COMPASS Recent Results and Future Physics

COMPASS at CERN: Overview

Pion Polarisability

Spectroscopy: Resonance Production and S-wave in

$$\pi^-(190\ GeV) + p \rightarrow \pi^- + \pi^- + \pi^+ + p_{recoil}$$

Nucleon Helicity Structure

Generalized Parton Distributions from Exclusive μ-nucleon Scattering

Transverse Spin Physics in SIDIS and Drell-Yan processes.

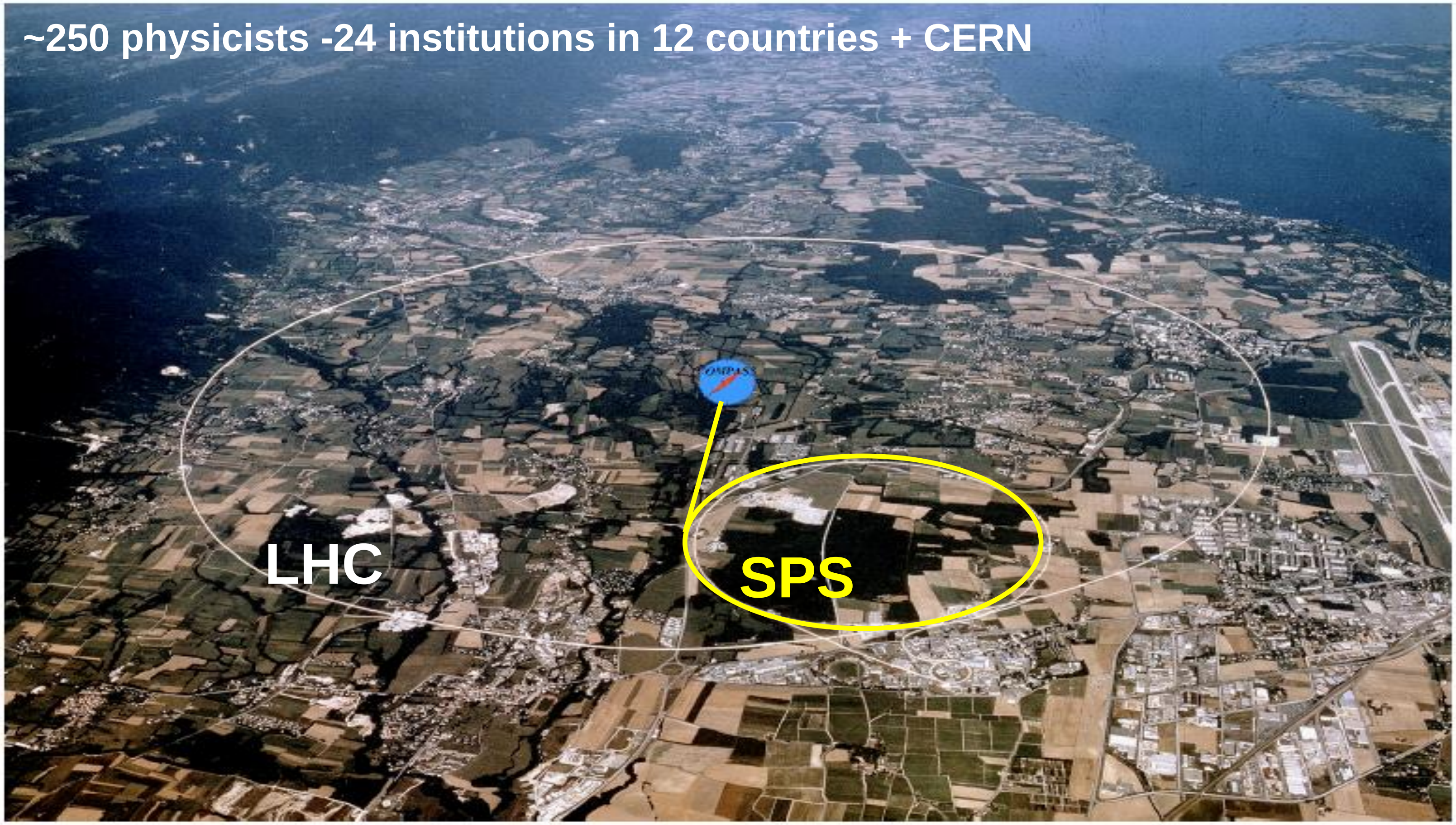
see Takahiro Iwata's and
Wen-Chen Chang's talks tomorrow.

Future Physics with RF separated Kaon and Anti-Proton Beams:

- o Meson Structure
- o Spectroscopy: Hadrons with Strangeness

COMPASS at the CERN SPS

COmmon Muon Proton Apparatus for Structure and Spectroscopy



COMPASS at the CERN SPS

COmmon Muon Proton Apparatus for Structure and Spectroscopy

Physics Program:

Hadron Spectroscopy (p-, π-, K-beams)

- Light mesons, glue-balls, exotic mesons
- Polarisability of the pion and kaon

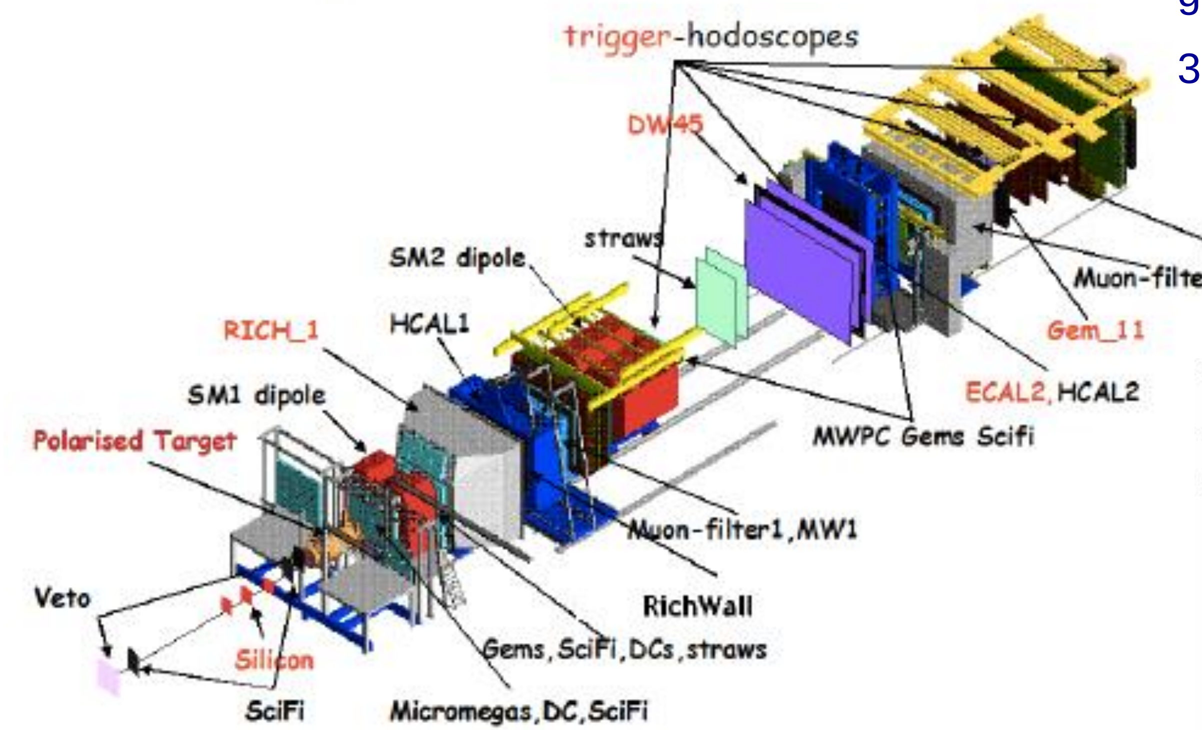
Nucleon Structure (μ-beam in DIS and SIDS and DY with π-beams)

- Longitudinal spin structure
- Transverse momentum and transverse spin structure
- GPDs

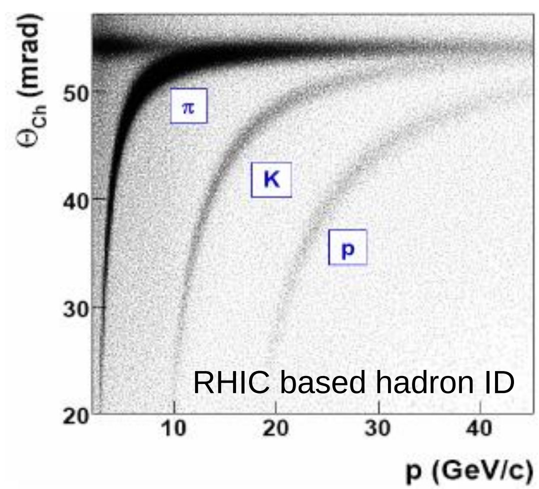
COMPASS – Important Instrumentation Features

Two staged large acceptance spectrometers with high rate capability:

1. Large Angle Spectrometer (LAS)
2. Small Angle Spectrometer (SAS)



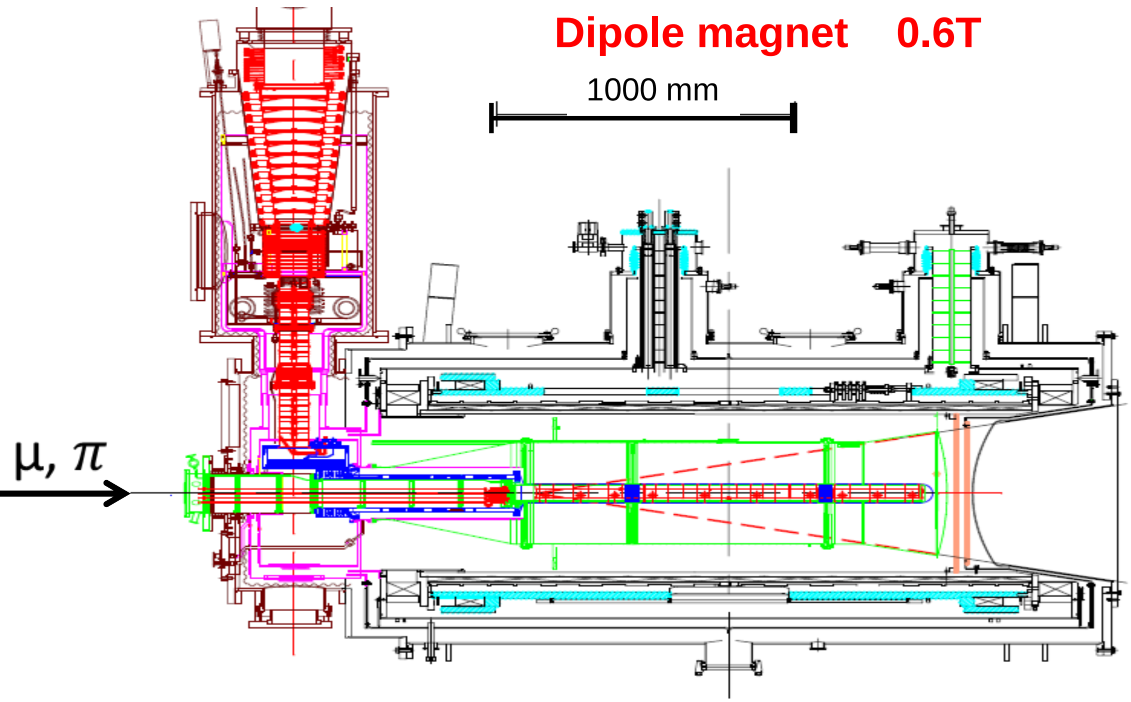
1. Muon, electron or hadron secondary beams with momenta from 20 to 250 GeV and intensities up to 10^8 particles per second.
2. Solid state polarised targets, NH_3 or ^{6}LiD, as well as liquid hydrogen target and nuclear targets.
3. Powerful tracking system – 350 planes.
4. Versatile PID – RICH, Muon Walls, Calorimeters.



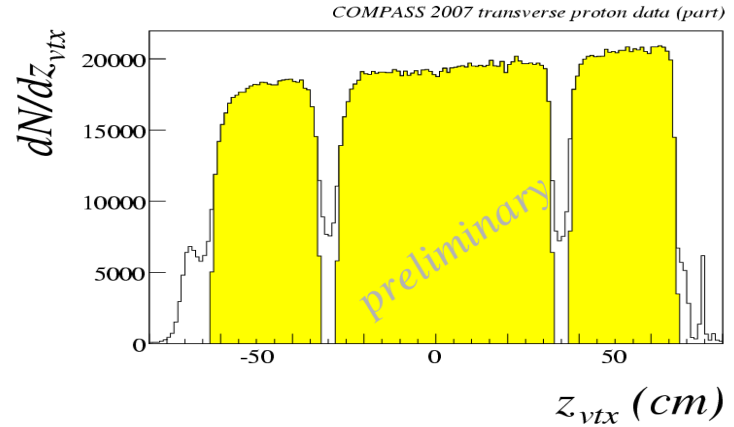
Important Instrumentation Features – Polarised Target

^{3}He – ^{4}He dilution refrigerator (T~50mK)

Solenoid 2.5T
Dipole magnet 0.6T



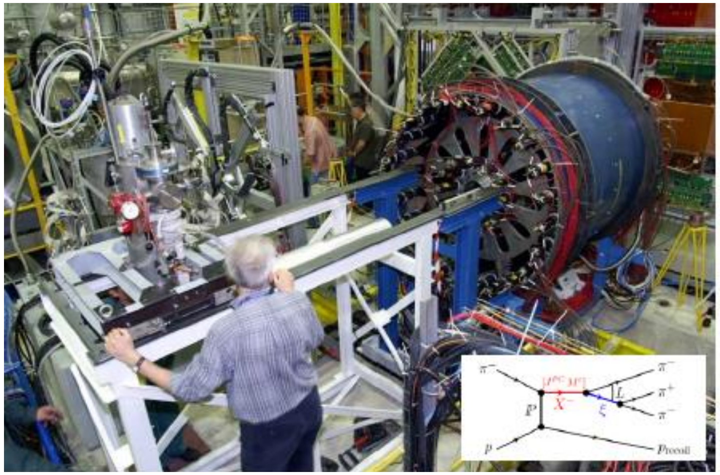
Vertex distribution for SIDIS



Opposite polarization in different target segments reversed frequently

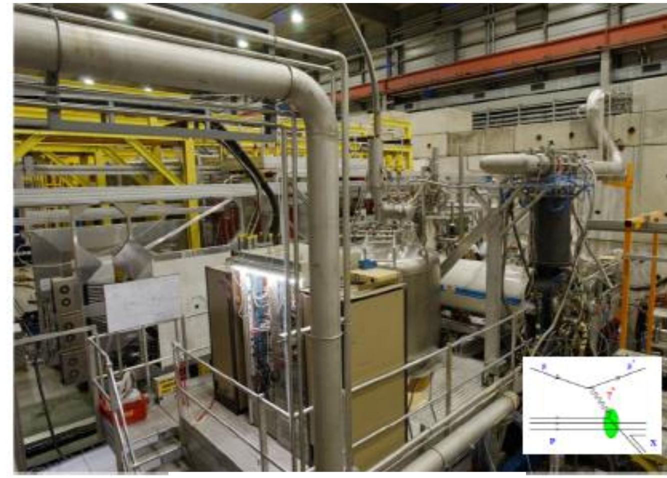
	d (^{6}LiD)	p (NH_3)
Polarization	**50%**	**90%**
Dilution factor	**40%**	**16%**

Versatile Apparatus - Expertise from Leading Instrumentation Groups in Europe and CERN



Hadron Spectroscopy & Polarisability

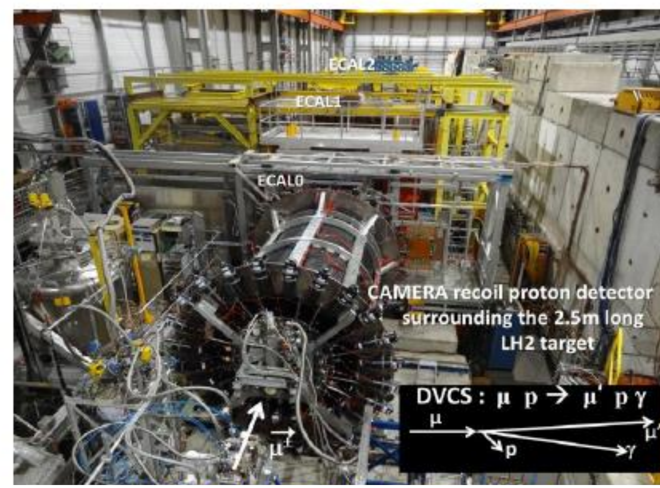
COMPASS-I
1997-2012



Polarised SIDIS

Polarised Drell-Yan

COMPASS-II
2012-2018



DVCS (GPDs) & unpolarised SIDIS

COMPASS I+II Data Sets

analyzed in 104 Ph.D. Theses

http://wwwcompass.cern.ch/compass/publications/theses

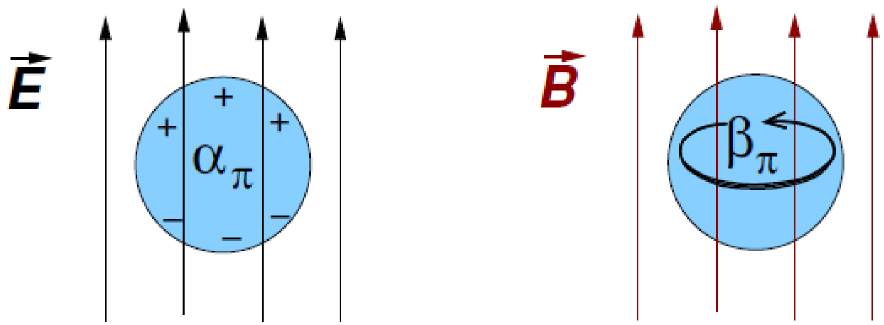
2002	Nucleon structure with	160 GeV μ	**L&T**	polarised **deuteron** target
2003	Nucleon structure with	160 GeV μ	**L&T**	polarised **deuteron** target
2004	Nucleon structure with	160 GeV μ	**L&T**	polarised **deuteron** target
2005	*CERN accelerators shut down*			
2006	Nucleon structure with	160 GeV μ	**L**	polarised **deuteron** target
2007	Nucleon structure with	160 GeV μ	**L&T**	polarised **proton** target
2008	Hadron spectroscopy			
2009	Hadron spectroscopy			
2010	Nucleon structure with	160 GeV μ	**T**	polarised **proton** target
2011	Nucleon structure with	190 GeV μ	**L**	polarised **proton** target
2012	Primakoff & DVCS / SIDIS test			
2013	*CERN accelerators shut down*			
2014	Test beam Drell-Yan process with π beam and T polarised proton target			
2015	Drell-Yan process with π beam and T polarised proton target			
2016	DVCS / SIDIS with μ beam and unpolarised proton target			
2017	DVCS / SIDIS with μ beam and unpolarised proton target			
2018	Drell-Yan process with π beam and T polarised proton target			

I

II

Measurement of Pion Polarisability α_π vs Meson Structure from Chiral Perturbation Theory/QCD

based on slides from Jan Friedrich and Stefan Huber at TU Munich



pion polarisabilities α_π, β_π in units of 10^{-4} fm^3

size of the pion $\sim$ 1 fm^3 [cf. atoms: polarisability $\approx$ size $\approx$ 1 Å^3]

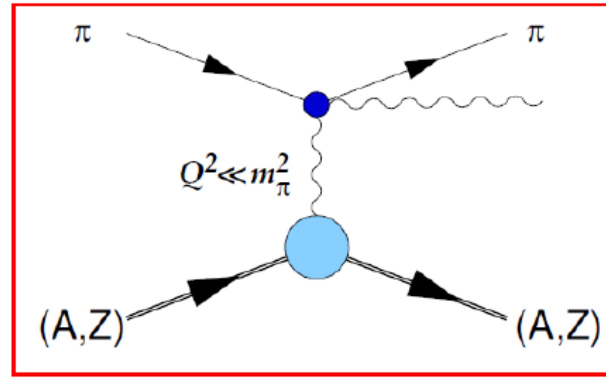
Theory: ChPT (2-loop) prediction:

$$\begin{aligned} \alpha_\pi - \beta_\pi &= 5.7 \pm 1.0 \\ \alpha_\pi + \beta_\pi &= 0.16 \pm 0.1 \end{aligned}$$

experiments for $\alpha_\pi - \beta_\pi$ lie in the range $4 \cdots 14$

($\alpha_\pi + \beta_\pi = 0$ assumed)

Experimental Technique: Pion Polarisability from $\pi + \mathrm{Ni} \rightarrow \pi + \gamma + \mathrm{Ni}'$



- Identify exclusive reactions

$$\pi\gamma_{\{\mathrm{Ni}\rightarrow\mathrm{Ni}'\}} \rightarrow \pi\gamma$$

at smallest momentum transfer $< 0.001\ \mathrm{GeV}^2/c^2$

- Assuming $\alpha_\pi + \beta_\pi = 0$, from the cross-section

$$R = \frac{\sigma(x_\gamma)}{\sigma_{\alpha_\pi=0}(x_\gamma)} = \frac{N_{meas}(x_\gamma)}{N_{sim}(x_\gamma)} = 1 - \frac{3}{2} \cdot \frac{m_\pi^3}{\alpha} \cdot \frac{x_\gamma^2}{1 - x_\gamma} \alpha_\pi$$

is derived, depending on $x_\gamma = E_{\gamma(lab)}/E_{Beam}$.
Measuring R the polarisability α_π can be concluded.

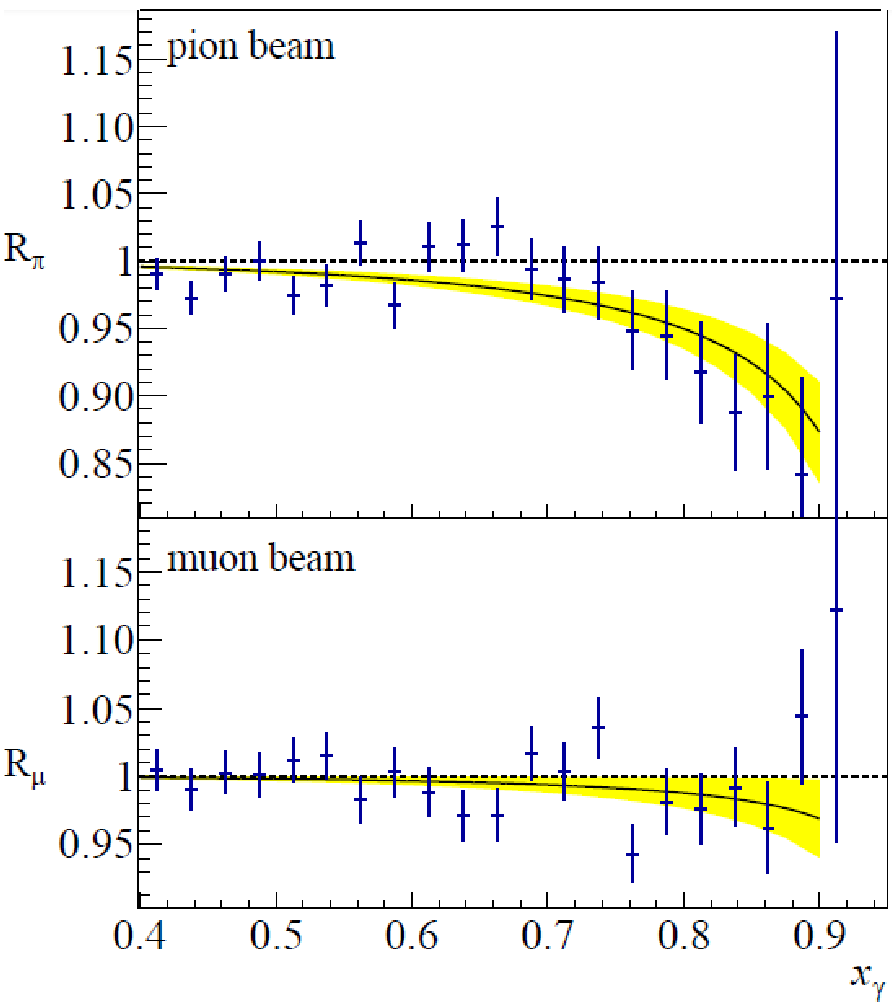
- Control systematics by

$$\mu\gamma_{\{\mathrm{Ni}\rightarrow\mathrm{Ni}'\}} \rightarrow \mu\gamma$$

and

$$K^- \rightarrow \pi^-\pi^0 \rightarrow \pi\gamma\gamma$$

Results for Pion Polarisability from $\pi + \mathrm{Ni} \rightarrow \pi + \gamma + \mathrm{Ni}'$ in COMPASS



$\alpha_\pi = (2.0 \pm 0.6_{stat}) \times 10^{-4}\ \mathrm{fm}^3$

(assuming $\alpha_\pi = -\beta_\pi$)

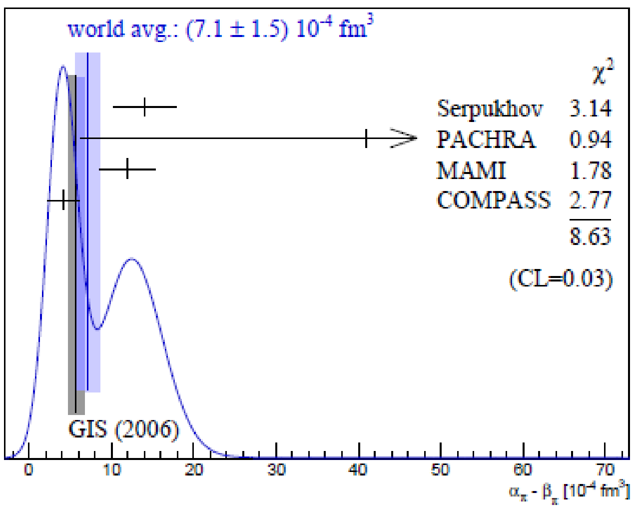
"false polarisability" from muon data:

$(0.5 \pm 0.5_{stat}) \times 10^{-4}\ \mathrm{fm}^3$

Phys. Rev. Lett. 114, 062002 (2015)

Pion Polarisability: COMPASS Results vs World Data and χPT Prediction

- COMPASS result:
  $\alpha_\pi = (2.0 \pm 0.6_{\text{stat}} \pm 0.7_{\text{syst.}}) \times 10^{-4}\,\text{fm}^3$
- Assumption: $\alpha_\pi = -\beta_\pi$
- In tension with previous measurements
- Measurement in agreement with χPT prediction
- Most precise determination of π^--polarizability

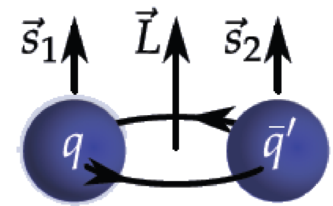


GIS'06: ChPT prediction, Gasser, Ivanov, Sainio, NPB745 (2006)

Meson Spectroscopy: Resonance Production in $\pi^-(190\ GeV) + p \rightarrow \pi^- + \pi^- + \pi^+ + p_{recoil}$

based on slides from Franco Bradamante, INFN Trieste and Jan Friedrich, TU Munich

$$S = 0, 1; \quad \vec{J} = \vec{L} + \vec{S}; \quad P = (-1)^{L+1}; \quad C = (-1)^{L+S}$$



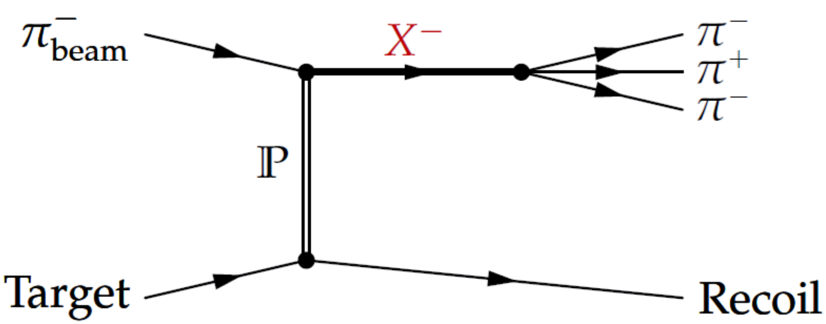
forbidden (exotic QN's)

$$J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}, \ldots$$

more states in QCD:

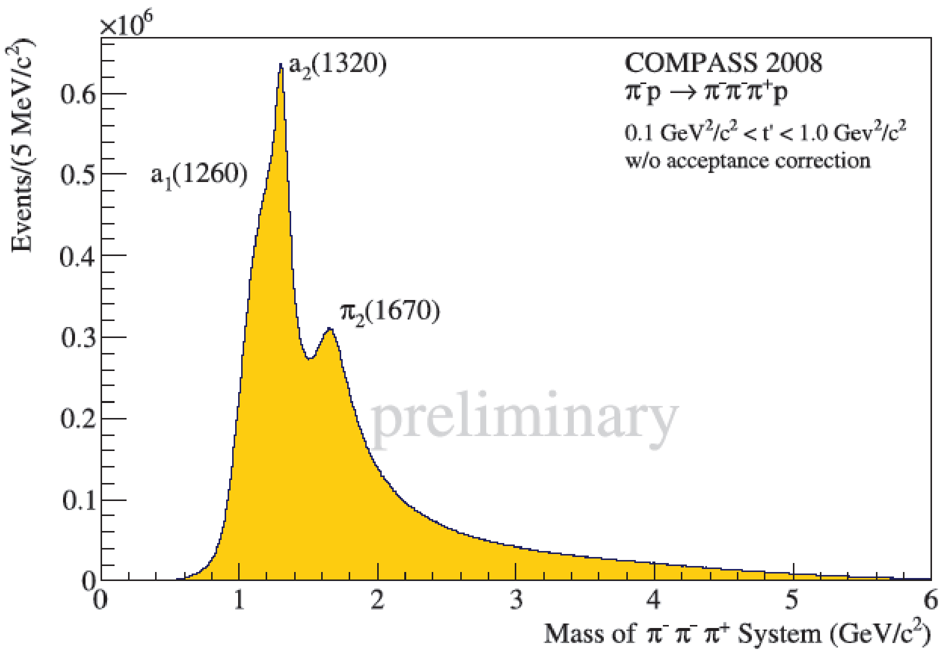
hybrids $|q\bar{q}g\rangle$, glueballs $|gg\rangle$, multiquark states $|q^2\bar{q}^2\rangle$

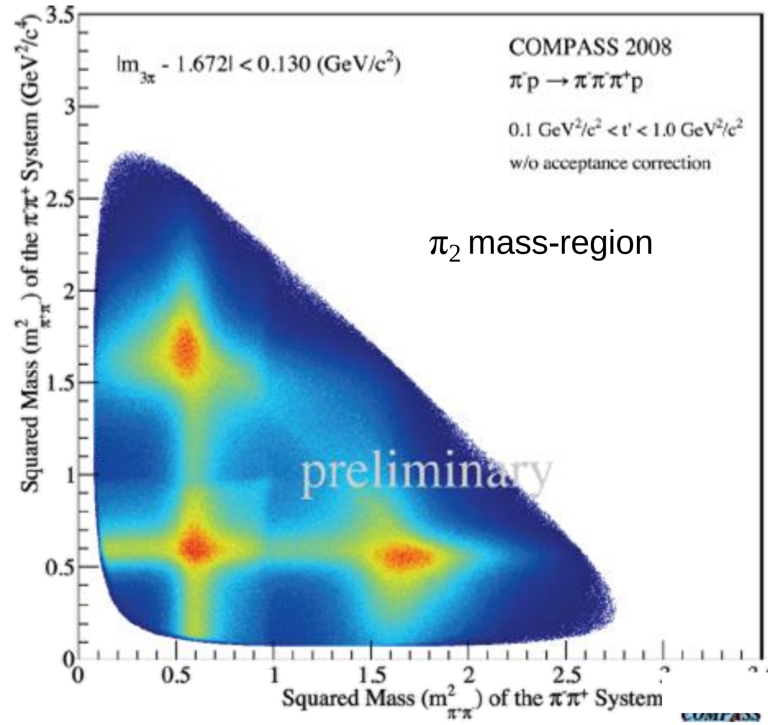
Diffractive dissociation:



Meson Spectroscopy: Resonance Production in $\pi^-(190\ GeV) + p \rightarrow \pi^- + \pi^- + \pi^+ + p_{recoil}$

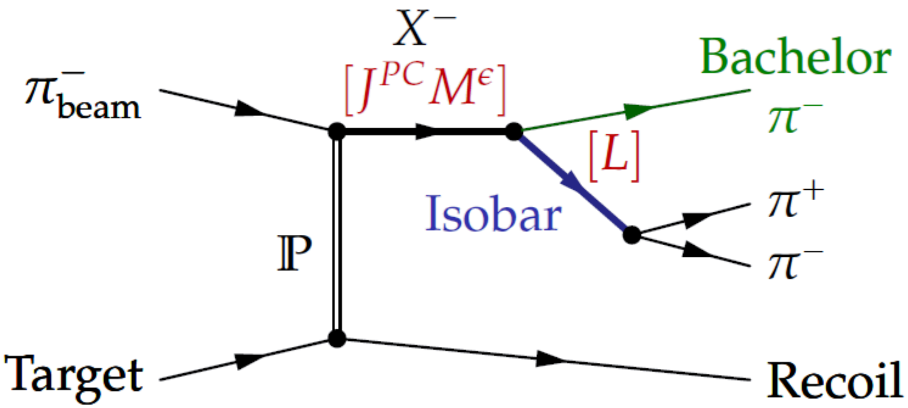
Data Sample with $96 \cdot 10^6$ events





Partial Wave Analysis in 100 Bins in $m_{3\pi}$ and 11 Bins in Four Momentum Transfer t

- **Isobar model:**

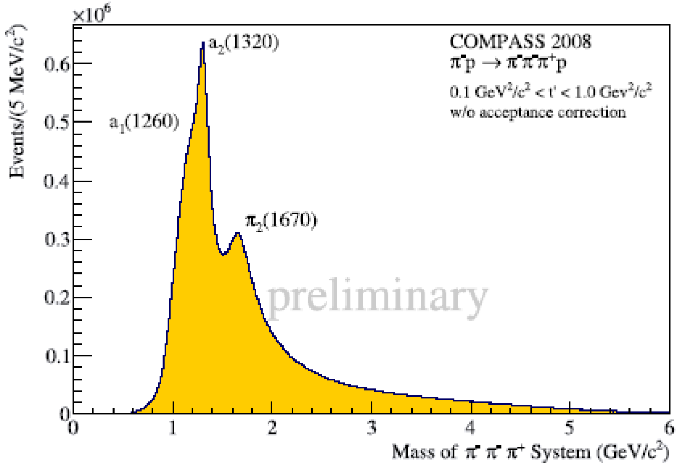


X decay is chain of successive two-body decays

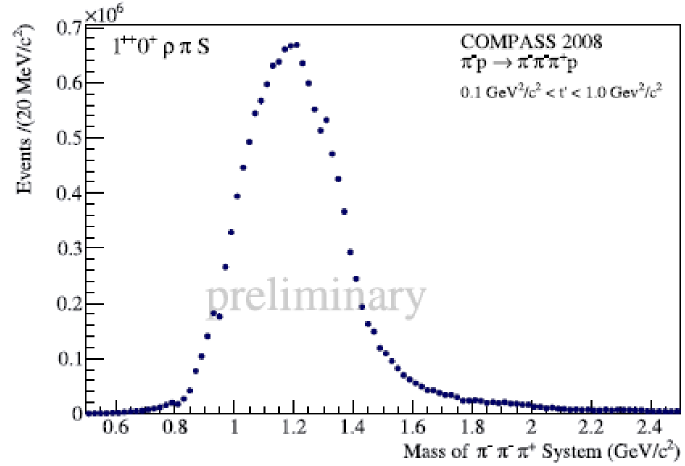
- **Analysis:**
  - Partial Wave Analysis (PWA) in mass bins with up to 88 waves
  - fit of spin-density matrix for major waves with Breit-Wigner

Known Waves in Good Agreement with PDG

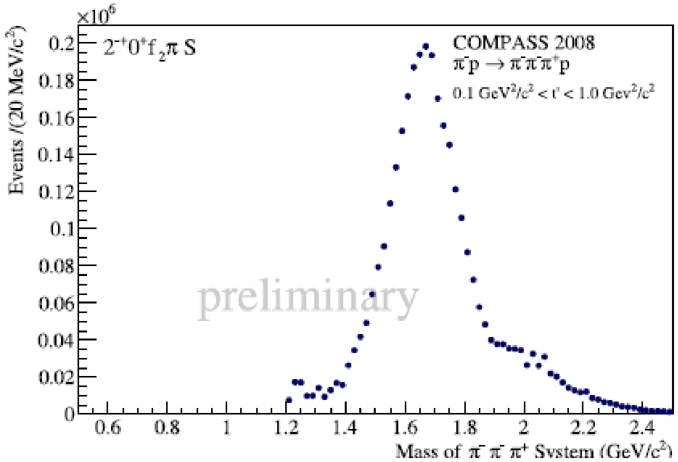
$\pi^- \pi^+ \pi^-$ invariant mass spectrum



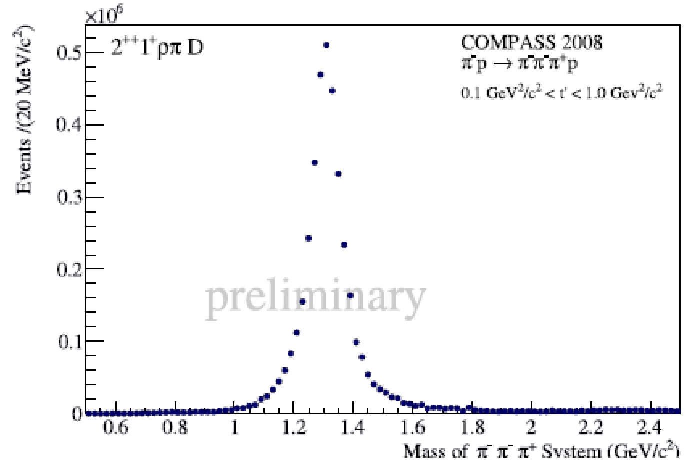
$1^{++} 0^+ [\rho\pi]S : a_1(1260)$



$2^{-+} 0^+ [f_2\pi]S : \pi_2(1670)$



$2^{++} 1^+ [\rho\pi]D : a_2(1320)$

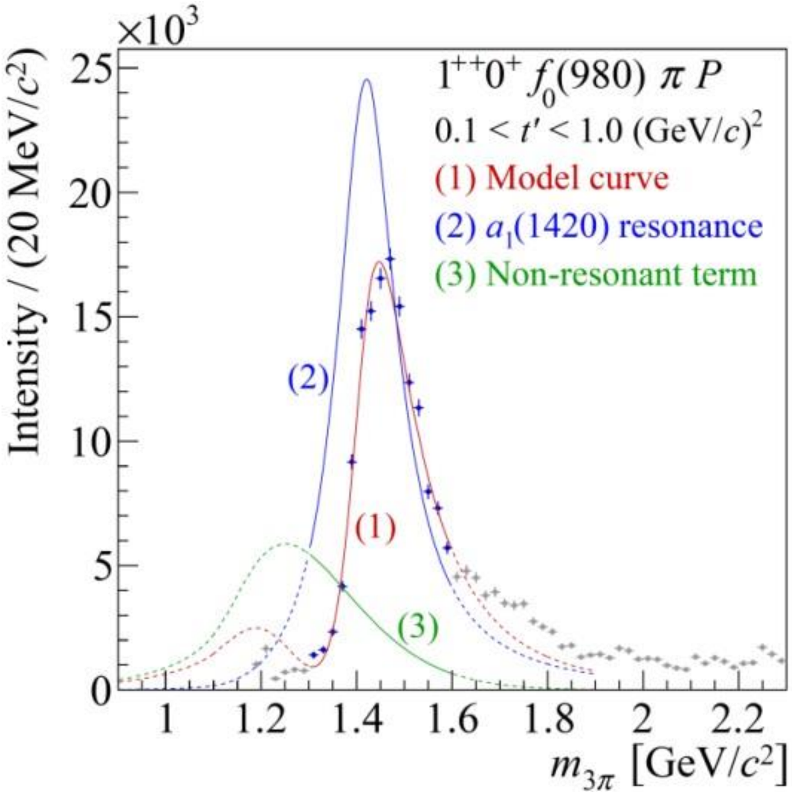


Observation of Axial-Vector Meson $a_1(1420)$

- Observation of a new narrow axial-vector meson $a_1(1420)$
  PRL 115 (2015) 082001

***3π* data sample**

~ $50 \cdot 10^6$ exclusive events factor 10 to 100 compared to previous experiment

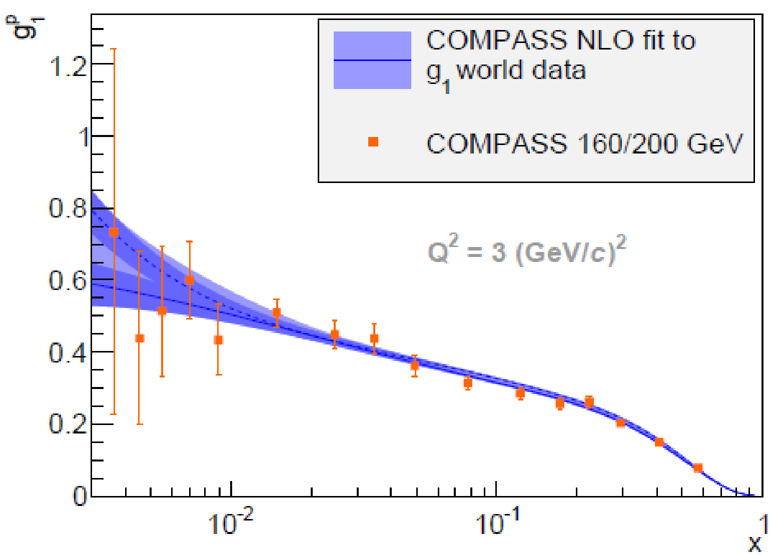


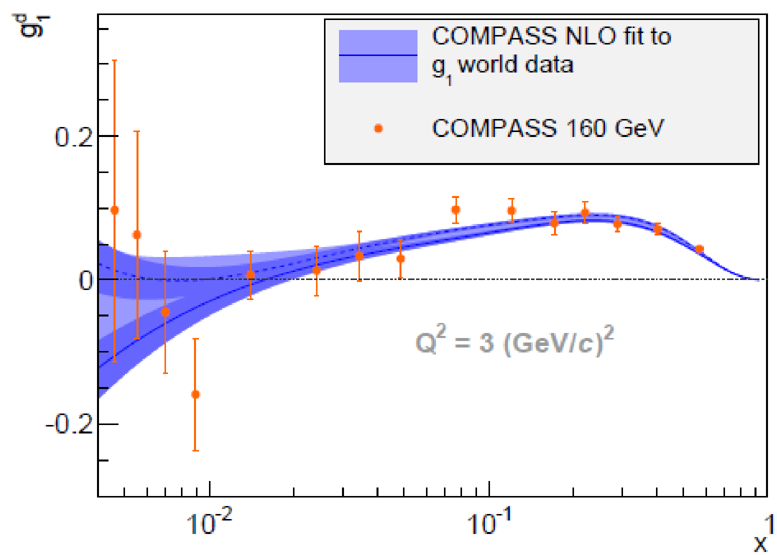
- **Long paper published:**

  Resonance Production and S-wave in
  $\pi^-(190\ GeV) + p \rightarrow \pi^- + \pi^- + \pi^+ + p_{recoil}$
  PRD 95 (2017) 032004

Polarised DIS of muons off proton and deuteron targets: Obtain $g_1^p(x)$ and $g_1^d(x)$ and Parton Helicity Distributions

COMPASS fit to $g_1(x)$ world data vs COMPASS data for $g_1^p(x)$ and $g_1^d(x)$



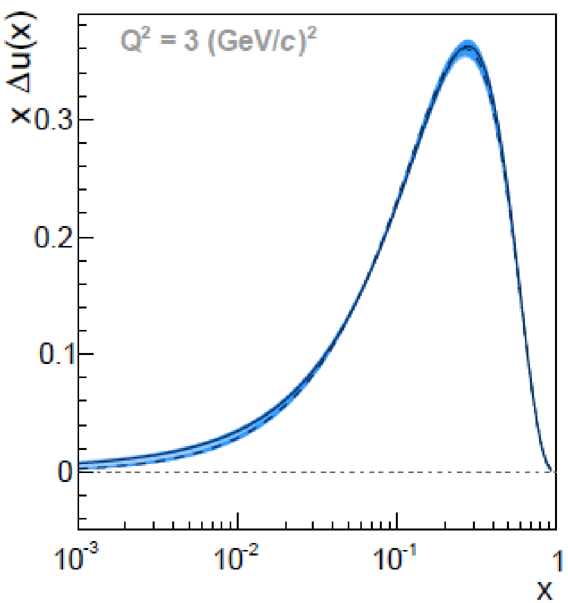


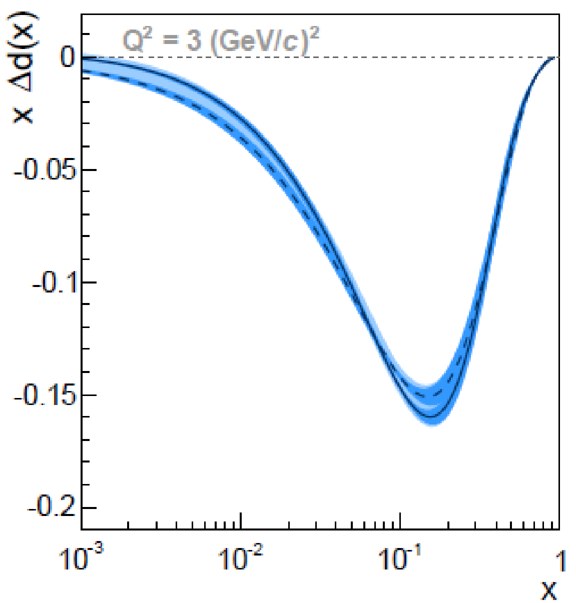
COMPASS, PLB 753 (2016) 18

Polarised DIS of muons off proton and deuteron targets: Obtain $g_1^p(x)$ and $g_1^d(x)$ and Parton Helicity Distributions

COMPASS fit to $g_1(x)$ world data:

returns $x\Delta u(x)$ and $x\Delta d(x)$ with small uncertainties





First moment	Value range at $Q^2 = 3\,(\mathrm{GeV}/c)^2$
$\Delta\Sigma$	[0.26 , 0.36]
$\Delta u + \Delta\bar{u}$	[0.82 , 0.85]
$\Delta d + \Delta\bar{d}$	[−0.45 , −0.42]
$\Delta s + \Delta\bar{s}$	[−0.11 , −0.08]

COMPASS, PLB 753 (2016) 18

DIS of polarised muons on polarized proton and deuteron targets: Obtain $g_1^{NS}(x)$ and test Bjorken Sum Rule

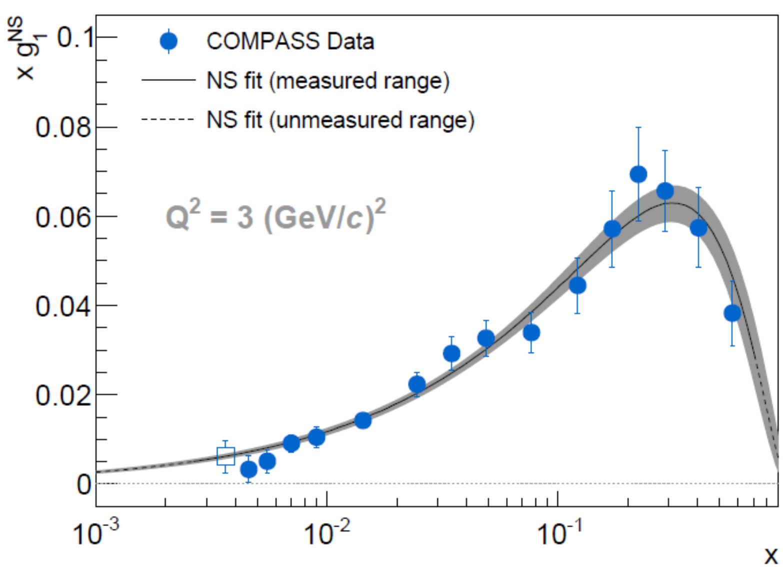
$$g_1^{\rm N}(x,Q^2) = \frac{1}{1-1.5\,\omega_{\rm D}} g_1^{\rm d}(x,Q^2)$$

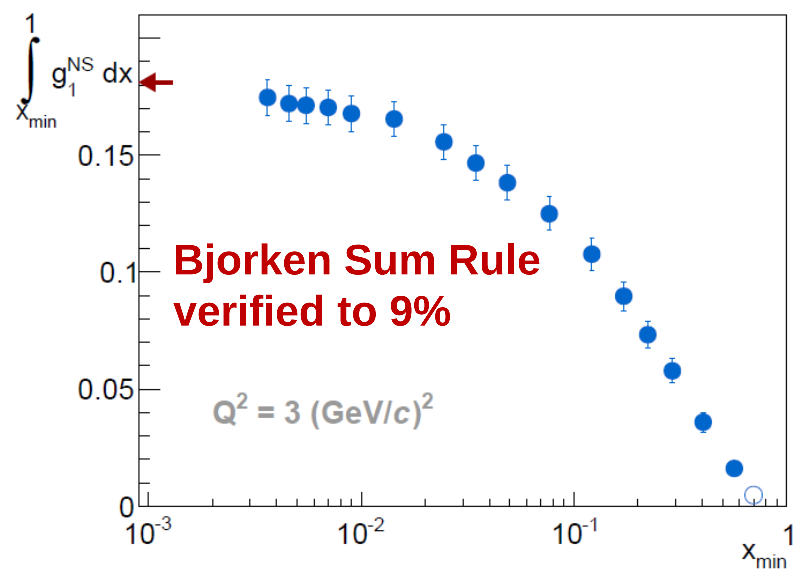
COMPASS, PLB 753 (2016) 18

$$g_1^{\rm NS}(x,Q^2) = g_1^{\rm p}(x,Q^2) - g_1^{\rm n}(x,Q^2) = 2\,[g_1^{\rm p}(x,Q^2) - g_1^{\rm N}(x,Q^2)]$$

Bjorken Sum Rule $\Gamma_1^{\rm NS}(Q^2) = \int_0^1 g_1^{\rm NS}(x,Q^2)\,{\rm d}x = \frac{1}{6}\left|\frac{g_{\rm A}}{g_{\rm V}}\right| C_1^{\rm NS}(Q^2)$

$$\Gamma_1^{\rm NS} = 0.181 \pm 0.008\,({\rm stat.}) \pm 0.014\,({\rm syst.})$$

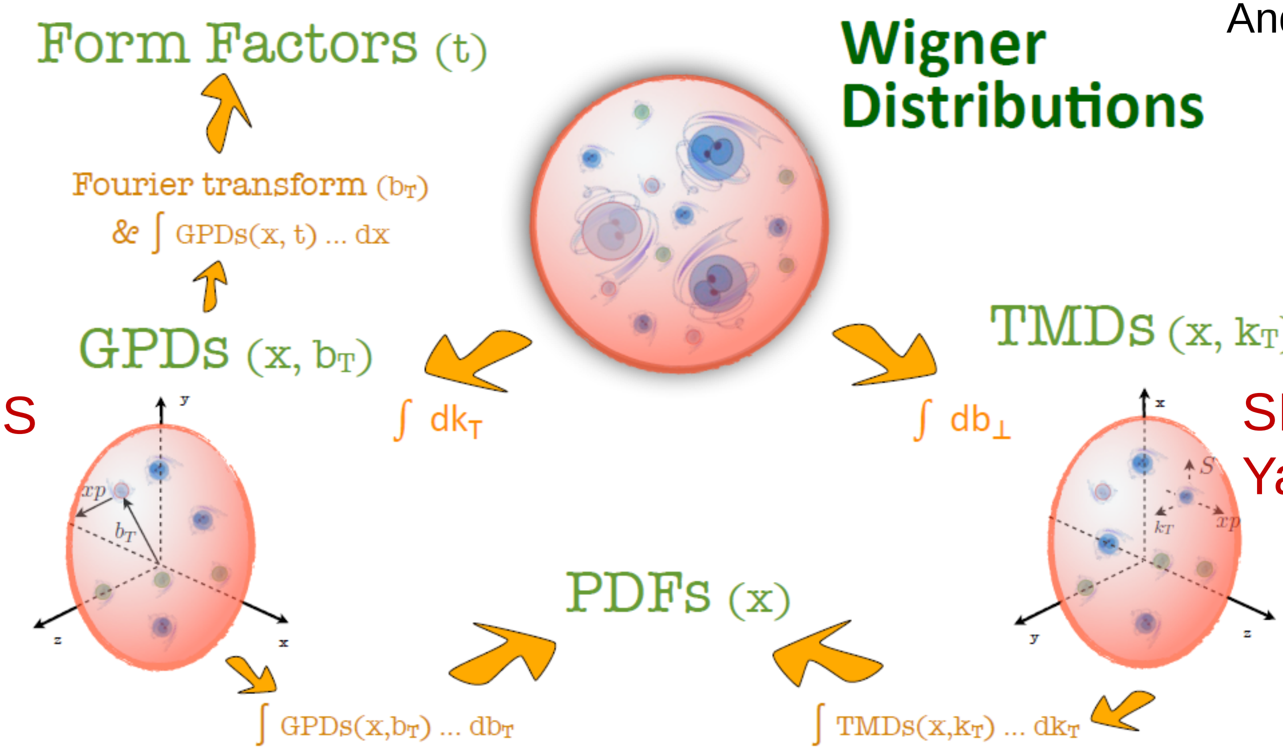




GPDs and TMDs: Towards a 3D Picture of the Nucleon

with slides from
Andrea Ferrero, Saclay

DVCS at COMPASS

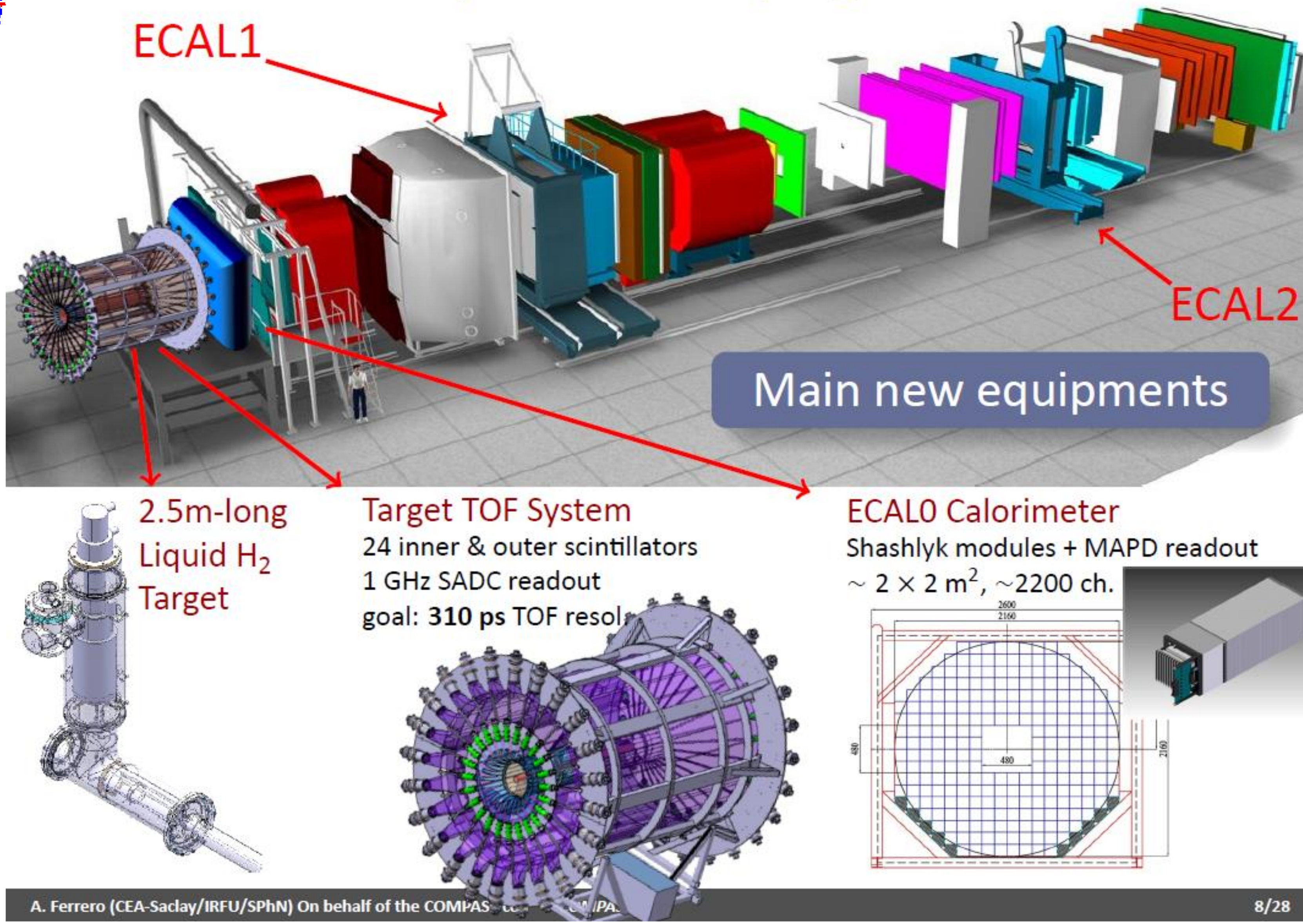


SIDIS + Drell-Yan at COMPASS

PDFs → $\Delta\Sigma$, ΔG

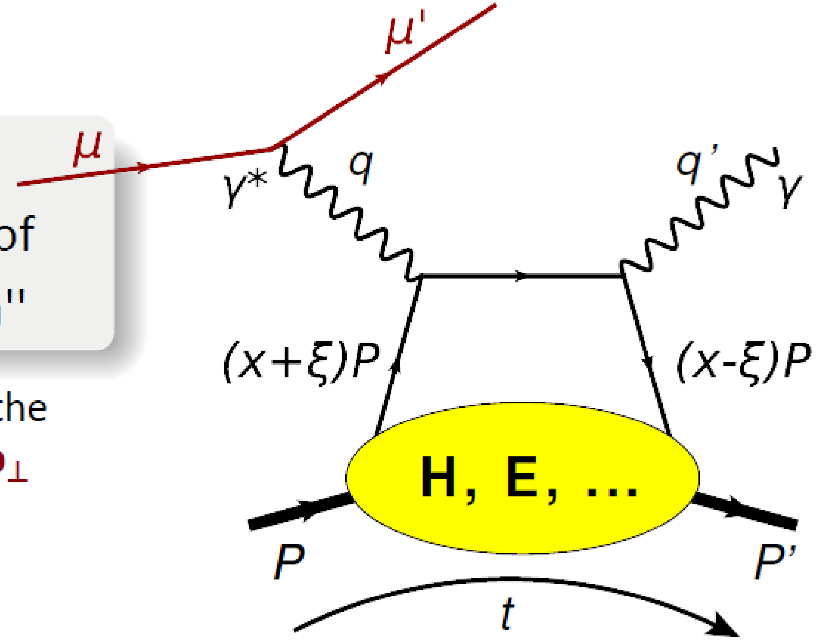
TMDs, GPDs → $\begin{cases} \text{nucleon"tomography"} \\ L_{q,g} \end{cases}$

The COMPASS set-up for the GPD program



Introduction to GPDs

``GPDs are **non-perturbative** objects entering the description of **hard exclusive** electroproduction''



They encode **CORRELATIONS** between the long. mom. $\mathbf{x}$ and the transv. position $\mathbf{b}_\perp$ of partons

Definition of variables:

- x: average long. momentum - NOT ACCESSIBLE
- ξ: long. mom. difference $\simeq$ $x_B/(2 - x_B)$
- t: four-momentum transfer related to $b_\perp$ via Fourier transform

Experimentally accessible through Compton Form Factors (CFFs):

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

$$\mathbf{Re}\mathcal{H}(\xi, \mathbf{t}) = \int \frac{\mathbf{dx\,H(x,x,t)}}{(\mathbf{x} - \xi)} + \mathbf{Dterm}$$

$$q^f(x, \boldsymbol{b}_\perp) = \int \frac{d^2\boldsymbol{\Delta}_\perp}{(2\pi)^2} e^{-i\boldsymbol{\Delta}_\perp \cdot \boldsymbol{b}_\perp} H^f(x, 0, -\boldsymbol{\Delta}_\perp^2)$$

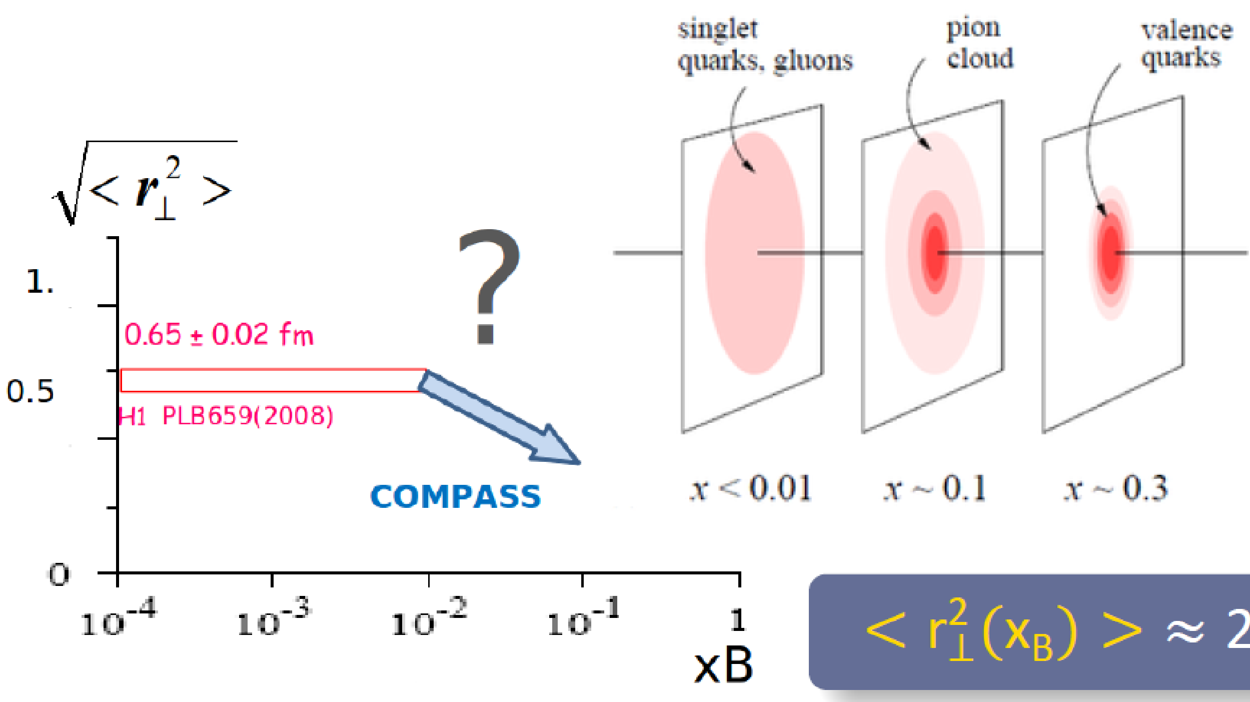
Related to impact parameter dependent quark distributions

Transverse Nucleon Imaging at COMPASS

Beam Charge and Spin **SUM**:

$$\mathbf{S_{CS,U} \equiv d\sigma(\mu^{+\leftarrow}) + d\sigma(\mu^{-\rightarrow}) \propto d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + K s^{Int}_1} \sin \boldsymbol{\phi}$$

Integration over ϕ and BH subtraction → $\mathbf{d\sigma^{DVCS}/dt \sim exp(-B|t|)}$



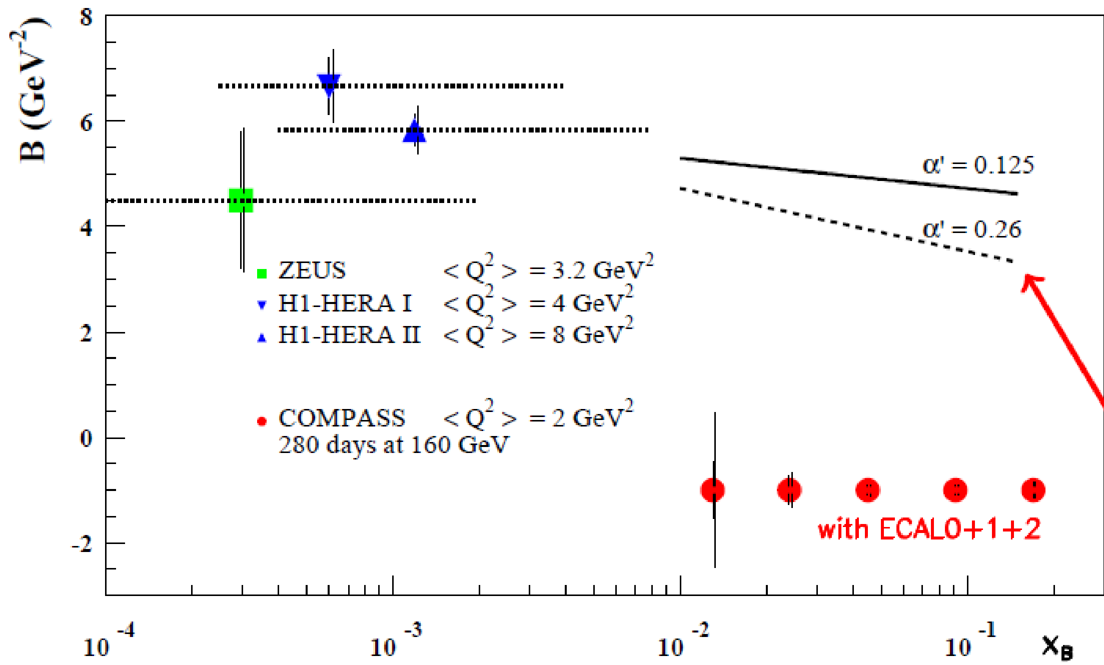
$$< r_\perp^2(x_B) > \approx 2B(x_B)$$

Transverse Nucleon Imaging at COMPASS

Beam Charge and Spin **SUM**:

$$\mathbf{S_{CS,U} \equiv d\sigma(\mu^{+\leftarrow}) + d\sigma(\mu^{-\rightarrow}) \propto d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + Ks^{Int}_1} \sin \boldsymbol{\phi}$$

Integration over ϕ and BH subtraction → $\mathbf{d\sigma^{DVCS}/dt \sim exp(-B|t|)}$



Ansatz at small $\mathbf{x_B}$:
$\mathbf{B(x_B) \simeq B_0 + 2\alpha' ln(x_0/x_B)}$

2 x 6 months of data
in 2016-2017

2.5 m LH_2 target

ε_{global} = 10%

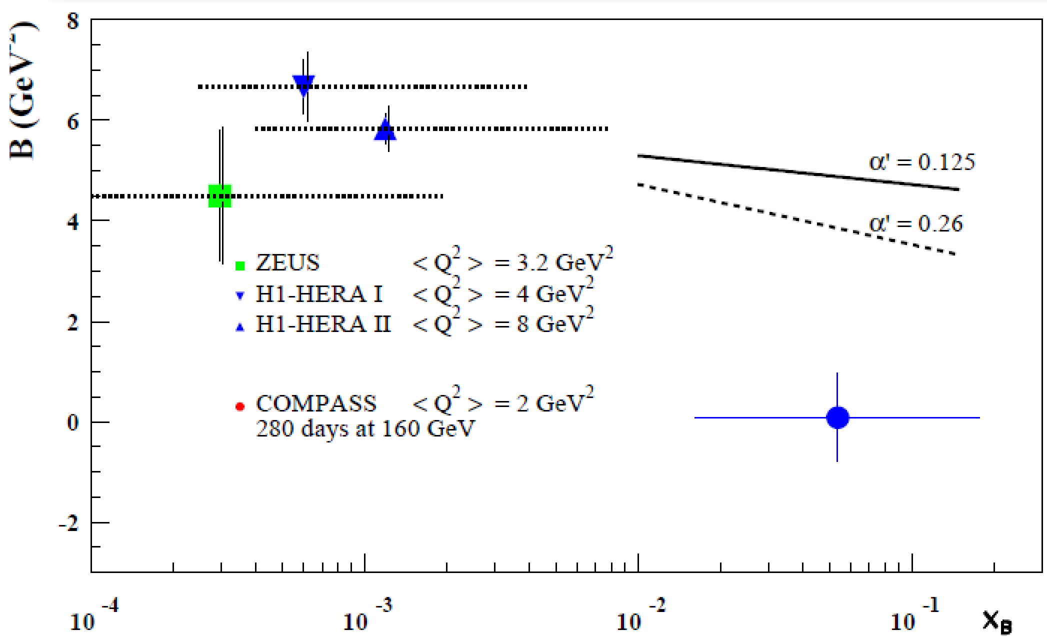
expected statistical and systematic uncertainties are shown

Results from 4 Week Test Run in 2012

Beam Charge and Spin **SUM**:

$$S_{CS,U} \equiv d\sigma(\mu^{+\leftarrow}) + d\sigma(\mu^{-\rightarrow}) \propto d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + K s_1^{Int} \sin\phi$$

Integration over ϕ and BH subtraction → $d\sigma^{DVCS}/dt \sim \exp(-B|t|)$

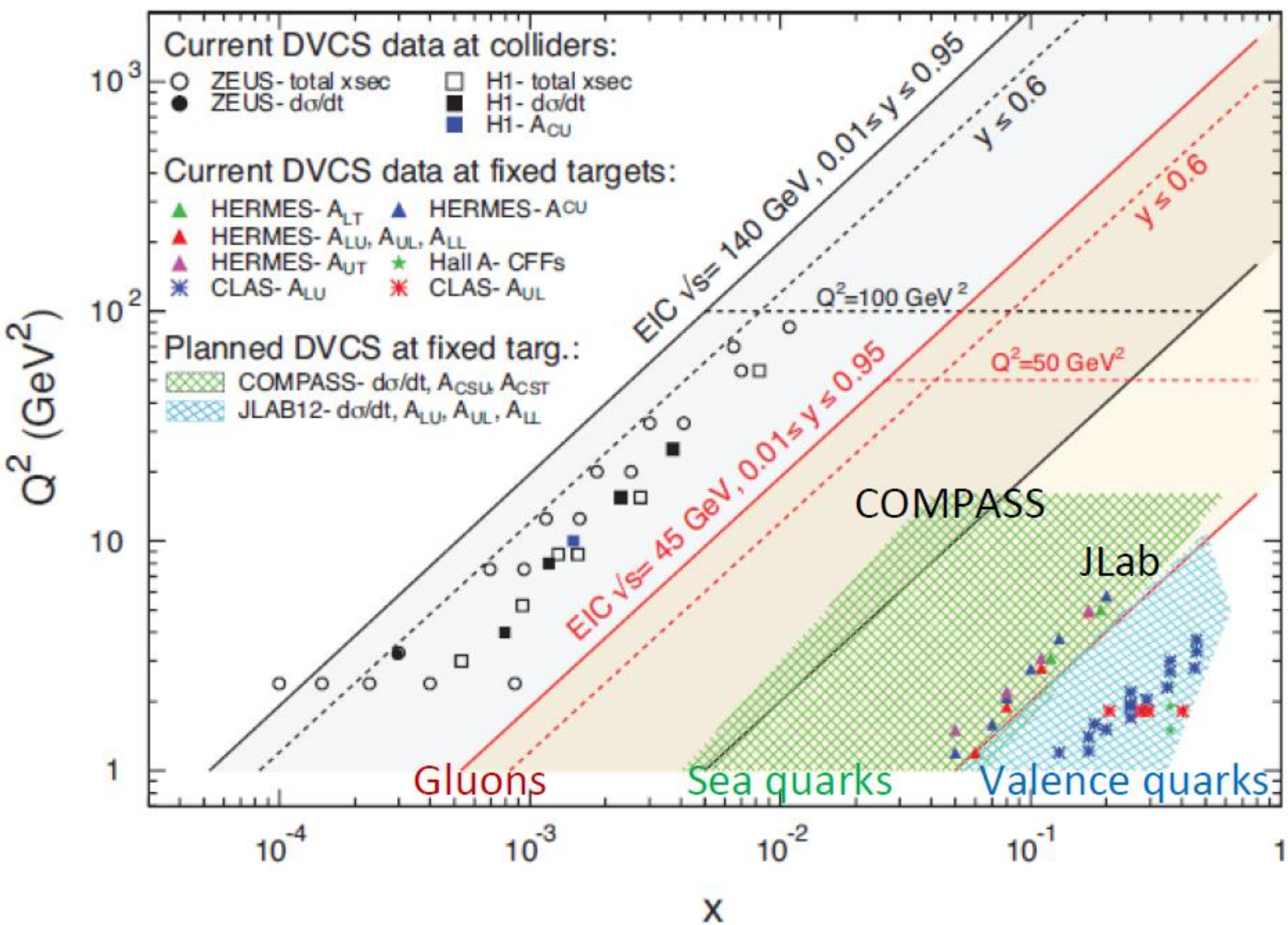


4 weeks in 2012

2.5 m LH_2 target

2016 analysis and 2017 data taking are underway

Kinematic Coverage: HERA, JLAB, HERMES vs COMPASS



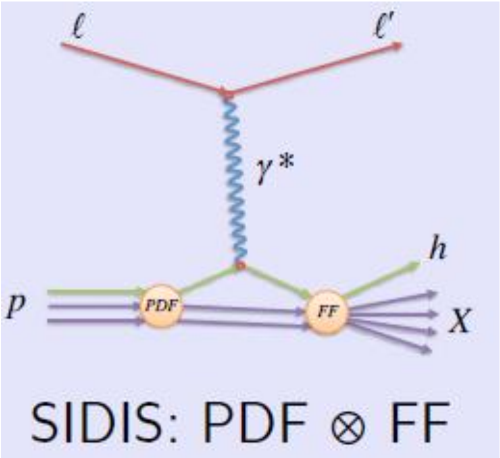
TMDs in SIDIS and DY

SIDIS:

$$A_{UU}^{\cos(2\phi_h)} \propto h_1^{\perp q} \otimes H_{1q}^{\perp h}$$

$$A_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp q} \otimes D_{1q}^{h}$$

$$A_{UT}^{\sin(\phi_h+\phi_S)} \propto h_1^{q} \otimes H_{1q}^{\perp h}$$



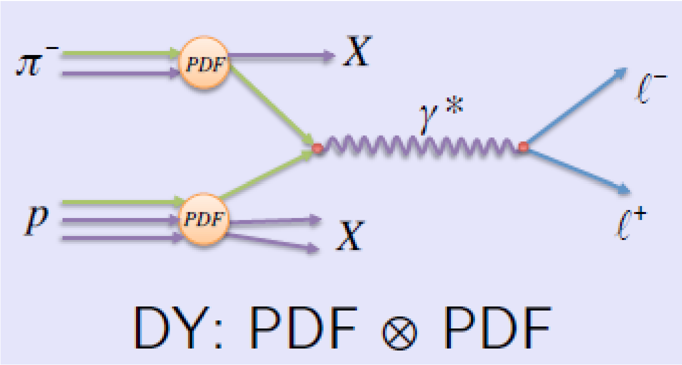
See Takahiro Iwata's talk Tuesday 15.00

DY:

$$A_{UU}^{\cos(2\phi_{CS})} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{\perp q}$$ Boer-Mulders

$$A_{UT}^{\sin(\phi_S)} \propto f_{1,\pi}^{q} \otimes f_{1T,p}^{\perp q}$$ Sivers

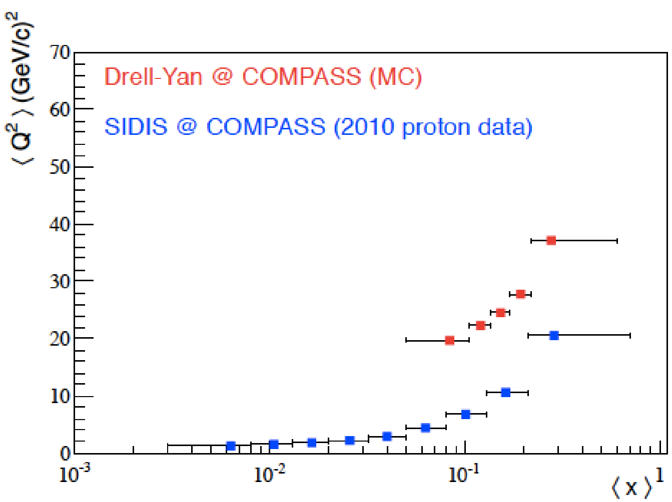
$$A_{UT}^{\sin(2\phi_{CS}-\phi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{q}$$ Transversity

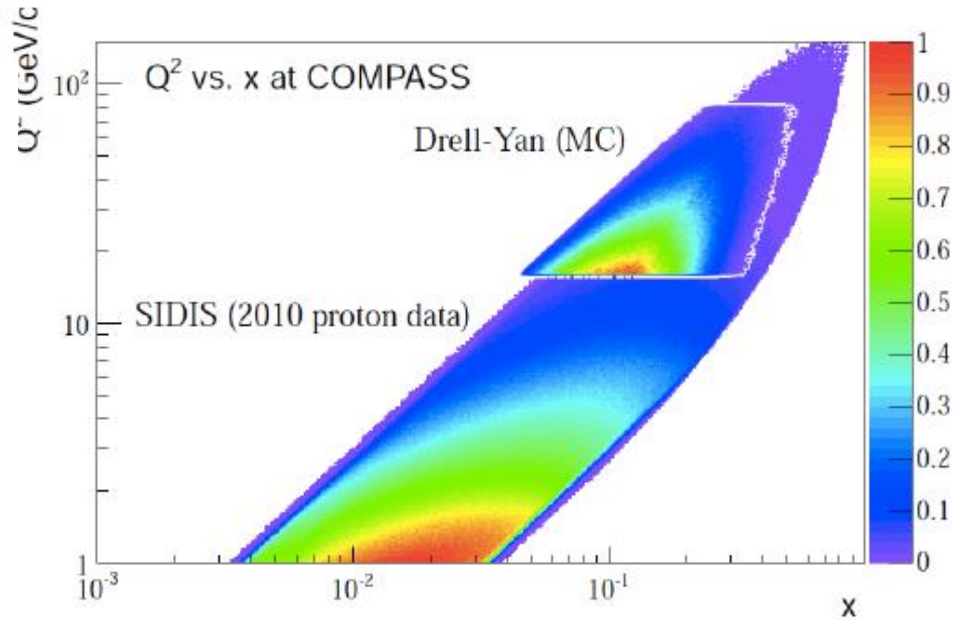


See Wen-Chen Chang's talk Tuesday 14.30

Kinematic Coverage: SIDIS vs Drell-Yan

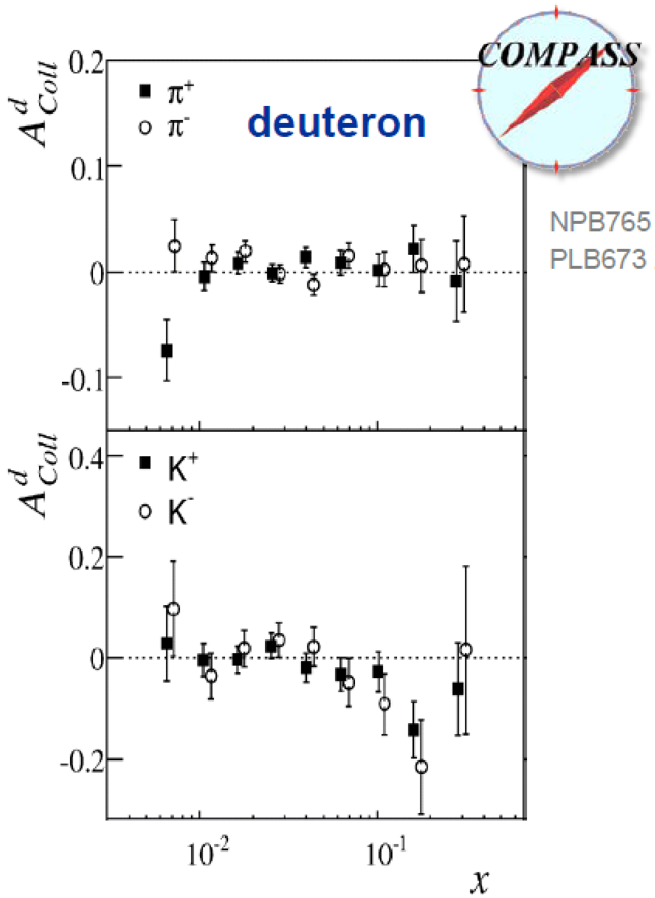
The phase space for Drell-Yan and SIDIS processes partially overlap in the x-Q^2 plane



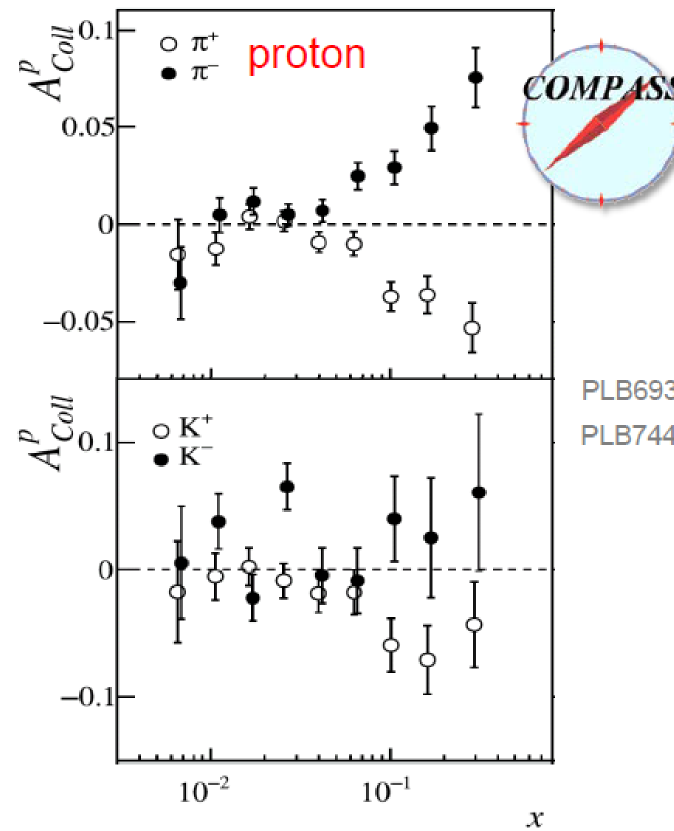


In the region of overlap in x, the average Q^2 in Drell-Yan is about two times larger compared to SIDIS

SIDIS Collins Asymmetries for Pions on Proton Targets



NPB765 2007
PLB673 2009



PLB693 2010
PLB744 2015

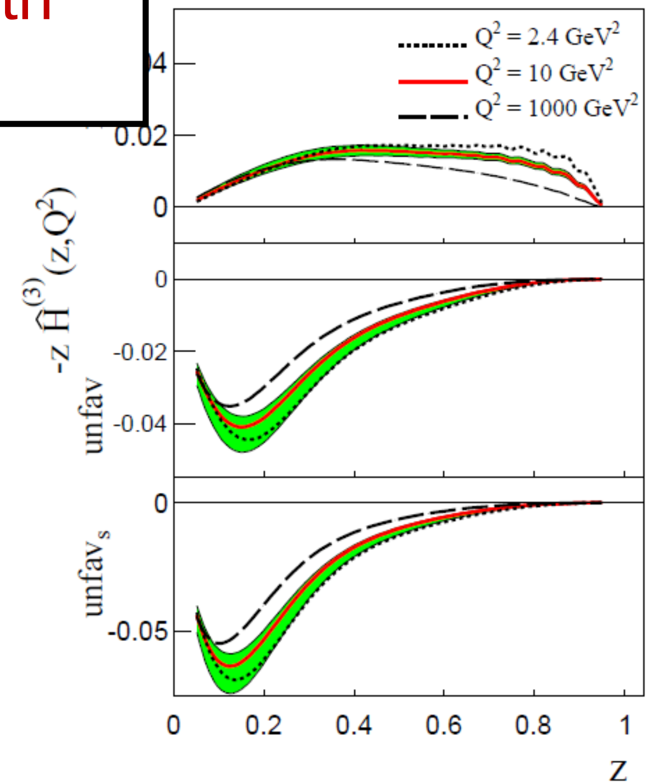
See Takahiro Iwata's talk Tuesday 15.00

Transversity and the Tensor Charge Extracted Using TMD Evolution and Recent Data Sets

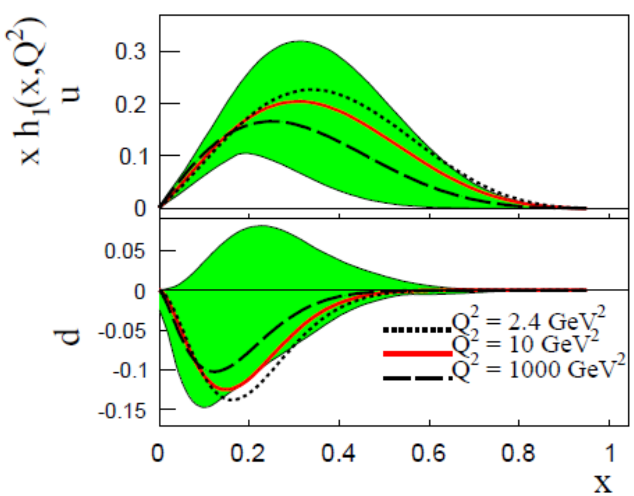
Errors in SIDIS measurements dominate. Uncertainties for d-quark Transversity will benefit from proposed additional COMPSS data taking with [6]LiD targets.

D93 (2016) 1, 014009

Favored and unfavored Collins FF



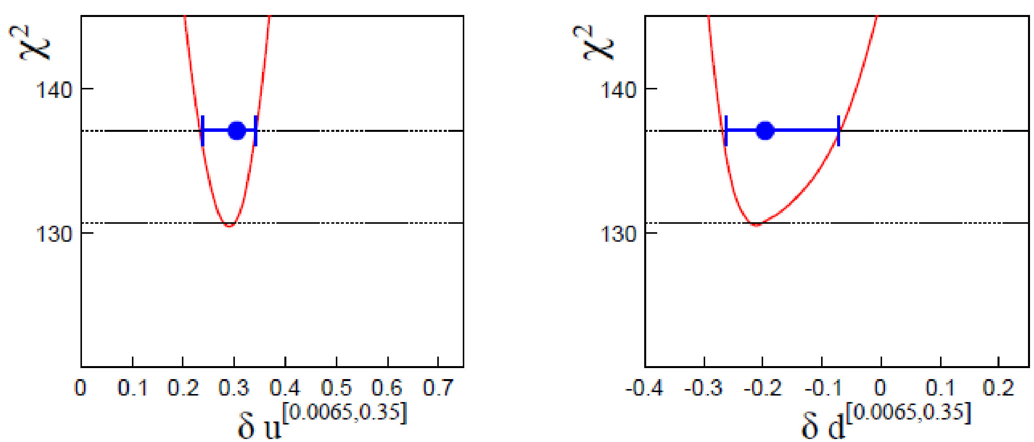
up and down transversity distributions



Transversity and the Tensor Charge Extracted Using TMD Evolution and Recent Data Sets

Z.-B. Kang., A. Prokudin, P. Sun, F. Yuan - Phys.Rev. D93 (2016) 1, 014009

up and down contributions to tensor charge



Integrals in data region

$$\delta u^{[0.0065,0.35]} = +0.30^{+0.04}_{-0.07}$$
$$\delta d^{[0.0065,0.35]} = -0.20^{+0.12}_{-0.07}$$

Integrals in [0,1]

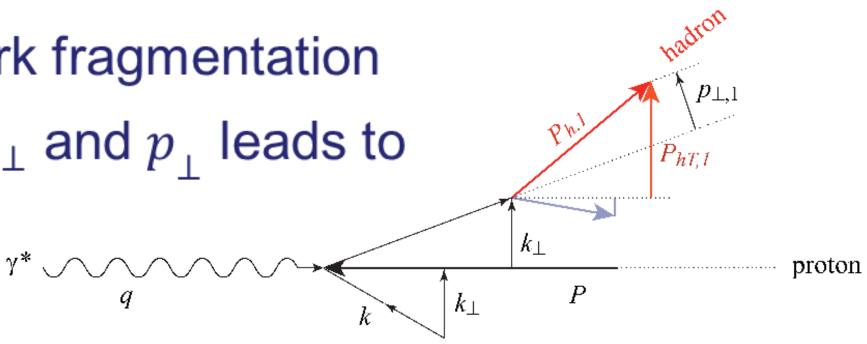
$$\delta u^{[0,1]} = +0.39^{+0.07}_{-0.11}$$
$$\delta d^{[0,1]} = -0.22^{+0.14}_{-0.08}$$

Evolution has significant effect
Need higher precision SIDIS data: COMPASS ^{6}LiD, Jlab 12 GeV
Need to extend data range to high and low x

Constraining the k_T-dependence of PDFs and p_T-dependence of FFs using the $p_{h,T}$ dependence of hadron multiplicities in unpolarised SIDIS as input to TMD global data analyses.

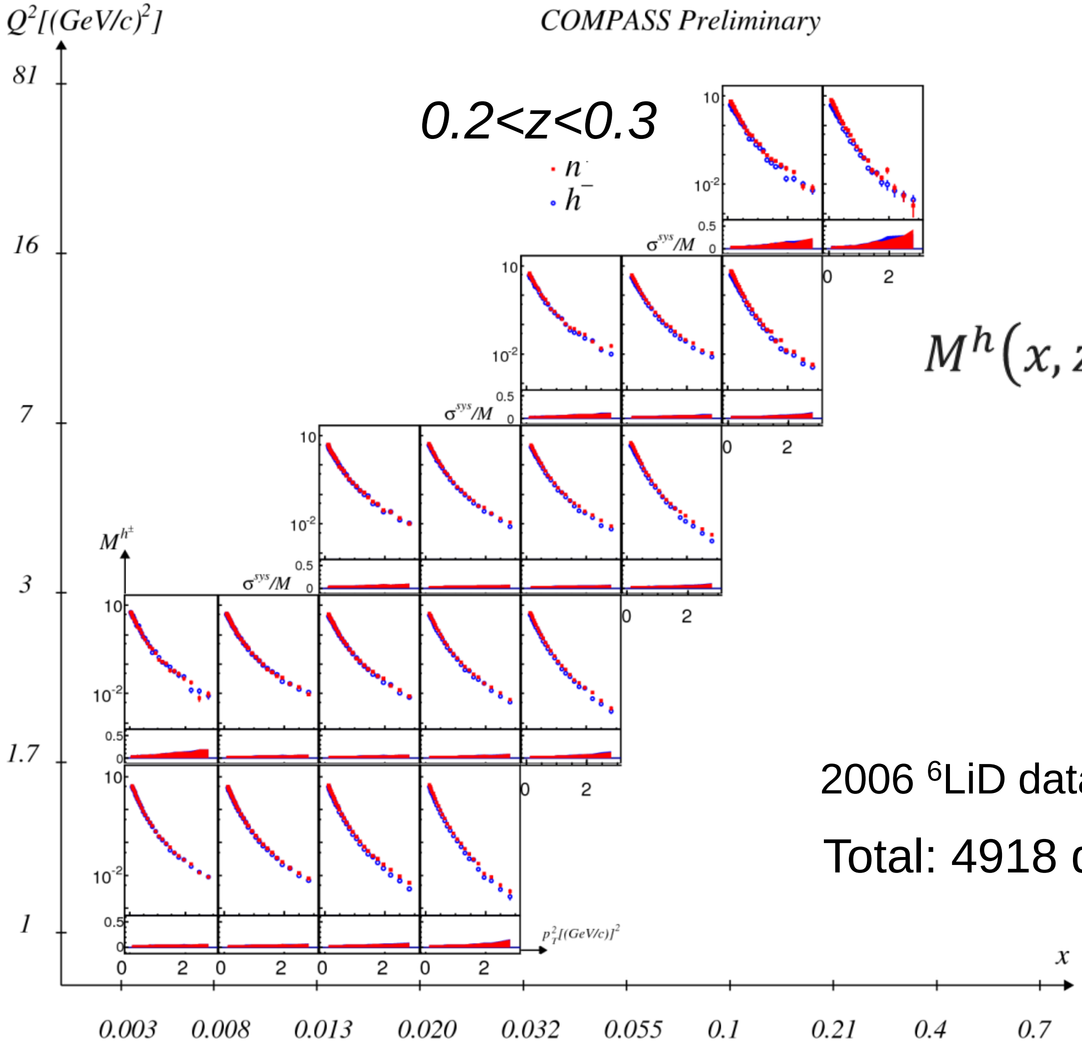
Transverse Momentum Dependence in the Unpolarised Cross Section

- The cross-section dependence on transverse hadron momentum, P_{hT}, results from:
  - intrinsic $k_\perp$ of the quarks
  - $p_\perp$ generated in the quark fragmentation
  - A Gaussian ansatz for $k_\perp$ and $p_\perp$ leads to
  - $\langle P_{hT}^2 \rangle = z^2 \langle k_\perp^2 \rangle + \langle p_\perp^2 \rangle$



- The azimuthal modulations in the unpolarized cross-sections originate from:
  - Intrinsic $k_\perp$ of the quarks
  - The Boer-Mulders PDF

Hadron Multiplicities vs x,Q^2, z and $p_{h,T}$



$$M^h(x, z, P_{hT}^2; Q^2) = \frac{d^5\sigma^h/dxdQ^2dzd^2\vec{p}_T}{d^2\sigma^{DIS}/dxdQ^2}$$

2006 ^{6}LiD data, COMPASS preliminary at Spin 2014

Total: 4918 data points

Global Analysis of Unpolarised TMD Multiplicities in SIDIS, DY and Z-Boson Production

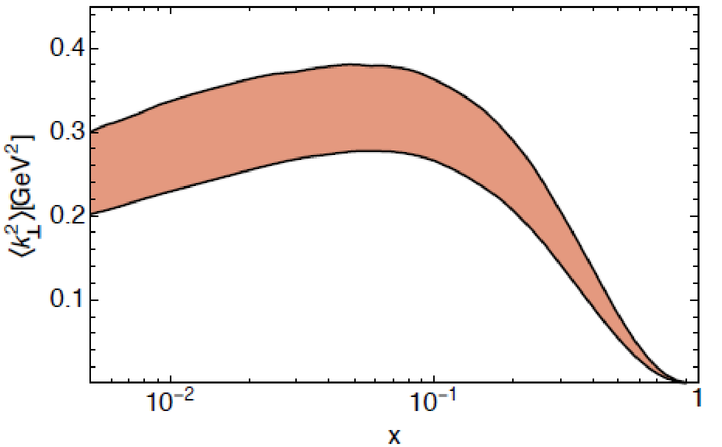
Bacchetta, Delcarro, Pisano, Radici, Signori
JHEP 1706 (2017) 081

HERMES & COMPASS SIDIS
Multiplicities vs p_T

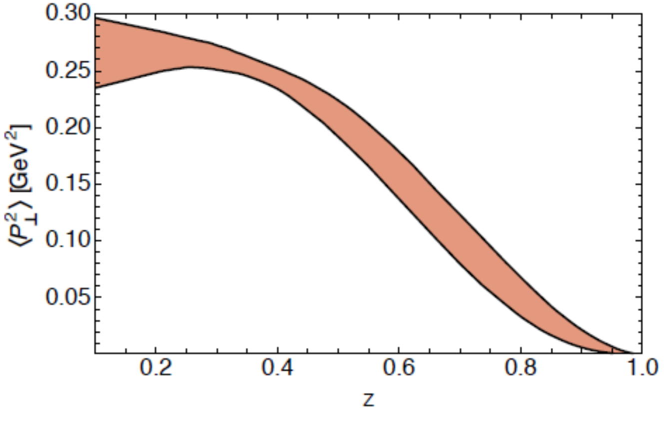
E288 and E605
DY cross sections vs q_T

D0 and CDF
Z-Boson cross sections vs q_T

Average parton $k^2_\perp$

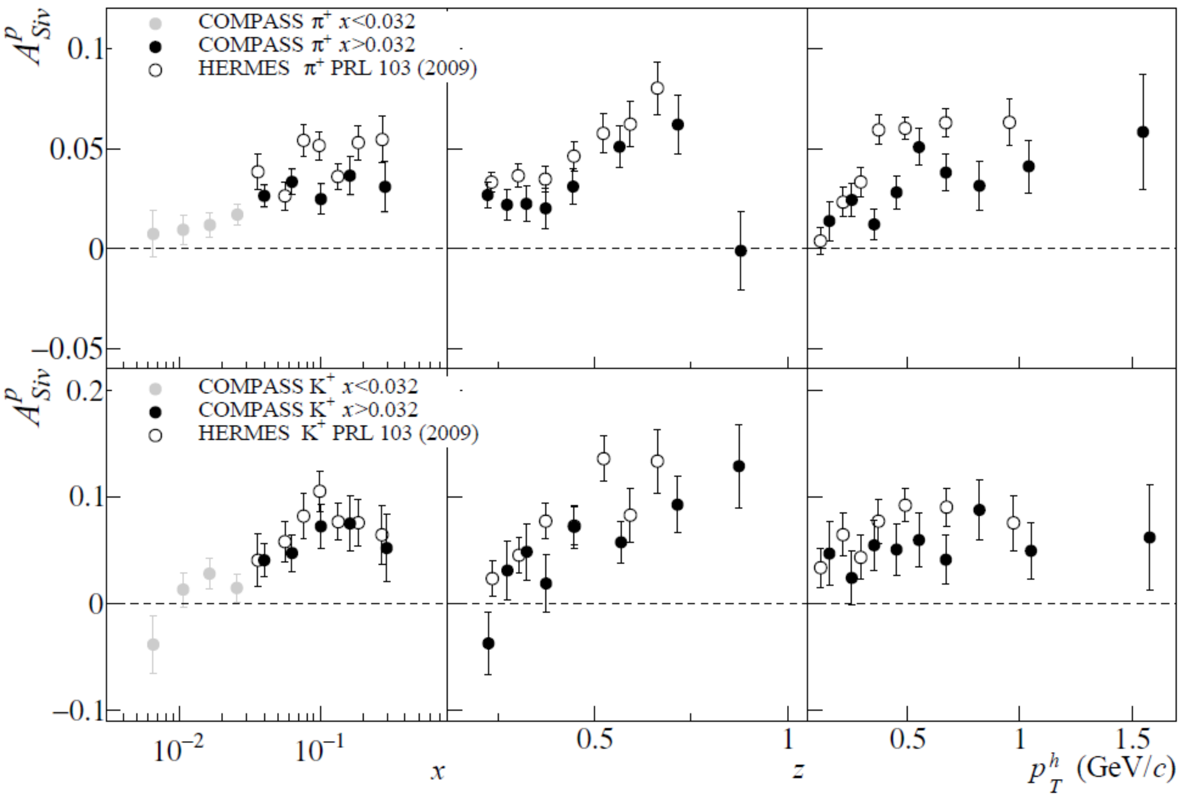


Average $P^2_\perp$ picked up in fragmentation



COMPASS and HERMES Sivers Asymmetries for π^+ vs K^+

COMPASS Phys.Lett. B744:250(2015)

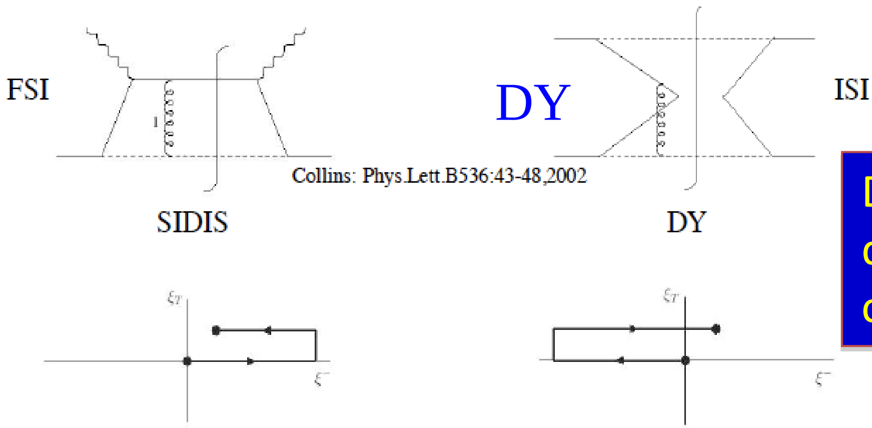


See Takahiro Iwata's talk Tuesday 15.00

Sivers asymmetries clearly established in SIDIS!

Sign Change of Sivers- and Boer-Mulders Functions Between SIDIS and DY

SIDIS



Direction of the gauge-link integrals of k_T dep. pdfs is process-dependent and changes its sign between SIDIS and DY

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

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

Need to confirm sign reversal in polarized Drell-Yan!

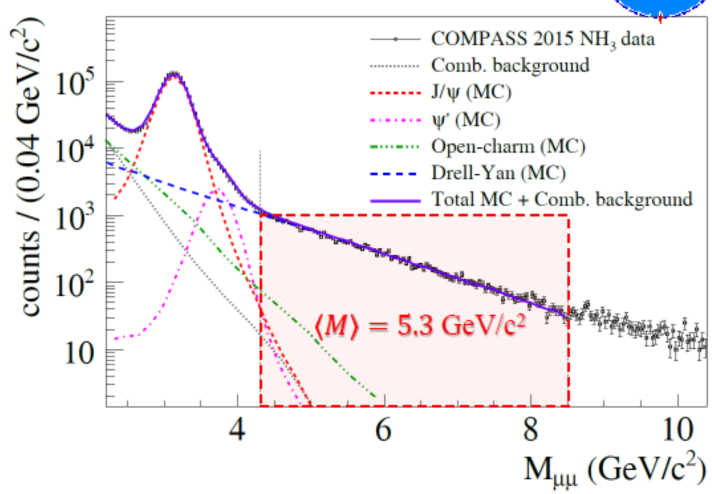
NSAC performance Milestone HP13 for 2015

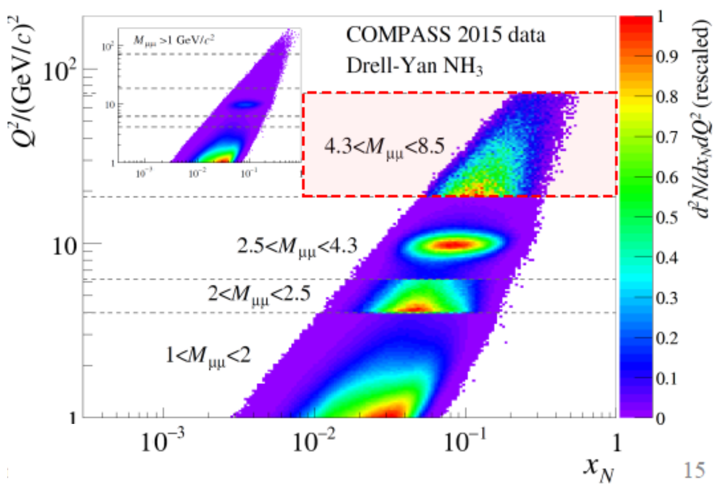
TEST “modified” universality of TMD pdfs!

New Drell-Yan Sivers Result

See Wen-Chen Chang's talk Tuesday 14.30

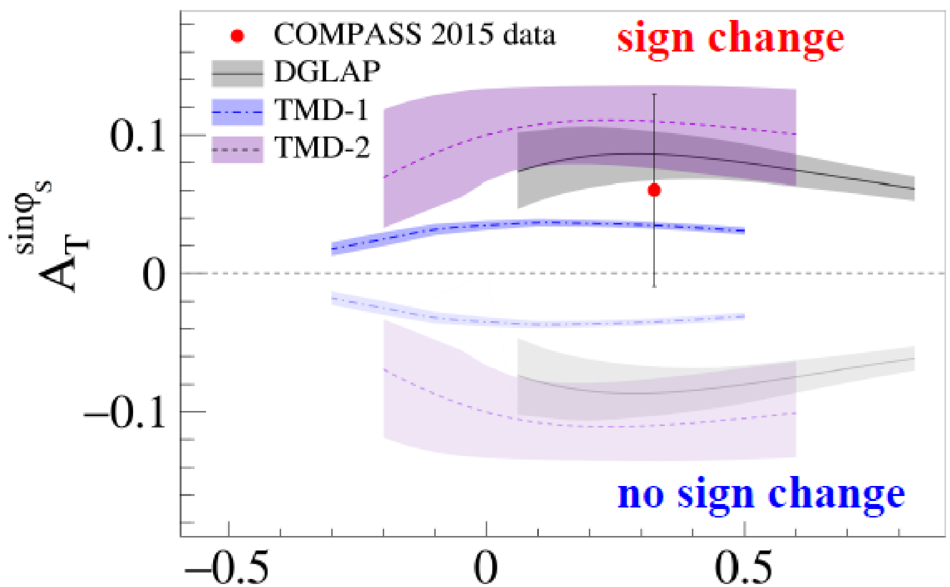
Final sample: 35 000 dimuons in HM





Released by
Barkur Parsamyan at DIS 2017
and Marcia Quaresma at IWHSS 2017

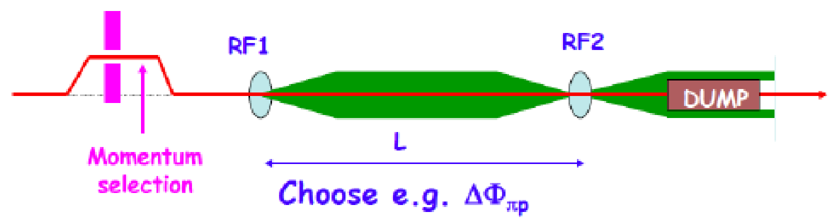
New! 03 April 2017
COMPASS
CERN-EP-2017-059
arXiv:1704.00488[hep-ex]



Future Plans: COMPASS++

with slides from Oleg Denisov,
Gerhard Mallot and Vincent Andrieux

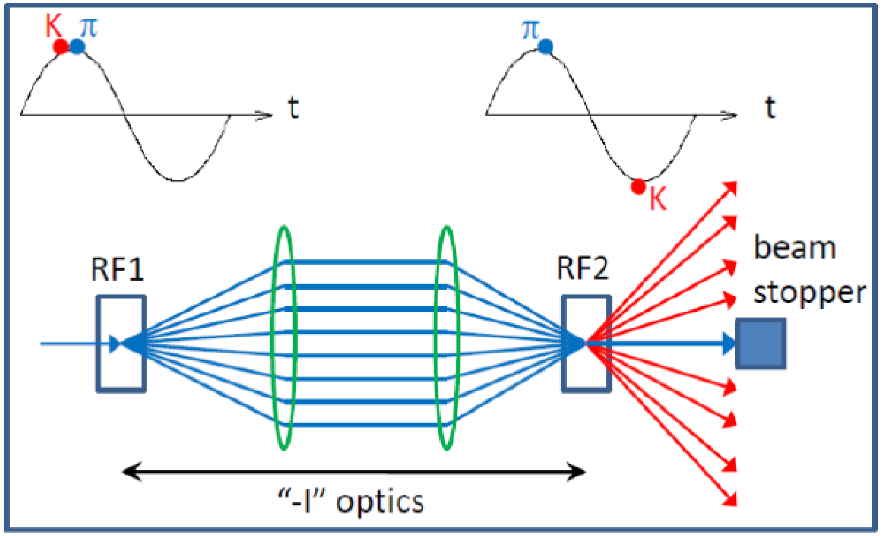
- COMPASS is preparing a Letter of Intent for a new round of experiments beyond 2020
- Open to new groups and ideas
- Starting point: Beyond 2020 workshop March 2016 at CERN
- Unique opportunity: RF separated kaon and antiproton beams (in M2)



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

- Goals: LoI in 2017, proposal in 2018
- Likely a 7-8 year endeavour

RF Separation of Hadrons in M2 Beamline: ➔ High Intensity K^- and $\bar{p}$-Beams !



- Deflection with 2 cavities
- Relative phase $= 0 \to$ dump
- Deflection of wanted particle given by $\Delta\phi \approx \frac{\pi f L}{c} \frac{m_w^2 - m_u^2}{p^2}$

To keep good separation, L should increase as $p^2 \to$ limits the beam momentum

Preliminary beam flux expectations for $2 \cdot 10^{13}$ppp:
$K^- / \bar{p}$: $\approx 1 \times 10^7$ particles per second for $\approx$ 10s
Enhancement by a factor of 50 compared to current beam

Physics Ideas for RF-Separated Beams

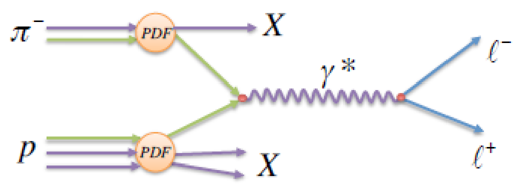
- **Spectroscopy with RF-separated beams**
  - Kaon: Hadron spectroscopy and diffraction
  - Kaon: polarisability
  - Kaon: gluon distribution with prompt photons
  - Antiproton: Charmonium hybrids and exotics (low p-bar energy)
- **Drell-Yan with RF-separated beams**
  - Kaon: DY with both polarised and unpolarised targets, kaon structure
  - Antiproton: DY, both polarised and unpolarised, TMDs

Physics Ideas Standard Beams

- **Physics with existing muon beam**
  - SIDIS with transverse polarised deuteron target
  - DVCS with transverse polarised proton target
- **Physics with existing pion/proton beam**
  - Pol. DY with deuteron target – flavour separation
  - Unpol. DY with various targets
  - x-section $p + \mathrm{He} \rightarrow \bar{p}\, X$ for dark matter

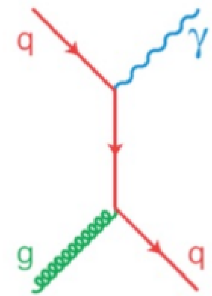
Accessing Meson Structure

Drell-Yan:



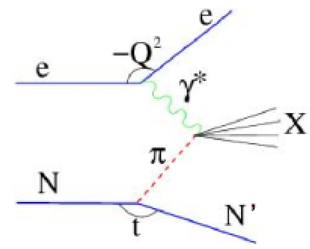
- 90's: NA3, NA10, E615
- 10's: COMPASS-II
- 20's: COMPASS++

Prompt photon productions:



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

DIS with leading N:



- 90's: H1, ZEUS
- 10's: JLAB TDIS
- 30's: EIC

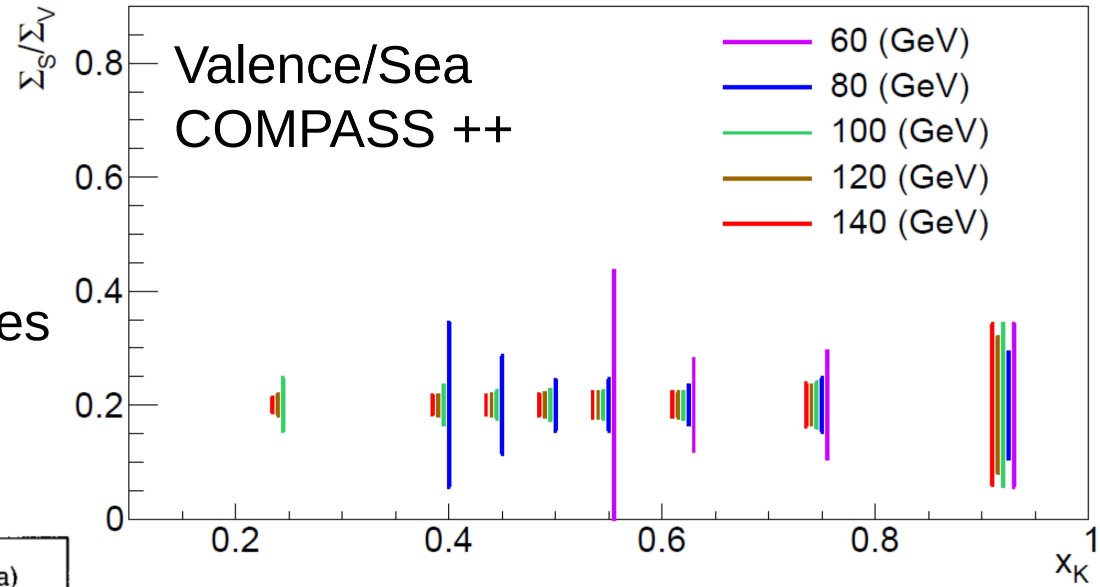
ECT workshop (Nov. 6-10, 2017): Dilepton Productions with Meson and Antiproton Beams

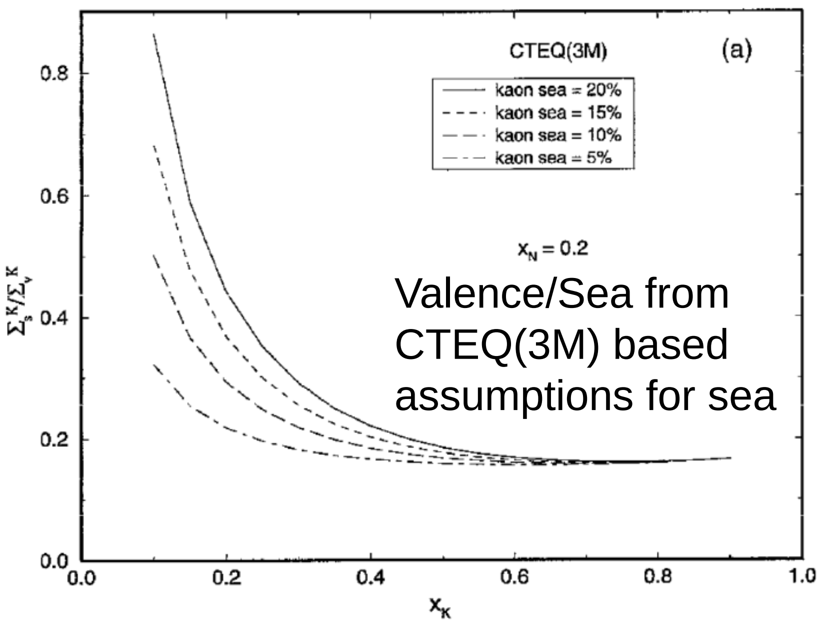
Argonne Workshop on π and K structure at an Electron-Ion Collider, June, 1-2, 2017

Example Valence/Sea Ratio For Kaons

If E_{beam}= 140 GeV statistical errors are 3%. Unique ability to determine Kaon pdfs.

COMPASS acceptances requires high beam momentum!





Upgrades needed:

- ➔ RF upgrade of M2 beamline
- ➔ New beamline PID
- ➔ LAS upgrades to increase acceptance

Summary:

COMPASS will complete data taking for Drell-Yan and exclusive physics through 2018. Analyses of SIDIS, exclusive processes, Drell-Yan and hadron spectroscopy data are in full swing.

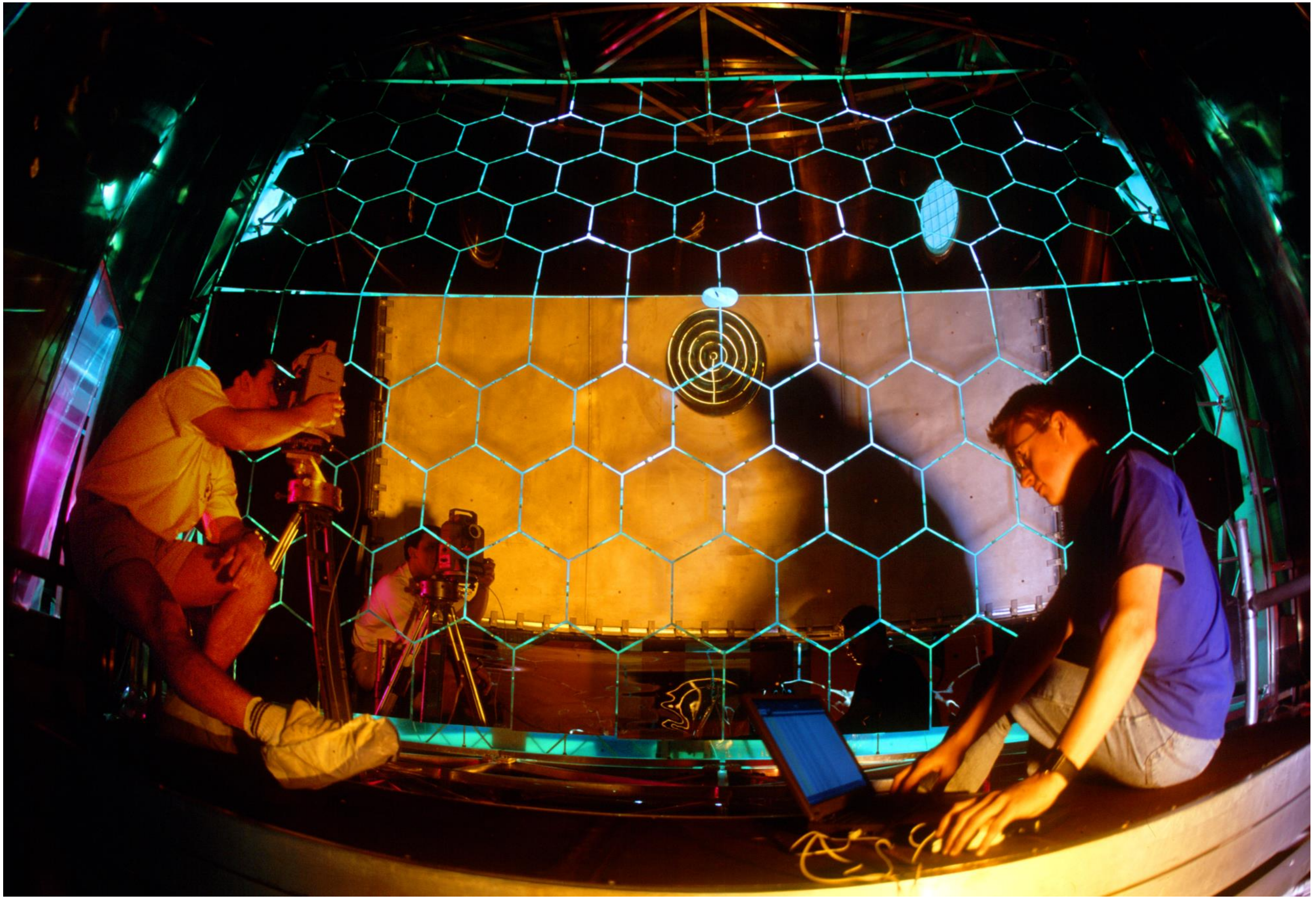
COMPASS ++

Many interesting topics in QCD physics exploiting its unique high energy hadron- and muon beams:

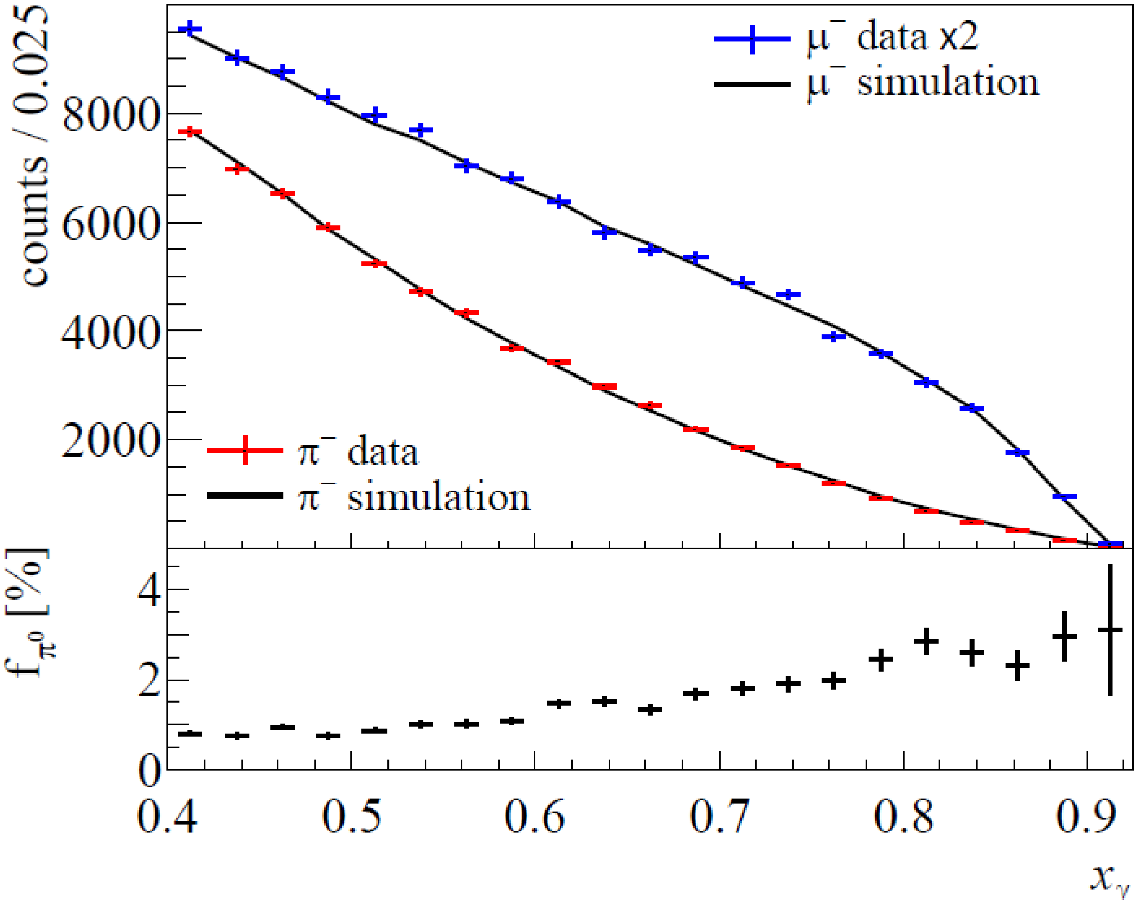
- o Nucleon spin structure with anti-proton beams
- o Spectroscopy with K^- and $\bar{p}$-Beams
- o Kaon Structure
- o Exclusive DVCS

Ideas, suggestions and new calloborators are highly welcome to join!

COMPASS RICH: INFN Trieste



Photon Energy Spectra for Pion and Muon Beams

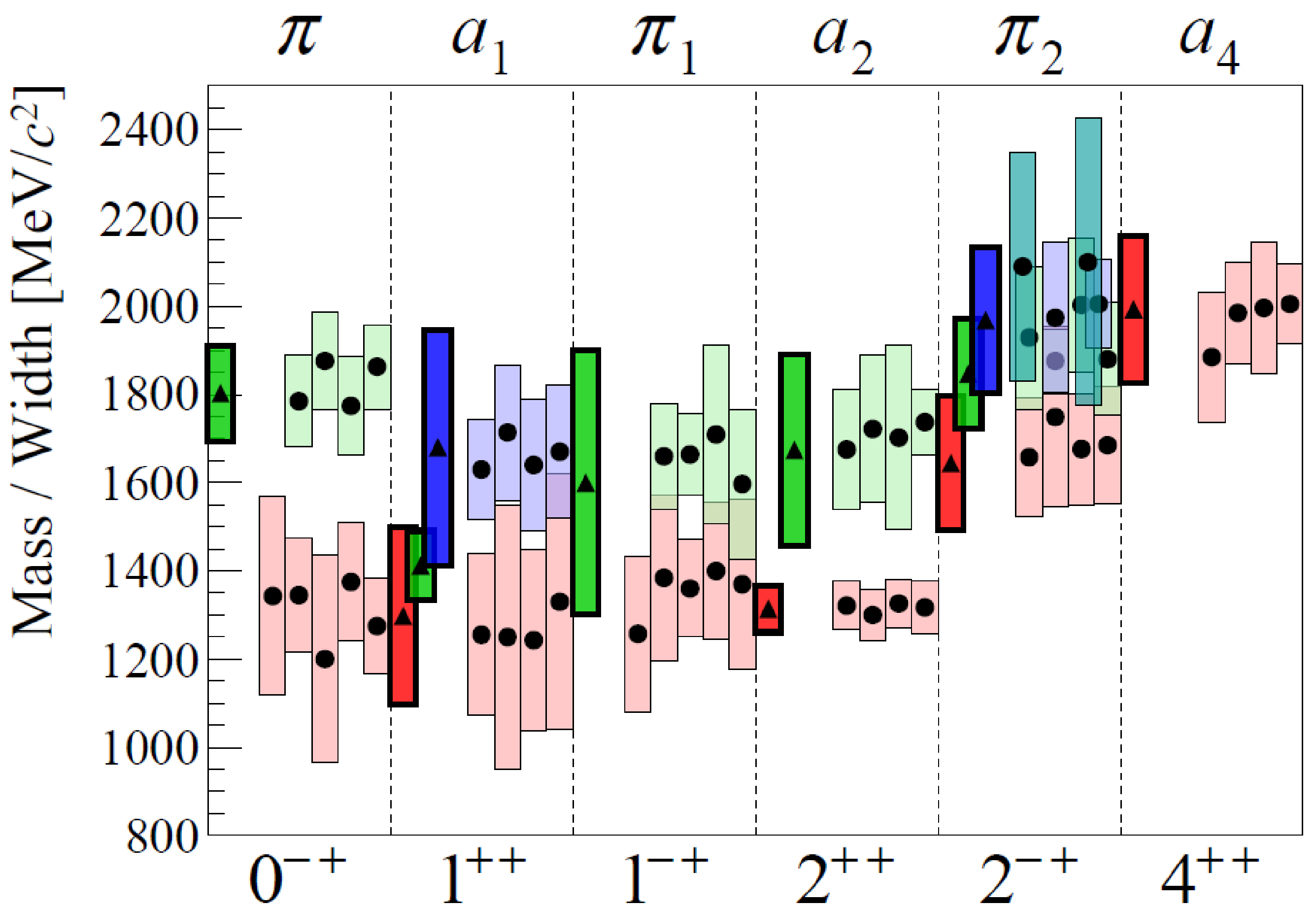


Phys. Rev. Lett. 114, 062002 (2015)

Simulation describes data well.
Small contamination from π^0.

Good control of systematics.

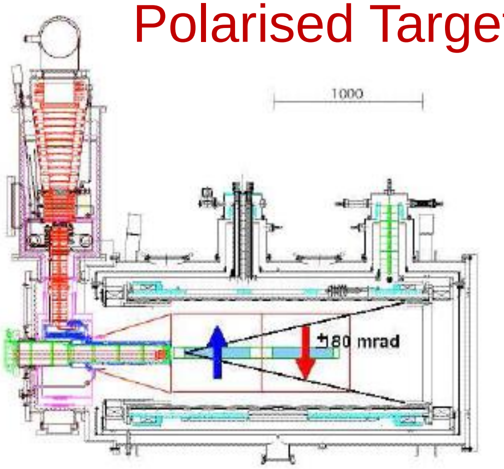
Summary: Resonance Production in $\pi^-(190\ GeV) + p \rightarrow \pi^- + \pi^- + \pi^+ + p_{recoil}$



arXiv:1509.00992 accepted for publication in PRD

Instrumentation Updates for Drell-Yan Physics

Polarised Target

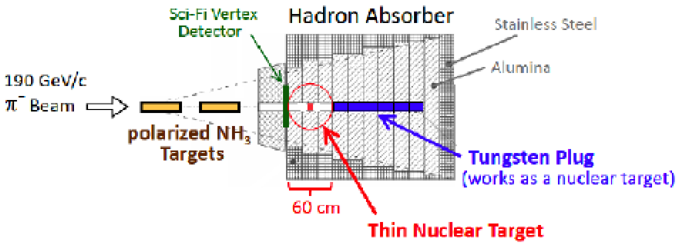


- Two cells of NH_3
- Polarisation ~ 80%
- Dilution factor ~ 22%

Hadron beam

190 GeV/c π beam (small contamination of K and $\bar{p}$)

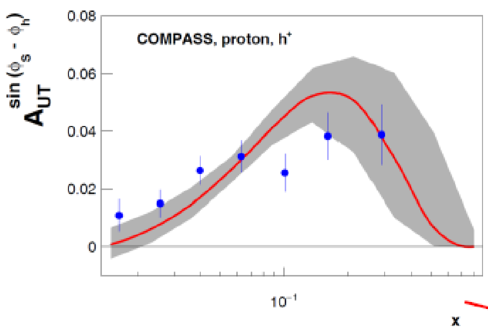
Hadron Absorber



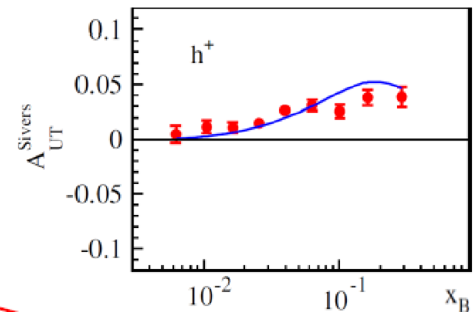
- Due to small cross-section, measurement requires high luminosity
- Hadron absorber downstream of target
  - Stops hadrons and non interacting beam
  - Degrade resolutions, two target cells, vertex detector
- Nuclear targets: Al and W $\Rightarrow$ unpolarised DY studies

Sivers Sign Change: 2 sigma

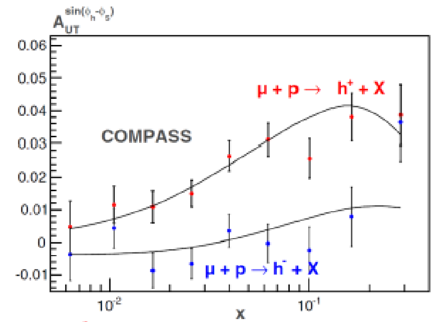
DGLAP (2016)
M. Anselmino et al., **arXiv:1612.06413**



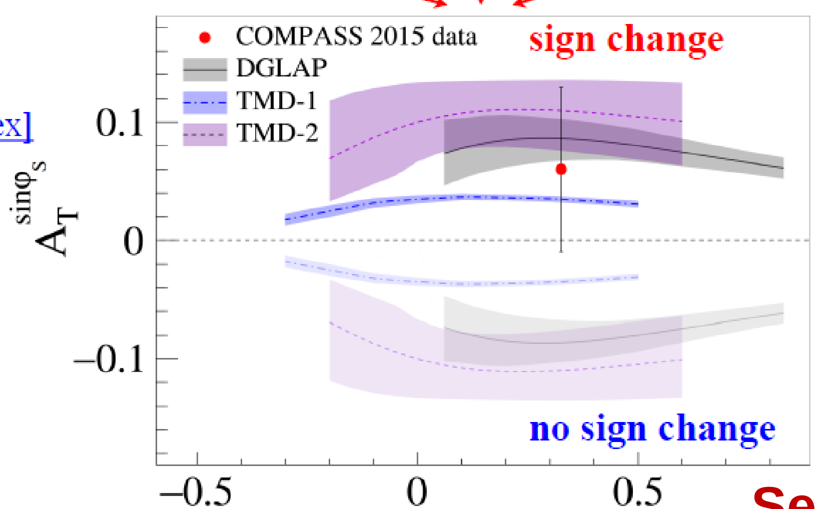
TMD-1 (2014)
M. G. Echevarria et al. **PRD89,074013**



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



New! **03 April 2017**
COMPASS
[CERN-EP-2017-059]
[arXiv:1704.00488[hep-ex]]



Additional Drell-Yan
Data taking in 2018!

See Wen-Chen Chang's talk Tuesday 14.30

Extraction of Transversity Distributions and Determination of the Tensor Charge

$\delta q(x)$ transversity
CFF(z) Collins FF
IFF(x) di-hadron FF

SIDIS

~ $\delta q(x) \times CFF(z)$
~ $\delta q(x) \times IFF(z)$

COMPASS

e^+e^-

~ $CFF(z_1) \times CFF(z_2)$
~ $IFF(z_1) \times IFF(z_2)$

pp → jets

~ $G(x_1) x \delta q(x_2) \times CFF(z)$

pp → $h^+ + h^- + X$

~ $G(x_1) x \delta q(x_2) \times IFF(z)$

πp → $l^+ + l^- + X$ Drell-Yan

~ $h_1^{\perp}(x_1) \times \delta q(x_2)$

Transversity, $\delta q(x)$
Tensor Charge

Theory

Lattice QCD: Tensor Charge = $\Sigma_{q=u,d} \int_0^1 \delta q(x) dx$