QCD and Forward Physics Results from CMS

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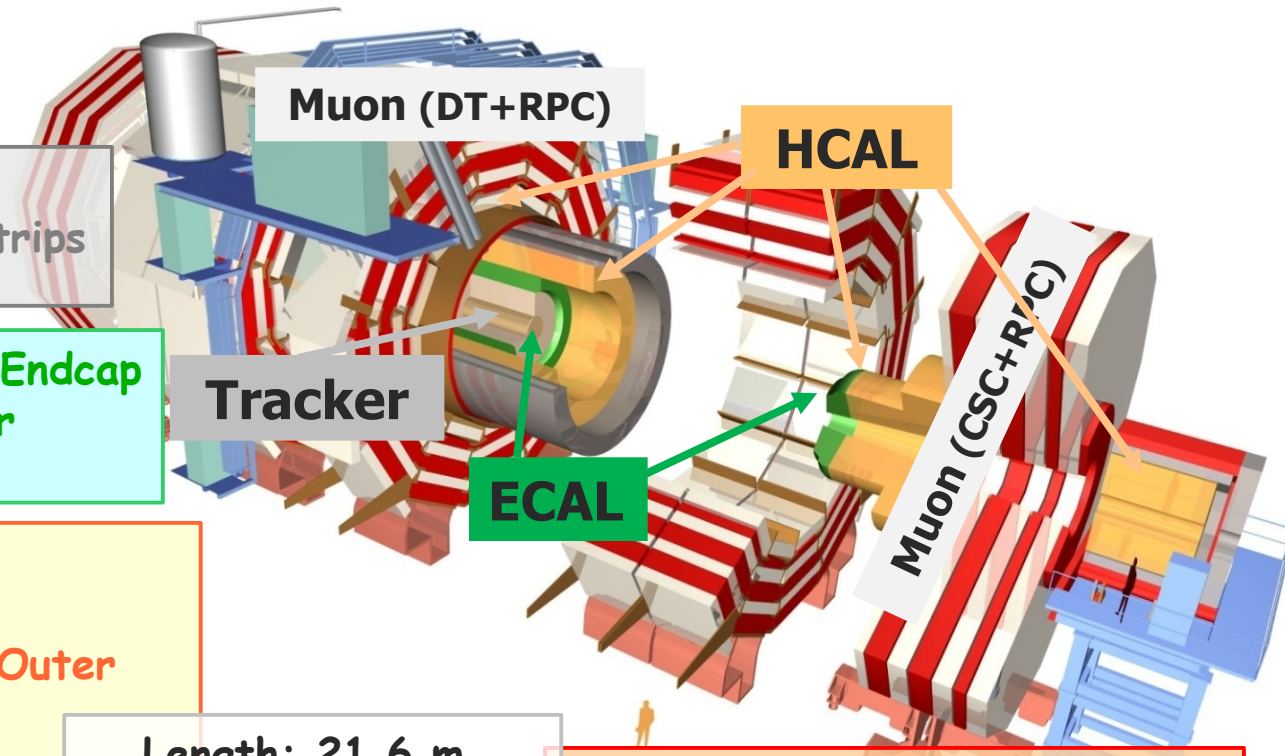
CMS Detector

Tracker
66M Si pixels & 10M Si strips

EM Calorimeter: Barrel & Endcap
PbWO4 crystal calorimeter

Hadronic calorimeter:
Brass & scintillator
Barrel, Endcap, Forward, Outer



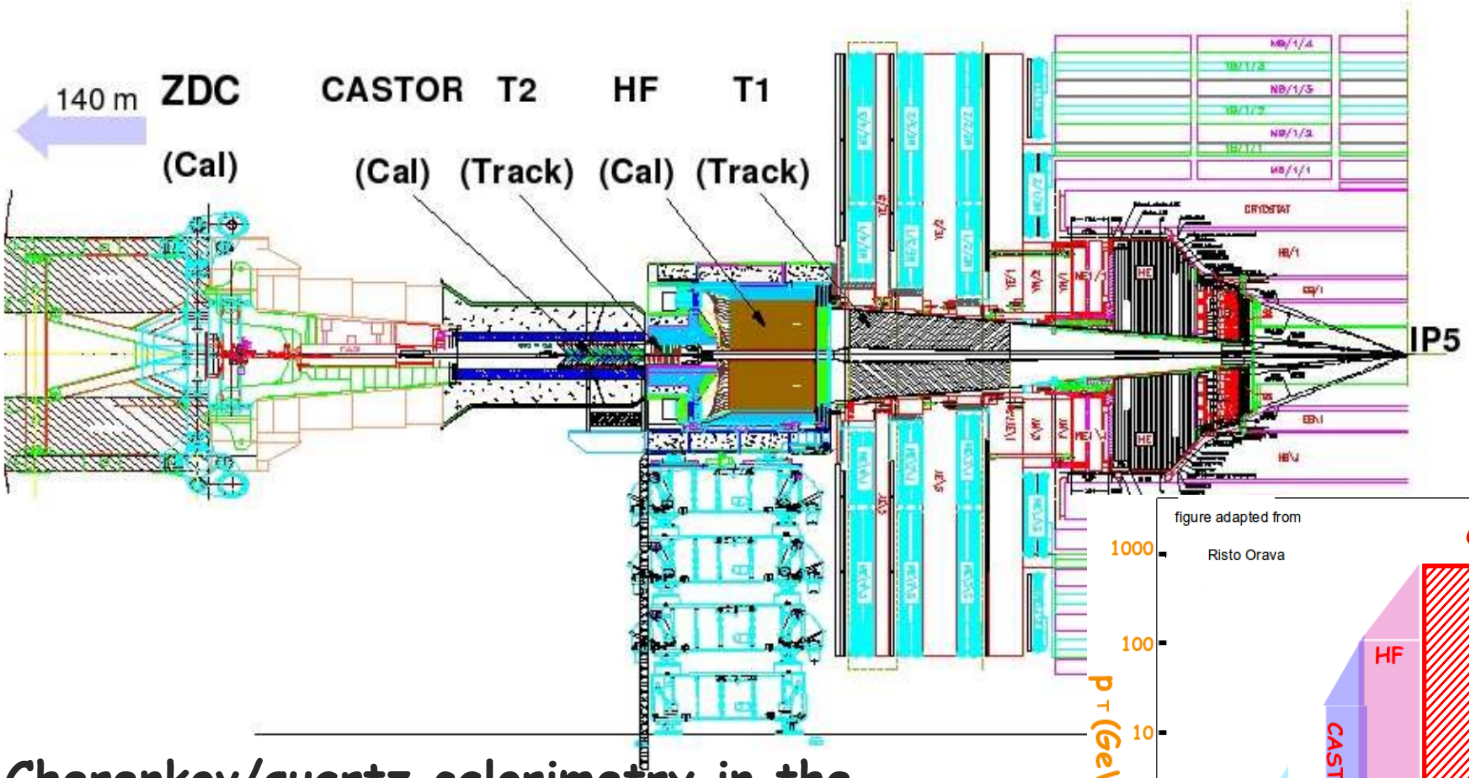
Length: 21.6 m
Diameter: 15 m
Weight:12500 tons

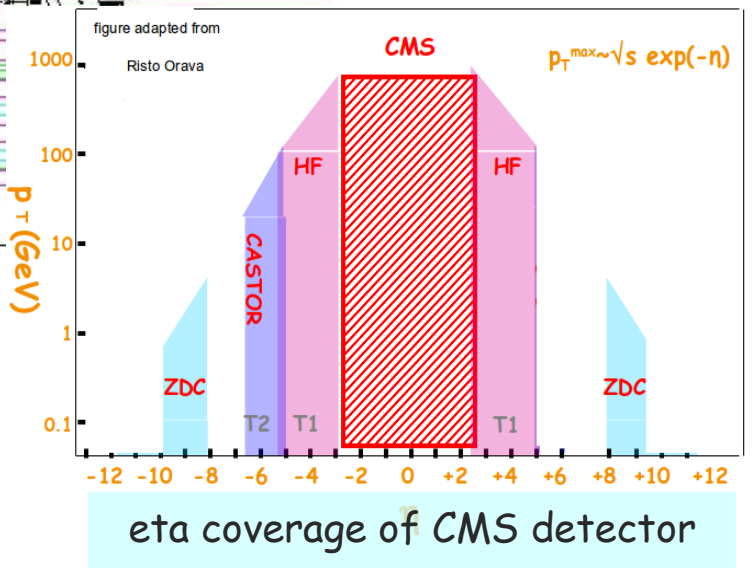
Muon chambers:

Barrel: Drift Tubes - Endcap: Cathode Strip Chambers -

Both interleaved with Resistive Plate Chambers

Forward Detectors





eta coverage of CMS detector

Cherenkov/quartz calorimetry in the forward region.
HadronForward (HF): Long and short quartz fibers alternated, embedded in iron absorbers.

Physics Topics Covered

A selection of recent (or almost) results on QCD

- Inelastic cross section new
- Measurement of UE with jets
- Measurement of UE with DY

Forward and diffraction

- Energy flow and LRG at hard scale (W/Z events)
- Hard diffraction in dijets new
- Exclusive procesess, $\gamma\gamma$, gg interactions new

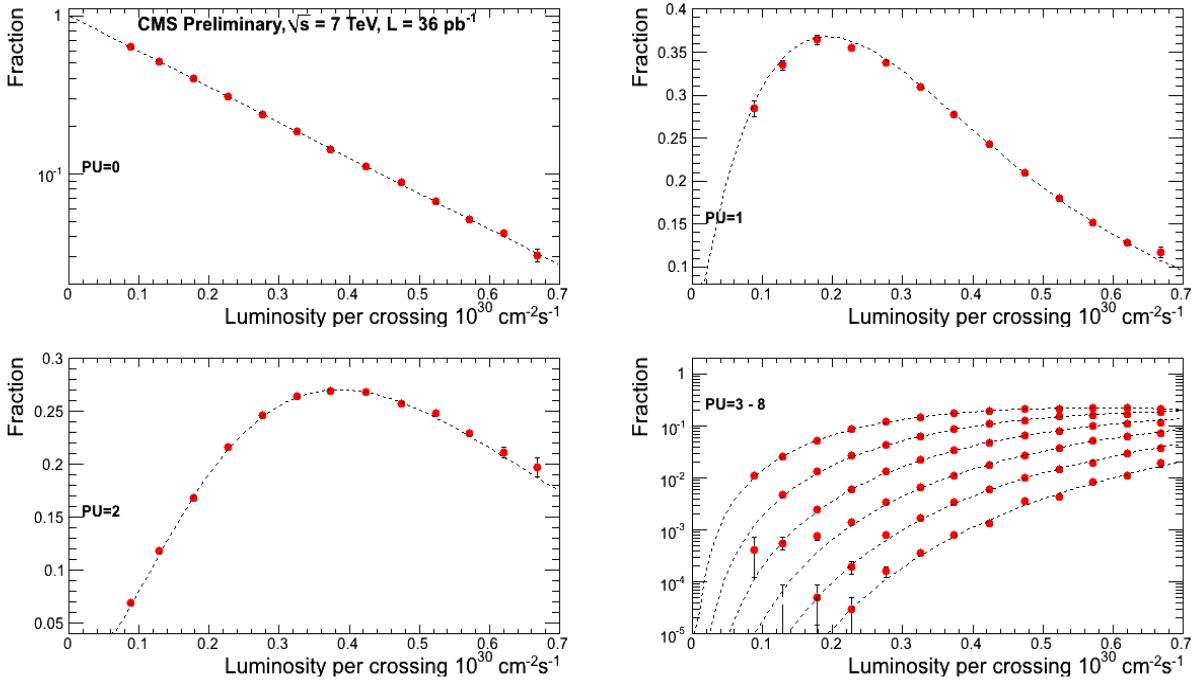
Total Inelastic pp Cross Section

Measured with **Forward Activity** and via **PileUP events distribution**

new **CMS-QCD11-002**

CMS-FWD-11-001

- Procedure: produce reconstructed vertex distribution in bins of BX luminosity



- Correct for vertex reconstruction inefficiency
- Derive sigma assuming PileUp events are randomly distributed according to Poisson probability as a function of Bunch Crossing Luminosity

$$P(n) = \frac{(L \cdot \sigma)^n}{n!} e^{-L \cdot \sigma}$$

Total Inelastic pp Cross Section

CMS-FWD-11-001

- 3 different hadron-level definitions of ***visible*** cross-section:

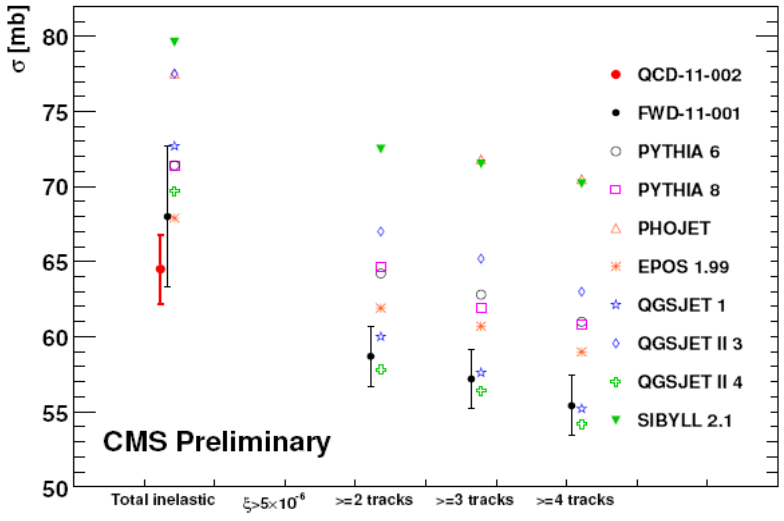
  at least **2,3** or **4 charged particles** with $|\eta| < 2.4$ and $p_t > 200$ MeV

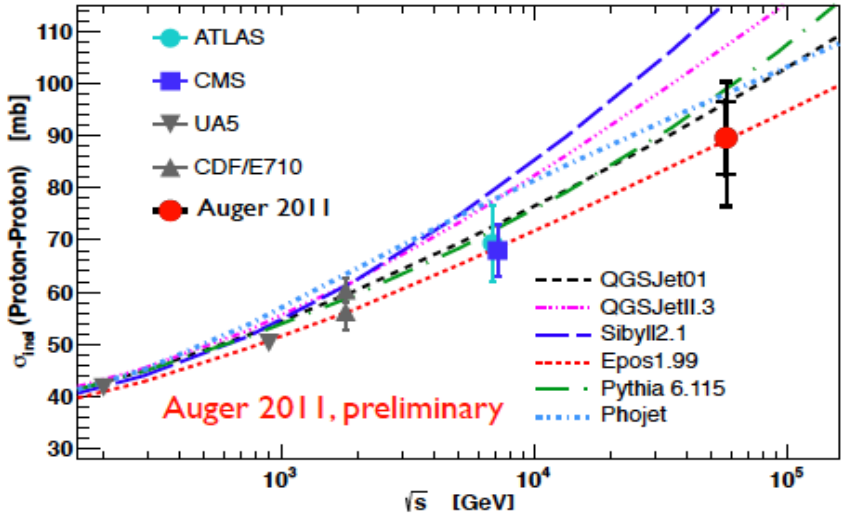
  σ_{2trk} = 58.7 ± 2 .0 (*syst*) ± 2.4 (*lumi*) mb

- Model-dependent **extrapolation** to estimate **total inelastic σ**

  Prediction from PYTHIA6, PYTHIA8, PHOJET, cosmic ray physics MC (QGSJET, SIBYLL, EPOS)

  σ_{inel} = 68 ± 2.0 (*syst*) ± 2.4 (*lumi*) ± 4 (*ext*) mb





Total Inelastic pp Cross Section

CMS-QCD11-002

Second measurement (just approved)

- Based on HF calorimeters activity in ZeroBias events, 2.76 μb^{-1} of data in early 2010 → very low PU
- Inelastic collisions **selection**:
  - energy in any of HFs > 5 GeV
  - counting corrected for $\varepsilon_{selection}$ from MC studies (PHOJET PYTHIA6 PYTHIA8), for PU and noise

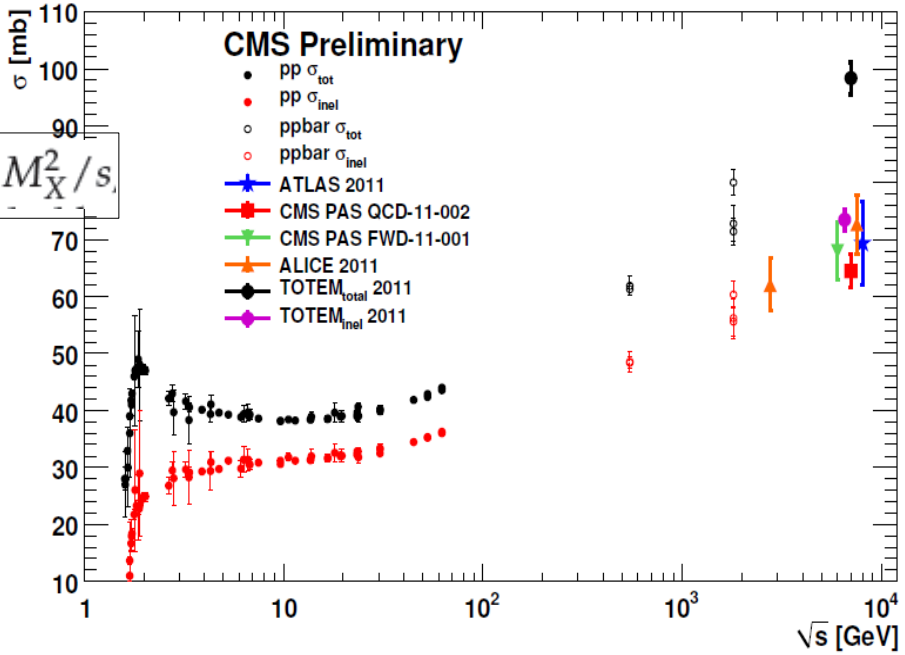
Cross section *(in mb)* for events with $\xi > 5 \times 10^{-6}$ (due to HF acceptance)

$$\xi = M_X^2/s$$

σ_{vis} = 60.2 ± 0.2 *(stat)* ± 1.1 *(syst)* ± 2.4 *(lumi)*

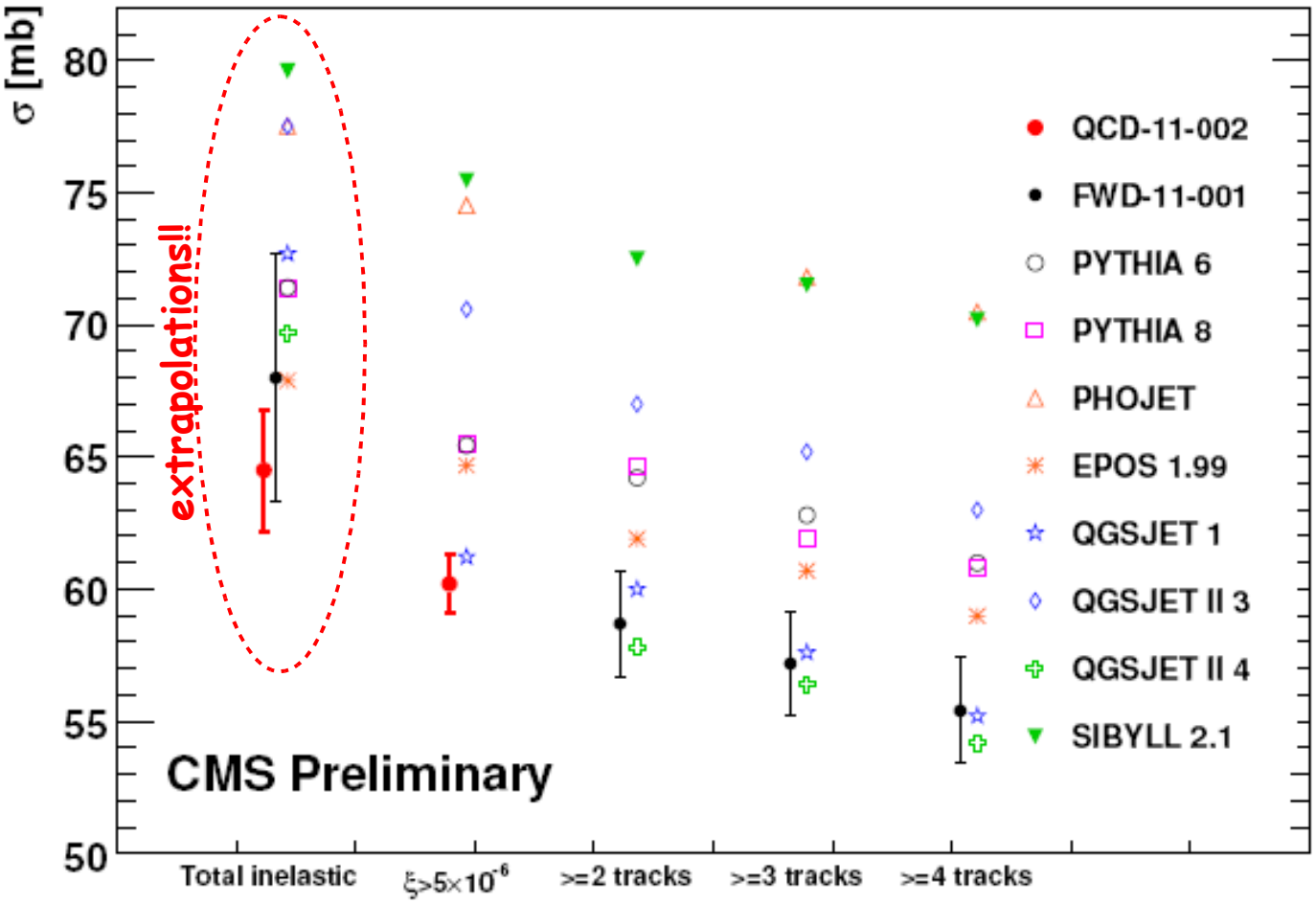
Extrapolation to full range (average from 6 different MCs):

σ_{inel} = 64.5 ± 0.2*(stat)* ± 1.5*(syst)* ± 2.6*(lumi)* ± 1.5*(extr.)*



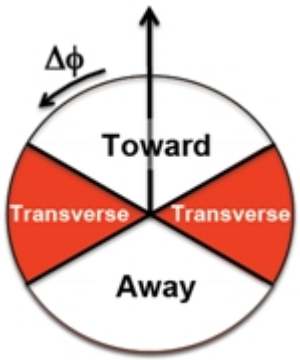
Total Inelastic pp Cross Section

CMS-QCD11-002



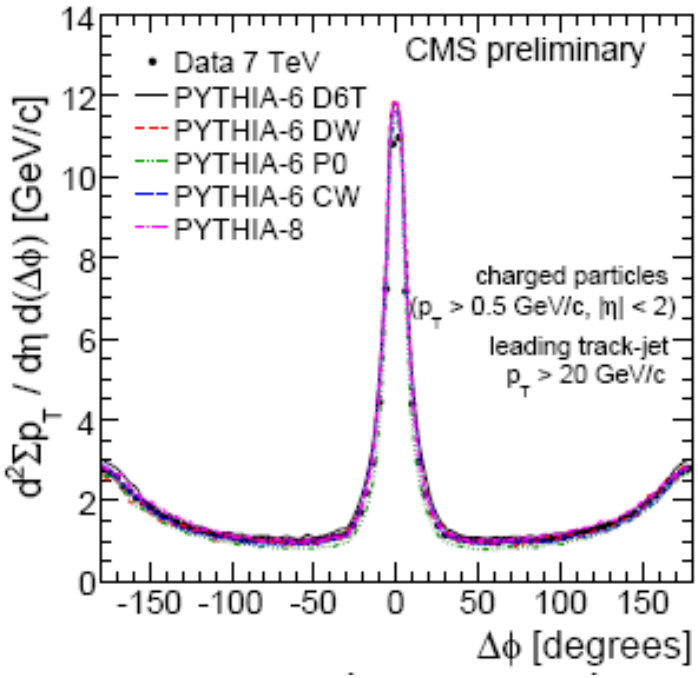
Underlying Event

CMS-QCD-10-035



Clusters of tracks, or clusters of calorimeter cells with largest p_t are called leading object → expected to reflect the direction of the parton in the hard scattering.

Transverse region is expected to be sensitive to underlying event

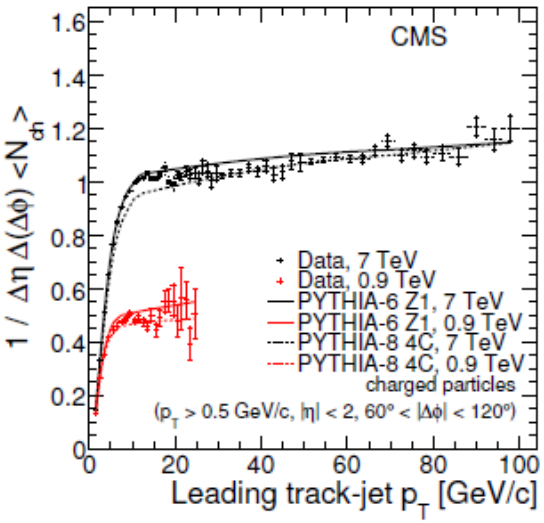


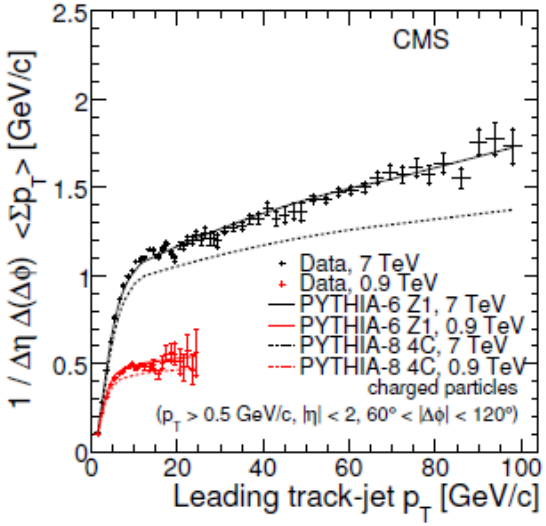
Look at particle production wrt a high energy object (track or jet), in transverse direction

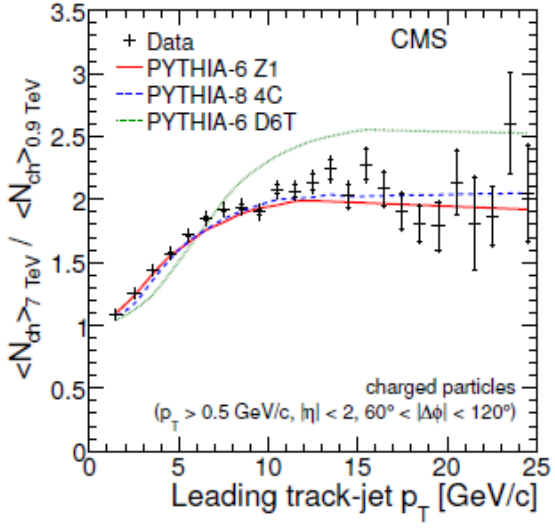
Important field for MC tuning and understanding of the interaction process

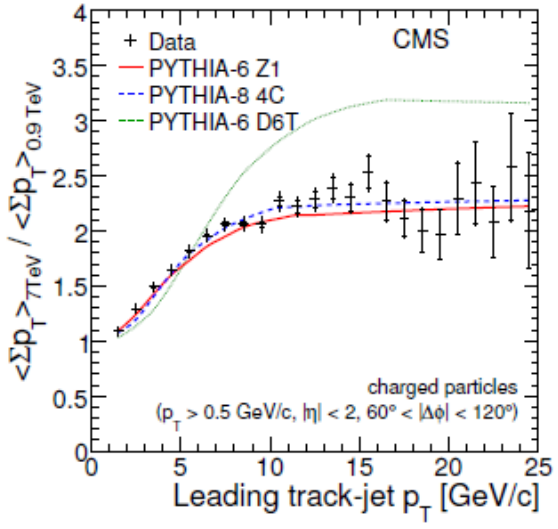
Sensitive to new effects, e.g. multi-parton interactions

Underlying Event









UE observables: Charged Particle density, Scalar Sum of Charged pT density in the transverse region

- The hard scale of the event is defined by the hardest track-jet
- UE activity shows a sharp increase up to p_t of 10 GeV
- Strong increase of UE activity from 0.9 to 7 TeV
- Particle production saturates (MPI saturation)

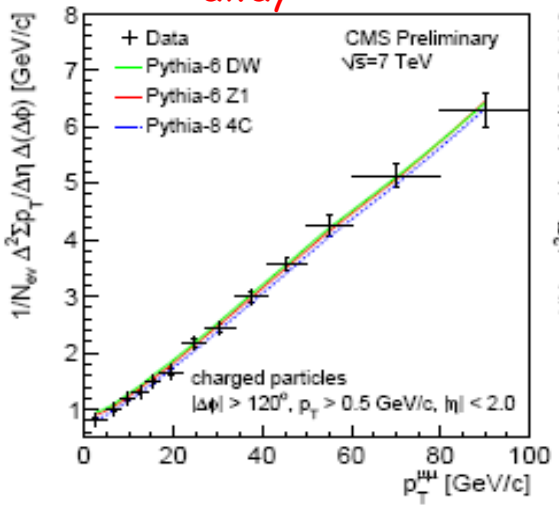
Underlying Event in DY Dimuons

CMS-QCD-10-040

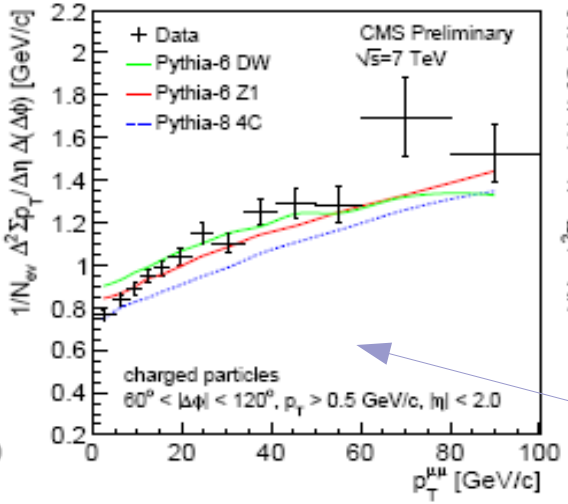
Complementary method: use of DY di-muon final state, with $m_{\mu\mu}$ close to Z [60-120] → good separation of primary hard scatter from the rest, very low background.

Average charged particle density, average Σpt_{CH} density studied in *away*, *towards* and *transverse* regions (wrt direction di-muons system) as a function of $m_{\mu\mu}$ and $p_t^{\mu\mu}$

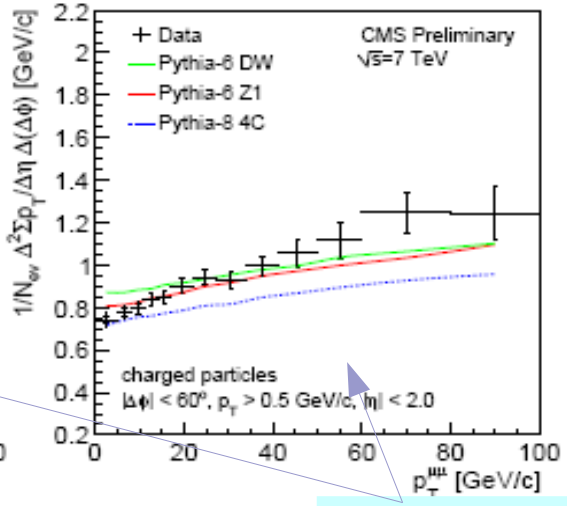
away



transverse



towards



Data compared with PYTHIA-8 4C , PYTHIA-6 Z1 and DW tunes (differ in PDF, implementation of radiation, fragmentation and MPI)

scale given by Zmass → lies well in MPI saturation region

Diffraction

Soft and Hard Diffraction:
Soft → evidence in MinimumBias events @ $\sqrt{s}$ = 0.9, 2.36 and 7 TeV

Hard Scale → evidence of diffractive component in Z,W events
measurement of DiJets diffractive cross section

Identification based on studies of **activity (or the lack of) in the forward region ($|\eta| > 3$) using the HF calorimeters**, or on **proton fractional momentum loss ξ distribution**, as obtained from calorimeter/tracker information

Observation of LRG at Hard Scale

CMS-FWD-10-008

Hard scale set by W or Z production

LRG and UE via energy flow study in forward detector and correlation with central track multiplicity

2010 pp data, $\sqrt{s}$ = 7 TeV, 36 pb^{-1} - one vertex event only

W → lν selection *

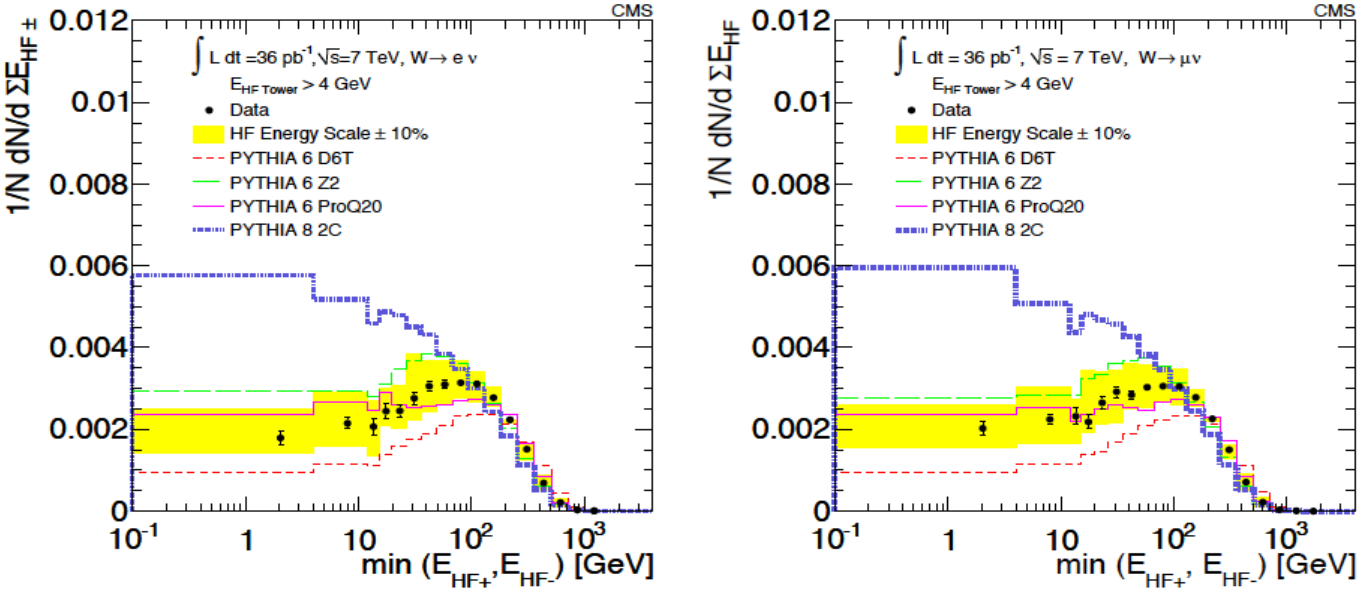
- an isolated electron or muon with pt > 25 GeV and |η| < 1.4
- ET, miss > 30 GeV (assigned to neutrino)
- mT (*l*,*ν*) > 60 GeV

Reject events with a secondary isolated lepton with pt>10 GeV → Background less than 1%.

* Here presenting only W results, being statistically more significant than Z events

Observation of LRG at Hard Scale

Monte Carlo: non-diffractive MC Pythia 6 and Pythia 8, and/or diffractive predictions from POMPYT (without MPI).
Large rapidity gap events: events with no individual energy deposit above 4 GeV in one of the HF → rapidity gap of 1.9 units.



Not clear conclusion from observed fraction of LRG events.

- Large tune dependence
- Pythia 8 2C overestimates the LRG events by factors

Hemisphere Correlation in W/Z

Signed pseudorapidity of leptons:

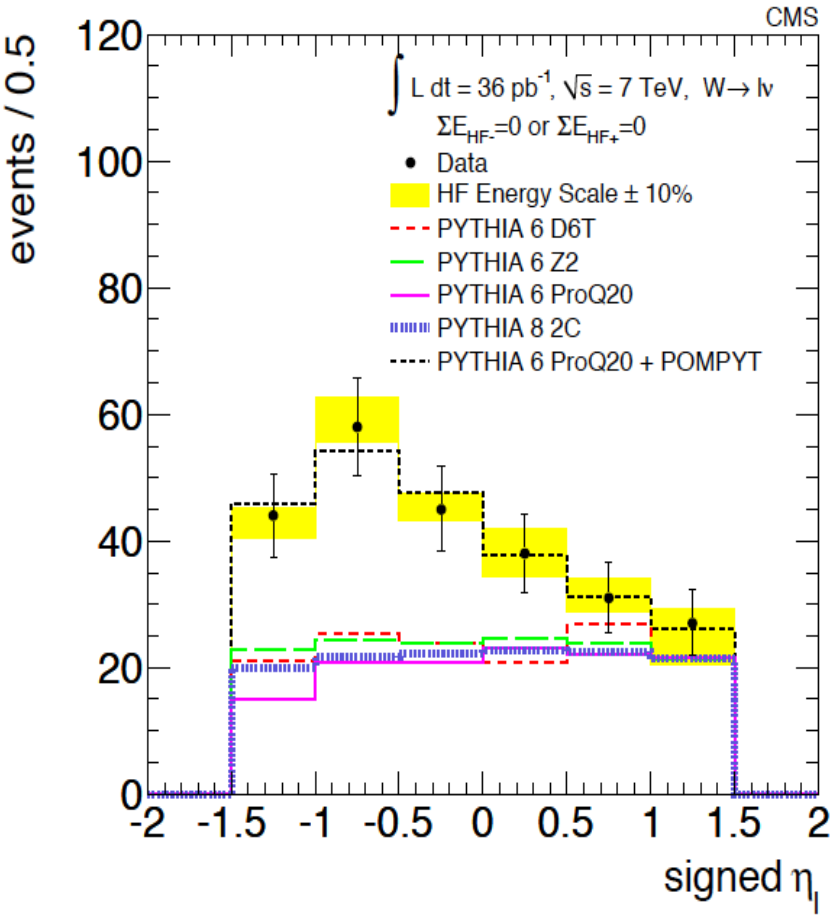
- positive if gap and lepton on same side

- negative if gap and lepton on opposite side

Data asymmetry (similar in Z events) can be described only with a mixture of non-diffractive and diffractive MC (PYTHIA6 + POMPYT)

Diffractive component (from best fit with fixed shapes)

50.0 ± 9.3(stat) ± 5.2(syst) %



First evidence of diffractive W/Z production at LHC

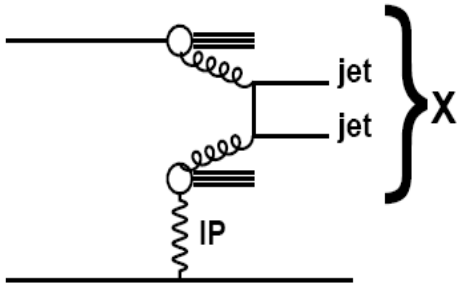
Diffractive Dijet Production

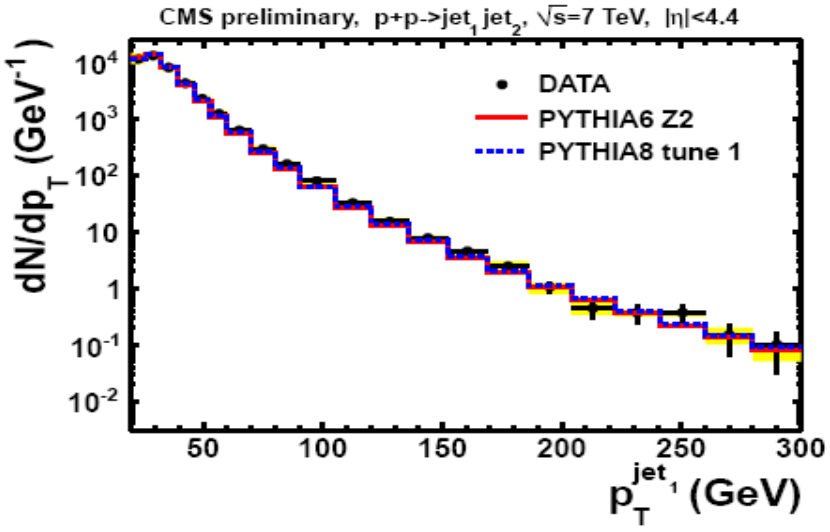
CMS-FWD-10-004

new

2010 data (2.7 nb^{-1}) ← very low PileUP sample

- single (hard) diffractive pp--> p jet jet in $|\eta| < 4.4$, $p_T > 20$ GeV
- LRG expected
- **study of ξ - proton fractional momentum loss - distribution**





ξ approximated at generator level by

$$\tilde{\xi}^{\pm} = \frac{\sum (E^i \pm p_z^i)}{\sqrt{s}} \simeq \frac{M_X^2}{s},$$

sum over all particles $\eta < 4.9$ (or $\eta > -4.9$)
$\xi^{\pm} \approx \xi$ for single diffractive events

$\xi^{\pm}$ reconstructed summing over all ParticleFlow objects in $|\eta| < 4.9$: particle candidates combining information from tracking and calorimeters

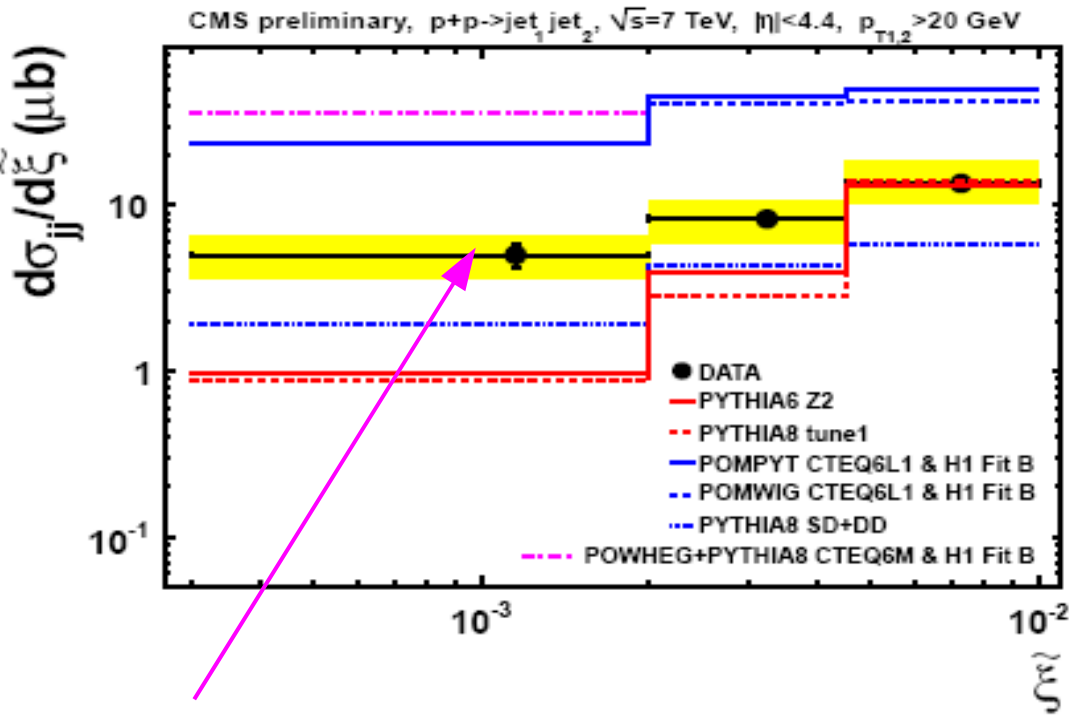
Diffractive Dijet Production

Measured $\tilde{\xi}$ distribution in dijet events described by a suitable combination of diffractive and non-diffractive MCs.

Differential Cross Section

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

Pythia6 Z2 , Pythia8 Tune1: no hard diffraction
POMPYT, POMWIG (SD LO) based on diffractive PDFs from HERA overestimate the measured cross section



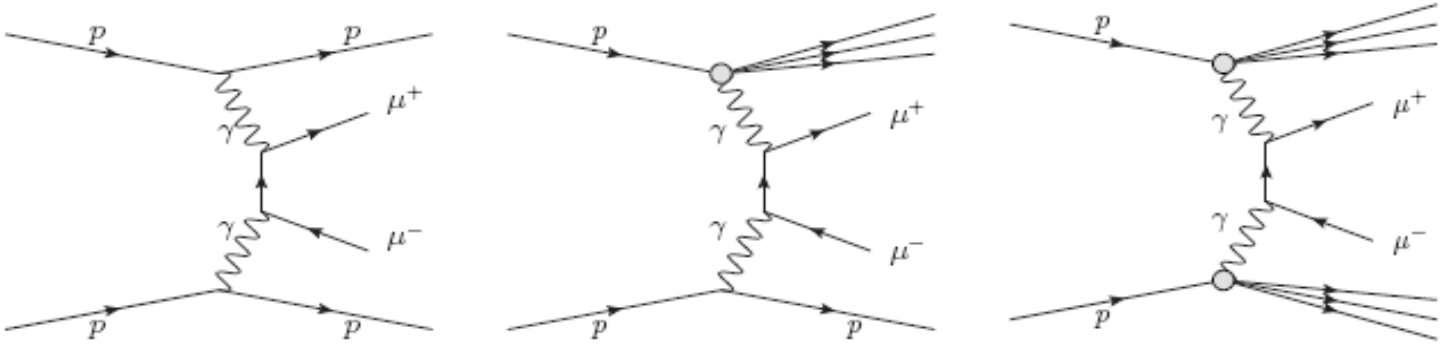
Low-$\tilde{\xi}$ events dominantly diffractive

Cross section measurement!

Suppression factor is 0.21±0.07. Correcting for proton-dissociative events ratio in data/MC → **rapidity-gap survival probability: 0.12±0.05**

Exclusive Dimuon Events

CMS-FWD-10-005



signal **backgrounds**

Exclusive two-photon production of muon pairs in 2010 (40 pb^{-1})

(or e+e- pairs → new! see next slides)

QED process very well predicted → absolute calibration of luminosity

Selection:

- one vertex with two tracks and no others associated (within 2 mm)
- muon pt > 4 GeV, $|\eta| < 2.1$, $m_{\mu\mu} > 11.5$
- **track veto efficiency with <PU> 3 → 92%**

veto size studied on ZeroBias events on DY MC sample

NB: exclusivity imposed using tracking systems only, applied at the primary vertex → full 2010 dataset

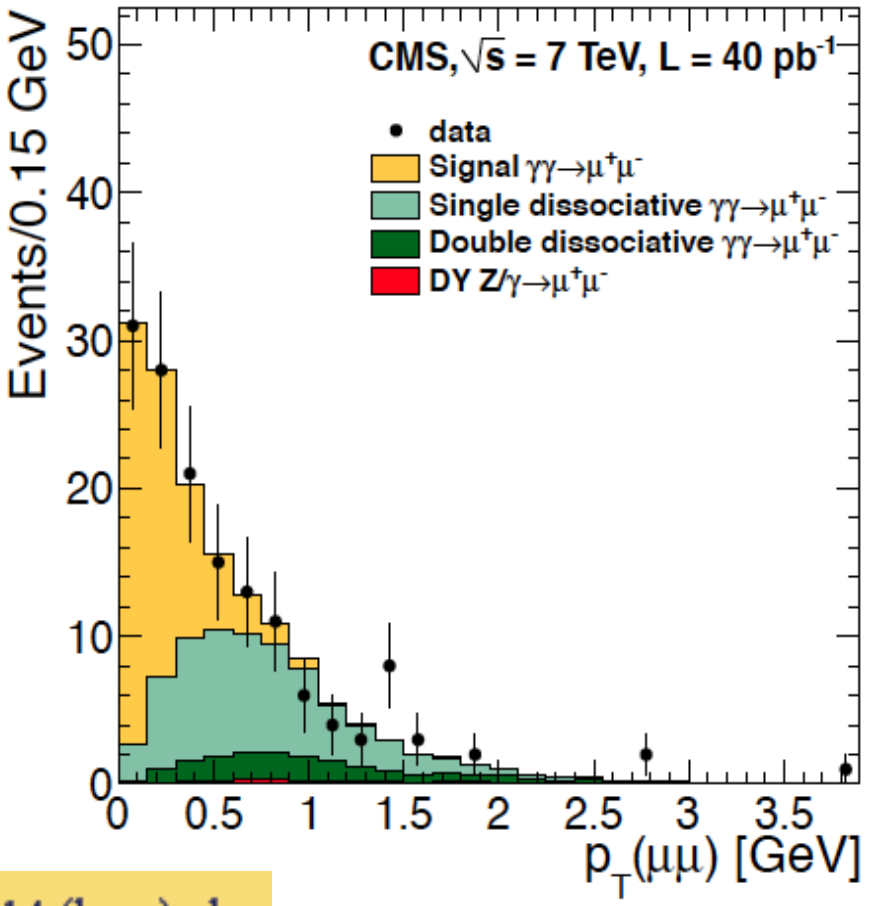
Exclusive Dimuon Events

2010 di-muon distributions compared to LPAIR QED MC

Good agreement with expectations for exclusive **$\gamma\gamma \rightarrow \mu\mu$ + proton dissociation components.**

Fit to the $p_t(\mu\mu)$ distribution to extract the signal:

Signal yield, single p-dissociation yield, and a correction to the slope of the p-dissociation are free parameters of the fit



$$\sigma = 3.38\ ^{+0.58}_{-0.55}\ (\text{stat.}) \pm 0.16\ (\text{syst.}) \pm 0.14\ (\text{lum.})\ \text{pb}$$
$$\text{Ratio} = 0.83\ ^{+0.14}_{-0.13}\ (\text{stat.}) \pm 0.04\ (\text{syst.})$$

Exclusive Diphotons, Dielectrons

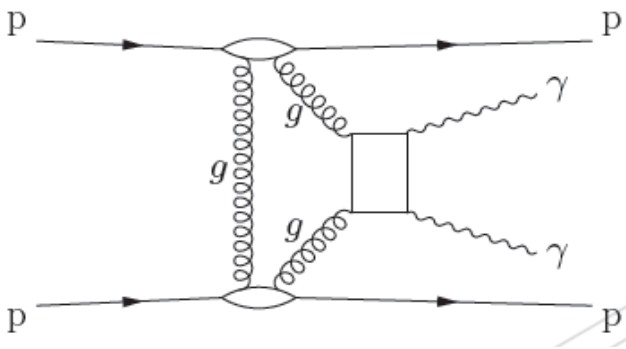
CMS-FWD-11-004 new

Excl γγ prod: proton pomeron exchange with gg → γγ

Excl e+e- prod: QED γγ → e+e- (as for μμ)

Selections:

- **2 reconstructed γγ or e+e- in $|\eta| < 2.5$, $E_T > 5.5$ GeV**
- exclusivity criteria: no additional tracks in tracker and no additional energy deposit (above noise thresholds) in calorimeters

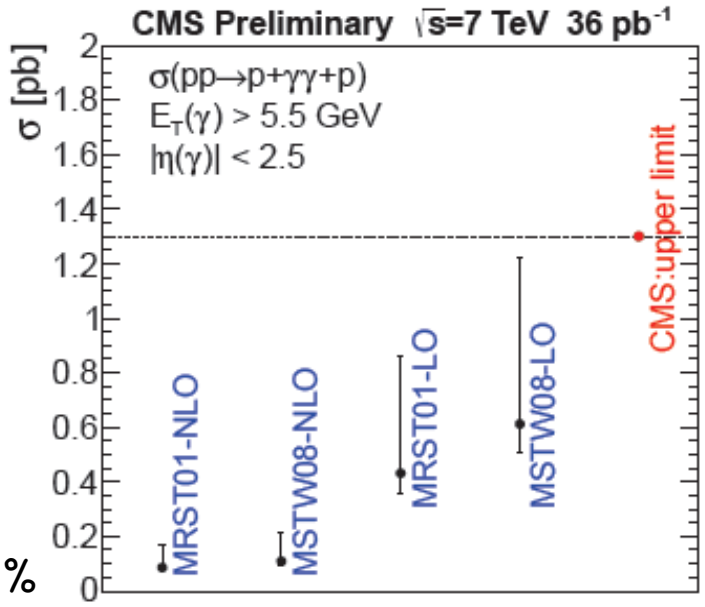


studied in Unpaired/ZeroBias w/o interactions

γγ : no events observed in 36 pb^{-1}

- Upper limit (includes semi-exclusive production with no visible particle in $|\eta| < 5.2$)

$$\sigma^{E_T(\gamma)>5.5\,\mathrm{GeV},\,|\eta(\gamma)|<2.5}_{\text{exclusive }\gamma\gamma\text{ production}} < 1.30\ \mathrm{pb}$$



Compared with 4 MCs, 2 PDF sets, LO and NLO.

- poor statistics to test NLO computations
- prob. of seeing 0 events in CMS if MSTW08-LO is 23%

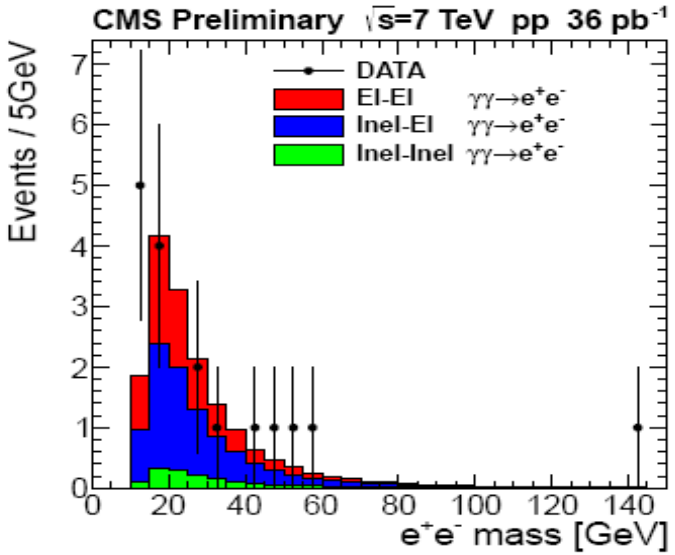
Exclusive Diphotons, Dielectrons

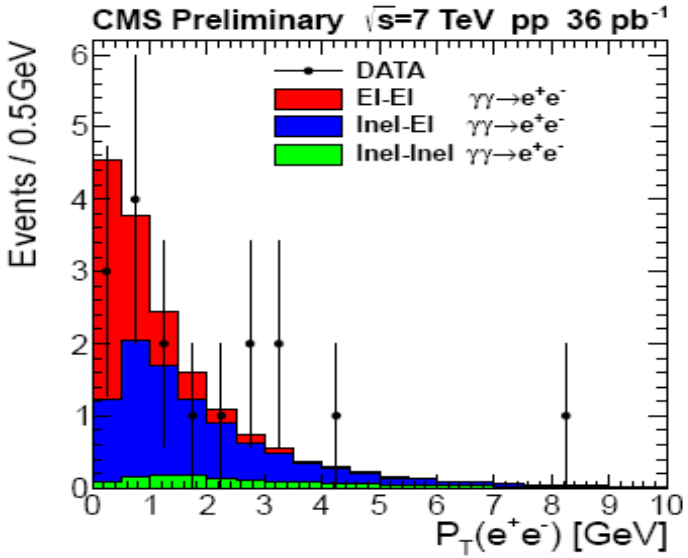
e^+e^- : 17 candidates on a background of 0.84 ± 0.28 (stat.) observed

theoretical **QED prediction** is 16.5 ± 1.7 (theo.) ± 1.2 (syst.) events

Semi-exclusive e^+e^- (when one or both protons dissociate and escape undetected) are here considered as signal.

Good agreement of kinematic distributions with QED predictions





Summary

QCD and Forward physics are strong parts of the CMS physics program: a lot of results already published and a lot more on the way...

This talk covered:

- **Inelastic Total Cross Section,**
- **Hard and Soft Diffraction**
- **Underlying Events with jets and muons in the final state**
- **Exclusive QED & QCD processes**

LHC provides unique opportunities to study a **wide range of QCD phenomena**. It has so far provided data at 3 energies, and this year will add a fourth one: **great occasion** for **model building** and **MC tuning**. We look forward to the new data at 8 TeV!

Backup slides

Total inelastic pp cross section

CMS-QCD11-002

Generator level ξ distributions for the inelastic events belonging to the 6 MC samples used for the extrapolation