Perspectives for Drell-Yan at FAIR

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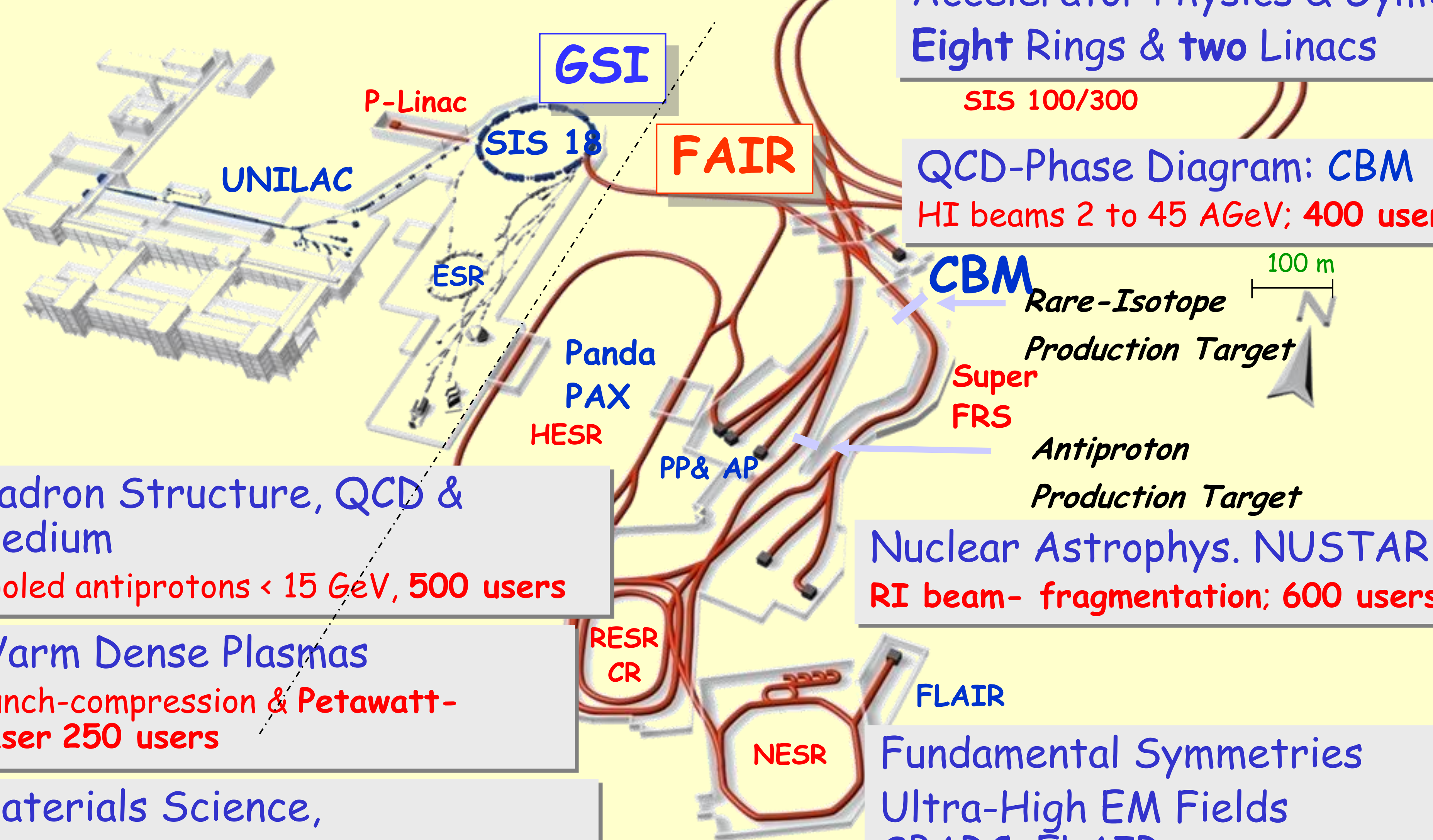
Studying the hadron structure in DY-reactions
CERN – 27.04.10

FAIR - Research highlights



Accelerator Physics & Gym
Eight Rings & two Linacs

QCD-Phase Diagram: CBM
HI beams 2 to 45 AGeV; **400 user**

Hadron Structure, QCD & Medium
Cooled antiprotons < 15 GeV, **500 users**

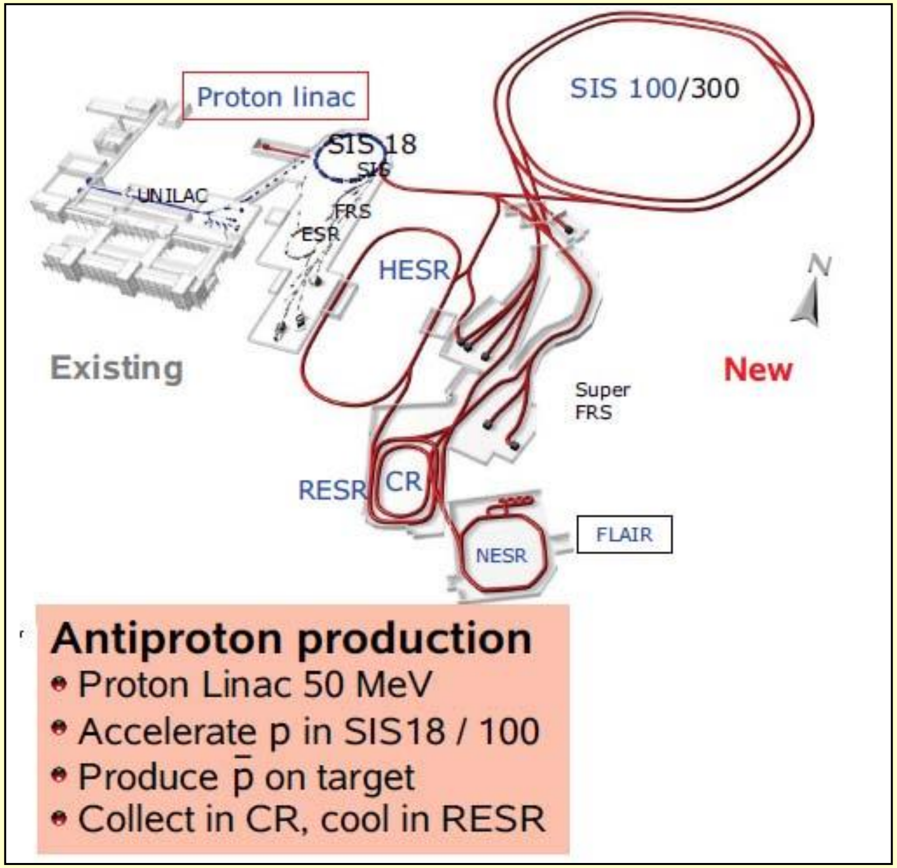
Warm Dense Plasmas
Bunch-compression & **Petawatt-Laser 250 users**

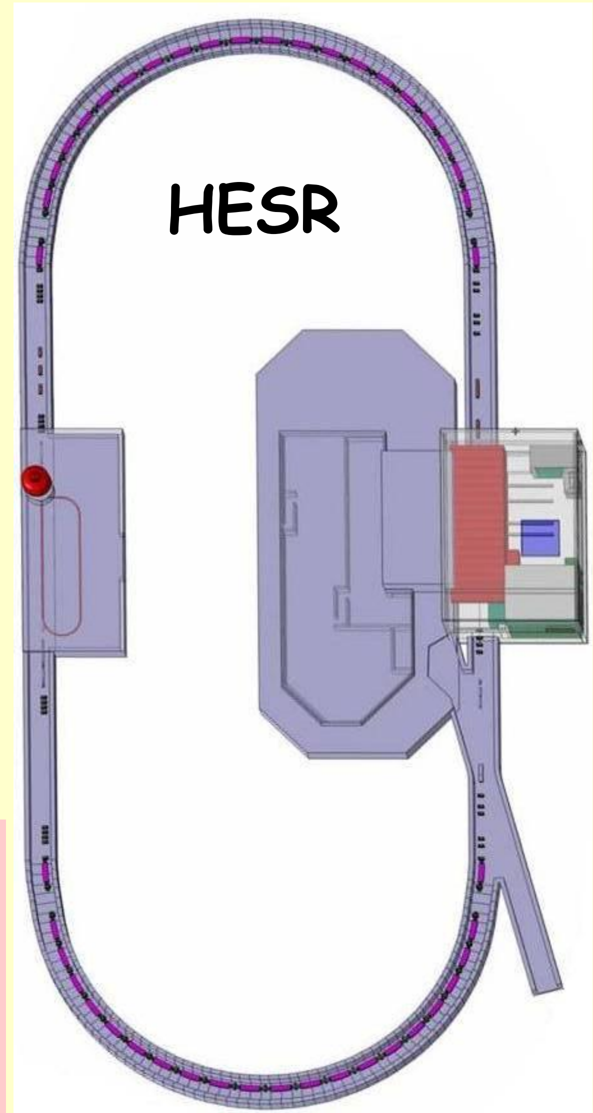
Materials Science, Space- and Radiation Biology
(Ion- & antiproton- beams; **350 users**

Nuclear Astrophys. NUSTAR
RI beam- fragmentation; 600 users

Fundamental Symmetries
Ultra-High EM Fields
SPARC; FLAIR
Antiprotons, Hi-Z ions; 250 users

Antiprotons at FAIR





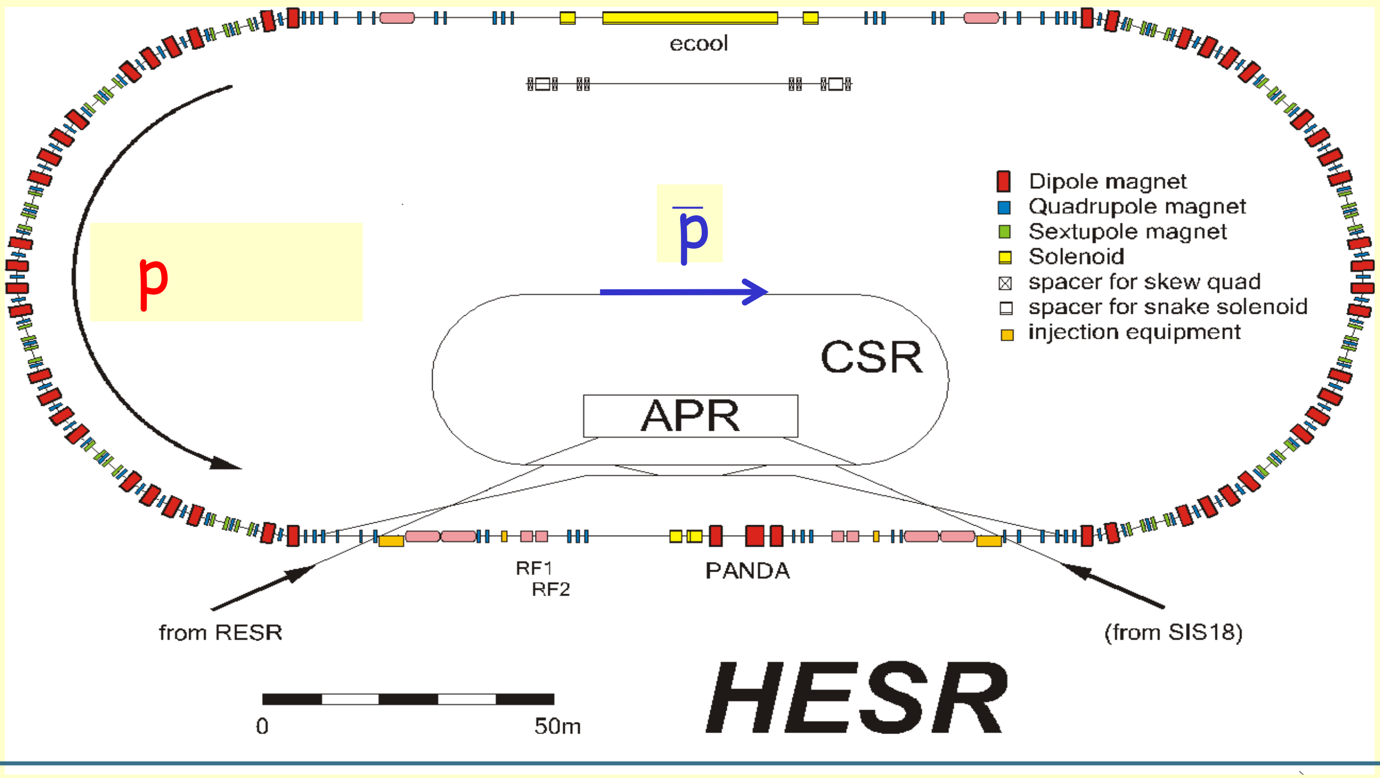
- Antiprotons with $1.5\ GeV/c \leq p \leq 15\ GeV/c$
- High luminosity: $2 \cdot 10^{32}\ cm^{-2}s^{-1}$
  - Thick targets: $4 \cdot 10^{15}\ cm^{-2}$
  - Long beam life time: >30 min
- High momentum resolution: $\Delta p/p \leq 4 \cdot 10^{-5}$
  - Phase space cooling

Polarized Antiproton EXperiments

Hadron Physics „Dream Machine"

Asymmetric (double-polarized)

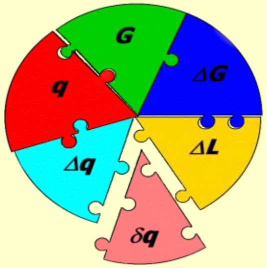
proton (15 GeV/c) – antiproton (3.5 GeV/c) collider

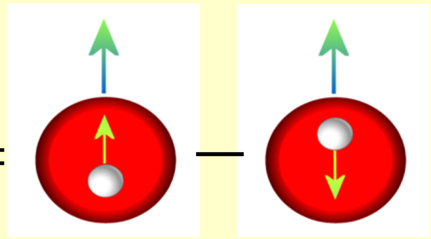


Outline

- DY with polarized antiprotons @ asymmetric collider
- Perspectives for single-single spin asymm. @ fixed target
- Status of polarized antiprotons studies

Transversity



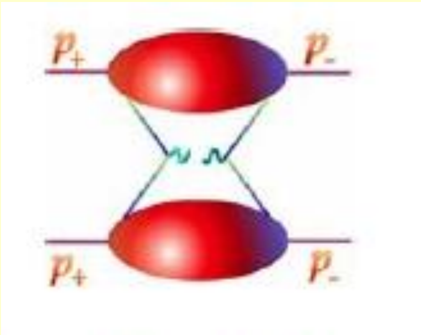
$h_1^q =$ 

transversely polarised quarks and nucleons

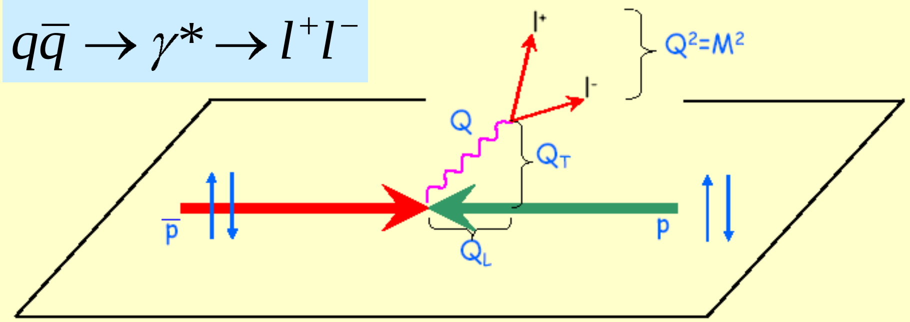
- Probes relativistic nature of quarks
- No gluon analog for spin-1/2 nucleon
- Different Q^2 evolution than Δq
- Sensitive to valence quark polarization

h_1 is chirally odd -> it needs a chirally odd partner

The "golden-gate" to transversity: h_1 from $\bar{p}\uparrow$-p $\uparrow$ Drell-Yan



Drell-Yan



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

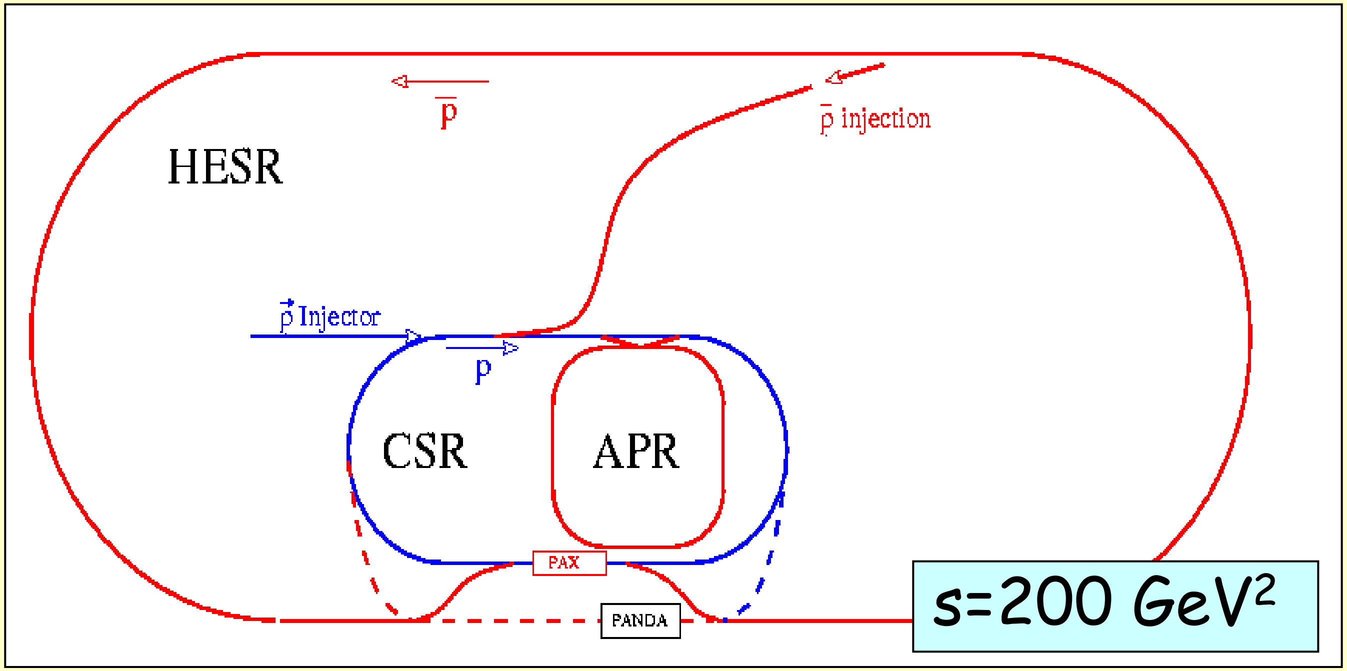
$q = u, \bar{u}, d, \bar{d}, ...$

M invariant Mass of lepton pair

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

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

PAX proposal: Phase II



EXPERIMENT:

Asymmetric collider:

- **polarized protons in HESR (p=15 GeV/c)**
- **polarized antiprotons in CSR (p=3.5 GeV/c)**

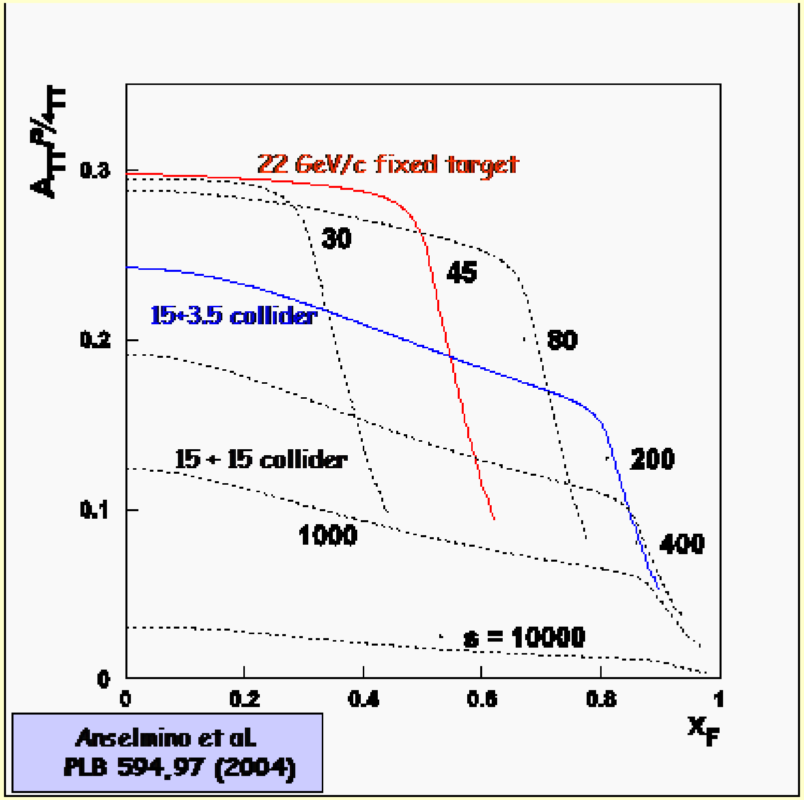
Luminosity: 1.5×10^{31} cm^{-2}s^{-1}

h_{1u} from $\bar{p}\uparrow$-$p\uparrow$ Drell-Yan at PAX

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

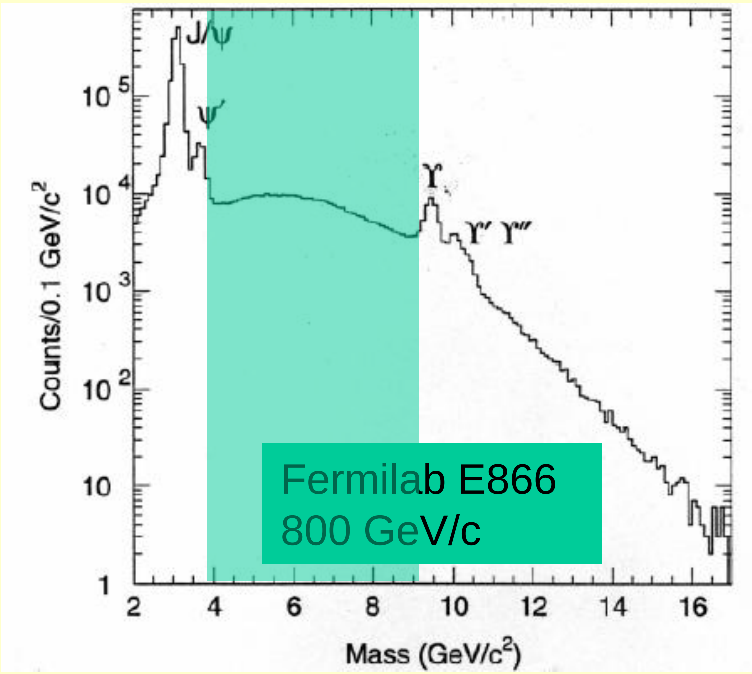
- u-dominance
- $|h_{1u}| > |h_{1d}|$

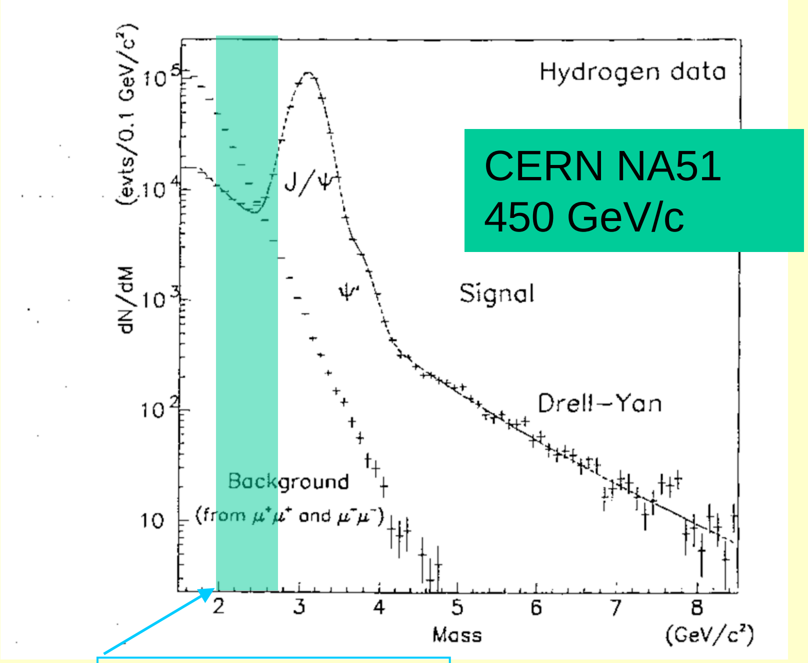
$$A_{TT} \approx \hat{a}_{TT} \frac{h_{1u}(x_1) h_{1u}(x_2)}{u(x_1) u(x_2)}$$



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

Events for Drell-Yan processes





$Q^2 > 4\ GeV^2$

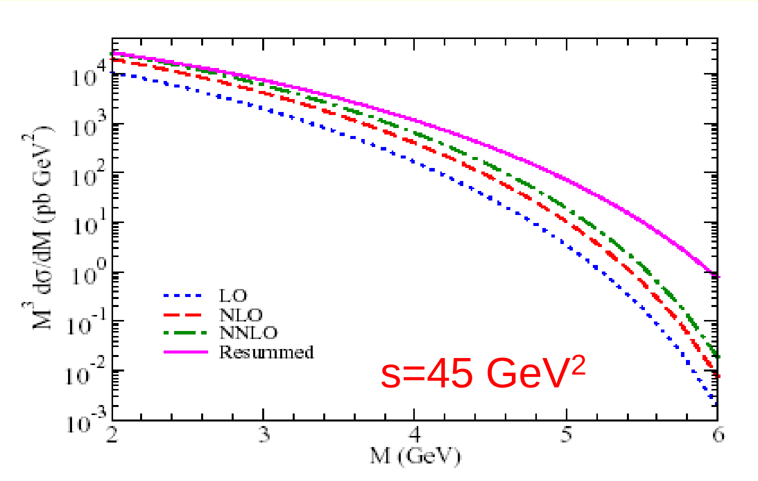
$$M \geq M_{J/\Psi}$$

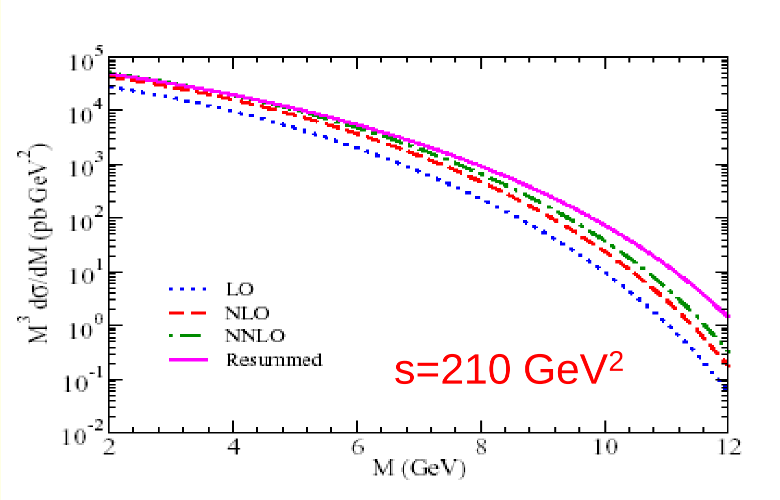
Usually taken as "safe region"

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

Radiative corrections

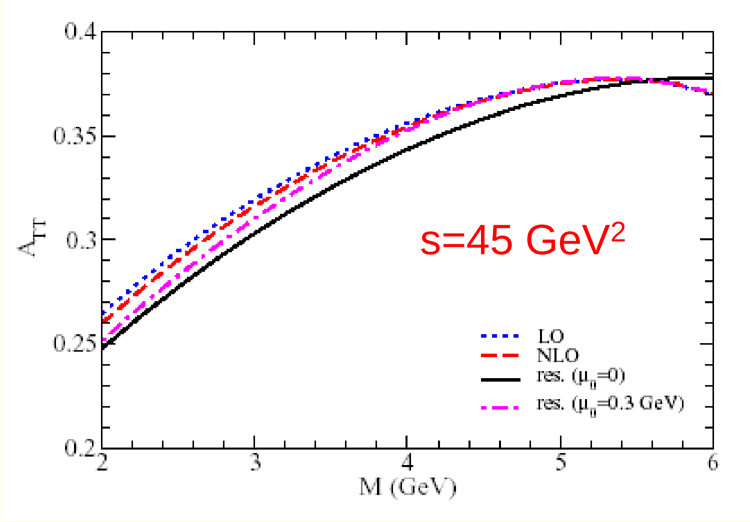
Cross-section

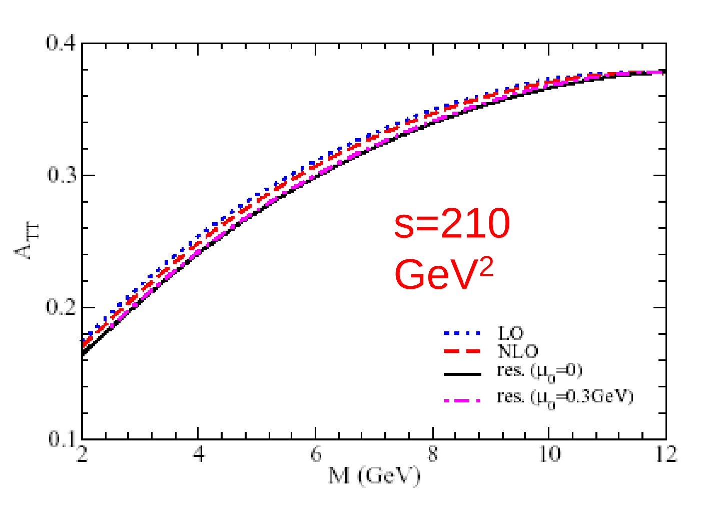




Shimizu et al. PRD71 (2005) 114007

Asymmetry





PAX Detector Concept

Physics: h_1 distribution $\sin^2\theta$
EMFF $\sin 2\theta$
pbar-p elastic high $|t|$

→ Azimuthally Symmetric:
BARREL GEOMETRY
LARGE ANGLES

Experiment: Flexible Facility

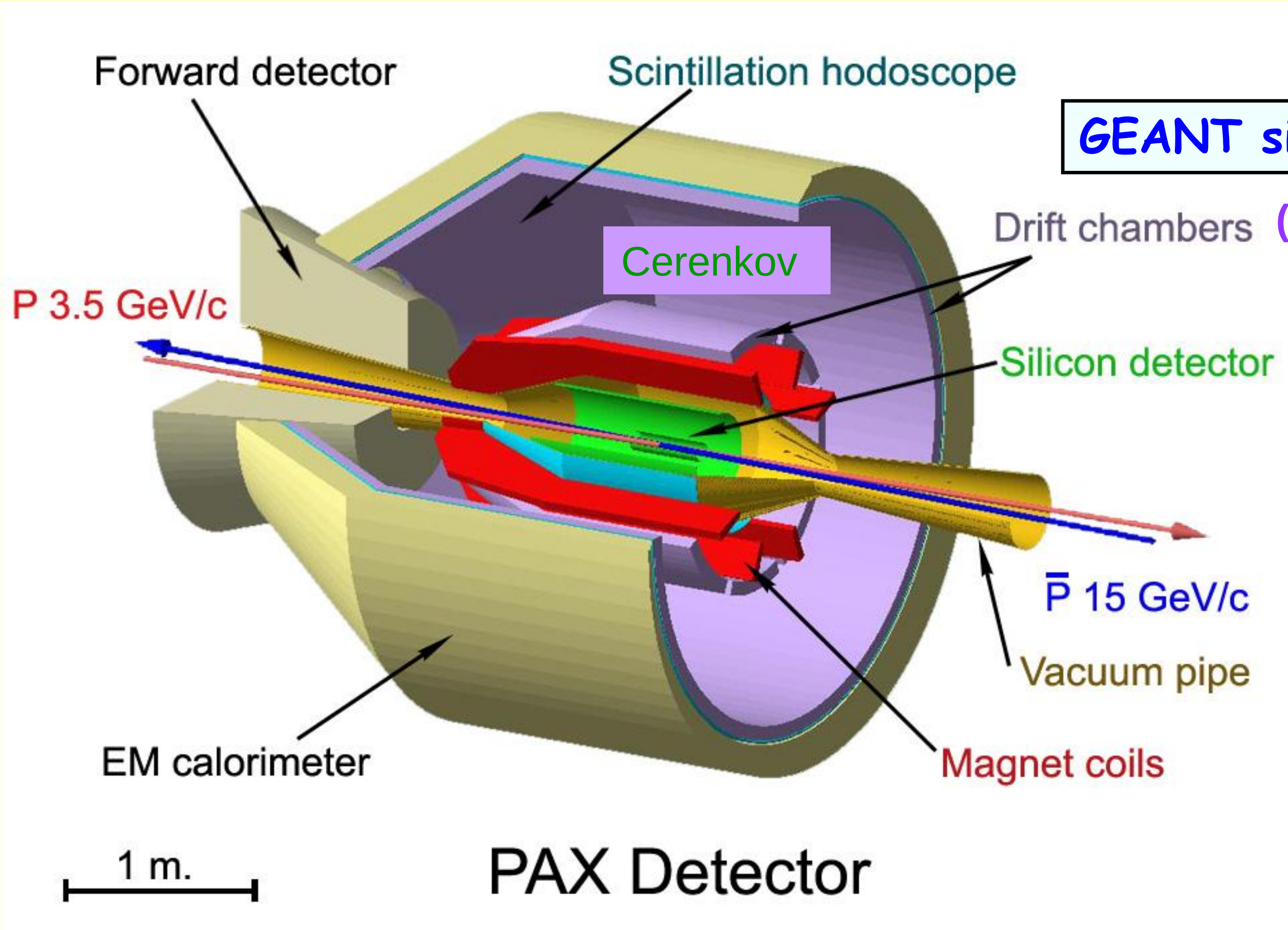
→ e^+e^-

Detector: Extremely rare DY signal (10^{-7} p-pbar)
Maximum Bjorken-x coverage (M interval)
Excellent PID (hadron/e rejection ~ 10^4)
High mass resolution (≤2 %)
Moderate lepton energies (0.5-5 GeV)

Magnet: Keeps beam polarization vertical
Compatible with Cerenkov
Compatible with pol. target

→ TOROID
NO FRINGE FIELD

PAX Detector Concept



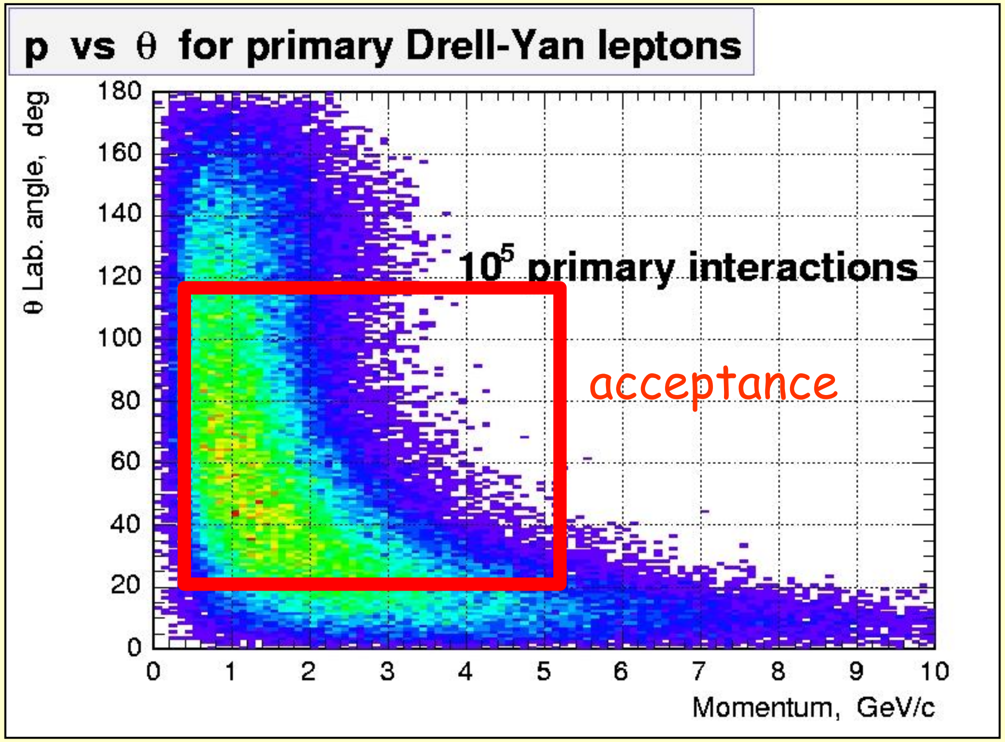
GEANT simulation

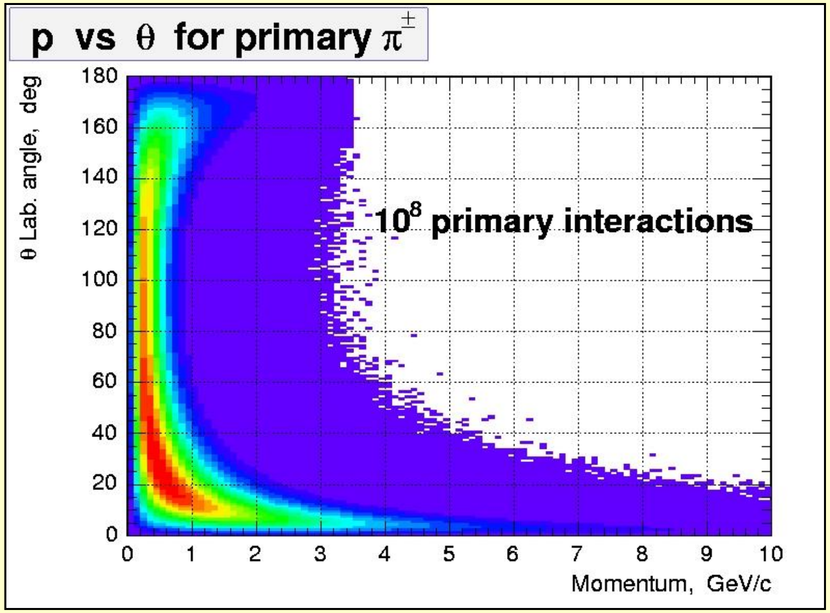
(200 μm)

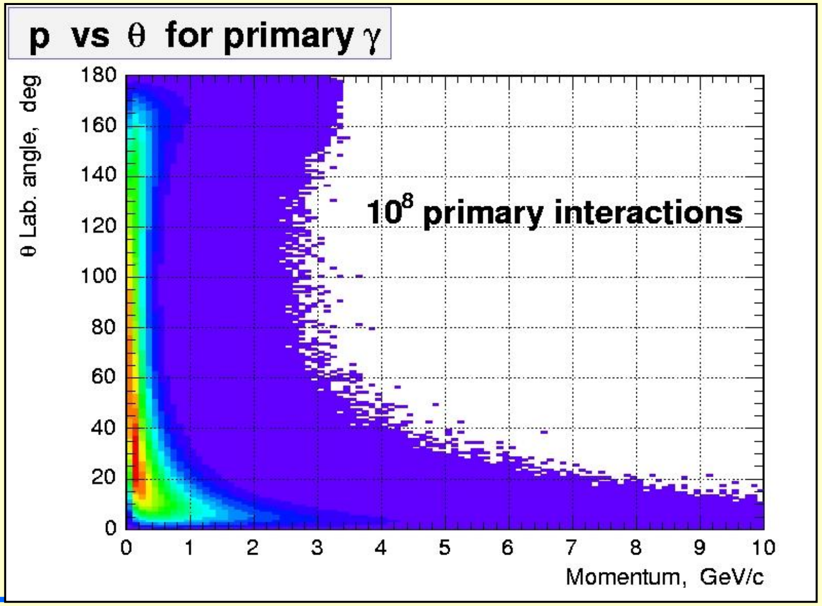
(20 μm)

Designed for Collider but compatible with fixed target

θ-p Phase Space



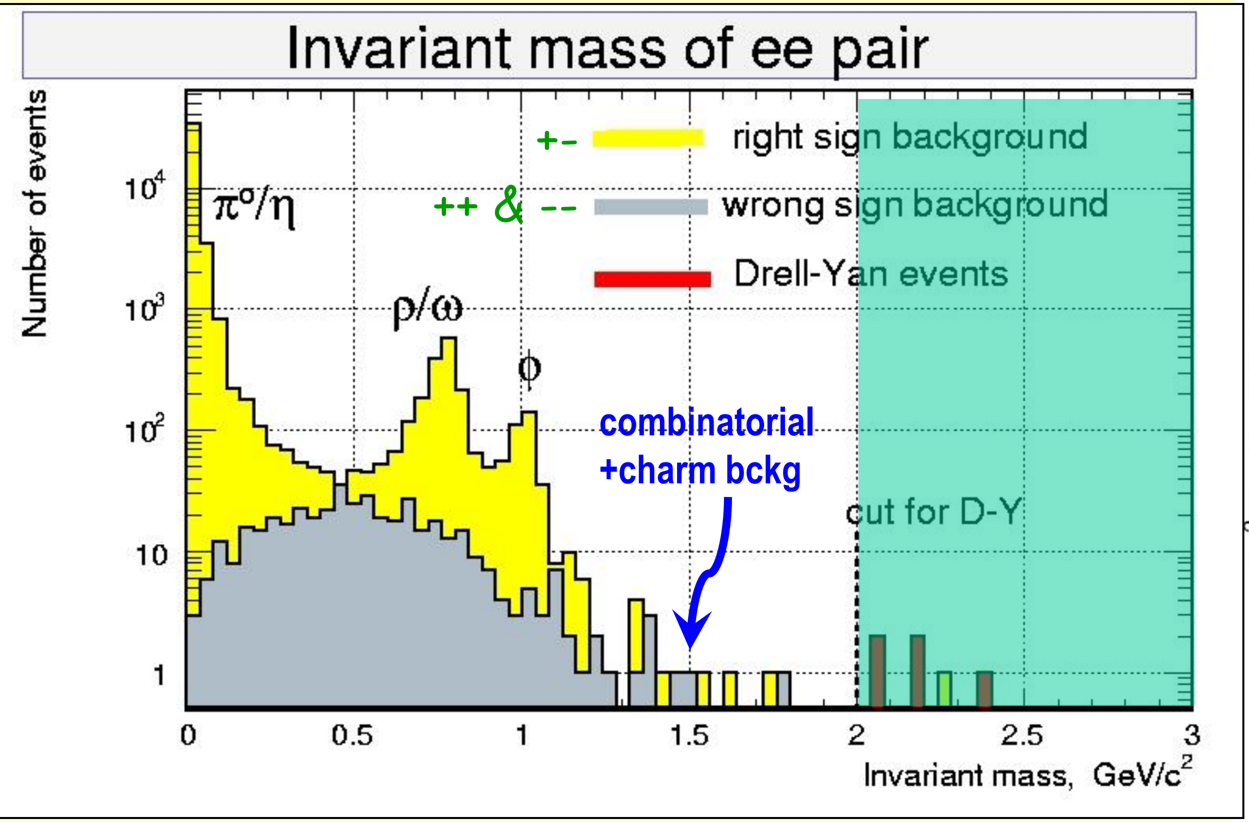


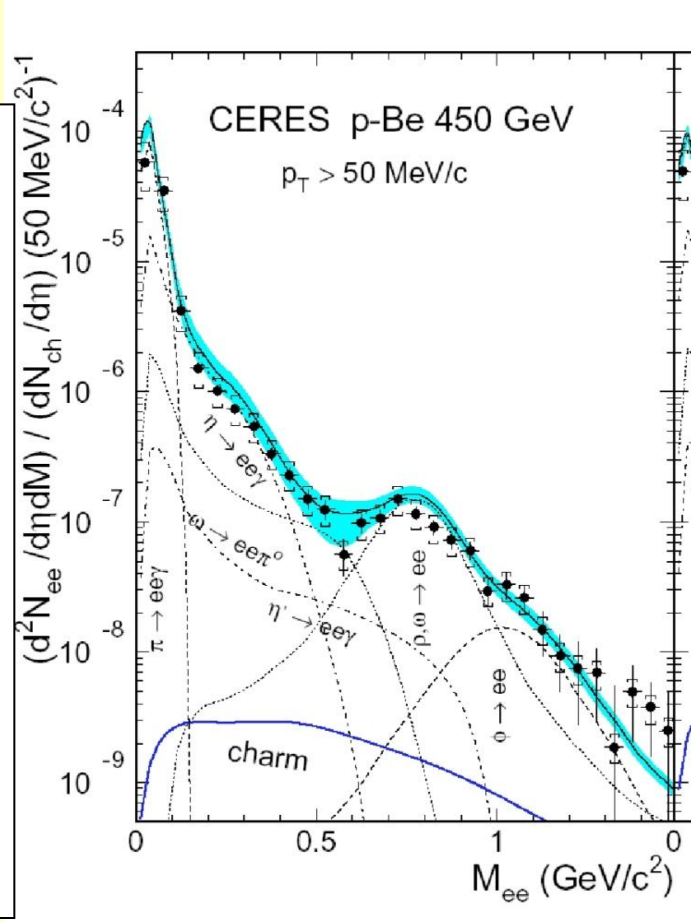


Background peaks at
- low energy
- forward direction

Background to Drell-Yan e^+e^-

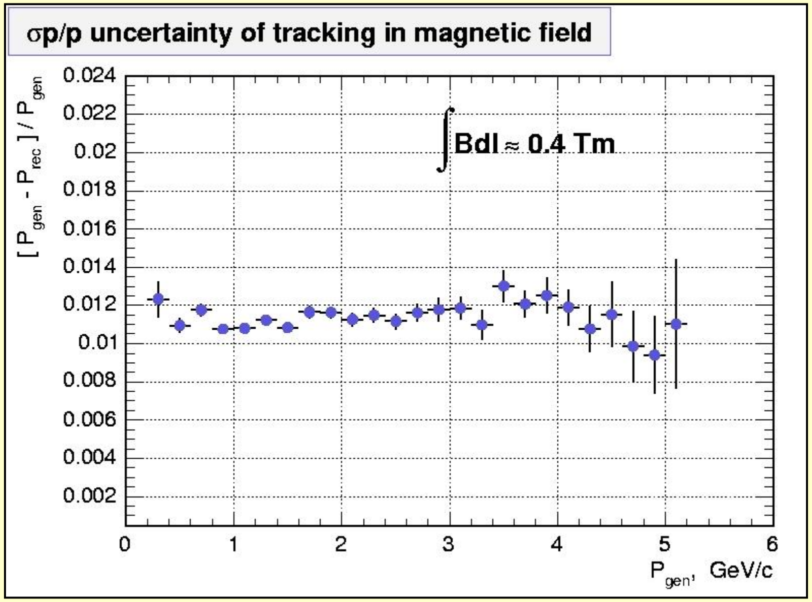
10 min. experiment: $2 \cdot 10^8$ p-pbar interactions
several DY events

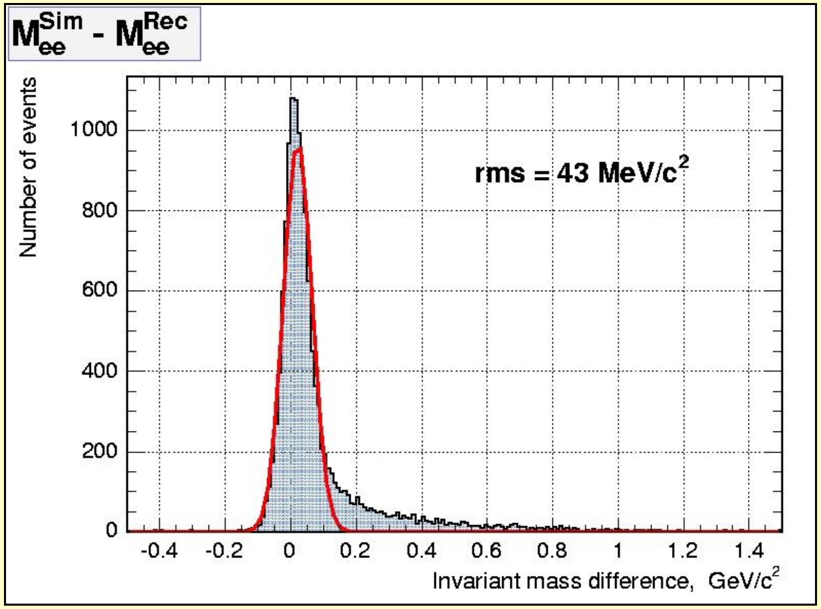


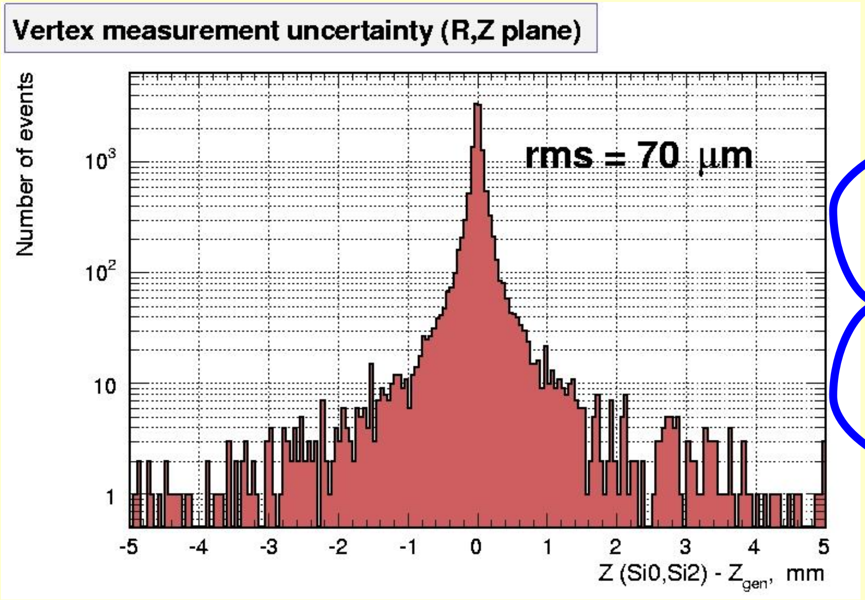


Background 1:1 to signal after PID, E>300 MeV, conversion veto, mass cut
* the combinatorial component can be subtracted (wrong-sign control sample)
* the charm can be reduced (vertex decay)

Resolution







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

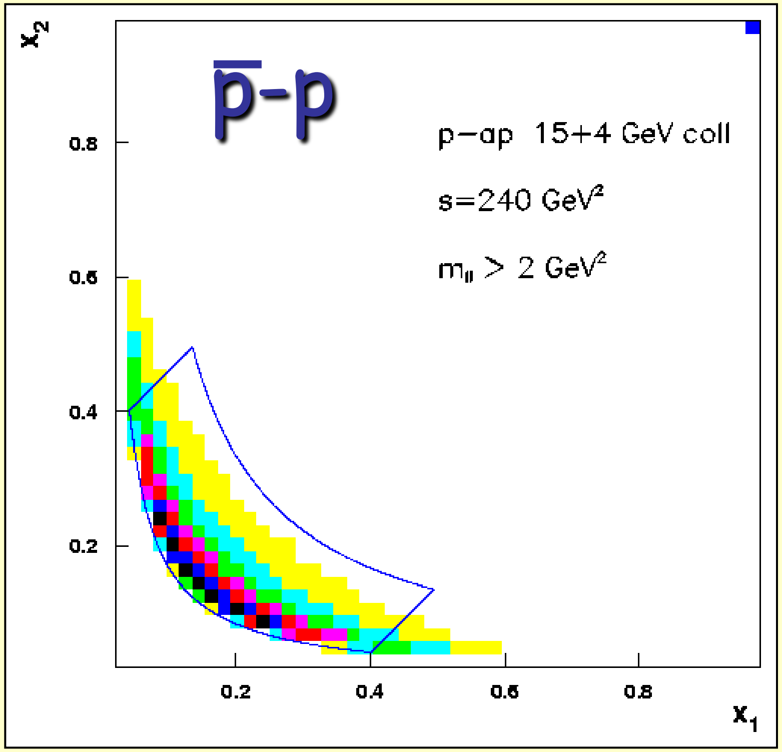
Mandatory to study M below J/ψ mass

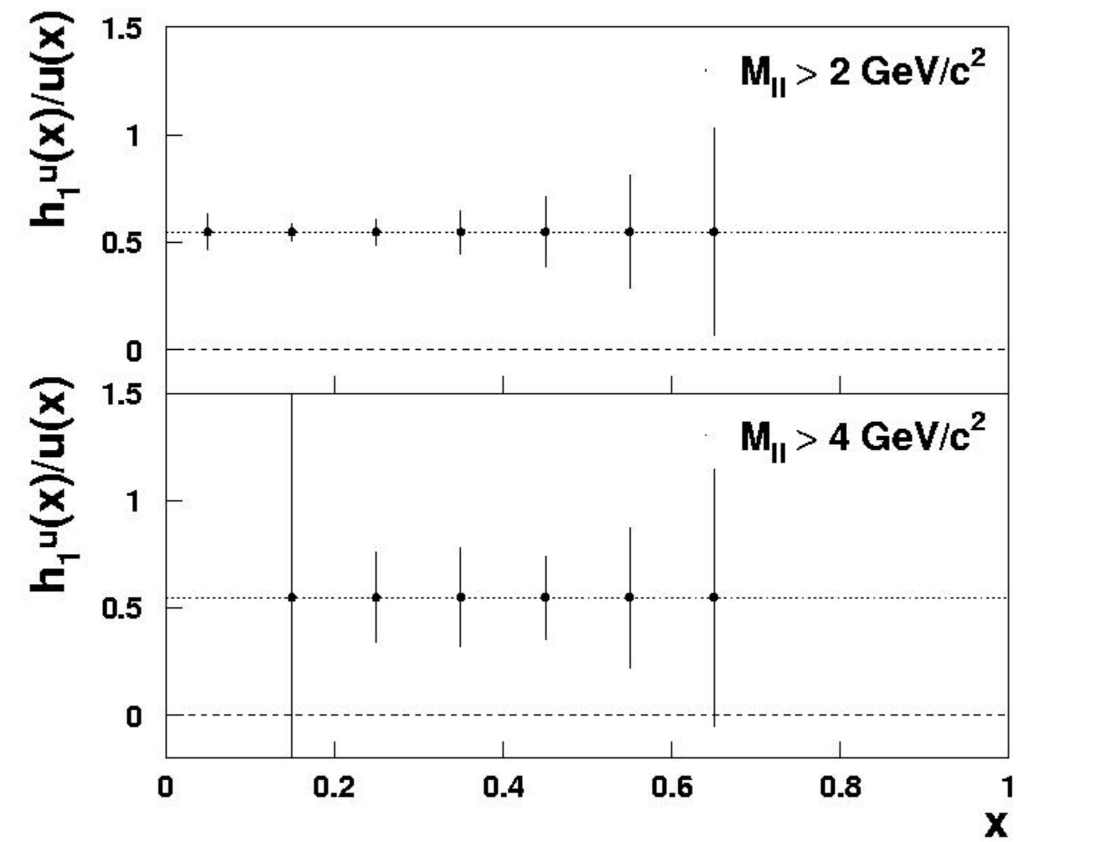
Vertex resolution high enough to study charm background

Precision in h_1 measurement

1 year of data taking at 15+3.5 GeV collider

$L = 1.5 \cdot 10^{31}\ cm^{-2}s^{-1}$
p↑=0.8
pbar↑=0.15





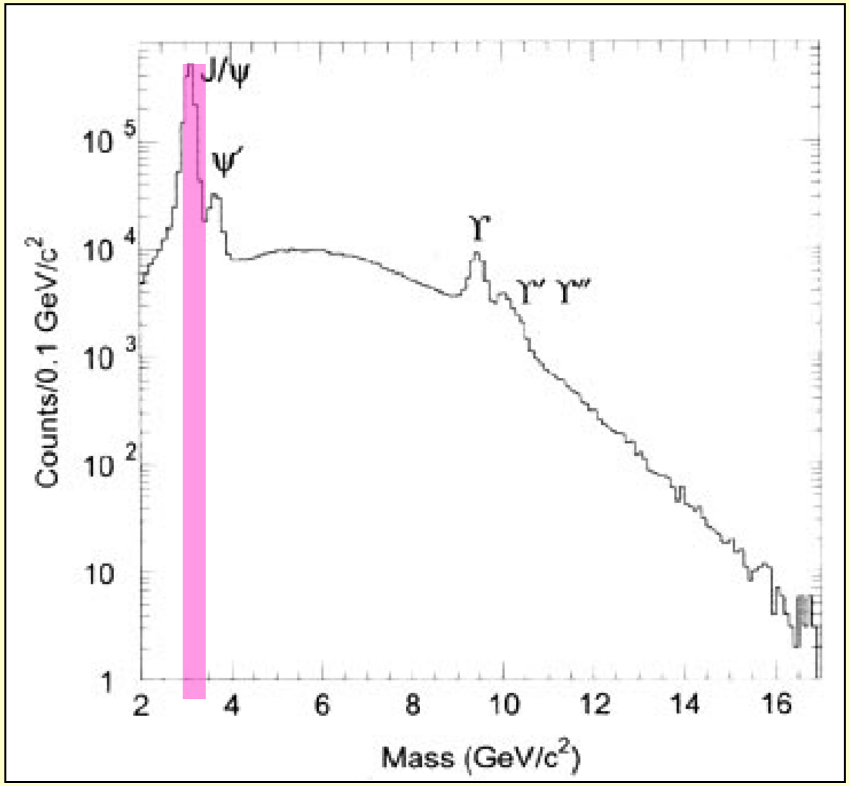
10 % precision on the h_1^u (x) in the valence region

More statistics from J/Ψ…

$q\bar{q} - J/\Psi$
$q\bar{q} - \gamma^*$
$q\bar{q} - e^+e^-$

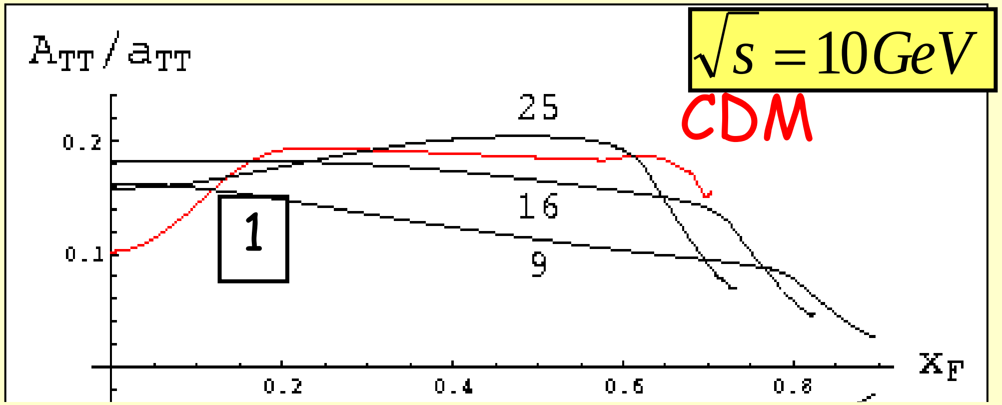
→ unknown vector coupling, but same Lorentz and spinor structure as other two processes

Unknown quantities cancel in the ratios for A_{TT}, but helicity structure remains!



Expected to double the statistics →Good mass resolution fundamental

What about p-p?



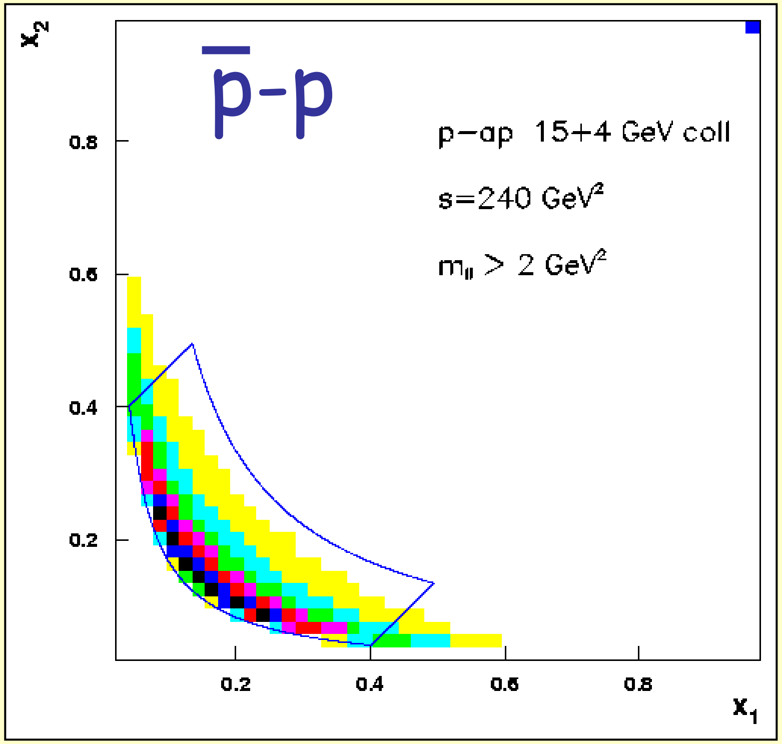
A. Drago (2006)

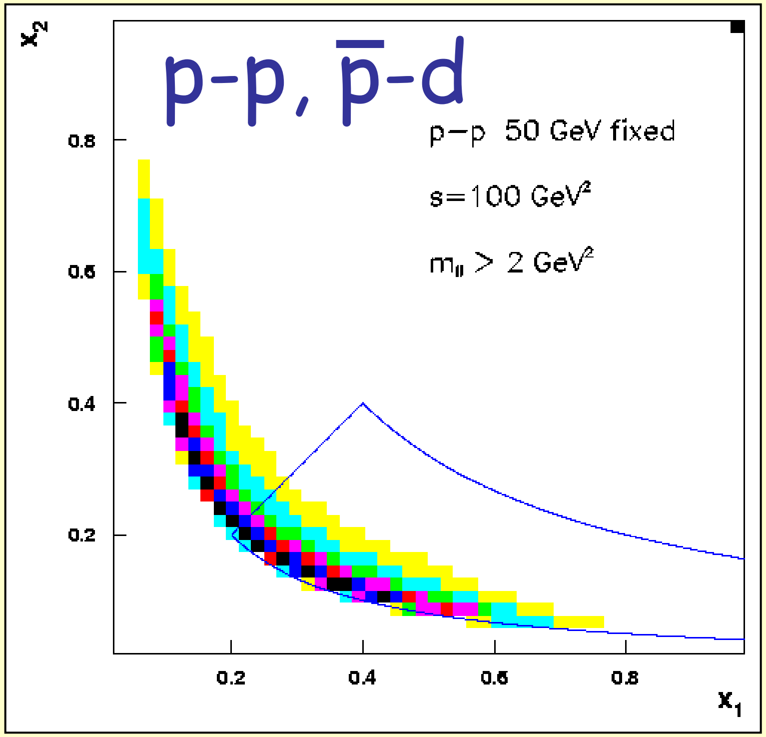
(Asymmetry evoluted under the assumption: $h_{1\bar{q}}(x, Q_0^2) = \Delta\bar{q}(x, Q_0^2)$)

Asymmetries are estimated to be large at PAX energies -> access to $h_{1\bar{u}}(x)$

RHIC:	$\tau = x_1x_2 \sim 10^{-3}$	$\rightarrow$	sea quarks	**(A_{TT} ~ 0.01)**
JPARC/U70:	$\tau = x_1x_2 \sim 10^{-1}$	$\rightarrow$	valence and sea	**(A_{TT} ~ 0.1)**
PAX:	$\tau = x_1x_2 \sim 10^{-1}$	$\rightarrow$	valence and sea	**(A_{TT} ~ 0.1)**

DY events distribution ($p^\uparrow\bar{p}^\uparrow$, $p^\uparrow p^\uparrow$ and $\bar{p}^\uparrow d^\uparrow$)





$M^2/s = x_1 x_2 \sim 0.02\text{-}0.3$

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

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

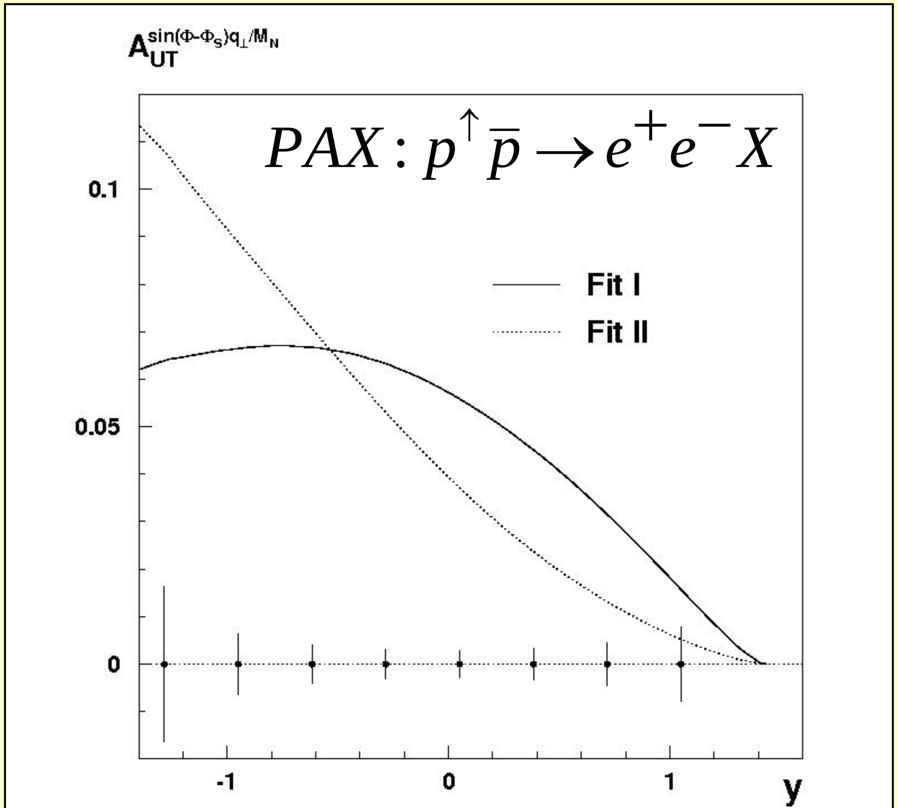
→ Extraction of h_{1d}, $h_{1\bar{q}}$ for $x<0.2$

$\bar{p}^\uparrow p^\uparrow$, $p^\uparrow p^\uparrow$, $\bar{p}^\uparrow d^\uparrow$: complete mapping of transversity

Single spin asymmetries:
Sivers function from pbar↑-p or pbar-p↑ Drell-Yan @ PAX

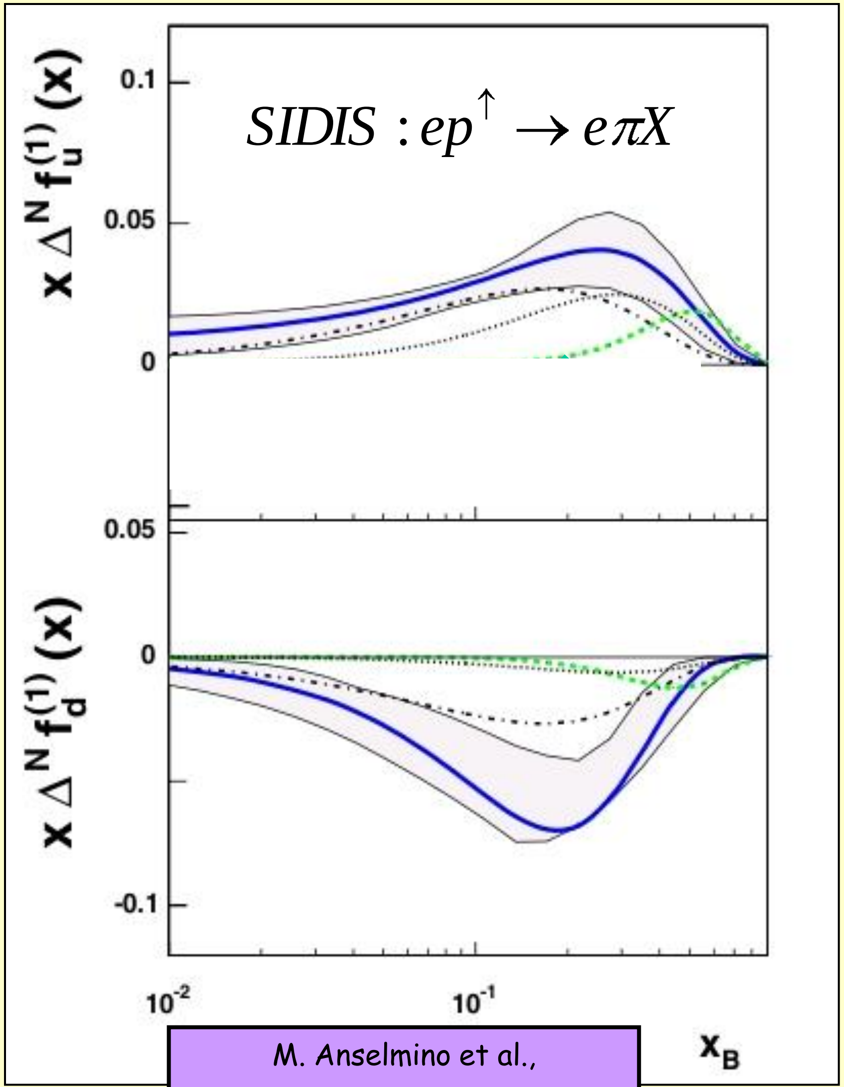
Test of Universality

$$f_{1T}^{\perp}(x, p_T^2)_{SIDIS} = -f_{1T}^{\perp}(x, p_T^2)_{DY}$$



A.V. Efremov et al.,
Phys. Lett. B 612, 233 (2005)

$$x_{1/2} = \sqrt{M^2/s}\ e^{\pm y}$$

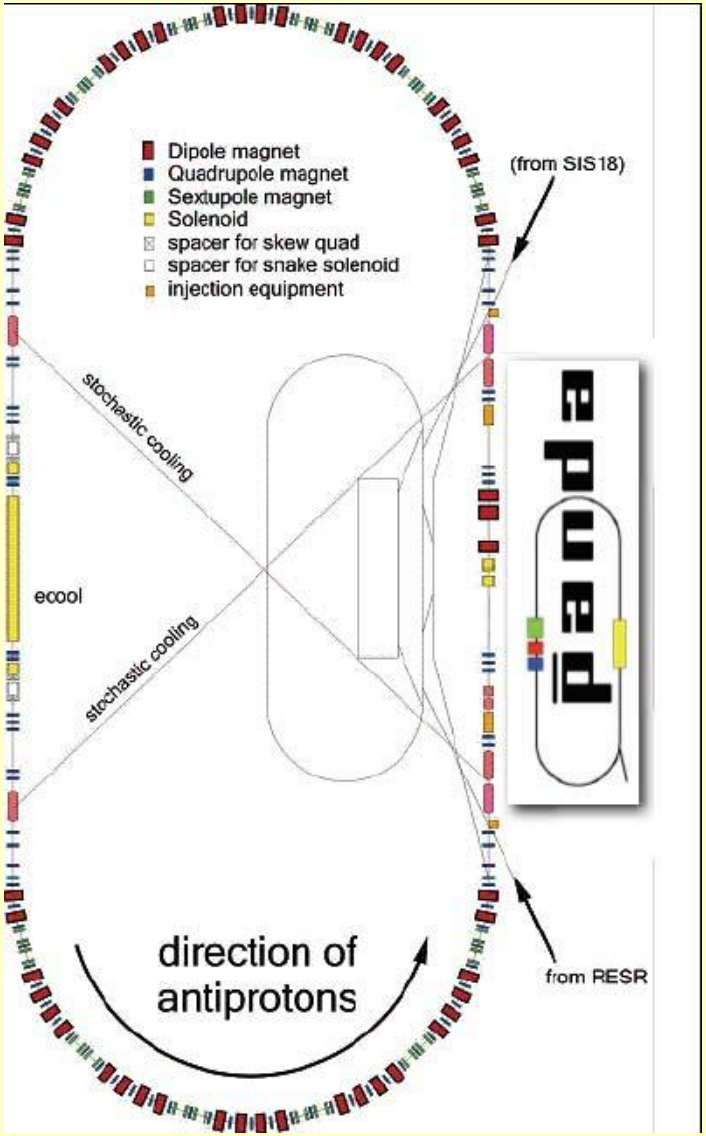


M. Anselmino et al.,
Phys. Rev. D72, 094007 (2005)

Fixed target experiments

DY measurements @ PANDA

- antiproton momentum
  1.5 GeV/c < p < 15 GeV/c
- Stochastic and electron cooling: $\Delta p/p < 10^{-5}$
- Luminosity > $10^{31} cm^{-2} s^{-1}$
- Hydrogen pellet or jet target, polarised Hydrogen under study
- Variety of nuclear targets



Measurement of Transversity

	non-TMD	TMD
self-sufficient	$\bar{p}^\uparrow p^\uparrow \to \ell\bar{\ell}X$ $p^\uparrow p^\uparrow \to$ (high-p_T jet) X	$p\bar{p}^\uparrow \to \ell\bar{\ell}X$ $\bar{p}p^\uparrow \to \ell\bar{\ell}X$
needs e^+e^-	$p\,p^\uparrow \to \Lambda^\uparrow X$ $e\,p^\uparrow \to e'\,\Lambda^\uparrow X$ $p\,p^\uparrow \to (\pi^+\pi^-)X$ $e\,p^\uparrow \to e'\,(\pi^+\pi^-)X$	$e\,p^\uparrow \to e'\,\pi\,X$

D. Boer, Ferrara (2008)

- There is only a single self-sufficient process with a single polarized beam
  - Single spin-asymmetry in $\bar{p}^\uparrow p$ or $p\bar{p}^\uparrow$ Drell-Yan

A "window" to transversity: pbar - p↑ $\rightarrow l^+l^- X$

Only self-sufficient single spin-asymmetry (involves TMDs)

Unpolarized DY production cross-section

$$d\sigma^{DY} \propto \bar{h}_1^{\perp}(x_1, k_{T1}^2) \otimes h_1^{\perp}(x_2, k_{T2}^2) \cos 2\phi$$

↑ Boer-Mulders ↑

→ analogue of BELLE cos2ϕ asymmetry

Single-polarized DY production cross-section

$$d\sigma^{DY} \propto \bar{f}_1(x_1, k_{T1}^2) \otimes f_{1T}^{\perp}(x_2, k_{T2}^2) \sin(\phi - \phi_{S2}) +$$

↑ Sivers

$$+ \bar{h}_1^{\perp}(x_1, k_{T1}^2) \otimes h_1(x_2, k_{T2}^2) \sin(\phi + \phi_{S2}) +$$

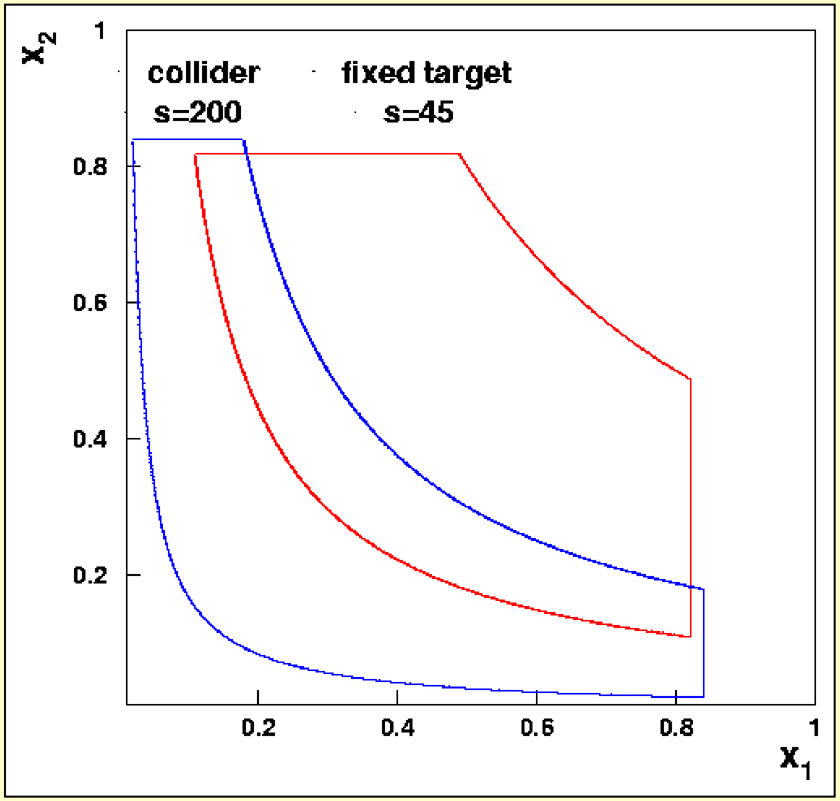
↑ Boer-Mulders ↑ Transversity

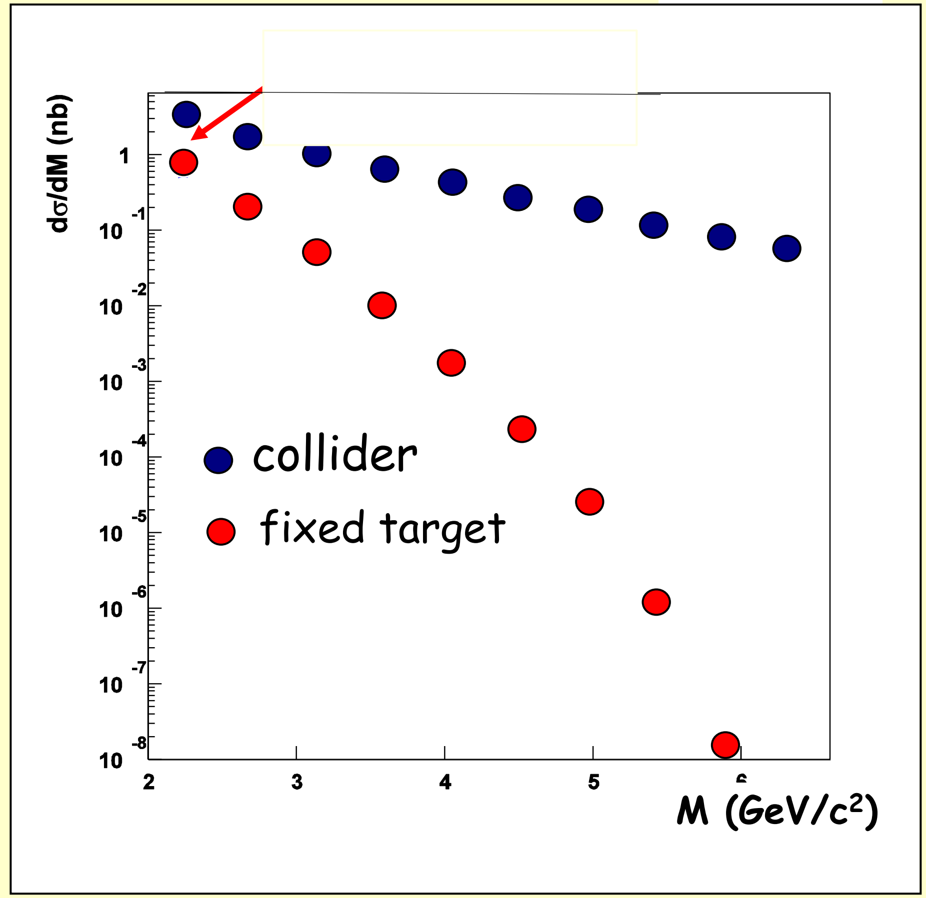
→ analogue of SIDIS Collins asymmetry

Kinematics and cross section

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

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

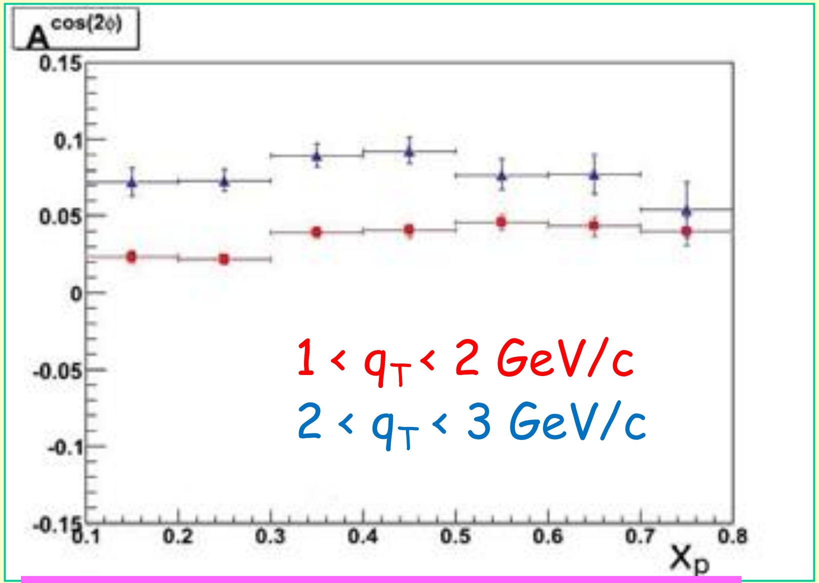




DY@PANDA: MC – Simulations I

A. Bianconi NIM A593, 562 (2008)

Unpolarized case: $\bar{p}\,p \rightarrow \mu^+\mu^- X$



M. Maggiora Univ. Torino and INFN (I)

5×10^5 events

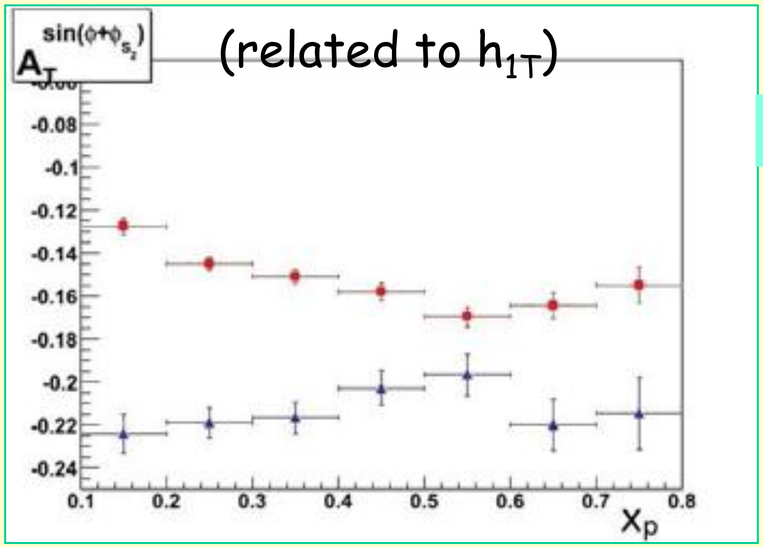
$1.5 < M^2_{l^+l^-} < 2.5$ GeV^2
$q_T > 1$ GeV/c
$60° < \theta^{CS}_{\mu+} < 120°$

Luminosity = 2×10^{32} cm^{-2}s^{-1}
σ = 0.8 nb
Rate = 0.16 s^{-1}

DY@PANDA: MC - Simulations II

A. Bianconi, M. Radici Phys. Rev. D71, 074014 (2005)

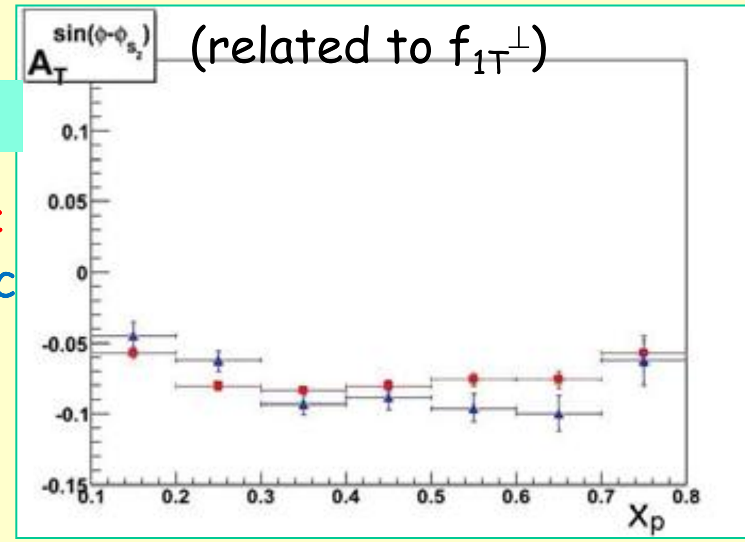
Single-spin asymmetry: $\bar{p}\, p\uparrow \rightarrow \mu^+\mu^- X$



5×10^5 events

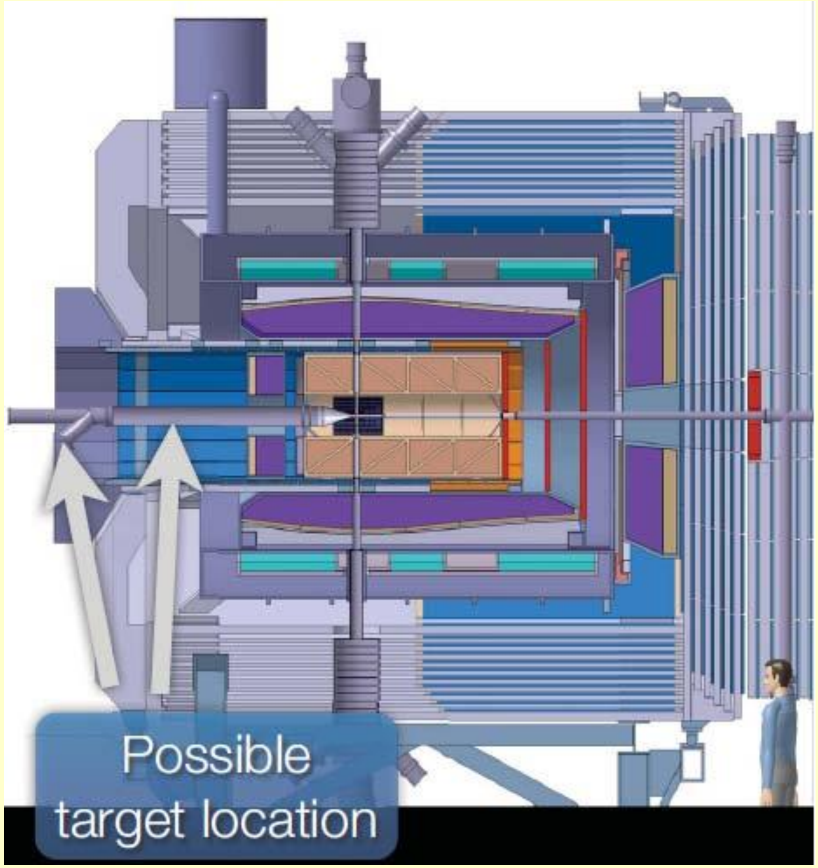
1 < q_T < 2 GeV/c

2 < q_T < 3 GeV/c



A polarized target in PANDA?

A very difficult task!



Positioning:
- Keep good PID for EM physics
- No parasitic run possible

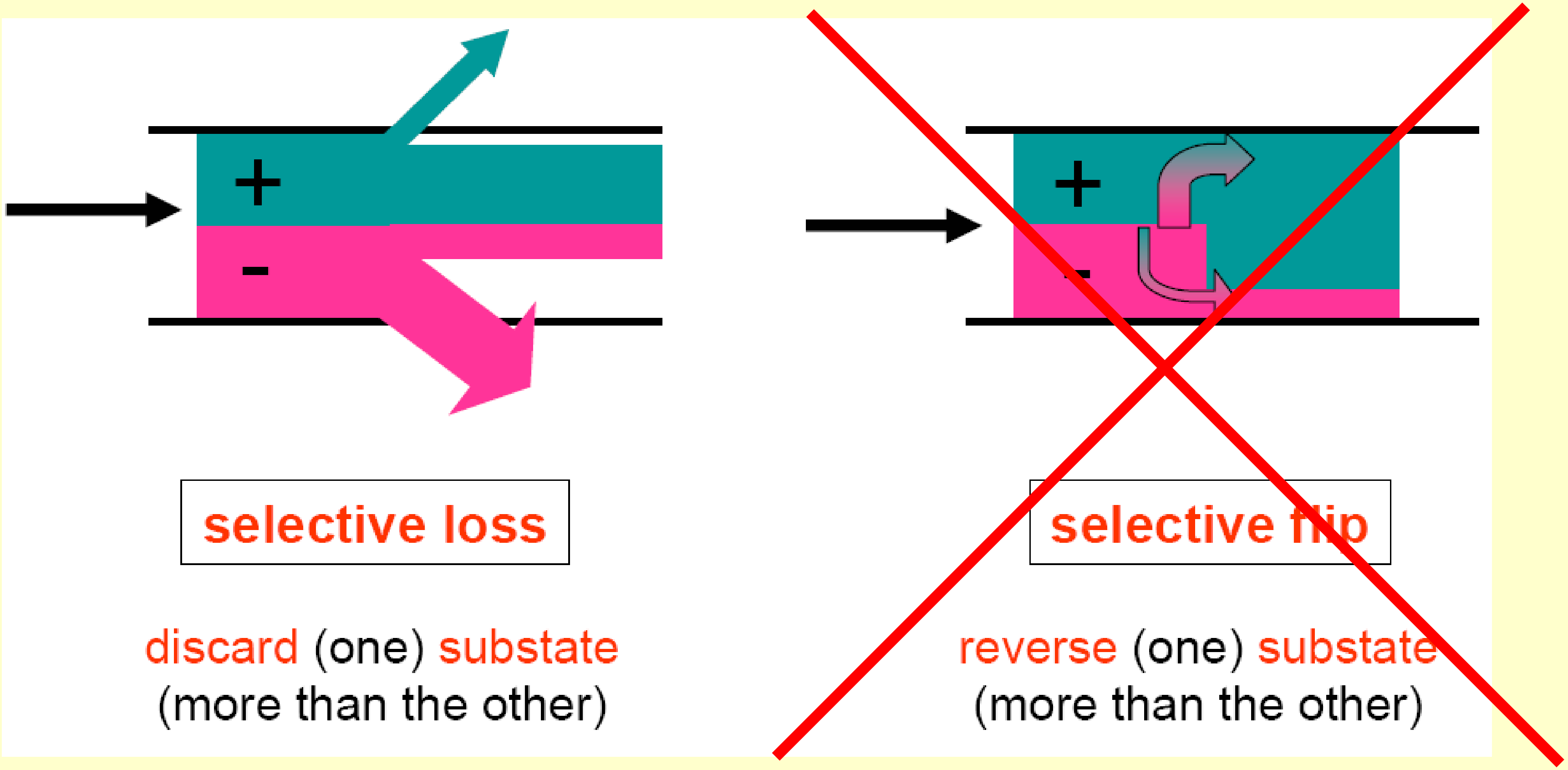
Technical issues:
- Transport of polarized gas
- Compensation of solenoidal field
- Pumping of polarized gas

Possible options:
- new detector with thoroidal field?
- additional IP in HESR?

Status of polarized antiproton-studies

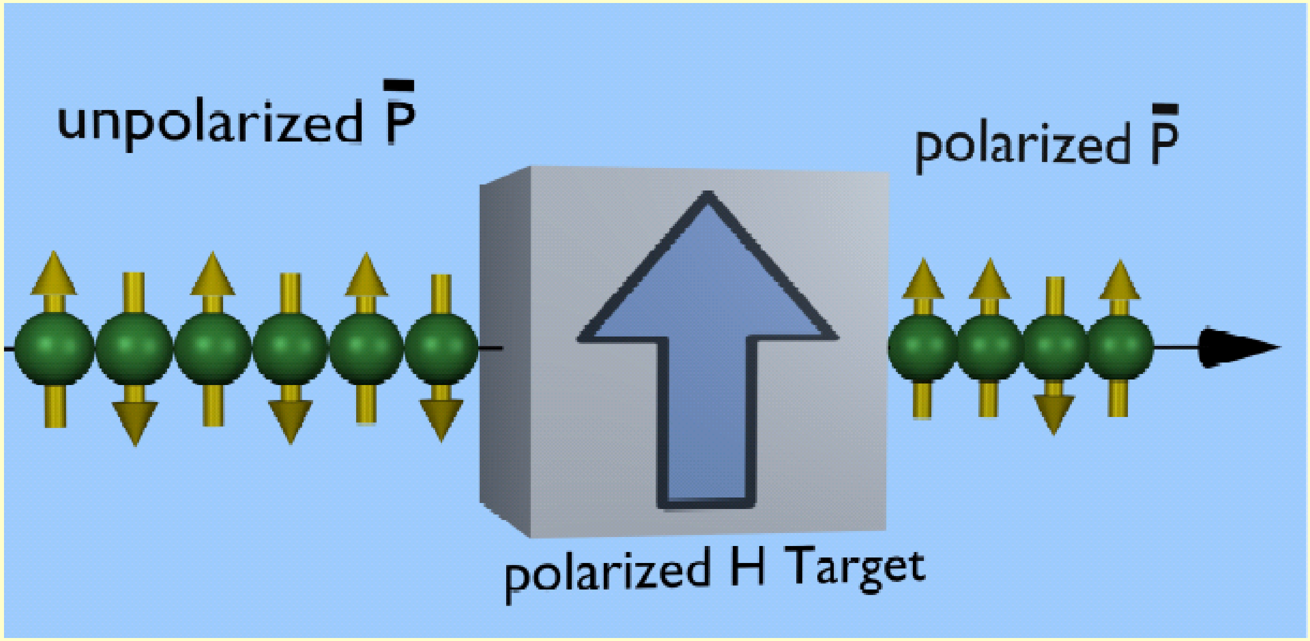
Polarized Antiprotons.
Two Methods: Loss versus spin flip

For an ensemble of spin ½ particles with projections + (↑) and – (↓)

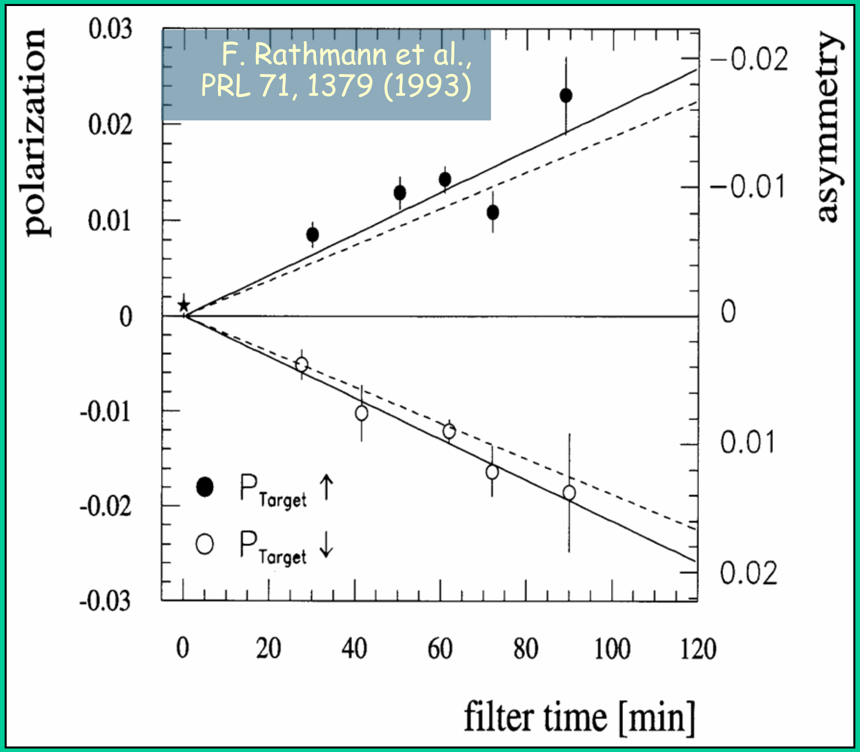


Spin-filtering

Polarization build-up of an initially unpolarized particle beam by repeated passage through a polarized hydrogen target:



Spin-filtering at TSR: „FILTEX" – proof-of-principle



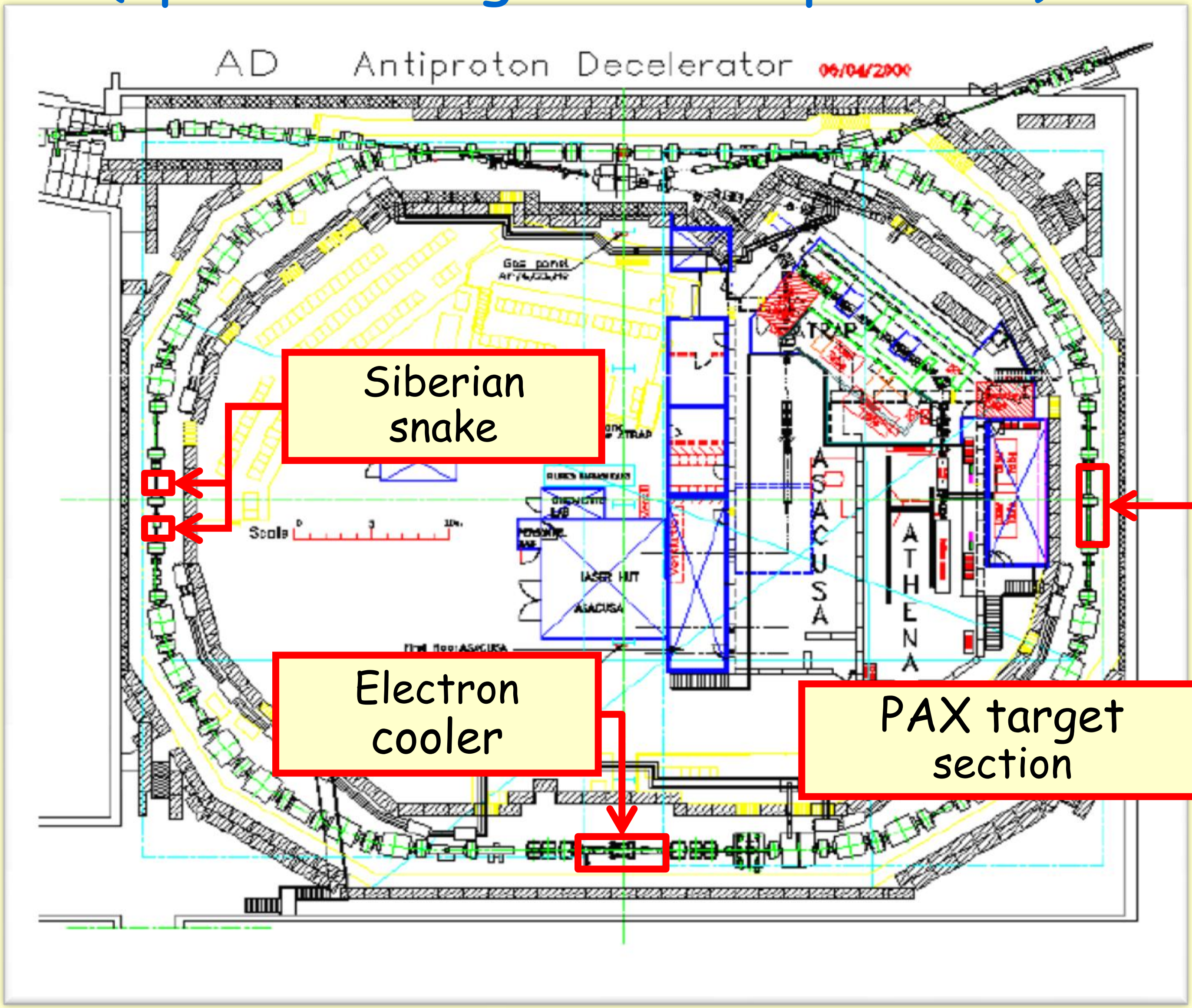
→ Spin filtering works for protons!

Polarization buildup process **quantitatively** understood!

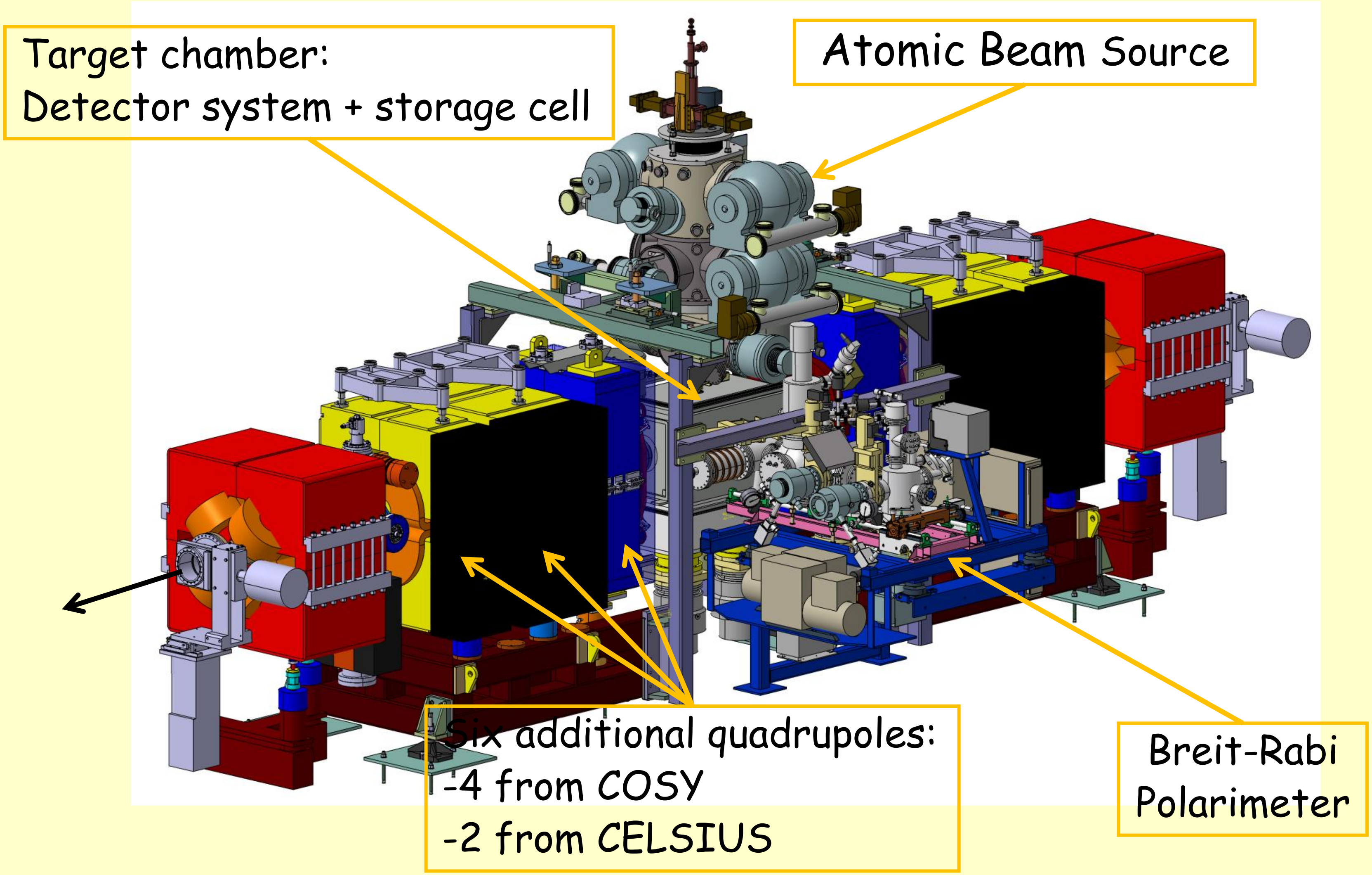
- TSR spin filtering with protons:
  σ^{exp}=73 ± 6 mb
- Average theoretical value:
  σ^{theo}=86 ± 2 mb
- Brief summary in: D. Oellers et al., Phys. Lett. B **674**, 269 (2009).

PAX submitted new proposal to find out how well spin filtering works for antiprotons (CERN-SPSC-2009-012 / SPSC-P-337)

PAX at the CERN-AD
(spin filtering with antiprotons)

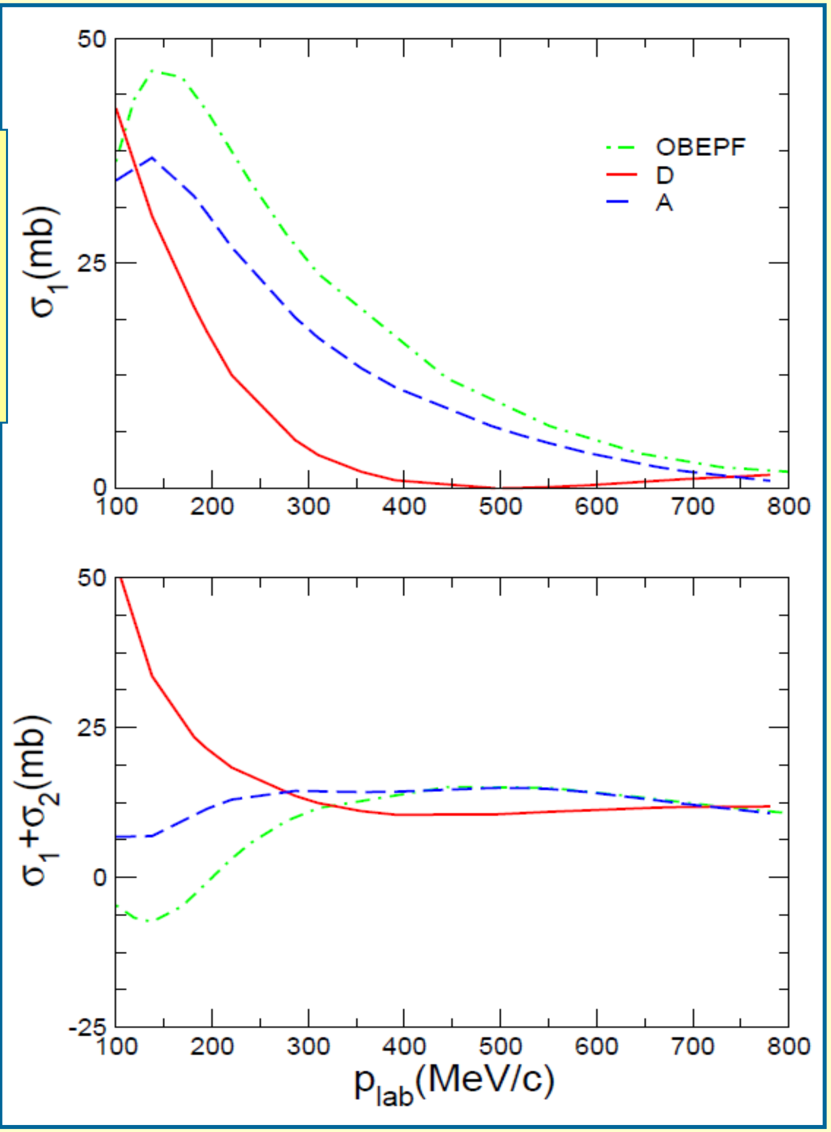


Experimental Setup for AD



Spin-dependence of the pbar-p interaction

- Measurement of the polarization buildup equivalent to the determination of σ_1 and σ_2
- Once a polarized antiproton beam is available, spin-correlation data can be measured at AD (50-500 MeV)



Model A: T. Hippchen et al., Phys. Rev. C 44, 1323 (1991).

Model OBEPF: J. Haidenbauer, K. Holinde, A.W. Thomas, Phys. Rev. C 45, 952 (1992).

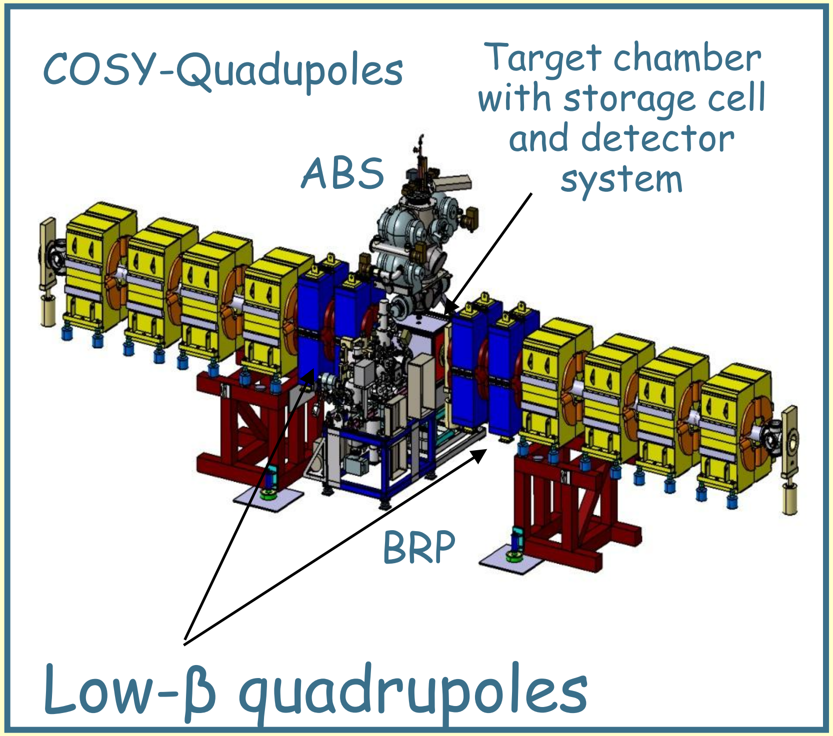
Model D: V. Mull, K. Holinde, Phys. Rev. C 51, 2360 (1995).

Spin-filtering studies at COSY- FZJ-Germany

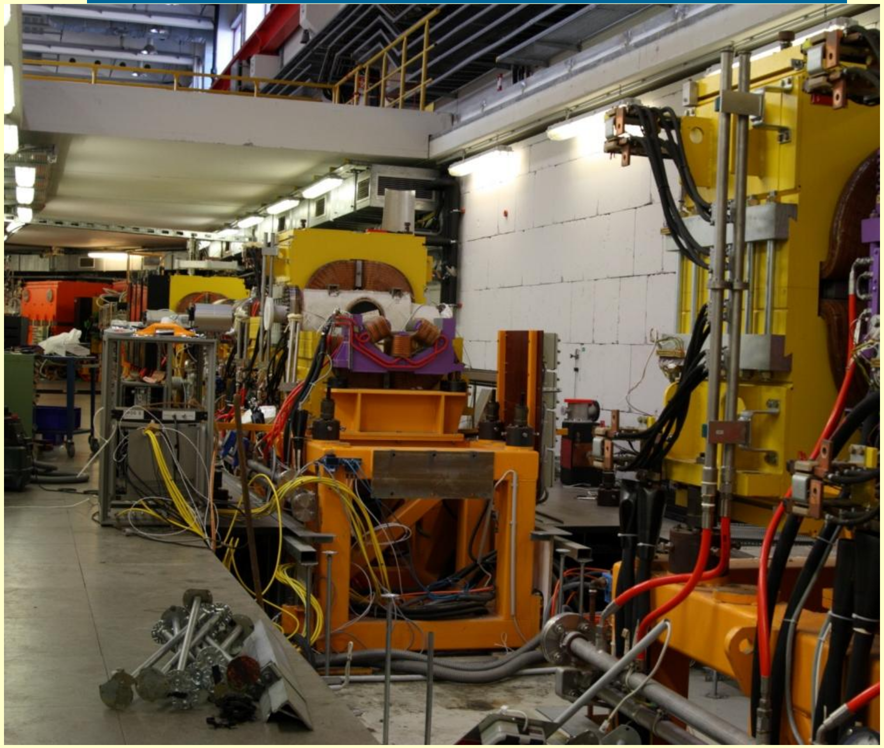
Main purpose:

1. Confirm understanding of spin-filtering with protons.
2. Commissioning of the experimental setup for AD

Proposal to COSY PAC
(submitted in July 2009)

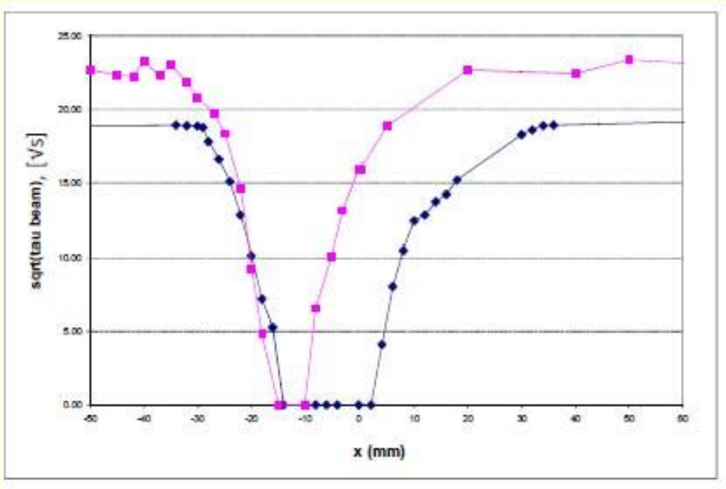


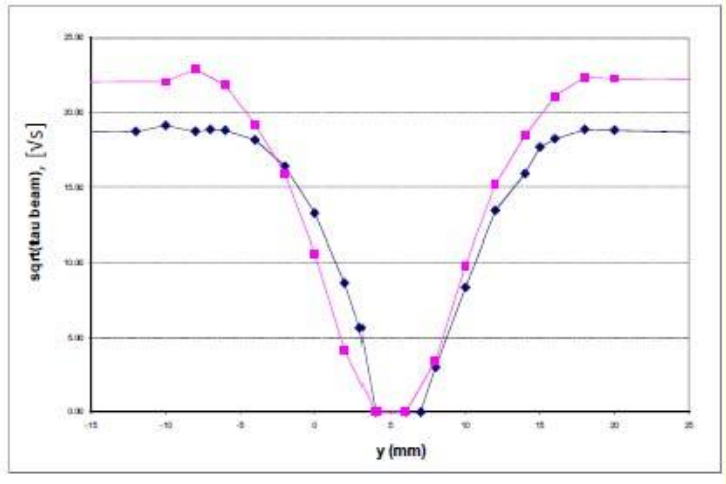
Low-β magnet installation at COSY
(summer 2009)



Low-b section commissioning (Feb. 2010)

Acceptance measurements with scrapers





- New low-β section
- Old lattice

Low-β section does not limit the machine acceptance

Conclusions

- Outstanding case for DY with polarized antiprotons

- Interesting perspectives for DY on fixed target
    - Polarized target in PANDA technical challenge

- Studies on polarized antiprotons undertaken by PAX Collab.

Ferrara International School Niccolò Cabeo


The Ferrara PhD School in Physics, in collaboration with the Pavia, Torino and Trieste Universities, has organized a permanent International School on hadron structure and interactions.

The School is mainly addressed to young PhD students, both theoreticians and experimentalists, although advanced PhD students as well as post-docs and young researchers are also welcome.


Every year the School will offer two levels of plenary lectures: one "pedagogical", on relevant subjects in hadron physics usually not covered in great detail in the normal undergraduate and graduate courses, and the other, more technical, on specific related items.

The school lasts one week, and includes several sections devoted to informal conversations with teachers. Every year proceedings of the lectures will be published and delivered to the students.

A permanent Advisory Scientific Committee serves the School by proposing, each year, the lecturers and reviewing the program. It also provides the necessary connections among the Universities and the laboratories involved, and eventually seeks for funding.


The main topic of this year is:

Transverse Momentum Dependent
Parton Distribution Functions


The first session of the school is announced:

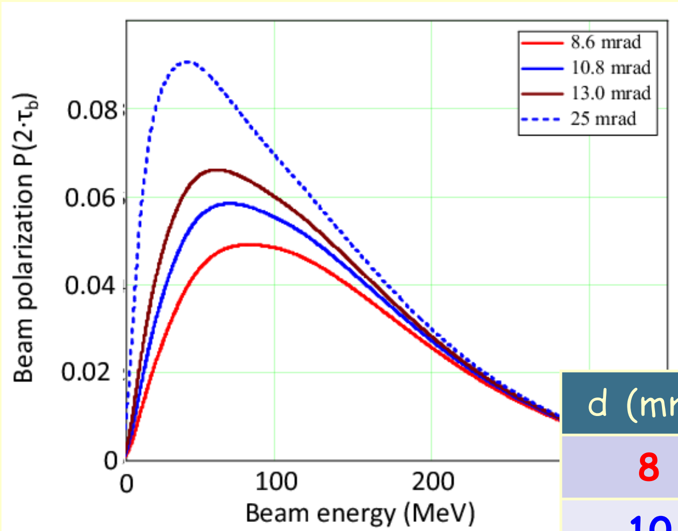
May, 24-28 2010
IUSS, Via delle Scienze 41b, 44100 Ferrara (Italy)

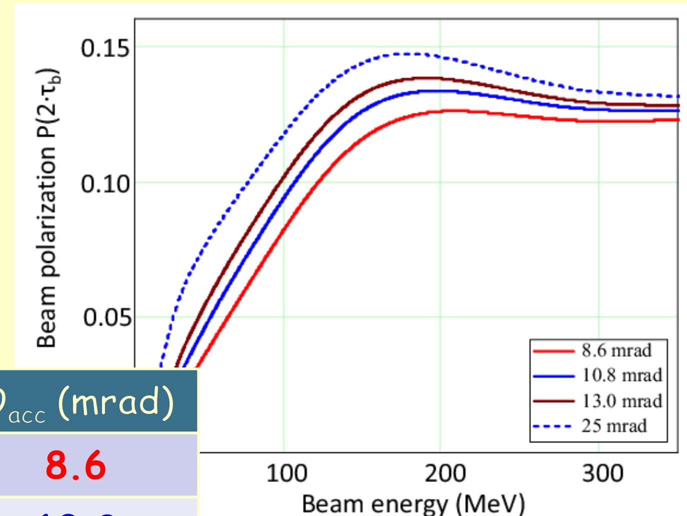
Expected polarizations after filtering for two lifetimes at AD

transverse

longitudinal

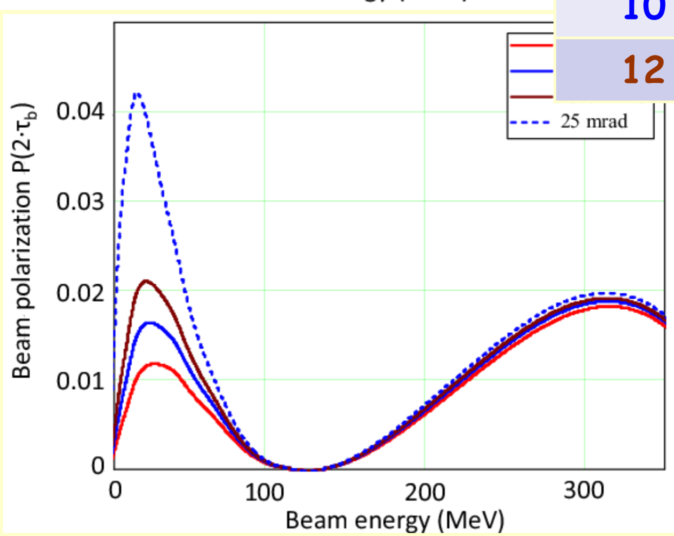
A

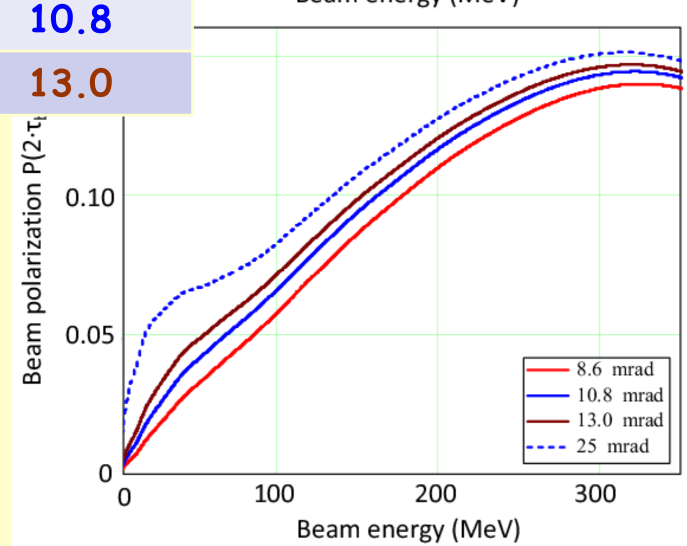




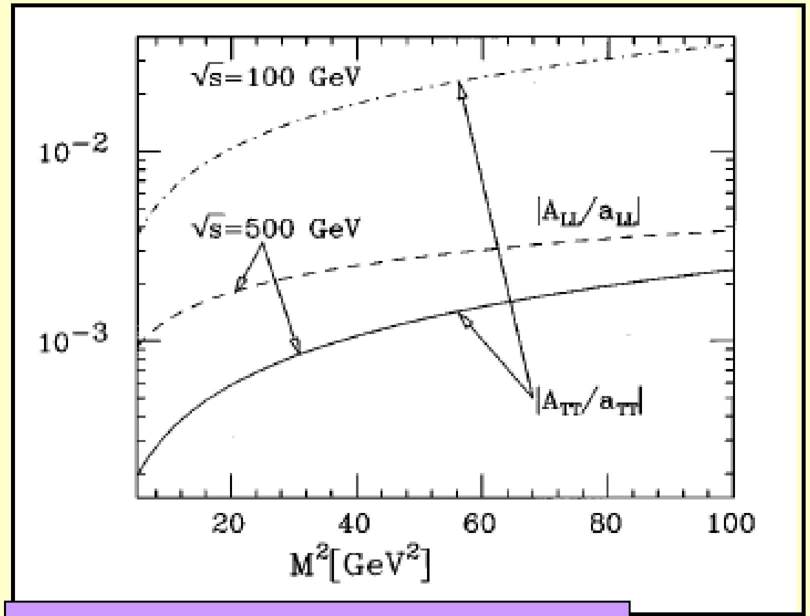
d (mm)	Θ_{acc} (mrad)
8	8.6
10	10.8
12	13.0

D

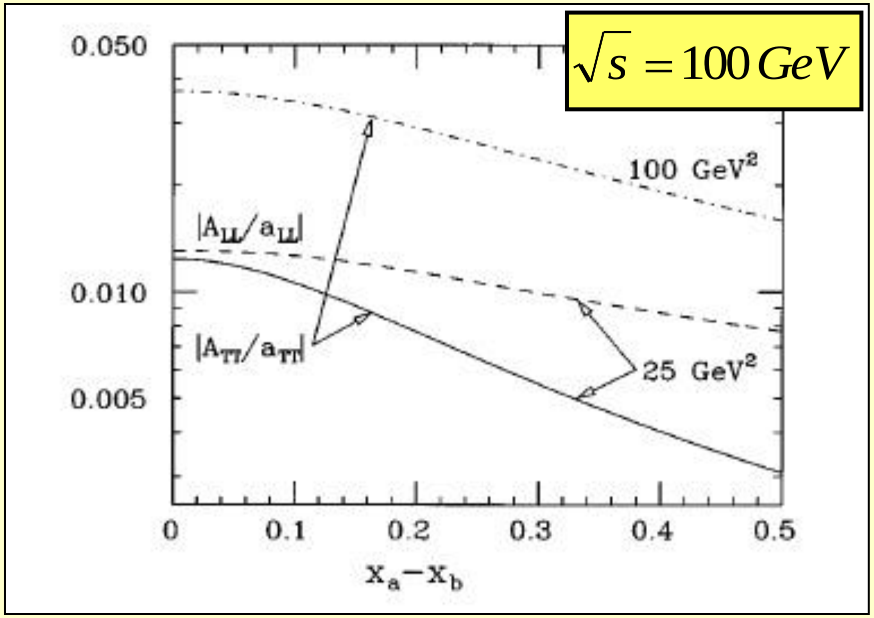


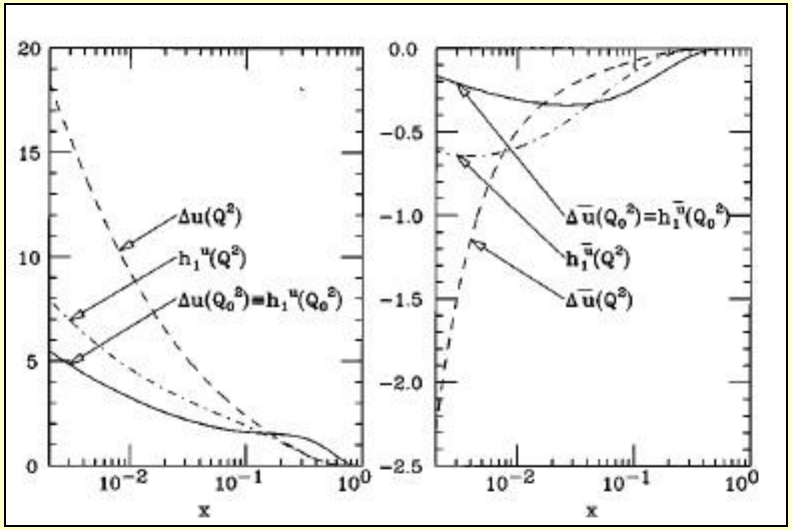


Higher energy p-p machine



V. Barone, T. Calarco and A. Drago
Phys. Rev. D 56 (1997) 527



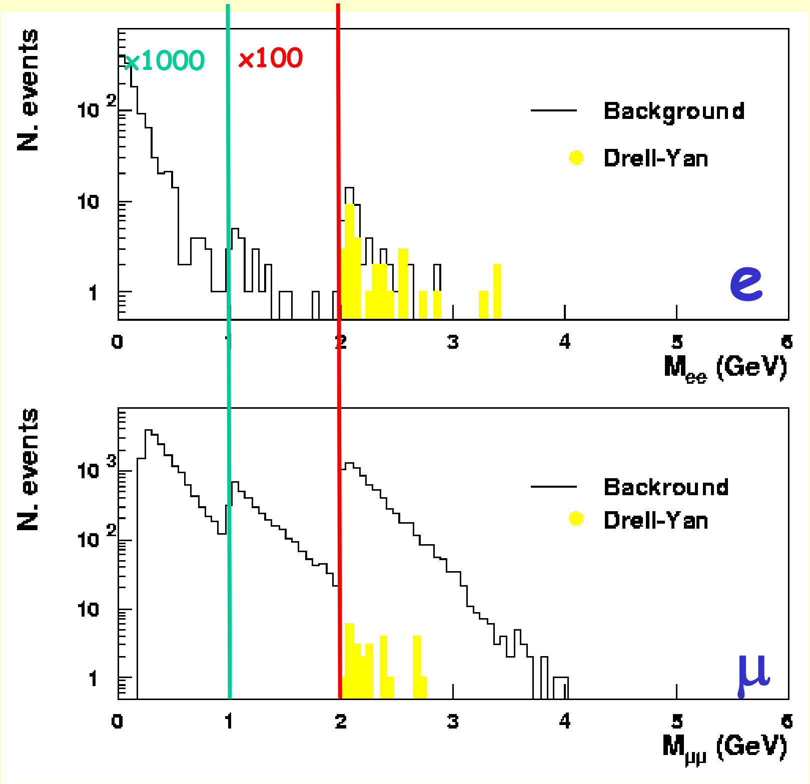


- s ↑
  - Asymmetry ↓
- $A_{LL} > A_{TT}$
- s_{JPARC} ideal

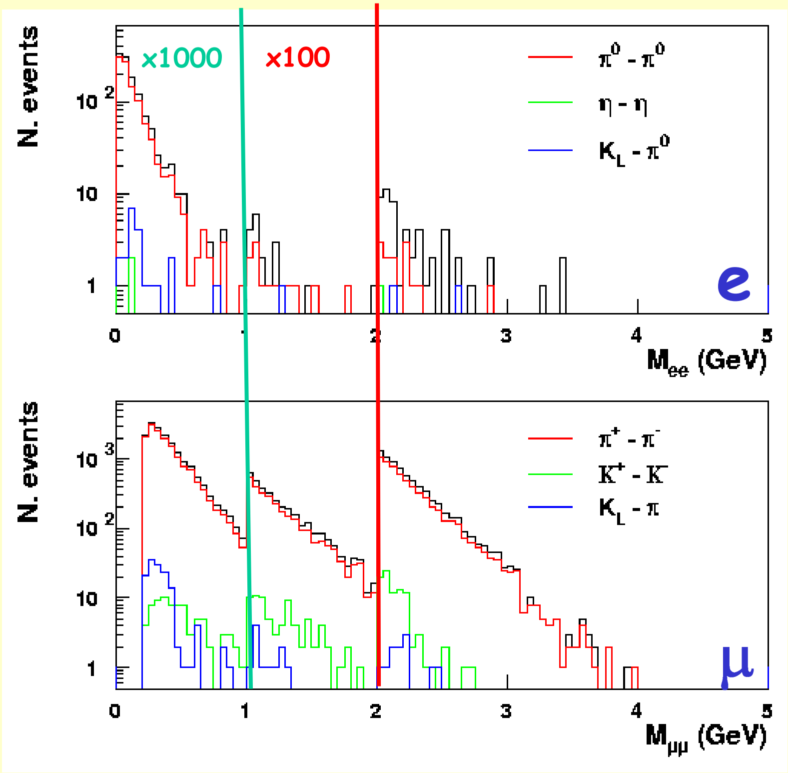
Background for $\bar{p}p \rightarrow e^+e^- X$

Preliminary PYTHIA result ($2 \cdot 10^9$ events)

Total background

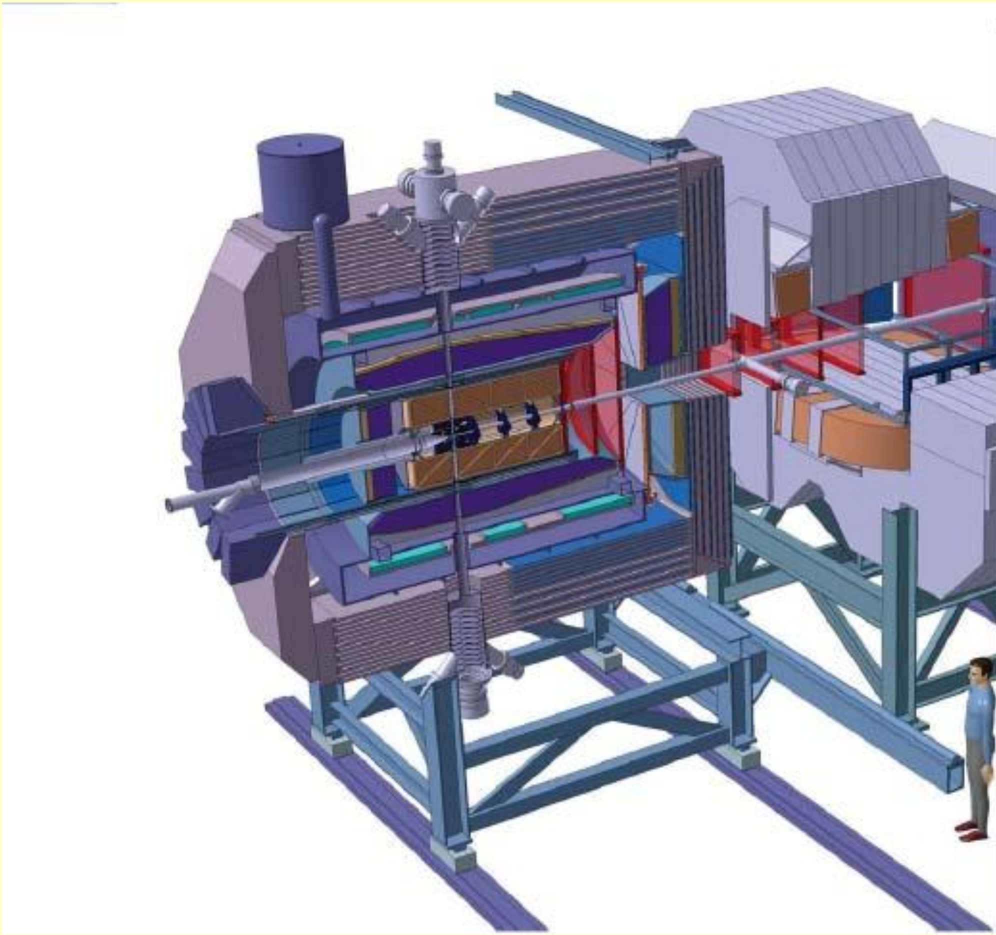


Background origin



- Background higher for μ than for e
- Background from charge coniugated mesons negligible for e.

The PANDA detector



- 4π acceptance
- High rate capability: $2\times10^7\ s^{-1}$ interactions
- Efficient event selection
  - → Sampling acquisition
- Momentum resolution ~1%
- Vertex info for D, K^0_S, Y ($c\tau$ = 317 μm for $D^{\pm}$)
  - → *Good tracking*
- Good PID (γ, e, μ, π, K, p)
  - → DIRC *ToF, dE/dx*
- γ-detection 1 MeV – 10 GeV
  - → *Crystal Calorimeter*

From DY to elastic e^+e^- production: Proton Electromagnetic Form Factors @fixed target

Background in pbar-p $\rightarrow e^+e^-$

- Reactions with at least 3 particles produced:
  (e^+e^-X, $\pi^+\pi^-X$,...)
  Particle identification and kinematics constraints
  $\rightarrow$ no problem (still to be quantified)
- Reactions with 2 charged particles ($\pi^+\pi^-$)
  - $\sigma(\pi^+\pi^-)/\sigma(e^+e^-) \approx 10^6$ (2μb/8pb at q^2=9.(GeV/c)^2)

    need rejection of $\bar{p}p \rightarrow \pi^+ \pi^-$ by 10^{-8}

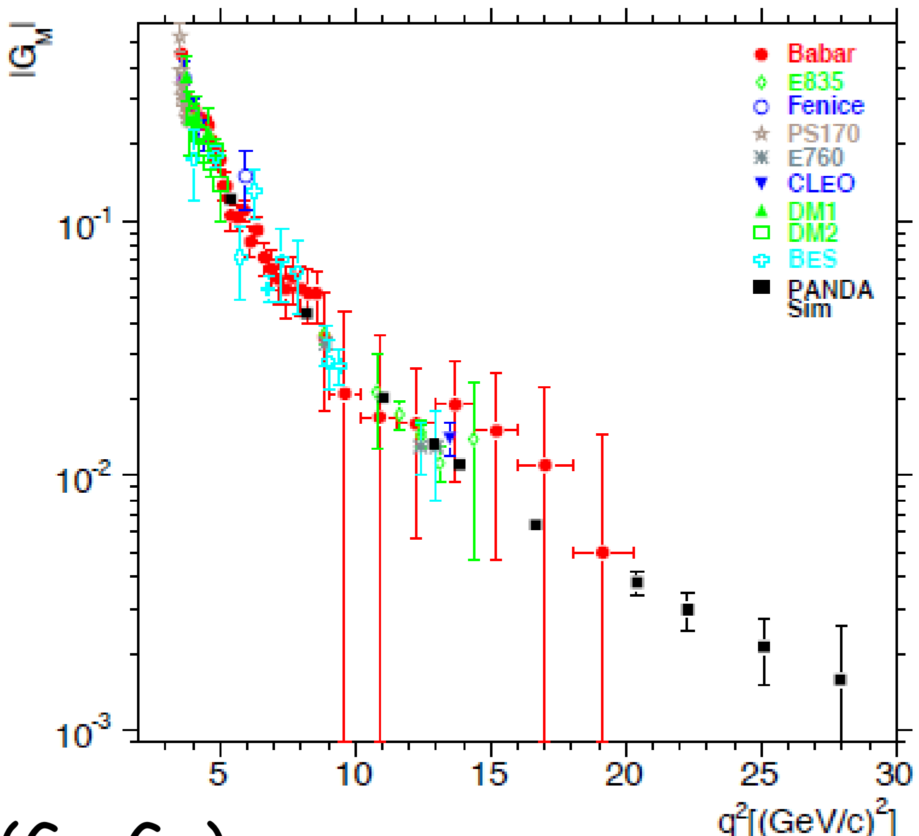
    binary event, mean reject. of 10^{-4} per π^+ and per π^-
  - very close kinematics
  - PID is crucial, EMC, DIRC, dE/dx

DY with e^+/e^- @ PANDA? Pion-rejection promisiong...

T_{p_bar} (GeV)	Q^2 $(GeV/c)^2$	θ_{CM}	θ_{lab}	p_{lab} (GeV/c)	one π Misident. Probability ECAL×DIRC×dE/dx	$\pi^+\pi^-$ Misident. Probability
1.	5.4	20°	13°	2.2	0.001 × 0.5 ×0.05 = 2.5 10^{-5}	0.1 10^{-9}
		160°	132°	0.57	0.033 × 0.003 ×0.03 = 3.0 10^{-6}	
		90°	54°	1.43	0.001 × 0.3 ×0.03 = 9. 10^{-6}	0.1 10^{-9}
		90°	54°	1.43	0.001 × 0.3 × 0.03 = 9. 10^{-6}	
2.5	8.2	20°	10°	3.7	0.001 × 1. ×0.05 = 5. 10^{-5}	0.3 10^{-9}
		160°	117°	0.7	0.014 × 0.014 × 0.03 = 6. 10^{-6}	
		90°	41°	2.2	0.001 × 1. × 0.03 = 3. 10^{-5}	0.9 10^{-9}
		90°	41°	2.2	0.001 × 1. × 0.03 = 3. 10^{-5}	
5.	12.9	20°	7.4°	6.1	0.001 × 1. × 0.1 = 10^{-4}	0.6 10^{-9}
		160°	102°	0.8	0.014 × 0.014 × 0.03 = 6. 10^{-6}	
		90°	32°	3.4	0.001 × 1. × 0.05 = 5. 10^{-5}	2.5 10^{-9}
		90°	32°	3.4	0.001 × 1. × 0.05 = 5. 10^{-5}	
10.	22.3	20°	5.4°	10.9	0.001 × 1. × 0.3 = 3. 10^{-4}	5.4 10^{-9}
		160°	85°	1.0	0.005 × 0.12 × 0.03 = 1.8 10^{-5}	
		90°	24°	5.95	0.001 × 1. × 0.1 = 1. 10^{-4}	10. 10^{-9}
		90°	24°	5.95	0.001 × 1. × 0.1 = 1. 10^{-4}	

F. Maas Univ. of Mainz – GSI (D)

Pbar-p -> e^+e^-
Statistical projection for timelike FF @ PANDA

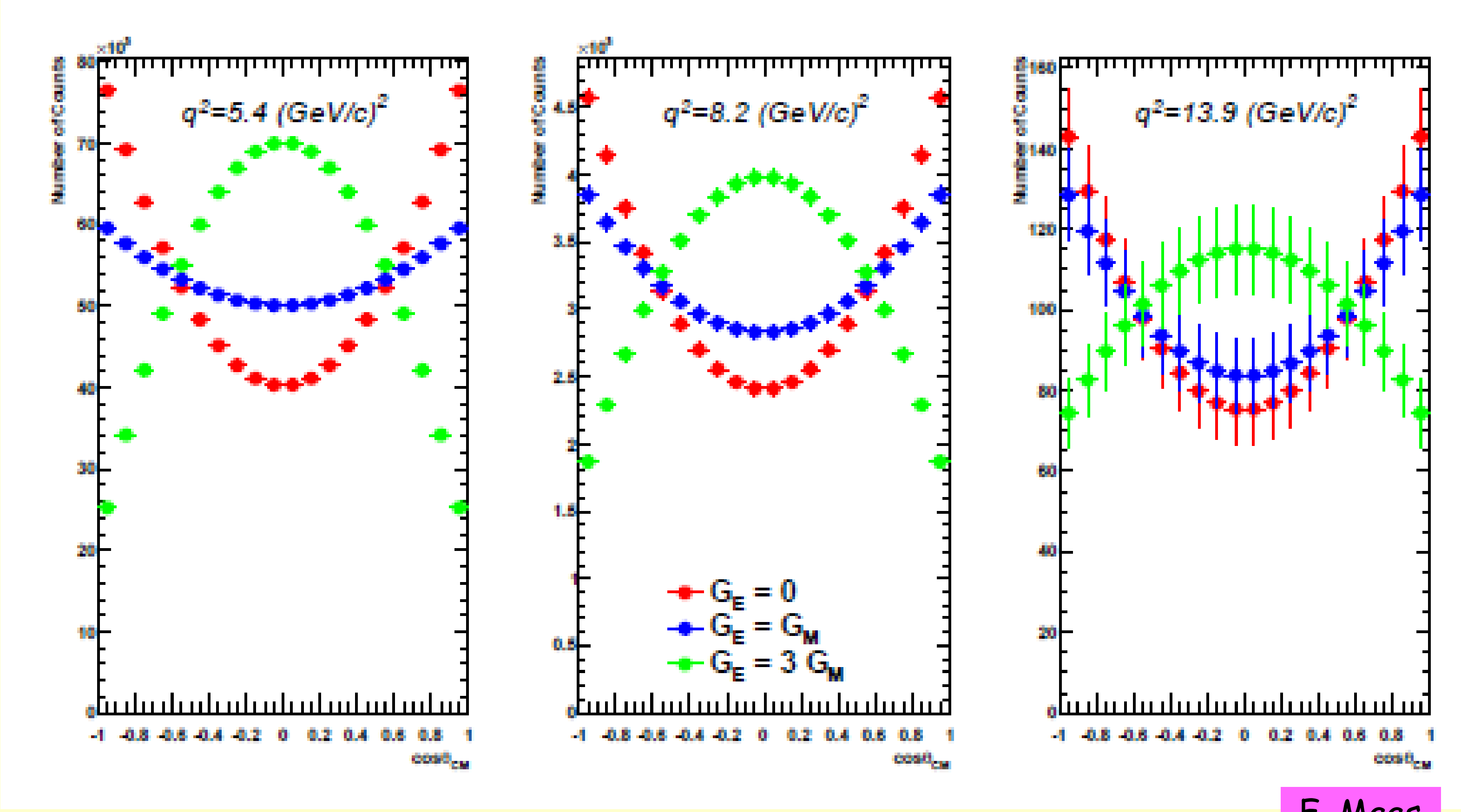


$(G_E=G_M)$

F. Maas (Mainz+GSI)

Measurement of G_E and G_M moduli @ PANDA

- Use of different angular dependence for G_E and G_M



F. Maas

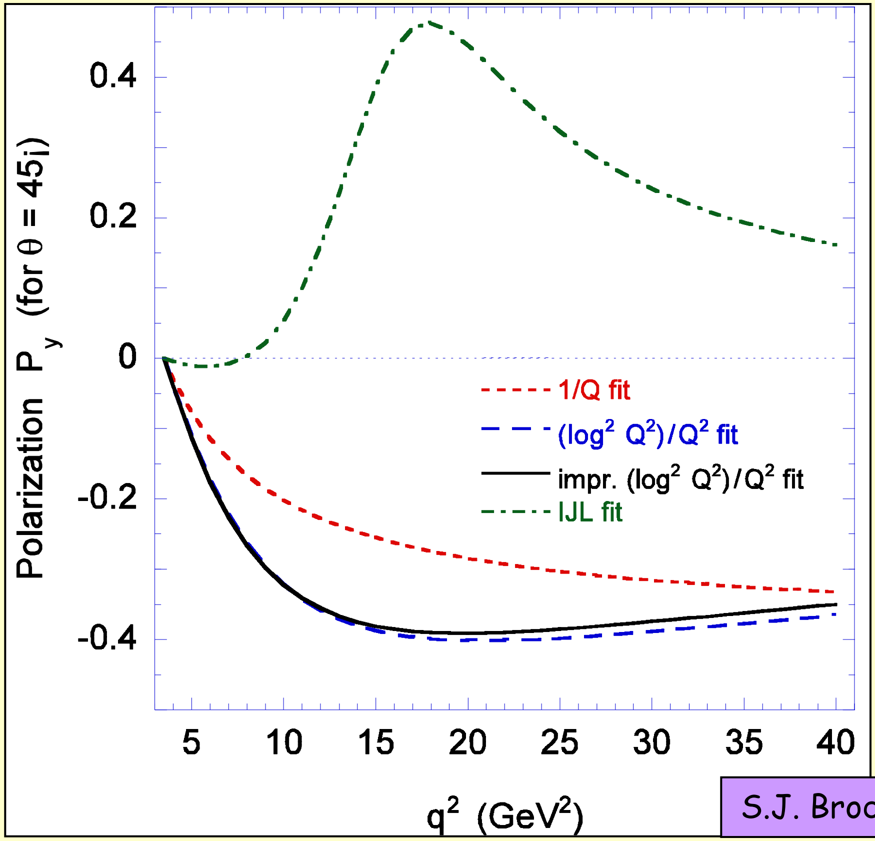
-Generated events: 2fb^{-1} (4 months @ 2×10^{32}cm^{-2}s^{-1})

Single Spin Observables

$$\frac{d\sigma}{d\Omega}(P_y) = \left(\frac{d\sigma}{d\Omega}\right)_0 [1 + \mathcal{A}P_y],$$

$$\mathcal{A} = \frac{\sin 2\theta \, Im G_E^* G_M}{D\sqrt{\tau}}, \quad D = |G_M|^2(1+\cos^2\theta) + \frac{1}{\tau}|G_E|^2 \sin^2\theta$$

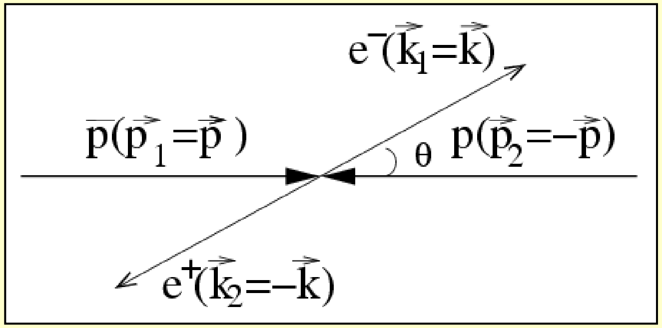
A. Z. Dubnickova, S. Dubnicka, M.P. Rekalo Nuovo Cimento A109, 241 (1996)



S.J. Brodsky, C.E. Carlson, J.R. Hiller, D.S. Hwang PRD 69, 054022 (2004)

- Contains imaginary part
  - Access relative phase
- Very sensitive to different models

Double polarized pbar-p annihilation:



$$\left(\frac{d\sigma}{d\Omega}\right)_0 A_{xx} = \sin^2\theta\left(|G_M|^2 + \frac{1}{\tau}|G_E|^2\right)\mathcal{N},$$

$$\left(\frac{d\sigma}{d\Omega}\right)_0 A_{yy} = -\sin^2\theta\left(|G_M|^2 - \frac{1}{\tau}|G_E|^2\right)\mathcal{N},$$

$$\left(\frac{d\sigma}{d\Omega}\right)_0 A_{zz} = \left[(1+\cos^2\theta)|G_M|^2 - \frac{1}{\tau}\sin^2\theta|G_E|^2\right]\mathcal{N},$$

$$\left(\frac{d\sigma}{d\Omega}\right)_0 A_{xz} = \left(\frac{d\sigma}{d\Omega}\right)_0 A_{zx} = \frac{1}{\sqrt{\tau}}\sin 2\theta\, Re G_E G_M^* \mathcal{N}.$$

E. Tomasi, F. Lacroix, C. Duterte, G.I. Gakh, EPJA 24, 419(2005)

- Most contain moduli G_E, G_M
  - Independent G_E-G_M separation
  - Test of Rosenbluth separation in the time-like region
- Access to G_E-G_M phase
- Very sensitive to different models (next transparencies)