COMPASS plans to measure GPDs

Jean-Marc Le Goff
DAPNIA/CEA-Saclay
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workshop on Orbital Angular Momentum

- The COMPASS experiment
- GPDs at COMPASS
- now: deep ρ production
- $\geq$2010: DVCS and HEMP

The COMPASS experiment

The COMPASS Collaboration

(230 Physicists from 12 Countries)

Dubna (LPP and LNP), Moscow (INR, LPI, State University), Protvino

CERN

Bielefeld, Bochum, Bonn (ISKP & PI), Erlangen, Freiburg, Heidelberg, Mainz, München (LMU & TU)

Warsaw (SINS), Warsaw (TU)

Prag

Helsinki

Nagoya

Lisboa

CEA-Saclay

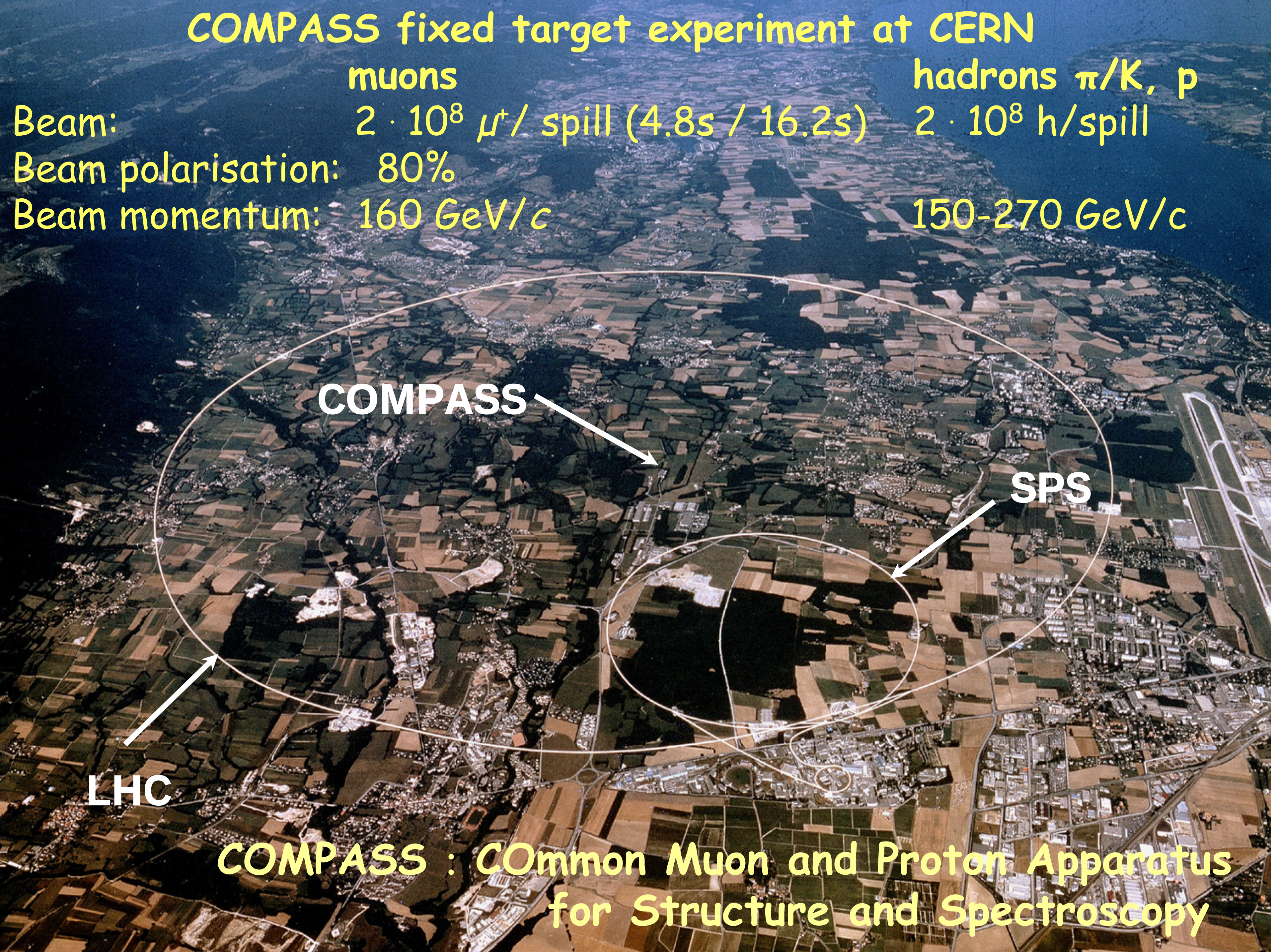
Torino(University,INFN), Trieste(University,INFN)

Burdwan, Calcutta

Tel Aviv

COMPASS fixed target experiment at CERN

	muons	hadrons π/K, p
Beam:	$2 \cdot 10^8$ μ^+/ spill (4.8s / 16.2s)	$2 \cdot 10^8$ h/spill
Beam polarisation:	80%	
Beam momentum:	160 GeV/c	150-270 GeV/c



COMPASS : COmmon Muon and Proton Apparatus for Structure and Spectroscopy

Physics goals

muon beam

nucleon spin structure

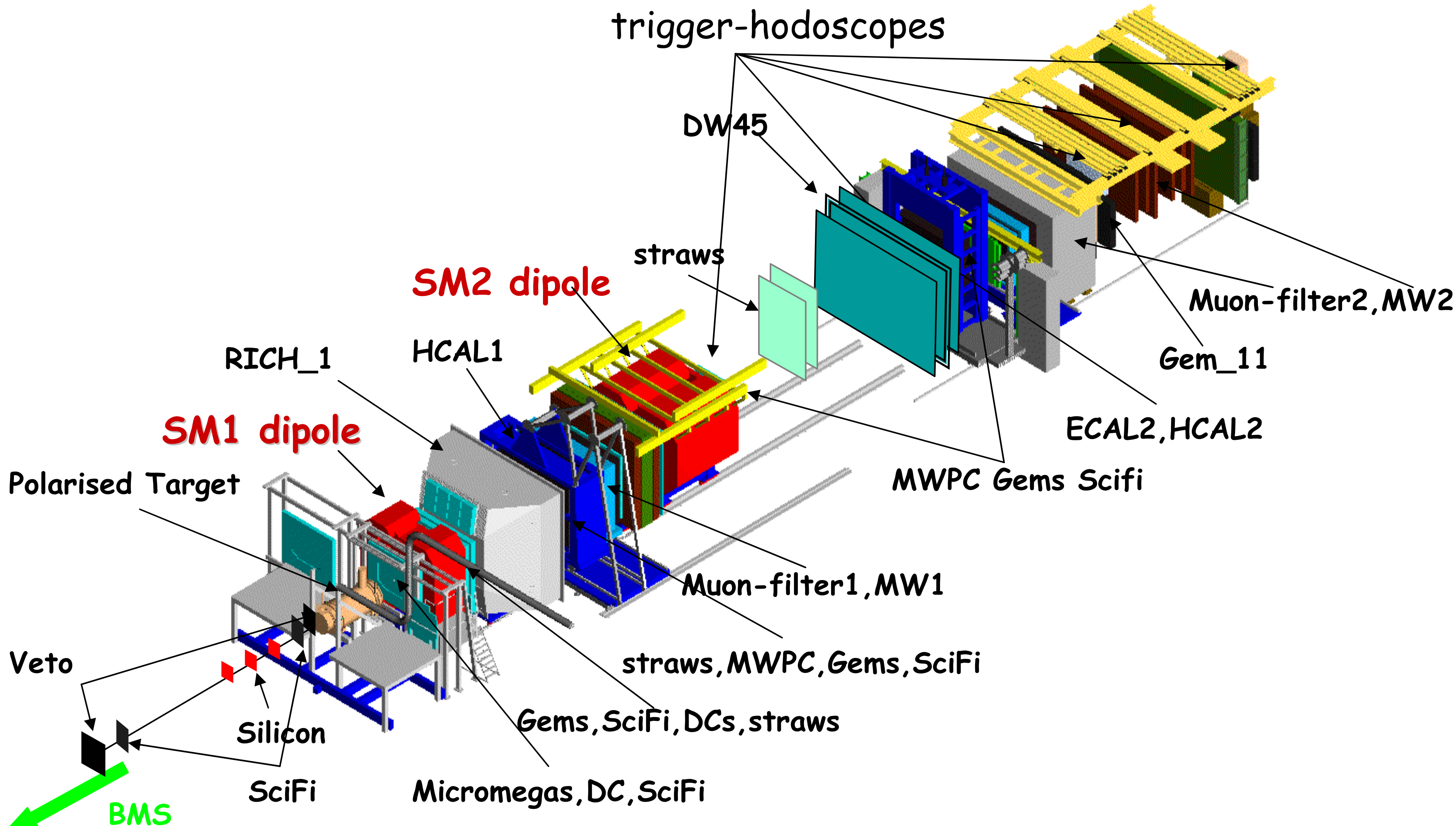
- Quark and **Gluon Polarization** in (longitudinally) polarized nucleons
- **transverse spin distribution** function $\Delta_T q(x)$
- Flavor dependent polarized quark helicity densities $\Delta q(x)$
- Lambda polarisation
- **Diffractive vector-meson production**

hadron beams

nucleon spectroscopy

- Primakoff-Reactions
  - **polarizability** of π and K
- **Exotics** : glueballs and hybrids
- **charmed** mesons and baryons
  - semi-leptonic decays
  - double-charmed baryons

Spectrometer 2002 → 2004

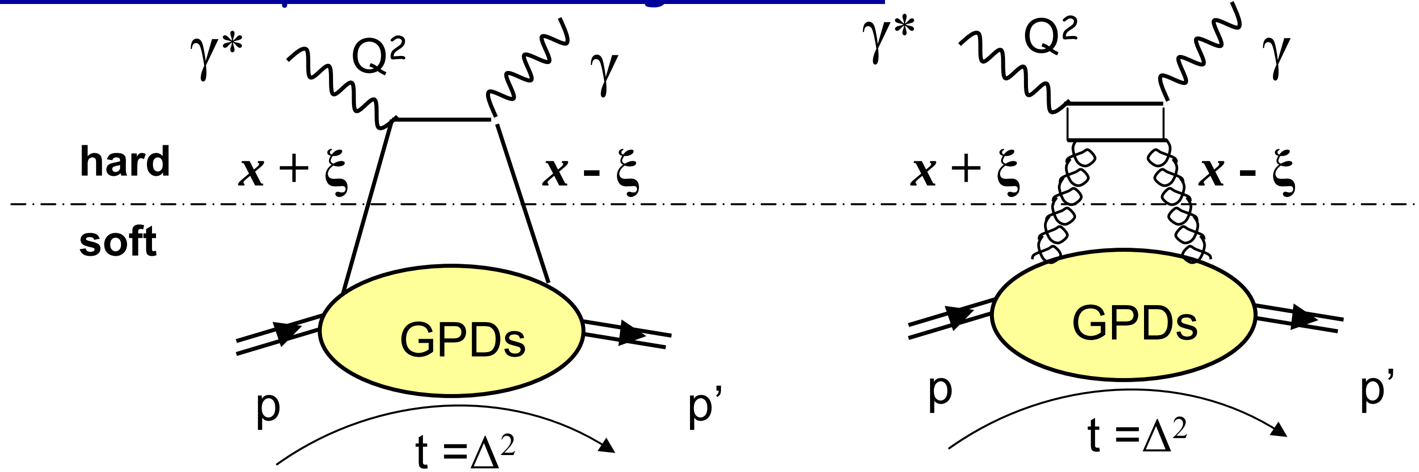


COMPASS and GPDs

measurement of GPDs

Deeply Virtual Compton Scattering (DVCS):

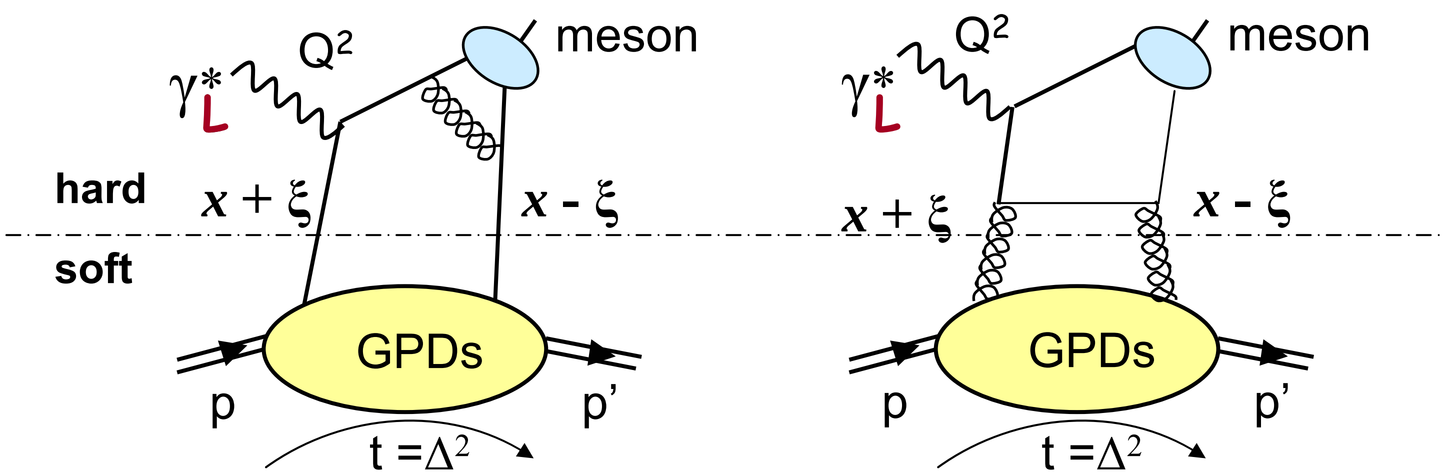
Collins *et al.*



Q^2 large

$t \ll Q^2$

Hard Exclusive Meson Production (HEMP):



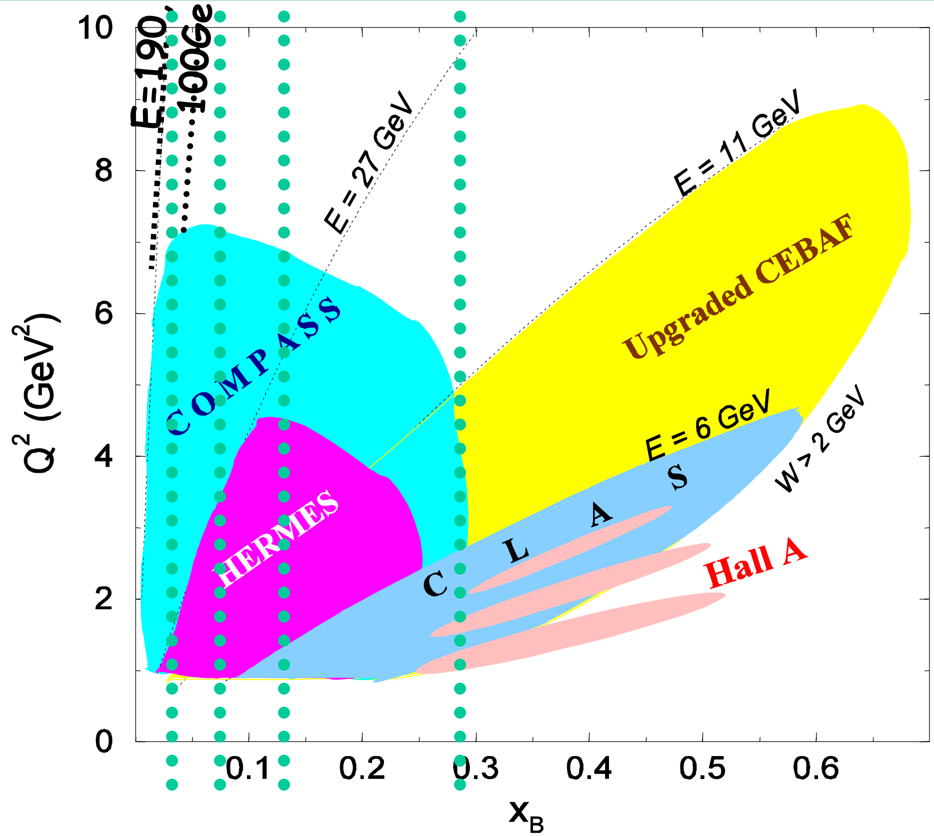
$+ \gamma^*_L$

Quark contribution

Gluon contribution

Complementarity of experiments

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 plans

Valence quarks

JLab
PRL87(2001)

if Nμ × 5 ⇒ $Q^2 < 17\ GeV^2$

Benefit of a higher muon intensity for GPDs study

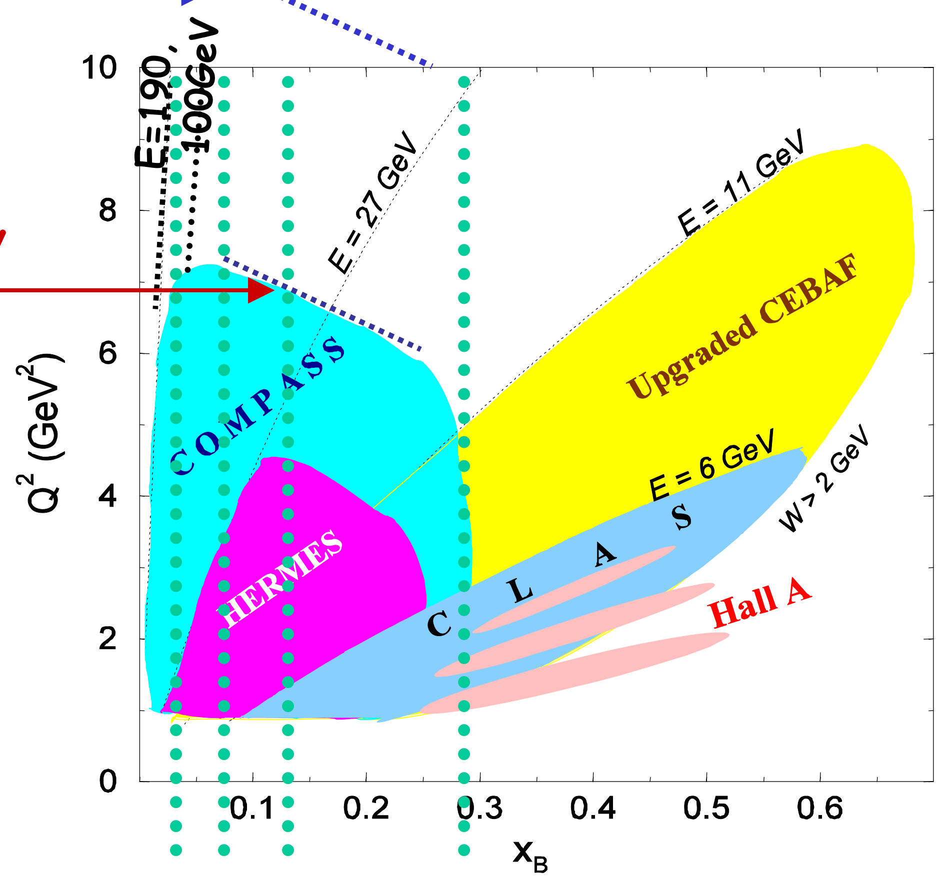
if Nμ × 2 ⇒ $Q^2 < 11\ GeV^2$

DVCS limited by luminosity

now $N_\mu = 2.10^8 \mu$ /SPS spill

⇒ $Q^2 < 7.5\ GeV^2$

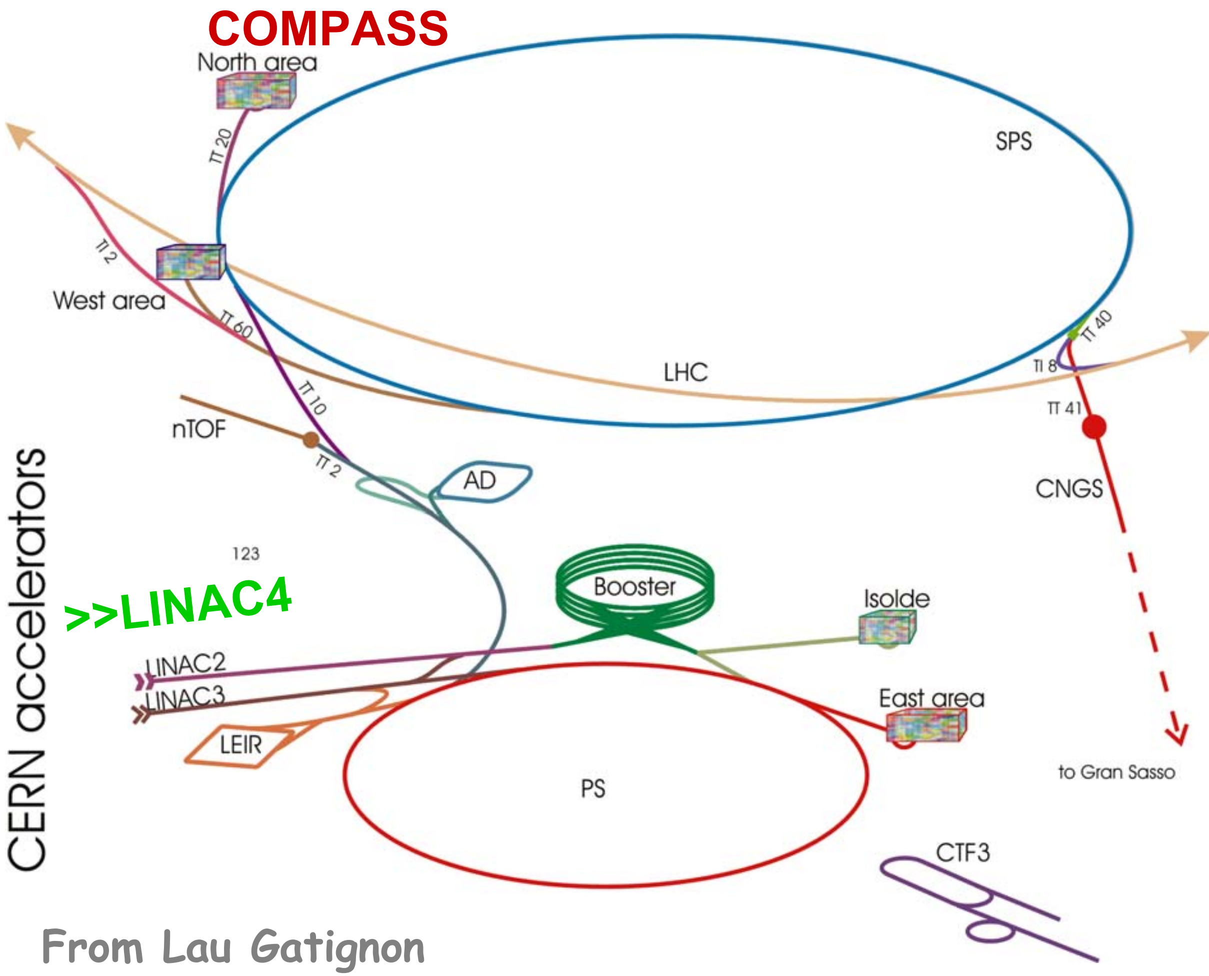
At fixed x_{Bj}, study in Q^2



μ flux at COMPASS in 2010 ?

☹ sharing CNGS/FT

☺ new Linac 4 → up to 10 times more p +improve μ line

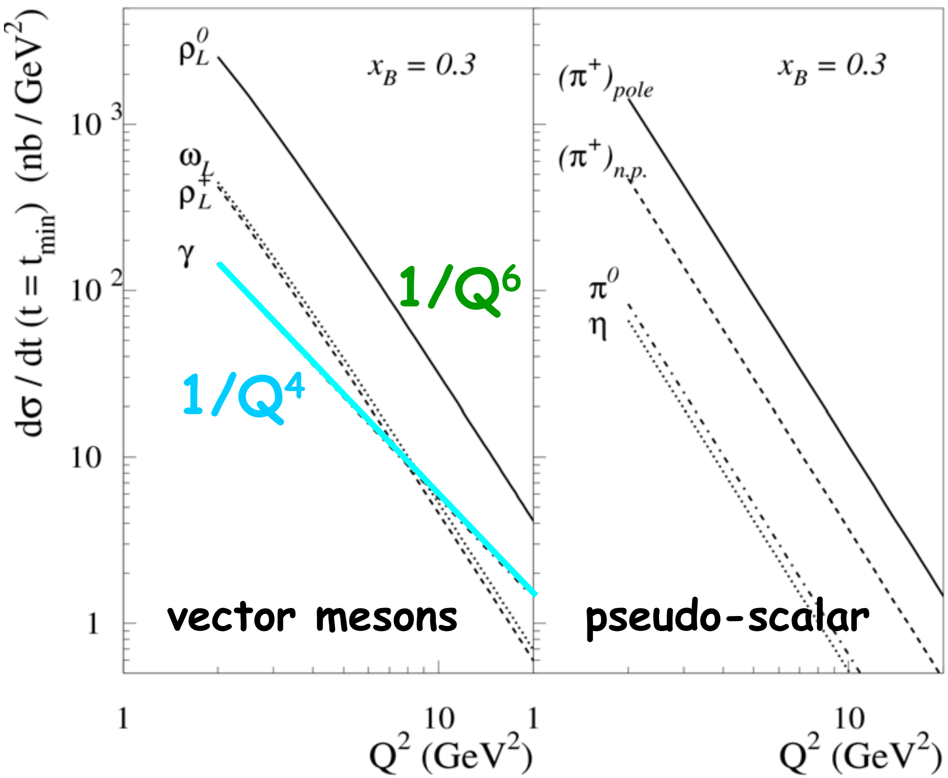


From Lau Gatignon

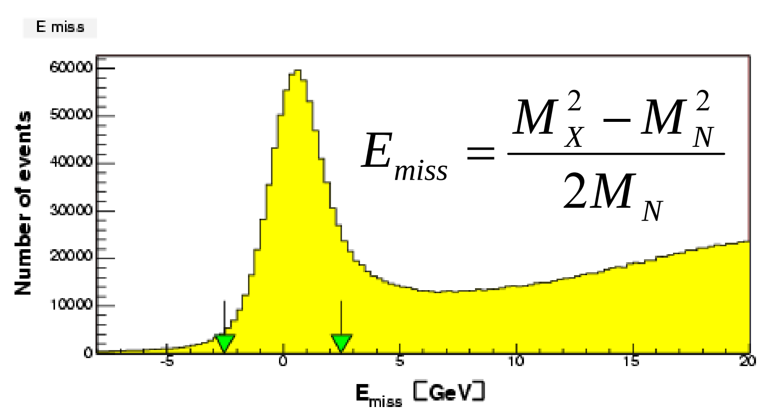
What can we measure now ?

DVCS, HEMP ?

Vanderhagen et al.:



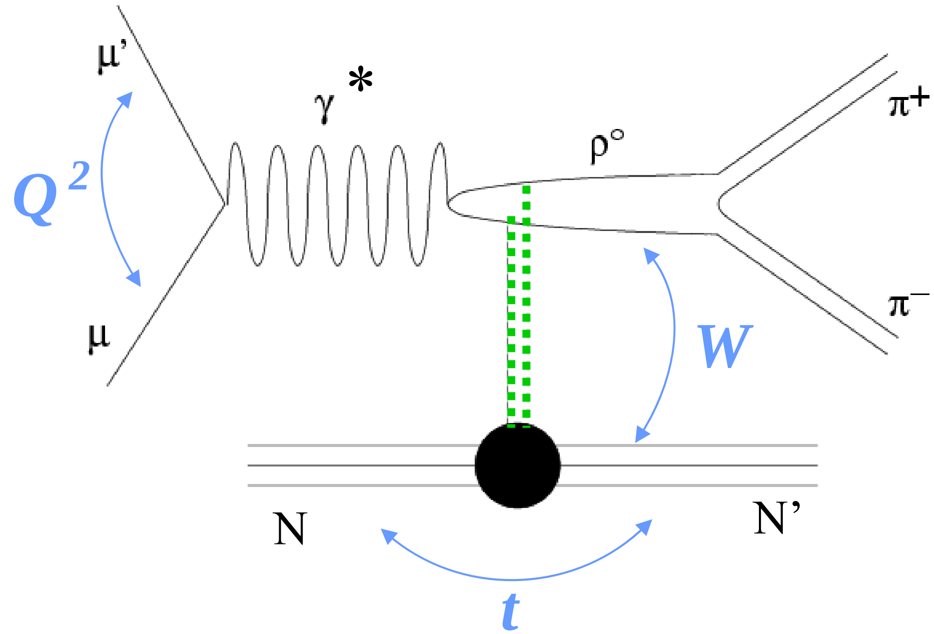
- σ_{DVCS} small, bckg
- HEMP factorization: γ_L
- vector meson decay
  $\rightarrow R=\sigma_T/\sigma_L$
- ρ^0 largest σ
- $\rho^0 \rightarrow \pi^+ \pi^-$, charged particules



$$E_{miss} = \frac{M_X^2 - M_N^2}{2M_N}$$

Diffractive ρ_0 production

$\mu N \rightarrow \mu' N' \rho_{\rightarrow \pi^+ \pi^-}$



Exp (NMC, E665, Zeus, H1, Hermes):

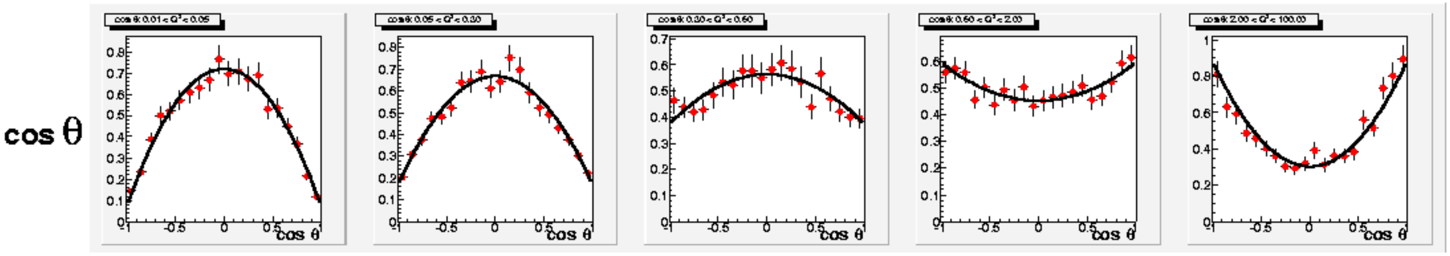
- $\lambda_\rho \approx \lambda_\gamma$ S-channel helicity conservation SCHC
- exchanged object has natural parity : $P=(-1)^J$ NPE

Spin properties of amplitudes

- angular dist. of $\rho \to \pi^+\pi^-$: spin density matrix el†
- they are bilinear combinations of
  helicity amplitudes : $T_{\lambda_\rho \lambda_\gamma} = A\left(\gamma^*(\lambda_\gamma) \to \rho(\lambda_\rho)\right)$
- $\lambda_\gamma = \pm 1, 0 \quad \lambda_\rho = \pm 1, 0 \quad \to$ 9 amplitudes
- if NPE $\quad T_{-\lambda_\rho -\lambda_\gamma} = (-1)^{\lambda_\rho - \lambda_\gamma} T_{\lambda_\rho \lambda_\gamma} \to$ 5 amplitudes
- T_{00}, T_{11} » T_{01}, T_{10} » T_{-11}
  SCHC   1 helicity flip   2 flips

r^{04}_{00} spin density matrix el^{t}

0.01 < Q² < 0.05 < Q² < 0.3 < Q² < 0.6 < Q² < 2.0 < Q² < 10 GeV²

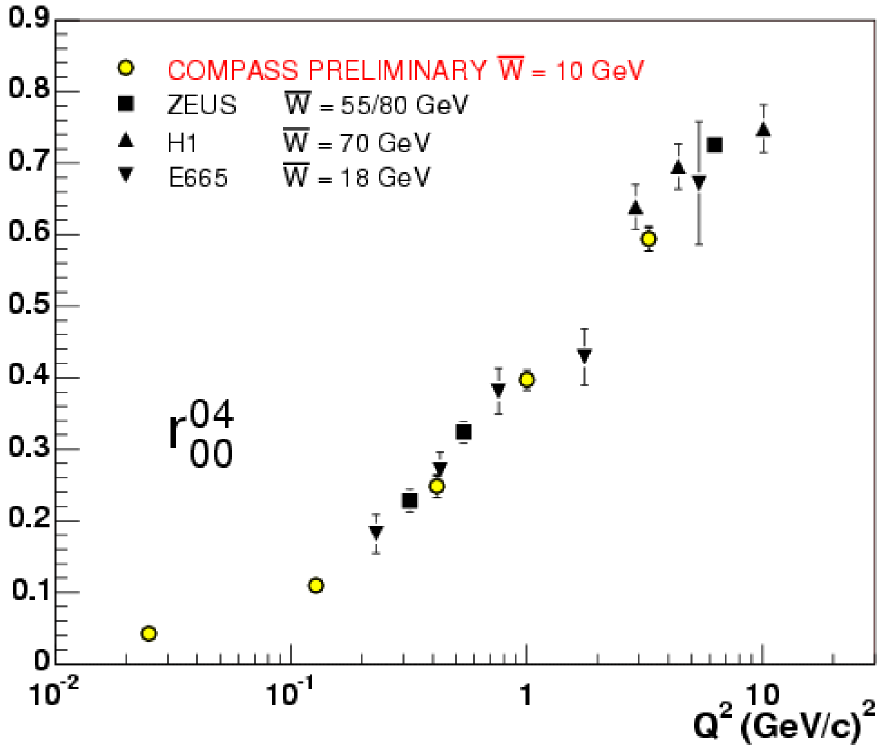


Distribution :

$$W(\cos\theta) = \frac{3}{4}\left[(1 - r^{04}_{00}) + (3r^{04}_{00} - 1)\cos^2\theta\right]$$

in terms of amplitudes:

$$r^{04}_{00} \sim \frac{|T_{01}|^2 + (\varepsilon + \delta)|T_{00}|^2}{\sigma_{Tot}} \xrightarrow{SCHC} \frac{\sigma_L}{\sigma_{Tot}}$$

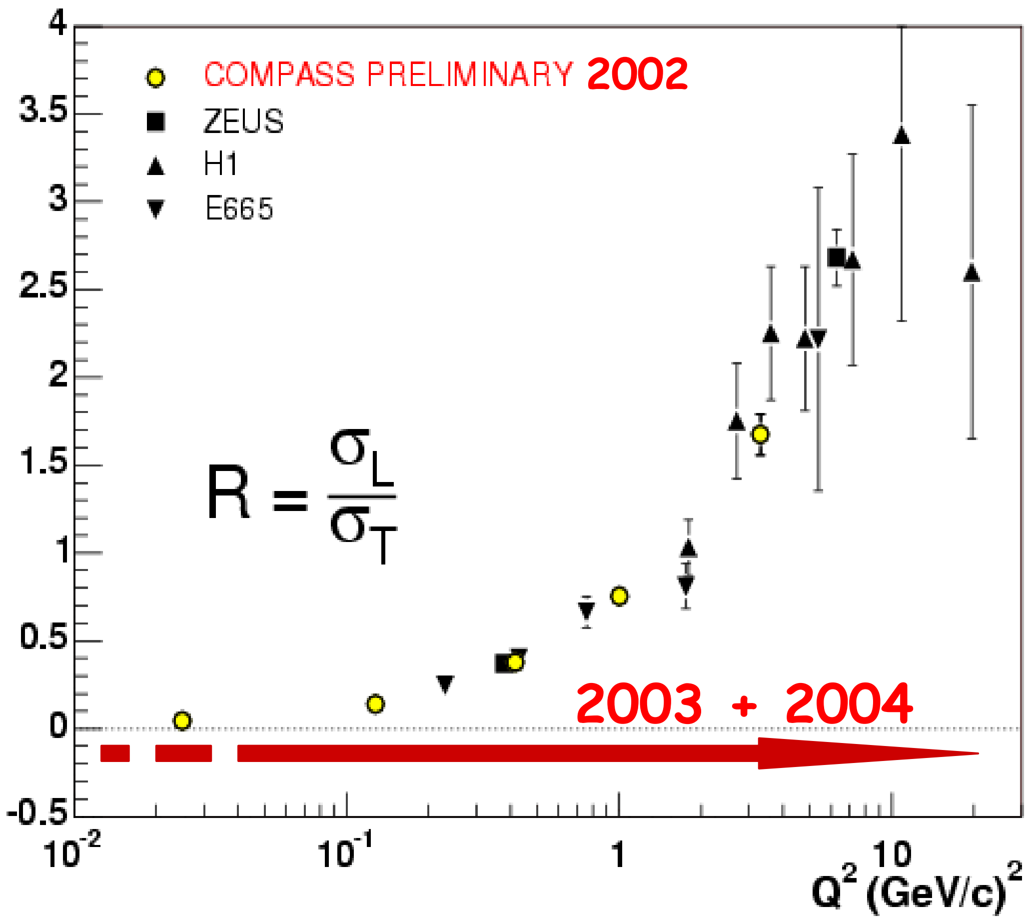


Determination of $R=\sigma_L/\sigma_T$

- If SCHC holds :

$$R = \frac{\sigma_L}{\sigma_T} = \frac{1}{(\varepsilon + \delta)} \frac{r_{00}^{04}}{1 - r_{00}^{04}}$$

- σ_L is dominant at $Q^2>2$
- 2002: high stat
  in large Q^2 range
- 2003 and 2004 data :
  - much more stat
  - better high Q^2 coverage



Conclusions on rho

- SCHC $\rightarrow$ R
- σ_{tot} + R $\rightarrow$ σ_L
- when $Q^2 > 2$ $\rightarrow$ $R > 1$: accurate σ_L
- we have transv. target spin asym $\rightarrow$ E/H
  important for Ji sum rule ($\int$E+H)
- exploratory measurement
  (no exclusivity, nuclear target)

Towards a dedicated experiment for DVCS and HEMP

Additions to COMPASS setup

2.5m liquid H2 target
to be designed and built
$\mathcal{L}$ = 1.3 10^{32} cm^{-2} s^{-1}

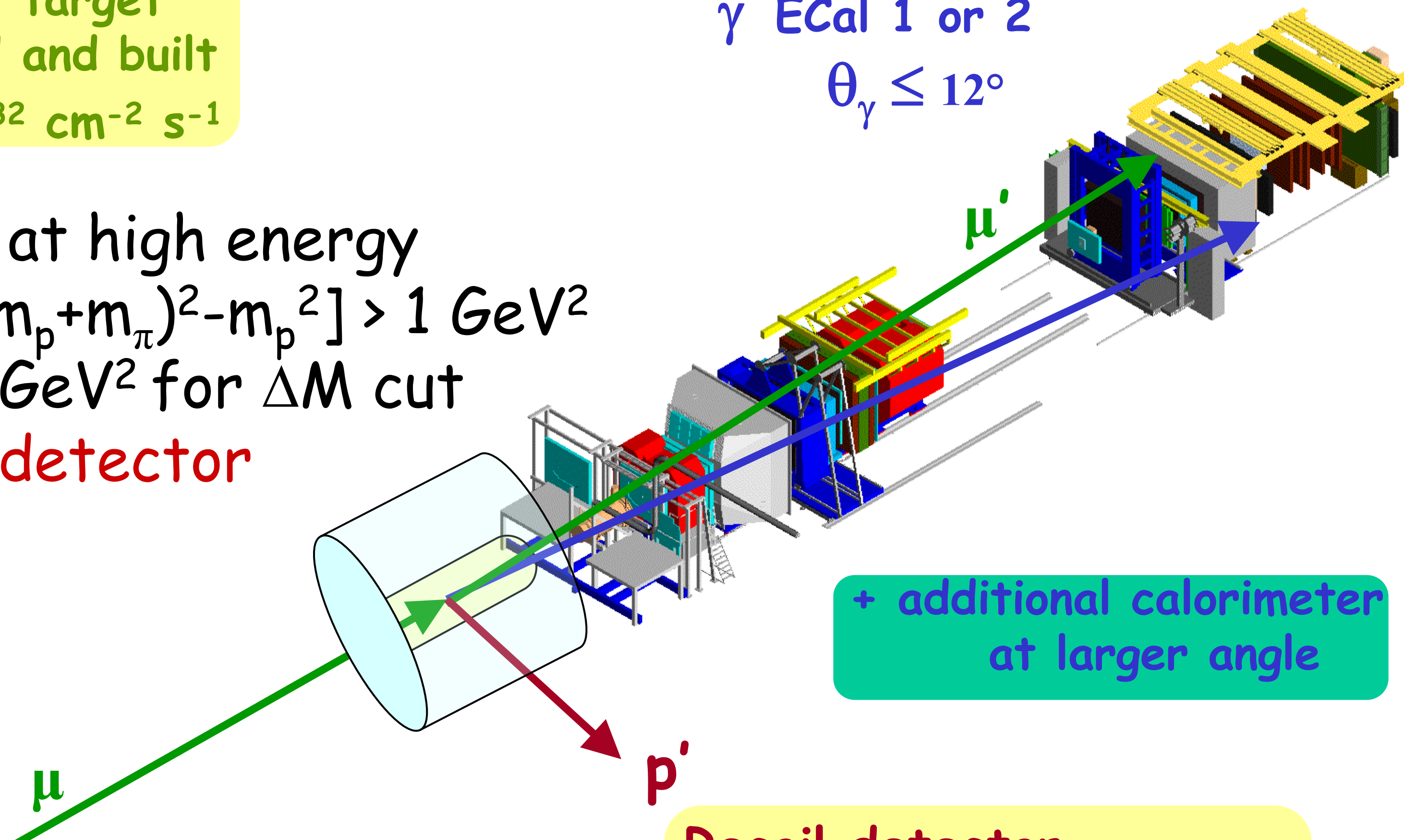
Exclusivity: at high energy

$\delta\Delta M^2 = \delta[(m_p+m_\pi)^2-m_p^2] > 1\ GeV^2$

need 0.25 GeV^2 for ΔM cut

→ hermetic detector

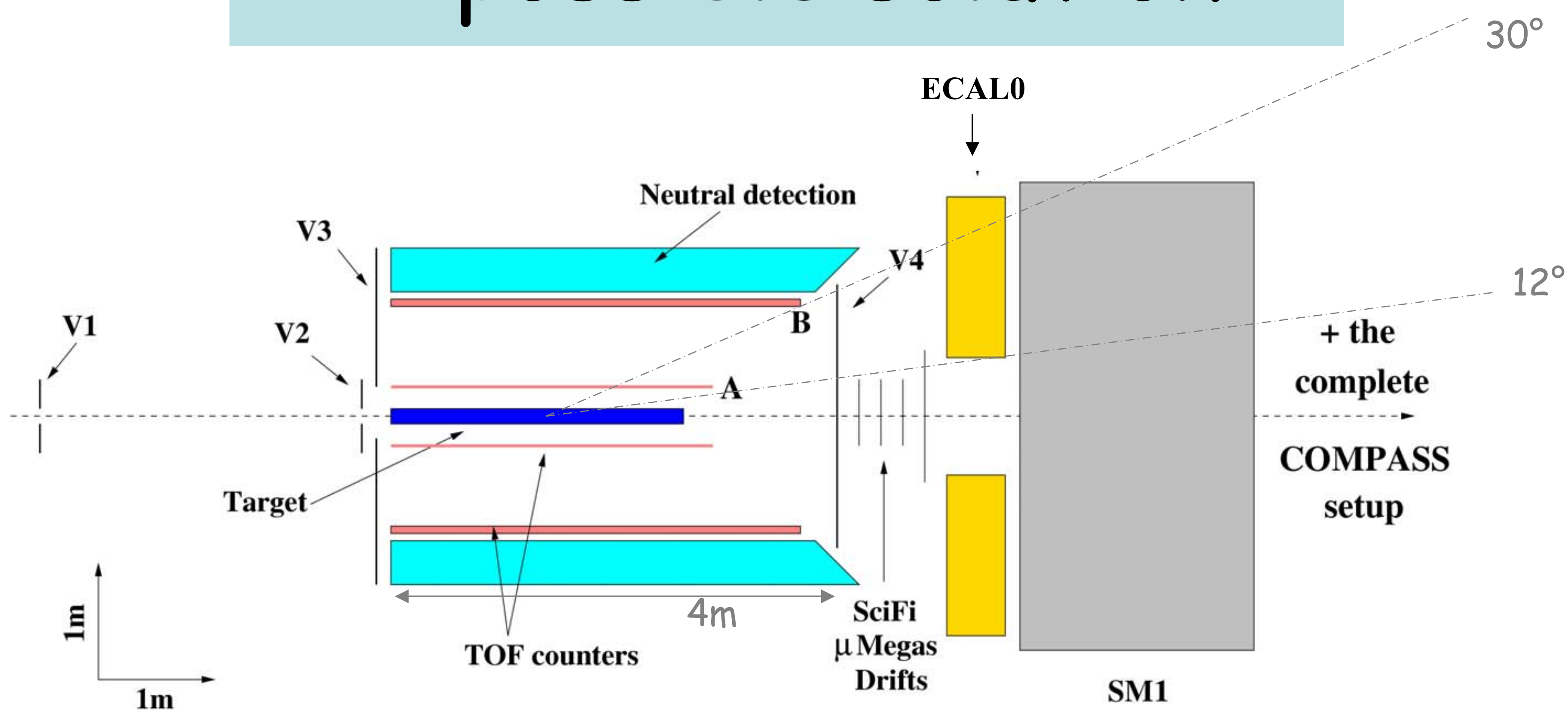
γ ECal 1 or 2
$\theta_\gamma \leq 12°$



+ additional calorimeter
at larger angle

Recoil detector
to insure exclusivity
to be designed and built

A possible solution



2004-2007:

Funding by European Union (Bonn-Mainz-Warsaw-Saclay)

45° sector recoil detector

- scintillating material studies (200ps ToF Resolution over 4m)
- fast triggering and multi-hit ADC/TDC system

DVCS background

DVCS: $\mu p \to \mu p \gamma$

with PYTHIA 6.1 simulate:

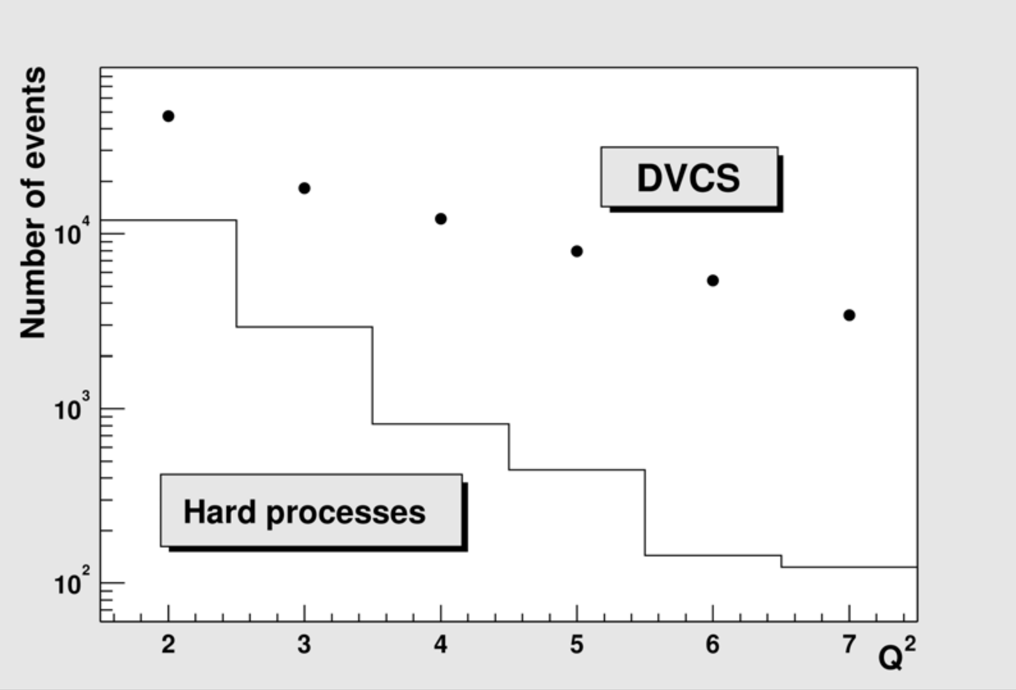
- HE$\pi°$P: $\mu p \to \mu p \pi°$ ↳ $\gamma\gamma$
- Dissociation of the proton: $\mu p \to \mu N^* \pi°$ ↳ $N\pi$
- DIS: $\mu p \to \mu p X$ with 1γ, $1\pi°$, $2\pi°$, η…

Acceptance cuts:

- $\theta_\gamma^{max} = 30°$
- $E_\gamma^{min} = 50$ MeV
- $\theta_{charged}^{max} = 30°$

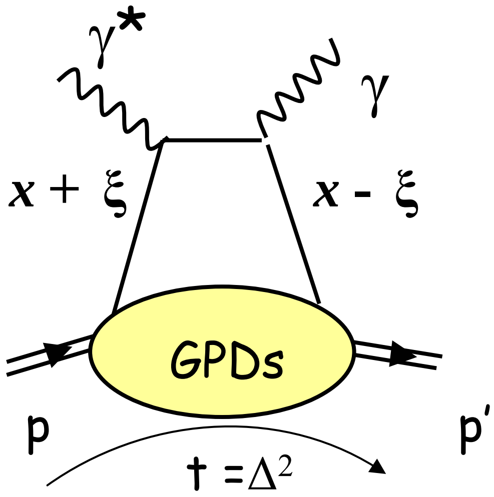
not included:

- Beam halo with hadronic contamination
- Beam pile-up
- Secondary interactions
- External Bremsstrahlung



GPD measurement

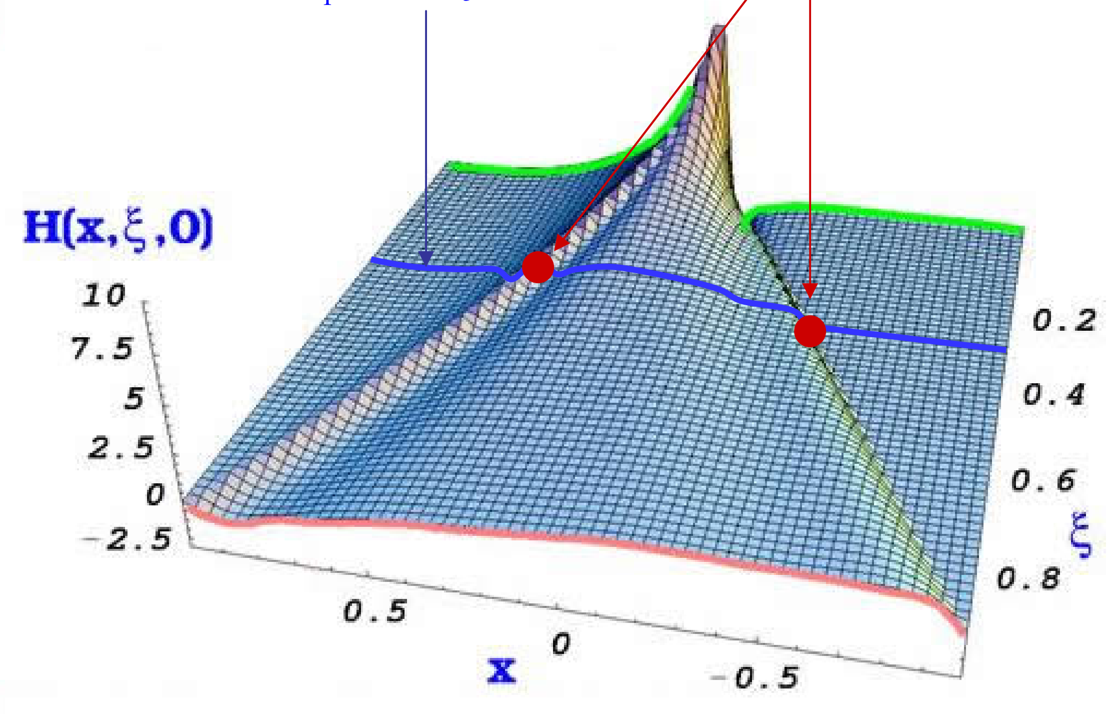
T_{DVCS}:

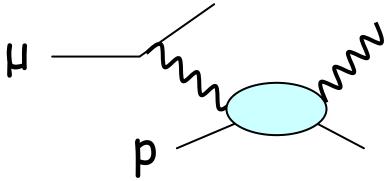


$$T^{DVCS} \approx \int_{-1}^{+1} \frac{H(x,\xi,t)}{x-\xi+i\varepsilon}dx \quad + \quad \cdots$$

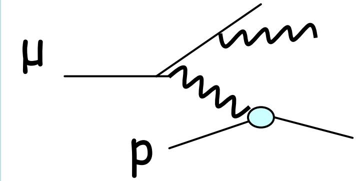
$$\approx P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x-\xi}dx \quad + \quad i\pi H(\xi,\xi,t) \quad + \quad \cdots$$

- $\xi \approx x_B/(2-x_B)$ and t are fixed
- loop over x

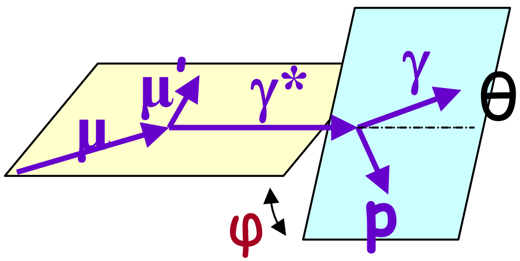




DVCS + Bethe-heitler



BH calculable

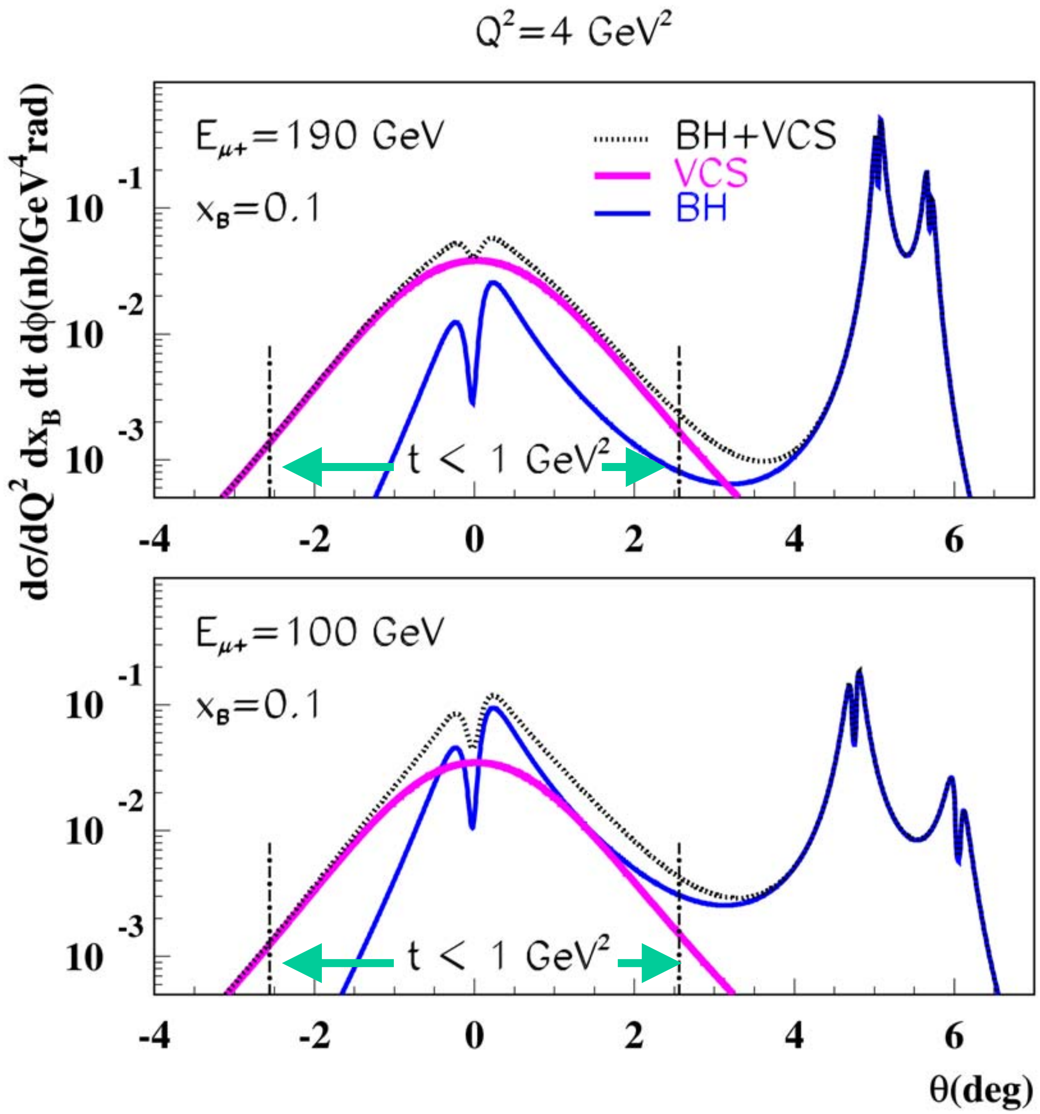


Higher energy: DVCS>>BH

⇒ DVCS Cross section

Smaller energy: DVCS~BH

⇒Interference term will provide the DVCS amplitude



DVCS + BH with $\overleftarrow{\mu}^{+}$ and $\overrightarrow{\mu}^{-}$

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

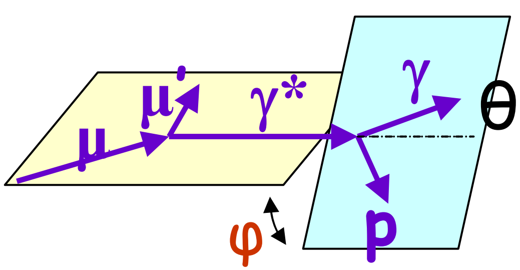
$$A^{DVCS}_{(\mu p \to \mu p \gamma)} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\pi H(x=\xi,\xi,t)$$

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

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

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

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



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

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

$\sigma^{\overleftarrow{\mu}+} - \sigma^{\overrightarrow{\mu}-}$ at 100 GeV

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

Model 1: $H(x,0,t) \sim q(x)\, F(t)$

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

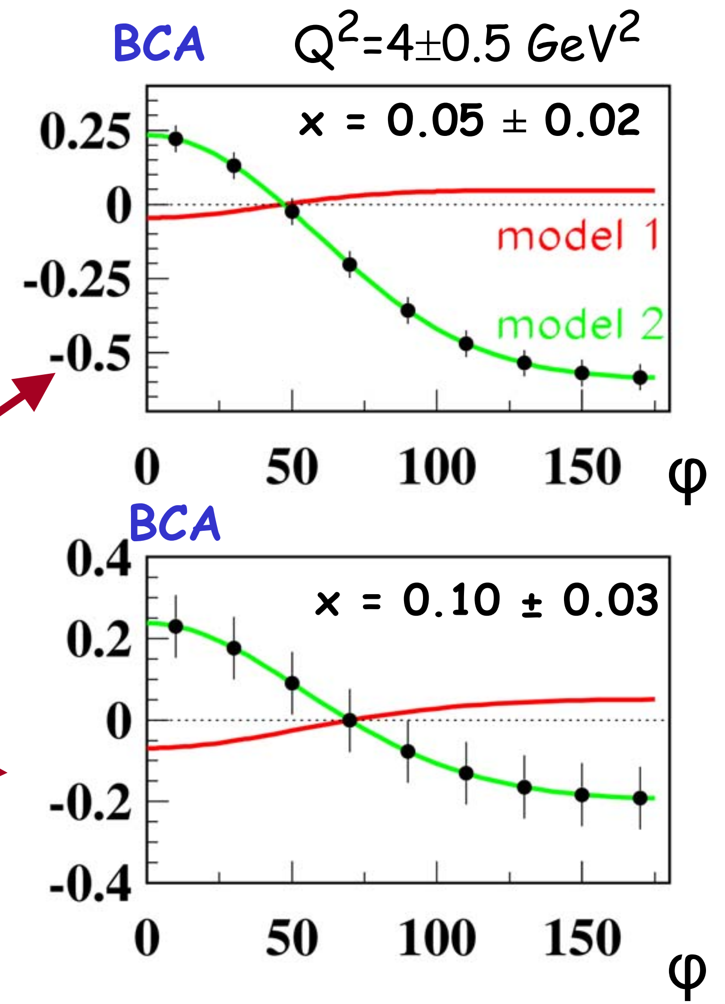
$= q(x) / x^{\alpha' t}$

assuming:

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

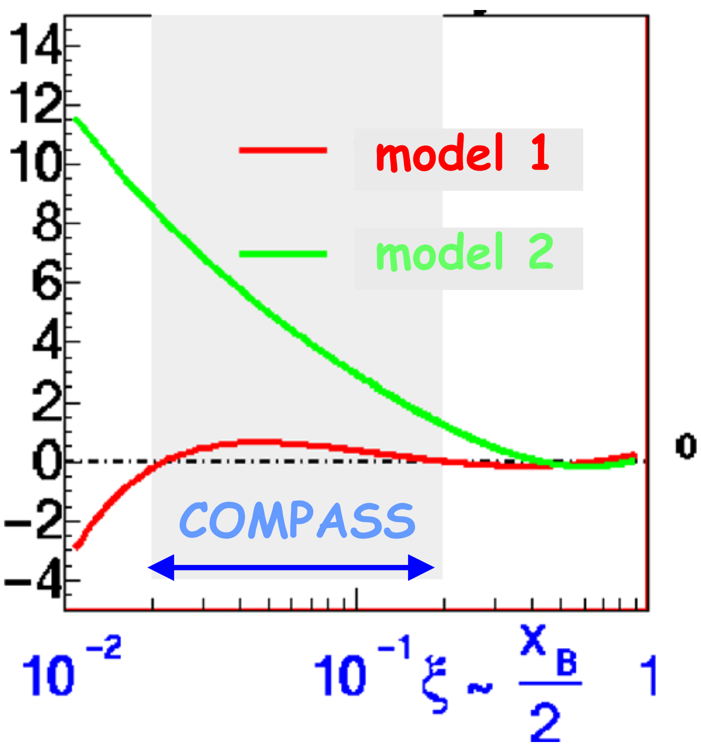
2 bins shown out of 18:

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



advantage of COMPASS kinematics

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



Model 1: $H(x,0,t) \sim q(x)\,F(t)$

Model 2: $H(x,0,t) = q(x)\, e^{\,t\,\langle b_\perp^2\rangle}$
$= q(x) \,/\, x^{\alpha' t}$

sensitive to different spatial distributions at different x

HEMP: filter of GPDs

Cross section:

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

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

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

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

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

Transverse single spin asymmetry : ~ E/H

HEMP in 2010

HEMP requires higher Q2 than DVCS

with liq H target and same μ flux as now:

- $\rho \rightarrow Q^2 = 20\ GeV^2$
- $\omega, \pi, \eta, \phi \rightarrow Q^2 = 7\ GeV^2$

if more $\mu \rightarrow$ higher Q^2

Roadmap for DVCS at COMPASS

2004-2009: ρ production: σ_L and transverse spin asym

2005 : "Expression of Interest": SPSC-EOI-005

2004-2007: recoil detector prototype

2008 ? : proposal

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

≥2010: dedicated GPD measurement

Measure OAM ?

- Ji sum rule relates total quark spin to GPDs H and E :

$$J^q = \frac{1}{2}\Delta\Sigma + L^q = \frac{1}{2}\int_{-1}^{1} x dx \left[H^q(x,\xi,0) + E^q(x,\xi,0) \right]$$

similar sum rule for gluons

To do :

1. Measure H and E
2. Perform flavor decomposition
3. Extrapolate to t=0
4. Integrate over x at fixed ξ

- Sivers asymmetries are also measured at COMPASS

SPARE

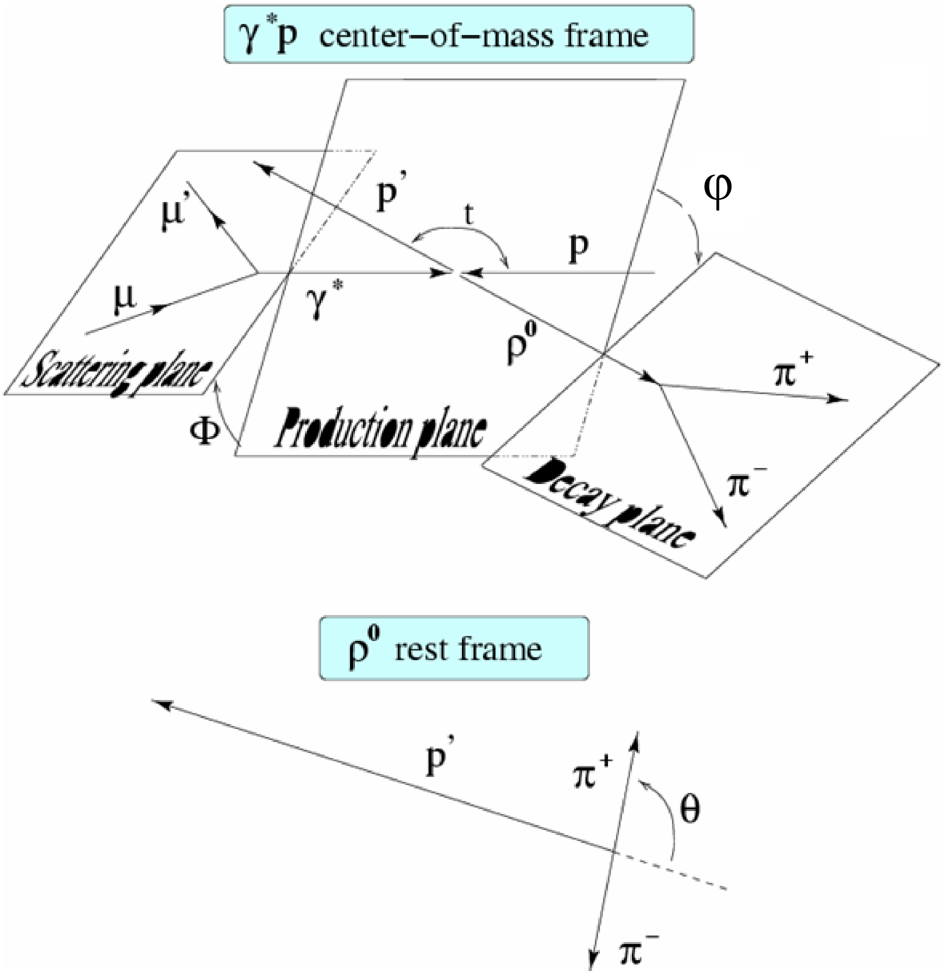
Key role of calorimetry

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

ECAL0 from 12 to 30°: to be designed
for background rejection

⇒ Careful study of γ and π^0 production
← COMPASS program with hadron beam

ρ^0 angular distributions $W(\cos\theta, \varphi, \Phi)$ depends on the Spin density matrix elements
⇨ 23 (15) observables with polarized (unpolarized) beam

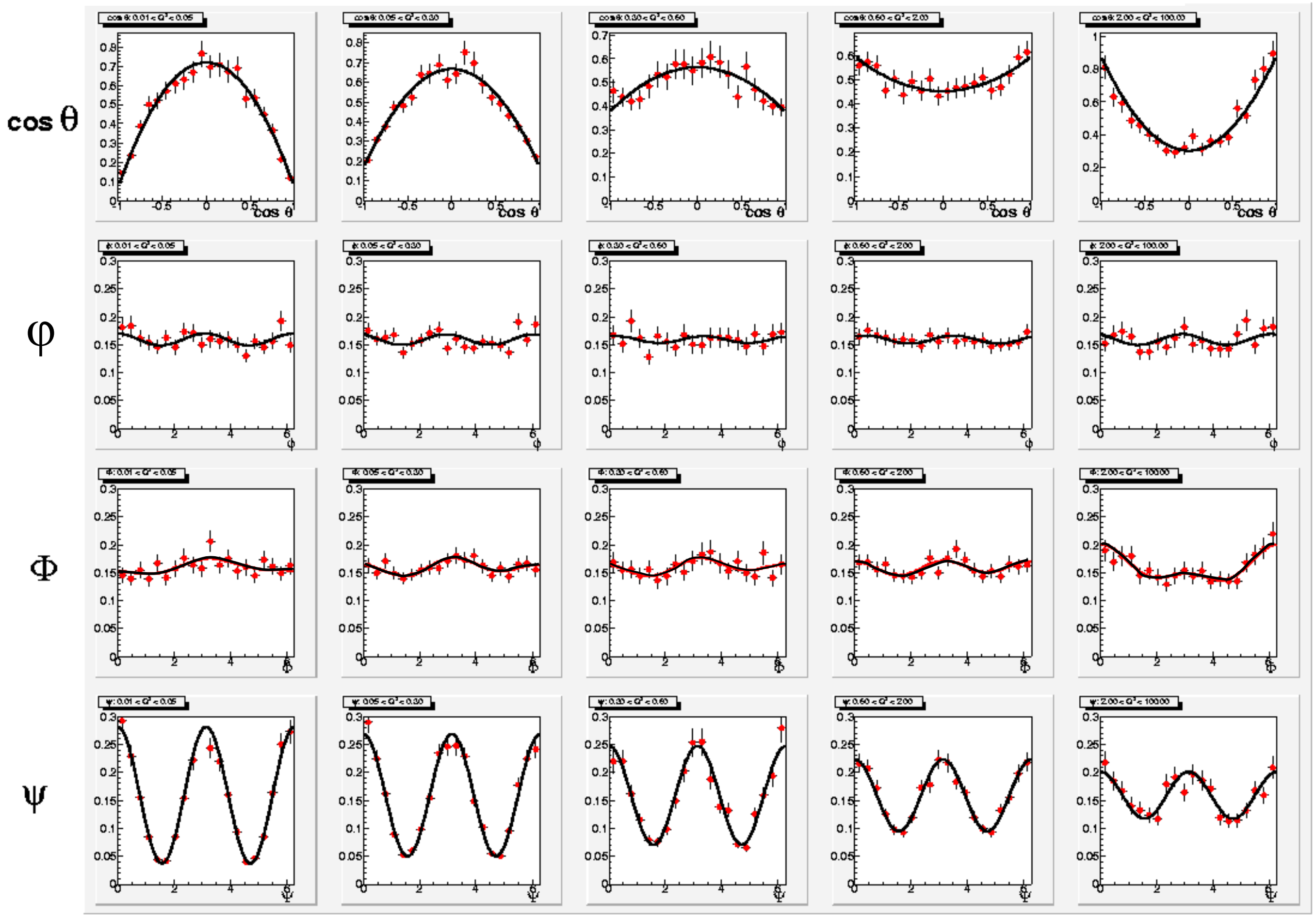


This analysis:
only one-dimensional angular distribution

We will use also:
$\psi = \varphi - \Phi$

Angular distributions

$0.01 < Q^2 < 0.05 < Q^2 < 0.3 < Q^2 < 0.6 < Q^2 < 2.0 < Q^2 < 10\ GeV^2$



Preliminary :

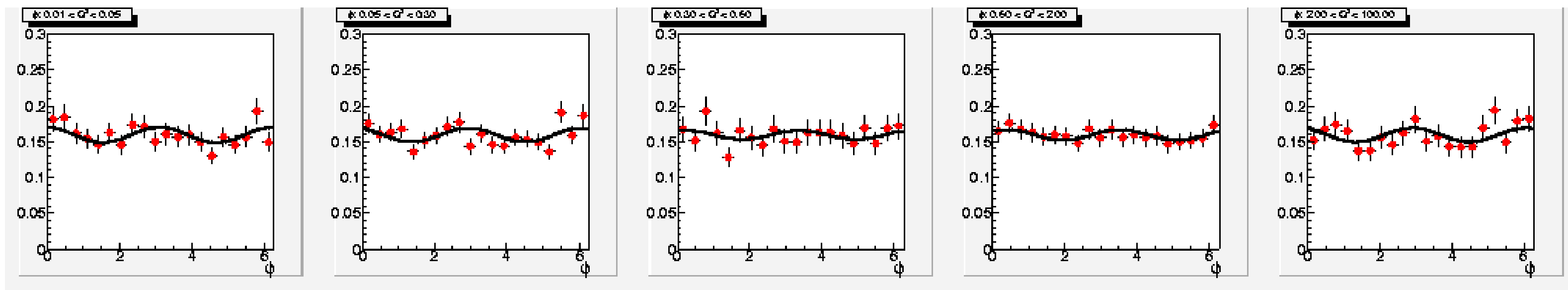
- Corrected for Acceptance, smearing and efficiency (MC:DIPSI gen)

- Background not subtracted

Statistical error only, limited by MC

Measurement of r^{04}_{1-1} and Im r^{3}_{1-1}

φ



Distribution :

$$W(\varphi) = \frac{1}{2\pi}\left[1 - 2r^{04}_{1-1}\cos 2\varphi + 2\,\mathrm{Im}\; r^{3}_{1-1} P_{\mu}\sqrt{1-\varepsilon^{2}}\,\sin 2\varphi\right]$$

beam polarisation

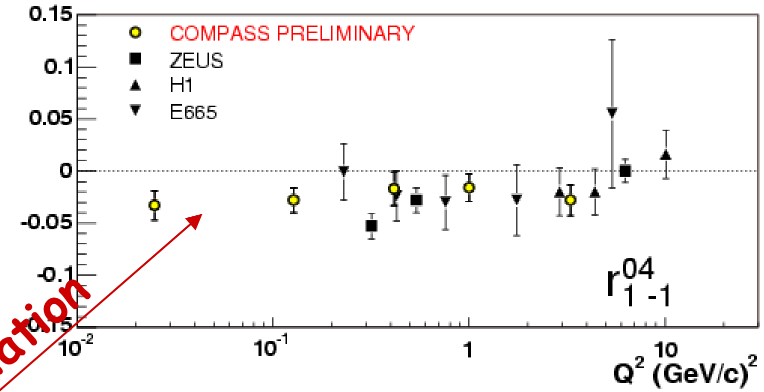
Spin density matrices:

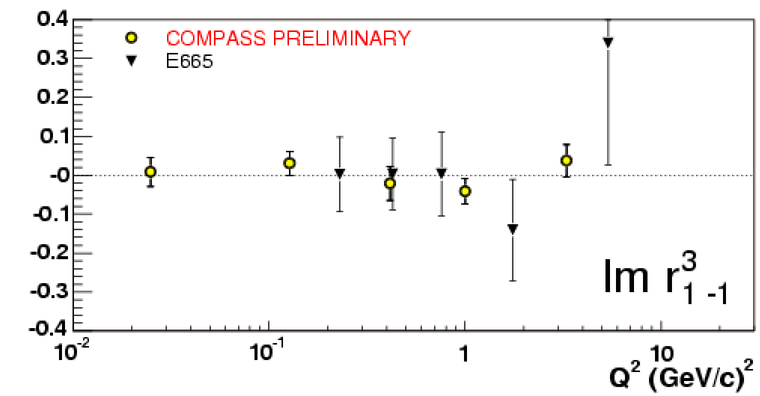
$$r^{04}_{1-1} \sim \frac{\mathrm{Re}(T_{11}T^{*}_{-11}) - (\varepsilon+\delta)|T_{10}|^{2}}{\sigma_{Tot}} = 0$$

$$\mathrm{Im}\;\; r^{3}_{1-1} = \ldots = 0$$

← **If SCHC holds**

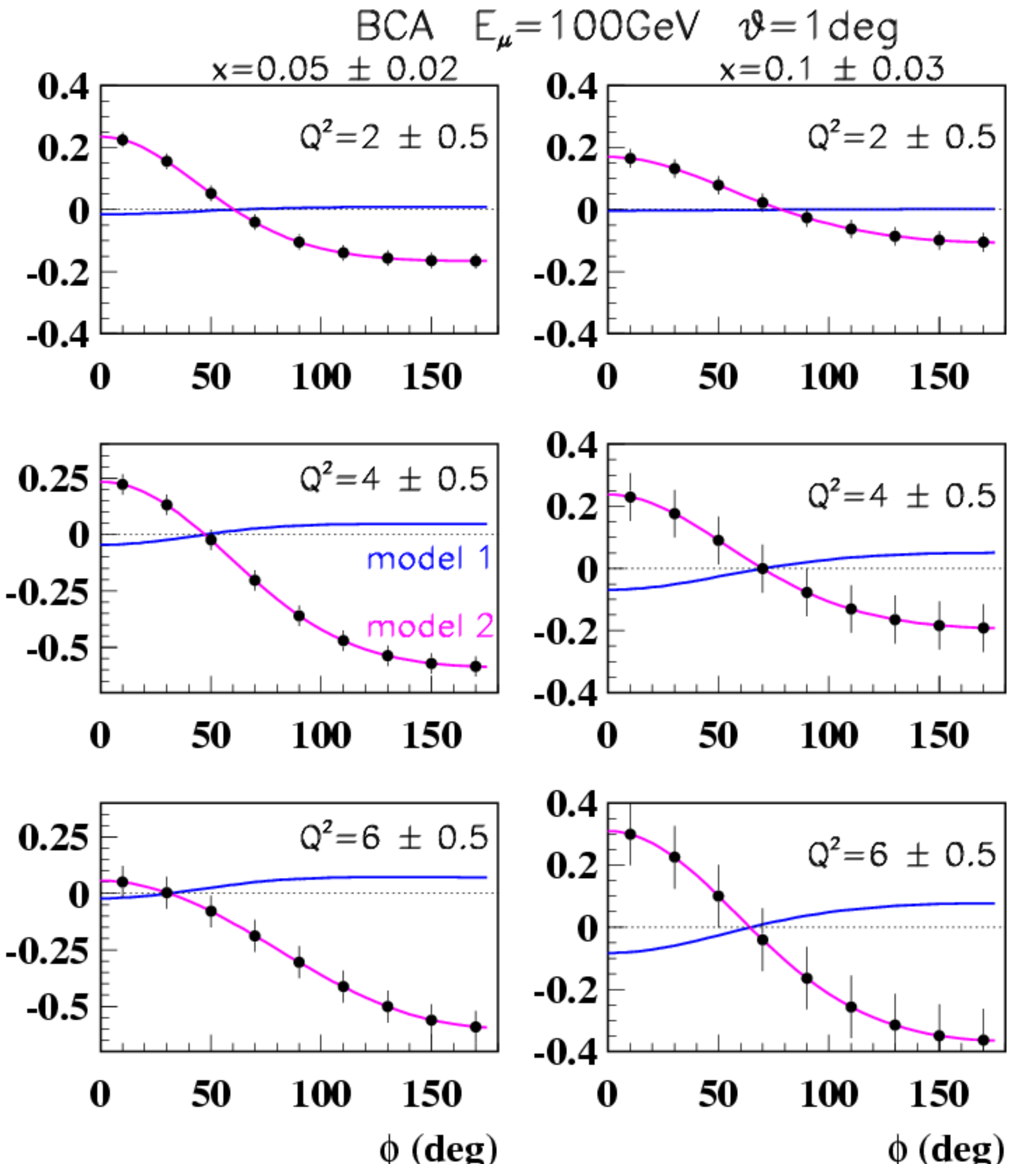
weak violation





COMPASS

6 angular distributions
among 18: 3 bins in x_{Bj}=0.05, 0.1, 0.2
6 bins in Q^2 from 2 to 7 GeV^2



BCA in DVCS projections for 1 year

HERMES