LA FISICA DELLO SPIN CON ANTIPROTONI @ GSI

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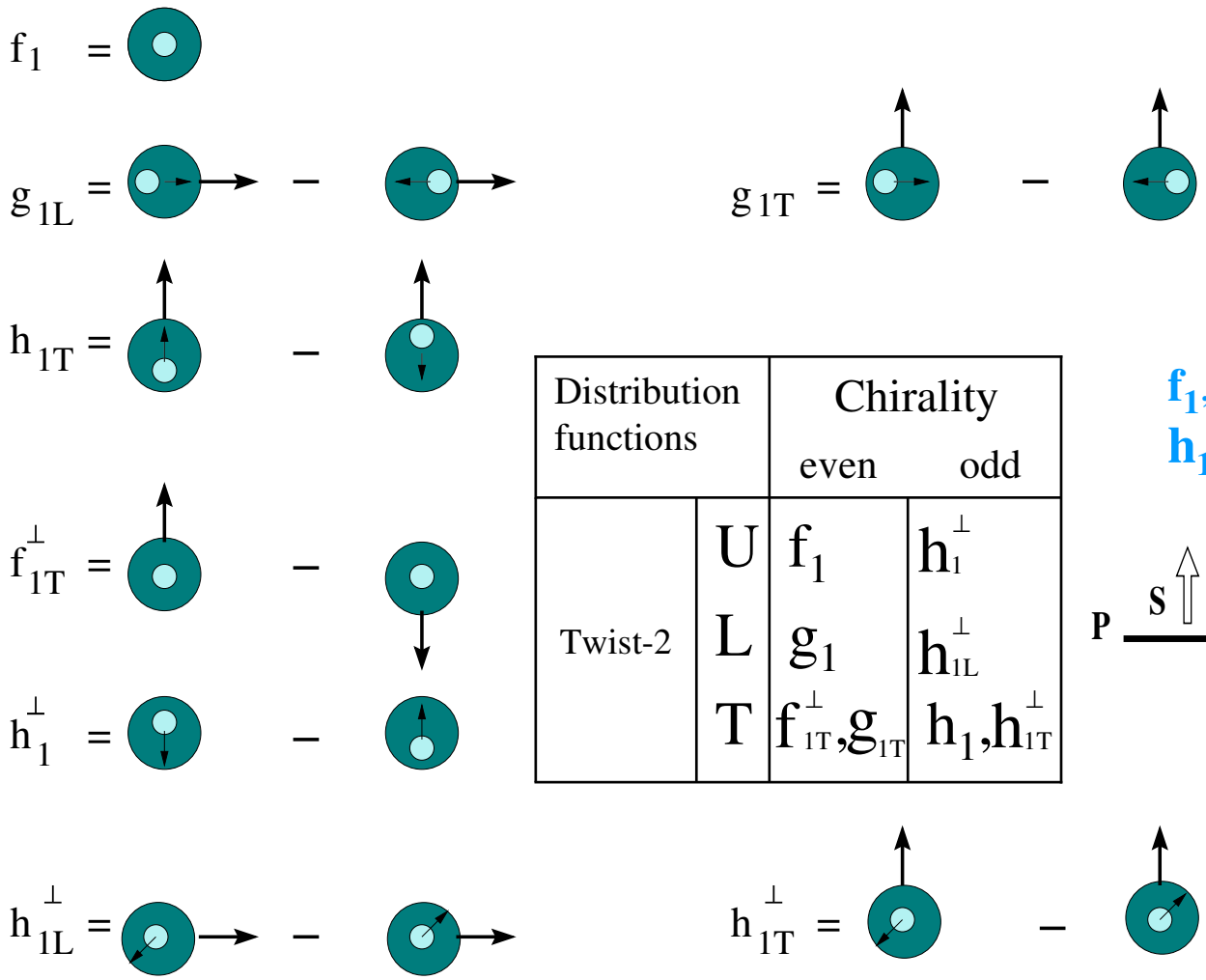
Introduction

- SIS300 @ GSI: $\bar{p}$ ($\bar{p}^{\uparrow}$) , $P_{\bar{p}} \geq 40$ GeV/c $\left(\lambda = 4 \cdot 10^{-2}\,\mathrm{fm}\right)$
- HESR @ GSI: $\bar{p}$ ($\bar{p}^{\uparrow}$) , $P_{\bar{p}} \leq 15$ GeV/c
- ASSIA: $\bar{p}$ ($\bar{p}^{\uparrow}$) from SIS300 to fixed target or $\bar{p}^{\uparrow}$ HESR collider
- PAX: $\bar{p}^{\uparrow}$ HESR to fixed target
- A complete description of nucleonic structure requires:
  - proton and gluon distribution functions
  - quark fragmentation functions

  @ leading twist and @ NLO
- Physics objectives:
  - Drell-Yan di-lepton production
  - spin observables in hadron production
  - electromagnetic form factors

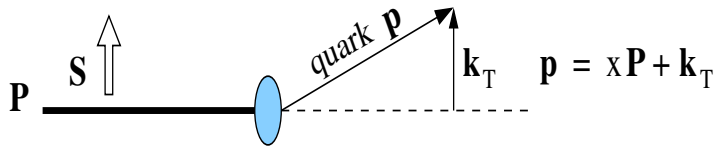
κ_T-dependent Parton Distributions

Twist-2 PDFs $\quad f_1^u(x) \equiv u(x),\ g_1^u(x) \equiv \Delta u(x),\ h_1^u(x) \equiv \delta u(x)$



Distribution functions		Chirality even	Chirality odd
Twist-2	U	f_1	$h_1^\perp$
	L	g_1	$h_{1L}^\perp$
	T	$f_{1T}^\perp, g_{1T}$	$h_1, h_{1T}^\perp$

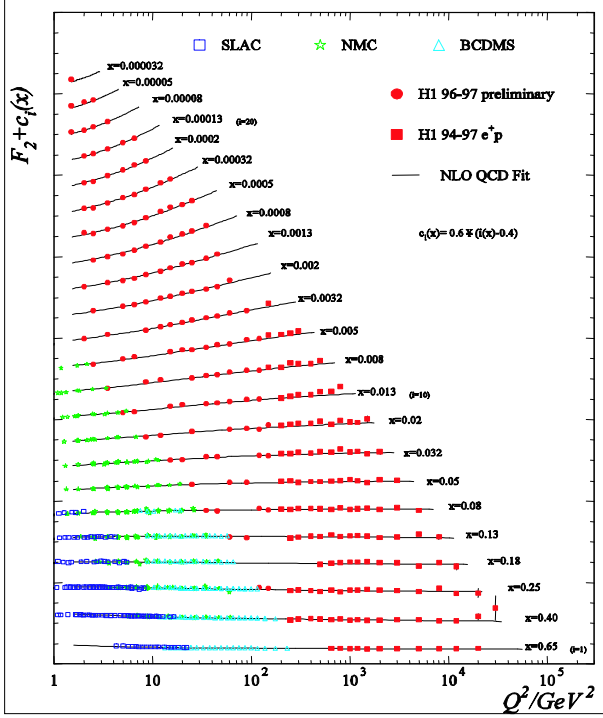
f_1, g_1 studied for decades:
h_1 essentially unknown



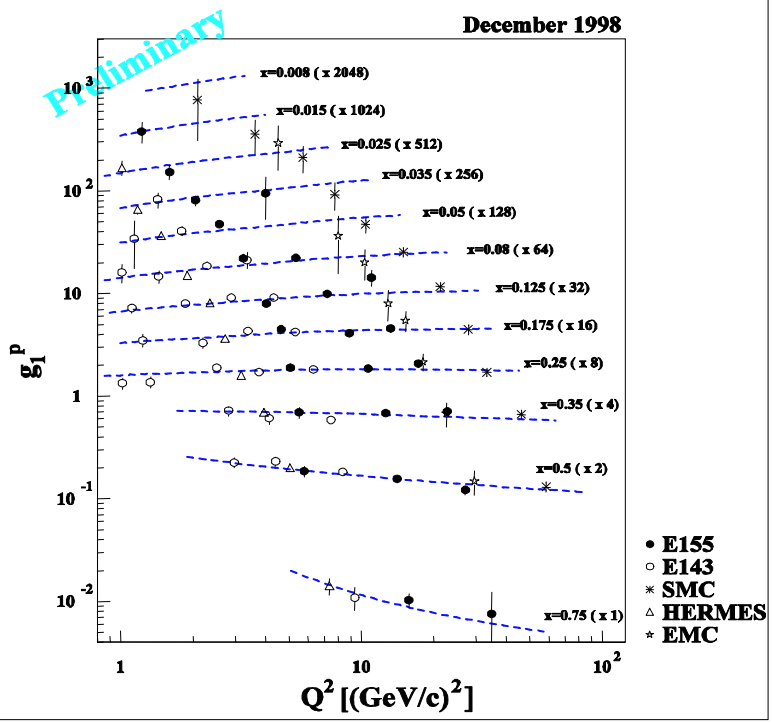
$$f_1(x) = \int d^2k_T f_1(x, k_T)$$

Status from literature

World data on F_2^p



World data on g_1^p



Well known and well modeled

Known, but poorly modeled

Transversity h_1 still unmeasured and poorly modeled

A review in Barone, Drago, Ratcliffe, Phys. Rep. 359 (2002) 1

Drell-Yan Di-Lepton Production $\bar{p}p \rightarrow \mu^+\mu^- X$

Why Drell Yan?

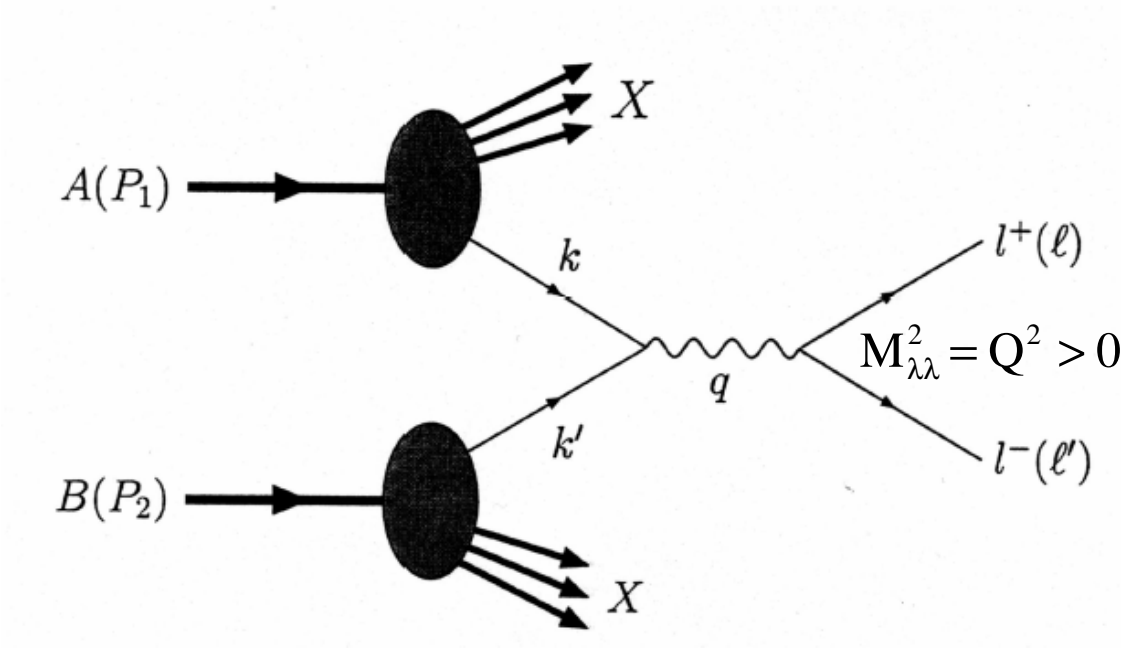
Asymmetries depend on PD only (SIDIS→convolution with QFF)

3 planes: plane $\perp$ to polarisation vectors
$p-\gamma^*$ plane
$\lambda^+\lambda^-\gamma^*$ plane

→ plenty of (single) spin effects

Why $\bar{p}$?

Each valence quark can contribuite to the diagram



Kinematics

$$x_1 = \frac{M^2}{2P_1 \bullet q} \qquad x_2 = \frac{M^2}{2P_2 \bullet q}$$

$$X_F = X_1 - X_2$$

$$\tau = x_1 x_2 = \frac{M^2}{s}$$

Drell-Yan Di-Lepton Production $\bar{p}p \rightarrow \mu^+\mu^- X$

$$\frac{d^2\sigma}{dM^2 dx_F} = \frac{4\alpha^2\pi}{9M^2 s}\frac{1}{x_1 + x_2}\sum_a e_a^2\left[f^a(x_1)f^{\bar{a}}(x_2) + f^{\bar{a}}(x1)f^a(x_2)\right]$$

Scaling:

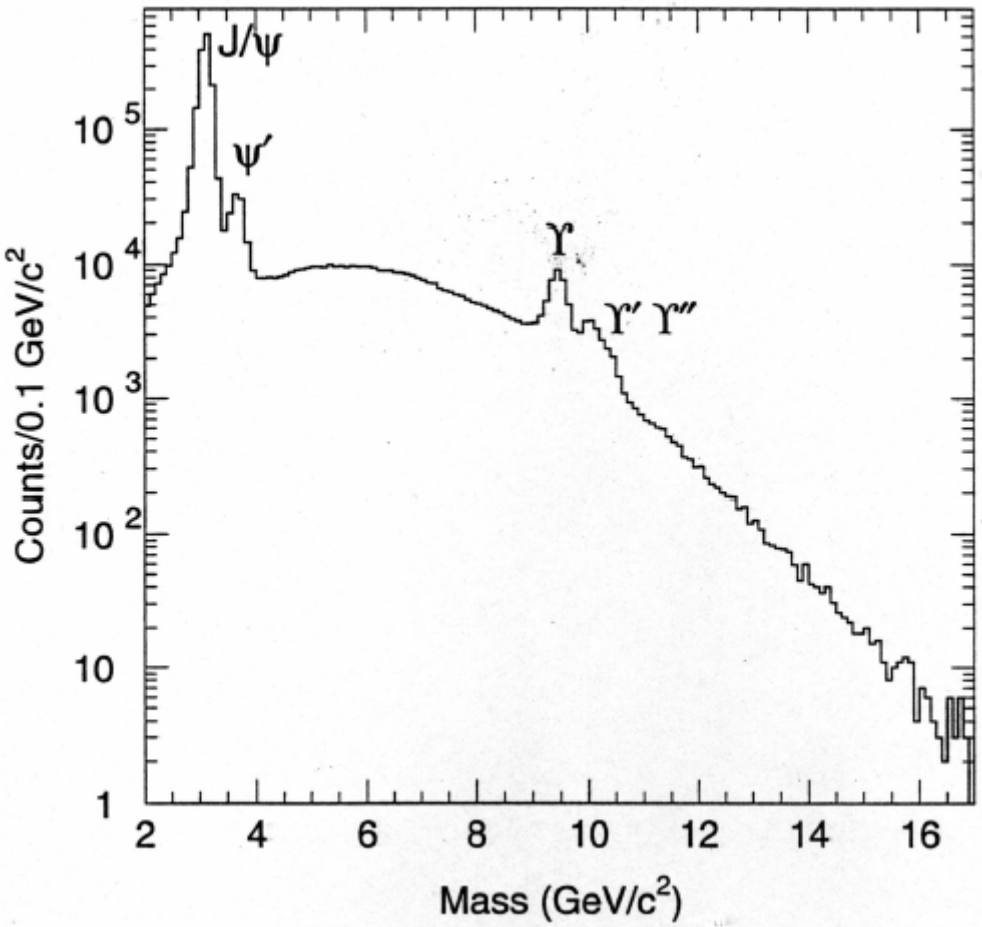
$$\frac{d^2\sigma}{d\sqrt{\tau}dx_F} \propto \frac{1}{s}$$

Full x_1,x_2 range $\Rightarrow \tau \in [0,1]$.

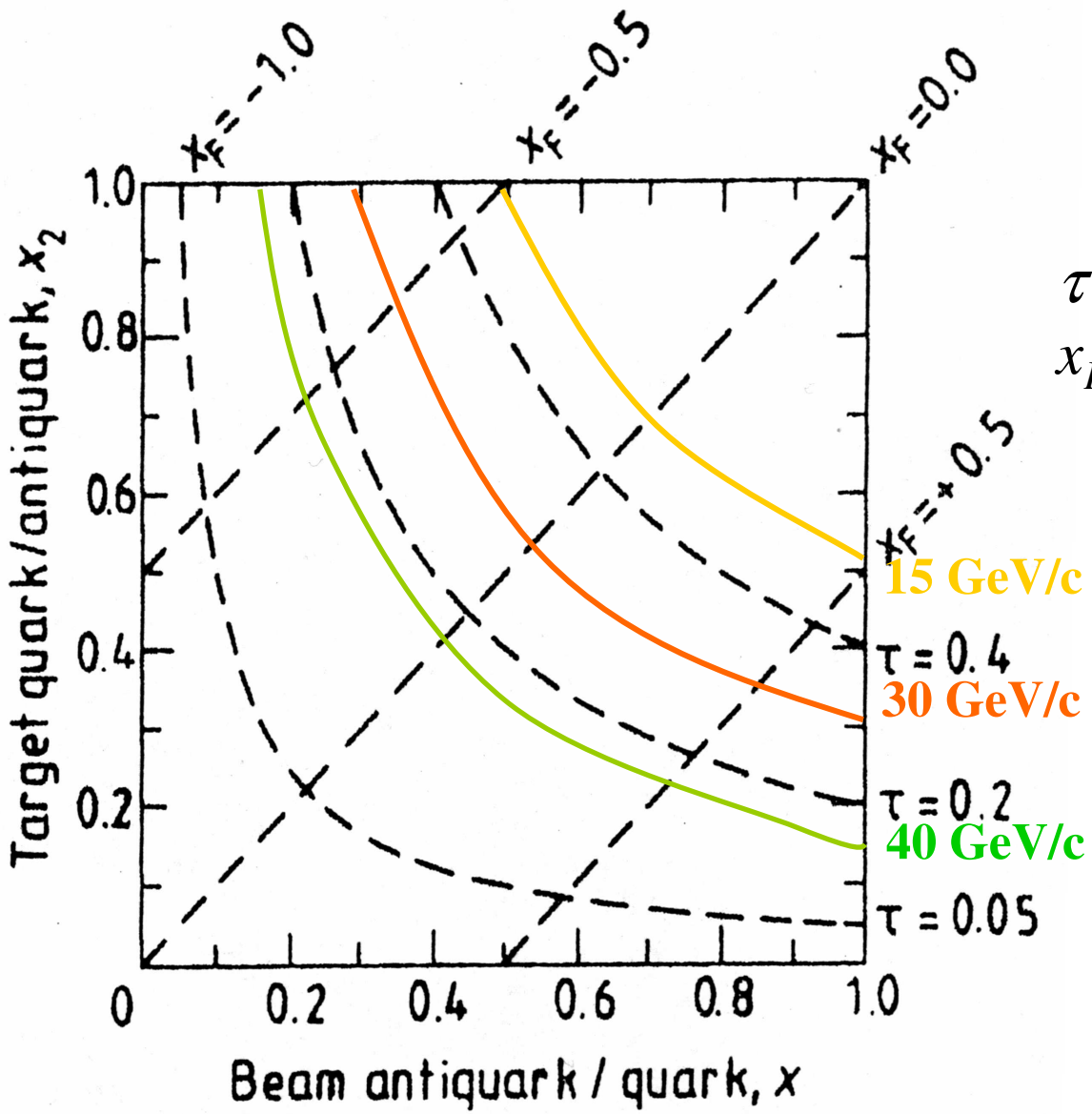
$\vec{p}_{BEAM} \geq 40$ Gev/c needed

$$\sigma_{\bar{p}p\rightarrow\mu^+\mu^- X} \approx 0.3\,\text{nb}^{[1]}$$

[1] Anassontzis et al., Phys. Rew. D38 (1988) 1377



Phase space for Drell-Yan processes



τ = const: hyperbolae

x_F = const: diagonal

PANDA

ASSIA

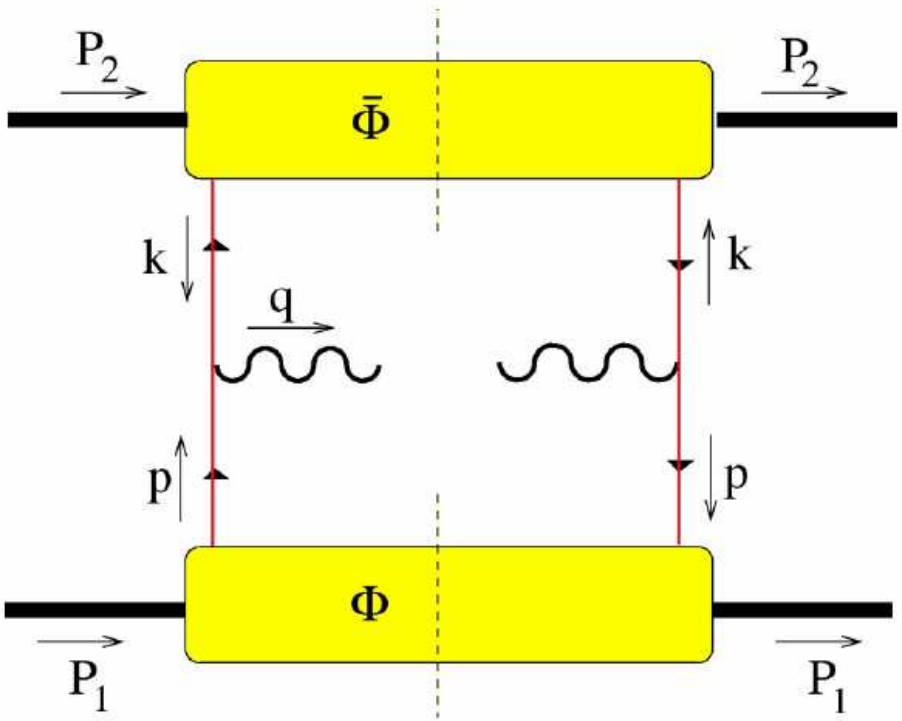
Drell-Yan Asymmetries — Polarised beam and target

Uncorrelated quark helicities $\Rightarrow$ access chirally-odd functions

TRANSVERSITY

Ideal because:

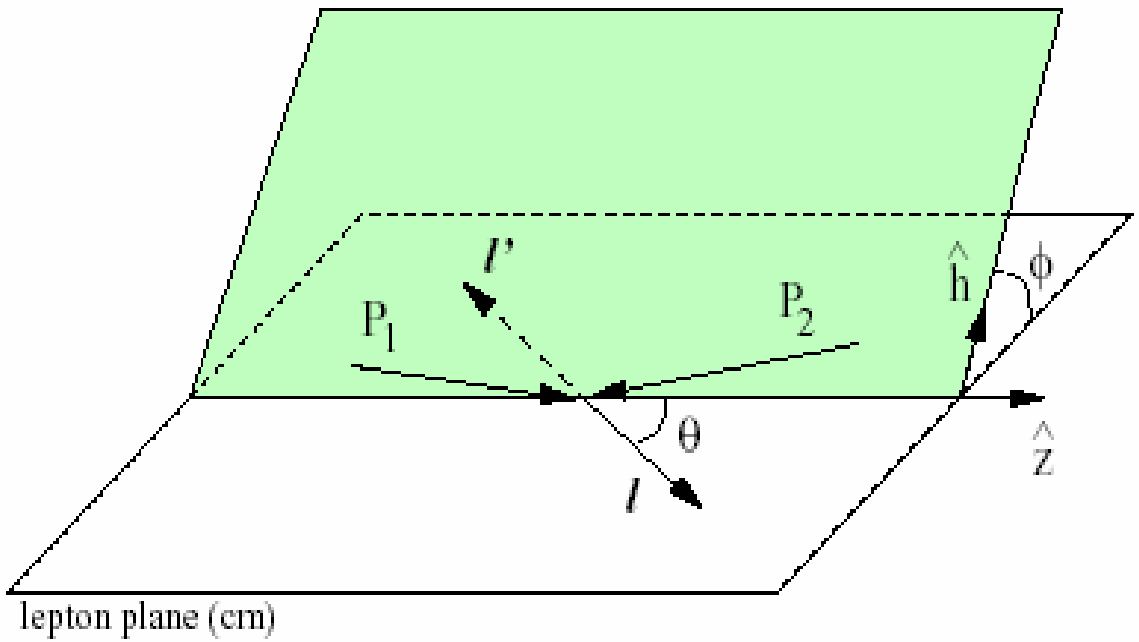
- h_1 not to be unfolded with fragmentation functions
- chirally odd functions not suppressed (like in DIS)



Drell-Yan Asymmetries — Polarised beam and target

$$A_{LL} = \frac{\sum_a e_a^2 g_1^a(x_1)\bar{g}_1^a(x_2)}{\sum_a e_a^2 f_1^a(x_1)\bar{f}_1^a(x_2)} \qquad A_{TT} = \frac{\sin^2\theta\cos 2\varphi}{1+\cos^2\theta}\frac{\sum_a e_a^2 h_1^a(x_1)h_1^{\bar{a}}(x_2)}{\sum_a e_a^2 f_1^a(x_1)f_1^{\bar{a}}(x_2)}$$

$$A_{LT} = \frac{2\sin 2\theta\cos\varphi}{1+\cos^2\theta}\frac{M}{\sqrt{Q^2}}\frac{\sum_a e_a^2\left(g_1^a(x_1)x_2 g_T^{\bar{a}}(x_2) - x_1 h_L^a(x_1)h_1^{\bar{a}}(x_2)\right)}{\sum_a e_a^2 f_1^a(x_1)f_1^{\bar{a}}(x_2)}$$



To be corrected for:

$$\frac{1}{P_B\ f\ P_T}$$

NH_3 polarised target:

$$f = \frac{3}{17} = 0.176$$

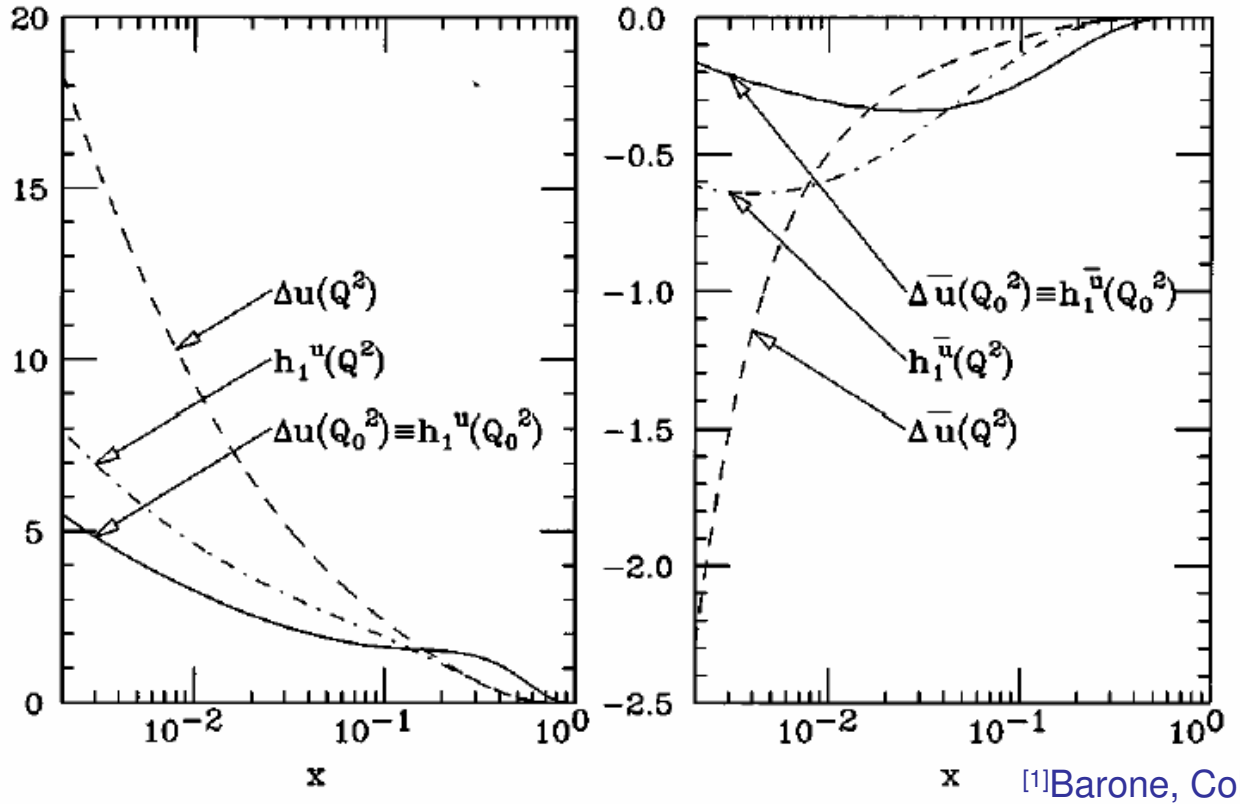
$$P_T \approx 0.85$$

Drell-Yan Asymmetries — Polarised beam and target

RICH energies: $\sqrt{s} = 100\,\text{GeV}$ $M^2 = 100$ ➡ $\tau \leq 10^{-2}$ ➡ small x_1 and/or x_2

$h_1^a(x,Q^2)$ evolution much slower[1] than $\Delta q(x,Q^2)$ and $q(x,Q^2)$ at small x

A_{TT} @ RICH very small, smaller $\sqrt{s}$ would help[1]



$Q_0^2 = 0.23\,\text{GeV}^2$

$Q^2 = 25\,\text{GeV}^2$

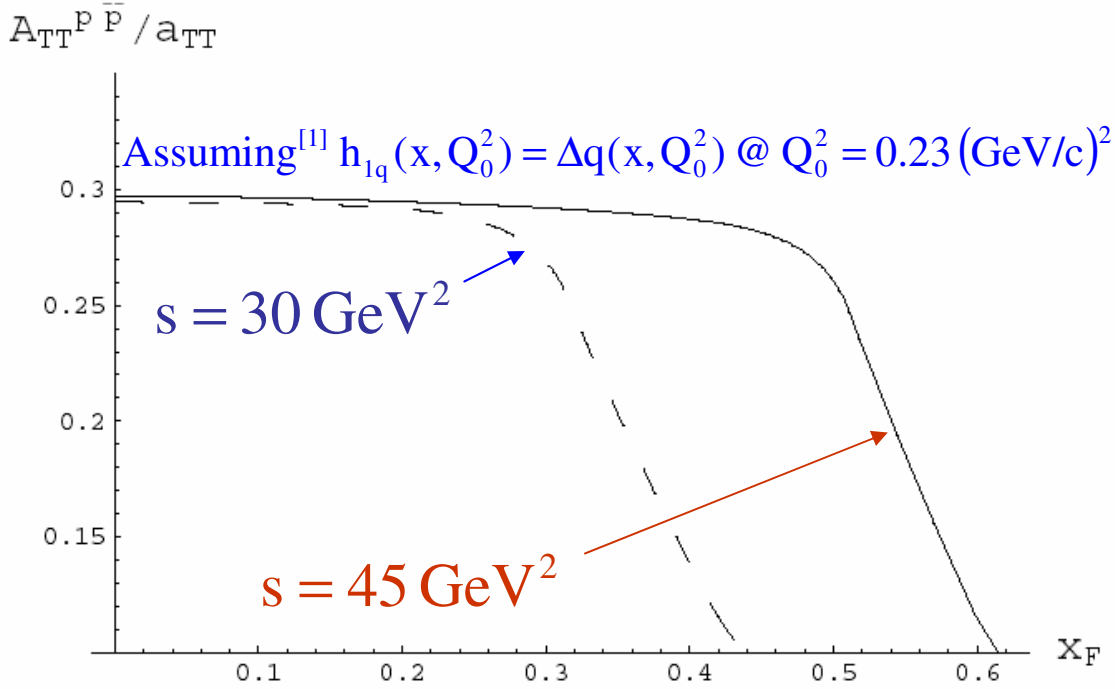
[1]Barone, Colarco and Drago, PRD56 (1997) 527.

Drell-Yan Asymmetries — Polarised beam and target

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

A_{TT} still small @ large $\sqrt{s}$ and M^2 due to slow evolution of $h_1^a(x, Q^2)$

Large A_{TT} expected[1] for $\sqrt{s}$ and M^2 not too large and τ not too small



HESR: $s_{max} = 30 \div 45\ \text{GeV}^2$

$M^2 \geq M_{J/\Psi}^2 \longrightarrow \tau \geq 0.3$

A_{TT} direct access to valence quark h_1

$$h_{1q_V}(x_1) \times h_{1q_V}(x_2)$$

[1] M. Anselmino et al.,hep-ph/0403114

Drell Yan Asymmetries — Unpolarised beam and target

Di-Lepton Rest Frame

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi}\frac{1}{\lambda+3}\left(1+\lambda\cos^2\theta+\mu\sin^2\theta\cos\varphi+\frac{\nu}{2}\sin^2\theta\cos2\varphi\right)$$

NLO pQCD: $\lambda \sim 1$, $\mu \sim 0$, $\upsilon \sim 0$

Experimental data [1]: $\upsilon \sim 30\ \%$

[1] J.S.Conway et al., Phys. Rev. D39(1989)92.

υ involves transverse spin effects at leading twist [2]:

$\cos2\varphi$ contribution to angular distribution provide:

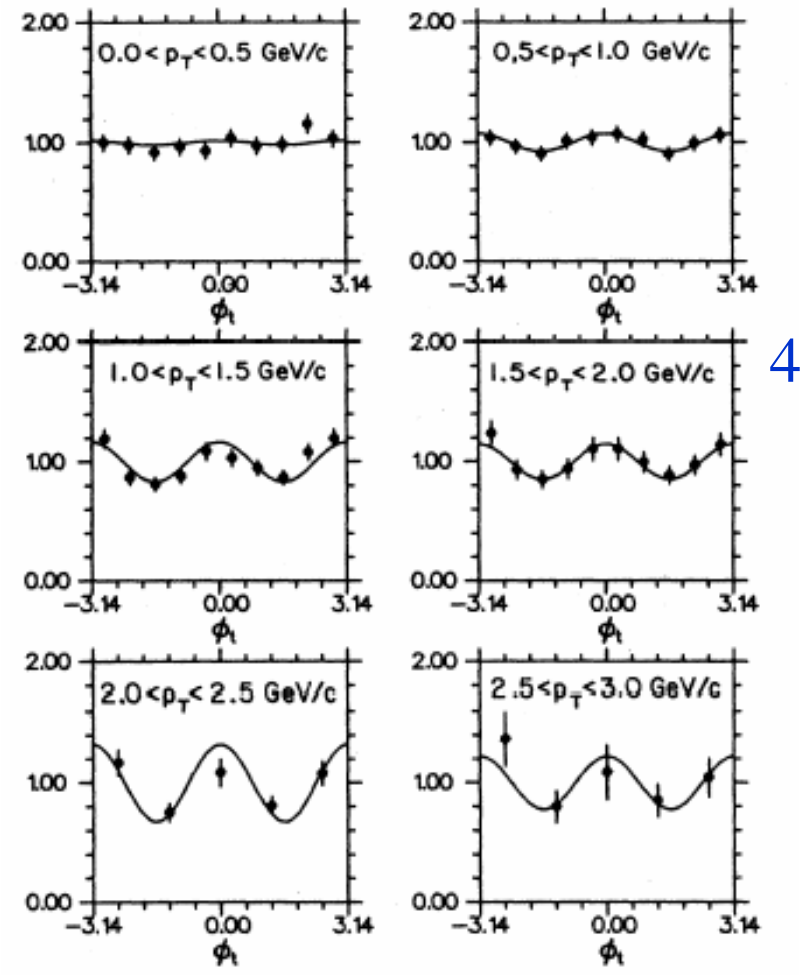
$$h_1^{\perp}(x_2,\kappa_{\perp}^2)\times\bar{h}_1^{\perp}(x_1,\kappa_{\perp}'^2)$$

[2] D. Boer et al., Phys. Rev. D60(1999)014012.

Angular distribution in CS frame

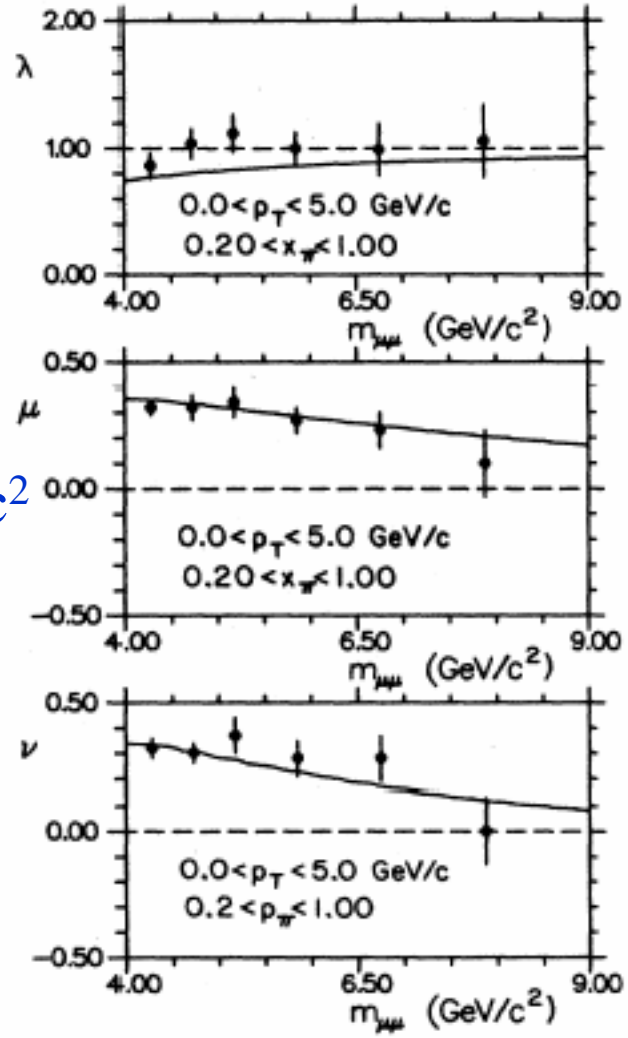
E615 @ Fermilab

π-N $\rightarrow$ μ+μ-X @ 252 GeV/c



$-0.6 < \cos\vartheta < 0.6$

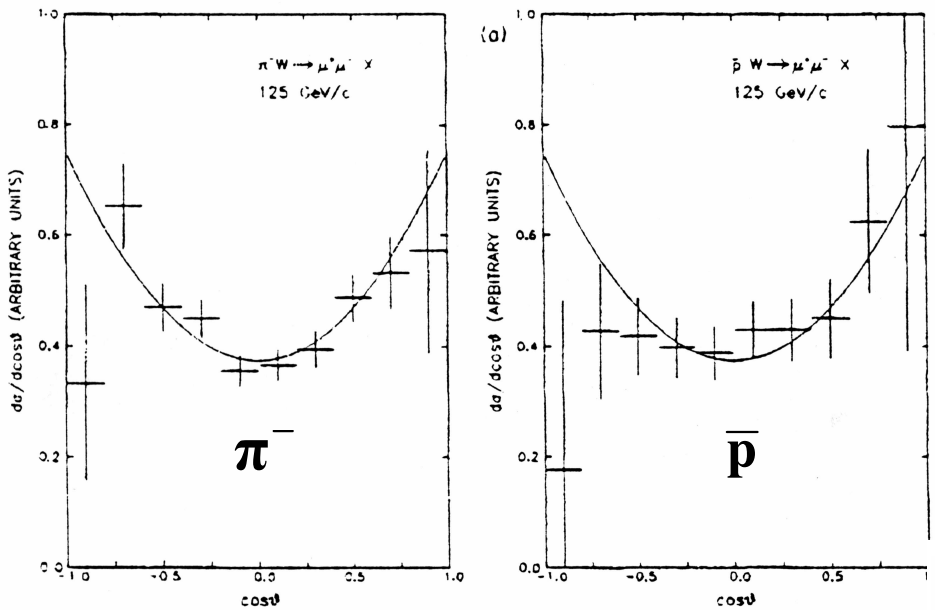
$4 < M < 8.5$ GeV/c^2



- cut on $\mathbf{P}_T$ selects asymmetry
- 30% asymmetry observed for π^-

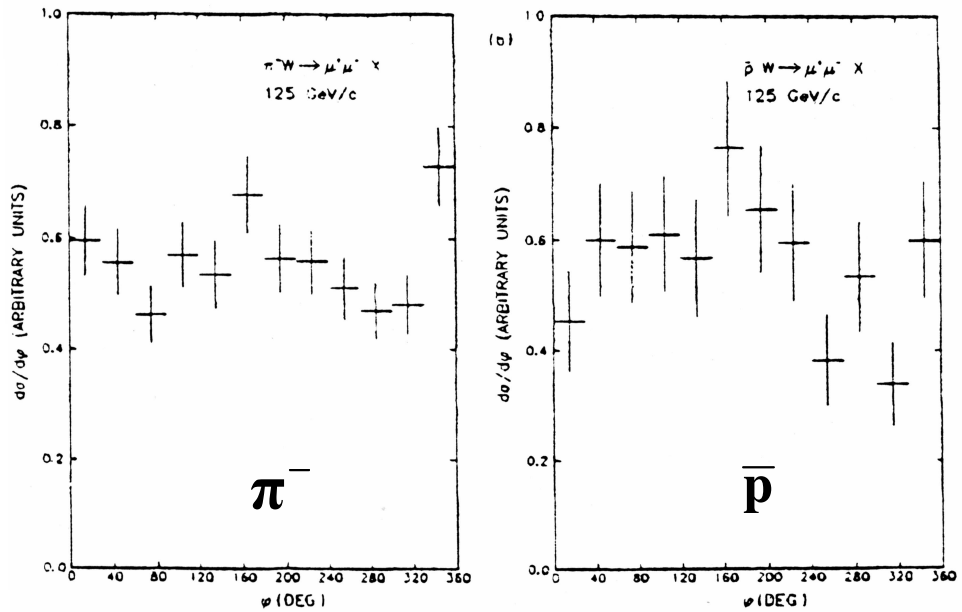
Conway et al, Phys. Rew. D39 (1989) 92

Angular distributions for $\bar{p}$ and π^- — π-N, $\bar{p}$N @ 125 GeV/c



- $\dfrac{d\sigma}{d\cos\vartheta}$ vs $\cos\vartheta$

- $\dfrac{d\sigma}{d\varphi}$ vs φ



E537 @ Fermilab

Anassontzis et al., Phys. Rew. D38 (1988) 1377

Drell-Yan Asymmetries — Unpolarised beam, polarised target

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} \propto \left(1+\cos^2\theta+\frac{\nu}{2}\sin^2\theta\cos 2\varphi+\rho\left|S_{1T}\right|\sin^2\theta\sin(\varphi-\varphi_{S_1})+\Lambda\right)$$

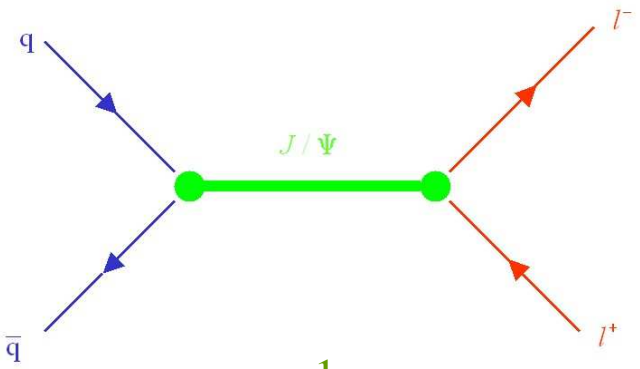
$\lambda \sim 1, \mu \sim 0$

$$A_T=\left|S_{1T}\right|\frac{2\sin 2\theta\sin(\varphi-\varphi_{S_1})}{1+\cos^2\theta}\frac{M}{\sqrt{Q^2}}\frac{\sum_a e_a^2\left[x_1 f_1^{a\perp}(x_1)f_1^{\bar{a}}(x_2)+x_2 h_1^{a}(x_1)h_1^{\bar{a}\perp}(x_2)\right]}{\sum_a e_a^2 f_1^{a}(x_1)f_1^{\bar{a}}(x_2)}$$

Even unpolarised beam is
a powerful tool to investigate
κ_T dependence of QDF

D. Boer et al., Phys. Rev. D60(1999)014012.

Drell-Yan Di-Lepton Production $\bar{p}p \to J/\Psi \to \mu^+\mu^- X$

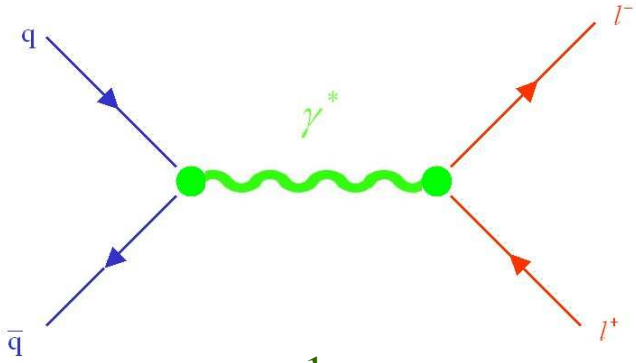


$$g_q^V \bar{v}\gamma^\mu u \frac{1}{M^2 - M^2_{J/\Psi} + i\Gamma M_{J/\Psi}} g_l^V \bar{u}\gamma^\mu v$$

vector couplings

same spinor structure

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



$$\bar{v}\gamma^\mu u \frac{1}{M^2} \bar{u}\gamma^\mu v$$

$$A_{TT}^{J/\Psi} = \frac{\sum_q g_q^V h_{1q}(x_1) h_{1q}(x_2)}{\sum_q g_q^V q(x_1) q(x_2)} \hat{a}_{TT} \underset{\text{large } x_1, x_2}{\approx} \frac{h_{1u}(x_1) h_{1u}(x_2)}{u(x_1) u(x_2)}$$

Measure A_{TT} in J/Ψ resonance region in $\bar{p}^\uparrow p^\uparrow$ reactions

$$x_F \cong 0 \quad , \quad x \cong \sqrt{\frac{M^2_{J/\Psi}}{s}} \quad \Rightarrow \quad \frac{A_{TT}}{\hat{a}_{TT}} \cong \left[\frac{h_{1u}(x)}{u(x)}\right]^2$$

$s = 45\,\text{GeV}^2 \qquad L = 1.5\,10^{31}\,\text{cm}^{-2}\,\text{s}^{-1}$

$$\int_6^{16} \frac{d\sigma}{dM^2} dM^2 \cong 9.6\,10^{-7}\,\text{GeV}^{-2} \quad \text{(cont. contrib.)}$$

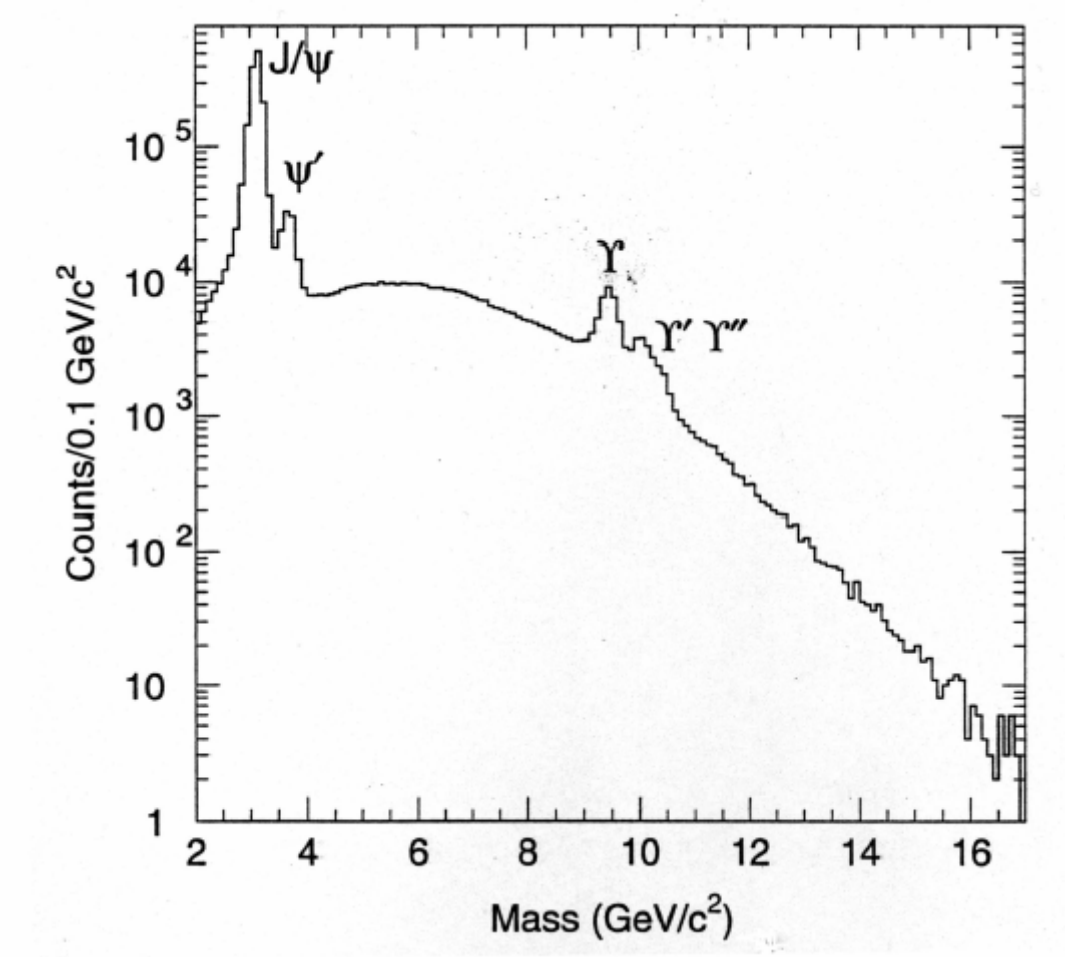
~ 160 ev/day , <x>≈0.4

Cross section large enough in this region

$$\delta_{A_{TT}} \cong 11\% \qquad \left(\delta = 1/\left(P_{\bar{p}} P_p \sqrt{N}\right)\right)$$

$$\left(P_{\bar{p}} \cong 5\% \quad P_p \cong 90\% \quad 240\,\text{days}\right)$$

Drell-Yan di-lepton cross section



Hyperon production Spin Asymmetries

Λ production in unpolarised pp-collision:

Several theoretical models:

- Static SU(6) + spin dependence in parton fragmentation/recombination [1-3]
- pQCD spin and transverse momentum of hadrons in fragmentation [4]

[1] T.A.DeGrand et al.,Phys. Rev D23 (1981) 1227.
[2] B. Andersoon et al., Phys. Lett. B85 (1979) 417.
[3] W.G.D.Dharmaratna, Phys. Rev. D41 (1990) 1731.
[4] M. Anselmino et al.,Phys. Rev. D63 (2001) 054029.

Analysing power

$$A_N = \frac{1}{P_B \cos\theta} \frac{N_\uparrow(\varphi) - N_\downarrow(\varphi)}{N_\uparrow(\varphi) + N_\downarrow(\varphi)}$$

Depolarisation

$$D_{NN} = \frac{1}{2P_B \cos\varphi}\left[P_{\Lambda\uparrow}(1 + P_B A_N \cos\varphi) - P_{\Lambda\downarrow}(1 - P_B A_N \cos\varphi)\right]$$

Key to distinguish between these models

Data available for D_{NN}:

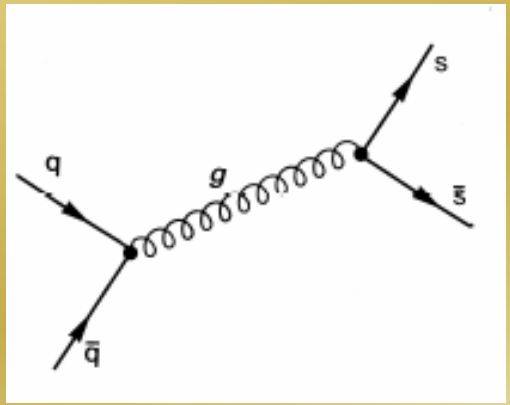
3.67 GeV/c	$D_{NN} < 0$
13.3 -18.5 GeV/c	$D_{NN} \sim 0$
200 GeV/c	$D_{NN} > 0$

D_{NN} @ 40 GeV/c MISSING

Hyperon production Spin Asymmetries

Polarised target: $\bar{p}p^{\uparrow} \rightarrow \bar{\Lambda} + \Lambda$.

Transverse target polarisation ➡ [1] complete determination of the spin structure of reaction



Existing data: PS185 (LEAR) [2]

[1] K.D. Paschke et al., Phys. Lett. B495 (2000) 49.
[2] PS185 Collaboration, K.D: Paschke et al., Nucl. Phys. A692 (2001) 55.

Models account correctly for cross sections.

Models do not account for D_{NN}^{Λ} or K_{NN}^{Λ} .

NEW DATA NEEDED

Transverse Single Spin Asymmetries

$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} - d\sigma^{\downarrow}} \qquad p^{\uparrow}p \rightarrow \pi X \qquad \bar{p}^{\uparrow}p \rightarrow \pi X$$

- π Production @ large x_F originate from valence quark:
  π^+: $A_N > 0$; π^-: $A_N < 0$ Correlated with expected u and d-quark polarisation
- A_N similar for $\sqrt{s}$ ranging from 6.6 up to 200 GeV

A_N related to fundamental properties of quark distribution/fragmentation

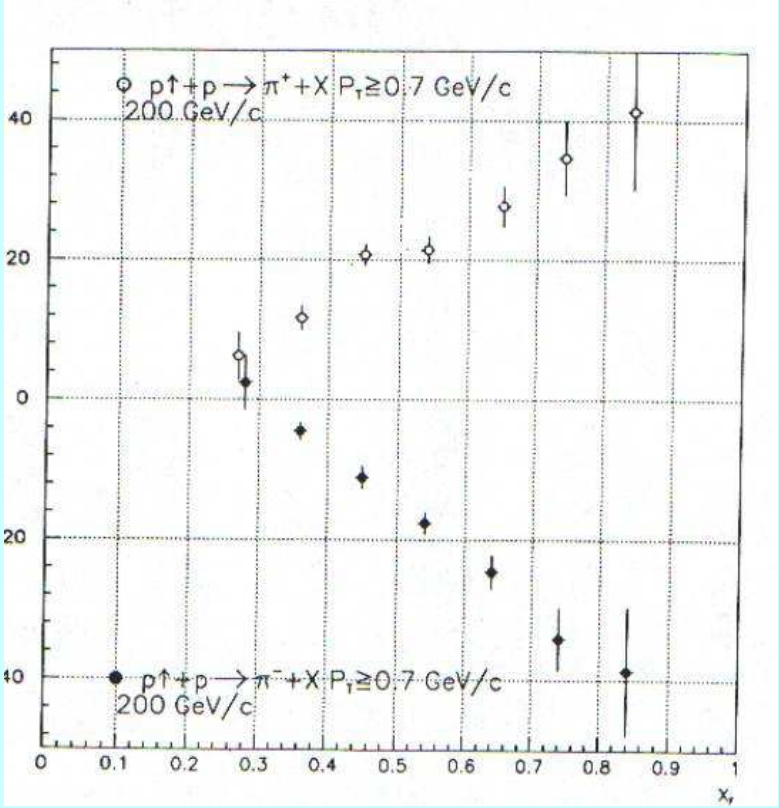
New experiment with polarised nucleon target, and $\bar{p}$ in a new kinematical region:

- new data available
- $A_{N,\bar{p}p^{\uparrow}\rightarrow\pi X}$ vs $A_{N,\bar{p}^{\uparrow}p\rightarrow\pi X}$
- DY-SSA (A_T) possible only @ RICH, $p^{\uparrow}p$-scattering:

$\sigma^{DY}_{\bar{p}p}$ @ smaller s >> σ^{DY}_{pp} @ large s

$p\uparrow + p \rightarrow \pi^+ + X$

E704 Tevatron FNAL 200GeV/c



Electromagnetic form-factors

FF in TL region ($\bar{p}p \rightarrow e^+e^-$) related to nucleon structure

New information with respect to SL FF (eN-scattering)

TL - FF:
- low statistic
- no polarisation phenomena

$\bar{p}p \rightarrow \mu^+\mu^-$:
- $\frac{d\sigma}{d\Omega}$
- analysing power

→ alternative way to FF

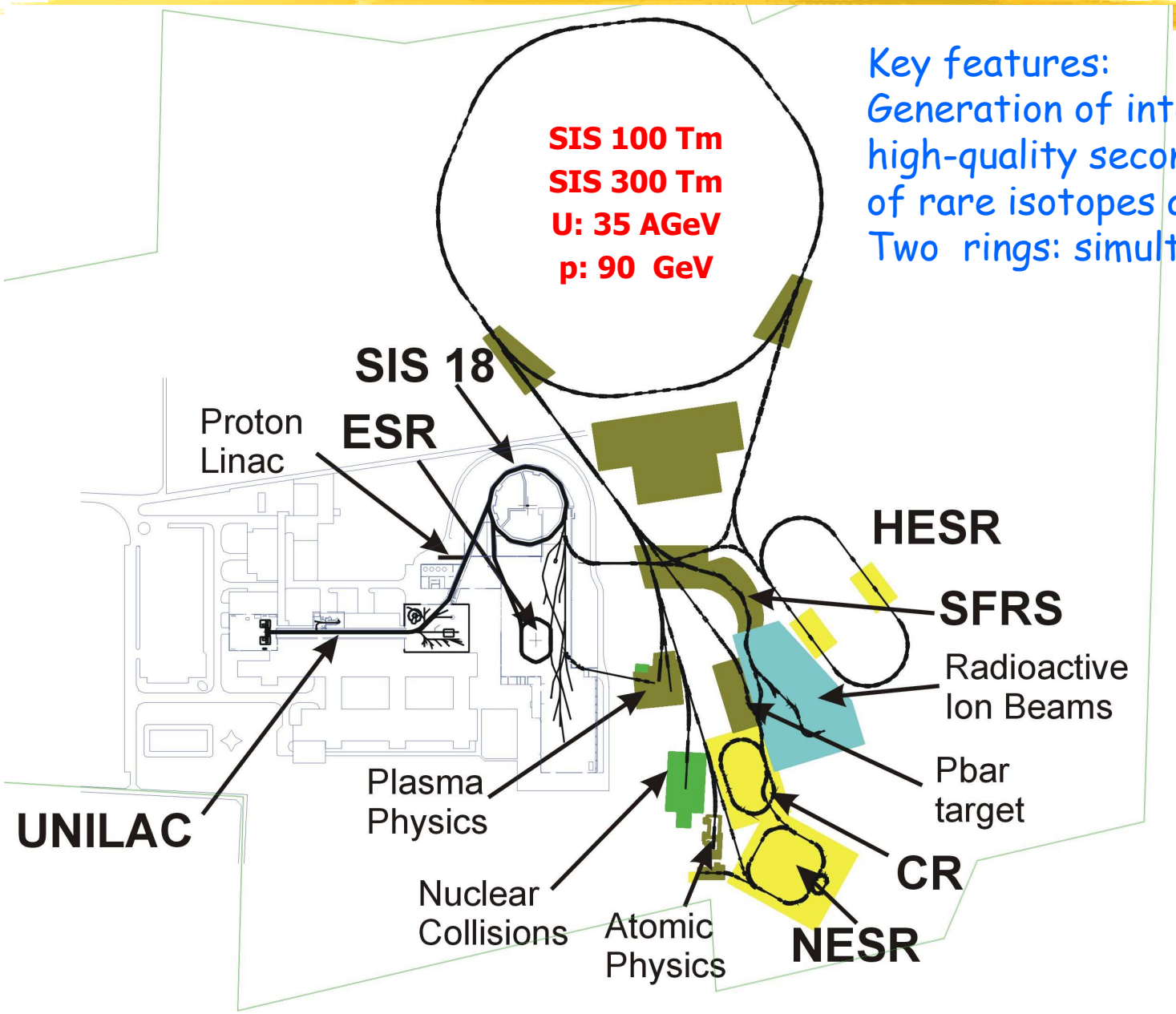
angular distribution → separation of electric and magnetic FF

analysing power → transverse polarisation of target $p^{\uparrow}$ leads to non zero analysing power

↓

Different prediction for models well reproducing SL data

Beam and Target



Key features:
Generation of intense,
high-quality secondary beams
of rare isotopes and antiprotons.
Two rings: simultaneous beams.

Beam and Target

HESR:

$$E_{\bar{p}} = 14.5\ \text{GeV}$$

$$L \leq 2 \cdot 10^{32}\,\text{cm}^{-2}\text{s}^{-1}$$

$$\Delta p / p \leq \pm 10^{-4}$$

Excellent but do not fit key requirement:

E > 40 GeV

PANDA:

design not compatible with polarised target

SIS300:

- $E_{\bar{p}} \geq 40\ \text{GeV}$, slow extraction
- $\Delta p / p \approx 2 \cdot 10^{-4}$, largely enough
- accumulation rate $7 \cdot 10^{10}\,\bar{p}/h$
- injection/extraction efficiency ~ 0.9

$\Rightarrow$ $1.5 \cdot 10^{7}\ \bar{p}/s$

Beam and Target - ASSIA

NH_3 10g/cm^3 : 2 x 10cm cells with opposite polarisation

$$f = \frac{3}{17} \qquad P_T \approx 0.85$$

$$L = \frac{3}{17} \cdot 10 \cdot 6 \cdot 10^{23} \cdot 1.5 \cdot 10^{7} = 1.5 \cdot 10^{31} m^{-2} s^{-1}$$

GSI modifications:

- extraction SIS100 → SIS300
  or injection CR → SIS300
- slow extraction SIS300 → beamline adapted to
  $E_{\bar{p}} \geq 40$ GeV
- experimental area adapted to handle expected
  radiation from $2 \cdot 10^7 \, \bar{p}/s$

Beam and Target - ASSIA

TARGET COMPASS like

Transverse and longitudinal polarisation

BEAM high luminosity and intensity $\bar{p}$

Eventually polarised $\bar{p}$-beam from SIS300

UNIQUE TOOL TO INVESTIGATE NUCLEON STRUCTURE

Alternative GSI solution - ASSIA

HESR → collider
polarised p and $\bar{p}$ beams

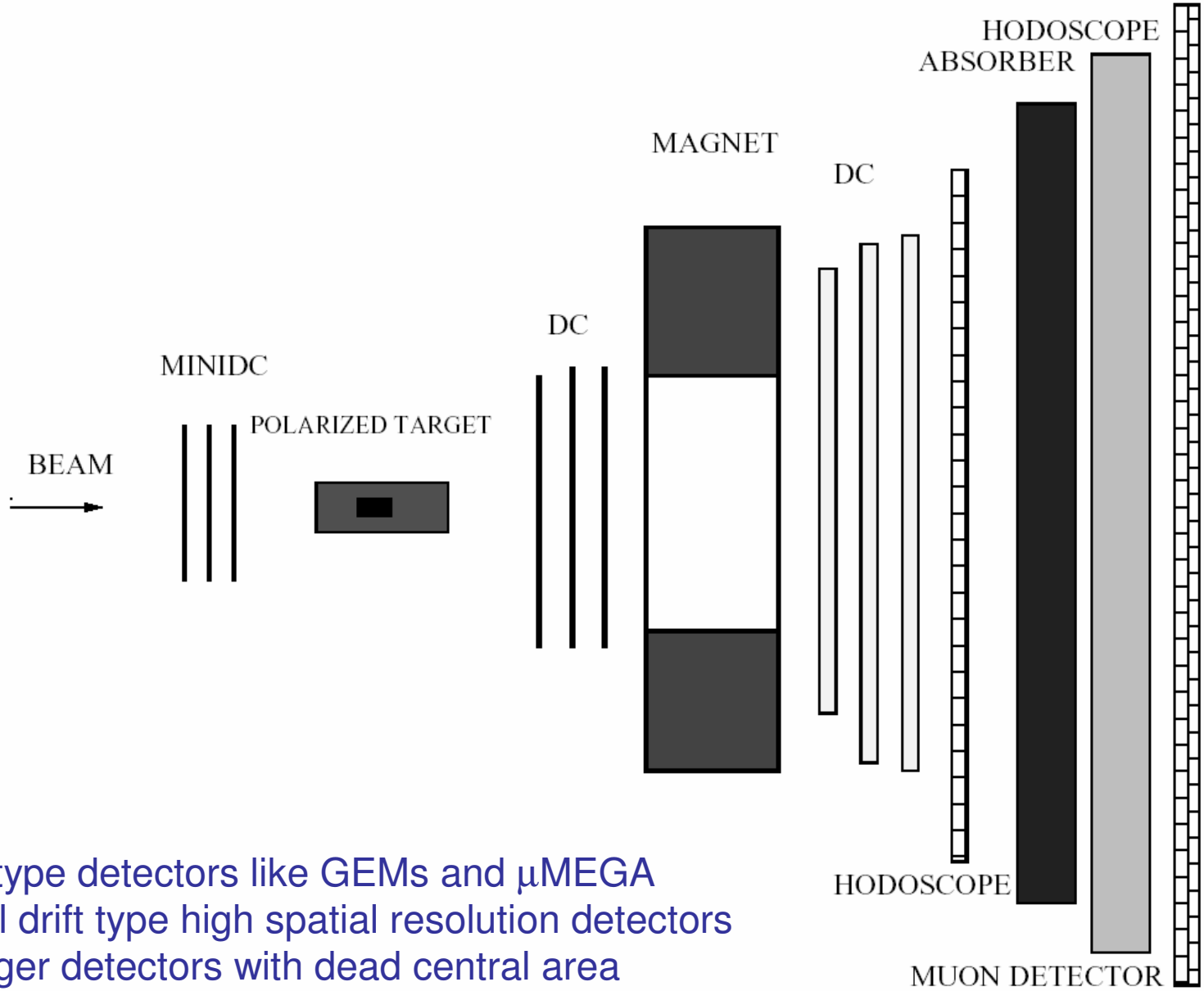
- Luminosity comparable to external target → KEY IUSSUE
- dilution factor f~1
- difficult to achieve polarisation $P_p \sim 0.85$
- required $\sqrt{s}$ achievable with present HESR performances (15 GeV/c)
- only transverse asymmetries can be measured
- $p^{\uparrow}$-beam required polarisation proton source and $P_p \geq 15$ GeV/c acceleration scheme preserving polarisation
- no additional beam extraction lines needed
- EXPERIMENTAL SETUP COMPLETELY DIFFERENT

Experimental setup - ASSIA

Possible setup scheme
similar to the COMPASS first spectrometer

- SM1 magnet (1Tm, stands $1.5 \cdot 10^7 \bar{p}/s$)
- GEM,MICROMEGA detetors $\sigma \leq 70\,\mu m$ smaller angle
- MWPC, STRAW detectors $\sigma \leq 1.5\,mm$ larger angle
- expected $\Lambda, \bar{\Lambda}$ resolution $\sigma \approx 2.5\,MeV/c^2$
- vertex resolution $\sigma = 2\,mm \div 1\,cm$
- HODOSCOPEs $\rightarrow$ Trigger
- sandwiches iron plates, Iarocci tubes, scintillator slabs $\rightarrow$ μId
- beam vacuum pipe along the apparatus

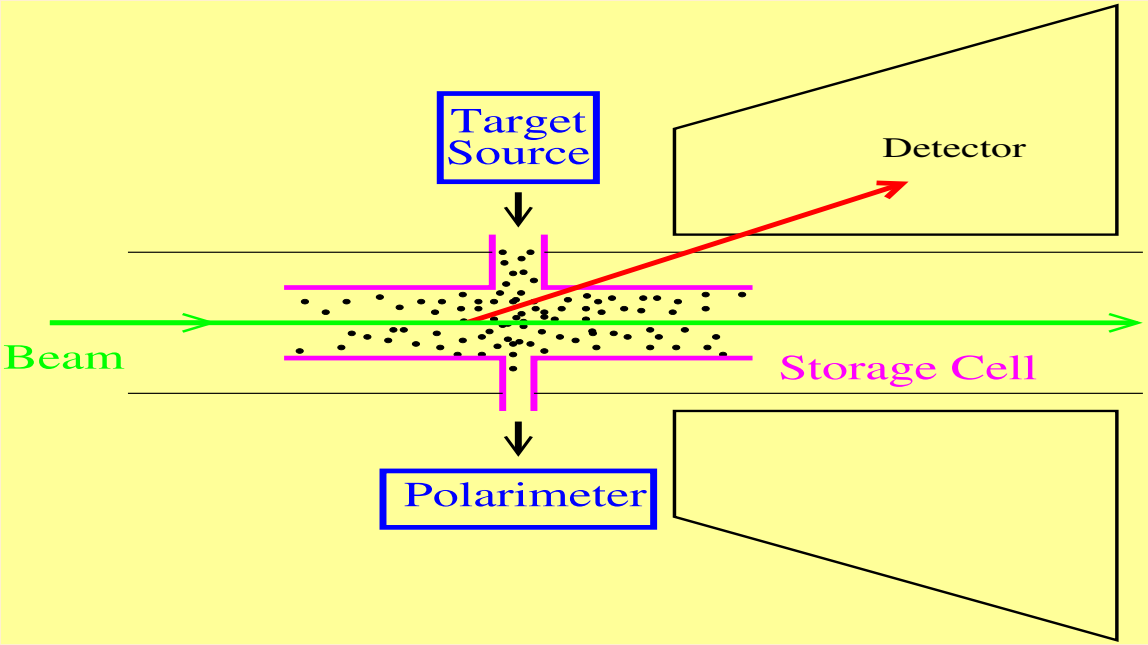
Sketch of the apparatus - ASSIA

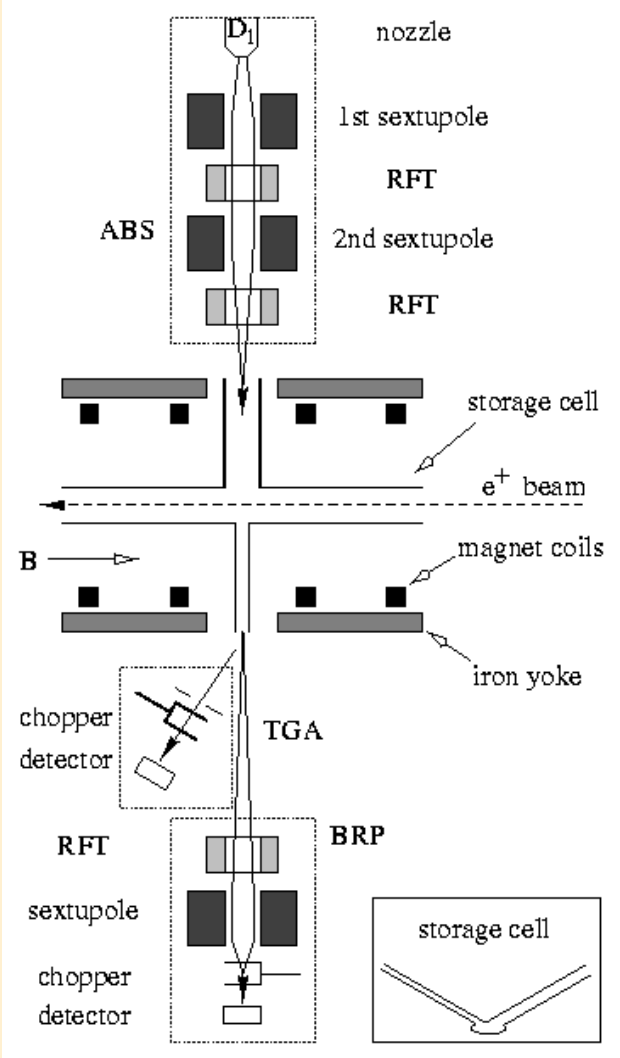


MINIDC : drift type detectors like GEMs and μMEGA
DC : small drift type high spatial resolution detectors
+ larger detectors with dead central area

Beam and Target - PAX

POLARISED INTERNAL TARGET "A LA HERMES"



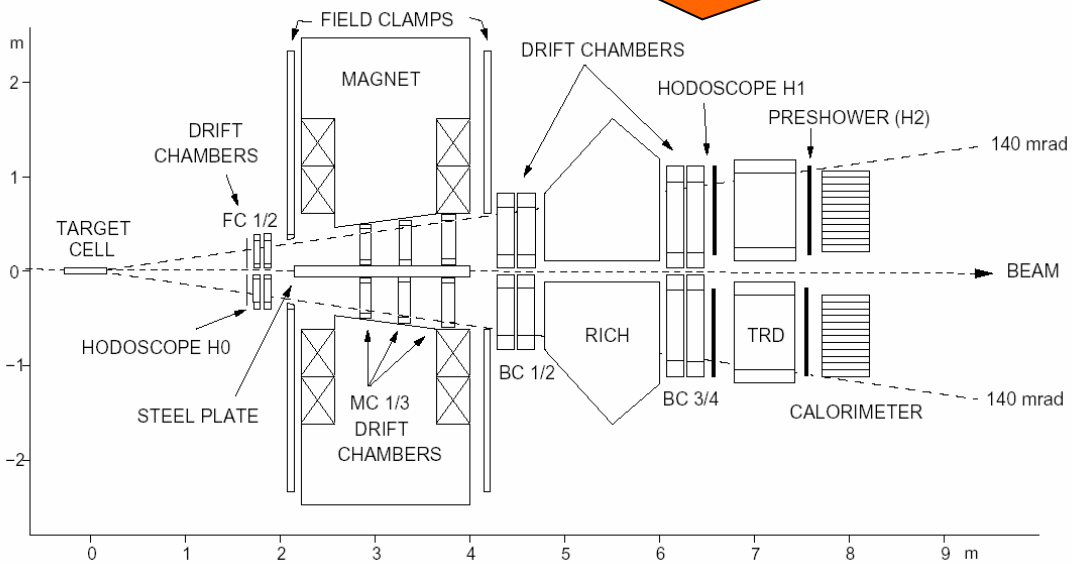


Hidrogen/Deuterium

Longitudinal Polarisation: $P \approx 0.85$

Transverse Polarisation: $P \approx 0.80$

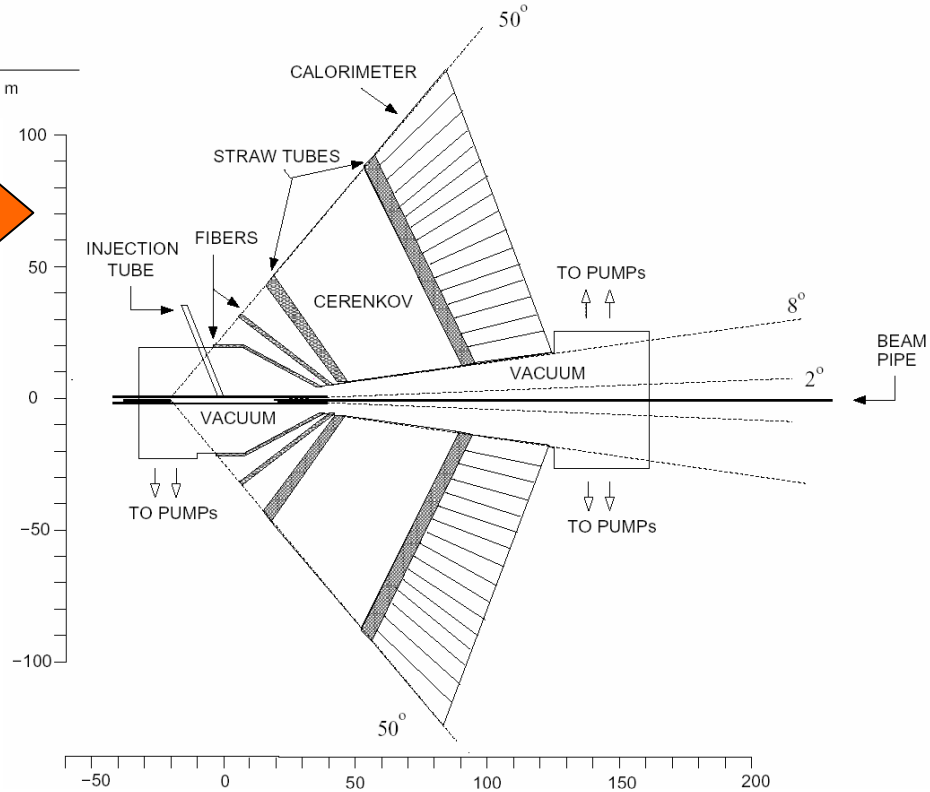
Sketch of the apparatus - PAX



Forward detector

(±8o acceptance) a la HERMES

- Identify unambiguously leading particles
- Measure precisely their momenta



Central Large Acceptance Detector a la E835

- Measure angles and energies of medium energy electromagnetic particles

Summary

Main goal: spin physics ➡ nucleon structure

DY di-lepton production ➡ distribution functions

Spin observables in hadron production ➡ fragmentation

Electromagnetic form factors

Ideal tools: polarised $\bar{p}$ beam, polarised nucleon target

Key issue: $\sqrt{s}$ in CM frame to span large x_1,x_2 domain

Slow extraction from SIS300	HESR $\bar{p}-p$ (collider)
⬇	⬇
polarised target, both P_L and P_T	no diluition factor

MORE WORK, SIMULATIONS NEEDED

DISCUSSION WITH GSI MANAGEMENT:

- what is feasable
- physics iussues