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ON BEHALF OF THE ATLAS AND CMS COLLABORATIONS

SOFT QCD AT ATLAS AND CMS

28th Rencontres de Blois

IN 15 MINUTES . . .

- Inelastic cross section
  - ATLAS and CMS at 13 TeV
- Minimum bias
  - Charged Particle distributions at 13 TeV from CMS and ATLAS
  - Energy Flow at 13 TeV from CMS
- Underlying event
  - Event shapes at 7 TeV from ATLAS

Compact Muon Solenoid experiment at CERN's LHC

CMS

ATLAS EXPERIMENT

TOTAL INELASTIC CROSS SECTION

- Non – Perturbative – cannot be calculated
  - Important to constrain phenomenological models
  - used to estimate pile-up
- ATLAS and CMS measure a fiducial cross sections first and then correct to the total.
  - The fiducial volume is defined by the total mass of particles measured on either side of the largest rapidity gap (M_X) and $\sqrt{s}$
    - $\xi = \frac{{M_X}^2}{s}$
  - Kinematically limited to $M_X > m_p$ ($\xi > 6 \times 10^{-9}$)
  - Fiducial limit is approximately $M_X > 13\ m_p$ ($\xi > 10^{-6}$)

ATLAS EXPERIMENT

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INELASTIC CROSS SECTION AT ATLAS

ATLAS-CONF-2015-038

- Event Selection election: 2 hits in Minimum Bias Trigger Scintillator (MBTS) counters

- Corrections and systematics are evaluated using Pythia 8, EPOS LHC and QGSJET-II

- Allows for variations in the diffractive model

- Comparison between inclusive and single sided event selections are used to constrain the diffractive component

ATLAS EXPERIMENT

INELASTIC CROSS SECTION AT CMS

CMS-PAS-FSQ-15-005

- 2 Fiducial regions
  - Hadronic Forward Calorimeters (HF) Only
    - $3.0 < |\eta| < 5.2$
  - Can add asymmetric region $-6.6 < \eta < -5.2$
    - CASTOR (B = 0T)
    - extends fiducial region down to $M_X > 4.1\ m_p$ ($\xi > 10^{-6}$)
- Pythia 6 and 8 used with a variety of models (and tunes)
- E > 5GeV in either of the HF, or Castor (if included)

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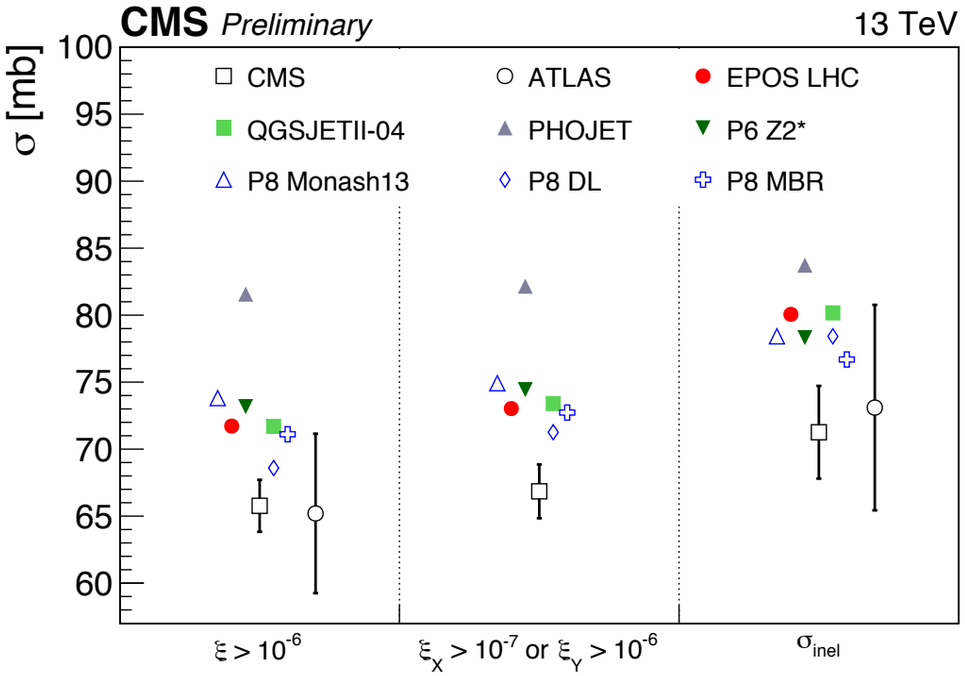
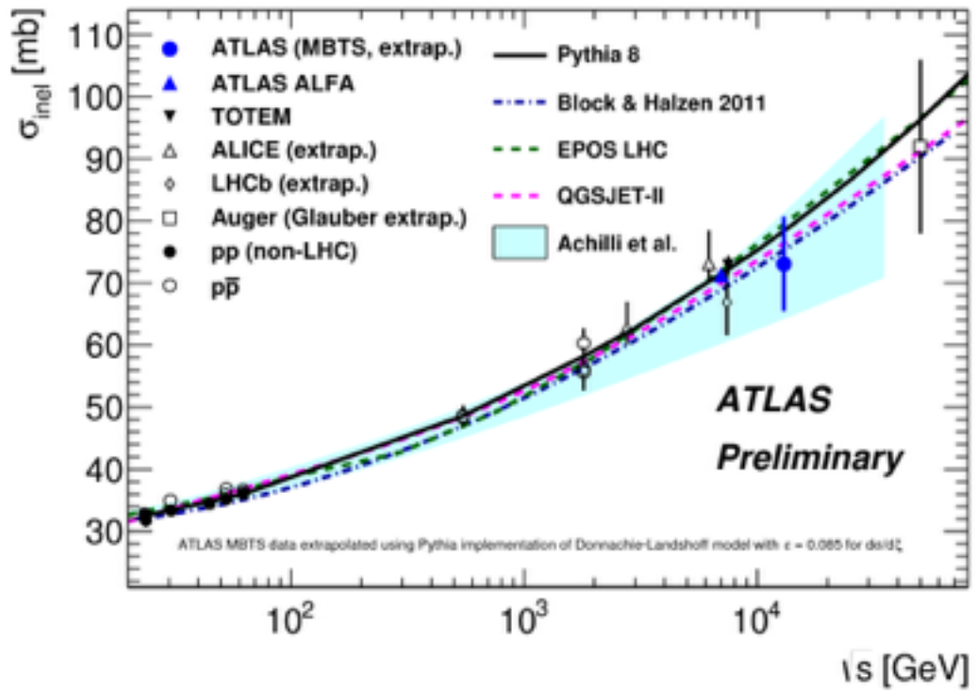
RESULTS

ATLAS and CMS measurements show good agreement,

phenomenological models over predict the value





CMS fiducial: σ = 65.77 ± 0.03 (stat.) ± 0.76 (sys.) ± 1.78 (lum.) mb

CMS (with CASTOR) fiducial: σ = = 66.85 ± 0.06 (stat.) ± 0.44 (sys.) ± 1.96 (lum.) mb

CMS total: σ = 71.26 ± 0.06 (stat.) ± 0.47 (sys.) ± 2.09 (lum.) ± 2.72 (ext.) mb

ATLAS fiducial: σ =65.2 ± 0.8 (exp.) ± 5.9 (lum.) mb

ATLAS total: σ =73.1 ± 0.9 (exp.) ± 6.6 (lum.) ± 3.8 (extr.) mb

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ATLAS EXPERIMENT

MINIMUM BIAS – CHARGED PARTICLE DISTRIBUTIONS

- probes the transition between perturbative and non-perturbative calculations
  - non-perturbative at low p_T, perturbative and high p_T
- Often used to tune free parameters in models.
  - used to validate model of pile-up simulation

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ATLAS EXPERIMENT

CMS CHARGED PARTICLE RAPIDITY DISTRIBUTIONS

CMS-PAS-FSQ-15-008

- 3.9 M zero-bias events, $\langle\mu\rangle = 1.3$
- Selection criteria:
  - one primary vertex, ($|z| < 15$ cm, 2 tracks, $d_0 < 0.2$cm)
  - Track selection: $p_T > 0.5$ GeV, $|\eta| < 2.4$
- Correction from Detector Level to Stable Particle Level done in categories defined by energy (or lack thereof) in the HF
  - SD, NSD, inelastic-enhanced
  - inclusive region ignores input from HF
- Analysis corrections based on PYTHIA8 CUETP8M1 and EPOS LHC

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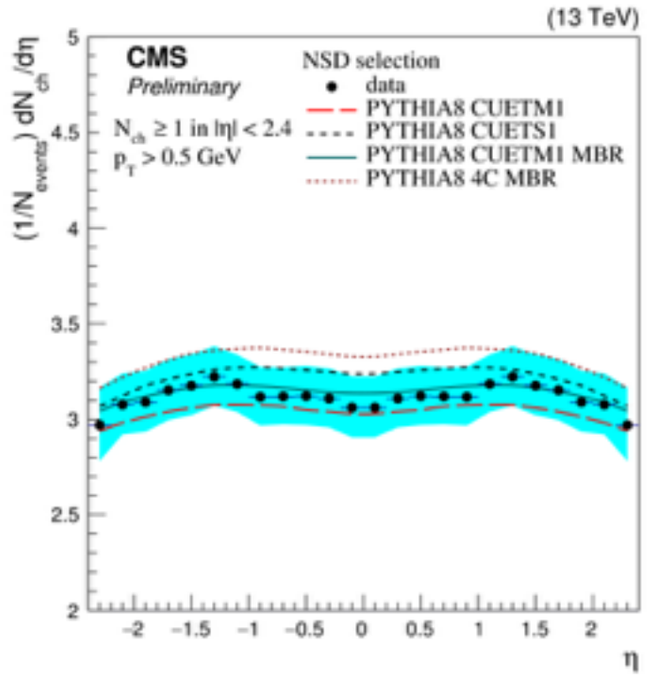
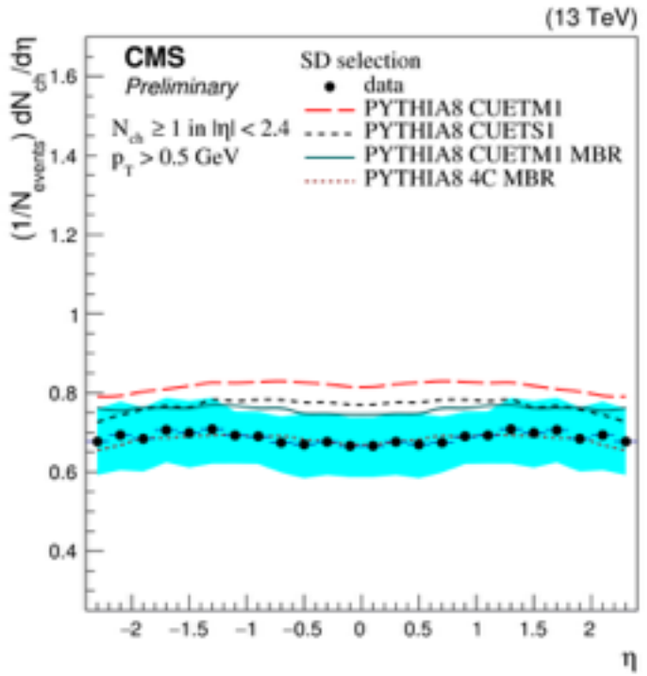
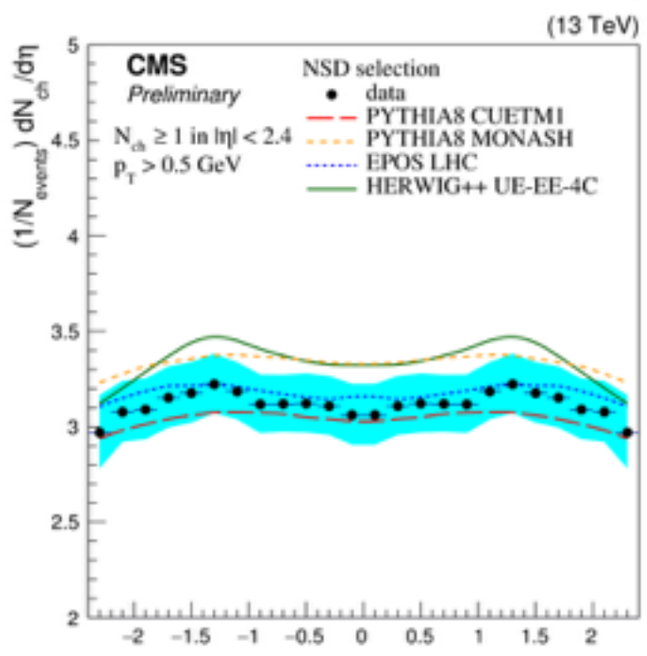
COMPARISONS BY CLASSIFICATION

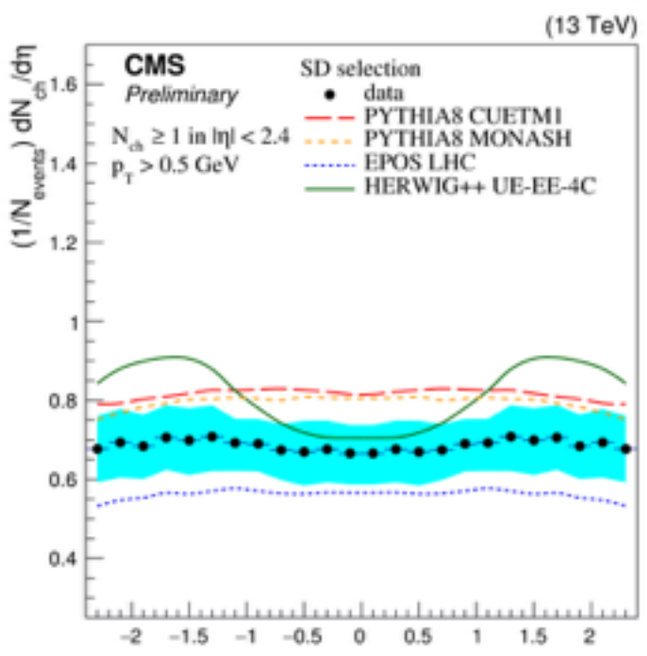
CMS-PAS-FSQ-15-008

- NSD Selection:
- Good Description:
  - EPOS
  - Pythia8
    - CUETM1









- SD Selection best described by:
  - Pythia8 MBR 4C
- Herwig does poorly

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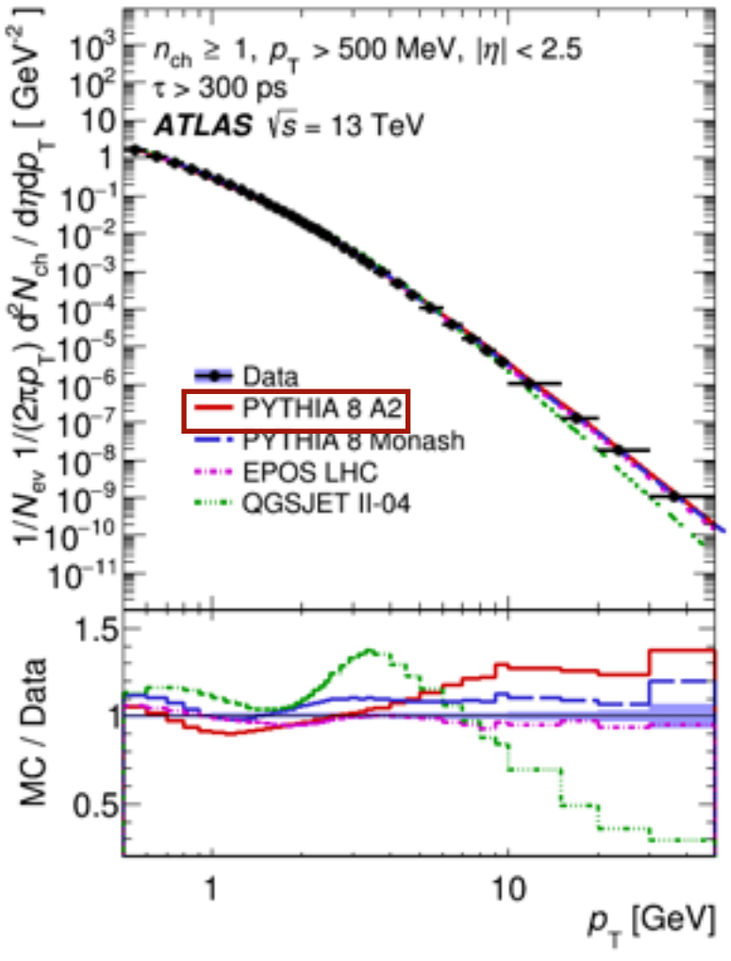
ATLAS CHARGED PARTICLE RAPIDITY DISTRIBUTIONS

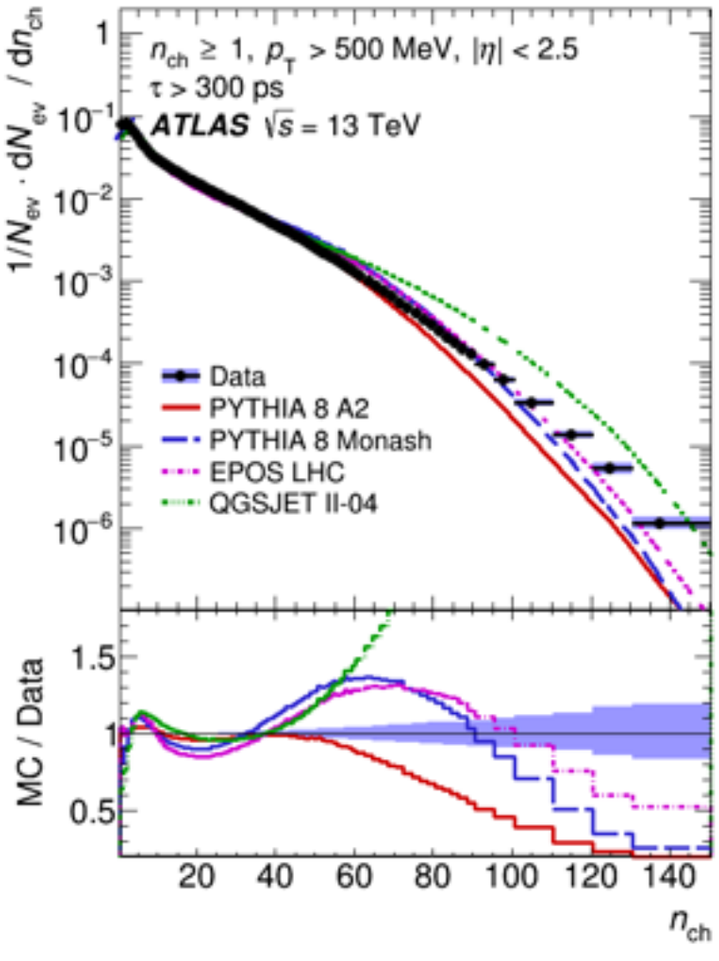
Physics Letters B (2016), Vol. 758, pp. 67-88

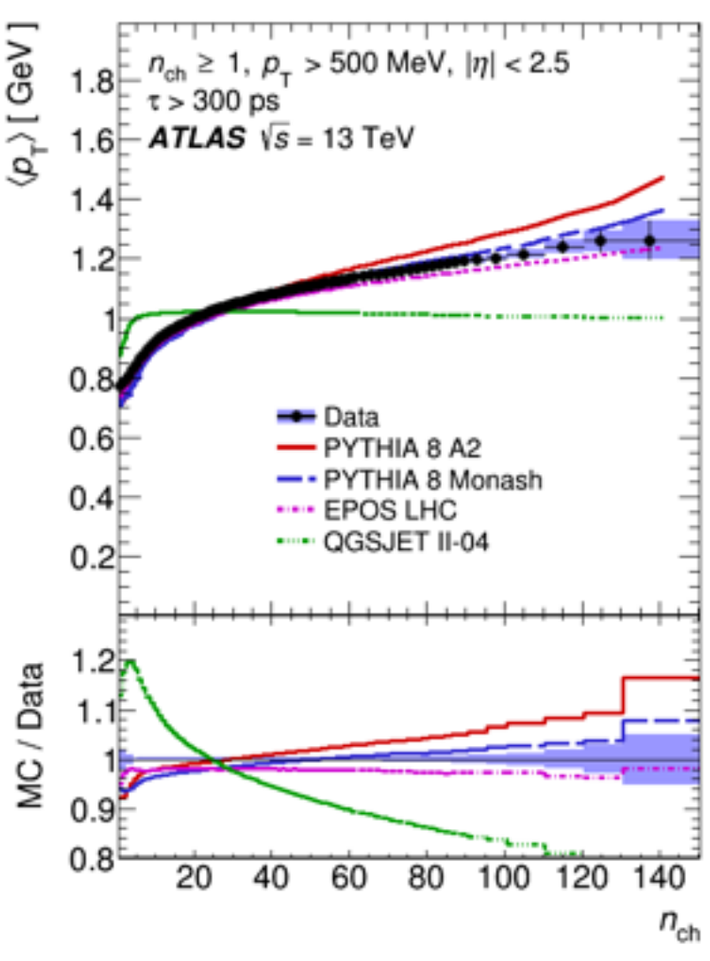
- 170 μb^{-1} with low beam currents , $<\mu> = 0.005$
- Selection Criteria:
  - Track selection:
    - $p_T > 0.5$ GeV, $|\eta| < 2.5$, 1 primary vertex [2 tracks ($p_T > 0.1$ GeV)]
- Bayesian unfolding to get the true p_T distribution
- Bayesian unfolding from N_{Track} to $N_{particle}$
- Dominant Uncertainty is from non-closure of unfolding

ATLAS EXPERIMENT

ATLAS CHARGED PARTICLE DISTRIBUTIONS

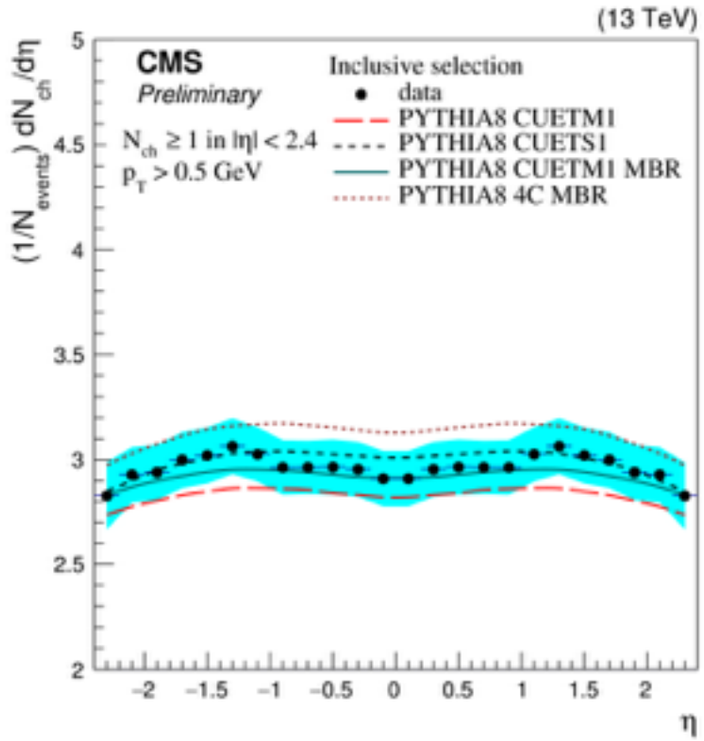


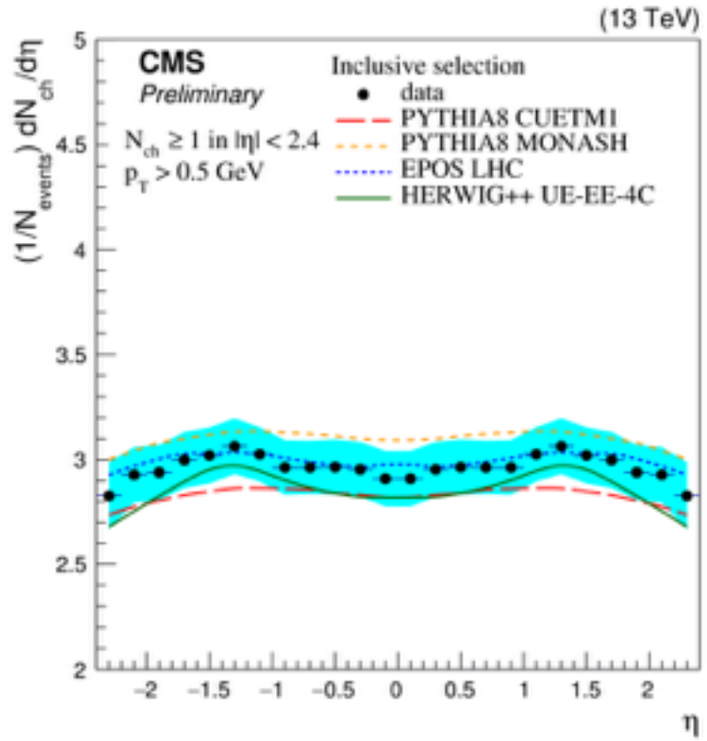


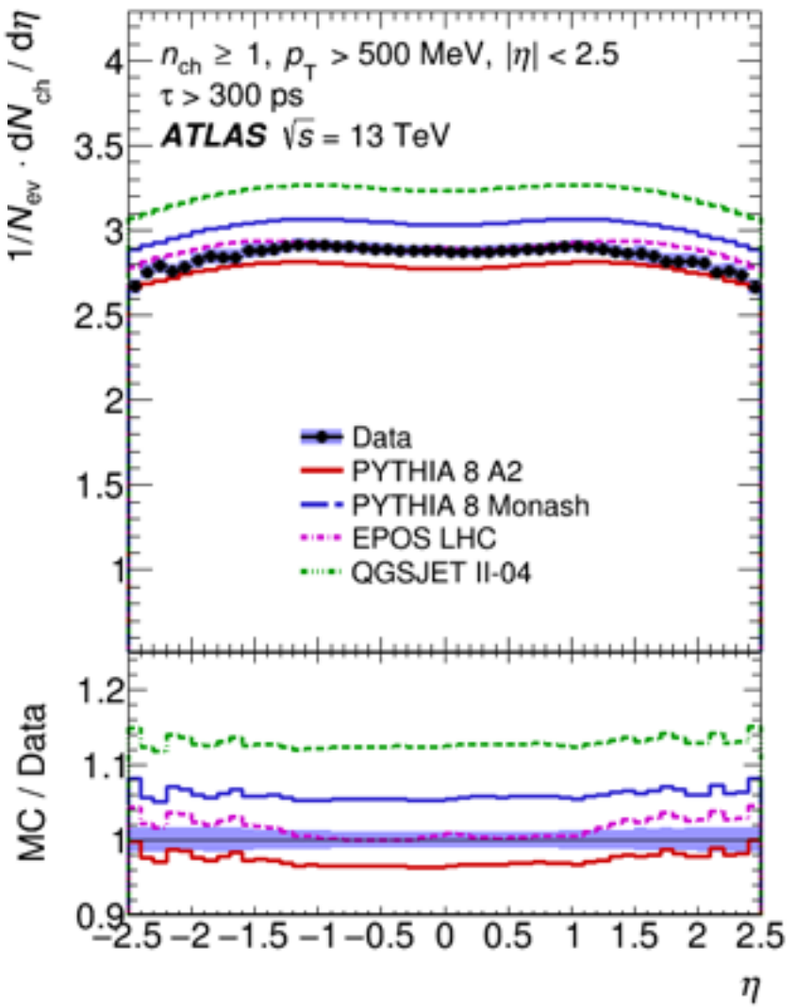


- EPOS-LHC does consistently better,
- QGSJET is the most systematically different

CHARGED PARTICLE RAPIDITY DISTRIBUTIONS: COMPARING ATLAS AND CMS







CMS and ATLAS distributions agree and are best reproduced by EPOS LHC

HERWIG does a better job with the inclusive samples

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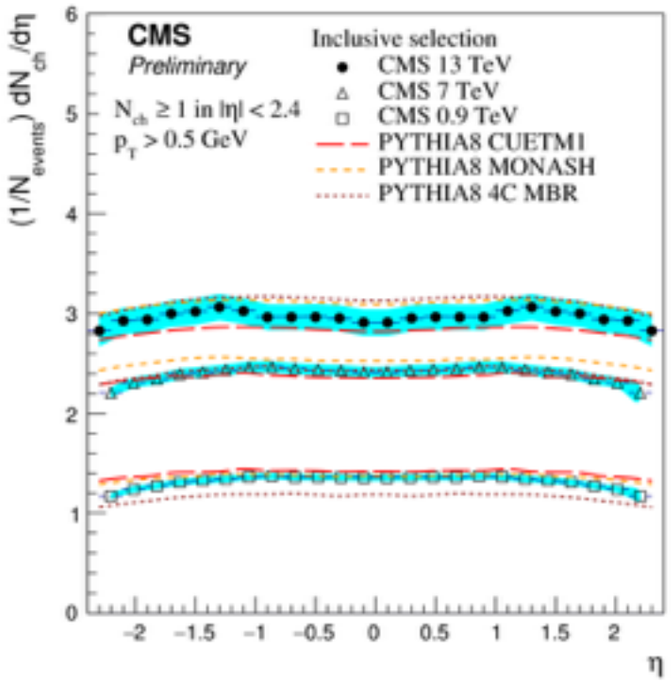
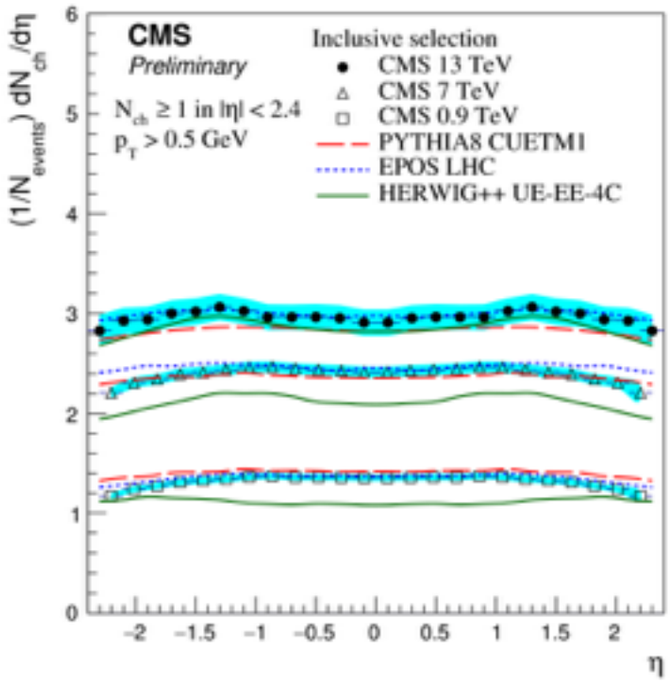
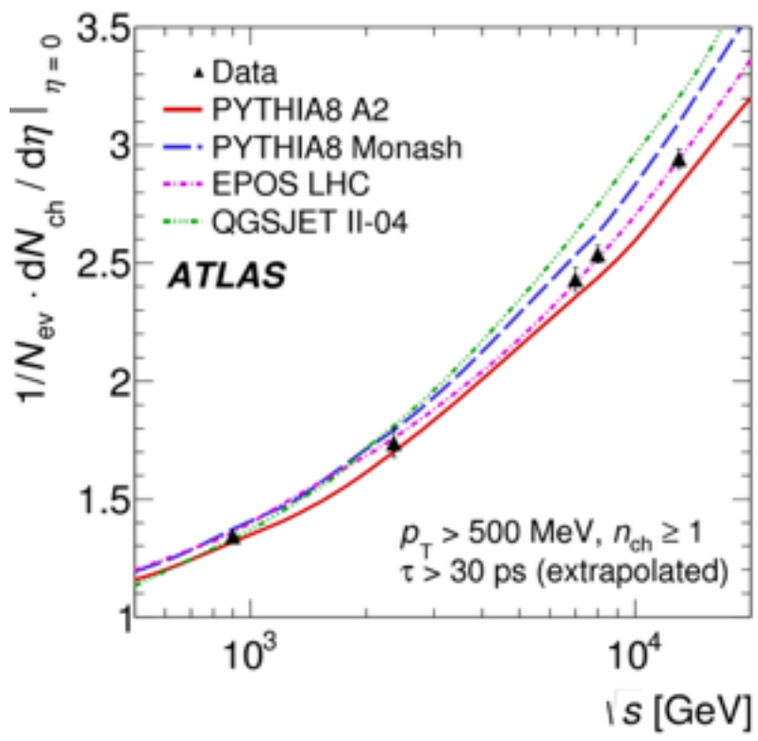
ATLAS EXPERIMENT

ENERGY DEPENDANCE







Pythia under predicts the distributions as the energy increases.

EPOS does a good job across the range of LHC energies

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ATLAS EXPERIMENT

PSEUDO RAPIDITY DEPENDANCE ON ENERGY FLOW

CMS-PAS-FSQ-15-006

- 0.06 nb^{-1}, with $0.05 < \langle\mu\rangle < 1.5$
- Calorimeter based energy flow at $3.15 < |\eta| < 6.6$
- Study of beam fragmentation
  - important information about energy in the forward direction
    - reflected in MC $\langle\mu\rangle$ reweighing
- Two Regions
  - Soft inclusive (activity on both sides $E_{Tower} > 4$ GeV) and
  - NSD enhanced (activity on only one side $E_{Tower} > 5$ GeV)
- Correction to particle level calculated as average of:
  - PYTHIA8 tune MONASH 2013,
  - PYTHIA8 tune 4C with MBR model,
  - EPOS-LHC and QGSJETII.4

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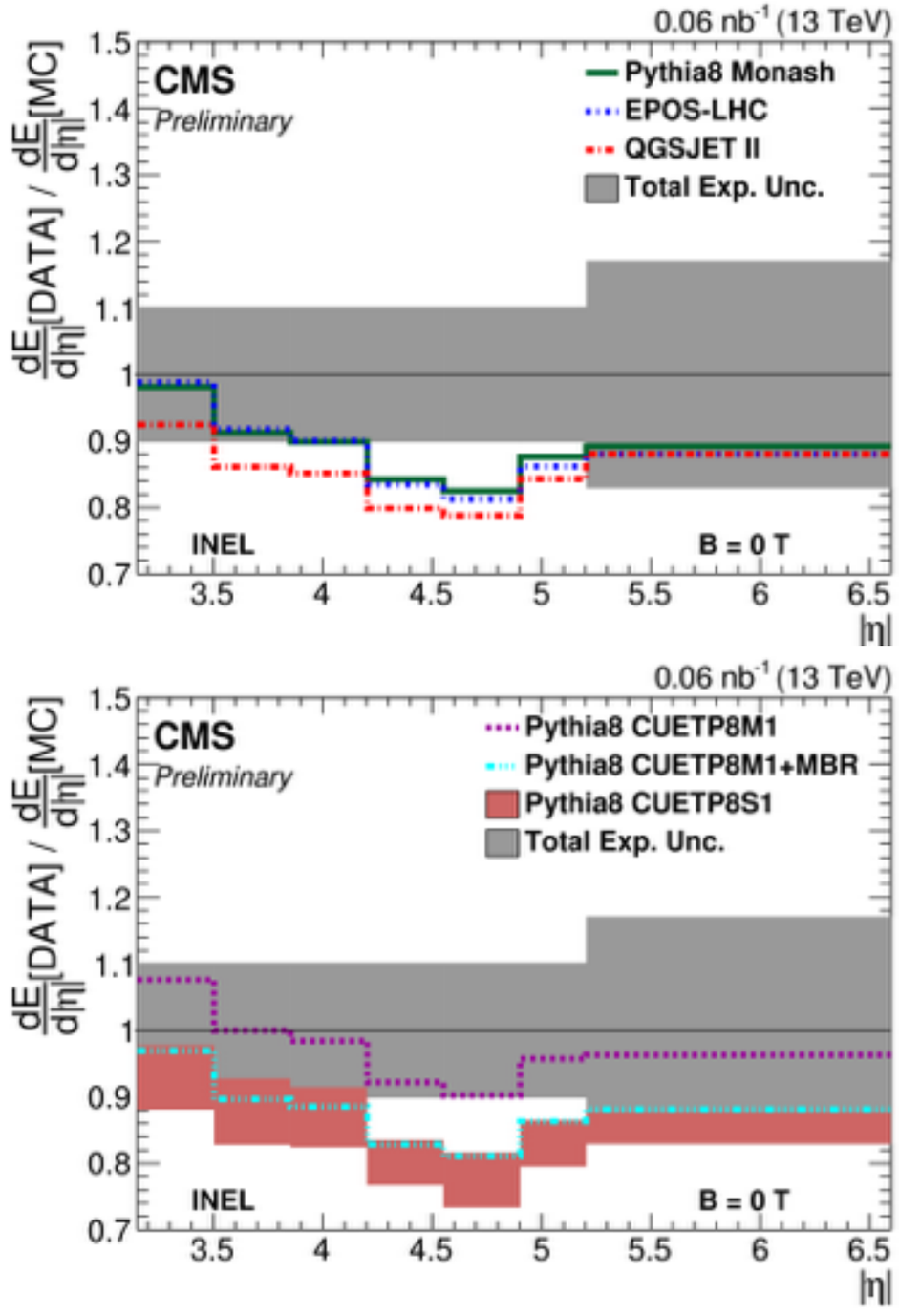
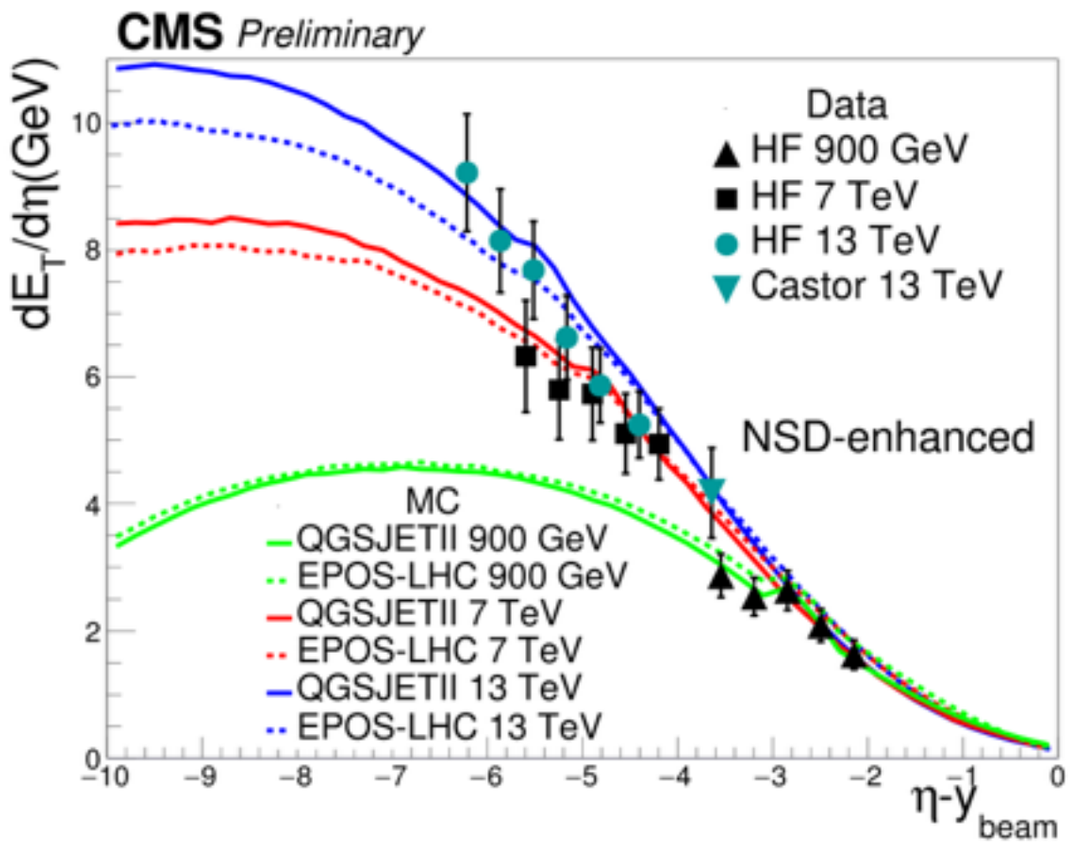
PSEUDO RAPIDITY DEPENDANCE ON ENERGY FLOW

CMS-PAS-FSQ-15-006





Data Best Described by Pythia8 CUETP8M1

in the pre-CASTOR bins the agreement degrades as

|η| increases

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ATLAS MEASUREMENT OF EVENT SHAPE OBSERVABLES

ARXIV:1602.08980

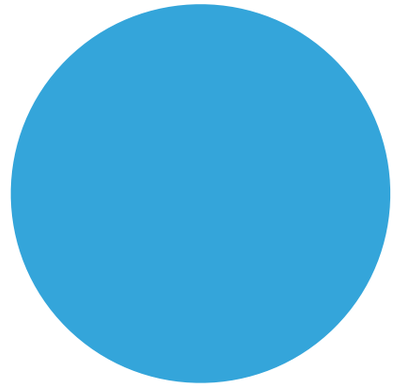
- Characterisation of the underlying event in Z Boson events as a function of the p_T of the Z Boson
  - 1.1 fb^{-1} of low μ data
    - complicated pile–up correction
- Distributions are unfolded based on Bayesian unfolding to account for non-primary particle, detector efficiencies and resolution effect
- Observables in two classes:
  - Not-sensitive to the number of particles
    - Spherocity, Transverse Thrust
  - Explicit dependance on the number of particle
    - n_{CH}

ATLAS EXPERIMENT

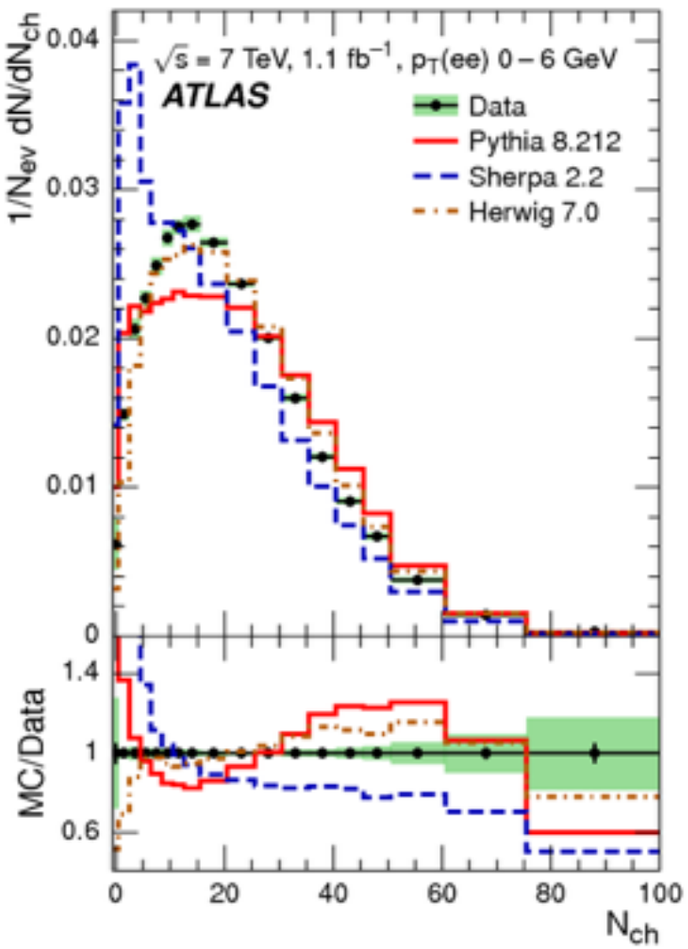
TRANSVERSE THRUST AND SPHEROCITY

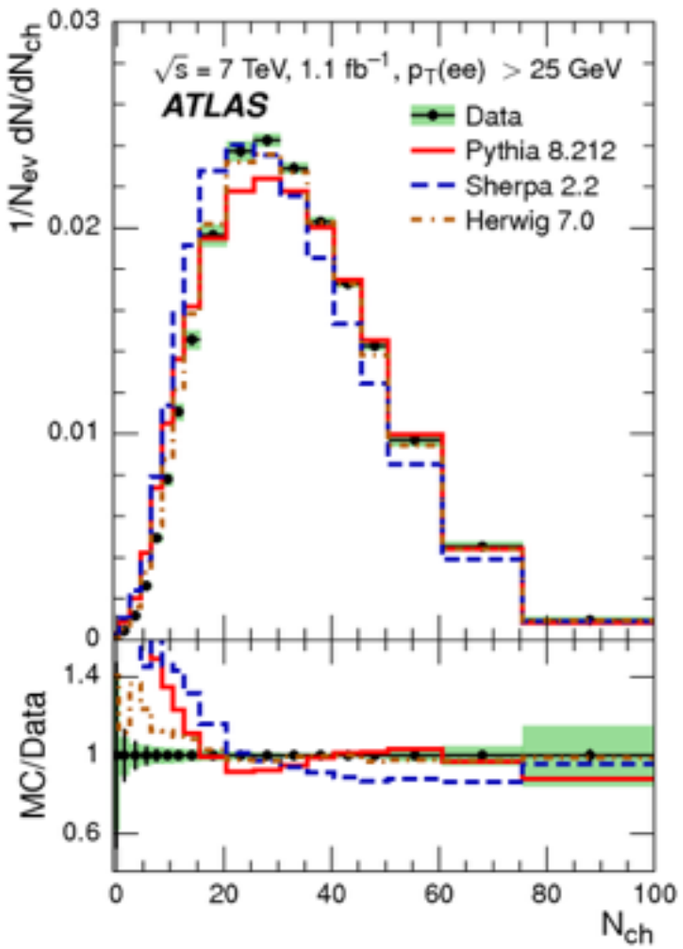
$$0 \quad \mathcal{S} \quad 1$$

$$1 \quad \mathcal{T} \quad 2/\pi$$



CHARGED PARTICLE DISTRIBUTIONS (EXPLICIT N_{PART} DEP)

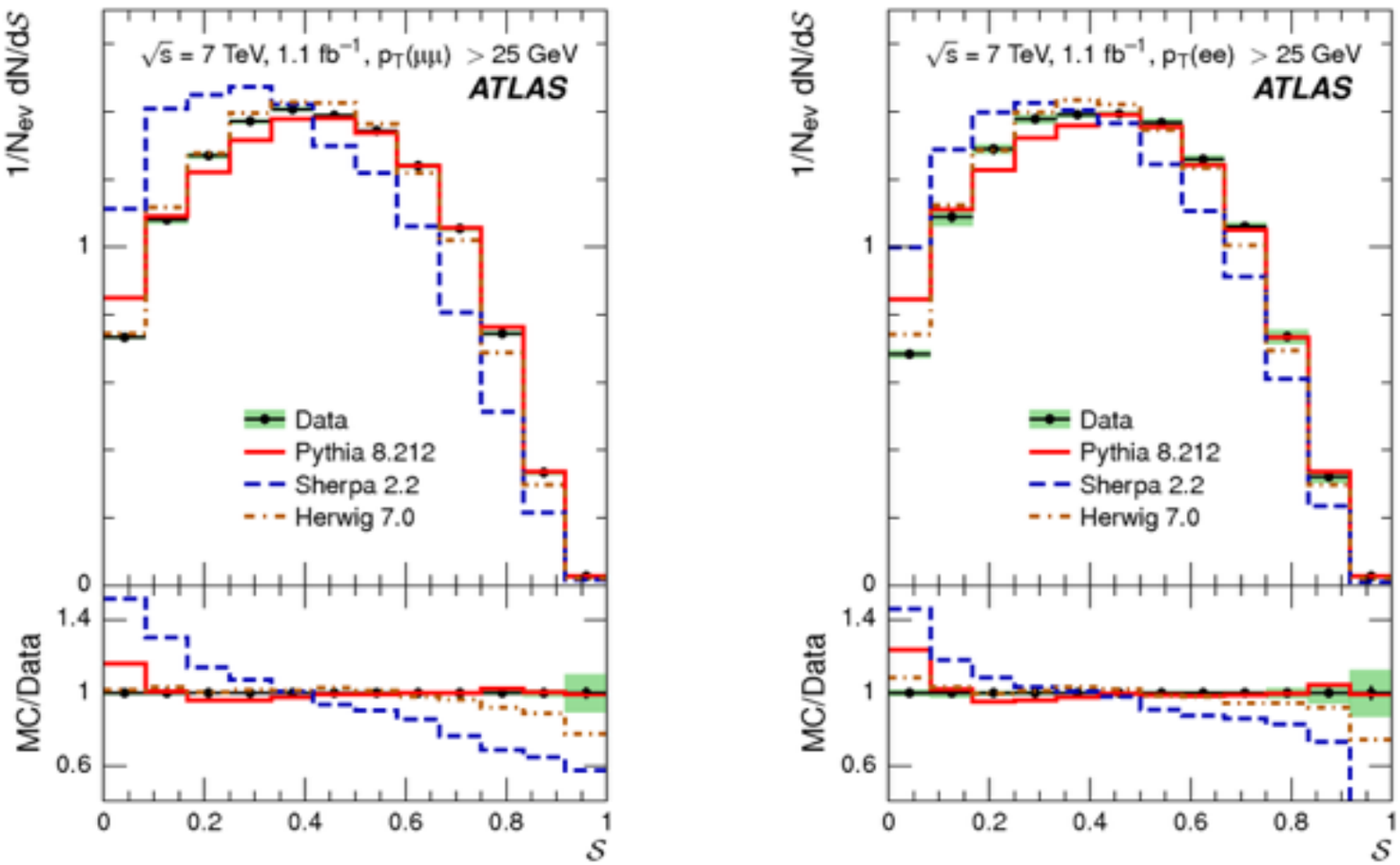




predictions get better with increasing pT

Herwig is consistently better

SPHEROCITY — (NOT SENSITIVE TO N_{PART})



Electron and Muon channels are similar

Pythia is consistently better

ATLAS EXPERIMENT

WHAT HAVE WE LEARNED ?

- ATLAS and CMS are taking slightly different, complementary approaches to the characterisation of the soft QCD regime
  - ATLAS and CMS measurements of these regions agree, and should help to constrain soft QCD models in order to allow for a better description of data at 13 TeV
  - Things that work well at 13 TeV:
    - EPOS – LHC does a good job of the central inclusive region
  - At 7 TeV
    - Pythia 8.212 – Topology based variables
    - Herwig 7.0 – multiplicity based variables

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ATLAS EXPERIMENT

ATLAS AND CMS CONTINUE TO MAKE GOOD PROGRESS TOWARDS A COMPLETE SET OF SOFT QCD MEASUREMENTS

- ATLAS Track-based Minimum Bias at 8 TeV arXiv:1603.02439
- ATLAS Hadronic Event shapes in Z events arXiv:1602.08980
- ATLAS Diffractive Dijet Production Physics Letters B 754 (2016), 214–234
- ATLAS Exclusive Dilepton Production Physics Letters B 749 (2015), 242-261
- CMS Underlying event measurements with leading particles and jets in pp collisions at $\sqrt{s}$ = 13 TeV CMS-PAS-FSQ-15-007
- CMS Dijet production with a large rapidity gap between the jets CMS-PAS-FSQ-12-001
- CMS Event generator tunes obtained from underlying event and multiparton scattering measurements EPJC 76 (2016) 155
- CMS Measurement of exclusive π+π−π+π− production in proton-proton collisions at $\sqrt{s}$ = 7 TeV CMS-PAS-FSQ-12-004

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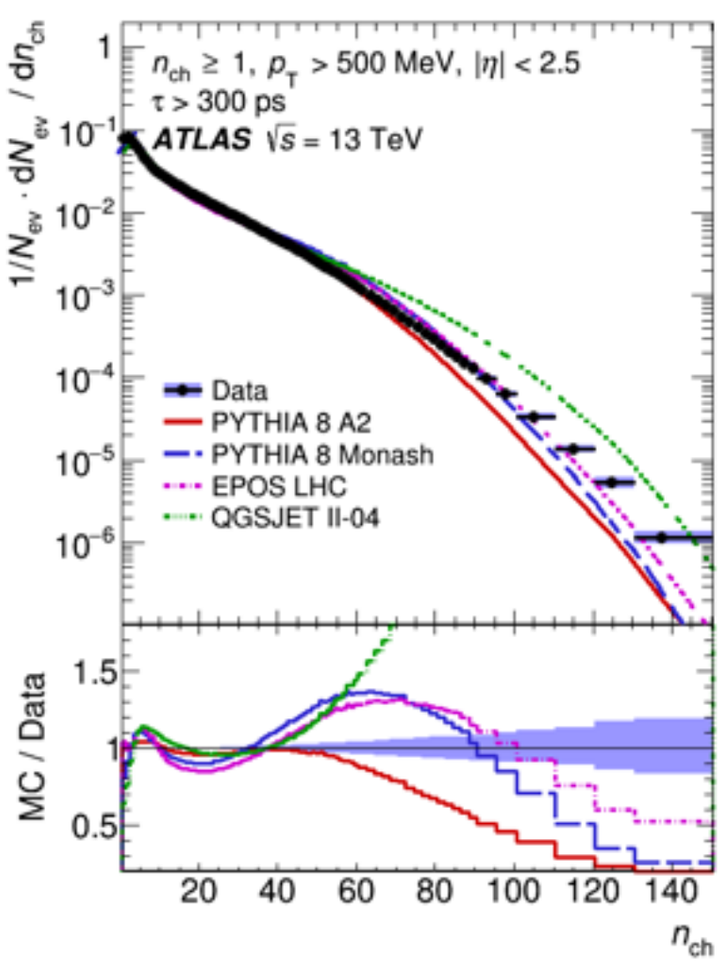
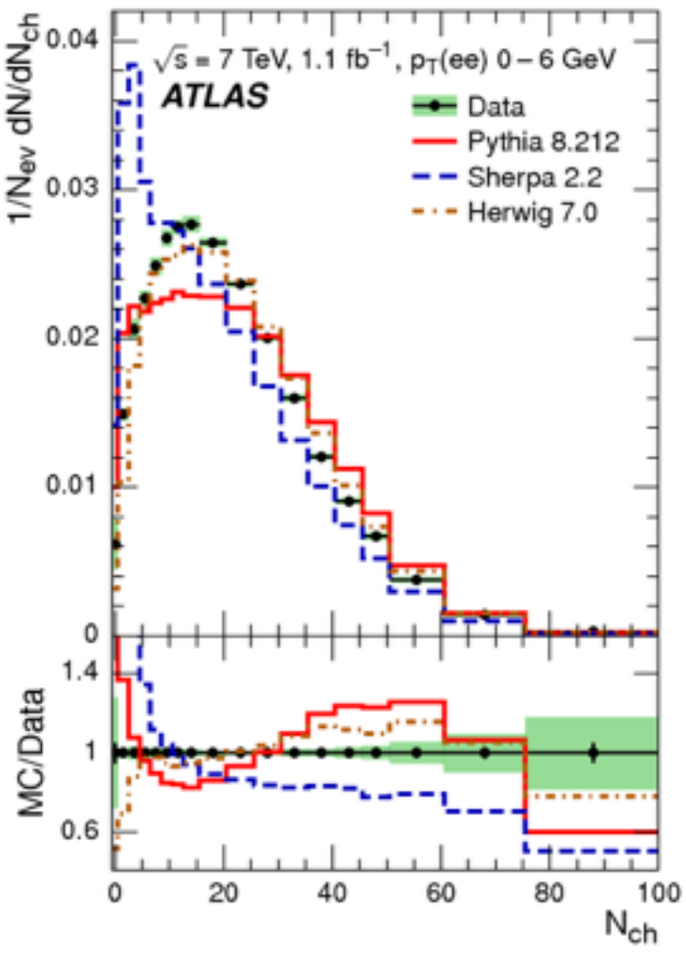
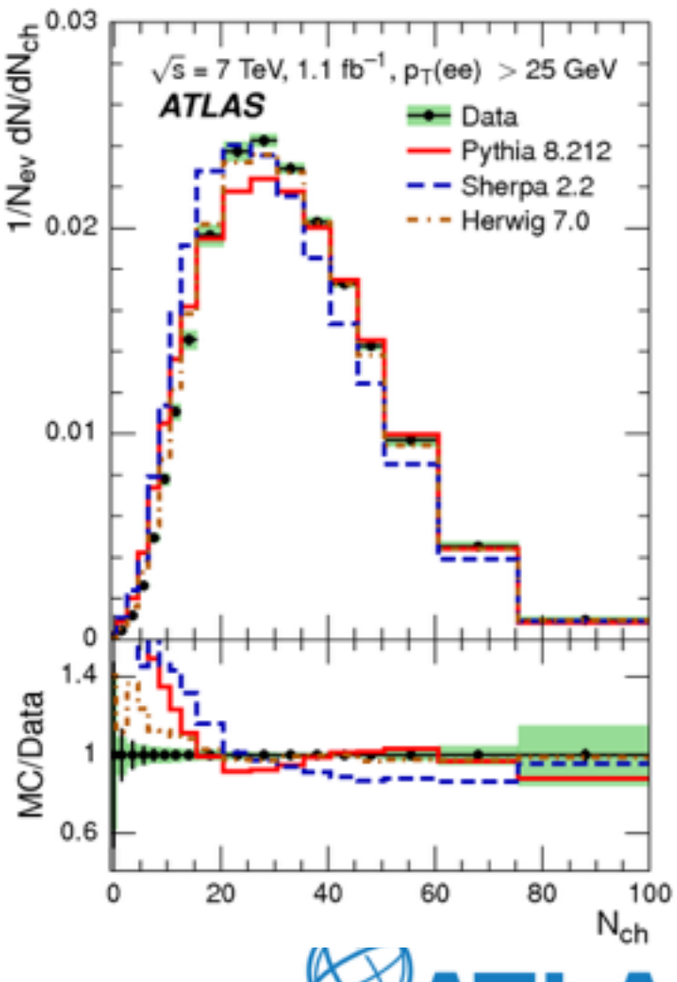
AND MANY MORE . . . ..

ATLAS EXPERIMENT

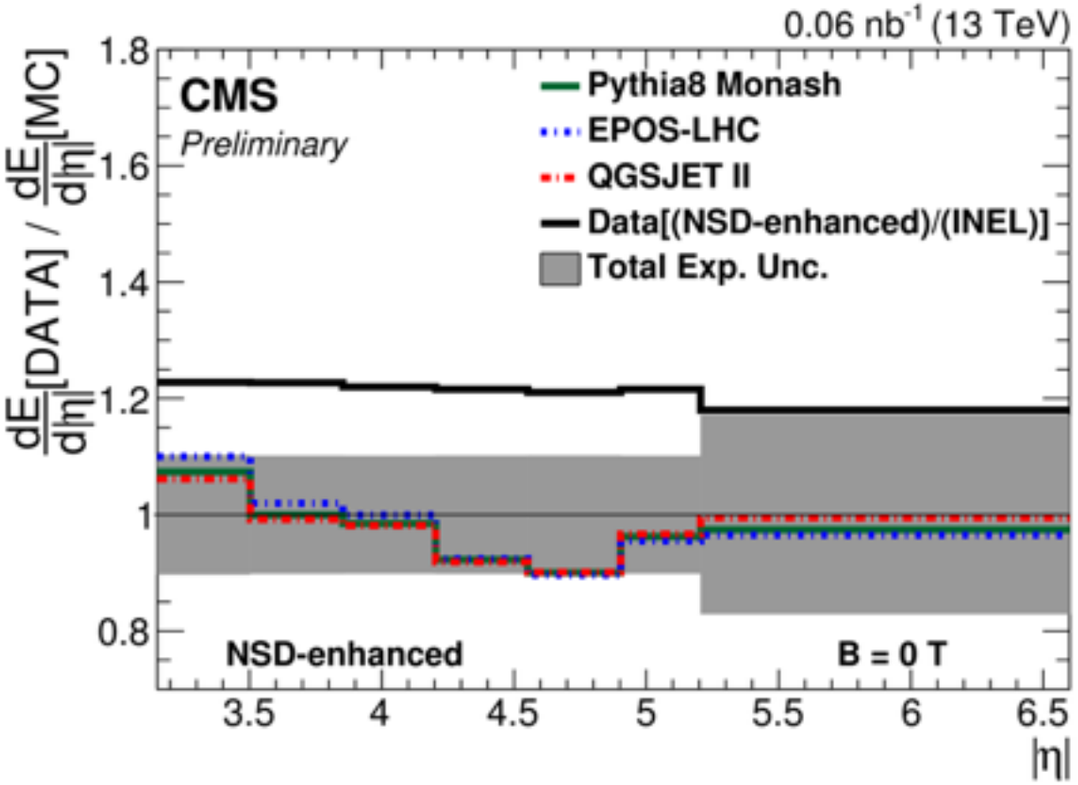
COMPARISON BETWEEN MINIMUM BIAS, AND Z BOSON DIST.

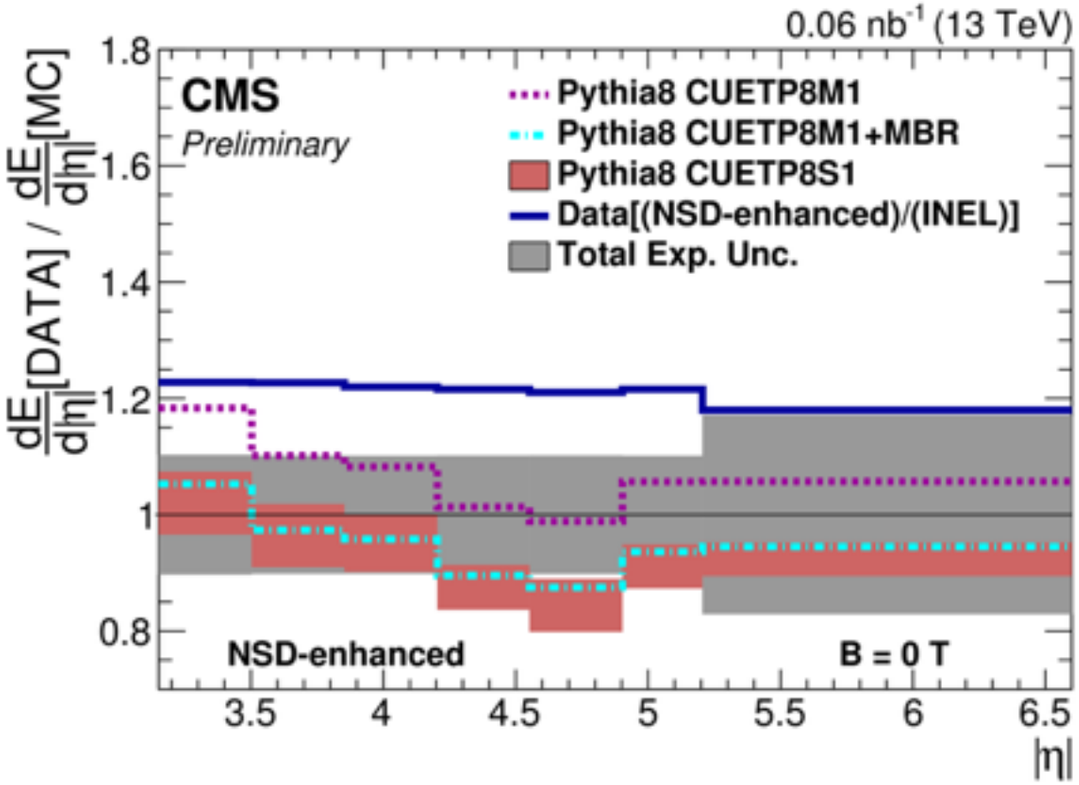






ATLAS EXPERIMENT





ATLAS EXPERIMENT