DSPIN-09

Future Polarised Drell-Yan experiments - probing hadron structure

Oleg Denisov
CERN and INFN sez. di Torino

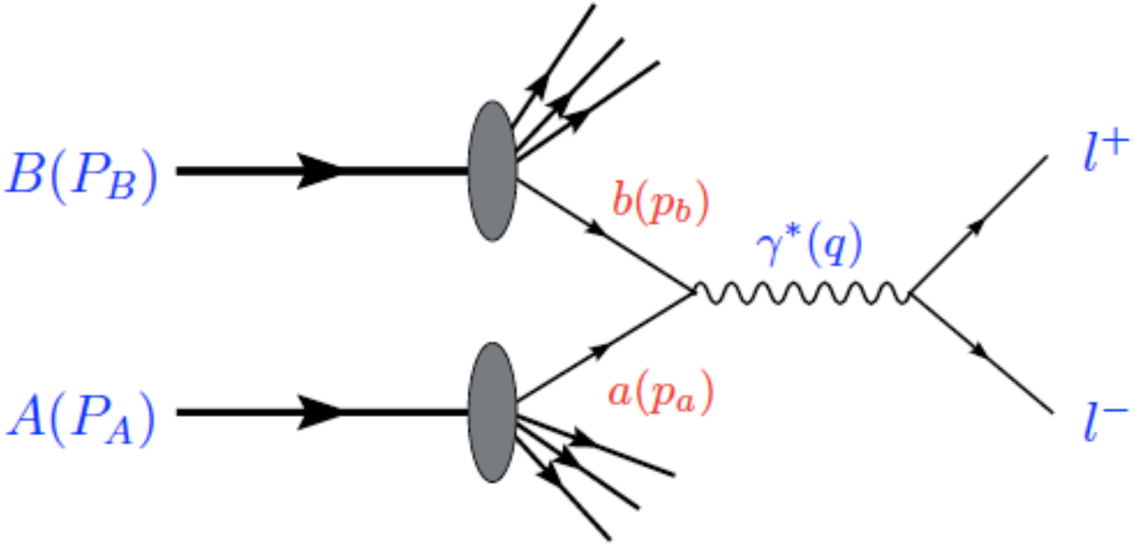
04.09.2009

Outline

- Drell-Yan – physics case (selected topics)
  - Kinematics
  - Unpolarised Drell-Yan
  - Single (Transverse) polarised Drell-Yan
  - Double polarised Drell-Yan
  - J/Psi production and J/Psi <-> DY duality
  - Access to GPDs?
- Some indications to the future Drell-Yan experiments
- Future Drell-Yan experiments:
  - Fixed target experiments (COMPASS, E906, J-Park)
  - Collider experiments (RHIC, NICA SPD, PAX (GSI)
- Some conclusions

Drell-Yan Kinematics (collinear case)

$$A + B \longrightarrow l^+ + l^- + X$$



$$P_A = \frac{\sqrt{s}}{2}(1,0,1)$$

$$P_B = \frac{\sqrt{s}}{2}(1,0,-1)$$

$$p_a = \frac{\sqrt{s}}{2}x_a(1,0,1)$$

$$p_b = \frac{\sqrt{s}}{2}x_b(1,0,-1)$$

- Collinear virtual photon:

$$q = p_a + p_b = (q_0, 0, q_L)$$

- Observing the dilepton we can "observe" the γ^* and directly have information on partons:

• $M^2 \equiv q^2 = (p_a + p_b)^2$ • $y \equiv \frac{1}{2}\ln\left(\frac{q_0+q_L}{q_0-q_L}\right) = \frac{1}{2}\ln\left(\frac{x_a}{x_b}\right)$ • $\boxed{\tau = x_a x_b = M^2/s}$

$$x_{a/b} = \frac{M}{\sqrt{s}}e^{\pm y} = \frac{q_0 \pm q_L}{\sqrt{s}}$$

S.Melis -> COMPASS

Drell-Yan Kinematics (transverse motion)

- If we consider the transverse motion of partons then:

$$p_a = \frac{\sqrt{s}}{2} x_a \left(1 + \frac{k_{\perp a}^2}{x_a^2 s}, \frac{2\boldsymbol{k}_{\perp a}}{x_a \sqrt{s}}, 1 + \frac{k_{\perp a}^2}{x_a^2 s}\right)$$

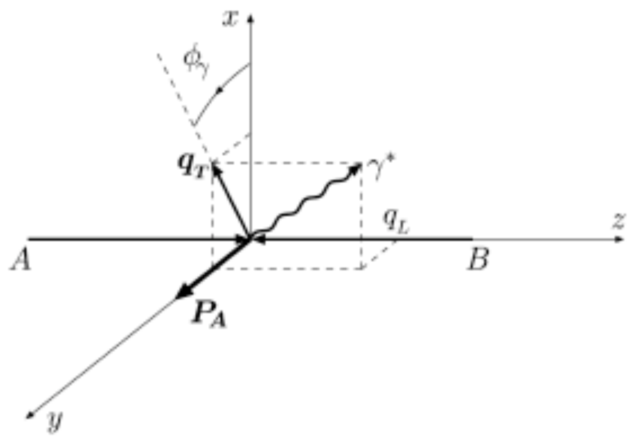
$$p_b = \frac{\sqrt{s}}{2} x_b \left(1 - \frac{k_{\perp b}^2}{x_b^2 s}, \frac{2\boldsymbol{k}_{\perp b}}{x_b \sqrt{s}}, -1 + \frac{k_{\perp b}^2}{x_b^2 s}\right)$$

- ... and the γ^* (dilepton) momentum has a transverse component in the h.c.m. frame

$$q = p_a + p_b = (q_0, \boldsymbol{q}_T, q_L)$$

$$\boxed{\boldsymbol{q}_T = \boldsymbol{k}_{\perp a} + \boldsymbol{k}_{\perp b}}$$

Only low q_T ($q_T^2 \ll q^2$)
have a non-perturbative origins



COMPASS

INFN Istituto Nazionale di Fisica Nucleare Sezione di Torino

Unpolirised Drell-Yan angular distributions

- A model indipendent expression for the angular distribution of the unpolarized Drell-Yan can be written by means of the so called helicity structure functions :

$$\frac{dN}{d\Omega} = \frac{3}{8\pi} \frac{W_T(1+\cos^2\theta) + W_L(1-\cos^2\theta) + W_\Delta \sin 2\theta \cos\phi + W_{\Delta\Delta} \sin^2\theta \cos 2\phi}{2W_T + W_L}$$

or in terms of the parameters λ, μ, ν:

$$\frac{dN}{d\Omega} = \frac{3}{4\pi(\lambda+3)} \left[1 + \lambda \cos^2\theta + \mu \sin 2\theta \cos\phi + (\nu/2) \sin^2\theta \cos 2\phi\right]$$

$$\lambda = \frac{W_T - W_L}{W_T + W_L}$$

$$\mu = \frac{W_\Delta}{W_T + W_L}$$

$$\nu = \frac{2W_{\Delta\Delta}}{W_T + W_L}$$

- Lam-Tung sum rule:

$$1 - \lambda = 2\nu \quad \text{or} \quad W_L = 2W_{\Delta\Delta}$$

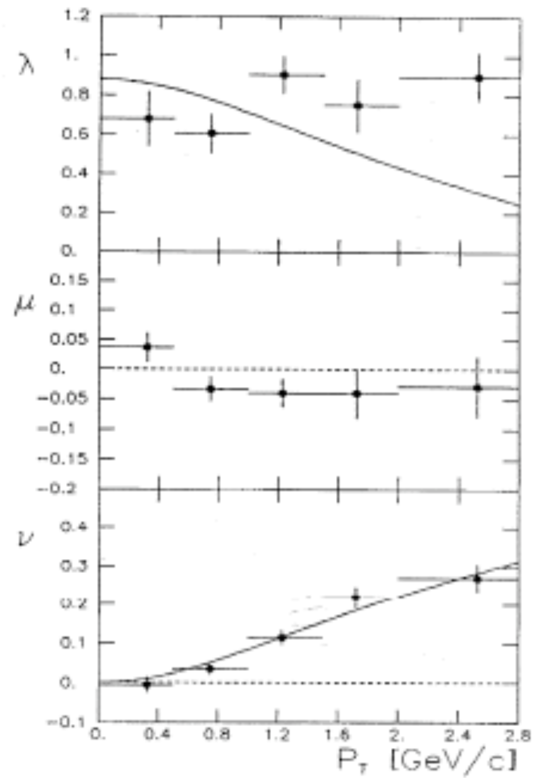
  - ◇ Parton model: $\lambda = 1\,,\ \ \nu = 0\,;$
  - ◇ α_s QCD corrections: $\lambda \neq 1\,,\ \ \nu \neq 0\,;$ but still $1 - \lambda = 2\nu$

- J.C. Collins and D.E. Soper, Phys. Rev. D 16,2219; C.S. Lam and W. Tung, Phys. Rev. D 18,2447

Unpolarised Drell-Yan angular distributions:
Lam-Tung sum rule violation

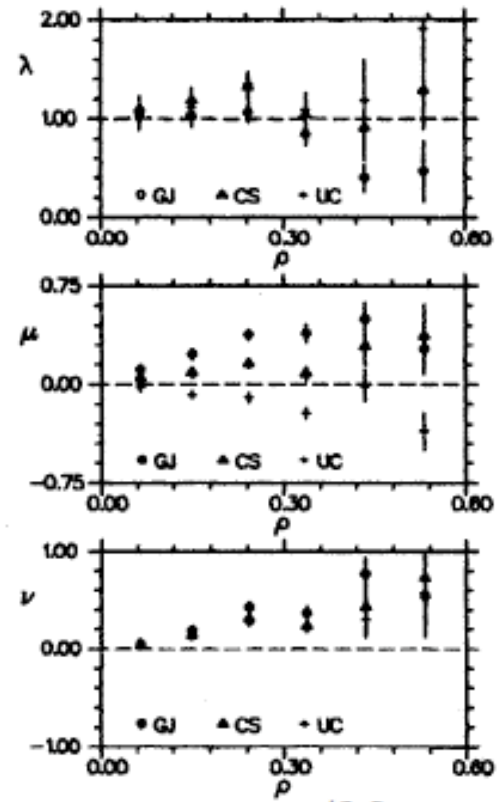
► NA10: $\pi^-(194\text{GeV}/c)W \to \mu^+\mu^-$

► E615: $\pi^-(252\text{GeV}/c)W \to \mu^+\mu^-$



(Collins Soper frame)

Falciano *et al*, Z.Phy. C 31, 513(1986)



$\rho = q_T/M$

Conway *et al*, Phys. Rev. D 39, 92(1989)

Unpolarised Drell-Yan angular distributions: Boer-Mulders function (cos(2ϕ) modulations)

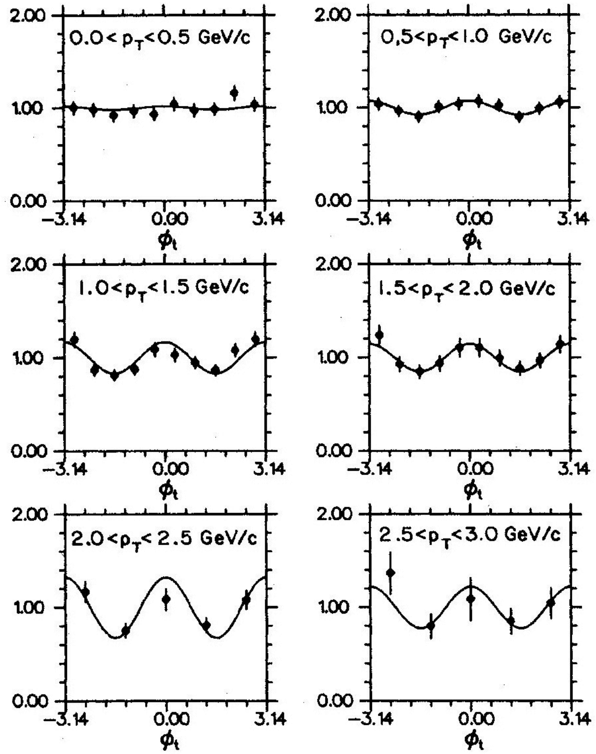
► Non perturbative effect: intrinsic transverse motion+Boer-Mulders function

$$\frac{d\sigma}{d^4q d\Omega} = \frac{\alpha^2}{6M^2 s} \sum_{a,\bar{a}} e_a^2 \Big\{ \underbrace{(1+\cos^2\theta)\mathcal{F}[f_1 \bar{f}_1]}_{\lambda \text{ term}} + \underbrace{\sin^2\theta \cos 2\phi \mathcal{F}[(2\hat{h}\cdot k_{\perp 1}\, \hat{h}\cdot k_{\perp 2})\frac{h_1^\perp \bar{h}_1^\perp}{M_1 M_2}]}_{\nu \text{ term}} \Big\}$$

where: $\mathcal{F}[f\bar{f}] = \int d^2k_{\perp 1} d^2k_{\perp 2} \delta^2(k_{\perp 1} + k_{\perp 2} - q_T) f^a(x_1, k_{\perp 1}^2) \bar{f}^a(x_2, k_{\perp 2}^2)$

$$\boxed{\diamond\ \nu = \frac{2\sum_{a,\bar{a}} e_a^2 \mathcal{F}\left[(2\hat{h}\cdot k_{\perp 1}\, \hat{h}\cdot k_{\perp 2})\frac{h_1^\perp \bar{h}_1^\perp}{M_1 M_2}\right]}{\sum_{a,\bar{a}} e_a^2 \mathcal{F}[f_1 \bar{f}_1]}}$$

DY mechanism is sensitive to k_T -induced effects



Drell-Yan cross section (general form)

Very recent paper by Arnold, Metz and Schlegel arXiv:0809.2262

$$
\begin{aligned}
\frac{d\sigma}{d^4q\, d\Omega} = \frac{\alpha_{em}^2}{F\, q^2} \times \\
& \Big\{ \Big((1+\cos^2\theta)\, F_{UU}^1 + (1-\cos^2\theta)\, F_{UU}^2 + \sin 2\theta \cos\phi\, F_{UU}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{UU}^{\cos 2\phi} \Big) \\
& + S_{aL} \Big(\sin 2\theta \sin\phi\, F_{LU}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{LU}^{\sin 2\phi} \Big) \\
& + S_{bL} \Big(\sin 2\theta \sin\phi\, F_{UL}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{UL}^{\sin 2\phi} \Big) \\
& + |\vec{S}_{aT}| \Big[\sin\phi_a \Big((1+\cos^2\theta)\, F_{TU}^1 + (1-\cos^2\theta)\, F_{TU}^2 + \sin 2\theta \cos\phi\, F_{TU}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{TU}^{\cos 2\phi} \Big) \\
& \qquad + \cos\phi_a \Big(\sin 2\theta \sin\phi\, F_{TU}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{TU}^{\sin 2\phi} \Big) \Big] \\
& + |\vec{S}_{bT}| \Big[\sin\phi_b \Big((1+\cos^2\theta)\, F_{UT}^1 + (1-\cos^2\theta)\, F_{UT}^2 + \sin 2\theta \cos\phi\, F_{UT}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{UT}^{\cos 2\phi} \Big) \\
& \qquad + \cos\phi_b \Big(\sin 2\theta \sin\phi\, F_{UT}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{UT}^{\sin 2\phi} \Big) \Big] \\
& + S_{aL}\, S_{bL} \Big((1+\cos^2\theta)\, F_{LL}^1 + (1-\cos^2\theta)\, F_{LL}^2 + \sin 2\theta \cos\phi\, F_{LL}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{LL}^{\cos 2\phi} \Big)
\end{aligned}
$$

Single polarised Drell-Yan: cross section

$$\frac{d\sigma}{d^4q d\Omega} = \frac{\alpha_{em}^2}{2sM^2} \times$$

$$\Big\{ \Big((1+\cos^2\theta) F_{UU}^1 + (1-\cos^2\theta) F_{UU}^2 + \sin 2\theta \cos\phi F_{UU}^{\cos\phi} + \sin^2\theta \cos 2\phi F_{UU}^{\cos 2\phi} \Big)$$

$$\boxed{\begin{aligned} &+|S_{BT}| \Big[\sin\phi_{S_B} \Big((1+\cos^2\theta) F_{UT}^1 + (1-\cos^2\theta) F_{UT}^2 + \sin 2\theta \cos\phi F_{UT}^{\cos\phi} + \sin^2\theta \cos 2\phi F_{UT}^{\cos 2\phi} \Big) \\ &\quad \cos\phi_{S_B} \Big(\sin 2\theta \sin\phi F_{UT}^{\sin\phi} + \sin^2\theta \sin 2\phi F_{UT}^{\sin 2\phi} \Big) \Big\} \end{aligned}}$$

- In parton model there are only 3 indipendent (combinations of) structure functions:

$$F_{UT}^1 \rightarrow \text{Sivers Effect}$$

$$F_{UT}^{\sin(2\phi-\phi_{S_B})} \rightarrow \text{Boer-Mulders} \otimes \text{transversity}$$

$$F_{UT}^{\sin(2\phi+\phi_{S_B})} \rightarrow \text{Boer-Mulders} \otimes h_{1T}^{\perp}$$

From Arnold et *al* arXiv:0809.2262

Single polarised Drell-Yan: SSA

$$\frac{d\sigma^{A^\uparrow B} - d\sigma^{A^\downarrow B}}{d\Omega dx_1 dx_2 d^2\boldsymbol{q}_T} = \frac{\alpha_{em}^2}{6M^2}\sum_{a,\bar{a}} e_a^2 \times$$

$$\Big\{|\boldsymbol{S}_{1T}|(1+\cos^2\theta)\sin(\phi-\phi_{S_1})\mathcal{F}\Big[\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_{\perp 1}\frac{f_{1T}\bar{f}_1}{M_1}\Big]$$

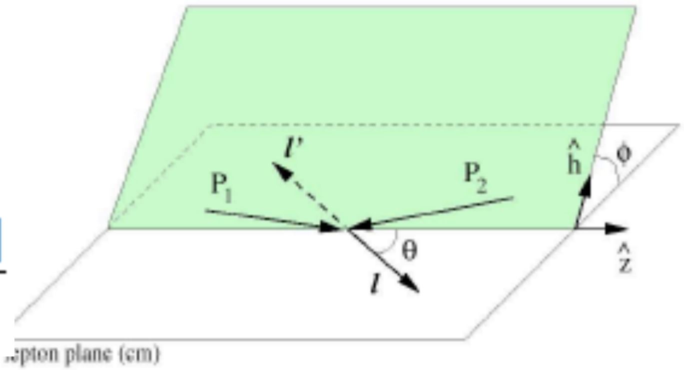
D. Boer, *Phys. Rev.* D60, 014012

$$-\sin^2\theta\,\sin(\phi+\phi_{S_1})\mathcal{F}\Big[\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_{\perp 2}\frac{h_1\bar{h}_1^\perp}{M_2}\Big]$$

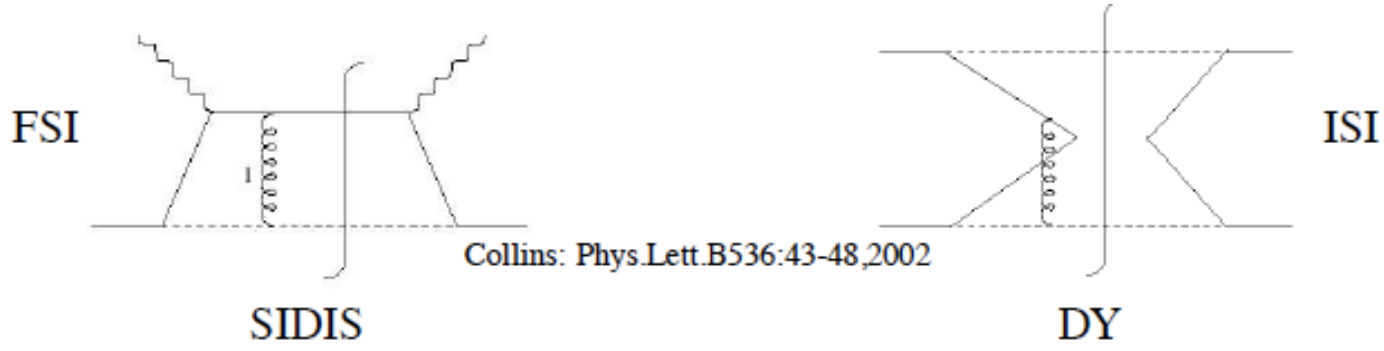
$$-\sin^2\theta\,\sin(3\phi-\phi_{S_1})\mathcal{F}\Big[\Big(4\,\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_{\perp 2}(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_{\perp 1})^2 - 2\,\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_{\perp 1}(\boldsymbol{k}_{\perp 1}\cdot\boldsymbol{k}_{\perp 2}) - \hat{\boldsymbol{h}}\cdot\boldsymbol{k}_{\perp 2}\boldsymbol{k}_{\perp 1}\Big)\frac{h_{1T}^\perp\bar{h}_1^\perp}{M_2}\Big]\Big\}$$

- θ and ϕ in the dilepton rest frame
- ϕ_{S_1} in the dilepton rest frame!

$$A_{h(f)} = \frac{\int d\Omega d\phi_S \sin(\phi\pm\phi_S)[d\sigma(\phi_S)-d\sigma(-\phi_S)]}{\int d\Omega d\phi_S[d\sigma(\phi_S)+d\sigma(-\phi_S)]}$$



TMD PDF effect SIDIS <->DY



A. Schafer – Mainz'09

➢ The sign of the gauge link is related to time direction of the Wilson line. For a T-odd function, it implies that the function changes sign for a past/future pointing Wilson line

$$h_1^\perp(x,\mathbf{k}_T)\Big|_{SIDIS} = -h_1^\perp(x,\mathbf{k}_T)\Big|_{DY}$$

$$f_{1T}^\perp(x,\mathbf{k}_T)\Big|_{SIDIS} = -f_{1T}^\perp(x,\mathbf{k}_T)\Big|_{DY}$$

J.C. Collins, Phys. Lett. B536 (2002) 43

Special thanks to A.V.Efremov

J. Collins, talk at LIGHT CONE 2008

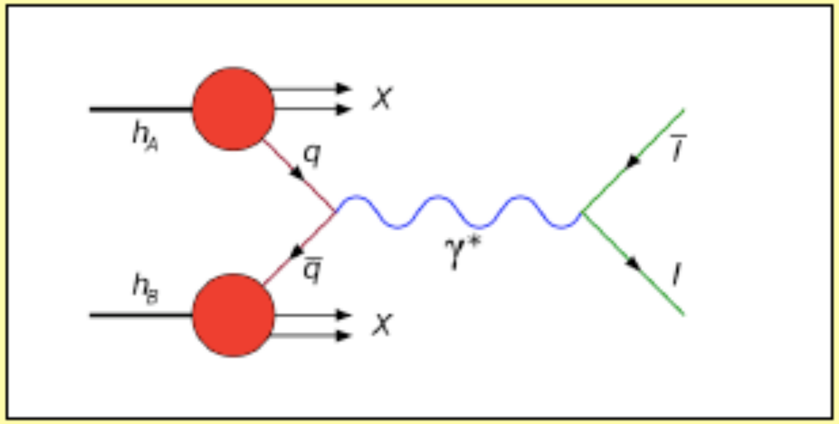
Double polarised Drell-Yan: direct access to Transversity

directly accessible uniquely via the double transverse spin asymmetry A_{TT} in the Drell-Yan production of lepton pairs

$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 h_1^q(x_1, M^2) h_1^{\bar{q}}(x_2, M^2)}{\sum_q e_q^2 q(x_1, M^2) \bar{q}(x_2, M^2)} \qquad q = u, \bar{u}, d, \bar{d}, \ldots$$

$$\hat{a}_{TT} = \frac{\sin^2 \vartheta}{1 + \cos^2 \vartheta} \cos 2\varphi$$

Spin asymmetry of the QED elementary process



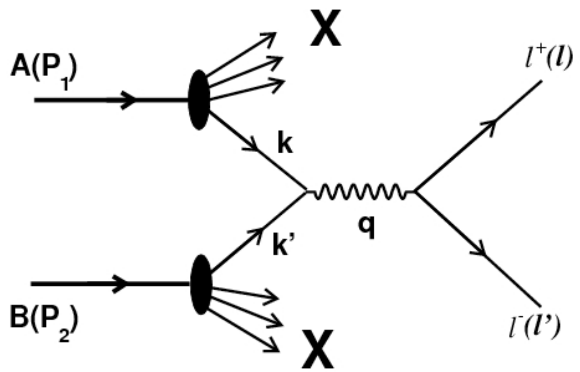
definitive observation of $h_1^q(x,Q^2)$ of the proton for the valence quarks (A_{TT} in Drell-Yan >0.2)

M.Nekipelov -> PAX

Feasibility study is underway, polarised antiprotons(>20%) - not a trivial issue

J/Ψ – Drell-Yan duality

- J/Ψ – DY duality → close analogy between Drell-Yan and J/Ψ production mechanism:
  - Occurs when the gluon-gluon fusion mechanism of the J/Ψ production is dominated by the quark-quark fusion mechanism
  - We can expect that the duality is valid in the COMPASS kinematic range
- Key issue for the applicability of the J/Ψ signal for the study of hadron spin structure
- J/Ψ production mechanism by itself is an important issue



$$\sigma_{q\bar{q}} = \frac{4\pi\alpha^2}{3M_{\mu\mu}^2} e_q^2$$

γ → J/Ψ substitution

$$16\pi^2\alpha^2 e_q^2 \rightarrow (g_q^{J/\psi})^2\,(g_\ell^{J/\psi})^2, \qquad \frac{1}{M^4} \rightarrow \frac{1}{(M^2 - M_{J/\psi}^2)^2 + M_{J/\psi}^2\Gamma_{J/\psi}^2},$$

Drell-Yan processes and access to GPDs

Very preliminary – feasibility is under discussion now, some indications:

- O.Teryaev: Drell-Yan pair production in the pion-nucleon collisions for large x_F (the region whose exploration is favourable in COMPASS kinematics) is sensitive to such an important and hot ingredient of pion structure as its light-cone distribution (DA). In other words in this kinematic range pion participate in the interaction coherently (as pion) rather then by only one of its quark.

References:

A.P.Bakulev, S.V.Mikhailov and N.G.Stefanis, Phys.Lett.B 508, 279 (2001)
A.Brandenburg, S.J.Brodsky, V.V.Khoze and D.Mueller, Phys.Rev.Lett. 73, 939 (1994)
A.Brandenburg, D.Mueller and O.V.Teryaev, Phys.Rev.D 53, 6180 (1996)

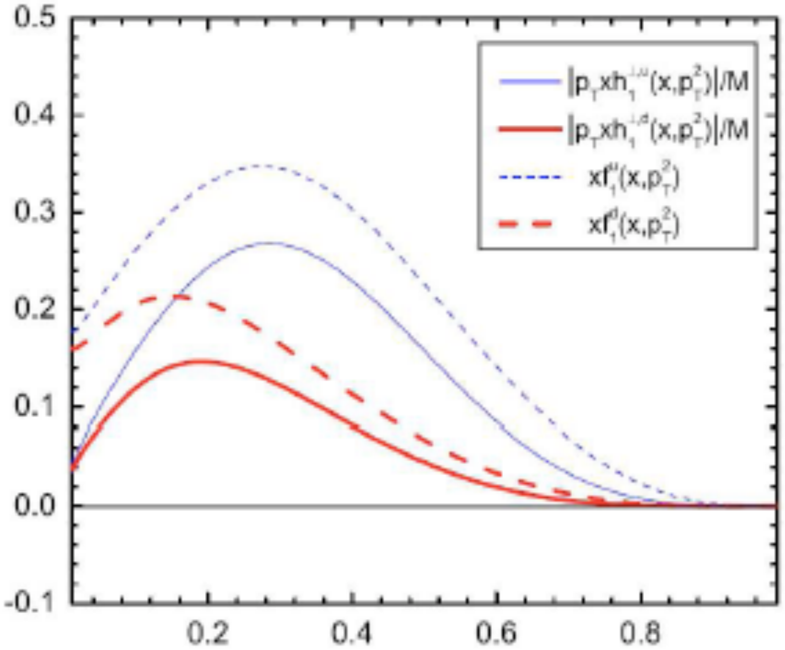
- B.Pire, O.Teryaev: Semiexclusive DY – crucial test of the GPDs universality (time-like process contrary to the Deep Inelastic scattering)

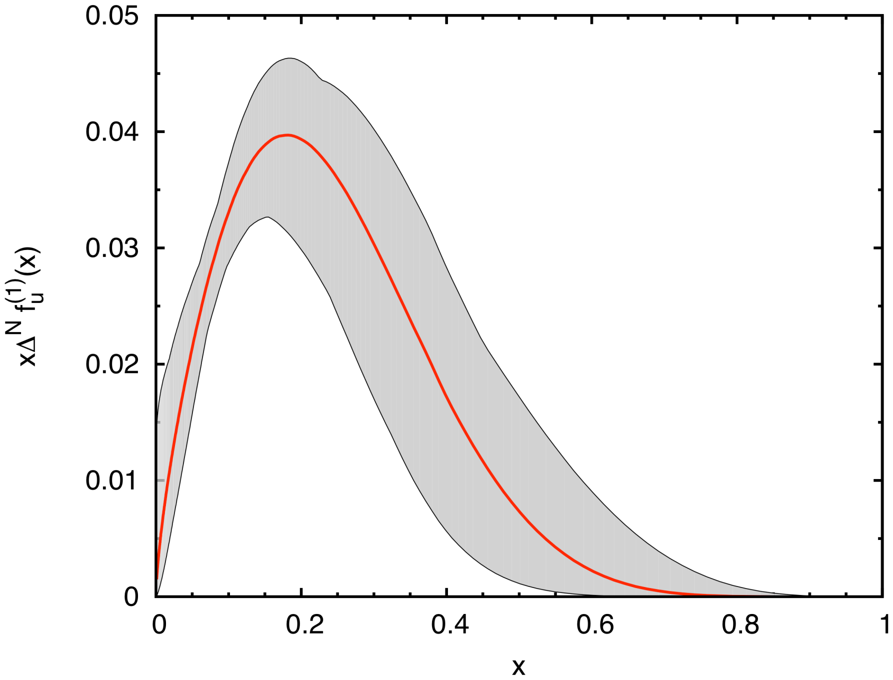
Reference:

B.Pire, L. Szymanowski, arXiv:0905.1258v1 [hep-ph] 8 May 2009

Some indications for the future Drell-Yan experiments

TMD PDFs – ALL are sizable in the valence quark region





► Boer-Mulder function for u and d quarks

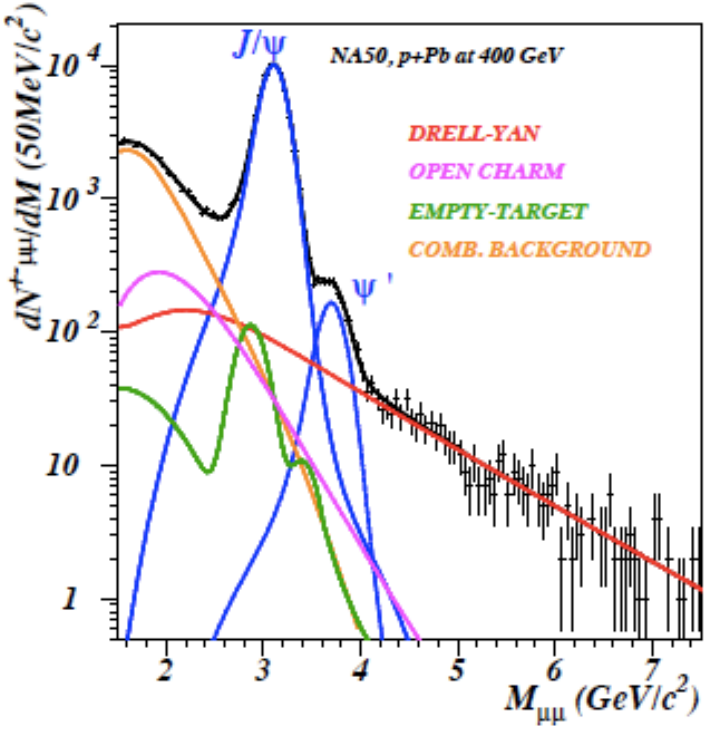
as extracted from $p + D$ data

from Zhang *et al Phys. Rev.* D77,0504011]

Sivers effect in Drell-Yan processes.
M. Anselmino, M. Boglione U. D'Alesio,
S. Melis, F. Murgia, A. Prokudin
Published in Phys.Rev.D79:054010, 2009

Some indications for the future Drell-Yan experiments

Safe region: 4. < M < 9. Gev/c^2



In the dimuon mass spectrum, 2 background sources must be considered:

- physics background:
  D and $\bar{D}$ decays to $\mu^{\pm}X$;
  J/ψ and ψ', also a subject of research.
- Combinatorial background
  π and K decaying to $\mu\nu$

The cleanest region to study Drell-Yan is $4. < M < 9.$ GeV/c^2

In the region $2.0 < M < 2.5$ GeV/c^2 there is important contribution from background sources.

Polarized Drell-Yan measurements in COMPASS C. Quintans

Some indications for the future Drell-Yan experiments

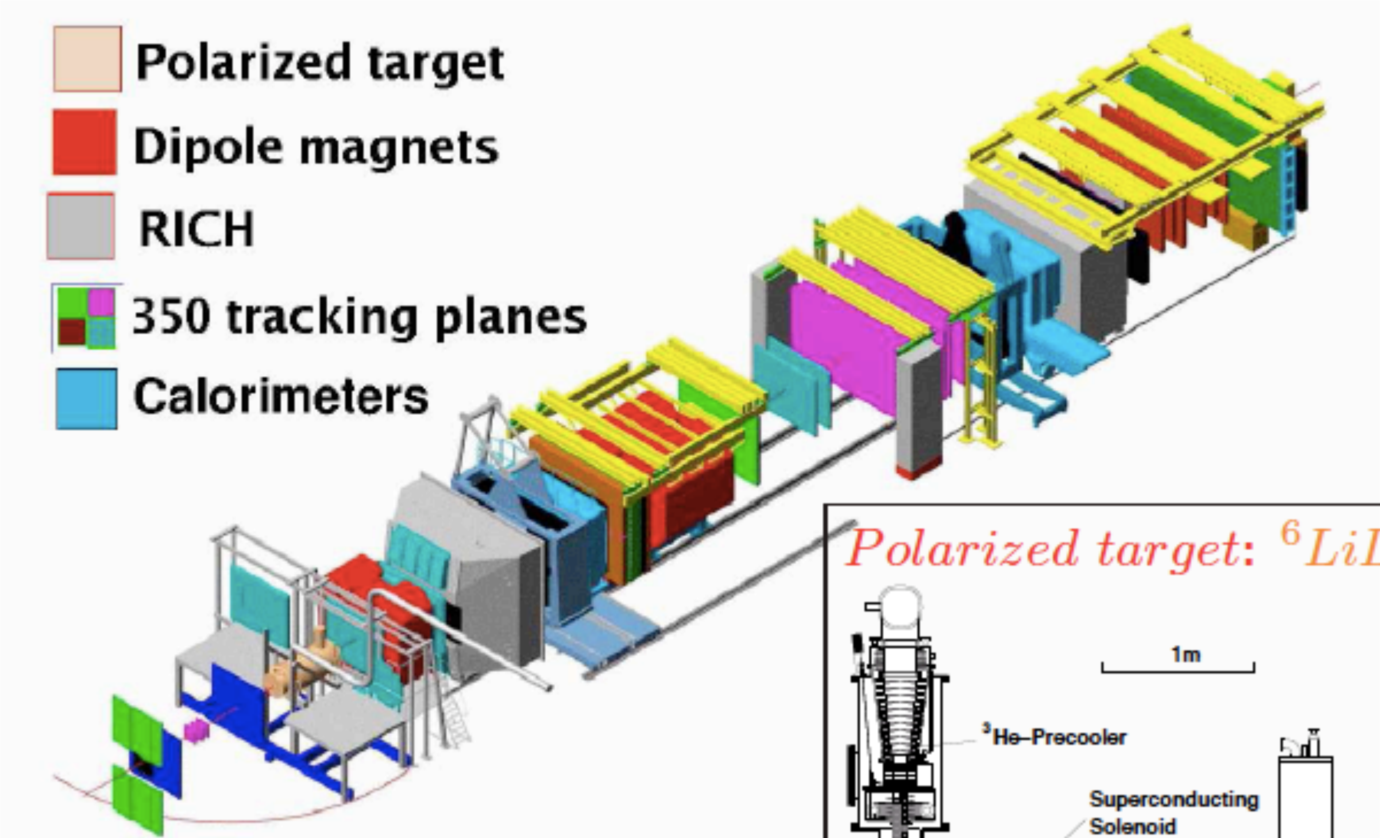
$$\delta A = \frac{1}{P_b f} \frac{1}{\sqrt{N_{sig}}} \sqrt{1 + \frac{N_{sig}}{N_{backg}}}$$

$$\tau = x_a x_b = M^2/s$$

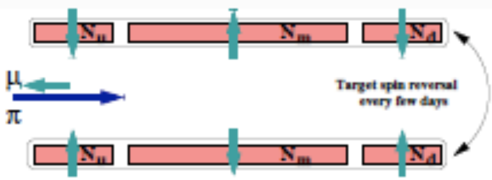
1. Drell-Yan experiments:
   - High luminosity (DY Cross Section is a fractions of nanobarns) and large angular acceptance, better pion or antiproton beams (valence anti-quark)
   - Sufficiently high energy to access 'safe' of background free M_{ll} range (4 GeV/c < M_{ll} < 9 GeV/c)
   - Good acceptance in the valence quark range $x_B > 0.05$ and kinematic range: $\tau = x_A x_B = M^2/s > 0.1$
2. Polarised Drell-Yan:
   - Good factor of merit (F_m), which can be represented as a product of the luminosity and beam (target) polarisation (dilution factor) ($F_m \sim L \times P_{beam}\ (f)$)

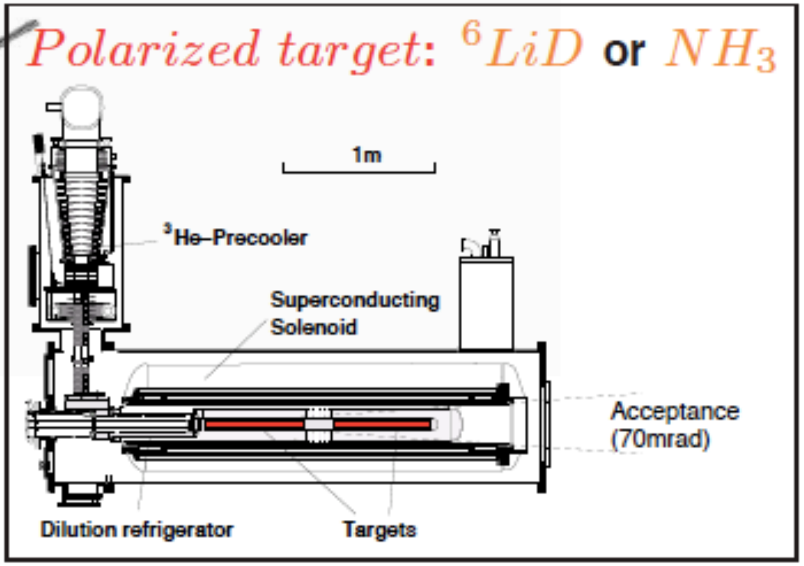
Future Drell-Yan experiment

- Fixed target experiments (COMPASS, E906, J-Park) characterised by:
  - Very high luminosity (>10^{33} cm^{-2}s^{-1})
  - Only muon in the final state (hadron absorber has to be used because of the ‘all forward’ geometry and high luminosity)
  - Light unpolarised targets (liquid hydrogen and deuterium) and solid state polirased targets (NH_3, ^6LD)
  - Pion, proton and (probably) antiproton (COMPASS) beams
- Collider experiments (RHIC, NICA SPD, PAX)
  - Moderate luminosity
  - High universality (not only TMD PDFs, J/Psi and related aspect but also formfactors, various hard processes – not a topic of this talk)


Polarized target
Dipole magnets
RICH
350 tracking planes
Calorimeters

μ or π beam


μ
π
Target spin reversal every few days


Polarized target: ^6LiD or NH_3
1m
^{3}He–Precooler
Superconducting Solenoid
Acceptance (70mrad)
Dilution refrigerator
Targets

Why Drell-Yan @ COMPASS

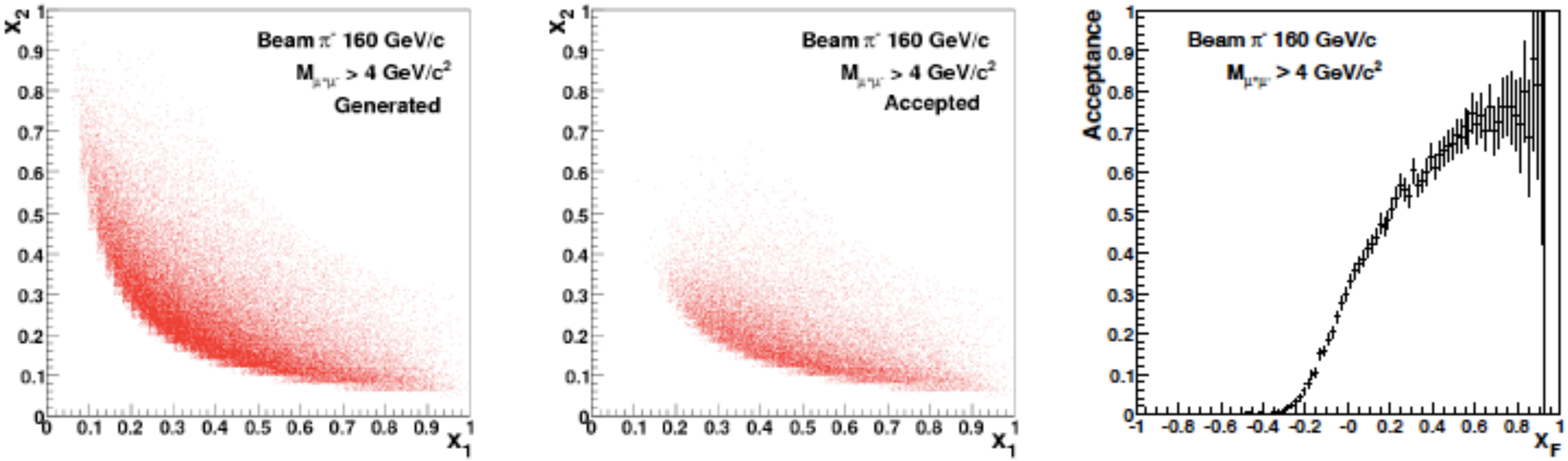
1. Large angular acceptance spectrometer
2. SPS M2 secondary beams with the intensity up to $6x10^7$ particles per second
3. Large acceptance COMPASS Superconducting Toroidal Magnet
4. Transversely polarized solid state proton target with a large relaxation time and high polarization, when going to spin frozen mode;
5. a detection system designed to stand relatively high particle fluxes;
6. a Data Acquisition System (DAQ) that can handle large amounts of data at large trigger rates;
7. The dedicated muon trigger system

For the moment we consider two step DY program:

- The program with high intensity pion beam
- The program with Radio Frequency separated antiproton beam

DY cross section and acceptance @ COMPASS

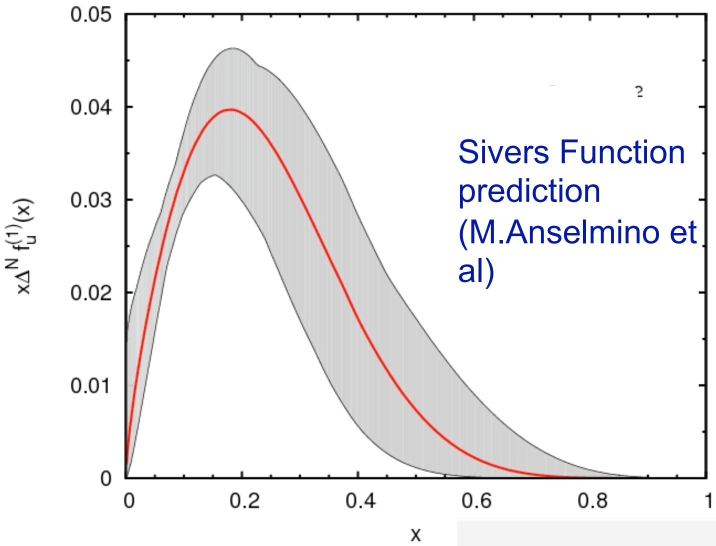
σ^{DY} (nb)	$2.0 < M_{\mu\mu} < 2.5$ (GeV/c^2)	$4. < M_{\mu\mu} < 9.$ (GeV/c^2)
s=200 GeV^2, p_π=106 GeV/c	1.2	0.10
s=300 GeV^2, p_π=160 GeV/c	1.4	0.17
s=400 GeV^2, p_π=213 GeV/c	1.6	0.24

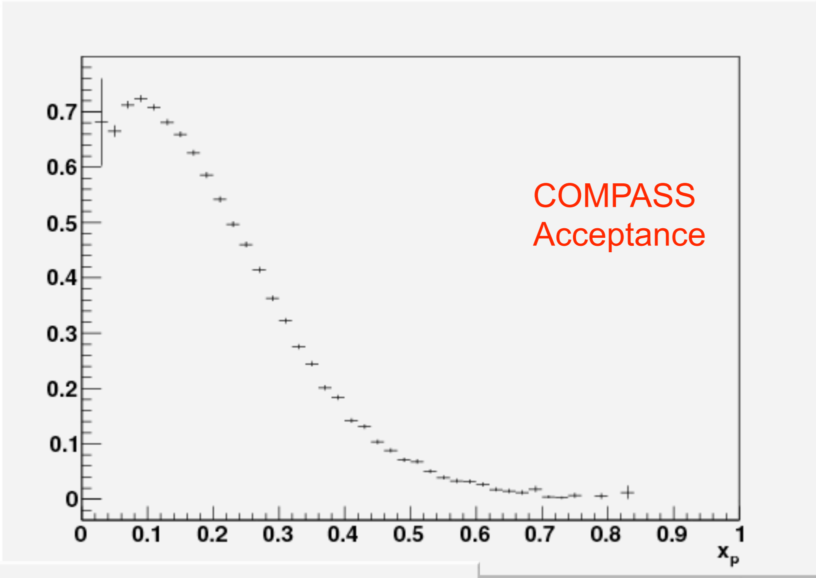


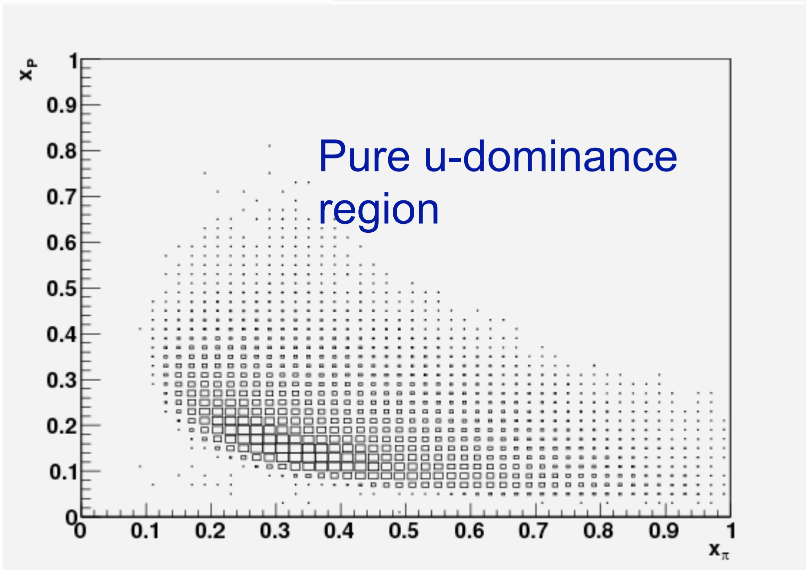
COMPASS acceptance is in the valence quarks region ($x > 0.1$). This is also the best region to measure the spin asymmetries, as expected from theory predictions.

C.Quintans -> COMPASS

DY acceptance @ COMPASS







Prediction for Sivers function as a function of x, COMPASS acceptance in x_p and acceptance coverage x_π.vs.x_p

Access to the TMD PDFs @ COMPASS

Near future: $(\pi^-, p^\uparrow)$

π^-: $(\bar{u}d)$ p: (uud)

In the valence region: $\boxed{\sigma^{DY} \propto f_{(\bar{u}|\pi^-)} \otimes f_{(u|p)}}$

where $f = h_1^\perp, f_1, f_{1T}^\perp, h_1, h_{1T}^\perp$

The following topics can be studied:

- Sivers function u_v quarks-dominance;
- Model dependent extraction of transversity and Boer-Mulders functions.

Longer term future: $(\bar{p}, p^\uparrow)$

$\bar{p}$: $(\bar{u}\bar{u}\bar{d})$ p: (uud)

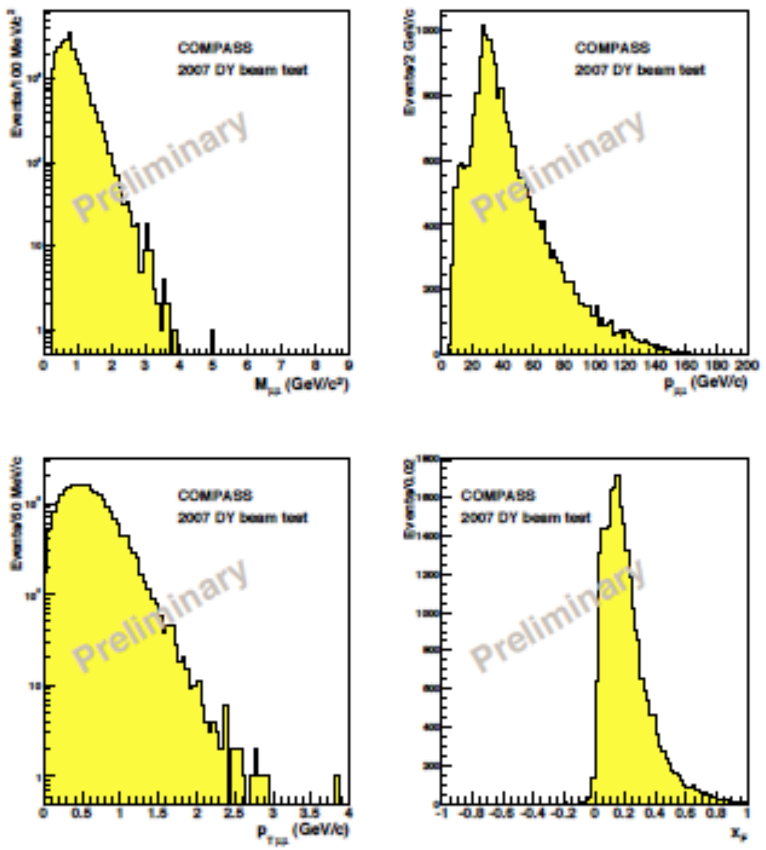
In this case, $f_{(\bar{u}|\bar{p})} = f_{(u|p)}$, thus

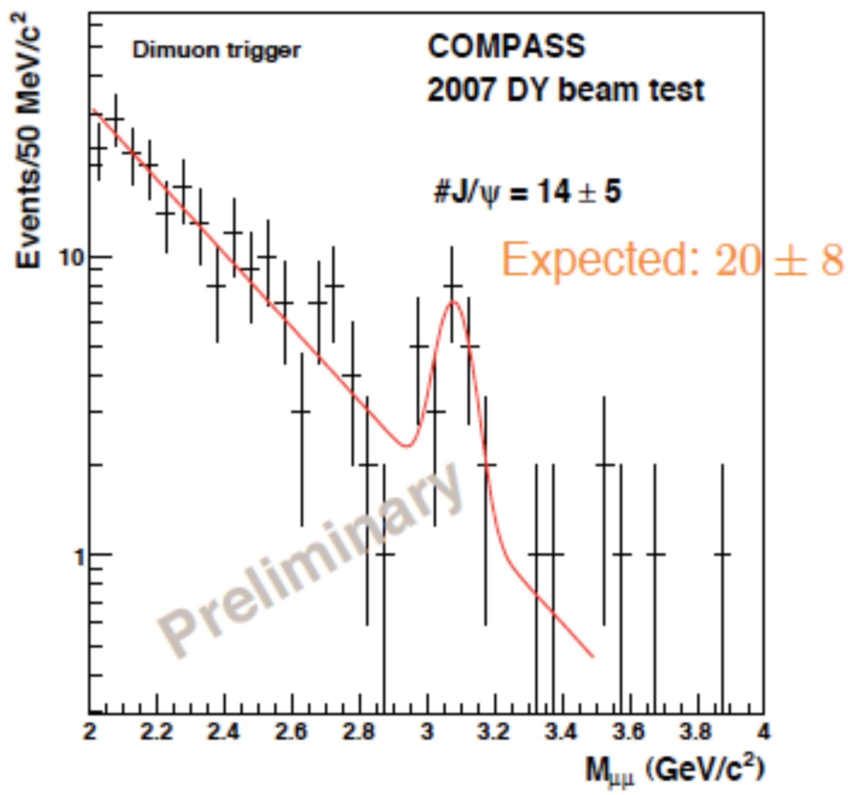
$$\boxed{\sigma^{DY} \propto f_{(u|p)} \otimes f_{(u|p)}}$$

- Model independent extraction of Sivers and transversity functions.

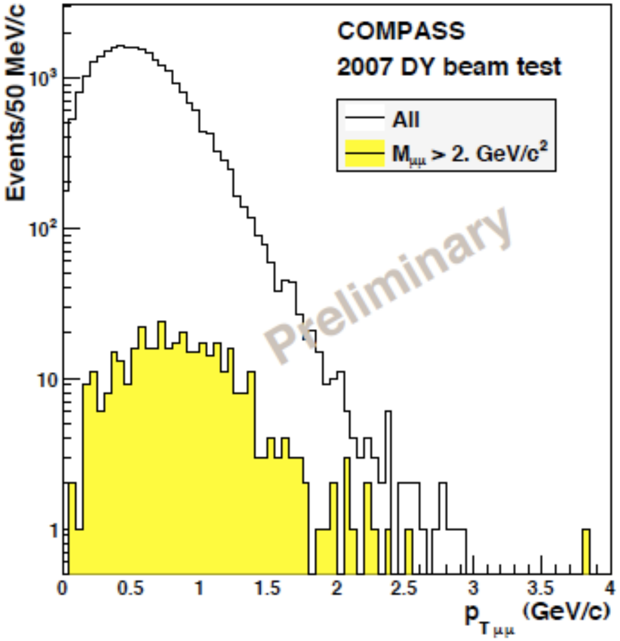
Feasibility test @ COMPASS

In 2007, with a π^- beam of 160 GeV/c on a NH_3 target, and without hadrons absorber: ≈ 90000 dimuon events (< 12 hours data-taking).



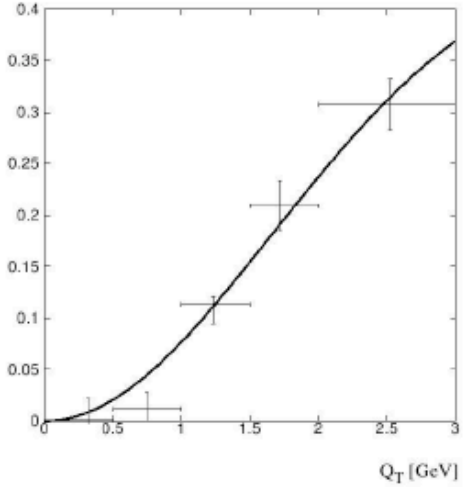


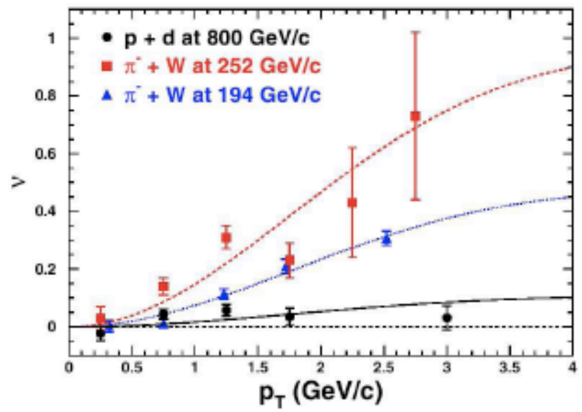
Pt range covered by COMPASS



COMPASS Pt coverage

Previous experiments:





- ν NA10 data at 194 Gev/c as function of Q_T fitted by means of a diquark model of the BM function [D.Boer, *Phys. Rev.* D60,014012.]
- Same model applied to $p + D$ data at FERMILAB. [Zhu et *al*, *Phys. Rev. Lett.* 99, 082301]

COMPASS

INFN
Istituto Nazionale di Fisica Nucleare Sezione di Torino

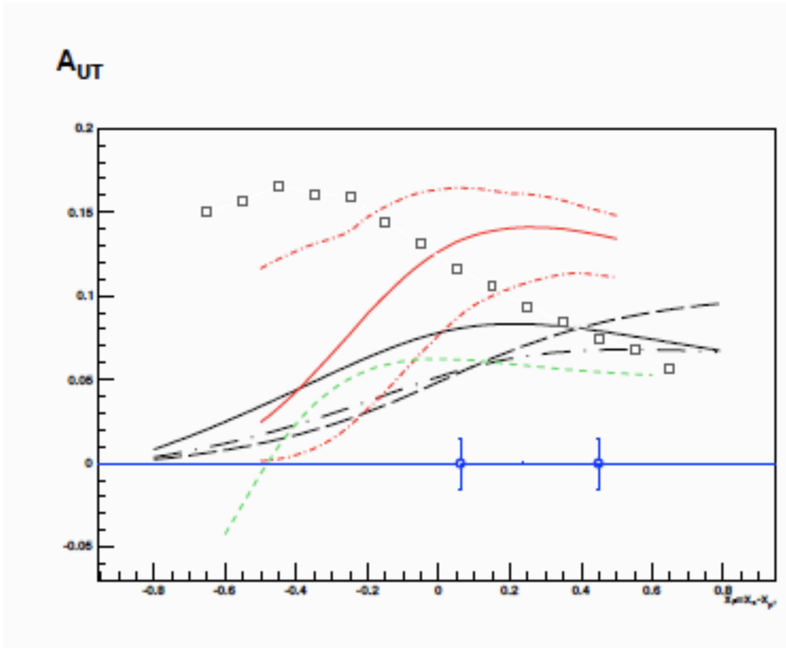
Sivers and expected statistical error @ COMPASS

With a beam intensity $I_{beam} = 6 \times 10^7$ particles/second,
a luminosity of $L = 1.7 \times 10^{33}\ cm^{-2} s^{-1}$ can be obtained.

$\hookrightarrow$ Assuming 2 years of data-taking, one can collect > 200000 DY events in the region $4 < M_{\mu\mu} < 9.$ GeV/c^2.

Predictions for the Sivers asymmetry in the COMPASS phase-space, for the mass region $4. < M < 9.$ GeV/c^2, compared to the expected statistical errors of the measurement:

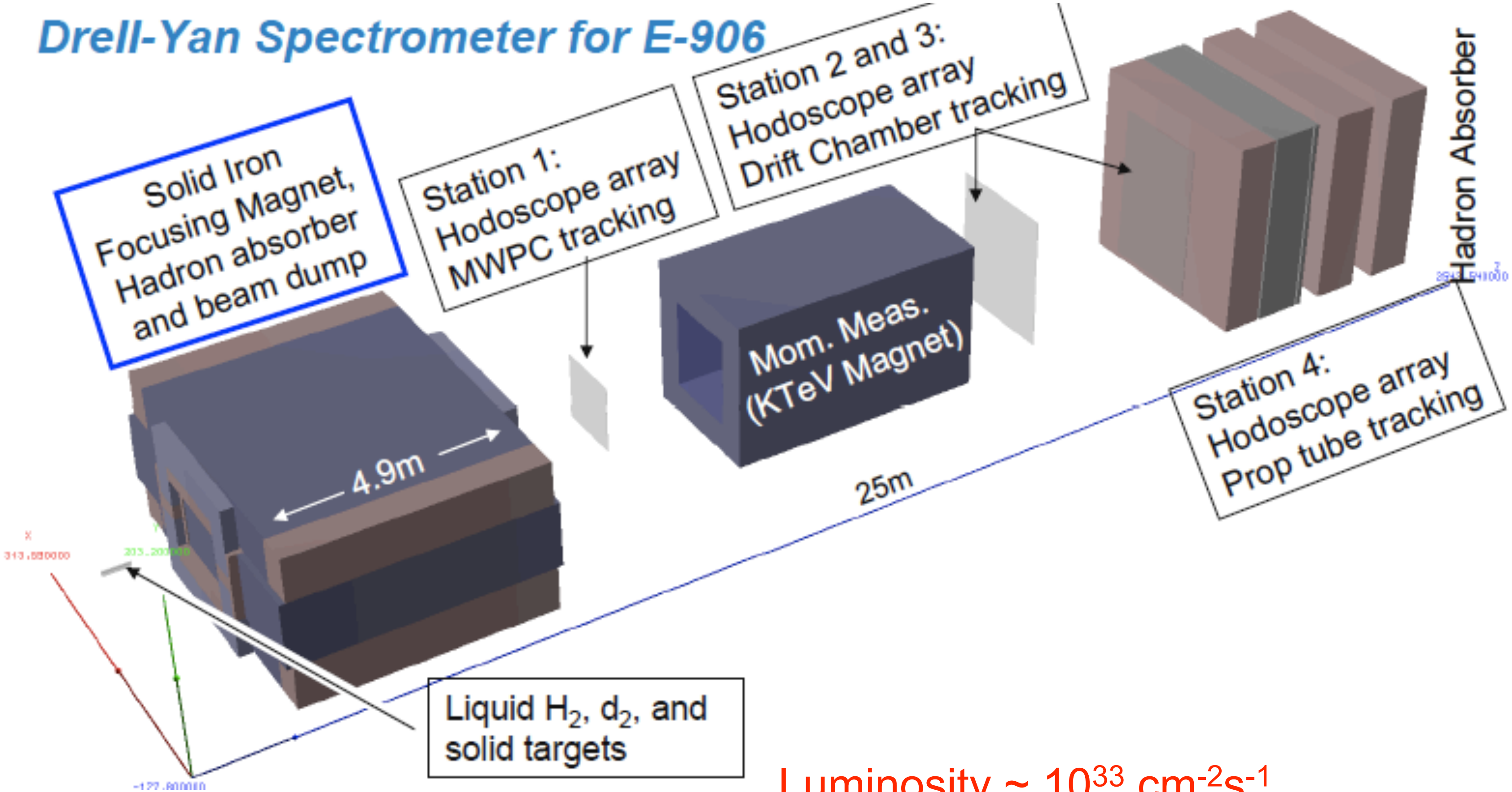
– solid and dashed: Efremov et al, PLB612(2005)233;
– dot-dashed: Collins et al, PRD73(2006)014021;
– solid, dot-dashed: Anselmino et al, PRD79(2009)054010;
– boxes: Bianconi et al, PRD73(2006)114002;
– short-dashed: Bacchetta et al, PRD78(2008)074010.



COMPASS: Summary

- Pion and, later, antiproton beams (50-200 GeV), Drell-Yan process dominated by the contribution from the valence quarks (both beam and target), $\tau = x_1 x_2 = Q^2/s \cong 0.05 \div 0.3$
- Solid state polarised targets, NH_3 and ^6LD, in case of hydrogen target – pure u-dominance
- Statistical error on single spin asymmetries is on the level 1÷2%
- LoI already submitted to CERN SPSC (January 2009), 'go ahead' for full proposal is obtained
- Proposal will be submitted to the SPSC by the end of 2010
- Approval is expected during the 2010
- First Drell-Yan data taking >2012

Other fixed target experiments: E906 and J-Park

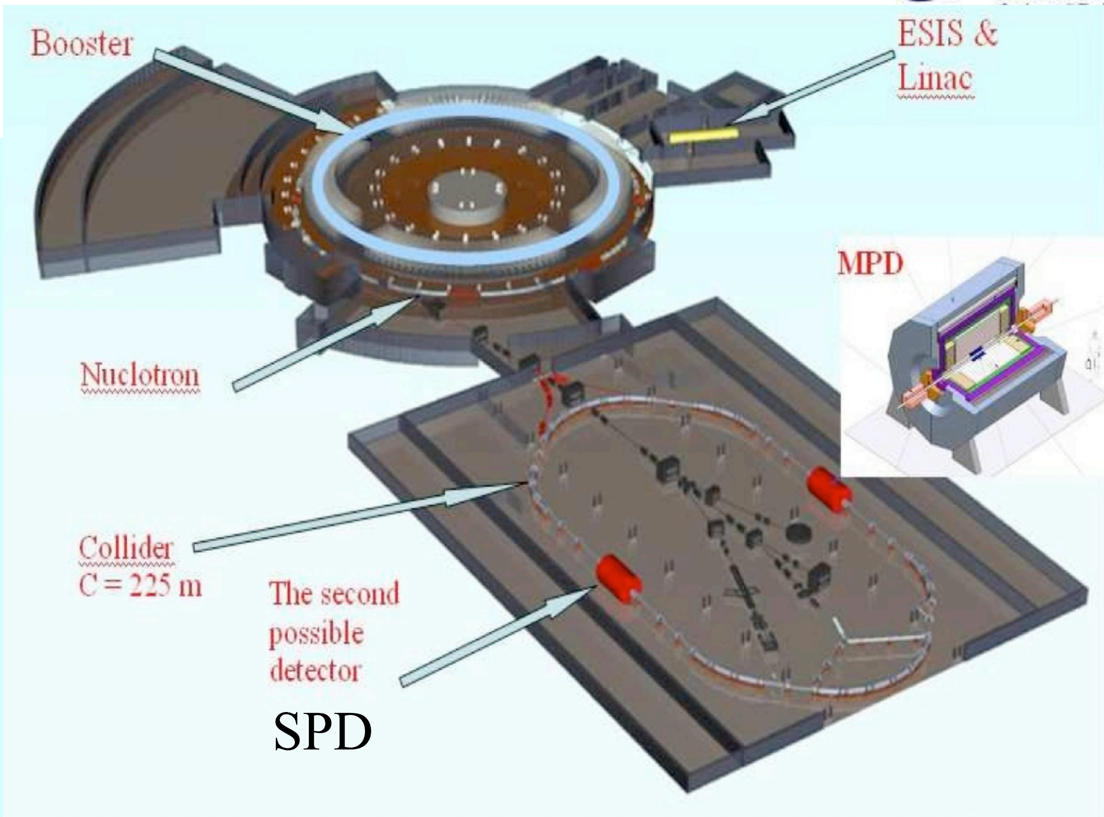


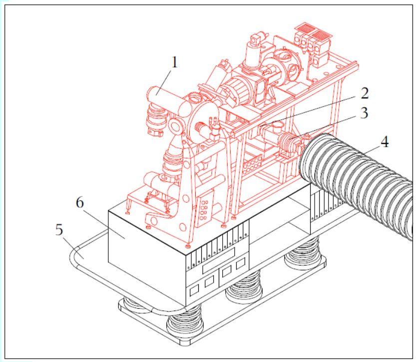
Luminosity ~ 10^{33} $cm^{-2}s^{-1}$
Beam energy – 120 GeV
Start dates > 2010
Unpolirised
Proton beam only

NICA Facility at JINR Dubna

NICA could provide unique possibilities for the spin program:

1. High energy proton and deuteron beams
2. High luminosity (> 10 ^{30} см$^{-2}$с$^{-1}$ for proton beam)
3. High polarization (>50%)
4. Spin rotation L/T
5. High precision of polarization measurements
6. 4 π geometry detector
7. Possibility to change beams energy with ~1 GeV step





Source of Polarized Ions *(CIPIOS based)* for Nuclotron-M / NICA complex
will provide ~ 10^{10} d (p)↑ */pulse*

A.Nagaytsev -> NICA SPD

29

NICA Spin Physics Detector (SPD)

SPD Group at JINR is working on the preparation of the spin physics program (LoI) for NICA to operate with polarized beams of light nucleus.

Studies of DY processes
Studies of J/Ψ production processes
Studies of elastic reactions
Polarimetry

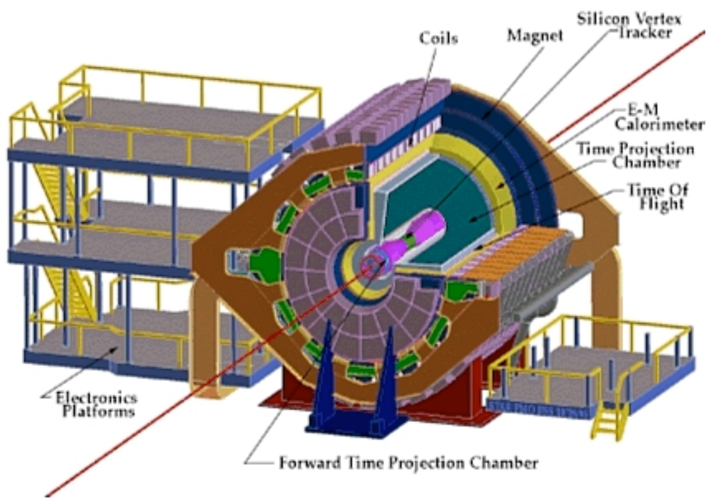
Spin effects in one and two hadron production processes
Spin effects in photoproduction
Spin effects in various exclusive reactions
Spectroscopy of quarkonia with any available decay modes

Diffractive processes
Hidden color in light nuclei
Color transparency
and others
(studies of unpolarised pp reactions:
direct photons, z-scaling etc)

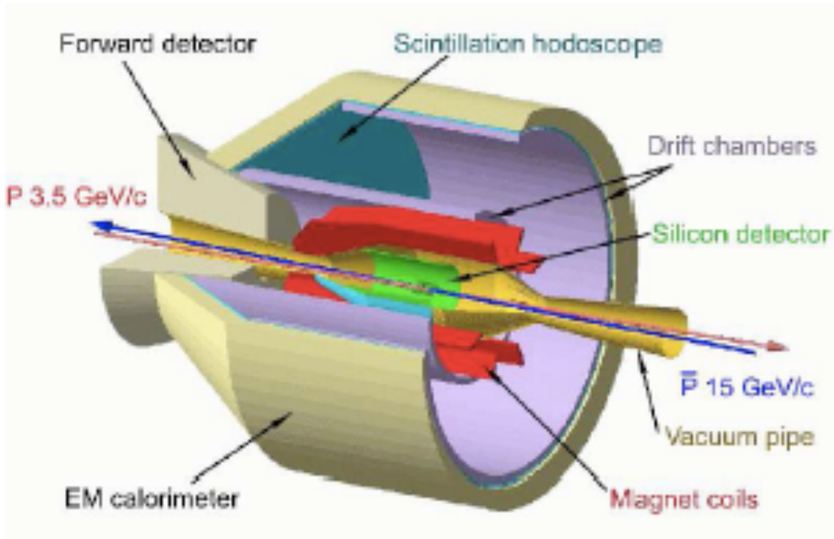
A.Nagaytsev -> NICA SPD

Other Collider experiments

the star experiment



- $L \approx 10^{31}$ cm^{-2}s^{-1} (polarized pp)
- $\sqrt{s}$ = 200 GeV
- pp collision
- $x_1 x_2 = 4\times10^{-4} \div 1\times10^{-2}$
- 201?



PAX Detector

- $L = 10^{31}$ cm^{-2} s^{-1}
- S = 30 GeV^2
- ppbar collisions, e^+e^- final state
- $x_1 x_2 = 0.2 \div 0.4$
- YEAR 202?

Drell-Yan experiments in the two next decades

1. European line:
   - COMPASS: pion beams (50-200 GeV) on polarised solid state targets (NH_3 and ^6LD) (>2012)
   - NICA SPD: proton-proton (polarised) collider (>2014)
   - COMPASS: antiproton beam (~100 GeV) on polarised solid state targets (NH_3 and ^6LD) (>2015)
   - PAX (GSI) polarised proton – polarised antiproton collider (>2020?, if feasibility is proved)
2. American-Japanese line:
   - RHIC: polarised proton-proton collisions, $\sqrt{s}$ = 200GeV
   - E906: proton beam(120 GeV) on unpolarised ^1H, ^2H, and nuclear targets (>2010)
   - J-Park: proton beam (30 GeV) on unpolarised target (>2010)
   - J-Park: polarised proton beam on (un)polarised target (>20??)

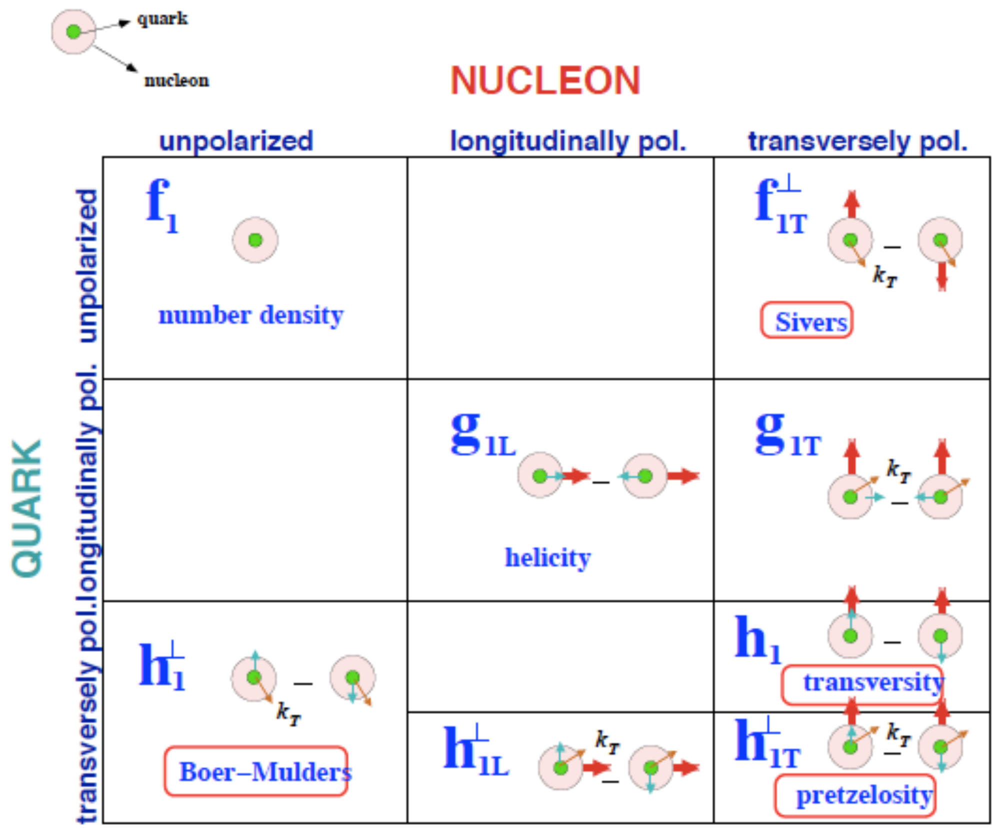
Some conclusions

- Next decade looks very promising for the new Drell-Yan experiments – a lot of activity in the field
- The new generation of the polarised Drell-Yan programs will contribute in decisive way into our understanding of the hadron structure
- Access to the valence quarks contributions as well as high luminosity seems to be an important prerequisits to the successful Drell-Yan experiment

- Spares

Parton distribution functions

Taking into account the intrinsic transverse momentum k_T of quarks, at LO **8 PDFs** are needed for a full description of the nucleon:

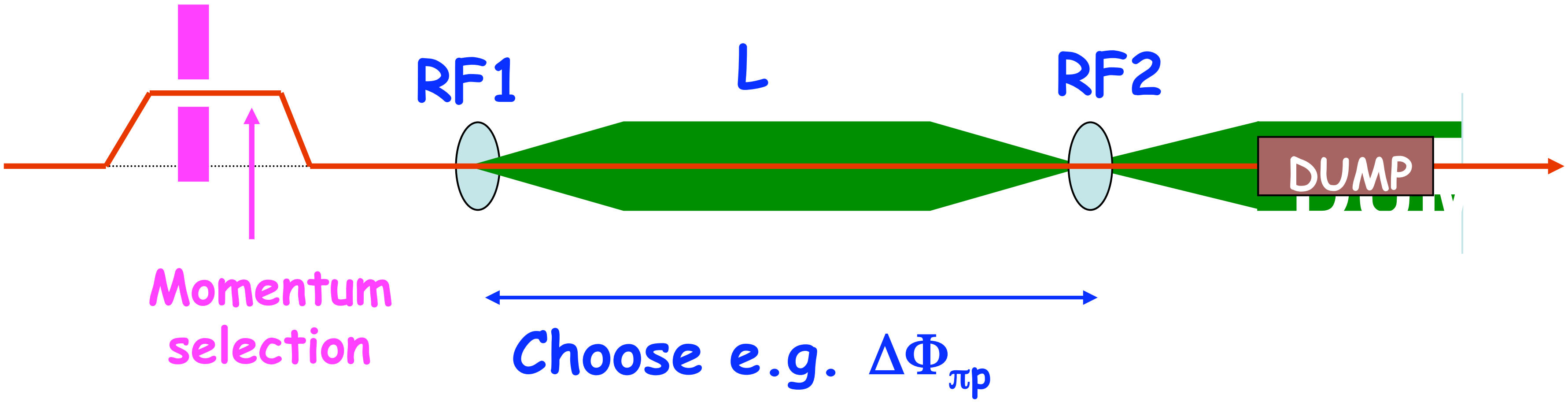


WHAT ABOUT A RF SEPARATED pbar BEAM ???

First and very preliminary thoughts, guided by

- recent studies for P326
- CKM studies by J.Doornbos/TRIUMF, e.g. http://trshare.triumf.ca/~trjd/rfbeam.ps.gz

E.g. a system with two cavities:



$$\Delta\Phi = 2\pi\,(L\,f\,/\,c)\,(\beta_1^{-1} - \beta_2^{-1}) \text{ with } \beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2)/2p^2$$

COMPASS wrt past DY experiments

	P (GeV/c)	I_{beam} (ps^{-1})	$\mathcal{L}$ $(cm^{-2}s^{-1}n^{-1})$	Number of days	$\int \mathcal{L}$ $(cm^{-2}n^{-1})$	Mass range (GeV/c^2)	Total number of events
NA3	150	2.5x10^7	1.48x10^{33}	≈ 81	5.10x10^{38}	> 4.1	21600
	200	1.5x10^7	0.90x10^{33}	≈ 11	1.14x10^{38}		4970
	280	1.5x10^7	0.90x10^{33}	≈ 62	2.78x10^{38}		20000
NA10	194	5x10^8	42.1x10^{33}	≈ 65	1.57x10^{40}	> 4.0	146700
	284	3x10^8	25.5x10^{33}	≈ 45	0.41x10^{40}		30500
	140				0.48x10^{40}		34300
NA50	450	1x10^9	41.7x10^{33}	≈ 5	0.11x10^{40}	> 4.5	2280
NA58	190	6x10^7	1.67x10^{33}	≈ 280	0.81x10^{40}	> 4.0	277200

Table 8: Some data on the past CERN Drell-Yan experiments as compared to the COMPASS future DY experiment.

Experiment	NA3	NA10	NA50	COMPASS
Beam/mom (GeV/c)	pi, p 200	pi-, 200	p, 450	pi-, 150-200
Intensity (p/s)	2×10^6	4×10^8	6×10^8	6×10^7
Absorber length (m)	1.5 (Fe)	4.8 (C+Fe)	5.2 (Al+C+Fe)	1.5 (AlO+W)
Beam dump (m)	1.5 (W+U)	4. (W+U)	4. (W+U)	1.5 W
Number of i.l.	9	17	15	5-13
Mass resol. (MeV)	170	100	100	≈ 100

Table 6: Some data on the past CERN Drell-Yan experiments as compared to the COMPASS future DY experiment.

Boer-Mulders in unpolarised DY at COMPASS

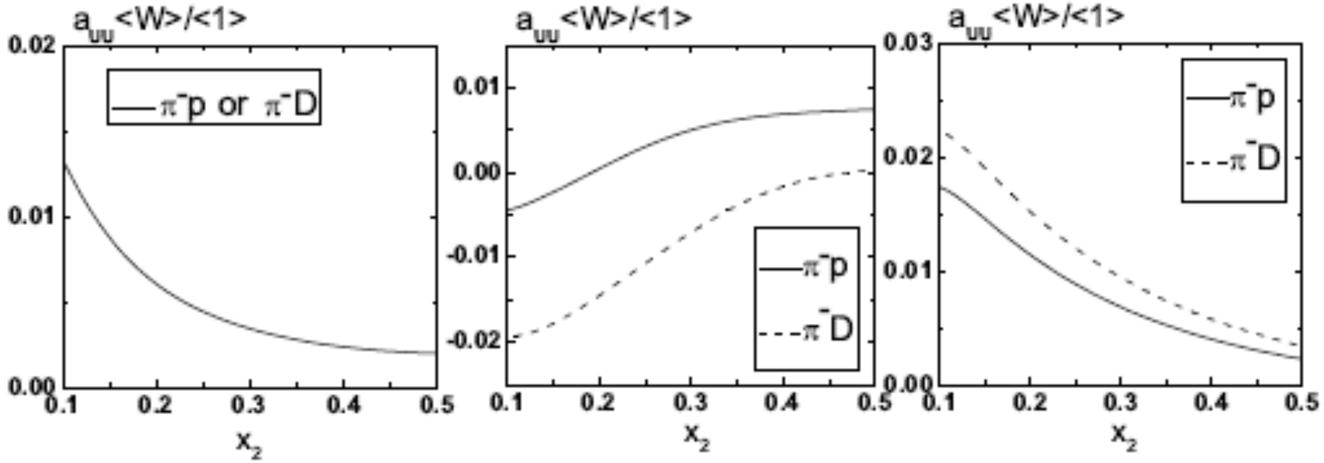


Fig. 2. The weighted $\cos 2\phi$ asymmetries in unpolarized $\pi^- p$ (solid line) and $\pi^- D$ (dashed line) Drell-Yan processes. (a) The MIT Bag model result. The two asymmetries are equal since $f_1^d/f_1^u = 1/2$ in the lowest bag mode in which case is used in calculation. (b) The axial-vector diquark model result. (c) The result from large-N_c.

We do not aim at a precise estimate of the asymmetries, only to a rough comparison among them.

$$\hat{\nu}_p = a_{UU}\frac{\langle W\rangle_{\pi^- p}}{\langle 1\rangle_{\pi^- p}} = \frac{h_{1\pi}^{\perp(1)}(x_1)h_1^{\perp(1),u}(x_2)}{f_{1\pi}(x_1)f_1^u(x_2)},$$

$$\hat{\nu}_D = a_{UU}\frac{\langle W\rangle_{\pi^- D}}{\langle 1\rangle_{\pi^- D}} = \frac{h_{1\pi}^{\perp(1)}(x_1)(h_1^{\perp(1),u}(x_2) + h_1^{\perp(1),d}(x_2))}{f_{1\pi}(x_1)(f_1^u(x_2) + f_1^d(x_2))},$$

Flavor separation of the Boer-Mulders function from unpolarized pi- p and pi- D Drell-Yan processes.
Zhun Lu, Bo-Qiang Ma, I. Schmidt
Phys.Lett.B639:494-498,2006