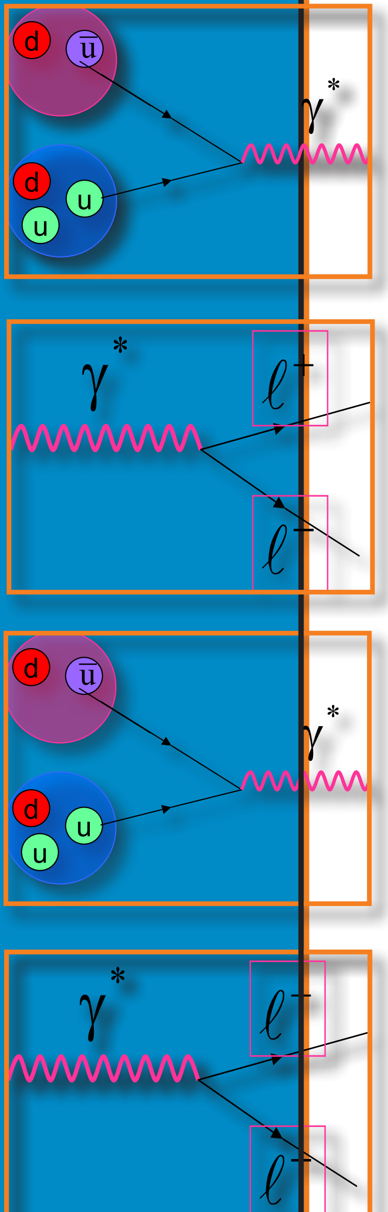


Future TMD DY-measurements at COMPASS - II

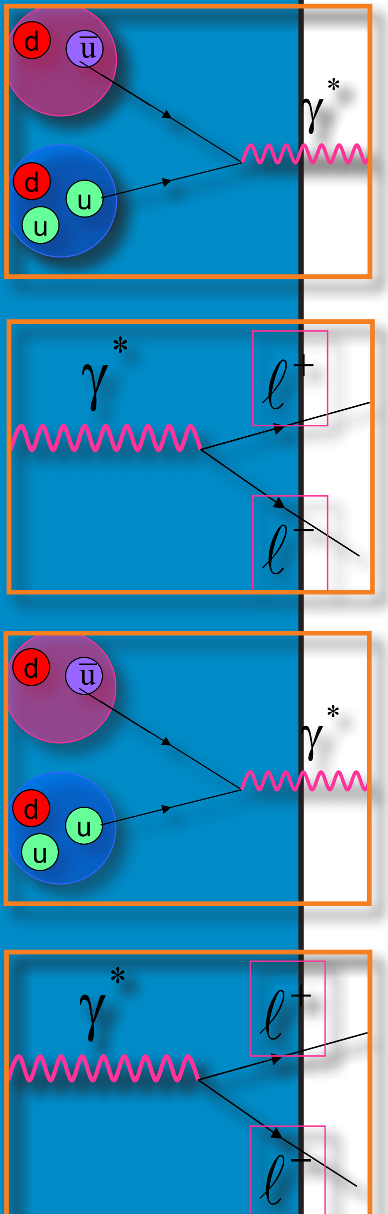
M. Chiosso, University of Torino and INFN
on behalf of the COMPASS Collaboration

COMPASS

INFN Istituto Nazionale di Fisica Nucleare

CLAS12 3rd European Workshop - Glasgow (Scotland)
20 - 22 June 2013

COMPASS-II Proposal



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

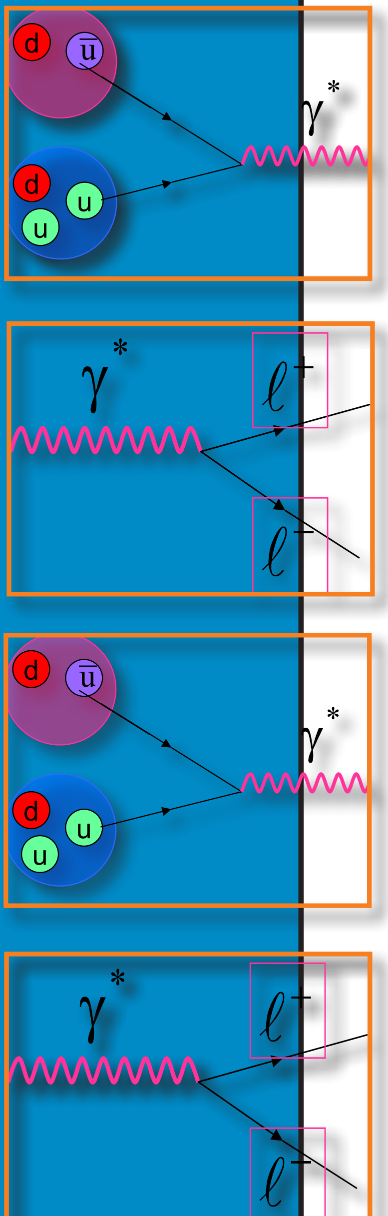
CERN–SPSC–2010–014
SPSC-P-340
May 17, 2010

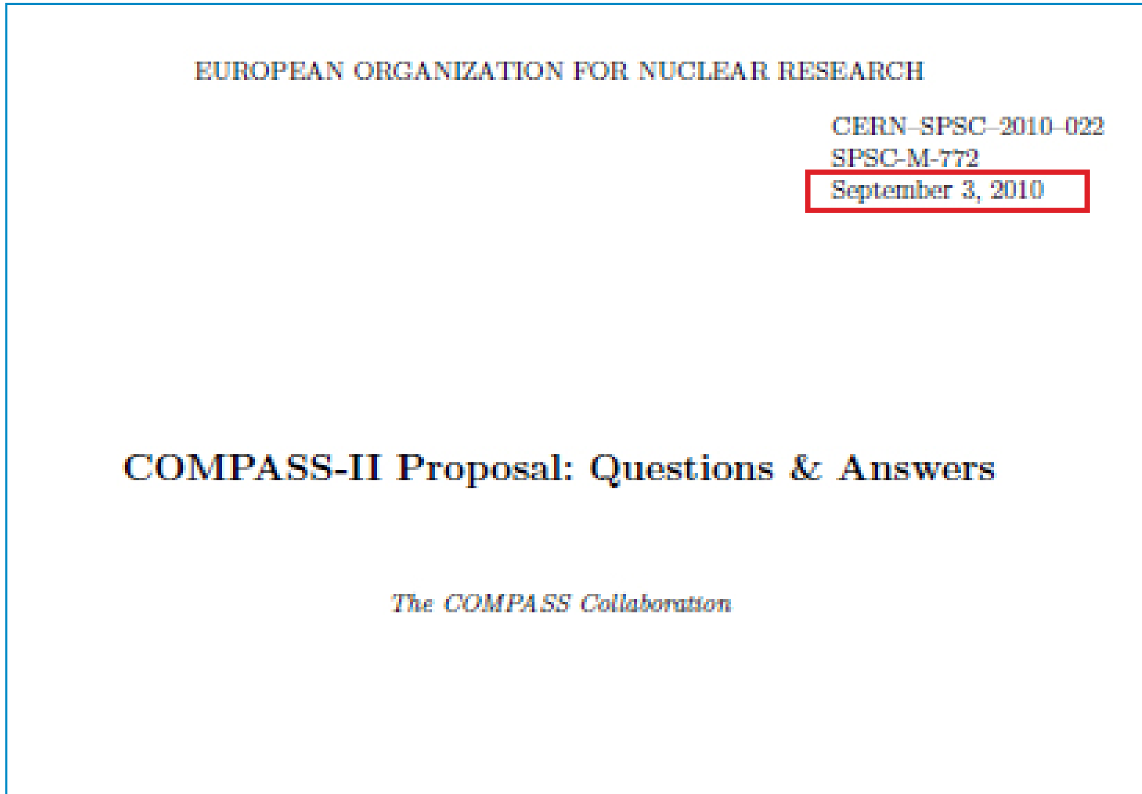
COMPASS-II Proposal

The COMPASS Collaboration

http://wwwcompass.cern.ch/compass/proposal/compass-II_proposal/compass-II_proposal.pdf

COMPASS-II Proposal




EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

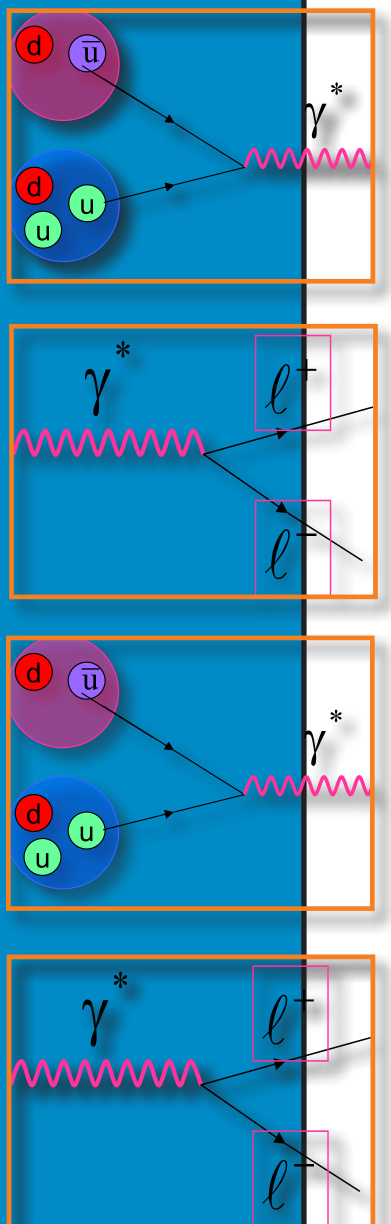
CERN–SPSC–2010–022
SPSC-M-772
September 3, 2010

COMPASS-II Proposal: Questions & Answers

The COMPASS Collaboration

http://wwwcompass.cern.ch/compass/proposal/compass-II_proposal/compass-II_QA_1.pdf

COMPASS-II Proposal




EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN–SPSC–2010–014
SPSC-P-340
May 17, 2010

Approved December 2010

COMPASS-II Proposal

The COMPASS Collaboration

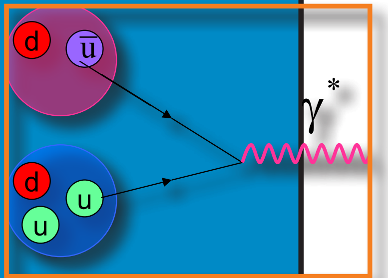
Generalized Parton Distributions (GPDs)

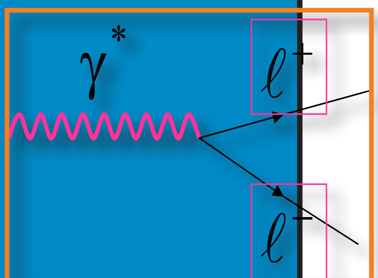
Measurements of unpolarised PDFs and TMD effects in SIDIS

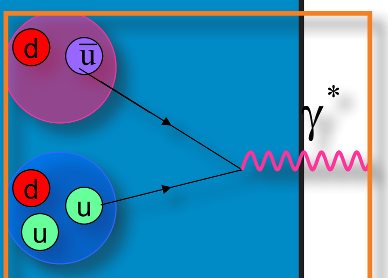
Pion-induced Drell-Yan muon pair production

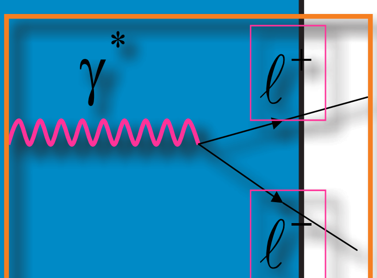
Primakoff scattering and pion polarisability

COMPASS-II Proposal









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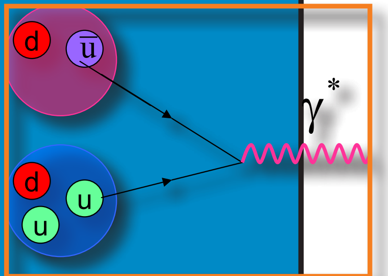
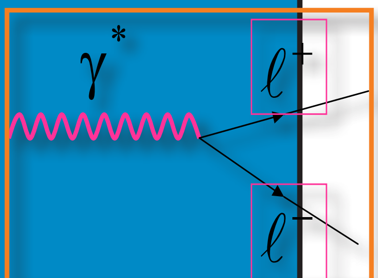
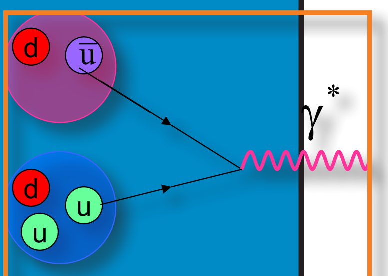
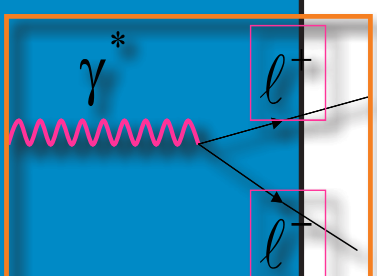
COMPASS-II @ CERN



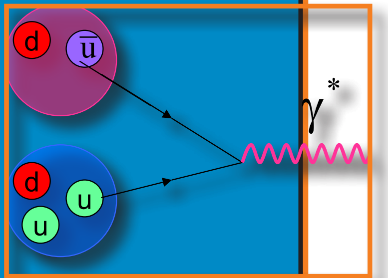


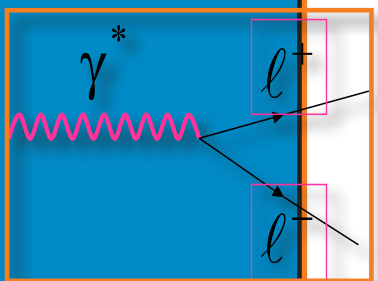


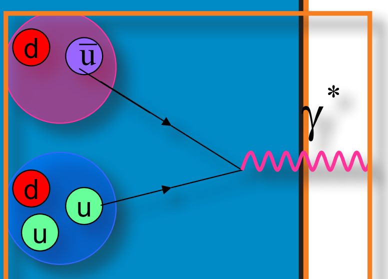


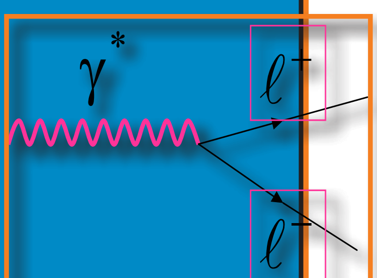
COmmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

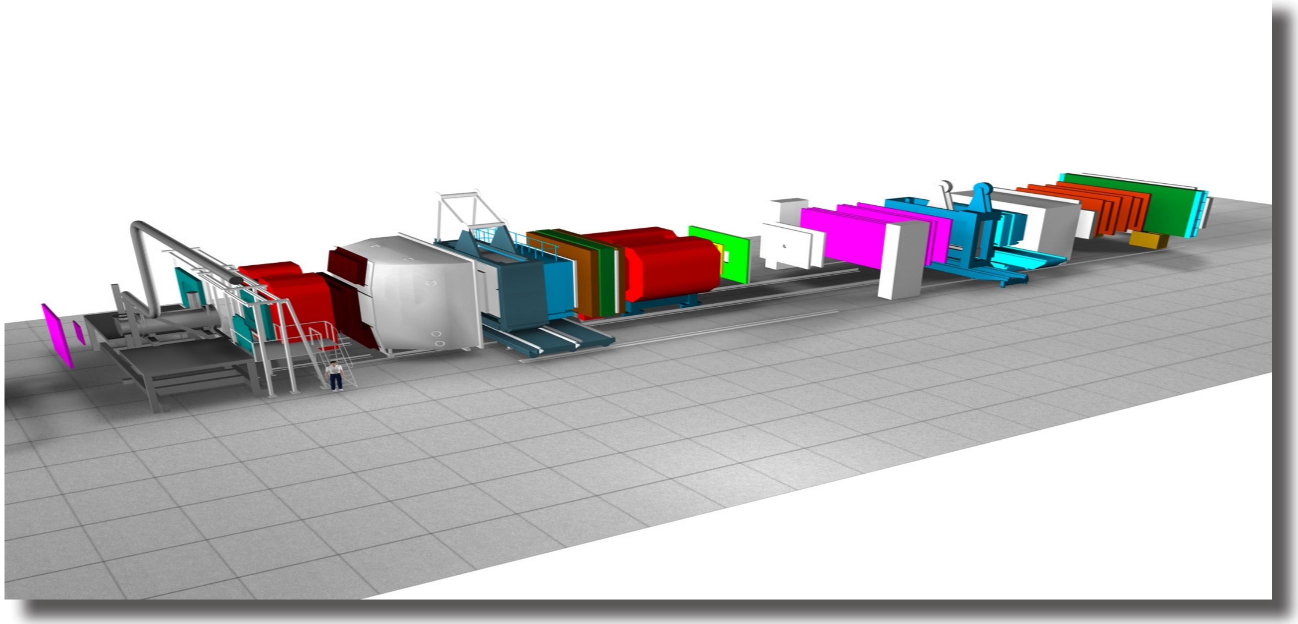
The COMPASS Spectrometer





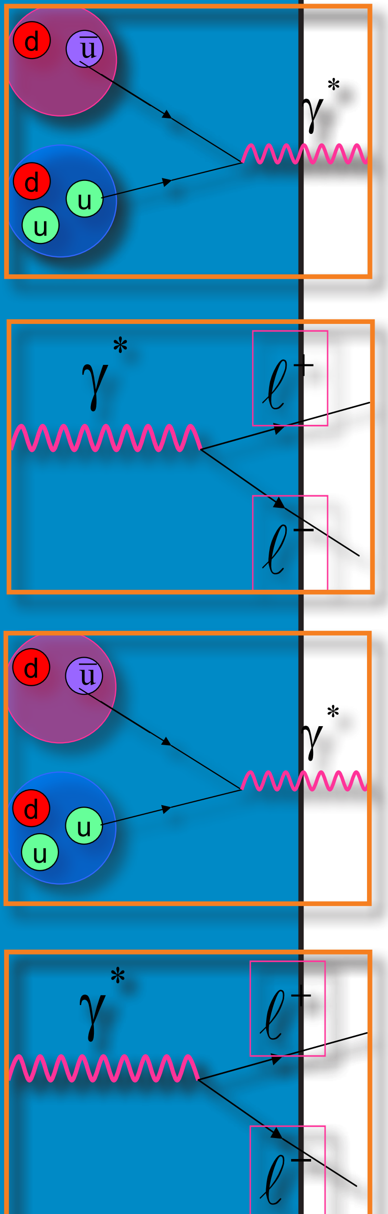






- Muon or hadron secondary beams
- Two stage magnetic spectrometer for large angular & momentum acceptance
- Solid state NH_3 (^6LiD) target
- Powerful tracking system – 350 planes
- Particle identification with:
  - Ring Imaging Cerenkov Counter
  - Electromagnetic calorimeters (ECAL1 and ECAL2)
  - Hadronic calorimeters
  - Hadron absorbers (Muon Walls)

COMPASS-II Schedule



COMPASS-II has been recommended by SPSC
and is approved by the Research Board

2012: Primakoff scattering and pion polarisabilities + DVCS test run

2013: SPS long shut-down

end of 2014: Unpolarised and Single polarised DY processes (test beam)

2015: Unpolarised and Single polarised DY processes

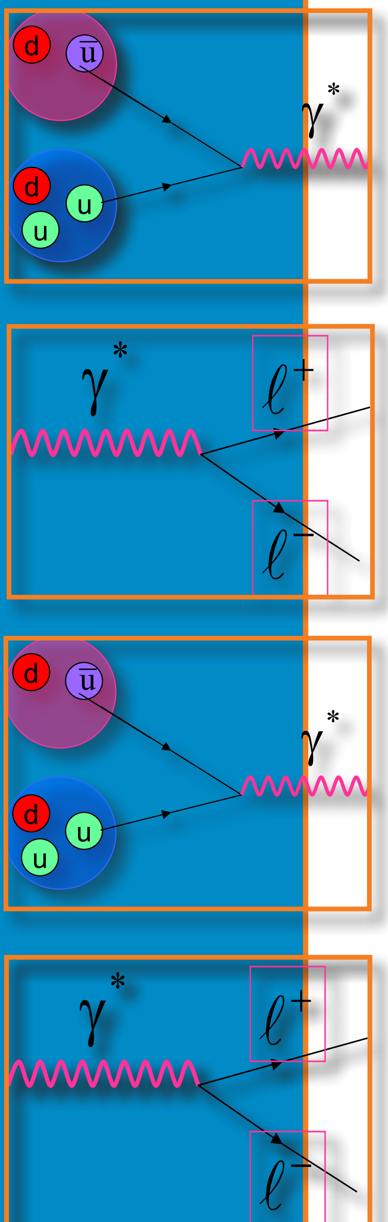
2016/2017: GPDs + in parallel SIDIS

2012:

Primakoff run untill 17 September 2012

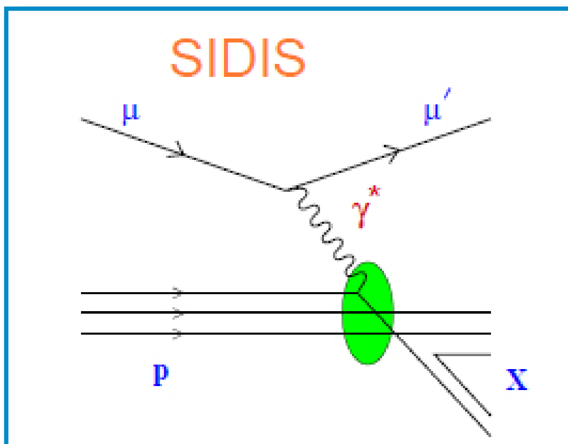
Changeover to DVCS

DVCS test run: 08 October - 03 December 2012

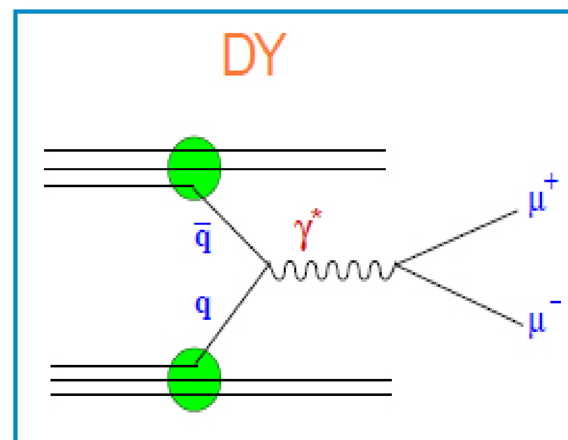


- Transversity and TMD PDFs
- TMDs universality
- J/ψ-Drell-Yan duality

TMD PDFs, like Sivers, can be accessed both from semi-inclusive DIS (SIDIS) and from the Drell-Yan process (DY).

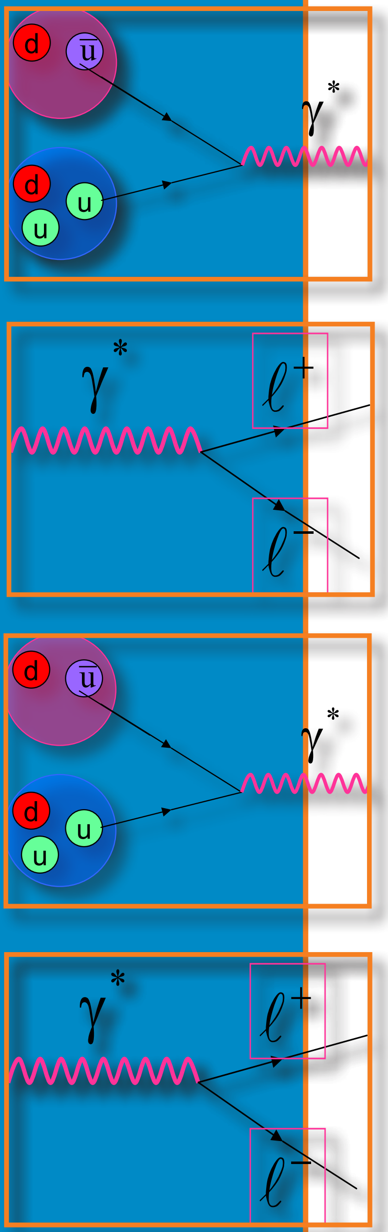


the amplitudes of azimuthal modulations are convolutions of PDFs and FFs



the amplitudes of azimuthal modulations are convolutions of PDFs only

Single polarized Drell-Yan



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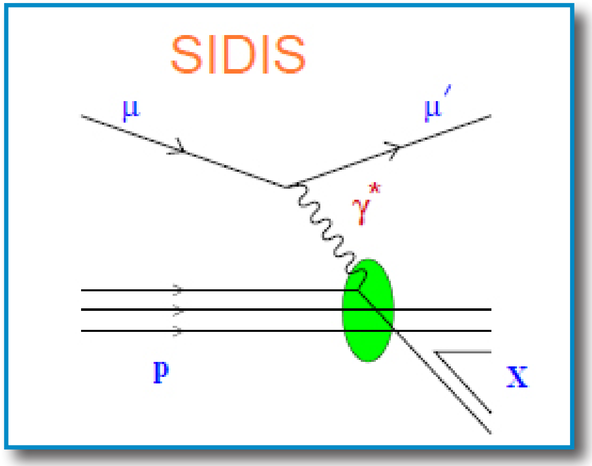
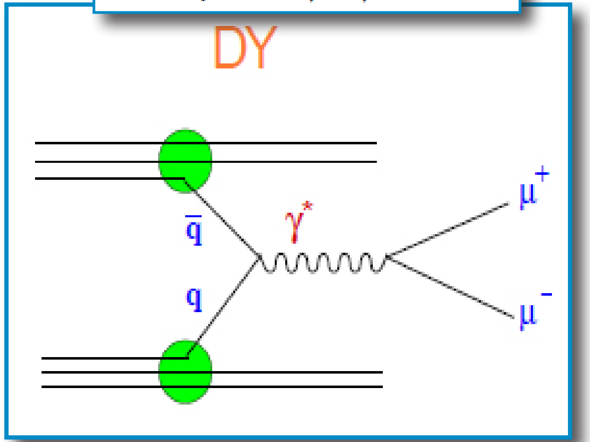


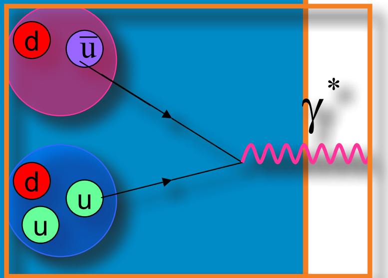
the amplitudes of azimuthal modulations are convolutions of PDFs and FFs

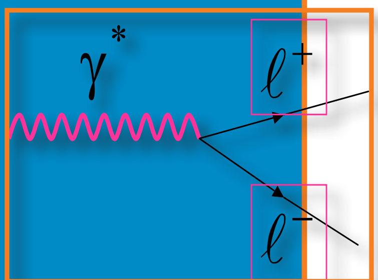
$\pi^- + p^\uparrow \rightarrow \mu^+\mu^- + X$

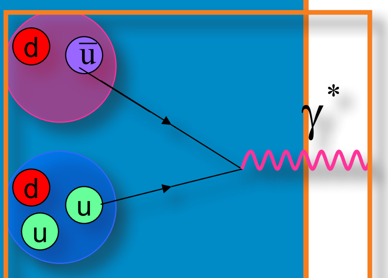


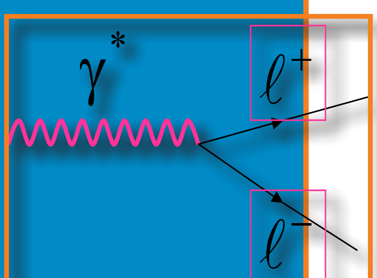
the amplitudes of azimuthal modulations are convolutions of PDFs only

Single polarized Drell-Yan









In a recent paper Arnold, Metz and Schlegel derived the full expression of the Drell-Yan cross-section, including unpolarized,transversely and longitudinally polarized terms [S. Arnold et al, Phys.Rev. D79 (2009)034005].

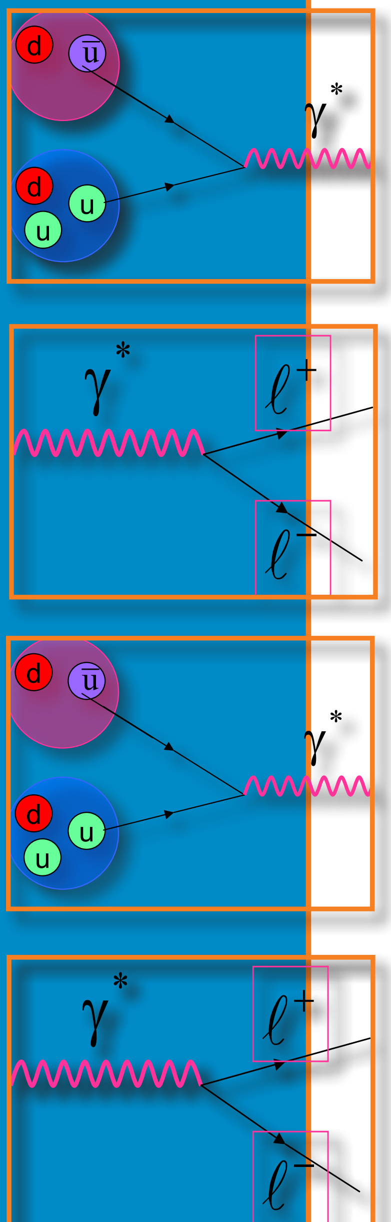
In single polarized DY, with transversely polarized target nucleons, the general expression of the cross-section (LO) is:

$$\frac{d\sigma}{d^4q d\Omega} = \frac{\alpha_{em}^2}{Fq^2}\hat{\sigma}_U \{(1 + D_{[\sin^2\theta]} A_U^{\cos 2\phi}\cos 2\phi) + |\vec{S}_T|[A_T^{\sin\phi_S}\sin\phi_S + D_{[\sin^2\theta]}(A_T^{\sin(2\phi+\phi_S)}\sin(2\phi+\phi_S) + A_T^{\sin(2\phi-\phi_S)}\sin(2\phi-\phi_S))]\}$$

A: azimuthal asymmetries; D: depolarization factor; S: target spin components; F: flux of incoming hadrons; σ_U: part of the cross-section surviving integration over ϕ and ϕ_S

ϕ_S : azimuthal angle of transverse target spin S_T in the target rest frame
ϕ : azimuthal angle of the lepton momenta in the Collins-Soper frame

Single Polarized Drell-Yan

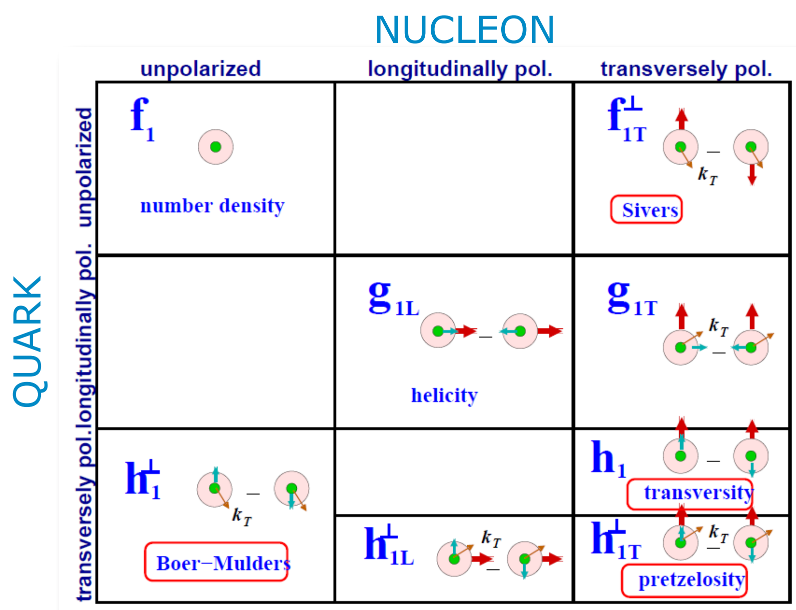


$A_U^{\cos 2\phi}$ gives access to the Boer-Mulders functions of the beam hadron and of the target nucleon

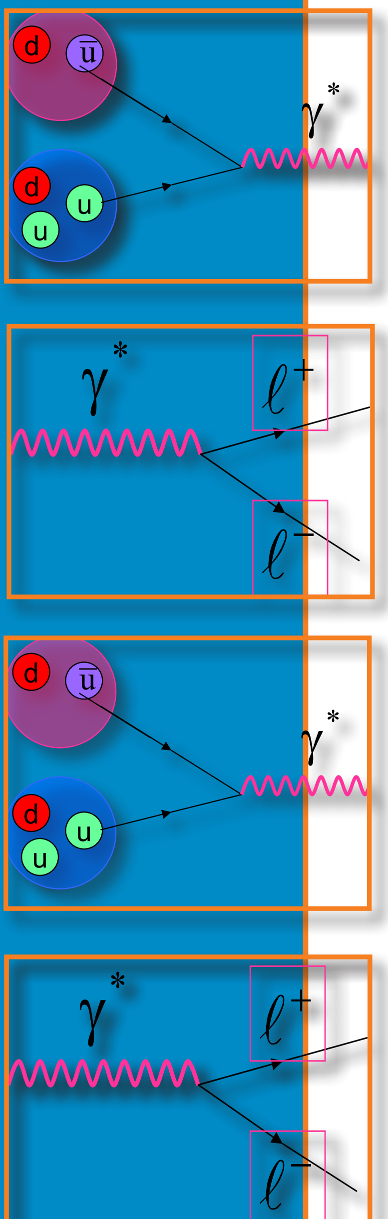
$A_T^{\sin\phi_S}$ to the Sivers function of the target nucleon

$A_T^{\sin(2\phi+\phi_S)}$ to the Boer-Mulders function of the beam hadron and to the pretzelosity function of the target nucleon

$A_T^{\sin(2\phi-\phi_S)}$ to the Boer-Mulders function of the beam hadron and to the transversity function of the target nucleon



DY vs SIDIS

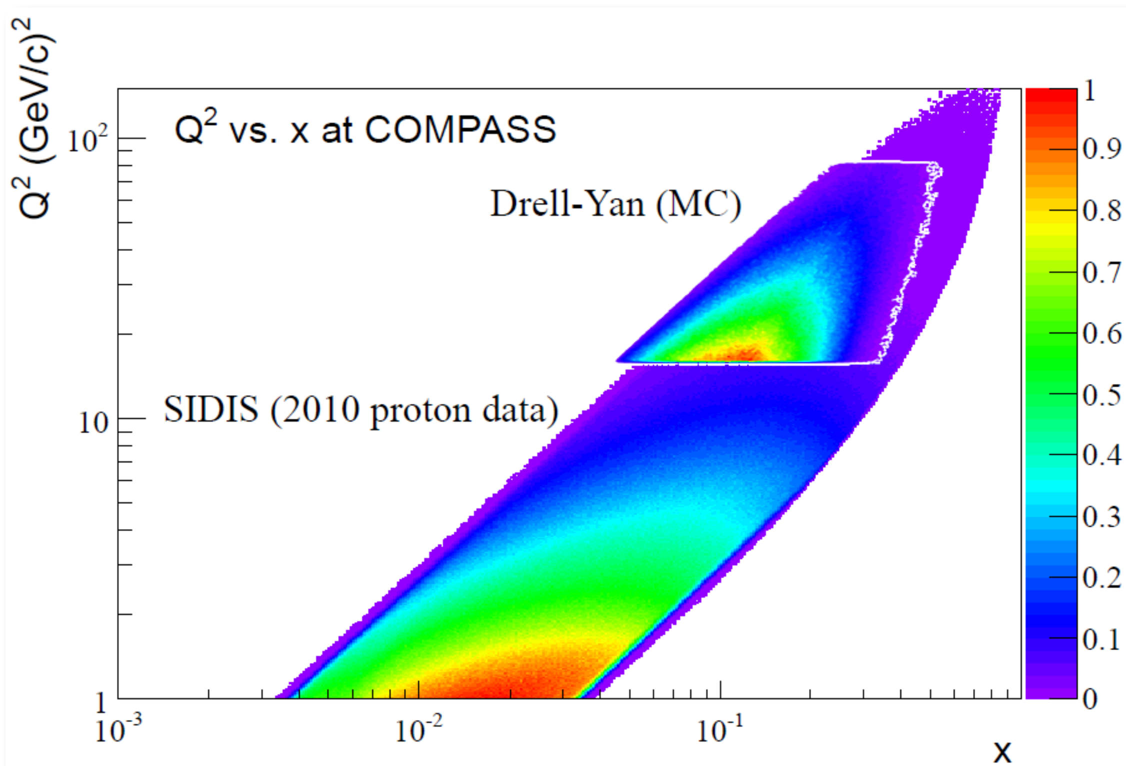


Change of sign of Sivers and Boer-Mulders functions?

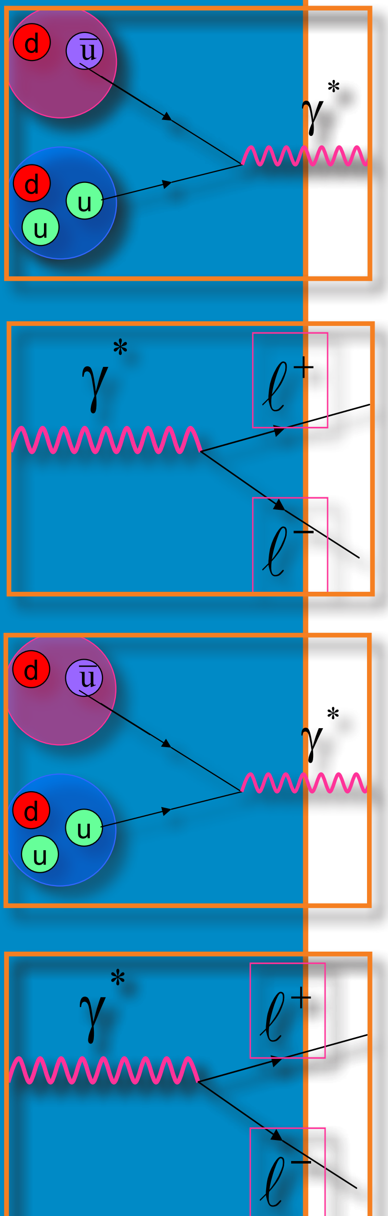
$$f_{1T}^{\perp}\Big|_{DY} = -f_{1T}^{\perp}\Big|_{DIS} \quad \text{and} \quad h_1^{\perp}\Big|_{DY} = -h_1^{\perp}\Big|_{DIS}$$

Critical test of universality of TMD factorization approach for the description of SSA.

In COMPASS, we have the opportunity to test this sign change using the same spectrometer and a transversely polarized target.



J/Ψ-DY duality



In spite of the large amount of experimental data on J/ψ production in various reaction, the production mechanism is still unclear.

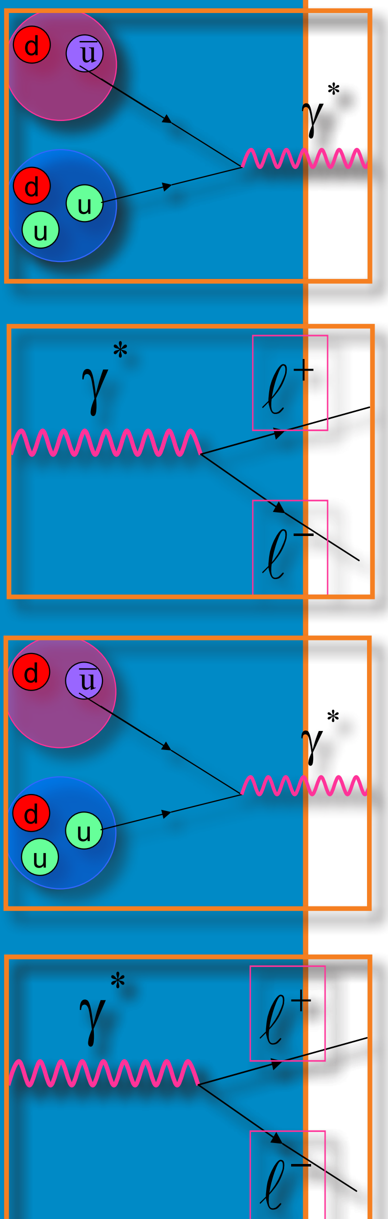
J/Ψ–DY duality —> model based on close analogy between Drell-Yan and J/Ψ production mechanism: occurs when the gluon-gluon fusion mechanism of the J/Ψ production is dominated by the q-q annihilation mechanism

$$\pi^- p^\uparrow \to J/\psi X \to \mu^+\mu^- X \qquad \pi^- p^\uparrow \to \gamma^* X \to \mu^+\mu^- X$$

From the study of J/ψ production in the dileptons decay channel:

- Check duality hypothesis – polarized J/ψ production cross-section
- Access PDFs from J/ψ events – larger statistics available

Polarized Drell-Yan experiments



What do we need to access spin dependent PDFs through DY?

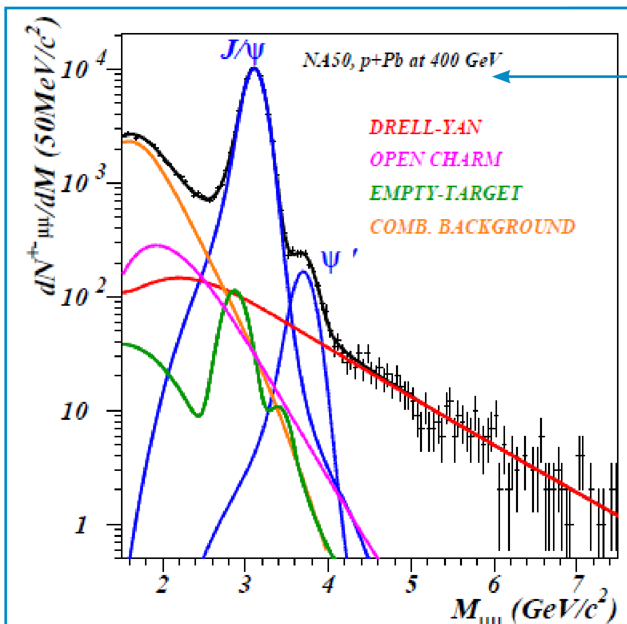
Polarized Drell-Yan experiments:

- High luminosity (DY Cross Section is a fraction of nanobarns) and large angular acceptance

- Sufficiently high energy to access 'safe' background free M range (4 GeV/c^2 < $M_{\mu\mu}$< 9 GeV/c^2)

- Good acceptance in the valence quark range

- Good figure of merit (FoM), which can be represented as a product of the luminosity, target polarisation (dilution factor f) and beam (target) polarisation



NA50: p @ 400 GeV/c in a Pb target; I about 10^9 particles/sec

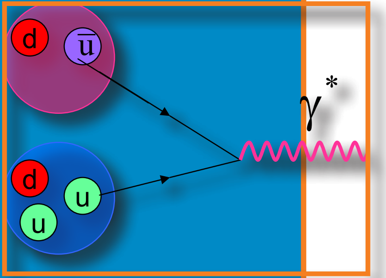
Even if the cross-section is low, M range 4 < $M_{\mu\mu}$ < 9 GeV/c^2 is the ideal sample to study azimuthal asymmetries in Drell-Yan, due to negligible background contamination.

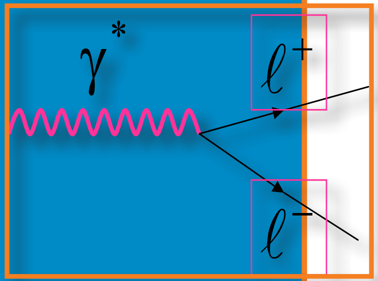
The combinatorial background is kept under control by the presence of a hadron absorber downstream of the target.

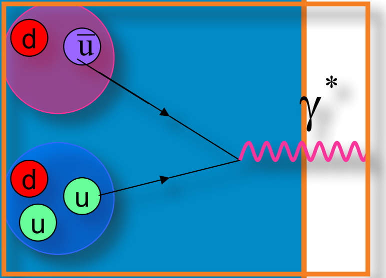
@ COMPASS: π^- @ 190 GeV/c in a NH_3 target; I up to 10^8 particles/sec:
comb. background 100 times lower (50% of total in intermediate M range 2. < $M_{\mu\mu}$ < 2.5 GeV/c^2)

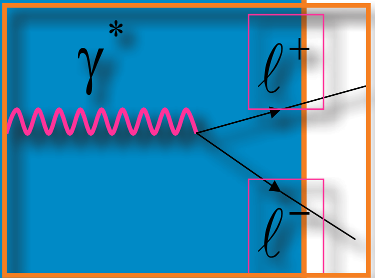
open charm contributes only at 15%

Drell-Yan @ COMPASS-II

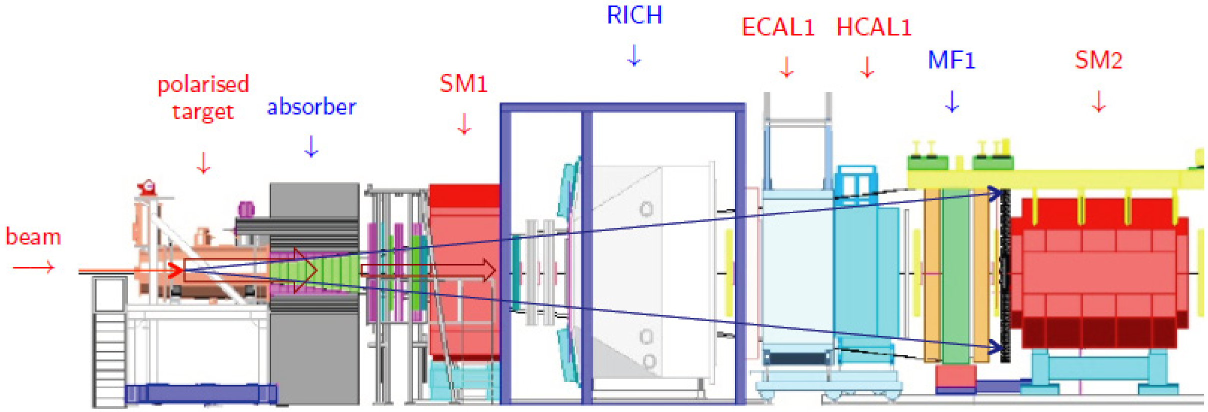




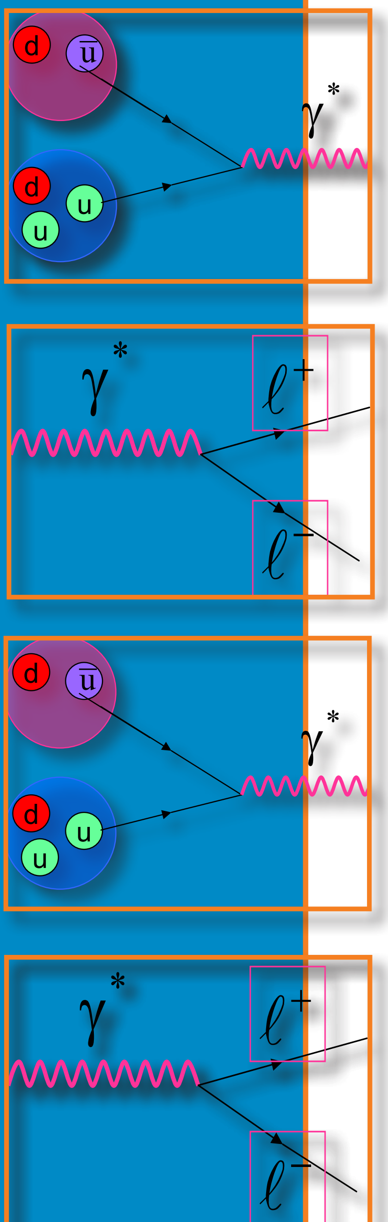


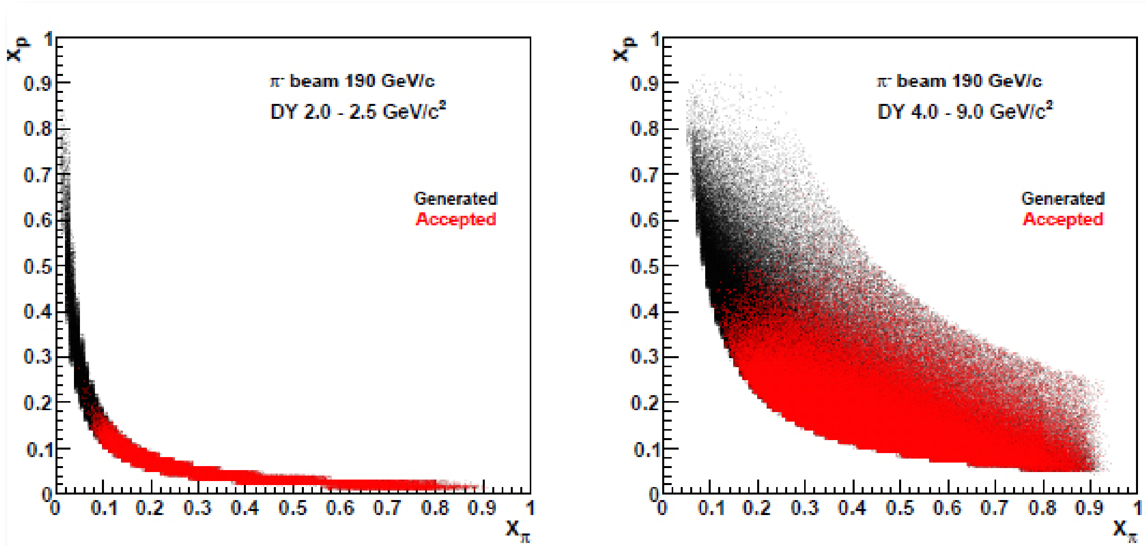


- Large angular acceptance spectrometer
- π^- beam at 190 GeV/c with the intensity up to 1×10^8 particles/second
- Large acceptance COMPASS Superconducting Solenoid Magnet
- Transversely polarized NH_3 2-cells target; target polarization: ~90%; dilution factor: 0.22
- Hadron absorber downstream of the target
- Vertex detector to improve the cell separation of events
- A detection system designed to stand relatively high particle fluxes
- A Data Acquisition System (DAQ) that can handle large amounts of data at large trigger rates
- Trigger based on hodoscope signals coincidence, homothetic and pointing to the target



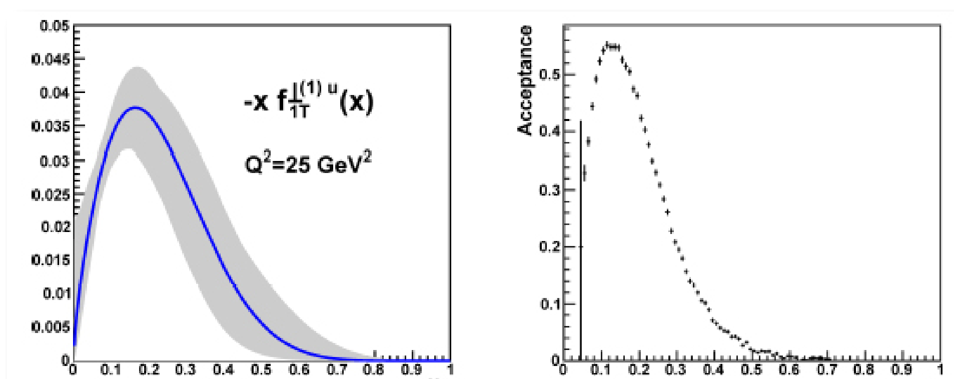
COMPASS-II DY Acceptance





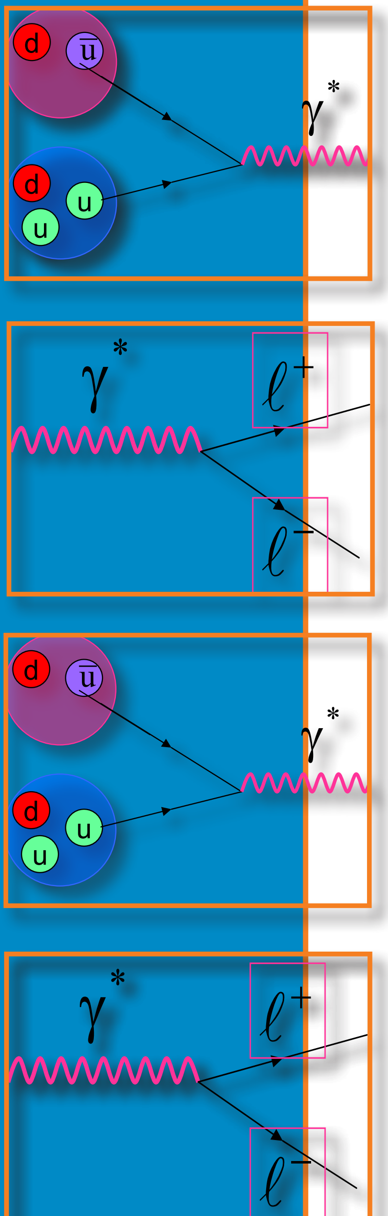
COMPASS acceptance is in the valence quarks region

For DY 4 < $M_{\mu\mu}$ < 9 GeV/c^2, we have x_p > 0.05 --> also the best region to measure spin asymmetries



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

Drell-Yan @ COMPASS-II: Feasibility



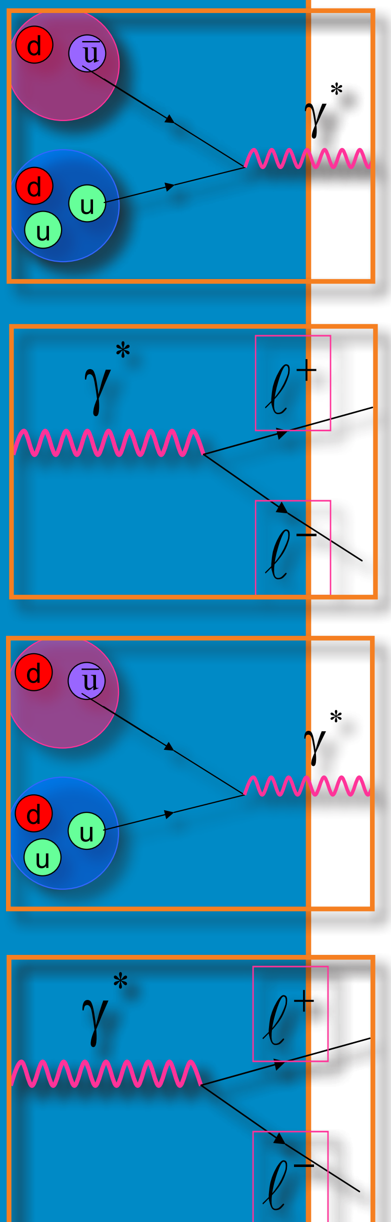
In 2007, 2008 and 2009 short Drell-Yan beam tests were performed, to check the feasibility of the measurement

In 2007, with a π^- beam of 160 GeV/c on a NH_3 target, and without hadron absorber: ≈ 90000 dimuon events (< 12 hours data-taking)

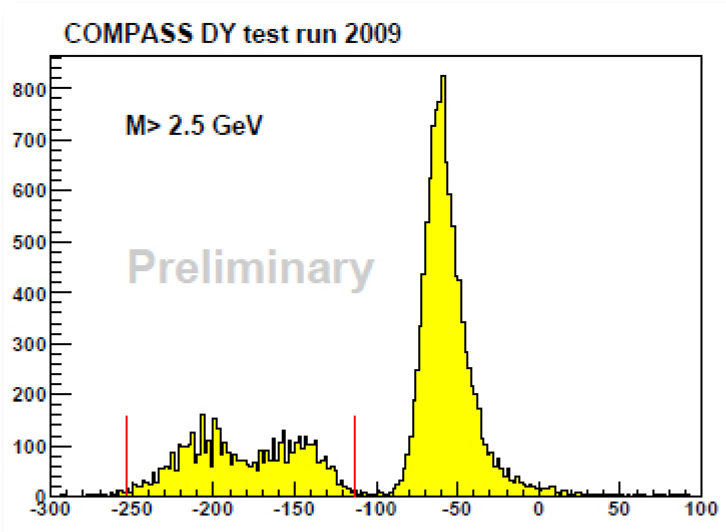
In 2008 a second beam test was performed, also with an open configuration of the spectrometer, a π^- beam of 190 GeV/c, and a polyethylene target

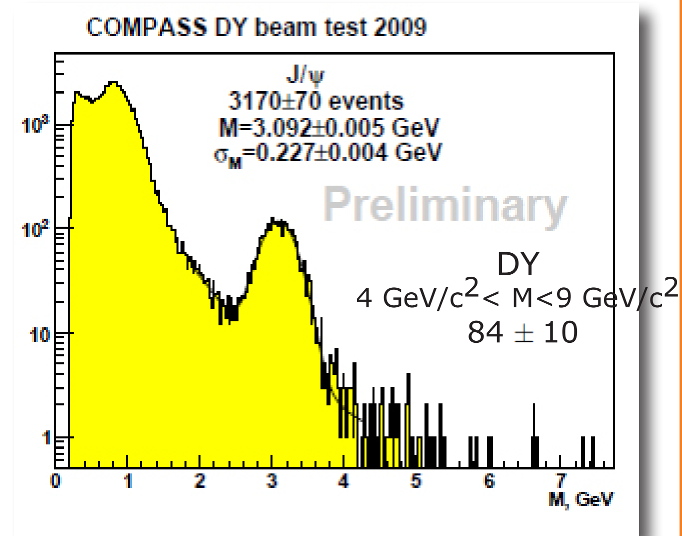
- The target temperature does not seem to increase signifcantly with the hadron beam, long polarization relaxation times measured (2007 beam test)
- Reasonable occupancies in the detectors closer to the target can only be achieved if a hadron absorber and beam plug is used (2008 beam test)
- Physics simulation were validated, within statistical errors (J/ψ peak and combinatorial background, in 2007 and 2009 beam tests)

Beam test 2009



π^- beam of 160 GeV/c on 2-cells polyethylene target. Setup including hadron absorber and a beam plug (3 days of data-taking)



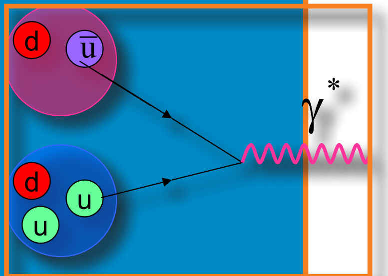


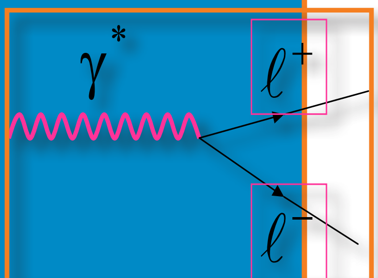
Reasonable Zvertex separation, allowing to distinguish the 2 target cells and the absorber

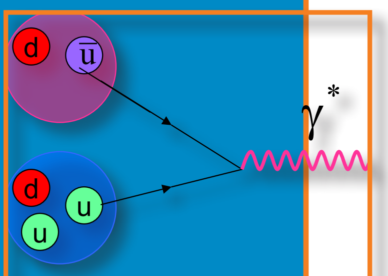
Data taken without the optimised dimuon trigger with target pointing capability

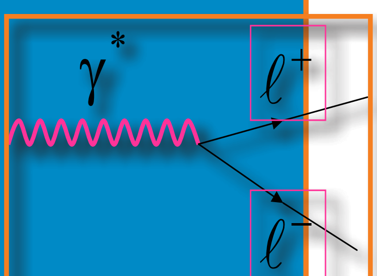
The expected number of J/Ψ and DY events from Monte-Carlo was confirmed:
expected J/Ψ: 3600 ± 600
expected DY events(4 GeV/c^2< M<9 GeV/c^2): 110 ± 22

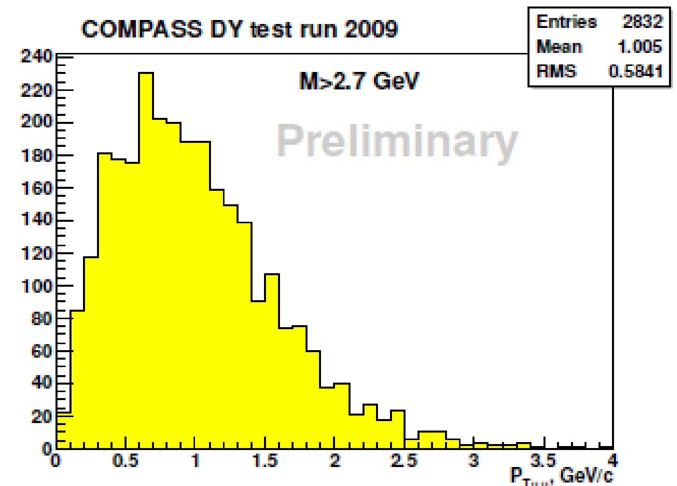
Beam test 2009



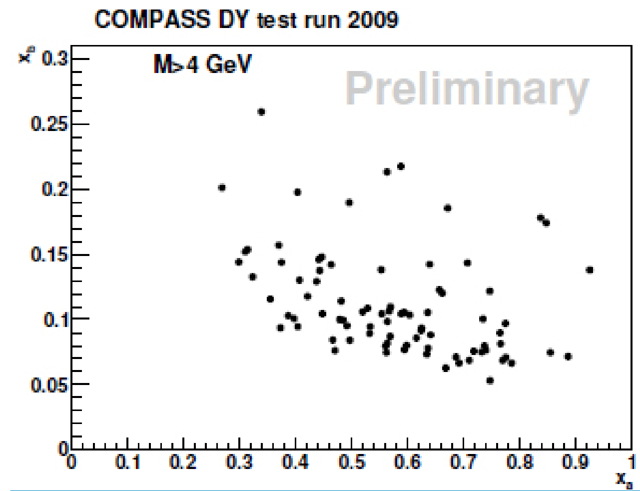




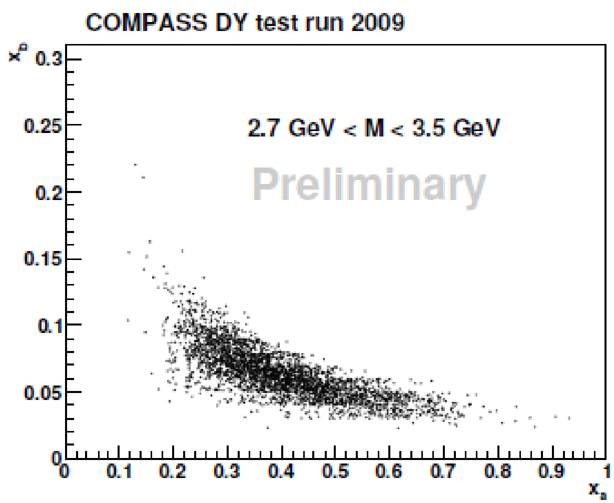




The mean value of p_T is about 1 GeV/c. This makes Compass sensitive to TMDs, which are expected to be accessible up to p_T = 2 GeV/c.

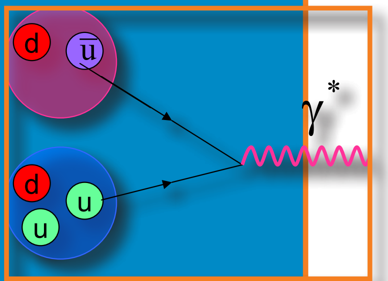


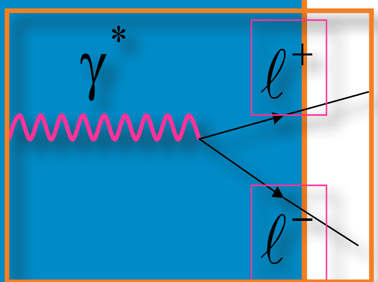
In the high mass range of the dimuon, Mμμ > 4GeV/c, both annihilating quarks belong to the valence quark range

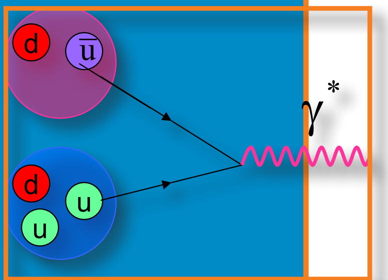


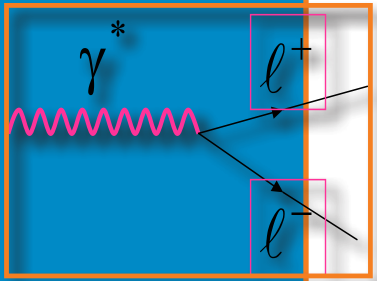
In case of the J/ψ the contribution of valence quarks is also dominant

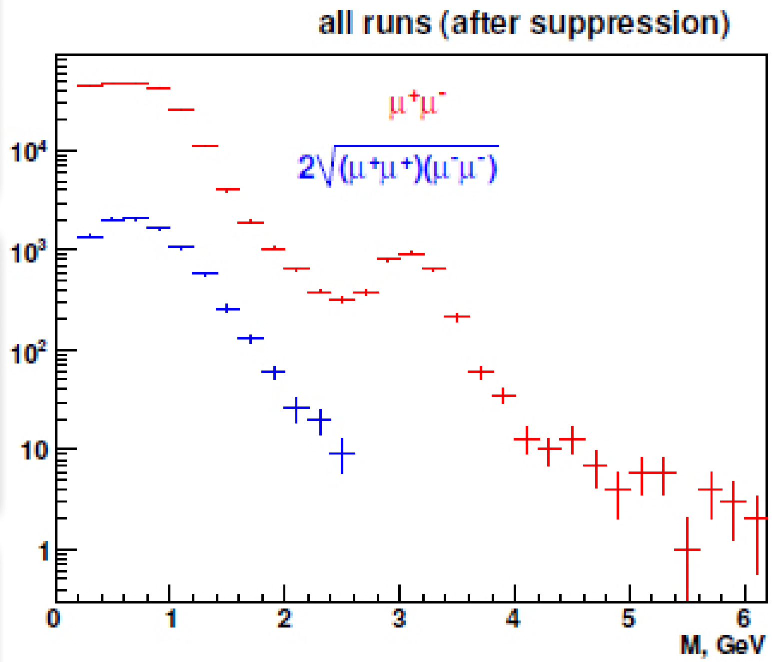
Beam test 2009











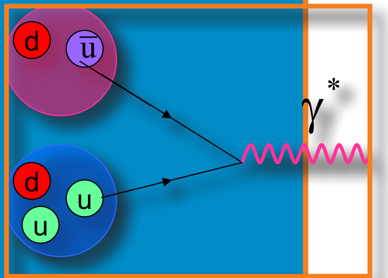
- 4. < Mμμ < 9. GeV/c^2 (HMR): clean DY signal
- 2. < Mμμ < 2.5 GeV/c^2 (IMR): contaminated with:

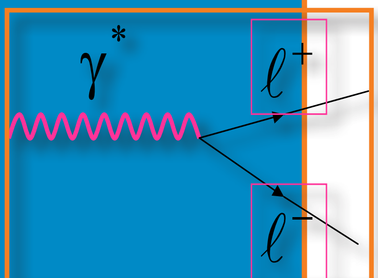
–> combinatorial background (a contribution that can be subtracted by using the like-sign muon pairs samples),

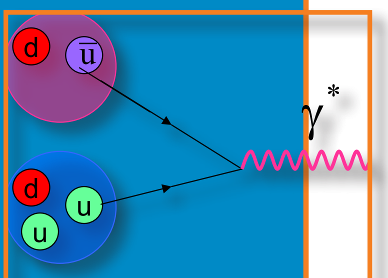
–> physics background mostly from uncorrelated decays of open-charm mesons (in the IMR: $N_{D\,D} / N_{DY} = 0.14$)

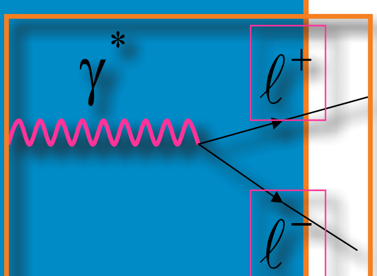
Combinatorial background (from uncorrelated π decays) is estimated using the measured like-sign $\mu^{\pm}\mu^{\pm}$ distributions: the absorber reduces the background by a factor 10 at $M_{\mu\mu}$ = 2 GeV/c^2

Expected event rates and statistical precision









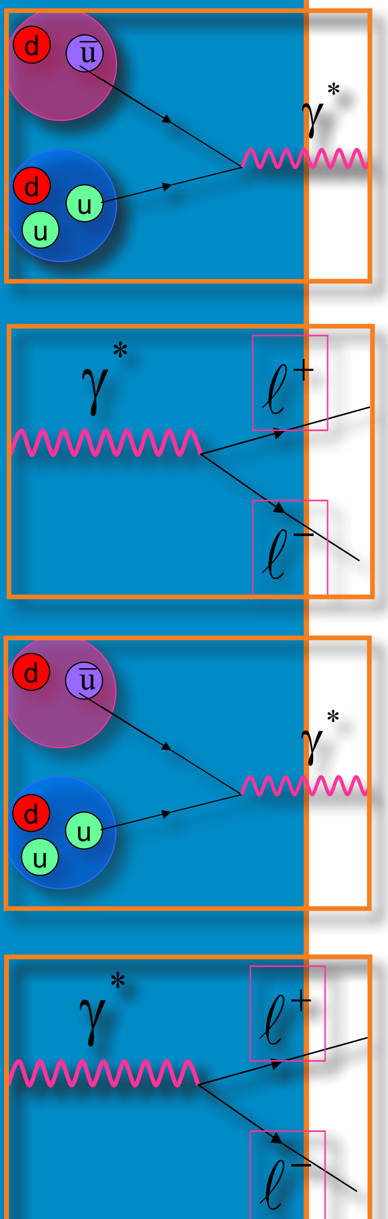
With a beam intensity of $I_{beam} = 6 \times 10^7$ particles/second, a luminosity of $L = 1.2 \times 10^{32}$ cm^{-2}s^{-1} can be obtained

In 280 days one can collect:
250.000 DY events with $4 < M_{\mu\mu} < 9$ GeV/c^2.
1.4×10^6 events DY events with $2 < M_{\mu\mu} < 2.5$ GeV/c^2.

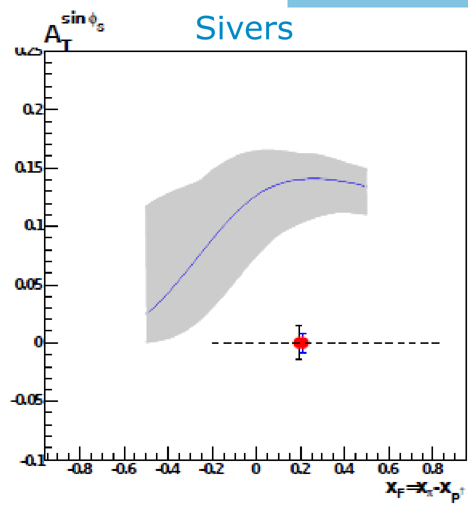
The expected statistical error in the asymmetries is:

Asymmetry	Dimuon mass (GeV/c^2)		
	$2 < M_{\mu\mu} < 2.5$	J/ψ region	$4 < M_{\mu\mu} < 9$
$\delta A_U^{\cos 2\phi}$	0.0020	0.0013	0.0045
$\delta A_T^{\sin \phi_S}$	0.0062	0.0040	0.0142
$\delta A_T^{\sin(2\phi+\phi_S)}$	0.0123	0.0080	0.0285
$\delta A_T^{\sin(2\phi-\phi_S)}$	0.0123	0.0080	0.0285

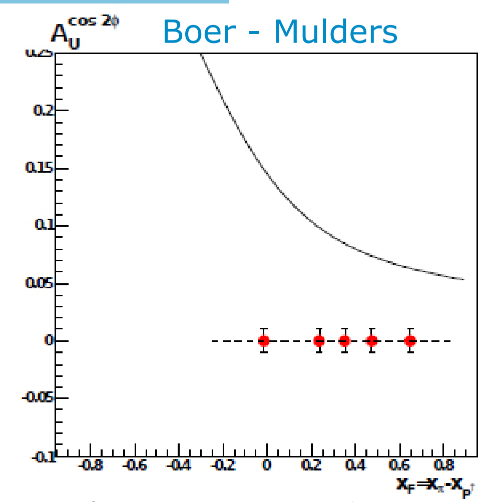
Asymmetries: comparing with theory prediction



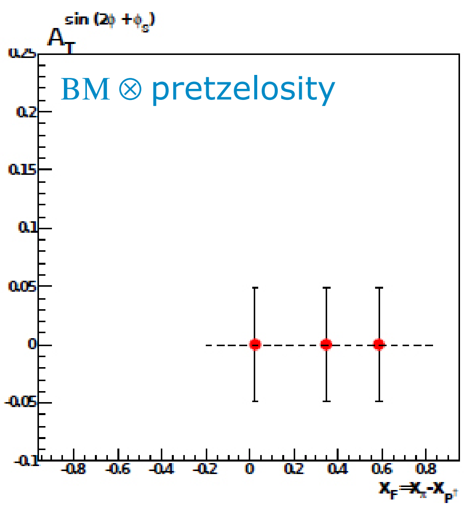
2 years of data taking
DY 4.-9. GeV/c^2

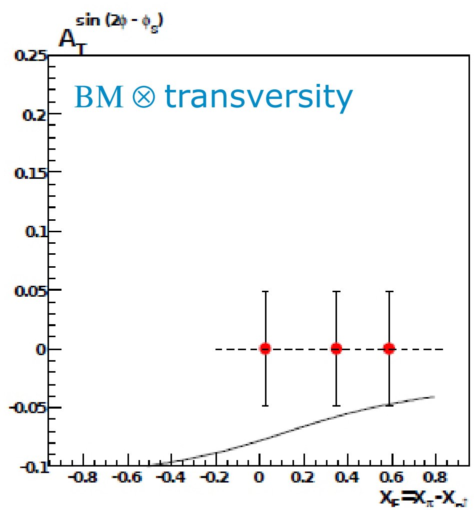


M. Anselmino et al., in Proceedings of Transversity 2008, 2009, ISBN:978-981-4277-77-8, p. 138



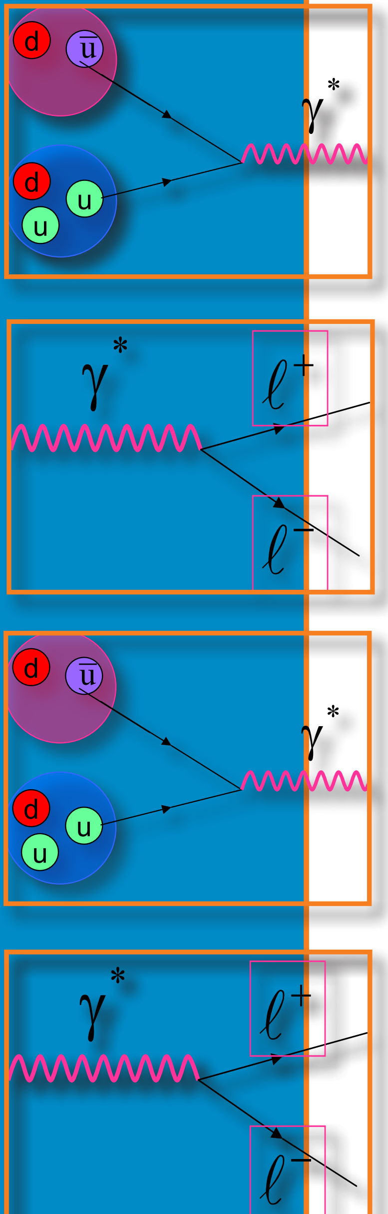
D. Boer, Phys. Rev. D60 (1999) 014012.
B. Zhang et al., Phys. Rev. D77 (2008) 054011.



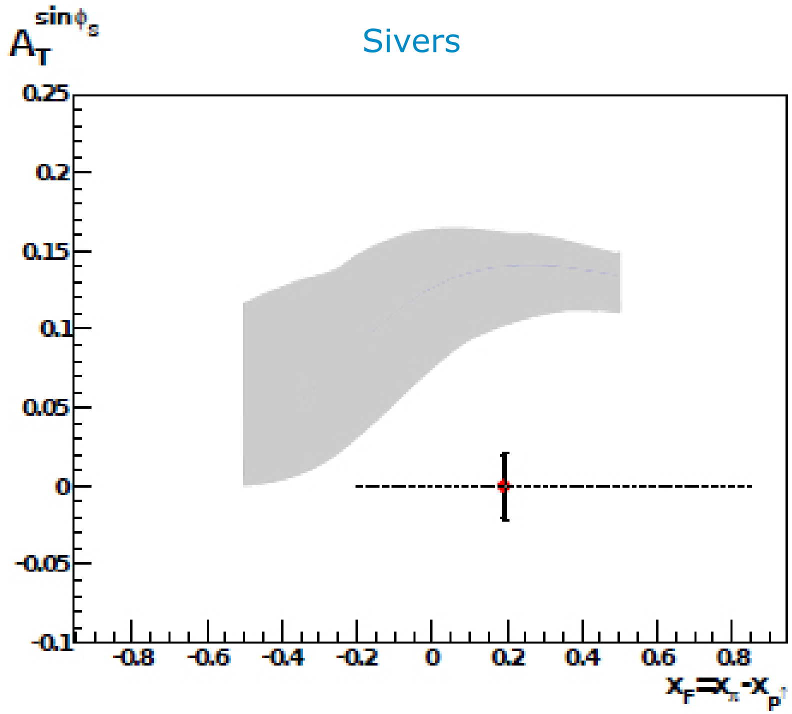


V. Barone et al., Phys. Rept. 359 (2002) 1.
V. Barone et al., Phys. Rev. D56 (1997) 527.

Asymmetries: comparing with theory prediction

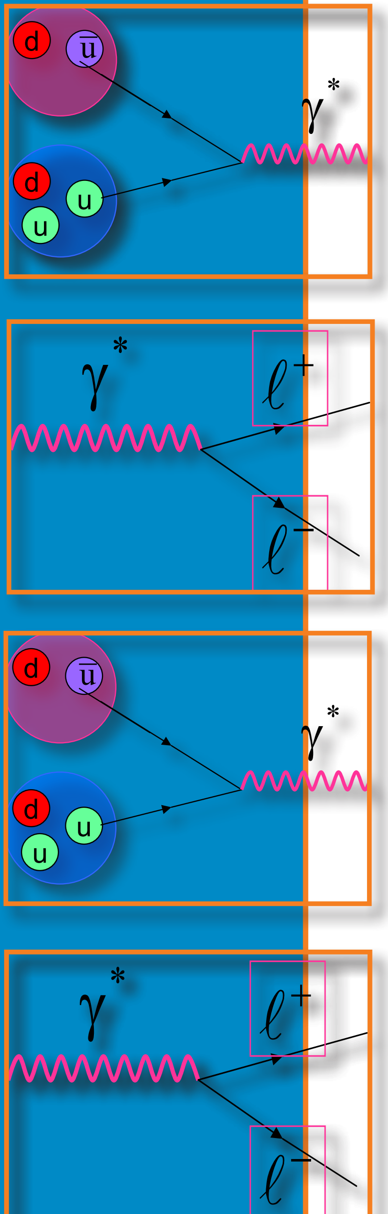


1 year of data taking
DY 4.-9. GeV/c^2



M. Anselmino et al.

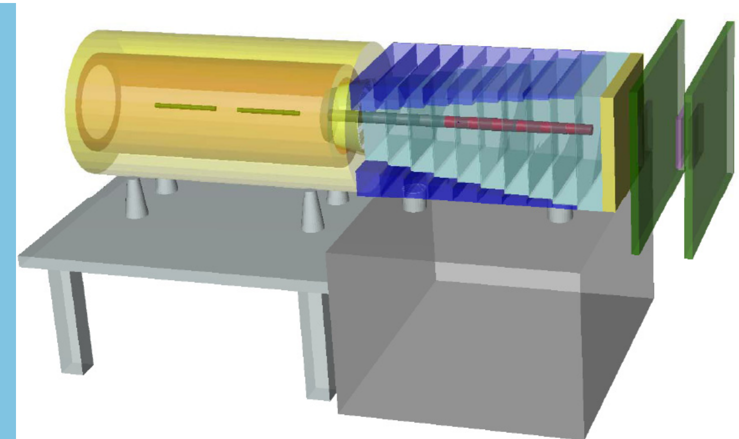
DY setup: new hardware developments

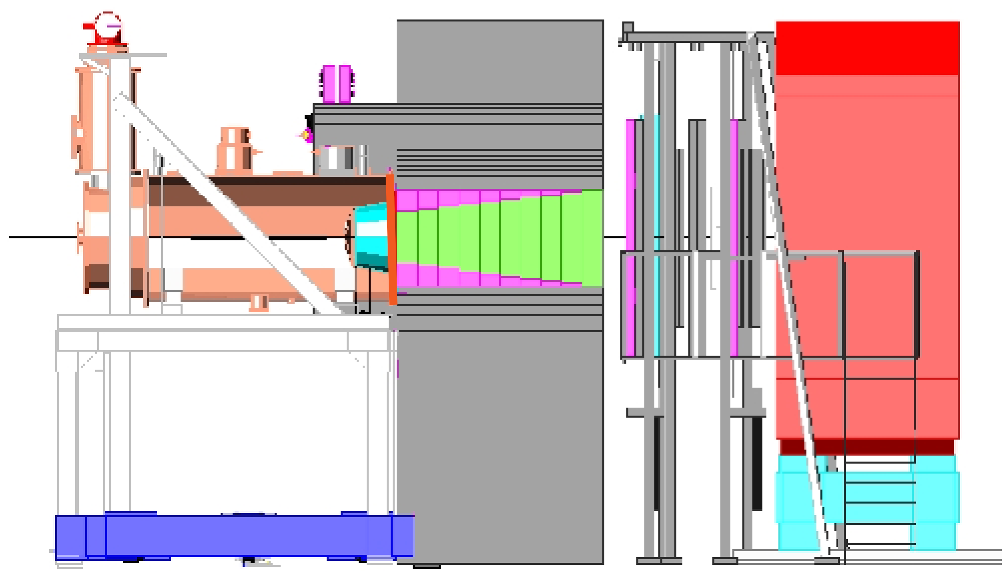


Two target cells (NH_3) inside the dipole (55 cm length, 4 cm diameter, spaced by 20 cm)

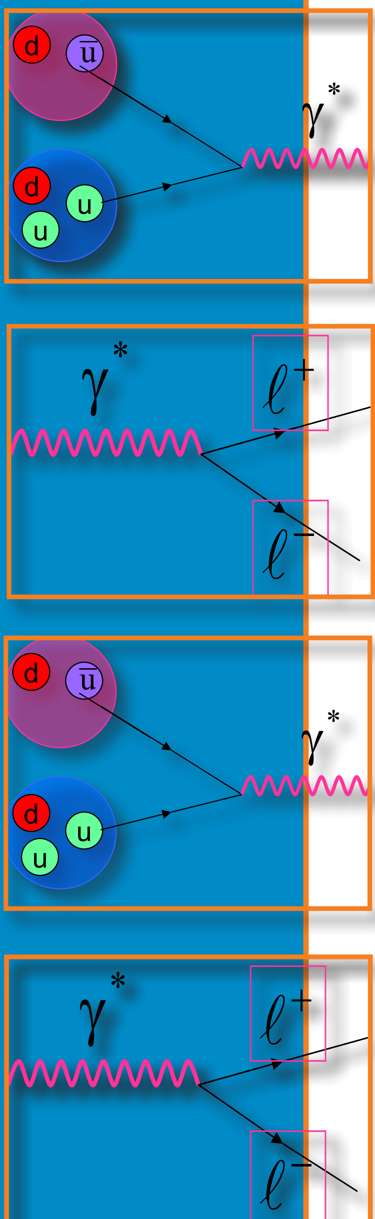
An absorber 236 cm long, downstream the target

Scintillator fibers detetor between target and absober to improve vertex resolution





DY setup: the absorber

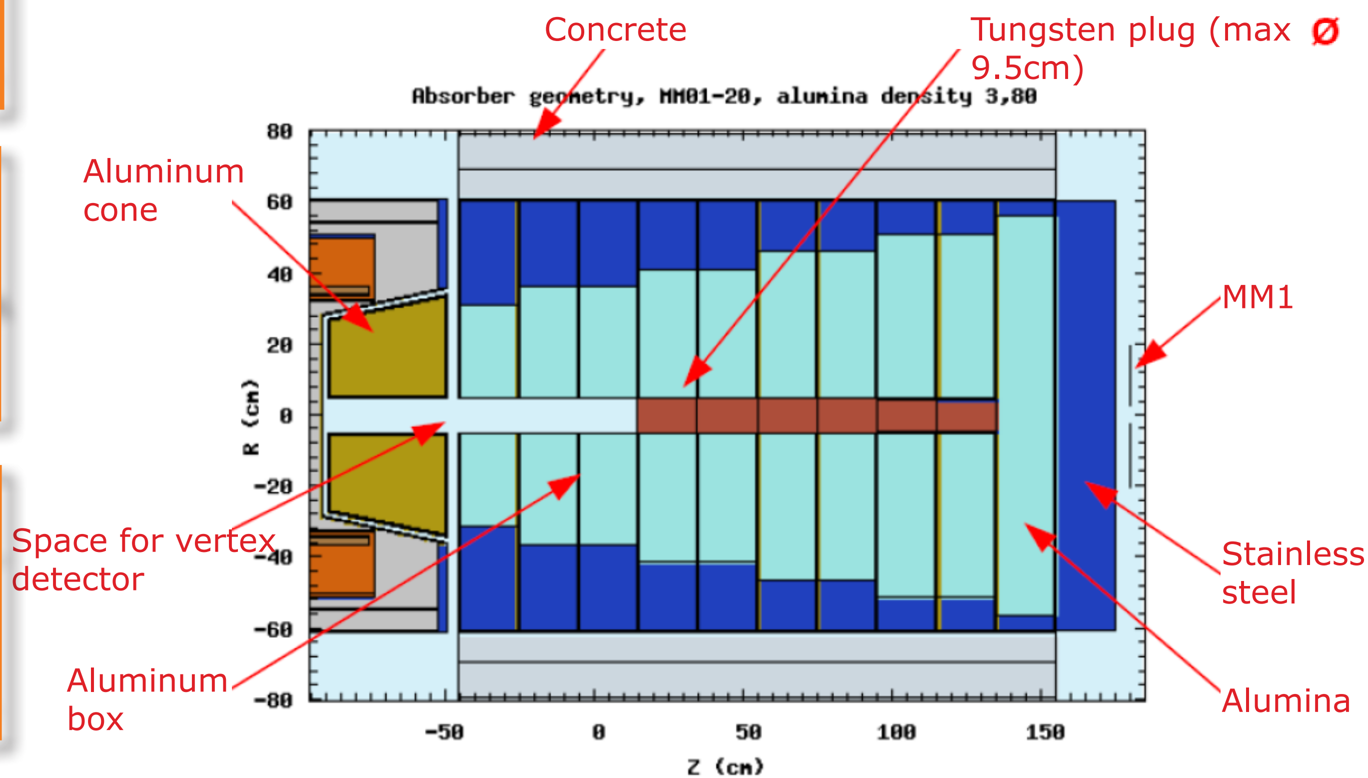


The absorber is 236 cm long, made of Al_2O_3

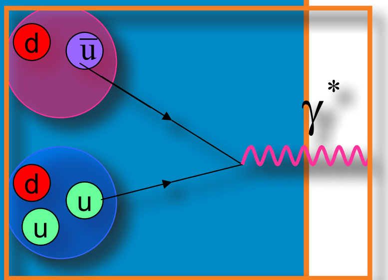
The plug is made of 6 discs of W 20 cm long each and 20 cm of Alumina in the most downstream part (total of 140 cm)

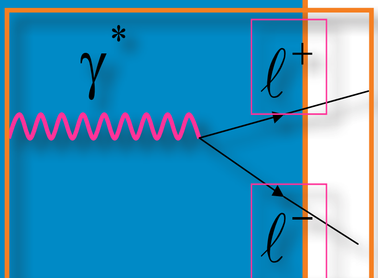
Number of radiation lengths (multiple scattering for muons):
$x/X_0 = 33.53$

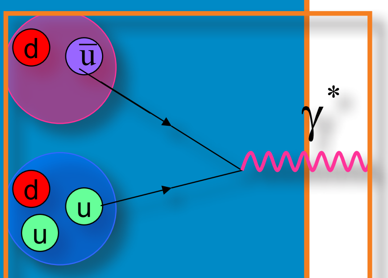
Number of interaction lengths (stopping power for pions):
$x/\lambda_{int} = 7.25$

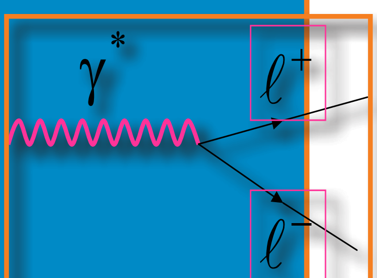


Summary





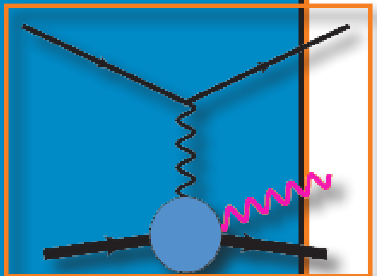


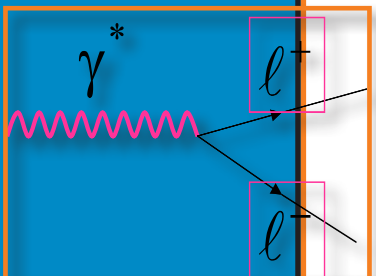


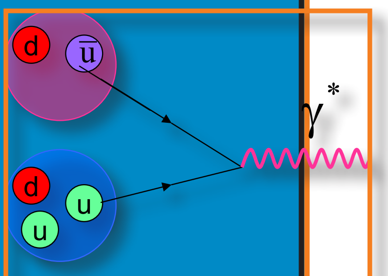
- Transversity and Sivers PDFs of the nucleon are addressed in COMPASS presently from semi-inclusive DIS.
- The opportunity to study, with the same spectrometer, the TMD PDFs from the Drell-Yan process is unique.
- COMPASS experimental conditions probe the valence quarks region, where TMD effects are expected to be sizable.
- The feasibility of the measurement was proven, after a series of beam tests.
- The COMPASS-II Proposal has been recommended by SPSC and is approved by the Research Board for a first period of 3 years including 1year for Drell-Yan.

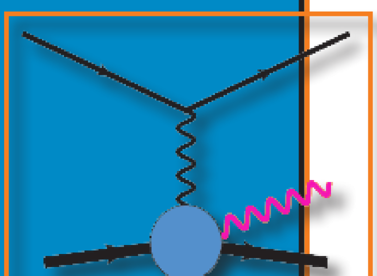
End of 2014 +2015	Single polarised Drell-Yan with π^- beam --> TMDs (Sivers and Boer-Mulders) sign change
2016+17	DVCS with μ^+ and μ^- beams on unpolarised protons
in parallel	unpolarised SIDIS --> PDFs, TMDs, FFs (in particular for strange)

Second year of Drell-Yan data taking?
...beyond 2017 --> TMDs (Sivers, Boer-Mulders, and Pretzelosity), transversity PDF





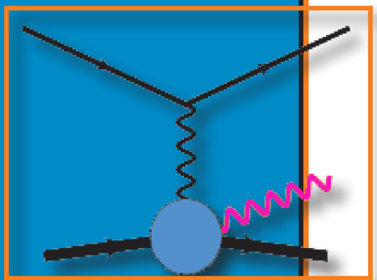


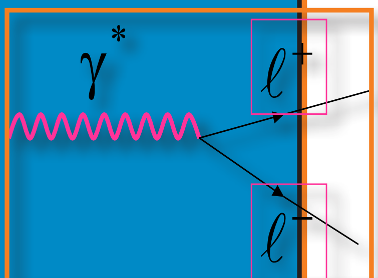


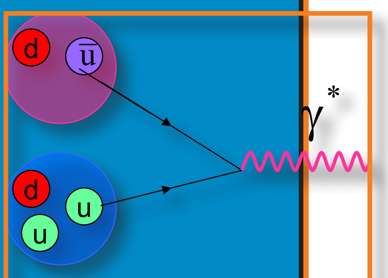
PART II - Spare slides

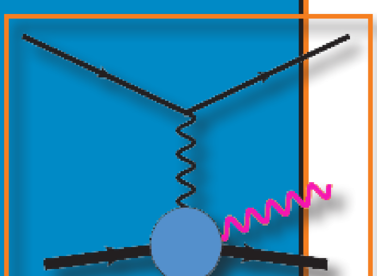
Semi-Inclusive DIS (in parallel with GPD programme)

Measurements of unpolarised PDFs and FFs in SIDIS









COMPASS I: ^6LiD and NH_3

COMPASS II: pure hydrogen target in parallel with DVCS and DVMP; 160 GeV/c muon beam

Goal:
Identified hadron multiplicities measurements:

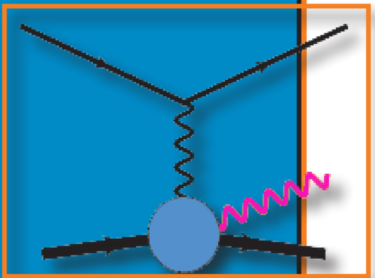
$$\frac{dN^h(x,z,Q^2)}{dN^{DIS}} = \frac{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

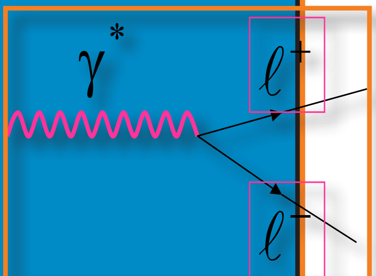
- flavor separation
- study of 4-dimensional dependencies in the kinematic variables x, Q^2, $p_T{}^2$ and z

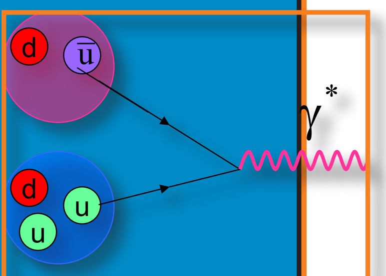
These SIDIS data will be used in global QCD analyses to constrain PDFs and FFs

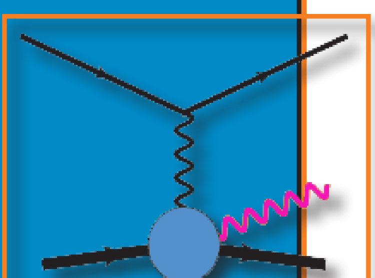
Direct LO determination of the unpolarised strange quark distribution function s(x) in the region 0.01 < x < 0.2, where its shape is unknown

Measurements of unpolarised PDFs and FFs in SIDIS









In SIDIS on an unpolarised target, hadron azimuthal asymmetries arise that give access to the distribution of intrinsic quark k_T as encoded in the T-odd Boer-Mulders function and also to higher-twist effects

$$\frac{d\sigma}{dx\,dy\,d\phi_h} = \frac{\alpha^2}{xyQ^2}\frac{1+(1-y)^2}{2}\Big[F_{UU} + \varepsilon_1 \cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon_2 \cos 2\phi_h F_{UU}^{\cos 2\phi_h} + \lambda_\mu \varepsilon_3 \sin\phi_h F_{LU}^{\sin\phi_h}\Big],$$

Cahn effect

Boer-Mulders TMD Collins FF + Cahn effect