Jet Results from CMS

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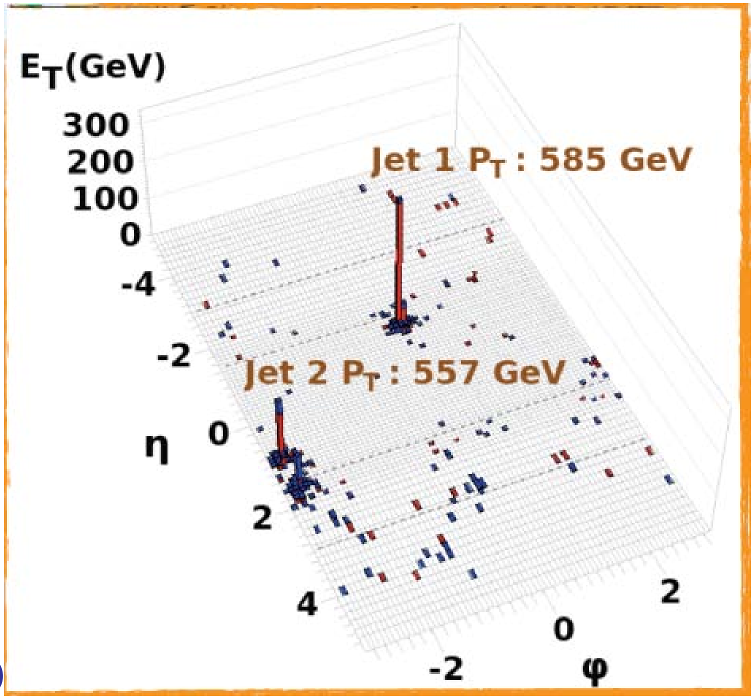
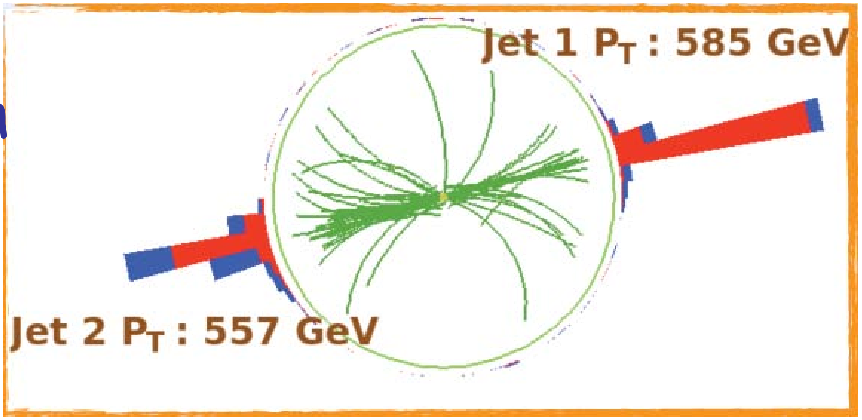
on behalf of the CMS collaboration

Outline

- Physics at the LHC
- Jet Reconstruction and Performance
  - Clustering Algorithms
  - Jet Energy Scale and Resolution
- Jet Measurements
  - Jet Shapes
  - Inclusive Jet Cross Section
  - Dijet Mass Spectrum and Ratio
  - Dijet Angular Distribution
  - Dijet Angular Decorrelation
  - 3-jet to 2-jet ratio
  - Event Shapes
  - W+jets
  - Direct Photon Production

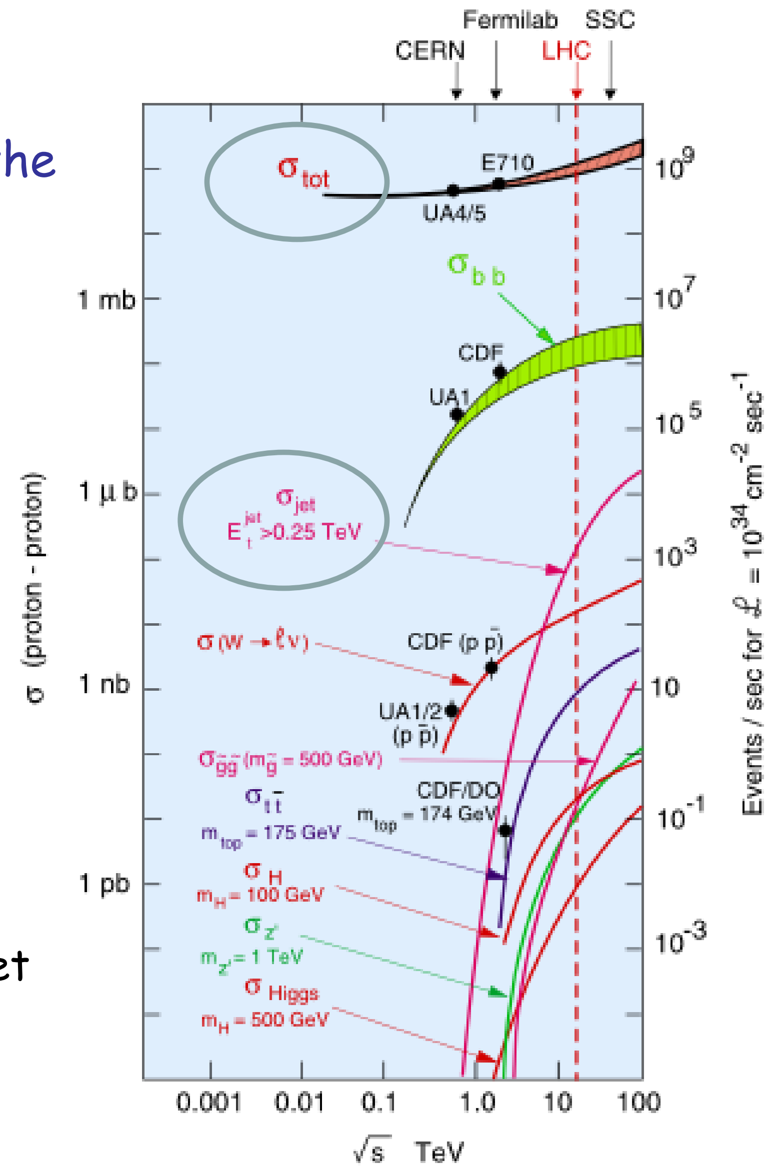




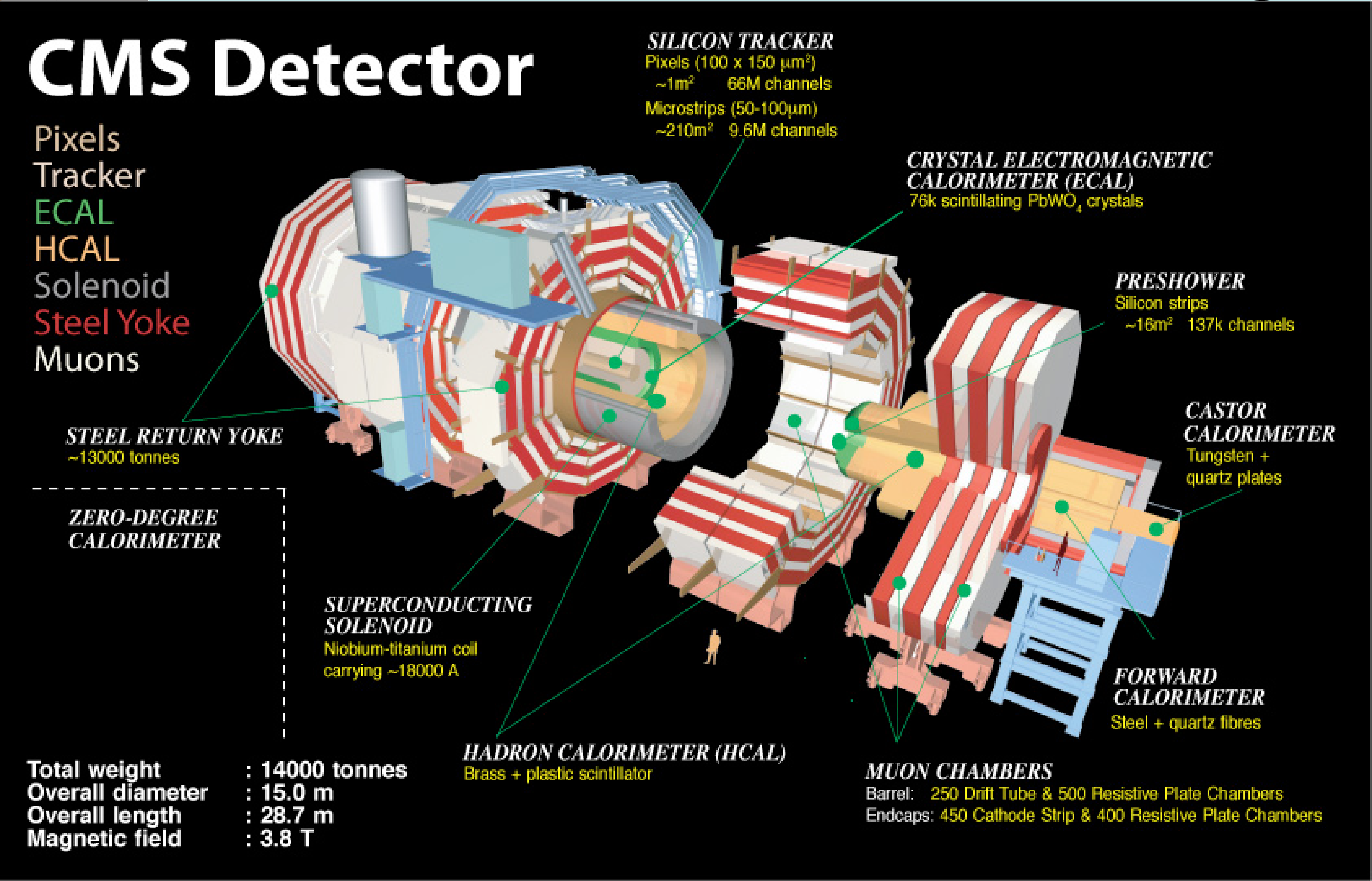
Jet Physics at the LHC

QCD High PT

- Total cross section ~100-120 mb
- The goal at startup is to re-establish the standard model (i.e., QCD, SM candles) in the LHC energy regime
  - σ(pT>250 GeV)
    - 100x higher than Tevatron
  - Electroweak
    - 10x higher than Tevatron
  - Top
    - 100x higher than Tevatron
- Jet measurements at LHC are important:
  - confront pQCD at the TeV scale
    - constrain PDFs
    - probe α_s
  - important backgrounds for SUSY and BSM searches
  - sensitive to new physics
    - quark substructure, excited quarks, dijet resonances, etc.
- QCD processes are not statistics limited!

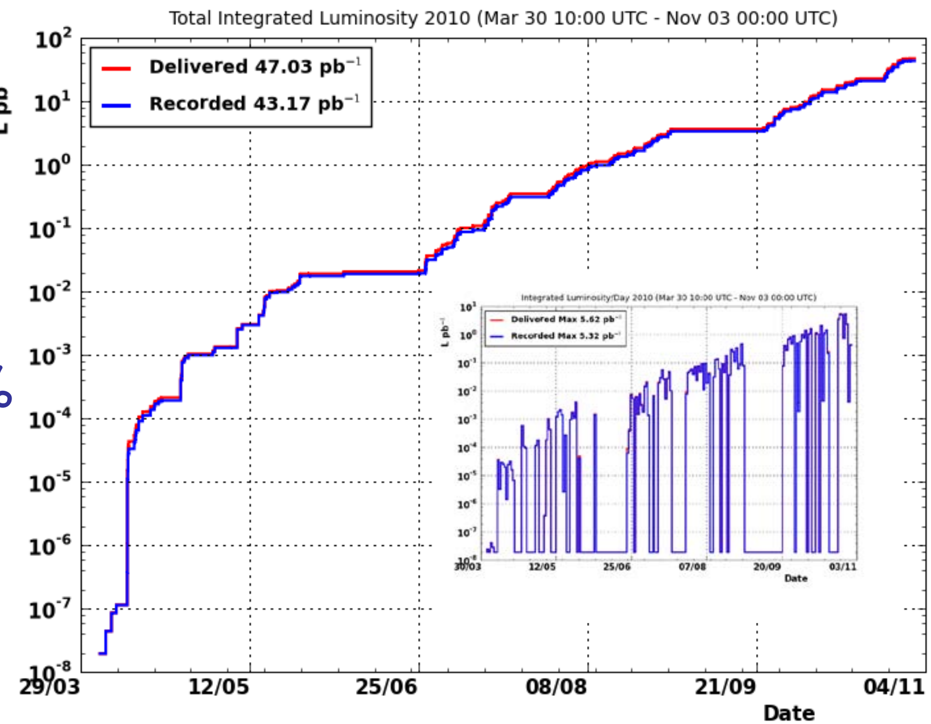


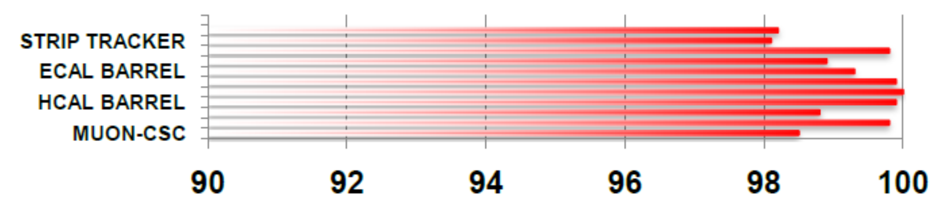
The CMS Detector



Integrated Luminosity in 2010

- 47 pb^{-1} *pp* data delivered by the CERN LHC
- 43 pb^{-1} recorded by CMS
  - Overall data taking efficiency greater than 90%
  - ~85% recorded with all subdetectors in perfect condition
- All subdetectors have at least 98% of all channels operational
- Luminosity uncertainty is currently 11%

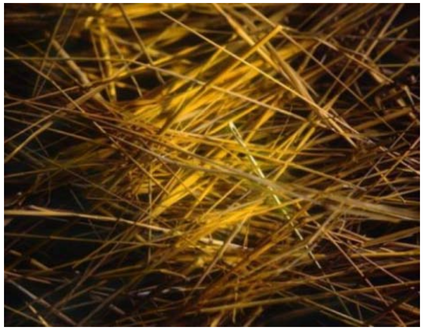




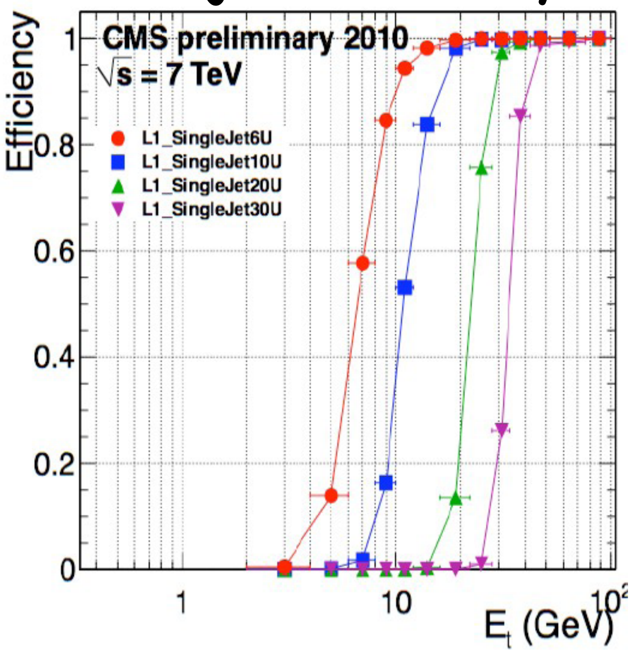
	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2

CMS Trigger System

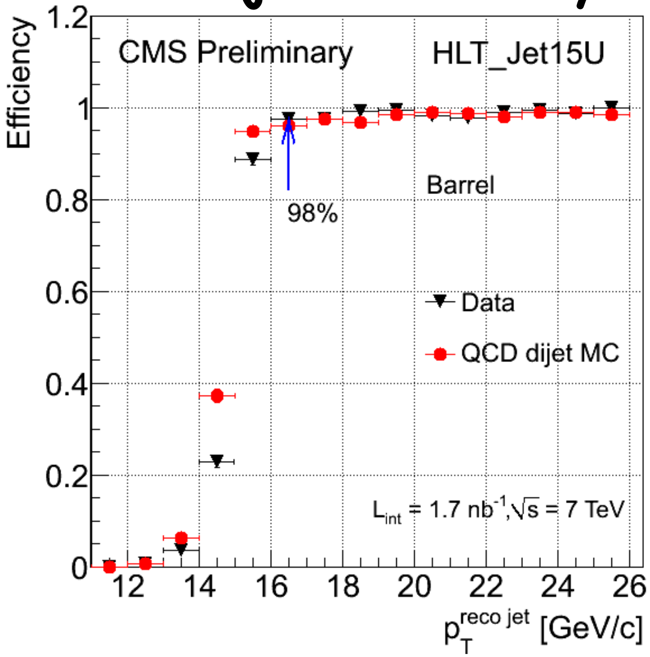
- Two-tiered system
  - L1: hardware, firmware
  - L2,L3 merged into HLT (high-level software)

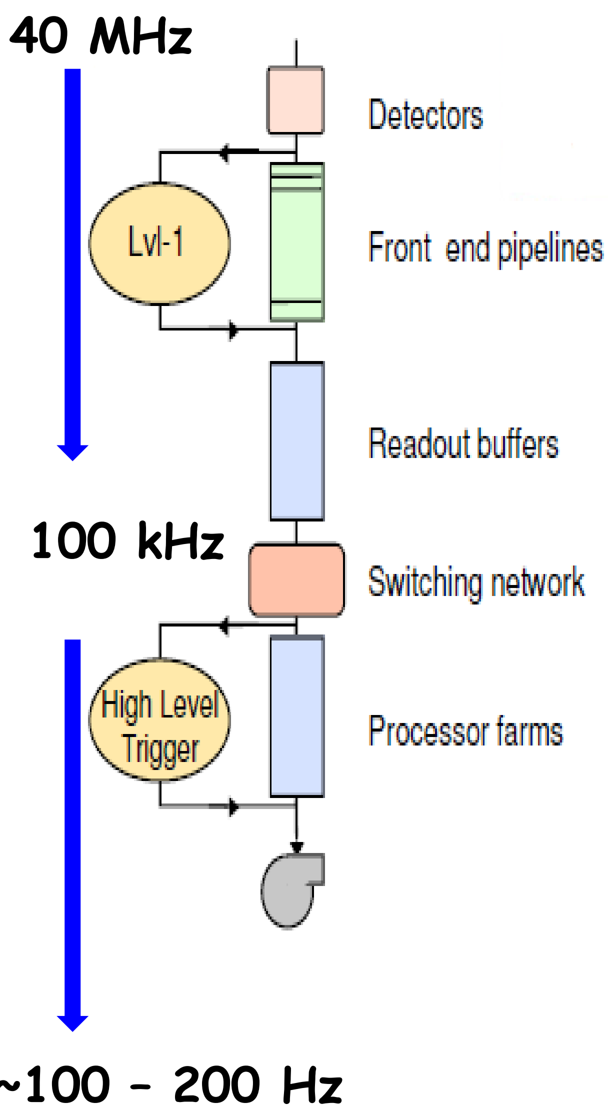


L1 jet efficiency



HLT jet efficiency

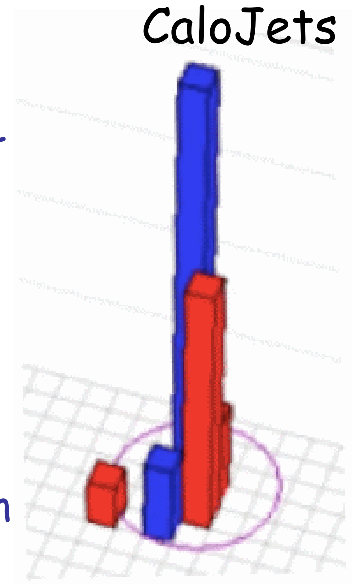


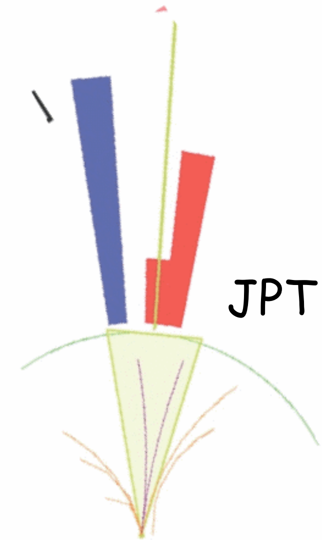


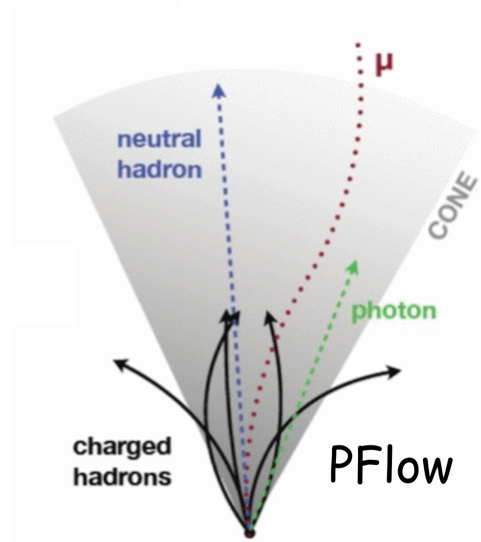
Jet Reconstruction at CMS

QCD High PT

- Calorimeter jets
  - Energy depositions in the ECAL and HCAL used to form CaloJets
- JetPlusTrack
  - Calorimeter jets corrected with tracker information
- Particle Flow jets
  - Reconstructed particles using information from all sub-detectors; separate calibration per particle type
- Track jets
  - Uses track input only
- Jet algorithms:
  - Default for p-p collisions is Anti-k_T
    - R=0.5, 0.7
  - Also studied SISCone, KT, and Iterative Cone (used in the trigger)



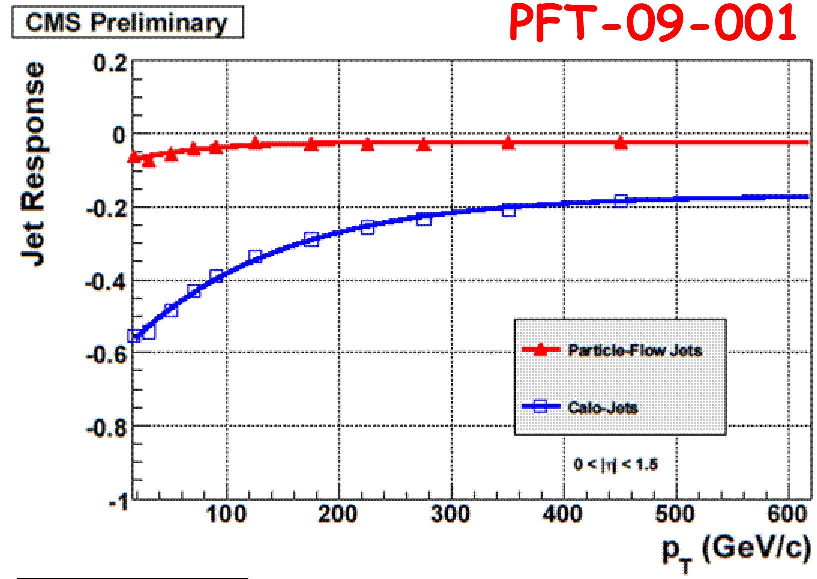


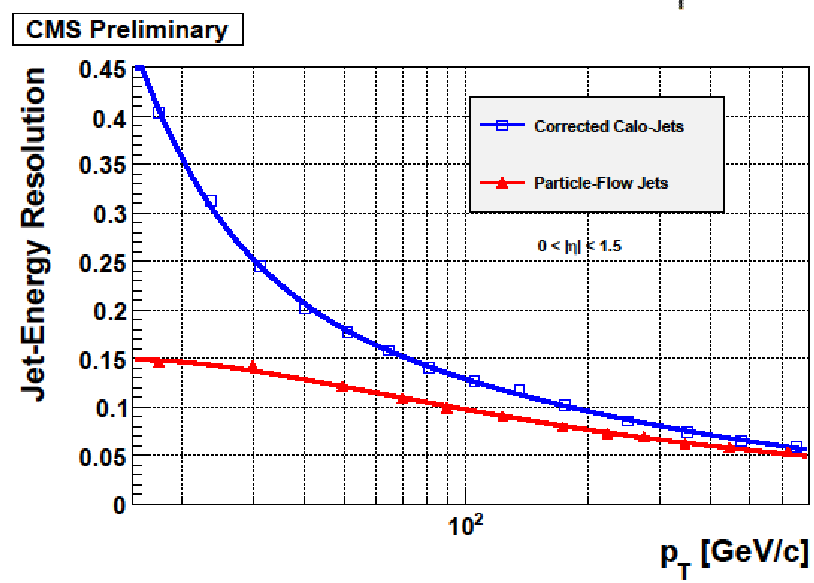


Particle Flow

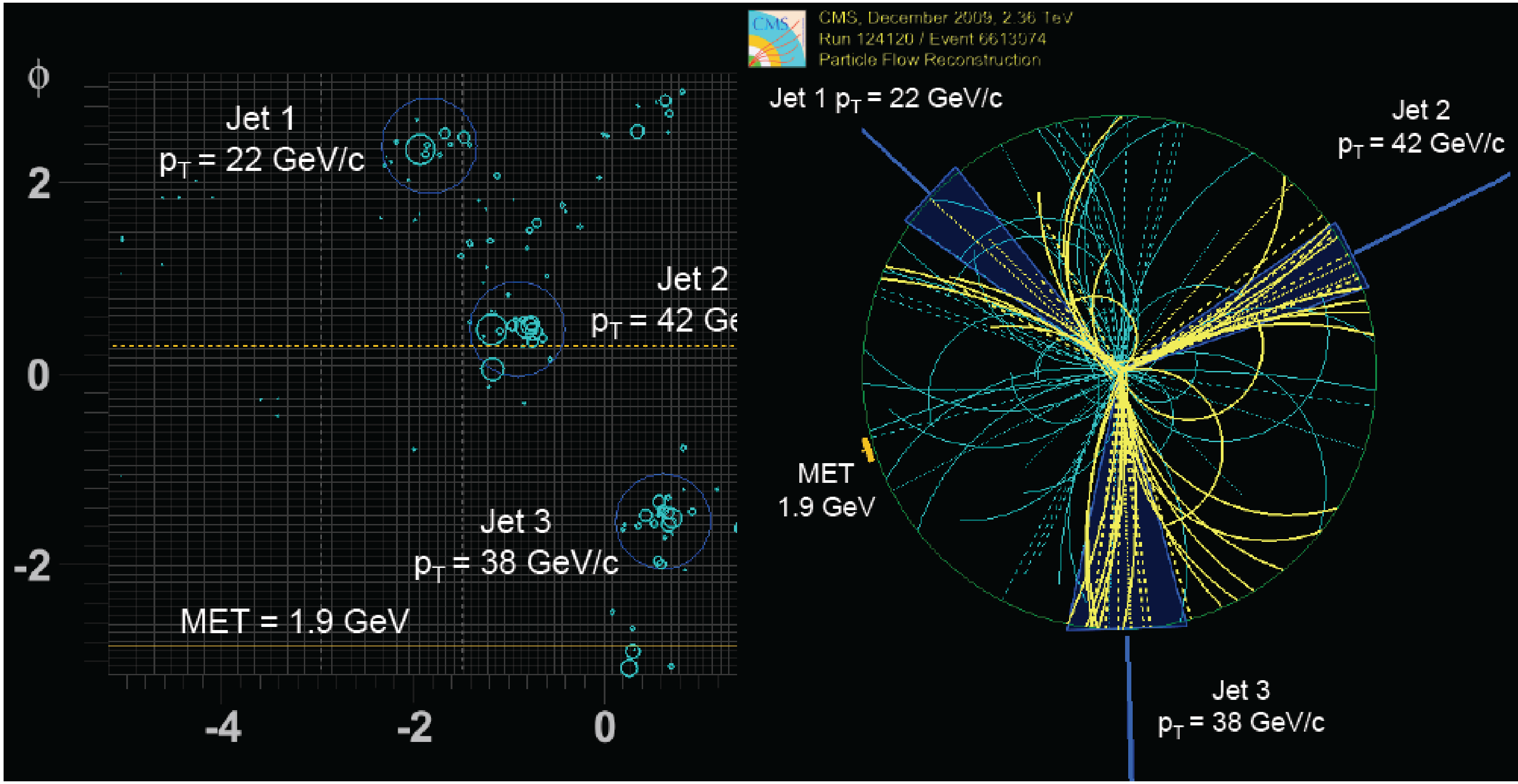
- Particle Flow is an event reconstruction technique that aims to reconstruct and identify all stable particles produced in a proton-proton collision, through the optimal combination of **all CMS sub-detectors**
  - Identify different groups of particles and calibrate their response individually
  - Charged hadron momenta are taken before modification by the magnetic field
- Particle flow is rapidly becoming the default reconstruction algorithm at CMS

PFT-09-001





Particle Flow



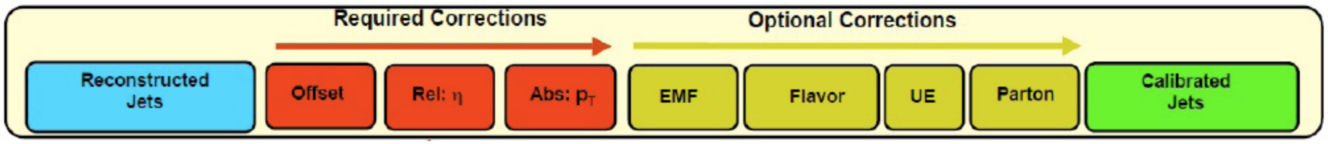
CMS-PAS-PFT-10-001

A particle-flow reconstructed event at 2.36 TeV

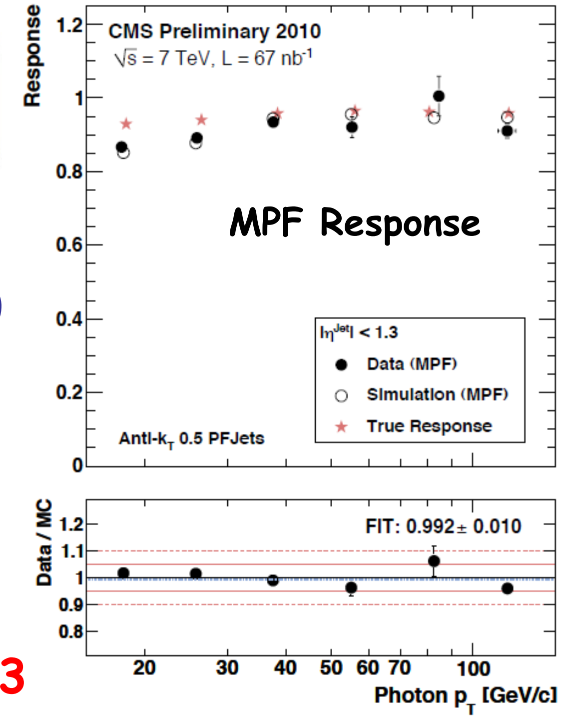
Circles – particle p_T Thinner circles – jets with $p_T > 20$ GeV/c

Jet Energy Calibration at CMS

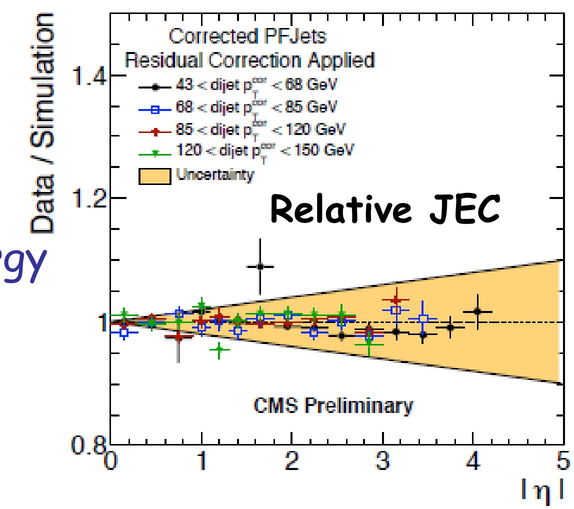
QCD High PT



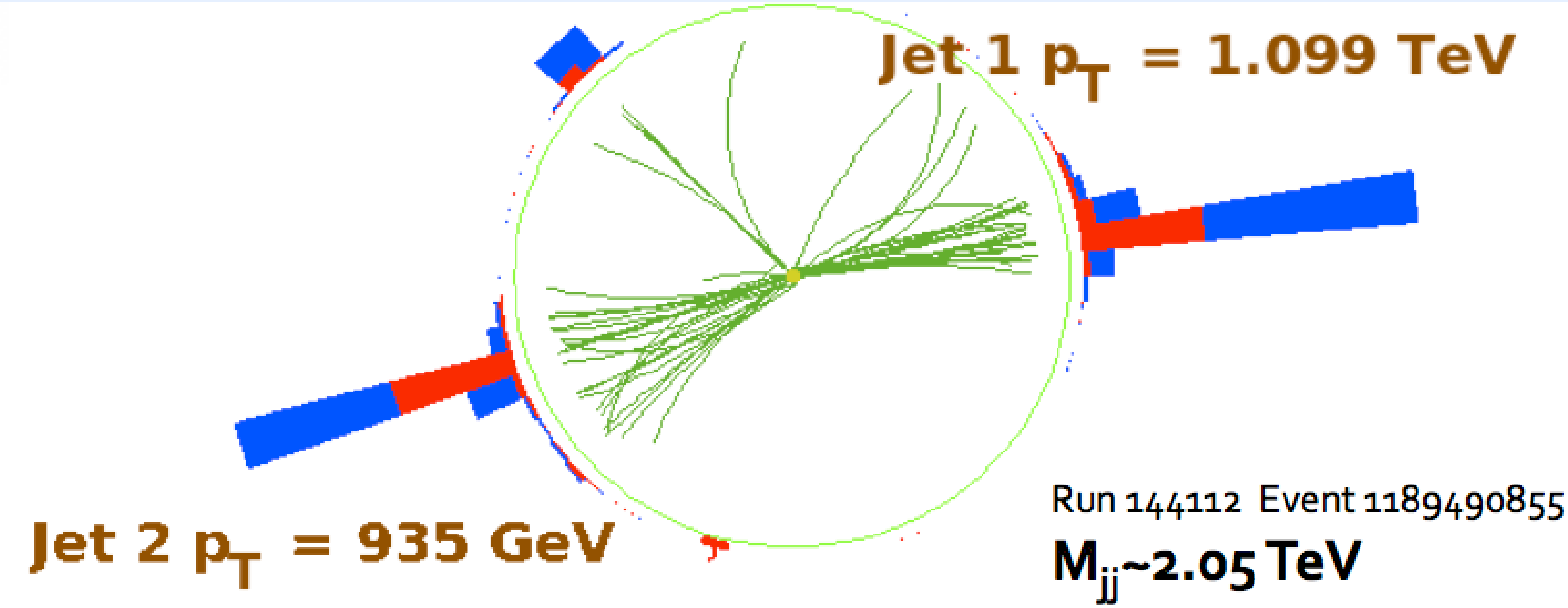
- Factorized approach (like Tevatron):
  - offset correction (removes pile-up and noise contribution)
  - relative correction (flattens the jet response in pseudorapidity)
  - absolute correction (flattens the jet response in p_T)
- Optional corrections:
  - electromagnetic fraction dependence
  - flavor dependence
  - parton level
  - underlying event
- Jet energy calibration from Monte Carlo truth
  - preliminary in-situ measurements with γ+jet pT balancing and of single particle response, indicate that the jet energy scale is known to better than 10%
  - Update! JES uncertainties now ~3-6% (JME-10-010)



JME-10-003



QCD Jet Measurements



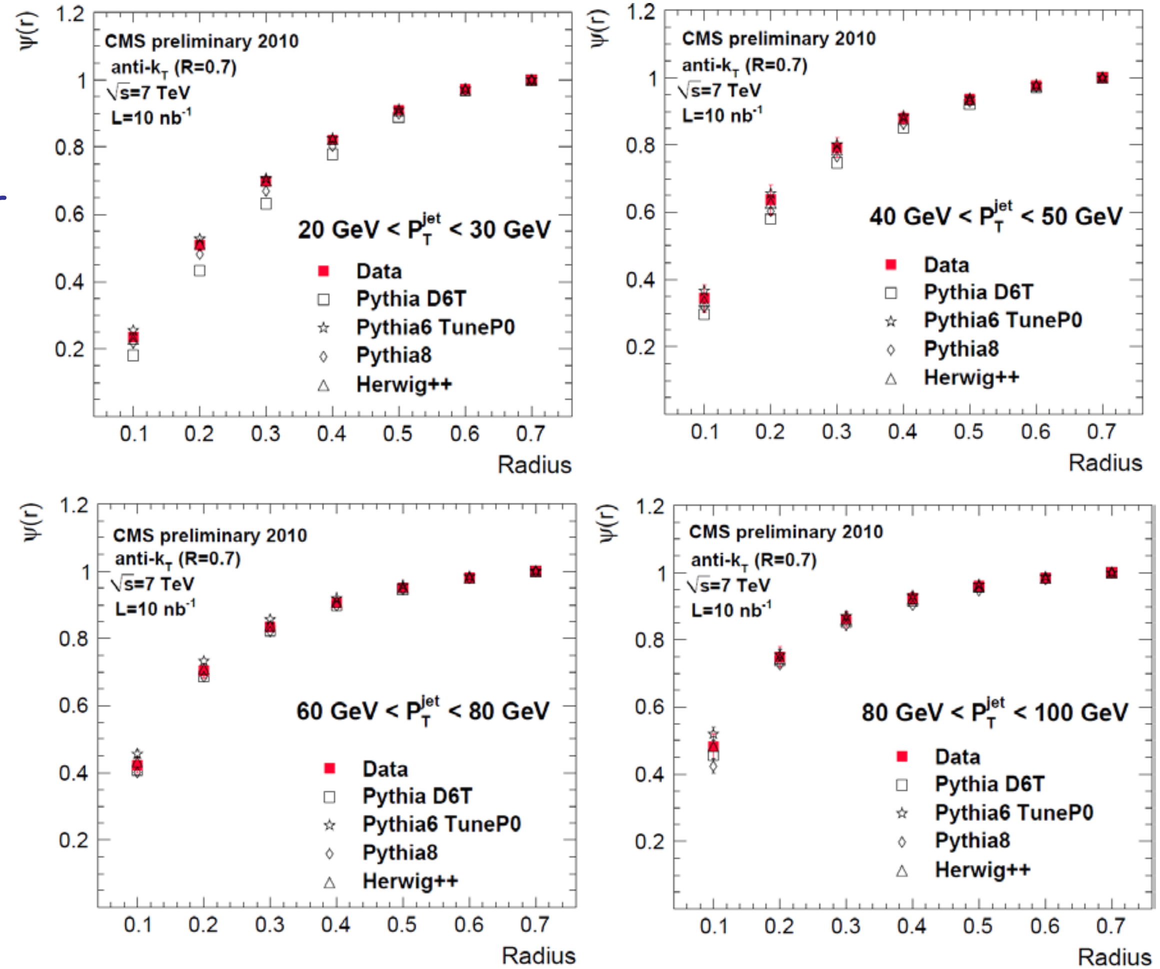
A high mass dijet event satisfying $\Delta\eta < 1.3$

Current highest mass dijet pair: ~2.7 TeV in 3.1 pb^{-1} of data

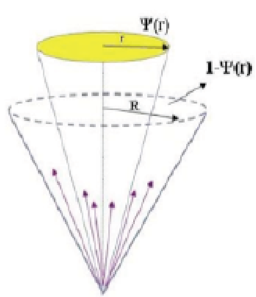
Jet Shapes

Dedicated talk on Friday by S. Bose QCD-10-014

- Jet shapes probe the transition between hard pQCD and soft gluon radiation
- Sensitive to the quark/gluon jet mixture
- Test of parton shower event generators at non-perturbative levels
- Useful for jet algorithm development and tuning



$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{P_T(0,r)}{P_T^{jet}(0,R)}$$

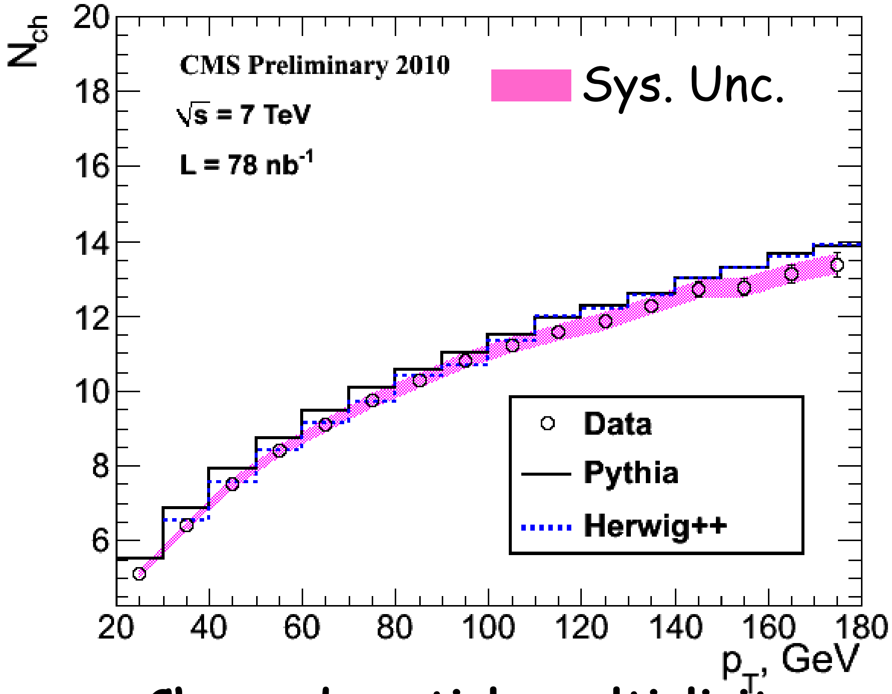


Integrated Jet Shape

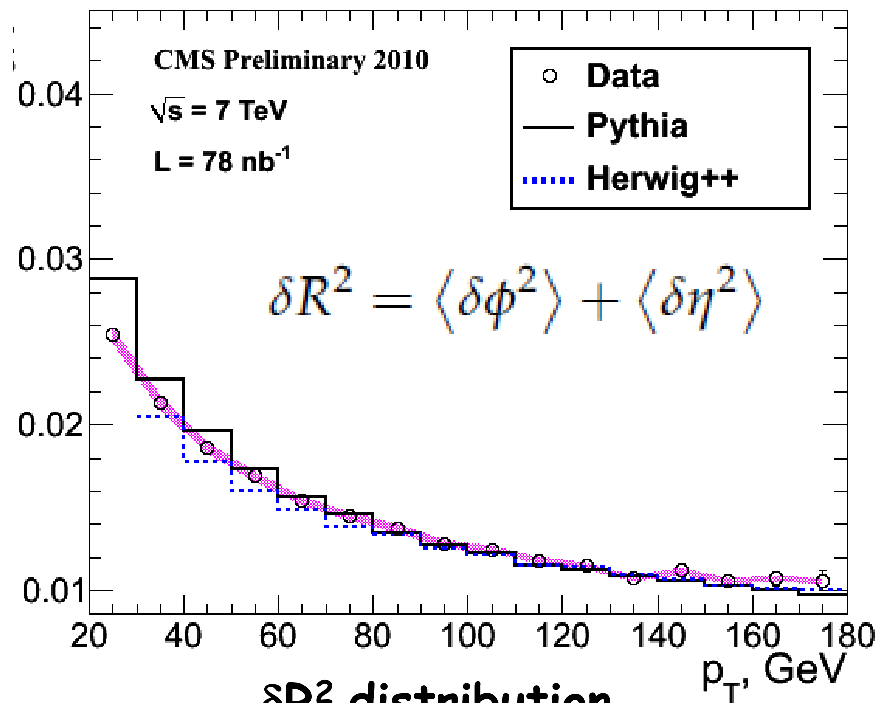
Jet Shapes

QCD High PT

QCD-10-014



Charged particle multiplicity



δR^2 distribution

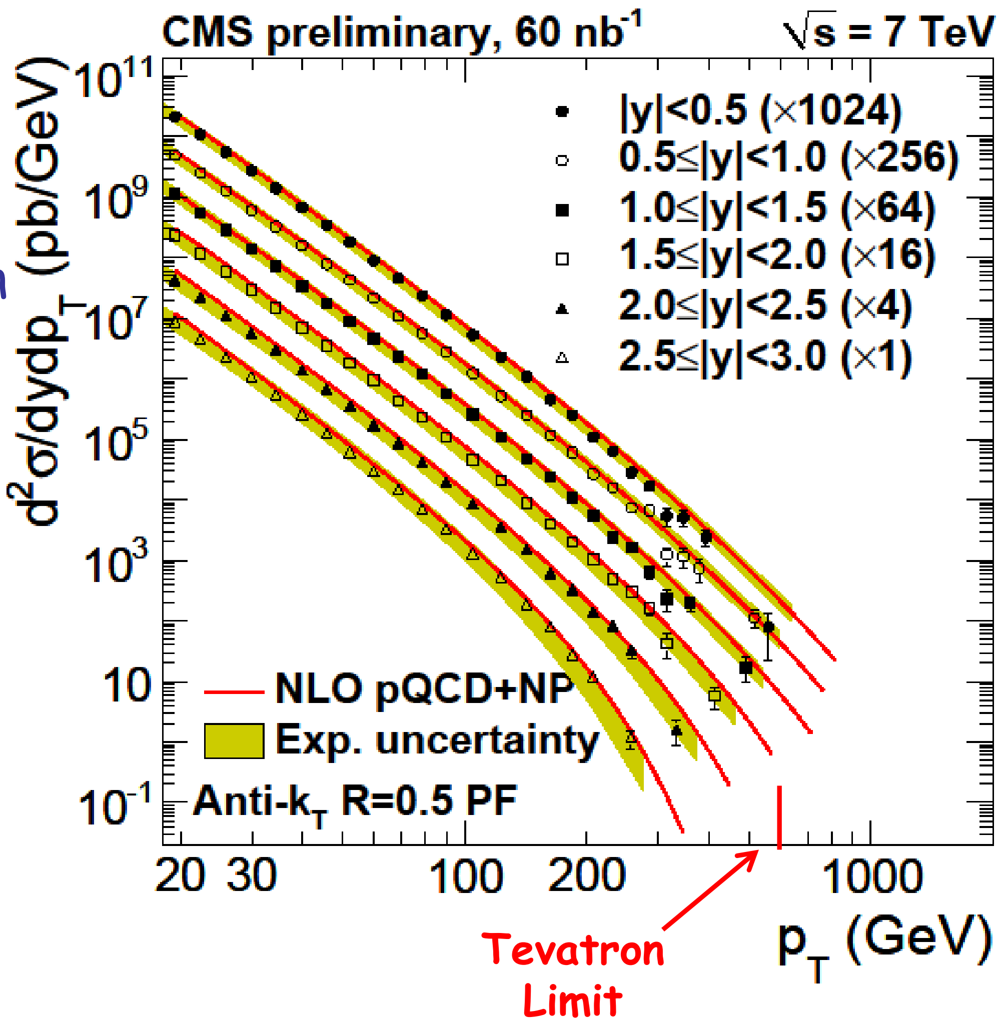
- At low jet transverse momentum ($20 < p_T < 50$ GeV) the measured jets are a few percent broader than predicted by HERWIG++ and narrower than predicted by PYTHIA D6T

Inclusive Jet Cross Section

QCD High PT

QCD-10-011

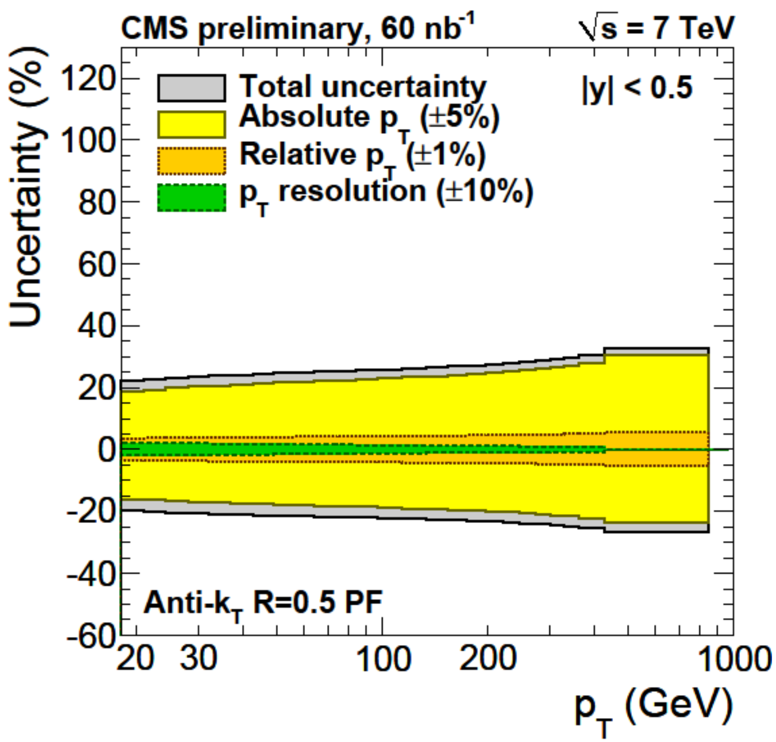
- Fundamental jet measurement
  - Used to constrain PDF's
  - Can probe contact interactions
- Inclusive jet pT spectra are in **good agreement with NLO theory** for all jet reconstruction types
- Large rapidity coverage up to |y|<3
- Measurement extending to very low p_T (~20 GeV) thanks to Particle Flow jet reco.
  - Tevatron lower limit ~50 GeV

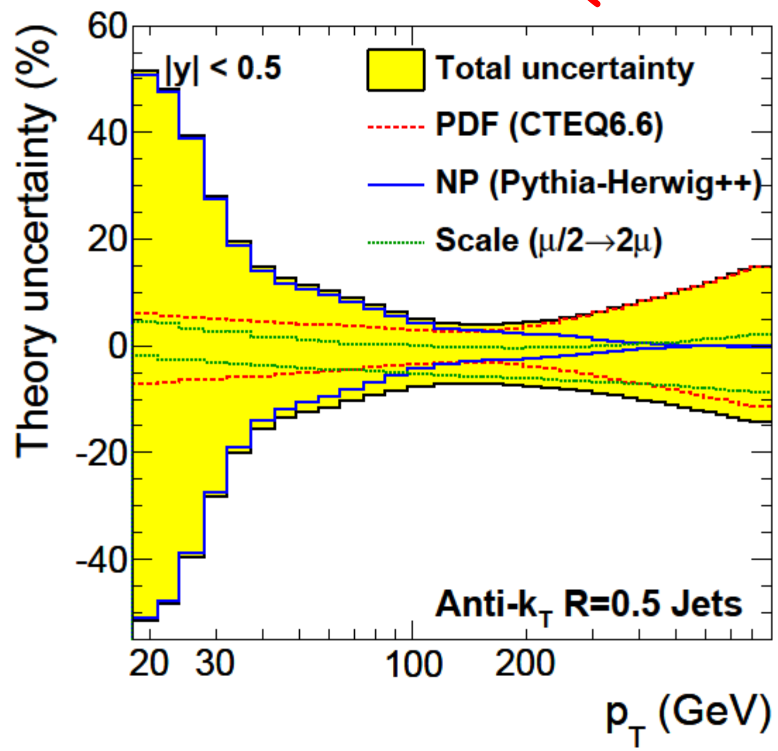


Inclusive Jet Cross Section

- Main systematic uncertainties. for inclusive jet cross section, as for most other jet analyses: jet energy scale (5-10%), jet resolutions (10%) and luminosity (11%)
- From theory side dominant systematic uncertainties are parton distributions (PDF), nonperturbative corrections (NP) and factorization/renormalization scales (μR,F)

QCD-10-011



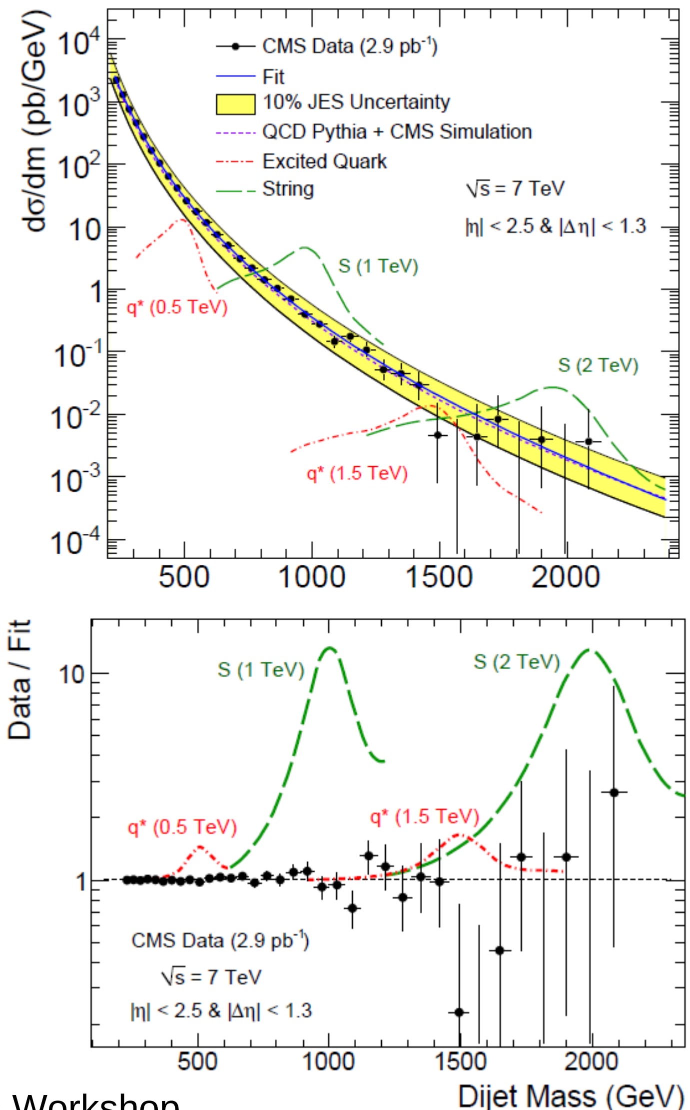


Dijet Mass Distribution

QCD High PT

- Good agreement between data and CMS simulation of QCD using PYTHIA
- Search for narrow resonances decaying to dijets with natural width less than experimental resolution
- Use a model-independent resonance search to obtain mass exclusion limits at the 95% confidence level for a variety of resonance models

Phys. Rev. Lett. 105, 211801 (2010)



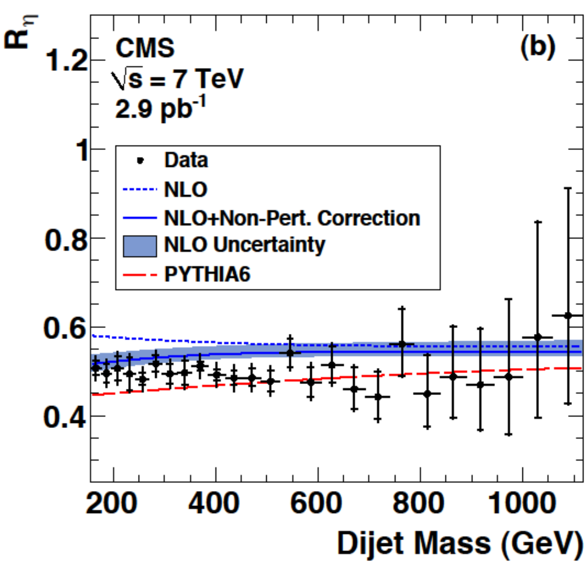
	Excluded Regions (TeV)
String Resonance	0.50-2.50
Excited Quark	0.50-1.58
Axigluon/Coloron	0.50-1.17, 1.47-1.52
E6 Diquark	0.50-0.58, 0.97-1.08, 1.45-1.60

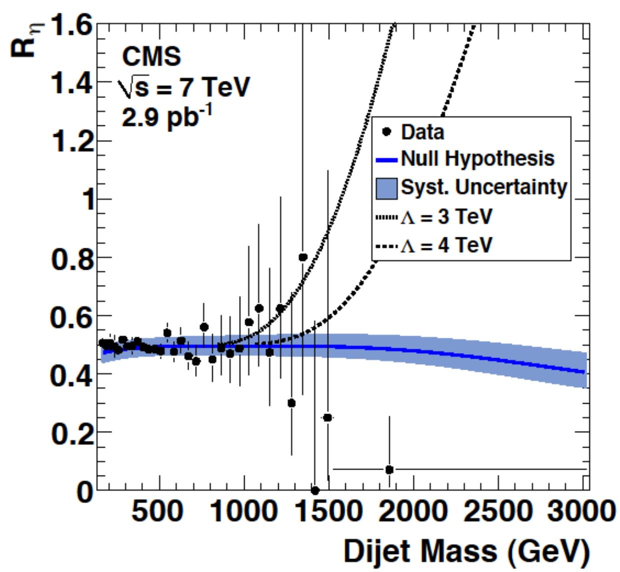
Dijet Centrality Ratio

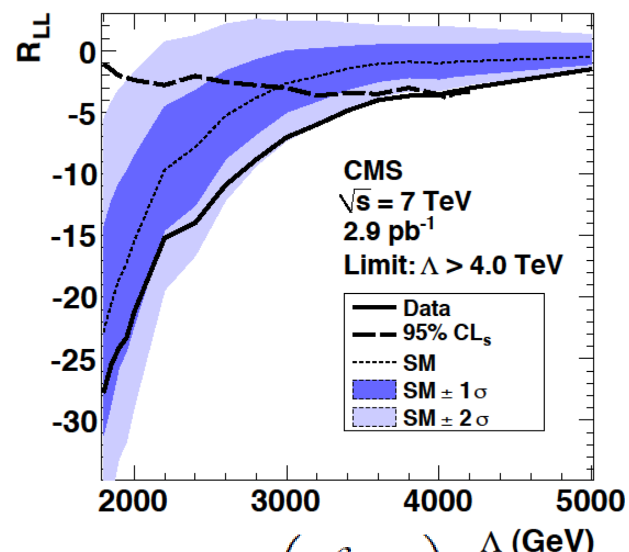
QCD High PT

- The dijet ratio is a simple measure of dijet angular distributions
  - $N(|\eta|<0.7)/N(0.7<|\eta|<1.3)$
  - Sensitive to contact interactions and dijet resonances
- Dijet ratio has low systematic uncertainties and is a precision test of QCD at startup
- Set limit on contact interaction scale Λ with frequentist inspired CL_S method
- We **exclude Λ<4.0 TeV** at 95% CL
- Expected exclusion of Λ < 2.9 TeV

(arXiv:1010.4439 accepted by PRL)







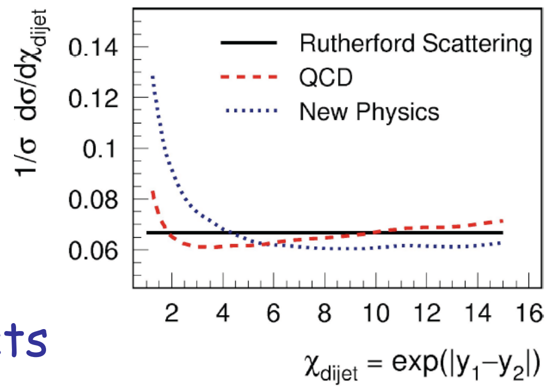
$$\mathcal{R}_{LL} = \ln\left(\frac{\mathcal{L}_{\rm alt}}{\mathcal{L}_{\rm QCD}}\right)$$

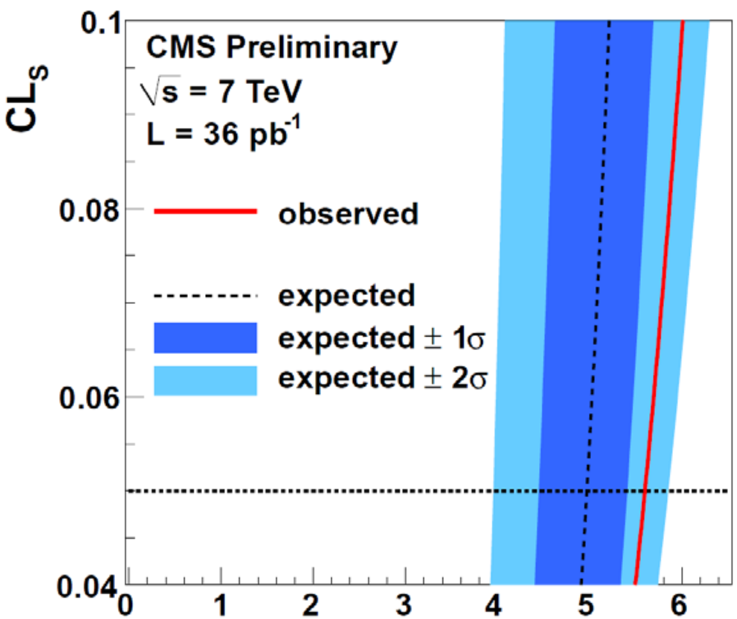
Dijet Angular Distributions

QCD High PT

QCD-10-016

- Angular distributions sensitive to new physics
- Insensitive to PDFs
- Reduced sensitivity to detector effects



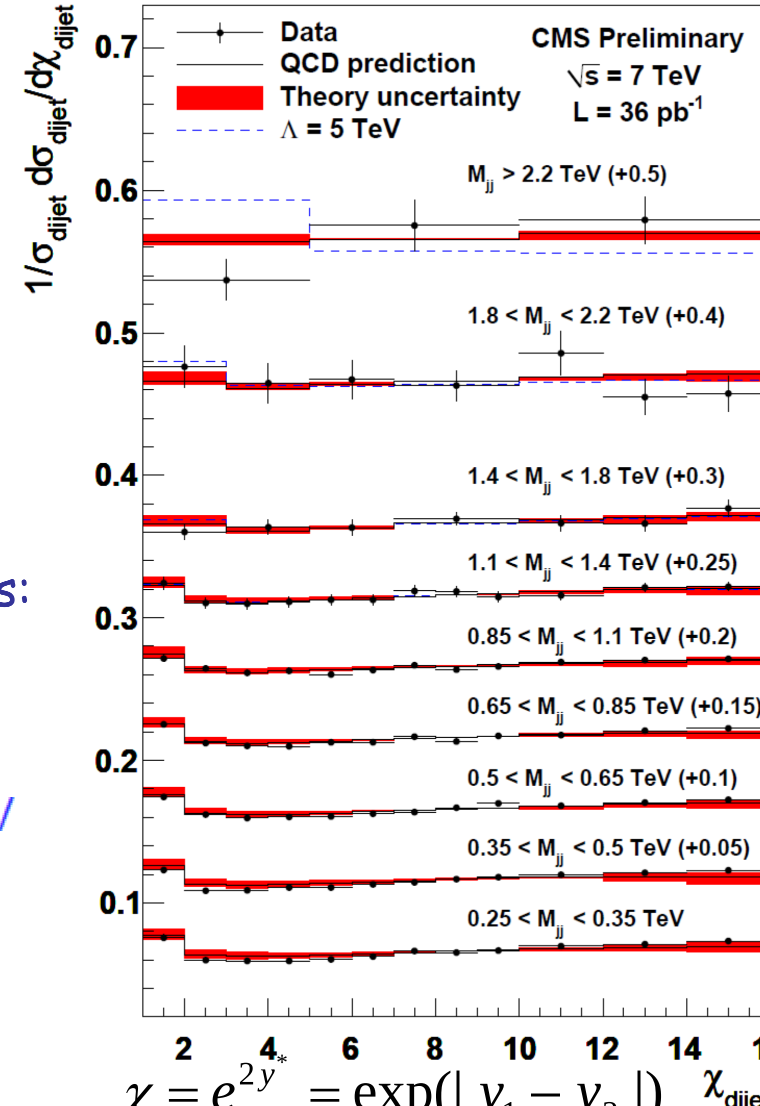


Observed limit with systematics:

$\Lambda > 5.6$ TeV

Expected limit:

$\Lambda > 5.0^{+0.4}_{-0.5}$ TeV



$$\chi = e^{2y^*} = \exp(|y_1 - y_2|)$$

Dijet Angular Decorrelation

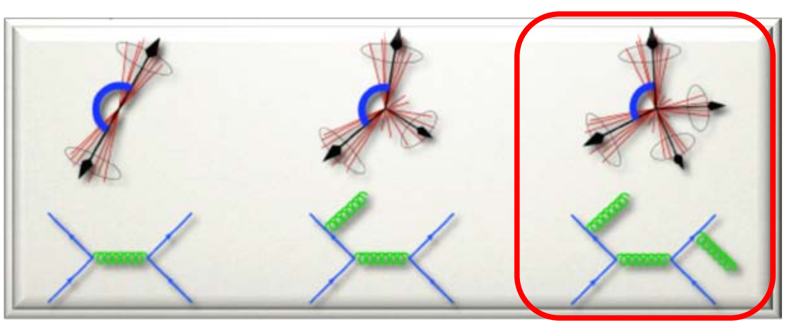
QCD High PT

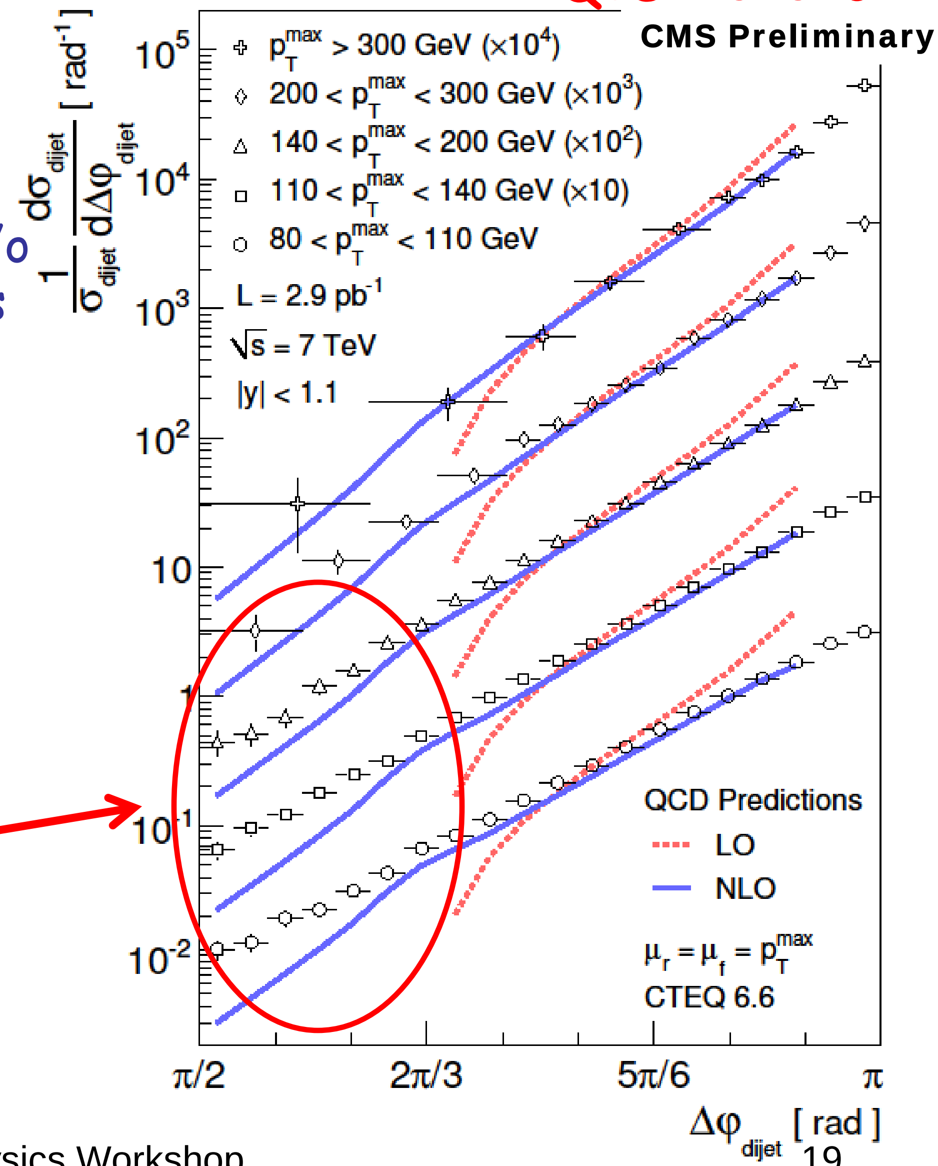
QCD-10-016

- Measurement of the azimuthal angle between the two leading jets.
- Δφ distribution of leading jets is sensitive to higher order radiation w/o explicitly measuring the radiated jets
- Shape Analysis:

$$f\left(\Delta\varphi_{\mathrm{dijet}}\right) = \frac{1}{\sigma_{\mathrm{dijet}}}\left|\frac{d\sigma_{\mathrm{dijet}}}{d\Delta\varphi_{\mathrm{dijet}}}\right|$$

  - Reduced sensitivity to theoretical (hadronization, underlying event) and experimental (JEC, luminosity) uncertainties

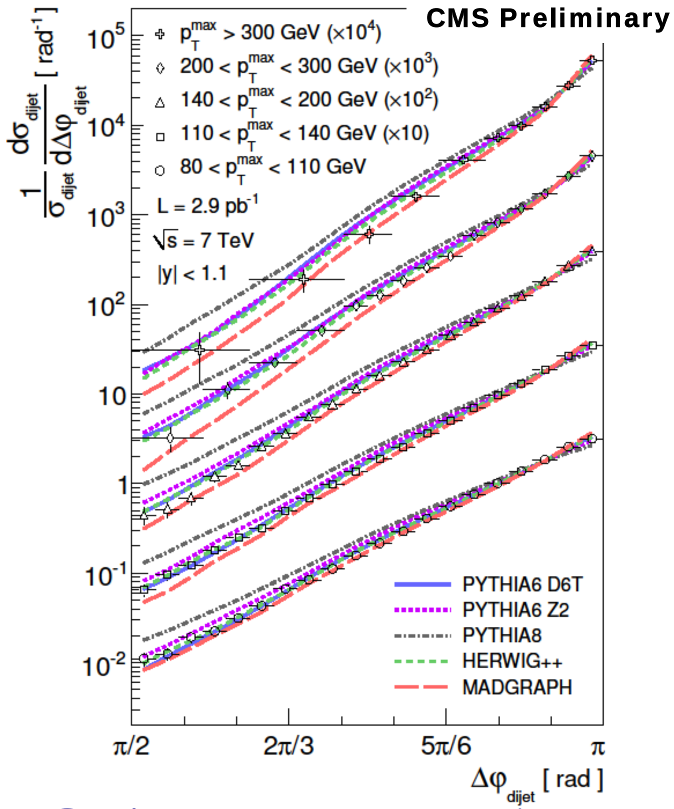


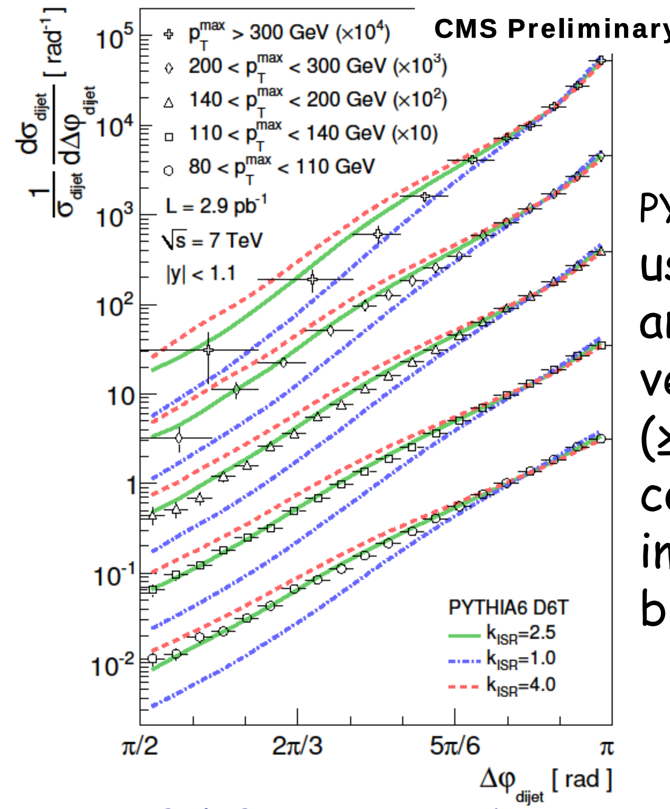


Dijet Angular Decorrelation

QCD High PT

QCD-10-016





PYTHIA 8.135 was used for this analysis. In newer versions of PYTHIA (≥ 8.145), the comparison is much improved due to a bug fix

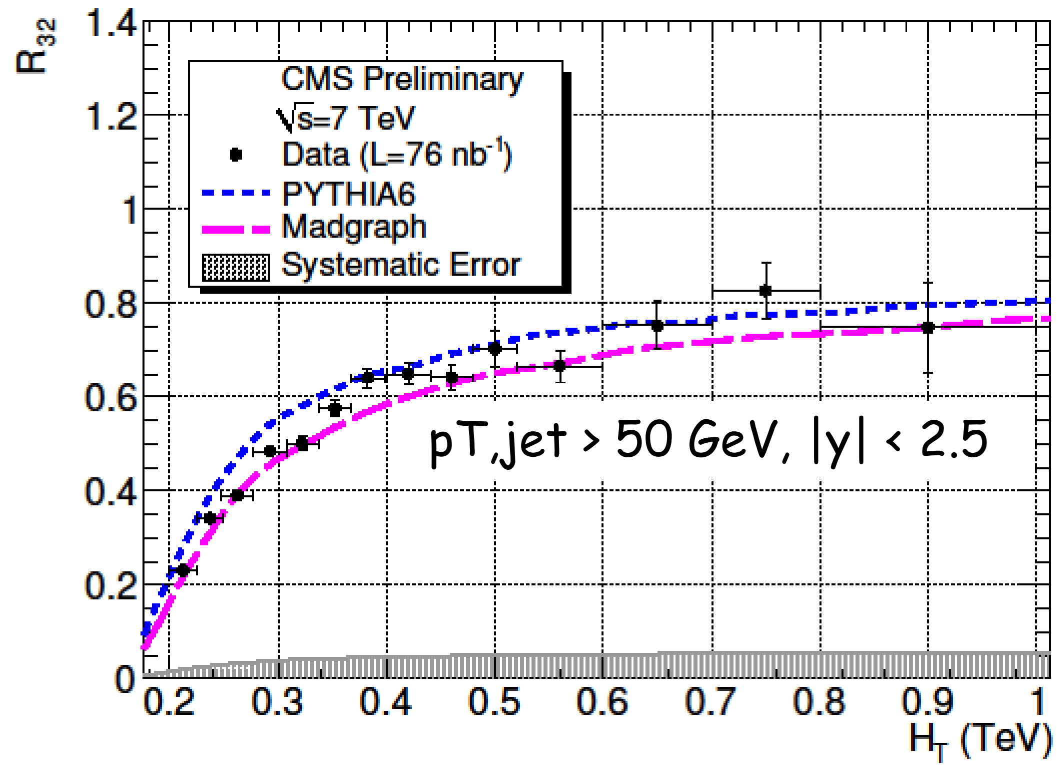
- Early measurement shown to be useful for tuning phenomenological parameters (ISR) in MC event generators
- PYTHIA6 and HERWIG++ are in reasonable agreement with the data
- Systematic uncertainties dominated by jet energy scale and jet energy resolution effects

3-Jet to 2-Jet Ratio

QCD-10-012

- Insensitive to PDFs, reduced luminosity, JEC uncertainty
- Plateau sensitive to strong coupling
- Good agreement found with PYTHIA and Madgraph within uncertainties

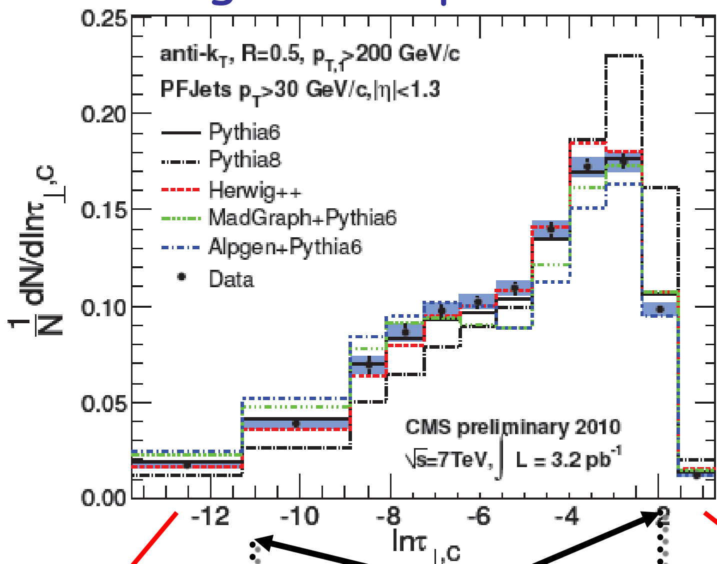
$$R_{32} = \frac{d\sigma_3/dH_T}{d\sigma_2/dH_T}$$



Event Shapes

QCD High PT

- Event shapes provide geometric information about energy flow in hadronic events
- Useful for tuning of MC models for non-perturbative effects
- Robust against experimental uncertainties



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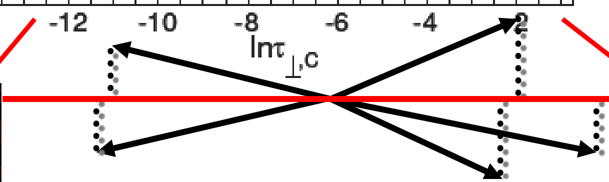
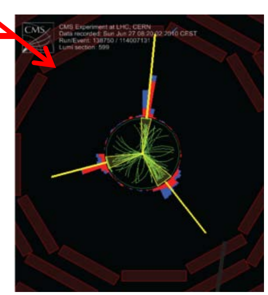
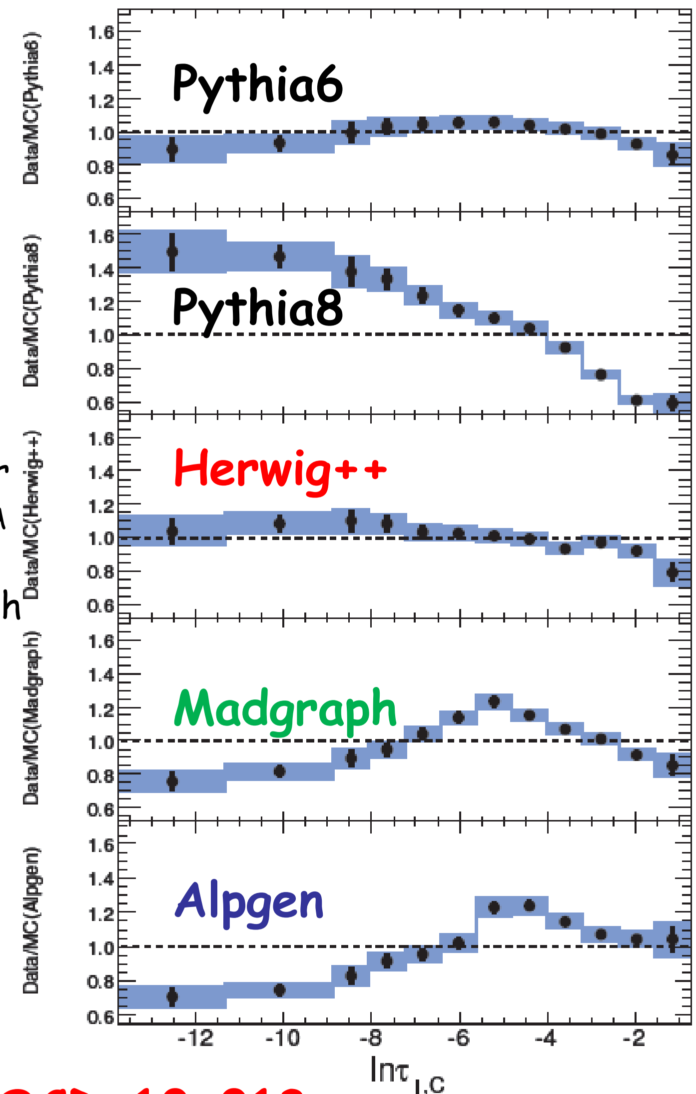




$$T_{\perp,C} \equiv \max_{\vec{n}_T} \frac{\sum_{i\in\mathcal{C}} |\vec{p}_{\perp,i}\cdot\vec{n}_T|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}$$

$$\ln\tau_{\perp,\mathcal{C}} = \ln(1 - T_{\perp,\mathcal{C}})$$

Central transverse thrust



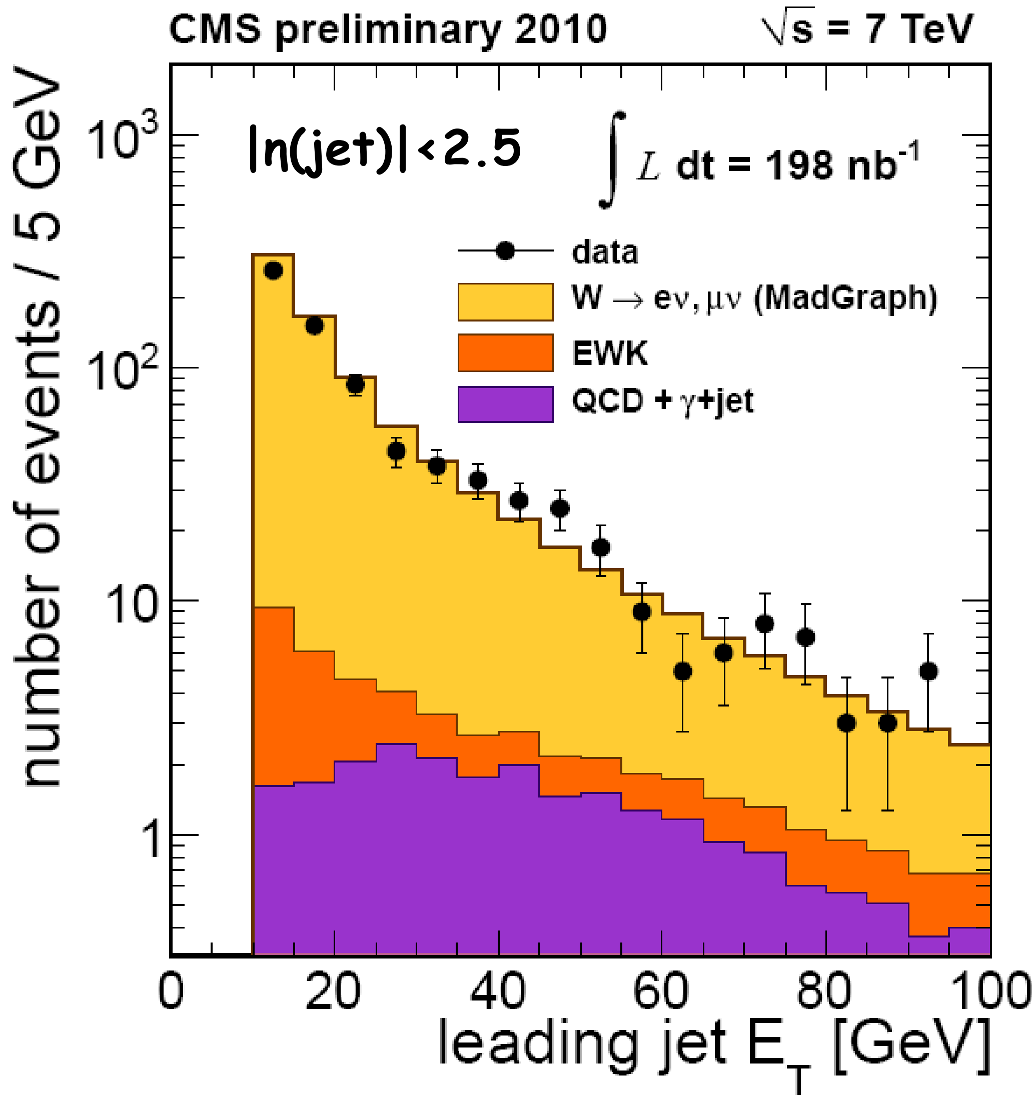
QCD-10-013

W+Jets Associated Production

QCD High PT

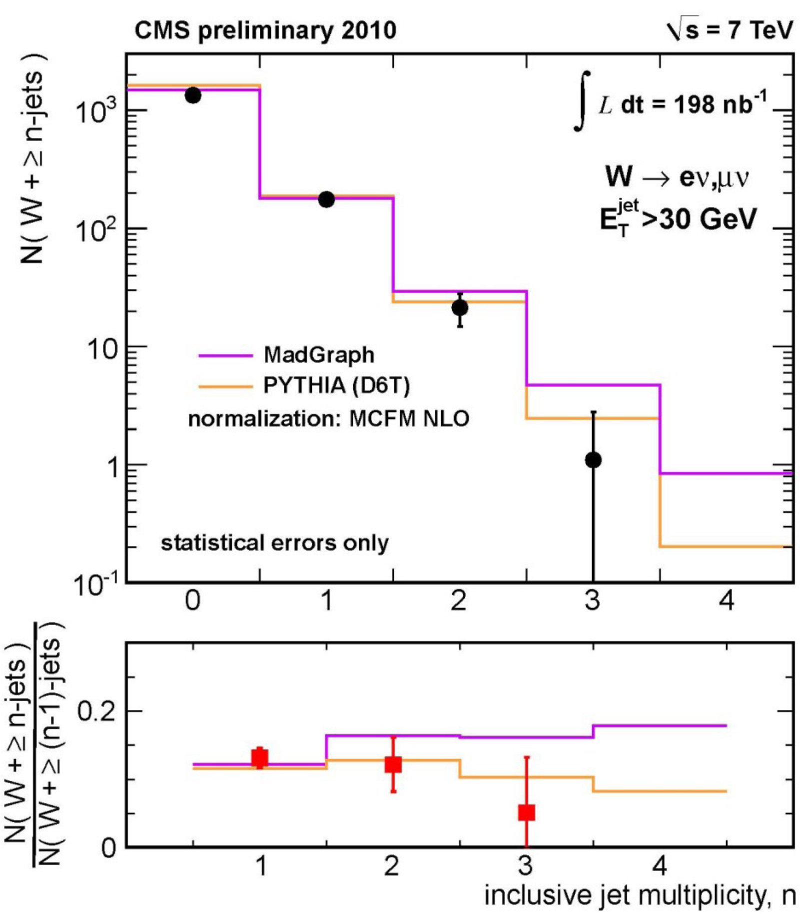
EWK-10-002

- Test of the standard model and pQCD
- Background to Top, Higgs, SUSY, etc
- Useful for jet energy scale calibration
- Jet reconstruction performed with Particle Flow and Anti-Kt algorithm ($\Delta R=0.5$)
- Lepton-jet separation $\Delta R>0.5$
- Statistical errors only shown
- Main systematic uncertainty:
  - jet energy scale (10-20%)

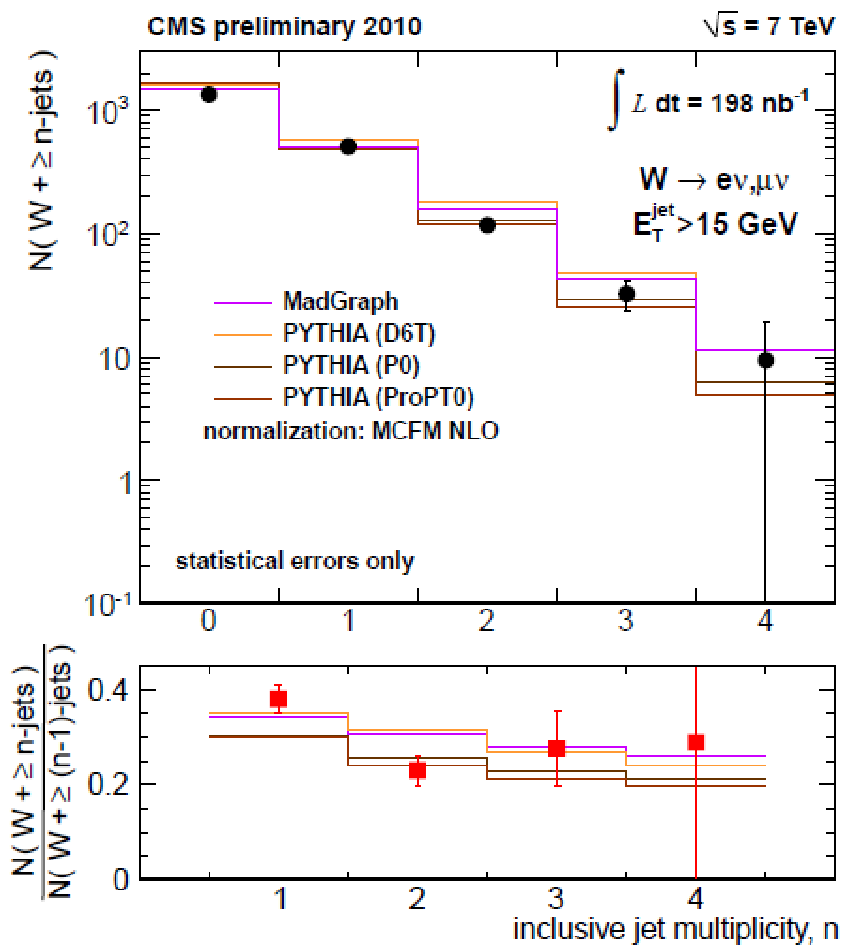


W+jets Associated Production

EWK-10-002



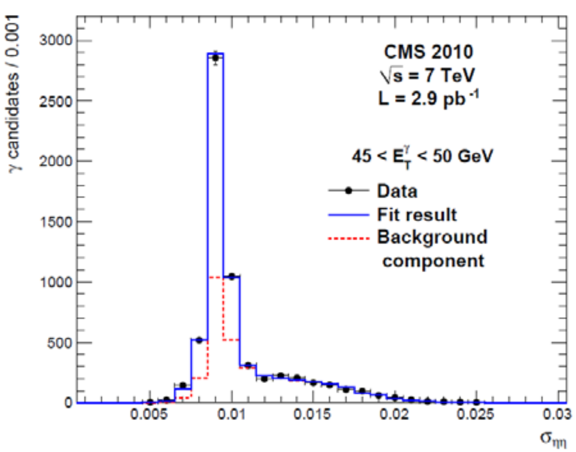
$E_T^{jet} > 30$ GeV



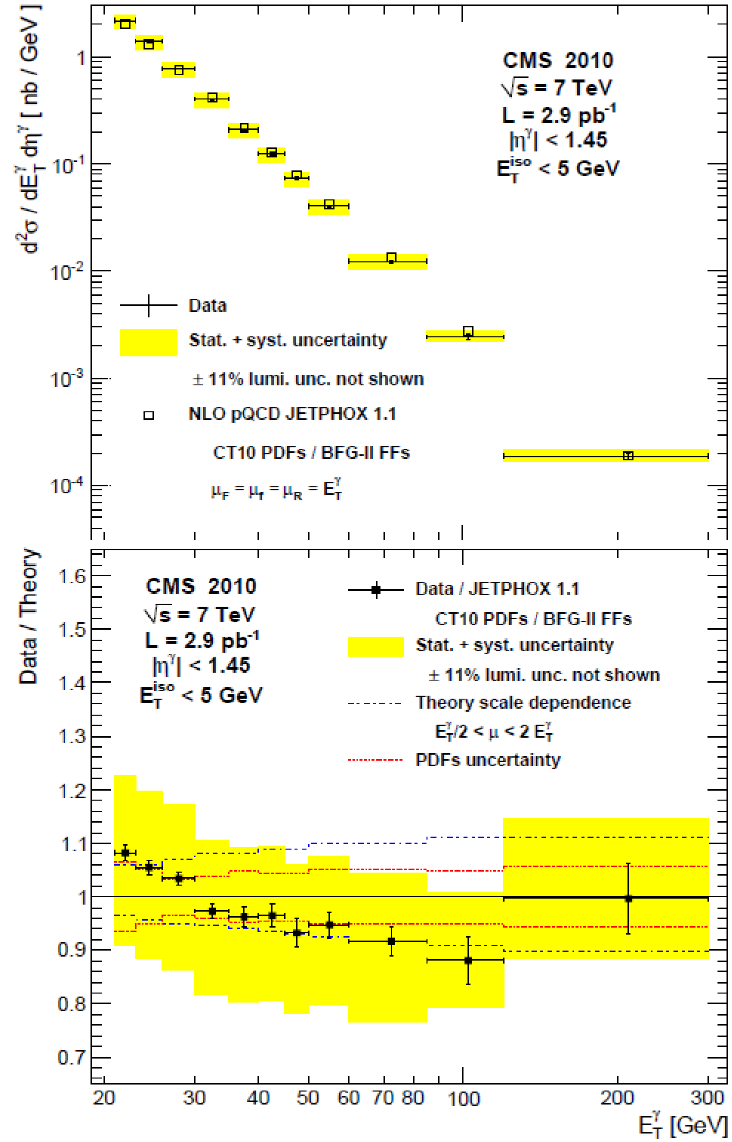
$E_T^{jet} > 15$ GeV

Direct Photon Production

- Important QCD measurement
  - sensitive to the gluon distribution
- Background to H->γγ, Exotica
- Jet energy scale calibration
- Measurement at higher Q^2 and lower $x_T=2E_T/\sqrt{s}$ than Tevatron
- 11% luminosity uncertainty not included on figures



arXiv:1012.0799



Summary

- LHC has performed amazingly well in 2010
- Already we have a rich variety of results from the high-p_T QCD program at CMS
- Many analyses are already beginning to exceed the Tevatron reach
- We are on our way towards many new and interesting physics results
- New physics might be around the corner!

CMS public results can be found at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults