XX International Workshop on Deep-Inelastic Scattering and Related Subjects

26-30 March 2012, University of Bonn

Probing Hard Diffraction at CMS

A. Vilela Pereira, on behalf of the CMS collaboration
INFN Torino

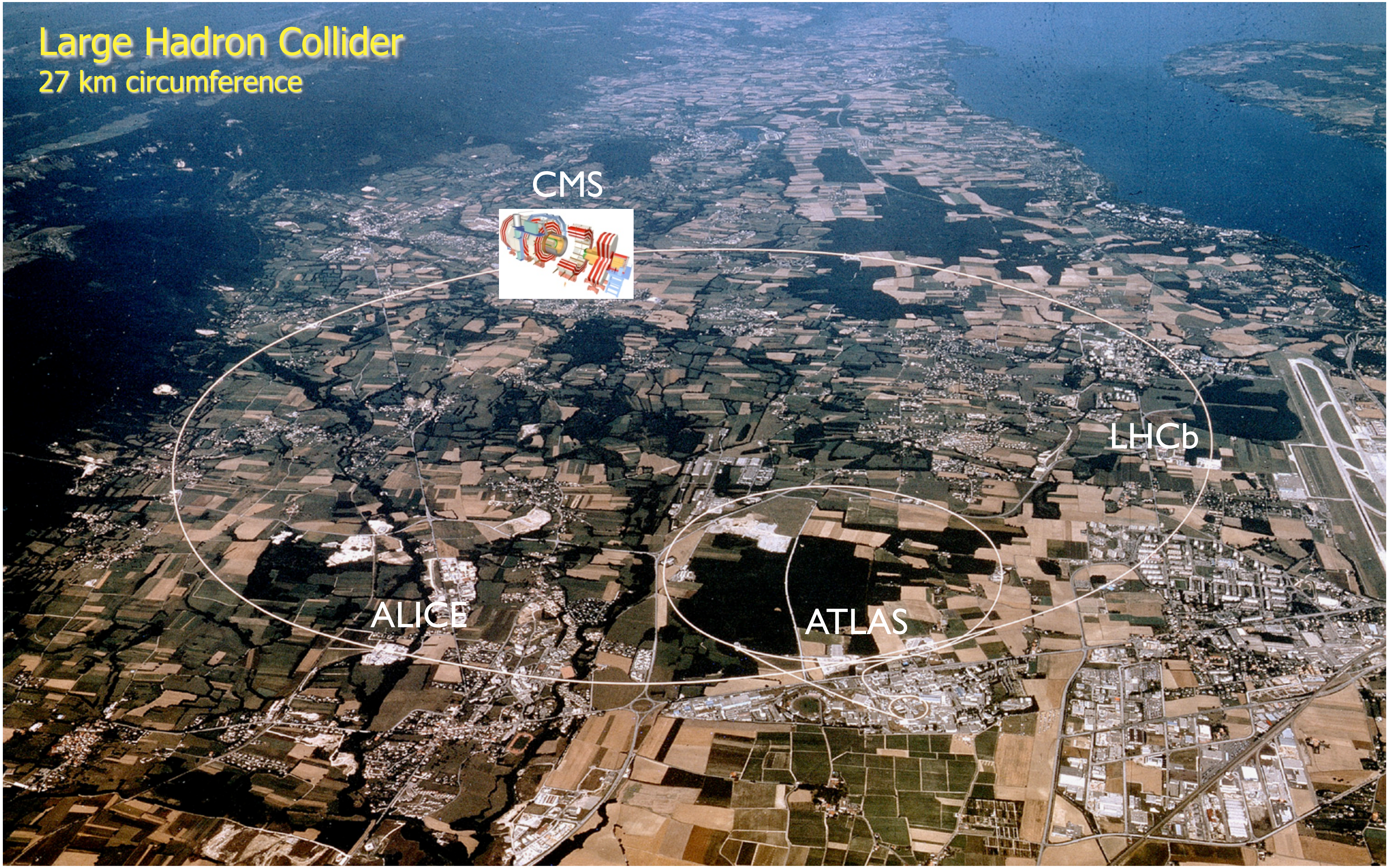
Outline

CMS detector & forward instrumentation

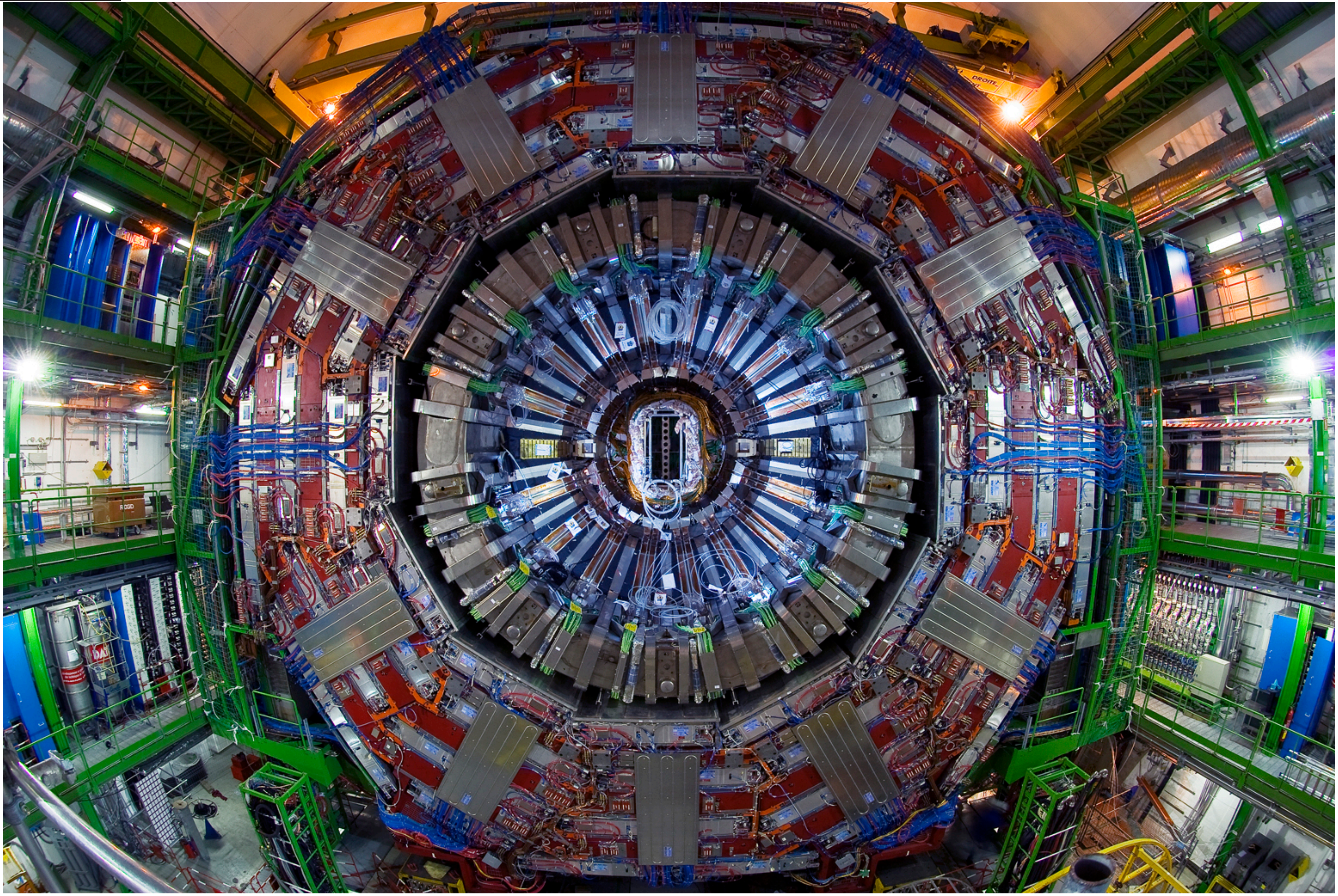
Probing hard diffraction I: Diffractive dijet production

Probing hard diffraction II: W/Z events with (pseudo-)rapidity gaps

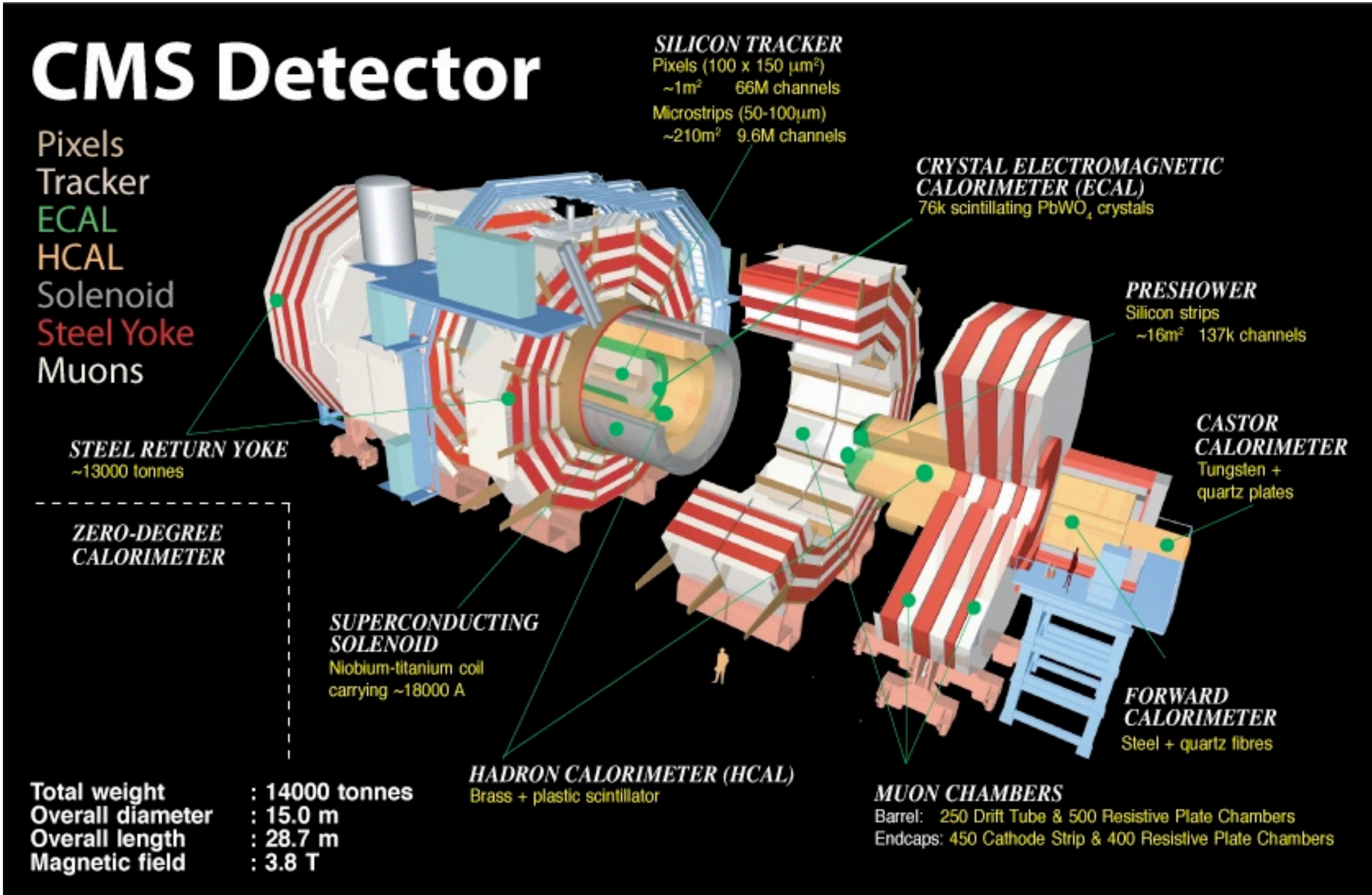
The CMS detector



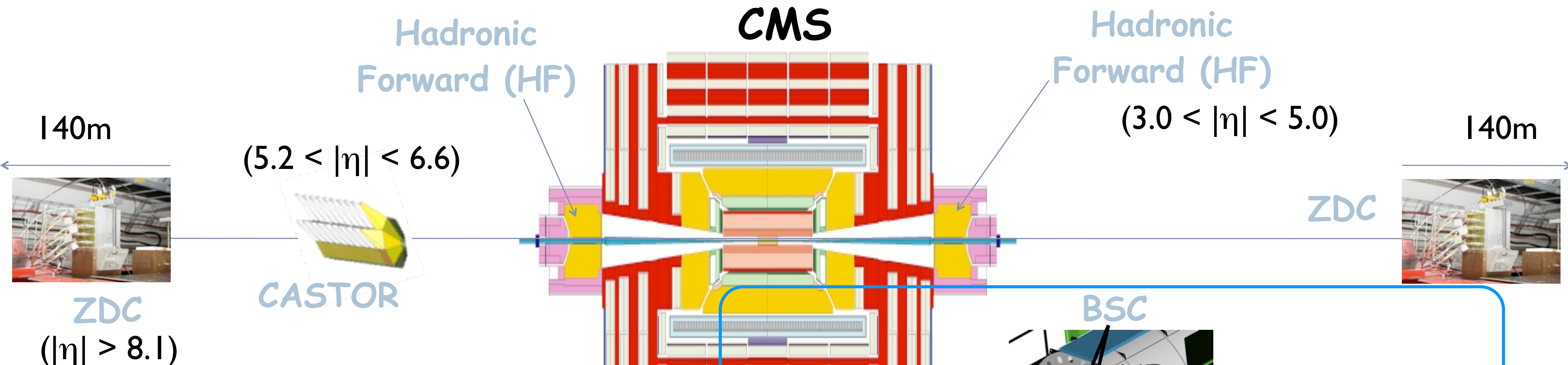
The CMS detector



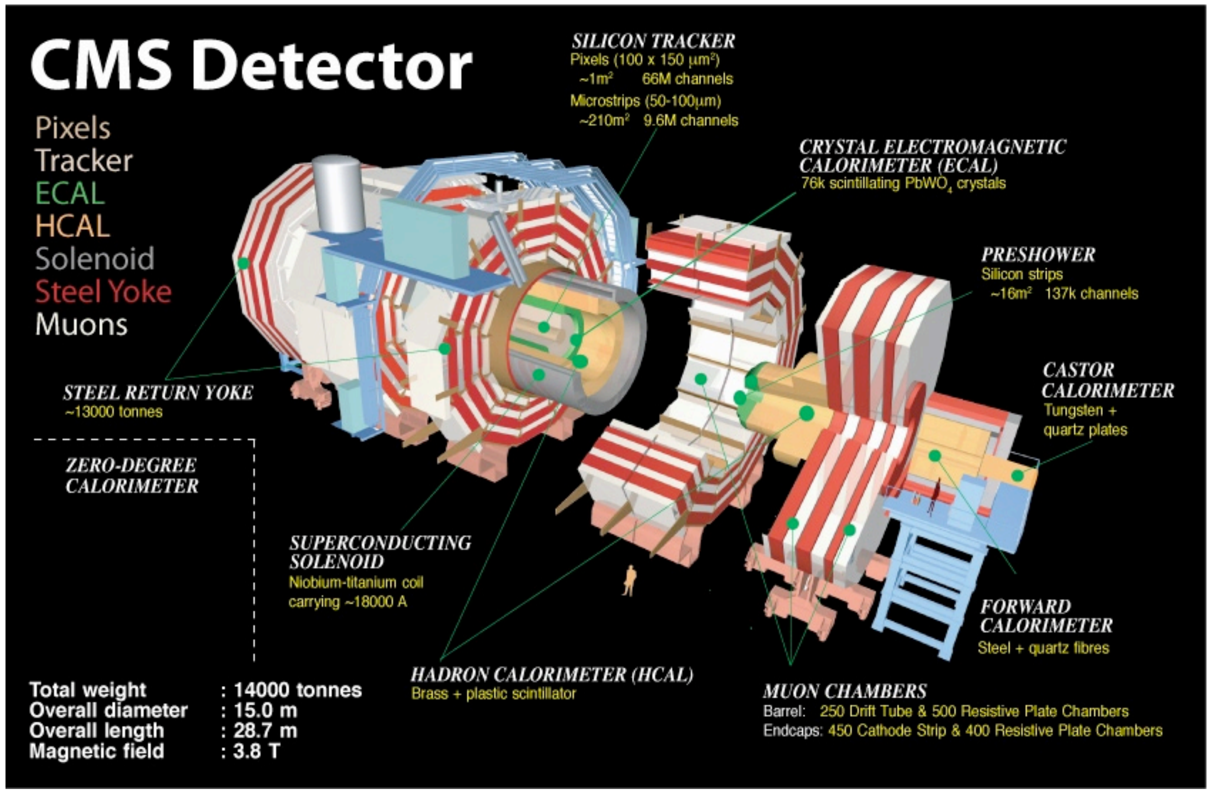
The CMS detector

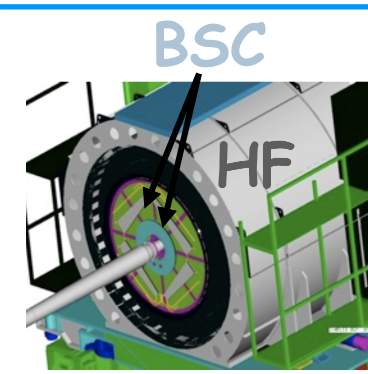


Forward detectors @ CMS



CASTOR & ZDC not used in results presented in this talk





Hadron Forward:

@11.2m from interaction point

Rapidity coverage: 3 < |η| < 5

Steel absorbers/quartz fibers (Long+short fibers)

0.175x0.175 η/φ segmentation

Acceptance limited to |η| < 4.9 at analysis level

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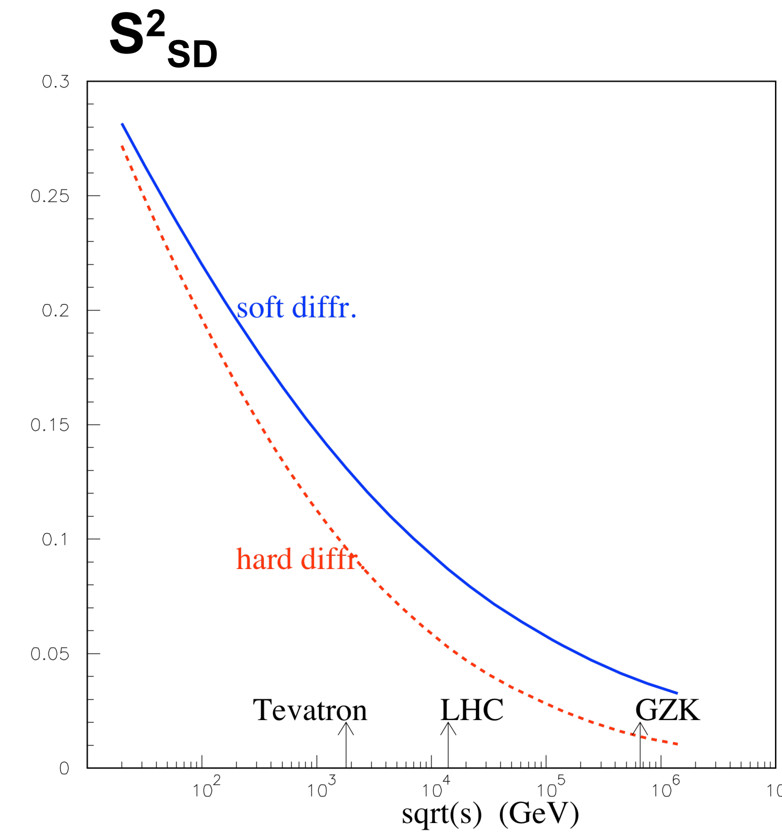
Probing hard diffraction

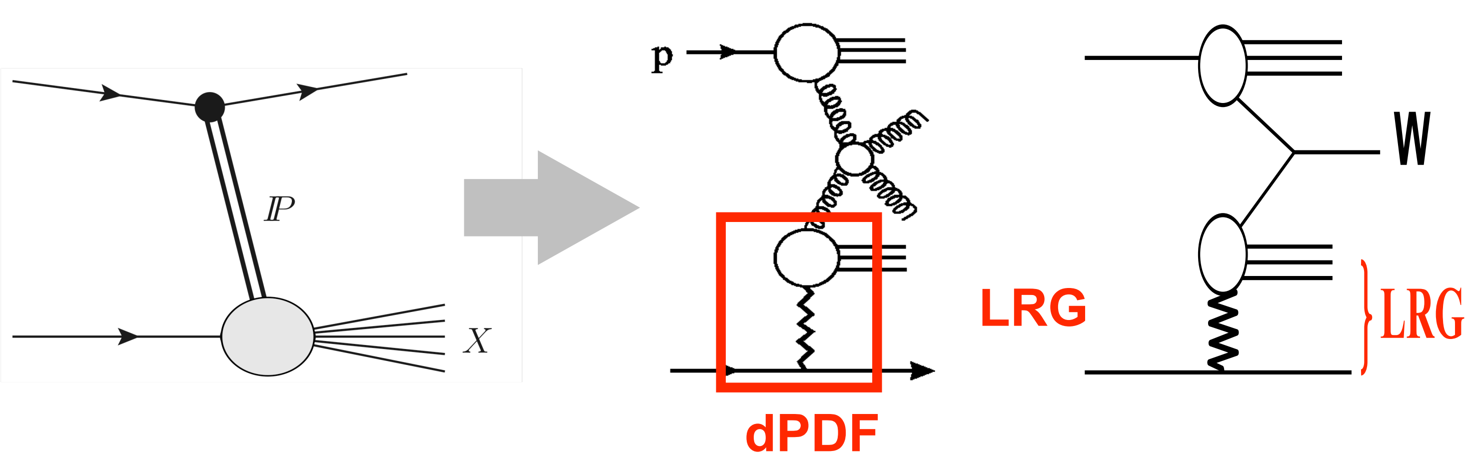
Diffractive events where a hard scale is present: high-p_T jets, W/Z's, ...

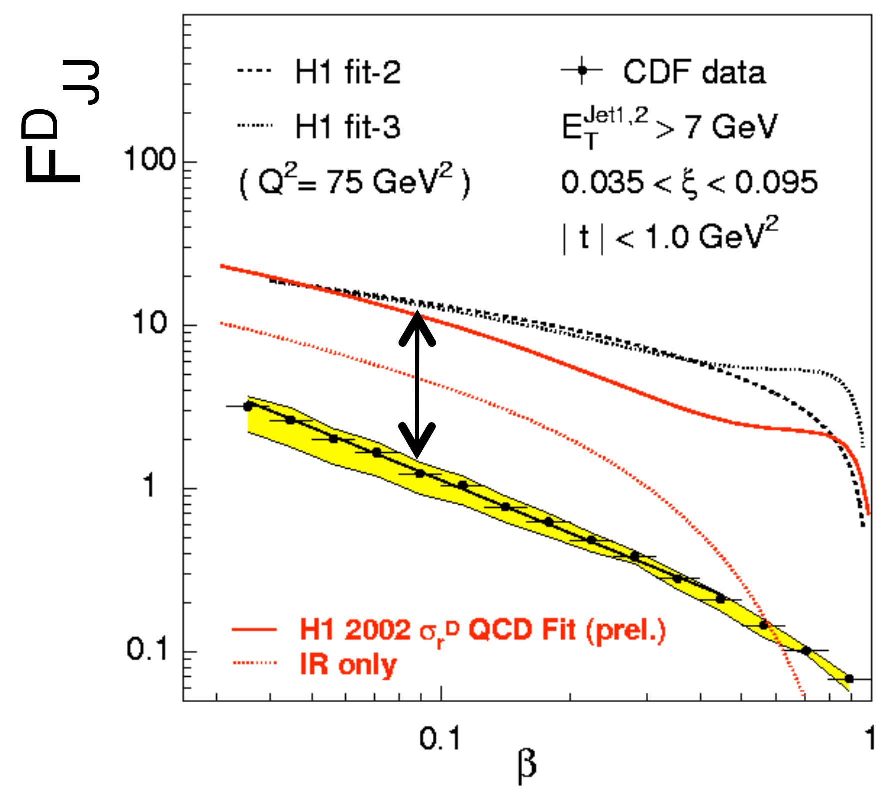
Extension of HERA/Tevatron studies on diffractive PDF's (dPDF), rapidity gap survival probability ($<S^2>$) & exclusive processes

Set the framework for future searches with proton tagging at high(er) luminosity



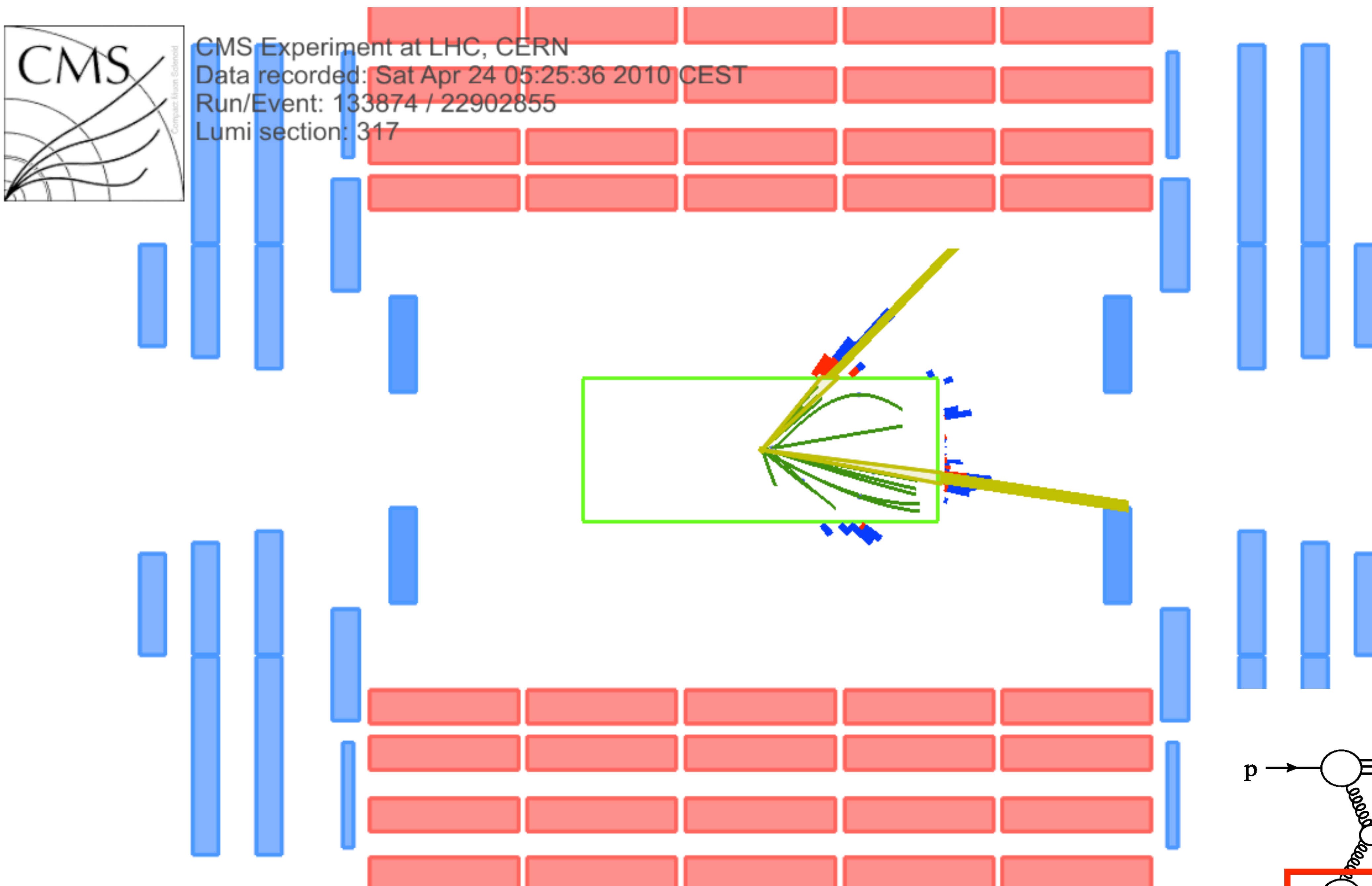
V.A.Khoze et al, Phys. Lett. B 643 (2006)

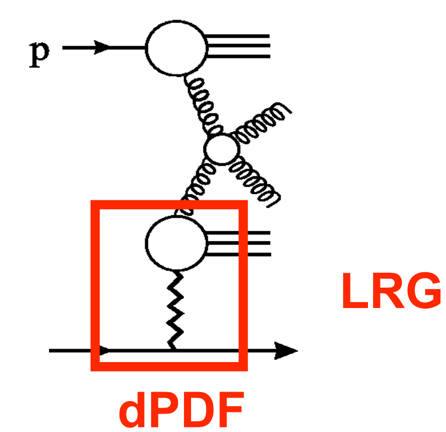




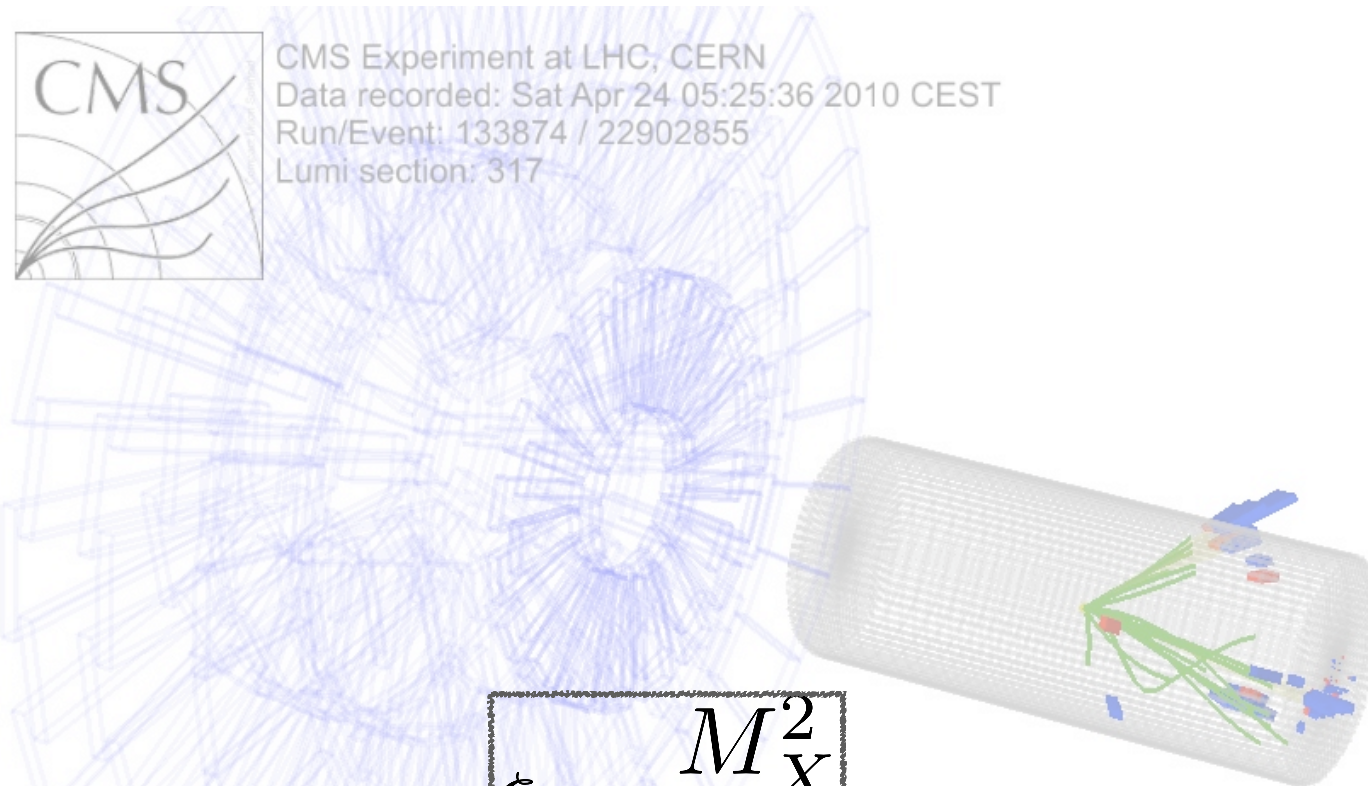
CDF Collaboration, Phys. Rev. Lett. 84, 5043 (2000)

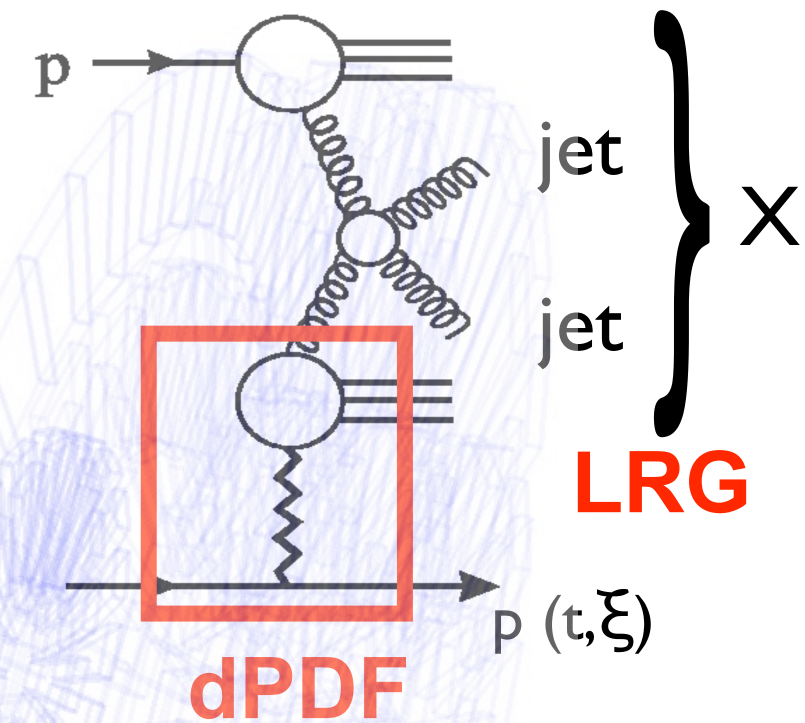
Diffractive dijet candidate





Kinematics & cross section





$$\xi = \frac{M_X^2}{s}$$

diffractive pdf:
"pomeron" flux ⊗ pdf

partonic cross section

$$\frac{d^2\sigma}{d\xi dt} = \sum \int dx_1 dx_2 \, f(\xi, t)\, f_{I\!P}(x_1, \mu)\, f_p(x_2, \mu)\, \hat{\sigma}$$

proton pdf

$$f(\xi, t) = \frac{e^{Bt}}{\xi^{2\alpha_{I\!P}(t)-1}}$$

Implemented in "hard-diffractive" MC's:
POMPYT, POMWIG, PYTHIA8, etc.

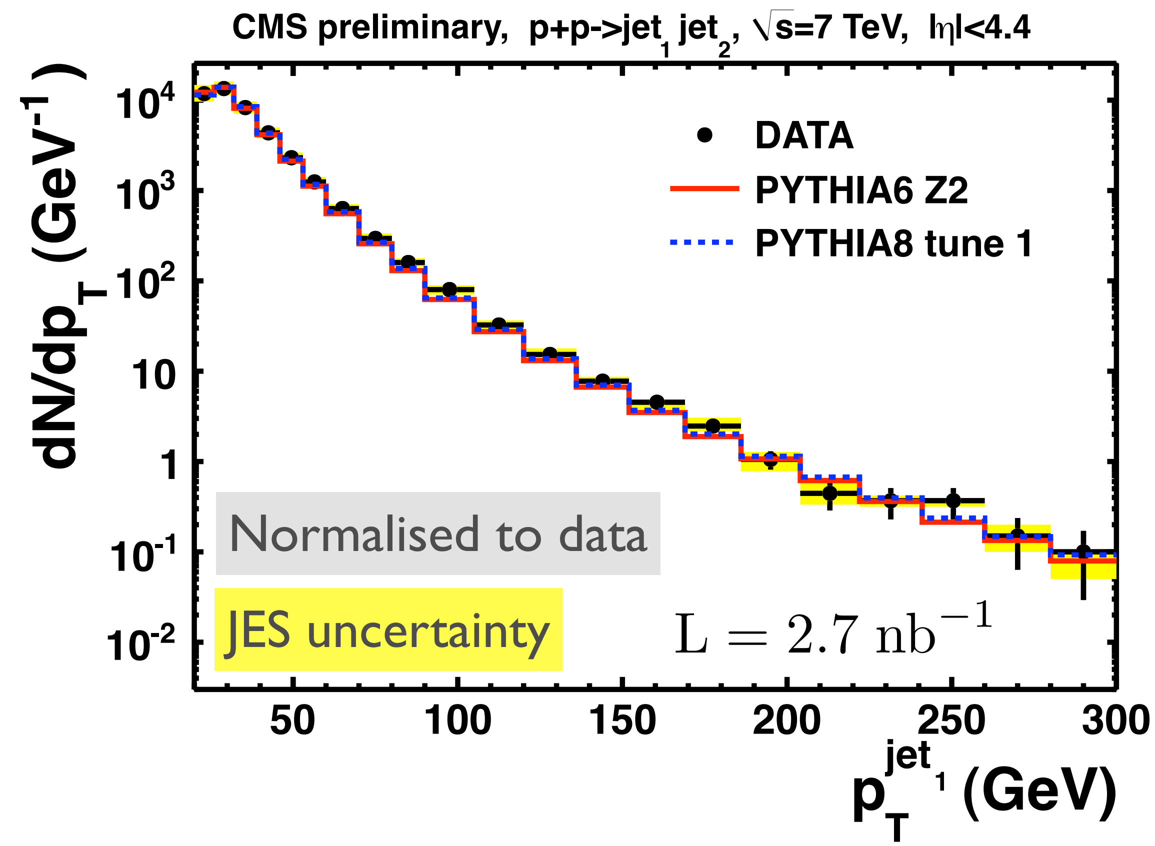
Event selection

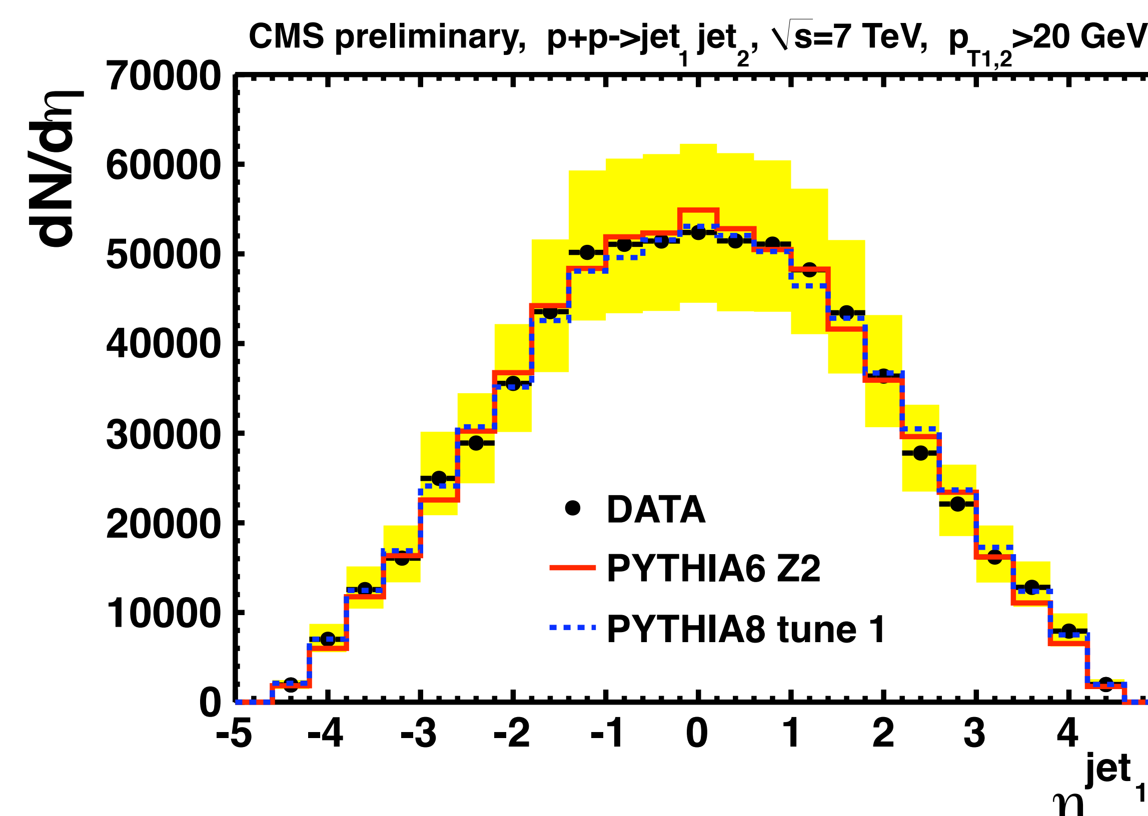
Low-p_T trigger at 6 GeV (uncorrected)

High quality vertex + beam background and noise rejection

At least two jets with $p_T > 20$ GeV and within $-4.4 < \eta < 4.4$

$\eta_{max(min)}$: most forward (backward) particle in the detector

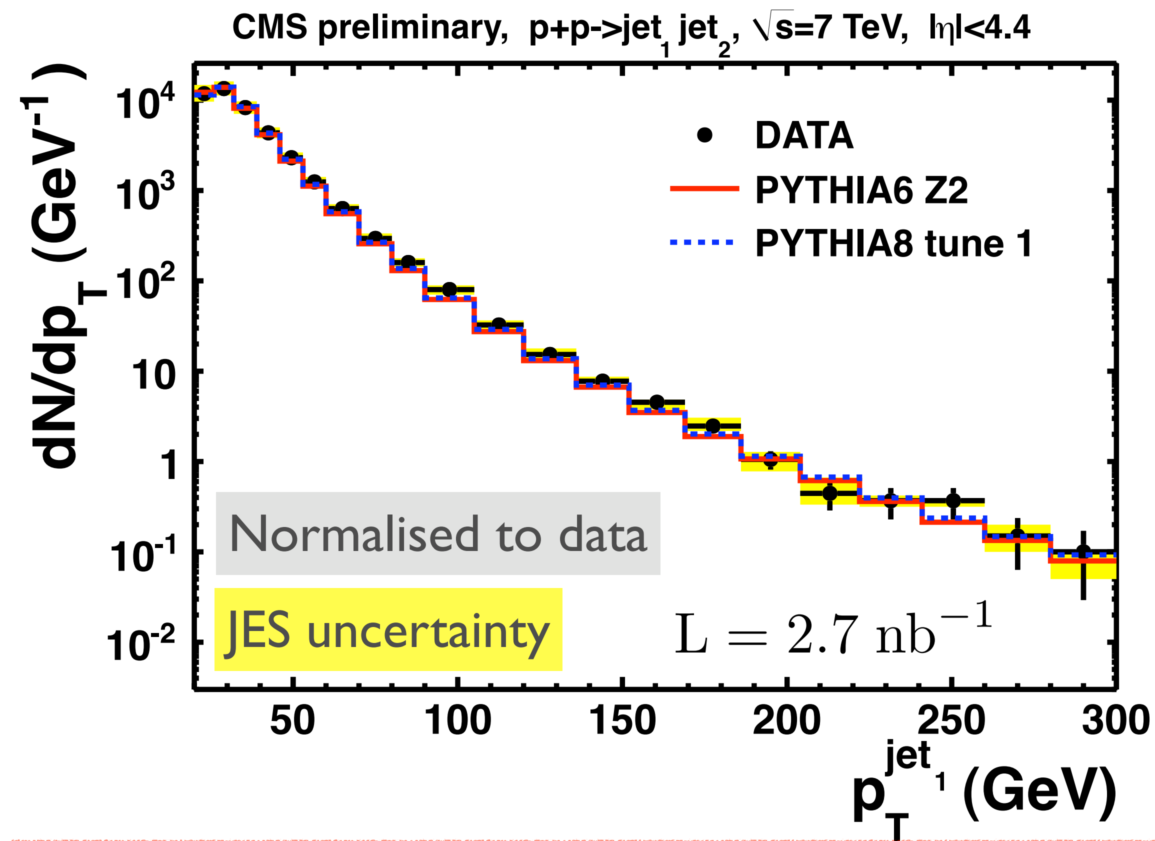




CMS PAS FWD-10-004

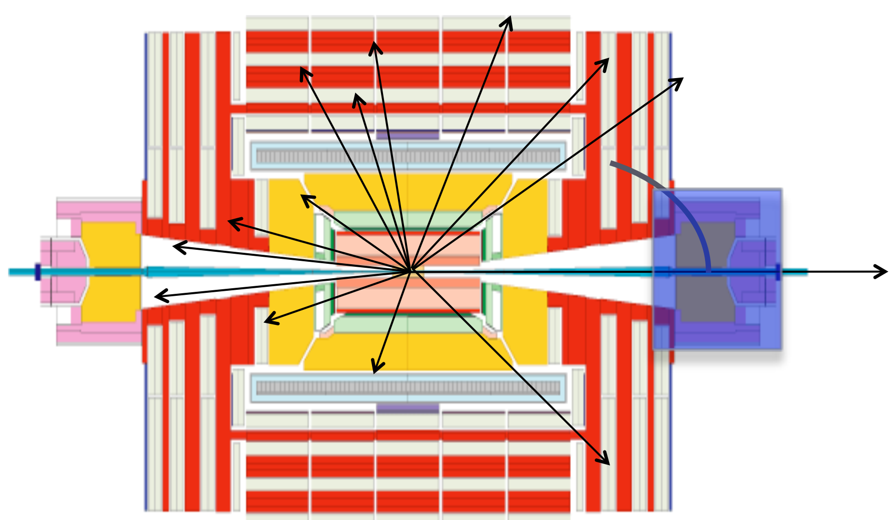
Event selection

- Low-p_T trigger at 6 GeV (uncorrected)
- High quality vertex + beam background and noise rejection
- At least two jets with p_T > 20 GeV and within $-4.4 < \eta < 4.4$
- $\eta_{max(min)}$: most forward (backward) particle in the detector

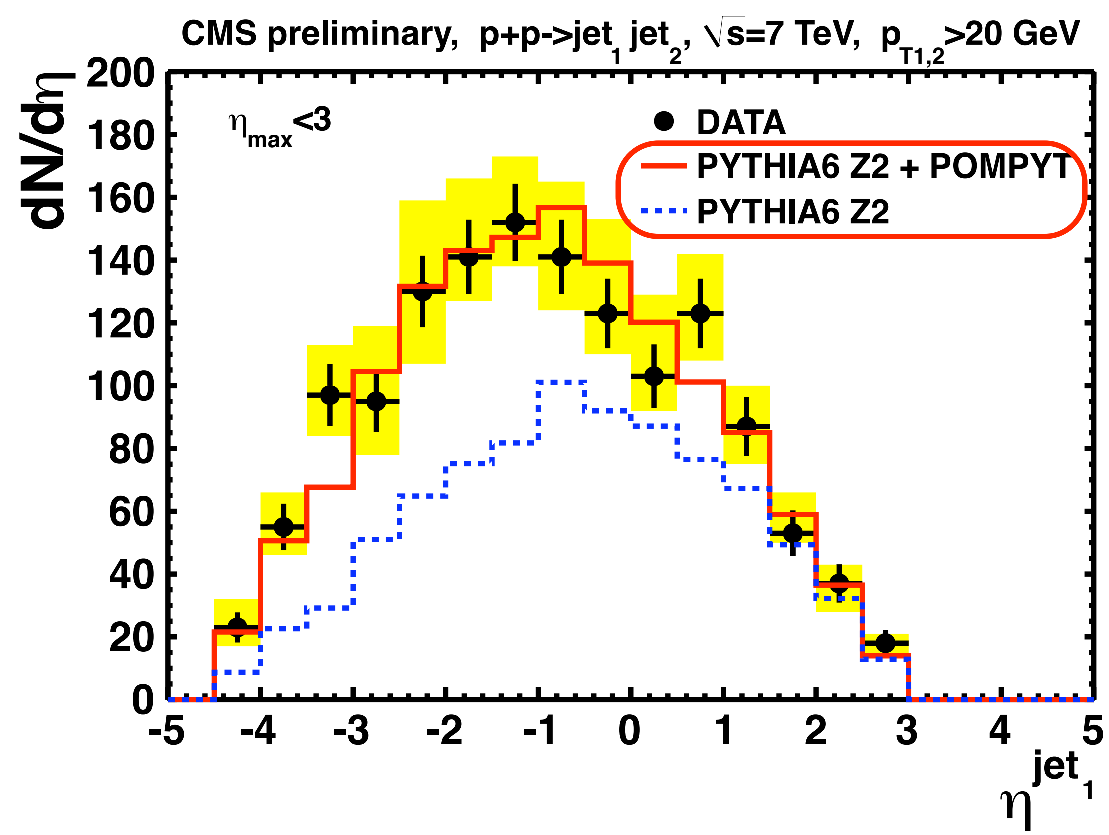


CMS PAS FWD-10-004

Forward η-gap selection



Selection comprising Δη ~ 1.9 in forward calorimeter (HF) acceptance



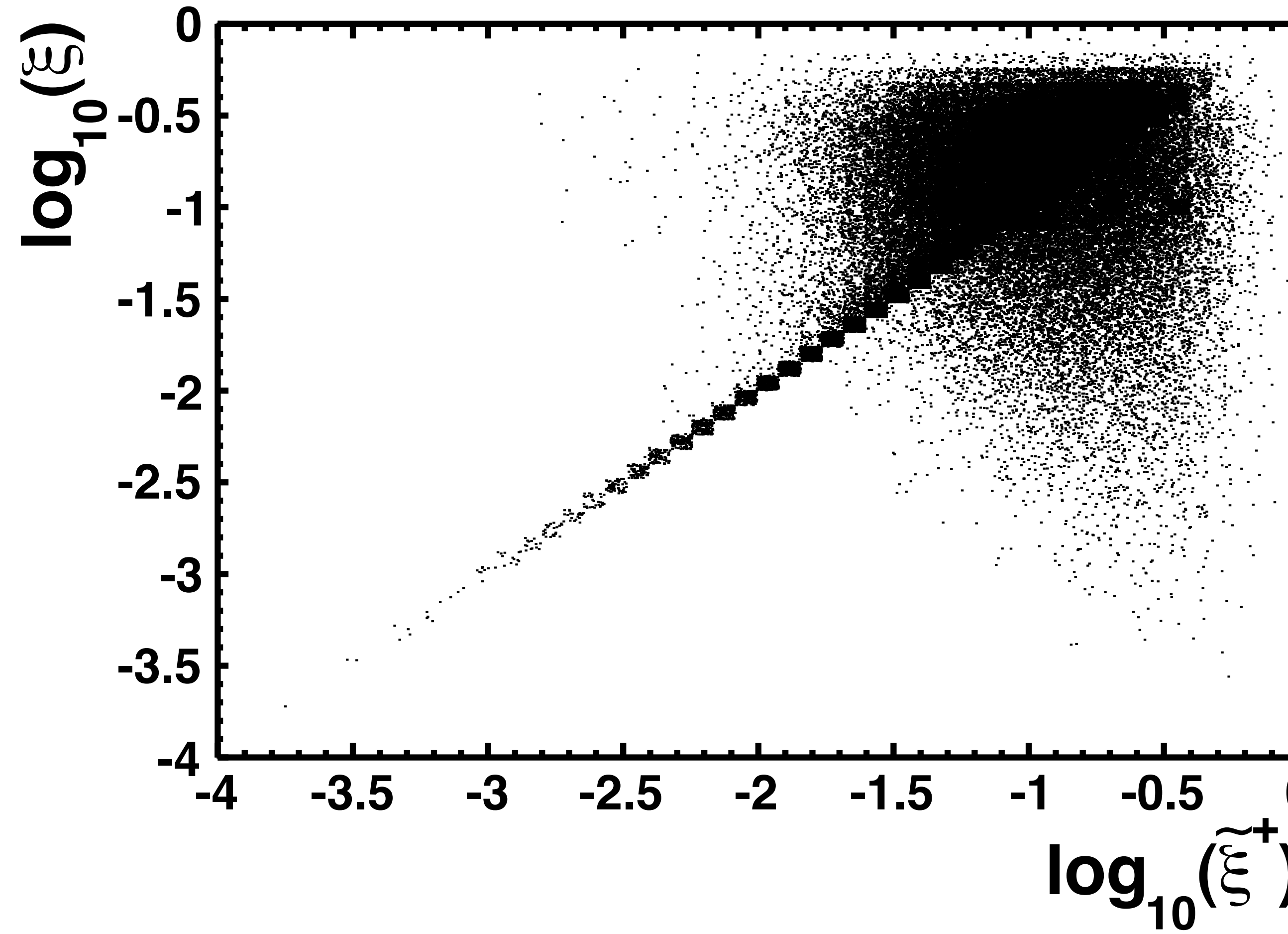
Normalised to fit of PYTHIA6 + POMPYT

ξ definition

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

$$\tilde{\xi}^+ = \frac{\sum (E + p_z)}{\sqrt{s}} \approx \frac{M_X^2}{s}$$

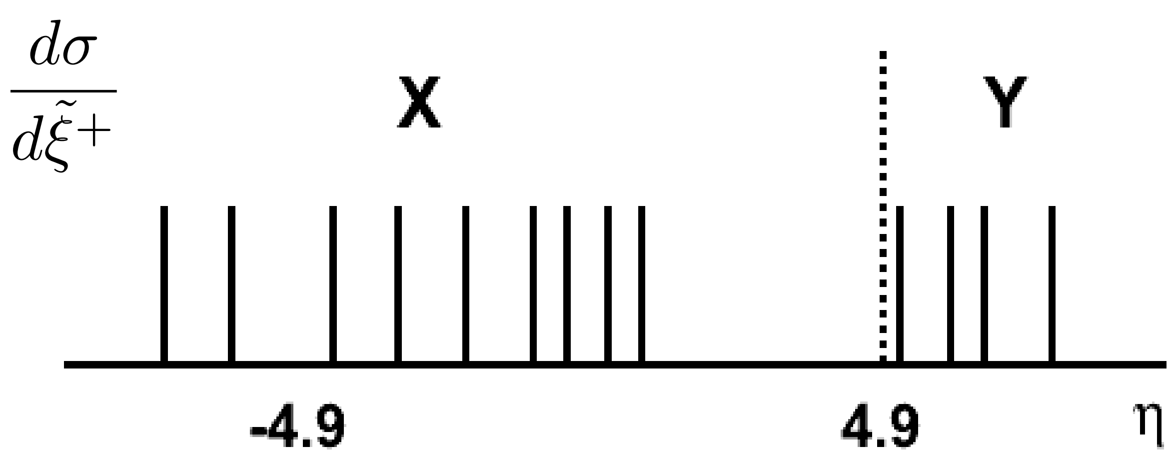
$$\tilde{\xi}^- = \frac{\sum (E - p_z)}{\sqrt{s}} \approx \frac{M_X^2}{s}$$



Defnition converges to "true" ξ (M_X^2/s) for SD events in low-ξ region

System X defined in acceptance region of CMS

System Y is undetected (M_Y mostly below ~ 12 GeV)



At reconstruction level, ξ is defined from all particles (using a particle-flow algorithm) above threshold, and a scale correction factor (resolution ~25%):

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

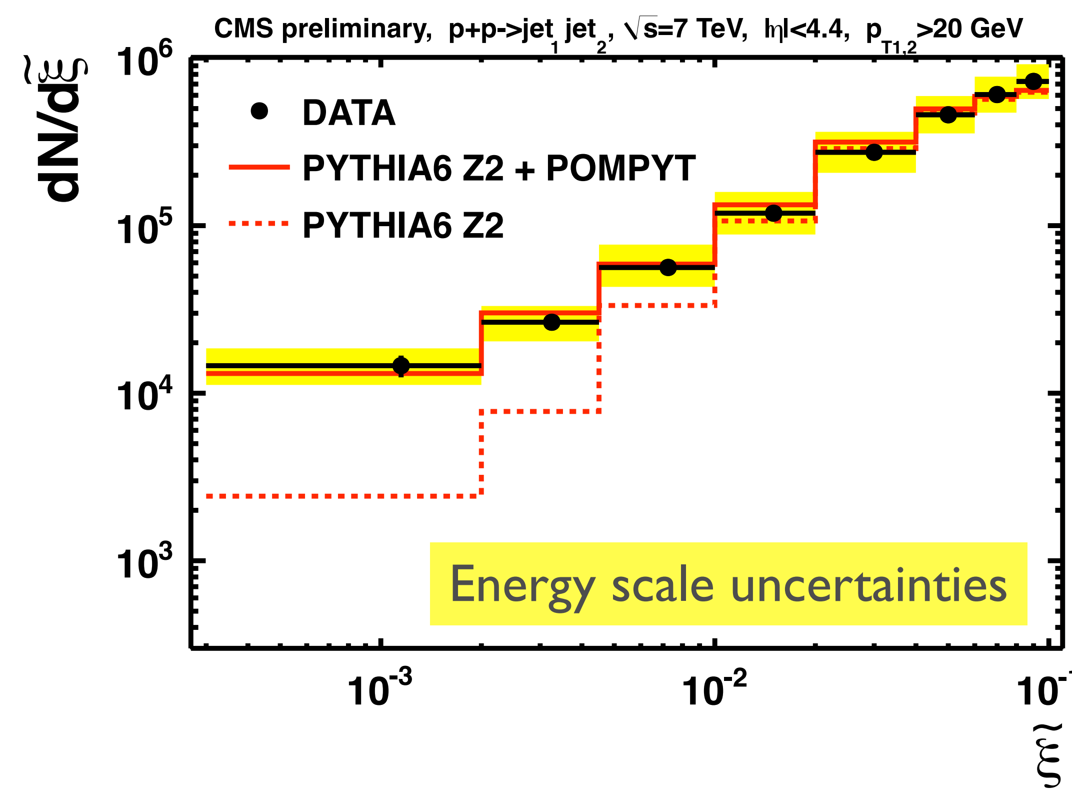
CMS PAS FWD-10-004

Event distributions

Distributions are obtained as a function of ξ^+ and ξ^-, and averaged

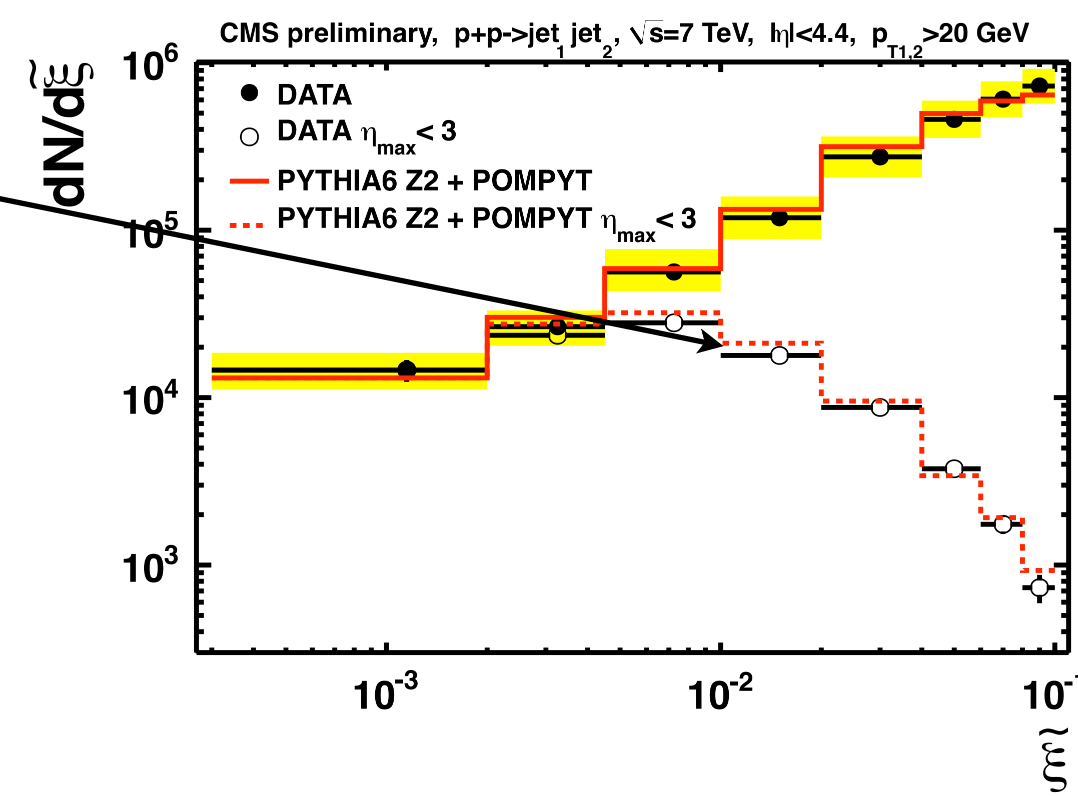
A combination of PYTHIA6 (Tune Z2) and POMPYT is used to describe the data, where their relative contributions are obtained from a fit to the ξ distribution

Note that different MC tunes would imply considerable variations in relative yields



Suppression of events with high ξ values after $\eta_{max} < 3$ (or $\eta_{min} > -3$) selection, while low-ξ region is mostly unaffected

Results in three ξ bins: (0.0003,0.002); (0.002,0.0045); (0.0045,0.01)



CMS PAS FWD-10-004

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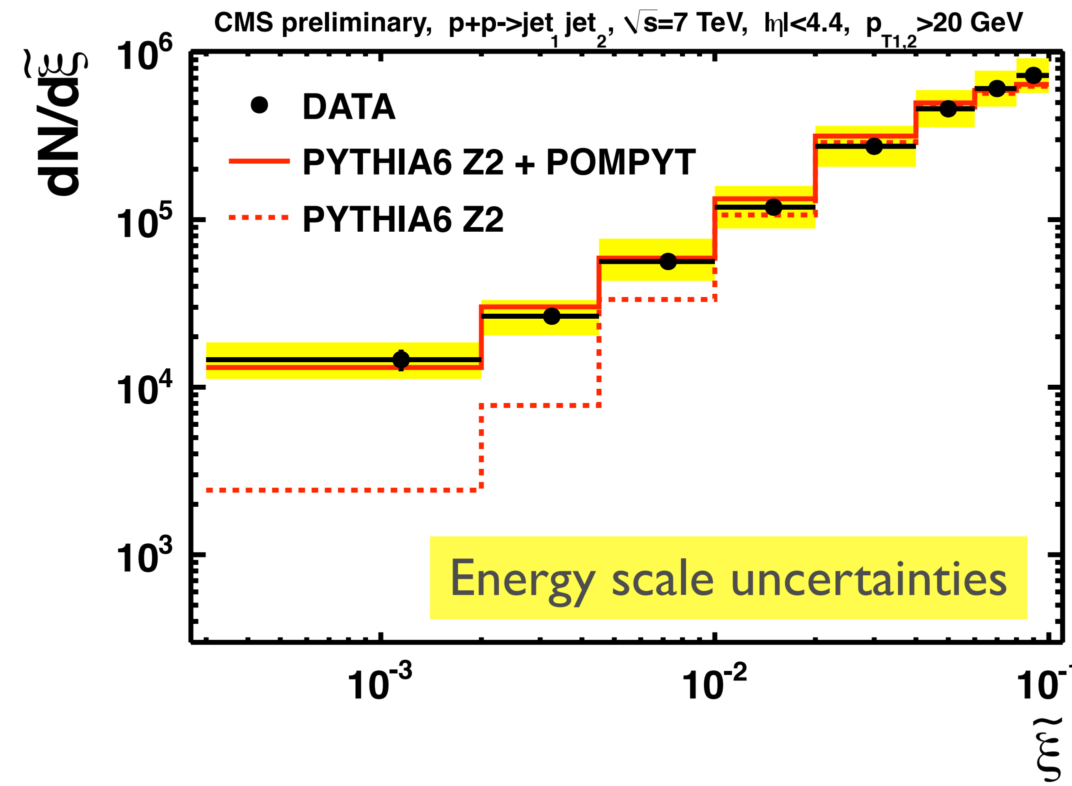

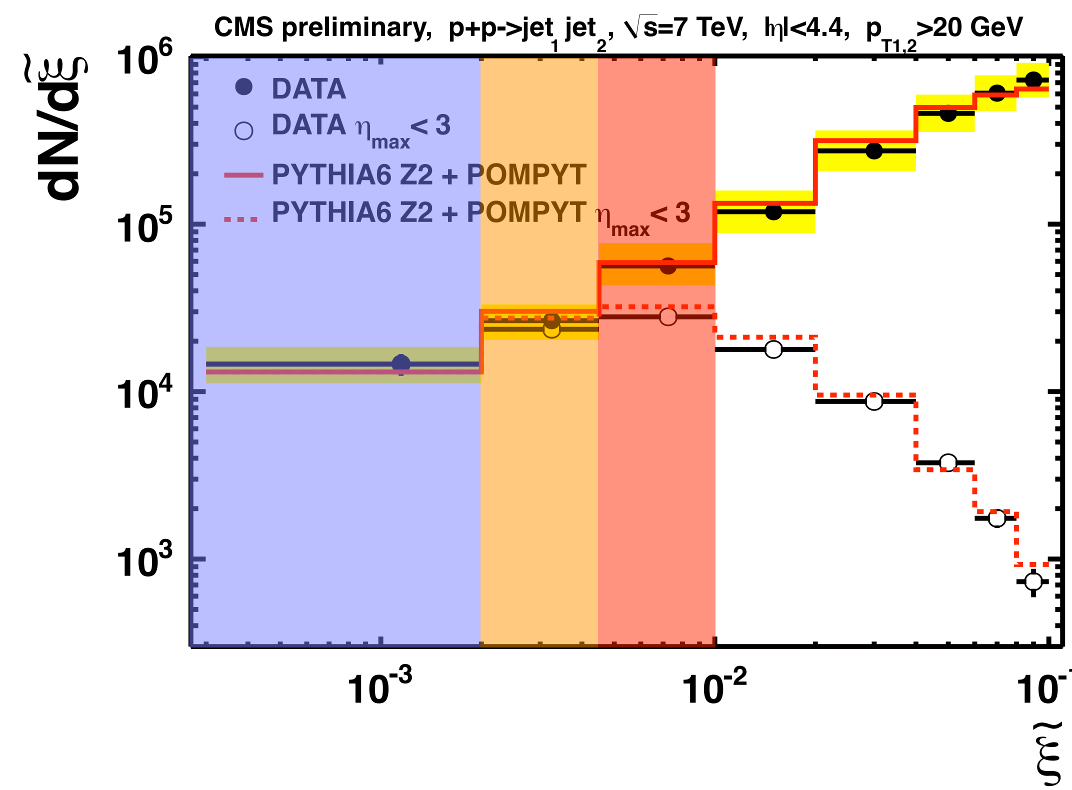

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Dijet cross sections

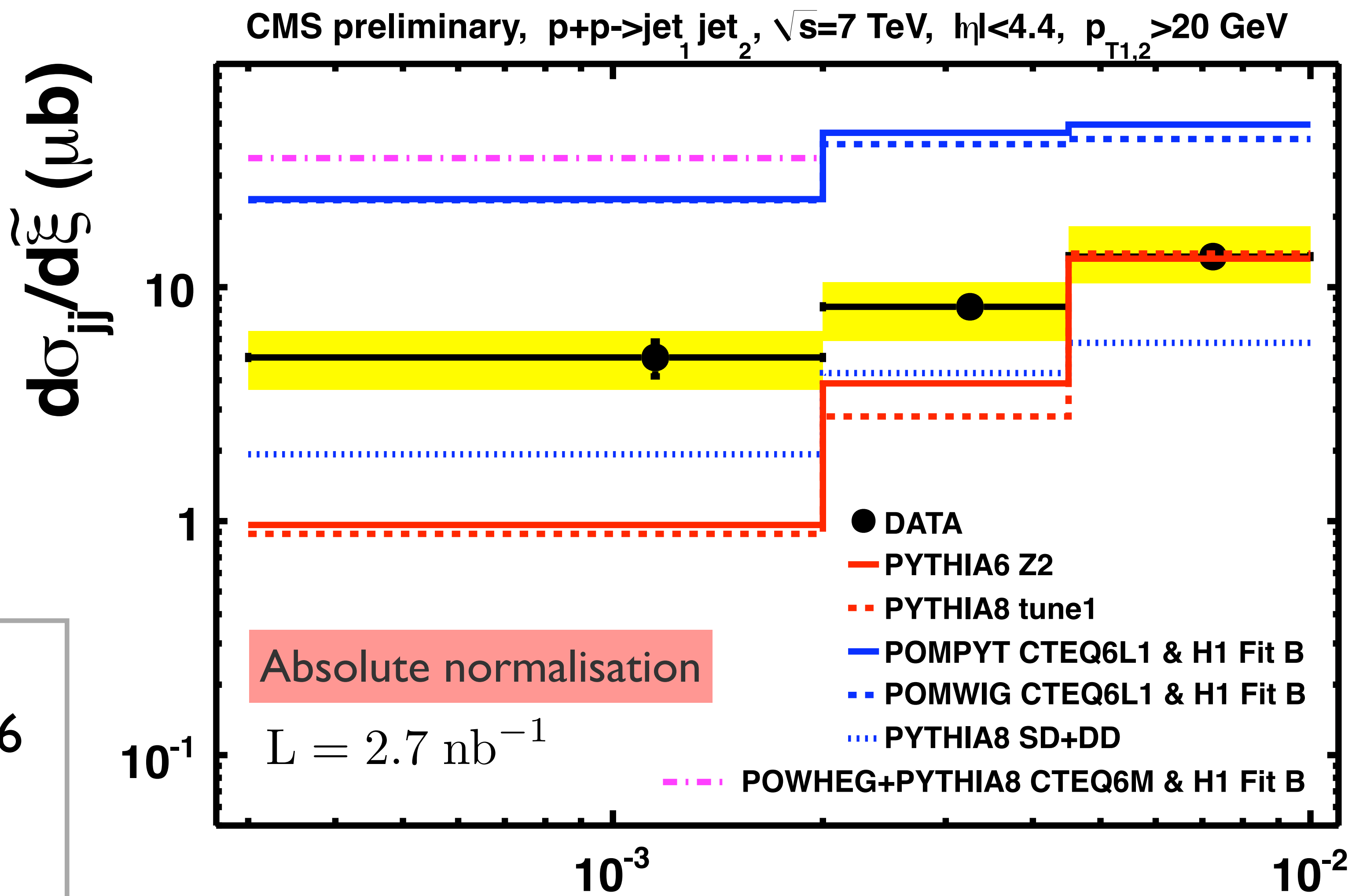
$$\frac{d\sigma_{\text{jj}}}{d\tilde{\xi}} = \frac{N^i_{\text{jj}}}{L \cdot \epsilon \cdot A^i \cdot \Delta\tilde{\xi}^i}$$

$$A^i_{\text{MC}} = \frac{N^i(\tilde{\xi}_{\text{Rec}})}{N^i(\tilde{\xi}_{\text{Gen}})}$$

Excess of events in low-ξ region with respect to non-diffractive MC's PYTHIA6 and PYTHIA8

POMPYT and POMWIG (LO) diffractive MC's as well as the NLO calculation from POWHEG, using diffractive PDFs, are a factor ~5 above the data in lowest ξ bin

PYTHIA8 diffractive cross sections are considerably lower due to different pomeron flux parametrisation



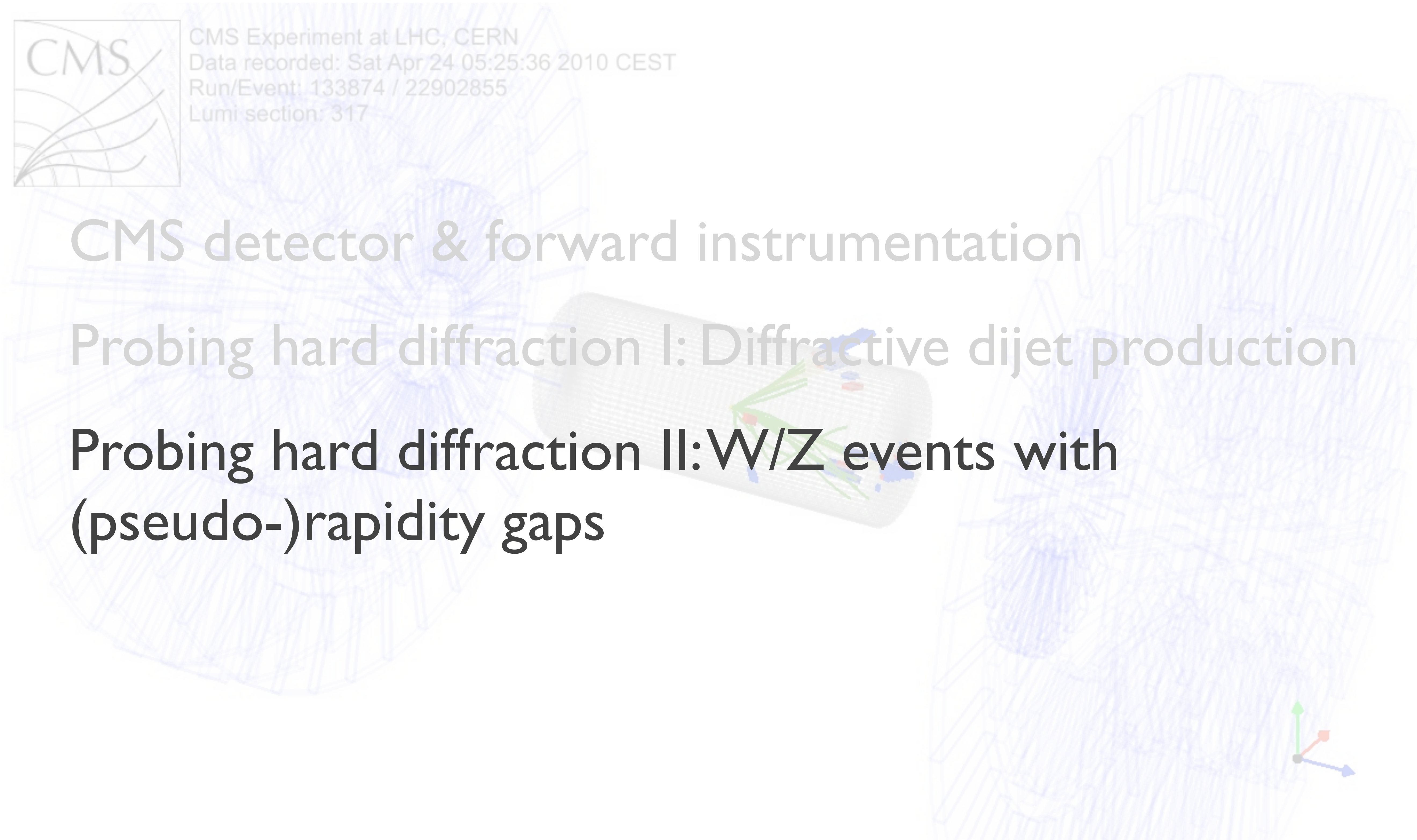
Normalisation discrepancies give upper limit predictions (including proton dissociation) to rapidity gap survival probability:

$$S^2_{\text{data/MC}} = 0.21 \pm 0.07\ (\text{LO MC})$$

$$S^2_{\text{data/MC}} = 0.14 \pm 0.05\ (\text{NLO MC})$$

CMS PAS FWD-10-004

Outline



- CMS detector & forward instrumentation
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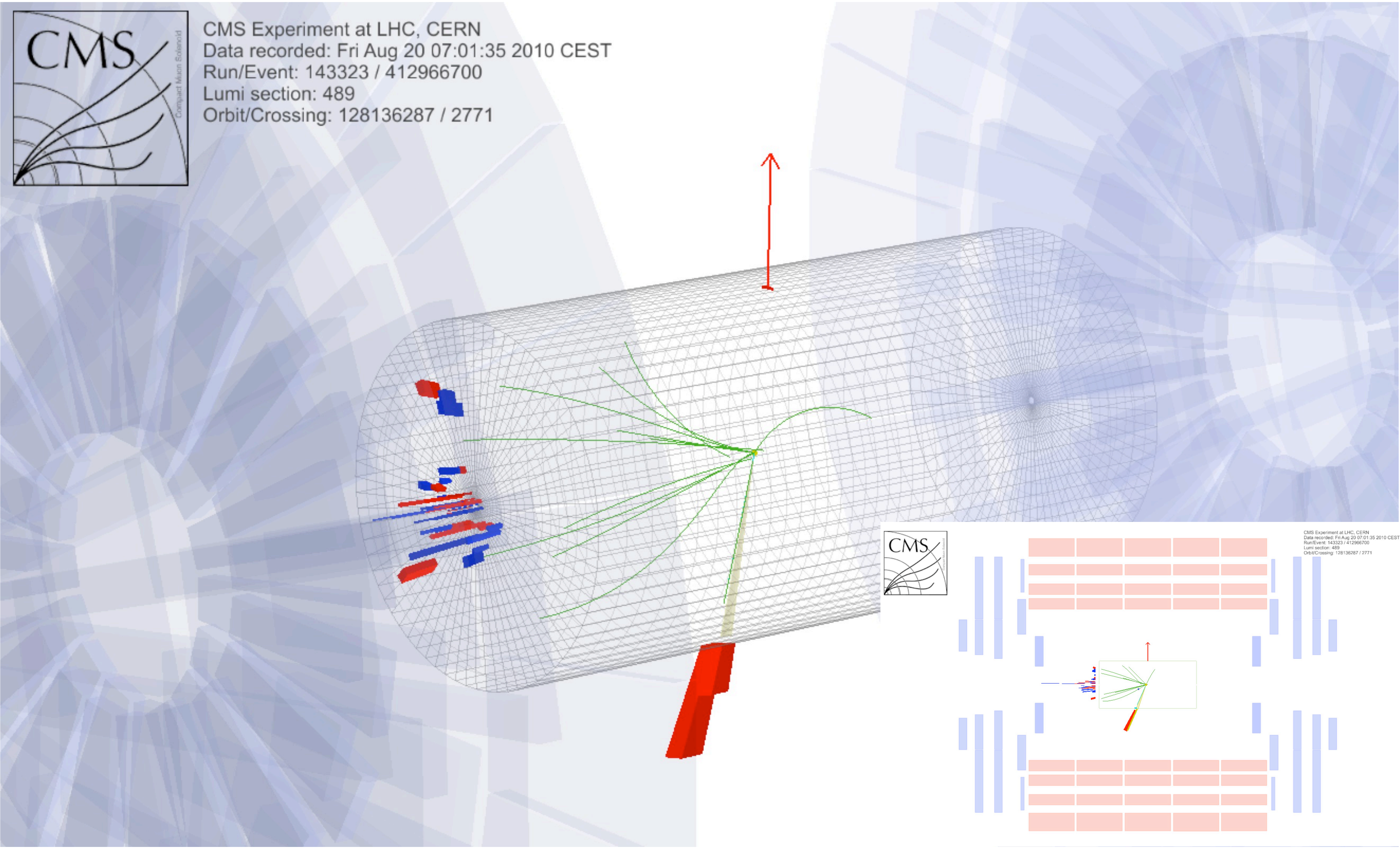
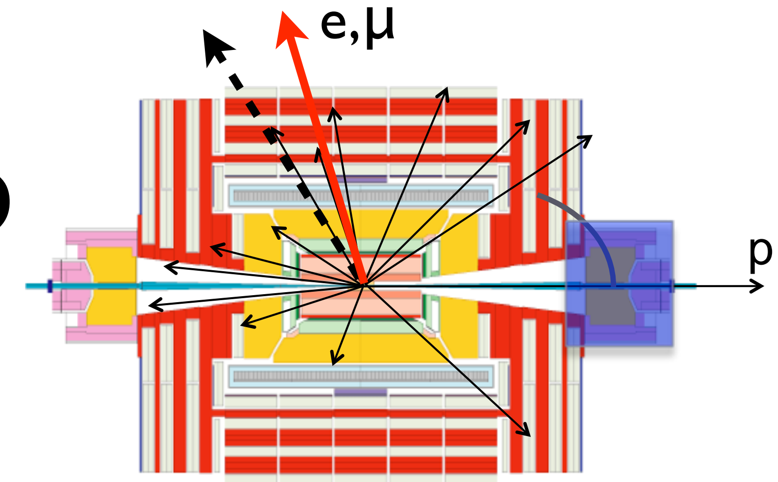
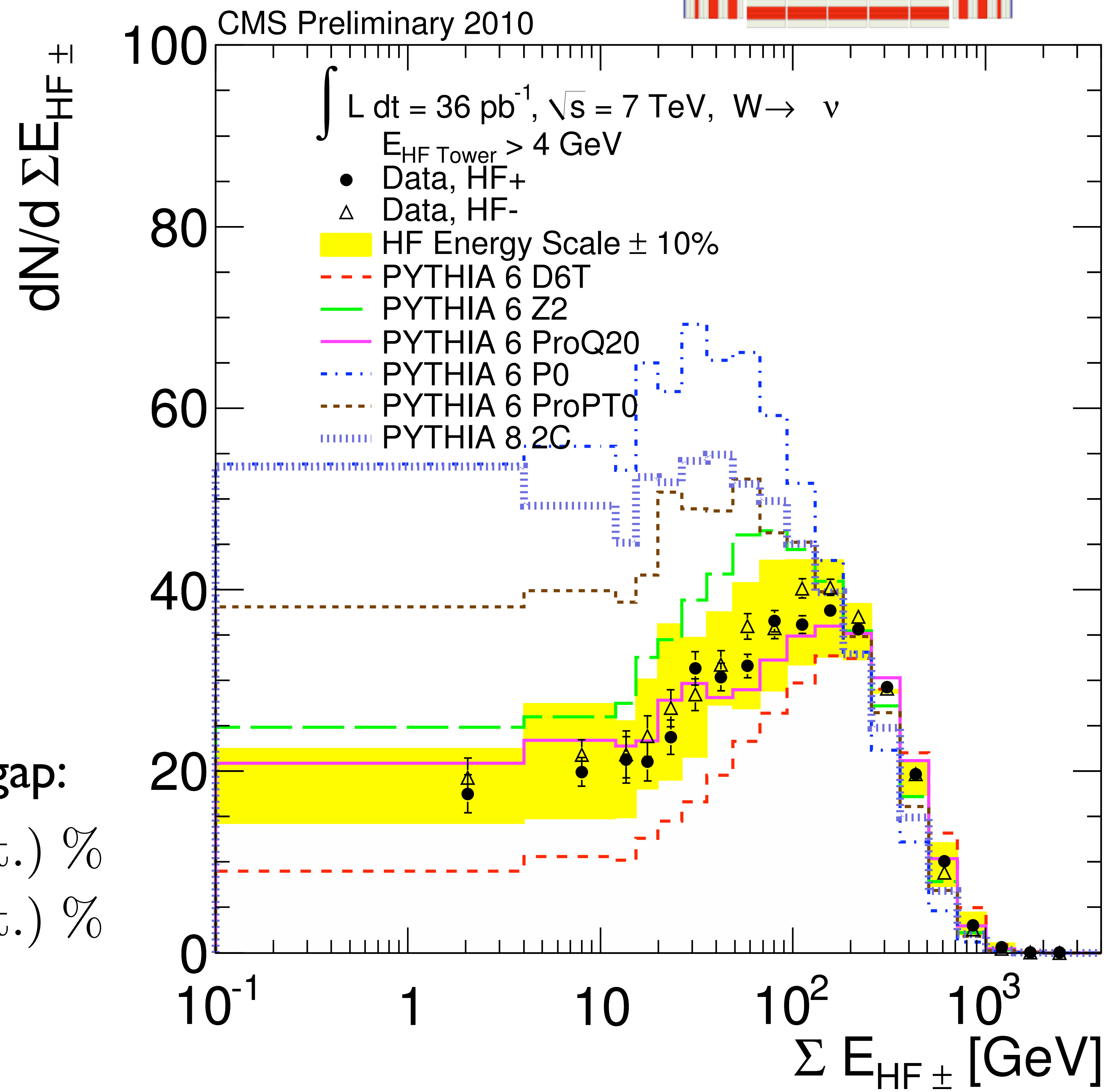
W/Z events with pseudorapidity gaps



W/Z events with an η-gap



- Diffractive component in W/Z data set
- Events with low energy deposits at the forward calorimeters
- Monte Carlo generators cannot describe the data (extensive studies on overall energy flow and correlations in supporting document)



Fraction of W/Z events with a forward gap:

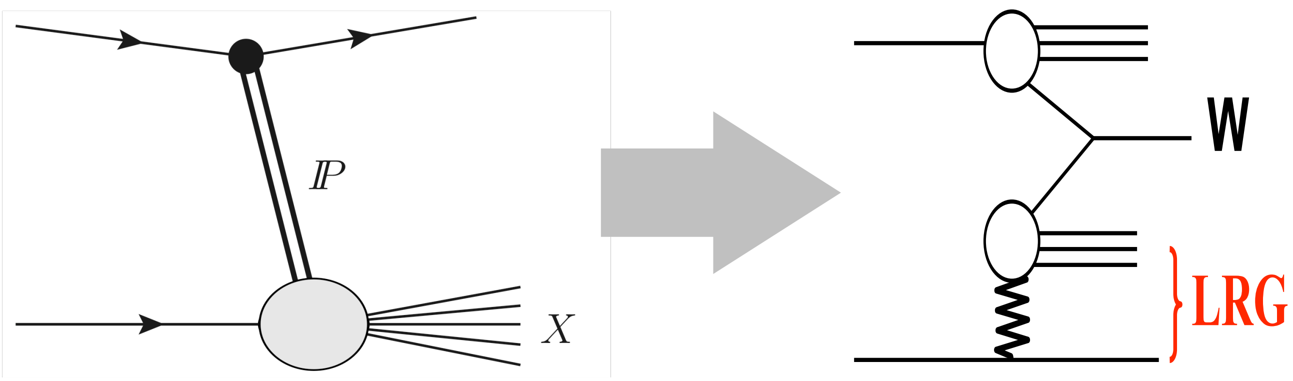
W→lν: $1.46 \pm 0.09(\mathrm{stat.}) \pm 0.38(\mathrm{syst.})\ \%$

Z→ll: $1.60 \pm 0.25(\mathrm{stat.}) \pm 0.42(\mathrm{syst.})\ \%$

CMS PAS FWD-10-008

Eur. Phys. J. C (2012) 72:1839

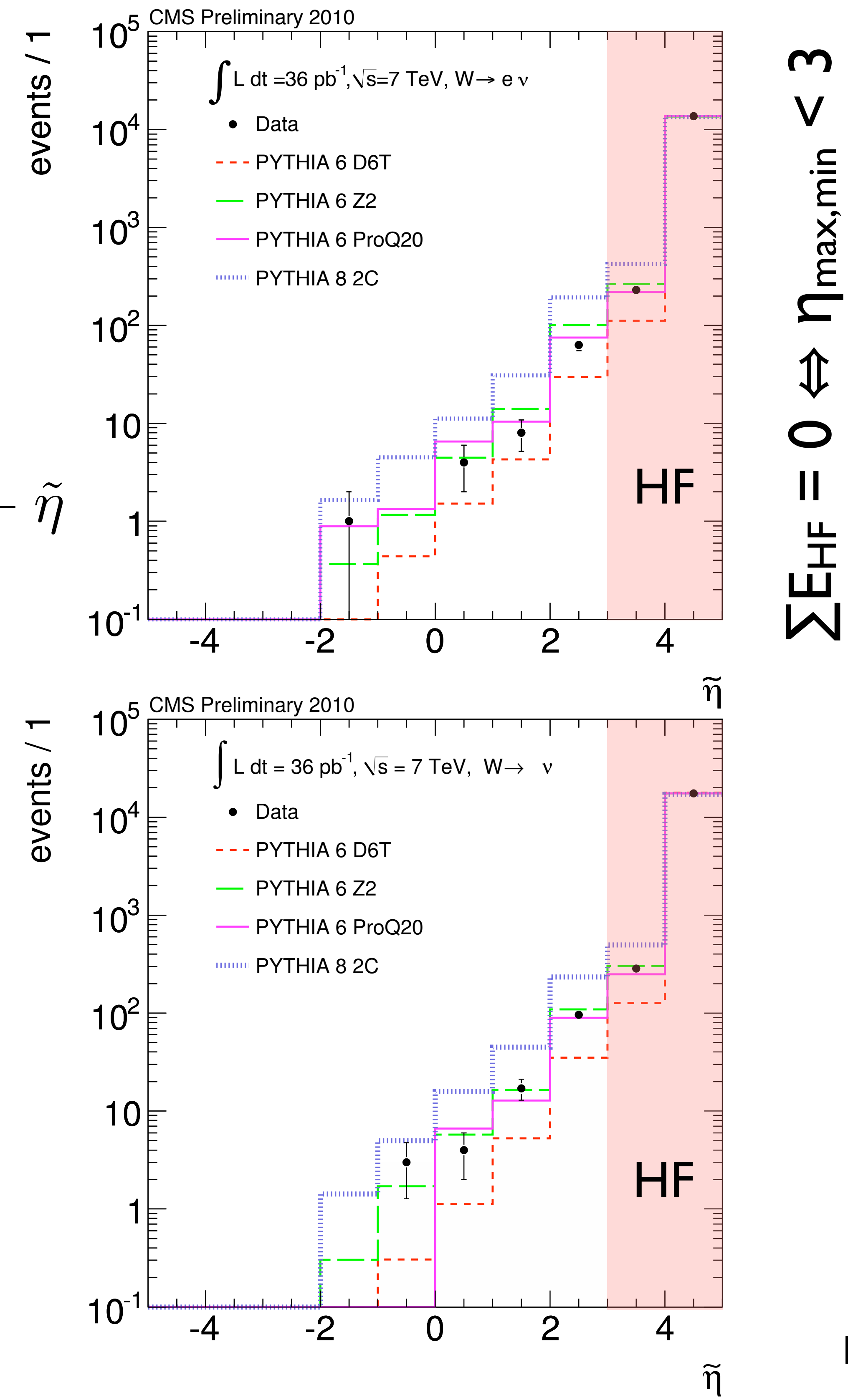
W→eν(μν) gap distributions



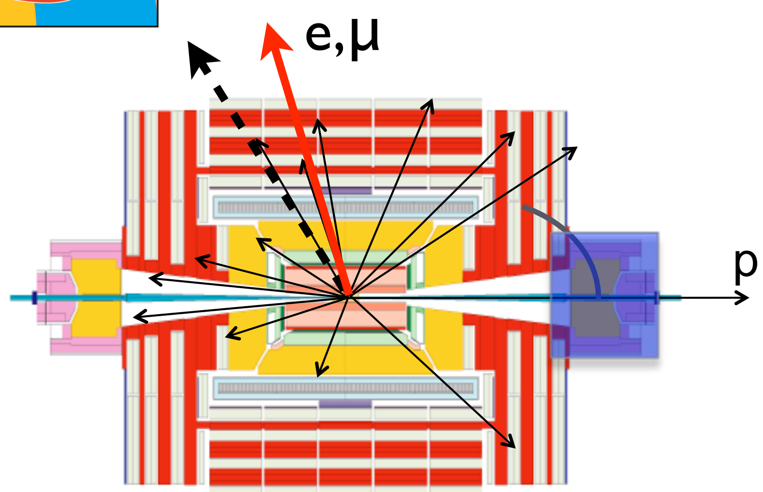
$$\Delta\eta^{\text{Gap}} \equiv 4.9 - \tilde{\eta}$$

- Single-vertex events to reject pile-up
- Gap size (Δη) distributions for W candidate events
- Note that large gap events from non-diffractive MC events as well as data
- Large dependence on MC tune

CMS PAS FWD-10-008

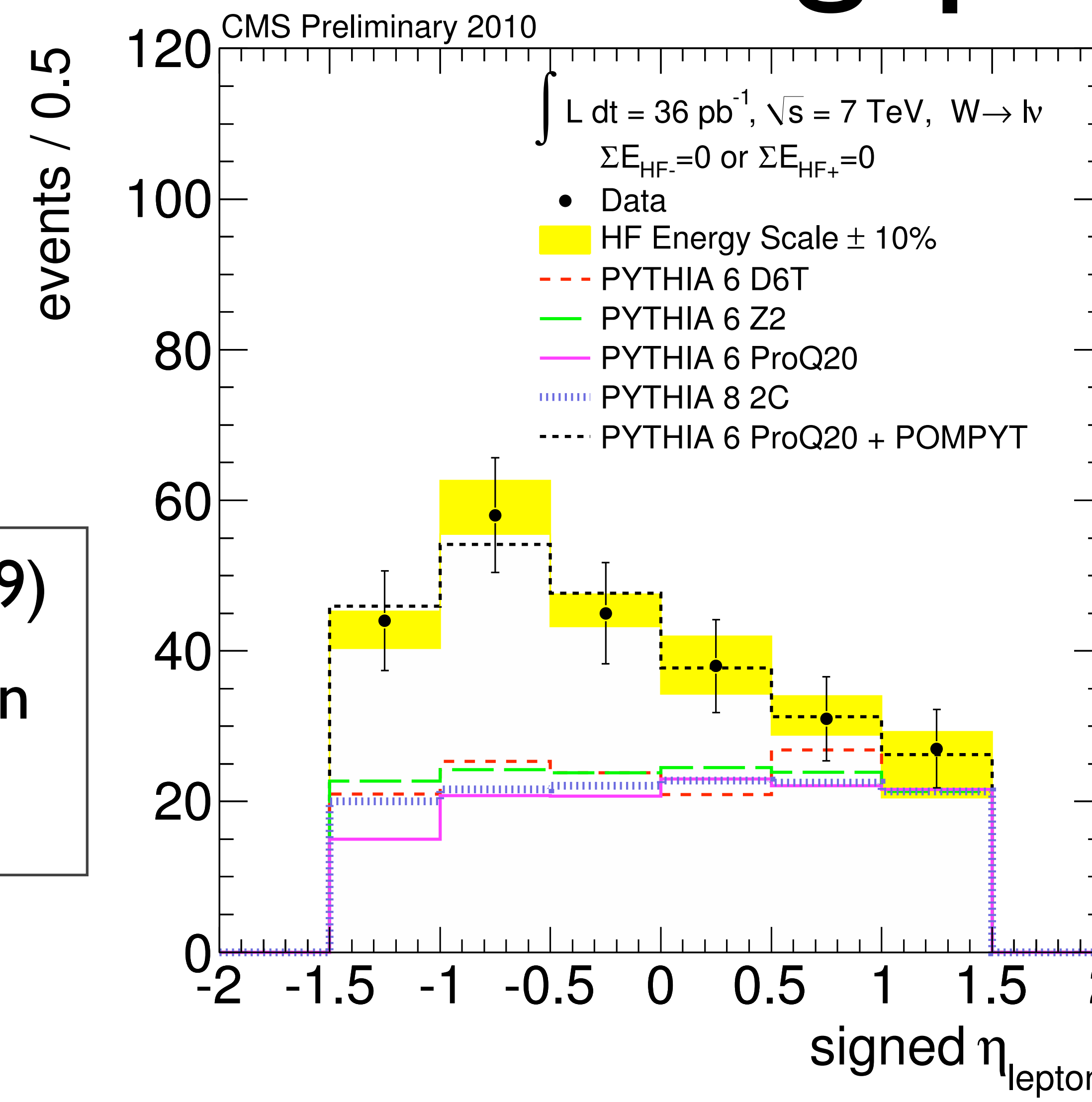


W→eν(μν) events with a gap



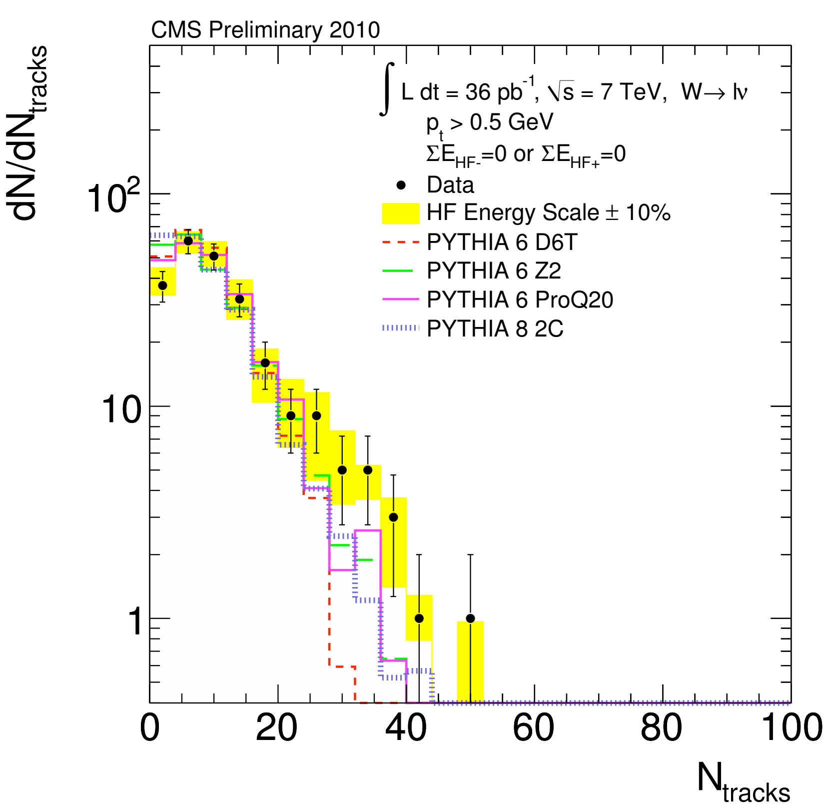
Forward gap selection in HF (3 < |η| < 4.9)

Signed η_{lepton} distribution (η_{lepton} < 0 when e,μ opposite to the pseudorapidity gap)



Normalised to fit of PYTHIA6 + POMPYT

CMS PAS FWD-10-008



Flat for non-diffractive, asymmetric for diffractive events

Evidence of diffractive W production in the data

Fit for PYTHIA (ND) + POMPYT (SD):

$$f_{\mathrm{SD}} = 50.0 \pm 9.3(\mathrm{stat.}) \pm 5.2(\mathrm{syst.})\ \%$$

(η-gap sample)

Summary

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

The differential dijet cross section has been measured, as a function of a variable (ξ) that approximates the momentum loss of protons in diffractive events

Diffractive dijet events dominate the low-ξ region. Comparing the measured cross section to diffractive MC predictions based on dPDFs from HERA, an estimate of the survival probability was obtained

A large asymmetry is observed with the charged lepton in the opposite or same hemisphere as the pseudorapidity gap signature, in a W/Z data set, consistent with diffractive W/Z production

These measurements give constraints on hard-diffractive processes at the LHC, diffractive PDFs, and especially estimates of the survival probability. They form a benchmark for future searches in exclusive & diffractive channels with near beam proton detectors at the LHC

Extra slides

Forward physics results at CMS

Low-x QCD & pdf's, diffraction, γ interactions, underlying event & MPI, etc.

Results on these subjects from the CMS collaboration, mostly with the data set collected during 2010

CMS PAS FWD-11-001: **Measurement of the inelastic pp cross section at 7 TeV**
CMS PAS FWD-10-005: **Measurement of the exclusive two-photon production of muon pairs**
CMS PAS FWD-10-001: **Observation of diffraction at 900 and 2360 GeV**
CMS PAS FWD-10-007: **Observation of diffraction at 7 TeV**
CMS PAS FWD-10-008: **Forward Energy Flow and Central Track Multiplicities in W and Z boson Events at 7 TeV (*Eur. Phys. J. C (2012) 72:1839*)**
CMS PAS FWD-10-004: **Evidence for hard-diffractive dijet production at 7 TeV**
CMS PAS FWD-11-004: **Search for central exclusive gamma pair production and observation of central exclusive electron pair production at 7 TeV**
CMS PAS FWD-10-011: **Forward energy flow**
CMS PAS FWD-10-003: **Measurement of forward jets at 7 TeV**
CMS PAS FWD-10-006: **Cross section measurement for simultaneous production of a central and a forward jet at 7 TeV**

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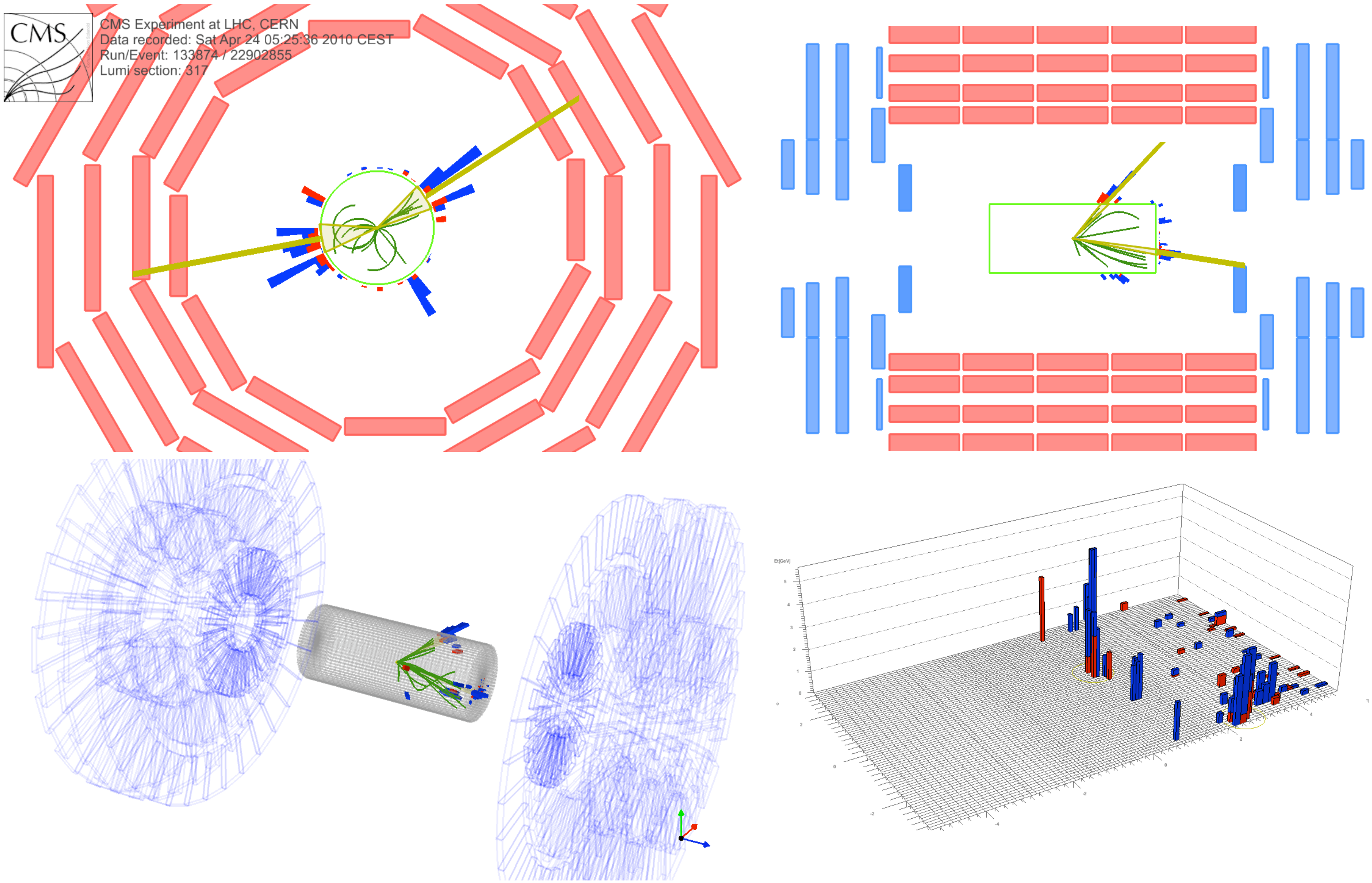
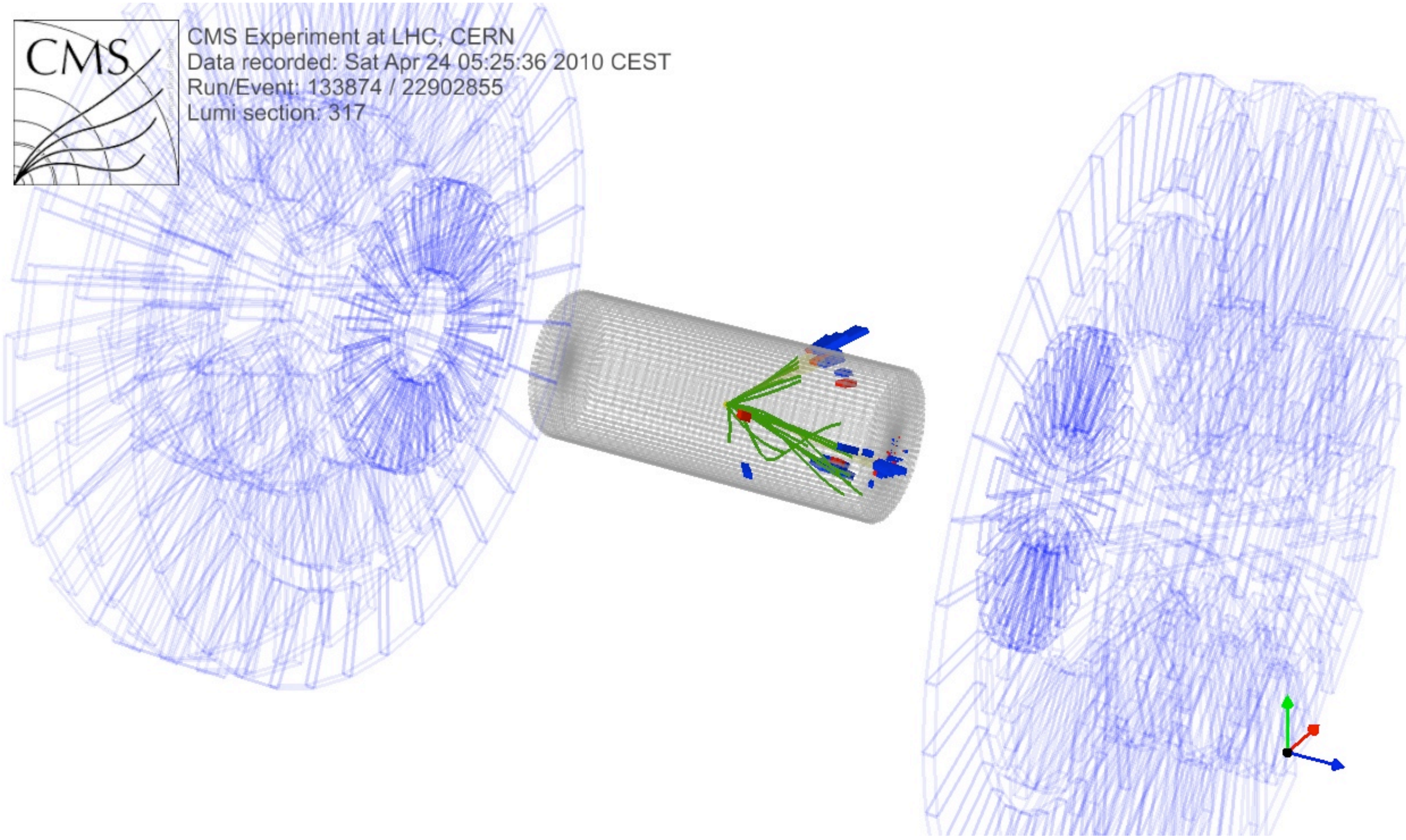
Diffractive dijet candidate



E(η < 3.0) > 1.5 GeV p_T(track) > 0.5 GeV
E(η ≥ 3.0) > 2.0 GeV

p_T (jet1) = 43.5 GeV, p_T (jet2) = 36.9 GeV
η (jet1) = 0.83, η (jet2) = 2.55

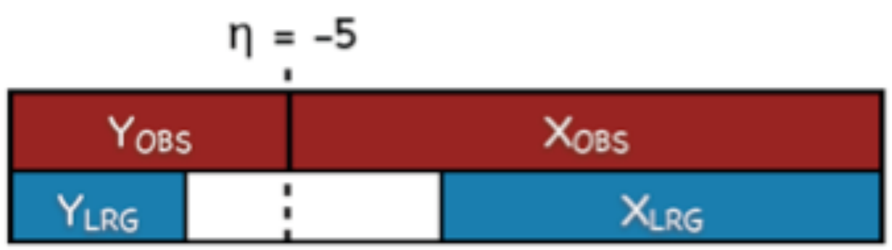
Diffractive dijet candidate



ξ definition

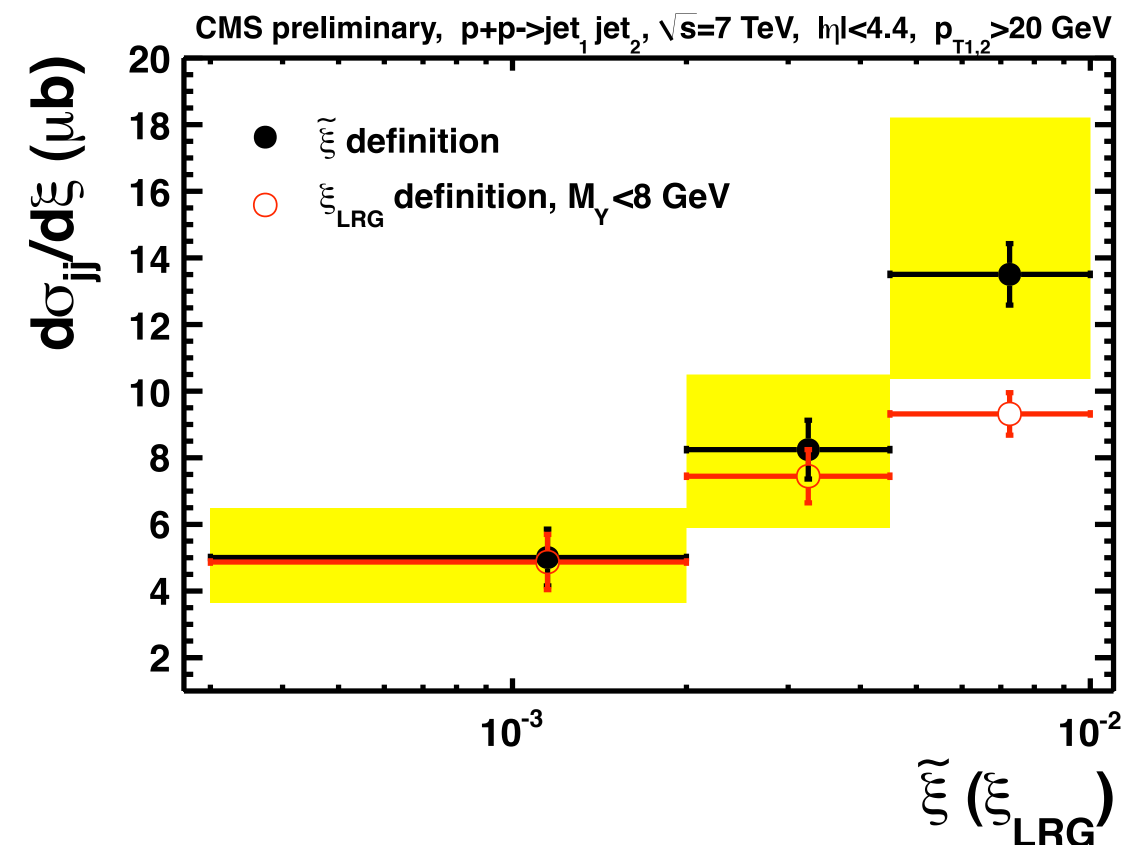
$$\tilde{\xi}^{\pm} = \frac{\sum (E \pm p_z)}{\sqrt{s}} \approx \frac{M_X^2}{s}$$

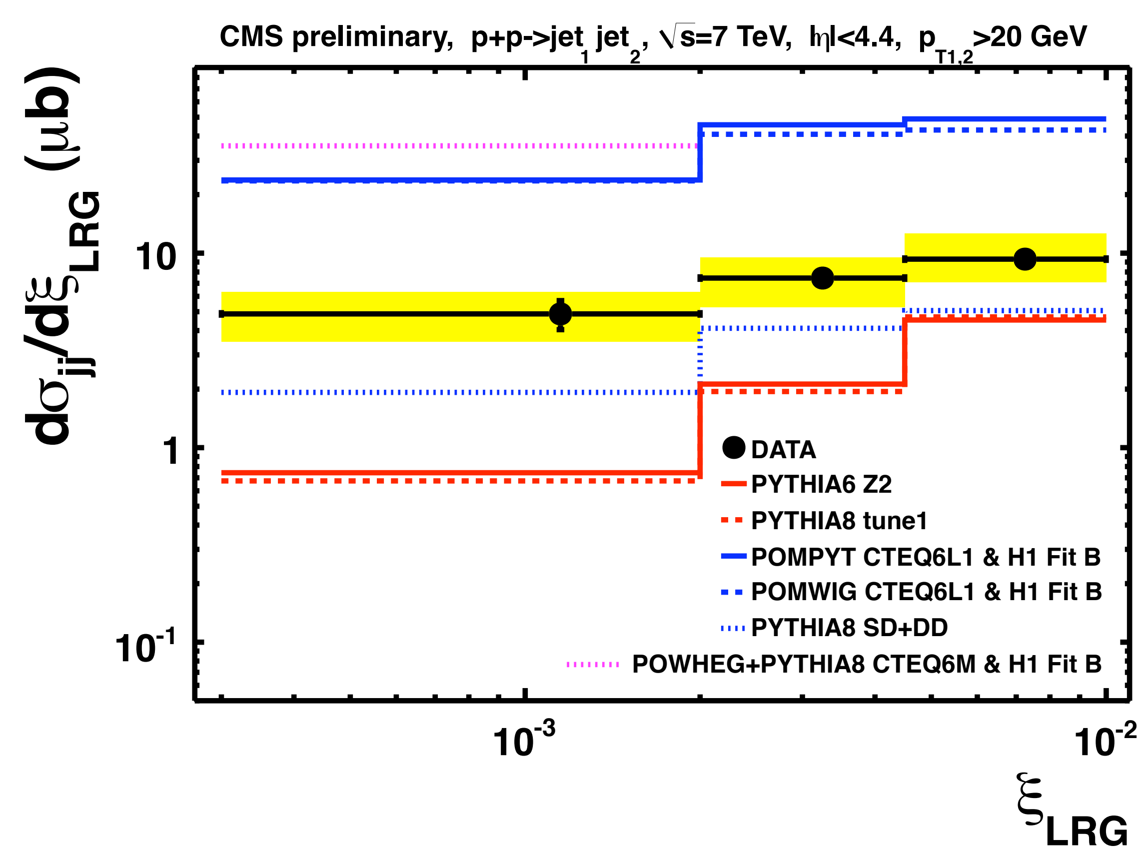
- ideal topology
  $M_{X,OBS} = M_{X,LRG}$



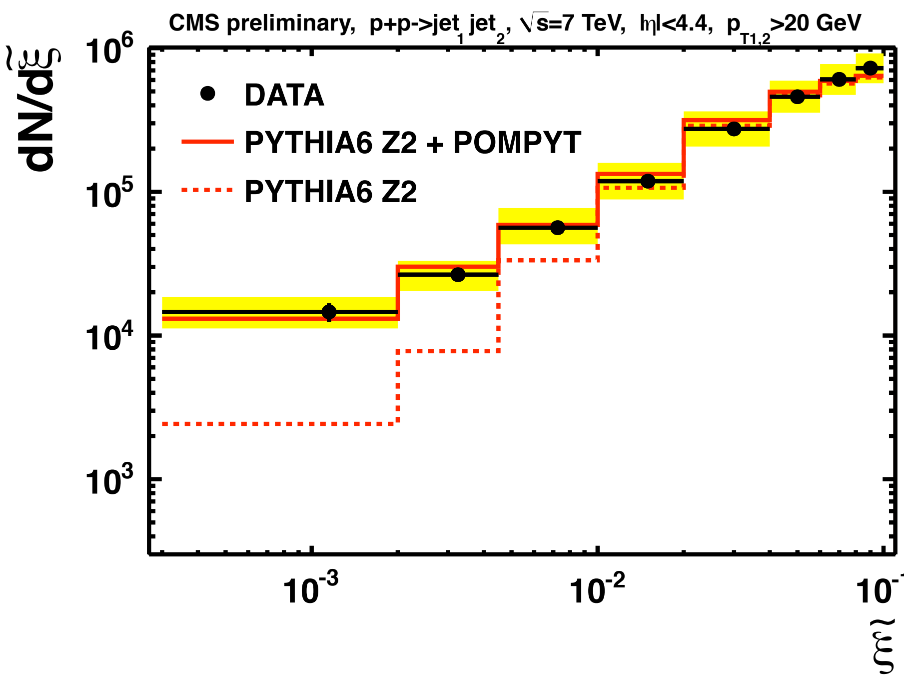
- X_{LRG} extends beyond detector acceptance
  $M_{X,OBS} \neq M_{X,LRG}$

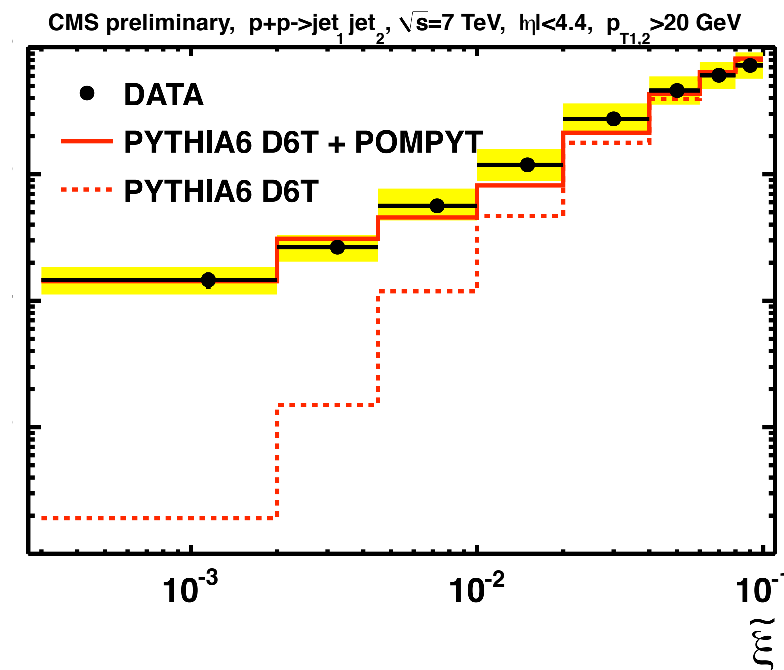
- Y_{LRG} penetrates detector acceptance
  $M_{X,OBS} \neq M_{X,LRG}$

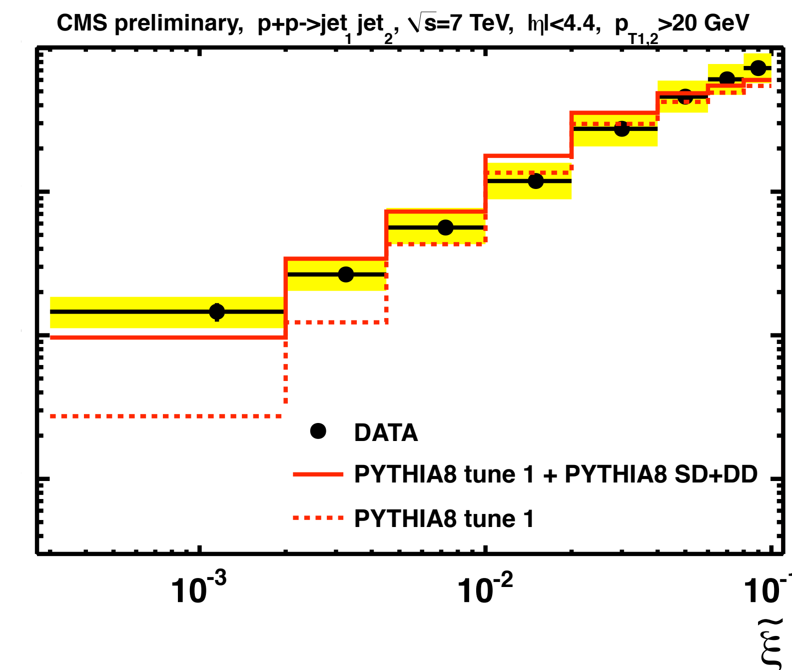




Event distributions







Systematic uncertainties

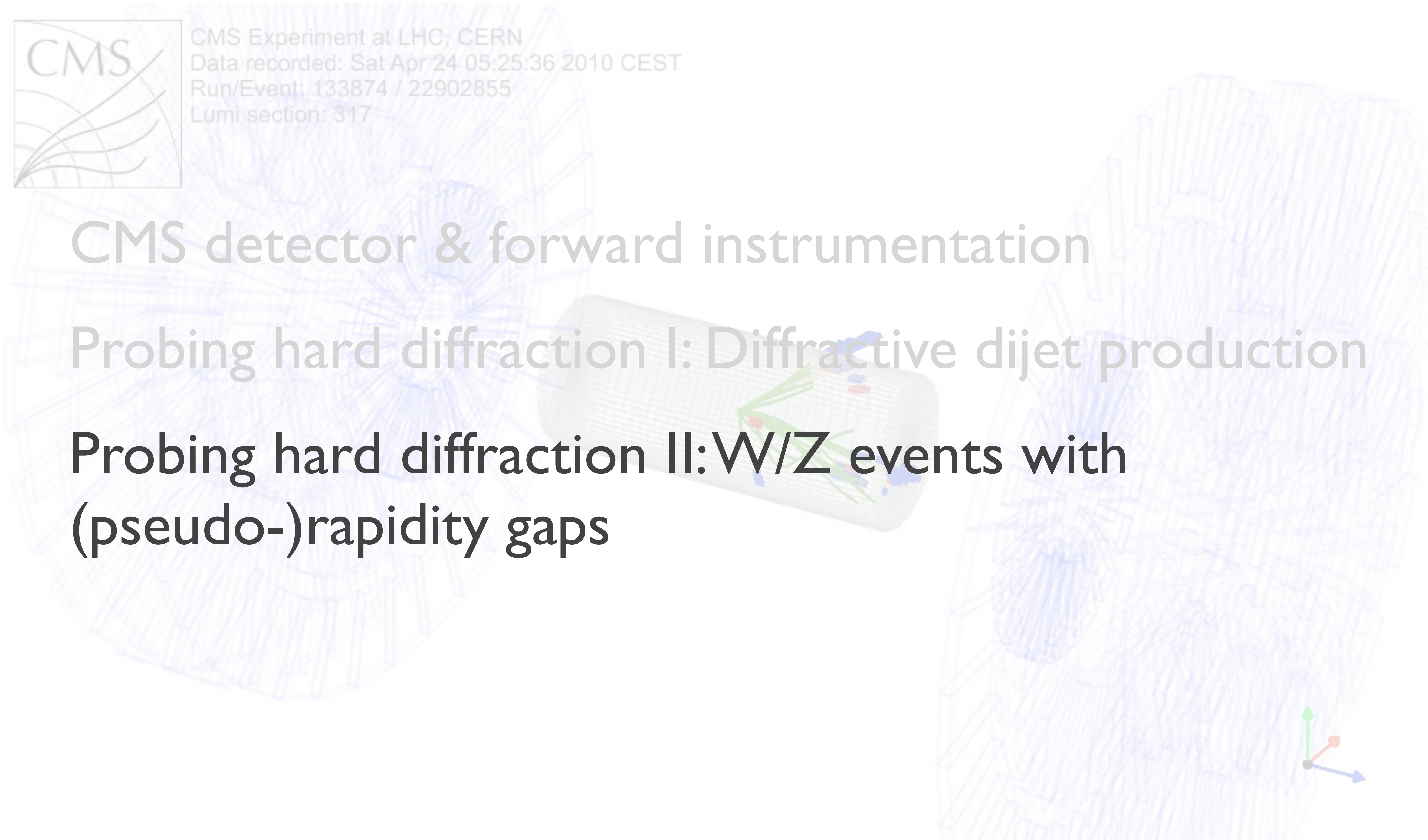
Largest contribution from Jet Energy Scale uncertainty

Average systematic error around 30%

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

Uncertainty source	$0.0003 < \tilde{\xi} < 0.002$	$0.002 < \tilde{\xi} < 0.004$	$0.0045 < \tilde{\xi} < 0.01$
1. Jet energy scale	$(+26/-19)\%$	$(+21/-20)\%$	$(+28/-16)\%$
2. Jet energy resolution	$(+5/-3)\%$	$(+2/-1)\%$	$(+3/-1)\%$
3. Calorimeter energy scale	$(+7/-14)\%$	$(+14/-8)\%$	$(+12/-10)\%$
4. MC uncertainty	$(+5/-6)\%$	$(+3/-14)\%$	$(+3/-3)\%$
5. HF threshold	$(+0/-6)\%$	$(+2/-0)\%$	$(+2/-0)\%$
6. Tracks p_T threshold	$(+0/-1)\%$	$(+1/-0)\%$	$(+0/-2)\%$
7. One vertex selection	$(+6/-0)\%$	$(+0/-1)\%$	$(+1/-0)\%$
8. Calorimeter jets	$(+0/-4)\%$	$(+0/-4)\%$	$(+2/-4)\%$
9. $\tilde{\xi}^{+}$, $\tilde{\xi}^{-}$ difference	$\pm 8\%$	$\pm 8\%$	$\pm 11\%$
10. η_{max} (η_{min}) cut	$(+0/-0)\%$	$(+3/-0)\%$	$(+9/-0)\%$
11. Trigger efficiency	$\pm 3\%$	$\pm 3\%$	$\pm 3\%$
12. Luminosity	$\pm 4\%$	$\pm 4\%$	$\pm 4\%$

Outline



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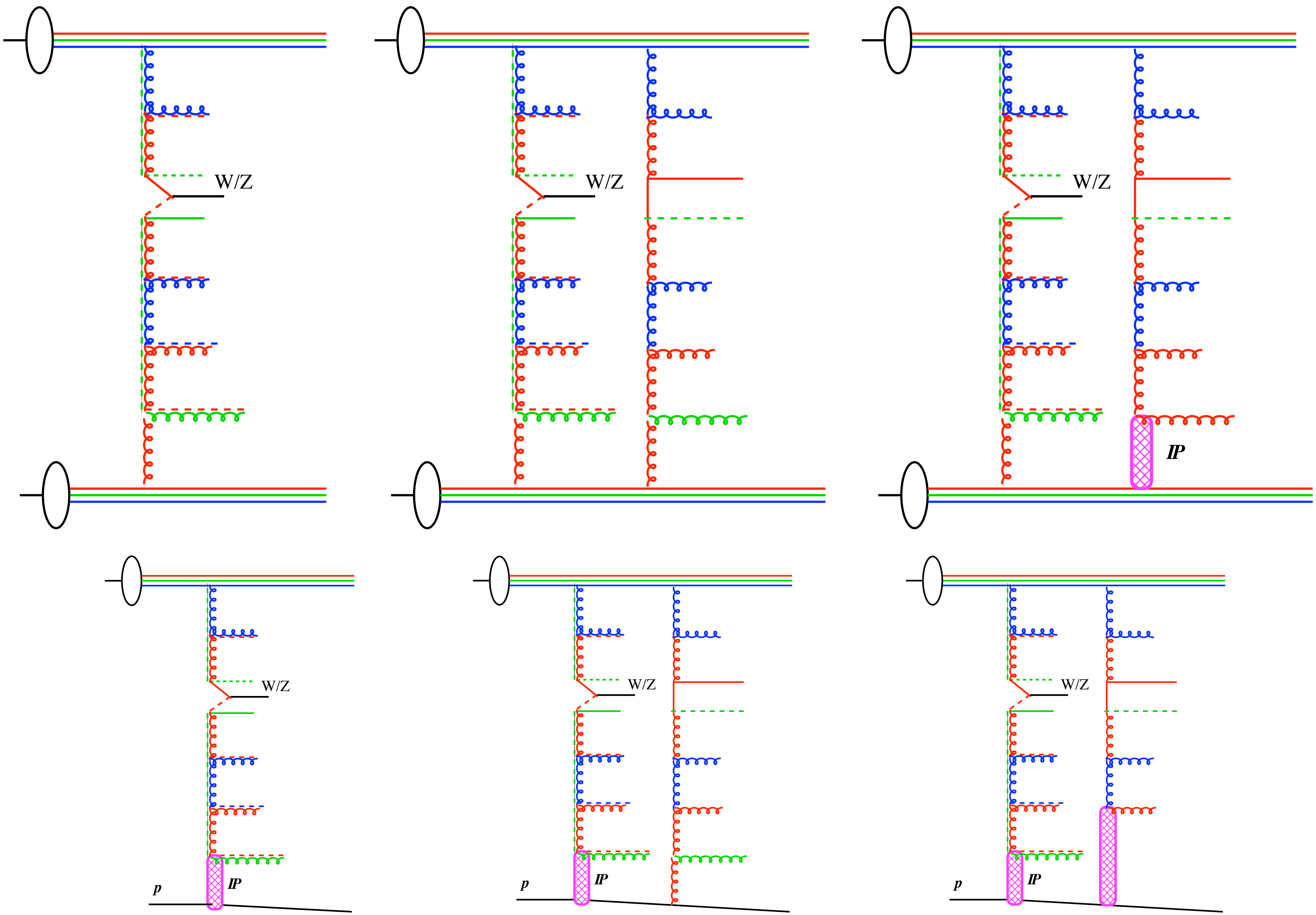
Probing hard diffraction II: W/Z events with (pseudo-)rapidity gaps

Underlying event in hard interactions

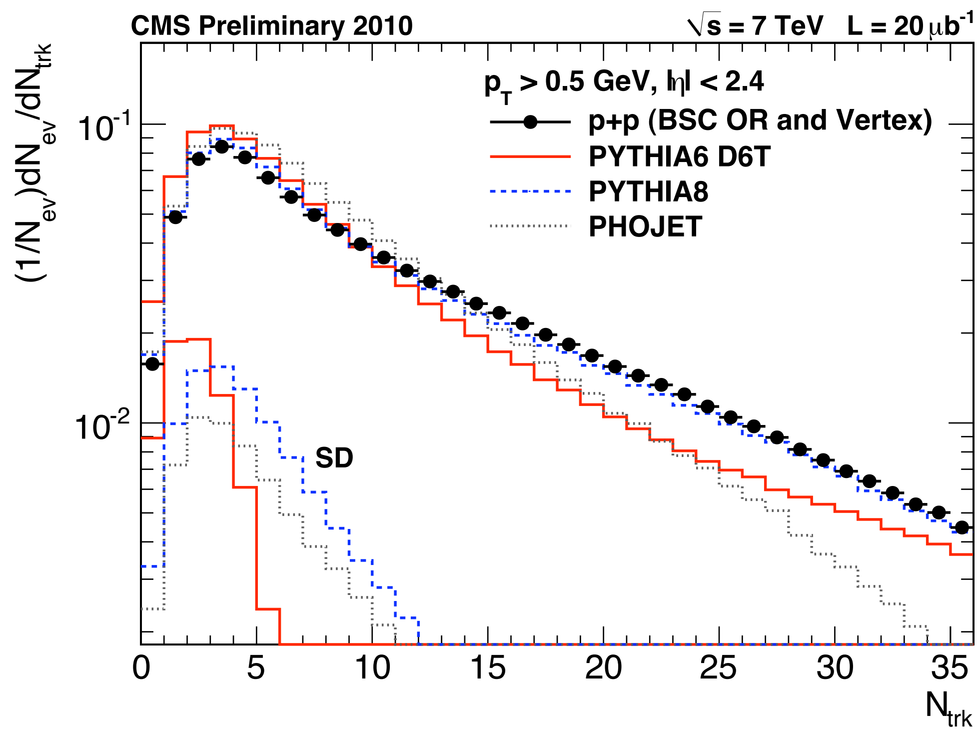


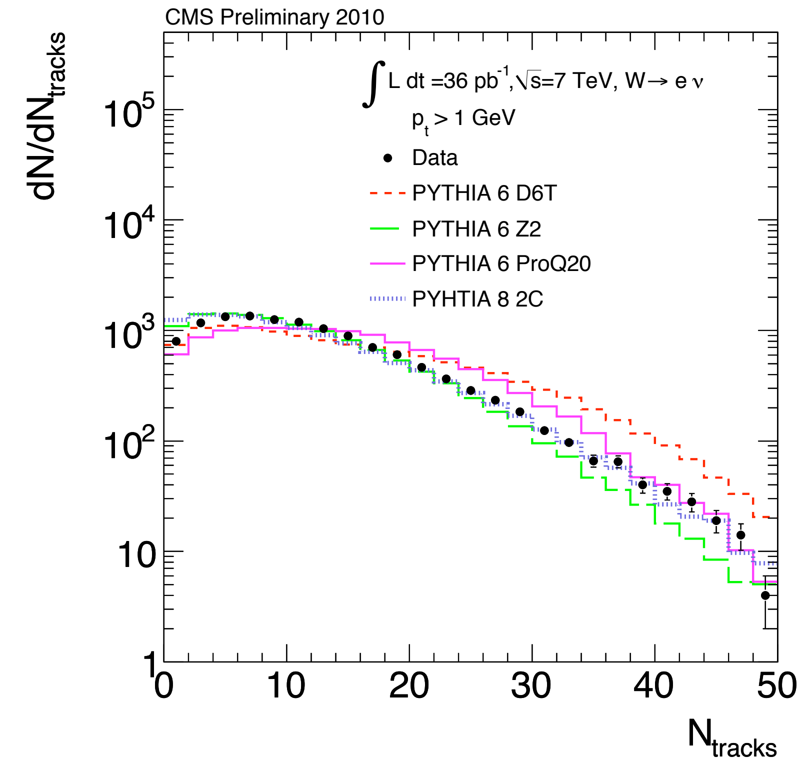
Central vs Forward energy flow

Minimum bias

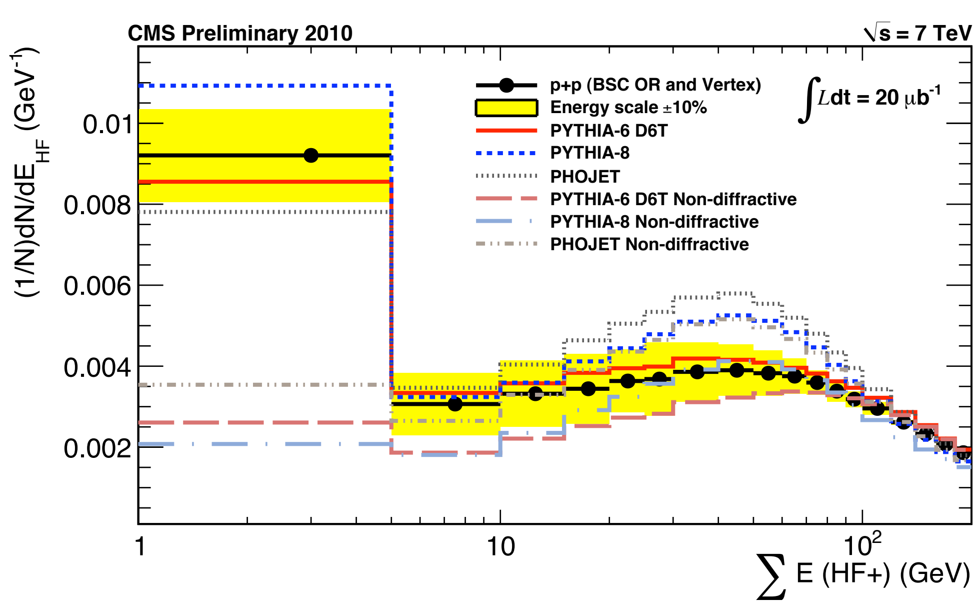
$pp \to WX$

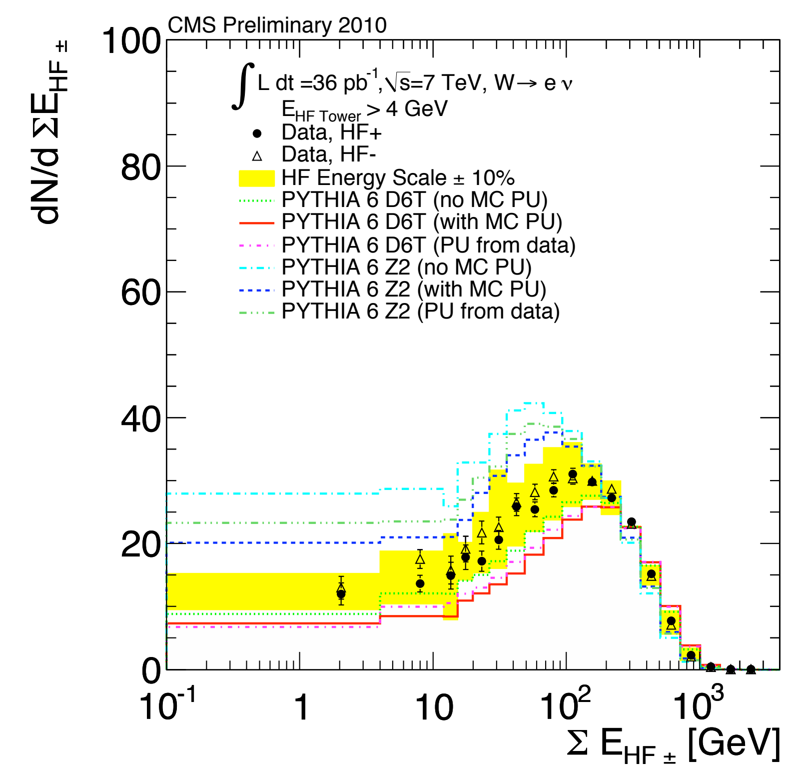
Central track multiplicity





Forward energy





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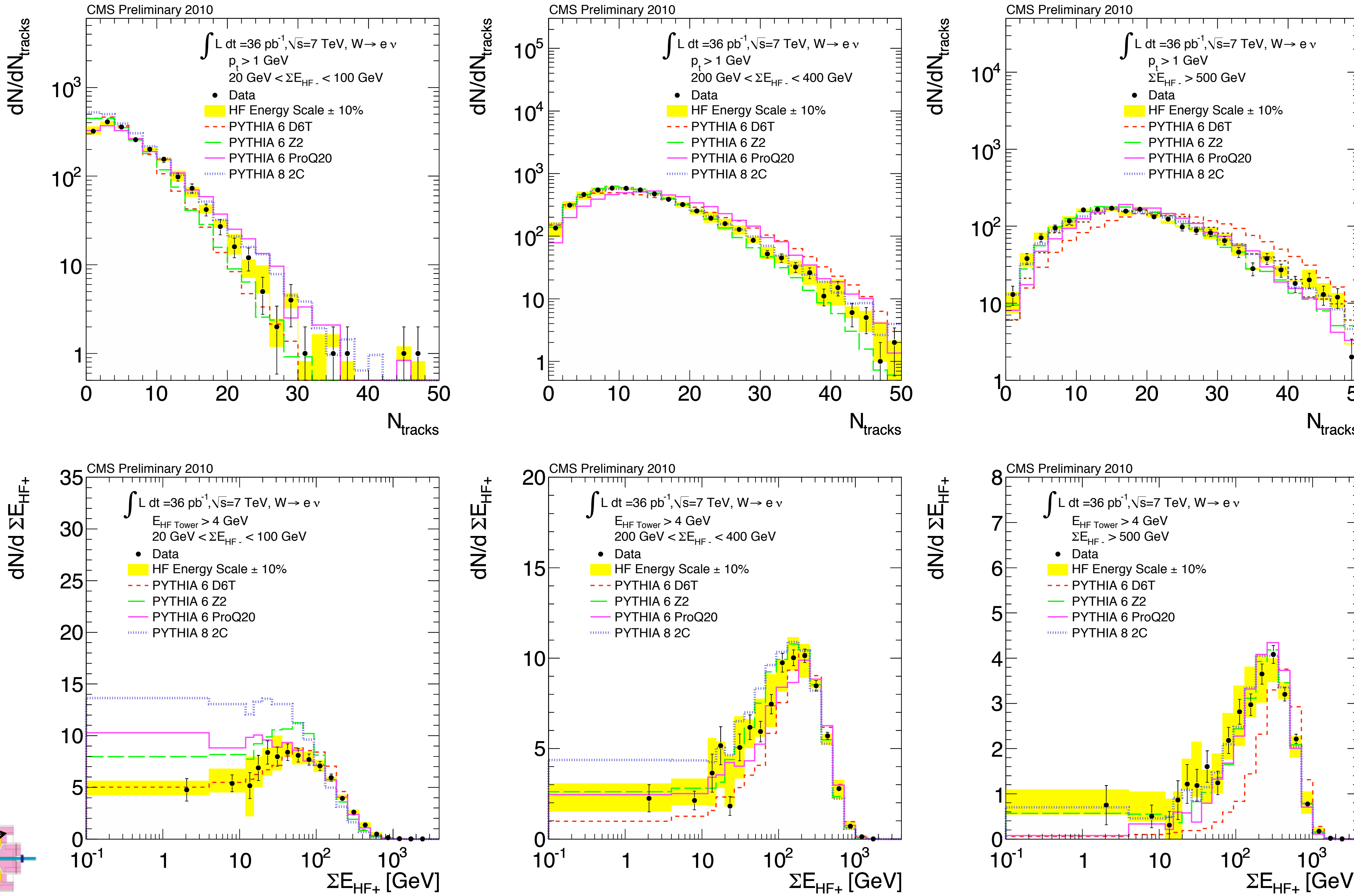
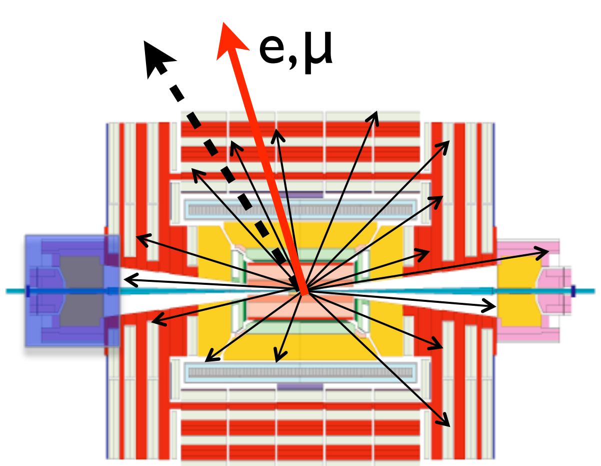
Central vs Forward energy flow

Central and forward activity with increasing forward deposition in the opposite side





$\sum E_{HF-}$

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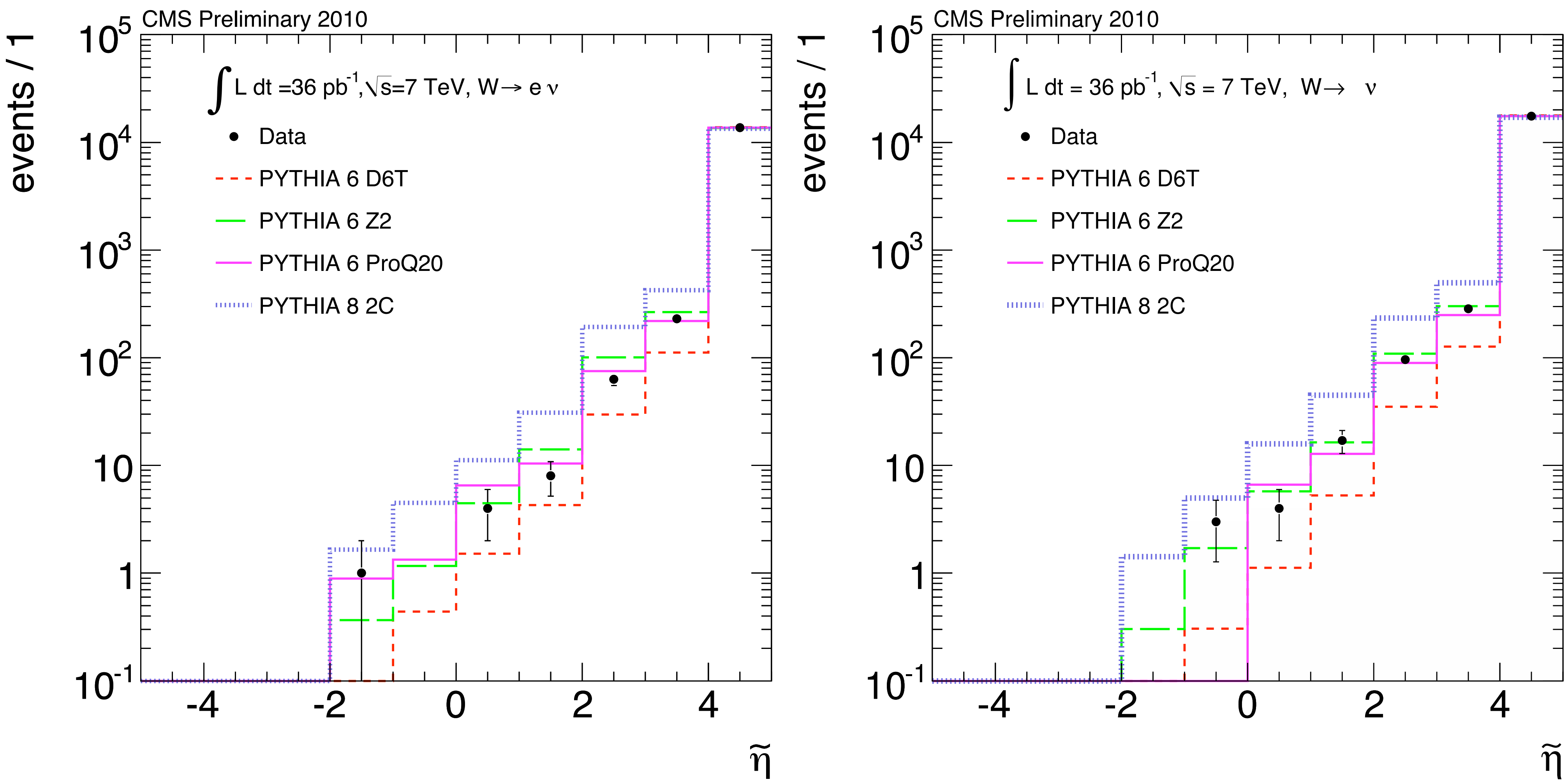

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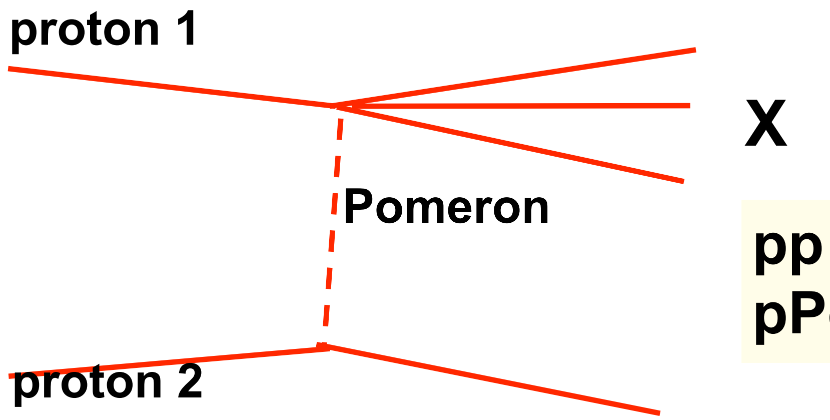
Meaning of $E \pm p_z$



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

Conversely, if proton 1 moves in the negative z direction (and proton 2, and Pomeron, in the positive z direction), $E(\text{proton } 1) + p_z(\text{proton } 1) \approx 0$, hence:

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

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