OVERVIEW OF COMPASS-I AND FUTURE PLANS

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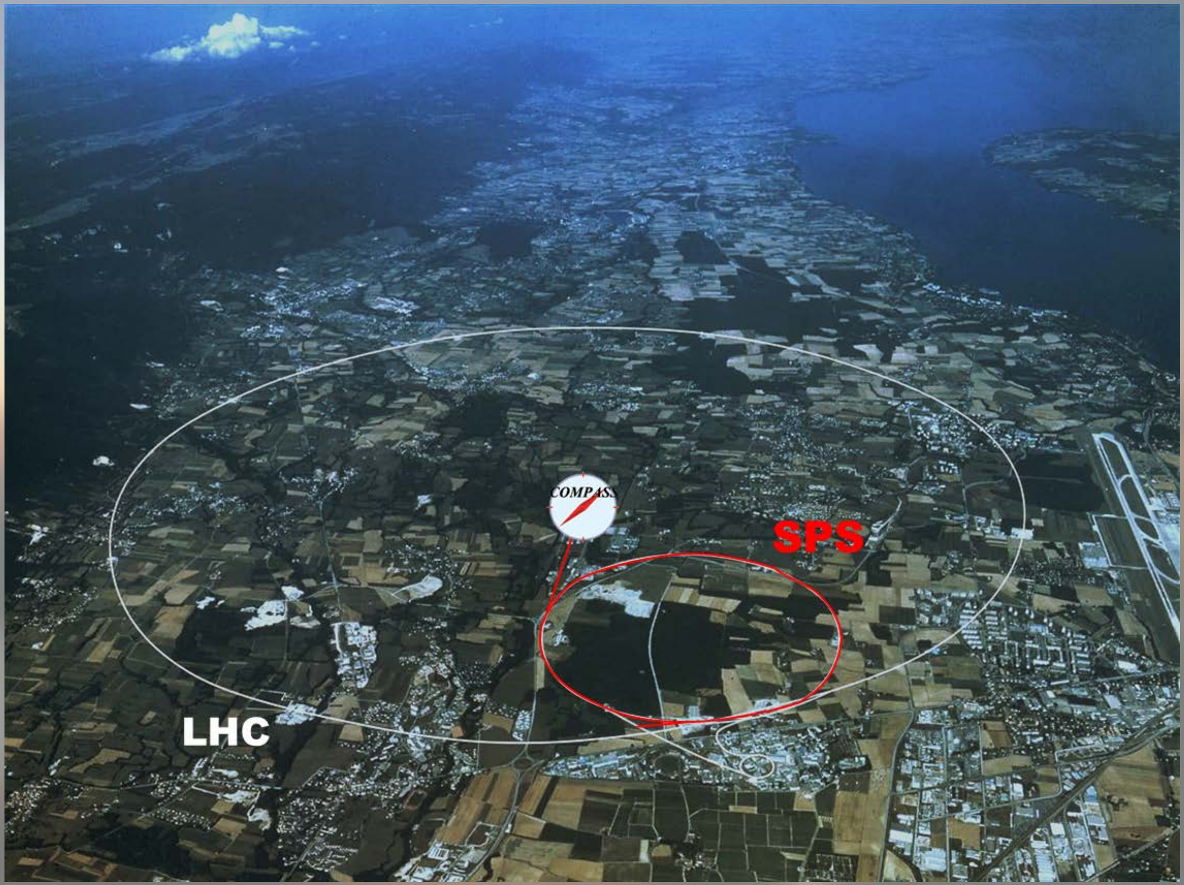
COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

Collaboration
~ 250 physicists
from 24 Institutions
of 13 Countries

- **fixed target**
- **experiment**
- **at the CERN SPS**

data taking: since 2002



COMPASS-I Collaboration

Дубна (LPP and LNP),
Москва (INR, LPI, State University),
Протвино

CERN

Bielefeld, Bochum,
Bonn (ISKP & PI),
Erlangen,
Heidelberg,
Freiburg, Mainz,
München
(LMU,TU)

Warsawa (SINS),
Warsawa (TU)

Nagoya

Helsinki

Praha (CU/CTU)
Liberec (TU)
Brno (ISI-ASCR)

Lisboa/Aveiro

Saclay

Calcutta (Matrivian)

Tel Aviv

Torino
(University,INFN),
Trieste
(University,INFN)

COMPASS-II Collaboration

Дубна (LPP and LNP), Москва (INR, LPI, State University), Протвино

CERN

Bochum, Bonn (ISKP & PI), Erlangen, Freiburg, Mainz, München TU

Warsawa (NCBJ), Warsawa (TU) Warsawa (U)

Yamagata

USA (UIUC)

Praha

Lisboa

Saclay

Burden, Calcutta

Tel Aviv

Torino (University,INFN), Trieste (University,INFN)

Taipei (AS)

COMPASS-I

- **high energy beam**
- **large angular acceptance**
- **broad kinematical range**

two stages spectrometer

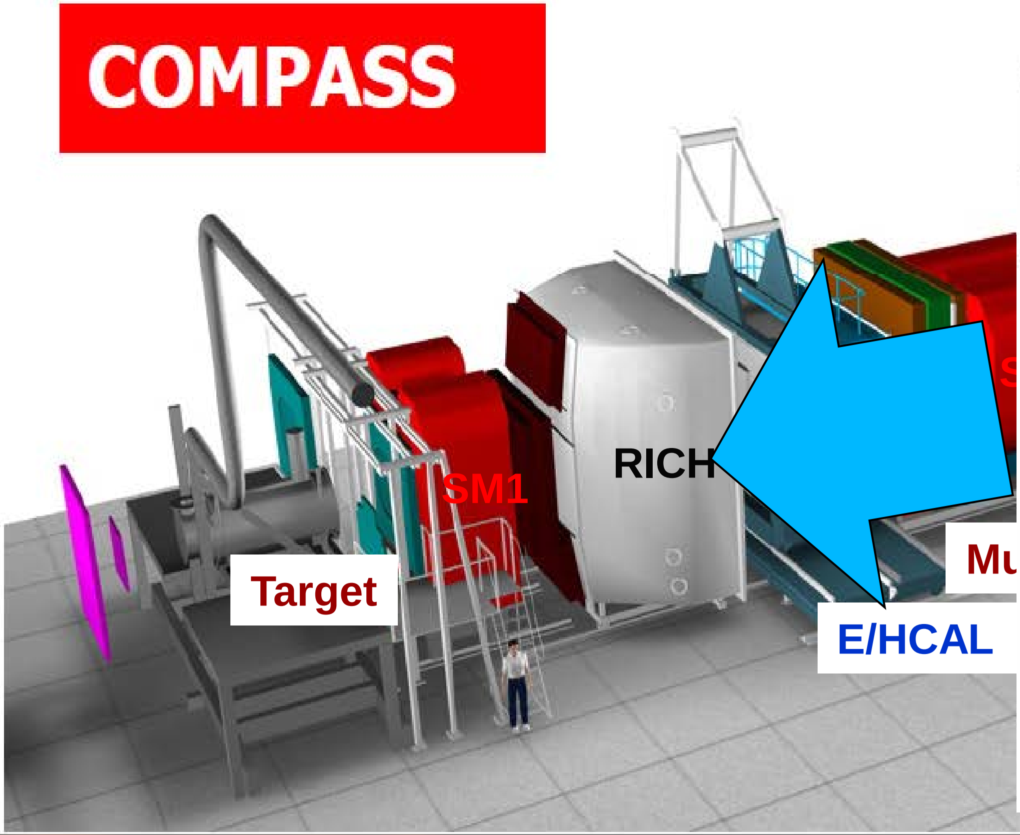
Large Angle Spectrometer (SM1)

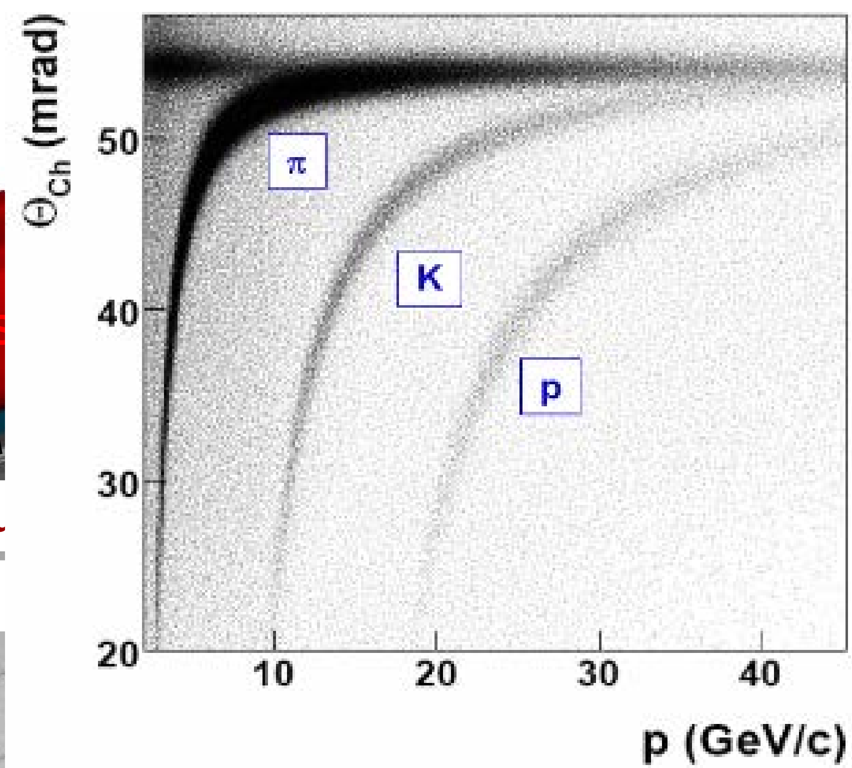
Small Angle Spectrometer (SM2)

radiator C_4F_{10}

threshold: π ~2 GeV/c

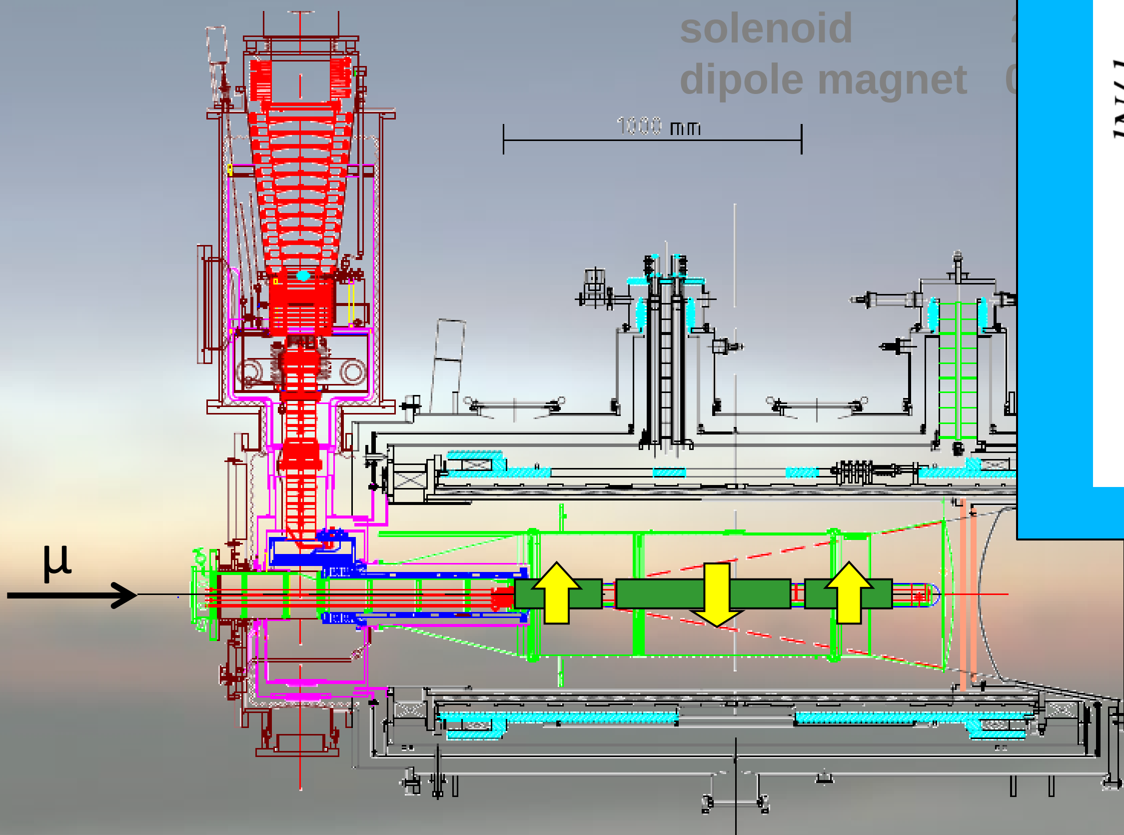
K ~ 10 GeV/c

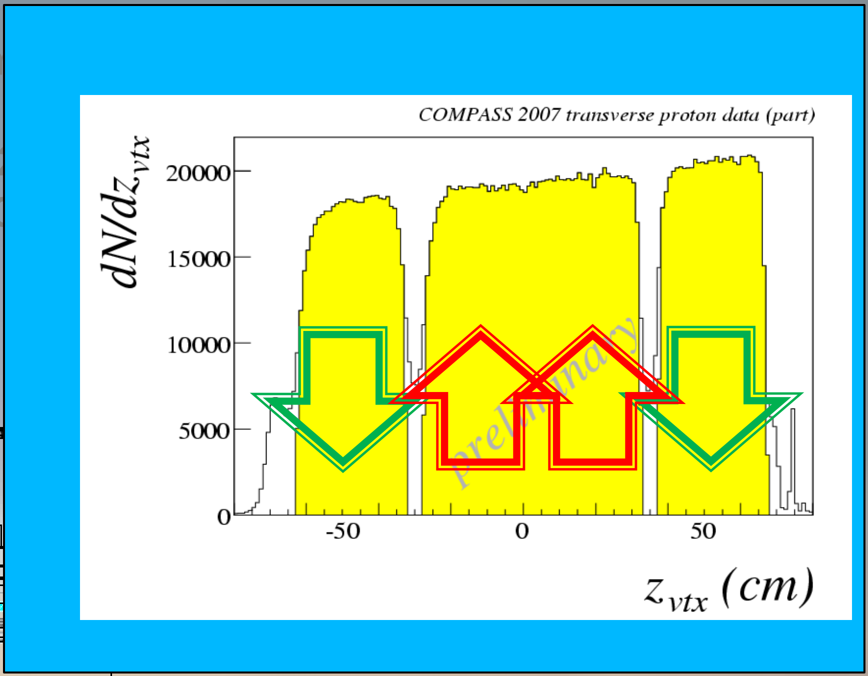




the polarized target system (>2005)

^3He – ^4He dilution refrigerator (T~50m





opposite polarisation

	d (^6LiD)	p (NH_3)
polarization	**50%**	**90%**
dilution factor	**40%**	**16%**

no evidence for relevant nuclear effects *(160 GeV)*

COMPASS – some facts

- Located at CERN North Area beam line
  - Possible beams: μ^+, μ^-, π^+, π^-, K $\rightarrow$ Several physics programs

- Experiments with muon beam
- Experiments with hadron beams

COMPASS - I (2002 – 2011)

- Spin structure, Gluon polarization
- Flavor decomposition
- Transversity
- Transverse Momentum-dependent PDF

- Pion polarizability
- Diffractive and Central production
- Light meson spectroscopy
- Baryon spectroscopy

COMPASS - II (2012 – 2017)

- DVCS and HEMP
- Unpolarized SIDIS and TMDs

- Pion and Kaon polarizabilities
- Drell-Yan studies

COMPASS – some facts

- Located at CERN North Area beam line
  - Possible beams: μ^+, μ^-, π^+, π^-, K → Several physics programs

- Experiments with muon beam
- Experiments with hadron beams

COMPASS - I (2002 – 2011)

- Spin structure
- p, d polarized target (L & T)
- Hadron spectroscopy
- Small LH_2 or nuclear targets

COMPASS - II (2012 – 2017)

- DVCS/Unpol SIDIS
- Long LH_2 target
- Drell-Yan studies
- Polarized target (T)

Reconfigurable target region - versatile experimental setup!

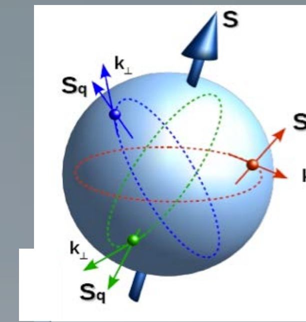
COMPASS data taking

muon beam	deuteron (^{6}LiD) polarised target	2002 2003 2004	L/T target polarisation
		2006	L target polarisation
	proton (NH_3) polarised target	2007	L /T target polarisation
hadron	LH target	2008 2009	
muon beam	proton (NH_3) polarised target	2010	T target polarisation
		2011	L target polarisation
Hadron	Ni target	2012	
muon beam	LH2 target	2012	Pilot DVCS & unpol. SIDIS

muon beam: 160 GeV/c longitudinal polarisation -80%
intensity $2\cdot10^8$ μ^+/spill (4.8s/16.2s)

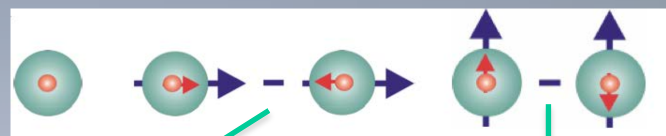
Structure of the Nucleon

The spin of the nucleon



Three twist-2 quark DF’s in collinear approximation ($\int dk_\perp$)

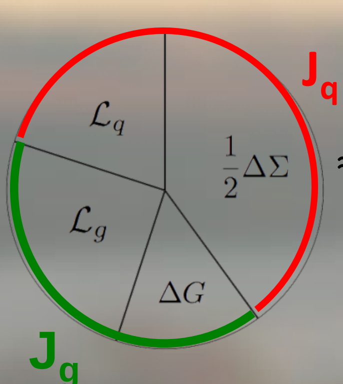
$$\Phi^{Tw-2}_{Coll}(x) = \frac{1}{2}\left\{ q(x) + S_L\gamma_5\Delta q(x) + S_T\gamma_5\gamma^1\Delta_T q(x)\right\} n^+$$



helicity

transversity

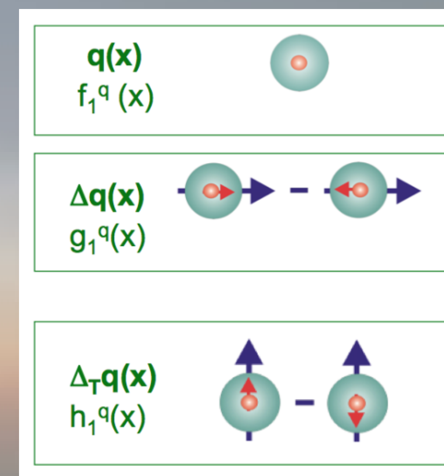
$$\frac{S_z^N}{\hbar} = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^g$$



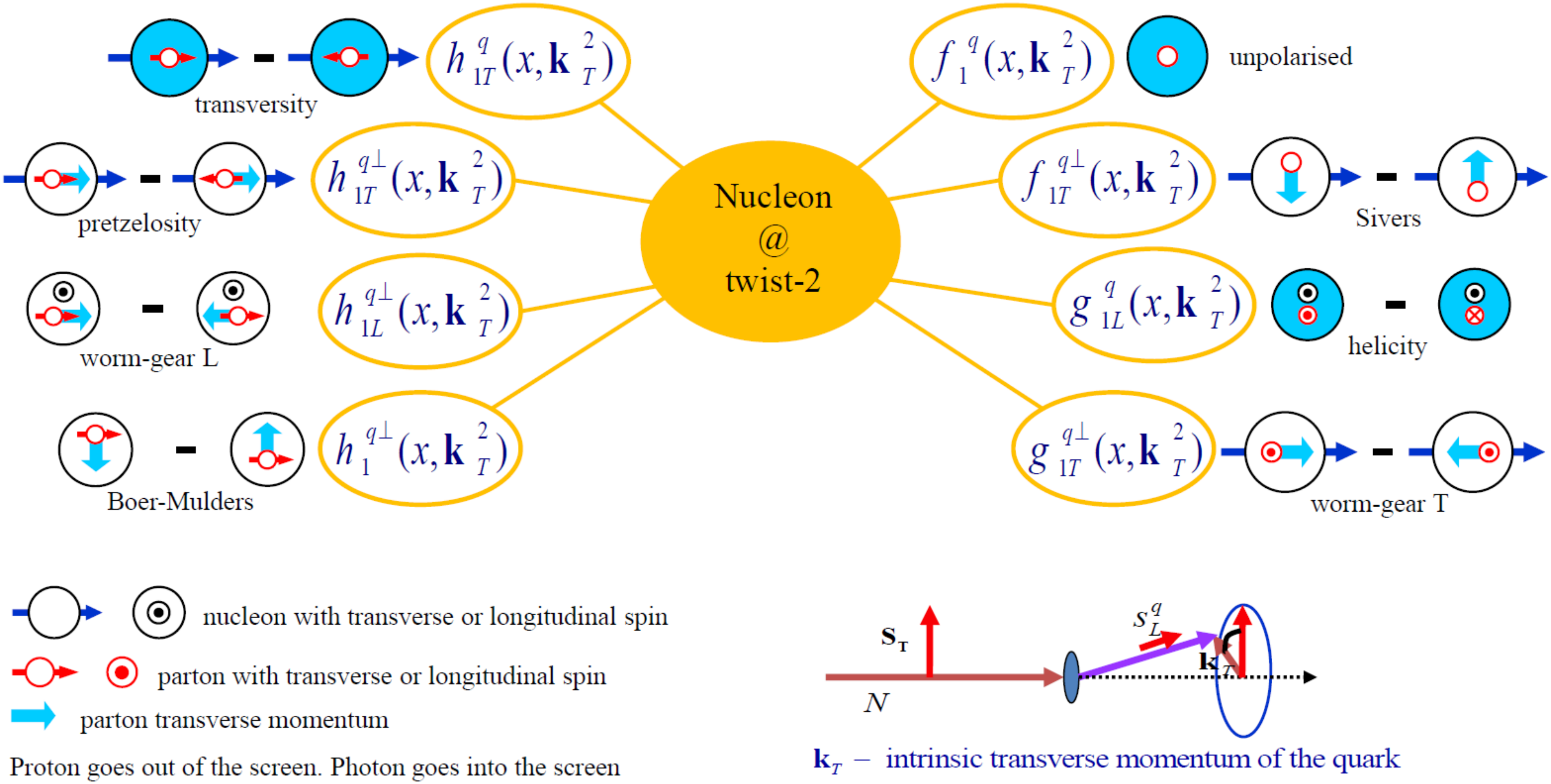
≈30% : **Spin puzzle**

NR limit
[boost, rotat.]=0

➡ $\Delta_T q(x,Q^2) = \Delta q(x,Q2)$



TMD Distribution Functions



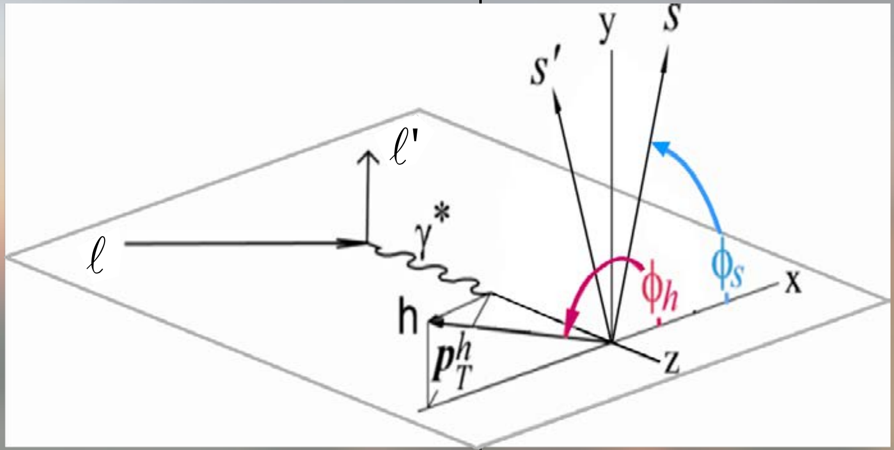
SIDIS x-Section

$$A_{U(L),T}^{w(\varphi_h,\varphi_S)} = \frac{F_{U(L),T}^{w(\varphi_h,\varphi_S)}}{F_{UU,T}+\varepsilon F_{UU,L}}$$

$$\varepsilon = \frac{1-y-\frac{1}{4}y^2\gamma^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}y^2\gamma^2},\quad \gamma = \frac{2xM}{Q}$$

$$\frac{d\sigma}{dx\,dy\,dz\,dP_{h\perp}^2\,d\varphi_h\,d\psi} = \left[\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\times\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\times$$

$$\left\{\begin{array}{l}
1+\cos\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}+\cos(2\varphi_h)\times\varepsilon A_{UU}^{\cos(2\varphi_h)}+\lambda\sin\varphi_h\times\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\varphi_h}+\\
S_L\left[\sin\varphi_h\times\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\varphi_h}+\sin(2\varphi_h)\times\varepsilon A_{UL}^{\sin(2\varphi_h)}\right]+\\
S_L\lambda\left[\sqrt{1-\varepsilon^2}A_{LL}+\cos\varphi_h\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\varphi_h}\right]+\\
\mathbf{S}_T\left[\begin{array}{l}
\sin\varphi_S\times\left(\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\varphi_S}\right)+\\
\sin(\varphi_h-\varphi_S)\times\left(A_{UT}^{\sin(\varphi_h-\varphi_S)}\right)+\\
\sin(\varphi_h+\varphi_S)\times\left(\varepsilon A_{UT}^{\sin(\varphi_h+\varphi_S)}\right)+\\
\sin(2\varphi_h-\varphi_S)\times\left(\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\varphi_h-\varphi_S)}\right)+\\
\sin(3\varphi_h-\varphi_S)\times\left(\varepsilon A_{UT}^{\sin(3\varphi_h-\varphi_S)}\right)
\end{array}\right]+\\
\mathbf{S}_T\lambda\left[\begin{array}{l}
\cos\varphi_S\times\left(\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\varphi_S}\right)+\\
\cos(\varphi_h-\varphi_S)\times\left(\sqrt{(1-\varepsilon^2)}A_{UT}^{\cos(\varphi_h-\varphi_S)}\right)+\\
\cos(2\varphi_h-\varphi_S)\times\left(\sqrt{2\varepsilon(1-\varepsilon)}A_{UT}^{\cos(2\varphi_h-\varphi_S)}\right)
\end{array}\right]
\end{array}\right\}$$



Top→Bottom

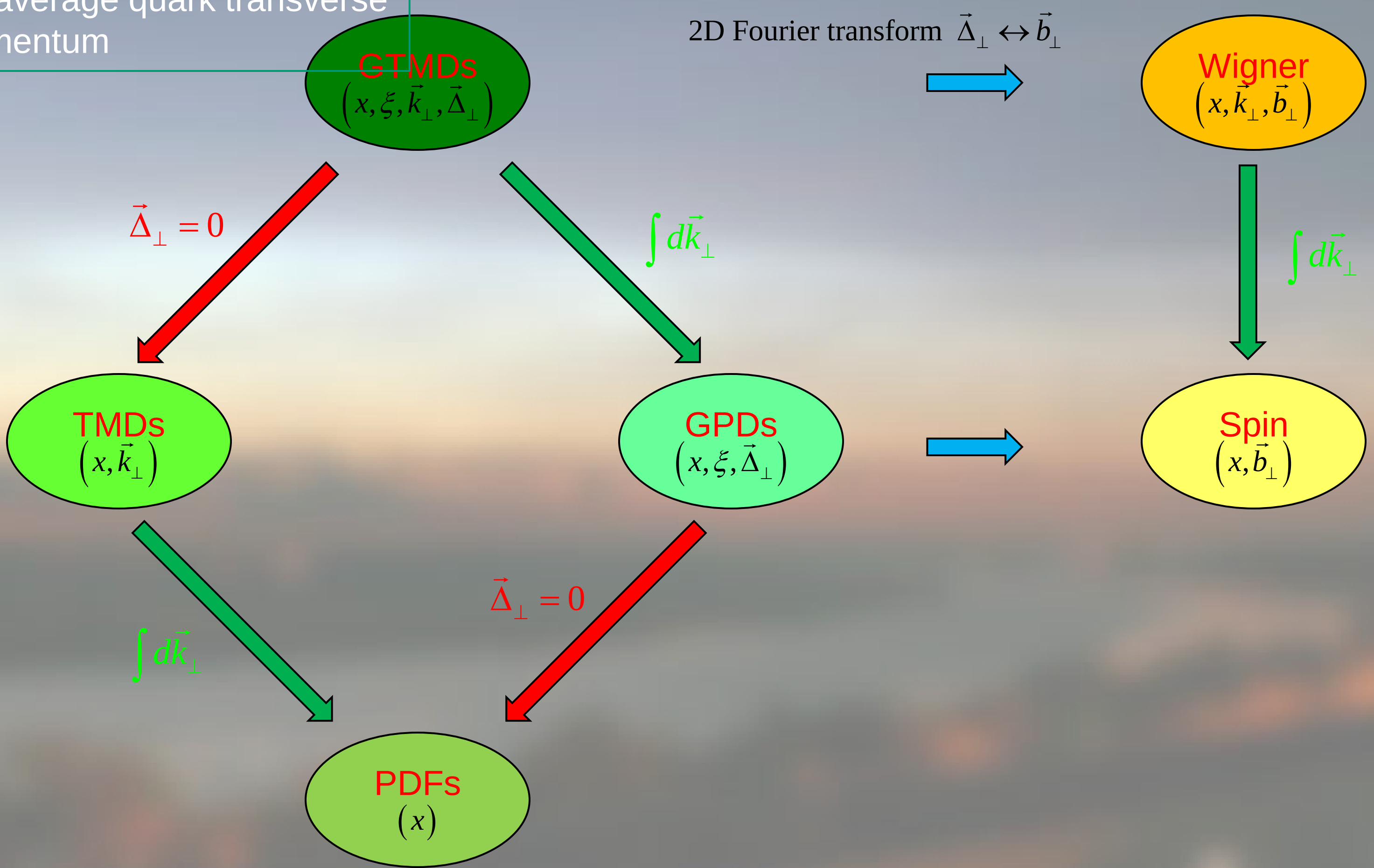
GTMDs

ξ: fraction of longitudinal momentum transver

x: average fraction of quark longitudinal momentum

$\vec{\Delta}_\perp$:: average transverse momentum transfer

$\vec{k}_\perp$: average quark transverse momentum



Longitudinal Structure of the Nucleon

Measurements:

A. Ivanov and A.S. Nunes

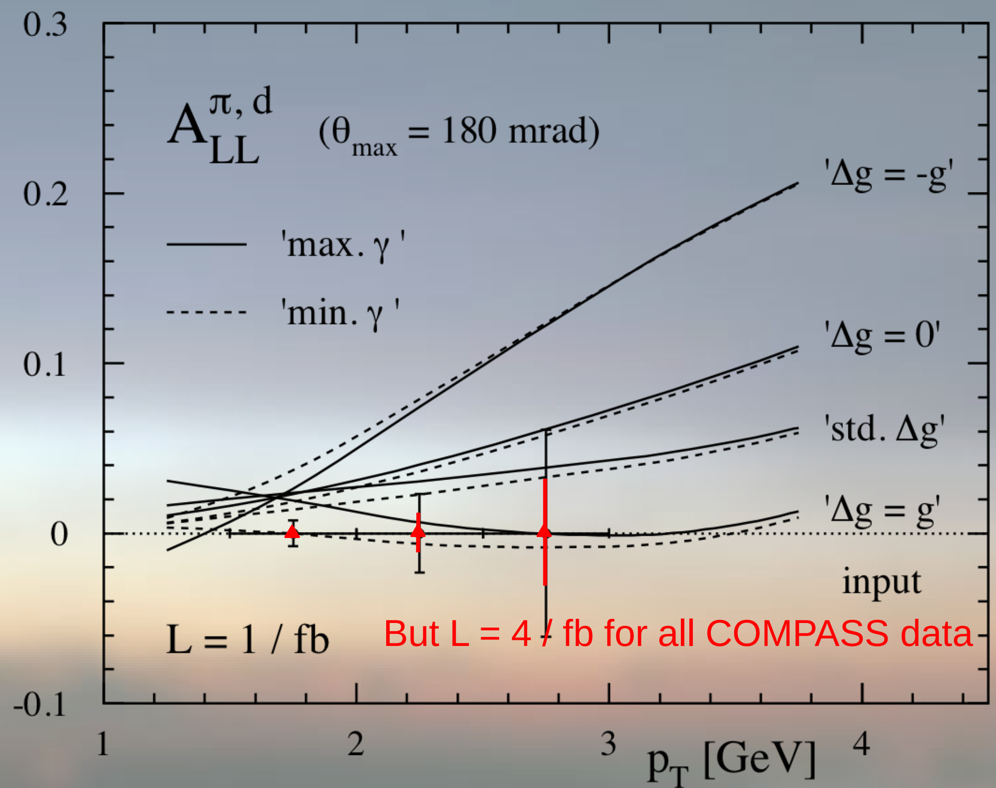
Year		
2006	$A_{LL}^{2h}(Q^2 < 0)$	$\Delta g/g$
2007	$g_1^d(x)$, $\int g_1^d(x)dx$	$\Delta\Sigma = \sum(\Delta q + \Delta\bar{q})$
2008	$A_{1,d}^{h^+-h^-}$	$\Delta u_v + \Delta d_v$
2009	$A_{1,d}, A_{1,d}^{\pi^\pm}, A_{1,d}^{K^\pm}$	$\Delta u_v + \Delta d_v, \Delta\bar{u} + \Delta\bar{d}, \Delta s(= \Delta\bar{s})$
2010	$g_1^p(x)$, $\int g_1^{NS}(x)dx$	$\lvert g_A/g_V \rvert$
2010	$A_{1,d}, A_{1,d}^{\pi^\pm}, A_{1,d}^{K^\pm}$ $A_{1,p}, A_{1,p}^{\pi^\pm}, A_{1,p}^{K^\pm}$	$\Delta u, \Delta d, \Delta\bar{u}, \Delta\bar{d}, \Delta\bar{d}, \Delta s, \Delta\bar{s}$
2013	A_{LL}^{2h}	$\Delta g/g$
2013	$A_D^{\gamma N}$	$\Delta g/g$ in LO and NLO

Results:

- $|g_A/g_V| = 1.28 \pm 0.07 \pm 0.10$
- $\Delta\Sigma = 0.30 \pm 0.01 \pm 0.02$
- $\Delta g/g$
  - $\Delta g/g\,(x \sim 0.13) = -0.06 \pm 0.21 \pm 0.08$ LO Open Charm
  - $\Delta g/g\,(x \sim 0.09) = +0.12 \pm 0.06 \pm 0.06$ LO High-p_T $Q^2>1$ $(GeV/c)^2$
  - $\Delta g/g\,(x \sim 0.09) = +0.01 \pm 0.06 \pm 0.06$ LO High-p_T $Q^2<1$ $(GeV/c)^2$
  - $\Delta g/g\,(x \sim 0.2) = -0.13 \pm 0.15 \pm 0.15$ NLO Open Charm

$A_{LL}^{1h}(p_T)$:polarized hadron γ-production

Projections by Jäger et al. for COMPASS with 1 fb^{-1} (=1/4 COMPASS stat.)

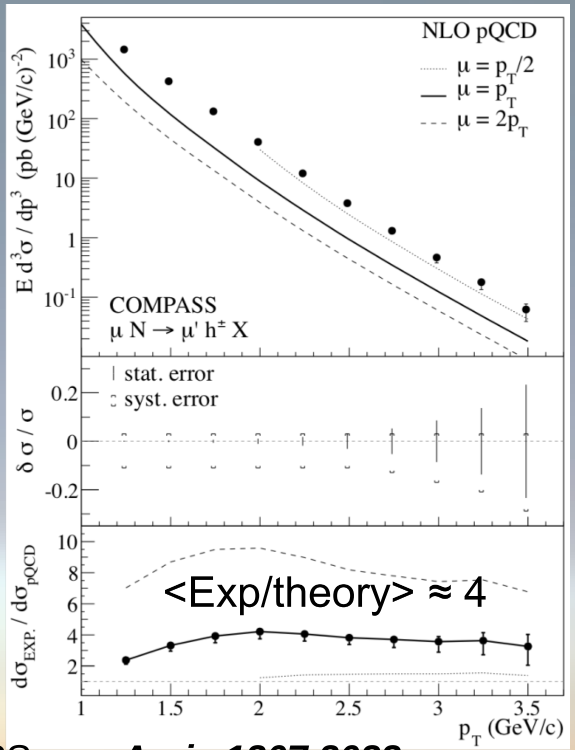


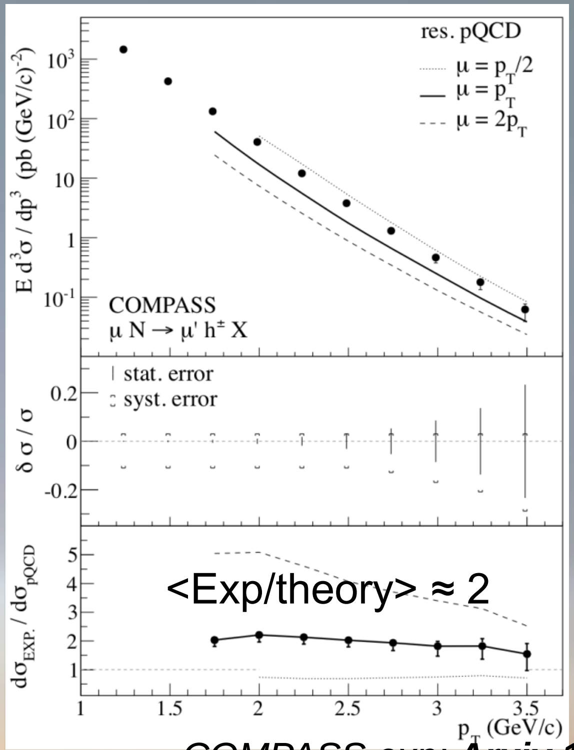
Jäger, Stratmann & Vogelsang: ***EPJ C44 (2005) 533***

So far, only NLO pQCD for polarized case (no resum.)

In perspective: constraining ΔG by $A_{LL}^{1h}(p_T)$ (**working on**)

High-p_T hadron production x-section



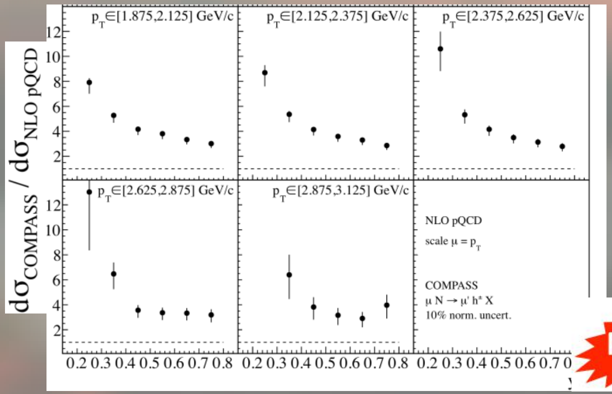


COMPASS exp: ***Arxiv 1207.2022***
Vogelsang et al. NLO pQCD : ***EPJ C44 (2005) 533***

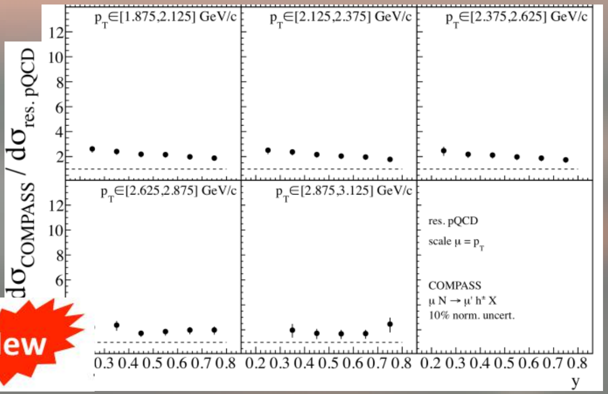
COMPASS exp: ***Arxiv 1207.2022***
Vogelsang et al. NLO pQCD + res. : ***Arxiv 1305.6468***

Strong y dep.

☹



New



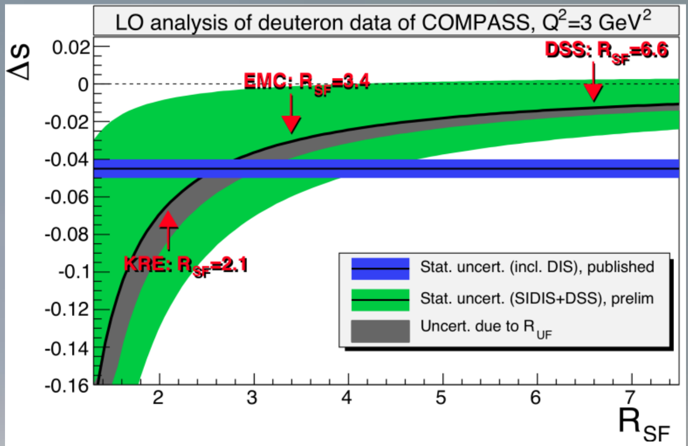
y dep. gone

☺

Strange sea polarization

INCONSISTENT RESULTS:

- From DIS $(\Delta s + \Delta \bar{s}) < 0$ (≈ -0.08) with $\Gamma_1^N \sim 0.05$ and $a_8 = 0.585$
- From SIDIS, no evidence of $(\Delta s + \Delta \bar{s})<0$ in $0.004 < x < 0.7$

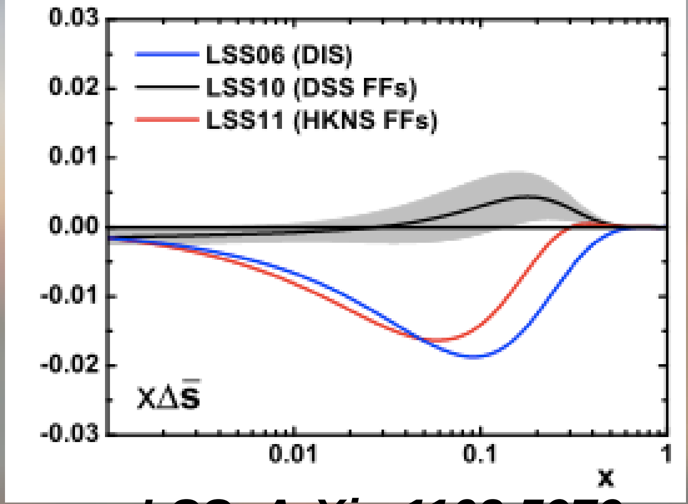


- $K^{\pm}$ asymmetries from deuteron data

$$\boxed{\frac{\Delta s}{s} = A_1^{\mathrm{d}} + \left(A_1^{K^+ + K^-} - A_1^{\mathrm{d}}\right)\frac{Q/s + \alpha}{\alpha - 0.8}}$$

- $Q = u + \bar{u} + d + \bar{d}$, $\alpha = \frac{2R_{UF} + 2R_{SF}}{3R_{UF} + 2}$

- $R_{UF} = \frac{\int D_d^{K^+}(z)\mathrm{d}z}{\int D_u^{K^+}(z)\mathrm{d}z}$, $R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)\mathrm{d}z}{\int D_u^{K^+}(z)\mathrm{d}z}$



LSS: ArXiv:1103.5979

Large sensitivity of Δs to « strange to favoured » FF ratio
→ try to extract R_{SF} from Kaon multiplicities

Hadron multiplicities

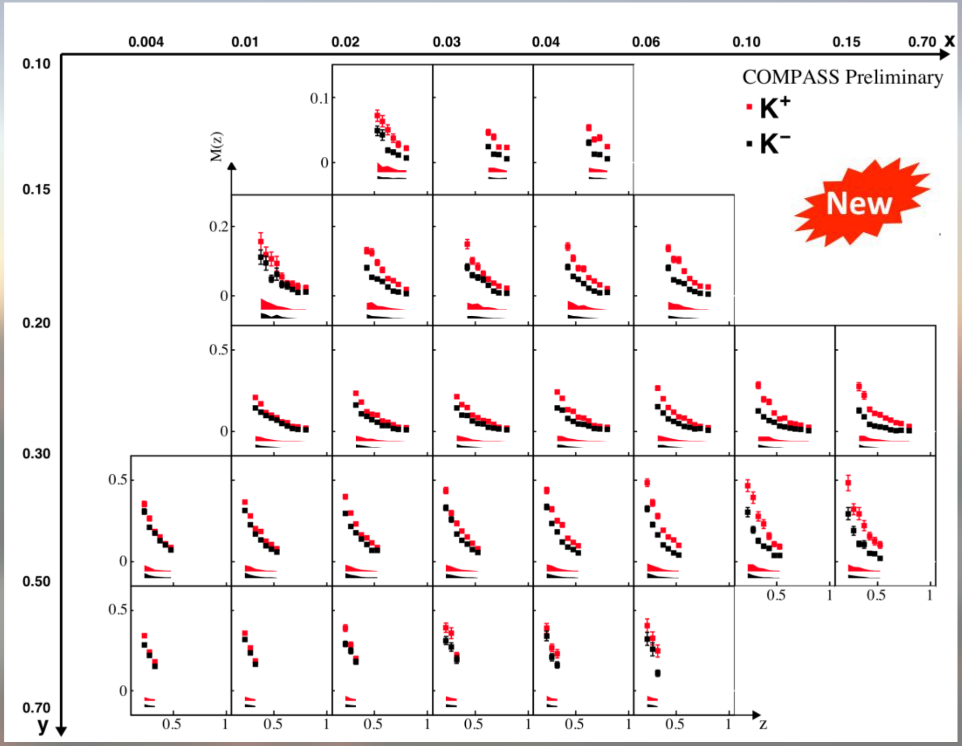
N. du Fresne

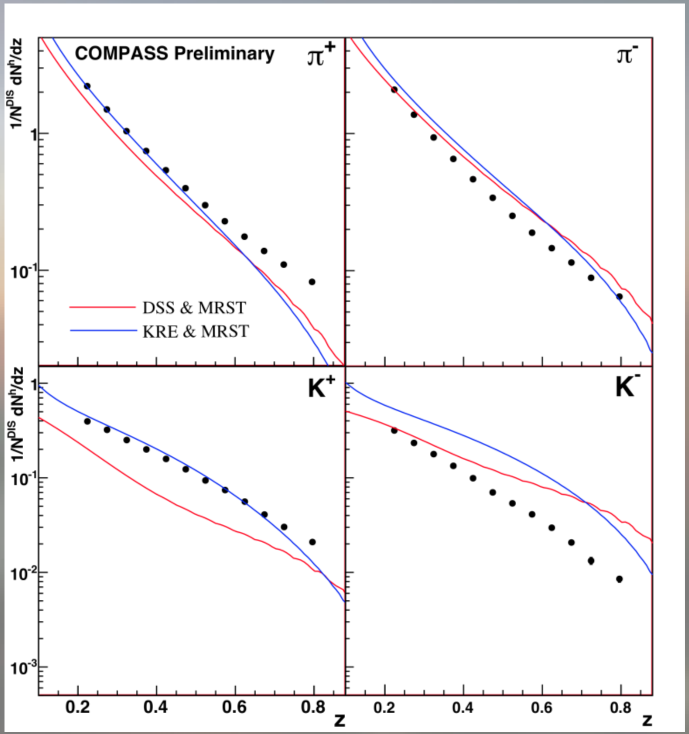
$$M^h(x,Q^2,z) = \frac{d^3\sigma^h/dxdQ^2dz}{d^2\sigma^{DIS}/dxdQ^2} = \frac{\sum_q e_q^2(q(x,Q^2)D_q^h(z)+\bar{q}(x,Q^2)D_{\bar{q}}^h(z))}{\sum_q e_q^2(q(x,Q^2)+\bar{q}(x,Q^2))}$$

h=π,K (identified by Ring Imaging Cerenkov)

➤M^h depend on unpolarized PDF's:

- *u(x),d(x) unpolarized PDF well known*
- *strange PDF s(x) less well known*





Transverse Structure of the Nucleon

Measurements:

F. Bradamante

Year		
2005	$A^h_{Siv,d}, A^h_{Col,d}$	First ^{6}LiD data
2006	$A^h_{Siv,d}, A^h_{Col,d}$	Full ^{6}LiD statistics
2009	$A^{\pi^\pm, K^\pm, K^0_S}_{Siv,d}, A^{\pi^\pm, K^\pm, K^0_S}_{Col,d}$	Full ^{6}LiD statistics
2010	$A^h_{Siv,p}, A^h_{Col,p}$	2007 NH_3 data
2012	$A^{sin\phi_{RS}}_{UT,d}, A^{sin\phi_{RS}}_{UT,p}$	Full ^{6}LiD and NH_3statistics
2012	$A^h_{Siv,p}, A^h_{Col,p}$	Full NH_3statistics
2012	$A^{sin(\phi_\rho - \phi_S)}_{UT,d}, A^{sin(\phi_\rho - \phi_S)}_{UT,p}$	Exclusive ρ^0 production− Full ^{6}LiD and NH_3statistics
2013	$dn^h/(dN^\mu dz\, dp_T^2)$	Unpolarized multiplicities on d

P. Sznajder

Few facts:

- The measurement of transversity was in the COMPASS 1996 proposal

> We propose to measure in semi-inclusive DIS on transversely polarised proton and deuterium targets the transverse spin distribution functions $\Delta_T q(x) = q_\uparrow(x) - q_\downarrow(x)$, where $\uparrow$ ($\downarrow$) indicates a quark polarisation parallel (antiparallel) to the transverse polarisation of the nucleon. Hadron identification allows to tag the quark flavour.

- The measurement of the Sivers PDF was added in the program soon after … the other TMD with the developments over the years

- This field has grown considerably

Sivers Asymmetry

Sivers: correlates nucleon spin & quark transverse momentum k_T /T-ODD

at LO:

$$A_{Siv} = \frac{\sum_q e_q^2 f_{1Tq}^{\perp} \otimes D_q^h}{\sum_q e_q^2 q \otimes D_q^h}$$

$$\boxed{\mu p^{\uparrow} \rightarrow \mu X h^{\pm}}$$

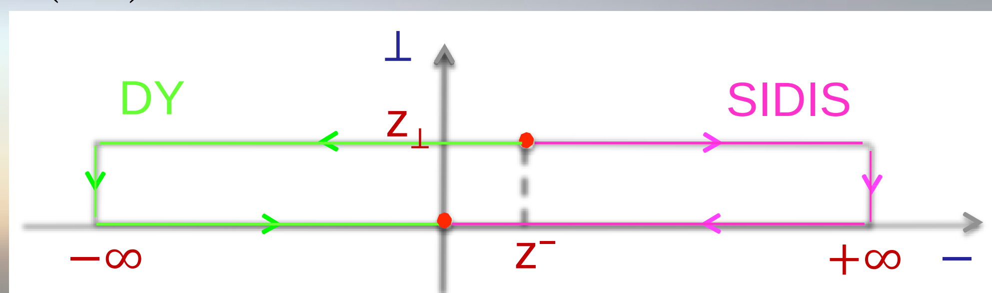
The Sivers PDF	
1992	Sivers proposes $f_{1Tq}^{\perp}$
1993	J. Collins proofs $f_{1Tq}^{\perp} = 0$ for T invariance
2002	S. Brodsky, Hwang and Schmidt demonstrate that $f_{1Tq}^{\perp}$ may be $\neq 0$ due to FSI
2002	J. Collins shows that $\left(f_{1Tq}^{\perp}\right)_{DY} = -\left(f_{1Tq}^{\perp}\right)_{SIDIS}$
2004	HERMES on p: $A_{Siv}^{\pi^+} \neq 0$ and $A_{Siv}^{\pi^-} = 0$
2004	COMPASS on d: $A_{Siv}^{\pi^+} = 0$ and $A_{Siv}^{\pi^-} = 0$
2008	COMPASS on p: $A_{Siv}^{\pi^+} \neq 0$ and $A_{Siv}^{\pi^-} = 0$

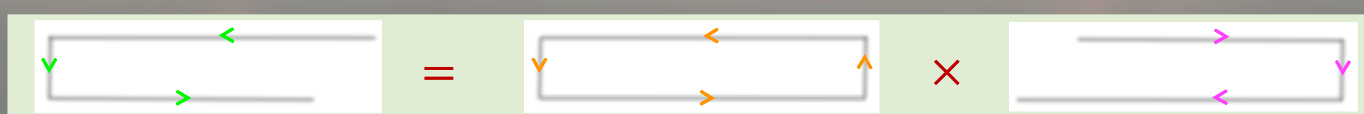
Sivers function:

a pseudo-univeral (process dependent) TMD

an intriguing consequence of the local color gauge invariance of the strong interaction and the corresponding non-trivial gauge-link structures.

$$f_{q/N^{\uparrow}}\left(x,\vec{k}_{\perp},\vec{S}\right)=\int\frac{dz^{-}d^{2}z_{\perp}}{(2\pi)^{3}}e^{i\left(xp^{+}z^{-}-\vec{k}_{\perp}\cdot\vec{z}_{\perp}\right)}\left\langle p,\vec{S}\right|\bar{\psi}_{q}\left(0^{-},\vec{0}_{\perp}\right)\mathcal{U}[\mathcal{C}_{b}]\frac{\gamma^{+}}{2}\,\psi_{q}\left(z^{-},\vec{z}_{\perp}\right)\left|p,\vec{S}\right\rangle$$





Parity and Time reversal invariance ⇒

$$\left(f_{1Tq}^{\perp}\right)_{DY}=-\left(f_{1Tq}^{\perp}\right)_{SIDIS}$$

Most critical test to TMD approach to SSA

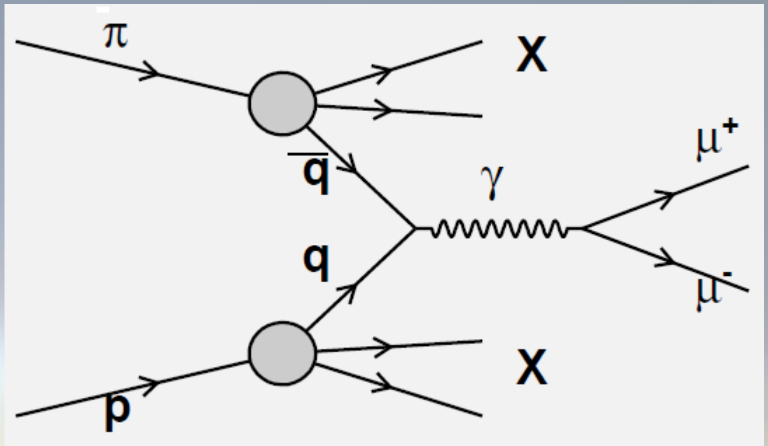
NEAR FUTURE:

- polarized DY
- unpolarized SIDIS
- DVCS

Polarized Drell-Yan

Drell-Yan $\pi^- p^\uparrow \rightarrow \mu^+ \mu^- X$

O. Denisov



Cross sections:

In SIDIS: convolution of a TMD with a fragmentation function

In DY: convolution of 2 TMDs $\sigma^{DY} \propto f_{\bar{u}|\pi^-} \otimes f_{u|p}$

→ complementary information and universality test

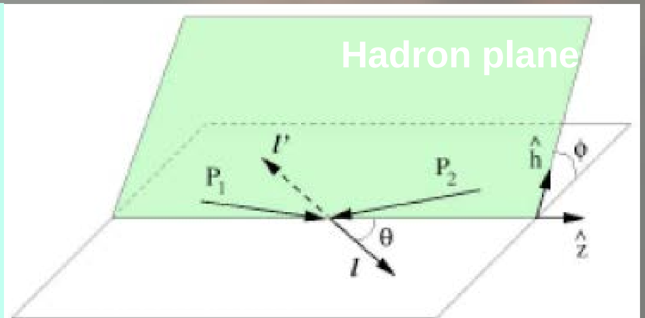
The polarized Drell-Yan process in $\pi^- p$

$$\frac{d\sigma}{d^4q\,d\Omega} = \left[\frac{\alpha^2}{Fq^2}\left(F_{UU}^1 + F_{UU}^1\right)\left(1 + A_{UU}^1\cos^2\theta\right)\right]\times$$

$$\left\{ \begin{array}{l} 1 + \cos\varphi \times D_{[\sin 2\theta]} A_{UU}^{\cos\varphi} + \cos(2\varphi)\times D_{[\sin^2\theta]} A_{UU}^{\cos(2\varphi_h)} + \\ S_L \left[\sin\varphi \times D_{[\sin 2\theta]} A_{UL}^{\sin\varphi} + \sin(2\varphi)\times D_{[\sin^2\theta]} A_{UL}^{\sin(2\varphi)}\right] + \\ \mathbf{S}_T \left[\begin{array}{l} \sin\varphi_S \times \left(D_{[1]} A_{UT}^{\sin\varphi_S} + D_{[\cos^2\theta]} \tilde{A}_{UT}^{\sin\varphi_S}\right) + \\ \sin(\varphi - \varphi_S)\times\left(D_{[\sin 2\theta]} A_{UT}^{\sin(\varphi-\varphi_S)}\right) + \\ \sin(\varphi + \varphi_S)\times\left(D_{[\sin 2\theta]} A_{UT}^{\sin(\varphi+\varphi_S)}\right) + \\ \sin(2\varphi - \varphi_S)\times\left(D_{[\sin^2\theta]} A_{UT}^{\sin(2\varphi-\varphi_S)}\right) + \\ \sin(2\varphi + \varphi_S)\times\left(D_{[\sin^2\theta]} A_{UU}^{\sin(2\varphi_h+\varphi_S)}\right) \end{array} \right] + \end{array} \right\}$$

➔Access to TMDs for incoming pion ⊗ target nucleon
TMD as Transversity, Sivers, Boer-Mulders, pretzelosity

Collins-Soper frame (of virtual photon)
θ, φ lepton plane wrt hadron plane
target rest frame
φ_S target transverse spin vector /virtual photon

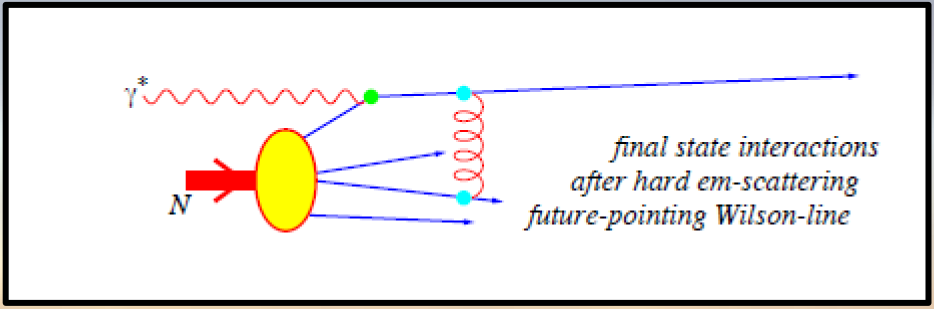


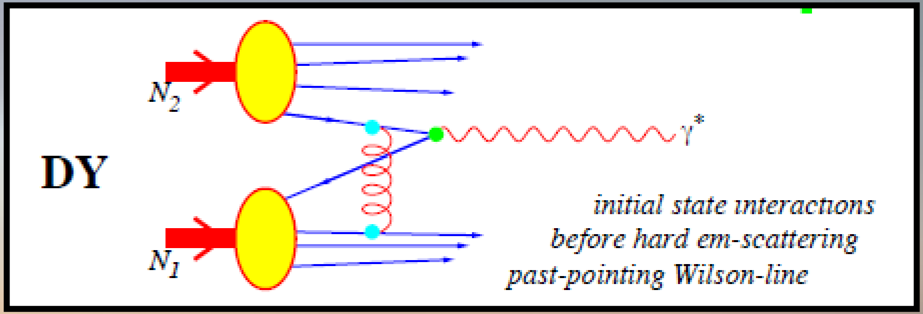
Test of universality

T-odd character of the Boer-Mulders and Sivers functions

In order not to be forced to vanish by time-reversal invariance
the SSA requires an interaction phase generated by
a rescattering of the struck parton in the field of the hadron remnant

Time reversal





these functions are process dependent, they change sign to provide the gauge invariance

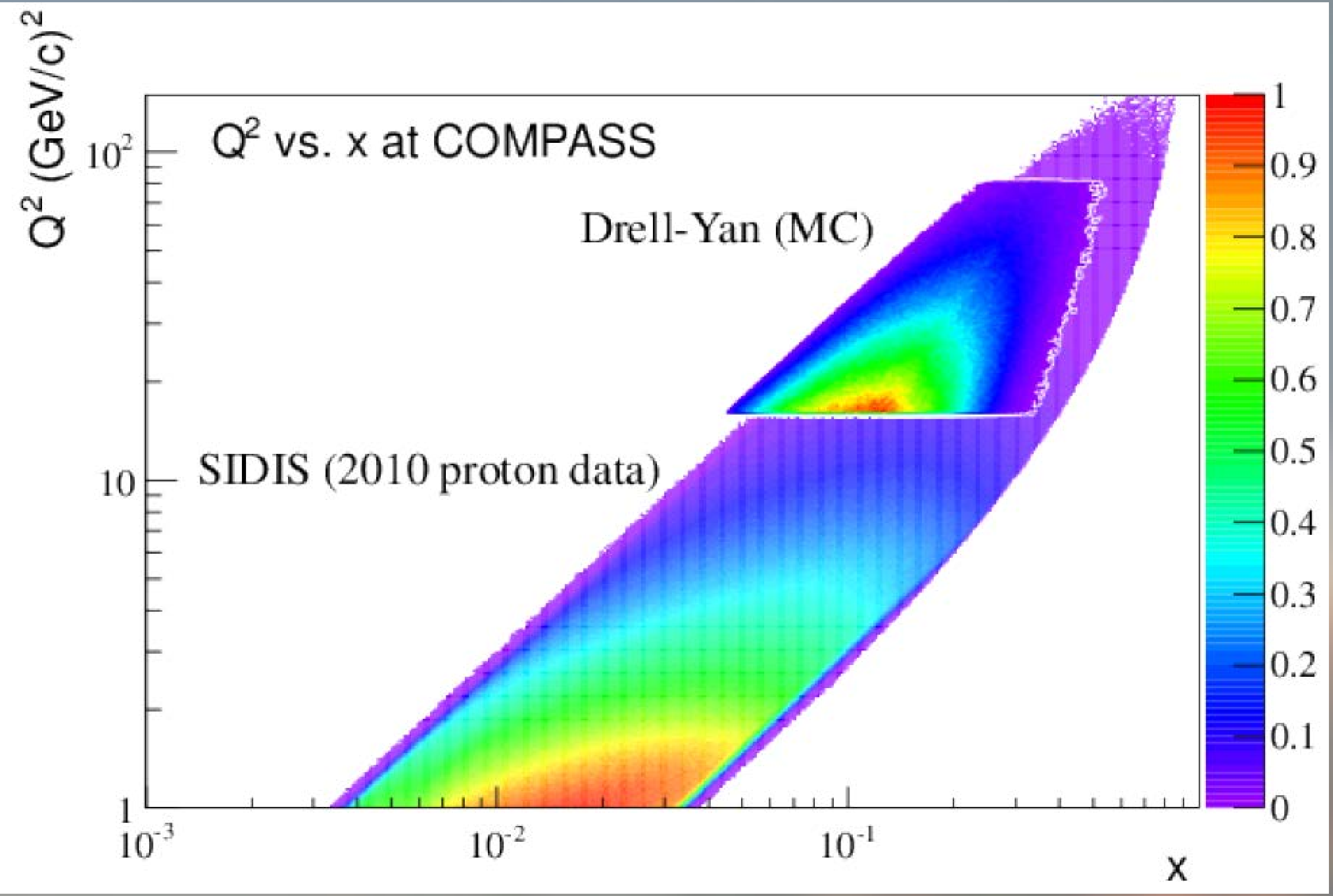
Boer-Mulders

$$\boxed{h_1^{\perp}(SIDIS) = -h_1^{\perp}(DY)}$$

Sivers

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

Q^2 vs x phase space at COMPASS



The phase spaces of the two processes overlap at COMPASS
➔ Consistent extraction of TMD DPFs in the same region

Importance of unpolarized SIDIS For TMDs

- The cross-section dependence from p_T^h results from:
  - intrinsic k_T of the quarks
  - $p_\perp$ generated in the quark fragmentation

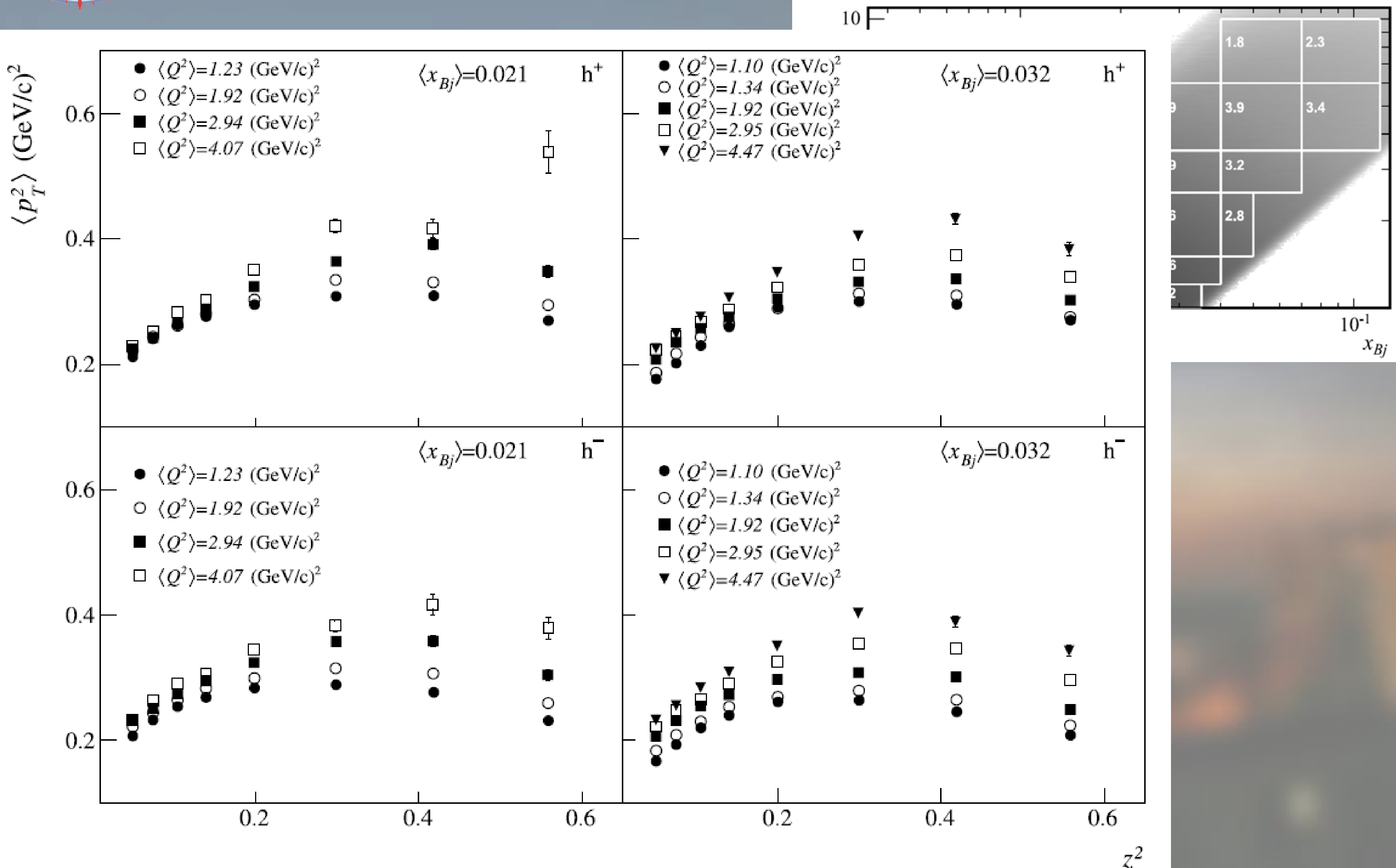
- The azimuthal modulations in the unpolarized cross-sections comes from:
  - Intrinsic k_T of the quarsk
  - The Boer-Mulders PDF

These are difficult measurements were one has to correct for the apparatus acceptance

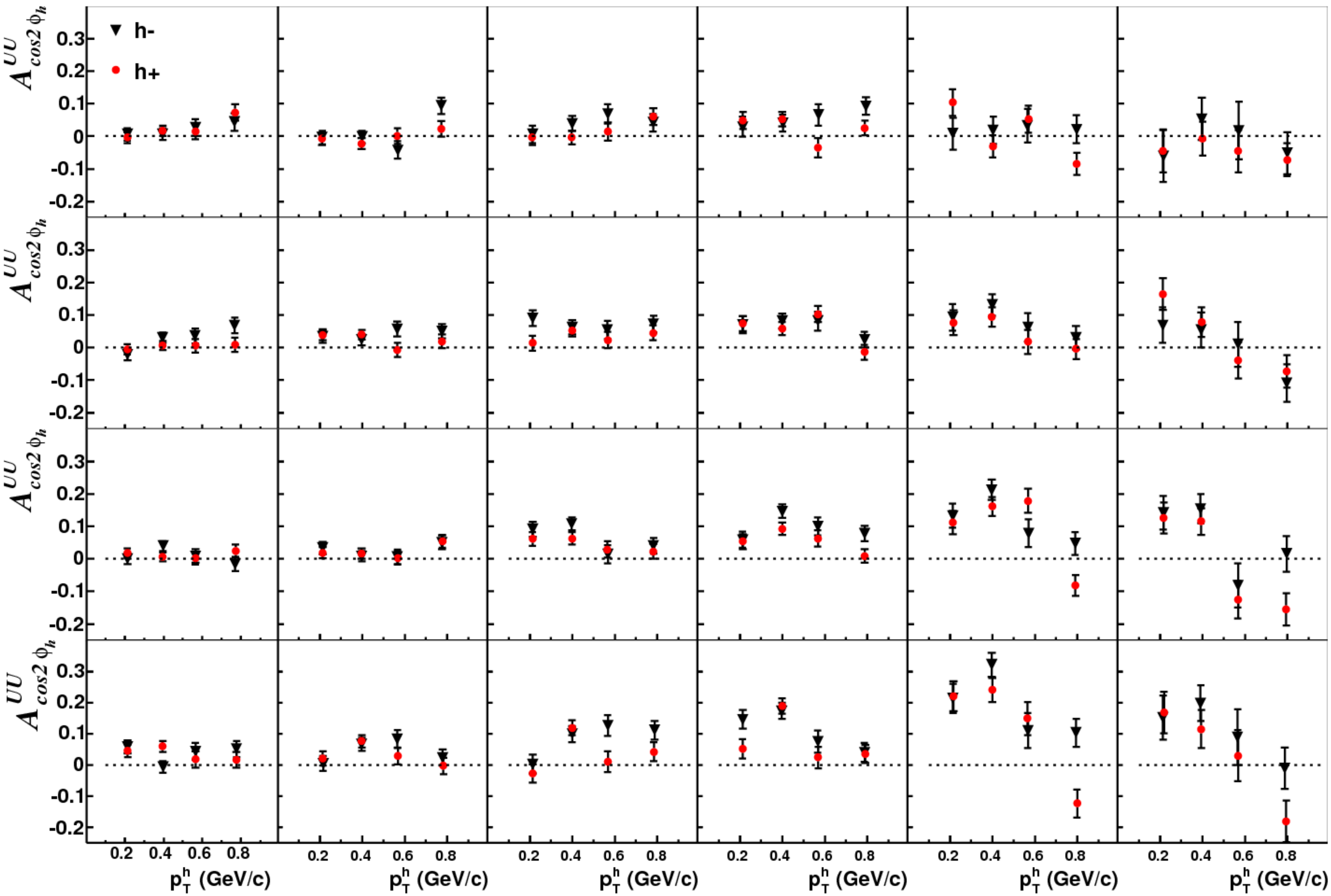
- COMPASS has
  - results on ^6LiD $(\sim d)$ from 2004/6 data
  - No measurements on p since on NH_3 $(\sim p)$ nuclear effects may be important

- ⇒COMPASS-II, measurements on LH_2 in parallel with DVCS

X-section dep. from p_T^h

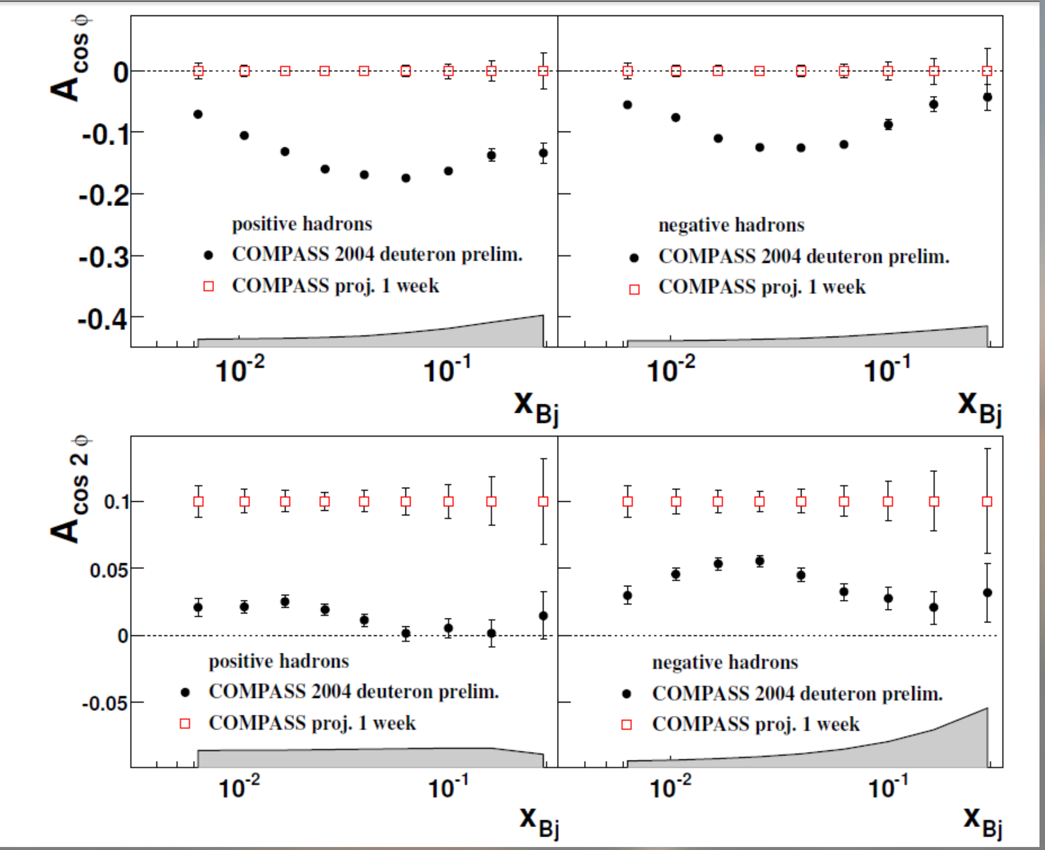


COMPASS ^{6}LiD (25% of 2004 data) preliminary



→ many data collected and still to be collected in SIDIS with GPD program

SIDIS AT COMPASS-II



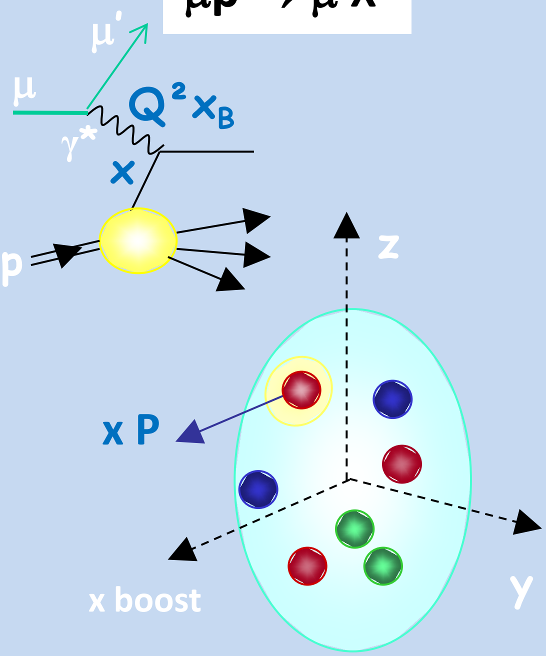
1 week with the 2.5 m long LH2 target

From inclusive to exclusive reactions (3D tomography)

A. Sandacz

Deep Inelastic Scattering

$\mu p \rightarrow \mu' X$

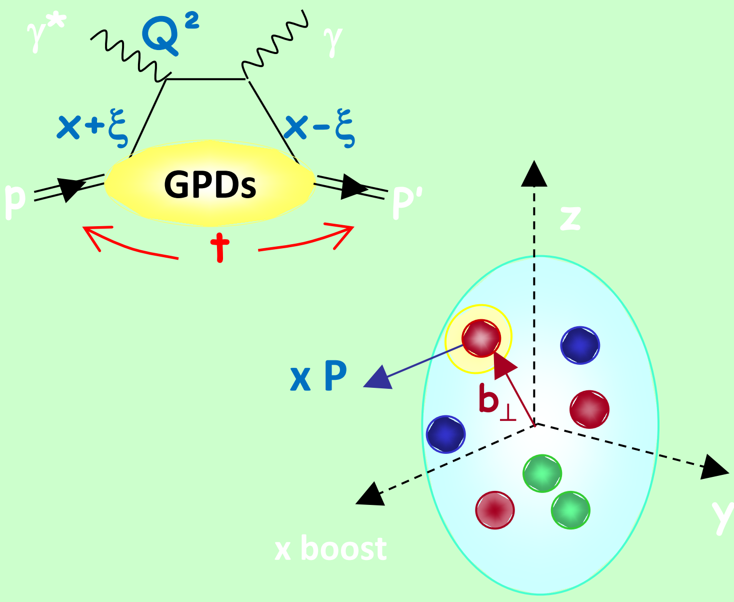


Partons distributions $q(x)$

P_x

Deeply Virtual Compton Scattering

$\mu p \rightarrow \mu' p' \gamma$

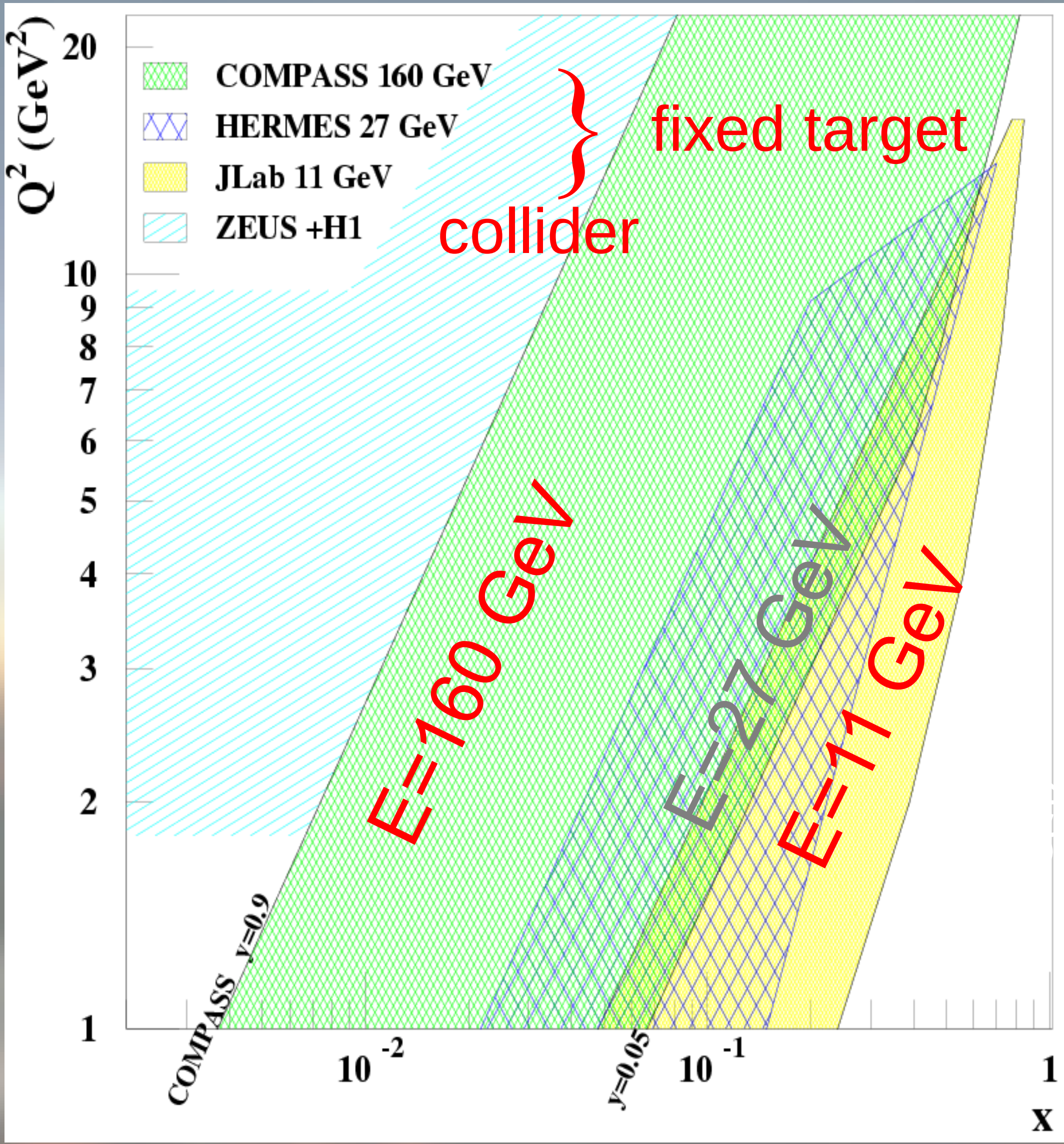


Generalized Partons Distrib. $H(x, \xi, t)$

$(P_{x,}\ b_\perp)$

Beyond collinear approximation -> Trans. Position ($b_\perp$) Dependent GPD in Excl. React.
-> as Trans. Momentum ($k_\perp$) Dep. PDF or TMD in SIDIS & DY

Kinematic domain (Q^2, x_B) for GPDs



COMPASS unique for GPDs

CERN High energy muon beam

- ✓ **100 - 190 GeV**
- ✓ **$\mu^{+\downarrow}$ and $\mu^{-\uparrow}$ available**
- ✓ **80% Polarisation with opposite polarization**
- ✓ **4.6 10^8 μ^+**

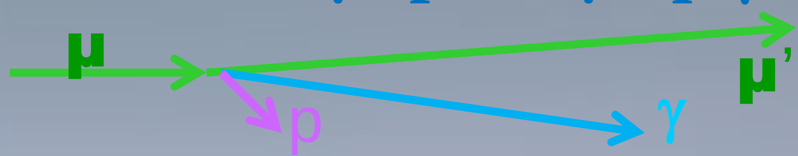
➔ **Lumi= 10^{32} cm^{-2} s^{-1} with 2.5m LH2 target**

- ➢ Explore the intermediate x_{Bj} region
- ➢ Uncovered region between ZEUS+H1 & HERMES **+ Jlab** before new colliders may be available

It's time to show the impact of COMPASS
=> goal of the 2012 DVCS pilot run

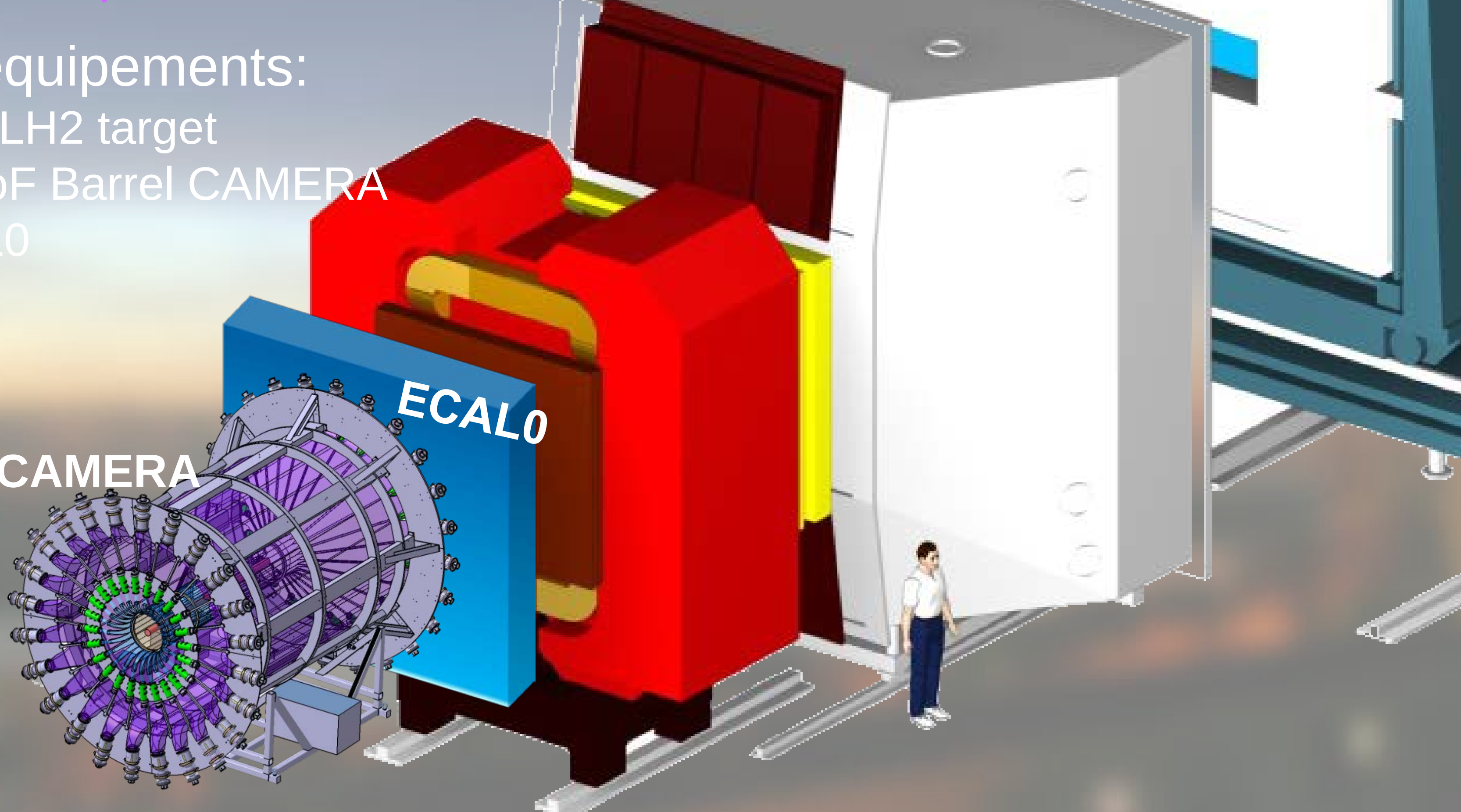
Upgrades of the COMPASS spectrometer

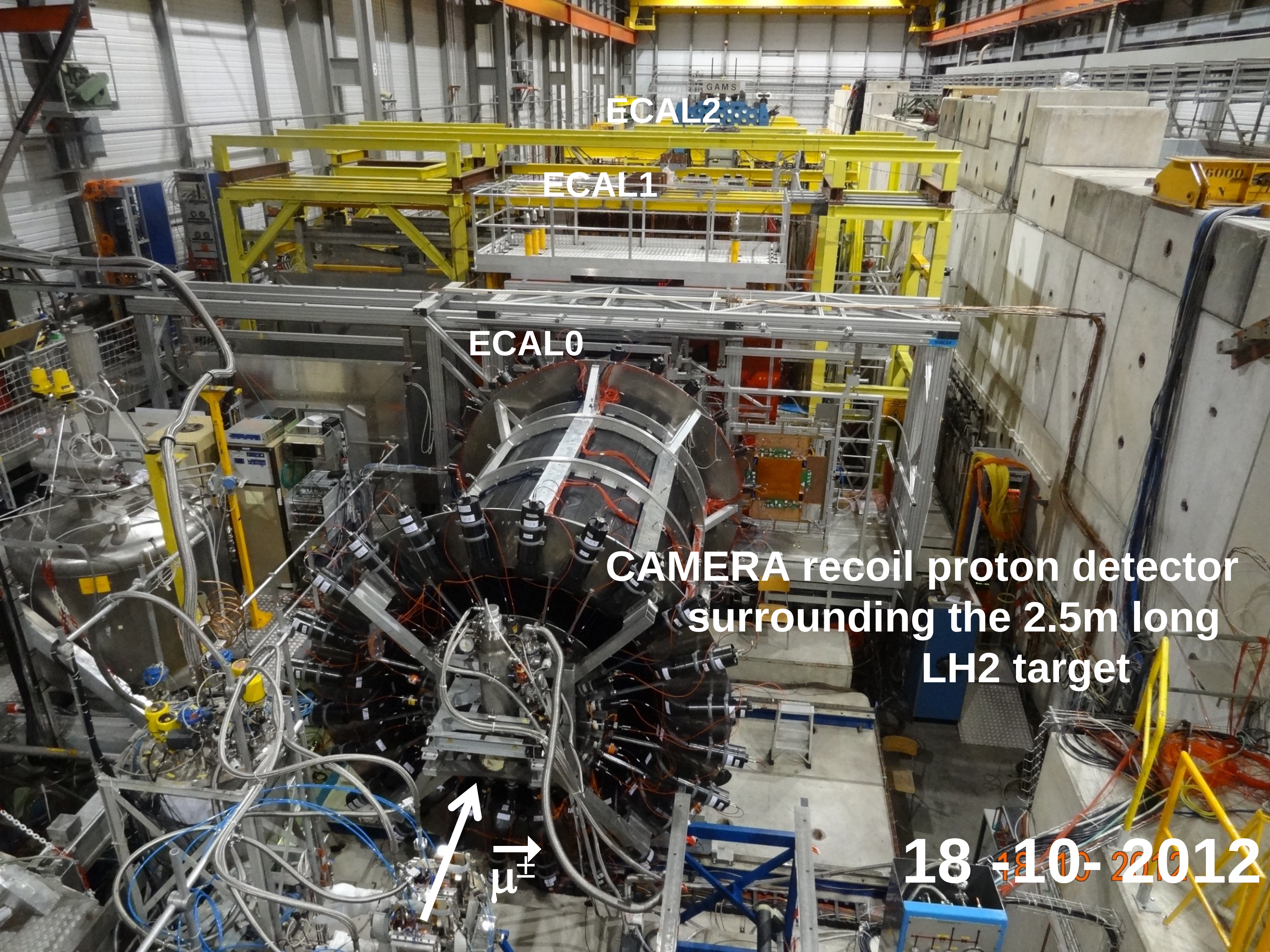
DVCS : $\mu\ p \rightarrow \mu'\ p\ \gamma$



New equipements:

- 2.5m LH2 target
- 4m ToF Barrel CAMERA
- ECAL0




GAMS
ECAL2
ECAL1
ECAL0
CAMERA recoil proton detector
surrounding the 2.5m long
LH2 target
$\vec{\mu}^{\pm}$
18-10-2012

Deeply Virtual Compton Scattering

$$d\boldsymbol{\sigma}_{(\mu p\rightarrow \mu p\gamma)} = d\boldsymbol{\sigma}^{BH} + d\boldsymbol{\sigma}^{DVCS}_{unpol} + \cancel{P_{\mu}\, d\boldsymbol{\sigma}^{DVCS}_{pol}}$$

$$+ \cancel{e_{\mu}}\, a^{BH}\, \mathcal{R}e\, A^{DVCS} \qquad + e_{\mu}\, P_{\mu}\, a^{BH}\, \mathcal{I}m\, A^{DVCS}$$

Phase 1: **the transverse imaging**

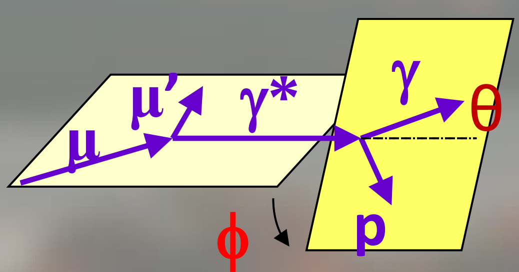
with $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam + unpolarized 2.5m long LH2 (proton) target

$$S_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow}) \propto d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + K\cdot s_1^{Int}\sin\varphi$$

Using $S_{CS,U}$ and BH subtraction and integration over ϕ

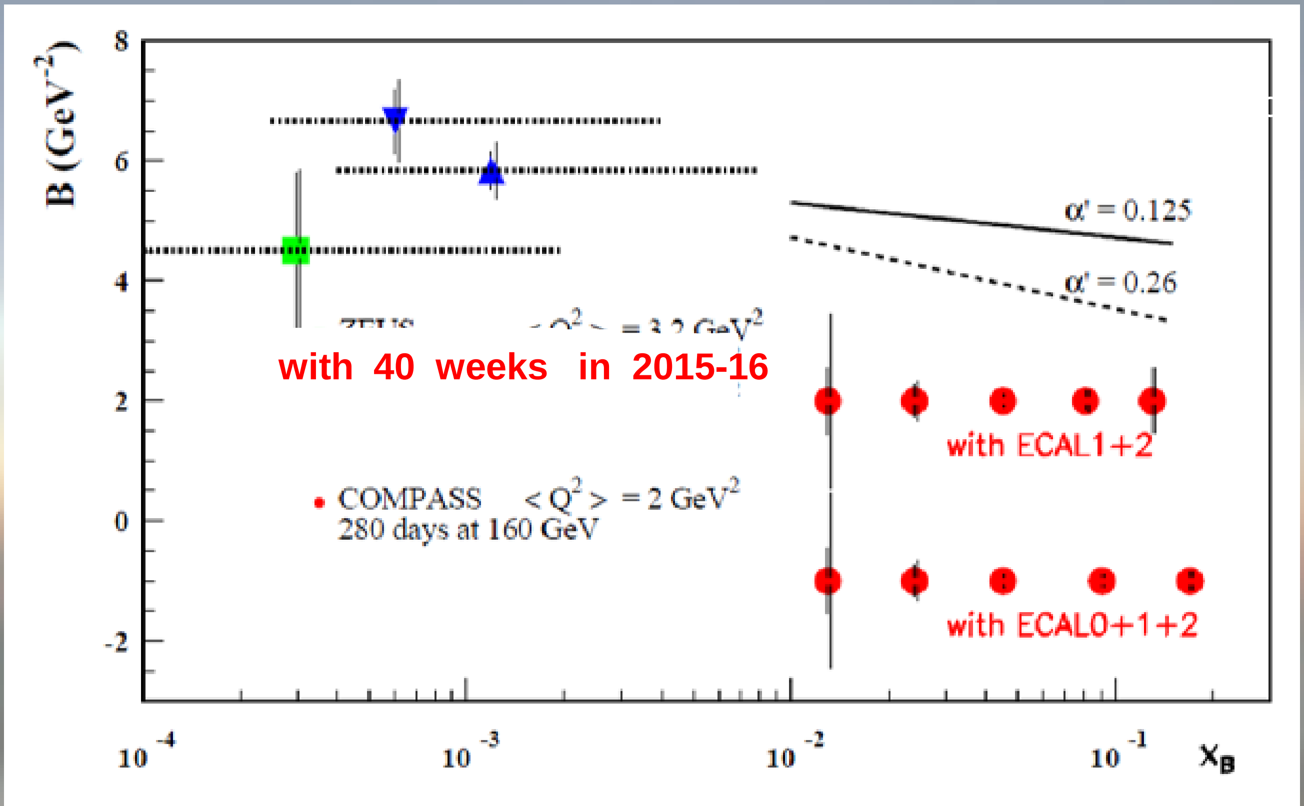
$\downarrow$

$d\sigma^{DVCS}/dt \sim \exp(-B|t|)$



Transverse imaging

$d\sigma^{DVCS}/dt \sim \exp(-B|t|)$



2 years of data
160 GeV muon beam
2.5m LH_2 target
$\varepsilon_{global} = 10\%$

ansatz at small x_B
inspired by
Regge Phenomenology:

$B(x_B) = b_0 + 2\,\alpha' \ln(x_0/x_B)$

α' slope of Regge traject

Deeply Virtual Compton Scattering

$$d\boldsymbol{\sigma}_{(\mu p\to\mu p\gamma)} = \cancel{d\boldsymbol{\sigma}^{BH}} + \cancel{d\boldsymbol{\sigma}^{DVCS}_{unpol}} + P_\mu\, d\boldsymbol{\sigma}^{DVCS}_{pol}$$

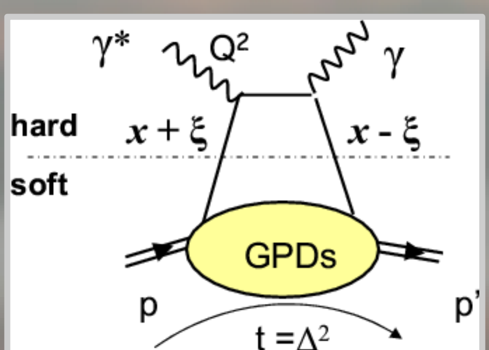
$$+\ e_\mu\, a^{BH}\, \mathcal{R}e\, A^{DVCS} \qquad + \cancel{e_\mu P_\mu}\, a^{BH}\, \mathcal{I}m$$

Phase 1: DVCS experiment to constrain GPD H

with $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam + unpolarized 2.5m long LH2 (proton) target

$$\mathcal{D}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow}) \propto \boxed{c_0^{Int} + c_1^{Int}\cos\phi} \quad \text{and} \quad c_{0,1}^{Int} \sim \mathcal{R}e(F_1\mathcal{H})$$

$$\mathcal{S}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow}) \propto \boxed{d\sigma^{BH} + c_0^{DVCS} + K\cdot s_1^{Int}\sin\varphi} \quad \text{and} \quad s_1^{Int} \sim \mathcal{I}m(F_1\mathcal{H})$$



$\xi \sim x_B / (2-x_B)$

Note: dominance of **H** at COMPASS kinematics

$$\mathcal{I}m\,\mathcal{H}(\xi,t) = \mathbf{H}(x=\xi,\xi,t)$$

$$\mathcal{R}e\,\mathcal{H}(\xi,t) = \mathcal{P}\int dx\, \frac{\mathbf{H}(x,\xi,t)}{x-\xi} = \mathcal{P}\int dx\, \frac{\mathbf{H}(x,x,t)}{x-\xi} + \mathbf{D}(t)$$

$\mathcal{R}e$ part of the *Compton Form Factors* linked to the *$\mathcal{D}$ term*

Summary for GPD @ COMPASS

GPDs investigated with Hard Exclusive Photon and Meson Production

COMPASS-II 2016-17: **with LH_2 target + RPD (phase 1)** $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ **160 GeV**

- ✓ the t-slope of the DVCS and HEMP cross section
  → transverse distribution of partons
- ✓ the Beam Charge and Spin Sum and Difference
  → $\mathcal{Re}\, T^{DVCS}$ and $\mathcal{Im}\, T^{DVCS}$ for the GPD H determination
- ✓ Vector Meson $\rho^0, \rho^+, \omega, \Phi$
- ✓ Pseudo-saclar π^0

Using the 2007-10 data: **transv. polarized NH_3 target without RPD**

More in the FUTURE:

	physics item	key aspects of the measurement
Hadron	glueballs	280 GeV beam, higher intensity, π, K and $\bar{p}$ separation
GPD	E	transversely polarized proton target
SIDIS	h_1^d with same accuracy as h_1^u $f_1^\perp$ evolution	transversely polarized deuteron target 100 GeV and transversely polarized proton target
DY	universality of TMD PDFs flavor separation test of the Lam-Tung relation EMC effect in DY	higher statistics with transversely polarized proton target transversely polarized deuteron target hydrogen target different nuclear targets

For the next 10 years

- before any collider is available,
- and complementary to Jlab 12 GeV

COMPASS@CERN can be a major player in QCD physics using its unique high energy both:

- hadron beam and
- positive and negative muon beams

Looking even further…a polarized lepton-nucleon collider well be a mandatory tool


Thank You