Results of DVCS measurement at COMPASS

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on behalf of the COMPASS collaboration

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Paphos, Cyrpus

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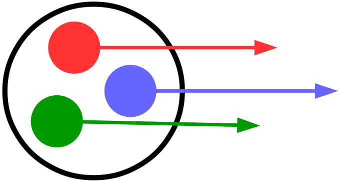
bmb+f - Förderschwerpunkt COMPASS Großgeräte der physikalischen Grundlagenforschung

COMPASS

STRONG 2020

Introduction



Classical quark-parton-model (QPM):

Nucleon described as longitudinal beam of fast moving quarks

Assumptions:

- No transverse momentum
  $\rightarrow$ Only longitudinal momentum fraction (x_{Bj})
- Quarks are free
  $\rightarrow$ No interaction between quarks considered

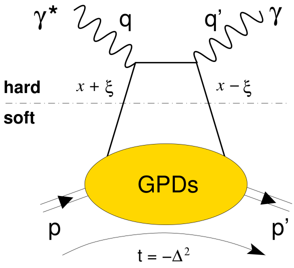
Structure of nucleon expressed by structure functions
$F_1(x_{Bj})$, $F_2(x_{Bj})$ (unpolarized)
$g_1(x_{Bj})$, $g_2(x_{Bj})$ (polarized)

Structure functions $\propto$ Parton Distribution Functions PDFs(x_{Bj})

Generalized Parton Distribution functions (GPDs)

Consider transverse extension of the nucleon

$\Rightarrow$ **Generalized Parton distribution functions (GPDs)**



Exclusive photon production:

$$\gamma^* N \rightarrow \gamma N$$

4 GPDs for each quark flavour

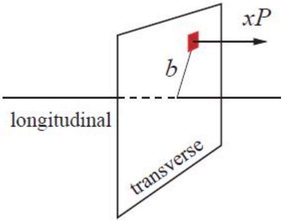
$H^f(x,\xi,t)$	$E^f(x,\xi,t)$	Spin flip
$\widetilde{H}^f(x,\xi,t)$	$\widetilde{E}^f(x,\xi,t)$	No spin flip

Set of kinematic dependence:

- x, ξ $\rightarrow$ longitudinal momentum fractions
  $x_{Bj} \sim 2\xi/(1+\xi)$, $x \rightarrow$ internal variable, model dependent
- t $\rightarrow$ momentum transfer to nucleon squared

Spacial distribution of quarks in the nucleon

- Momentum space to position space:
  $\Delta \to b$ (Fourier Transformation)
  b:Impact parameter
  (transverse position respect to proton c.m.))
- Forward limit $\xi = 0$



Probability density function

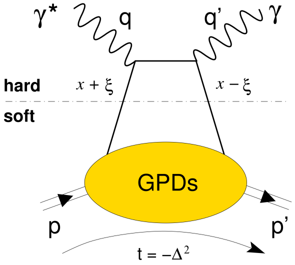
$$q^f(x, \boldsymbol{b}) = \frac{1}{(2\pi)^2} \int d^2\Delta e^{-i\boldsymbol{b}\cdot\Delta} H^f(x, \xi = 0, t)$$

Interpretation:

Probability to find a parton (flavour f) having a longitudinal momentum xP at a transverse distance b

$\to$ Tomography of the nucleon

Generalized Parton Distribution functions (GPDs) II



GPDs not experimental observables
$\rightarrow$ expressed by ...

Compton Form Factors (CFFs)

$$\mathcal{H}(\xi, t) \qquad \mathcal{E}(\xi, t)$$
$$\widetilde{\mathcal{H}}(\xi, t) \qquad \widetilde{\mathcal{E}}(\xi, t)$$

CFFs complex numbers

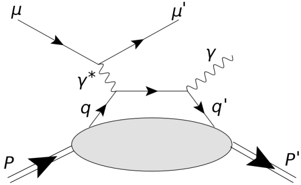
$$Re\mathcal{H}(\xi, t) \overset{LO}{=} \mathcal{P} \int_{-1}^{1} dx H(x, \xi, t) \frac{1}{x-\xi}$$
$$Im\mathcal{H}(\xi, t) \overset{LO}{=} H(\pm\xi, \xi, t)$$

Exclusive photon production:

$$\gamma^* N \rightarrow \gamma N$$

$\Rightarrow$ **Sensitive to CFFs**

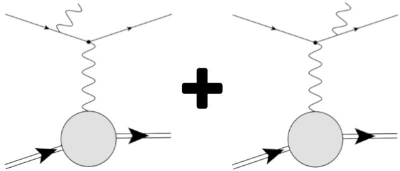
Exclusive photon production @ COMPASS



Deeply Virtual Compton Scattering (DVCS)

$$\mu + p \rightarrow \mu' + p' + \gamma$$

Bethe-Heitler (Bremsstrahlung)
$\rightarrow$ same final state



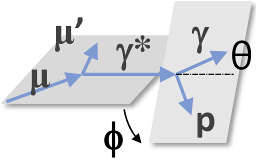
Cross section of excl. photon production:

$$\sigma(\mu p \rightarrow \mu' \gamma p') = \sigma_{DVCS} + \sigma_{BH} + \sigma_{Int.}$$

Measurement @ COMPASS

Kinematic dependencies:

- Q^2 : 4-momentum of γ^*
- ν : Energy of γ^*
- t : Momentum transfer to proton
- ϕ : Angle between scattering plane (γ^*) and production plane (γ)



$\Rightarrow$ Measure **angular distribution of real photon**

Identify exclusive photon events:

$$\left.\begin{array}{l}\text{Incoming muon}\\ \text{Scattered muon}\\ \text{Recoil proton}\\ \text{Real photon}\end{array}\right\}\ \text{overconstrained}$$

Data taking @COMPASS:

- 2012 test run for 4 weeks
  $\rightarrow$ Analysis finished and published
- Long runs dedicated to DVCS in 2016/17
  $\rightarrow$ Analysis ongoing

Outline

COMPASS setup (2016/2017)

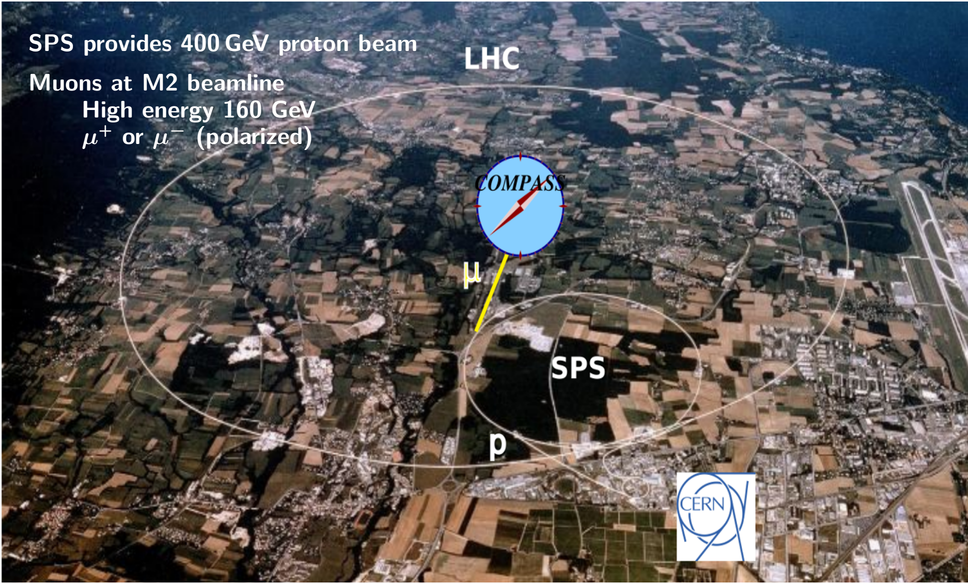
Analysis of 2016 data

Results of 2012 analysis

SPS provides 400 GeV proton beam

Muons at M2 beamline

- High energy 160 GeV
- μ^+ or μ^- (polarized)

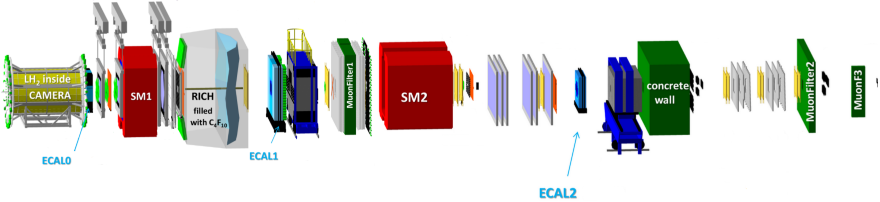


COMPASS spectrometer setup (2016/17)

Two staged forward spectrometer SM1 + SM2

- Liquid hydrogen target (2.5m, ∅4cm)
- Proton recoil detector (CAMERA)
- ECAL0, ECAL1 and ECAL2 (Photon detection)
- Muon trigger system (μID)

$\sim$ 300 tracking detector planes



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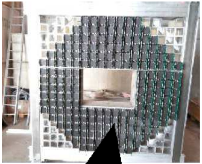
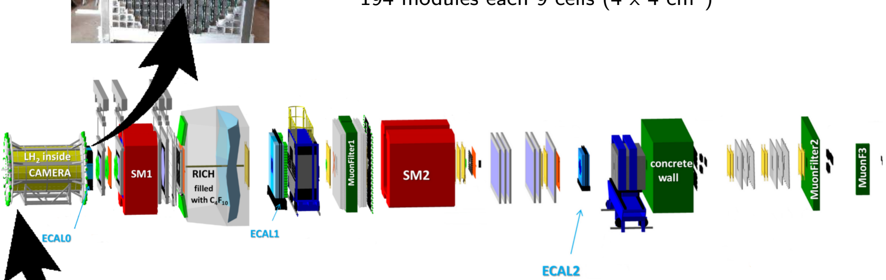
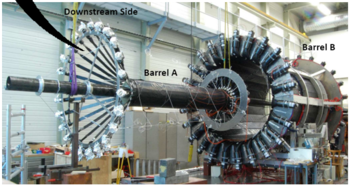


ECAL0:

Sampling calorimeter (lead scintillator sandwich)
$\sim$ 2 x 2 m^2, hole 60cm x 84cm
194 modules each 9 cells (4 x 4 cm^2)

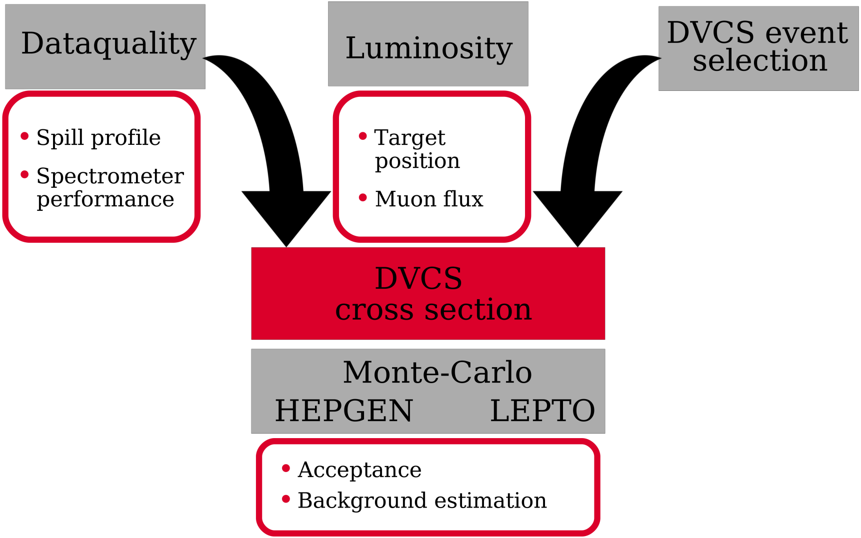




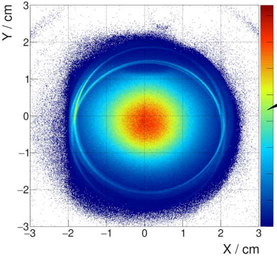
CAMERA:

Inner & outer ring each 24 scintillator slabs
TOF measurement

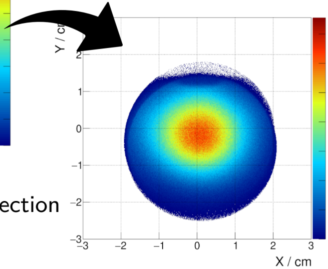
The road to the DVCS cross section



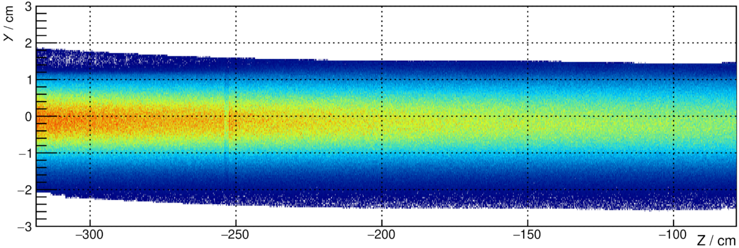
Target position (2016)



Only μ interact with liquid hydrogen
$\Rightarrow$Define radial target cut



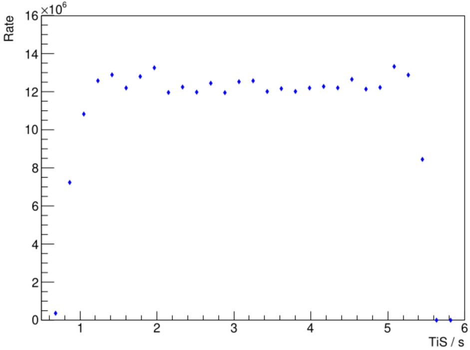
- Target bent in vertical direction
- Gaseous hydrogen
  $\rightarrow$ additional cut



Dataquality checks

Stable flux conditions:

- Slow extraction of SPS beam
  - Intensity rises
  - Flat top for ~5s
  - Intensity drops
- Interested in flat top region
  $\rightarrow \pm$ 15% of flat top avg.
- Define begin and end of spill
  (Time in Spill window)
- Relevant for flux analysis
  (typ. Flux $\sim 7 \cdot 10^7\ \mu$/spill)



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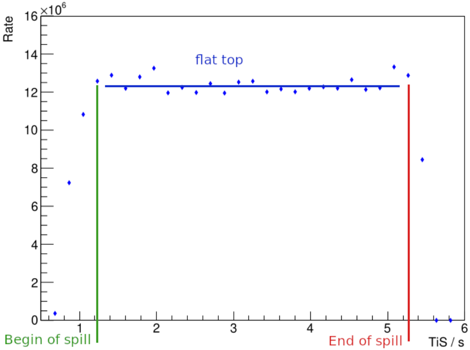


Selection of exclusive single photon events

- **Select incoming muon**
  $\rightarrow$ Use same selection as for muon flux
- **Search scattered muon**
  - Vertex with only one outgoing charged track (same charge as inc. muon)
  - Sufficient momentum transfer to proton
- **Get real photons**
  - Check for a single photon
  - Photon energy above a defined threshold in one ECAL
- **Get recoil proton canditates**
  - TOF measurement
  - Identify proton candidates

$\rightarrow$ Improve event selection by adding **"exclusivity cuts"**

Cuts:

Incoming μ:

- Track would pass full target length
- 140 GeV/c< p <180 GeV/c

Scattered μ:

- $Q^2 > 1$ (GeV/c)^2
- 0.05 GeV/c< y <0.95 GeV/c

Real photon:

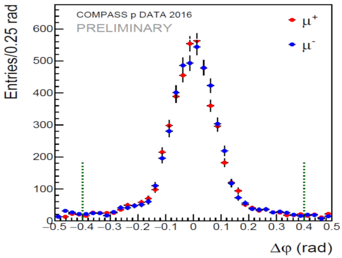
- ECAL0 thr. $=$ 4 GeV
- ECAL1 thr. $=$ 5 GeV
- ECAL2 thr. $=$ 10 GeV

Proton candidates:

- β >0.1

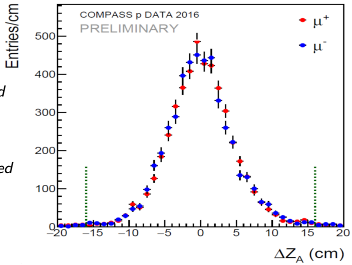
Exclusivity cuts

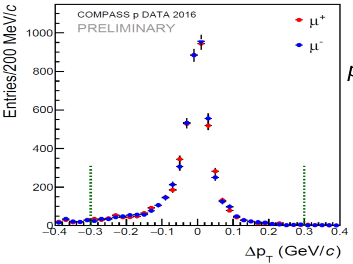
Difference between spectrometer prediction and CAMERA measurement



Azimuthal angle:
$\Delta\phi = \phi^{meas} - \phi^{pred}$

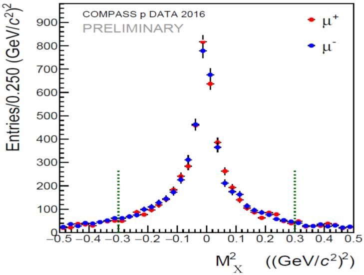
Vertex pointing:
$\Delta Z_A = Z_A^{meas} - Z_A^{pred}$





p_t balance:
$\Delta p_t = p_t^{meas} - p_t^{pred}$

4-mom. balance:
$M_X^2 = (P_i - P_f)^2$



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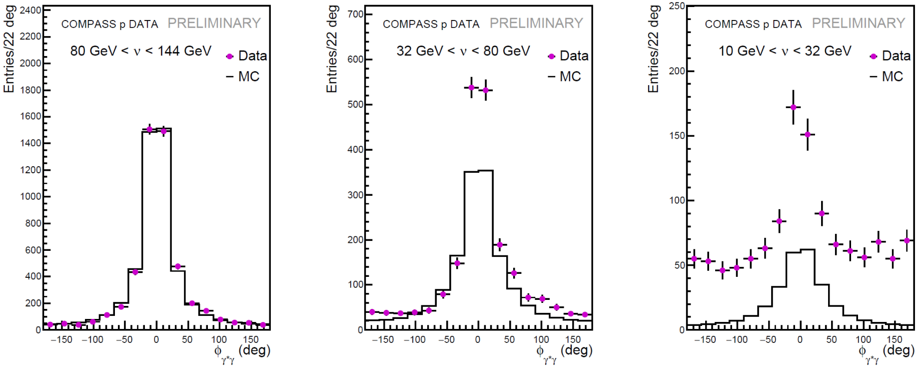
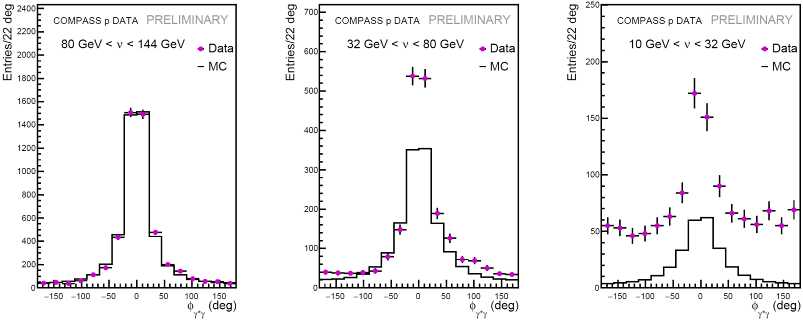
First results of 2016 analysis

First presented at DIS2019



Only 13% of the 2016/2017 data set

BH process **very well known** over a wide kinematic range
$\rightarrow$ MC sample for the BH (HEPGEN)



Handling BH contribution:

- Kinematic range where **BH is dominant**
  $\rightarrow$ Normalice real and MC data according their luminosity
  $\rightarrow$ Cross check of luminosity
- DVCS contribution by **substracting the BH** from the data

Contribution of the Bethe-Heitler

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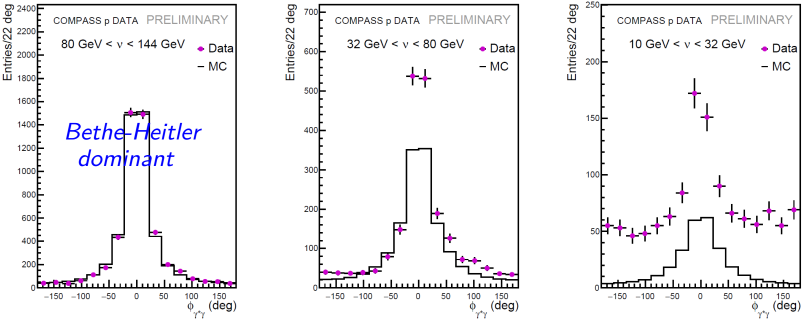

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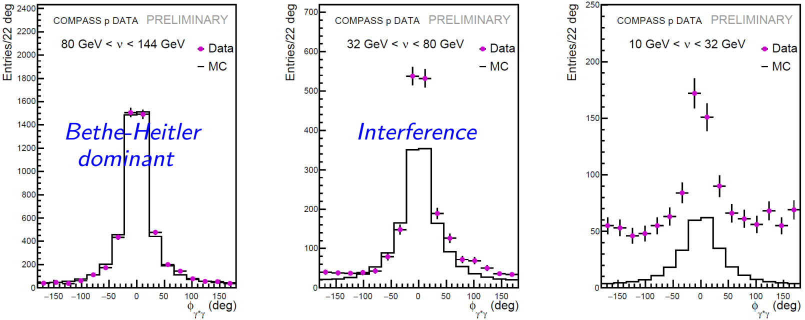

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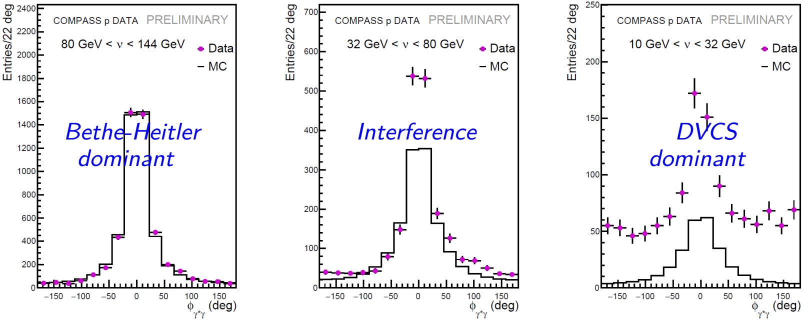

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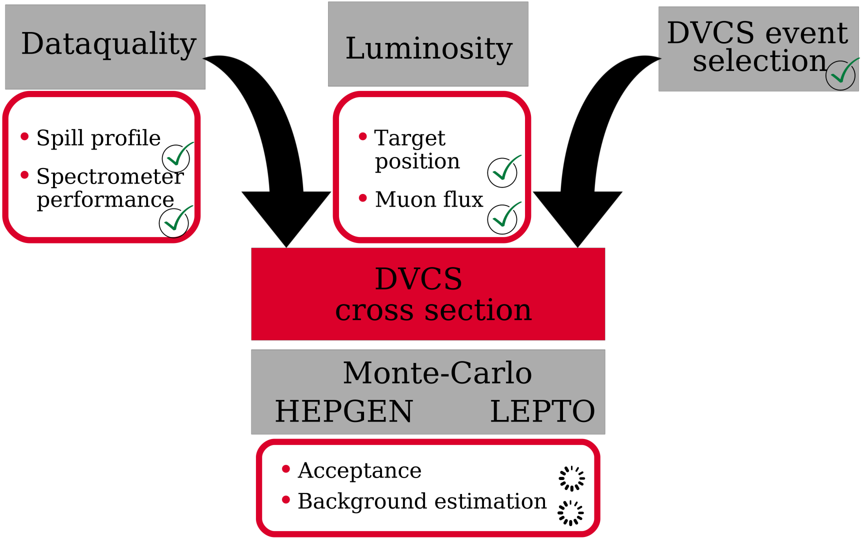
Status 2016



Dataquality
Spill profile
Spectrometer performance
Luminosity
Target position
Muon flux
DVCS event selection
DVCS cross section
Monte-Carlo
HEPGEN
LEPTO
Acceptance
Background estimation

Continue with 2012 data

Binning (2012)

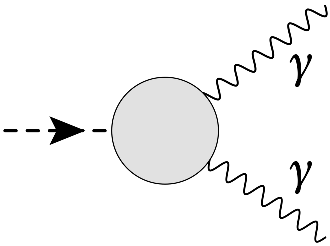
1 $(\mathrm{GeV/c})^2$	$<$	Q^2	$<$	5 $(\mathrm{GeV/c})^2$	4 bins
0.08 $(\mathrm{GeV/c})^2$	$<$	$\|t\|$	$<$	0.64 $(\mathrm{GeV/c})^2$	4 bins
$-\pi$	$<$	$\phi_{\gamma^*\gamma}$	$<$	π	10 bins
10 GeV	$<$	ν	$<$	32 GeV	

π^0 Background

Photons via **decay of**

$\pi^0 \to \gamma\gamma$

One photon as exclusive photon (above ECAL thr.) detected



π^0 production channel:

- Exclusive: $\mu + p \to \mu + p + \pi^0$
- Semi inclusive: $\mu + p \to \mu + \pi^0 + X$

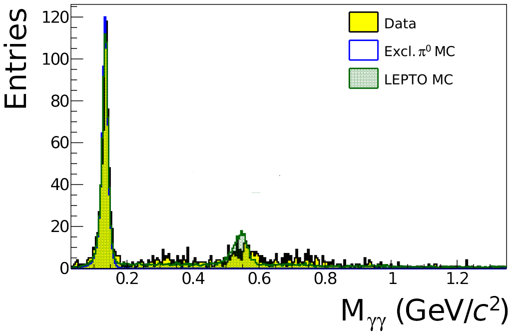
Handling the π^0 background

Scenario 1:

- **Both** γ are being **detected**
- Contribution can be **extracted directly** from the data

Method:

- Combining "high" energetic photon to all other photons ($E_\gamma < ECAL_{thr}$) (within one event) $\Rightarrow$ **photon pairs**
  $\rightarrow$ Invariant mass spectrum
  $\Rightarrow$ π_0 peak



Yield of Monte-Carlos I

Scenario 2:

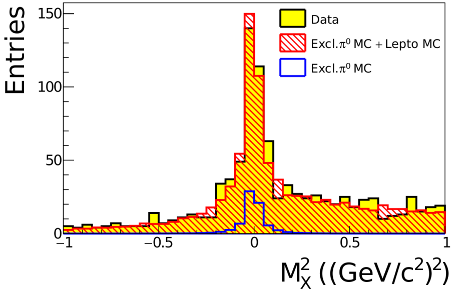
- One **photon escapes detection**
- **MC Simulation** is needed to describe the data

Simulation of ... exclusive π_0 production (via HEPGEN++)
semi-inclusive π_0 production (via LEPTO)

Yield of each MC to describe the data?

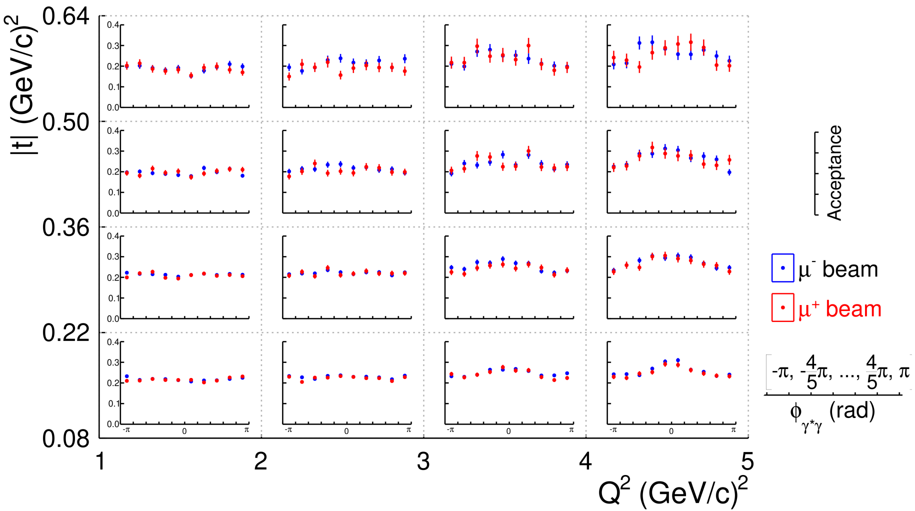
Idea:

- Choose **variables sensitve to additional particles** in final state (semi inclusive)
- **Fit the MC samples** to the **shape of the distribution** in the data



Acceptance $a(Q^2, |t|, \phi)$

$\rightarrow \nu$ DVCS domain



Analyse the t-slope of the cross section

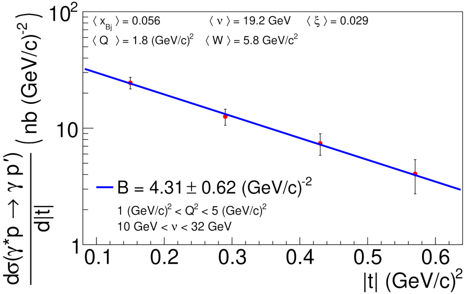
To go from μp to $\gamma^* p$:

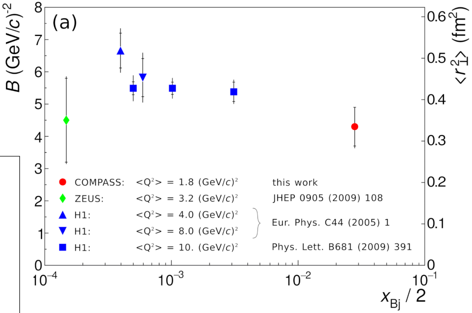
$$\frac{d\sigma^{\mu p}}{dQ^2 d\nu d\Phi dt} \rightarrow \frac{d\sigma^{\gamma^* p}}{dt d\phi} \text{ by multiplying with } \frac{1}{\Gamma(Q^2,\nu,E_\mu)}$$

$\Gamma(Q^2, \nu, E_\mu)$: Flux of transverse virtual photons

No ϕ dependence observed
$\Rightarrow$ add up ϕ bins

fit $\propto e^{B|t|}$





arXiv:1802.02739

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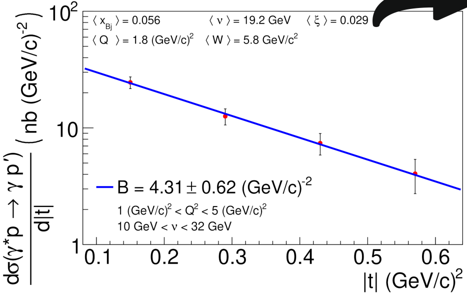
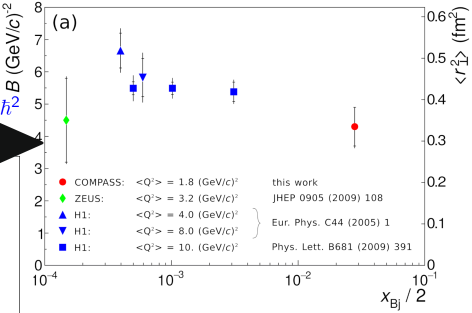
$\langle r_\perp^2 \rangle = 2\langle B(x_{Bj})\rangle \hbar^2$

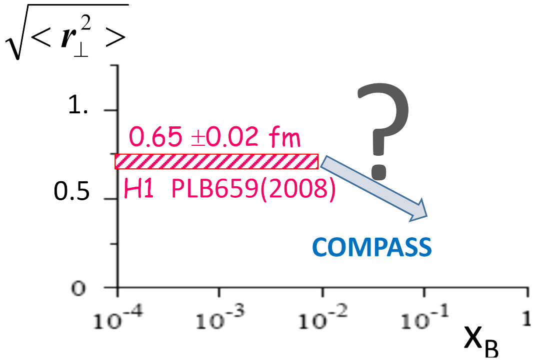




$$\sqrt{\langle r_\perp^2 \rangle} = (0.58 \pm 0.04_{stat} \,{}^{+0.01}_{-0.02}|_{sys} \pm 0.04_{model})\text{fm}$$

arXiv:1802.02739

Future results



Thank you for your attention.