Karlsruher Institut für Technologie

Jet measurements with CMS

On behalf of the CMS Collaboration

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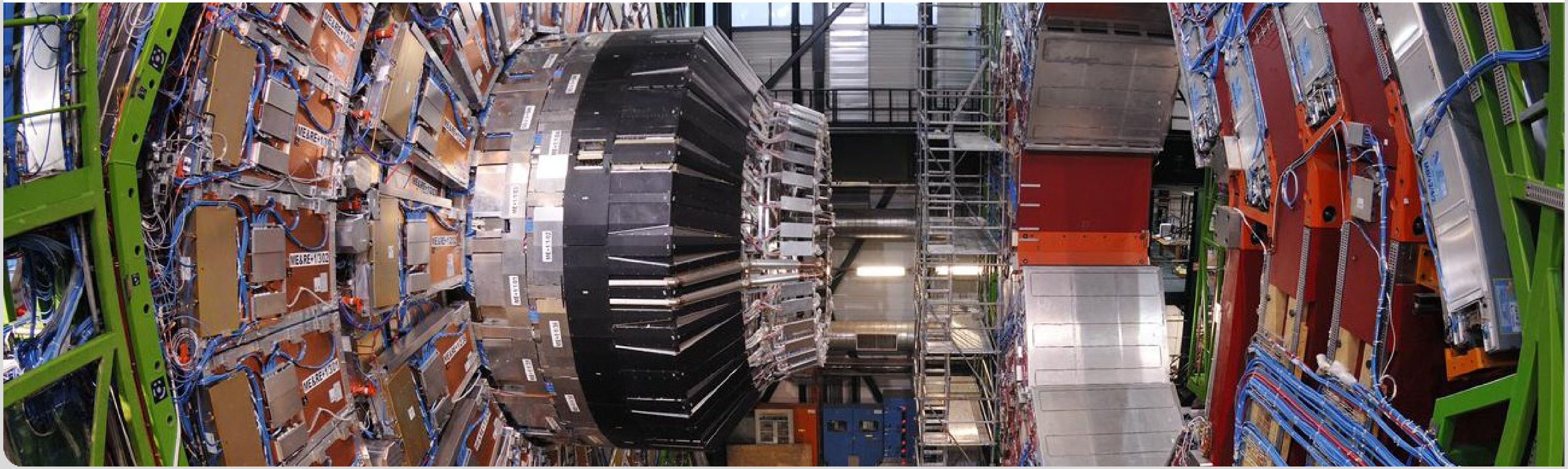
INSTITUT FÜR EXPERIMENTELLE KERNPHYSIK (EKP) · FAKULTÄT FÜR PHYSIK

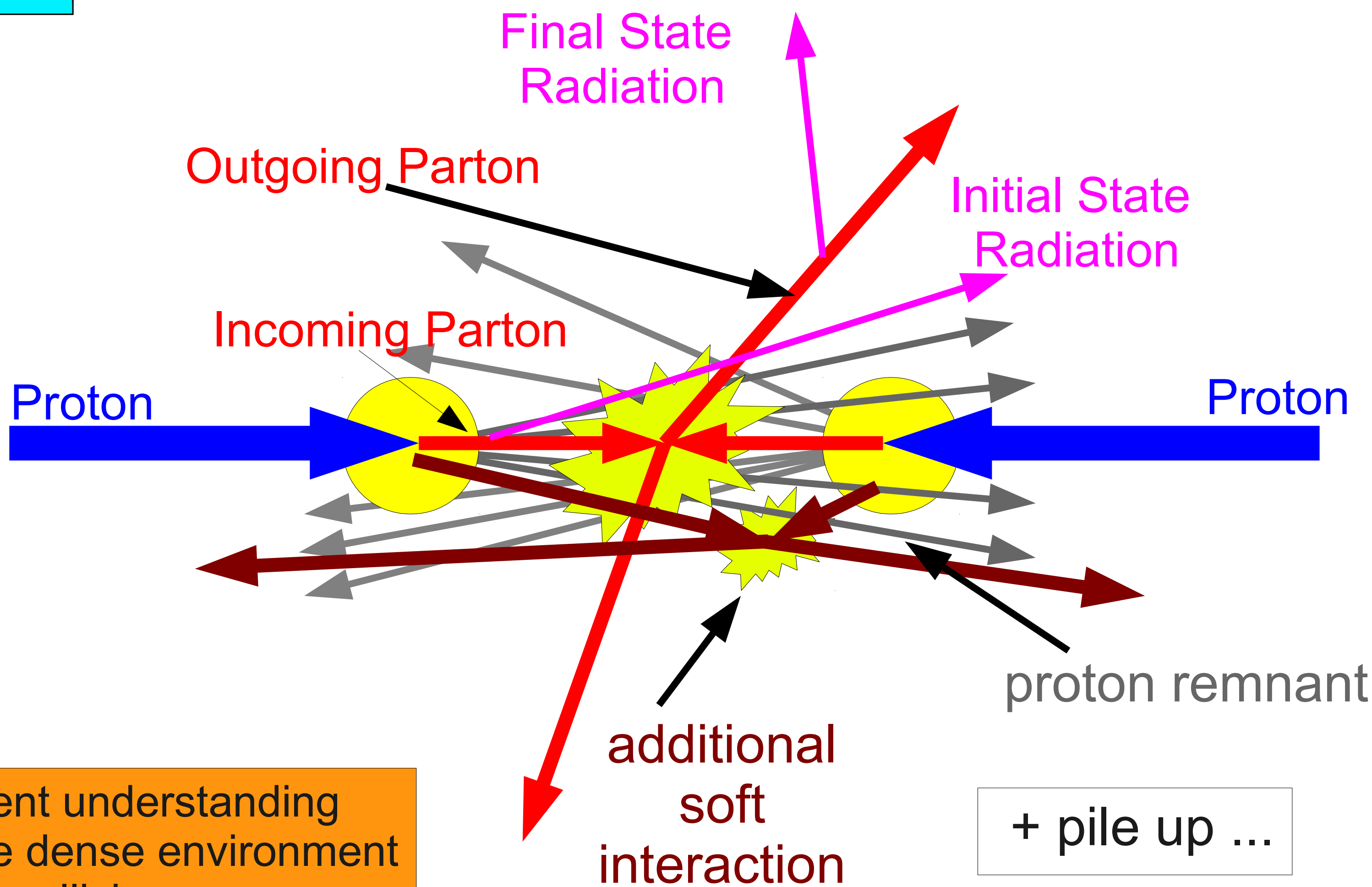


Outline

- Event Topology
- CMS
- Jets
  - Algorithms
  - Input Types
  - Jet Energy Scale and Resolution
- Theory Comparison
- Measurements
  - Dijet Angular Distributions
  - Inclusive Jets
  - Dijet Mass
  - Dijet Decorrelations
  - 3jet/2jet Ratios
- Future Measurements
  - Jet Observables to constrain α_s or PDFs

CMS public results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults
For most results papers are already or will soon appear on CDS!

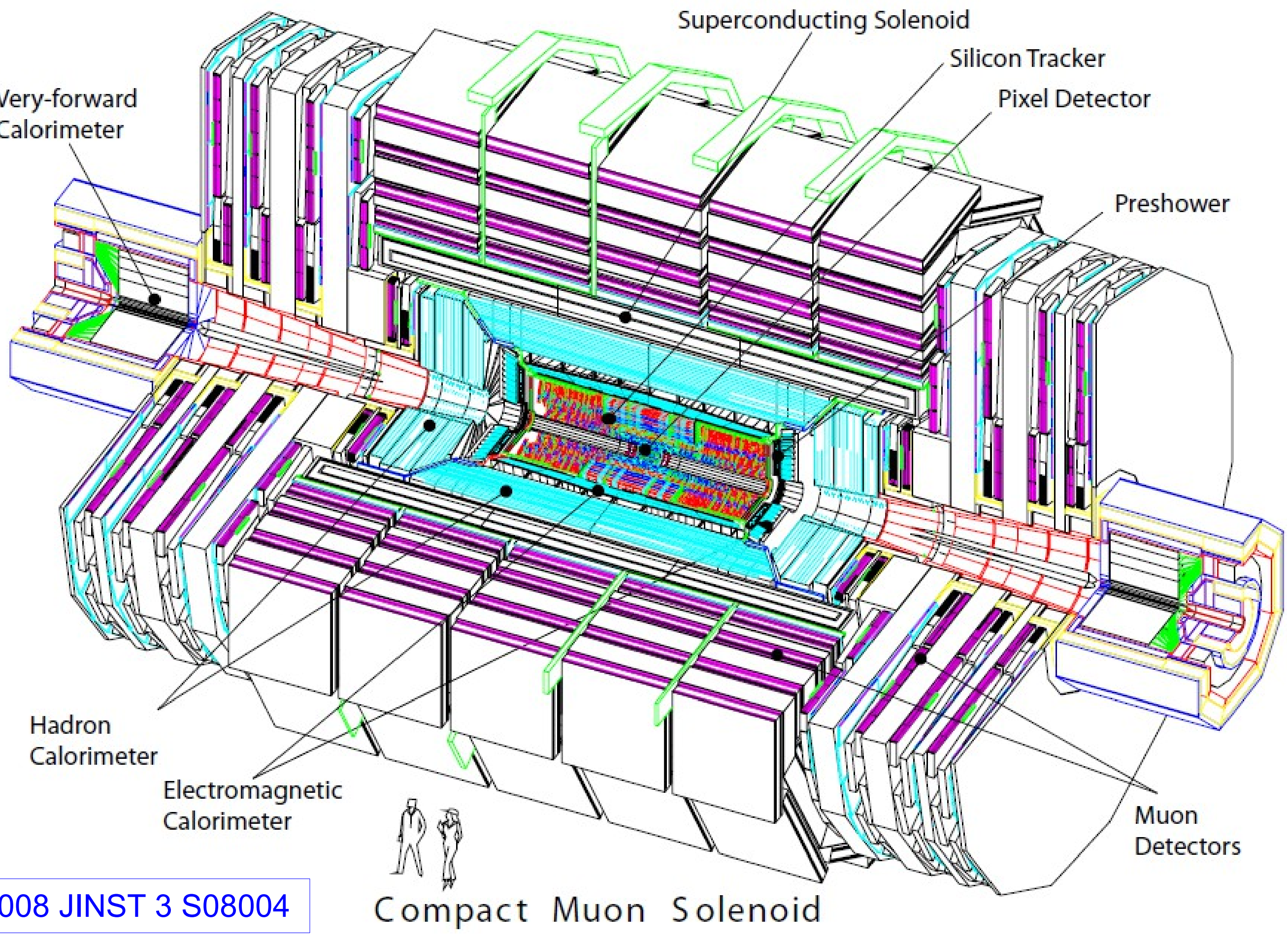
Typical Event Topology



+ pile up ...

Current understanding of the dense environment of pp collisions

The CMS Detector

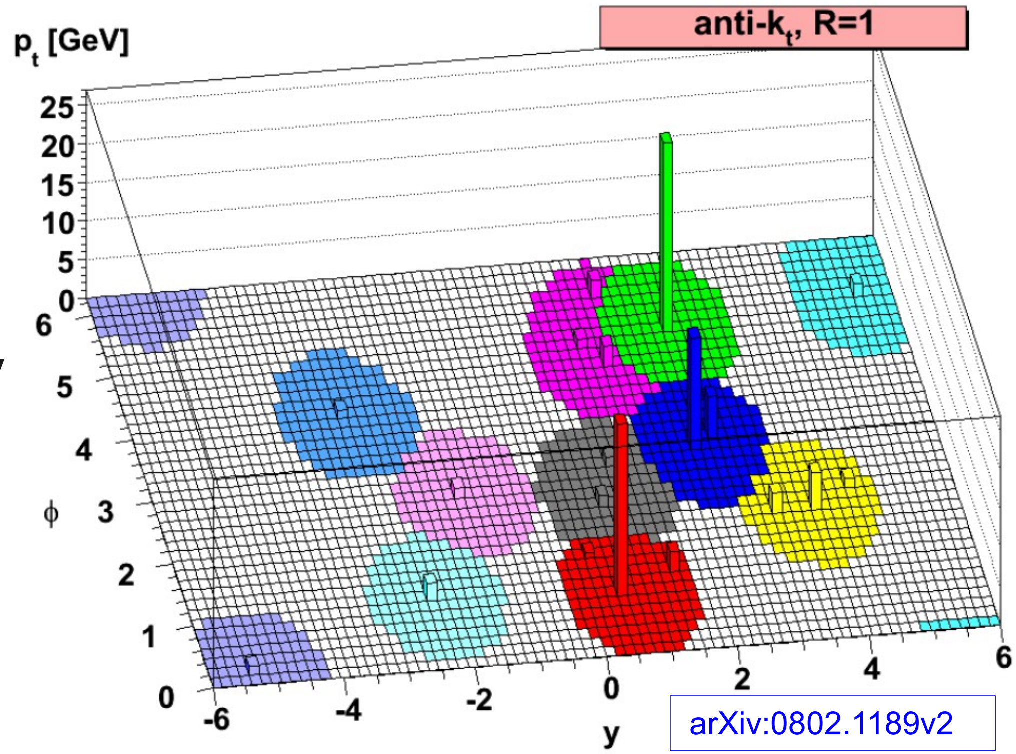


2008 JINST 3 S08004

- Combine all sub-components for jet analysis using the Particle Flow algorithm
- High Pt jets mostly determined by calorimeter information, therefore basic Calorimeter Jets used as cross check

Jet Algorithm

- Baseline algorithm used in the 2010 analyses is anti-kt with R=0.5
- Active Jet Area determination used for pileup treatment
- Other types, and especially larger R are planned to be considered for the upcoming analysis of 2011



Jet Input

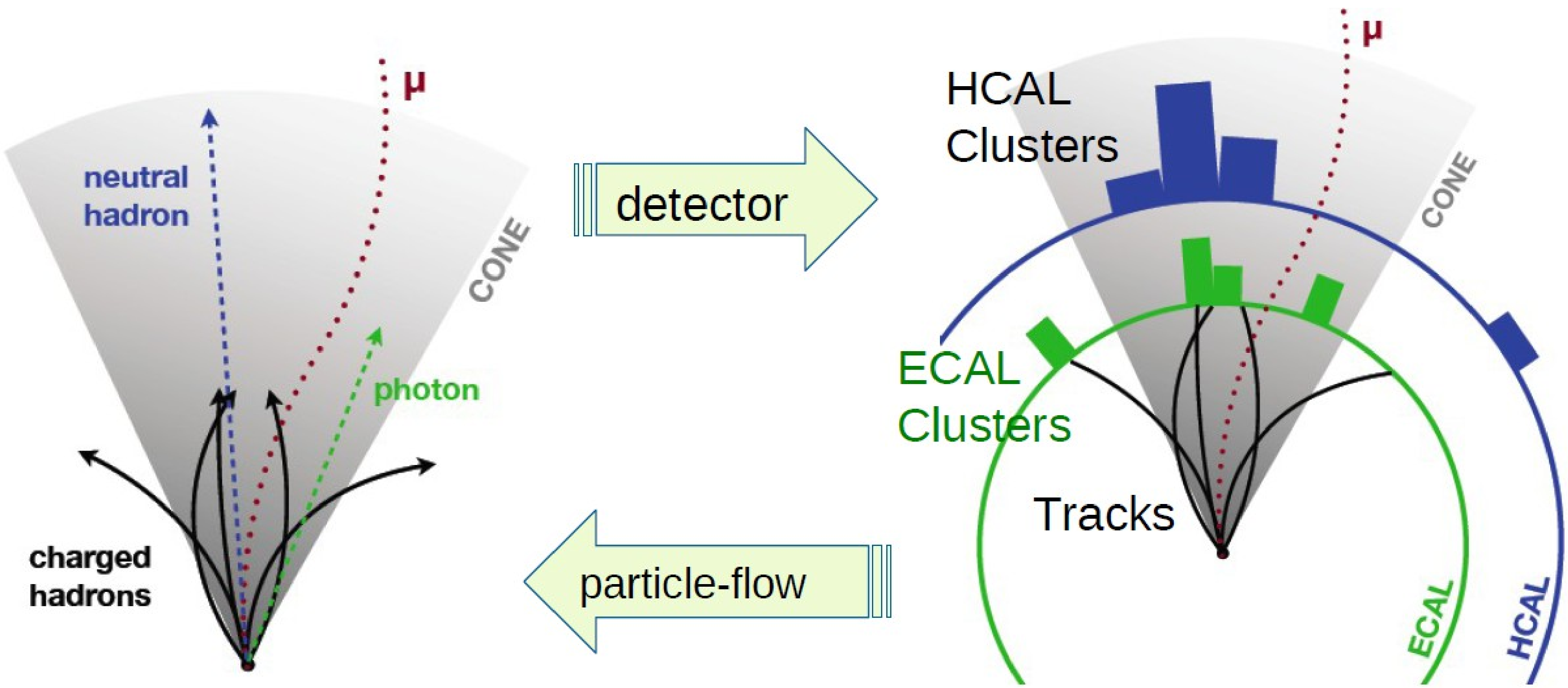
- CaloJets from "CaloTowers":
  Eta-phi segments combining Hadron Calorimeter layer measurements with the underlying, finer grained cells of the Electromagnetic Calorimeter are used as input to the jet algorithm.

- ParticleFlow-Jets using all subdetectors:
  All energy or charge deposits are reconstructed with a method specialized for the detector component used. A disambiguation of the objects is performed and finally particles are identified which can be used by the higher level algorithms almost like MC generator particles. Their fourvectors are passed to the jet algorithm.

PFT-09-001, PFT-10-002

http://cdsweb.cern.ch/record/1194487/files/PFT-09-001-pas.pdf
http://cdsweb.cern.ch/record/1279341/files/PFT-10-002-pas.pdf

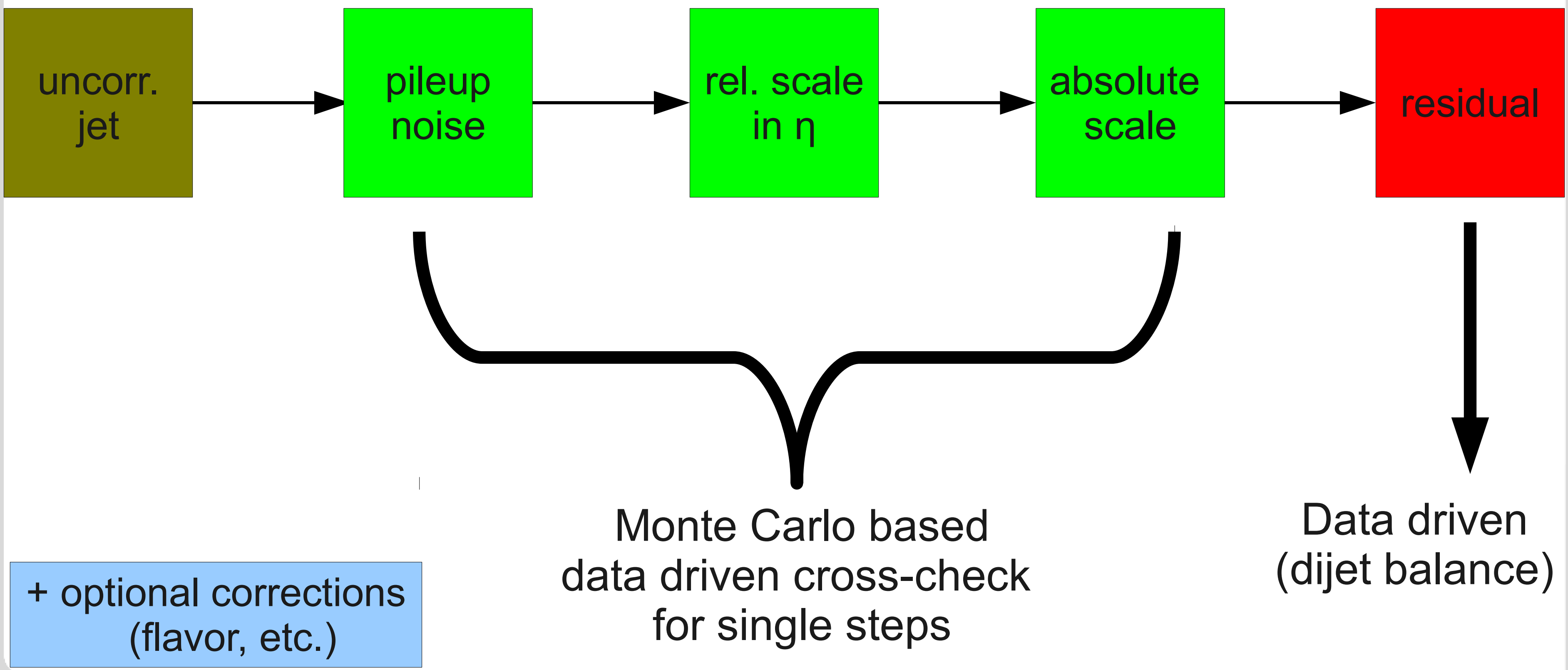
Particle Flow Concept



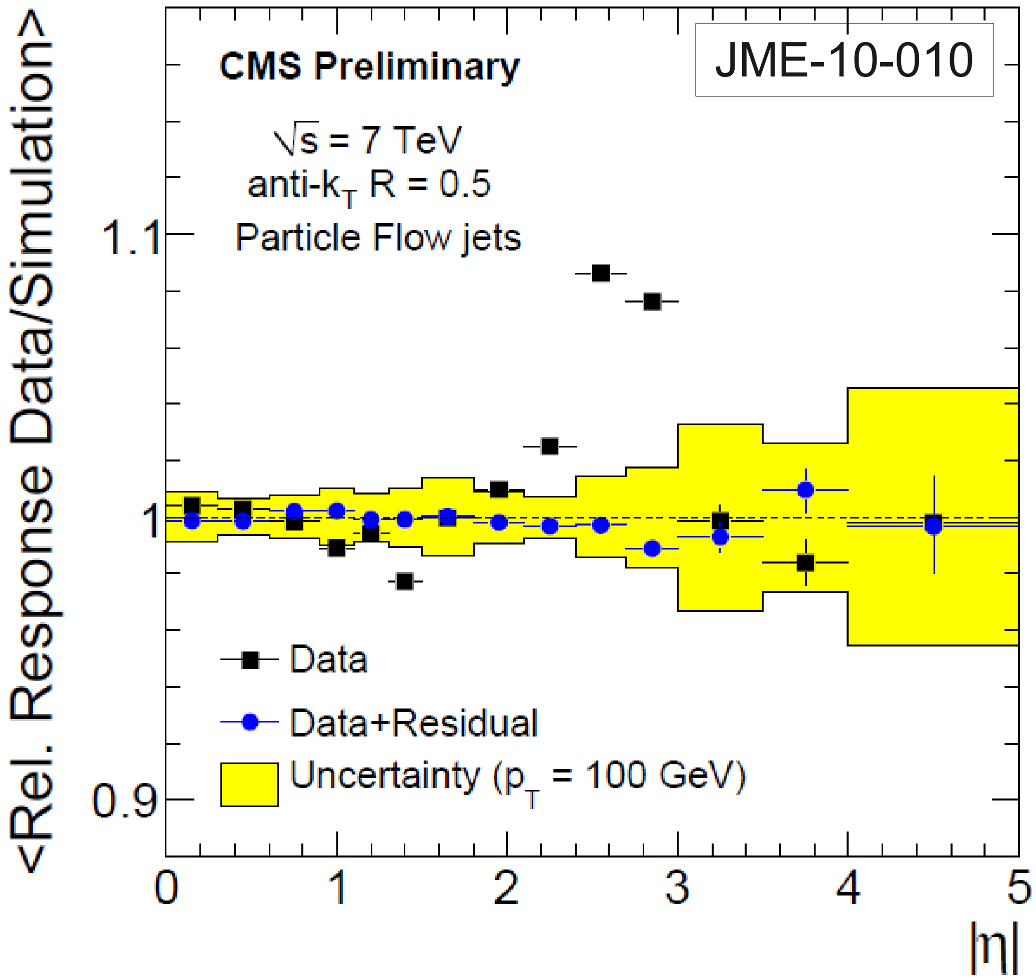
Apply signal type-dependent corrections,
disambiguation
particle type association

Jet Performance with Data (1/4)

- CMS Factorized Approach for Jet Energy Scale (JES) corrections:



Jet Performance with Data (2/4)



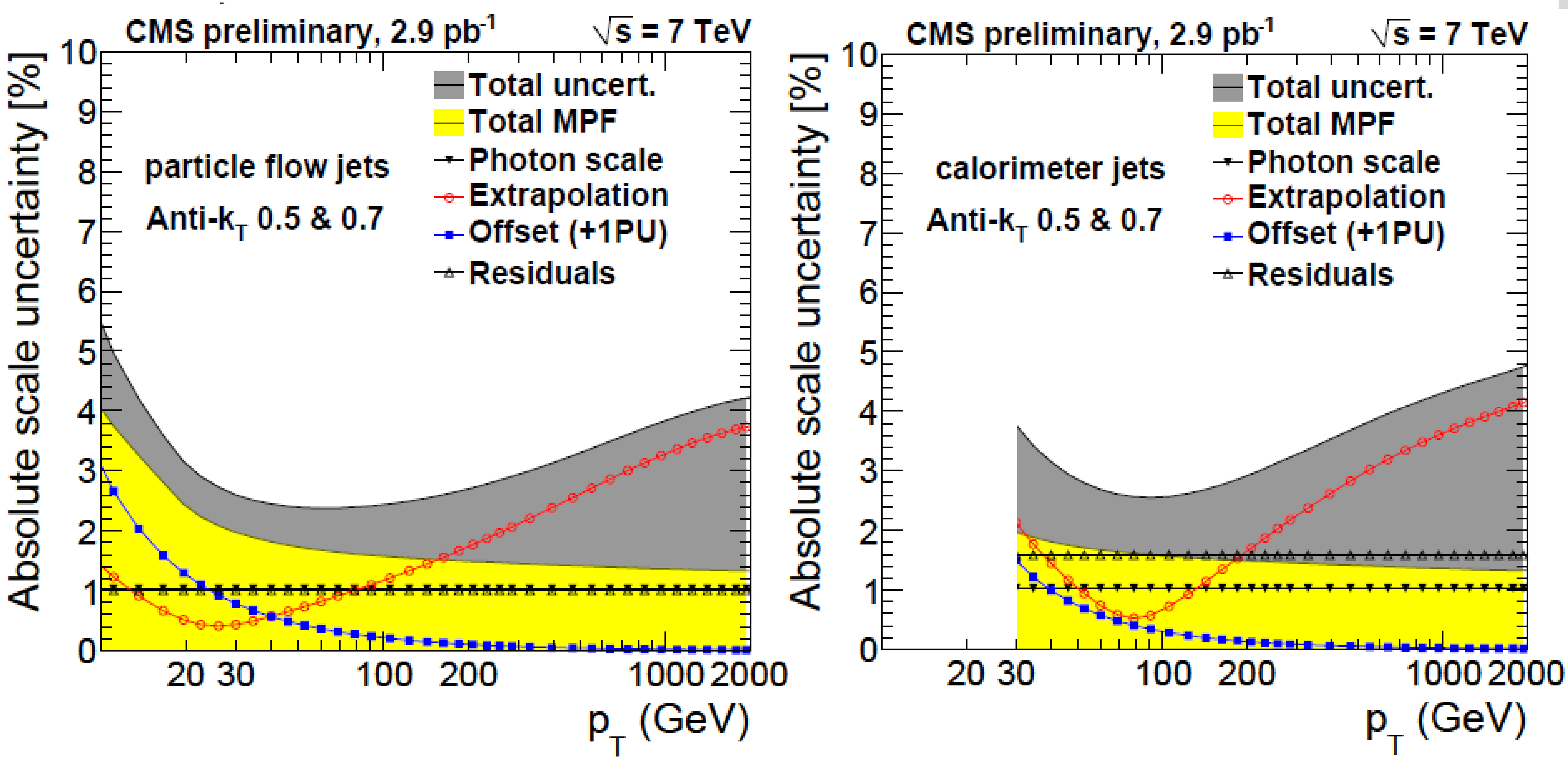
Cross check: Relative response in data and Monte Carlo.

Nice data-MC agreement for the response ratios after applying residual corrections

Jet Performance with Data (3/4)

JME-10-010

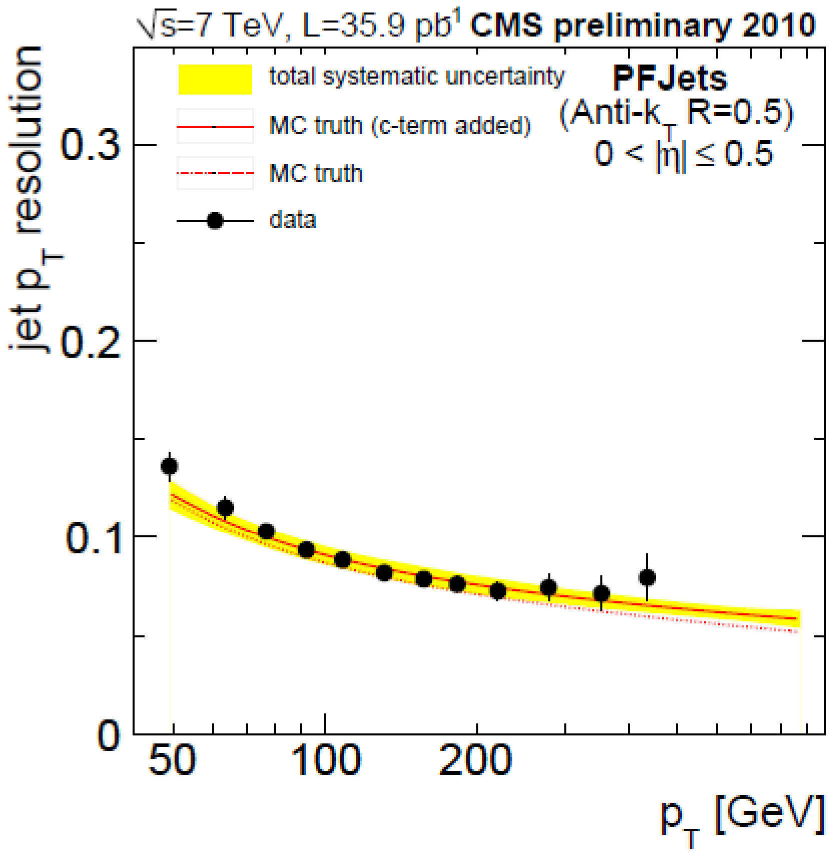
Jet Energy Scale Uncertainty

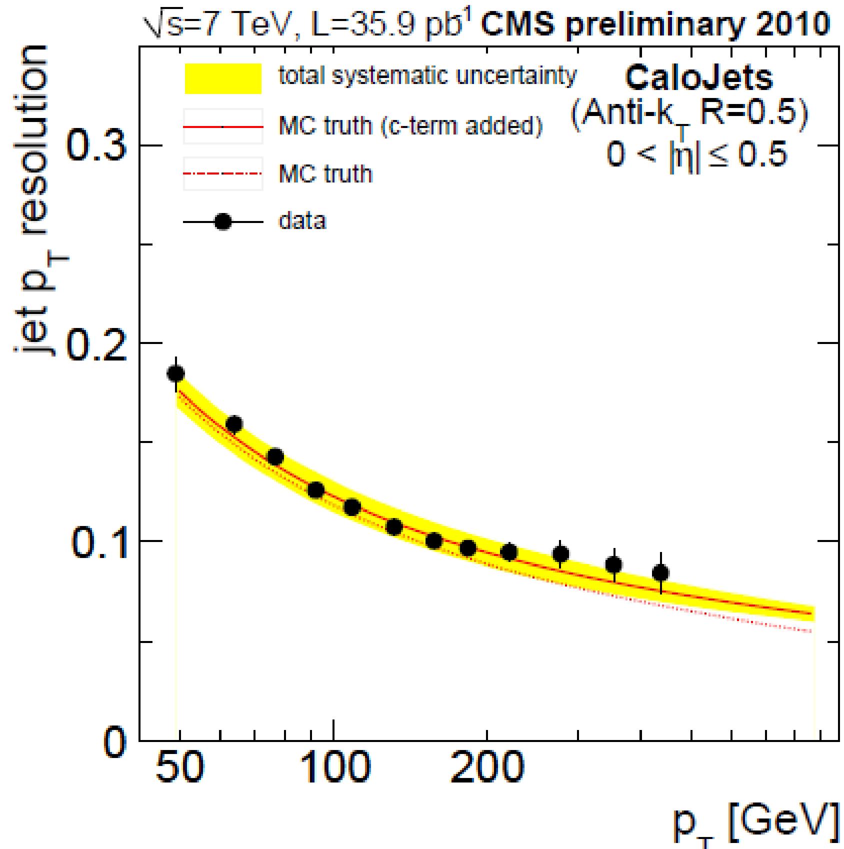


Jet Performance with Data (4/4)

JME-10-014

Jet p_T Resolution





- Resolution determined from Monte Carlo
- Confirmed by Asymmetry method in Data

$$\frac{\sigma(p_T)}{p_T} = \sqrt{\mathrm{sgn}(N) \cdot \left(\frac{N}{p_T}\right)^2 + S^2 \cdot p_T^{(M-1)} + C^2}$$

Theory Comparison PDF4LHC

PoS(DIS 2010)036

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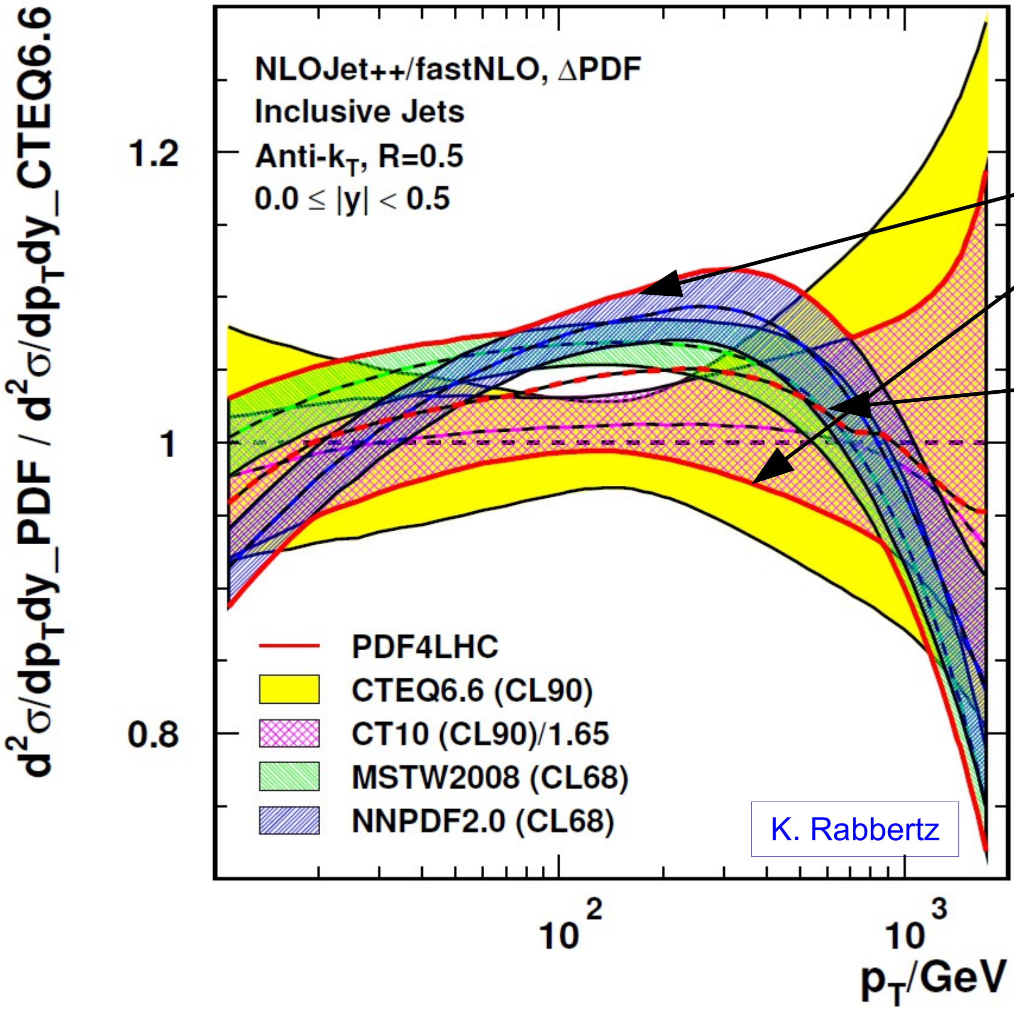


<u>Example: Inclusive Jets</u>

PDF4LHC/CTEQ6.6

Envelope uncertainty (1σ)

Central value, used in comparisons

PDF4LHC suggestion is meant to test general compatibility of observables with pQCD predictions.

Not to be used for dedicated pdf tests or measures of α_S.

Measurements

Dijet Angular Distributions (1/2)

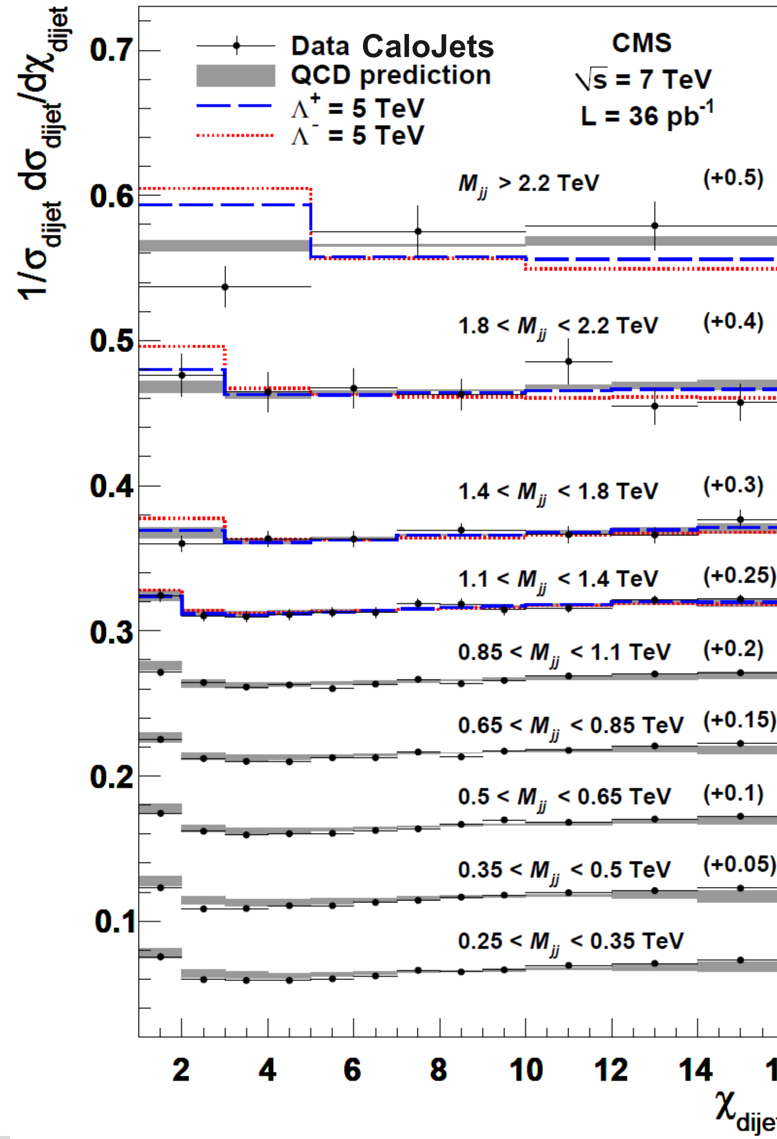
QCD-10-016

arXiv:1102.2020v1

- Reduced sensitivity to overall JES, JER
- Slight sensitivity to rap dependence of JES → overall < 2.5% on X_{Dijet}
- Theory comparison: Cteq 6.6 only.

$X_{Dijet}=(1 + |\cos\theta^*|)/(1 - |\cos\theta^*|)$ with $|\cos\theta^*| = \tanh(0.5^*|y_1 - y_2|)$ with y_1 and y_2 the rapidities of the leading dijets.

- X_{Dijet} is flat for Rutherford, modifications can distinguish QCD and new Physics, especially sensitive: small X_{Dijet}.

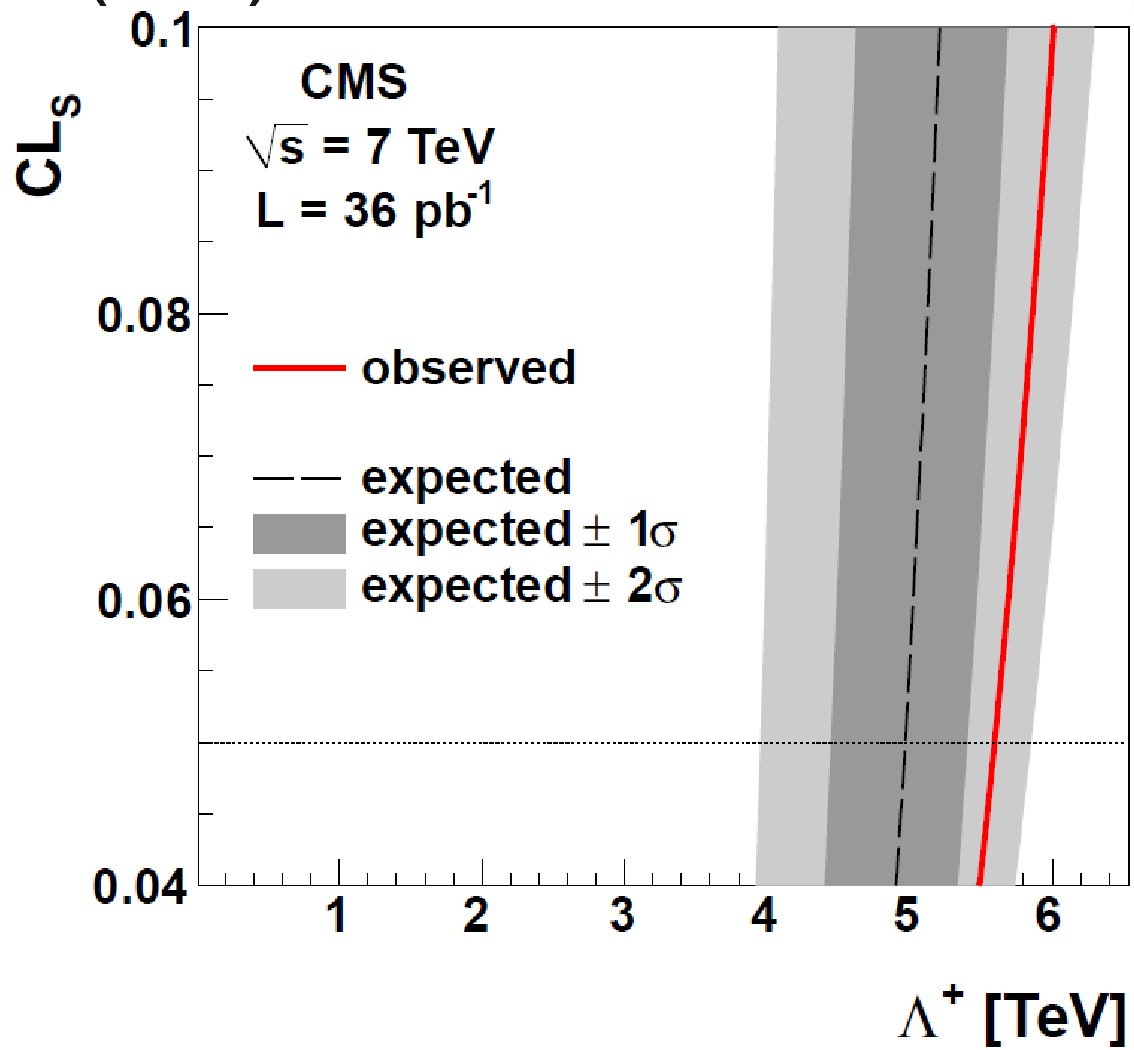


Dijet Angluar Distributions (2/2)

QCD-10-016

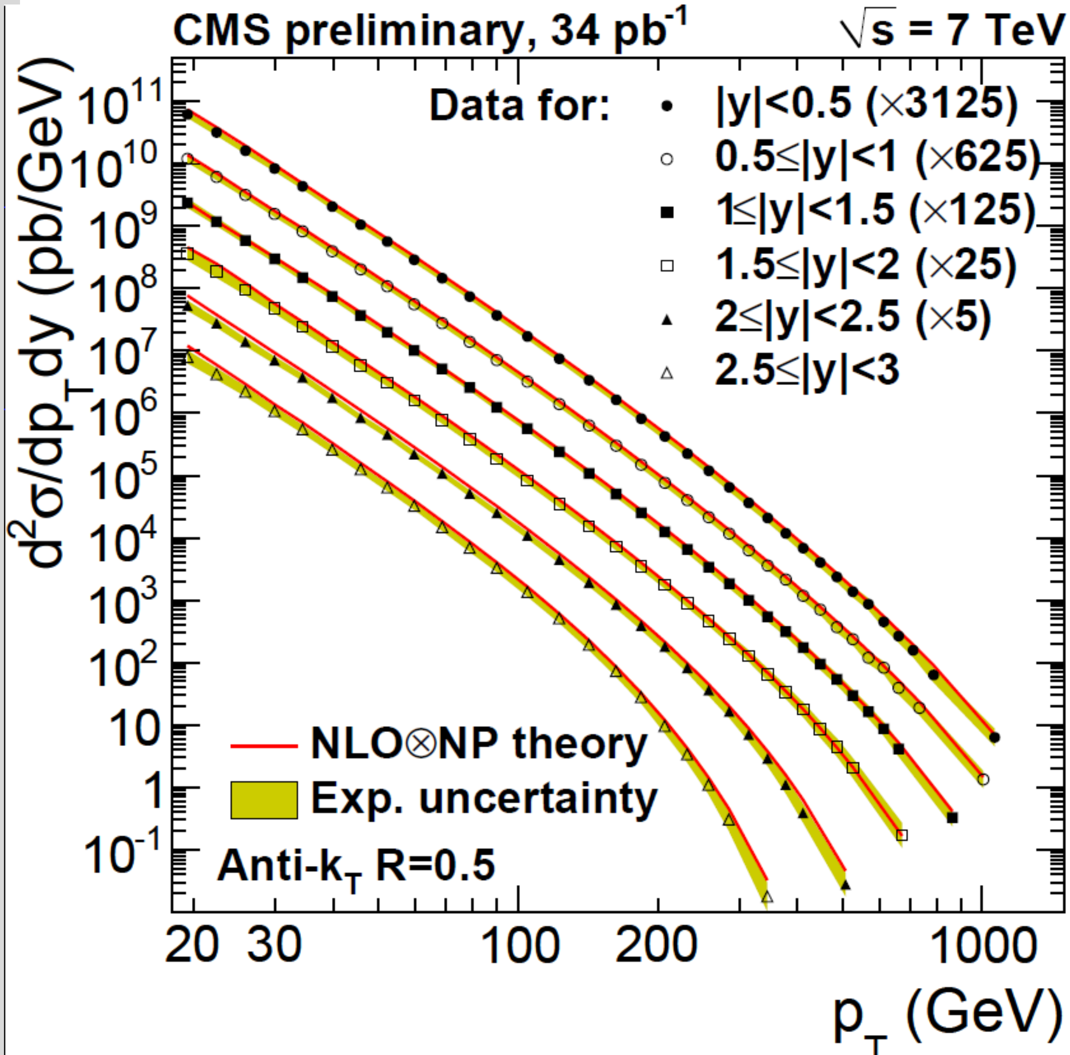
arXiv:1102.2020v1

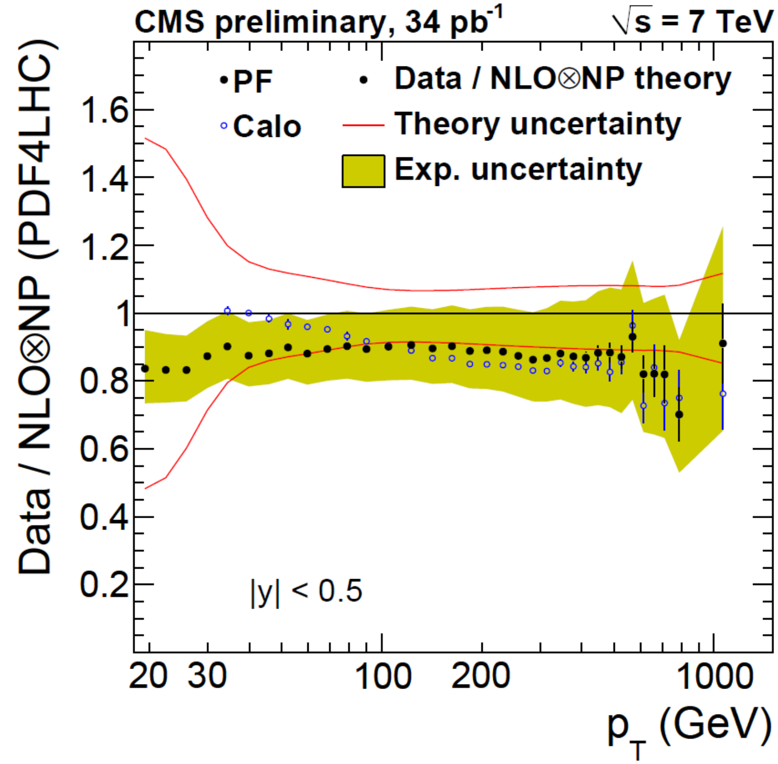
- No sign for new physics found
- CL_S lower limits (95% exclusion):
  $\Lambda^+ > 5.6$ TeV
  $\Lambda^- > 6.7$ TeV



Inclusive Jet Cross Section (1/2)

QCD-10-011



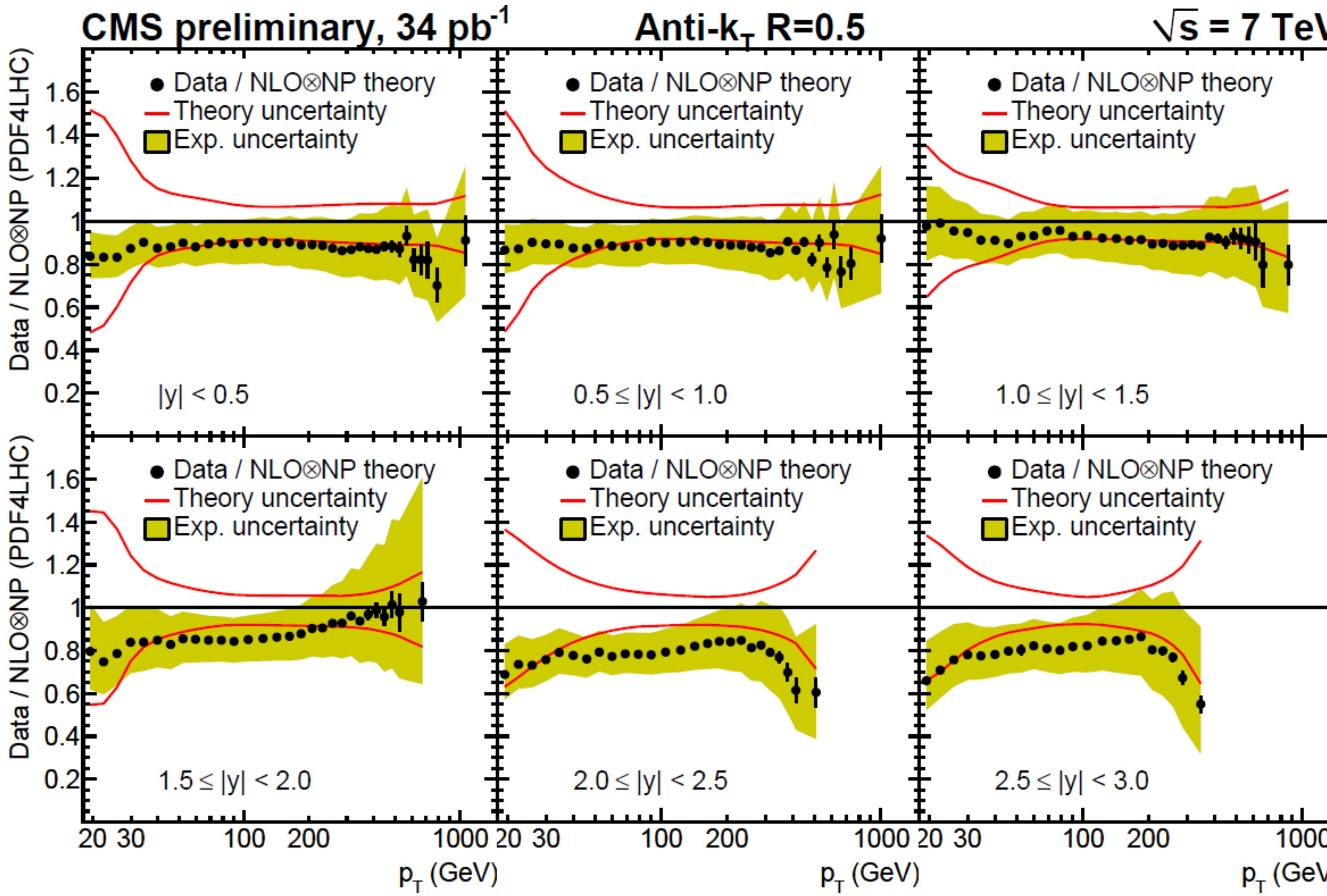


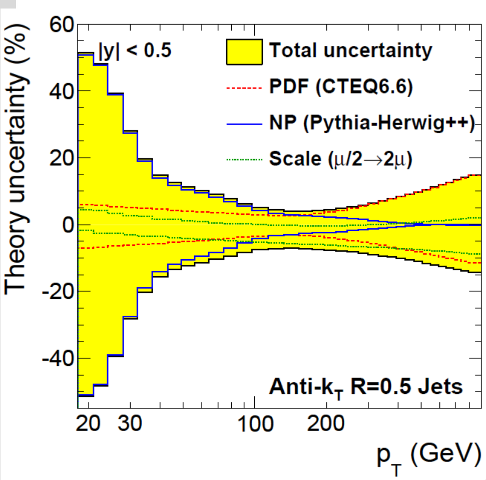
- Spectra corrected for energy scale and resolution effects
- Non perturbatively corrected
- NLO theory agrees well within uncertainties.
- PF and CaloJets agree well within their systematic uncertainties.

Inclusive Jet Cross Section (2/2)

QCD-10-011

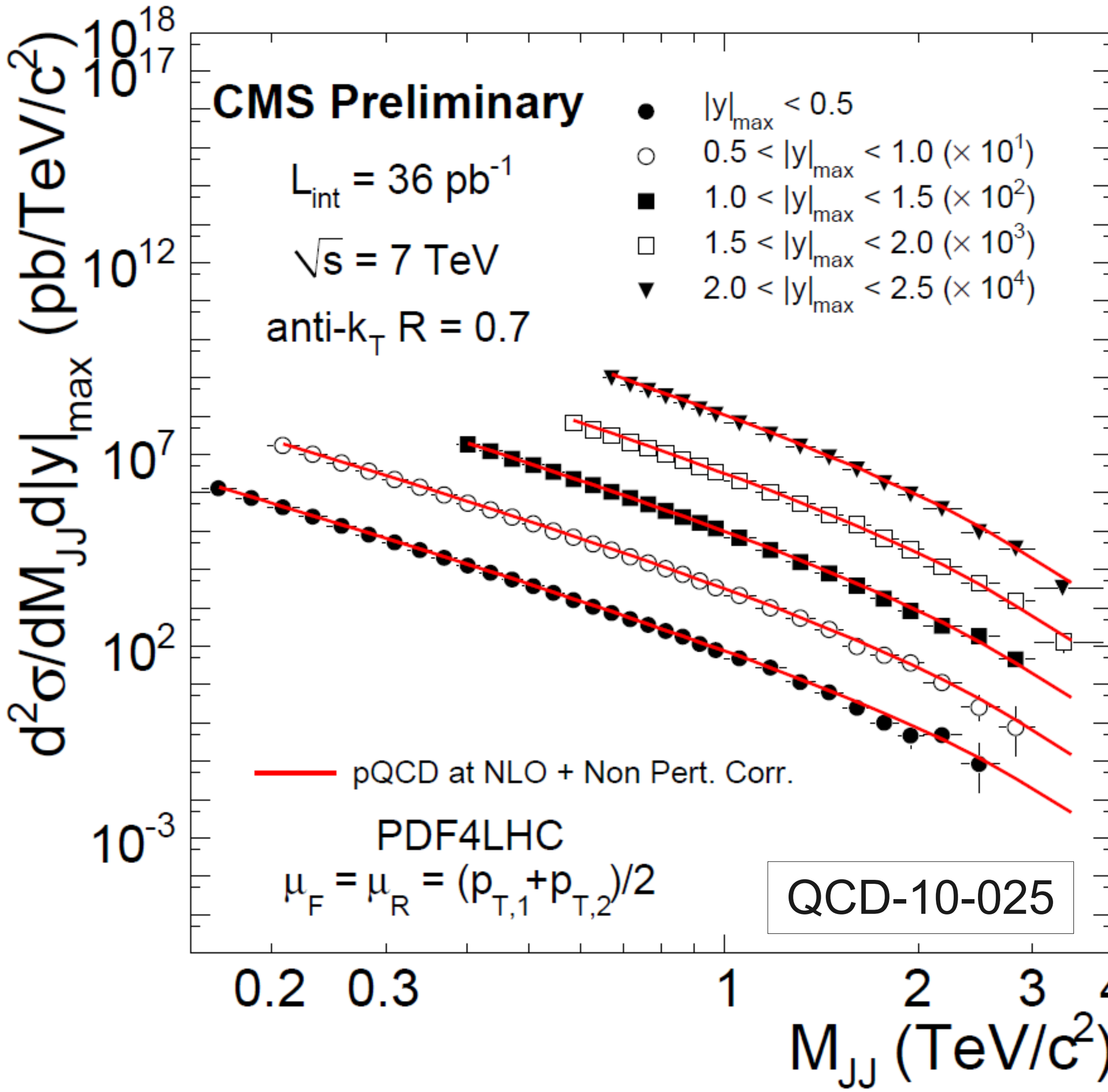
- Allover good agreement with pQCD
- Data slightly below theory
- Observation increases for outer rapidities





Dijet Mass (1/2)

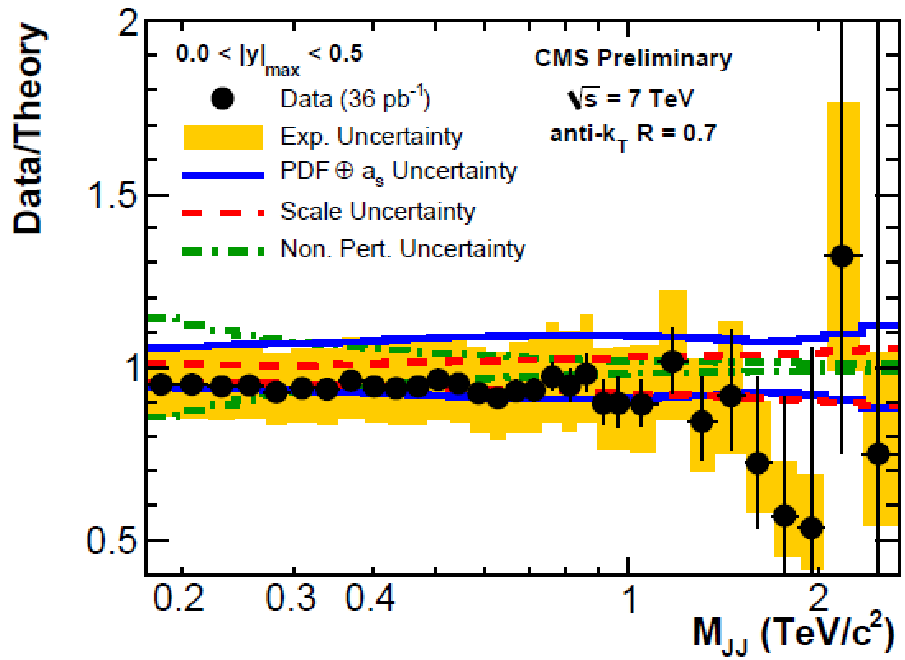
- Nice agreement between data and pQCD+Non Pert. Correction
- Compatibility tests v.s. PDF4LHC suggestions
- Anti-kt R=0.7 used here
- Particle Flow input

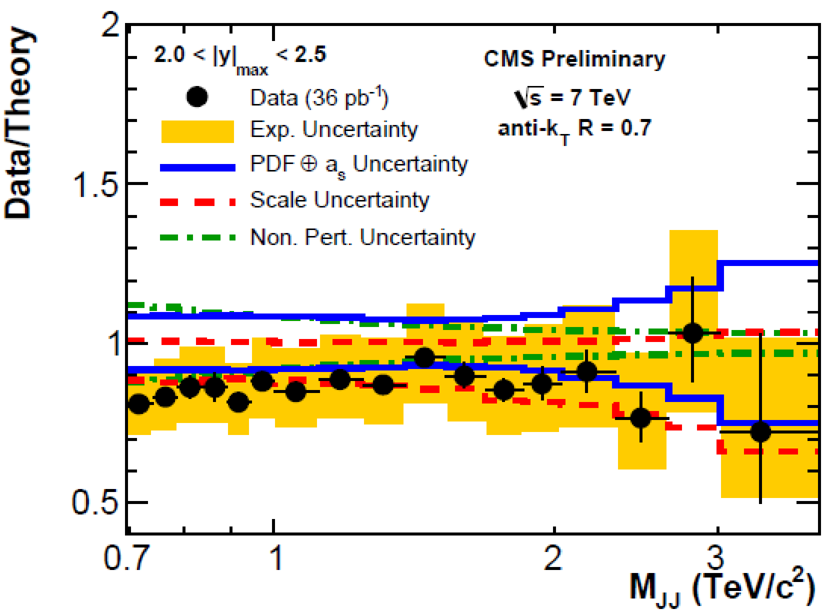


Dijet Mass (2/2)

QCD-10-025

- Smaller exp. uncertainty than incl. jets due to better dijet mass resolution
- Nice agreement to NLO theory within theory and exp. uncertainty
- Exp. And theory uceratinties of similar size





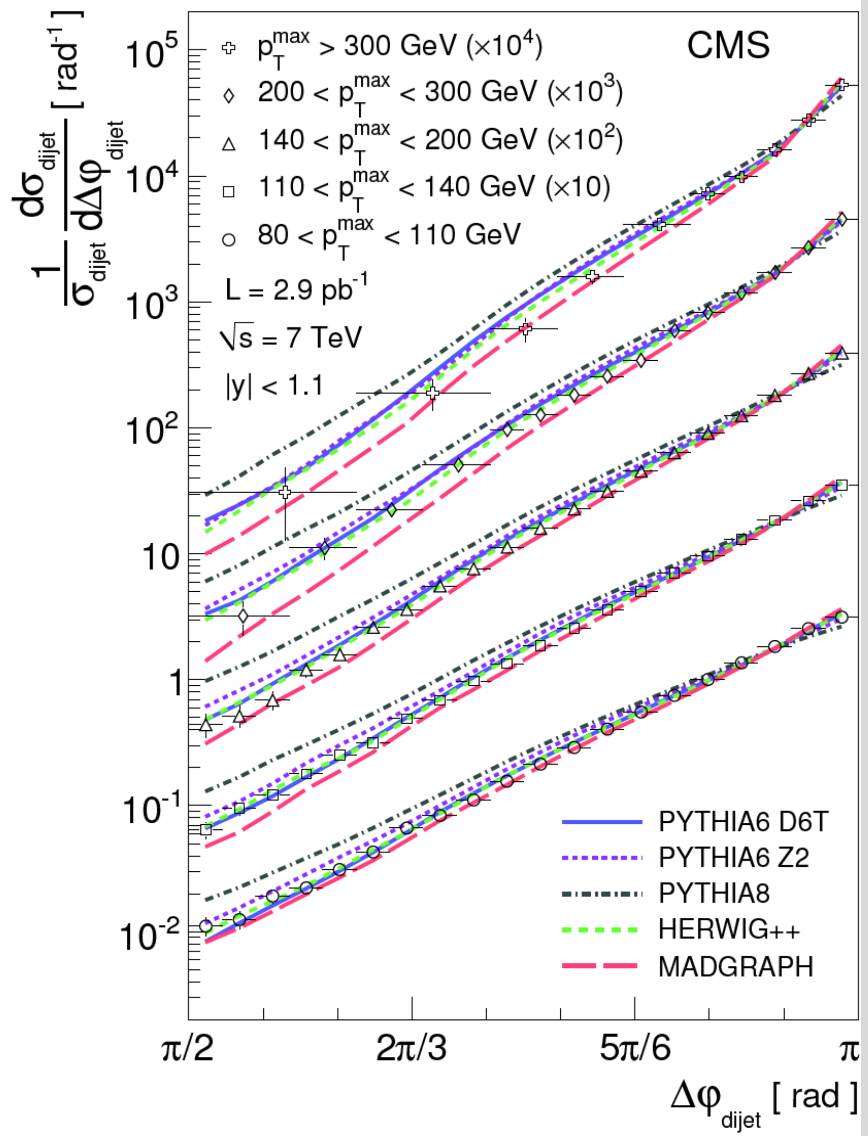
- Slightly larger uncertainty but also slightly larger deviation in outer rapidities

Dijet Azimuthal Decorrelations (1/2)

QCD-10-016

PhysRevLett.106.122003, arXiv:1101.5029

- Measure dPhi of the two leading (Particle Flow) anti-kt (R=0.5) jets
- Sensitive to additional radiation
- ~ π → 2 Jet Event
  ~ 2π/3 → 3 Jet Event
  < 2π/3 → multijet range
- Madgraph 4.4.32 undershoots, Pythia 8.135 overshoots for smaller $d\varphi_{dijet}$
- MADGRAPH, HERWIG++ and Pythia 6 (D6T,Z2) do quite well

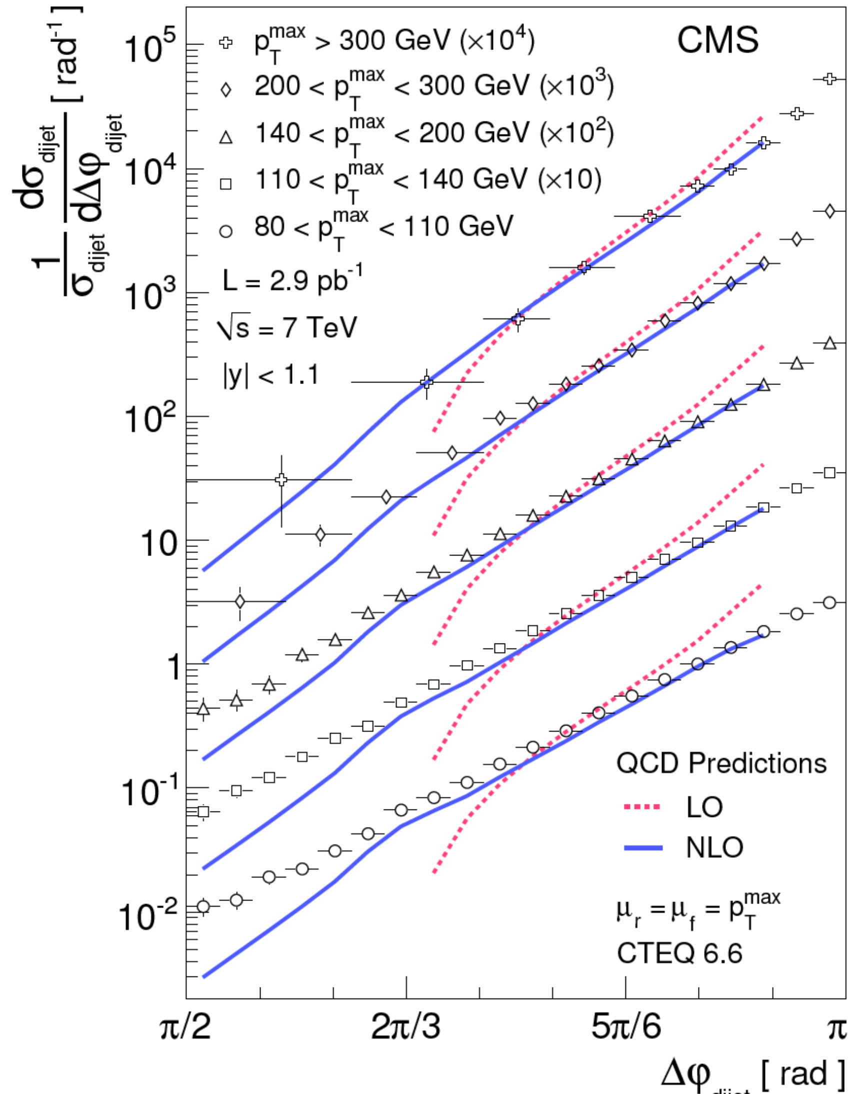


Dijet Azimuthal Decorrelations (2/2)

QCD-10-016

PhysRevLett.106.122003, arXiv:1101.5029

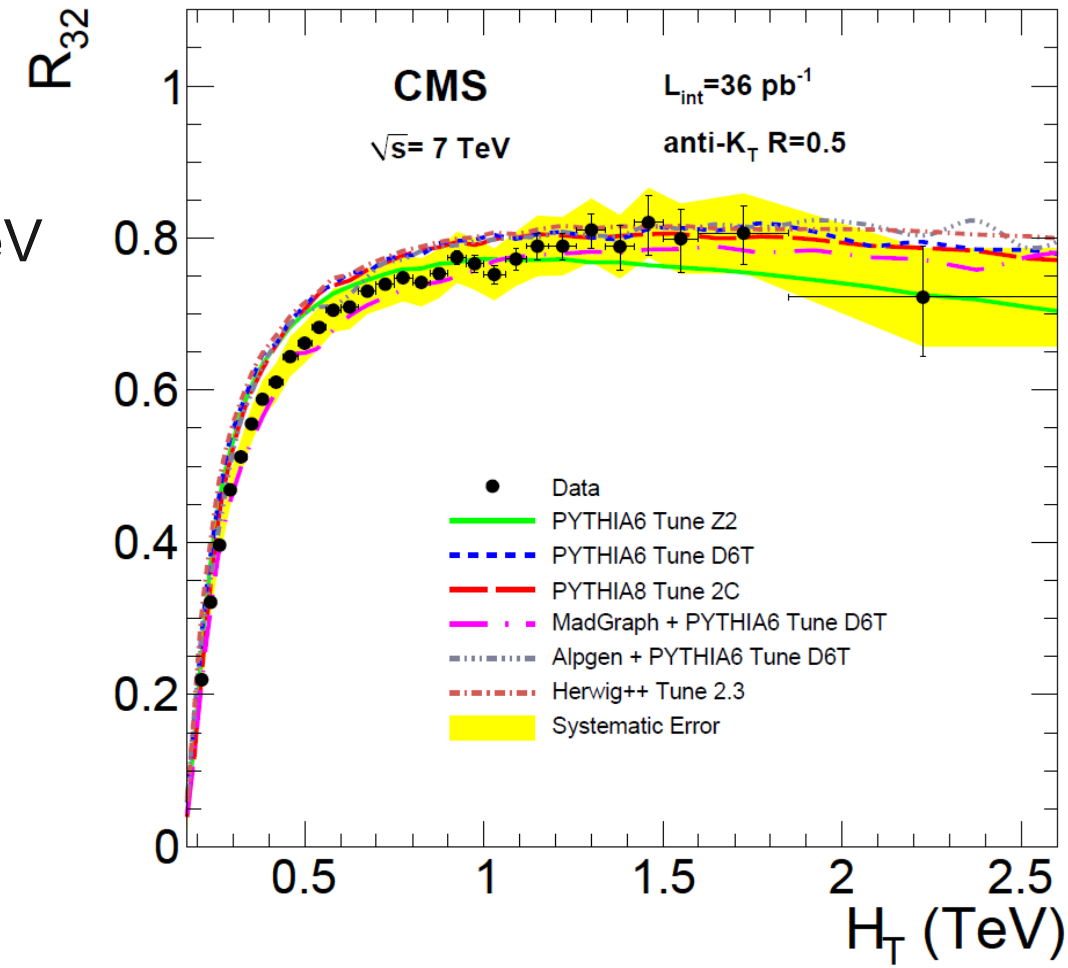
- Comparison to non-perturbatively corrected pQCD
- NLO/LO: NLOJET++ (Z.Nagy) and FASTNLO (T. Kluge, K. Rabbertz, M. Wobisch)
- The effective “order” depends on the angle. While NLO is “real” NLO at ~π, it is effectively LO only after 2π/3, getting worse for lower values



3-Jet/2-Jet Ratio

QCD-10-012

- Def:
  - H_T: $\Sigma P_{T,Jets}$
  - $P_{T,Lead}$>60 GeV, H_T>0.2 TeV
  - $P_{T,Jet}$>50 GeV
- Cancellation of most systematics
- Monte Carlo Tuning

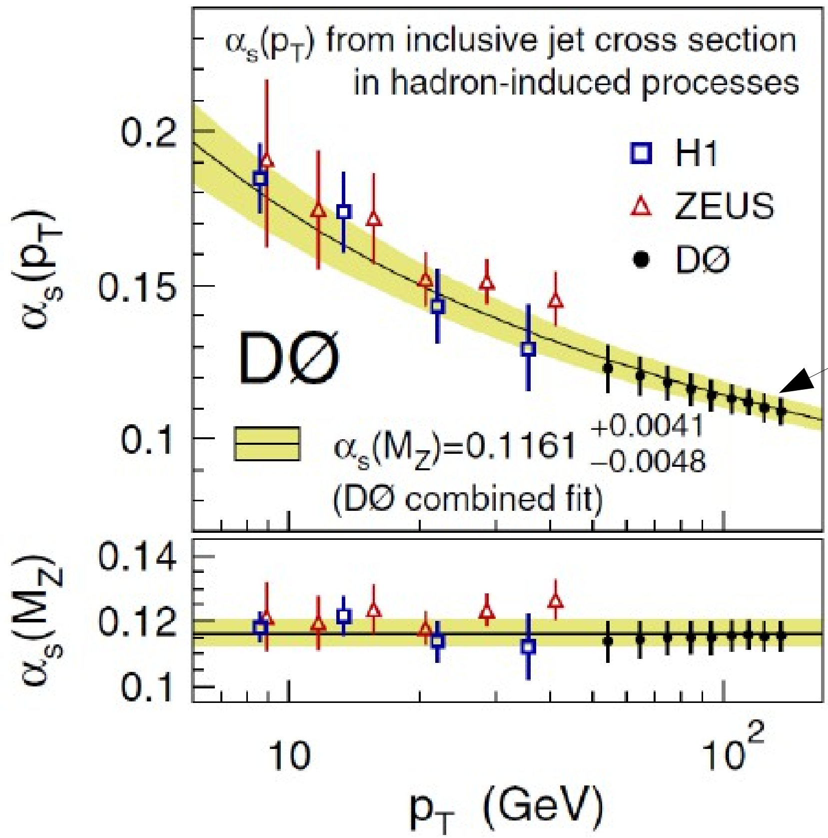


Future Jet Measurements (1/3)

- Increasing statistics will allow to push down on JES (1% possible?)
- Luminosity uncertainty already dropped to 4%
- Jet measurements will potentially start to tackle PDFs and α_s
- What observables have the highest precision/impact?

Future Jet Measurements (2/3)

- Direct impact on α_s probably limited (large systematics)



potential direct measure of α_s

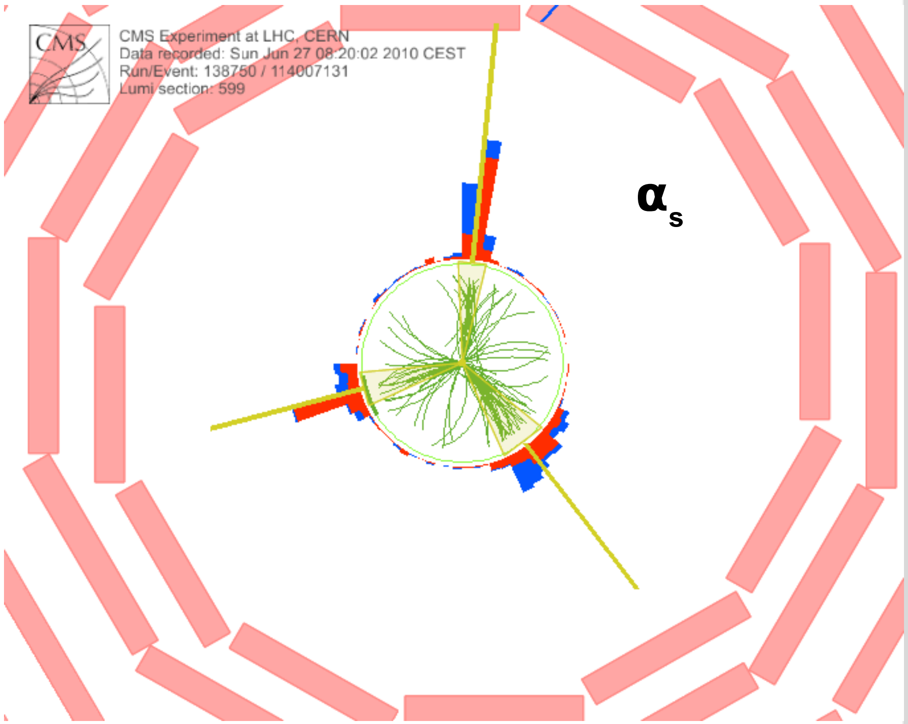
CDF 2002: α_s = 0.1178 + 0.0081 – 0.0095
D0 2009: α_s = 0.1161 + 0.0041 – 0.0048
PDG 2010: α_s = 0.1184 +/- 0.0007

(a bit to do for alpha_s from jets)

CDF- PhysRevLett.88.042001, D0 – PhysRevD.80.111107

Future Jet Measurements (3/3)

- Indirect measurements using cross section rates or event variables:
  - Reduce dependence of systematics
  - However, not all observables sensitive to pQCD α_s (e.g. 3jet/2jet ratio definition needs optimization for α_s sensitivity)



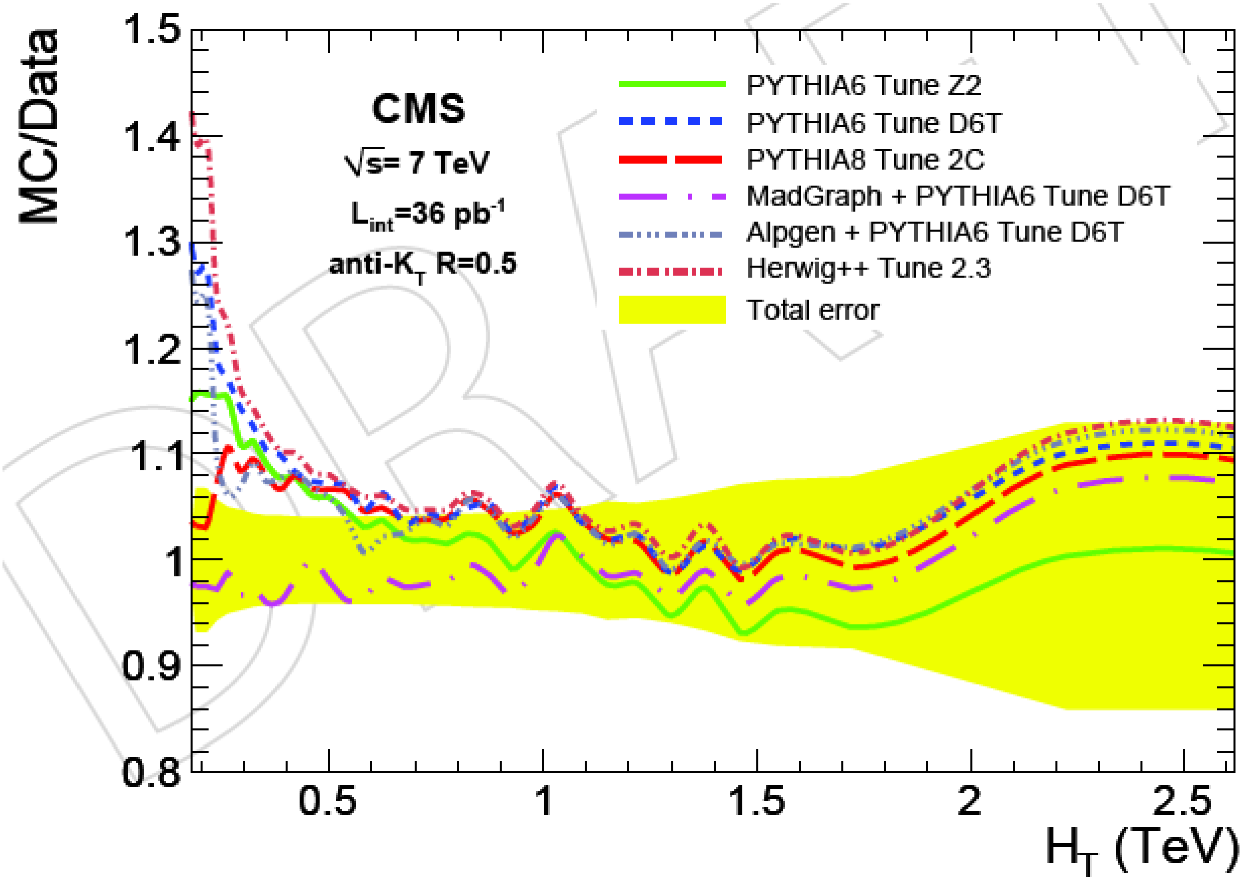
Conclusion/Outlook

- Jet p_T range already exceeds Tevatron measurements
- With increasing statistics the uncertainties on jet quantities drop
- No sign for new physics on high p_T jet observables yet
- pQCD nicely describes jet quantities in the new energy regime
- Stay tuned for indeep probes of α_S or PDFs

Thank you for your attention. - Questions?

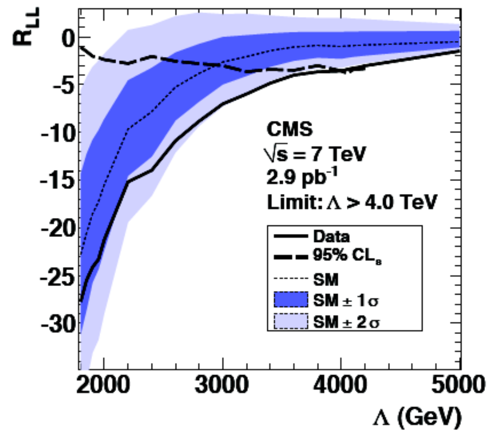
BACKUP

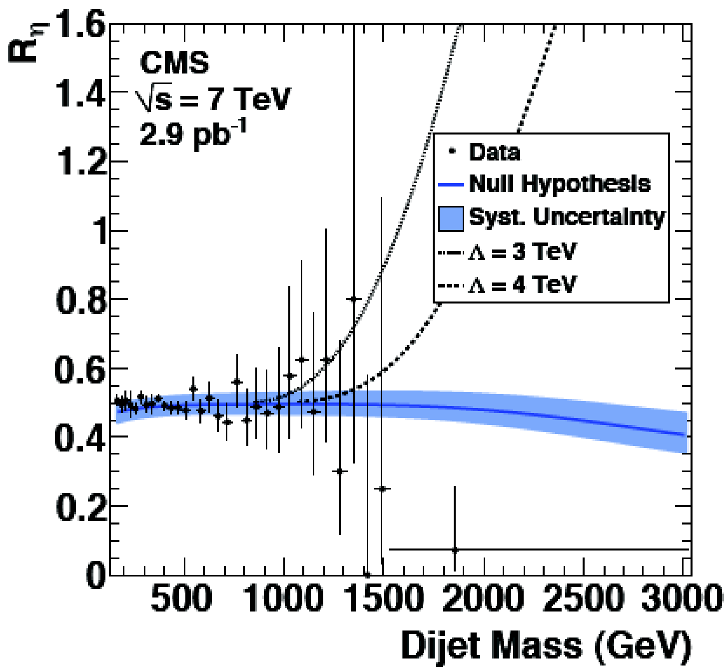
2-Jet/3-Jet


CMS
$\sqrt{s}$= 7 TeV
L_{int}=36 pb^{-1}
anti-K_T R=0.5
PYTHIA6 Tune Z2
PYTHIA6 Tune D6T
PYTHIA8 Tune 2C
MadGraph + PYTHIA6 Tune D6T
Alpgen + PYTHIA6 Tune D6T
Herwig++ Tune 2.3
Total error
MC/Data
H_T (TeV)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.5
1
1.5
2
2.5

DiJet Centrality Ratio

- Rate of DijetMass cross section between central and more forward region sensitive to new physics
- Reduced sensitivity to JES and the like due to Ratio
- Contact interactions were excluded up to 4.0 TeV @ 2.6 1/pb



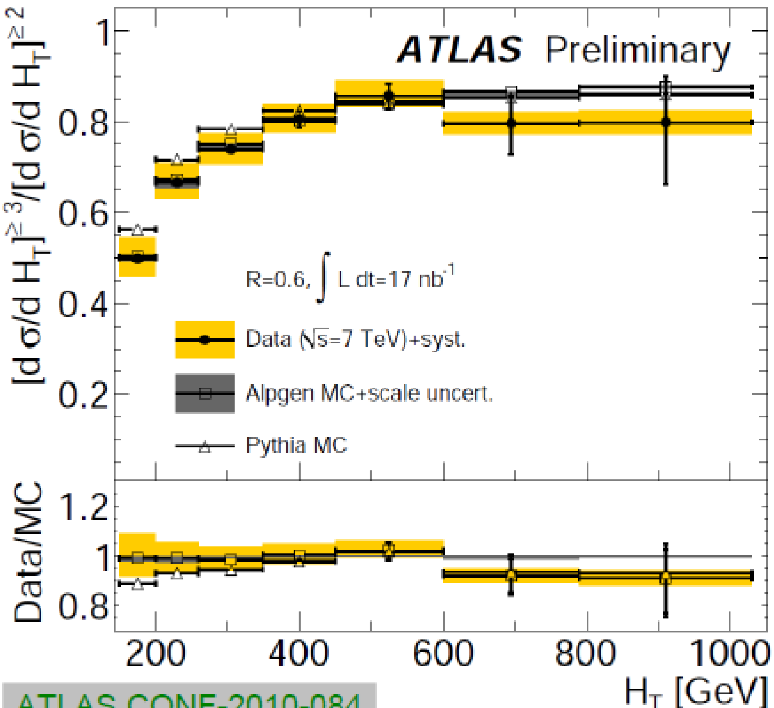


EXO-10-002

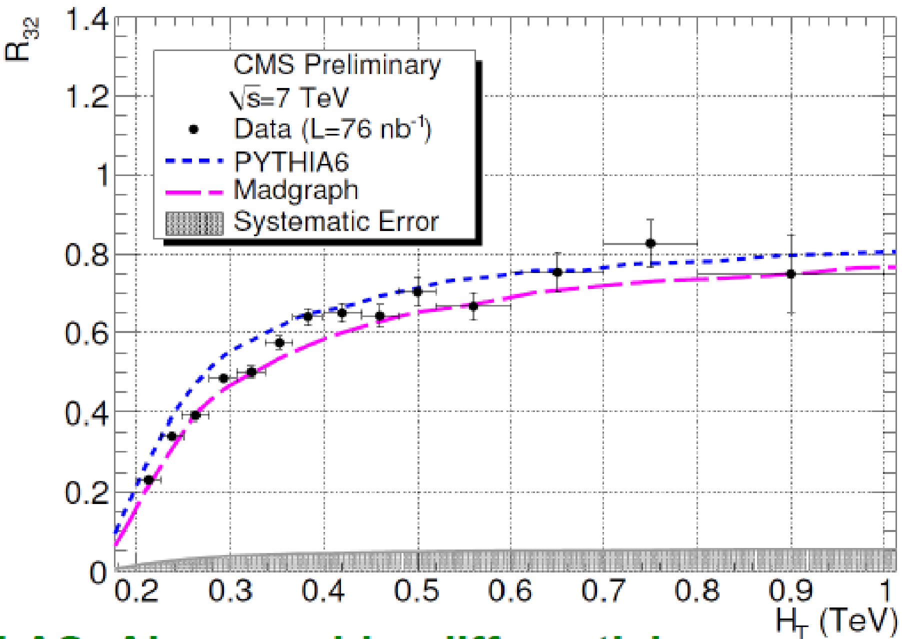
Inclusive 3+/2+ Jet Ratio

ATLAS: anti-kT R=0.6, |y| < 2.8
p_{Ti} > 30 GeV, p_{T1} > 60 GeV
$H_T = \Sigma |p_{Ti}|$
exp. Uncertainty < ~ 10%

CMS: anti-kT R=0.5, |y| < 2.5
p_{Ti} > 50 GeV, p_{T1} > 60 GeV
$H_T = \Sigma |p_{Ti}|$
exp. Uncertainty < ~ 10%



ATLAS CONF-2010-084

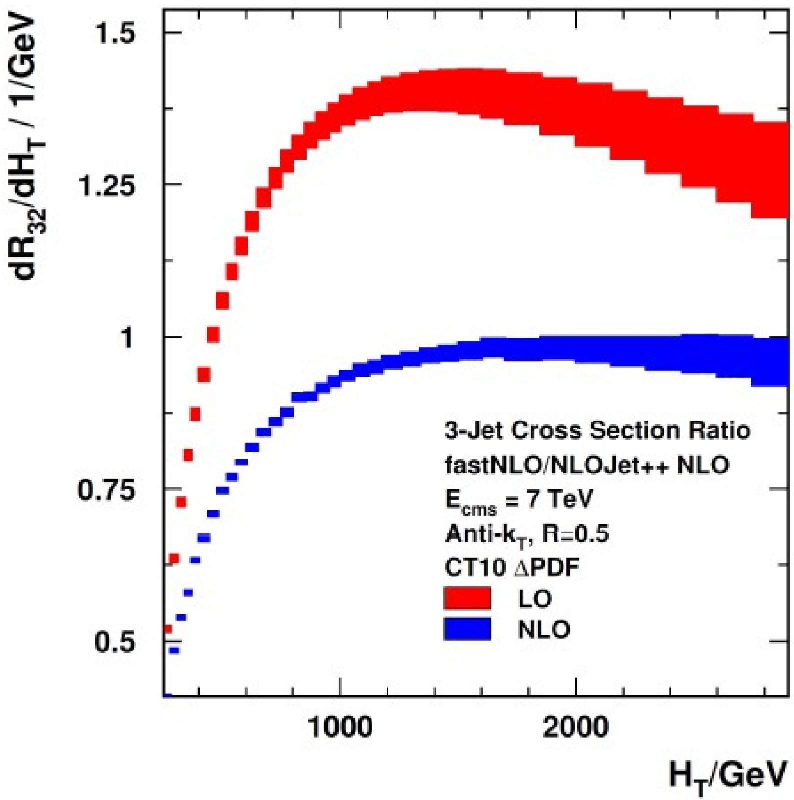


ATLAS: Also consider differential 2-jet Rate (~> event shape ...)

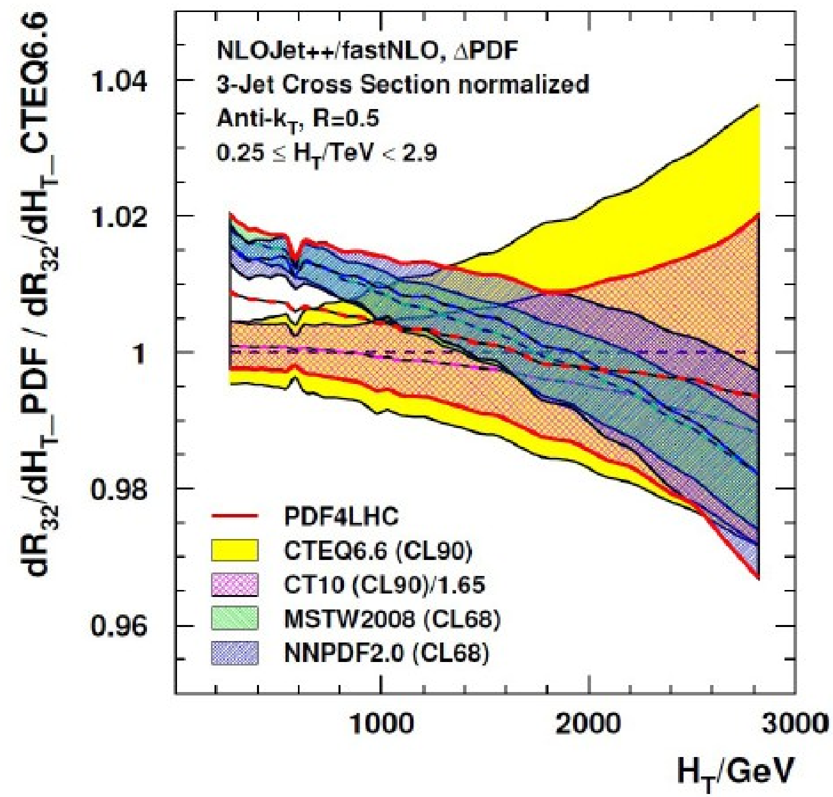
CMS-QCD-10-012

3+/2+: NLO Prediction & ΔPDF

CMS like selection
(ATLAS not very different)
LO > 1 ?!
K factors ~ 0.67



PDF uncertainty reduced by a factor ~ 10 in ratio



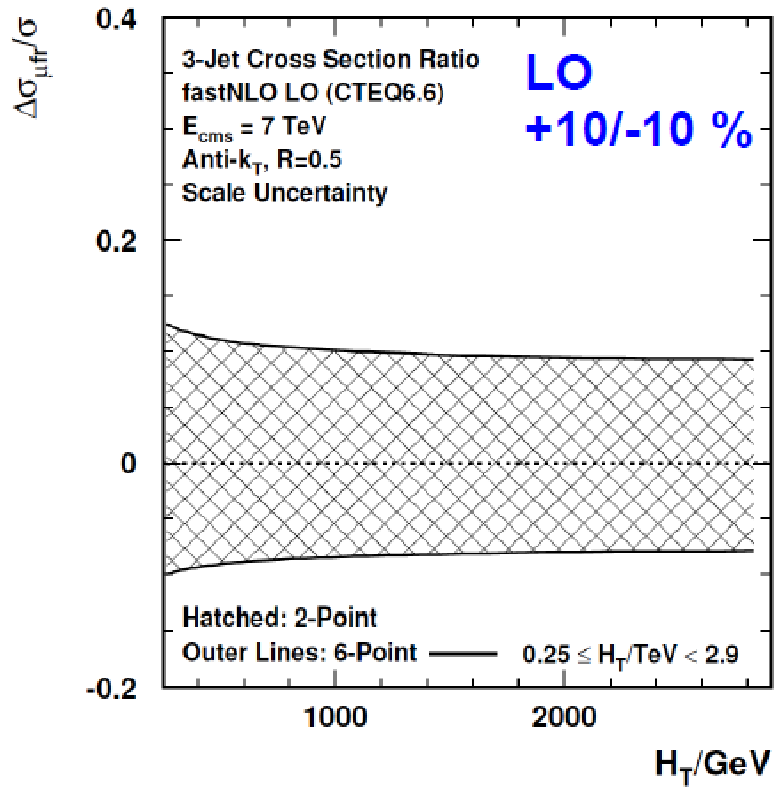
3+/2+: Scale Dependence

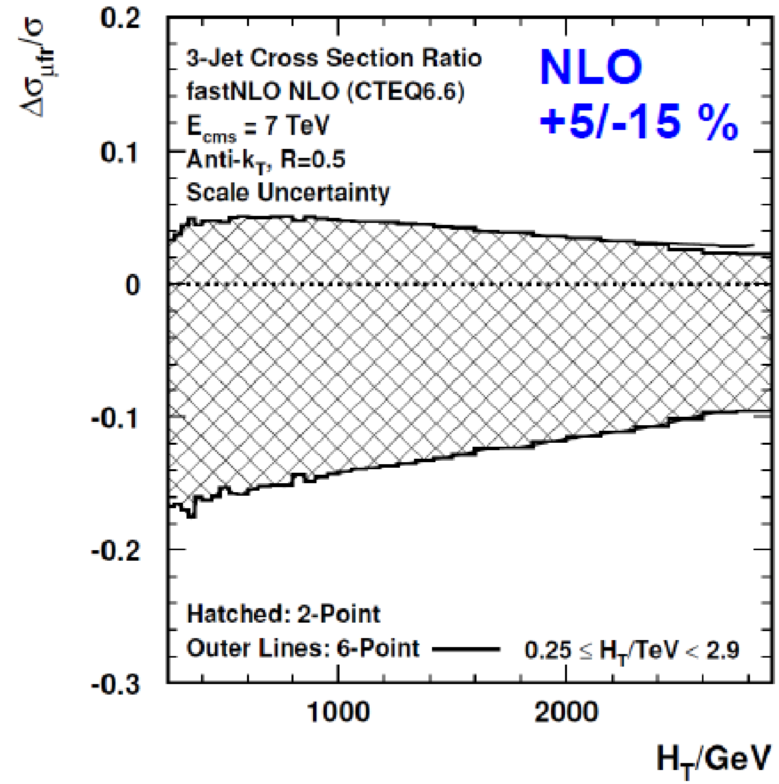
Simultaneous variation in numerator and denominator

No large difference between symmetric and add. asymm. scale variations

No real improvement when going to NLO ...

ATLAS quotes 5 % from Alpgen



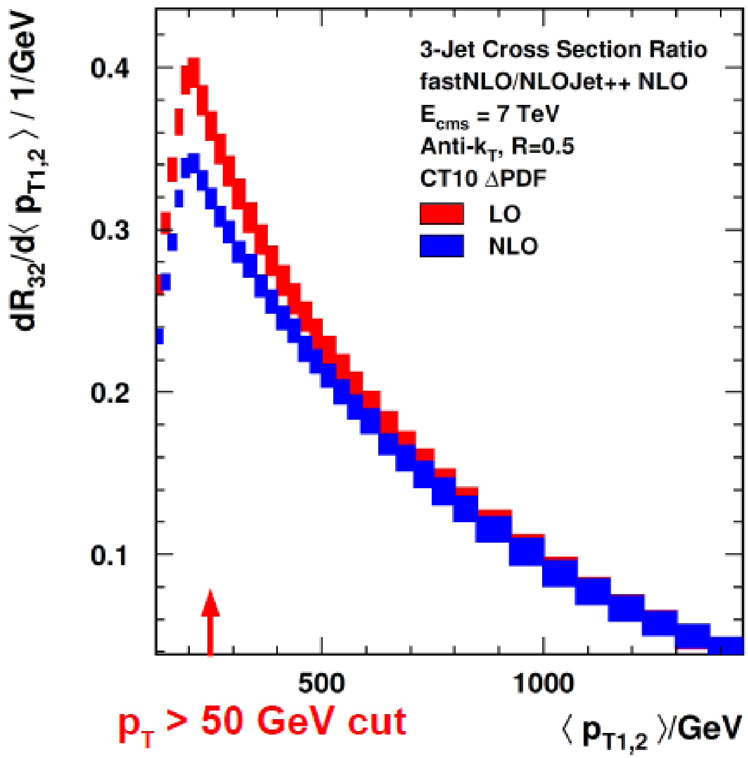


3+/2+ Revisited

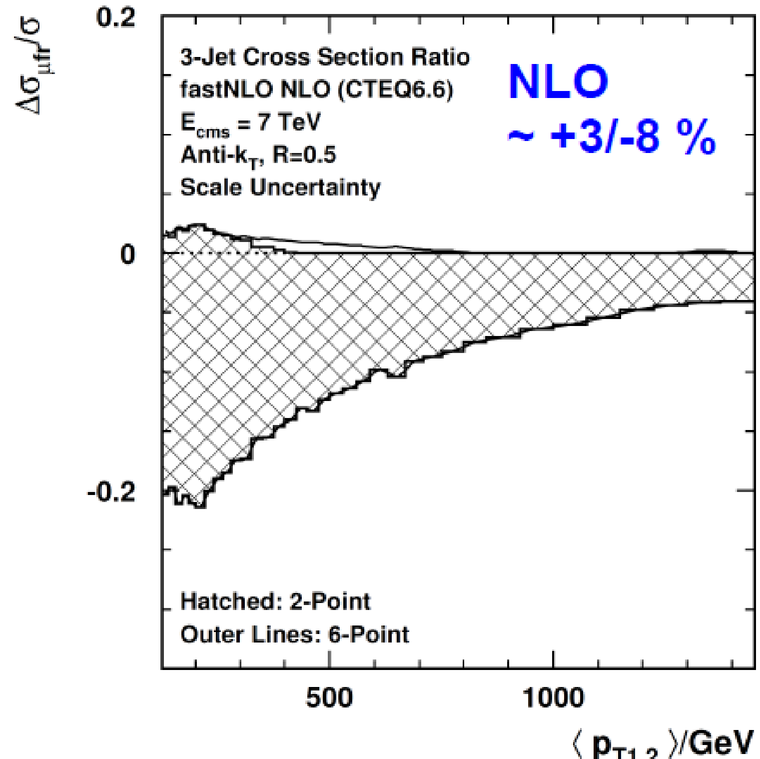
Made some adaptations after chat with Gavin Salam:

- changed scale from H_T to average dijet p_T: $<p_{T1,2}>$
- require hard third jet: $p_{T3} > 0.25$ times $<p_{T1,2}>$

Not optimal yet, but clearly better

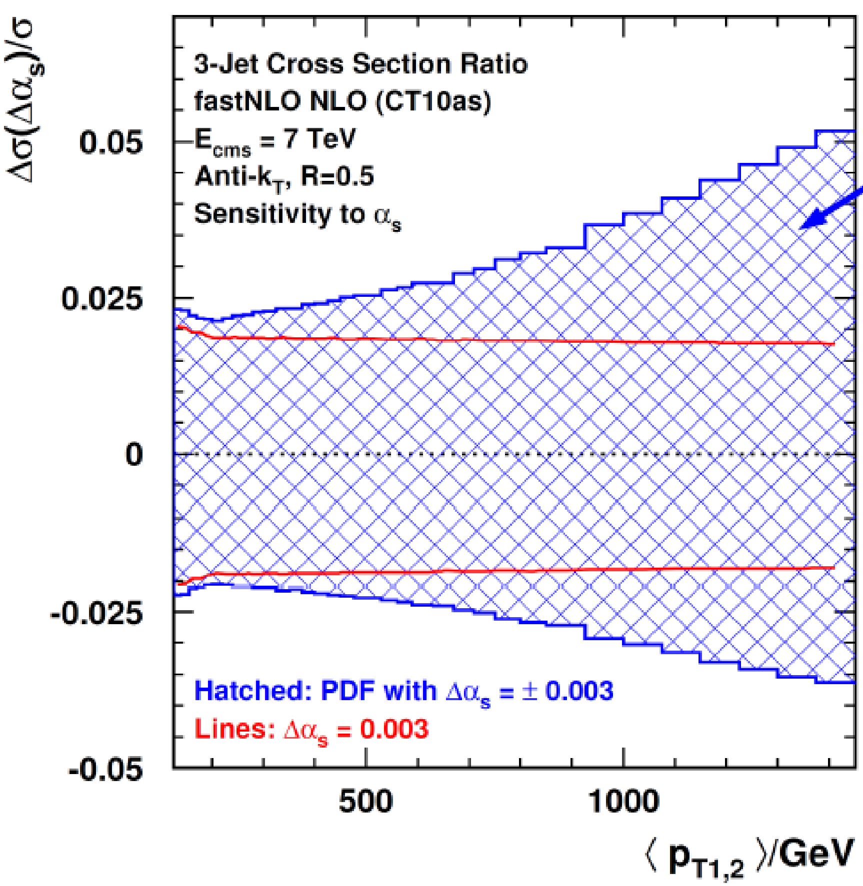


p_T > 50 GeV cut



3+/2+: Sensitivity to α_s

α_s Sensitivity



CT10as members with
$\alpha_s = 0.118 \pm 0.003$

$\alpha_s(M_Z)$ only changed
$\alpha_s = 0.118 \pm 0.003$

To be further investigated ...