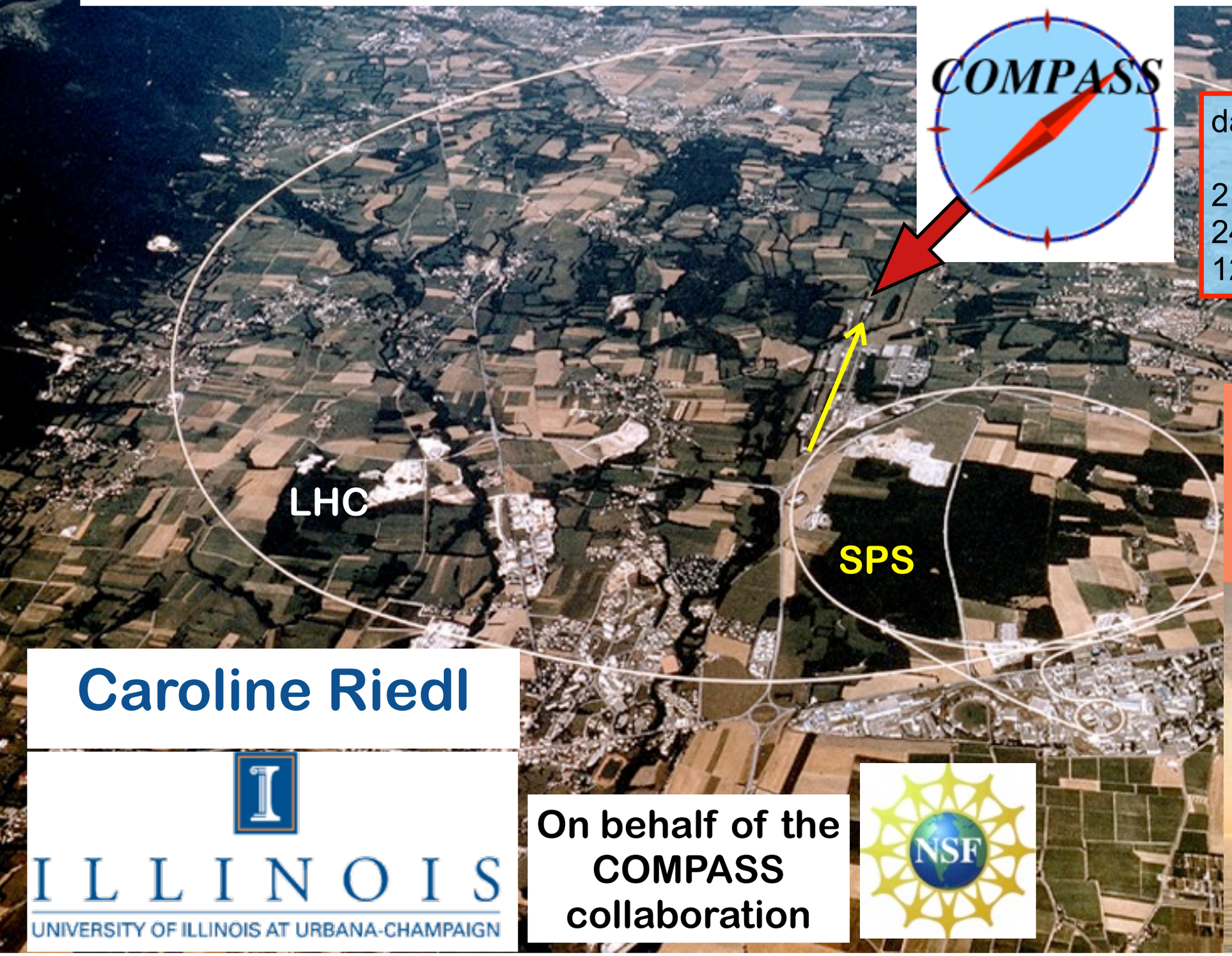
Spin-dependent pion-induced Drell-Yan measurement at



COMPASS

data taking since 2002

218 physicists from
24 institutions and
12 countries + CERN

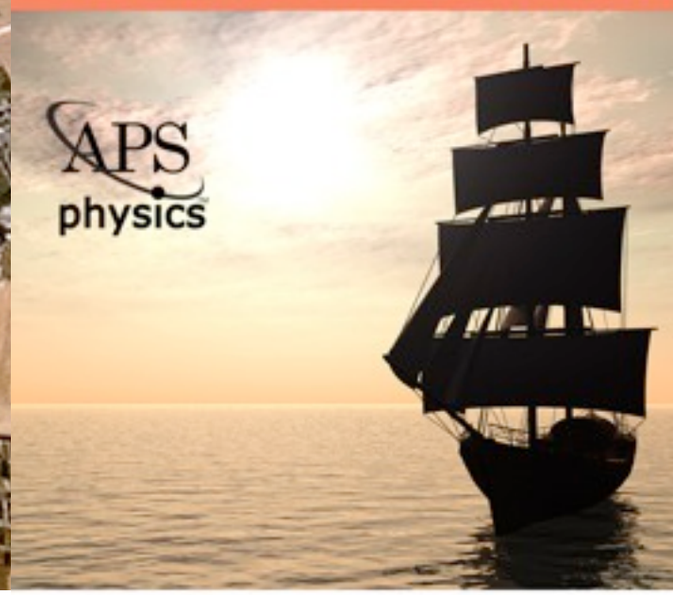
Caroline Riedl

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

On behalf of the COMPASS collaboration

NSF

DNP2013
OCTOBER 23-26 NEWPORT NEWS, VA



COMPASS-II

COMPASS @ CERN
COmmon Muon and Proton Apparatus
for Structure and Spectroscopy

Beams

400 GeV SPS protons onto conversion target
⇒ mesons with intensity up to 10^8 particles/s

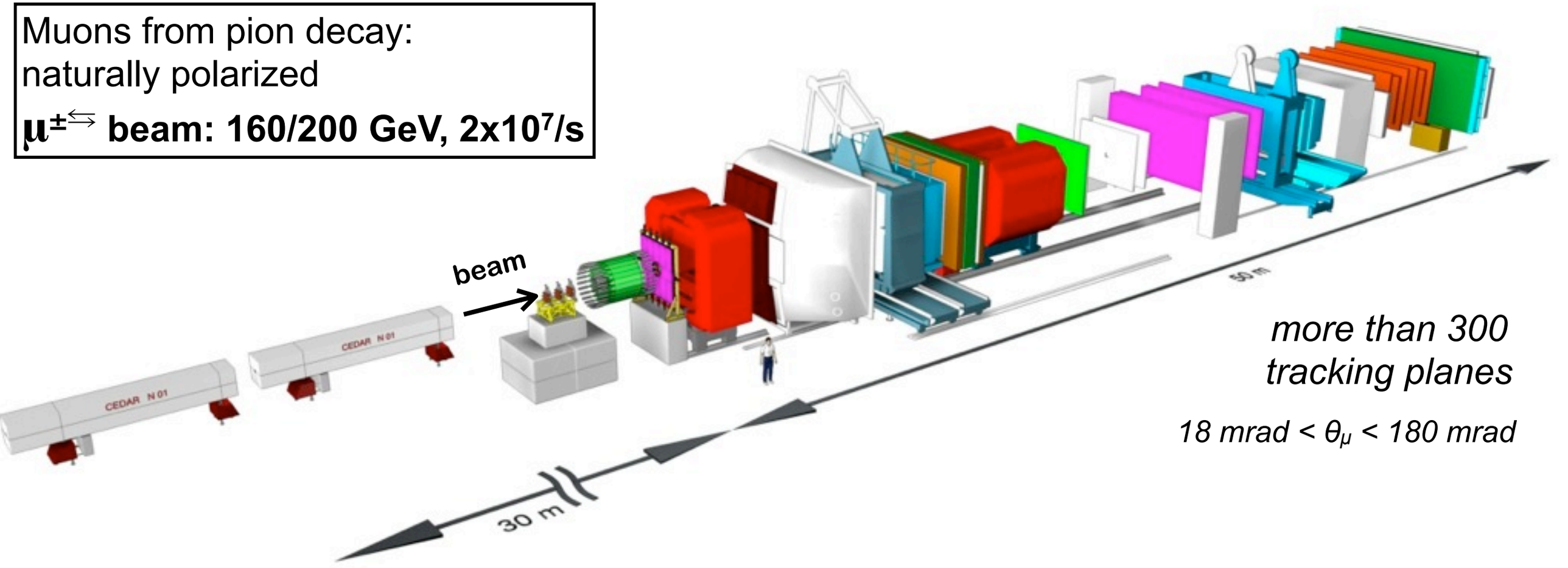
h^- beam: 190 GeV, π/K/p 97/2/1%

Muons from pion decay:
naturally polarized

$\mu^{\pm\leftrightarrows}$ beam: 160/200 GeV, 2×10^7/s

TMD run (Drell-Yan): 2015
on transversely polarized NH_3 target
commissioning run end of 2014

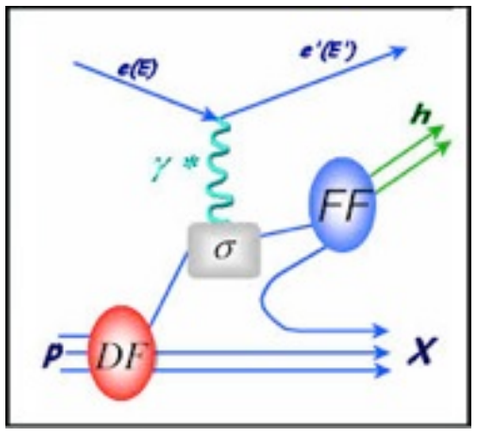
GPD run (with SIDIS): 2016/17
on unpolarized liquid hydrogen target



more than 300 tracking planes

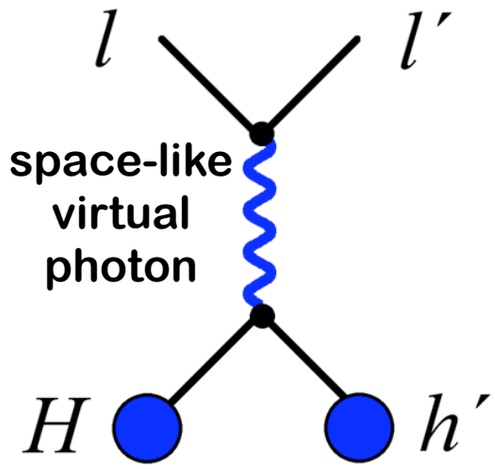
18 mrad < θ_μ < 180 mrad

Probing the partonic structure of hadrons



(SI)DIS

$DF \otimes FF$

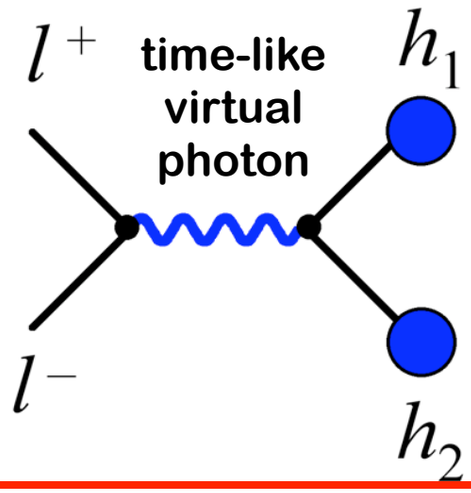


Probe universality

Assumption: factorization applies
Caveat: might break down @high-x

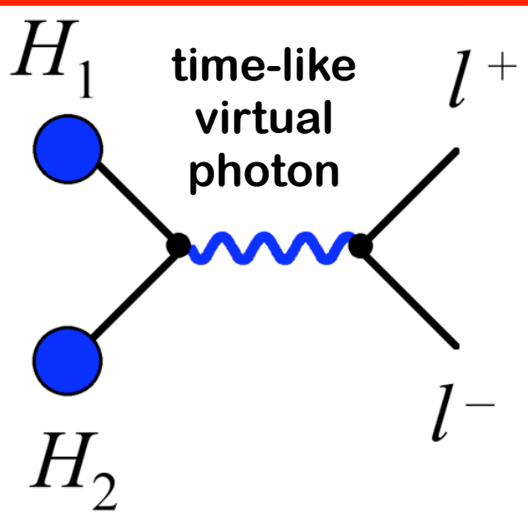
electron-positron annihilation

$FF \otimes FF$



Drell-Yan (DY)

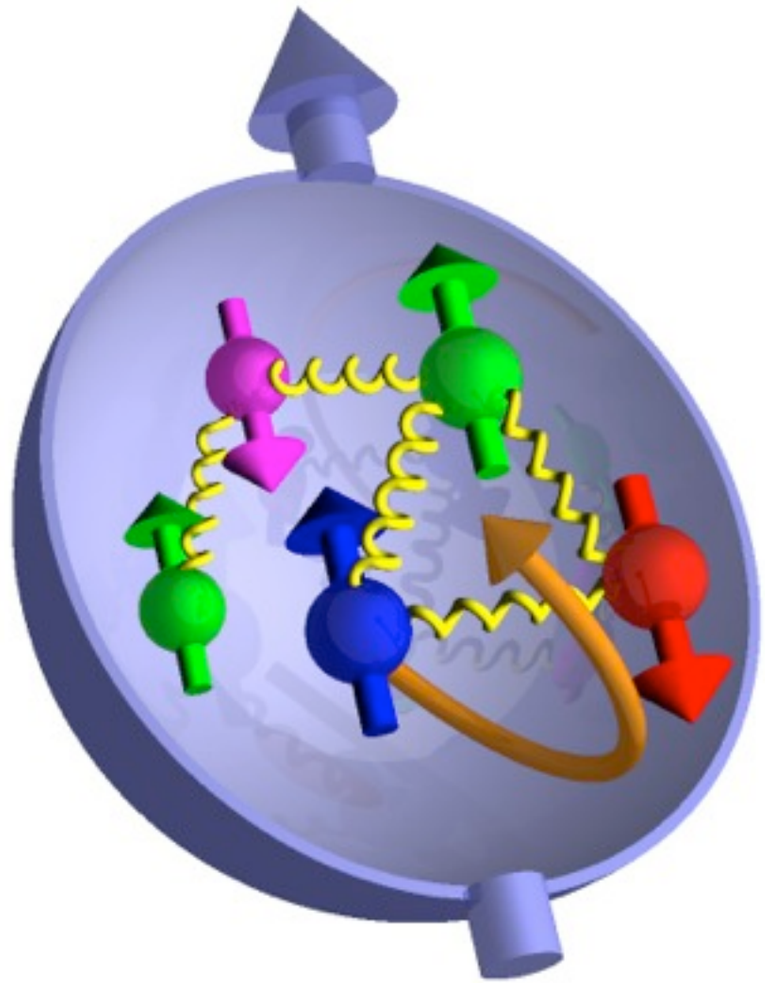
$DF \otimes DF$



time

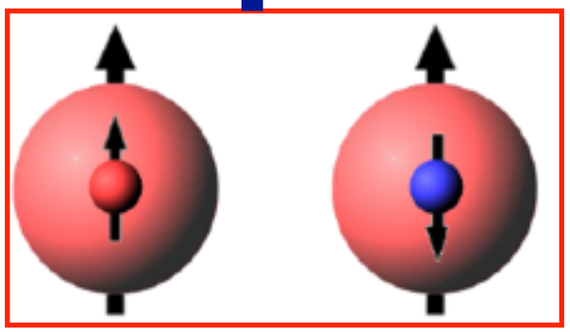
TMDs: Transverse-Momentum dependent PDFs

GPDs: Generalized Parton Distributions

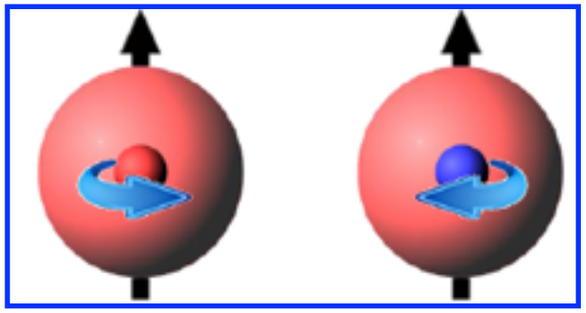


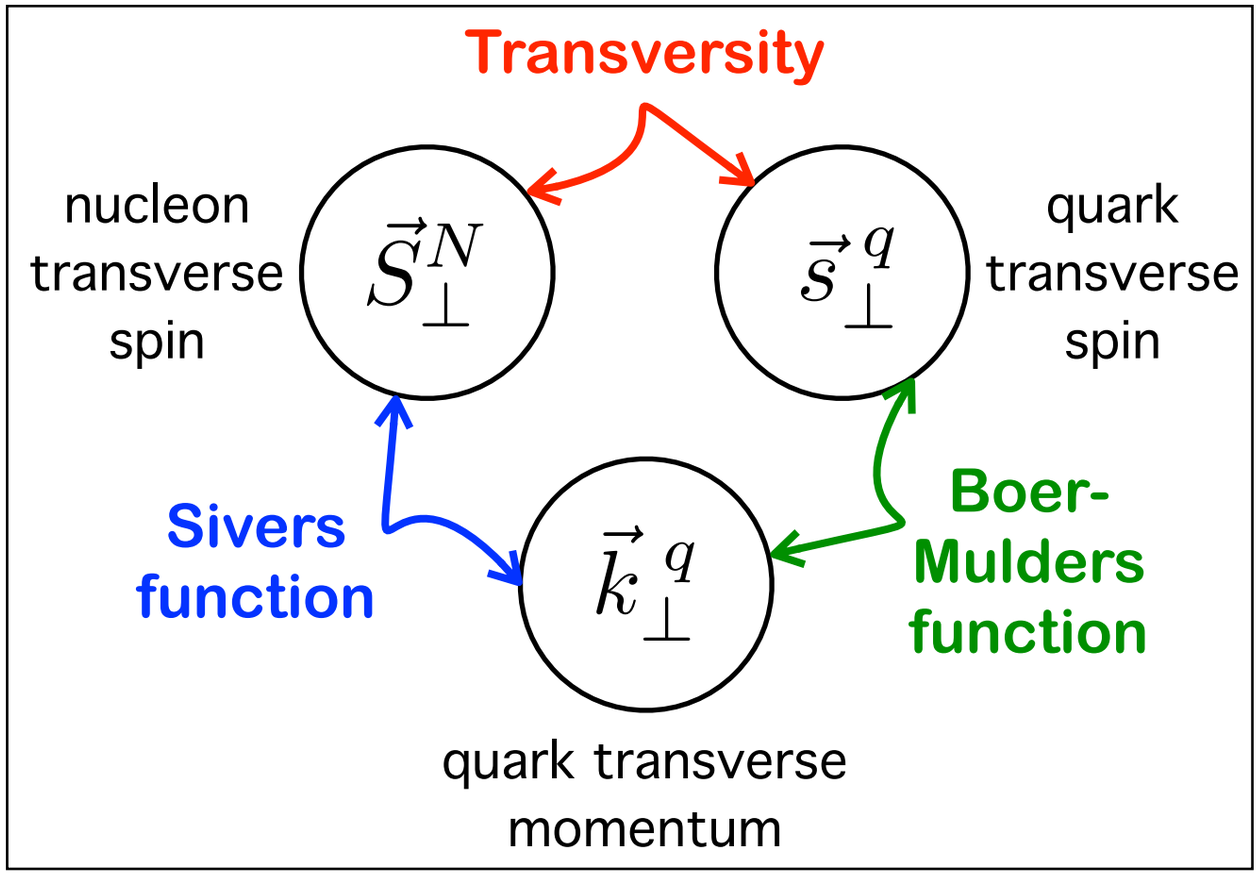
TMDs in spin-dependent Drell-Yan

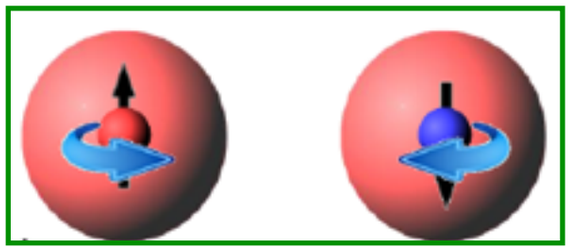
TMDs: Transverse-Momentum dependent PDFs



The missing spin program







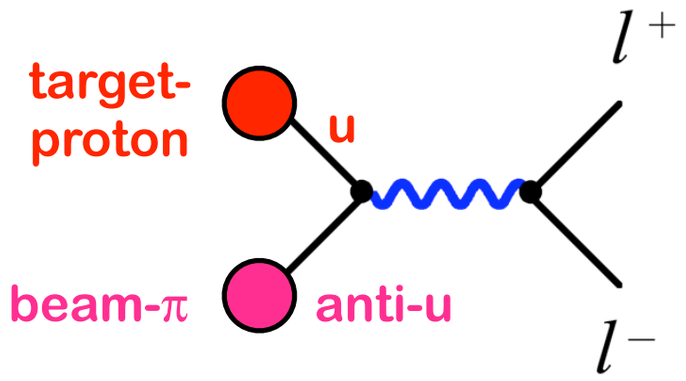
- Are Sivers and Boer-Mulders **universal**?
  - Expect **sign switch** of these naïve time-reversal-odd TMDs in DY wrt SIDIS: fundamental QCD prediction due to gauge invariance

- Experimental verification: crucial test of non-perturbative QCD and TMD physics
  - Origin of large Single Spin Asymmetries $p^{\uparrow}p \rightarrow \pi X$ at FNAL and BNL?
  - Validity of QCD factorization?

Angular dependence of Drell-Yan cross section

Drell-Yan $\boxed{\mathrm{DF} \otimes \mathrm{DF}}$

$$\sigma^{\mathrm{DY}} \propto f_{\overline{u}|\pi} \otimes f_{u|p}$$



dominated by u-ubar annihilation

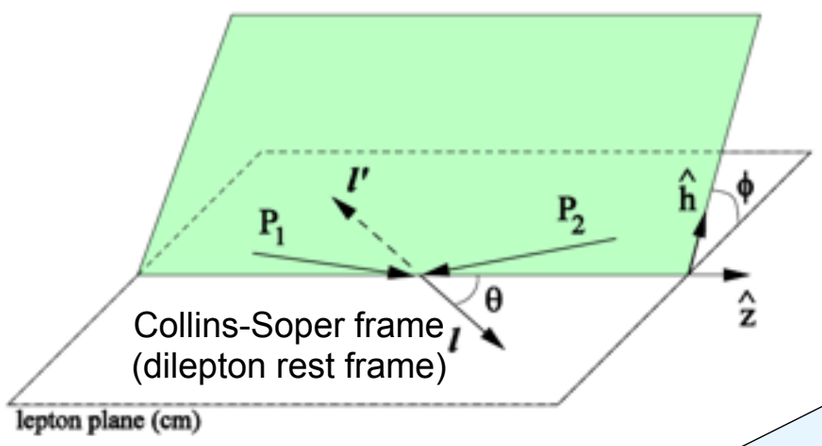
Spin-integrated cross section:

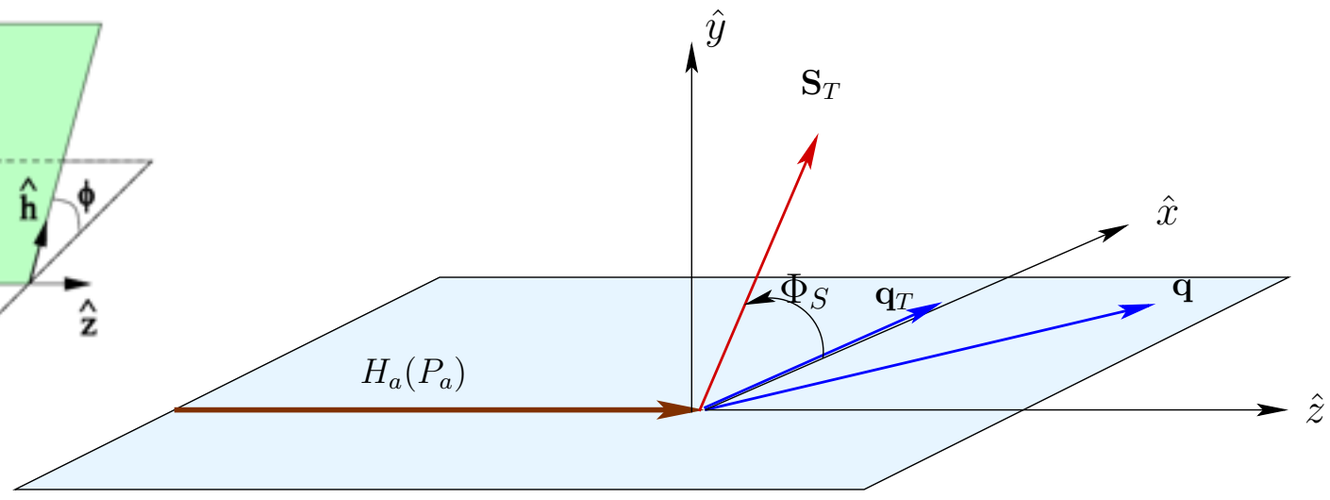
"Naive Drell-Yan" in collinear (k_T=0) qqbar annihilation $\quad \dfrac{d\sigma}{d\Omega} \propto 1 + \cos^2\theta$

+ k_T + higher O(α_S): $\quad \dfrac{d\sigma}{d\Omega} \propto 1 + \lambda\cos^2\theta + \mu\sin(2\theta)\cos\phi + \dfrac{\nu}{2}\sin^2\theta\cos(2\phi)$

$1 - \lambda = 2\nu$ Lam-Tung relation

Boer-Mulders (BM) modulation



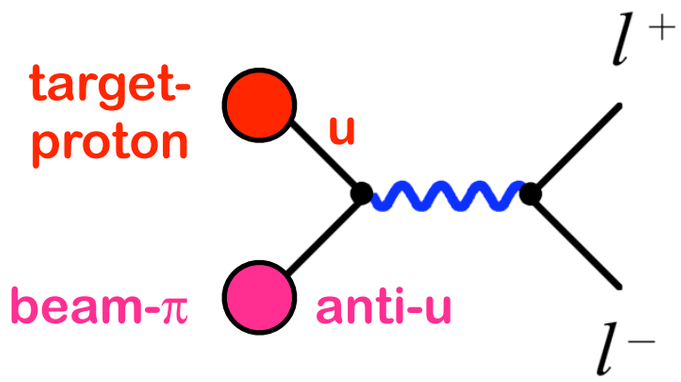


Measure magnitude of azimuthal modulations in cross section: **"Single-Spin Asymmetries" SSA**

Angular dependence of Drell-Yan cross section

Drell-Yan $\boxed{\mathrm{DF} \otimes \mathrm{DF}}$

$$\sigma^{\mathrm{DY}} \propto f_{\overline{u}|\pi} \otimes f_{u|p}$$



dominated by u-ubar annihilation

$$\mathrm{d}\sigma(\pi^- p^\uparrow \to \mu^+\mu^- X) = 1 + \boxed{\overline{h}_1^\perp} \otimes \boxed{h_1^\perp} \cos(2\phi)$$

$$+ |S_T| \Big[\boxed{\overline{f}_1} \otimes \boxed{\overline{f}_{1T}^\perp} \sin\phi_S$$

$$+ \boxed{\overline{h}_1^\perp} \otimes \boxed{h_{1T}^\perp} \sin(2\phi + \phi_S)$$

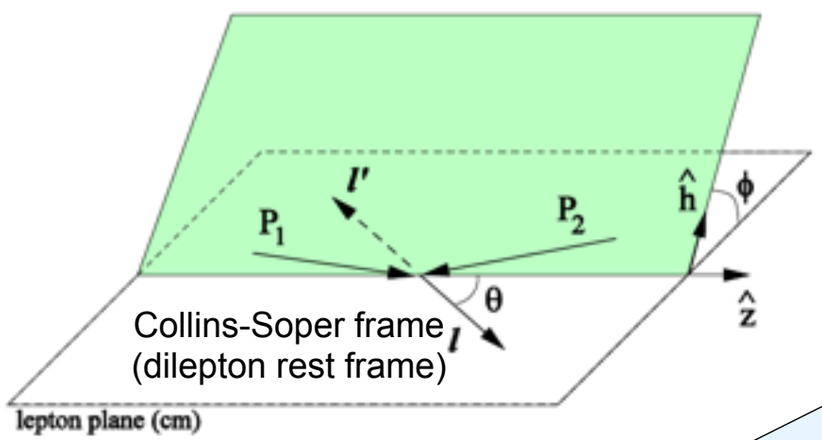
$$+ \boxed{\overline{h}_1^\perp} \otimes \boxed{h_1} \sin(2\phi - \phi_S) \Big]$$

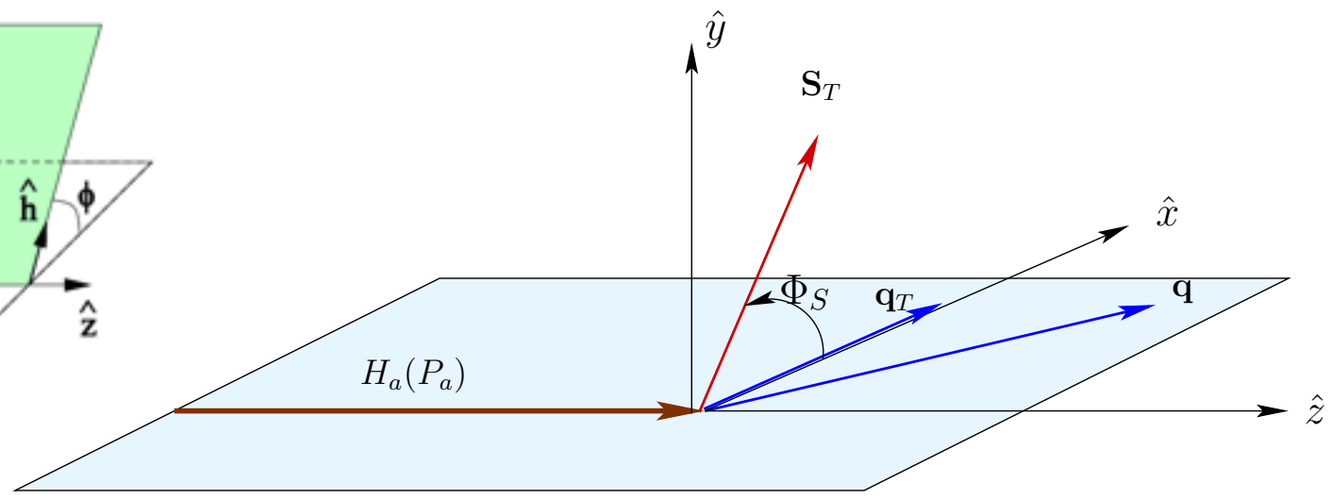
$(BM)_\pi \otimes (BM)_p$

$(f_1)_\pi \otimes (Sivers)_p$

$(BM)_\pi \otimes (Pretzelosity)_p$

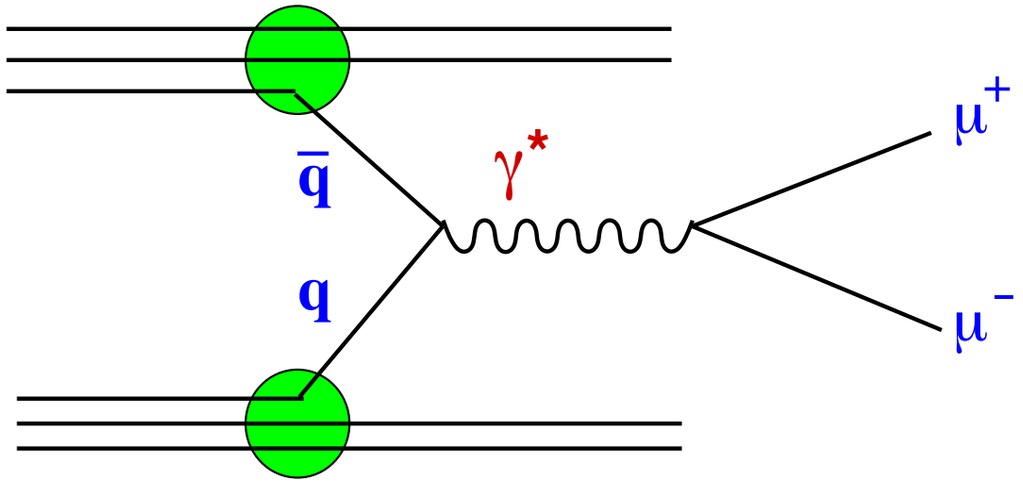
$(BM)_\pi \otimes (Transversity)_p$





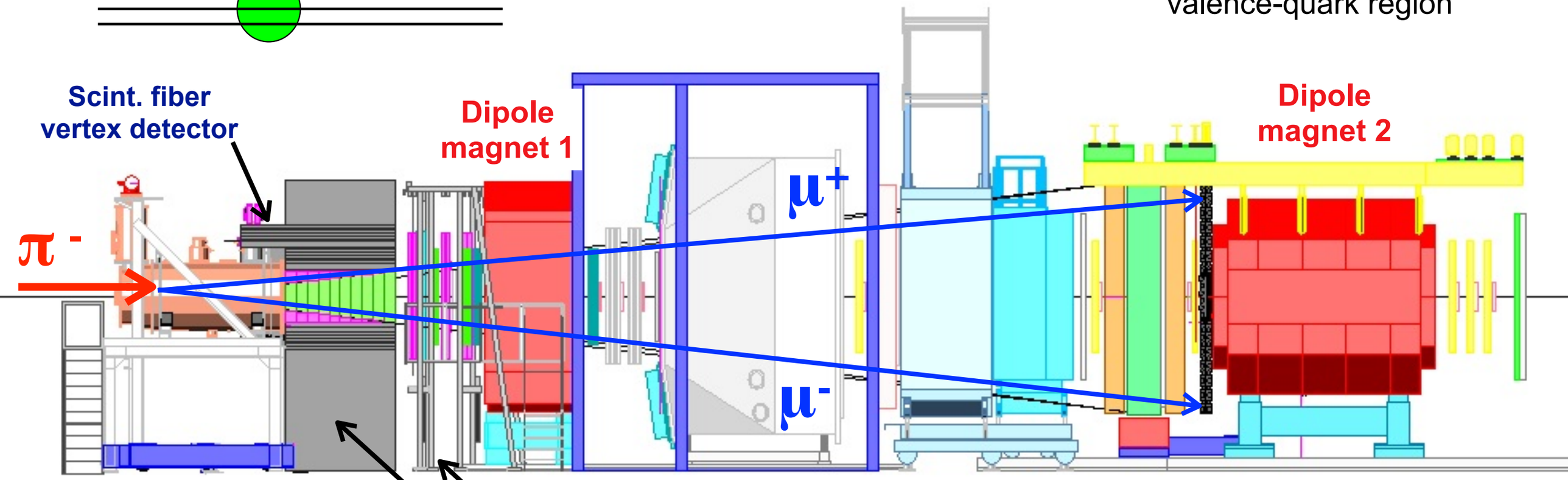
Measure magnitude of azimuthal modulations in cross section: **"Single-Spin Asymmetries" SSA**

Pion-induced Drell-Yan at COMPASS-II



Small cross section ➜ need high-intensity hadron beam

Tracking system - **Large**- and Small-Angle Spectrometer
➜ large acceptance for valence-quark region



Transversely polarized NH_3 target

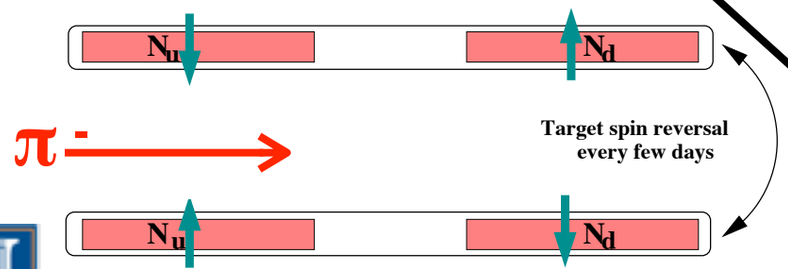
RICH-I hadron ID

Calorimetry

μ ID

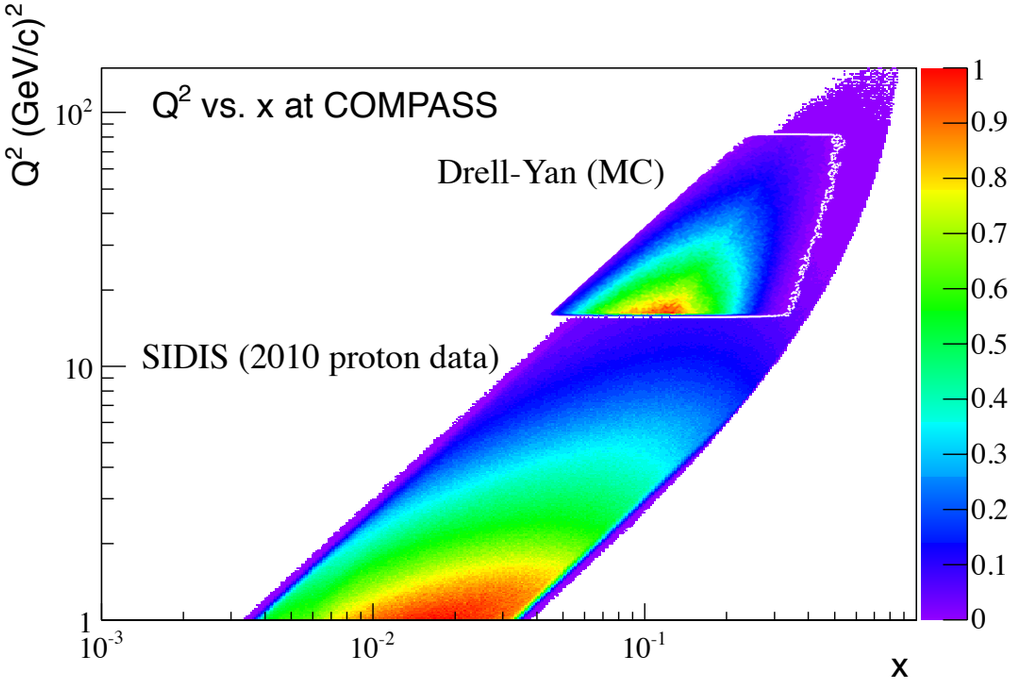
Muon trigger 1st spectrometer

new drift chamber DC5



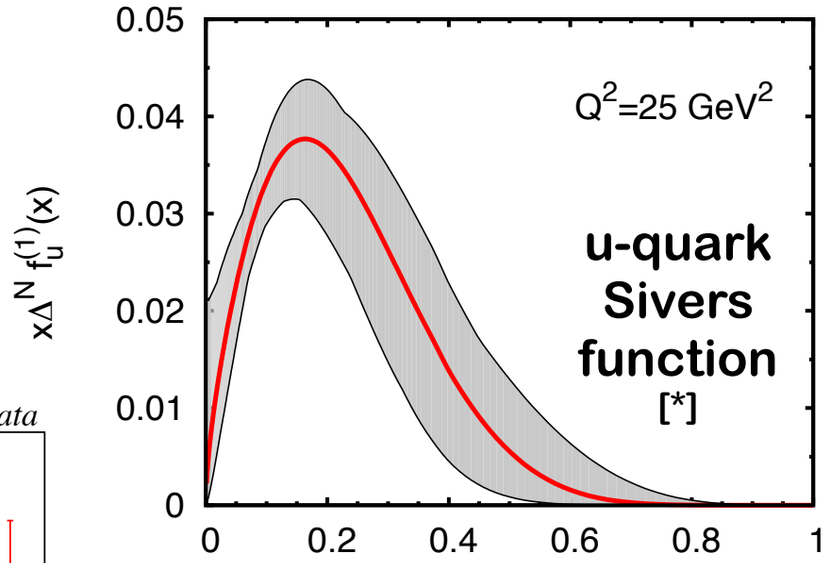
240cm Al_2O_3 **hadron absorber** and 120cm Tungsten **beam plug**

Phase space of COMPASS-II Drell-Yan data



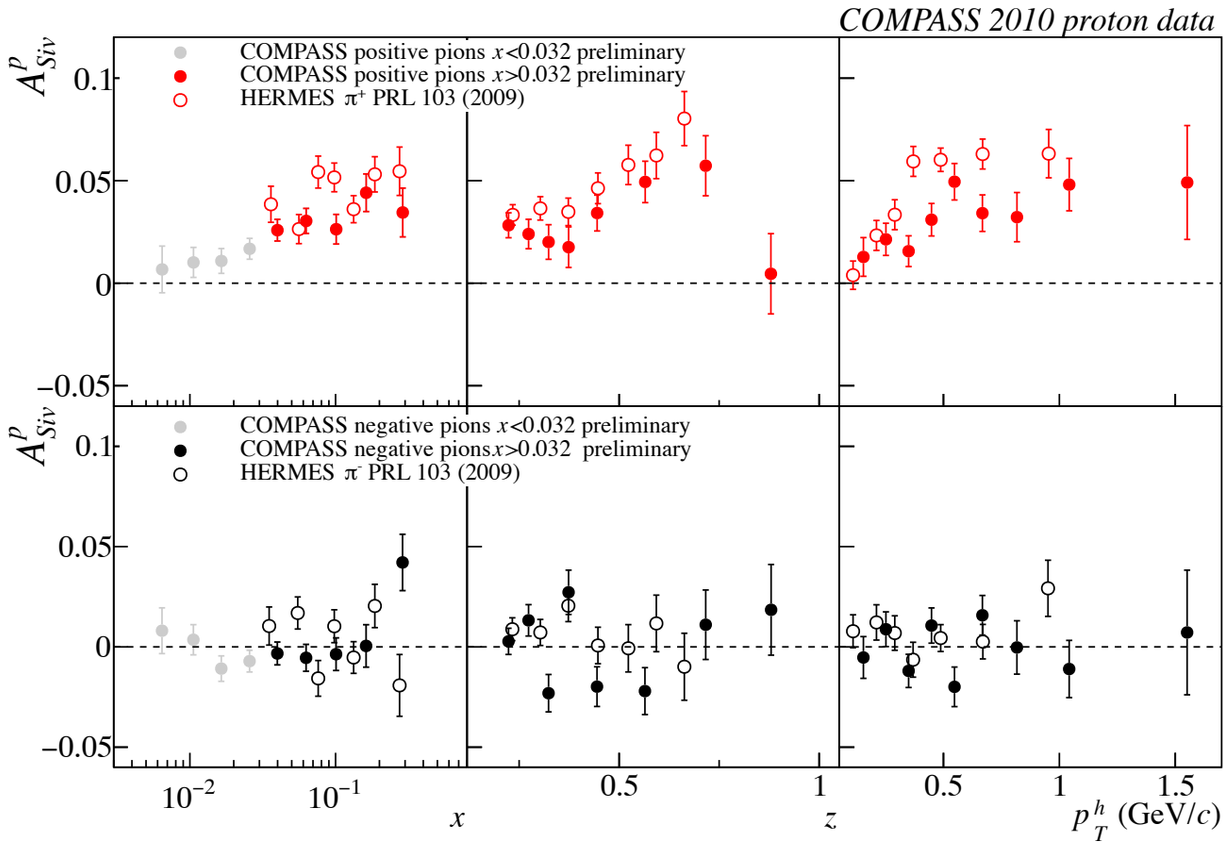
Kinematic overlap of DY and SIDIS data for clear answer on sign-change question

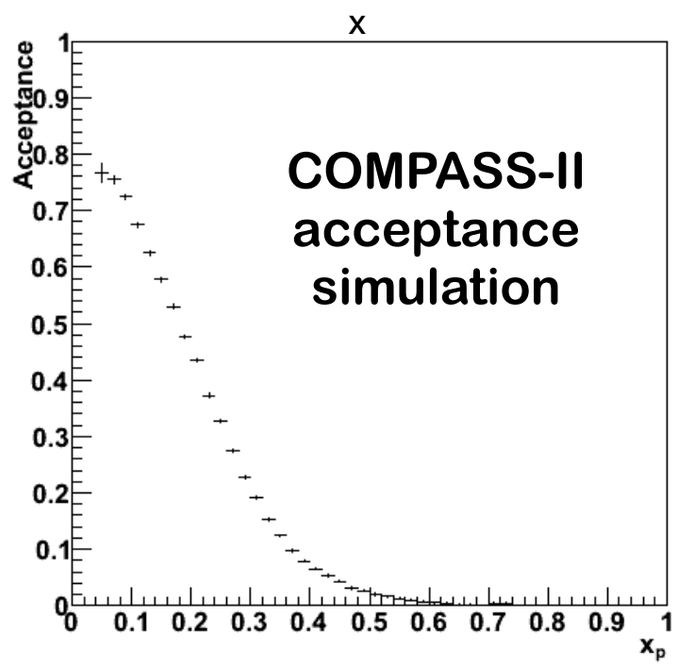
Will probe **valence-quark region** → Sivers function of large magnitude.



Sivers asymmetry in **SIDIS** measured to be clearly different from zero!

COMPASS ●
HERMES ○

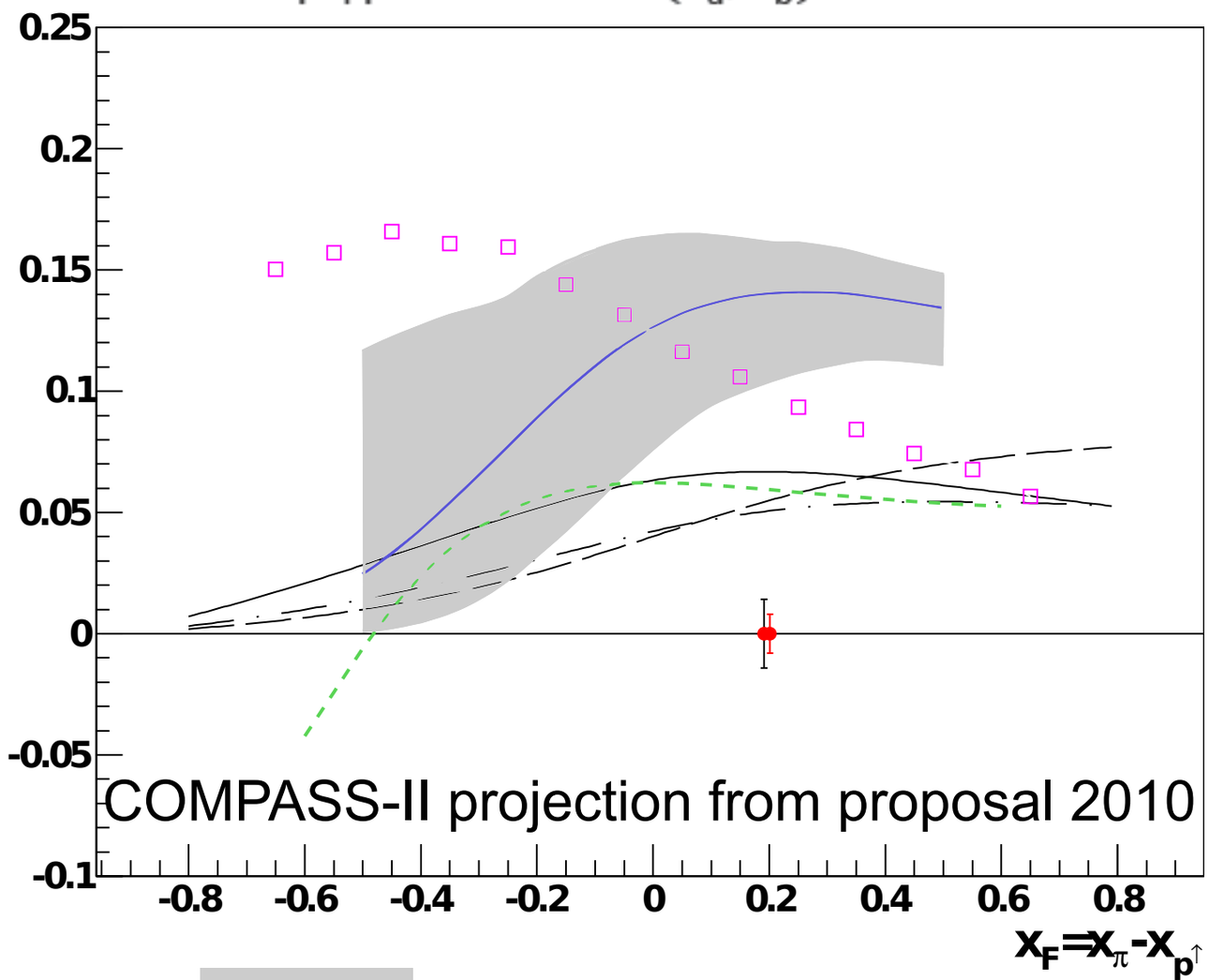




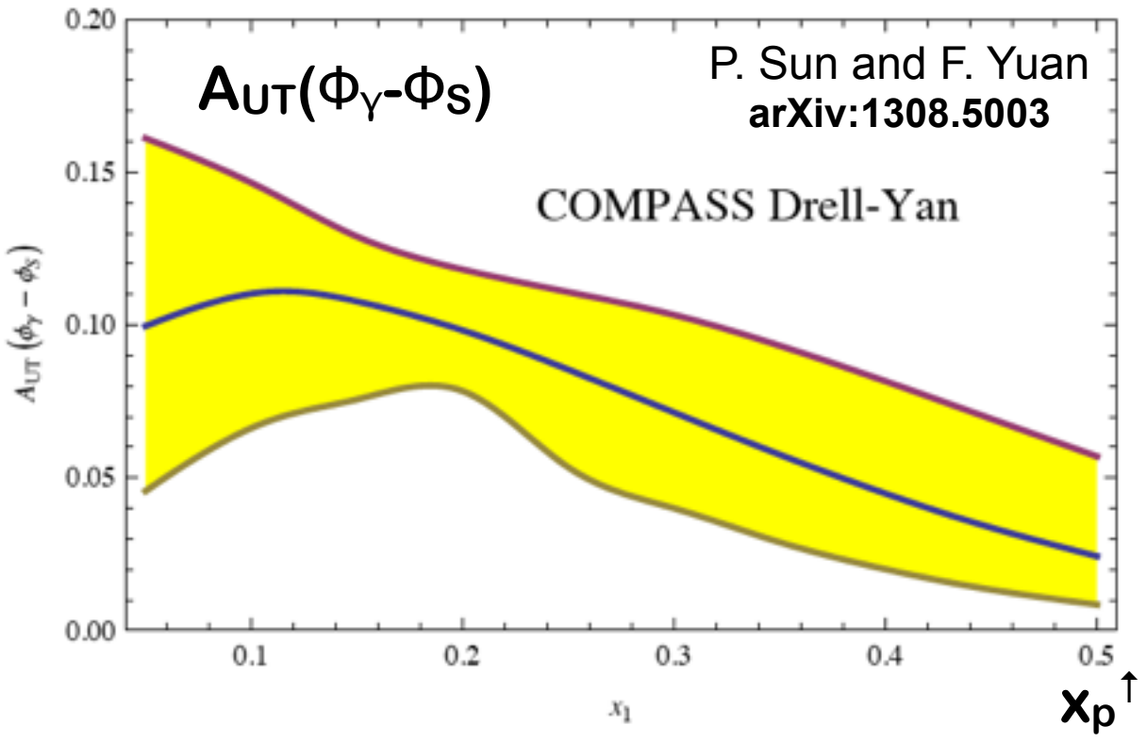
[*] M. Anselmino et al., Eur. Phys. J. A39 (2009) 89.

Sivers asymmetry: predictions

$$A_T^{\sin\phi_S} = \frac{2}{f|S_T|} \frac{\int d\phi_S d\phi \frac{dN(x_a,x_b,\phi,\phi_S)}{d\phi d\phi_S} \sin\phi_S}{N(x_a,x_b)}$$



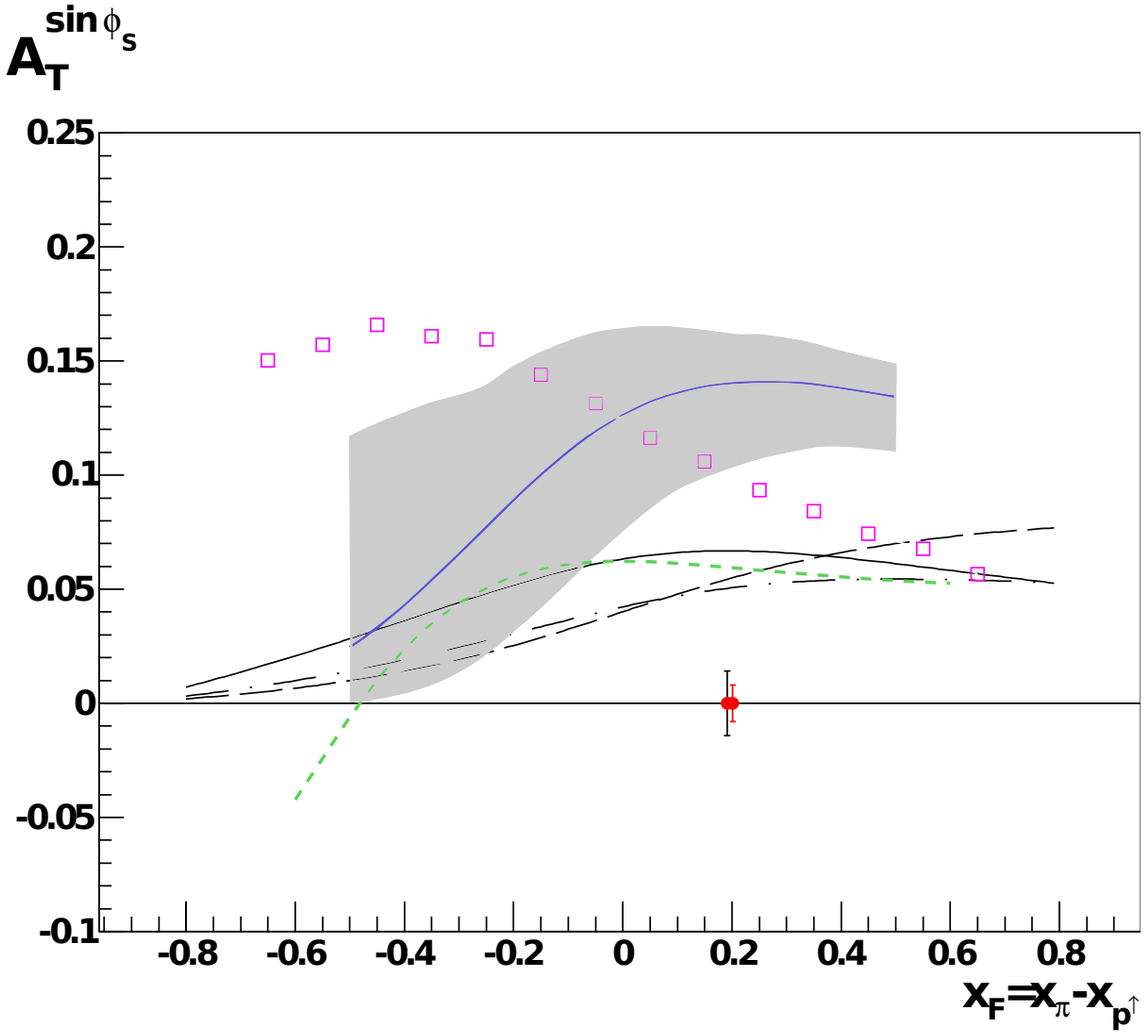
Anselmino et al., PRD 79 (2009)
Efremov et al., PLB 612 (2005)
Collins et al., PRD 73 (2006)
Bianconi et al., PRD 73 (2006)
Bacchetta et al., PRD 78 (2008)



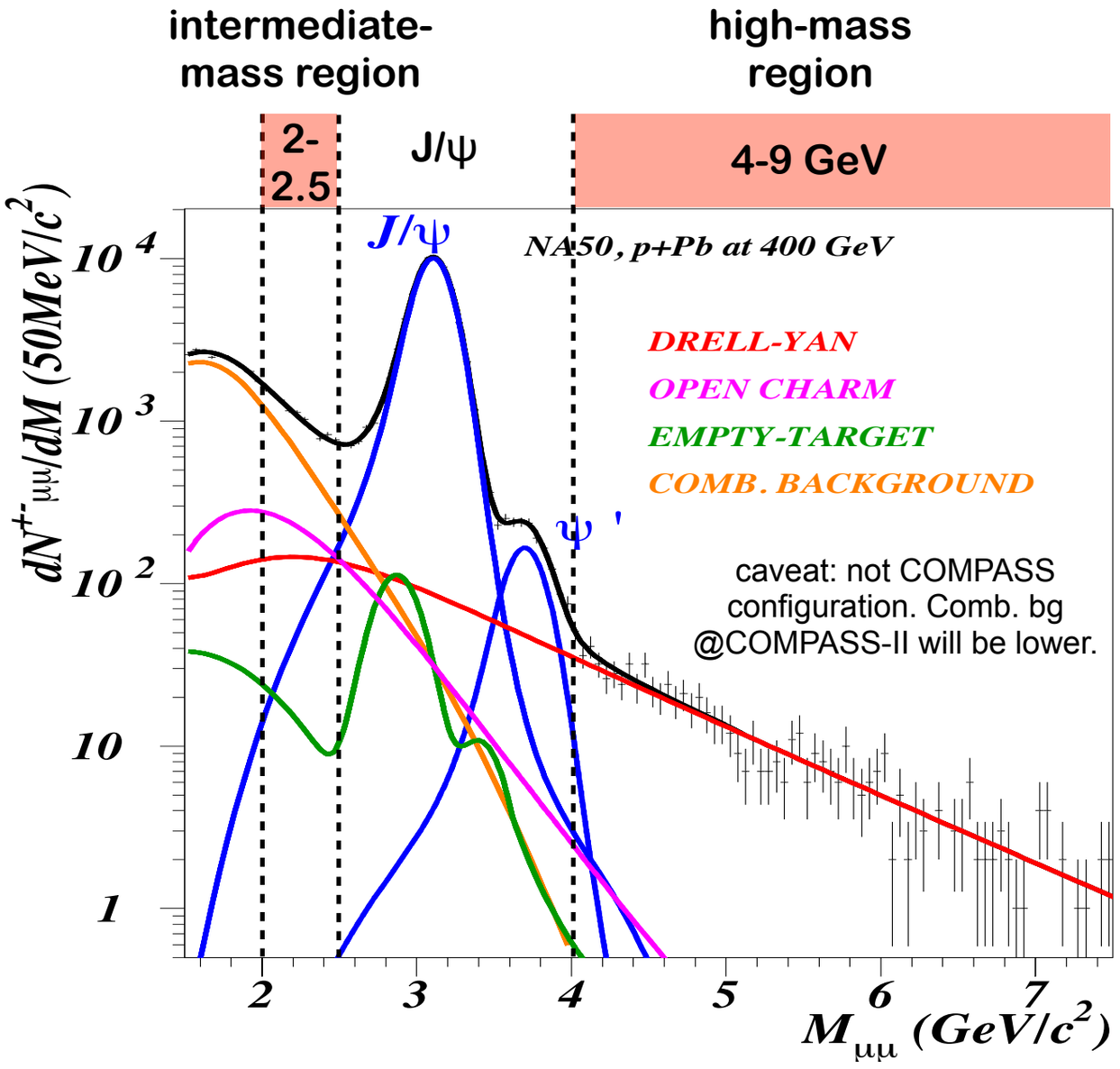
COMPASS polarized Drell-Yan: projections

(all numbers from 2010 COMPASS-II proposal)

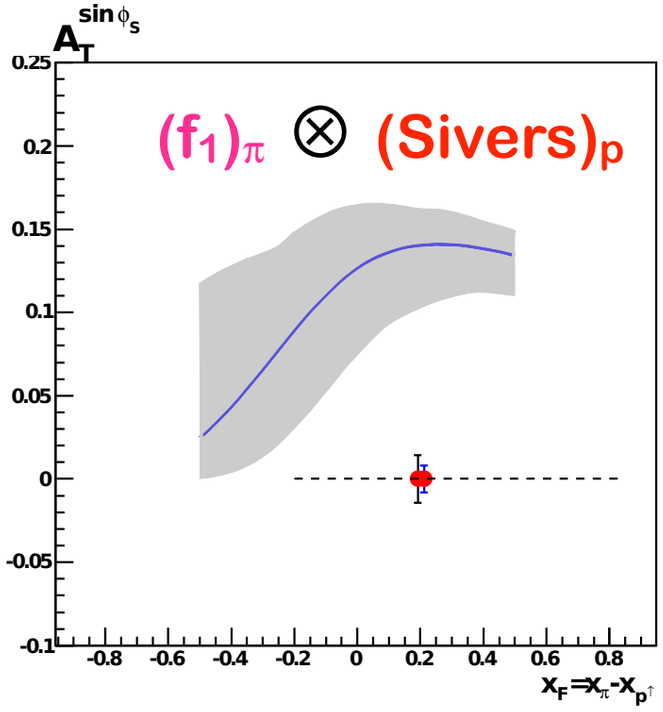
$6 \cdot 10^8$ π/spill (duration 9.6s every 48s)
1.1m trans. pol. target
Lumi=$1.2 \cdot 10^{32}$ $cm^{-2}s^{-1}$
beam energy = 190 GeV

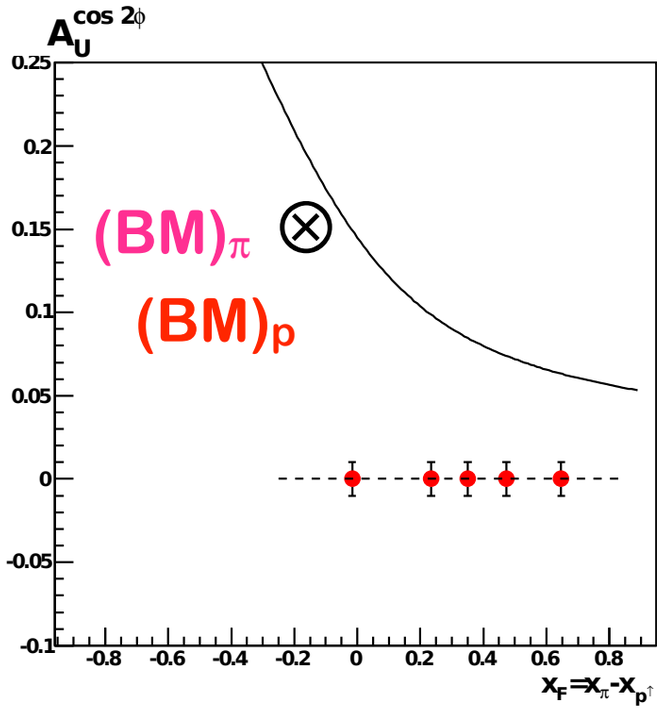


Projection: 2 years running (140 days/a)
- 230k DY events 4 GeV < $M_{\mu\mu}$ < 9 GeV
- 1.4 M DY events 2 GeV < $M_{\mu\mu}$ < 2.5 GeV



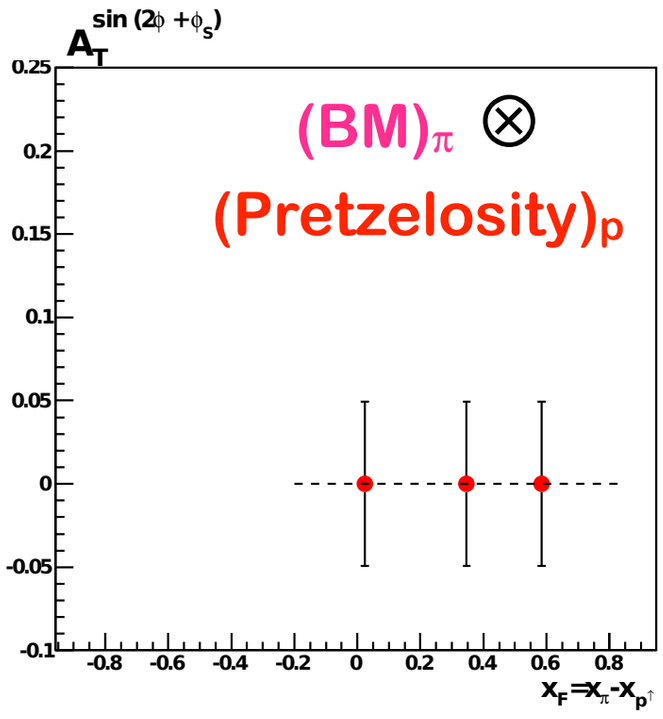
COMPASS-II projections and beam test

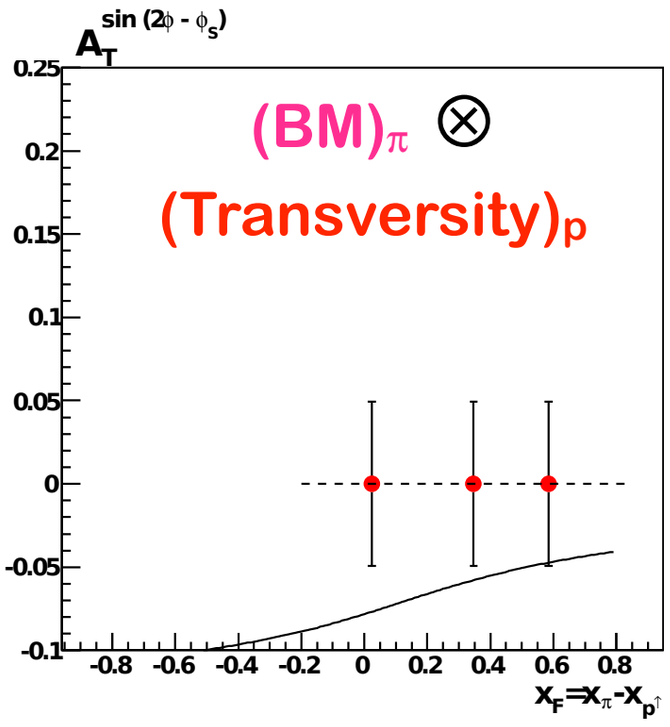




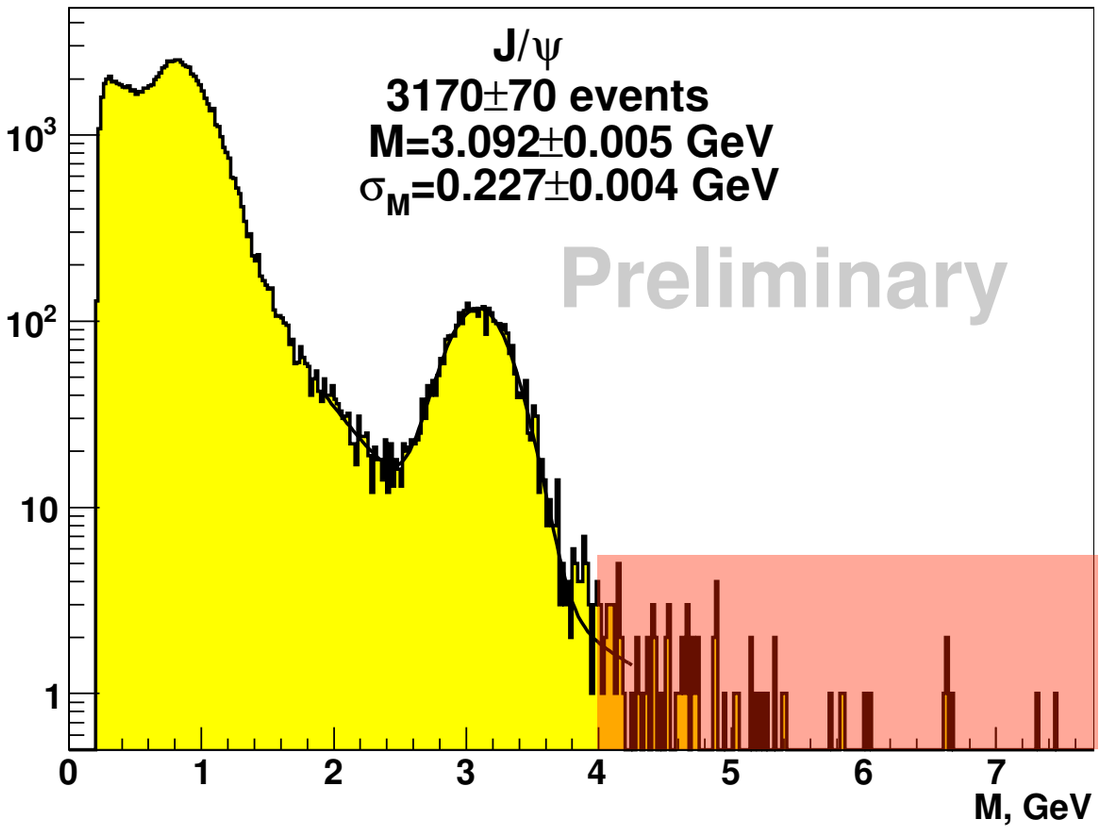
$$\mathrm{d}\sigma(\pi^- p^\uparrow \to \mu^+\mu^- X)$$

High-mass region
beyond J/ψ threshold
- high signal/background
- but low cross section

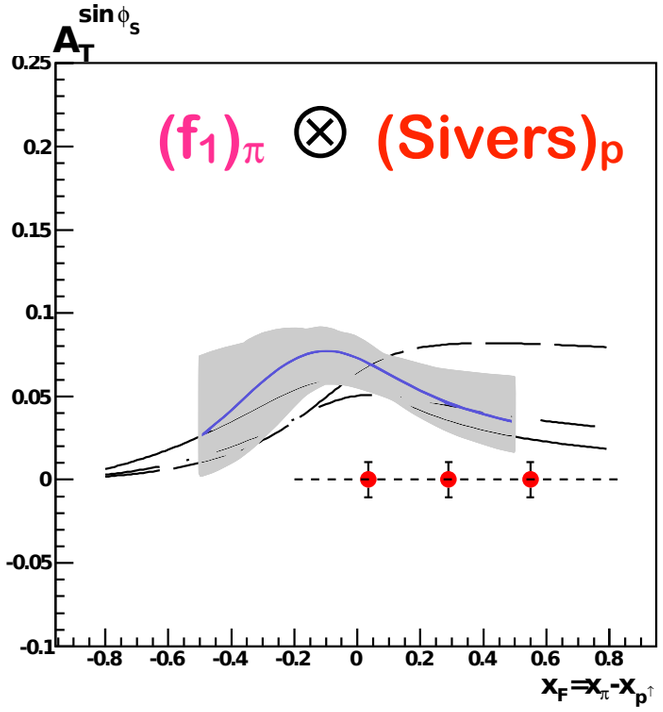


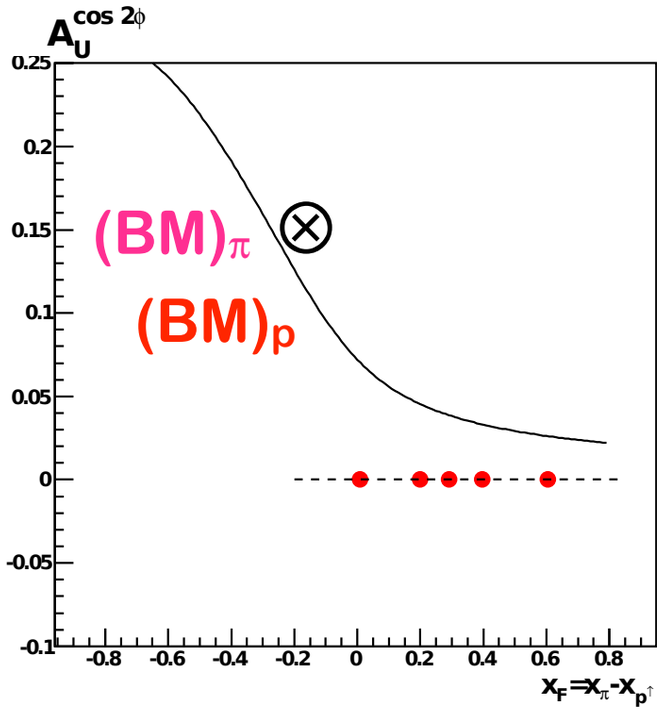


COMPASS DY beam test 2009



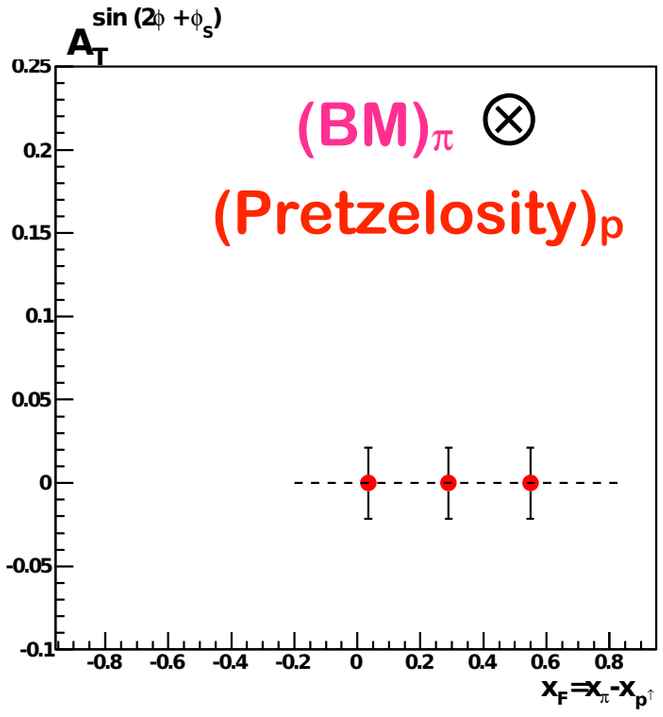
COMPASS-II projections and beam test

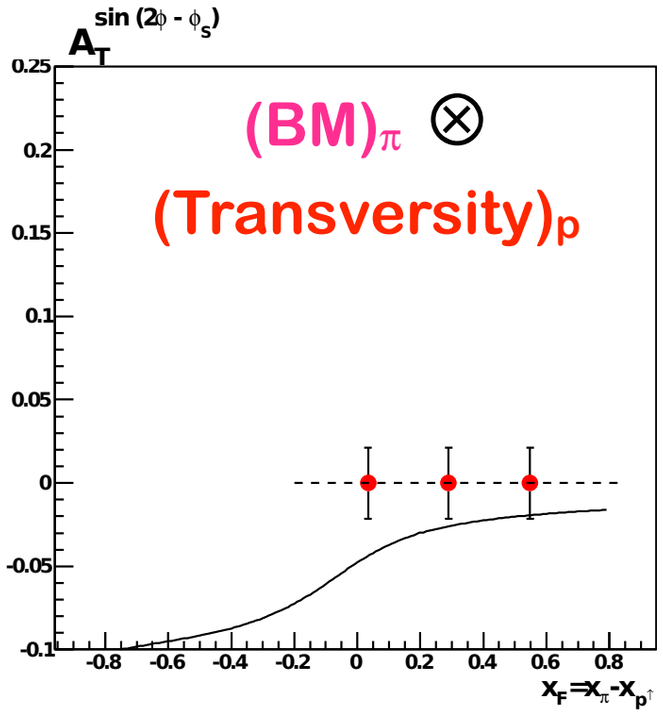


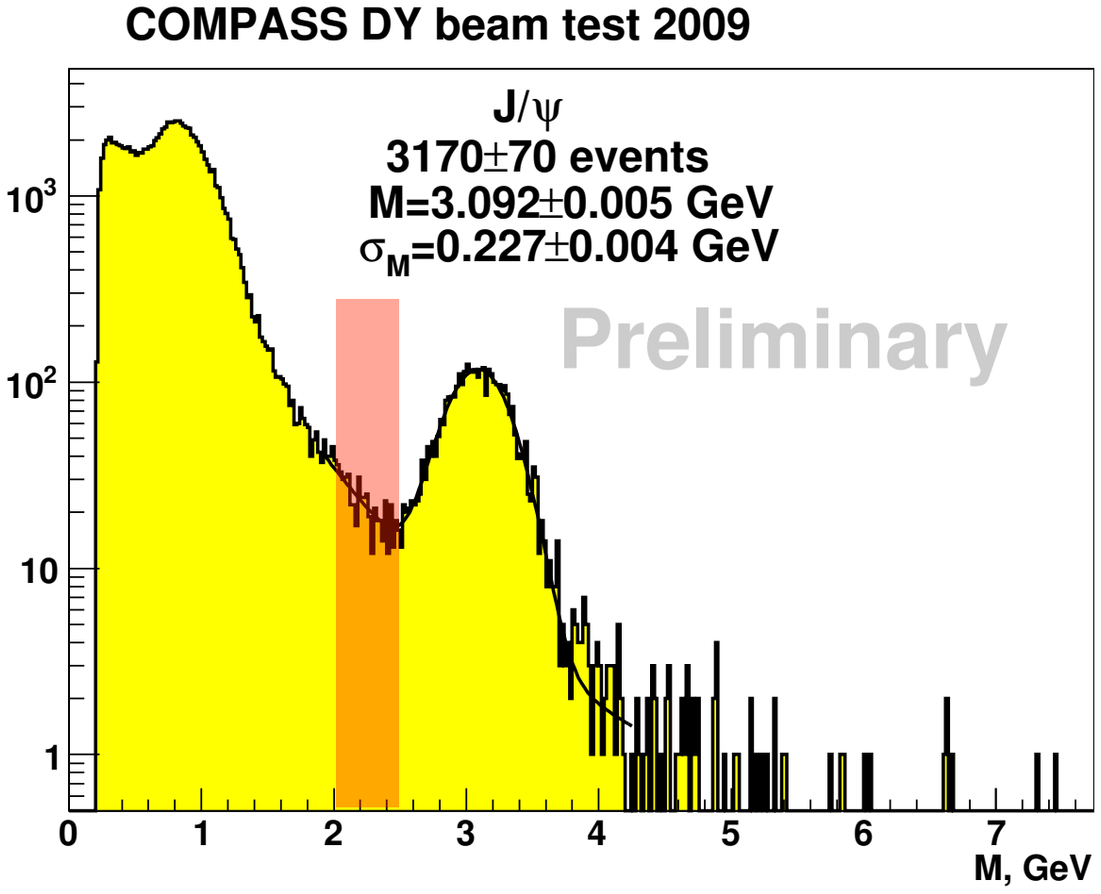


$$\mathrm{d}\sigma(\pi^- p^\uparrow \to \mu^+\mu^- X)$$

Intermediate-mass region
- high cross section
- but low signal/background







Beam test 2009: 190 GeV π^- beam
($8 \cdot 10^7$ π^-/spill) on 2 40cm-CH_2 cells

Summary and outlook: polarized Drell-Yan at COMPASS-II

$$\mathrm{d}\sigma(\pi^- p^\uparrow \to \mu^+\mu^- X)$$

- 2015: **first polarized Drell-Yan measurement** ever!
  Also first and only meson-induced DY since more than 25 years.

pion beam: 190 GeV

- Measure modulations of TMDs - Sivers, Boer-Mulders, Pretzelosity -, and Transversity. **Sign switch of Sivers amplitude** and other time-reversal-odd TMDs in Drell-Yan vs. SIDIS?

- Feasibility of the measurement proven in a series of **beam tests**.

- Requires several **detector upgrades**: hadron absorber, scintillating-fiber vertex detector, drift chamber, muon trigger.

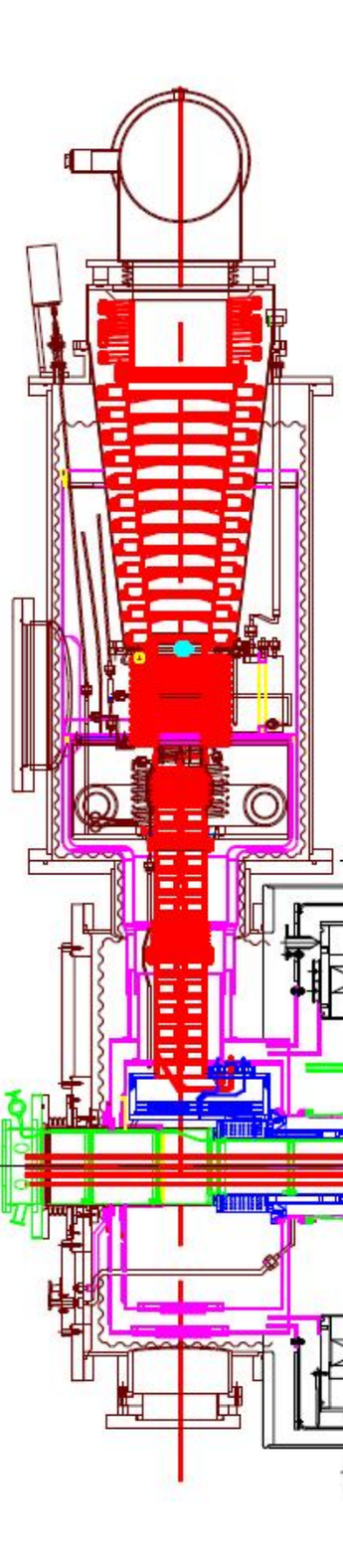
- **Outlook**:
  - Nuclear target into pion beam? Flavor-dependent EMC effect, ...
  - 2nd year of Drell-Yan @COMPASS-II beyond 2017 is planned.

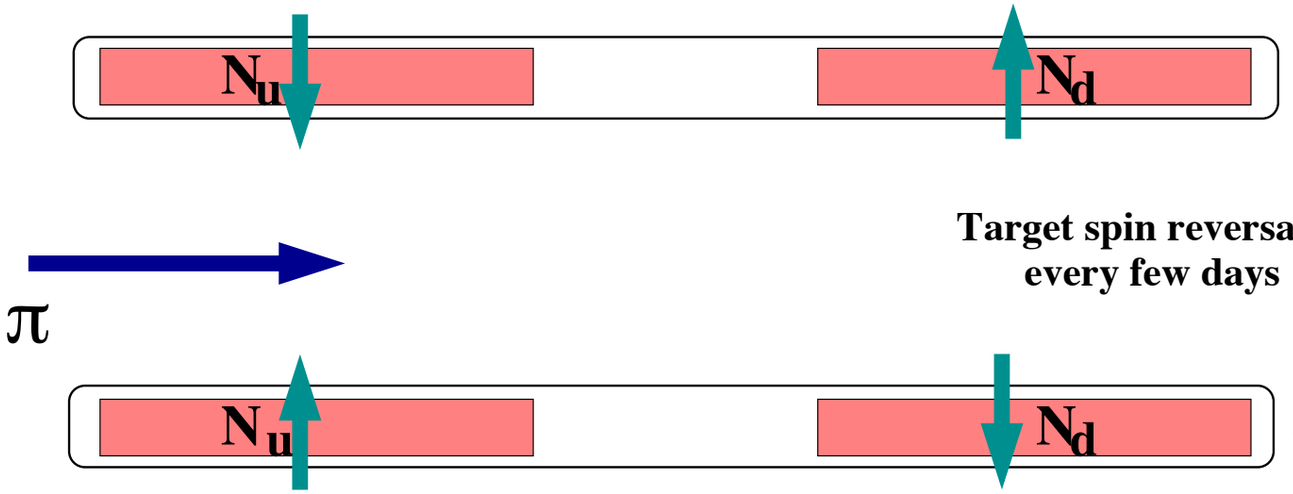
COMPASS-II 2010 proposal recommended by SPSC and approved by the Research Board for a first period of 3 years including 1 year for **Drell-Yan**.
http://wwwcompass.cern.ch/compass/proposal/compass-II_proposal/compass-II_proposal.pdf

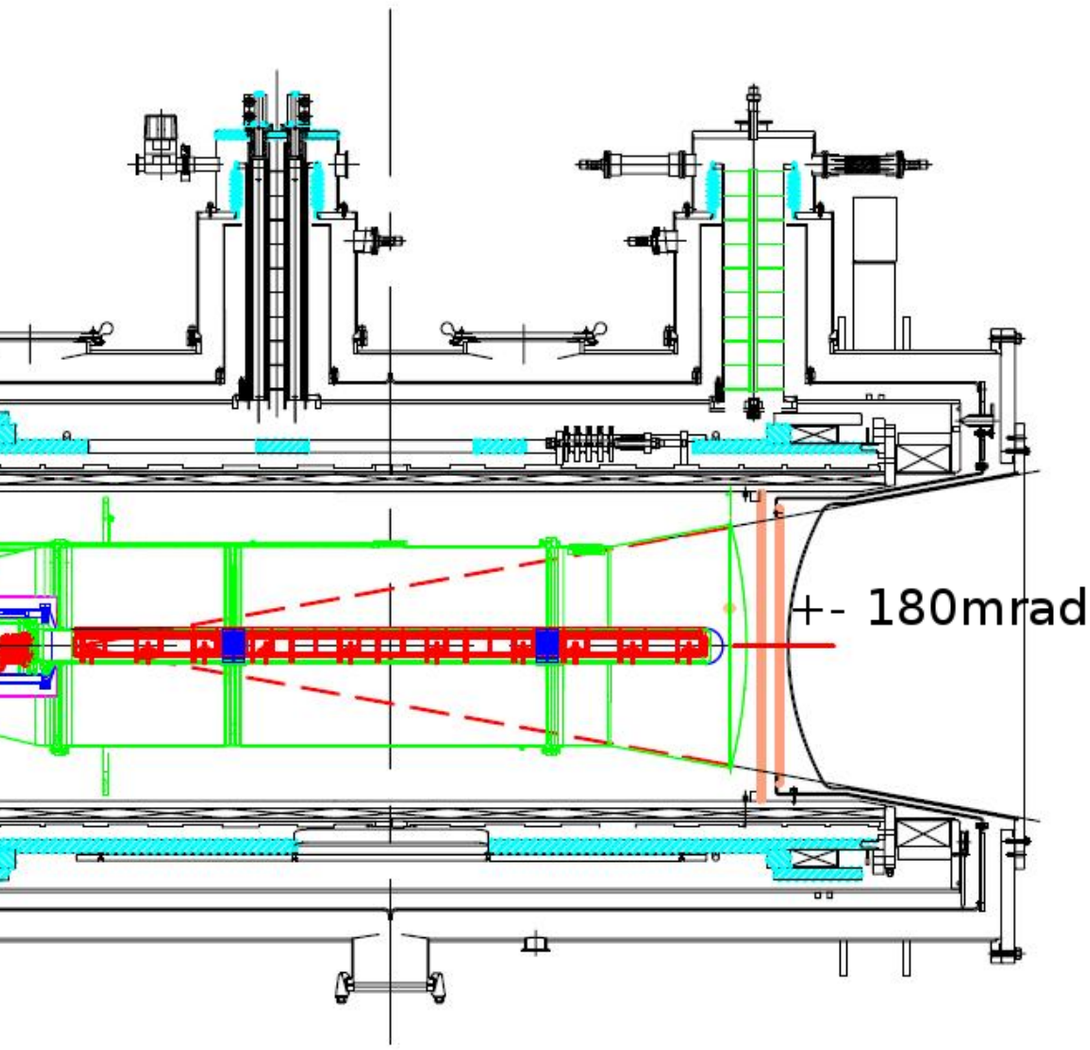
Thank you for material to: A. Ferrero, O. Denisov, C. Quintans, E. Zemlyanichkina

Backup

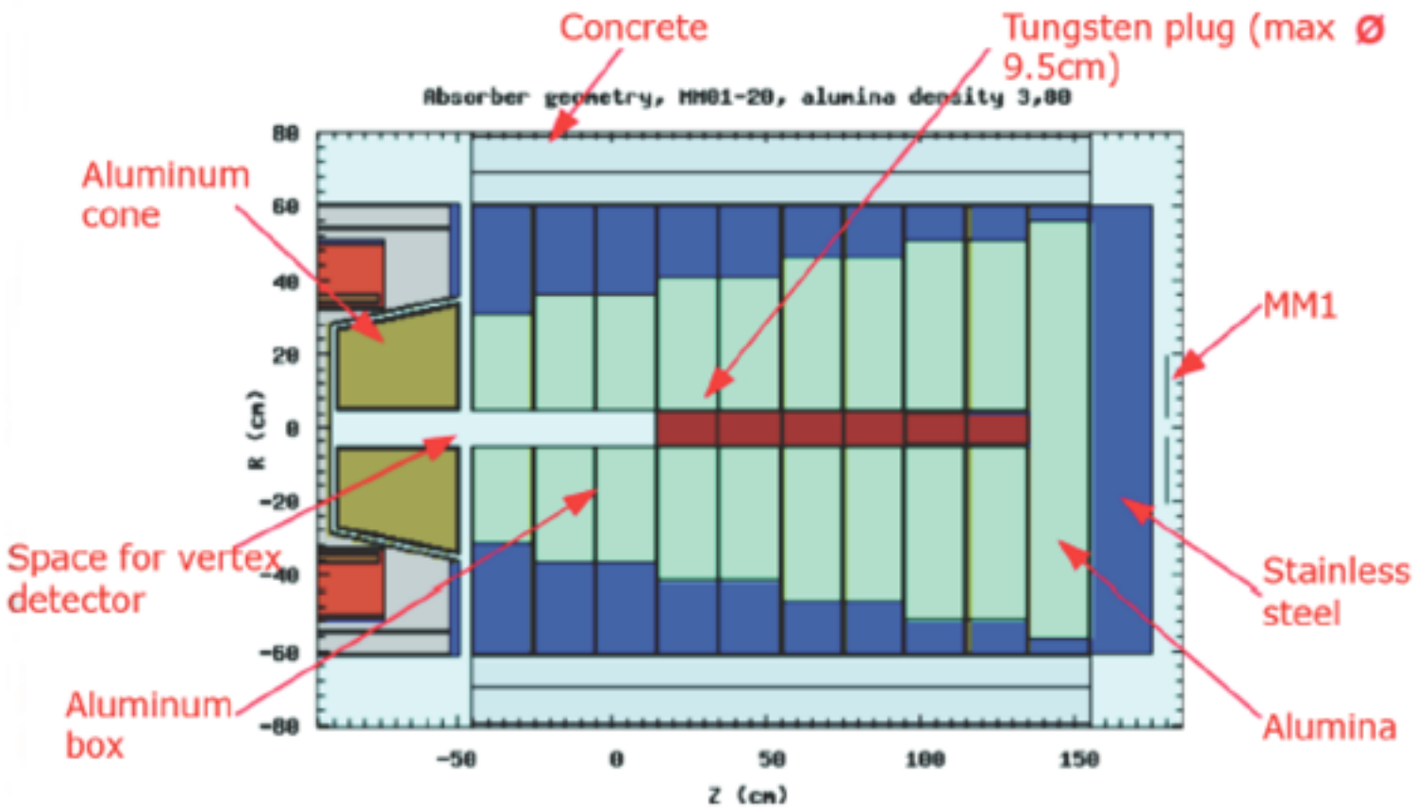
The transversely polarized NH_3 target







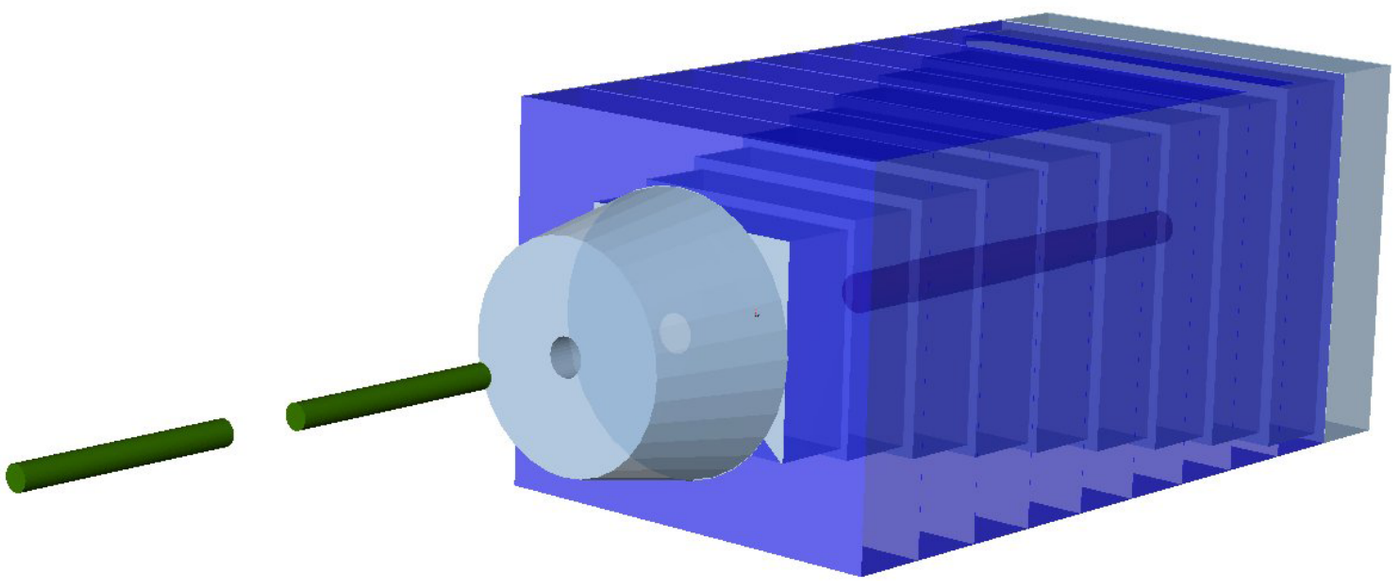
The hadron absorber



Structure of the hadron absorber:

- 120cm tungsten beam plug
- aluminium conical part
- 200cm alumina (Al_2O_3)
- Stainless steel shielding sandwiches

+ absorber surrounded by
2m of iron-free concrete on each side



Minimize multiple scattering of muons and maximize stopping power for hadrons.

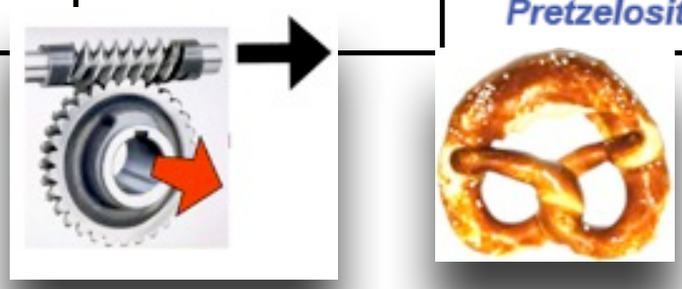
Transverse-Momentum Dependent PDFs (TMDs)

Distribution Functions (DF)

Diagonal 'survives' integration over transverse momentum k_T. "Collinear analysis"

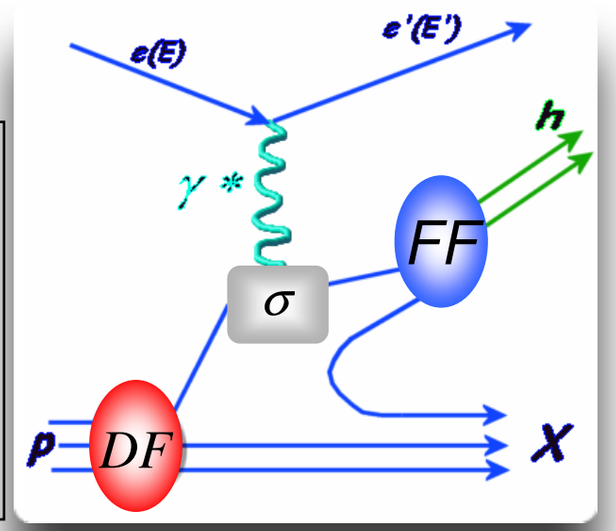
nucleon \ quark polarization	U	L	T
U	f_1 Number Density		$h_1^\perp$ Boer Mulders
L		g_1 Helicity	$h_{1L}^\perp$ Worm-gear
T	$f_{1T}^\perp$ Sivers	$g_{1T}^\perp$ Worm-gear	h_1 Transversity $h_{1T}^\perp$ Pretzelosity

chiral odd



factorization

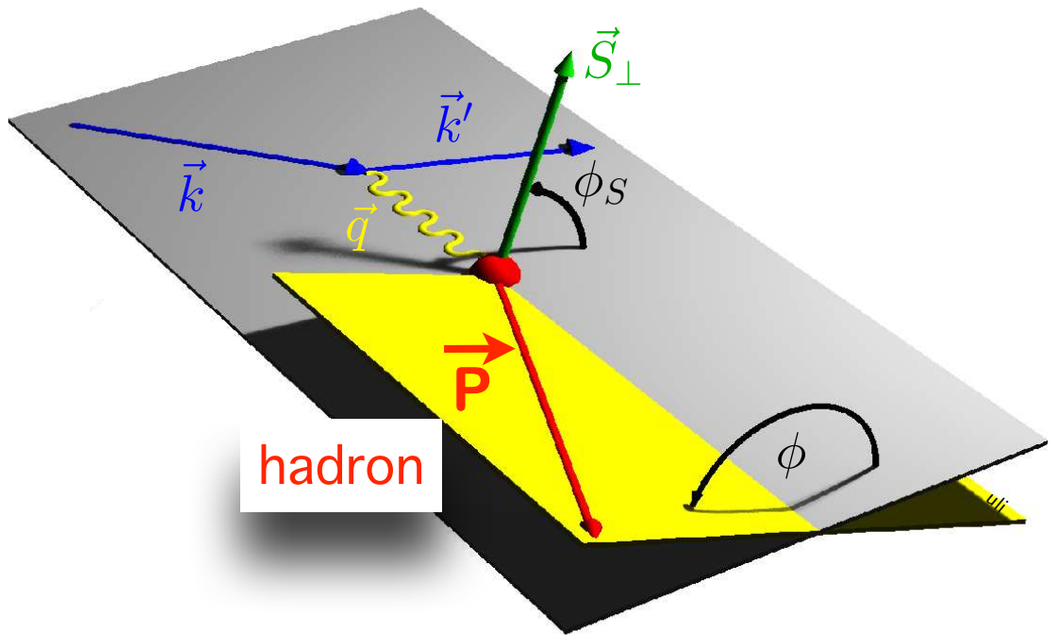
$\sigma^{ep\to ehX} = \Sigma_q$ (**FF** $\otimes$ $\sigma^{eq\to eq}$ $\otimes$ **DF**)



Fragmentation Function (FF)

☛ TMDs depend on the longitudinal and transverse momentum of a parton inside a hadron.

☛ Describe strength of various spin-spin or spin-orbit correlations of the parton-hadron system.



Future Drell-Yan experiments

- Programs for future Drell-Yan measurements:
  nucleon-nucleon at
  - SeaQuest (Fermilab)
  - RHIC (Brookhaven)
  - J-PARC (KEK)
  - IHEP (Protvino)
  - JINR (Dubna)

  anti(p)-nucleon at
  - FAIR (GSI)

  pion-nucleon at
  - COMPASS (CERN)

  Only existing meson plan!

- Past measurements exclusively considered the unpolarized cross section, future ones also aim for polarization measurements.
  - transversely polarized DY: spin-dependent TMDs
  - longitudinally polarized DY: quark helicity