Tagging photon interactions at the LHC

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On behalf of the Louvain Photon group:

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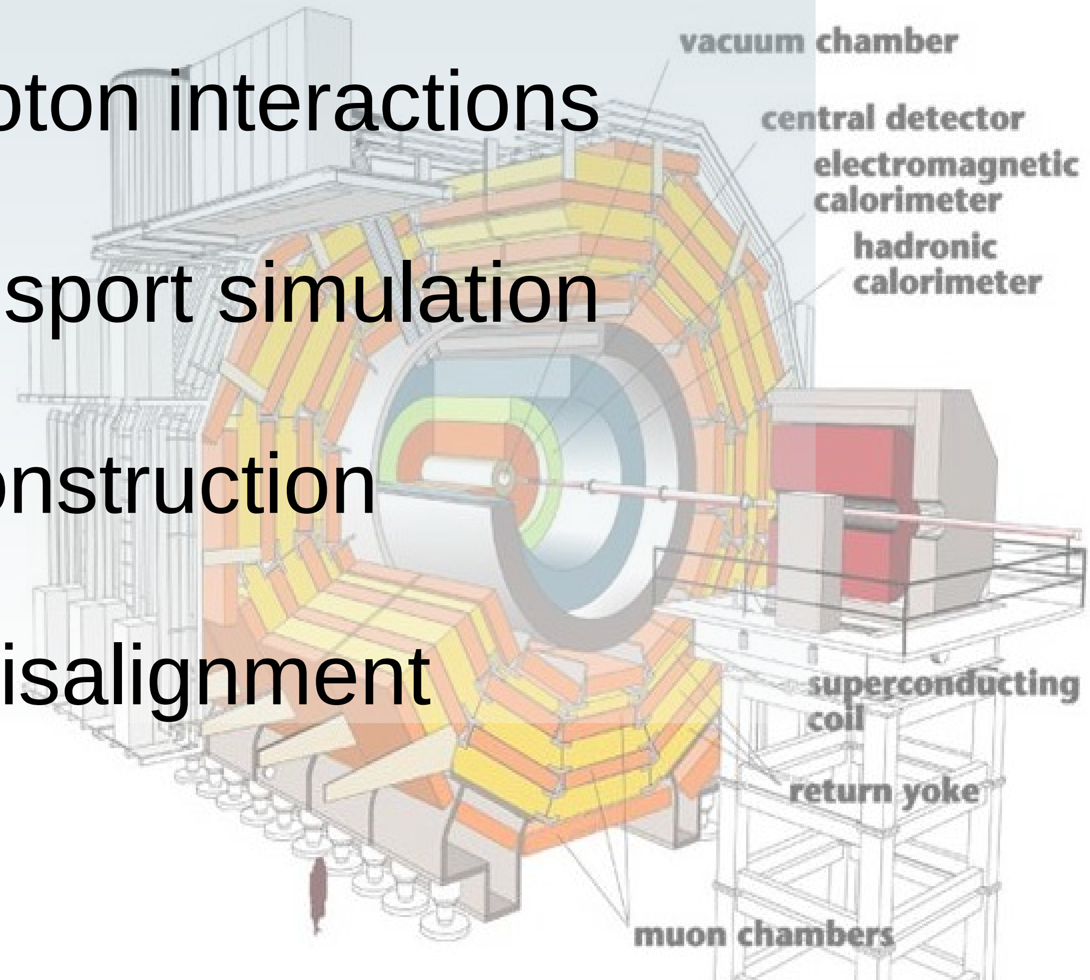
K. Piotrzkowski, X. Rouby, N. Schul, M. Vander Donckt

Overview

- γ-induced physics at LHC
- Tagging photon interactions
- Particle transport simulation
- Photon reconstruction
- Beamline misalignment



Photon-induced physics

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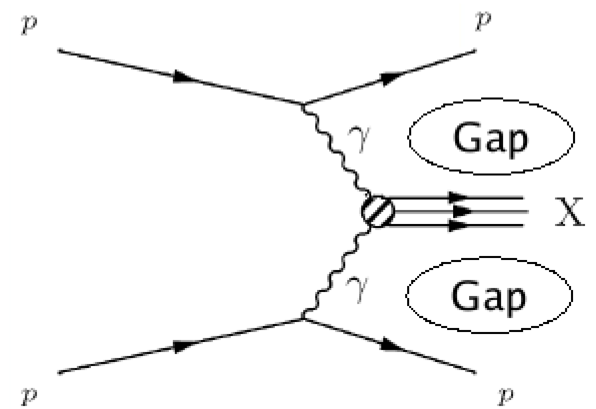
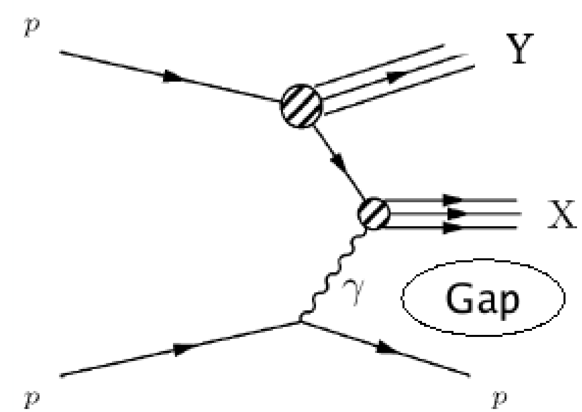
LHC – also a photon-photon and photon-proton collider

γ γ – interactions



γ p – interactions



Photon-induced physics

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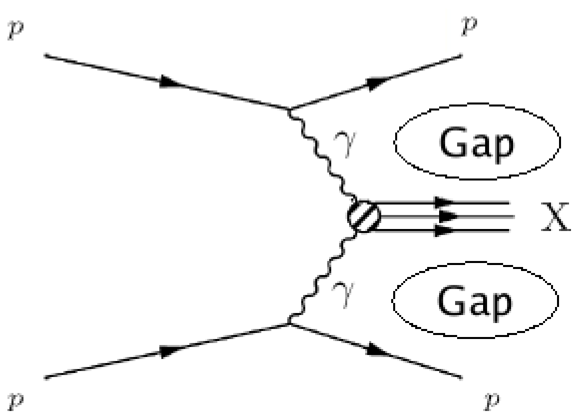
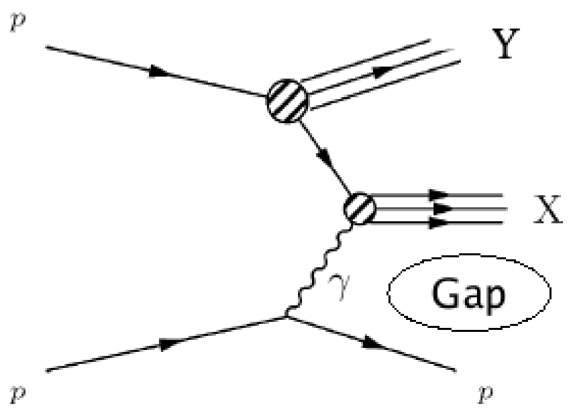
Colorless exchange

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





Tagging γ-interactions

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Photon physics

Tagging

- Rapidity gaps

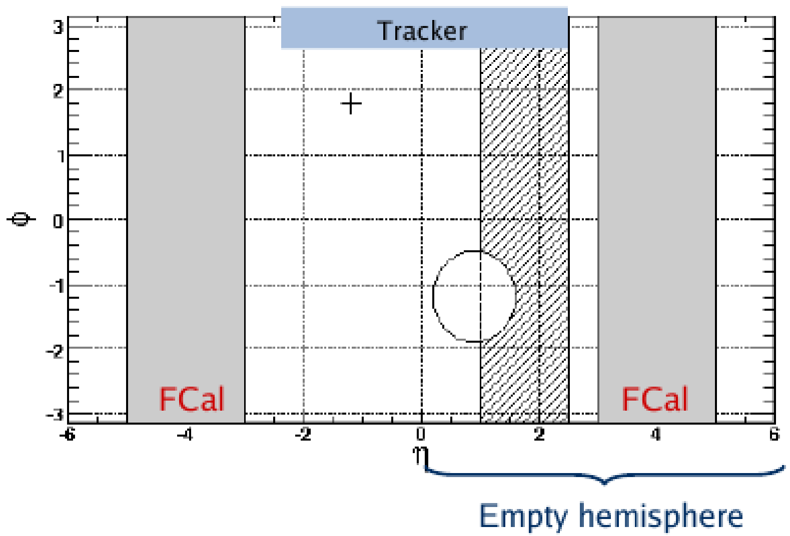
- p taggers

Hector

Reconstruction

Misalignment

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



e.g. $\gamma\,p$ – interactions

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

b) cut on the maximum allowed value for this energy

See S. Ovyn's talk

Rapgap: region devoid of particles

Tagging γ-interactions

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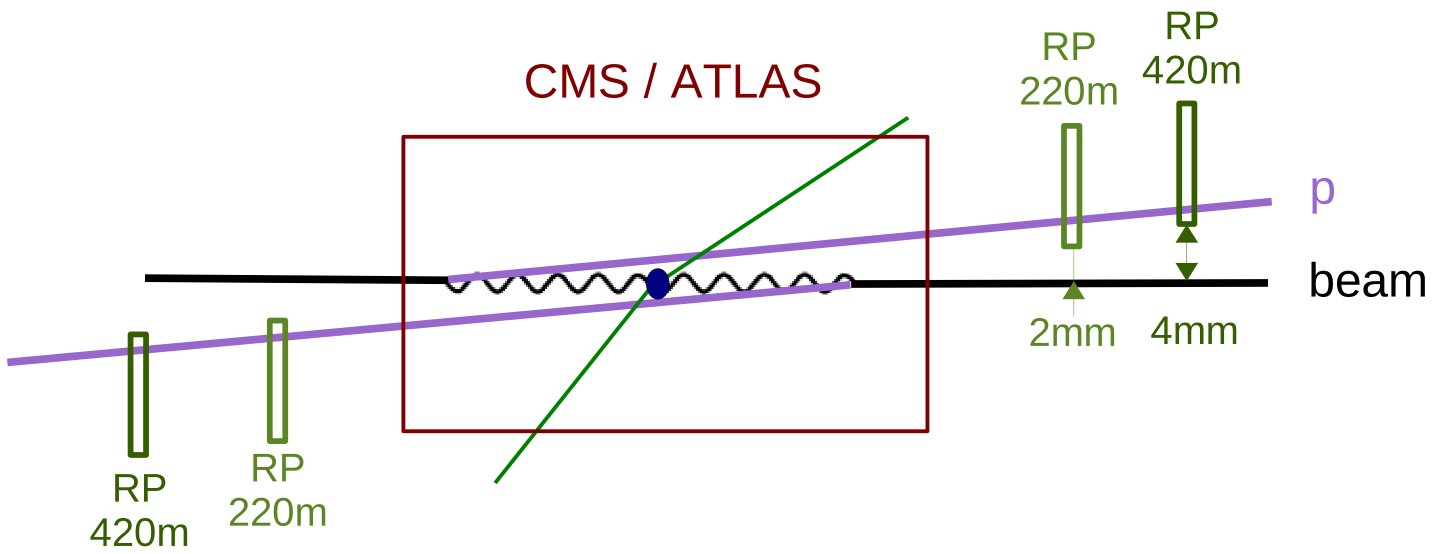
2) Using very forward proton taggers



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

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

Proton transport simulation

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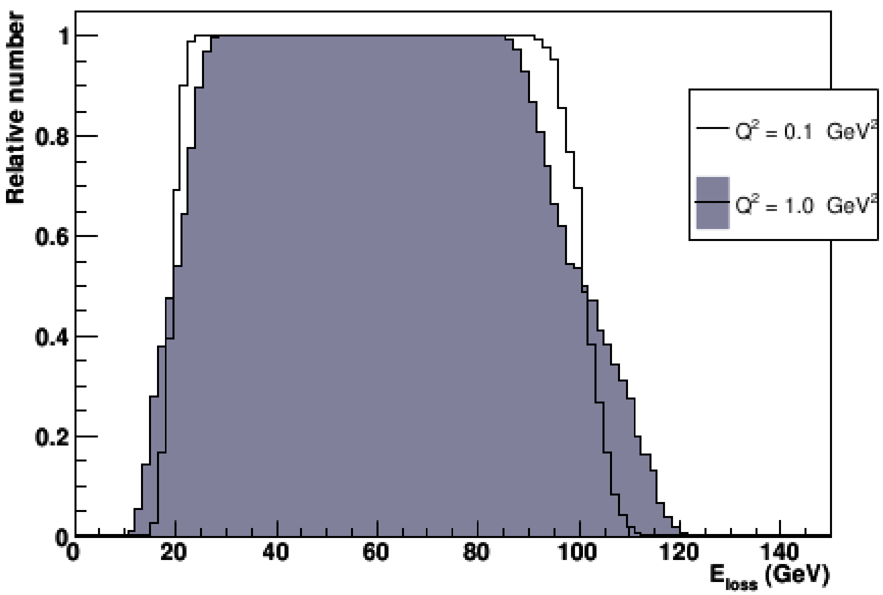
Relation between proton E_{loss} and its path in beamline ?

Requirements for near-beam very forward detectors ?

Reconstruction of photon kinematics ?

...



FP420 acceptance :

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

HECTOR: implementation

X. Rouby

Matrix representation of the transport :

$$X(s) = X(0)\underbrace{M_1 M_2 \ldots M_n}_{M_{\text{beamline}}}$$

Where :

$$X = (x, x', y, y', E, 1)$$

X is the phase-space vector of the particle

Bending and Focussing

$$M = \begin{pmatrix} A & A & 0 & 0 & 0 & 0 \\ A & A & 0 & 0 & 0 & 0 \\ 0 & 0 & B & B & 0 & 0 \\ 0 & 0 & B & B & 0 & 0 \\ D & D & 0 & 0 & 1 & 0 \\ K & K & K & K & 0 & 1 \end{pmatrix}$$

M_i are the matrices associated to the magnets

Energy dependence of M_i as a correction to linearity

HECTOR: implementation

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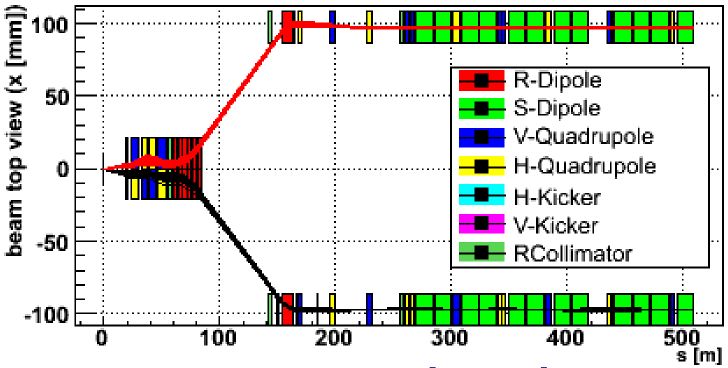
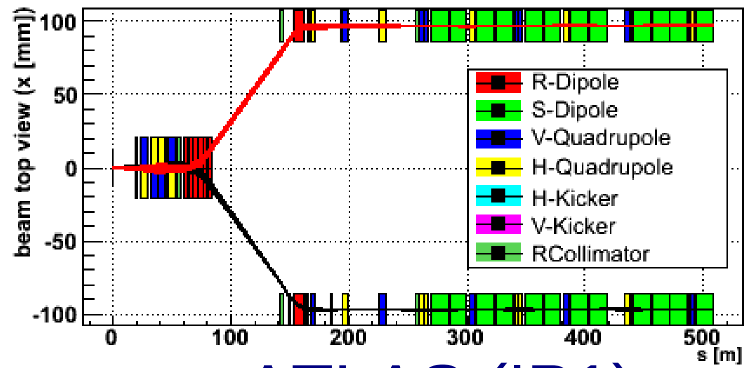
Photon physics
Tagging
Hector
- implementation
- validation
- forward det's
Reconstruction
Misalignment

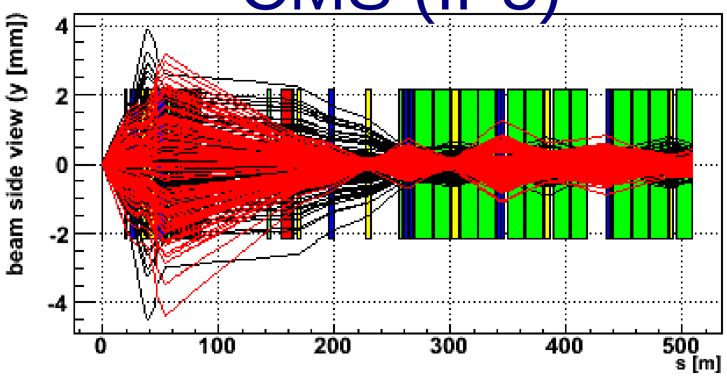


top

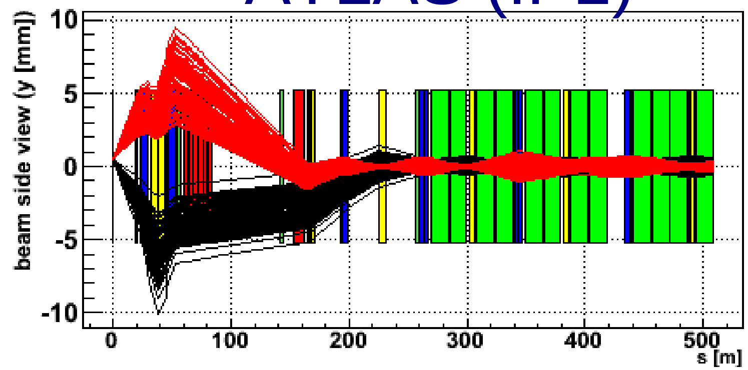


CMS (IP5)

ATLAS (IP1)



side



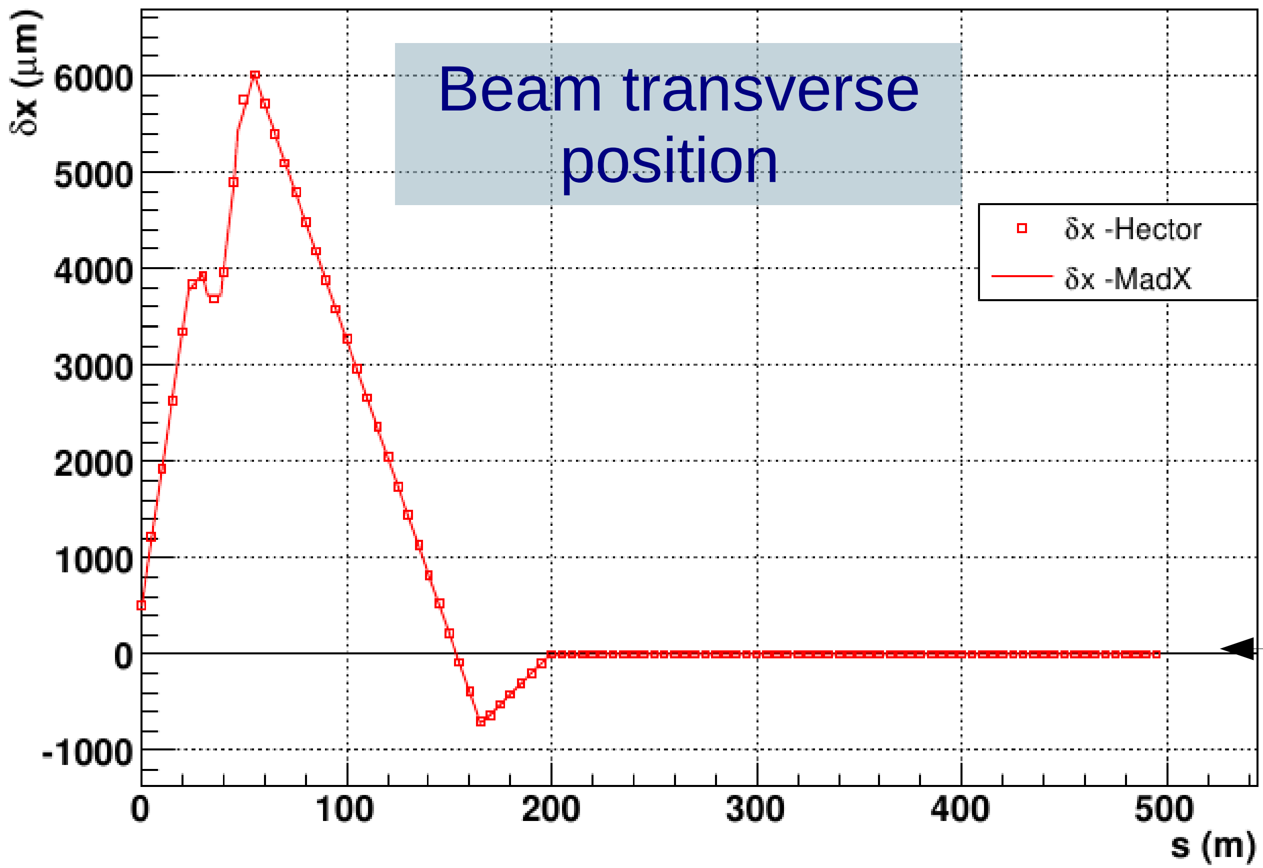
Horizontal crossing plane

Vertical crossing plane

Input Needed:

- effective field strength / length
- magnet position / aperture

HECTOR: validation



Very good agreement

< 0.5 µm

Ideal path

Distance from IP5

Comparing to MAD-X (LHC beam transport software)

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Photon physics
Tagging
Hector
- implementation
- **validation**
- forward det's
Reconstruction
Misalignment

HECTOR: validation

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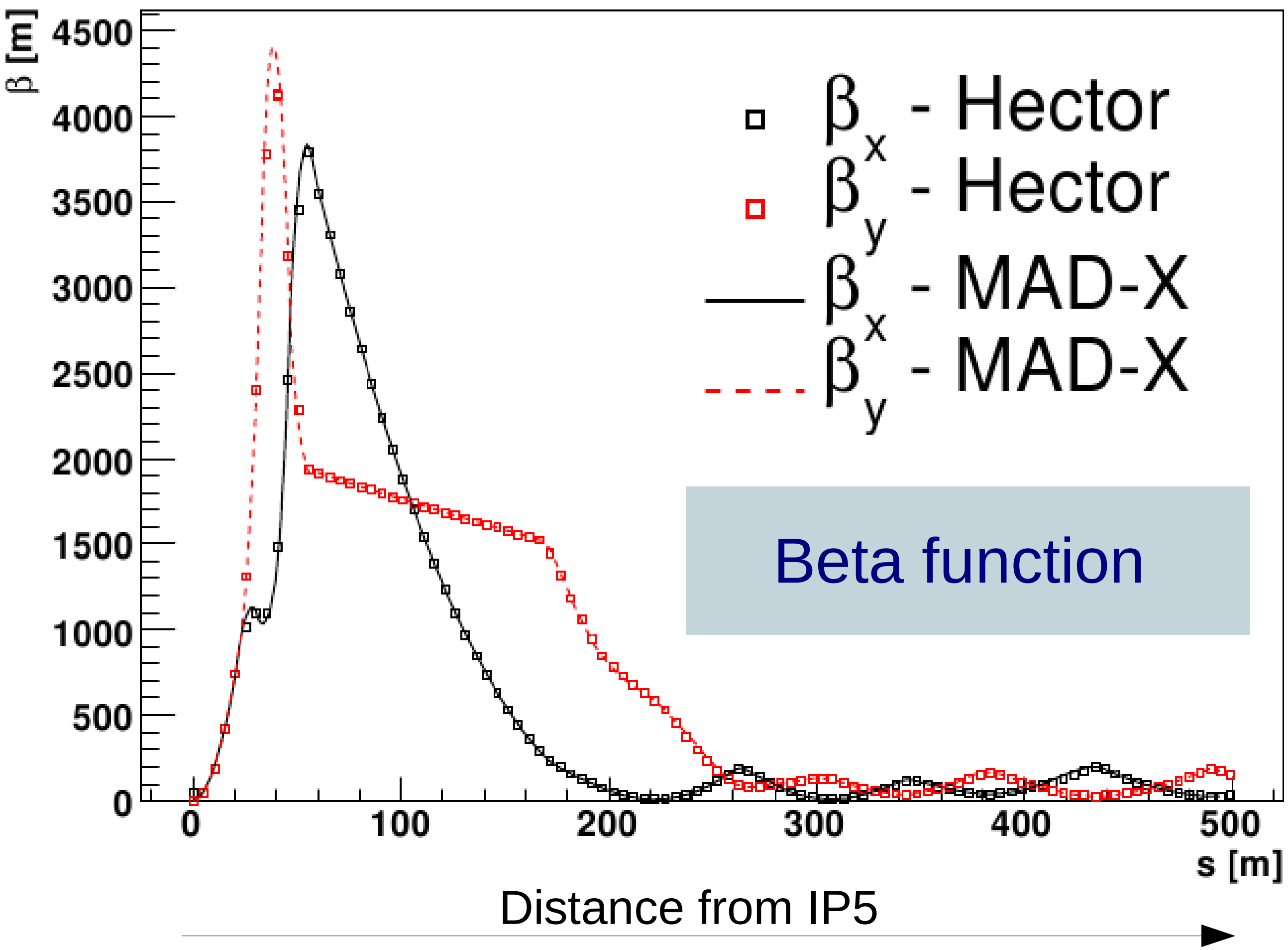
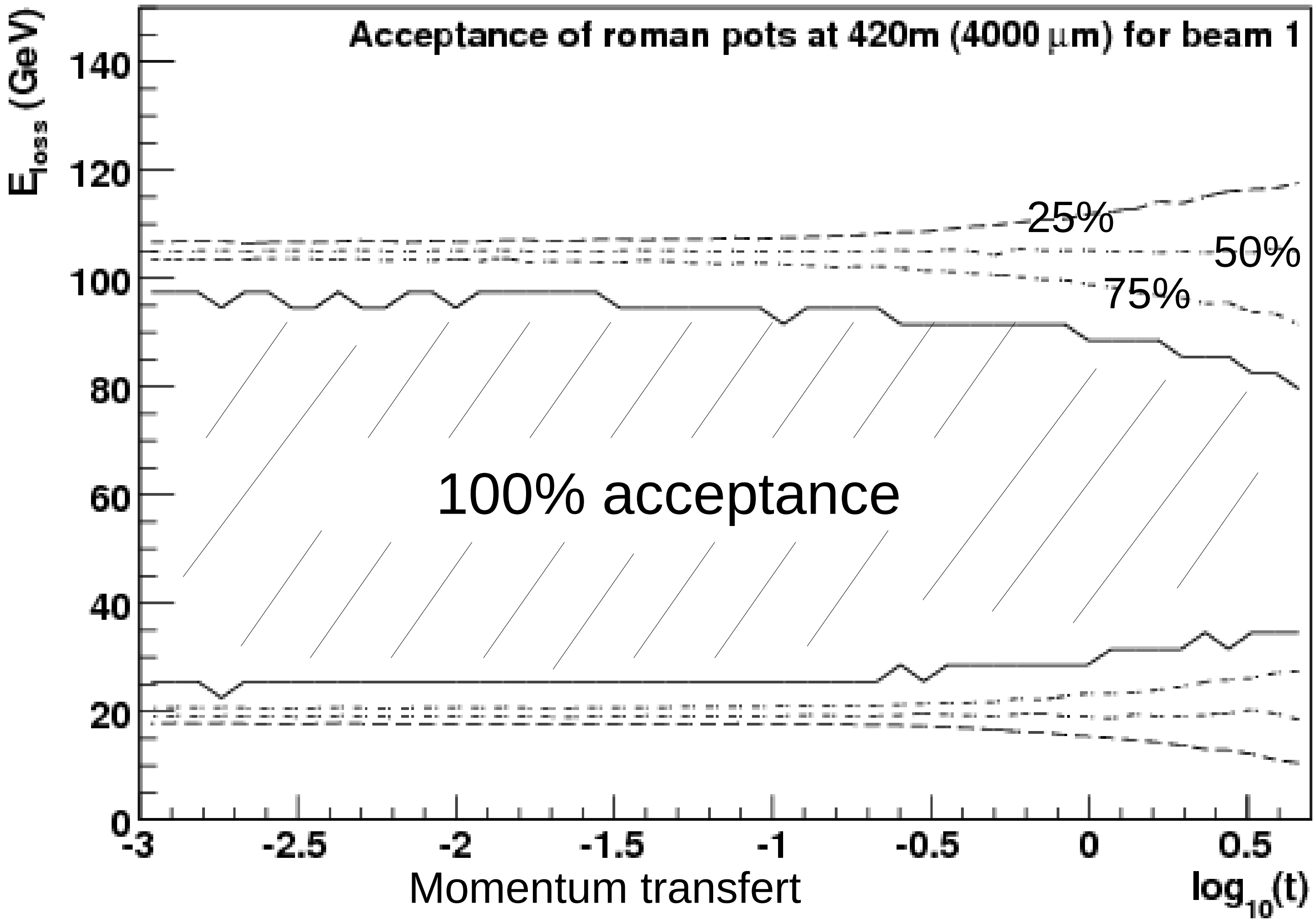


Comparing to MAD-X

Detector characterization with Hector

Energy loss is the key variable !

Detector acceptance



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Photon physics
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Detector characterization with Hector

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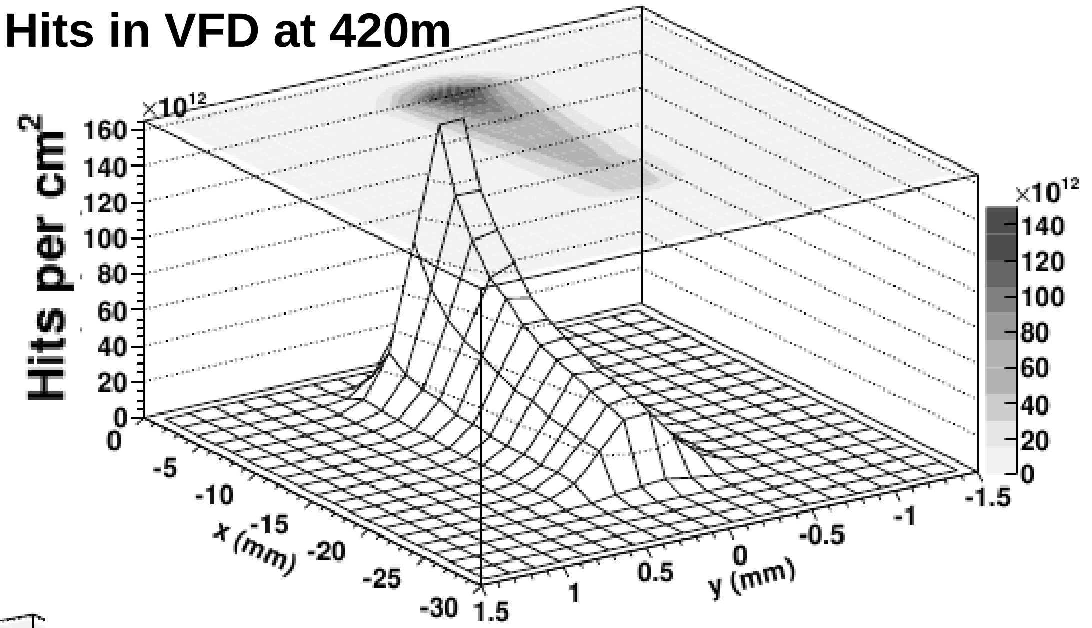
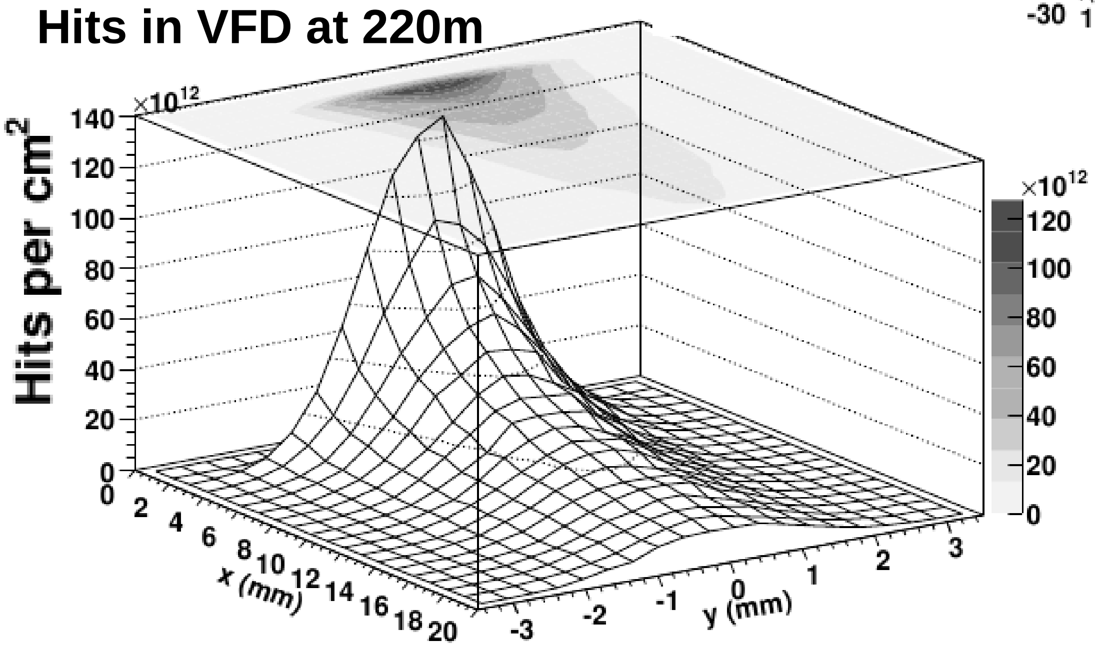
Misalignment

pp → pX

L= 20 fb^{-1}





Fluences

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Chromaticity grid

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

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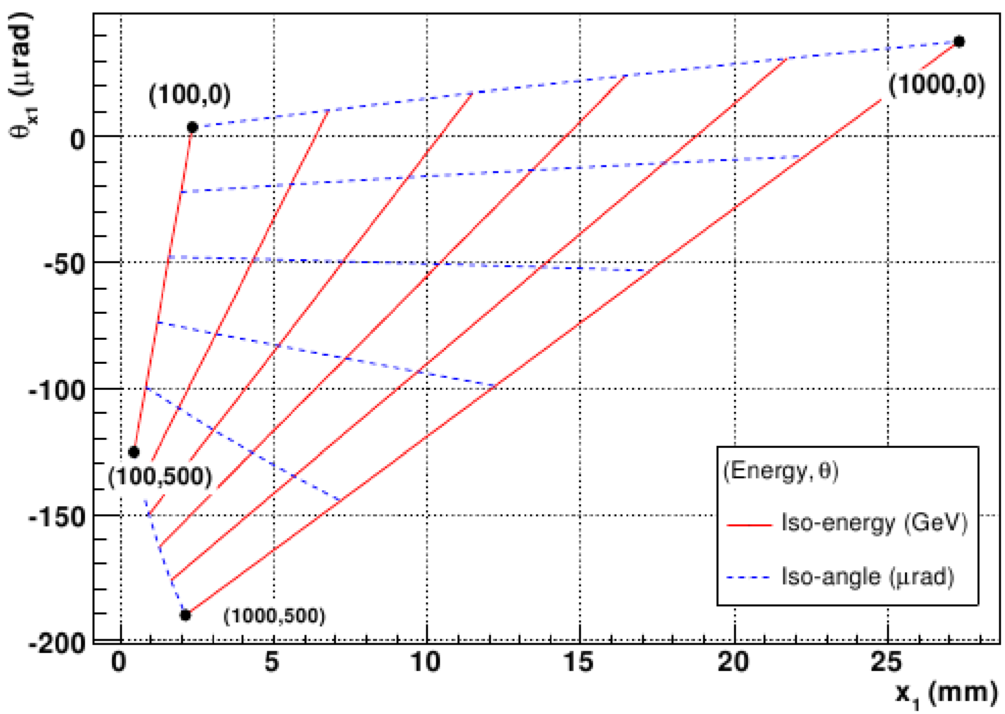
Forward detectors at 220m from IP5



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 detectot acceptance !

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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 !

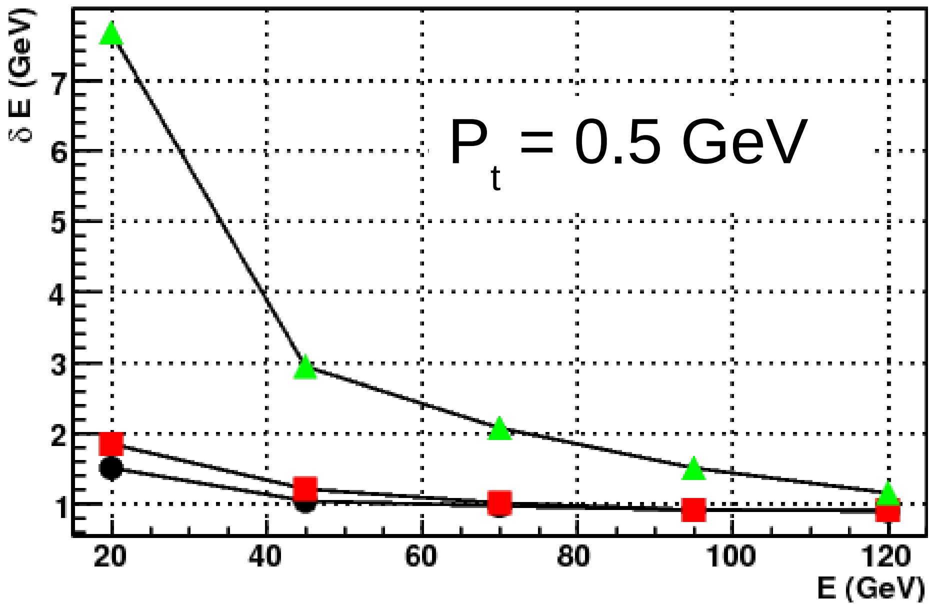
Goal: reconstructing photon E and Q^2 from the forward detector measurement

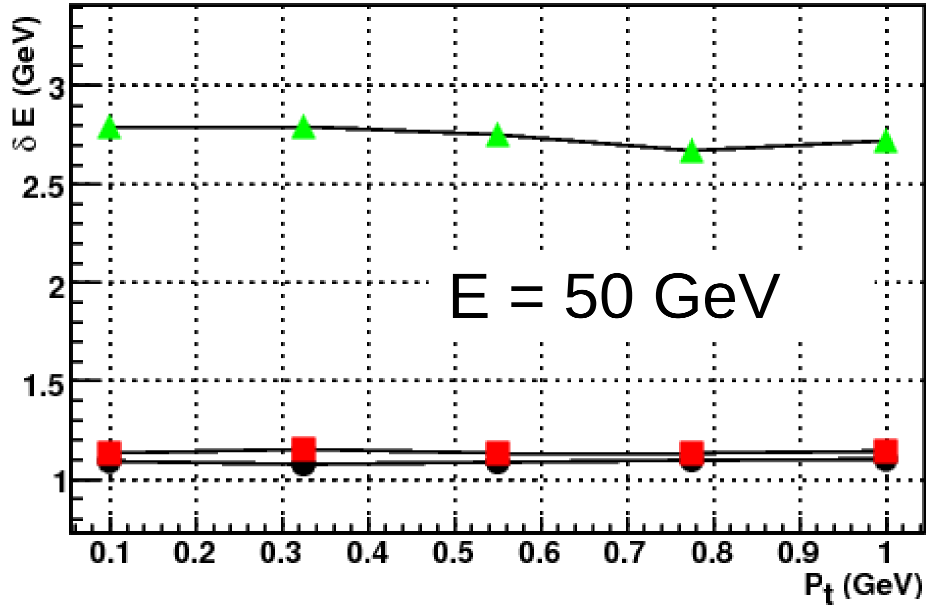
Resolution on reconstructed energy:

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

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

Reconstruction





Forward detectors at 420m + 428m

Energy Resolution

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

Detector resolution

- ▲ 30 µm
- ■ 5 µm
- ● perfect

Reconstruction

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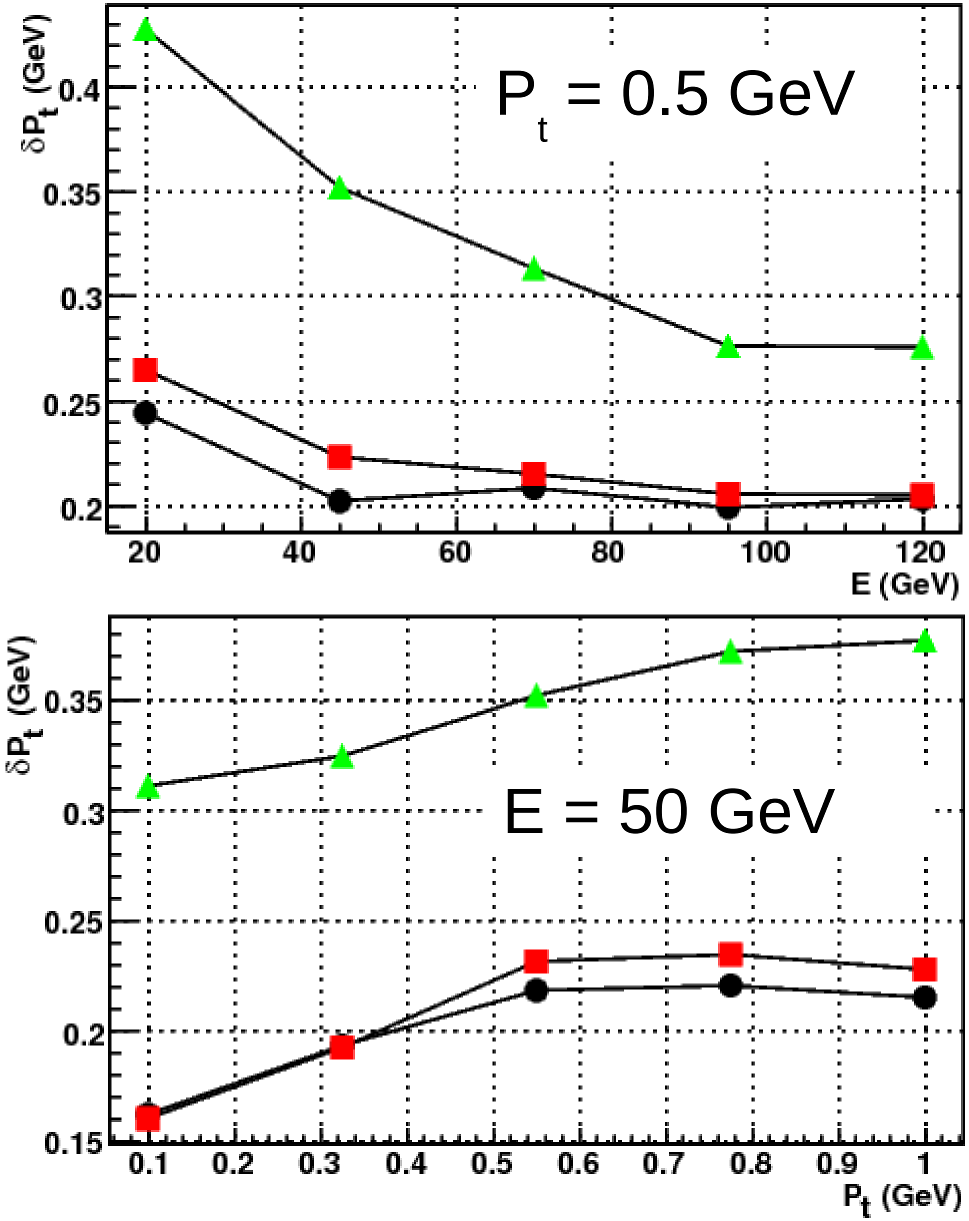
Photon physics
Tagging
Hector
Reconstruction
- chrom. grids
- principles
- **resolutions**
Misalignment



Forward detectors at 420m + 428m

P_T Resolution

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

Detector resolution
- ▲ 30 µm
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Misalignment of the beamline

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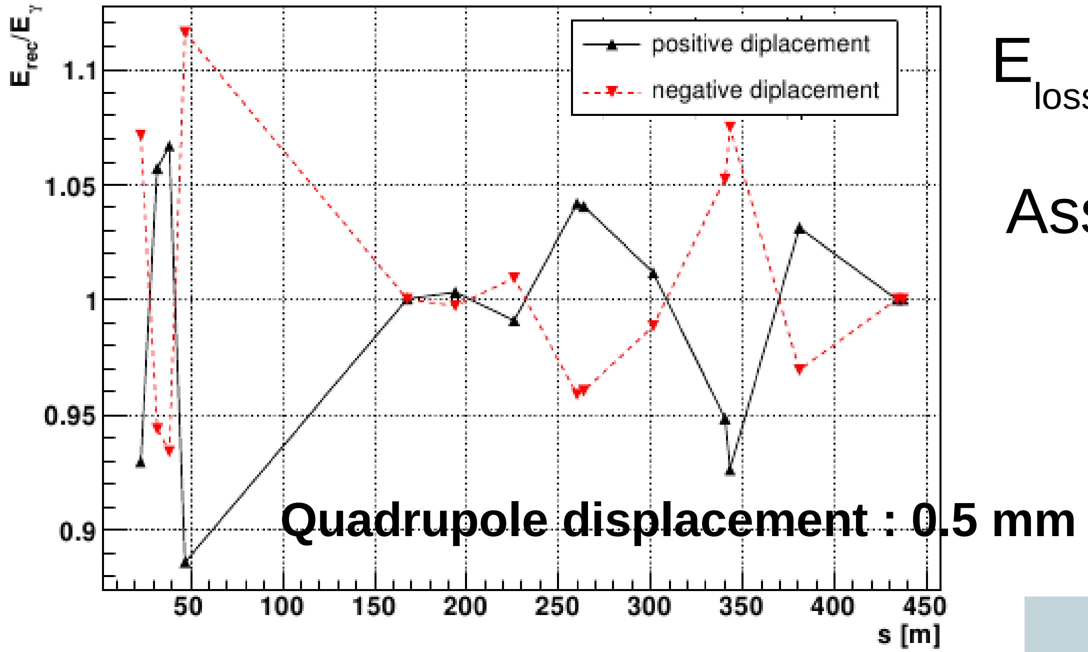

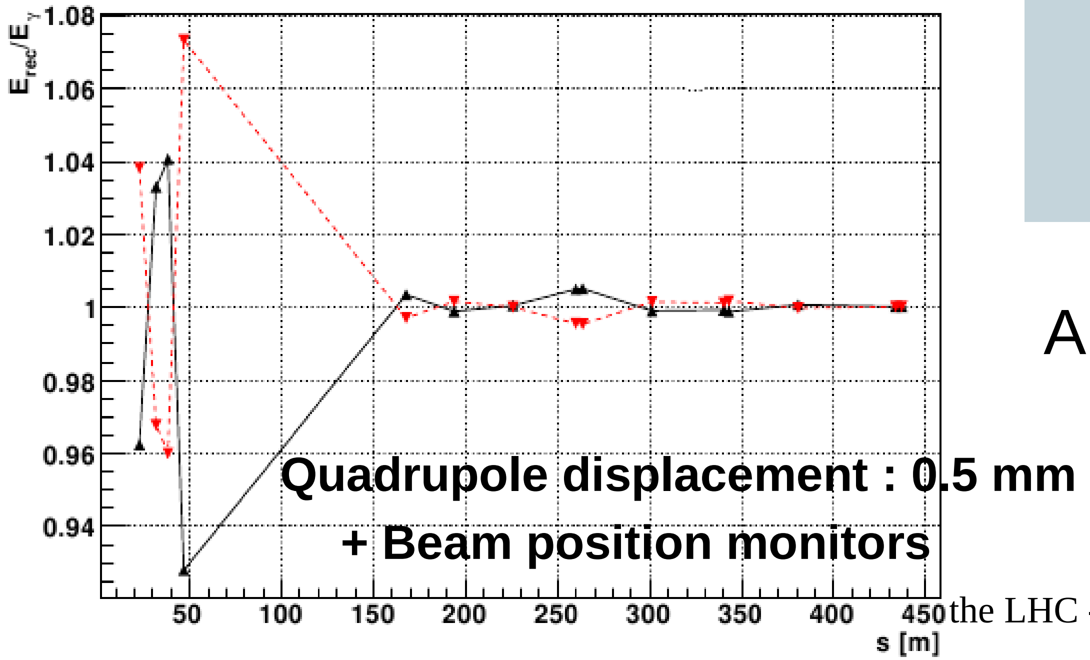

E_{loss} = 100 GeV

Assumes :
ideal beamline BUT 1 displaced quadrupole

Impact on reconstructed energy

Also assumes :
perfect knowledge of beamline position at 420m

Misalignment of the beamline

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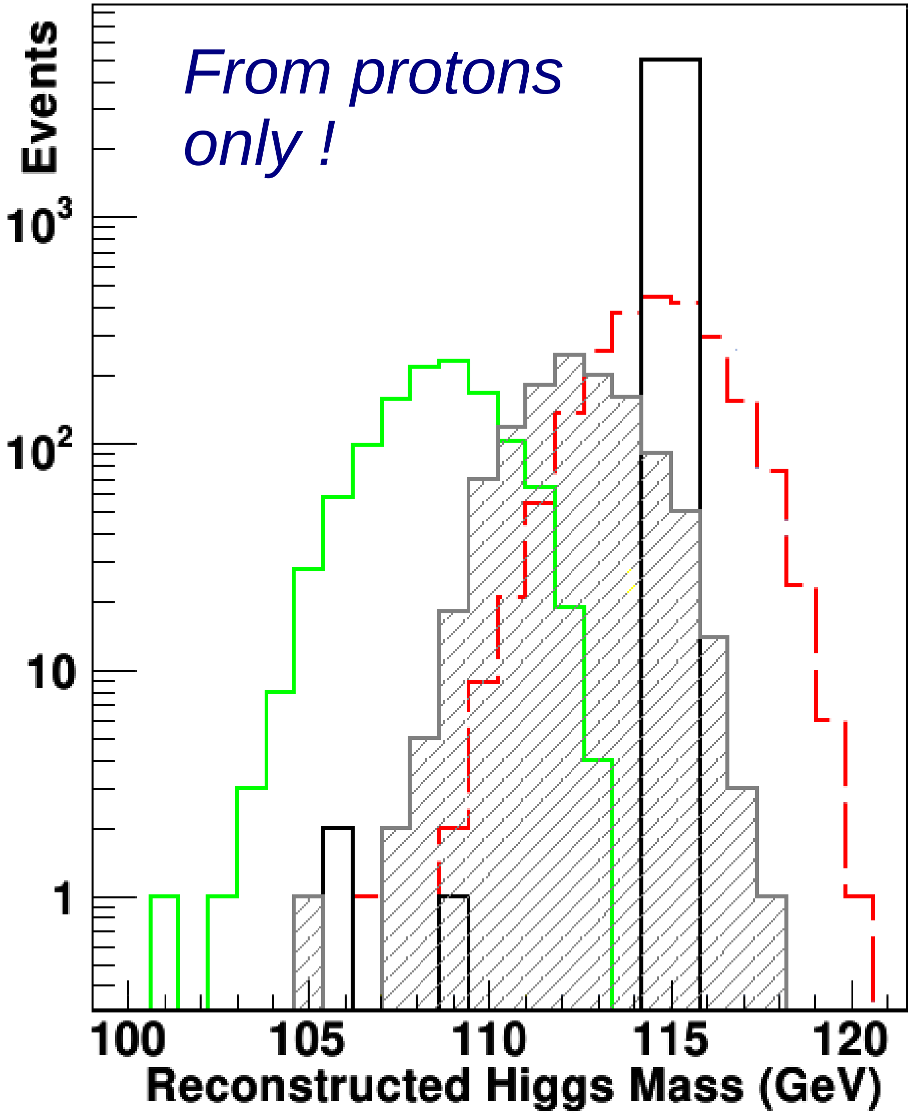
$pp(\gamma\gamma \rightarrow H)pp$



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

Exclusive dimuons

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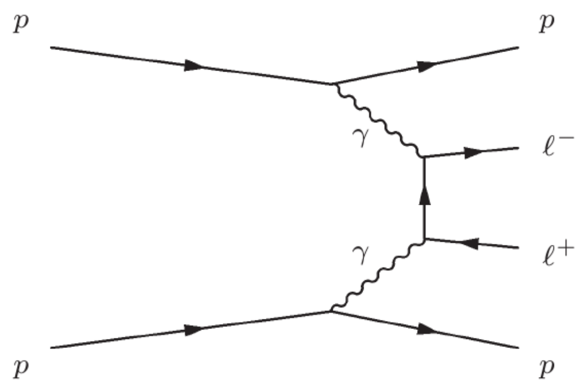
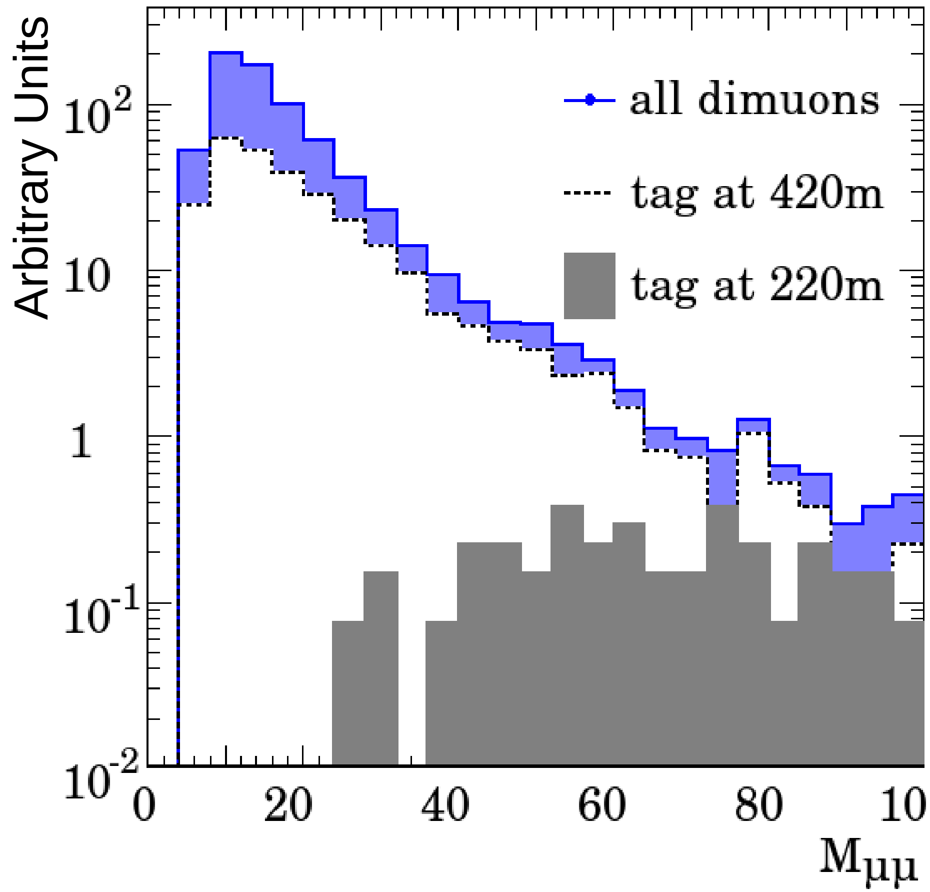


1) Measuring both muons in central detector

2) Tagging at least one proton

See J. Hollar's talk



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

Misalignment of the beamline

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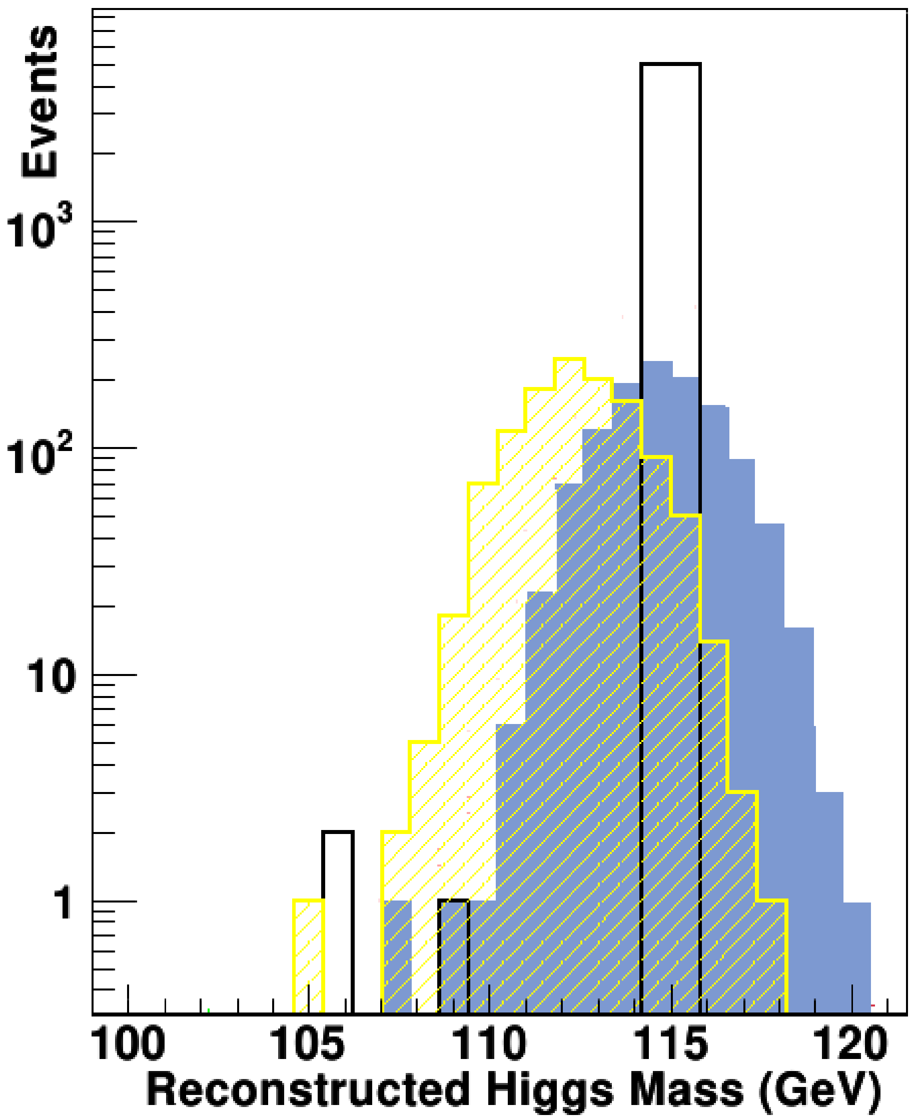
$pp(\gamma\gamma \rightarrow H)pp$



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 ($100pb^{-1}$)

Summary and conclusions

Tagging photon physics relies on:

- Using rapidity gaps
- Using forward proton taggers

A correct simulation of the proton transport in the beamline is very important

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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Forward detectors around IP5

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Photon physics

Hector

- implementation

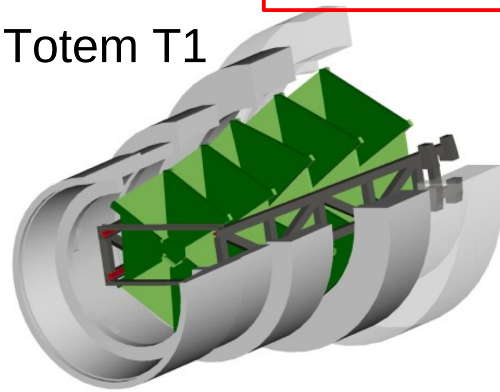
- validation

- applications

Edgeless det.

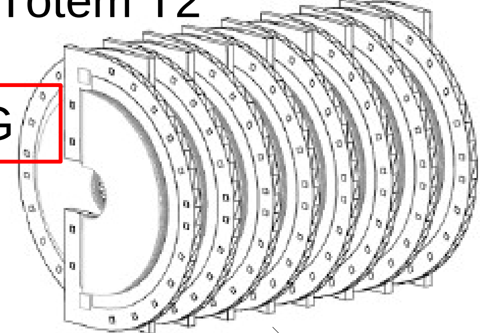
Excl. dileptons

Totem T1

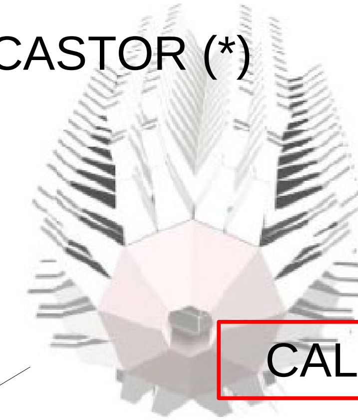


TRACKING

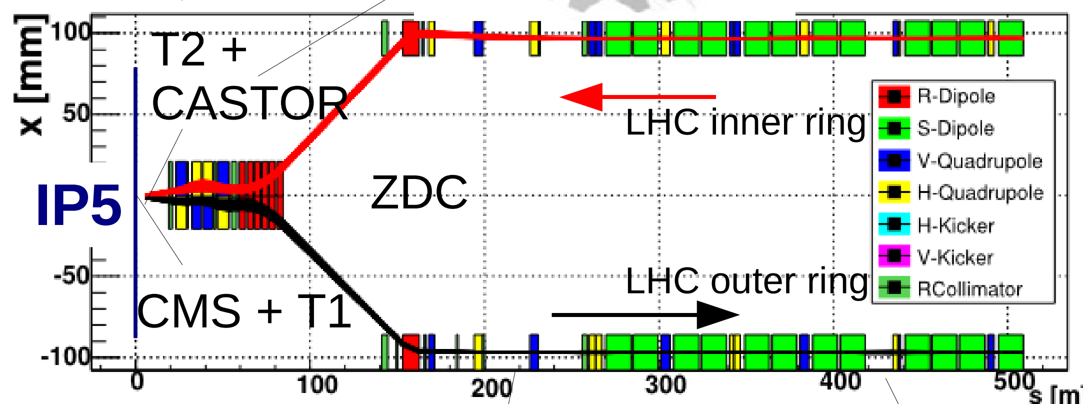
Totem T2



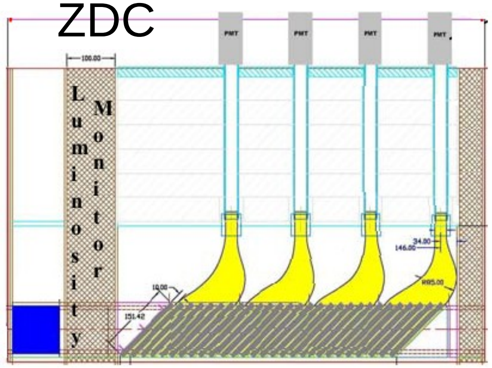
CASTOR (*)



CALORIMETRY



ZDC

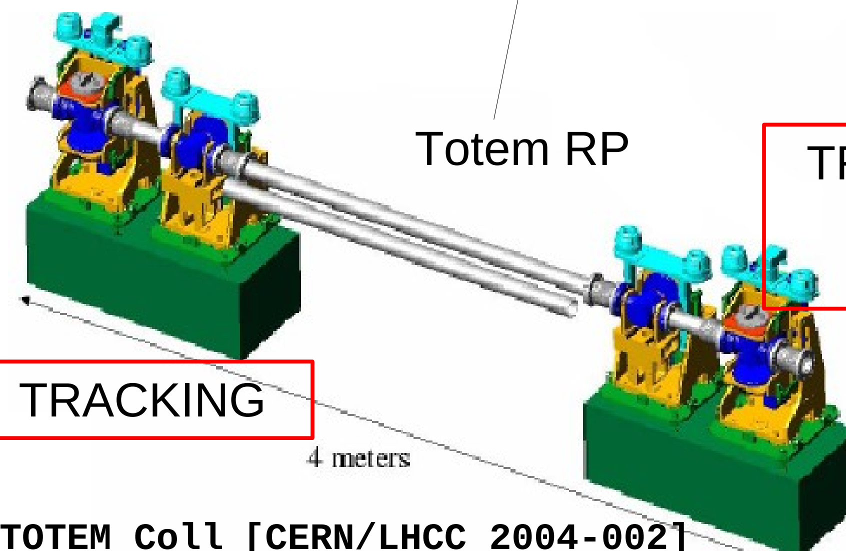


CALORIMETRY
neutrals

FP420

TRACKING
&
TIMING

Totem RP



TRACKING

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

TOTEM Coll [CERN/LHCC 2004-002]

Hector performance

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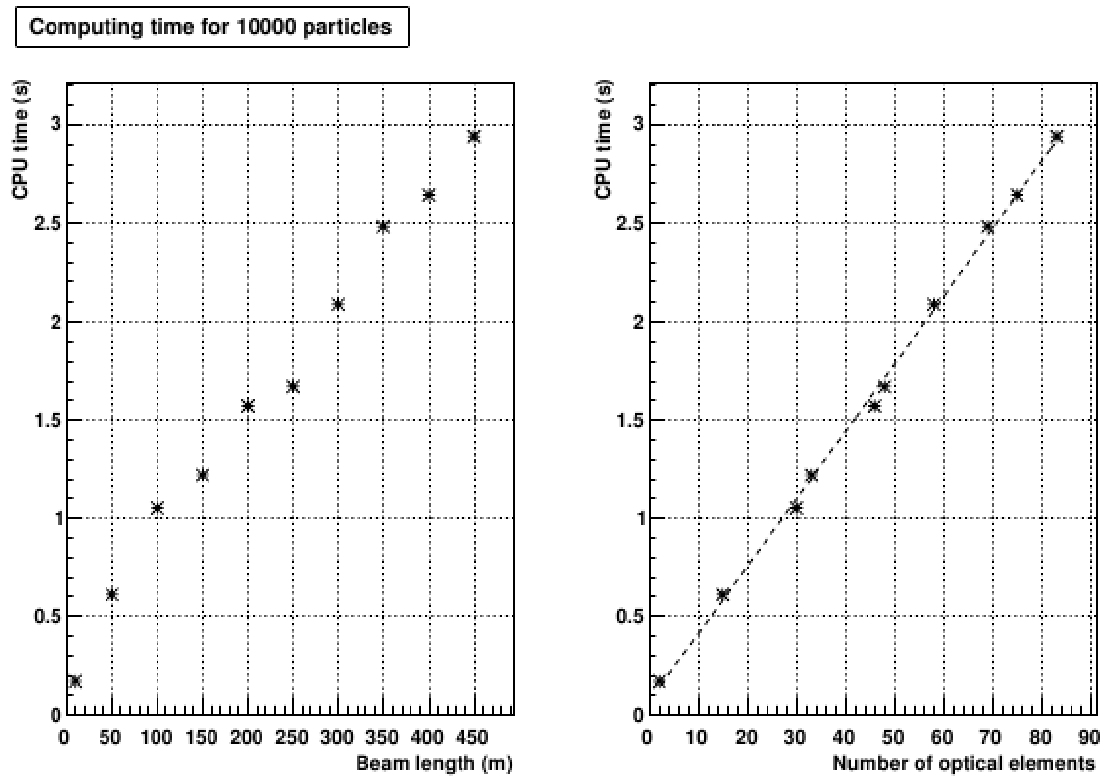
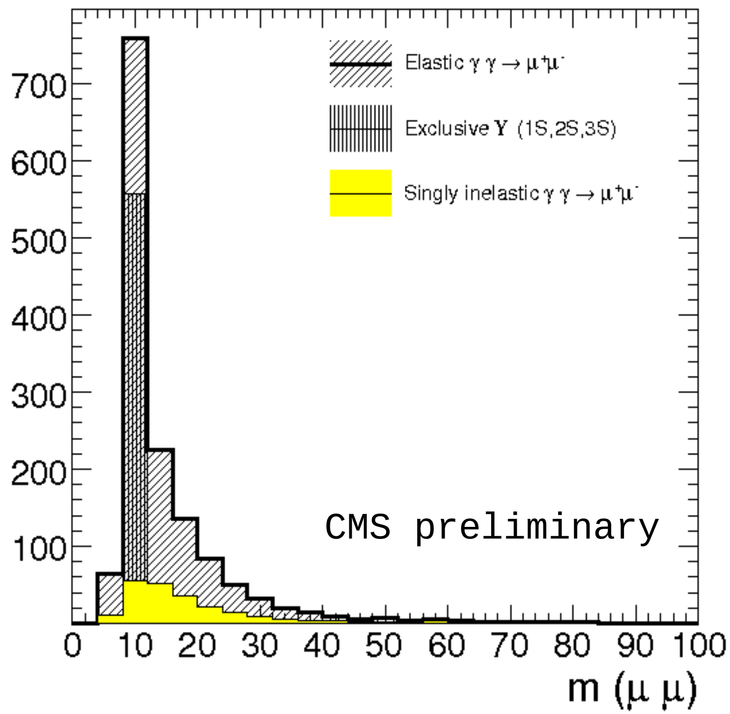


Exclusive dimuons

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

X. Rouby

Photon physics
Hector
Edgeless det.
Excl. dileptons
- dimuons
- dielectrons
- upsilon



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