MPI and UE corrections to jet measurements and influence on PDF determination and α_s

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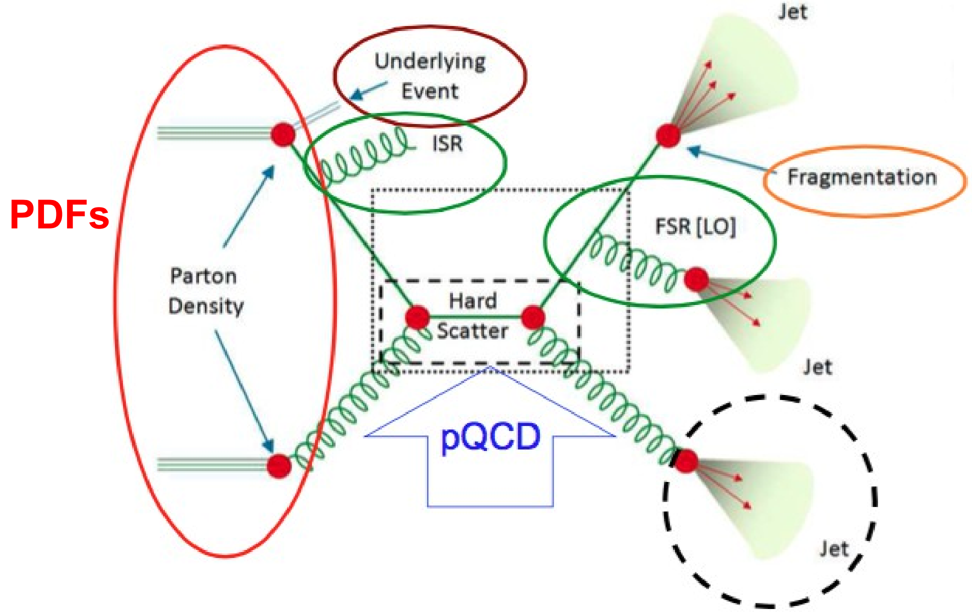
Outline

- Introduction
- QCD @ Hadron Collider
- Non-Perturbative Correction
  - Non-Perturbative Correction for LO
  - Non-Perturbative Correction for NLO
- Parton Shower Correction
  - Longitudinal Momentum Shifts in PS
- Effect of Parton Shower and NP Corrections total Cross Section
- Summary

QCD @ Hadron Colliders

- QCD is the theory of strong interaction describing the interactions between quarks and gluons.



- The basic elements of a QCD process
  - The proton structure → encapsulated into the universal PDFs
  - Hard scattering → evaluated with the perturbation theory
  - Parton shower and hadronization
  - study initial and final state radiation
  - Multiparton scattering and underlying event activity → approximated by MC programs with some tuning parameters

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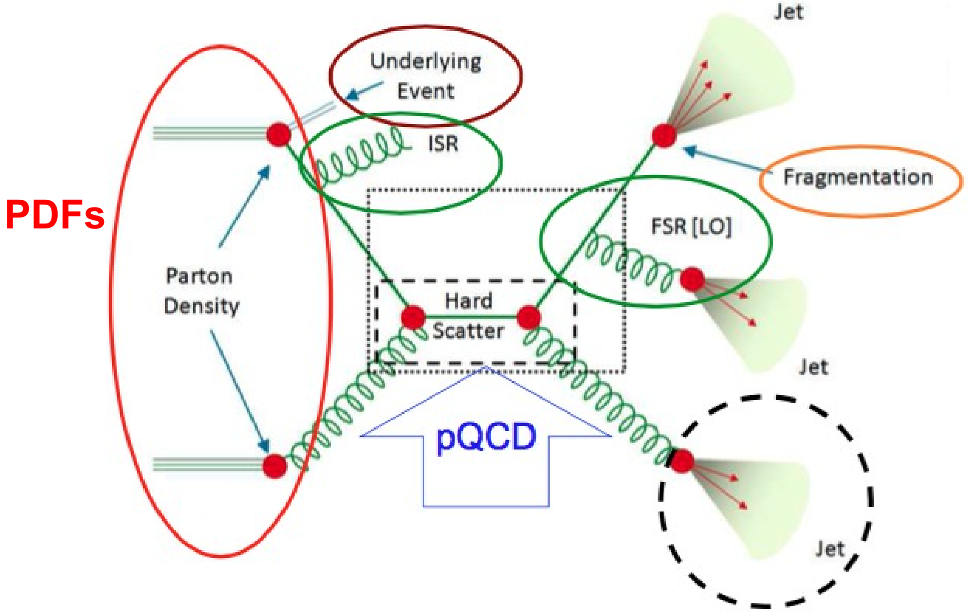

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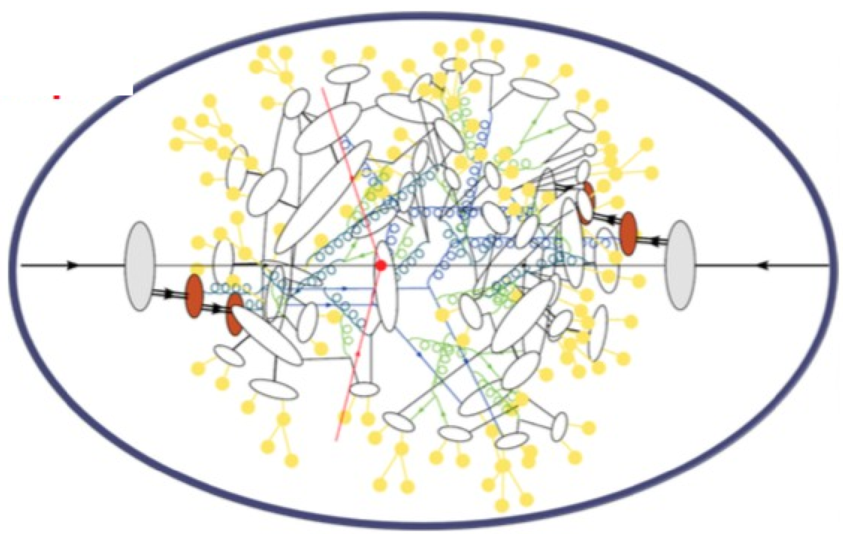
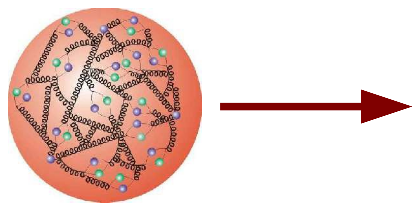
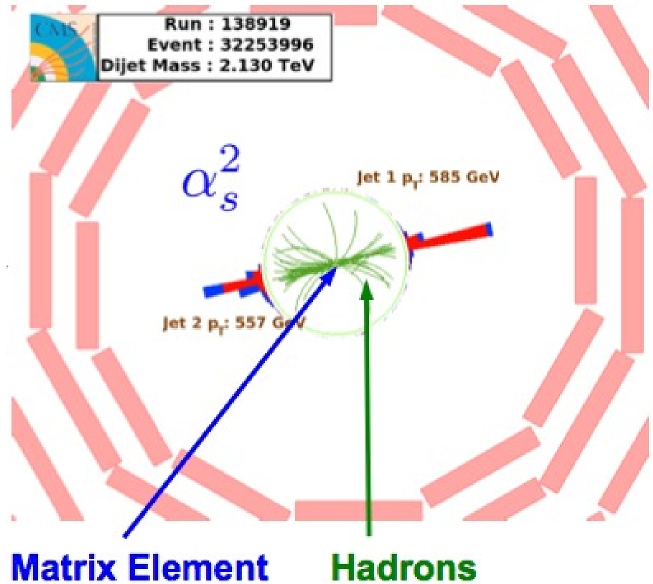


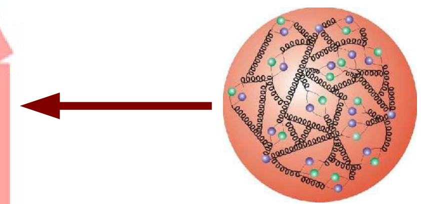
But reality is more complex

Measurements of jet final states are important:

Proton Structure (PDF)





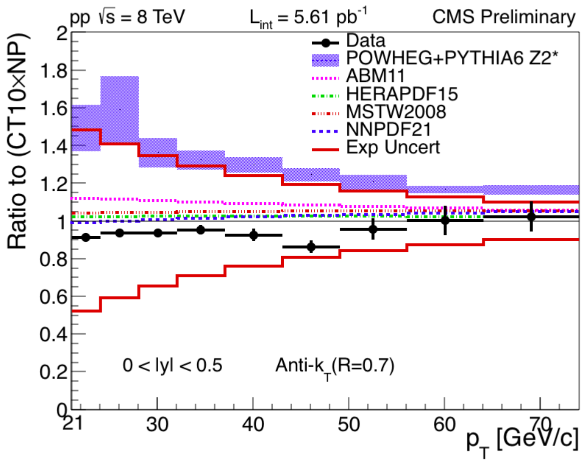


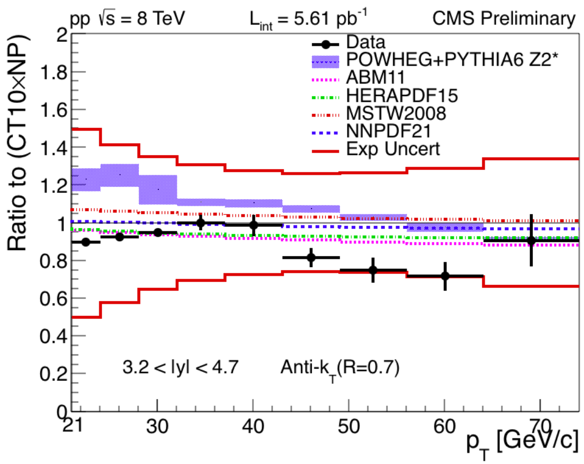
Proton Structure (PDF)

- Production of jets are abundant in hadron colliders (i.e. jet laboratories)
  - Learn about hard QCD
  - proton structure,
  - non-perturbative (NP) effects
  - strong coupling constant α_s

- In high energy physics experimental data is compared to NLO theory calculations
- The theoretical predictions for the jet cross sections consist of NLO QCD calculation and NP correction to account for MPI and hadronisation effects.

Inclusive Jet Cross Sections @ 8 TeV





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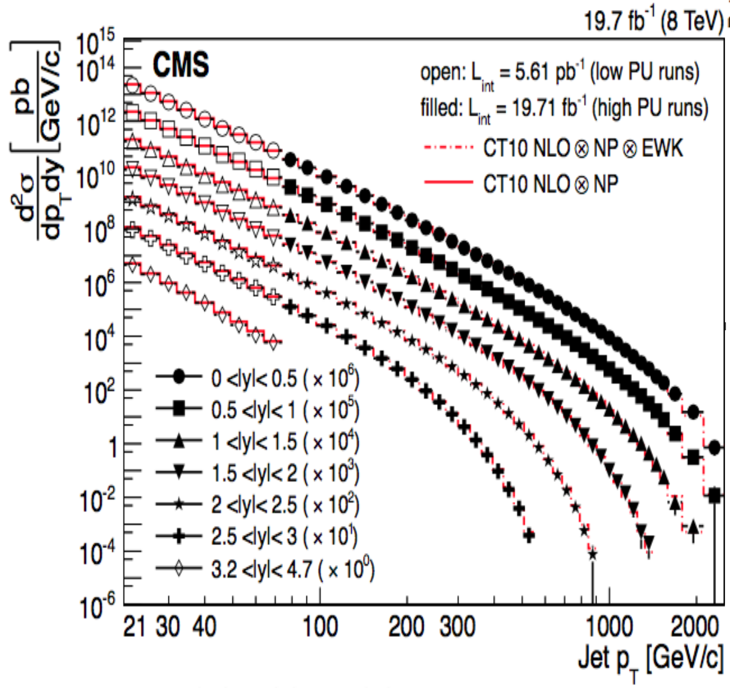
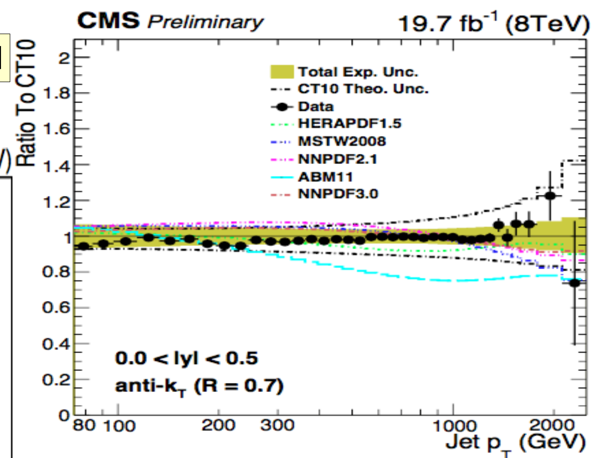
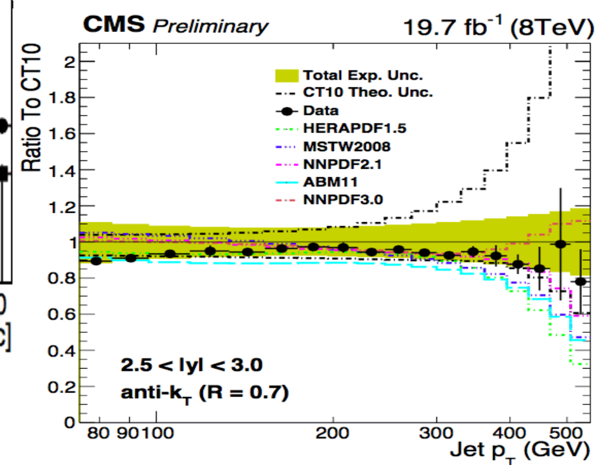






- First preliminary measurements @ 8 TeV
- Dedicated measurement with low PU data
  - full coverage of CMS: |y| < 4.7
  - p_T > 21 GeV (for fwd.jets p_T < 80 GeV)

- Experimental uncertainties comparable to theoretical ones
- NLOґ NP pQCD predictions compatible with data

Non-Perturbative (NP) Correction

- Comparisons of experimental data with theoretical predictions for collider processes containing hadronic jets rely on Shower Monte Carlo (SMC) event generators
  - include corrections to perturbative calculations from hadronization, parton showering, multiple parton collisions.

- The scattering phenomena between partons within a colliding proton, i.e. MPI, cannot be modelled well within the perturbative framework.

- The same is true for the hadronization procedure by virtue of which the colored partons combine together to form color-neutral particles.

- In order to account for effects of MPI and hadronization, a NP correction is applied to the NLO prediction.

- To obtain NP correction both leading order (LO) and NLO event generators are used.

NP Correction for LO

- The NP correction for LO is evaluated by averaging those provided by P Y T H I A 6 (version 4.26), using tuneZ2*, and HERWIG++ (version 2.4.2), using tune UE.

$$C_{LO}^{NP} = \frac{d^2\sigma}{dp_T\,dy}(LO+PS+MPI+HAD) / \frac{d^2\sigma}{dp_T\,dy}(LO+PS)$$

  » numerator : PS, MPI and hadronization effects switched ON
  » denominator: only PS effects

- These corrections are combined with NLO parton-level results
  – a potential inconsistency arises because the radiative correction from the first gluon emission is treated at different levels of accuracy in the two parts of the calculation.

- alternative method which avoids this is to use NLO Monte Carlo (NLO-MC) generators to determine the correction.

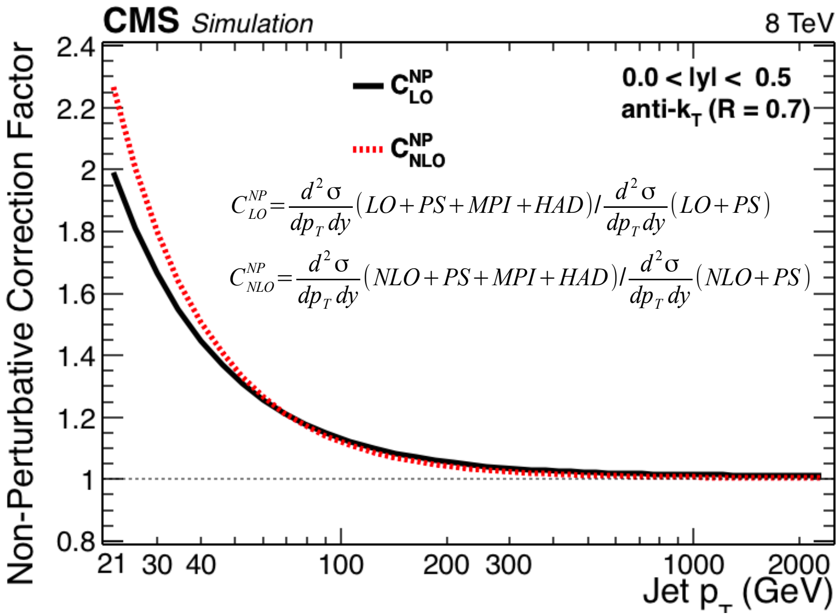
NP Correction for NLO

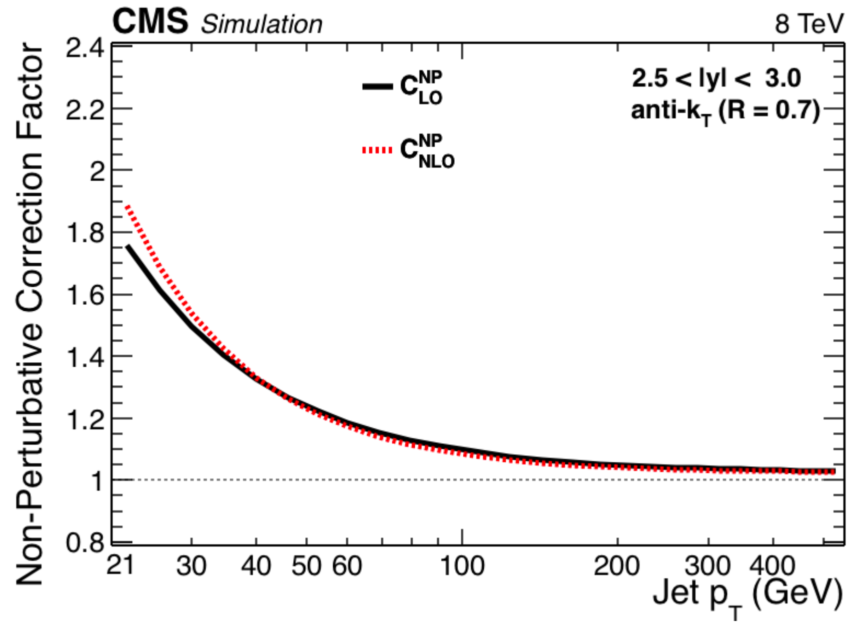
- The NLO NP correction is derived using P O W H E G , interfaced with P Y T H I A 6 (version 4.26) for PS, MPI and hadronization.
  - The NLO NP correction factors are derived in this case averaging the results for two different tunes of PYTHIA6, Z2* and P11.

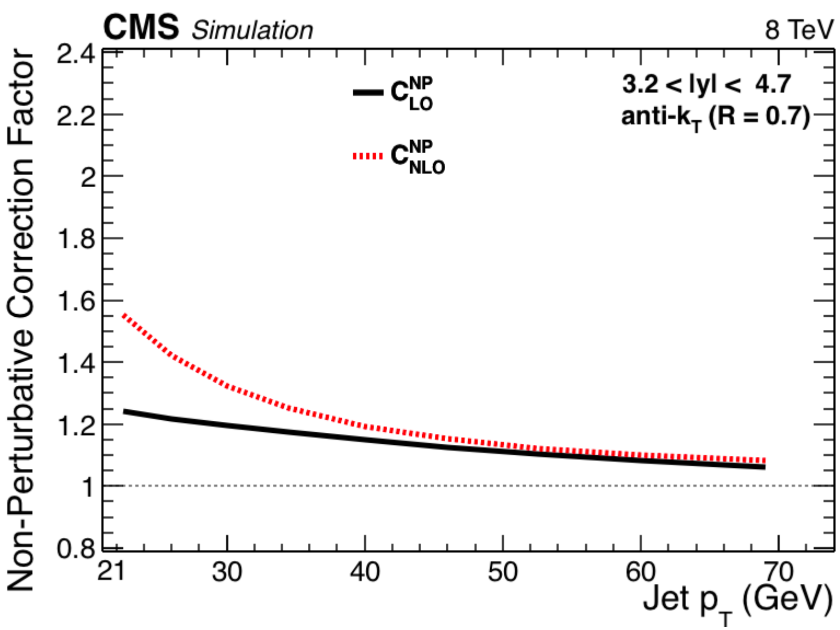
$$C_{NLO}^{NP} = \frac{d^2\sigma}{dp_T dy}(NLO+PS+MPI+HAD) / \frac{d^2\sigma}{dp_T dy}(NLO+PS)$$

- The events are generated within the POWHEG BOX framework1 and are showered with the SMC PYTHIA6.
  - The hard matrix element is determined at NLO and is matched with the PS, which take into account higher order radiation contributions.

NP Correction for LO and NLO

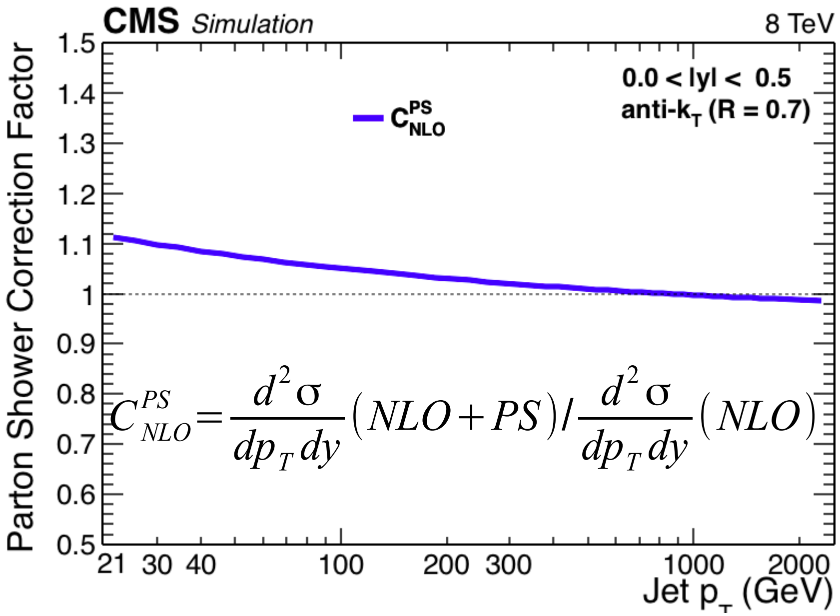




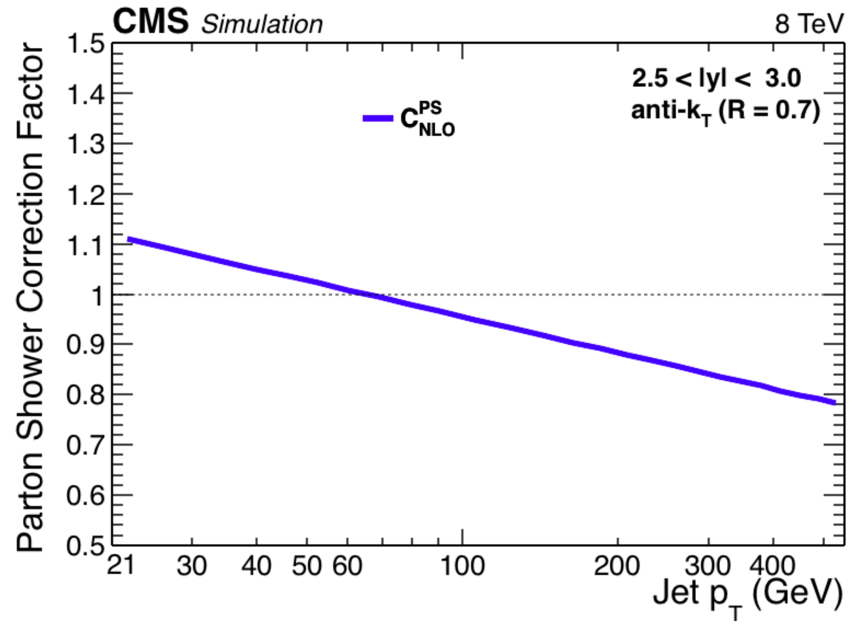


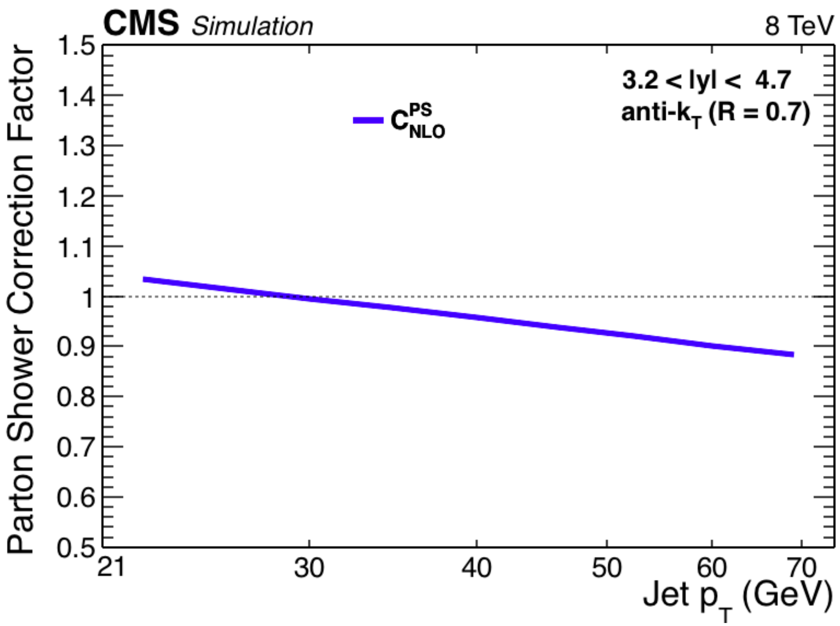
- The difference in the NP correction obtained by a LO or a NLO calculation is due to the matching of MPI to the NLO calculation.
- The MPI p_T scale is smaller than the transverse momentum of the hard process, which is defined by the average p_T of the hard partons in the process.
- The size of these corrections ranges from **23% at low pT down to 1% at the highest pT of 2.5 TeV**.

Parton Shower Correction



$$C_{NLO}^{PS} = \frac{d^2\sigma}{dp_T\,dy}(NLO+PS) / \frac{d^2\sigma}{dp_T\,dy}(NLO)$$

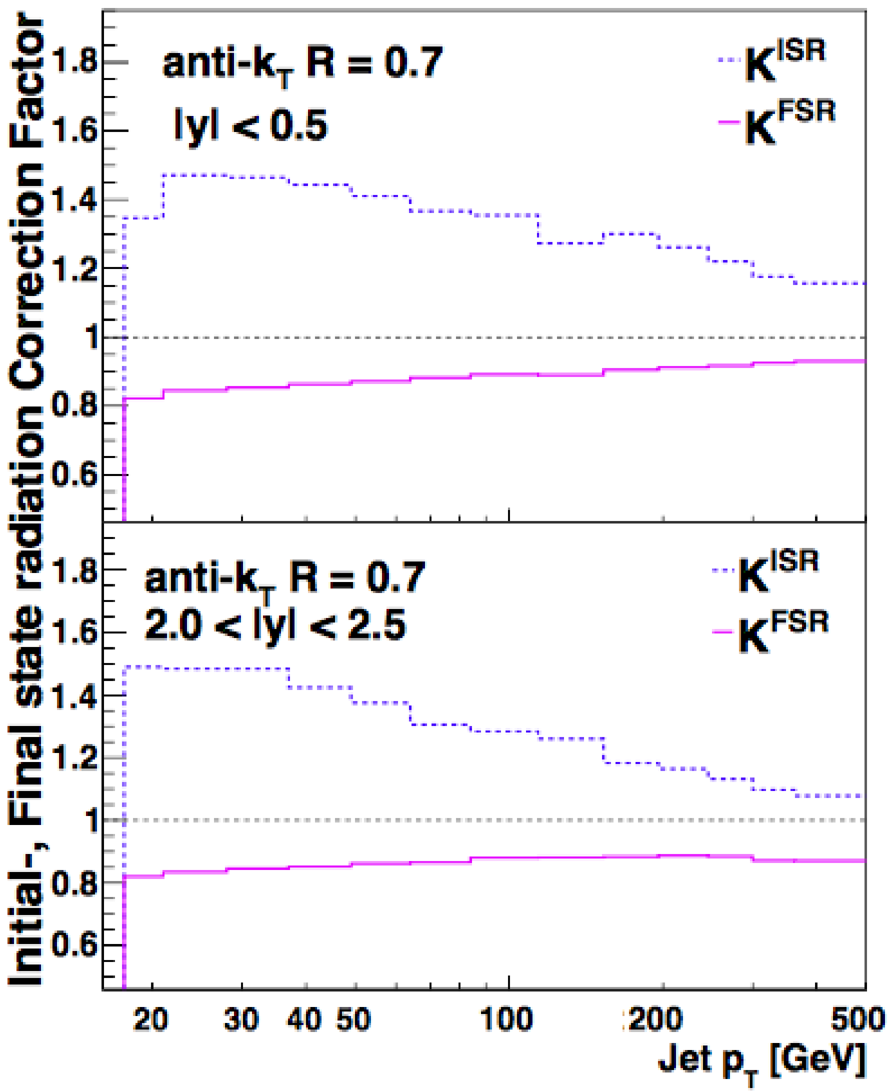




- PS correction factor to account for parton emission is shown.
- PS correction depends on p_T and y
  - Especially in the forward region the correction gives a finite effect also at high p_T.
  - In general the effect of PS is largest at large y.

Parton Shower Correction

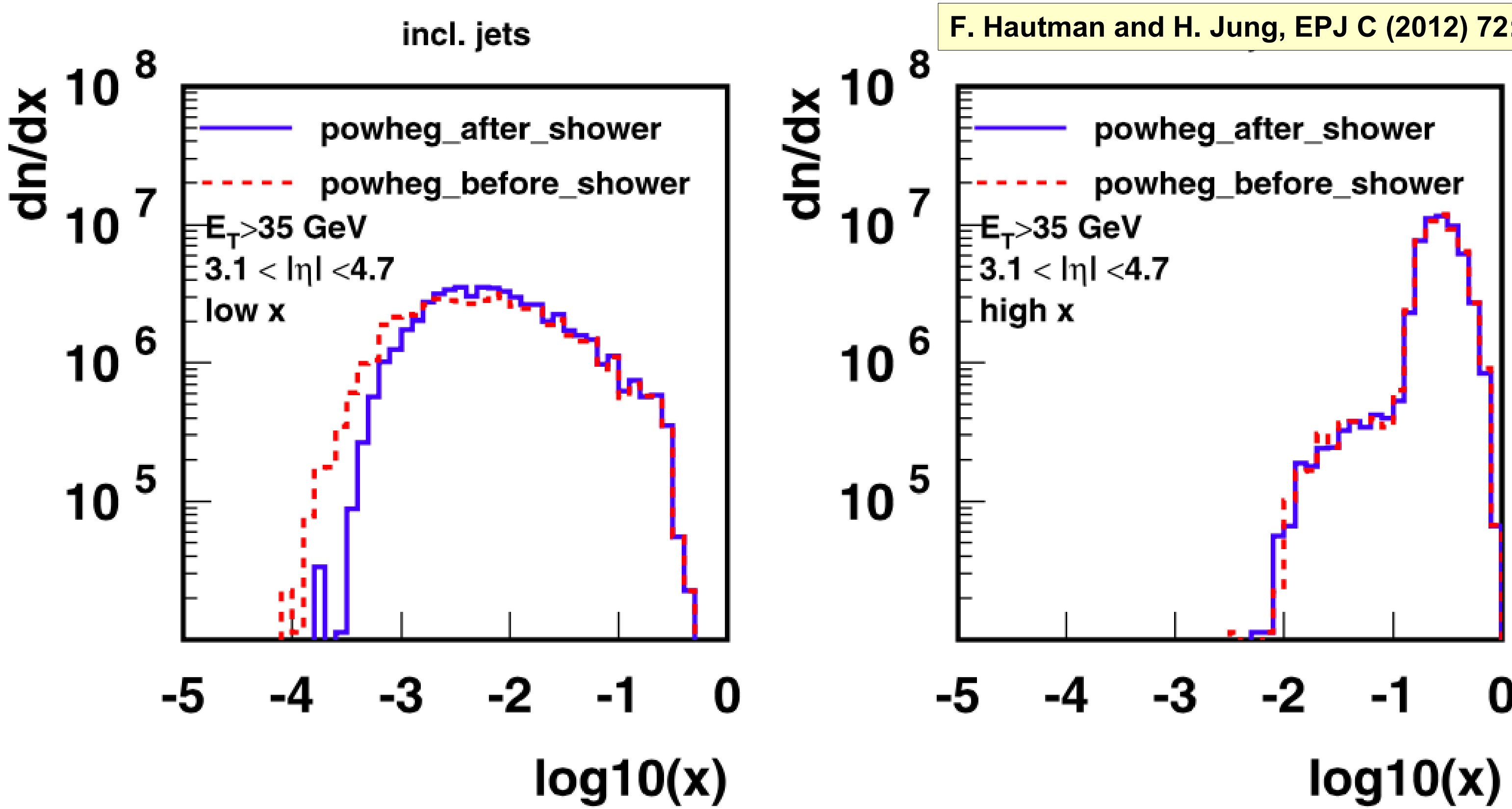
S. Dooling et al. ArXiv:1212.6164



- ISR and FSR effects are considered independently
  - But indeed both are interconnected!
- The combined effects cannot be obtained by simply adding up the individual contributions
- ISR largest at low p_T
- FSR significant for all p_T

Longitudinal Momentum Shifts in PS

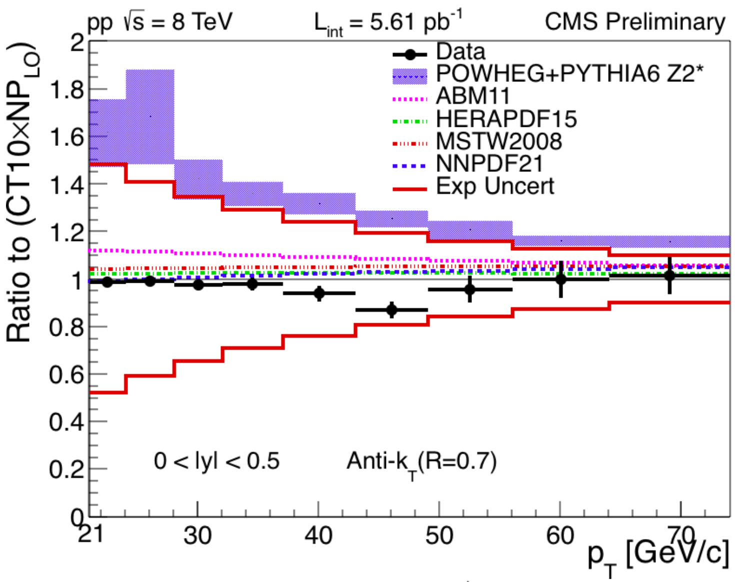
F. Hautman and H. Jung, EPJ C (2012) 72:2254



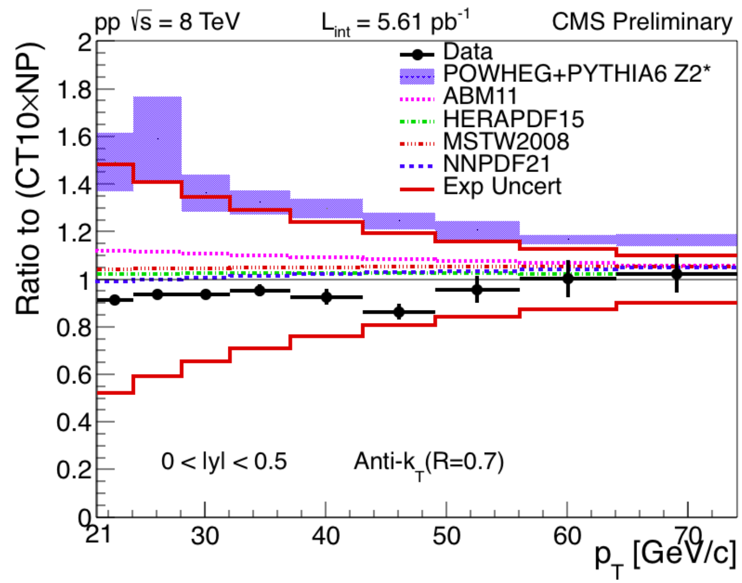
- Parton longitudinal momentum fraction x before and after PS for the low -x partons in inclusive jet production at high y
- Results are obtained using the PYTHIA PS tune S0 and CTEQ6M pdfs
- No MPI and hadronisation effects included.
- The kinematical reshuffling in the longitudinal momentum fraction is significant for low-x partons
- Highly asymmetric parton kinematics!

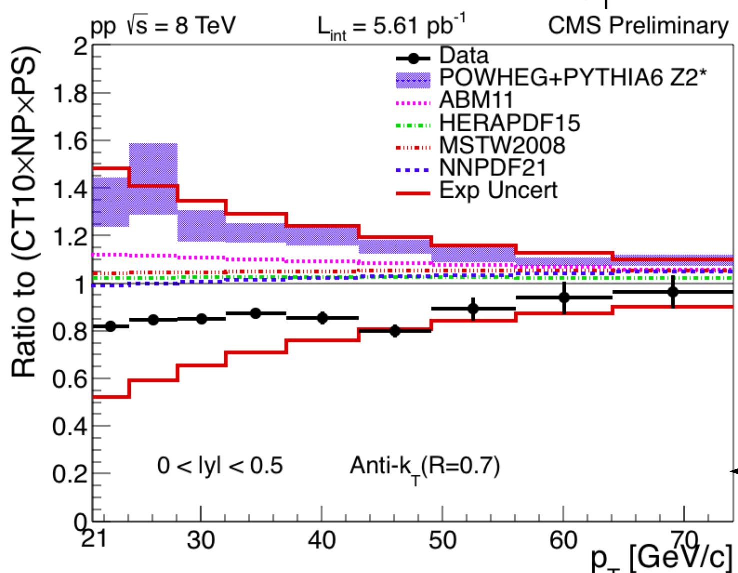
Effect of NP and PS Corrections on Total Cross Section

$$\frac{d^2\sigma_{Theo}}{dp_T\,dy} = \frac{d^2\sigma_{NLO}}{dp_T\,dy} \times (C^{NP}_{LO})$$



$$\frac{d^2\sigma_{Theo}}{dp_T\,dy} = \frac{d^2\sigma_{NLO}}{dp_T\,dy} \times \left(\frac{C^{NP}_{LO} + C^{NP}_{NLO}}{2}\right)$$





- Ratio of data over theory prediction using the CT10 PDF set shown for **0 < |y| < 0.5**
- For comparison predictions employing five other PDF sets are shown

$$\frac{d^2\sigma_{Theo}}{dp_T\,dy} = \frac{d^2\sigma_{NLO}}{dp_T\,dy} \times C^{PS}_{NLO} \times \left(\frac{C^{NP}_{LO} + C^{NP}_{NLO}}{2}\right)$$

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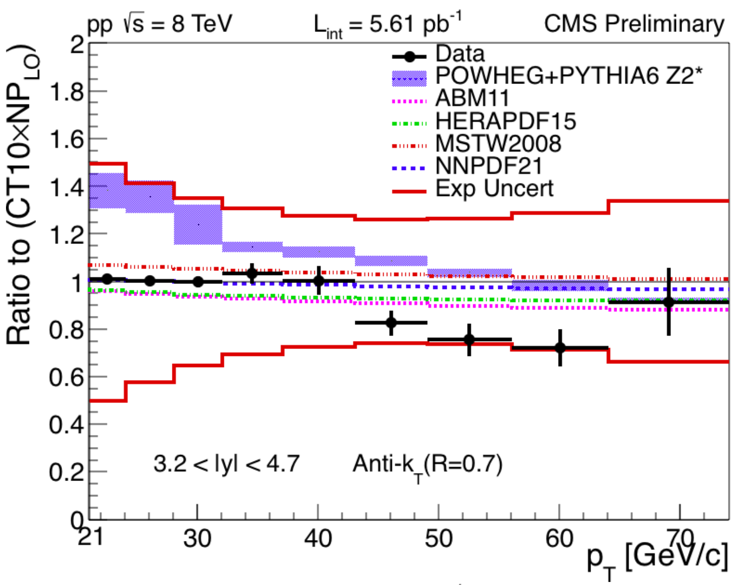

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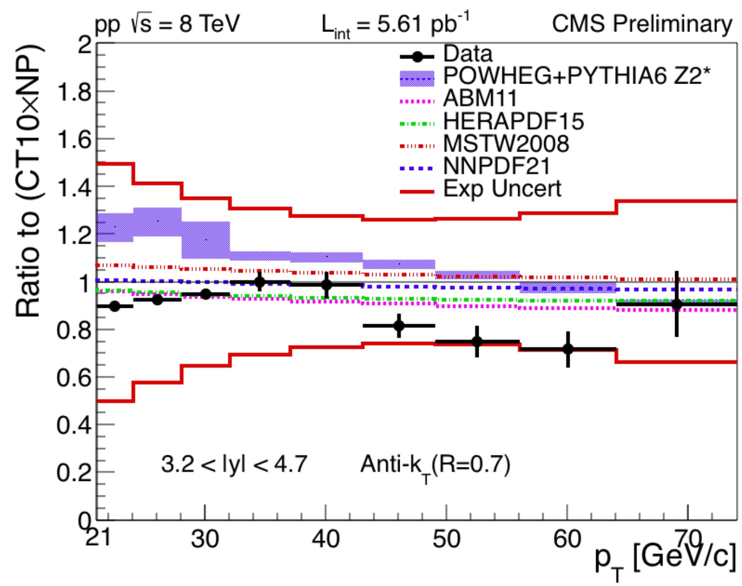

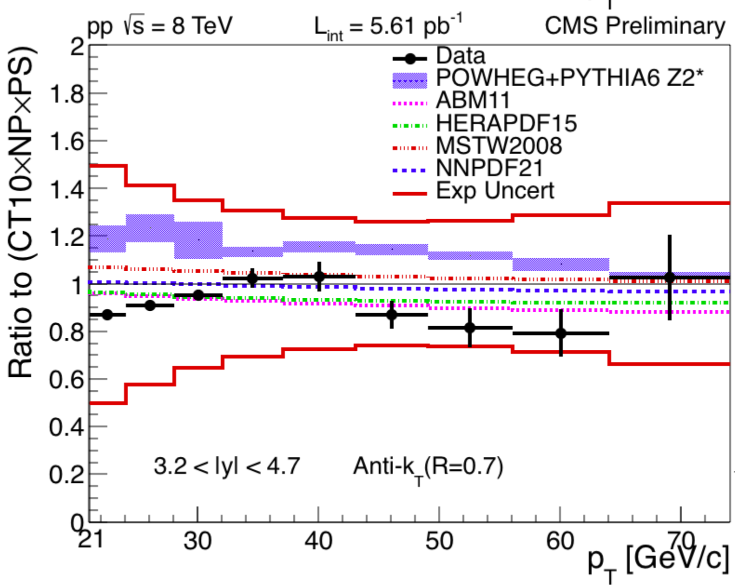

- Ratio of data over theory prediction using the CT10 PDF set shown for 3.2 < |y| < 4.7
- For comparison predictions employing five other PDF sets are shown

$$\frac{d^2\sigma_{Theo}}{dp_T\,dy} = \frac{d^2\sigma_{NLO}}{dp_T\,dy} \times C_{NLO}^{PS} \times \left(\frac{C_{LO}^{NP} + C_{NLO}^{NP}}{2}\right)$$

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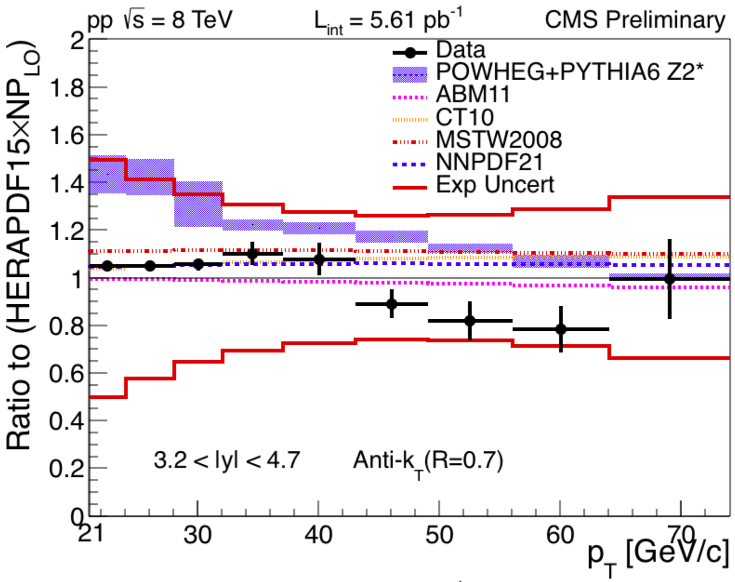

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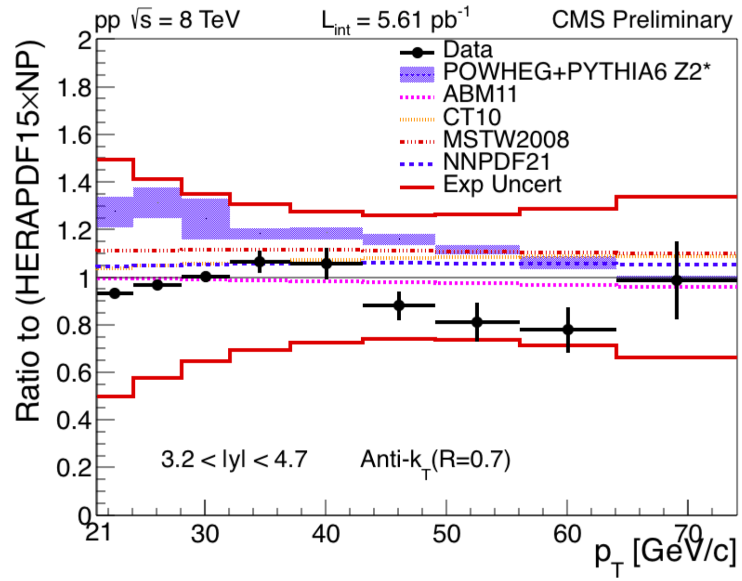
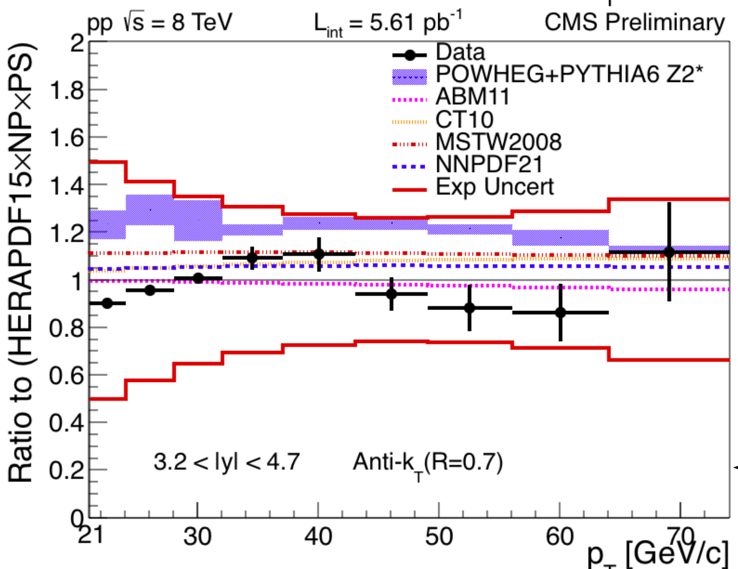
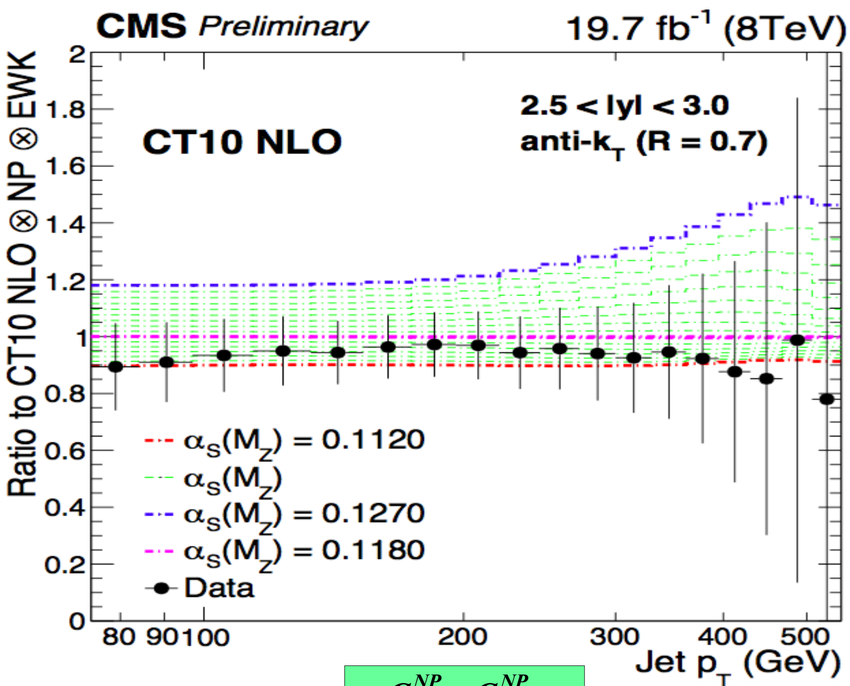




- Ratio of data over theory prediction using the HERAPDF1.5 PDF set shown for 3.2 < |y| < 4.7
- For comparison predictions employing five other PDF sets are shown

$$\frac{d^2\sigma_{Theo}}{dp_T\,dy} = \frac{d^2\sigma_{NLO}}{dp_T\,dy} \times C^{PS}_{NLO} \times \left(\frac{C^{NP}_{LO} + C^{NP}_{NLO}}{2}\right)$$

PDF determination and α_s



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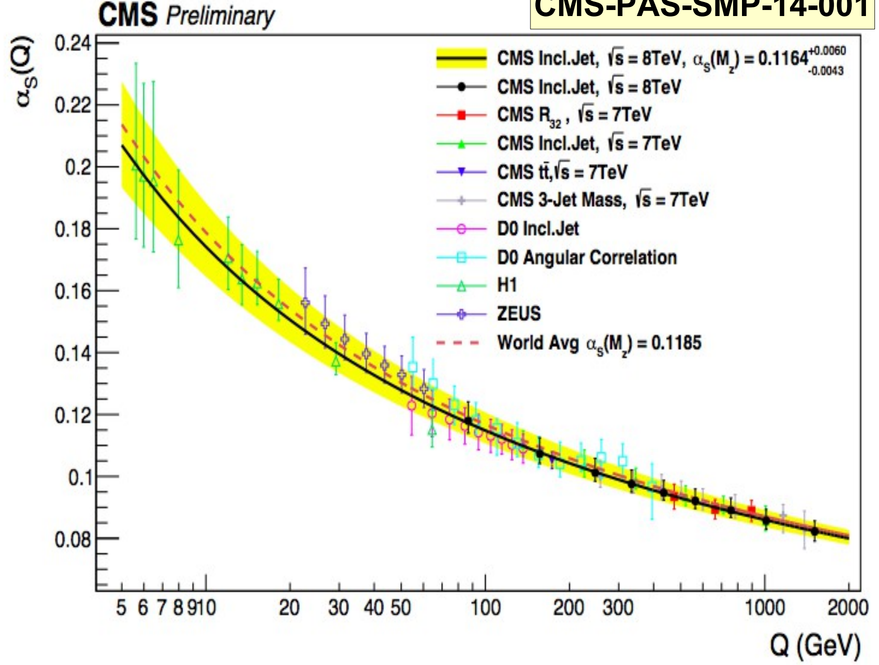
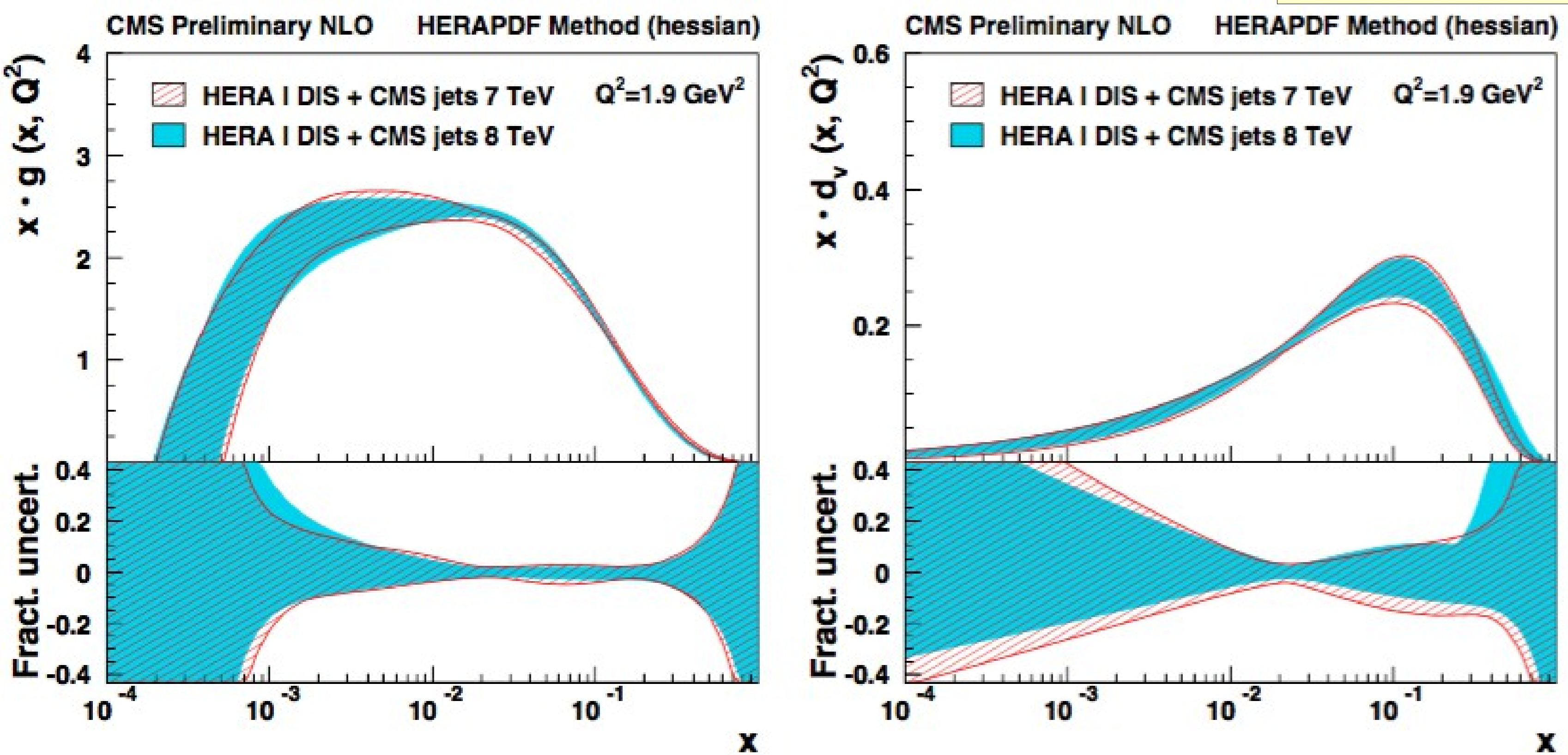


- Corrections for NP $\left(\frac{C^{NP}_{LO}+C^{NP}_{NLO}}{2}\right)$ and electroweak effecs are applied to compare with data.
- A crosscheck with PS is also done with CT10 NLO PDF set w/wo PS effects
  - good agreement with each other within the estimated uncertainty limits.
- The best value obtained by using the CT10 NLO PDF set: input value of $\alpha_s(M_z)$ varies from 0.1110 to 0.1130
- New CMS measurement is in very good agreement with results obtained by previous experiments.
  - Analysis constrains the $_{S}$(Q) running for 86 GeV < Q < 1.5 TeV.

$$\alpha_S(M_Z)(\mathrm{NLO}) = 0.1164^{+0.0025}_{-0.0029}(\mathrm{PDF})^{+0.0053}_{-0.0028}(\mathrm{Scale}) \pm 0.0001(\mathrm{NP})^{+0.0014}_{-0.0015}(\mathrm{Exp}) = 0.1164^{+0.0060}_{-0.0043}$$

PDF determination and α_s

CMS-PAS-SMP-14-001



■ The open-source QCD fit framework for PDF determination HERAFitter, version 1.1.1, is used with the partons evolved by using the DGLAP equations at NLO, as implemented in the QCDNUM program

■ Perturbative QCD, supplemented by a **small NP correction** $\left(\frac{C^{NP}_{LO}+C^{NP}_{NLO}}{2}\right)$, is able to well describe the data over a wide range of p_T and y and over many orders of magnitude in cross section.

■ **This new inclusive jet cross section measurement probes a wide range in x and momentum scale Q**

» hence can be used to constrain PDFs in a new kinematic regime.

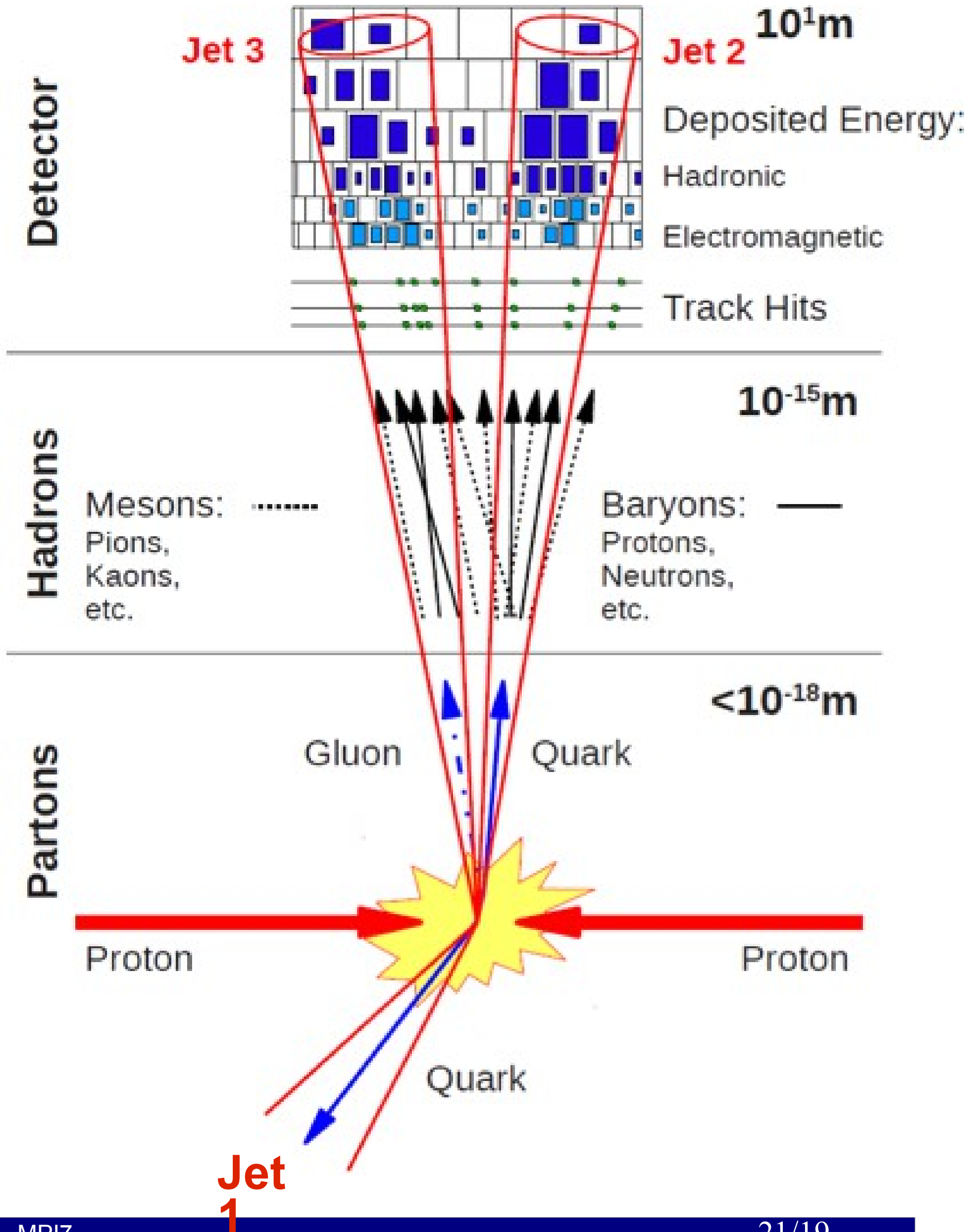
Summary

- NP correction factors for LO and NLO have non-negligible differences at low to intermediate jet p_T
- PS correction factor has significant effects
  - over the whole p_T range
  - largest at large jet y.
- NP corrections
  - change the shape of jet distributions
  - affect significantly the comparison of theory predictions with experimental data
  - also have influence on determinations of parton distributions

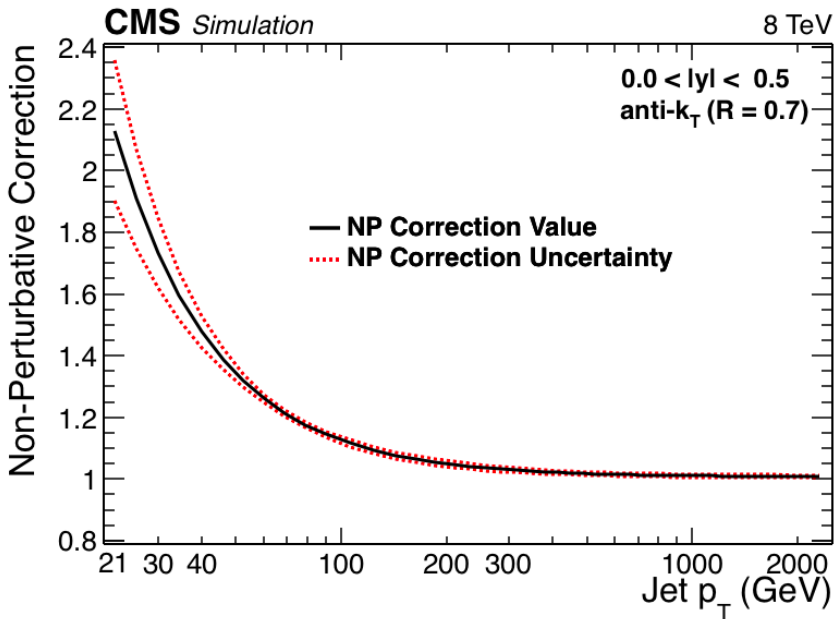
BACKUP

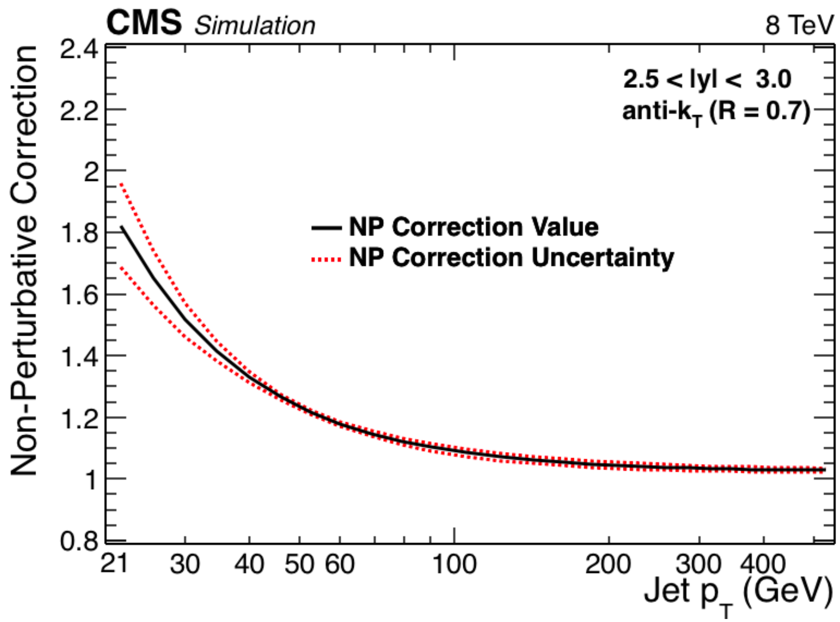
What are the jets?

- Good correspondence between
  - The detector measurements
  - Final state particles
  - Hard partons



NP Correction





The NP correction C^{NP} is an average of the LO- and NLO-based estimates

$$C^{NP} = \left(\frac{C^{NP}_{LO} + C^{NP}_{NLO}}{2}\right)$$

Half the width of the envelope of these predictions is used as the uncertainty due to NP correction.

Jet 1