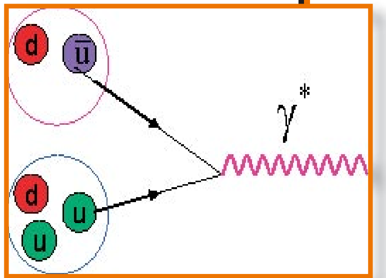
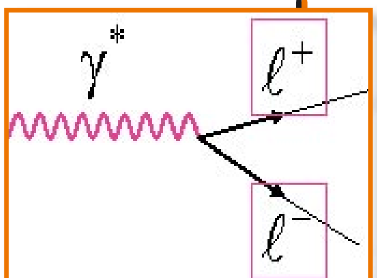
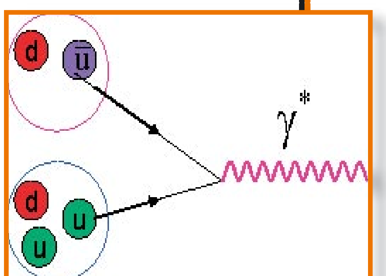
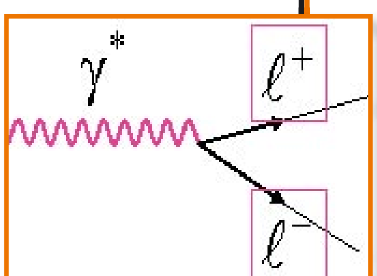






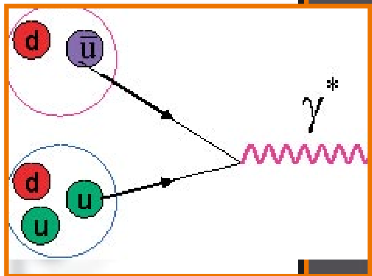


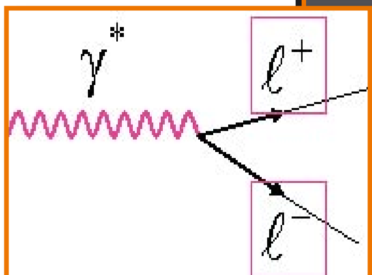
COMPASS Drell-Yan Proposal

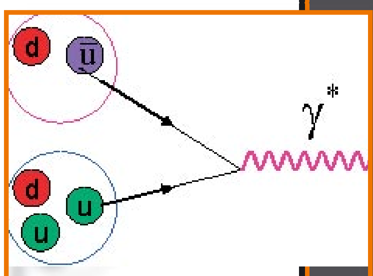
M. Chiosso, INFN Torino
on behalf of the COMPASS Collaboration

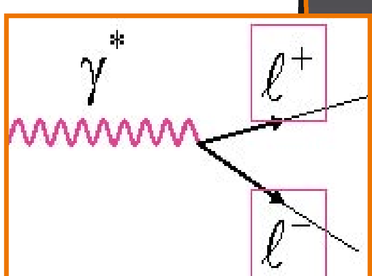
Drell-Yan Workshop - Santa Fe (USA)
October 31 - November 1 2010

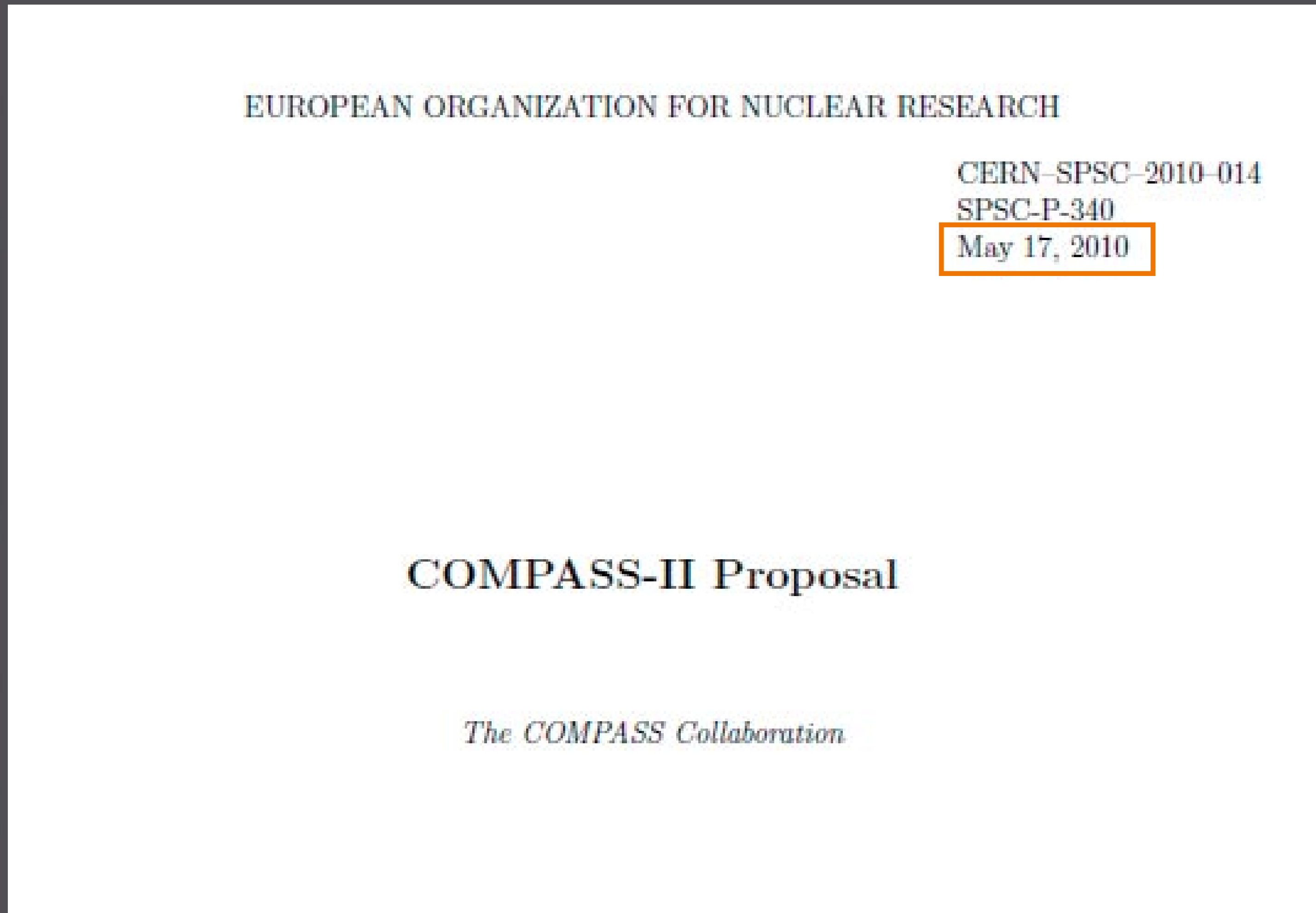
COMPASS-II Proposal











EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

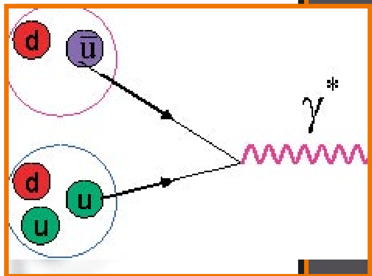
CERN–SPSC–2010–014
SPSC-P-340
May 17, 2010

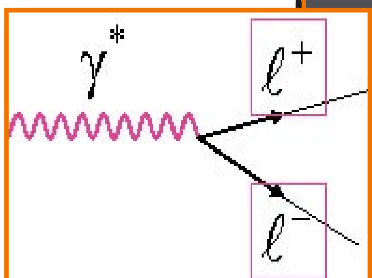
COMPASS-II Proposal

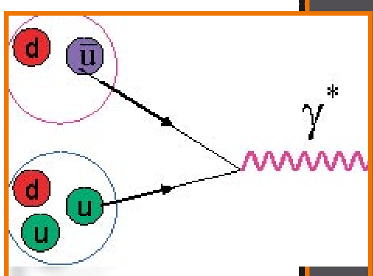
The COMPASS Collaboration

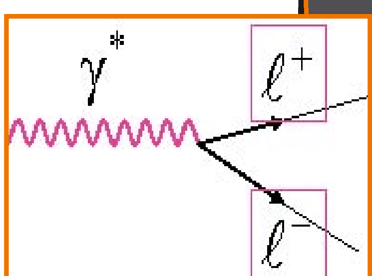
http://wwwcompass.cern.ch/compass/proposal/compass-II_proposal/compass-II_proposal.pdf

COMPASS-II Proposal









EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

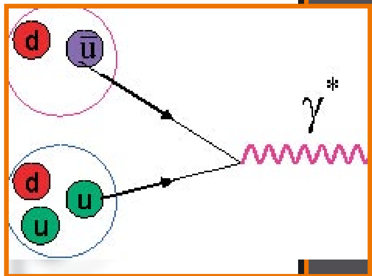
CERN–SPSC–2010–022
SPSC-M-772
September 3, 2010

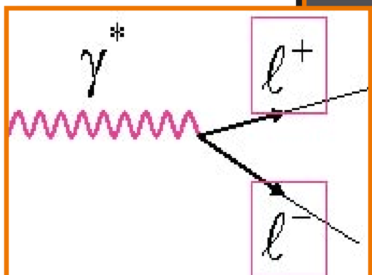
COMPASS-II Proposal: Questions & Answers

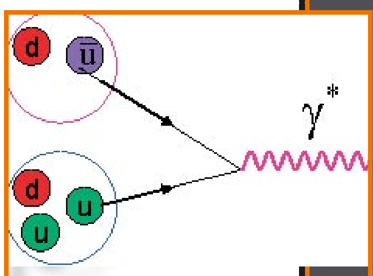
The COMPASS Collaboration

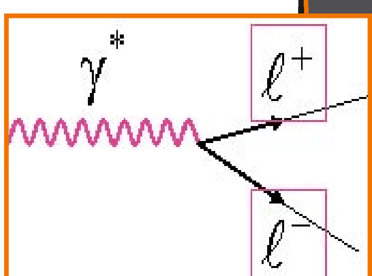
http://wwwcompass.cern.ch/compass/proposal/compass-II_proposal/compass-II_QA_1.pdf

COMPASS-II Proposal







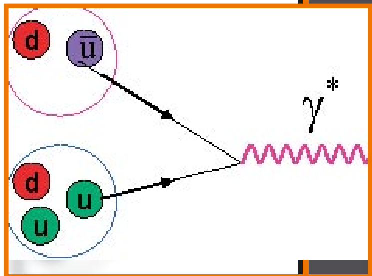


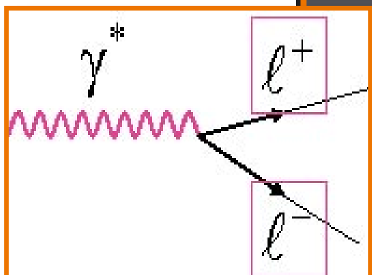
Subject: SPSC approval
Date: Fri, October 1, 2010 12:10 pm
To: “compass-authors” <compass-authors@cern.ch>

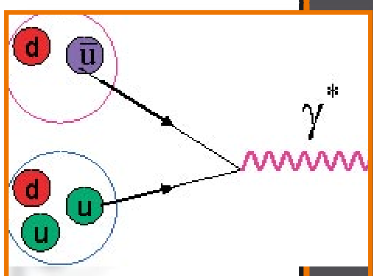
Dear Colleague,

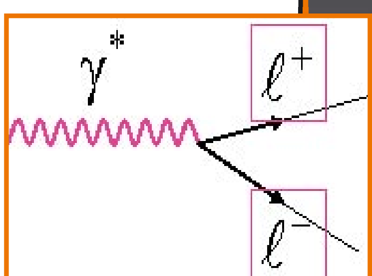
in its meeting last Wednesday the SPSC decided to recommend the COMPASS-II proposal to the Research Board for approval. The initial recommendation is for 3 years (likely 2013-2015). The SPSC also proposes a schedule of two years GPD and one year DY.

COMPASS experiment at CERN







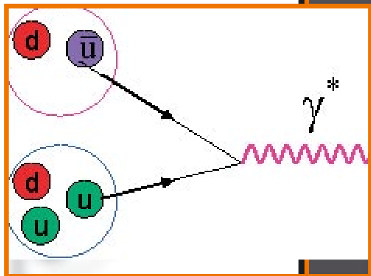


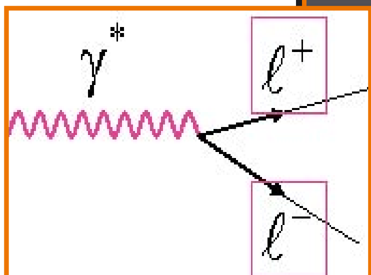
COmmon **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

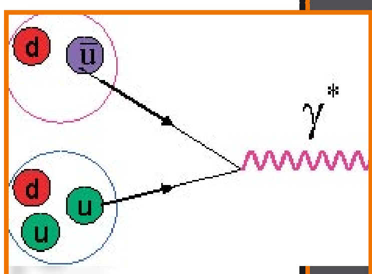
CERN SPS M2 beam line:
μ^+, μ^-, hadron beams between 50 GeV and 280 GeV

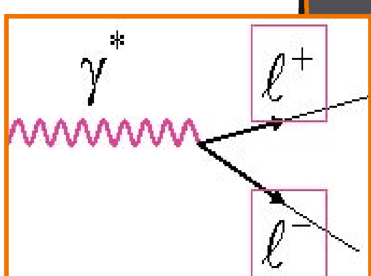
270 physicists, 25 institutes, 11 countries

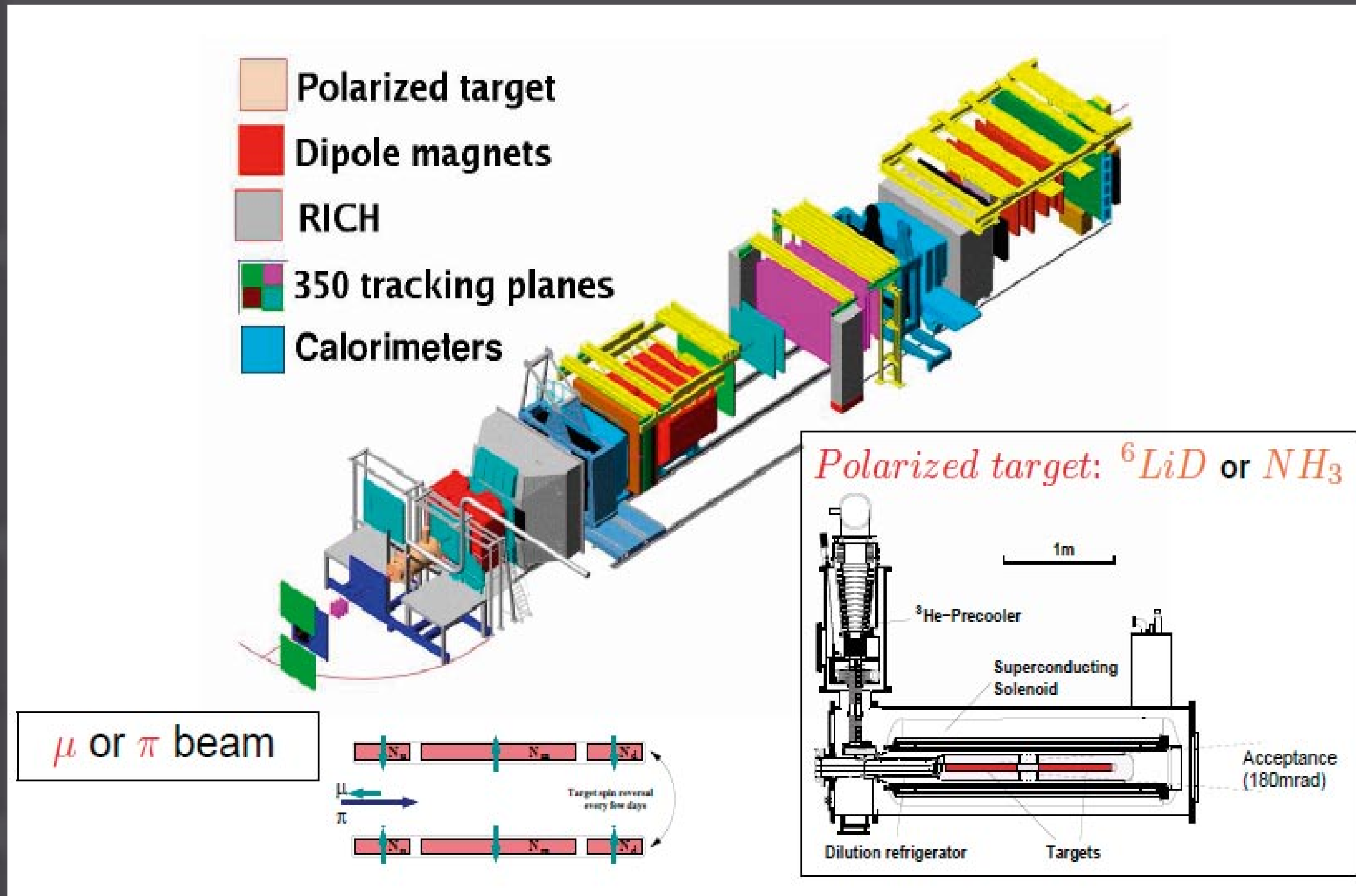
COMPASS experiment at CERN





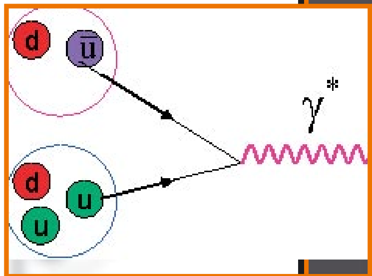


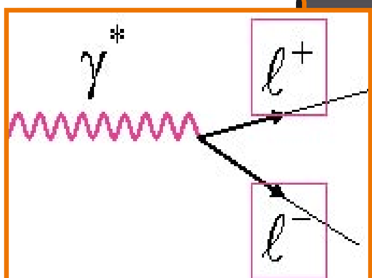


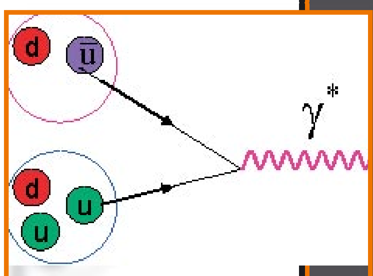


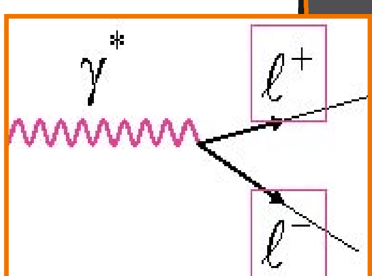
More than 10 years ago, the Compass experiment was conceived as COmmon Muon and Proton apparatus for Structure and Spectroscopy", capable of addressing a large variety of open problems in both hadron structure and spectroscopy.

COMPASS DY Proposal



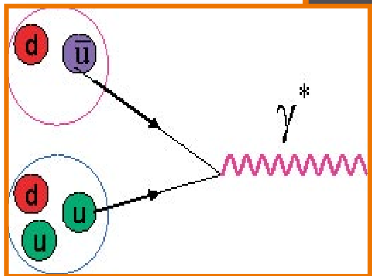


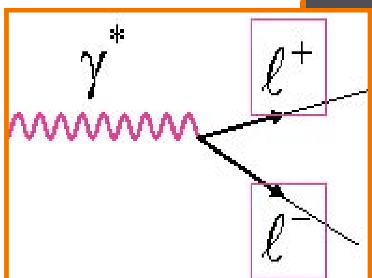


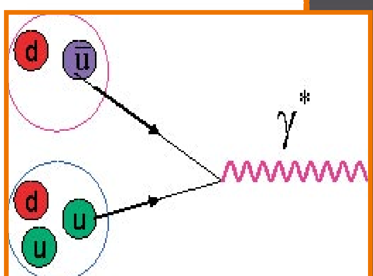


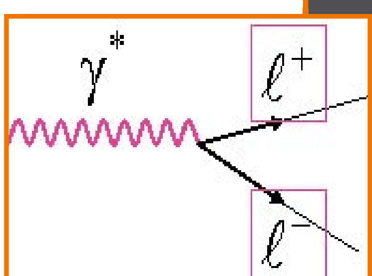
- Single polarized Drell-Yan
- Transversity and TMD PDFs
- PDFs universality
- J/ψ-Drell-Yan duality
- Drell-Yan in the COMPASS experiment
- Test beam for study of feasibility
- Kinematic domain, acceptance and expected events rate
- Expected asymmetries and statistic errors

Single polarized Drell-Yan



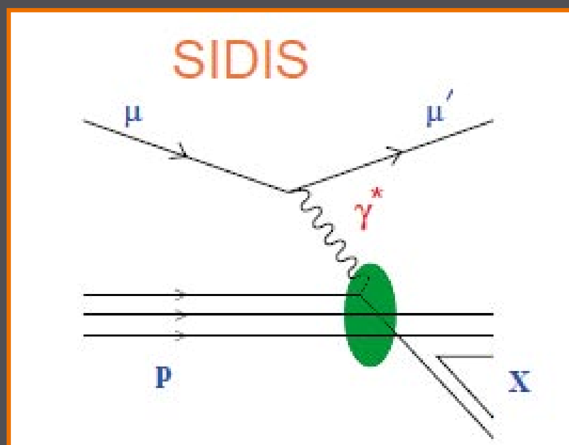


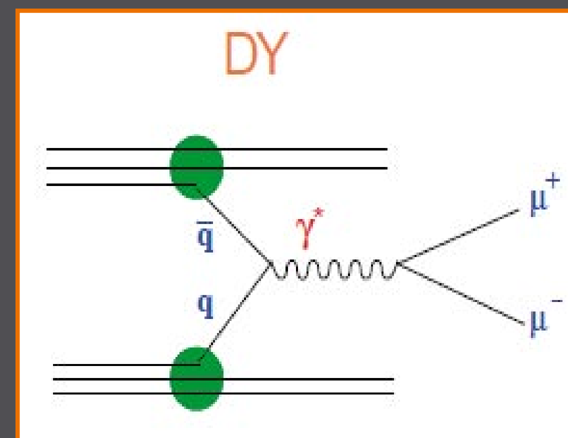




- Single polarized Drell-Yan
- Transversity and TMD PDFs
- PDFs universality
- J/ψ-Drell-Yan duality

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

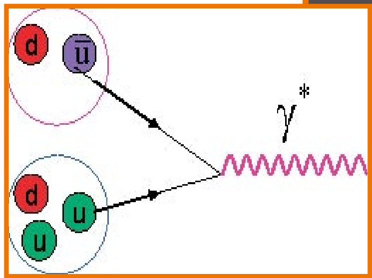


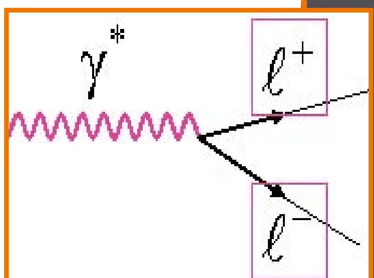


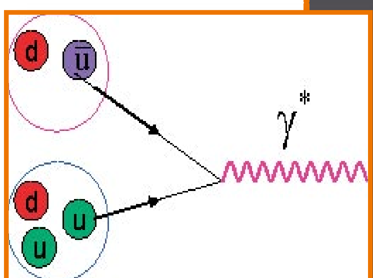
The spin asymmetry is proportional to PDF ⊗ FF:

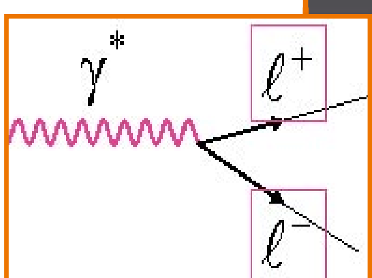
The spin asymmetry is proportional to PDF^b ⊗ FF^t:
If unpolarized beam and transversely polarized target

Single polarized Drell-Yan









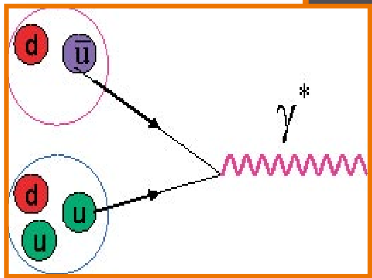
In a recent paper Arnold, Metz and Schlegel derived the full expression of the Drell-Yan cross-section, including unpolarized, transversely and longitudinally polarized terms [S. Arnold et al, Phys.Rev. D79 (2009)034005].

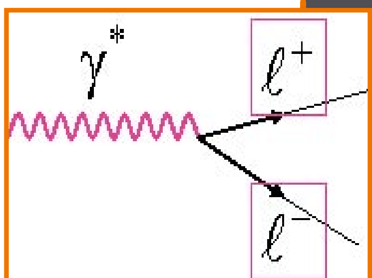
In single polarized DY, with transversely polarized target nucleons, the general expression of the cross-section (LO) is:

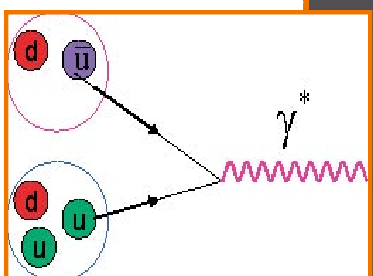
$$
\begin{aligned}
\frac{d\sigma}{d^4q\,d\Omega} = \frac{\alpha_{em}^2}{Fq^2}\hat{\sigma}_U \{ & (1 + D_{[\sin^2\theta]} A_U^{\cos 2\phi} \cos 2\phi) \\
& + |\vec{S}_T| [A_T^{\sin\phi_S} \sin\phi_S + D_{[\sin^2\theta]} (A_T^{\sin(2\phi+\phi_S)} \sin(2\phi+\phi_S) \\
& + A_T^{\sin(2\phi-\phi_S)} \sin(2\phi-\phi_S))]\}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

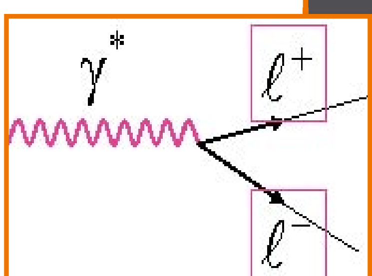
A: azimuthal asymmetries; D: depolarization factor; S: target spin components; F: flux of incoming hadrons; σ_U: part of the cross-section surviving integration over ϕ and ϕ_S

Single Polarized Drell-Yan









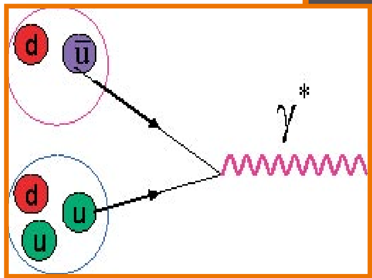
$A_U^{\cos 2\phi}$ gives access to the Boer-Mulders functions of the incoming hadrons

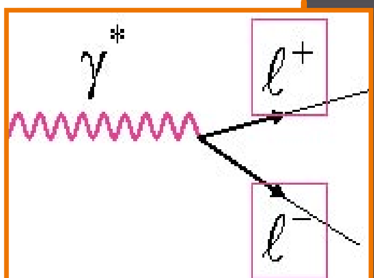
$A_T^{\sin\phi S}$ to the Sivers function of the target nucleon

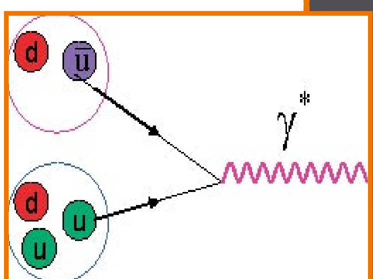
$A_T^{\sin(2\phi+\phi S)}$ to the Boer-Mulders function of the beam hadron and to the pretzelosity function of the target nucleon

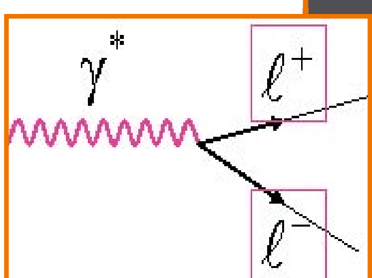
$A_T^{\sin(2\phi-\phi S)}$ to the Boer-Mulders function of the beam hadron and to the transversity function of the target nucleon

Transverse momentum dependent PDFs









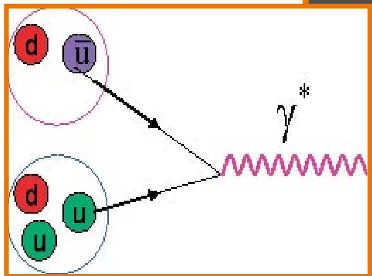
The transverse momentum dependent (TMD) PDFs of the nucleon carry important information about the nucleon spin dynamics:

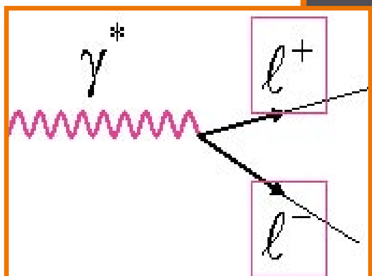
- Sivers: the $f^{\perp}_{1T}(x, k^2_T)$ function describes the distortion of the probability distribution of a non-polarized quark when it is inside a transversely polarized nucleon.

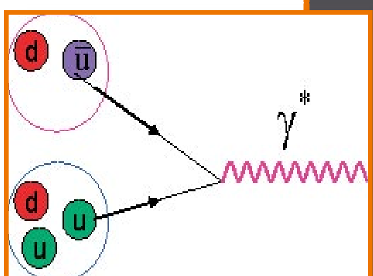
- Boer-Mulders: the $h^{\perp}_{1}(x, k^2_T)$ function describes the correlation between the transverse spin and the transverse momentum of a quark inside a unpolarized hadron.

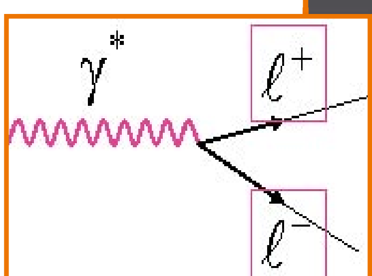
- Pretzelosity: the $h^{\perp}_{1T}(x, k^2_T)$ function describes the transverse polarization of a quark, along its intrinsic k_T direction.

SIDIS vs DY









Change of sign of Sivers and Boer-Mulders functions?

$$f_{1T}^{\perp}(x_1,k_T^{2})_{DY} = -f_{1T}^{\perp}(x_2,k_T^{2})_{SIDIS}$$

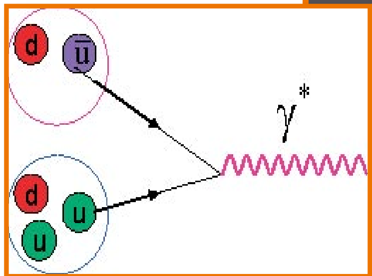
J.C. Collins, Phys. Lett. B536 (2002) 43

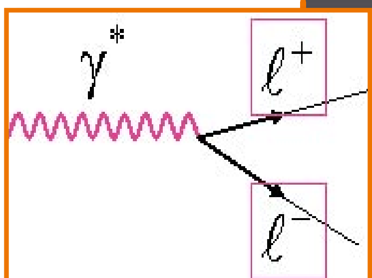
$$h_{1T}^{\perp}(x_1,k_T^{2})_{DY} = -h_{1T}^{\perp}(x_2,k_T^{2})_{SIDIS}$$

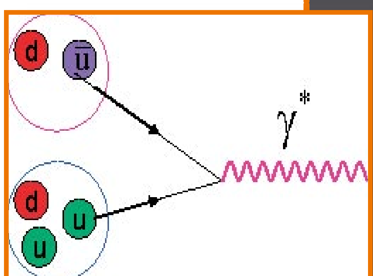
J.C. Collins, talk at LIGHT CONE 2008

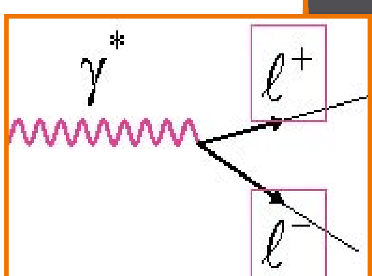
Critical test of universality of TMD factorization approach for the description of SSA.

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.

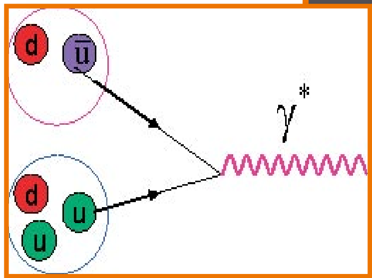
J/Ψ-DY duality ⟹ model based on close analogy between Drell-Yan and J/Ψ production mechanism: occurs when the gluon-gluon fusion mechanism of the J/Ψ production is dominated by the q-$\bar{q}$ annihilation mechanism

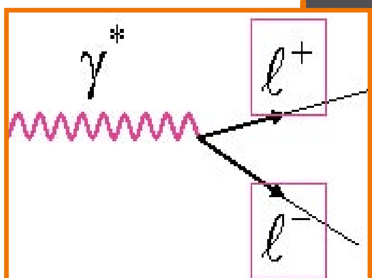
$$\pi^- p^\uparrow \to J/\psi X \to \mu^+\mu^- X \qquad \pi^- p^\uparrow \to \gamma^* X \to \mu^+\mu^- X$$

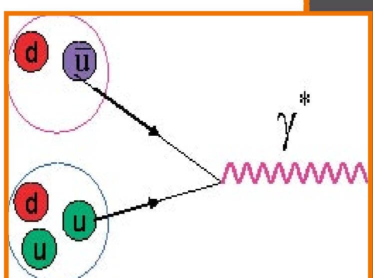
From the study of J/ψ production in the dileptons decay channel:

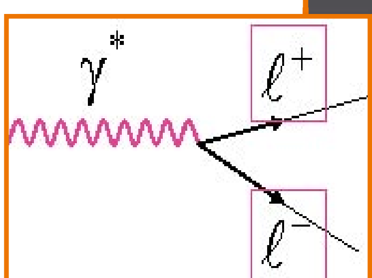
- Check duality hypothesis – polarized J/ψ production cross-section
- Access PDFs from J/ψ events – larger statistics available

Polarized Drell-Yan experiments









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

Polarized Drell-Yan experiments:

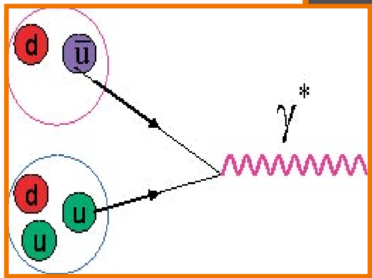
- High luminosity (DY Cross Section is a fraction of nanobarns) and large angular acceptance,

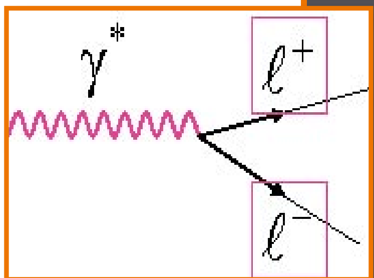
- Sufficiently high energy to access ‘safe’ background free M range (4 GeV/c^2 < M< 9 GeV/c^2)

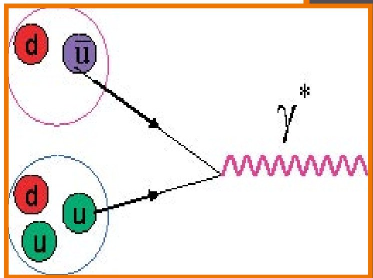
- Good acceptance in the valence quark range

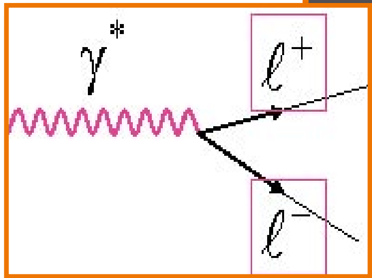
- Good factor of merit (FoM), which can be represented as a product of the luminosity, target polarisation (dilution factor f) and beam(target) polarisation

Drell-Yan @ COMPASS

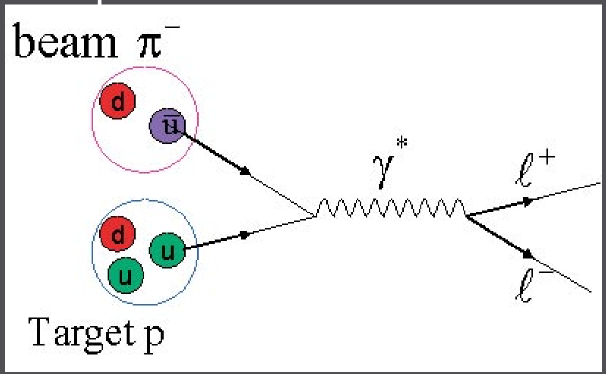






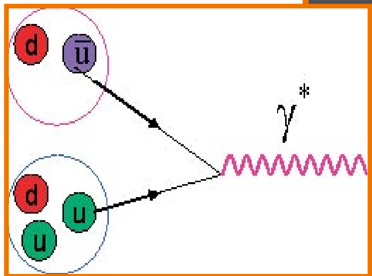


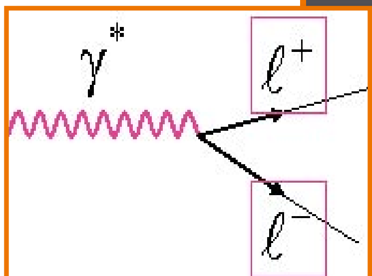
Transversity and Sivers PDFs of the nucleon are addressed in COMPASS presently, from semi-inclusive DIS.
The opportunity to study, with the same spectrometer, the TMD PDFs from the Drell-Yan process is unique.

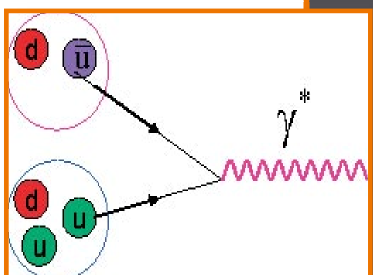


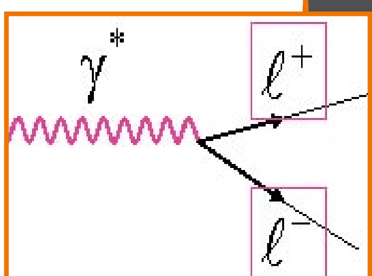
- Large angular acceptance spectrometer
- SPS M2 secondary beams with the intensity up to 6×10^7 particles per second
- Large acceptance COMPASS Superconducting Solenoid Magnet
- Solid state polarized target working in frozen spin mode with long relaxation time;
- A detection system designed to stand relatively high particle fluxes;
- A Data Acquisition System (DAQ) that can handle large amounts of data at large trigger rates

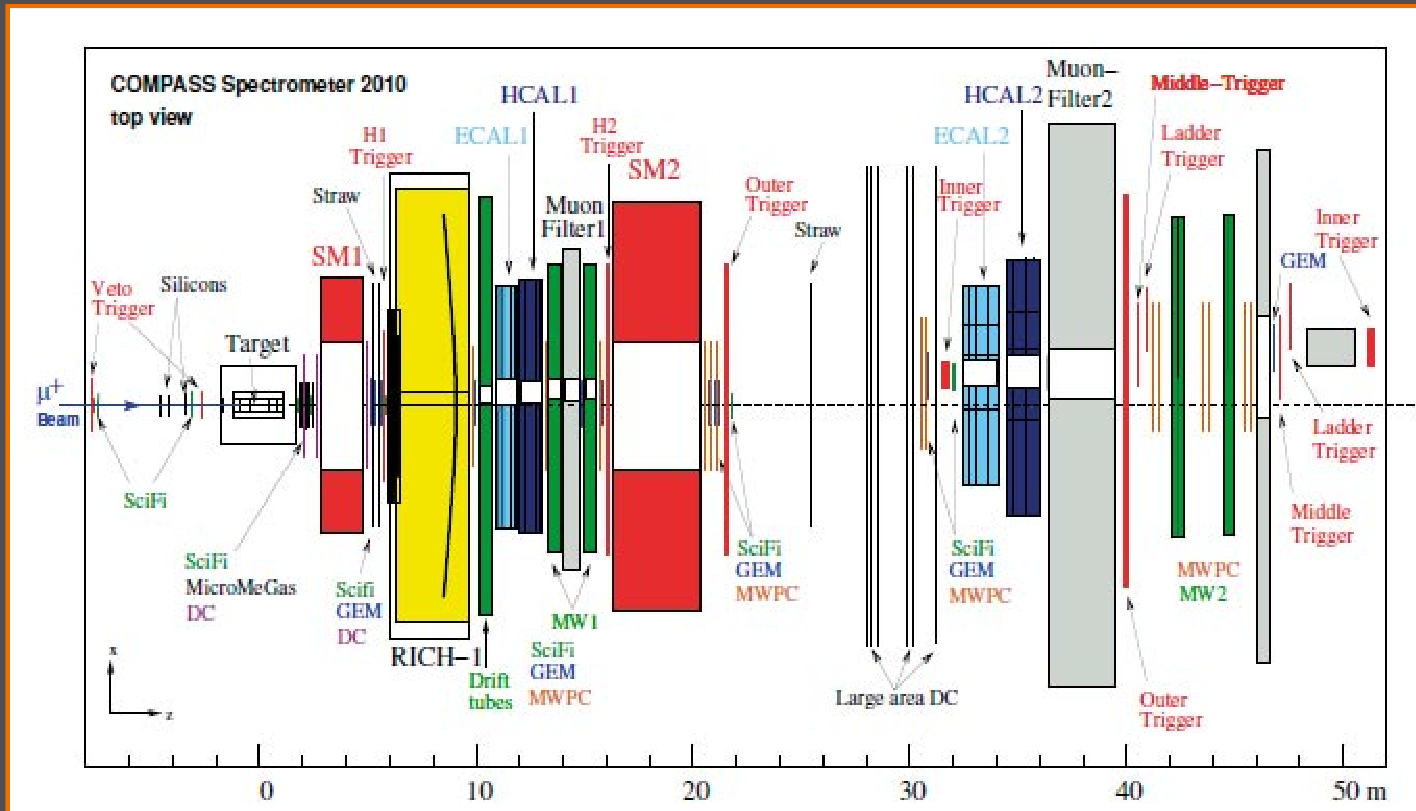
The COMPASS spectrometer



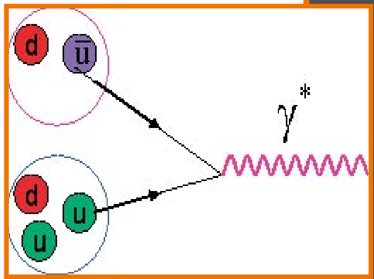


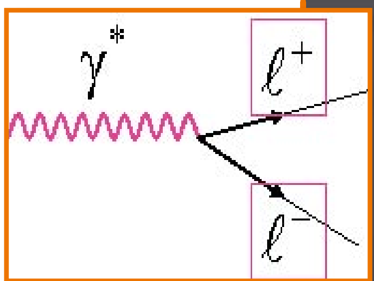


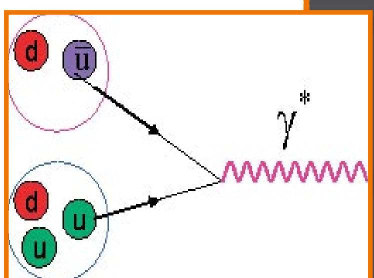


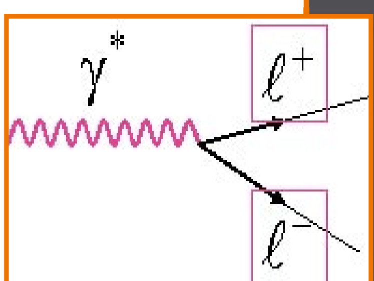


Drell-Yan at COMPASS: Feasibility



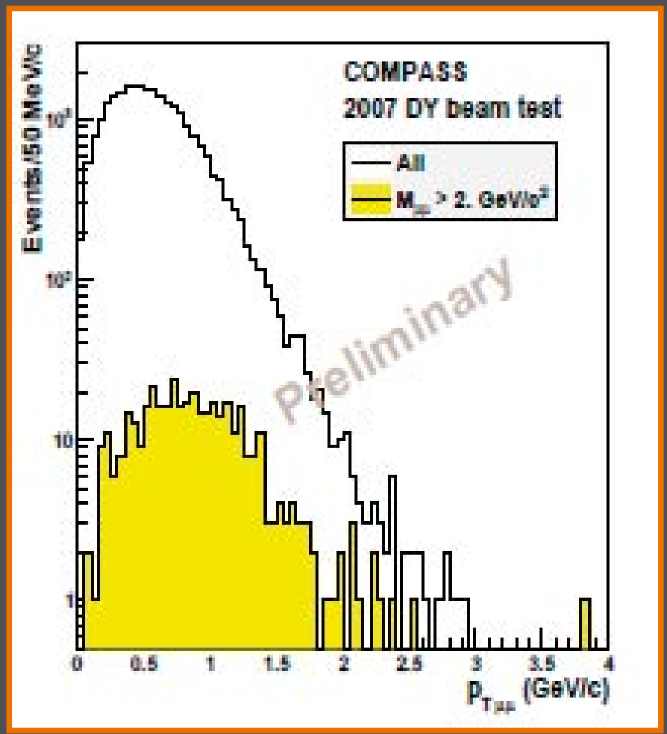


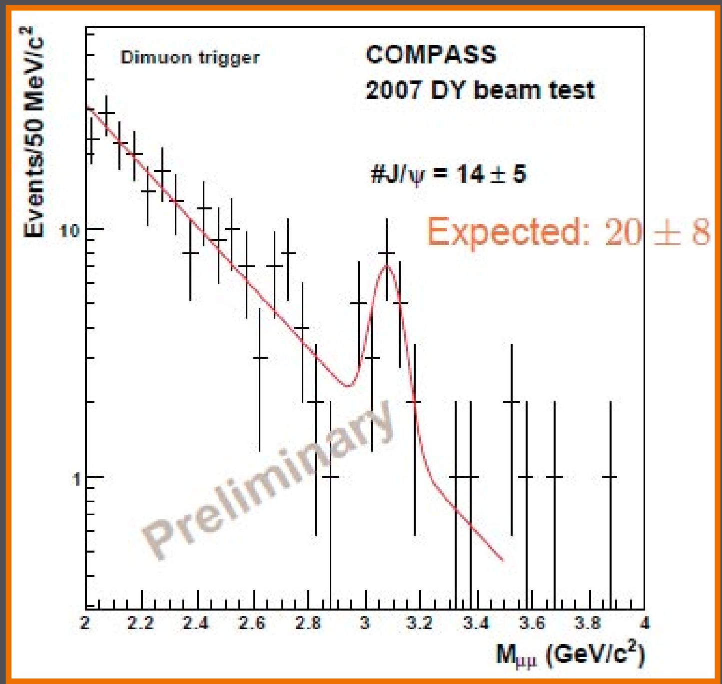




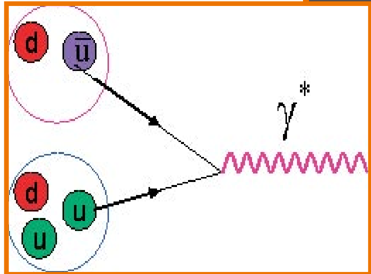
In 2007, 2008 and 2009 short Drell-Yan beam tests were performed, to check the feasibility of the measurement.

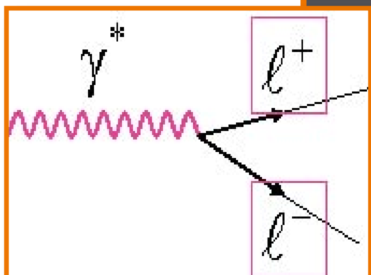
In 2007, with a π^- beam of 160 GeV/c on a NH3 target, and without hadrons absorber: ≈ 90000 dimuon events (< 12 hours data-taking).

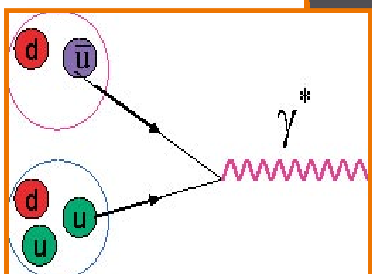


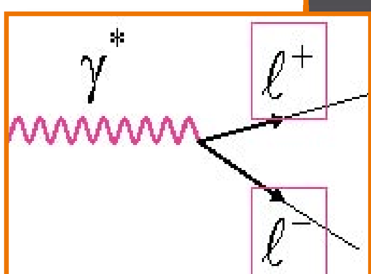


Beam tests in COMPASS



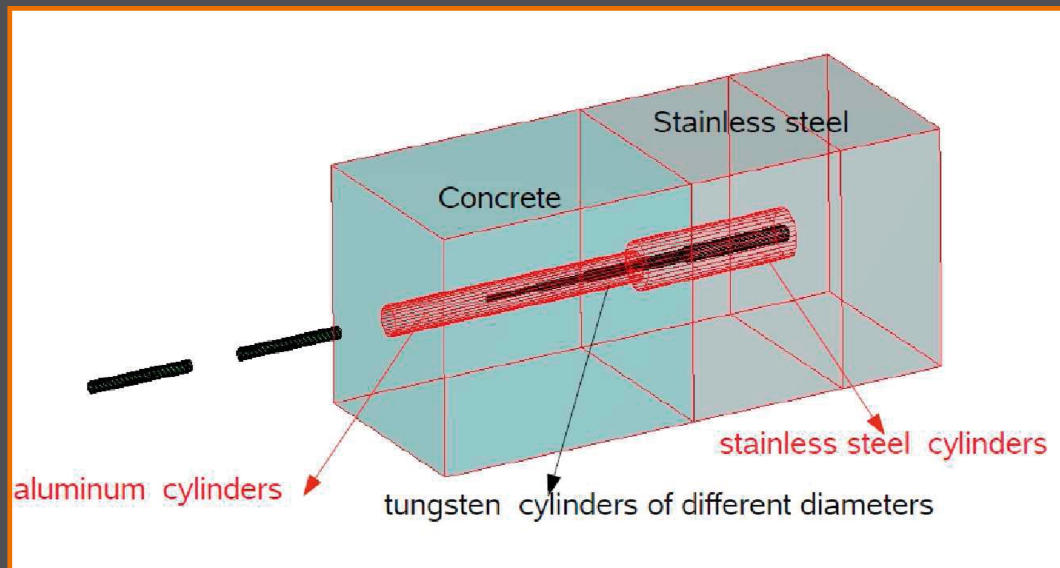




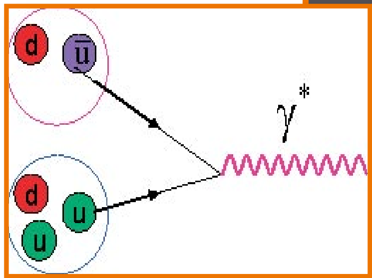


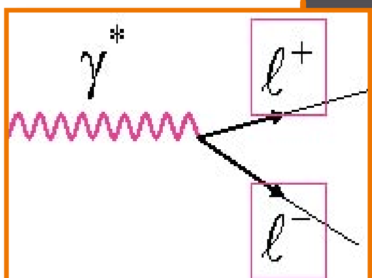
In 2008, a test without hadron absorber and increasing the π^- beam intensity show that even at 1/4 of the needed beam intensity the detectors occupancy was too large ⟹ need hadrons absorber.

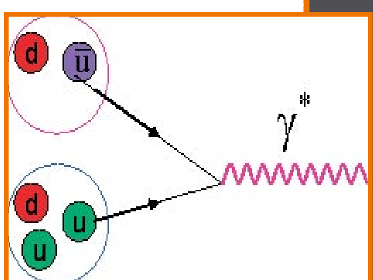
In 2009 an absorber was placed after the target: 1 meter long concrete block + 1 meter long stainless steel.

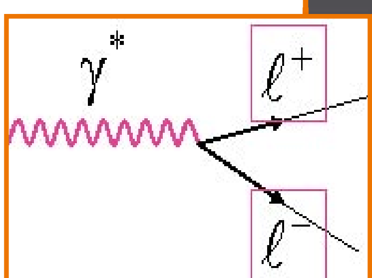


Beam Tests in COMPASS
The hadron absorber

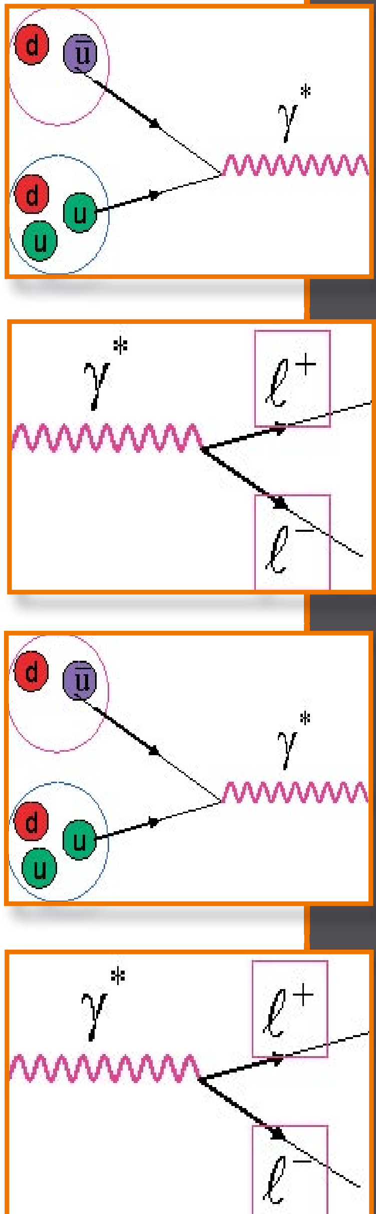


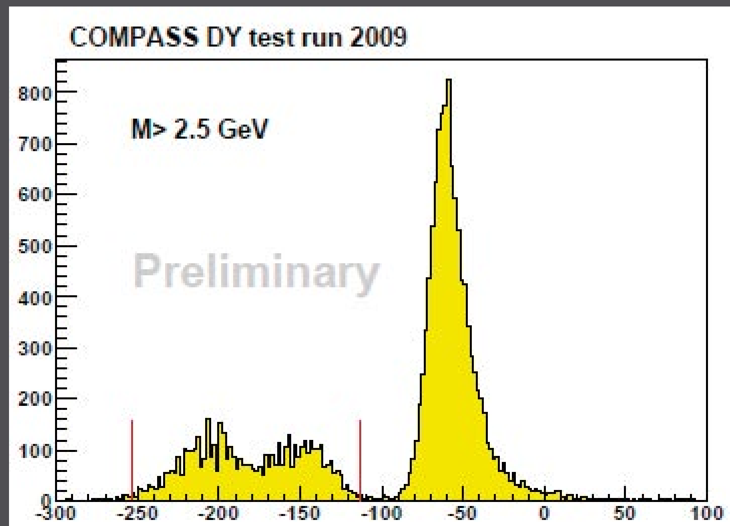




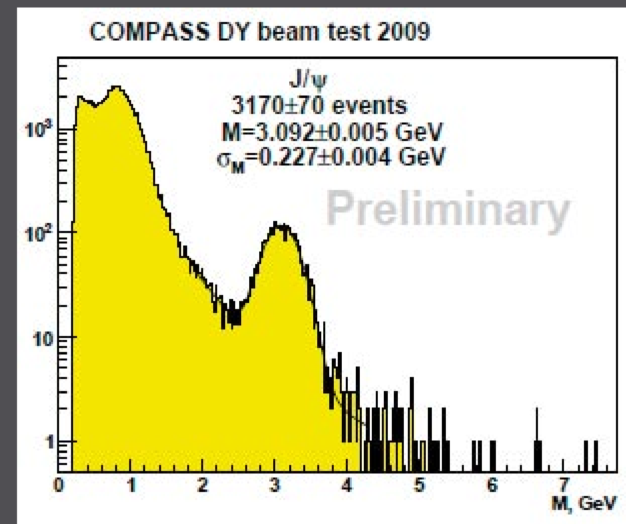


Beam test 2009 results





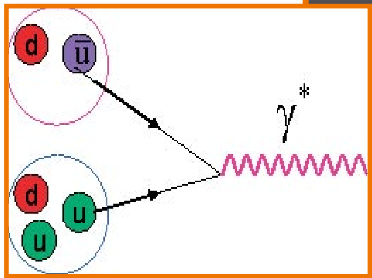
Reasonable Zvertex separation, allowing to distinguish the 2 target cells and the absorber.

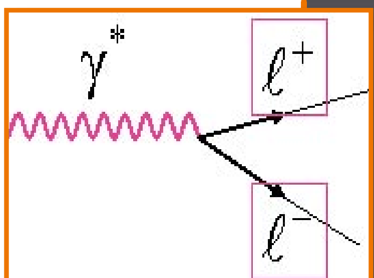


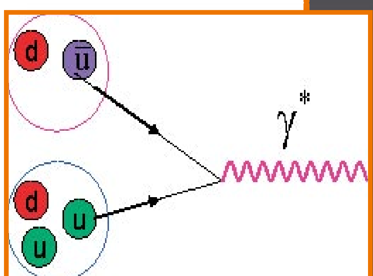
Mass resolution as expected from Monte-Carlo, but worse than in previous experiments ⇒ reconstruction programs still need optimization.

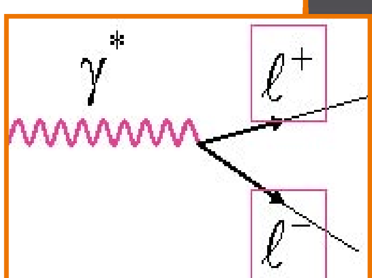
J/Ψ events: expected: 3.600 +- 600
DY events: expected: 110 +- 22
obtained: 84+-10

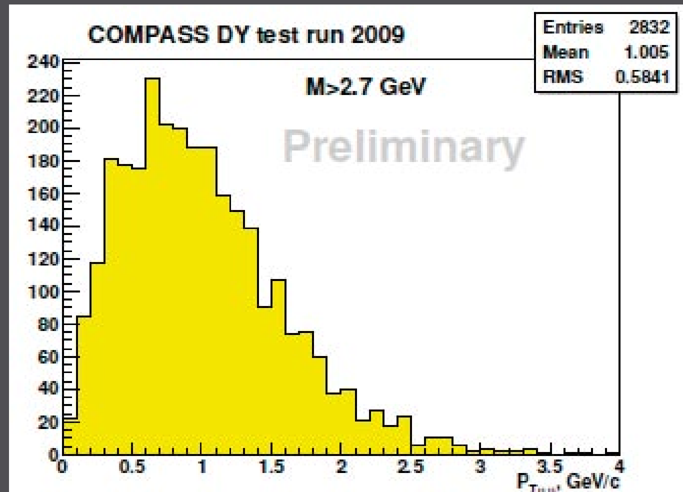
Beam test 2009 results



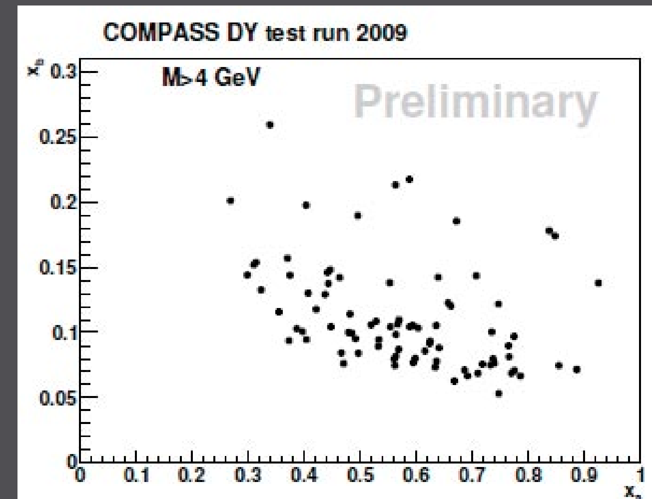




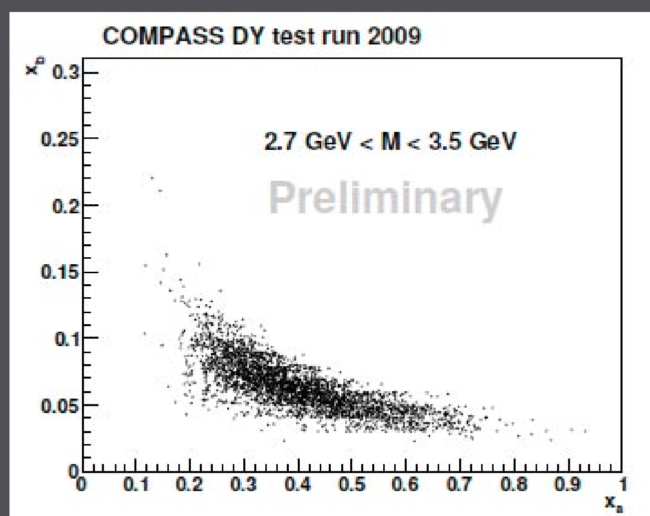




The mean value of p_T is about 1 GeV/c. This makes Compass sensitive to TMDs, which are expected to be accessible up to p_T 2 GeV/c.

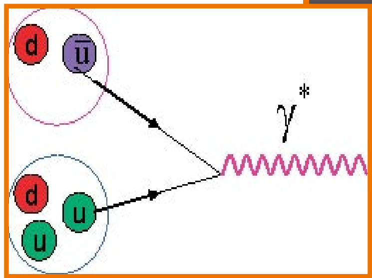


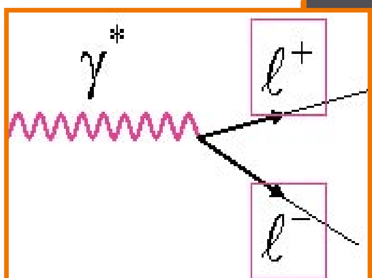
In the high mass range of the dimuon, $M_{\mu\mu}$ > 4GeV/c, both annihilating quarks belong to the valence quark range

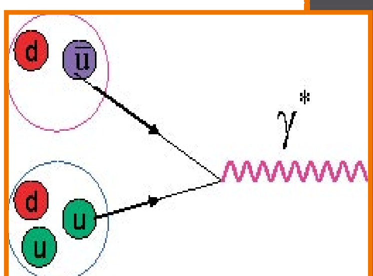


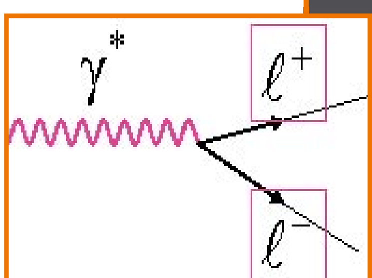
In case of the J/ψ the contribution of valence quarks is also dominant

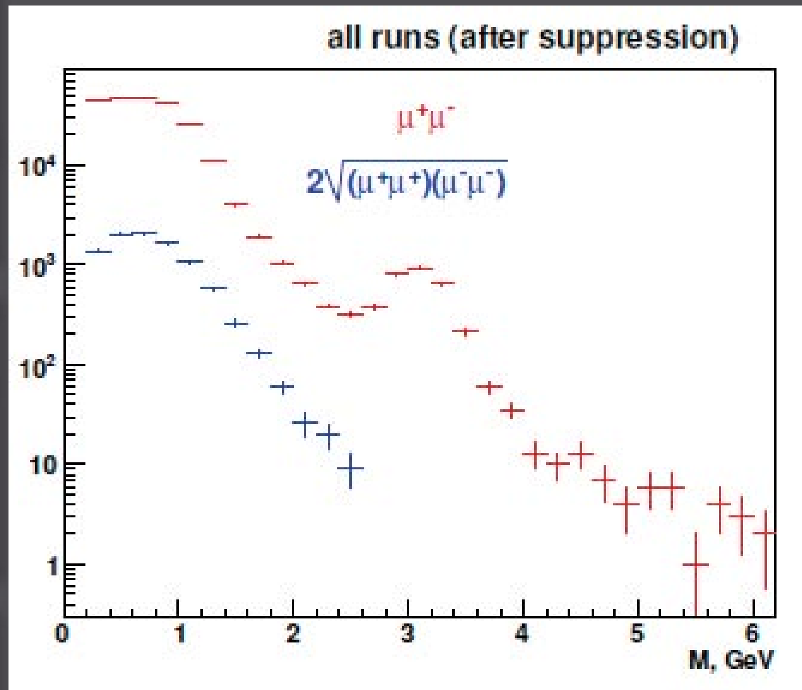
Beam test 2009 results











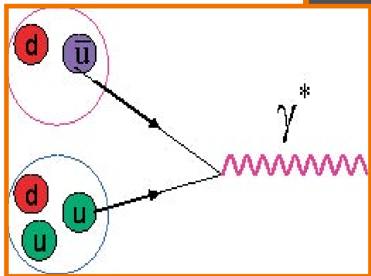
- 4. < Mμμ < 9. GeV/c2 (HMR): clean DY signal
- 2. < Mμμ < 2.5 GeV/c2 (IMR): contaminated with:

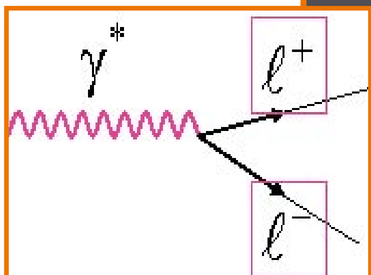
–> combinatorial background (a contribution that can be subtracted by using the like-sign muon pairs samples),

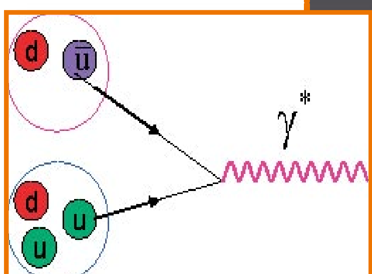
–> physics background mostly from uncorrelated decays of open-charm mesons (in the IMR: $N_{D\bar{D}}$ / N_{DY} = 0.14)

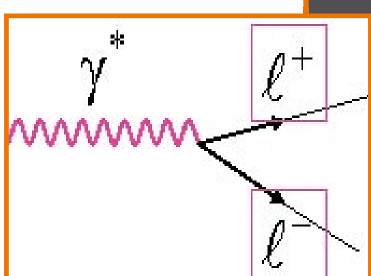
Combinatorial background (from uncorrelated π decays) is estimated using the measured like-sign μμ distributions: the presence of the absorber reduces the background by a factor ≈ 10 at $M_{\mu\mu}$ = 2 GeV/c^2, at I_{beam} ≈1.5 x 10^8 π^- per spill

Beam test 2009 results
radiation protection issues



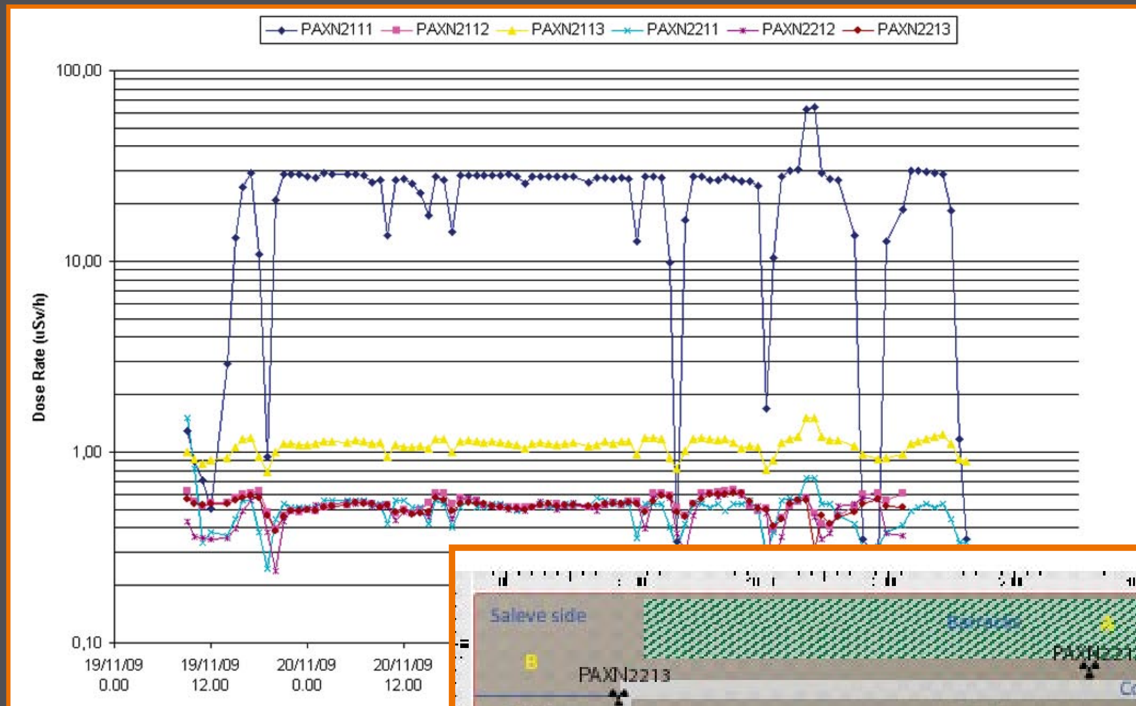


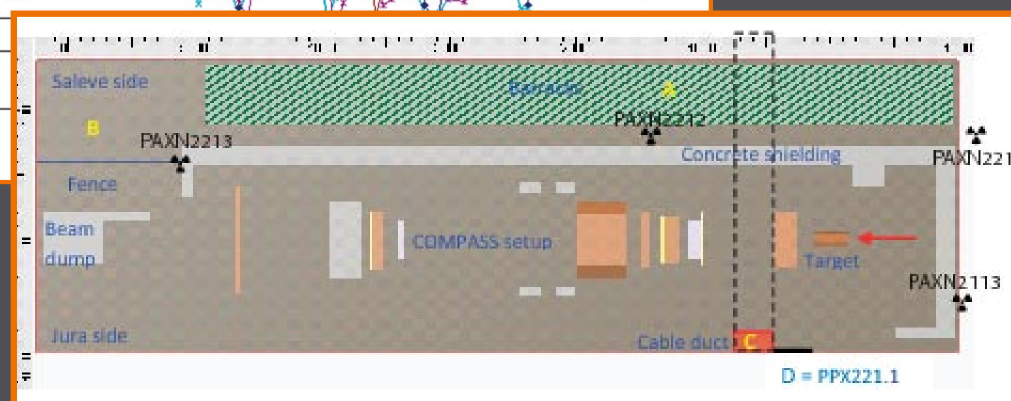




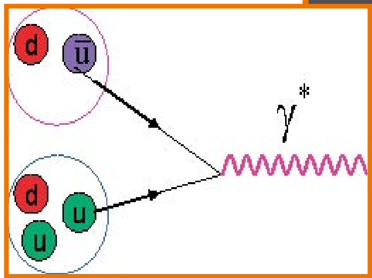
RP - the detected radiation level is factor 6 lower than allowed one (3 υSv), in a good agreement with simulations done by COMPASS and CERN RP (pion beam intensity ~8x10^7 pions per spill (9.6 seconds))

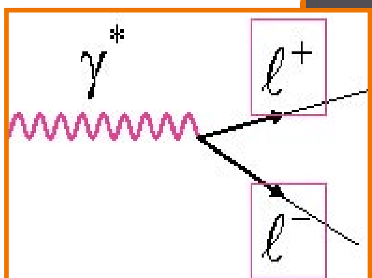
The tracking detectors occupancy downstream of hadron absorber is factor 10 lower compare to the normal muon running conditions

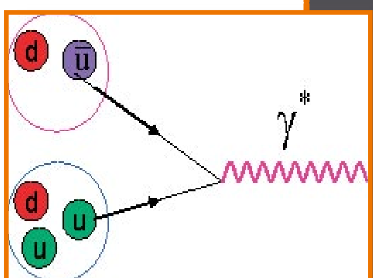


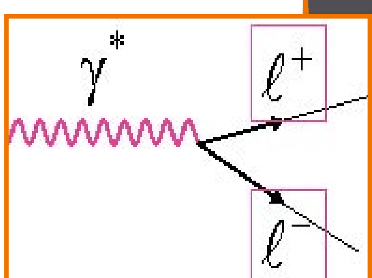


Proposed DY setup

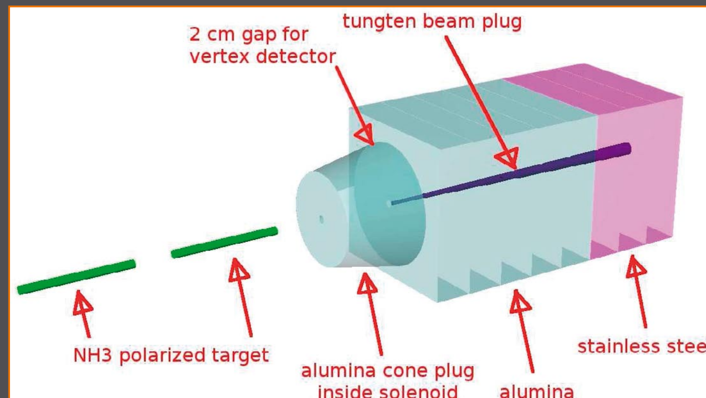


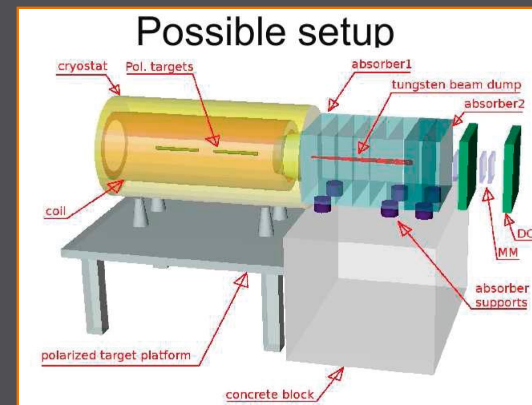






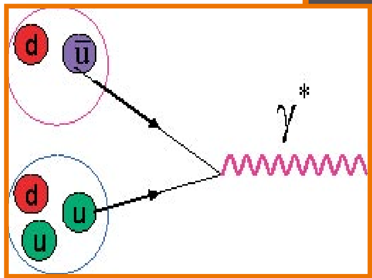
Beam tests demonstrated the feasibility of the Drell-Yan measurement, and pointed aspects to improve.

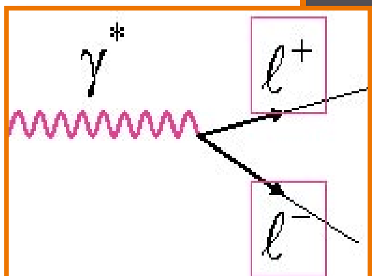


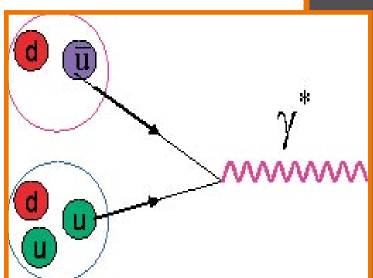


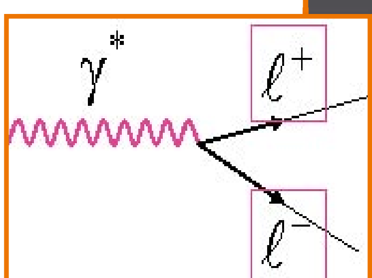
- 2 target cells (55 + 55 cm), spaced by 20 cm, filled with NH3, inside sole-noid.
- Absorber at least 2 m long (Al_2O_3 + steel), with beam plug (W) inside, 1 m long.
- 2 large area hodoscopes, for dimuon trigger in the 1st spectrometer.
- Possibility to add a vertexing detector between target and absorber.

DY cross-section and phase space covered



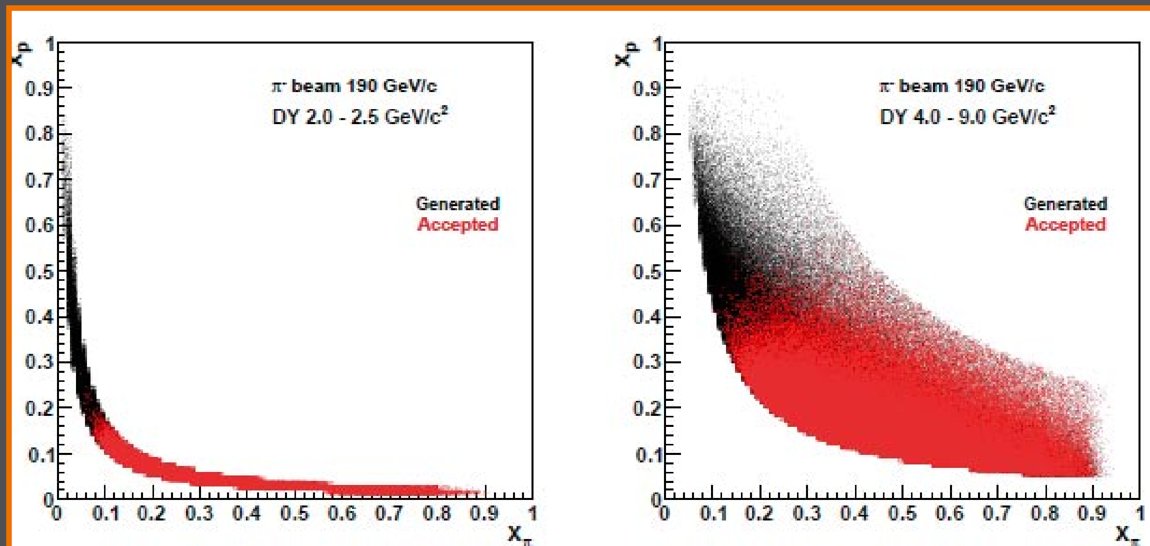






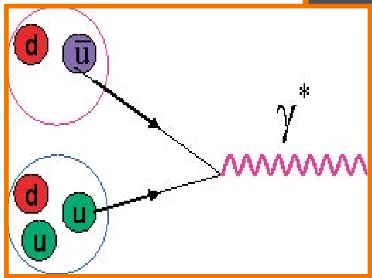
From Pythia 6.2:

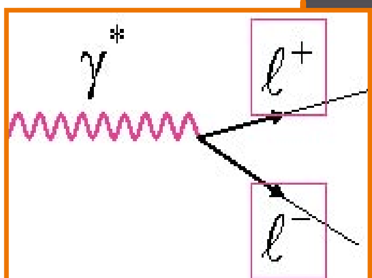
π^- momentum (GeV/c)	$\sigma^{DY\to\mu\mu}_{\pi^- - \mathrm{NH_3}}$ (nb) $\mathrm{NH_3}$	
	$2 < M_{\mu\mu} < 2.5$	$4 < M_{\mu\mu} < 9$
160	5.9	1.1
190	6.2	1.3
213	6.4	1.4

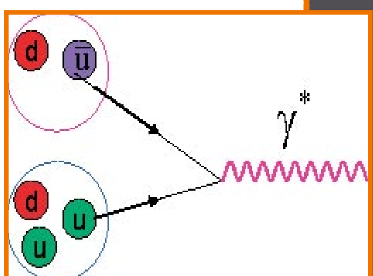


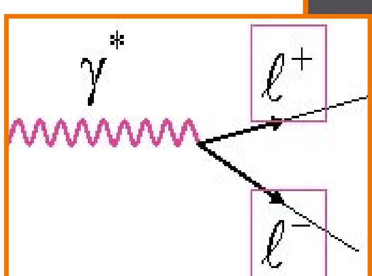
COMPASS acceptance is in the valence quarks region (x > 0.05).
Also the best region to measure spin asymmetries.

Acceptances





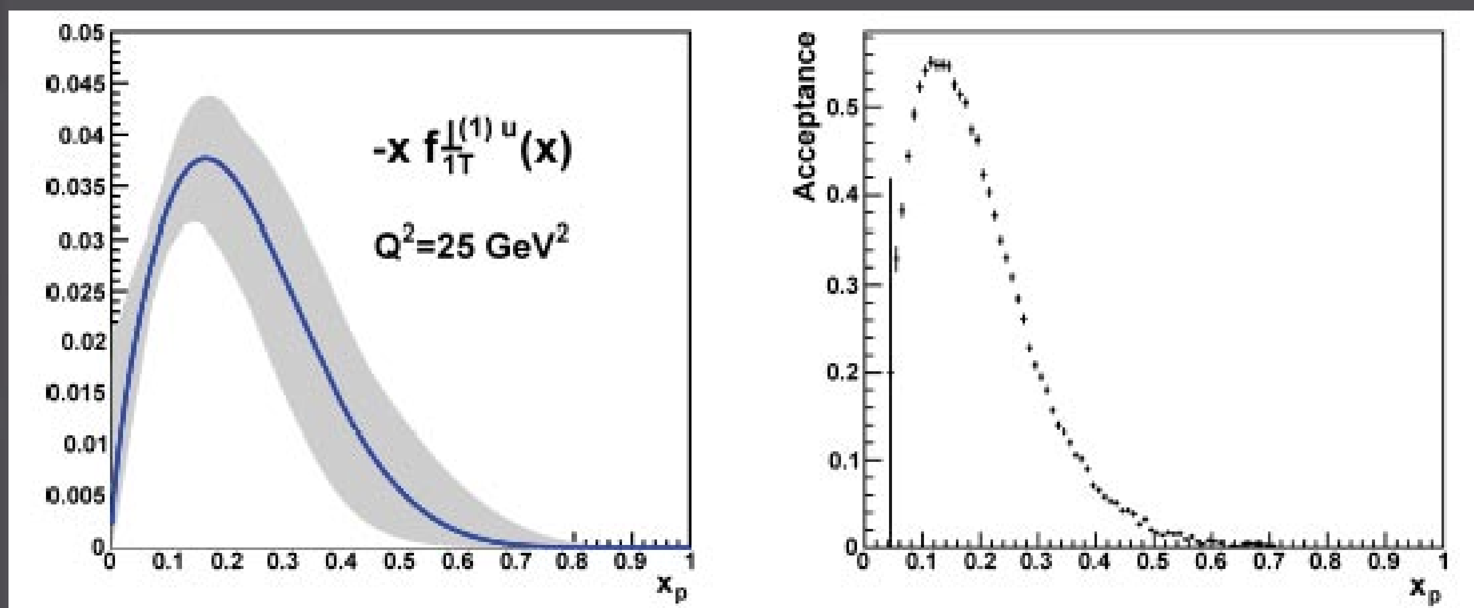




The DY dimuons acceptance is estimated from a full Monte-Carlo.

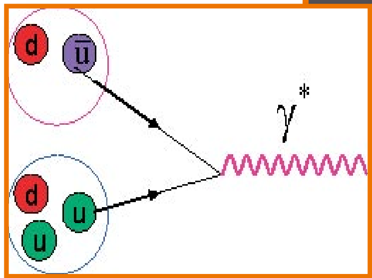
Mass range (GeV/c^2)	Average acceptance (%)	LAS	LAS+SAS	SAS
4–9	35	64	40	4
2–2.5	43	32	54	20

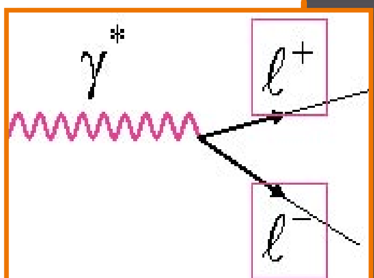
DY 4.-9. GeV/c^2

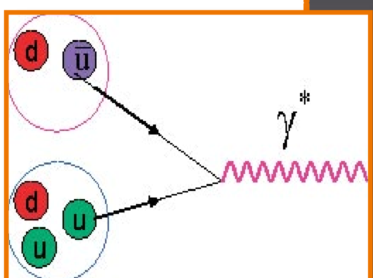


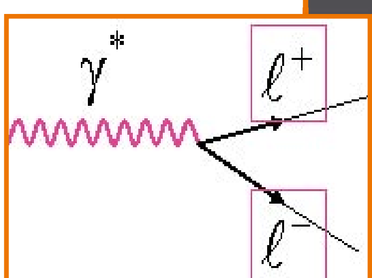
M. Anselmino et al., Eur. Phys. J. A39 (2009) 89.

Expected event rates









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

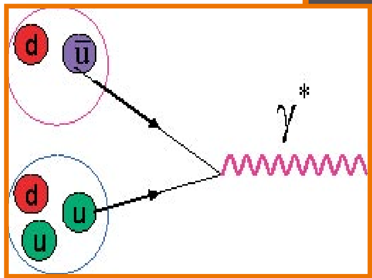
π^- momentum (GeV/c)	DY rate (/day)	
	$2 < M_{\mu\mu} < 2.5$	$4 < M_{\mu\mu} < 9$
160	4600	700
190	4900	800
213	5000	900

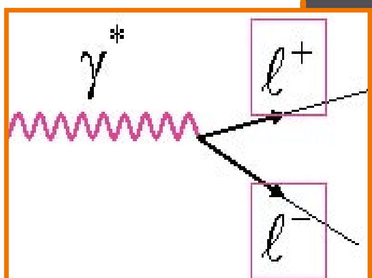
Assuming 2 years of data-taking (140 days/year), one can collect:

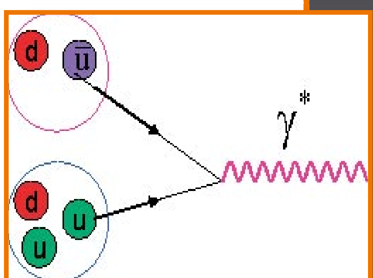
- 230×10^3 events in DY HMR;
- 1.4×10^6 events in the DY IMR.

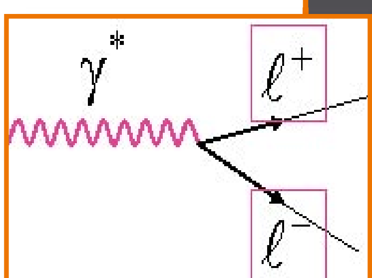
$$R = \mathcal{L}\ \sigma_{\pi^- \mathrm{NH_3}}\ K_{DY}\ d_{spill}\ n_{spill}\ E_{tot}$$

Asymmetries: expected statistical precision









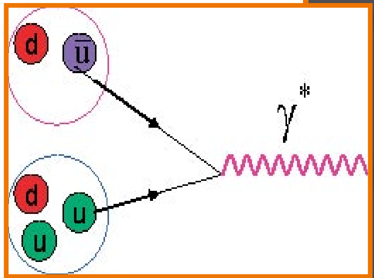
For π^- beam at 190 GeV/c and 2 years of data-taking:

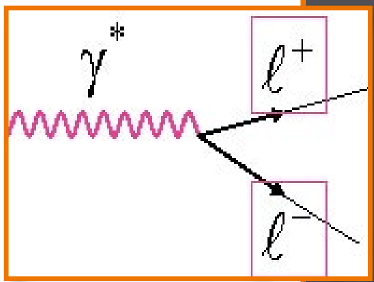
Asymmetry	Dimuon mass (GeV/c^2)		
	$2 < M_{\mu\mu} < 2.5$	J/ψ region	$4 < M_{\mu\mu} < 9$
$\delta\, A_U^{\cos 2\phi}$	0.0020	0.0013	0.0045
$\delta\, A_T^{\sin \phi_S}$	0.0062	0.0040	0.0142
$\delta\, A_T^{\sin(2\phi+\phi_S)}$	0.0123	0.008	0.0285
$\delta\, A_T^{\sin(2\phi-\phi_S)}$	0.0123	0.008	0.0285

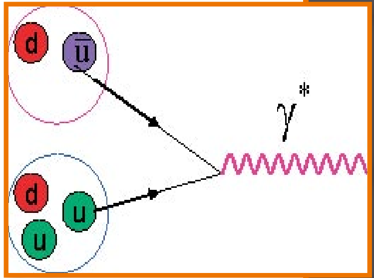
Example:

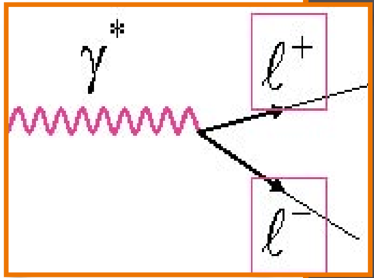
$$\delta A_T^{\sin\phi_S}(x_a, x_b) = \frac{1}{f\,|\vec{S}_T|}\,\frac{\sqrt{2}}{\sqrt{N(x_a,x_b)}}$$

Asymmetries: comparing with theory prediction

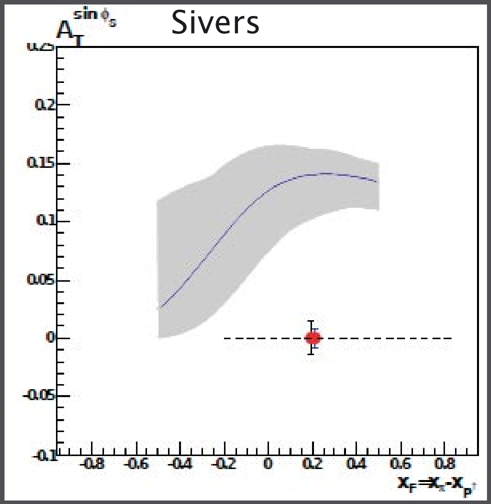




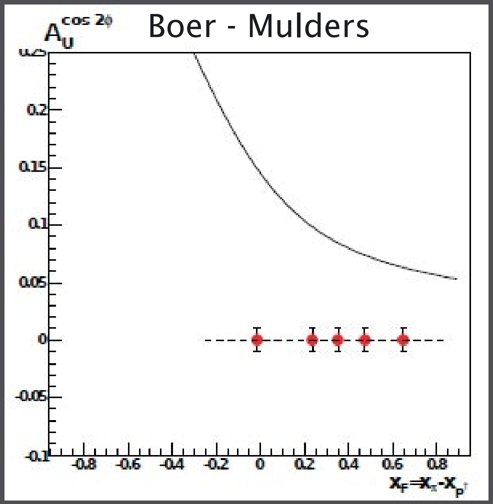




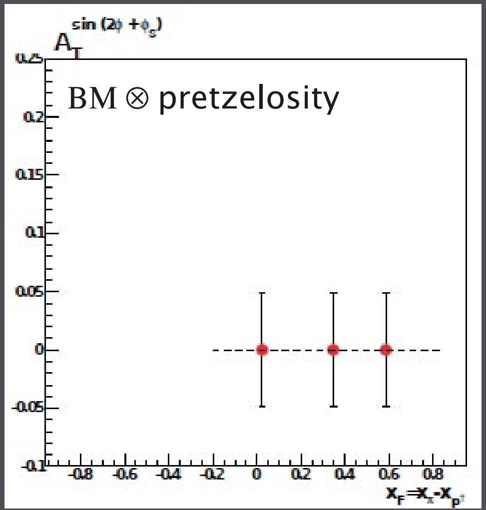
2 years of data taking
DY 4.-9. GeV/c²

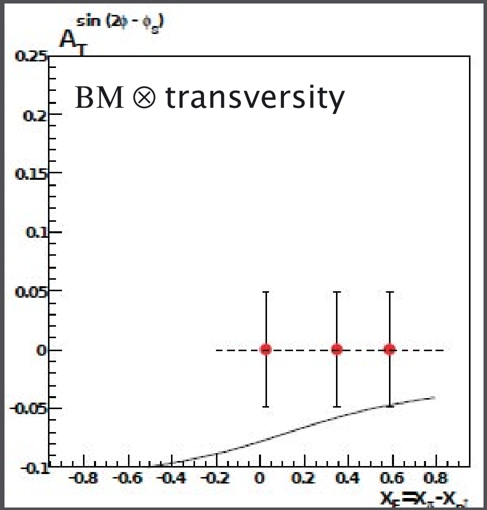


M. Anselmino et al., in Proceedings of Transversity 2008, 2009, ISBN:978-981-4277-77-8, p. 138



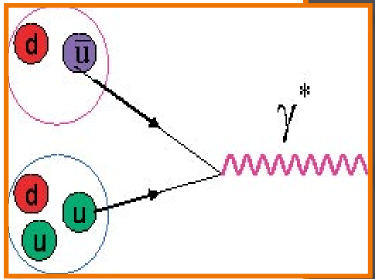
D. Boer, Phys. Rev. D60 (1999) 014012.
B. Zhang et al., Phys. Rev. D77 (2008) 054011.

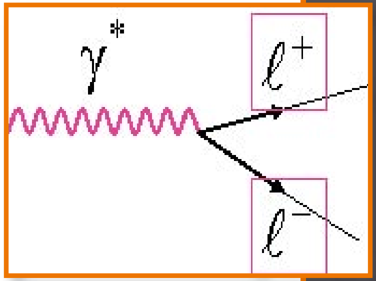


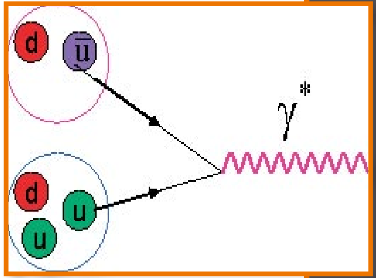


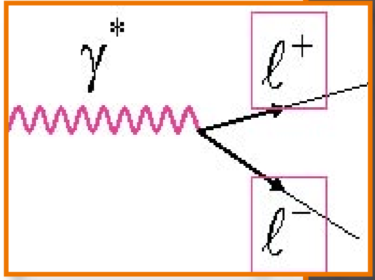
V. Barone et al., Phys. Rept. 359 (2002) 1.
V. Barone et al., Phys. Rev. D56 (1997) 527.

Asymmetries: comparing with theory prediction



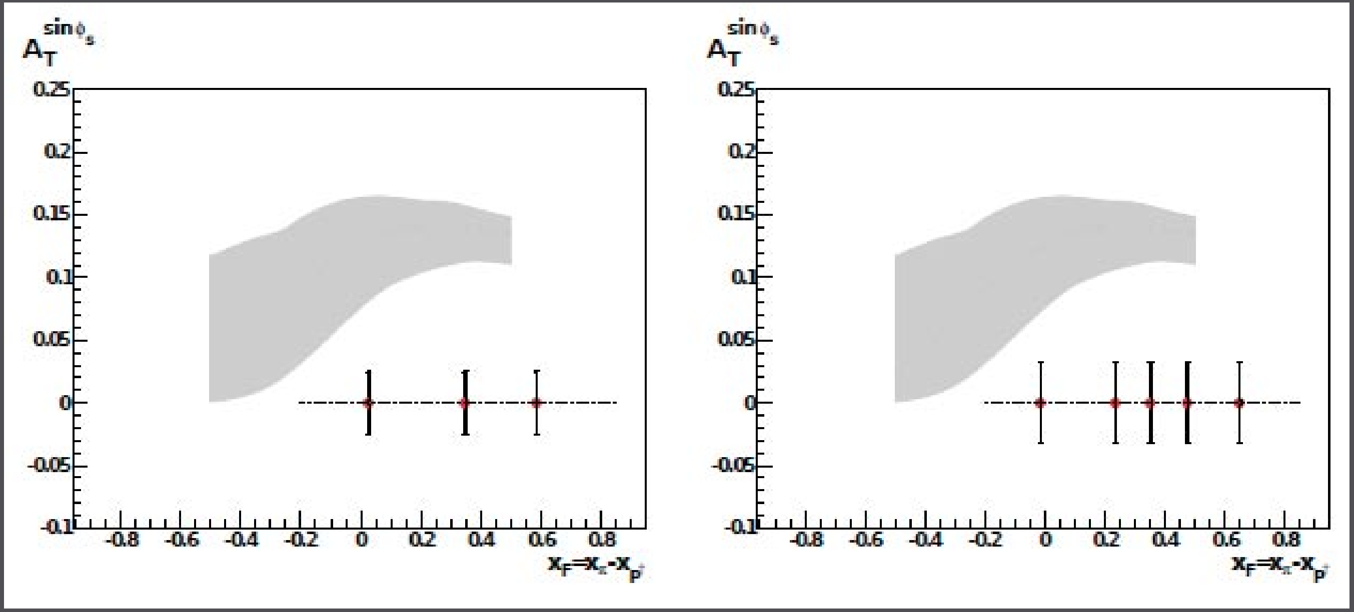






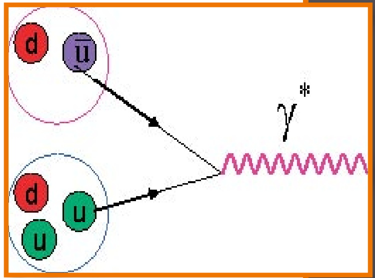
At which x_f quoting the Sivers?

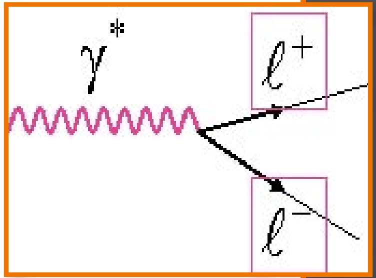
2 years of data taking
DY 4.-9. GeV/c²

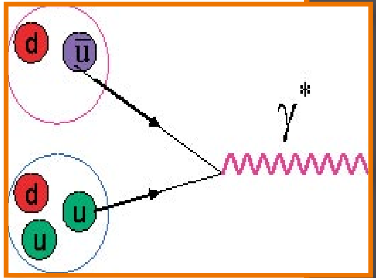


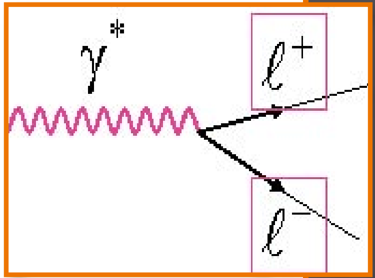
Expected statistical error of the Sivers asymmetry for a measurement in three (left) and five (right) bins in x_F assuming two years of data taking

Asymmetries: comparing with theory prediction

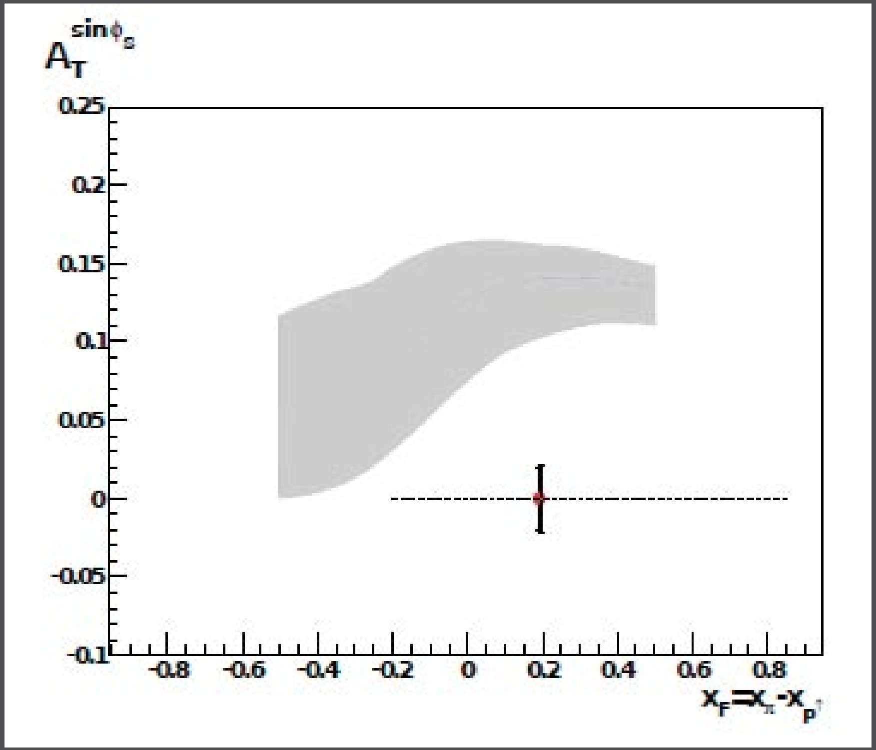




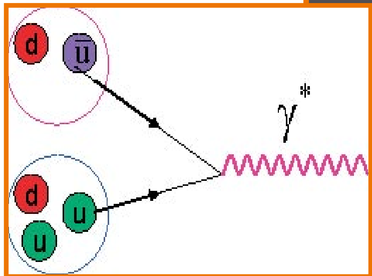


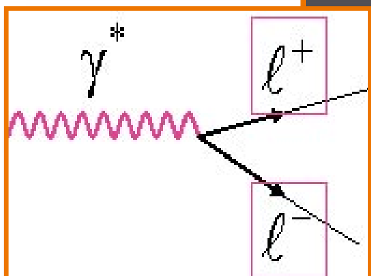


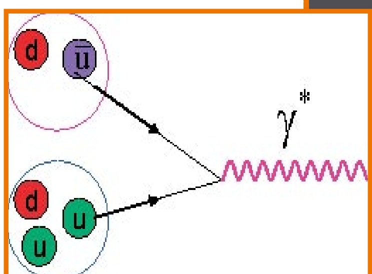
1 year of data taking
DY 4.- 9. GeV/c²

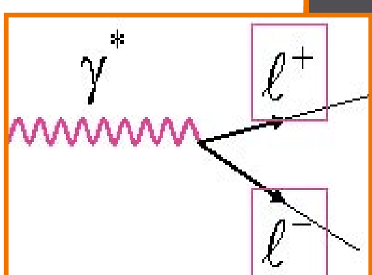


Summary









- 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 ($\tau = M^2/s = 0.05$ to 0.3)

- The feasibility of the measurement was proven, after a series of beam tests.

- The COMPASS-II Proposal has been submitted on May 17th 2010 and recommended to the Research Board for approval.

- COMPASS could start to take DY data in 2013 (in 2012 an accelator shut-down has been foreseen).