



GPD program at COMPASS

GDR PH-QCD, annual meeting

Nov 27, 2013

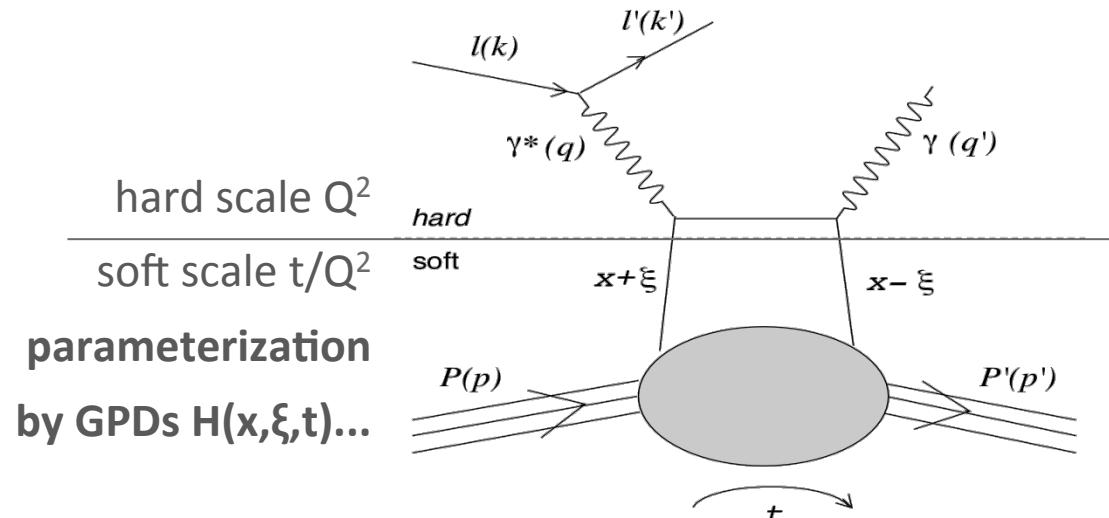
Marie Boer, CEA-Saclay/SPhN and CNRS/IPN-Orsay

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- ✧ Physics motivations
- ✧ Results on exclusive production of ρ°
- ✧ Spectrometer upgrades
- ✧ Measurements to access DVCS cross section
- ✧ GPD program and ongoing analysis

Generalized Parton Distributions

Access to Generalized Parton Distributions through deep exclusive processes

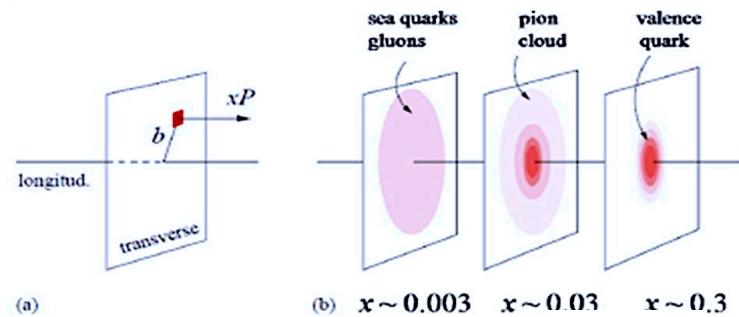


Deeply Virtual Compton Scattering (DVCS) $\ell^- P \rightarrow \ell^- P' \gamma$

GPD = non local, non forward

Nucleon tomography

⇒ correlation b_\perp and x



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

$$P = P'$$

Deep inelastic scattering (DIS)
parton distribution functions $q(x)$
⇒ x = longitudinal momentum

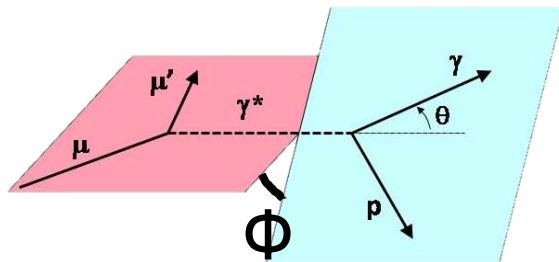
GPD moments in x
1st moment: Elastic Form Factor (t dependance)
2d moment: Angular momentum

Measurement of DVCS

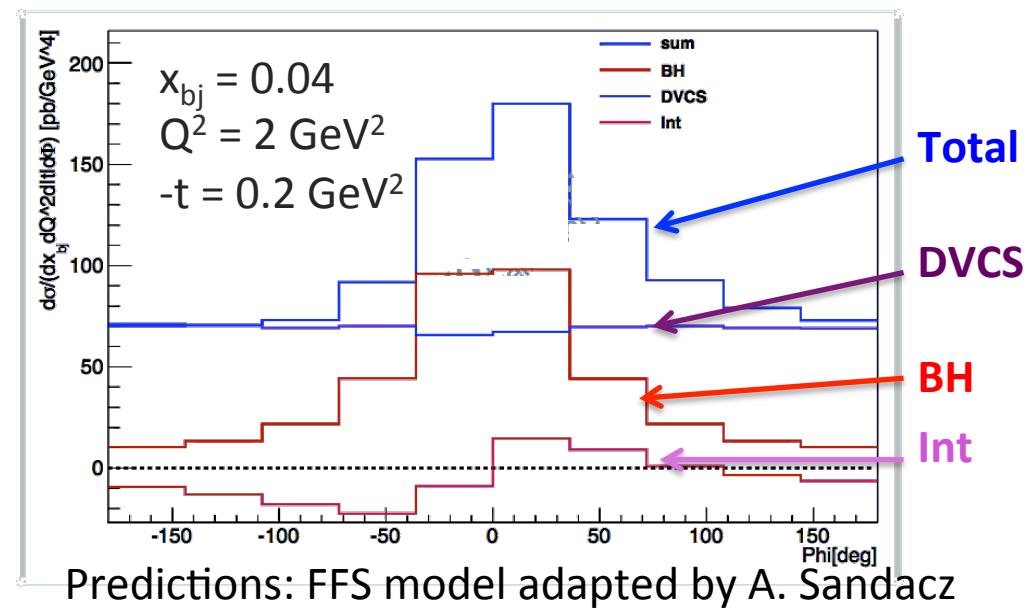
$$d\sigma_{\text{mes}} = \text{DVCS} + \text{Bethe-Heitler} + \text{Interference}$$

DVCS
 sensitive to GPDs
 \approx flat in Φ

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



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



Extraction of GPDs at COMPASS

160 GeV $\mu^+ \leftarrow$ and $\mu^- \rightarrow$ (polarisation $\approx 80\%$)
mostly sensitive to H

unpolarized target: liquid H₂

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

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

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

$$d\sigma^{\mu^{+/-}} + d\sigma^{\mu^{+/-}} \propto BH + \text{DVCS}_{unpol} + Im(I) \Rightarrow Im(I) \propto c_n \sin \Phi \Rightarrow \underline{Im(\mathcal{H})} \propto H(\xi, \xi, t)$$

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

$d\sigma/dt$ needs 3% accuracy
in normalization

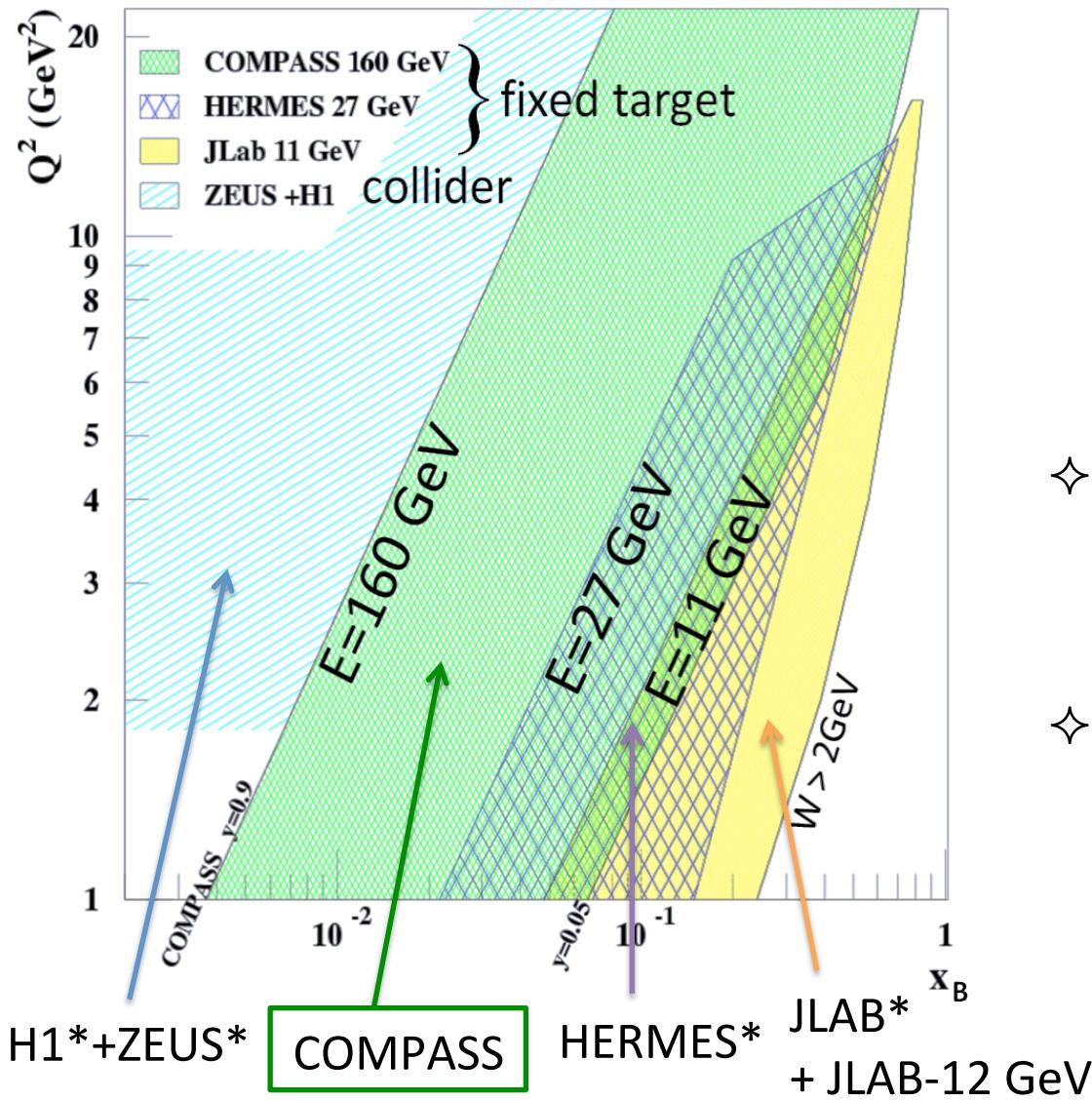
Sum & Difference

Cross sections with opposite
beam **charge & helicity**

Φ harmonics decomposition of **Interference** term

\Rightarrow provides a good access to **both Real and Im** part of
Compton amplitude, constrain D-term for DD models

Why to study DVCS at COMPASS?



COMPASS:

160 GeV $\mu^+ \leftarrow$ and $\mu^- \rightarrow$
fixed target: liquid H₂
polarisation $\approx 80\%$

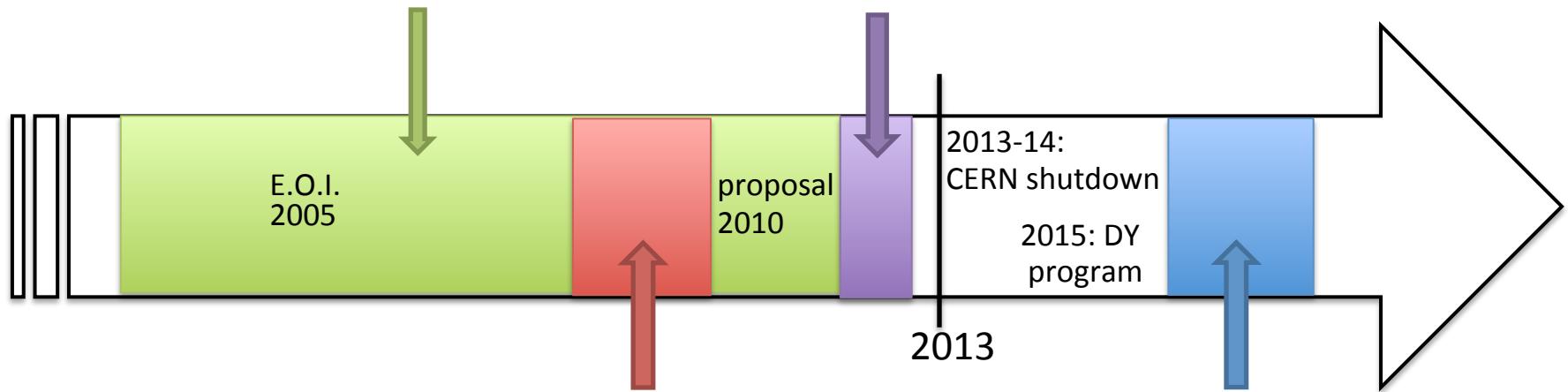
- ✧ explore the uncovered x_{bj} region between H1+ZEUS and HERMES+JLAB
- ✧ sensitive to sea quark and gluon distributions

* published results

Schedule of the GPD program

Vector meson production (2002-2011)
// & \perp polarized target (H, D)
Without recoil detector
 \Rightarrow target spin asymmetries, SDME

2012 DVCS test run 2012 (1 month)
2.5 m H₂ target, long recoil detector,
 μ^+ & μ^- beam
 \Rightarrow access $d\sigma^{\text{DVCS}}/dt$



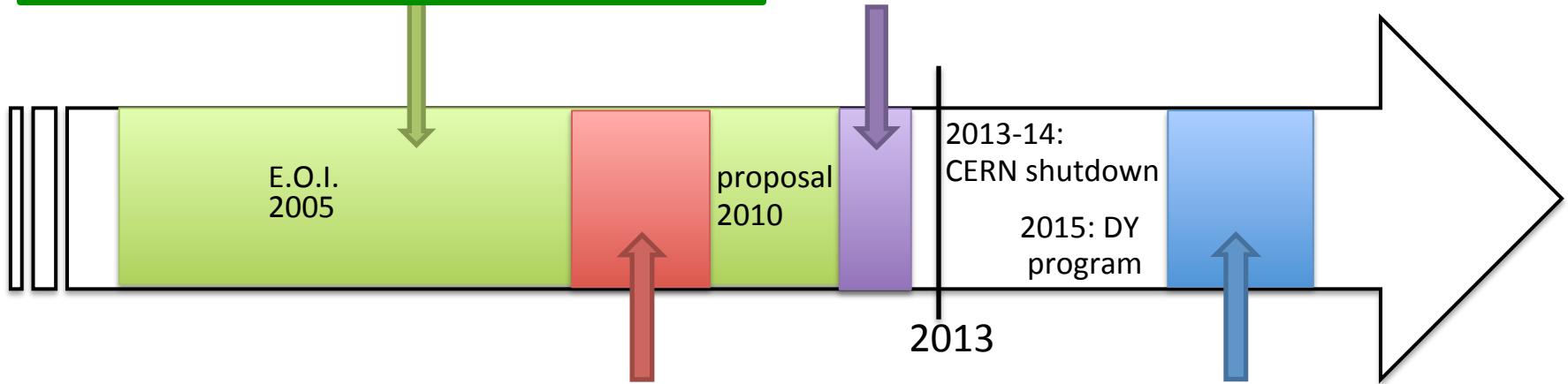
DVCS test runs 2008, 2009 (1 week)
40 cm target + short recoil detector
check feasibility of DVCS program,
first measurement of $\sigma^{\text{BH+DVCS}}$

DVCS full run
2016-2017 (2x6 months)
 \Rightarrow access to GPD H

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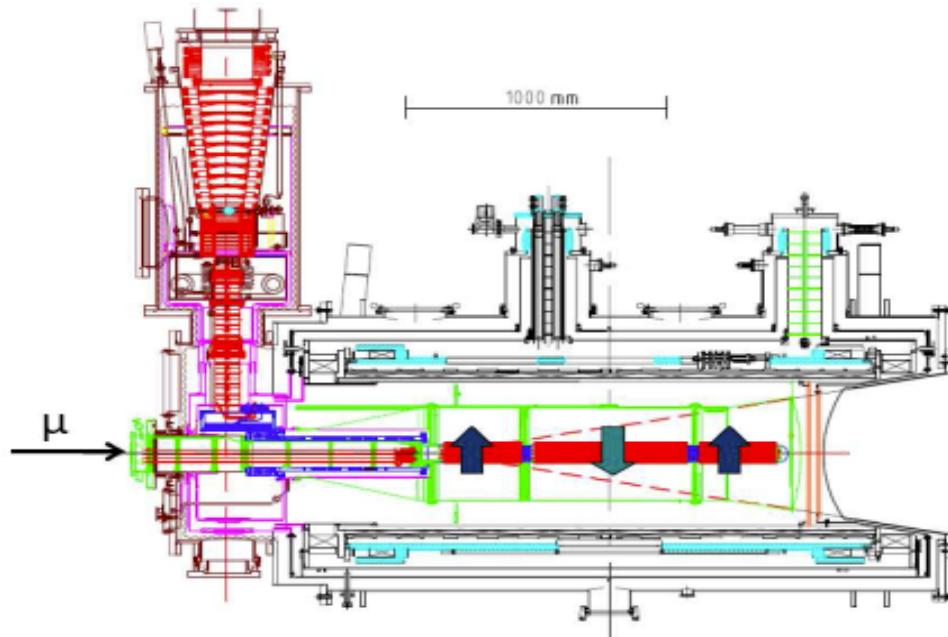
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Exclusive production of ρ°

2002-2011, without recoil detector, NH_3 or ${}^6\text{LiD}$ polarized target
L and T target spin asymmetries + beam spin asymmetries

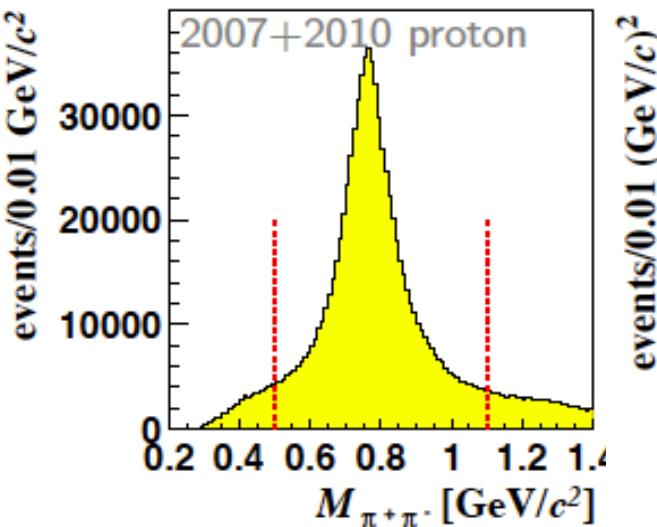
- Spin Density Matrix Element
- Asymmetries and cross section sensitive to different combination of GPDs
 $\sigma^{\rho^{\circ}} \rightarrow$ chiral even GPDs ...
- Flavor separation of GPDs using meson production
 $H^{\rho^{\circ}} \propto 2/3 H^u + 1/3 H^d + 3/8 H^g$



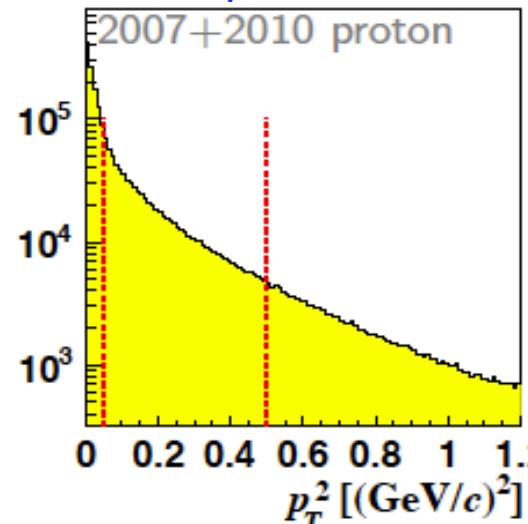
NH_3 transversely
polarized target
3 cells
30-60-30 cm long
 $p=90\%$, $f=16\%$

Exclusive production of ρ° : analysis

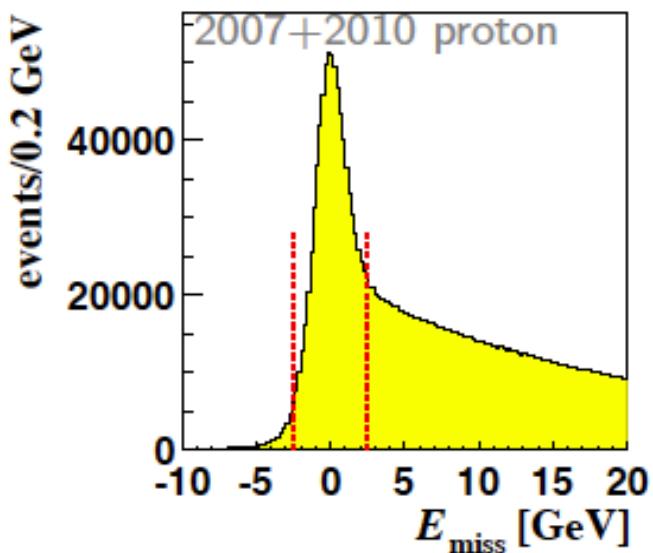
ρ° mass
 $0.5 < M_{\pi\pi} < 1.1 \text{ GeV}$



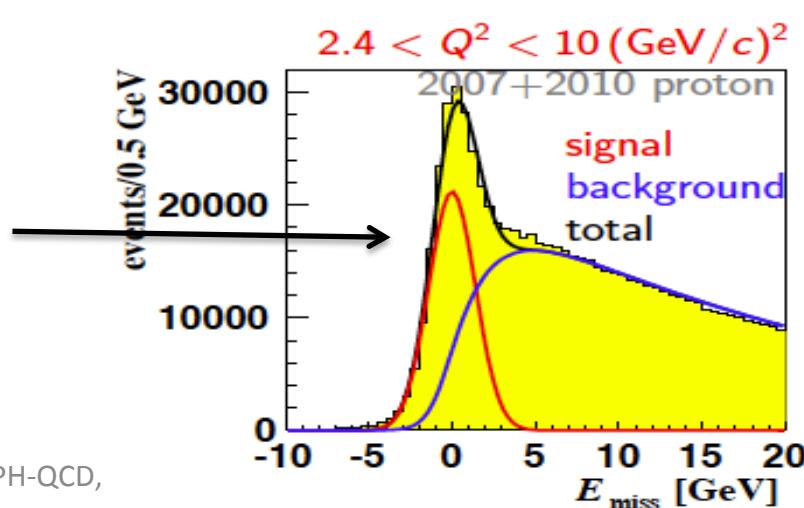
For coherent production
and SIDIS background
 $0.05 < p_T^2 < 0.5 \text{ GeV}^2$



Exclusivity (without recoil)
 $|M_X^2 - M_p^2/2M_p| < 2.5 \text{ GeV}$

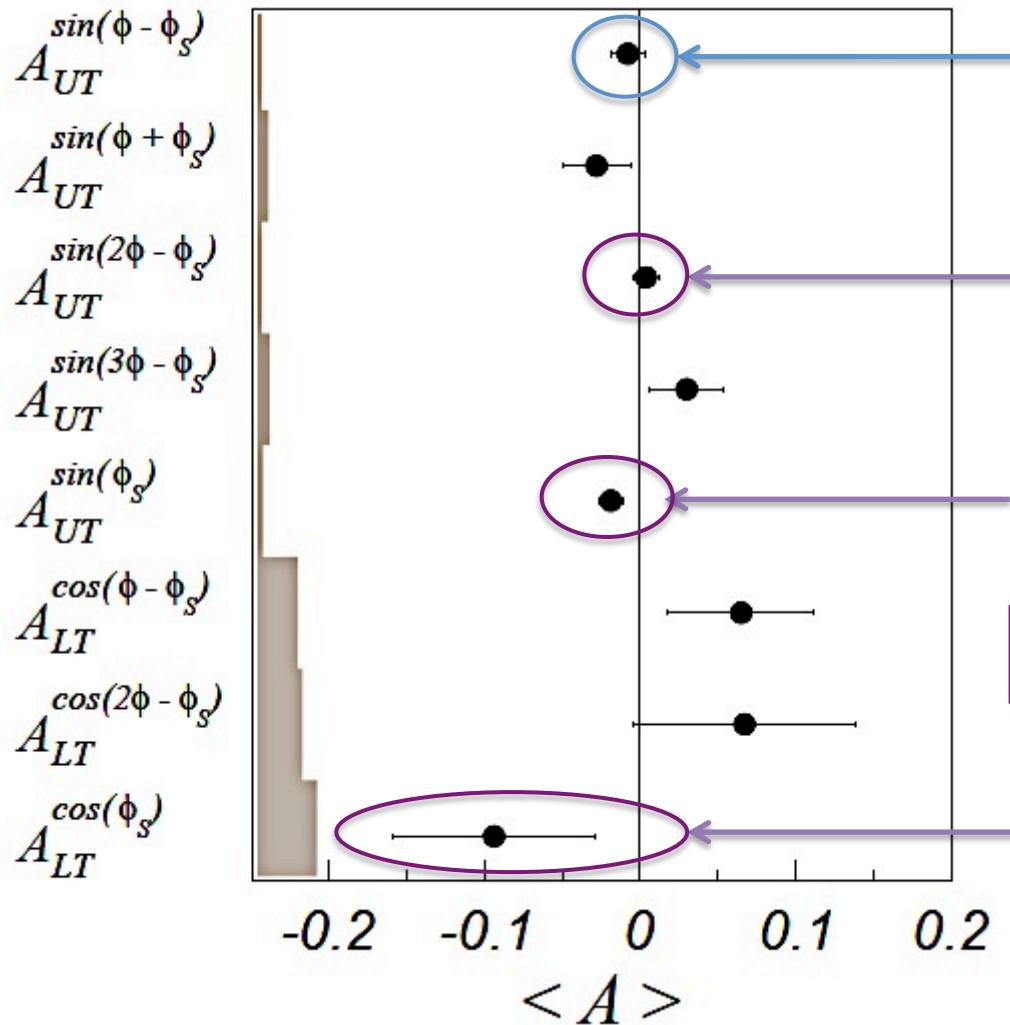


bin/bin SIDIS subtraction from
Monte-Carlo shape and assuming
gaussian distribution for signal



Exclusive ρ^0 : results on asymmetries

Target transverse spin (+ beam spin) asymmetries



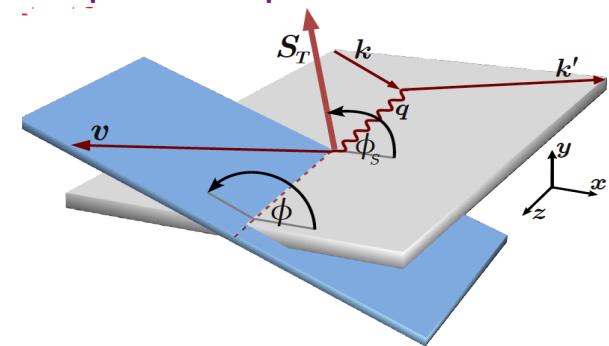
$\propto \text{Im } (\mathcal{E}^* \mathcal{H}) \rightarrow \text{GPD E}$
 Expect cancellation between gluon and sea contribution and for valence $E^u \sim -E^d$
 \rightarrow exclusive ω in progress

$\propto \text{Im } (\mathcal{E}^* \mathcal{E}_T)$

$\propto \text{Im } (\mathcal{E}^* \mathcal{E}_T - \mathcal{H}^* \mathcal{H}_T)$

non zero transverse GPD H_T

$\propto \text{Re } (\mathcal{E}^* \mathcal{E}_T - \mathcal{H}^* \mathcal{H}_T)$



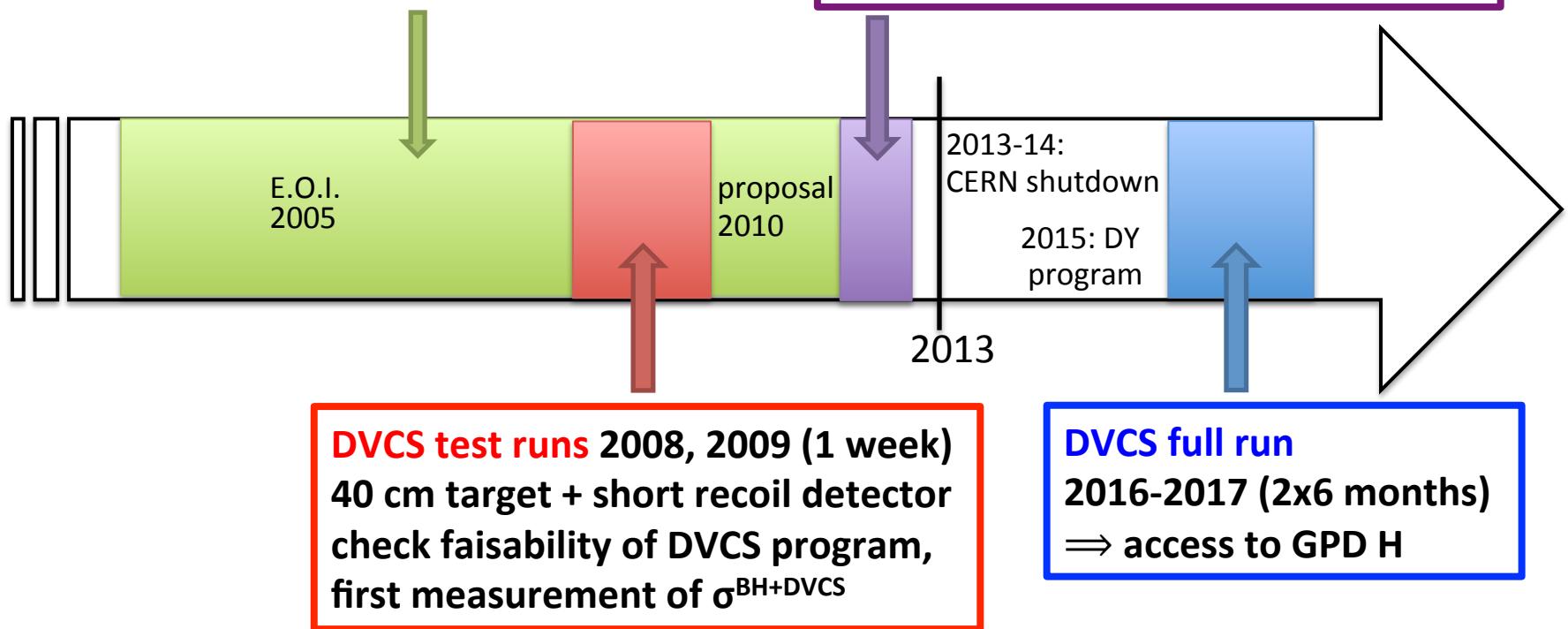
$$W = 8.1 \text{ GeV}/c^2, p_T^2 = 0.2 \text{ (GeV}/c)^2, Q^2 = 2.2 \text{ (GeV}/c)^2$$

COMPASS 2007-2010, without recoil detector

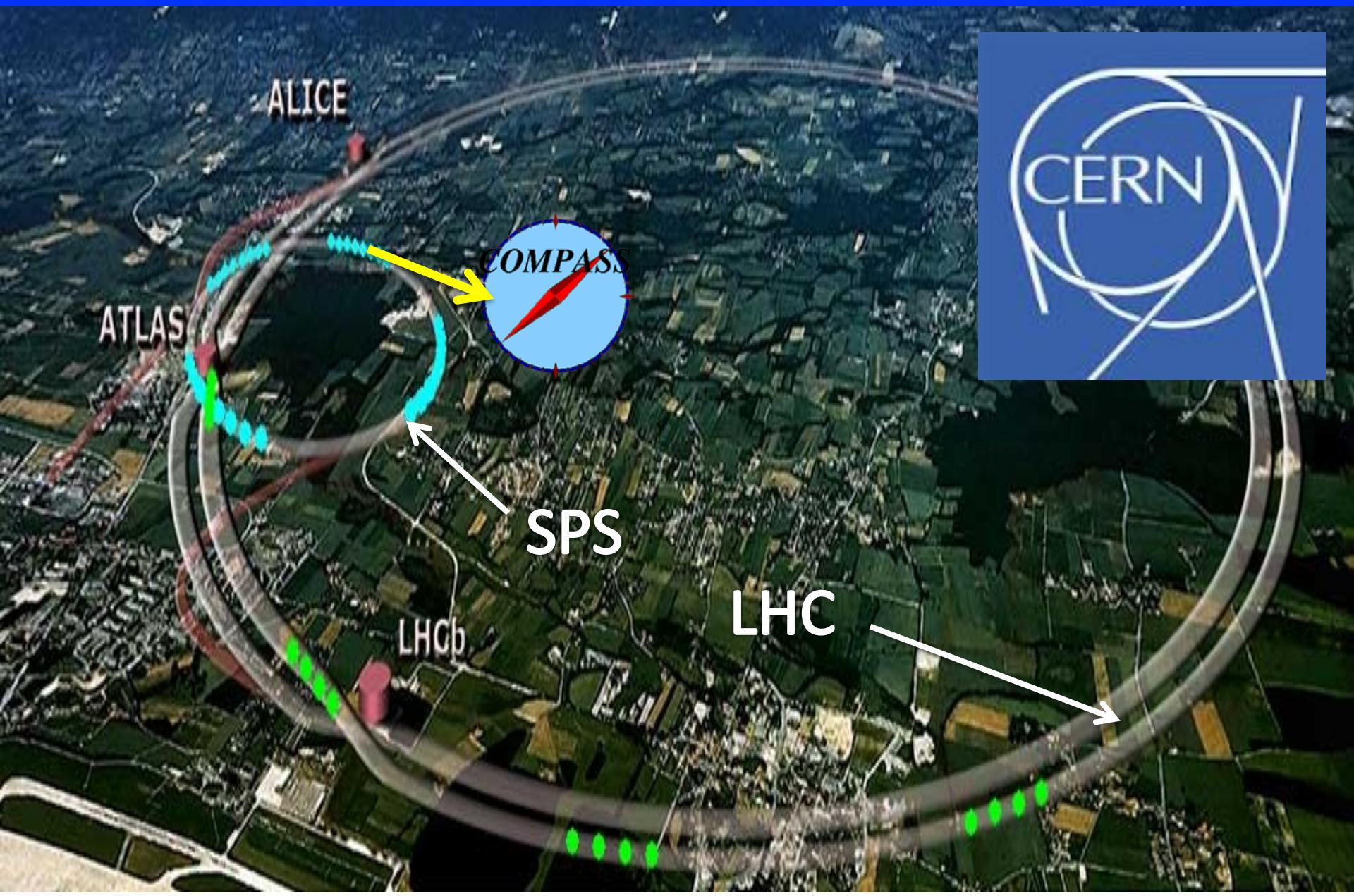
arXiv: 1310.1454v2 (Oct. 2013) subm. to Phys. Lett. B

Schedule: spectrometer upgrades

Vector meson production (2002-2011)
// & \perp polarized target (H, D)
Without recoil detector
 \Rightarrow target spin asymmetries, SDME

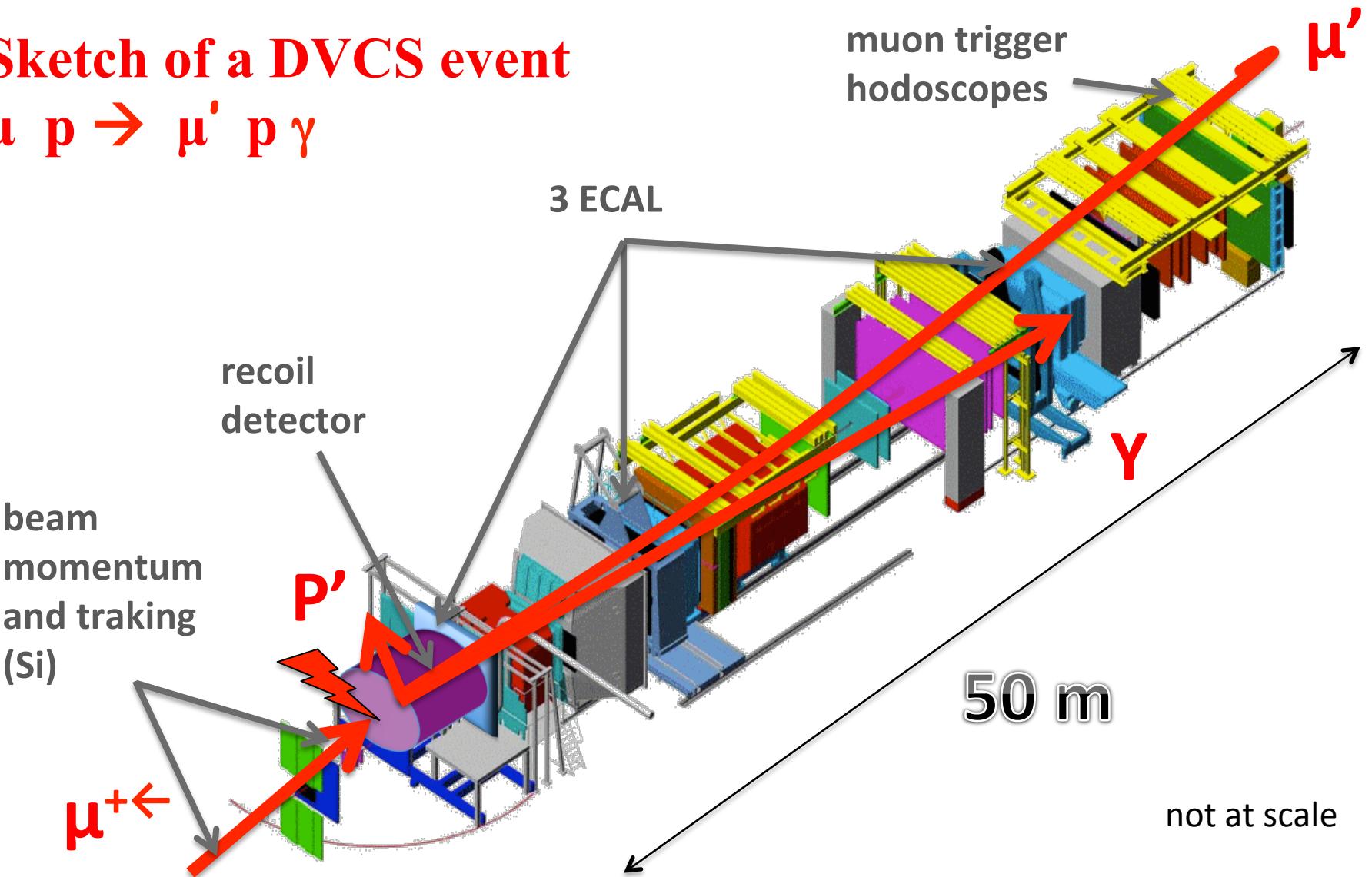


COMPASS at CERN, SPS



COMPASS spectrometer for DVCS studies

Sketch of a DVCS event
 $\mu^- p \rightarrow \mu'^- p \gamma$



Upgrades for DVCS studies

New equipments

large angle ECAL, shashlik,
5-7%/ \sqrt{E} , $E=0.1-30$ GeV

active area in 2012

CAMERA recoil detector

4 m ToF Barrel

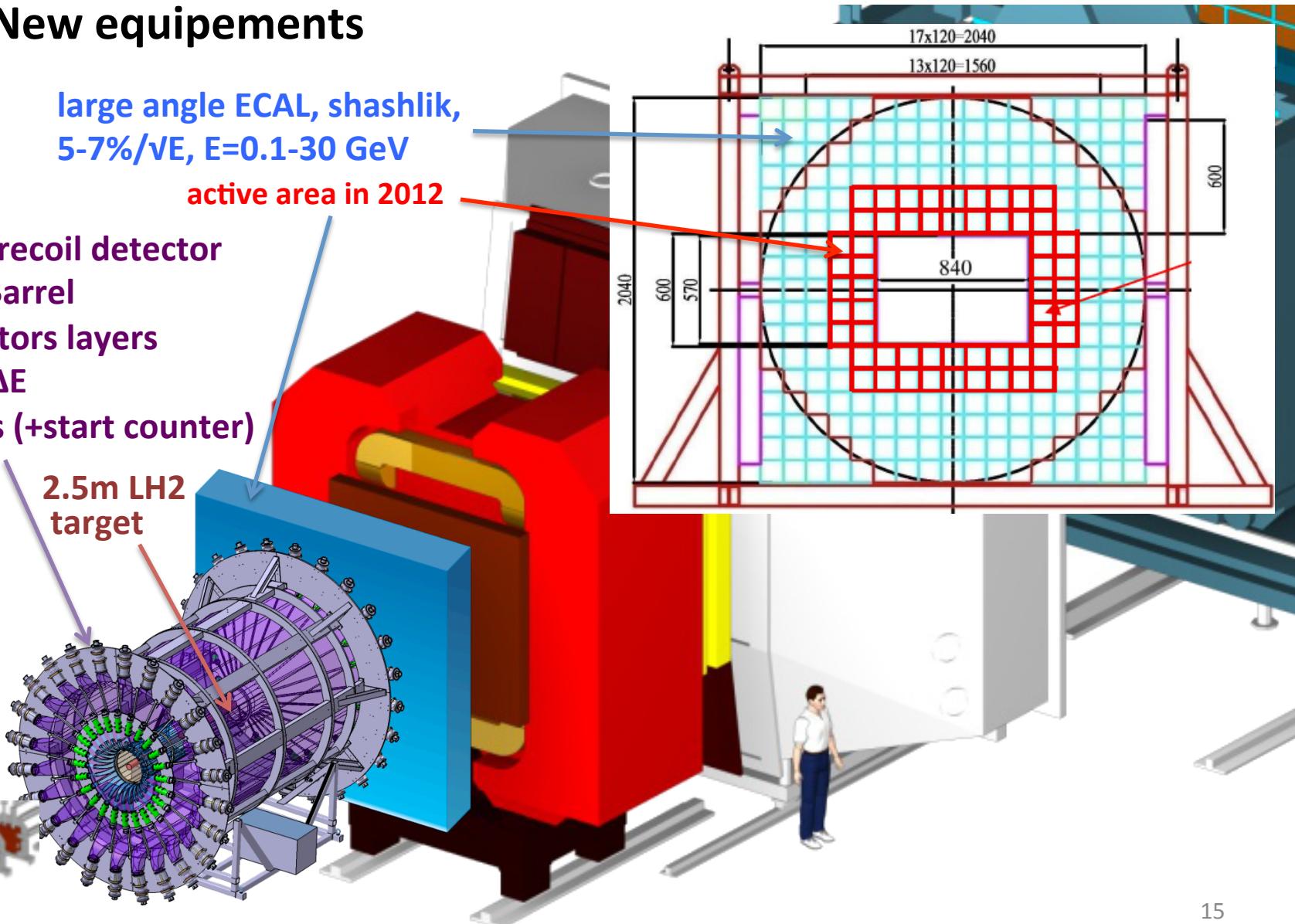
2 scintillators layers

TOF and ΔE

$\Delta t \approx 300$ ps (+start counter)

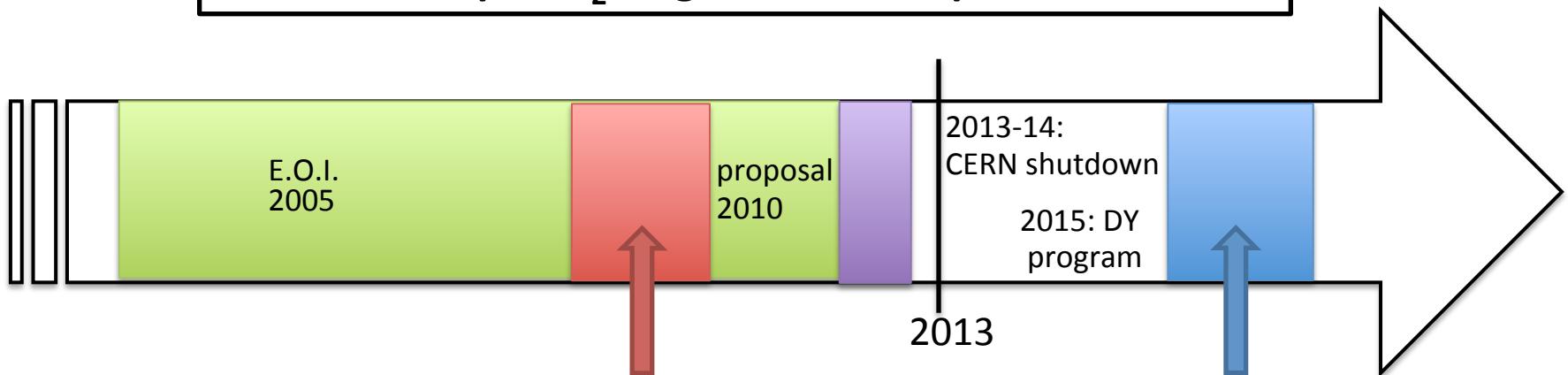
2.5m LH2 target

Si beam tracking



Schedule: 2009 DVCS test run analysis

Analysis method and preliminary results
for DVCS cross section using 2009-DVCS test run,
with short liquid H₂ target and recoil proton detector



DVCS test runs 2008, 2009 (1 week)
40 cm target + short recoil detector
check feasibility of DVCS program,
first measurement of $\sigma^{\text{BH+DVCS}}$

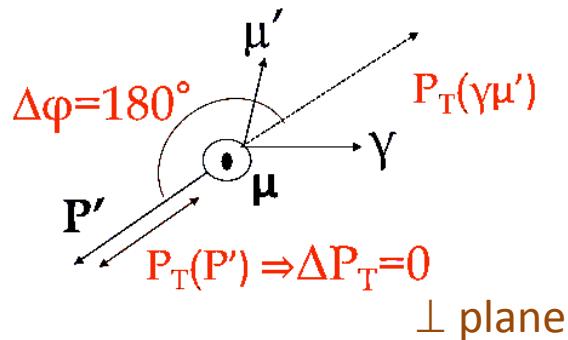
DVCS full run
2016-2017 (2x6 months)
⇒ access to GPD H

DVCS selection using recoil detector

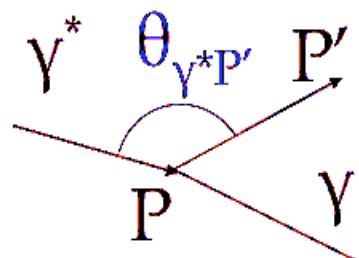
Exclusivity selections: all final state particles are detected
 final state overconstrained \Rightarrow low level of background



Momentum balance
 $\Delta\phi$ & ΔP_T



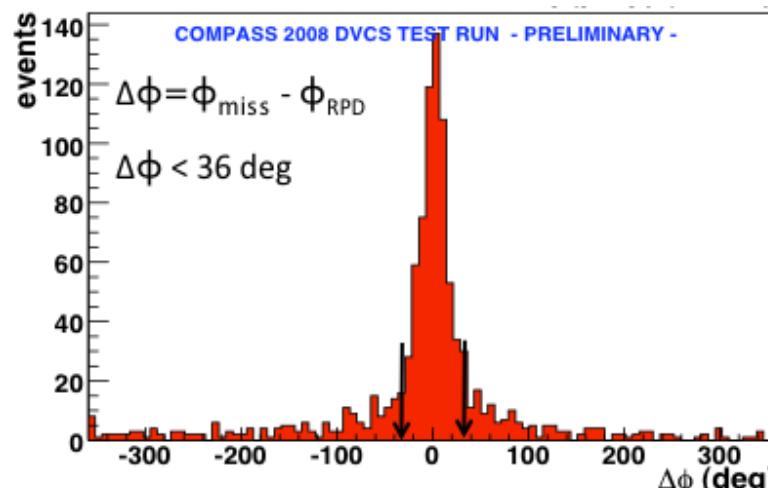
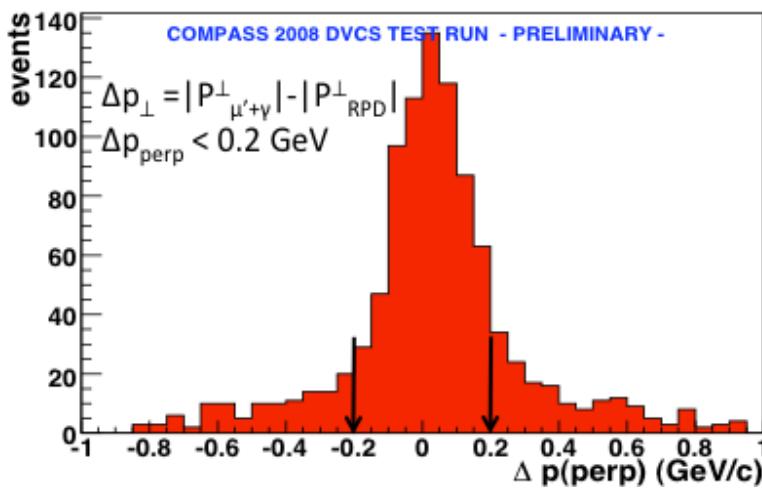
Scattering angles
 $\theta(\mu, \mu', t)$ vs $\theta(\mu, \mu', p)$



Missing mass and energy

$$\Delta M^2 = [(P + \mu) - (P' + \mu' + \gamma)]^2$$

$$\Delta E = E_i - E_f$$



Acceptance correction

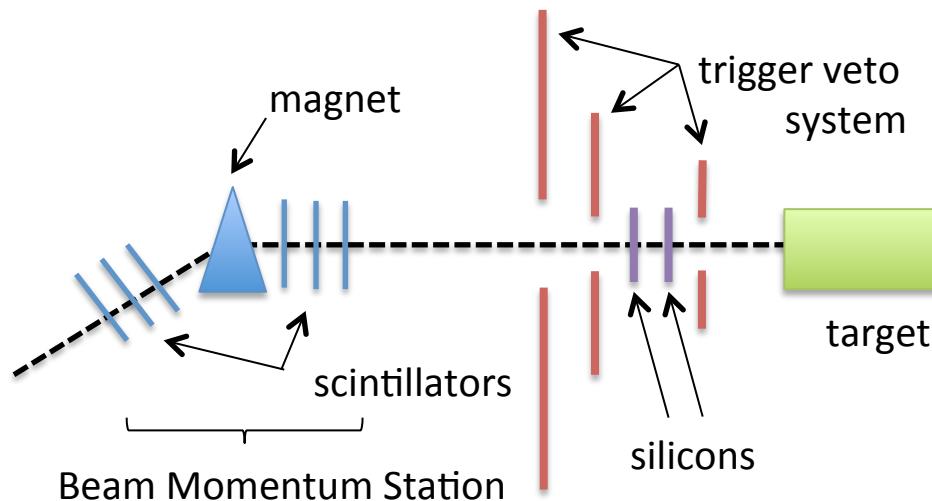
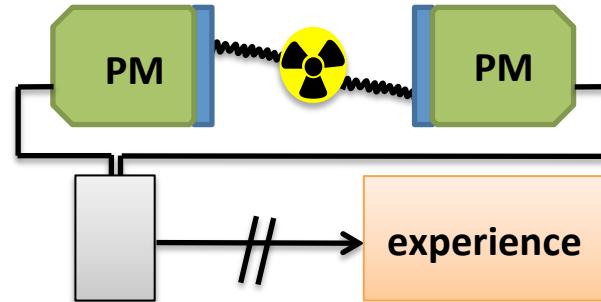
- ✧ Spectrometer simulation: GEANT3 + GEANT4 (under development)
- ✧ Generator:
 - Exclusive meson production according to [Goloskokov and Kroll model](#)
 - DVCS: [Frankfurt, Freund and Strikman model](#) (Phys.Lett. B460 (1999) 417-424) with modifications for COMPASS (Sandacz, Sznajder, arXiv:1207.0333) [HEPGEN]
 - DIS: LEPTO

⇒ acceptance is corrected by 4-dim. weighting of events

Luminosity measurement in 2009

N beam tracks during random trigger gate \rightarrow effective flux \rightarrow effective luminosity

Random trigger
provided by radioactive source
 ≈ 300 Hz, $\Delta t_{\text{trigger}} = 4$ ns



- momentum for **each** beam track
- selections as “physical analysis”
- \rightarrow **effective flux**, reduce systematics

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

Goal: 3% error for DVCS cross section

Check of normalization and systematics

- ✧ Check luminosity for absolute normalization of cross sections by comparing measured $F_2(x,Q^2)$ with parameterizations of world results on F_2
- ✧ Check of $\mu+$ and $\mu-$ consistency
- ✧ Systematics studies for DIS and for DVCS

⇒ **normalization is validated**

⇒ **systematics are taken into account**

Background reductions

- ✧ Rates are estimated using Monte Carlo simulations
- ✧ Corrections by events weighting (bin/bin)

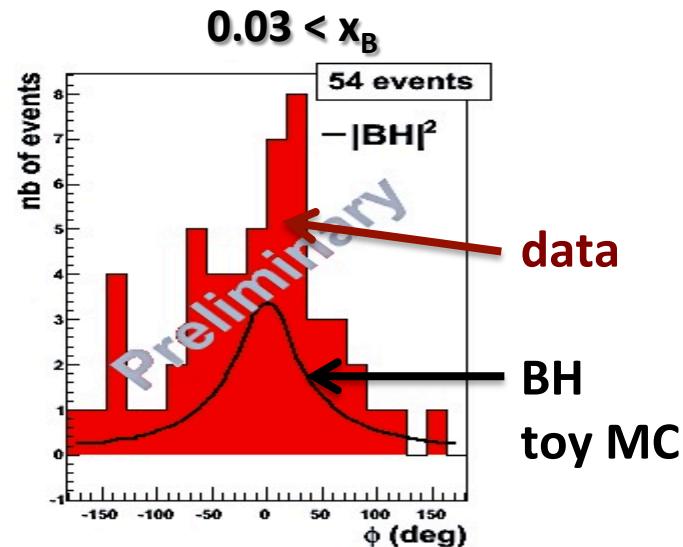
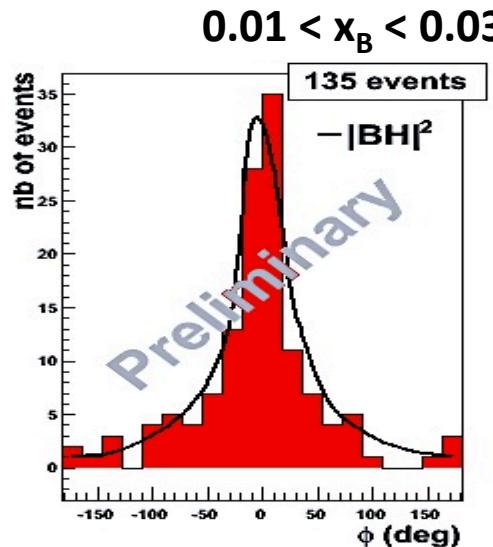
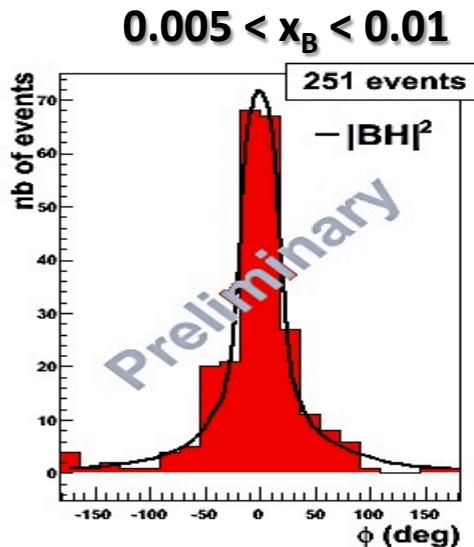
- semi-inclusive: $\mu P \rightarrow \mu' P' \pi^\circ/\eta \dots \rightarrow \mu' P' \gamma X$

- exclusive π° : $\mu P \rightarrow \mu' P' \pi^\circ \rightarrow \mu' P' \gamma Y$

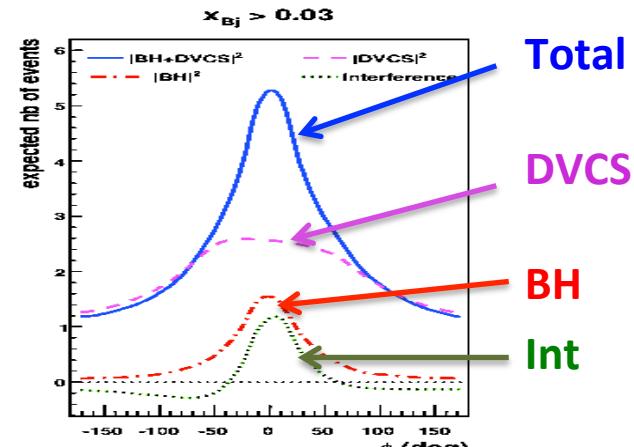
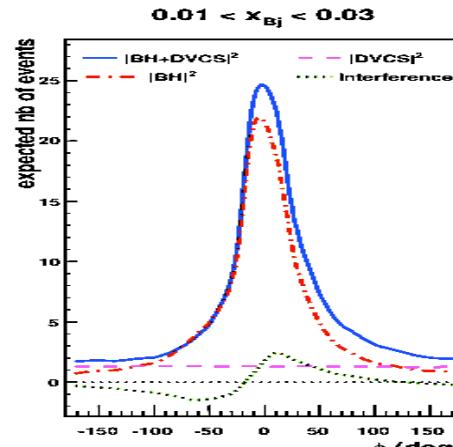
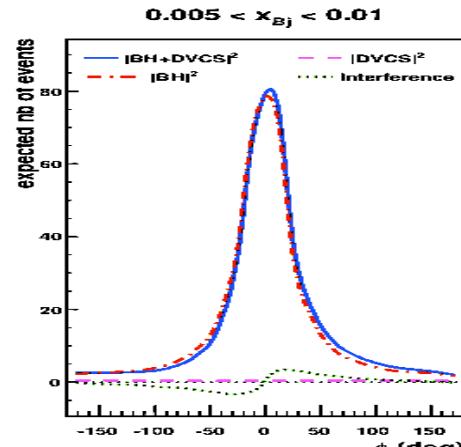
- diffractive dissociation of P' : $\mu P \rightarrow \mu' P^* \gamma \rightarrow \mu' P' \gamma X$

- ✧ rates are expected to be under control at COMPASS kinematics
- ✧ exclusive π° background is deduced according to the cross section measured using the same data with a similar analysis method

Preliminary results for DVCS: 2009 test run



Simulation of expected yields for 2009 setup



BH = good reference

measure interference

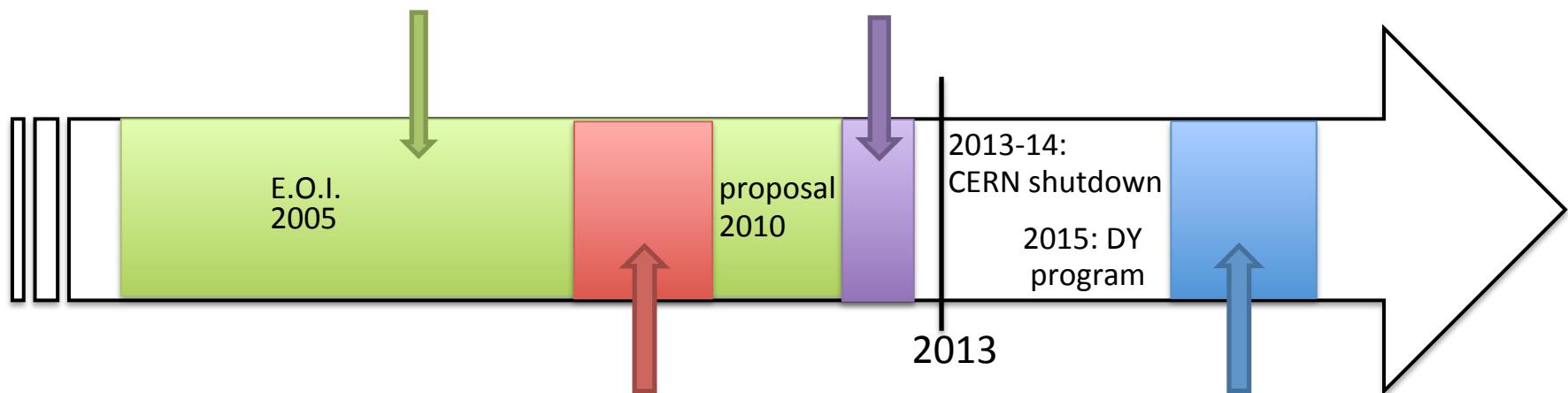
larger DVCS contribution

Excess at large x_{bj} interpreted to come from DVCS

Schedule: GPD program predictions

Vector meson production (2002-2011)
// & \perp polarized target (H, D)
Without recoil detector
 \Rightarrow target spin asymmetries, SDME

2012 DVCS test run 2012 (1 month)
2.5 m H₂ target, long recoil detector,
 μ^+ & μ^- beam
 \Rightarrow access $d\sigma^{\text{DVCS}}/dt$

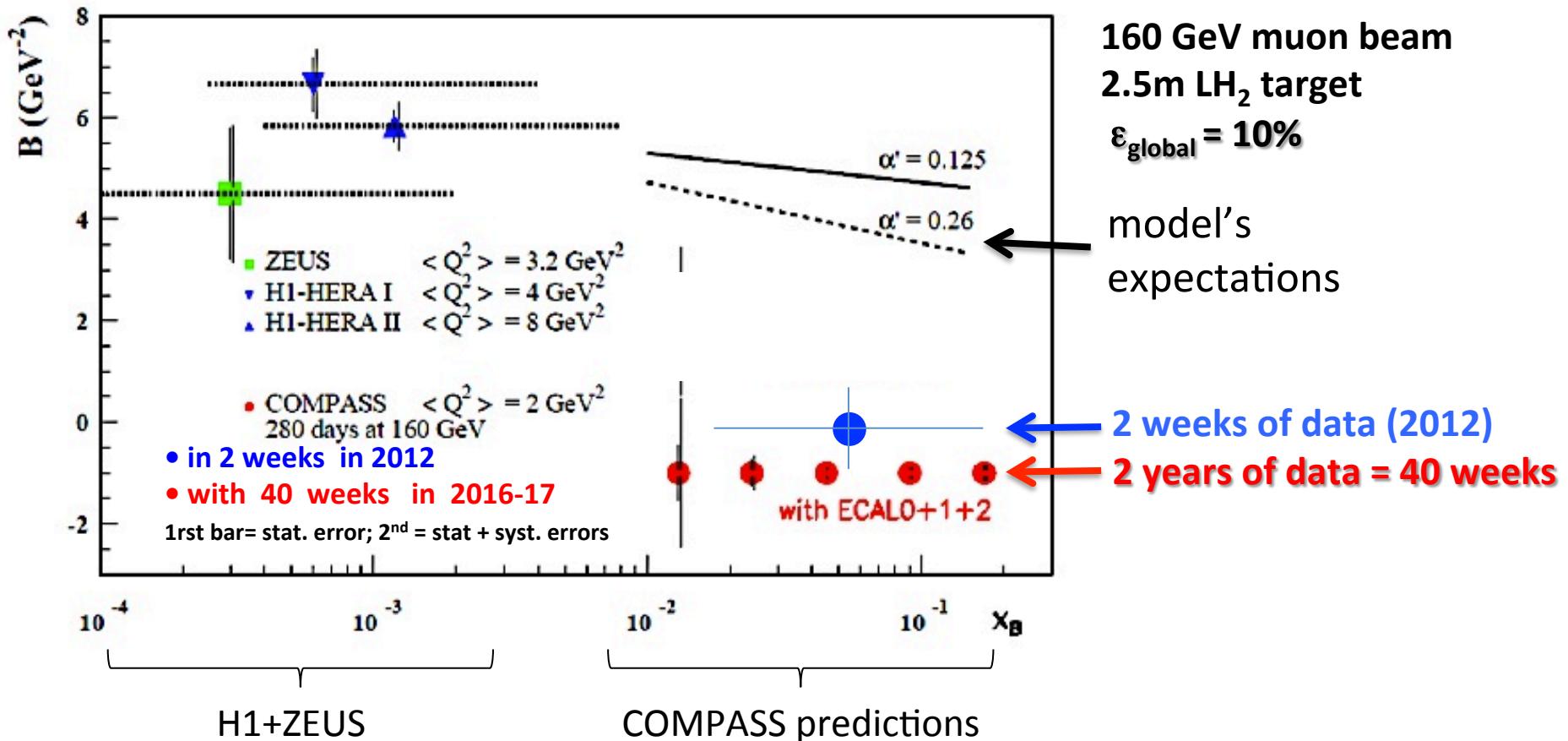


Predictions for DVCS – t dependance

« transverse size of the proton »

$$\frac{d\sigma^{DVCS}}{dt} \propto e^{B(x_{bj}) t}$$

$$\frac{r_\perp}{2} \simeq B(x_{bj}) = B_0 + 2\alpha' \ln \frac{x_0}{x_{bj}}$$



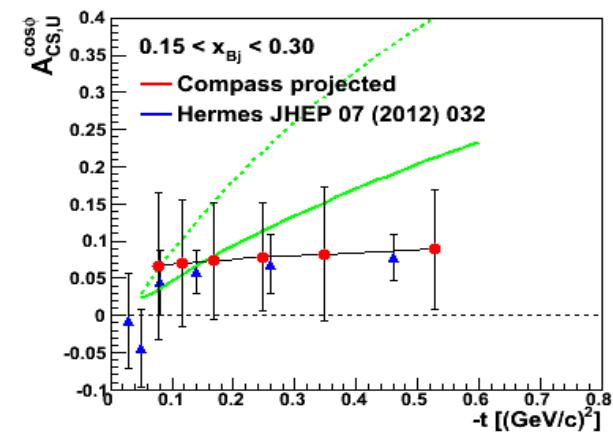
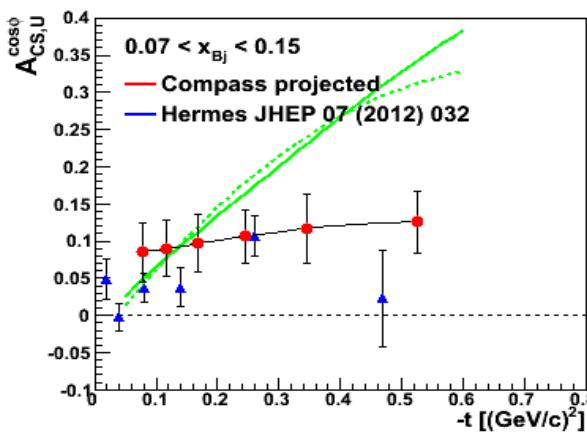
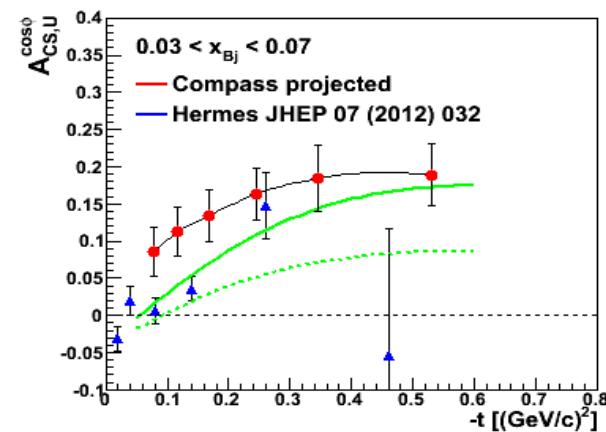
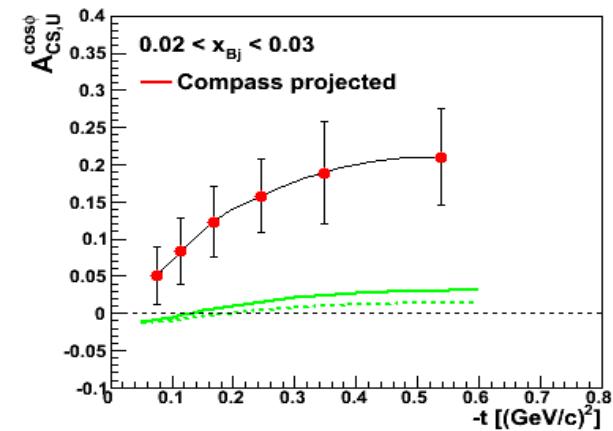
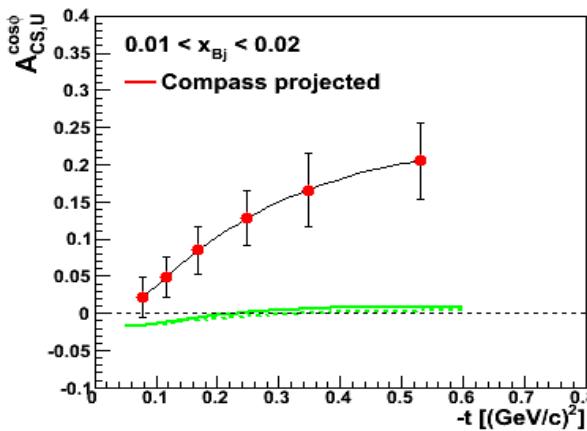
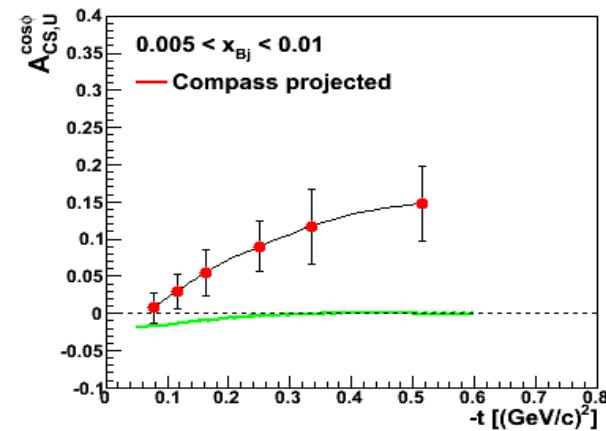
Predictions for DVCS – $\text{Re}(F_1 \mathcal{H})$

Beam spin and charge asymmetry:

$\cos \Phi$ 1st moment $\Rightarrow \text{Re}(F_1 \mathcal{H})$

Important to constrain GPD fits

- Mueller's fits to world data
- VGG
- COMPASS projections: 2 years

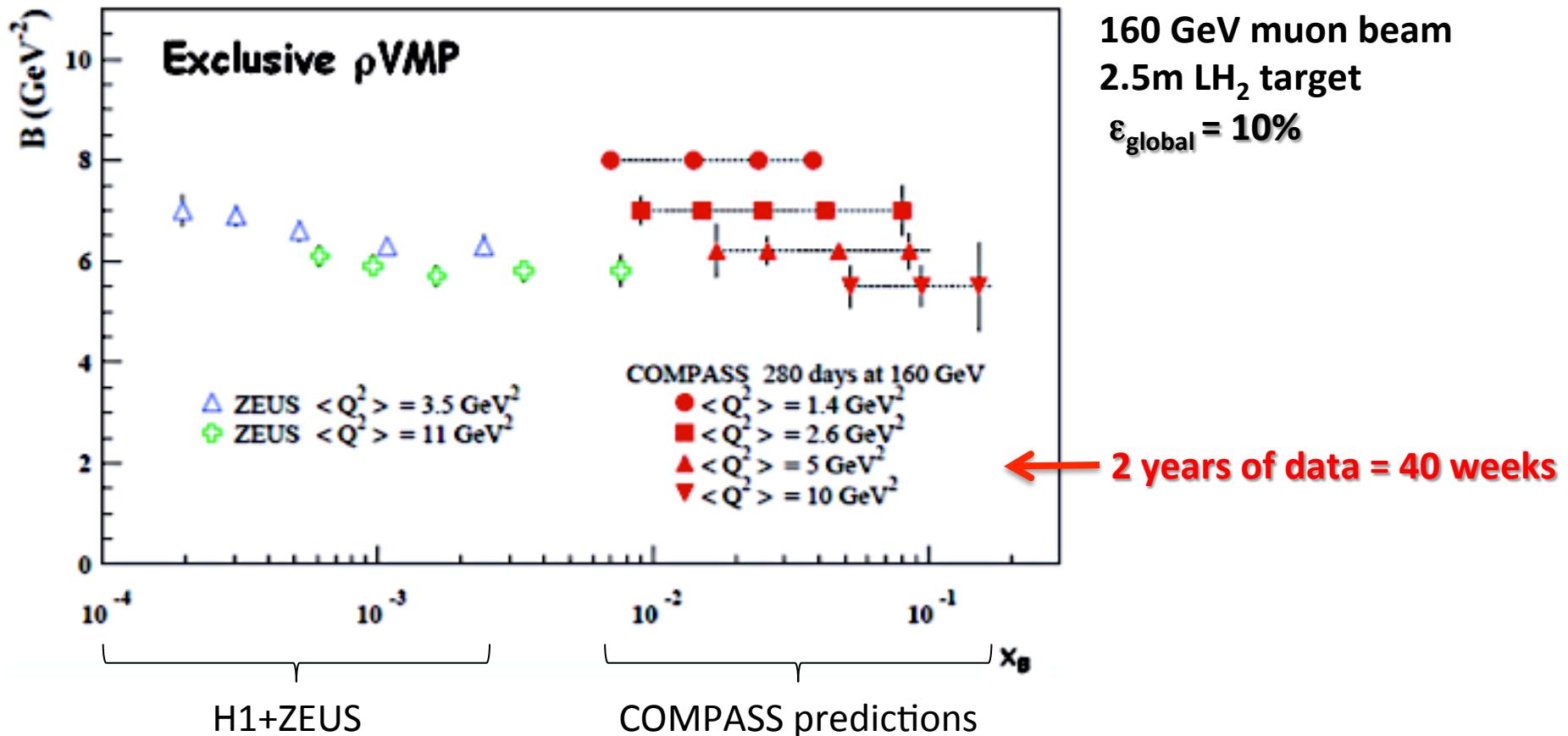


Predictions for vector mesons – t dep.

sensitive to the size of the nucleon and the transverse size of the meson

$$\frac{d\sigma^{DVCS}}{dt} \propto e^{B(x_{bj}) t}$$

$$\frac{r_{\perp}}{2} \simeq B(x_{bj}) = B_0 + 2\alpha' \ln \frac{x_0}{x_{bj}}$$



CONCLUSION

- ✧ Unique kinematical range for GPDs studies
- ✧ Non zero transverse GPD H_T from exclusive ρ° asymmetries
 $A_{\text{UT}}^{\sin \phi_S} = -0.019 \pm 0.008 \text{ (stat.)} \pm 0.003 \text{ (syst.)}$
- ✧ Promising results for DVCS in 2009
- ✧ Analysis of 2012 DVCS run ongoing, and future 2016-17 long run will provide measurement of DVCS cross section and access to GPDs