Polarised Physics at PANDA energies

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WHY ?

Spin degrees of freedom can explain otherwise surpring phenomena and bring new insights into the nulcear matter structure

Nucleon structure and Polarized reactions

Proton Electromagnetic Formfactors

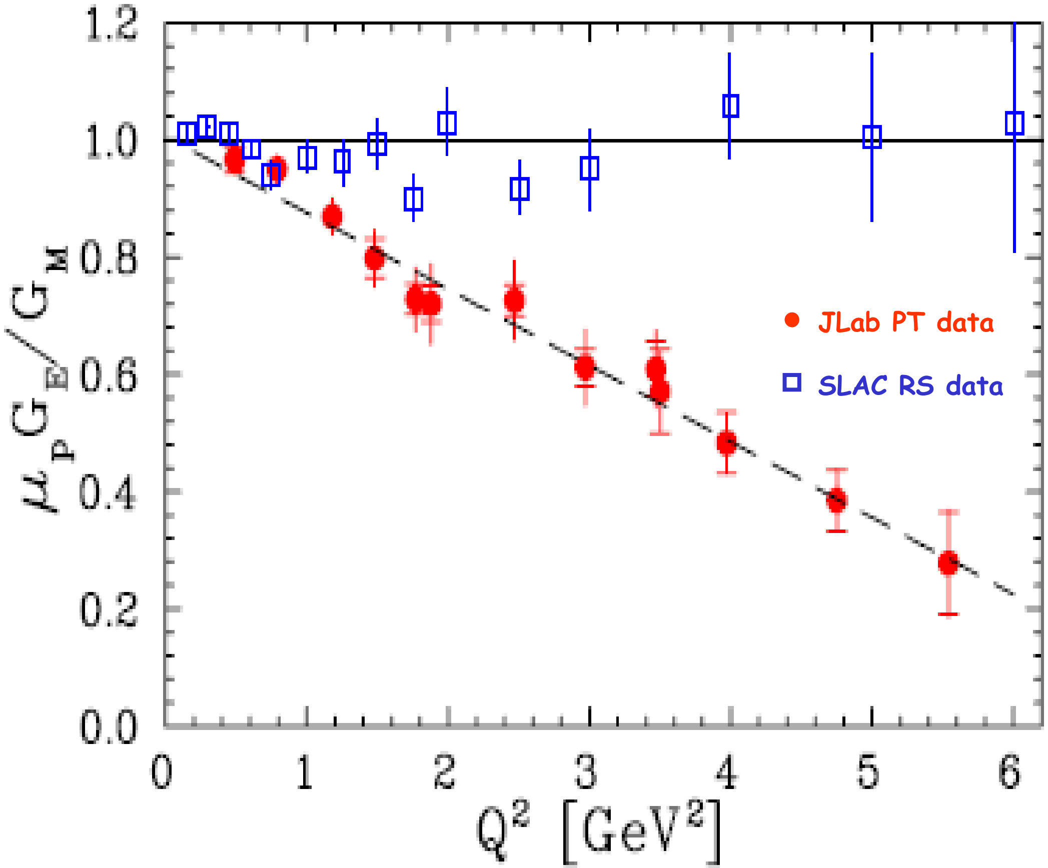


FIG. 1. (Color online) Ratio of electric to magnetic form factor as extracted by Rosenbluth measurements (hollow squares) and from the JLab measurements of recoil polarization (solid circles). The dashed line is the fit to the polarization transfer data.

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

COMPARISON BETWEEN ROSENBLUTH SEPARATION AND POLARIZATION TRANSFER TECNIQUES

TWO DIFFERENTS METHODS

TWO DIFFERENTS RESULTS

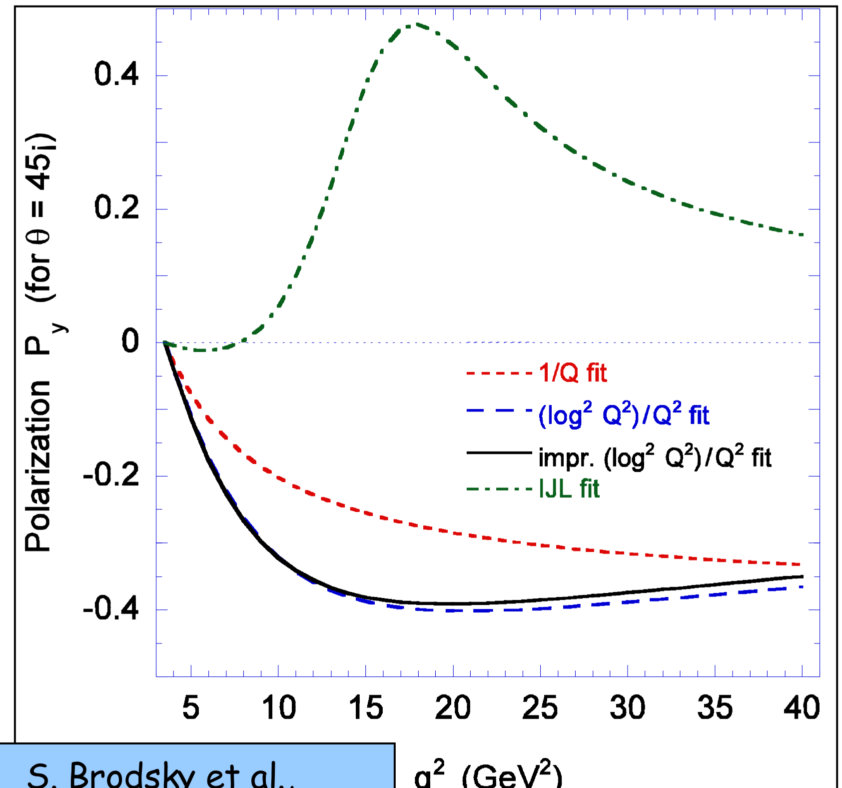
Proton Electromagnetic Formfactors

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

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

$$\tau = q^2/4m_p^2$$

- 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



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

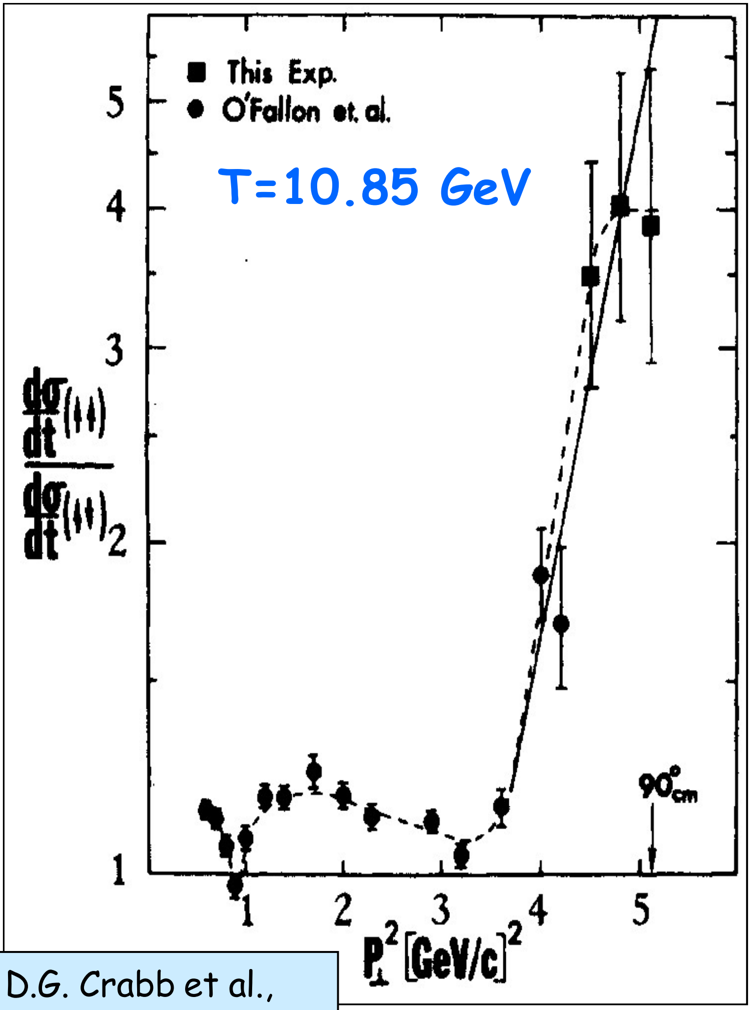
Hard pbar-p elastic Scattering

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



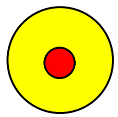
D.G. Crabb et al., PRL 41, 1257 (1978)

Parton distributions: Transversity and TMDs

Quark structure of the nucleon

Unpolarized DF

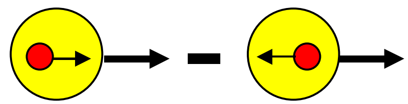
$$q(x,Q^2)=q^+ + q^-$$



WELL KNOWN

Helicity DF

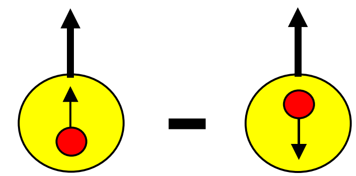
$$\Delta q(x,Q^2)=q^+ - q^-$$



KNOWN

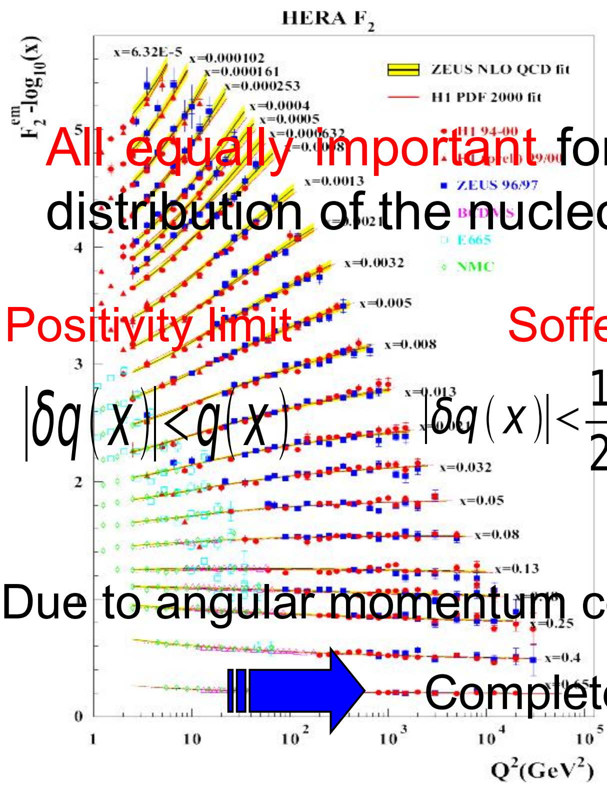
Transversity DF

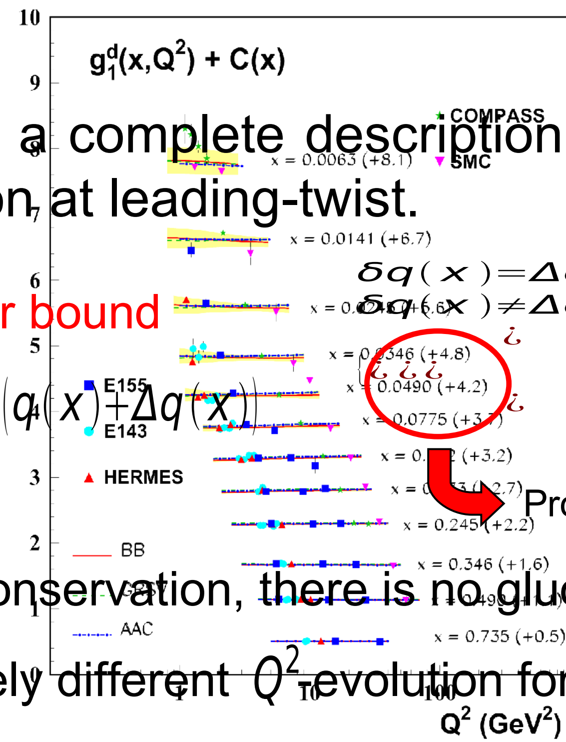
$$\delta q(x,Q^2)=q^\uparrow - q^\downarrow$$



FIRST GLIMPSE!!!

[Anselmino et al. PRD75 (2007)]





All equally important for a complete description of momentum and spin distribution of the nucleon at leading-twist.

Positivity limit

$$|\delta q(x)| < q(x)$$

Soffer bound

$$|\delta q(x)| < \frac{1}{2}\left(q(x)+\Delta q(x)\right)$$

$\delta q(x)=\Delta q(x)$ non-relativistic regime

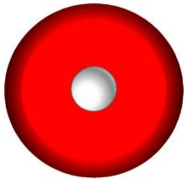
$\delta q(x)\neq\Delta q(x)$ relativistic regime

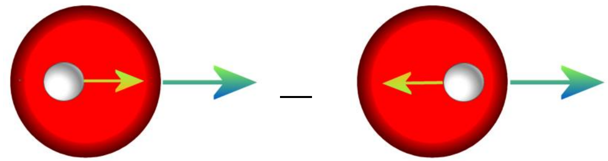
Probes relativistic nature of quarks

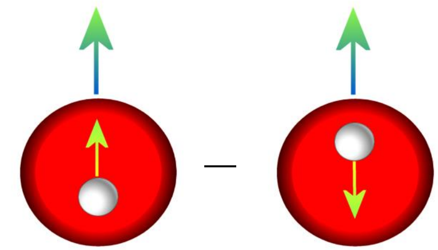
Due to angular momentum conservation, there is no gluon transversity in the nucleon

Completely different Q^2-evolution for Δq and δq !!

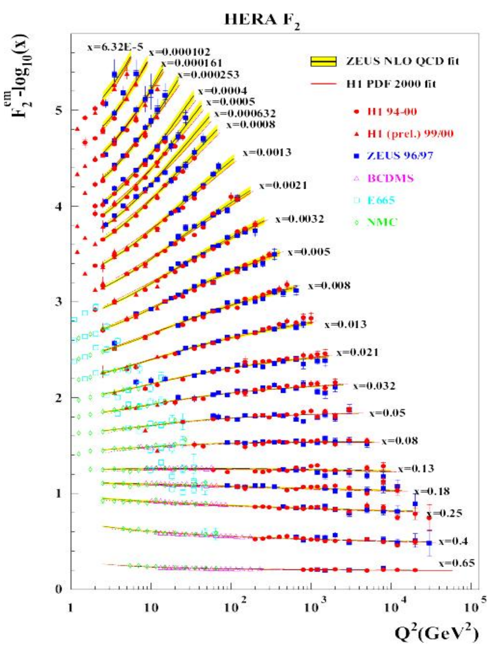
Quark structure of the nucleon

$f_1^q =$ 

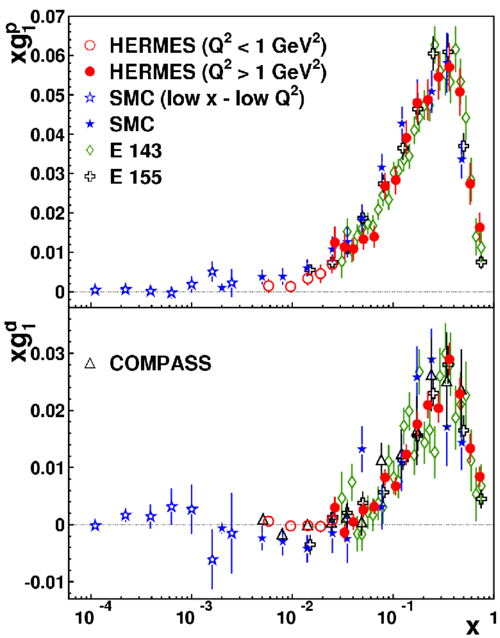
$g_1^q =$ 

$h_1^q =$ 

unpolarised quarks and nucleons

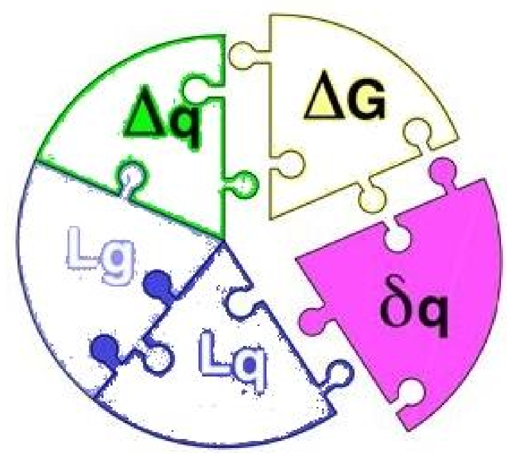


longitudinally polarised quarks and nucleons



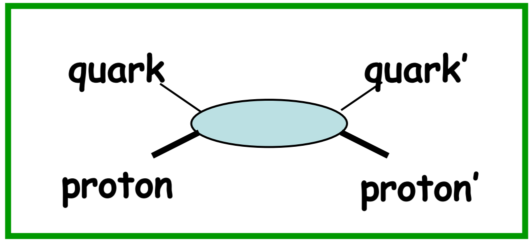
transversely polarised quarks and nucleons

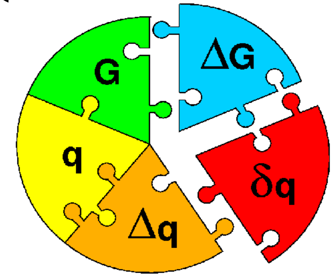
Only a glimpse !



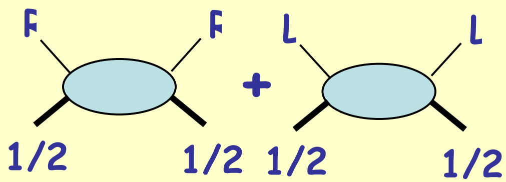
Leading Twist Distribution Functions

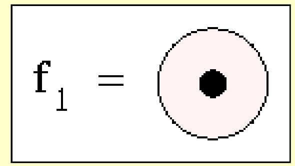
Probabilistic interpretation in helicity base:





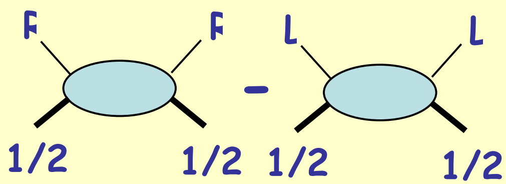
$f_1(x)$

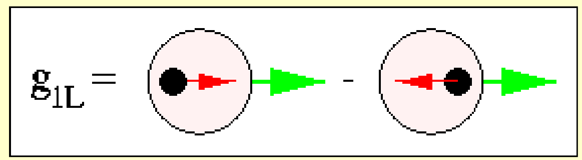




q(x) spin averaged
(well known)

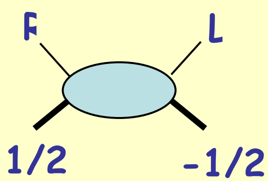
$g_1(x)$





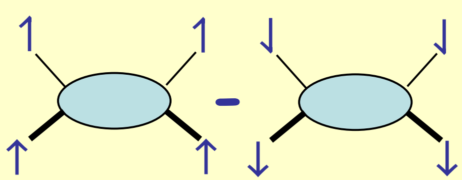
Δq(x) helicity diff.
(known)

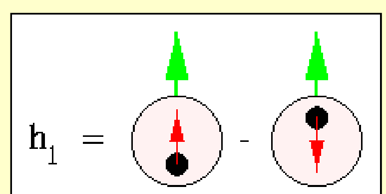
$h_1(x)$



No probabilistic interpretation in the helicity base (off diagonal)

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

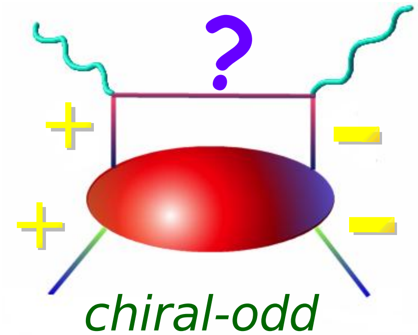




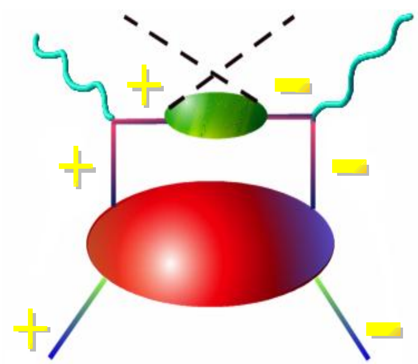
δq(x) helicity flip
(unknown)

How can one measure transversity?

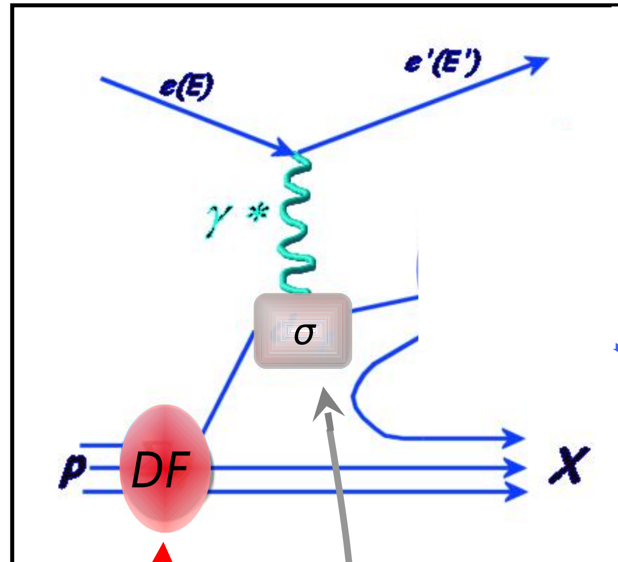
Need another chiral-odd object!



chiral odd
fragmentation
function



SIDIS: $l\, N^{\uparrow} \rightarrow l'\, h\, X$



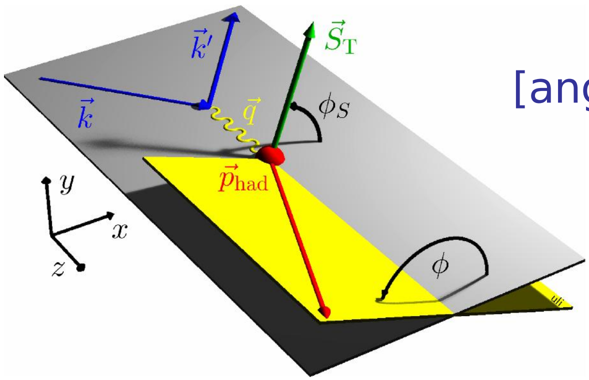
$$\sigma^{ep\rightarrow ehX} = \sum_q \delta q \otimes \sigma^{eq\rightarrow eq} \otimes H_1^{\perp}$$

chiral even!

Transversity

Collins FF

Asymmetries and moments

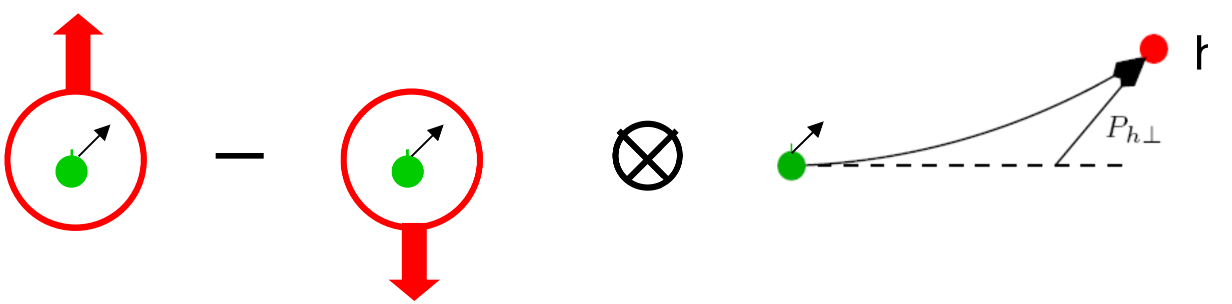


[angle and moments definitions according to Trento conventions

$$A_{UT}^{h}(\varphi,\varphi_S)=\frac{1}{|S_T|}\frac{N_h^{\uparrow}(\varphi,\varphi_S)-N_h^{\downarrow}(\varphi,\varphi_S)}{N_h^{\uparrow}(\varphi,\varphi_S)+N_h^{\downarrow}(\varphi,\varphi_S)}=$$

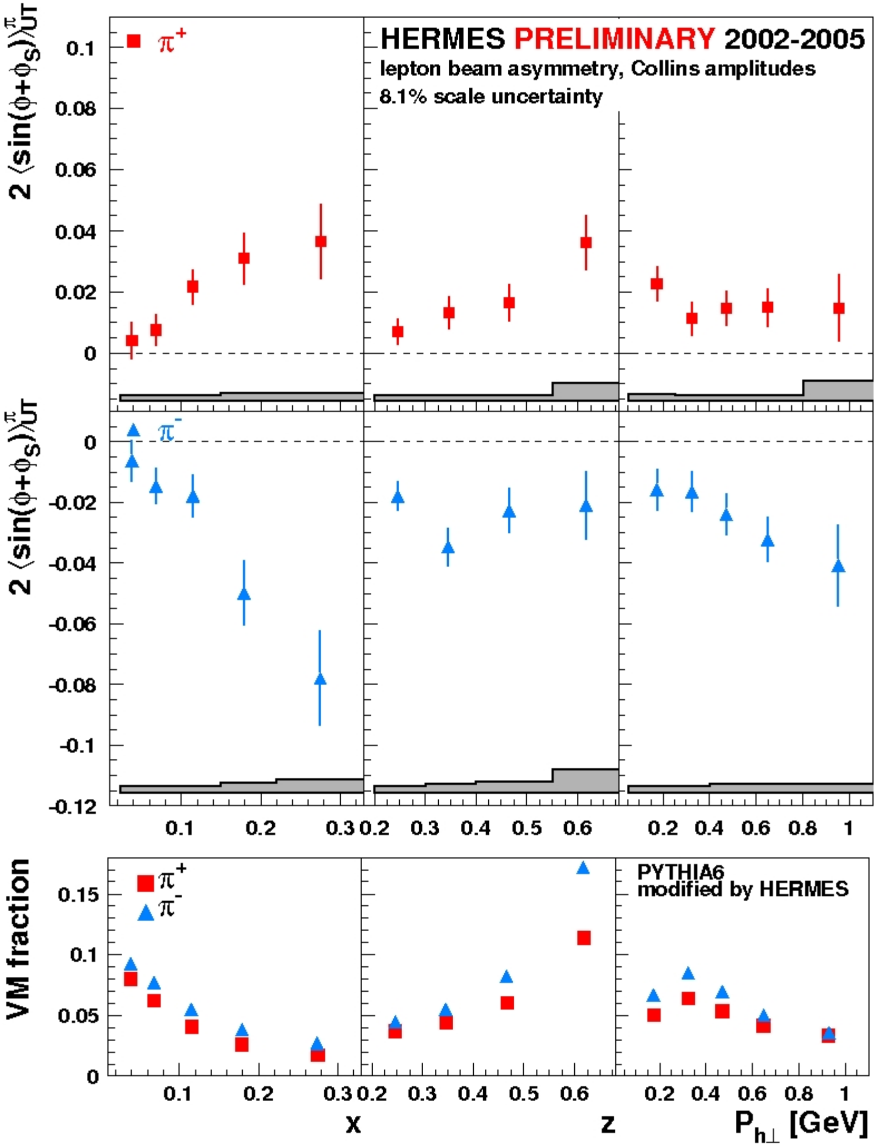
Collins moment

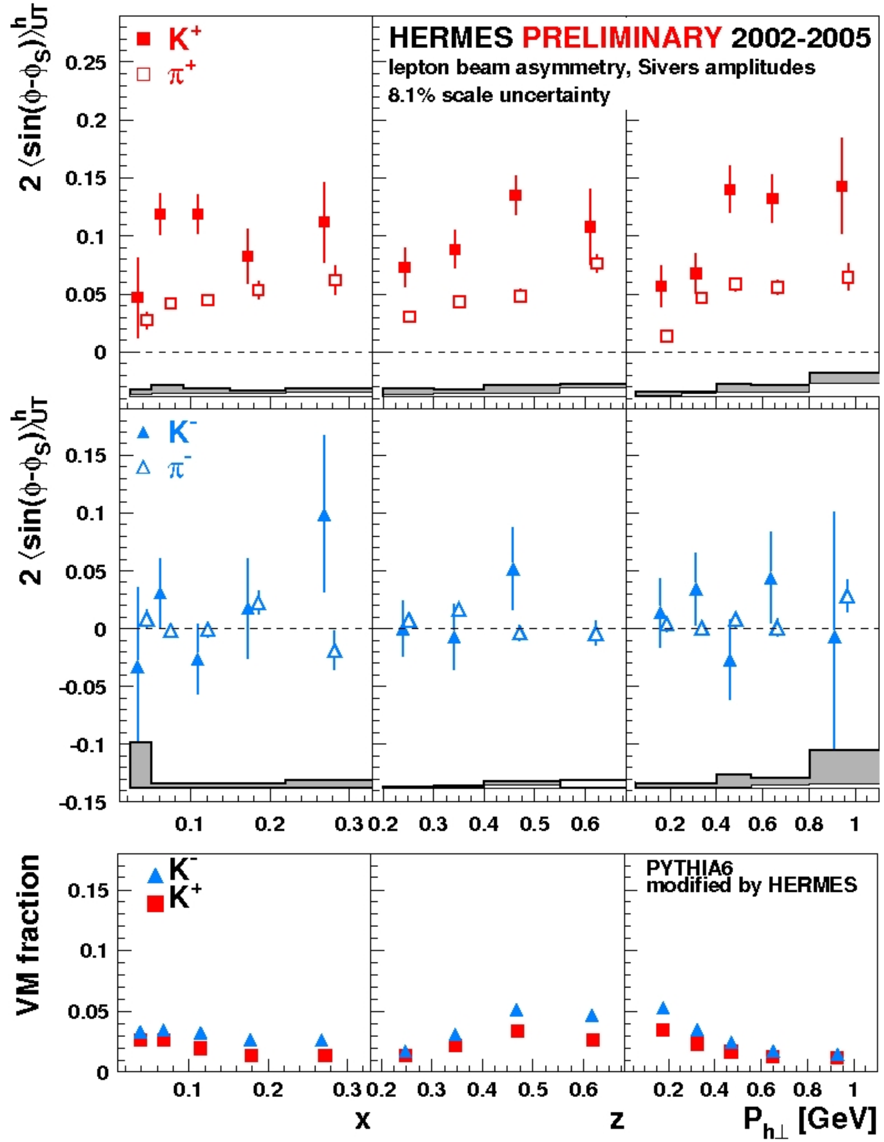
$$\text{¿}\ldots\sin(\varphi+\varphi_S)\cdot\frac{\sum_q e_q^2 I\left[\ldots\delta q(x,\vec{p}_T^{\,2})\cdot H_1^{\text{¿}q}(z,\vec{k}_T^{\,2})\right]}{\sum_q e_q^2 q(x)\cdot D_1^q(z)}$$



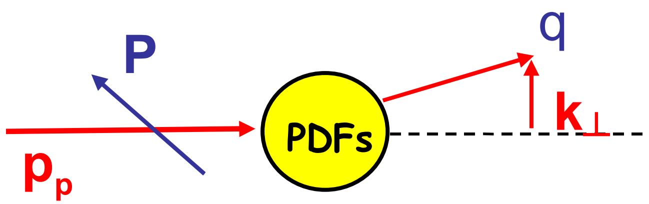
Collins and Sivers from SIDIS

$A_{coll}(\varphi+\varphi_S) \propto h_1^q(x) H_1^{\perp q}(z)$ $A_{siv}(\varphi-\varphi_S) \propto f_{1T}^{\perp}(x) D_1(z)$

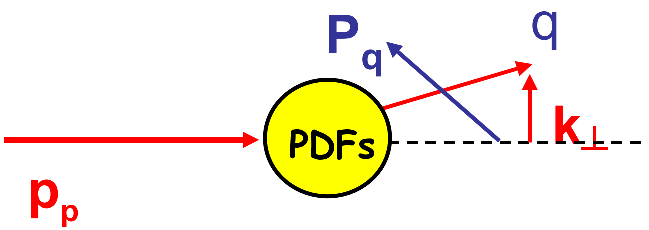




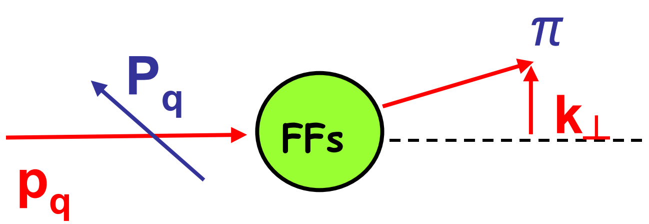
Correlation Functions



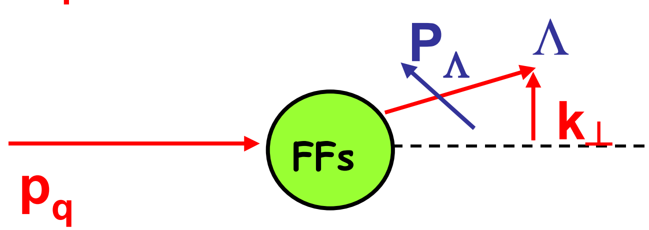
Sivers effect = number of partons in polarized proton depends on $\mathbf{P} \cdot (\mathbf{p} \times \mathbf{k}_\perp)$



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



Collins effect = fragmentation of polarized quark depends on $\mathbf{P}_q \cdot (\mathbf{p}_q \times \mathbf{k}_\perp)$



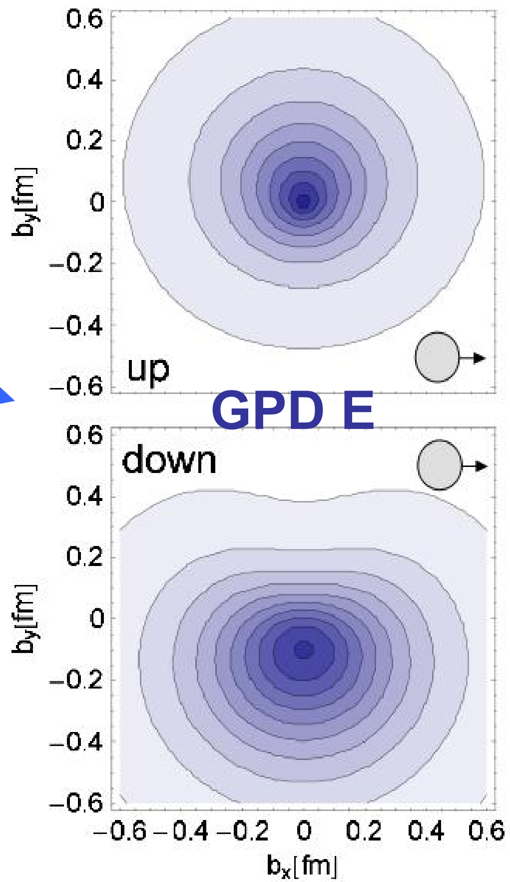
Polarizing FF = polarization of hadrons from unpolarized partons depends on $\mathbf{P}_\Lambda \cdot (\mathbf{p}_q \times \mathbf{k}_\perp)$

These effects may generate SSA

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

TMDs Correlation Functions

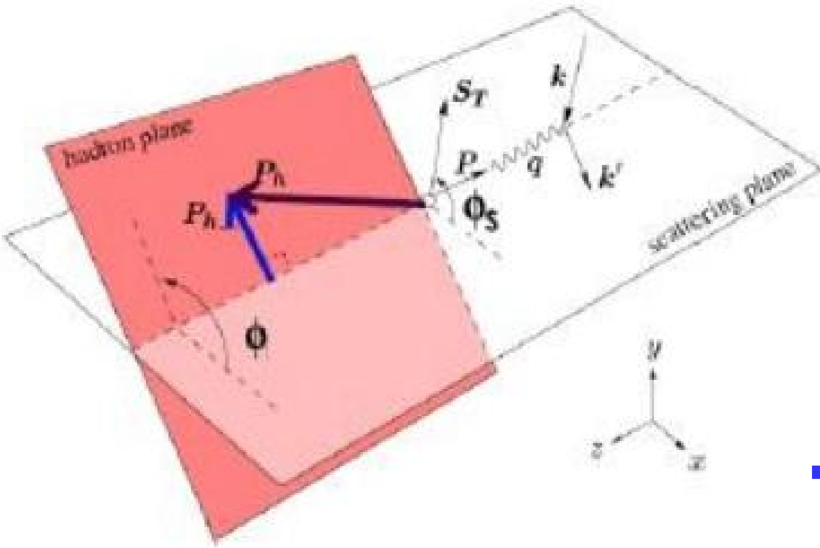
N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	$g_{1T}^\perp$	h_1 $h_{1T}^\perp$



SIVERS

Quark orbital angular momentum

SIDIS cross section



Explicit dependence on transverse momentum of hadron $P_{h\perp}$

→ Factorization ?
Universality ?

Convolution of two unknown functions

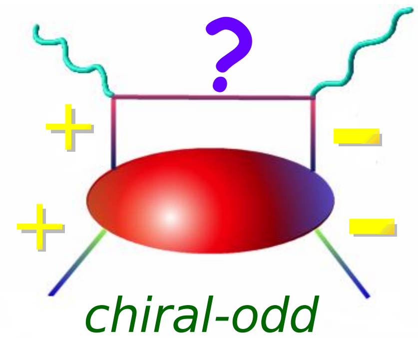
→ Assumptions on $k_\perp$ dependence !
Exp. acceptance on $P_{h\perp}$?

$$\frac{k_T\cdot \hat{P}_{h\perp}¿}{M}\delta q(x,\vec{k}_T)\cdot H_{1,q}^{¿}(z,\vec{p}_{¿})$$
¿
¿
$$+\dots$$
$$\sigma_{UT}\propto S_T\sin(\varphi+\varphi_S)\sum_q e_q^2 I¿$$
¿

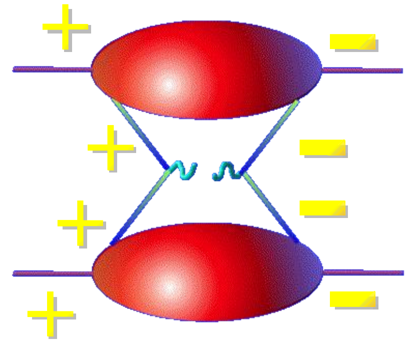
We need new observables

How can one measure transversity?

Need another chiral-odd object!

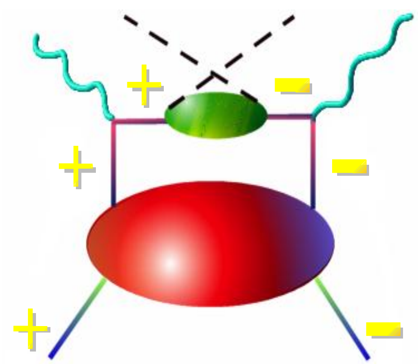


double helicity flip



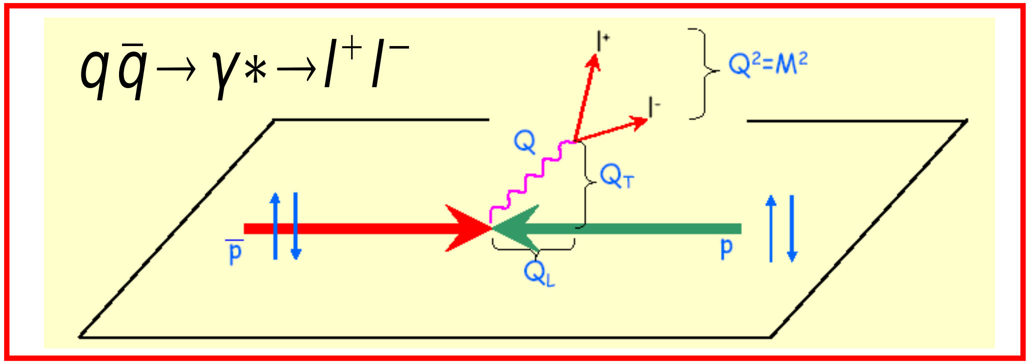
Drell-Yan: $p^{\uparrow} p^{\uparrow} \to l l \; X$

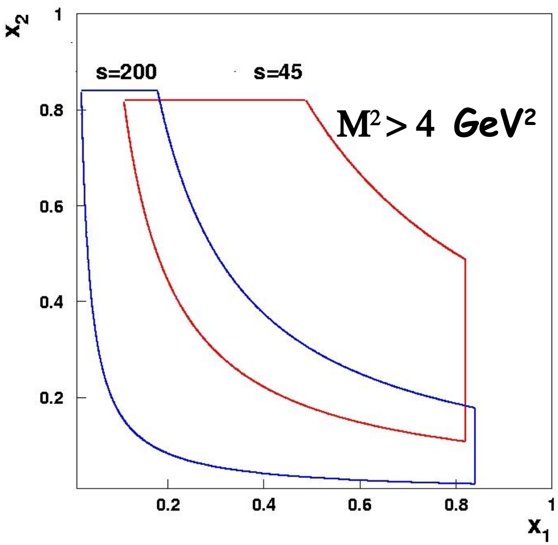
chiral odd fragmentation function

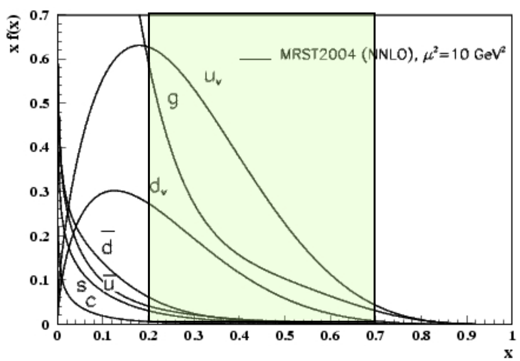


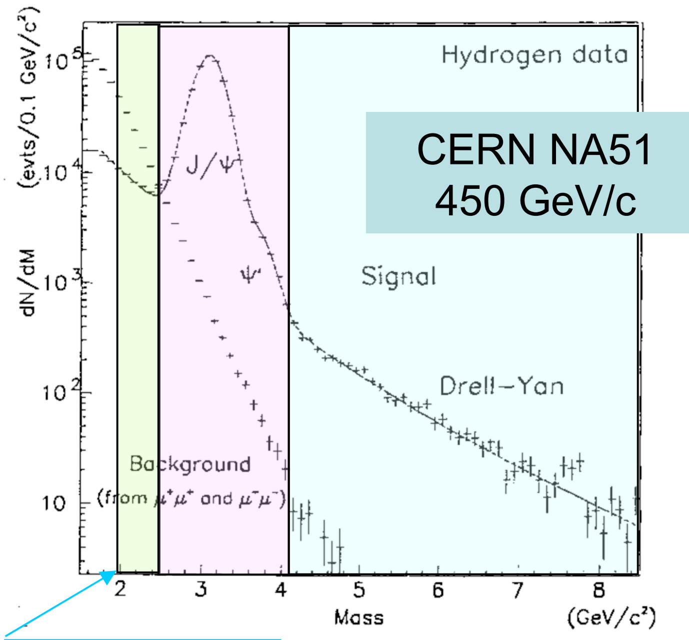
SIDIS: $l \; N^{\uparrow} \to l' h \; X$

Drell-Yan









Q²>4 GeV²

1 nb out of 50 mb total xsec

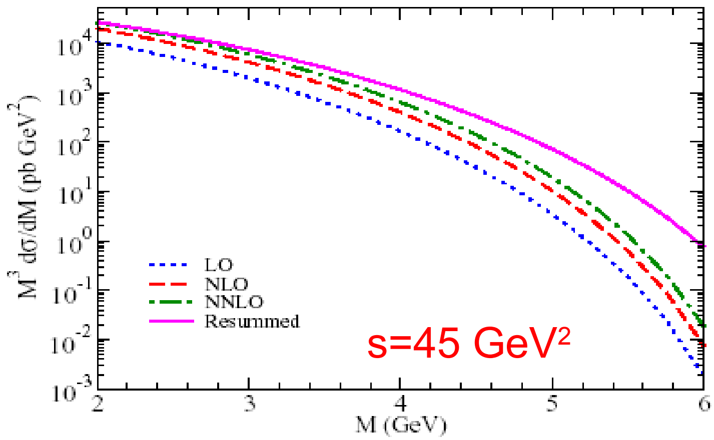
$$\frac{d^2\sigma}{dM^2 dx_F} = \frac{4\pi\alpha^2}{9M^2 s}\frac{1}{x_1+x_2}\sum_q e_q^2\left[q(x_1)\bar{q}(x_2)+\bar{q}(x_1)q(x_2)\right]$$

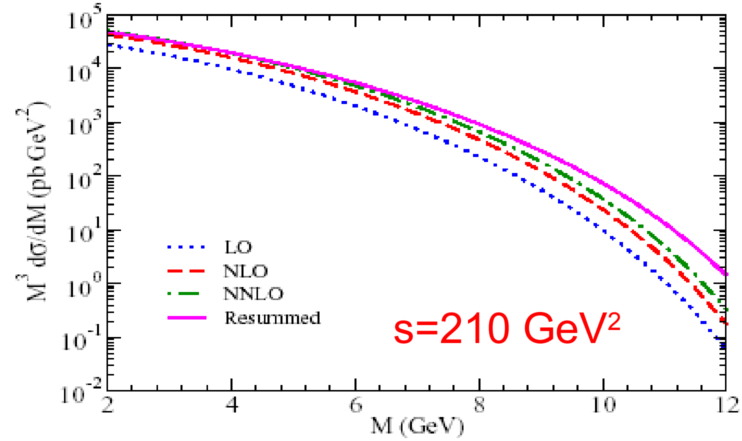
$q = u, \bar{u}, d, \bar{d}, \ldots$

M invariant Mass of lepton pair

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

Cross-section

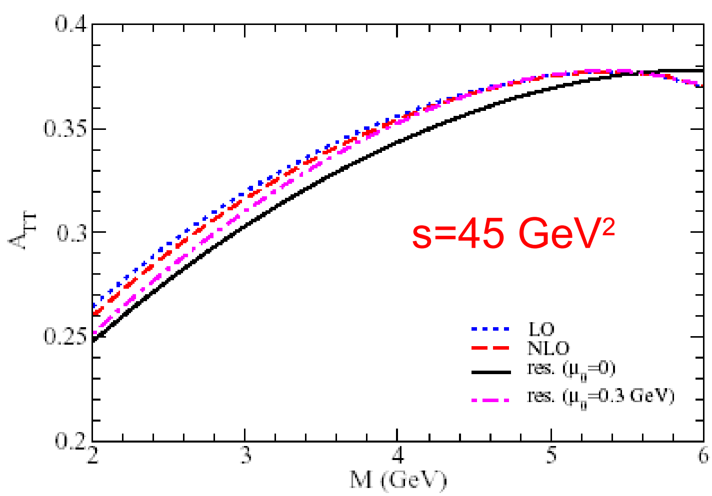


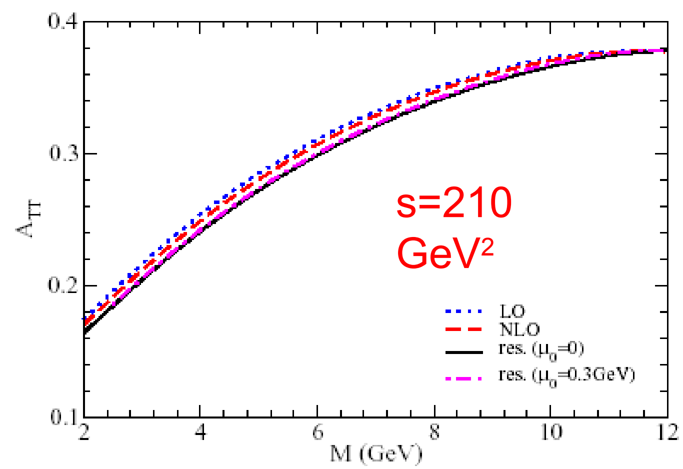


H. Shimizu et al., hep-ph/0503270

V. Barone et al., in preparation

Asymmetry





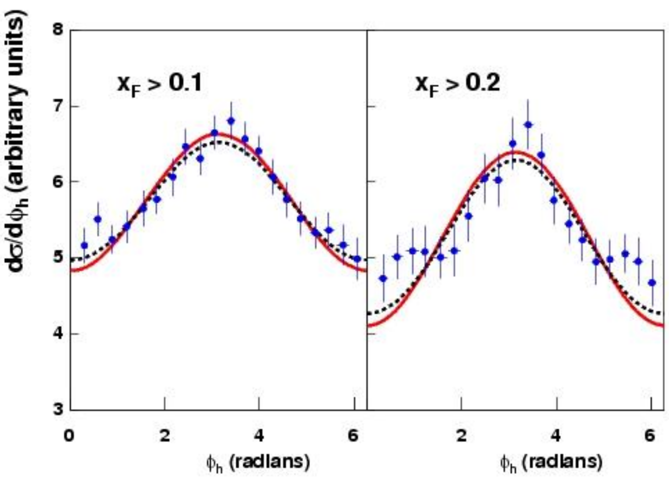
QCD corrections might be very large at smaller values of M, for cross-sections, not for A_{TT}: K-factor almost spin-independent

Unpolarized interactions

SIDIS

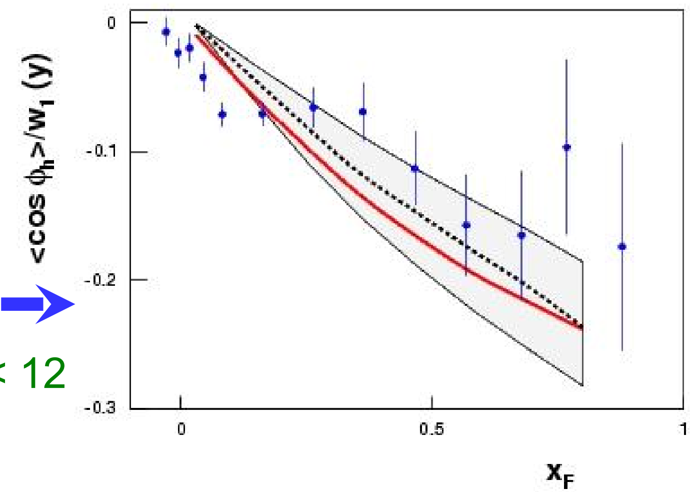
$$\frac{d^5\sigma}{dx\,dQ^2\,dz\,d\varphi_h\,dP_{h\perp}^2} \propto F_{UU,T} + \left[\sqrt{2\varepsilon(1+\varepsilon)}\cos\varphi_h F_{UU}^{\cos\varphi_h} + \varepsilon\cdot\cos 2\varphi_h F_{UU}^{\cos 2\varphi_h}\right]$$

Intrinsic $k_\perp$



EMC $\mu p \to \mu h X$

$\sqrt{s}$ = 20 GeV 3.5 < p_T < 12



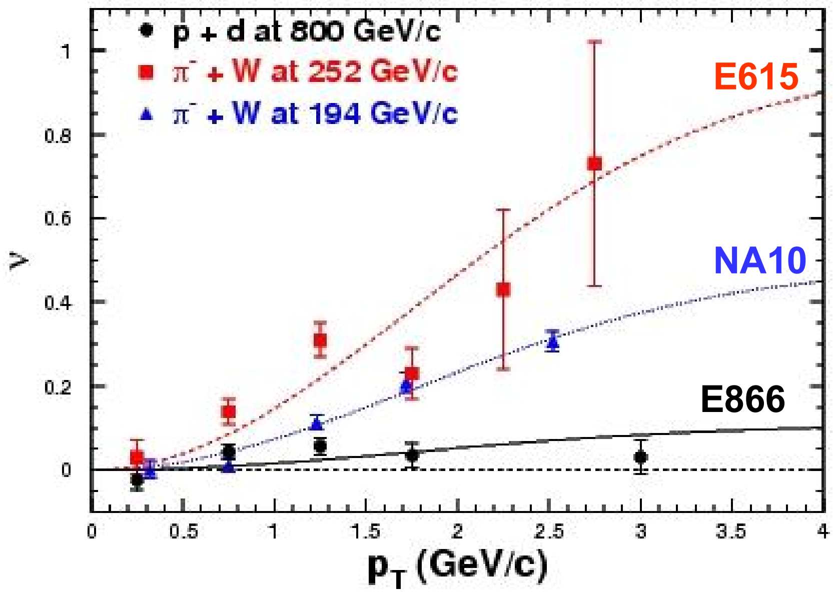
Unpolarized interactions

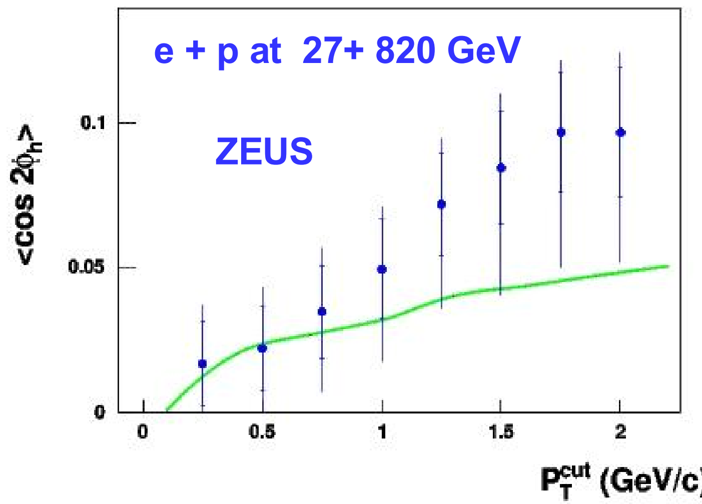
SIDIS

$$\frac{d^5\sigma}{dxdQ^2dzd\varphi_h dP_{h\perp}^2} \propto F_{UU,T} + \left[\sqrt{2\varepsilon(1+\varepsilon)}\cos\varphi_h F_{UU}^{\cos\varphi_h} + \varepsilon\cdot\cos 2\varphi_h F_{UU}^{\cos 2\varphi_h}\right]$$

Drell-Yan

$$\frac{d\sigma}{d\Omega} \propto 1 + \lambda\cos^2\theta + \mu\sin 2\theta + \frac{\nu}{2}\sin^2\theta\cos 2\varphi$$

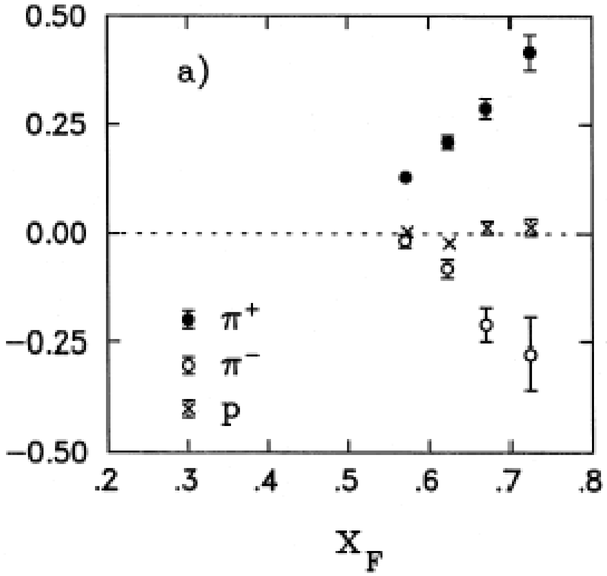




$$\nu \approx h_{1q}^{\perp} \times h_{1\bar{q}}^{\perp}$$

$$F_{UU}^{\cos 2\varphi_h} \approx h_{1q}^{\perp} \otimes H_{1q}^{h\perp}$$

SSA, pp → πX

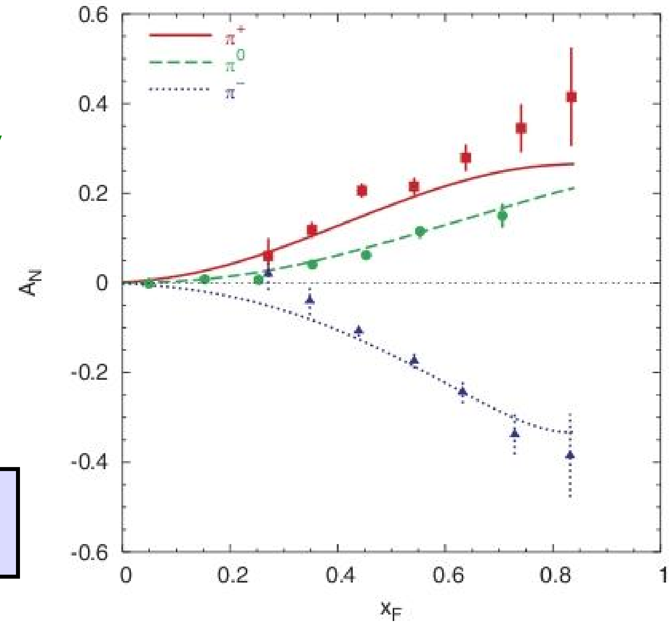


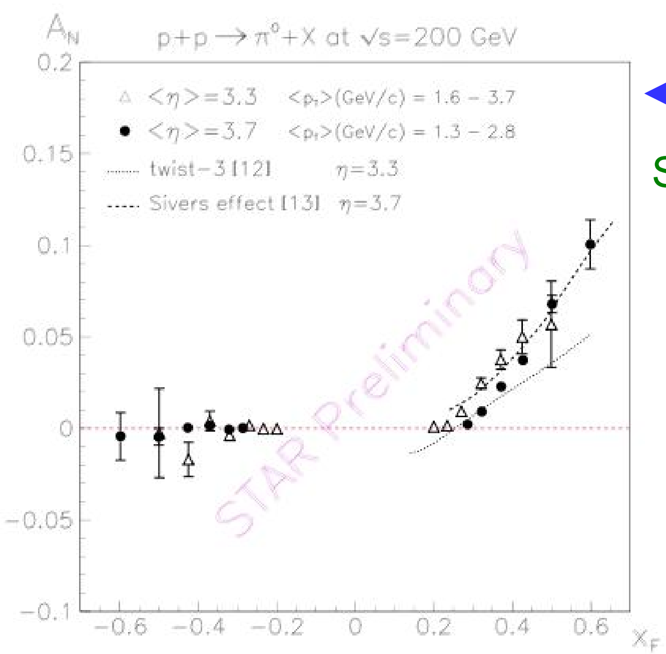
BNL-AGS $\sqrt{s}$ = 6.6 GeV
0.6 < p_T < 1.2 $p^\uparrow p$

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

U.D'Alesio and F.Murgia

Phys Rev D 70, 074009

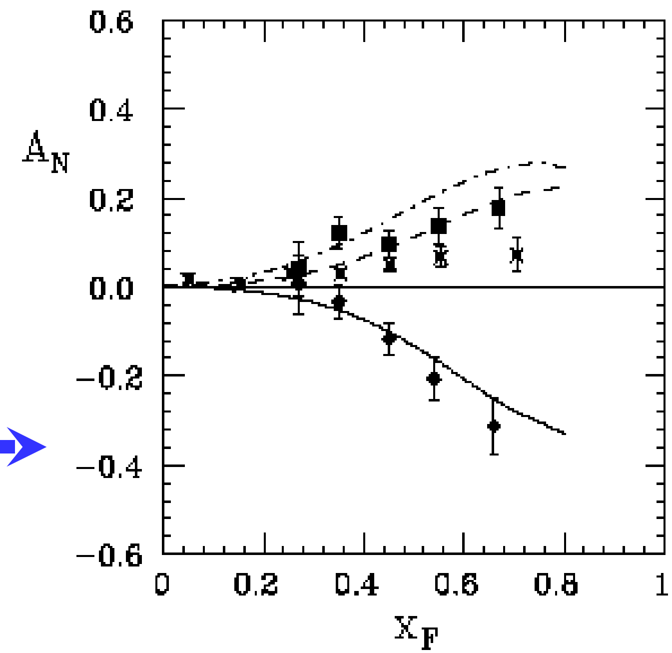




STAR-RHIC: $p^\uparrow p \to \pi^0 X$

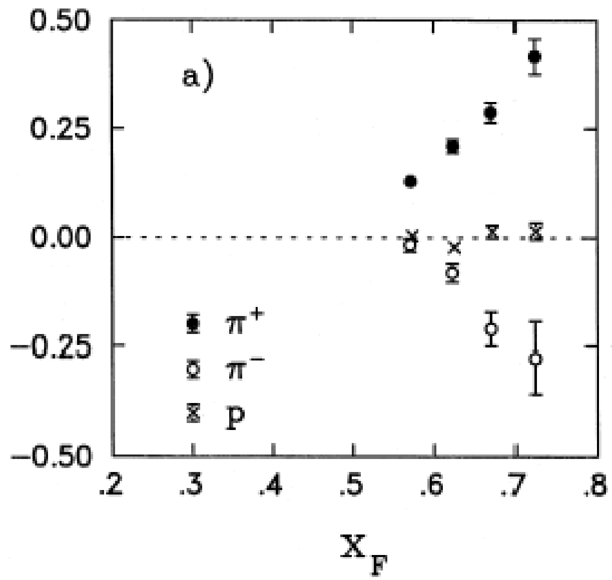
$\sqrt{s}$ = 200 GeV 1 < p_T < 3

Sivers



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

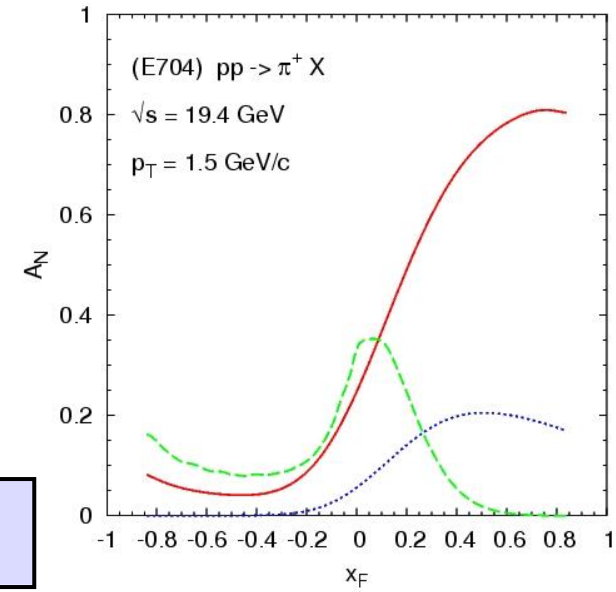
SSA, pp → πX

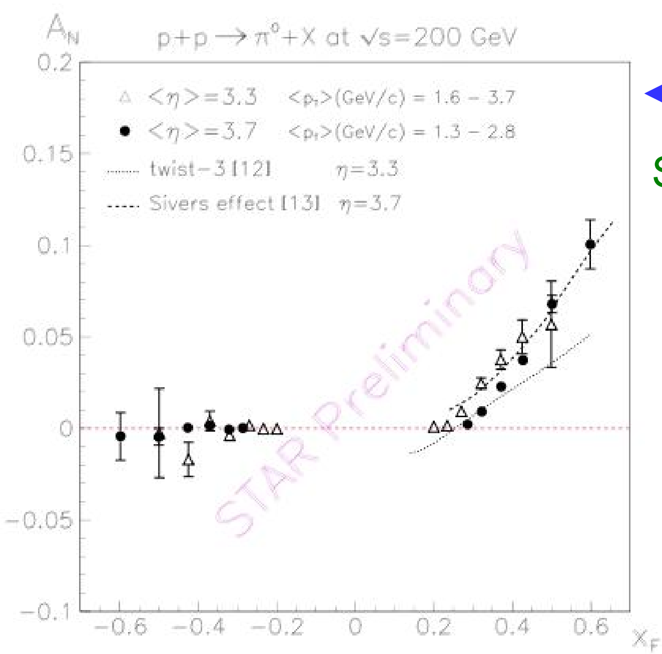


BNL-AGS $\sqrt{s}$ = 6.6 GeV
0.6 < p_T < 1.2 $p^{\uparrow}p$

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

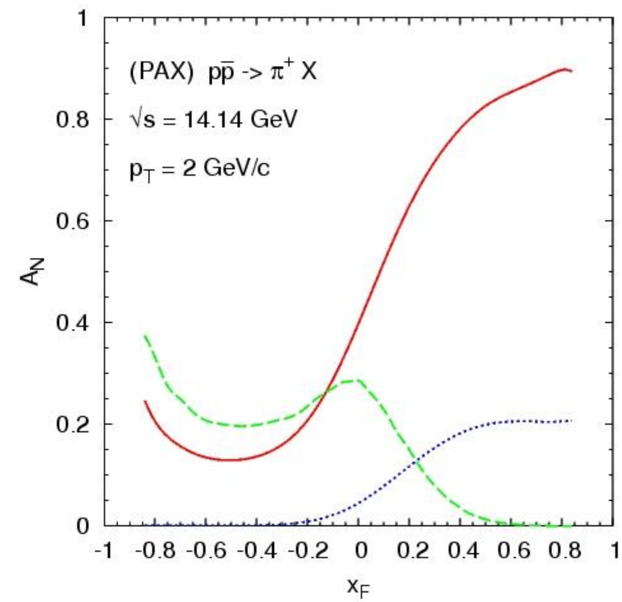
M. Anselmino et al.
hep-ph/0509035





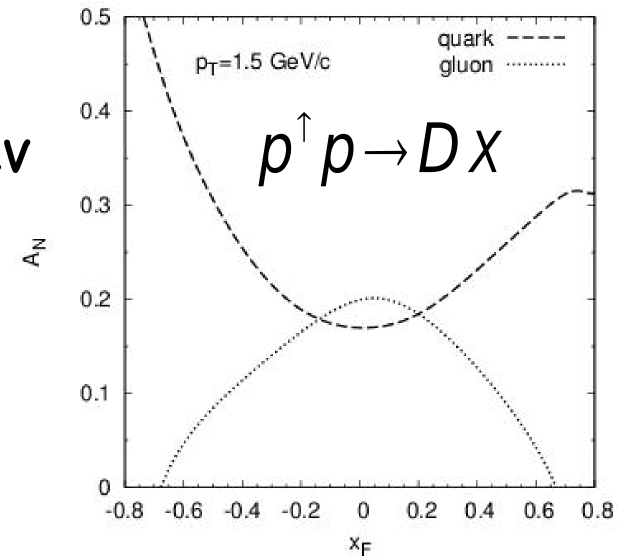
STAR-RHIC: $p^{\uparrow}p \rightarrow \pi^0 X$
$\sqrt{s}$ = 200 GeV 1 < p_T < 3

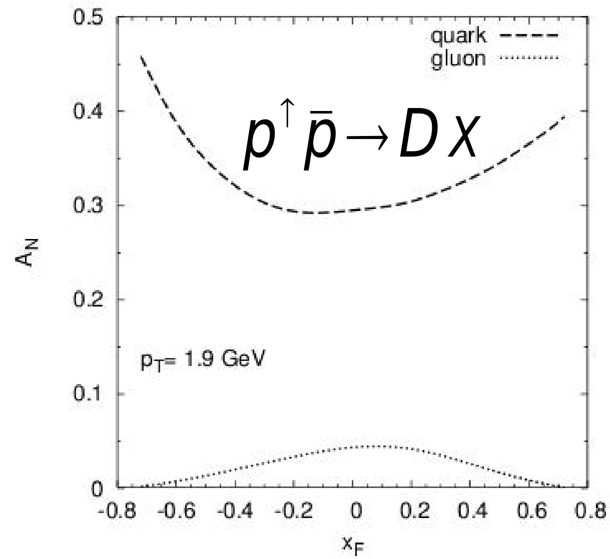
HESR $\sqrt{s}$ =15 GeV
0.7 < p_T < 2.0 $\bar{p}^{\uparrow}p$



SSA and TMDs

$\sqrt{s}$=10 GeV





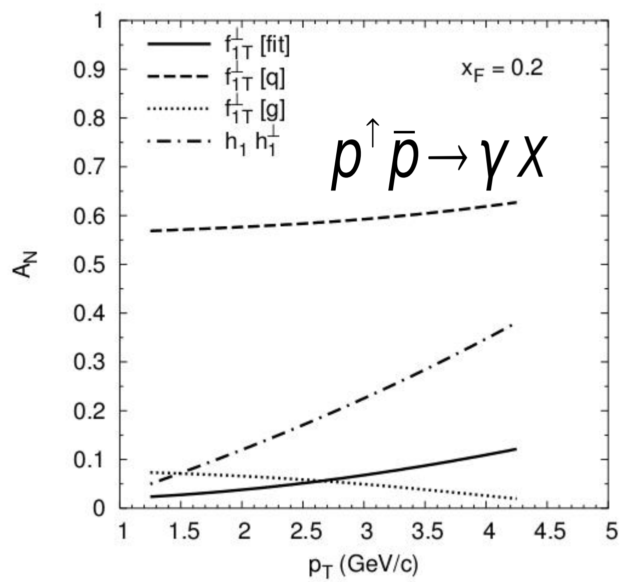
$\sqrt{s}$=15 GeV

U.D'Alesio and F. Murgia
hep-ph/0612208

No Collins effect in s-channel

$$q\bar{q} \to c\bar{c}$$

No fragmentation process

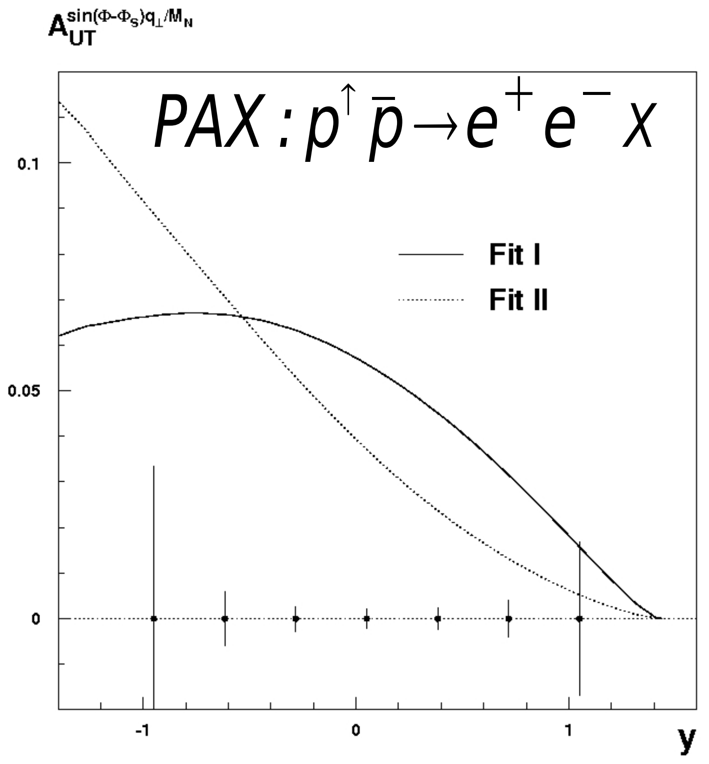


$\sqrt{s}$=15 GeV

Sivers from DY

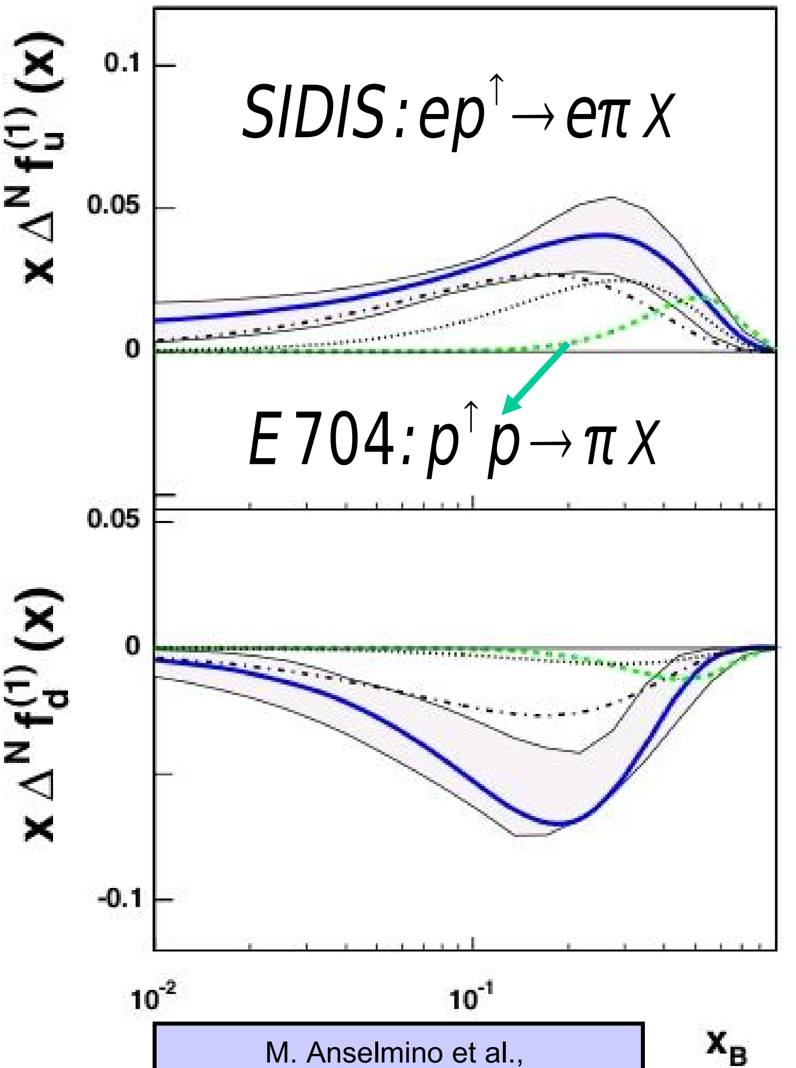
Test of Universality

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



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

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

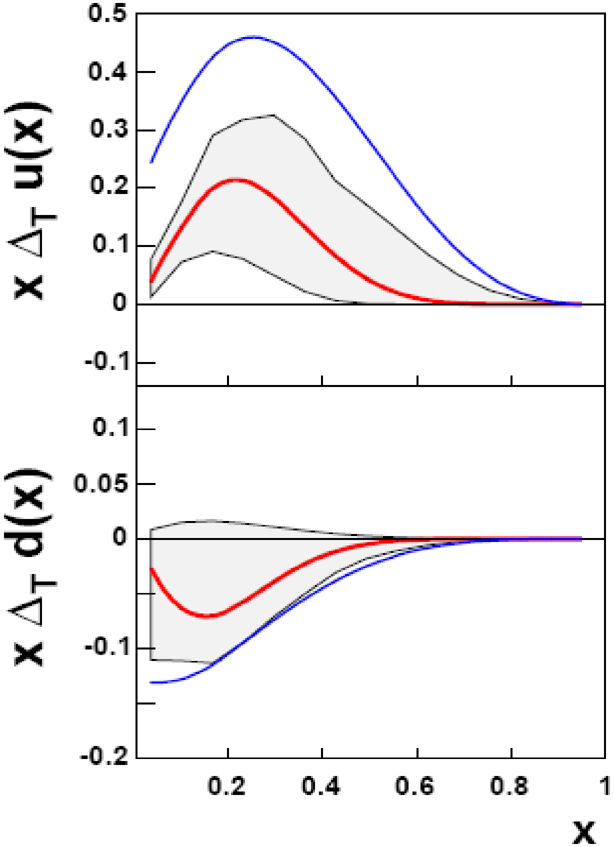


M. Anselmino et al.,
Phys. Rev. D72, 094007 (2005)

Transversity and Collins function

N/q	U	L	T
U	f_1		$h_1^{\perp}$
L		g_1	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	$g_{1T}^{\perp}$	h_1 $h_{1T}^{\perp}$

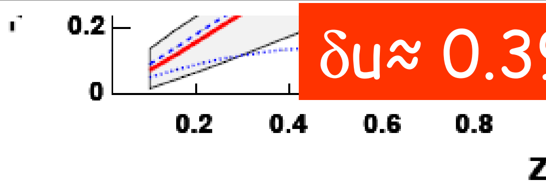
Transversity



Collins function

Tensor charges

Model [Ref.]	Δu	Δd	$\Delta\Sigma$	δu	δd	$\|\delta u/\delta d\|$	Q_0[GeV]	$\delta u(Q^2)$	$\delta d(Q^2)$
NRQM ⋆	1.33	-0.33	1	1.33	-0.33	4.03	0.28	0.97	-0.24
MIT [14] ⋄	0.87	-0.22	0.65	1.09	-0.27	4.04	0.87	0.99	-0.25
CDM [92] ⊕	1.08	-0.29	0.79	1.22	-0.31	3.94	0.40	0.99	-0.25
CQSM1 [223] ×	0.90	-0.48	0.37	1.12	-0.42	2.67	0.60	0.97	-0.37
CQSM2 [226] +	0.88	-0.53	0.35	0.89	-0.33	2.70	0.60	0.77	-0.29
CQM [231] ⊗	0.65	-0.22	0.43	0.80	-0.15	5.33	0.80	0.72	-0.13
LC [86] ∘	1.00	-0.25	0.75	1.17	-0.29	4.03	0.28	0.85	-0.21
Spect. [252] ∗	1.10	-0.18	0.92	1.22	-0.25	4.88	0.25	0.83	-0.17
Lattice [260] ▷	0.64	-0.35	0.29	0.84	-0.23	3.65	1.40	0.80	-0.22



$\delta u \approx 0.39, \quad \delta d \approx -0.16$

M. Wakamatsu
arXiv: 0705.2917

M. Anselmino et al.
hep-ph/0008186

Soffer inequality

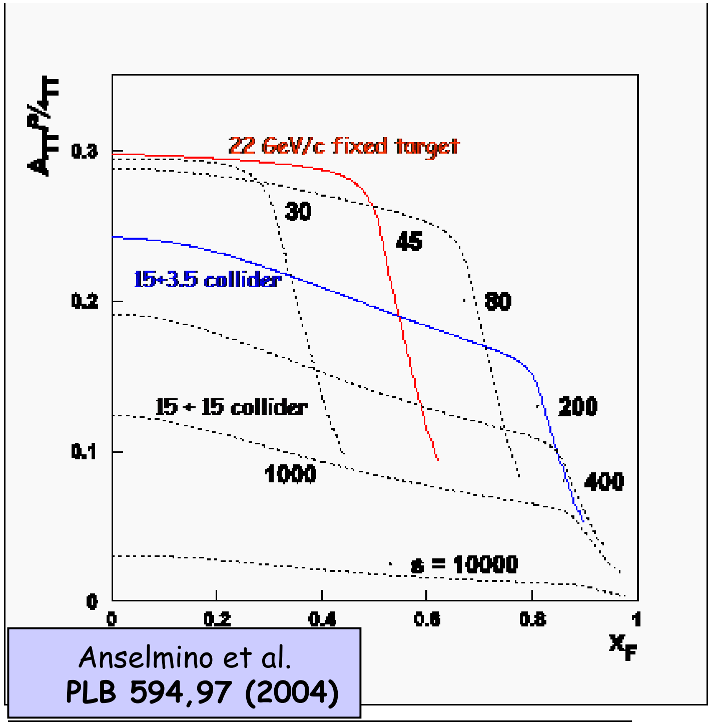
$$f(x) + \Delta f(x) \geq 2|\Delta_T f(x)|$$

h_1 from $\bar{p}$-p Drell-Yan

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

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

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



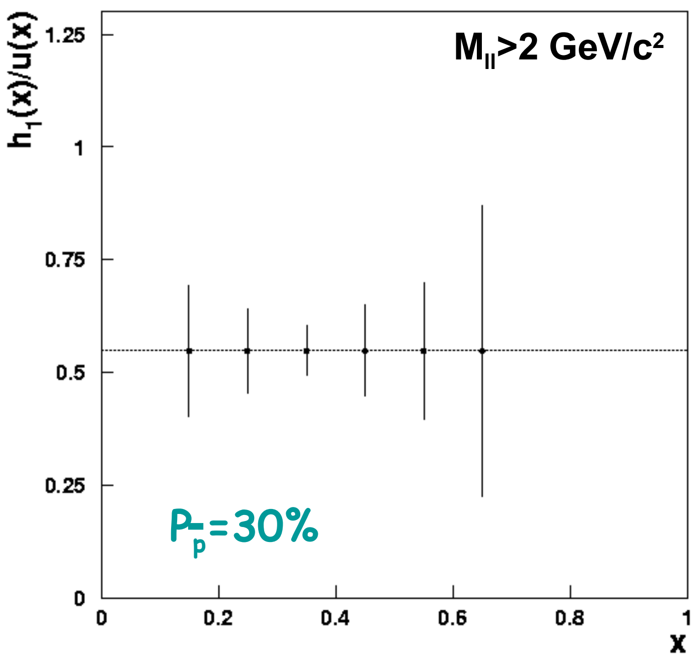
Anselmino et al.
PLB 594,97 (2004)

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

HESR : $M^2/s=x_1x_2$~0.3-0.5
valence quarks
(A_{TT} large ~ 0.3)

Estimated signal for h_1

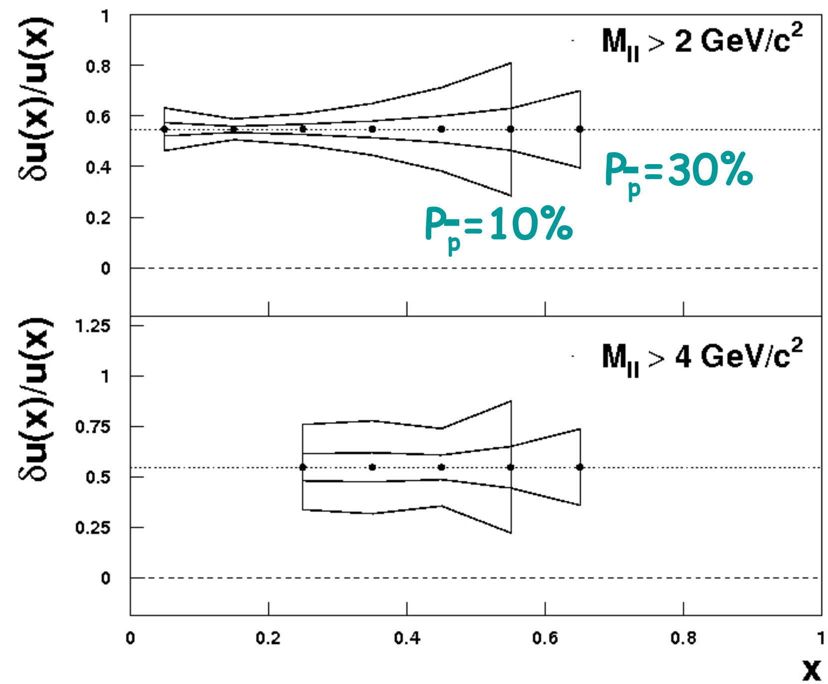
1 year of data taking (200 days)



Fixed target:

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

first unambiguos extraction
20 % precision for $h_{1u}(x)$
in the valence region



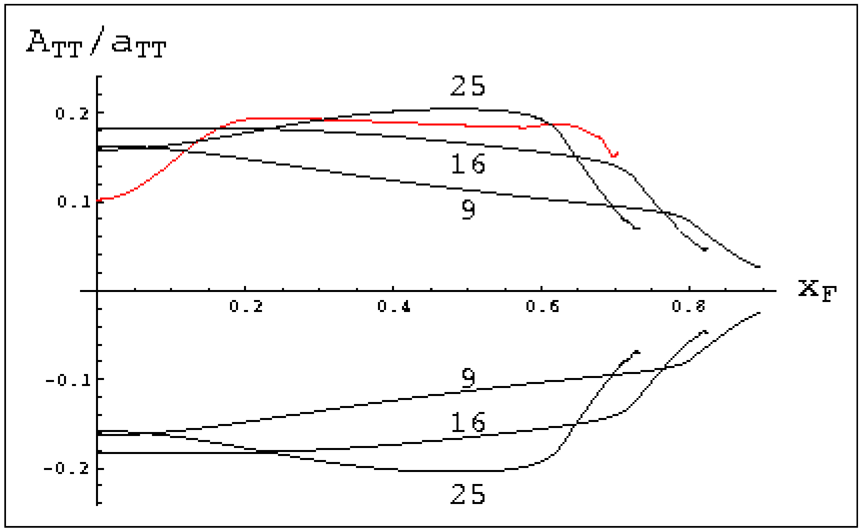
Collider:

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

"safe" region accessible
10 % precision for $h_{1u}(x)$
in an extended x region

h_1 from p-p Drell-Yan

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



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

1year run: ≈ 0.03 error on the A_{TT} asymmetry

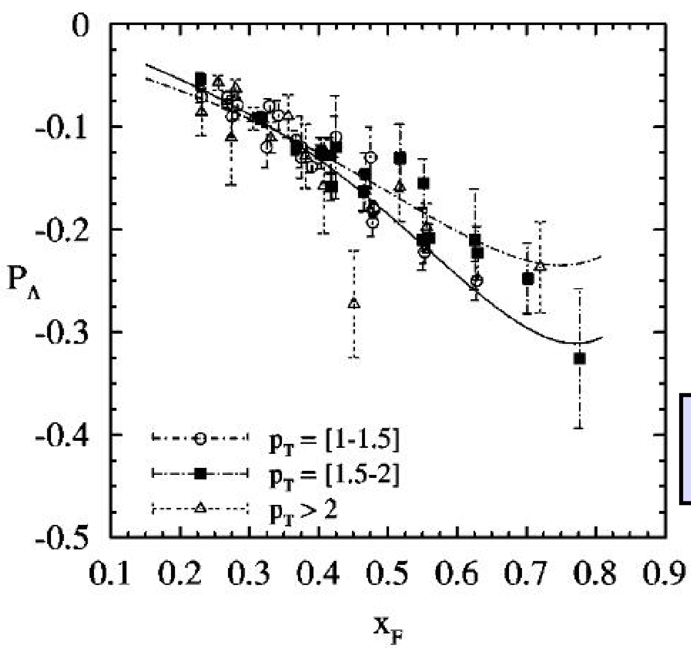
Barone, Calarco, Drago

Martin, Schäfer, Stratmann, Vogelsang

RHIC:	$M^2/s=x_1x_2\sim10^{-3}$ →	sea quarks	(A_{TT} ~ 0.01)
JPARC/U70:	$M^2/s=x_1x_2\sim10^{-1}-10^{-2}$ →	valence and sea	(A_{TT} ~ 0.1)
HESR:	$M^2/s=x_1x_2\sim10^{-1}-10^{-2}$ →	valence and sea	(A_{TT} ~ 0.1)

Hadron spectroscopy:
Partial wave analysis

Lambda polarisation



pBe→$\Lambda^{\uparrow}$X

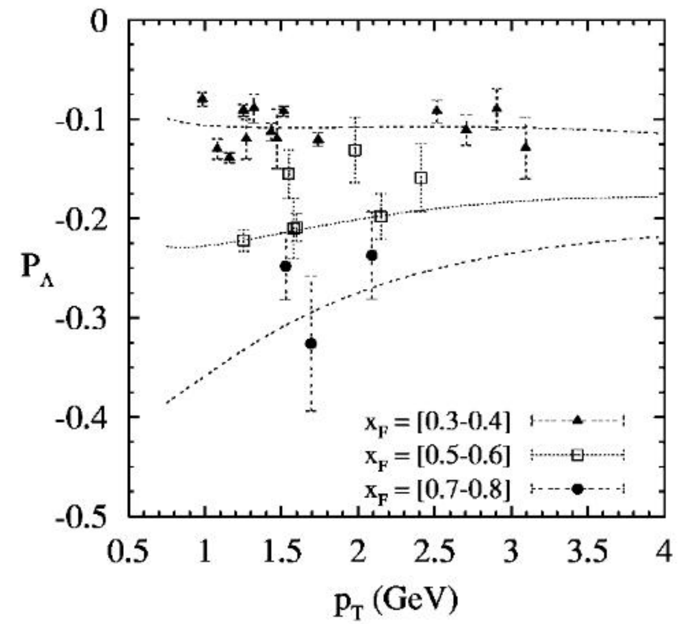
$\sqrt{s}$ = 80-100 GeV

1 < p_T < 4 GeV

Polarizing FF

M. Anselmino et al.

Hep-ph/0008186



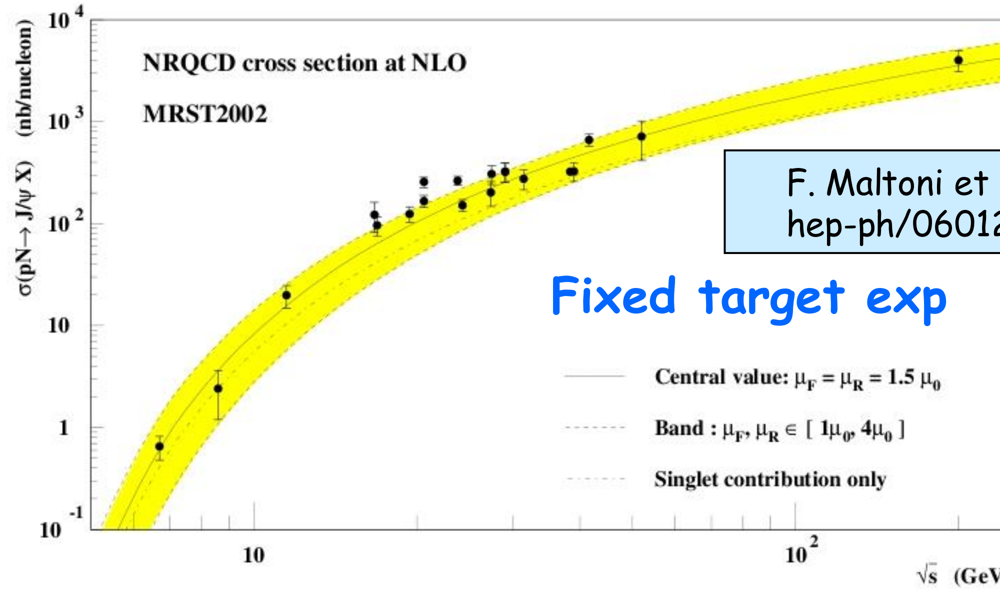
J/ψ,ψ' production

NRQCD

Able to reproduce the unpolarized xsec

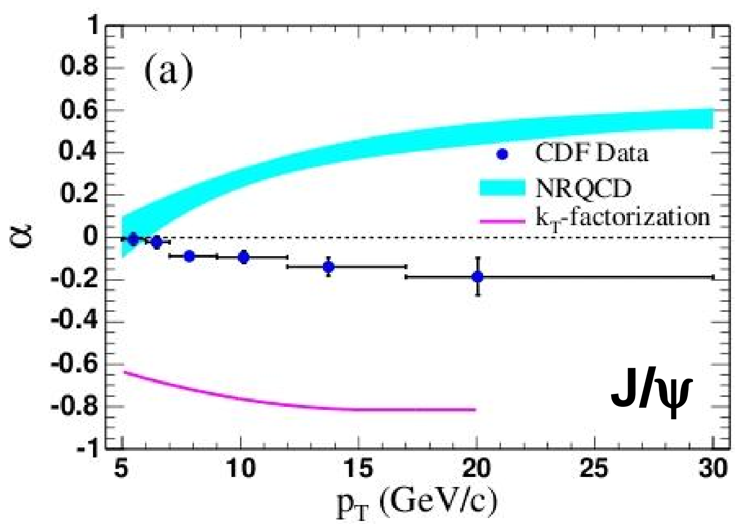
Fails in predicting polarization vs p_T at CDF

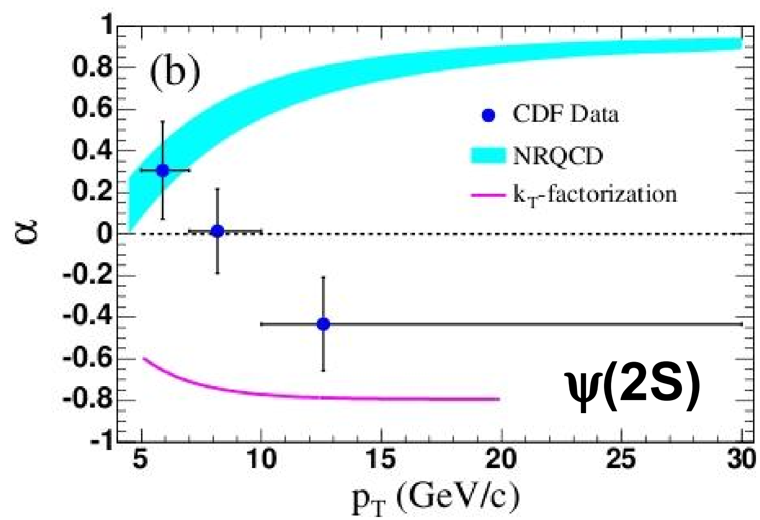
$$\frac{dN}{d\cos\theta} \propto 1+\alpha\cos^2\theta$$



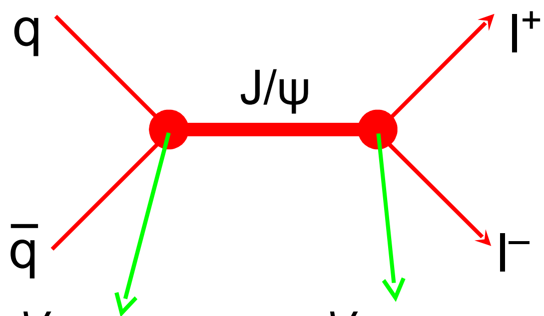
F. Maltoni et al., hep-ph/0601203

Fixed target exp

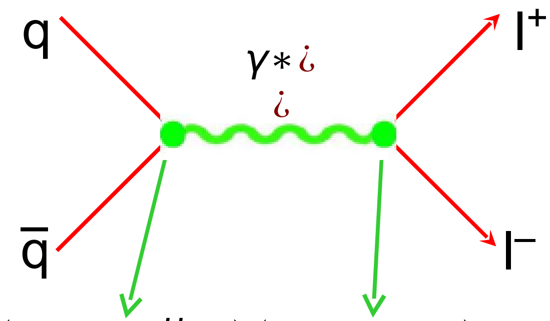




$$p\bar{p} \to J/\Psi X \to l^+ l^- X$$



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



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

all vector couplings, same spinor structure

$\Rightarrow$ $\hat{a}_{TT}^{J/\Psi} = \hat{a}_{TT}^{\gamma*¿}$ ¿

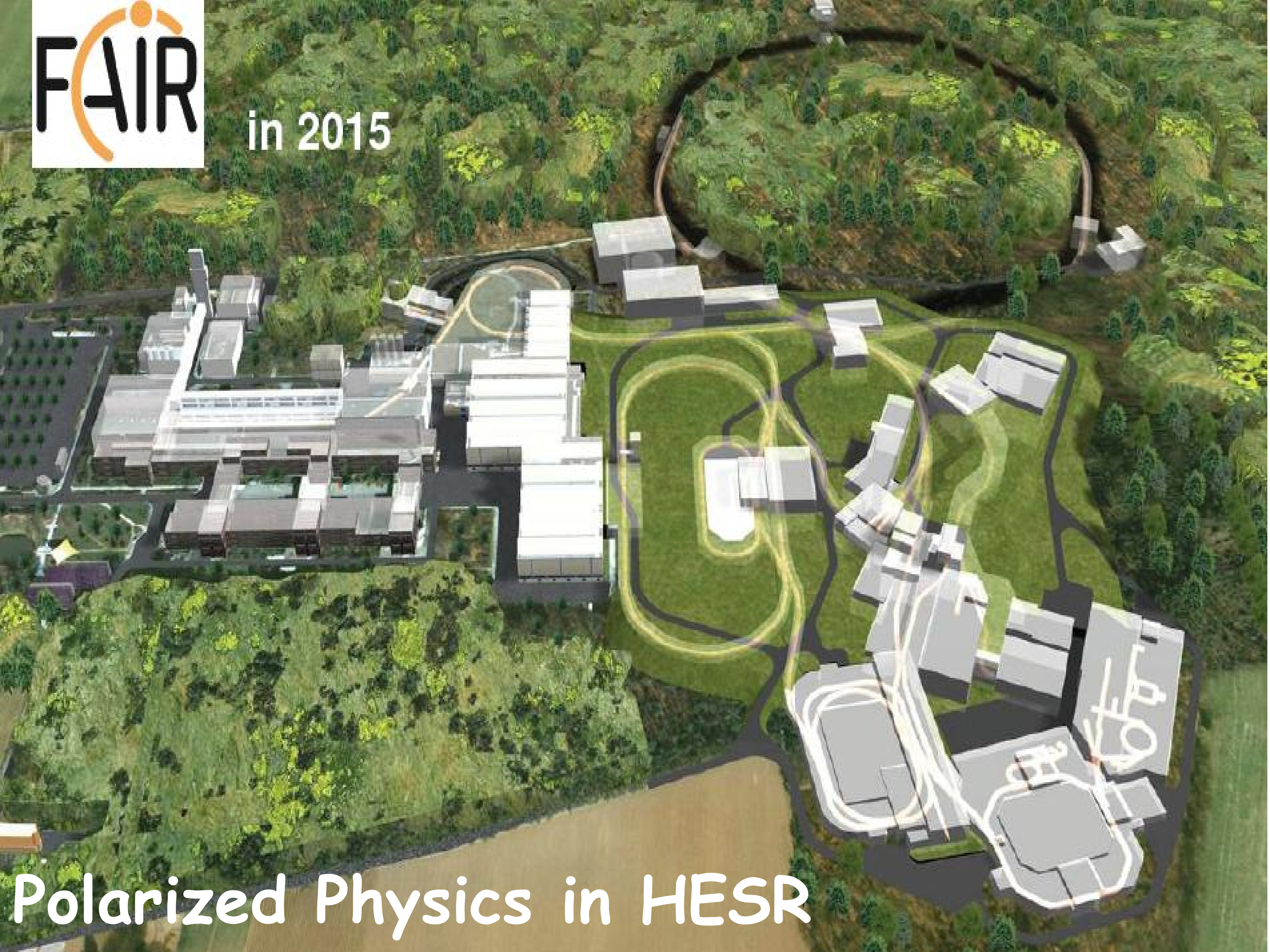
M. A., V. Barone, A. Drago and N. Nikolaev

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

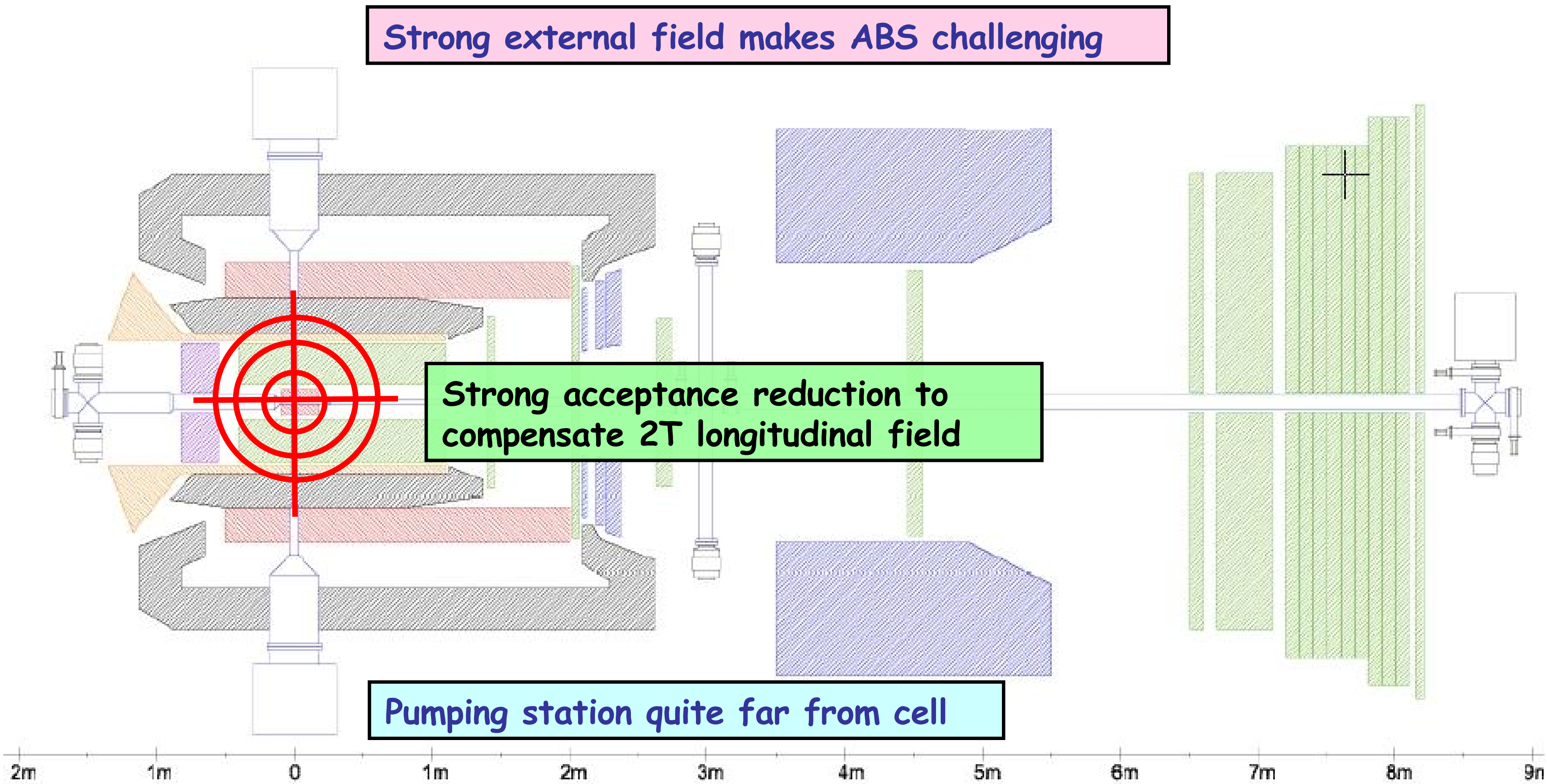
$\Rightarrow$ measure A_{TT} also in J/ψ resonance region

ANKE vs new interaction point at COSY

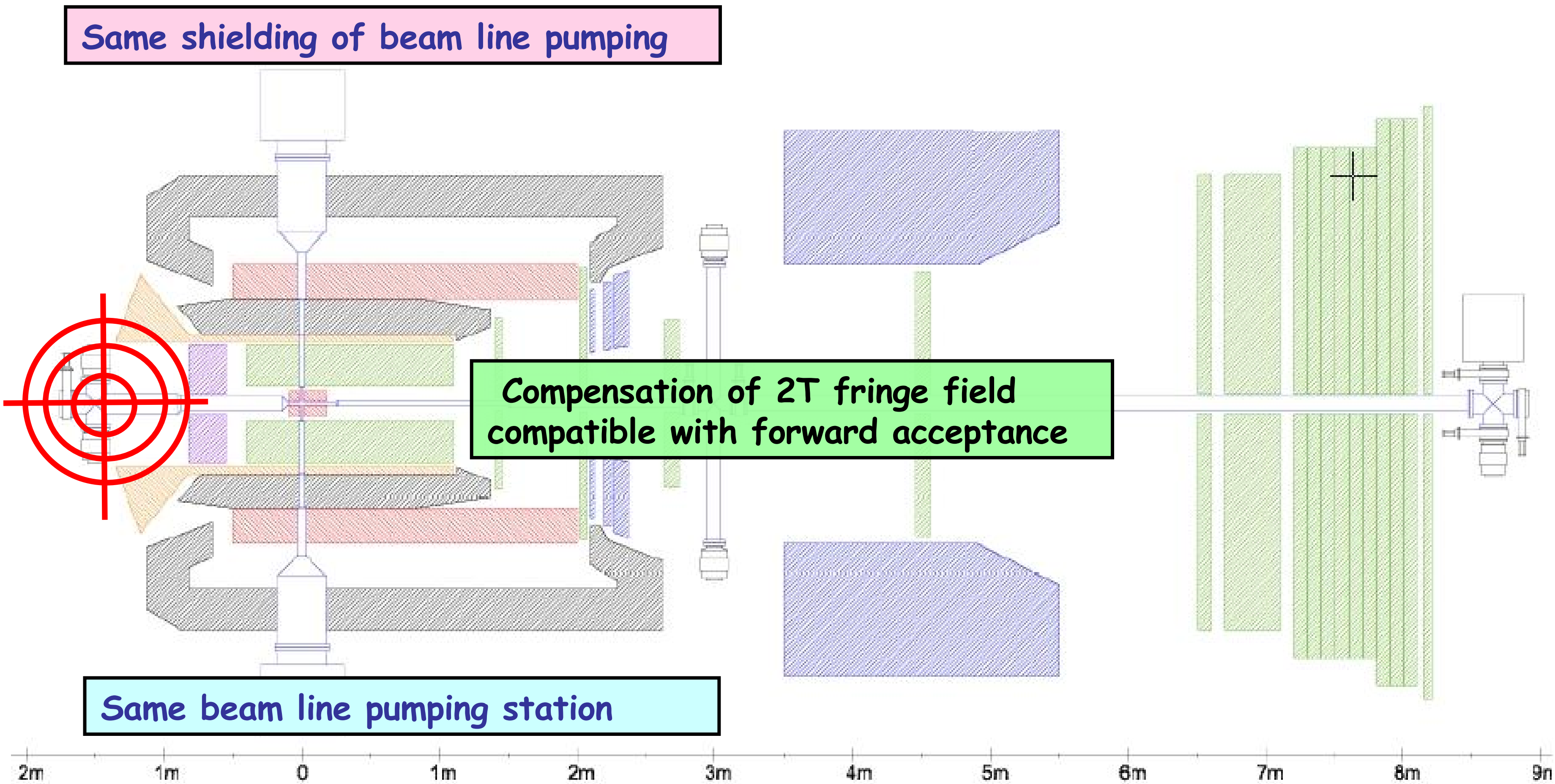
	Fixed target s=2-30 GeV^2		Collider s=30-200 GeV^2	
	SSA	DSA	SSA	DSA
Elastic p-pbar		$\sigma(\uparrow\uparrow)/\sigma(\uparrow\downarrow)$		
Pbar p -> e+e-	EMFF phases	|GM|, |GE|		
Pbar p -> e+e-X	Sivers sign, TMDs	Transversity	Sivers	Transversity
Pbar p -> h X	TMDs		TMDs	
Pbar p -> γ X	Sivers		Sivers	
Pbar p -> D X	Sivers		Sivers	
Pbar p -> J/ψ X	NRQCD		NRQCD	
…………				


FAIR
in 2015
Polarized Physics in HESR

Transverse Polarized Target at (0,0)



Transverse Polarized Target at (-150,0)

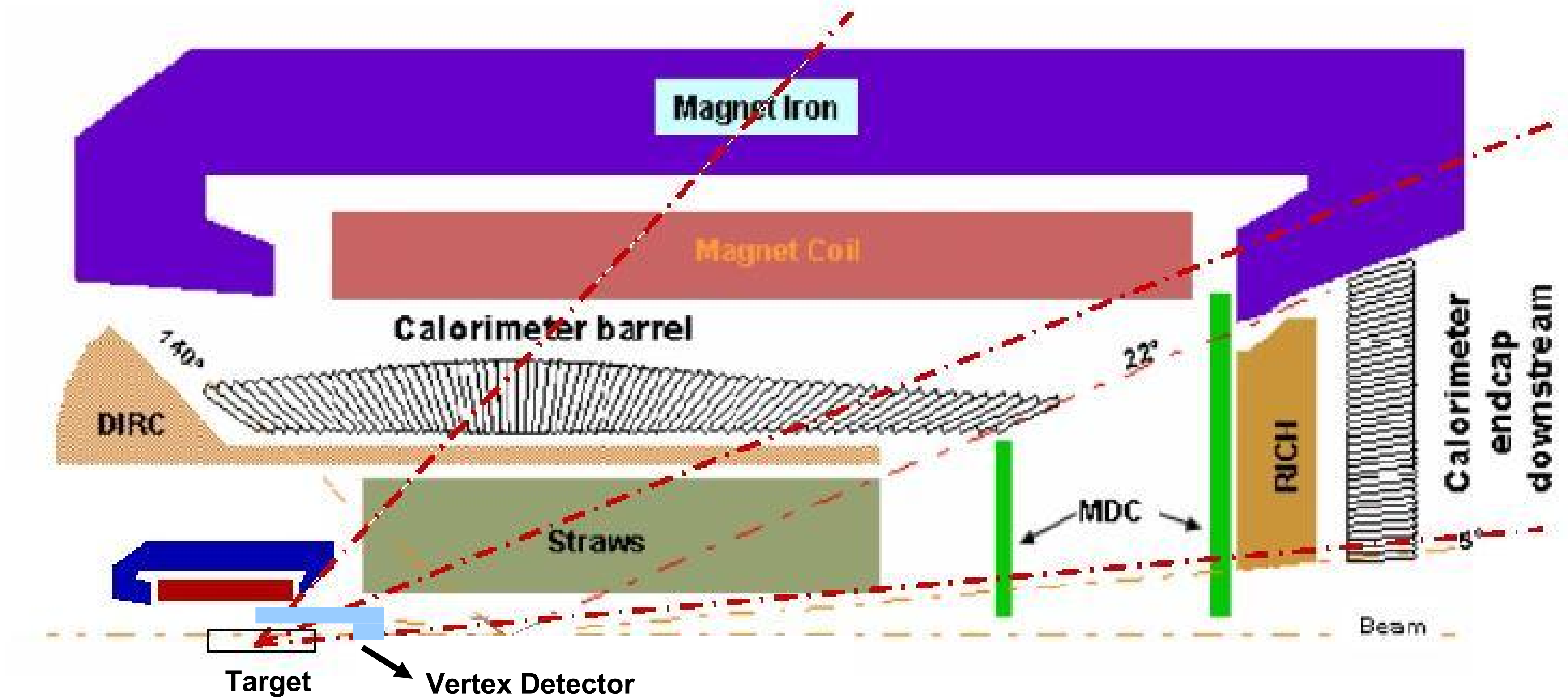


PAX spin-filtering set-up in PANDA-hypernuclei lay-out

Transverse Polarized Target at (-150,0)

- Free space simplifies the problem
- Free forward acceptance

- No wide angle acceptance
- The set-up looses in projectivity



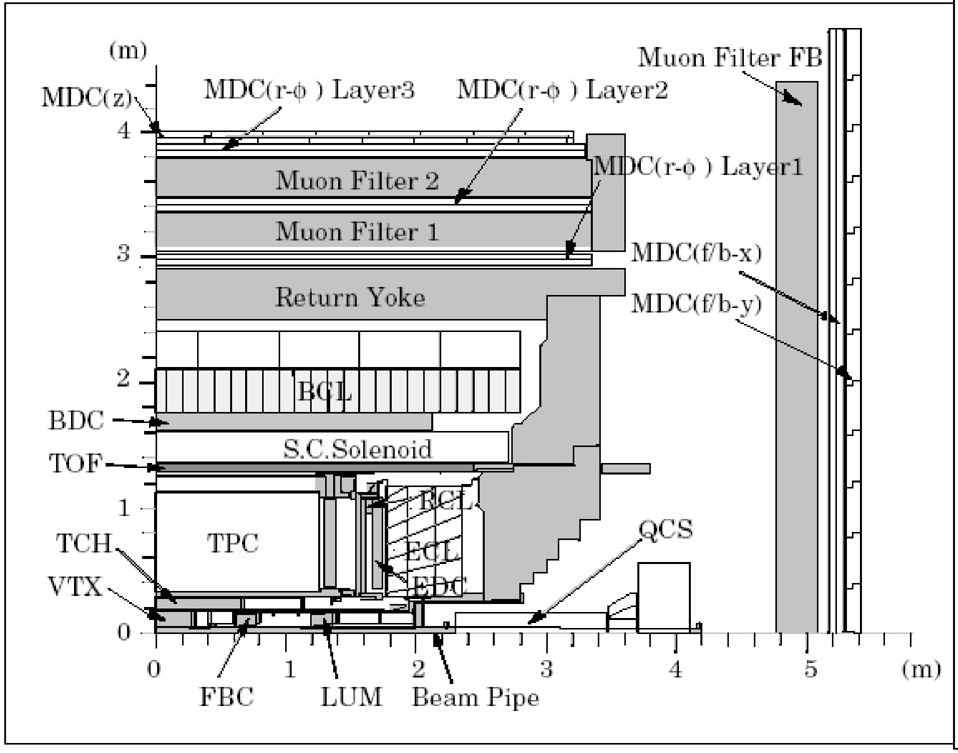
PANDA and spin

- Upstream IP
- Minimal modifications to PANDA
- Space for additional detectors
- Dedicated set-up and run

- Central IP
- New central spectrometer
- Toroid (?)
- Helmoltz coils (?)

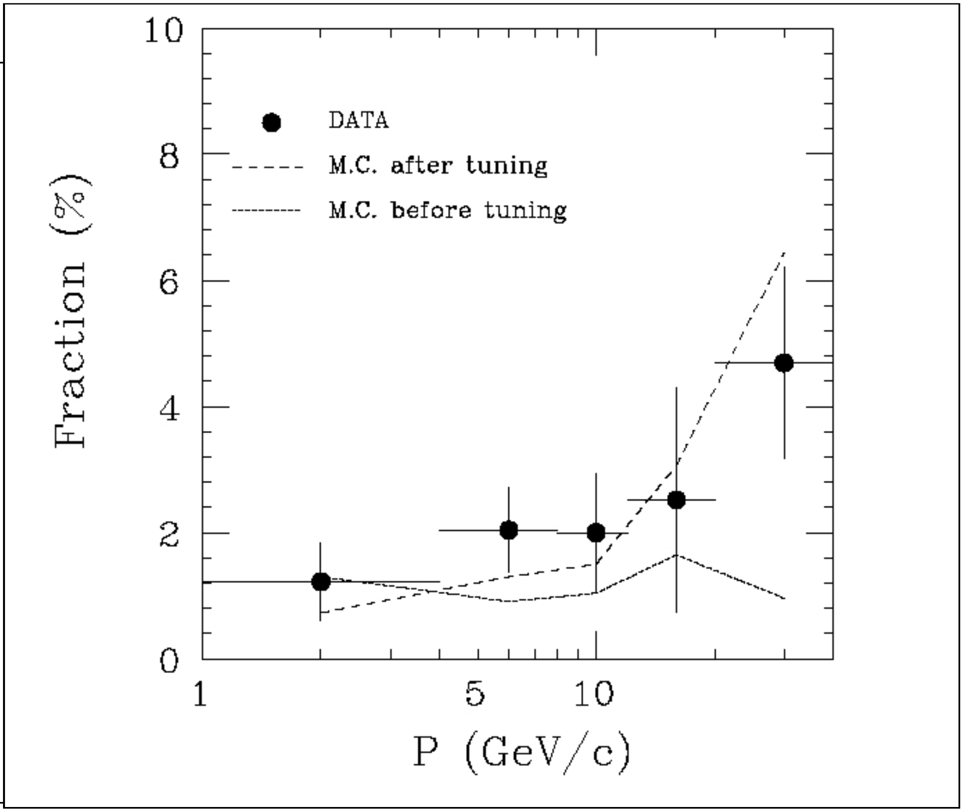
TOPAZ measurement

DY at PANDA requires π/e rejection ~ $10^4, 10^5$



PANDA like geometry

$e^+e^- \to \tau^+\tau^- \to n\pi$ reaction



10^{-2} pion contamination

PANDA and spin

- Upstream IP
- Minimal modifications to PANDA
- Space for additional detectors
- Dedicated set-up and run

- Central IP
- New central spectrometer
- Toroid (?)
- Helmoltz coils (?)

- Electron ID:
- E/P (p/e ~ few hundreds)
- dE/dx (p/e ~ few tens)

Hard QCD with spin at FAIR

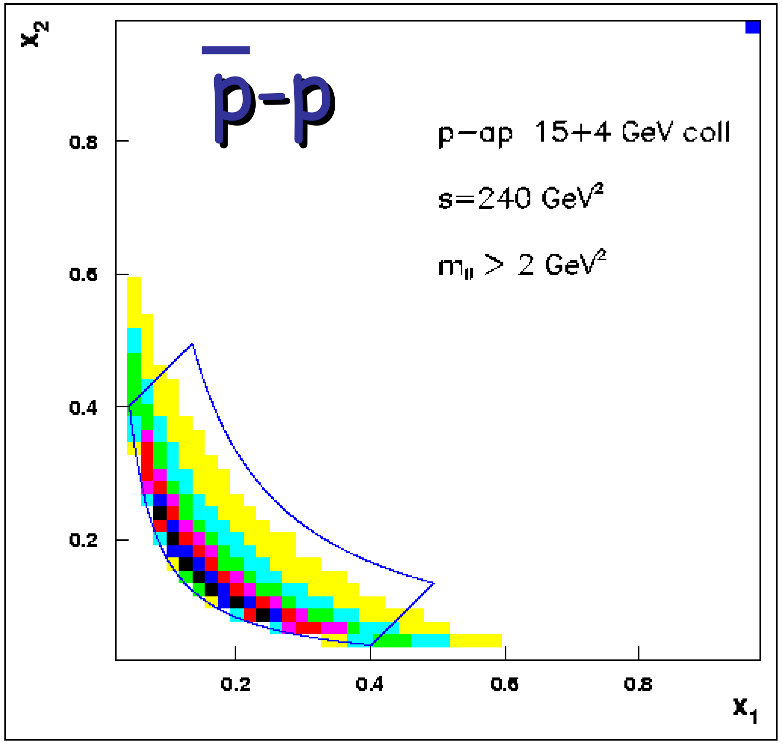
- Breakthroughs of knowledge !
  - * parton distributions: transversity (1st extraction)
  - * SSA and TMDs (new class of phenomena)
  - * EMFF (hystorical approach revised)
  - * hadron spectroscopy (partial wave analysis)

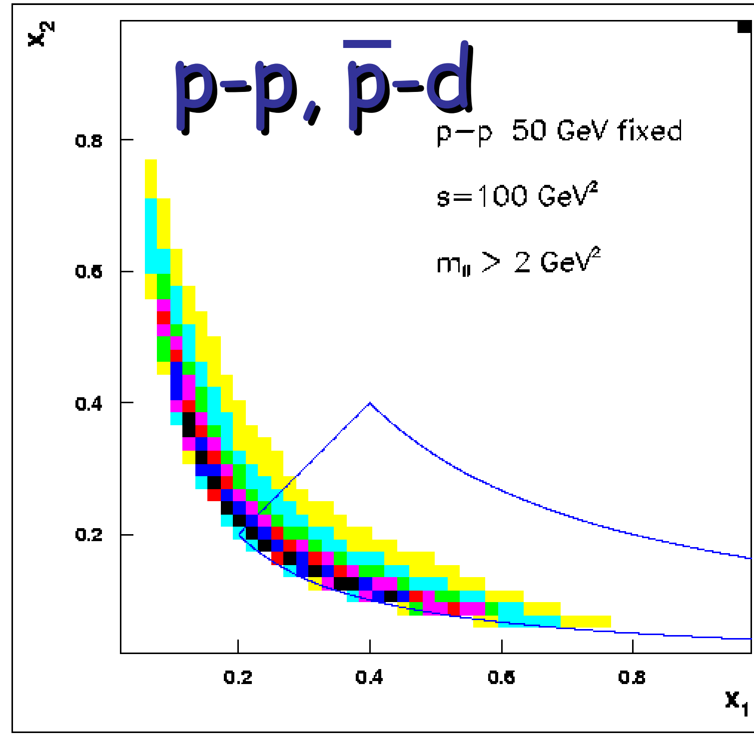
- Great potential of FAIR pbar project

- Spin observables are good players in the game

- Closer collaboration among PANDA and PAX communities is of great importance

DY events distribution





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

At $x_1 = x_2$ $A_{TT} \sim h_{1u}^2$ → Extraction of h_{1d}, $h_{1\bar{q}}$

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

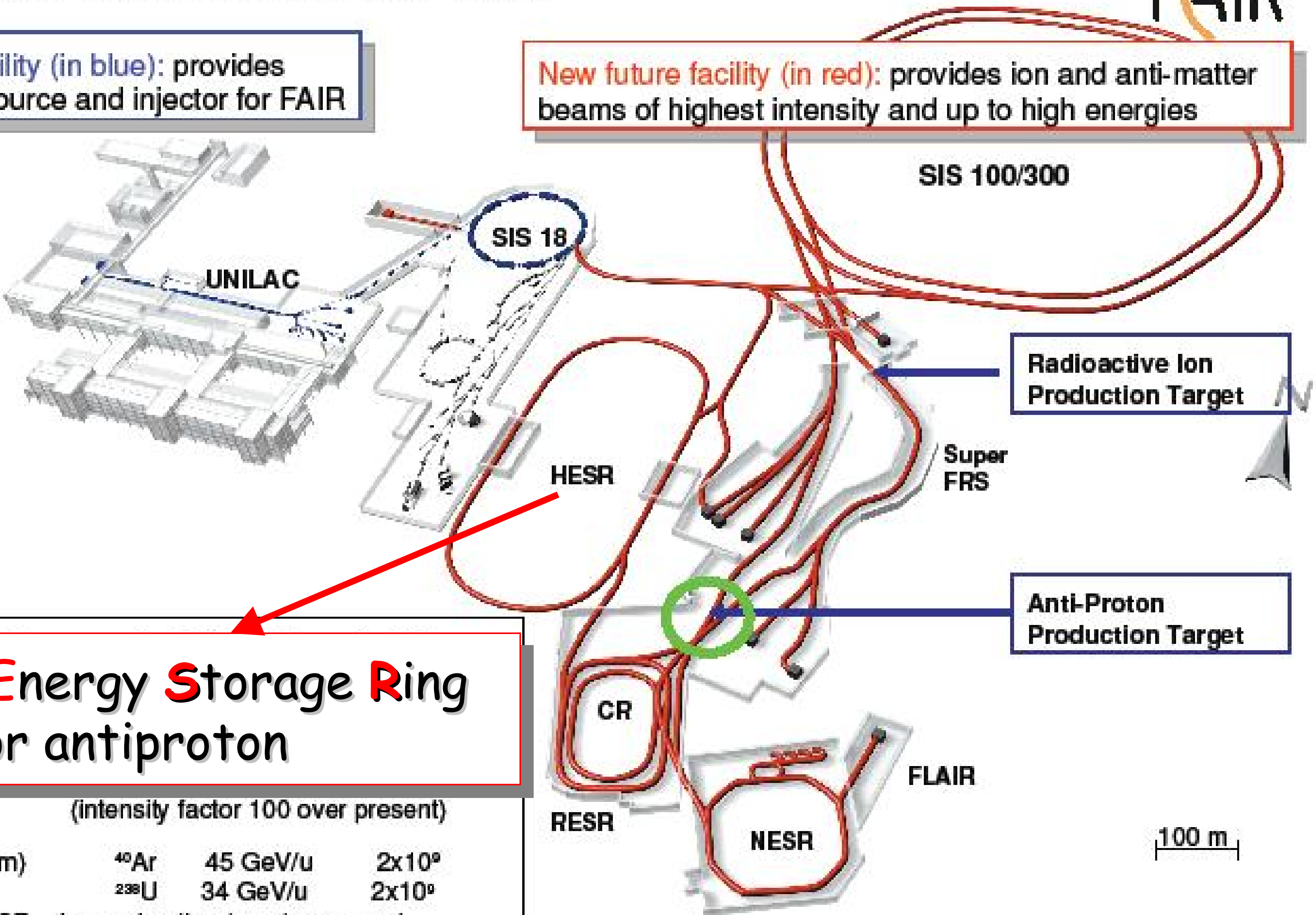
for $x < 0.2$

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

Technical Realization of FAIR

Existing facility (in blue): provides ion-beam source and injector for FAIR

New future facility (in red): provides ion and anti-matter beams of highest intensity and up to high energies

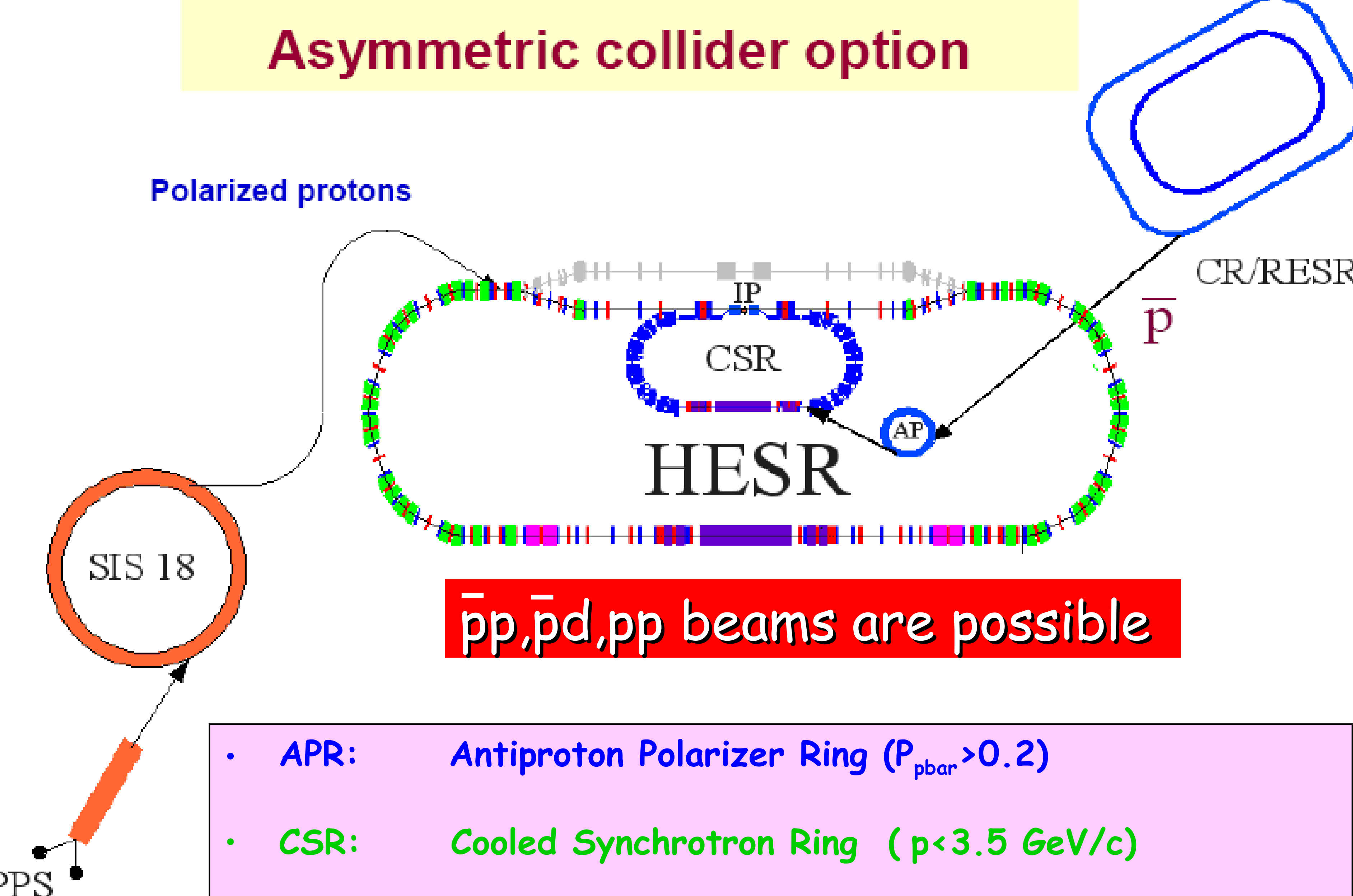


High Energy Storage Ring for antiproton

(intensity factor 100 over present)

SIS300 (300Tm)	^{40}Ar	45 GeV/u	2×10^{9}
	^{238}U	34 GeV/u	2×10^{9}
CR/RESR/NESR	ion and antiproton storage and experiment rings		
HESR	antiprotons	14 GeV	~10^{11}
SuperFRS	rare-isotope beams	1 GeV/u	<10^{9}

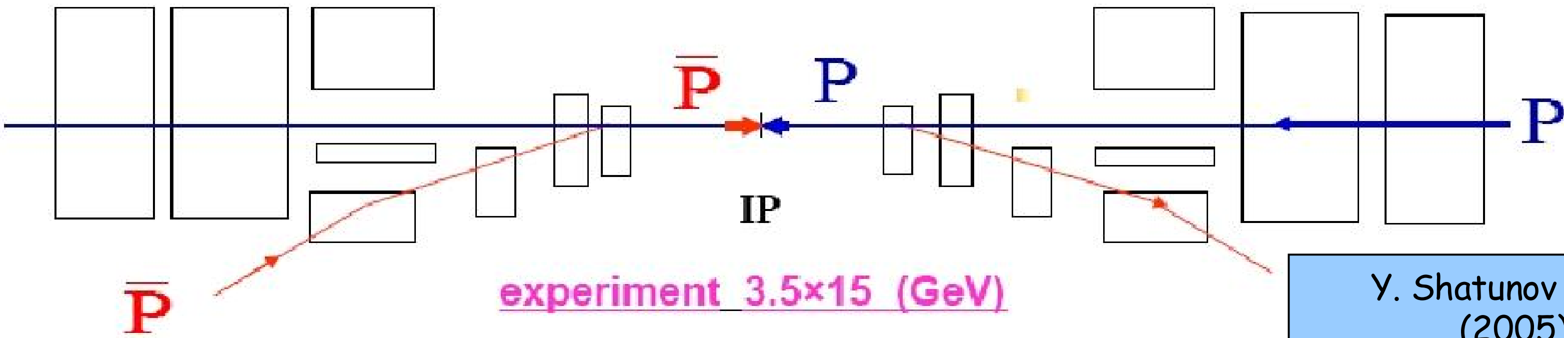
Asymmetric collider option



$\bar{p}p$,$\bar{p}d$,pp beams are possible

- 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)

Sketch of the interaction area



experiment 3.5×15 (GeV)

Y. Shatunov et al., (2005)

Ring circumferences,	l_1 / l_2	536 /134	m
Beam energies	E_p / E_{p_bar}	15 / 3.5	GeV
Total number of antiprotons,	N_P	0.1 / 0.3 / 1	10^{12}
Total number of protons,	$N_{\overline{P}}$	7 / 7/ 7	10^{12}
Proton beam emittance,	ε_P	2.5 / 2.5 / 2.5	10^{-6} cm · rad.
Antiproton beam emittance,	$\varepsilon_{\overline{P}}$	0.25 / 0.75 / 2.5	10^{-6} cm · rad
Space charge tune shift,	$\Delta\nu_{\overline{P}}$	0.1 / 0.1 / 0.1	
Beam-beam parameter,	$\xi_{\overline{P}}$	?	
Luminosity	L_{max} (l=2m)	5 / 5 / 5	10^{31} cm^{-2} · s^{-1}

Asymmetric collider Luminosity up to $5 \cdot 10^{31}$ cm^{-2}s^{-1}

PHENIX @ RICH [p,p]

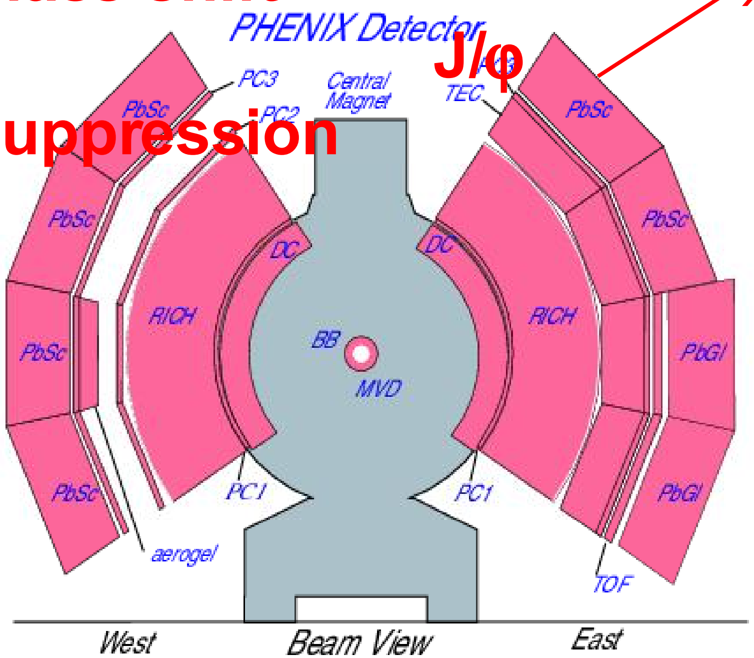
Polarized pp parton distributions

Collider of Proton and heavy ions (Au,Pb)

Single-e spectra Heavy-flavor

e^+e^- pairs φ,ω,ρ mass shift

J/φ suppression



90 150 cm path 2 %

Electron ID: CALO

Pb Scintillator hadrons - timing

Lead Glass energy - granularity

π re... e ~ 10^4

Polarized Antiproton eXperiments

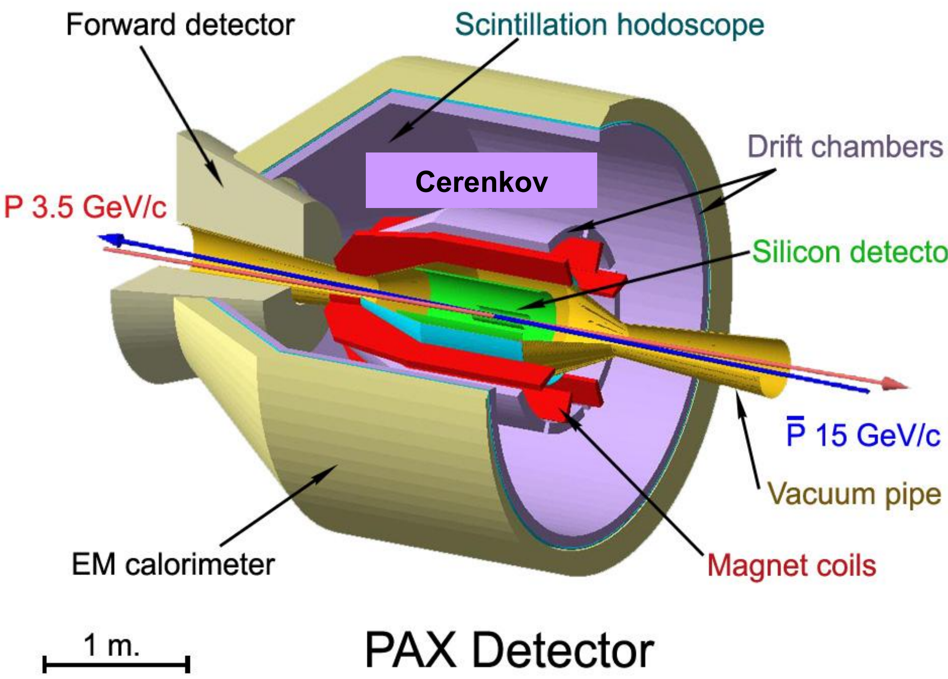
Nucleon structure: polarized reactions

pbar-p elastic

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

Proton EFFs

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



Parton distribution: transversity

Drell-Yan

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

SSA

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

Charmonium

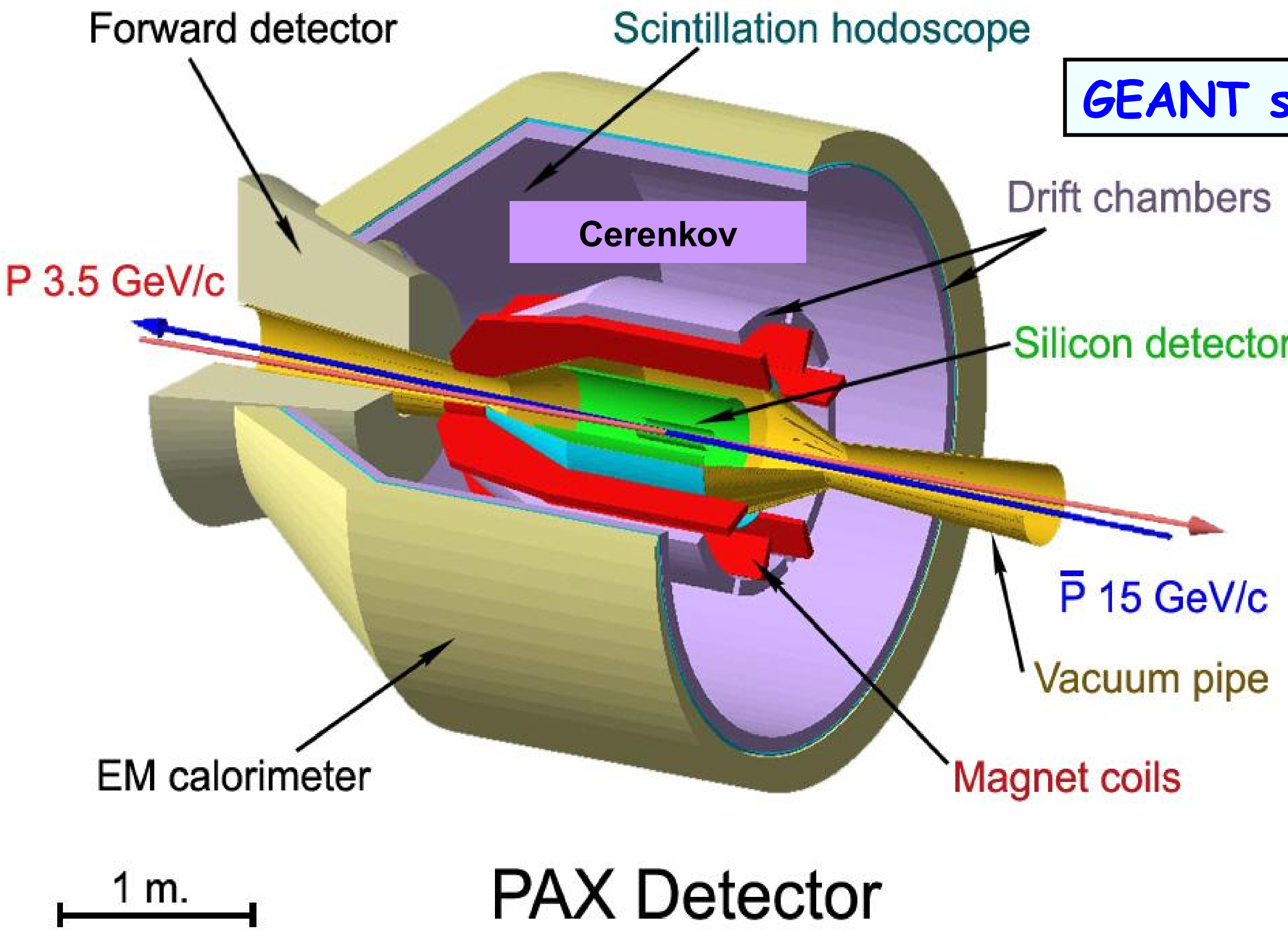
$$p^{\uparrow}\bar{p}^{\uparrow}\to J/\psi X$$

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

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

PAX Detector Concept

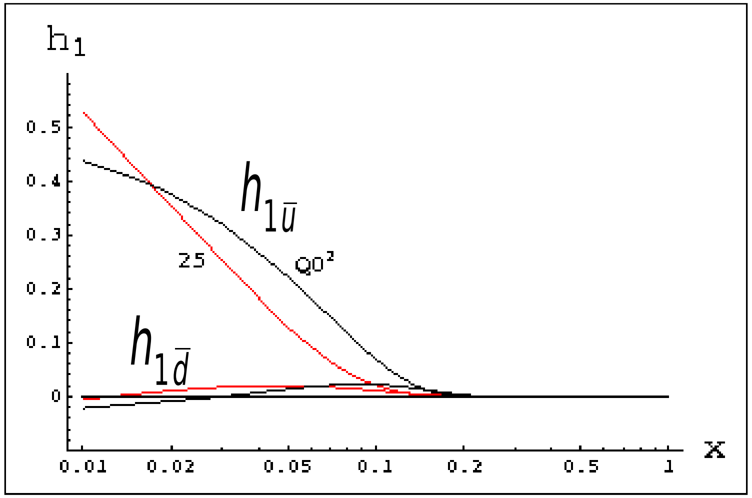
GEANT simulation



Designed for Collider but compatible with fixed target

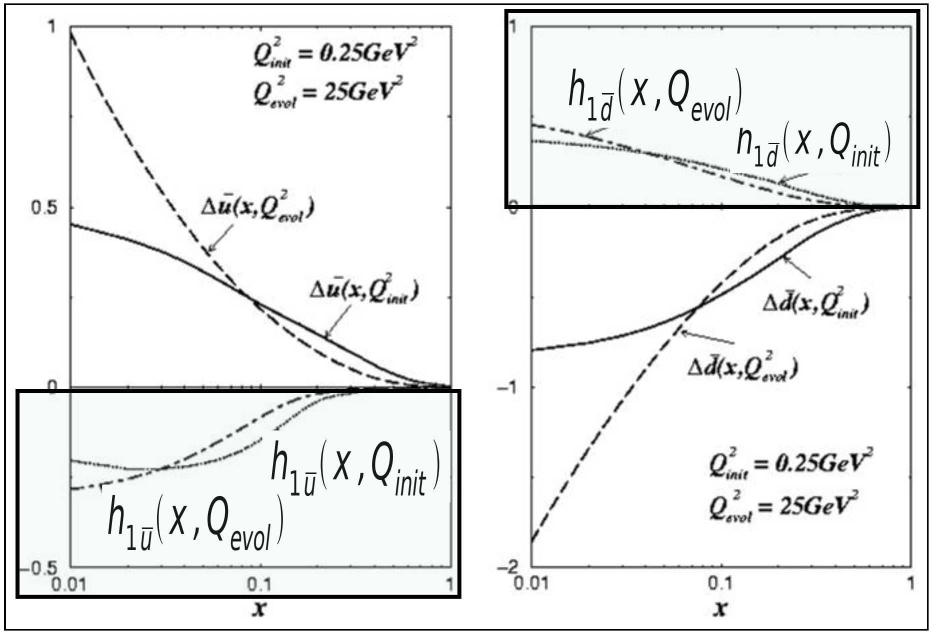
Transverse sea

CDM



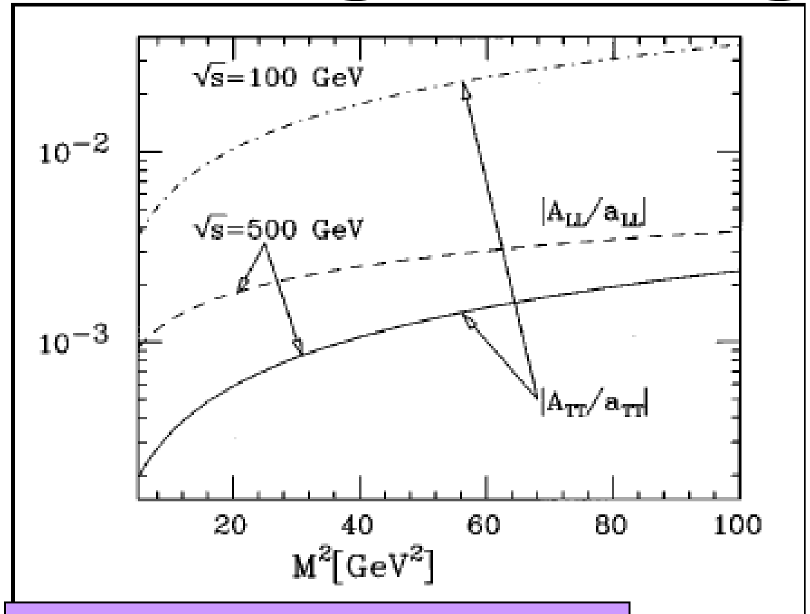
V. Barone, T. Calarco and A. Drago
Phys. Lett. B 390 (1997) 287

CQSM

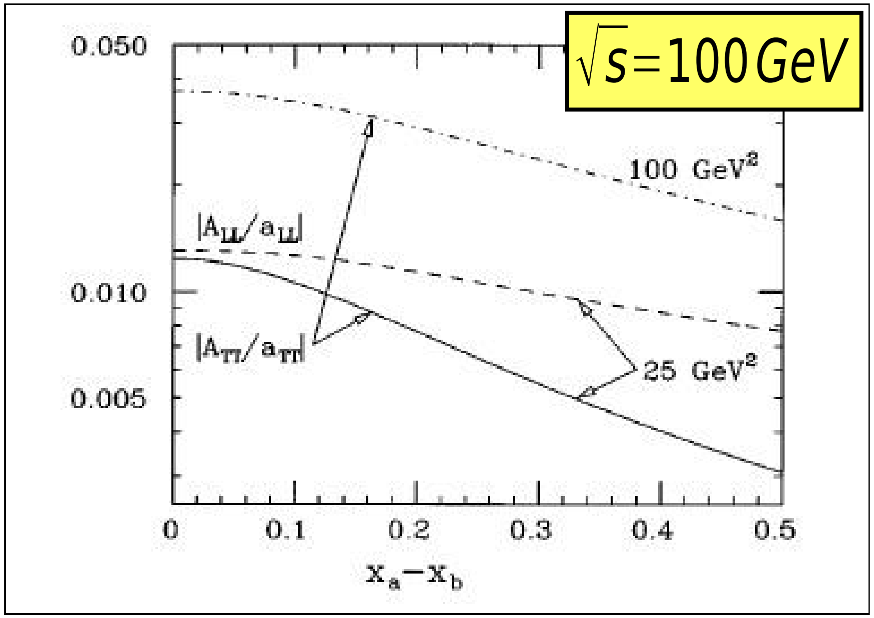


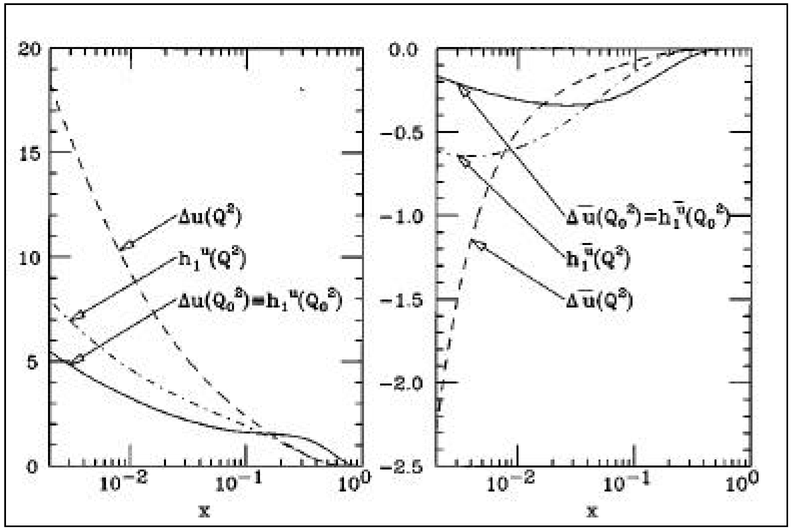
M. Wakamatsu and T. Kubota
Phys. Rev. D 63 (1999) 034020

High energy p-p machine



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





Small asymmetries

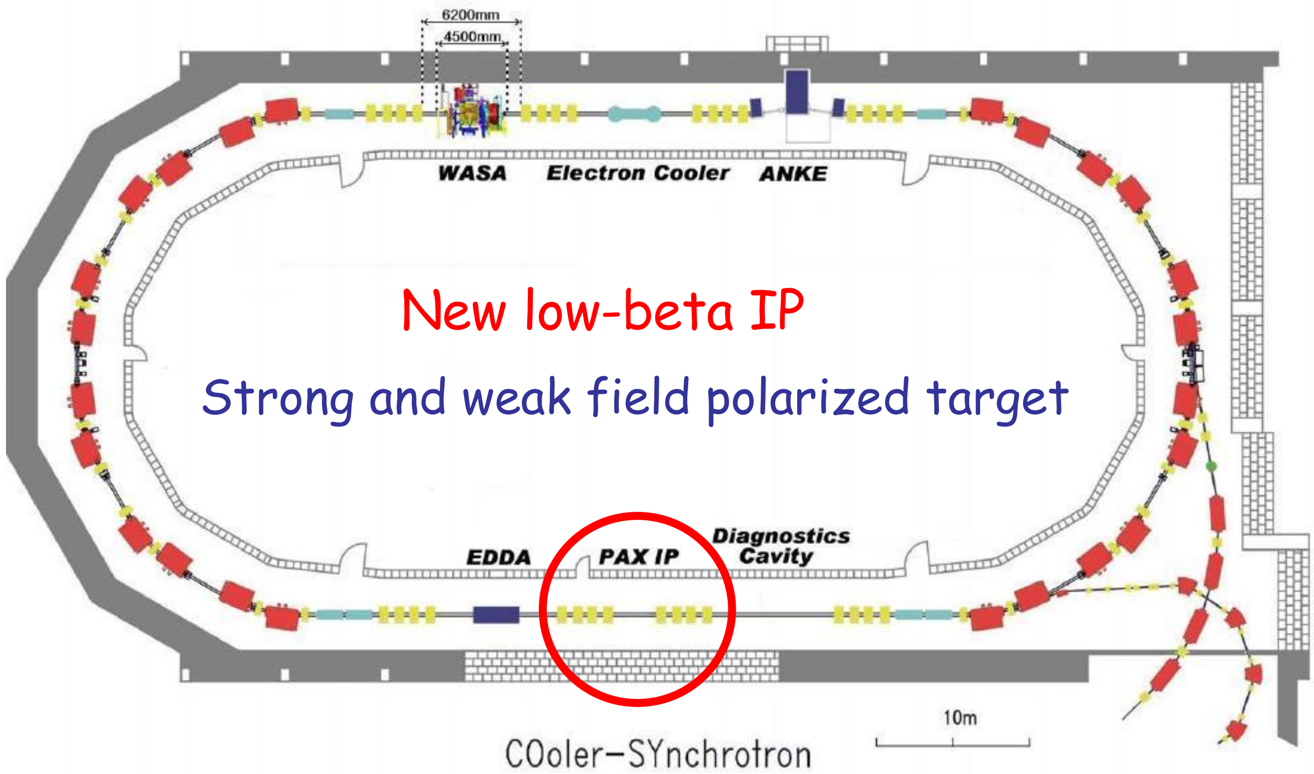
Vector, axial and tensor charges

$$\int_{-1}^{+1} \mathrm{d}x\, f(x) = \int_0^1 \mathrm{d}x \left[f(x) - \bar{f}(x) \right] = g_V \,,$$

$$\int_{-1}^{+1} \mathrm{d}x\, \Delta f(x) = \int_0^1 \mathrm{d}x \left[\Delta f(x) + \Delta \bar{f}(x) \right] = g_A \,,$$

$$\int_{-1}^{+1} \mathrm{d}x\, \Delta_T f(x) = \int_0^1 \mathrm{d}x \left[\Delta_T f(x) - \Delta_T \bar{f}(x) \right] = g_T \,.$$

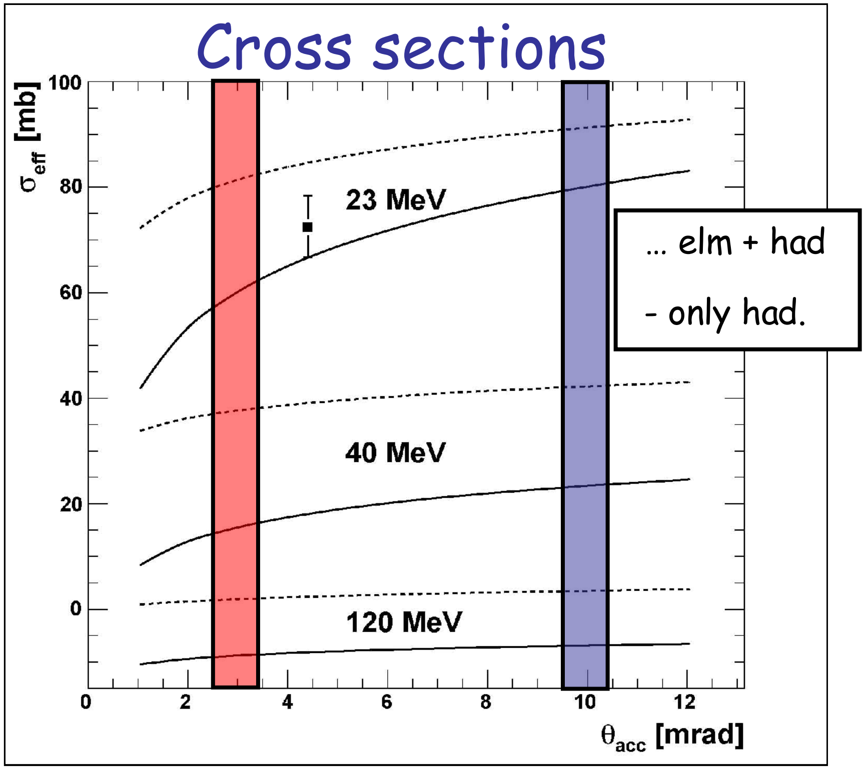
Measurements at COSY at FZJ (2008-2009)

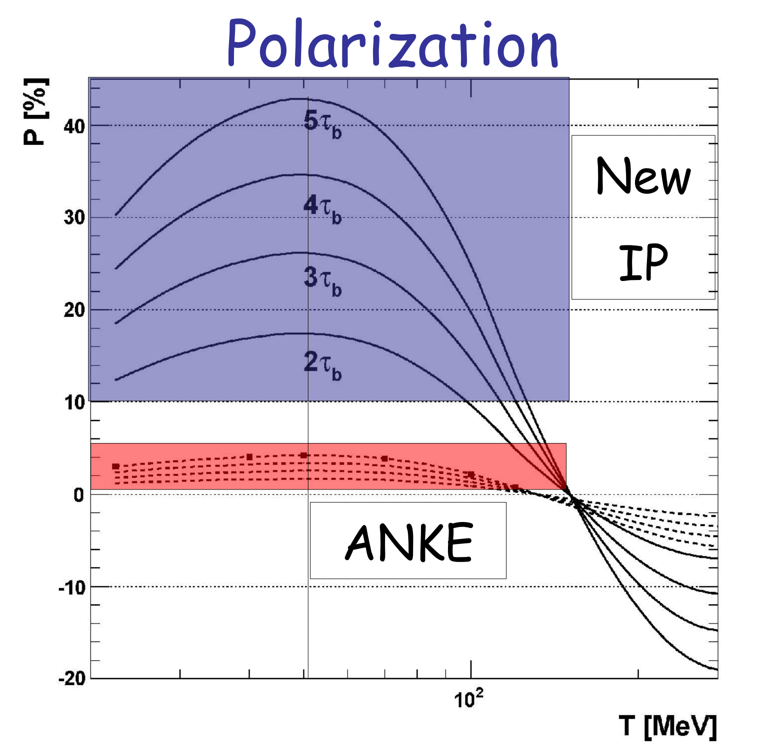


Goals: Disentangle ***h*** and ***e*** effects

Commissioning of AD setup

ANKE vs new interaction point





T=40 MeV

N_{inj}=1.5x10^{10}

PIT	Filter. time	Polar.	Total rate	Meas. Time (Δ 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	2τ = 5 h	16 %	2.2x10^4 s^{-1}	1 s

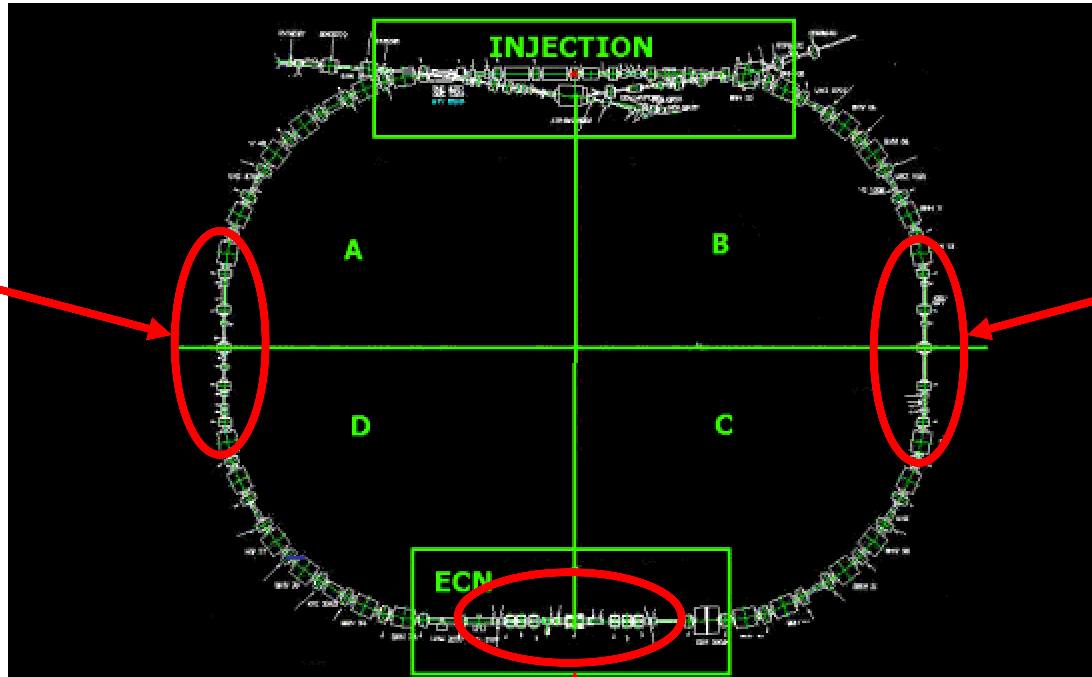
Measurements at AD at CERN (2009-2010)

study of spin-filtering in $p\bar{p}$ scattering

Target

Commissioned

At COSY



Snake

For longitudial

Polarization

T:5 MeV÷2.8 GeV

$N_p = 3\cdot 10^7$

E-cooler

Measurement of effective polarization cross-section.

Both transverse and longitudinal.

Variable ring acceptance.and beam energy

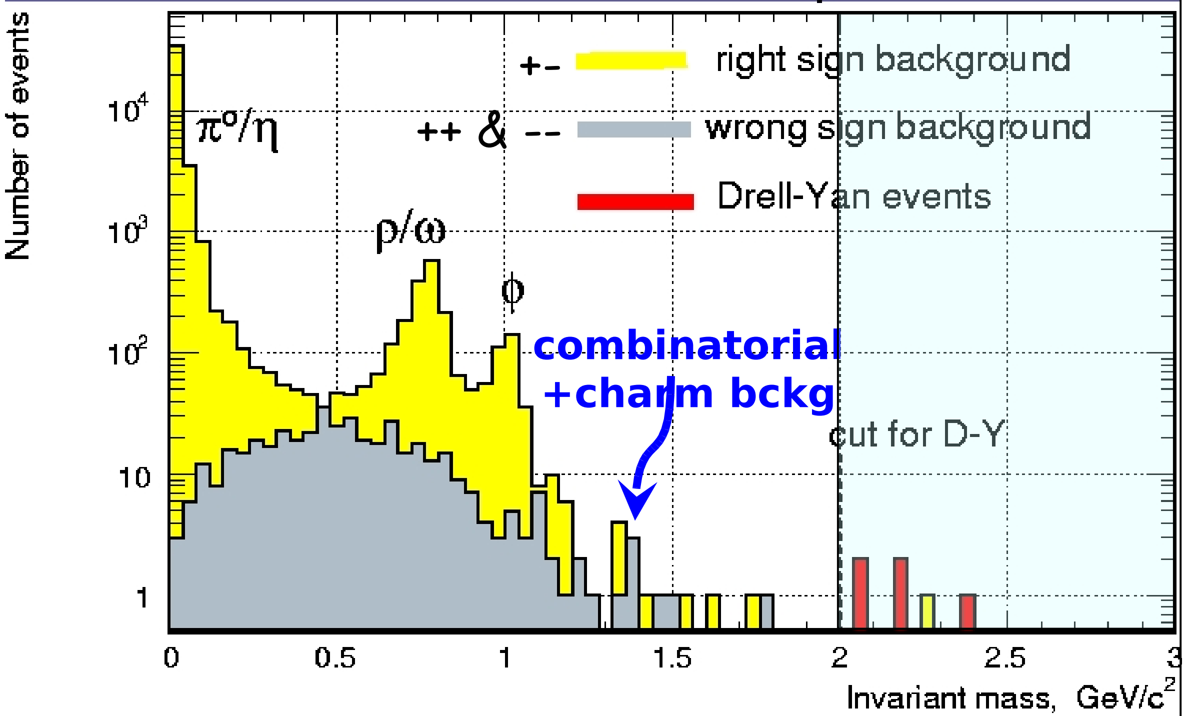
H and D terget

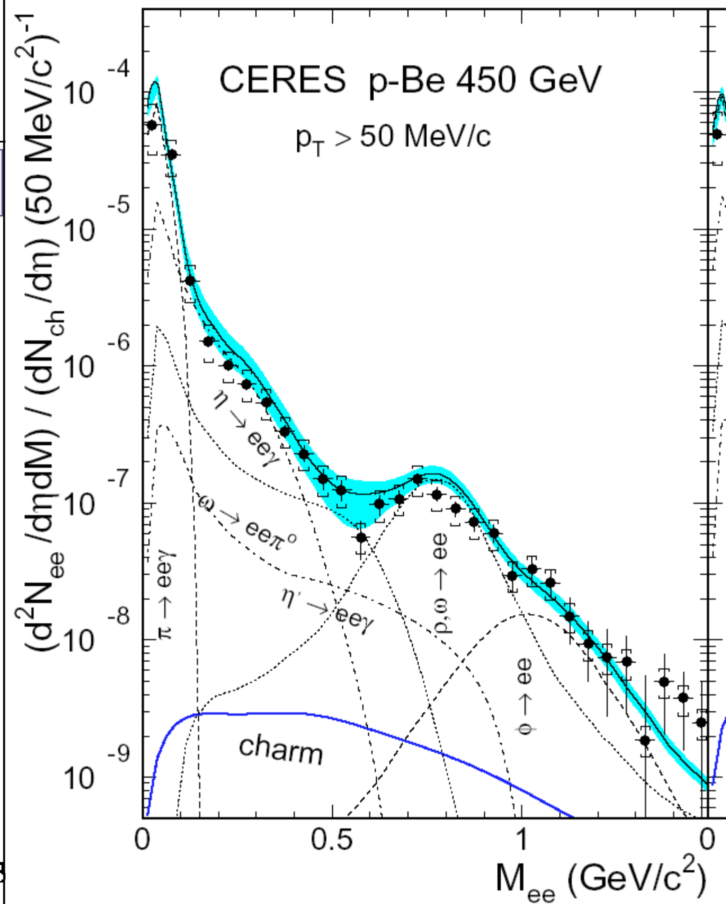
First measurement at all for spin correlations in $\bar{p}p$ (not pure text experiment!)

Background to Drell-Yan e^+e^-

½ hour experiment: $2\cdot10^8$ p-pbar interactions
several DY events

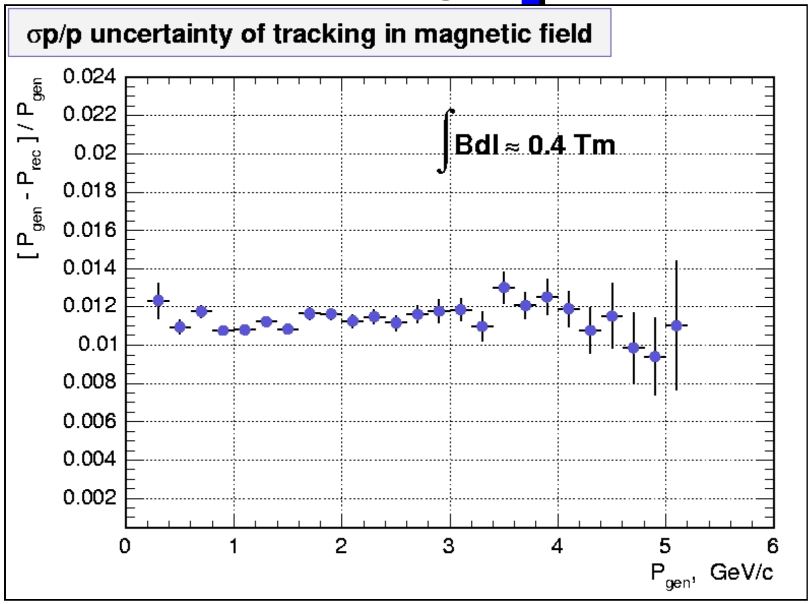
Invariant mass of ee pair

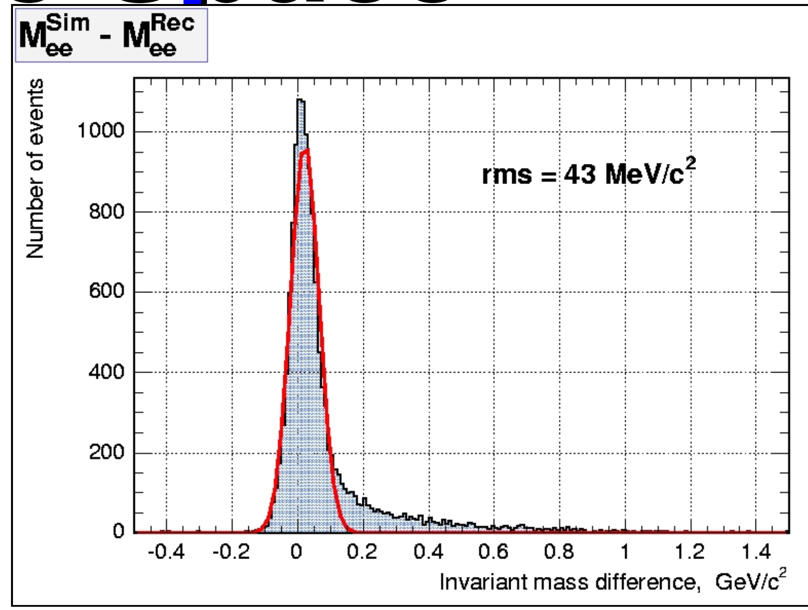


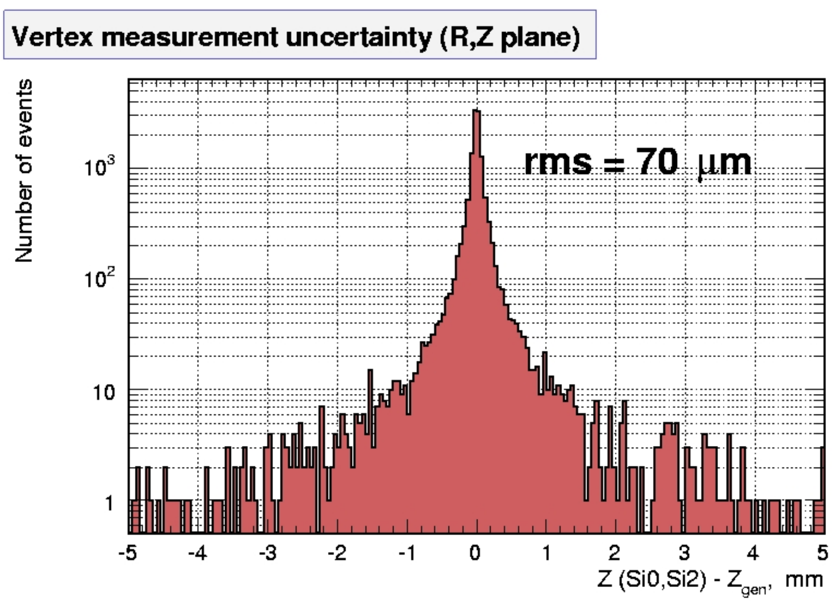


Background 1:1 to signal after PID, E>300 MeV, conversion veto, mass cut
* the combinatorial component can be subtracted (wrong-sign control sample)
* the charm can be reduced (vertex decay)

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