Experimental studies of generalised parton distributions

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- **Physics motivation**
- **Deeply virtual Compton scattering**
- **Experimental results**
- **Future plans**

bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

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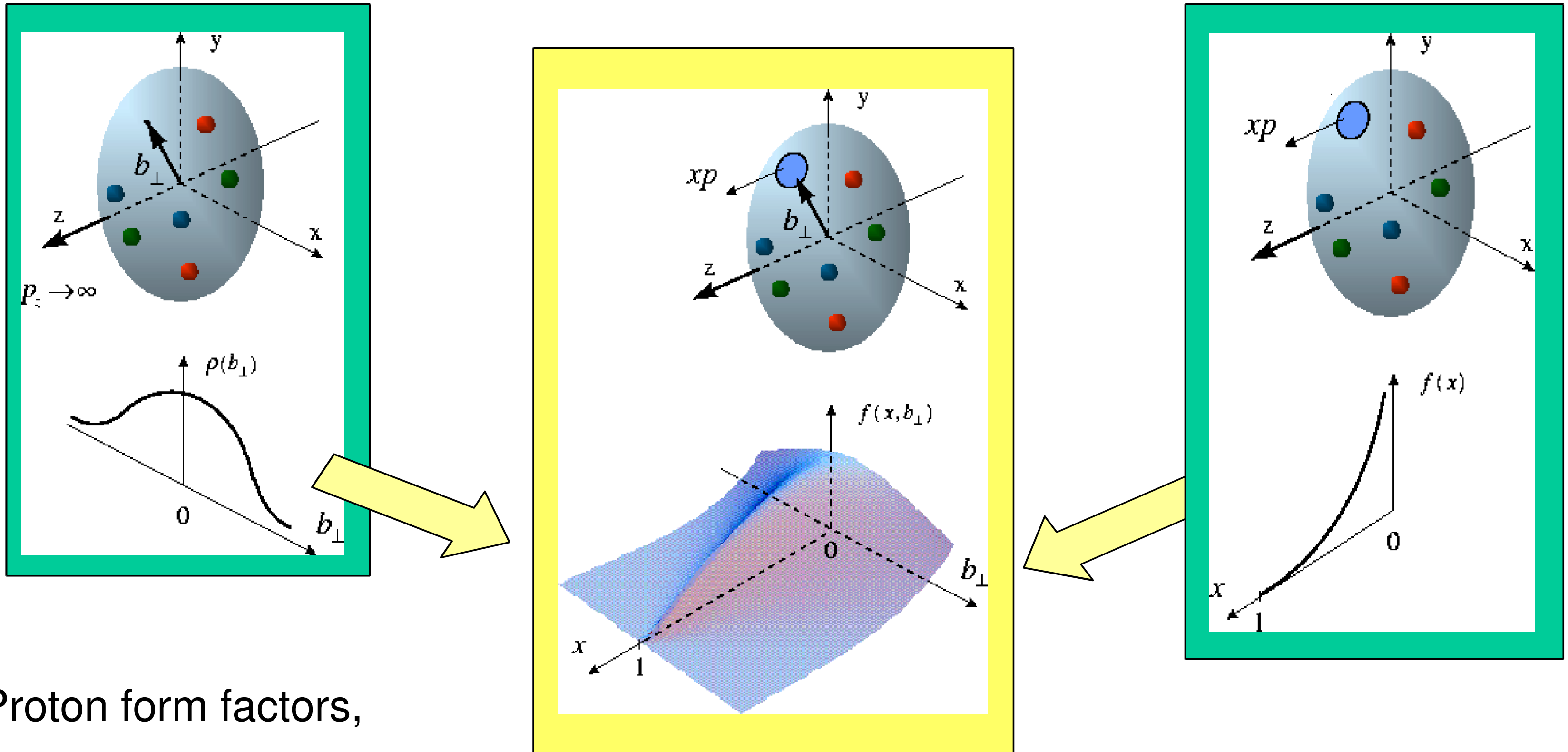
Motivation

D. Mueller, X. Ji, A. Radyushkin, A. Belitsky, …
M. Burkardt, … Interpretation in impact parameter space



Proton form factors,
transverse charge &
current densities

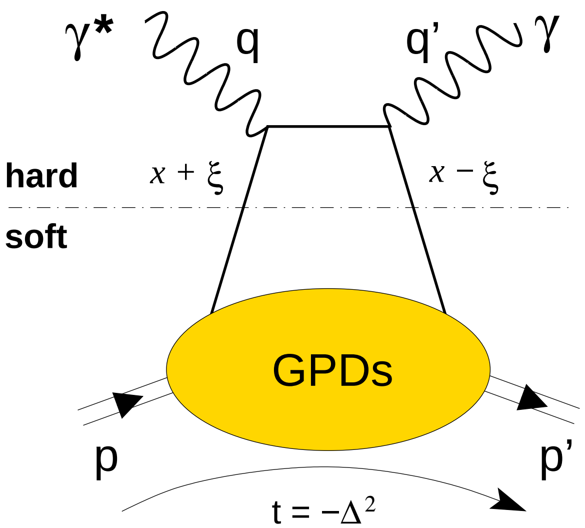
Correlated quark momentum and helicity distributions in transverse space - GPDs

Structure functions,
quark longitudinal momentum & helicity distributions

Slide from V.D. Volker, LANL 2007

Access GPD through hard exclusive reactions

DVCS



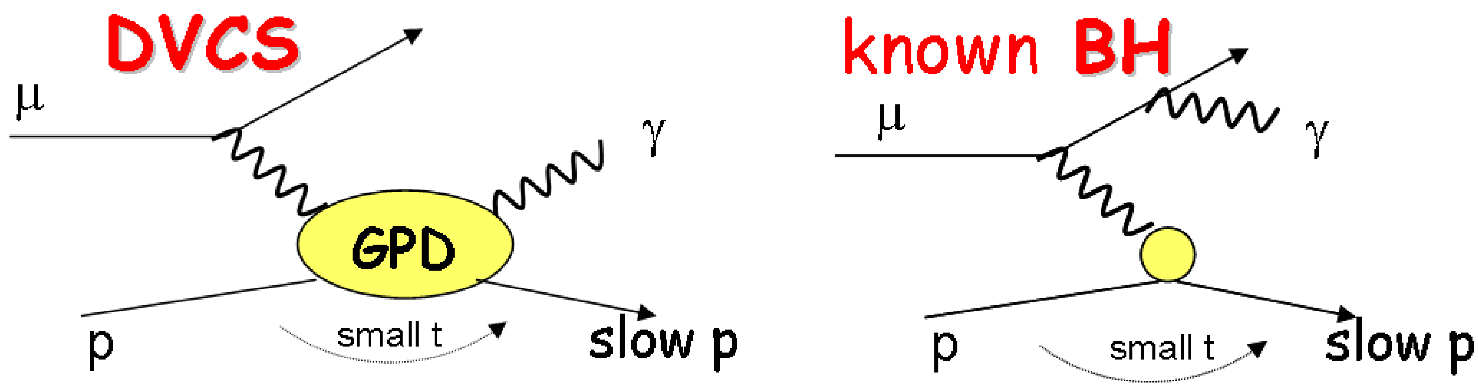
- generalised parton distributions for quarks and gluons $H^f, E^f, \widetilde{H}^f, \widetilde{E}^f(x,\xi,t)$
- limits: $q(x) = H(x,0,0)$ normal PDF
  $F(t) = \int \mathrm{d}x\, H(x,\xi,t)$ elastic FF
- Factorisation for Q^2 large, $t < 1$ GeV^2
- H, $\widetilde{H}$ conserve nucleon helicity
  E, $\widetilde{E}$ flip nucleon helicity
- H, E refer to unpolarised distributions
  $\widetilde{H}$, $\widetilde{E}$ refer to polarised distributions

- **Ji's sumrule**

$$J^f = \frac{1}{2} \lim_{t\to 0} \int_{-1}^{1} \mathrm{d}x\; x\; \left[H^f(x,\xi,t) + E^f(x,\xi,t)\right]$$

J^f: total angular momentum contribution of quark f

Experimental challenge



- **interference** of DVCS and Bethe Heitler

$$\mathrm{d}\sigma = \mathrm{d}\sigma^{BH} + \mathrm{d}\sigma^{DVCS} + \text{interference term}$$

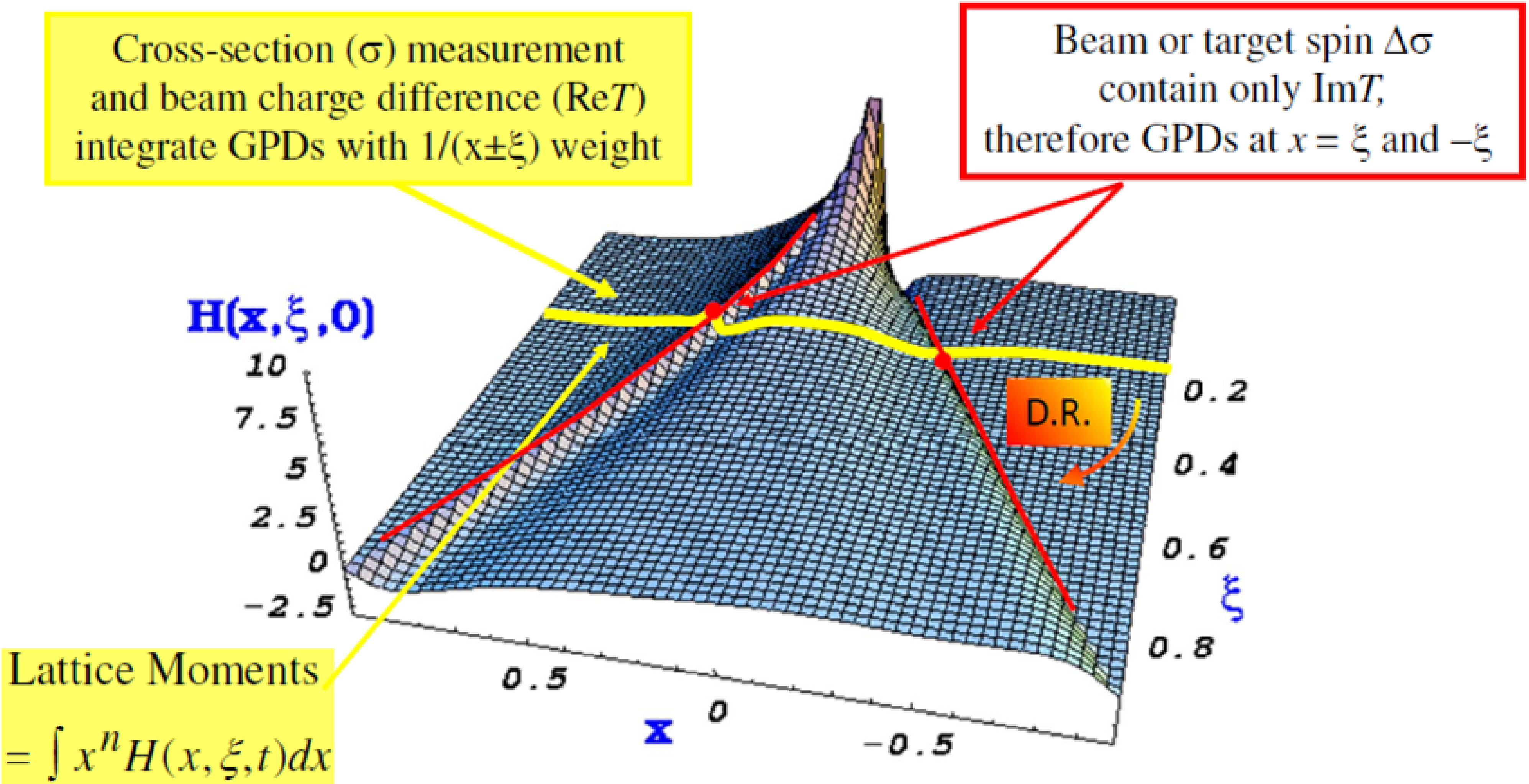
- $\mathrm{d}\sigma^{DVCS}$ and interference term related to **Compton form factor** $\mathcal{H}(\xi, t)$
- can be used to extract **GPDs**, mainly GPD H at high energies

$$\mathrm{Im}\, \mathcal{H}(\xi, t) \stackrel{\mathrm{LO}}{=} H(\xi, \xi, t)$$

$$\mathrm{Re}\, \mathcal{H}(\xi, t) \stackrel{\mathrm{LO}}{=} \mathcal{P} \int_{-1}^{1} \mathrm{d}x\ H(x, \xi, t) \frac{1}{x - \xi}$$

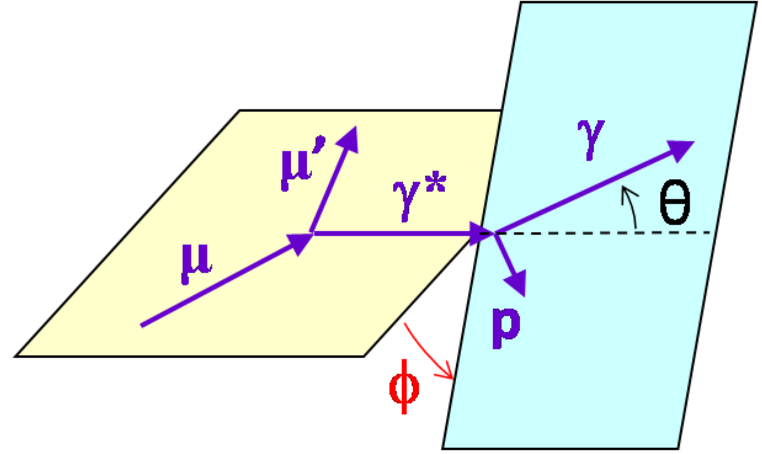
- BH known, control of experiment; DVCS also $\mathrm{d}\sigma^{DVCS}/\mathrm{d}|t|$

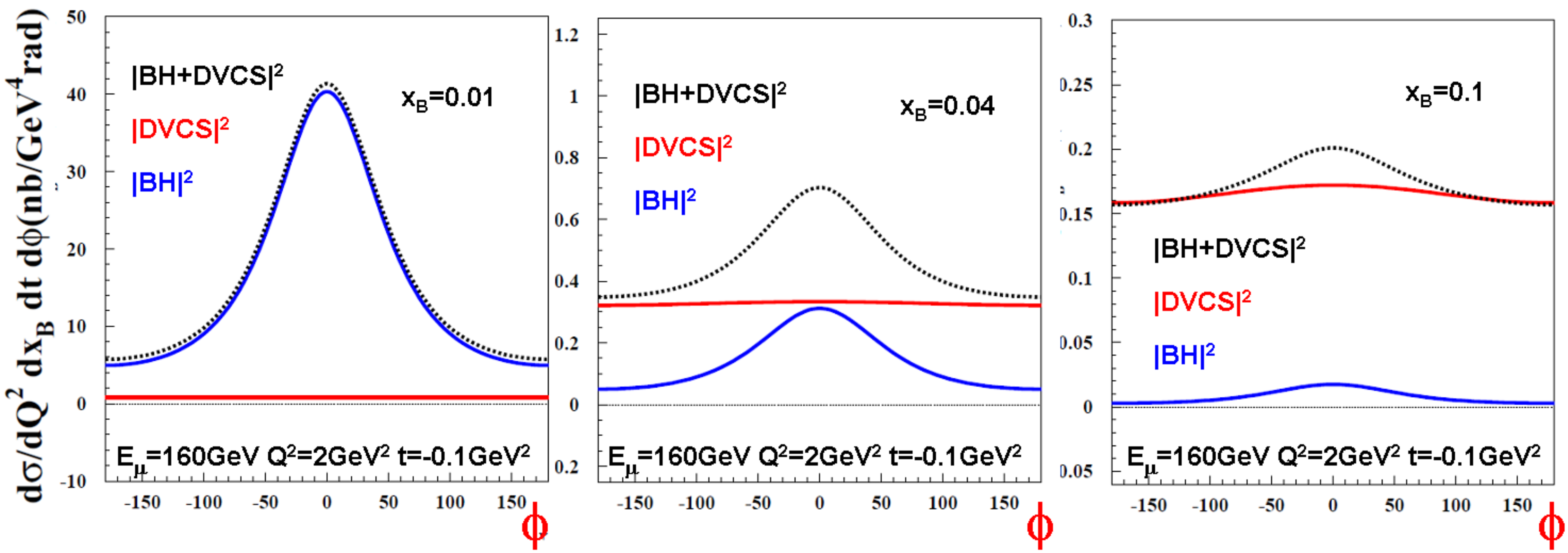
Generalised parton distributions



Azimuthal angular dependence

- **separation** of DVCS and BH via ϕ dependence
- e.g. $Q^2 = 2\,\mathrm{GeV}^2$, $|t| = 0.1\,\mathrm{GeV}^2$





BH dominates, excellent reference yield

BH and DVCS compatible, DVCS amplitude from interference

DVCS dominates, study of $\mathrm{d}\sigma/\mathrm{d}|t|$, difficult at low energies

Parametrisations of GPDs

- **predictions with different models**

  with factorisation: $H(x,\xi,t) \propto q(x)F(t)$

  with Regge motivated t dependence: x-t correlation

  – idea: core of fast partons, meson cloud at larger distance
  $H(x,0,t) \propto q(x)\exp(-B|t|)$
  – Ansatz: $B = 1/2\,\langle b_\perp^2\rangle = B_0 + 2\alpha' \ln\frac{x_0}{x}$
  (α' slope of Regge trajectory)
  – valence quarks: $\alpha' \sim 1$ GeV^{-2} from form factors, gluons: α' small

- **analysis of data**

  local fits to $\mathrm{Im}\,\mathcal{H}$, $\mathrm{Re}\,\mathcal{H}$ indep. (M.Guidal)

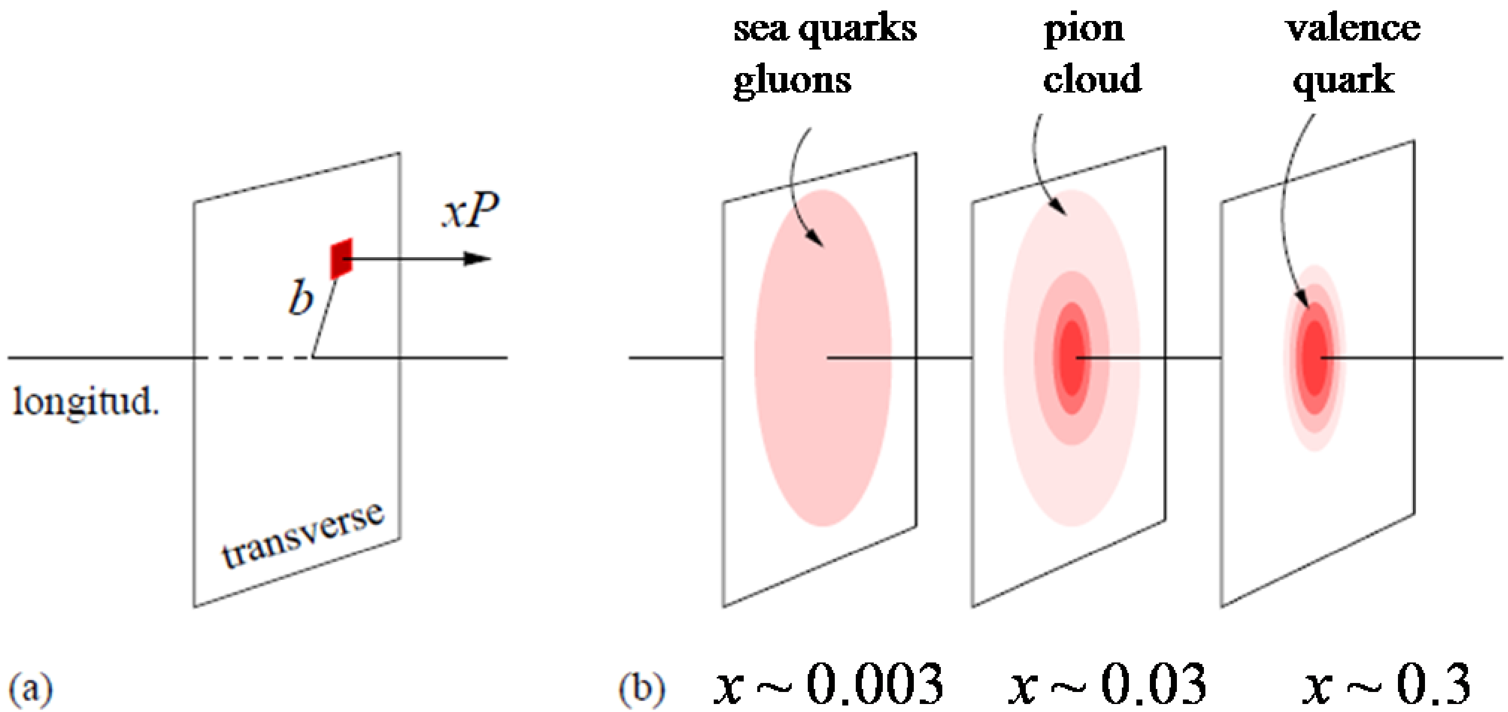
  global fits: all kinematic bins at the same time, parametrisation of CFF or GPD (G.Goldstein, K.Kumericki and D.Müller)

  hybrids: local/global fits (H.Moutarde)

  neural networks for PDF, work started for GPDs (K.Kumericki and D. MUller)

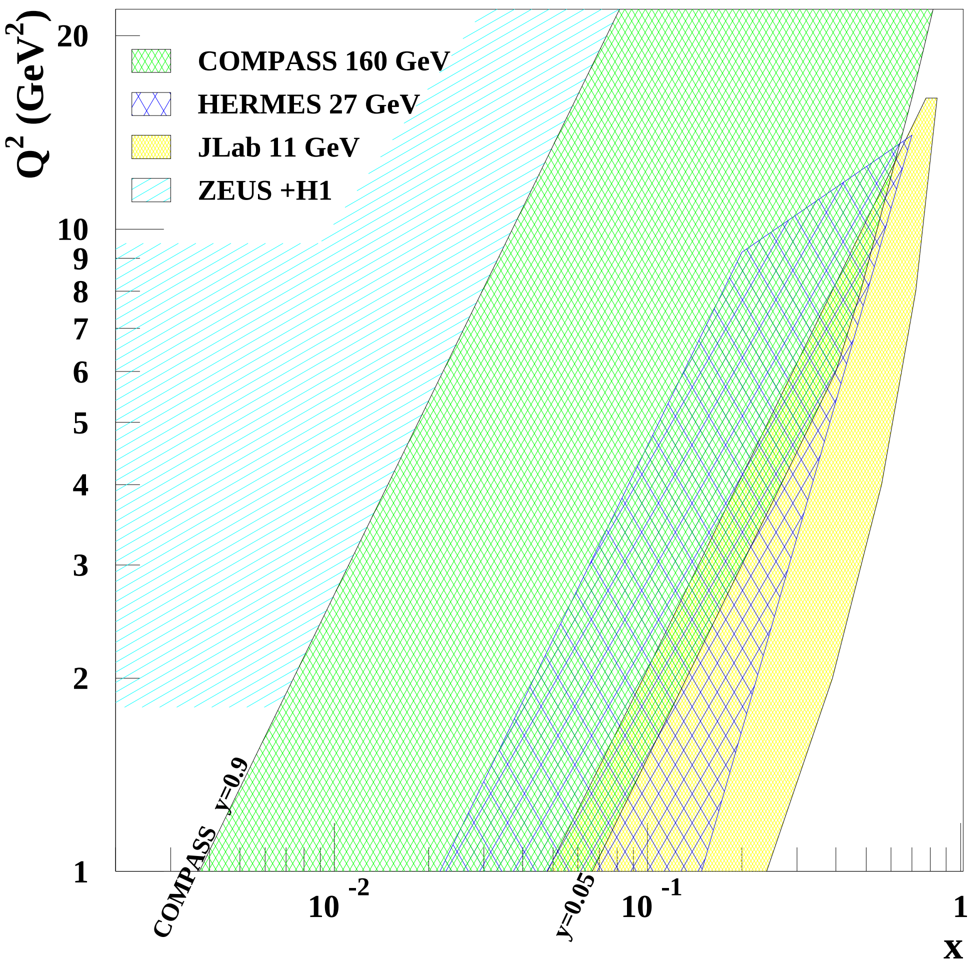
Nucleon tomography

- GPDs allow simultaneous measurement of longitudinal momentum and transverse spatial structure



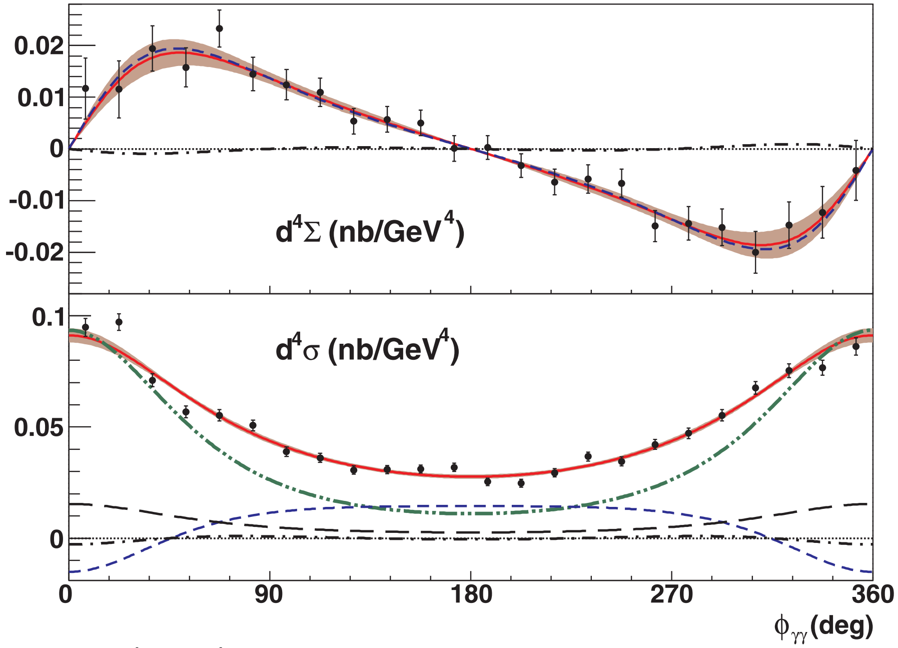
- for $\xi \to 0$: $t = -\boldsymbol{\Delta}_\perp^2$ purely transverse and
$$q^f(x, \boldsymbol{b}_\perp) = \int \frac{\mathrm{d}^2\boldsymbol{\Delta}_\perp}{(2\pi)^2} e^{-i\boldsymbol{\Delta}_\perp \cdot \boldsymbol{b}_\perp} H^f(x, 0, -\boldsymbol{\Delta}_\perp^2)$$
- $\boldsymbol{b}_\perp$ distance to center of momentum (b in figure is $\boldsymbol{b}_\perp$)

Experiments



- **JLAB:**
  - DVCS cross sections, asymmetries
  - Hall A:
    high precision, limited kinematics
  - Hall B:
    wide kinematics, "limited" precision
  - very different systematics
- **HERMES:**
  - beam charge (BCA) and spin (BSA) asymmetries
  - transverse asymmetries
  - ongoing analysis with recoil detector
- **H1/ZEUS**
  - DVCS cross section, t dependence, beam charge asymmetries

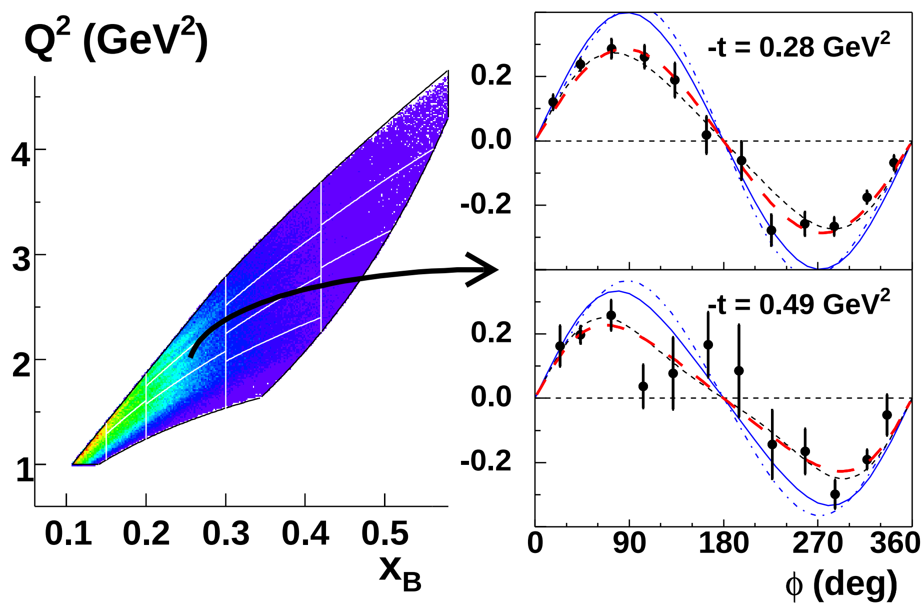
JLAB: Hall A and Hall B



PRL97(2006)262002

- E00-110: DVCS cross section with unpol.p target, check of factorisation
- E03-116: measurement with d target
- E07-007: "Rosenbluth" sep. of Compton amplitudes

PRL100(2008)162002

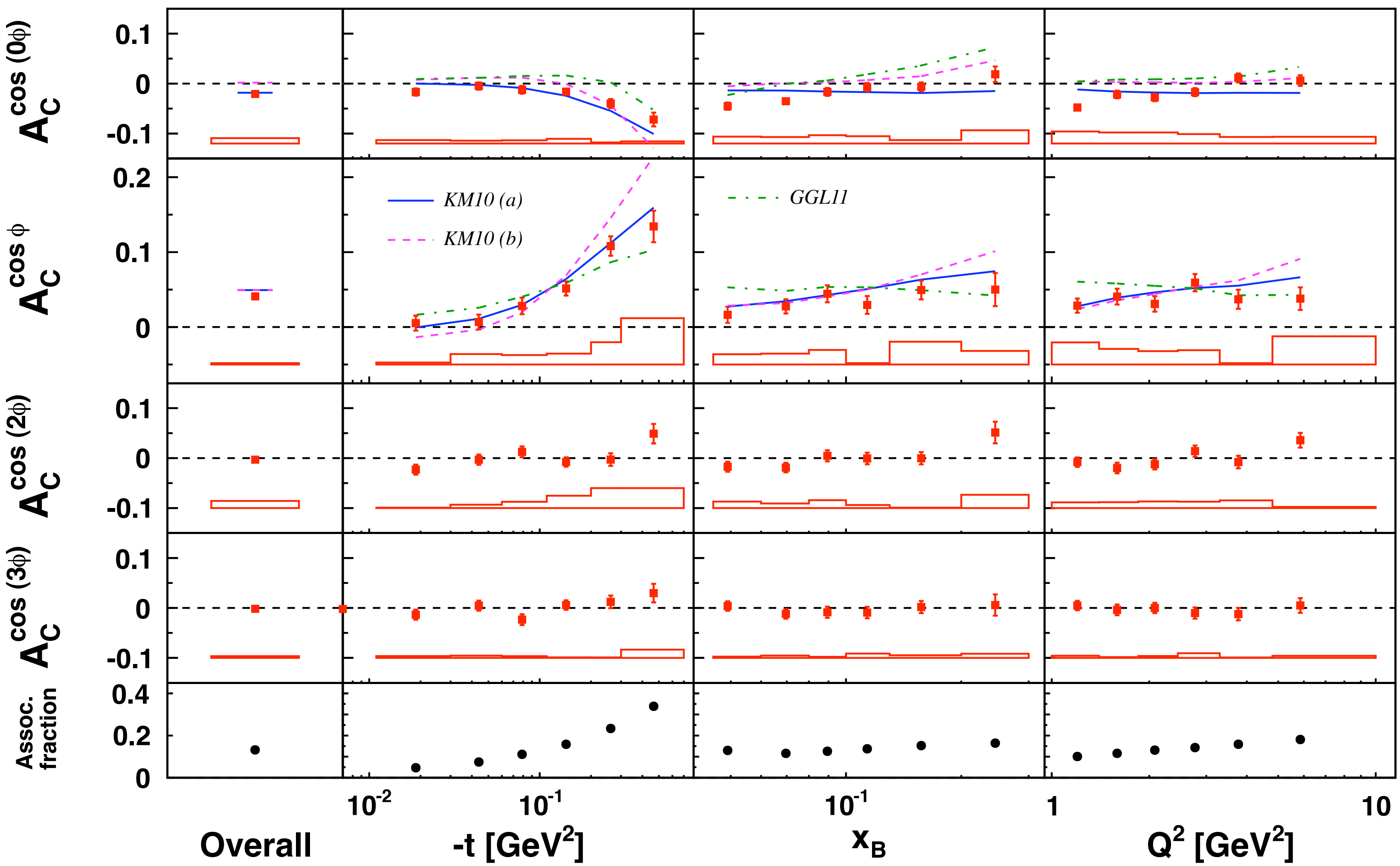


- CLAS (E01-113, E06-003): BSA in large kinematic range
- not well described by current modells
- E05-114: TSA with pol. NH_3 target

DVCS at HERMES

Results on BCA and BSA: arXiV:1203.6287

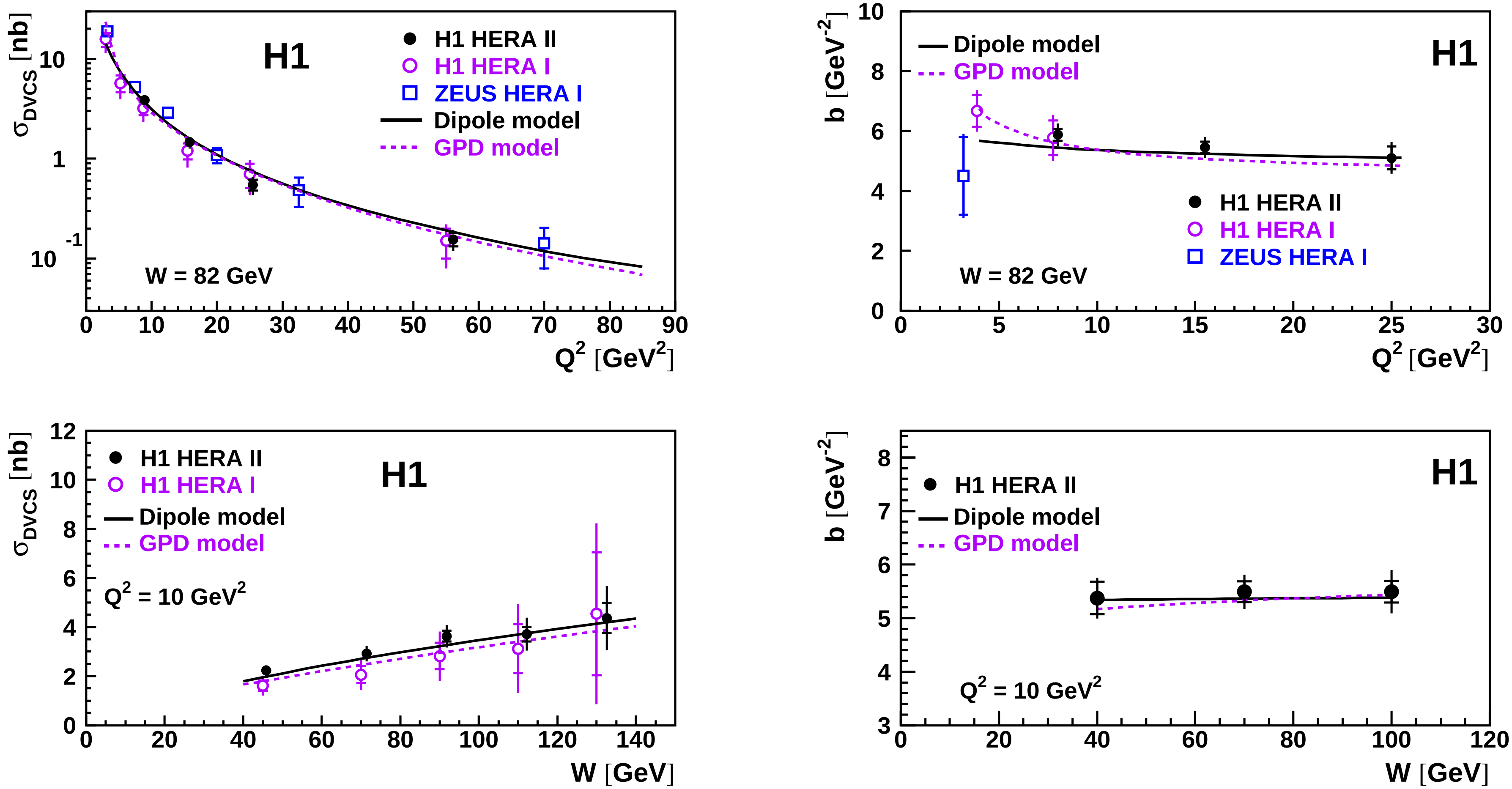
combined 1996-2005 and new 2006-7 data using missing mass technique



- $\cos\phi$ term related to Re H, $\cos 0\phi$ kinematically suppressed

DVCS at H1

DVCS cross section: Q^2, W, t dependence



Nucleon tomography: t slope b related to size of nucleon at low x

Future plans: JLAB12

several experiments planned

- Hall A: E12-06-114
  - follow up of E00-110
  - $e^{\uparrow}p \longrightarrow ep\gamma$ at fixed x, several Q^2, several beam energies
  - high precision cross section measurements for t-dependence, $\mathrm{Im}\,\mathcal{H}$, $\mathrm{Re}\,\mathcal{H}$

- Hall B: E12-06-119
  - follow up of E01-113, E06-003, E05-114
  - large kinematic coverage with CLAS at 11 GeV, high statistics
  - extension to low and high x $(0.1 < x < 0.7)$
  - second phase: polarised NH_3 target
  - BSA(x, t, Q^2), TSA(x, t, Q^2)

- Hall B: E12-11-003
  - using CLAS at 11 GeV plus new recoil neutron detector
  - BSA(x, t, Q^2) in large kinematic range
  - flavour separation of GPD H

Future plans: COMPASS

Exclusive measurements: DVCS and HEMP

Phase 1:

2.5 m lH_2 target
4 m long recoil detector

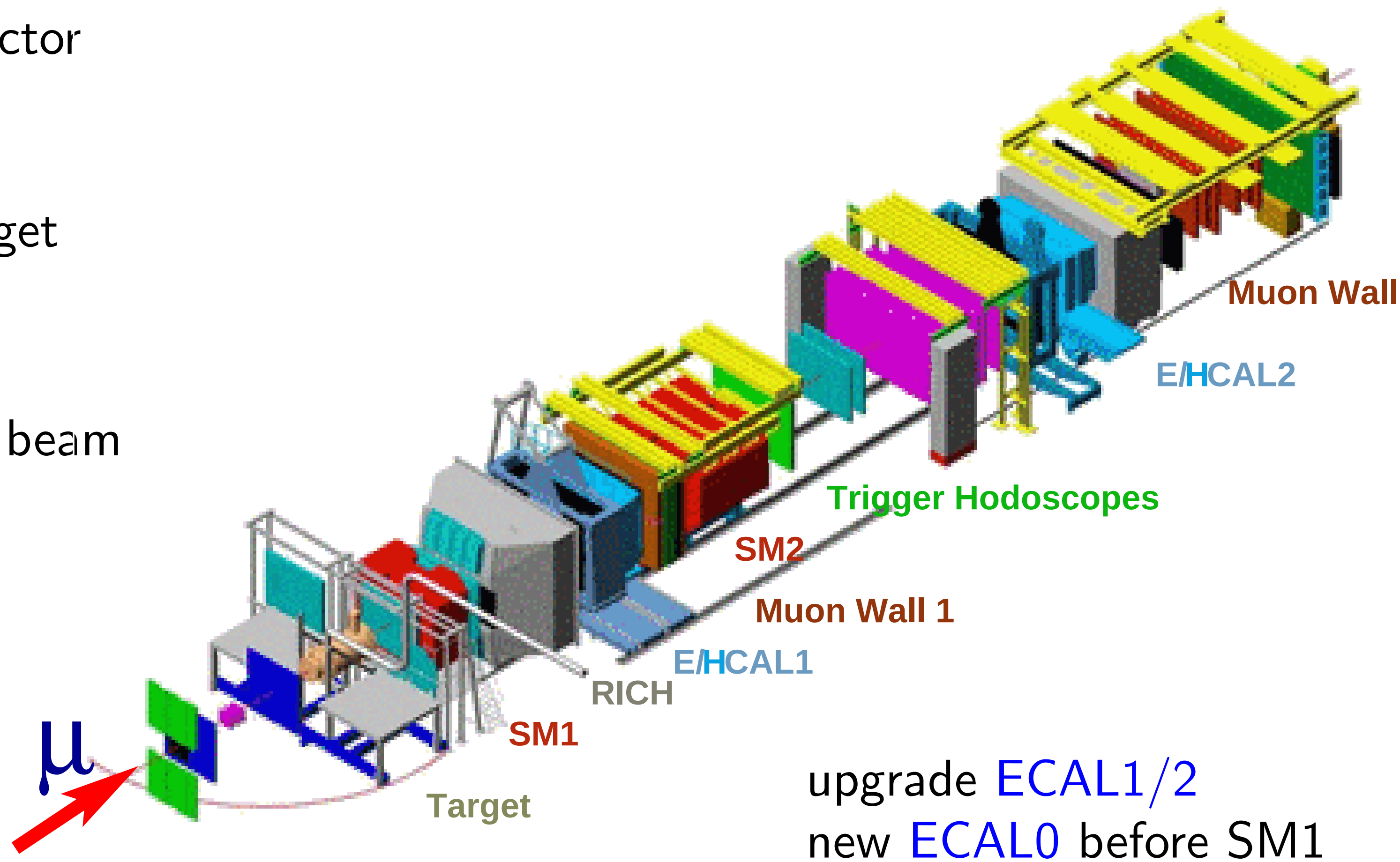
Phase 2:

transversely pol. target
with recoildetector

polarised CERN $\mu^{\pm}$ beam

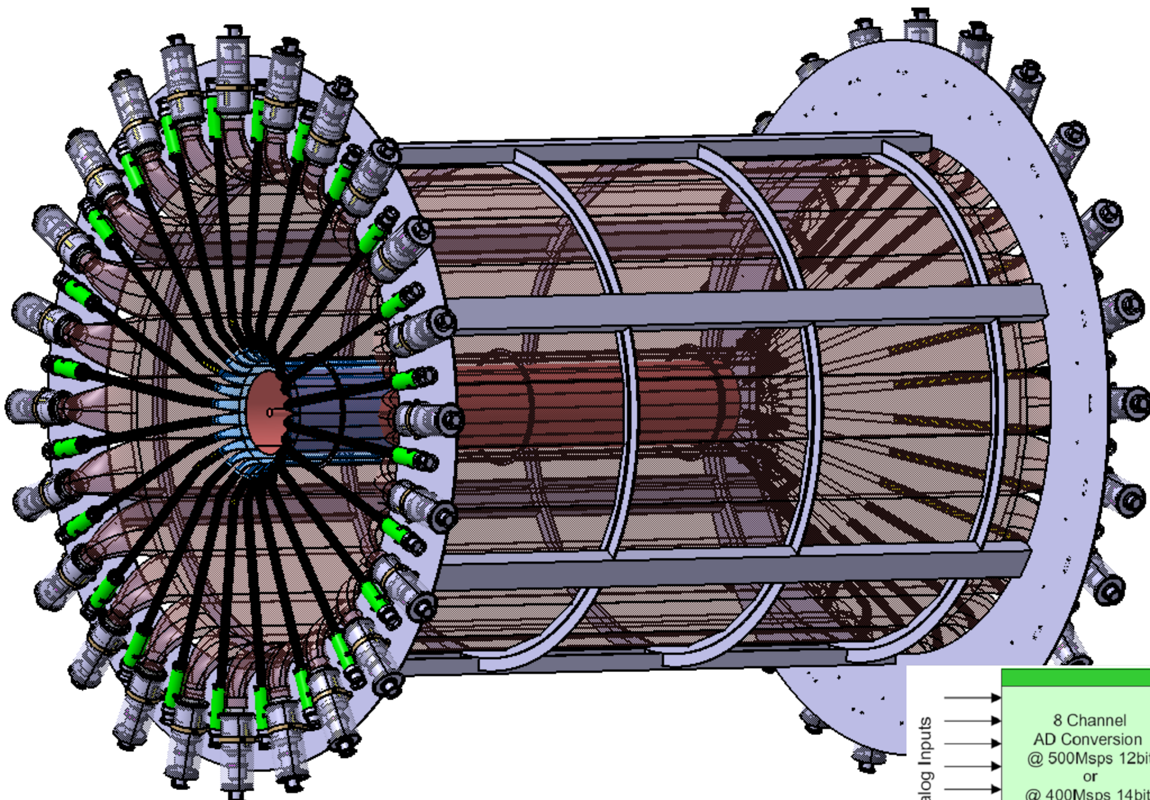
high precision
beam flux
and acceptance
determination

trigger in large
kinematic range



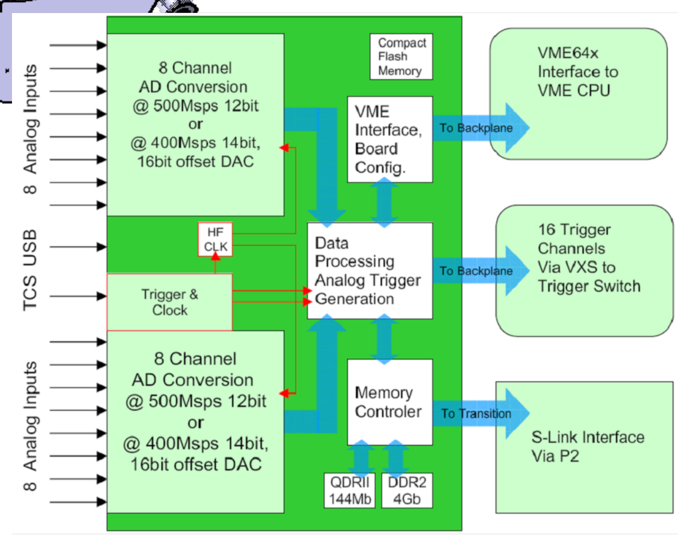
upgrade ECAL1/2
new ECAL0 before SM1

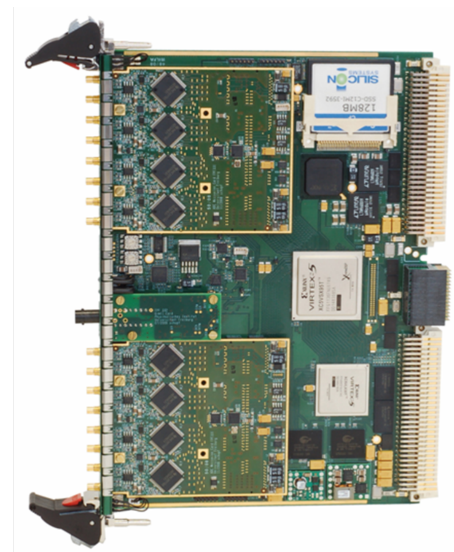
Target and recoil detector



- 2.5 m **IH$_2$**, 40 mm diameter
- minimum thickness of cryostat and target cell
- density fluctuations $< 3\%$
- **TOF dectetor** 2 layers of scintillators
- 300 ps time resolution

- high occupancy due to δ rays
- **Gandalf Project**:
  1GHz digitisation of signals to cope with high rate

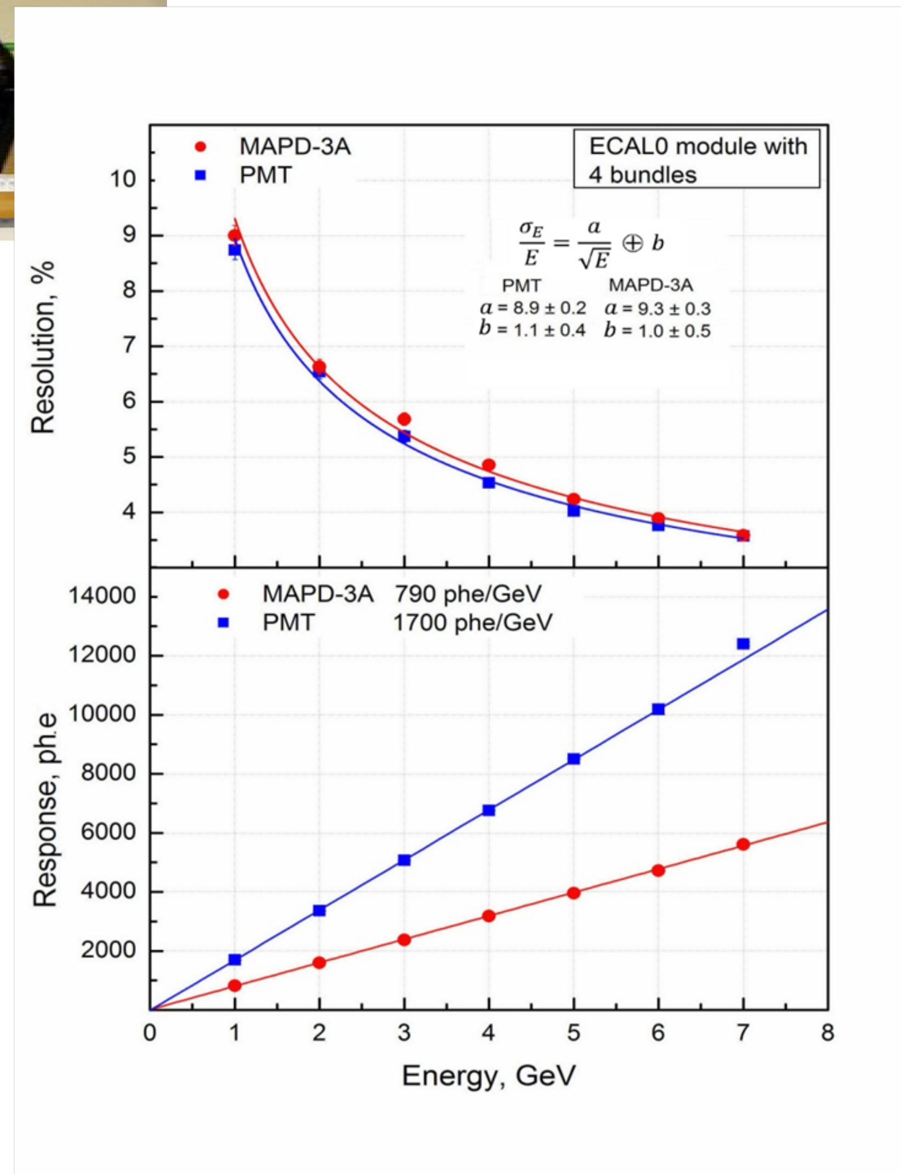




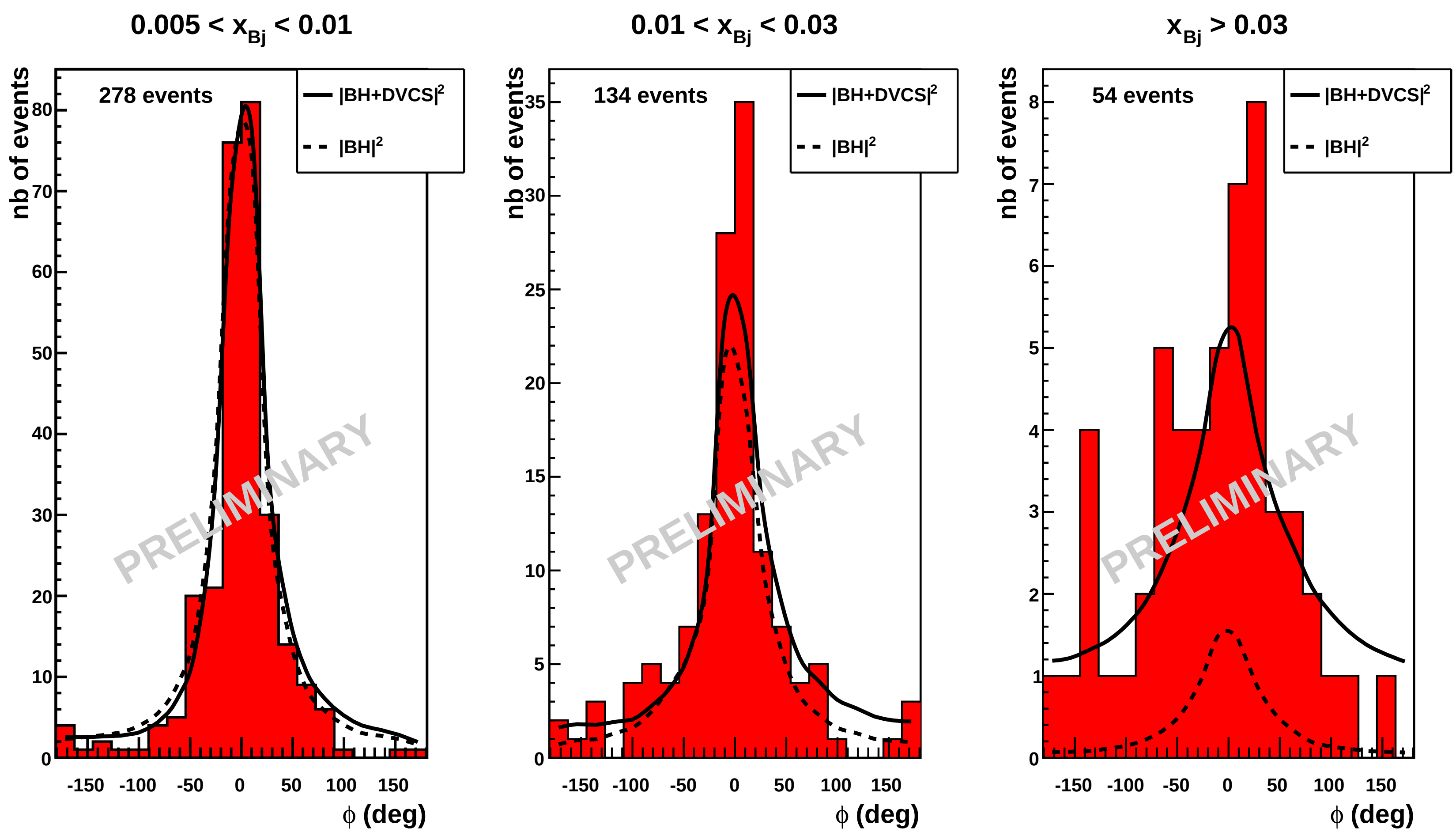
Electromagnetic calorimeter ECAL0

- Shashlik modules (length about 35 cm)
- scintillator lead sandwich with 15 radiation length
- light read-out with wave length shifting fibres
- avalanche micropixel photo diodes need temp. stability $\leq 0.2K$
- test at CERN T9 beam and at muon beam

$\Longrightarrow$ ok for GPD measurements



2009 test measurement



- result confirms expectations
- shape in ϕ determined by current photon acceptance in ECAL1/2
- ECAL0 needed for more uniform acceptance in ϕ

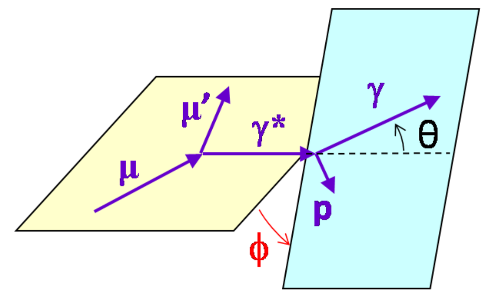
$\Longrightarrow$ clear DVCS signal observed at $Q^2 > 1$ GeV^2, $x_{Bj} > 0.03$

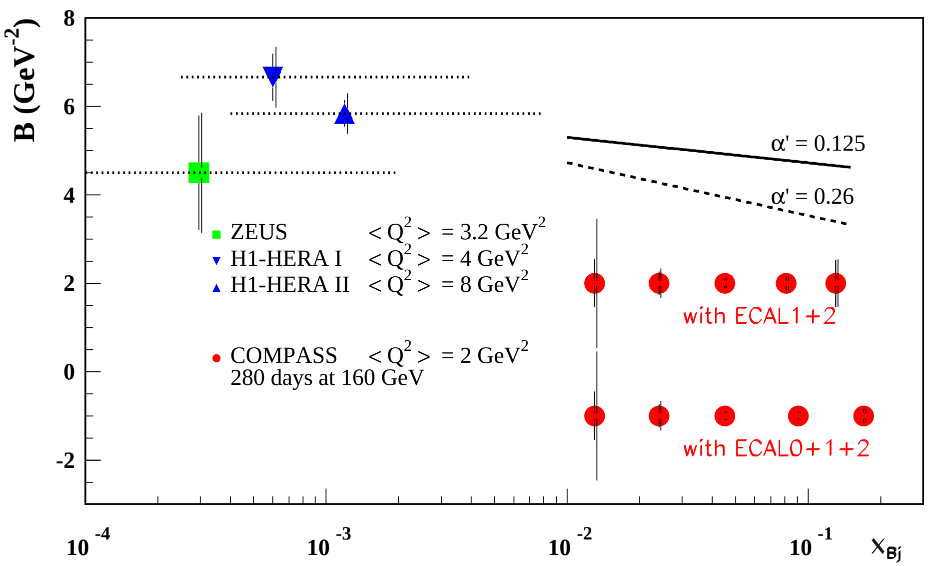
Projected results

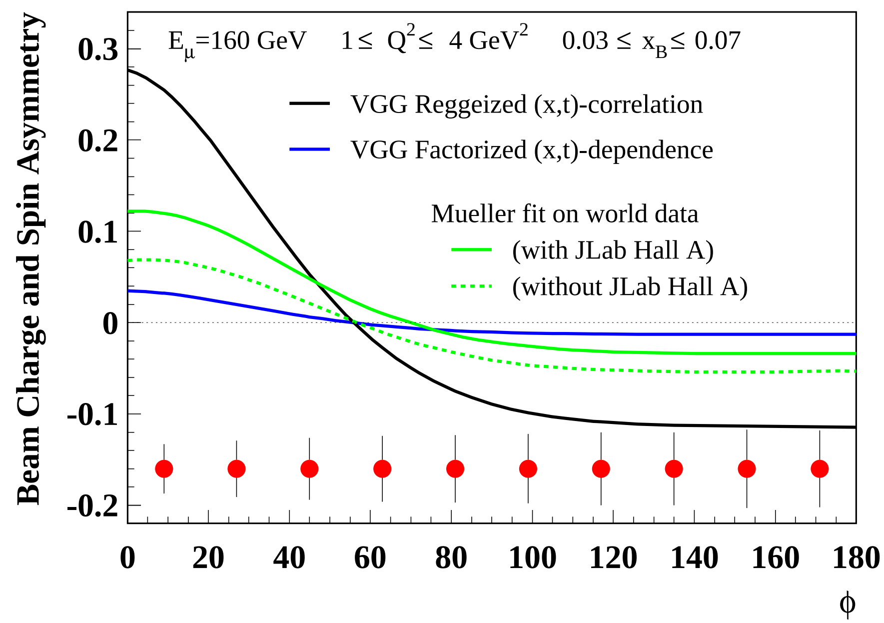
projections with
2 years of data
$\varepsilon_{global} = 10\%$
$L = 1222$ pb^{-1}

- **Transverse imaging**:
  $B(x) \sim 1/2 \langle r_\perp^2(x) \rangle$
  no model dependence

- **Azimuthal dependence**:
  $\mathrm{Re}\mathcal{H}$, $\mathrm{Im}\mathcal{H}$
  comparison to different models







Summary

- GPDs are a new active field (exp. and theoret.)
- DVCS is the golden channel for GPDs
  in addition hard exclusive meson production
- first round of high statistics experiments at JLAB and DESY
- compelling GPD programm at JLAB12 and CERN
- COMPASS will fill the gap between H1/ZEUS and JLAB/HERMES
  - phase 1: study of GPD H with unpolarised proton target
  - phase 2: study of GPD E with transversely polarised NH_3
  - dress rehearsal for phase 1: this autumn

Deeply virtual meson production

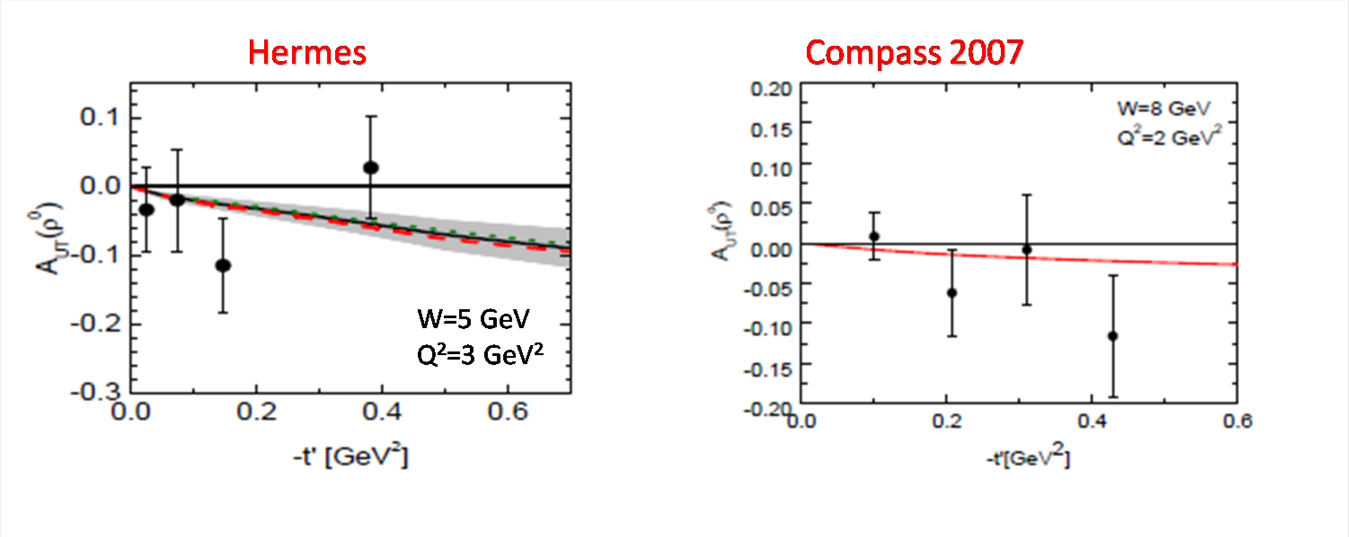
$$H_{\rho^0} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}H^u + \frac{1}{3}H^d + \frac{3}{8}H^g\right), \quad H_\omega = \frac{1}{\sqrt{2}}\left(\frac{2}{3}H^u - \frac{1}{3}H^d + \frac{1}{8}H^g\right), \; H_\phi = -\frac{1}{3}H^s - \frac{1}{8}H^g$$

- **cross section measurement:** $\Longrightarrow \rho : \omega : \phi \approx 9 : 1 : 2$ at large Q^2

  Vector meson production (ρ, ω, Φ) $\Longrightarrow H, E$
  Pseudo-scalar production (π, η.....) $\Longrightarrow \widetilde{H}, \widetilde{E}$

- **transversely pol. target asymmetries:** constraint of E/H

$$A_{UT}(\rho^0) \propto \sqrt{|-t'|}\mathrm{Im}(\mathcal{E}^*\mathcal{H})/|\mathcal{H}|^2$$



larger effects expected for ω, ρ^+

Towards GPD E

measurements with transversely polarised target

$$\mathcal{D}_{CS,T} \equiv d\sigma_T(\mu^{+\downarrow}) - d\sigma_T(\mu^{-\uparrow})$$
$$\overset{\text{LO}}{\propto} \sin(\phi-\phi_S)(\, c^I_{0T} + c^I_{1T}\cos\phi)$$

$$c^I_{1T} \propto \text{Im}\left((2-x)\,F_1\,\mathcal{E} - 4\,\frac{1-x}{2-x}\,F_2\,\mathcal{H}\right)$$

projections with
2 years of data
$\varepsilon_{global} = 10\%$
1.2 m pol. NH_3
target (f=0.26)