Observation of diffraction in minimum bias events at LHC

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(on behalf of the CMS Collaboration)

Talk based on the paper

Available on the CERN CDS information server **CMS PAS FWD-10-001**

CMS Physics Analysis Summary

Contact: cms-pag-conveners-fwd@cern.ch 2010/06/14

Observation of diffraction in proton-proton collisions at 900 and 2360 GeV centre-of-mass energies at the LHC

The CMS Collaboration

Abstract

The observation of inclusive diffraction at LHC with the CMS detector at $\sqrt{s} = 900$ and 2360 GeV is presented, along with a comparison of the data with the predictions of the PYTHIA and PHOJET generators.

Thanks for the input from the ARC(*), the HCAL DPG and the FWD PAG(*)

(*) ARC members:
Rino Castadi (chairperson), David d'Enterria and Gabor Veres

(*) FWD PAG members:
Michele Arneodo, Alexander Proskuryakov, Antonio Vilela Pereira

http://cdsweb.cern.ch/record/1271073/files/FWD-10-001-pas.pdf

Outline

Introduction

Experimental Apparatus

Event Selection

Monte Carlo simulation and acceptance

Results: Data vs MC comparison

Summary

Processes classification

PYTHIA6.205/PHOJET1.12 predictions for cross sections at √s=14 TeV

$\sigma_{tot}(101.5/119mb) \rightarrow \sigma_{elas}(22.2/34.4mb)$

$\sigma_{tot}(101.5/119mb) \rightarrow \sigma_{inelas}(79.3/84.5mb)$

$\sigma_{inelas}(79.3/84.5mb) \rightarrow \sigma_{mb}(55.2/68mb)$

$\sigma_{inelas}(79.3/84.5mb) \rightarrow \sigma_{diff}(24.1/16.5mb)$

$\sigma_{diff}(24.1/16.5mb) \rightarrow \sigma_{sd}(14.3/11mb)$

$\sigma_{diff}(24.1/16.5mb) \rightarrow \sigma_{dd}(9.8/4.1mb)$

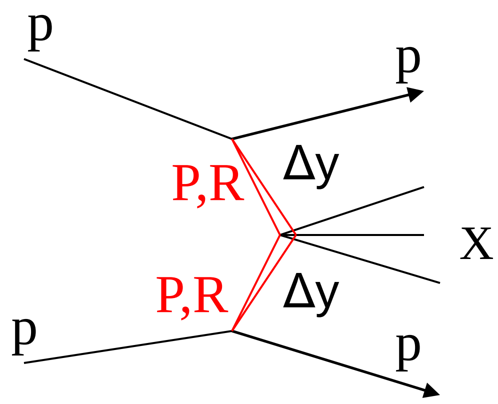
$\sigma_{diff}(24.1/16.5mb) \rightarrow \sigma_{cd}(\sim 1.4mb)$

15-25 % events at LHC energy
should be produced in diffractive processes

Constraint on diffractive contribution is essential to

- **understand the MB data set and improve the MB MC tunes**
- **improve knowledge about PU**

Diffractive and non-diffractive events



Diffractive (central) event

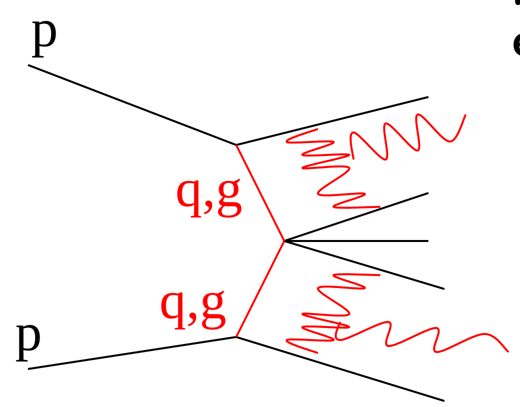
Exchange of color singlets:
Reggeons, Pomerons

- **momentum loss of the leading protons**

$$\xi = \frac{\Delta p}{p} < 0.05 - 0.1$$

- **rapidity gaps**

$$\Delta y \approx -\ln(\xi)$$



Non-Diffractive event

Exchange of color triplets, octets

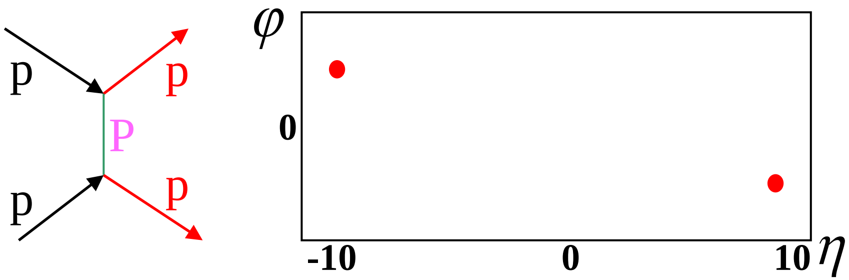
- **exponential suppression of rapidity gaps**
(gaps filled by color exchange in hadronization)

Events topologies

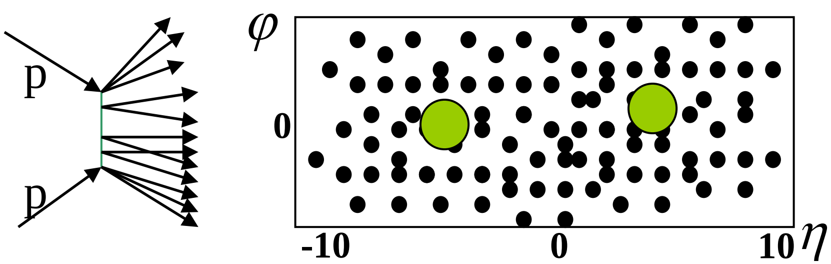
Elastic and inelastic

Soft and Hard Diffraction

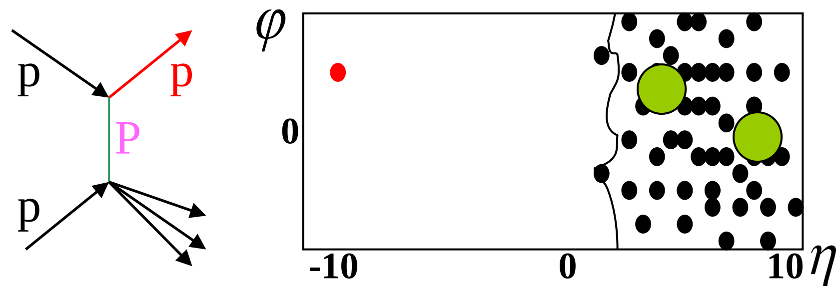
Elastic Scattering



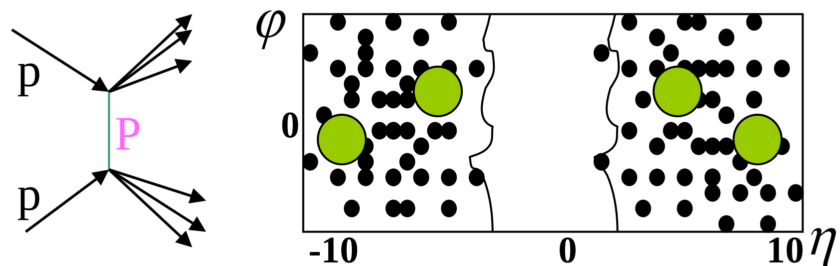
Minimum Bias



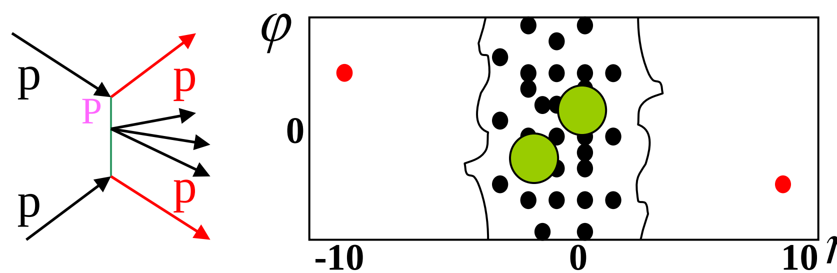
Single Diffraction



Double Diffraction



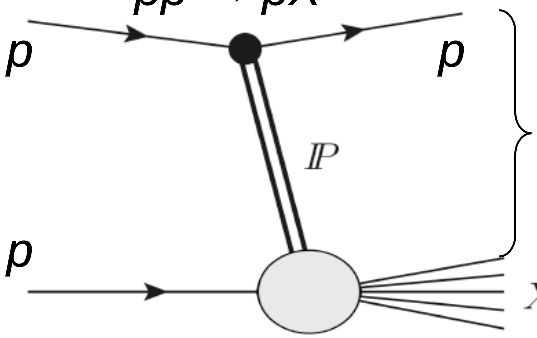
Central Diffraction



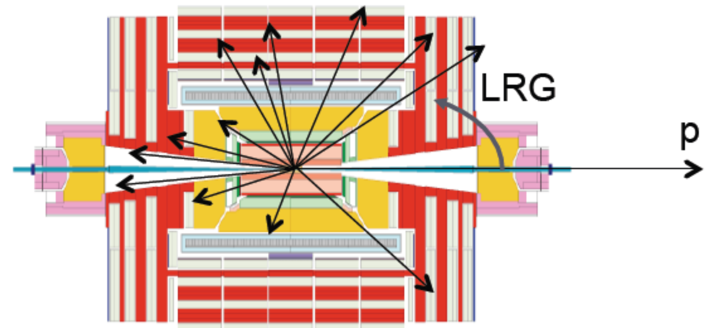
Diffractive and non-difractive

Single Diffraction

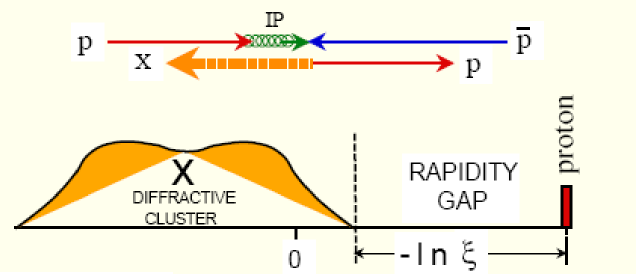
$pp \rightarrow pX$



Δy - LRG

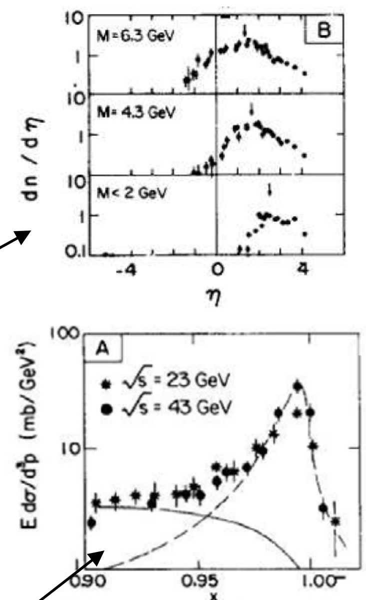


M.Albrow pic. from Tevatron

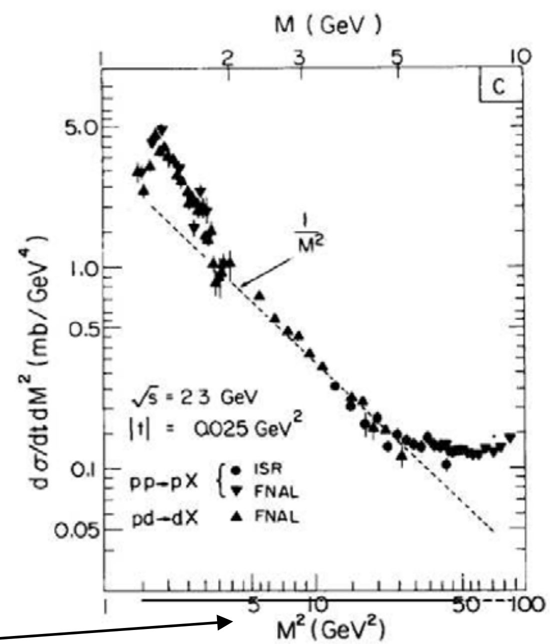


$\xi = M_X^2/s$ η_{max} $\ln(2p/p_T)$

$$\Delta y \approx -\ln \xi = \ln s - \ln M^2$$



ξ=1-x



$$\frac{d\sigma_{sd(AX)}(s)}{dt\, dM^2} = \frac{g_{3\mathbb{P}}}{16\pi} \beta^2_{A\mathbb{P}} \beta_{B\mathbb{P}} \frac{1}{M^2} \exp(B_{sd(AX)} t)\, F_{sd}$$

$\sigma \sim 1/M^2 = 1/\xi$

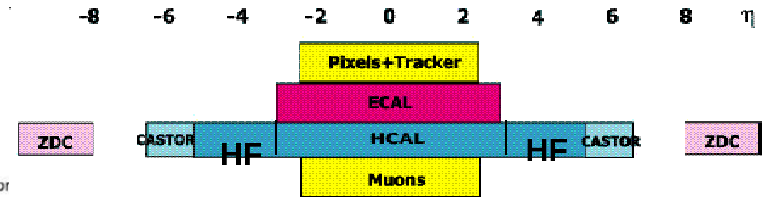
$\xi \sim \Sigma(E \pm pz)$

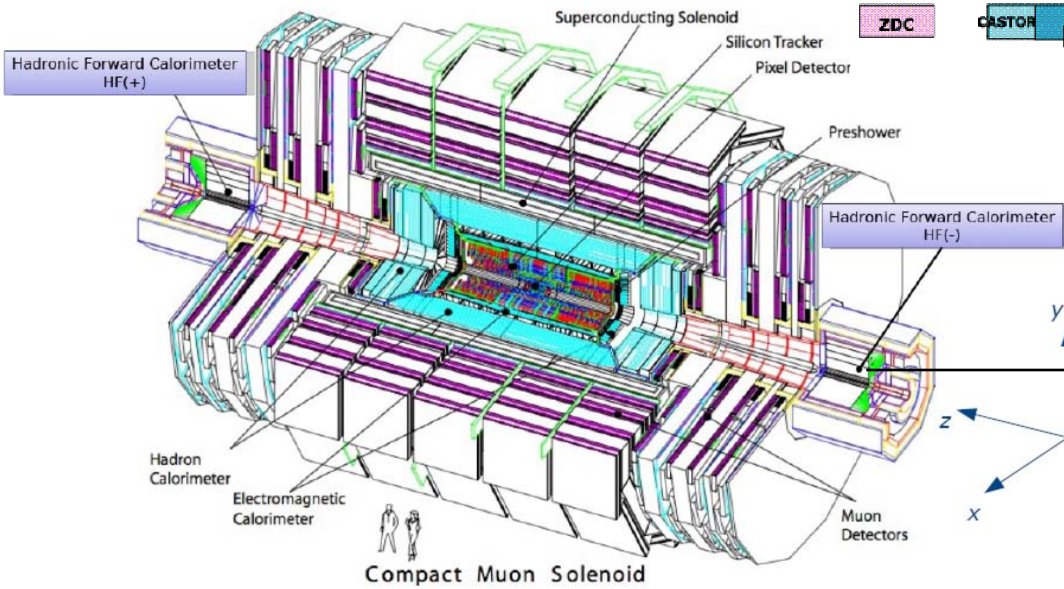
diffractive peak expected at low values of variable Σ(E ± pz)

ISR data (R201) ~35y. before
Phys.Rep.55, No. 1(1979)1-132.

Experimental apparatus

CMS Detector

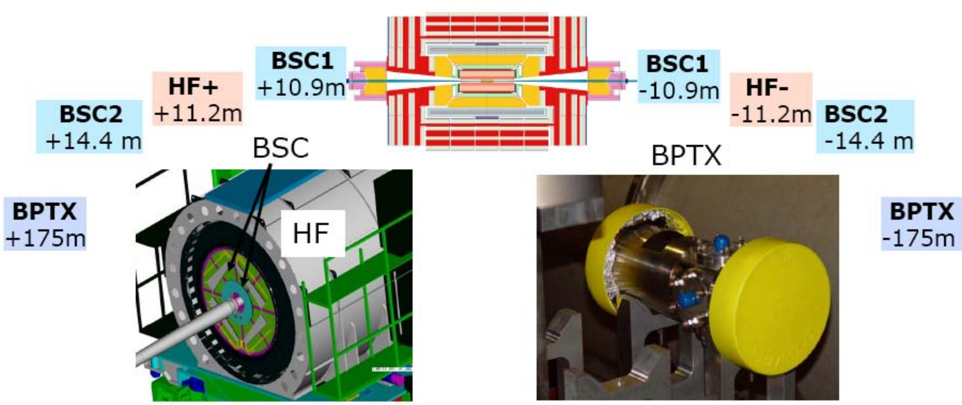




Hadron Forward:

- @11.2m from interaction point
- rapidity coverage: $3 < |\eta| < 5$
- Steel absorbers/ quartz fibers (Long +short fibers)
- 0.175x0.175 η/φ segmentation

Trigger System



- Beam Scintillator Counters
- located at ± 10.86 m from IP (± 14.4 m for BSC2)
- designed to provide hit and coincidence rates

- Beam Pick-up Timing for the eXperiments
- designed to provide precise info on the bunch structure and timing of the incoming beam

SD event selection

Trigger of CMS readout:

- signal in any of the BSC in coincidence with a signal from either of the two BPTX

Offline selections:

- BPTX signals from both beams passing the IP in conjunction with a signal in either of the BSCs (the coincidence of the BSCs would have suppressed SD signals);

- a primary vertex with $|z| < 15$ cm and a transverse distance from the z axis < 2 cm; at least three tracks be used in the vertex fitting;

- rejection of beam-halo event candidates: these events have hits in the BSCs with timing consistent with that of a particle traversing horizontally the apparatus;

- rejection of beam-background events: the fraction of high-quality tracks was required to be greater than 25% for events with at least 10 reconstructed tracks;

- rejection of events with large signals consistent with noise in HCAL;

- threshold of 4 GeV in HF, of 3 GeV in the other calorimeters

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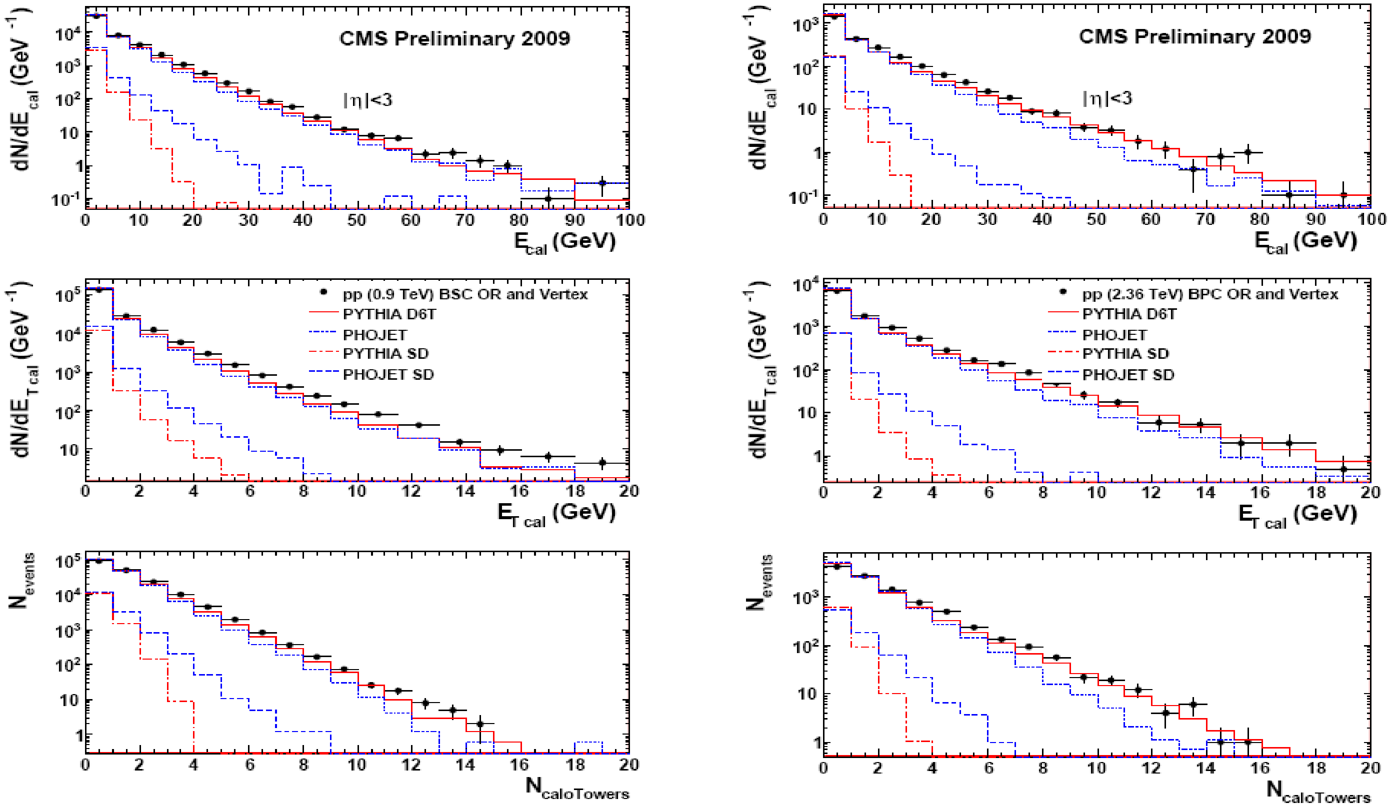
Finally, 207345 events were selected at 900 GeV and 11848 events at 2360 GeV

MC simulation

- Events generators: PYTHIA6 (with different tunes of MPI: <u>D6T</u>, DW and CW)
  PHOJET1.12-35
- CMS detector response: CMSSW based on GEANT4
- Position and width of beam adjusted with data
- Reconstruction and selection cuts as for data

Control distributions for Ecal, Et_cal, Ncalo_tower (except HF), uncorrected

900 GeV **2360 GeV**



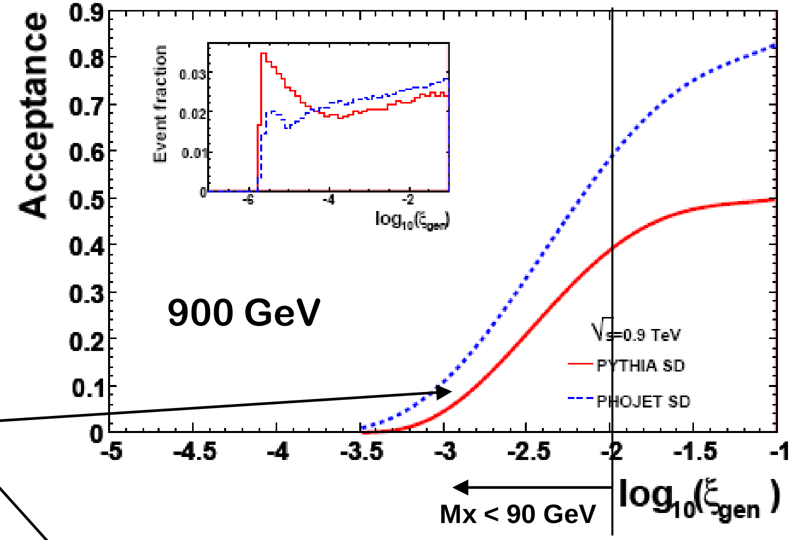
The agreement of data and MC is satisfactory

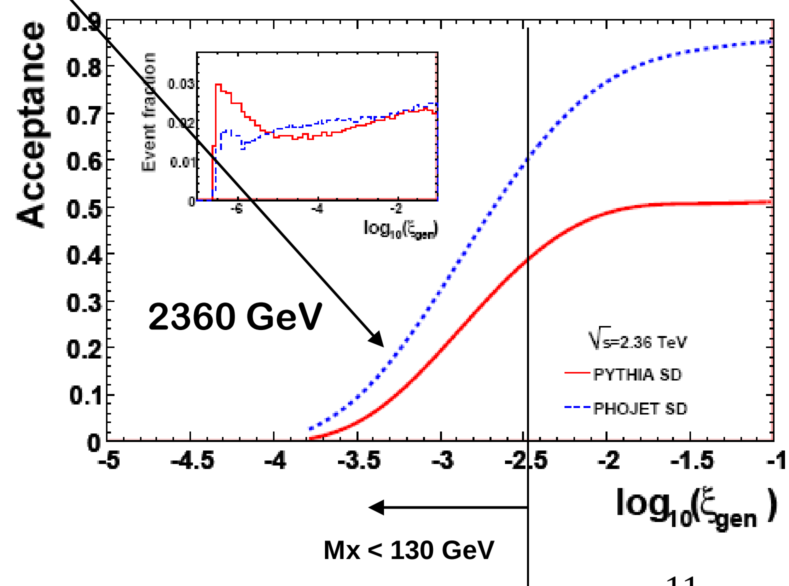
Acceptance

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

- PYTHIA and PHOJET have a substantially different modeling of diffraction (composition, fragmentation, etc.), resulting in different selection efficiencies

- Low efficiency at low ξ for selecting events which:
  - escape undetected with very low ξ
  - have almost no charged activity.





Total efficiency for SD:
900 GeV: 18% (PYTHIA), 32% (PHOJET)
2360 GeV: 20% (PYTHIA), 37% (PHOJET)

For Non-diffractive events (ND):
~ 85 % for both generator and energies

Result: definition of variables

The selected events are plotted as a function of:

- $E \pm p_z = \sum (E_i \pm p_{z,i})$ - the sum runs over all CaloTowers, where
  E_i is the tower energy,
  $p_{z,i} = E_i \cos\theta_i$,
  θ_i is the angle between the z axis and the direction defined by the center of the tower and the nominal interaction point.

  Diffractive peak expected at low values of this variable, reflecting the peaking of the cross section at small ξ.

- E_{HF} - the energy deposition in the HF.

- N_{HF} - the multiplicity of the towers above threshold in the HF.

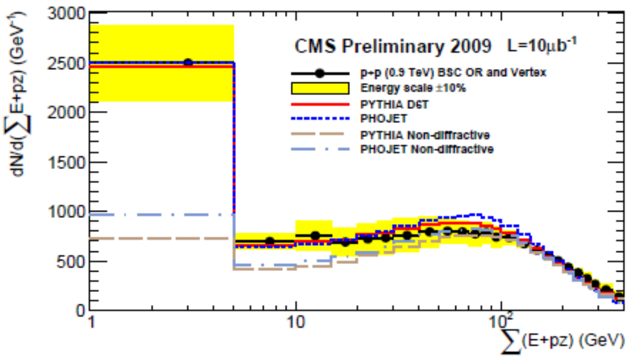
  Diffractive peak expected at low tower multiplicity and at low energy deposition, reflecting the presence of a large rapidity gap over HF.

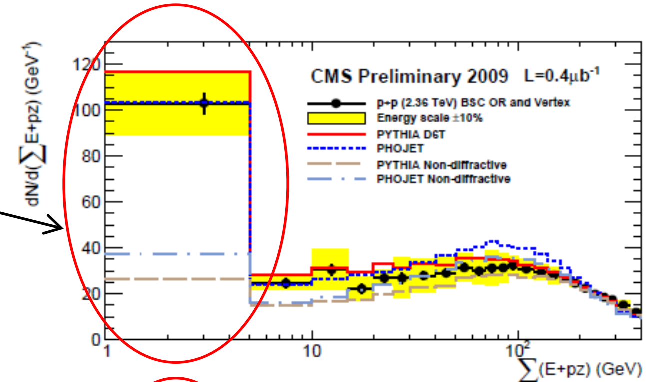
Result: SD observation

The distributions are uncorrected. The yellow bands illustrate the effect of a 10% energy scale uncertainty.

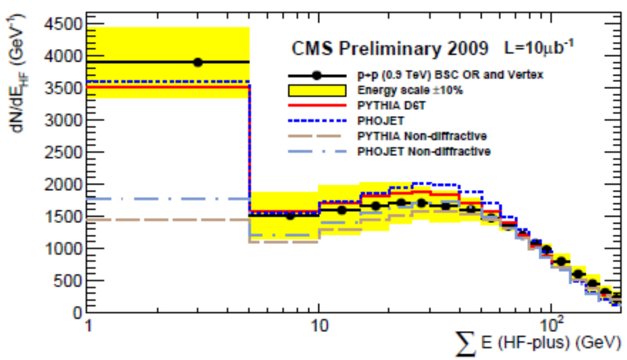
900 GeV

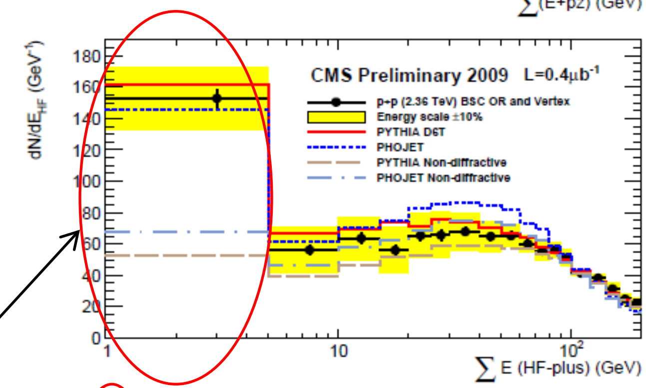
2360 GeV





SD seen in E+pz distribution due to cross section peaking at small values of ξ

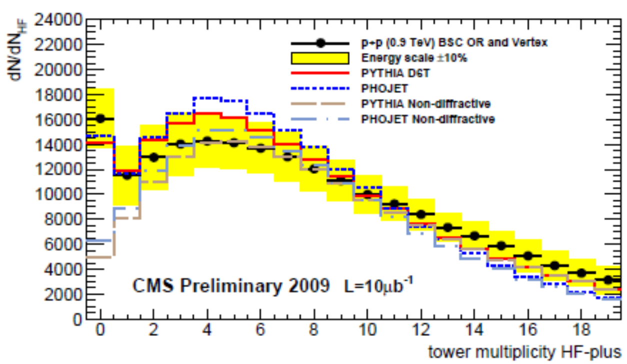


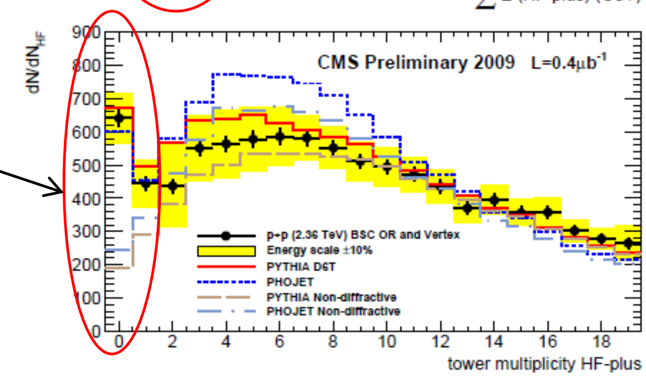


SD seen by the absence of forward hadronic activity due to the presence of a LRG

in HF total energy deposit

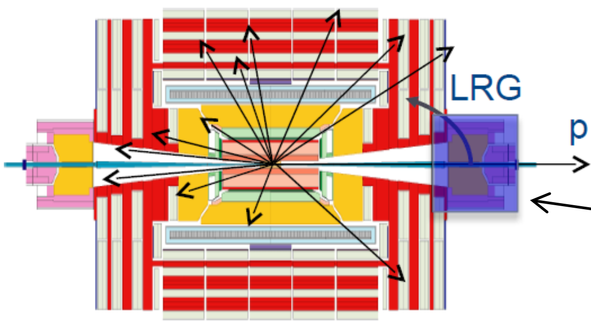
In HF tower multiplicity





Result: Enriched Diffractive Sample

The distributions are uncorrected. The yellow bands illustrate the effect of a 10% energy scale uncertainty.

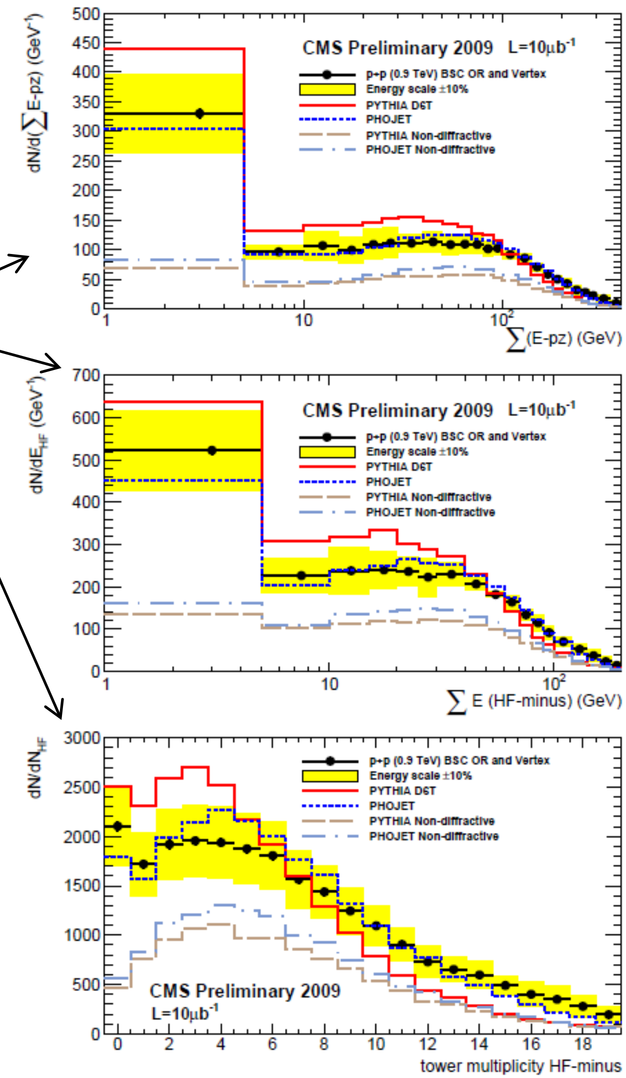


LRG provides with requirement of low activity in the one side of CMS (HF+ or HF-)

$E(HF+) < 8$ GeV

It enhances the diffractive component of the data

900 GeV



- **Uncorrected data shown and compared to PYTHIA D6T & PHOJET**
- **At both energies a clear diffractive contribution is evident**
- **PYTHIA describes better the non-diffractive part of the spectrum**
- **PHOJET gives a better description of the diffractive system**

Comparison with different PYTHIA tunes: D6T, DW, CW

PYTHIA MPI tunes

- Perturbative 2-to-2 partonic cross-section is regularized in PYTHIA by the introduction of a cutoff pt0:

$$\sigma \propto 1/(p_t^2 + p_{t0}^2)^2$$

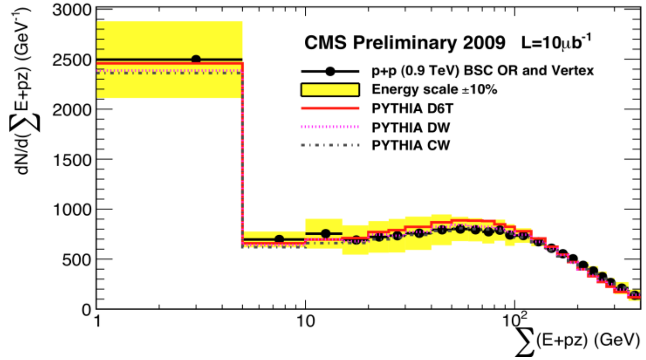
- pt0 governs the description of the amount of MPI: larger MPI activity for smaller values of pt0

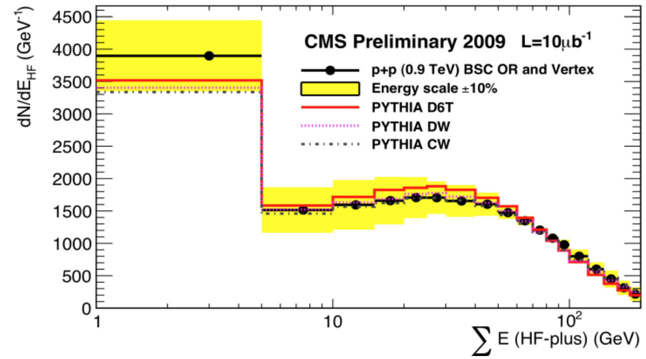
  - $p_{t0}(\sqrt{s}) = p_{t0}(\sqrt{s_0}) \ (\sqrt{s} / \sqrt{s_0})^{\epsilon}$

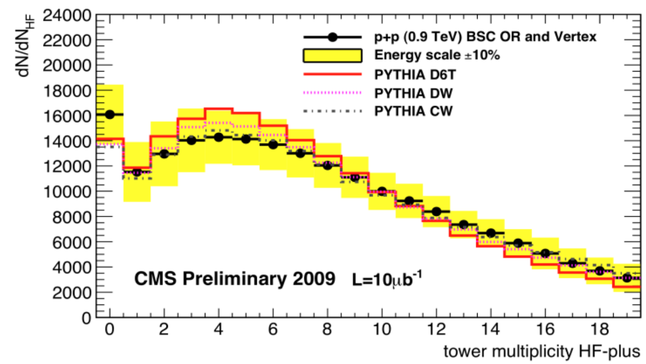
  - D6T: p_{t0}= 1.84, $\sqrt{s_0}$ = 1.96 TeV, ϵ = 0.16
  - DW: p_{t0}= 1.9, $\sqrt{s_0}$ = 1.8 TeV, ϵ = 0.25
  - CW900A: p_{t0}= 1.8, $\sqrt{s_0}$ = 1.8 TeV, ϵ = 0.30

PYTHIA tunes D6T, DW and CW900A give similar overall description

900 GeV







Summary

- First observation of SD events at LHC in pp collisions at 900 & 2360 GeV

  - SD events observed in two ways:
    peak at low ξ values and
    presence of a Large Rapidity Gap

- Comparison to the MC event generators PYTHIA and PHOJET

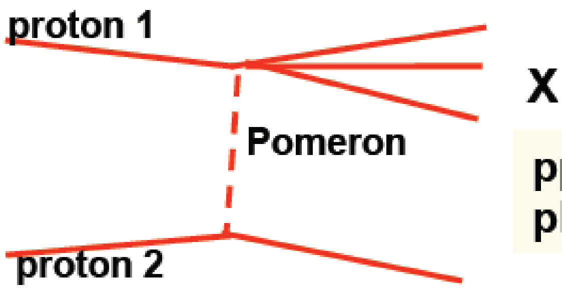
  - PYTHIA gives a better description of non-diffractive part of the spectrum,
  - PHOJET describes the diffractive contribution better

- Constraint from diffraction important to improve MB MC tunes

  - PYTHIA tunes D6T, DW and CW give similar overall description

BACK UP SLIDES

Meaning of (E ± pz)



pp --> pX
pPomeron --> X

- $\Sigma(E \pm p_z)$ runs over all calo towers
- Measure for the momentum of the Pomeron = momentum loss of the proton

Momentum and energy conservation:
$E(\text{Pomeron}) + E(\text{proton 1}) = E(X)$
$p_z(\text{Pomeron}) + p_z(\text{proton 1}) = p_z(X)$

Recall: in SD events proton loses almost none of its initial momentum.

If proton 1 moves in positive z direction: $E(\text{proton 1}) - p_z(\text{proton 1}) \approx 0$ (and proton 2, and Pomeron, move in the negative z direction)

Hence:
$E(\text{Pomeron}) - p_z(\text{Pomeron}) \approx 2E(\text{Pomeron}) \approx E(X) + p_z(X)$

i.e. $\xi = 2E(\text{Pomeron})/\sqrt{s} \approx (E(X) + p_z(X))/\sqrt{s}$