Hadron structure studies in a single-polarised Drell–Yan process at COMPASS

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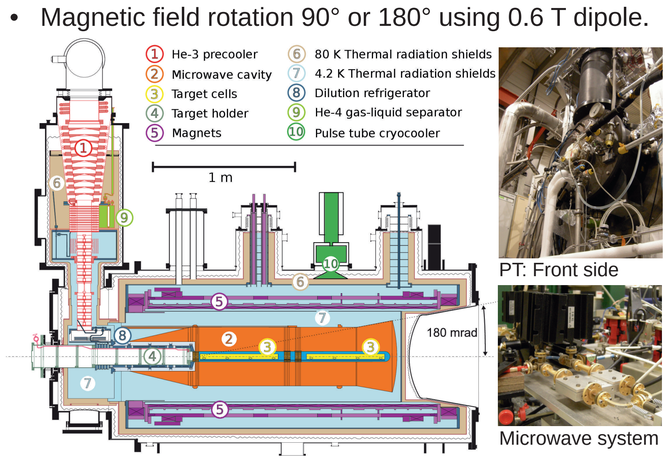
COMPASS Collaboration

- International – 24 institutes from 13 countries.
- About 220 physicists, wide physics program [1].

Polarized target

- PT for DY [2,3]: 2 cells, ⌀ 4 cm, each 55 cm long.
- Material: solid state NH_3 (polarizable − H nuclei).
- Cells oppositely polarized → positive and negative temperature of the spin ansambles.
- Paramagnetic centres (e^- spins) polarized in 2.5 T field of a superconducting magnet, transfer to nuclei by microwaves.
- 'Frozen spin' mode at ~65 mK reached by a dilution cryostat (cooling by dilution of ^3He in ^4He).
- Magnetic field rotation 90° or 180° using 0.6 T dipole.

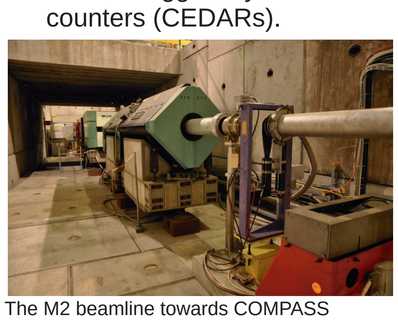


PT: Front side

Microwave system

Negative pion beam

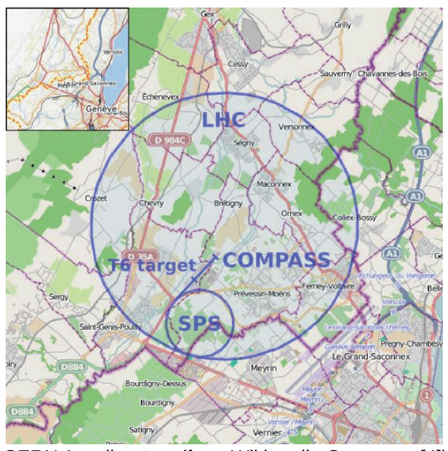
- 190 GeV, 10^9 π/spill of 10 s.
- Produced by SPS protons hitting a primary target.
- 97% π^-, 2.5% K^-, 0.5% p^-,
- can be tagged by Cherenkov counters (CEDARs).



The M2 beamline towards COMPASS

Experimental area

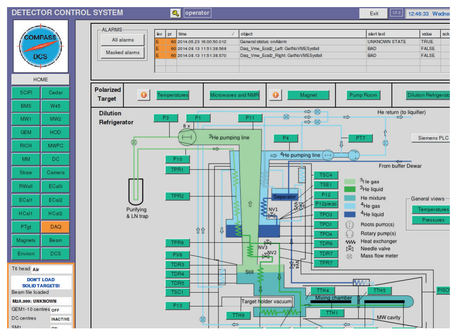
- CERN, Geneva (CH/FR),
- Super Proton Synchrotron (SPS) North Area,

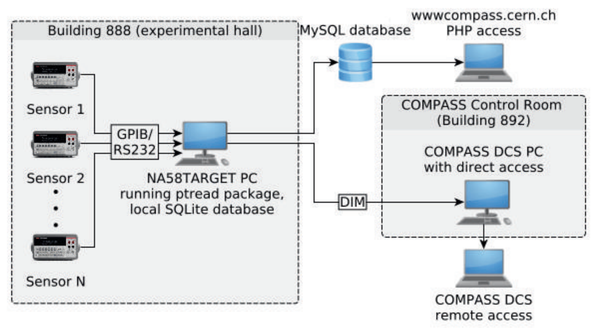


CERN Accellerators (from Wikimedia Commons [4])

Target dilution cryostat new remote monitoring

- Control-room moved away from the experimental building
- New Linux-based, modular software – ptread [2]:
- Instruments (thermometers, pressure gauges etc.) connected by GPIB or RS232 interfaces.
- Measurements sent to the centralised COMPASS DCS via DIM service





Spectrometer magnets

Muon filters

- Enable to distinguish muons thanks to their easy penetration through materials.

Hadron absorber

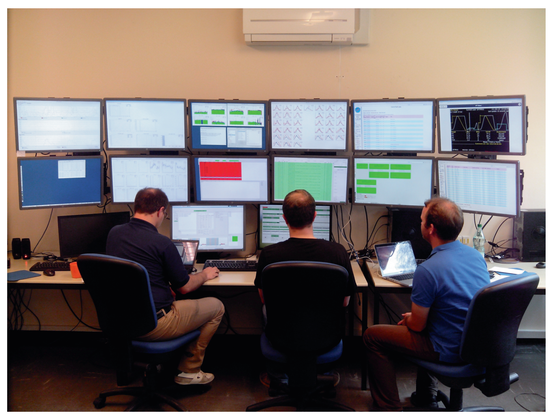
- μ filter, ensures reasonable detector occupancies.

Trigger

- Scintillating hodoscopes,
- trigger on coincidence of 2 signals (dimuon).

Data taking

- July 8 – November 12, 2015.
- The ~18 weeks = 9 periods, each having 2 weeks with reversed target polarisation.
- In total 34 904 Drell–Yan events in invariant mass range 4.3 < M < 8.5 GeV/c^2 were collected (all selections applied).
- Second data taking in 2018.



The remote control-room of COMPASS.

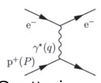
Tracking

- About 350 detector planes,
- Different kinds: Micromegas, GEM, drift chambers, MWPC, mini drift tubes.

Drit chamber operation.

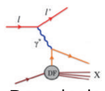
Hadron structure

- Parton model, born in the late 60's: nucleon is made of point-like constituents (partons).



$$\frac{d\sigma}{dx\,dQ^2} = \frac{4\pi\alpha^2}{Q^4} e^2$$

Scattering of a lepton on a point-like proton.



$$\frac{d\sigma}{dx\,dQ^2} = \frac{4\pi\alpha^2}{Q^4} \sum_i e_i^2 f_i(x)$$

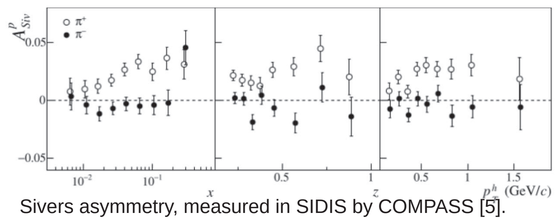
Deep inelastic scattering (DIS) on partons, breaking the proton.

- $f_i(x)$ – parton distribution function (PDF), x – fraction of p mom. carried by the parton.
- Spin-dependent PDFs: helicity and transversity
- Parton transverse momentum (k_T^2) dependent (TMD) PDFs:

		Parton hadron polarization		
		Unpolarized	Longitudinal	Transverse
P	U	$f_1(x, k_T^2)$ (number density)		$f_{1T}^{\perp}(x, k_T^2)$ (Sivers)
a	L		$q_1(x, k_T^2)$ (helicity)	$g_{1T}(x, k_T^2)$
r	T	$h_1^{\perp}(x, k_T^2)$ (Boer–Mulders)	$h_{1L}^{\perp}(x, k_T^2)$	$h_1(x, k_T^2)$ (transversity) $h_{1T}^{\perp}(x, k_T^2)$
t o n p.				

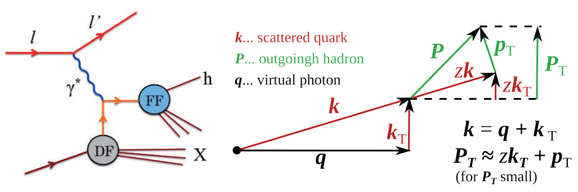
Sivers effect

- Observed in semi-inclusive DIS on HERMES and COMPASS as a left-right asymmetry in the production of hadrons (π and K).



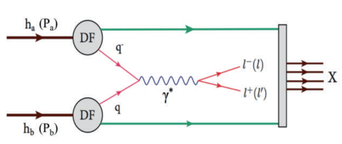
Sivers asymmetry, measured in SIDIS by COMPASS [5].

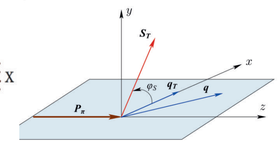
- Can be explained (for small P_T) by correlation of k_T of quarks with spin of the parent transversely polarised hadron, i.e. the Sivers function.



Drell–Yan process

- Production of dileptons in hadron interaction, in leading ord. by quark-antiquark annihilation.





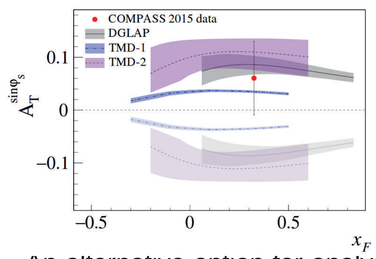
- COMPASS 2015 and 2018:

$\pi^-(P_\pi) + p^\uparrow(P_p) \rightarrow \gamma^*(q) + X \rightarrow \mu^-(k) + \mu^+(k') + X$

- Cross-section in leading order TMD approach:

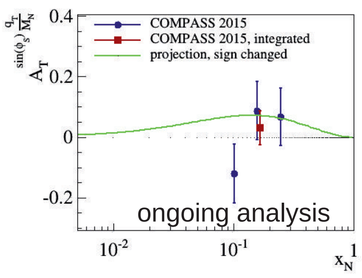
$$\frac{d\sigma_{DY}}{d^4q\,d\Omega} = \frac{\alpha^2}{CQ^2}\Big\{(1+\cos^2\theta)F_U^1 + \sin^2\theta\,\cos 2\phi\,F_U^{\cos 2\phi} + |S_T|\Big[(1+\cos^2\theta)\sin\phi_S\,F_T^{\sin\phi_S} + \sin^2\theta\,\sin(2\phi+\phi_S)F_T^{\sin(2\phi+\phi_S)} + \sin^2\theta\,\sin(2\phi-\phi_S)F_T^{\sin(2\phi-\phi_S)}\Big]\Big\}$$

- Structure functions F are (in TMD formalism) convolutions of TMD PDFs.
- Sivers effect expected, but with opposite sign.
- COMPASS has tested this with the same apparatus, and kinematic range.



Sivers asymmetry in the Drell–Yan process, measured by COMPASS, compared with three theoretical predictions [6].

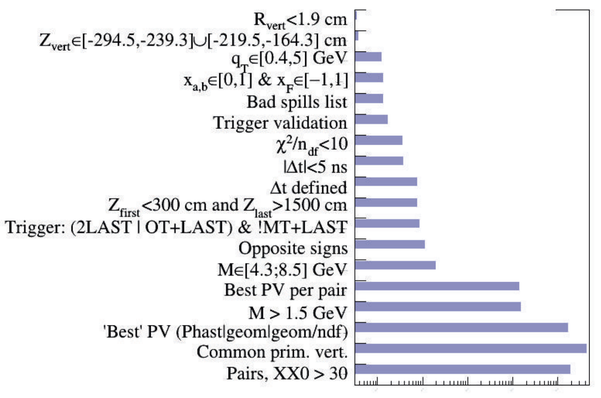
- An alternative option for analysis: Use weighting of events with powers of q_T to disentangle the convolution of TMD PDFs [7].

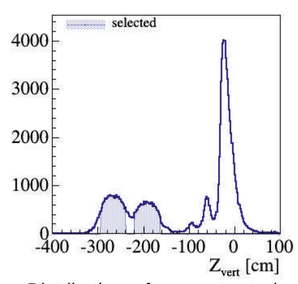


Sivers asymmetry in the Drell–Yan process weigted with q_T, measured by COMPASS, compared with an estimate based on weighted asymmetry in SIDIS process, measured by COMPASS [8].

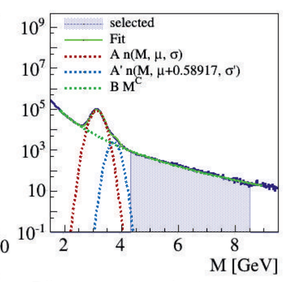
Data selection

- Dimuon selection,
- high invariant mass selected to supress physics background,
- time and MT trigger (low polar angles) cuts to supress combinatorial background (muons from beam pion decay),
- data quality cuts (apparatus stability – "bad spills", track chi², low q_T – lower resolution in azimuthal angles),
- target cells selected.

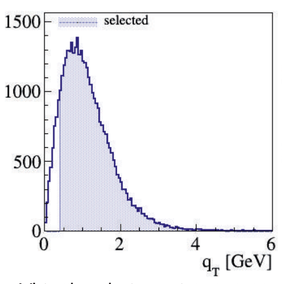




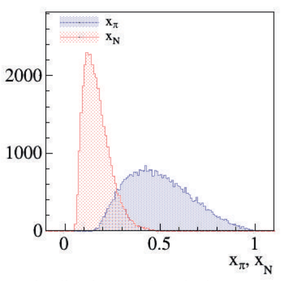
Distribution of reconstructed vertices. The target cells and the absorber can be seen.



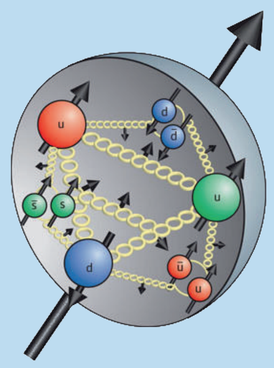
Dilepton invariant mass. Region above the charmonia was used.



Virtual photon transverse momentum. Low q_T is cut because of lower resolution.



Distribution of Bjorken x. Both for p and π lies in the valence region.



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References

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[2] J. Matoušek et al. (COMPASS PT group), in Proceedings of the 22nd International Spin Symposium, Urbana-Champaign, USA (2017).

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[5] C. Adolph et al. (COMPASS), PLB 744 (2015) 250.

[6] M. Aghasyan et al. (COMPASS), CERN-EP-2017-059, arXiv:1704.00488 [hep-ex], submitted to Phys. Rev. Lett.

[7] A. V. Efremov, et al., Phys. Lett. B612 (2005) 233–244, arXiv:hep-ph/0412353.

[8] F. Bradamante (COMPASS), in Proceedings of the 22nd International Spin Symposium, Urbana-Champaign, USA. 2017. arXiv:1702.00621 [hep-ex].