XVIII Workshop on High Energy Spin Physics

DSPIN-19

Dubna, Russia, September 2-6, 2019

Recent results from Drell-Yan experiments and prospectives

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MEMBER STATES

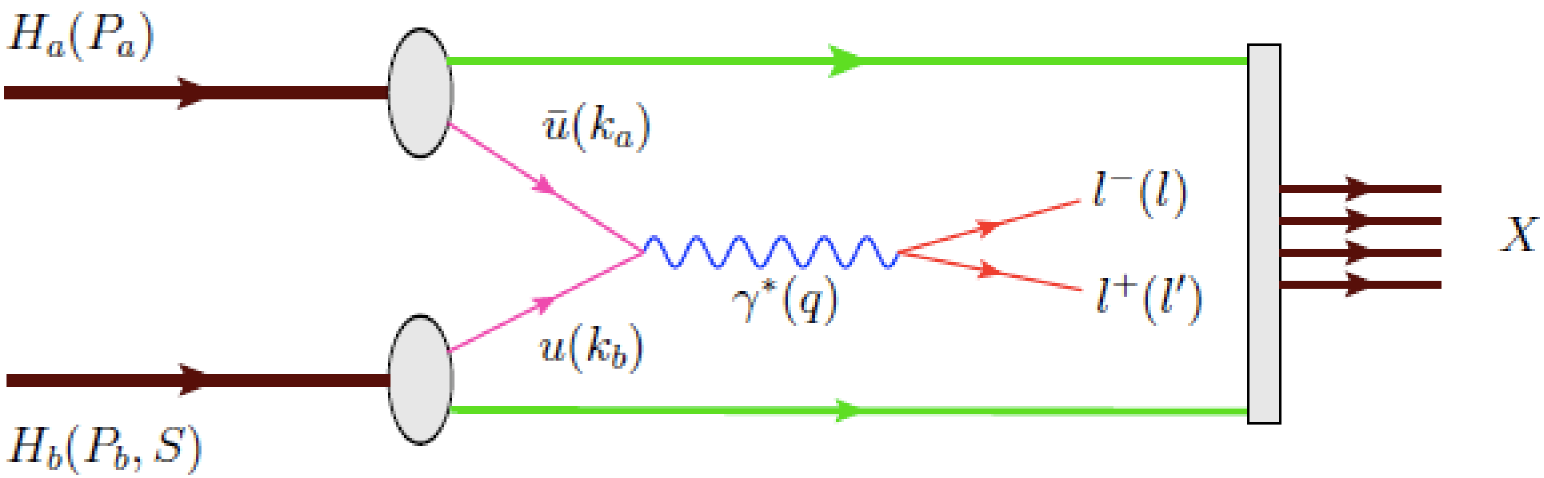
Outline

- 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



$P_{a(b)}$	the momentum of the beam (target) hadron,
$s \quad = (P_a + P_b)^2,$	the total centre-of-mass energy squared,
$x_{a(b)} = q^2/(2P_{a(b)} \cdot q),$	the momentum fraction carried by a parton from $H_{a(b)}$,
$x_F \quad = x_a - x_b,$	the Feynman variable,
$M^2_{\mu\mu} = Q^2 = q^2 = s\ x_a\ x_b,$	the invariant mass squared of the dimuon,
$\mathbf{k}_{Ta(b)}$	the transverse component of the quark momentum,
$\mathbf{q}_T = \mathbf{P}_T = \mathbf{k}_{Ta} + \mathbf{k}_{Tb}$	the transverse component of the momentum of the virtual photon.

Status of the theory: Pion-induced DY, DY Cross section calculations theoretical calculations - COMPASS

Very big progress recently achieved: NLL threshold re-summation mechanism with non-perturbative term - good experimental data description – K-factors issue is not there anymore (M. Aicher, A. Sch¨afer and W. Vogelsang, Phys.Rev.Lett. 105 (2010) 252003)

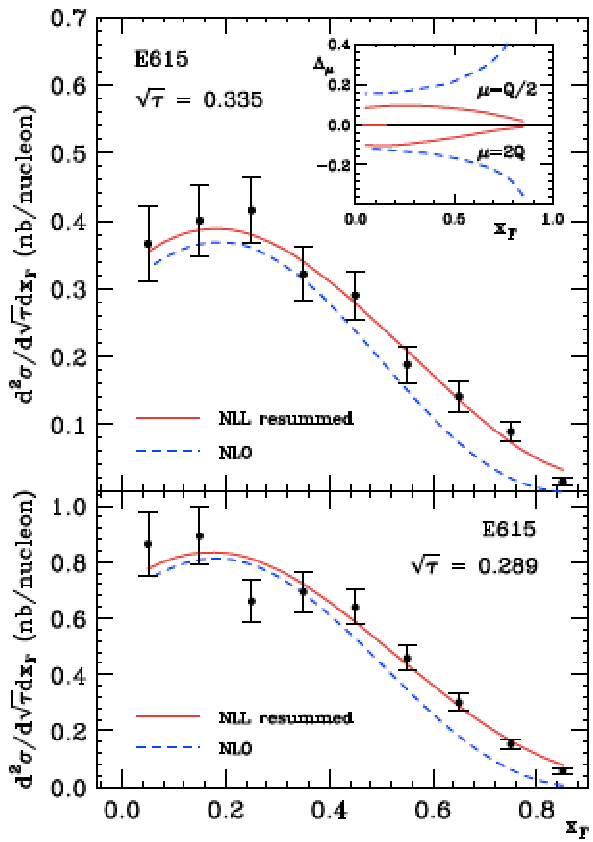


FIG. 2: Comparison of our NLL-resummed Drell-Yan cross section based on fit 3 to some of the E615 Drell-Yan data. The inset in the upper figure shows the scale variation of the resummed and the NLO cross sections (see the text).

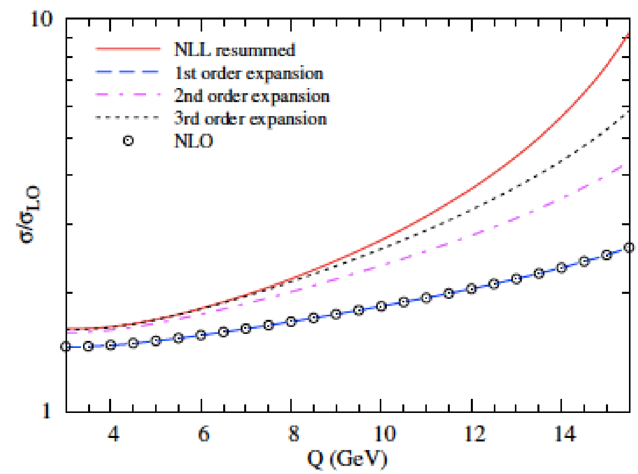


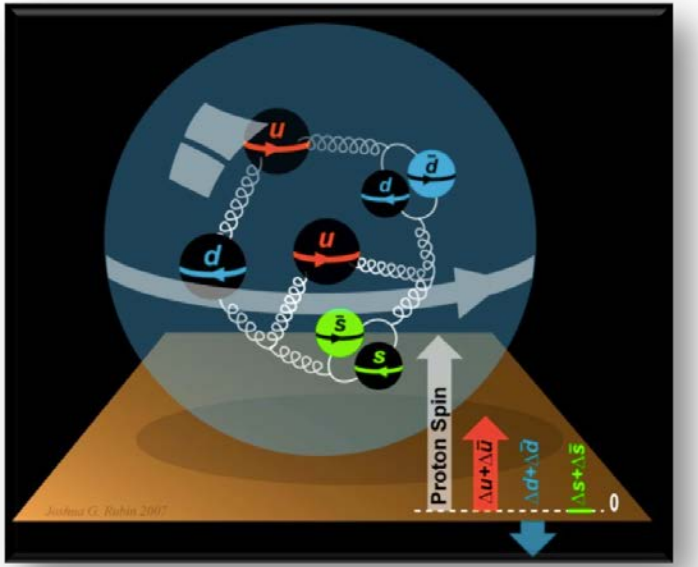
FIG. 2: "K-factors" as defined in Eq. (27) at $\sqrt{S} = 19$ GeV as functions of the lepton pair mass Q, at NLO (symbols) and for the NLL-resummed case. Also shown are the expansions of the resummed cross section to first, second and third order in the strong coupling.

The case of COMPASS (M. Aicher, A. Sch¨afer and . Vogelsang Phys.Rev. D83 (2011) 114023)

Introduction to the Spin I

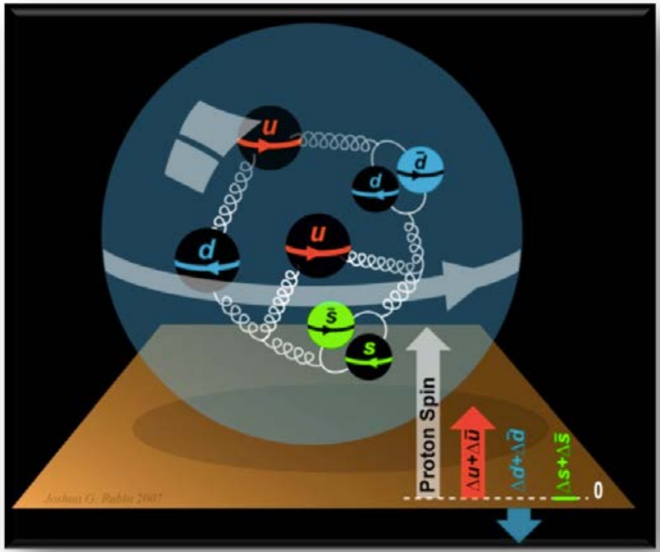
On the one hand - Almost all visible matter of the universe we are able to observe consists of nucleons.

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".

Introduction to the Spin II



Nucleon spin ½ = ½ ΔΣ + ΔG + L

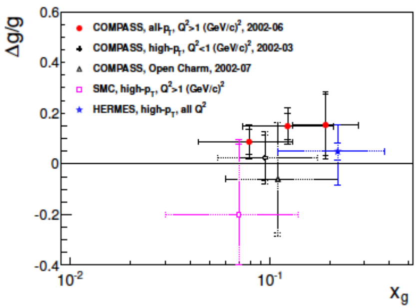
quark gluon orbital mom.

ΔΣ : sum over u, d, s, ū, d̄, s̄
Can take any value: superposition of several states

$\Delta q = \overrightarrow{q} - \overleftarrow{q}$
Parton spin parallel or anti parallel to nucleon spin

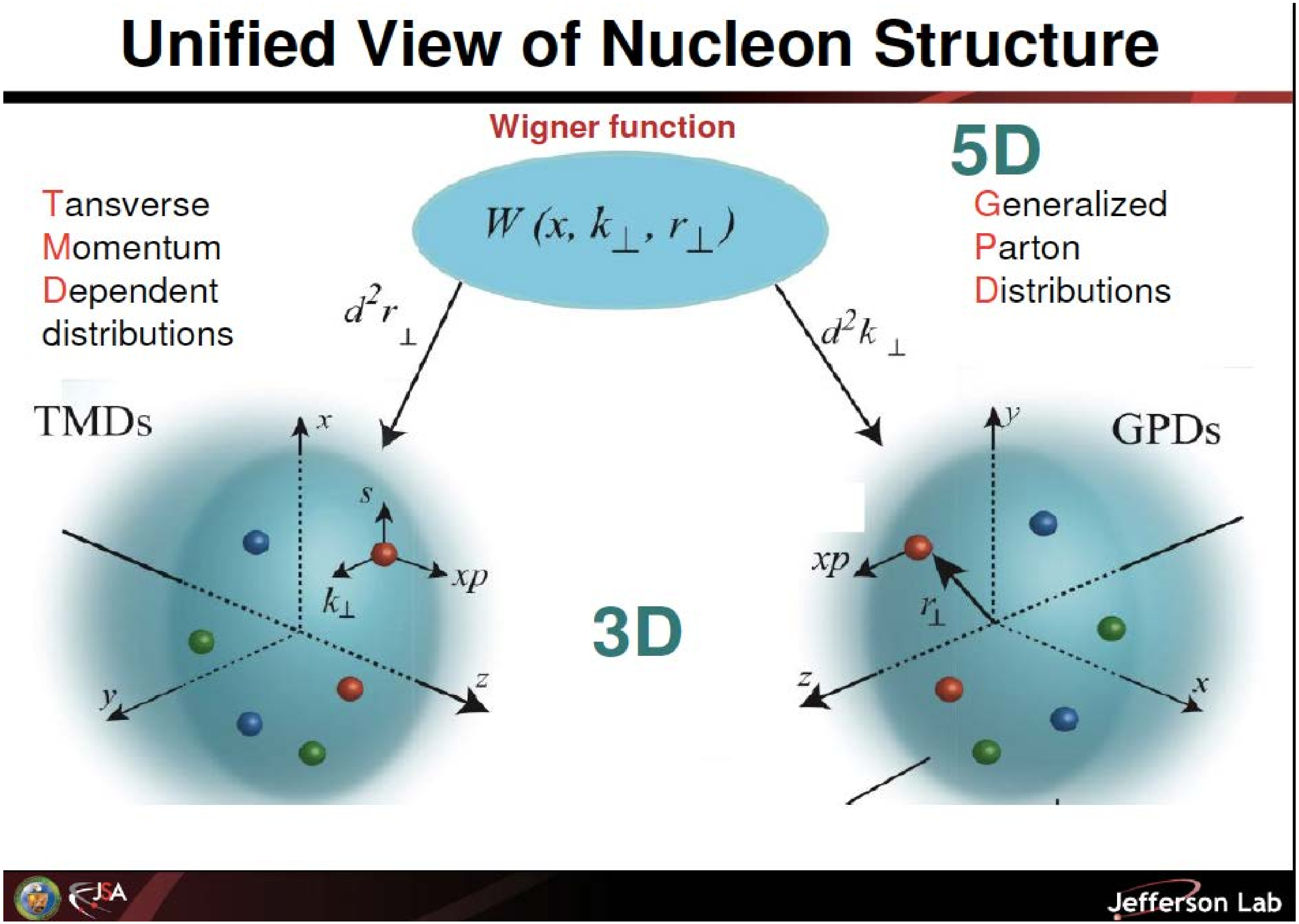
First two component were extensively studied in the SIDIS experiments with the longitudinally polarised target (collinear case approach): spin fraction carried by quarks and gluons is not sufficient to describe ½ nucleon spin (Spin Crisis, continued):

- Quark spin contribution ΔΣ=0.24 (Q^2=10 $(GeV/c)^2$ DSSV *arXiv:0804.0422)*
- COMPASS Open charm measurement and other direct measurements ➔ ΔG/G is positive but small



➔
In order to create Angular Momentum of partons spin-orbit correlation has to be taken into account ➔ transverse momentum of the quark k_T appears ➔ **3D structure of the Nucleon has to be studied**

3D structure of nucleon II



Leading Order (TMD) PDFs

Huge progress has been made over the part 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 (columns) / **Quark polarization** (rows)

	unpol.	long. pol.	transv. pol.
unpol.	f_1 Number Density		$f_{1T}^{\perp}$ Sivers
long. pol.		g_1 Helicity	g_{1T} Worm Gear
transv. pol.	$h_1^{\perp}$ Boer-Mulders	$h_{1L}^{\perp}$ Worm Gear	h_1 Transversity; $h_{1T}^{\perp}$ Pretzelosity

$f_{1T}^{\perp}(x,k_T^2)$ Sivers function

the correlation between the transverse spin of the nucleon and the transverse momentum of the quark.

$h_1^{\perp}(x,k_T^2)$ Boer-Mulders function

the correlation between the transverse spin and the transverse momentum of a quark in unpolarized nucleon.

$h_{1T}^{\perp}(x,k_T^2)$ 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:

↪ Check the predictions:

$$f_{1T}^{\perp}(DY) = -f_{1T}^{\perp}(SIDIS)$$

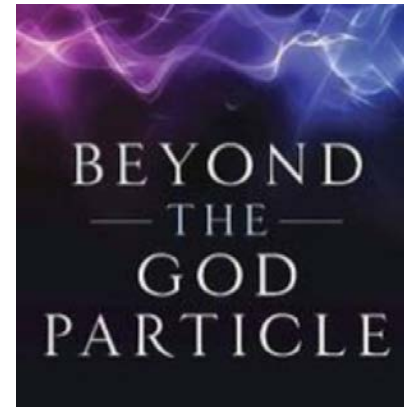
$$h_{1}^{\perp}(DY) = -h_{1}^{\perp}(SIDIS)$$

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

QCD Preamble (Mass crisis)

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

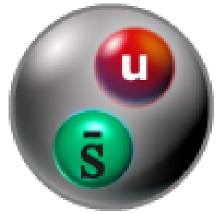
- Strong Interaction Sector of the Standard Model (i.e. QCD) is a key to understanding the origin, existence and properties of almost all visible matter.

QCD Preamble (Mass crisis Higgs-generated mass .vs. emergent mass)

Pion

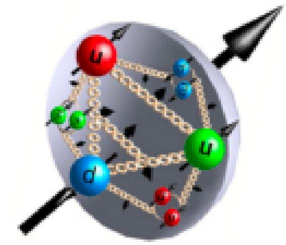
- $M_\pi \sim 140$MeV
- Spin 0
- 2 light valence quarks

Kaon



- $M_K \sim 490$MeV
- Spin 0
- 1 light and 1 "heavy" valence quarks

Proton



- $M_p \sim 940$MeV
- Spin 1/2
- 3 light valence quarks

Higgs generated masses:

$M_{(u+d)}$ ~ 7 MeV

$M_{(u+s)}$ ~ 100 MeV

$M_{(u+u+d)}$ ~ 10 MeV

Higgs mechanism produce ~few percent of the mass of almost all visible matter ➔ QCD

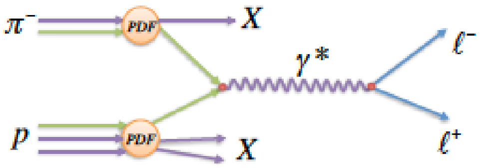
QCD Preamble (Mass crisis
Higgs-generated mass .vs. emergent mass)

Questions to be answered:

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

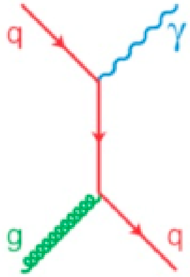
Methods:

Drell-Yan:



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

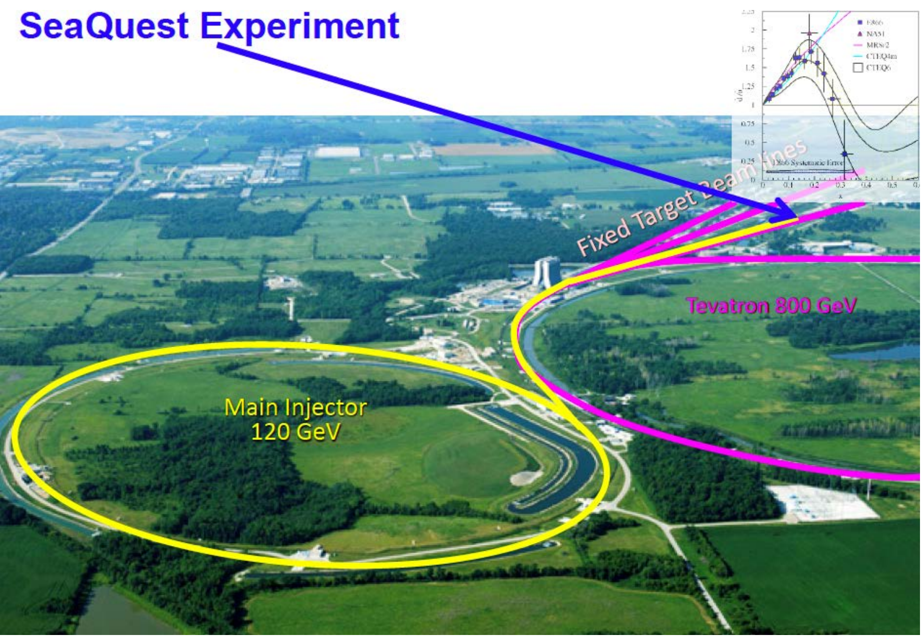
Prompt photon production:



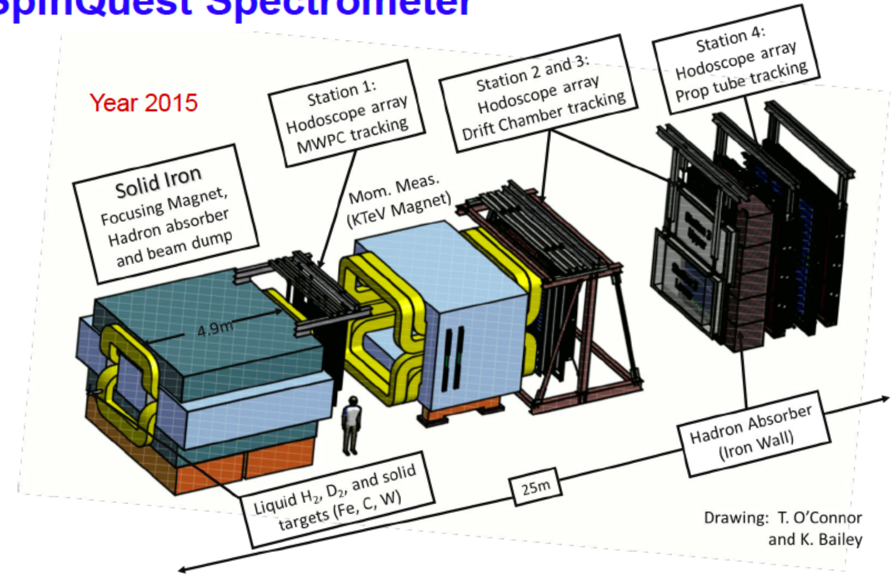
- 90's: NA24, W70
- 20's: COMPASS++

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

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



SpinQuest Spectrometer



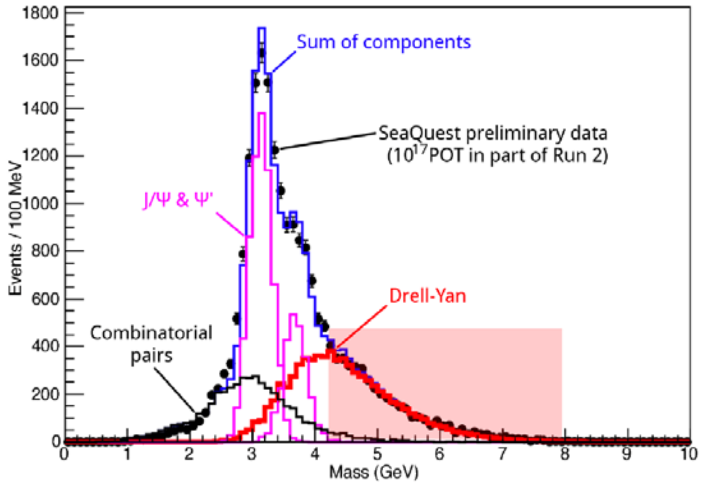
120 GeV protons from the Main Injector

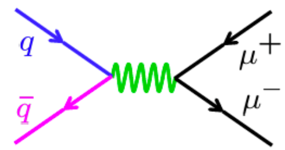
- 4.3s beam spill every 60 sec
- 19ns RF, ~10Ks p/RF bucket
- $5x10^{12}$ p/spill
- Total integrated POT for E1039 (2-year): $1.4x10^{18}$ POT

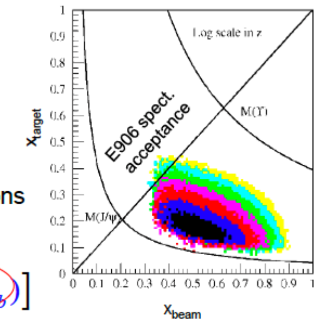
Unpolarized Beam and Target w/ SeaQuest detector

- **E-906/SeaQuest**: 120 GeV p from Main Injector on LH_2, LD_2, C, Fe, W targets
  → **high-x Drell Yan**
- Science run: March 2014 - July 2017
  ➞ dbar/ubar asymmetry, Quark energy loss

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







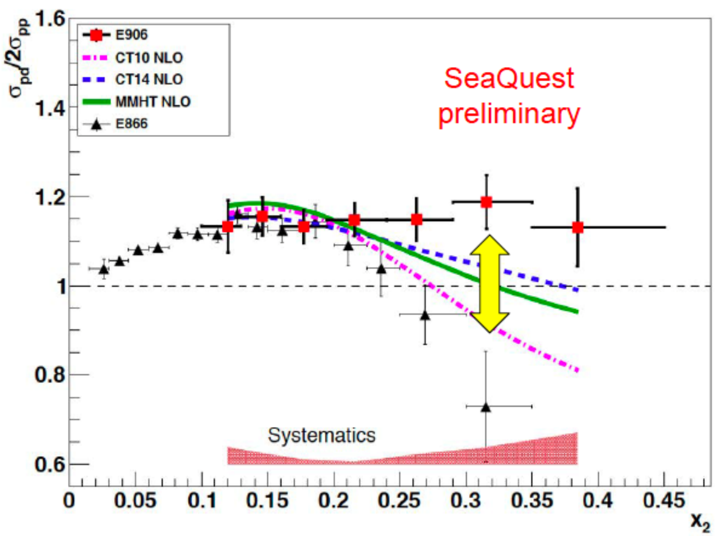
- Cross section: convolution of beam and target parton distributions

$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{x_b x_t s} \sum_{q\in\{u,d,s,\ldots\}} e_q^2 \left[\bar{q}_t(x_t) q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)\right]$$

beam: valence quarks at high x

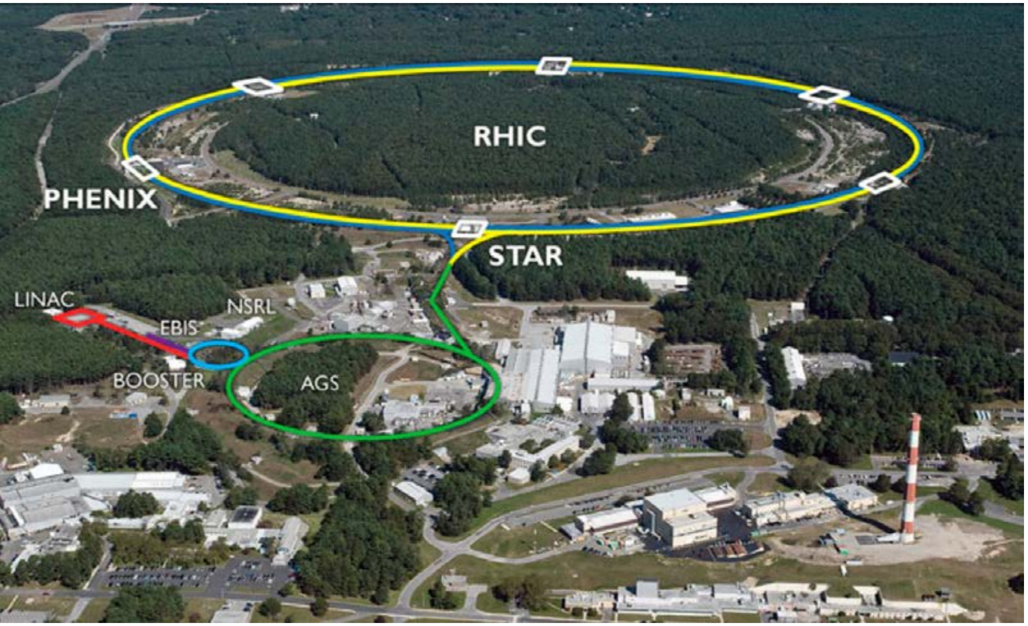
target: sea quarks at low/intermediate x

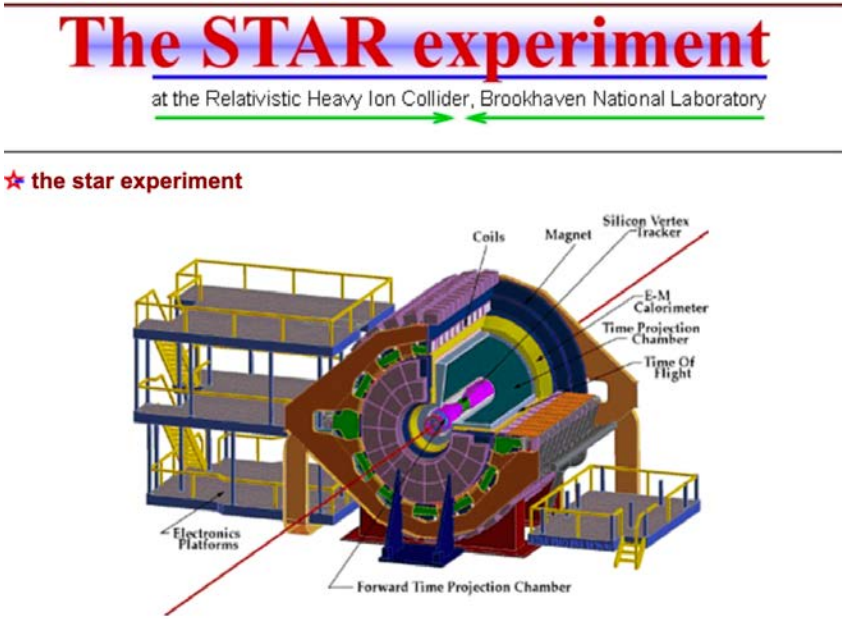
$$\frac{\sigma^{pd}}{2\sigma^{pp}} = \frac{1}{2}\left[1 + \frac{\bar{d}(x)}{\bar{u}(x)}\right]$$



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





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

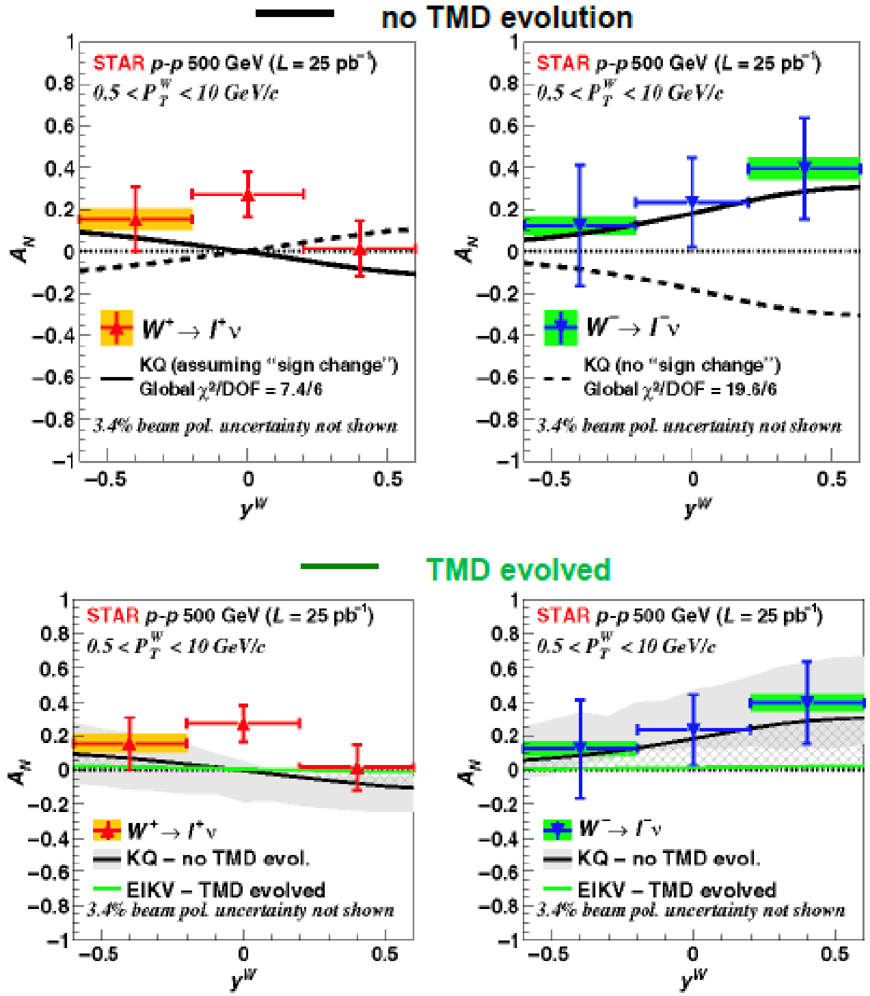
Recent results from Drell-Yan experiments (structure and spin): STAR (RHIC) II

- **RHIC p+p (500 Gev):** W$^{+/-}$ TSSA

$$A_N(W^+) \sim \left(\Delta^N f_{u/p^\uparrow} \otimes f_{\bar{d}/p} + \Delta^N f_{\bar{d}/p^\uparrow} \otimes f_{u/p}\right)$$

$$A_N(W^-) \sim \left(\Delta^N f_{\bar{u}/p^\uparrow} \otimes f_{d/p} + \Delta^N f_{d/p^\uparrow} \otimes f_{\bar{u}/p}\right)$$

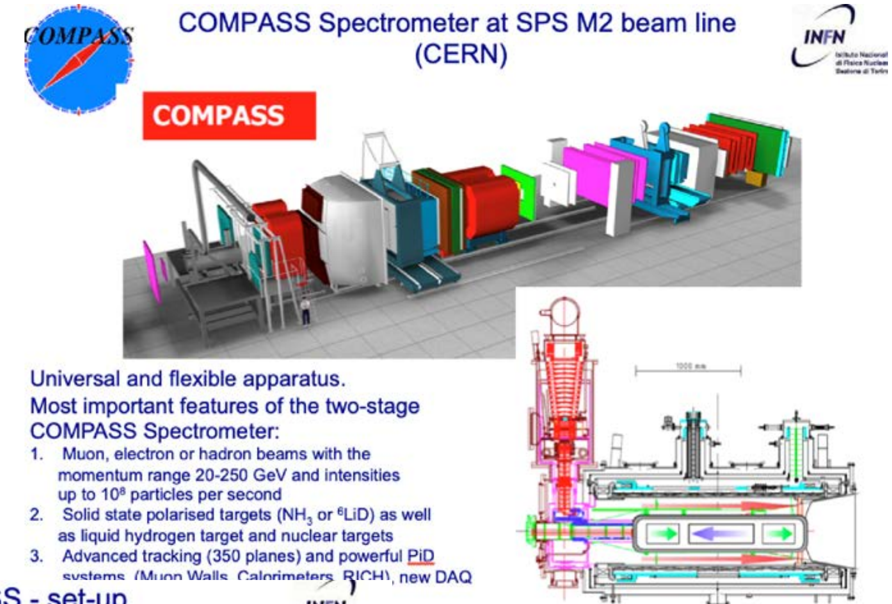
- **Sivers asymmetry:**
  - ➡ quark flavor identified
  - ➡ high Q^2
  - ➡ statistically limited: O(10%)
  - ➡ data favor sign-change
    if TMD evolution effects small
  - ➡ more data from 2017 (400 pb^{-1}) soon

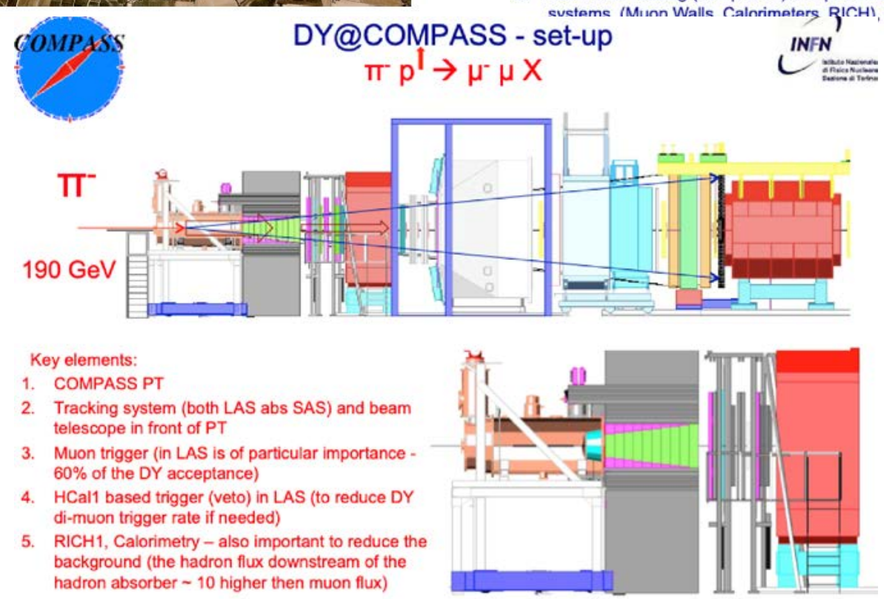


PRL **116** (2016) 132301

COMPASS facility at CERN (SPS)

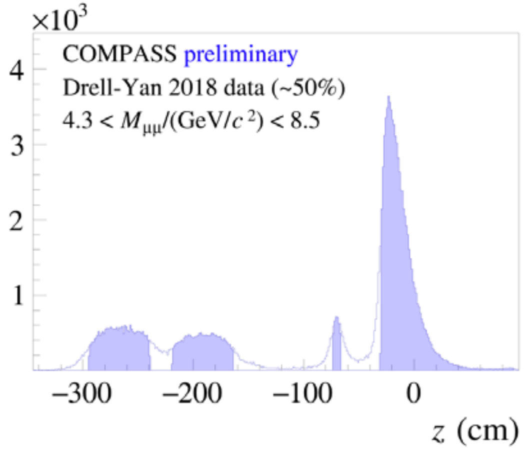
COmmon Muon Proton Apparatus for Structure and Spectroscopy

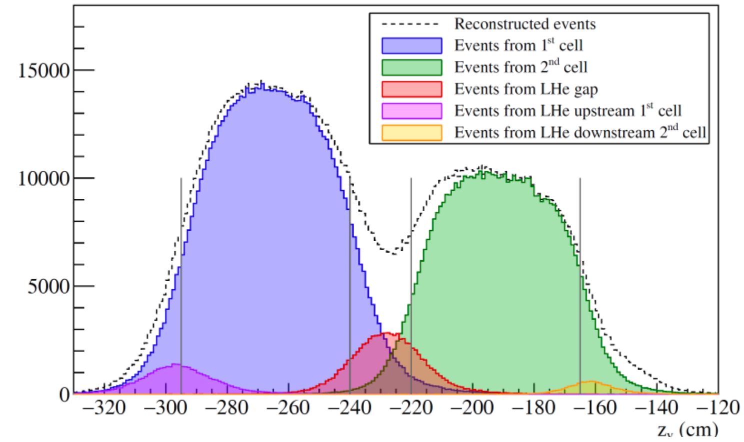


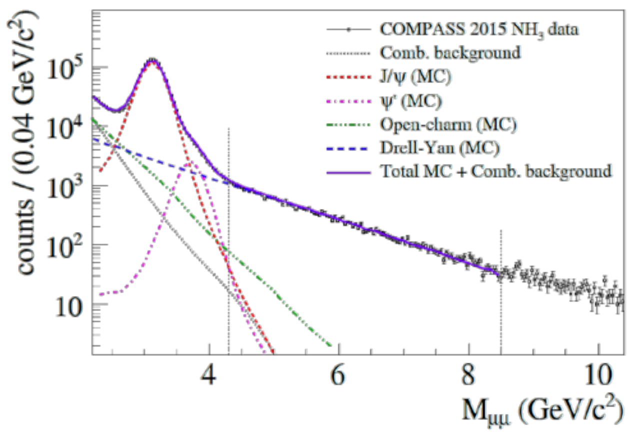


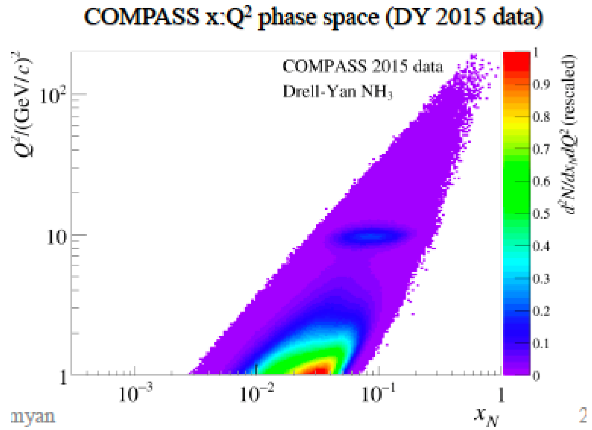
DY@COMPASS 2015 and 2018 Run

- First ever polarised Drell-Yan experiment was successfully performed in 2015 at COMPASS



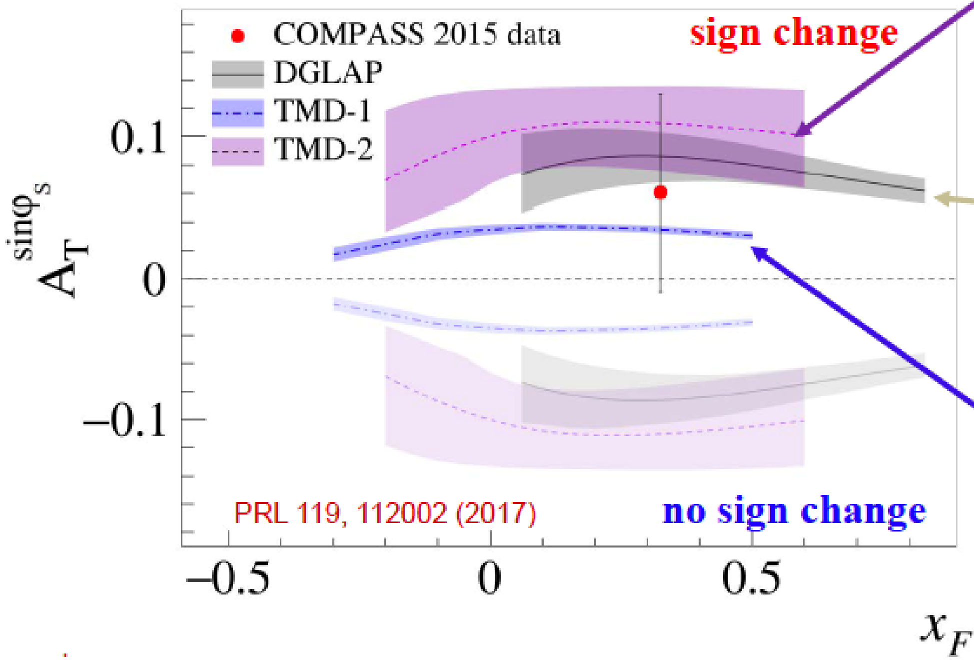






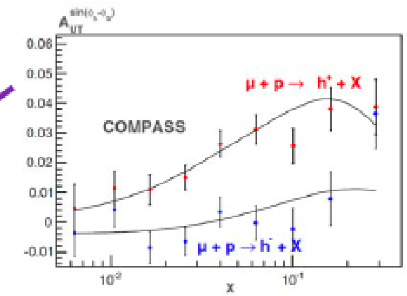
DY@COMPASS 2015 Run

- COMPASS: 190 GeV π^- beam on transverse polarized H target (NH_3)
  - ➡ 2015 data (4 months)
  - ➡ Transverse target polarization ~80%
  - ➡ **consistent w/ sign change!**

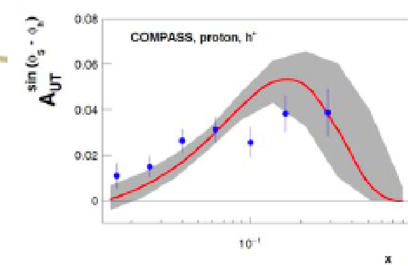


$$A_T^{\sin\varphi_s} = 0.060 \pm 0.057(stat.) \pm 0.040(sys.)$$

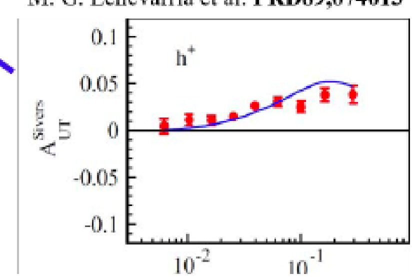
TMD-2 (2013)
P. Sun, F. Yuan, **PRD88, 114012**



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



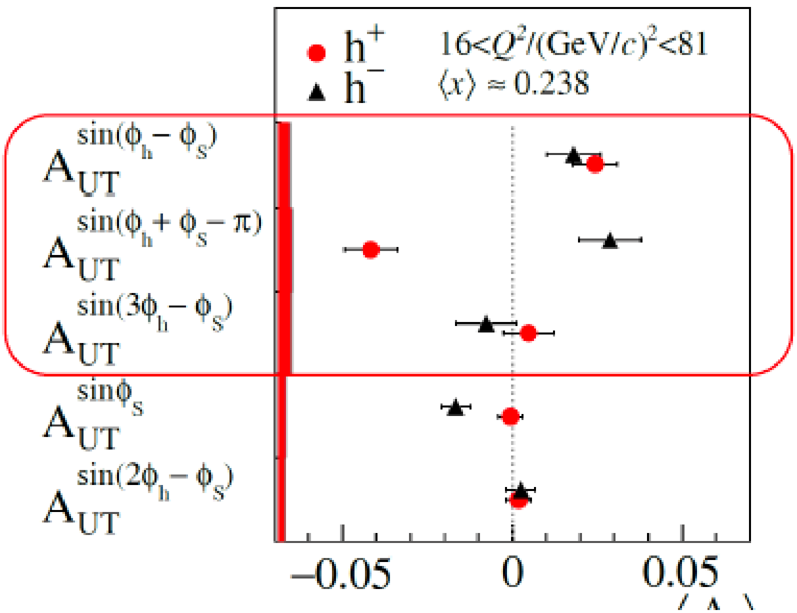
TMD-1 (2014)
M. G. Echevarria et al. **PRD89,074013**



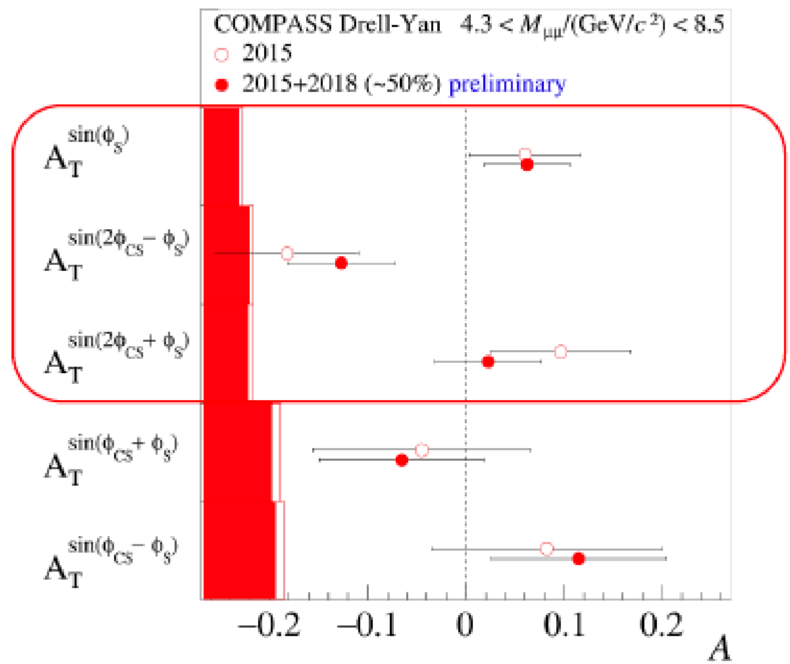
Ref: W.C. Chang (Academia Sinica) & J-C Peng (UIUC)

DY@COMPASS 2015/2018 Run

COMPASS PLB 770 (2017) 138



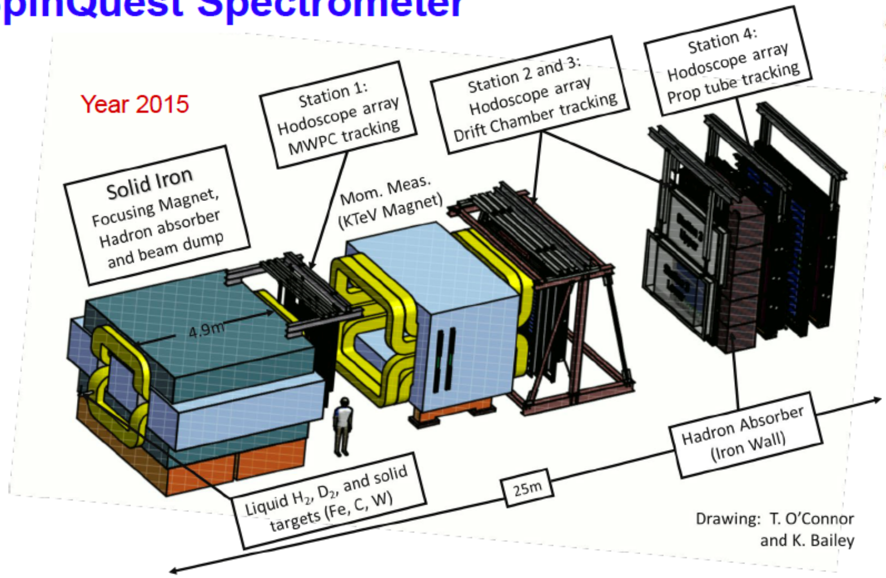
COMPASS 2015 + 2018 (~50%)



COMPASS-II preliminary
2015 + 50% 2018 results

Drell-Yan prospectives: (spin crisis) SpinQuest (FermiLab) I

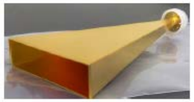
SpinQuest Spectrometer

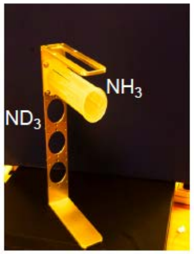


120 GeV protons from the Main Injector

- 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

- field: 5T @ 1K
- targets: NH_3 and ND_3
- 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





Ref: Andi Klein (LANL)

Unpolarized Beam and polarized Target (w/ upgraded SeaQuest detector)

- **E-1039/SpinQuest**: SeaQuest w/ pol NH_3/ND_3 targets: 2019-2021
  - ➞ probe sea quark distributions

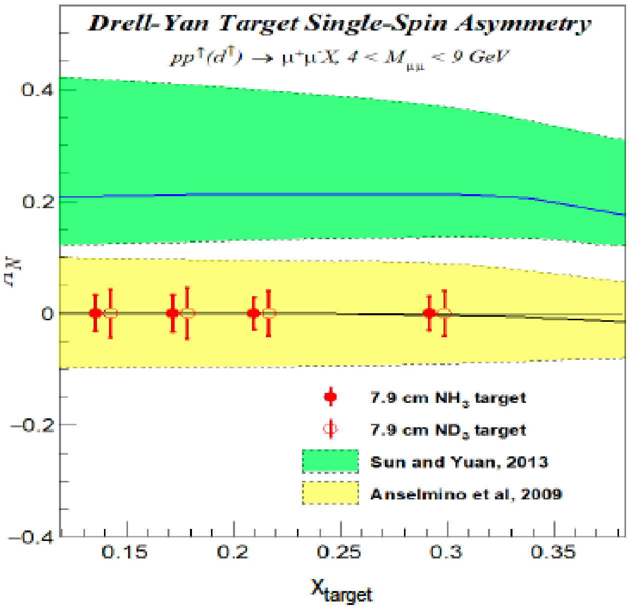
Polarized Beam and polarized Target

→ 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

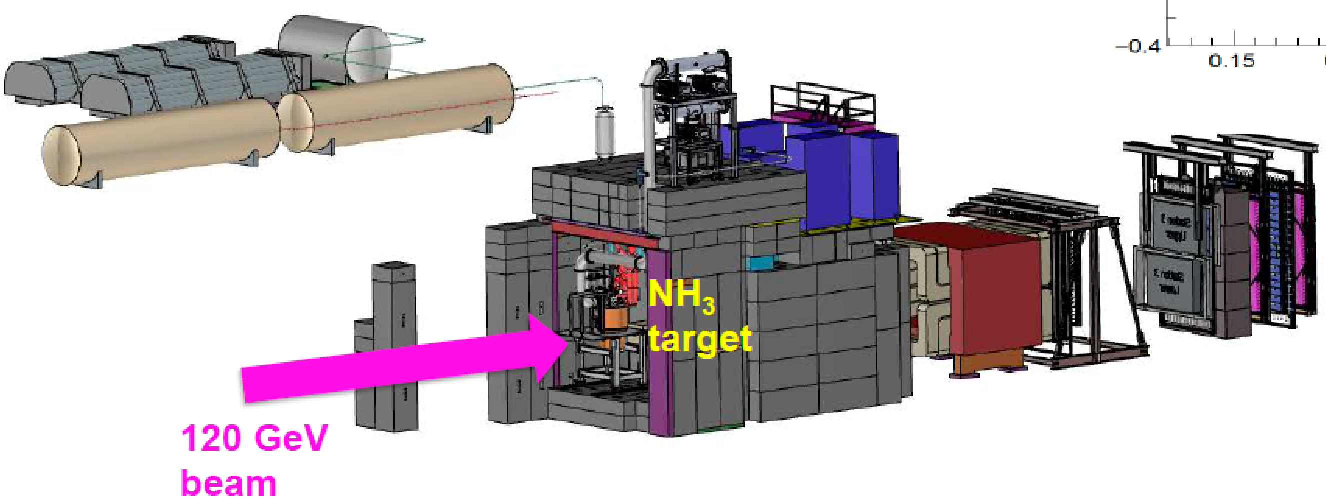
Drell-Yan prospectives: (spin crisis) SpinQuest (FermiLab) II

E1039 proposal



- 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+



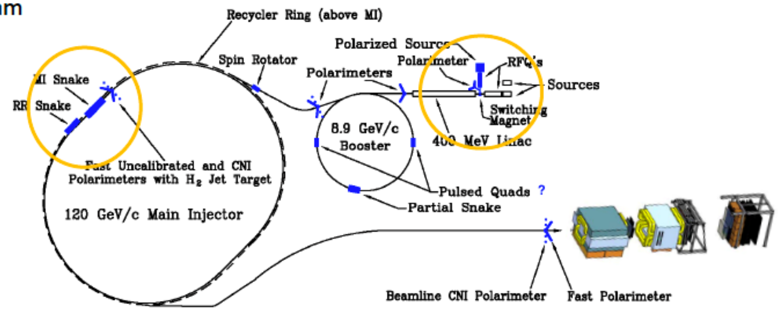
Ref: M. Liu (LANL)

Drell-Yan prospectives: (spin crisis) SpinQuest (FermiLab) III

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

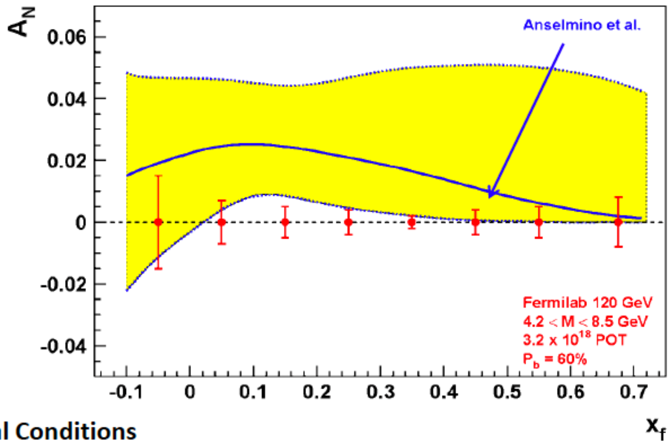
The Plan:

- 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



1.3 Mio DY events with no dilution

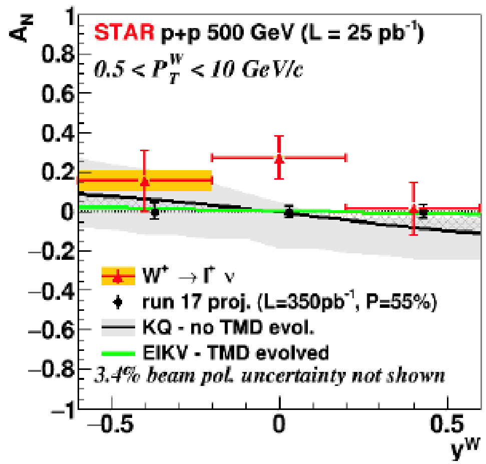
- **Experimental Conditions**
  - same as SeaQuest
  - luminosity: L_{av} = 2 x 10^{35} (10% of available beam time: I_{av} = 15 nA)

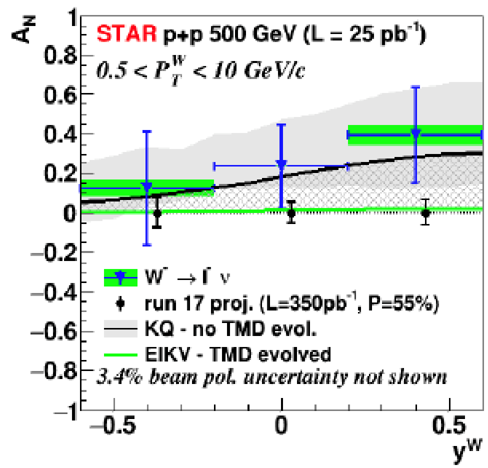
Drell-Yan prospectives: (spin/mass crisis) STAR (RHIC) I

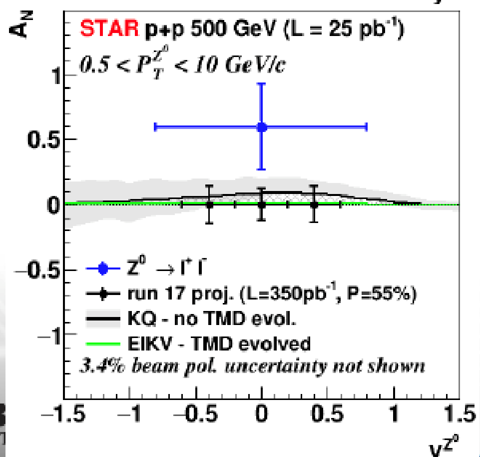
Expected uncertainties from 2017 Transverse Run (500 GeV)

Collected:

350 pb^{-1} → 14 times Run-11 for -1 < η < 1.8 → A_N $W^{+/-}$ & Z^0, Collins, ...







Will provide data to constrain

→ TMD evolution,

→ sea-quark Sivers fct

→ through rapidity distribution → neg. η

→ test of Sivers fct. non-universality

→ Z^0 very clean channel no corrections

NT-2017 The Flavor Structure of Nucleon Sea 6 ENER

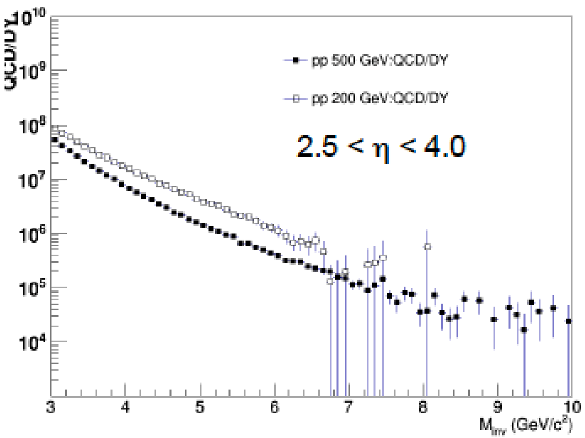
Drell-Yan prospectives: (spin crisis) STAR (RHIC) II

STAR Forward Detector upgrade & DY

DY@STAR FOR 500 GeV

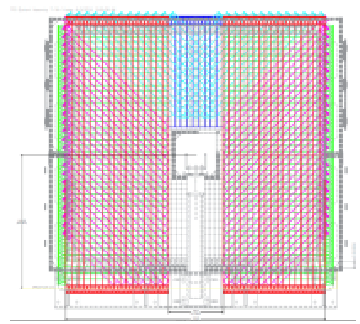
Kinematics:

DY e+e- in $2.5 < \eta < 4.0$ $4.0\ GeV < M_{e+e-} < 9.0\ GeV$



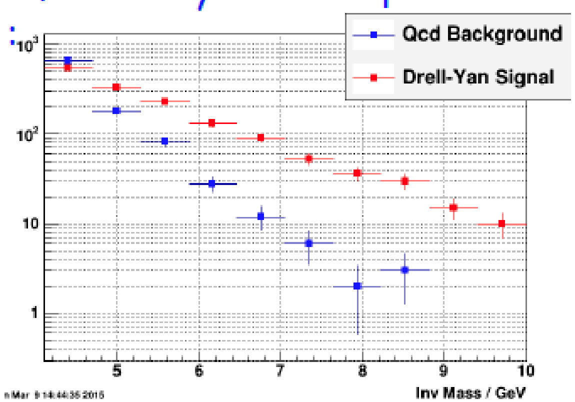
Add a postshower to the preshower & the FMS

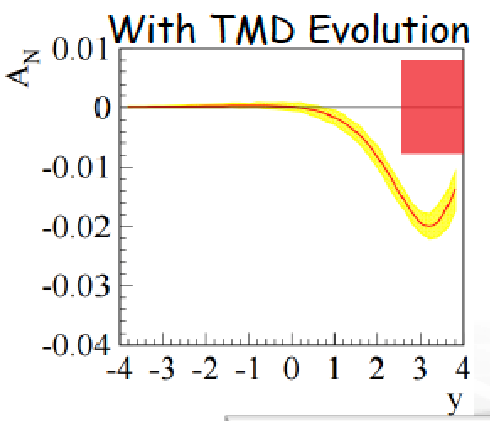
will be able to measure A_N DY

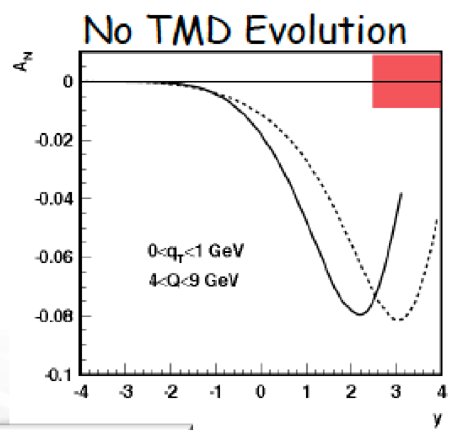


Design follows successful Preshower design
→ 3 layers of u, x, y with SiPM readout

After analysis $2.5 < \eta < 4.0$







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

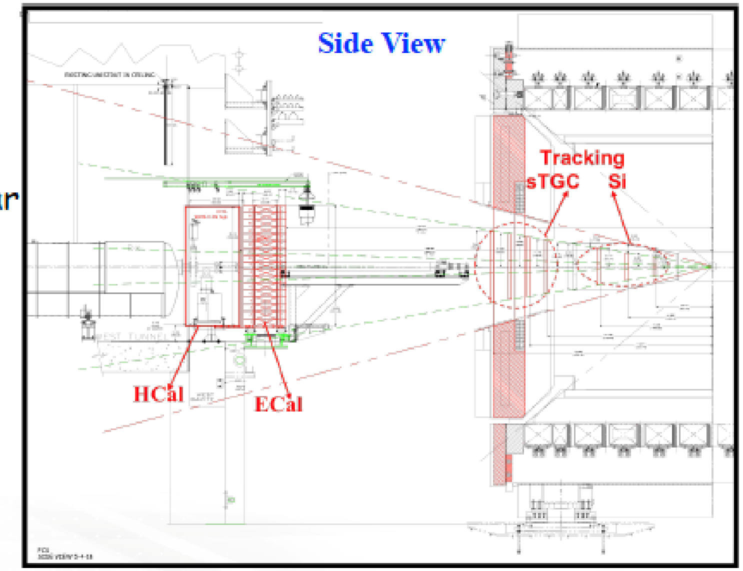
- the mission of the RHIC physics program in cold and hot QCD
- fully realize the scientific promise of the EIC
  - lay the groundwork for the EIC, both scientifically and by refining exp. requirements
  - Test EIC detector technologies under real conditions, i.e SiPMs

Scientific goals:

p+p:
3-dim. characterization of the proton in momentum and spatial coordinates

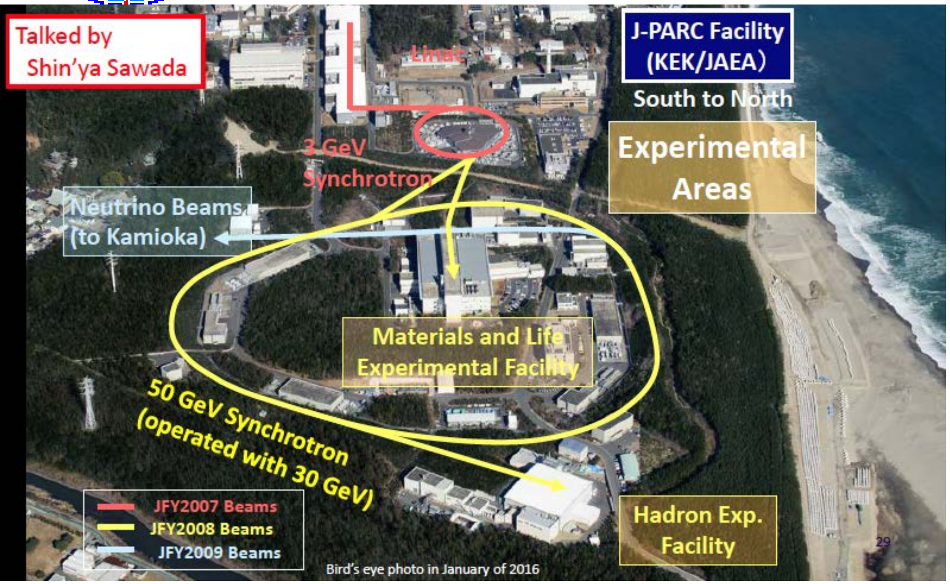
p+A
Nature of initial state and hadronization in nuclear collisions
Onset and A-dependence of saturation

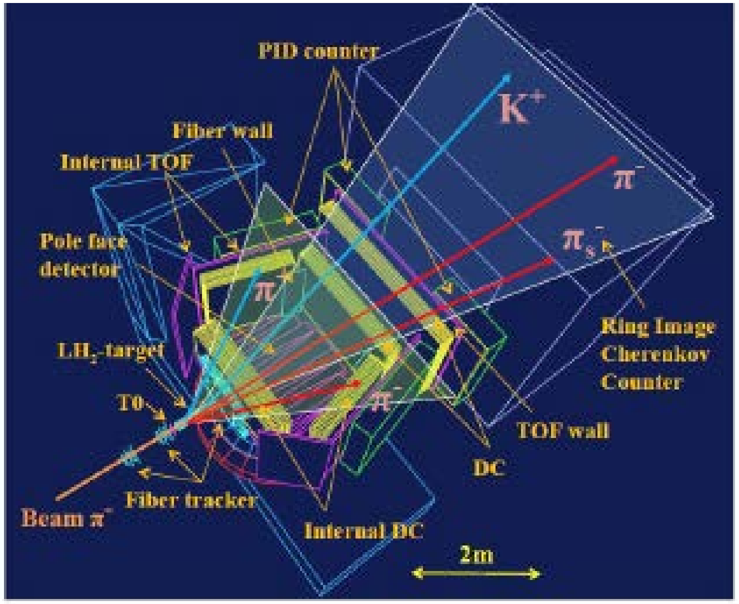
A+A
Longitudinal medium characterization
Precision flow measurements via long range correlations



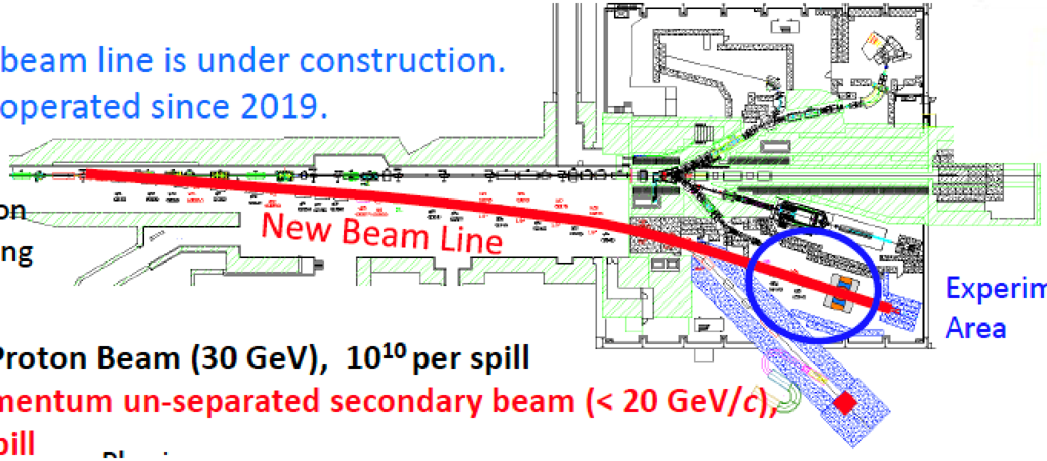
Upgrade includes:
Forward Calorimeter System: EM and Hadronic
Forward Tracking System: Si + sTGCs

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





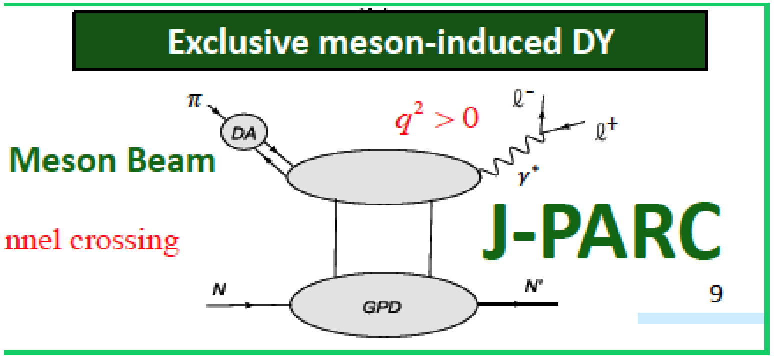
The new beam line is under construction.
It will be operated since 2019.



Stage-1 approved by J-PARC PAC-18, August 12, 2014.

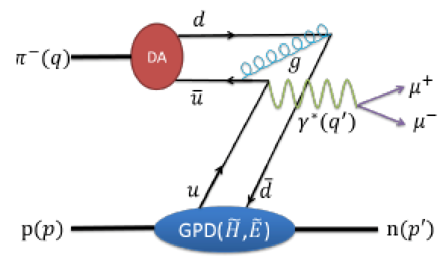
- **Primary Proton Beam (30 GeV), 10^{10} per spill**
- **High Momentum un-separated secondary beam (< 20 GeV/c), 10^8 per spill**

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



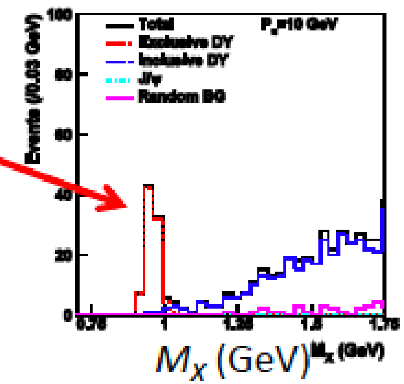
Exclusive pion-induced DY

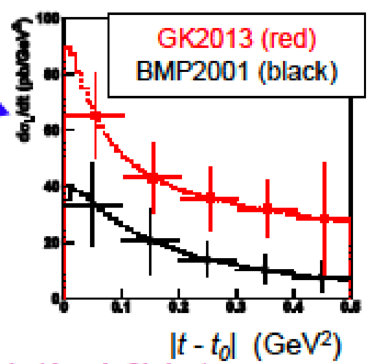
$\pi N \to \gamma^* N'$



- E50 experiment (Stage-1 approved by J-PARC) + μ-ID extension
  - ➡ **10-20 GeV π^-** beam on high momentum beam line at J-PARC
  - ➡ good missing mass resolution in exclusive DY events $(\pi^- p \to \mu^+ \mu^- n)$
  - ➡ Statistical accuracy adequate for discriminating between predictions from two current GPD models.

P_π = 10 GeV



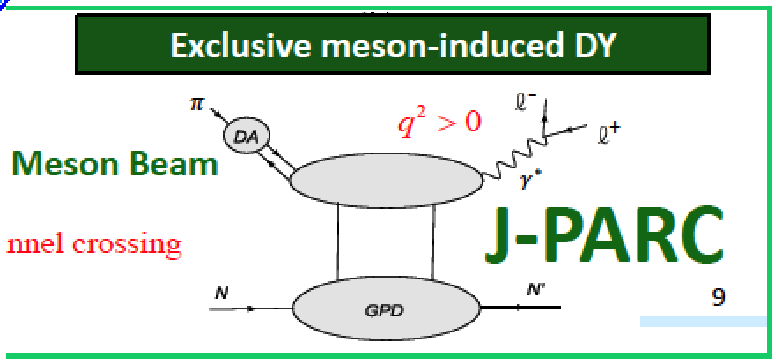


GK2013: P. Kroll et al. Eur.Phys.J.C73, 2278 (2013)

BMP2001: E.R. Berger et al. Phys.Lett.B523, 265 (2001)

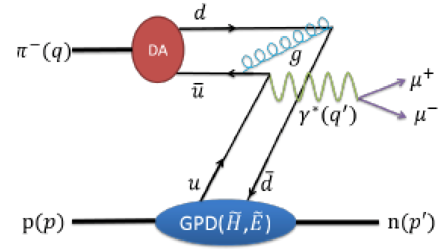
Ref: T. Sawada (Acad. Sinica)

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



Exclusive pion-induced DY

$\pi\, N \to \gamma^* N'$



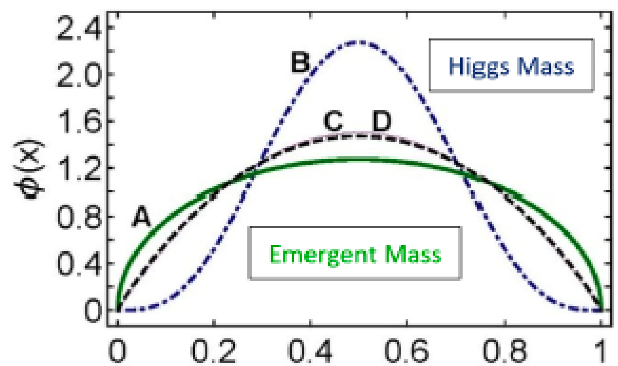


FIG. 3: Left Panel. Twist-two parton distribution amplitudes at a resolving scale $\zeta = 2\,\mathrm{GeV} =: \zeta_2$. **A** solid (green) curve – pion ⇐ emergent mass generation is dominant; **B** dot-dashed (blue) curve – η_c meson ⇐ Higgs mechanism is the primary source of mass generation; **C** 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 ⇐ 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

[hep-ex] 25 Jan 2019

Letter of Intent:

A New QCD facility at the M2 beam line of the CERN SPS*

COMPASS++†/AMBER‡

B. Adams[13,12], C.A. Aidala[1], R. Akhunzyanov[14], G.D. Alexeev[14], M.G. Alexeev[41], A. Amoroso[41,42],

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

Program	Physics Goals	Beam Energy [GeV]	Beam Intensity [s^{-1}]	Trigger Rate [kHz]	Beam Type	Target	Earliest start time, duration	Hardware additions
muon-proton elastic scattering	Precision proton-radius measurement	100	$4 \cdot 10^6$	100	$\mu^\pm$	high-pressure H2	2022 1 year	active TPC, SciFi trigger, silicon veto,
Hard exclusive reactions	GPD E	160	$2 \cdot 10^7$	10	$\mu^\pm$	$NH_3^\uparrow$	2022 2 years	recoil silicon, modified polarised target magnet
Input for Dark Matter Search	$\overline{p}$ production cross section	20-280	$5 \cdot 10^5$	25	p	LH2, LHe	2022 1 month	liquid helium target
$\overline{p}$-induced spectroscopy	Heavy quark exotics	12, 20	$5 \cdot 10^7$	25	$\overline{p}$	LH2	2022 2 years	target spectrometer: tracking, calorimetry
Drell-Yan	Pion PDFs	190	$7 \cdot 10^7$	25	$\pi^\pm$	C/W	2022 1-2 years	
Drell-Yan (RF)	Kaon PDFs & Nucleon TMDs	~100	10^8	25-50	$K^\pm, \overline{p}$	$NH_3^\uparrow$, C/W	2026 2-3 years	"active absorber", vertex detector
Primakoff (RF)	Kaon polarisa-bility & pion life time	~100	$5 \cdot 10^6$	> 10	K^-	Ni	non-exclusive 2026 1 year	
Prompt Photons (RF)	Meson gluon PDFs	≥ 100	$5 \cdot 10^6$	10-100	$K^\pm$ $\pi^\pm$	LH2, Ni	non-exclusive 2026 1-2 years	hodoscope
K-induced Spectroscopy (RF)	High-precision strange-meson spectrum	50-100	$5 \cdot 10^6$	25	K^-	LH2	2026 1 year	recoil TOF, forward PID
Vector mesons (RF)	Spin Density Matrix Elements	50-100	$5 \cdot 10^6$	10-100	$K^\pm, \pi^\pm$	from H to Pb	2026 1 year	

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

Shorter term 2021/22 ÷~ 2026/28 (N.B. 2019/20 and 2025/26 – LS2 and LS3) :

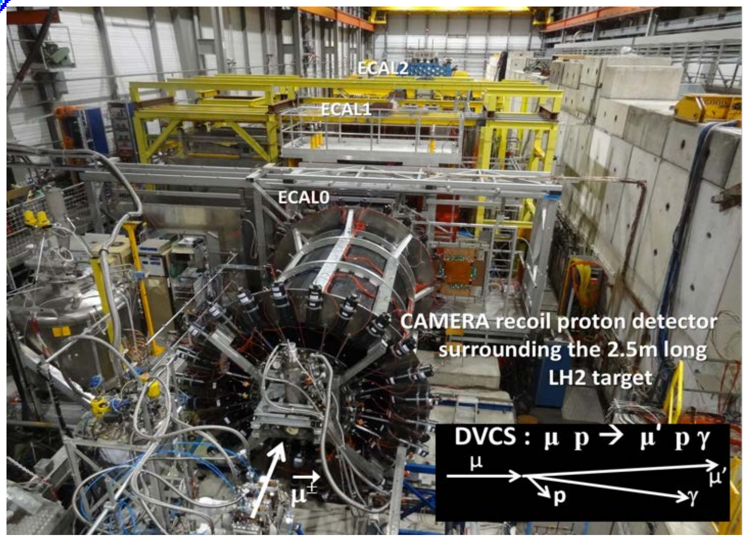
a.) Standard muon beam:
- 1. DVCS with trans. polarised proton target
- 2. Proton radius measurement in elastic muon proton scattering

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



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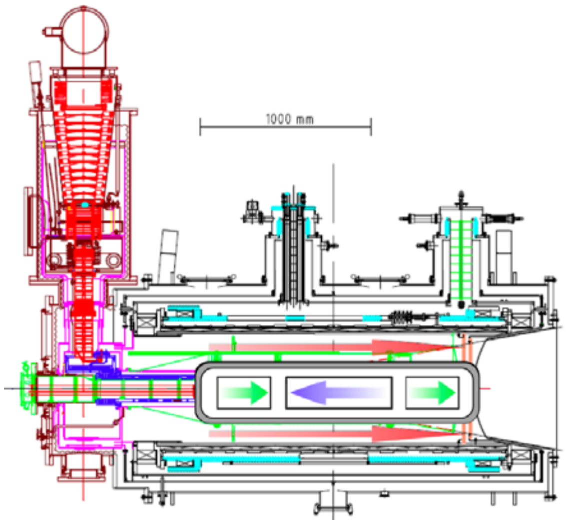


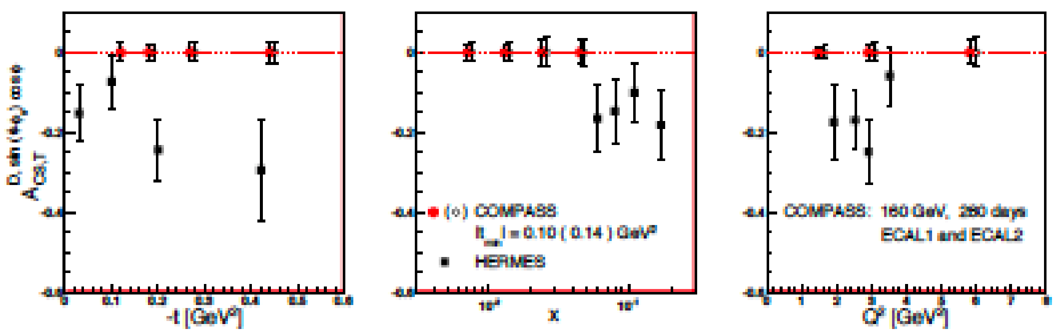


Figure 4: Expected statistical accuracy of $A_{CS,T}^{D,\sin(\phi-\phi_s)\cos\phi}$ as a function of $-t$, x_B and Q^2 from a 280 days measurement with the COMPASS spectrometer, using a 160 GeV muon beam and a transversely polarised NH_3 target. Solid and open circles correspond to a minimum accessible $|t_{min}|$ of 0.10 GeV^2 and 0.14 GeV^2, respectively. Also shown is the asymmetry $A_{U,T}^{\sin(\phi-\phi_s)\cos\phi}$ measured at HERMES [29] with its statistical errors. Figure from ref. [35].

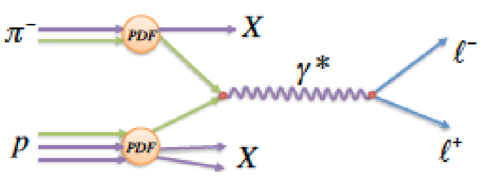
QCD Preamble (Mass crisis
Higgs-generated mass .vs. emergent mass)

Questions to be answered:

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

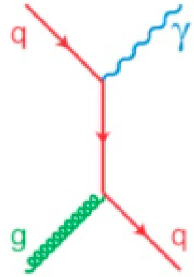
Methods:

Drell-Yan:



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

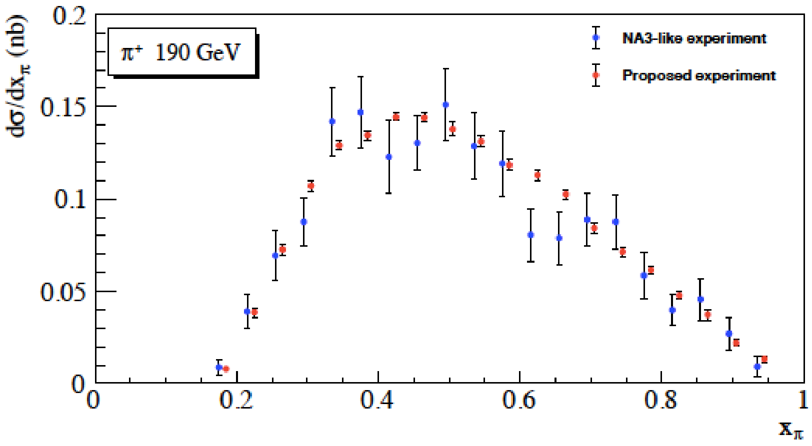
Prompt photon production:

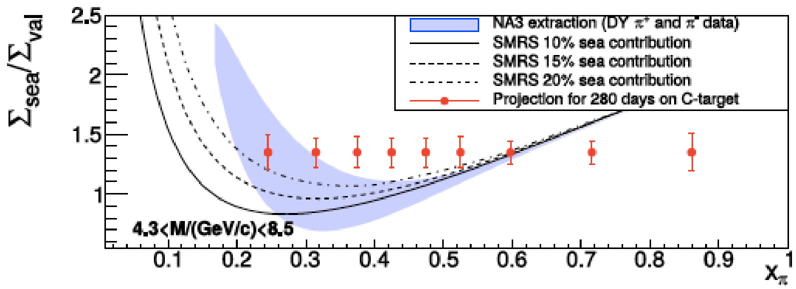


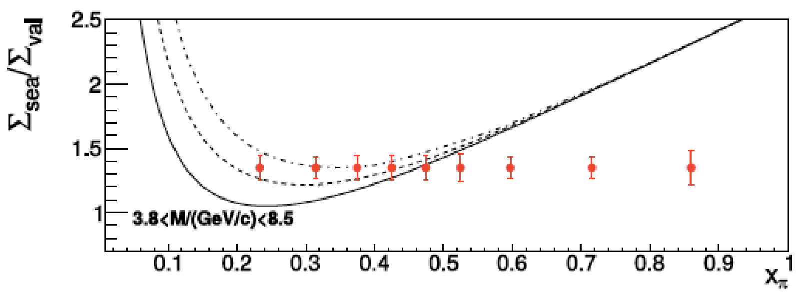
- 90's: NA24, W70
- 20's: COMPASS++

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

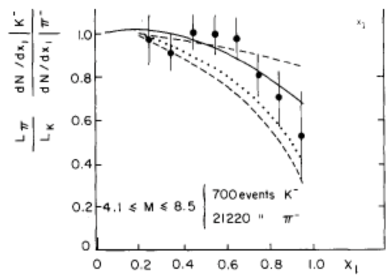
- $\Sigma_V = \sigma^{\pi^- C} - \sigma^{\pi^+ C}$: only valence-valence
- $\Sigma_S = 4\sigma^{\pi^+ C} - \sigma^{\pi^- C}$: no valence-valence
- Collect at least a **factor 10 more statistics** than presently available
- Minimize nuclear effects on target side
  - Projection for 2×140 days of Drell-Yan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

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

Sole measurement from NA3

J. Badier *et al.*, PLB93 354 (1984)

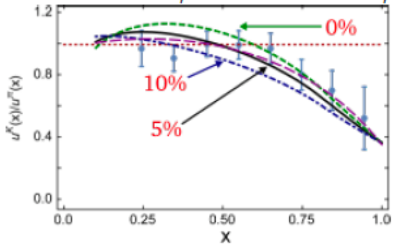
- Limited statistics: 700 events with K^-
- Sensitivity to $SU(3)_f$ breaking
- Mostly only model predictions

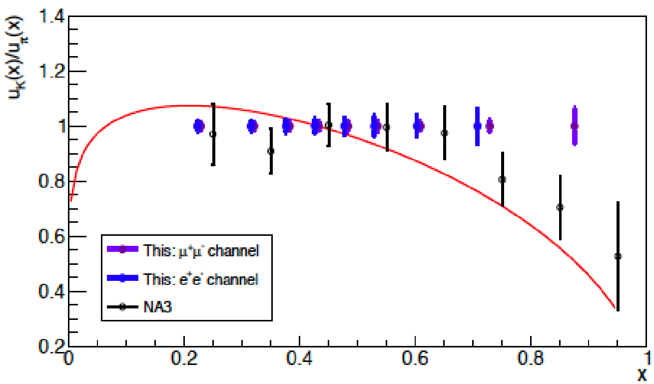


Interesting observation: At hadronic scale gluons carry only 5% of K's momentum *vs* $\sim$30% in π

- Scarce data on *u*-valence
- No measurements on gluons
- No measurements on sea quarks

C. Chen *et al.*, PRD 93 074021, 2016

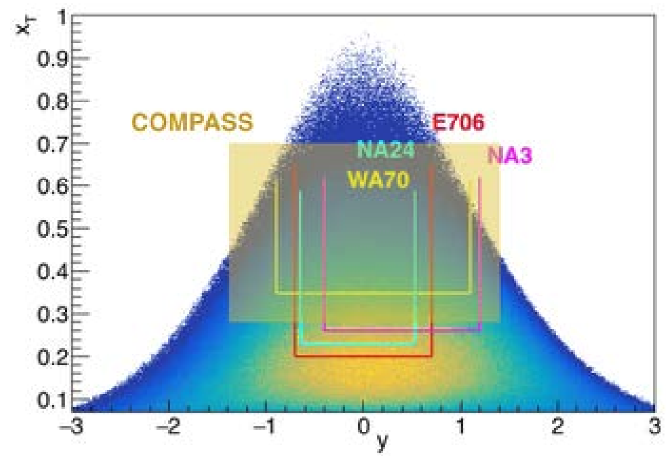




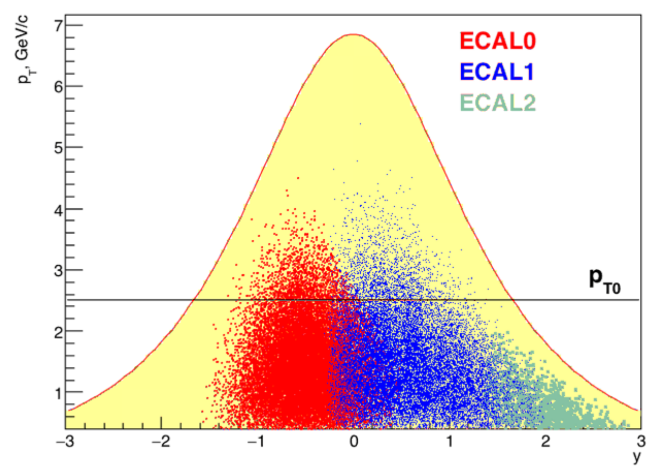
Drell-Yan prospectives: (mass crisis) COMPASS++/AMBER V

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)

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.



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 crisises 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!

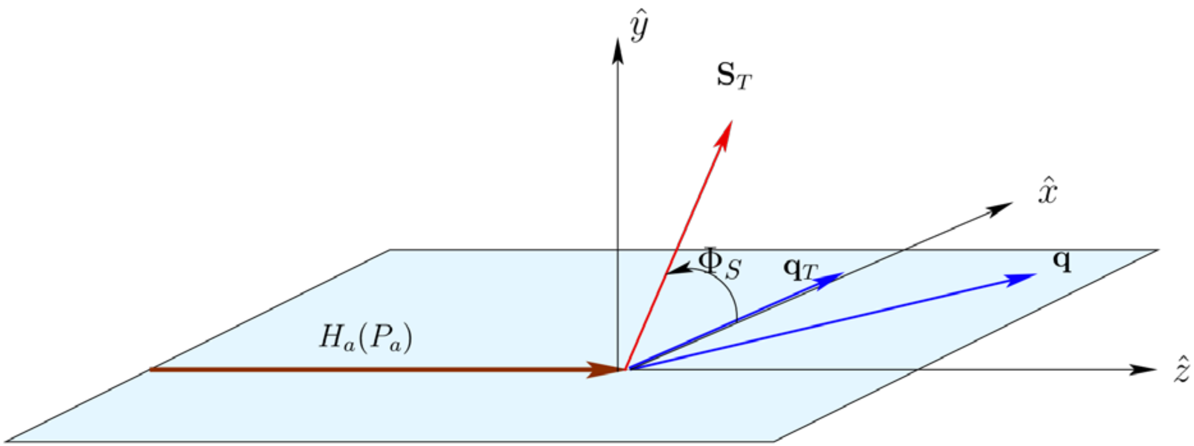
- Spares

Running/planed Drell-Yan experiments

Experiment	Particles	Energy (GeV)	x_b or x_t	Luminosity (cm^{-2} s^{-1})		P_b or P_t (f)	rFOM#	Timeline
COMPASS (CERN)	$\pi^{\pm} + p^{\uparrow}$	190 GeV $\sqrt{s} = 19$	$x_t = 0.1 – 0.3$	2×10^{32}	0.14	$P_t = 80\%$ f = 0.22	1.0×10^{-3}	2014-2015, 2018
PANDA (GSI)	pbar + $p^{\uparrow}$	15 GeV $\sqrt{s} = 5.5$	$x_t = 0.2 – 0.4$	2×10^{32}	0.07	$P_t = 90\%$ f = 0.22	1.1×10^{-4}	>2025
AFTER	$p^{\uparrow} + p$	7 TeV $\sqrt{s} = 120$	$x_b = 0.1 – 0.9$	2×10^{32}	0.06	$P_b =$ 100%?	2.3×10^{-5}	>2020
NICA (JINR)	$p^{\uparrow} + p$	collider $\sqrt{s} = 26$	$x_b = 0.1 – 0.8$	1×10^{32}	0.04	$P_b = 70\%$	6.8×10^{-5}	>2023
PHENIX/STAR (RHIC)	$p^{\uparrow} + p^{\uparrow}$	collider $\sqrt{s} = 510$	$x_b = 0.05 – 0.1$	2×10^{32}	0.08	$P_b = 60\%$	1.0×10^{-3}	>2018
sPHENIX (RHIC)	$p^{\uparrow} + p^{\uparrow}$	$\sqrt{s} = 200$ $\sqrt{s} = 510$	$x_b = 0.1 – 0.5$ $x_b = 0.05 – 0.6$	8×10^{31} 6×10^{32}	0.08	$P_b = 60\%$ $P_b = 50\%$	4.0×10^{-4} 2.1×10^{-3}	>2021
SeaQuest (FNAL: E-906)	p + p	120 GeV $\sqrt{s} = 15$	$x_b = 0.35 – 0.9$ $x_t = 0.1 – 0.45$	3.4×10^{35}	---	---	---	2012 - 2017
Pol tgt DY‡ (FNAL: E-1039)	$p + p^{\uparrow}$	120 GeV $\sqrt{s} = 15$	$x_t = 0.1 – 0.45$	4.4×10^{35}	0 – 0.2*	$P_t = 85\%$ f = 0.176	0.15	2018-2019
Pol beam DY § (FNAL: E-1027)	$p^{\uparrow} + p$	120 GeV $\sqrt{s} = 15$	$x_b = 0.35 – 0.9$	2×10^{35}	0.04	$P_b = 60\%$	1	2020

‡ 8 cm NH_3 target / § L= 1×10^{36} cm^{-2} s^{-1} (LH_2 tgt limited) / L= 2×10^{35} cm^{-2} s^{-1} (10% of MI beam limited)

Coordinate systems



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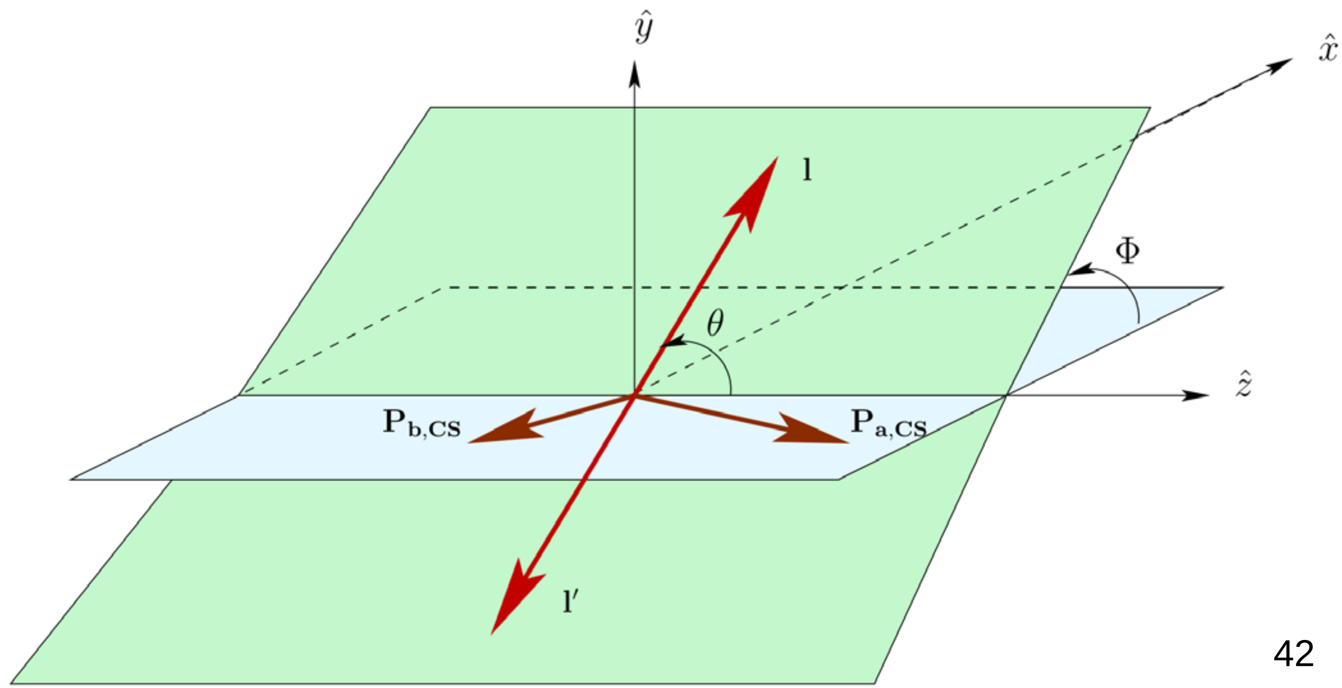

Collins-Soper