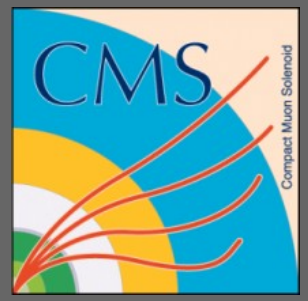


Exclusive and diffractive physics results from CMS

Robert Ciesielski *on behalf of the CMS collaboration*

(The Rockefeller University)

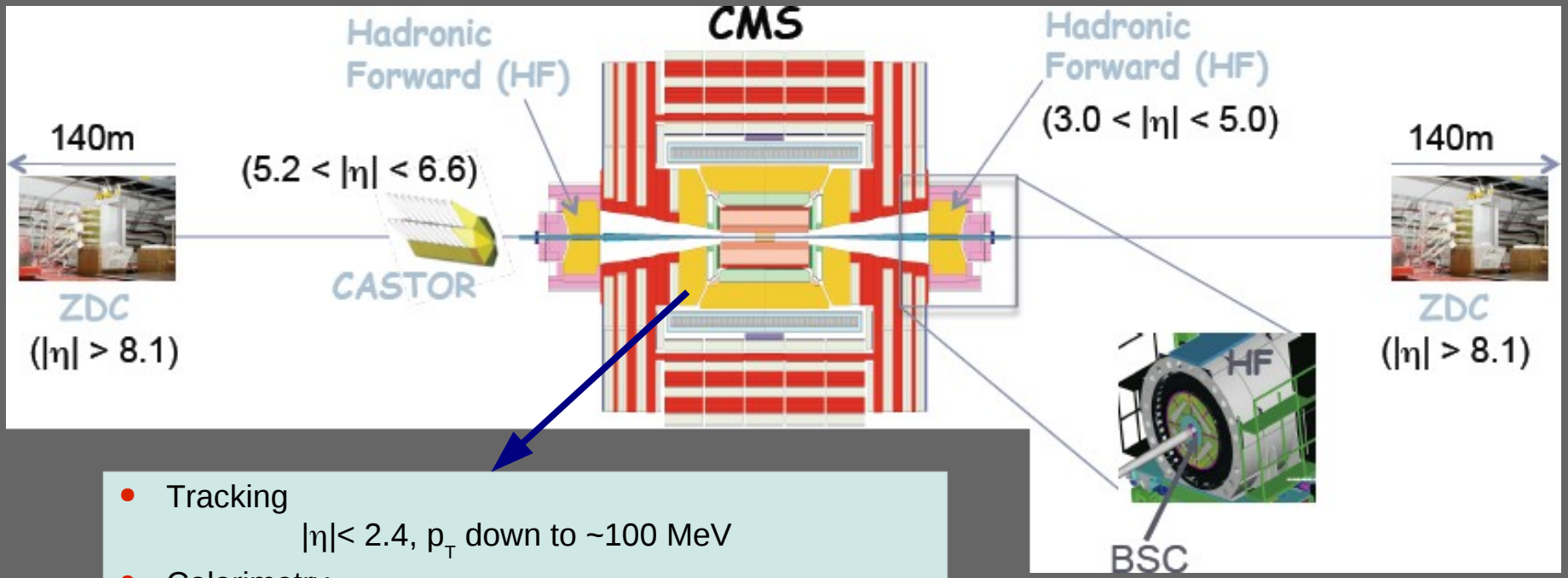
ICHEP 2012, 36th International Conference on High Energy Physics,

4-11 July 2012, Melbourne, Australia

Outline

- Observation of inclusive (soft) diffraction at 0.9, 2.36 and 7 TeV
  CMS PAS FWD-10-001, FWD-10-07
- **Hard diffraction**
  - Diffractive dijets (new)
    CMS PAS FWD-10-004
  - Energy flow and rapidity gaps at hard scale (W/Z events)
    Eur.Phys.J.C (2012) 72:1839
- **Exclusive processes**
  - $\gamma\gamma \to \mu\mu$ production
    JHEP 01:052,2012
  - $\gamma\gamma \to ee$ and search for central exclusive $\gamma\gamma$ production (new)
    CMS PAS FWD-11-004

CMS detector

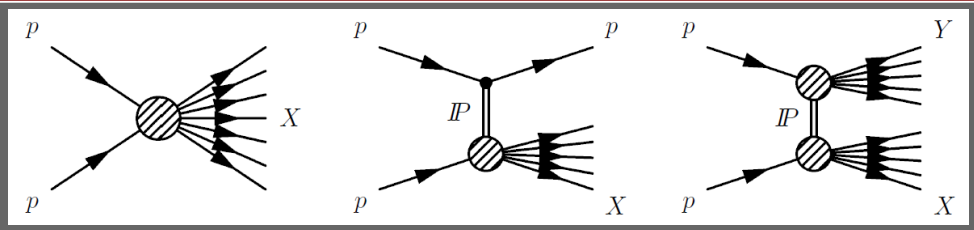


- Tracking
  $|\eta| < 2.4$, p_T down to ~100 MeV
- Calorimetry
  Electromagnetic calorimeter $|\eta| < 3.0$
  Hadronic calorimeter (HB,HE,HF) $|\eta| < 5.0$
- Muons
  $|\eta| < 2.4$, $p_T > 3$ GeV (barrel)

- Forward detectors:
  - HF, hadron forward calorimeter (10m from IP) $3 < |\eta| < 5$
  - BSC, beam scintillator counters (in front of HF) $3.2 < |\eta| < 4.7$
  - CASTOR calorimeter (one side only) $-6.6 < \eta < -5.2$
  - ZDC (zero degree calorimeter) $|\eta| > 8.1$

Observation of soft diffraction

- Early CMS result based on dedicated runs (no PileUp) from 2009 and 2010 data
- Minimum-Bias trigger (hit in either of BSCs) + vertex
- Study activity in one of the forward calorimeters (HF)



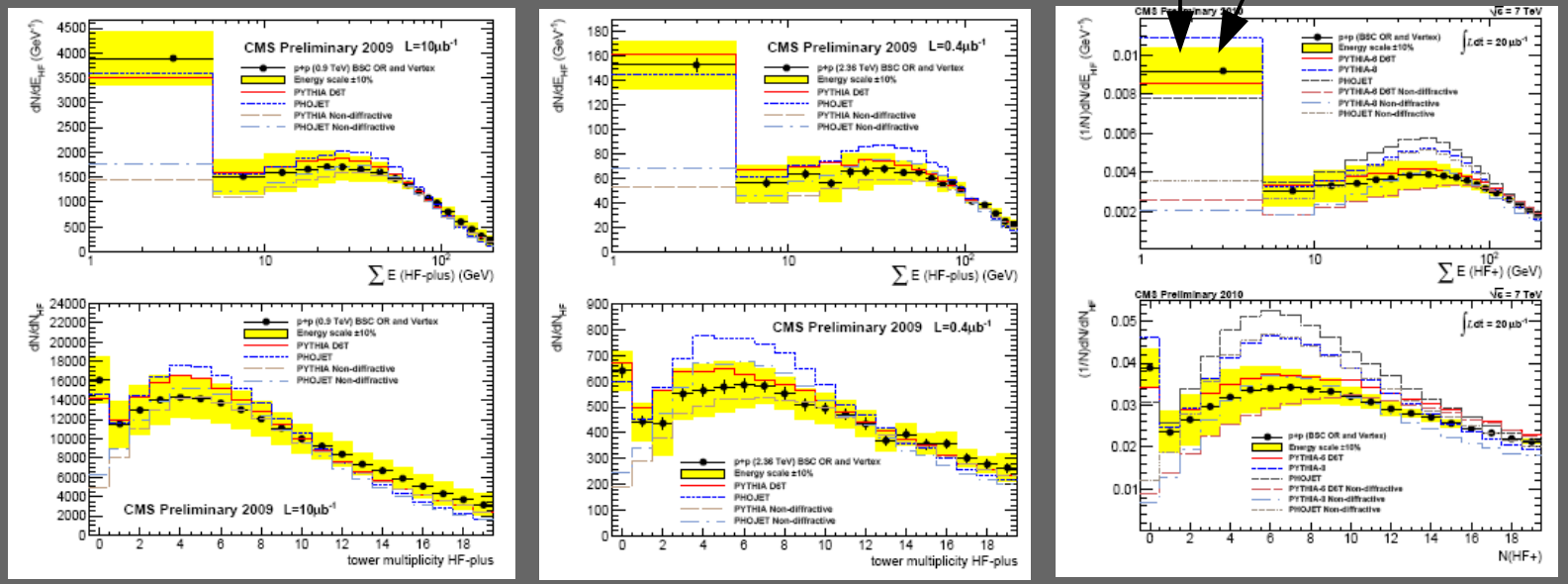
non-diffractive | single-diffractive | double-diffractive

Data compared to Pythia6, Pythia8 and Phojet with and without diffraction.
At low HF energy deposits excess of data wrt non-diffractive MC.
None of the models describe the features of the data.

√s=0.9 TeV | √s=2.36 TeV | √s=7 TeV

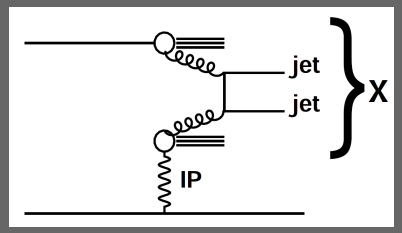
Energy in HF

HF tower multiplicity

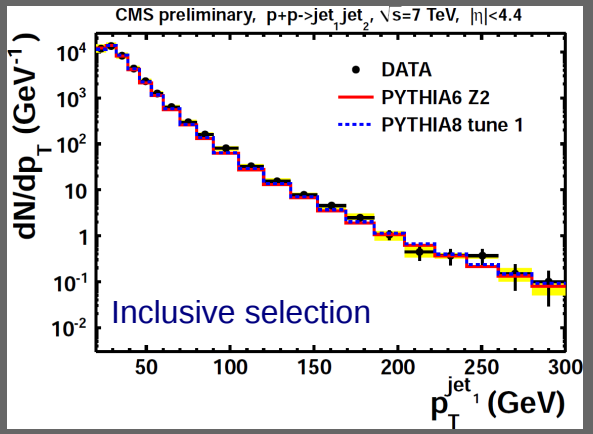


CMS PAS FWD-10-001, FWD-10-07

Diffractive dijets



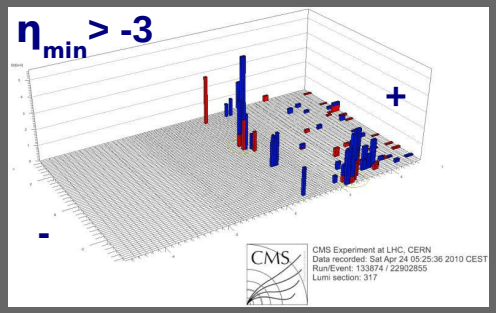
Measure hard diffractive process and compare to pQCD-based theory predictions (gap-survival probability at 7 TeV).



- Analysis based on 2010 data (2.7 nb^{-1}) with negligible PileUp
- Single- jet trigger, anti-kt 0.5, vertex.
- At least 2 jets with p_T>20 GeV and $|\eta|$<4.4
- Based on Particle Flow objects (tracking+calorimetry)

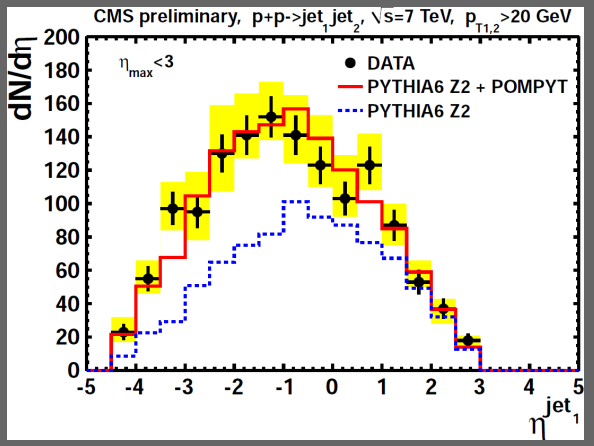
Large Rapidity Gap (LRG): require most forward (or backward) PF object in the event to satisfy $\eta_{max} < 3$ (or $\eta_{min} > -3$).

Corresponds to no individual energy deposit above 4 GeV in HF+ (or HF-). Rapidity gap of 1.9 units.



LRG data described by a combination of diffractive (POMPYT) and non-diffractive (PYTHIA6 Z2) samples

relative fraction from the fit to the data



Di-jet cross section

Inclusive di-jet cross section extracted in 3 bins of ξ.

$$\frac{d\sigma_{jj}}{d\tilde{\xi}} = \frac{N^i_{jj}}{L \cdot \epsilon \cdot A^i \cdot \Delta\tilde{\xi}^i}$$

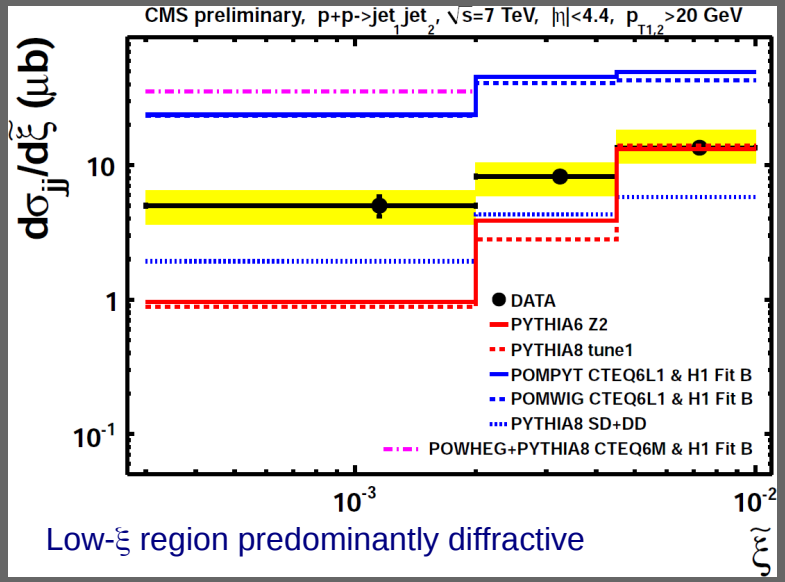
For single-diffractive events ξ approximates proton fractional momentum loss.

$$\tilde{\xi}^{\pm} = \frac{\sum (E^i \pm p^i_z)}{\sqrt{s}} \simeq \frac{M^2_X}{s}$$

ξ reconstructed from PF objects.
ξ+ (ξ-) corresponds to the gap on positive (negative) side.

Excess of events in low-ξ region wrt non-diffractive PYTHIA6 and PYTHIA8 MC.

POMPYT and POMWIG (LO) diffractive MCs and NLO calculations from POMWEG, using diffractive PDFs, are a factor ~5 above the data in the lowest-ξ bin.



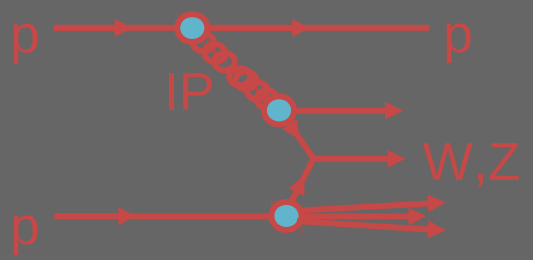
Low-ξ region predominantly diffractive

Data/MC suppression factor is: 0.21 ±0.07 (LO MC)
0.14 ±0.05 (NLO MC).
After proton-dissociation correction, the ratio can be interpreted in terms of rapidity-gap survival probability of 0.12 ±0.05 (LO MC) and 0.08 ±0.04 (NLO MC).

$\tilde{\xi}$ bin	$\Delta\sigma_{jj}/\Delta\tilde{\xi}$ (μb)
$0.0003 < \tilde{\xi} < 0.002$	$5.0 \pm 0.9(\text{stat.})^{+1.5}_{-1.4}(\text{syst.})$
$0.002 < \tilde{\xi} < 0.0045$	$8.2 \pm 0.9(\text{stat.})^{+2.3}_{-2.3}(\text{syst.})$
$0.0045 < \tilde{\xi} < 0.01$	$13.5 \pm 0.9(\text{stat.})^{+4.7}_{-3.1}(\text{syst.})$

Forward energy flow and rapidity gaps with W/Z events

Study of energy flow in the forward region.
Diffractive component in W/Z sample.

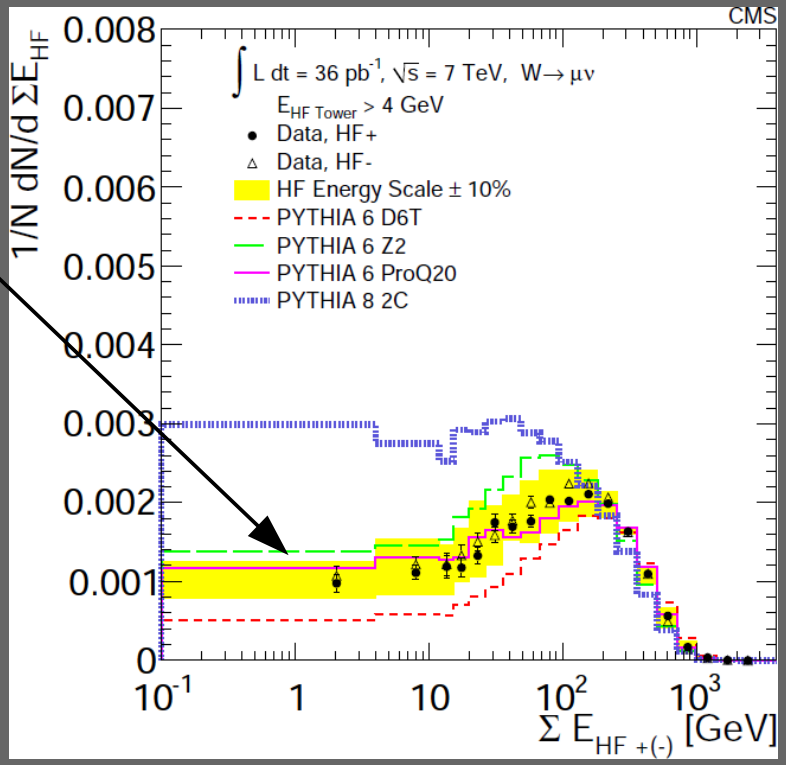


- Analysis based on full 2010 dataset (36 pb^{-1})
- Only single-vertex events to suppress PileUp
- Selection for leptonic W/Z decays follows inclusive cross section measurements
  iso. lepton with p_T>25 GeV and $|\eta|$<1.4, $E_{T,miss}$>30 GeV, m_T>60 GeV

LRG events: events with no individual energy deposit above 4 GeV in one of HF. Rapidity gap of 1.9 units.

Wide range of (non-diffractive) predictions, tune dependent:
- Excess of gap events compared to PYTHIA6 D6T
- Deficit compared to PYTHIA6 Z2 and Pythia8.

Monte Carlo generators cannot describe the data.



Fraction of gap events:

$W \to l\nu$ = 1.46 ± 0.09 (stat.) ± 0.38 (syst.) %

$Z \to ll$ = 1.60 ± 0.25 (stat.) ± 0.42 (syst.) %

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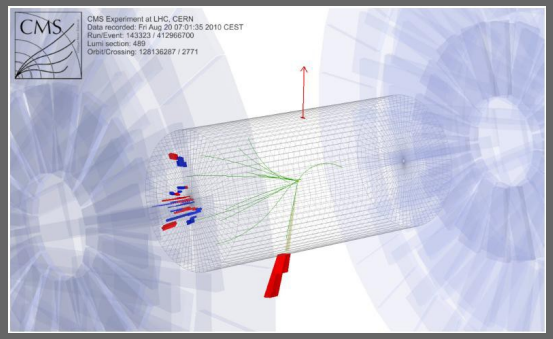
Forward energy flow and rapidity gaps with W/Z events

Hemisphere correlation

Signed pseudorapidity of lepton, η_l:

positive - if gap and lepton on the same side
negative - if gap and lepton on the opposite side.

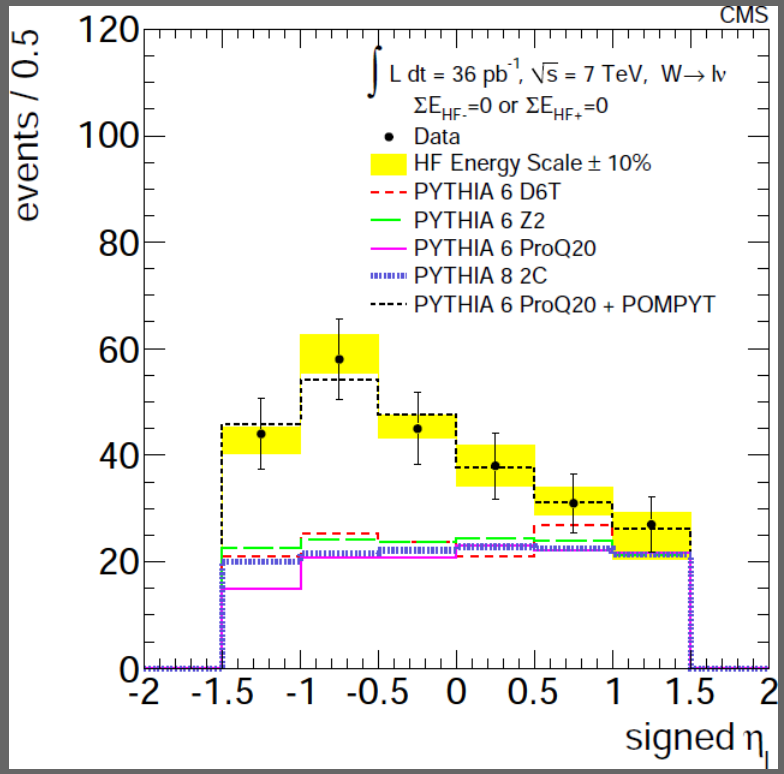


- **Large asymmetry in model including W/Z prodiction in single-dissociation diffraction (POMPYT)**
- **No significant asymmetry in non-diffractive PYTHIA W/Z samples, independent of the tune**

Diffractive component in LRG W/Z sample:
from best with with PYTHIA (ND) and POMPYT (SD) MC

f_{SD} = 50.0 ± 9.3 (stat.) ± 5.2 (syst.) %

First evidence of diffractive W/Z production at LHC



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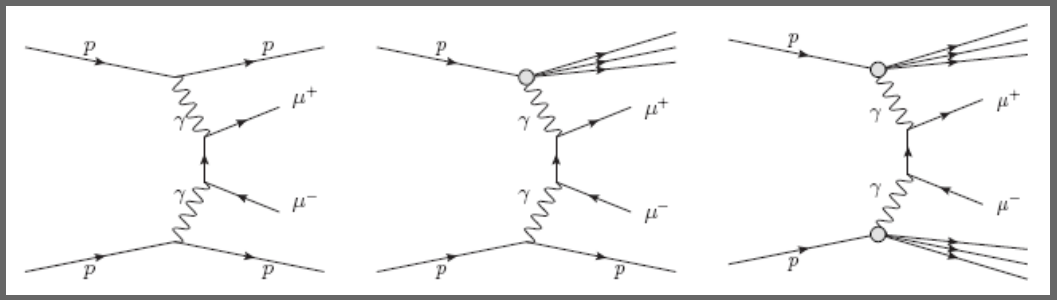
Exclusive $\gamma\gamma \to \mu\mu$ production



QED process, accurate theory predictions:
- **Complementary luminosity calibration.**
- **Control sample for other exclusive processes theoretically less certain (exclusive $\gamma\gamma$ or Higgs production).**

Dominant background – proton dissociation
(uncertainty in modelling of low mass dissociated system)

- Analysis based on full 2010 dataset (40 pb^{-1})
- Di-muon trigger + tracking information (calorimeters not used)
- Vertex with 2 tracks, no other track within 2mm (track veto)
- Kinematic cuts: muon $p_T > 4$ GeV, $|\eta| < 2.1$, $m(\mu\mu) > 11.5$ GeV
- Back-to-back topology: $\Delta\varphi > 162$ deg., $\Delta p_T < 1$ GeV

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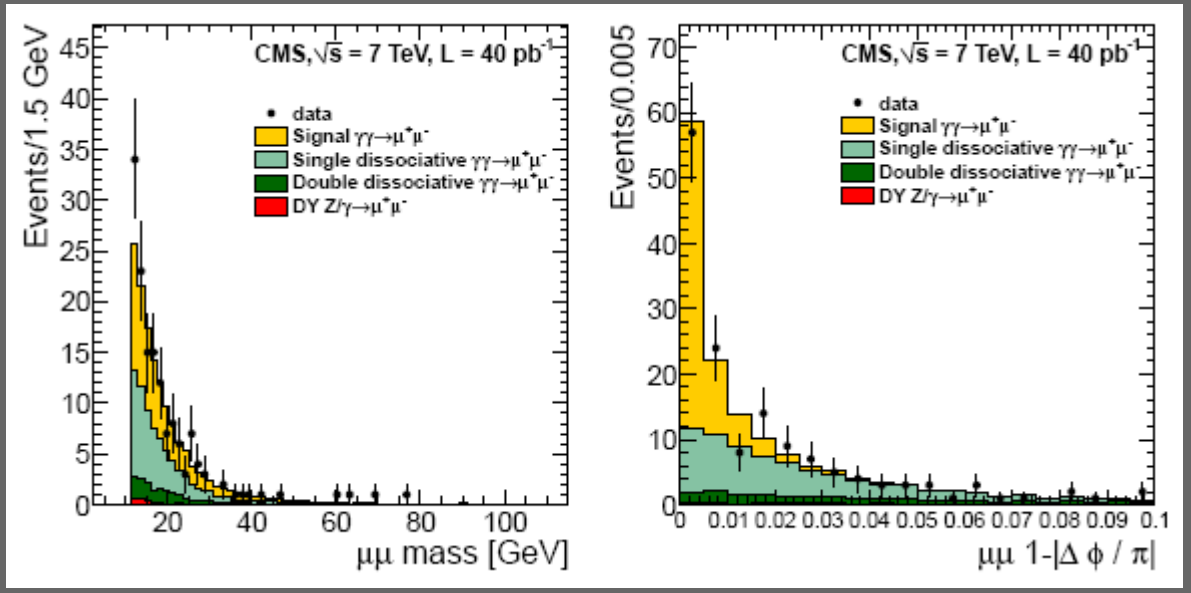
Exclusivity defined by track veto retains efficiency with high PileUp! (~92% at PU=3)

Good agreement of kinematic distributions with LPAIR prediction



Exclusive $\gamma\gamma \to \mu\mu$ cross section

Exclusive cross section and ratio to LPAIR prediction extracted from the fit to $p_T(\mu\mu)$ distribution.

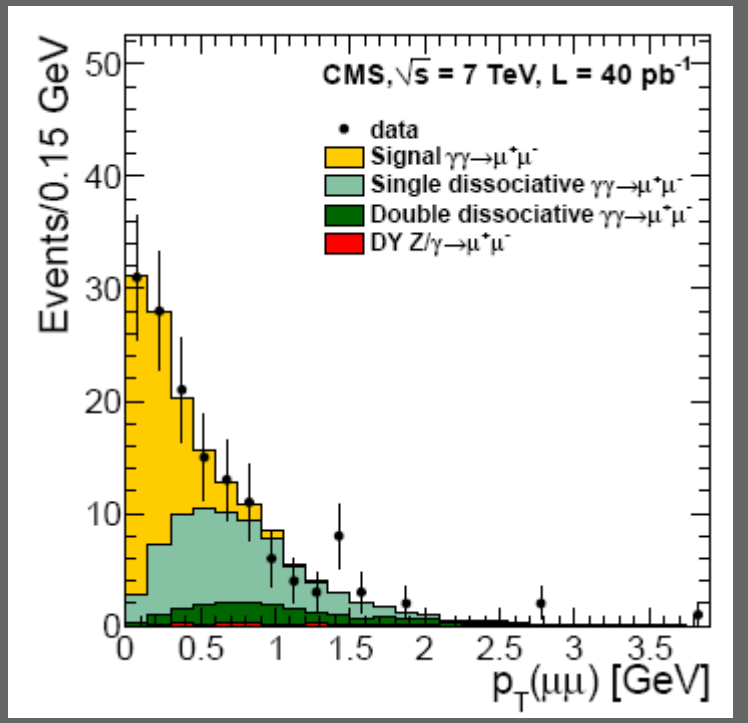
Free parameters of the fit: signal yield, single proton-dissociation yield and the correction to the shape of the proton-dissociaton sample (negligible).

Results of the fit:

$\sigma = 3.38^{+0.58}_{-0.55}$ (stat.) ± 0.16 (syst.) ± 0.14 (lumi.) *pb*

ratio to MC $= 0.83^{+0.14}_{-0.13}$ *(stat.)* ± 0.04 *(syst.)*

Consistent with expectations at ~ 1σ.



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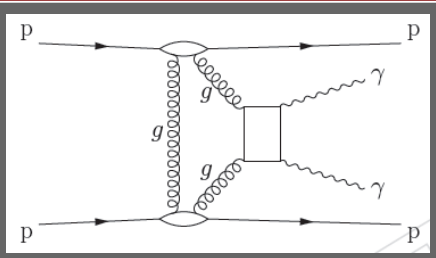
$\gamma\gamma \to ee$ production and search for central exclusive $\gamma\gamma$ production



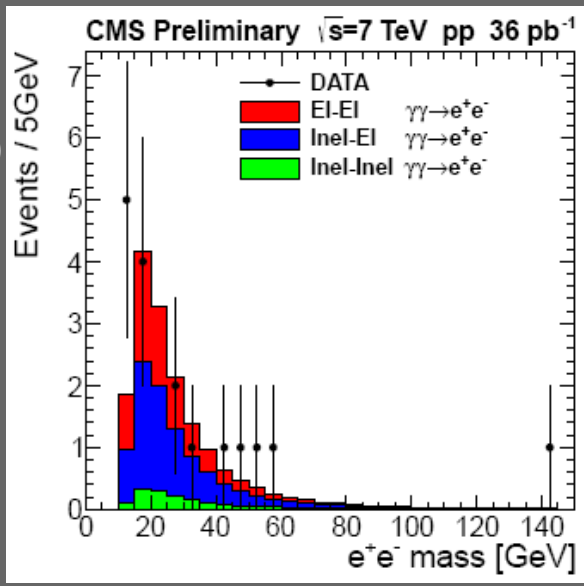
Exclusive *ee* production – QED process (similarly to $\mu\mu$)
Exclusive $\gamma\gamma$ production – QCD process

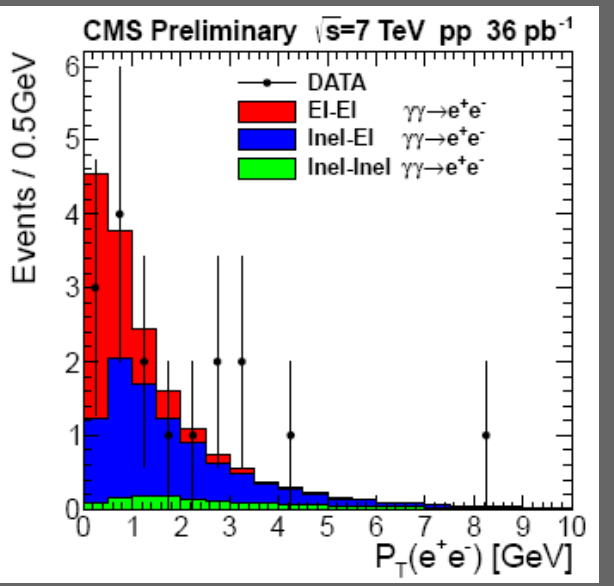
- Analysis based on full 2010 dataset (36 pb^{-1})
- Trigger: two electromagnetic objects. Offline: two high-quality electrons or photons.
- Exclusivity criteria: no additional tracks, no additional energy deposit in calorimeters (eff.=0.145 $\pm$0.008)
- Kinematic cuts: $E_T > 5.5$ GeV, $|\eta| < 2.5$
- Back-to-back topology: $\Delta\varphi > 2.5$ rad

Exclusive *ee*:

17 candidates observed in data.
Background expectations: 0.84$\pm$0.28 (stat.)

Predicted by LPAIR:
16.5$\pm$1.7 (theory) $\pm$ 1.2 (stat.)
(elastic and proton dissociation).





Very good agreement between data and LPAIR prediction.

Provides validation of experimental procedure for $\gamma\gamma$ search.

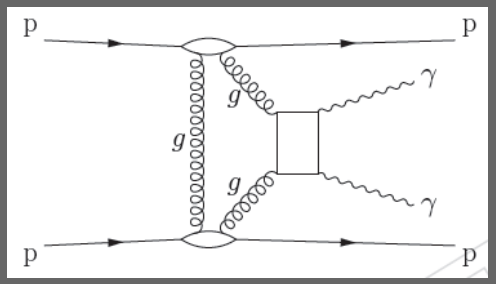
$\gamma\gamma \to ee$ production and search for central exclusive $\gamma\gamma$ production

Exclusive $\gamma\gamma$ production:

No events observed after all selections.

Upper limit on exclusive + proton dissociation production of $\gamma\gamma$ with $E_T > 5.5$ GeV, $|\eta| < 2.5$:

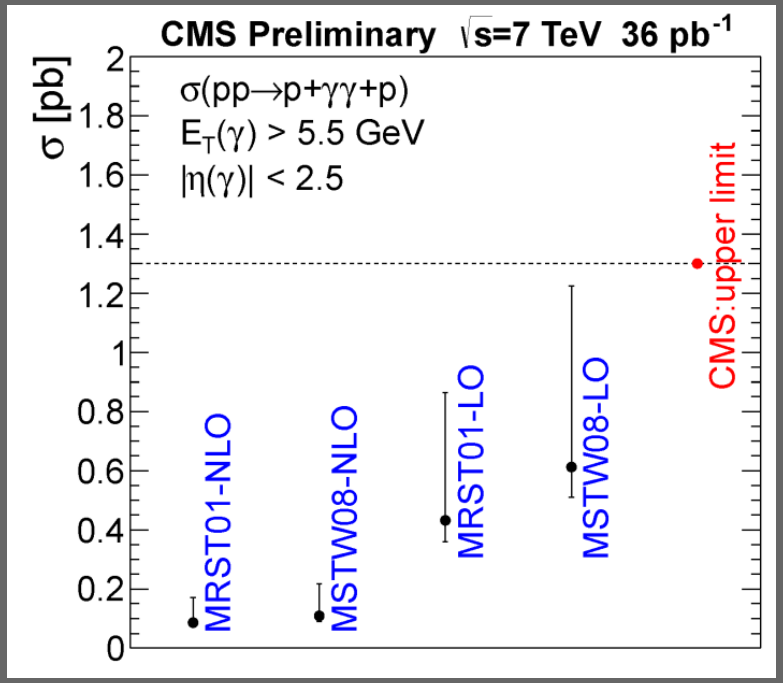
$\sigma < 1.30$ pb @95% CL



Results compared to prediction of ExHume MC with several LO/NLO PDF sets.

Poor statistics to test NLO calculations.

Probability of seeing 0 events wrt. MSTW08-LO prediction is 23%.



CMS PAS FWD-11-004

Summary

- **CMS results presented on:**
  - Soft diffraction at 0.9, 2.36 and 7 TeV
  - Diffractive dijets
  - Energy flow and rapidity gaps with W/Z events
  - Exclusive $\gamma\gamma \to \mu\mu$ production
  - Exclusive $\gamma\gamma \to ee$ and search for central exclusive $\gamma\gamma$ production
- **Prospects:**
  - Many new results expected - ongoing analyses with 2010/early 2011 data, possible low-pileUp runs in 2012
  - Only beginning to exploit the potential of forward detectors (CASTOR, ZDC, CMS, CMS+TOTEM common runs).

Stay tuned! And check the latest CMS results at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ