



Antoine VIDON,  
*on behalf of the COMPASS collaboration*

*Exclusive single photon  
muon production  
at COMPASS*



*Valerio Minetti*

DIS 2019 - Torino

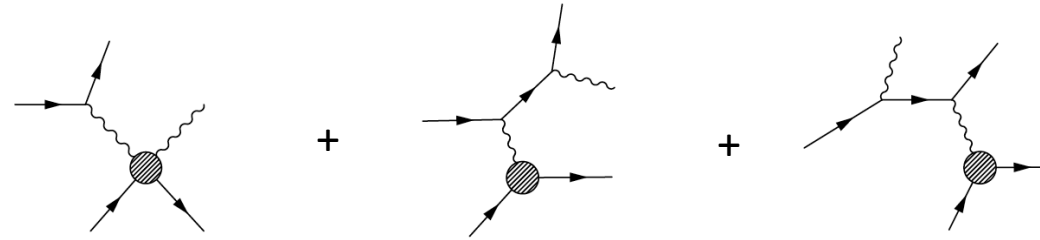
# Deeply Virtual Compton Scattering (DVCS)

D. Mueller *et al*, Fortsch. Phys. 42 (1994)

X.D. Ji, PRL 78 (1997), PRD 55 (1997)

A. V. Radyushkin, PLB 385 (1996), PRD 56 (1997)

**DVCS :  $lp \rightarrow l' p' \gamma$**



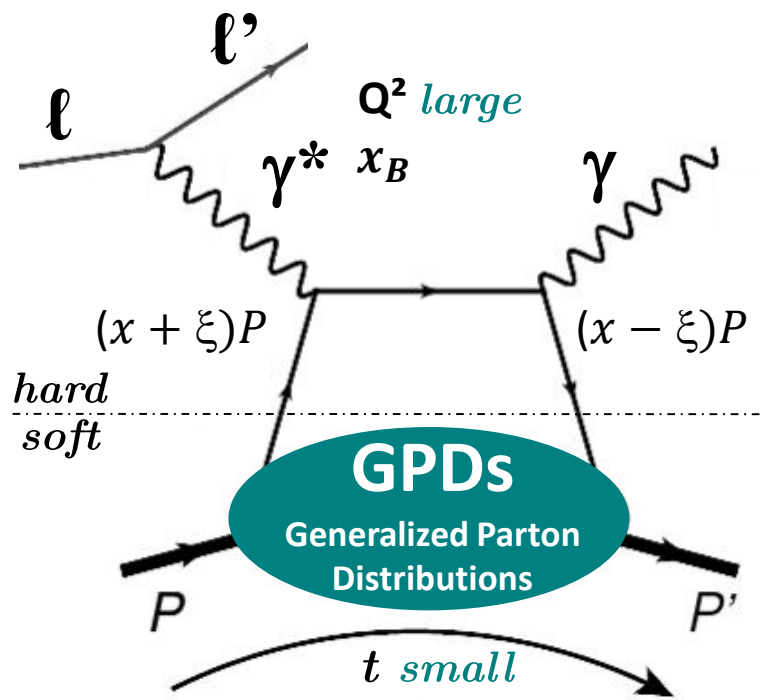
DVCS

Bethe-Heitler

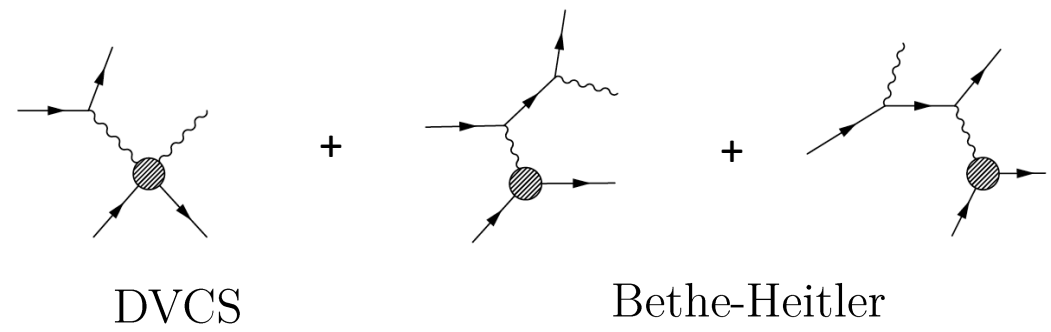
**DVMP :  $lp \rightarrow l' p' \pi, \rho, \omega$  or  $\phi$  or  $J/\psi$ ...**

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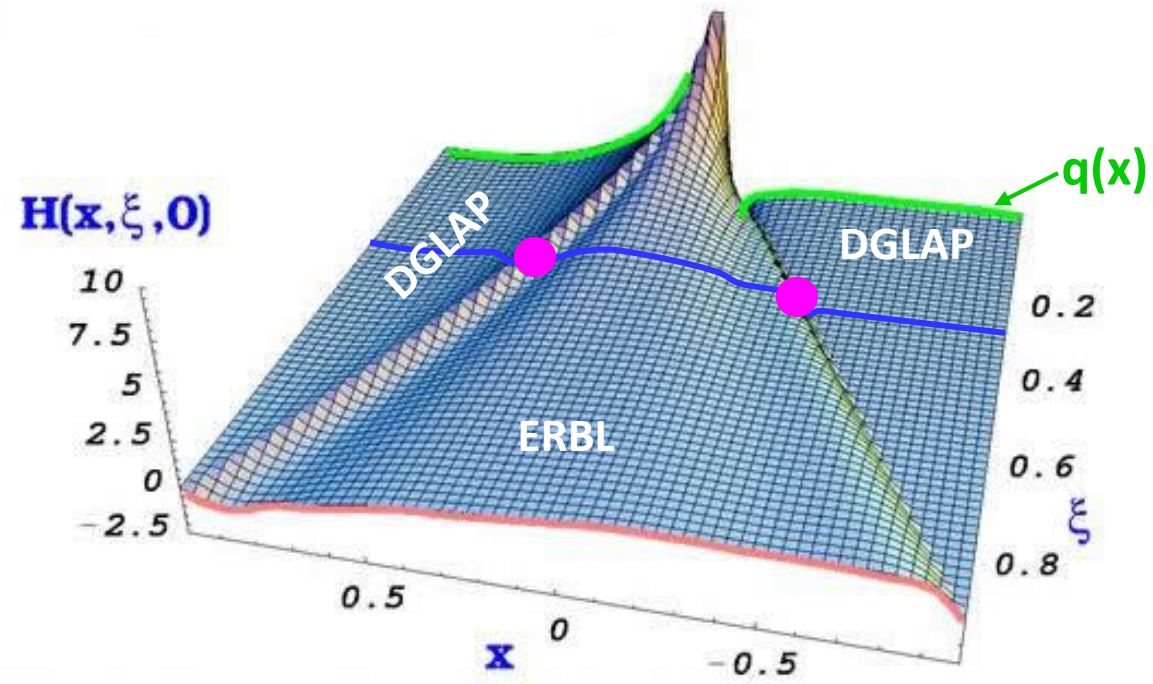
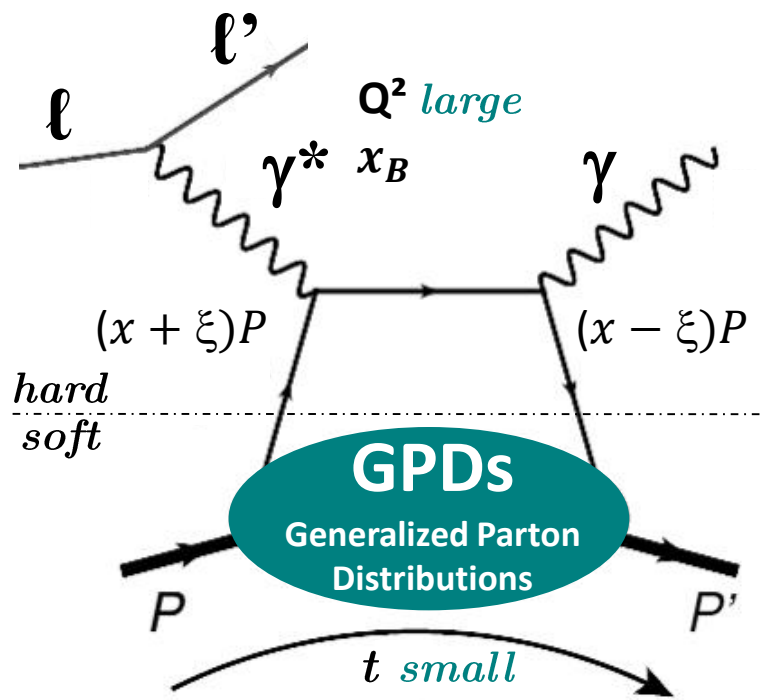
*Variables measured in an experiment:*

- $E_\ell, Q^2, x_B \sim 2\xi / (1 + \xi),$
- $t$  (or  $\theta_{\gamma^* \gamma}$ )
- $\phi$  ( $l l'$  plane /  $\gamma \gamma^*$  plane)

- $x$ : average long. momentum
- $\xi$ : long. mom. difference
- $t$ : four-momentum transfer related to  $b_\perp$  via Fourier transform

# Deeply Virtual Compton Scattering (DVCS)

Goeke, Polyakov, Vanderhaeghen, PNP 47 (2001)



The amplitude DVCS at LT & LO in  $\alpha_s$  (GPD  $H$ , Compton Form Factor  $\mathcal{H}$ ) :

$$\mathcal{H} = \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi + i\epsilon} = \mathcal{P} \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi} - i\pi H(x \pm \xi, x, t)$$

$$\Re \mathcal{H}(\xi, t) = \int dx \frac{\text{Im} \mathcal{H}(x, t)}{x - \xi} + d(t)$$

# COMPASS Setup for DVCS run



LHC

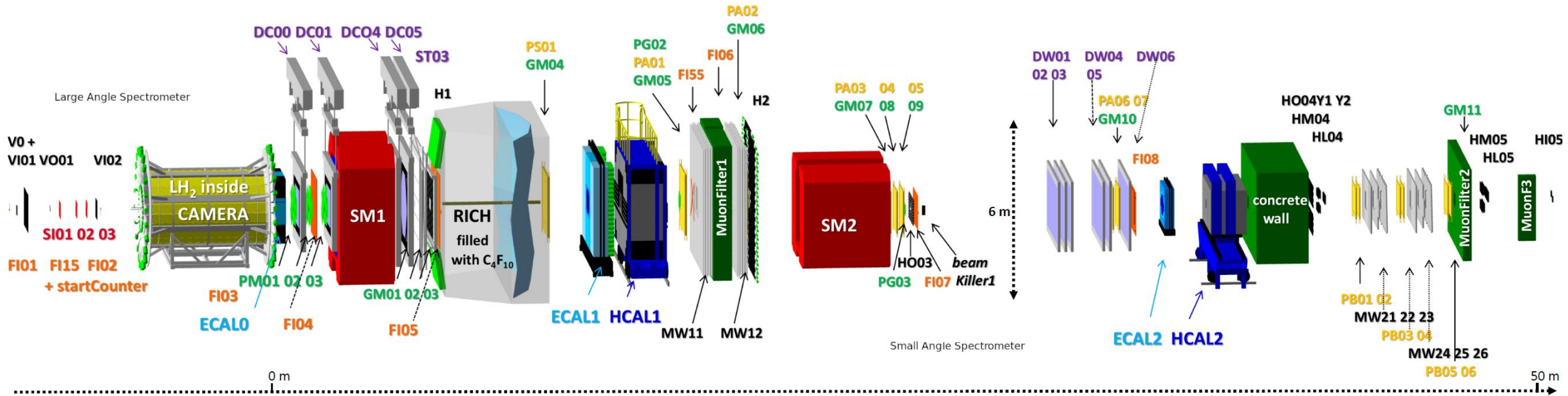
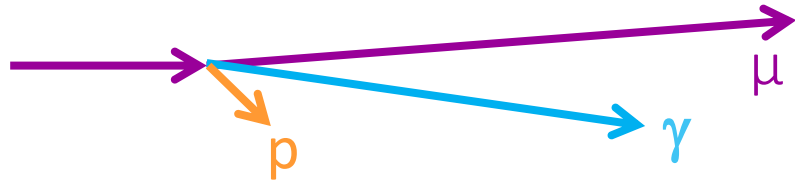


SPS

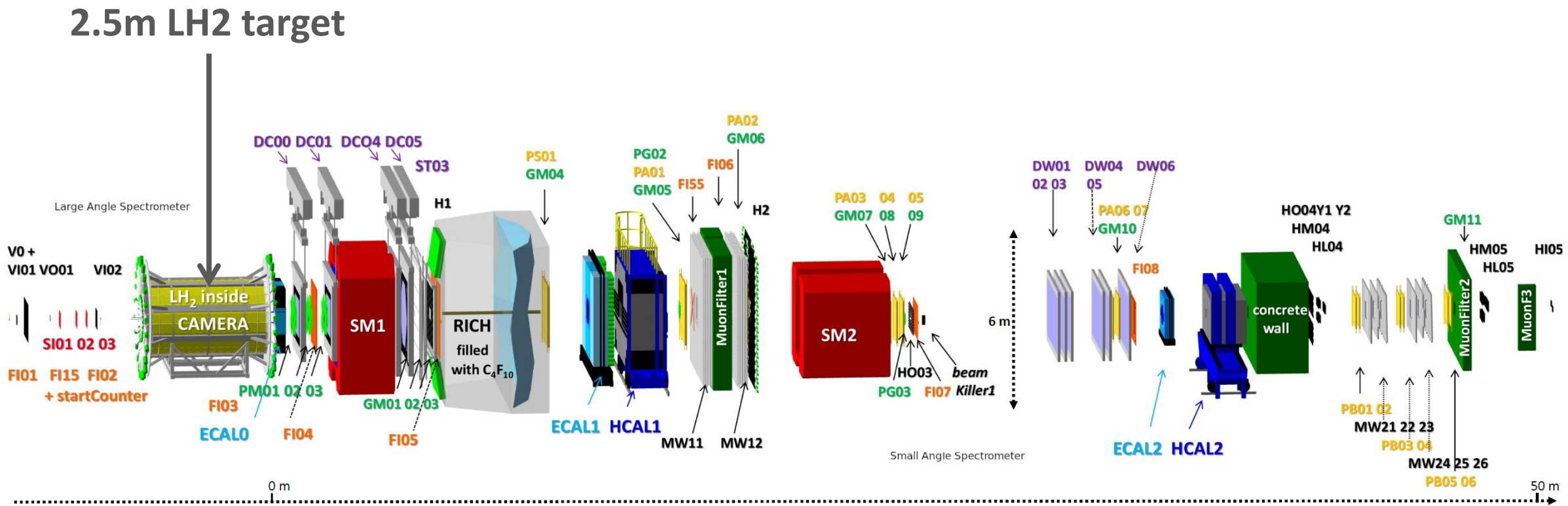
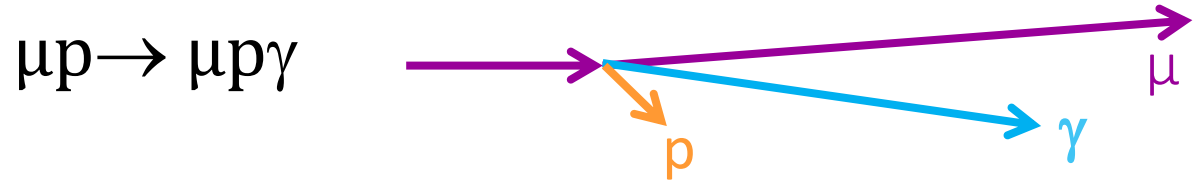


# COMPASS 2016/2017 setup

$\mu p \rightarrow \mu p \gamma$



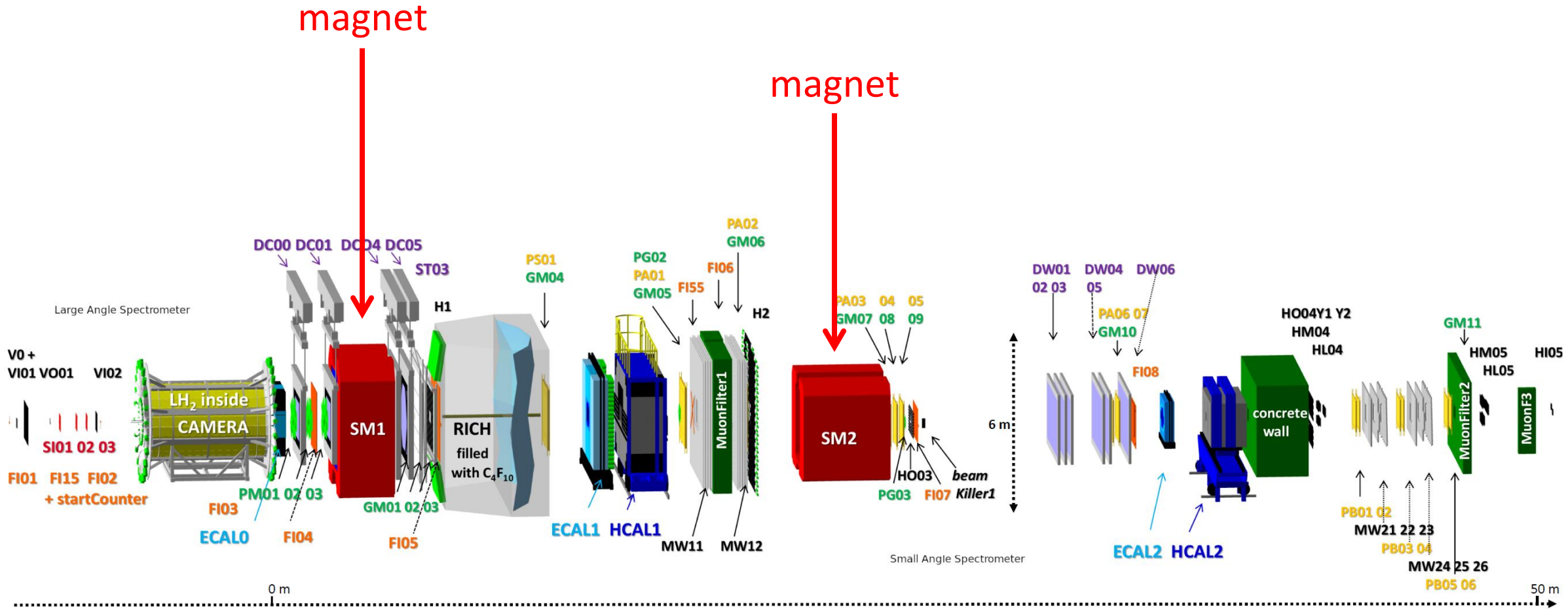
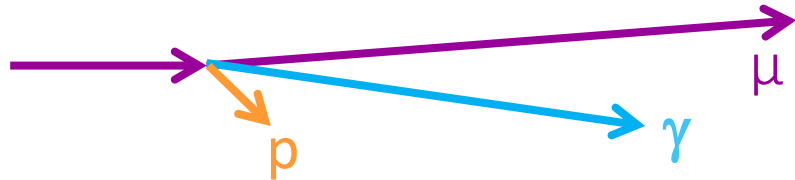
# COMPASS 2016/2017 setup





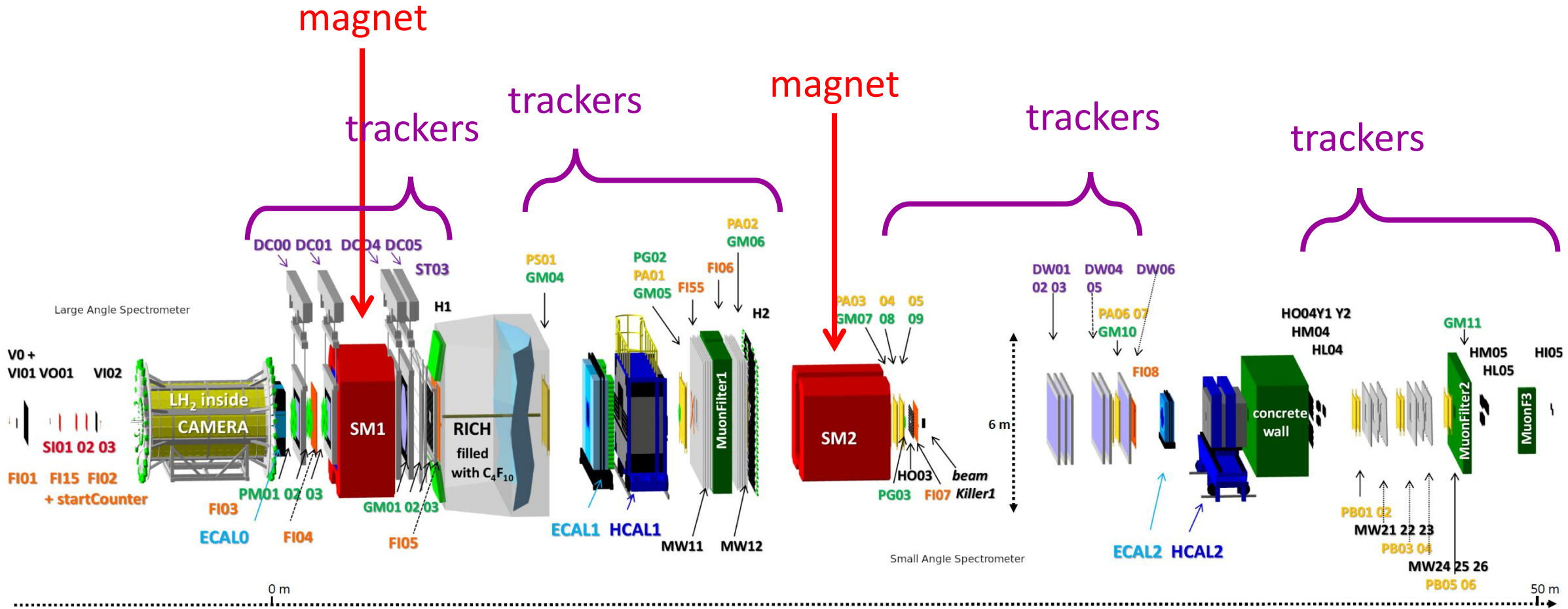
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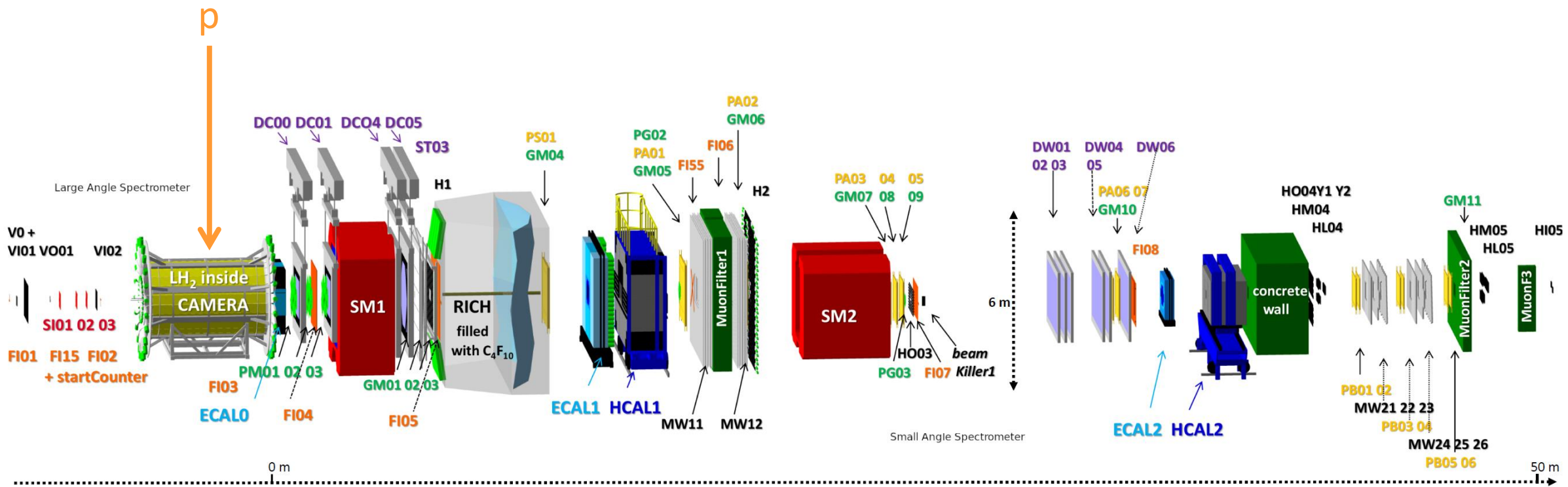
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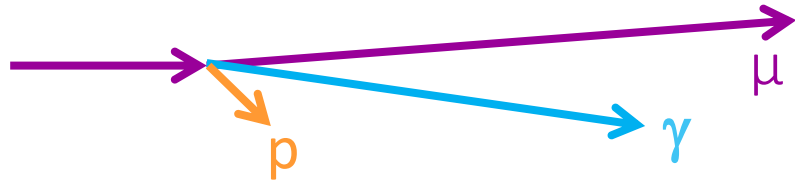
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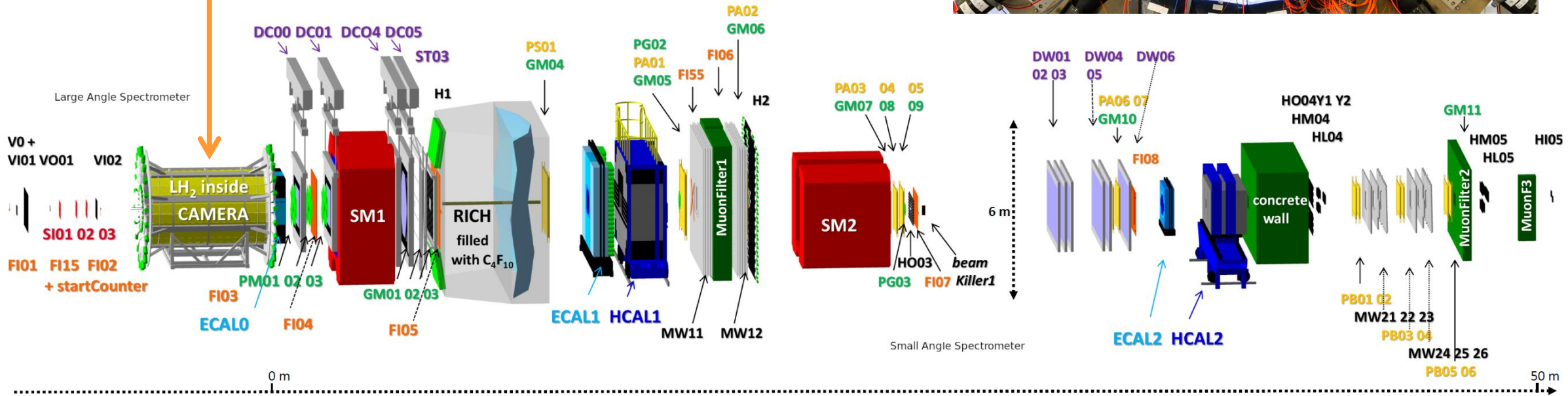
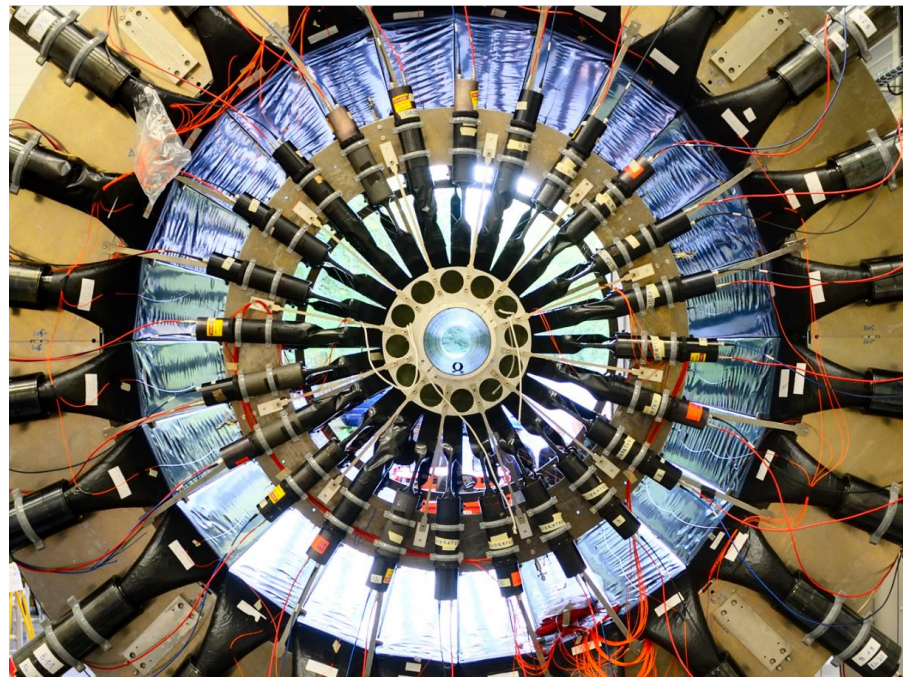
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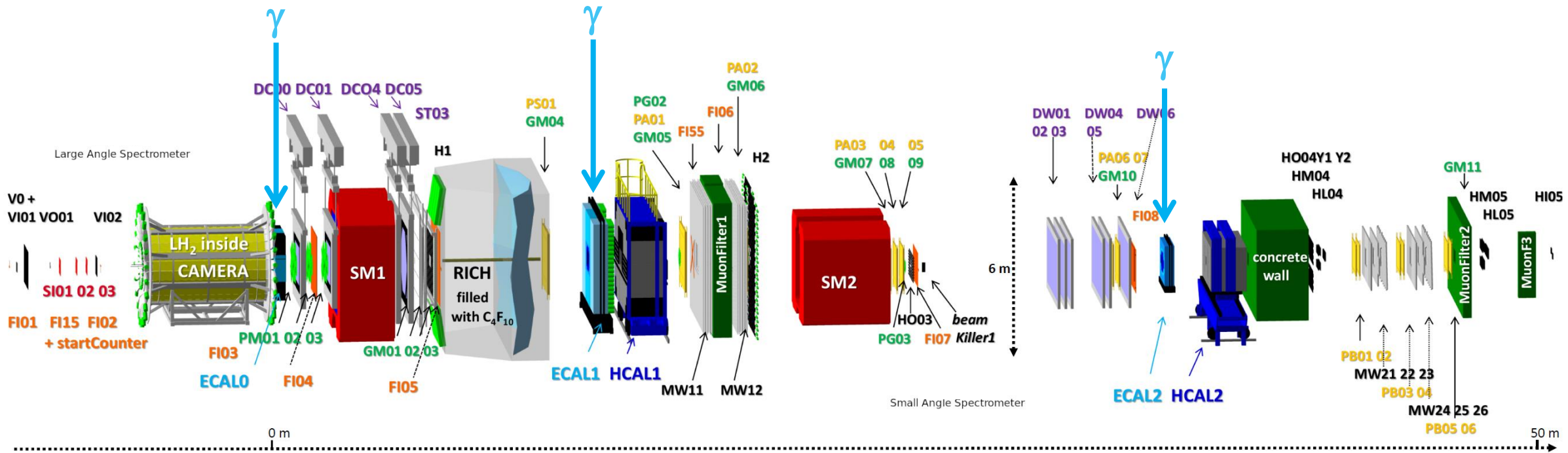
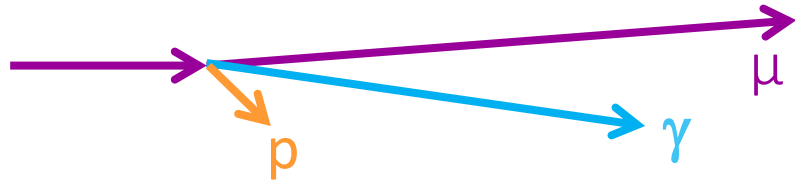
**CAMERA : L=4m Ø=2m**

24 inner & outer scintillators separated by about 1m  
1 GHz SADC readout, 330ps ToF resolution

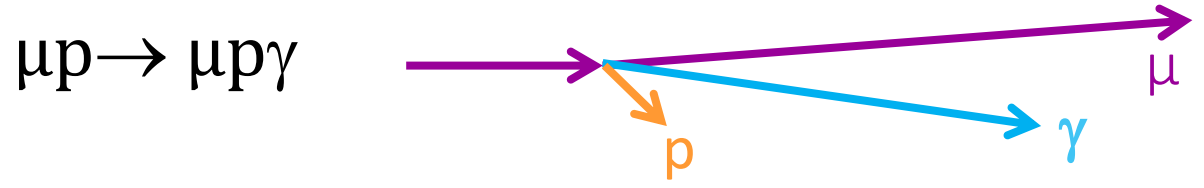


# COMPASS 2016/2017 setup

$\mu p \rightarrow \mu p \gamma$

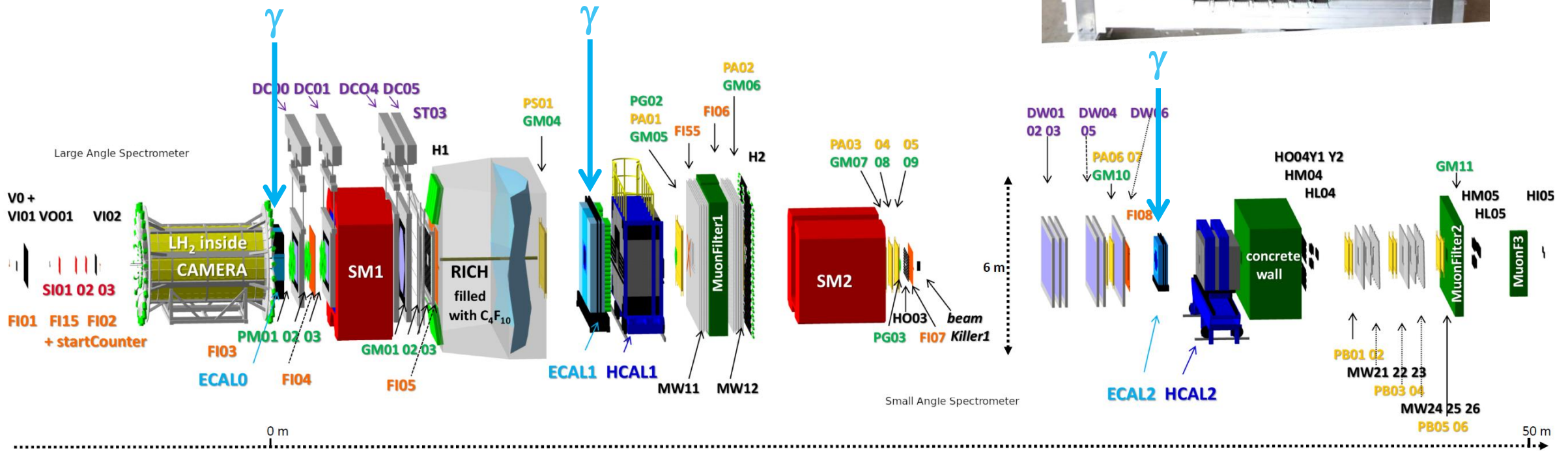
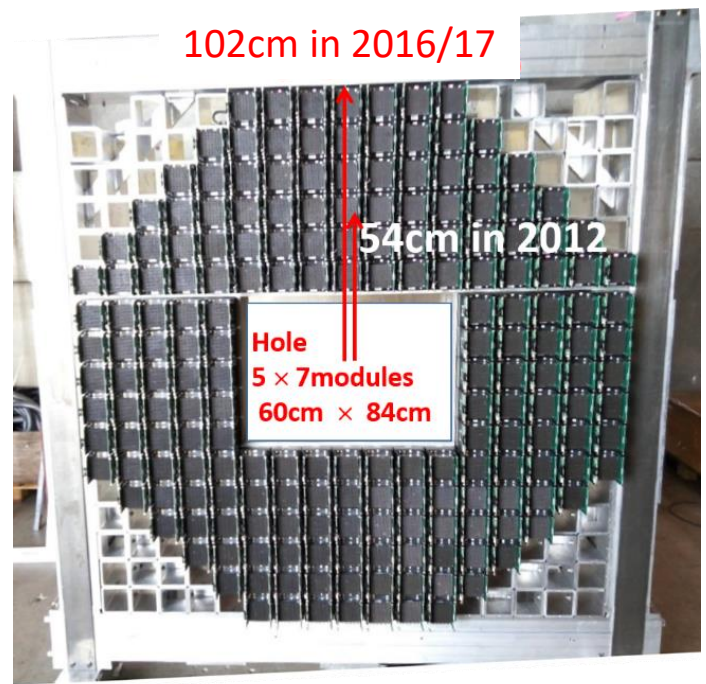


# COMPASS 2016/2017 setup



## ECAL0: $2 \times 2 \text{ m}^2$

Shashlyk modules + MAPD readout  
 one module is made of 9 cells ( $4 \times 4 \text{ cm}^2$ ) = 194 modules or 1746 cells



# COMPASS 2012 Pilot run

# COMPASS 2012 Pilot run

## Exclusivity variables

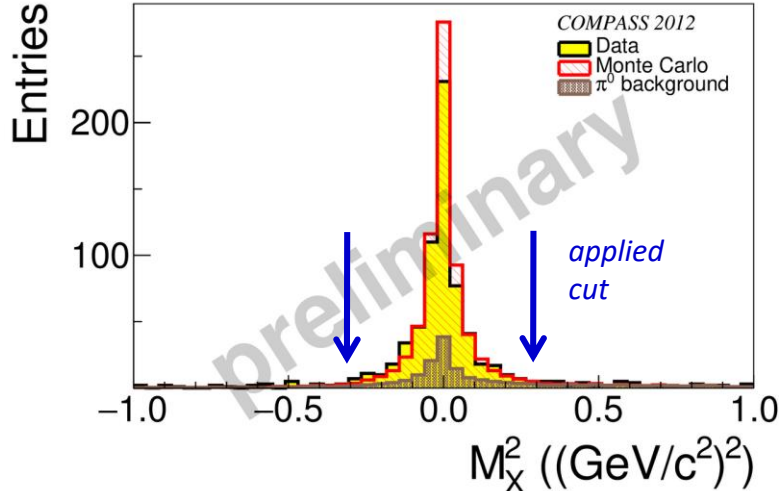
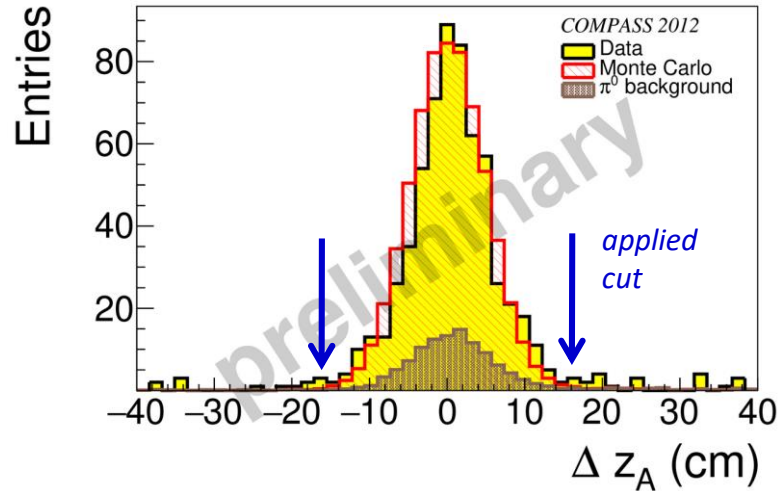
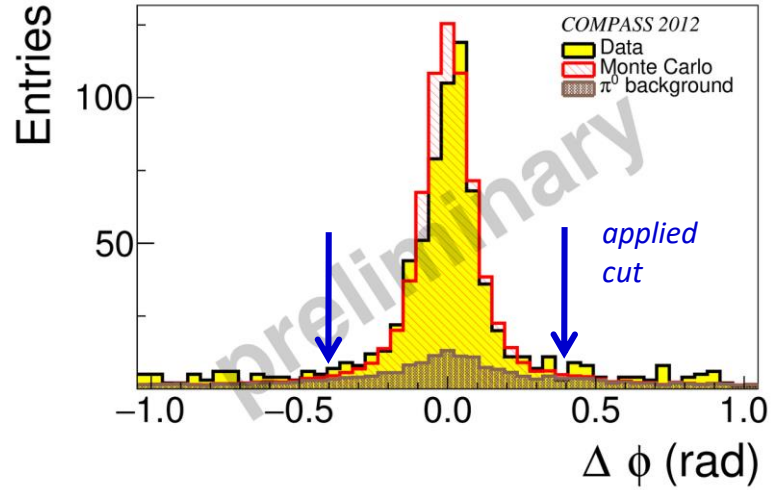
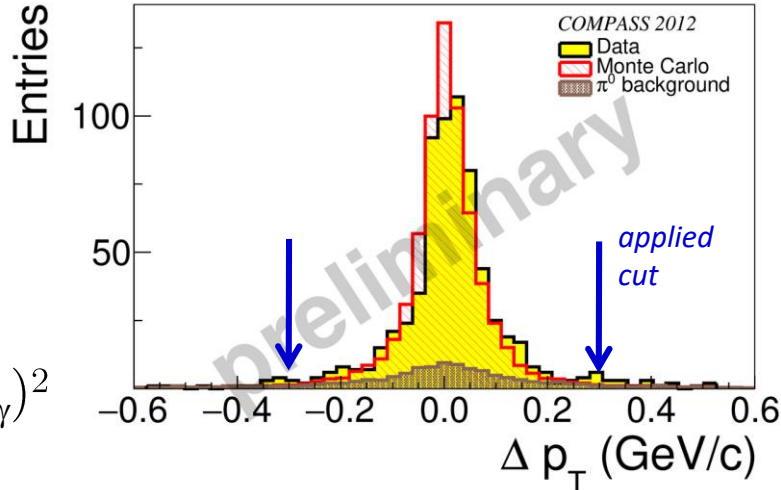
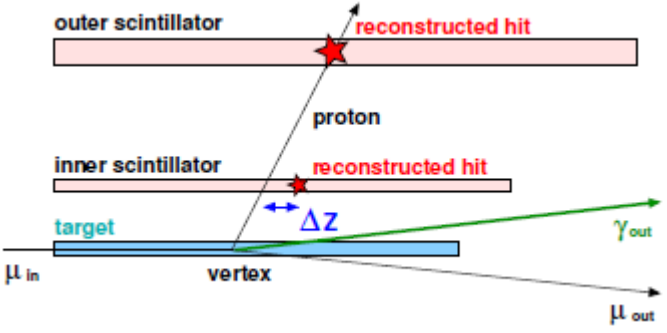
$x_B > 0.03$   
 $10 < \nu < 32 \text{ GeV}$

$$\Delta p_T = p_T^{\text{cam}} - p_T^{\text{spec}}$$

$$\Delta \phi = \phi^{\text{cam}} - \phi^{\text{spec}}$$

$$\Delta z_A = z_A^{\text{cam}} - z_A^{\text{Z}_B \text{ and vertex}}$$

$$M_{X=0}^2 = (p_{\mu_{\text{in}}} + p_{p_{\text{in}}} - p_{\mu_{\text{out}}} - p_{p_{\text{out}}} - p_{\gamma})^2$$





$\pi^0$  are one of the main background sources for excl. photon events.

Two possible cases:

**Visible** (both  $\gamma$  detected  $\rightarrow$  subtracted)

the DVCS photon after all exclusivity cuts is combined with all detected photons below the DVCS threshold: 4,5,10 GeV in ECAL0, 1, 2 respectively

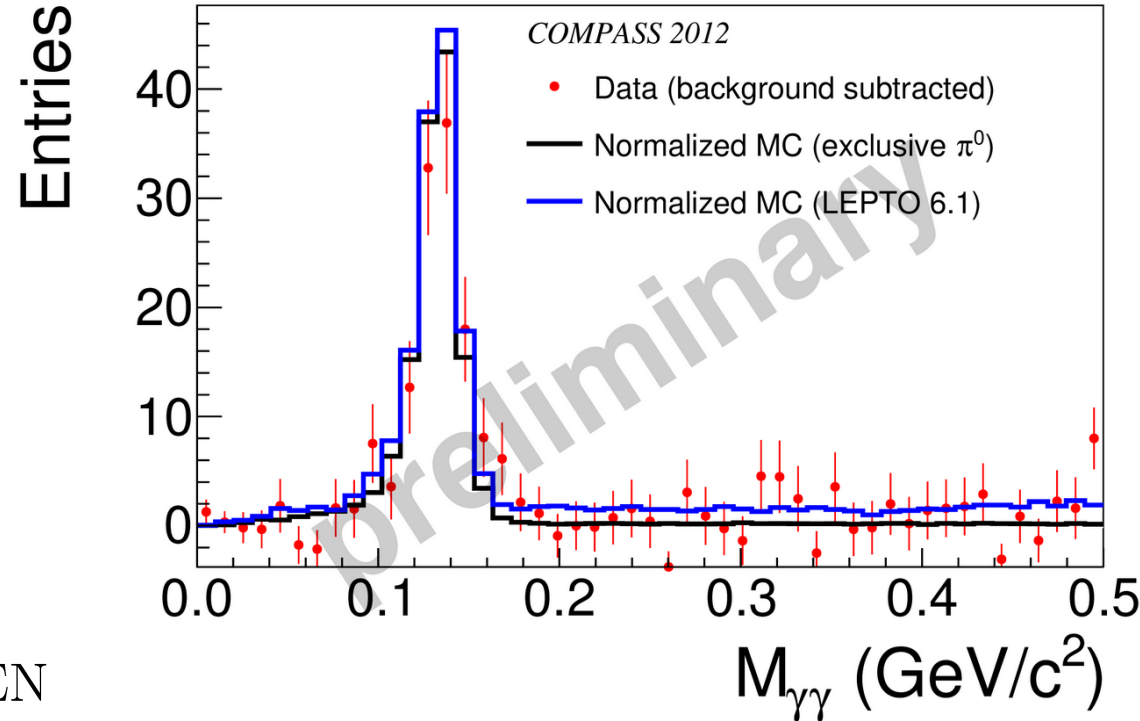
**Invisible** (one  $\gamma$  lost  $\rightarrow$  estimated by MC)

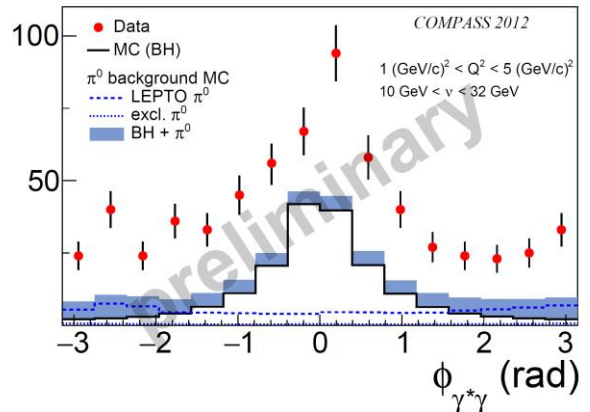
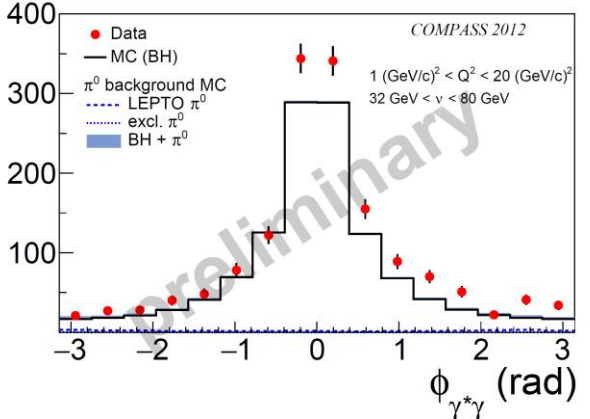
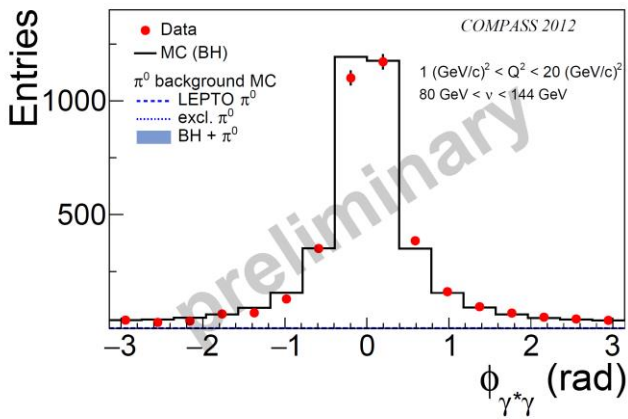
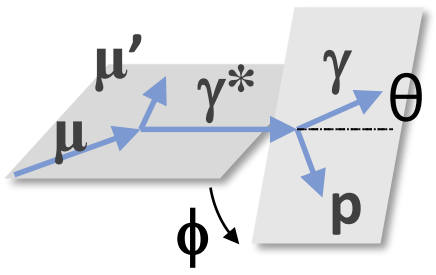
**Semi-inclusive LEPTO 6.1**

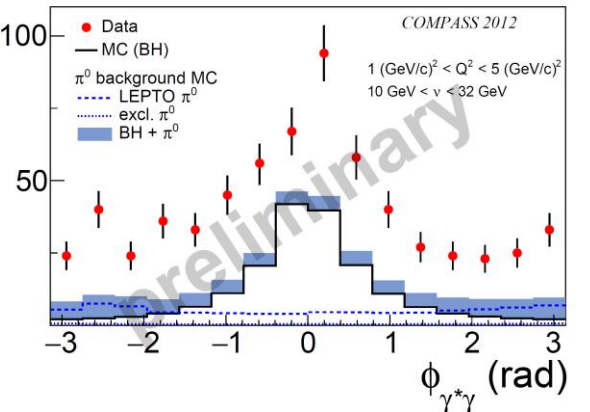
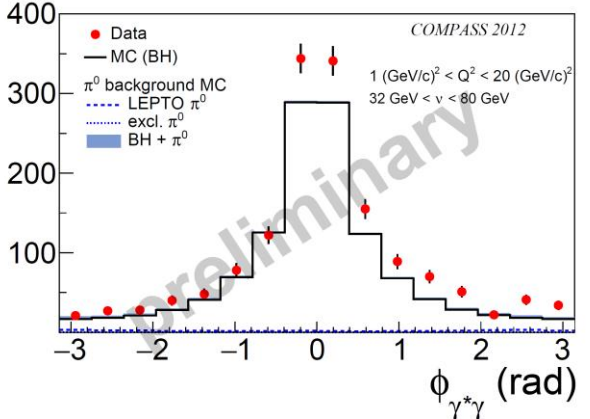
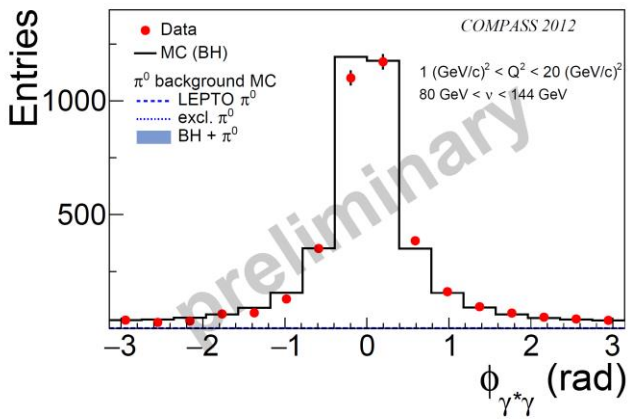
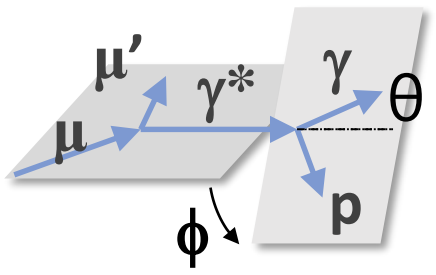
**Exclusive HEPGEN  $\pi^0$**

(Goloskokov-Kroll model)

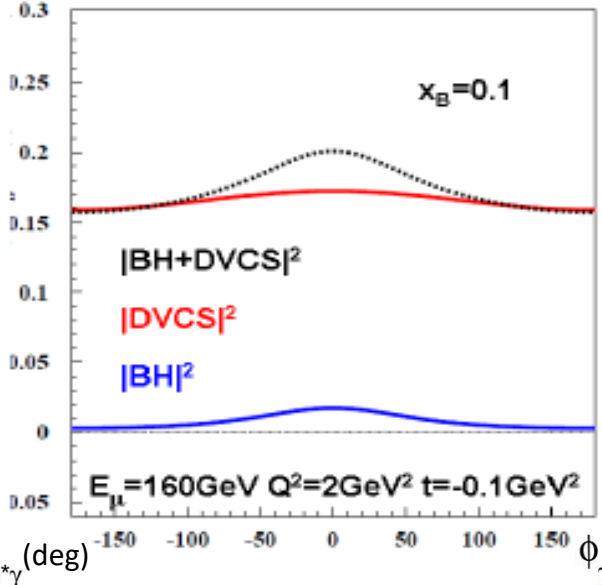
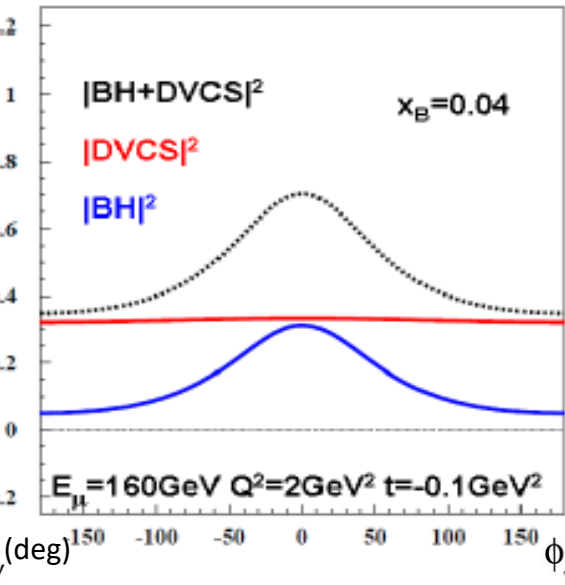
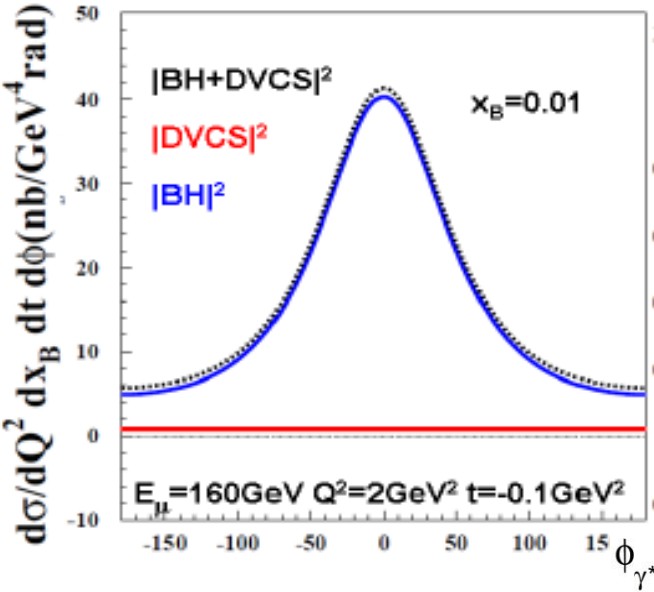
the sum of the 2 contributions LEPTO and HEPGEN is normalized to  $M_{\gamma\gamma}$  peak in real data







$$d\sigma \propto |T^{BH}|^2 + \text{Interference Term} + |T^{DVCS}|^2$$



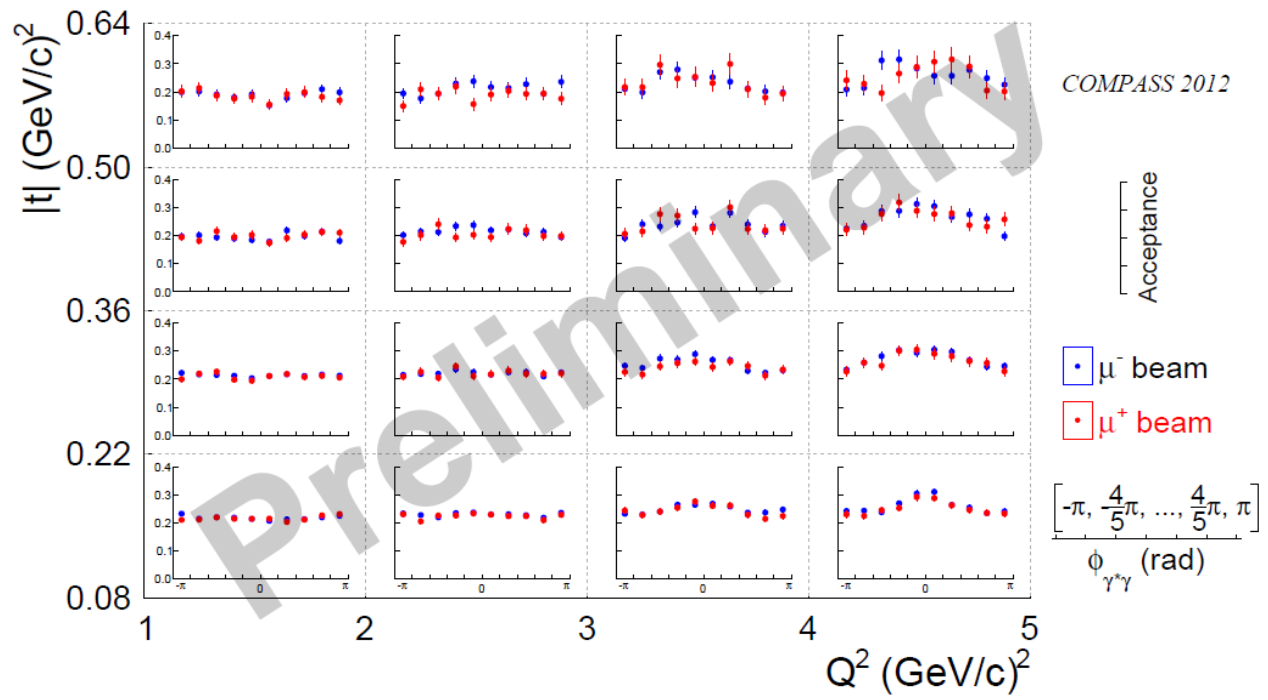
$$\begin{aligned}\mathcal{S}_{CS,U} &\equiv d\sigma^{\leftarrow+} + d\sigma^{\rightarrow-} = 2[d\sigma^{BH} + d\sigma_{unpol}^{DVCS} + \text{Im } I] \\ &= 2[d\sigma^{BH} + c_0^{DVCS} + c_1^{DVCS} \cos \phi + c_2^{DVCS} \cos 2\phi + s_1^I \sin \phi + s_2^I \sin 2\phi]\end{aligned}$$

# COMPASS 2012 Pilot run

$\phi$  integrated cross section

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 \end{aligned}$$

$$\frac{d^3\sigma_T^{\mu p}}{dQ^2 d\nu dt} = \int_{-\pi}^{\pi} d\phi (d\sigma - d\sigma^{BH}) \propto c_0^{DVCS}$$



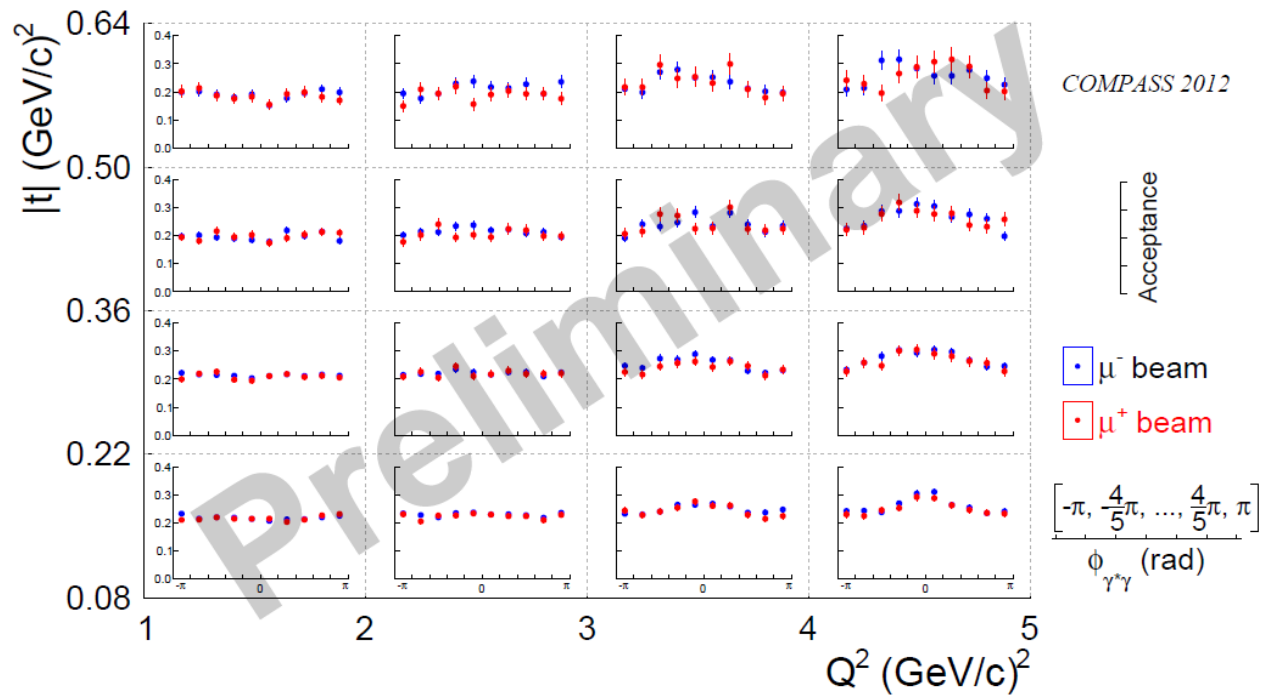
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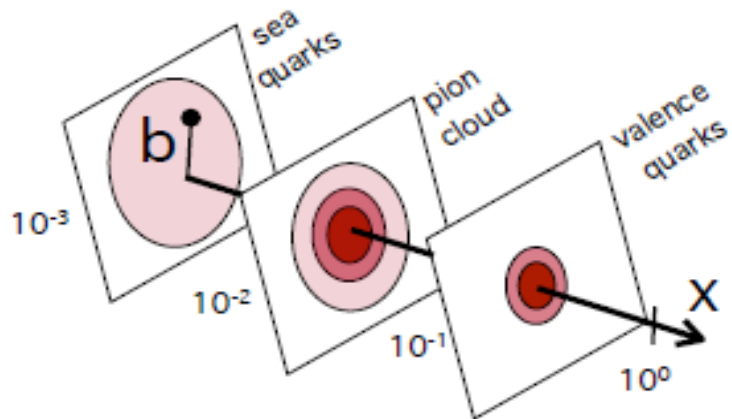
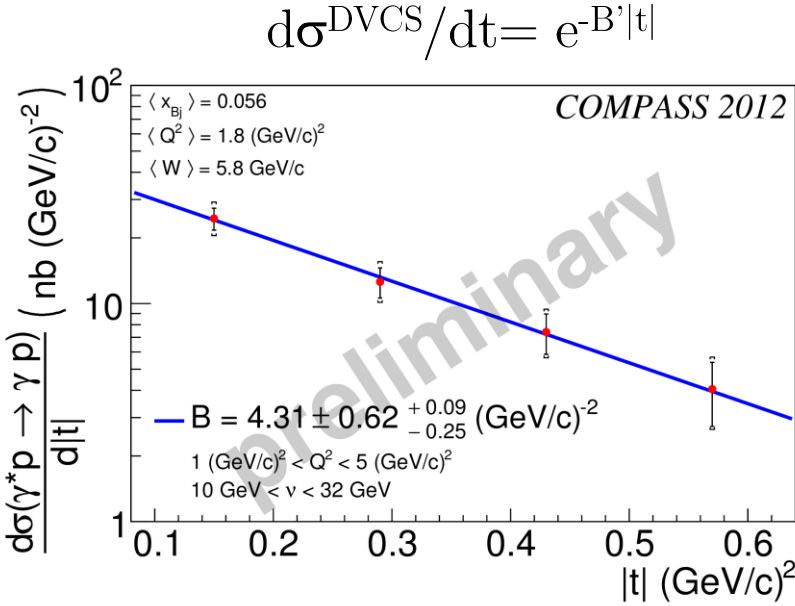
$$\frac{d^3\sigma_T^{\mu p}}{dQ^2 d\nu dt} = \int_{-\pi}^{\pi} d\phi (d\sigma - d\sigma^{BH}) \propto c_0^{DVCS}$$

$$\frac{d\sigma^{\gamma^* p}}{dt} = \frac{1}{\Gamma(Q^2, \nu, E_\mu)} \frac{d^3\sigma_T^{\mu p}}{dQ^2 d\nu dt}$$



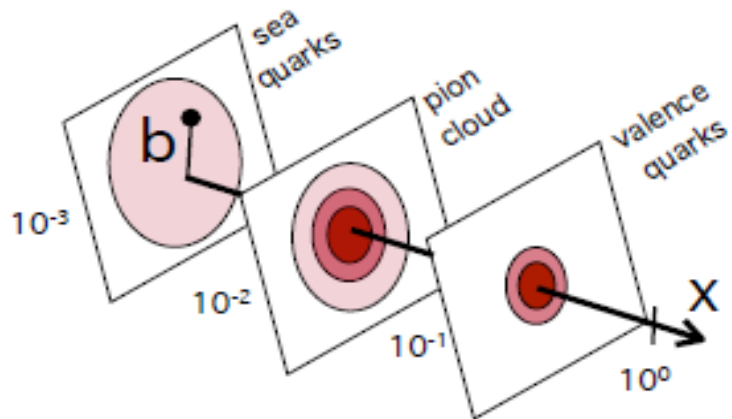
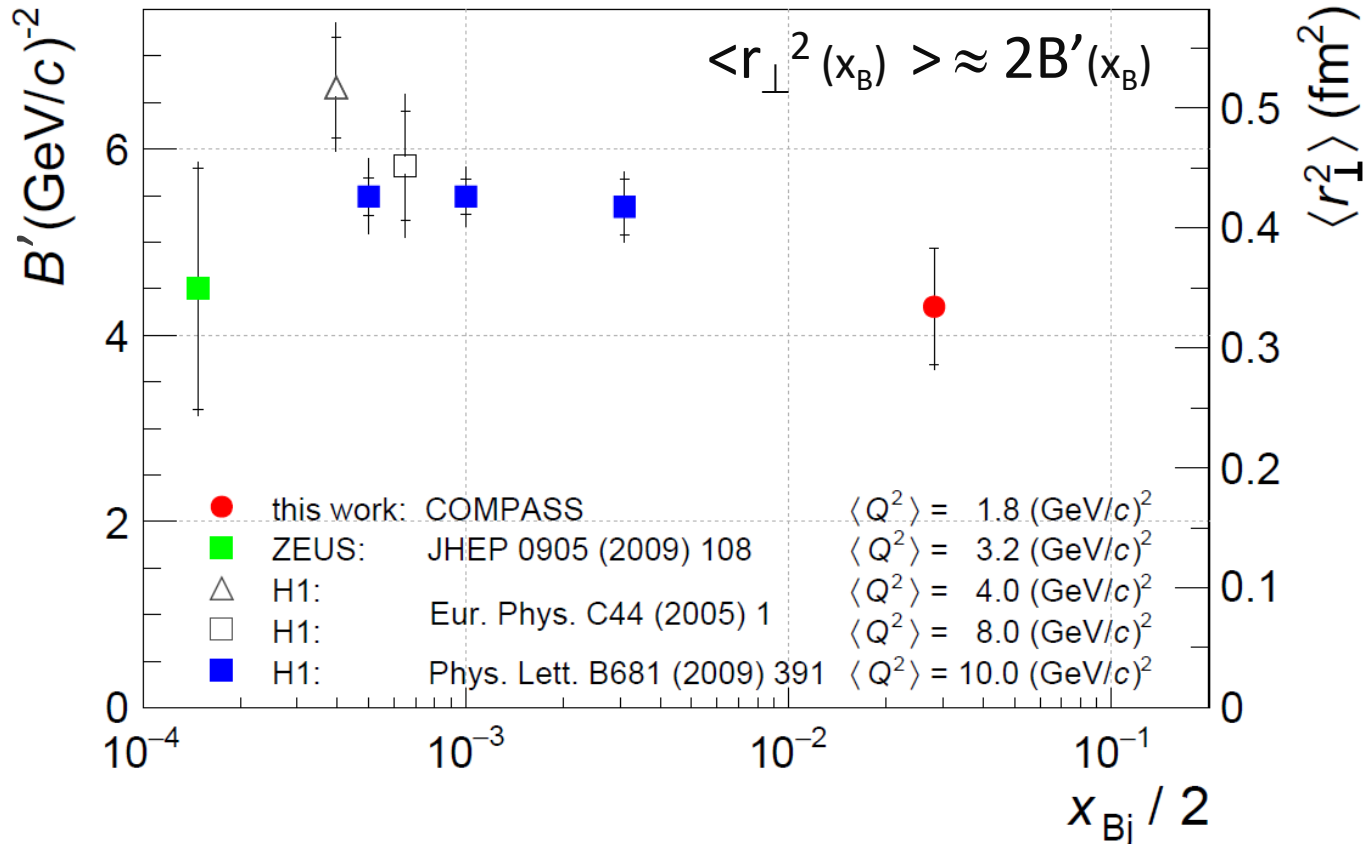
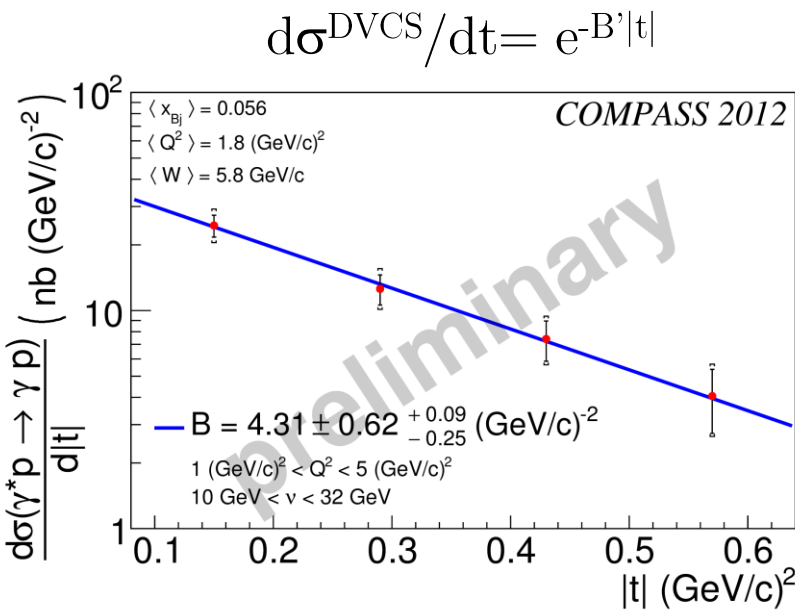
# COMPASS 2012 Pilot run

*transverse extension of partons* submitted to PLB  
arXiv:1802.02739[hep-ex]



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$$B' = (4.31 \pm 0.62_{\text{stat}} \pm 0.09_{\text{sys}}) \text{ (GeV/c)}^{-2}$$

$$\sqrt{\langle r_{\perp}^2 \rangle} = (0.58 \pm 0.04_{\text{stat}} \pm 0.01_{\text{sys}}) \text{ fm}$$



# COMPASS 2016/2017 first insight

# COMPASS 2016 insight

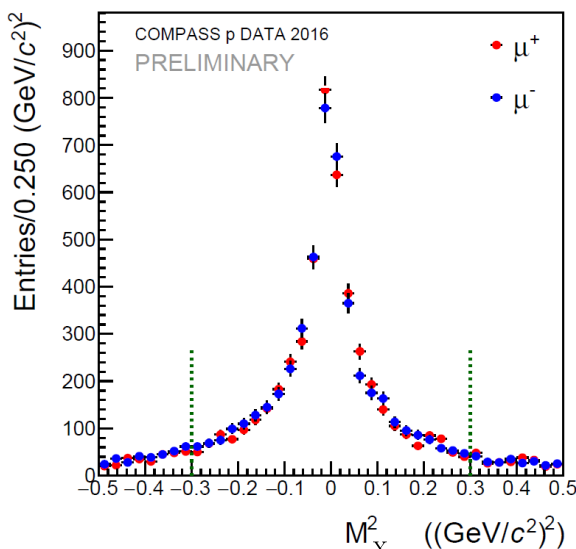
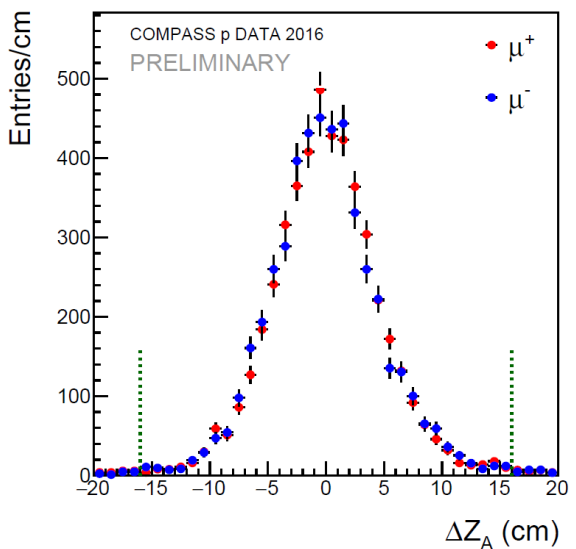
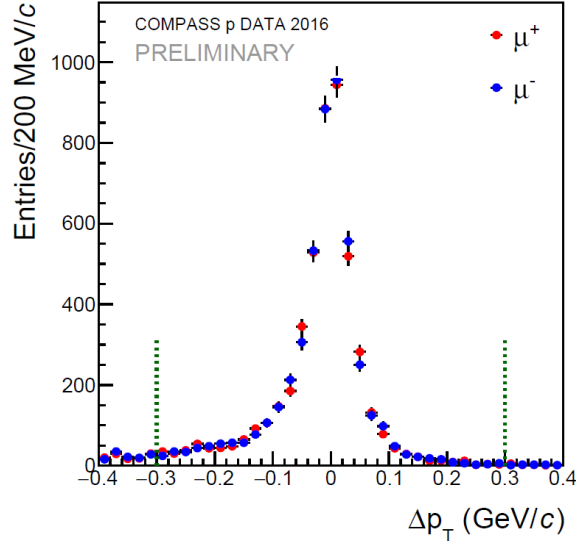
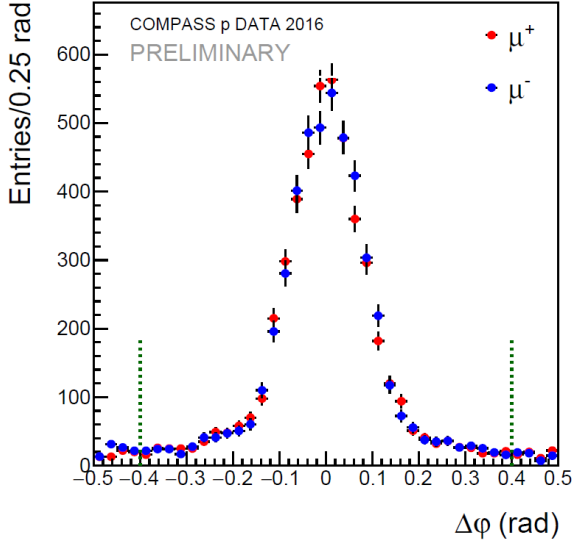
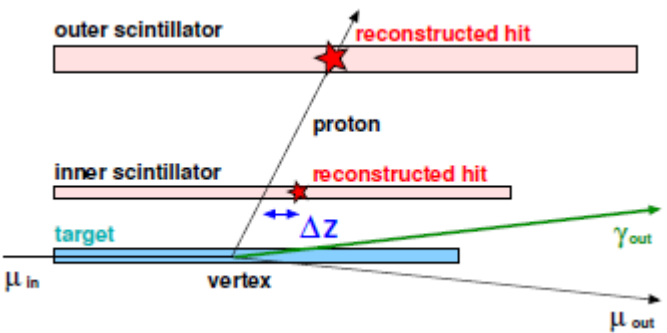
## Exclusivity variables

$$\Delta p_T = p_T^{\text{cam}} - p_T^{\text{spec}}$$

$$\Delta \varphi = \varphi^{\text{cam}} - \varphi^{\text{spec}}$$

$$\Delta z_A = z_A^{\text{cam}} - z_A^{\text{Z}_B \text{ and vertex}}$$

$$M_{X=0}^2 = (p_{\mu_{\text{in}}} + p_{p_{\text{in}}} - p_{\mu_{\text{out}}} - p_{p_{\text{out}}} - p_{\gamma})^2$$



# COMPASS 2016 insight

## Exclusivity variables

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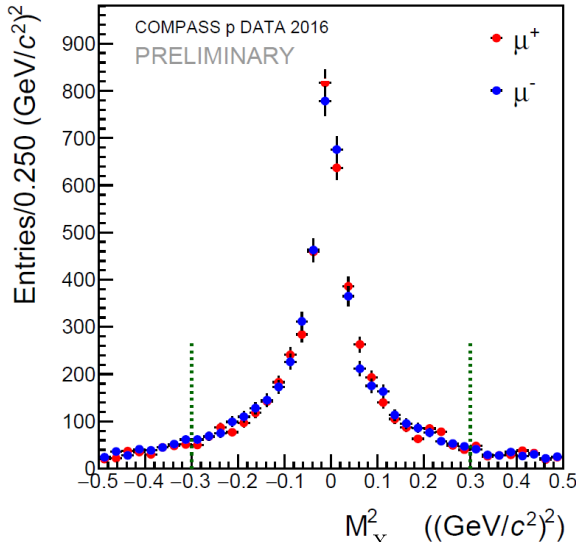
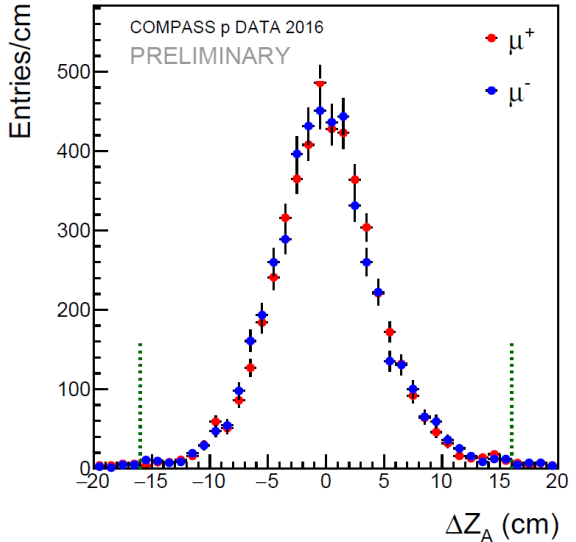
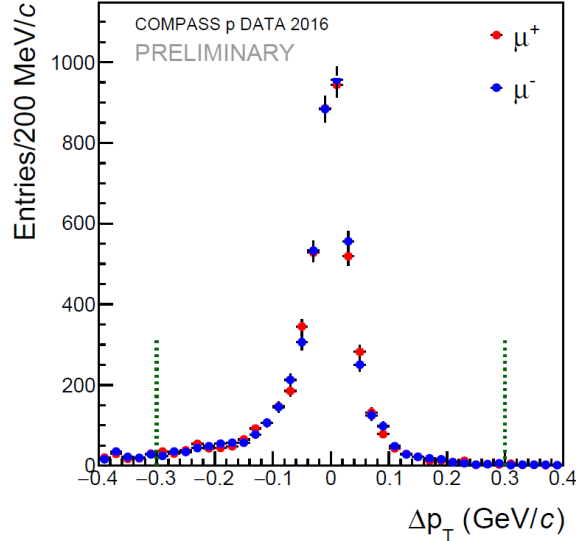
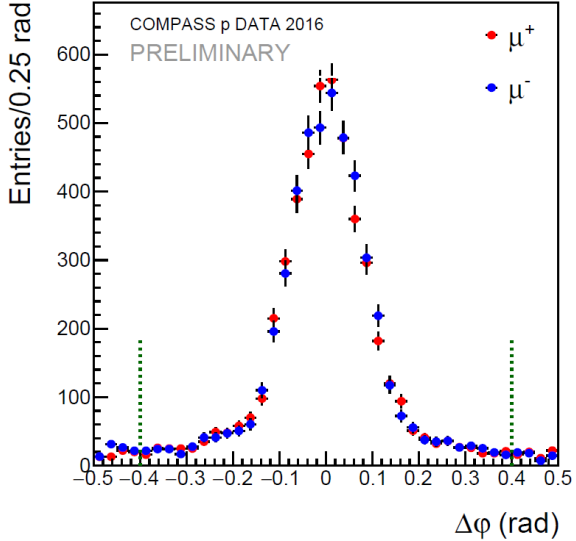
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$$d\sigma^{\leftarrow+} + d\sigma^{\rightarrow-} \quad t\text{-slope}$$

$$d\sigma^{\leftarrow+} - d\sigma^{\rightarrow-} \quad d\text{-term}$$



# COMPASS 2016 insight

## Exclusivity variables

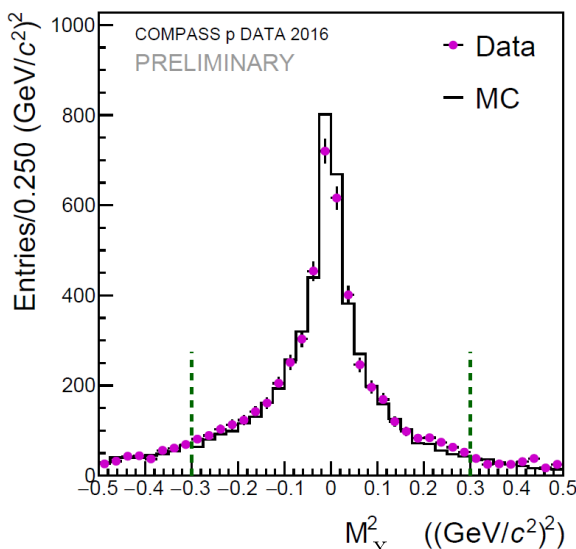
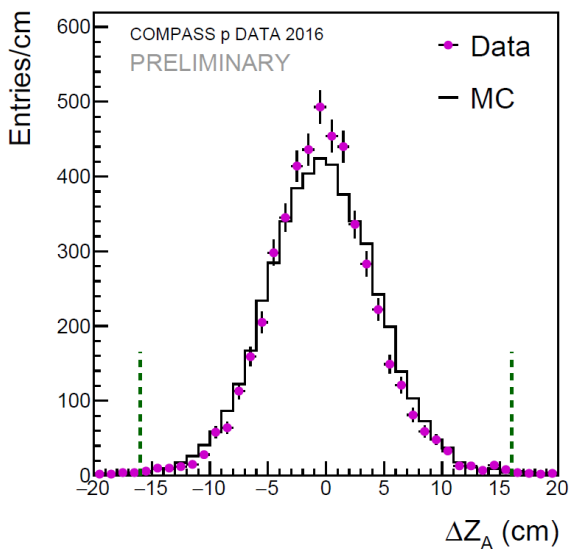
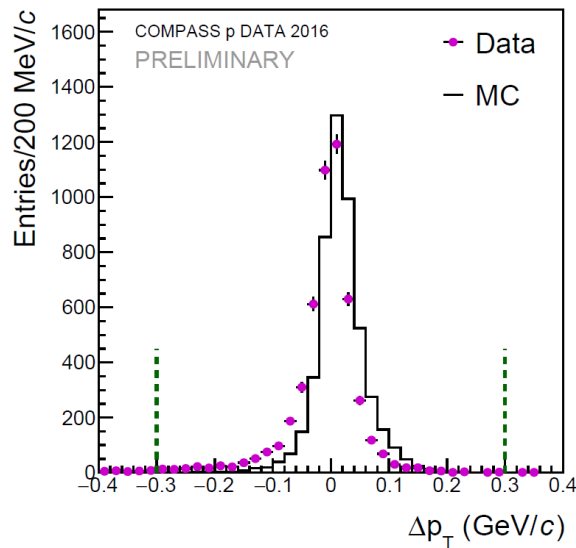
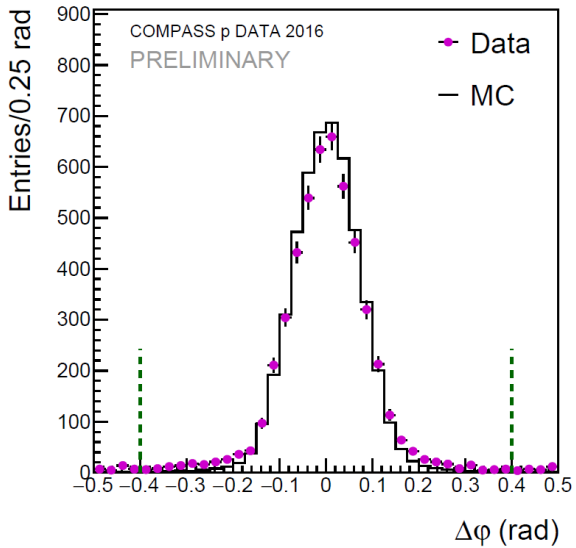
Bethe-Heitler MC  
80 < nu < 144 GeV

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$$\Delta \varphi = \varphi^{\text{cam}} - \varphi^{\text{spec}}$$

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$$M_{X=0}^2 = (p_{\mu_{in}} + p_{p_{in}} - p_{\mu_{out}} - p_{p_{out}} - p_{\gamma})^2$$

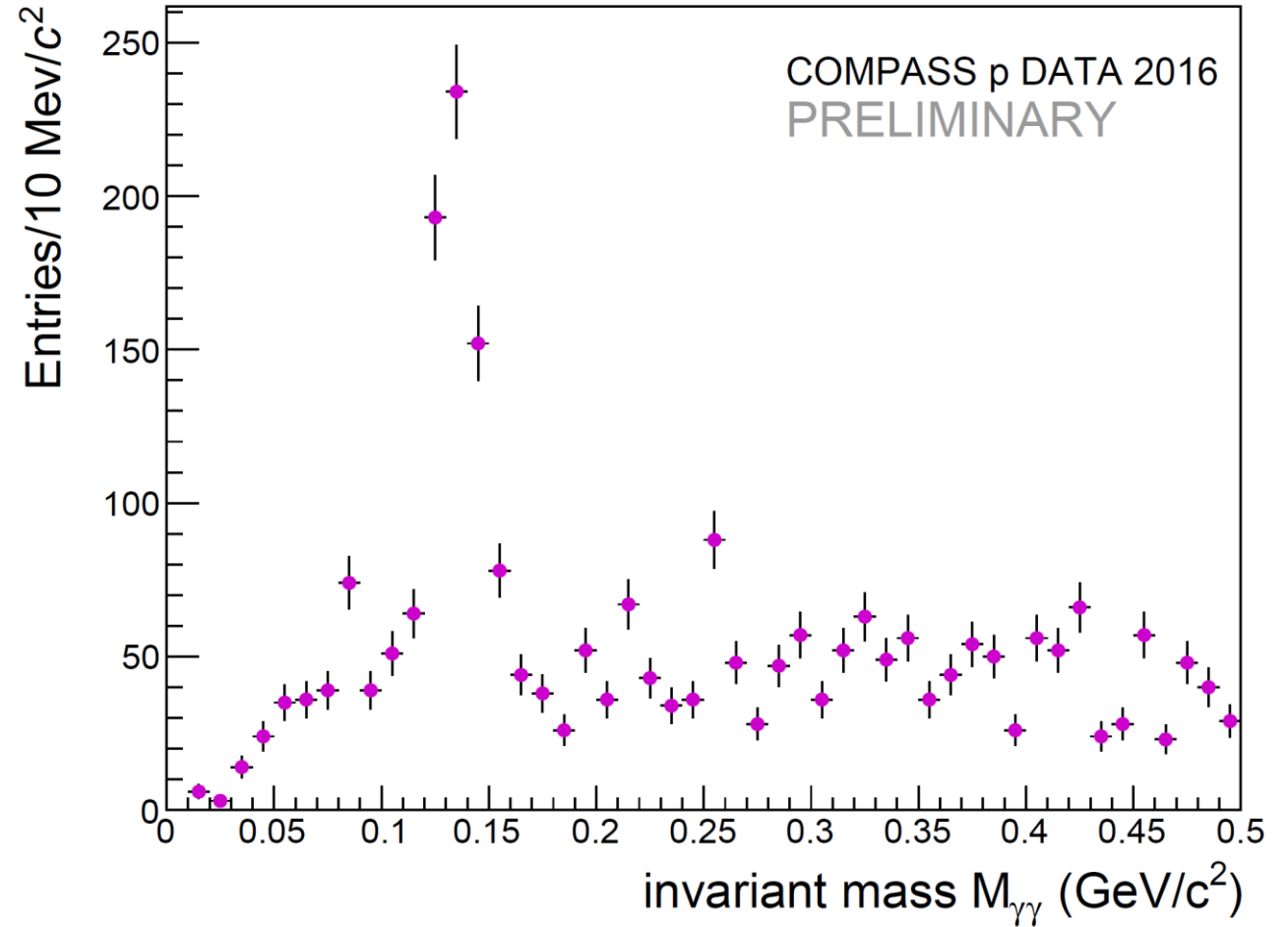
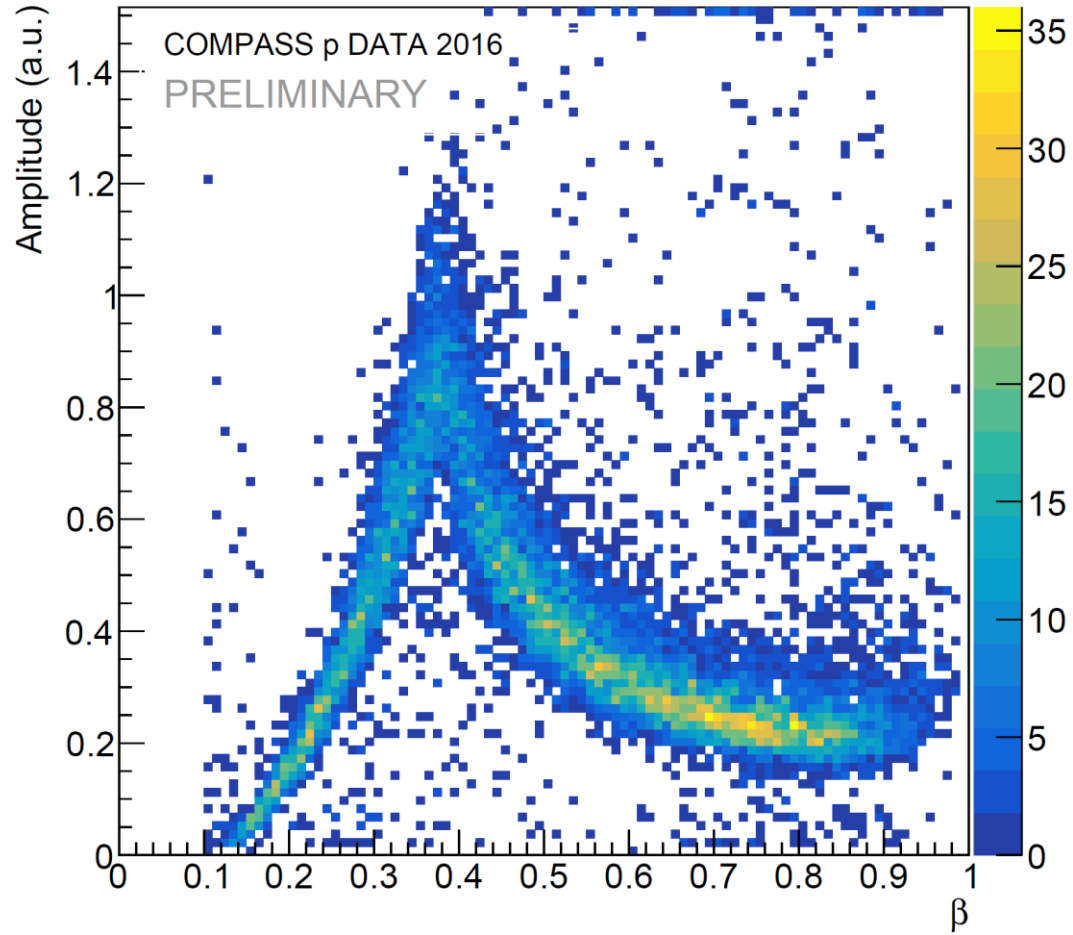


## BLUE WATERS

This research is part of the *Blue Waters* sustained-petascale computing project, which is supported by the *National Science Foundation* (awards OCI-0725070 and ACI-1238993) and the state of Illinois. *Blue Waters* is a joint effort of the *University of Illinois at Urbana-Champaign* and its National Center for Supercomputing Applications. This work is also part of the "Mapping Proton Quark Structure using Petabytes of COMPASS Data" PRAC allocation supported by the National Science Foundation (award number OCI 1713684).

# COMPASS 2016 insight

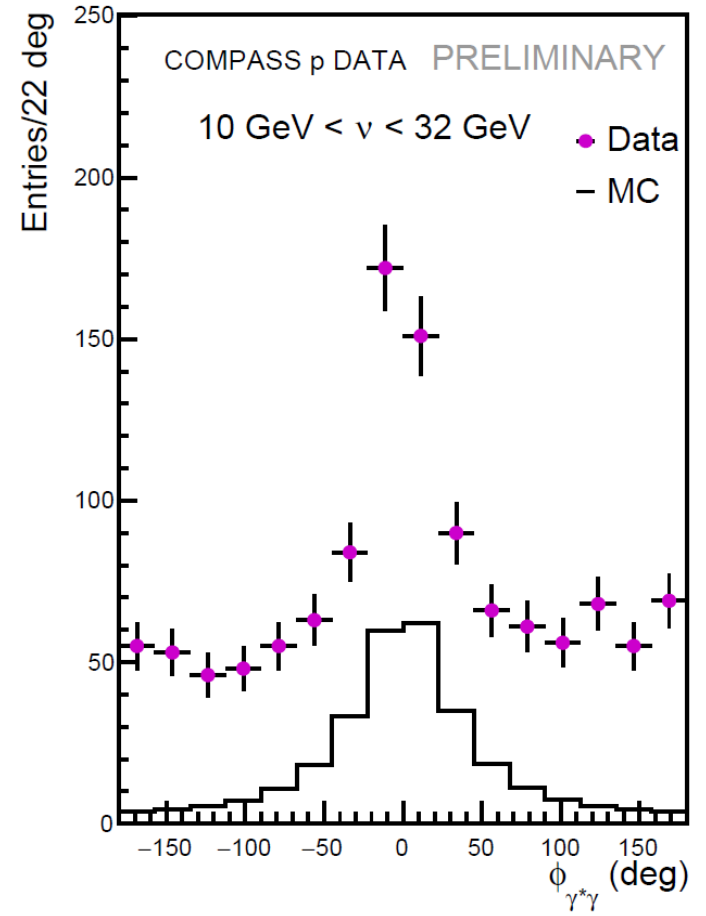
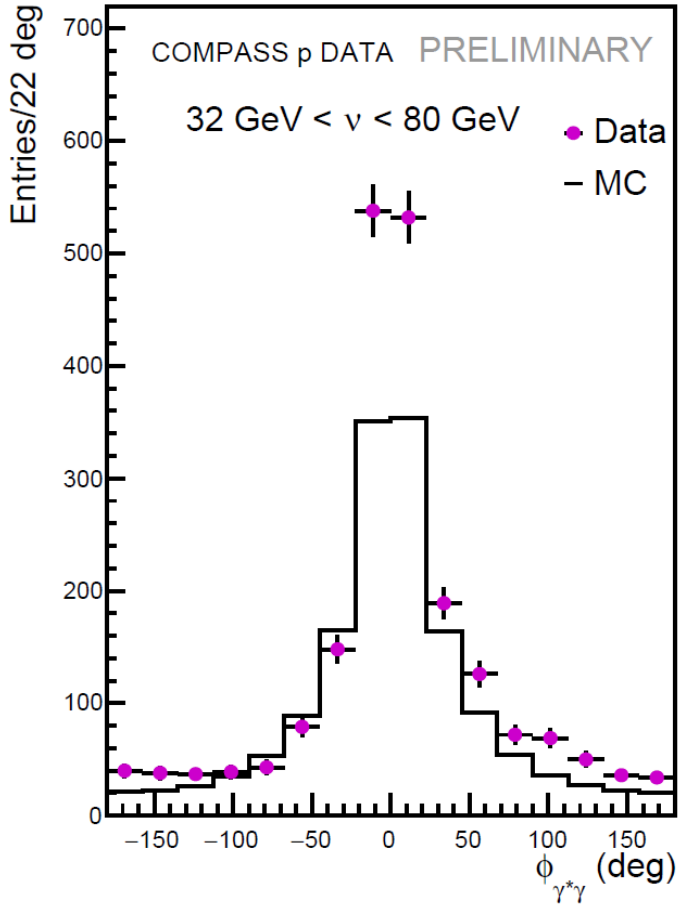
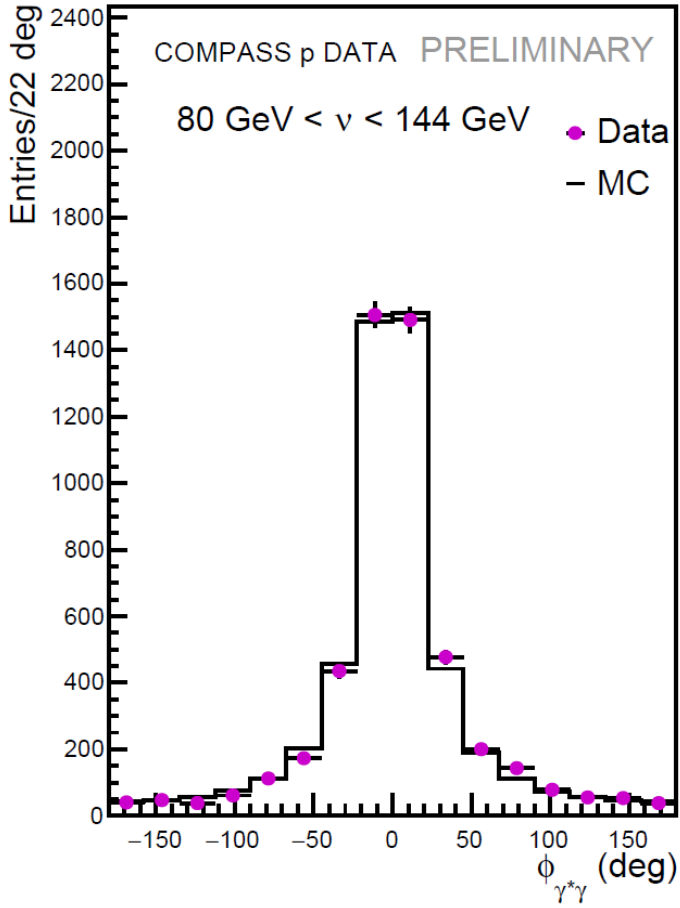
*recoil proton and visible  $\pi^0$  background*



# COMPASS 2016 insight

$\phi$  modulation

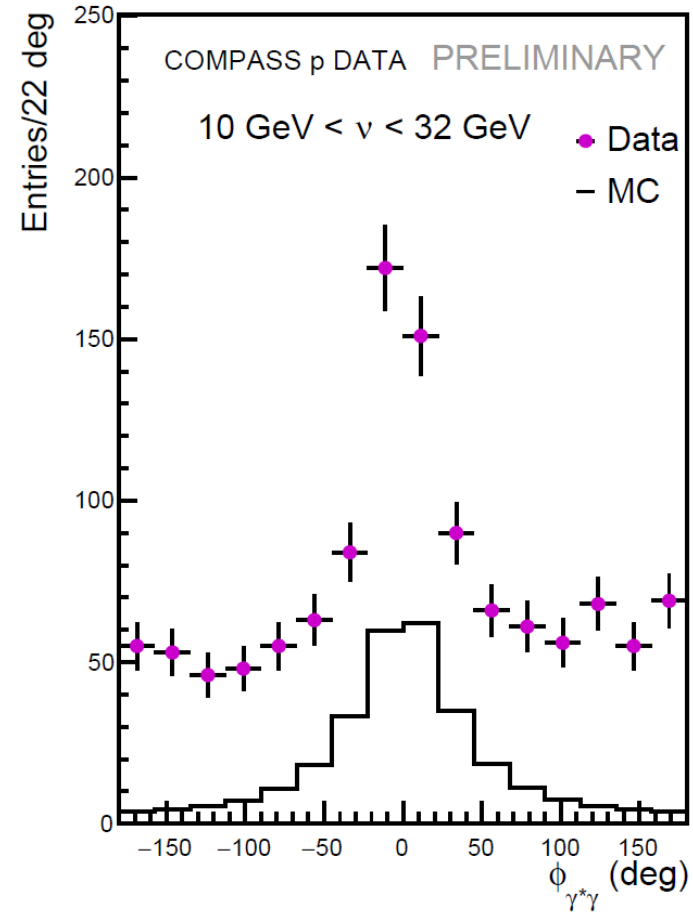
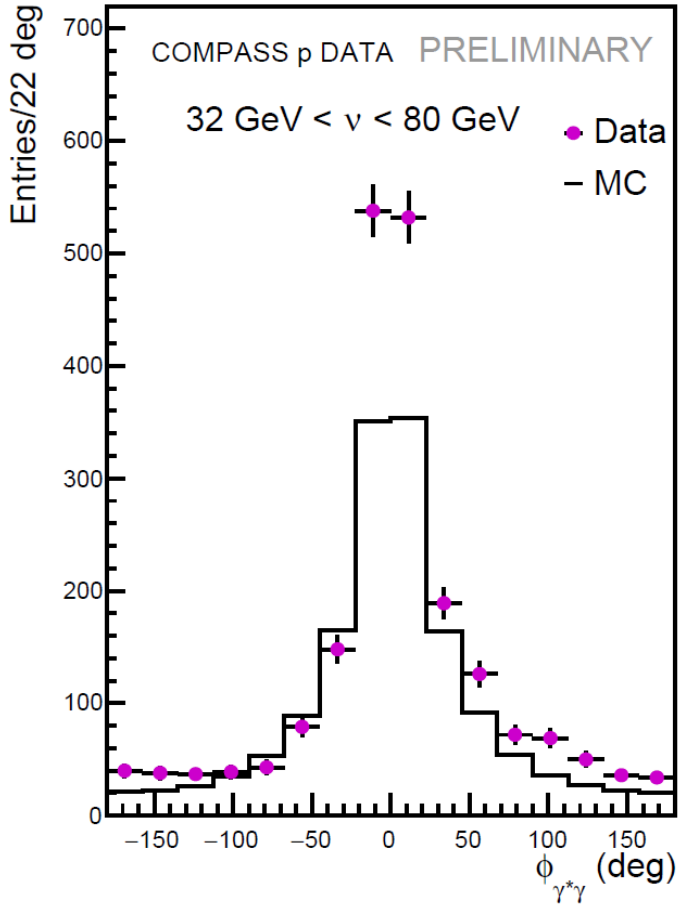
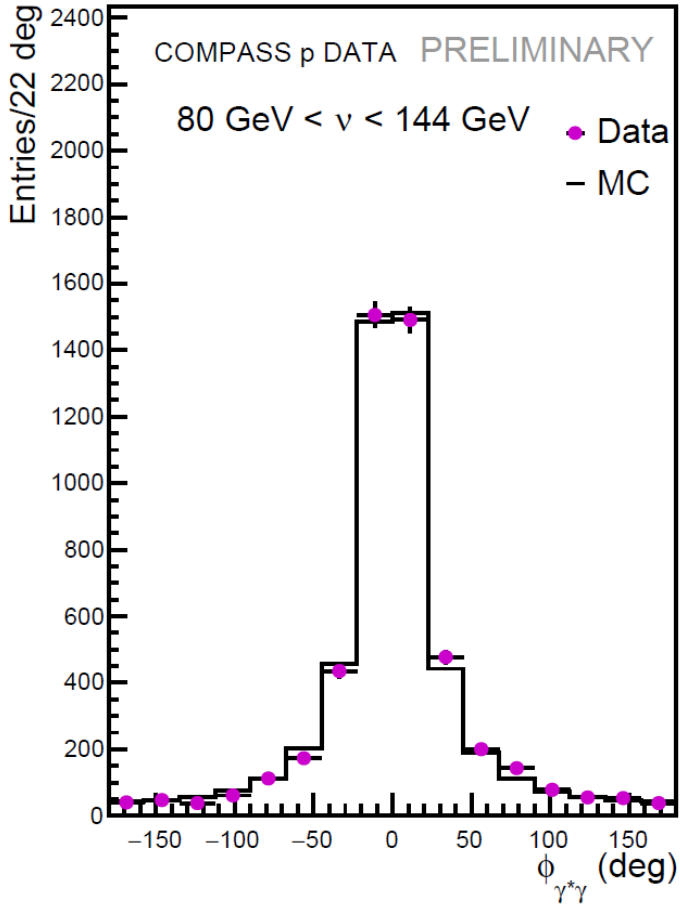
Bethe-Heitler MC *normalized to high nu bin*  
*Invisible  $\pi^0$  to be removed*



# COMPASS 2016 insight

$\phi$  modulation

Bethe-Heitler MC *normalized to high nu bin*  
*Invisible  $\pi^0$  to be removed*



*Only 13% of 2016/2017 data !*