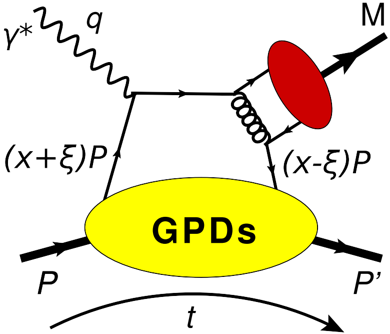
Hard Exclusive Meson Production at COMPASS

and Future DVCS Measurements at COMPASS-II

Heiner Wollny
CEA-Saclay Irfu/SPhN
on behalf of COMPASS

Hard Exclusive Meson Production



Cross section measurements:

- Pseudo-scalar: $\pi, \eta, .. \Rightarrow \tilde{H}$
- Vector meson: $\rho, \omega, \phi, .. \Rightarrow H$

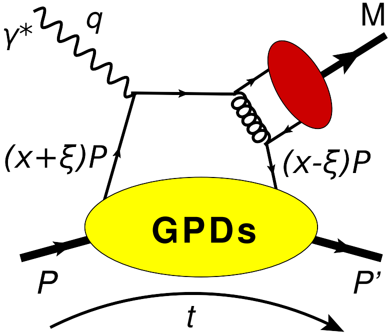
Allow for flavour separation:

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

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

$$H_{\phi} = -\frac{1}{3}H^s - \frac{1}{8}H^g$$

Hard Exclusive Meson Production



Cross section measurements:

- Pseudo-scalar: $\pi, \eta, .. \Rightarrow \tilde{H}$ & $\tilde{E}$
- Vector meson: $\rho, \omega, \phi, .. \Rightarrow H$ & E

Vector meson production from transversely polarised target:

- Asymmetry $\propto E/H$

Allow for flavour separation:

$$E_{\rho^0} = \frac{1}{\sqrt{2}} \left(\frac{2}{3} E^u + \frac{1}{3} E^d + \frac{3}{8} E^g \right)$$

$$E_{\omega} = \frac{1}{\sqrt{2}} \left(\frac{2}{3} E^u - \frac{1}{3} E^d + \frac{1}{8} E^g \right)$$

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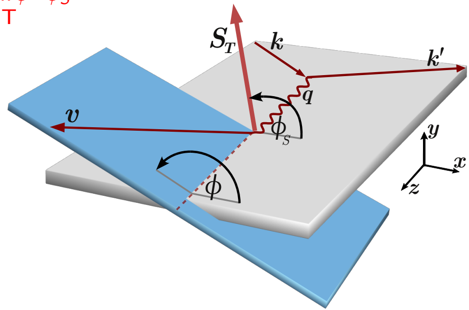
HEMP: Transversely Polarised Target

Transverse target spin asymmetry: $A_{\mathrm{UT}}^{\sin\phi-\phi_S}$

$$A_{\mathrm{UT}}^{\sin\phi-\phi_S} \propto \sqrt{|-t'|}\,\frac{\mathrm{Im}(\mathcal{E}^*\,\mathcal{H})}{|\mathcal{H}|^2}$$

- $\mathcal{E}$ and $\mathcal{H}$ are weighted sums of GPDs $E^{q,g}$ and $H^{q,g}$

$\rightsquigarrow$ provide access to GPD E



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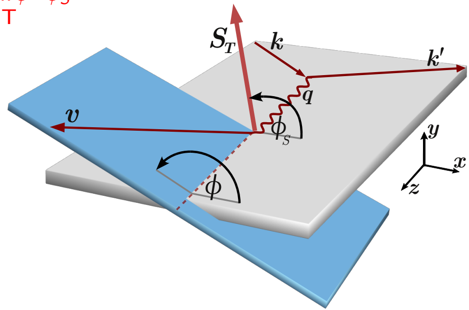

Ji's sum rule:

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

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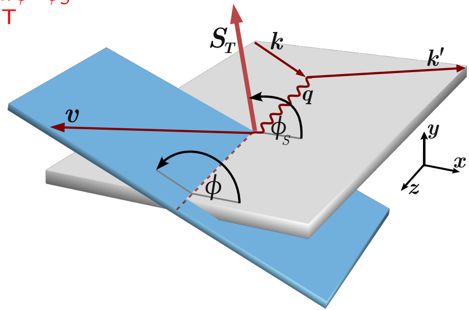

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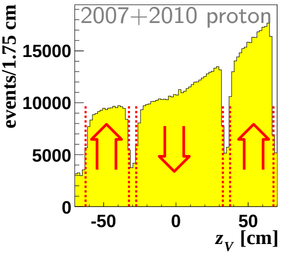
$A_{\mathrm{UT}}^{\sin\phi-\phi_S}$ in exclusive ρ^0 production studied at COMPASS using technique of missing energy

Used Data and Selection of Exclusive ρ^0

- Analysed data:

  2003 & 2004 ^{6}LiD target (polarised deuterons)

  2007 & 2010 NH_3 target (polarised protons)



- Measurements with 160 GeV/c μ^+ beam
- Event signature: $\mu\, N \rightarrow \mu'\, N'\, \rho^0$

  Analysed decay channel: $\rho^0 \rightarrow \pi^+\pi^-$ BR $\approx 100\,\%$

- DIS regime:

  $Q^2 > 1\,(\mathrm{GeV}/c)^2$

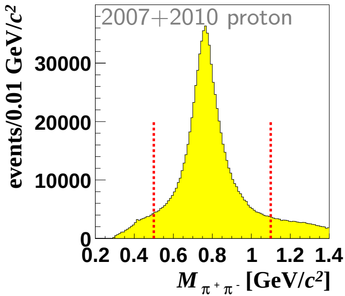
  $0.1 < y < 0.9$

  $W > 5\,\mathrm{GeV}/c^2$

- Suppression of SIDIS background

  $Q^2 < 10\,(\mathrm{GeV}/c)^2$

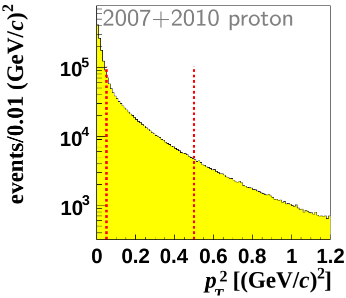
Selection of Exclusive ρ^0



- Assuming for both hadrons pion masses:

  $0.5 < M_{\pi\pi} < 1.1\,\text{GeV}/c^2$

  $\rightsquigarrow$ maximisation of purity of exclusive ρ^0 w.r.t. non resonant $\pi^+\pi^-$



- Suppression of SIDIS background:

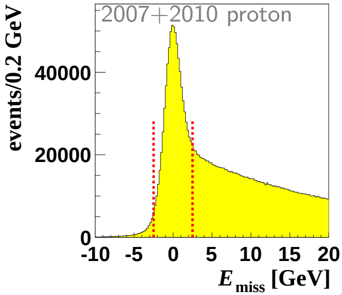
  $p_T^2 < 0.5\,(\text{GeV}/c)^2$

- suppression of coherent production on target nuclei:

  $0.05 < p_T^2\,(\text{GeV}/c)^2$ (for NH_3)

  $0.1 < p_T^2\,(\text{GeV}/c)^2$ (for LiD_6)

Selection of Exclusive ρ^0



- Exclusivity of the reaction:

$$-2.5 < E_{miss} < 2.5\,\text{GeV}$$

$$E_{miss} = \frac{M_X^2 - M_P^2}{2M_P} = E_{\gamma*} - E_{\rho^0} + t/(2M_P)$$

$\approx 14\,\%$ contamination of diffractive dissociation

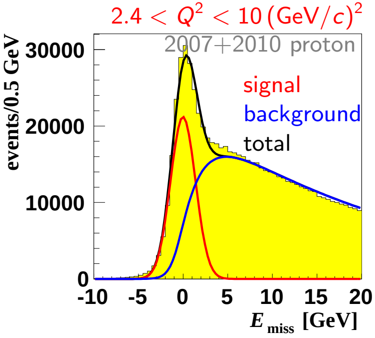
No attempt to remove this (motivated by HERA)

- Fraction of SIDIS background: $5\,\%$ - $40\,\%$ (depending on kinematics)

$\rightsquigarrow$ Procedure to determine number of background events individually in each kinematic bin (needed for the asymmetry extraction):

x, Q^2 or p_T^2 and $\phi - \phi_S$, target cell and polarisation state

SIDIS Background Determination



Signal + background fits:

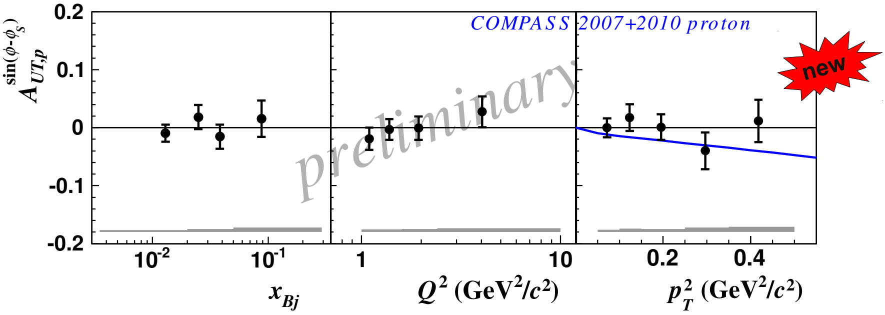
- Gaussian distribution for the signal of exclusive events
- Fixed shape for SIDIS background determined from Monte Carlo (parameterised in appropriate bins)

$\rightsquigarrow$ Background is determined in each bin and is subtracted from measured number of events

- Asymmetry extraction with binned maximum likelihood method

Using Gaussian probabilities to account for non-Poissonian nature of background subtracted event numbers.

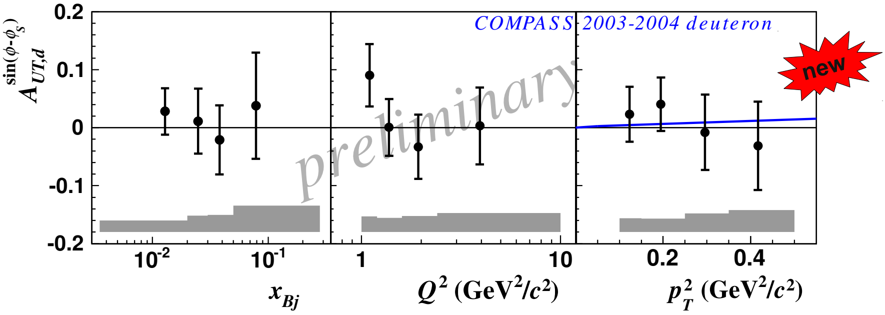
Result $A_{UT,p}^{\sin\phi-\phi_S}$ - NH_3 2007+2010



- Asymmetries are small, compatible with zero within uncertainties
- In agreement with model: Goloskokov and Kroll, Eur. Phys. J. C 59 4 (2009)

$\rightsquigarrow$ approximate cancellation of E^u and E^d $\left(E_{\rho^0} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}E^u + \frac{1}{3}E^d + \frac{3}{8}E^g\right)\right)$

Result $A_{UT,d}^{\sin\phi-\phi_S}$ - ^{6}LiD 2003+2004

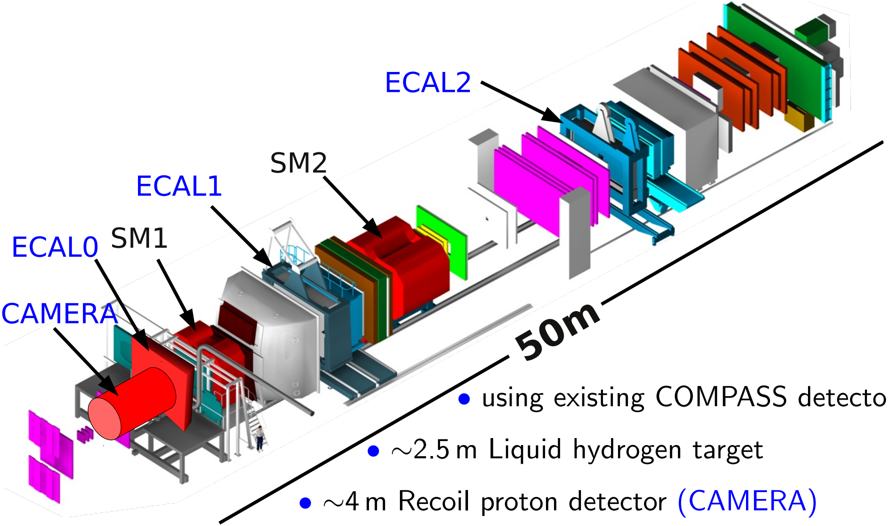


- Asymmetries are small, compatible with zero within uncertainties
- In agreement with model: Goloskokov and Kroll, Eur. Phys. J. C 59 4 (2009)
- Paper will be published soon

COMPASS-II has been recommended by SPSC
and is approved by the Research Board

2012	Primakoff with π, K beam $\rightarrow$ Test of chiral perturbation theory one month pilot run of DVCS with μ^+ and μ^- beams
2013	SPS shut down
2014	Drell-Yan with π beam $\rightarrow$ TMDs
2015+16	DVCS & HEMP with μ^+ and μ^- beams

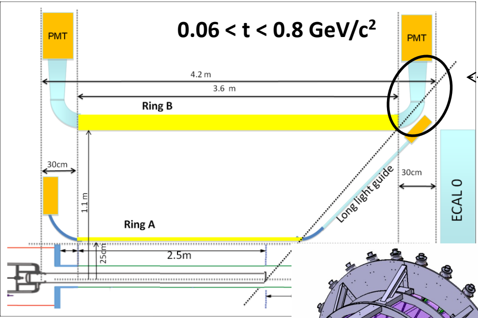
COMPASS-II (DVCS programme) @ CERN/SPS

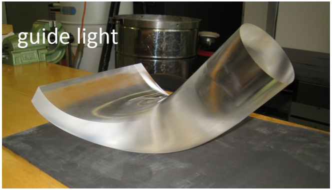


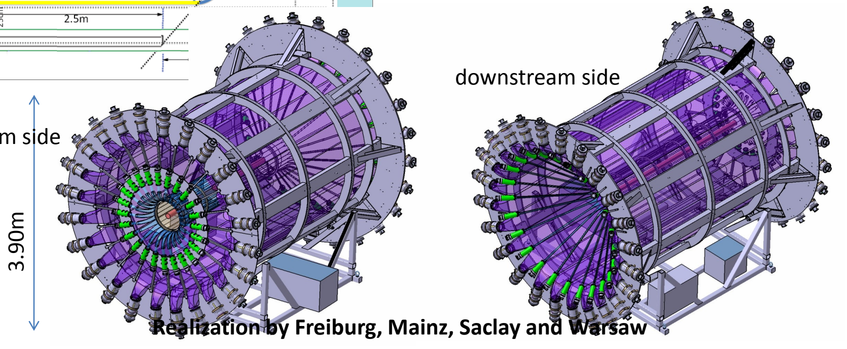
- using existing COMPASS detector
- ~2.5 m Liquid hydrogen target
- ~4 m Recoil proton detector (CAMERA)
- New large angle em. calorimeter in front of SM1 (ECAL0) (prototype for 2012)

Recoil Proton Detector: CAMERA

ToF between 2 rings of scintillators   σ(ToF) < 300ps



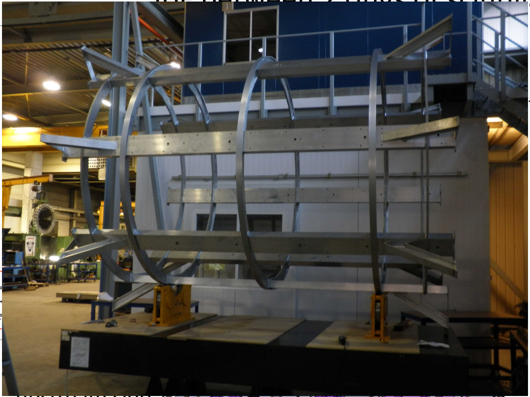


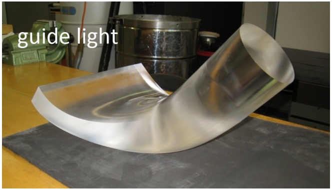


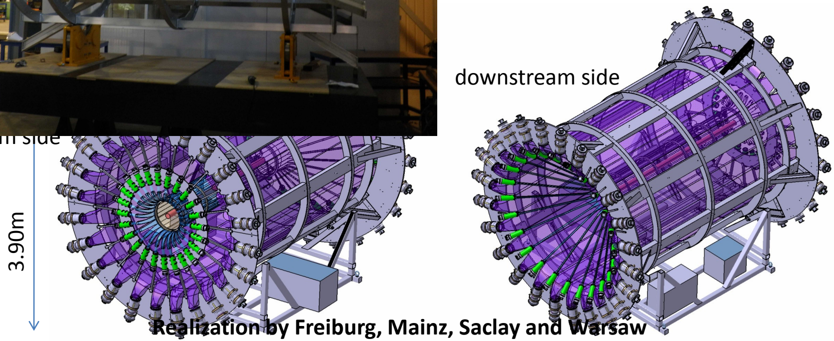
Realization by Freiburg, Mainz, Saclay and Warsaw

Recoil Proton Detector: CAMERA

ToF between 2 rings of scintillators $\sigma(\text{ToF}) < 300\text{ps}$







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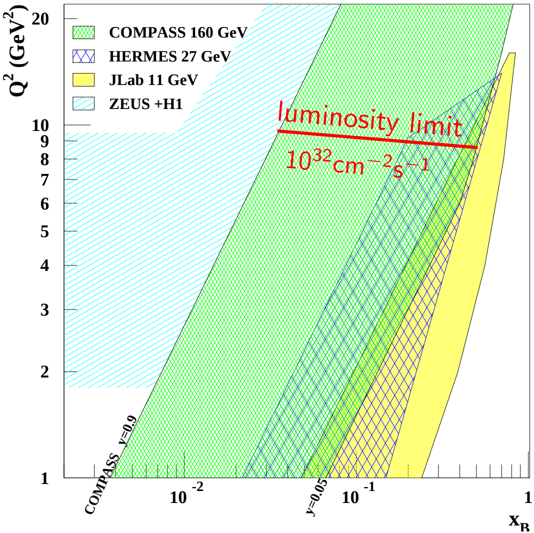
Unique Feature of COMPASS-II @ CERN/SPS



- μ^+ and μ^- beams
- momentum: 100 – 190 GeV/c
- polarisation: 80 %

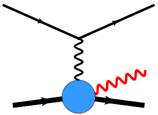
  opposite for μ^+ and μ^-

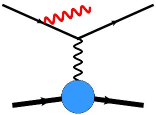
$\rightsquigarrow$ Beam Charge and Spin Sum/Difference

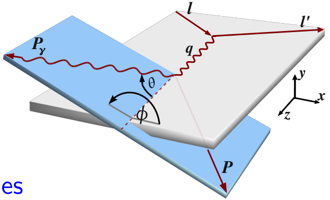
- coverage of intermediate x_{Bj}

$\rightsquigarrow$ unexplored region between ZEUS+H1 and HERMES+JLab

$\mu p \rightarrow \mu' p' \gamma$: Interference with Bethe-Heitler



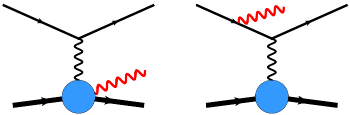




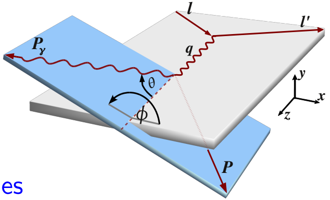
both processes interfere on level of amplitudes

$$d\sigma_{(\mu p \rightarrow \mu' p' \gamma)} \propto |T^{BH}|^2 + \text{Interference Term} + |T^{DVCS}|^2$$

$\mu p \to \mu' p' \gamma$: Interference with Bethe-Heitler



Deep VCS   Bethe-Heitler



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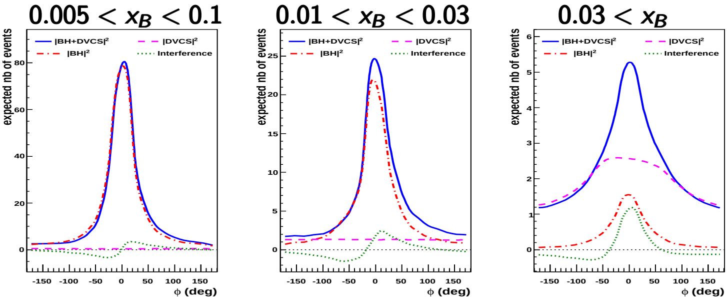
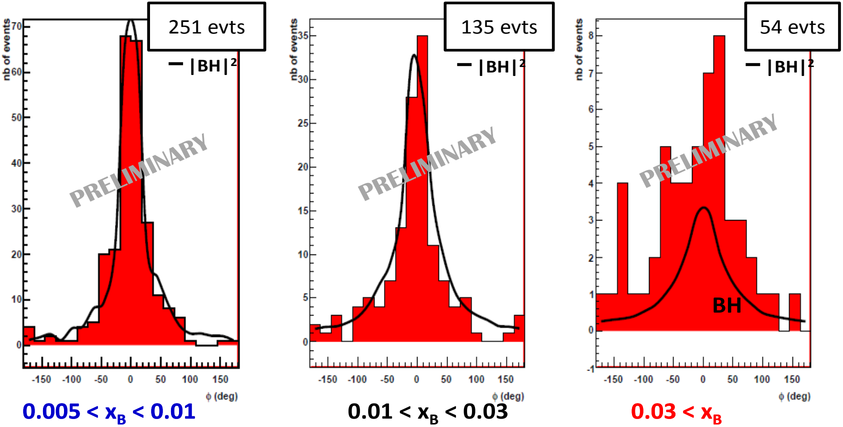


MC simulation for COMPASS without ECAL0

BH dominates   Interference   DVCS dominates

$\rightsquigarrow$ reference yield

2009 test: DVCS and BH Signal



- measurement with 40 cm LH_2 target + 1 m RPD
- Excess of events for $x_B > 0.03 \leadsto$ DVCS events

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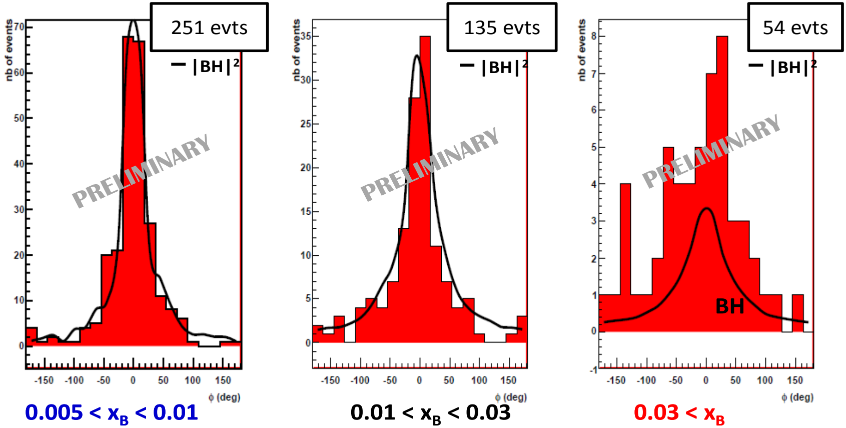

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- Excess of events for $x_B > 0.03 \rightsquigarrow$ DVCS events

This year we expect to increase statistics by factor 20!

Summary and Outlook

- Transverse target spin asymmetry $A_{UT}^{\sin(\phi-\phi_S)}$ measured
  for protons and deuterons
  publication of the paper is expected soon
- COMPASS-II will investigate quark GPDs with DVCS
  - Covered x_B/Q^2 regime not accessible to any other experiment in the near future
  - Change of beam charge and polarisation - UNIQUE
  - Study nucleon transversal dimension as function of x_B (Tomography)
  - Constrain GPD H through ϕ dependence of $\mathcal{D}_{CS,U}$ and $\mathcal{S}_{CS,U}$
- Complementary information from hard exclusive meson production
- One month pilot run in 2012; two years running in 2015 and 2016

Thank You!

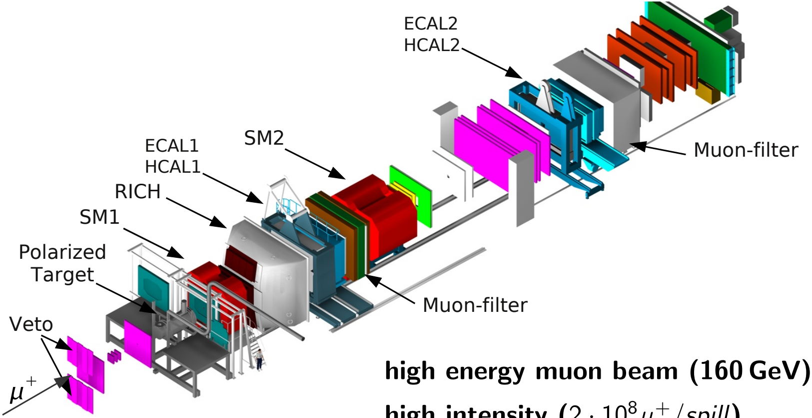
Back Up

COMPASS-II @ CERN/SPS

COMPASS-II will start this year (2012)

230 physicists, 10 countries, 25 institutes

COMPASS Detector (muon setup) @ CERN/SPS



high energy muon beam (160 GeV)

high intensity $(2 \cdot 10^8 \mu^+ / spill)$

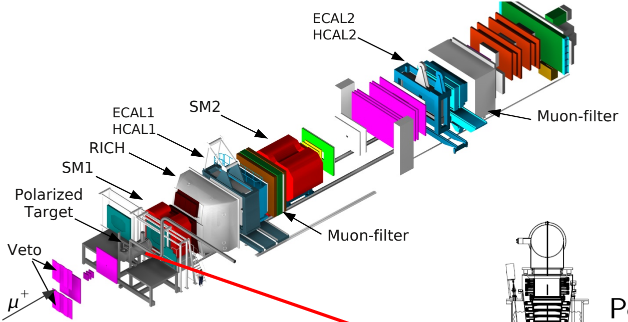
naturally polarised ($\sim 80\,\%$)

two stages spectrometer:

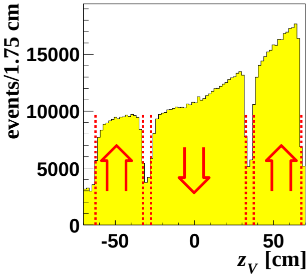
$\rightsquigarrow$ **large angular acceptance** $(0 \leq \theta_{lab} \leq 180\,\text{mrad})$

$\rightsquigarrow$ **broad kinematical range in** x **and** Q^2

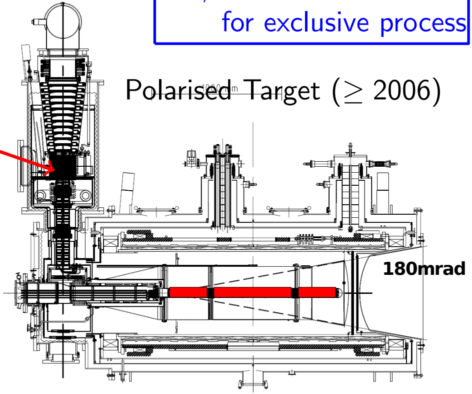
COMPASS Detector (muon setup) @ CERN/SPS



^{6}LiD or NH_3
50/90 % polarisation
45/25 % dilution factor
for exclusive process

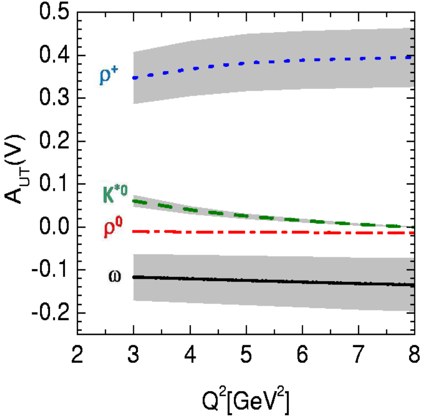


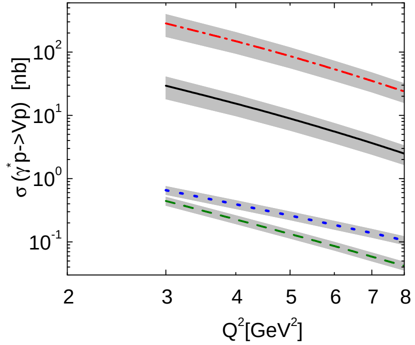
Polarised Target ($\geq$ 2006)



Prediction for Exclusive Vector Meson Production

Goloskokov and Kroll Eur. Phys. J. C 59 4 (2009)





$$E_{\rho^0} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}E^u + \frac{1}{3}E^d + \frac{3}{8}E^g\right)$$

$$E_{\omega} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}E^u - \frac{1}{3}E^d + \frac{1}{8}E^g\right)$$

1D Binned Maximum Likelihood

Coupling of samples with opposite target polarisation:

$u^{\uparrow}$, $d^{\downarrow}$ and $u^{\downarrow}$, $d^{\uparrow}$ (i.e. for 2007 $u = U + D$, $d = M$)

12 bins in $\Phi = \phi - \phi_S \rightarrow j = \{1, .., 12\}$

$$N^{\uparrow}_{ju} = C \frac{a^{\downarrow}_{jd} a^{\downarrow}_{ju}}{a^{\uparrow}_{jd}} (1 + A \cdot \sin(\Phi_j)) \qquad N^{\downarrow}_{jd} = a^{\downarrow}_{jd} (1 - A \cdot \sin(\Phi_j))$$

$$N^{\downarrow}_{ju} = a^{\downarrow}_{ju} (1 - A \cdot \sin(\Phi_j)) \qquad N^{\uparrow}_{jd} = a^{\uparrow}_{jd} (1 + A \cdot \sin(\Phi_j))$$

$$C = \frac{a^{\uparrow}_{ju} a^{\uparrow}_{jd}}{a^{\downarrow}_{ju} a^{\downarrow}_{jd}}, \quad \text{reasonable assumption}$$

$\rightsquigarrow 4 \cdot 12 = 48$ nonlinear equations

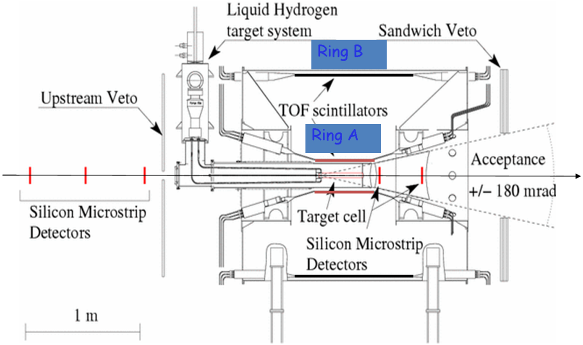
$\rightsquigarrow 1 + 1 + 3 \cdot 12 = 38$ fit parameter

in case of statistical errors maximum likelihood fit with poissonian statistics, otherwise with Gaussian probabilities

DVCS: Testrun 2008 and 2009

Beam Tests @ COMPASS during hadron programme:

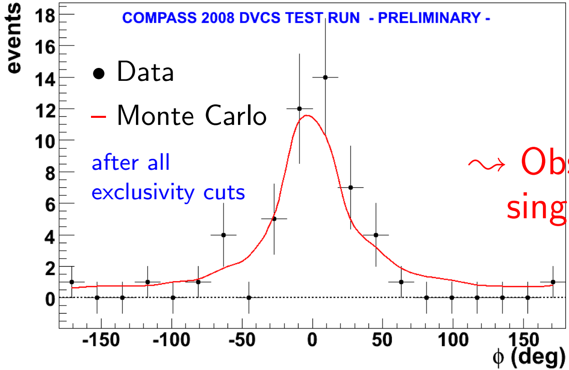
- 2008 (8 hours)
- 2009 (10 times statistics of 2008)



Target Setup for the Hadron Programme (2008-2009):

- Target: 40 cm LH_2
- Recoil Detector (1 m long)
- ECAL1 & ECAL2

2008 test: Bethe-Heitler Signal

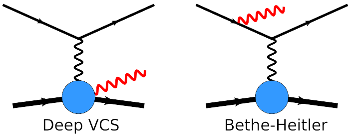


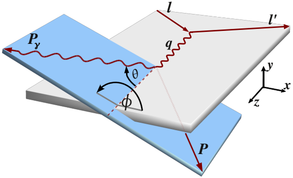
$\rightsquigarrow$ Observation of exclusive single photon production

- $\epsilon_{\mu p \to \mu' p' \gamma} = 0.32 \pm 0.13$
- SPS & COMPASS availability
- DAQ dead time
- Trigger efficiency

global efficiency: $\epsilon_{global} = 0.13 \pm 0.05$

Deeply Virtual Compton Scattering





$$d\sigma_{(\mu p \to \mu' p' \gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu d\sigma^{DVCS}_{pol} + e_\mu a^{BH} \mathrm{Re}(T^{DVCS}) + e_\mu P_\mu a^{BH} \mathrm{Im}(T^{DVCS})$$

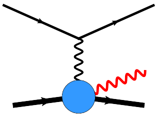
- Beam charge and Spin sum:

$$\mathcal{S}_{CS,U} = d\sigma^{+\leftarrow} + d\sigma^{-\rightarrow} = 2\left(d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + e_\mu P_\mu a^{BH} \mathrm{Im}(T^{DVCS})\right)$$

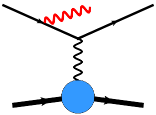
- ϕ dependence gives access to GPD H

$\propto \sin\phi$

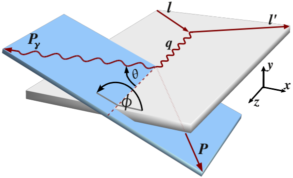
Deeply Virtual Compton Scattering



Deep VCS



Bethe-Heitler



$$d\sigma_{(\mu p \to \mu' p' \gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu d\sigma^{DVCS}_{pol}$$
$$+ e_\mu a^{BH} \mathrm{Re}(T^{DVCS}) + e_\mu P_\mu a^{BH} \mathrm{Im}(T^{DVCS})$$

- Beam charge and Spin sum:

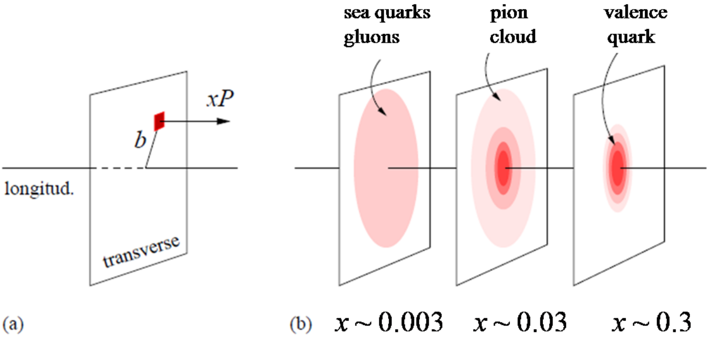
$$\mathcal{S}_{CS,U} = d\sigma^{+\leftarrow} + d\sigma^{-\rightarrow} = 2\left(d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + e_\mu P_\mu a^{BH} \mathrm{Im}(T^{DVCS})\right)$$

$\propto \sin\phi$

- ϕ dependence gives access to GPD H
- Integration over ϕ and subtracting BH:

$d\sigma^{DVCS}/dt \sim exp(-B|t|)$ 'nucleon transverse imaging'

DVCS: Transverse Size of the Nucleon

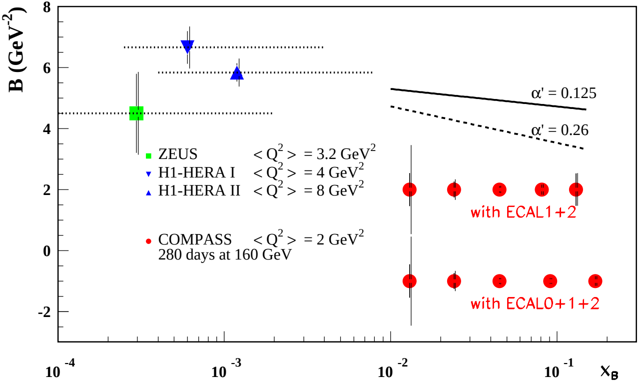


- Integration over ϕ and subtracting BH:

  $d\sigma^{DVCS}/dt \sim exp(-B|t|)$

  $B(x_B) \sim \frac{1}{2}\langle r_{\perp}^2(x_B)\rangle$

DVCS: Transverse Size of the Nucleon



Input for projections:

- $L = 1222\,pb^{-1}$

  2 years of data
- $\epsilon_{global} = 10\,\%$
- 160 GeV/c muon beam
- 2.5 m LH_2 target

- Integration over ϕ and subtracting BH:

  $d\sigma^{DVCS}/dt \sim exp(-B|t|)$

  $B(x_B) \sim \frac{1}{2}\langle r_\perp^2(x_B)\rangle$
- Ansatz at small x_B: $(x \sim x_B)$

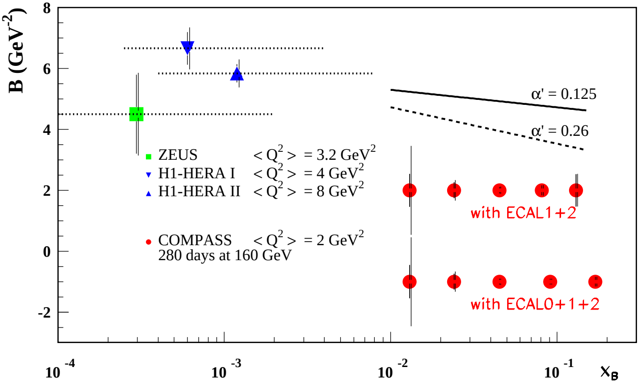
  $B(x_B) = b_0 + 2\alpha' ln(x_0/x_B)$

Accuracy $> 2.5\,\sigma$

for: $\alpha' > 0.26$ (with ECAL 1+2)

for: $\alpha' > 0.125$ (with ECAL 0+1+2)

DVCS: Transverse Size of the Nucleon



Input for projections:

- L=1222 pb^{-1}
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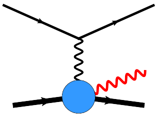
- $\epsilon_{global} = 10\,\%$
- 160 GeV/c muon beam
- 2.5 m LH_2 target

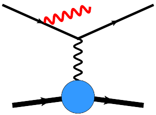
In 2012 we can determine one mean value of B:

1 week of data taking with 2.5 m LH_2 target and 4 m RPD

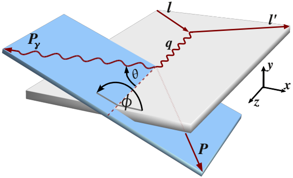
$\rightsquigarrow$ 1/40 of the complete statistics



Deep VCS

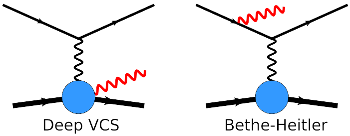


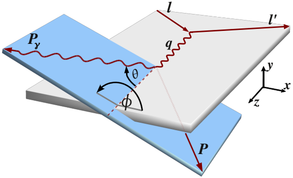
Bethe-Heitler



$$\mathrm{d}\sigma_{(\mu p\rightarrow\mu' p'\gamma)} = \mathrm{d}\sigma^{BH} + \mathrm{d}\sigma^{DVCS}_{unpol} + P_\mu \mathrm{d}\sigma^{DVCS}_{pol} + e_\mu a^{BH}\mathrm{Re}(T^{DVCS}) + e_\mu P_\mu a^{BH}\mathrm{Im}(T^{DVCS})$$

Deeply Virtual Compton Scattering





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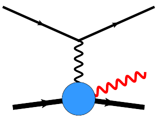
- Beam charge and Spin difference:

$$\mathcal{D}_{CS,U} = d\sigma^{+\leftarrow} - d\sigma^{-\rightarrow} = 2\left(P_\mu d\sigma^{DVCS}_{pol} + e_\mu a^{BH} \mathrm{Re}(T^{DVCS})\right)$$

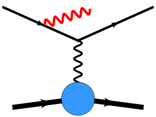
$\Rightarrow$ BH contribution cancels

$\rightsquigarrow$ control detector acceptance and beam flux with high precision

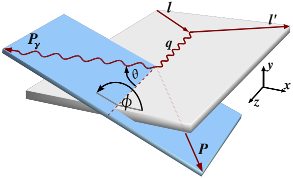
Deeply Virtual Compton Scattering



Deep VCS



Bethe-Heitler



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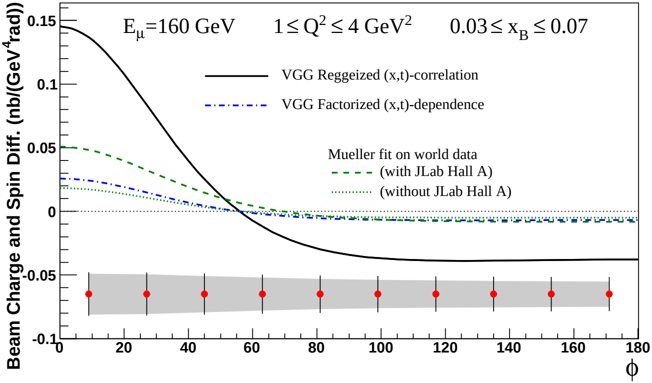
$\Rightarrow$ BH contribution cancels

$\rightsquigarrow$ control detector acceptance and beam flux with high precision

$$\propto c_0^{Int} + c_1^{Int} \cos\phi$$

$$c_{0,1}^{Int} \propto \mathrm{Re}(F_1 \mathcal{H})$$

DVCS: Beam Charge and Spin Difference



Input for projections:

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- 2.5 m LH_2 target

$$\mathrm{Re}(\mathcal{H}(\xi,t)) = \sum_f e_f^2 \left[\mathcal{P}\int \mathrm{d}x\, \mathrm{H}^f(x,\xi,t)\left(\frac{1}{x-\xi} \mp \frac{1}{x+\xi}\right)\right]$$

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