Deeply Virtual Compton Scattering at COMPASS

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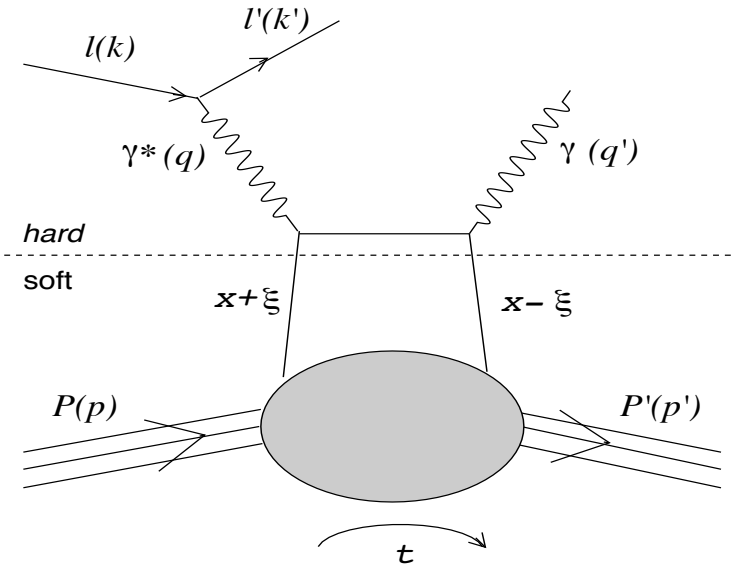
CONTENTS

- ✧ COMPASS-II GPD program
- ✧ Upgrades of the spectrometer
- ✧ DVCS analysis
- ✧ Exclusive ρ°: Chiral-odd GPD

Nucleon structure
Deeply Virtual Compton Scattering (DVCS)
Deeply Virtual Meson Scattering (DVMP)

at COMPASS:
μ P → μ' P' γ



hard scale Q^2
soft scale t/Q^2

DVCS at leading twist

✧ Soft part: Generalized Parton Distributions GPDs H^q E^q; $\tilde{H}^q$; $\tilde{E}^q$
(non local-non forward matrix elements)

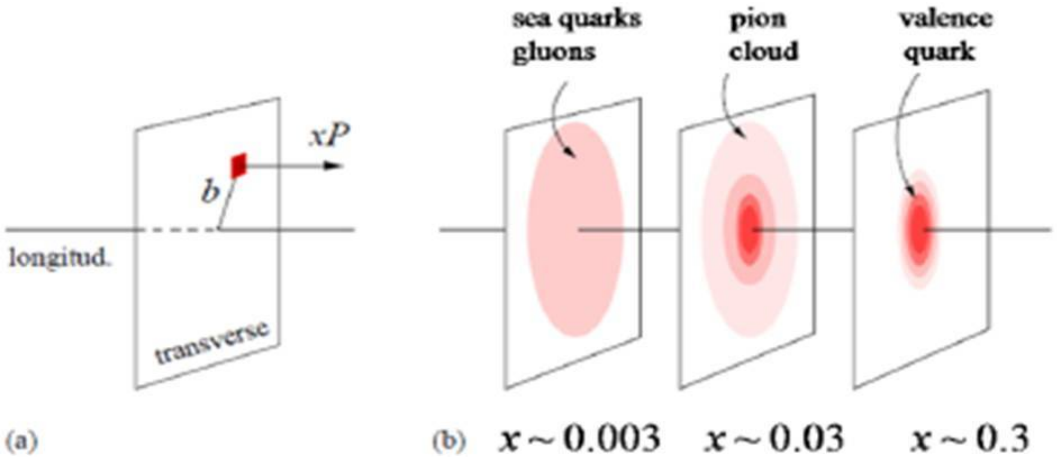
✧ Cross section measurement α Compton Form Factors $\mathcal{H}$...

see M. Guidal and J. Qiu talks

GPDs interpretations

Nucleon tomography "transverse size" vs x_{bj} (parton)

$$H(x, \xi = 0, t = -\Delta_\perp^2) \longrightarrow H(x, b_\perp)$$



GPDs moments in x

n=1 GPD → Form factors

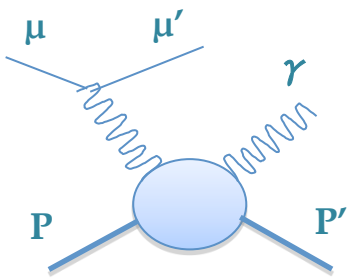
n=2 orbital momentum → Ji sum rule

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

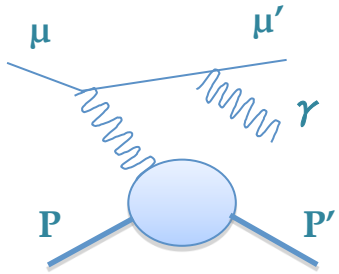
see F. Sabatié talk

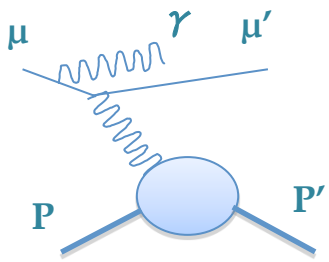
Exclusive production of a photon
$\mu P \rightarrow \mu' P' \gamma$

$d\sigma_{mes}$ =



+

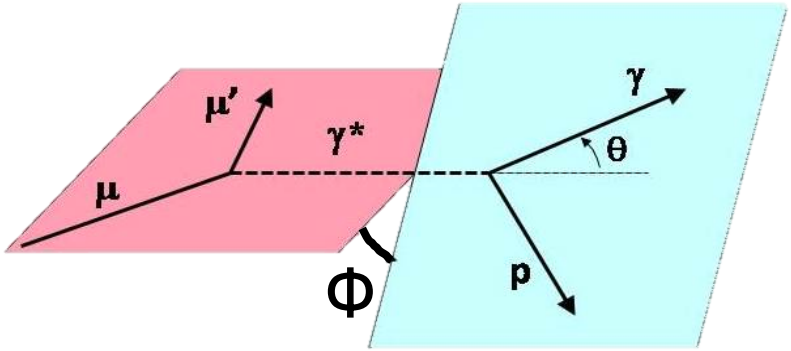




+ Interference

DVCS
sensitive to GPDs
flat in Φ

Bethe-Heitler
sensitive to Form Factors
γ scattered in leptonic plane $\Phi \mapsto 0$



Φ = angle between leptonic and photon scattering ("hadronic") plane

How can we extract Compton Form Factors at COMPASS?

$\mu P \rightarrow \mu' P' \gamma$

160 GeV $\mu^{+\leftarrow}$ and $\mu^{-\rightarrow}$ (polarisation ≈ 80%) unpolarized target: liquid H_2

mostly sensitive to H

Measurement of $x_{bj} \approx 2\xi$, Q^2, t, Φ; extraction of GPDs using $\frac{d^4\sigma^{\mu^{+\leftarrow}} \pm d^4\sigma^{\mu^{-\rightarrow}}}{dx_{bj} dQ^2 d|t| d\phi}$

$$\frac{d^4\sigma(lP \rightarrow l' P' \gamma)}{dx_{bj} dQ^2 d|t| d\phi} = d\sigma^{BH} + \left(d\sigma^{DVCS}_{unpol} + P_l d\sigma^{DVCS}_{pol} \right) + e_l \left(Re(I) + P_l Im(I) \right)$$

$$d\sigma^{\mu^{+\leftarrow}} + d\sigma^{\mu^{-\rightarrow}} \propto BH + DVCS_{unpol} + Im(I) \Rightarrow Im(I) \propto c_n \sin\Phi \Rightarrow \boldsymbol{Im(\mathcal{H}) \propto H(\xi, \xi, t)}$$

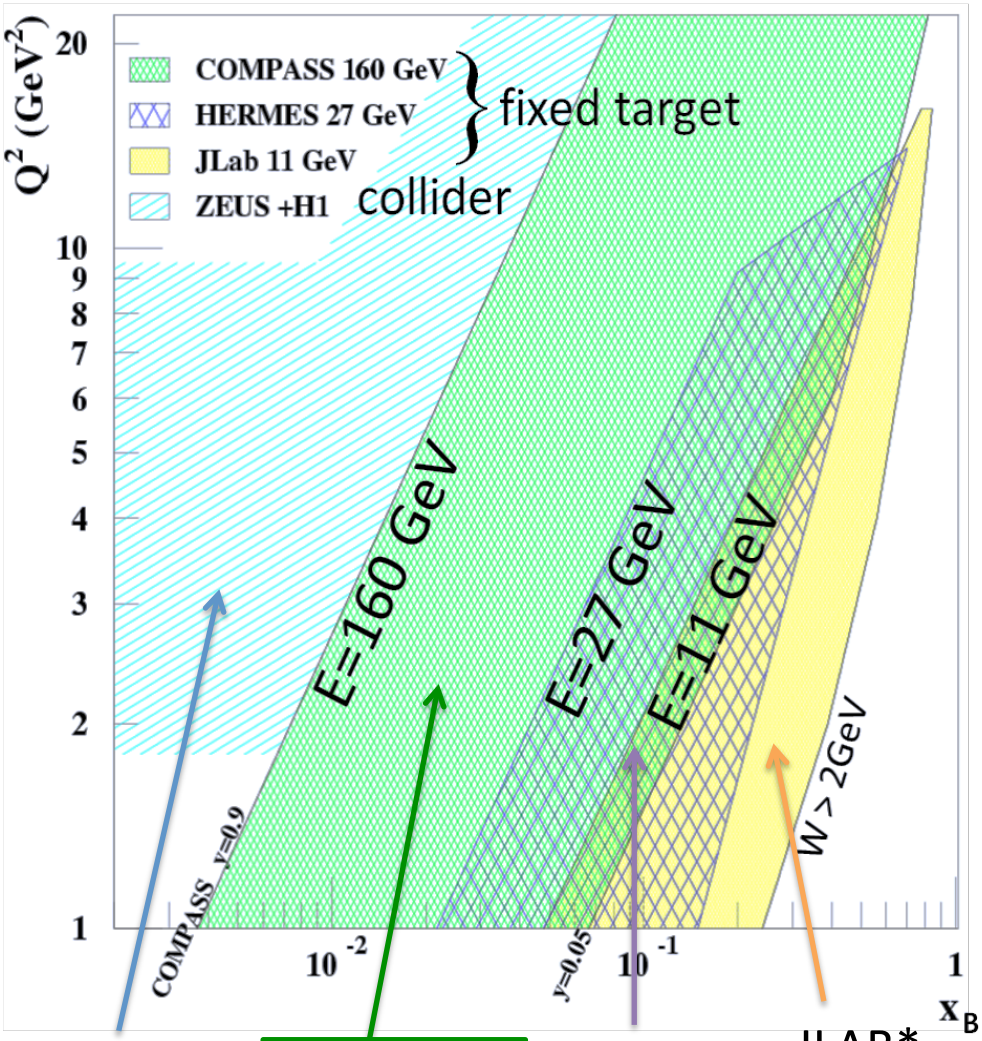
$$d\sigma^{\mu^{+\leftarrow}} - d\sigma^{\mu^{-\rightarrow}} \propto DVCS_{pol} + Re(I) \Rightarrow Re(I) \propto c_n \cos\Phi \Rightarrow \boldsymbol{Re(\mathcal{H}) \propto \int dx\, H(x, \xi, t) \left(\frac{1}{\xi - x} - \frac{1}{\xi + x} \right)}$$

Sum & Difference
Cross sections with opposite **charge & helicity** (BCSA)

Φ harmonics decomposition of **Interference** term

⇒ provides a good access to **both Real & Im** part of Compton amplitude

Why to study DVCS at COMPASS?



COMPASS:

160 GeV $\mu^{+\leftarrow}$ and $\mu^{-\rightarrow}$

fixed target: liquid H_2

polarisation ≈ 80%

- ✧ **explore the uncovered x_{bj} region between H1+ZEUS and HERMES+JLAB**
- ✧ **sensitive to sea quark and gluon distributions**

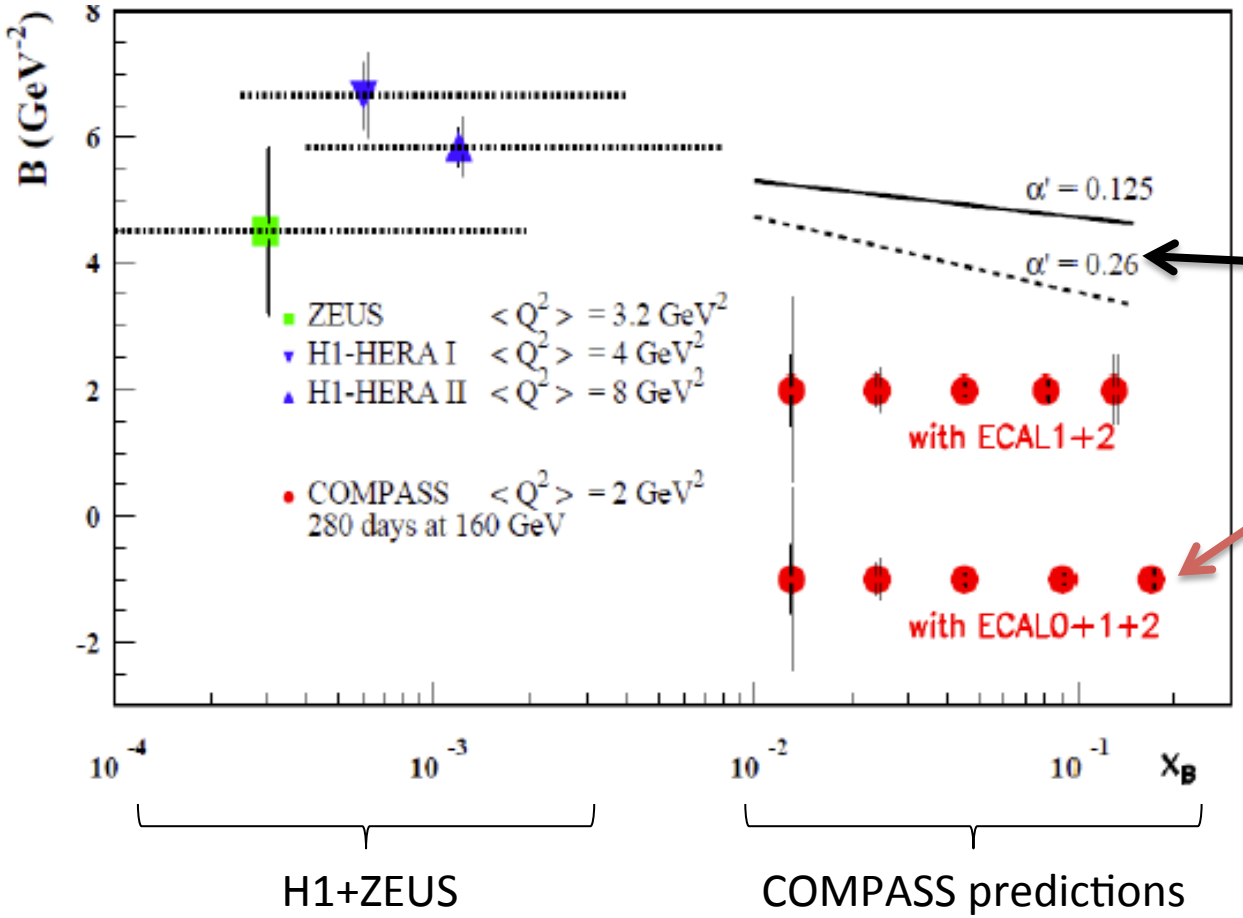
H1*+ZEUS* | COMPASS | HERMES* | JLAB* + JLAB-12 GeV

* published results

Expected results for σ^{DVCS} - t dependance

« transverse size of the proton »

$$\frac{d\sigma^{DVCS}}{dt} \propto e^{B(x_{bj})\,t} \qquad \frac{r_\perp}{2} \simeq B(x_{bj}) = B_0 + 2\alpha' \ln\frac{x_0}{x_{bj}}$$



model's predictions

stat. + syst. for 2x6 months of data taking

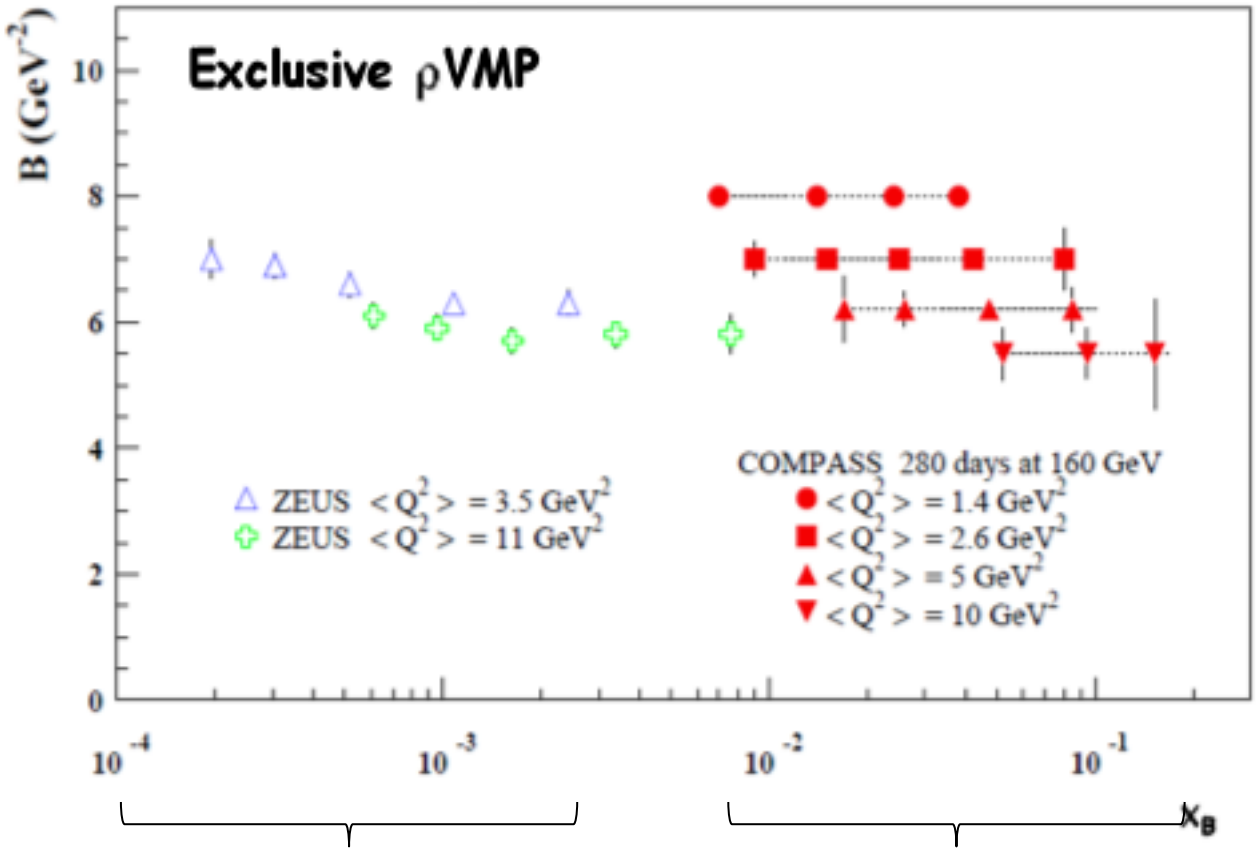
H1+ZEUS

COMPASS predictions

Expectations for vector meson production: ρ°

Sensitive to nucleon size and transverse size of the meson

$$\frac{d\sigma^{DVCS}}{dt} \propto e^{B(x_{bj})\,t} \qquad \frac{r_\perp^2}{2} \simeq B(x_{bj}) = B_0 + 2\alpha' \ln\frac{x_0}{x_{bj}}$$



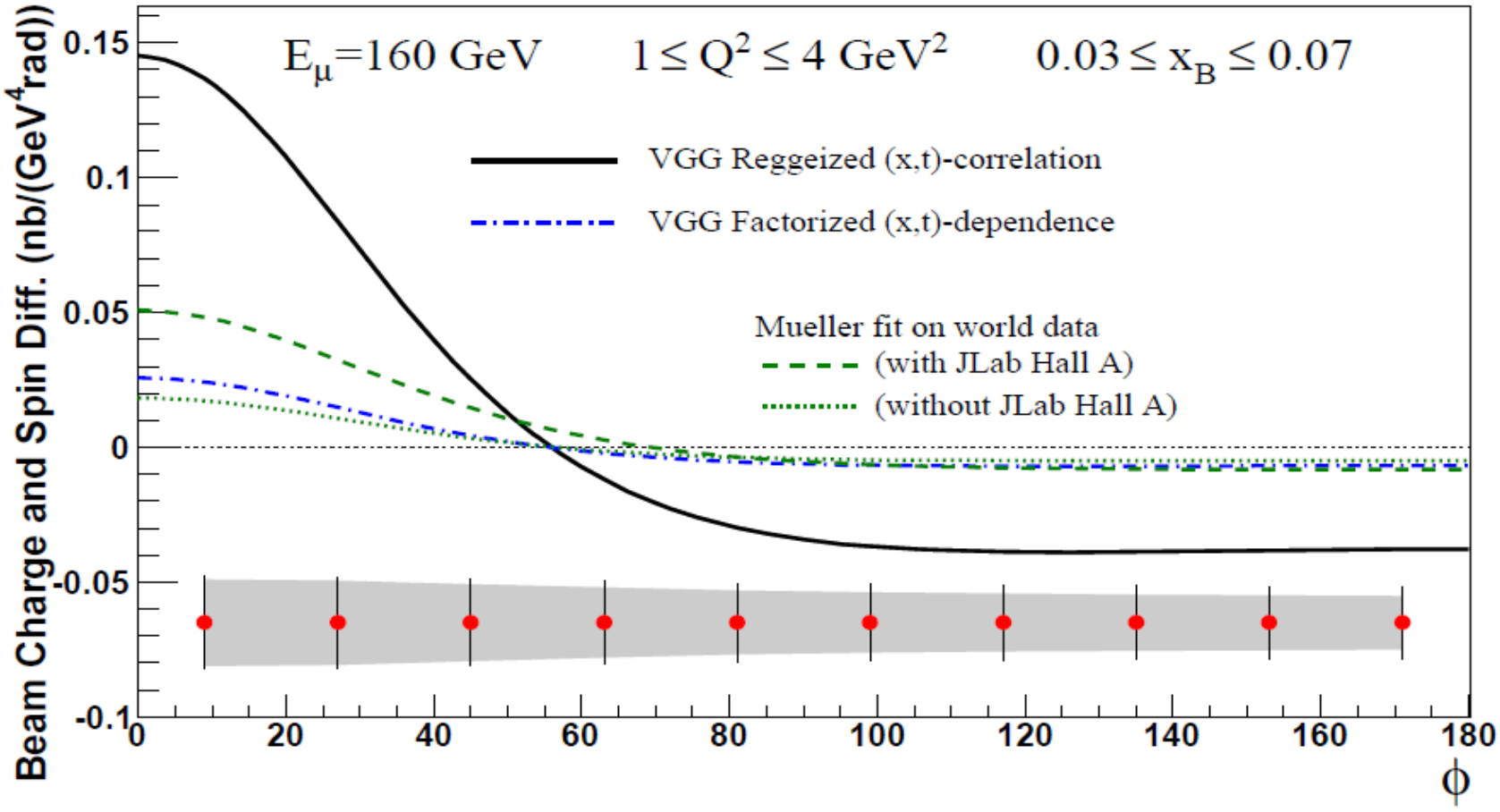
H1+ZEUS

COMPASS predictions

stat. + syst. for 2x6 months of data taking

Expectations for $d\sigma(\mu^{+\leftarrow}) - d\sigma(\mu^{-\rightarrow})$

$d\sigma(\mu^{+\leftarrow}) - d\sigma(\mu^{-\rightarrow}) \;\alpha\; F_1 \mathcal{R}e\,\mathcal{H}$



Systematic errors : 3% charge-dependent effect between μ+ and μ-

GPD program at COMPASS

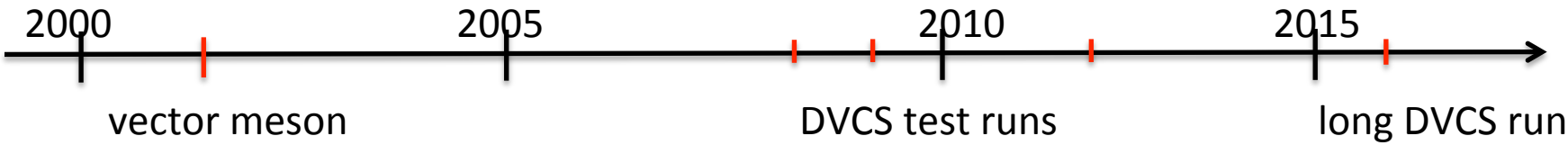
- **Vector meson production** (2002-2011)
  // & ⊥ polarized target (H, D) ⟹ target spin asymetries, SDME
  Without recoil detector

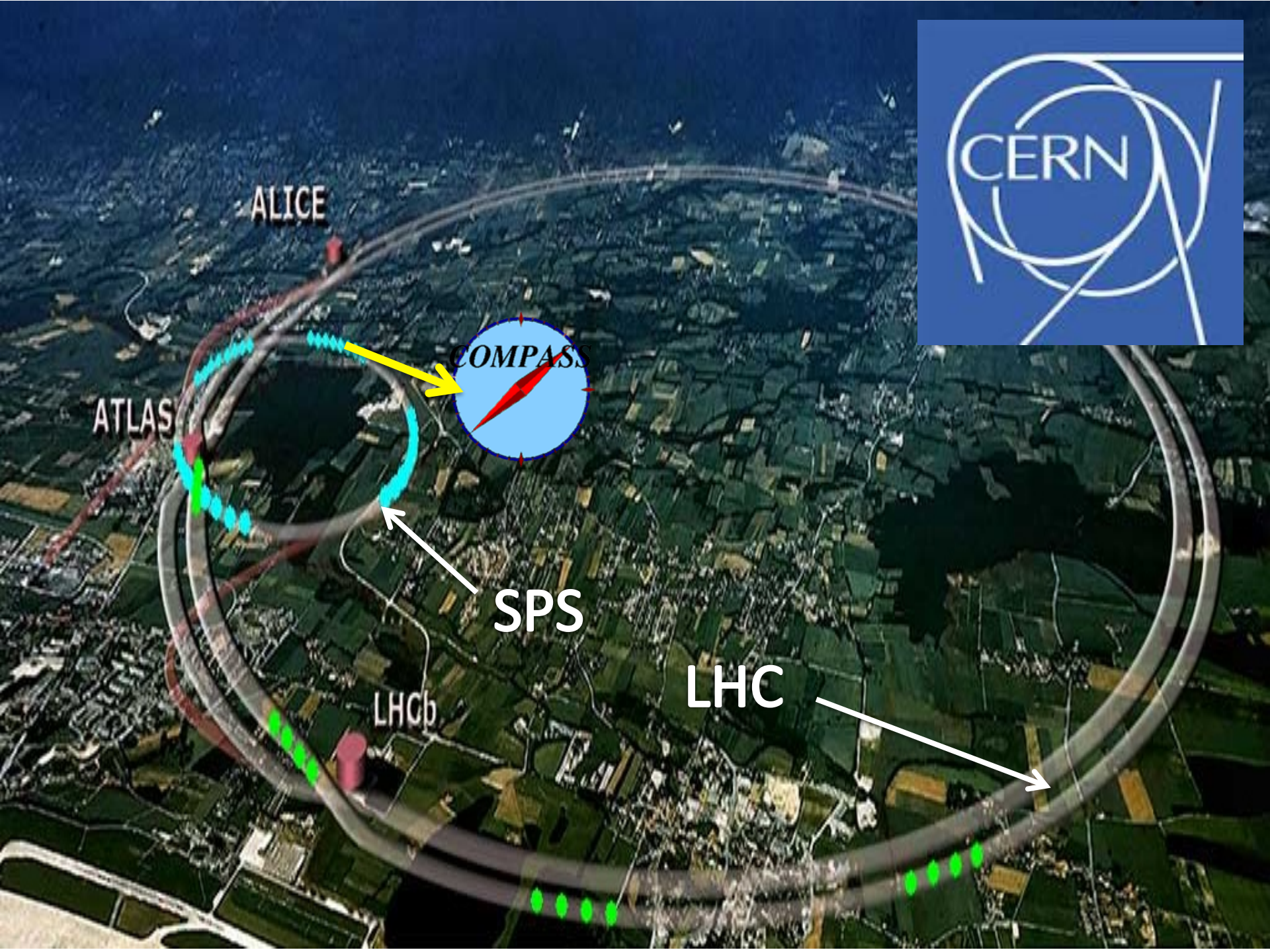
- **DVCS test runs** 2008, 2009 (1 week)
  40 cm unpolarized target + short **recoil detector** (reduced setup)
  check faisability of DVCS program, first measurement of σ^{DVCS} at COMPASS

- **2012 DVCS run** 2012 (1 month)
  optimized setup: long recoil detector (CAMERA) + large angle ECAL
  + 2.5 m liquid H_2 target, μ^+ & μ^- beam
  possibility of (Sum & Diff) of σ ⟹ access $d\sigma^{DVCS}/dt$

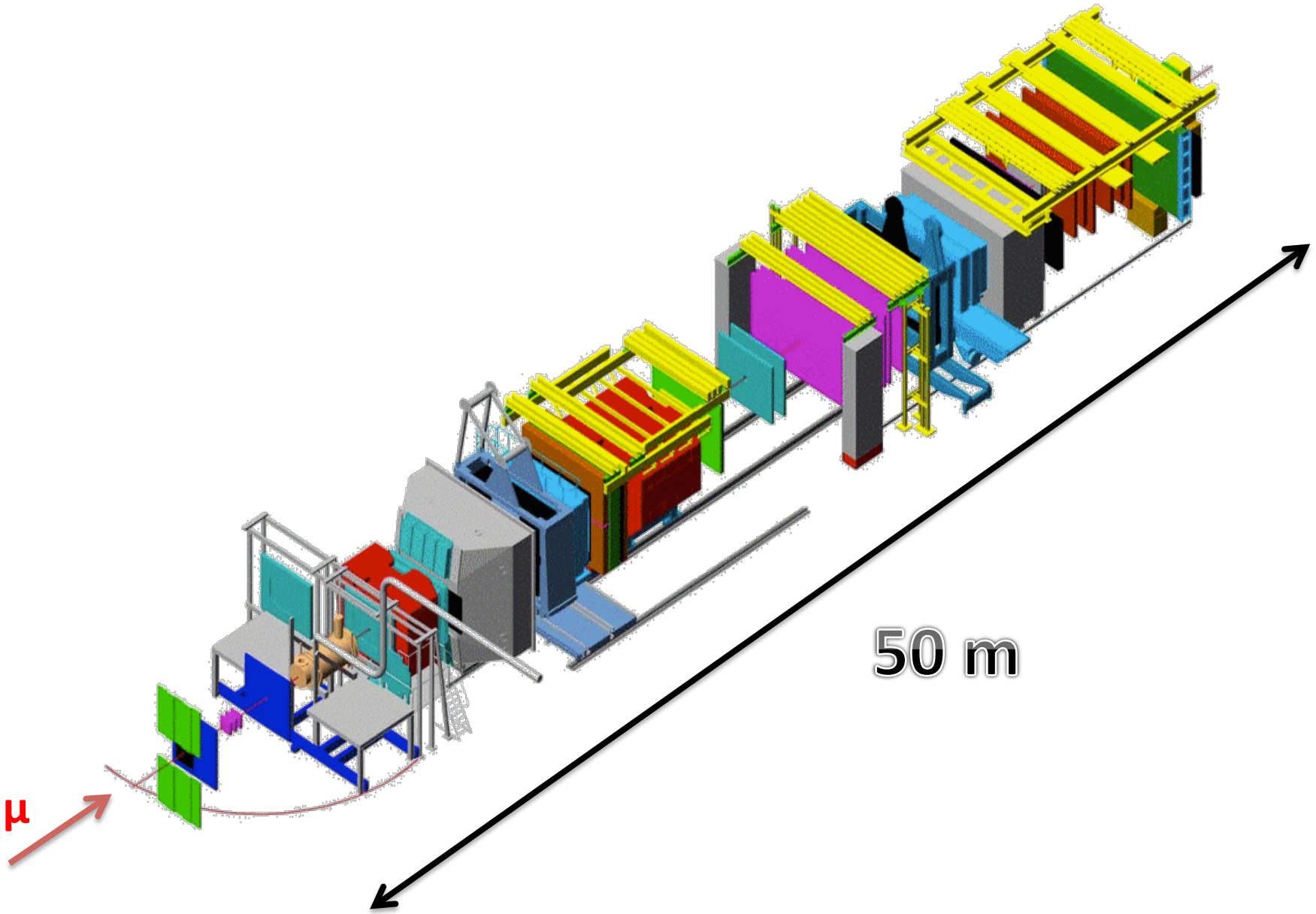
- **DVCS run** 2016-2017 (2x6 month)
  ⟹ access to GPD H

- **Future addendum**
  ⊥ polarized target ⟹ access to GPD E




CERN
ALICE
COMPASS
ATLAS
SPS
LHCb
LHC

COMPASS Spectrometer



COMPASS 2009 setup (DVCS test run) & upgrades

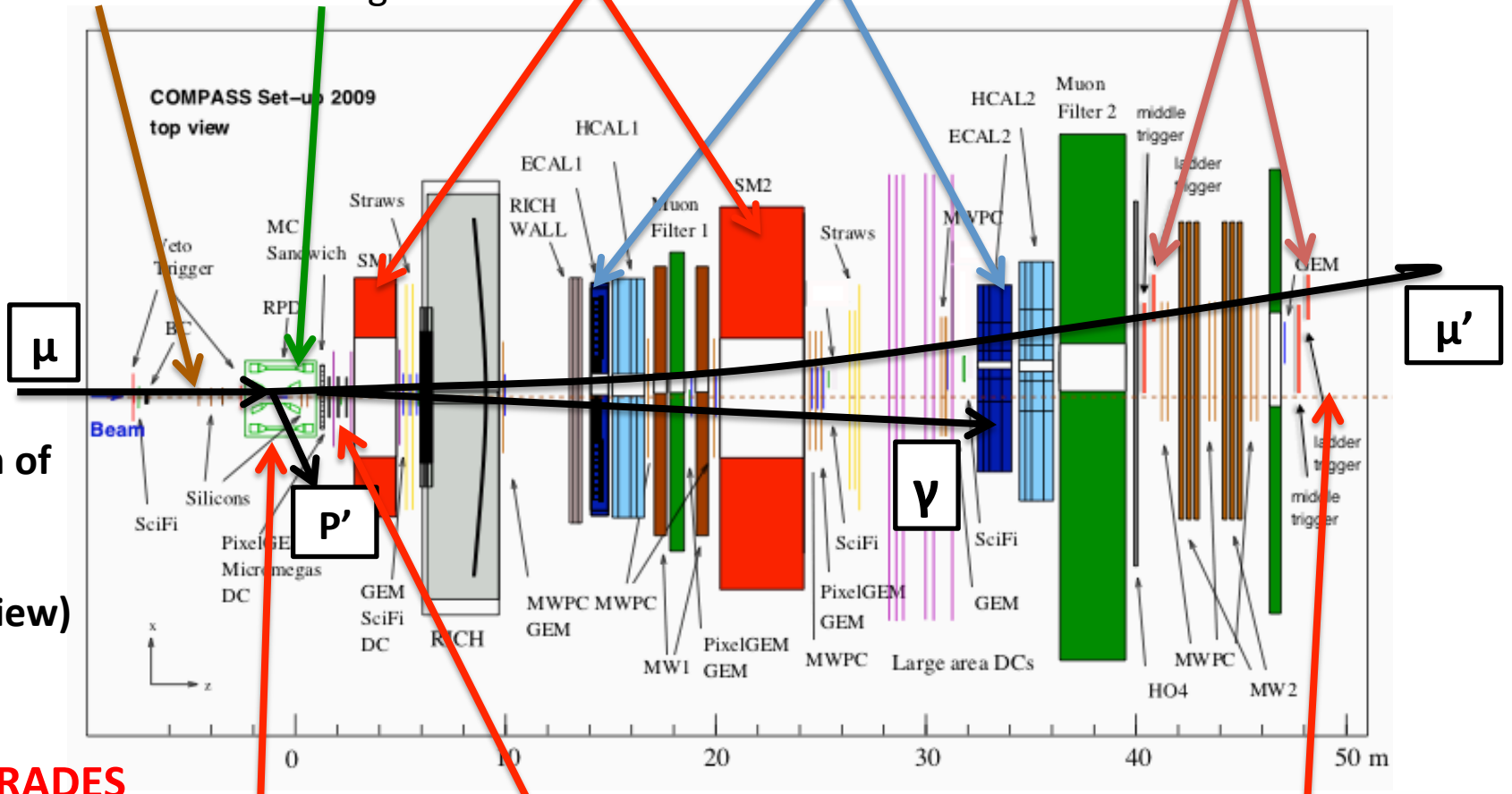
silicons
beam momentum
measurement

40cm Recoil
Proton Detector
LH2 target

dipoles

2 ECAL

trigger
hodoscopes



sketch of
DVCS
event
(top view)

UPGRADES

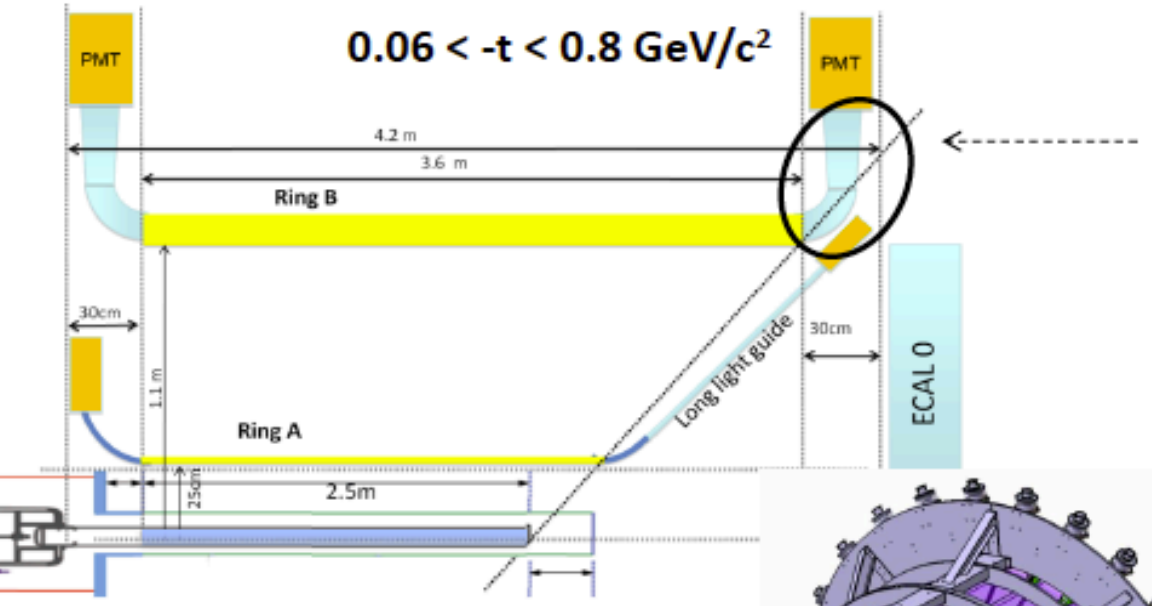
2.5m liquid H2 target
CAMERA long recoil
detector

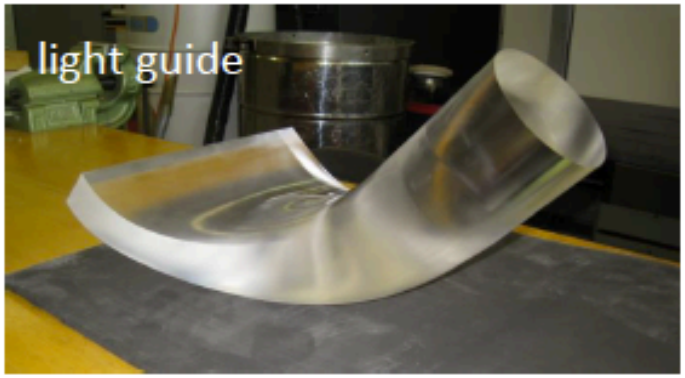
Large angle ECAL:
low E photons
¼ working in 2012

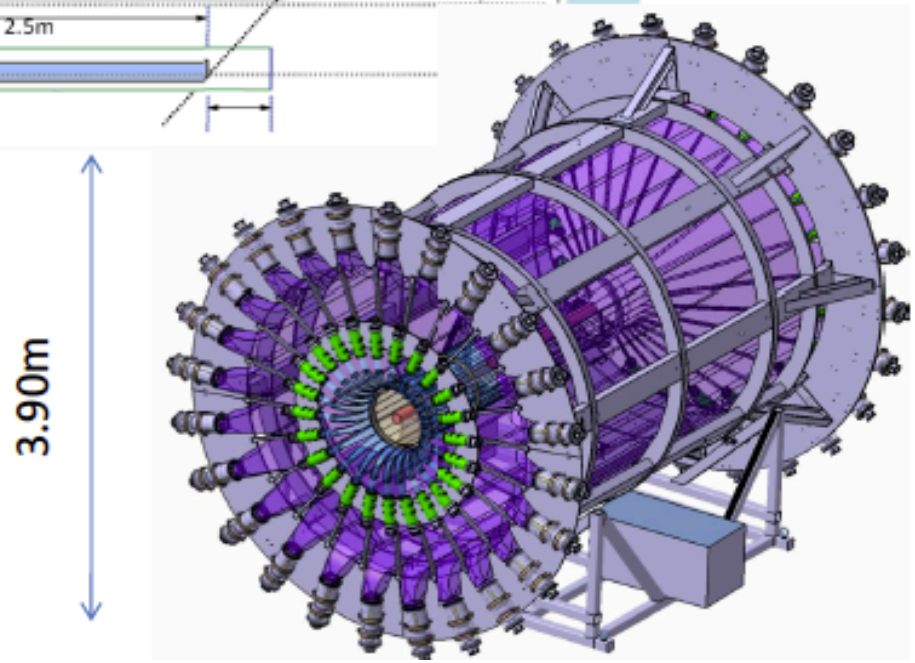
Large angle trigger:
extend kinematic coverage

Recoil Proton Detector CAMERA

ToF between 2 rings of plastic scintillators σ(ToF) < 350ps







Specifications

Ring A :

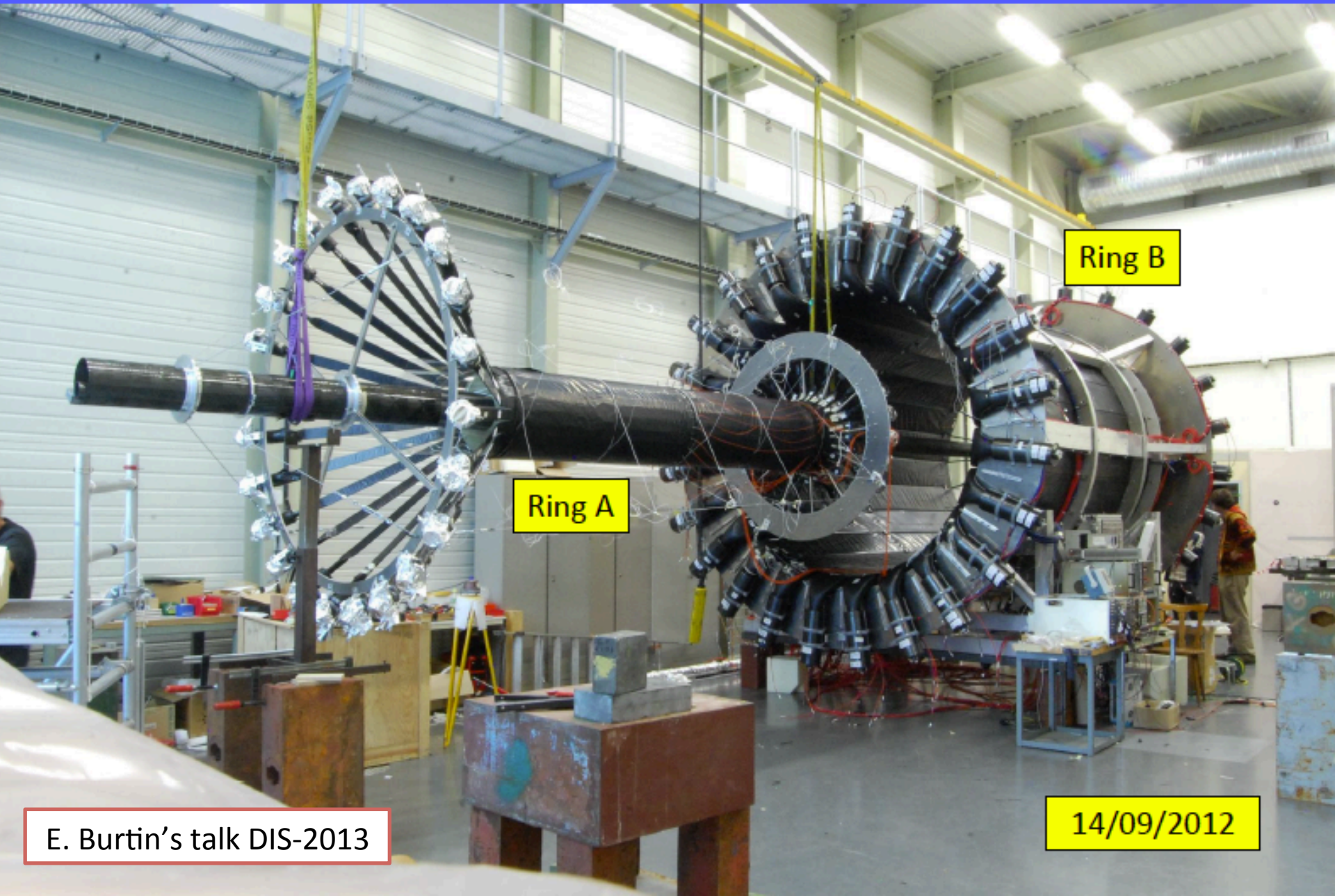
- 4mm thick, 280 cm long
- 310 ps
- Light holding structure

Ring B :

- 5cm thick, 360 cm long
- 180ps

E. Burtin's talk DIS-2013

Mounting in clean room at CERN

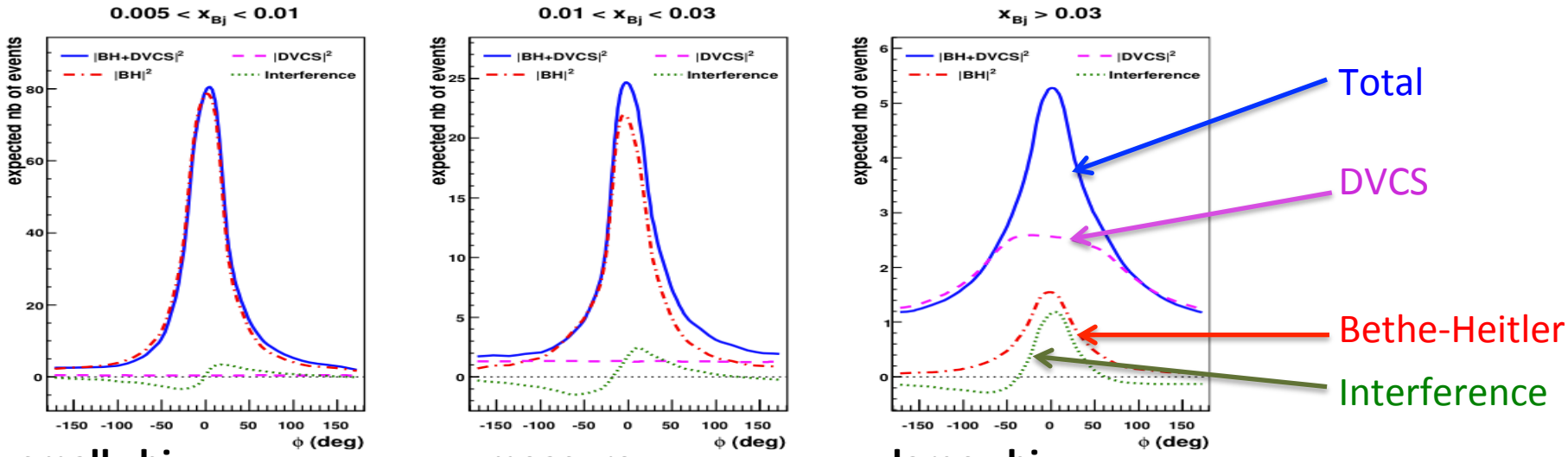


E. Burtin's talk DIS-2013

COMPASS-II proposal
CERN-SPSC-2010-014

Analysis of 2009 DVCS test run

Simulation of expected yields for 2009 setup

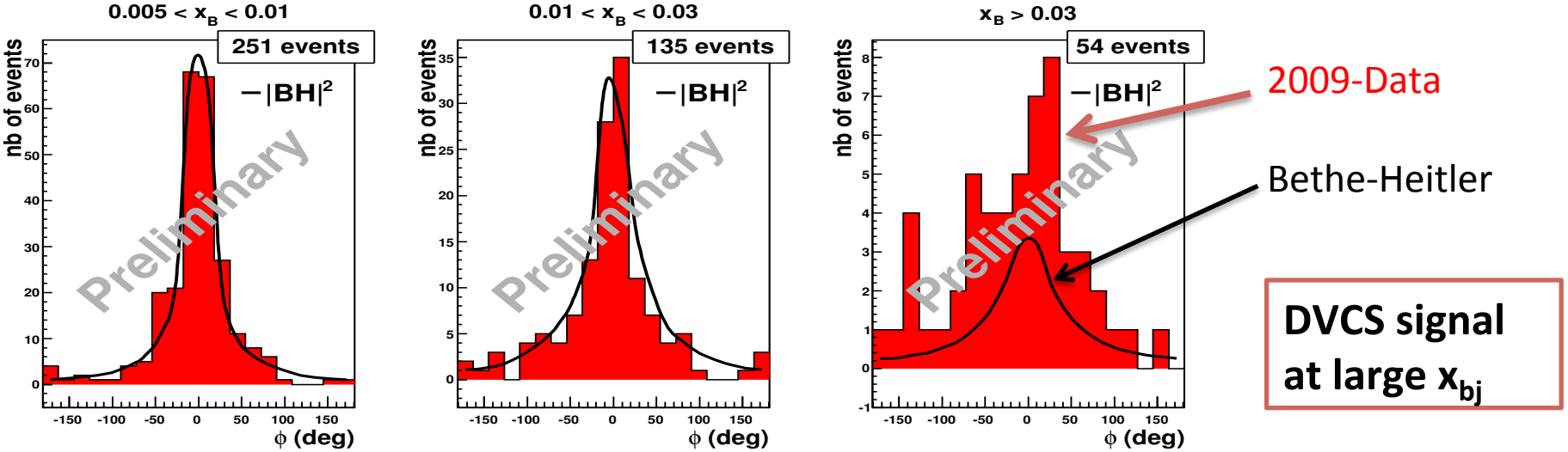


small xbj
BH = good reference

measure
Interference

large xbj
larger DVCS amplitude

preliminary results: reconstructed events

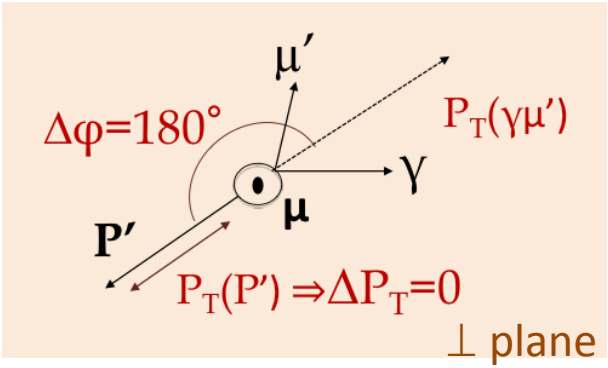


DVCS signal at large x_{bj}

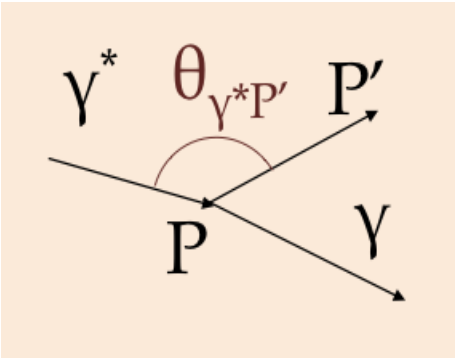
Method for DVCS analysis

Exclusivity selections: all final state particles are detected

Momentum balance
$\Delta\phi$ & ΔP_T



Scattering angles
θ(μ,μ',t) vs θ(μ,μ',p)

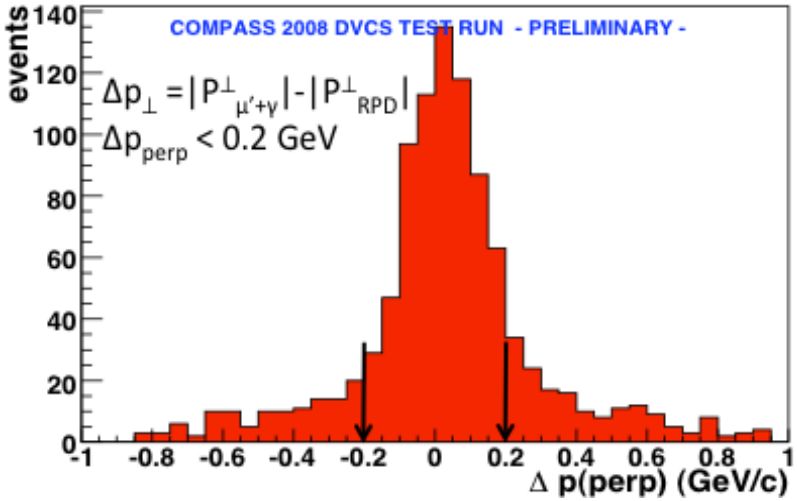


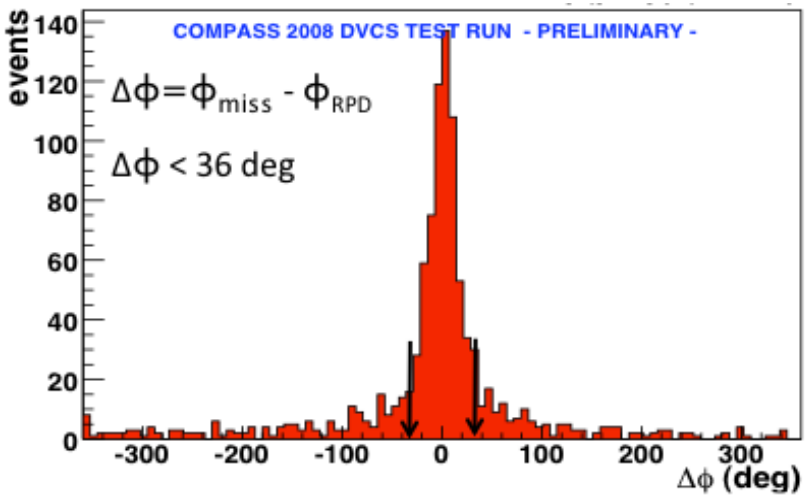
Missing mass² & energy

$$M^2_{undet} = [(P+\mu) - (P'+\mu'+\gamma)]^2$$

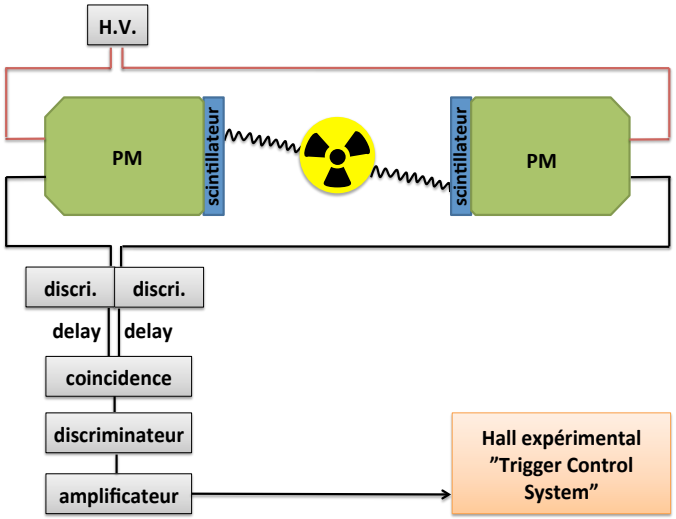
$$E_{undet} = E_i - E_f$$

Recoil proton detection: final state overconstrained ⟹ low level of background in DVCS





Normalization: luminosity



- ✧ random trigger provided by radioactive source
- ✧ tracking and momentum for **each** beam track
- ✧ μ tracks counted during Δt of trigger, same conditions as "physical analysis"
  → **effective flux**, reduce a lot of systematics

instant flux: $F(\mu^+) / F(\mu^-) = 2.4$

Goal: 3% error for DVCS cross section

Luminosity check: F_2 measurement

- Check luminosity for absolute normalization of cross sections by comparing measured $F_2(x,Q2)$ with parameterizations of world results on F_2
- Check of μ+ and μ- consistancy
- Systematics studies

Monte Carlo simulations

✧ Spectrometer simulation: GEANT3 + GEANT4 under development

✧ Generator:

- Exclusive meson production according to Goloskokov and Kroll model
- DVCS: Frankfurt, Freund and Strikman model (Phys.Lett. B460 (1999) 417-424) with modifications for COMPASS (Sandacz, Sznajder, arXiv:1207.0333)

acceptance is corrected by 4-dim. weighting of events

Background treatment

Rates are estimated using Monte Carlo simulations

Corrections by events weighting (bin/bin)

- semi-inclusive: **$\mu P \rightarrow \mu' P' \pi^\circ/\eta... \rightarrow \mu' P' \gamma X$**
- exclusive π°: **$\mu P \rightarrow \mu' P' \pi^\circ \rightarrow \mu' P' \gamma \gamma$**
- diffractive dissoc. of P': **$\mu P \rightarrow \mu' P^* \gamma \rightarrow \mu' P' \gamma X$**

- ✧ **Rates are expected to be under control at COMPASS kinematic**
- ✧ **π° background is deduced from the exclusive π° cross section measurement**

Exclusive vector meson production

Transverse target spin asymmetries in exclusive ρ^0 muoproduction

The COMPASS collaboration

Abstract

Exclusive production of ρ^0 mesons was studied at the COMPASS experiment by scattering 160 GeV/c muons off transversely polarised protons. Five single-spin and three double-spin azimuthal asymmetries were measured as a function of Q^2, x_{Bj}, or p_T^2. The $\sin\phi_S$ asymmetry is found to be $-0.019 \pm 0.008(stat.) \pm 0.003(syst.)$. All other asymmetries are also found to be of small magnitude and consistent with zero within experimental uncertainties. Very recent calculations using a GPD-based model agree well with the present results. The data is interpreted as evidence for the existence of chiral-odd, transverse generalized parton distributions.

arXiv: 1310.1454v2 (Oct. 2013) subm. to Phys. Lett. B

Exclusive ρ° meson production

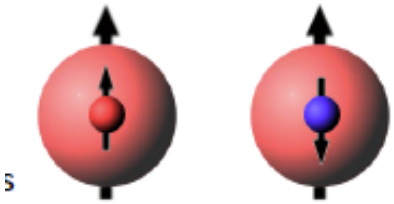
Exclusive meson production:
flavor separation for GPDs and constraints on other GPDs

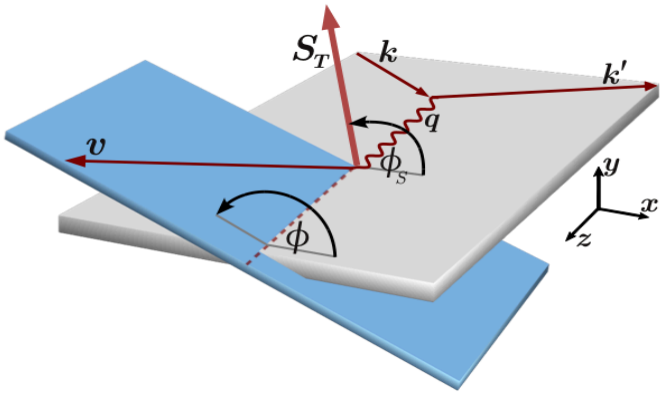
✧ Dominant transition: $\gamma^*_L \rightarrow \rho^\circ_L$ chiral even GPD H and E

✧ Asymetries measurement: **$\mu^{+\leftarrow}$ off transversely polarised proton**
⇒ constraints on other GPDs

$A_{UT}^{\sin(\phi - \phi_s)}$ GPD E related to supressed $\gamma^*_T \rightarrow \rho^\circ_T$ transition

$A_{UT}^{\sin(\phi_s) \text{ or } \sin(2\phi - \phi_s)}$ **chiral-odd GPDs H_T**
correspond to $\gamma^*_T \rightarrow \rho^\circ_L$



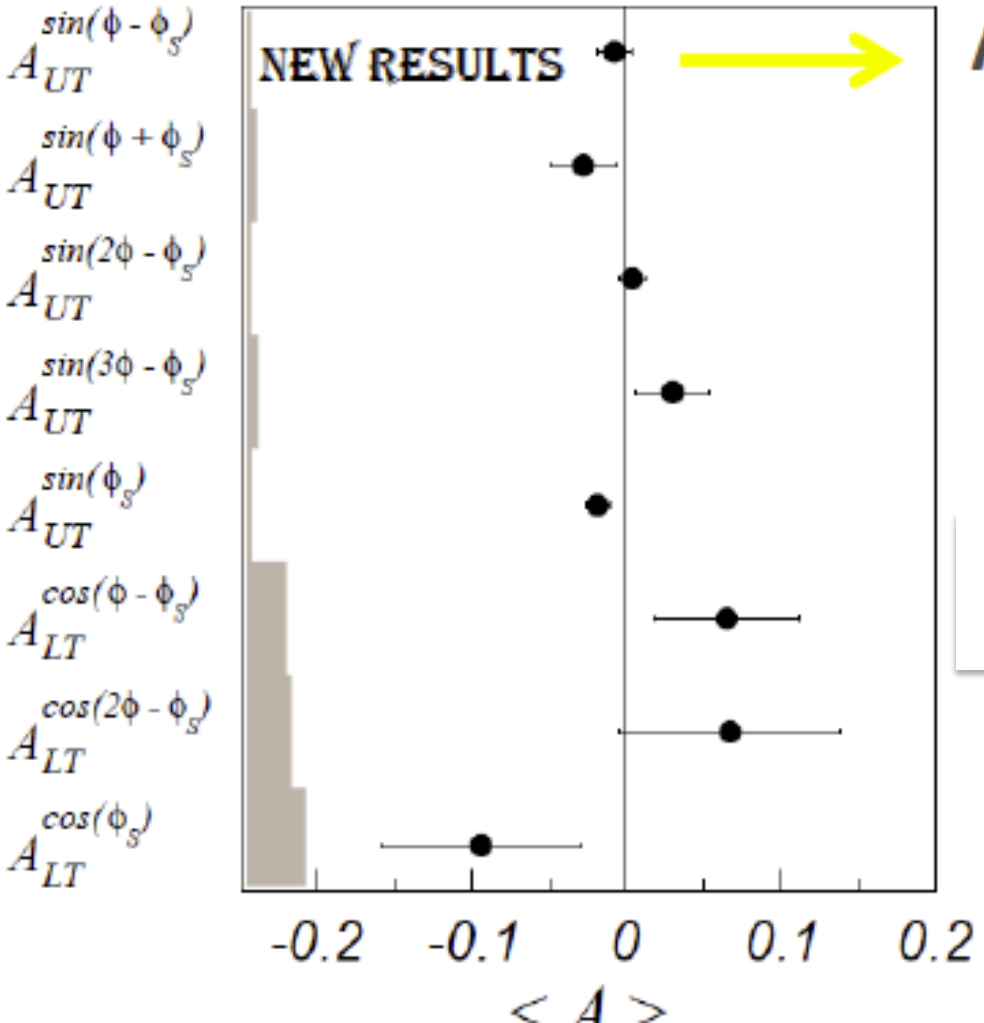


Exclusive ρ° off ⊥ pol. protons

$\mu\ p \rightarrow \mu' + \rho^0 + p_{\text{non détecté}}$
$\rho^0 \hookrightarrow \pi^+\pi^-$

COMPASS 2007-2010,without recoil detector

$W = 8.1\ \text{GeV}/c^2,\ p_T^2 = 0.2\ (\text{GeV}/c)^2,\ Q^2 = 2.2\ (\text{GeV}/c)^2$



$A_{UT}^{\sin(\phi - \phi_S)} \propto Im(\mathcal{E}^* \mathcal{H})$

$E\rho^0 \propto 2/3\ E^u + 1/3\ E^d + 3/8\ E^g$

Cancellation between gluon and sea contributions and $E^{u\ val} \sim -E^{d\ val}$

NPB865 (2012) 1

Exclusive ρ° off ⊥ pol. protons

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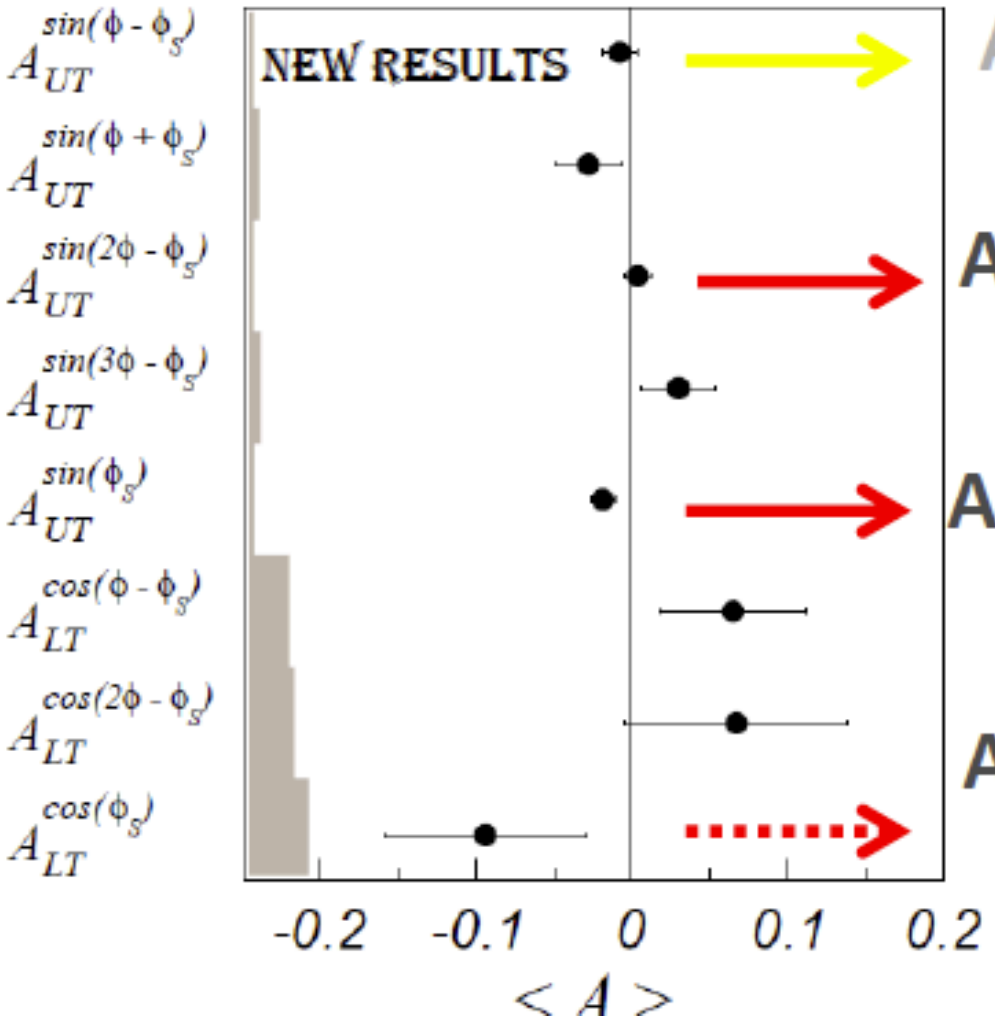

$A_{UT}^{\sin(\phi - \phi_S)} \propto Im(E^* H)$

$Im(E^*_T H_T)$

$A_{UT}^{\sin(2\phi - \phi_S)} \propto Im(E^* \bar{E}_T)$

$A_{UT}^{\sin(\phi_S)} \propto Im(E^* \bar{E}_T - H^* H_T)$

$A_{LT}^{\cos(\phi_S)} \propto Re(E^* \bar{E}_T - H^* H_T)$

→ H_T should be not small

Submited to PLB submited

CONCLUSION

✧ COMPASS-II GPD program started

- unique kinematical range to study GPDs
- upgrades of the spectrometer: 2012-DVCS run (1 month)
- preliminary studies on DVCS cross section with 2009 run

✧ Vector meson production

$A_{\mathrm{UT}}^{\sin\phi_S}$ = -0.019 ± 0.008 (stat.) ± 0.003 (syst.)

- 1st experimental evidence for the existence of chiral-odd GPD H_T