


Physics of forward jets at CMS

Grzegorz Brona
(CERN)

on behalf of
CMS Collaboration

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The Outline

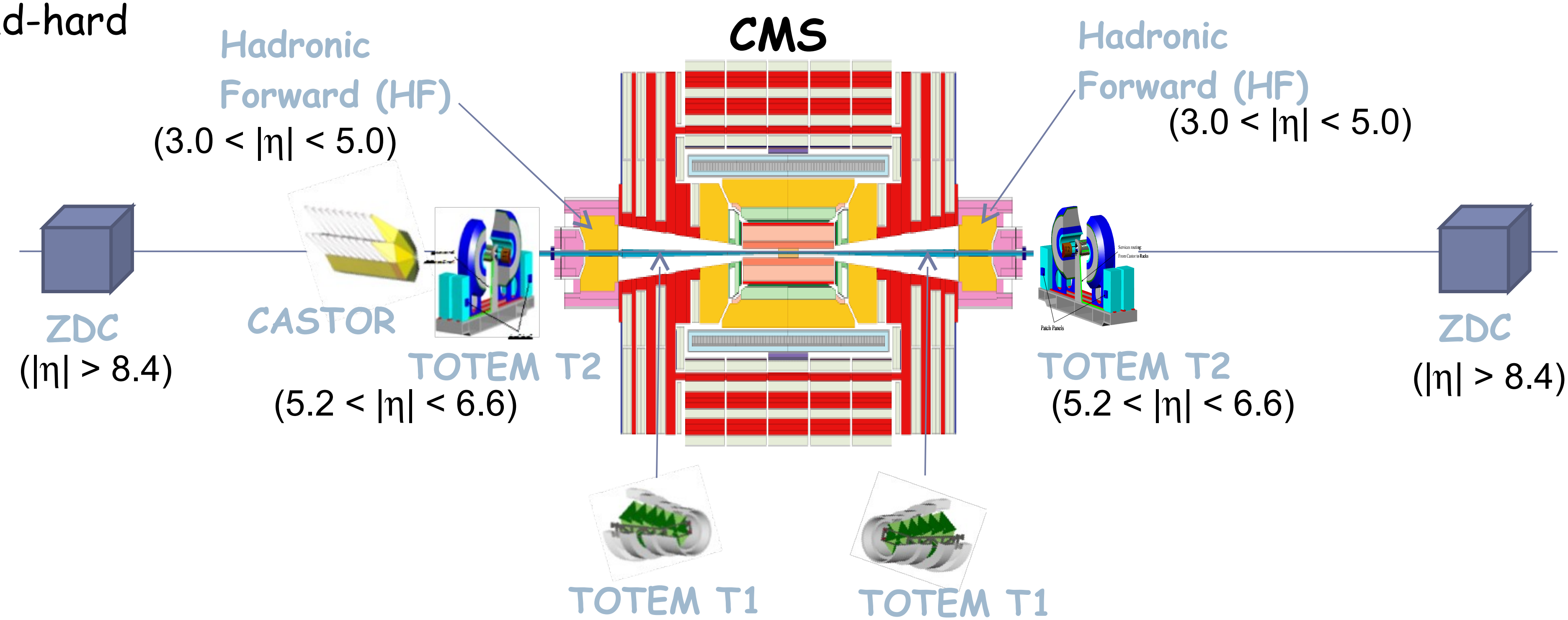
- Apparatus
- Forward energy flow measurement
- Forward jets at CMS
    - Monte Carlo predictions
    - Observation of forward jets
    - Jets correlation measurements
    - Diffractive jets
- Outlook and Summary

Apparatus

The CMS detector

Requirements:

- Detectors covering forward and backward rapidities
- Energy deposites measurement
- Rad-hard



- Hadronic Forward calorimeters (HF)
- Zero Degree Calorimeter (ZDC)
- Centauro And STrange Objects Research (CASTOR) – calorimeter

- **TOTEM** – separate experiment:
  - T1 – in front of the HF, 7.5 m from IP
  - T2 – in front of CASTOR, 13.6 m from IP
  - RP – 147 & 149 and 216 & 220 m from IP

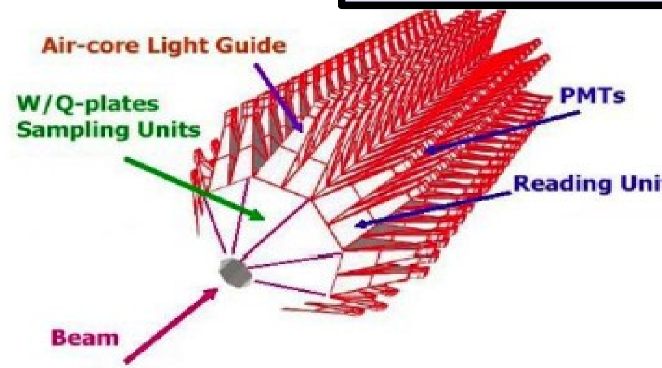
The CMS forward detectors

HF

- Located at 11.2 m from IP
- Rapidity coverage: $3 < |\eta| < 5$
- 0.175x0.175 segmentation in η and ϕ
- Steel absorbers and embedded radiation-hard quartz fibers for fast collection of Cherenkov light

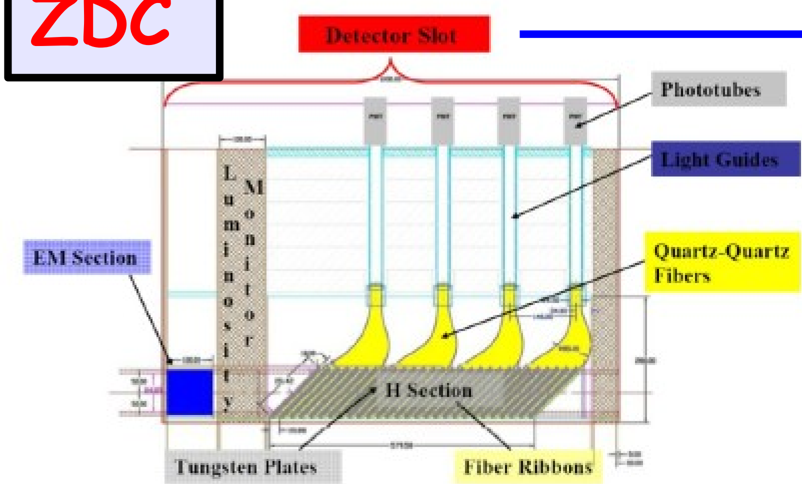
CASTOR

- Located at 14.3 m from IP
- Rapidity coverage: $-6.6 < \eta < -5.2$
- Segmentation in ϕ (16 sectors)
- 14 modules (2EM+12HAD)
- Alternate tungsten absorbers and quartz plates



see: S. Ochesanu talk

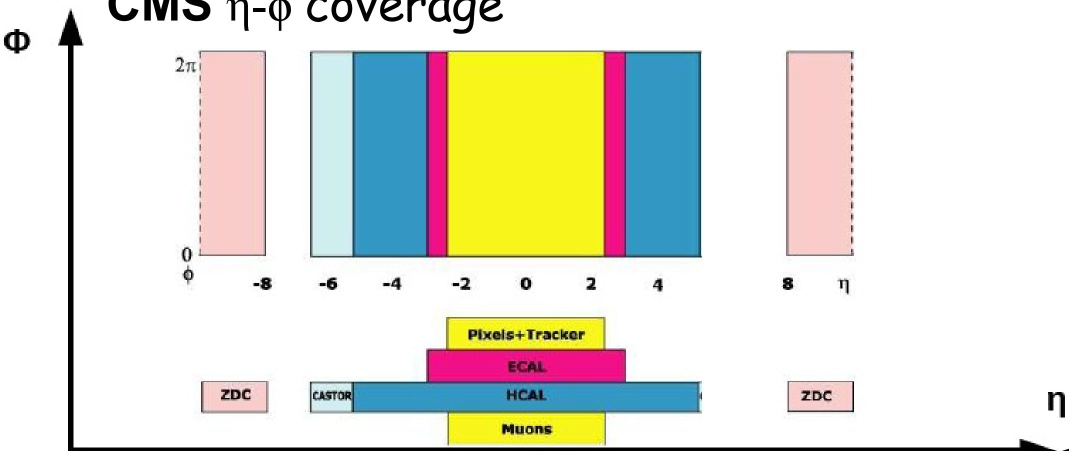
ZDC



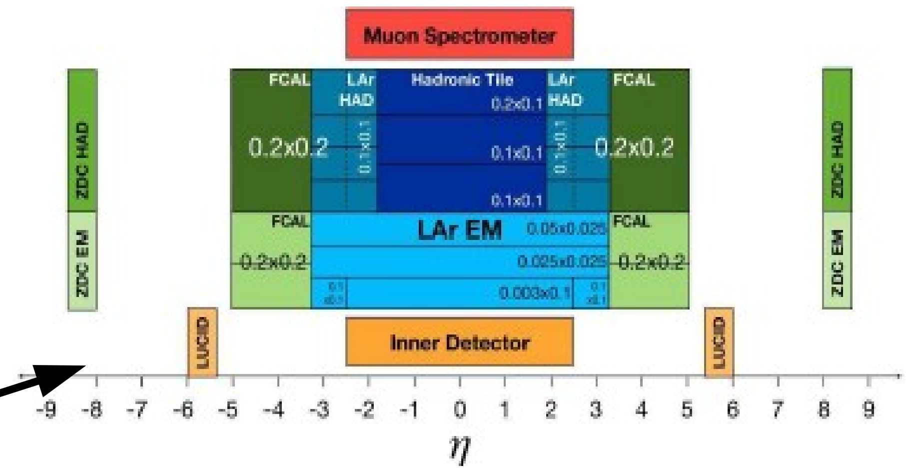
- Located at 140 m from IP
- Rapidity coverage: $|\eta| > 8.1$
- Tungsten/quartz Cherenkov calorimeter with separated EM and HAD sections
- Detection of neutrals (γ, π^0, n)

The coverage

CMS η-φ coverage

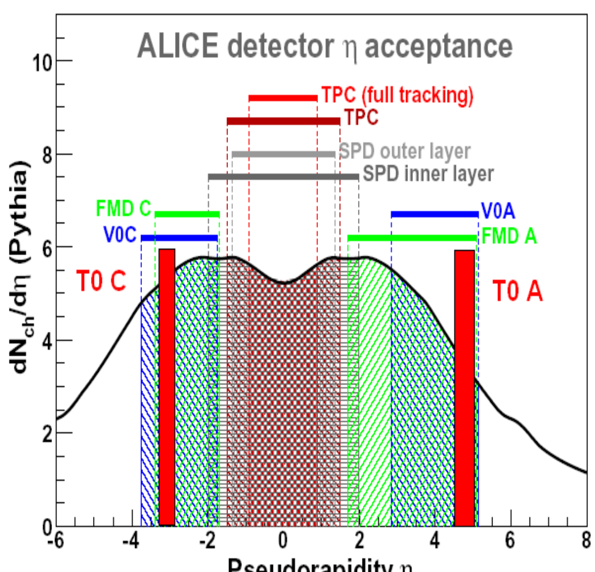


ATLAS η coverage

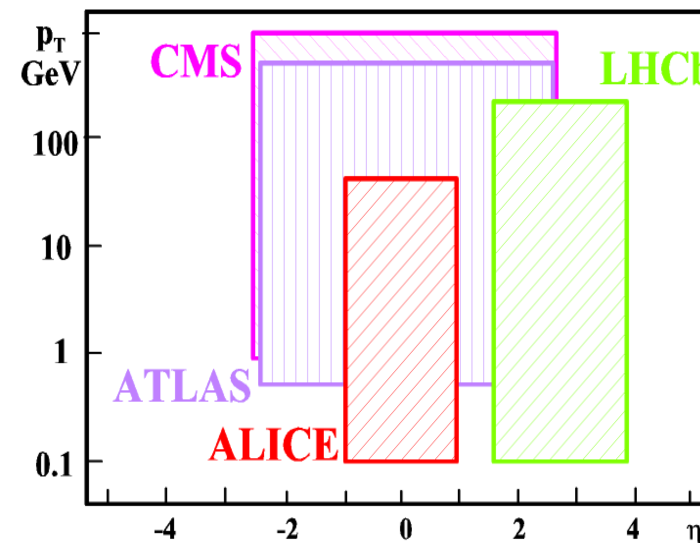


Similar coverage for **ATLAS**:

- FCAL
- LUCID - 5.6 < |η| < 5.9 → pointing Cherenkov counters (lumi monitor+gap)
- ZDC - |η| > 8.3



Central barrel coverage:

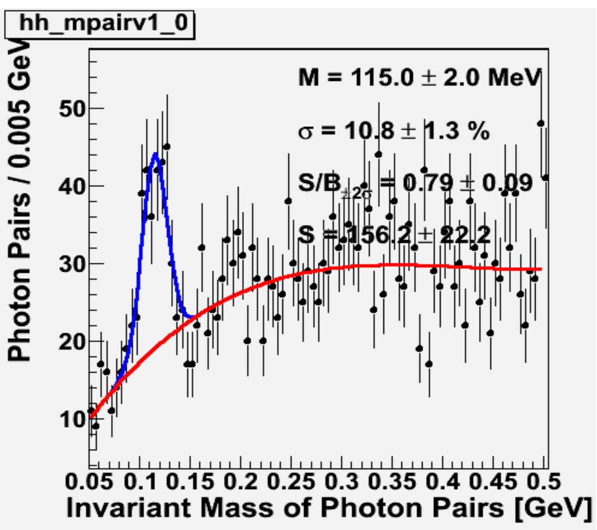


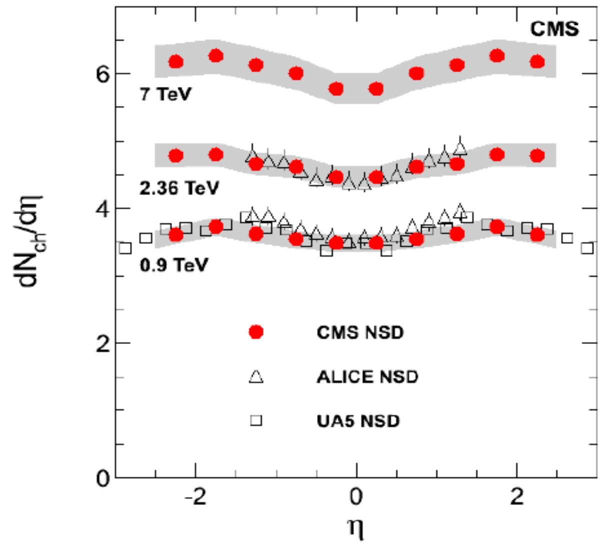
Future: far detectors

In the LHC era...

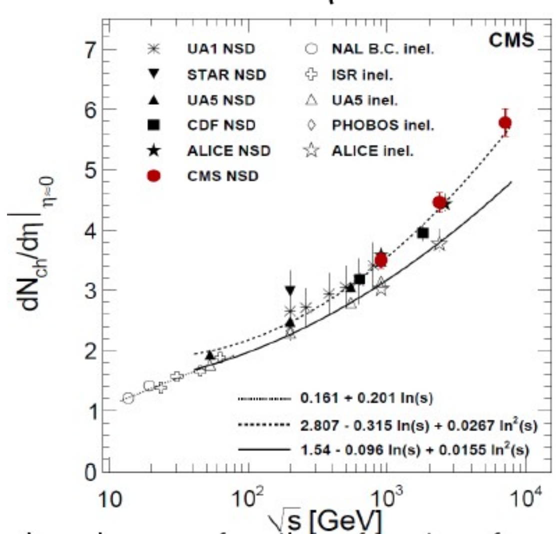
- First data from collisions at 900 GeV collected in 2009 - ~10 μb^{-1}
- Runs taken with 2360 GeV - <1 μb^{-1}
- LHC restarted 30 March 2010 with 7000 GeV (a few days – 900 GeV)

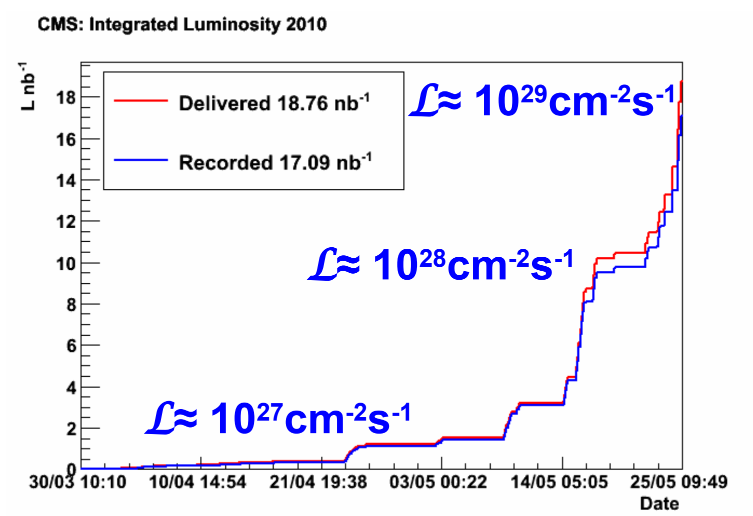
Within the first 5 min





Accepted by PRL →



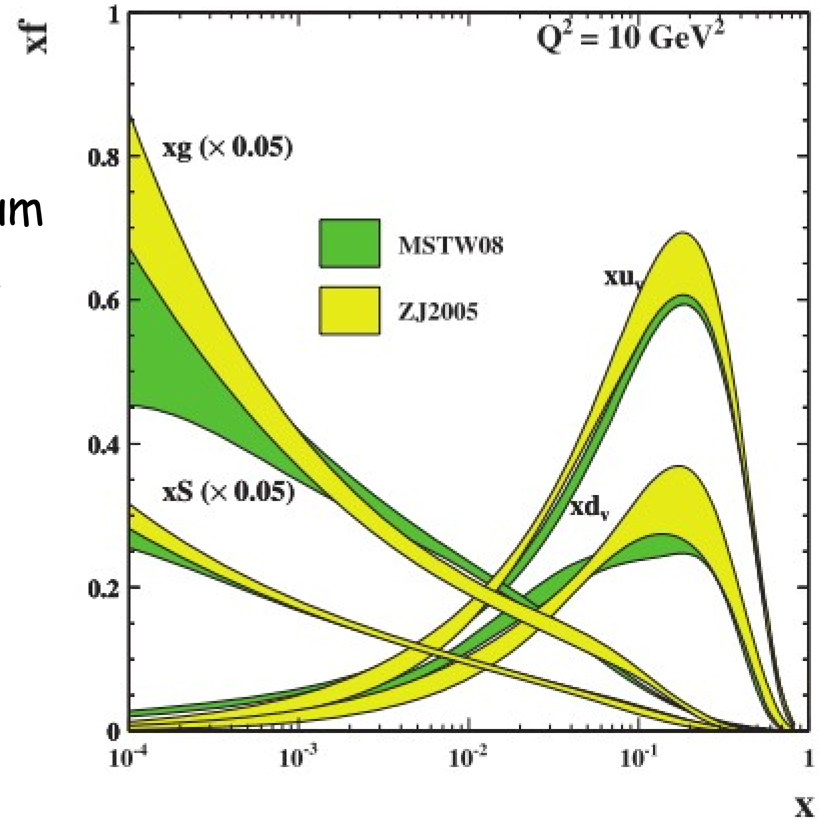


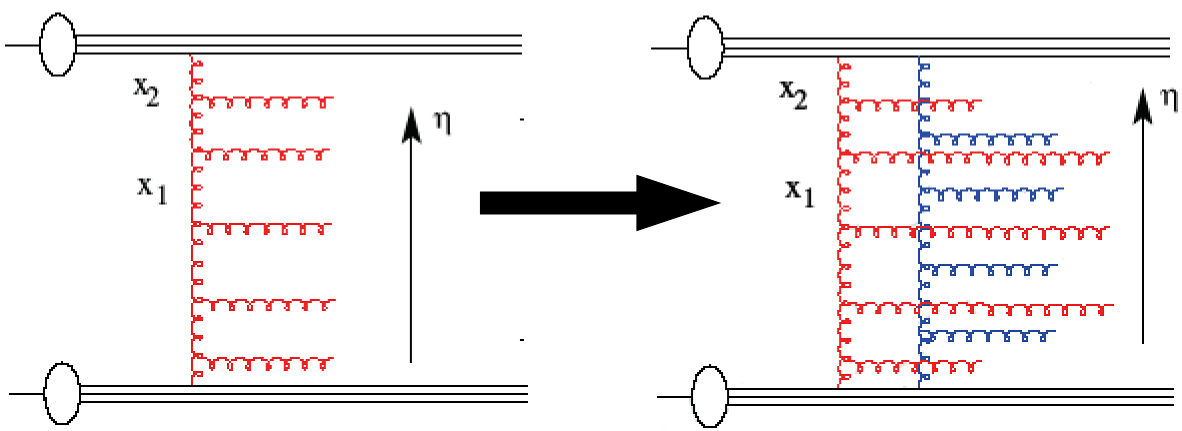
see: A. Anastassov talk

Energy flow in the forward region

Energy flow in the forward region

- A logical step before going to jets studies
  - but also a meaningful, new physics result
- At very large centre of mass energies, the momentum fraction of the proton carried by the partons in the hard scattering (x_1, x_2) can become very small and the parton densities become very large.
- Probability for more than one partonic interaction per event increases.
- This approach is described in the models of multiparton interactions.
- Models implemented in Monte Carlo event generators need parameters to be adjusted to describe the measurement.
- Parameters tuned to data from Tevatron (|η|<3).





Energy flow in the forward region

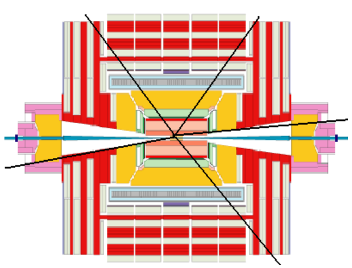
- MPI model included in PYTHIA. The parameters of the model can be tuned – different sets of parameter values define different tunes.
- Avoid differgences in hard scattering and MPI: $$\frac{1}{p_T^4} \rightarrow \frac{1}{(p_T^2 + p_{T0}^2)^2}$$
- Where p_{T0} is parametrized: $$p_{T0}(\sqrt{s}) = p_{T0}(\sqrt{s_0})\left(\frac{\sqrt{s}}{\sqrt{s_0}}\right)^{\epsilon}$$
- Different pdfs, cuts for ISR and FSR, fragmentation model

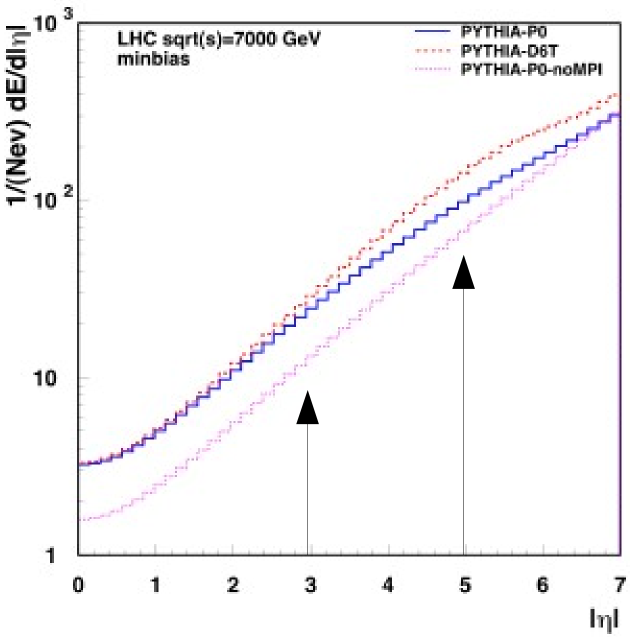
		D6T (108)	DW (103)	Pro-Q20 (129)	P0 (320)
pdfs		CTEQ6L	CTEQ5L	CTEQ5L	CTEQ5L
p_{t0}	PARP(82)	1.84 GeV	1.9 GeV	1.9 GeV	2.0 GeV
E_0	PARP(89)	1.96 TeV	1.8 TeV	1.8 TeV	1.8 TeV
ϵ	PARP(90)	0.16	0.25	0.22	0.26
fragmentation	standard	standard	standard	professor LEP tune	professor LEP tune
Q^2_{max} factor (ISR)	PARP(67)	2.5	2.5	2.65	1.0
Q^2_{max} factor (FSR)	PARP(71)	4.0	4.0	4.0	2.0

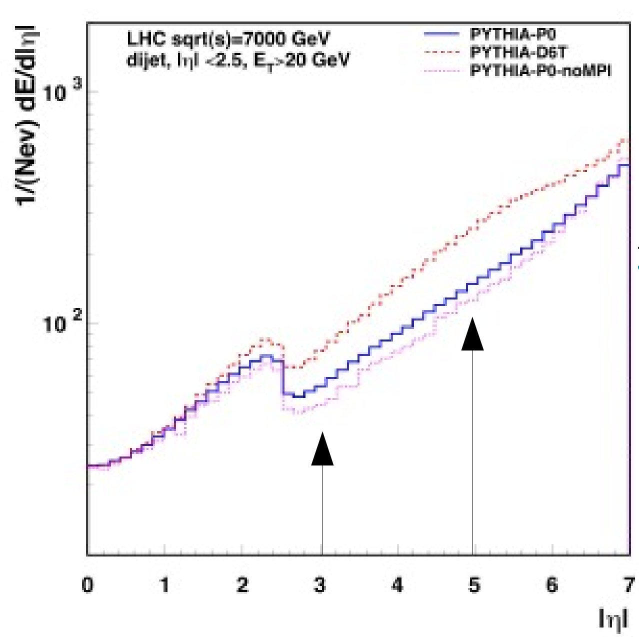
Energy flow in the forward region

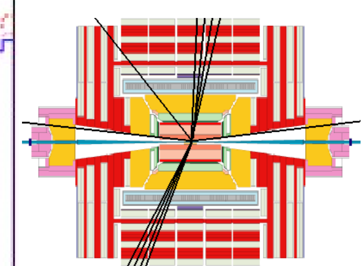
- The extrapolation of models to larger |η| is very uncertain, differences up to factors 5.
- The extrapolation of models to larger energies is also uncertain.
- Provide input to the determination of the parameters for the multiparton interaction models.

Predictions at generator level for two samples and for two Pythia6 tunes with MPI and no-MPI scenario









Energy flow in the forward region

- Measurement done with Hadronic Forward calorimeter: **$3.152 < |\eta| < 4.903$**
- Plans: extend it to CASTOR and to ZDC
- Three different cms energies included: 900 GeV, 2360 GeV, 7000 GeV
- The measurement done at the detector level – no factors correcting it to the hadron level applied
- A comparison with the Monte Carlo generators predictions at the detector level

  - Distributions studied:

$$E_{FLOW}(dijet) = \frac{1}{N_{dijet}} \frac{\Delta E}{\Delta \eta}(dijet)$$

$$E_{FLOW}(minbias) = \frac{1}{N_{minbias}} \frac{\Delta E}{\Delta \eta}(minbias)$$

- Definition of Minimum Bias sample: all events trigger with MB trigger: activity at both sides of IP + vertex reconstructed

- Definition of Dijet sample: for 900/2360 GeV $p_T > 8$ GeV, for 7000 GeV $p_T > 20$ GeV

Energy flow in the forward region

Systematic effects on the measurement:

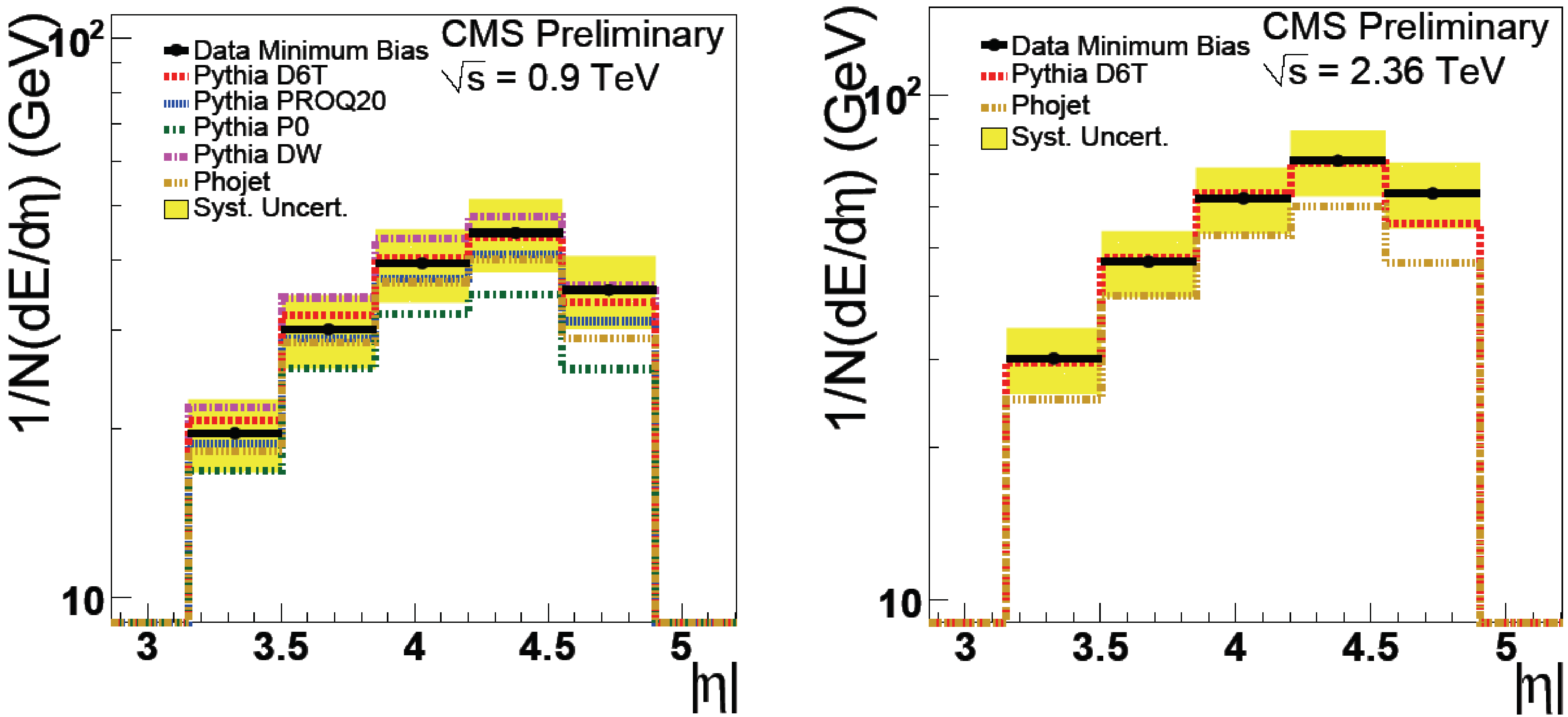
- Energy scale of HF (calibration → 15% - will improve in future)
- Position of interaction vertex
- Direct PMT hits → 3%
- Remaining noises in HF CaloTowers
- Random channel-by-channel miscalibration
- No beam-beam interactions

Negligible with comparison to HF energy scale

Effect	Minimum bias sample	Dijet sample
Energy scale	15%	15%
Primary vertex z position	1%	1%
Photomultiplier hits	3%	3%
Energy deposit cut in calorimeter towers	2%	2%
Channel-by-channel miscalibration	1%	1%
Total	15%	15%

Energy flow in the forward region

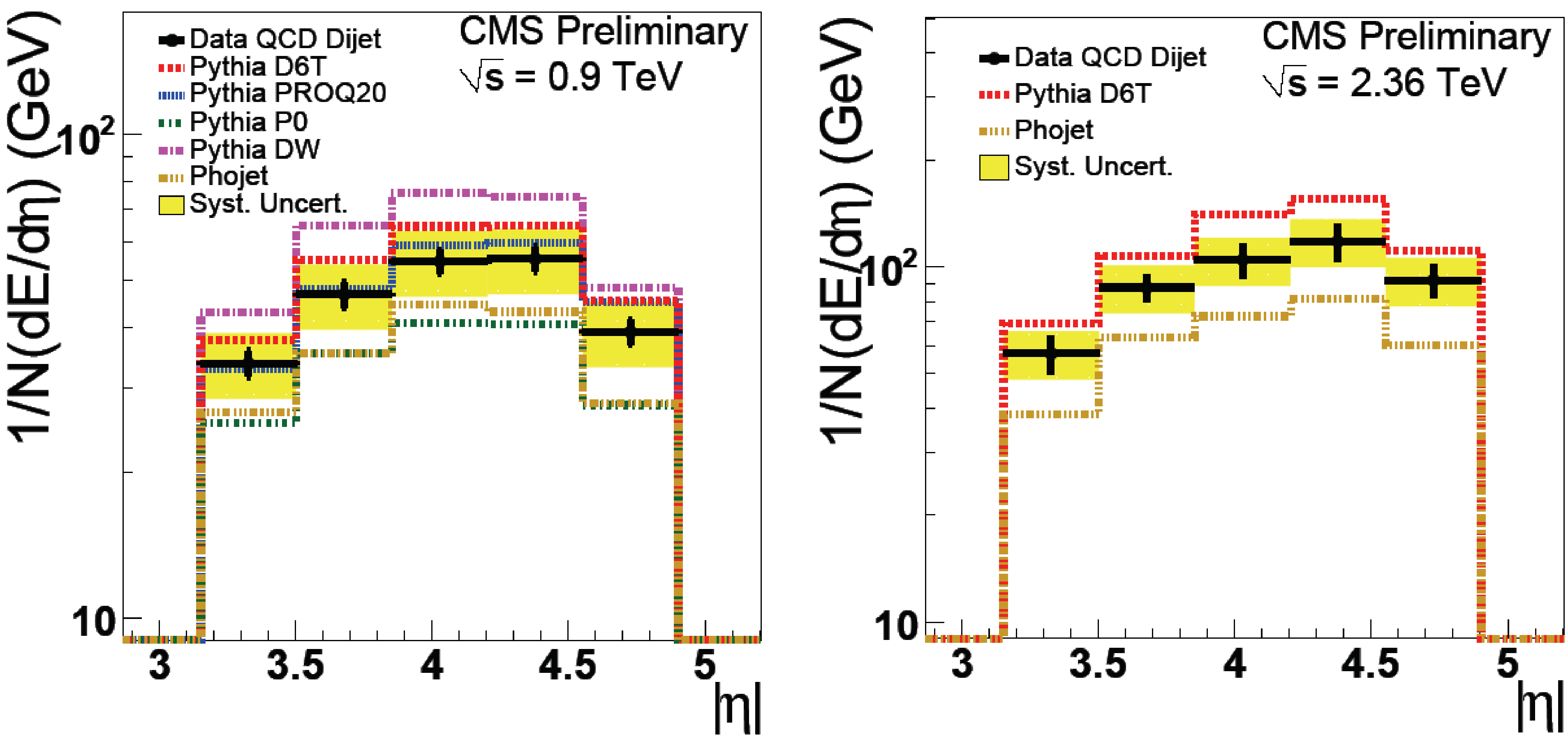
Energy flow in the Minimum Bias sample at 900/2360 GeV:



At 900 GeV the energy flow in minimum bias events is best described by the D6T tune, whereas the PROQ20, P0 tune and PHOJET is lower than the measurement.

Energy flow in the forward region

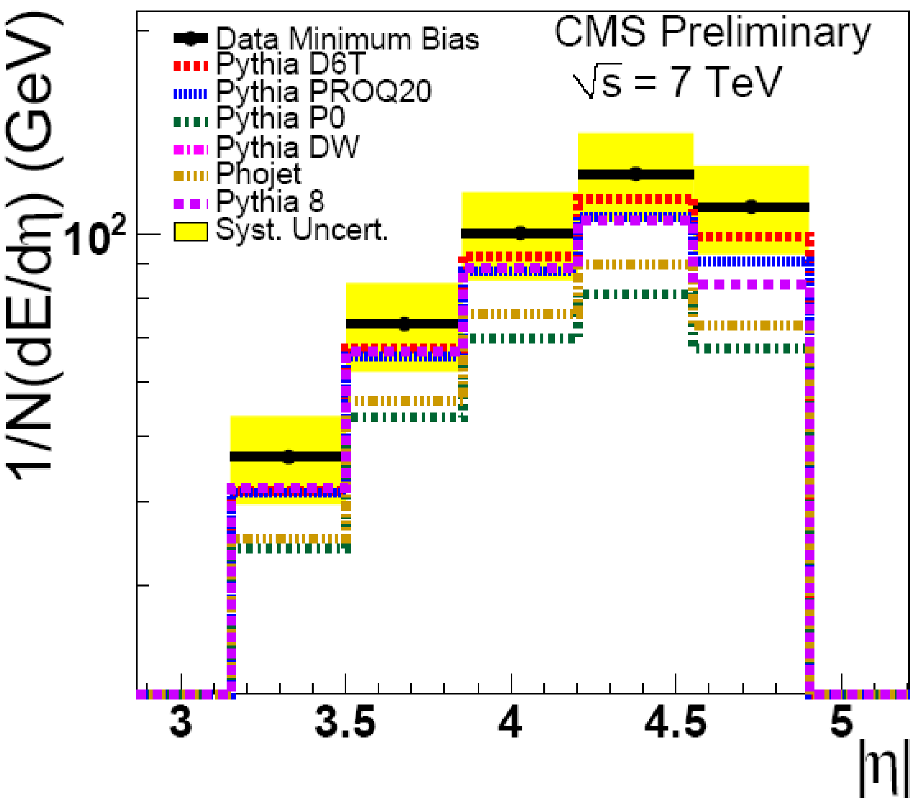
Energy flow in the Dijet sample at 900/2360 GeV:

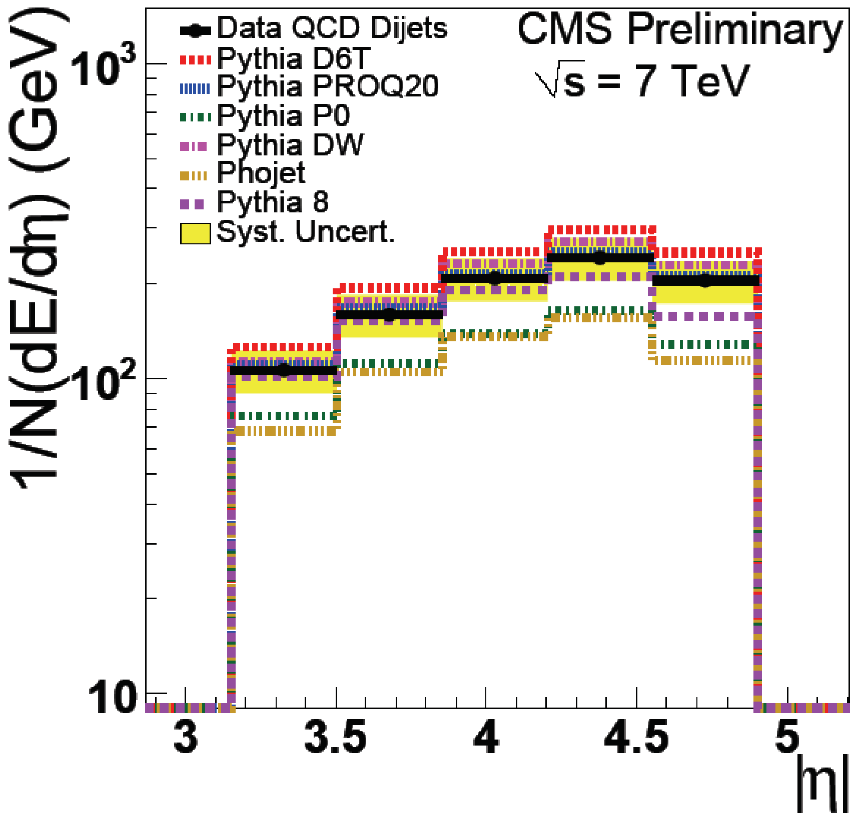


In dijet events the increase of energy flow with increasing centre-of-mass energy is reproduced by the simulations. Here, the D6T tune predicts too high energy flow, whereas the PROQ20 tune is best and the P0 tune and PHOJET is too low.

Energy flow in the forward region

Energy flow in the MB and Dijet samples at 7000 GeV:



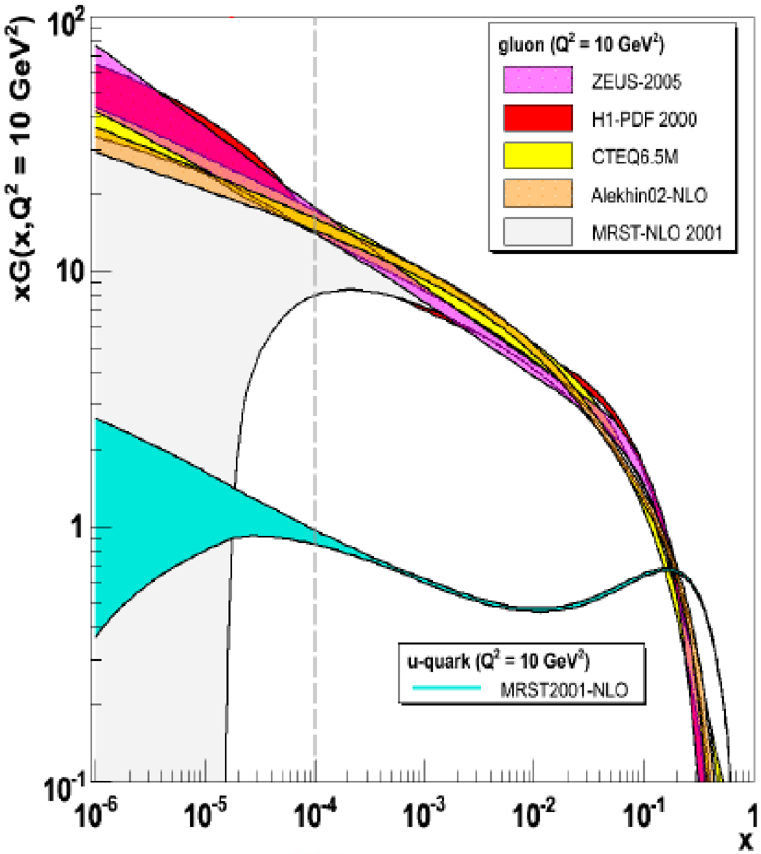


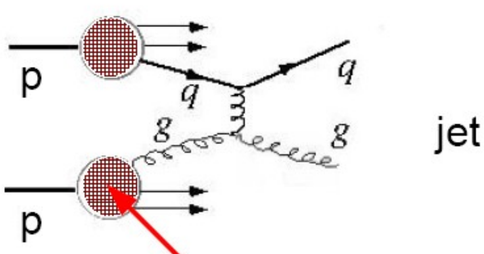
- At 7000 GeV the predicted energy flow in minimum bias events is below the measurement for all tunes, the prediction of PYTHIA8 is similar to the tune PROQ20.
- For dijet sample D6T tune predicts too high energy flow, whereas the PROQ20 tune and PYTHIA8 are best and the P0 tune and PHOJET is too low.

Forward Jets at CMS

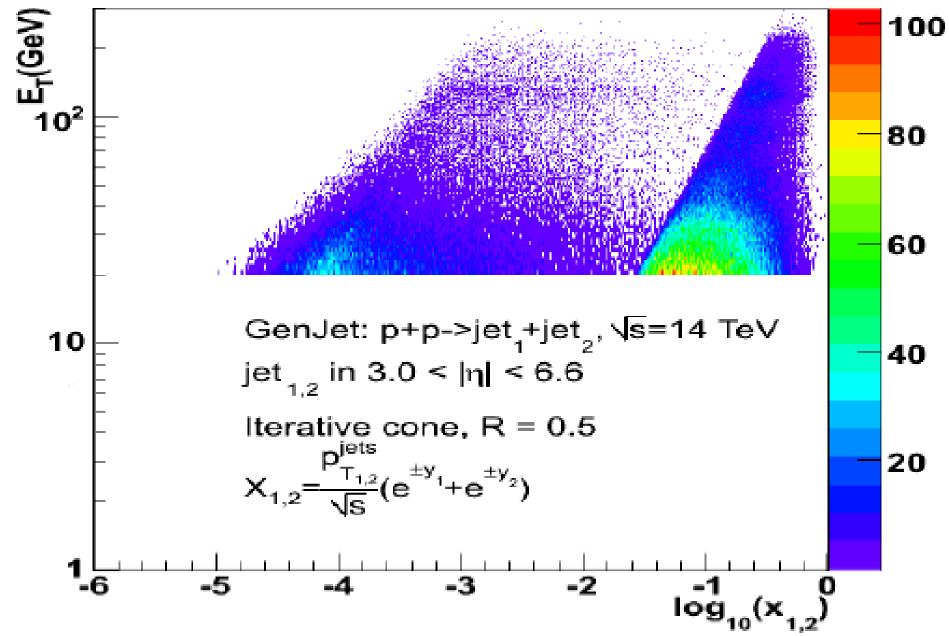
Forward Jets at CMS

Small x gluon density poorly constrained:

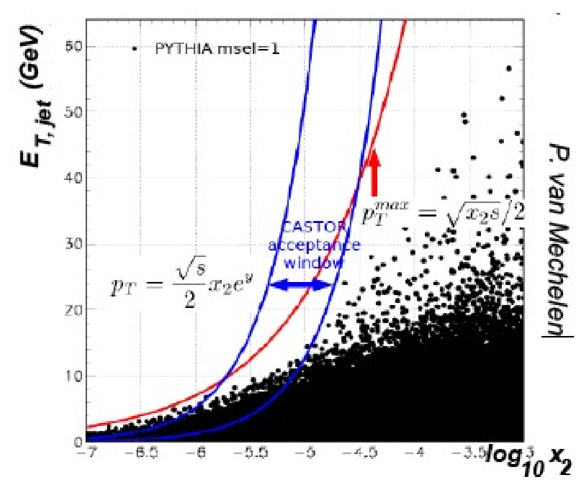




dσ(pp->jet)=PDF(x_1,Q^2)⊗PDF(x_2,Q^2)⊗dσ(qg->jet)



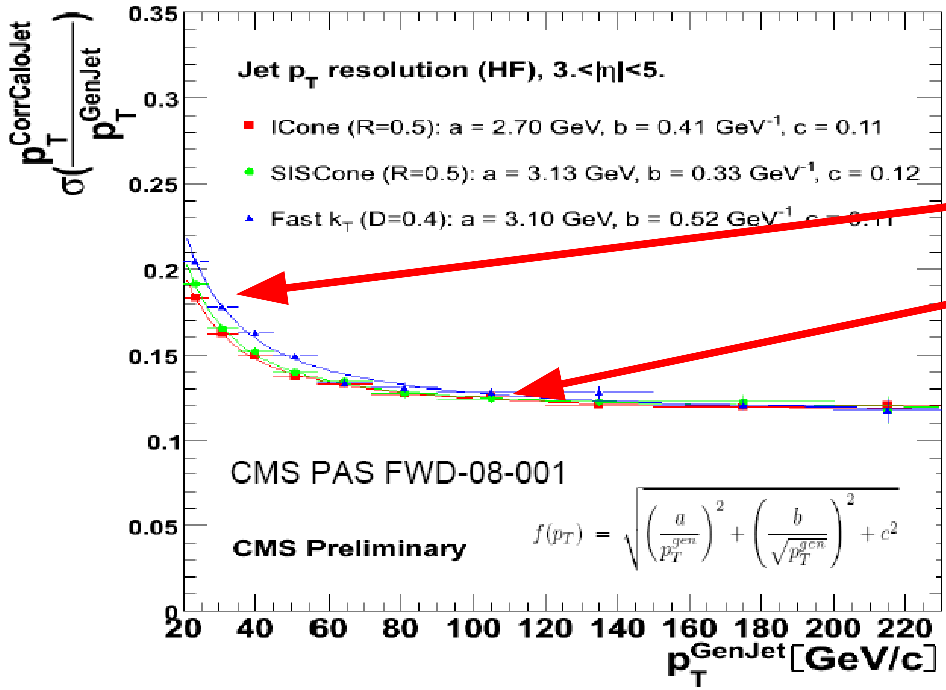
(PYTHIA default PDF: CTEQ5L)



Studies done with MC for 14 TeV

Forward Jets at CMS

Studies done with MC for 14 TeV



p_T resolution:

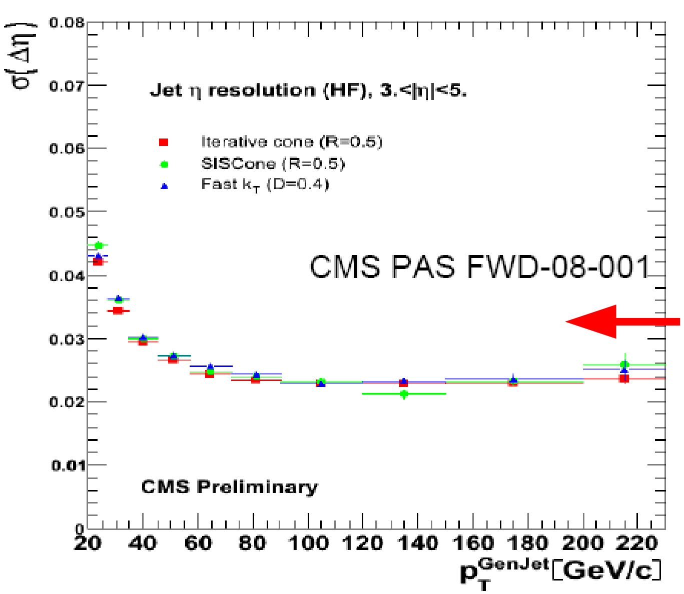
~20% for p_T~20 GeV

~12% for p_T>100 GeV

φ resolution:

~0.05 for p_T~20 GeV

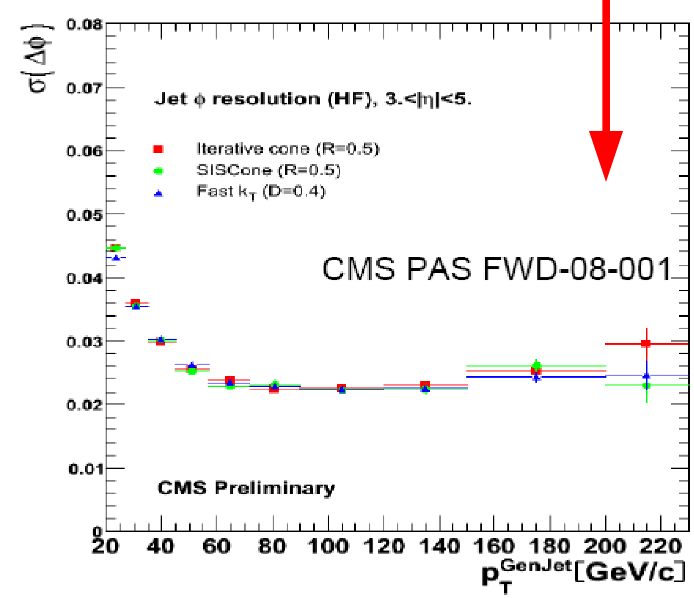
~0.02 for p_T>100 GeV



η resolution:

~0.05 for p_T~20 GeV

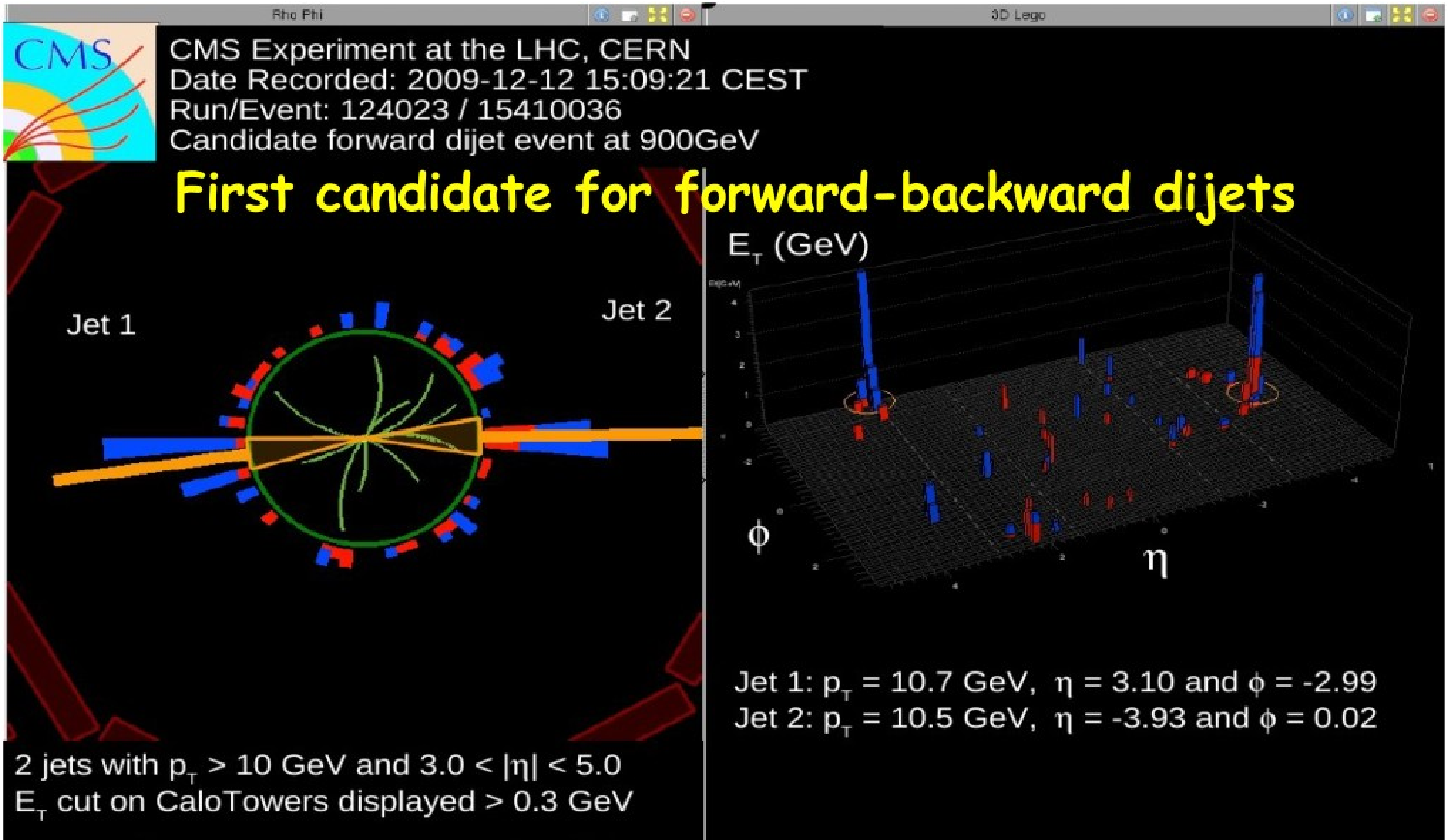
~0.02 for p_T>100 GeV



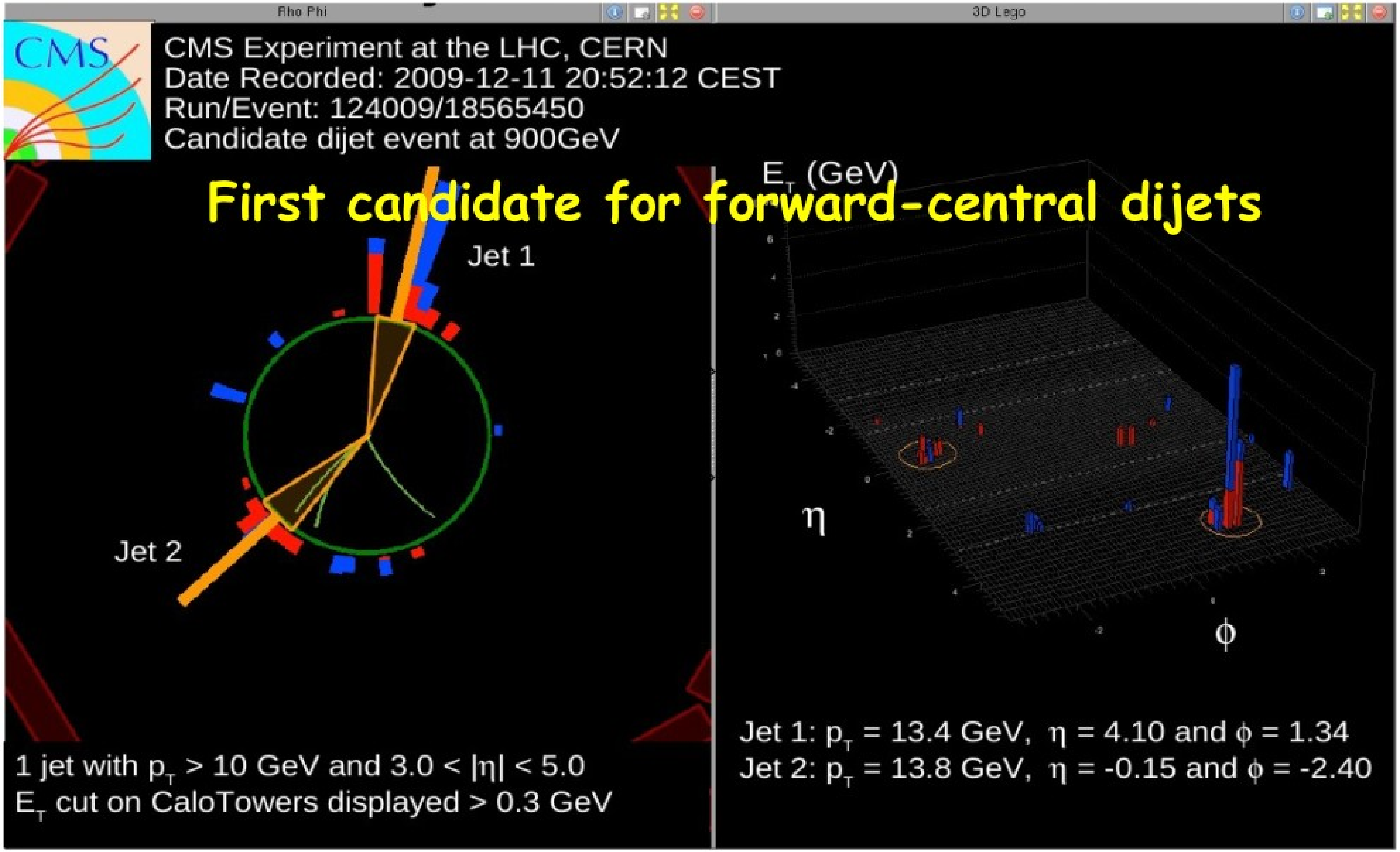
First Forward Jets from CMS

- First forward jets observed in 2009 LHC data
- 900 GeV center-of-mass energy
- Forward jets: $3 < |\eta| < 5$
- $p_T > 10$ GeV

First Forward Jets from CMS

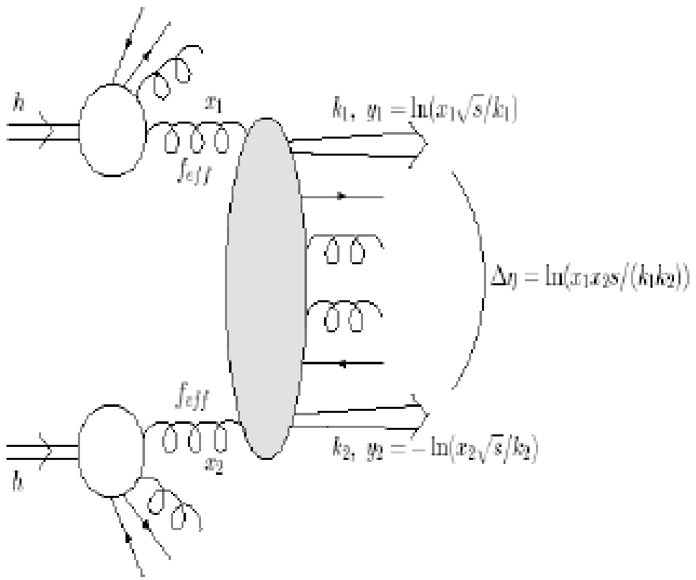


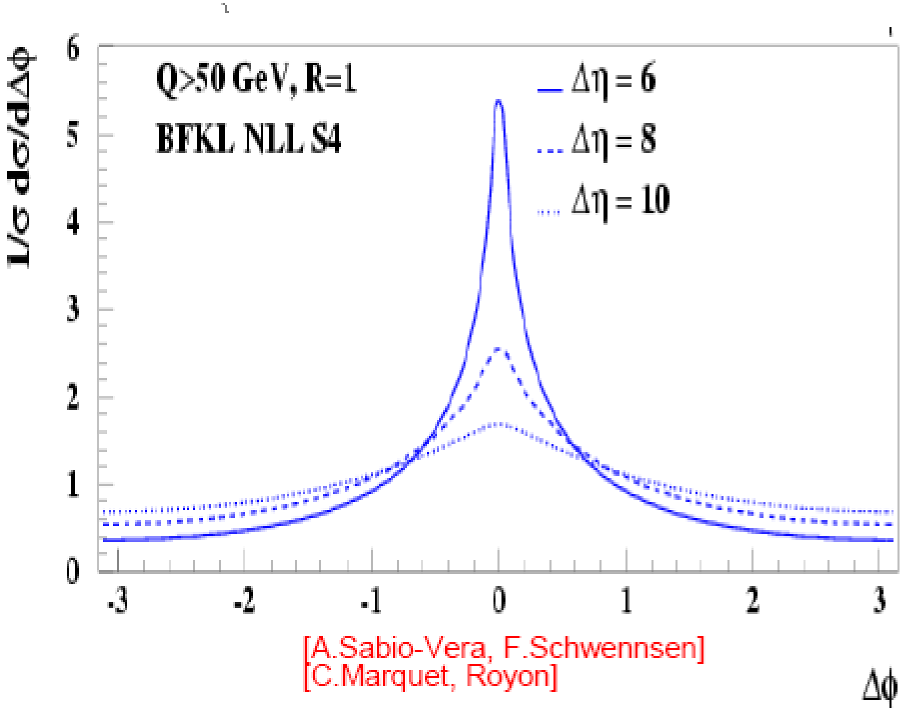
First Forward Jets from CMS



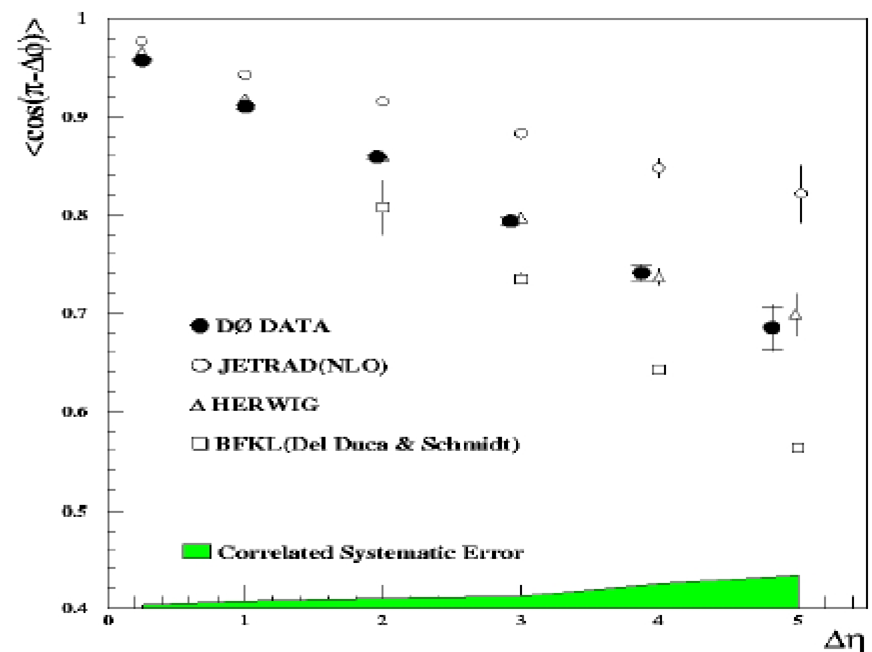
Jets correlations

- Mueller-Navelet dijets → large Δη separation
- Testing BFKL evolution
- Extra radiation between two jets will smear back-to-back correlation
- 6-10 units in Δη for HF





[A.Sabio-Vera, F.Schwennsen]
[C.Marquet, Royon]



S. Abachi et al. [DO Collaboration]
Phys. Rev. Lett. 77, 595 (1996).

A new CMS trigger will select dijet events with large Δη

Jets correlations

Other possible observables:

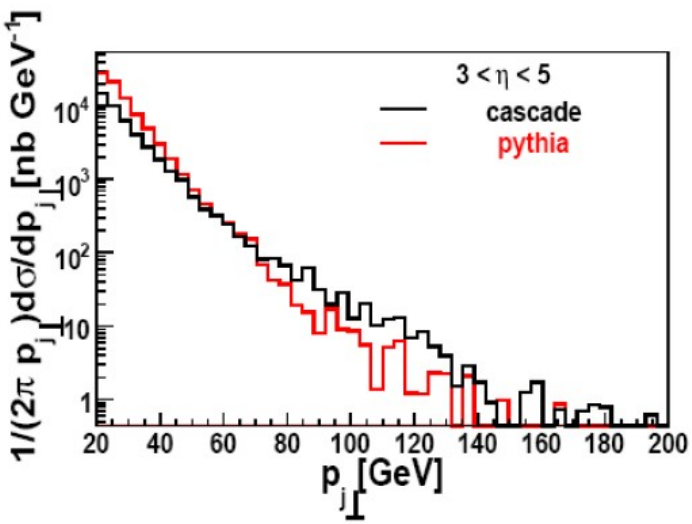
1. Dijet K-factor = inclusive dijet / “exclusive” dijet

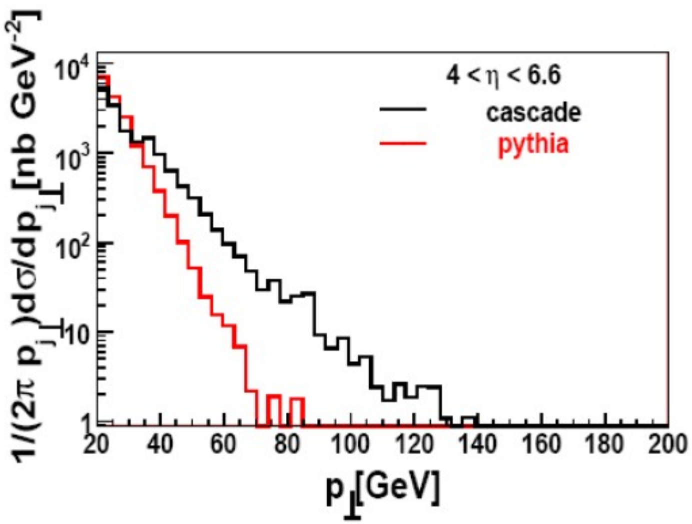
Inclusive dijet V.Kim & G. Pivovarov (96-98)

Most forward/backward dijet A.Mueller & H.Navelet (87)

2.

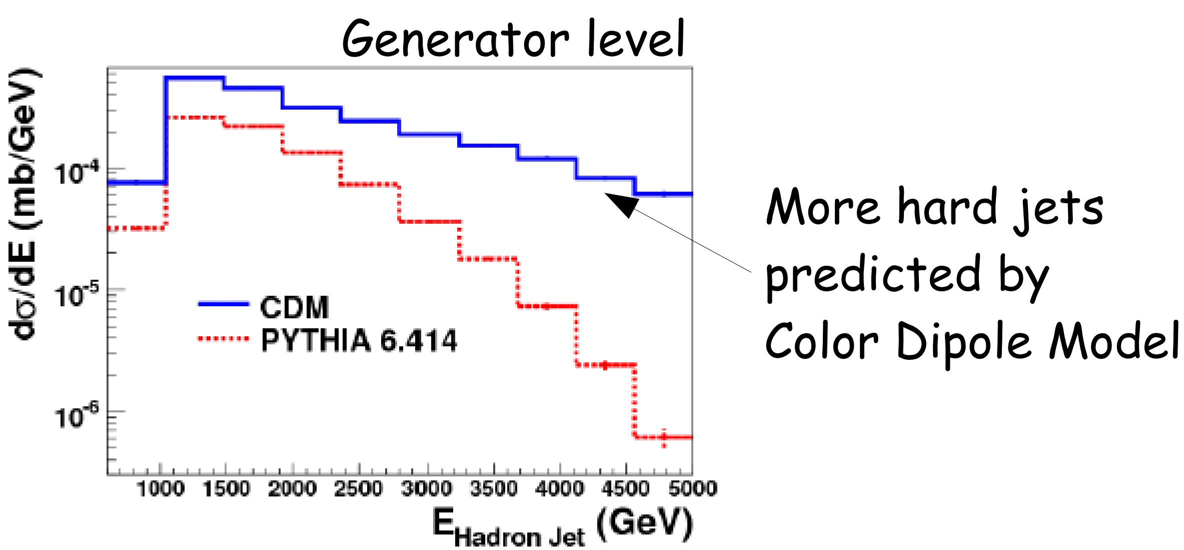
Central jet	Forward jet	Central jet	Forward jet
$\lvert y_j \rvert < 2$	$3 < y_j < 5$	$\lvert y_j \rvert < 2$	$4. < y_j < 6.6$
$p_{jt} > 20\text{GeV}$	$p_{jt} > 20\text{GeV}$	$p_{jt} > 20\text{GeV}$	$p_{jt} > 20\text{GeV}$

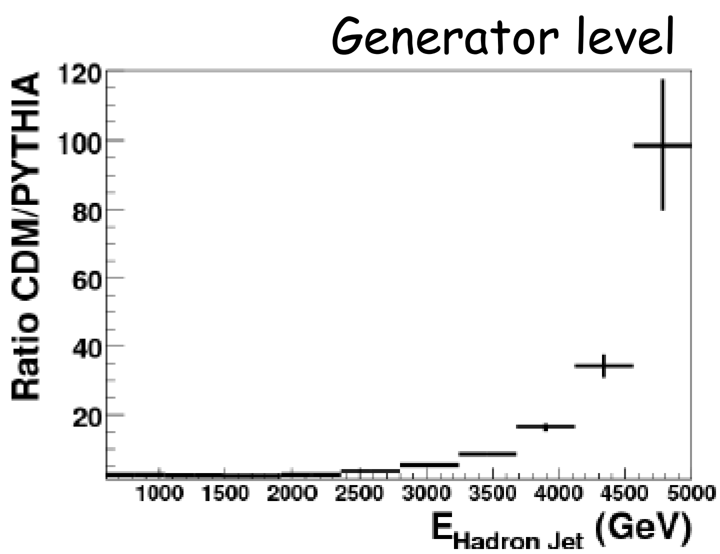




Jets with CASTOR

Selection: 2 central jets, Et>50 GeV
1 jet in CASTOR region, Et>10 GeV





Both PYTHIA and ARIADNE are run together with Multiparton Interactions Tune A. (Tune A = to TEVATRON data.)

- A good tool to distinguish between DGLAP and non-DGLAP types of QCD evolution
- Also extend Mueller-Navelet studies into CASTOR acceptance

SD production of W and dijets

- Both are hard diffractive processes characterized by the presence of a hard scale and a Large Rapidity Gap in the final state.

- Sensitive to the diffractive structure function of the proton

sensitive to the quark component of the proton

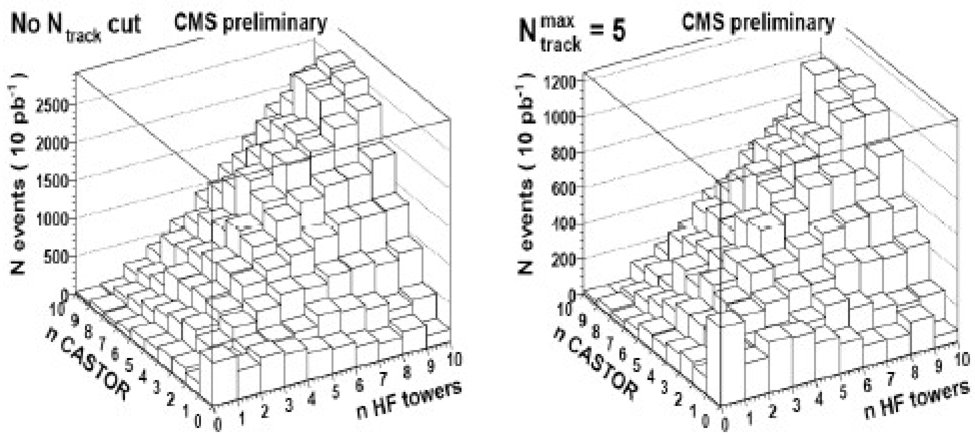
sensitive to the gluon component of the proton

- selection of diffractive candidates using the multiplicity distributions in the central tracker and HF/CASTOR: diffractive events on average have lower multiplicity in the central region and in the "gap side"

SD production of W and dijets

- **Dijets production:**

  O(300) evts/10 pb^{-1} in
  [n(Castor), n (HF)] = [0,0] bin



Diffractive events peak at zero

Next step: measurement of the ratio of SD to the total yields for W and dijet production giving an access to the estimation of:

- the rapidity gap survival probability
- the quark/gluon component in the diffractive PDFs of the proton

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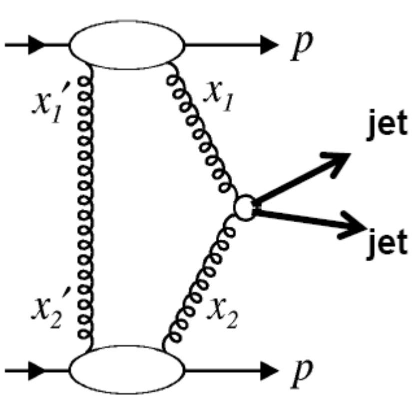
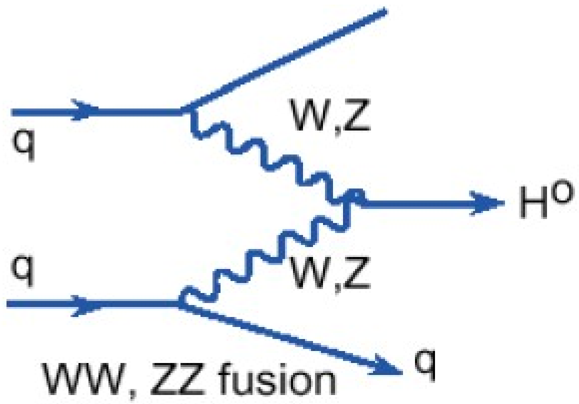


- Two jets produced exclusively
- $R_{jj} = M_{jj}/M_X$ variable (for CEP close to ~1)
- Observation at Tevatron (Phys. Rev. D77, 05, 2004)
- σ ~ O(10) pb at LHC energies (large sample)
- Central two – three jets production can be used to constrain Sudakov factor

Long term plans



Leptonic H decay:

qqH → jj WW → jj lvlv

Low activity in central region, forward jets

Graviton production in trans-Planckian regime

G. Giudice, R. Ratazzi & J. Wells (99,02)

t-channel gravition contribution

↓

large mass dijet with large rapidity interval

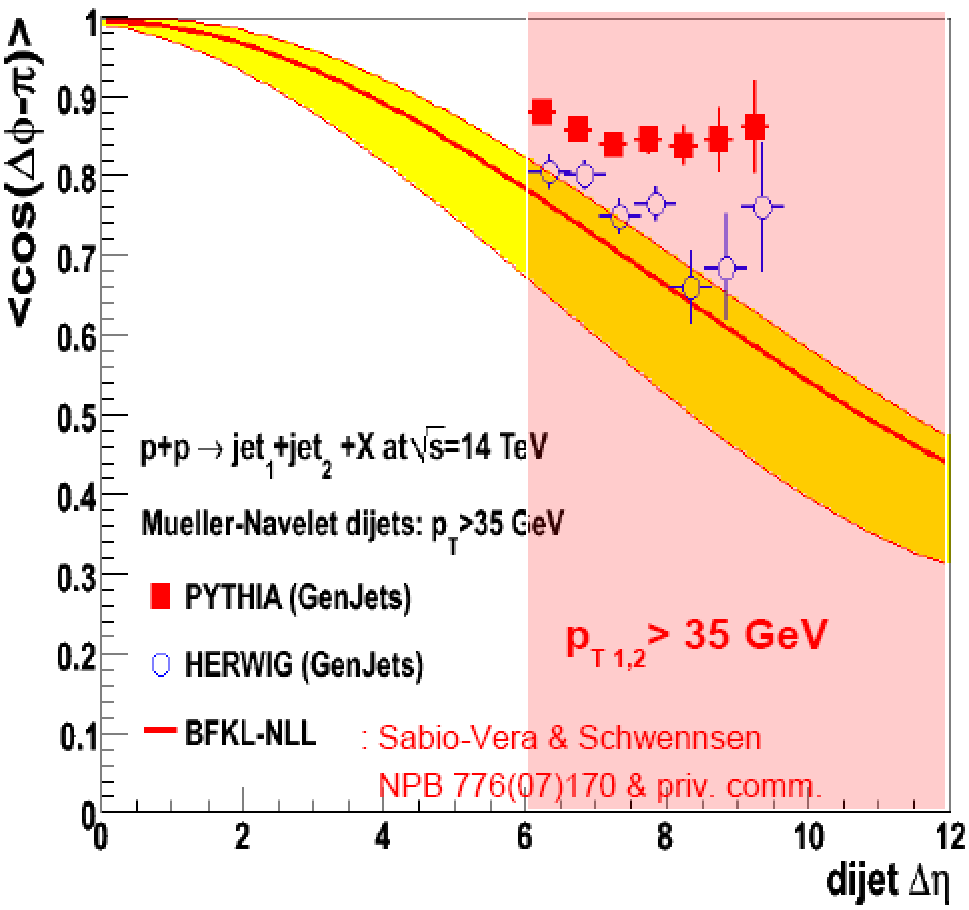
few hundred pb^{-1}

Summary

- CMS forward detectors are taking data
- Very early results available → 900/2360/7000 GeV
    - Forward energy flow measurement – input to the UE tunes
    - First observation of jets in $|\eta|>3$
- Early results will come soon:
    - Inclusive jet spectra
    - First correlations
- Larger rapidities – CASTOR see: S. Ochesanu talk
- Diffraction jets and exclusive jets production with ~100 pb^{-1}
- FWD jets studies after 2011 → 14 TeV
    - Forward jets studies repeated for 14 TeV
    - Higgs search
    - Exotica search

Extensive forward jets program for all integrated luminosities

Jets correlations



Average cos(Δφ-π) as a function of Δη

HERWIG shows ~15% more decorrelation than PYTHIA and ~20% less than BFKL analytical estimates

Parton showering & hadronization has to be taken into account