CMS results on diffraction

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on behalf of the CMS collaboration

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Outline

- **Introduction**
- **Measurements from CMS**
  - Observations of diffraction at $\sqrt{s}$=0.9, 2.36 and 7 TeV
  - Forward activity and large rapidity gaps in W/Z events
  - Forward energy flow in MB and dijet events
- **Summary**

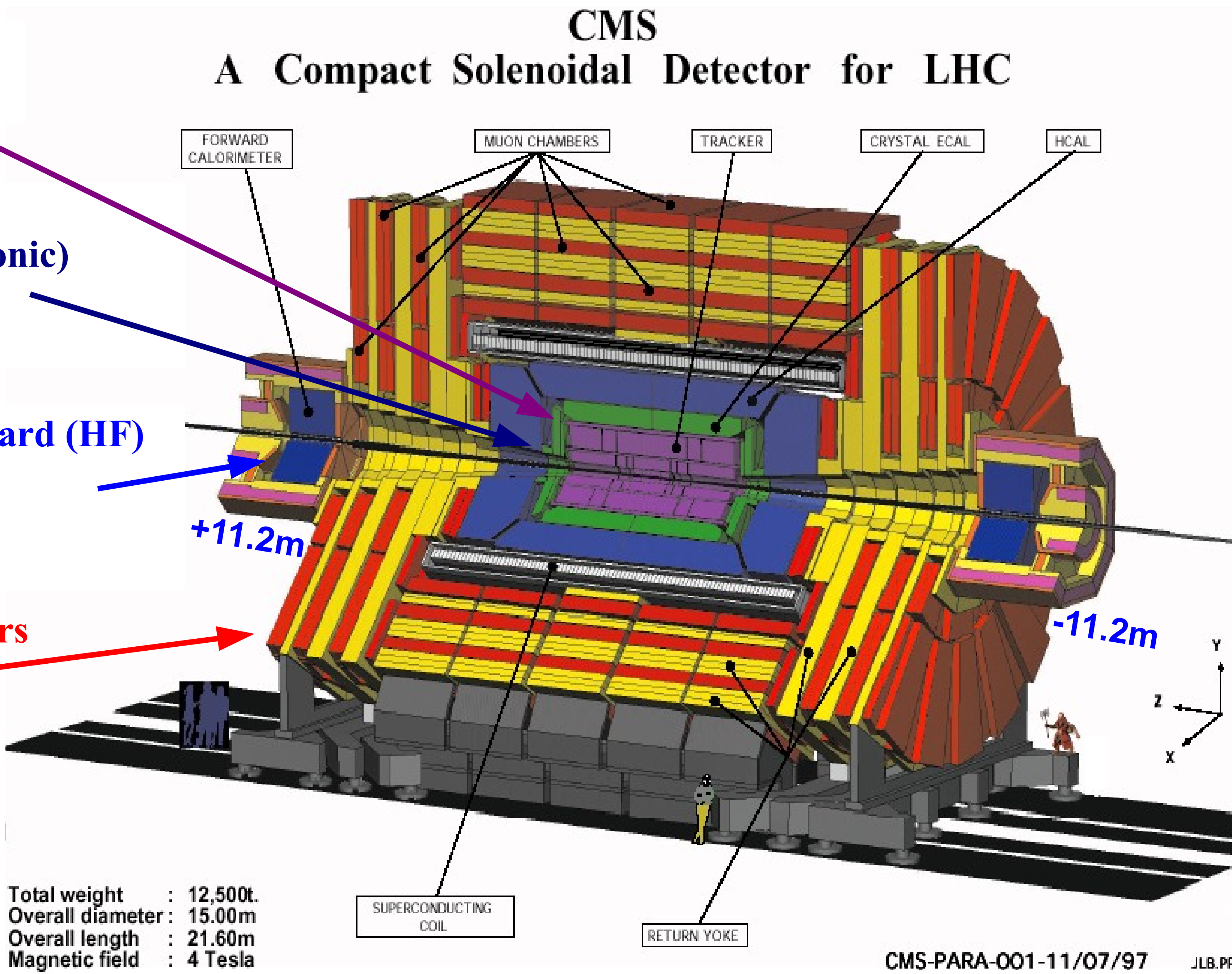
The CMS detector

Tracker
|η| < 2.5

Calorimeters
(EM and Hadronic)
|η| < 3.0

Hadronic Forward (HF)
Calorimeters
2.9 < |η| < 5.2

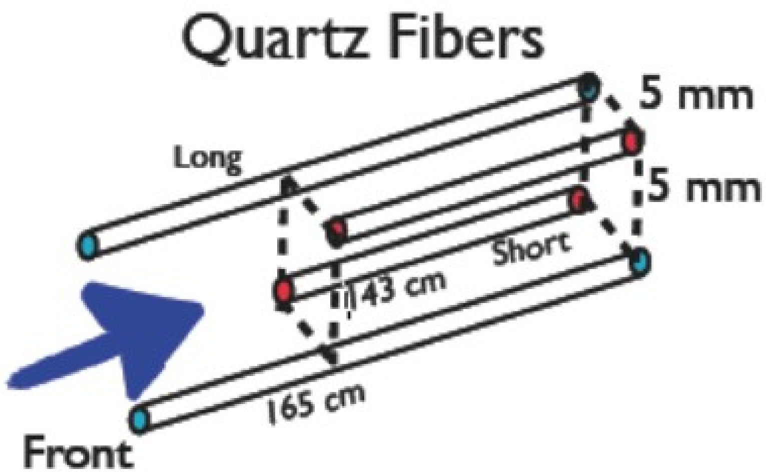
Muon Chambers
|η| < 2.5



The Hadronic Forward Detectors

- Cherenkov light calorimeters.
  Iron absorbers with quartz fibers embedded.

- Long and short fibers alternated to distinguish energy deposits of different particles types.
  Long and short fibers separated in read out.

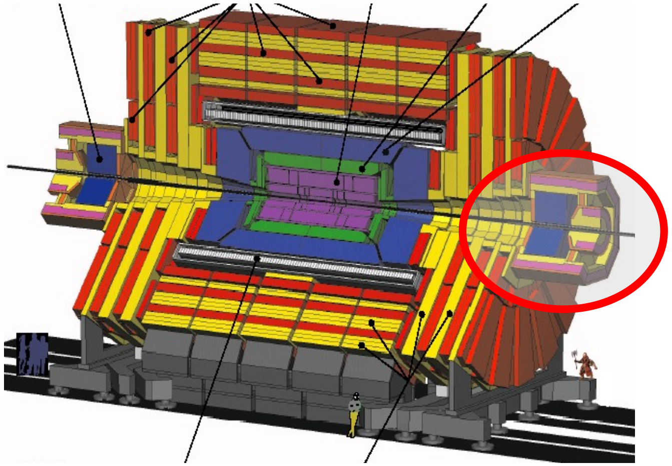


- 12 x 36 segments in η x Φ.

Fiber read out connected to r-Φ wedges.

Introduction

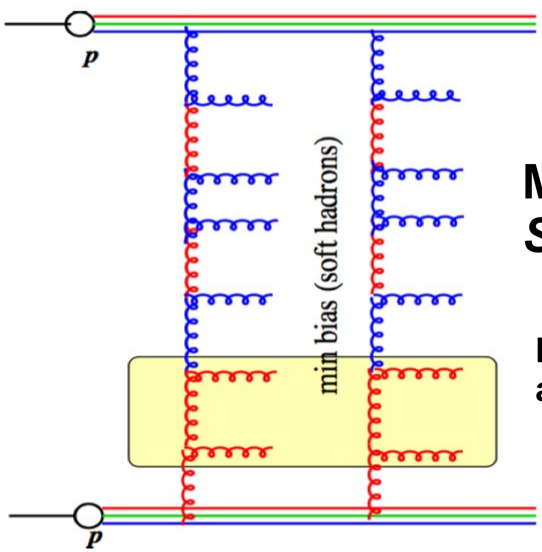
The presented measurements are based on studies of activity and energy deposits (or the lack of energy) in the forward region using the HF calorimeters.



Main observables:

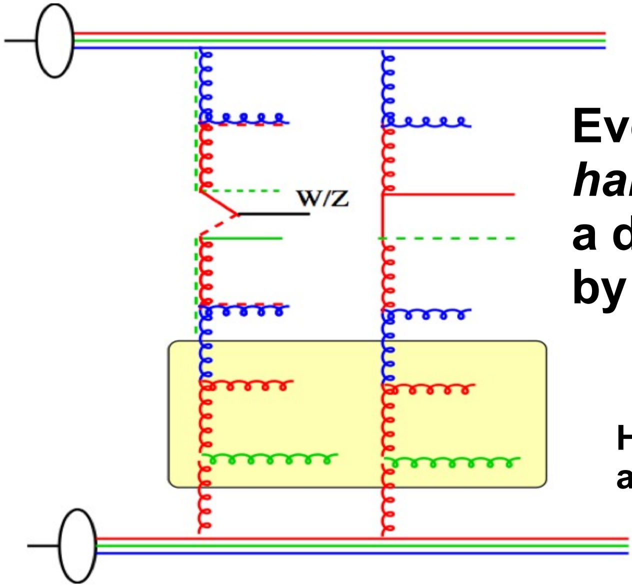
$\sum E_{HF+}$, $\sum E_{HF-}$, $\sum (E_{HF+/-}-p_z)$, $\sum N_{chrgd,HF+/-}$

Study events with different scales:



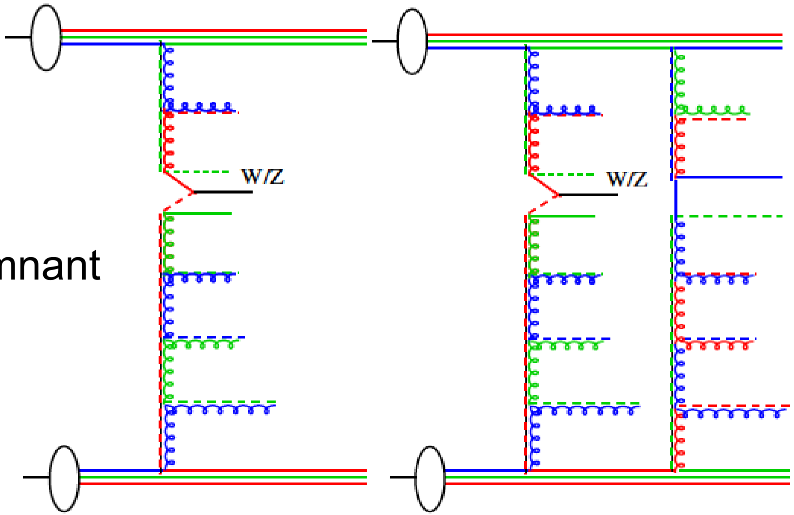
MB events
Small scale

Low (forward) activity



Events with *hard scale* set by a di-jet system or by W/Z production

High (forward) activity

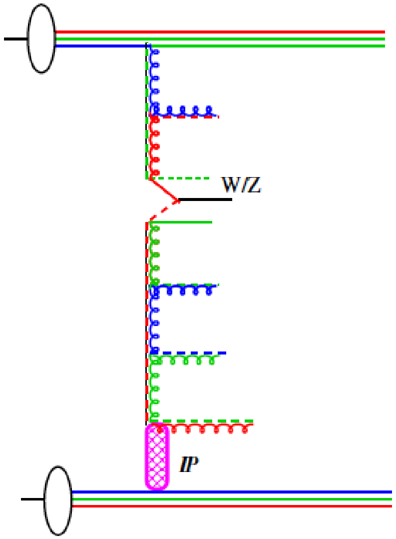


Energy flow in the forward region

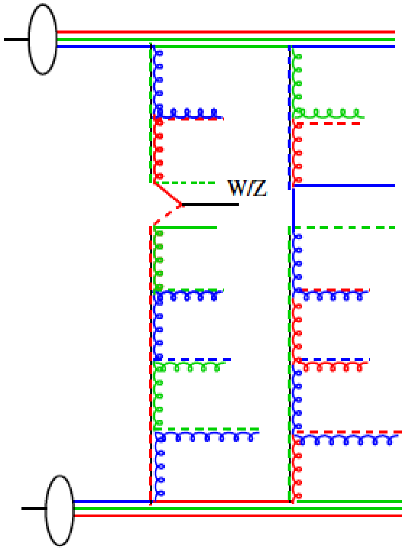
→ Sensitivity to parton dynamics
→ Study the underlying event and multi-parton interactions
→ Information about color (re)connections to the proton remnant
→ Correlations between central and forward activities

Events with a large rapidity gap
(events with no or little activity in the forward region)

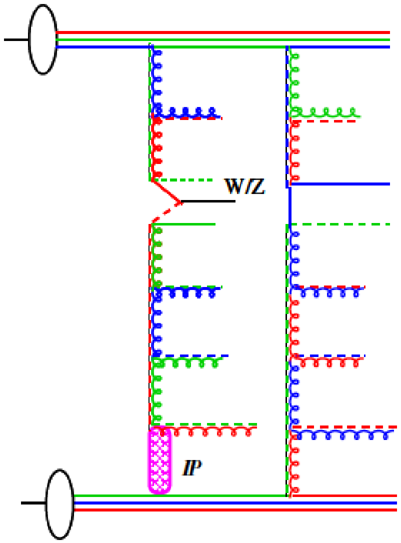
- **Rapidity gaps from Pomeron exchanges**



- **Rapidity gaps from multiplicity fluctuations**



- **MPI affecting the gap survival probability (factorization breaking)**



Measurement of the activity in the forward and backward region in MB events - which leads to an observation of diffraction

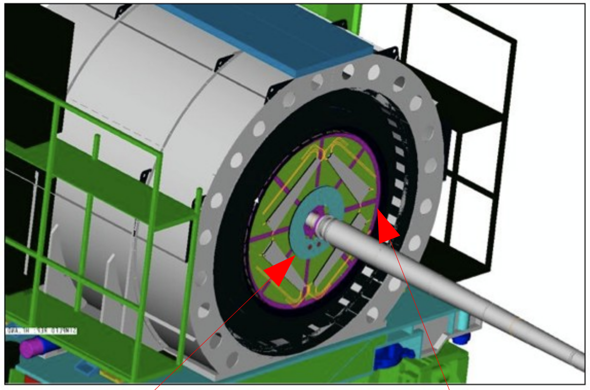
MB Event selection

Data:

$\sqrt{s}$ = 0.9 TeV, 10 μb^{-1}
$\sqrt{s}$ = 2.36 TeV, 0.4 μb^{-1}
$\sqrt{s}$ = 7 TeV, 20 μb^{-1}

Selection:

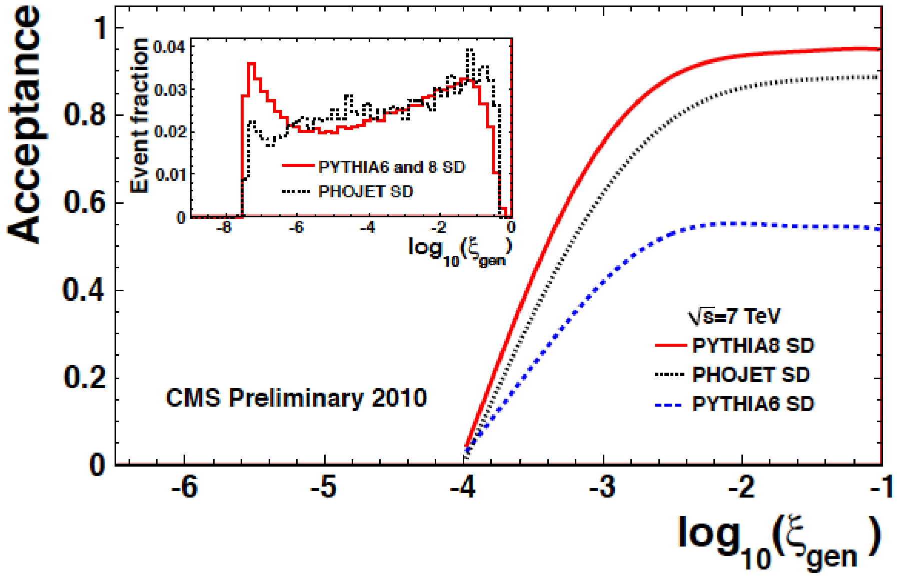
- **A signal in either of the beam pickups (BPTX), and**
- **a hit in either of the Beam Scintillator Counters (BSC)**
- High quality primary vertex
- Beam halo and beam background reductions
- Calorimeter noise cleaning



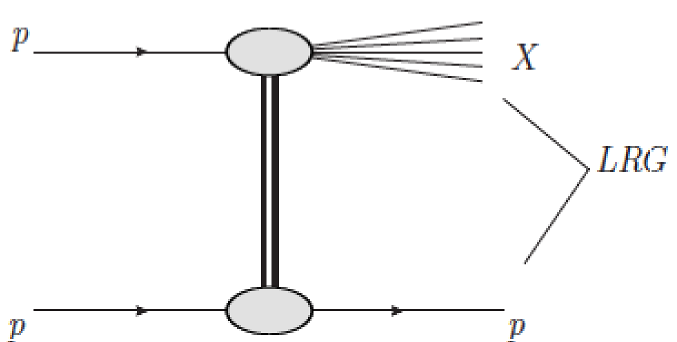
Beam Scintillator Counter (3.2<|η|< 4.7)

Hadronic Forward (HF) Calorimeter (2.9<|η|< 5.2)

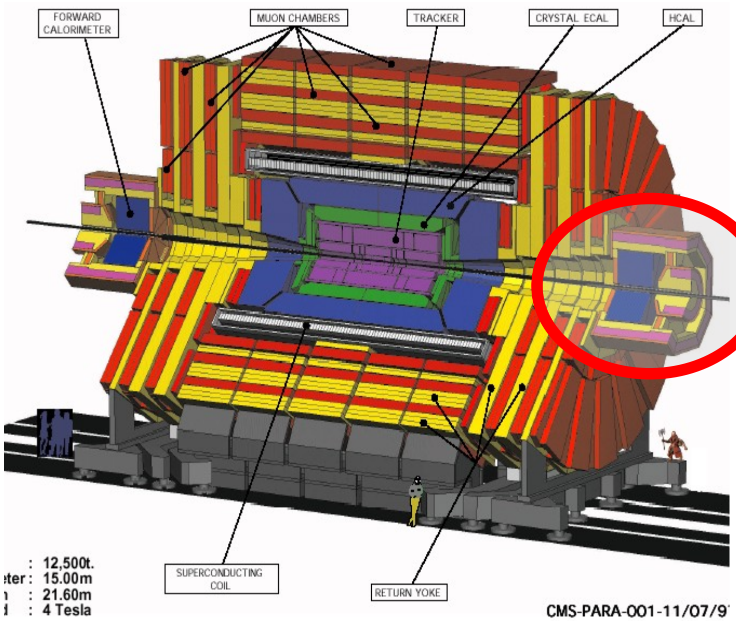
Acceptance for SD events, as a function of the energy loss of the scattered proton, **ξ.**



Low acceptance at low $\xi = M_X^2/s$, where the system *x* may escape undetected.



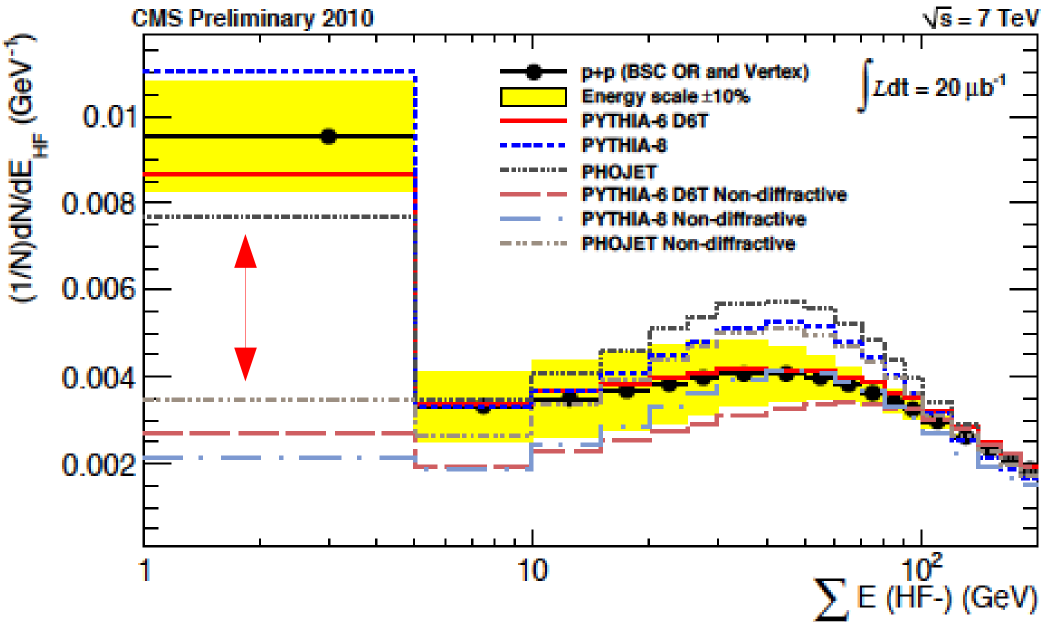
CMS-FWD-10-007



Measure activity in one of the hadronic forward calorimeters (HF), $2.9<|\eta|< 5.2$.

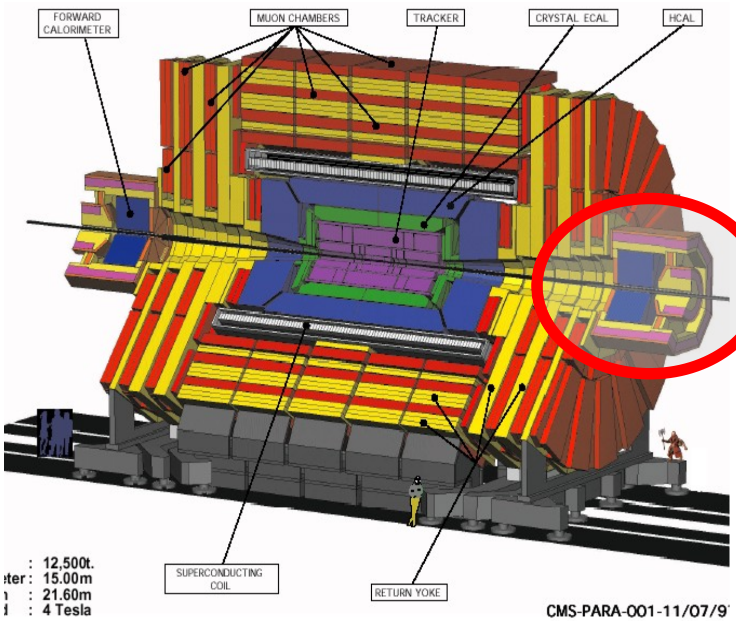
Large contribution from diffractive events at low energy and multiplicity deposits.

Energy deposit in one of the HFs:



- **Pythia 6, Pythia 8 and Phojet w and w/o diffraction, compared to data**
- **At low energy deposits ("LRG") – Non-diffractive predictions underestimate the data by a factor of 4-5.**

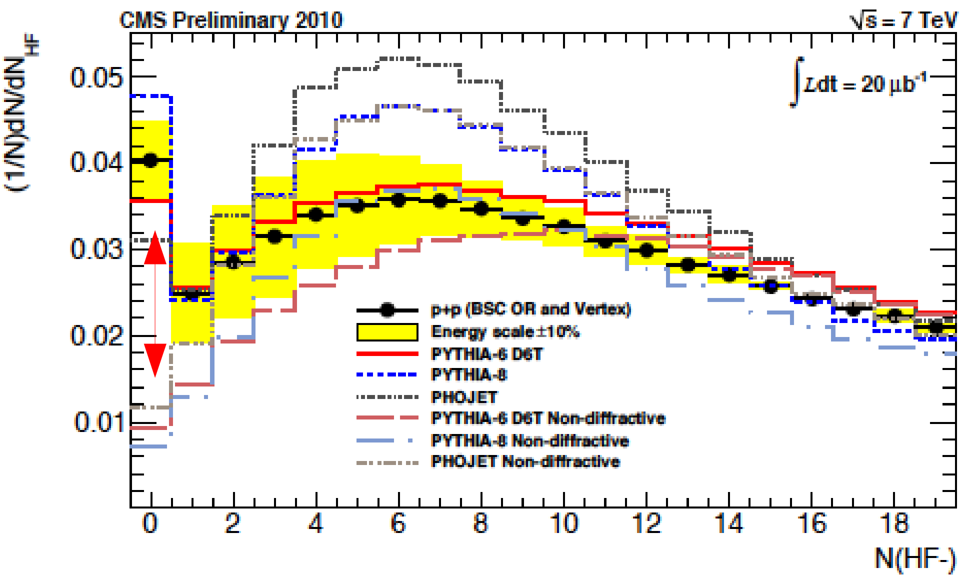
Use activity in HF to study diffraction



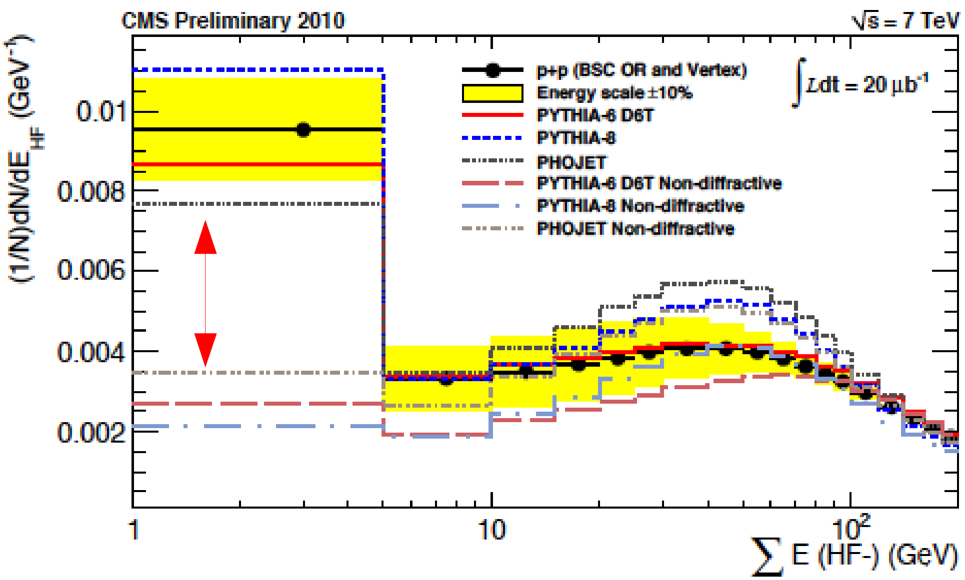
Measure activity in one of the hadronic forward calorimeters (HF), 2.9<|η|< 5.2.

Large contribution from diffractive events at low energy and multiplicity deposits.

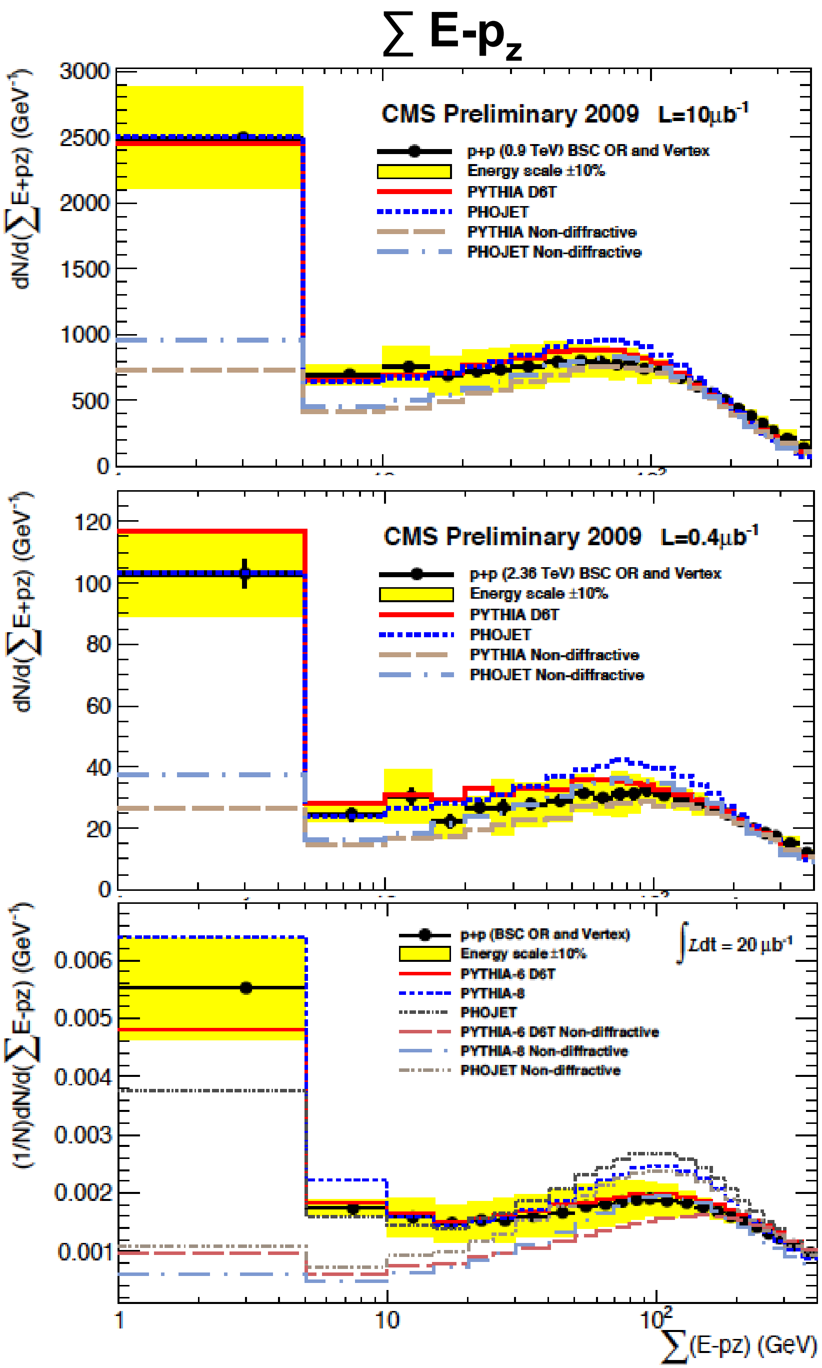
Number of towers in on of the HFs:



Energy deposit in one of the HFs:



Repeated at all beam energies



$\sqrt{s}$=0.9 TeV

$\sqrt{s}$=2.36 TeV

$\sqrt{s}$=7 TeV

Some energy dependence.
Somewhat higher diffractive component at higher center-of-mass energies (judging from MC w and w/o diffraction).

CMS-FWD-10-001
CMS-FWD-10-007

Same distributions in events with a hard scale set by W or Z production

Analysis

Data: pp, √s = 7 TeV, 2010, 36 pb^{-1}

CMS-FWD-10-008
arXiv:1110.0181

W → *lν* event selection*:

Isolation criteria for leptons: $$\frac{E_{lepton}}{E_{\Delta R<0.3}} > 0.9$$

Select events with:

– an isolated **electron or muon** with $p_t > 25$ GeV and $|\eta| < 1.4$

– $E_{T,\,miss} >$ 30 GeV (assigned to neutrino)

– $m_T\,(l,\nu) > 60$ GeV

Reject events with a secondary isolated lepton with p_t>10 GeV.

→ Background less than 1%.

Main observable (same as before):

Energy deposit in the forward and backward hadronic forward calorimeter (2.9 < |η| < 5.2), $\sum \mathbf{E}_{\mathbf{HF+}}$ and $\sum \mathbf{E}_{\mathbf{HF-}}$

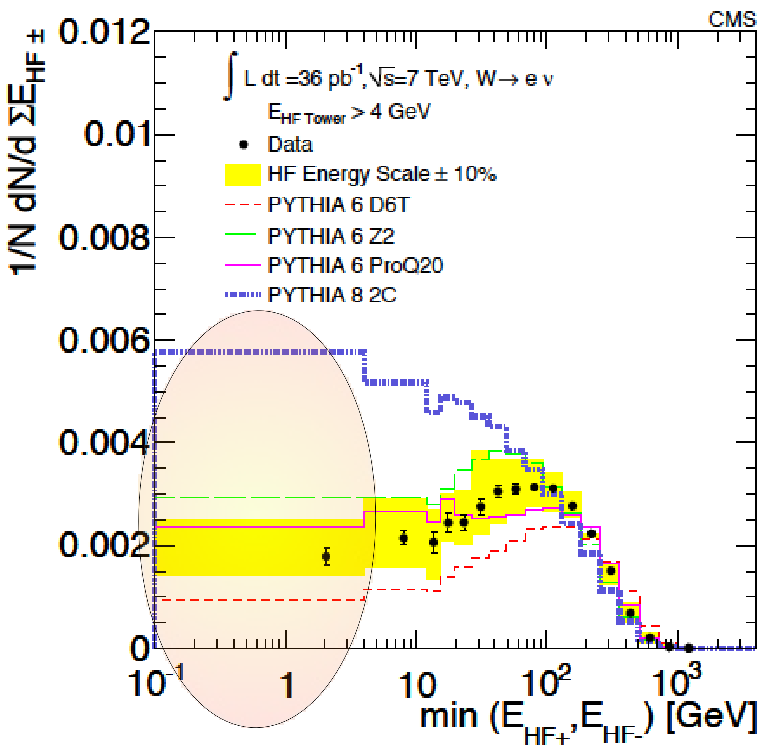
Monte Carlo:

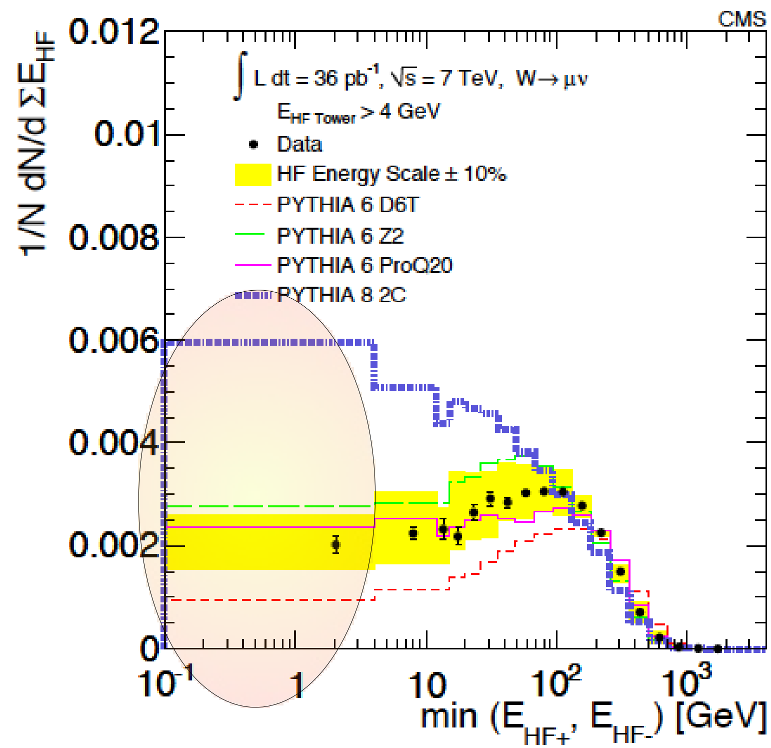
Data are compared to non-diffractive MC predictions from Pythia 6 and Pythia 8, and/or diffractive predictions from POMPYT+PYTHIA6 (without MPI).

* Similar measurement for Z events, but here we focus on the more statistically significant W analysis.

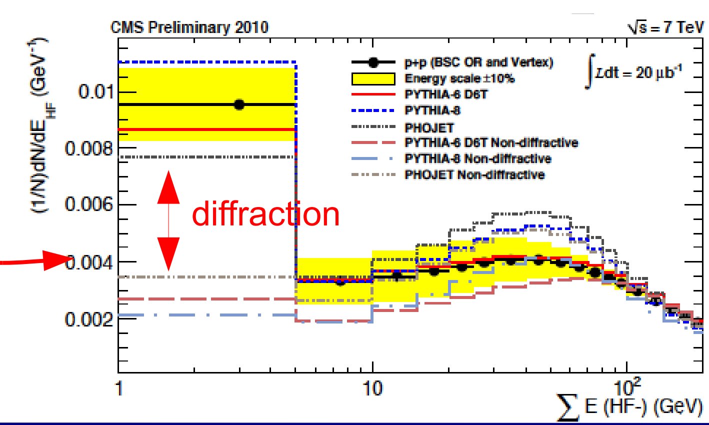
W events with LRG

- **Large rapidity gap events:**
  Events with **no individual energy deposit above 4 GeV** in one of the HF calorimeters.
  That corresponds to a rapidity gap of 1.9 units.



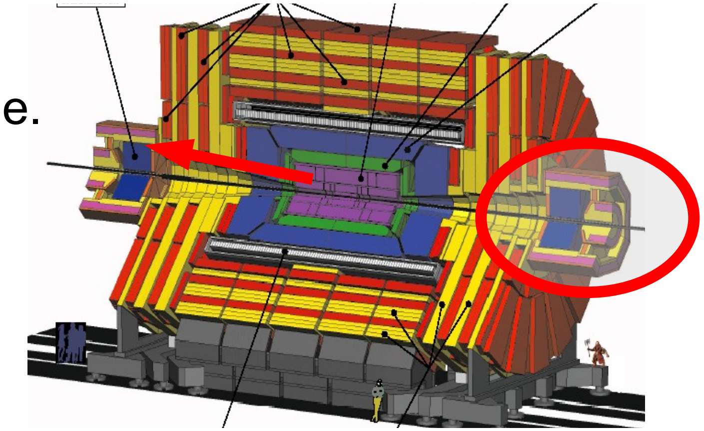


- Data compared to non-diffractive MC
- **Diffraction not needed to describe the LRG events.**
  C.f. inclusive MB measurement a few slides ago
- Large tune dependence
- Pythia 8 2C overestimates the LRG events by factors.



Backward forward correlations

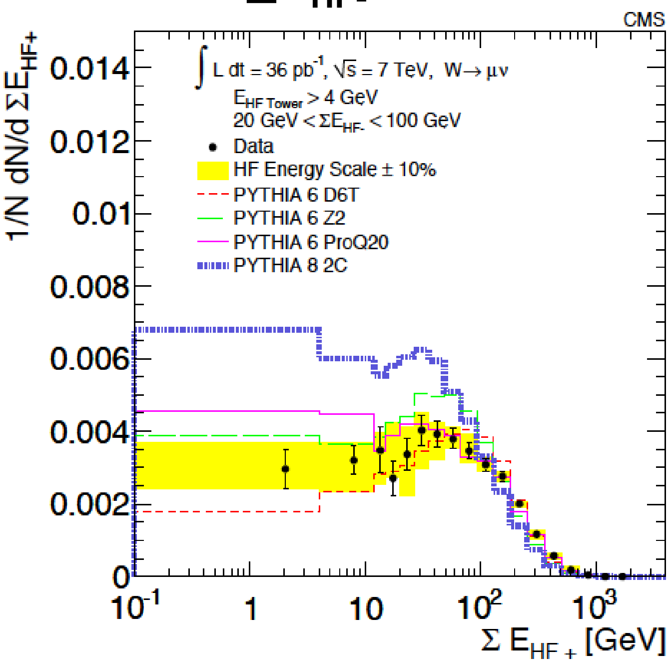
Require energy deposit on one side.



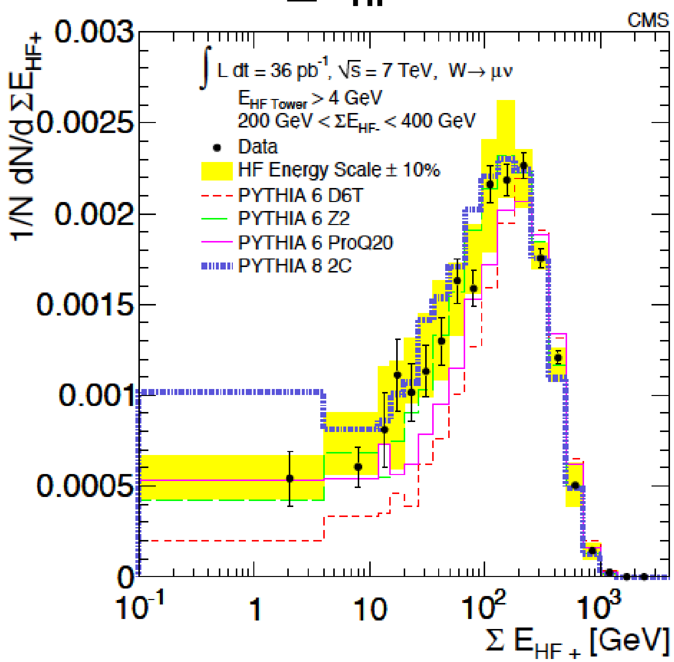
W → μν events

Measure energy deposit on the other side.

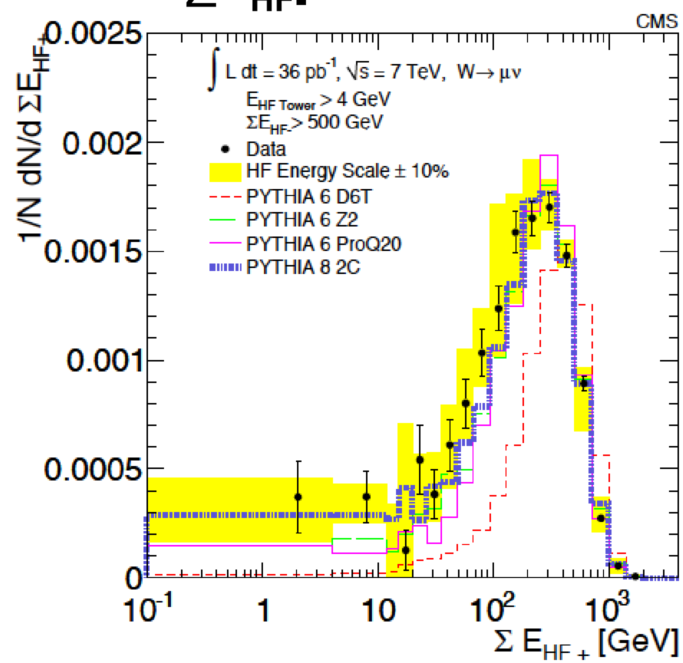
20 < ∑E_HF- < 100 GeV



200 < ∑E_HF- < 400 GeV



∑E_HF- > 500 GeV

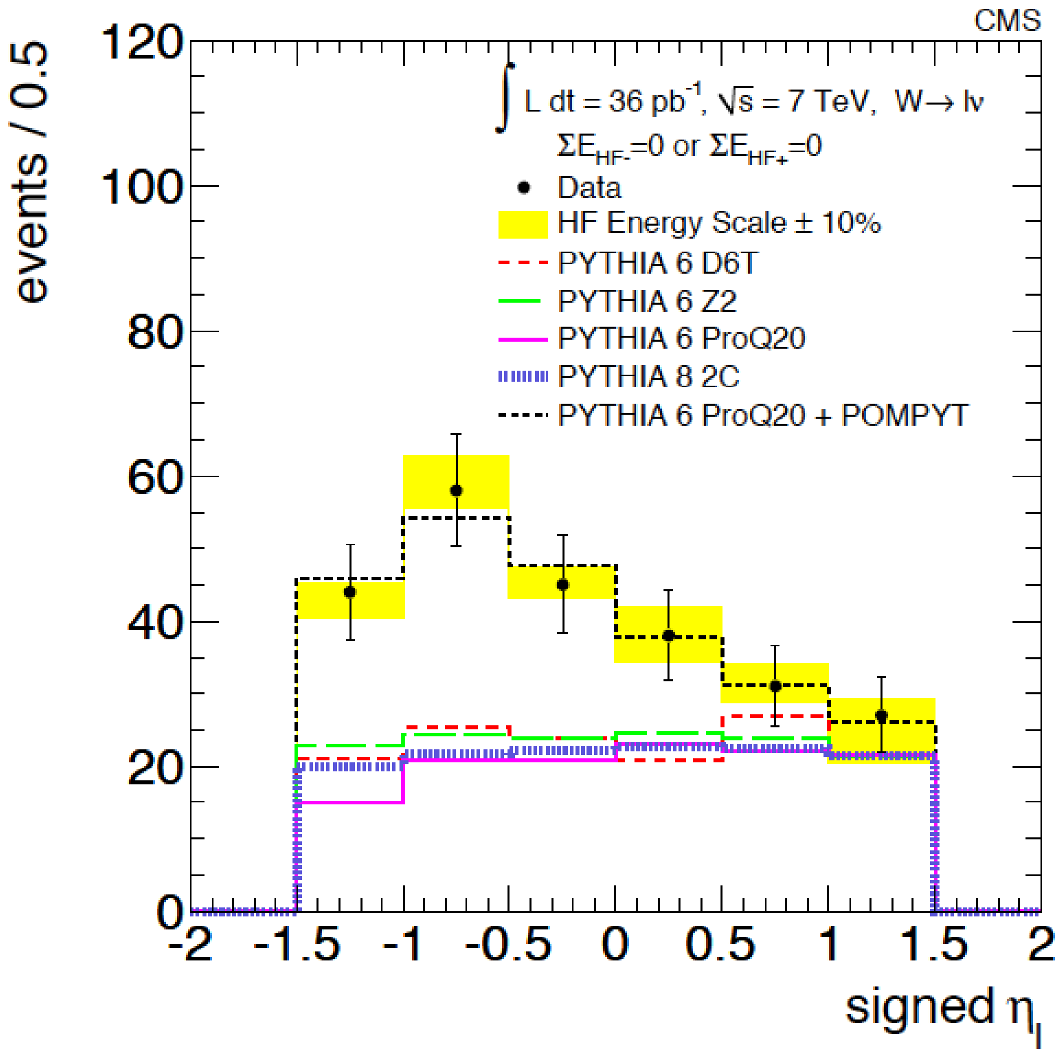


- Correlation between forward and backward energy.
- Data compared to non-diffractive MC.
  Energy dependence. Tune dependence.

Signed lepton pseudorapidity distribution for LRG events.

Gap and lepton on **same side** → **η_l positive**

Gap and lepton on **different sides** → **η_l negative**



- **Non-diffractive MC: Flat**
- **Diffractive MC needed to describe the asymmetry.**
- **Mix of nondiffractive+diffractive MC** (PYTHIA 6+POMPYT) describes the asymmetry.

  Diffractive component:
  50.0 ± 9.3(stat) ± 5.2(syst) %
  (fitted value from MC mix)

  First evidence of diffractive W production at LHC.

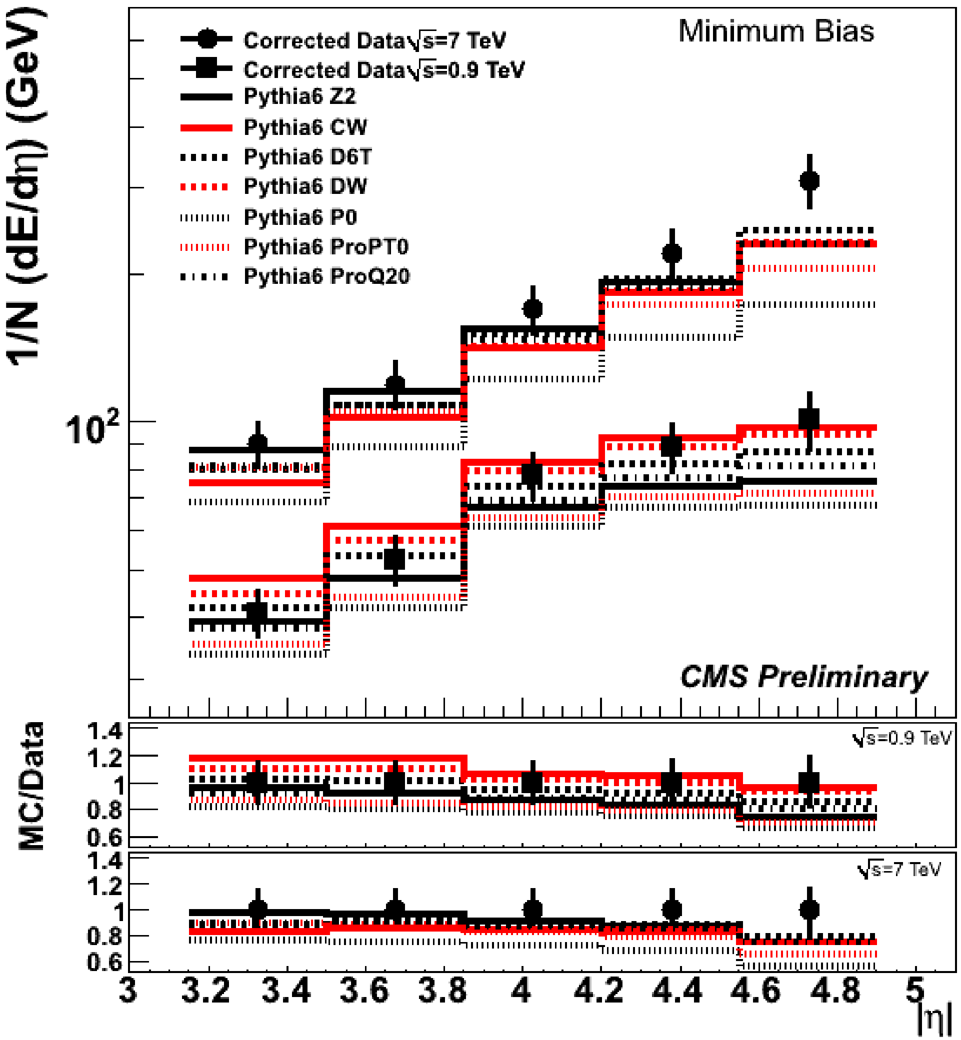
- Asymmetry also seen in Z events, but less statistically significant

Mean energy flow as a function of rapidity in MB and di-jet events (non single-diffractive events)

Forward Energy Flow in MB Events

$$\frac{1}{N}\frac{dE}{d\eta}[GeV]$$ **measured for all particles in 3.15<|η|<4.9**

MB event selection: At least one charged particle in both the forward and the backward region. (SD events suppressed)

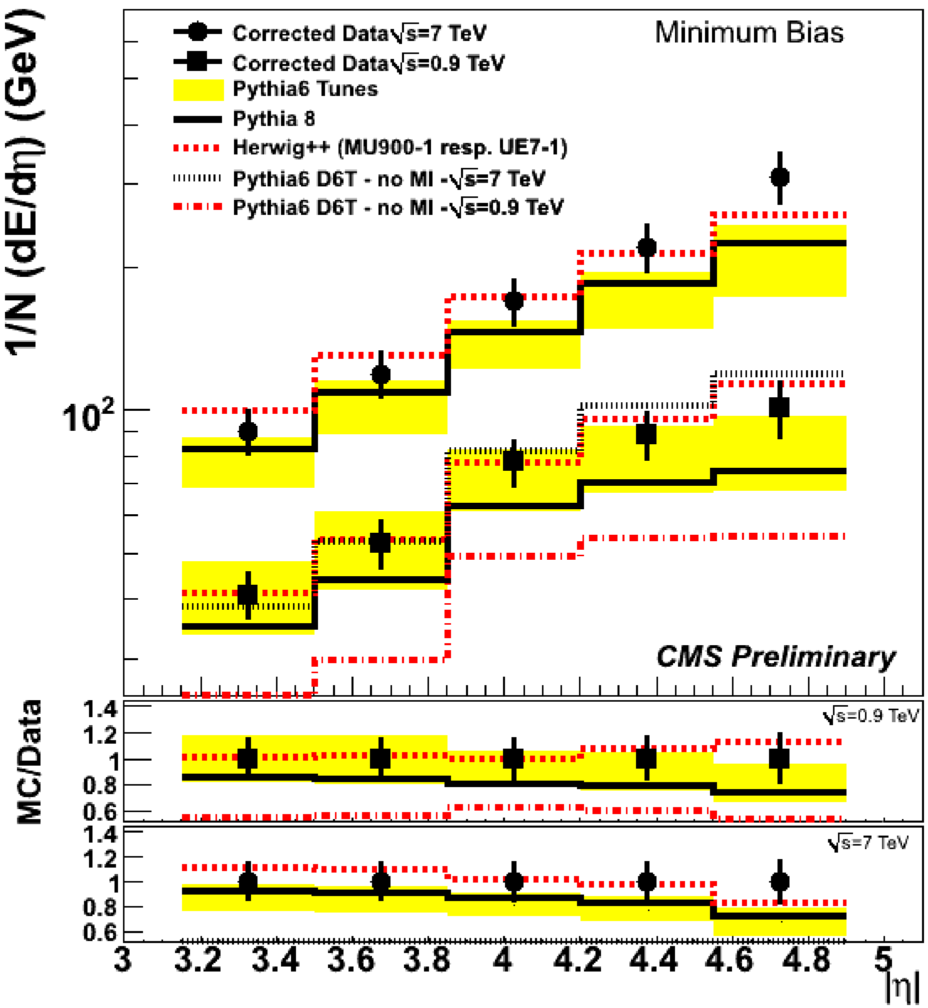


- **Strong dependence on c.o.m energy.**
- **Energy flow increase with η (closer to beam remnant)**
- **No Pythia 6 tune describe the √s = 7 TeV data at high eta.**
- **Several tunes equally good within errors.**

CMS-FWD-10-011
arXiv:1110.0211

$$\frac{1}{N}\frac{dE}{d\eta}[GeV]$$ **measured for all particles in 3.15<|η|<4.9**

MB event selection: One charged particle in both the forward and the backward region. (SD events suppressed)



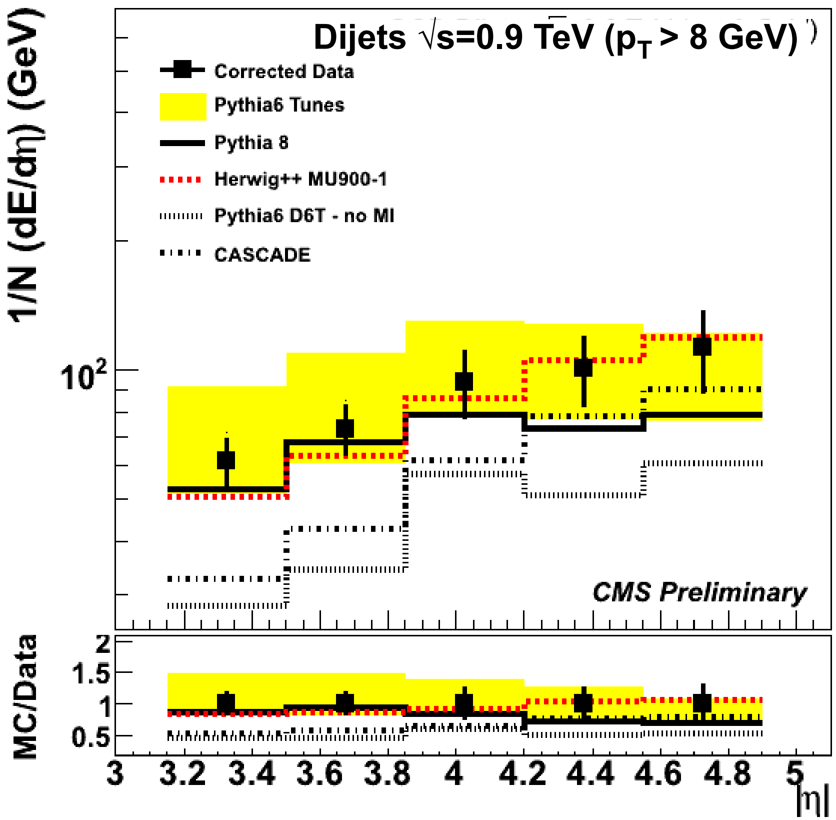
- **Pythia 6 band composed from the different Pythia 6 tunes on the last slide.**
- **Herwig++ describes the data using center-of-mass specific tunes.**
- **Pythia 8 fails at high eta**
- **Significant contribution from multiparton interactions.**

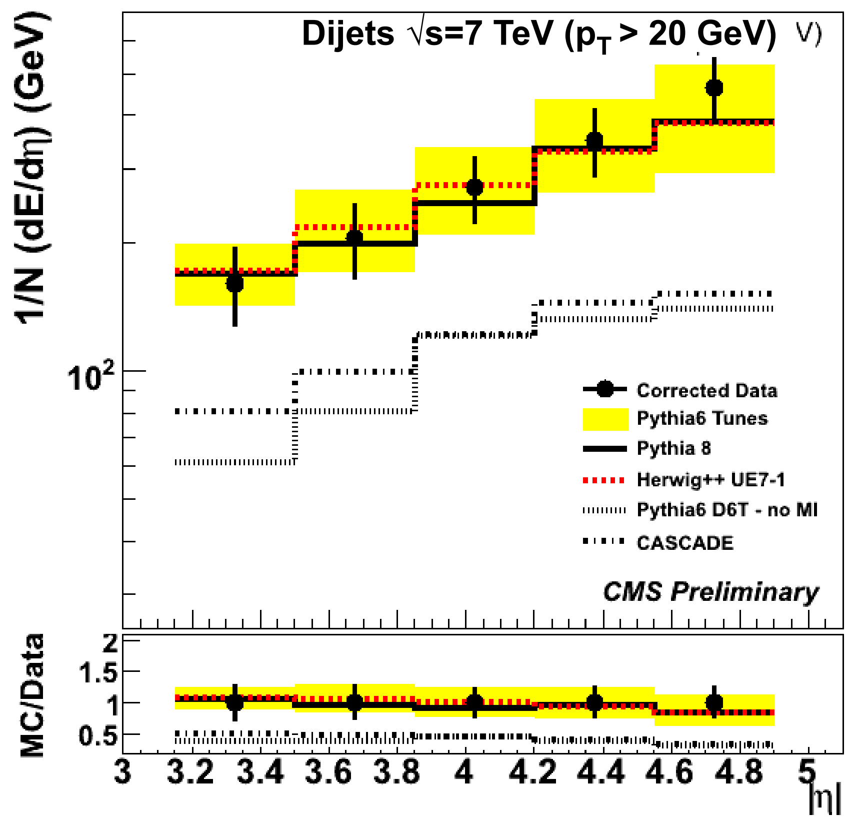
CMS-FWD-10-011
arXiv:1110.0211

Forward Energy Flow in Dijet Events

Events with a hard sub-system.
Sub-sample to the MB event sample.

Anti-kt algorithm (R=0.5)	$\sqrt{s}$=0.9 TeV	$\sqrt{s}$=7 TeV
High p_T	p_T > 8 GeV	p_T > 20 GeV
Central	$\|\eta\|$ < 2.5	
Back-to-back	$\|\Delta\varphi_{jet1,jet2} - \pi\|$ < 1	

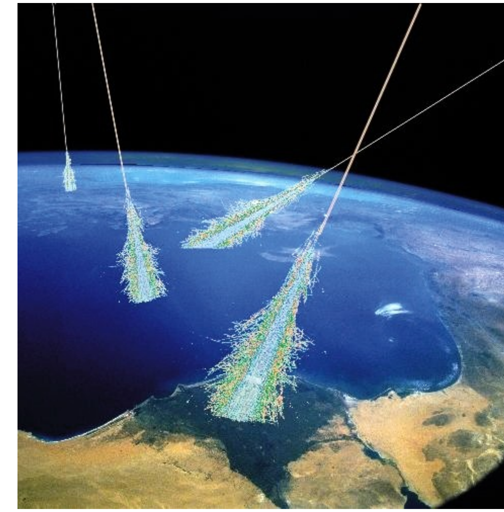




- Significantly higher forward energy flow in dijet events than in MB.
- Pythia 8 describes the data at $\sqrt{s}$=7 TeV.
- Herwig++ good, when using c.o.m. specific tunes.
- Large contribution from MI.
- Cascade (k_t-factorization based MC, no MI) – somewhat more activity than Pythia 6 w/o MI.

Comparison to Cosmic Ray MC

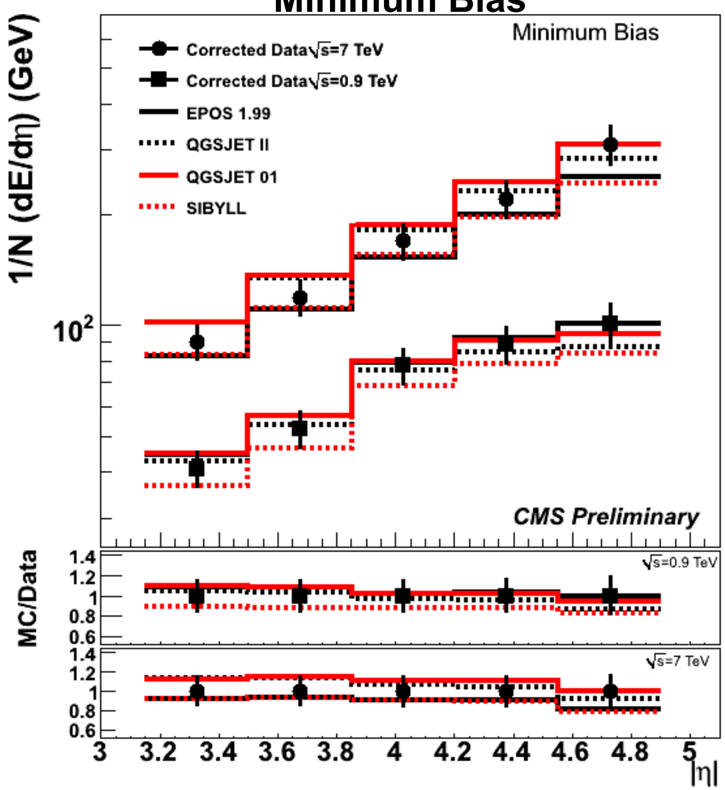
Forward energy flow overall very good description by cosmic ray MC generators.



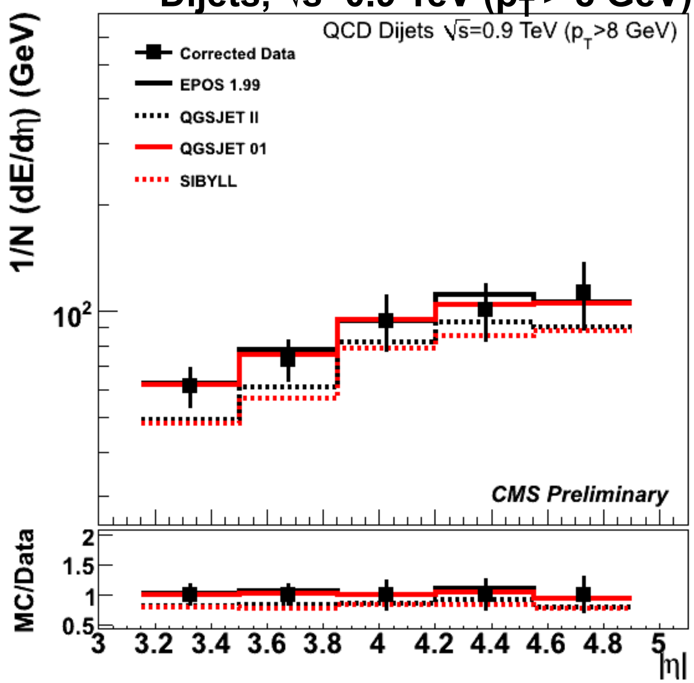
MC originally made for cosmic ray – of which 90% are protons – interactions with the atmosphere.

Forward particle production important in air shower models – majority of the energy carried by the forward particles.

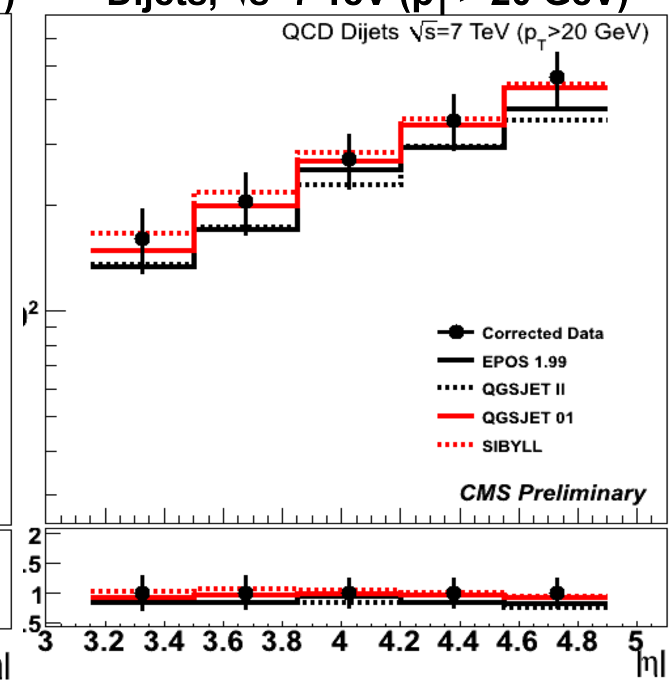
Minimum Bias



Dijets, $\sqrt{s}$=0.9 TeV (p_T > 8 GeV)



Dijets, $\sqrt{s}$=7 TeV (p_T > 20 GeV)



Summary

Summary

- Several observations based on measurements of the activity in the HF Calorimeters ($2.9<|\eta|< 5.2$).

- **Inclusive energy measurements at low scales (MB) – not too bad understanding of data by MC.**

- **With increasing scale – the MC description of data get worse. Large tune and model dependencies.**

- Evidence for **single diffractive events with a large rapidity gap** is seen in ***MB*** triggered events **at $\sqrt{s}$ = 0.9, 2.36 and 7 TeV**.

- In **events with a hard scale set by a W or Z** *diffraction is not needed in MC in order to describe the LRG events*.

  However the **asymmetry in the signed charged lepton pseudo rapidity in W or Z events**, *is* only described by diffractive MC.
  First evidence of diffraction in W/Z events at LHC. (~ 50% diffraction.)