COMPASS with high intensity muon beams and unpolarized target

Generalized Parton Distributions (GPDs)

sensitivity to the COMPASS kinematics

DVCS with polarized μ+ and μ-
Meson production (present ρ studies)

} For a complete experiment

High luminosity and Recoil Detection

Other accurate measurements with the same setup
for Structure Functions Study and Color Transparency

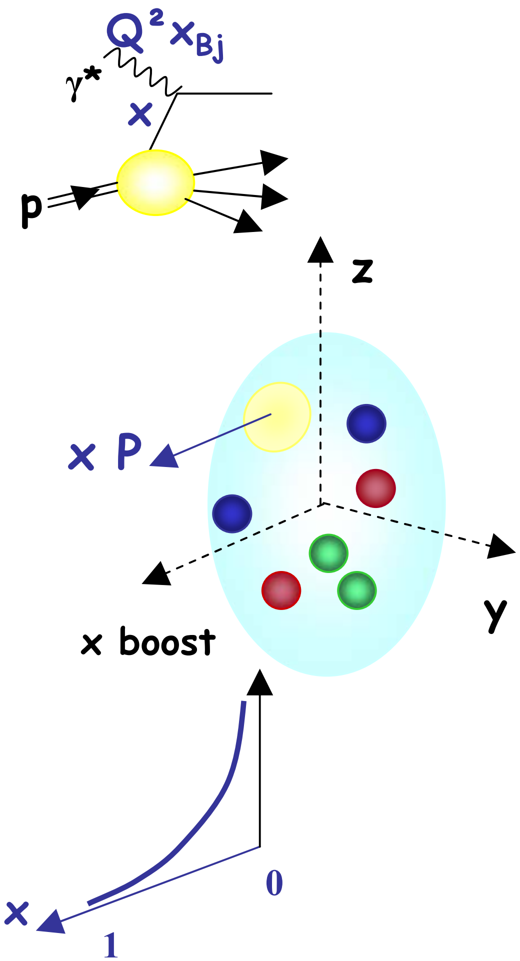
Nicole d'Hose (CEA Saclay) and Horst Fischer (Universität Freiburg)

SPSC meeting at Villars - 25 September 2004

GPDs ≡ a 3-dimensional picture of the partonic nucleon structure

Deep Inelastic Scattering

$ep \rightarrow eX$

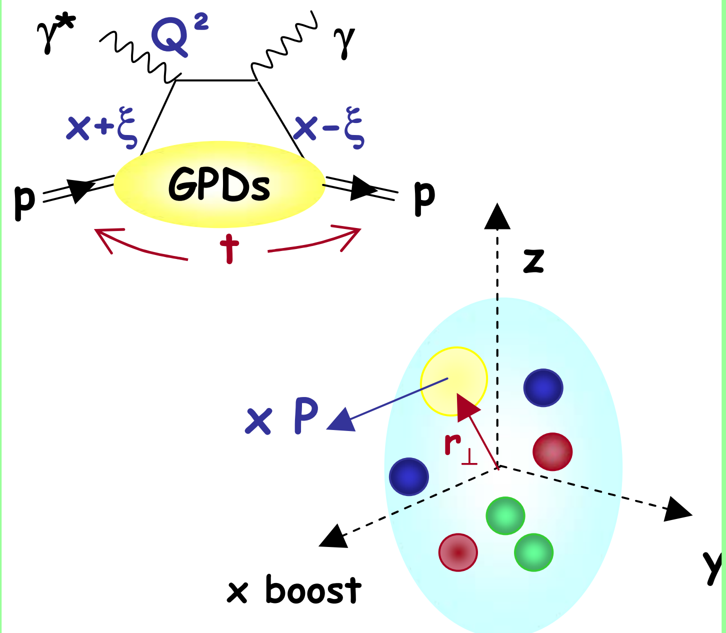


Parton Density q (x)

P_x

Hard Exclusive Scattering
Deeply Virtual Compton Scattering

$ep \rightarrow ep\gamma$



Generalized

Parton Distribution $H(x,\xi,t)$

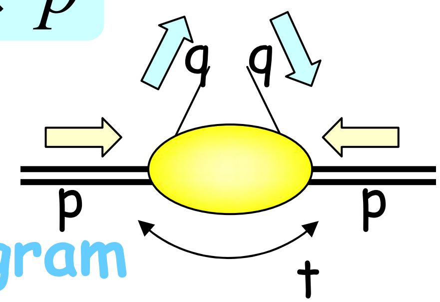
$(\,P_x,\ r_{y,z}\,)$

Burkard, Belitsky, Müller, Ralston, Pire

Why GPDs are promising?

Goal: correlation between the 2 pieces of information:
- -distribution of longitudinal momentum carried by the partons $\vec{p}$
- -distribution in the transverse plane $\vec{r}$

⇨ Implication of orbital angular momentum $\vec{r} \times \vec{p}$ to the total spin of a nucleon



in the context of the COMPASS program

⇨ Knowledge of the transverse size of parton distribution

in hadron-hadron collisions such as at LHC, RHIC

What do we learn from the 3 dimensional picture ($P_{x}, r_{y,z}$) ?

1. Lattice calculation: Negele *et al.*, NP Proc. Suppl. 128 (2004)

- fast parton close to the N center ≡ small valence quark core
- slow parton far from the N center ≡ widely sea q and gluons

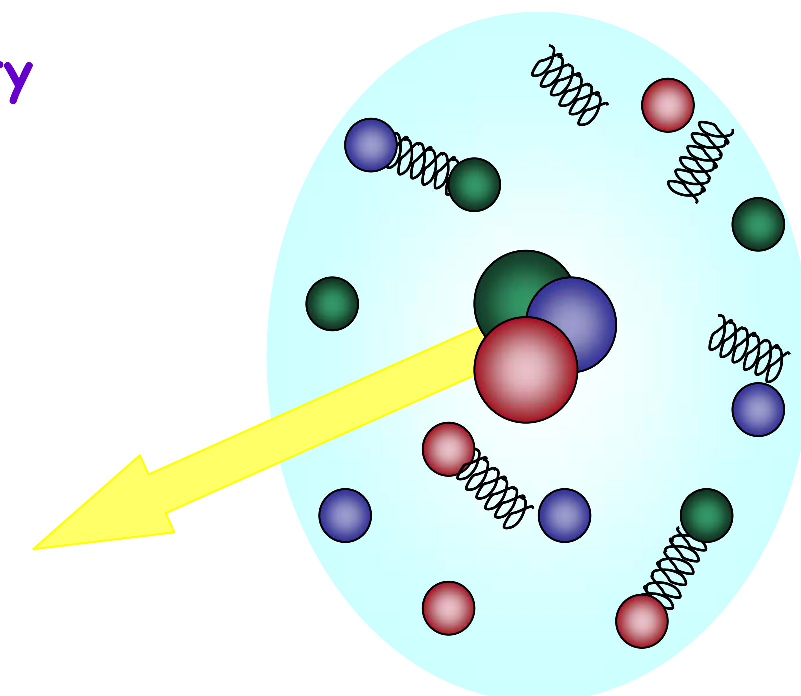
2. Chiral Dynamics: Strikman *et al.*, PRD69 (2004)

at large distance, the gluon density
is generated by the pion cloud

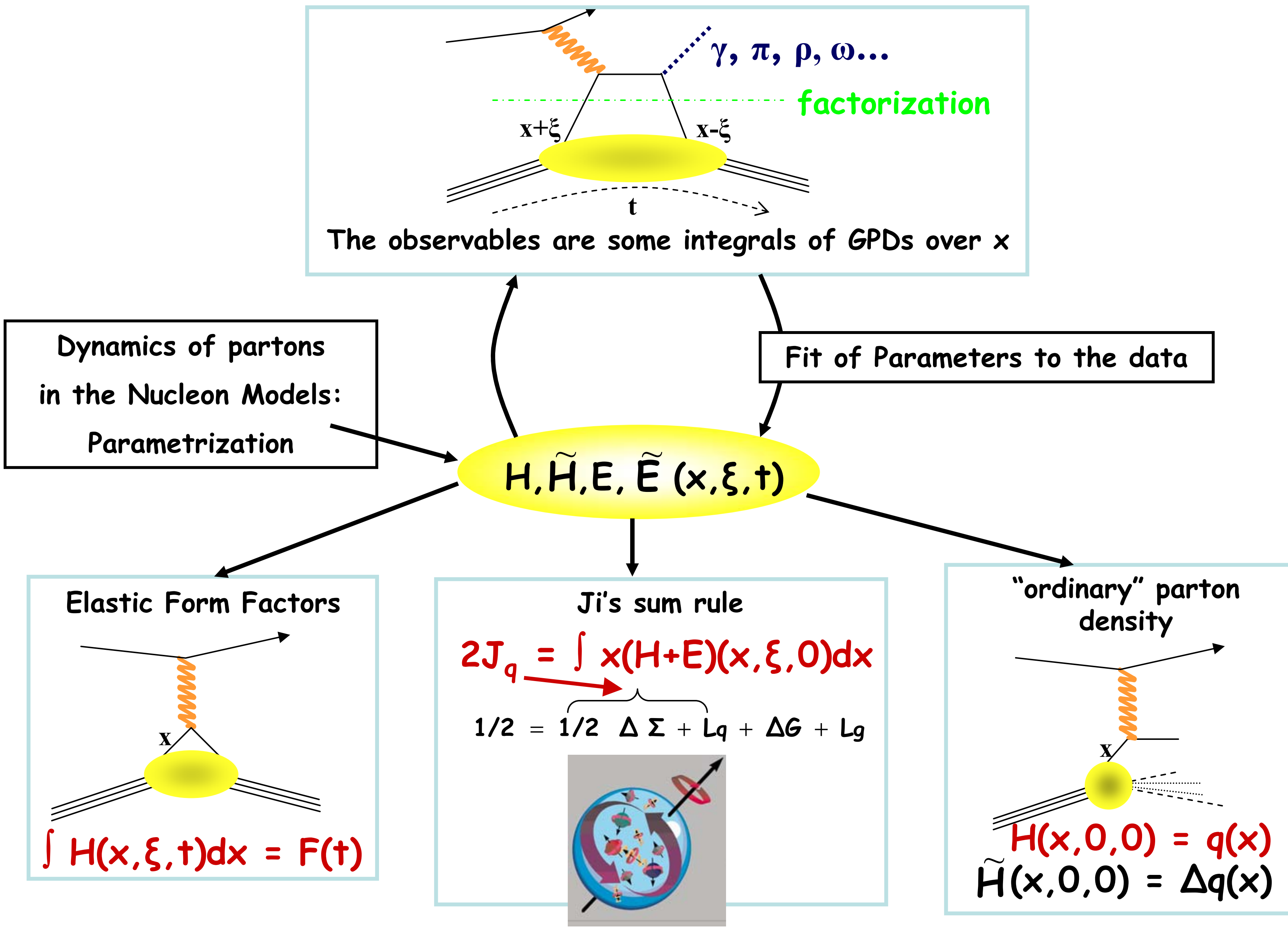
significant increase of
the N transverse size

if $x_{Bj} < m_{\pi}/m_{p} = 0.14$

COMPASS domain



GPDs and relations to the physical observables



Parametrization of GPDs

Model 1: $H(x,\xi,t) \sim q(x)\, F(t)$

Model 2: is more realistic
it considers that fast partons in the small valence core
and slow partons at larger distance (wider meson cloud)

it includes correlation between x and t

$\langle b^2_\perp \rangle = \alpha' \ln 1/x$ transverse extension of partons in hadronic collisions

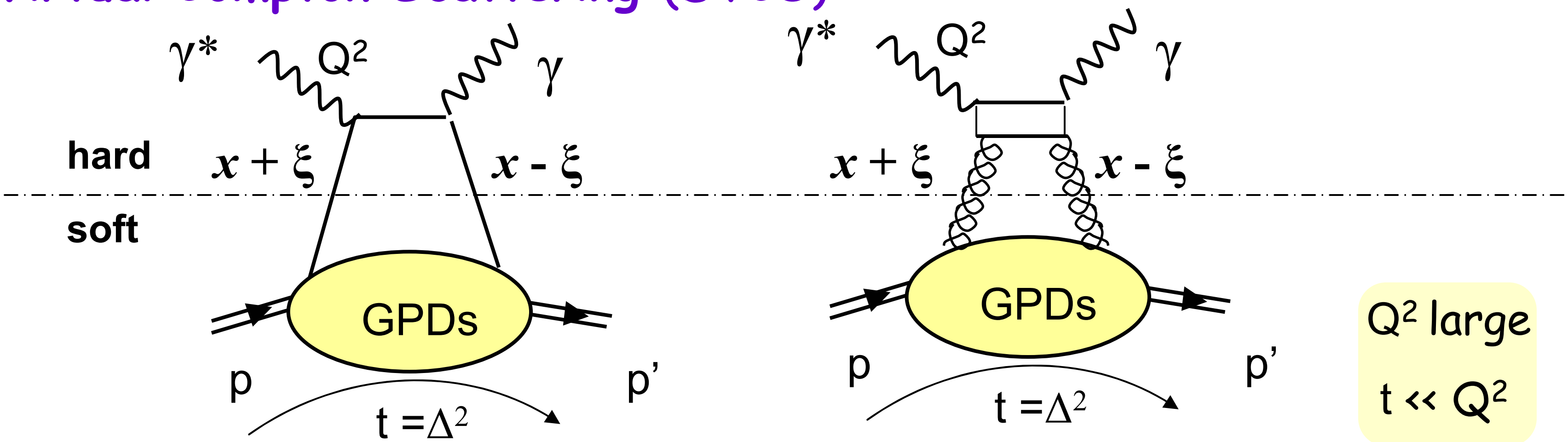
$\Rightarrow$ $H(x,0,t) = q(x)\, e^{t \langle b_\perp^2 \rangle} = q(x) / x^{\alpha' t}$ (α' slope of Regge traject.)

This ansatz reproduces the
Chiral quark-soliton model: Goeke *et al.*, NP47 (2001)

Necessity of factorization to access GPDs

Deeply Virtual Compton Scattering (DVCS):

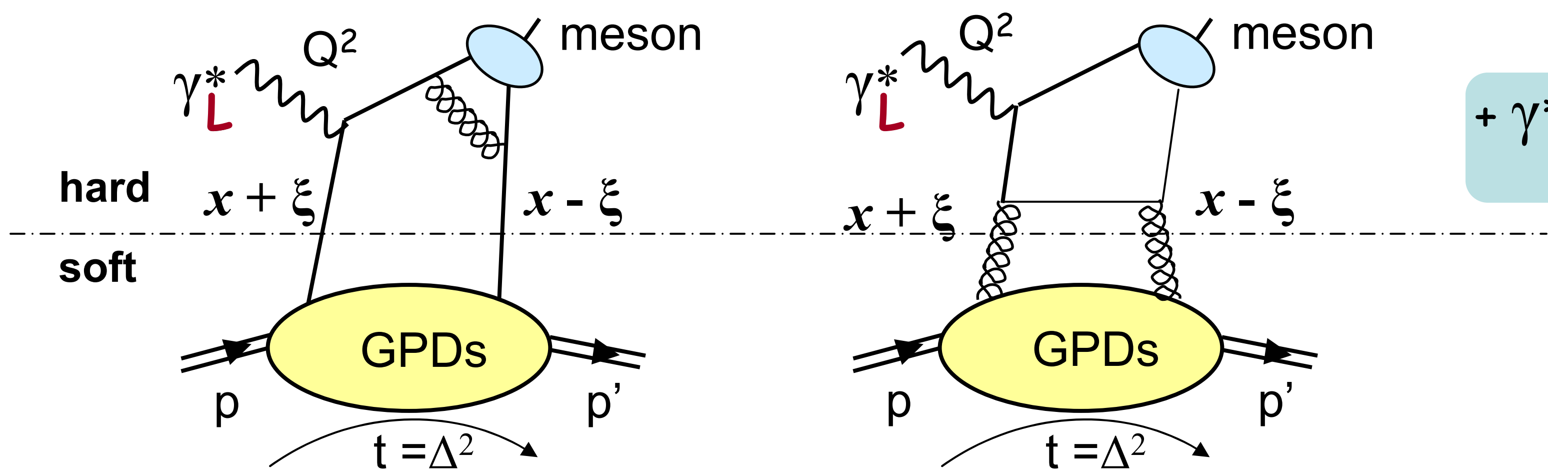
Collins *et al.*



Q^2 large

$t \ll Q^2$

Hard Exclusive Meson Production (HEMP):



+ γ^*_L

Quark contribution

Gluon contribution

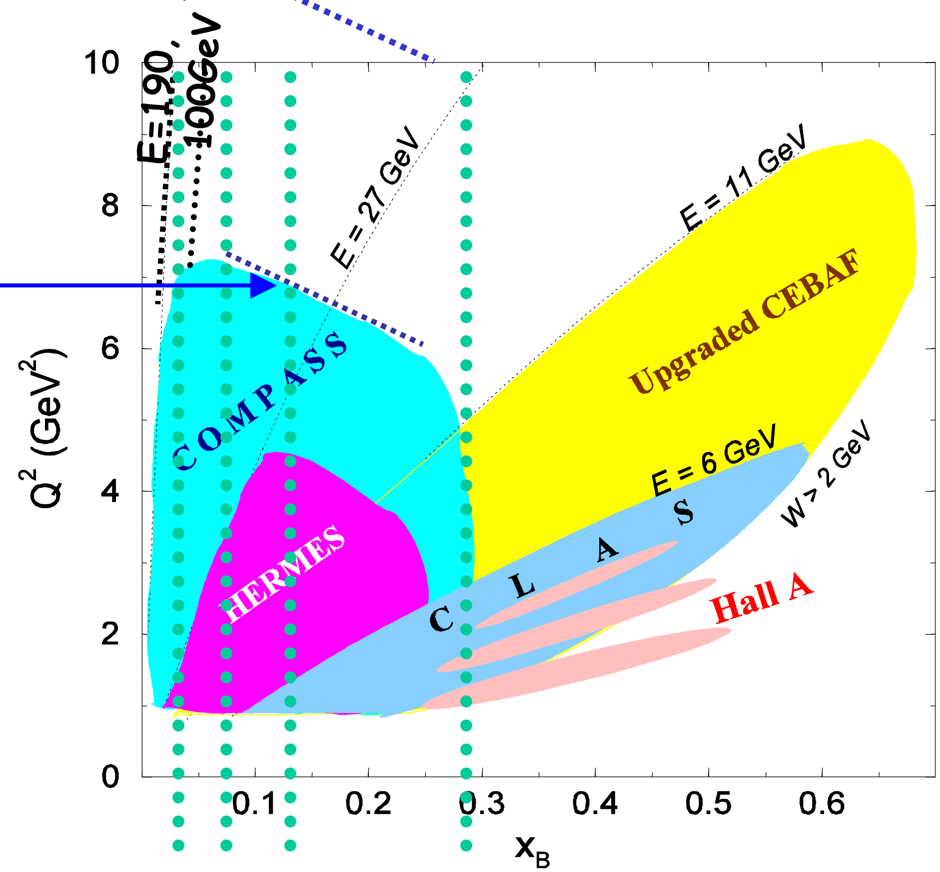
Complementarity of the experiments in the world

if Nμ × 2 $\Longrightarrow$ Q^2 < 11 GeV^2
for DVCS

Limitation by luminosity

now Nμ= 2.10^8μ per SPS spill
for DVCS
$\Longrightarrow$ Q^2 < 7.5 GeV^2

At fixed x_{Bj}, study in Q^2



0.0001< x_{Bj} < 0.01
Gluons

H1 and ZEUS
PLB517(2001) PLB573(2003)

Valence and sea quarks
And Gluons

Hermes PRL87(2001)
COMPASS

Valence quarks

JLab
PRL87(2001)

if Nμ × 2 ⟹ $Q^2 < 11\ GeV^2$
for DVCS

Limitation by luminosity

now Nμ= 2.10[8]μ per SPS spill
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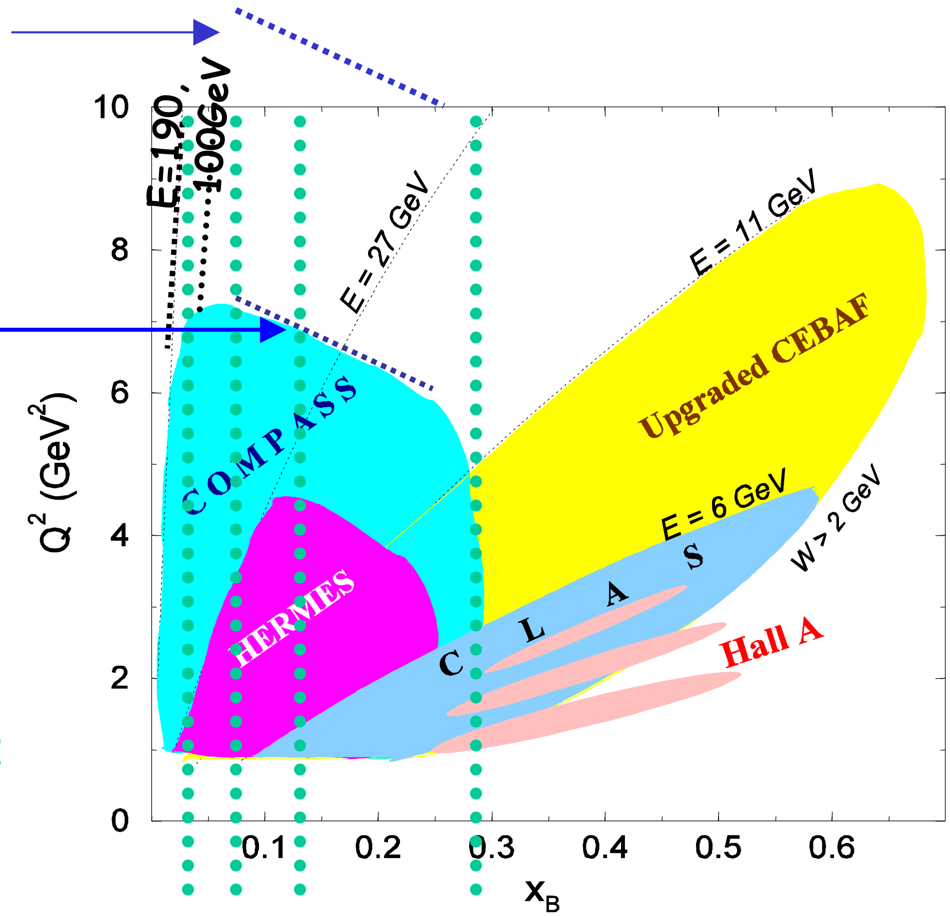


At fixed x_{Bj}, study in Q^2

$0.0001 < x_{Bj} < 0.01$ Gluons	Valence and sea quarks And Gluons	Valence quarks
H1 and ZEUS	Hermes COMPASS	JLab

the highest luminosity with the Muon Beams

Based on 2004 beam characteristics

$N\mu=2.10^8$ per SPS cycle

duration 5.2s repetition each 16.8s

with a new 2.5m liquid hydrogen target $\Rightarrow$ $\mathcal{L}=1.3\ 10^{32}\ cm^{-2}s^{-1}$

with the 1.2m ^{6}LiD target $\Rightarrow$ $\mathcal{L}=4.2\ 10^{32}\ cm^{-2}s^{-1}$

one year of data taking ≡ 150 days ≡ $7.2\ 10^5$ spills/year

In 2010?

sharing CNGS/FT operations

new Linac4 (160GeV, H^-) as injector for the PSB

improvements on the muon line

what could be the available proton/muon flux?

Polarized μ+ and μ- beams

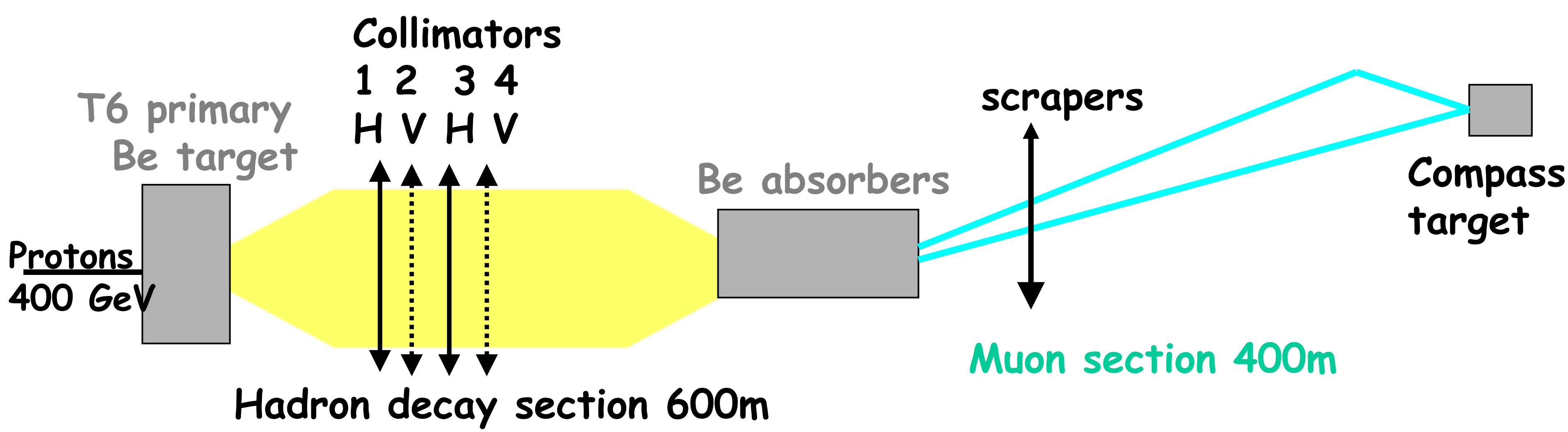
Requirements for DVCS:
-same energy
-maximum intensity
-opposite polarisation to a few %

Solution proposed by Lau Gatignon:

1) To select P_π=110GeV and P_μ=100GeV to maximise the muon flux

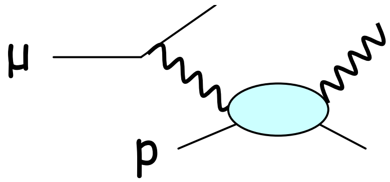
2) To keep constant the collimator settings which define the π and μ momentum spreads
⇒ Pol μ+ = -0.8 and Pol μ- = +0.8

3) Nμ+ ~ 2.× Nμ-

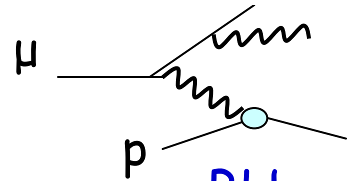


1.3 10^{13} *protons/spill*

2.10^8 *muons/spill*



DVCS+ Bethe Heitler



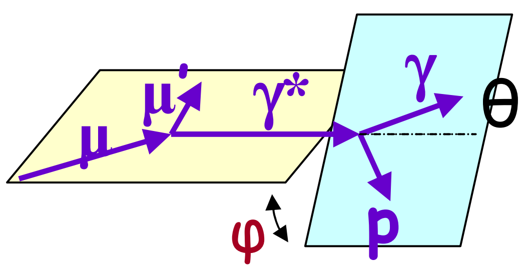
BH calculable

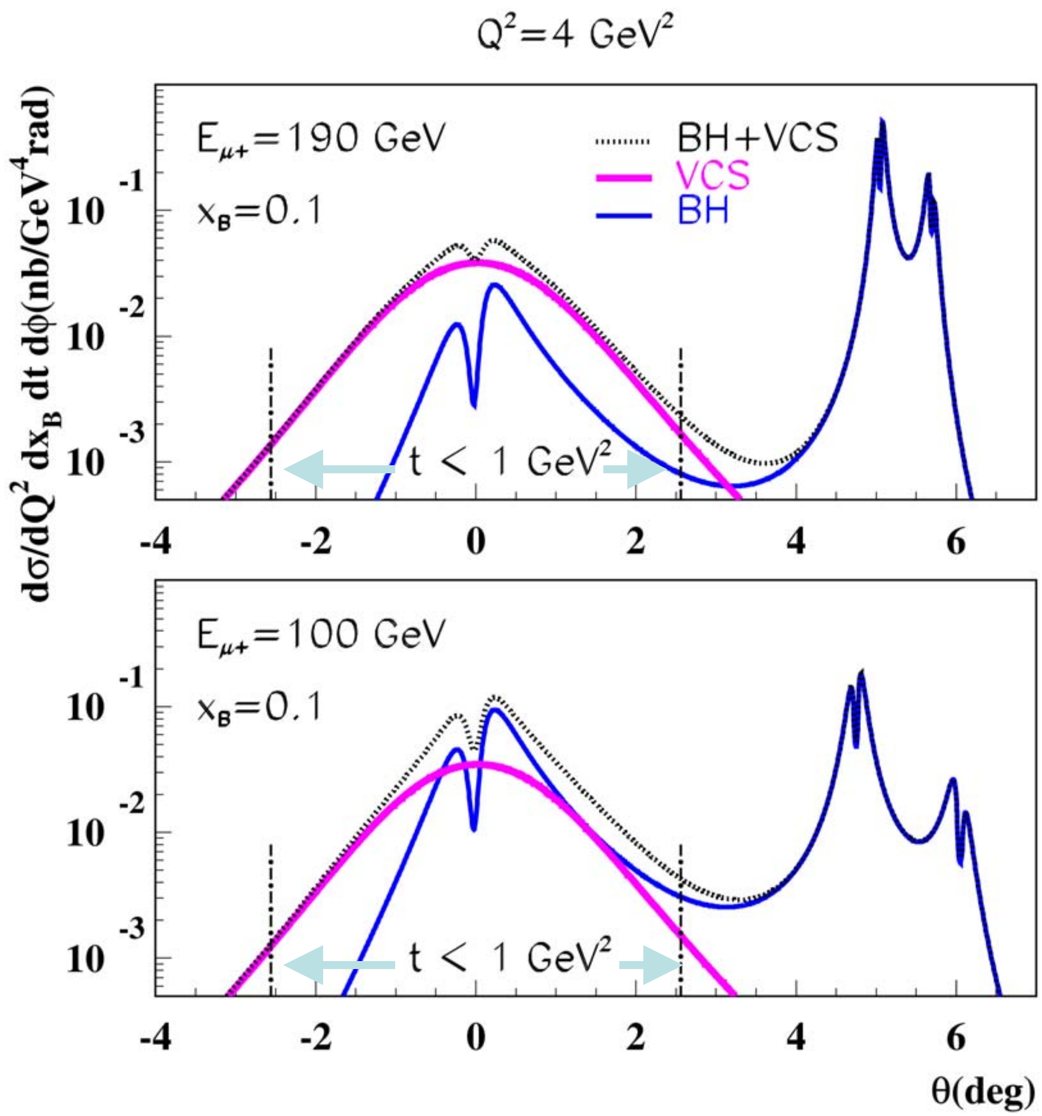
The high energy muon beam at COMPASS allows to play with the relative contributions DVCS-BH which depend on

$$1/y = 2\, m_p\, E_\ell\, x_{Bj}\, /Q^2$$

Higher energy: DVCS>>BH
⇒ DVCS Cross section

Smaller energy: DVCS~BH
⇒Interference term will provide the DVCS amplitude





Advantage of $\overleftarrow{\mu}^{+}$ and $\vec{\mu}^{-}$ for Deeply virtual Compton scattering (+Bethe-Heitler)

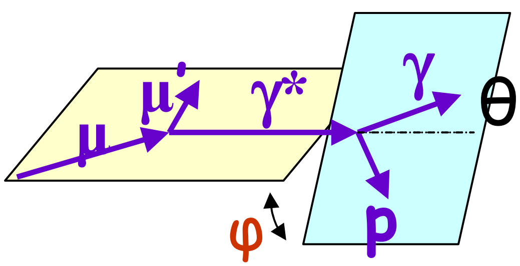
$$\mathcal{A}^{DVCS}_{(\mu p\rightarrow\mu p\gamma)} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\,\pi\, H(x=\xi,\xi,t)$$

t, $\xi \sim x_{Bj/2}$ fixed

$$d\sigma_{(\mu p\rightarrow\mu p\gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu\, d\sigma^{DVCS}_{pol}$$

$$+\, e_\mu\, a^{BH}\, \mathcal{R}e\, \mathcal{A}^{DVCS} + e_\mu P_\mu\, a^{BH}\, \mathcal{I}m\, \mathcal{A}^{DVCS}$$

$\times \cos n\varphi$ $\times \sin n\varphi$



$P_{\mu+}=-0.8$ $P_{\mu-}=+0.8$

$$\sigma^{\overleftarrow{\mu}+} + \sigma^{\vec{\mu}-} \sim H(x=\xi,\xi,t)$$

$$\sigma^{\overleftarrow{\mu}+} - \sigma^{\vec{\mu}-} \sim \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}$$

Diehl

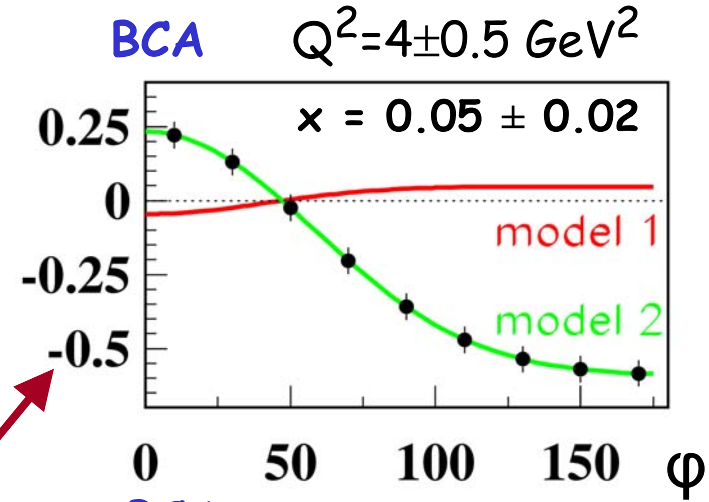
DVCS Beam Charge Asymmetry (BCA) measured with the 100 GeV muon beam at COMPASS

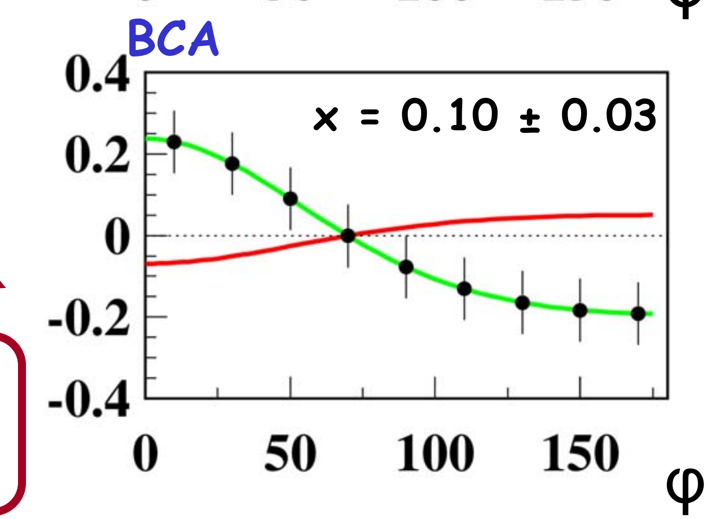
$$\sigma^{\overleftarrow{\mu}+} - \sigma^{\vec{\mu}-} \sim \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}$$

Model 1: $H(x,\xi,t) \sim q(x)\, F(t)$

Model 2: $H(x,0,t) = q(x)\, e^{t \langle b_\perp^2 \rangle}$

$= q(x) / x^{\alpha' t}$





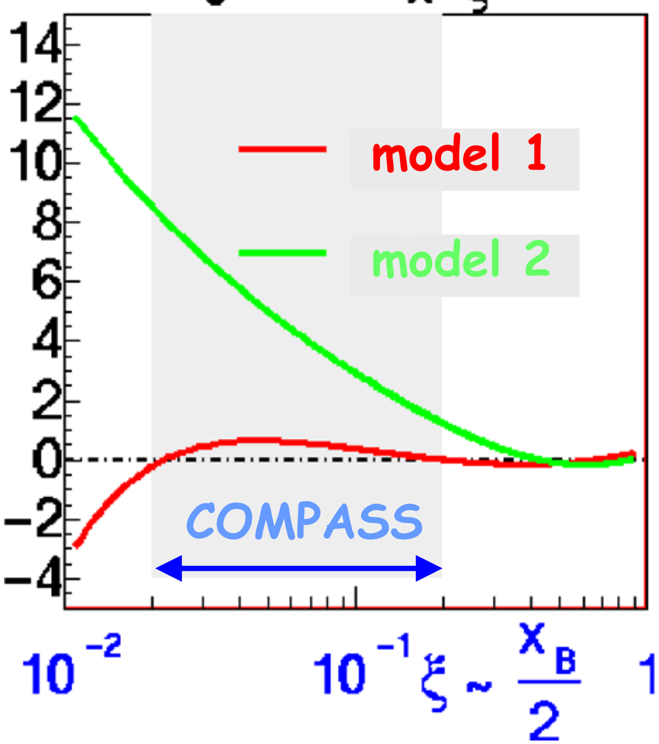
$\mathcal{L}$ = 1.3 10^{32} cm^{-2} s^{-1}
efficiency=25%
150 days data taking

Only 2/18 data sets

In total 3 bins in x_{Bj}= 0.05, 0.1, 0.2
6 bins in Q^2 from 2 to 7 GeV^2

Advantage of the kinematical domain of COMPASS

BCA $\sim P\left(\int dx \frac{H(x,\xi,t)}{x-\xi}\right)$



Model 1: $H(x,\xi,t) \sim q(x)\, F(t)$

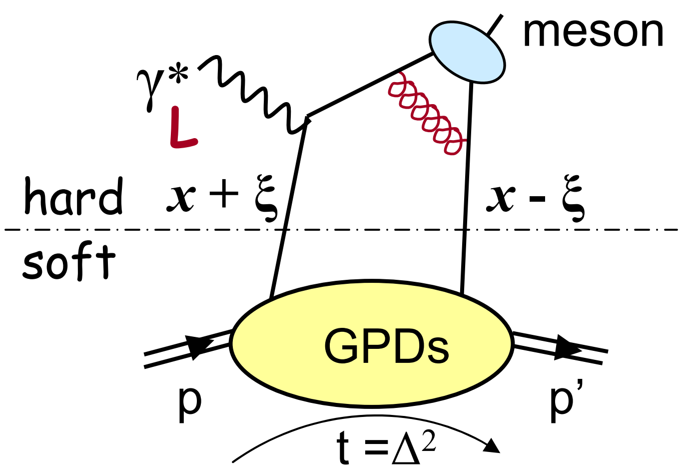
Model 2: $H(x,0,t) = q(x)\, e^{\,t\,\langle b_\perp^2 \rangle}$

$= q(x) \,/\, x^{\alpha' t}$

sensitivity to the different spatial distribution of partons ↗ when x_{Bj} ↘

range of COMPASS

Hard exclusive meson production ($\rho, \omega, \phi \ldots, \pi, \eta \ldots$)

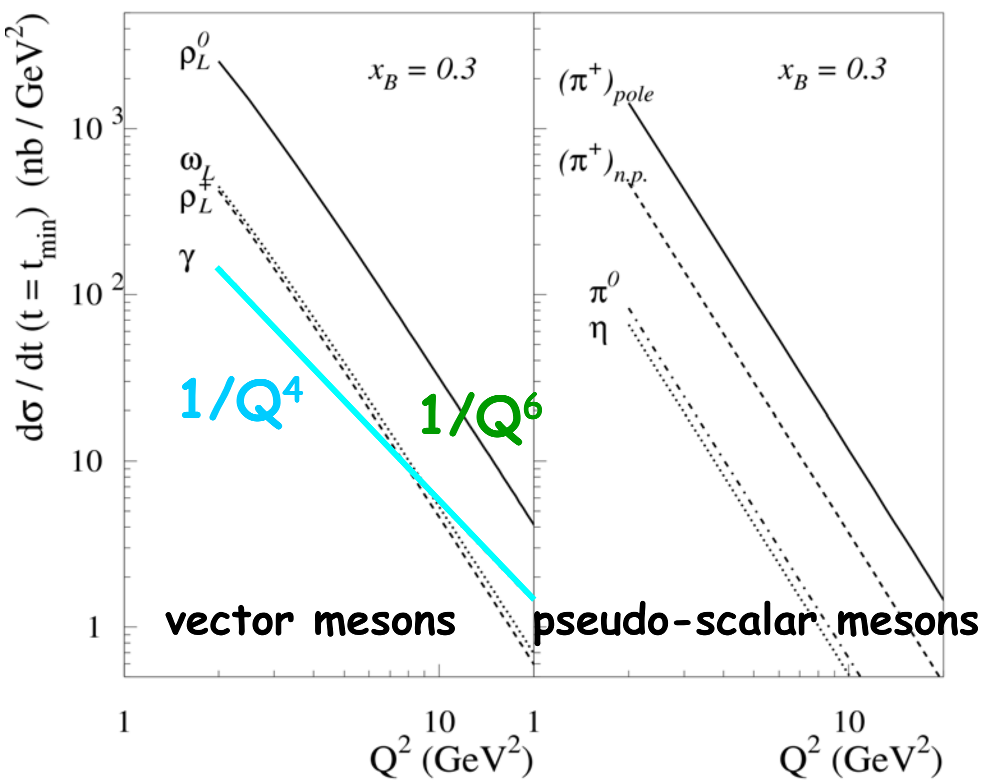


Collins et al. (PRD56 1997):

1. factorization applies only for γ^*_L

2. $\sigma_T << \sigma_L$

Scaling predictions:



ρ^0 largest production → present study with COMPASS

$\rho^0 \rightarrow \pi^+ \pi^-$

Selection of γ^*_L

Pseudo-scalar meson (spin 0) as π $\Rightarrow$ Rosenbluth separation

$$\sigma_{tot} = \sigma_T + \varepsilon\,\sigma_L$$

Vector meson (spin 1) as ρ^0 $\Rightarrow$ angular distribution of $\rho^0 \to \pi^+\pi^-$

+ s-channel-helicity-conservation in $p(\gamma^*_L, \rho_L)p$

With COMPASS + $\vec{\mu}$
Complete angular distribution

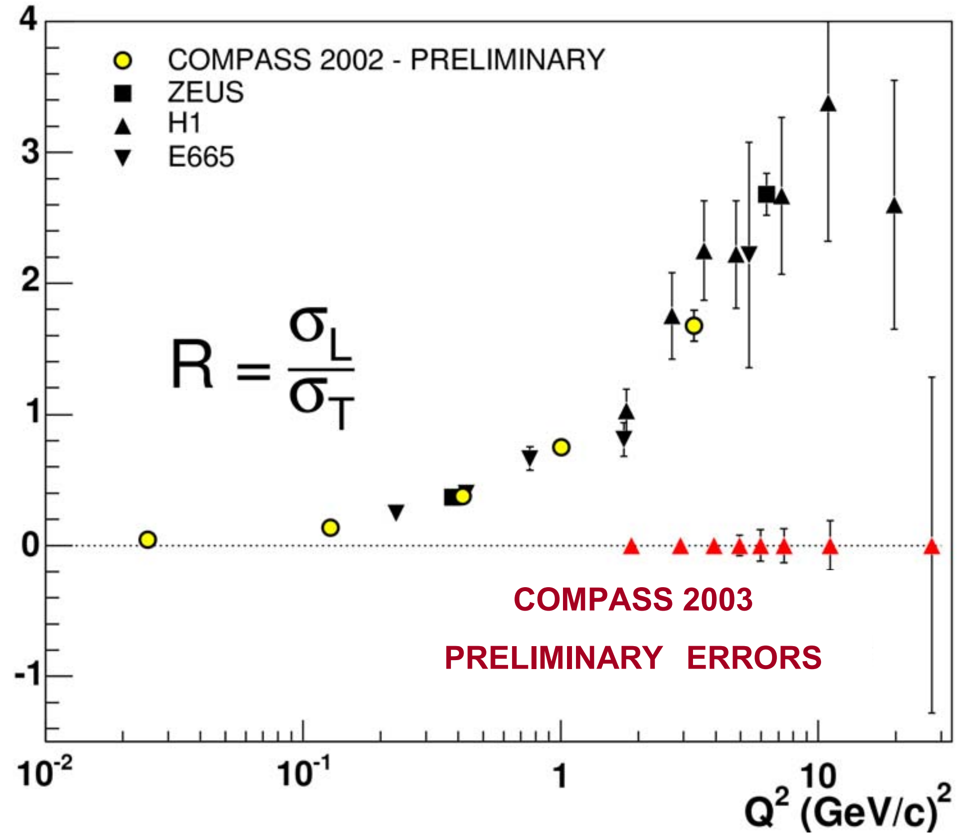
$\Rightarrow$ Full control of SCHC

COMPASS 2003

50 days $\mathcal{L} = 4.2\ 10^{32}\ cm^{-2}\ s^{-1}$

~ Equivalent to predictions 2010

150 days $\mathcal{L} = 1.3\ 10^{32}\ cm^{-2}\ s^{-1}$



" Longitudinal " Meson production : filter of GPDs

Cross section:

Vector meson production $(\rho, \omega, \phi ...)$ $\Rightarrow$ H & E

Pseudo-scalar production $(\pi, \eta ...)$ $\Rightarrow$ $\tilde{H}$ & $\tilde{E}$

$$H\rho^0 = 1/\sqrt{2}\ (2/3\ H^u + 1/3\ H^d + 3/8\ H^g)$$

$$H\omega = 1/\sqrt{2}\ (2/3\ H^u - 1/3\ H^d + 1/8\ H^g)$$

$$H\phi = -1/3\ H^s - 1/8\ H^g$$

Single spin asymmetry ~ E/H

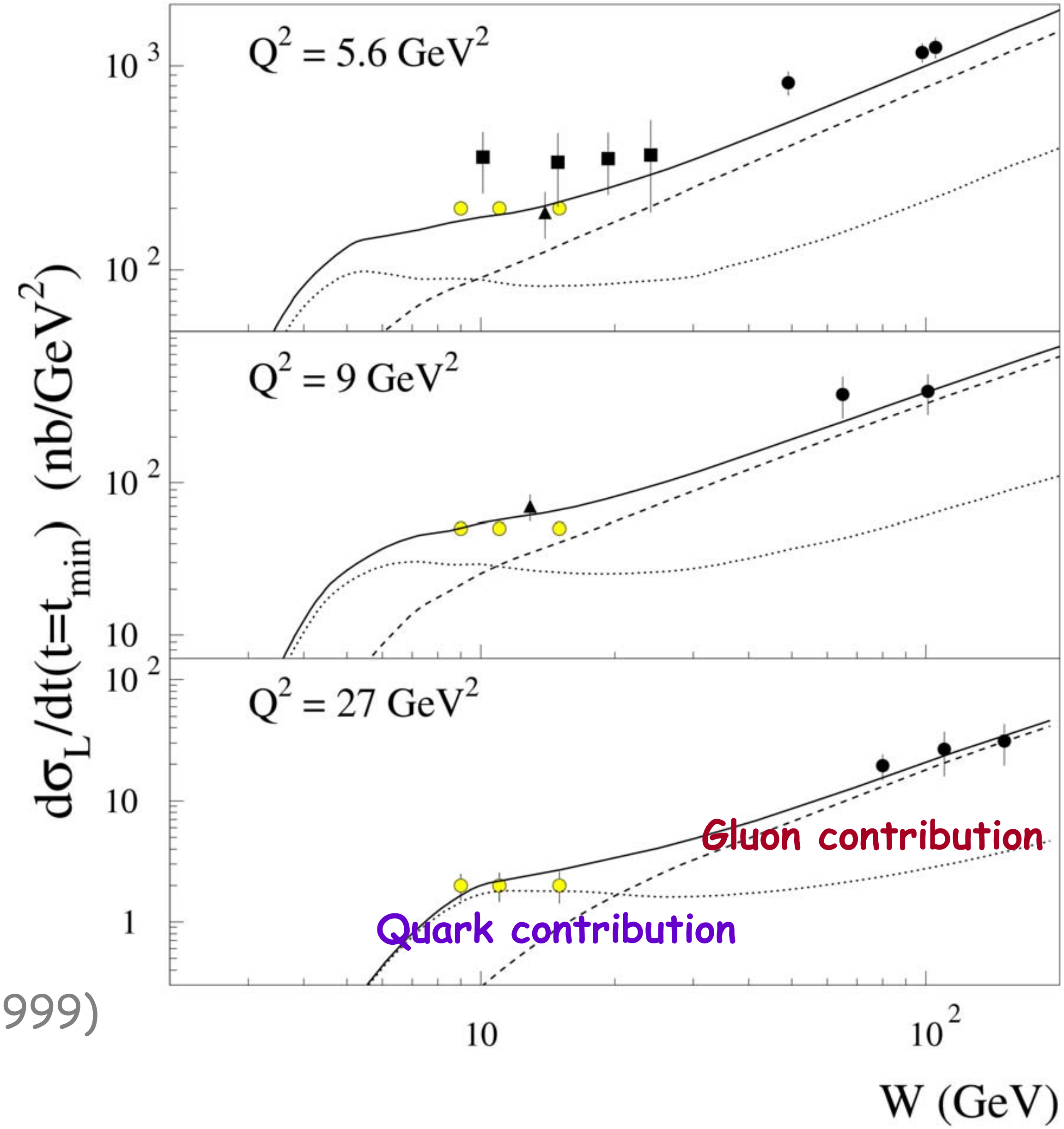
for a transverse polarized target
(can be investigated at COMPASS during transversity measurement)

Quark and gluon contributions

$\gamma^* + p \rightarrow \rho^0_L + p$

▲ NMC 94
■ E665 97
● ZEUS 93+95

○ Preliminary errors
for COMPASS 2003 (^{6}LiD)
≡ COMPASS 2010 (H)



Gluon GPD calculations:
Frankfurt *et al.* PRD54 (1996)

Quark GPD calculations:
Vanderhaeghen *et al.* PRD60 (1999)

Meson Production in the future around 2010

With a liquid Hydrogen target and the same muon flux than now

Measurement of hard exclusive meson production

ρ comfortable statistics until Q^2= 20 GeV^2

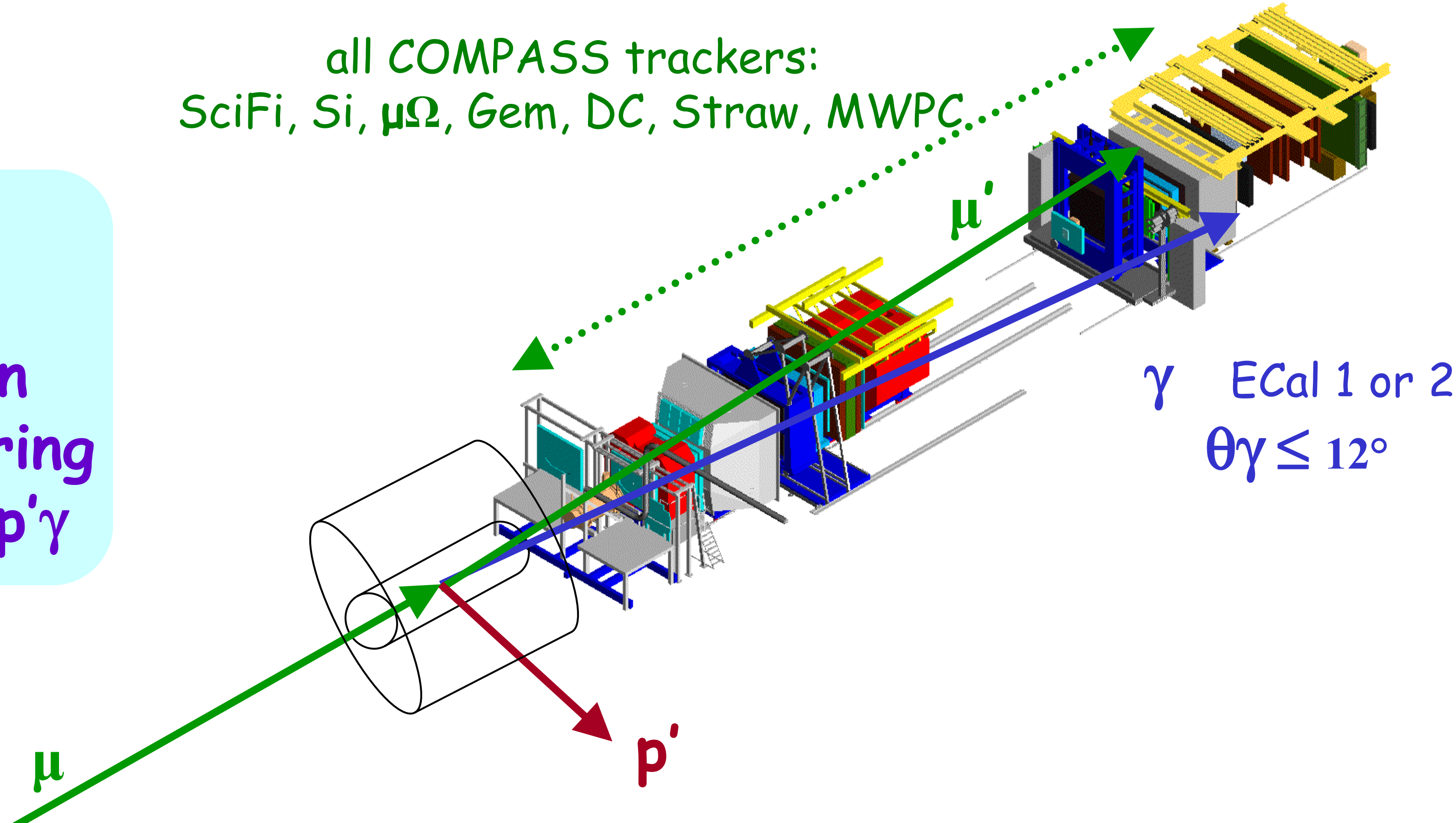
ω π η ϕ ⟶ Q^2= 7 GeV^2

Benefit of an increase in intensity for an extension of the range in Q^2

NB: for ω results from JLab the SCHC was not observed at Q^2 < 4GeV^2 and large x_{Bj}~ 0.4

Necessity to complete at large angle the high resolution COMPASS spectrometer

Deeply Virtual Compton Scattering
$\mu p \rightarrow \mu' p' \gamma$



By a recoil detector to insure the exclusivity of the reaction

Key role of the Calorimetry

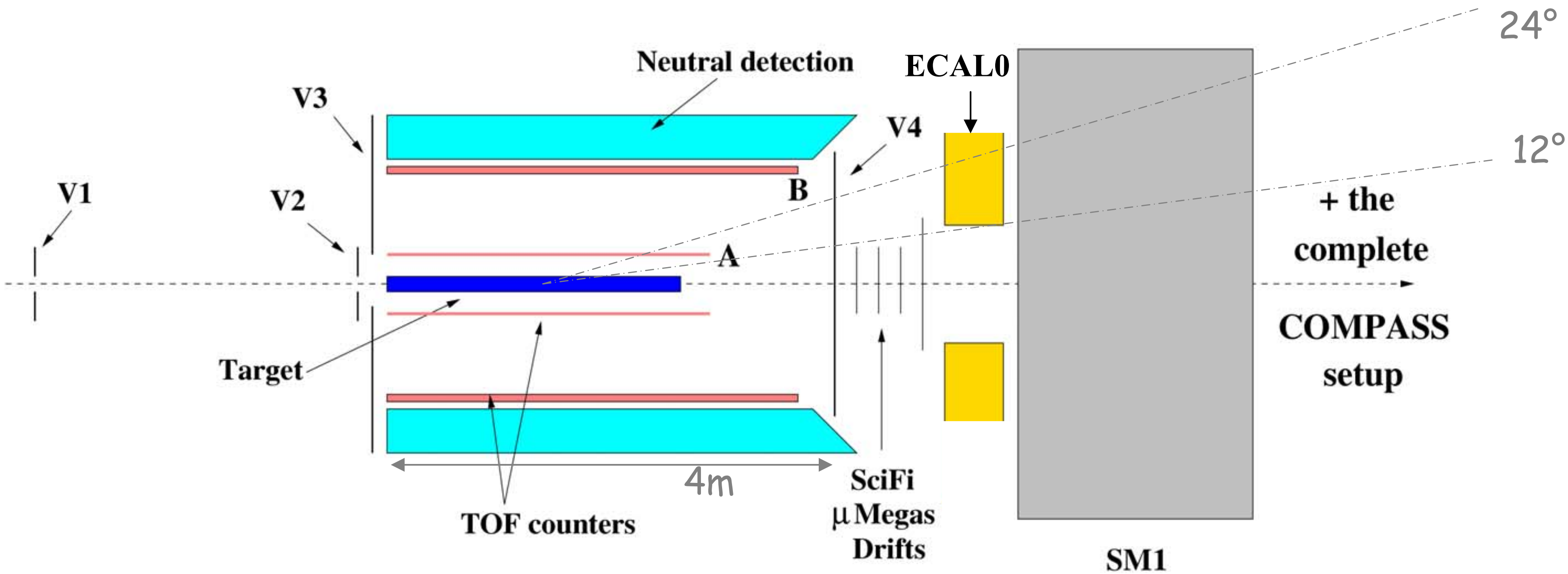
ECAL2 from 0.4 to 2° mainly lead glass GAMS
ECAL1 from 2 to 12° good energy and position resolution
for 2 photons separation
in a high rate environment

ECAL0 from 12 to 24° to be designed
for background rejection

⇒ Intensive Study of photon and pi0 production
linked to the hadron program

Additional equipment to the COMPASS setup

A possible solution (proposed in the Workshop on the Future Physics at COMPASS 26 Sept 2002)



challenge: 200ps ToF Resolution for 4m scintillating system

⇨ an accurate t measurement for 3-dim GPD representation in order to get the spatial information

Goal of the JRA (Bonn-Mainz-Warsaw-Saclay) in the EU FP6:
Realisation of a prototype detector consisting of a 45° sector

Other accurate measurement with the same setup

Parasitic:

- Structure Function F_2 on Hydrogen

Dedicated targets:

- Evolution of F_2 in the nuclear matter
  Shadowing effect on light nuclei
  (Smirnov EPJC (1999))

- Color Transparency on C and Pb

Universal Structure Functions

DIS ep→eX
$$\frac{d^2\sigma}{dxdQ^2} = \frac{4\pi\alpha^2}{xQ^2}\left(F_2(x,Q^2)(1-y-\frac{Q^2}{4E^2}) + xy^2 F_1(x,Q^2)\right)$$

$$\frac{d^2\sigma}{dxdQ^2} = \Gamma\left(\sigma_T(x,Q^2) + \varepsilon\sigma_L(x,Q^2)\right) \qquad R(x,Q^2) = \frac{\sigma_L(x,Q^2)}{\sigma_T(x,Q^2)}$$

$$\frac{d^2\sigma}{dxdQ^2} = \frac{4\pi\alpha^2}{Q^4}\frac{F_2(x,Q^2)}{x}\left(1-y-\frac{Q^2}{4E^2} + \frac{y^2+Q^2/E^2}{2(1+R(x,Q^2))}\right)$$

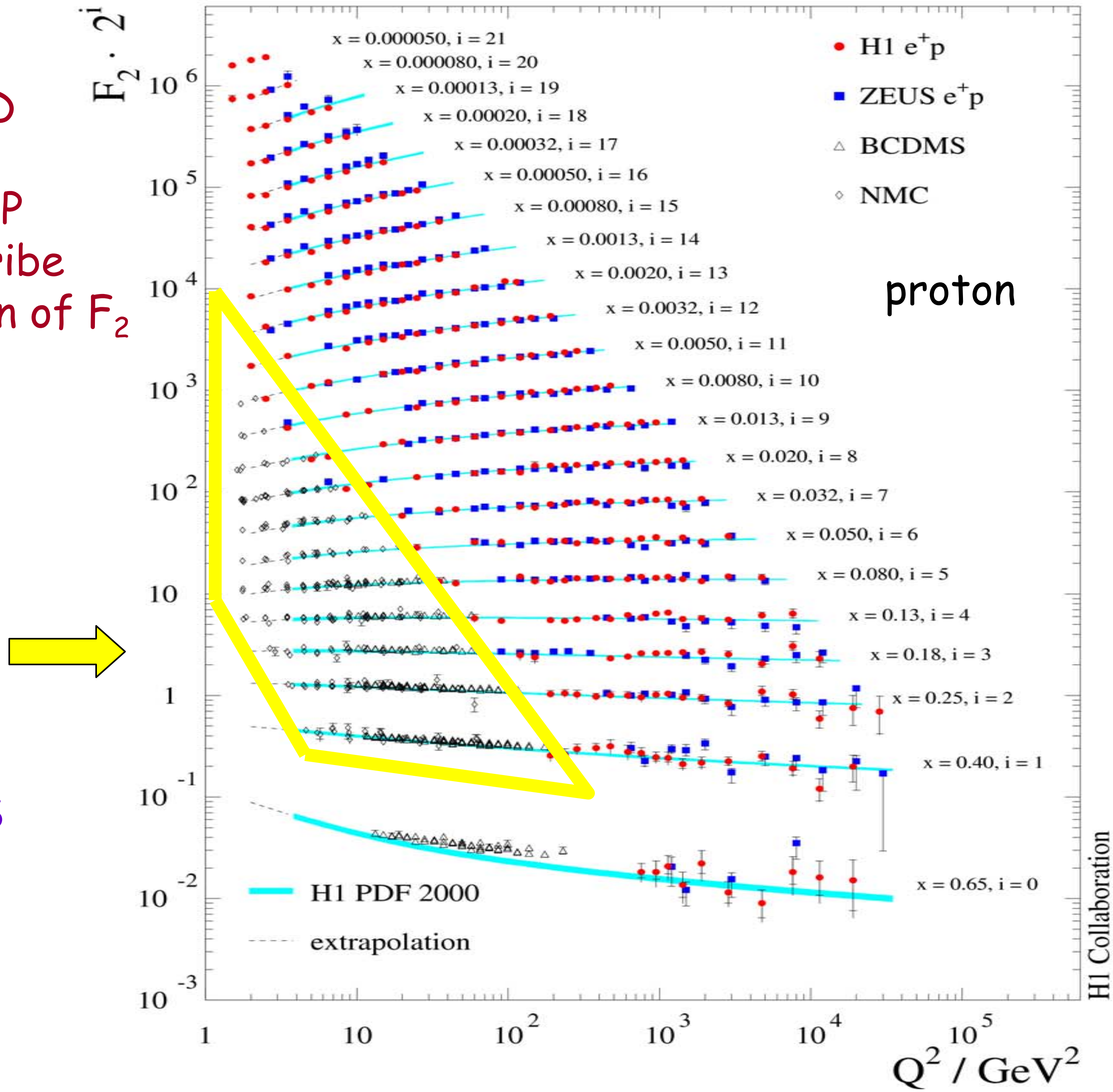
They provide the parton distributions
$$F_2(x,Q^2) = x\sum_q e_q^2\left(q(x,Q^2) + \bar{q}(x,Q^2)\right)$$

New measurements of F_2 and R are beneficial if they have improved statistics and systematical errors or if they are in new kinematical domains

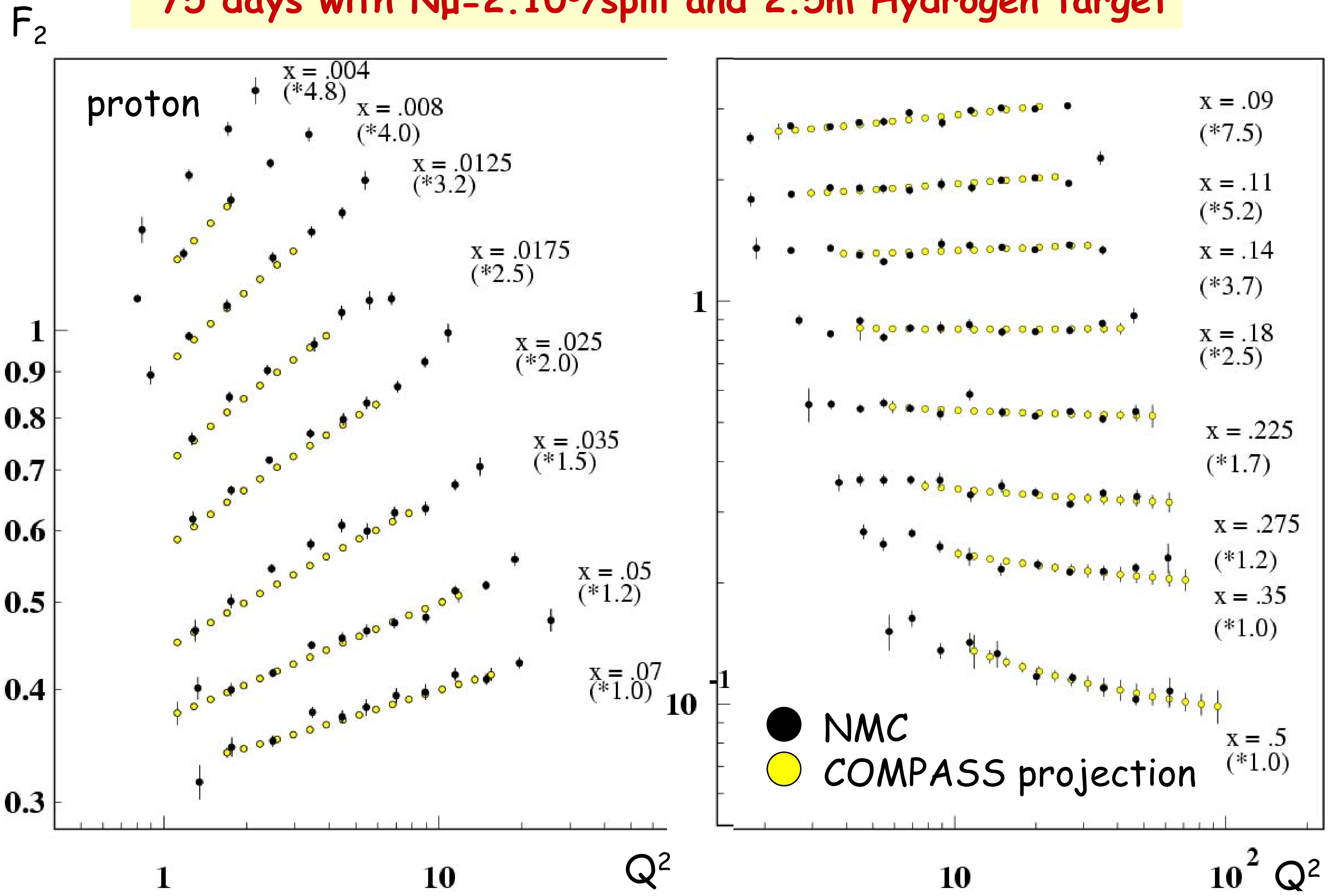
Success of QCD

The NLO DGLAP equations describe the Q^2 evolution of F_2

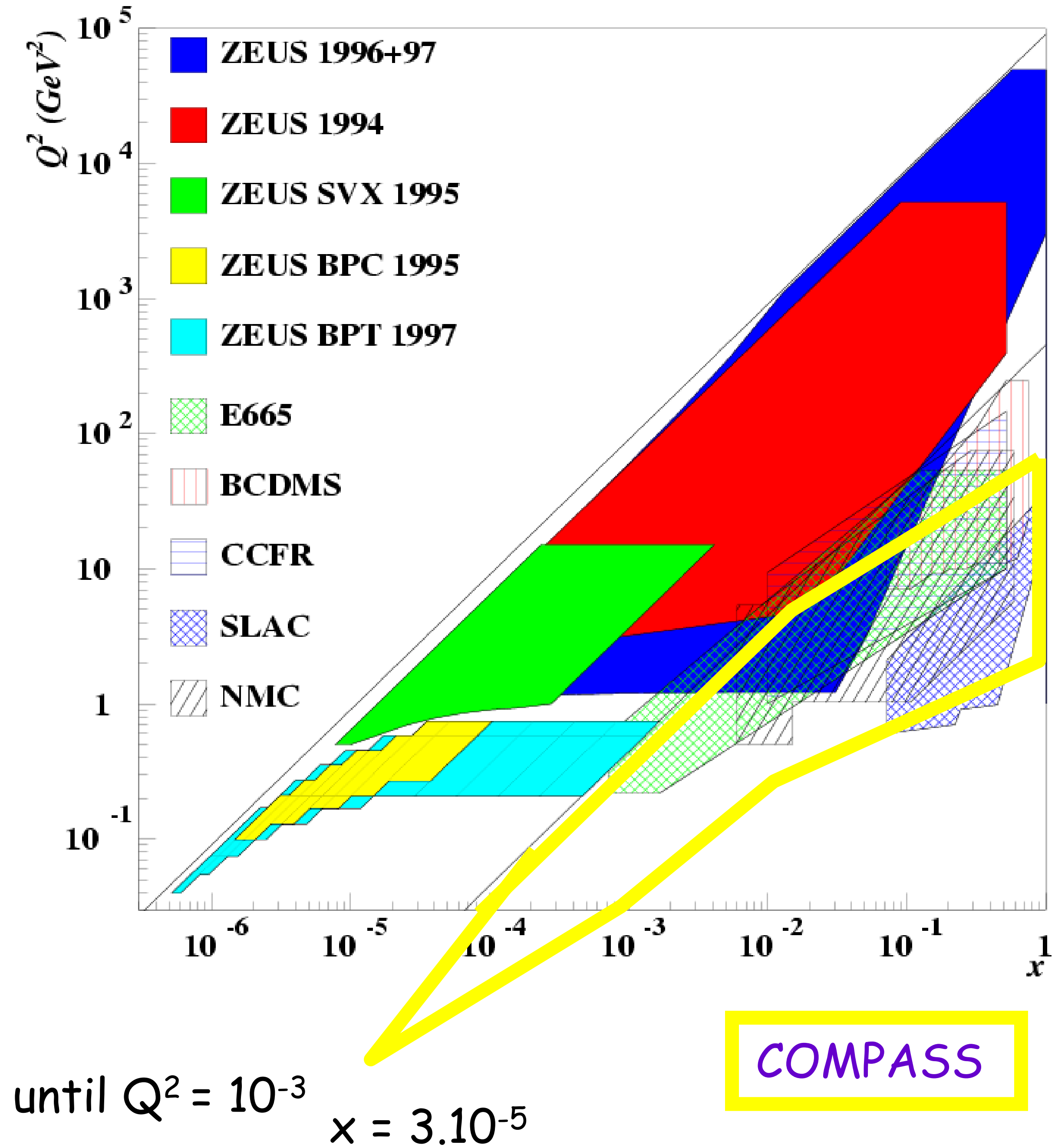
Possible
New
Accurate
Measurement
At COMPASS



Projection for COMPASS
75 days with Nμ=2.10⁸/spill and 2.5m Hydrogen target



Kinematical domains for colliders and fixed target experiments



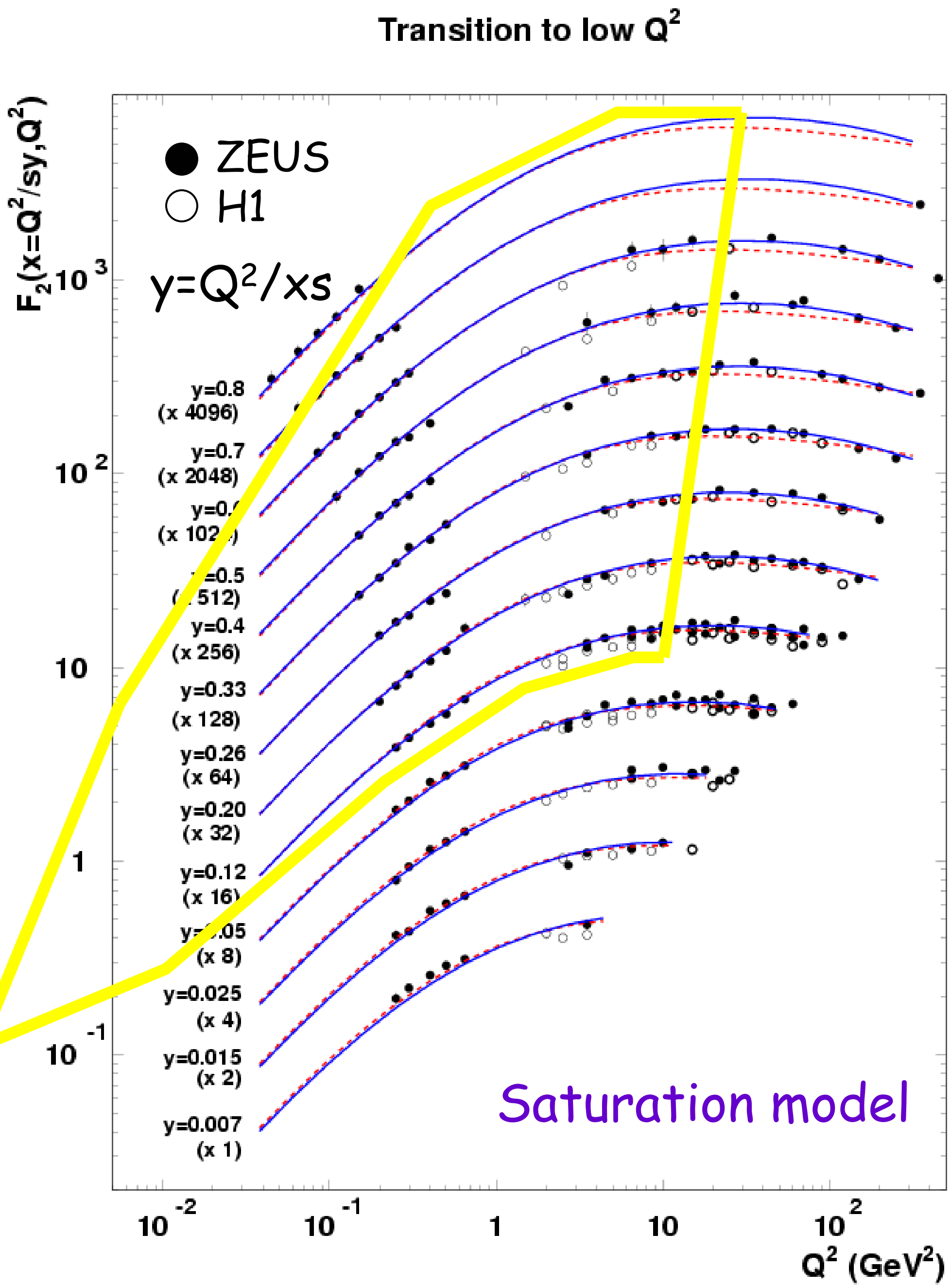
Understanding of low x physics

New phenomena
Coherent interaction of partons
Log1/x in the QCD evolution

Transition
from high to low Q^2
to understand confinement

Saturation model

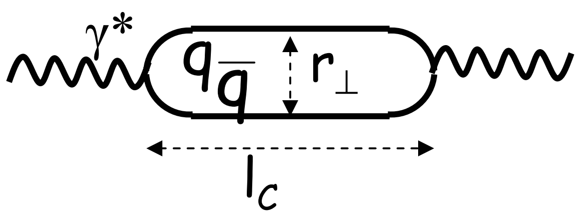
New data at low x low Q^2
with COMPASS

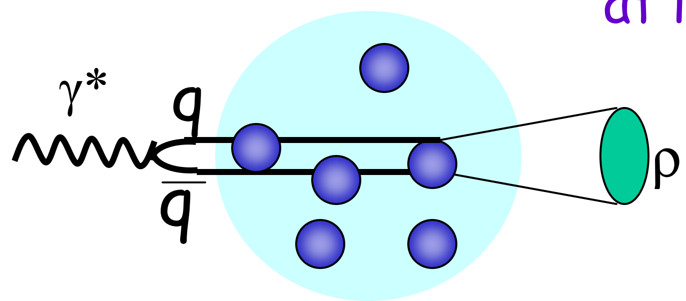


Bartels, Golec-Biernat, Kowalski PRD66 (2002)

Color Transparency CT via exclusive vector meson production

QCD prediction
∃ small color singlet object for which interactions with nuclear medium vanish
at large Q^2





Small size configuration SSC

$r_\perp = k/Q$ k varies with quark mass

$r_\perp(u\bar{u}) \approx r_\perp(d\bar{d}) \approx 0.3\text{fm}$ at Q^2=10 GeV^2 | $r_{\perp\rho} \approx$ 1fm

SSC interaction in pQCD $\sigma_{q\bar{q}N}(r_\perp, x_{Bj}) \approx$ 3mb at $x_{Bj}=10^{-2}$ | $\sigma_{\rho N} \approx$ 25mb

on quasi-free nucleons in nuclei

CT: $T = \frac{\sigma_A / A}{\sigma_N} \rightarrow 1$ when $Q^2 \nearrow$

Coherence length

$$l_C = \frac{2\nu}{Q^2 + M_{q\bar{q}}^{\;2}}$$

Coherence effects can mimic CT

l_C= 1-6fm at HERMES
1-20fm at COMPASS
1-200fm at E665

r_{Pb}=11fm

Color Transparency CT via exclusive vector meson production

complete programme for CT at COMPASS

- A, Q^2 and x_{Bj} dependence of cross sections for ρ (or ϕ,J/Ψ…) production
- Study at fixed coherence length
- Measure both coherent $\mu A \rightarrow \mu \rho A$ and incoherent $\mu A \rightarrow \mu \rho N(A-1)$
- Measure σ_L and σ_T

On C and Pb of 70g/cm2
2.10^8 μ/spill
38 days equally distributed
$\varepsilon_{SPS+COMPASS}$=25%

Large number of events
in the COMPASS acceptance

Eμ=190 GeV

$2 < Q^2 < 20$ GeV^2
$0.006 < x_{Bj} < 0.1$

$1 < l_c < 20$fm r_{Pb}=11fm

Competition to COMPASS

measurements at COMPASS in 2010
in the x_{Bj} intermediate range
compared to:

HERMES 2 data years until 2007
equivalent integrated luminosity/year
with a new recoil detector
reduced kinematical domain in Q^2

e-RHIC in the far future around 2015?
high energy in the collider mode
high luminosity

Rq: H1 and ZEUS until 2007 ($x_{Bj}<10^{-2}$)
JLab 11 GeV in 2010 (large x_{Bj})

Roadmap for GPDs at COMPASS

2004-2009

Present COMPASS experiment with a polarized target
Complete analysis of ρ production
→ SCHC study in a large range in Q^2 0.02-25 GeV^2
→ E/H investigation with the transverse polarized target

2004-2006

Realization of the recoil detector prototype within the JRA
JRA/FP6: Bonn, Mainz and Warsaw and CEA Saclay

We are considering to submit a proposal in 2006

→ **2007-2009 :** construction of the recoil detector
cryogenic target, ECal0

2010-2015 : GPDs and related physics at COMPASS