# Exclusive dilepton production at the LHC with CMS

X. Rouby, S. Ovyn

Université catholique de Louvain
Center for Particle Physics and Phenomenology (CP3)

J.J. Hollar (LLNL)

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# Outline

- Exclusive dimuons :

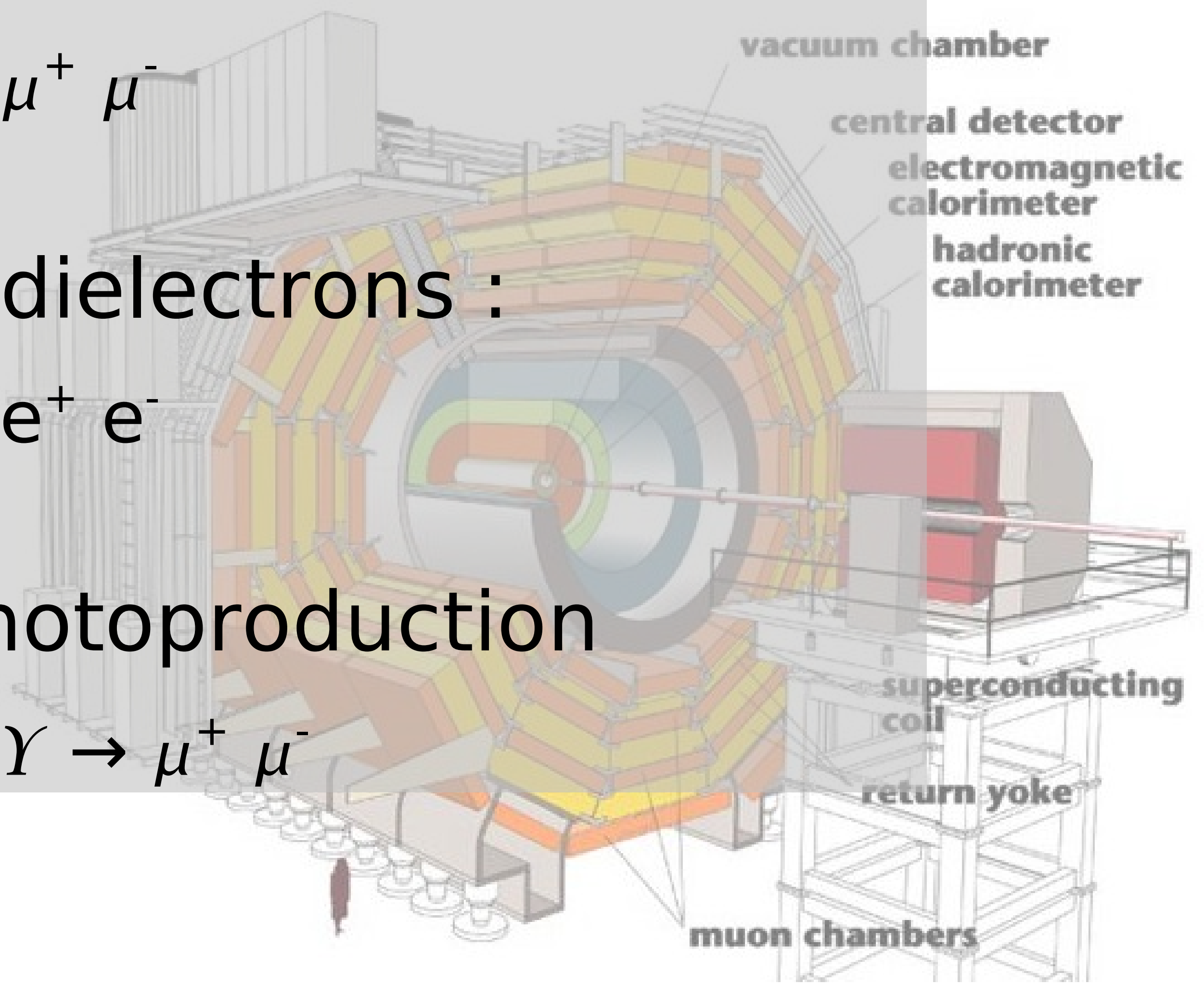
$$\gamma\gamma \rightarrow \mu^{+}\ \mu^{-}$$

- Exclusive dielectrons :

$$\gamma\gamma \rightarrow e^{+}\ e^{-}$$

- Upsilon photoproduction

$$\gamma p \rightarrow \Upsilon \rightarrow \mu^{+}\ \mu^{-}$$



# Exclusive dimuons

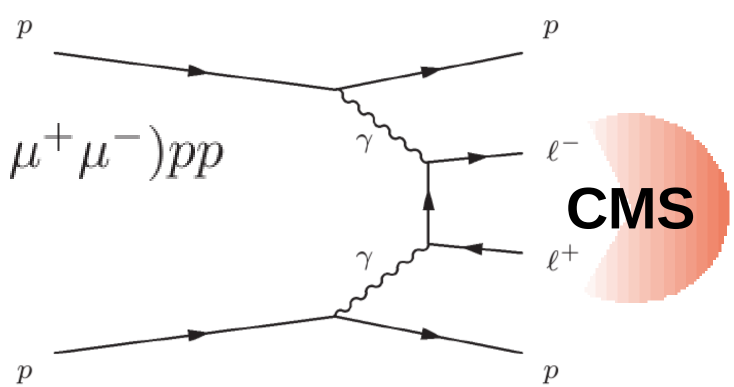
# Exclusive dimuons



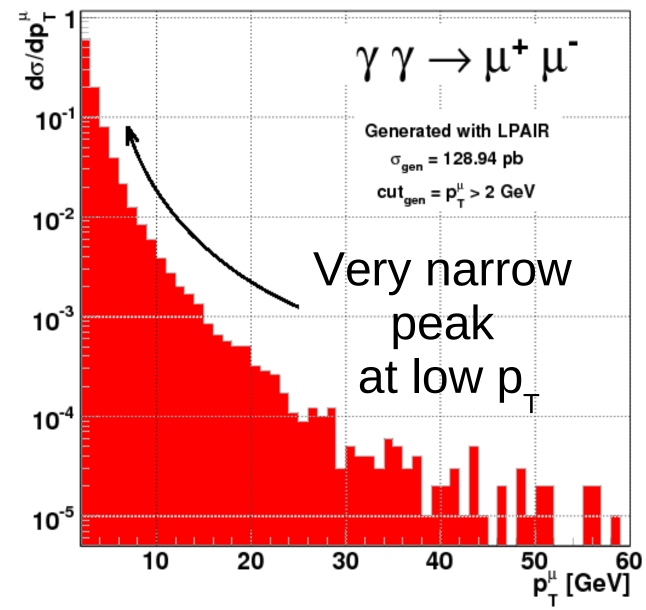
LHC as a photon collider !

## photon – photon interactions

$$pp(\gamma\gamma \rightarrow \mu^+\mu^-)pp$$




Muon $p_T$




**Total cross section (LPAIR):**

$1.47 \times 10^8$ fb – no cut

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

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

**Large cross section**

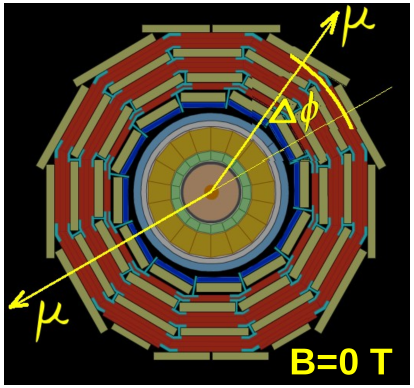
Very well known: QED

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

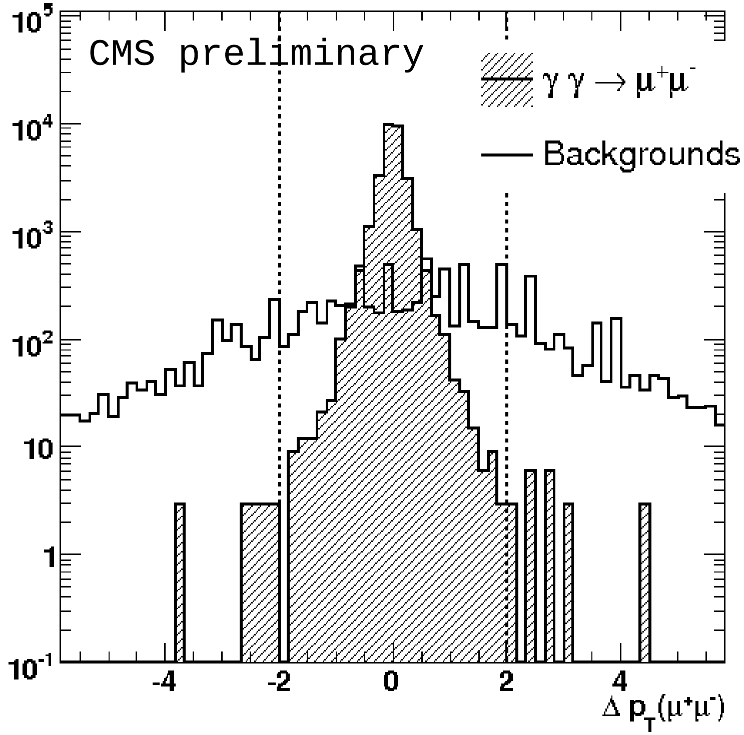
Exclusive pair of muons

(Almost) no proton remnant in CMS

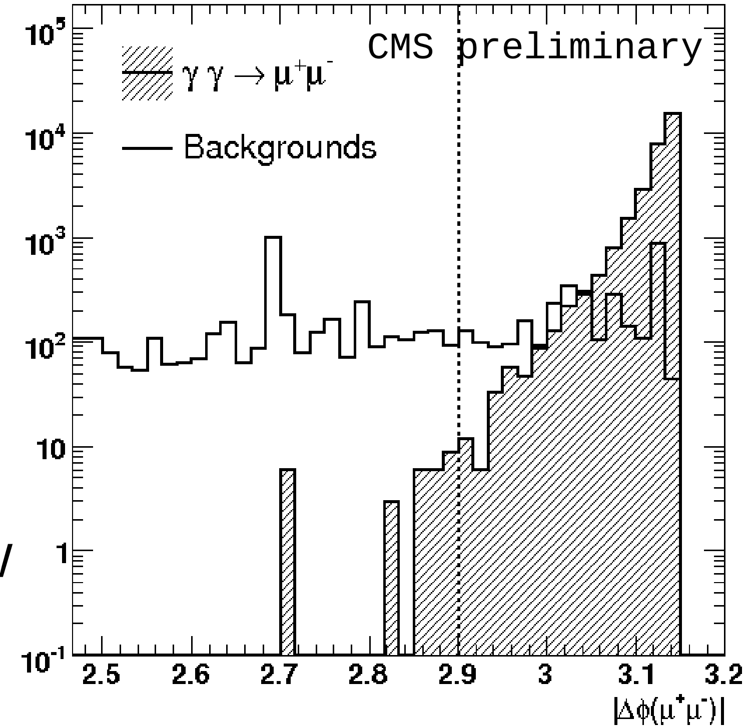
# Exclusive dimuons




- <u>Trigger</u> (online selection) :
  - $p_T$ > 3 GeV (default CMS di-muon trigger)
  - Central pseudorapidity (|η|<2.5)
- <u>Analysis</u> (offline selection) :




CMSSW 1_6_0

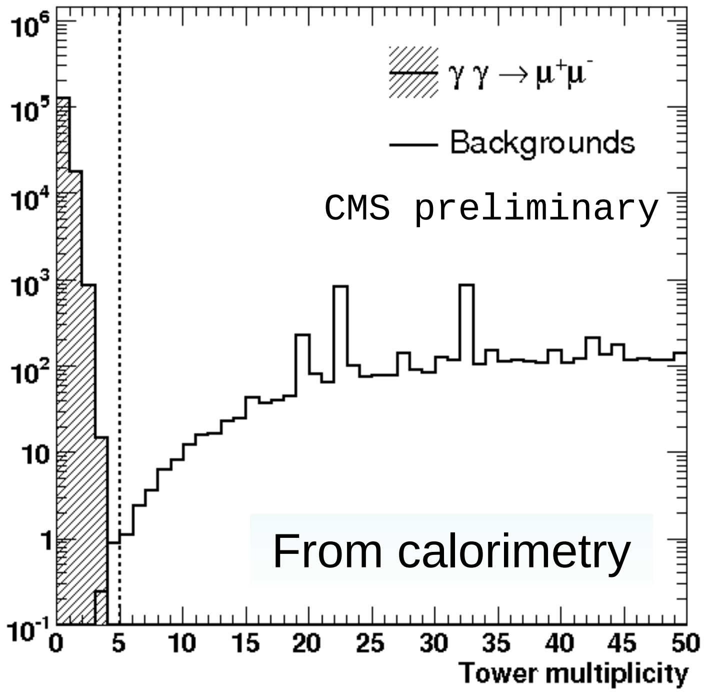


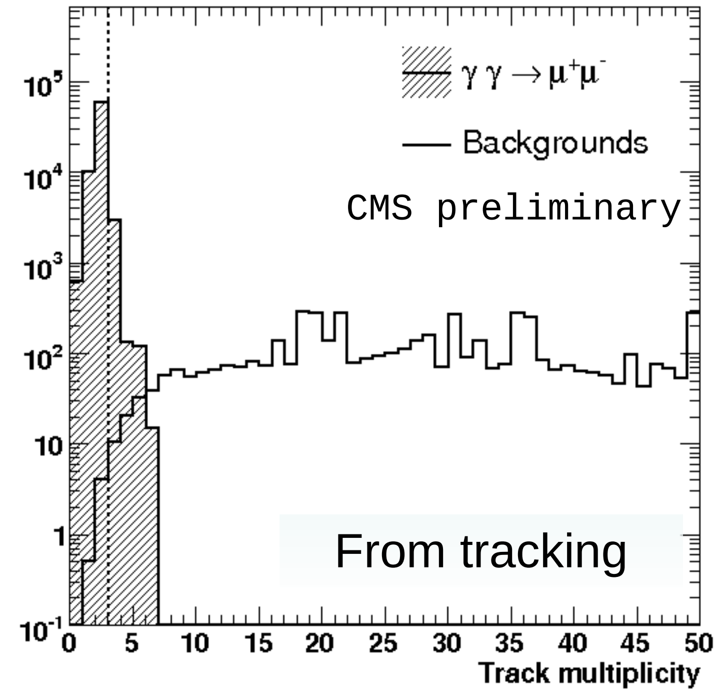

Balance in transverse momentum

Balance in acoplanarity

# Exclusive dimuons

- <u>Analysis</u>: (continued)
  - Exclusivity conditions: only 2 muons are expected



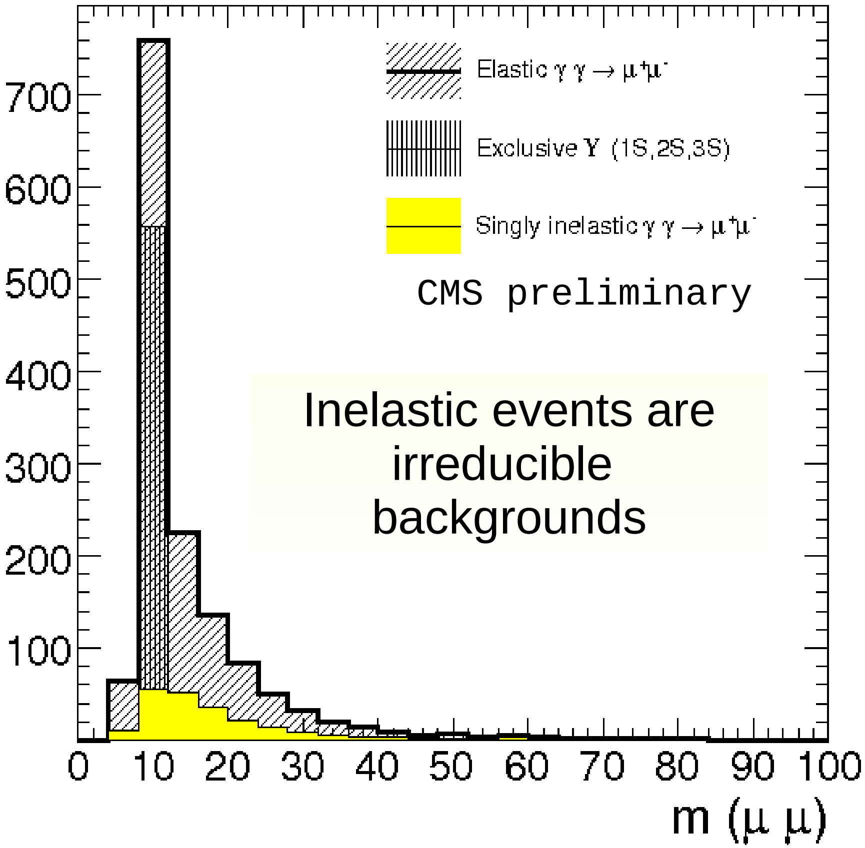




Reducible background events include:

- Drell-Yann processes
- W pairs
- Heavy quark decays


Outline
**Excl. Dimuons**
- intro
- **selection**
- measurement
- applications
Excl. Dielectrons
Dissociation
Y photoproduct.
Conclusions

# Exclusive dimuons




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

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

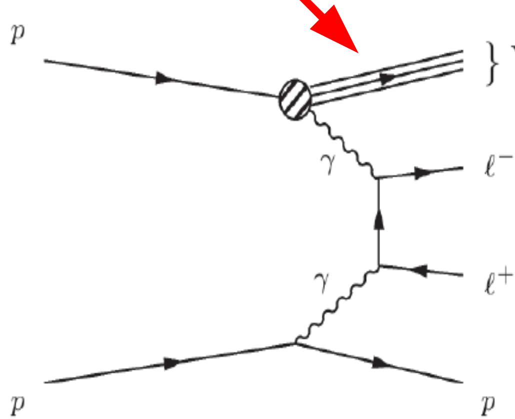
$$N_{inelastic}(\gamma\gamma \to \mu^+\mu^-) = 636 \pm 25(stat) \pm 121(model)$$

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

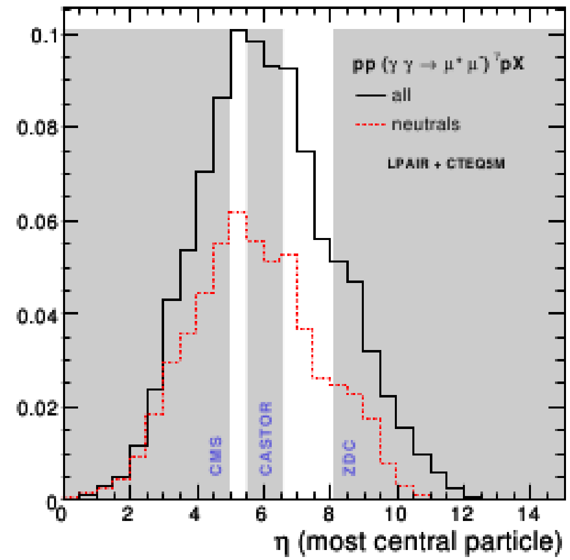
For an integrated luminosity L=100 $pb^{-1}$, without pile-up

# Dissociative backgrounds

At least one of the two interacting proton dissociates



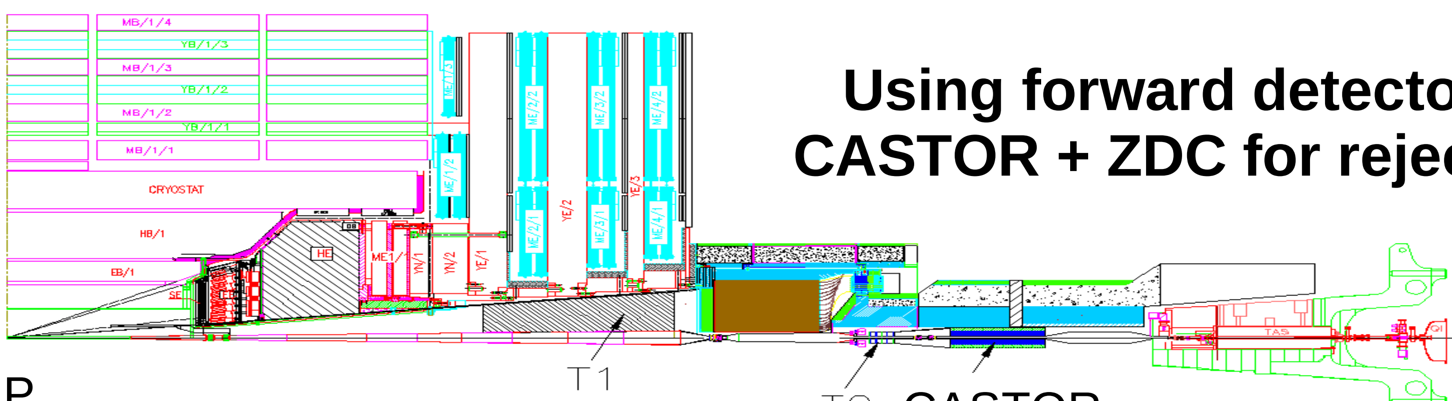

Same final state !




The proton remnant could remain unseen by CMS !

Inelastic events are irreducible backgrounds

**Using forward detectors CASTOR + ZDC for rejection**




IP

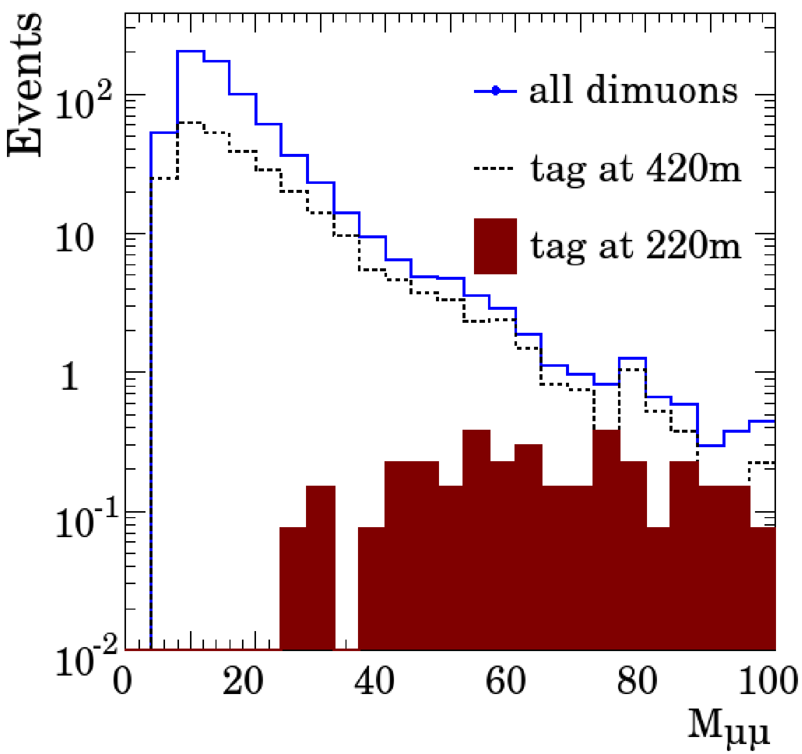
CASTOR @ 16 m

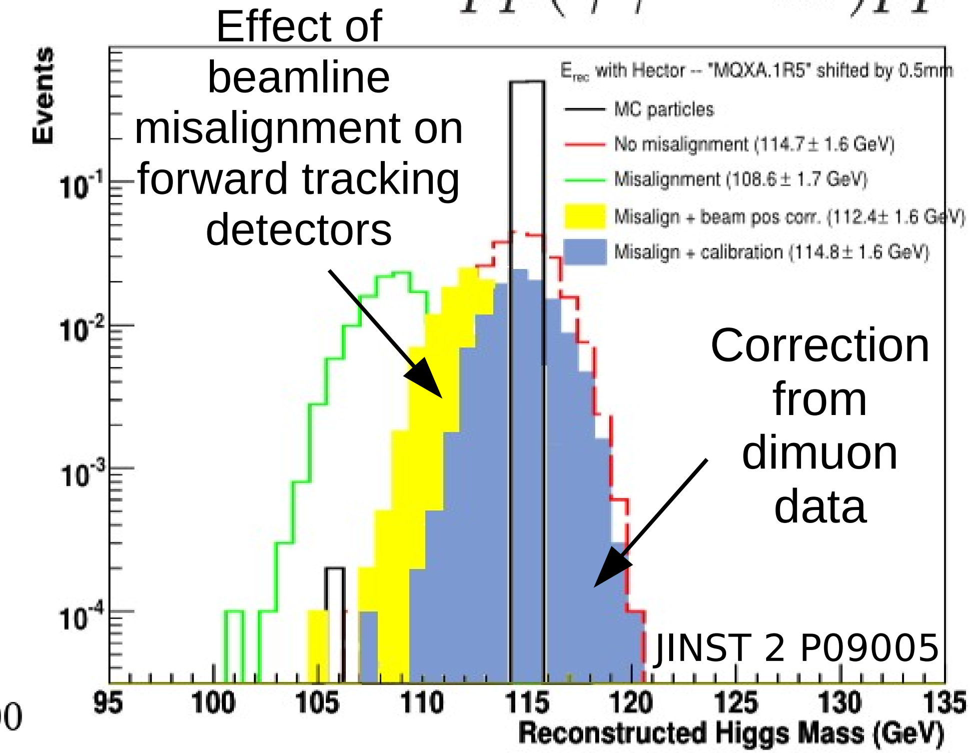
ZDC @ 140 m

# Exclusive dimuons

- Applications
  - Luminosity normalization: offline calibration of lumi monitors ~4%
    - Reducible background: small
    - Irreducible background: manageable
  - Forward detector calibration+ alignment

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



# Exclusive dielectrons

# Exclusive dielectrons

Outline
Excl. dimuons
**Excl. Dielectrons**
**- intro**
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- measurement
Dissociation
Y photoproduct.
Conclusions

Similar process:
exclusive production of an electron-positron pair $pp(\gamma\gamma \rightarrow e^+e^-)pp$

**Total cross section (LPAIR) :**

$7.1 \times 10^{12}$ fb – no cut

10.4 fb – $p_T > 5.5$ GeV : elastic case : the protons remain intact

13.6 fb – $p_T > 5.5$ GeV : inelastic case : one proton dissociates

Like dimuons:

- Electrons are balanced in $\Delta p_T$ and $\Delta\Phi$
- $p_T$ distribution is really peaked at low values

Unlinke dimuons

- Electrons are more difficult to reconstruct => higher thresholds

Dedicated trigger required !

# Exclusive dielectrons



## Level 1 selection of $\gamma\gamma \to l^+l^-$ events

Very low luminosity phase

$\gamma\gamma \to \mu^+\mu^-$

- Thresholds of the default dimuon triggers are already as low as 3 GeV (L1) and (HLT)
-

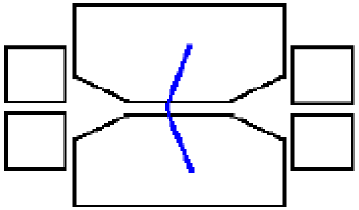
$\gamma\gamma \to e^+e^-$

- Very low transverse momentum of the leptons
- High threshold of the defaults di-egamma trigger
- → Need a special trigger

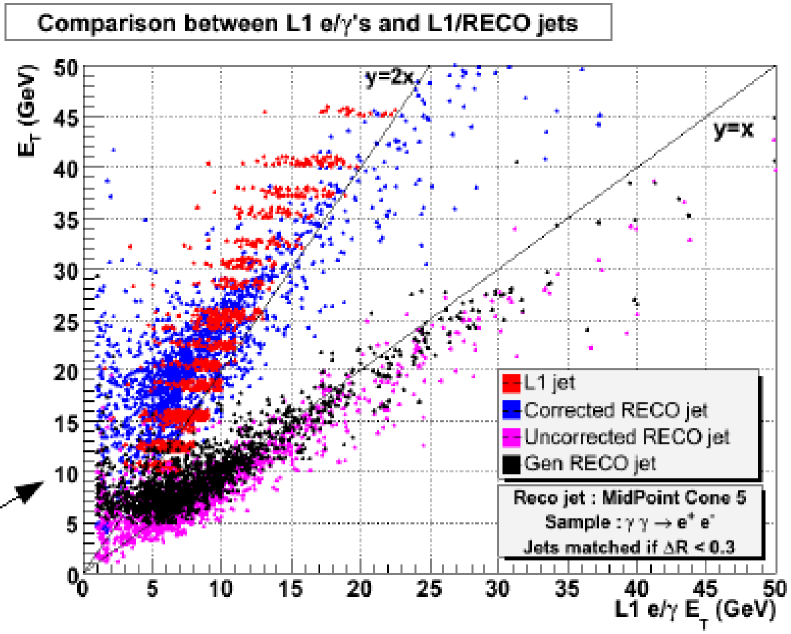
•Goals :

- decrease the thresholds of the default level1 triggers
- preserve the output rate

Add exclusivity requirement specific to $\gamma\gamma \to l^+l^-$



L1 e/γ are seen as jets candidates



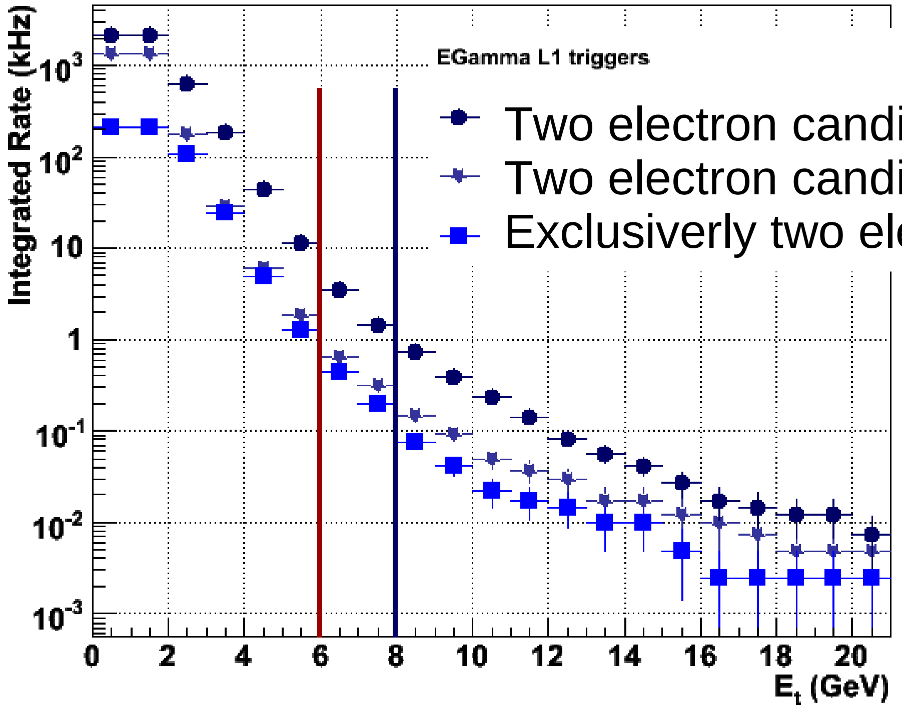

Depends on the energy scale applied on the jets

# Exclusive dielectrons



Trigger conditions :

- at least 2 e/γ candidates with a $p_T$ bigger than a threshold value
- nothing else ...




LPAIR
$p_T^e > 5.5$ GeV

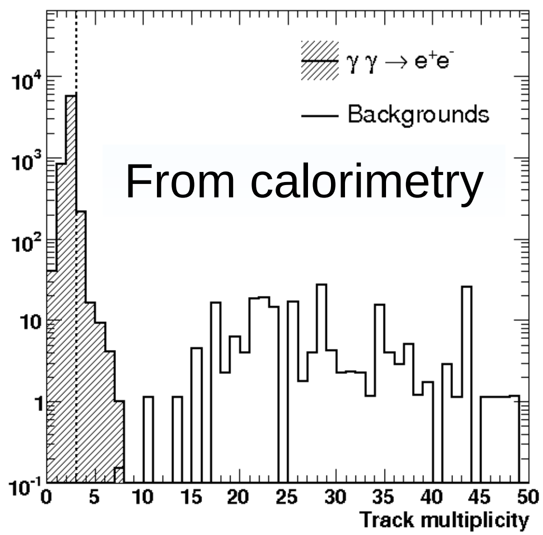
Rates for $10^{32}$ $cm^{-2}$ $s^{-1}$

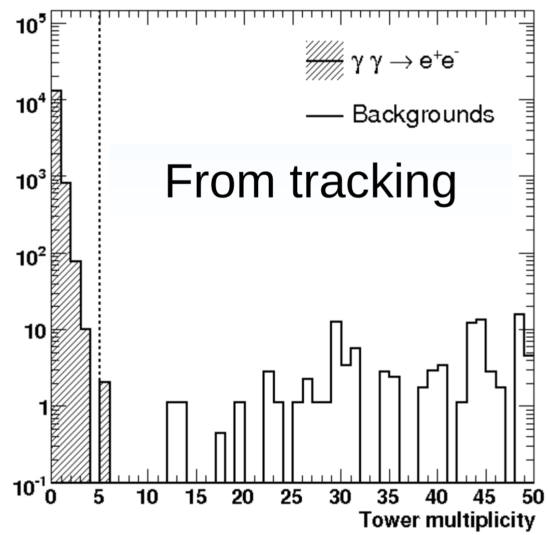
| | $p_T^e$ (GeV) | Rates (kHz) | $\epsilon$(%) |
|---|---|---|---|
| Default trigger | 8 | 0.73 | 10.99 |
| New trigger | 6 | 0.45 | 15.91 |

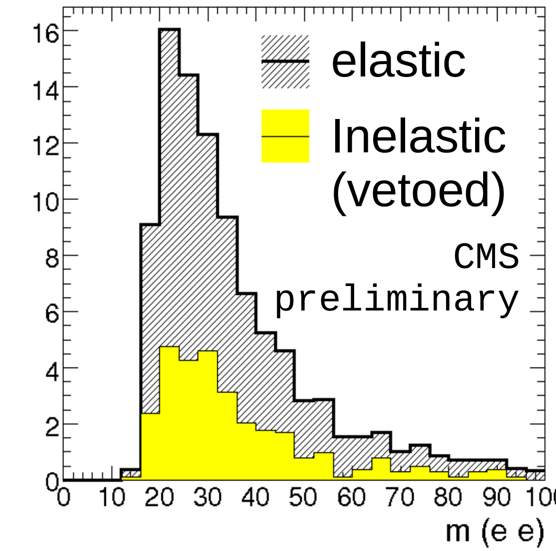
Events passing the exclusive 2 e/γ trigger must satisfy a dedicated High Level Trigger

# Exclusive dielectrons

- Selection (continued)
  - Balance in acoplanarity and in $E_T$
  - Exclusivity conditions : tracking + calorimetry




L = 100 $pb^{-1}$

$$N_{elastic}(\gamma\gamma \rightarrow e^+e^-) = 67 \pm 8(stat)$$

$$N_{inelastic}(\gamma\gamma \rightarrow e^+e^-) = 82 \pm 9(stat) \pm 15(model)$$

$$N^{w/veto}_{inelastic}(\gamma\gamma \rightarrow e^+e^-) = 31 \pm 6(stat) \pm 6(model)$$

Interesting but 10x smaller sample than for dimuons

# Upsilon photoproduction

# Upsilon

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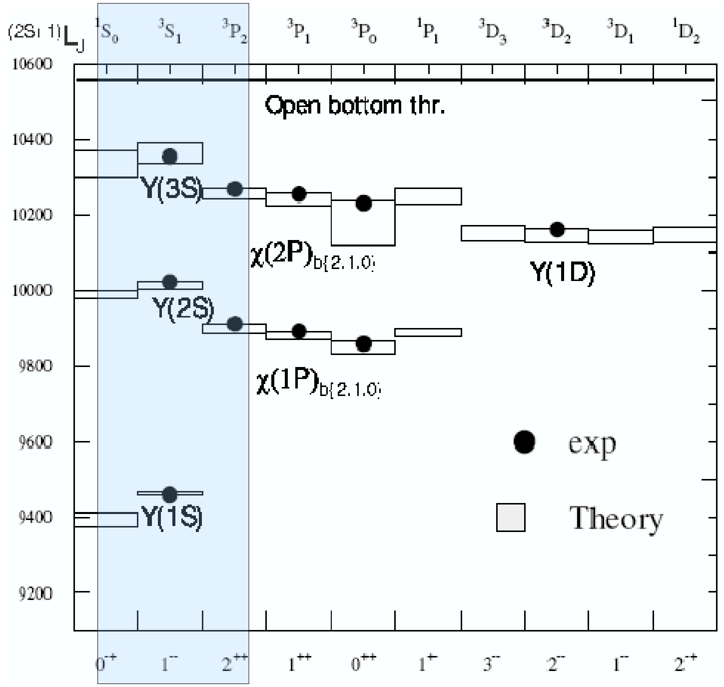
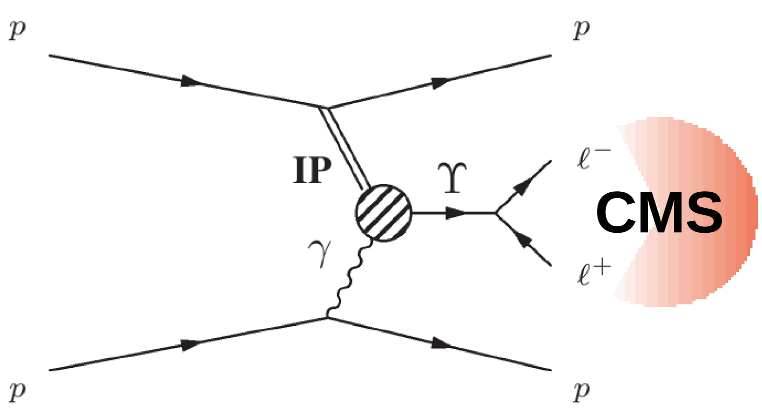
## bottomonium family




Upsilon Υ photoproduction



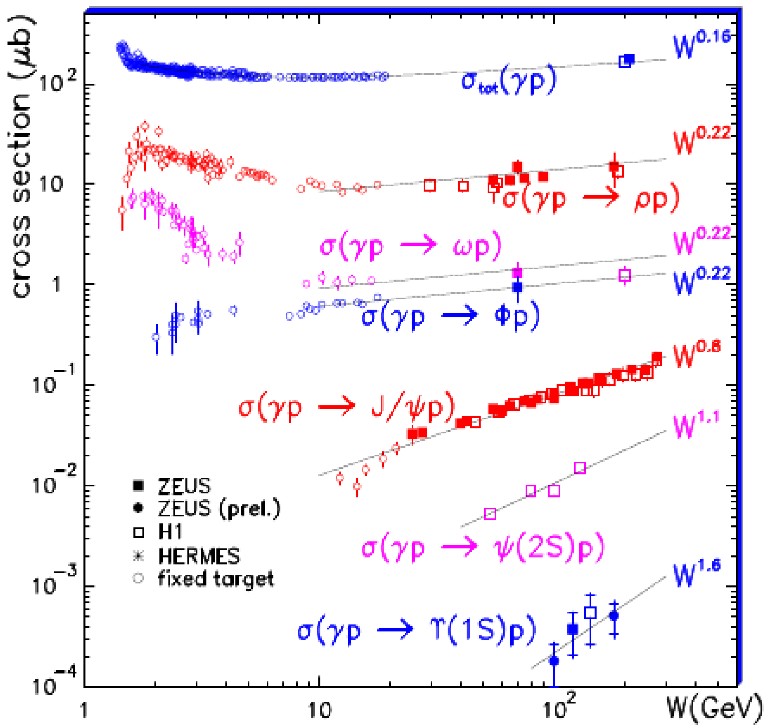

photon – proton interaction

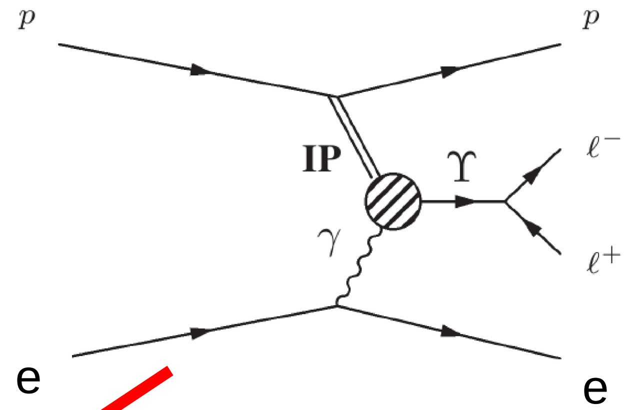
## Mass and branching ratio

| | | |
|---|---|---|
| (1S) | m = 9.46 GeV | BR(μμ) = 2.48% |
| (2S) | m = 10.02 GeV | BR(μμ) = 1.93% |
| (3S) | m = 10.36 GeV | BR(μμ) = 2.18% |

# Upsilon: Cross sections

HERA measurements



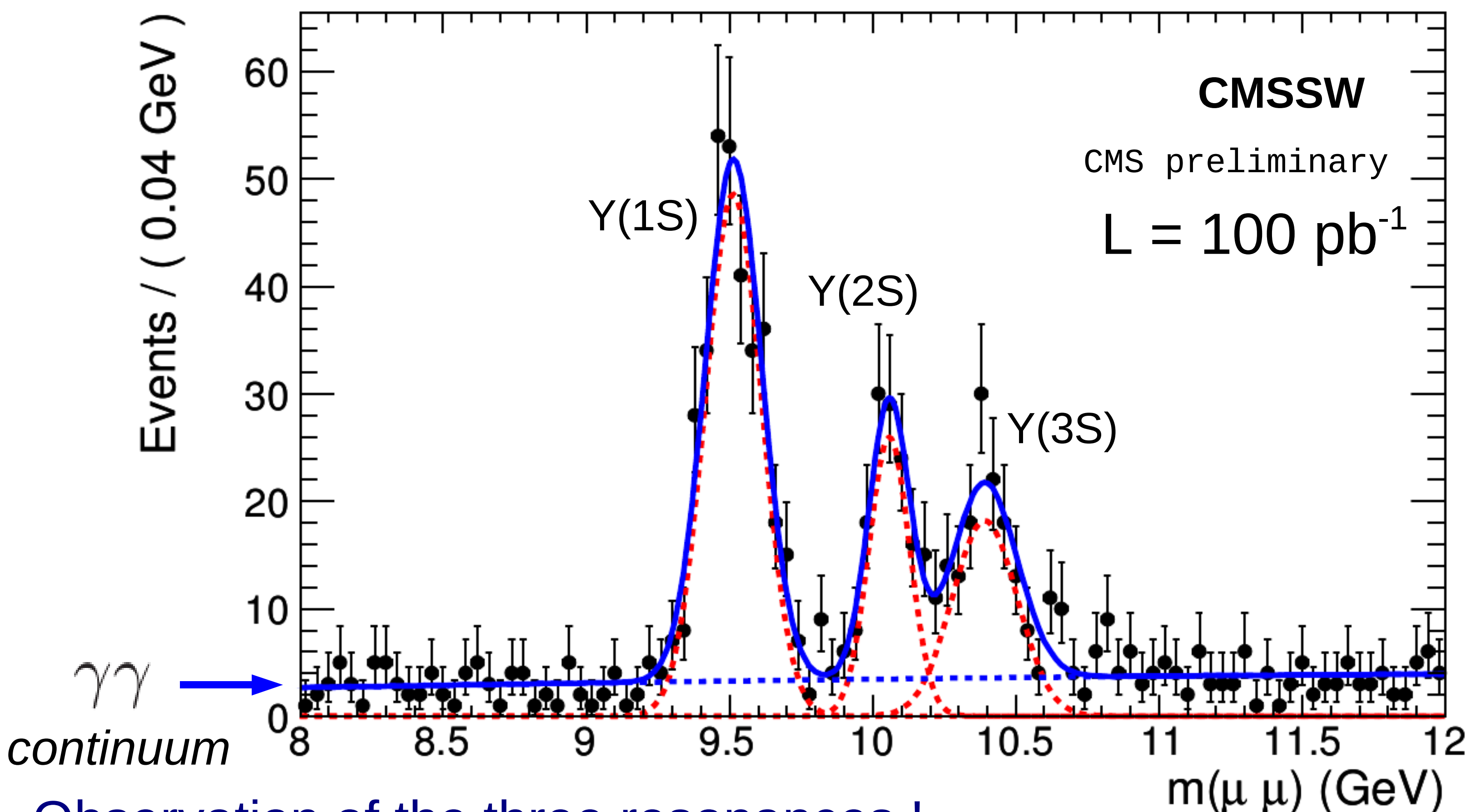

## Predictions

| Process | $\sigma_{prod}$ (pb) | Generator |
|---|---|---|
| $\gamma I\!P \to \Upsilon \to \mu^+\mu^-$ | 12 (1S) | PHITI |
| $\gamma I\!P \to \Upsilon \to \mu^+\mu^-$ | 39 (1S), 13 (2S), 10 (3S) | STARLIGHT |

# Upsilon: measurement



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

Exclusive dilepton production:

- High cross sections
- Few backgrounds: early physics at LHC
- Luminosity normalization
- Alignment of forward detectors

Upsilon photoproduction

- Cross section measurement

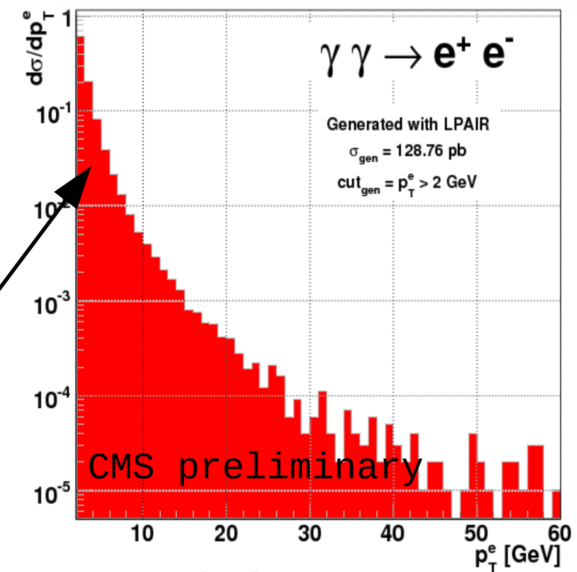
# Back-up slides

# Exclusive electrons

Similar process:
exclusive production of an electron-positron pair

$$pp(\gamma\gamma \to e^+e^-)pp$$

electron $p_T$




Very narrow peak at low $p_T$

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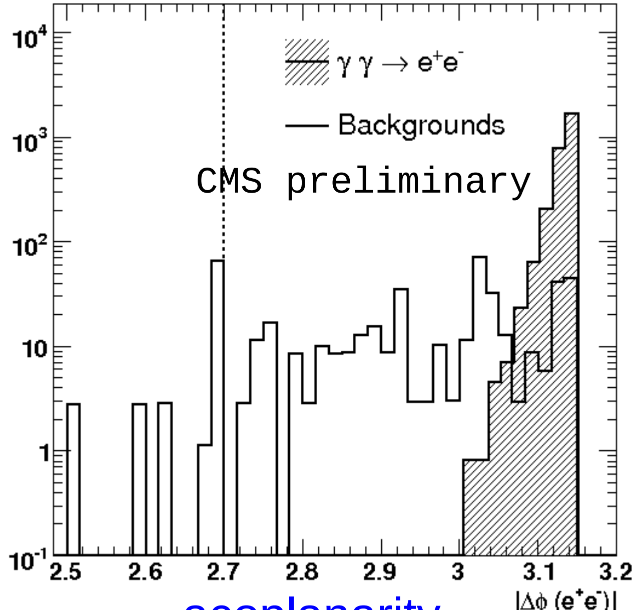
Unlinke dimuons
- Electrons are more difficult to reconstruct => higher thresholds

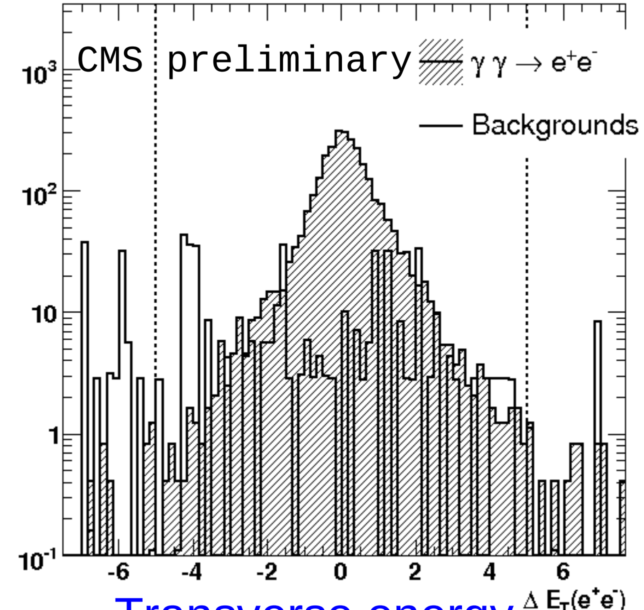
# Exclusive dielectrons

Excl. Dielectrons
- intro
- **selection**
- measurement

- Trigger : $p_T$ > 6 GeV + exclusivity  S. Ovyn's talk
  - Dedicated L1+HLT triggers
- Selection : similar to μ μ
  - Balance in acoplanarity and in $E_T$
  - Exclusivity conditions : tracking + calorimetry




acoplanarity



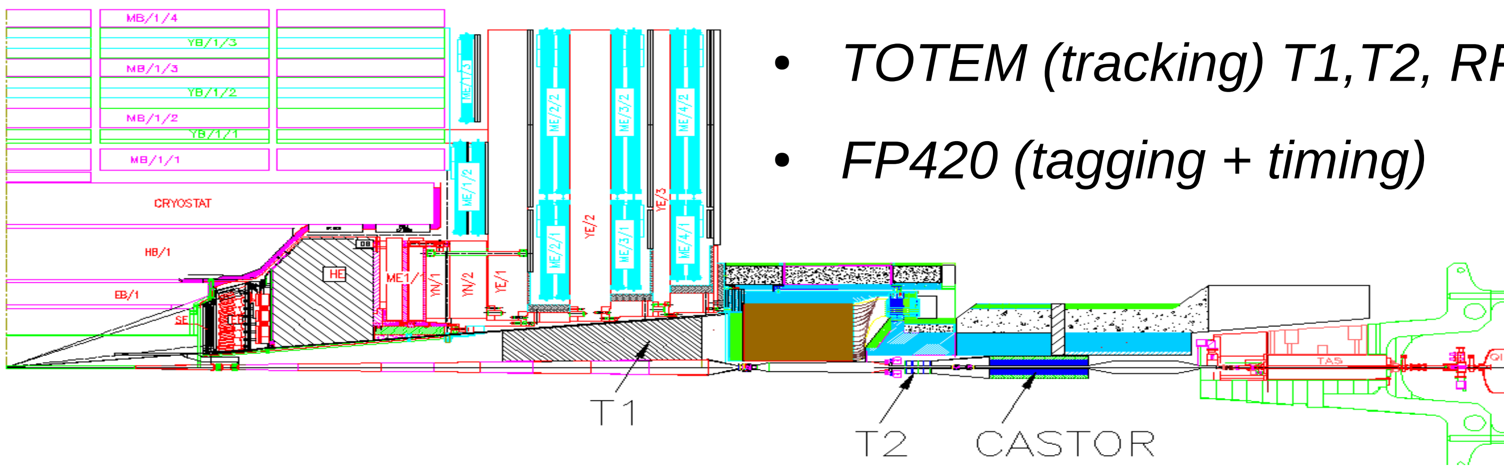

Transverse energy

# Forward detectors around IP5



| | |
|---|---|
| CMS tracking : | $0 < \|\eta\| < 2.5$ |
| CMS calorimetry : | $0 < \|\eta\| < 5$ |

- CASTOR (calorimeter)
- ZDC (calorimeter)
- *TOTEM (tracking) T1,T2, RP*
- *FP420 (tagging + timing)*




**CMS & TOTEM Coll [CERN/LHCC 2006-039/G-124]**

**Common physics programme for CMS + TOTEM**

Joint data taking → nominal optics

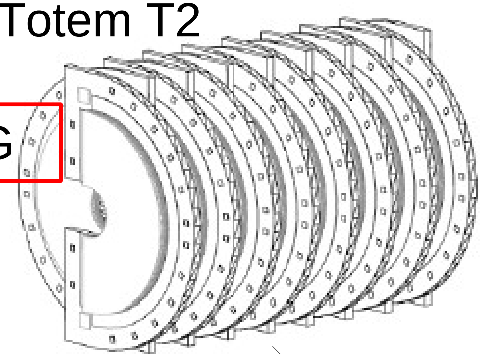
Compatible TOTEM/CMS DAQ for trigger

# Forward detectors around IP5

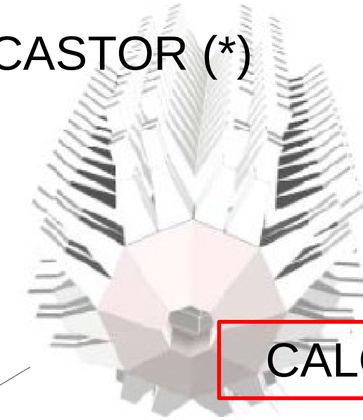


Totem T2

TRACKING

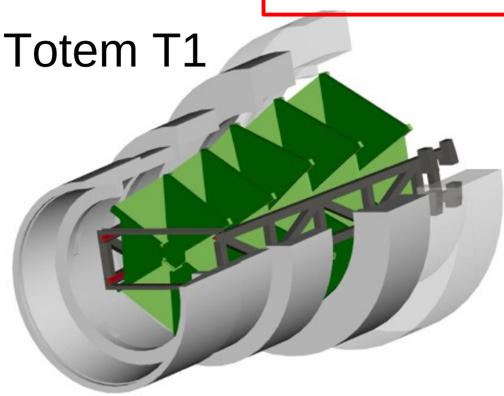


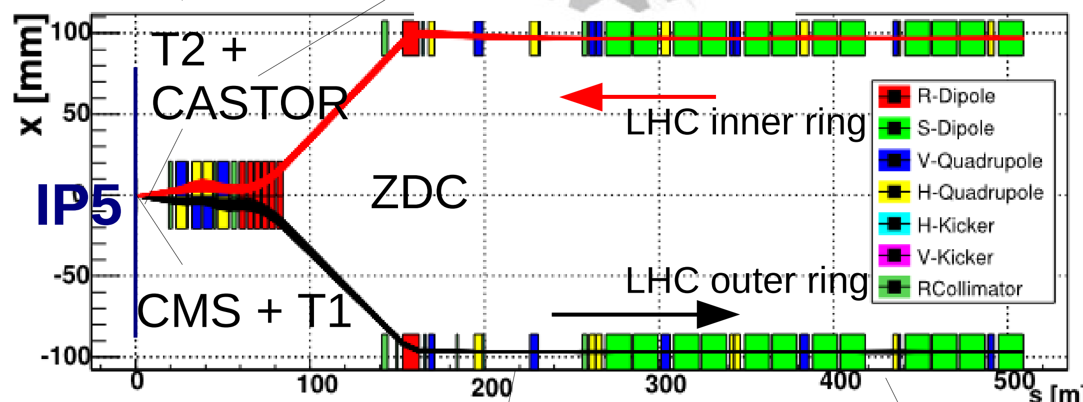
CASTOR (*)



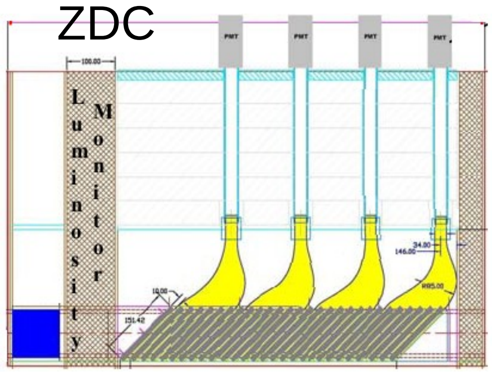
CALORIMETRY

Totem T1






ZDC

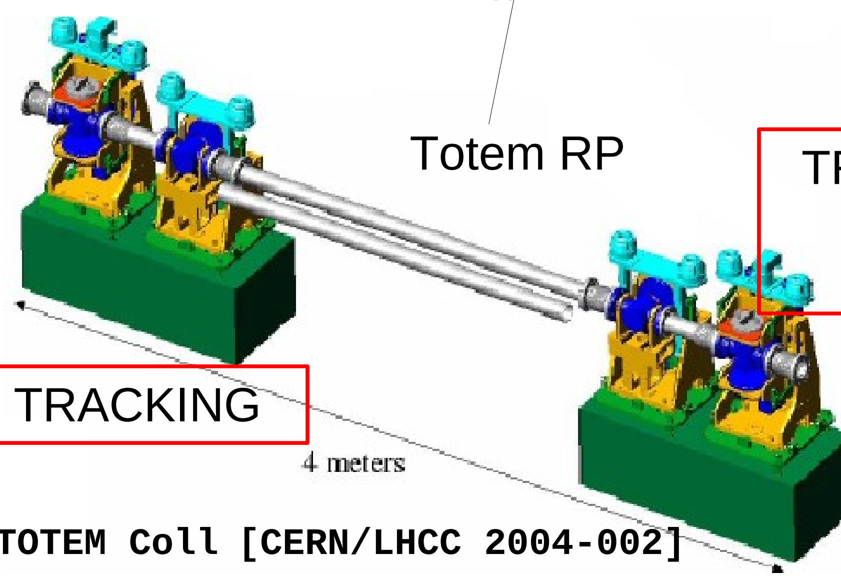



CALORIMETRY
neutrals

FP420

TRACKING
&
TIMING

Totem RP




TRACKING

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

TOTEM Coll [CERN/LHCC 2004-002]