Exclusive production of muon pairs in the CMS experiment

Xavier Rouby – Strasbourg – Nov. 21rst, 2008
Albert-Ludwigs-Universität Freiburg

LHC & CMS

central & forward detectors

Exclusive muon pairs

gamma-gamma fusion

theory & motivations

selection

applications

Upsilon photoproduction

theory & measurement

This work was done during my Ph.D. in the Université Catholique de Louvain (Belgium)

The LHC accelerator

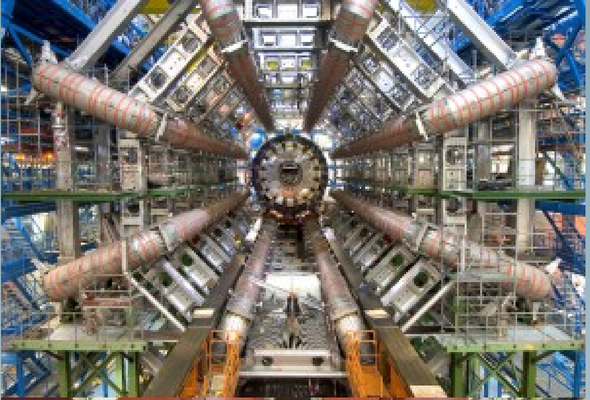
LHC : Large Hadron Collider

Goal: study the structure of matter with particles colliding at very high energies

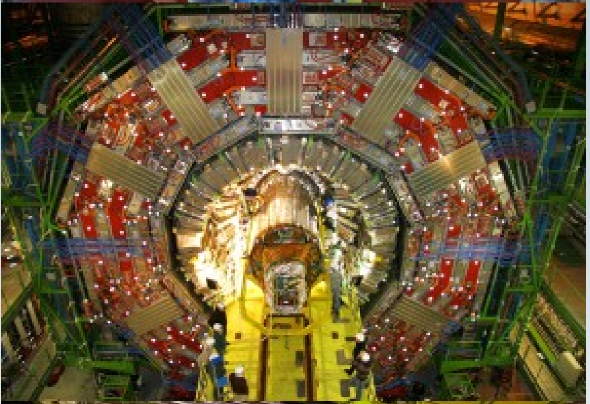
CERN – Genève (Suisse)

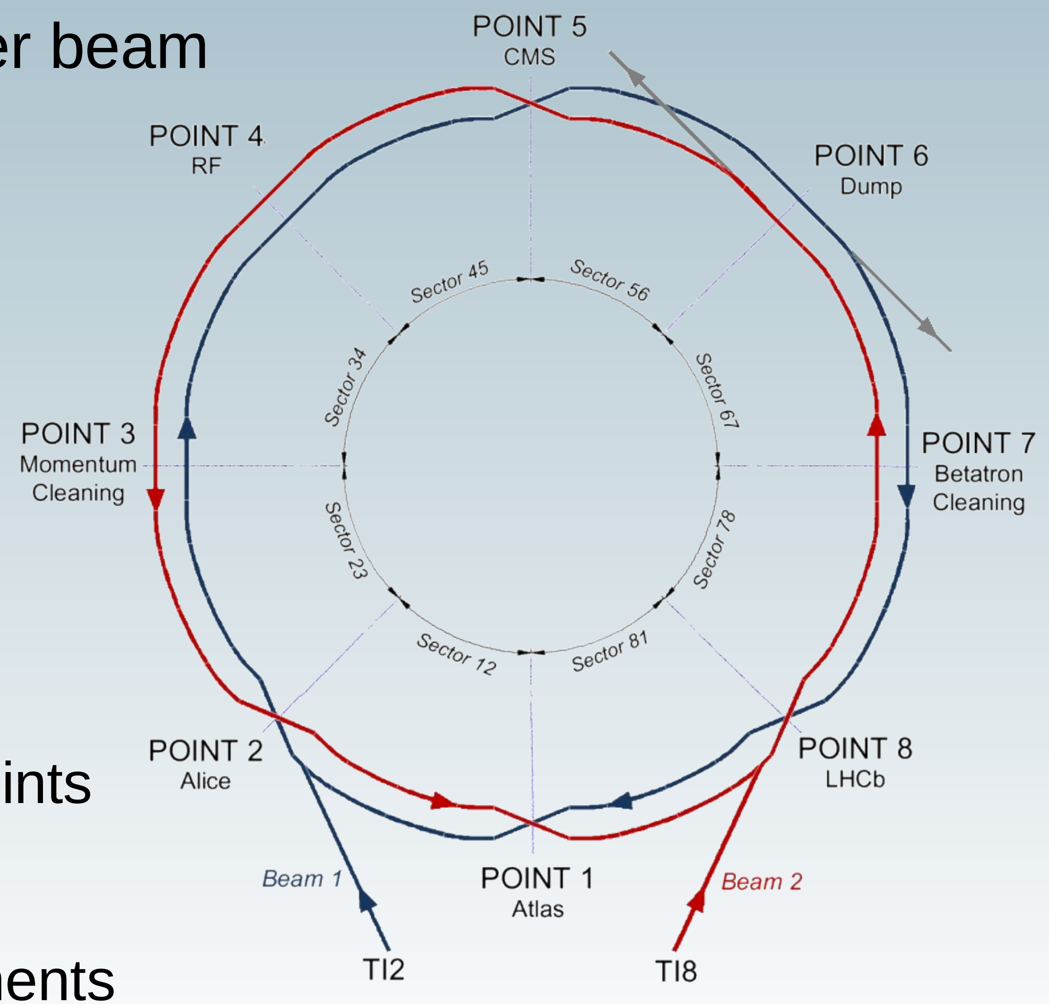
Large Hadron Collider

- 100 m underground
- 27 km circumference
- 2 proton beams
- 7 TeV per beam


ATLAS


ALICE


CMS



4 interaction points

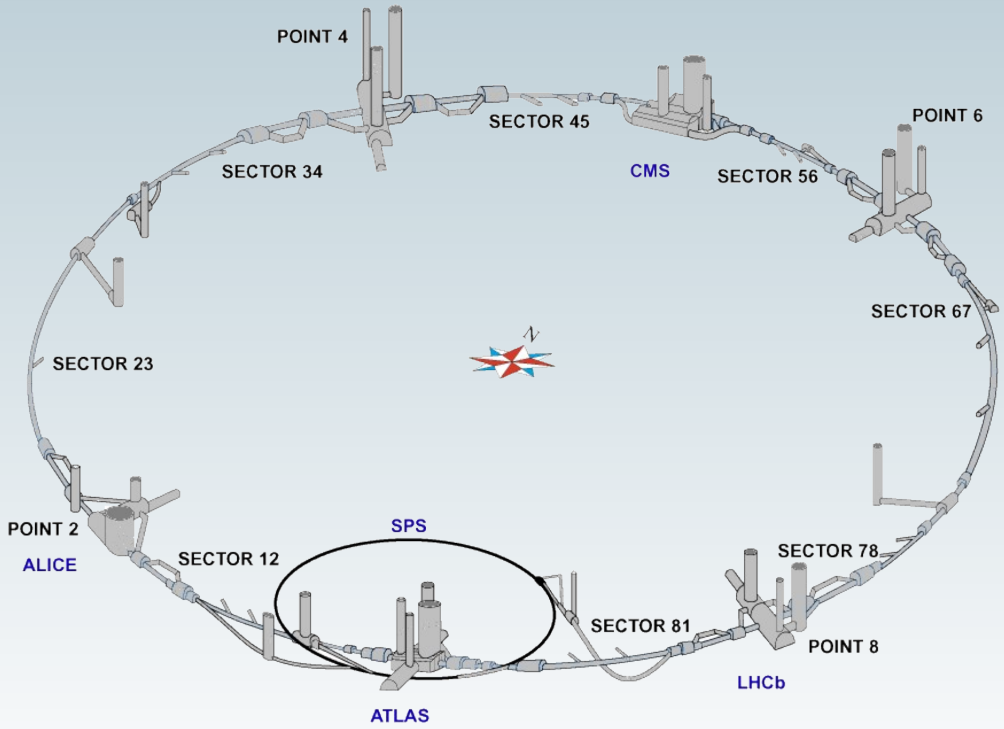
=

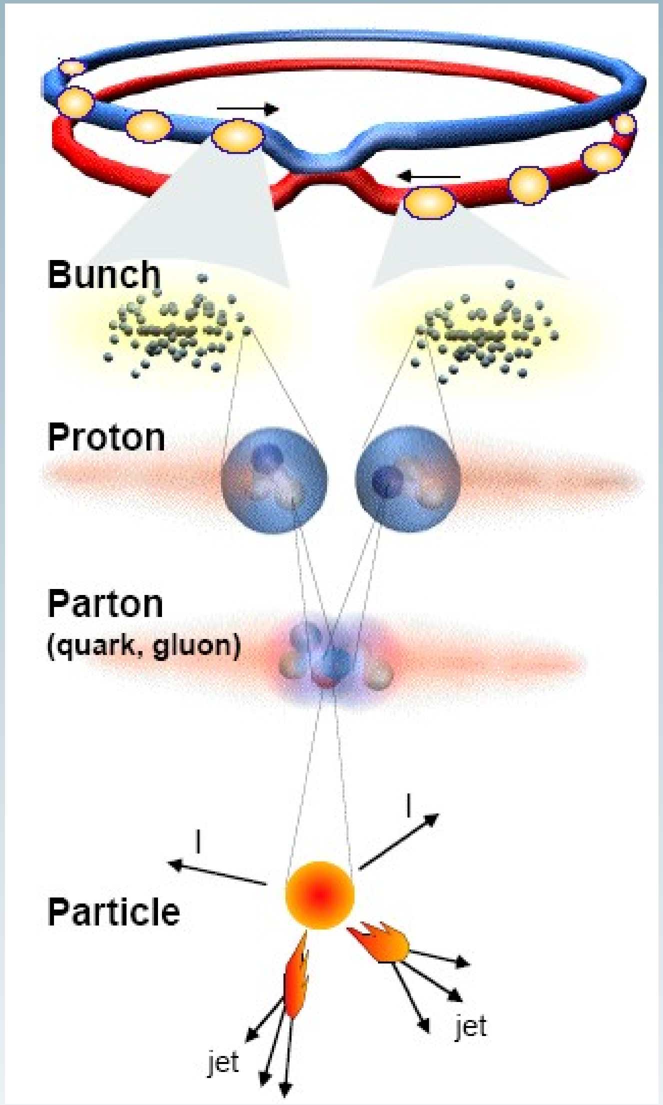
4 large experiments


LHCb

Large Hadron Collider

- 2835 x 2835 bunches
- 10^{11} protons per bunch
- 40 000 000 beam crossings per second

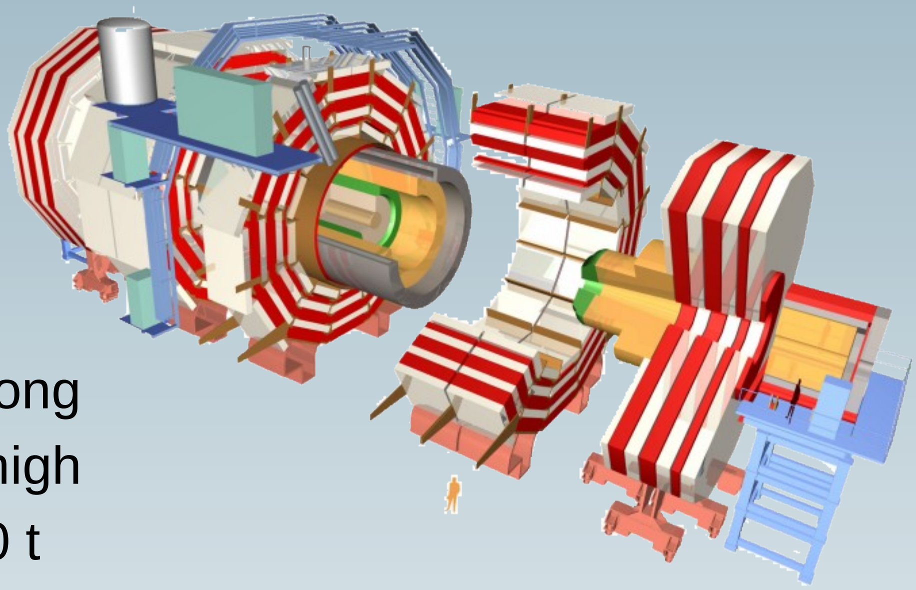




The CMS experiment

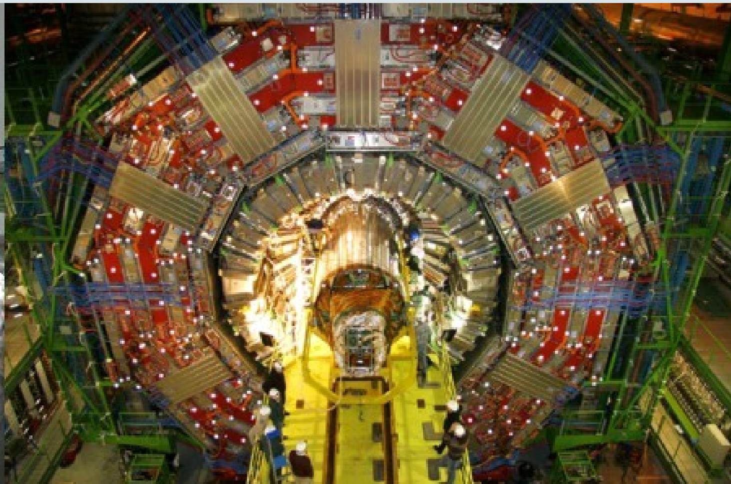
The CMS experiment

Central detector



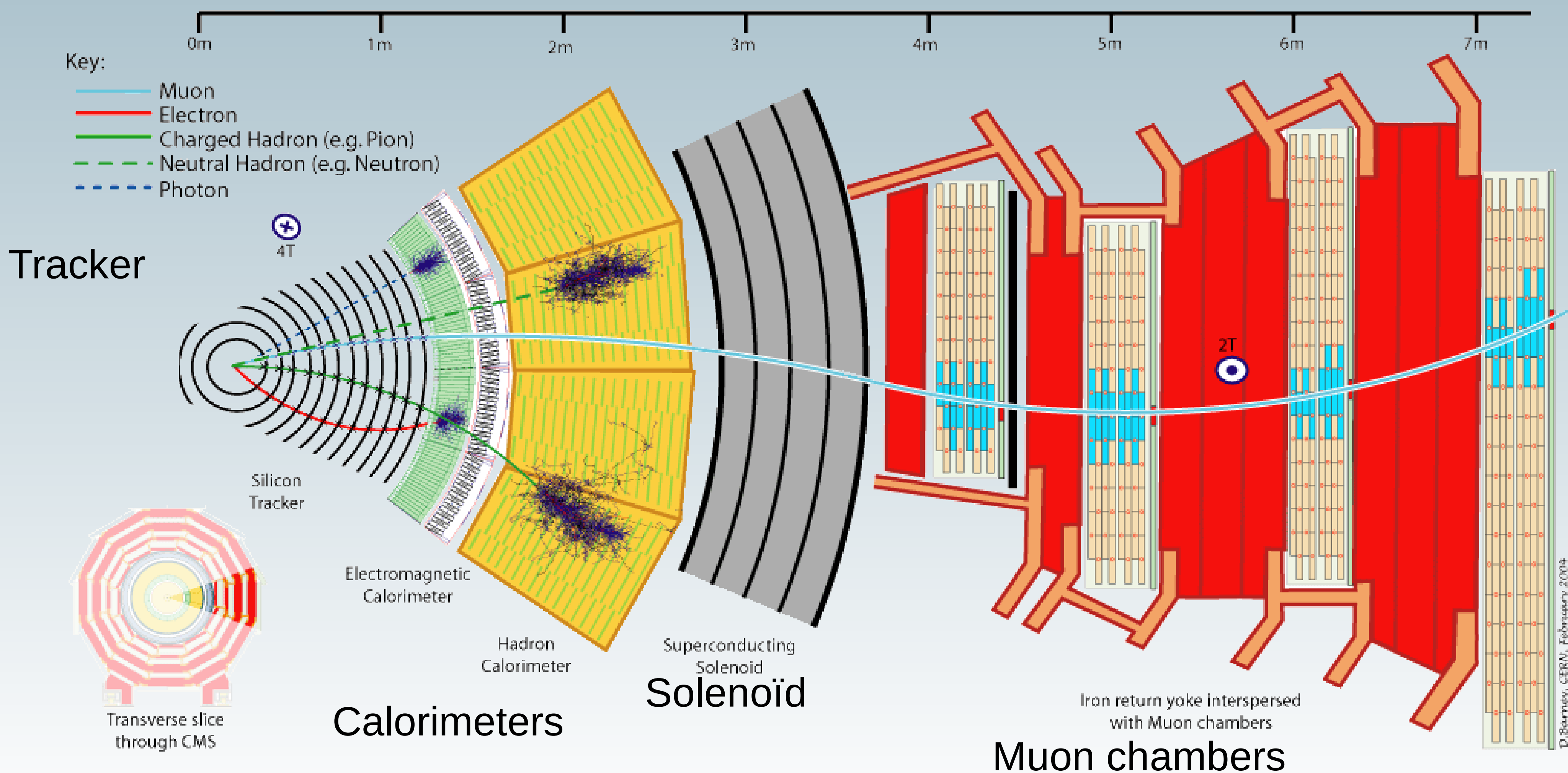
21 m long
15 m high
12 500 t

Generic experiment for the study of Physics within and beyond the Standard Model (Higgs, SUSY, ...).



The CMS experiment

The central detector is composed by several layers, for the identification and the measurement of the particles.



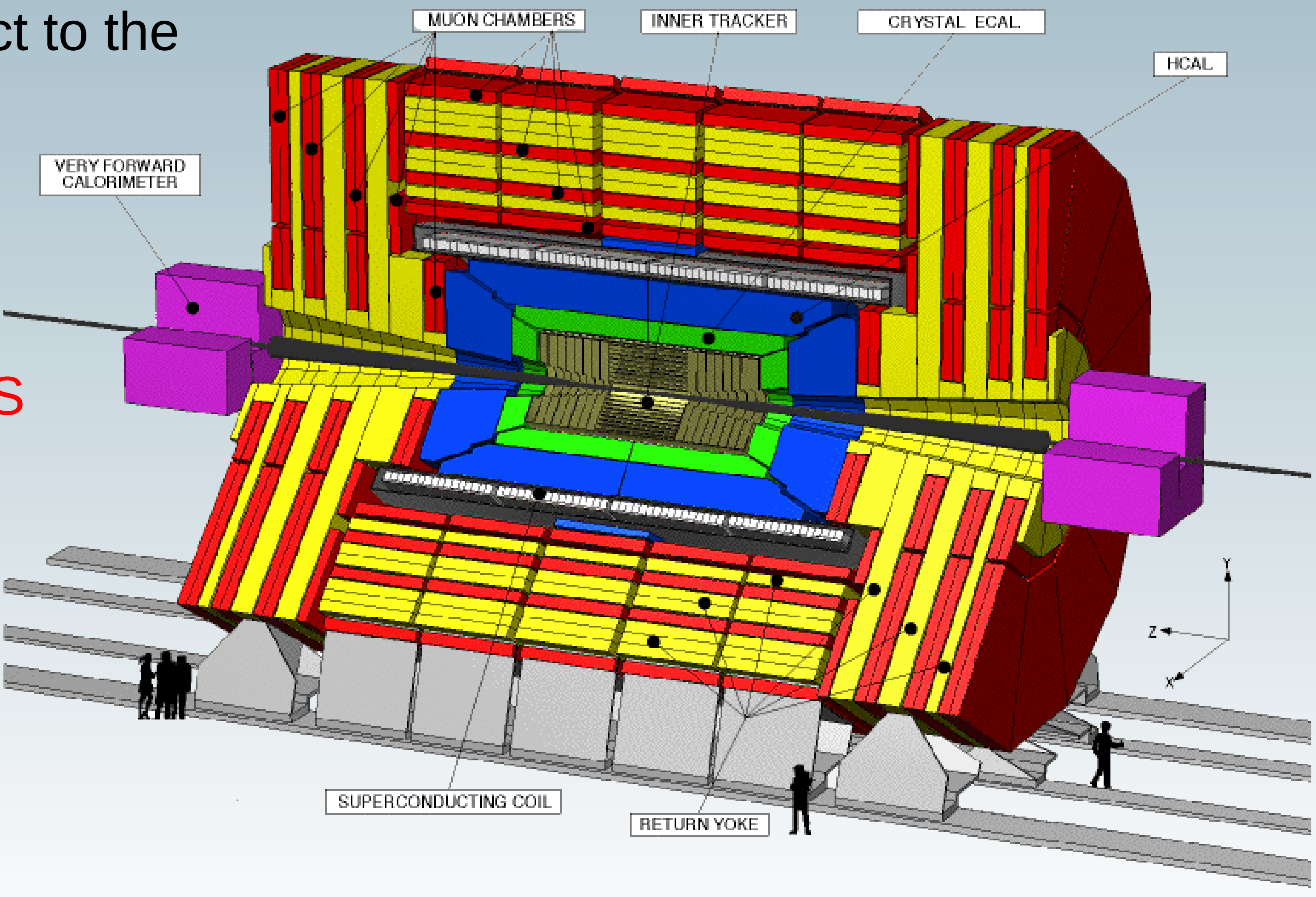
CMS: forward detectors

Tracking: -2.5 < η < 2.5

Calorimeters: -5 < η < 5

Some final state particles are emitted or are scattered with a very small angle with respect to the beam direction.

These can escape from CMS by the beampipe without being detected.



CMS: forward detectors

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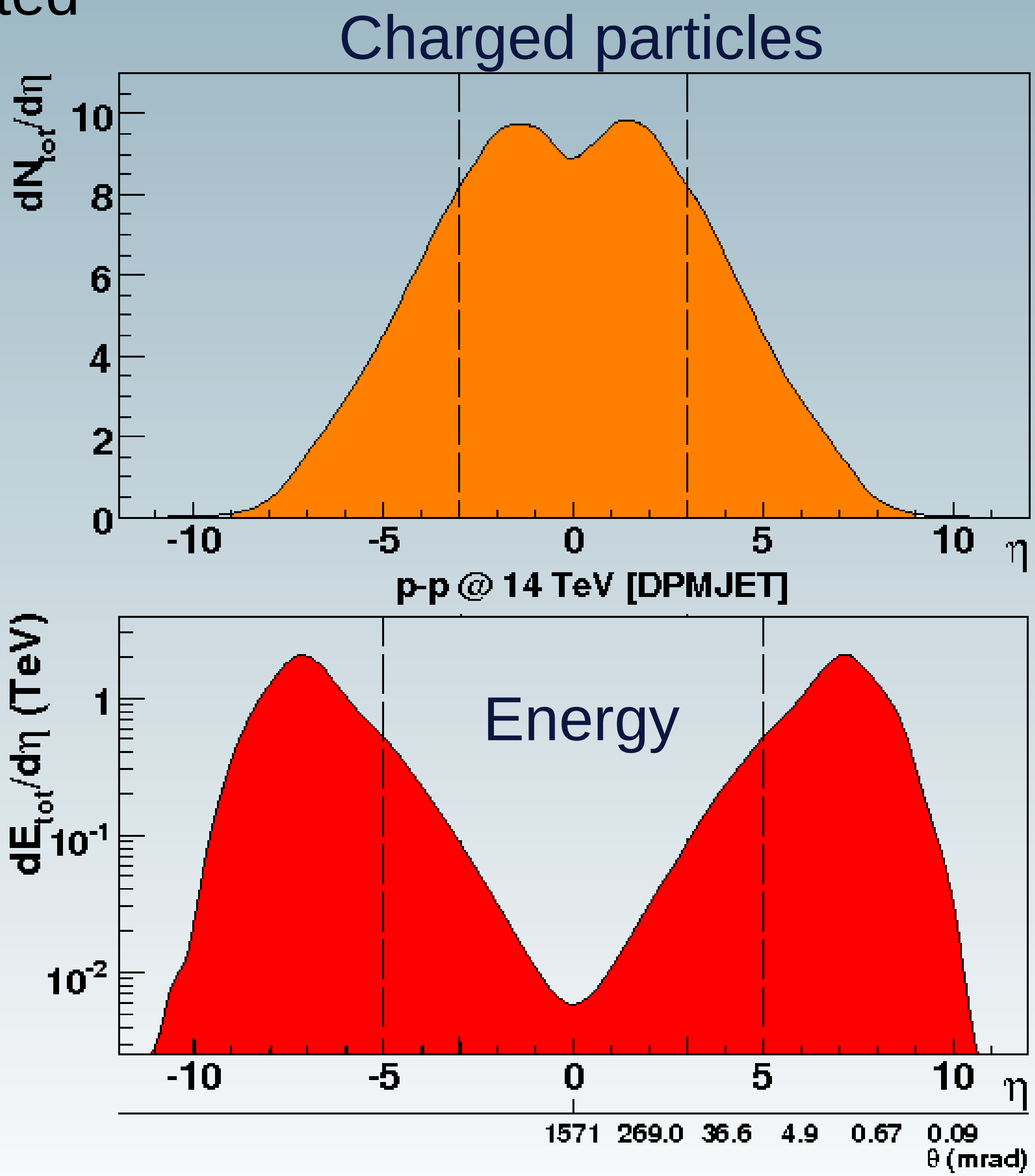
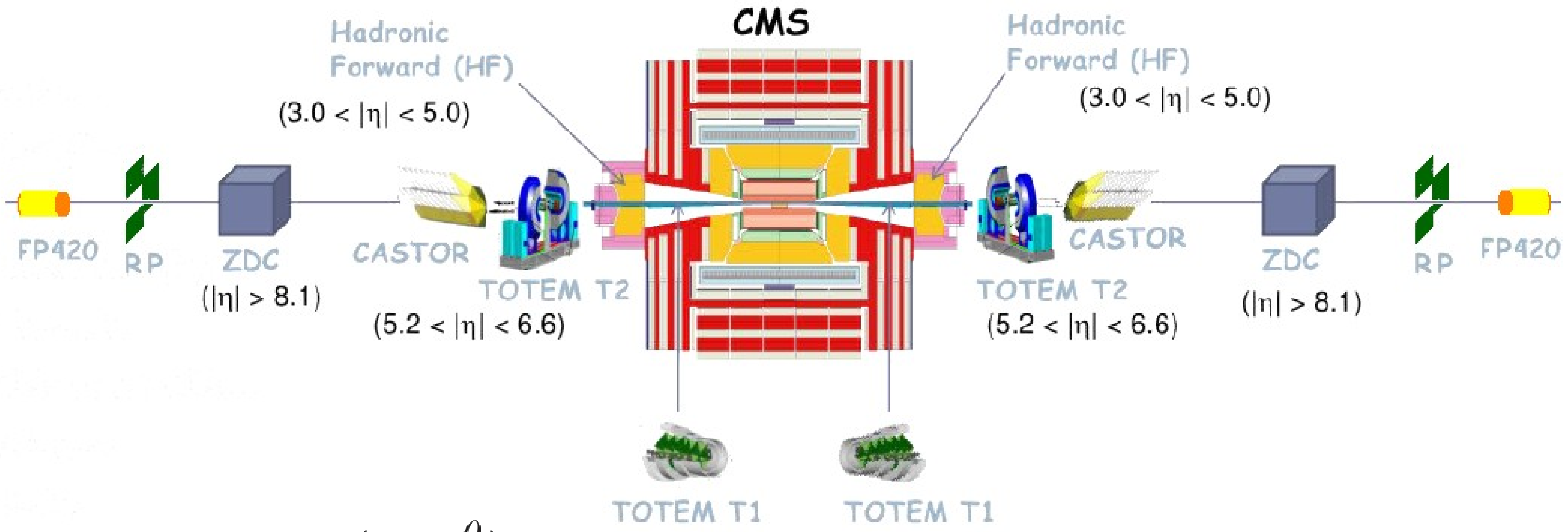


D. d'Enterria, [hep-ex/0708.0551]

CMS: forward detectors

Some distant detectors have been added in order to increase the coverage of the experiment. Moreover, a common physics programme has been settled with the TOTEM experiment



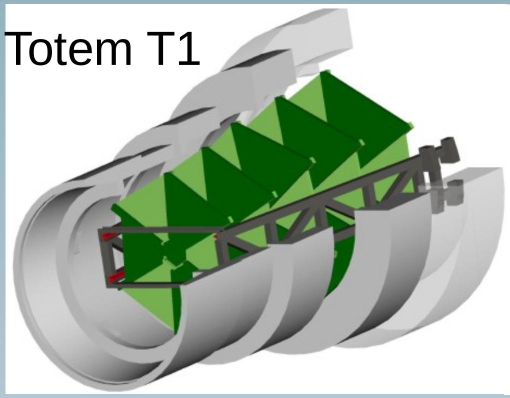
$$\eta = -\ln\left(\tan\frac{\theta}{2}\right)$$

CASTOR, ZDC : Calorimeters

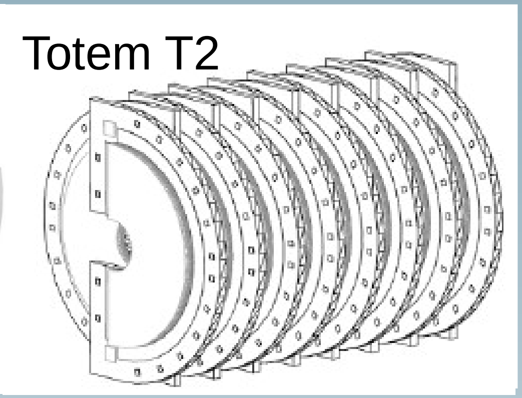
T1, T2, RP, FP420 : tracking

CMS: forward detectors

Totem T1



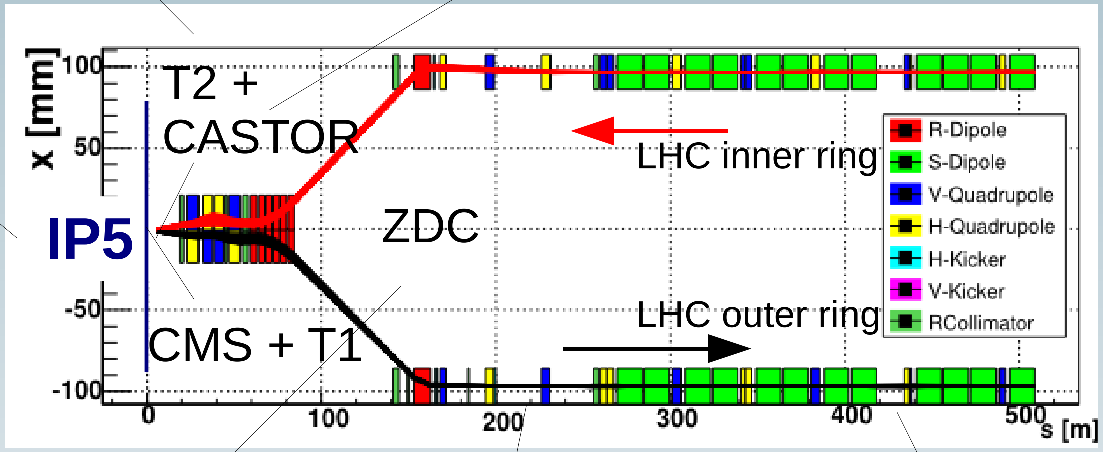
Totem T2



CASTOR (*)

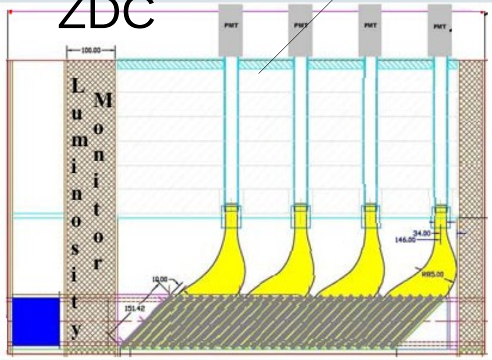
CALORIMETRY

TRACKING



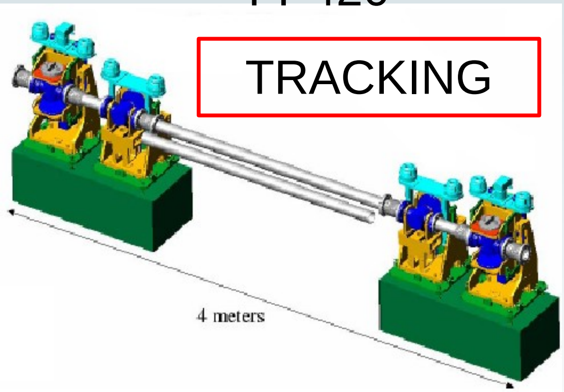
CALORIMETRY
neutrals

ZDC



Totem RP

FP420

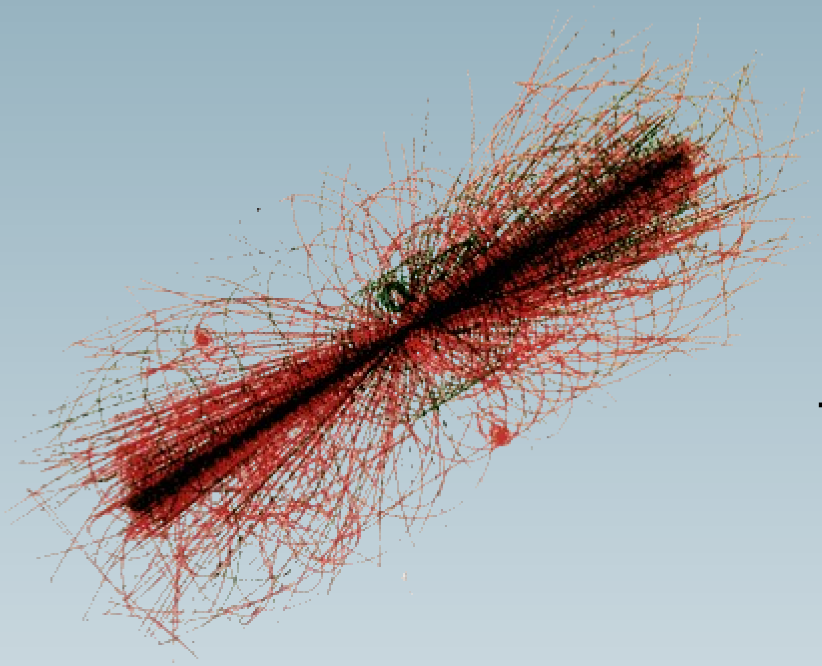


TRACKING

TOTEM Coll [CERN/LHCC 2004-002]
X. Rouby, CMS CR-2008/020

Photon-induced processes

Collisions at the LHC

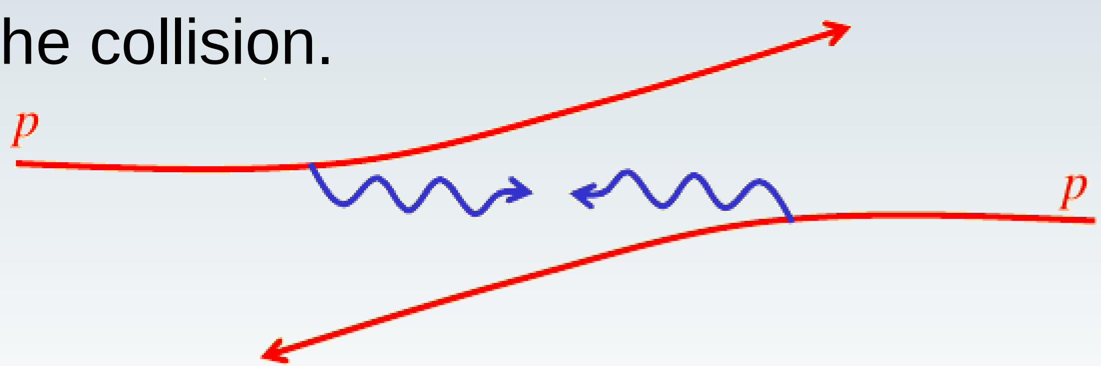


Protons are not elementary particles and they will mainly interact with the

strong force

This leads to a lot of particle observed in the final state

However, if protons interact through the exchange of one or several photons, there is a significant probability that they stay intact and survive from the collision.



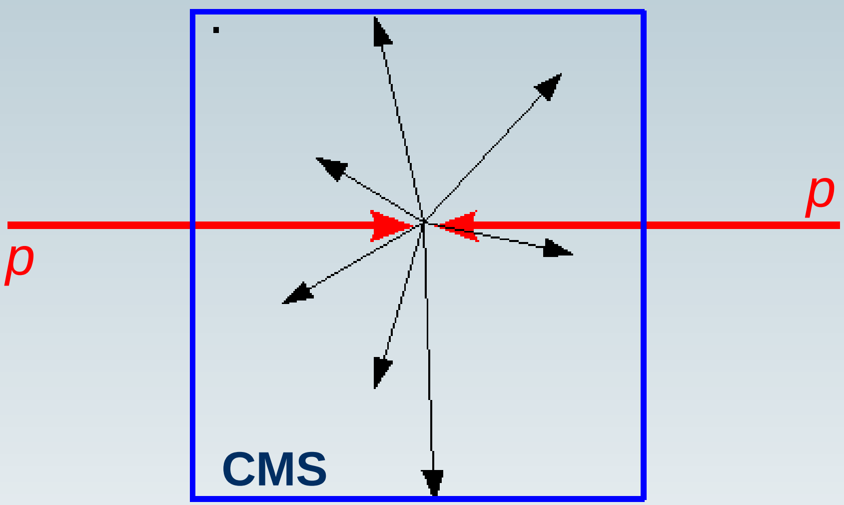
Photon exchanges

Direct consequence:

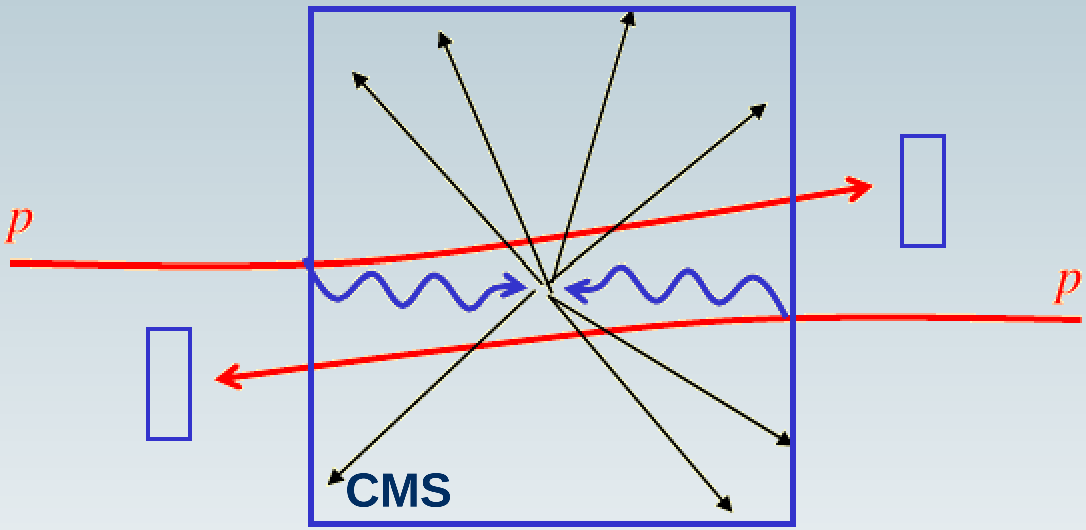
- The observed final state contains far less particles.

Cleaner final state!

- At least one protons is scattered in the forward region with a very small angle



Proton-proton interaction



Photon-photon interaction

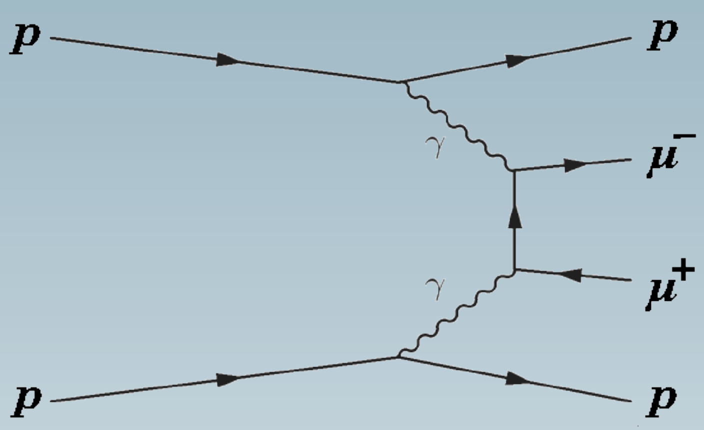
➡ The detection of the forward proton(s) allows to tag the photon interactions from the usual proton-proton collision.

Production of exclusive pairs of muons

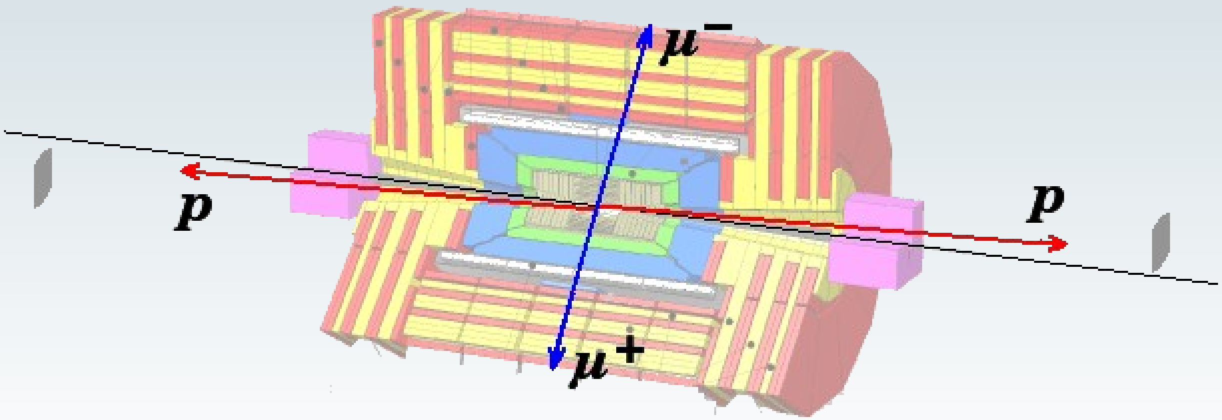
Exclusive muon pairs

Work with S. Ovyn et J. J. Hollar
J. Hollar, S. Ovyn, X. Rouby, CMS AN-2007/032

The incoming protons interact via two photons. The photon-photon fusion yields a $\mu^{+}\mu^{-}$ pair.



Due to the photon emission,, the protons are *elastically* scattered, with a tiny angle with respect to the beam direction.

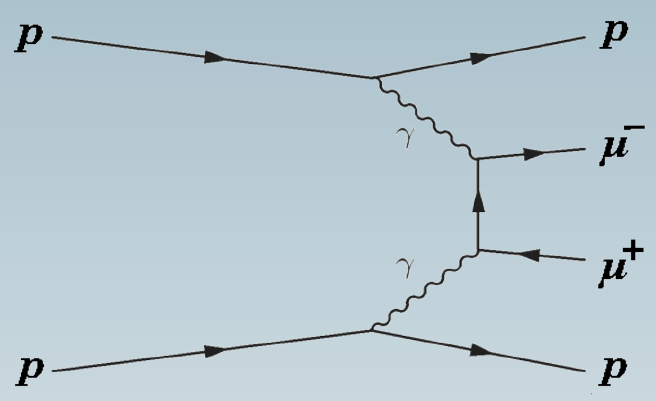


- Muons: measured by CMS.
- Protons: seen in the forward detectors.

Exclusive muon pairs

Motivations:

- Theoretically well known process. (<1% on σ)
- Easy selection; few processes have a similar signature.
- CMS is made for muon measurement



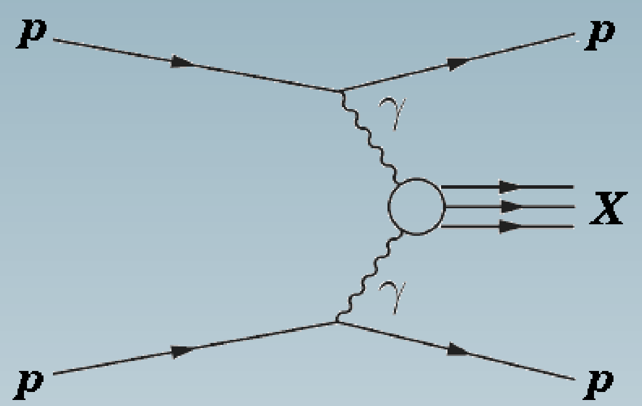
- Observing such muon pairs allow to measure the integrated luminosity (L) provided by the LHC to CMS, which is crucial to compare predictions (σ) to data (N):

$$N = L\,\sigma$$

Equivalent Photon Approximation

The incoming proton beam can be seen

as an flux of photon



LHC as a photon collider!

EPA: Equivalent Photon Approximation

Collision (pp) = collision (γ γ) x flux$_1$(γ) x flux$_2$(γ)

$$d\sigma_{pp} = \sigma_{\gamma\gamma}(x_1, x_2, s)\ dN(x_1, Q_1^2)\ dN(x_2, Q_2^2)$$

V. M. Budnev et al, Phys. Rept. 15 (1974) 181.

The EPA approximation allows to factorize

the photon emission from the collision process

Exclusive muon pairs

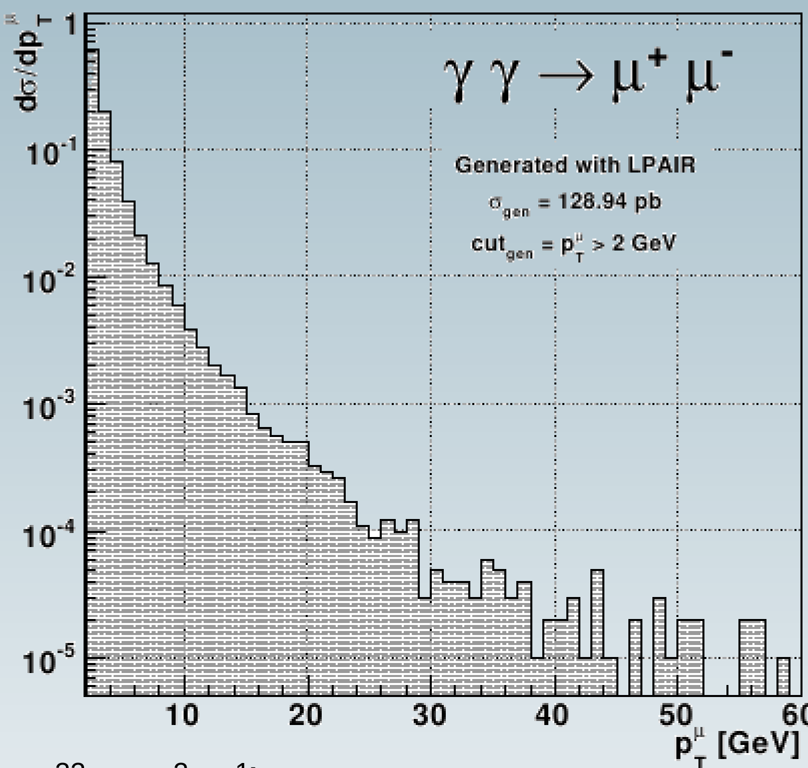
Total cross section (LPAIR):

1.47×10^8 fb – no cut

74.7×10^3 fb – $p_T > 2.5$ GeV: elastic case: the protons remain intact

76.2×10^3 fb – $p_T > 2.5$ GeV: inelastic case: one proton dissociates

Muon p_T



Large cross section

Very well known: QED

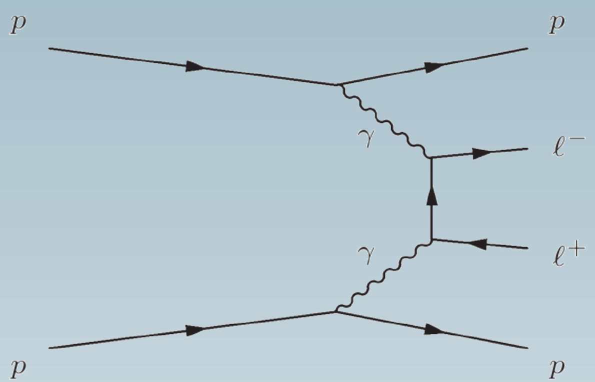
Very clean final state (if pile-up neglected: $L < 10^{33}$ cm^{-2} s^{-1})

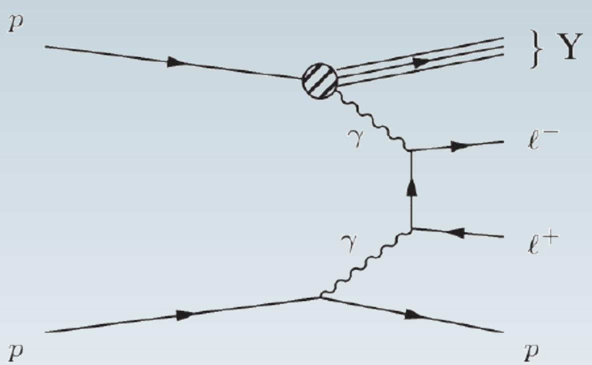
Exclusive pair of muons

(Almost) no proton remnant in CMS

Exclusive muon pairs: backgrounds

- Signal and main backgrounds





photon-photon (LPAIR)

– no cut:
1.47×10^{8} fb (elastic)

– $p_T > 2.5$ GeV
74.7×10^{3} fb (elastic)

– $p_T > 2.5$ GeV
76.2×10^{3} fb (inelastic)

Reducible background events include:

- Drell-Yann processes
- W pairs
- Heavy quark decays
  (Upsilon exclusive photoproduction)

Exclusive muon pairs: selection

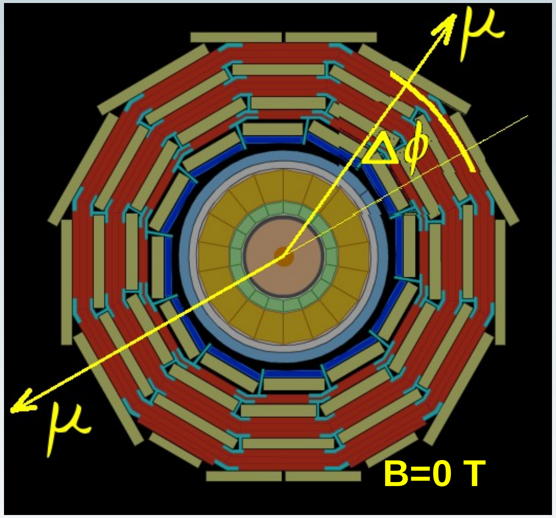
- The selection of these events by CMS is possible thanks to the following characteristics:

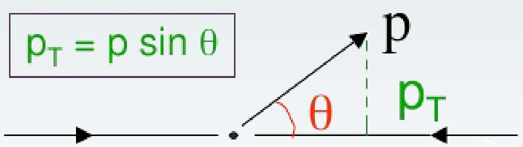
1° Exclusivity requirement:

only two muons in CMS

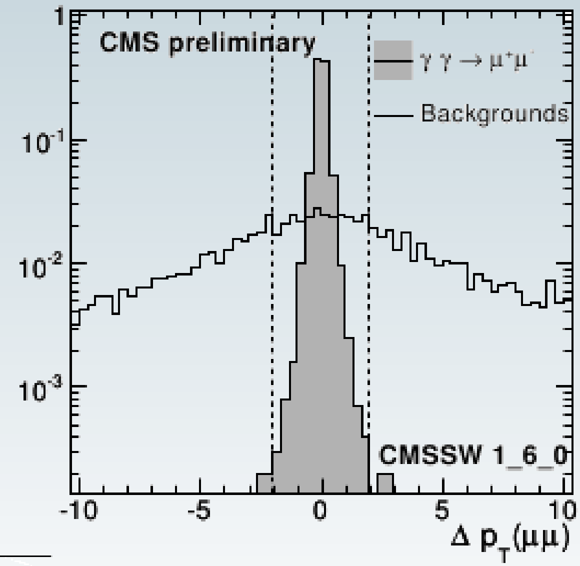
2° Kinematical requirements:

Very good balance of the direction and the momentum of each muon, in the transverse plane





Plane transverse to the beam

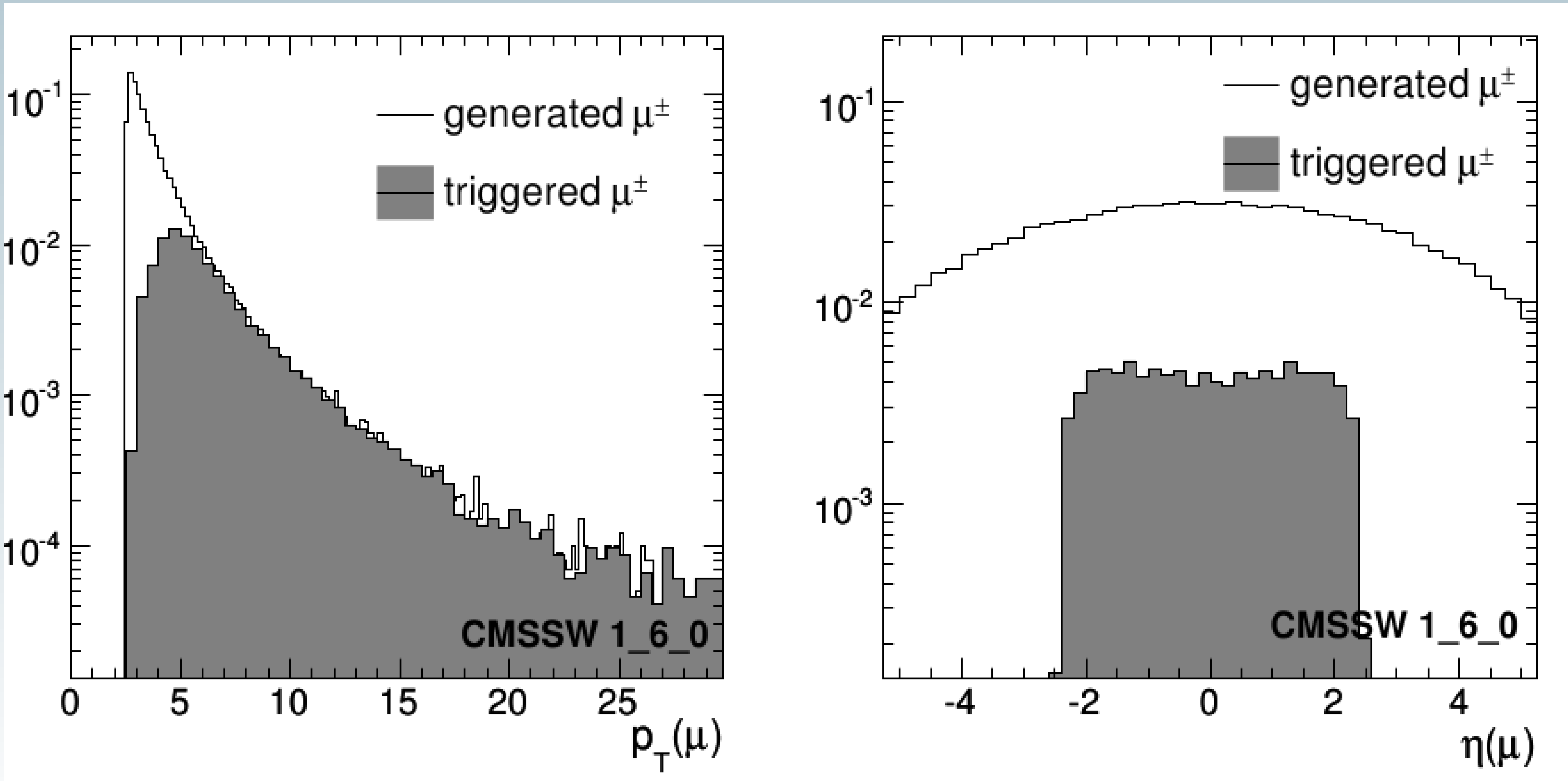


Exclusive muon pairs: selection

- Trigger (online selection) :

  p_T > 3 GeV (default CMS di-muon trigger) at low luminosity

  Central pseudorapidity ($|\eta|<2.4$)

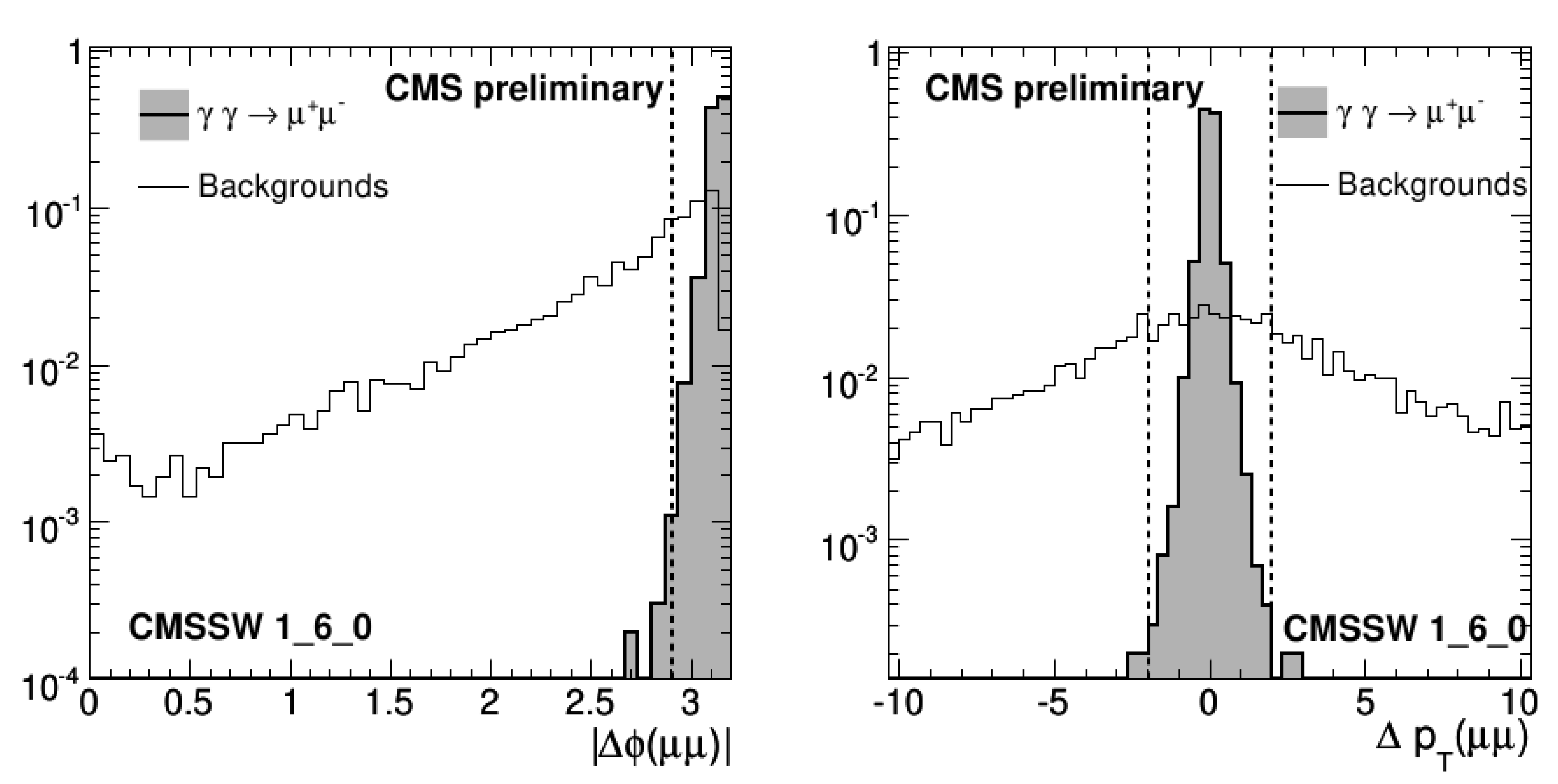


Exclusive muon pairs: selection

- Offline selection

  - Kinematical requirements

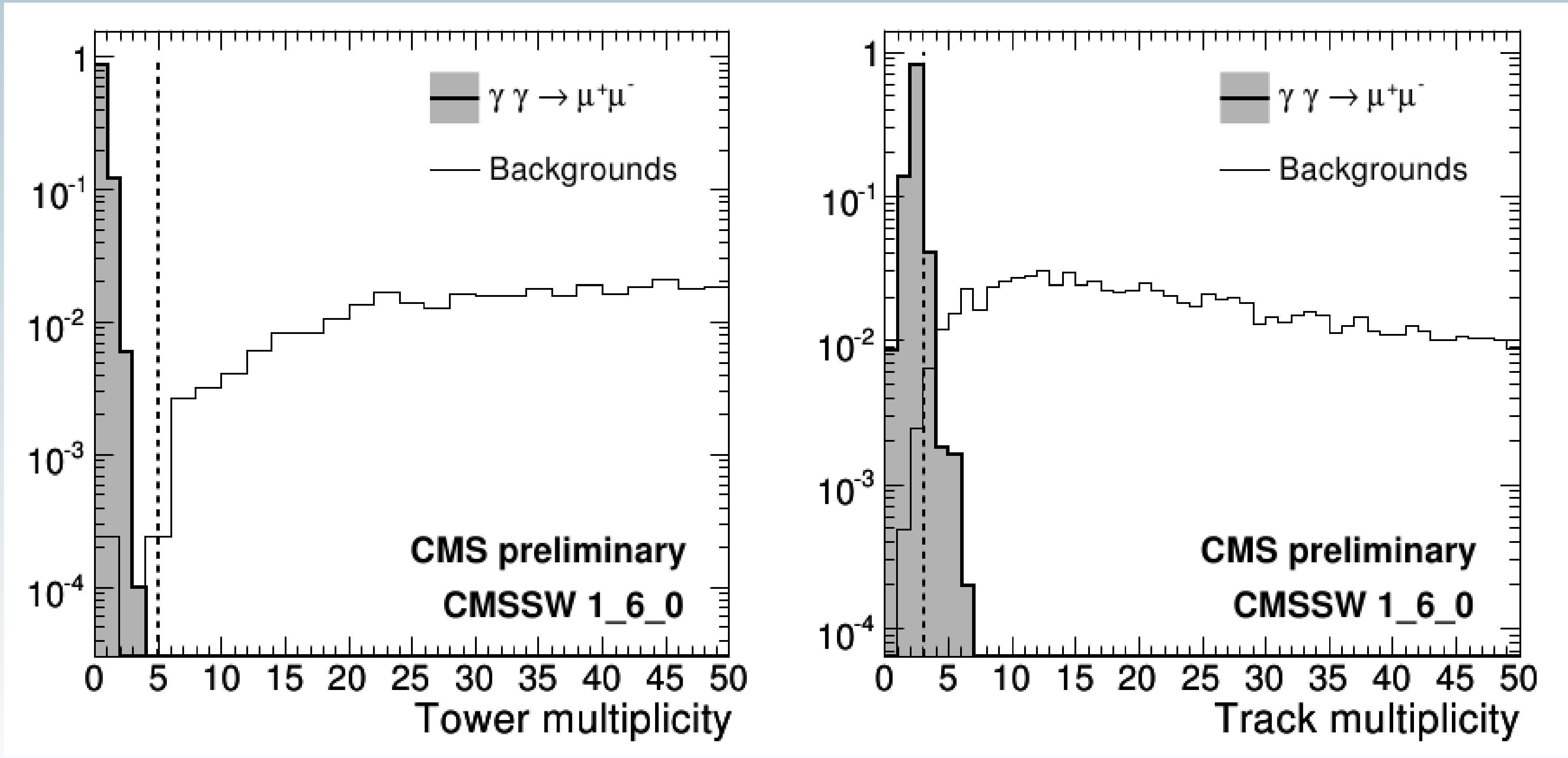
Back-to-back muons in the transverse plane



Exclusive muon pairs: selection

- Offline selection
  - Exclusivity requirements

    Only 2 muons are expected



Exclusive muon pairs: results

Selection efficiency

	$\mu\mu$	**inel**	$\mathbf{DY}_1$	$\mathbf{DY}_2$	$\mathbf{DY}_3$
$\|\Delta\phi\| > 2.9$	99.9	57.8	10.1	23.9	53.5
$\|\Delta p_T\| < 2.0$ GeV	99.8	49.4	7.9	10.9	10.6
N(towers) < 5	99.8	47.6	< 7.0	< 0.26	< 0.14
N(tracks) < 3	95.4	45.8	< 3.5	< 0.16	< 0.14

Without the "Forward detector veto"

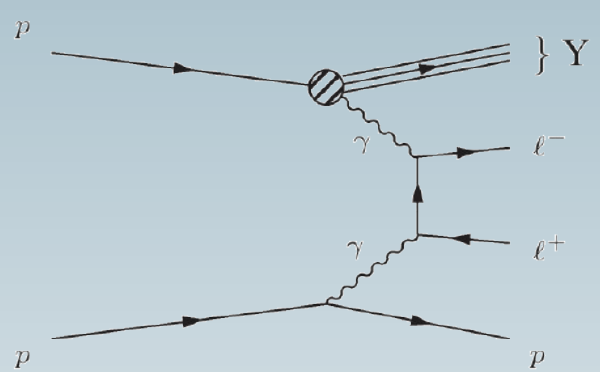
Selection summary

	$\mu\mu$	**inel**	$\mathbf{DY}_1$	$\mathbf{DY}_2$	$\mathbf{DY}_3$	Υ
σ (pb)	74.7	76.2	18,910	2976	899	62
N (events)	100k	20k	96.6k	3M	3M	16k
ϵ_{trig} (%)	10.0	18.3	0.1	4.8	9.7	8.5
ϵ_{sel} (%)	95.4	45.8	< 3.5	< 0.16	< 0.14	95.0
σ_{vis} (pb)	7.09	6.38	< 0.59	< 0.003	< 0.001	5.02

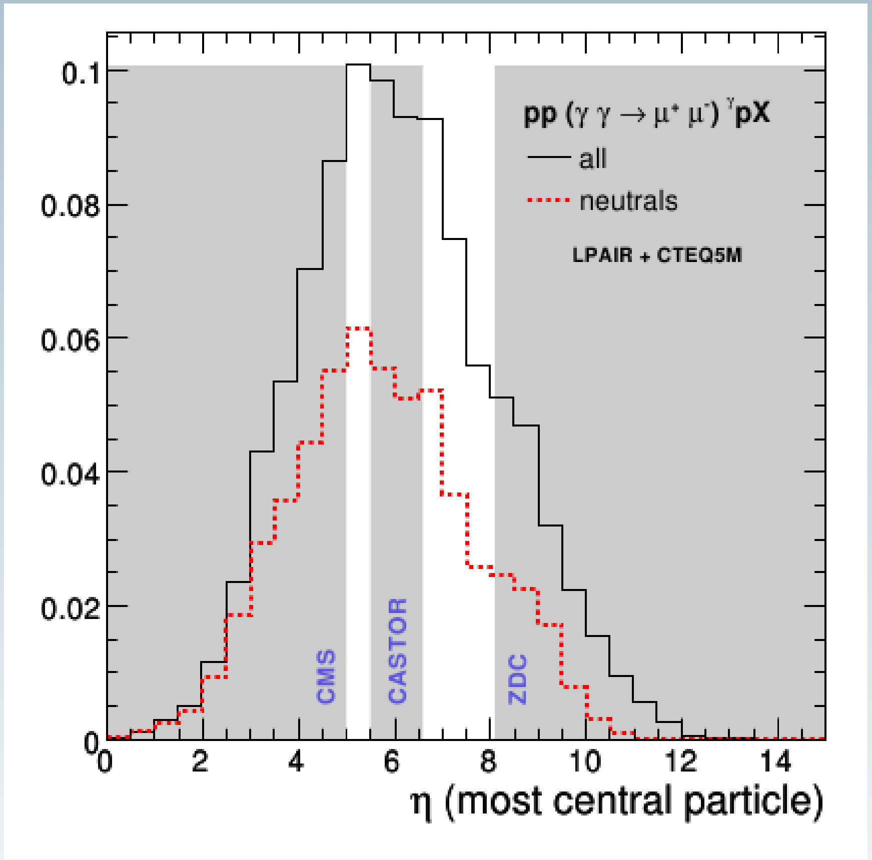
Without the "Forward detector veto"

Exclusive muon pairs: backgrounds

Rejection of inelastic events



The remnant of the broken proton can be seen in the forward detectors (T2+CASTOR, ZDC)



"Forward detector veto"

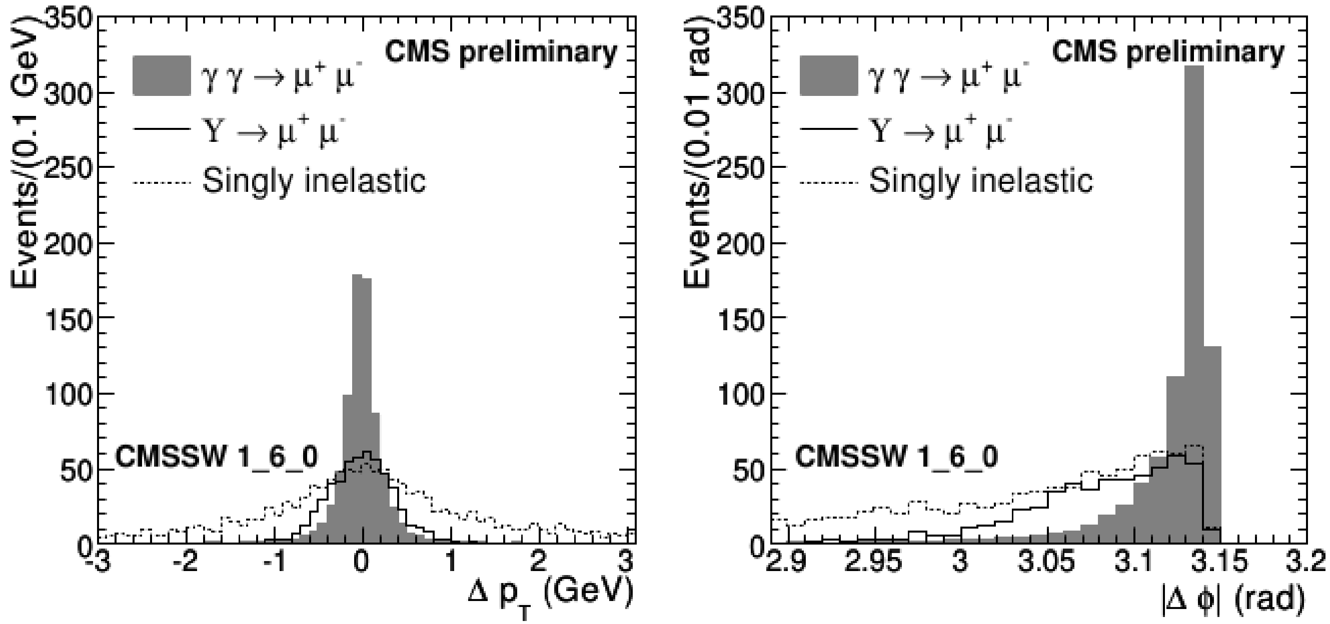
Exclusive muon pairs: results

Selection results, after L=100pb^{-1}

$$N_{elastic}(\gamma\gamma \rightarrow \mu^+\mu^-) = 709 \pm 27(stat)$$

$$N_{inelastic}(\gamma\gamma \rightarrow \mu^+\mu^-) = 636 \pm 25(stat) \pm 121(model)$$

$$N^{w/veto}_{inelastic}(\gamma\gamma \rightarrow \mu^+\mu^-) = 223 \pm 15(stat) \pm 42(model)$$



Applications

Luminosity measurement

The global selection efficiency is known from the MC analysis.

$$\Upsilon - \text{veto}: \quad M_{\mu\mu} < 9 \text{ GeV OR } M_{\mu\mu} > 11 \text{ GeV}$$

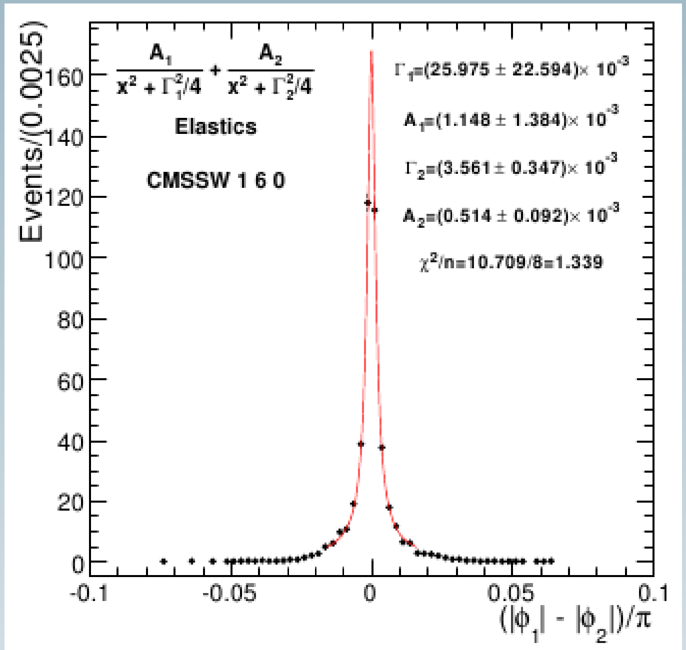
$$\mathrm{L} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\epsilon\ \sigma}$$

The cross-section σ is very well known theoretically (<1%)

$$N_{elastic}(\gamma\gamma \to \mu^+\mu^-) = 426 \pm 21(stat) \pm 4(th)$$

$$N^{w/o\ veto}_{inelastic}(\gamma\gamma \to \mu^+\mu^-) = 407 \pm 20(stat) \pm 77(model)$$

$$N^{w/\ veto}_{inelastic}(\gamma\gamma \to \mu^+\mu^-) = 141 \pm 12(stat) \pm 27(model)$$



Determination of N_{bkg}

Luminosity measurement

$$L = \frac{N_{\rm obs} - N_{\rm bkg}}{\epsilon\ \sigma}$$

Systematic uncertainties are kept under control

Acceptance	1.5%	Calibration using inclusive low p_T muon
Muon p_T scale	$< 0.3\%$	Use $\gamma p \to \Upsilon p \to \mu^+\mu^- p$
Calorimetric excl.	2%	Monitoring and masking the noisy calotowers and/or forward rap gap without calorimeter excl.
Tracking excl.	–	Use tracking algorithm dedicated to low p_T track reconstruction
Acoplanarity fit	1.5%	More data and/or other types of fit.

Syst. errors < 3%

At L=100 pb^{-1}, the statistical error dominates.

Luminosity measurement

X. Rouby, K. Piotrzkowski, CMS AN 2008/061

$$\mathrm{L} = \frac{N_{\mathrm{obs}} - N_{\mathrm{bkg}}}{\epsilon\ \sigma}$$

Overall uncertainty < 7%

Scenario (i): $\mathrm{L}_{true} = 100\ \mathrm{pb}^{-1}$

$$\mathrm{L}_{meas} = 96.8 \pm 6.1(stat) \pm 1.0(th) \pm 2.9(syst)\ \mathrm{pb}^{-1}$$

Scenario (ii): $\mathrm{L}_{true} = 100\ \mathrm{pb}^{-1}$ with forward calorimeter veto

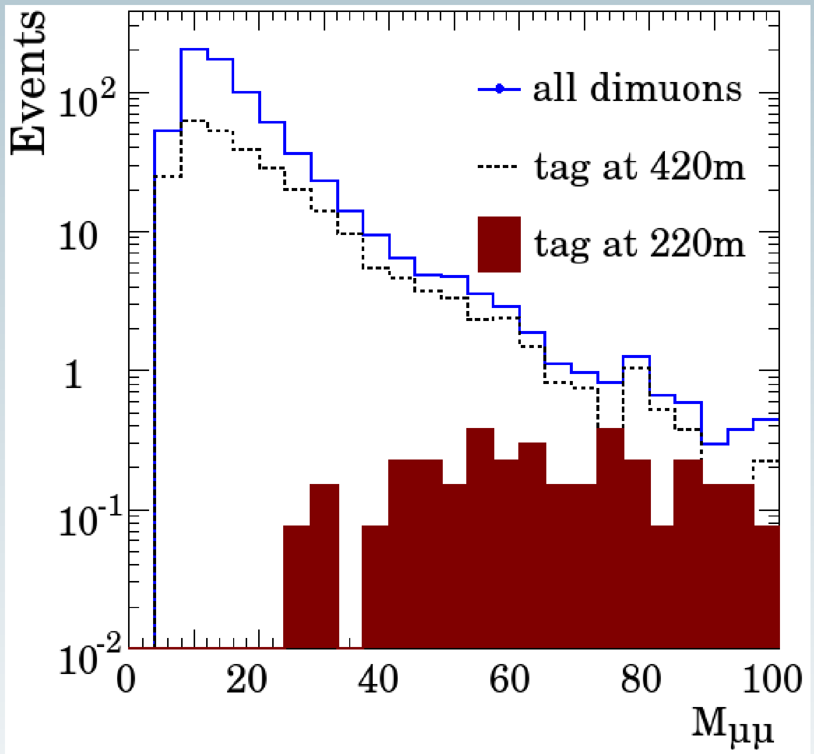
$$\mathrm{L}_{meas} = 99.4 \pm 5.3(stat) \pm 1.0(th) \pm 2.9(syst)\ \mathrm{pb}^{-1}.$$

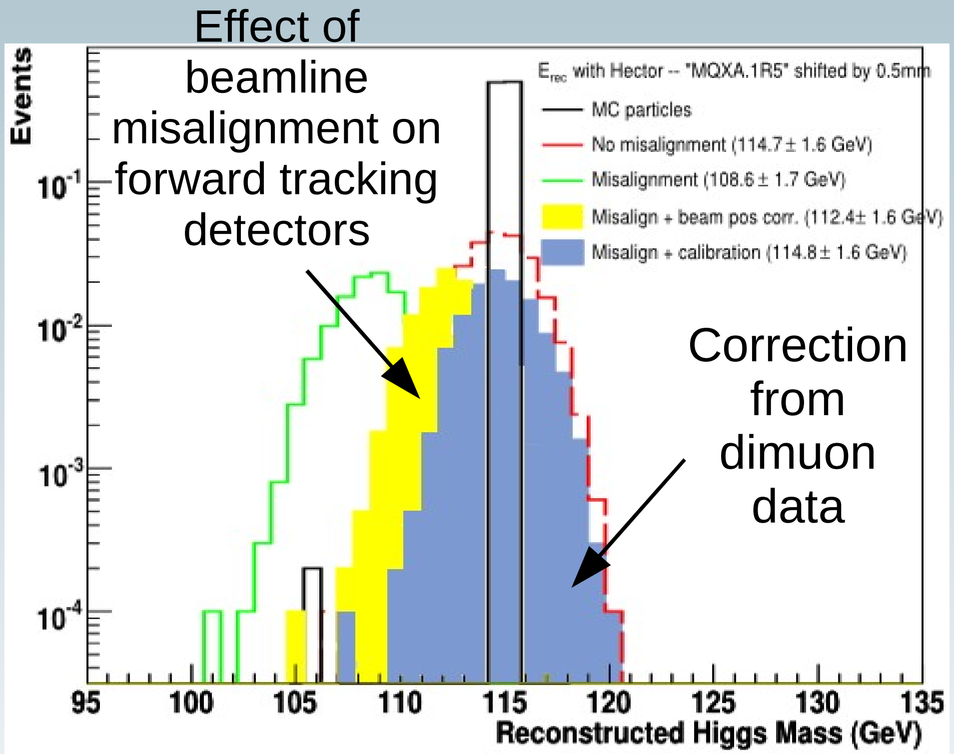
At low luminosity (low pile-up) this method looks the best one for the absolute luminosity measurement in CMS

Alignment of the forward detectors

– Luminosity normalization: offline calibration of lumi monitors
– Forward detector calibration+ alignment

Rouby, de Favereau, Piotrzkowski
[JINST 2 P09005]



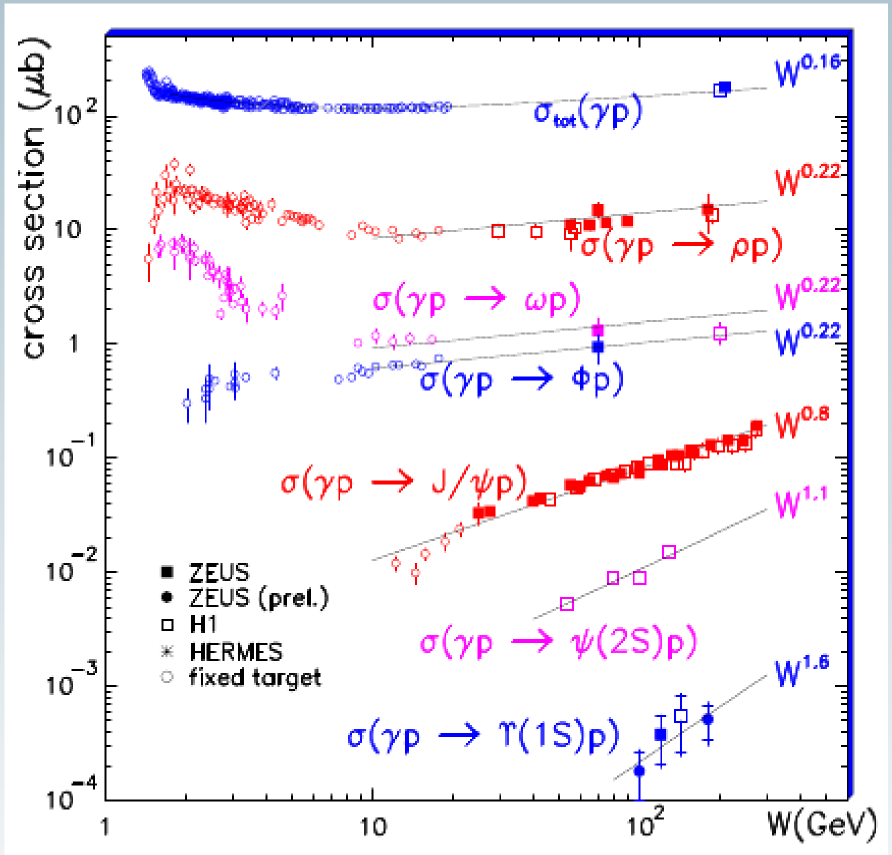


Upsilon photoproduction

Upsilon meson production

Upsilon : Υ = (bb)

HERA measurements



Cross Section: badly known

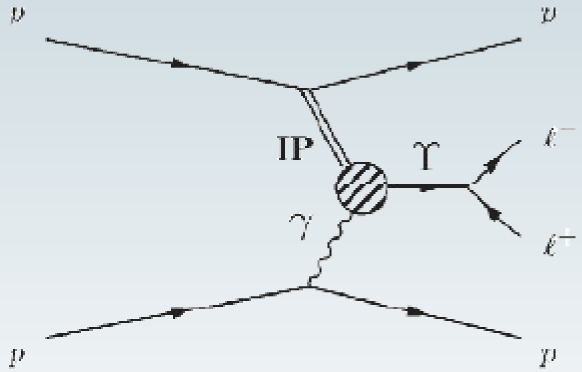
but the upsilon masses are very

precisely measured

(narrow resonances)

This can serve as a calibration

tool for the experiment

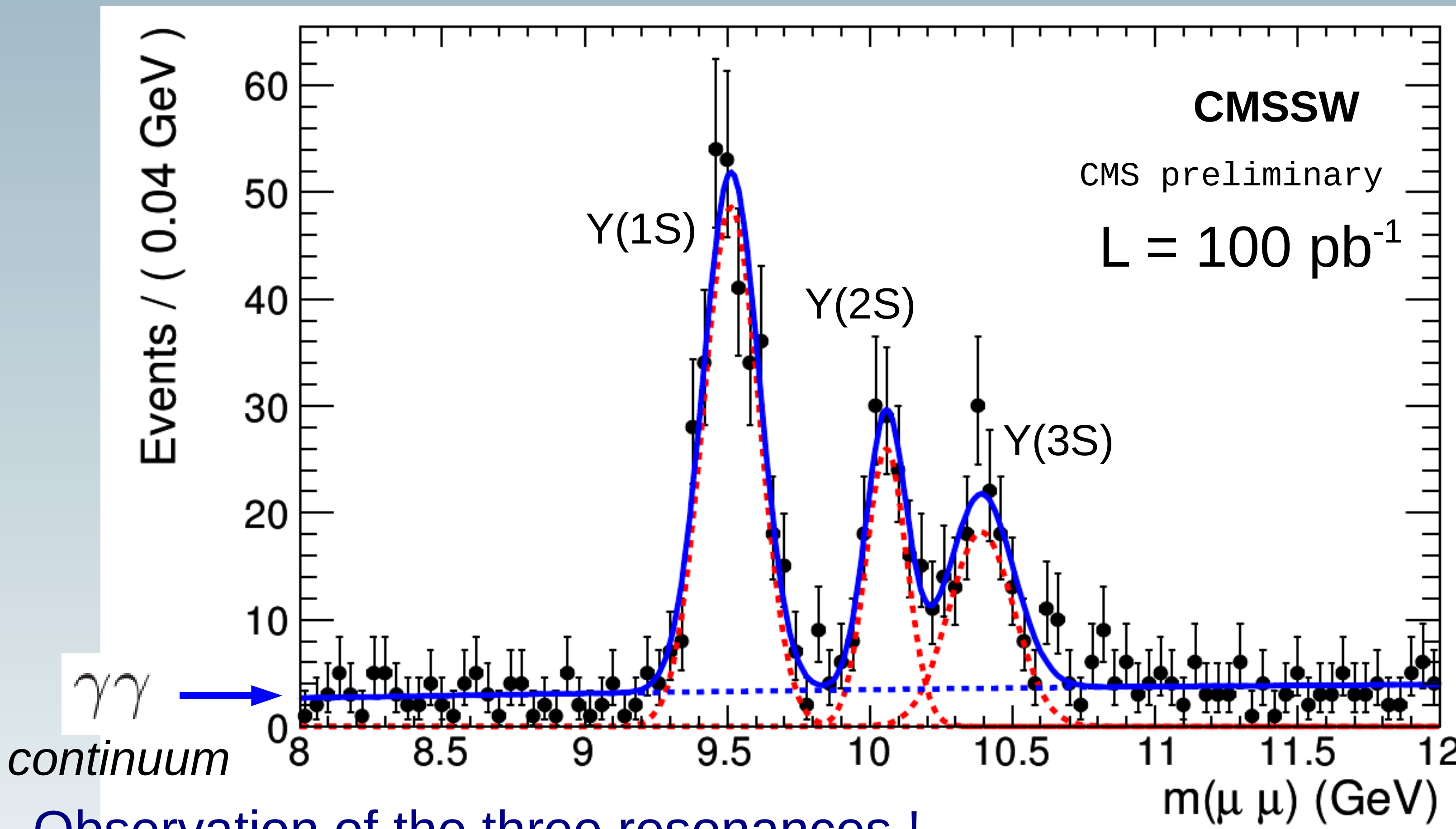


Same dimuon final state!

Upsilon meson production

J. Hollar, S. Ovyn, X. Rouby [CMS PAS DIF-07-001]

Selection of the dimuon pairs as before



Observation of the three resonances !

– low p_T track calibration

– detector alignment

– sensitivity to very low-x distributions

Conclusions

- Photon physics at the LHC:
  - Using LHC as a photon collider! Nice final states, with a lot of physics within and beyond the Standard Model.
- $\gamma\ \gamma \to \mu^+ \mu^-$:
  - Very interesting final state: easy selection, early physics, well known theoretically
  - Absolute luminosity measurement
  - Forward detector alignment
- $\gamma p \to Y \mu^+ \mu^-$:
  - Improving HERA measurements. Cross-section measurement. Calibration tool for the detector

X. Rouby, PhD Thesis: http://www.dart-europe.eu/index.php/record/view/139668

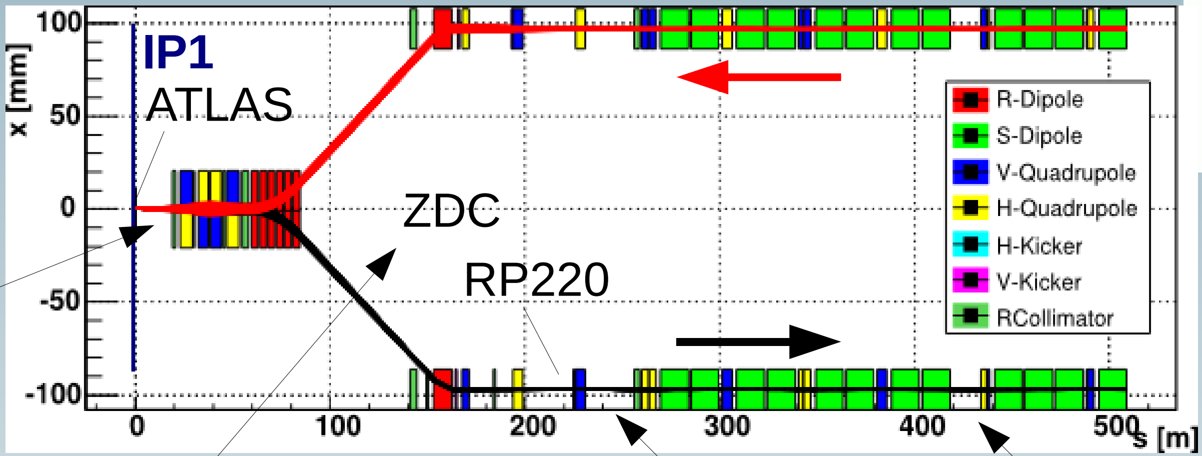
Informations complémentaires

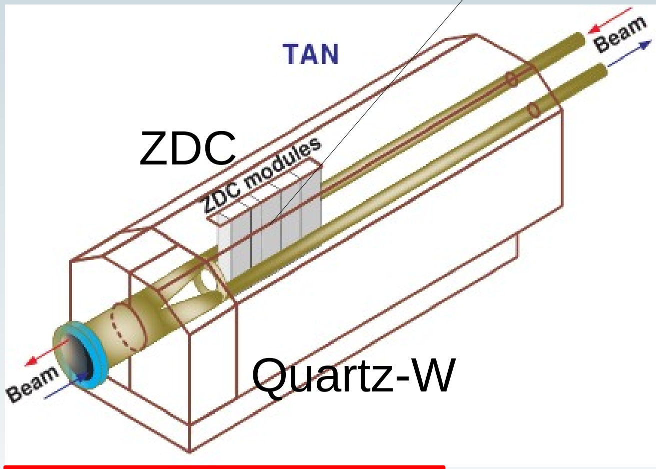
Forward detectors for ATLAS

LUMI

LUCID

Cerenkov



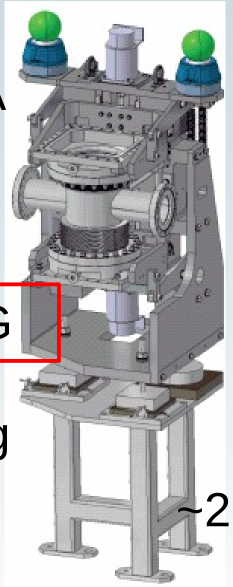


ZDC

Quartz-W

CALORIMETRY
neutrals

ALFA



TRACKING

Scintillating fibers

~2009

FP420

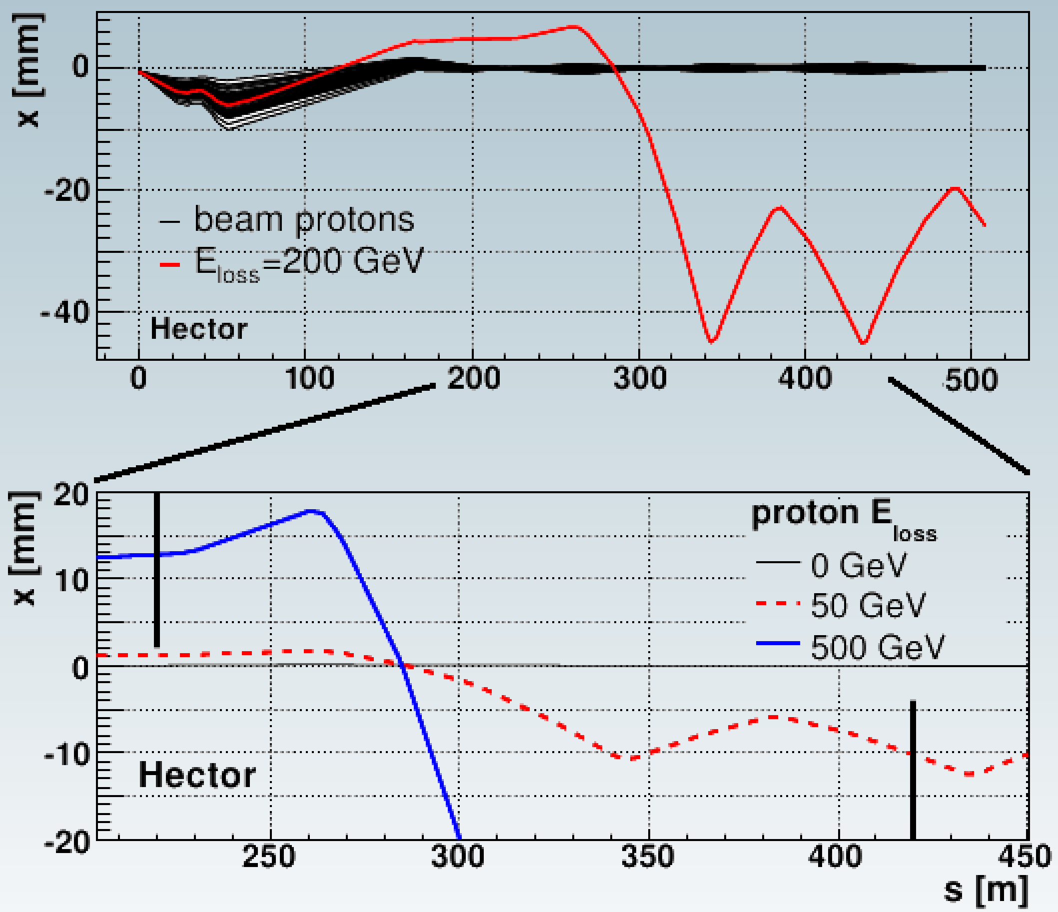
Si + Cerenkov

TRACK & TIMING

~2010

Détections des protons émis à très petits angles

Un proton émis à très petit angle peut s'échapper de CMS par le tube du faisceau, sans être détecté.



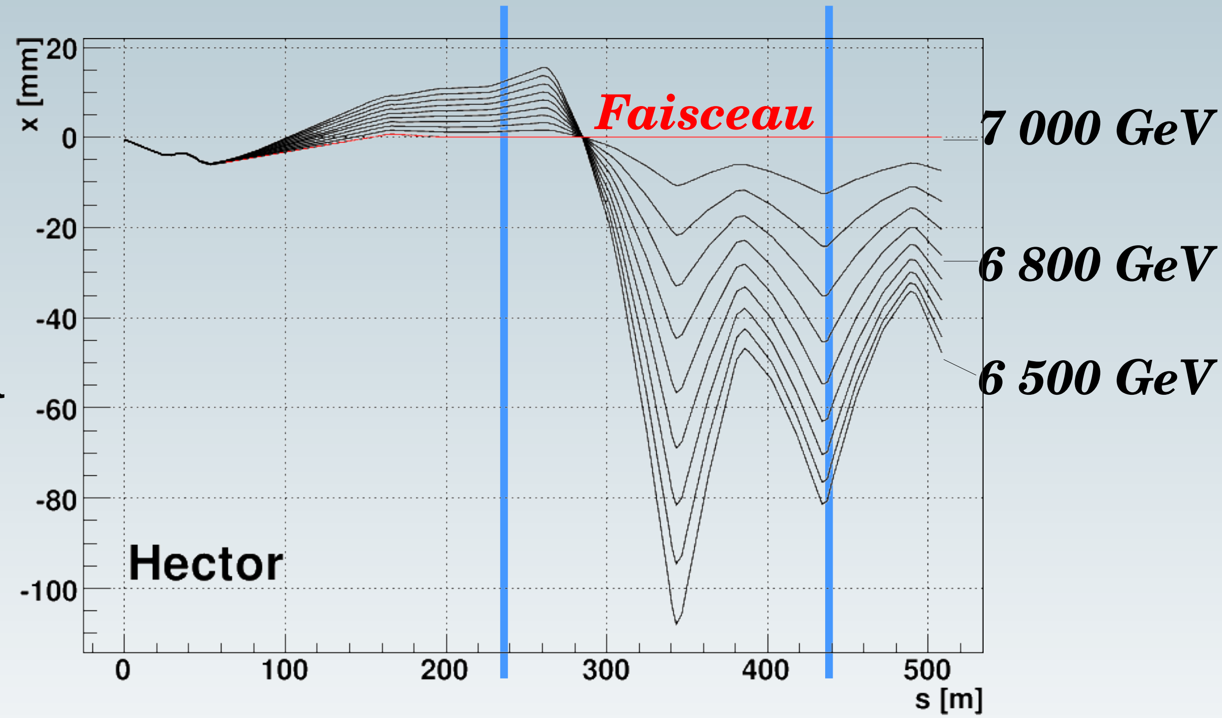
S'il a perdu de l'énergie, sa trajectoire sera différente de celle des protons du faisceau.

➡ Il est possible de l'observer en utilisant les détecteurs situés le long de la ligne de faisceau

Détecteurs de protons diffusés

Les protons *diffusés vers l'avant* ont une énergie proche de celle du faisceau, mais légèrement inférieure. Leur trajectoire suit, plus ou moins, celle du faisceau.

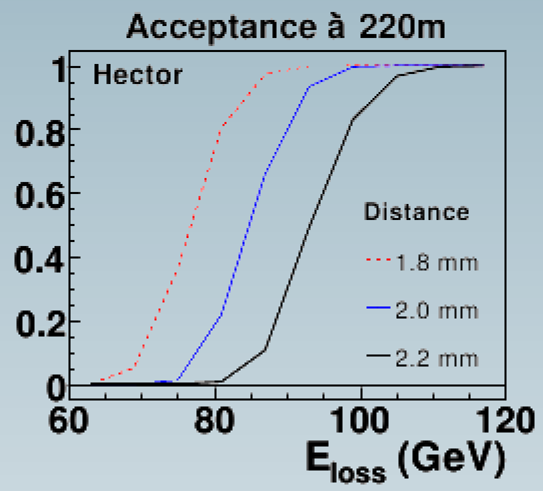
Il est donc possible de détecter ces protons à l'aide de senseurs placés à quelques millimètres du faisceau.

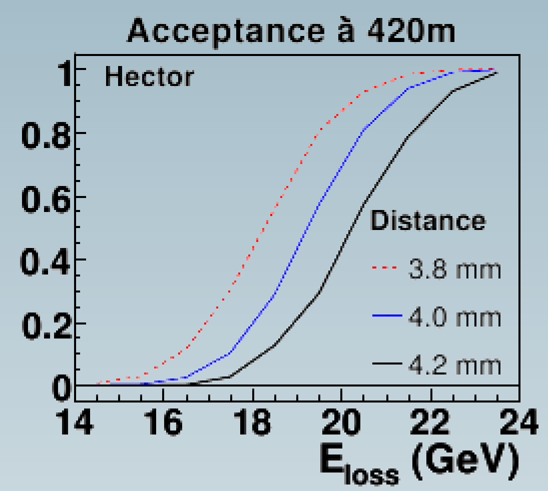


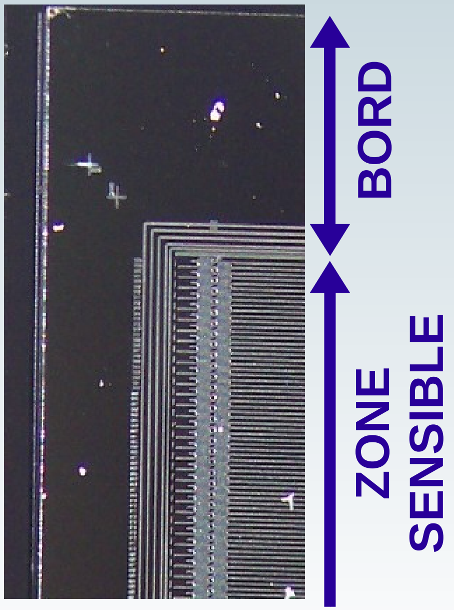
perte d'énergie ↔ éloignement

Détecteurs de protons diffusés

Plus le détecteur est proche du faisceau, plus grande est la gamme des énergies qu'il couvre.







Nécessité de minimiser la distance entre le bord physique et la zone sensible du détecteur. Cette distance doit être de quelques dizaines de microns.

On parle alors de *détecteur sans bord.*

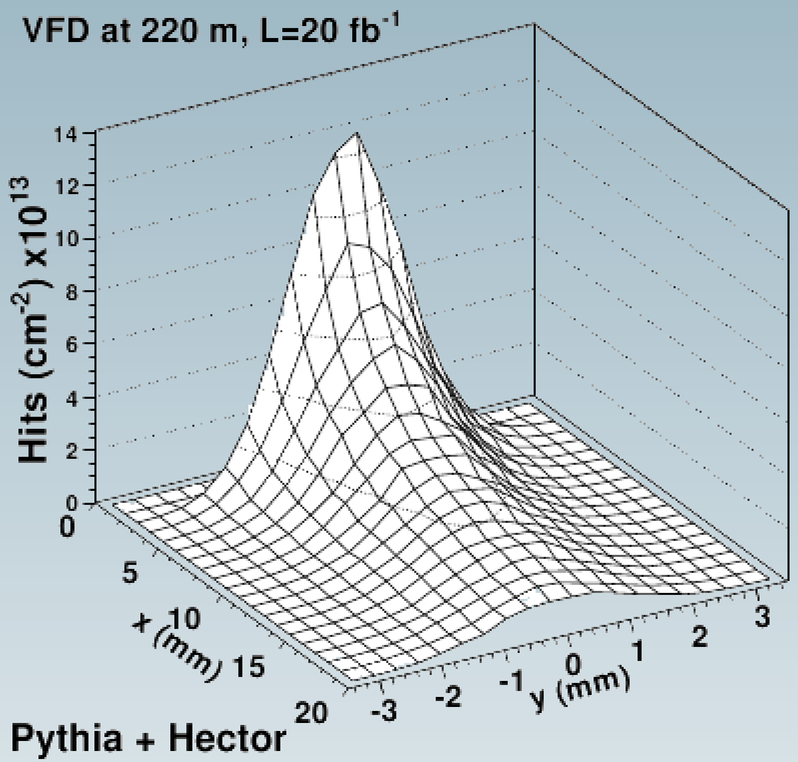
Détecteurs “sans bord”

<u>Contrainte supplémentaire</u> :

les détecteurs doivent également

être très résistants aux radiations

O(10^{14}-10^{15}) protons/an/cm²



Solution : détecteurs sans bord au silicium

→ Développement de détecteurs *coupés.*