Recent results from Drell-Yan experiments and prospectives

Oleg Denisov, CERN / INFN-Turin
Outline

• Drell-Yan process
• DY as important probe to resolve:
  – Spin Crisis
  – Mass Crisis
• Recent results from Drell-Yan experiments (structure and spin)
  – SeaQuest (FermiLab)
  – STAR (RHIC)
  – COMPASS
• Drell-Yan prospectives: (spin/mass crisis)
  – SpinQuest (FermiLab)
  – STAR, sPHENIX (RHIC)
  – Jparc (Japan)
  – COMPASS++/AMBER
• Some conclusions

Disclaimer: no LHC results reviewed, Drell-Yan at NICA – separate talk
Special thanks to Dustin K., Elke A., Wolfgang L., Vincent A. ….. for materials
Drell-Yan process

\[
P_{a(b)} \\
s = (P_a + P_b)^2, \\
x_{a(b)} = q^2/(2P_{a(b)} \cdot q), \\
x_F = x_a - x_b, \\
M_{\mu\mu}^2 = Q^2 = q^2 = x_a x_b, \\
k_{T_{a(b)}} \\
q_T = P_T = k_{T_a} + k_{T_b}
\]

the momentum of the beam (target) hadron, the total centre-of-mass energy squared, the momentum fraction carried by a parton from \( H_{a(b)} \), the Feynman variable, the invariant mass squared of the dimuon, the transverse component of the quark momentum, the transverse component of the momentum of the virtual photon.


FIG. 2: “K-factors” as defined in Eq. (27) at $\sqrt{S} = 19$ GeV as functions of the lepton pair mass $Q$, at NLO (symbols) and for the NLL-resummed case. Also shown are the expansions of the resummed cross section to first, second and third order in the strong coupling.
On the one hand - Almost all visible matter of the universe we are able to observe consists of nucleons.

On the other hand - **SPIN is a fundamental quantum number** (Pauli principle), to some extent define a rules on how the atomic/nuclear matter is constructed.

Thus we better understand well how the spin of the nucleon (and hadron in general) is “constructed”.
First two component were extensively studied in the SIDIS experiments with the longitudinally polarised target (collinear case approach): spin fraction carried by quarks and gluons is not sufficient to describe \( \frac{1}{2} \) nucleon spin (Spin Crisis, continued):

\[
\text{Nucleon spin } \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L
\]

- Quark spin contribution \( \Delta \Sigma = 0.24 \) (\( Q^2 = 10 \text{ (GeV/c)}^2 \)) DSSV arXiv:0804.0422)
- COMPASS Open charm measurement and other direct measurements \( \Rightarrow \) \( \Delta G/G \) is positive but small

\( \Delta \Sigma \) : sum over \( u, d, s, u, d, s \)

Can take any value: superposition of several states

\( \Delta q = \vec{q} - \vec{q} \)

Parton spin parallel or anti parallel to nucleon spin

In order to create Angular Momentum of partons spin-orbit correlation has to be taken into account \( \Rightarrow \) transverse momentum of the quark \( k_T \) appears \( \Rightarrow 3D \text{ structure of the Nucleon has to be studied} \)
Unified View of Nucleon Structure

Wigner function

\[ W(x, k_{\perp}, r_{\perp}) \]

Transverse
Momentum
Dependent
distributions

TMDs

Generalized
Parton
Distributions

GPDs

3D structure of nucleon II
Huge progress has been made over the past 20 years in a study of TMD PDF in SIDIS, pp collisions and in DY.

**IMPORTANT:** modern TMD formalism still to be validated as TMD factorisation is not yet proven.

### Nucleon polarization

<table>
<thead>
<tr>
<th>Quark polarization</th>
<th>unpol.</th>
<th>long. pol.</th>
<th>transv. pol.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Density</td>
<td>$f_i$</td>
<td>$f^\perp_{iT}$</td>
<td>Sivers</td>
</tr>
<tr>
<td></td>
<td>unpol.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$g_i$</td>
<td>$g^\perp_{iT}$</td>
<td>Worm Gear</td>
</tr>
<tr>
<td></td>
<td>long. pol.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$h^\perp_I$</td>
<td>$h^\perp_{iT}$</td>
<td>Transversity</td>
</tr>
<tr>
<td></td>
<td>transv. pol.</td>
<td></td>
<td>Pretzelosity</td>
</tr>
</tbody>
</table>

- $f_{iT}(x, k_T^2)$: Sivers function
  - The correlation between the transverse spin of the nucleon and the transverse momentum of the quark.

- $h^\perp_I(x, k_T^2)$: Boer-Mulders function
  - The correlation between the transverse spin and the transverse momentum of a quark in unpolarized nucleon.

- $h^\perp_{iT}(x, k_T^2)$: Pretzelosity function
  - The polarization of a quark along its $k_T$ direction, making accessible to the orbital angular momentum information.
T-odd TMDs (Sivers, Boer-Mulders) restricted universality SIDIS ↔ DY

The time-reversal odd character of the Sivers and Boer-Mulders PDFs lead to the prediction of a sign change when accessed from SIDIS or from Drell-Yan processes:

\[ f_{1T}^{+}(DY) = -f_{1T}^{+}(SIDIS) \]
\[ h_{1}^{+}(DY) = -h_{1}^{+}(SIDIS) \]

Its experimental confirmation is considered a crucial test of non-perturbative QCD.

1. In case sign change is not confirmed we have to rethink TMD PDF factorisation – major problem of the TMD approach
2. Sivers function is very important by itself as gives a model-dependent access to Angular Momentum of partons
What we are made from and how it happened?

- Striking Higgs-boson discovery even if extremely important is NOT the origin of mass:
  - Higgs-boson mechanism produce a little fraction of mass
  - Higgs-generated mass-scales explain neither the “huge” proton mass nor the pion nearly masslessness
  - So very little input on ORIGIN, NATURE and STRUCTURE of nearly all visible matter

- Strong Interaction Sector of the Standard Model (i.e. QCD) is a key to understanding the origin, existence and properties of almost all visible matter.
QCD Preamble (Mass crisis Higgs-generated mass vs. emergent mass)

Higgs generated masses:
- $M_{(u+d)} \sim 7$ MeV
- $M_{(u+s)} \sim 100$ MeV
- $M_{(u+u+d)} \sim 10$ MeV

Higgs mechanism produce ~few percent of the mass of almost all visible matter ➔ QCD
QCD Preamble (Mass crisis Higgs-generated mass vs. emergent mass)

Questions to be answered:

• Mass difference pion/proton/kaon
• Mass generation mechanism (emergent mass vs. Higgs)
• Gluon content, especially important pion/kaon striking difference

Methods:

Drell-Yan:

Prompt photon production:

• 90’s: NA3, NA10, E615
• 10’s: COMPASS-II
• 20’s: COMPASS++

As well J/Psi production and pi/K diffractive scattering at very low $t$. 

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Recent results from Drell-Yan experiments (structure and spin): SeaQuest (FermiLab)

**Unpolarized Beam and Target w/ SeaQuest detector**

- **E-906/SeaQuest**: 120 GeV p from Main Injector on LH₂, LD₂, C, Fe, W targets → high-x Drell Yan
- Science run: March 2014 - July 2017 → dbar/ubar asymmetry, Quark energy loss

**Year 2015**

120 GeV protons from the Main Injector
- 4.3s beam spill every 60 sec
- 19ns RF, ~10Ks p/RF bucket
- 5x10^{12} p/spill
- Total integrated POT for E1039 (2-year): 1.4x10^{18} POT
Recent results from Drell-Yan experiments (structure and spin): SeaQuest (FermiLab) II

Striking preliminary results: disagreement with E866 at large x??? (800 GeV proton beam)
**Recent results from Drell-Yan experiments (structure and spin): STAR (RHIC) I**

<table>
<thead>
<tr>
<th></th>
<th>$A_N(W^{+/-},Z^0)$</th>
<th>$A_N(DY)$</th>
<th>$A_N(\gamma)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitive to Sivers effect non-universality through TMDs</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Sensitive to Sivers effect non-universality through Twist-3 $T_{q,F}(x,x)$</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Sensitive to TMD or Twist-3 evolution</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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Recent results from Drell-Yan experiments (structure and spin): STAR (RHIC) II

- **RHIC p+p (500 Gev): \( W^{+/-} \) TSSA**
  
  \[
  A_N(W^+) \sim (\Delta^N f_{u/p}^\uparrow \otimes f_{d/p} + \Delta^N f_{d/p}^\uparrow \otimes f_{u/p}) \\
  A_N(W^-) \sim (\Delta^N f_{u/p}^\uparrow \otimes f_{d/p} + \Delta^N f_{d/p}^\uparrow \otimes f_{u/p})
  \]

- **Sivers asymmetry:**
  - quark flavor identified
  - high \( Q^2 \)
  - statistically limited: \( O(10\%) \)
  - data favor sign-change
    - if TMD evolution effects small
  - more data from 2017 (400 pb\(^{-1}\)) soon

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PRL 116 (2016) 132301

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COMPASS facility at CERN (SPS)

Universal and flexible apparatus. Most important features of the two-stage COMPASS Spectrometer:
1. Muon, electron or hadron beams with the momentum range 20-250 GeV and intensities up to \(10^9\) particles per second.
2. Solid state polarised targets (\(\text{NH}_3\) or \(\text{LiD}\)) as well as liquid hydrogen target and nuclear targets.
3. Advanced tracking (390 planes) and powerful PID systems (Muon, NIM, Calorimetry, RICH), new DAQ.

DY@COMPASS - set-up
\[ \pi^+ p \rightarrow \mu^+ \mu^- X \]

Key elements:
1. COMPASS PT
2. Tracking system (both LAS abs SAS) and beam telescope in front of PT
3. Muon trigger (in LAS is of particular importance - 60% of the DY acceptance)
4. HCAL based trigger (veto) in LAS (to reduce DY di-muon trigger rate if needed)
5. RICH1. Calorimetry – also important to reduce the background (the hadron flux downstream of the hadron absorber ~ 10 higher than muon flux)

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DY@COMPASS 2015 and 2018 Run

• First ever polarised Drell-Yan experiment was successfully performed in 2015 at COMPASS
COMPASS: 190 GeV π beam on transverse polarized H target (NH₃)

- 2015 data (4 months)
- Transverse target polarization ~80%
- consistent w/ sign change!

\[ A_T^{\sin \varphi_5} = 0.060 \pm 0.057 \text{(stat.)} \pm 0.040 \text{(sys.)} \]

Ref: W.C. Chang (Academia Sinica) & J-C Peng (UIUC)

TMD-2 (2013)
P. Sun, F. Yuan, PRD88, 114012

DGLAP (2016)
M. Anselmino et al., arXiv:1612.06413

TMD-1 (2014)
M. G. Echevarria et al. PRD89, 074013
COMPASS-II preliminary
2015 + 50% 2018 results
Drell-Yan prospectives: (spin crisis)
SpinQuest (FermiLab) I

SpinQuest Spectrometer

- field: 5T @ 1K
- targets: NH₃ and ND₃
- elliptical: 1.9 cm x 2.1 cm (x,y), l:7.9 cm (z)
- 3 active cells, 1 empty
- helium consumption 100 l/day

120 GeV protons from the Main Injector
- 4.3s beam spill every 60 sec
- 19ns RF, ~10Ks p/RF bucket
- 5x10¹² p/spill
- Total integrated POT for E1039 (2-year): 1.4x10¹⁸ POT

Unpolarized Beam and polarized Target (w/ upgraded SeaQuest detector)
- **E-1039/SpinQuest**: SeaQuest w/ pol NH₃/ND₃ targets: 2019-2021
  → probe sea quark distributions

Polarized Beam and polarized Target
→ development of high-luminosity facility for polarized Drell Yan
- **E-1027**: pol p beam on (un)pol tgt (2021+?)
  → Sivers sign change (valence quark)
  → TMD physics program complementary to future EIC program
Drell-Yan prospectives: (spin crisis)
SpinQuest (FermiLab) II

- DOE approval, March 2018
- Fermilab stage-2 approval, May 2018
- E906 decommissioned 6/2018
- Polarized target to be installed by fall of 2019
- E1039 commissioning starts in late 2019
- Run for 2+ years, 2019-2021+

Ref: M. Liu (LANL)
Drell-Yan prospectives: (spin crisis) SpinQuest (FermiLab) III

Let’s Polarize the Beam at Fermilab (E-1027)

The Plan:
- Use SpinQuest Spectrometer
- Add polarized beam

Expected Precision from E-1027 at Fermilab

- Probe Valence Quark Sivers Asymmetry with a polarized proton beam at SeaQuest

Experimental Conditions
- same as SeaQuest
- luminosity: $L_{av} = 2 \times 10^{35}$ (10% of available beam time: $I_{av} = 15$ nA)
Drell-Yan prospectives: (spin/mass crisis)
STAR (RHIC) I

Expected uncertainties from 2017 Transverse Run (500 GeV)

Collected:
350 pb⁻¹ → 14 times Run-11 for -1 < \( \eta \) < 1.8 → \( A_N \) \( W^+/\) & \( Z^0 \), Collins, ......

Will provide data to constrain
→ TMD evolution,
→ sea-quark Sivers fct
→ through rapidity distribution → neg. \( \eta \)
→ test of Sivers fct. non-universality
→ \( Z^0 \) very clean channel no corrections
Drell-Yan prospectives: (spin crisis)  
STAR (RHIC) II 

STAR Forward Detector upgrade & DY 

**DY@STAR FOR 500 GeV** 

**Kinematics:**  
DY $e^+e^-$ in $2.5 < \eta < 4.0$  
$4.0 \text{ GeV} < M_{e^+e^-} < 9.0 \text{ GeV}$  

Add a postshower to the preshower & the FMS  
will be able to measure $A_N$ DY 

Design follows successful  
Pre-eshower design  
\( \rightarrow \) 3 layers of $u, x, y$ with  
SiPM readout 

After analysis $2.5 < \eta < 4.0$  

With TMD Evolution  
No TMD Evolution
Drell-Yan prospectives: (spin crisis)
STAR (RHIC) III
Further STAR Forward Detector upgrade

2021+: FORWARD UPGRADE

Objective:
unique program addressing several fundamental questions in QCD
→ essential to
  □ the mission of the RHIC physics program in cold and hot QCD
  □ fully realize the scientific promise of the EIC
    ➢ lay the groundwork for the EIC, both scientifically and by refining exp. requirements
    ➢ Test EIC detector technologies under real conditions, i.e. SiPMs

Scientific goals:
p+p:
  3-dim. characterization of the proton in momentum and spatial coordinates
p+A
  Nature of initial state and hadronization in nuclear collisions
A+A
  Onset and A-dependence of saturation
  Longitudinal medium characterization
  Precision flow measurements via long range correlations

Upgrade includes:
Forward Calorimeter System: EM and Hadronic
Forward Tracking System: Si + sTGCs
Drell-Yan prospectives: (spin/mass crisis)
J-PARC I

The new beam line is under construction. It will be operated since 2019.

- Primary Proton Beam (30 GeV), $10^{10}$ per spill
- High Momentum un-separated secondary beam (< 20 GeV/c), $10^8$ per spill

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Drell-Yan prospectives: (spin/mass crisis) J-PARC II

Exclusive meson-induced DY

Meson Beam

$q^2 > 0$

J-PARC

Exclusive pion-induced DY

$\pi N \rightarrow \gamma^* N'$

E50 experiment (Stage-1 approved by J-PARC) + $\mu$-ID extension

$10-20$ GeV $\pi^-$ beam on high momentum beam line at J-PARC

good missing mass resolution in exclusive DY events ($\pi^- p \rightarrow \mu^+ \mu^- n$)

Statistical accuracy adequate for discriminating between predictions from two current GPD models.

GK2013 (red)
BMP2001 (black)

Ref: T. Sawada (Acad. Sinica)

FIG. 3: **Left Panel.** Twist-two parton distribution amplitudes at a resolving scale $\zeta = 2 \text{GeV} =: \zeta_2$. 

- **A** solid (green) curve – pion $\leftrightarrow$ emergent mass generation is dominant; 
- **B** dot-dashed (blue) curve – $\eta_c$ meson $\leftrightarrow$ Higgs mechanism is the primary source of mass generation; 
- **C** solid (thin, purple) curve – asymptotic profile, $6x(1-x)$; and 
- **D** dashed (black) curve – “heavy-pion”, i.e. a pion-like pseudo-scalar meson in which the valence-quark current masses take values corresponding to a strange quark $\leftrightarrow$ the boundary, where emergent and Higgs-driven mass generation are equally important. 

**Right Panel.** Ratio of valence $u$-quark PDFs in
Drell-Yan prospectives: (spin/mass crisis)
COMPASS++/AMBER I

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SPSC-2019–003
SPSC-I–250
January 25, 2019

http://arxiv.org/abs/1808.00848

Letter of Intent:
A New QCD facility at the M2 beam line of the CERN SPS

COMPASS++/AMBER

B. Adams, C.A. Aidala, R. Akhunzyanov, G.D. Alexeev, M.G. Alexeev, A. Amoroso,
# Drell-Yan perspectives: (spin/mass crisis)

**COMPASS++/AMBER II**

<table>
<thead>
<tr>
<th>Program</th>
<th>Physics Goals</th>
<th>Beam Energy [GeV]</th>
<th>Beam Intensity [s^{-1}]</th>
<th>Trigger Rate [kHz]</th>
<th>Beam Type</th>
<th>Target</th>
<th>Earliest start time, duration</th>
<th>Hardware additions</th>
</tr>
</thead>
<tbody>
<tr>
<td>muon-proton elastic scattering</td>
<td>Precision proton-radius measurement</td>
<td>100</td>
<td>$4 \cdot 10^6$</td>
<td>100</td>
<td>$\mu^\pm$</td>
<td>high-pressure H2</td>
<td>2022</td>
<td>1 year</td>
</tr>
<tr>
<td>Hard exclusive reactions</td>
<td>GPD $E$</td>
<td>160</td>
<td>$2 \cdot 10^7$</td>
<td>10</td>
<td>$\mu^\pm$</td>
<td>NH$_3$</td>
<td>2022</td>
<td>2 years</td>
</tr>
<tr>
<td>Input for Dark Matter Search</td>
<td>$\bar{p}$ production cross section</td>
<td>20-280</td>
<td>$5 \cdot 10^7$</td>
<td>25</td>
<td>$\bar{p}$</td>
<td>LH$_2$, LHe</td>
<td>2022</td>
<td>1 month</td>
</tr>
<tr>
<td>$\bar{p}$-induced spectroscopy</td>
<td>Heavy quark exotics</td>
<td>12, 20</td>
<td>$5 \cdot 10^7$</td>
<td>25</td>
<td>$\bar{p}$</td>
<td>LH$_2$</td>
<td>2022</td>
<td>2 years</td>
</tr>
<tr>
<td>Drell-Yan</td>
<td>Pion PDFs</td>
<td>190</td>
<td>$7 \cdot 10^7$</td>
<td>25</td>
<td>$\pi^\pm$</td>
<td>C/W</td>
<td>2022</td>
<td>1-2 years</td>
</tr>
<tr>
<td>Drell-Yan (RF)</td>
<td>Kaon PDFs &amp; Nucleon TMDs</td>
<td>$\sim$100</td>
<td>$10^8$</td>
<td>25-50</td>
<td>$K^\pm, \bar{p}$</td>
<td>NH$_3$, C/W</td>
<td>2026</td>
<td>2-3 years</td>
</tr>
<tr>
<td>Primakoff (RF)</td>
<td>Kaon polarisability &amp; pion life time</td>
<td>$\sim$100</td>
<td>$5 \cdot 10^6$</td>
<td>$&gt; 10$</td>
<td>$K^-$</td>
<td>Ni</td>
<td>2026</td>
<td>1 year</td>
</tr>
<tr>
<td>Prompt Photons (RF)</td>
<td>Meson gluon PDFs</td>
<td>$\geq$ 100</td>
<td>$5 \cdot 10^6$</td>
<td>10-100</td>
<td>$K^\pm, \pi^\pm$</td>
<td>LH$_2$, Ni</td>
<td>2026</td>
<td>1-2 years</td>
</tr>
<tr>
<td>K-induced Spectroscopy (RF)</td>
<td>High-precision strange-meson spectrum</td>
<td>50-100</td>
<td>$5 \cdot 10^6$</td>
<td>25</td>
<td>$K^-$</td>
<td>LH$_2$</td>
<td>2026</td>
<td>1 year</td>
</tr>
<tr>
<td>Vector mesons (RF)</td>
<td>Spin Density Matrix Elements</td>
<td>50-100</td>
<td>$5 \cdot 10^6$</td>
<td>10-100</td>
<td>$K^\pm, \pi^\pm$</td>
<td>from H to Pb</td>
<td>2026</td>
<td>1 year</td>
</tr>
</tbody>
</table>

Table 2: Requirements for future programmes at the M2 beam line after 2021. Muon beams are in blue, conventional hadron beams in green, and RF-separated hadron beams in red.
Drell-Yan prospectives: (spin/mass crisis)
COMPASS++/AMBER III

Two stages program:
First stage (shorter term) – existing extracted beams
Second stage (longer term) – RF-separated extracted kaon and antiproton beams


a.) Standard muon beam:
- 1. DVCS with trans. polarised proton target
- 2. Proton radius measurement in elastic muon proton scattering

b.) Standard hadron beam:
- 1. Unpolarised DY with various targets
- 2. Absolute cross-section measurements p + He -> pbar X
- 3. Hadron spectroscopy with antiproton

Longer term (New RF-separated beam will be ready ≥ 2026):

- 1. Hadron spectroscopy
- 2. Drell-Yan physics
- 3. Primakoff with kaon beam
- 4. Direct Photons with kaon
Drell-Yan prospectives: (spin crisis)
COMPASS++/AMBER IV - GPD

Figure 4: Expected statistical accuracy of $A_{CS,T}^{D\sin(\theta - \phi_3)\cos \phi}$ as a function of $-t$, $x_B$ and $Q^2$ from a 280 days measurement with the COMPASS spectrometer, using a 160 GeV muon beam and a transversely polarised NH$_3$ target. Solid and open circles correspond to a minimum accessible $|t_{\text{min}}|$ of 0.10 GeV$^2$ and 0.14 GeV$^2$, respectively. Also shown is the asymmetry $A_{UT}^{\sin(\theta - \phi_3)\cos \phi}$ measured at HERMES [29] with its statistical errors. Figure from ref. [35].
QCD Preamble (Mass crisis Higgs-generated mass .vs. emergent mass)

Questions to be answered:

• Mass difference pion/proton/kaon
• Mass generation mechanism (emergent mass .vs. Higgs)
• Gluon content, especially important pion/kaon striking difference

Methods:

As well J/Psi production and pi/K diffractive scattering at very low $t$. 
Drell-Yan prospectives: (mass crisis)
COMPASS++/AMBER V

Pion structure in pion induce DY
Expected accuracy as compared to NA3

- $\Sigma_V = \sigma^{\pi^-C} - \sigma^{\pi^+C}$: only valence-valence
- $\Sigma_S = 4\sigma^{\pi^+C} - \sigma^{\pi^-C}$: no valence-valence
- Collect at least a factor 10 more statistics than presently available
- Minimize nuclear effects on target side
  - Projection for $2 \times 140$ days of Drell-Yan data taking
  - $\pi^+$ to $\pi^-$ 10:1 time sharing
  - 190 GeV beams on Carbon target $(1.9\lambda_{int})$
  - Improvement of shielding to double the intensity is under investigation

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Drell-Yan prospectives: (mass crisis) COMPASS++/AMBER VI

Extremely important to compare the gluon content of kaon and pion (emergent mass)

Sole measurement from NA3
J. Badier et al., PLB93 354 (1984)

- Limited statistics: 700 events with $K^-$
- Sensitivity to $SU(3)_f$ breaking
- Mostly only model predictions

Interesting observation: At hadronic scale gluons carry only 5% of $K$'s momentum vs $\sim 30\%$ in $\pi$

- Scarce data on $u$-valence
- No measurements on gluons
- No measurements on sea quarks
Pythia-based MC simulation for prompt photons production was used for preliminary estimation of kinematic range accessible at COMPASS. It was compared with corresponding ranges accessible by previous experiments with pion beams.

Full MC simulation for prompt photons and minimum bias events was performed for K+ beam of 100 GeV/c and the COMPASS setup configuration of 2017 DVCS run. Possibilities to identify signal and reject background were tested. Some optimization of the setup from point of the material budget was tested.

At the moment there is no experimental information about gluon contribution in kaon. Calculations based on Dyson-Schwinger equations predict 6 times smaller contribution at hadronic scale in respect to pion (Phys. Rev. D93 (7) (2016) 074021).

Drell-Yan prospectives: (mass crisis) 
COMPASS++/AMBER V
NO competitors
Summary

• After quite a while several Drell-Yan experiments providing data

• Drell-Yan as probe will provide an unique input in order to finally resolve the spin and may be mass crises as fundamental issues to be addressed:
  – TMD factorisation
  – Pion and kaon structure, gluon content, other properties

• Running Drell-Yan experiments is a beginning of the story, new facilities are under construction, SPD at NICA one of them
THANKS!
• Spares
### Running/planed Drell-Yan experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Particles</th>
<th>Energy (GeV)</th>
<th>$x_b$ or $x_t$</th>
<th>Luminosity ($cm^{-2} s^{-1}$)</th>
<th>$P_b$ or $P_t$ (f)</th>
<th>rFOM$^#$</th>
<th>Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COMPASS (CERN)</strong></td>
<td>$\pi^\pm + p^\uparrow$</td>
<td>190 GeV $\sqrt{s} = 19$</td>
<td>$x_t = 0.1 – 0.3$</td>
<td>2 x $10^{32}$</td>
<td>$P_t = 80%$ $f = 0.22$</td>
<td>$1.0 \times 10^{-3}$</td>
<td>2014-2015, 2018</td>
</tr>
<tr>
<td><strong>PANDA (GSI)</strong></td>
<td>$p^{\text{bar}} + p^\uparrow$</td>
<td>15 GeV $\sqrt{s} = 5.5$</td>
<td>$x_t = 0.2 – 0.4$</td>
<td>2 x $10^{32}$</td>
<td>$P_t = 90%$ $f = 0.22$</td>
<td>$1.1 \times 10^{-4}$</td>
<td>&gt;2025</td>
</tr>
<tr>
<td><strong>AFTER</strong></td>
<td>$p^\uparrow + p$</td>
<td>7 TeV $\sqrt{s} = 120$</td>
<td>$x_b = 0.1 – 0.9$</td>
<td>2 x $10^{32}$</td>
<td>$P_b = 100%$?</td>
<td>$2.3 \times 10^{-5}$</td>
<td>&gt;2020</td>
</tr>
<tr>
<td><strong>NICA (JINR)</strong></td>
<td>$p^\uparrow + p$</td>
<td>collider $\sqrt{s} = 26$</td>
<td>$x_b = 0.1 – 0.8$</td>
<td>1 x $10^{32}$</td>
<td>$P_b = 70%$</td>
<td>$6.8 \times 10^{-5}$</td>
<td>&gt;2023</td>
</tr>
<tr>
<td><strong>PHENIX/STAR (RHIC)</strong></td>
<td>$p^\uparrow + p^\uparrow$</td>
<td>collider $\sqrt{s} = 510$</td>
<td>$x_b = 0.05 – 0.1$</td>
<td>2 x $10^{32}$</td>
<td>$P_b = 60%$</td>
<td>$1.0 \times 10^{-3}$</td>
<td>&gt;2018</td>
</tr>
<tr>
<td>sPHENIX (RHIC)</td>
<td>$p^\uparrow + p^\uparrow$</td>
<td>collider $\sqrt{s} = 200$ $\sqrt{s} = 510$</td>
<td>$x_b = 0.1 – 0.5$ $x_b = 0.05 – 0.6$</td>
<td>8 x $10^{31}$ 6 x $10^{32}$</td>
<td>$P_b = 60%$ $P_b = 50%$</td>
<td>$4.0 \times 10^{-4}$ 2.1 x $10^{-3}$</td>
<td>&gt;2021</td>
</tr>
<tr>
<td><strong>SeaQuest (FNAL: E-906)</strong></td>
<td>$p + p$</td>
<td>120 GeV $\sqrt{s} = 15$</td>
<td>$x_b = 0.35 – 0.9$</td>
<td>$x_t = 0.1 – 0.45$</td>
<td>$3.4 \times 10^{35}$</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Pol tgt DY‡ (FNAL: E-1039)</strong></td>
<td>$p + p^\uparrow$</td>
<td>120 GeV $\sqrt{s} = 15$</td>
<td>$x_t = 0.1 – 0.45$</td>
<td>$4.4 \times 10^{35}$</td>
<td>$P_t = 85%$ $f = 0.176$</td>
<td>0.15</td>
<td>2018-2019</td>
</tr>
<tr>
<td><strong>Pol beam DY§ (FNAL: E-1027)</strong></td>
<td>$p^\uparrow + p$</td>
<td>120 GeV $\sqrt{s} = 15$</td>
<td>$x_b = 0.35 – 0.9$</td>
<td>$2 \times 10^{35}$</td>
<td>$P_b = 60%$</td>
<td>1</td>
<td>2020</td>
</tr>
</tbody>
</table>

‡ 8 cm NH$_3$ target / § $L = 1 \times 10^{36}$ cm$^2$ s$^{-1}$ (LH$_2$ tgt limited) / $L = 2 \times 10^{35}$ cm$^{-2}$ s$^{-1}$ (10% of MI beam limited)
Coordinate systems

Collins-Soper

TF