Impact of PDFs in tuning LO and NLO MC Generators in CMS

Parton Distributions for the LHC

Samantha Dooling
on behalf of the CMS Collaboration

Outline

- Tuning effort in CMS
  - Pythia UE tunes: three Pythia8 tunes and two Pythia6 tunes
  - Sensitivity to PDFs
  - Energy dependence of the underlying event (UE) tunes for 13 TeV
- Tuning gluon PDF at small-x
- Effect of parton shower - Effect in PDF determination?

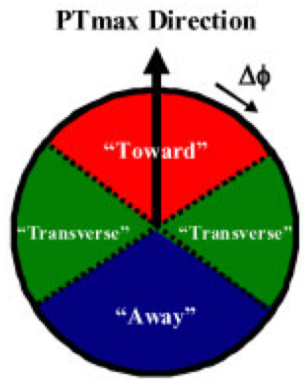
- Results are based on:

CMS-PAS-GEN-14-001

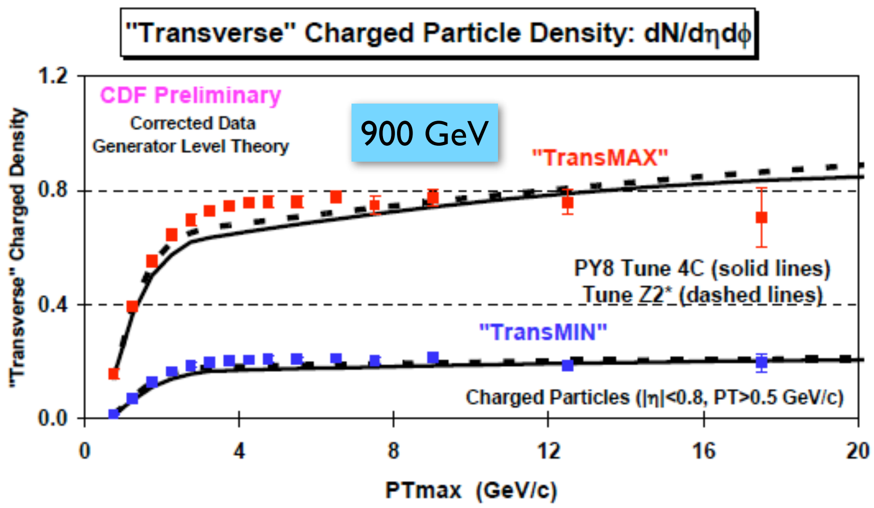
Underlying Event Tunes and Double Parton Scattering

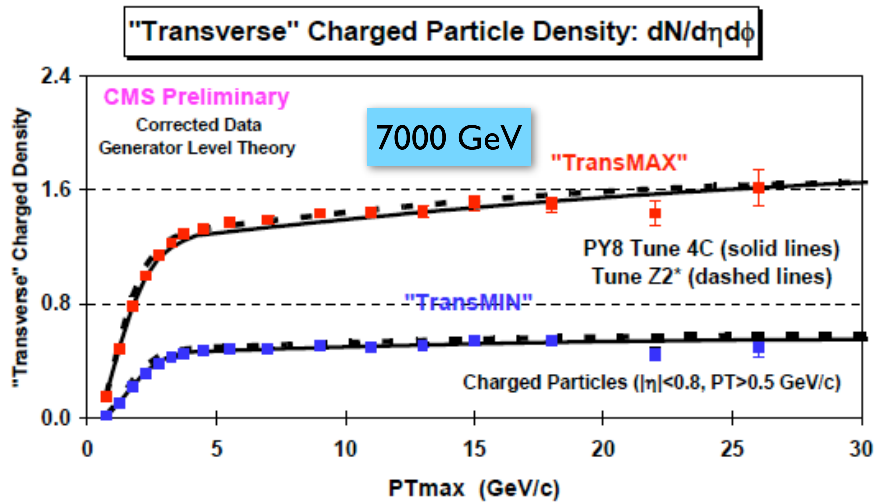
Tuning to UE Data

- Underlying Event observables
- Divided in η-ϕ space
- Direction is defined by leading charged particle
- Charged particle density and charged particle PTsum density



Figures from R. Field





- Pythia tunes do not describe the energy dependence
- Tuning of Pythia to UE data for more precise prediction at 13TeV

Tuning Pythia Parameters

- Tuning Software: Rivet and Professor

- Start with Pythia6 Z2*lep and Pythia8 4C
- Vary parameters, which are sensitive to the underlying event
- Tune to CDF and CMS data at different center-of-mass energies
- Use two different PDF sets CTEQ6L1 and HERAPDF1.5LO

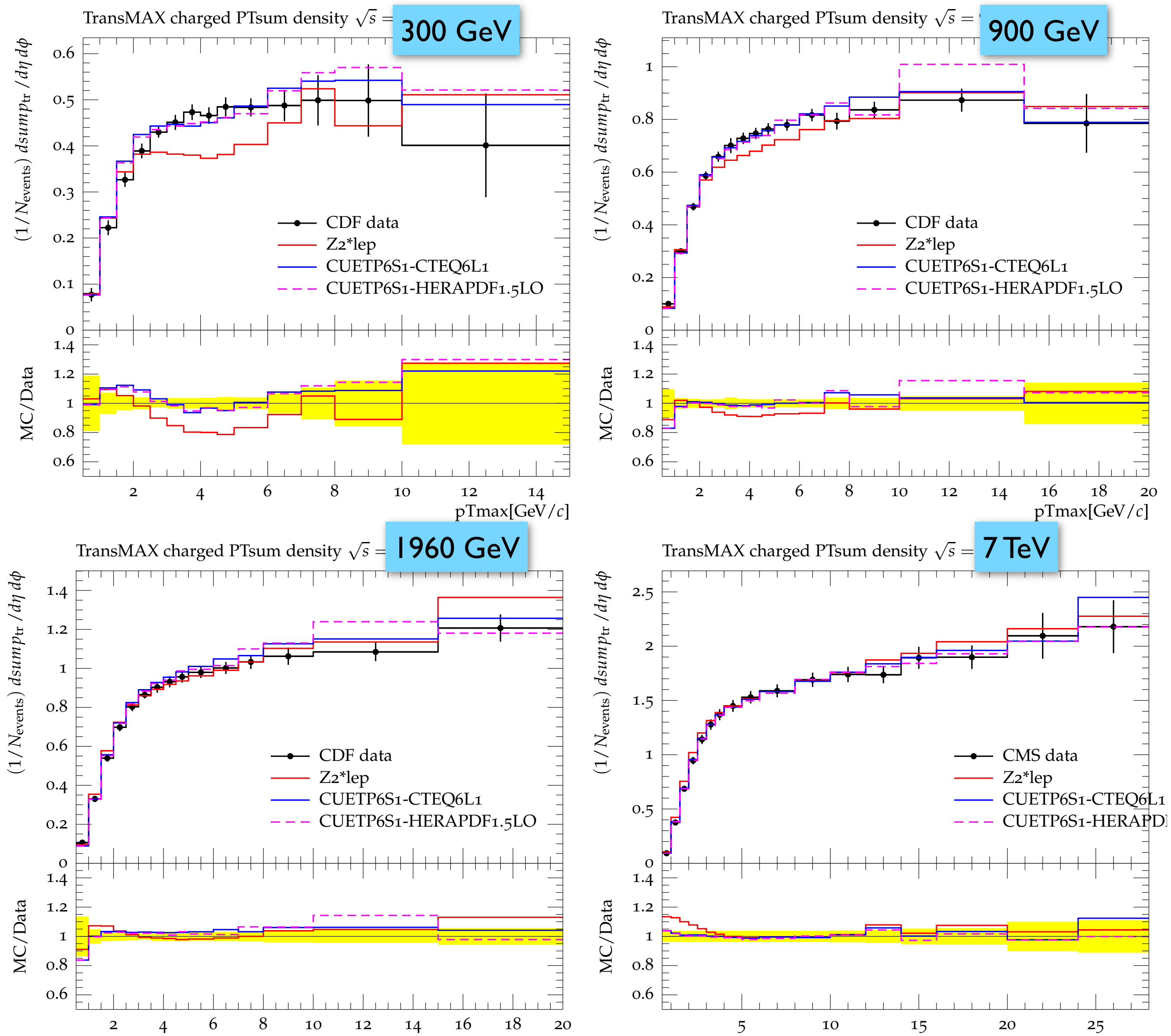
PYTHIA 6 Parameter	Tuning Range	Tune Z2*lep	CUETP6S1 CTEQ6L1	CUETP6S1 HERAPDF1.5LO
PARP(82) - MPI Cut-off (GeV)	1.6 - 2.2	1.921	1.9096	1.946
PARP(90) - MPI Energy Extrapolation	0.18 - 0.28	0.227	0.2479	0.250
PARP(77) - CR Suppression	0.25 - 1.15	1.016	0.6646	0.667
PARP(78) - CR Strength	0.2 - 0.8	0.538	0.5454	0.537
PARP(83) C- Matter fraction in core	0.1 - 1.0	0.356	0.8217	0.490

- Matter fraction in core is most sensitive to PDFs in tuning

CUETP6S1 Tunes

CMS-PAS-GEN-14-001

TransMax charged PTsum density



- Pythia6 tunes compared to CDF and CMS UE data
- Improvement in CUET tunes especially at small transverse momenta
- Similar results for CUETP6S1
  - CTEQ6L1 and
  - HERAPDF1.5LO

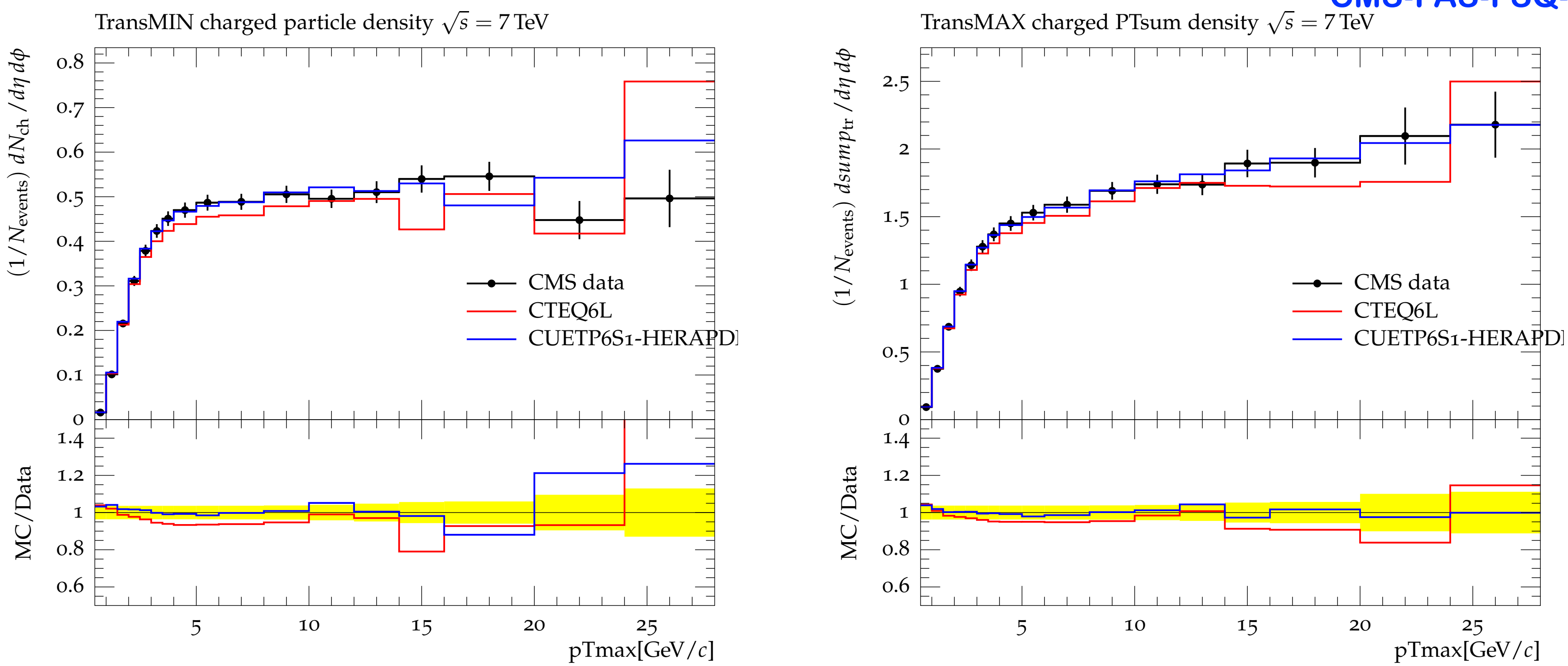
Effect of PDF in UE Tune

- Change PDF in tuned CMS tune!

TransMax charged PTsum density

- CTEQ6L1: CUETP6S1 tuned with PDF set HERAPDF1.5LO but events generated with CTEQ6L1
- CUETP6S1-HERAPDF1.5LO: CUETP6S1 tuned with PDF HERAPDF1.5LO

CMS-PAS-FSQ-12-020



- Predictions with wrong PDF underestimate the data by ~5-10%
- Tuning is sensitive to PDF!!

LO PDFs in Shower Monte Carlo (SMC) Generators

Which PDFs shall we use in the SMC?

- Torbjörn Sjöstrand:
  - LO PDF is strongly recommended to use in SMC (Pythia6, Pythia8)
  - ISR is generated with backward evolution scheme (based on ratios of PDFs)
  - Differences between PDF sets divide out: at large x and Q^2 scales it is safe to use LO or NLO PDFs

LO PDFs in Shower Monte Carlo (SMC) Generators

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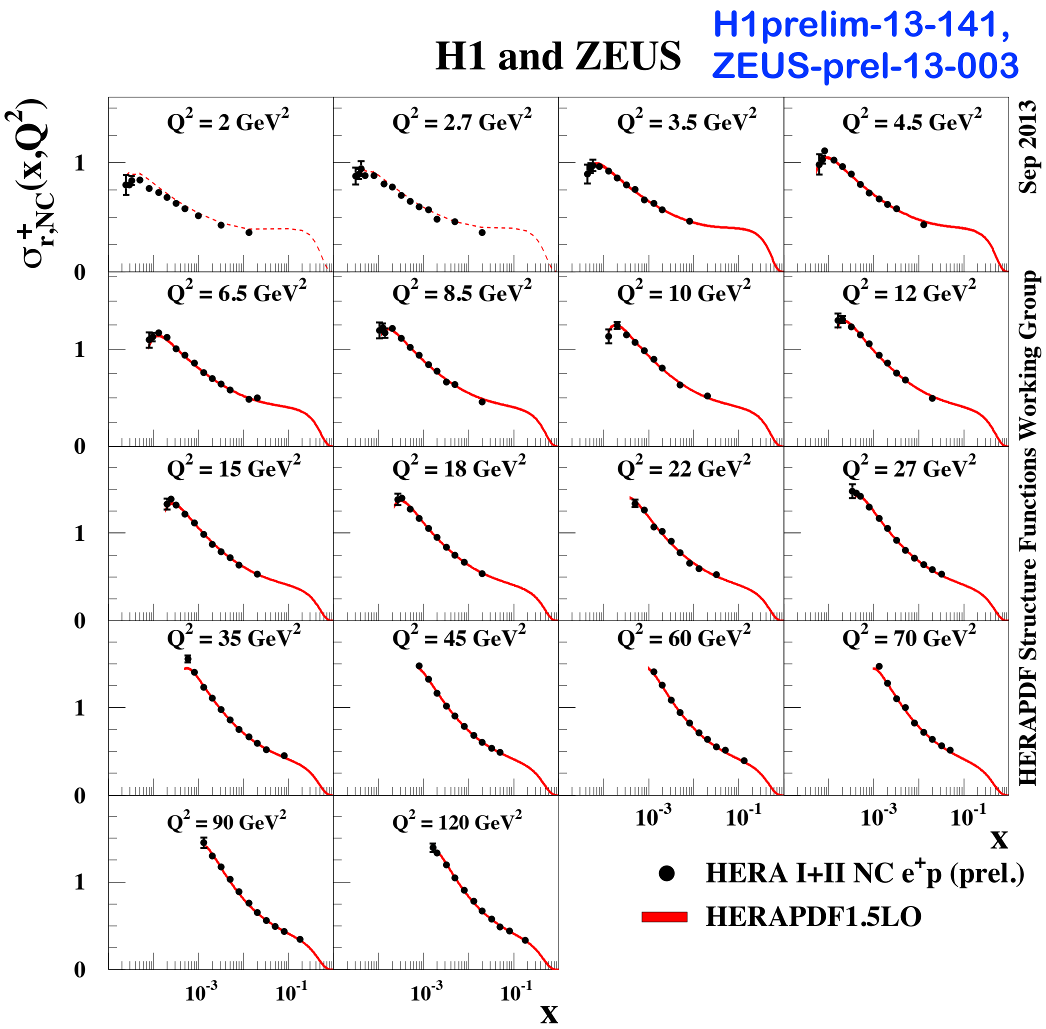
Why is this important?

- Higher energies at the LHC will cover measurements to lower values of the parton momentum fraction x
- HERAPDF1.5LO

HERAPDF1.5LO

Why LO PDF?

- Emphasis on the small-x structure functions
- Valid at small scales: important for accurate PDFs in MC generators
- Precise predictions for UE properties and MB events and simulation of pileup events



- LO Fit to ZEUS and HERA data
- χ^2 still reasonably good (slightly higher compared to NLO)
- Good agreement is achieved compared to data

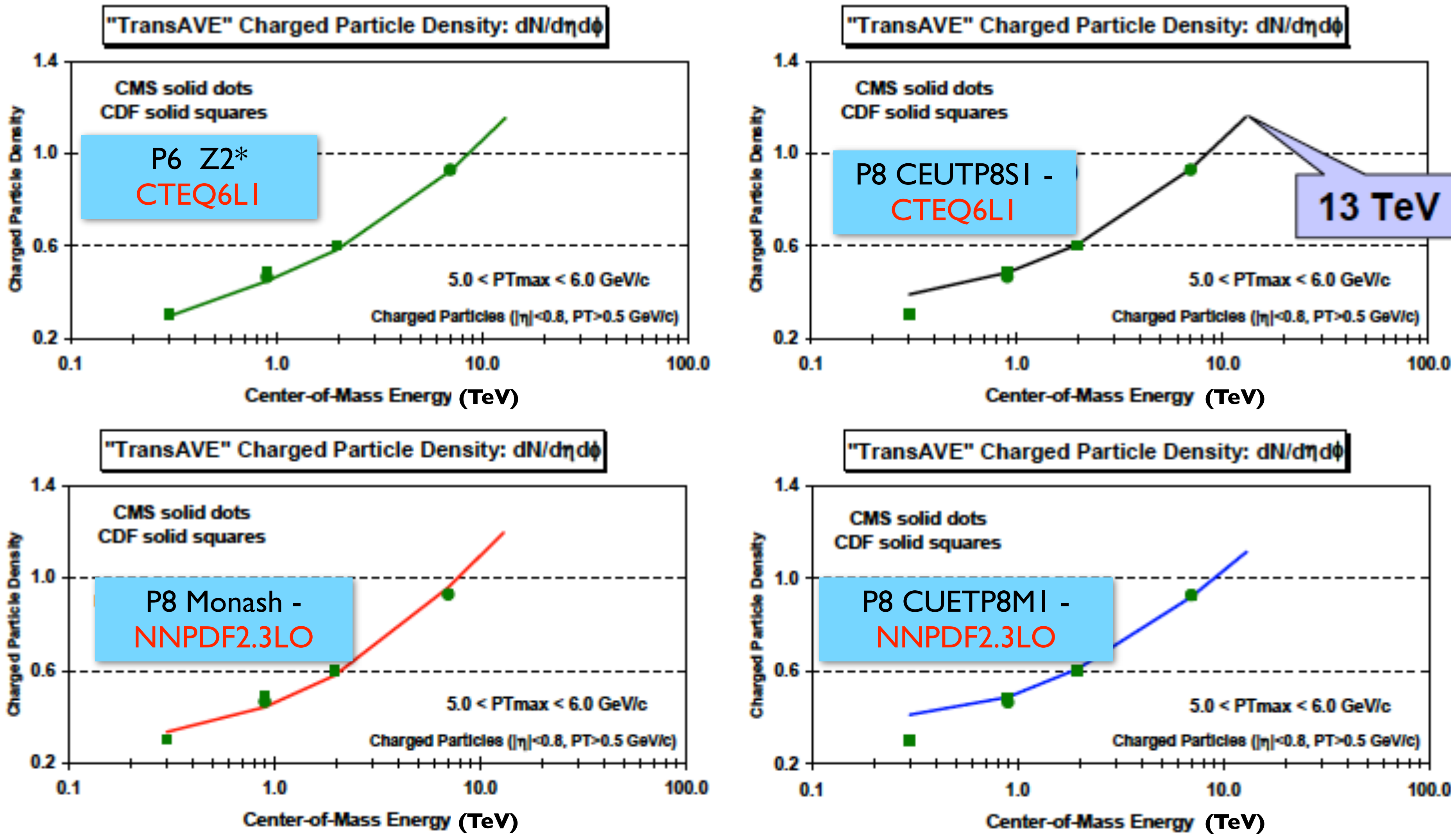
Available CMS UE Tunes

- Pythia6 CUETP6S1-CTEQ6L1 and CUETP6S1-HERAPDF1.5LO
  - Start with tune Z2*lep
  - CTEQ6L1 and HERAPDF1.5LO
  - Tuned to CDF and CMS UE data at 300, 900, 1960 and 7000 GeV
- Pythia8 CUETP8S1-CTEQ6L1 and CUETP8S1-HERAPDF1.5LO
  - Start with tune 4C
  - CTEQ6L1 and HERAPDF1.5LO
  - Tuned to CDF and CMS UE data at 900, 1960 and 7000 GeV
- Pythia8 CUETP8M1-NNPDF2.3LO
  - Start with Monash tune (P.Skands, S. Carrazza, J.Rojo, Eur.Phys.J. C74 (2014) 8)
  - NNPDF2.3LO
  - Tuned to CDF and CMS UE data at 900, 1960 and 7000 GeV

Energy Dependence

- Charged particle density as a function of the center-of-mass energy

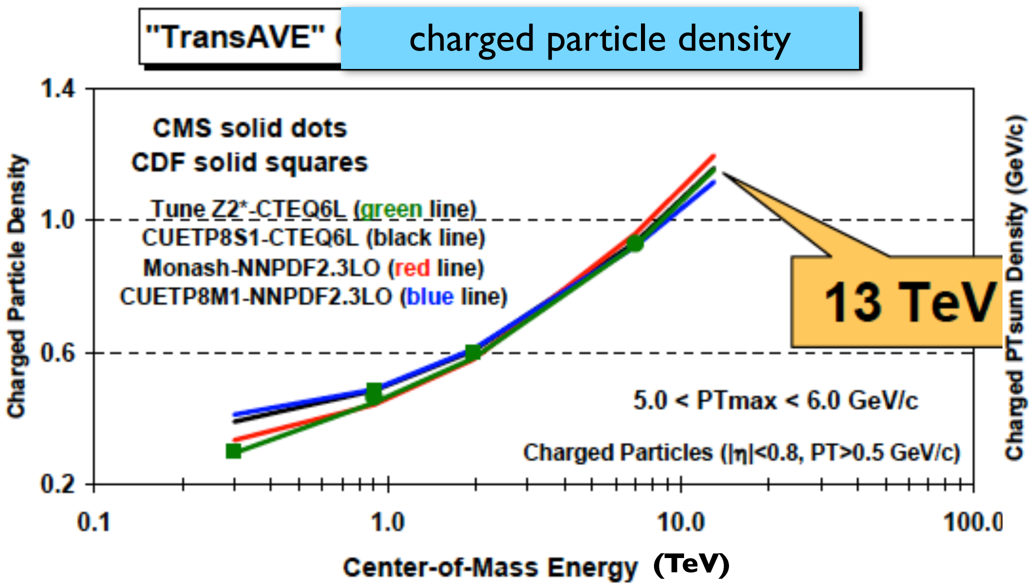
Figures from R. Field

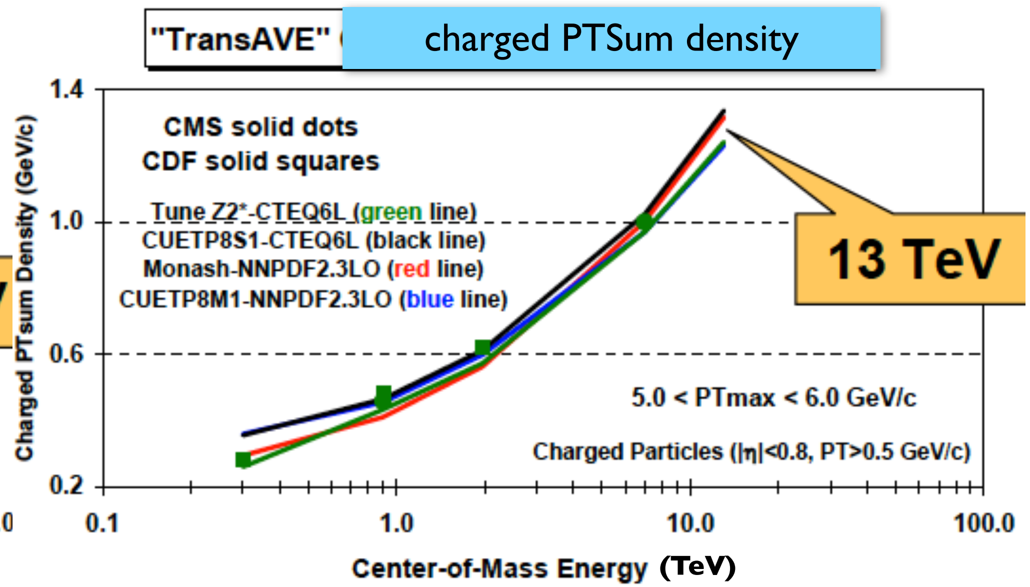


Predictions at 13 TeV

- CMS UE tunes with various LO PDF sets
- Predictions at 13 TeV are included
- Differences at 13 TeV between tunes (different PDFs) increase
- Different comparison also between charged particle density and charged PTsum

Figures from R. Field

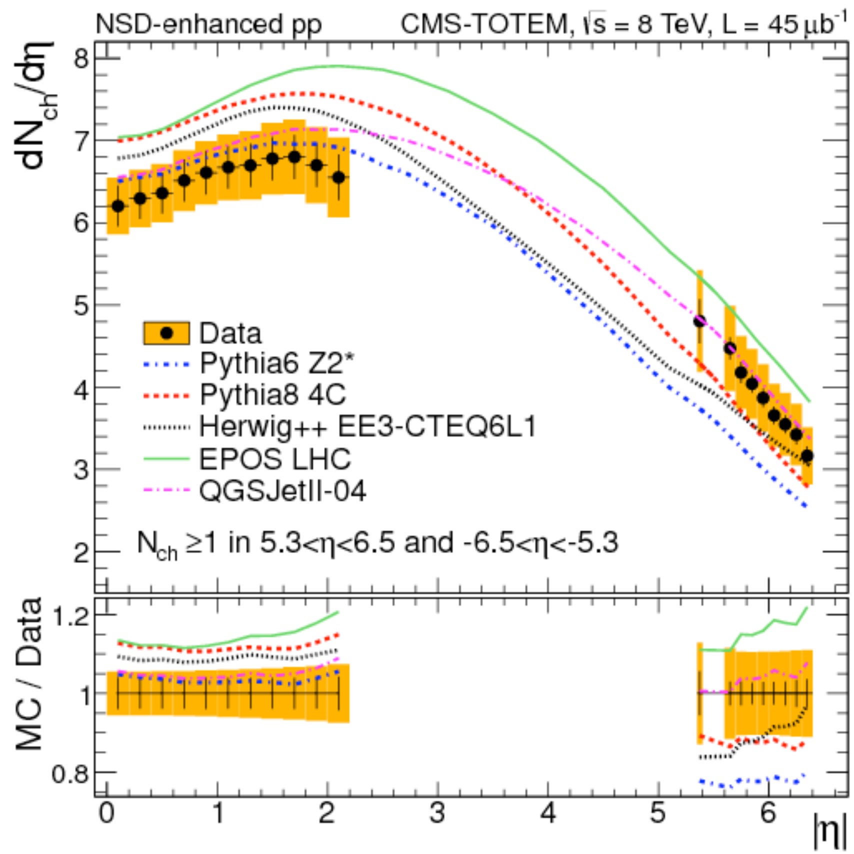




Tuning Gluon PDF

- Motivation
  - dN/dη measurement by CMS and TOTEM Experiments
  - No MC prediction is able to describe the full η region
  - Improve small-x gluon distribution to get the dN/dη correct

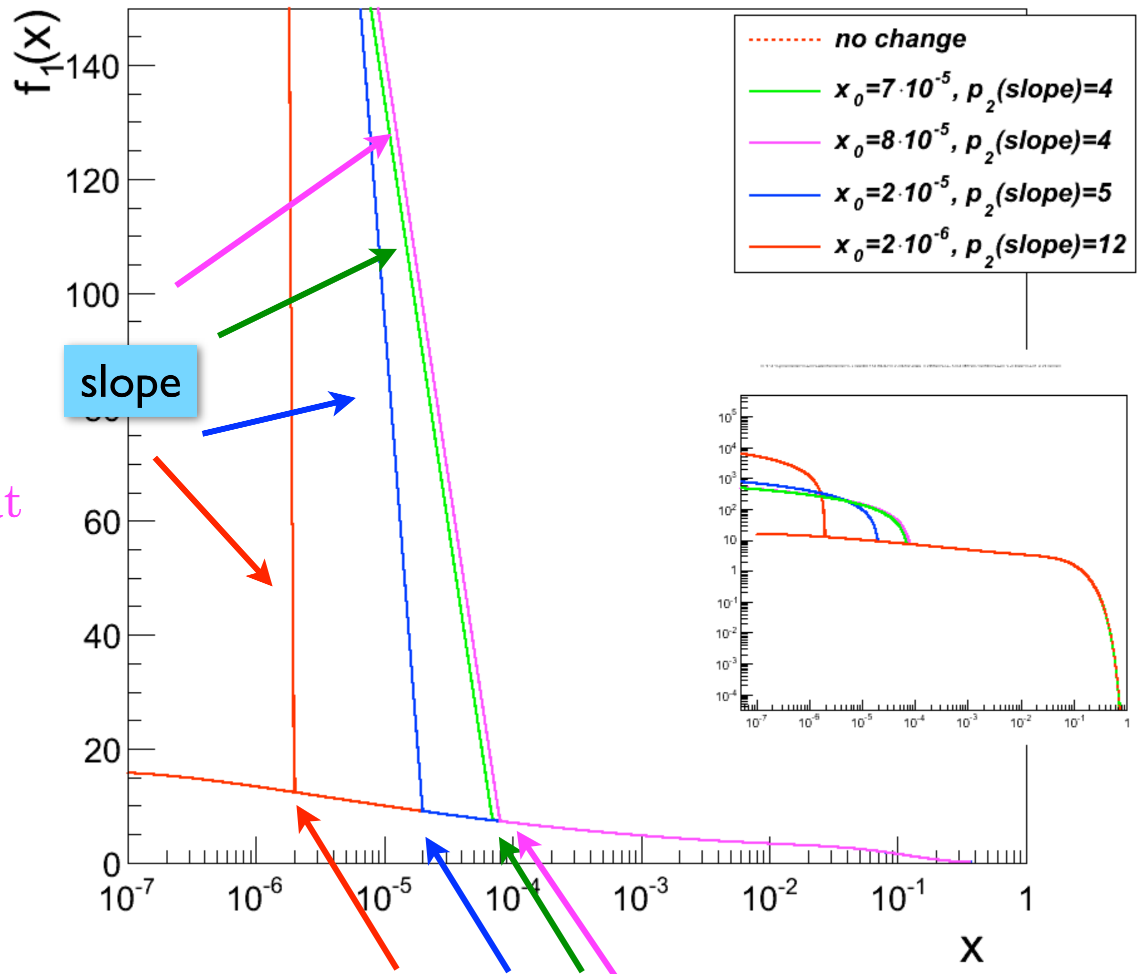
EPJC 74 (2014) 2053



- Use the CMS tune and vary the low-x gluon distribution to try to improve the fit to the forward region
- Hera F2 data still has to be described by modified gluon distribution

Tuning Gluon PDF at small-x

- Strategy
  - Toy model: change the gluon PDF in the small-x region
  - Start with HERALO PDF functions f(x)
  - Modify the gluon distribution at small-x by adding a function $f_1(x, p_1, p_2)$
  - f_1 depends on two parameters $p_1 = x_0$ and $p_2 =$ slope

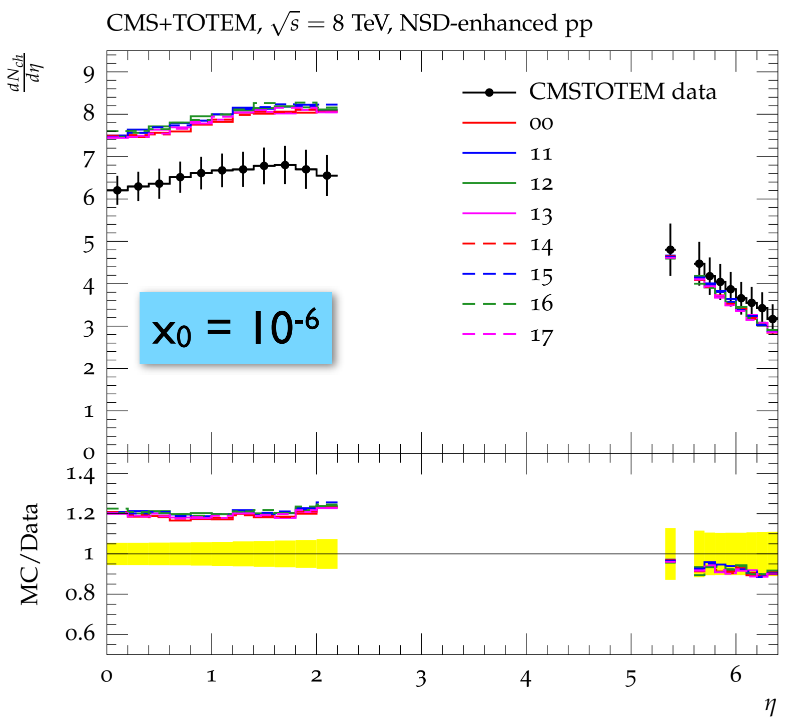


- PDF is changed in a region where gluon distribution is not constrained and data is still described

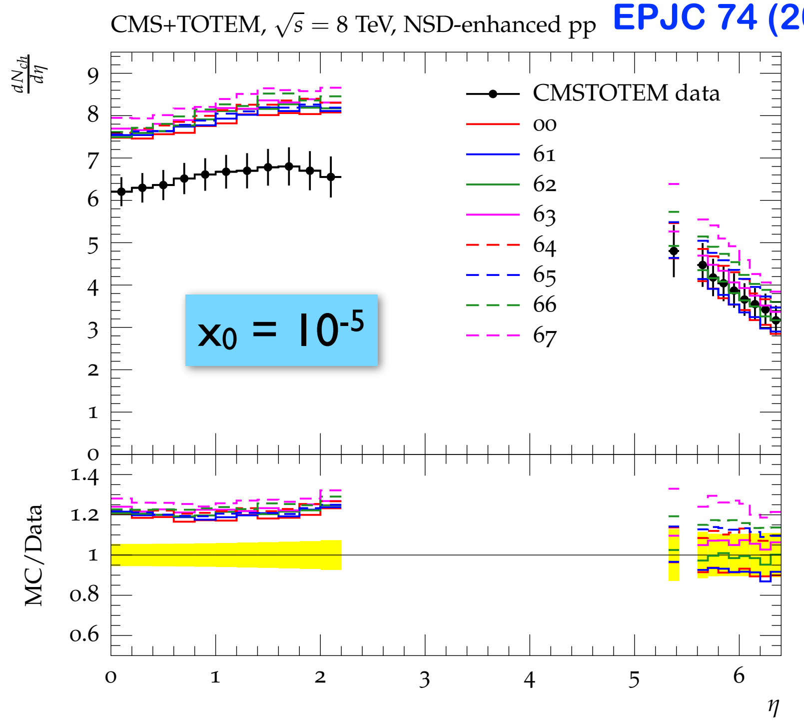
x_0
Starting point of modification

dN/dη with small-x Gluon PDF

- New PDF including function f_1 (two different offsets and different slopes)
- Measurement is sensitive to change of gluon PDF at small-x
- Forward region is much more sensitive to PDF at $x_0 = 10^{-5}$

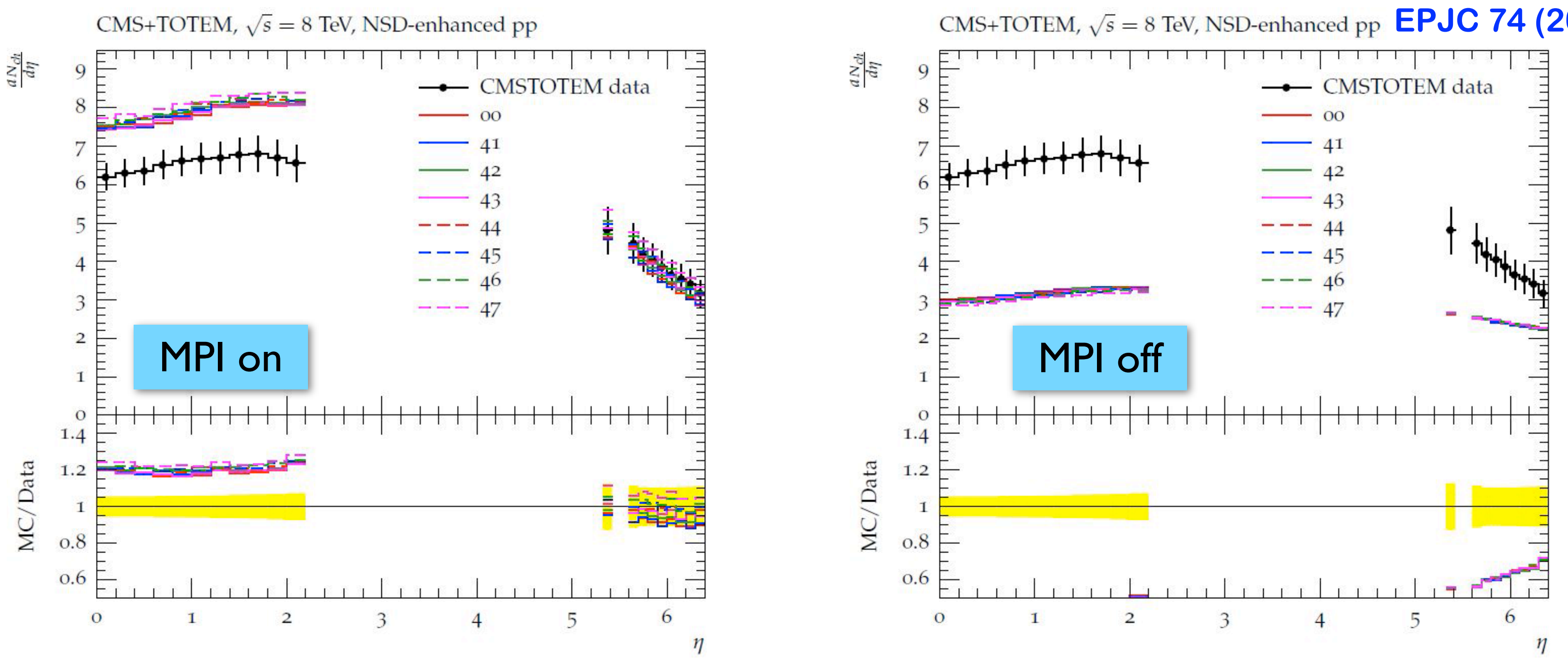


EPJC 74 (2014) 2053



Effect of MPI

- Effect is significant at forward and central pseudorapidity range
- Comparison to CMS data is affected by changing the gluon PDF at small-x
- Tune Pythia8 including the toy model PDF to the UE data from CDF and CMS



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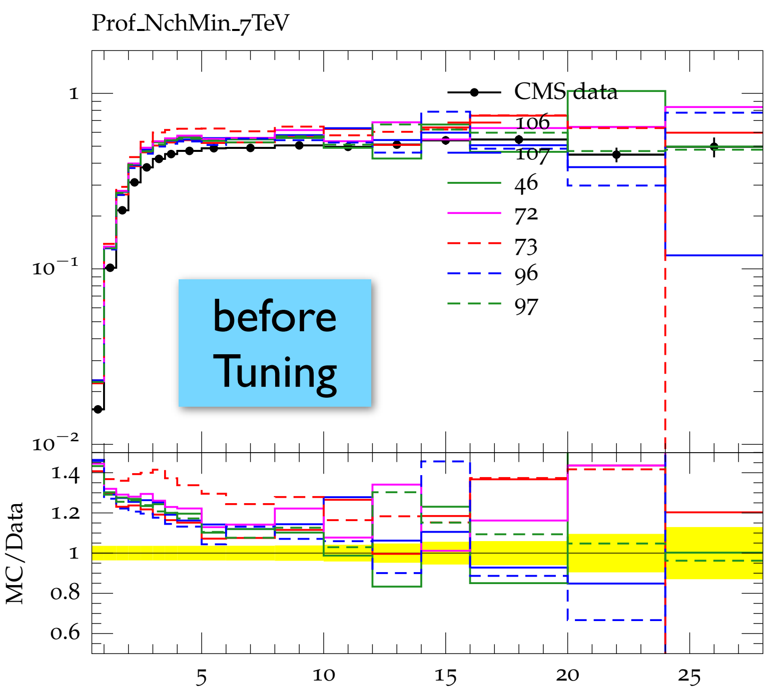
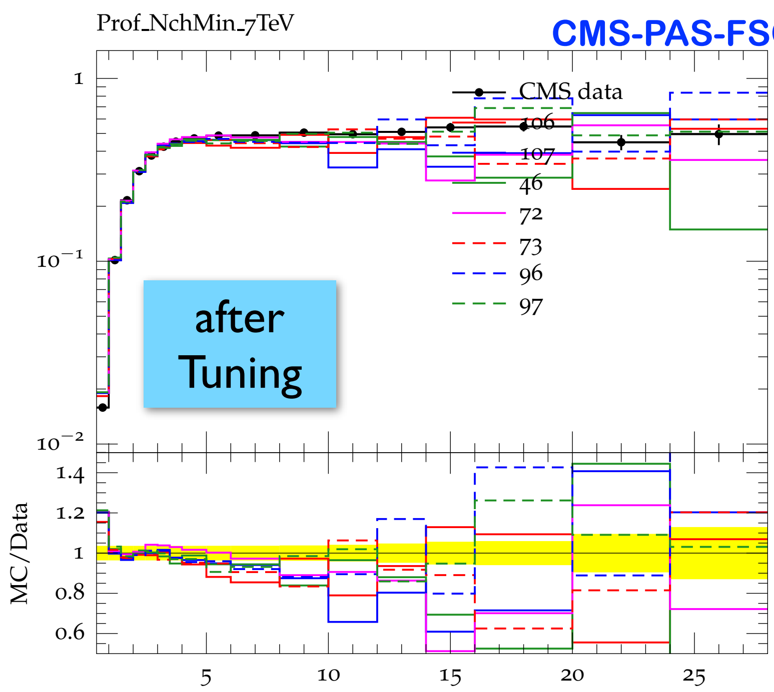
Need of Re-tuning

- Use the CMS tune and vary the low-x gluon distribution to try to improve the fit to the forward region
  - BUT: Change of the PDF - need to be re-tuned
  - Tune to CDF and CMS data

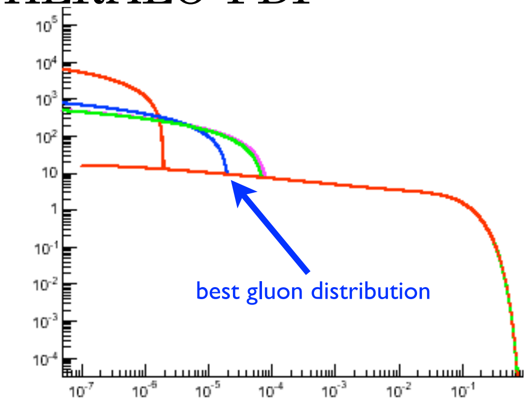




CMS-PAS-FSQ-12-020

dN/dη re-tuned and improve PDF at small-x

- Re-tune UE parameters of CUETP8S1 tune with toy model HERALO PDF
- Improvement in the central and forward region after tuning
- Best agreement is achieved with $x_0 = 2*10^{-5}$ and slope = 5
- Still MC below the data in the central region



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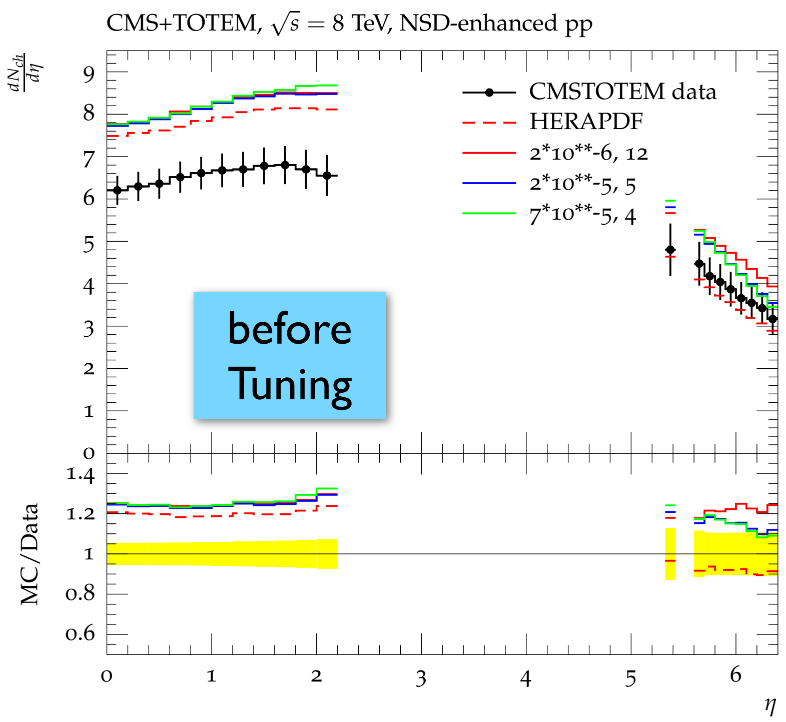
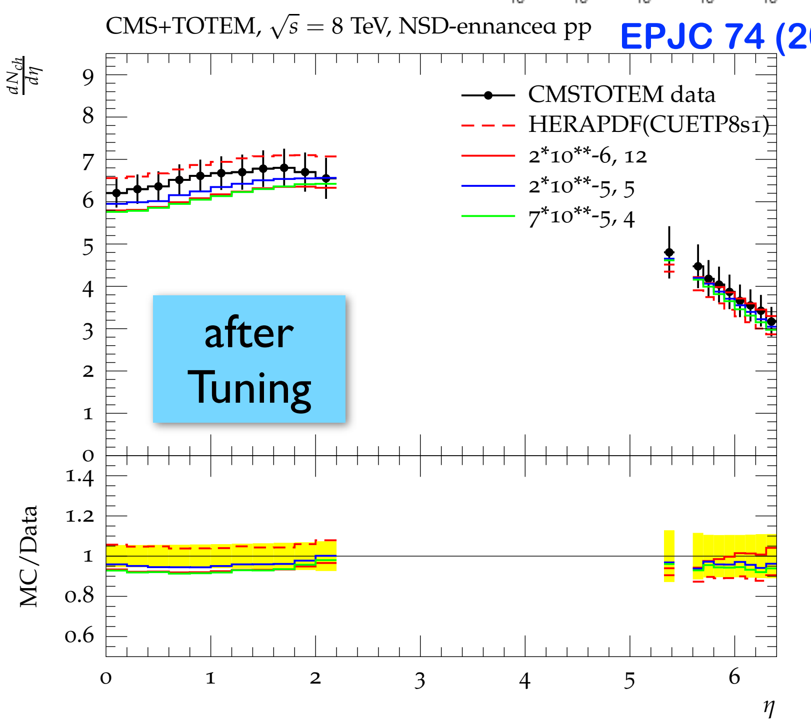
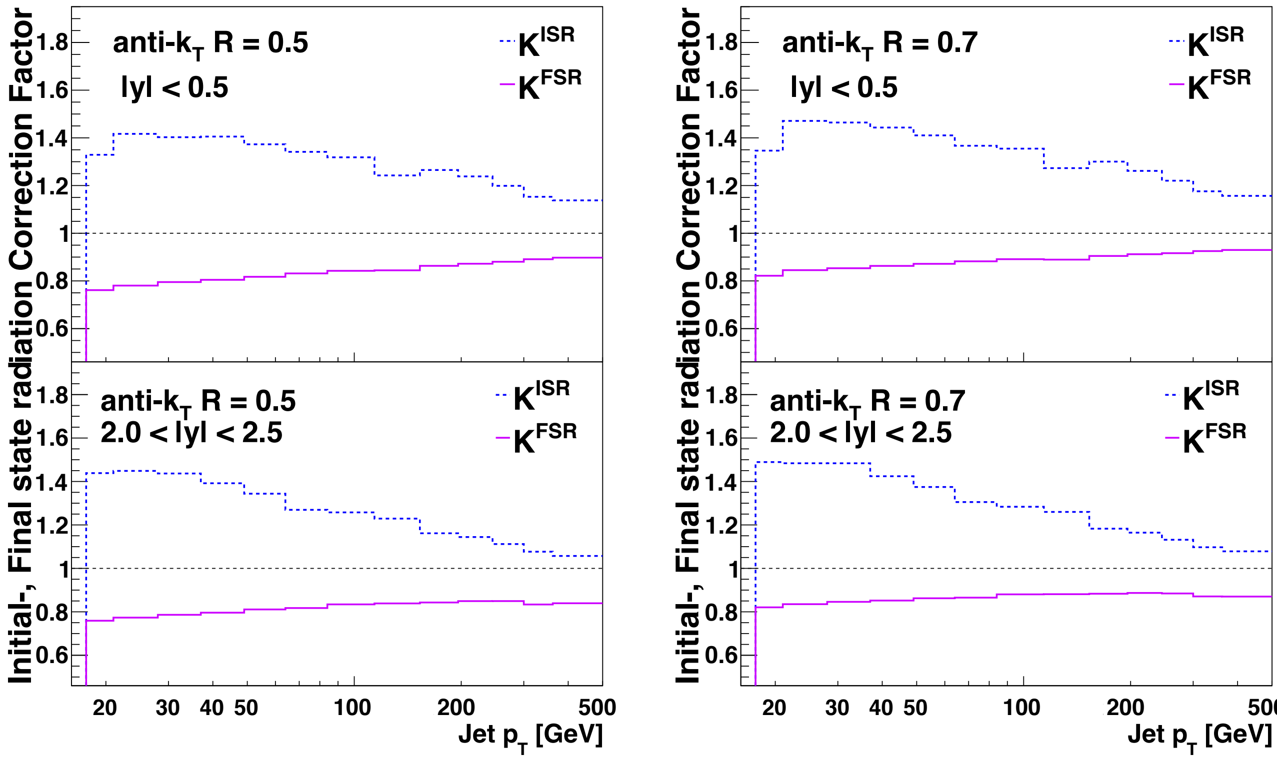




Effect of Parton Shower on PDFs

- Motivation
  - Effect of parton shower in inclusive jet measurements (estimated by Powheg +Pythia6)
  - Effect of transverse momentum can also change the PDF

Phys.Rev. D87 094009 (2013)



Influence of parton shower on PDF determination?

Effect of Parton Shower on PDFs

Influence of parton shower on PDF determination?

- Parton Shower effect (using Powheg+Pythia6) is significant
- Taking into account the k_t dependence already at the beginning of the calculation

Need of PDFs in Powheg, which are determined including parton showers?

- Including parton showers in PDFs will reduce effect of the parton shower correction?
- How can it be systematically estimated?

Summary

- New CMS Underlying Event tunes are available for Pythia6 and Pythia8
- Tuning is sensitive to PDF (CTEQ6L1, HERALPDF1.5LO)
- Importance of LO PDF in SMC
- First predictions at 13 TeV
- Systematic study of changing HERALO PDF at small-x
  - Underlying event parameters have to be re-tuned
  - PDF is changed in a region where gluon distribution is not constrained and data is still described
- Which impact does the parton shower have on PDF determination?
  - How can it be systematically estimated?

Backup

Tuning Pythia Parameters

PYTHIA 6 Parameter	Tuning Range	Tune Z2*lep	CUETP6S1 CTEQ6L1	CUETP6S1 HERAPDF1.5LO
PARP(82) - MPI Cut-off (GeV)	1.6 - 2.2	1.921	1.9096	1.946
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PARP(77) - CR Suppression	0.25 - 1.15	1.016	0.6646	0.667
PARP(78) - CR Strength	0.2 - 0.8	0.538	0.5454	0.537
PARP(83) C- Matter fraction in core	0.1 - 1.0	0.356	0.8217	0.490
Reduced χ^2	-	-	0.915	–

PYTHIA 8 Parameter	Tuning Range	Tune 4C	CUETP8S1-CTEQ6L1	CUETP8S1-HERAPDF1.5LO
MultipleInteractions:pT0Ref (GeV)	1.0 - 3.0	2.085	3.1006	2.0001
MultipleInteractions:ecmPow	0.0 - 0.4	0.19	0.2106	0.2499
MultipleInteractions:expPow	0.4 - 10.0	2.0	1.6089	1.6905
BeamRemnants:reconnectRange	0.0 - 9.0	1.5	3.3126	6.0964
Reduced χ^2	-	-	0.952	1.13

Parameter Snippet CUETP6S1 - CTEQ6L1

```
pythiaUESettings = cms.vstring('MSTU(21)=1     ! Check on possible errors during program execution',
      'MSTJ(22)=2     ! Decay those unstable particles',
      'PARJ(71)=10 .  ! for which ctau  10 mm',
      'MSTP(33)=0     ! no K factors in hard cross sections',
      'MSTP(2)=1      ! which order running alphaS',
      'MSTP(51)=10042 ! structure function chosen (external PDF CTEQ6L1)',
      'MSTP(52)=2     ! work with LHAPDF',
   'PARP(82)=1.9096 ! pt cutoff for multiparton interactions',
      'PARP(89)=1800. ! sqrts for which PARP82 is set',
      'PARP(90)=0.2479! Multiple interactions: rescaling power',
      'MSTP(95)=6     ! CR (color reconnection parameters)',
      'PARP(77)=0.6646 ! CR',
      'PARP(78)=0.5454 ! CR',
      'PARP(80)=0.1   ! Prob. colored parton from BBR',
      'PARP(83)=0.8217 ! Multiple interactions: matter distribution parameter',
      'PARP(84)=0.651 ! Multiple interactions: matter distribution parameter',
      'PARP(62)=1.025 ! ISR cutoff',
      'MSTP(91)=1     ! Gaussian primordial kT',
      'PARP(93)=10.0  ! primordial kT-max',
      'MSTP(81)=21    ! multiple parton interactions 1 is Pythia default',
      'MSTP(82)=4     ! Defines the multi-parton model',
      'PARJ(1) =  0.08 ! HAD diquark suppression',
      'PARJ(2) = 0.21 ! HAD strangeness suppression',
      'PARJ(3) = 0.94 ! HAD strange diquark suppression',
      'PARJ(4) = 0.04 ! HAD vectior diquark suppression',
      'PARJ(11) = 0.35 ! HAD P(vector meson), u and d only',
      'PARJ(12) = 0.35 ! HAD P(vector meson) contains ',
      'PARJ(13) = 0.54 ! HAD P(vector meson), heavy quarks',
      'PARJ(21) = 0.34 ! HAD fragmentation pt',
      'PARJ(25) = 0.63 ! HAD eta0 suppression',
      'PARJ(26) = 0.12 ! HAD eta0 suppression'
),
```

Parameter Snippet CUETP6S1 - HERAPDF1.5LO

```
pythiaUESettings = cms.vstring('MSTU(21)=1     ! Check on possible errors during program execution',
      'MSTJ(22)=2     ! Decay those unstable particles',
      'PARJ(71)=10 .  ! for which ctau  10 mm',
      'MSTP(33)=0     ! no K factors in hard cross sections',
      'MSTP(2)=1      ! which order running alphaS',
      'MSTP(51)=10042 ! structure function chosen (external PDF CTEQ6L1)',
      'MSTP(52)=2     ! work with LHAPDF',
   'PARP(82)=1.946 ! pt cutoff for multiparton interactions',
      'PARP(89)=1800. ! sqrts for which PARP82 is set',
      'PARP(90)=0.250! Multiple interactions: rescaling power',
      'MSTP(95)=6     ! CR (color reconnection parameters)',
      'PARP(77)=0.667 ! CR',
      'PARP(78)=0.537 ! CR',
      'PARP(80)=0.1   ! Prob. colored parton from BBR',
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      'PARP(62)=1.025 ! ISR cutoff',
      'MSTP(91)=1     ! Gaussian primordial kT',
      'PARP(93)=10.0  ! primordial kT-max',
      'MSTP(81)=21    ! multiple parton interactions 1 is Pythia default',
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      'PARJ(25) = 0.63 ! HAD eta0 suppression',
      'PARJ(26) = 0.12 ! HAD eta0 suppression'
),
```

Parameter Snippet CUETP8S1 - CTEQ6L1

```
     import FWCore.ParameterSet.Config as cms

##from Configuration.Generator.PythiaUESettings_cfi import *

generator = cms.EDFilter("Pythia8GeneratorFilter",
    pythiaHepMCVerbosity = cms.untracked.bool(False),
    maxEventsToPrint = cms.untracked.int32(0),
    pythiaPylistVerbosity = cms.untracked.int32(0),
    filterEfficiency = cms.untracked.double(1.0),
    crossSection = cms.untracked.double(-1.),
    comEnergy = cms.double(7000.0),
    PythiaParameters = cms.PSet(
    processParameters = cms.vstring('Main:timesAllowErrors    = 10000',
        'ParticleDecays:limitTau0 = on',
        'ParticleDecays:tauMax = 10',
        'SoftQCD:minBias = on',
        'SoftQCD:singleDiffractive = on',
        'SoftQCD:doubleDiffractive = on',
        'Tune:pp 5',
        'Tune:ee 3',
        'MultipleInteractions:pT0Ref=2.1006',
        'MultipleInteractions:ecmPow=0.21057',
        'MultipleInteractions:expPow=1.6089',
     'BeamRemnants:reconnectRange=3.31257',
        ),
        parameterSets = cms.vstring('processParameters')
        )
                                 )
ProductionFilterSequence = cms.Sequence(generator)
```

Parameter Snippet CUETP8S1 - HERAPDF1.5LO

```
     import FWCore.ParameterSet.Config as cms

##from Configuration.Generator.PythiaUESettings_cfi import *

generator = cms.EDFilter("Pythia8GeneratorFilter",
    pythiaHepMCVerbosity = cms.untracked.bool(False),
    maxEventsToPrint = cms.untracked.int32(0),
    pythiaPylistVerbosity = cms.untracked.int32(0),
    filterEfficiency = cms.untracked.double(1.0),
    crossSection = cms.untracked.double(-1.),
    comEnergy = cms.double(2760.0),
    PythiaParameters = cms.PSet(
    processParameters = cms.vstring('Main:timesAllowErrors    = 10000',
        'ParticleDecays:limitTau0 = on',
        'ParticleDecays:tauMax = 10',
        'SoftQCD:minBias = on',
        'SoftQCD:singleDiffractive = on',
        'SoftQCD:doubleDiffractive = on',
        'Tune:pp 5',
        'Tune:ee 3',
        'PDF:useLHAPDF=on',
     'PDF:LHAPDFset=/scratch/hh/dust/naf/cms/user/gunnep/Professor/CMSSW_5_3_9/src/Lhepdf/HERAPDF1.5LO_EIG.LHgrid',
        'MultipleInteractions:pT0Ref=2.000072e+00',
     'MultipleInteractions:ecmPow=2.498802e-01',
     'MultipleInteractions:expPow=1.690506e+00',
     'BeamRemnants:reconnectRange=6.096364e+00',
        ),
        parameterSets = cms.vstring('processParameters')
        )
                                 )
ProductionFilterSequence = cms.Sequence(generator)
```

Parameter Snippet CUETP8M1 - NNPDF23

```
     import FWCore.ParameterSet.Config as cms

pythia8CUEP8M1SettingsBlock = cms.PSet(
    pythia8CUEP8M1Settings = cms.vstring(
        'Tune:pp 14',
        'Tune:ee 7',
        'MultipleInteractions:pT0Ref=2.4024',
        'MultipleInteractions:ecmPow=0.25208',
        'MultipleInteractions:expPow=1.6',
    )
)
```

Tune Validation

CMS-GEN-14-001

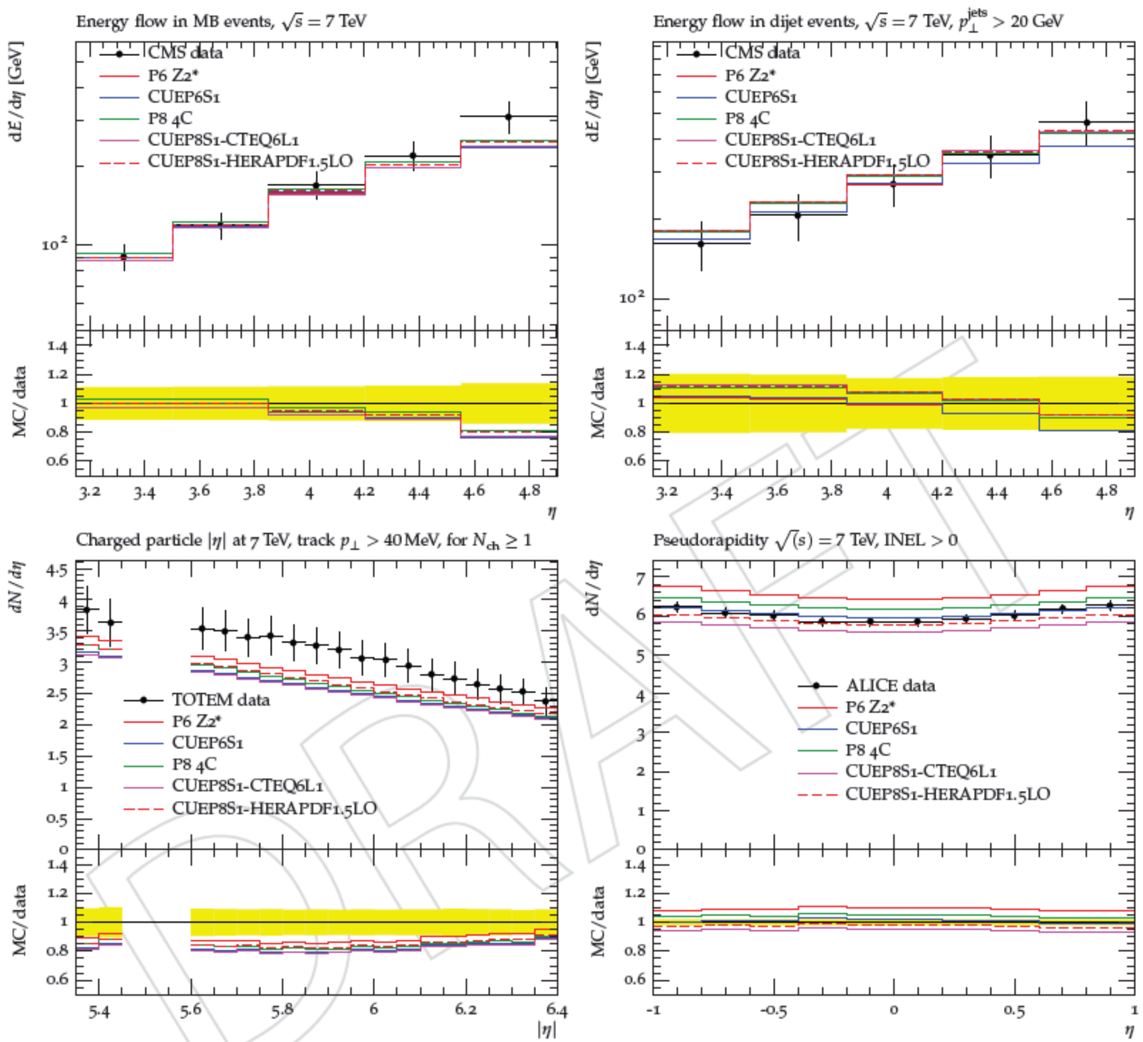


Figure 9: CMS data on the forward energy flow in MB (top left) and dijet (top right) events, ALICE data and TOTEM data on charged particle pseudorapidity in, respectively, the central and forward region. The data are compared with PYTHIA 6 tune Z2*, PYTHIA 8 Tune 4C, the new PYTHIA 6 tune, and the two new CMS PYTHIA 8 tunes using CTEQ6L1 and the HERAPDF1.5LO. Also shows the ratio of the tunes with the data.

Tune Validation

CMS-GEN-14-001

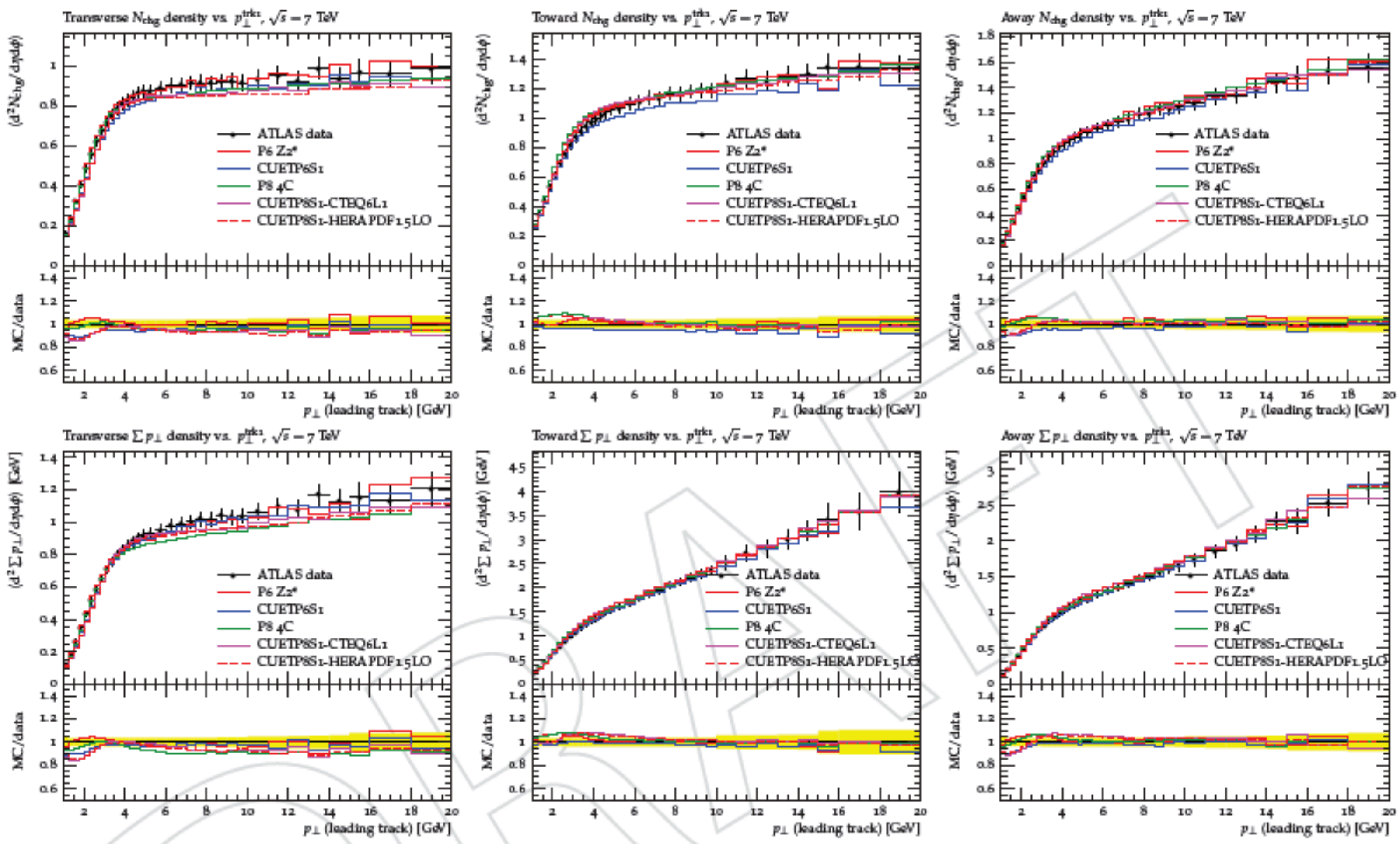


Figure 10: ATLAS data on the charged particle multiplicity N_{ch} (top) and p_T sum (bottom) measured in the transverse (left), toward (center) and away (right) regions. The data are compared with PYTHIA 6 tune Z2*, PYTHIA 8 Tune 4C, the new PYTHIA 6 tune, and the two new CMS PYTHIA 8 tunes using CTEQ6L1 and the HERAPDF1.5LO. Also shows the ratio of the tunes with the data.

Predictions at 13 TeV

CMS-GEN-14-001

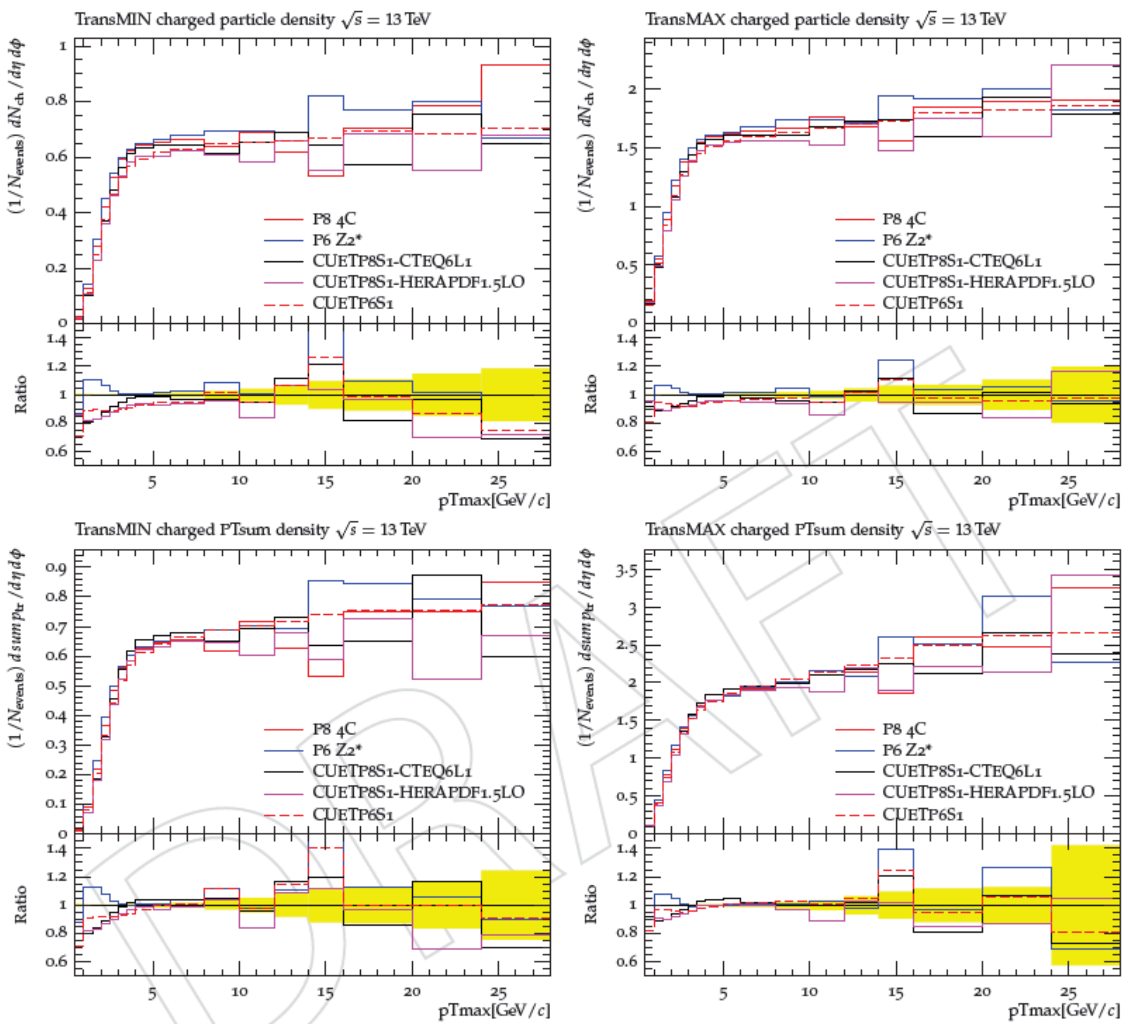
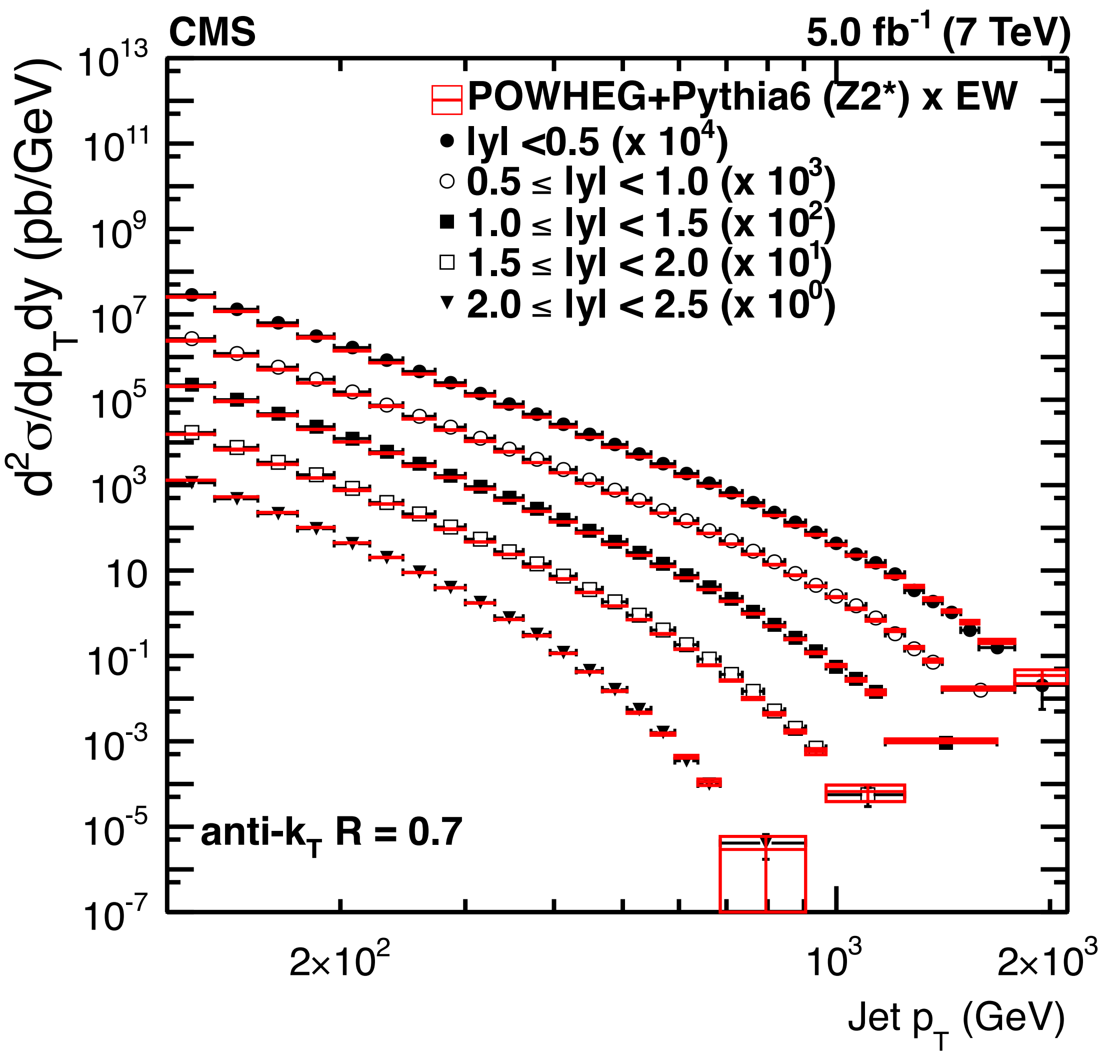


Figure 11: Predictions for pp collisions at 13 TeV for PYTHIA 8 Tune 4C, PYTHIA 6 tune Z2*, the two new CMS PYTHIA 8 tunes using CTEQ6L1 and the HERAPDF1.5LO, and the the new CMS PYTHIA 6 tune: charged particle density (left column) and p_T sum density (right column) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ in the "transMIN" (top row), and the "transMAX" (bottom row) regions as defined by the leading charged particle, as a function of p_T max. Also shown are the ratios of the new CMS tunes to Tune 4C.

Inclusive Jet Cross Section

SMP-12-028, arXiv: 1410.6765



NP & PS Corrections

SMP-12-028, arXiv: 1410.6765