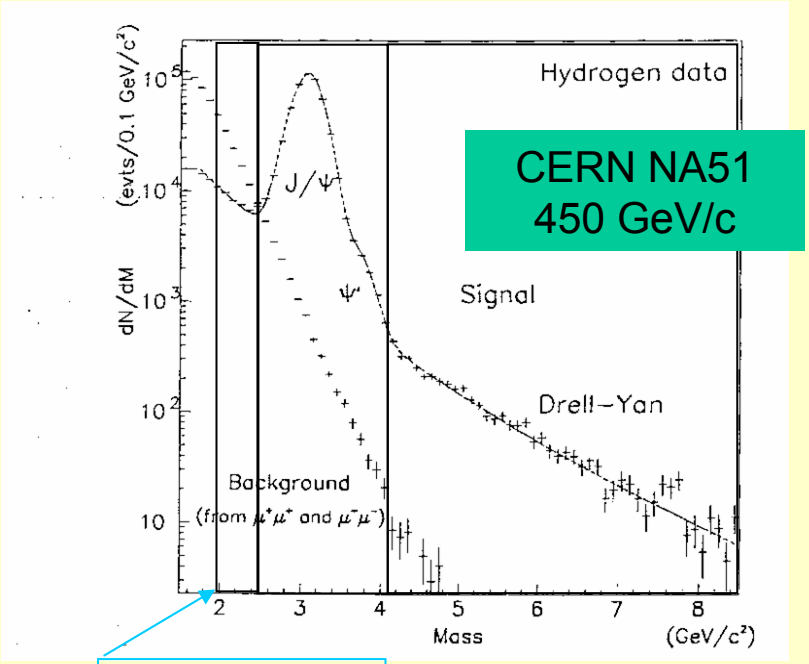
Kinematics for Drell-Yan processes





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

Usually taken as "safe region"

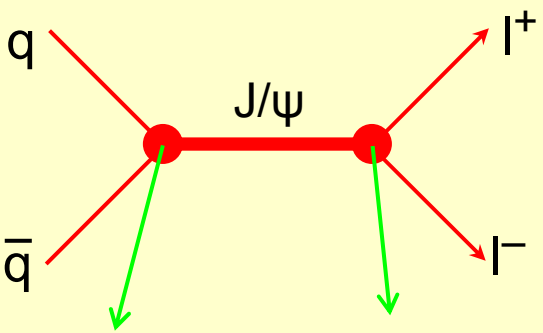
$$\tau \geq \frac{M^2_{J/\Psi}}{s}$$

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

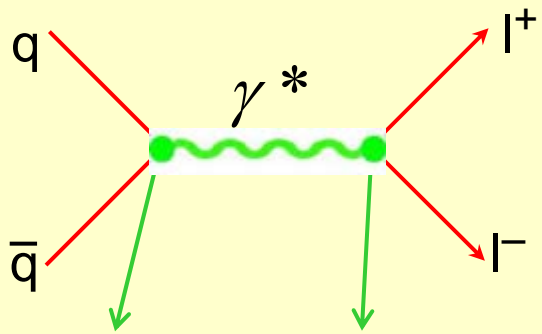
H. Shimizu, G. Sterman, W. Vogelsang and H. Yokoya, hep-ph/0503270

V. Barone et al., in preparation

$$p\bar{p} \to J/\Psi\, X \to l^+ l^-$$



$$\frac{(g_q^V \bar{v}\gamma^\mu u)(g_l^V \bar{u}\gamma_\mu v)}{M^2 - M_{J/\Psi}^2 + i\,\Gamma M_{J/\Psi}}$$



$$\frac{(e_q \bar{v}\gamma^\mu u)(e\,\bar{u}\gamma_\mu v)}{M^2}$$

all vector couplings, same spinor structure

$$\hat{a}_{TT}^{J/\Psi} = \hat{a}_{TT}^{\gamma^*}$$ and, at large x_1, x_2

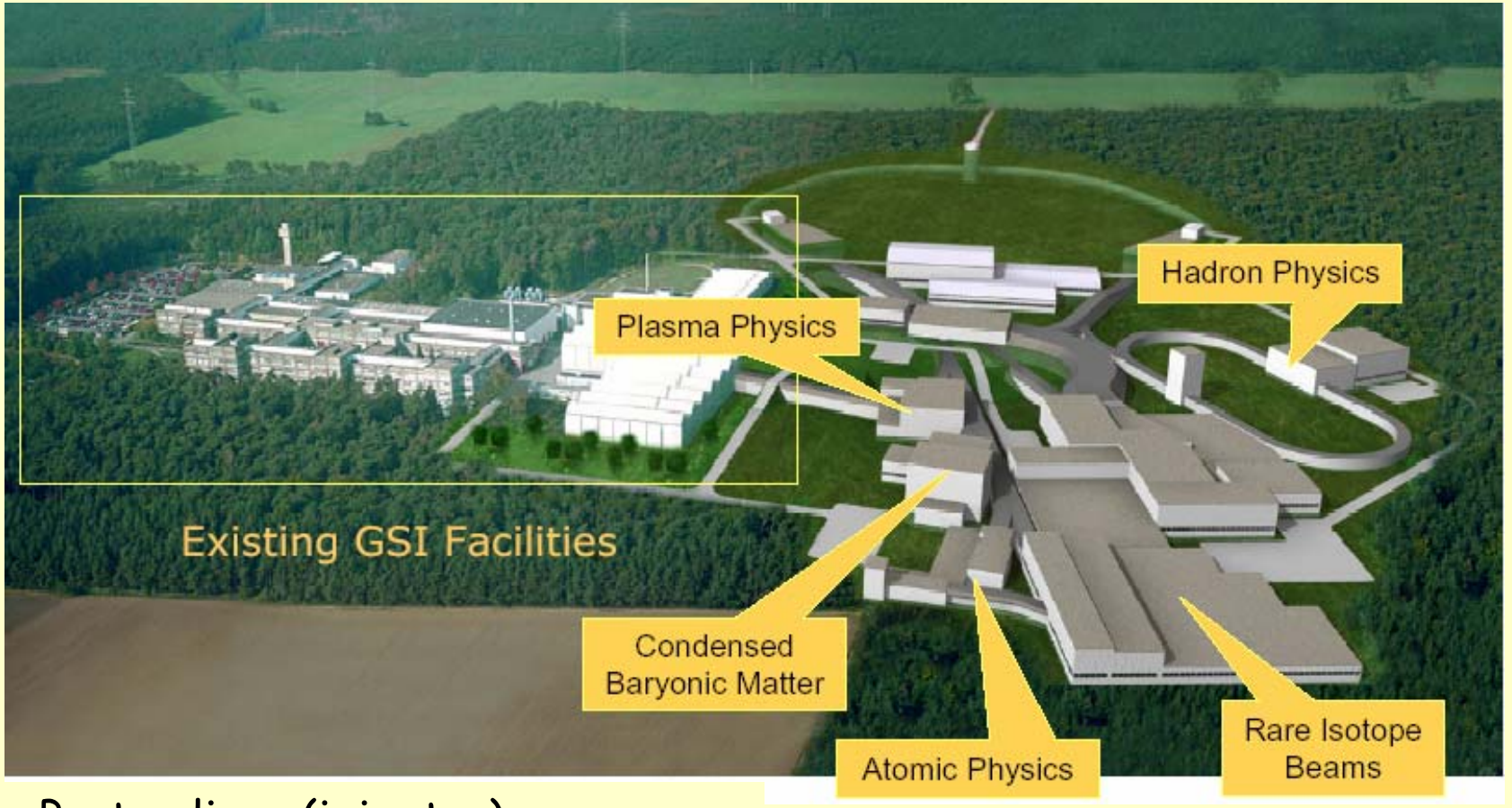
$$A_{TT} \approx \hat{a}_{TT} \frac{\sum_q (g_q^V)^2 h_{1q}(x_1) h_{1q}(x_2)}{\sum_q (g_q^V)^2 q(x_1) q(x_2)} \approx \frac{h_{1u}(x_1) h_{1u}(x_2)}{u(x_1) u(x_2)}$$

measure A_{TT} also in J/ψ resonance region

M. A., V. Barone, A. Drago and N. Nikolaev

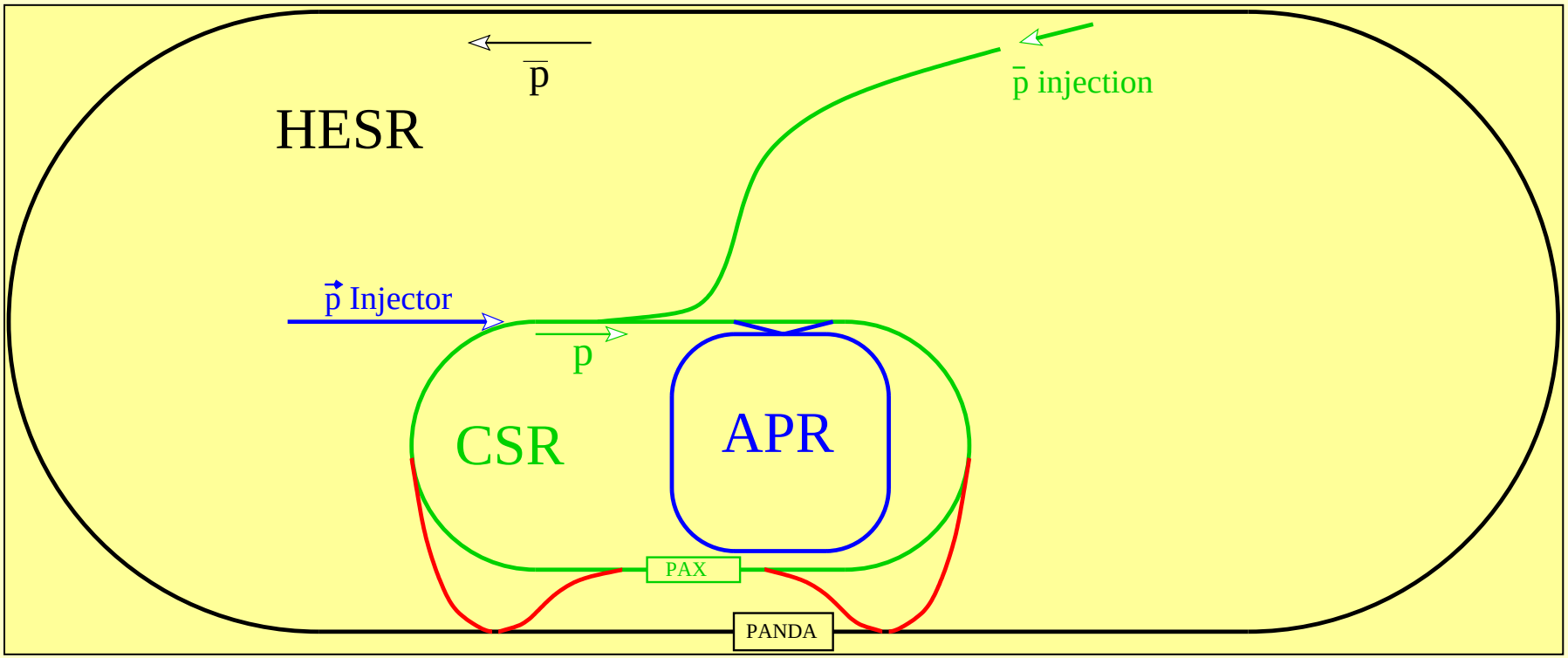
The FAIR project

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



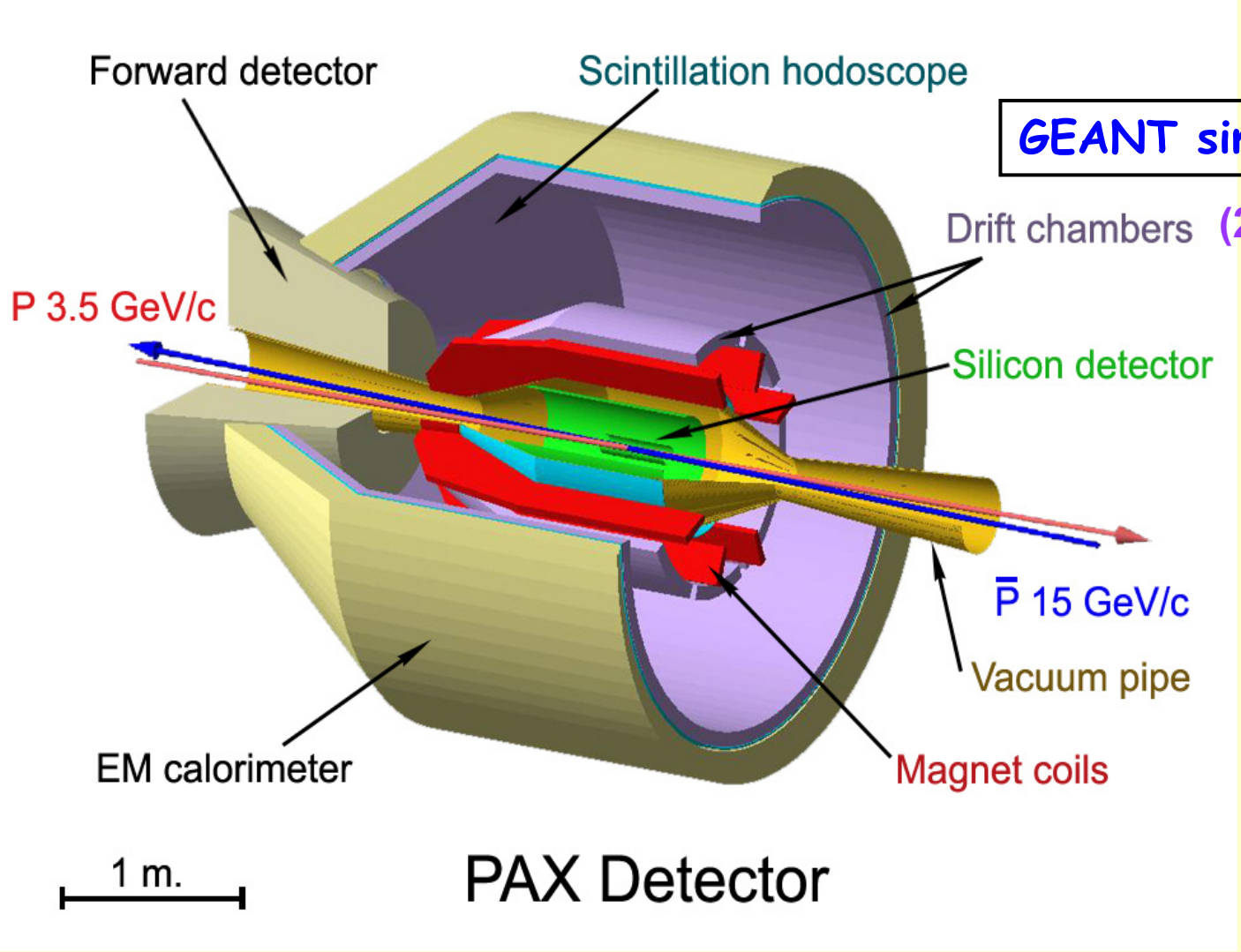
-Proton linac (injector)
-2 synchrotons (30 GeV p)
-A number of storage rings
→ Parallel beams operation

PAX Accelerator Setup



- **APR:** Antiproton Polarizer Ring (P_{pbar}>0.2)
- **CSR:** Cooled Synchrotron Ring (p<3.5 GeV/c)
- **HESR:** High Energy Synchrotron Ring (p<15 GeV/c)

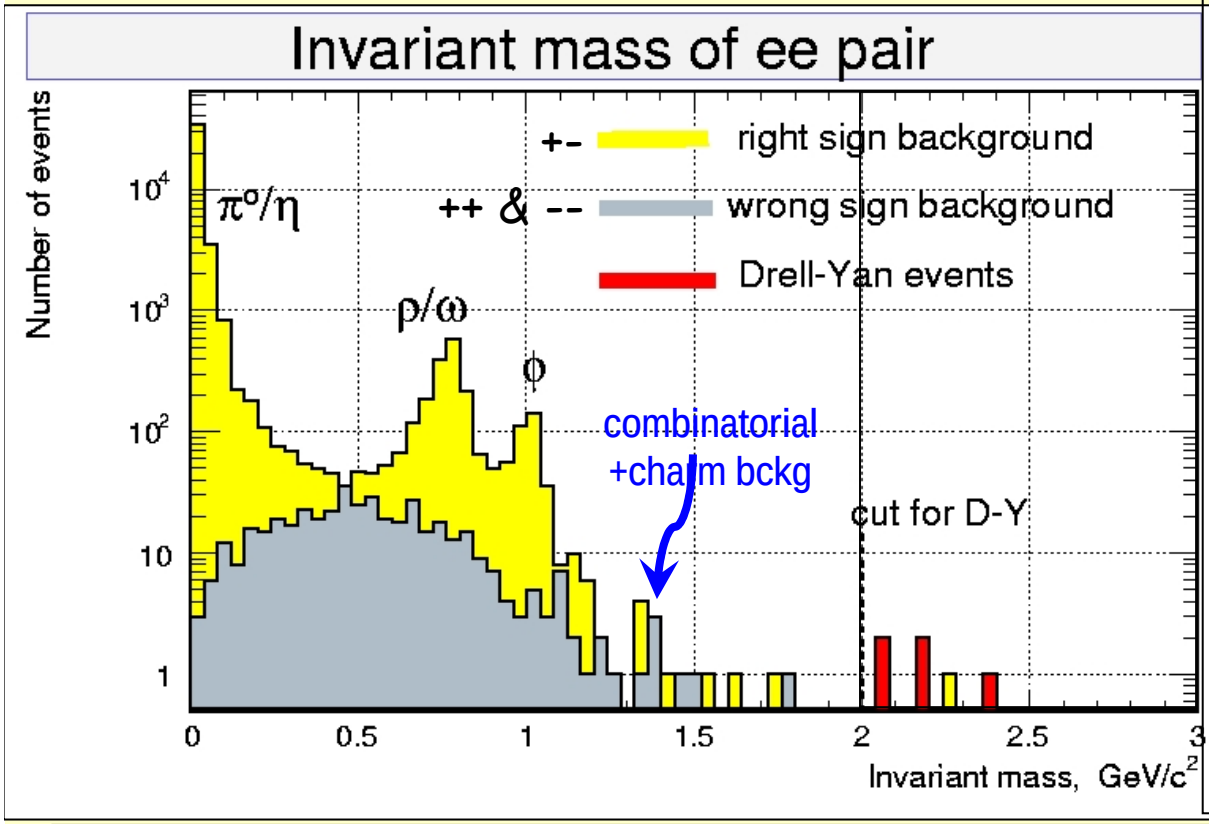
PAX Detector Concept

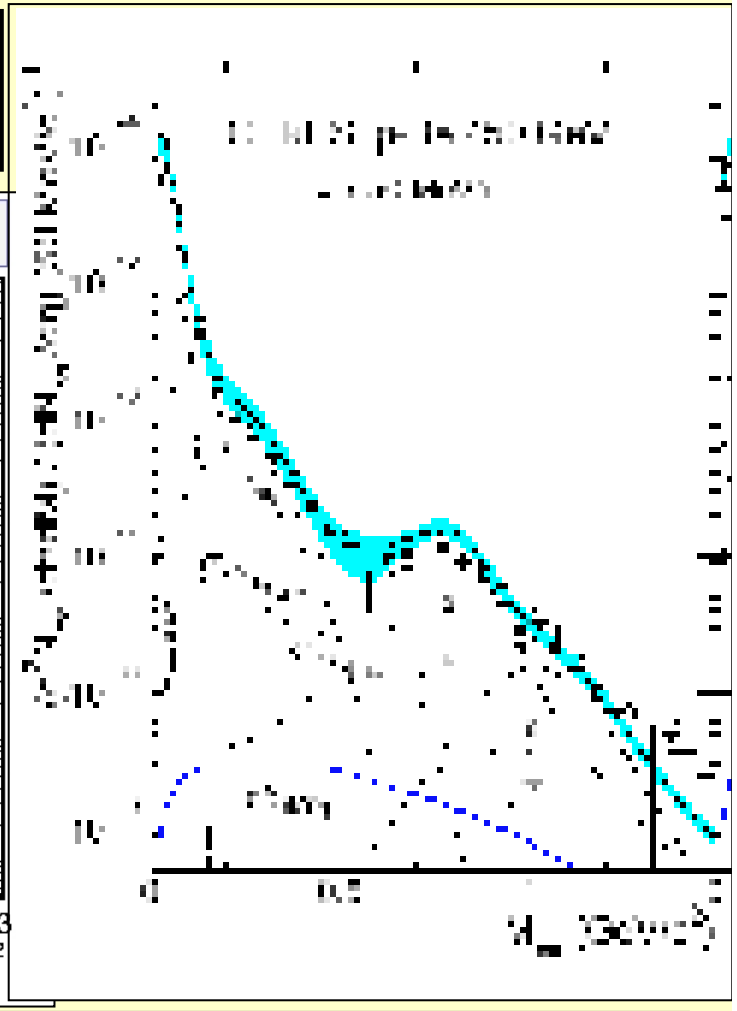


Designed for Collider but compatible with fixed target

Background to Drell-Yan e^+e^-

½ hour experiment: $2 \cdot 10^8$ p-pbar interactions
several DY events

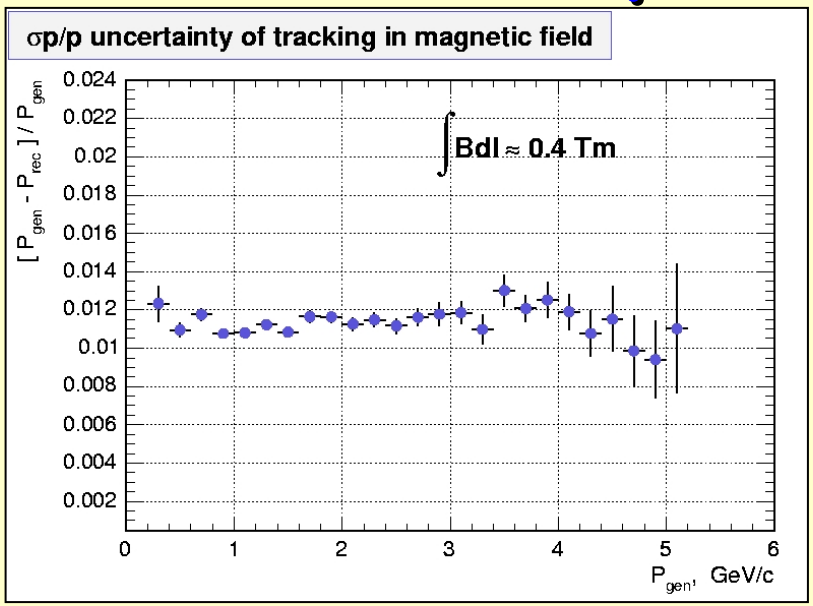


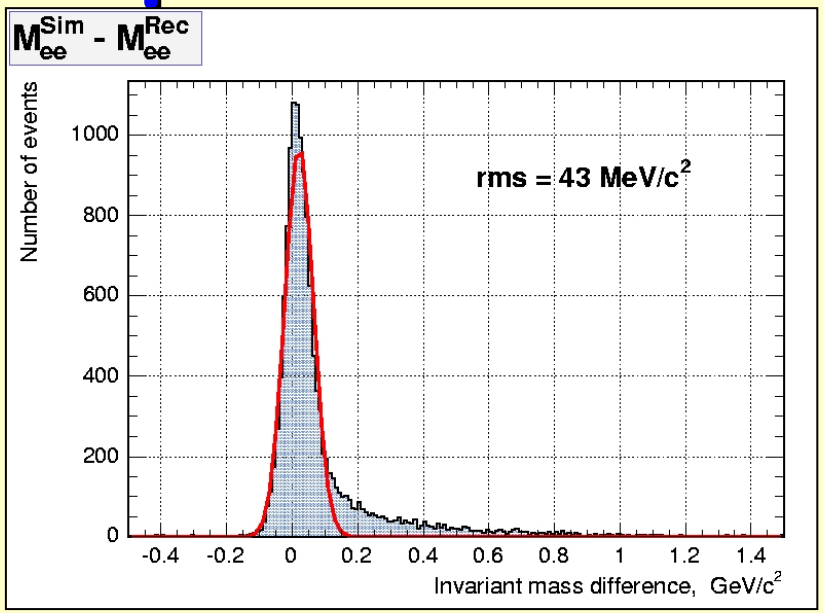


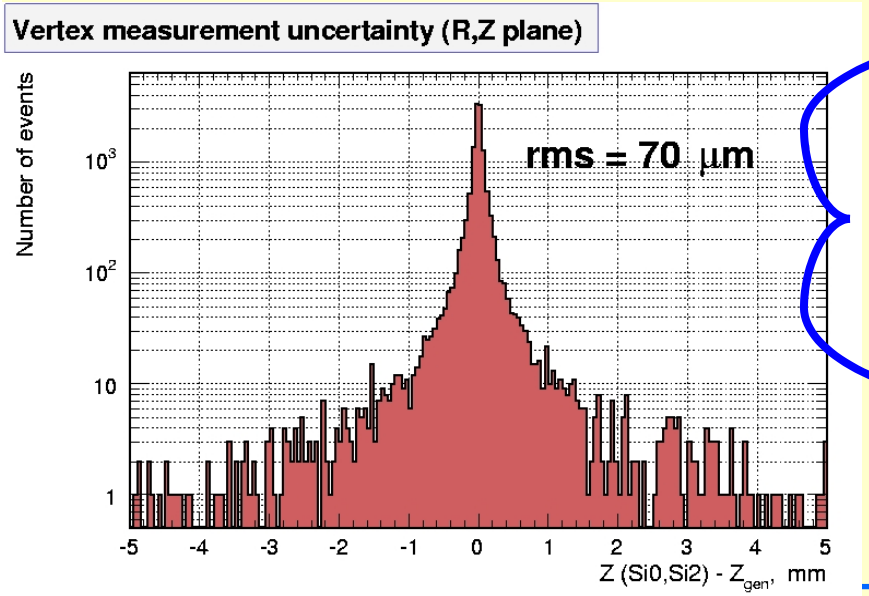
Background 1:1 to signal after PID, E>300 MeV, conversion veto, mass cut

* the combinatorial component can be subtracted (wrong-sign control sample)
* the charm can be reduced (vertex decay)

θ-p Phase Space





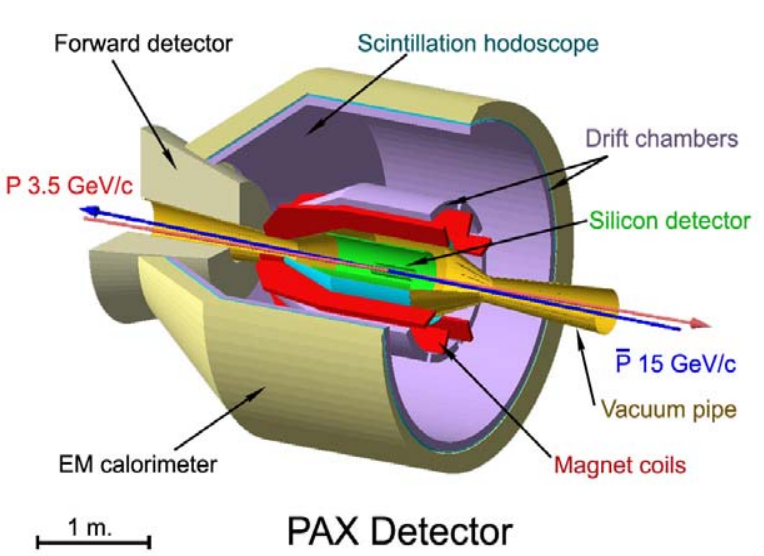


Better than 2% mass resol
* x dependence of h_1
* resonance vs continuum

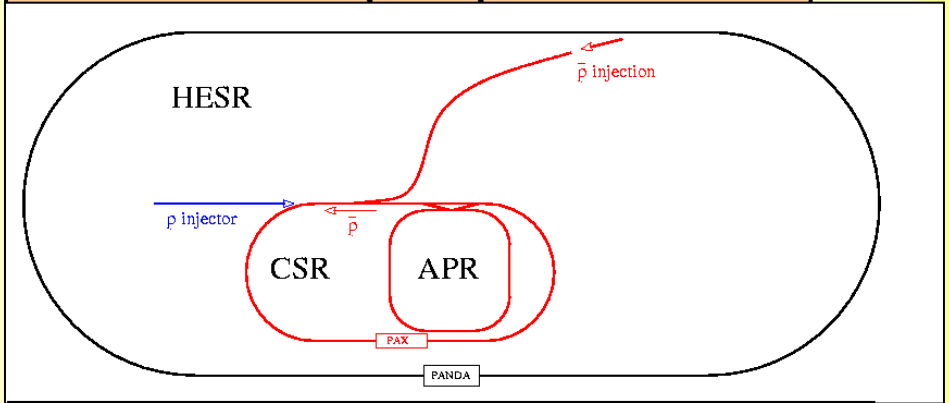
Mandatory to study M below J/ψ mass

Vertex resolution high enough to study charm background

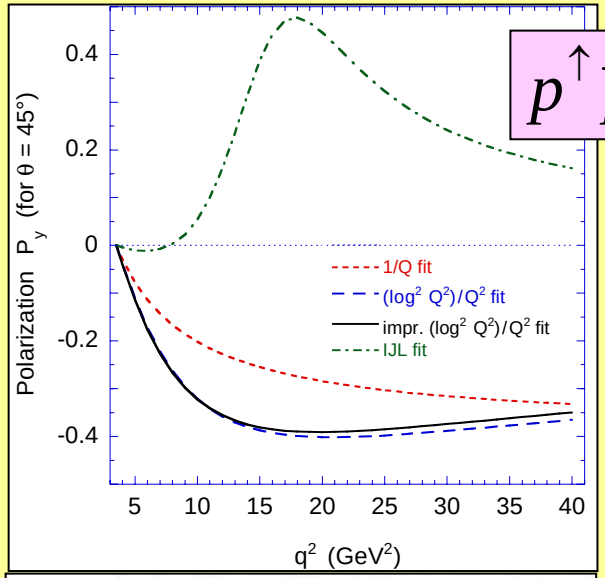
Polarized Antiproton eXperiments



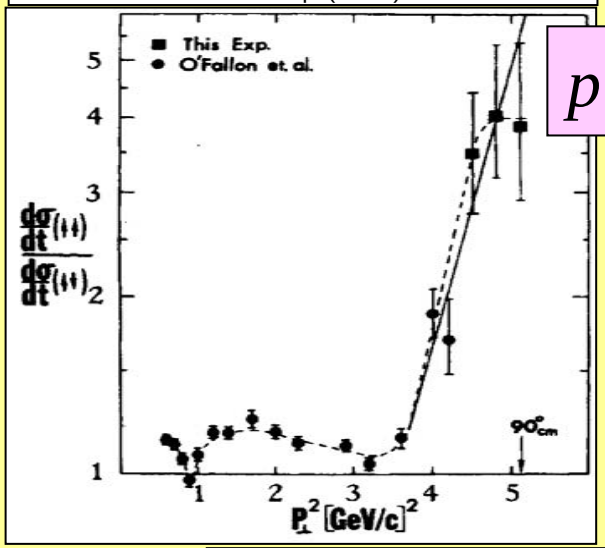
Phase I: Proton time-like FFs
Hard pbar-p elastic scatt.



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



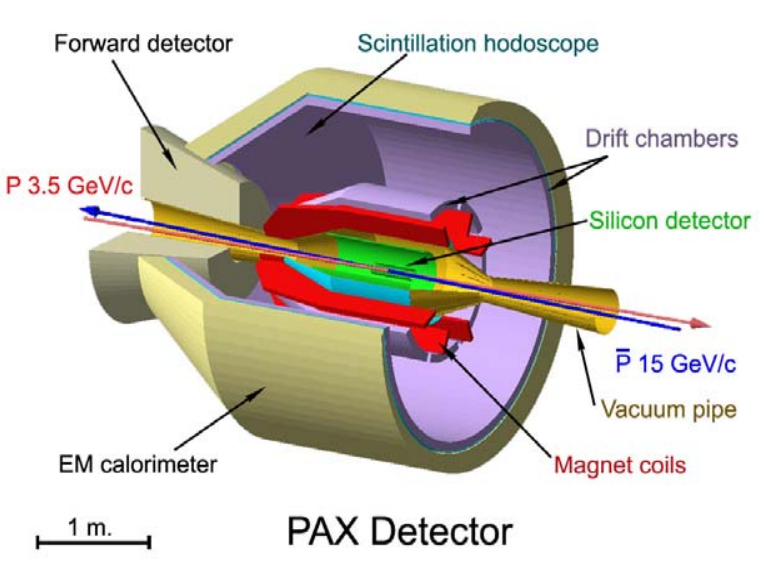
$p^{\uparrow}\bar{p}^{\uparrow} \rightarrow e^{+}e^{-}$



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

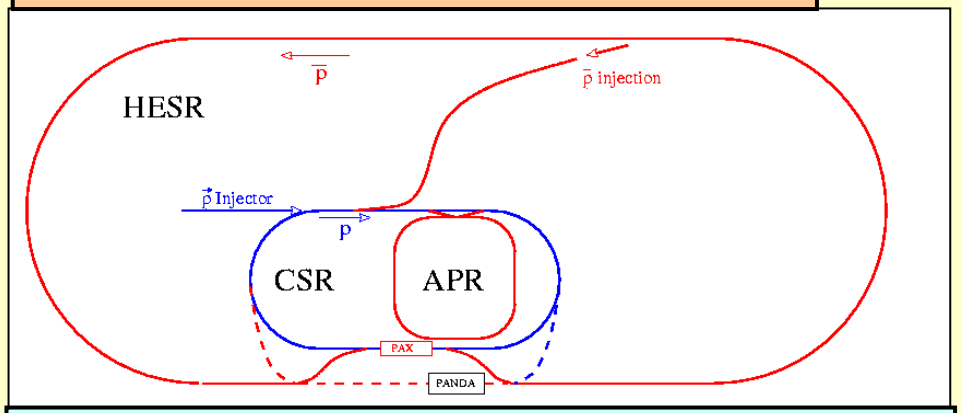
From few hours to few weeks measurements

Polarized Antiproton eXperiments

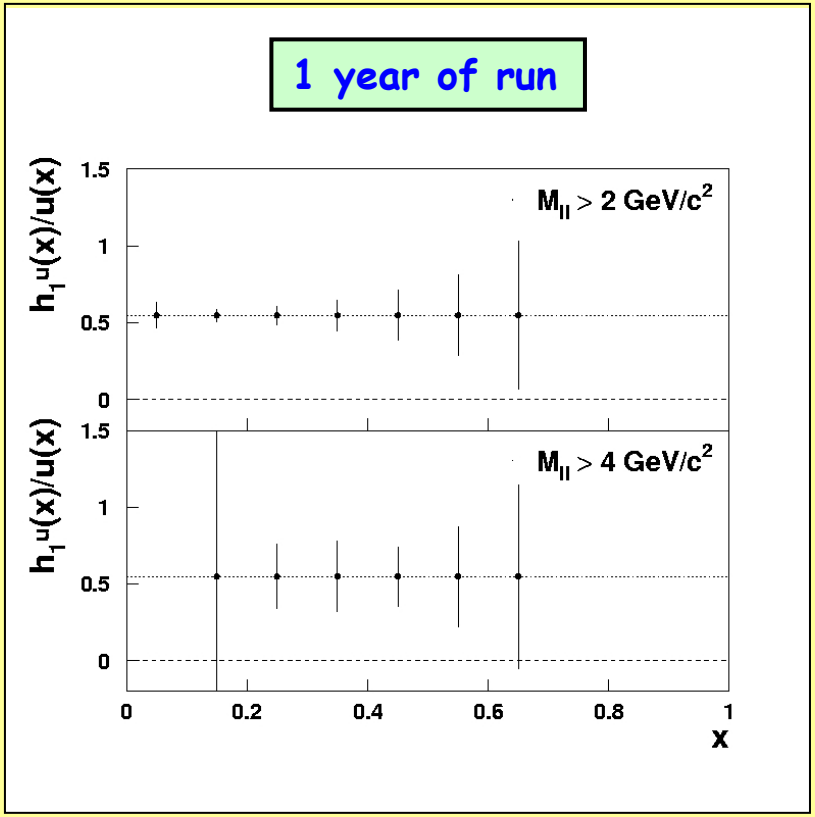


$$p^{\uparrow}\bar{p}^{\uparrow} \rightarrow e^{+}e^{-}X$$

Phase II: Transversity Distribution



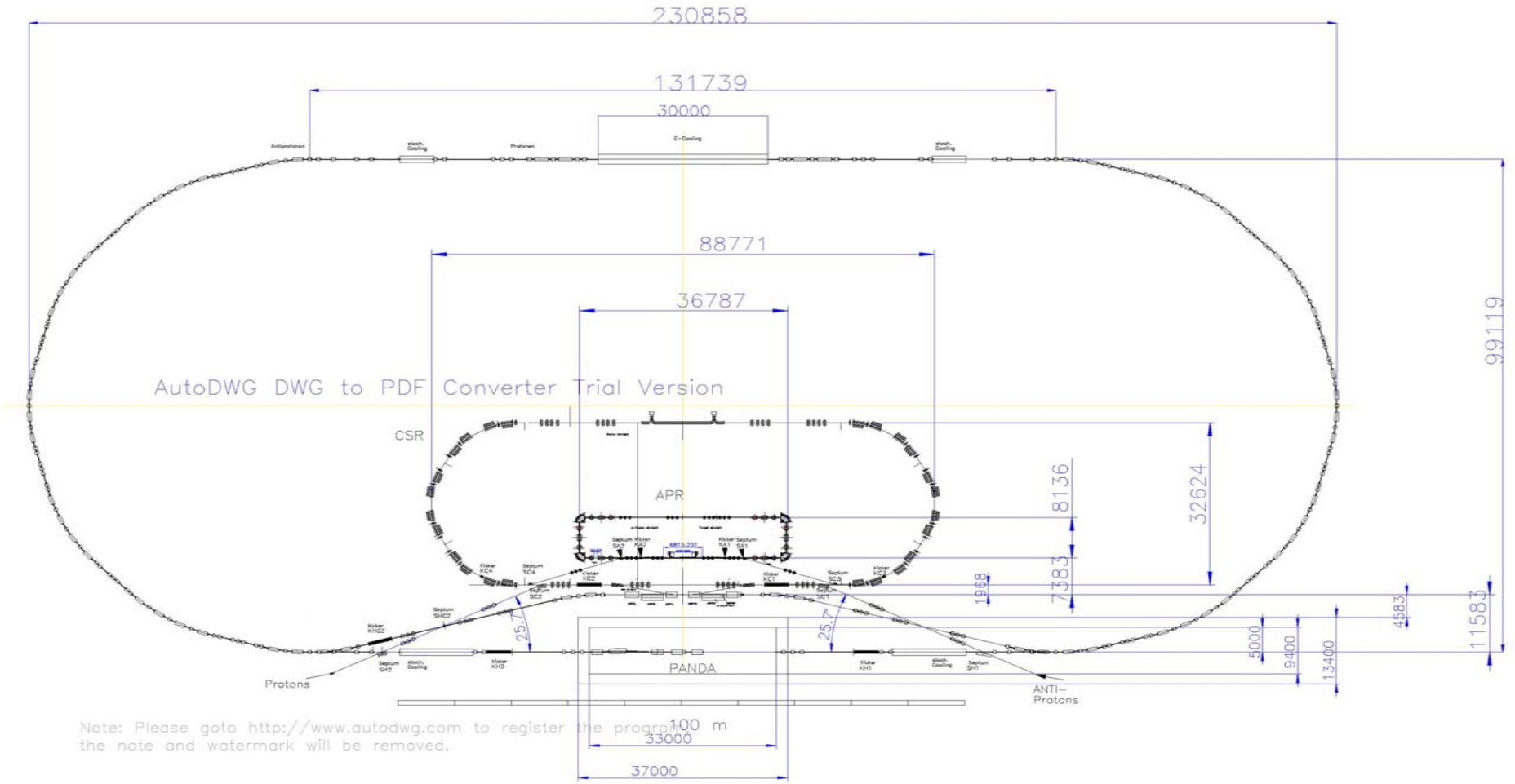
Asymmetric collider ($\sqrt{s}$=15 GeV):
polarized antiprotons in HESR (p=15 GeV/c)
polarized protons in CSR (p=3.5 GeV/c)



10 % precision on the $h_{1u}(x)$ in the valence region

RINGS SETUP

Asymmetric collider **Luminosity up to 10^{31} $cm^{-2}s^{-1}$**

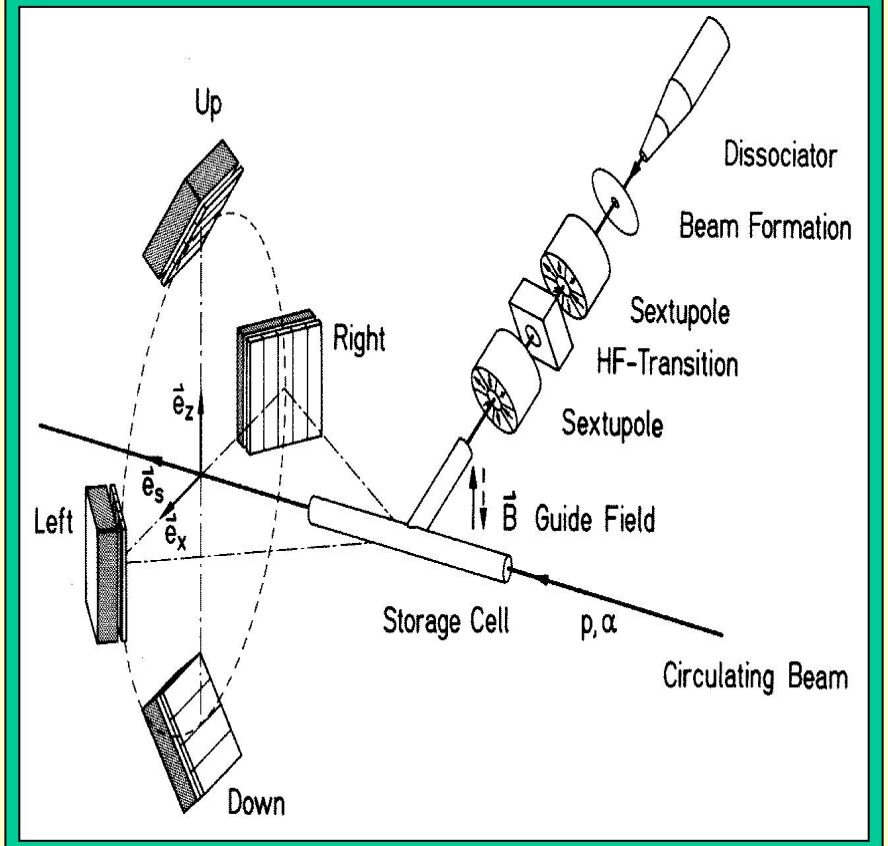


See talk by Y. Shatunov, D. Prasuhn, A. Garishvili, A. Smirnov

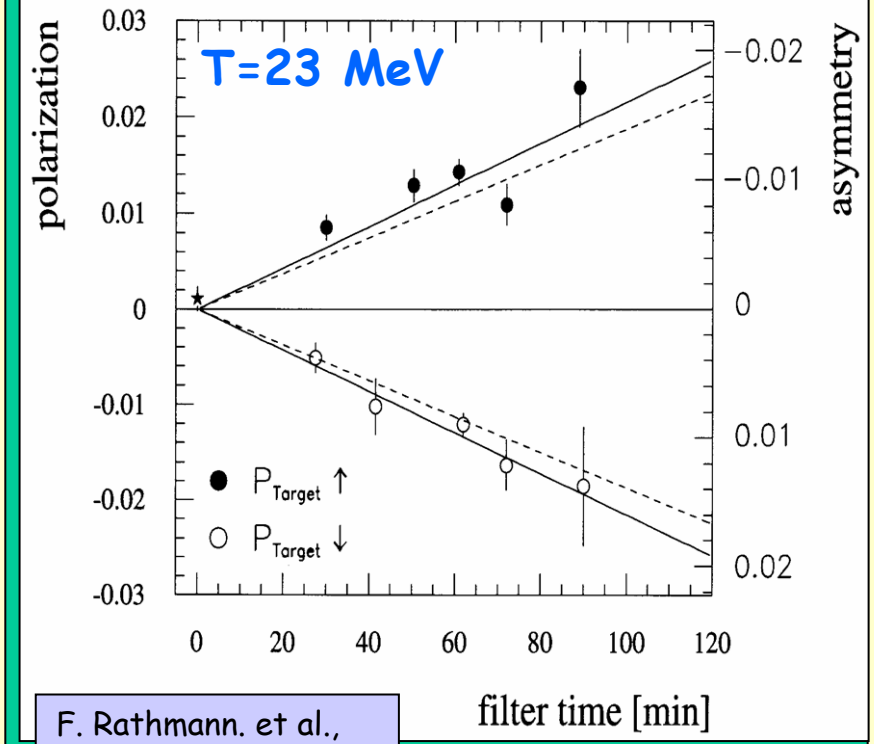
Antiproton Polarization

1992 Filter Test at TSR with protons

Experimental Setup



Results



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

Experimental Proof of Principle

Spin-filtering: Present situation

Spin filtering works, but:

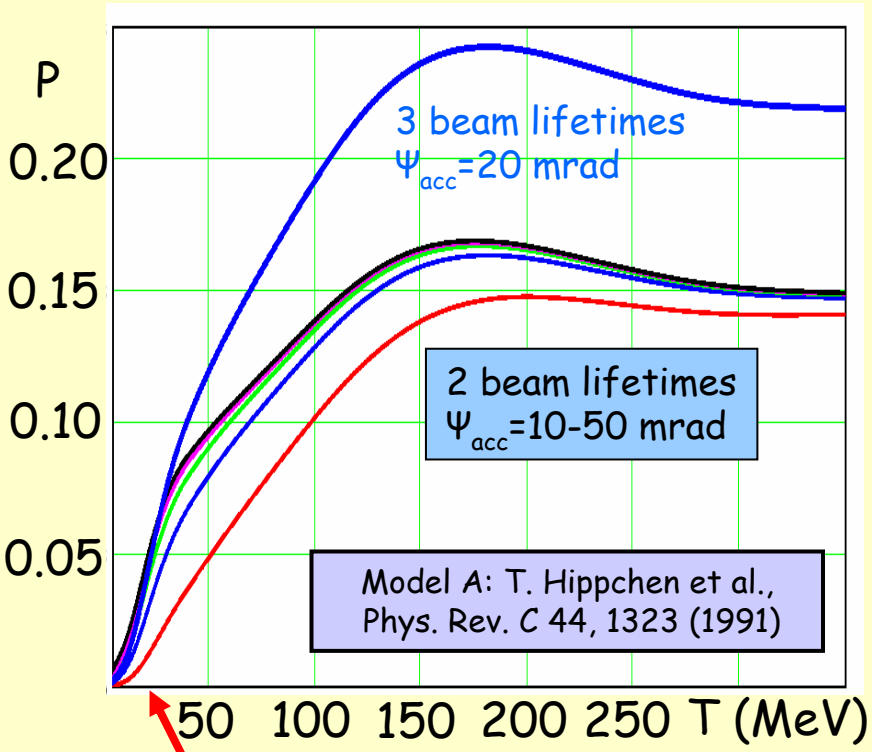
- controversial interpretations of TSR result
- no experimental basis for antiprotons

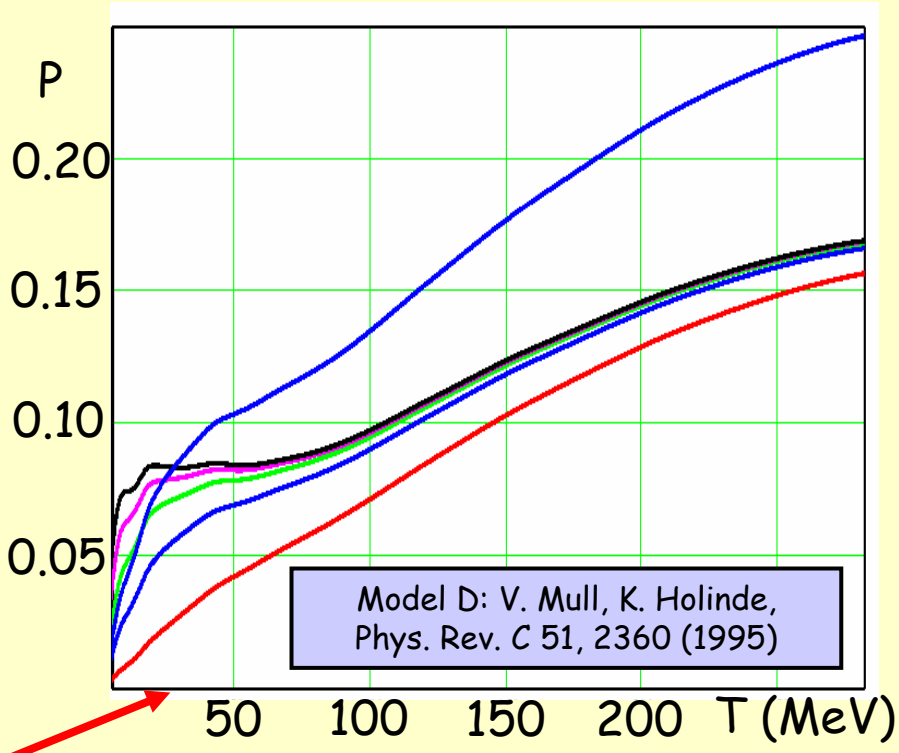
Experimental tests:
- Protons (COSY at FZJ)
- Antiprotons (AD at CERN)

See talk by
P. Lenisa, F. Rathmann

Hadronic Interaction in p-pbar: Longitudinal Case

Beam Polarization





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

Summary

- PAX project has an innovative spin physics program
  - * transversity
  - * SSA
  - * EMFF
  - * hard p-pbar scatterings
  - * polarized charmonium production

- A method to obtain an antiproton beam with high degree of polarization has to be optimized (APR)

- PAX viable accelerator setup at FAIR provides fexible 2nd IP really matched to the physics items
  - * lots of interesting QCD physics in PAX Phase-I
  - * asymmetric collider ideal to map transversity (Phase-II)

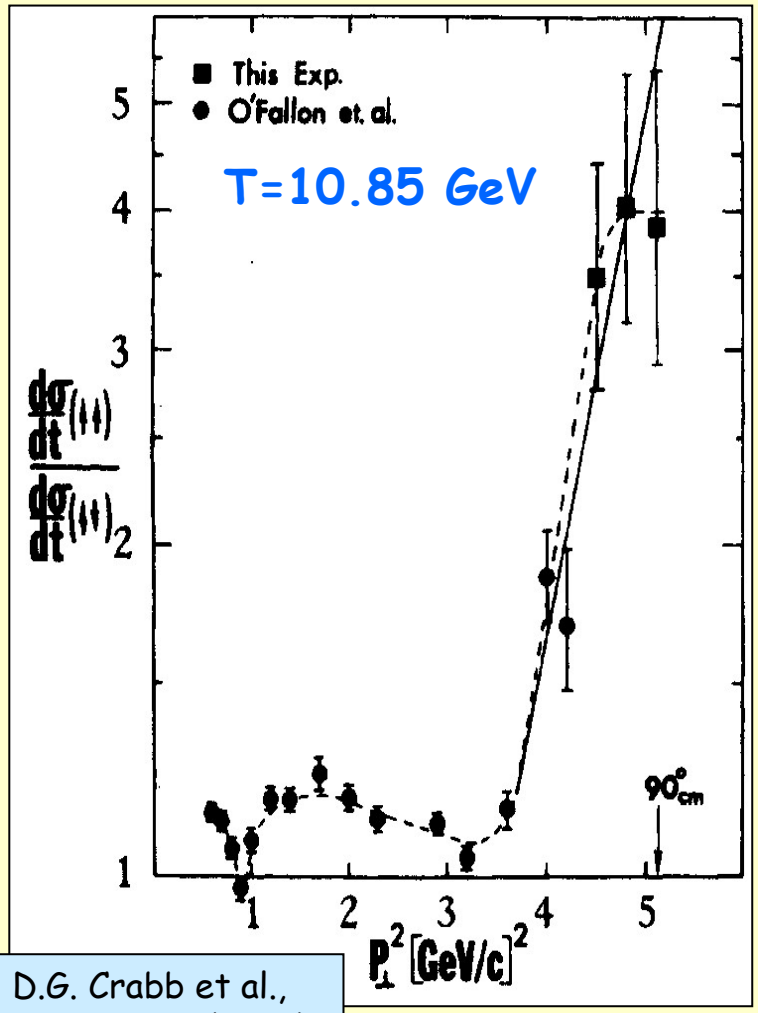
Timeline

Fall 2006	Technical Proposal for COSY-ANKE
2007	Propedeutical studies at COSY-ANKE Technical Proposal for COSY-New IP Technical Proposal for AD
2006-08	Design and construction phase COSY
2008	Spin-filtering studies at COSY Commissioning of AD experiment
2009	Installation at AD
2009-2010	Spin-filtering studies at AD

pp Elastic Scattering from ZGS

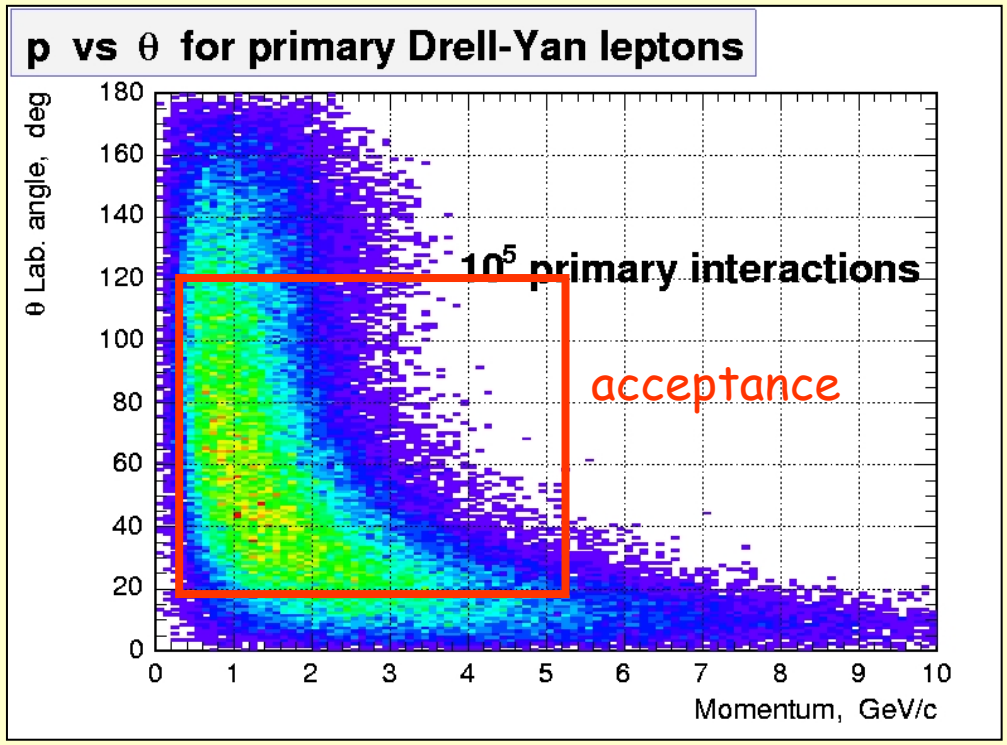
Spin-dependence at large-$P_\perp$ ($90°_{cm}$):
Hard scattering takes place only with spins ↑↑.

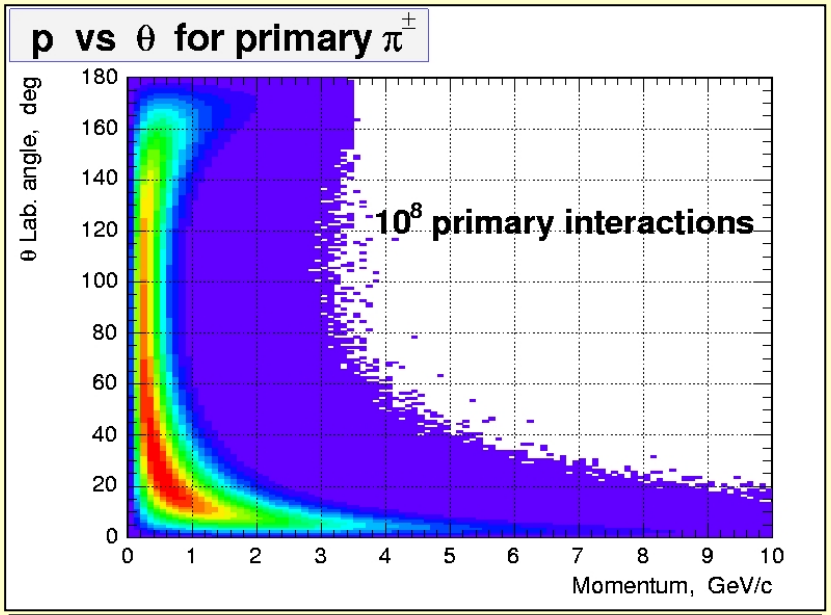
Similar studies in $\bar{p}p$ elastic scattering

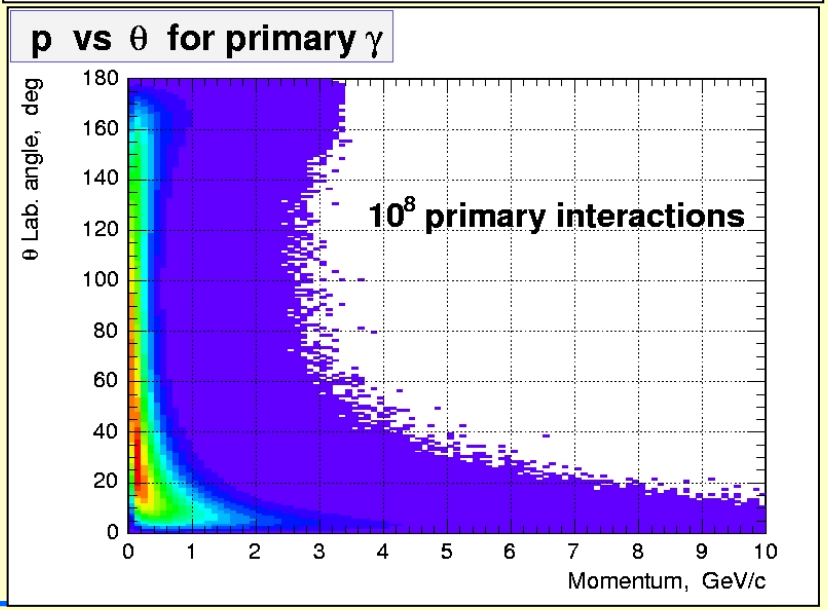


D.G. Crabb et al.,
PRL 41, 1257 (1978)

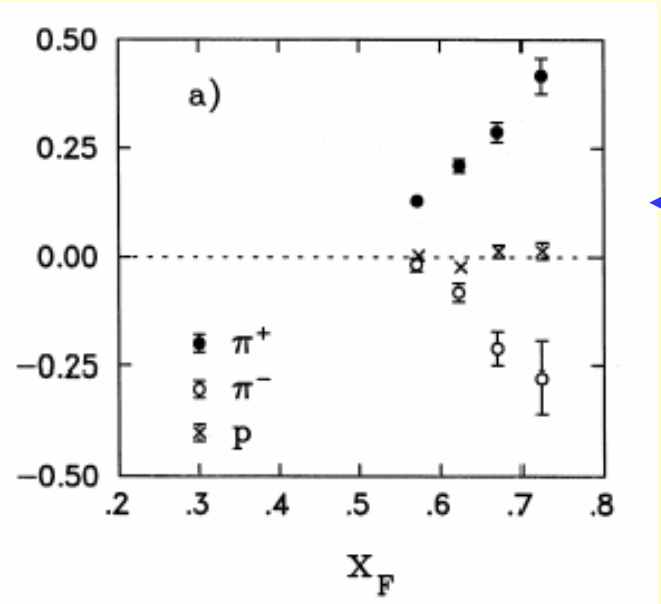
θ-p Phase Space





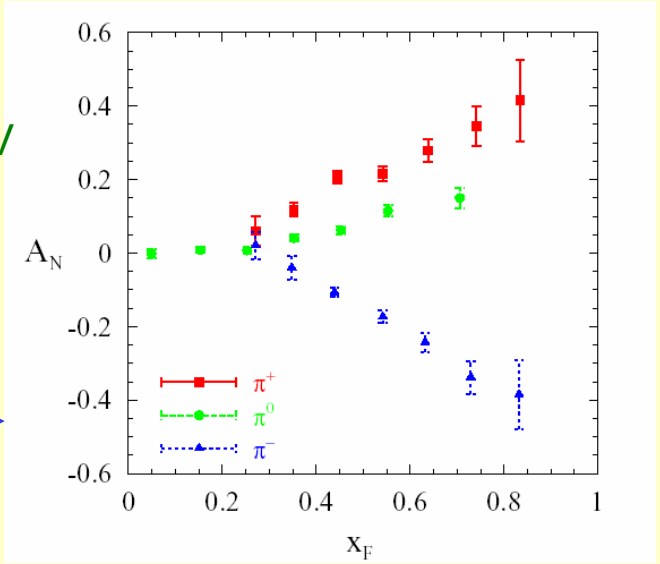


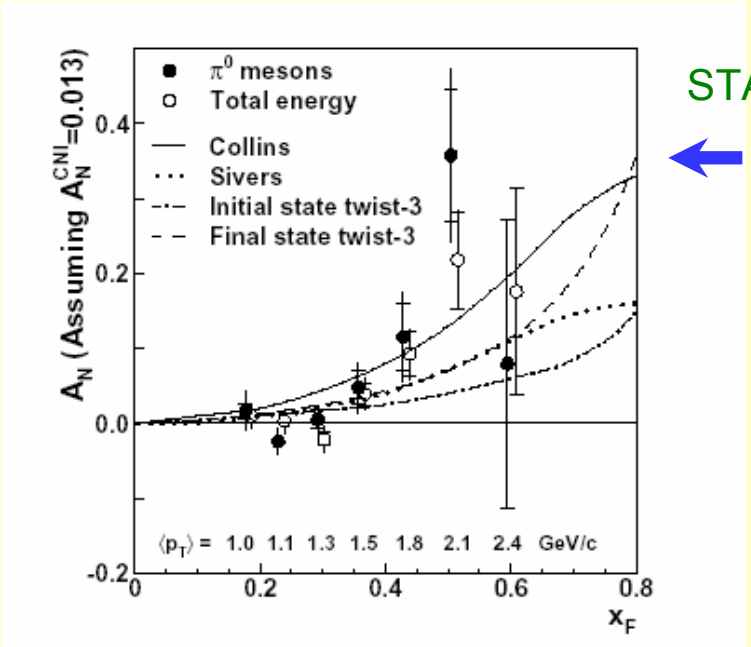
Background peaks at
* low energy
* forward direction



BNL-AGS $\sqrt{s}$ = 6.6 GeV
$0.6 < p_T < 1.2$ $p^{\uparrow}p$

E704 $\sqrt{s}$ = 20 GeV
$0.7 < p_T < 2.0$ $p^{\uparrow}p$

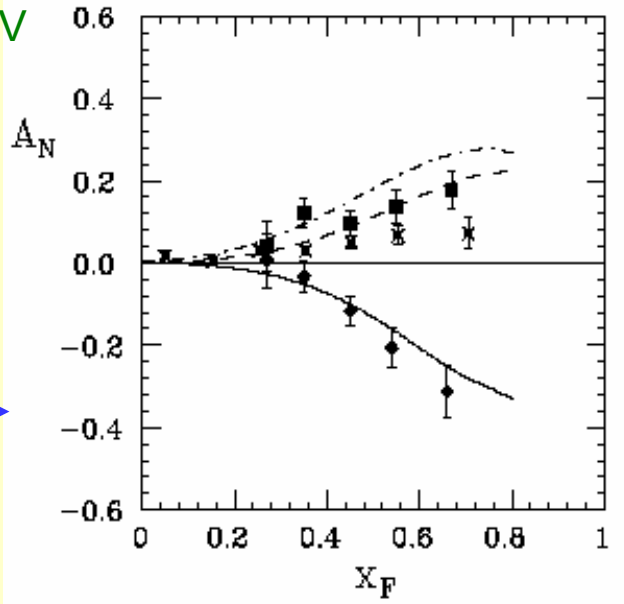




STAR-RHIC $\sqrt{s}$ = 200 GeV
$1.1 < p_T < 2.5$ $p^{\uparrow}p$

E704 $\sqrt{s}$ = 20 GeV
$0.7 < p_T < 2.0$ $\bar{p}^{\uparrow}p$

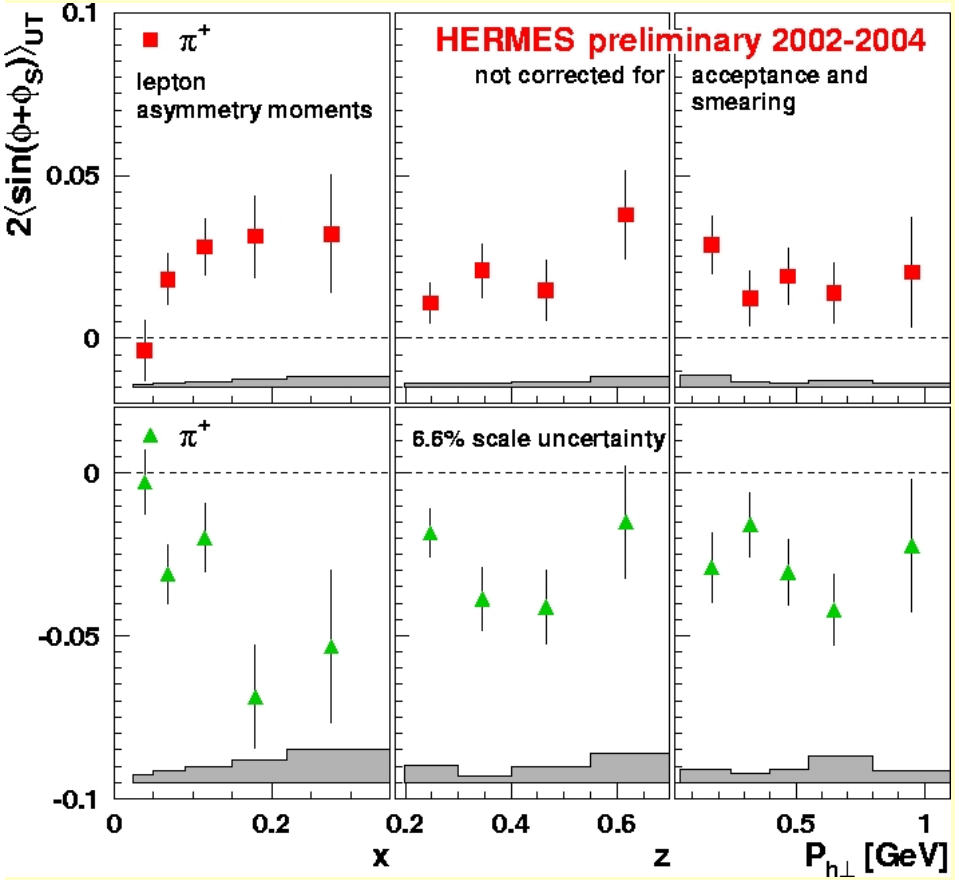
SSA, $pp \rightarrow \pi X$

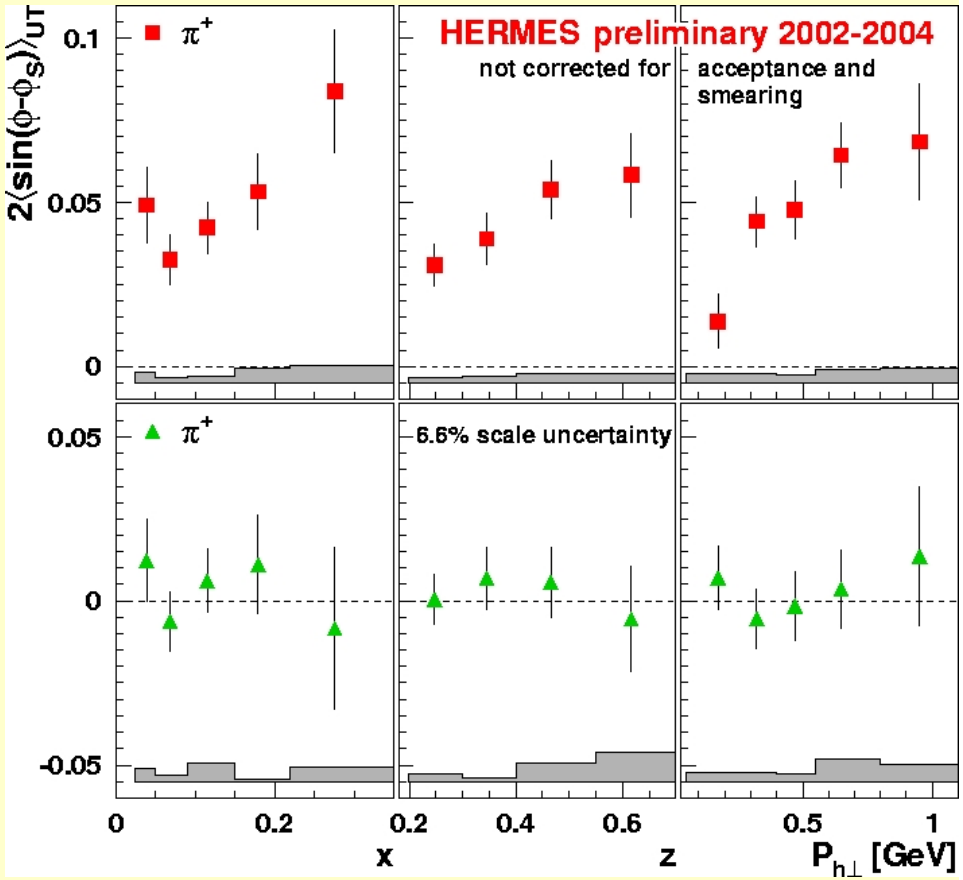


Collins

HERMES

Sivers





See talk by
L. Pappalardo

SSA, SIDIS