ASSIA LOI

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Introduction

- SIS300 @ GSI: $\bar{p}$, $P_{\bar{p}} \geq 40\ \text{GeV/c}$ $\left(\lambda = 4 \cdot 10^{-2}\,\text{fm}\right)$

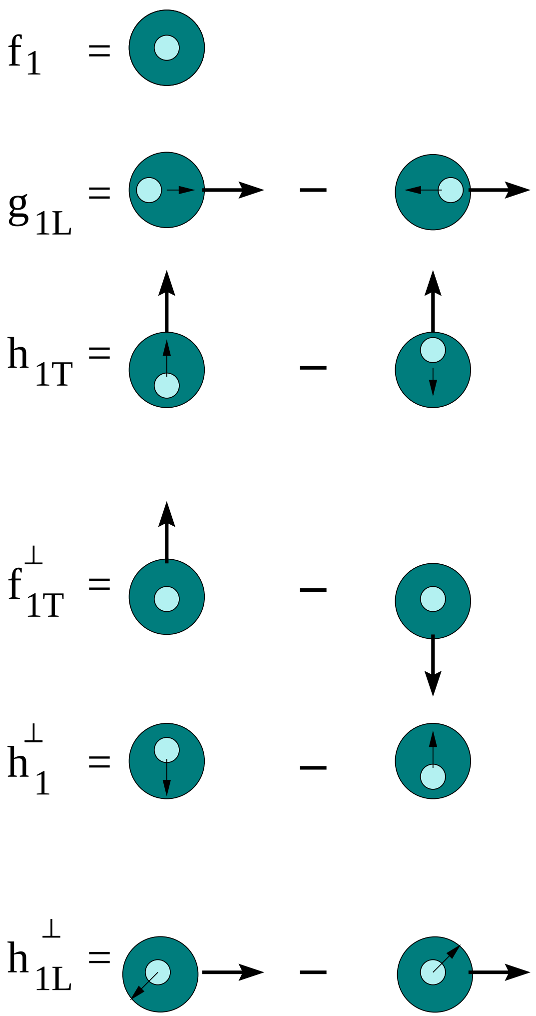
- A complete description of nucleonic structure requires:
  - proton and gluon distribution functions
  - quark fragmentation functions

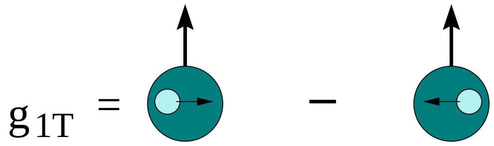
@ leading twist and @ NLO

- Physics objectives:
  - Drell-Yan di-lepton production
  - spin observables in hadron production
  - electromagnetic form factors

κ_T-dependent Parton Distributions

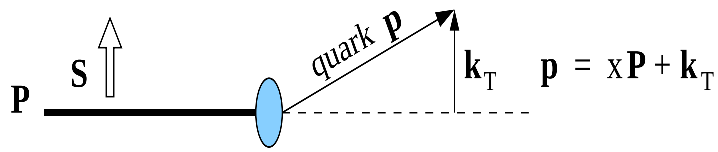
Twist-2 PDFs $\quad f_1^u(x) \equiv u(x),\ g_1^u(x) \equiv \Delta u(x),\ h_1^u(x) \equiv \delta u(x)$



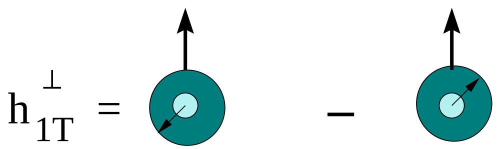


Distribution functions		Chirality even	odd
Twist-2	U	f_1	$h_1^{\perp}$
	L	g_1	$h_{1L}^{\perp}$
	T	$f_{1T}^{\perp}, g_{1T}$	$h_1, h_{1T}^{\perp}$

f_1, g_1 studied for decades:
h_1 essentially unknown



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



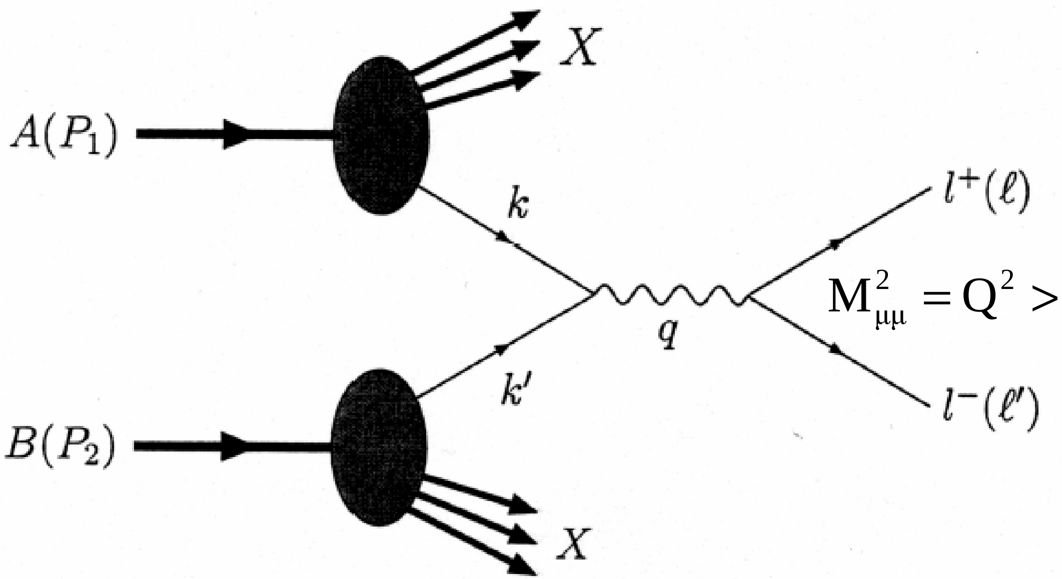
Drell-Yan Di-Lepton Production $\bar{p}p \rightarrow \mu^+\mu^- X$

Why Drell-Yan?

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

Why $\bar{p}$?

Each valence quark can contribuite to the diagram



$$M^2_{\mu\mu} = Q^2 > 0$$

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 $\bar{p}p \to \mu^+\mu^- X$

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

Scaling:

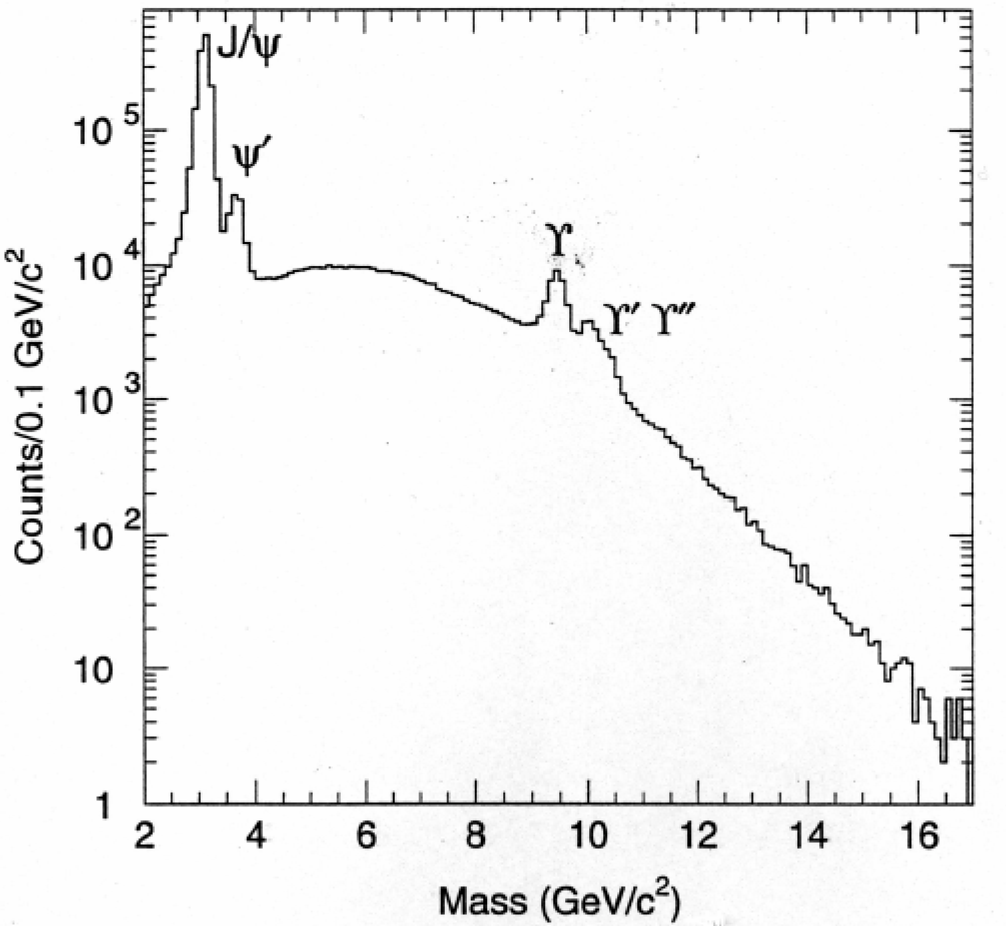
$$\frac{d^2\sigma}{d\sqrt{\tau}dx_F} \propto \frac{1}{s}$$

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

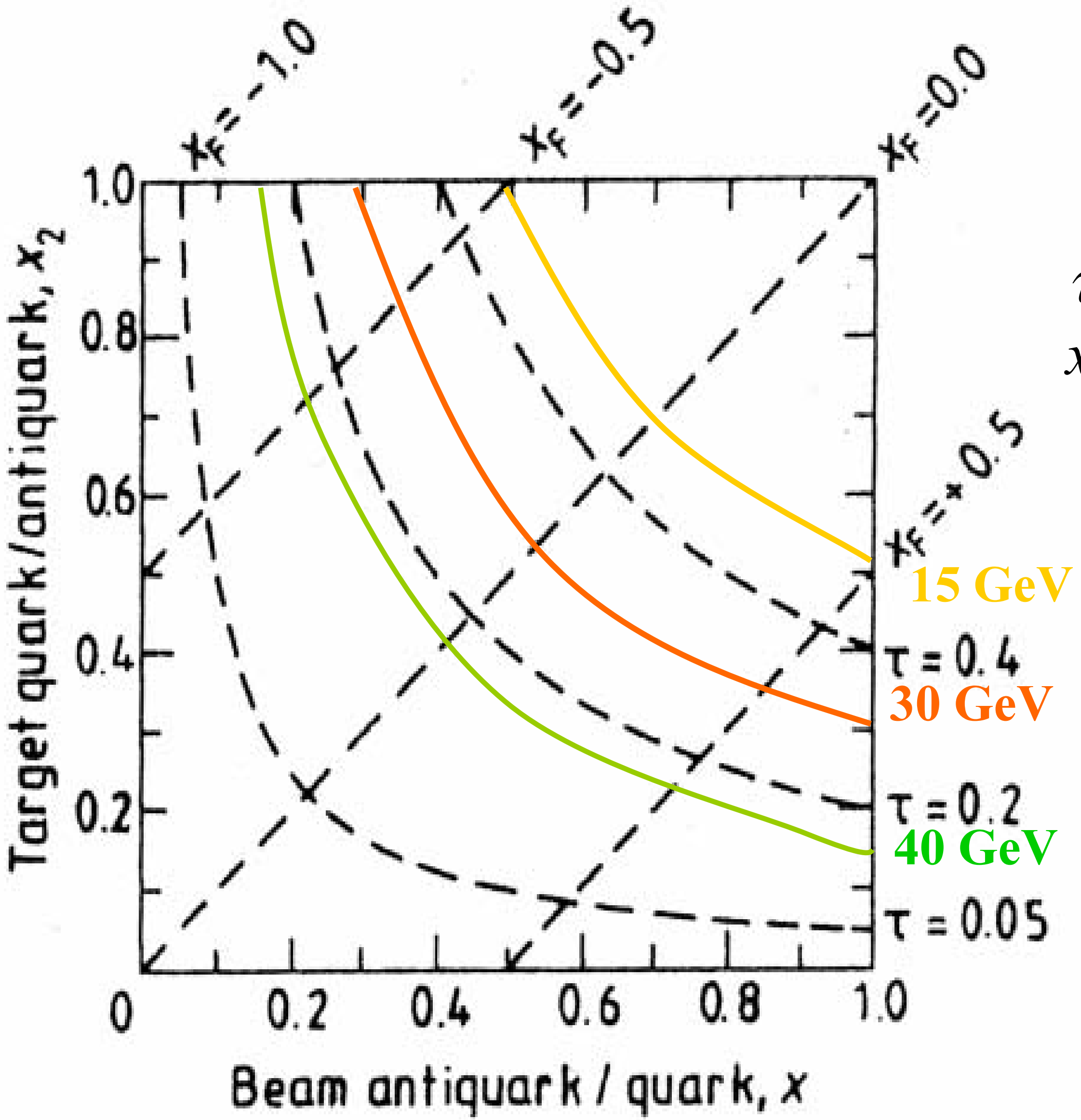
$\vec{p}_{BEAM} \geq 40\,\mathrm{Gev/c}$ needed

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

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



Phase space for Drell-Yan processes



τ = const: hyperbolae

x_F = const: diagonal

PANDA

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Drell-Yan Asymmetries — Polarised beam and target

Uncorrelated quark helicities ⇒ access chirally odd functions

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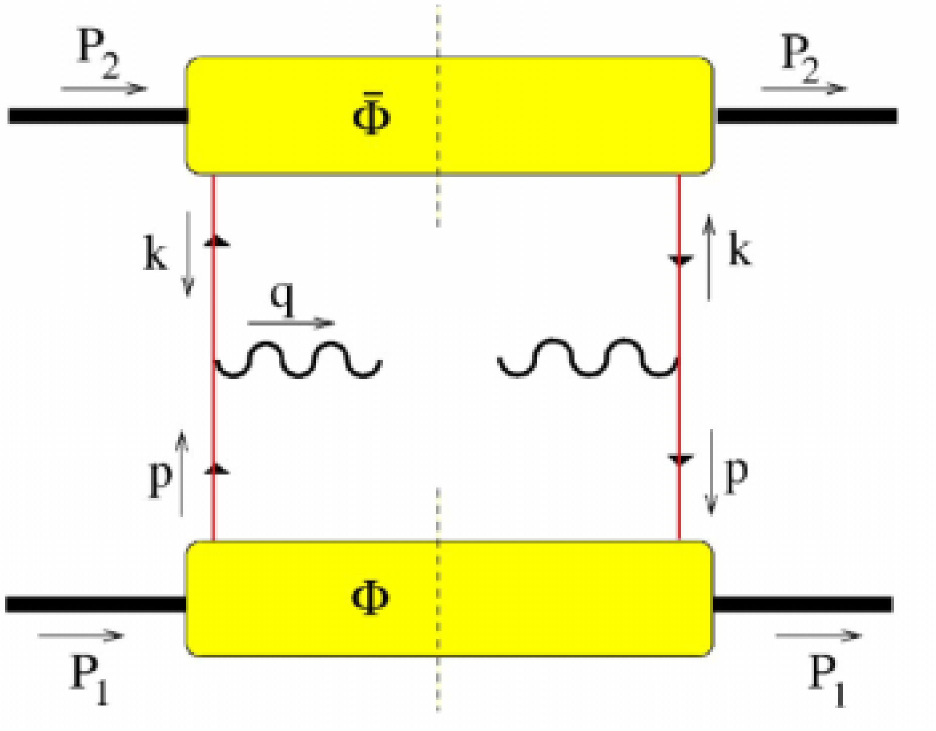
TRASVERSITY

Ideal because:

- h_1 not to be unfolded with fragmentation functions

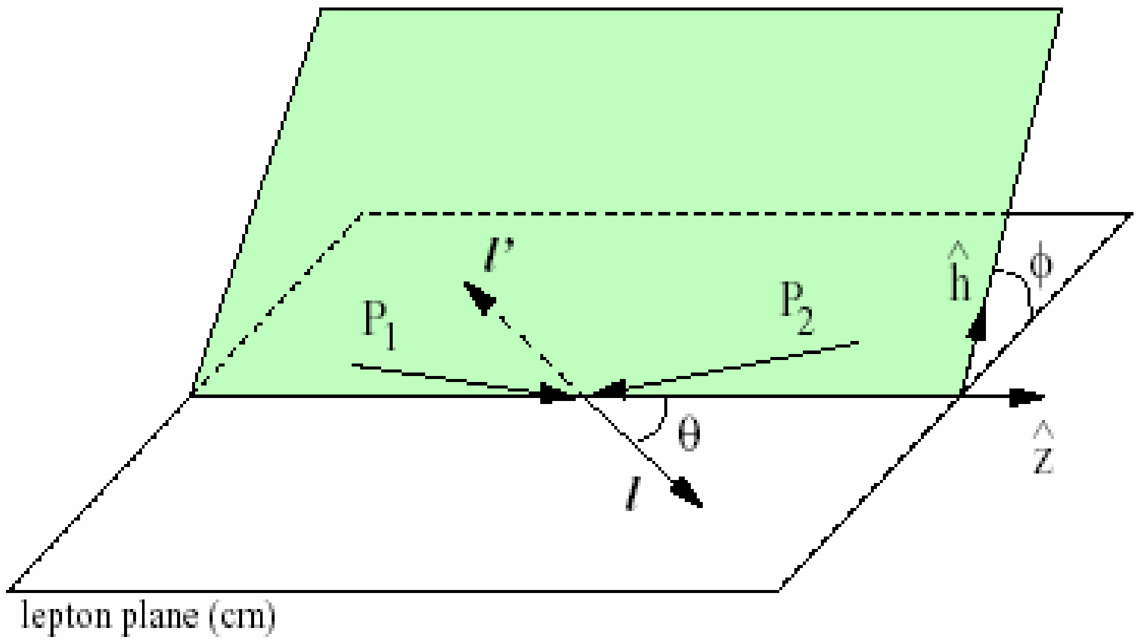
- chirally odd functions not suppressed (like in DIS)



Drell-Yan Asymmetries — Polarised beam and target

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

$$A_{LT} = \frac{2\sin 2\theta\cos\varphi}{1+\cos^2\theta}\,\frac{M}{\sqrt{Q^2}}\,\frac{\sum_a e_a^2\left(g_1^a(x_1)\,x_2\,g_T^{\bar{a}}(x_2) - x_1 h_L^a(x_1)\bar{h}_1^a(x_2)\right)}{\sum_a e_a^2 f_1^a(x_1)\bar{f}_1^a(x_2)}$$



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 — 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]:

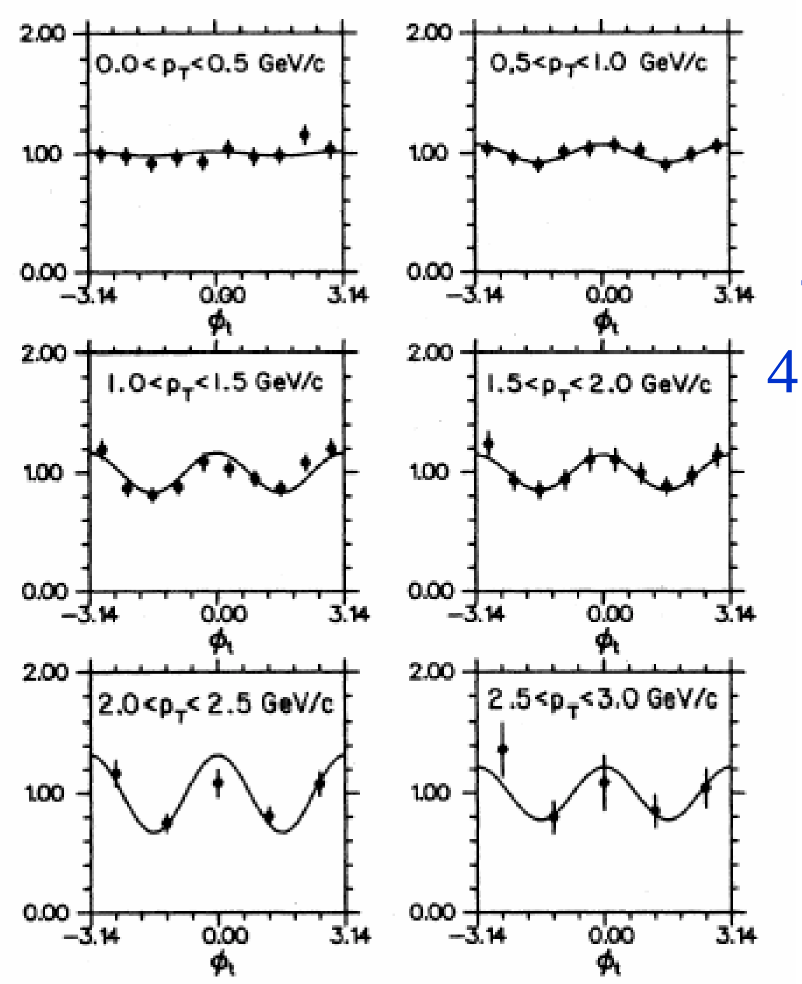
$\cos 2\varphi$ contribution to angular distribution provide:

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

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

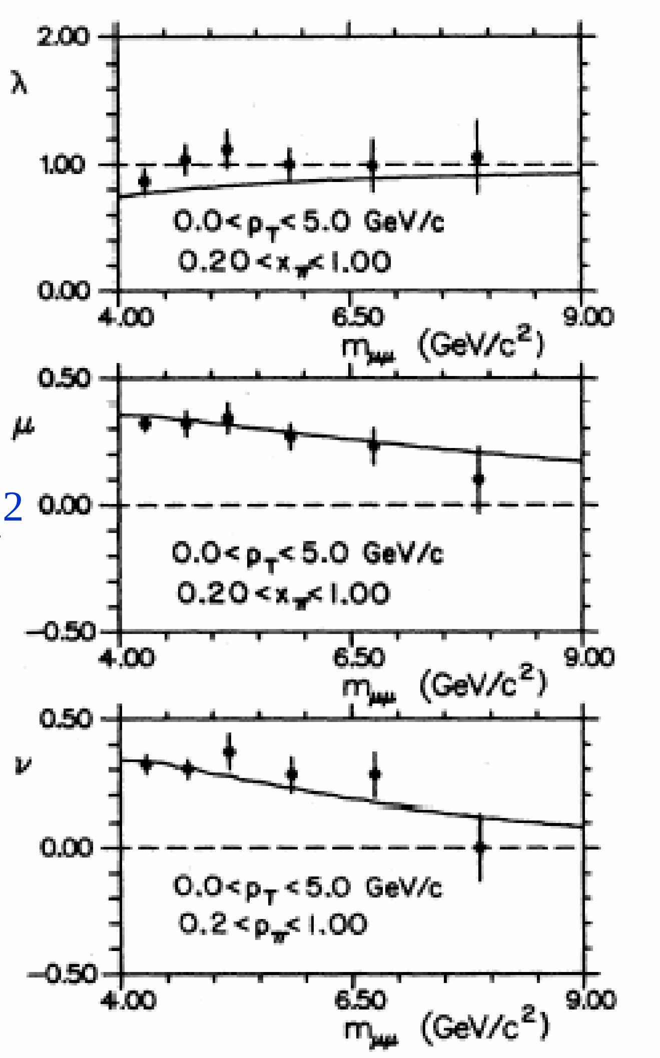
Angular distribution in CS frame

π-N $\rightarrow$ μ+μ-X @ 252 GeV/c



$-0.6 < \cos\vartheta < 0.6$

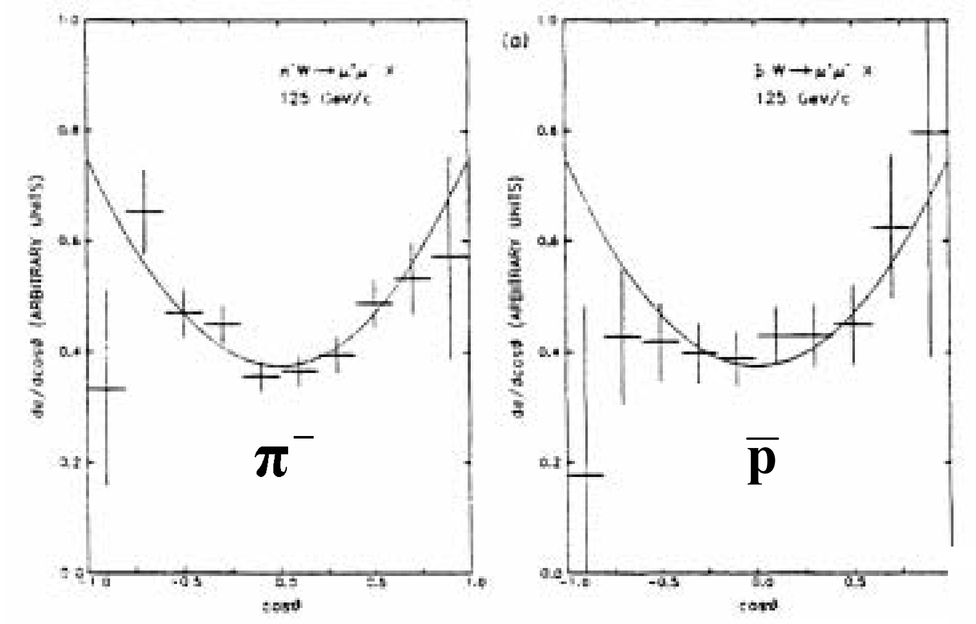
$4 < M < 8.5$ GeV/c^2



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

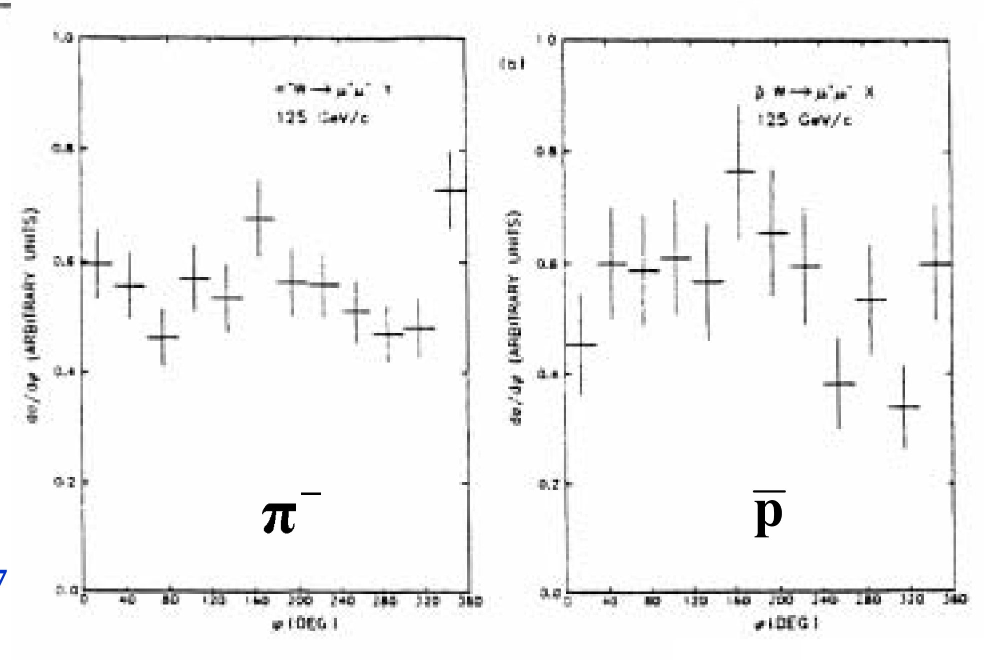
- cut on $\mathbf{P}_T$ selects asymmetry
- 30% asymmetry observed for π^-

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



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

Drell-Yan Asymmetries — Unpolarised beam, polarised target

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

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

$$A_T=\left|S_{1T}\right|\frac{2\sin 2\theta\sin(\varphi+\varphi_{S_1})}{1+\cos^2\theta}\frac{M}{\sqrt{Q^2}}\frac{\sum_a e_a^2\left[x_1 f_{1}^{a\perp}(x_1)\bar{f}_1^a(x_2)+x_2 h_1^a(x_1)\bar{h}_1^{a\perp}(x_2)\right]}{\sum_a e_a^2 f_1^a(x_1)\bar{f}_1^a(x_2)}$$

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

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

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}:

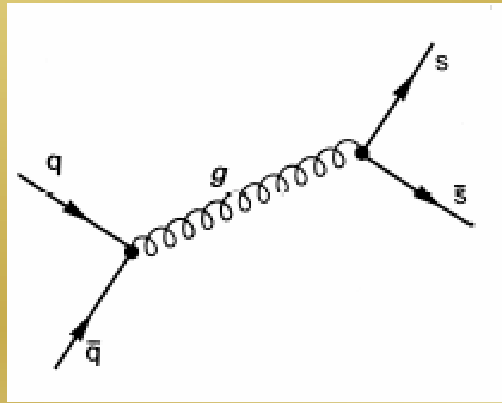
3.67 GeV/c	$D_{NN} < 0$
13.3 -18.5 GeV/c	$D_{NN} \sim 0$
200 GeV/c	$D_{NN} > 0$

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

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

$$p^{\uparrow} p \rightarrow \pi X \qquad \bar{p}^{\uparrow} p \rightarrow \pi X$$

- 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 $P_{\bar{p}}$ ranging from 6.6 up to 200 GeV

  A_N related to fundamental properties of quark distribution/fragmentation

- $A_{N,\bar{p}p^{\uparrow}\rightarrow\pi X}$ vs $A_{N,\bar{p}^{\uparrow}p\rightarrow\pi X}$

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

- new data available
- DY-SSA possible only @ RICH, $p^{\uparrow}p$-scattering: $\sigma^{DY}_{\bar{p}p}$ @ smaller s >> σ^{DY}_{pp} @ large s

$$\bar{p}p \rightarrow \mu^{+}\mu^{-}X$$ @ GSI unique possibility

Electromagnetic form-factors

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

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

TL-FF:
- low statistic
- no polarisation phenomena

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

→ alternative way to FF

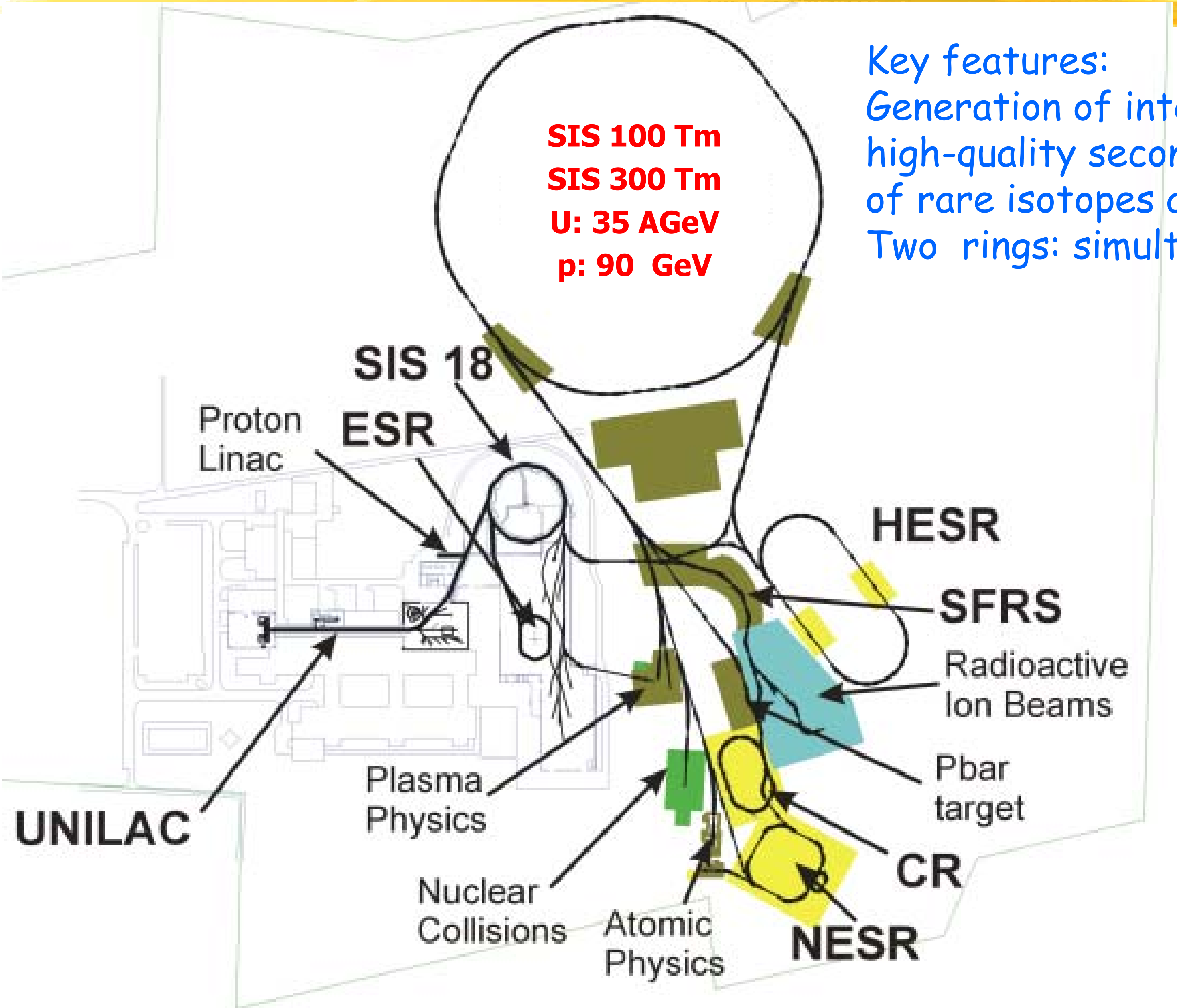
angular distribution → separation of electric and magnetic FF

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:

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

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

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

Excellent but do not fit key requirement:

E > 40 GeV

PANDA:

design not compatible with polarised target

SIS300:

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

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

Beam and Target

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

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

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

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

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

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
- $p^{\updownarrow}$ 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

Possible setup scheme similar to the COMPASS first spectrometer

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

Summary

Main goal: spin physics → nucleon structure

DY dɨ lepton production → distribution functions

Spin observables in hadron production → fragmentation

Electromagnetic form factors

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

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

Slow extraction from SIS300	HESR as a $\bar{p}-p$ 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