Photon interactions at the LHC

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On behalf of the Louvain Photon group:

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K. Piotrzkowski, X. Rouby, N. Schul, M. Vander Donckt

Overview

- γ-induced physics at LHC
- Tagging photon interactions
- Transport simulation and reconstruction

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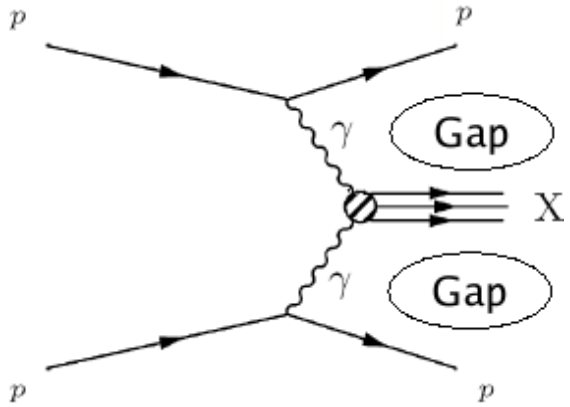
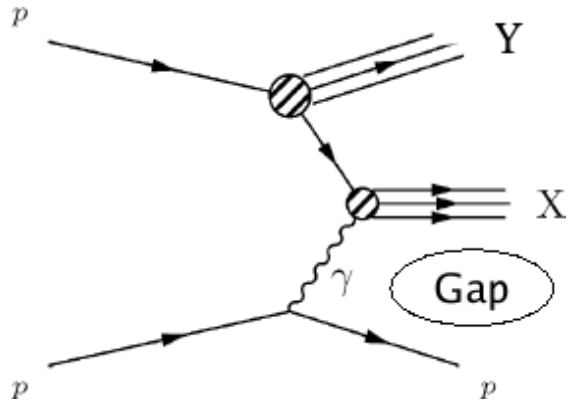
Photon-induced physics

LHC – also a photon-photon and photon-proton collider

$\gamma\,\gamma$ – interactions



γ p – interactions



Photon-induced physics

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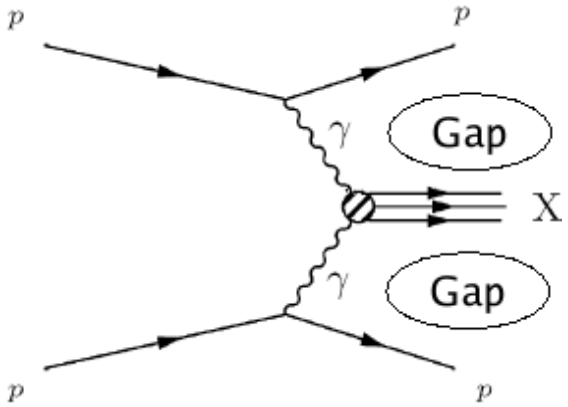
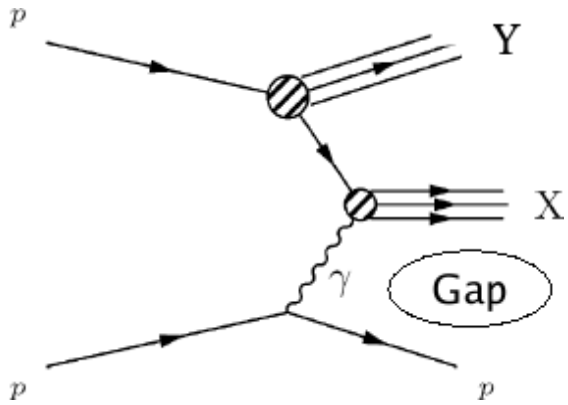
Colorless exchange

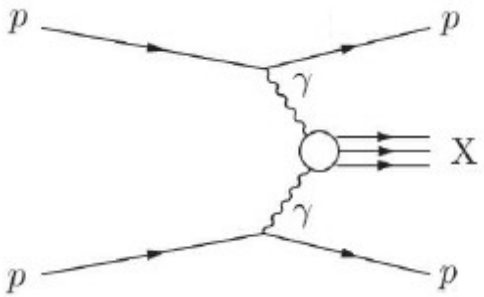
- Leading proton scattered (in)elastically
- Low activity in a large pseudorapidity region of the detector





Photon induced interactions

$\gamma\gamma$ collisions at the LHC (14 TeV)



Equivalent Photon Approximation

$$\sigma_{pp(\gamma\gamma\to X)pp} = \int_{W_{\min}}^{\sqrt{s}} dW \, \frac{dL_{\gamma\gamma}}{dW} \, \sigma_{\gamma\gamma\to X}(W)$$

with $$\frac{dL_{\gamma\gamma}}{dW} = \int_{W^2/s}^{1} 2W \, f_\gamma(x) \, f_\gamma\left(\frac{W^2}{xs}\right) \frac{dx}{xs}$$

$$f_\gamma = \int_{Q^2_{\min}}^{Q^2_{\max}} dN(E, Q^2) dQ^2$$

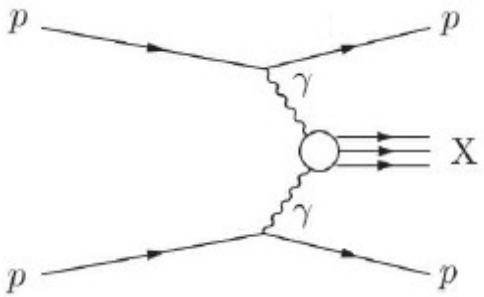
photon flux

$$x = E_\gamma / E \qquad s = 4E^2$$

The EPA factorises the $\gamma\gamma$ interaction from the photon exchange

Photon induced interactions

$\gamma\gamma$ collisions at the LHC (14 TeV)



Equivalent Photon Approximation

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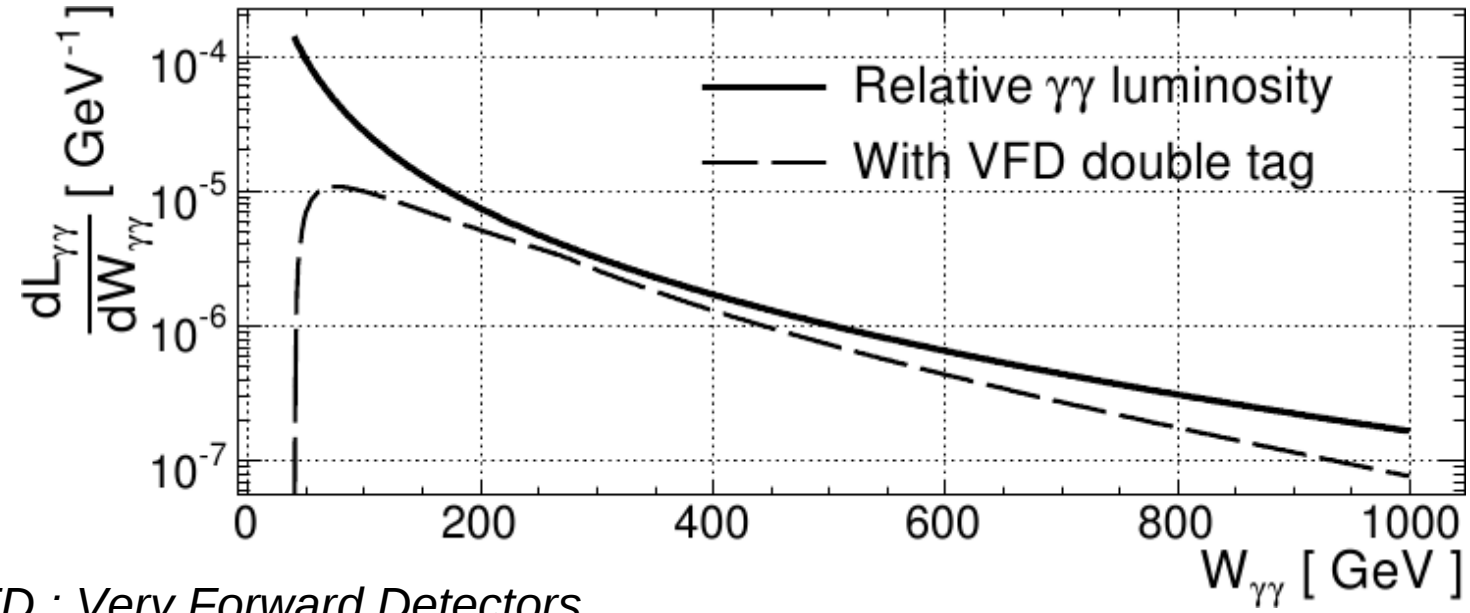

VFD : Very Forward Detectors (Totem RP, FP420)

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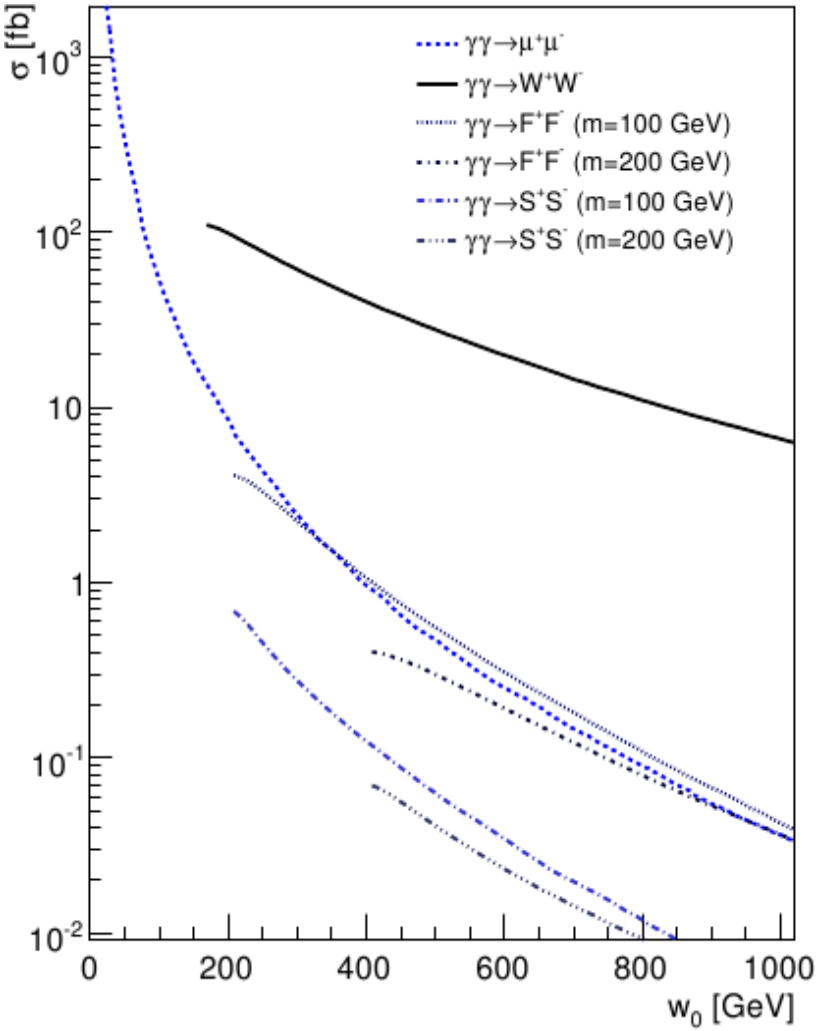
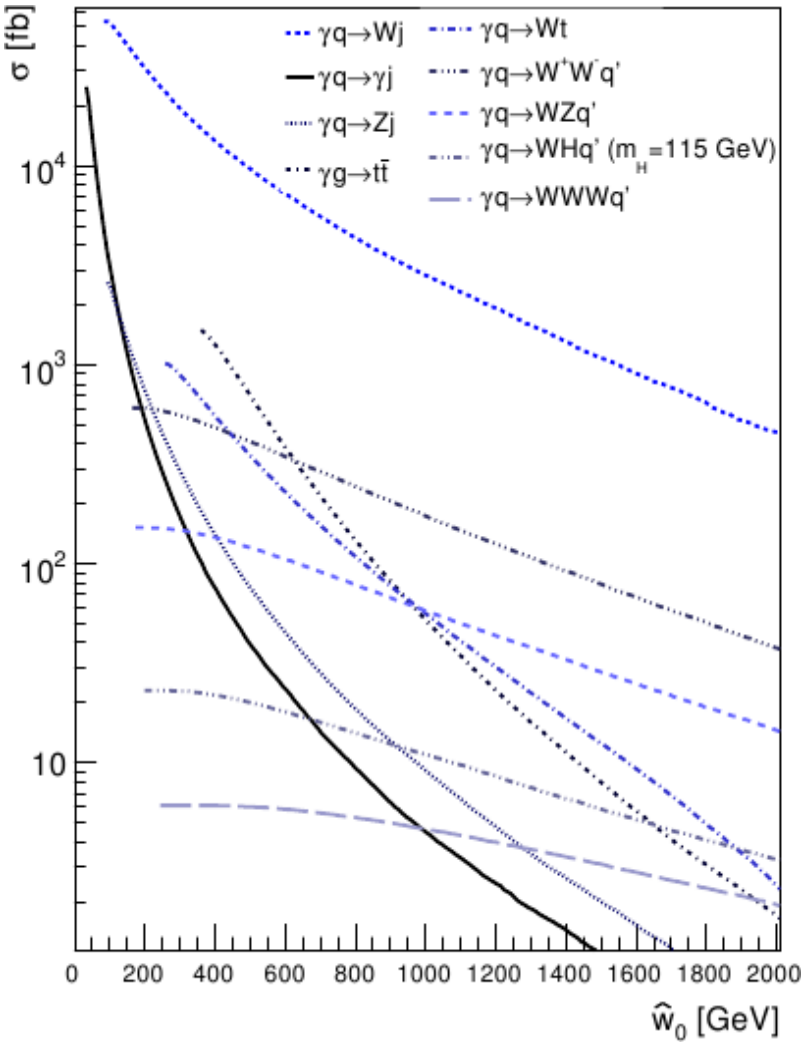
Photon induced interactions

γ γ and γ p collisions at the LHC (14 TeV)



Minimal photon photon c.m.s energy



Minimal photon parton c.m.s energy

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Photon induced interactions

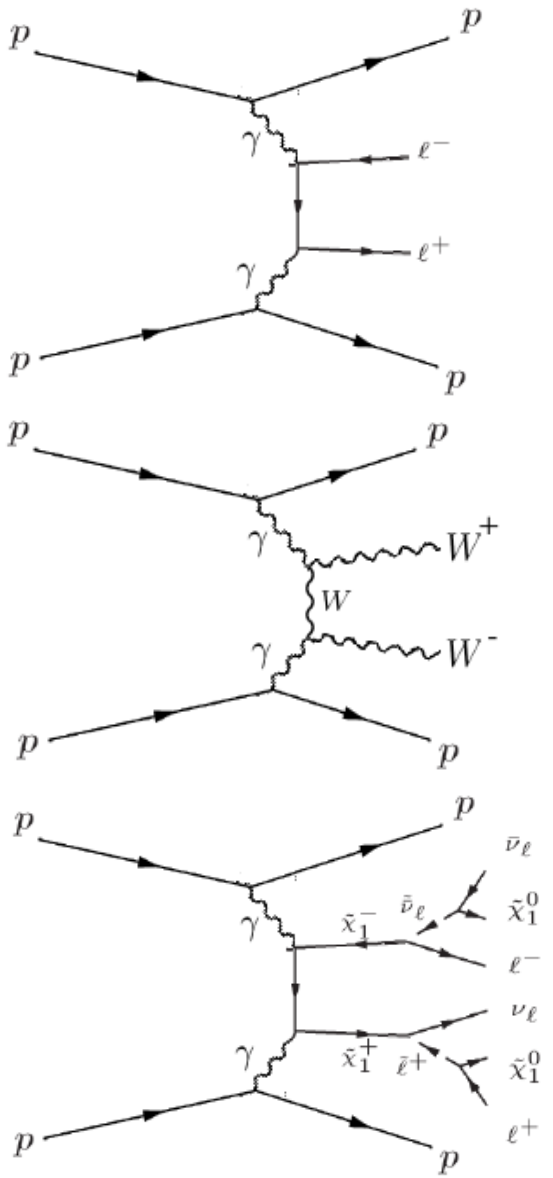
γ γ collision at the LHC (14 TeV)

Cross sections for pp ⟶ ppX

Process	σ_{prod} (fb)		
$\gamma\gamma \to \mu^+\mu^-$	74.7	$\times 10^3$	$p_T > 2.5$ GeV
$\gamma\gamma \to e^+e^-$	10.4	$\times 10^3$	$p_T > 5.5$ GeV
$\gamma\gamma \to W^+W^-$	108.5		-
$\gamma\gamma \to f^+f^-$	4.064		$m_f = 100$ GeV
$\gamma\gamma \to \tilde{f}^+\tilde{f}^-$	0.680		$m_{\tilde{f}} = 100$ GeV
$\gamma\gamma \to H \to b\bar{b}$	0.154		$m_H = 120$ GeV
$\gamma\gamma \to m\bar{m}$	~ 5	$\times 10^3$	$m_m = 1000$ GeV

- Exclusive dileptons: large σ
- γγ W W coupling accessible
- SUSY, ...

Tagging necessary to reject the large pp backgrounds



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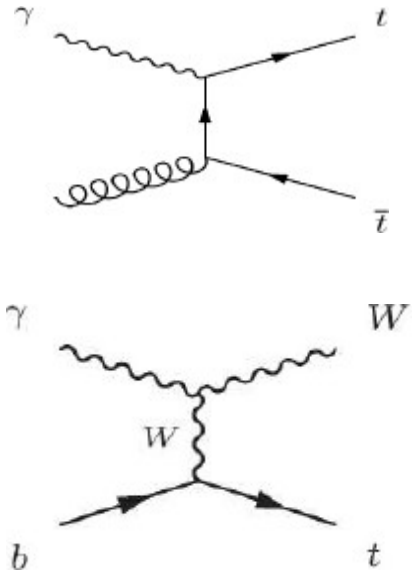
Photon induced interactions

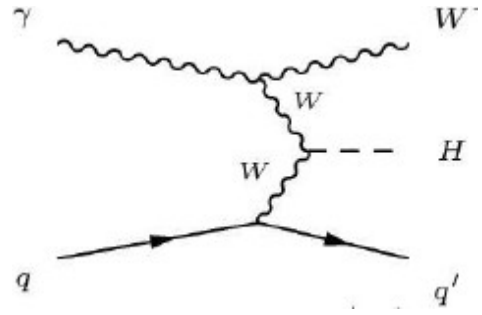
γ p collision at the LHC (14 TeV)

Cross sections for pp ⟶ pX

Process	σ_{prod} (fb)	
$\gamma q \to W H q'$	23.0	$m_H = 115$ GeV
$\gamma q \to W H q'$	17.5	$m_H = 170$ GeV
$\gamma q/g \to W X$	> 90	-
$\gamma g \to t\bar{t}$	1.54	-
$\gamma q \to W t$	1.01	-
$\gamma q \to t$	$(368\ k^2_{tu\gamma} + 122\ k^2_{tc\gamma}) \times 10^3$	-



- Higher luminosities than γγ
- Large variety of processes
- Significant cross-sections up to 2 TeV
- Alternative way to pp interactions to study Higgs, top physics, new physics
- Large survival probability factor



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Photon interaction tagging

- Large Rapidity Gap
  - large detector region devoid of particles
- Forward proton measurement
  - Using dedicated instruments (RP220, FP420)
  - Using a proper simulation of the proton transport in the LHC beamline and a proper reconstruction of the proton variables, from the VFD measurement

Depending on the luminosity

Tagging γ-interactions

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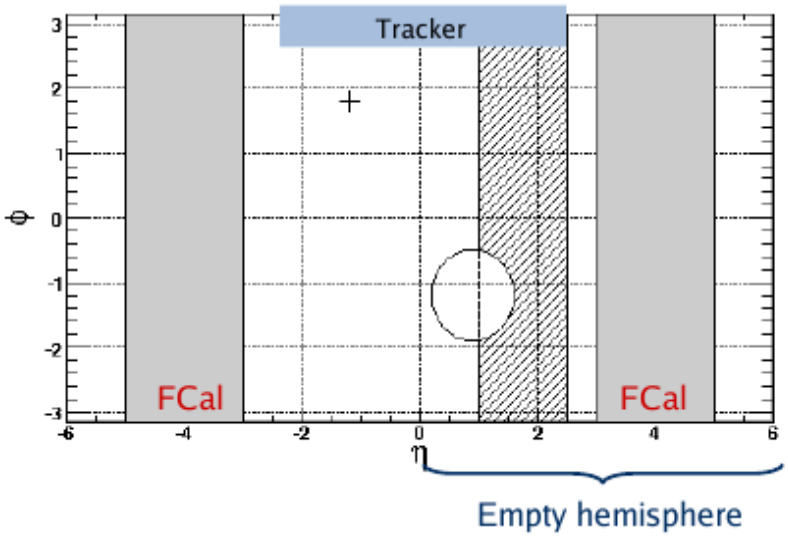
1) Large Rapidity Gaps in forward region of the central detector



For no pile-up conditions

e.g. γ p – interactions

a) choose the « photon-side » minimum of energy in both fwd calos

b) cut on the maximum allowed value for this energy

Rapgap: region devoid of particles

Tagging γ-interactions

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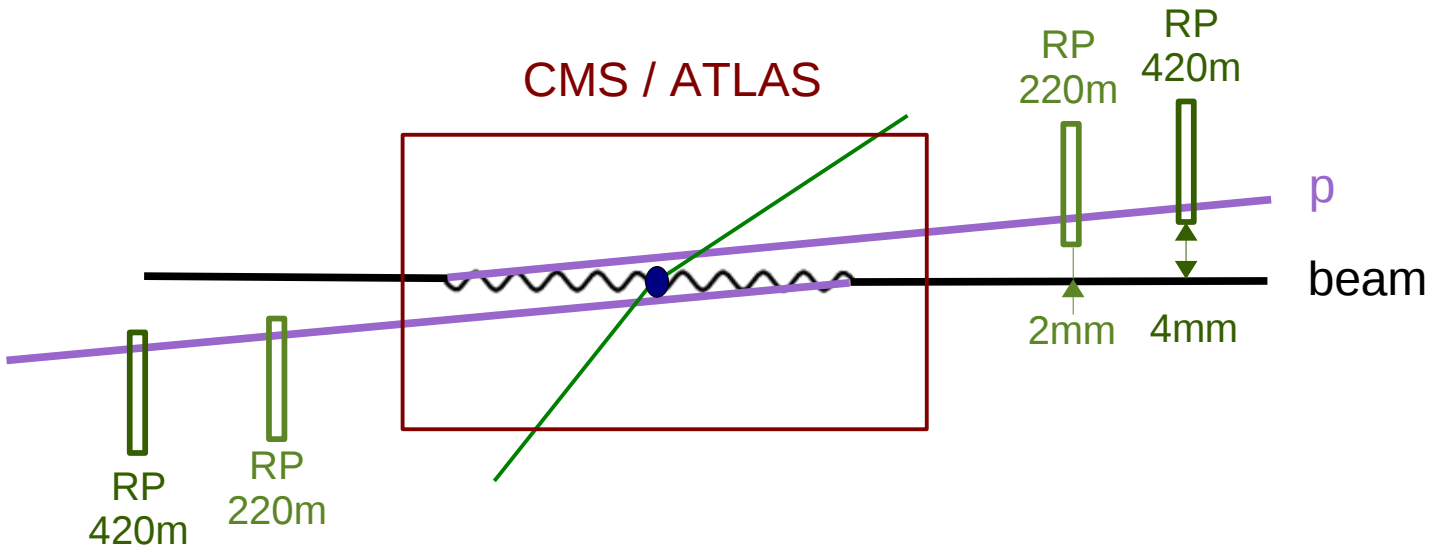
2) Using very forward proton taggers



a) The proton is scattered elastically

b) It escapes from the central detector with the beam, but with lower energy

c) It is seen by very forward detectors

Suitable with pile-up events

Need for a realistic simulation of the proton path in the beamline

Proton transport simulation

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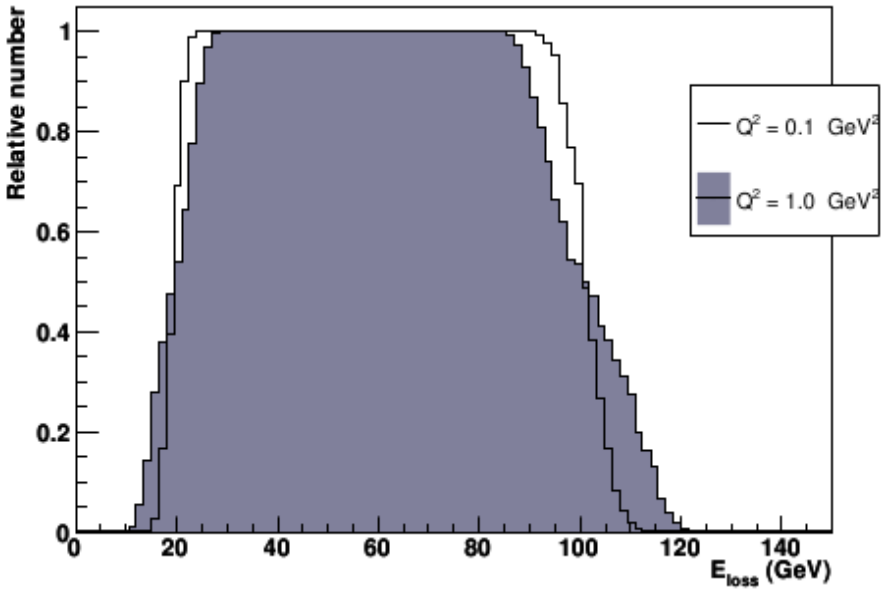
Relation between proton E_{loss} and its path in beamline ?

Requirements for near-beam very forward detectors ?

Reconstruction of photon kinematics ?

…



FP420 acceptance,
4 mm from the beam :

20 GeV < tagged photon E < 110 GeV

HECTOR, a fast simulator for the transport of particles in beamlines

JINST 2 P09005,
arXiv:0707.1198v2 [physics.acc-ph]
X. Rouby, J. de Favereau, K. Piotrzkowski

Detector characterisation

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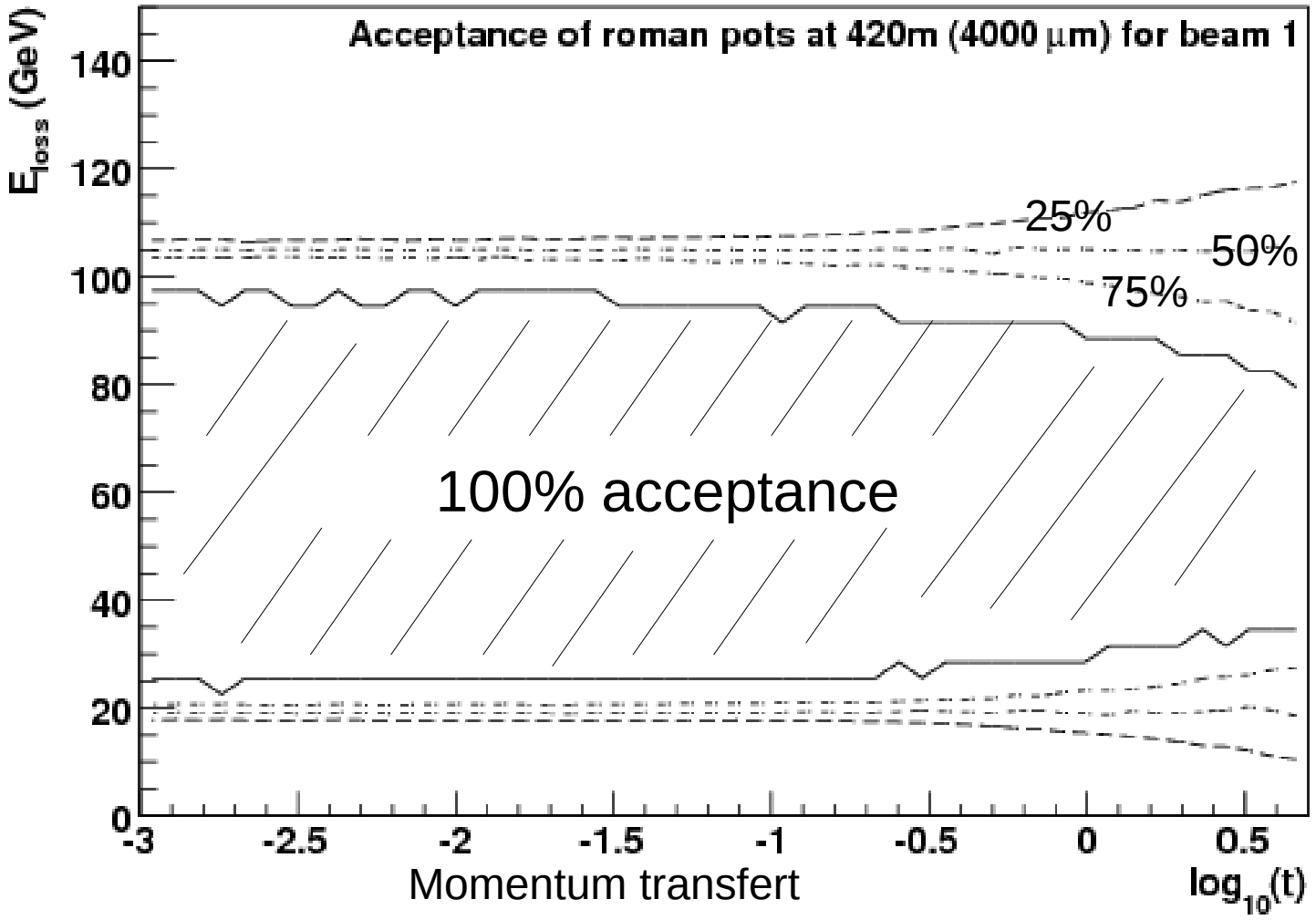
Energy loss is the key variable !

Detector acceptance



Chromaticity grid

Given a measured position/angle at RP, what was the proton energy/angle at IP?

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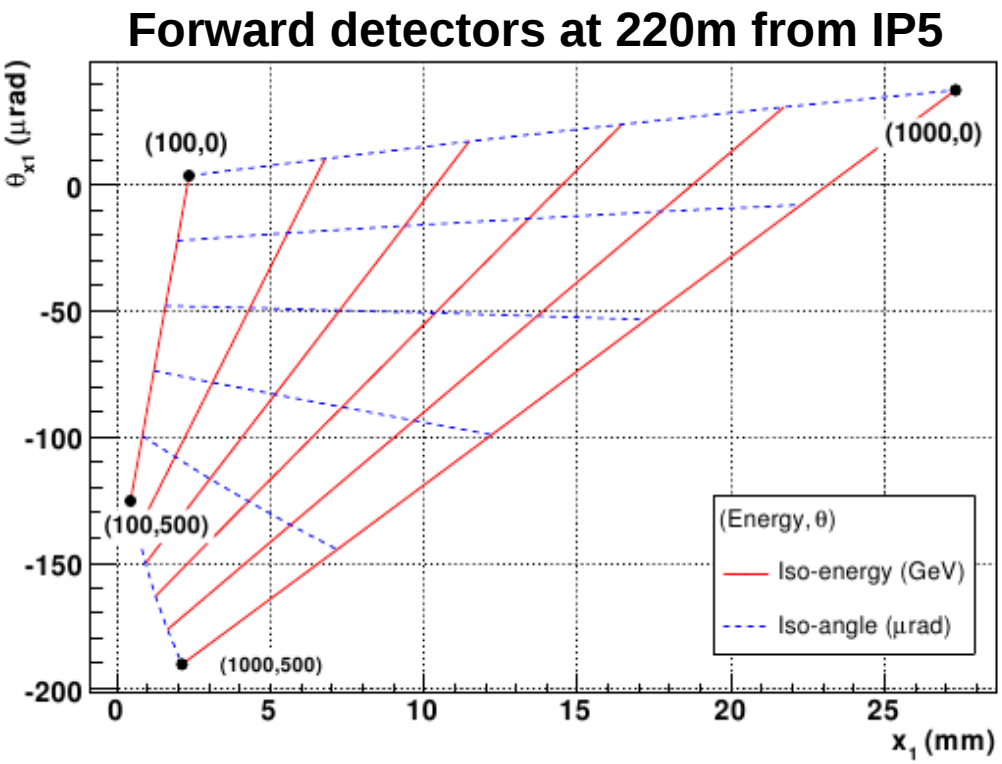

1) Choose a proton, with a given energy loss and initial angle
2) Propagate it to your 2 roman pots.
3) Measure x, x'

[100 ; 1000] GeV ← Remember the detector acceptance !

Reconstruction

$$\begin{cases} x_s = a_s x_0 + b_s x_0' + d_s E \\ x_s' = \alpha_s x_0 + \beta_s x_0' + \gamma_s E \end{cases}$$

Too many unknowns !

Goal: reconstructing photon E and Q^2 from the forward detector measurement

Resolution on reconstructed energy:

$$\sigma_E^2 = \sigma_0^2 + \sigma_{vtx}^2 + \sigma_{ang}^2 + \sigma_{det}^2$$

- σ_0^2: Beam E dispersion
- σ_{vtx}^2, σ_{ang}^2: Vertex spread
- σ_{det}^2: Detector resolution (position)

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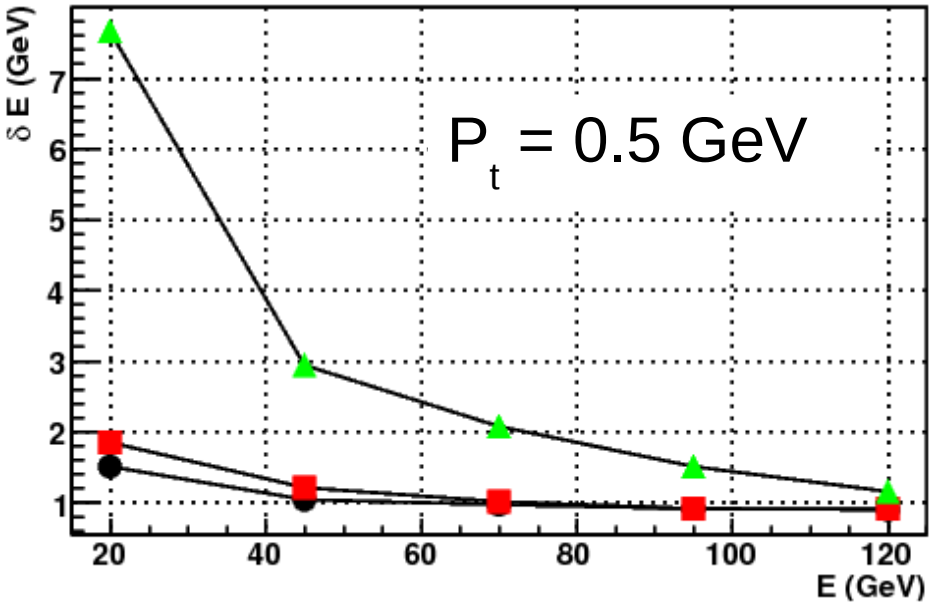
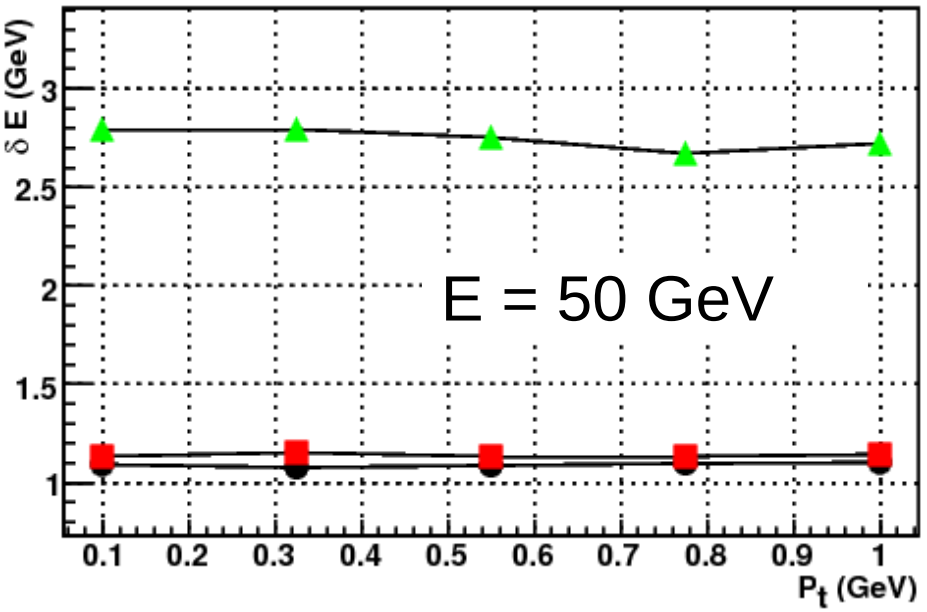
Reconstruction





Forward detectors at 420m + 428m

Energy Resolution

$$P_t \simeq \sqrt{Q^2}$$

Detector resolution

- 30 μm
- 5 μm
- perfect

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Misalignment of the beamline

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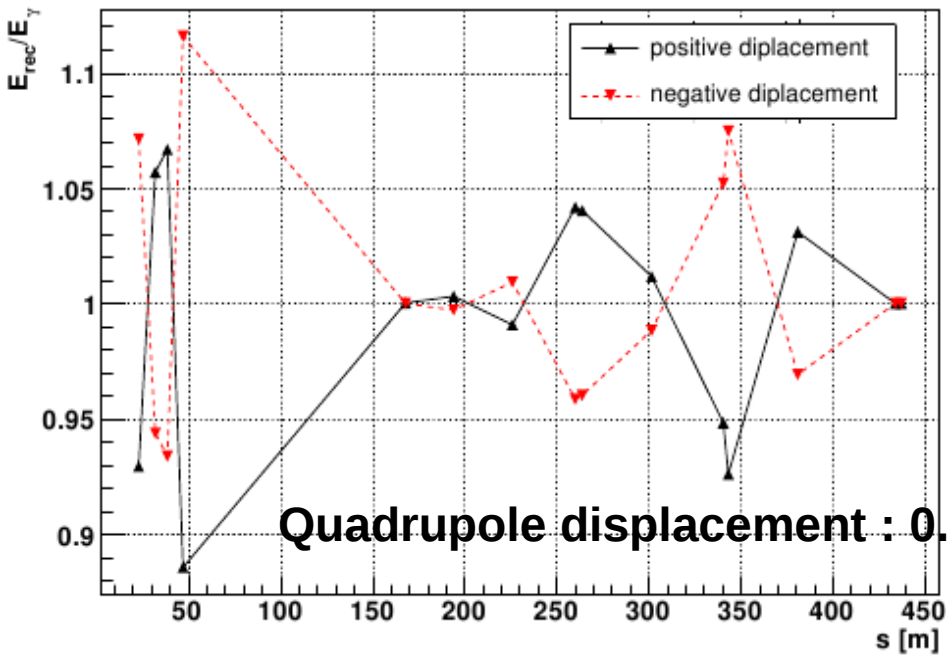
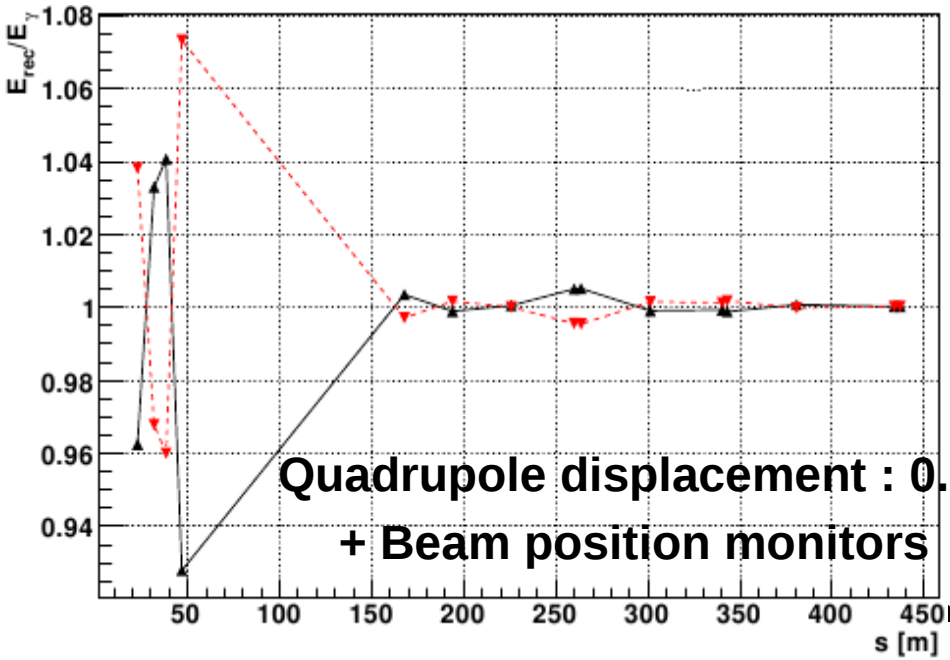


Quadrupole displacement : 0.5 mm



Quadrupole displacement : 0.5 mm
+ Beam position monitors

E_{loss} = 100 GeV

Assumes :
ideal beamline BUT 1 displaced quadrupole

Impact on reconstructed energy

Also assumes :
perfect knowledge of beamline position at 420m

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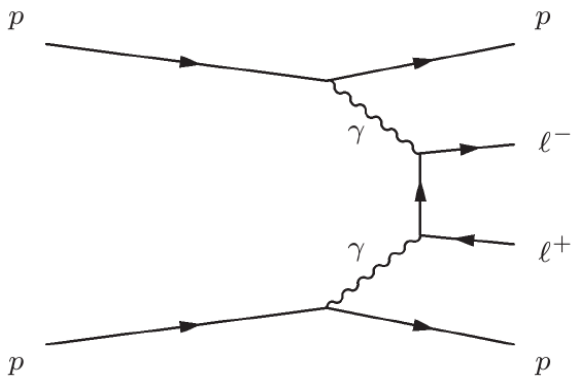
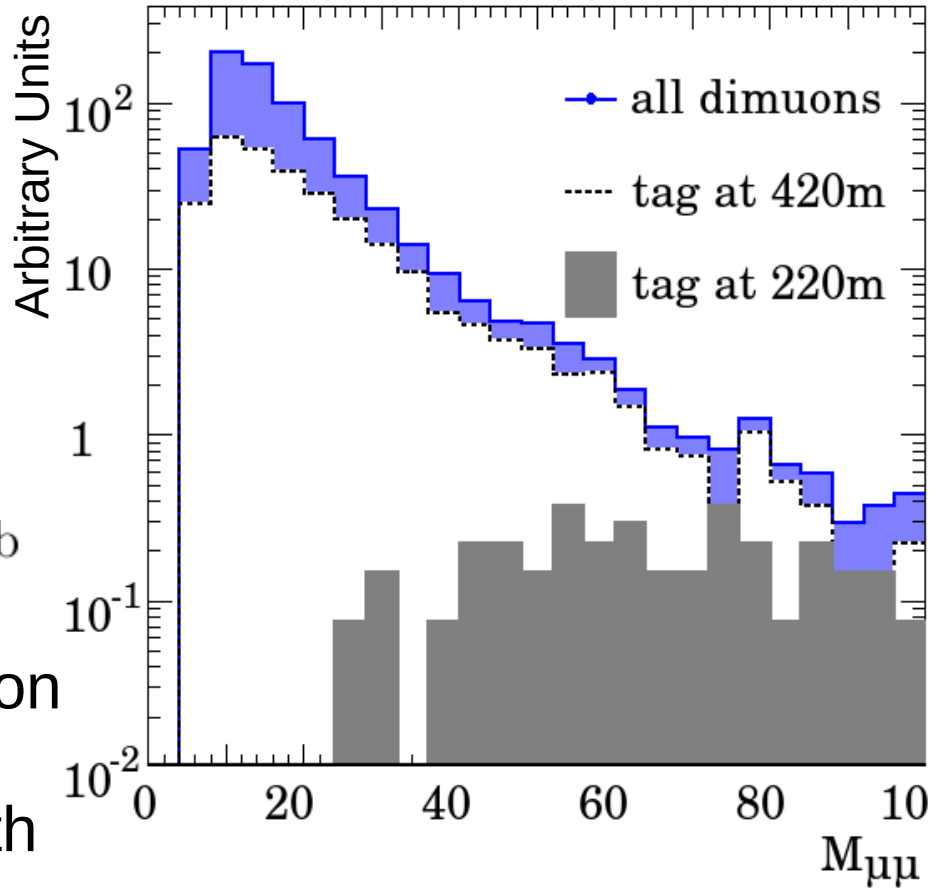
Exclusive dimuons





1) Measuring both muons in central detector $\sigma_{vis} \approx 7$ pb

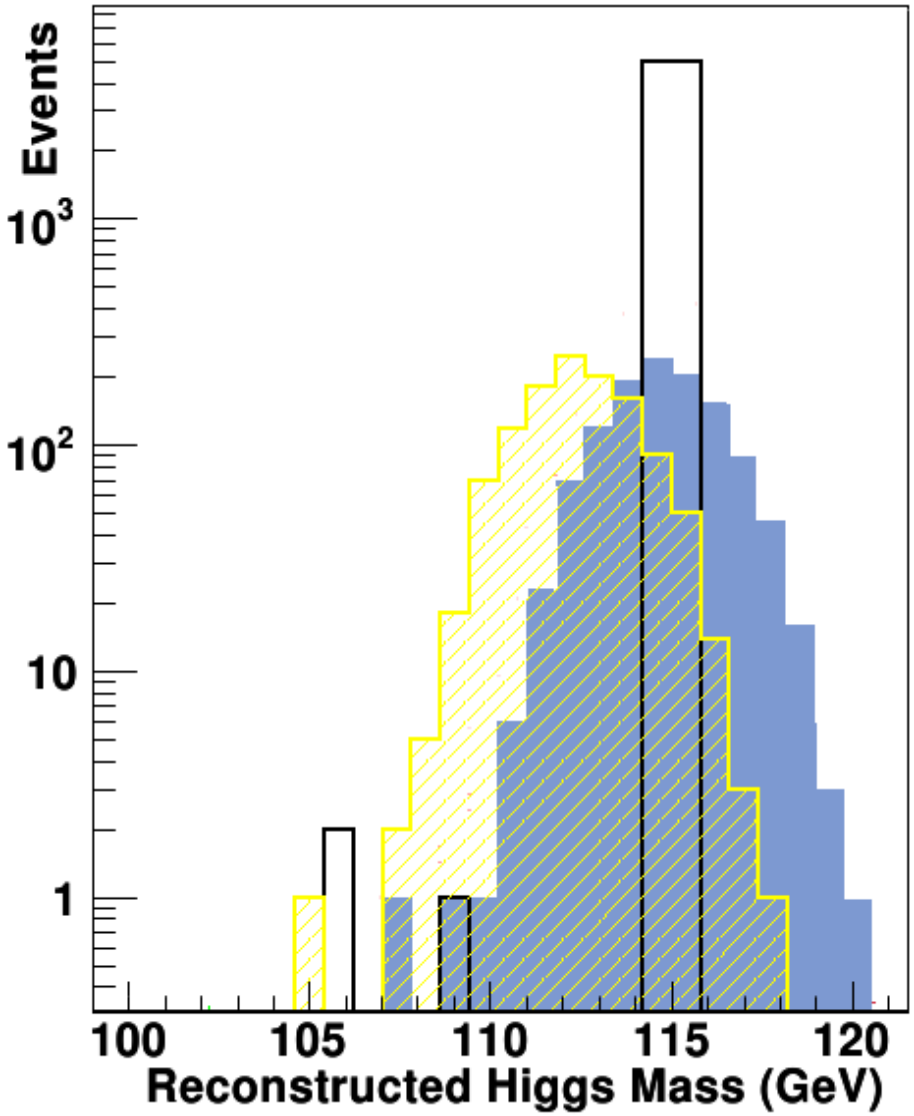
2) Tagging at least one proton

3) Energy reconstruction with very good resolution

Most of the selected exclusive muon pairs have a proton within forward detector acceptance !

Misalignment of the beamline

$pp(\gamma\gamma \rightarrow H)pp$



Missing mass

Generator level

1 Misaligned quadrupole + perfect knowledge of beam position at 420m

Using dimuon data for FP420 calibration

No more bias

Calibration based here on 700 dimuon events ($100pb^{-1}$)

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References

- Photon interactions
  - J. de Favereau et al., *High energy photon interactions at the LHC*, CP3-08-04.
  - K. Piotrzkowski, Tagging two-photon production at the LHC, Phys. Rev D 63 (2001) 071502
  - S. Ovyn, 0806.4841 [hep-ph], 0806.1157 [hep-ph]
    N. Schul, K. Piotrzkowski 0806.1097 [hep-ph],
    J. De Favereau et al 0806.4886 [hep-ph]
    X. Rouby 0806.4941 [hep-ex]
  - [CMS Collaboration] J.J. Hollar, S. Ovyn, X. Rouby, $\gamma\,\gamma \rightarrow \ell^+\,\ell^-$ and $\gamma\,p \rightarrow \Upsilon \rightarrow \ell^+\,\ell^-$ production, CMS PAS DIF-07-001
- Particle transport
  - X. Rouby, J. de Favereau, K. Piotrzkowski, JINST 2 P09005; 0707.1198v2 [physics.acc-ph]

Summary and conclusions

Very rich and promising programme for photon physics at the LHC

- $\gamma\gamma$ and γp

Tagging photon physics relies on:

- Using rapidity gaps
- Using forward proton taggers

The impact of beamline misalignment requires a calibration of forward detectors with events like exclusive dimuons

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Back-up slides

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Equivalent Photon Approximation

Photon flux:

$$dN(E_\gamma, Q^2, E) = \frac{\alpha}{\pi}\,\frac{dQ^2}{Q^2}\,\frac{dE_\gamma}{E_\gamma}\left[\left(1-\frac{E_\gamma}{E}\right)\left(1-\frac{Q^2_{\min}}{Q^2}\right)+\frac{E_\gamma^2}{2E^2}\right], \qquad (1.5)$$

$$\sigma_{pp(\gamma p\to X)pY} = \int_{s_{\min}/s}^{1} dx\; f_\gamma(x)\;\sigma_{\gamma p\to X}(x)\;, \qquad (1.17)$$

with $f_\gamma = \int_{Q^2_{\min}}^{Q^2_{\max}} dN(E,Q^2)dQ^2.$

$$\sigma_{pp(\gamma\gamma\to X)pp} = \int_{W_{\min}}^{\sqrt{s}} dW\;\frac{d\mathrm{L}_{\gamma\gamma}}{dW}\;\sigma_{\gamma\gamma\to X}(W)\;, \qquad (1.19)$$

with $\frac{dL_{\gamma\gamma}}{dW} = \int_{W^2/s}^{1} 2W\; f_\gamma(x)\; f_\gamma\left(\frac{W^2}{xs}\right)\;\frac{dx}{xs}$

V. M. Budnev, I. F. Ginzburg, G. V. Meledin and V. G. Serbo, Equivalent Photon Approximation, Phys. Rept. 15 (1974) 181.

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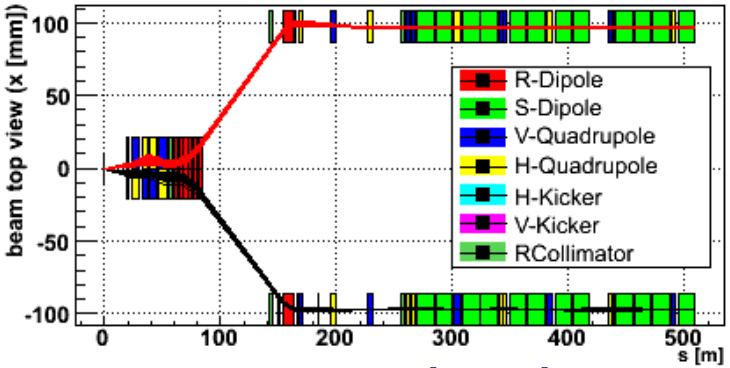
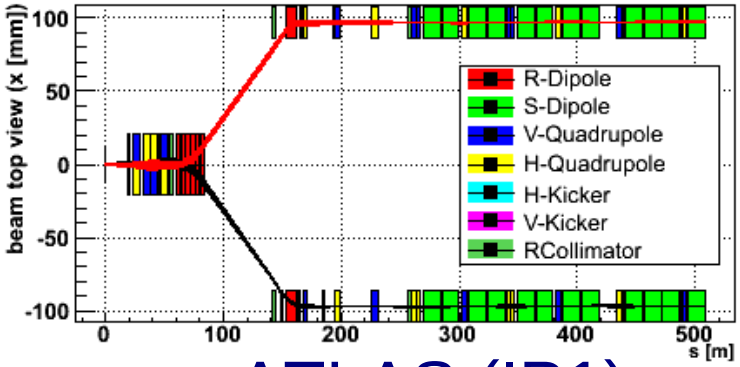
HECTOR: implementation

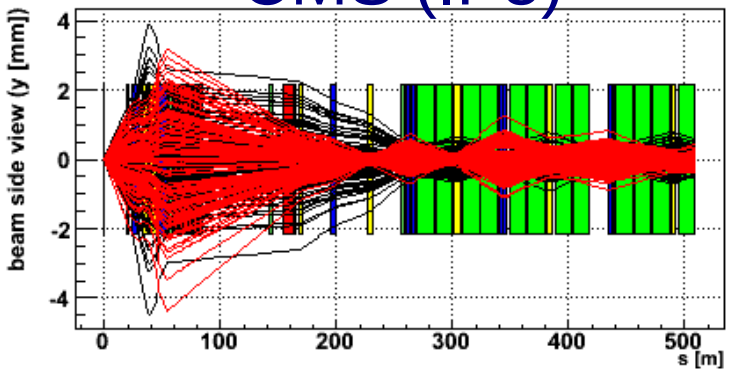


top

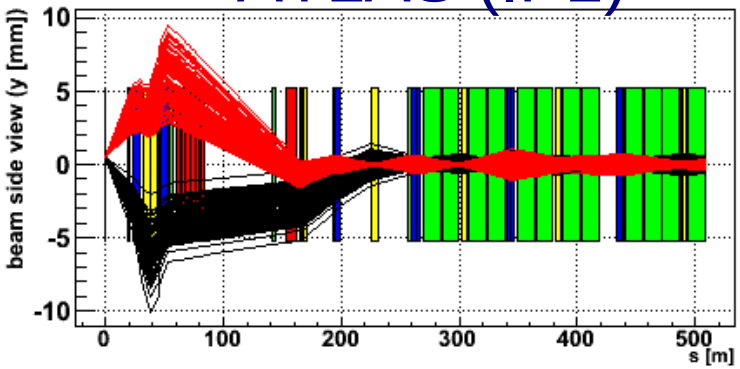


CMS (IP5)

ATLAS (IP1)



side



Horizontal crossing plane

Vertical crossing plane

Input Needed:

- effective field strength / length
- magnet position / aperture

Forward detectors around IP5

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Photon physics

Hector

- implementation

- validation

- applications

Edgeless det.

Excl. dileptons

Totem T2

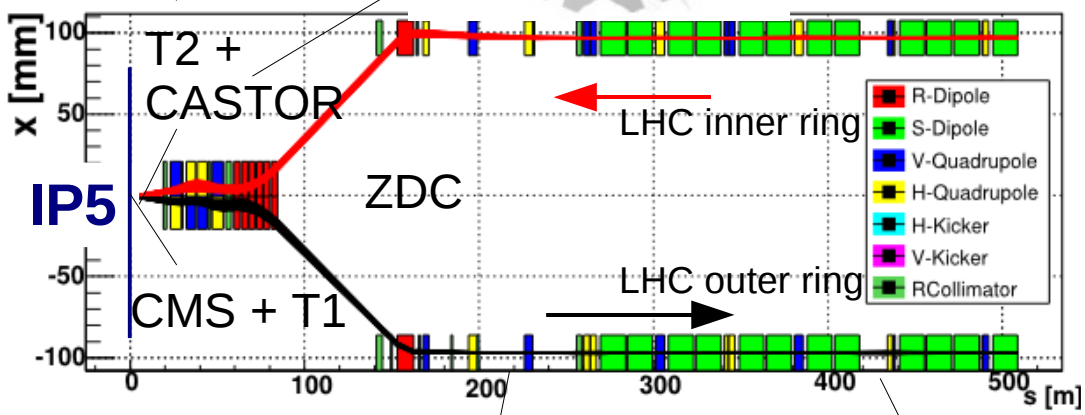
TRACKING

CASTOR (*)

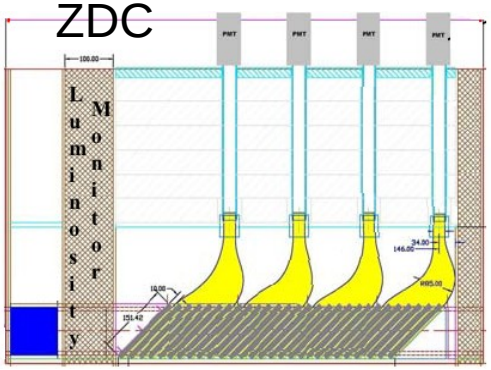
CMS

Totem T1

CALORIMETRY



ZDC

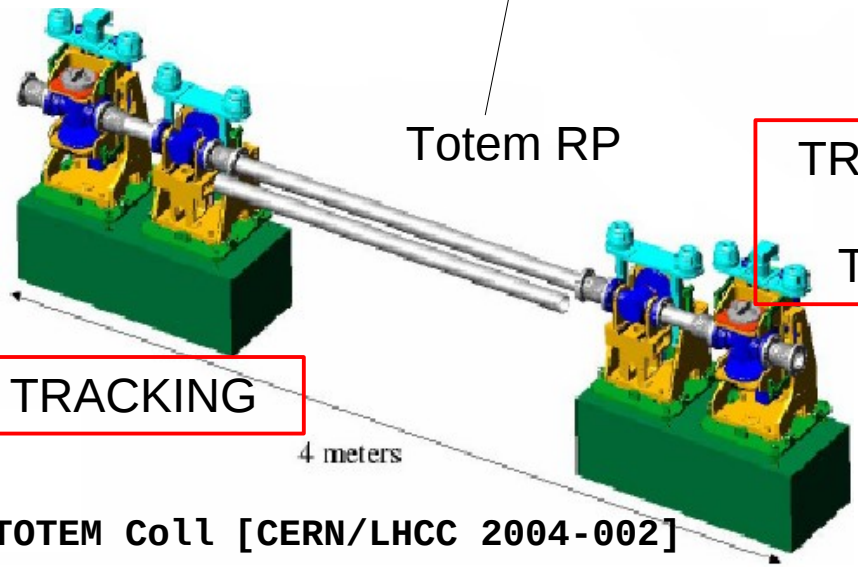


CALORIMETRY
neutrals

FP420

Totem RP

TRACKING
&
TIMING



TRACKING

CASTOR:
(*) First one installed in 2008
Second one in 2009 if funded

TOTEM Coll [CERN/LHCC 2004-002]

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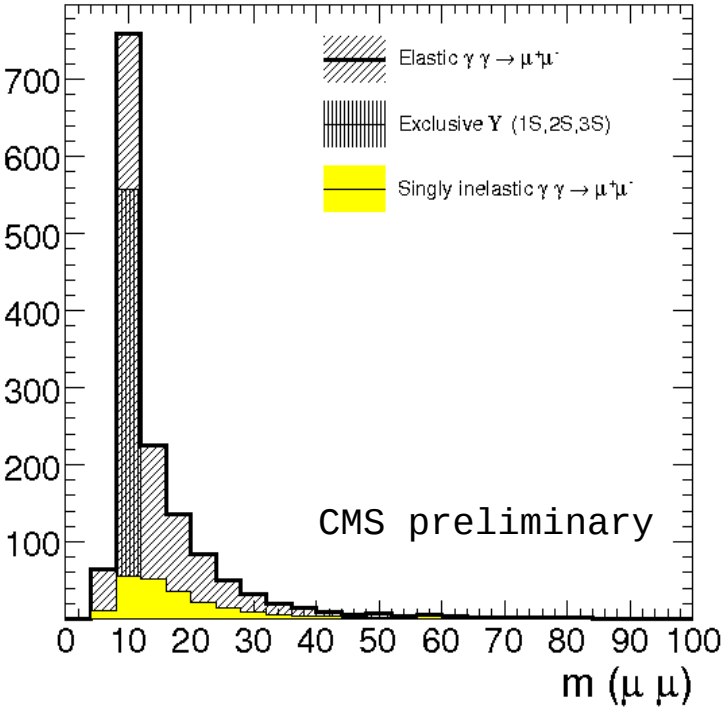
Exclusive dimuons

JJ Hollar, S Ovyn, X Rouby
CMS PAS DIF-07-001



Overall selection

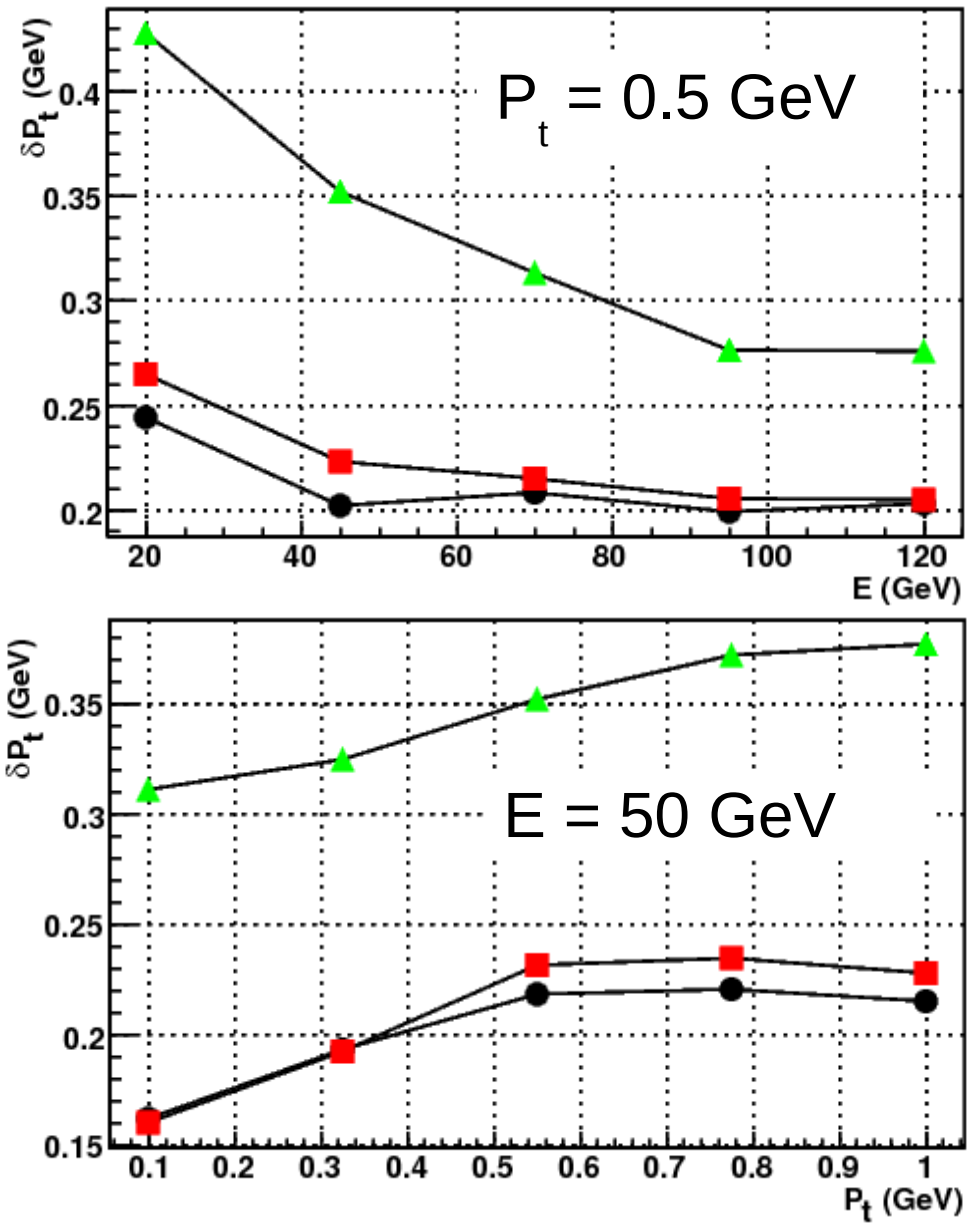
* p_T and $\Delta\phi$ balance
* calorimetric and tracking exclusivities

« *inelastic* » = one proton dissociates
« *with veto* » = dissociation product seen by one of the forward detectors

$$N_{elastic}(\gamma\gamma \to \mu^+\mu^-) = 709 \pm 27(stat)$$
$$N_{inelastic}(\gamma\gamma \to \mu^+\mu^-) = 636 \pm 25(stat) \pm 121(model)$$
$$N^{w/veto}_{inelastic}(\gamma\gamma \to \mu^+\mu^-) = 223 \pm 15(stat) \pm 42(model)$$

For an integrated luminosity L=100 pb^{-1}, without pile-up

Reconstruction



Forward detectors at 420m + 428m

P_T Resolution

$$P_t \simeq \sqrt{Q^2}$$

Detector resolution

- 30 µm
- 5 µm
- perfect

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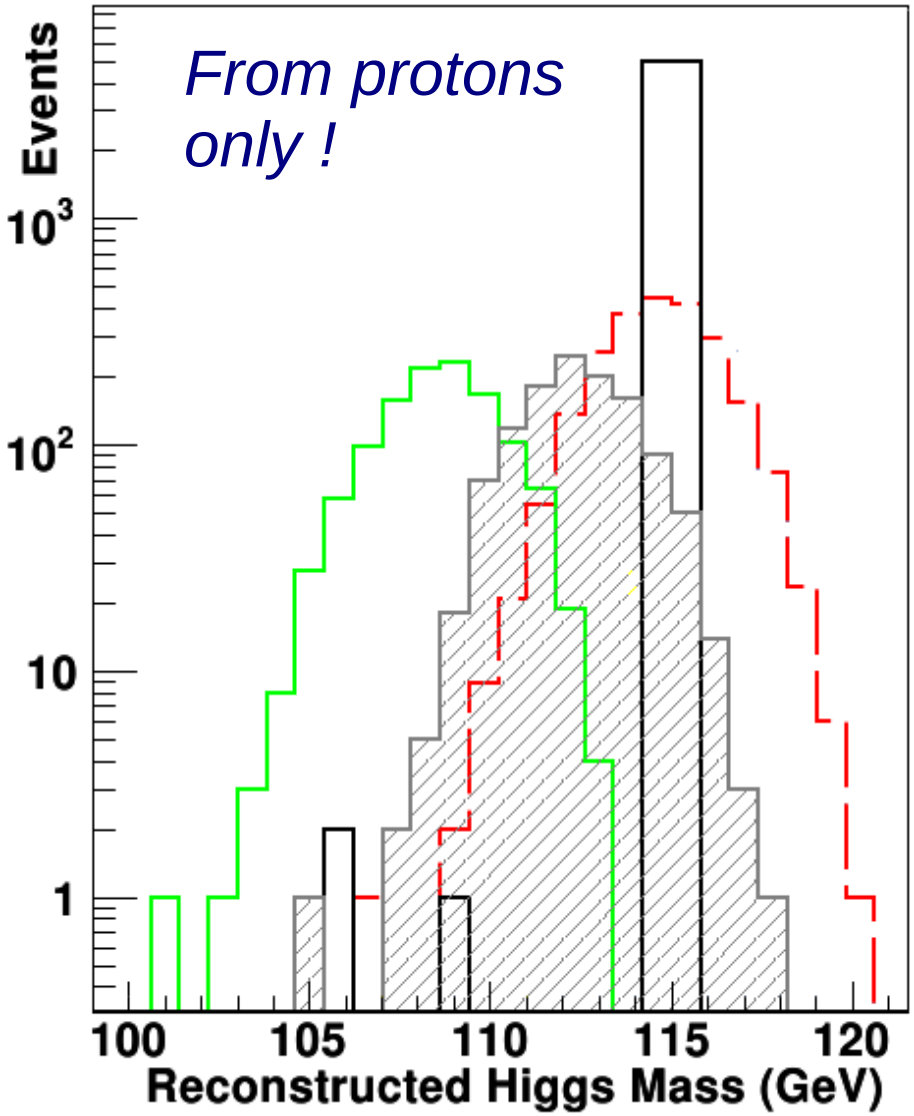
Misalignment of the beamline

$pp(\gamma\gamma \to H)pp$



Missing mass

- Generator Level
- Bare transport with ideal beamline
- 1 Misaligned quadrupole MQXA.1R5 by 0.5mm
- 1 Misaligned quadrupole + perfect knowledge of beam position at 420m

- Clear bias
- Visible beamline aperture effect

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