COMPASS II : COMPASS Future Programs

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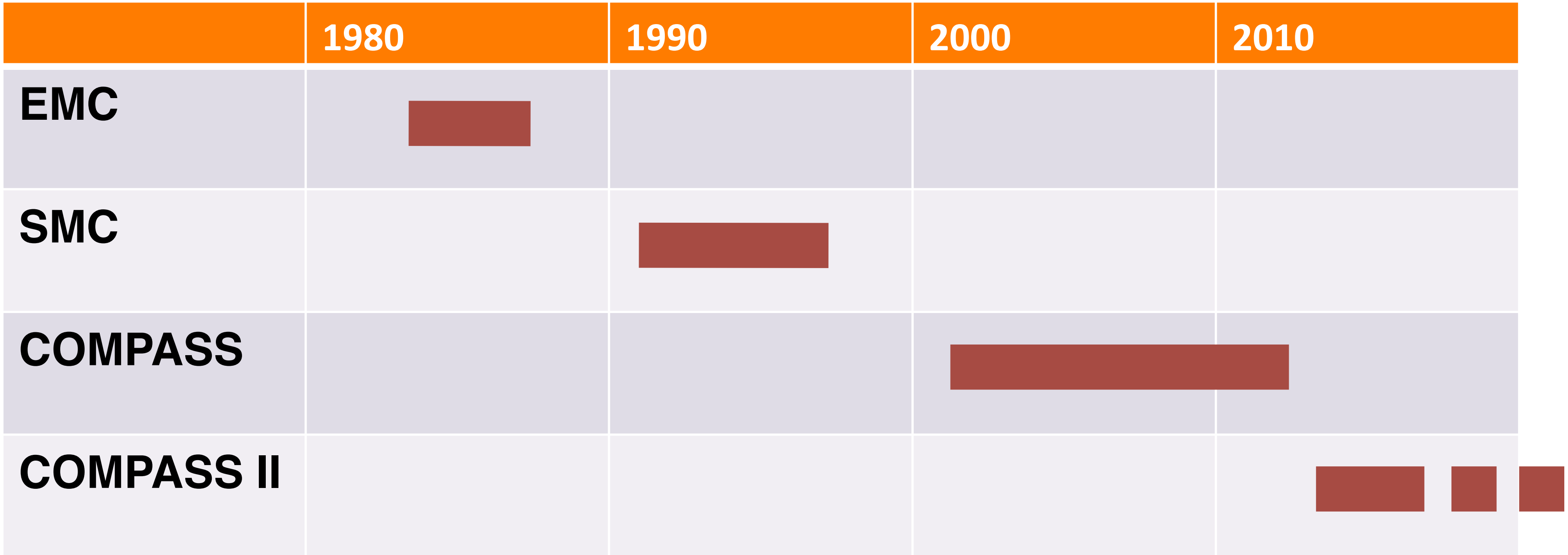
8th Circum-Pan-Pacific Symposium on High Energy Spin Physics: PacSPIN2011

June 20-24, 2011 in Cairns, QLD, Australia

Experiments on nucleon spin research at CERN

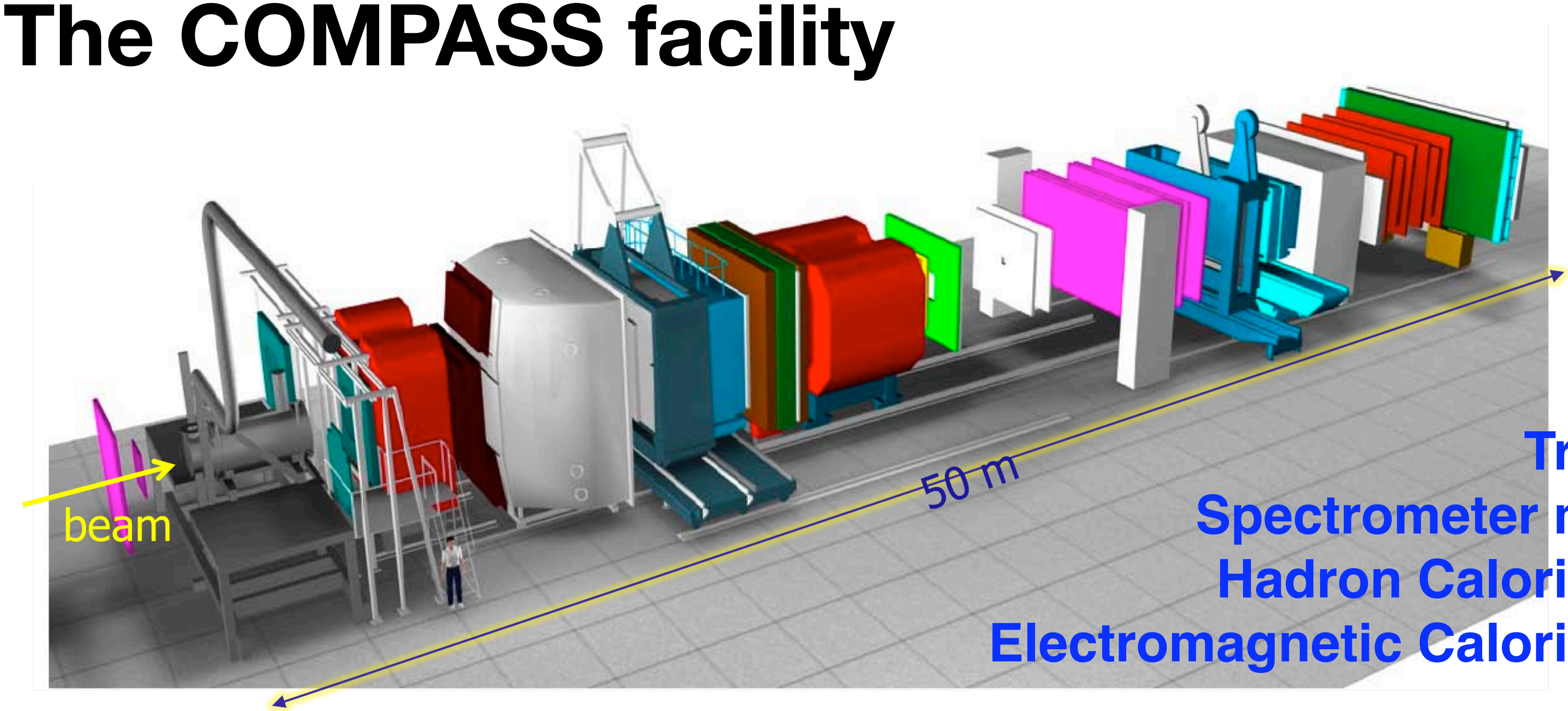


- COMPASS provides results of
  g1(x), ΔG/G, Flavor separation (Δs(x)), $f_{1T}^{\perp}(x), h_1(x)$,…….

  ➡ See the talks of Takahiro Iwata and Celso Franco

- COMPASS II was approved by CERN Research Board in 2010.

The COMPASS facility



Trackers
Spectrometer magnet
Hadron Calorimeters
Electromagnetic Calorimeters

Beam :

Polarized lepton beam : μ^+, μ^- 50-280 GeV/c (80% polarization @ 160GeV)
Hadrom beam : π^+,π, K^+, K^-,P

Target :

Polarized proton and deuteron target
Liquid hydrogen target
Thin nucleus target

Many combinations of the beam & the target

New programs (COMPASS II)

approved by CERN Research Board in 2010

- Polarized Drell-Yan measurement

  TMD PDFs — *π^- beam with polarized proton target*

- GPD measurement

  Transverse imaging — *μ^+ μ^- beam with liquid hydrogen target*

- Pion and Kaon polarizability

  Chiral perturbation theory — *π^-, K^- (μ^-) beam with nucleus target*

With a upgraded COMPASS spectrometer

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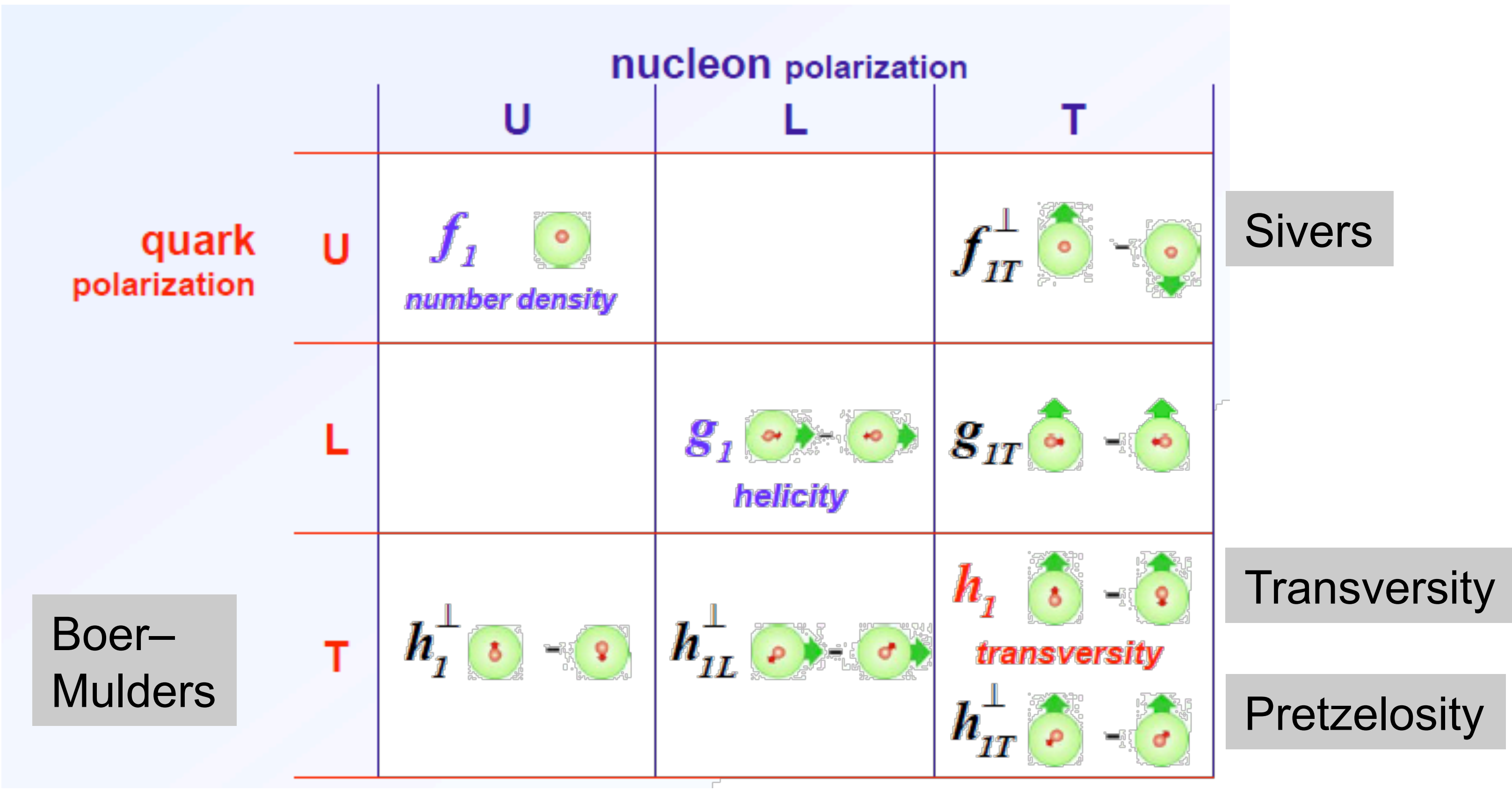
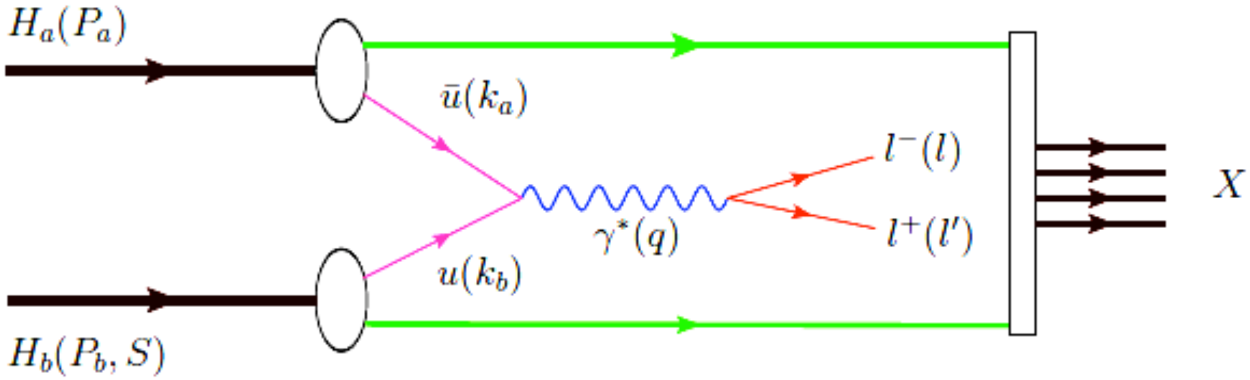
With a upgraded COMPASS spectrometer

TMD parton distributions

- 8 intrinsic transverse momentum dependent PDFs at LO
- Asymmetries with different angular dependences on hadron and spin azimuthal angles, Φ_h and Φ_s



Drell-Yan process and its angular distribution



$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi(\lambda+3)}\left[1+\lambda\cos^2\theta+\mu\sin 2\theta\cos\phi+\frac{\nu}{2}\sin^2\theta\cos 2\phi\right]$$

- The collinearity hypothesis would imply λ=1 and μ=ν=0.

- NA10 (CERN) and E615 (Fermlab)

  ➡ modulation of cos2ϕ up to 30%

- Intrinsic transverse momentum k_T of quarks inside hadron

  ➡ 2 Boer-Mulders PDFs interaction
  Between target and beam quarks

Single polarized Drell-Yan cross section

The LO expansion of the single polarized Drell-Yan cross section is

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

- $A_U^{\cos 2\phi} : (BM)_\pi \otimes (BM)_P$
- $A_T^{\sin\phi_S} : (f_1)_\pi \otimes (Sivers)_P$
- $A_T^{\sin(2\phi+\phi_S)} : (BM)_\pi \otimes (\mathrm{Pr}etz.)_P$
- $A_T^{\sin(2\phi-\phi_S)} : (BM)_\pi \otimes (Trans.)_P$

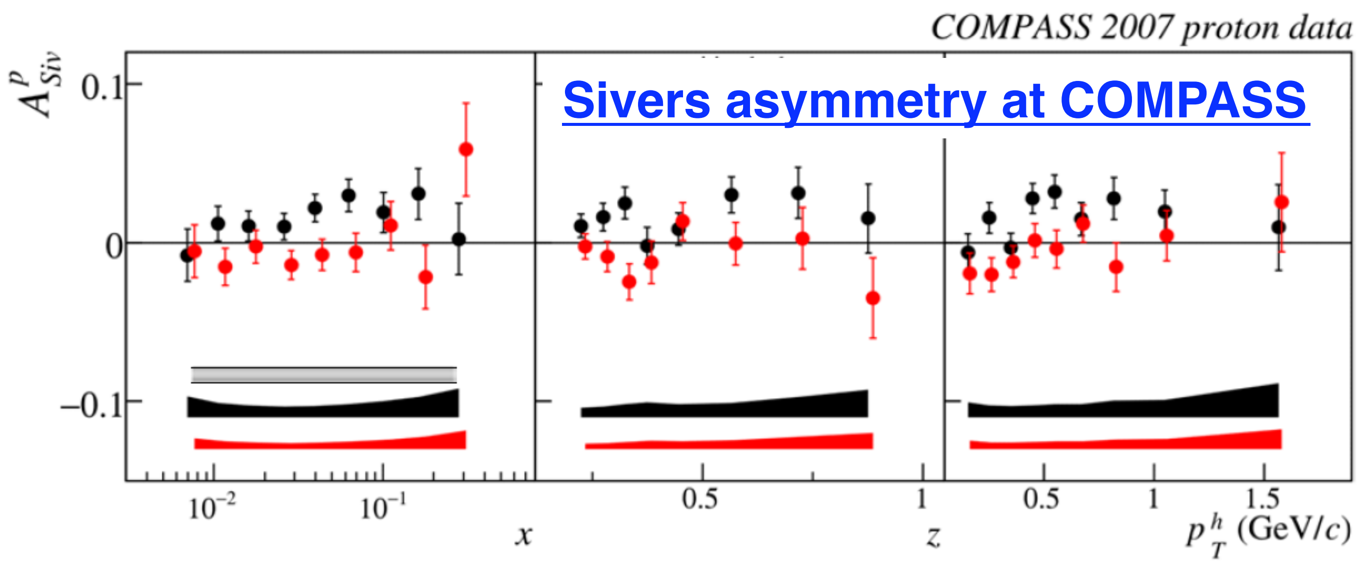
A : azimuthal asymmetries :: convolution of 2 PDFs
D : depolarization factor
S : target spin component
$\hat{\sigma}_U$: part of the cross-section surviving integration over ϕ and ϕ_s
F : $4\sqrt{(P_a \cdot P_b)^2 - M_a^2 M_b^2}$

Universality of TMD PDFs

Because Sivers and Boer-Mulders PDFs are "Time-reversal odd", they are expected to change the sign when measured from SIDIS or from DY:

$$f_{1T}^{\perp}\Big|_{DY} = -f_{1T}^{\perp}\Big|_{SIDIS} \qquad h_1^{\perp}\Big|_{DY} = -h_1^{\perp}\Big|_{SIDIS}$$

We have the opportunity to test this sign change using the same Spectrometer and the transversely polarized target at COMPASS.

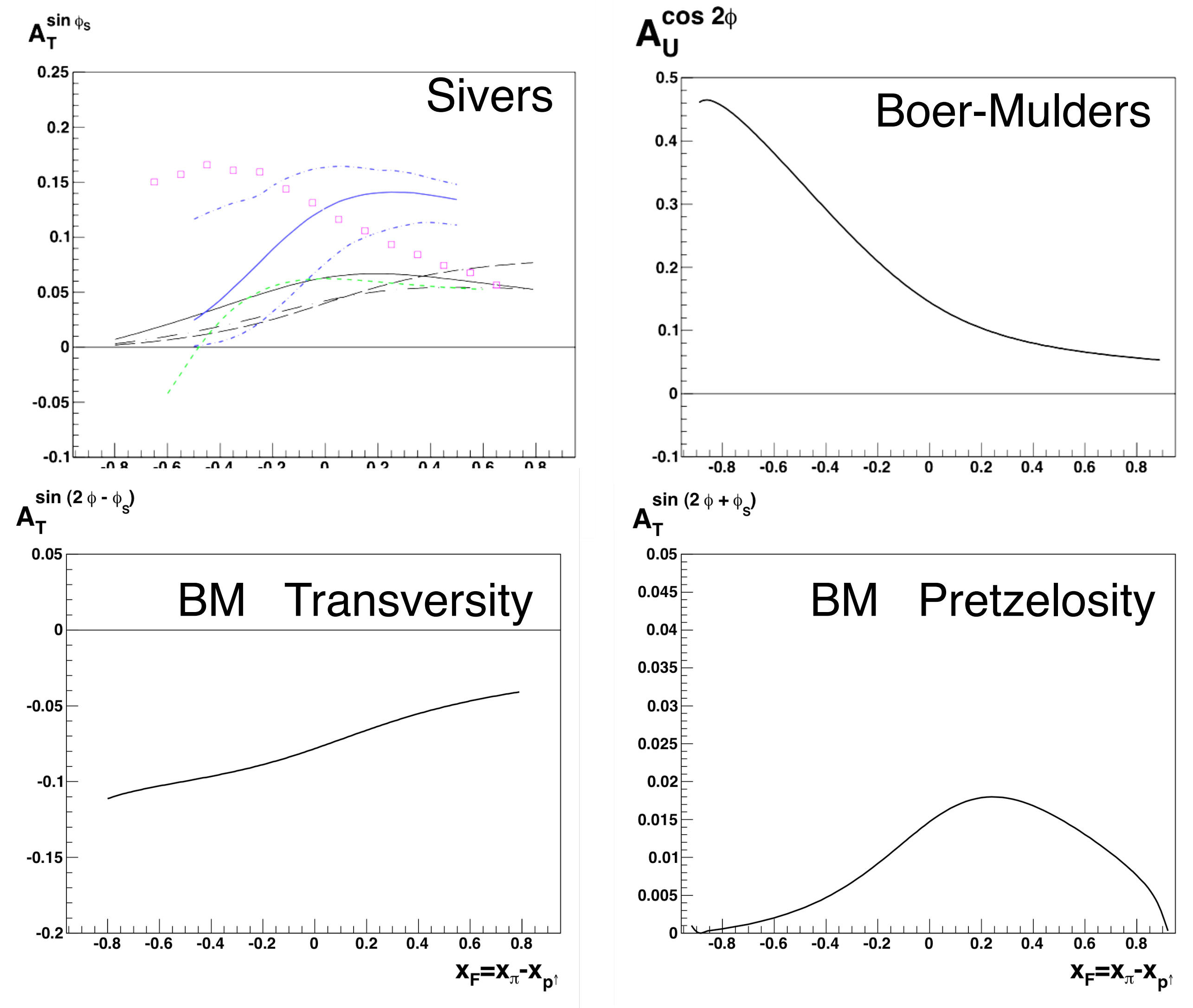


PLB692(2010)240

Positive hadron
Negative hadron

Theory predictions

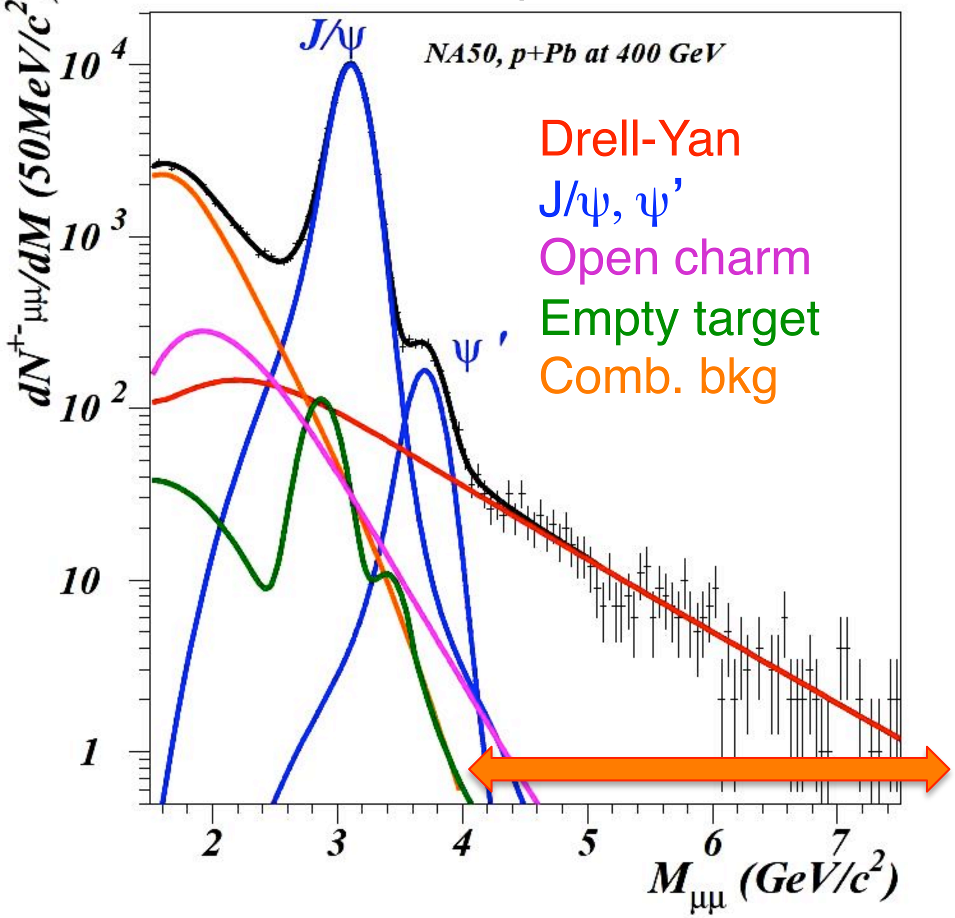
DY 4.0 – 9.0 GeV/c2 in the COMPASS Setup



PLB612(2005)233,
PRD73(2006)014021,
PRD79(2009)054010,
PRD(2006)114002,
PRD78(2008)074010,
PRD77(2008)054011,
PPN41(2010)64

Signal and background

Dimuon mass spectrum (NA50)



<u>2 backgrounds sources</u>

- Physics background
  D, $\bar{D}$ and J/ψ decays to $\mu^+\mu^- X$

- Combinatorial background
  π and K decaying to $\mu\nu$

Better region to study Drell-Yan is 4 < M GeV/c².

Event rates and statistical accuracy

Luminosity 1.2 x 10^{32} $cm^{-2}s^{-1}$ (Beam intensity : 6 x 10^7 pions/s)

➡ 800 DY events per day with $4 < M < 9$ GeV/c^2

Assuming 2 years of data taking (280 days)

➡ 230k events in $4 < M < 9$ GeV/c^2 region

This will translate into the statistical errors of the asymmetries.

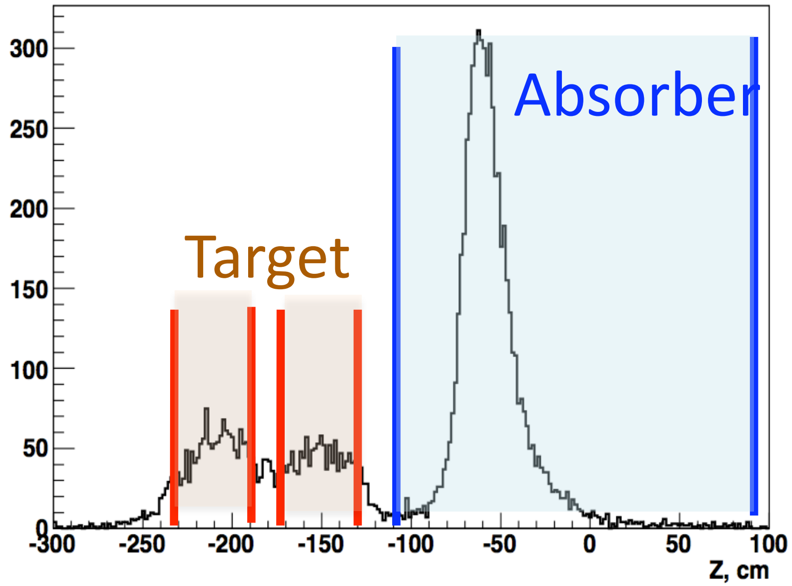
Asymmetry	Dimuon mass (GeV/c^2)		
	$2 < M_{\mu\mu} < 2.5$	J/ψ region	$4 < M_{\mu\mu} < 9$
$\delta A_U^{\cos 2\phi}$	0.0020	0.0013	0.0045
$\delta A_T^{\sin \phi_S}$	0.0062	0.0040	0.0142
$\delta A_T^{\sin(2\phi+\phi_S)}$	0.0123	0.008	0.0285
$\delta A_T^{\sin(2\phi-\phi_S)}$	0.0123	0.008	0.0285

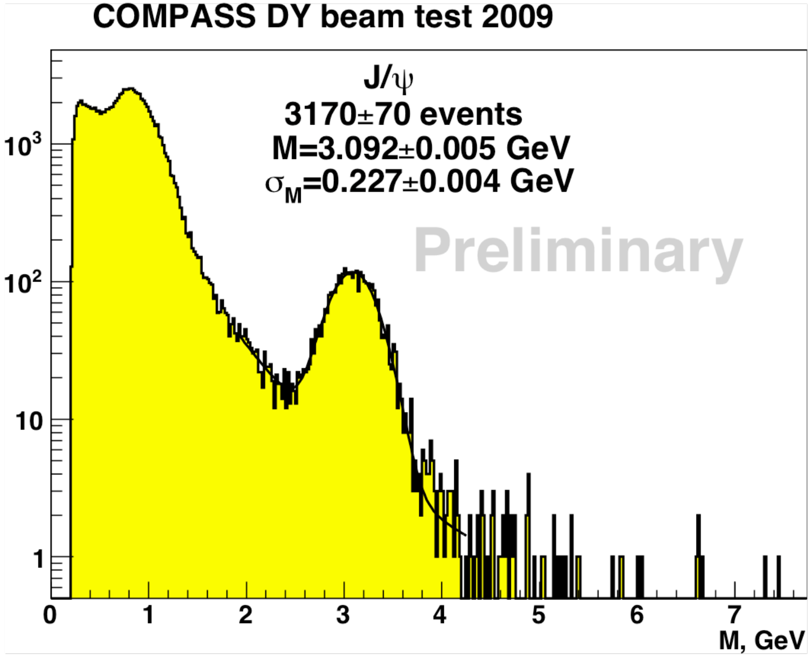
Possibility to study the asymmetries in the several x_F bins.

Beam test in 2009

190 GeV π^- beam + CH_2(40cm+40cm) target
3 days data taking

Vertex distribution in beam axis
(M > 2 GeV/c^2)





- The 2 target cells and the absorber can be distinguished.
- The mass resolution is expected.
- The absorber reduced combinatorial background by a factor about 10 at M = 2 GeV.

COMPASS polarized solid target system

Large acceptance COMPASS Magnet

Transverse polarization

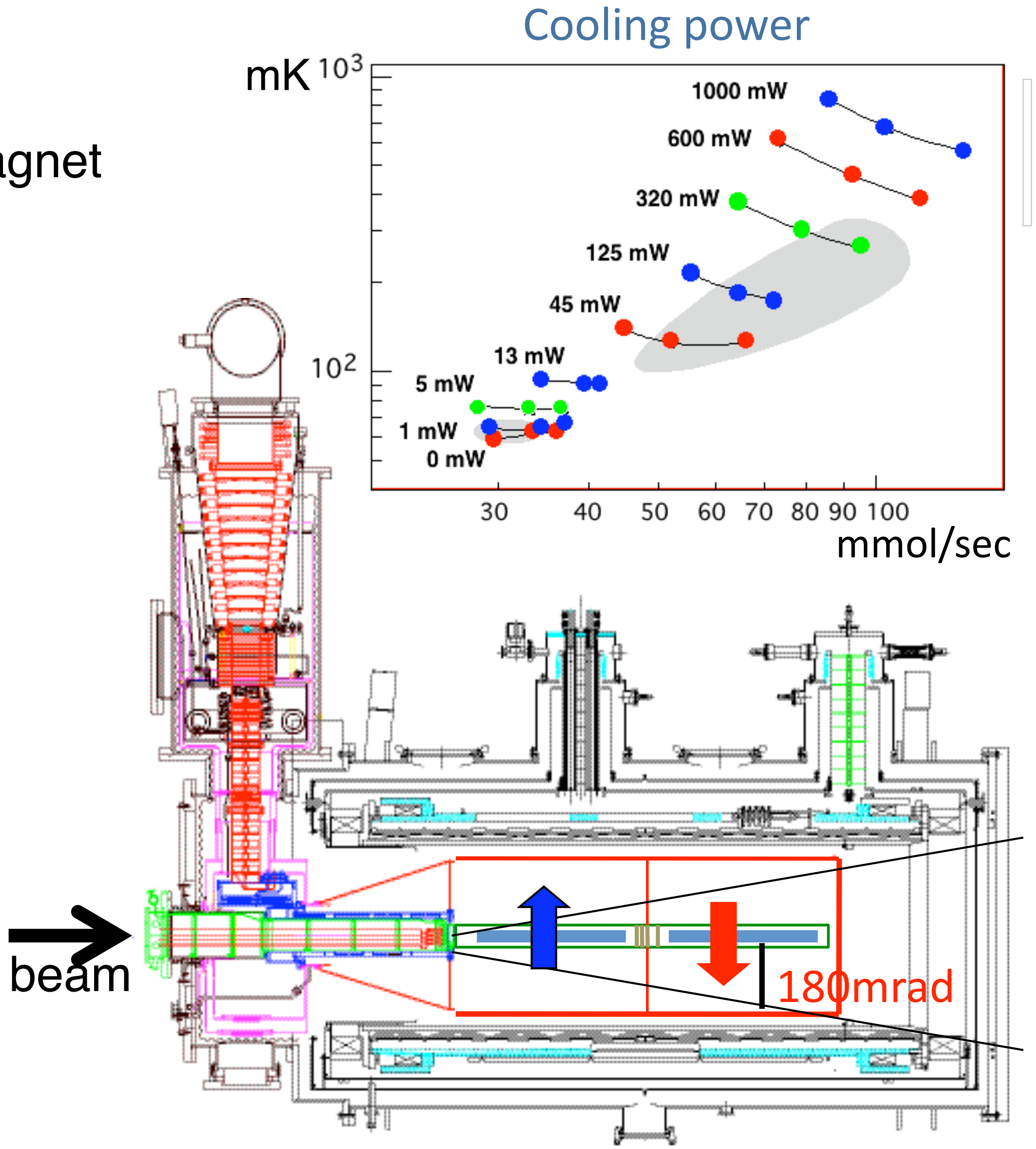
- Frozen spin target at 0.6 T dipole magnet
  (after polarizing at 2.5 T solenoid)

Cooling power

- Many secondly particles
  – nuclear interaction
- 2 mW heat input expected
  with 6 x 10^7 pions/s
- 5 mW cooling power at 70mK

Target cell

- Target area: 130 cm long
  with < ±30 ppm
- 2 cells (55, 55 cm long)
  20 cm gap



Proton target materials

Figure of Merit

$$PT_{FoM} = f^2 \times P_T{}^2 \times \rho \times F_f$$

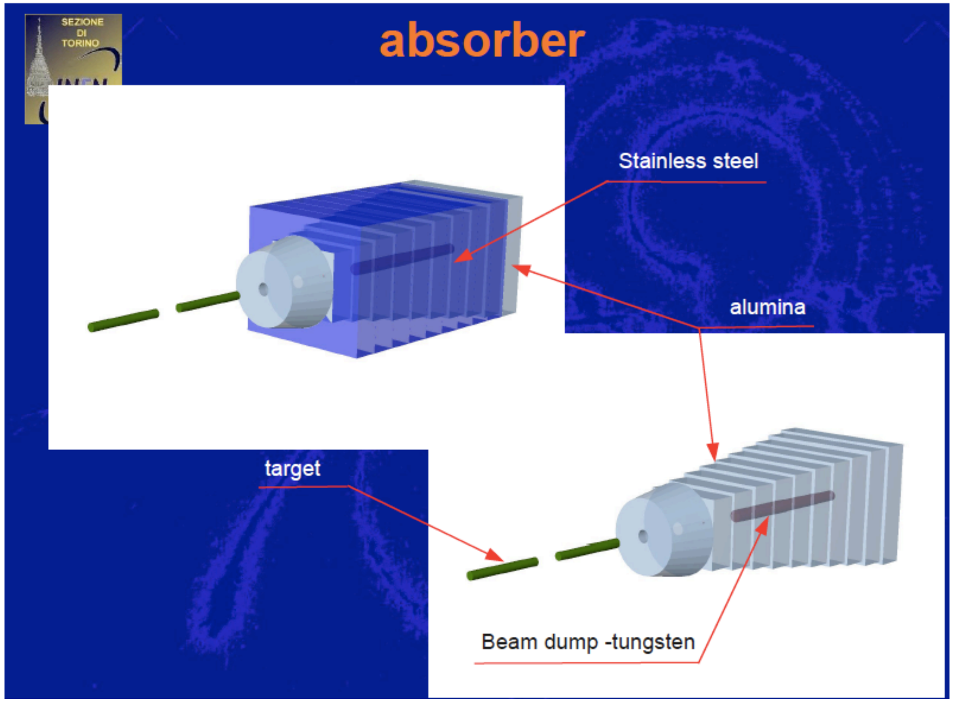
f : dilution factor
ρ : density
F_f : packing factor

	H-butanol	NH_3	^7LiH
P_T	0.90	0.90	0.56 (H) * 0.38 (^{7}Li)
ρ	0.985	0.853	0.820
f	0.135	0.176	0.125 (H) 0.125 (^{7}Li)
F_f	0.62	0.50	0.55
PT_{FoM}	1	1.2	0.7

-Normalized by H-butanol
-Magnetic field 2.5T
- Relaxation time NH_3 4000h at 60 mK and 0.6T
- If ^{7}LiH reach 90%, PT_{FoM} is 2.1.

* J. Ball, NIM. A 526 (2004) 7.

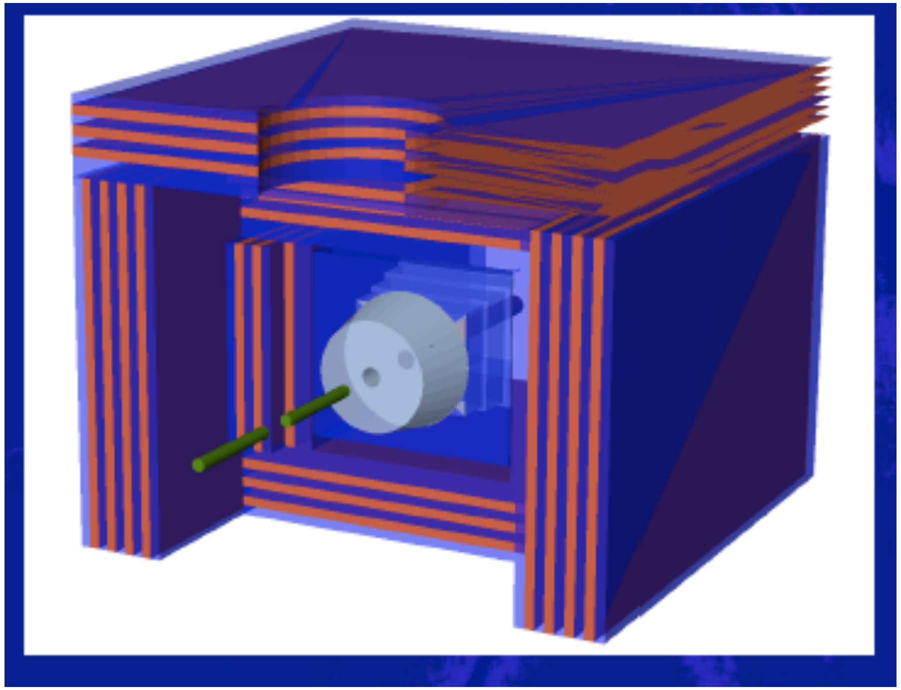
Hadron absorber



Al_2O_3 – ideal material, very good ratio X/λ with 2.4 m long
+ stainless steel and W (1.2 m Long in the beam pipe)

	X_0 [g/cm²]	ρ [g/cm³]	$\lambda_{int}(\pi)$ [g/cm²]
Concrete	26,60	2,30	128,6
Alumina	27,94	3,97	129,3
Stainless Steel	13,94	7,90	160,9
Carbon	42,7	2,27	117,8

- Compatible with the PT system
- Reduction of radiation level
- Possible to access to the PT instrumentation
- Non-magnetic material



New programs (COMPASS II)

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- Polarized Drell-Yan measurement
  TMD PDF *π^- beam with polarized proton target*
- GPD measurement *μ^+ μ^- beam with liquid hydrogen target*
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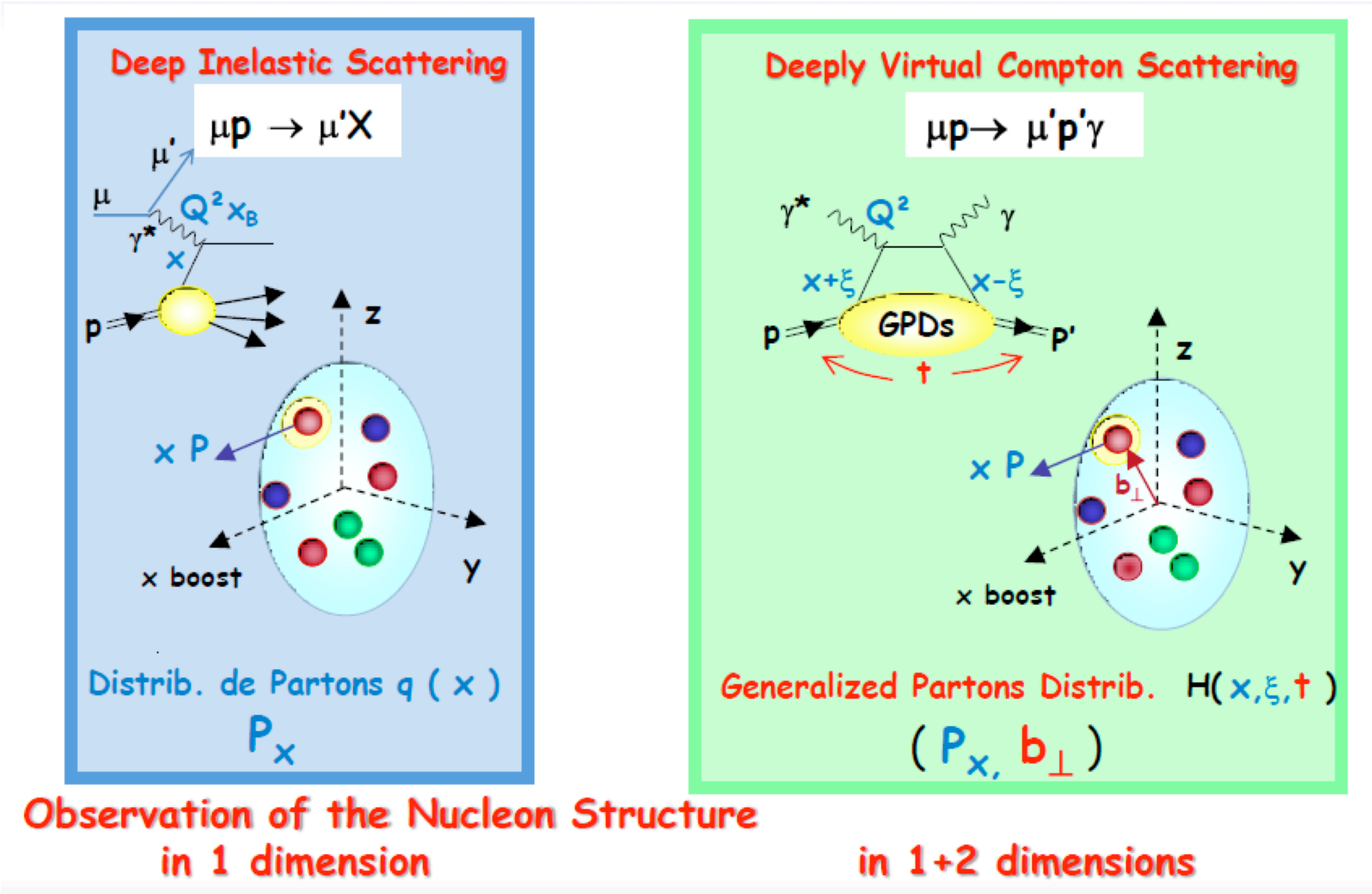
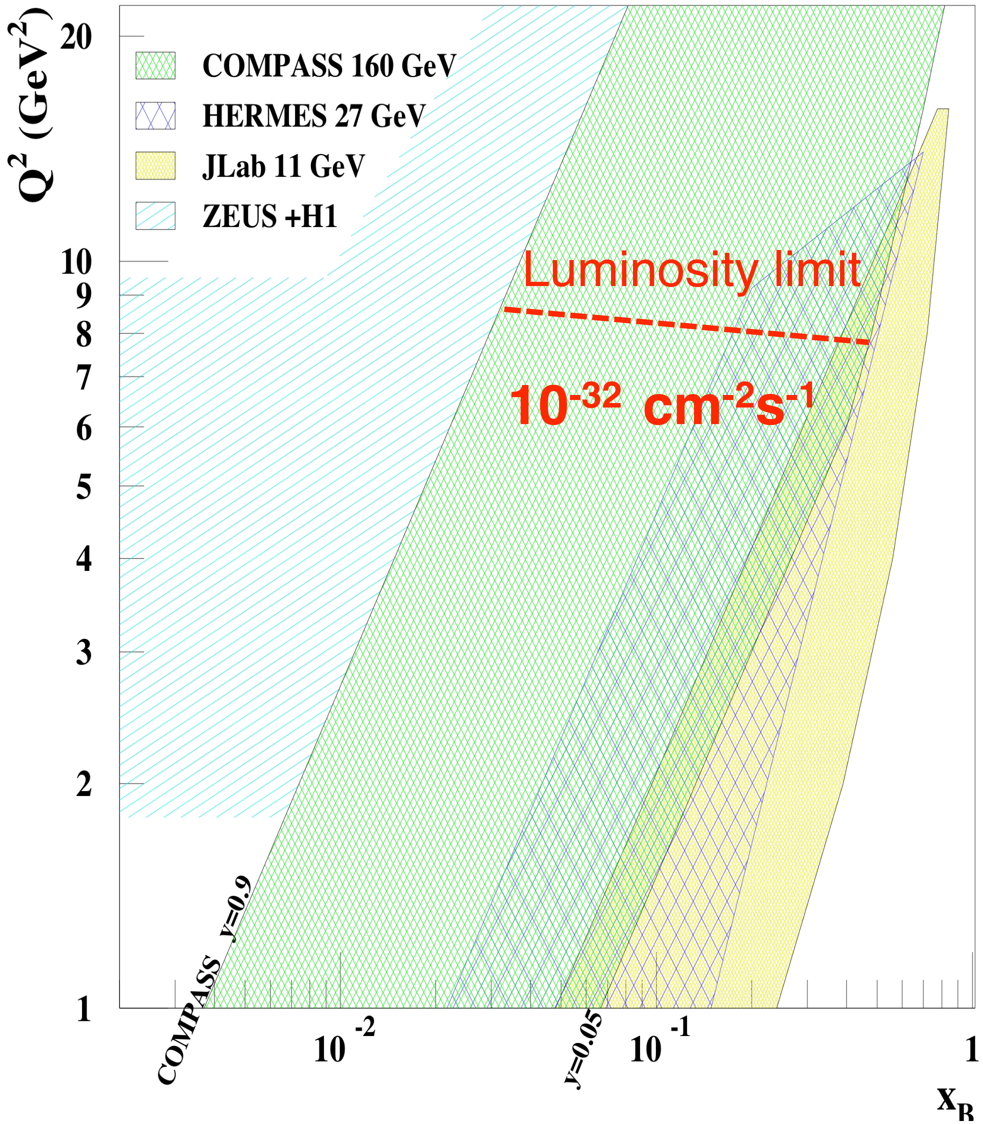
With a upgraded COMPASS spectrometer

From inclusive reaction to exclusive reactions



Why COMPASS II for GPDs ?

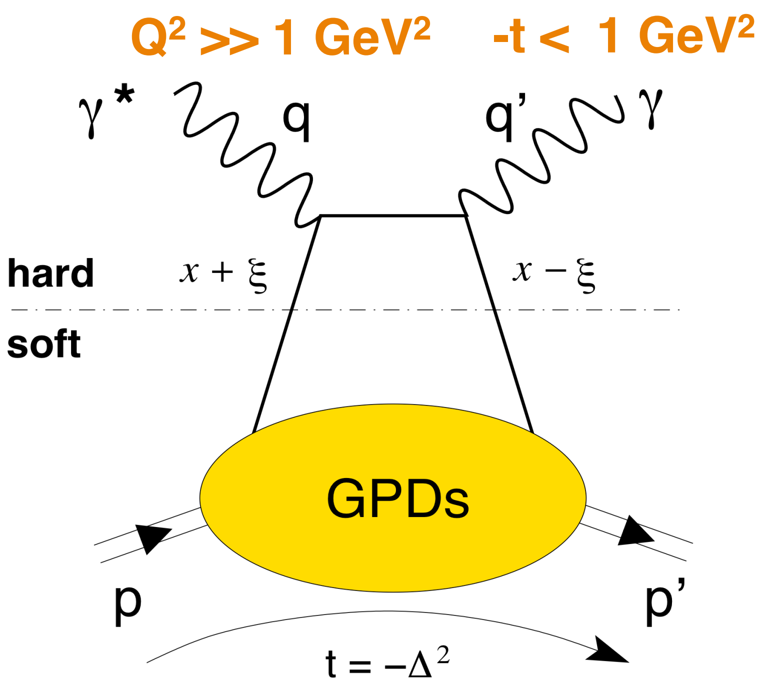


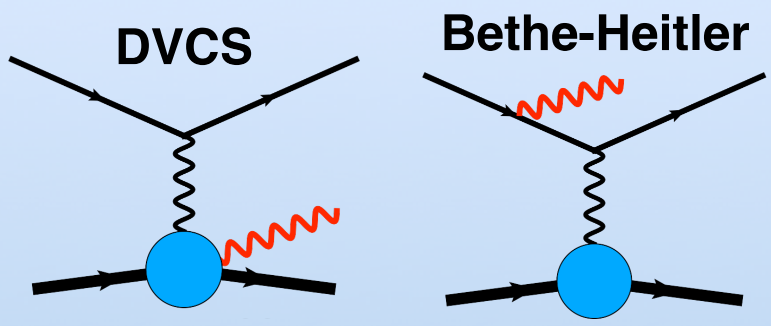
- Explore uncovered region between ZEUS/H1 and HERMES+Jlab

- μ^+ and μ^- beam
- Momentum 100 – 190 GeV
- 80% polarization (at 160 GeV)
- Opposite polarization between μ^+ and μ^-

Deeply Virtual Compton Scattering

GPDs can be accessed from the hard exclusive DVCS processes.





The total cross section is the coherent sum of DVCS and BH

<u>Polarized muon beam with unpolarized target</u> : **GPD *H***

$$d\sigma_{(\mu p \to \mu p \gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu d\sigma^{DVCS}_{pol} + e_\mu a^{BH}\,\mathrm{Re}(I) + e_\mu P_\mu\,\mathrm{Im}(I)$$

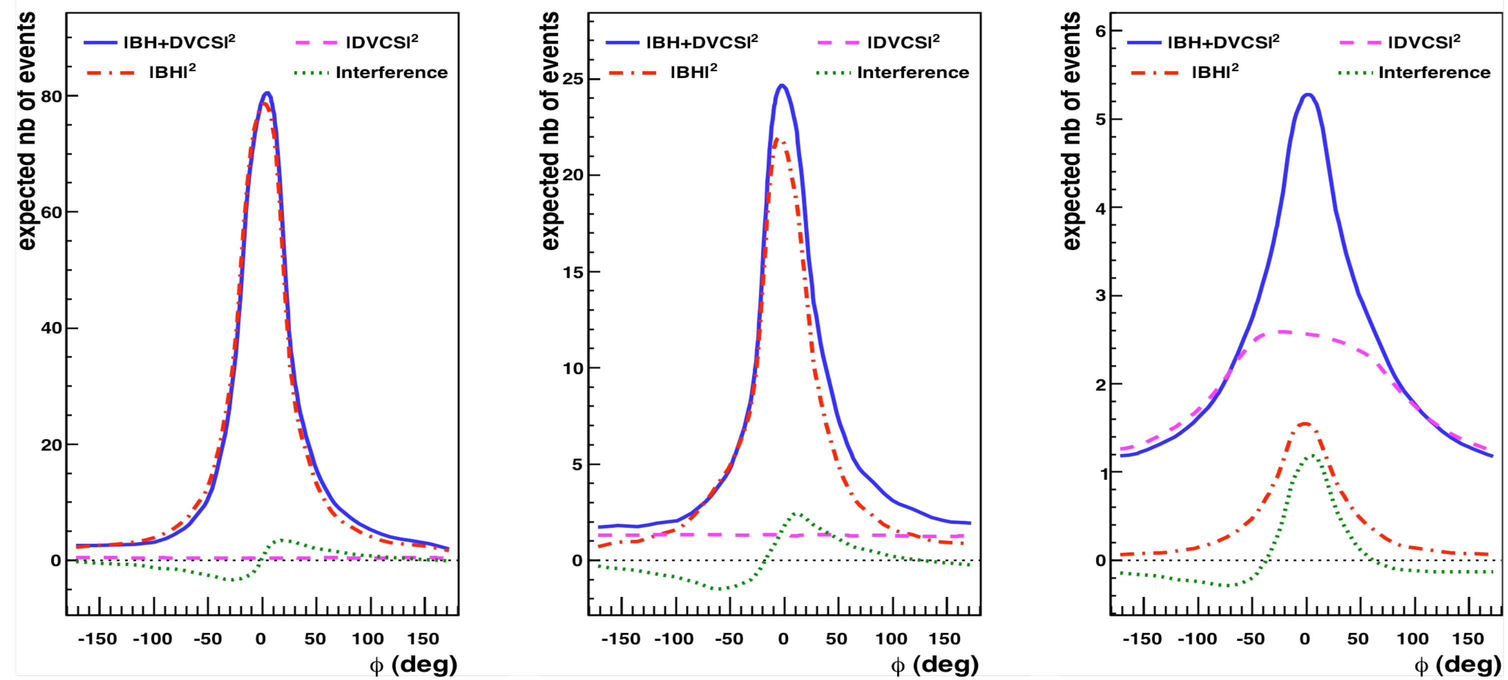
$d\sigma^{BH}$: well known

I : interference term

Bethe-Heitler and DVCS cross sections at 160 GeV

$$d\sigma \propto \left|T^{DVCS}\right|^2 + \left|T^{BH}\right|^2 + InterferenceTerm$$

$0.005<X_{BJ}<0.01$ **$0.01<X_{BJ}<0.03$** **$X_{BJ}>0.03$**



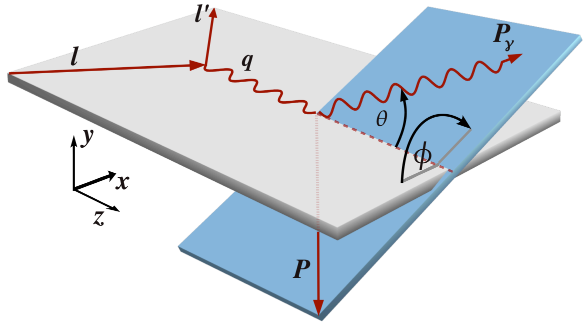
BH dominates
Reference yield

Interference
ReT^{DVCS} & ImT^{DVCS}

DVCS dominates
Transverse Image

MC: COMPASS setup with Ecal1+2

Access to GPD *H*



Beam Charge and Spin Sum

$$S_{CS,U} = d\sigma^{+\leftarrow} + d\sigma^{-\rightarrow} = 2\left(d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + e_\mu P_\mu \underline{\mathrm{Im}(I)}\right)$$

$$\Rightarrow s_1^I \sin\phi + s_2^I \sin 2\phi$$

Access to the GPD *H* $\quad s_1^I \propto \mathrm{Im}(F_1, \mathcal{H})$

Compton form factor

Beam Charge and Spin Difference

The BH process is independent of beam charge and polarization.

$$D_{CS,U} = d\sigma^{+\leftarrow} - d\sigma^{-\rightarrow} = 2\left(P_\mu d\sigma^{DVCS}_{pol} + e_\mu \underline{\mathrm{Re}(I)}\right)$$

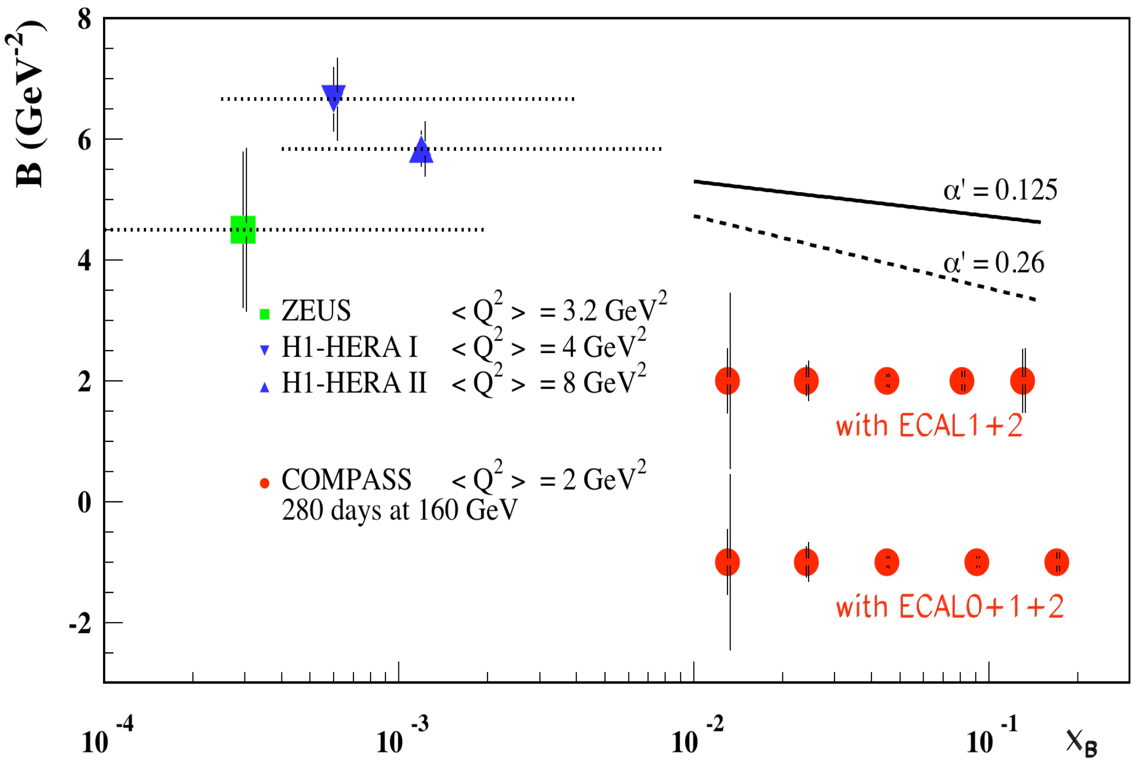
Phase II

$$\Rightarrow c_0^I + c_1^I \cos\phi + c_2^I \cos 2\phi + c_3^I \cos 3\phi$$

One can access GPD *E*
with a measurement of DVCS
using transversely polarized proton target

$$c_1^I \propto \mathrm{Re}(F_1, \mathcal{H})$$

Transverse imaging



2 years of data (280days)
160 GeV polarized muon beam
- μ+ 70 days
- μ- 210days
2.5m LH2 target

t-slope parameter $B(x_B)$

simple ansatz:

$$B(x_B) = B_0 + 2\alpha' \log(x_0/x_B)$$

The exclusive cross section is parametrized as

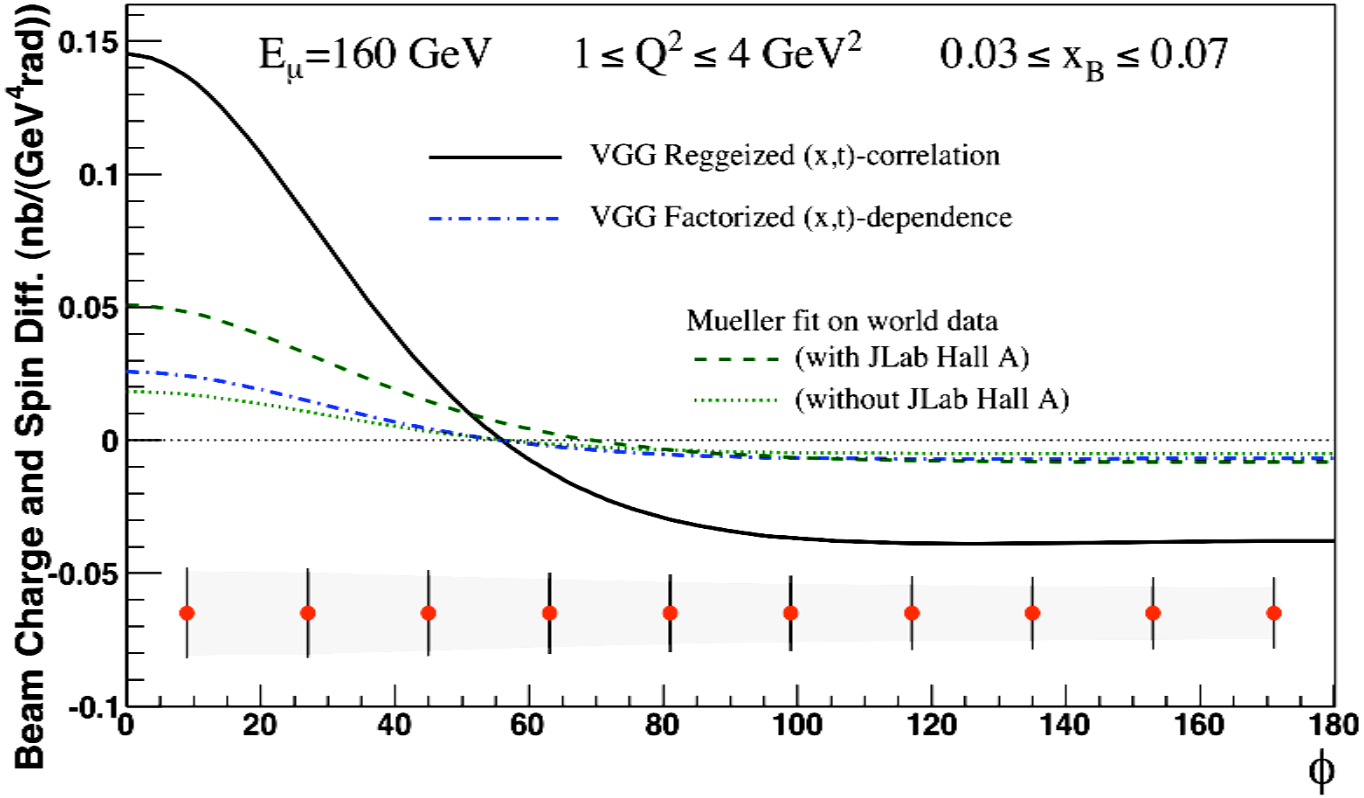
$$d\sigma/dt \propto \exp(-B(x_B)|t|)$$

$B(x_B)$ can be extracted without any models

$$\langle r_\perp^2(x_B) \rangle \approx 2 \cdot B(x_B)$$

the transverse size of the nucleon

Beam charge & spin difference $D_{CS,U}$



L = 1222 pb^{-1}
ε_{global} = 10 %

- Control detector acceptance and beam flux with high precision
- Error band assumes a 3 % systematic uncertainty between μ^+ and μ^-
- Use inclusive events and BH for check

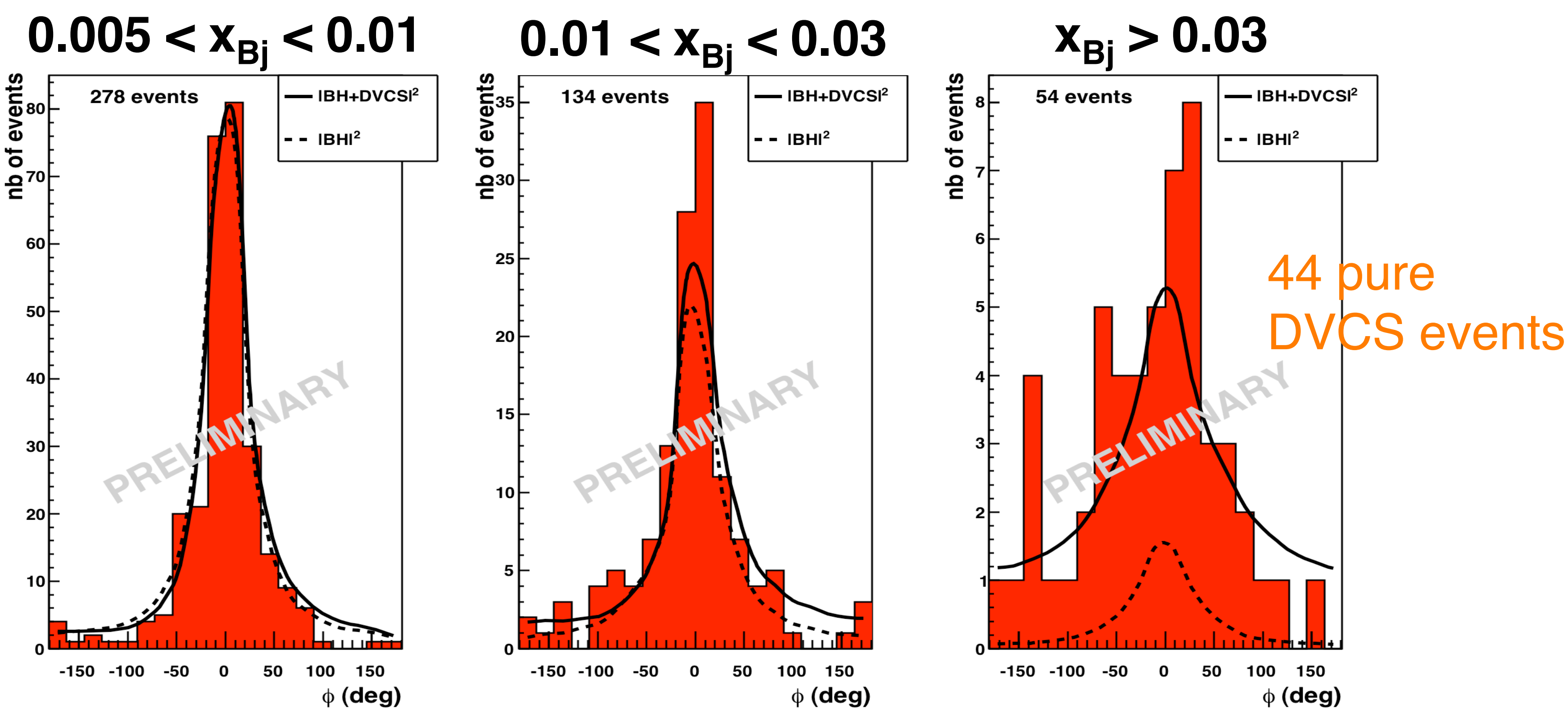
Beam test in 2008 and 2009

With 40cm long LH2 target and 1m long recoil proton detector

Observation of BH and DVCS events

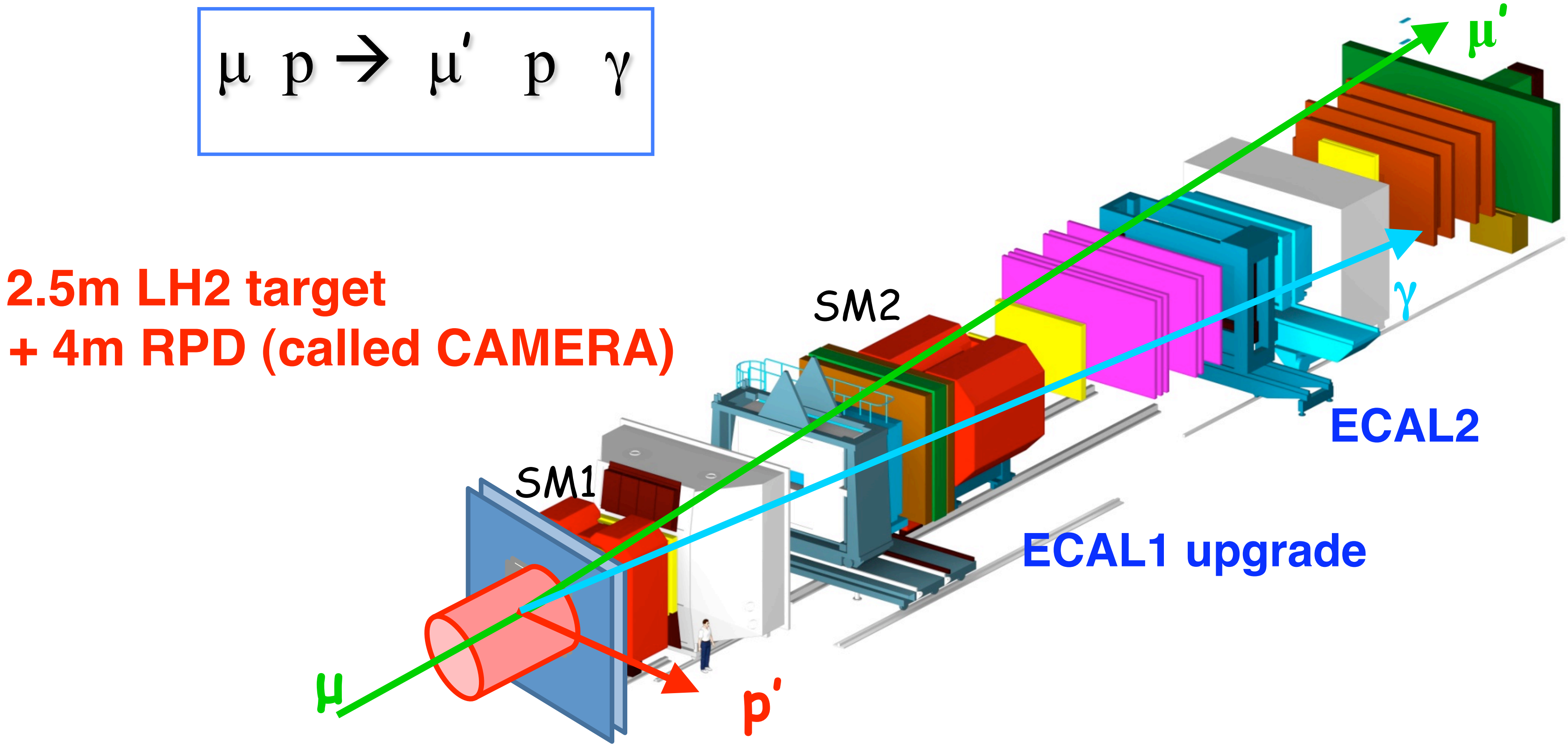
2008 : observation of exclusive single photon production

2009 : observation of BH and DVCS events



COMPASS II setup for DVCS

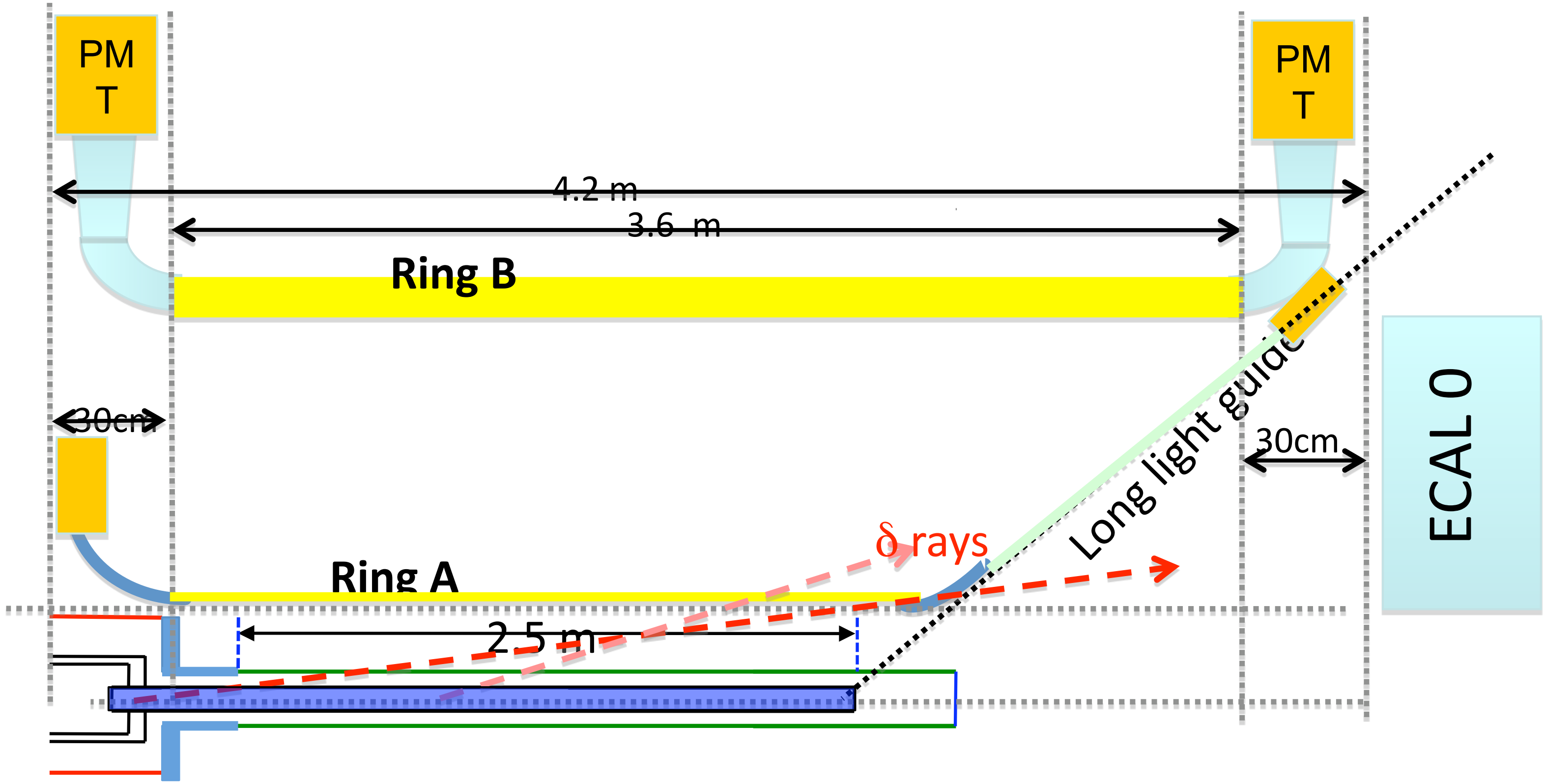
$\mu \; p \rightarrow \mu' \; p \; \gamma$



+ ECAL0 before SM1

(for higher acceptance in large X_B)

New target and RPD (CAMERA)



LH2 : 2.5m long and 4cm diameter
minimum thickness of cryostat -> 1 mm thickness carbon fiber tube

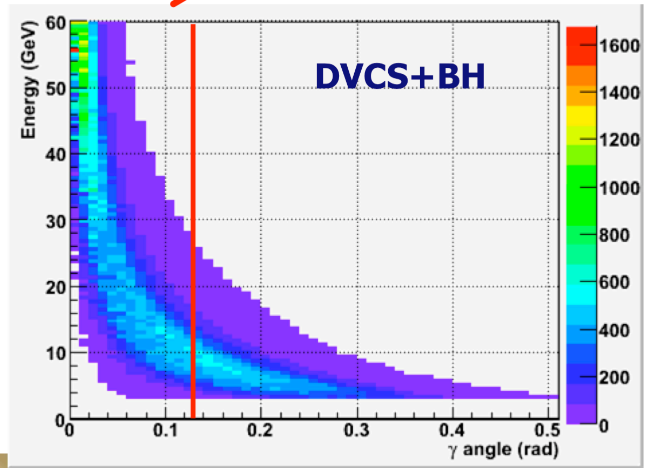
RPD : 2.8/3.6 m long scintillator slabs, 2 layers
< 300 ps time resolution for TOF

New electromagnetic calorimeter : ECAL0

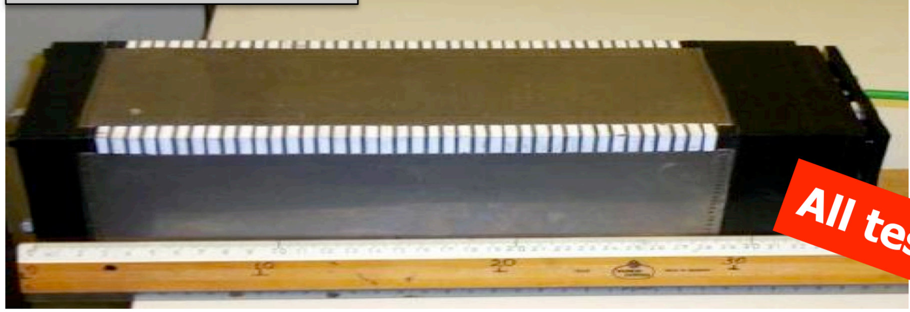
Requirements

- Photon energy range 0.2- 30 GeV
- Size: 260 x 260 cm² ;
- Granularity 12 x 12 cm²
- Energy resolution < 10.0%/√E (GeV)
- Thickness < 50 cm,
- Insensitive to the magnetic field.

existing
ECAL1&2



Shaschlyk module



All tested

MAPD

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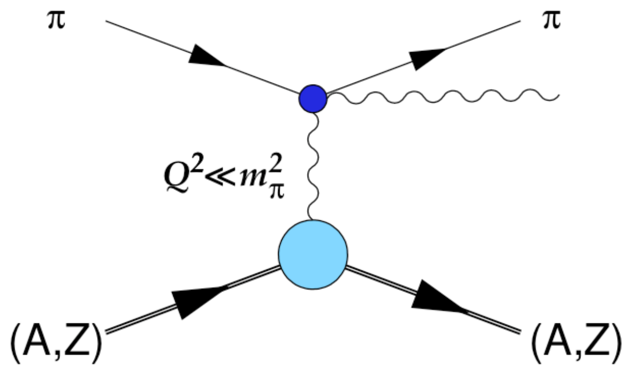
With a upgraded COMPASS spectrometer

Pion and polarisability measurement

The Primakoff reaction
(embedding the pion Compton scattering)

$$\pi^- Z \rightarrow \pi^- Z \gamma$$



The differential cross section

$$\frac{d\sigma_{\pi\gamma}}{d\Omega_{cm}} = \frac{\alpha^2\left(s^2 z_+^2 + m_\pi^4 z_-^2\right)}{s\left(sz_+ + m_\pi^2 z_-\right)^2} - \frac{\alpha\, m_\pi^3\left(s - m_\pi^2\right)^2}{4s^2\left(sz_+ + m_\pi^2 z_-\right)} \cdot P$$

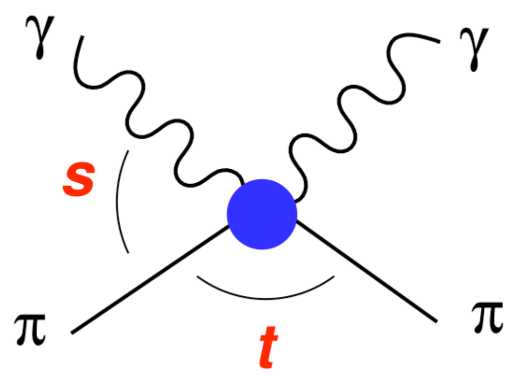
P : the pion polarizability term

$z_\pm = 1 \pm \cos\theta_{cm}$

θ_{cm} : the scattering angle in CM system

s : the Mandelstam variables

Pion and polarisability measurement



The pion polarizability term P for the differential cross section

$$P = z_-^2(\alpha_\pi - \beta_\pi) + \frac{s^2}{m_\pi^4} z_+^2(\alpha_\pi + \beta_\pi) - \frac{\left(s - m_\pi^2\right)^2}{24s} z_-^3(\alpha_2 - \beta_2)$$

Leading order

s-dependent

α_π, β_π : the pion electric and magnetic dipole polarizabilities

$\alpha_2 - \beta_2$: the quadrupole polarizability difference

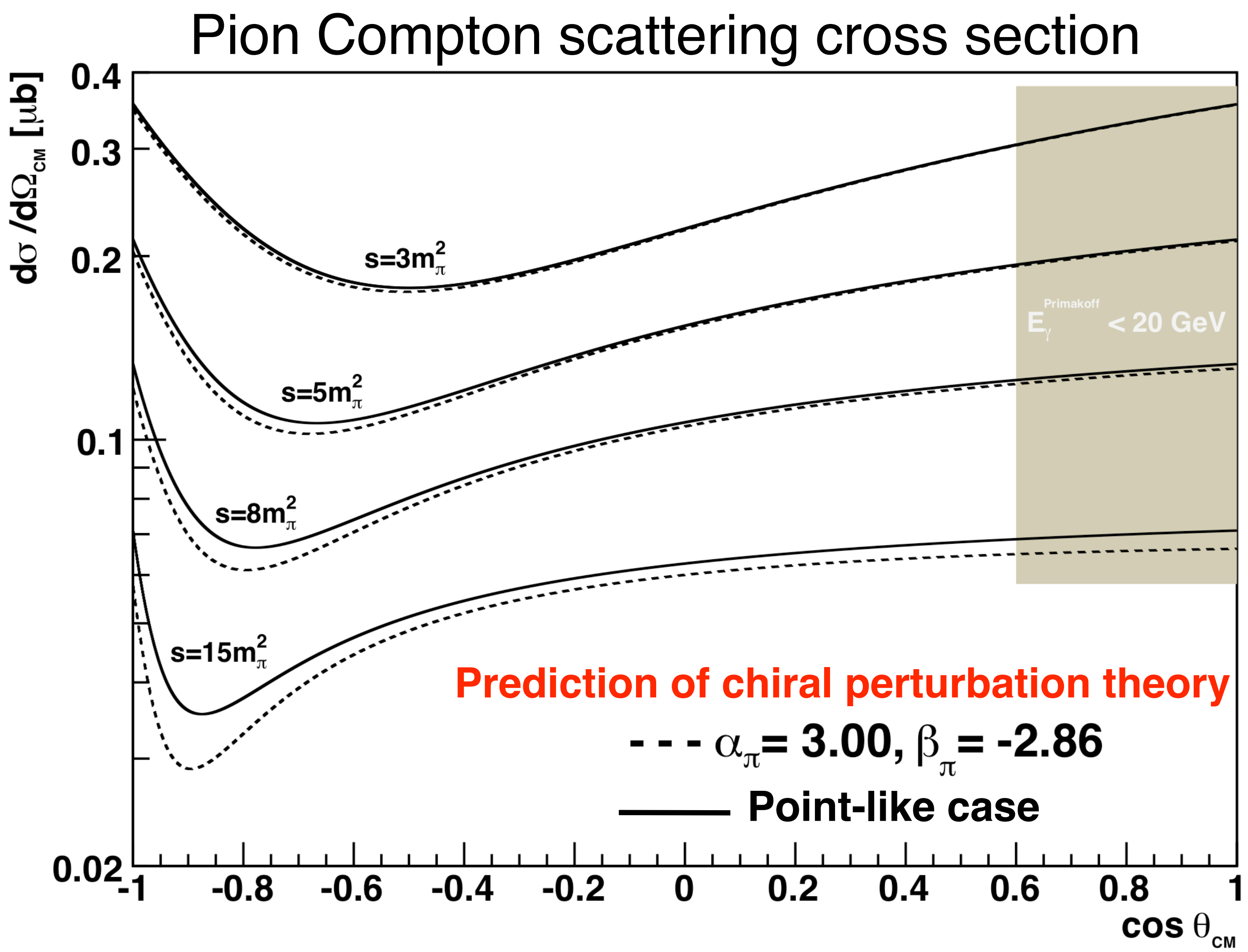
Kaon polarizability will be obtained
by Primakoff scattering with charged Kaons at COMPASS.

Theoretical predictions on pion

Model	Parameter	$[10^{-4} fm^3]$
χPT	$\alpha_\pi - \beta_\pi$	5.7 ± 1.0
	$\alpha_\pi + \beta_\pi$	0.16
NJL	$\alpha_\pi - \beta_\pi$	9.8
QCM	$\alpha_\pi - \beta_\pi$	7.05
	$\alpha_\pi + \beta_\pi$	0.23
QCD sum rules	$\alpha_\pi - \beta_\pi$	11.2 ± 1.0
Dispersion sum rules	$\alpha_\pi - \beta_\pi$	13.60 ± 2.15
	$\alpha_\pi + \beta_\pi$	0.166 ± 0.024

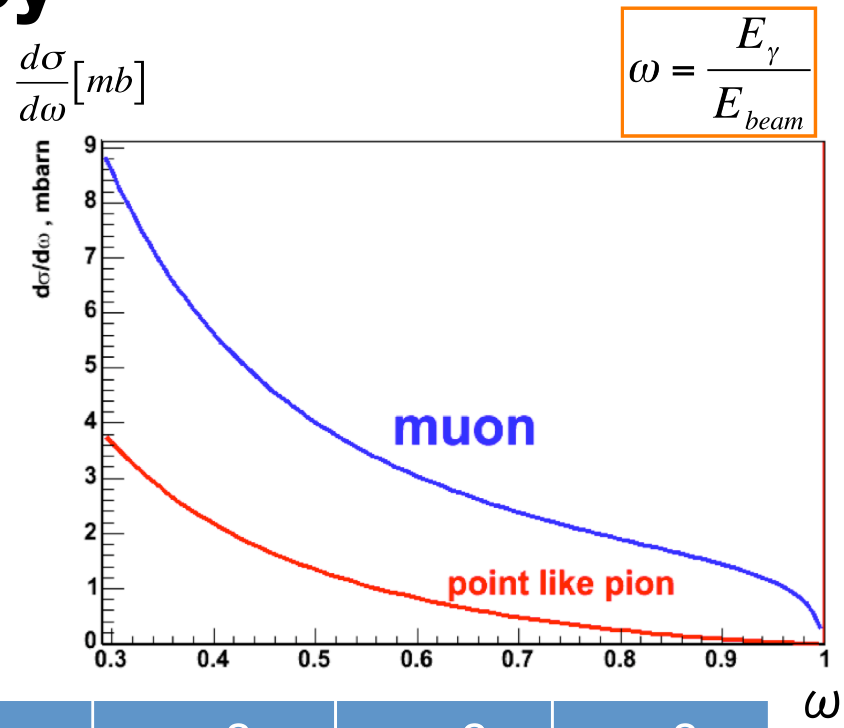
- Different theoretical models ➔ Different values
- Experimental measurement ➔ Stringent test of theoretical approaches

Polarizability effect



Self-test with muon beam and measurement accuracy

- Pion and muon beams available
  - Same momentum and setup configuration
- Muon is the point-like particle.
  - Primakoff cross section should correspond to theoretically predicted one.
- The study of systematic effects



Expected total errors

Days	π beam, days	μ beam, days	Flux π, 10^{11}	Flux μ10^{11}	α_π-β_π σ_{tot}	α_π+β_π σ_{tot}	α_2-β_2 σ_{tot}
120	90	30	59	12	±0.66	±0.025	±1.94
					ChPT prediction 5.70	0.16	16

K beam 90 days 1.4 x 10^{11} flux : $\sigma_{tot}(\alpha_K - \beta_K)$ ±0.08, (ChPT prediction 1.0)

Summary and time line

- The COMPASS facility provides many combinations of the beam and the target.

- New programs are approved by CERN in 2010.
  - Polarized Drell-Yan for TMD PDFs.
  - GPDs for transversal imaging
  - Primakoff for pion and kaon polarizability

Schedule of the programs in the proposal

2012 : Primakoff

2013 : SPS Shutdown

2014 – 2016 : GPDs + DY