Exclusive single photon production in muon-proton scattering at COMPASS

Johannes Giarra

on behalf of the COMPASS collaboration

EINN2019

27. Oct - 02. Nov.

Paphos, Cyrpus

Frontiers and Careers in Photonuclear Physics

JOHANNES GUTENBERG UNIVERSITÄT MAINZ JG|U

bmb+f - Förderschwerpunkt COMPASS Großgeräte der physikalischen Grundlagenforschung

COMPASS

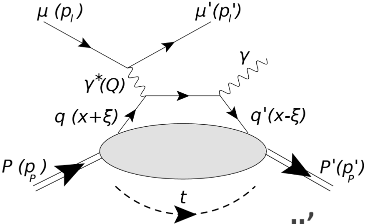
STRONG 2020

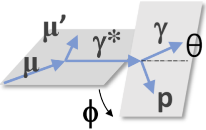
Introduction

- Classical Quark Parton Model (QPM)
  $\rightarrow$ Distribution of longitudinal momentum of quarks in the nucleon (PDFs)
- Consider transvers extension of the nucleon
  $\Rightarrow$ **Generalized Parton Distribution functions (GPDs)**
  $\rightarrow$ Provide information of the **transvers position of the quark** in the nucleon
- Properties of GPDs can be investigated by processes where **only a single photon is produced**
  $\rightarrow$ **Deeply Virtual Compton Scattering (DVCS)**
- In 2012 a first test measurement of the DVCS was performed at COMPASS (analysed and published)
- In 2016/17 a long term measurement was performed

$\Rightarrow$ **Determine the DVCS cross section**

Deeply Virtual Compton Scattering (DVCS) at COMPASS





DVCS process:

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

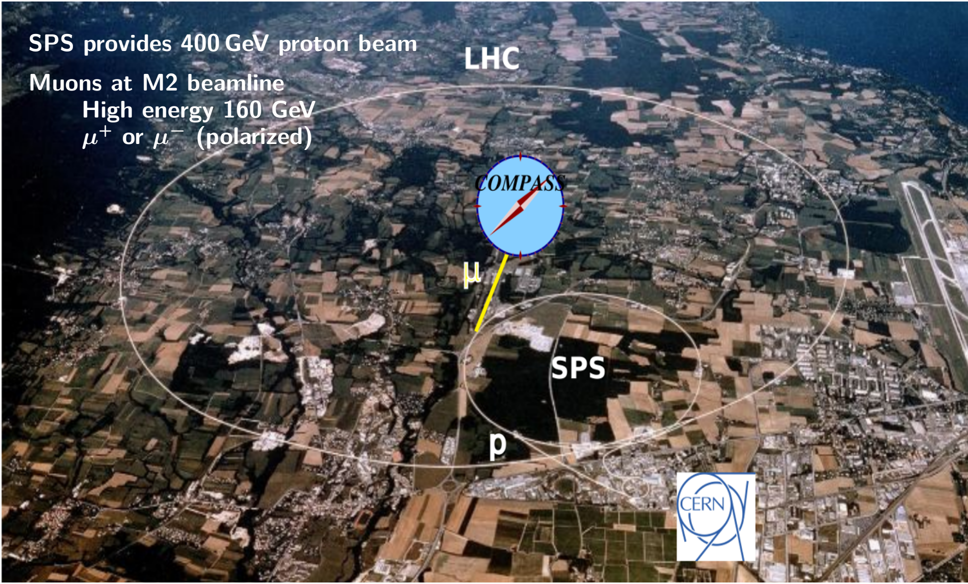
$\rightarrow$ Process with same final state:
Bethe-Heitler (Bremsstrahlung)

Kinematic dependencies:

- Q^2 : 4-momentum of virtual photon
- ν : Energy of virtual photon
- t : Momentum transfer to proton
- ϕ : Angle between plane of virtual photon and plane of real photon

Cross section for exclusive photon production:

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

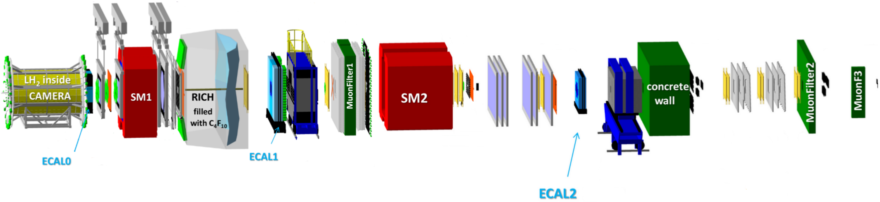

SPS provides 400 GeV proton beam
Muons at M2 beamline
High energy 160 GeV
μ^+ or μ^- (polarized)
LHC
COMPASS
μ
SPS
p
CERN

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

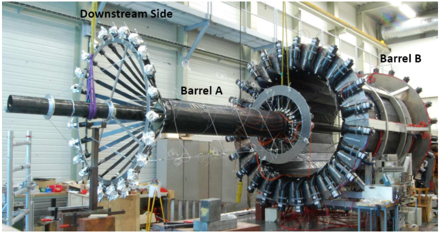


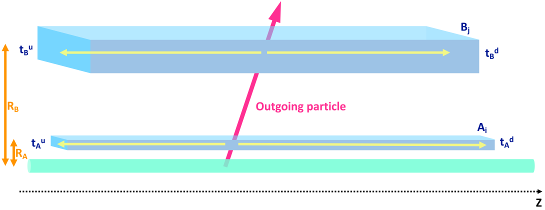
Muon acceptance range:

$$Q^2 < 100\ (\mathrm{GeV}/c)^2$$
$$x_{Bj} > 10^{-5}$$

Proton identification using CAMERA

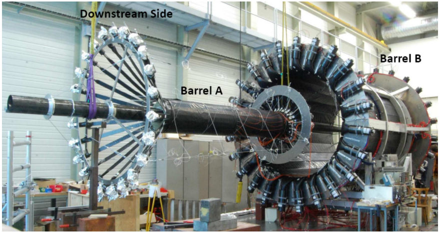
- Two concentric cylinder made of scintillator slabs (24 slabs each)
  - Inner ring slab thickness 1 cm
  - Outer ring slab thickness 5 cm
- Time Of Flight (TOF) measurement between inner ring and outer ring
- Calculate β =DOF/TOF

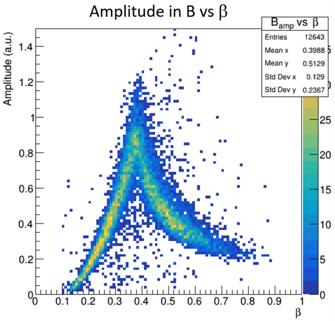




Proton identification using CAMERA

- Two concentric cylinder made of scintillator slabs (24 slabs each)
  - Inner ring slab thickness 1 cm
  - Outer ring slab thickness 5 cm
- Time Of Flight (TOF) measurement between inner ring and outer ring
- Calculate β =DOF/TOF





- Energy loss in outer ring VS β
- Clean signal of protons

The road to the DVCS cross section

Dataquality

- Spill profile
- Spectrometer performance

Luminosity

- Target position
- Muon flux

DVCS event selection

DVCS cross section

Monte-Carlo

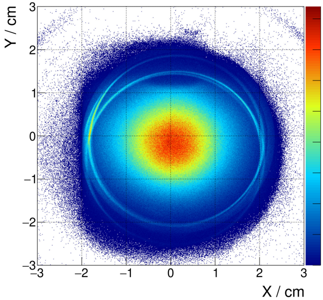
HEPGEN LEPTO

- Acceptance
- Background estimation

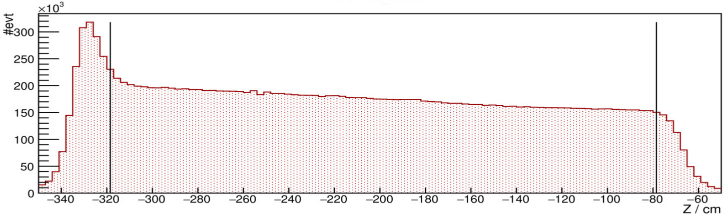
How to determine the target position?

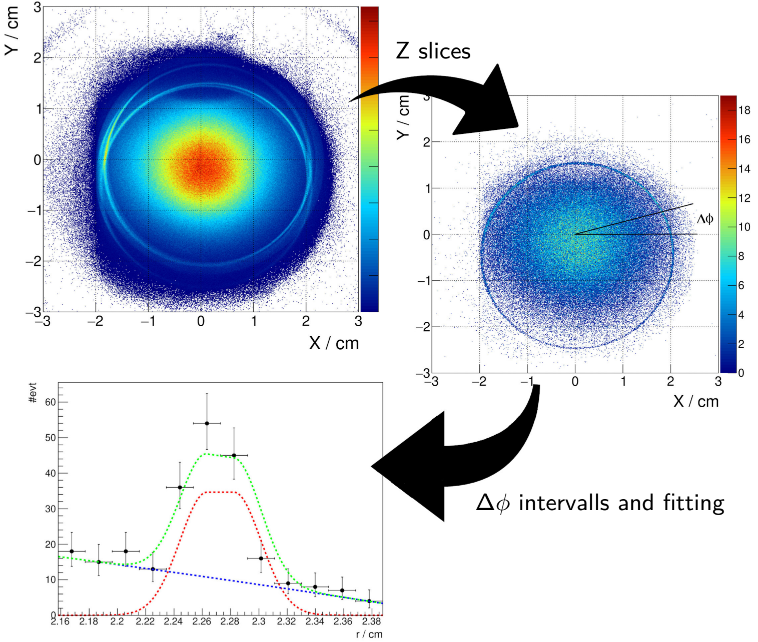
...reconstruct the target position from data.

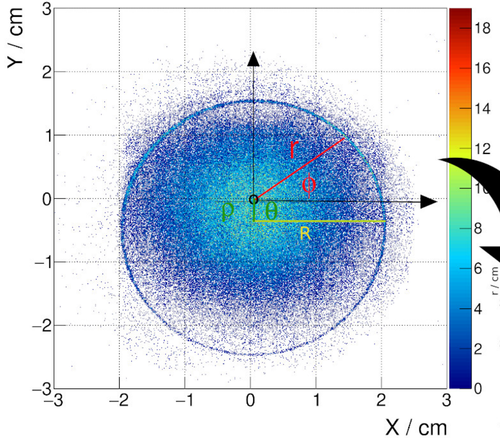
Muon beam also interacts with target container



- **Target container:**
  - Kapton foil
  - 2.5m long, 4 cm diameter
- X-Y projection of vertex distribution along the full target
  - Beam profile (diameter 2 cm)
  - Not centered in coordinate system of spectrometer
- For data analysis only vertices inside target volume $\rightarrow$ define radial cut

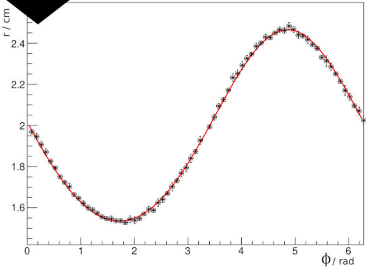



Y / cm
X / cm
Z slices
Y / cm
X / cm
Δφ
#evt
r / cm
Δφ intervalls and fitting

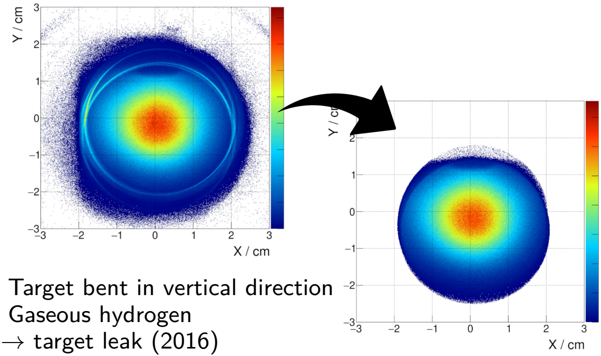


Function for $r(\phi)$ in spectrometer system:

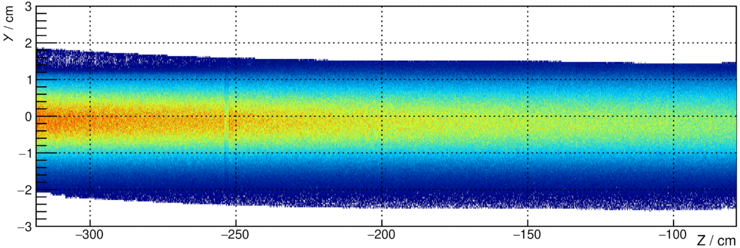
$$r(\phi) = -\rho \cdot \cos(\phi - \theta)$$
$$\sqrt{(\rho \cdot \cos(\phi - \theta))^2 + R^2 - \rho^2}$$



Target position (2016)



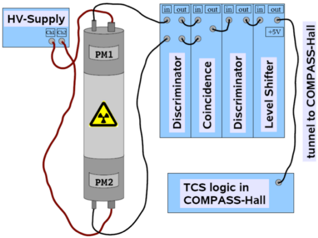
- Target bent in vertical direction
- Gaseous hydrogen
  → target leak (2016)



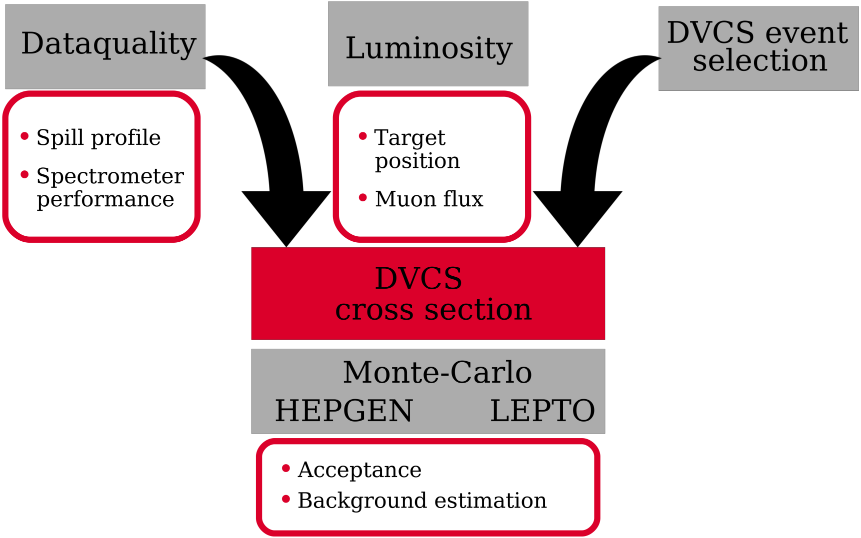
Determine muon flux I

Idea:
Use a true random trigger to measure reconstructed muon flux

- **True Random trigger**
  - Na^{22} (β^+ source) between two PMTs
  - e^+e^- annihilation
  - 2γ measured in coincidence
    $\Rightarrow$ Trigger signal
  - Signal send to experimental area and fed into trigger logic
- **Flux:**
  $$\text{Flux}_{\text{RT}}[1/s] = \frac{\#\text{ of RT beam tracks}}{\#\text{ RT attempts}\cdot\text{RT time gate}}$$
  $\rightarrow$ Data selection to determine number of beam tracks
- **Luminosity $\mathcal{L}$**
  $$\mathcal{L} = \#\text{ of target protons} \cdot \text{Flux}$$

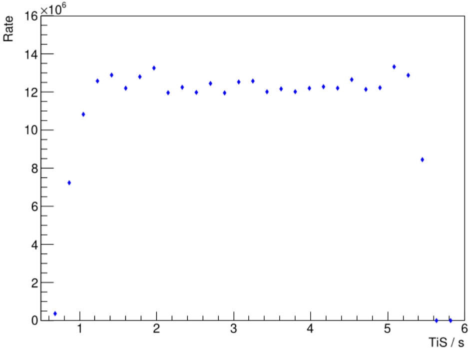


The road to the DVCS cross section



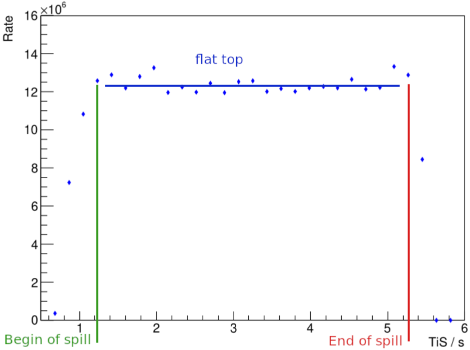
Spill profile

- **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)



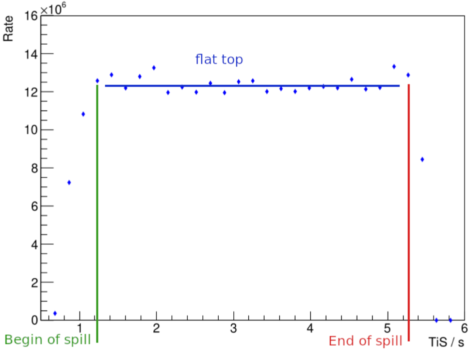
Spill profile

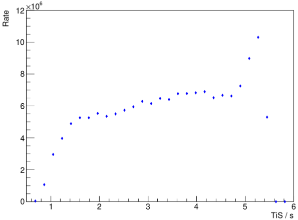
- **Slow extraction of SPS beam**
  - Intensity rises
  - Flat top for ∼5s
  - Intensity drops
- Interested in **flat top region**
  → ± 15% of flat top avg.
- Define **begin** and **end of spill**
  (Time in Spill window)
- Relevant for flux analysis
  (typ. Flux $\sim 7\cdot 10^7$ μ/spill)



Spill profile

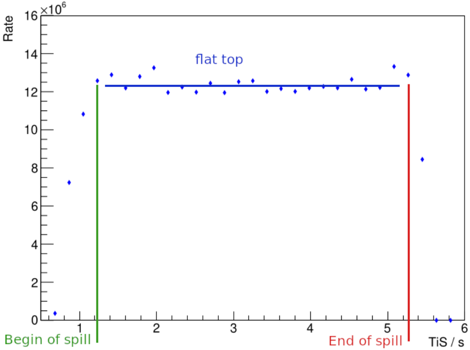
- **Slow extraction of SPS beam**
  - Intensity rises
  - Flat top for ∼5s
  - Intensity drops
- Interested in **flat top region**
  $\rightarrow \pm$ 15% of flat top avg.
- Define **begin** and **end of spill**
  (Time in Spill window)
- Relevant for flux analysis
  (typ. Flux $\sim 7{\cdot}10^7\ \mu$/spill)

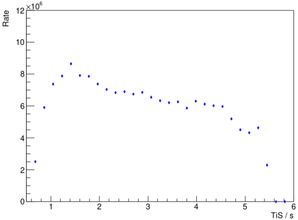




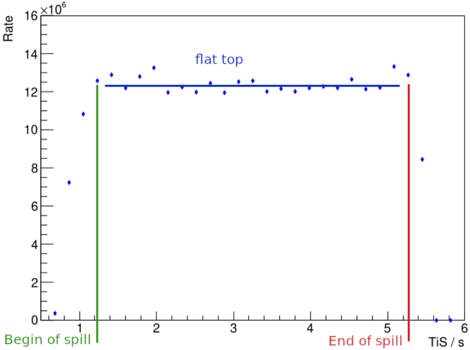
Spill profile

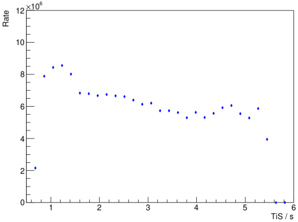
- **Slow extraction of SPS beam**
  - Intensity rises
  - Flat top for $\sim$5s
  - Intensity drops
- Interested in **flat top region**
  $\rightarrow \pm$ 15% of flat top avg.
- Define **begin** and **end of spill**
  (Time in Spill window)
- Relevant for flux analysis
  (typ. Flux $\sim 7 \cdot 10^7$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





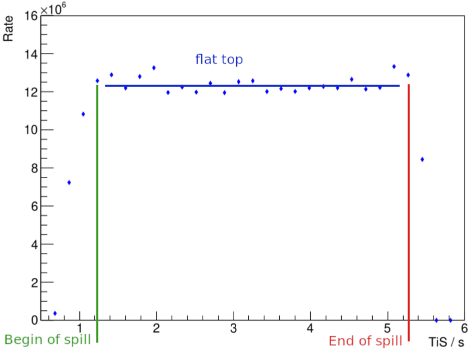
- **Slow extraction of SPS beam**
  - Intensity rises
  - Flat top for ∼5s
  - Intensity drops
- Interested in **flat top region**
  → ± 15% of flat top avg.
- Define **begin** and **end of spill**
  (Time in Spill window)
- Relevant for flux analysis
  (typ. Flux $\sim 7{\cdot}10^7\ \mu$/spill)

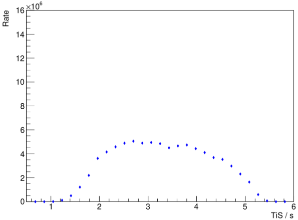




Spill profile

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



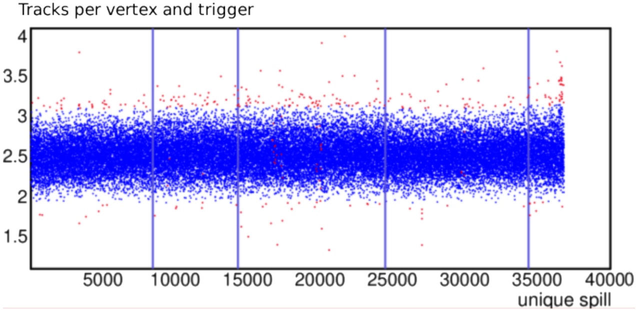


Spectrometer performance

Checks:

- Find **parameters** which **indicate the performance**
- **Compare parameter** of a spill to the parameter of **previous and later spills** $\rightarrow$ **Reject if too few spills show similar behaviour**

e.g. Reconstructed tracks per vertex, trigger and spill



The road to the DVCS cross section

Dataquality

- Spill profile
- Spectrometer performance

Luminosity

- Target position
- Muon flux

DVCS event selection

DVCS cross section

Monte-Carlo

HEPGEN LEPTO

- Acceptance
- Background estimation

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
  - Energy beyond a threshold in eiter one of the ECALs
- **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

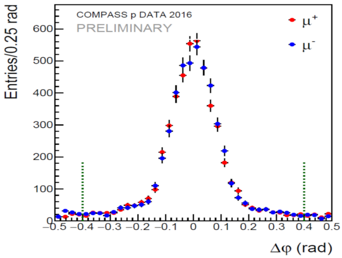
Real photon:

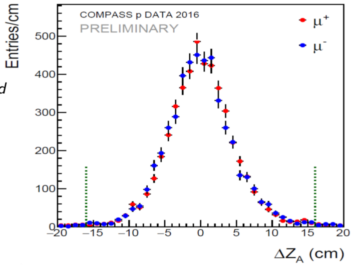
- ECAL0 thr. $=$ 4 GeV
- ECAL1 thr. $=$ 5 GeV
- ECAL2 thr. $=$ 10 GeV

Proton candidates:

- $\beta >$0.1

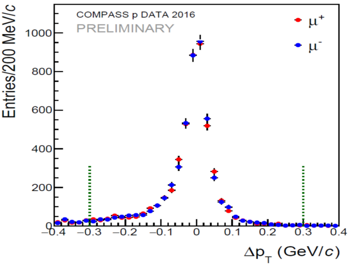
Difference between spectrometer prediction and CAMERA measurement

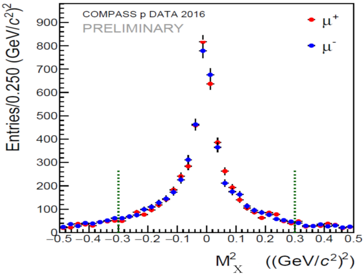




Vertex pointing:
$\Delta Z_A = Z_A^{meas.} - Z_A^{pred}$

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

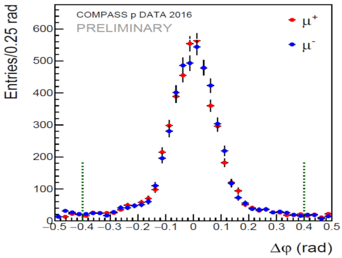




p_t balance:
$p_t = p_t^{meas.} - p_t^{pred}$

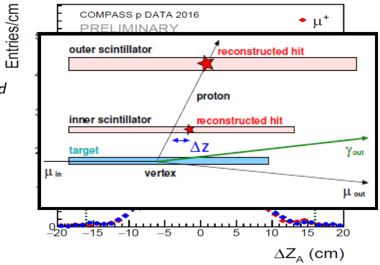
4-mom. balance:
$M_X^2 = (P_i - P_f)^2$

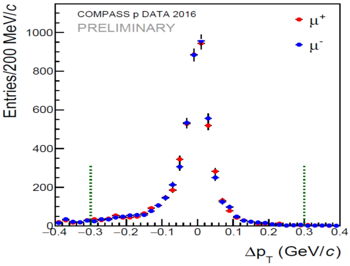
Difference between spectrometer prediction and CAMERA measurement



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

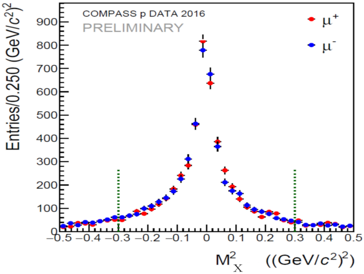
Azimuthal angle:
$\Delta\phi = \phi^{meas.} - \phi^{pred}$





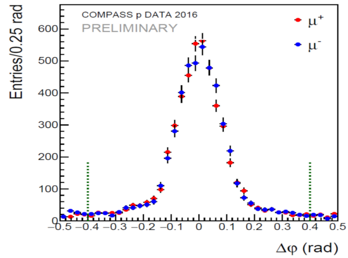
p_t balance:
$p_t = p_t^{meas.} - p_t^{pred}$

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



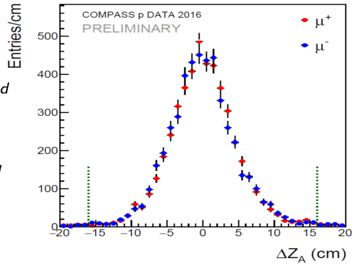
Exclusivity cuts

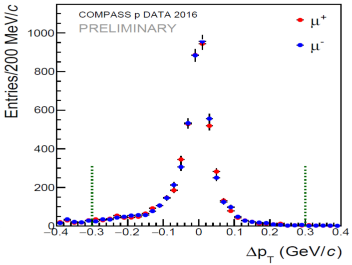
Difference between spectrometer prediction and CAMERA measurement



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

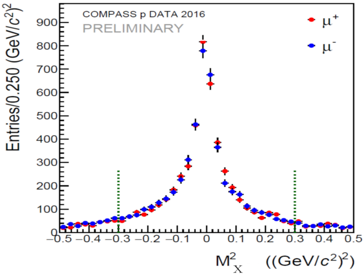
Azimuthal angle:
$\Delta\phi = \phi^{meas.} - \phi^{pred}$

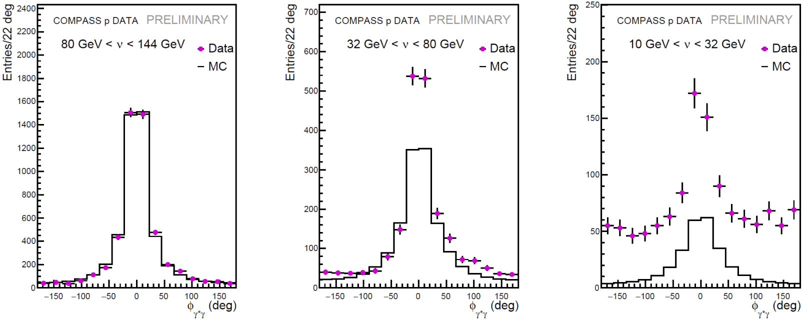




p_t balance:
$p_t = p_t^{meas.} - p_t^{pred}$

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



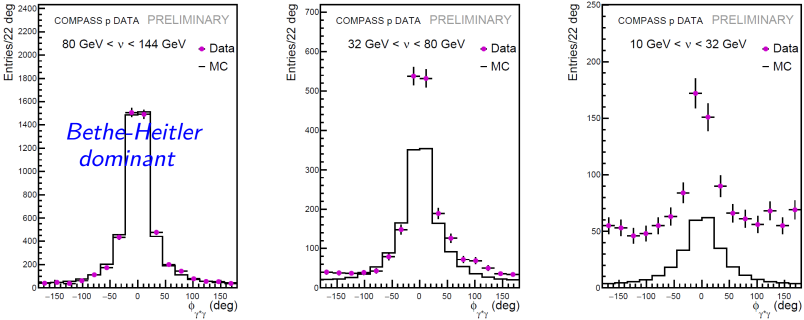


BH process **very well known** over a wide kinematic range
$\rightarrow$ MC sample for the BH (HEPGEN)

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

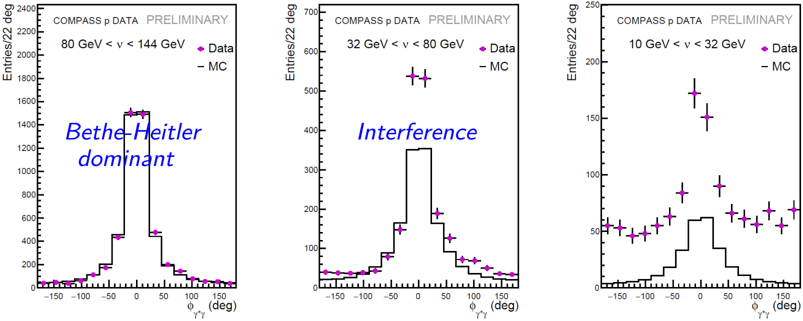


BH process **very well known** over a wide kinematic range
$\rightarrow$ MC sample for the BH (HEPGEN)

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

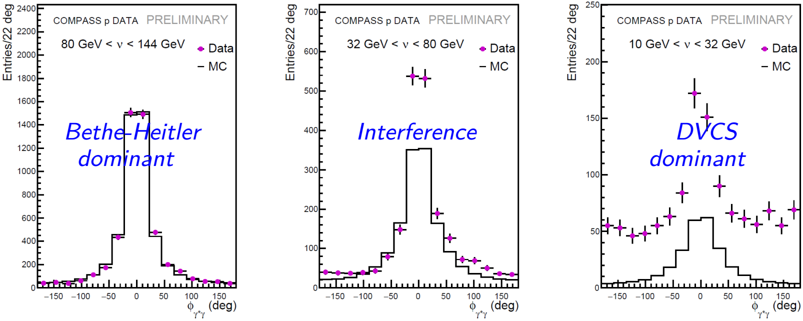


BH process **very well known** over a wide kinematic range
→ MC sample for the BH (HEPGEN)

Handling BH contribution:

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

Contribution of the Bethe-Heitler



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

Handling BH contribution:

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

Status

Dataquality

- Spill profile ✓
- Spectrometer performance ✓

Luminosity

- Target position ✓
- Muon flux ✓

DVCS event selection ✓

DVCS cross section

Monte-Carlo

HEPGEN LEPTO

- Acceptance
- Background estimation

Outlook

- Determination of π^0 background
  - Photons produced by decay of π^0 can be missidentified as exclusive photons
  - MC simulation needed to estimate contribution
- MC quality checks (compare reconstructed MC and real data)
  - Kinematic distributions
  - Detector responses (Efficiencies)
- Produce a sufficient amount of MC data both for LEPTO and HEPGEN to determine the background
  - LEPTO and HEPGEN for the semi-inclusive and exclusive part of π^0 contribution
- Acceptance $a(Q^2, \nu, |t|)$

For each bin:

$$a = \frac{N_{reconstructed}}{N_{generated}}$$

$N_{generated}$: # generated events passing cut for flux

$N_{reconstructed}$: # reconstucted events passing entire set of cuts for single-photon production

Thank you for your attention.