Pseudorapidity Distributions of Charged Particles, and Leading Track and Charged Mini-jet Cross-sections

QCD Results from the combined CMS-TOTEM run

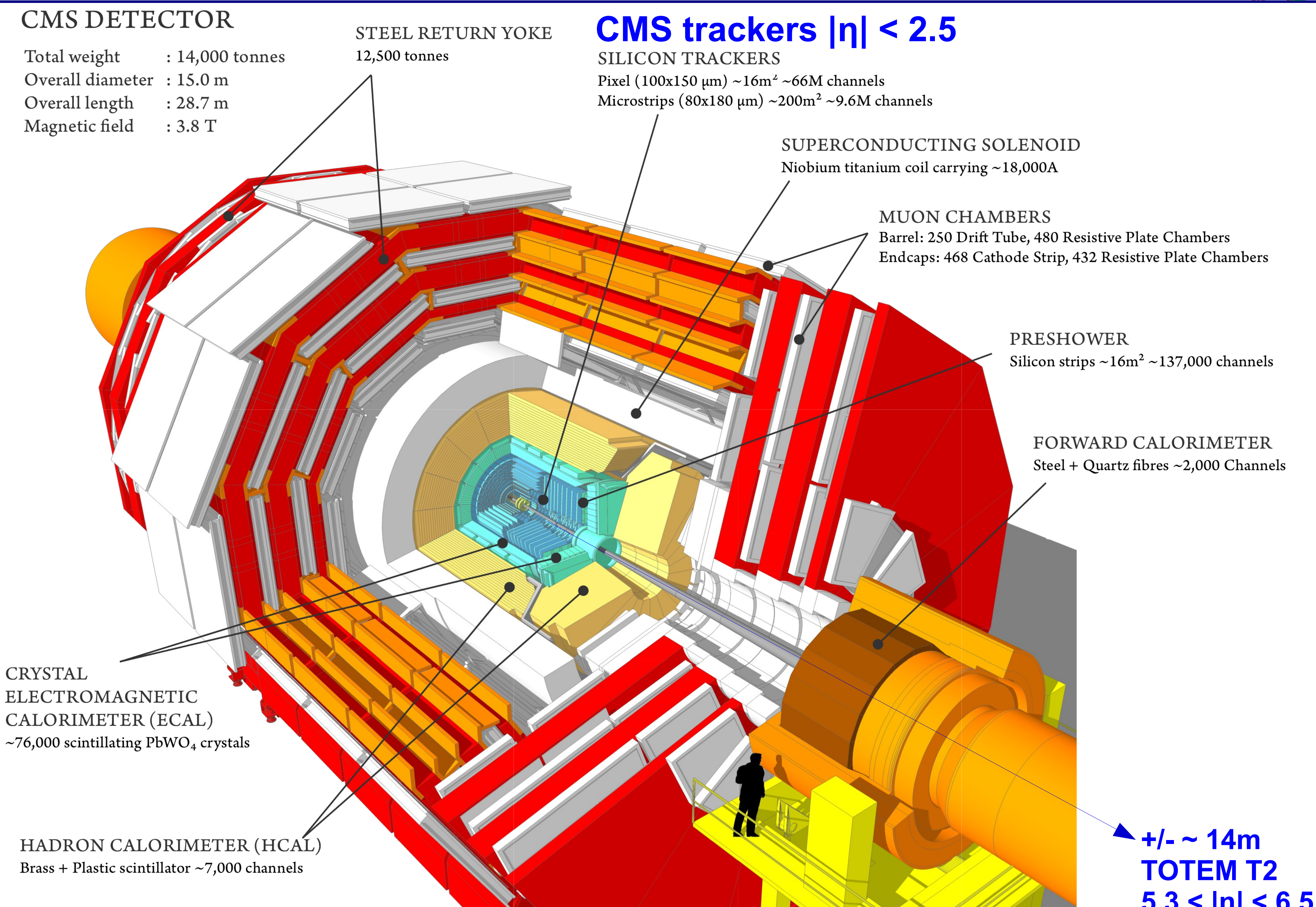
A. Knutsson (Universiteit Antwerpen)
on behalf of CMS and TOTEM Collaboration

Lowx 2014, Kyoto, 17 – 21 June 2014

Introduction
Measurement of dN/dη
Measurement of leading tracks and jets at low Pt
Summary

CMS-FSQ-12-026, http://arxiv.org/abs/arXiv:1405.0722 (submitted to EPJC)
CMS-PAS-FSQ-12-032, http://cds.cern.ch/record/1700112 (prelim.)

CMS and T2 Detectors



CMS and T2 Common Run

Data

- Common CMS+TOTEM data taking 2012. Run with low pile-up at $\sqrt{s}$ = 8 TeV.
  (μ = 0.04, non standard high β^* = 90m optics configuration.)

- Minimum-Bias events triggered by TOTEM T2:
  at least one track with p_t > 40 MeV in 5.3 < $|\eta|$ < 6.5

Samples defined off-line with primary tracks

- Inclusive sample:
  at least one track with p_t > 40 MeV in 5.3 < $|\eta|$ < 6.5
- Non-single diffraction enhanced:
  at least one track with p_t > 40 MeV in 5.3 < η < 6.5 AND -6.5 < η < -5.3
- Single diffraction enhanced:
  at least one track with p_t > 40 MeV in only 5.3 < η < 6.5 OR only in -6.5 < η < -5.3

Measurements in this talk

- $dN/d\eta$ of charged particles in $|\eta|$<2.2 and 5.3 < $|\eta|$ < 6.4
  Common off-line analysis.

- Integrated normalized cross-sections for leading charged particles and leading charged particle jets at very low pt. ($|\eta|$<2.4)

dN/dη of charged particles

Pseudorapidity distributions of charged particles:

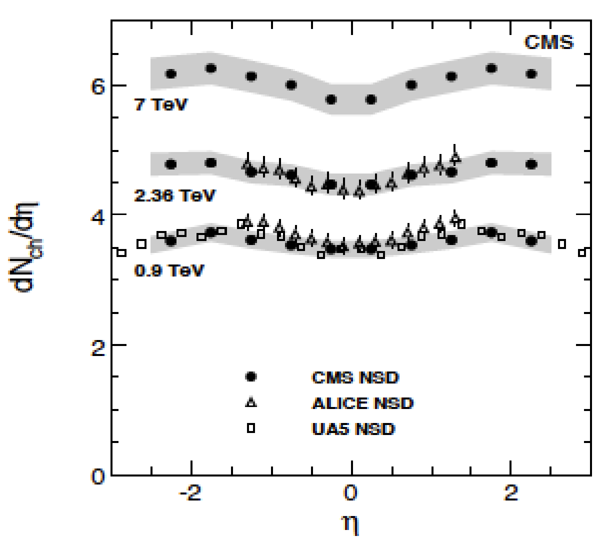
- Essential for understanding hadron production and contributions from soft and hard scattering

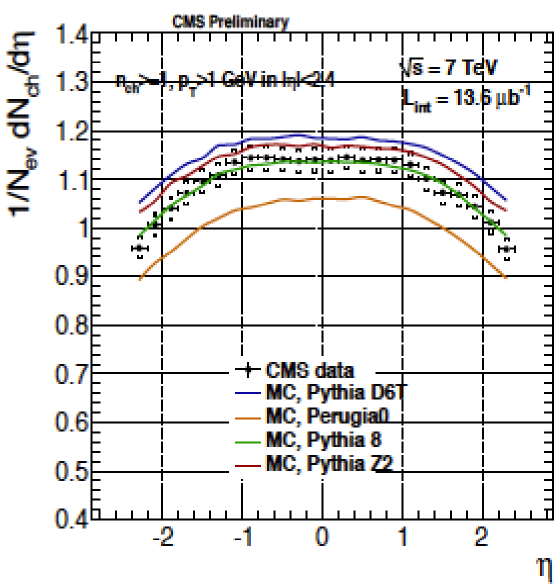
- Bulk of particles from semi-hard (multi)parton interactions → phenomenolocial models and tuning of MC

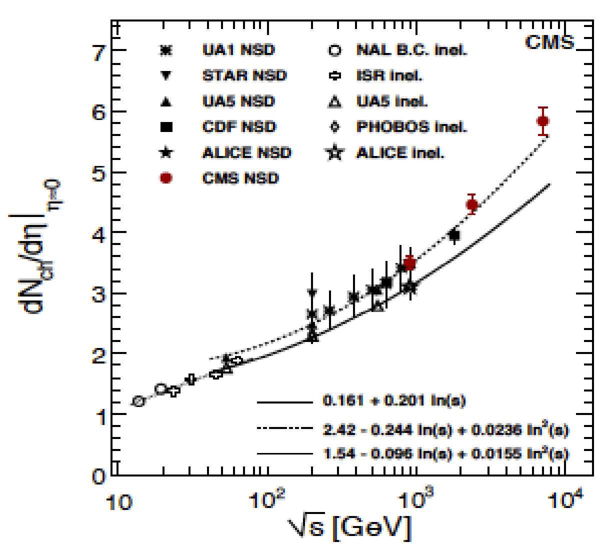
- Measurement in common data taking with CSM+TOTEM at √s=8 TeV:
  tracks with **p_t>0.1 GeV in |η|<2.2** and **p_t>0.04 GeV in 5.3<|η|< 6.4**

- dN/dη in very forward region, earlier explored by TOTEM and LHCb at 7 TeV

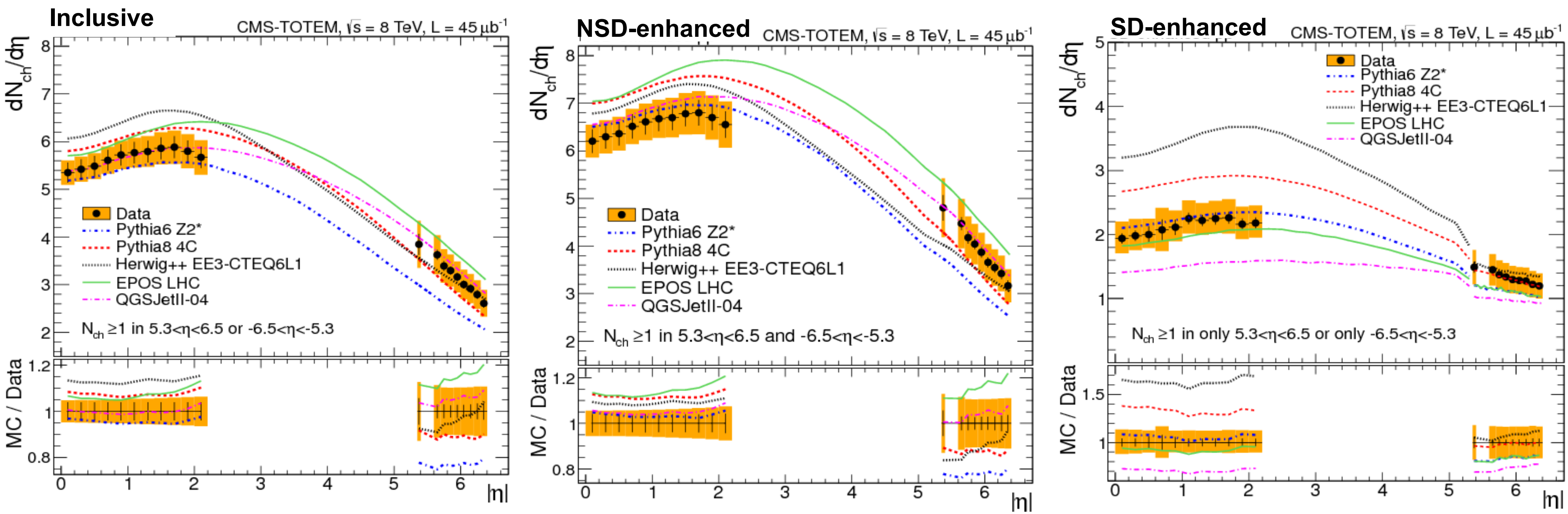
- Complements previous dN/dη measurements in central region made at different √s :







dN/dη results



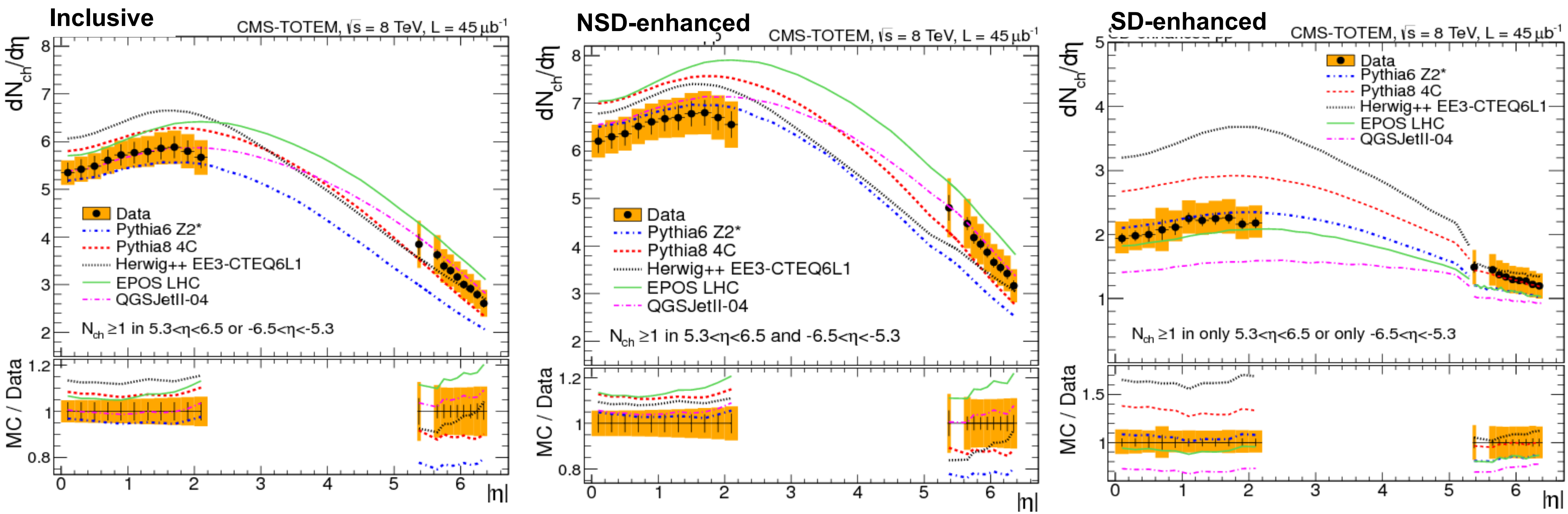
Measurement corrected to stable particle level:

Charged particles with $p_t>0$ in $|\eta|<2.2$ and $5.3<|\eta|< 6.4$

Trigger selection mimicked at stable particle level:

- Inclusive:
  At least one charged particle with $p_t> 0$ in $5.3 < |\eta| < 6.5$
- NSD-enhanced:
  At least one charged particle with $p_t> 0$ in $5.3 < \eta < 6.5$ AND $-6.5 < \eta < -5.3$
- SD-enhanced:
  At least one charged particle with $p_t> 0$ only in $5.3 < \eta < 6.5$ OR only in $-6.5 < \eta < -5.3$

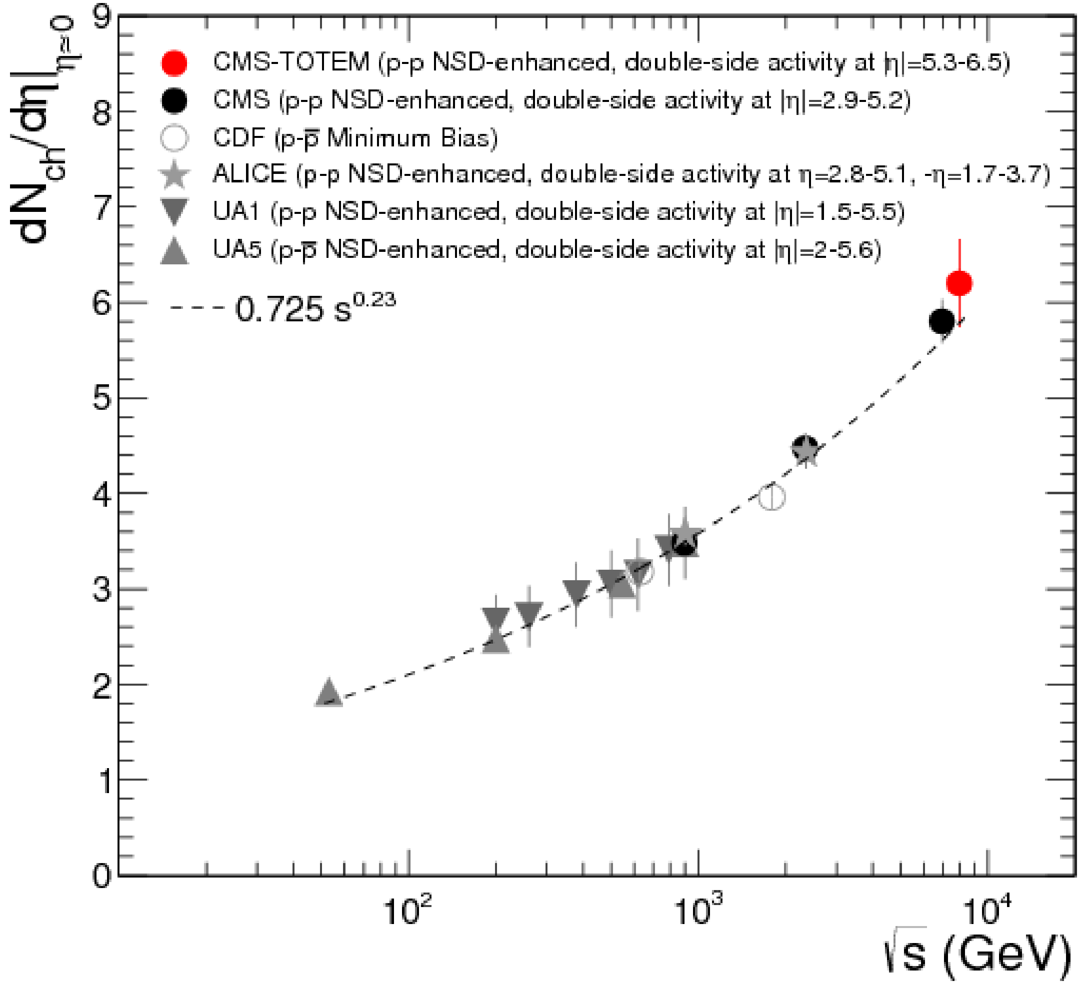
dN/dη results



- Large model sensitivity
- MC description of data varies between different event samples
- Cosmic Ray MC QGSJET describes inclusive and NSD-enhanced over full eta range
  Otherwise no model describes the shape of the eta spectrum.
- SD-enhanced: Large spread between predictions. Pythia6 Z2* describes the data.

dN/dη results

Center of mass energy dependence of $dN_{ch}/d\eta|_{\eta=0}$



- NSD events at √s = 53-8000 GeV
- New result (red bullet) follows power law (~ s^{ε}, ε= 0.23)

Leading tracks and jets

Introduction

Analyses motivated by:

Jet production and the inelastic *pp* cross section at the LHC

A. Grebenyuk[a], F. Hautmann[b], H. Jung[a,c], P. Katsas[a] and A. Knutsson[a]

Abstract

We suggest that, if current measurements of inclusive jet production for central rapidities at the LHC are extended to lower transverse momenta, one could define a visible cross section sensitive to the unitarity bound set by the recent determination of the inelastic proton-proton cross section.

arXiv:1209.6265v1 [hep-ph] 27 Sept 2012

Phys.Rev. D86 (2012) 117501

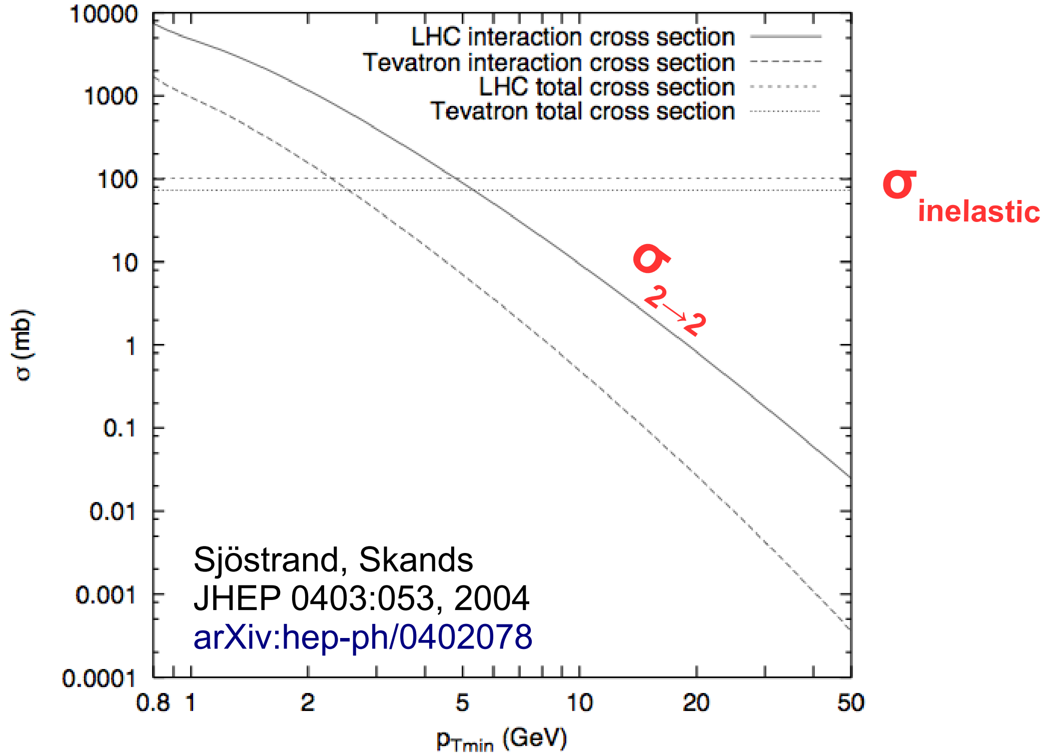
Introduction

- Total cross-section for 2→2 process given by

$$\sigma(p_{T\ min}) = \int_{p_{T\ min}} dp_T^2 \int_{-\infty}^{\infty} dy \frac{d^2\sigma}{dp_T^2\, dy}$$

- Divergent towards low $p_{T,min}$ and eventually the total 2→2 cross-section becomes larger than the total inelastic cross-section.

- At LHC this happens around ~5 GeV at LHC.



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• **Divergent towards low $p_{T,min}$ and eventually the total 2→2 cross-section becomes larger than the total inelastic cross-section.**

• **Thus, in theory, the cross-section needs to be tamed.**

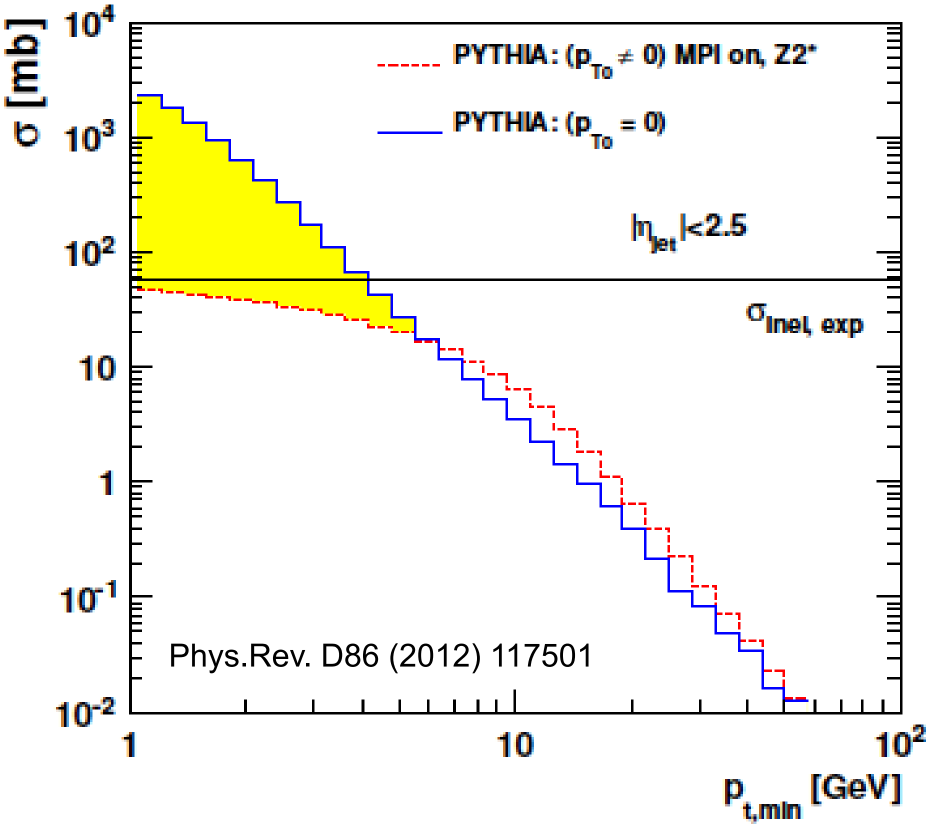
For example, in Pythia, the rise of the 2→2 cross-section is "tamed" by

1. Regularization factor for the cross-section

$$\sigma \to \sigma \times \frac{\alpha_s(p_t + p_{t0})}{\alpha_s(p_t)} \frac{p_t^4}{(p_t^2 + p_{t0}^2)^2}$$

where p_{T0} is determined by tuning to data.

2. MPI: $\langle n_{MPI} \rangle = \sigma_{2\to2}/\sigma_{Total}$



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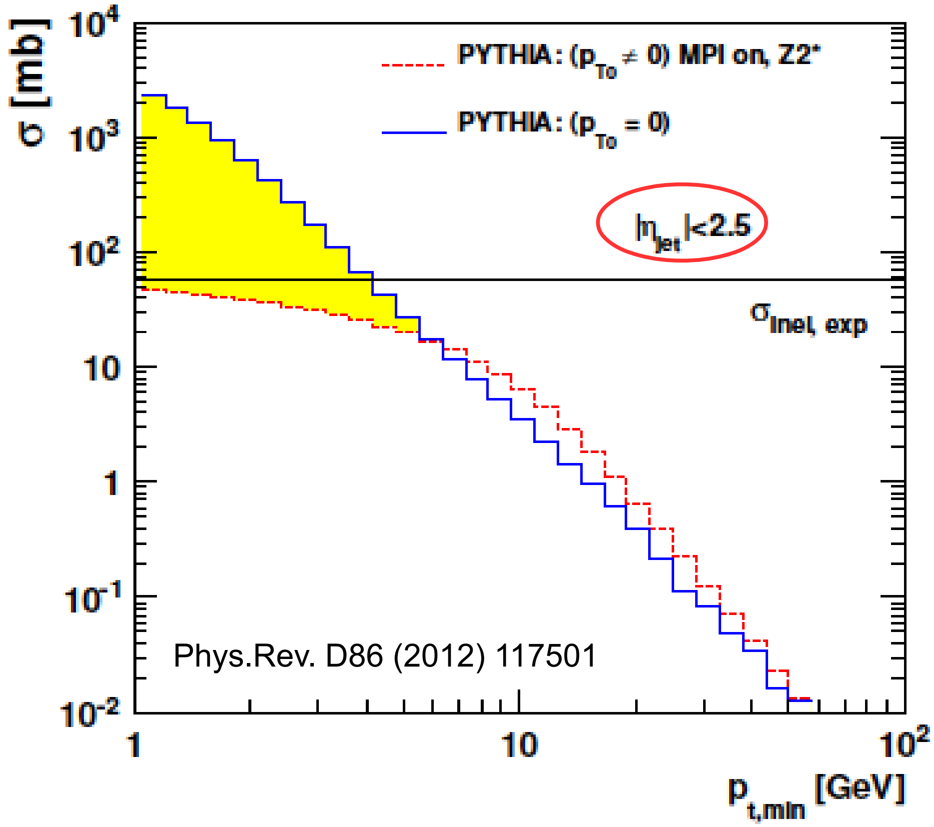
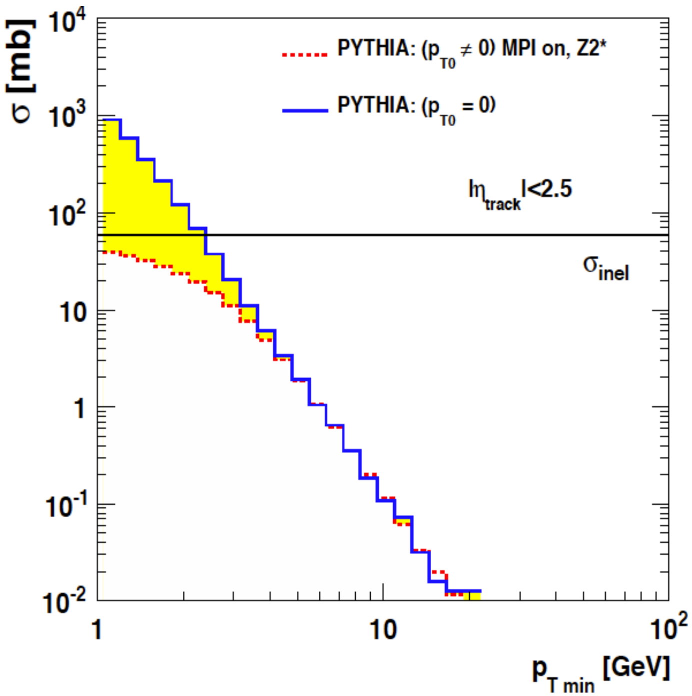
Can be studied in a range accessible by the experiments.



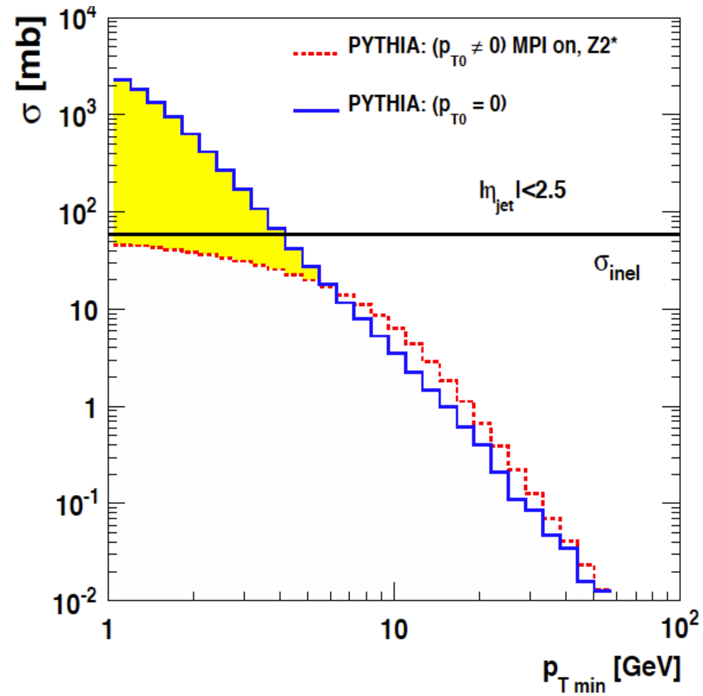
Tracks vs Jets

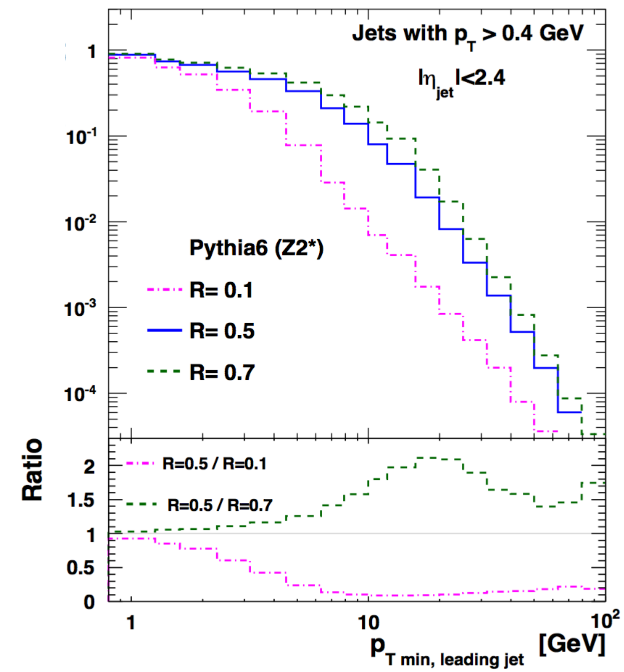
- Measurement possible to do with tracks and track jets.

Leading charged particles



Leading charged particle jets





- Different shapes of the cross-sections. The jet events are shifted towards higher values. More than just the leading particle clustered in the jet. UE important for the jets.

- When radius parameter in the jet algorithm is decreased the shape of the jet cross-section approaches the leading track cross-section.

Data and selections

- Common CMS+TOTEM data taking. Run with very low pile-up at $\sqrt{s}$ = 8 TeV (2012). (Non standard high β^* = 90m optics configuration.)

- Inclusive MB events triggered by TOTEM T2:
  At least one track with p_t > 40 MeV in $5.3 < |\eta| < 6.5$

- Track selection:
  $|\eta| < 2.4$, $p_t > 0.4$ GeV

→ Measurement of the **normalized integrated *leading track* cross-section.**

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- Track-jets:
  Anti-k_t algorithm. R = 0.5.
  Input: Tracks with $|\eta| < 2.4$ and p_t > 0.4 GeV.
  Jet selection: The leading jet in $|\eta| < 1.9$ with p_t > 1 GeV.

  → Measurement of the **normalized integrated *leading track-jet* cross-section.**

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  → Measurement of the **normalized integrated *leading track-jet* cross-section.**

- *Measurement corrected to stable particle level defined by cuts corresponding to above.*

Measurement

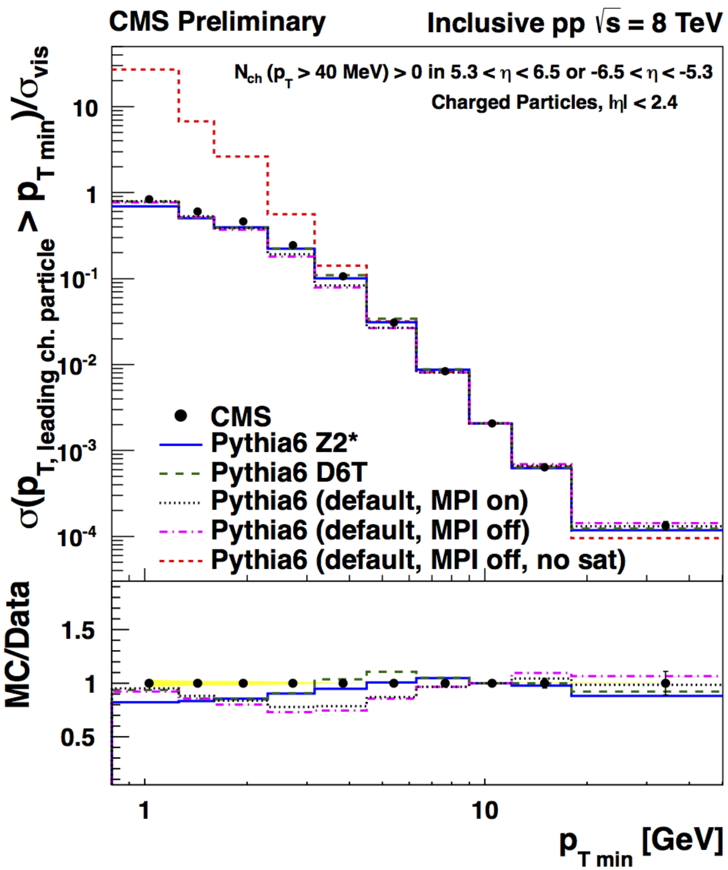
- **Normalized integrated** charged-particle or charged particle jet **event cross-section** as a function of $p_{T,min}$ for events with a leading charged particle (jet) with $p_T > p_{T,min}$.

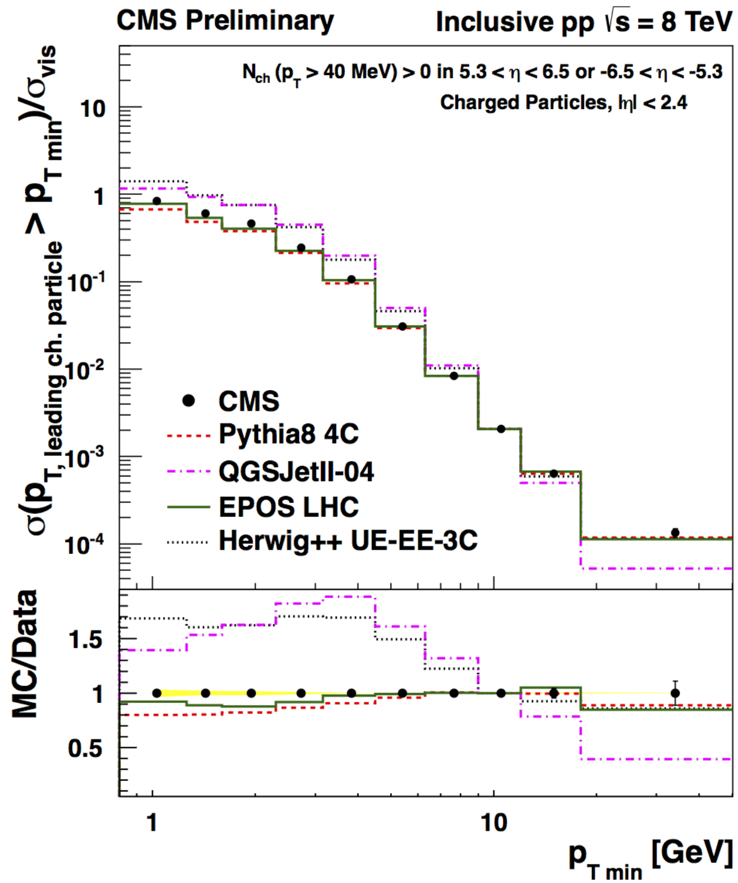
$$D(p_{\mathrm{T,min}}) = \frac{1}{N_{\mathrm{events}}} \sum_{p_{\mathrm{T,leading}} > p_{\mathrm{T,min}}} \Delta p_{\mathrm{T,\,leading}} \left(\frac{dN_{\mathrm{ch}}}{dp_{\mathrm{T,leading}}} \right)$$

- Measurement to normalized to events (N_{events}) with a leading charged particle with $|\eta|<2.4$ and $p_T > 0.4$ GeV

Results – leading jets and tracks

Normalized Leading Charged Particle Cross-sections

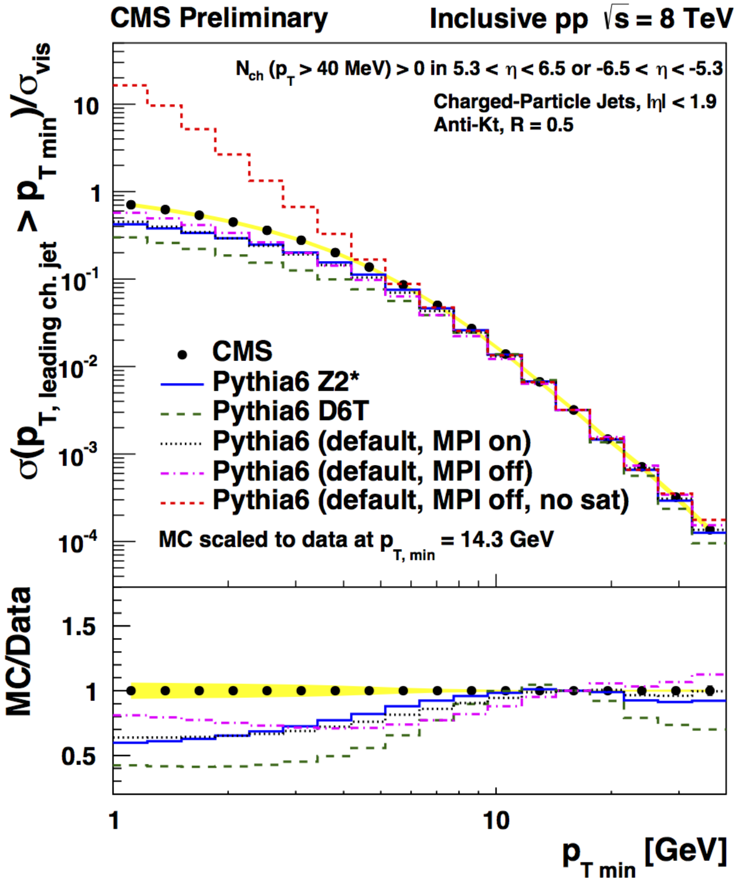


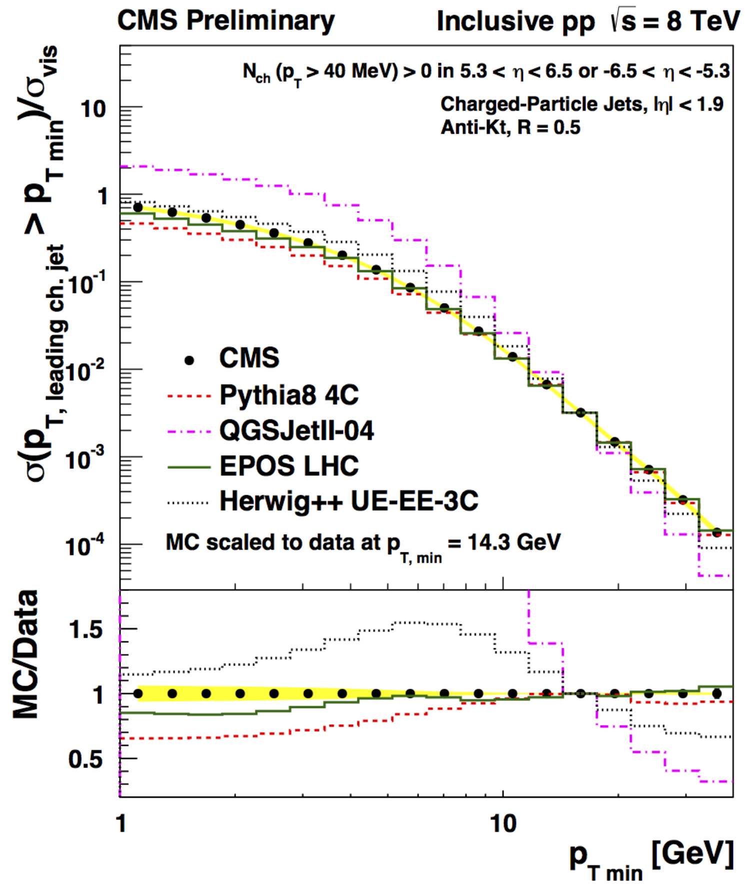


Normalized cross-sections for events with a central leading charged particle with $p_T > p_{T,min}$ as a function $p_{T,min}$.

- Normalized event cross-sections.
  - → No sensitivity to particle multiplicities in events.
  - → Distribution converges to one by construction.

    Looking for effects at low p_T - MC scaled to data at $p_{T,min}$ = 9 GeV.
- Large difference between models. Tune sensitivity.
- Pythia and Herwig do not describe the data.
- Cosmic Ray Monte Carlos: EPOS good. QGSJET fails.



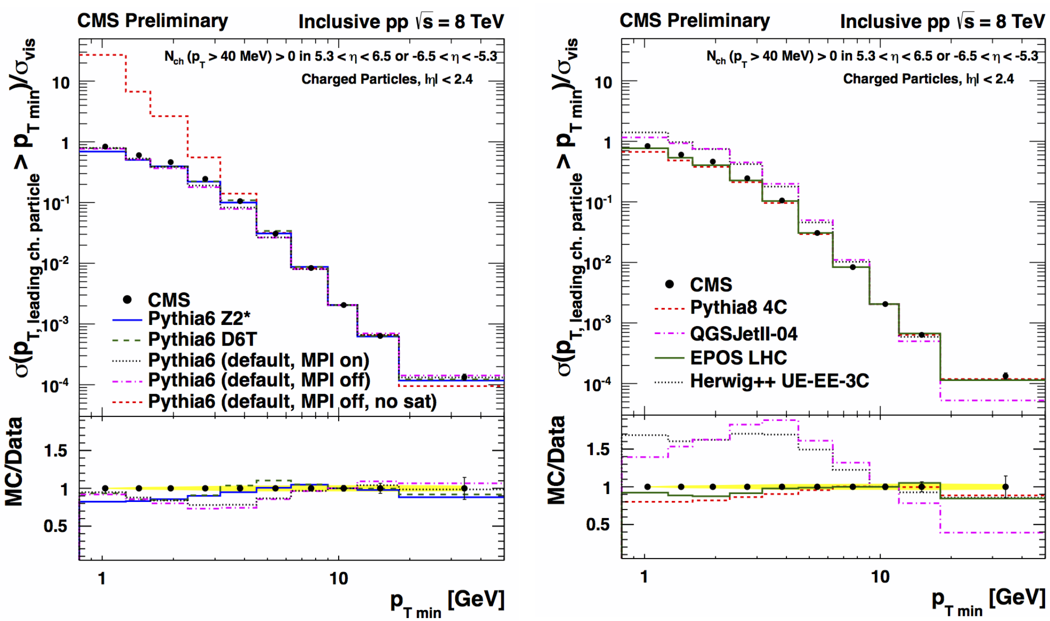


Normalized cross-sections for events with a central leading charged particle with $p_T > p_{T,min}$ as a function $p_{T,min}$.

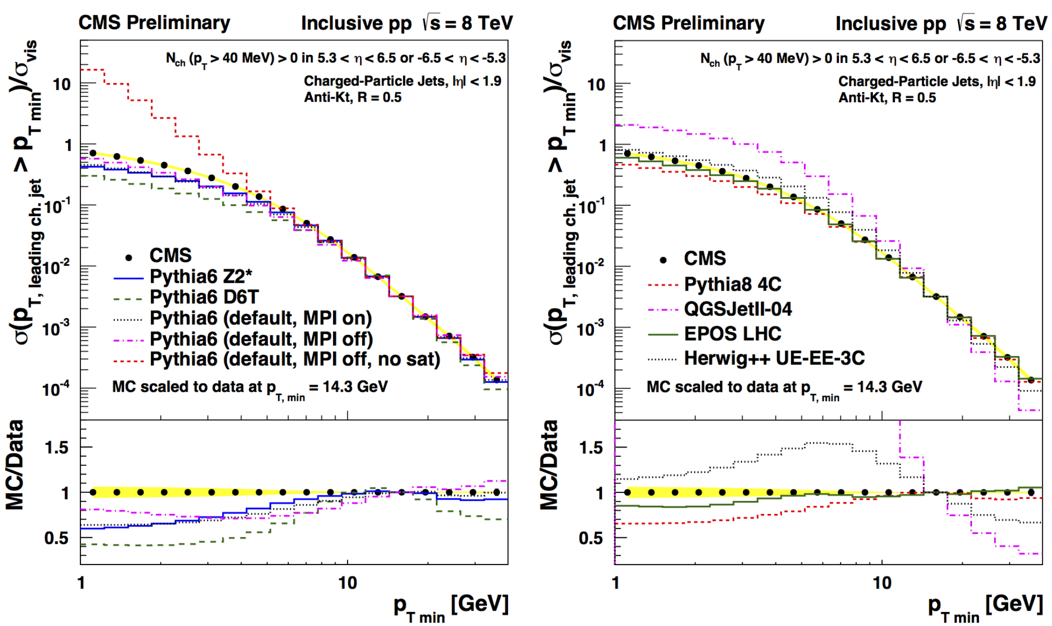
- Normalized event cross-sections.
  - → No sensitivity to jet multiplicities in events.
  - → Distribution converges to one by construction.
    Looking for effects at low p_T - MC scaled to data at $p_{T,min}$ = 14 GeV.
- Larger difference between models. Tune sensitivity.
- Pythia and Herwig do not describe the data.
- Cosmic Ray Monte Carlos: EPOS good. QGSJET fails.

Comparison Track vs Jet measurement

Leading charged particles



Leading charged particle jets



- Different shapes for leading jets and leading charged particles.
- More activity than just the leading track clustered in the jet. Thus, UE important for the jets.

  → The p_t is shifted towards higher value in jets compared to leading charged particles.

  → Larger spread between different MC predictions in the jet measurement.

  → Larger deviation between MC and data for the jets compared to the charged particles.

  → MC somewhat better description of the charge particle measurement.

Summary

Charged particle eta distributions:

- dN/dη for inclusive, NSD- and SD-enhanced events, over large η range.
- Measurement input to test and tuning of MC models.
- No model describes full η spectrum in all samples.
  Cosmic ray MC QGSJET describes inclusive and NSD sample. Pythia6 Z2* describes SD.

Normalized integrated event cross-sections for leading charged particles and jets:

- The integrated distributions probe the transition from the pertubative to the non-pertubative regions, and are sensitive to the “taming of the cross-section”.
- Difference between the charge particle and the charge particle jet measurement. Jets larger sensitivity to MPI and UE.
- The measurements are in general not well describe by the models. Only EPOS provides a decent description of the data.

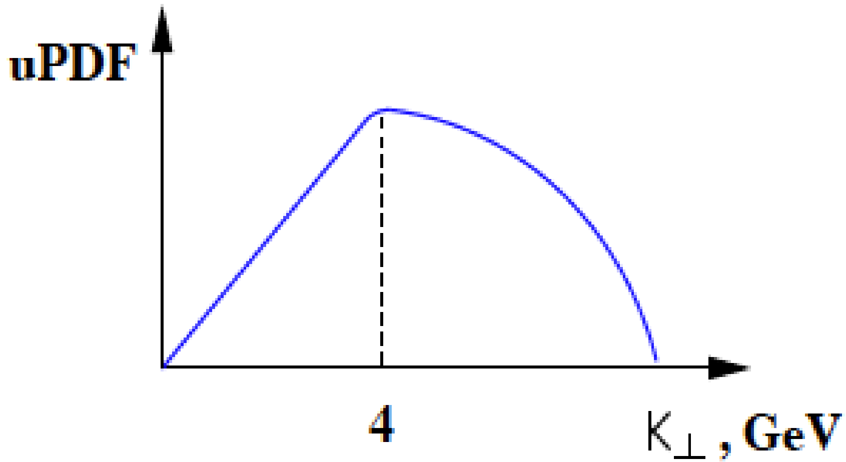
BACKUP

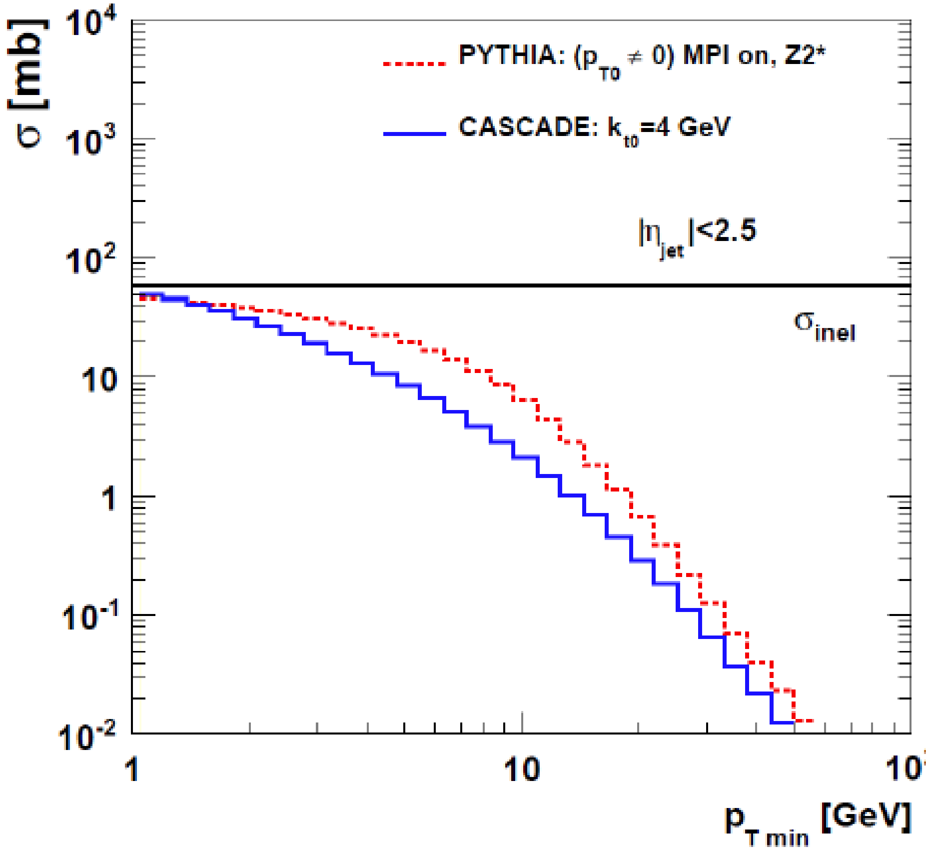
Sensitivity to saturation

- Tame the divergence by using saturated PDFs.

- CASCADE. KT-factorization based MC generator.
  Low-pT behavior from:
  - ME dependence (low-p_T rise from k_T << p_T, slower rise for k_T)
  - unintegrated PDF $f(x,k_T,\mu)$ - suppression of uPDF at low k_T

Modification of uPDF such that it goes to 0 for kT → 0.





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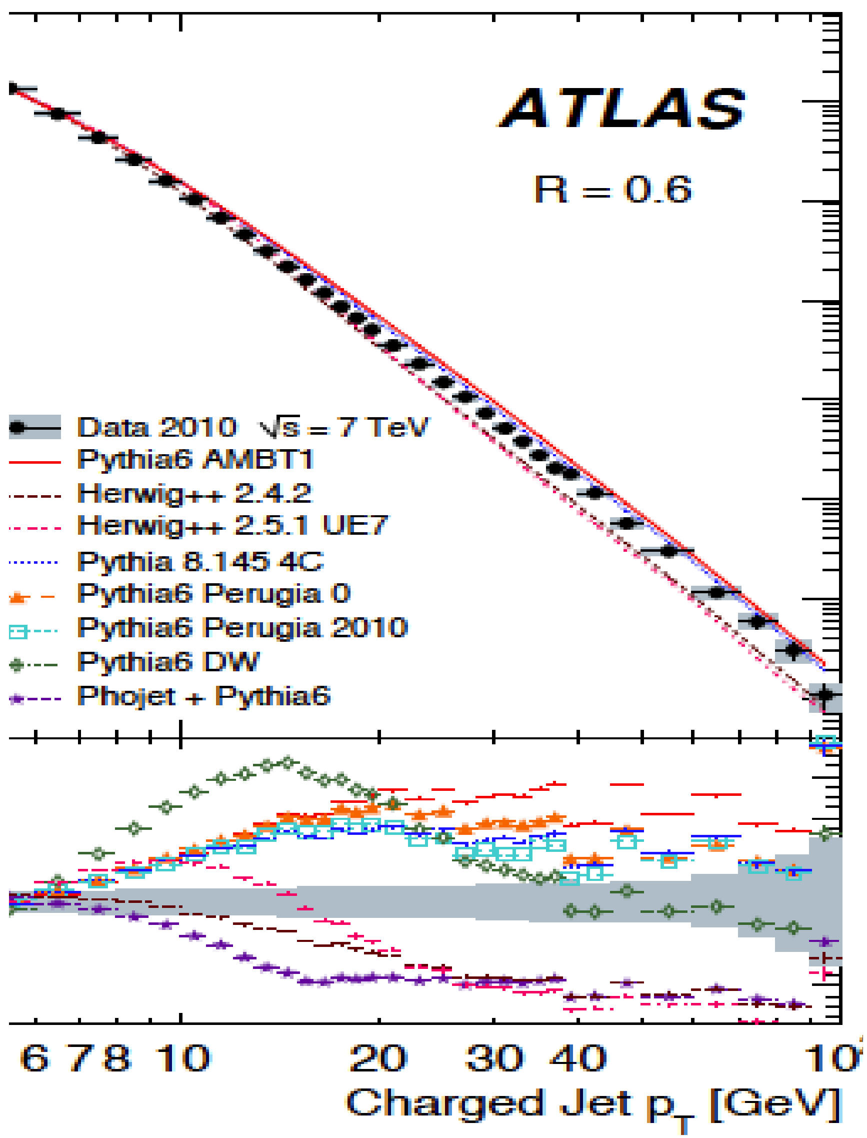

Cross-section of jets with

p_T > 4 GeV

|η| < 1.9

MC area normalised to data.

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Data well described at low pt.

MC fails at high pt.