# CMS results on Soft and Hard Diffraction

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# OUTLINE

- Inclusive/soft diffraction at 0.9, 2.36, 7 TeV

  ***CMS PAS FWD-10-007, FWD-10-001***

- W/Z with rapidity gaps

  ***Eur.Phys.J.C72:1839,2012***

- Diffractive dijets

  ***CMS PAS FWD-10-004***

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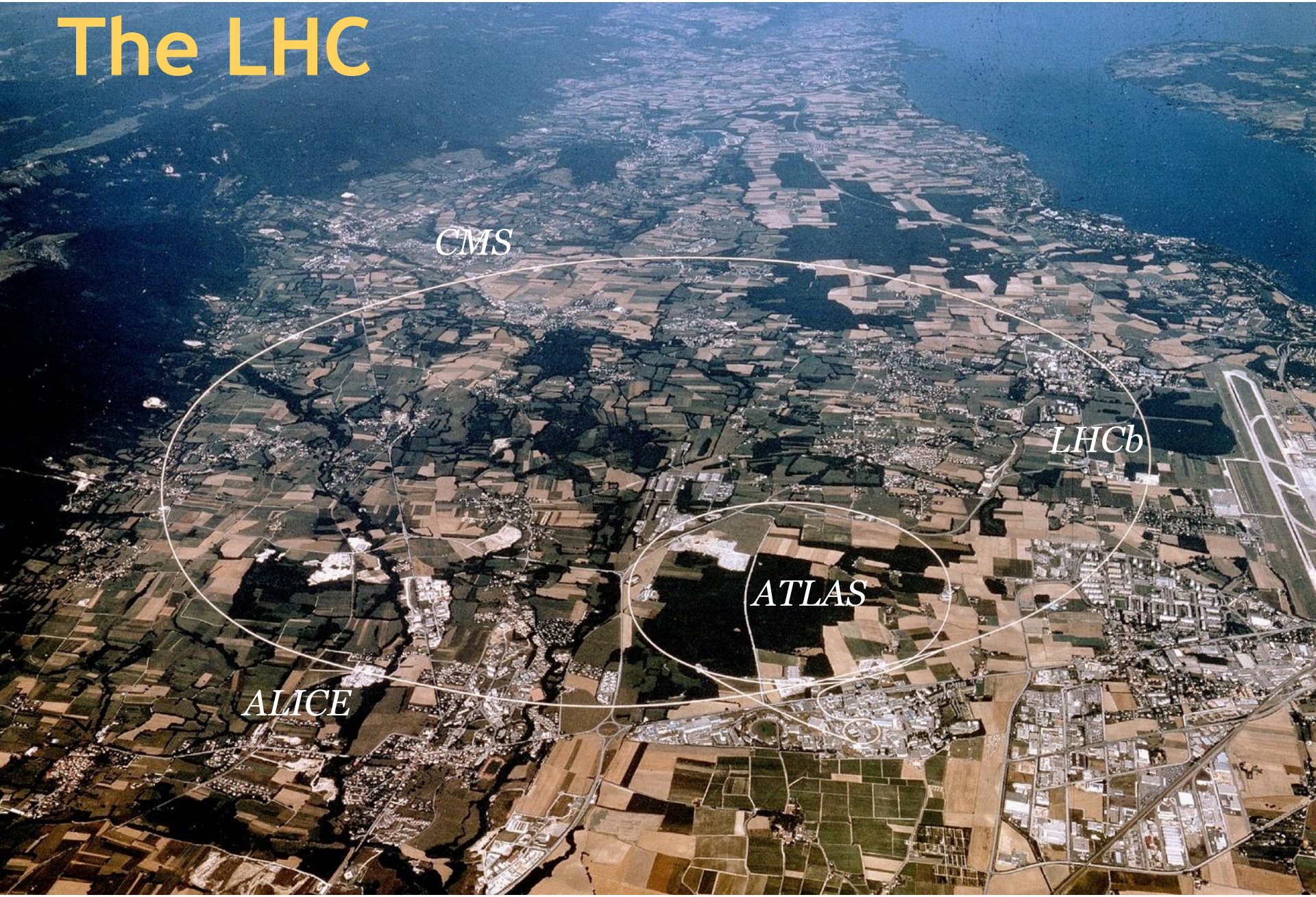
**CMS talks at this workshop:**

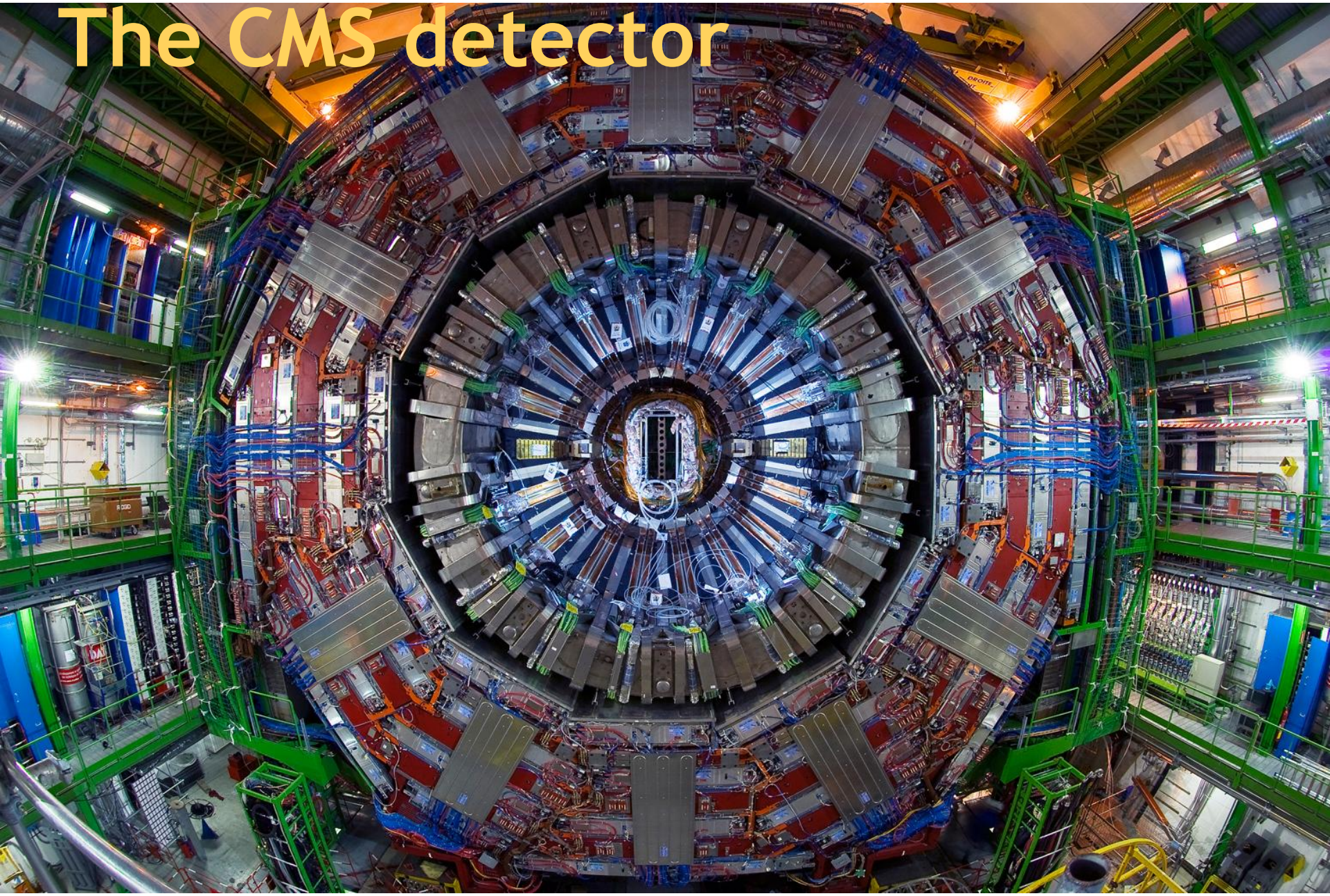
| | |
|---|---|
| Recent CMS results on soft QCD and MPI | *Sunil Bansal* |
| Recent CMS results on exclusive production | *Wenbo Li* |
| Recent CMS results on small-x QCD | *Grzegorz Brona* |

**Many more results at:**
***https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ***

# The LHC

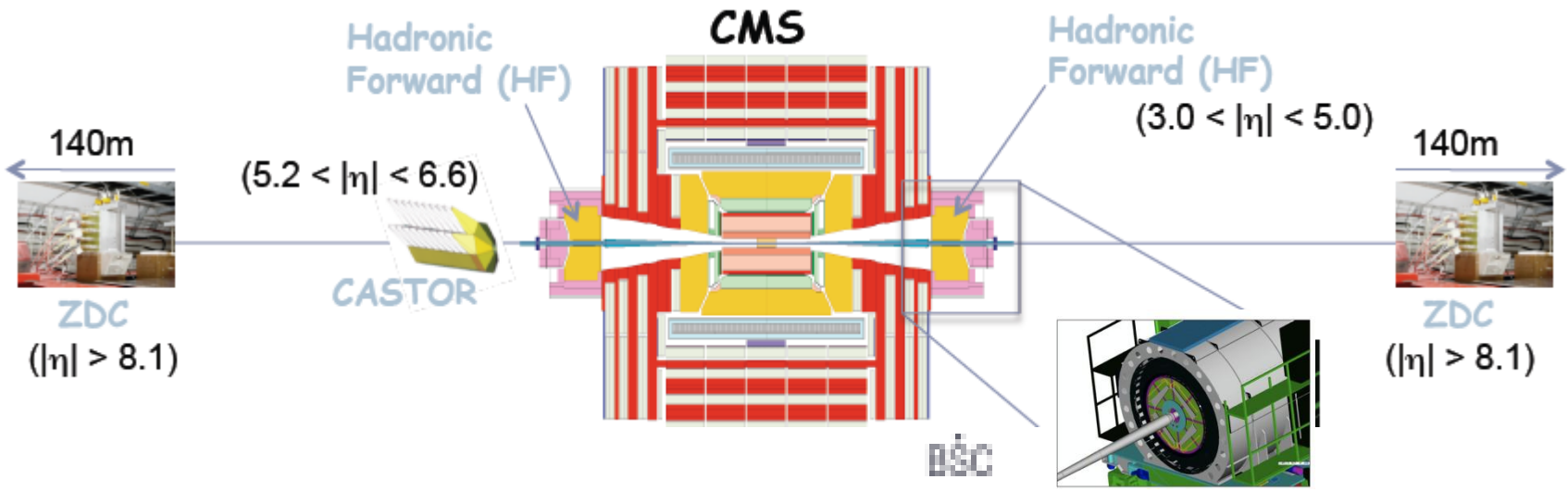


# The CMS detector



# CMS Detectors

*N.B. only detectors highlighted in blue are used in these analyses*




## Calorimetry

Hadronic Forward (HF) $|\eta| < 5.2$

Electromagnetic calorimeter $|\eta| < 3.0$

## Tracking

$|\eta| < 2.4$, $p_T$ to ~100MeV

## Muons

$|\eta| < 2.4$, $p_T > 3$GeV (barrel)

# CMS Detectors

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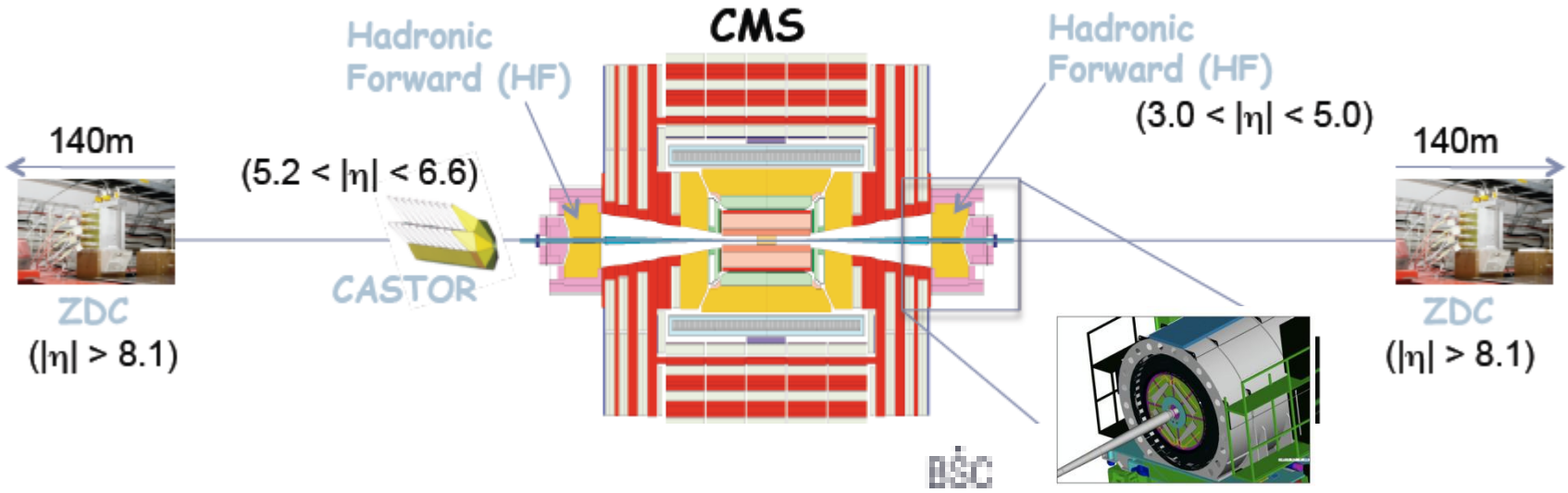
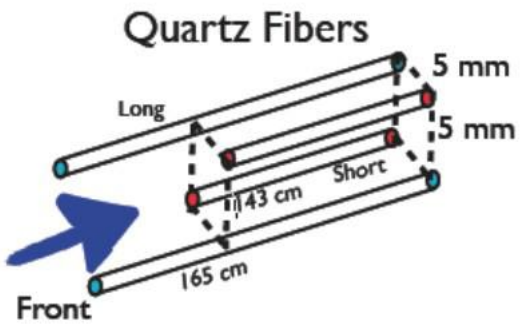



## Hadron Forward (HF):

at 11.2m from interaction point

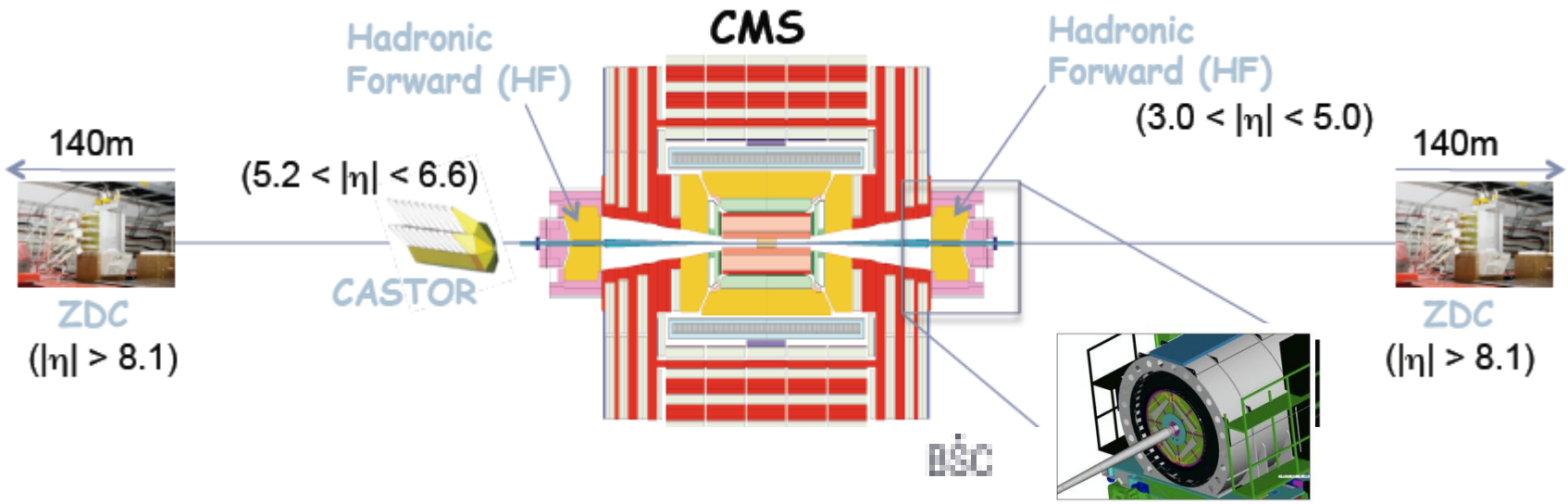
Rapidity coverage: $3 < |\eta| < 5$

Steel absorbers/quartz fibers (Long+short fibers)

0.175x0.175 $\eta/\varphi$ segmentation

# CMS Forward Detectors

*N.B. only detectors highlighted in blue are used in these analyses*

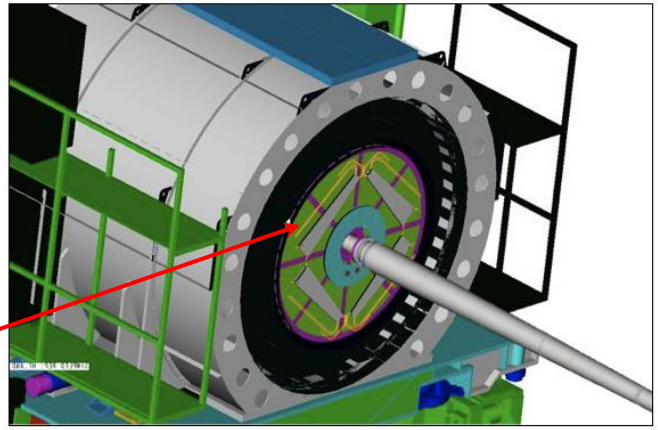



**CASTOR:** -5.2 > η > -6.6 (one side only)

**Zero Degree Calorimeter (ZDC):** |η| > 8.1

**Beam Scinitillator Counters (BSC):**
10.9 m from IP5, used for minimum bias triggers in 2010

# Soft Diffraction at CMS



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

**Events are selected**

by triggering on
- a signal in the beam pickups (BPTX), and
- a hit in either of the BSCs

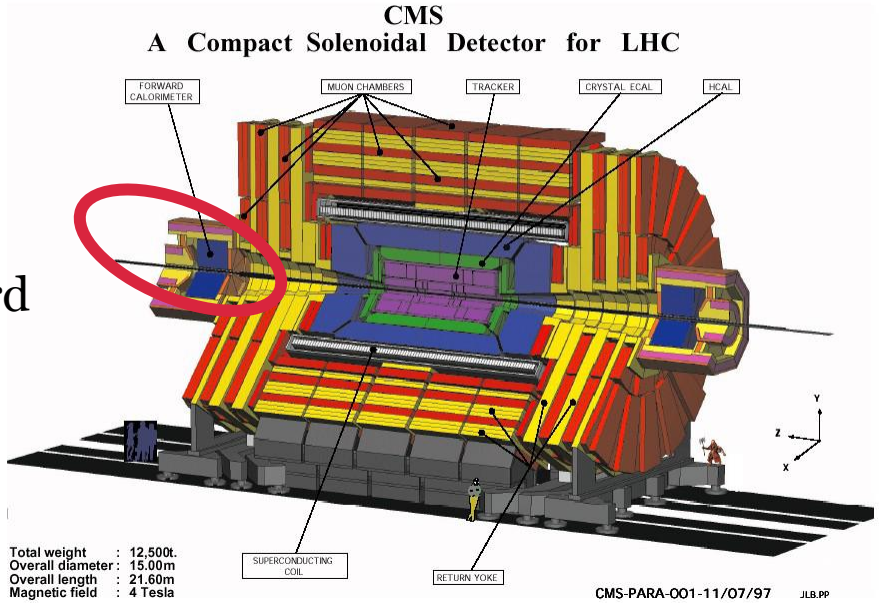
**Require:**

- High quality primary vertex
-Beam halo and beam background reduction

**Measure:**

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

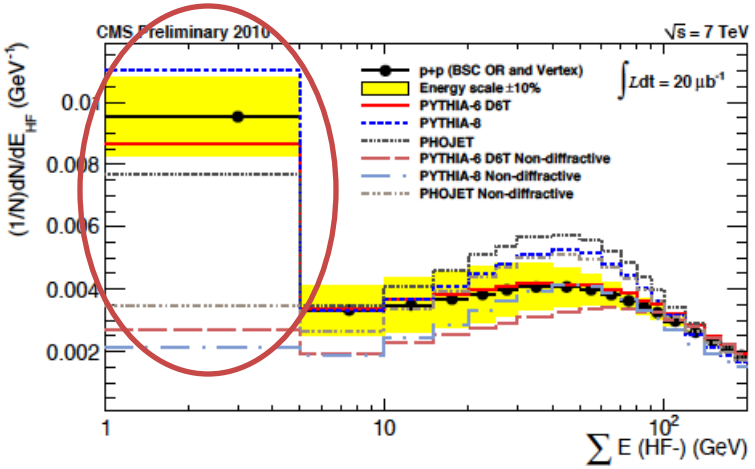
variables $\sum(E \pm p_z)$ proportional to $\xi$ the momentum loss of the $p$ using information from all final state particles



# Soft Diffraction

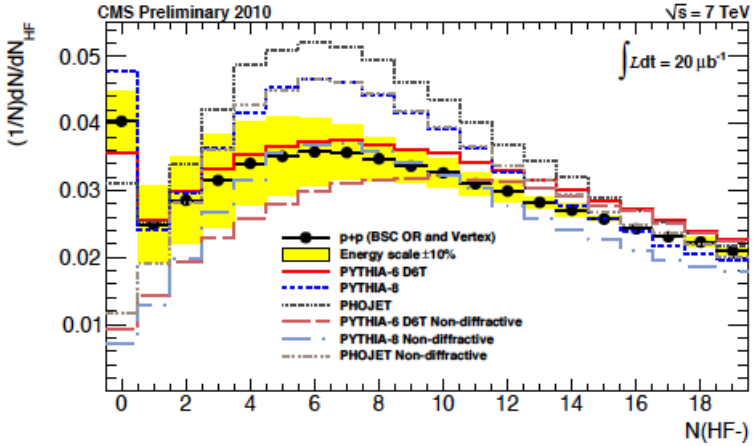
Data compared to
Pythia 6, Pythia 8 and Phojet
with and without diffraction

At low energy deposits ("LRG") – ND predictions underestimate the data by a factor of 4-5.

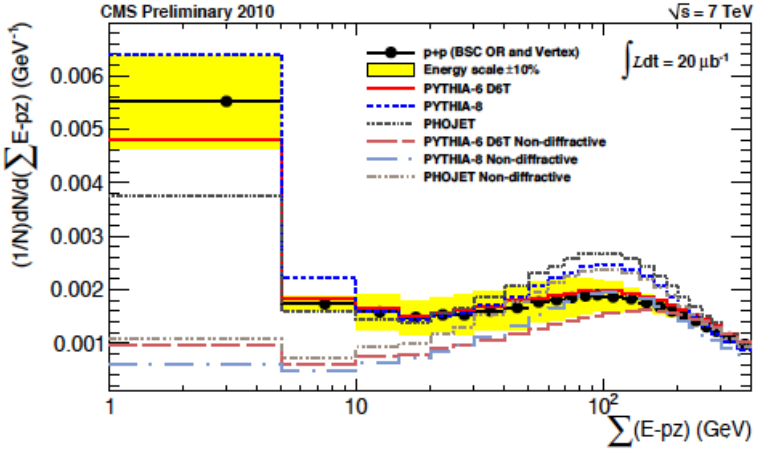



***Energy deposit in one of the HFs***

**None of the models describe all features of the data**




***Number of towers in one of the HFs***

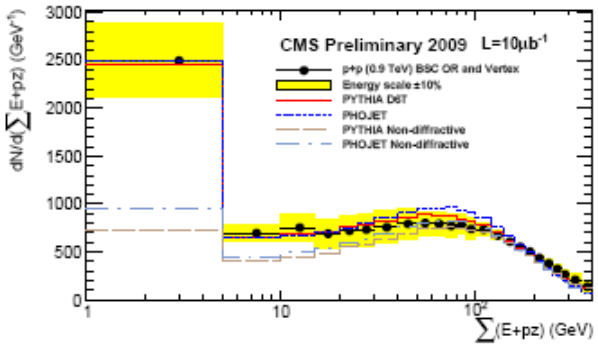


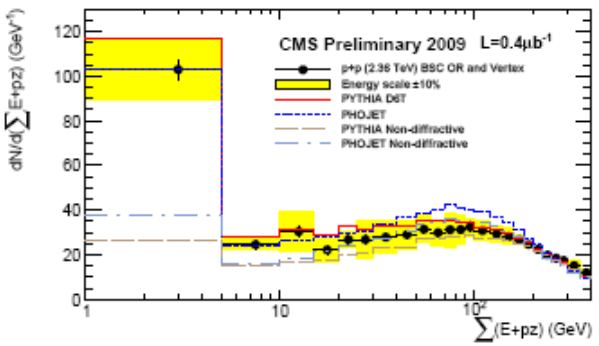

***$\sum(E\text{-}p_z)$ ~ to momentum loss of the p***

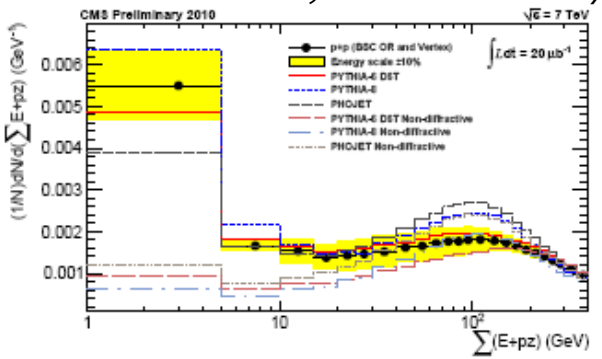
# Observation of Diffraction

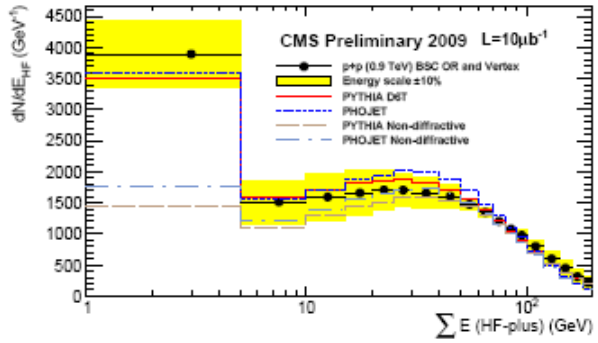
**✓s=0.9 TeV** **✓s=2.36 TeV** **✓s=7 TeV**

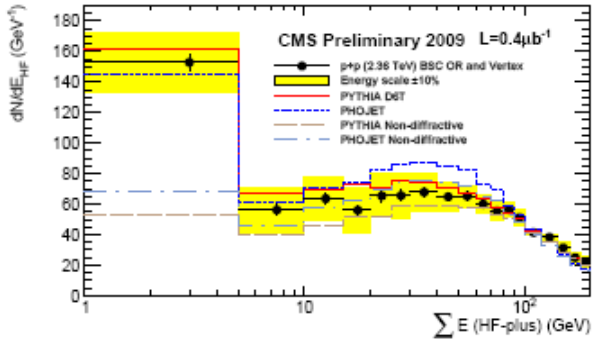
*CMS PAS FWD-10-001, FWD-10-007*

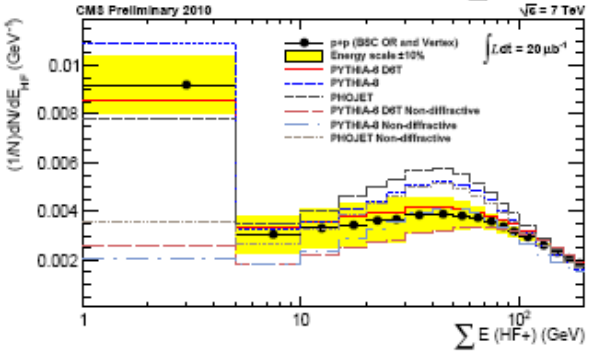


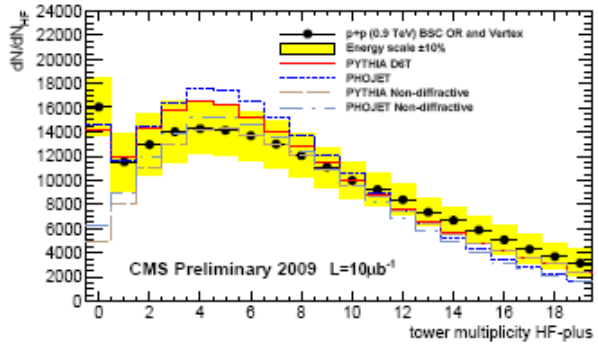



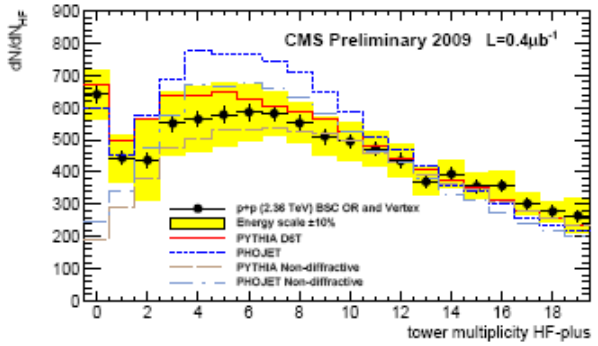



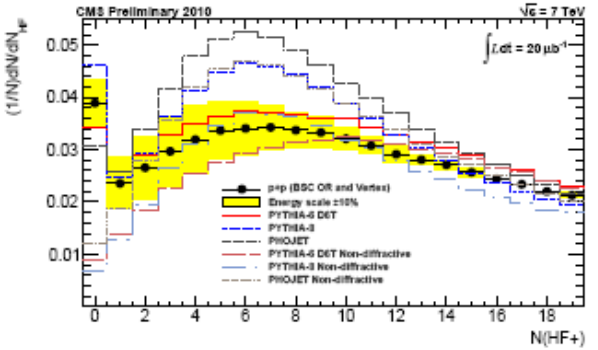



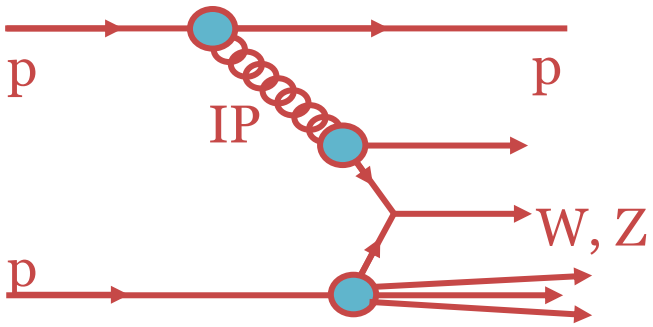



# Diffractive W/Z Production

*Eur.Phys.J.C72:1839,2012*

*Analysis based on full 2010 dataset (36pb$^{-1}$)*




## Events are selected

**by triggering on**

standard high-pT lepton triggers,

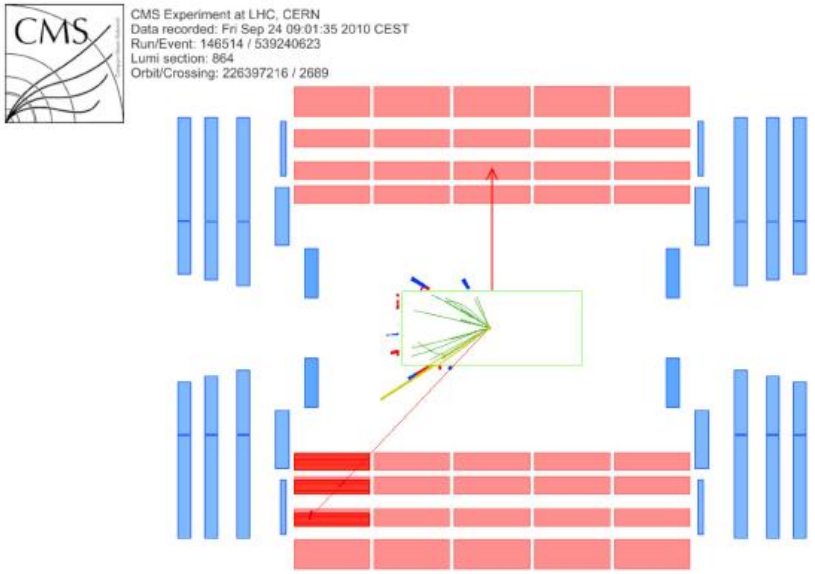
W/Z selection based on inclusive cross-section measurements

## Require:

**to suppress pile-up**

only W/Z events with a single-vertex are used

Residual contamination from soft pileup events studied in MC, and in data as a function of average instantaneous luminosity



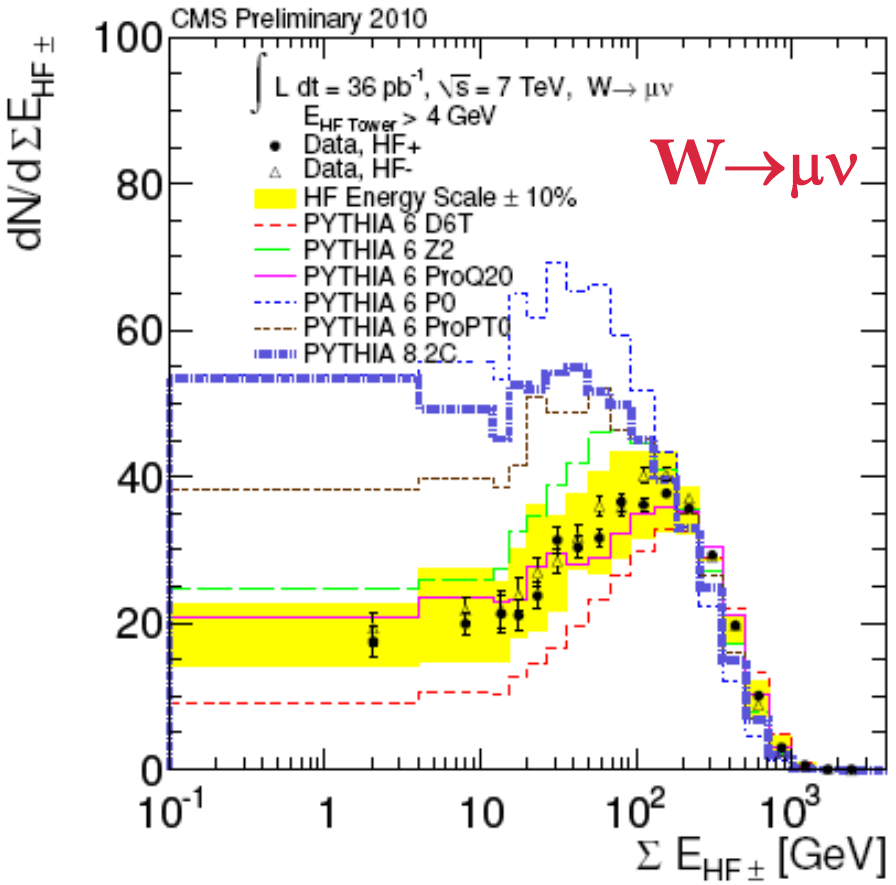

**for diffractive selection:**

no energy deposit in HF

LRG, Calo. Tower Energy > 4 GeV

# W/Z events with rapidity gaps

*Eur.Phys.J.C72:1839,2012*




**Measure the fraction of gap events, and compare to various models**

Wide range of predictions

Excess of gap events compared to Pythia 6 D6T tune

Deficit compared to Pythia 6 Z2, Pythia 8

**Monte Carlo generators cannot describe the data**

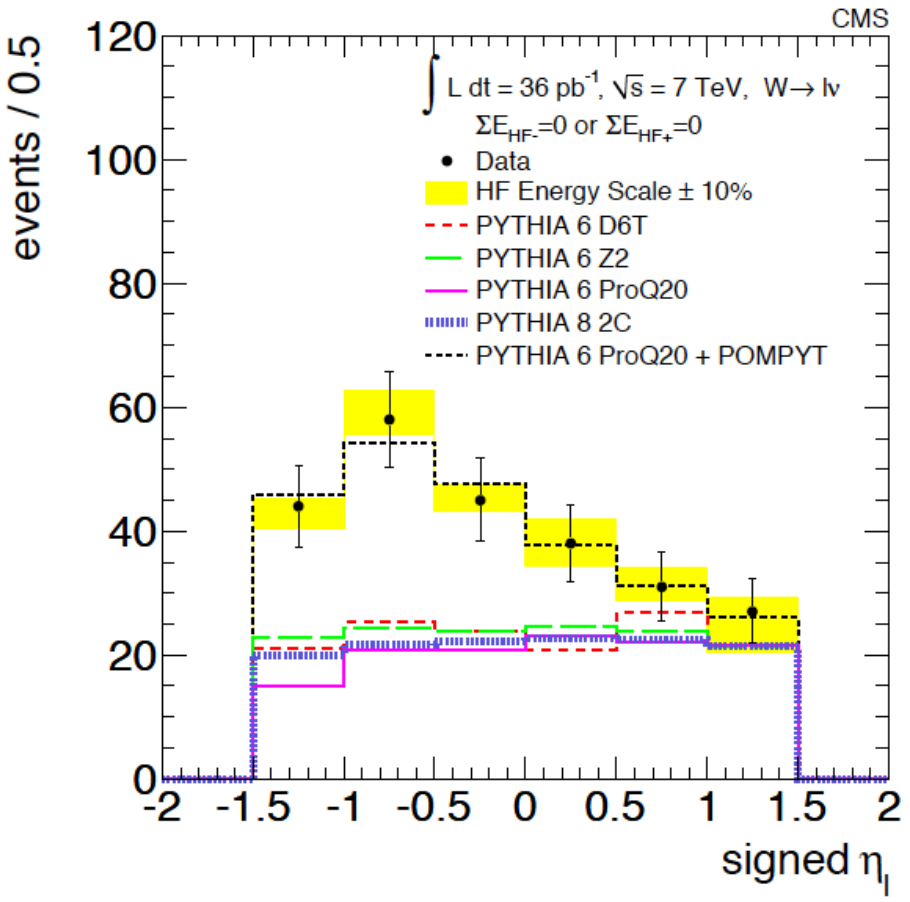
**Fraction of W/Z events with a forward gap:**

**W→lν:** ***1.46 ± 0.09(stat.) ± 0.38(syst.) %***

**Z →ll:** ***1.60 ± 0.25(stat.) ± 0.42(syst.) %***

# W/Z events with rapidity gaps

*Eur.Phys.J.C72:1839,2012*




**Alternative approach** – exploit asymmetry between signed lepton and the gap side

Gap and lepton on **same side** → **$\eta_l$ positive**

Gap and lepton on **opposite sides** → **$\eta_l$ negative**

Large asymmetry in models including hard diffraction (POMPYT)

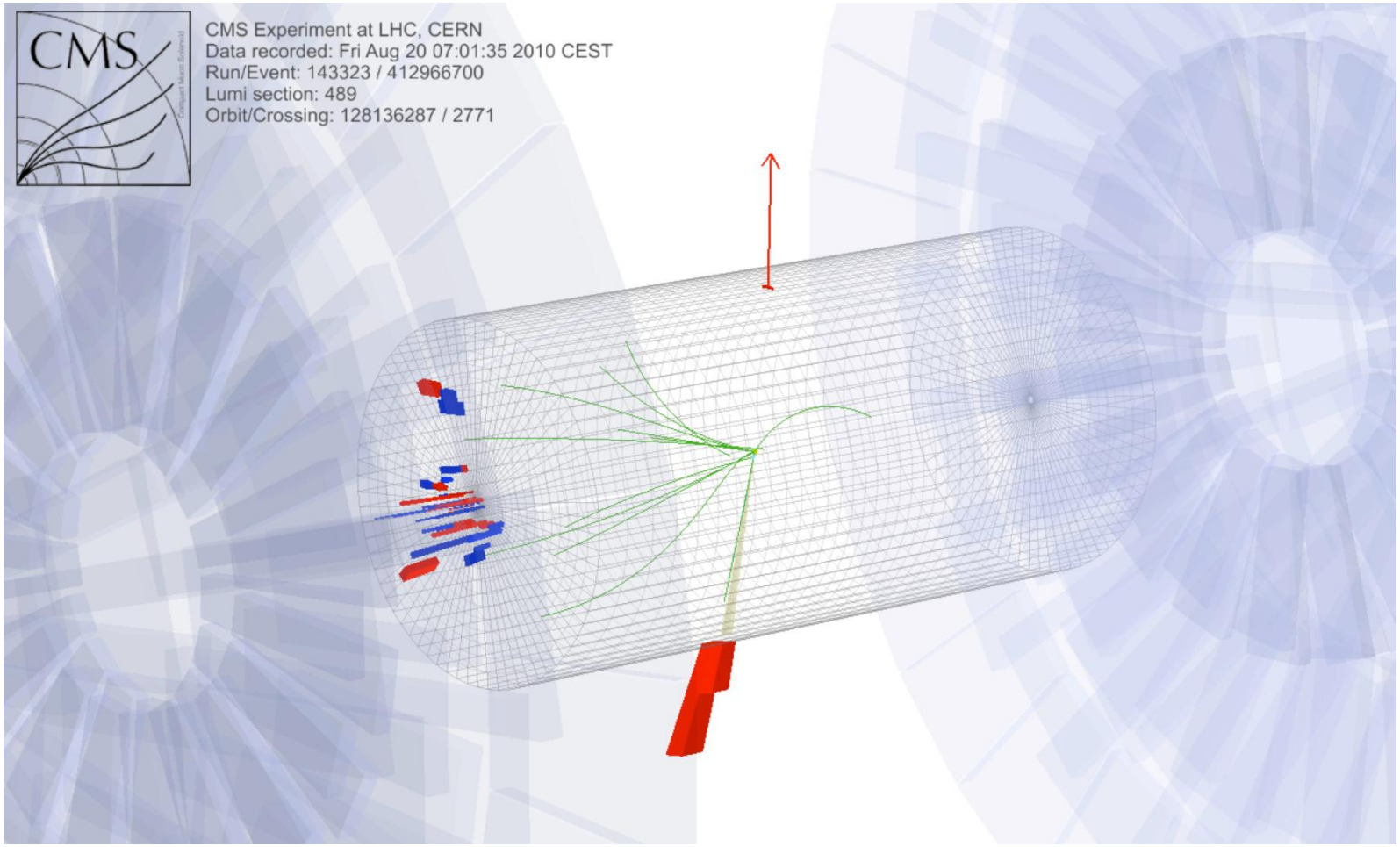
No significant asymmetry in non-diffractive PYTHIA W/Z samples ~independent of the tune

**Diffractive component in LRG W/Z sample**

**50.0 ± 9.3(stat.) ± 5.2(syst.) %**

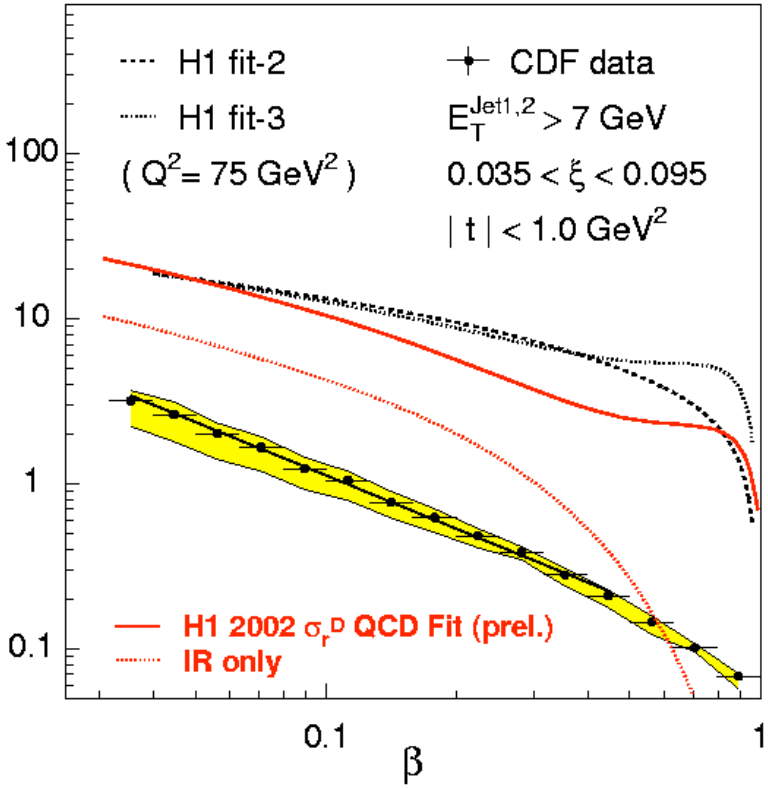
***fitted value from MC mix of POMPYT and ND PYTHIA***

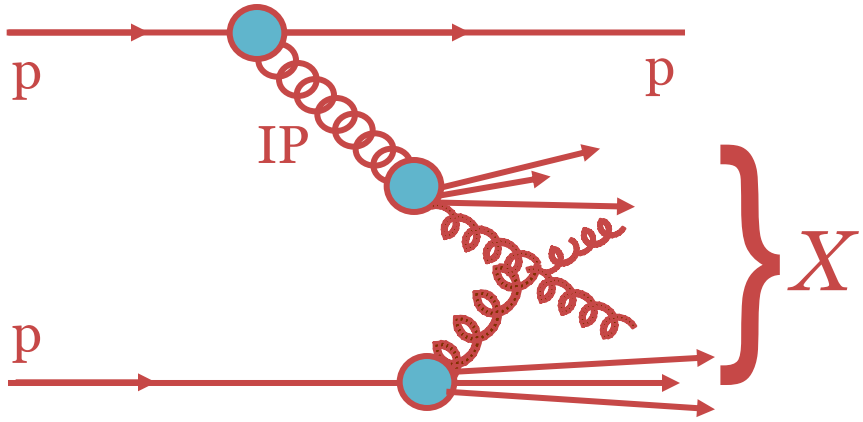
# Diffractive W Event Candidate



# Diffractive Dijet Production

**Previous measurements of hard diffractive processes in pp (Tevatron), ep (HERA)**




$\xi = M_X^2/s \sim$ fractional momentum loss of the scattered $p$

$$f_{diff}(\xi,t,x_1,\mu) = f(\xi,t)\, f_P(x_1,\mu)$$

*dPDF* — *Pomeron flux* — *Pomeron str.function*

$$d^2\sigma/d\xi dt = \sum x_1 x_2\, f(\xi,t)\, f_P(x_1,\mu)\, f_p(x_2,\mu)\, \hat{\sigma}$$

*PDF*

# Diffractive Dijet Production

*Analysis based on low pile-up 2010 data (2.7 nb$^{-1}$)*

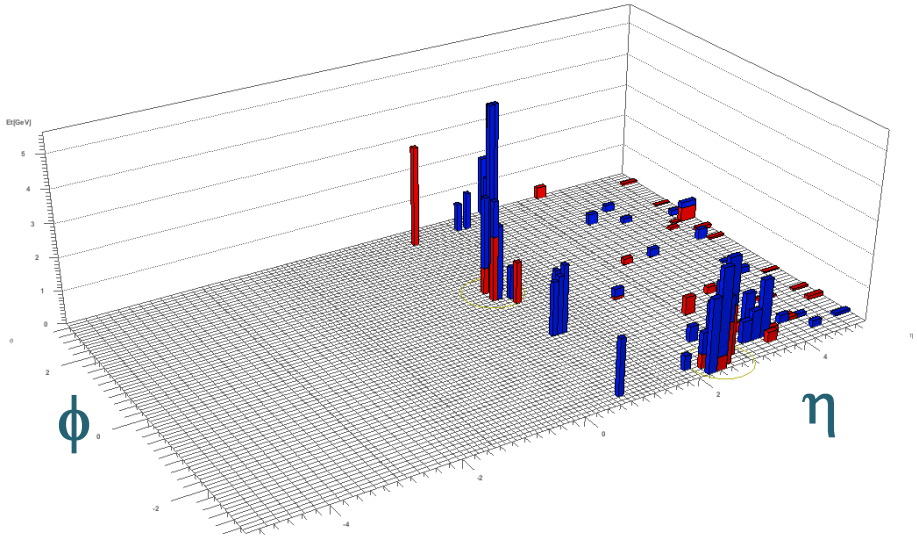
**Events are selected**
**by triggering on**
single jets with $p_T$>6 GeV
anti-$k_T$ algorithm R=0.5

**Require:**
**off-line cuts**
at least 2 jets with
$E_T$>20 GeV and $|\eta|$<4.4
Standard vertex and track quality selections

**for $\xi$ reconstruction:**
Based on Particle Flow (PF) objects above noise threshold
global event reconstruction, combining charged tracking and calorimetry

CMS Experiment at LHC, CERN
Data recorded: Sat Apr 24 05:25:36 2010 CEST
Run/Event: 133874 / 22902855
Lumi section: 317

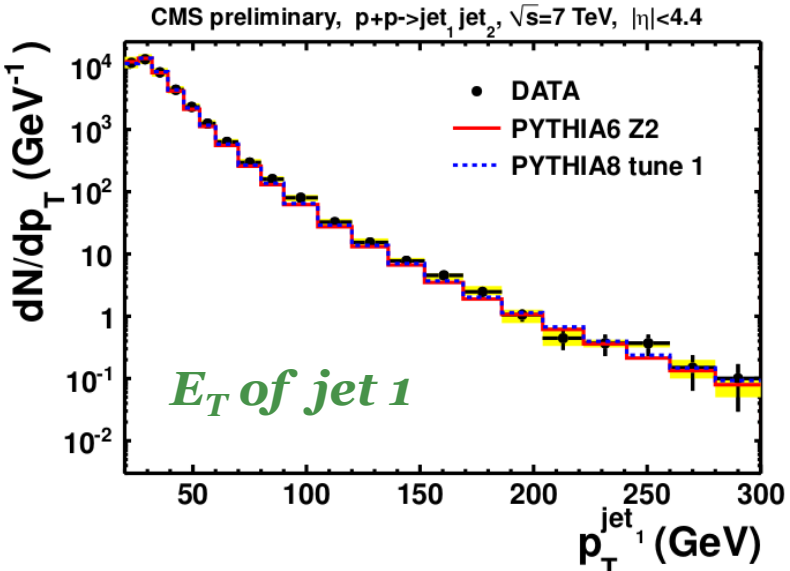
*CMS PAS FWD-10-004*

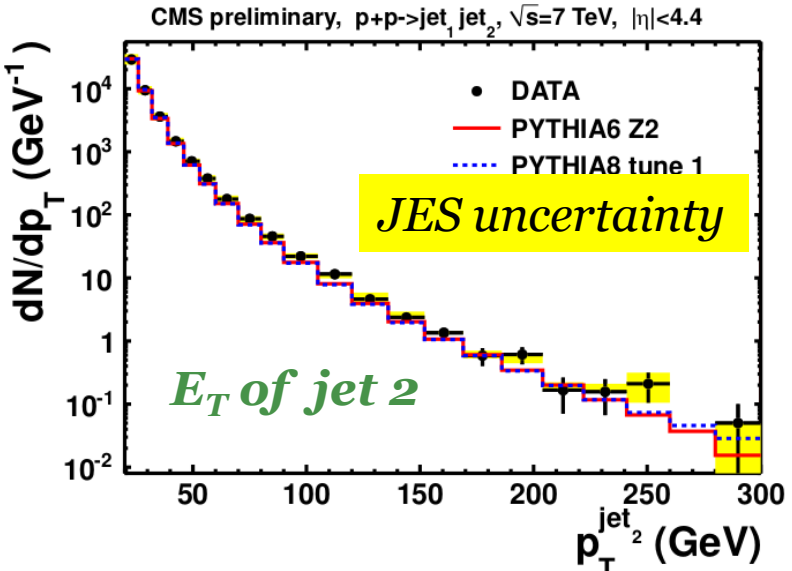


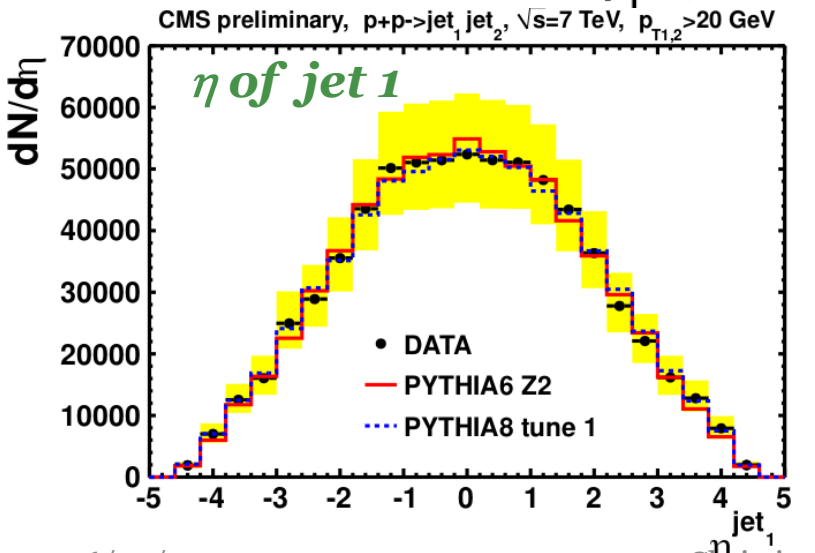

$p_T$(jet1) = 43.5 GeV, $p_T$(jet2) = 36.9 GeV
$\eta$ (jet1) = 0.83, $\eta$ (jet2) = 2.55

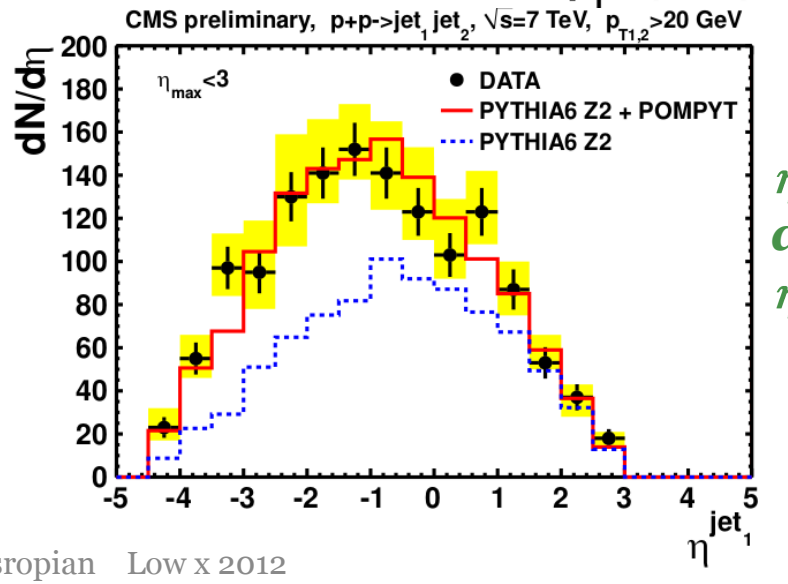
# Dijets: Kinematic distributions

*CMS PAS FWD-10-004*




*η of jet 1 after $\eta_{max}<3$*

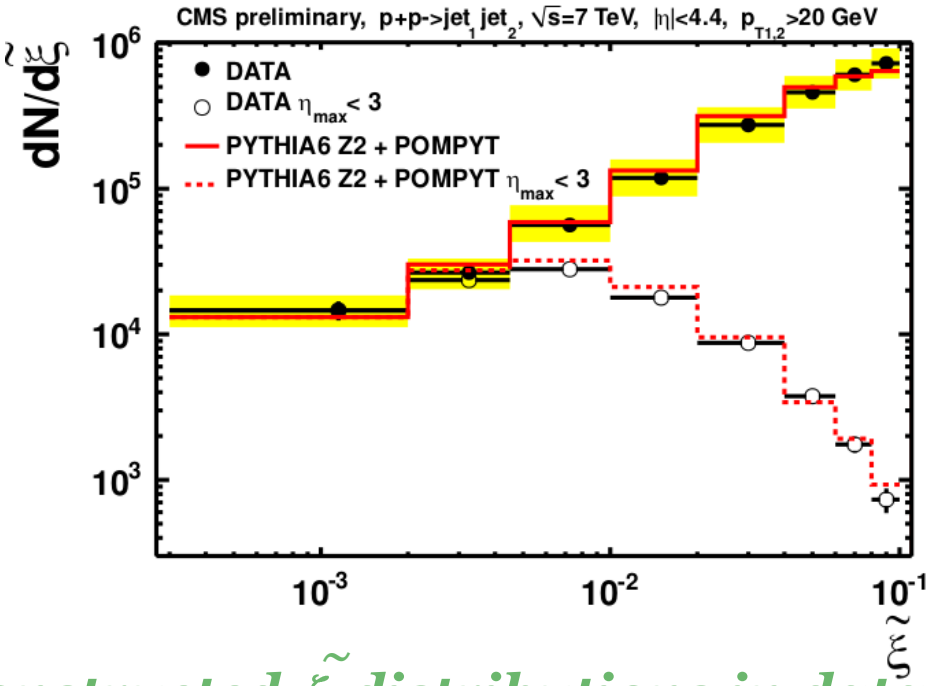
# Diffractive Dijets

**To enhance diffractive contribution:**

Require the most forward(backward) PF particle in the event satisfy $\eta_{max} < 3$ ($\eta_{min} > -3$)

Corresponds to a gap of 1.9 units
no Particle Flow objects in HF
with energy deposit > 4 GeV

*CMS PAS FWD-10-004*




***Reconstructed $\tilde{\xi}$ distributions in data and MC after $\eta_{max}<3$ ($\eta_{min}>-3$) cuts***

$$\tilde{\xi}^{\pm} = C\sum(E \pm p_Z)/\sqrt{s}$$

summed over all final state particles with $\eta < 4.9$ ($\xi^+$) or $\eta > -4.9$ ($\xi^-$):

***C*** – correction factor determined from MC by comparing generated and reconstructed values of $\xi$

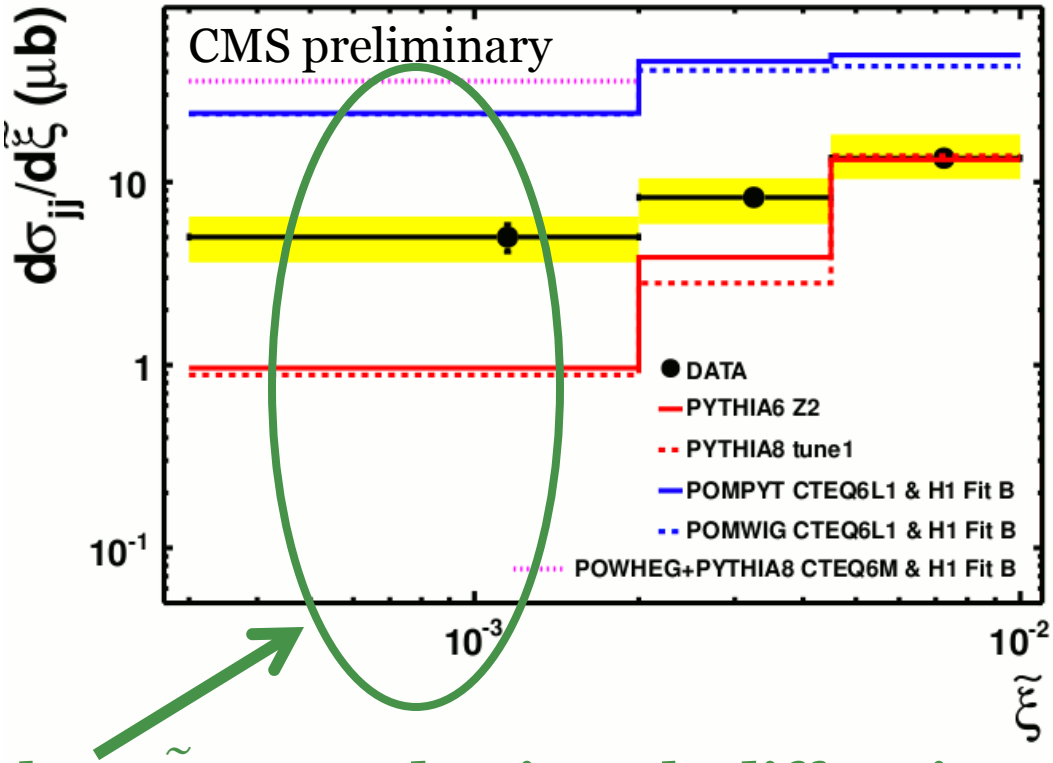
Definition converges to "true"

$\xi = M_X^2/s$ for SD events with low-$\xi$

Distributions are described by combination of POMPYT and PYTHIA6 Z2,
the relative contributions determined from the fit to $\xi$ before $\eta_{max/min}$ cuts

# Differential Cross Section for Dijet Production as a function of $\tilde{\xi}$

*CMS PAS FWD-10-004*




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

Significant excess over PYTHIA6 D6T/PYTHIA8 at low $\xi$

Deficit compared to diffractive POMWIG/POMPYT MC's without gap survival effects

Interpret in terms of *"gap survival"* under different model assumptions

**low-$\tilde{\xi}$ events dominantly diffractive**

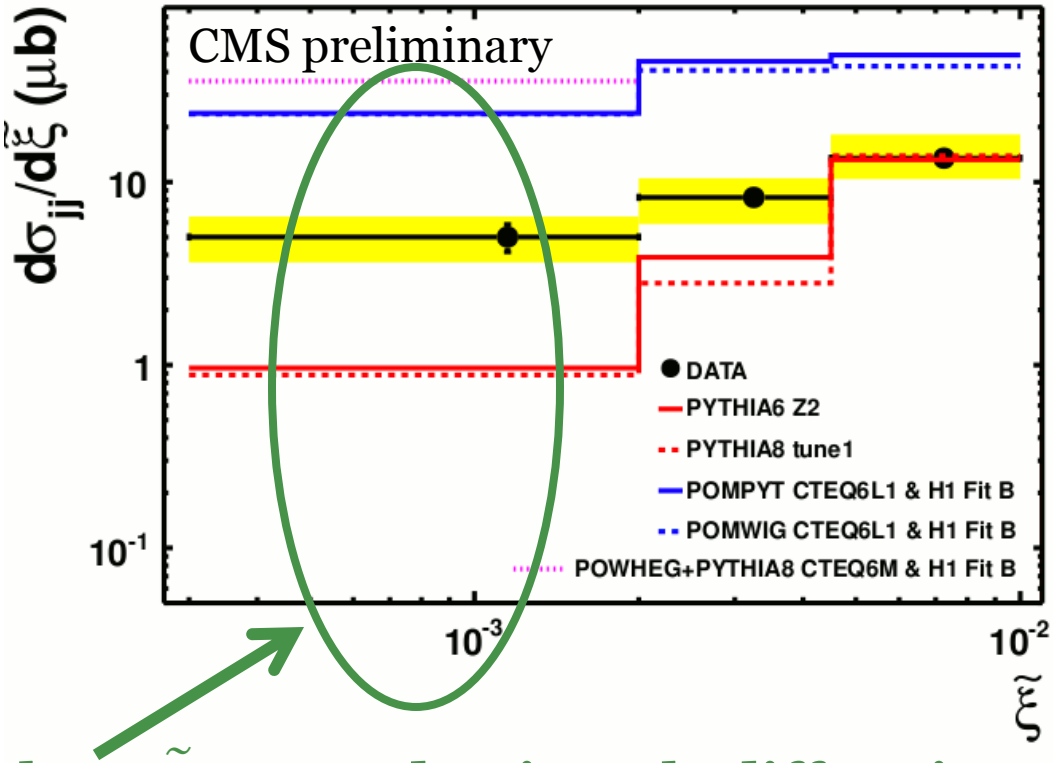
| $\tilde{\xi}$ bin | $\Delta\sigma_{jj}/\Delta\tilde{\xi}$ (μb) |
|---|---|
| $0.0003 < \tilde{\xi} < 0.002$ | $5.0 \pm 0.9(\text{stat.})^{+1.5}_{-1.4}(\text{syst.})$ |
| $0.002 < \tilde{\xi} < 0.0045$ | $8.2 \pm 0.9(\text{stat.})^{+2.3}_{-2.3}(\text{syst.})$ |
| $0.0045 < \tilde{\xi} < 0.01$ | $13.5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

*upper limit*

**$S^2_{data/MC}$ = 0.21 ± 0.07 (LO MC)**
**$S^2_{data/MC}$ = 0.14 ± 0.05 (NLO MC)**

# Differential Cross Section for Dijet Production as a function of $\tilde{\xi}$

*CMS PAS FWD-10-004*

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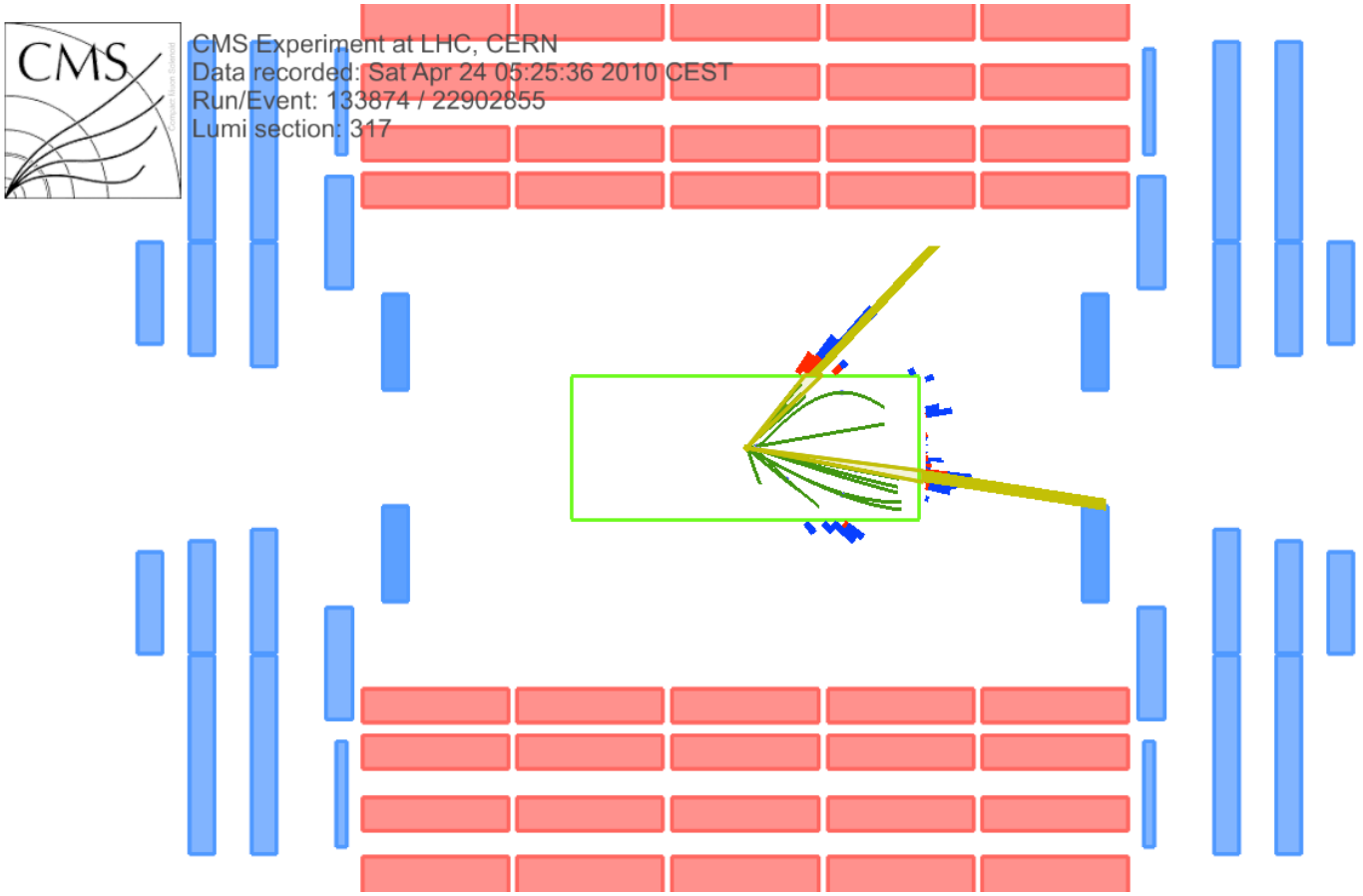
| $0.002 < \tilde{\xi} < 0.0045$ | $8.2 \pm 0.9(\text{stat.})^{+2.3}_{-2.3}(\text{syst.})$ |
| $0.0045 < \tilde{\xi} < 0.01$ | $13.5 \pm 0.9(\text{stat.})^{+4.7}_{-3.1}(\text{syst.})$ |

*after taking into account proton dissociation*

**$S^2_{data/MC}$ = 0.12 ± 0.05 (LO MC)**
**$S^2_{data/MC}$ = 0.08 ± 0.04 (NLO MC)**

# Diffractive Dijet Event Candidate



# Conclusions

**Observation of diffraction in pp collisions at .9, 2.36 and 7 TeV**

**First measurements of hard diffraction at the LHC, associated with high-$p_T$ jets and W/Z bosons**

No models reproduce all aspects of forward energy flow/multiplicities in inclusive diffraction or *W/Z analyses*

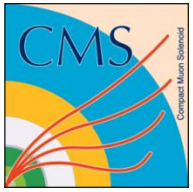
Constraints on survival probabilities at 7 TeV from diffractive dijet cross-section

**Prospects**

Many analyses still to be done with 2010/early 2011 data
Low-pileup runs in 2012

Only beginning to exploit the potential of forward detectors (CASTOR, ZDC, FSC, CMS+TOTEM combination) for physics analysis

***Stay tuned !***


CMS
Compact Muon Solenoid