The CMS QCD-related results from the first LHC data

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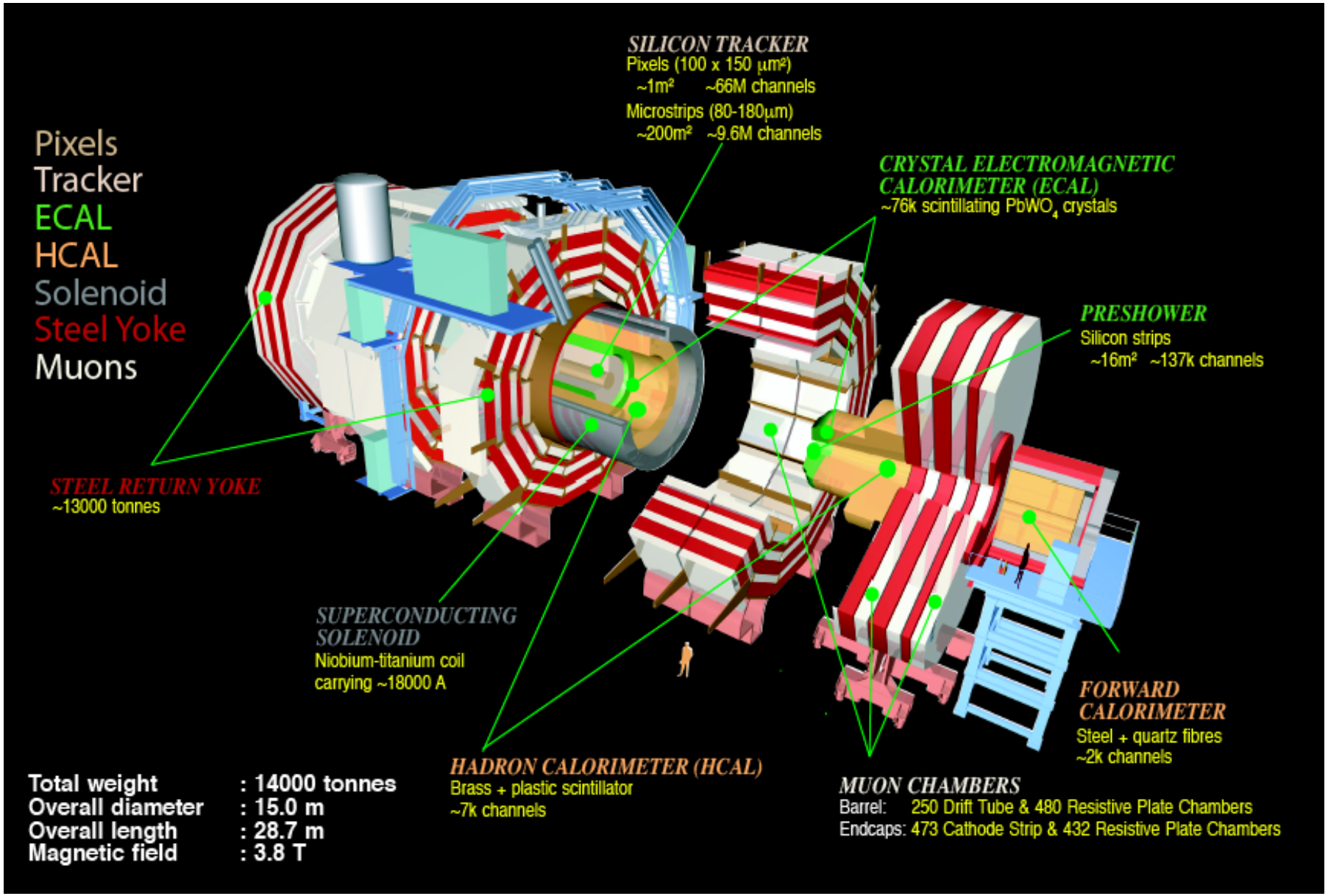
on behalf of the CMS Collaboration

Excited QCD 2011, Les Houches, Rhône-Alpes (France)

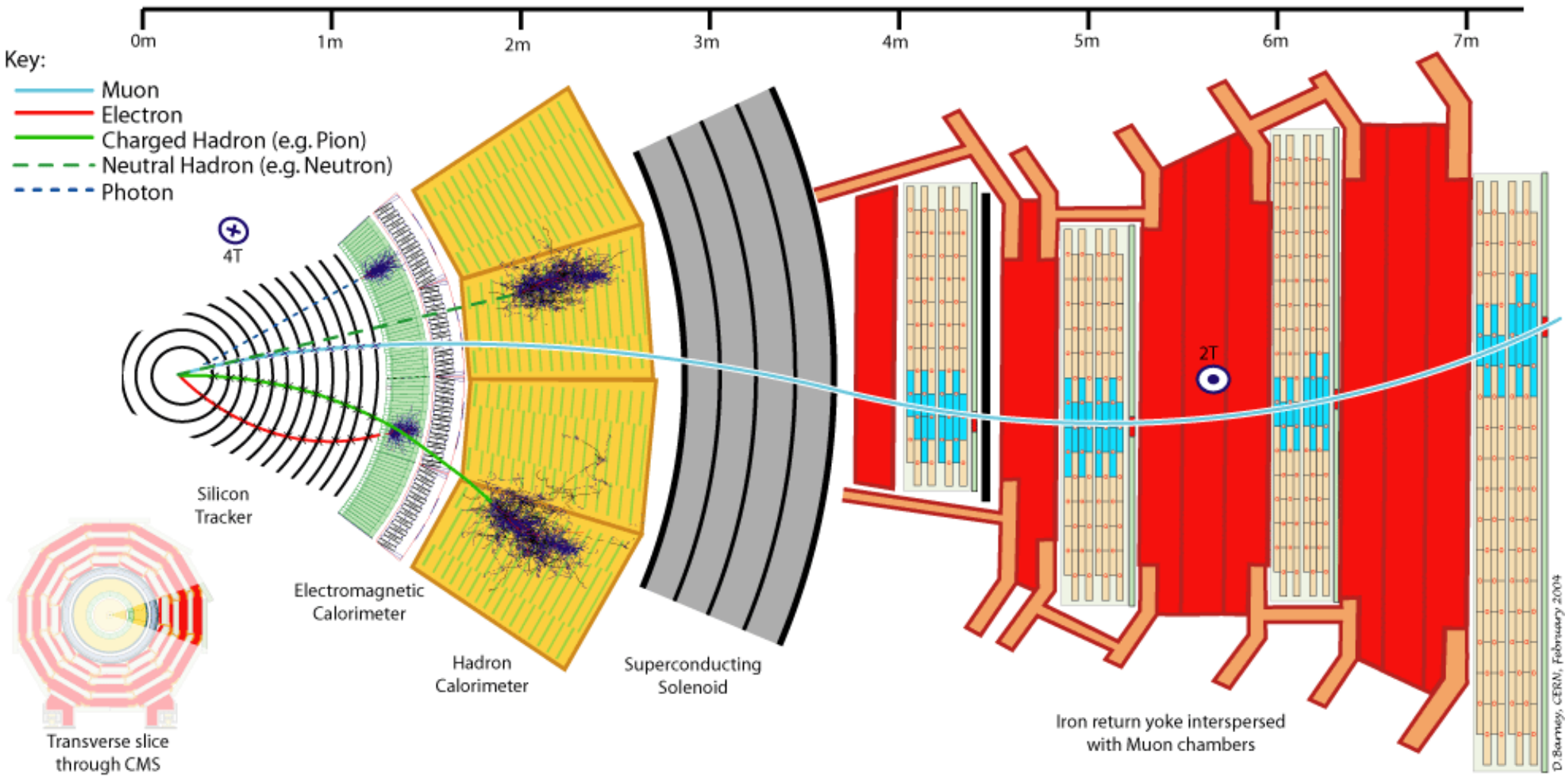
Outline

- CMS Experiment (Quick)
- 2010 Operation in CMS
- QCD
- Forward Physics
- Heavy Ion Physics
- Summary
- Conclusions
- References

CMS DETECTOR

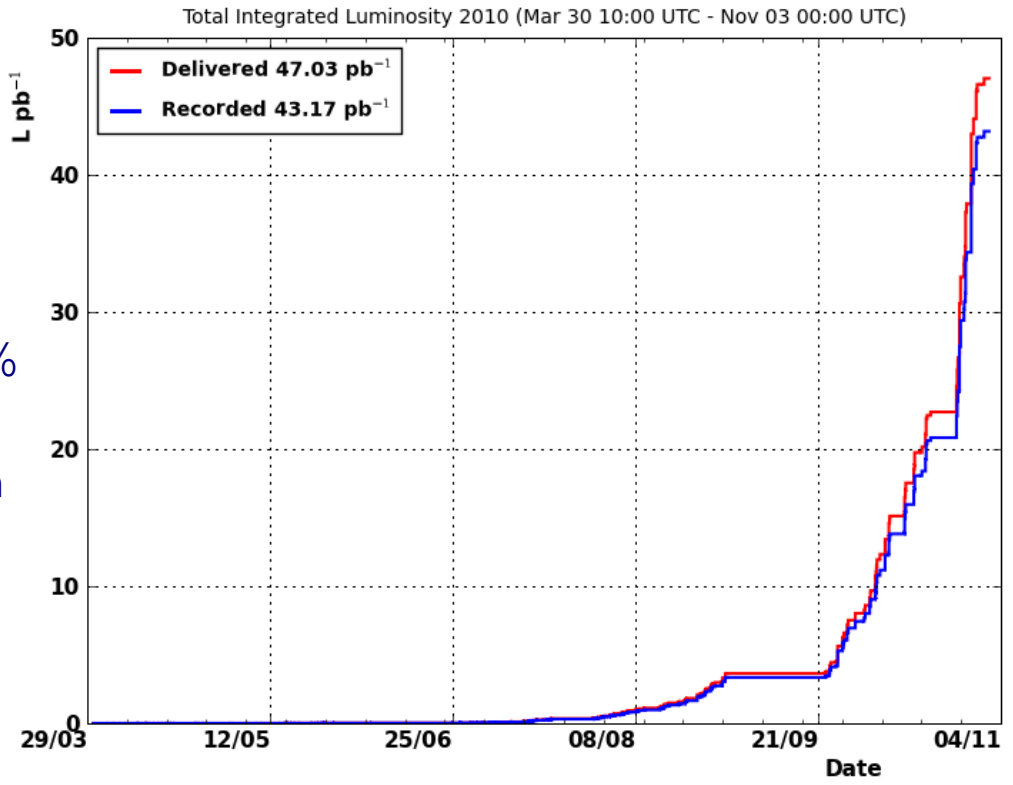


CMS DETECTOR



2010 Operation in CMS

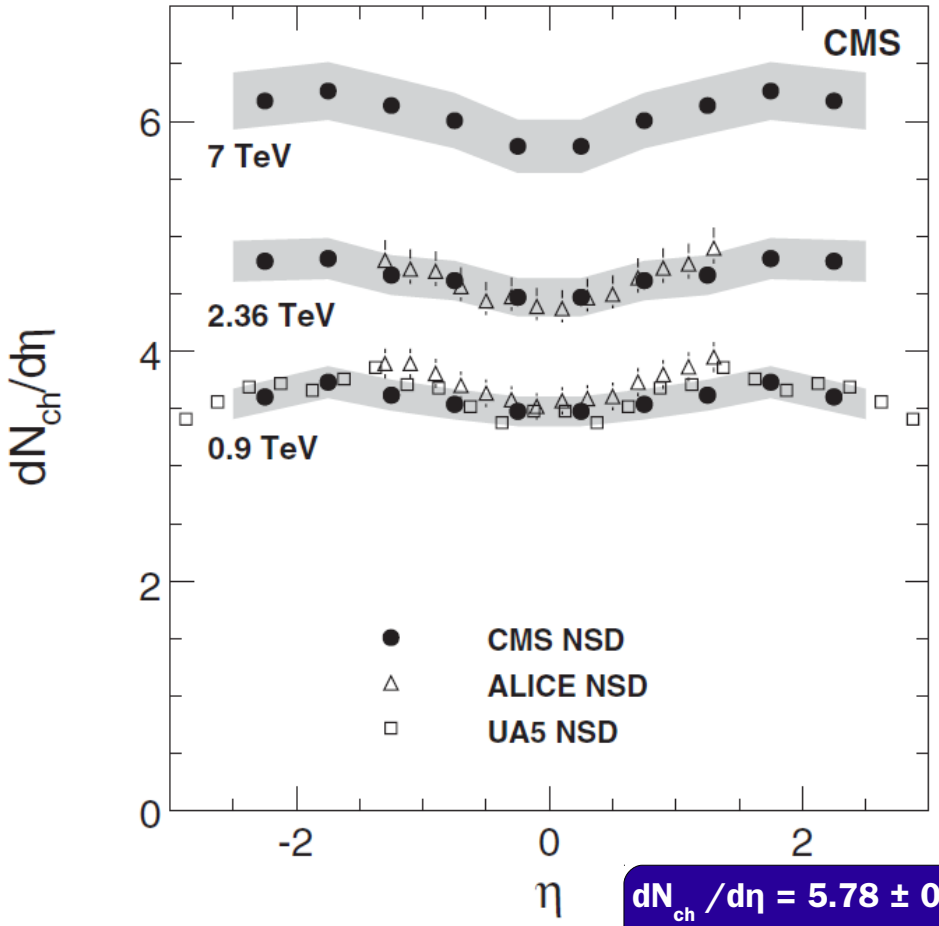
- 47 pb^{-1} pp collision data delivered by the LHC at $\sqrt{s}$=7 TeV
- Recorded luminosity 43.17 pb^{-1}
  - CMS data taking efficiency is greater than 90%
  - 85% of the data recorded while the CMS with all its sub-detectors
- LHC delivered over 9 μb^{-1} of Pb+Pb at $\sqrt{s_{NN}}$ = 2.76 TeV
- Overall luminosity has 11% uncertainty for the time being

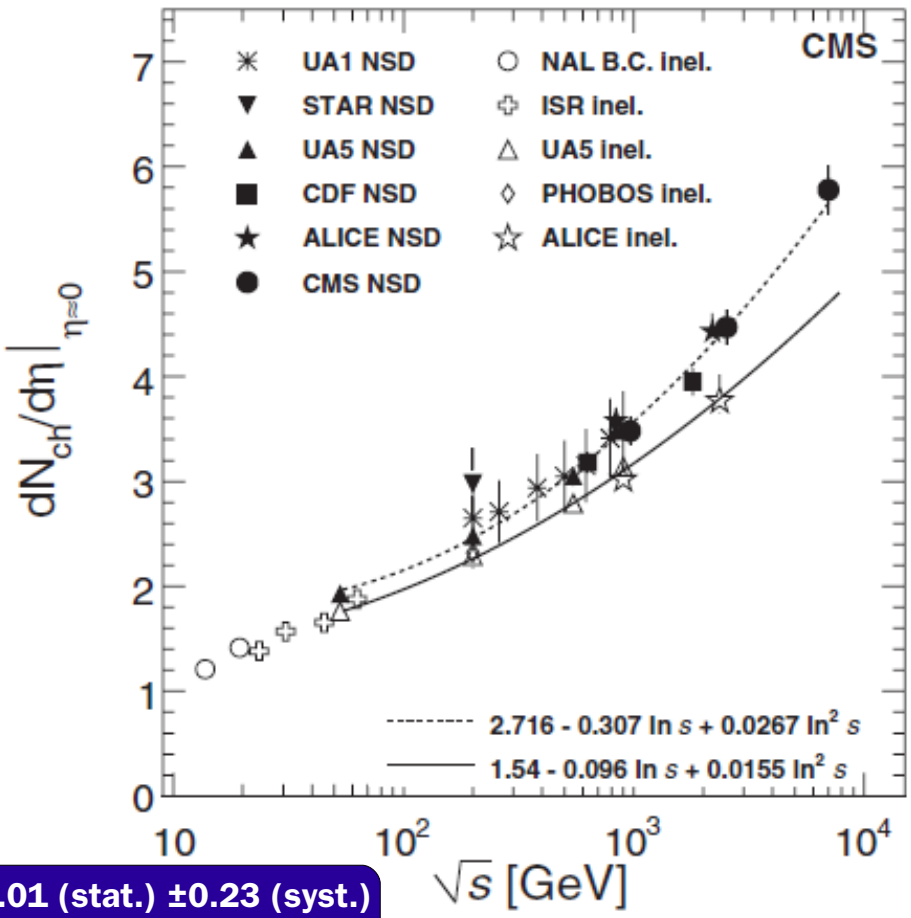


QCD Results

(soft p_T results)

Transverse momentum and pseudorapidity distributions of charged hadrons, PRL 105, 022002 (2010)

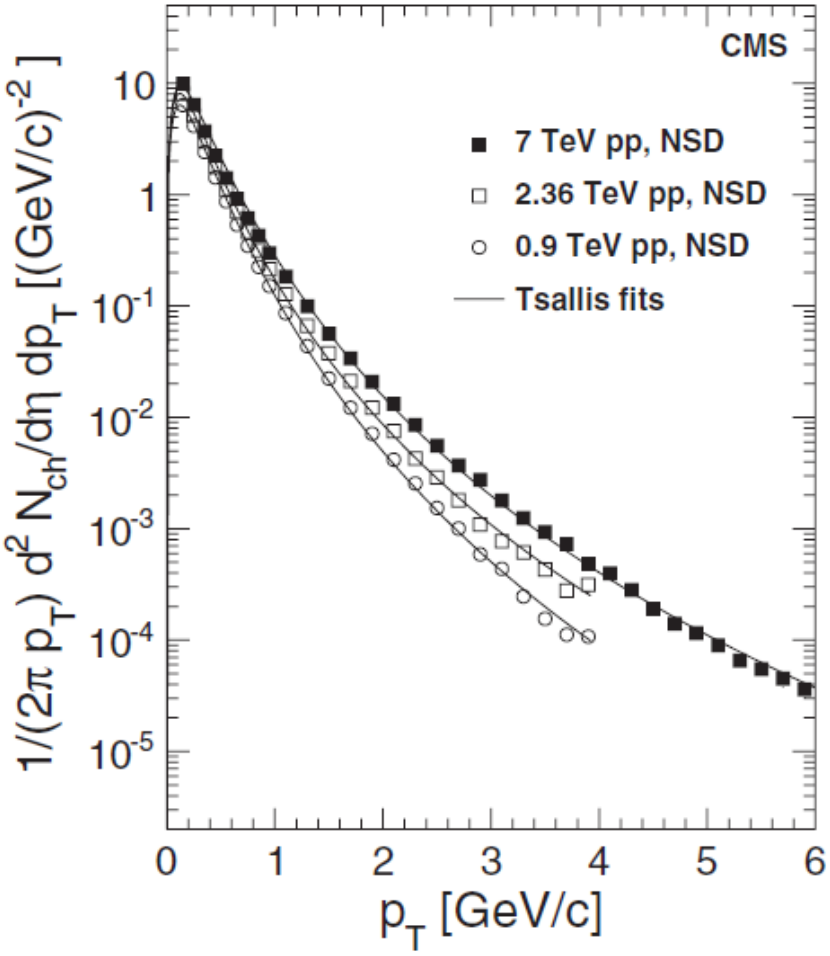


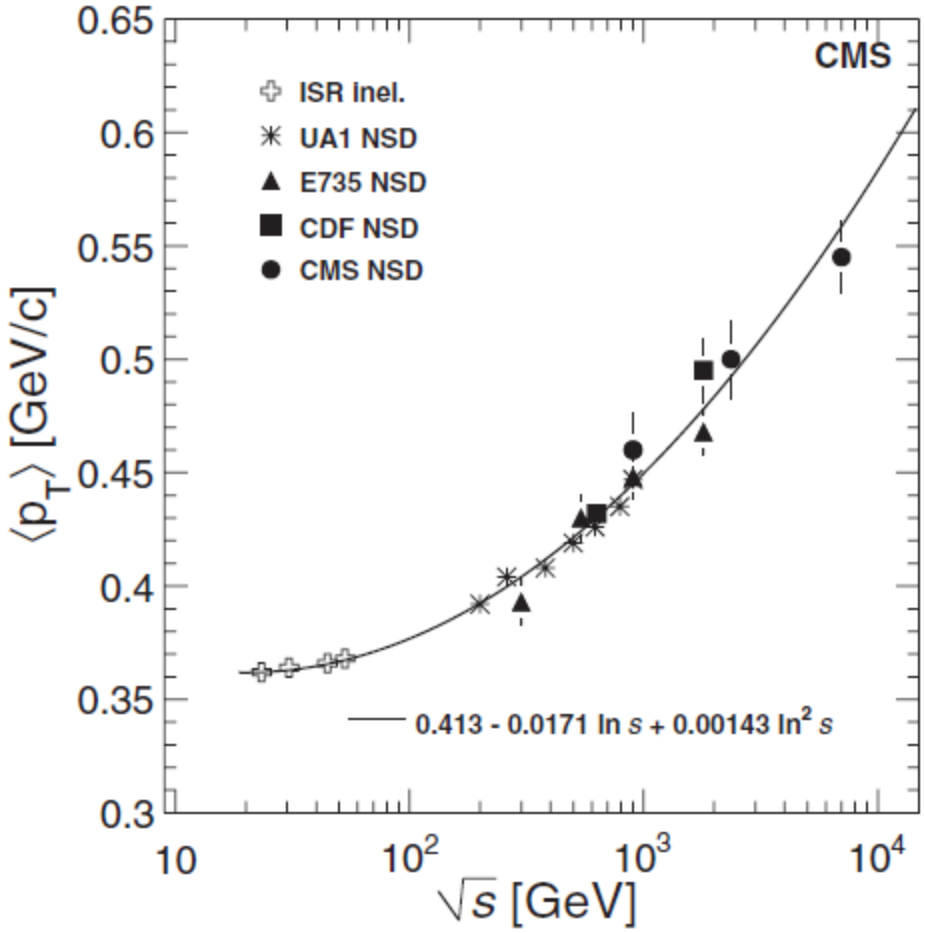


$dN_{ch}/d\eta$ = 5.78 ± 0.01 (stat.) ±0.23 (syst.) for NSD events at √s=7 TeV

- $dN_{ch}/d\eta$ was calculated for √s=0.9, 2.36 and 7 TeV by using the silicon pixel and the strip tracker with three different methods. (JHEP02(2010)041, CMS-QCD-10-06, CMS-QCD-09-10)
- Measurement at √s=0.9 TeV is in agreement with the measurements from other previous experiments.

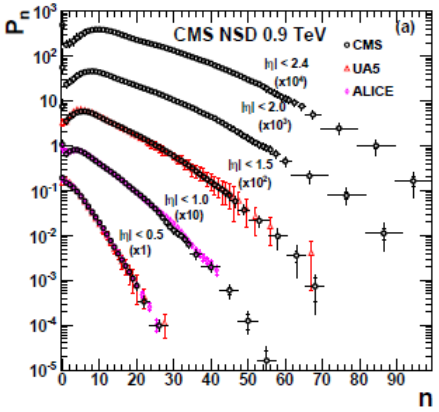
Transverse momentum and pseudorapidity distributions of charged hadrons, PRL 105, 022002 (2010)

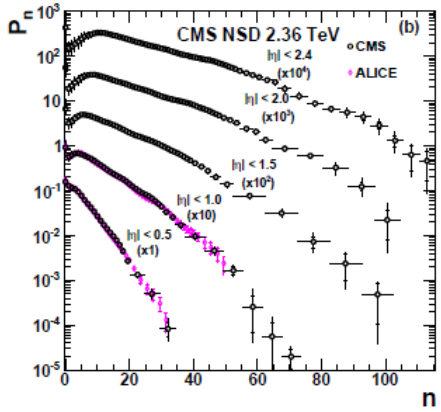




- $1/(2\pi p_T)\, d^2 N_{ch}/d\eta\, dp_T$ was calculated for $\sqrt{s}$=0.9, 2.36 and 7 TeV by using the silicon pixel and the strip tracker with three different methods.

Charged particle multiplicities in pp interactions at √s = 0.9, 2.36, and 7 TeV (CMS-QCD-10-004)



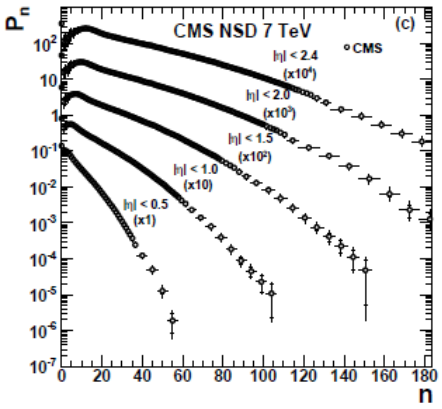


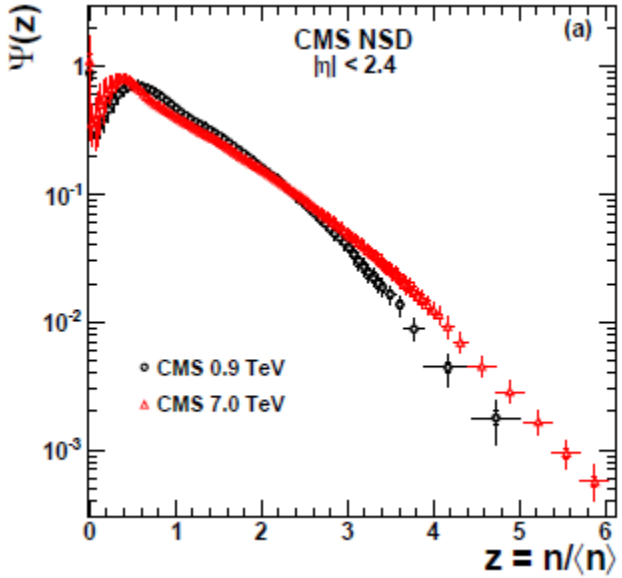
- Multiplicity (n) is measured by counting the number of tracks associated with a primary vertex

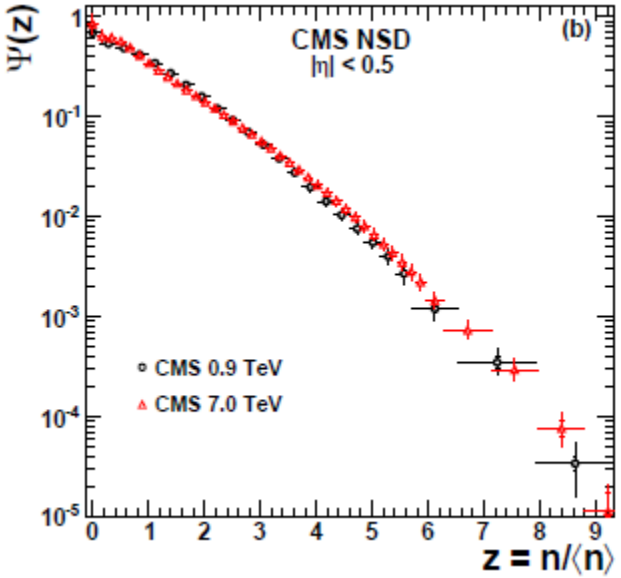
KNO Scaling

$\Psi(z)=P_n\langle n\rangle$ and $z=n/\langle n\rangle$

P_n is energy independent







- A strong violation of KNO (Koba, Nielsen, Olesen) scaling was observed for large pseudo-rapidity interval $|\eta|<2.4$

QCD Results

(high p_T results)

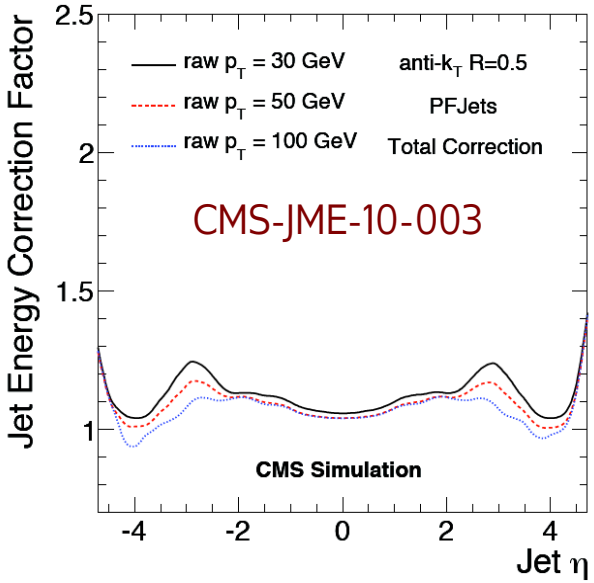
Jet Reconstruction and Calibration in CMS

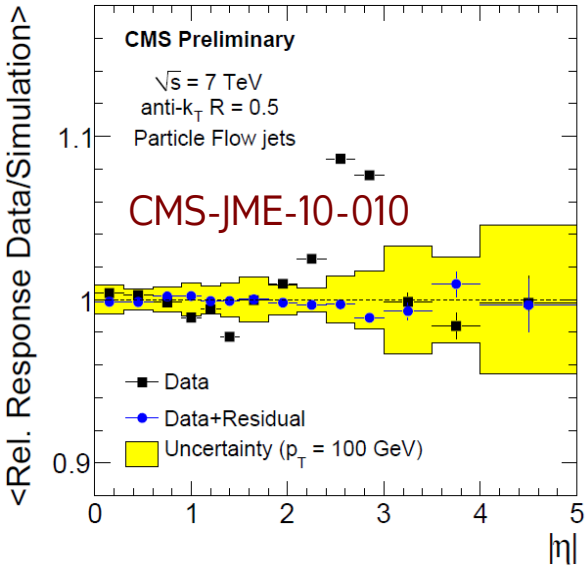
Jet Reconstruction

- Jets are the experimental signatures of quarks and gluons
- A jet algorithm is a set of mathematical rules which reconstructs a jet from observed spray of particles

$$d_{ij} = p_{T,i}^{2p} \qquad d_{ij} = min(p_{T,i}^{2p}, p_{T,j}^{2p}) \frac{\Delta R_{ij}^2}{D^2}$$

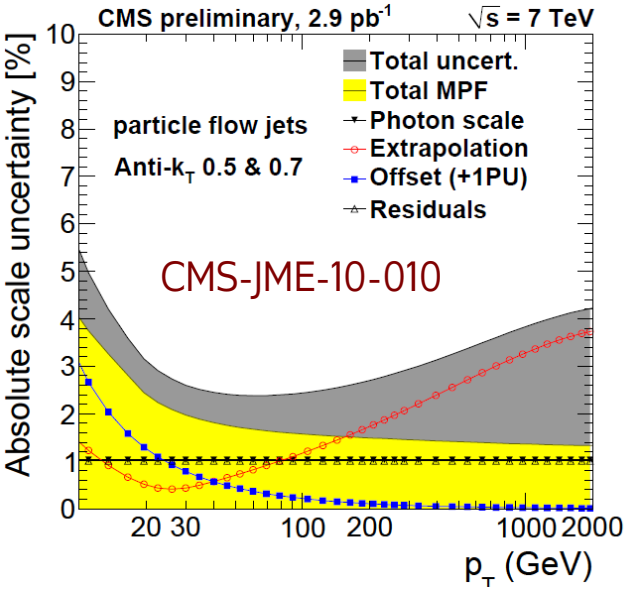
- Default CMS jet reconstruction is "anti-k_T jet" algorithm with *p=-1* in the expression above





Jet Energy Calibration

- Factorized approach used like in Tevatron
  - offset correction
  - relative correction
  - absolute correction
- *In-situ* residual correction
  - dijet p_T balance
  - MPF method adopted from DØ



- Jet Calibration vs. η is better than 1%
- Jet Energy scale uncertainty is 3-5% over the whole p_T range

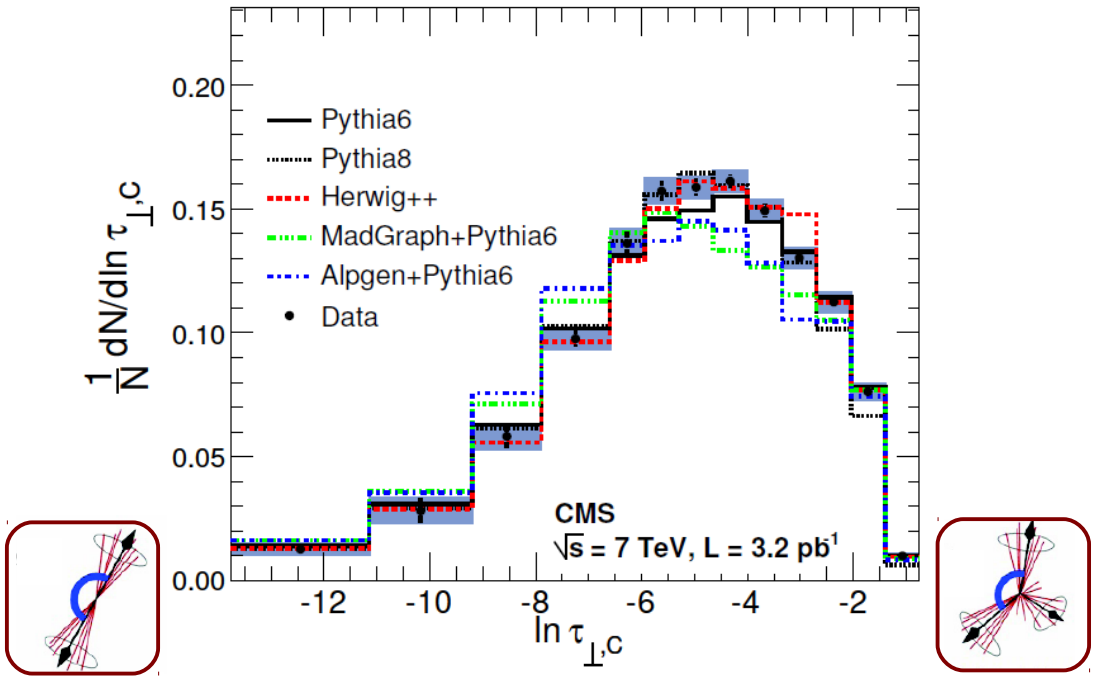
First Measurement of Hadronic Event Shapes in pp Collisions at √s = 7 TeV, CMS-QCD-10-013

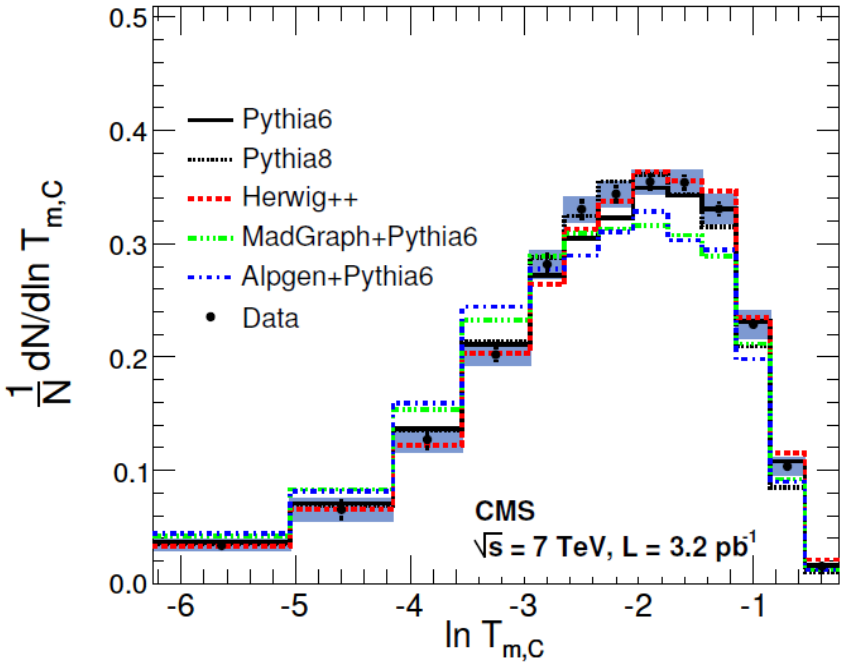
The central transverse thrust is defined:

$$\tau_{\perp,\mathcal{C}} \equiv 1 - \max_{\hat{n}_\mathrm{T}} \frac{\sum_i |\vec{p}_{\perp,i} \cdot \hat{n}_\mathrm{T}|}{\sum_i p_{\perp,i}}$$

$$T_{m,\mathcal{C}} \equiv \frac{\sum_i |\vec{p}_{\perp,i} \times \hat{n}_{\mathrm{T},\mathcal{C}}|}{\sum_i p_{\perp,i}}$$

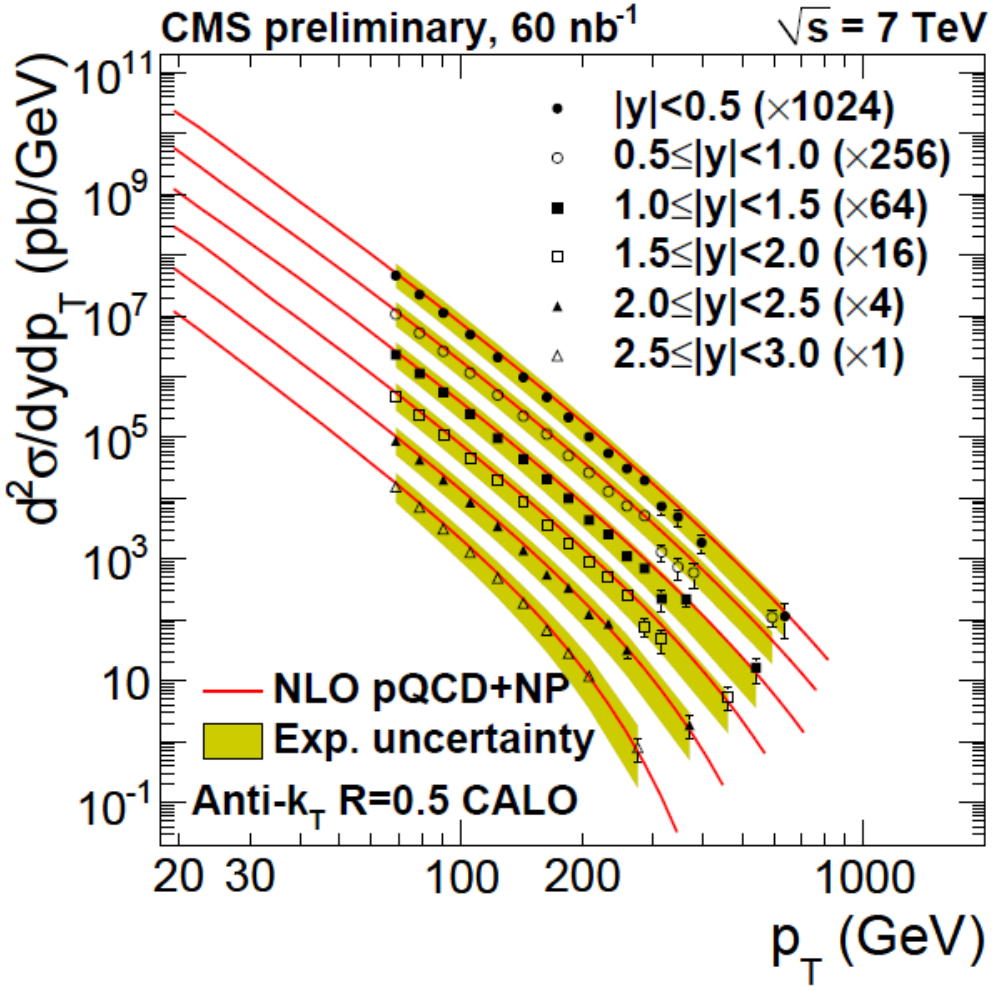
- Provides geometric information about the hadronic final states
- Expected that energy-scale uncertainties should cancel to a large extent
- A valuable tool for early measurements of the properties of QCD multijet events at the LHC and the tuning of MC
- The event-shape distributions from PYTHIA6, PYTHIA8, and HERWIG++ show satisfactory agreement with the data, while discrepancies are found between the data and predictions from ALPGEN and MADGRAPH models



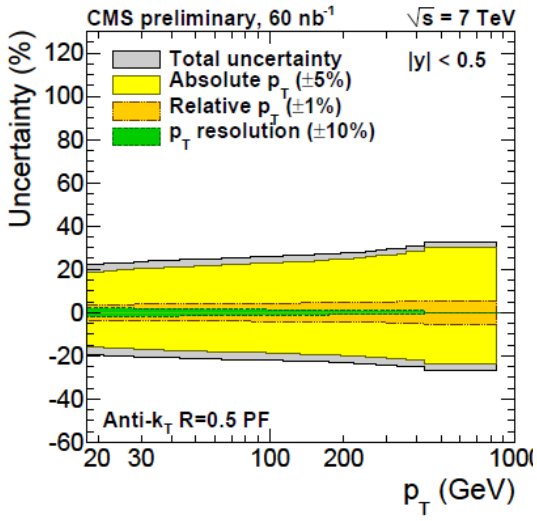


Measurement of the Inclusive Jet Cross Section in pp Collisions at 7 TeV, CMS-QCD-10-011

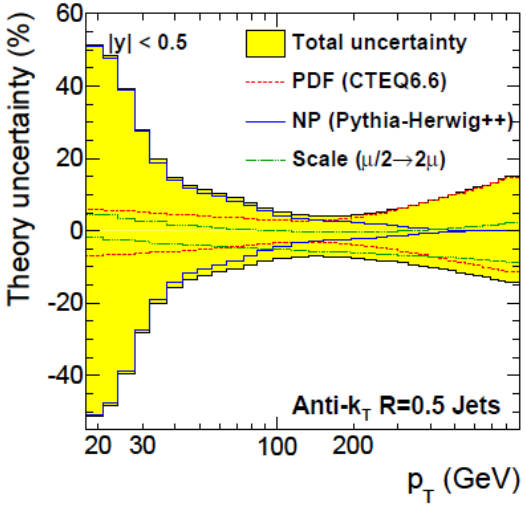
- Extends the high p_T limit of this kind of measurement beyond the Tevatron limit
- Uses 3 different type of jet collections (Calorimeter, JetPlusTracks, Particle Flow) giving compatible results.
- JES, Jet p_T resolution and Luminosity are the main sources of systematic uncertainty
- Good agreement between data and NLO @pQCD



Experimental Uncertainty



Theoretical Uncertainty



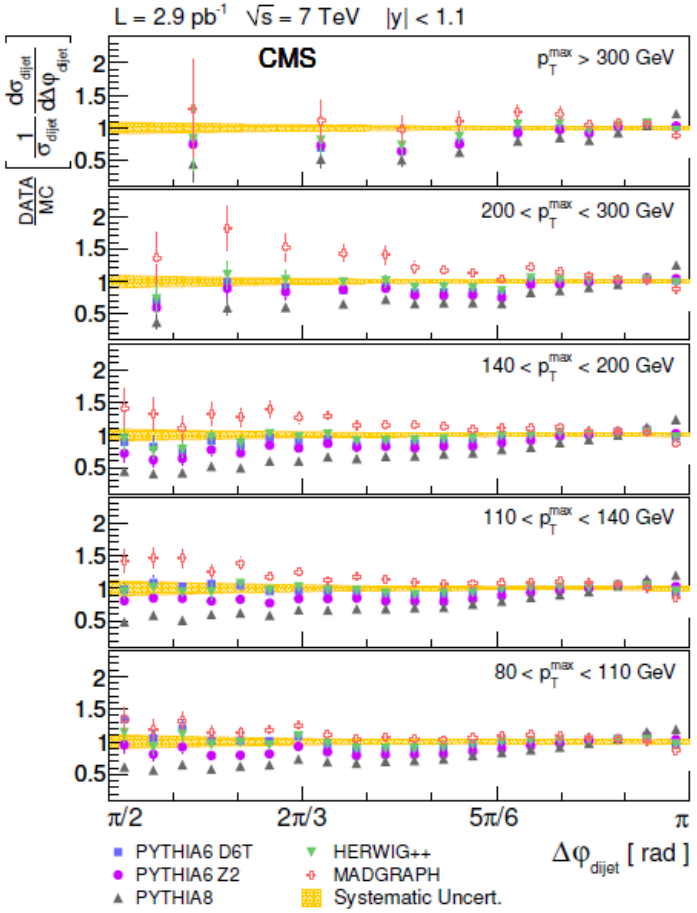
- An updated measurement with more integrated luminosity is on the way

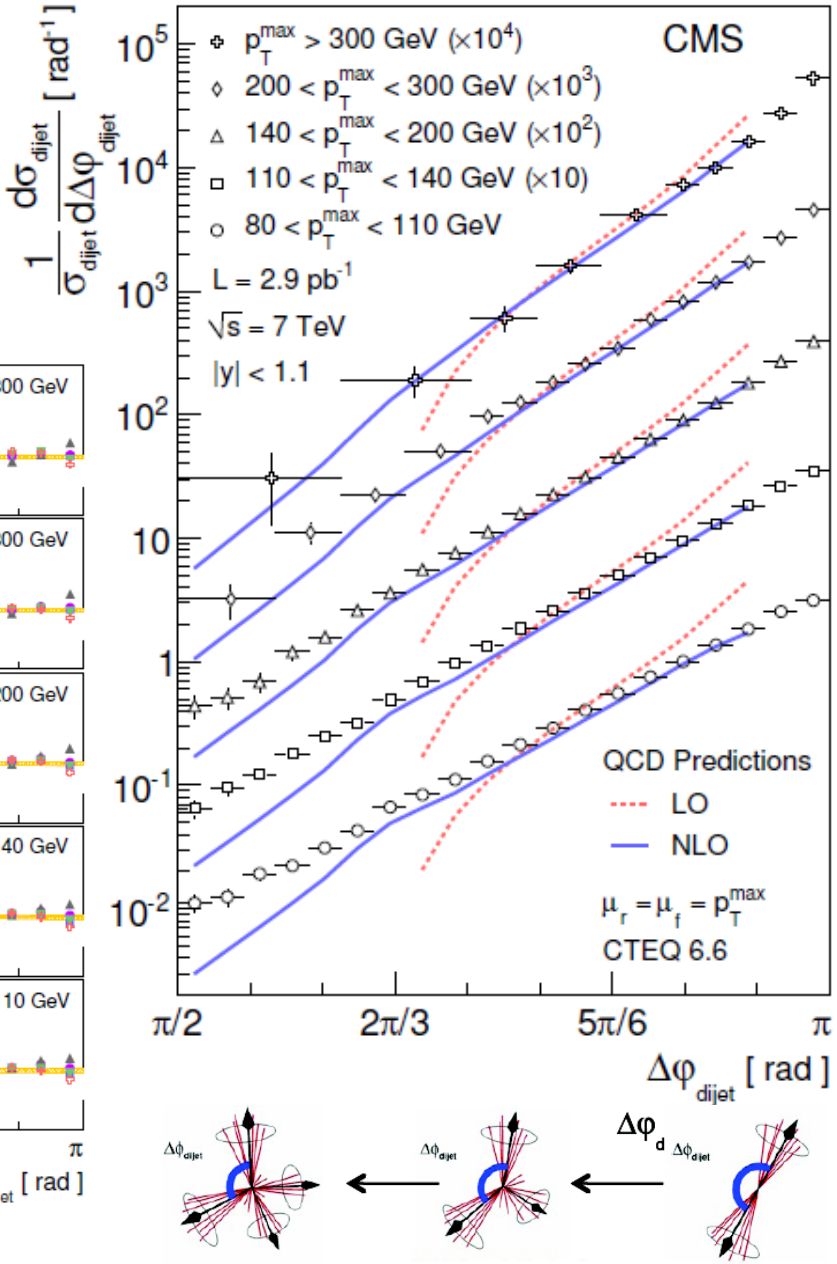
Dijet Azimuthal Decorrelations in pp Collisions at pp √s = 7 TeV, CMS-QCD-10-026

- Measurement of the azimuthal angle between two leading jets

$$\Delta\phi_{dijet} = |\phi_{jet1} - \phi_{jet2}|$$

- Δϕ distribution is sensitive to the higher order radiation
- Useful for tuning phenomenological parameters (ISR) in MC event generators
- Pythia6 and Herwig++ are in reasonable agreement with data

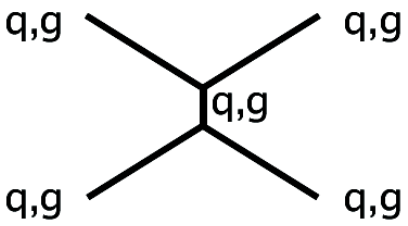




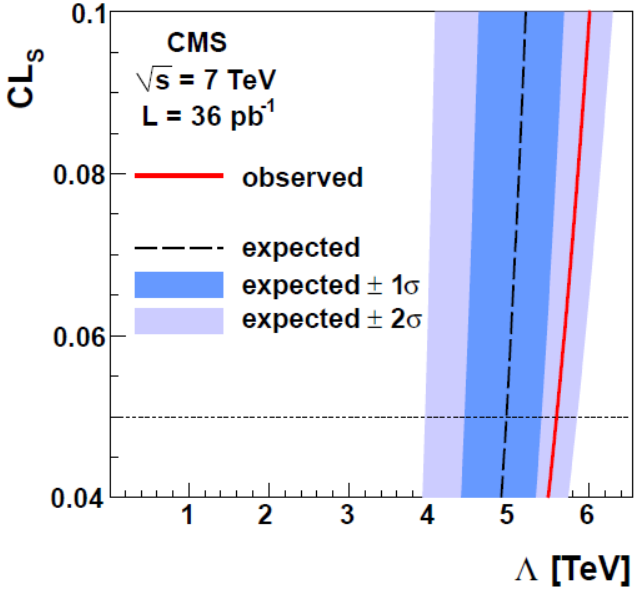
Measurement of Dijet Angular Distributions and Search for Quark Compositeness in pp Collisions at √s = 7 TeV, CMS-QCD-10-016

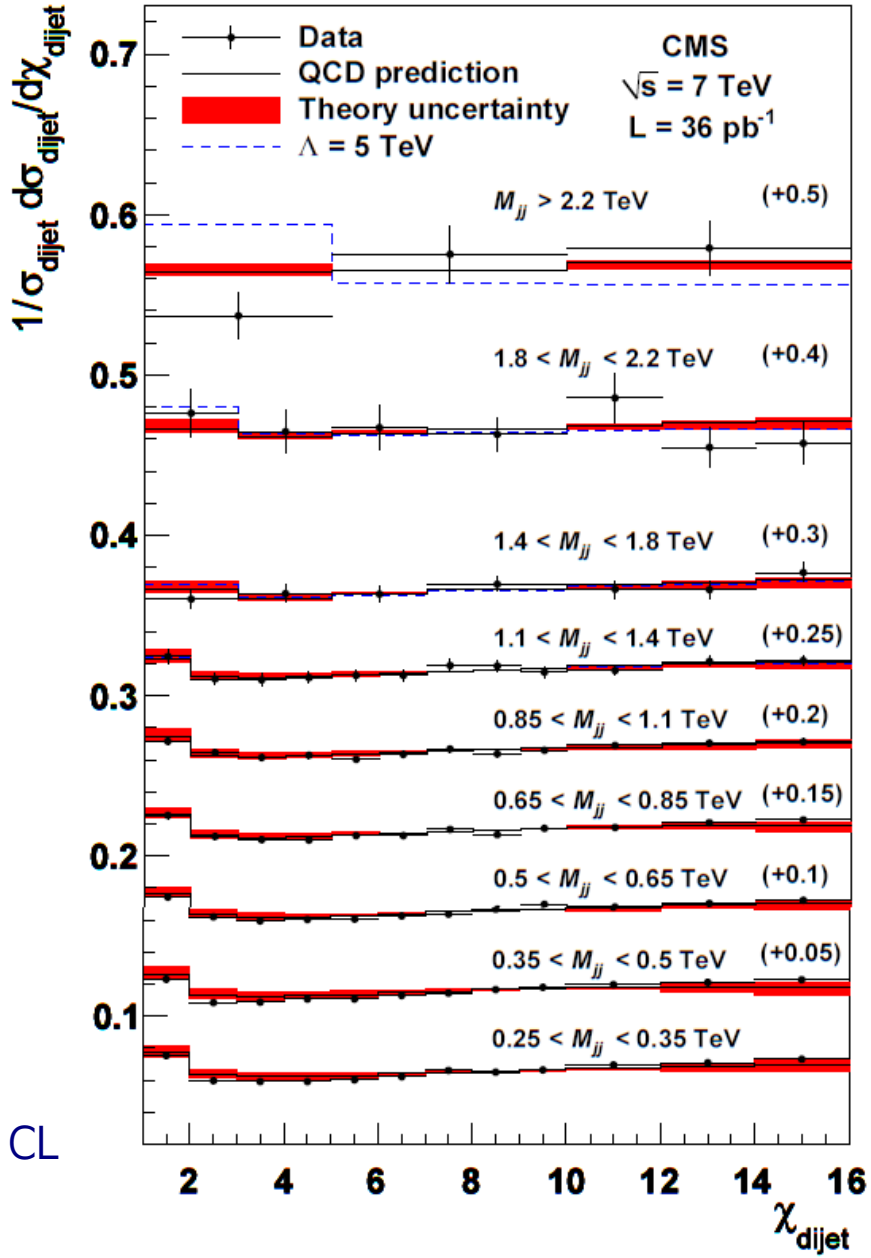
The observable χ is defined as:

$$\chi_{dijet} = e^{|y_1 - y_2|} \sim \frac{1 + |cos\theta^*|}{1 - |cos\theta^*|}$$



QCD t-channel is flat in χ





- χ_{dijet} dijet distributions are found to be in good agreement with NLO pQCD predictions

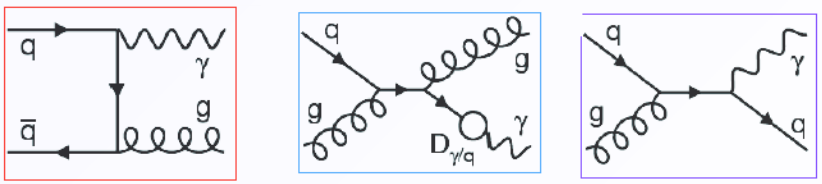
- Excluded contact interaction scale Λ< 5.6 TeV at the 95% CL where expected limit at: Λ< 5.0 TeV

QCD Results

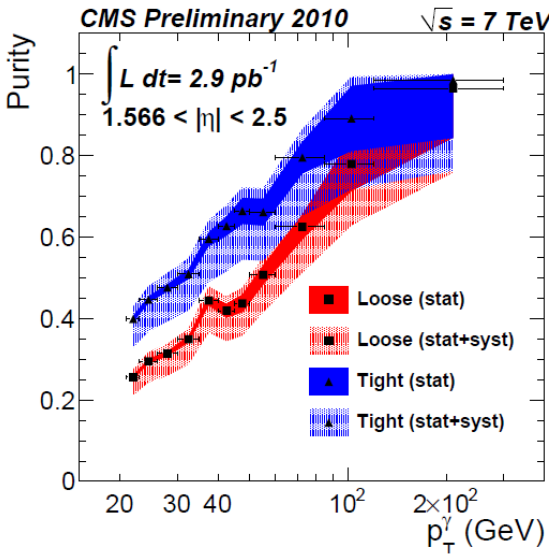
(photon results)

Isolated Photon (γ) Reconstruction and Identification in CMS, CMS-EGM-10-006

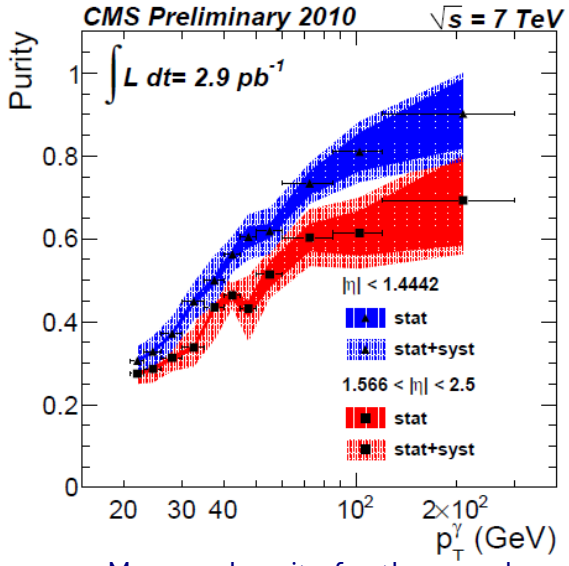
- Identification of isolated photons plays a crucial role in the context of Higgs and some new physics searches at the LHC as it allows to discriminate against standard model background



isolated single photons are produced either directly in the hard scattering, via quark-gluon Compton scattering and quark-anti-quark annihilation, or via the collinear fragmentation of a parton produced with large transverse momentum

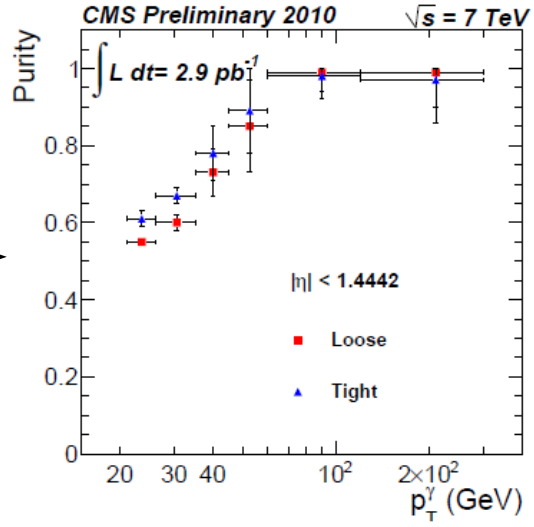


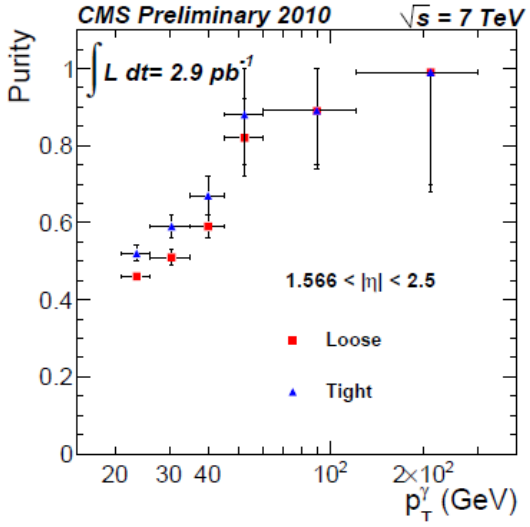
- Measured purity for the sample defined by the cluster shape method as a function of photon p_T



- Measured purity for the sample defined by the isolation method as a function of photon p_T

Measured purity for the sample defined by the conversion method as a function of photon p_T

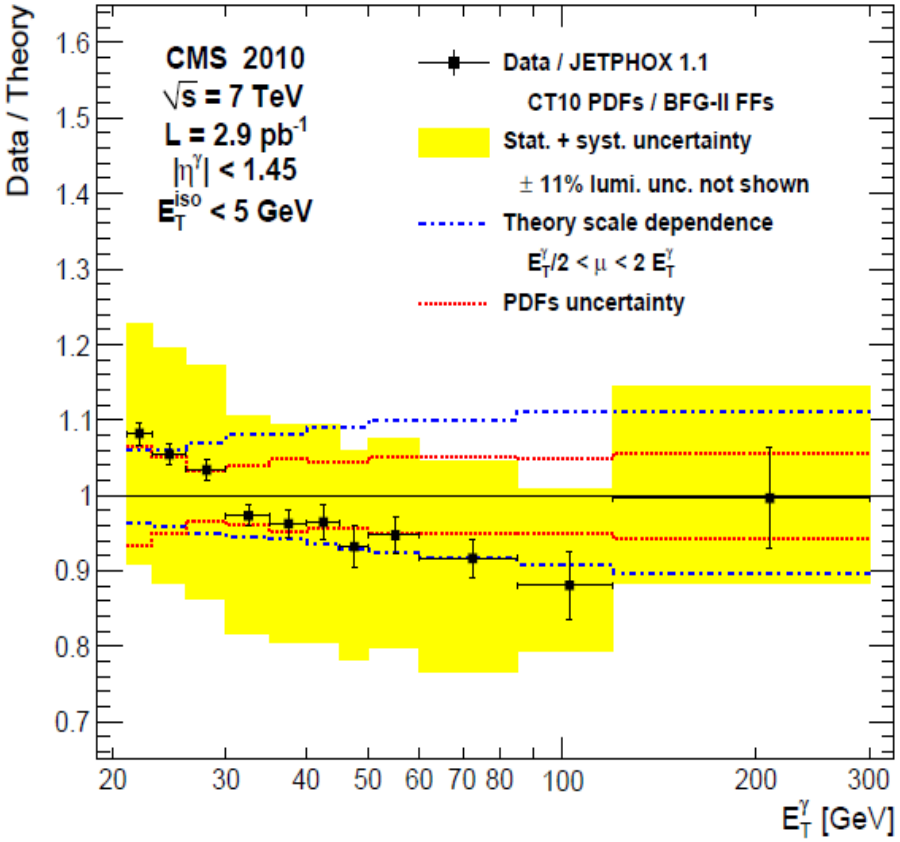


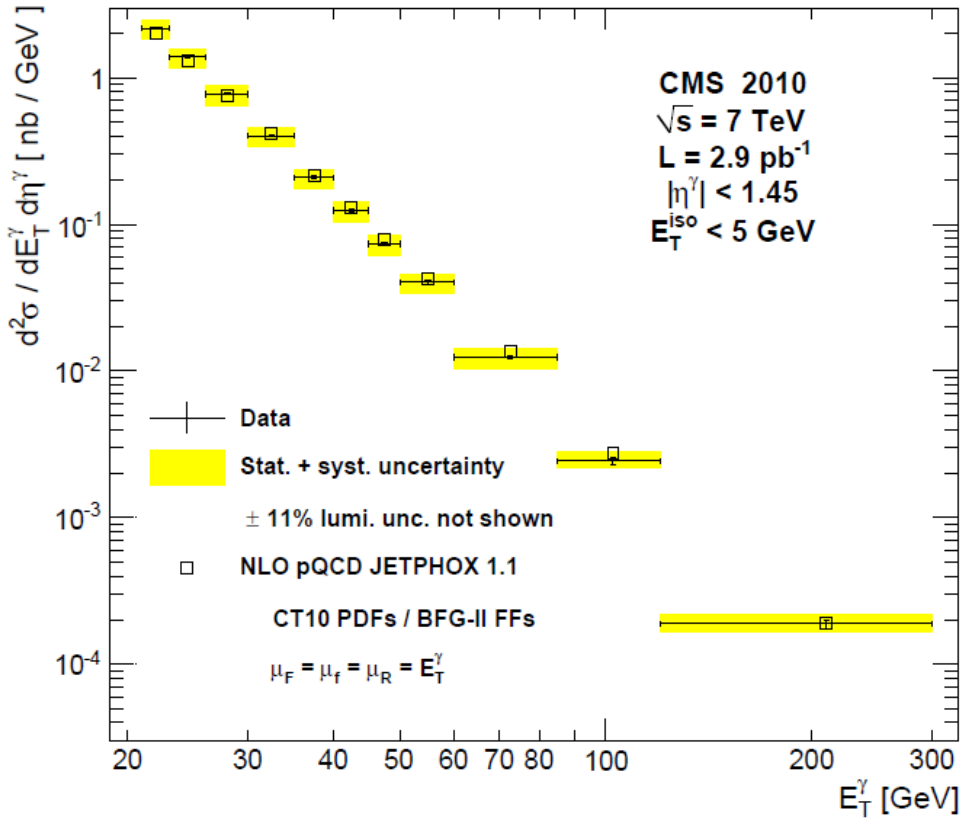


Measurement of the Isolated Prompt Photon Production Cross Section in pp Collisions at √s = 7 TeV, CMS-QCD-10-019

Cross section measurement formula:

$$\frac{d^2\sigma}{dE_T^\gamma d\eta^\gamma} = \frac{N^\gamma}{L \cdot U \cdot \epsilon \cdot \Delta E_T^\gamma \cdot \Delta\eta^\gamma}$$

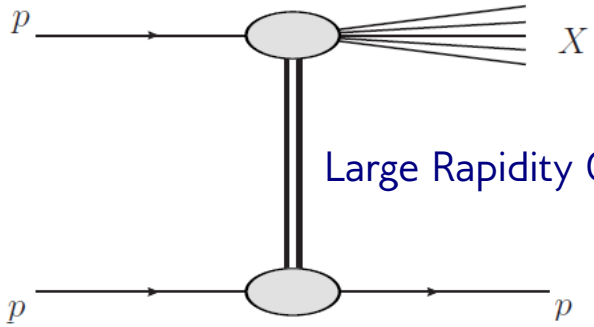




- Good agreement with the NLO predictions from JETPHOX
- Better described by the theoretical predictions that previous measurements

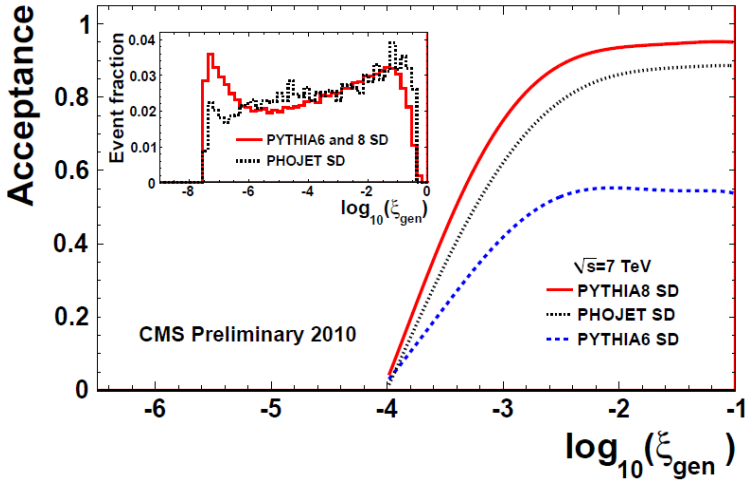
Forward Physics Results

Observation of diffraction in proton-proton collisions at 7 TeV centre-of-mass energies at the LHC, CMS-FWD-10-007



- Single Diffractive Event acceptance is high enough to observe them at LHC
- CMS calorimeters' pseudo-rapidity coverage is -5>η>5
- $Energy_{HF-}$ <8 GeV was required (LRG)

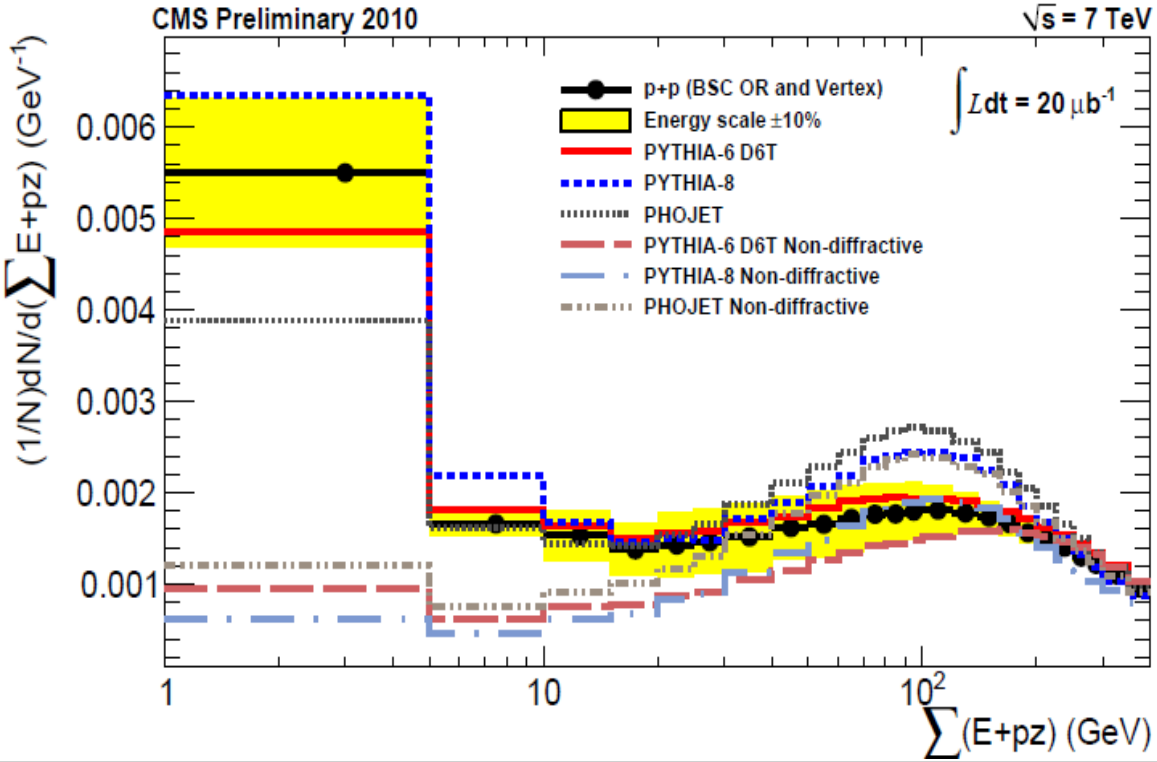
ξ : the fractional energy loss of the scattered proton



the sum runs over all calorimeter towers, including HF

$$\sum(E_i \pm p_{z,i}) = \sum E_i(1 + cos\theta_i)$$

Single-diffractive events appear as a peak at small values of the variable E± pz, which is proportional to ξ, the proton fractional energy loss, reflecting the 1/ξ behaviour of the diffractive cross section

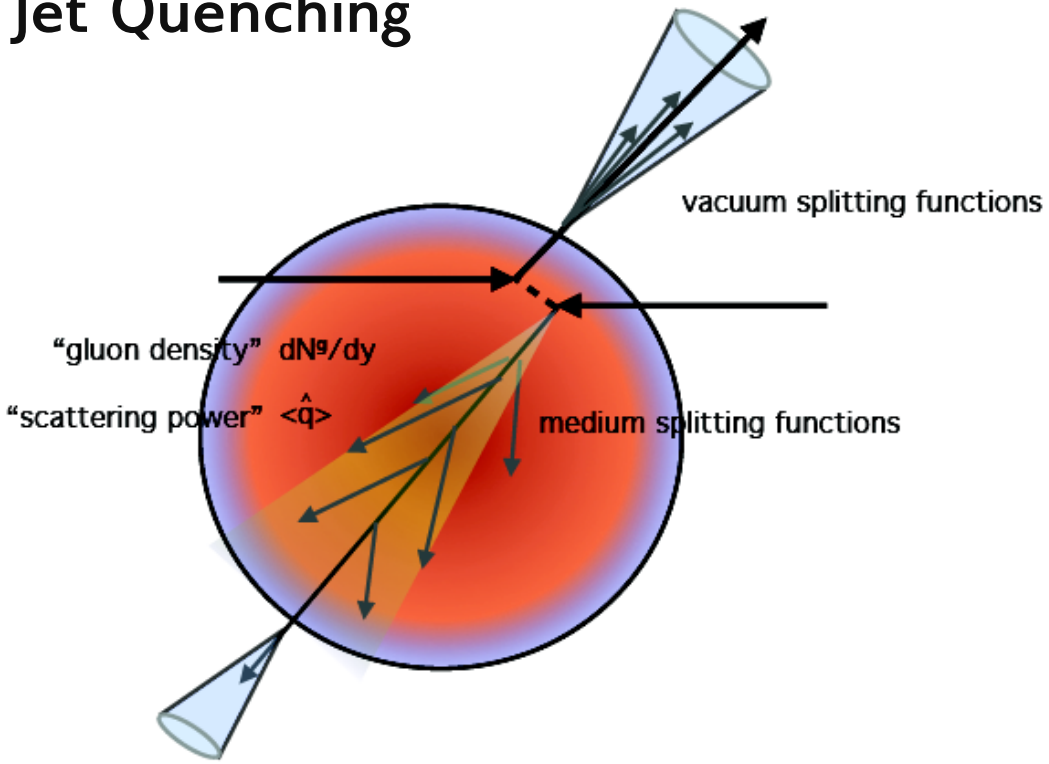


Heavy Ion Results

Observation and studies of jet quenching in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, CMS-HIN-10-004

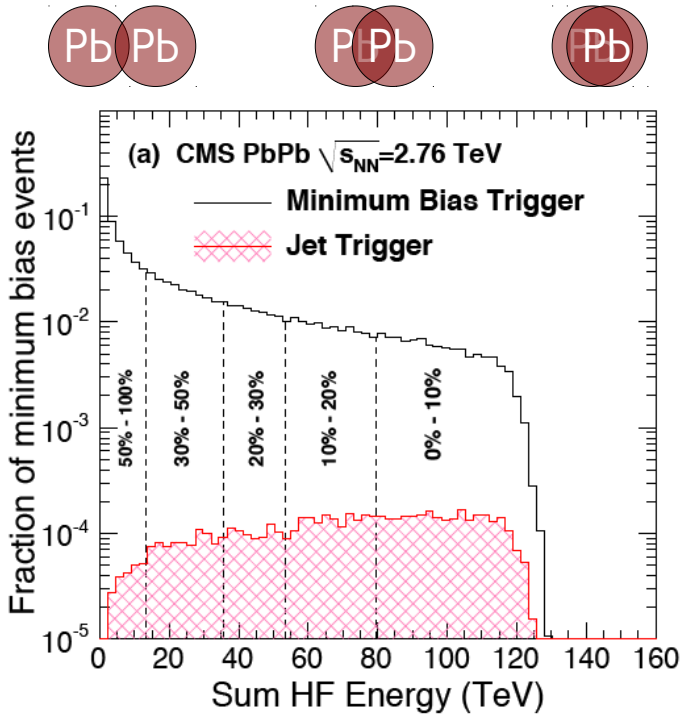
- Study QCD at extreme temperatures and densities (μs after Big Bang)
- To explore properties of new form of matter (QGP) proposed at high energy densities: above 1 GeV/fm^3

Experimental Signature:
Jet Quenching



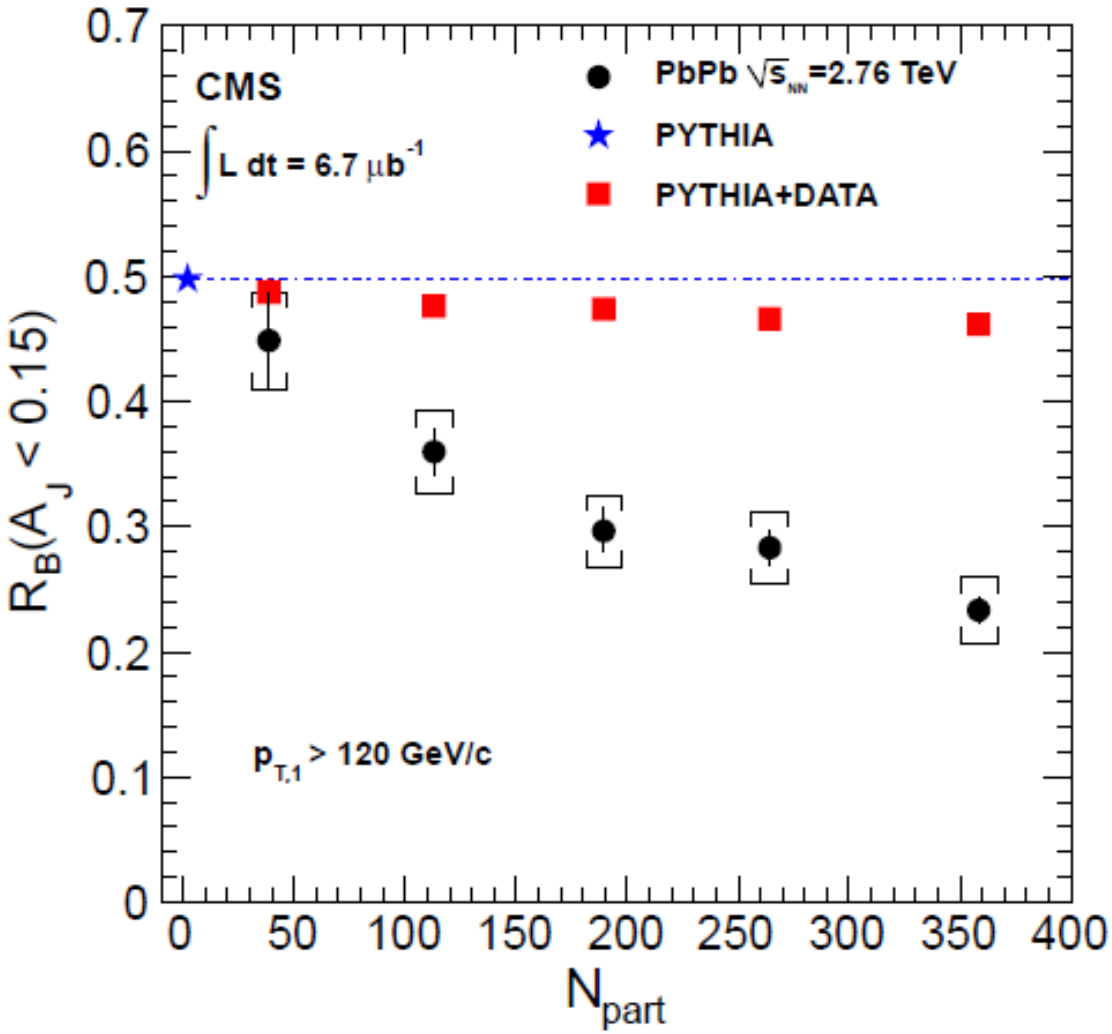
Observation and studies of jet quenching in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, CMS-HIN-10-004

Centrality Determination



JES insensitive dijet asymmetry is defined as:

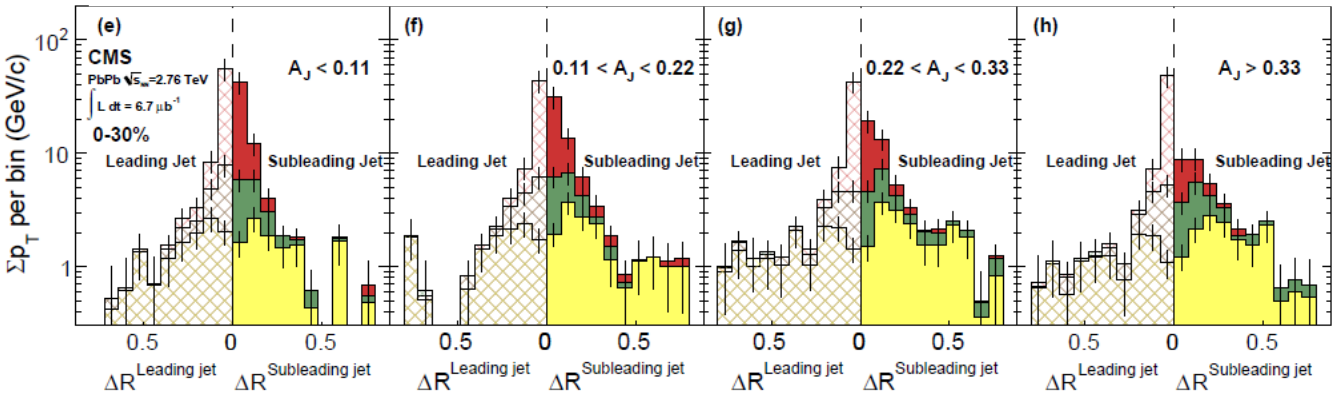
$$A_J = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}$$



- The fraction of balanced dijets smoothly decreases with the increasing centrality

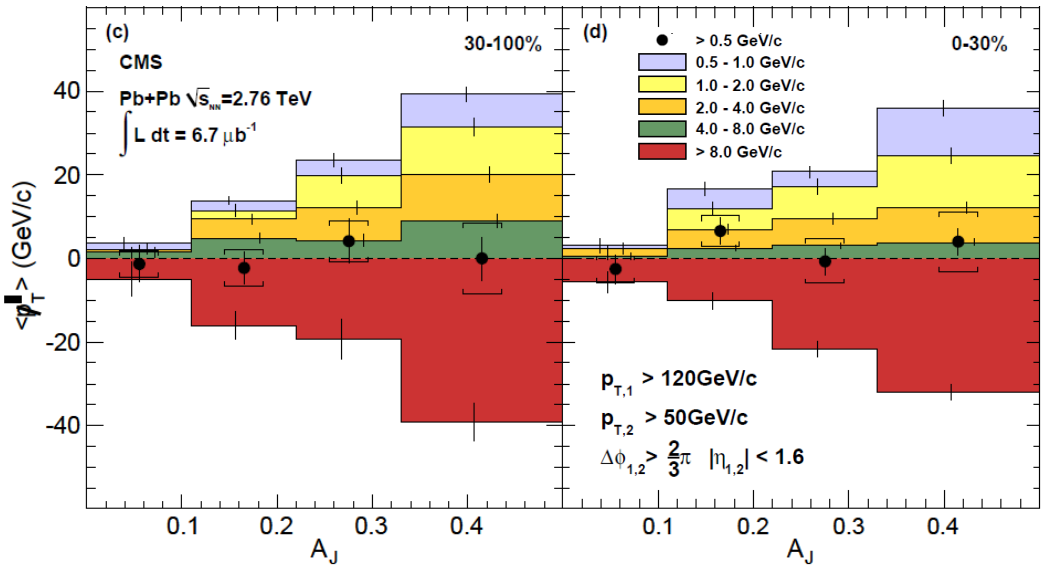
Observation and studies of jet quenching in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, CMS-HIN-10-004

Jet-Track Correllations



- In data a large fraction of the balance is carried by tracks with p_T < 2.0 GeV/c and $\Delta R > 0.8$

Momentum Balance Through Missing p_T



Sum of the track transverse momenta projected onto leading jet axis

$$\not{p}_{\mathrm{T}}^{\parallel} = \sum_{\mathrm{i}} -p_{\mathrm{T}}^{\mathrm{i}} \cos\left(\phi_{\mathrm{i}} - \phi_{\mathrm{Leading\ Jet}}\right)$$

- Momentum balance recovered by low-pT tracks, especially in more central events

Conclusions

- The year 2010 was excellent for LHC
- CMS proved itself as a multi-purpose detector with its various results at the cutting edge of the HEP Physics
- The data characteristics is in agreement with the QCD predictions.
- Many results have been published and lots of is going to be published soon
- This talk was intended to be a demonstration of the latest CMS results related to the QCD, Heavy Ion and Forward Physics areas from the first LHC data
- All results presented here and more can be found from:
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

References

- CMS-QCD-09-010 : "Transverse momentum and pseudo-rapidity distributions of charged hadrons in proton-proton collisions at √s=0.9 and 2.36 TeV"
- CMS-QCD-10-004 : "Charged particle multiplicities at sqrt(s)=0.9, 2.36 and 7 TeV"
- CMS-QCD-10-006 : "Transverse-momentum and pseudo-rapidity distributions of charged hadrons in pp collisions at √s= 7 TeV"
- CMS-QCD-10-006 : "Measurement of the Inclusive Jet Cross Section in pp Collisions at 7 TeV"
- CMS-QCD-10-012 : "Measurement of the 3-jet to 2-jet Cross Section Ratio in pp Collisions at sqrt(s) = 7 TeV"
- CMS-QCD-10-013 : "Hadronic Event Shapes in pp Collisions at 7 TeV"
- CMS-QCD-10-016 : "Measurement of Dijet Angular Distributions and Search for Quark Compositeness in pp Collisions at √s = 7 TeV"
- CMS-QCD-10-026 : "Dijet Azimuthal Decorrelations in pp Collisions at at sqrt(s) = 7 TeV"
- CMS-FWD-10-007 : "Observation of diffraction in proton-proton collisions at 7 TeV centre-of-mass energies at the LHC"
- CMS-HIN-10-004 : "Observation and studies of jet quenching in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV"
- CMS-JME-10-010 : "Determination of the Jet Energy Scale in CMS with pp Collisions at √s = 7 TeV"
- CMS-JME-10-003 : "Jet Performance in pp Collisions at √s = 7 TeV"
- CMS-EGM-10-006 : "Isolated Photon Reconstruction and Identification at √s = 7 TeV"
- PRL 105 (2010) 211801: "Search for Dijet Resonances in 7 TeV pp Collisions at CMS"
- PRL 105 (2010) 262001 : "Search for Quark Compositeness with the Dijet Centrality Ratio in pp Collisions at √s=7 TeV"

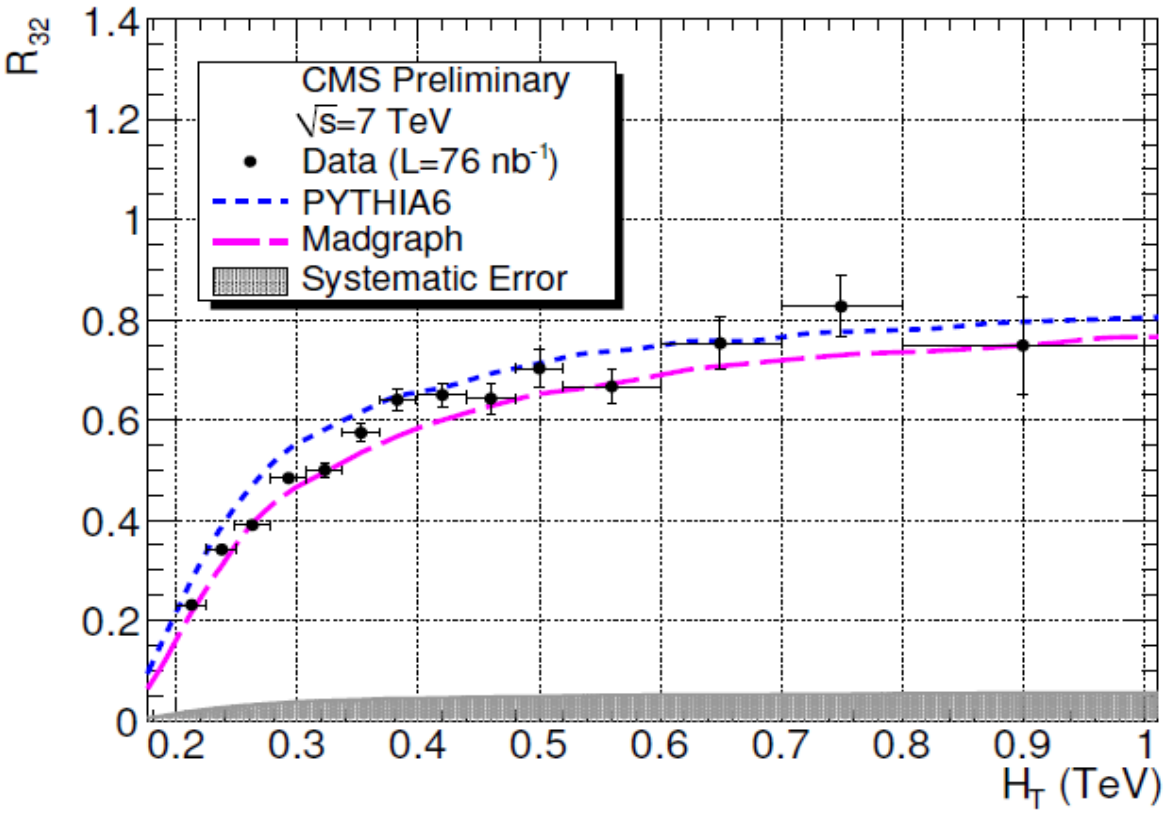
Back-up Slides

Measurement of the 3-jet to 2-jet Cross Section Ratio in pp Collisions at √s = 7 TeV, CMS-QCD-010-012

3-jet to 2-jet Ratio is defined:

$$R_{32} = \frac{d\sigma_3/dH_T}{d\sigma_2/dH_T}$$

H_T is defined as the scalar transverse momentum sum of all jets



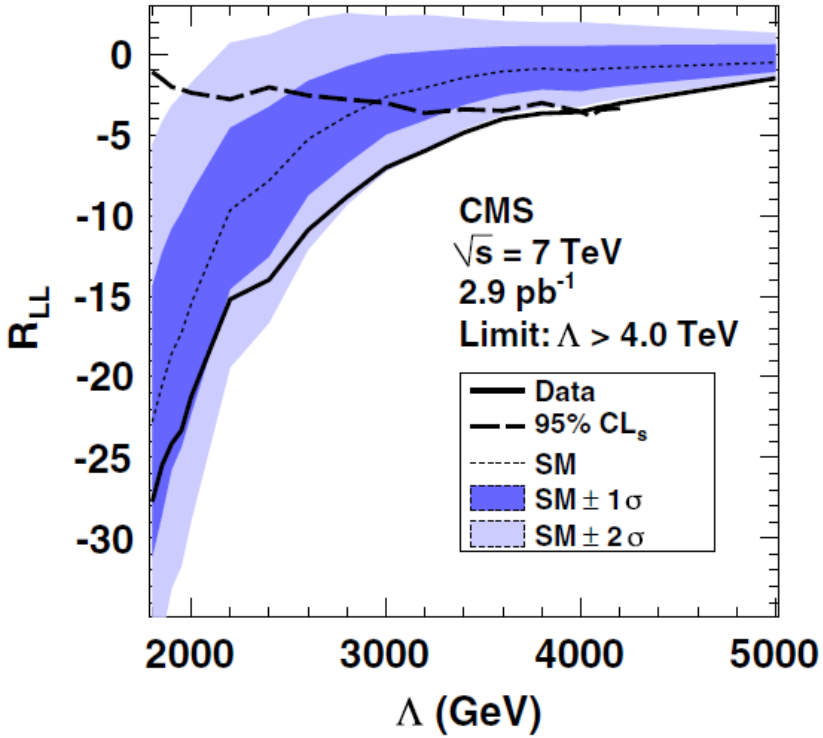
- The plateau of the ratio is sensitive to QCD coupling constant α(s)
- Less sensitive to the dominant Jet Energy Scale (JES) uncertainty than inclusive measurements.
- The agreement is good with PYTHIA6 and Madgraph within uncertainties
- A new result with more integrated luminosity is on the way

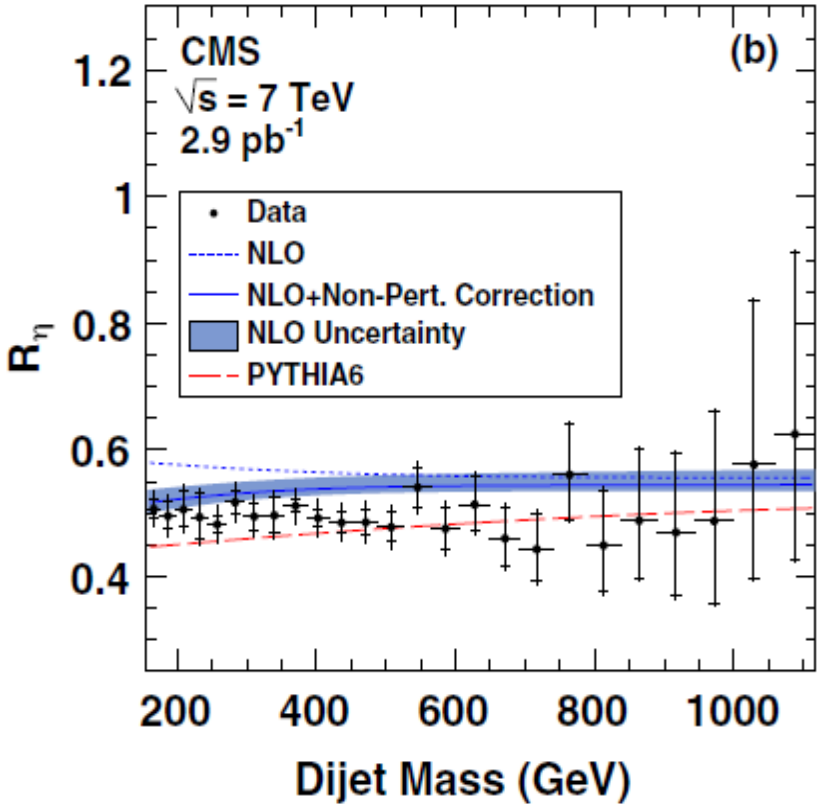
Search for Quark Compositeness with the Dijet Centrality Ratio in pp Collisions at √s=7 TeV, PRL 105, 262001 (2010)

Dijet Centrality Ratio is defined:

N(|η|<0.7) / N(0.7<|η|<1.3)

- Dijet Centrality Ratio is sensitive to contact interactions
- Low systematic uncertainties



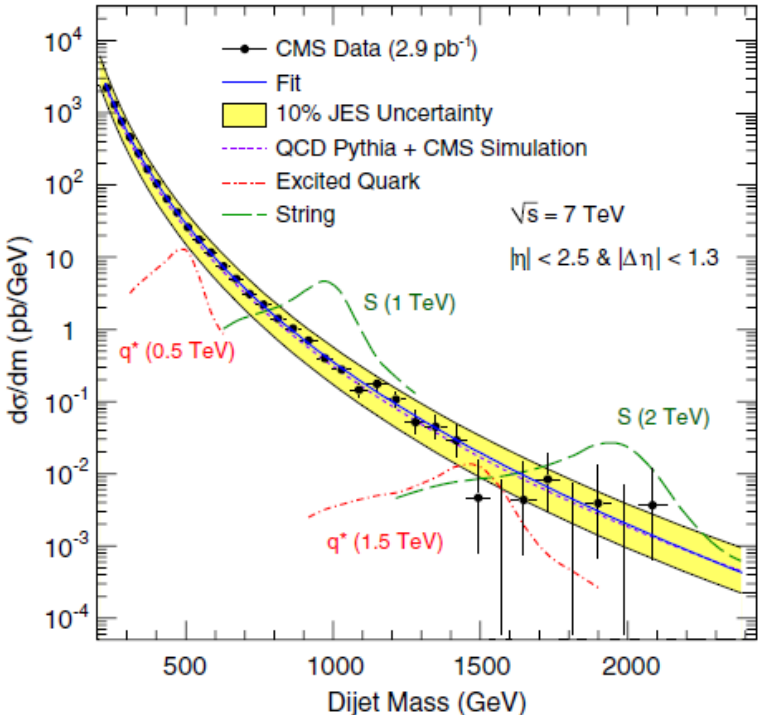


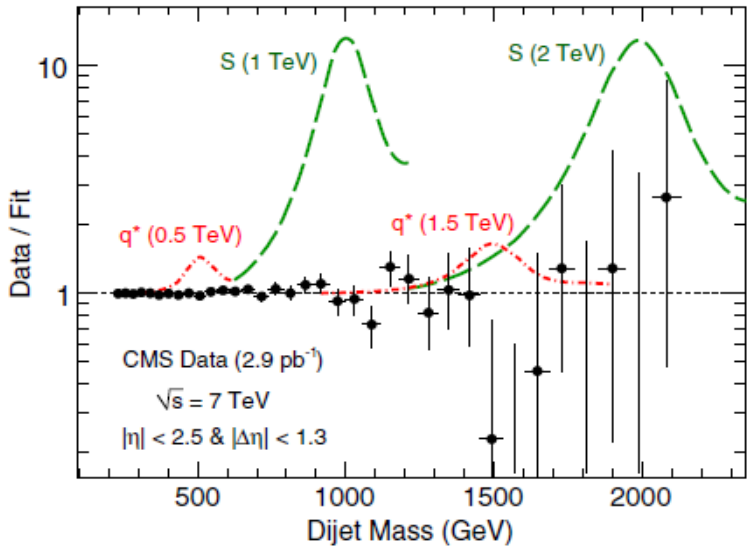
- Limit on CI scale Lambda using frequentist inspired CL_S:

  Exclude Λ < 4.0 TeV at 95% CL

  While the expected limit: Λ < 2.9 TeV

Search for Dijet Resonances in 7 TeV pp Collisions at CMS, PRL 105 (2010) 211801





- Search for narrow resonances in the dijet invariant mass spectrum
- Data is in good agreement with PYTHIA6+CMS Simulation
- A model independent search has been performed to obtain mass exclusion limits at 95% CL for different resonance models.

Model	Excluded Region (TeV)
String Resonance	0.50 - 2.50
Excited Quark	0.50 - 1.58
E6 Diquark	0.50 - 0.58, 0.97 – 1.08, 1.45 - 1.60
Axigluon/Coloron	0.50 - 1.17, 1.47 - 1.52