Future COMPASS Drell-Yan experiment

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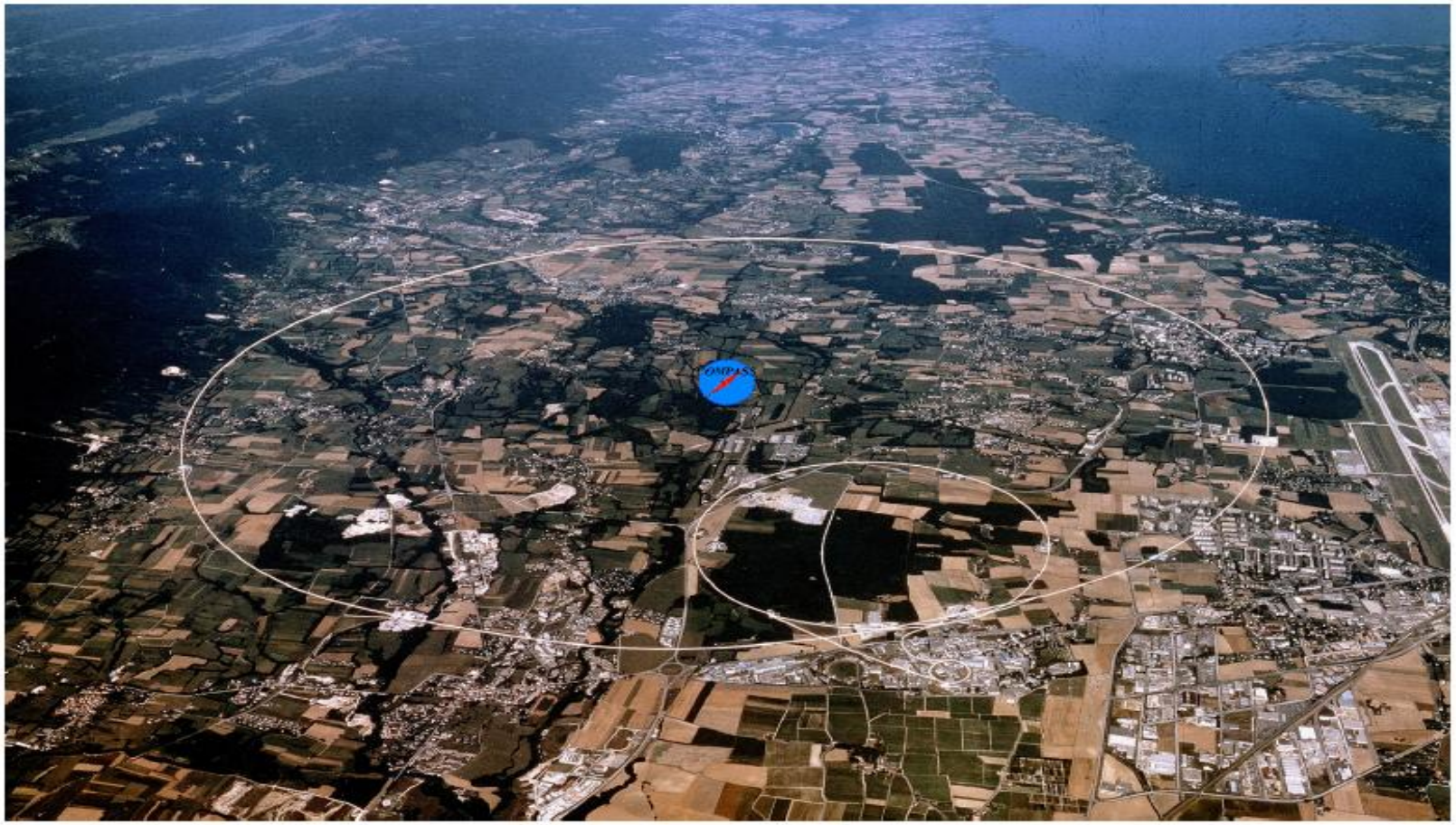
CERN and INFN sez. di Torino
20.04.2010

Outline

- DY@COMPASS – physics – see presentations by Daniel, Paul, Werner, ……. First day of the Workshop
- DY@COMPASS – set-up
- DY@COMPASS - kinematic range
  - Valence quark contribution is dominant
  - ‘Pure’ u-ubar channel
  - $\langle P_T \rangle \sim 1$GeV – TMDs induced effects expected to be dominant
- DY@COMPASS - feasibility
- Projections
- Conclusions

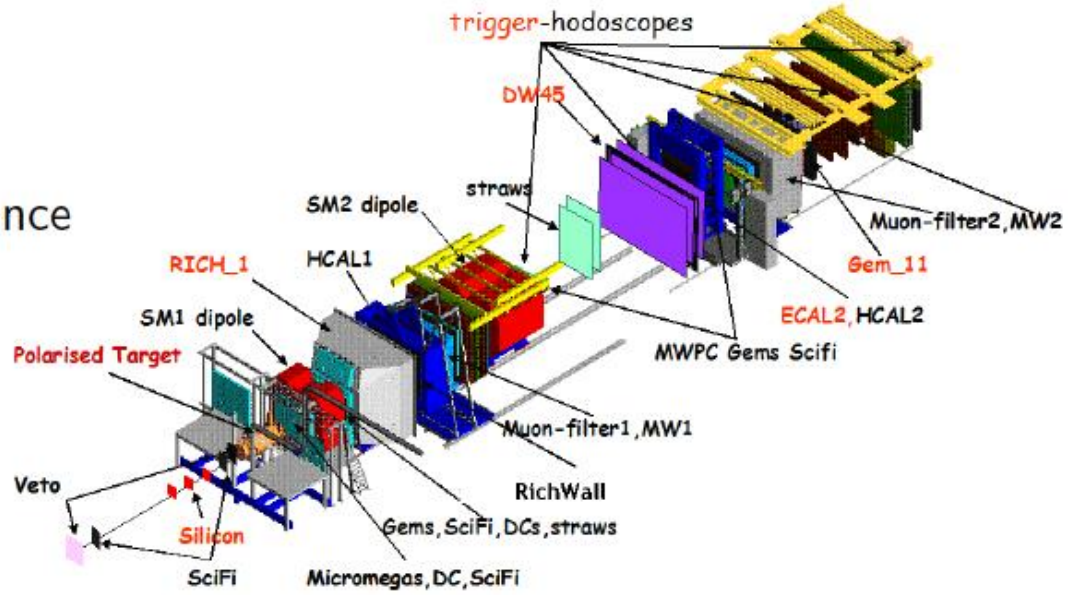
COMPASS facility at CERN (SPS) I

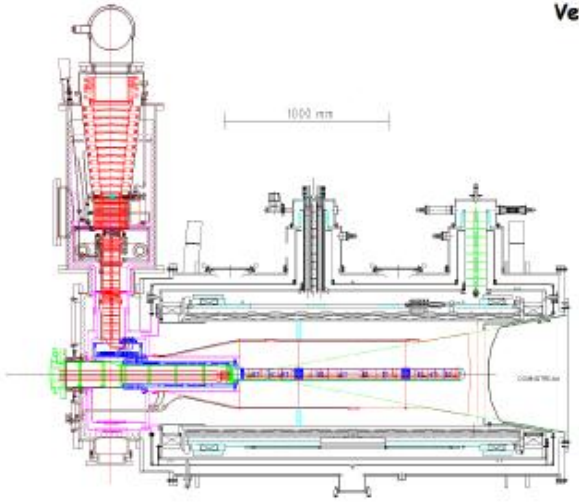
COmmon Muon Proton Apparatus for Structure and Spectroscopy



COMPASS facility at CERN (SPS) II

- μ, p, π, K beam
- 50-270 GeV/c momentum
- $\pm$180 mrad angular acceptance

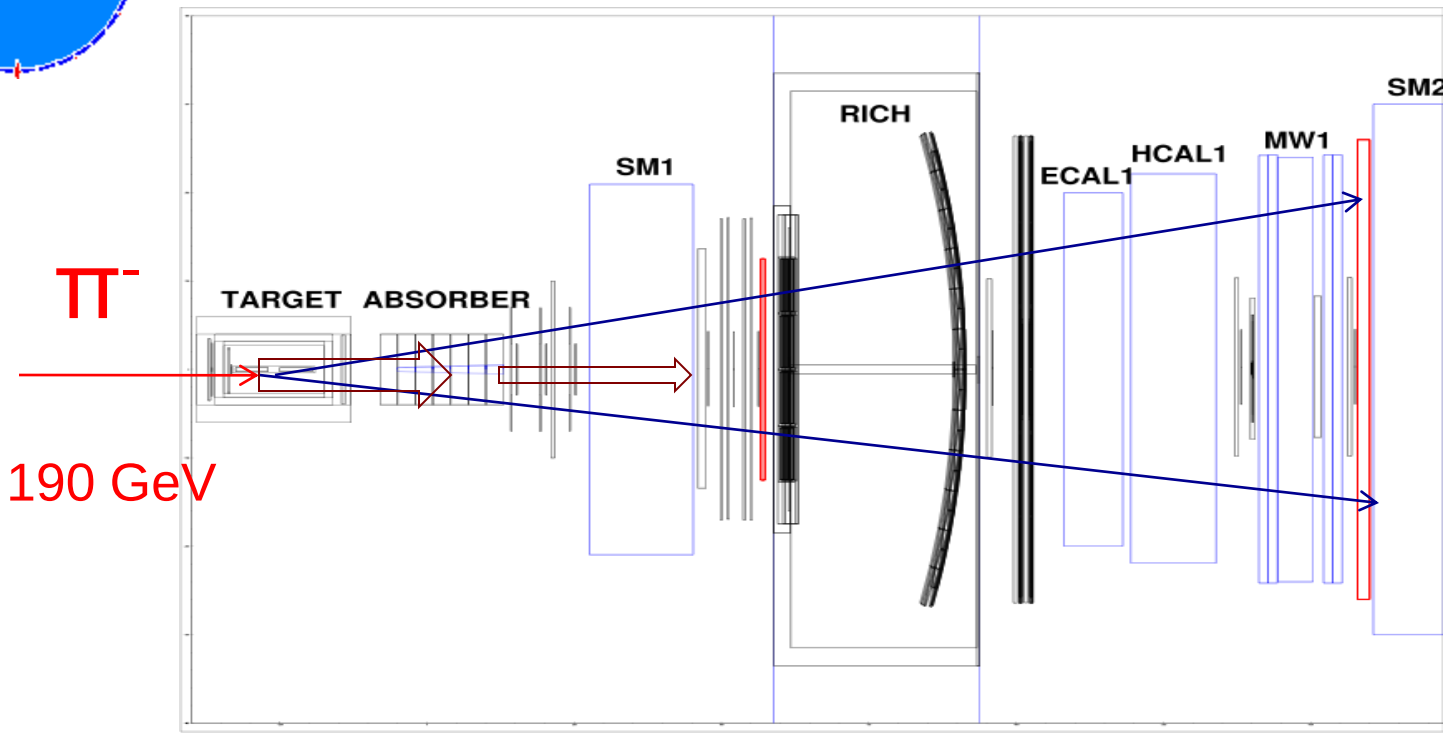




- NH_3 target polarisation $\sim$90%
- dilution factor 0.14
- three cells target

DY@COMPASS - set-up

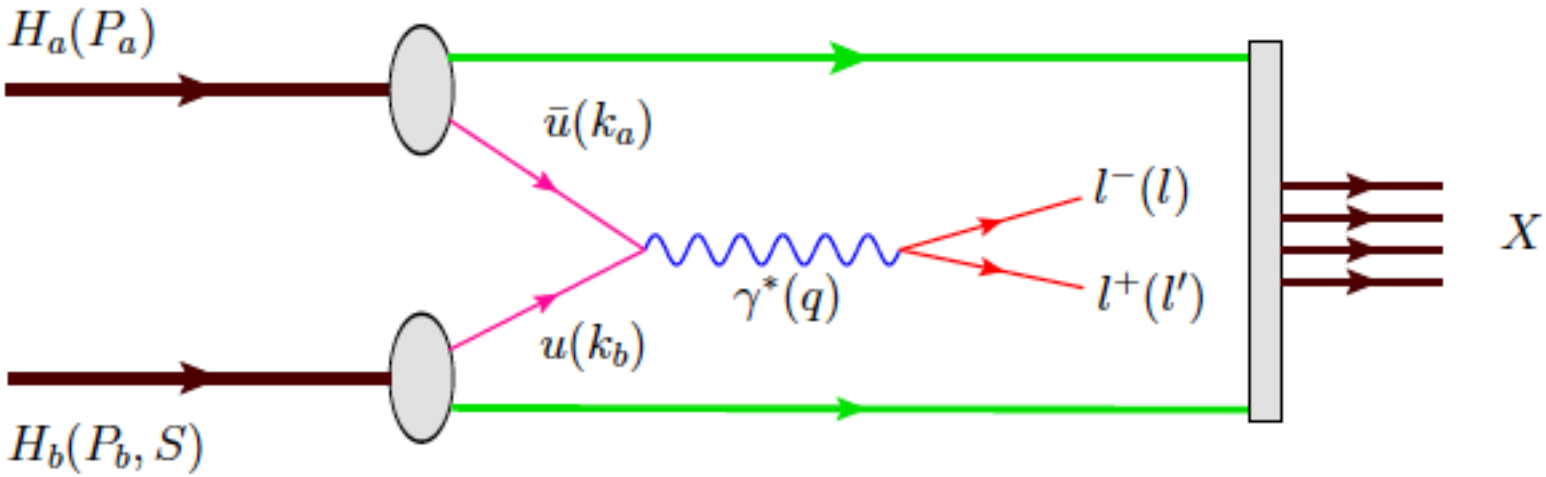
$\pi^- p \rightarrow \mu^- \mu X$



Key elements:

1. COMPASS PT
2. Tracking system (both LAS abs SAS) and beam telescope in front of PT
3. Muon trigger (in LAS is of particular importance - 60% of the DY acceptance)
4. RICH1, Calorimetry – also important to reduce the background (the hadron flux downstream of the hadron absorber ~ 10 higher then muon flux)

Drell-Yan Kinematics

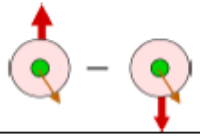
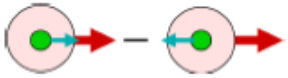
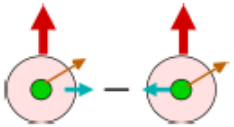
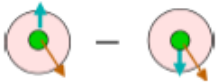
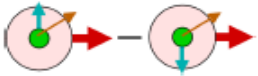


$P_{a(b)}$	the momentum of the beam (target) hadron,
$s = (P_a + P_b)^2$,	the total centre-of-mass energy squared,
$x_{a(b)} = q^2/(2P_{a(b)} \cdot q)$,	the momentum fraction carried by a parton from $H_{a(b)}$,
$x_F = x_a - x_b$,	the Feynman variable,
$M^2_{\mu\mu} = Q^2 = q^2 = s\ x_a\ x_b$,	the invariant mass squared of the dimuon,
$\mathbf{k}_{Ta(b)}$	the transverse component of the quark momentum,
$\mathbf{q}_T = \mathbf{P}_T = \mathbf{k}_{Ta} + \mathbf{k}_{Tb}$	the transverse component of the momentum of the virtual photon.

LO TMD PDFs – unique feature of the COMPASS

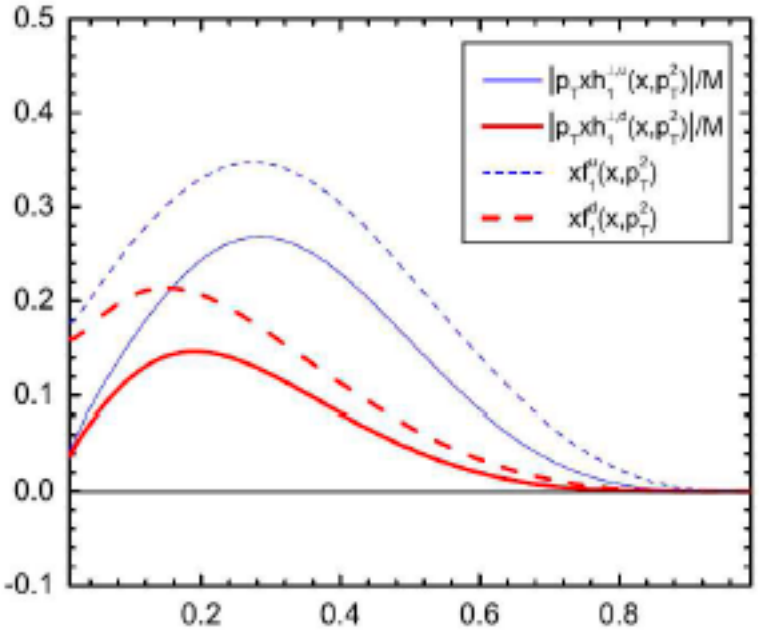
When the parton transverse momentum (k_T) dependence is taken into account, eight parton distribution functions are used to describe the nucleon at LO

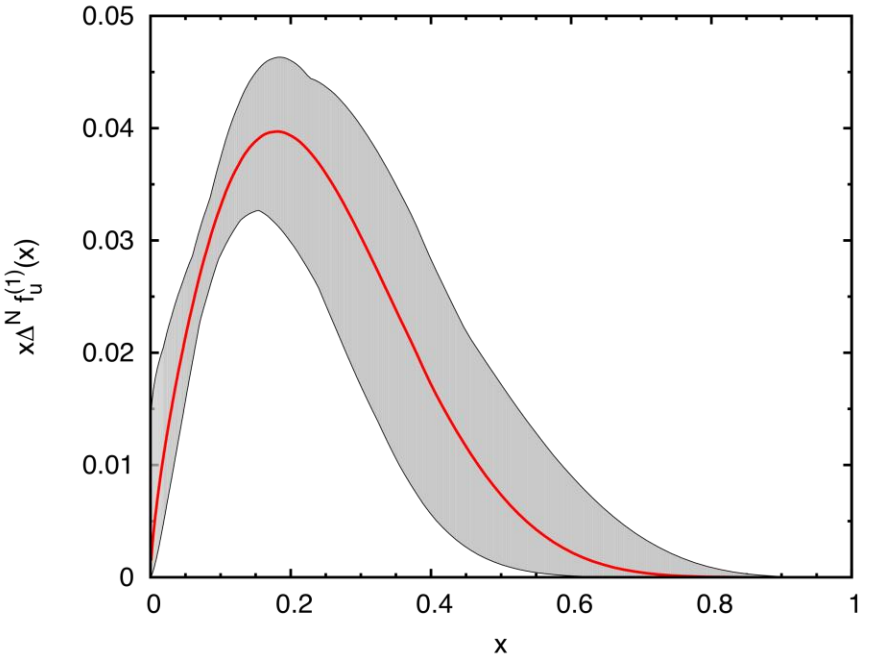
nucleon

quark \ nucleon	unpol.	long. pol.	transv. pol.
unpol.	f_1 		$f_{1T}^{\perp}$ Sivers 
long. pol.		g_{1L} 	g_{1T} 
transv. pol.	$h_1^{\perp}$ B-M 	$h_{1L}^{\perp}$ 	h_1 transv.  $h_{1T}^{\perp}$ Pretzl. 

DY@COMPASS kinematics - Indication

TMD PDFs – ALL are sizable in the valence quark region





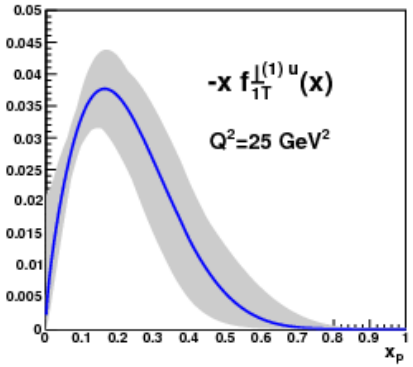
- Boer-Mulder function for u and d quarks as extracted from $p + D$ data from Zhang *et al Phys. Rev.* D77,0504011]

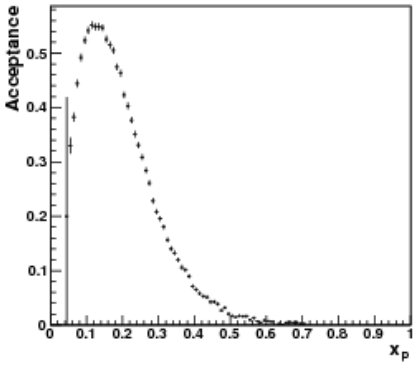
Sivers effect in Drell-Yan processes. M. Anselmino, M. Boglione U. D'Alesio, S. Melis, F. Murgia, A. Prokudin Published in Phys.Rev.D79:054010, 2009

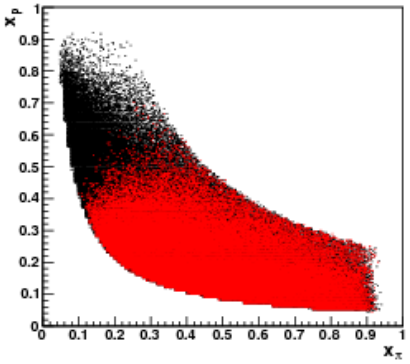
DY@COMPASS – kinematics - valence quark range

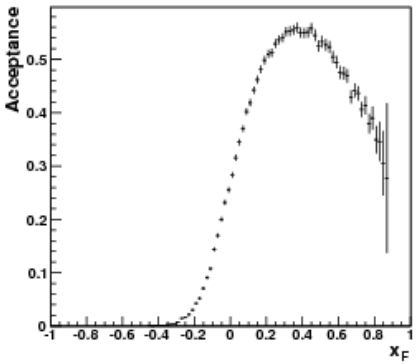
$\pi^- p \rightarrow \mu^- \mu X$

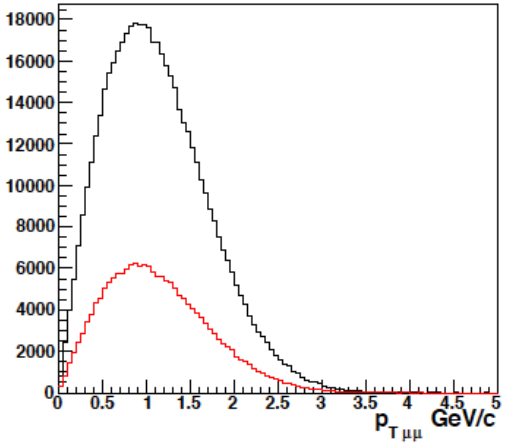
- In our case ($\pi^- p \rightarrow \mu^- \mu X$) contribution from valence quarks is dominant
- In COMPASS kinematics u-ubar dominance
- $\langle P_T \rangle \sim 1$GeV – TMDs induced effects expected to be dominant with respect to the higher QCD corrections









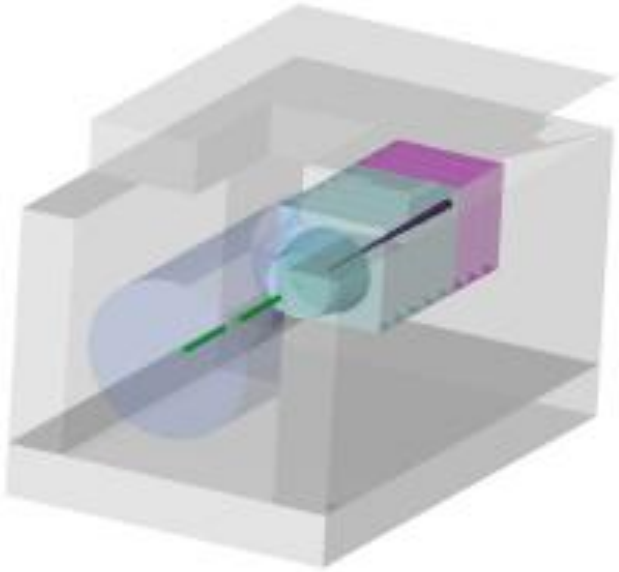


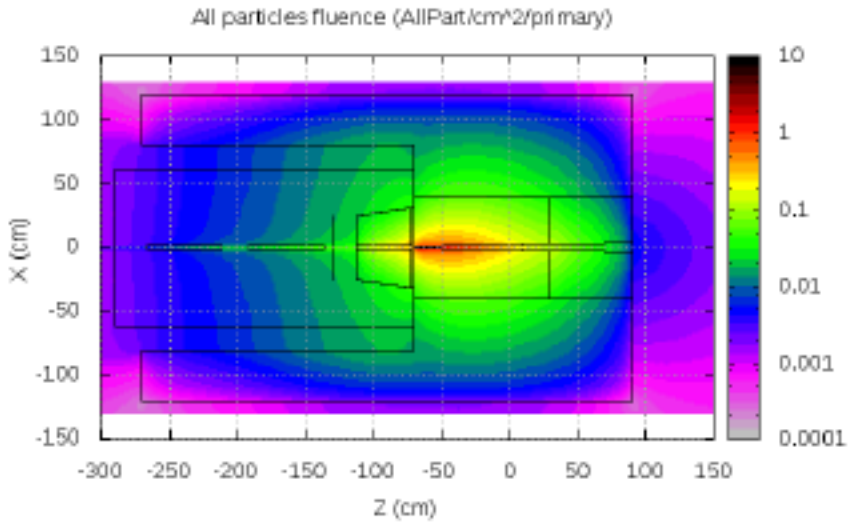
DY@COMPASS - feasibility

- Small cross section - High luminosity experiment
- Polarised target is the key instrument of the program
- Radioprotection issue – experiment similar to NA3
- Detector occupancies
- Trigger rates
- DY event rate (J/Psi as a monitoring signal)
- Physics background study:
  - D-Dbar semi-leptonic decays
  - Combinatorial background from π and K
- COMPASS spectrometer kinematic range

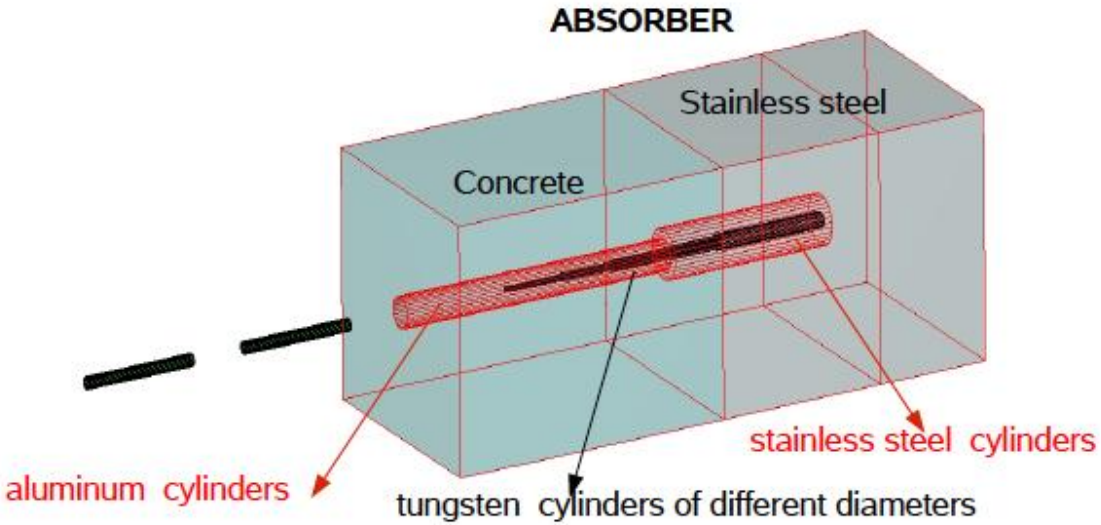
DY@COMPASS - feasibility - PT

- Beam of the intensity up to 10^8 s^{-1} normally not a problem
- Expected heat input ~ 2 mW will not affect relaxation time, refrigerator cooling power is sufficient (~ 5 mW)
- Beam spot has to stay large (~ 1 cm HWHM) – implemented in MC
- The radiation dose is simulated with FLUKA (cross-checked with Radio-Protection group) – the results are communicated to PT group





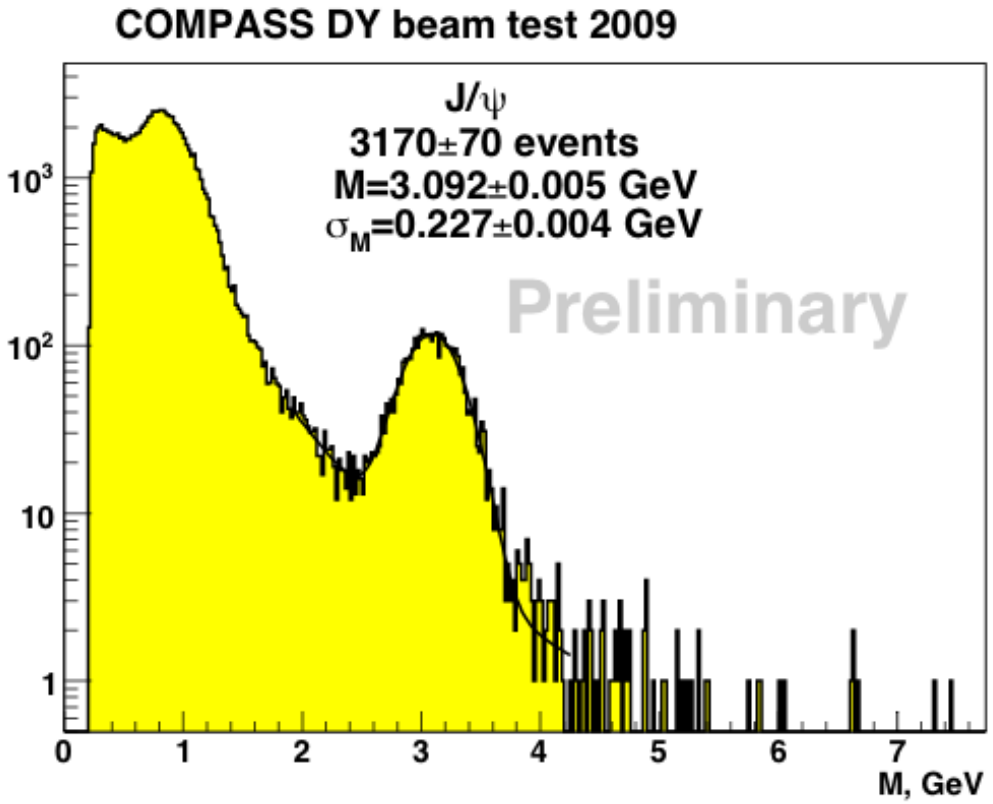
DY Feasibility@COMPASS
Beam Test 2009 – very important (2007, 2008)



DY Feasibility@COMPASS
Beam Test 2009 (with hadron absorber III)

DY@COMPASS - feasibility - Signal

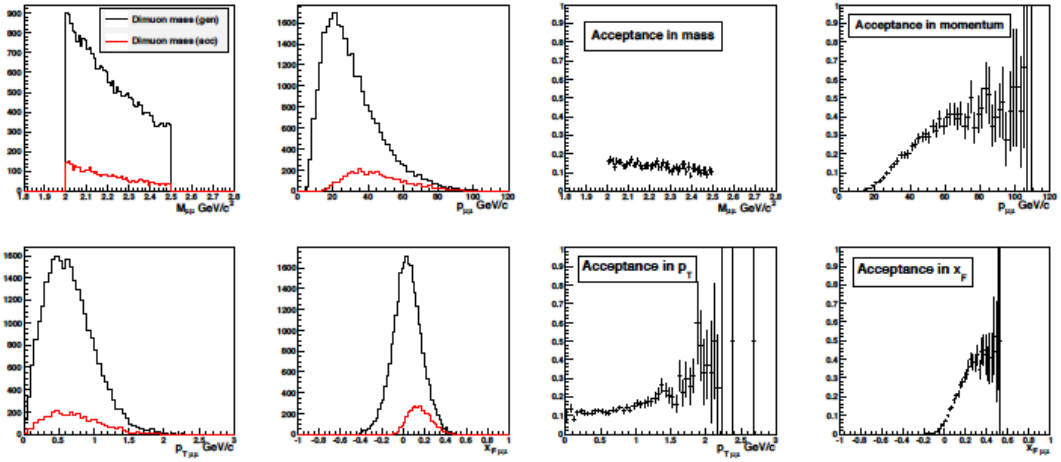
- Expected according to the proposal J/Psi and Drell-Yan yields: 3600±600 and 110±22 (normalized to 2009 beam flux ~3.7 x 10^{11})
- Measured in 2009 beam test J/Psi yield is 3170±70, and DY yield is 84±10



DY@COMPASS - feasibility – Background I – D-Dbar

- Calculated by MC
- Negligible in both HM and IM ranges (~15% contribution in IM)

Acceptance for open-charm 2.0 - 2.5 GeV/c^2

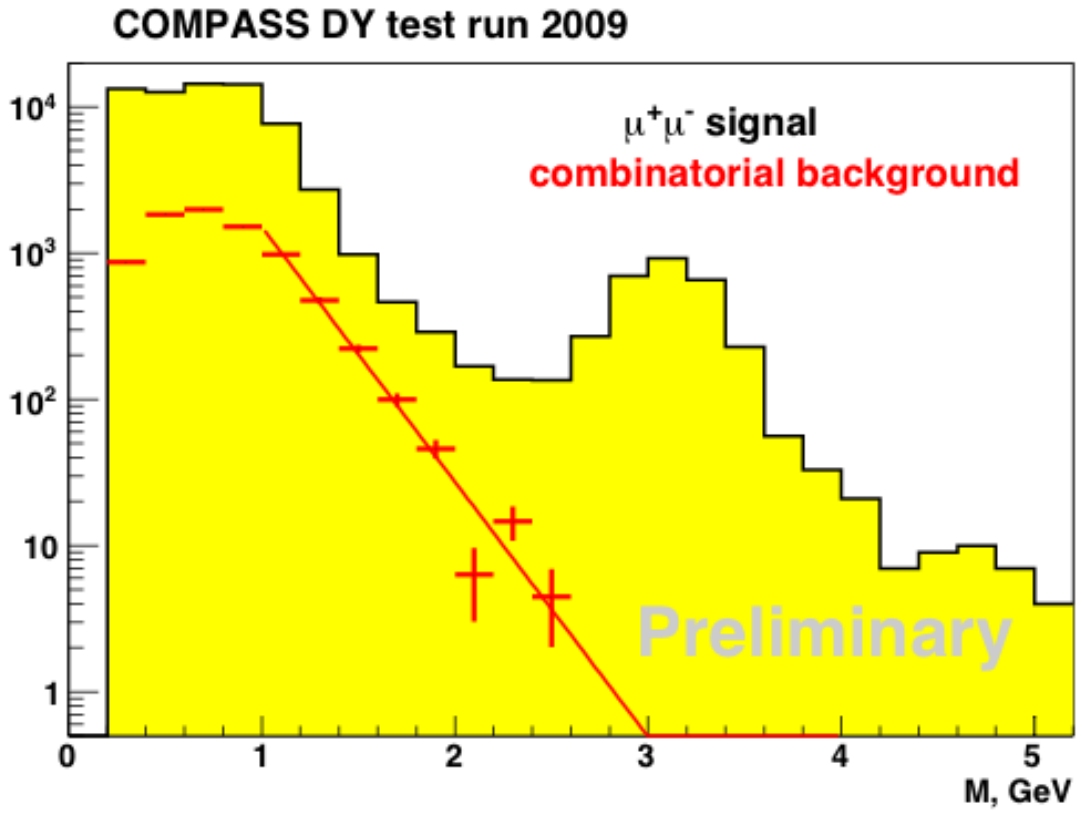


As in the IMR the acceptances are 14% for open-charm and 43% for DY, the ratio of observable events in the dimuon mass spectra will be

$N_{DD}/N_{DY} = (5.47 \times 0.14)/(12.46 \times 0.43) = 0.14$.

DY@COMPASS - feasibility – Background II – Combinatorial

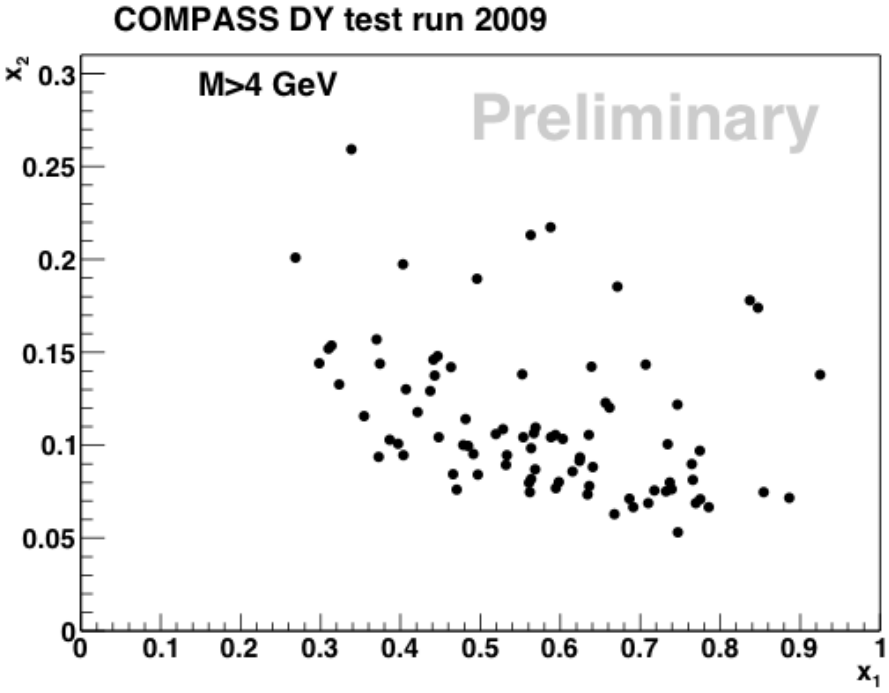
- 2009 beam test id very important
- Combinatorial background suppressed by ~10 at 2.0 GeV/c dimuon invariant mass (beam intensity ~8 times lower wrt Proposal)

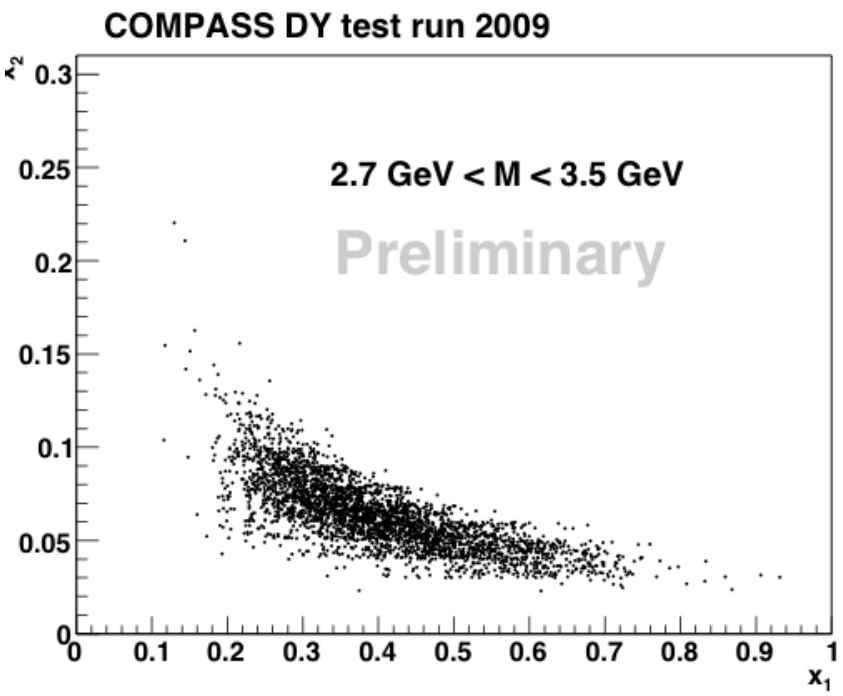


DY@COMPASS - feasibility – Kinematics I

- Valence quark range for both J/Psi and DY

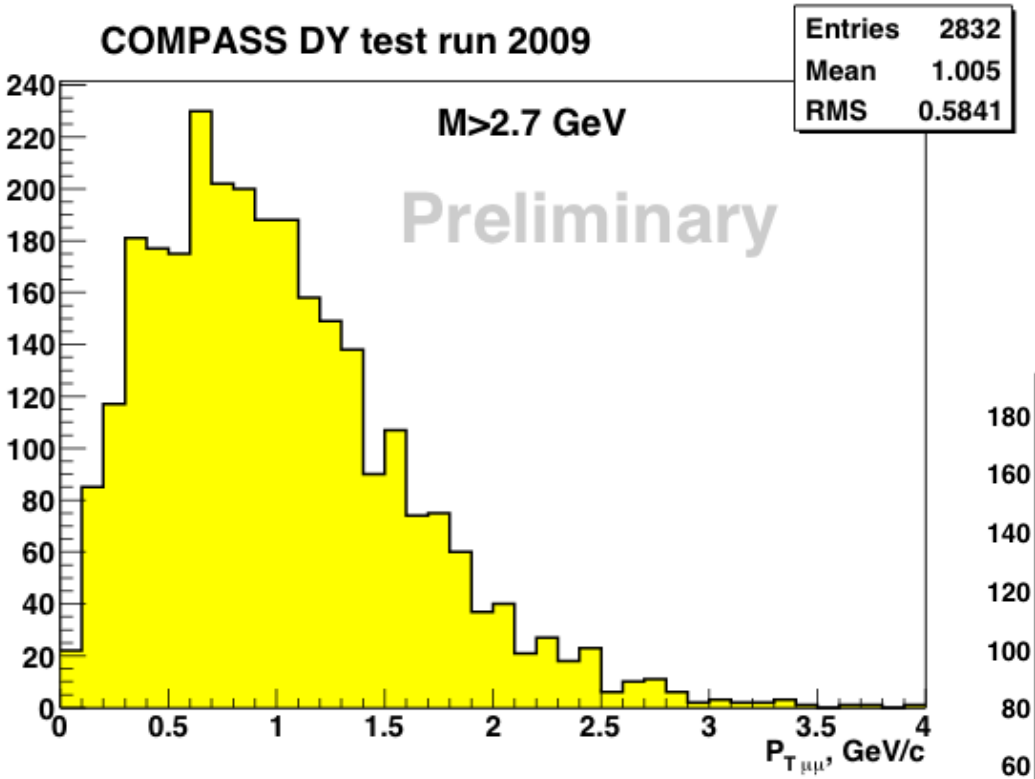
$$x_1 = \frac{Q^2}{P_1 q},$$
$$x_2 = \frac{Q^2}{P_2 q},$$
$$x_f = x_1 - x_2,$$

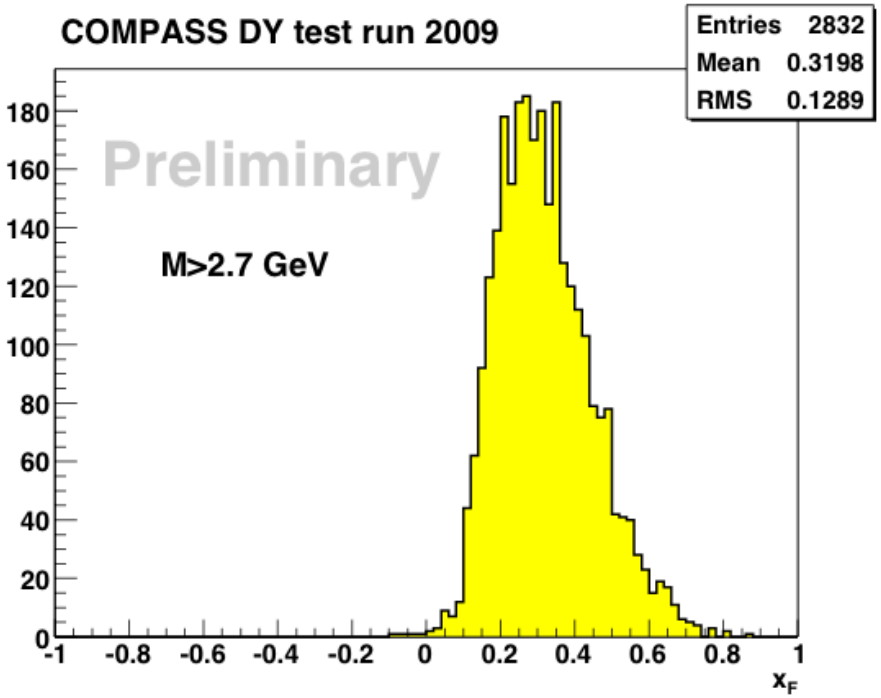




DY@COMPASS - feasibility – Kinematics II

q_T and x_F ranges





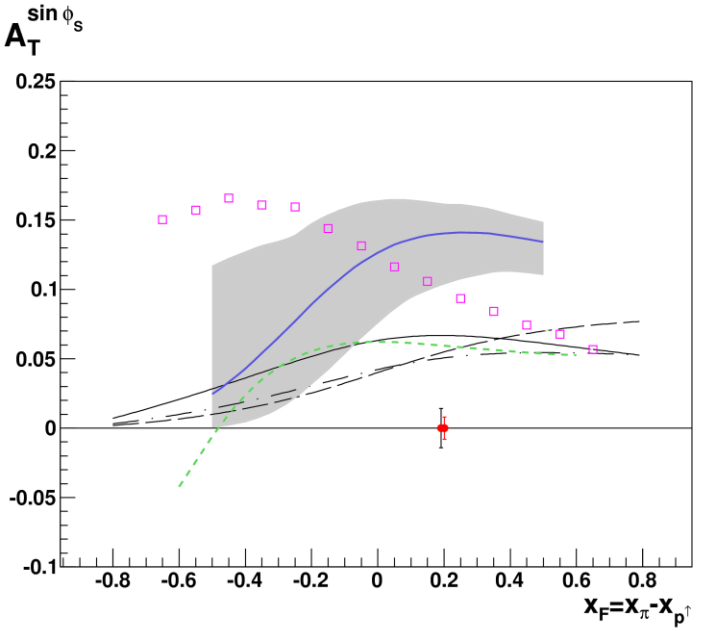
DY@COMPASS projections I

With a beam intensity $I_{beam} = 6 \times 10^7$ particles/second,
a luminosity of $L = 1.7 \times 10^{33}\ cm^{-2}s^{-1}$ can be obtained.

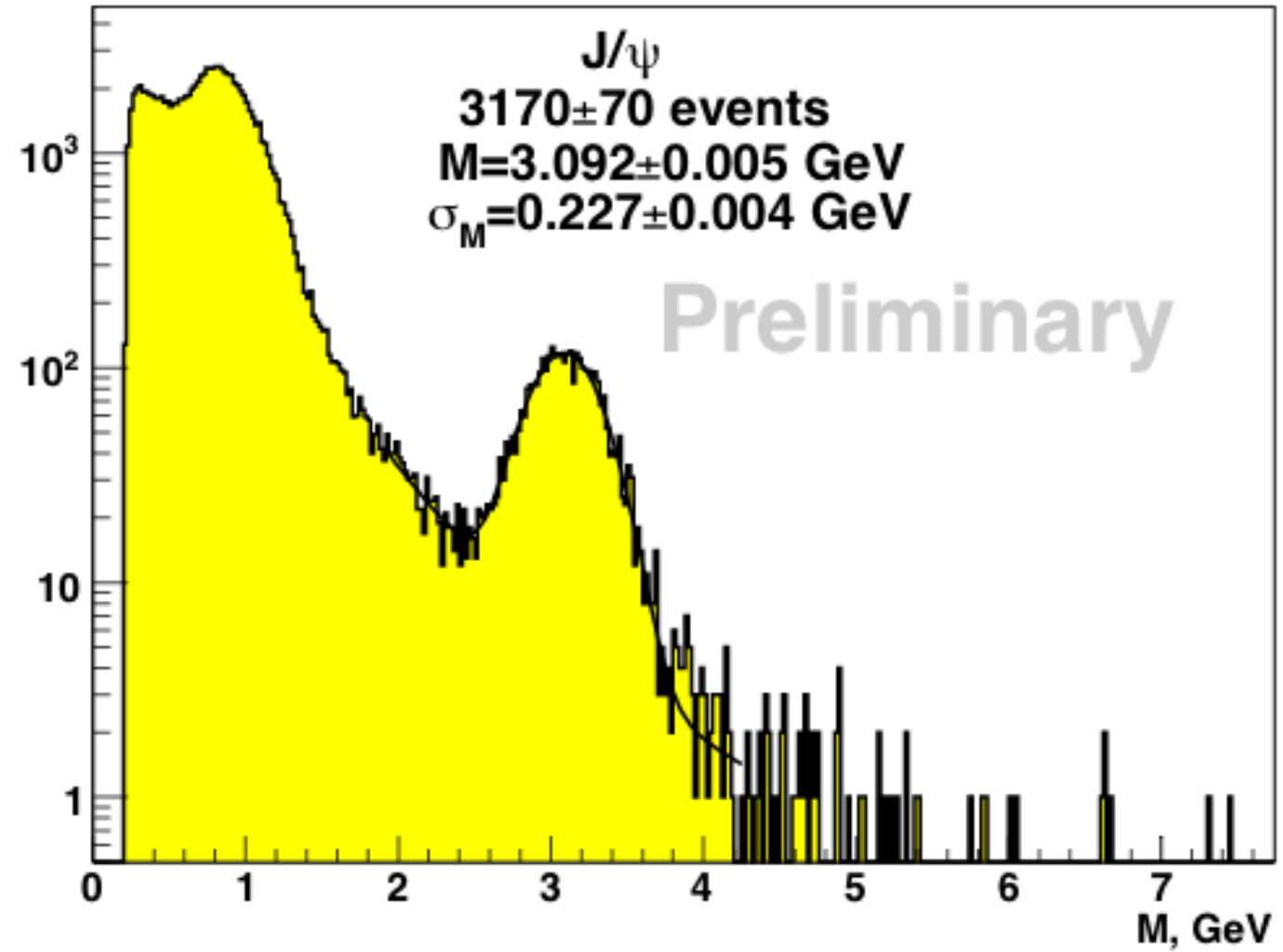
↪ Assuming 2 years of data-taking, one can collect > 200000 DY events in the region $4 < M_{\mu\mu} < 9.$ GeV/c^2.

Predictions for the Sivers asymmetry in the COMPASS phase-space, for the mass region $4. < M < 9.$ GeV/c^2, compared to the expected statistical errors of the measurement:

– solid and dashed: Efremov et al, PLB612(2005)233;
– dot-dashed: Collins et al, PRD73(2006)014021;
– solid, dot-dashed: Anselmino et al, PRD79(2009)054010;
– boxes: Bianconi et al, PRD73(2006)114002;
– short-dashed: Bacchetta et al, PRD78(2008)074010.

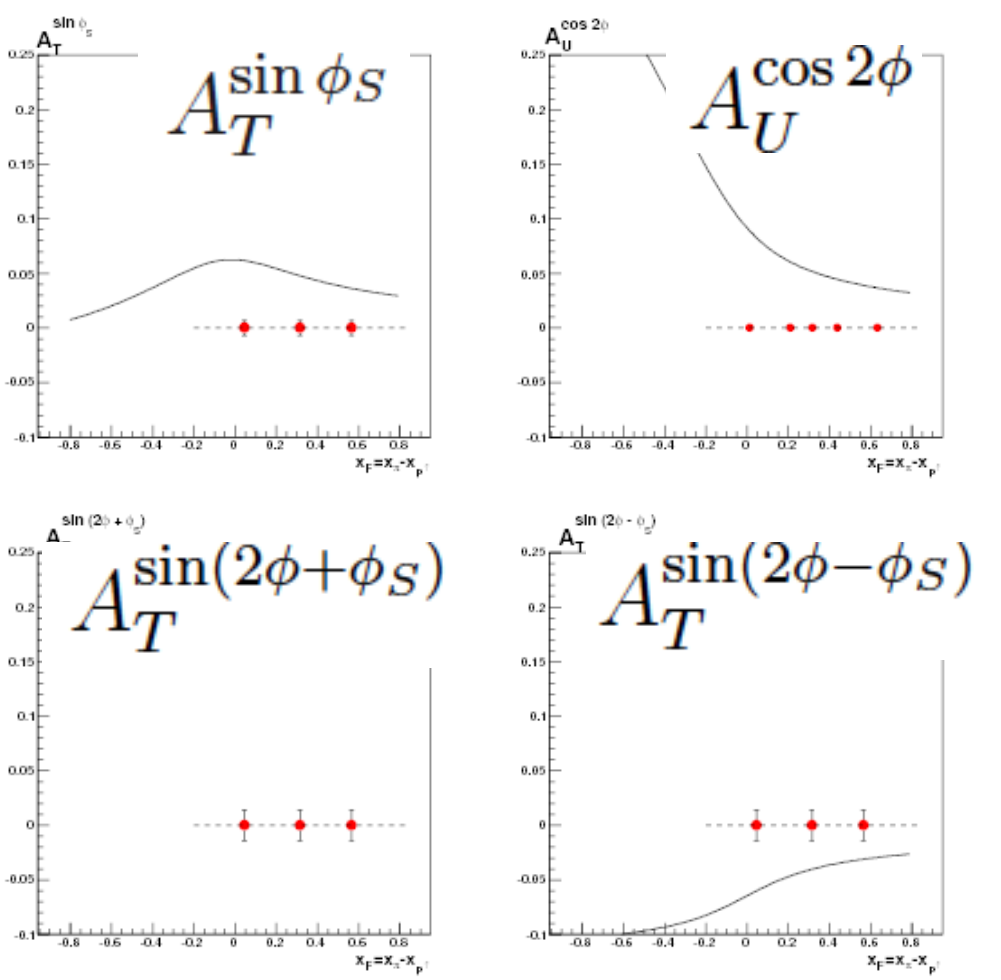


DY@COMPASS projections II



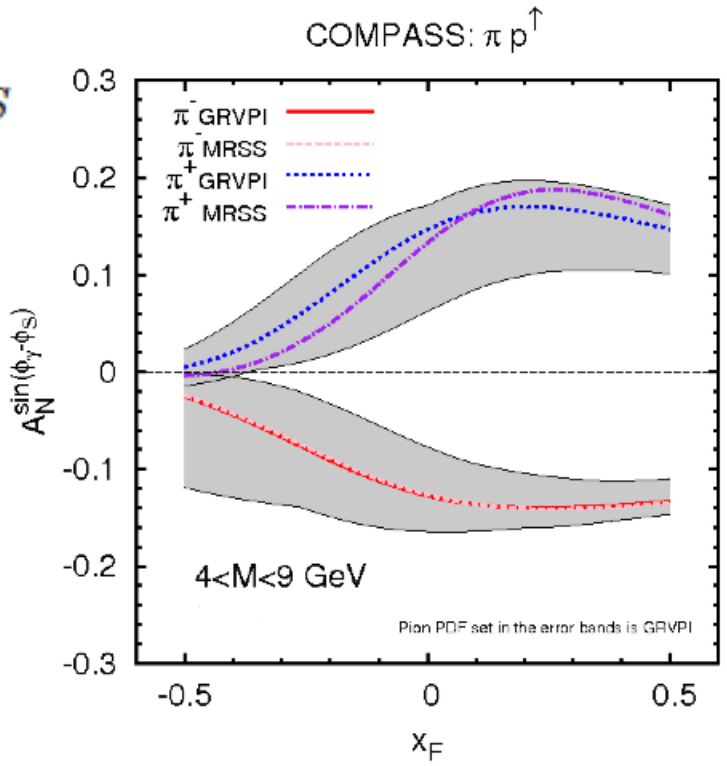
DY@COMPASS projections III

J/ψ region: $2.9 \leq M_{\mu\mu} \leq 3.2\ \mathrm{GeV/c^2}$



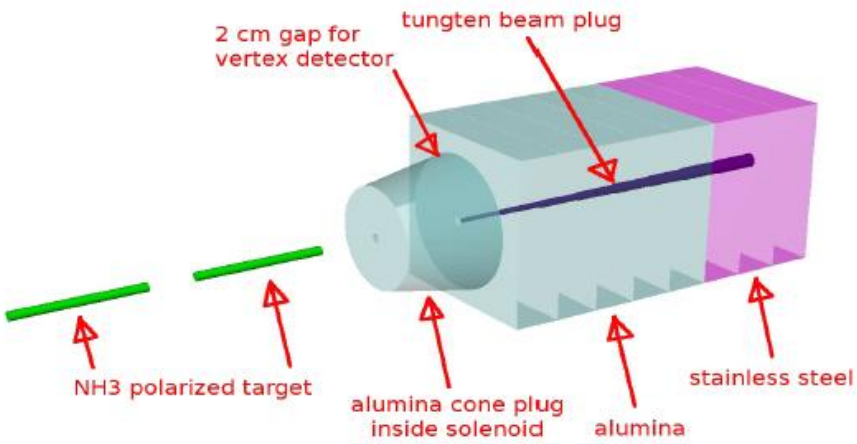
DY@COMPASS uncertainty coming from the pion PDFs

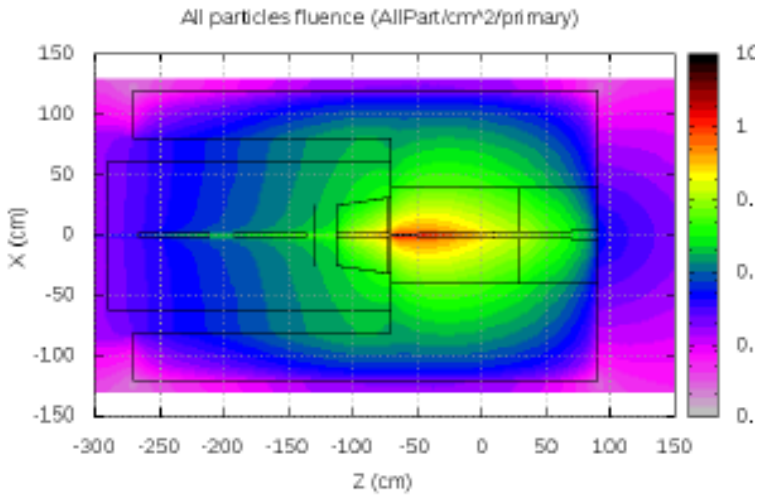
$A_T^{\sin\phi_S}$



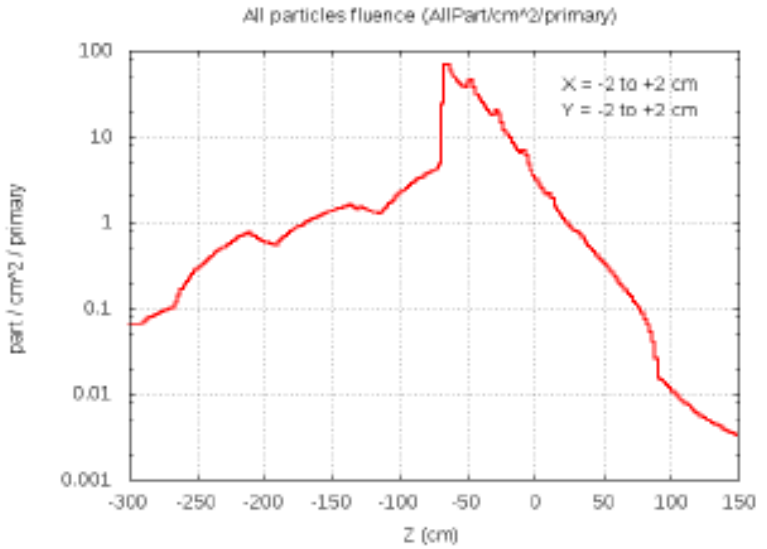
In case of $\pi^- p$ scattering the valence pion $\bar{u}$ unpolarised PDF is well known and there is no difference between two pdf sets. In case of $\pi^+ p$ scattering there is a little contamination coming from sea $\bar{u}$ of the pion, which annihilates with valence u quark of the proton, because the distribution functions are weighted in the cross section with e_q^2, and the $\bar{u}u$ contribution is multiplied by factor 4/9 while the $\bar{d}d$ by factor 1/9. Thus, the contribution from the sea $\bar{u}$ of the pion can not be neglected, it is less known with respect to valence PDFs and it explains the difference from one data set (GRVPI) to another (MRSS).

DY@COMPASS upgrades: Absorber





- The absorber geometry and composition is optimized taking into account the experience of past DY experiments
- The MC (FLUKA) simulation of the stopping power as well as particle fluxes downstream of the absorber is performed
- The recommendations on the RP shielding is worked out (cross-check by CERN RP group is in progress)



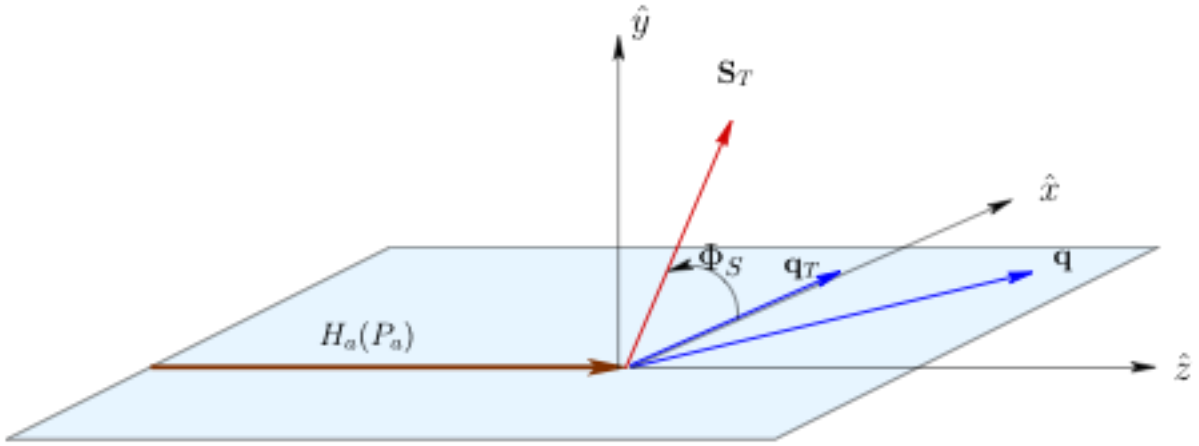
DT@COMPASS: Summary

- Can be first ever polarised Drell-Yan experiment, sensitive to TMD PDFs induced effects
- DY@COMPASS process dominated by the contribution from the valence quarks ($\tau = x_1 x_2 = Q^2/s \cong 0.05 \div 0.3$), it is pure u-dominance channel because of the π^- beam
- Physics program is broad (Daniel, Paul, Werner, Bernard….)
- Key measurement:
  - TMD PDF universality test SIDIS ←→ DY
  - T-odd TMD (Sivers and Boer-Mulders) sign change from SIDIS to DY – if sign change is not conformed for my QCD is 'useless'
- Now we can say (after the series of beam tests) that the feasibility is proven
- Statistical error on single spin asymmetries of 1÷2% can be achieved in two years of data taking (useful event yield is confirmed by the results of 2009 beam test)
- The proposal will be submitted by the end of May, if accepted we can hope for first DY exposition in 2013 or 2014.
- In case we successful the DY measurement with antiproton beam can be considered as a continuation of the program

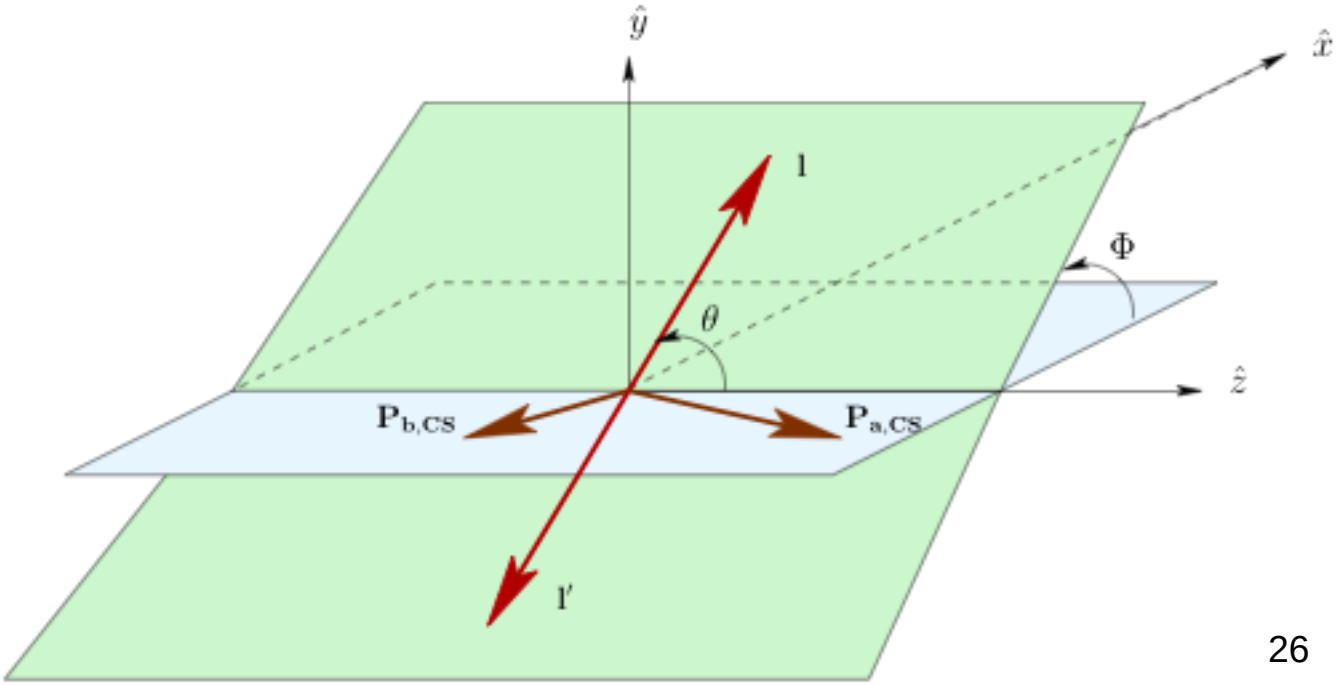
- Spares

Coordinate systems

TF



Collins-Soper



Drell-Yan Kinematics (transverse motion)

- If we consider the transverse motion of partons then:

$$p_a = \frac{\sqrt{s}}{2} x_a \left(1 + \frac{k_{\perp a}^2}{x_a^2 s}, \frac{2\boldsymbol{k}_{\perp a}}{x_a \sqrt{s}}, 1 + \frac{k_{\perp a}^2}{x_a^2 s}\right)$$

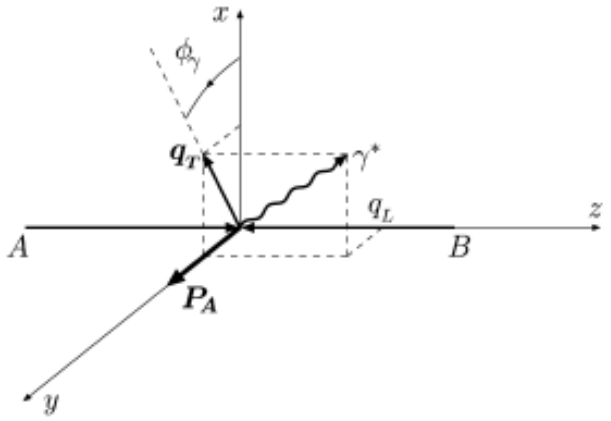
$$p_b = \frac{\sqrt{s}}{2} x_b \left(1 - \frac{k_{\perp b}^2}{x_b^2 s}, \frac{2\boldsymbol{k}_{\perp b}}{x_b \sqrt{s}}, -1 + \frac{k_{\perp b}^2}{x_b^2 s}\right)$$

- ... and the γ^* (dilepton) momentum has a transverse component in the h.c.m. frame

$$q = p_a + p_b = (q_0, \boldsymbol{q}_T, q_L)$$

$$\boldsymbol{q}_T = \boldsymbol{k}_{\perp a} + \boldsymbol{k}_{\perp b}$$

Only low q_T ($q_T^2 \ll q^2$)
have a non-perturbative origins



In other words is dominated by the contribution from TMD PDFs

Drell-Yan Workshop at CERN, April 26-27

Studying the hadron structure in Drell-Yan reactions

26-27 April 2010 *CERN*

- **Overview**
- Programme
- Registration
  - Registration Form
- List of registrants
- Laptop and Wireless access
- Access Cards
- Accomodation
- How to get to CERN

Support

Since a long time the Drell-Yan (DY) process is considered to be a powerful tool to study hadron structure. In the past, several experiments were successfully carried out using unpolarised beams and targets. Nowadays, taking into account the much advanced understanding of the spin structure of the nucleon, we are discussing a new generation of DY measurements using polarised beams and/or targets.

The COMPASS collaboration is currently preparing a proposal for future studies of nucleon structure beyond 2011. One of the main aims is a first measurement of transverse-momentum-dependent parton distributions (TMDs) using the Drell-Yan process on a transversely polarised proton target hit by a pion beam. Among the distributions to be studied are Sivers, Boer-Mulders and pretzelosity TMDs as well as transversely polarised quark distributions.

The workshop will review ongoing theoretical and experimental efforts related to the Drell-Yan process. Detailed presentations and discussions of the theoretical aspects will be complemented by descriptions of planned fixed-target and collider experiments.

Organizers: Paula Bordalo (LIP-Lisbon and IST/UTL)
Oleg Denisov (CERN/INFN-Torino)
Eva-Maria Kabuss (Mainz)
Fabienne Kunne (CEA Saclay)
Alain Magnon (CEA Saclay)
Gerhard Mallot (CERN)
Anna Martin (Univ. Trieste and INFN-Trieste)
Wolf-Dieter Nowak (CERN)
Daniele Panzieri (Univ. Alessandria and INFN-Torino)

Dates: from 26 April 2010 09:00 to 27 April 2010 18:00

Location: *CERN*
Salle Andersson
Room: 40-S2-A01

Drell-Yan Workshop at CERN, April 26-27

Monday 26 April 2010

09:00 - 09:05	Welcome *05'* (CERN (40-2-A01)
09:05 - 09:35	Theory Overview *30'* Speakers: Daniel Boer
09:35 - 09:45	Discussion *10'*
09:45 - 10:15	Experiment overview *30'* Speakers: Paul Reimer
10:15 - 10:25	Discussion *10'*
10:25 - 10:55	QCD corrections for the DY process *30'* Speakers: Werner Vogelsang
10:55 - 11:10	Discussion *15'*
11:10 - 11:30	Coffee Break
11:30 - 12:00	General form of the DY cross-section *30'* Speakers: Marc Schlegel
12:00 - 12:15	Discussion *15'*
12:15 - 12:45	Single transversely polarised DY, observables, TMDs *30'* Speakers: Aram Kotzinian
12:45 - 13:00	Discussion *15'*
13:00 - 14:30	Lunch Break
14:30 - 15:00	TMD universality, factorization and sign change SIDIS-DY *30'* Speakers: Alessandro Bacchetta
15:00 - 15:15	Discussion *15'*
15:15 - 15:45	TMD phenomenology in SIDIS and DY *30'* Speakers: Stefano Melis
15:45 - 16:00	Discussion *15'*
16:00 - 16:30	Coffee Break
16:30 - 18:00	Theory - round table (topics: key issues in DY measurements, models, predictions,

Drell-Yan Workshop at CERN, April 26-27

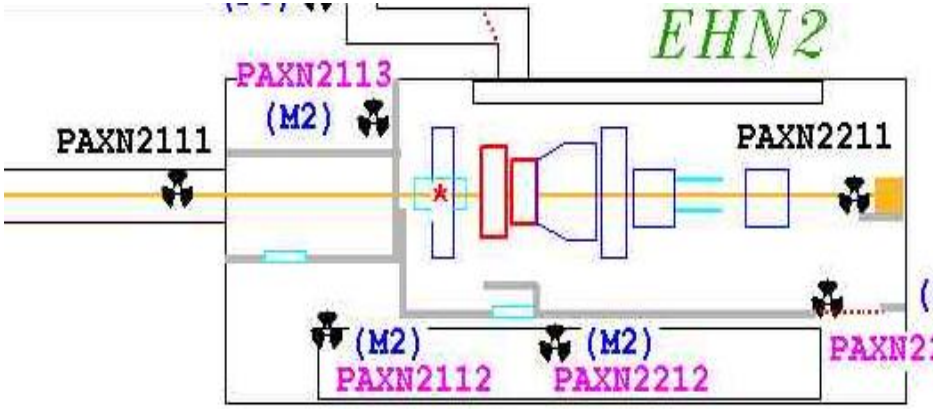
exclusive DY, GPDs) *1h30'*
Speakers: Oleg Teryaev, Marco Radici

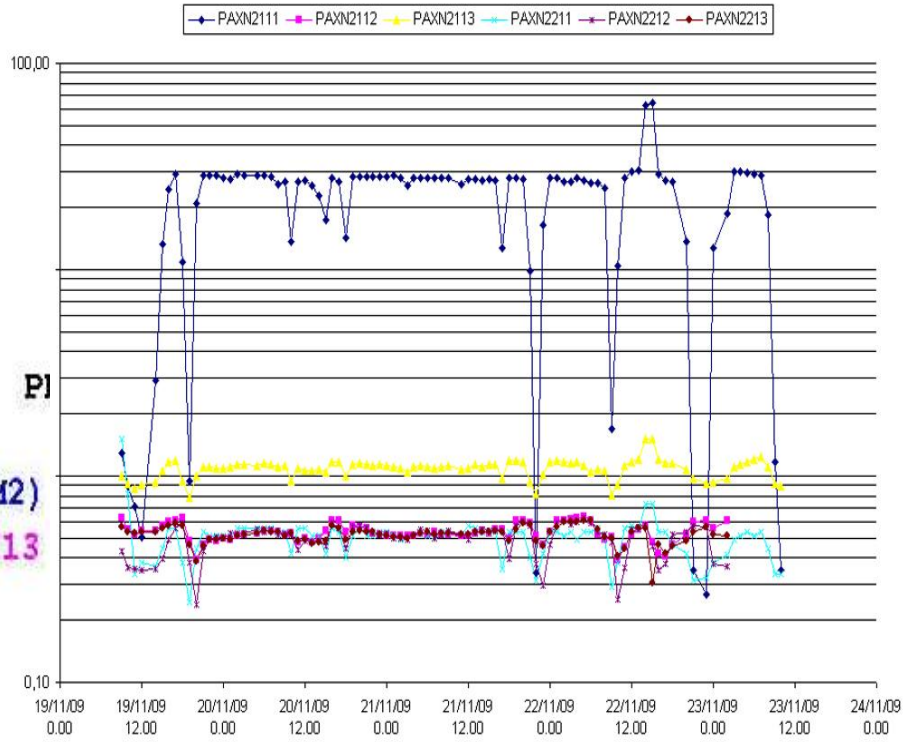
Tuesday 27 April 2010

09:00 - 09:20	Future Drell-Yan fixed target experiments at Fermilab *20'* Speakers: Wolfgang Lorenzon
09:20 - 09:30	Discussion *10'*
09:30 - 09:50	Future Drell-Yan collider experiments *20'* Speakers: Matthias Grosse Perdekamp
09:50 - 10:00	Discussion *10'*
10:00 - 10:20	Future Drell-Yan experiments at J-Parc and at RHIC (internal target) *20'* Speakers: Yuji Goto
10:20 - 10:30	Discussion *10'*
10:30 - 11:00	Coffee Break
11:00 - 11:20	Future Drell-Yan experiments at GSI *20'* Speakers: Paolo Lenisa
11:20 - 11:30	Discussion *10'*
11:30 - 11:50	Future Drell-Yan program at NICA *20'* Speakers: Alexander Nagaytsev
11:50 - 12:00	Discussion *10'*
12:00 - 12:20	Future COMPASS Drell-Yan experiment *20'* Speakers: N.N.
12:20 - 12:30	Discussion *10'*
12:30 - 13:00	Concluding remarks *30'* Speakers: Mauro Anselmino
13:00 - 14:30	Lunch break
14:30 - 17:00	Visit to the COMPASS experiment (optional) Location: COMPASS Experiment (Prevessin Site 888)

DY@COMPASS - feasibility - RP

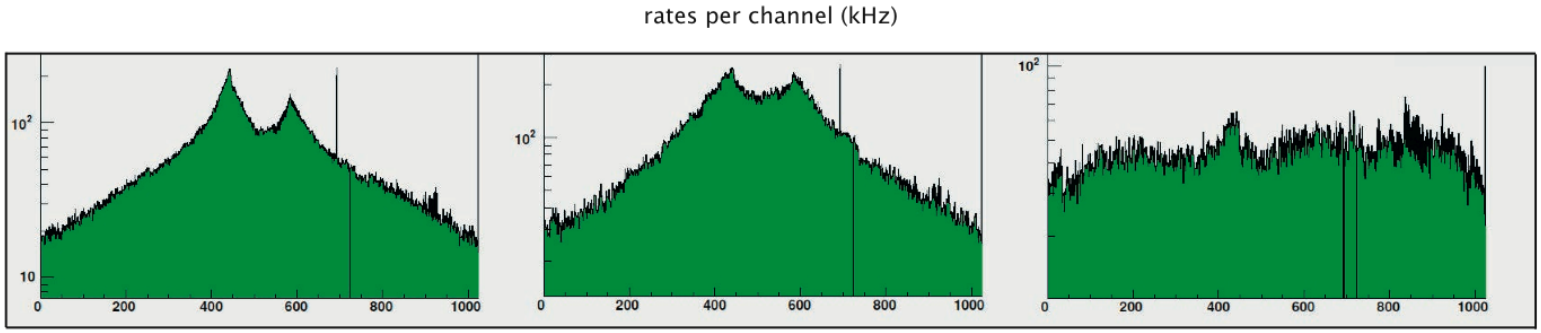
- Very important 2009 beam test
- At 1.5x10^8 /spill stays below 0.5 uSv (allowed 3 uSv)
- Conclusion by CERN RP group – well under control





DY@COMPASS - feasibility - occupancies

- Very important 2009 beam test
- Occupancies are ~ factor 10 lower with respect to standard muon or hadron spectroscopy running



DY@COMPASS - feasibility - trigger

- Very important 2009 beam test
- Sort of muon trigger was implemented in LAS based on HCal1
- Trigger rate < 50 kEvents/spill

Controller Status: okay ?

onSpill: 0 Spill: 6 Triggers: 248745

Prescaler Status: okay ?

num	name	div	attempts	triggers	MTi/attempts
0	LTi	1	41400	41400	1.77
1	MT+HCAL1m	1	328	328	222.87
2	LT+HCAL1m	1	608	608	120.23
3	OT+HCAL1m	1	175	175	417.73
4	HCAL2m	1	55187	55187	1.32
5	VetoInner	1000	1545636	1546	0.05
6	Halo	500	337107	675	0.22
7	BeamT	1000	52180988	52181	0.00
8	MTi	1	73102	73102	1.00
9	HCAL1m	10	697729	69773	0.10
10	OTi	1	1910	1910	38.27
11	TRand	100	307974	3080	0.24
deadtime not available				299965	----

Deadtime: 2_10_250 v plot

Controller Status: okay ?

onSpill: 0 Spill: 0 Triggers: 0

Prescaler Status: okay ?

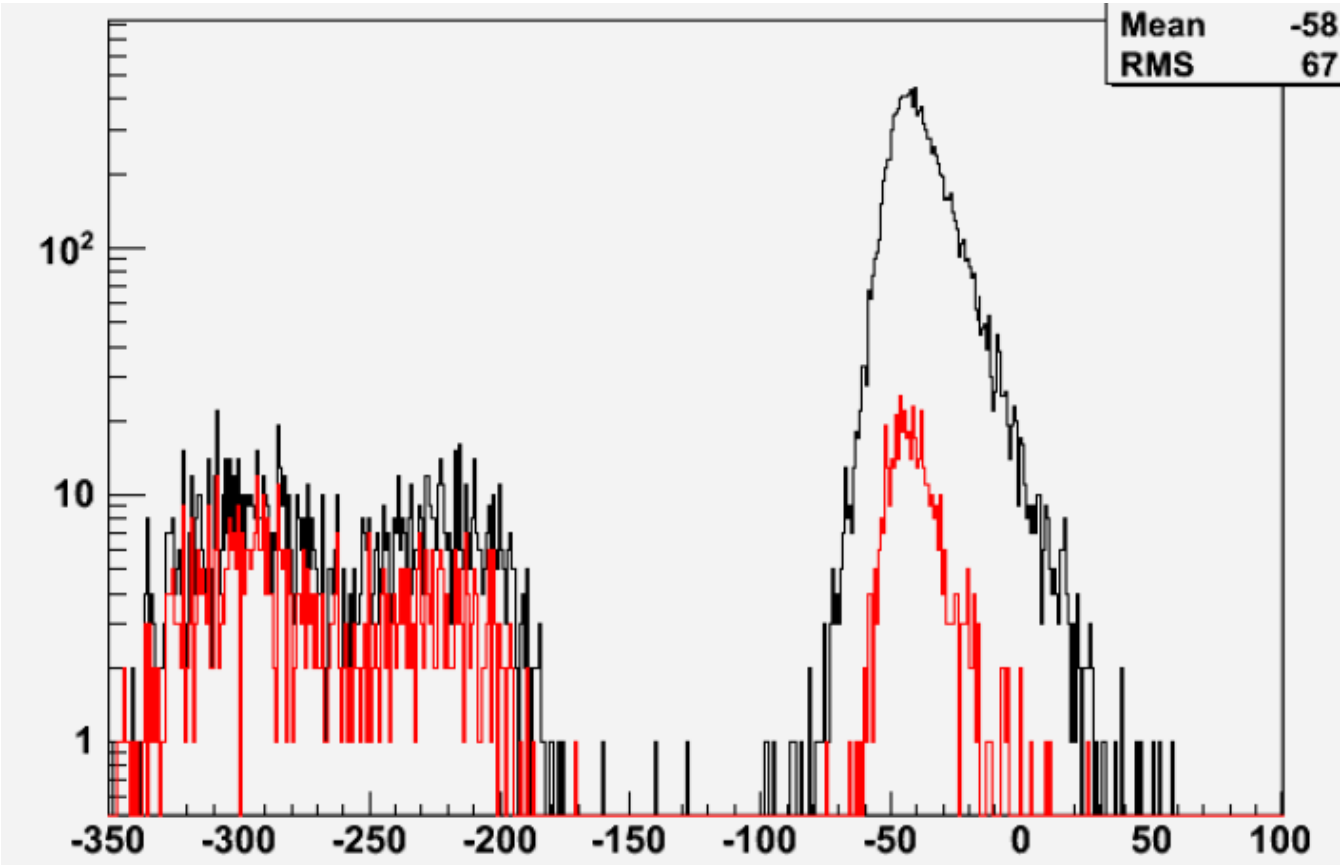
num	name	div	attempts	triggers	MTi/attempts
0	LTi	1	69885	69885	1.79
1	MT+HCAL1m	1	836	836	149.36
2	LT+HCAL1m	1	1333	1333	93.67
3	OT+HCAL1m	1	354	354	352.73
4	HCAL2m	1	98873	98873	1.26
5	VetoInner	1000	2806971	2807	0.04
6	Halo	500	663445	1327	0.19
7	BeamT	10000	71812665	7182	0.00
8	MTi	1	124867	124867	1.00
9	HCAL1m	100	1091782	10918	0.11
10	OTi	1	3398	3398	36.75
11	TRand	100	307851	3079	0.41
deadtime not available				324859	----

Deadtime: 2_10_250 v plot

UPGRADES:
DY@COMPASS upgrades: Trigger

Mass Range GeV	Global acceptance %	LAS	LAS+SAS	SAS
$4-9$	35	64	40	4
$2-2.5$	43	32	54	20

Table 2: Global and partial acceptance of the spectrometer for dimuons belonging to two mass ranges .



Competition and complementarity

Facility		Type	s (GeV^2)	Timeline
RHIC (STAR)	[134]	collider, $p^{\Uparrow}p$	200^2	> 2013
E906 (Fermilab)	[135]	fixed target, pp,	250	> 2011
J-PARC	[136]	fixed target, $pp^{\Uparrow}$, $\pi p^{\Uparrow}$	$60 \div 100$	> 2015
GSI (PAX)	[137]	collider, $\overline{p}^{\Uparrow}p^{\Uparrow}$	200	> 2017
GSI (Panda)	[138]	fixed target, $\overline{p}p$	30	> 2016
NICA	[139]	collider, $p^{\Uparrow}p^{\Uparrow}$, $d^{\Uparrow}d^{\Uparrow}$	676	> 2014
COMPASS	(this letter)	fixed target, $\pi^- p^{\Uparrow}$	300÷400	> 2012

Table 10: Future Drell–Yan experiments.

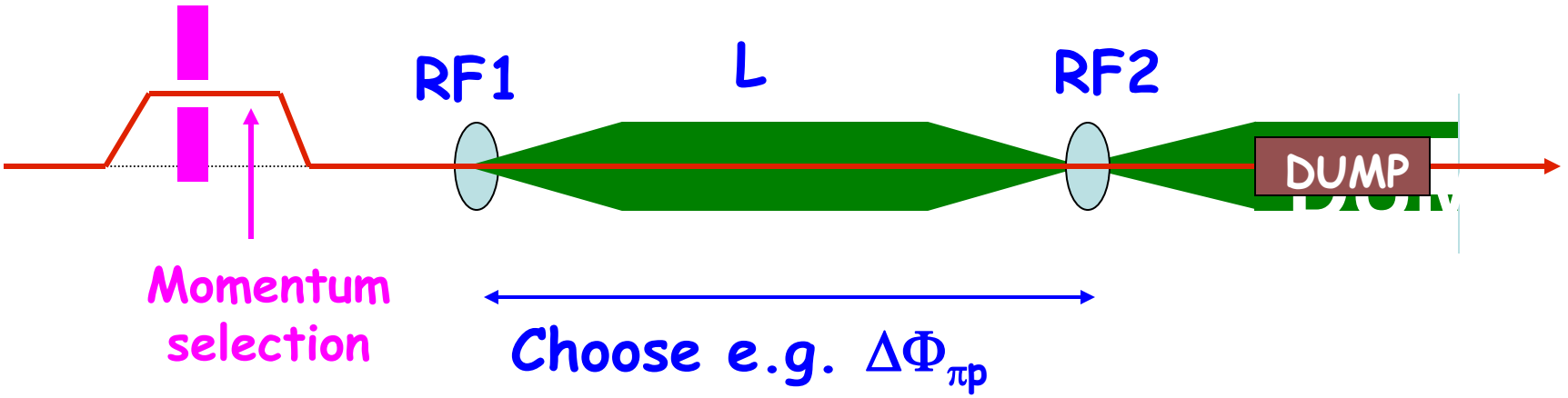
DY@COMPASS upgrades: beam telescope and additional tracking station downstream of PT

- Beam telescope upstream of the COMPASS PT
  - Radiation hardness (beam intensity ~ 6×10^7 s^{-1}), 280 days in total
  - Good time resolution (~ few ns)
  - Moderate space resolution (50-100 um)
- Most probable, the additional tracking station will help to vertex resolution, further MC required. NA50 experience is not positive, but with ~ 10 higher intensity
- The issue will be discussed on one of the forthcoming TB meetings

WHAT ABOUT A RF SEPARATED pbar BEAM ???

First and very preliminary thoughts, guided by
- recent studies for P326
- CKM studies by J.Doornbos/TRIUMF, e.g. http://trshare.triumf.ca/~trjd/rfbeam.ps.gz

E.g. a system with two cavities:



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