Minimum Bias Measurements at the LHC

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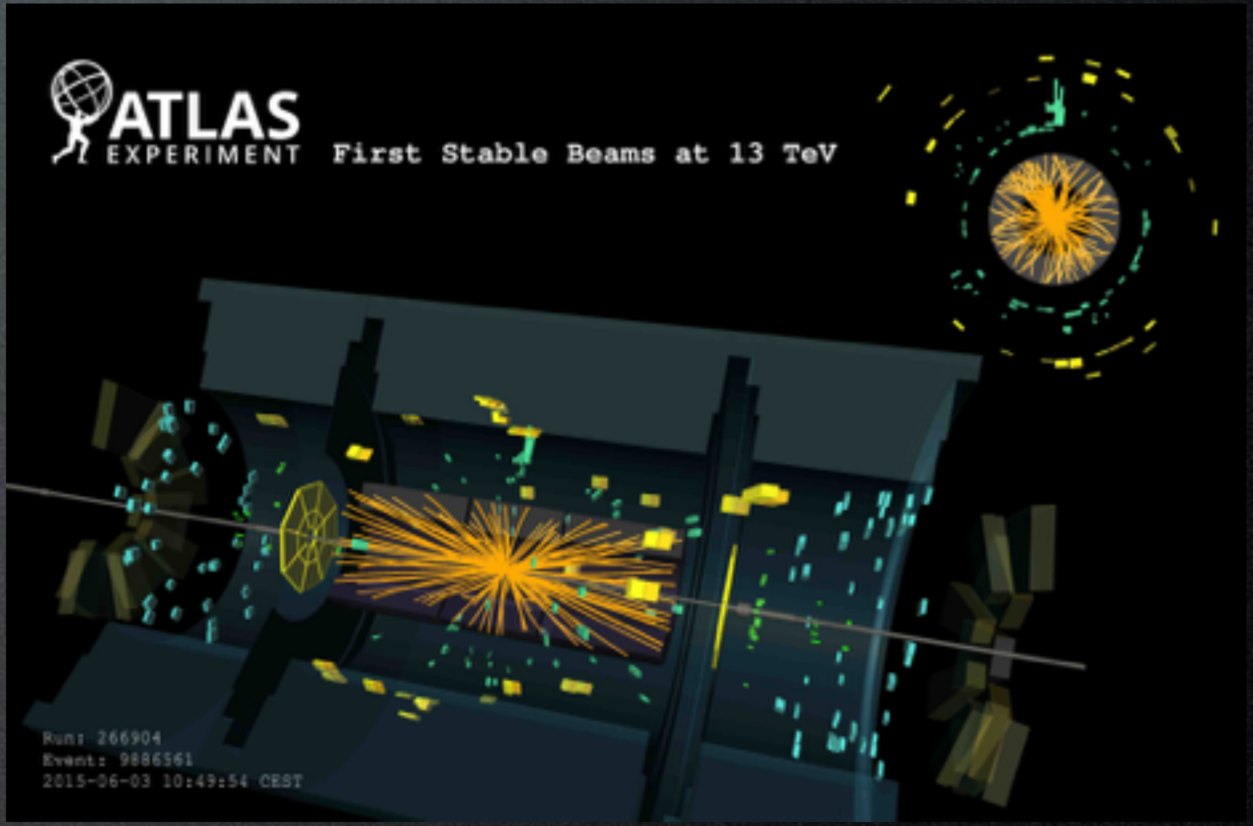
On behalf of ATLAS and CMS collaborations

International Conference on High Energy Physics, Chicago, August 2016

Minimum Bias?

- Events selected with a minimally biased trigger selection.
- Measurements performed with both with tracks and clusters.
- Complementary information.



Not to be confused with Underlying Event or Pileup

Why important?

- Pedestal activity to all physics processes
- Not perturbative processes
- Cant subtract the contribution on an event-by-event basis
- Modelled in Monte Carlo Generators

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Monte Carlo Models

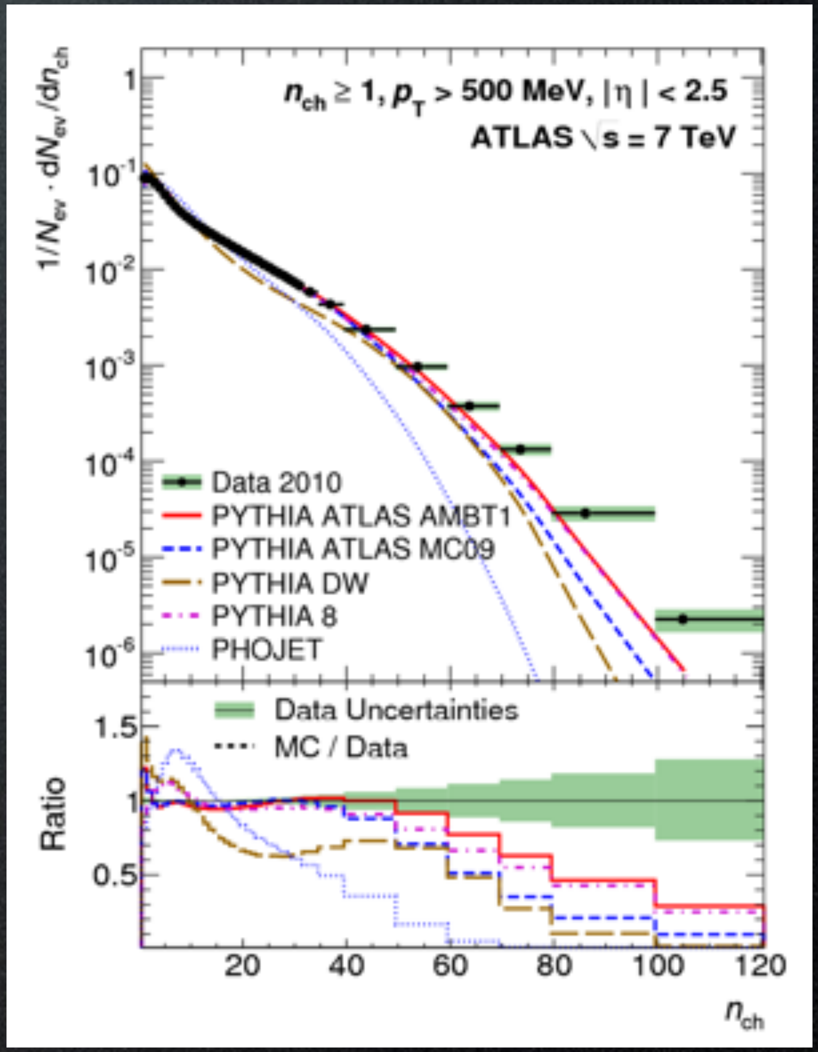
<table>
<tr><td>Pythia8 4C</td><td>(Author) MB+UE tune with CTEQ6L1</td></tr>
<tr><td>Pythia8 Monash</td><td>(Author) MB+UE tune with NNPDF2.3LO</td></tr>
<tr><td>Pythia8 CUETP8S1</td><td>(CMS) UE tune based on 4C</td></tr>
<tr><td>Pythia8 CUETP8M1</td><td>(CMS) UE tune based on Monash</td></tr>
<tr><td>Pythia8 A2</td><td>(ATLAS) Minbias/Central ET flow tune based on 4C</td></tr>
<tr><td>Herwig++ UE-EE-5C</td><td>(Author) UE tune with energy scaling using CTEQ6L1</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Epos LHC</td><td rowspan="3">Based on Gribov’s Pomeron exchange/collective flow approach, use LHC and fixed target experiment data to describe hadron and nuclear collisions.</td></tr>
<tr><td>QGSJET-II</td></tr>
<tr><td>Sibyll</td></tr>
</table>

Parton Shower

Cosmic Ray/Air Shower

Looking back ...

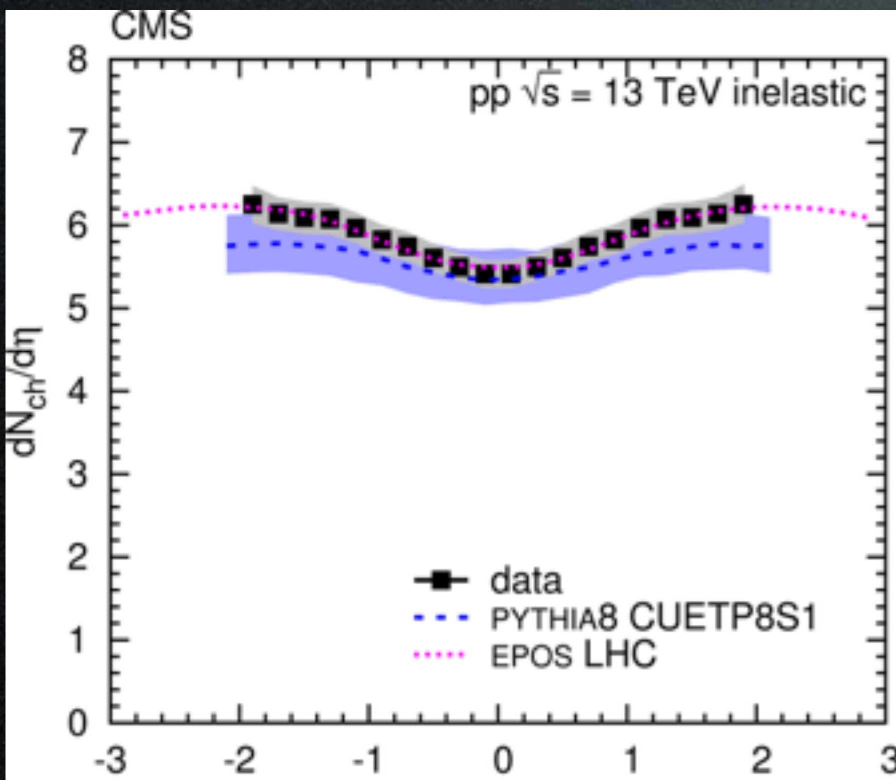
- Measurements at the beginning of Run 1 showed bad description of data by then-existing (mostly from Tevatron) Monte Carlo models and tunes.
- Significant effort went in both theory and experimental communities to improve the modelling, using LHC Run 1 data.
- Big question we had at the beginning of Run 2: can these models describe the 13 TeV data?



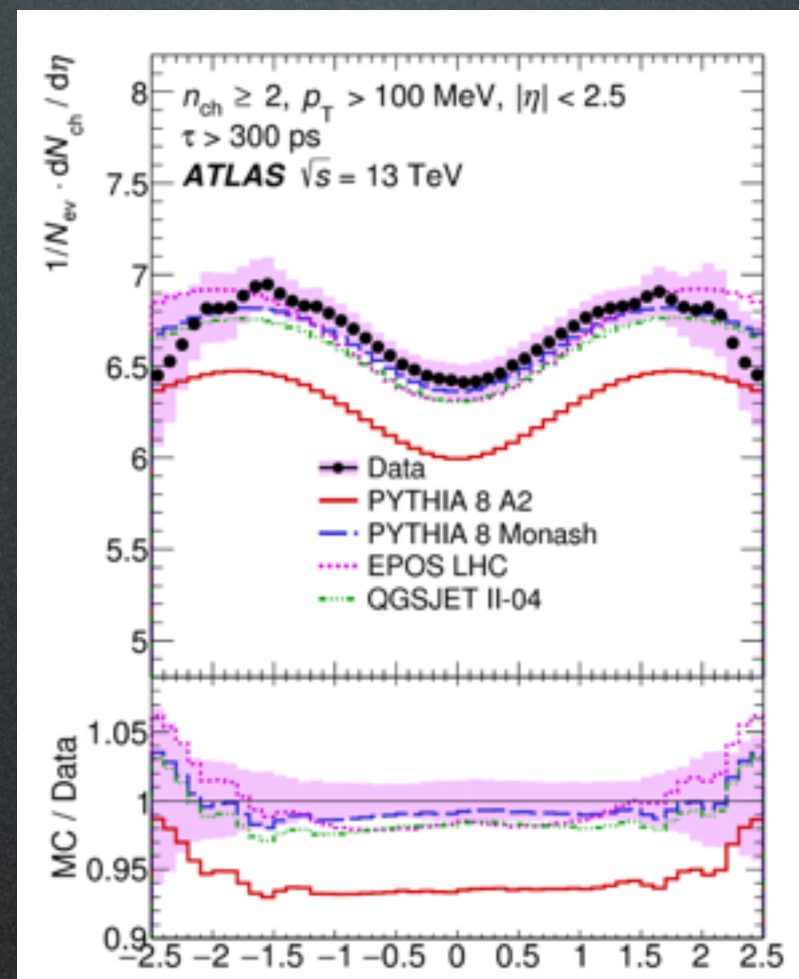
New J. Phys. 13 (2011) 053033

Charged Particle Pseudorapidity

Higher transverse momentum threshold



Phys. Lett. B 751 (2015) 143



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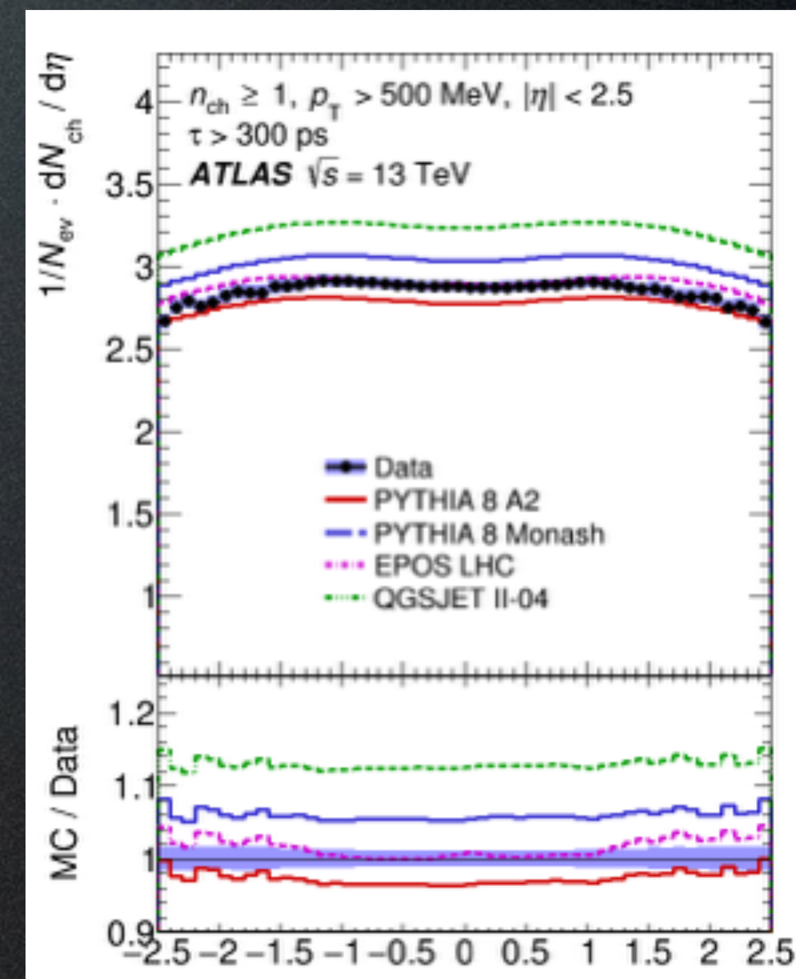
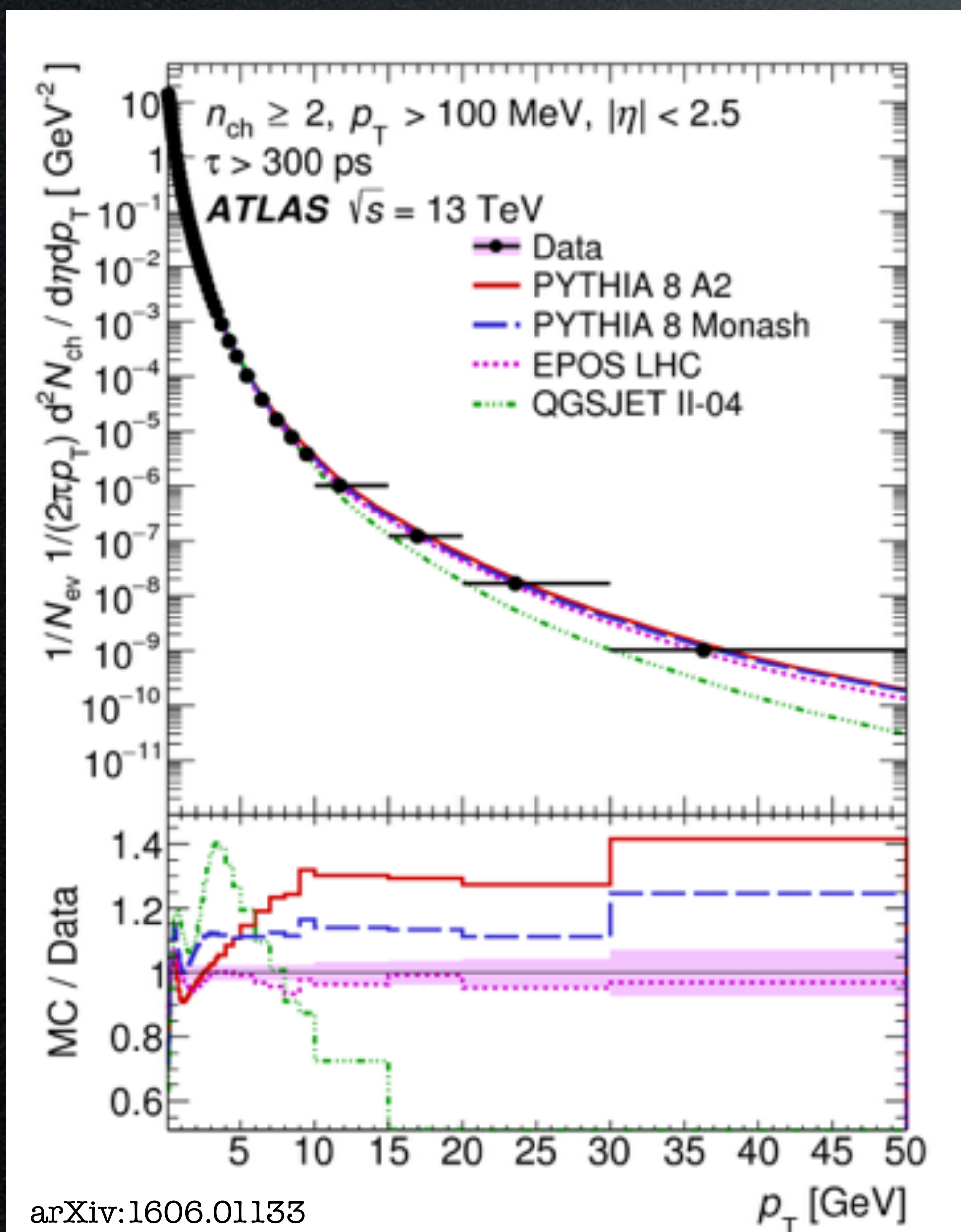


Physics Letters B (2016), Vol. 758, pp. 67-88

Overall Epos is the best, stark difference in A2 predictions going from 100 to 500 MeV

Charged Particle Transverse Momentum

Higher transverse momentum threshold



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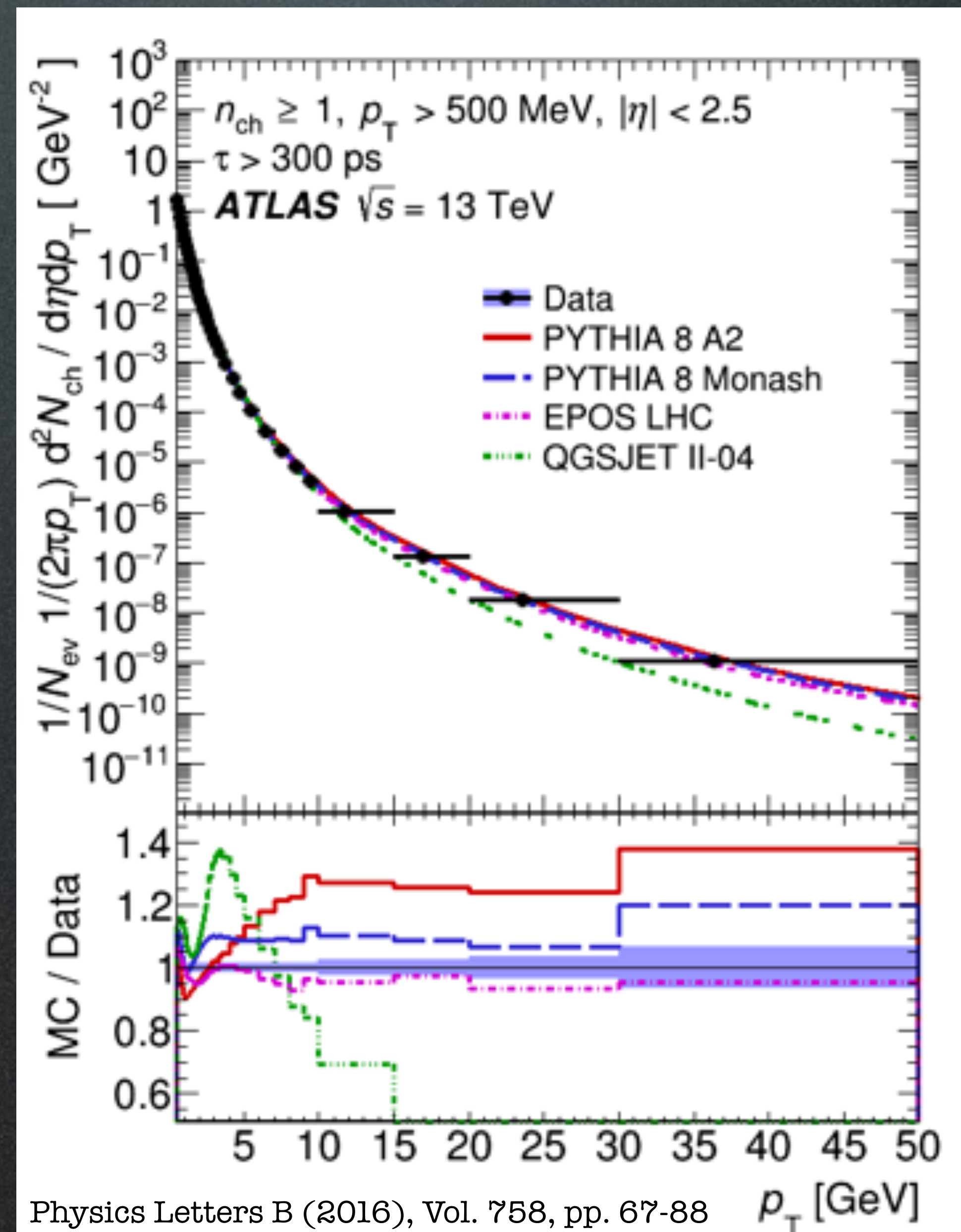


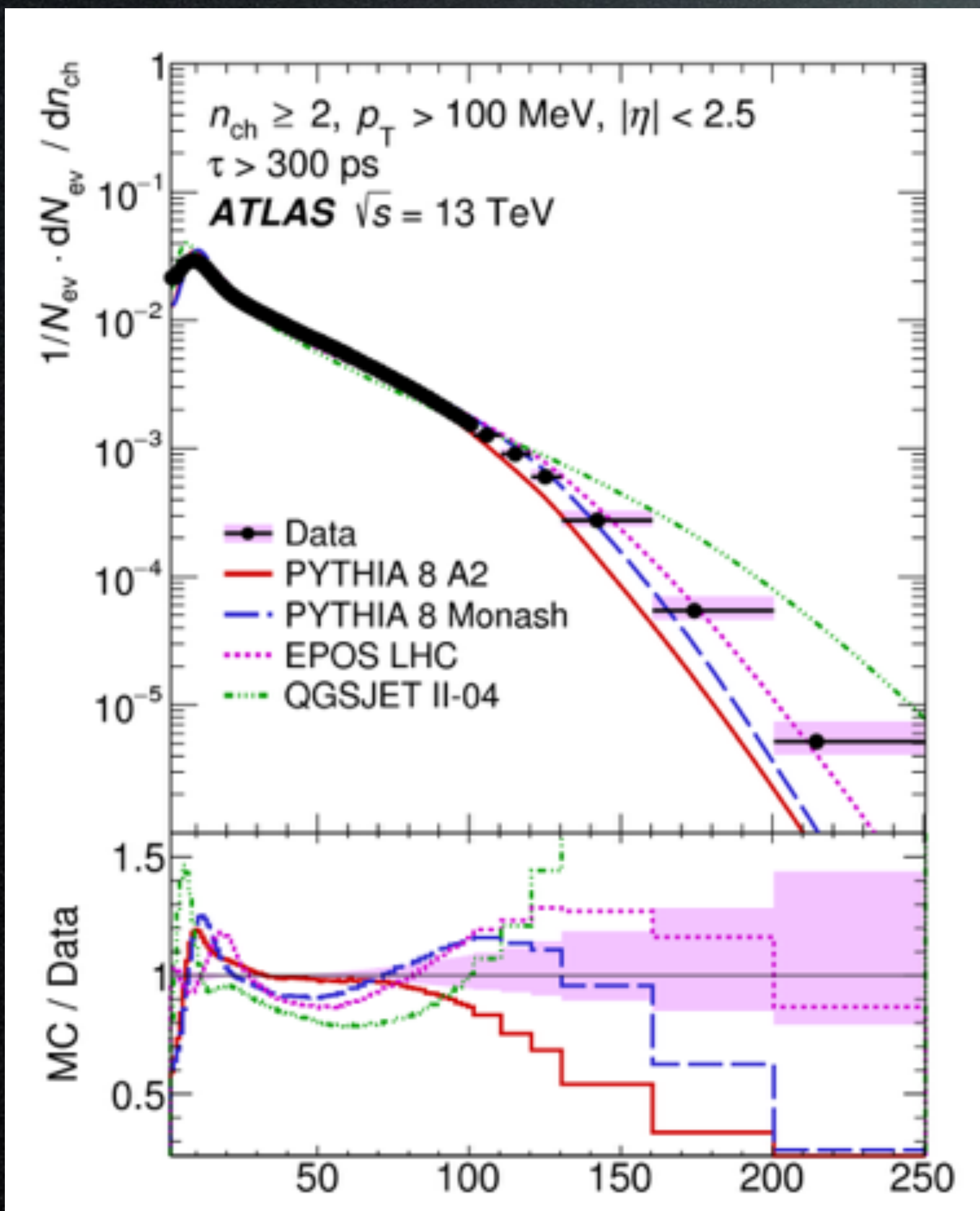
Physics Letters B (2016), Vol. 758, pp. 67-88

Epos is best for both

A2 and Monash are competitive but not over the full range

Charged Particle Multiplicity

Higher transverse momentum threshold



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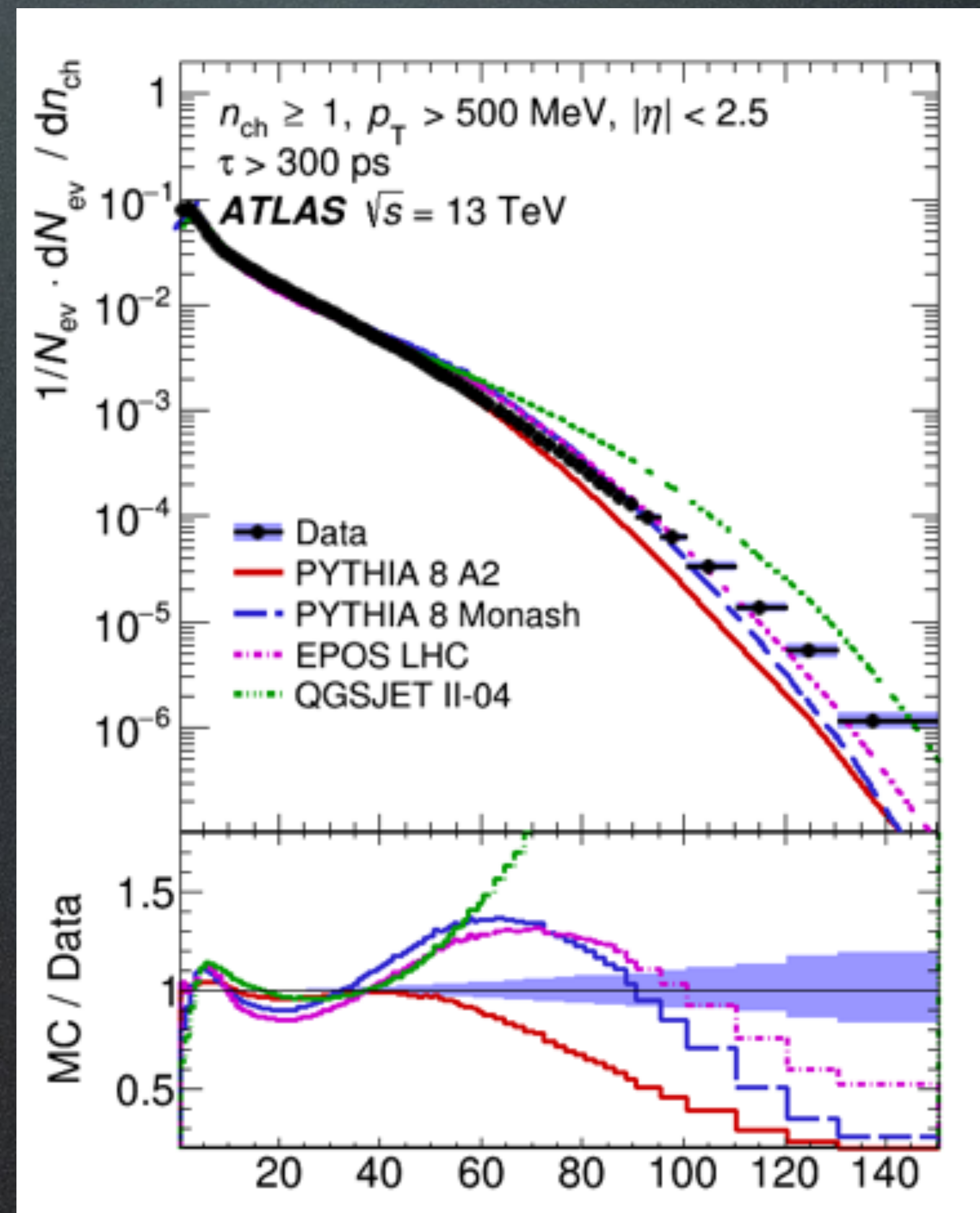


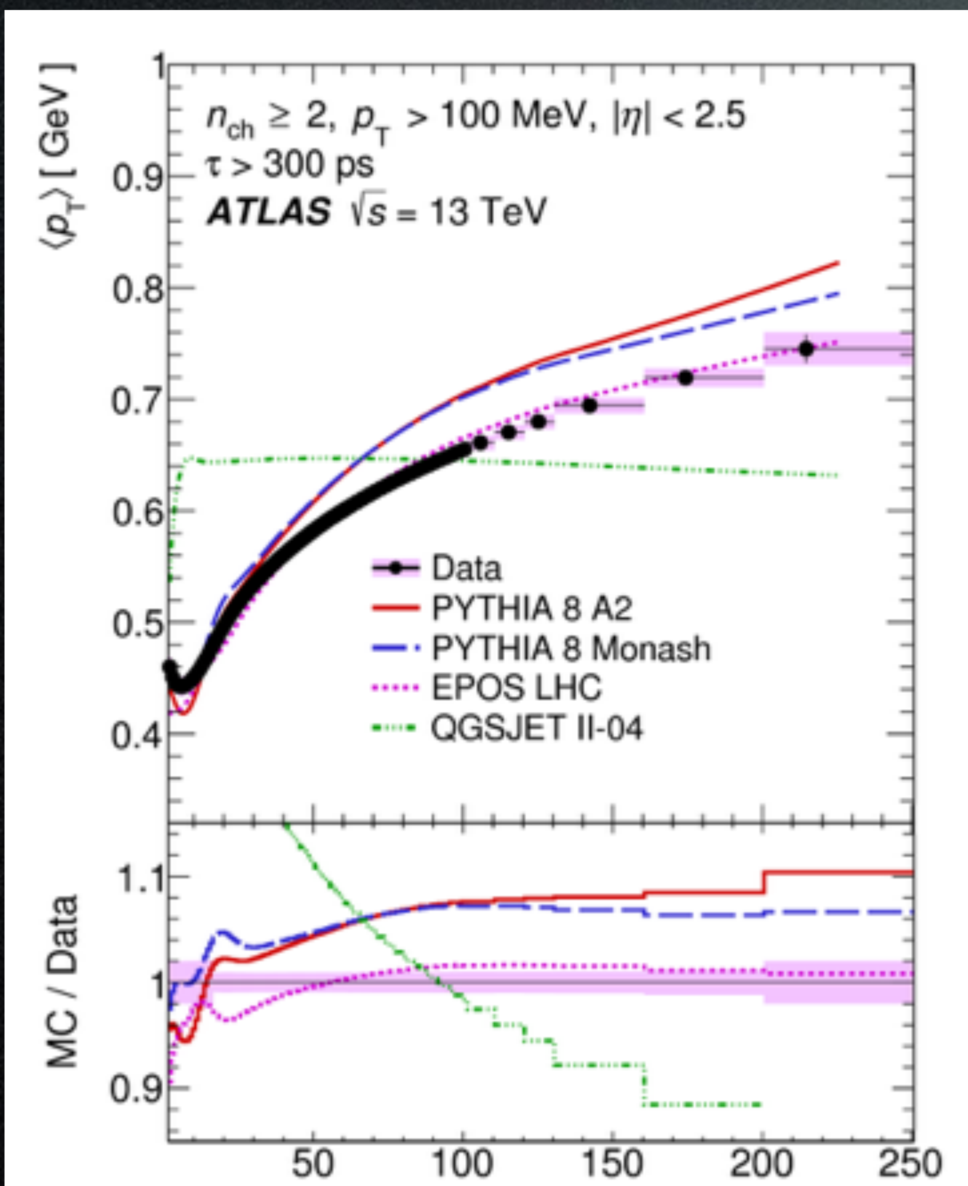
Physics Letters B (2016), Vol. 758, pp. 67-88

Similar trends

None of the models do well over the whole range

Mean Transverse Momentum against Multiplicity Correlation

Higher transverse momentum threshold



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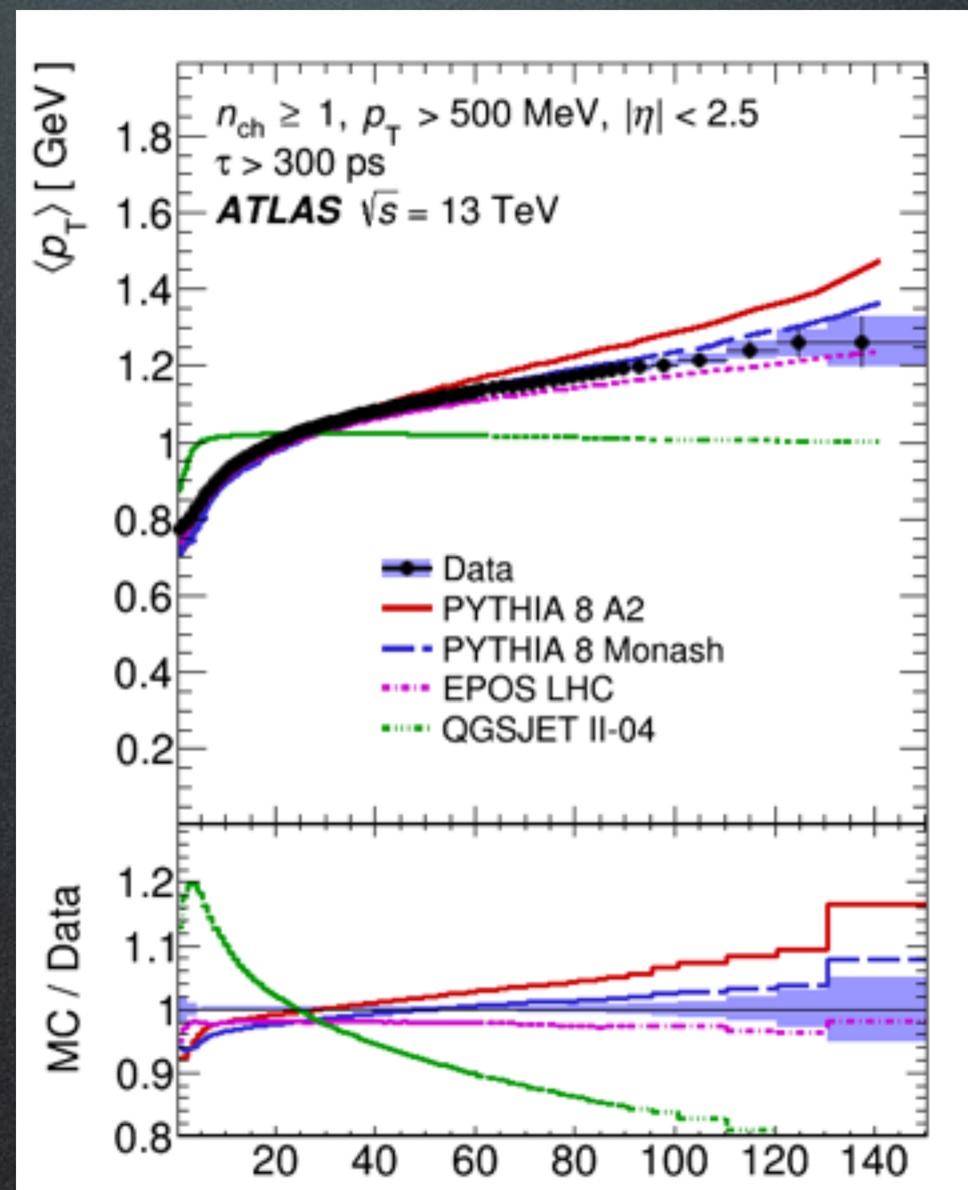

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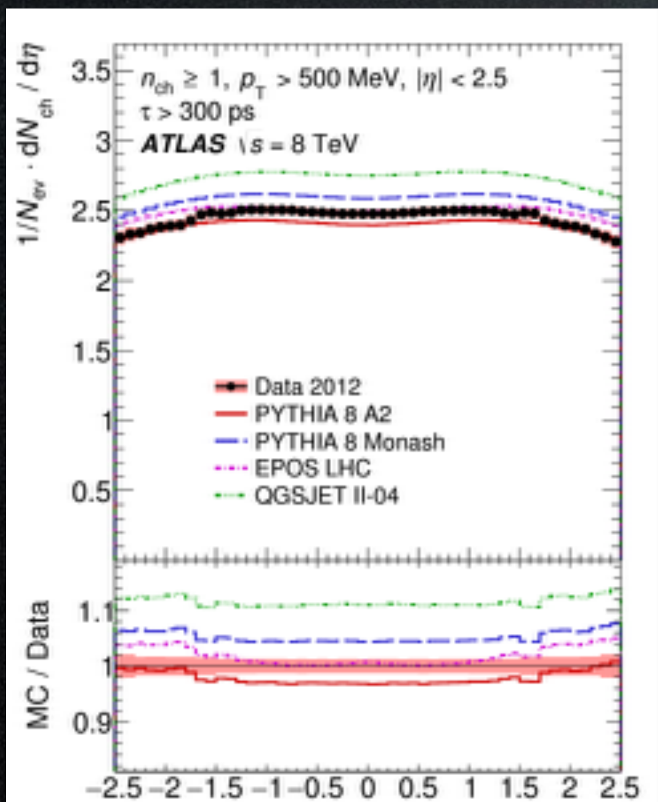
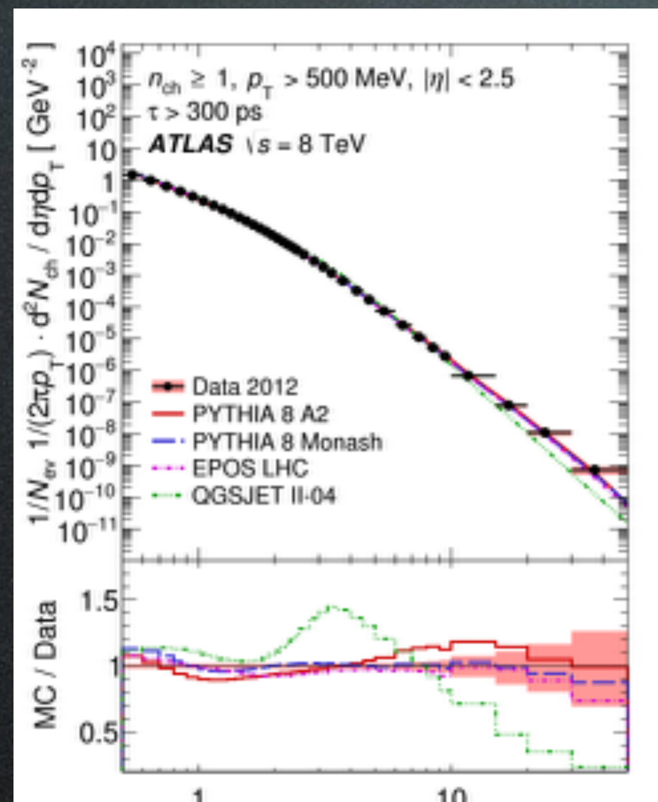
Correlation depends on colour reconnection

Better modelled at 500 MeV, QGSJETII has no CR

Charged Particle Distributions at 8 TeV



Eur. Phys. J. C (2016) 76: 403.



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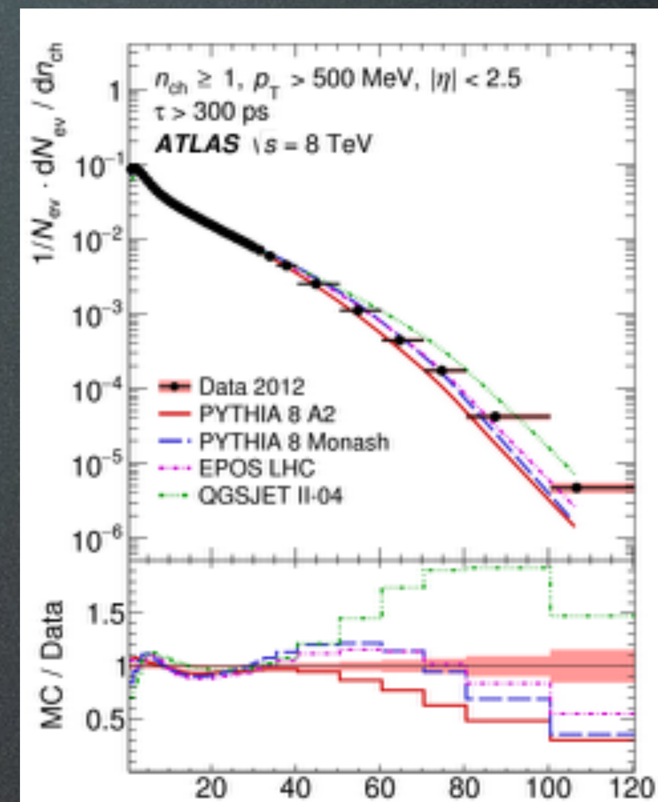

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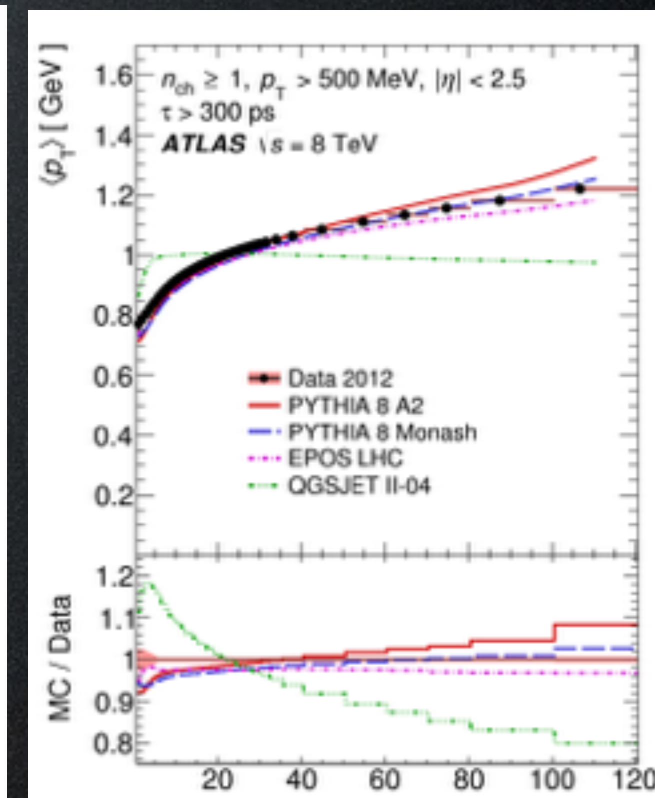

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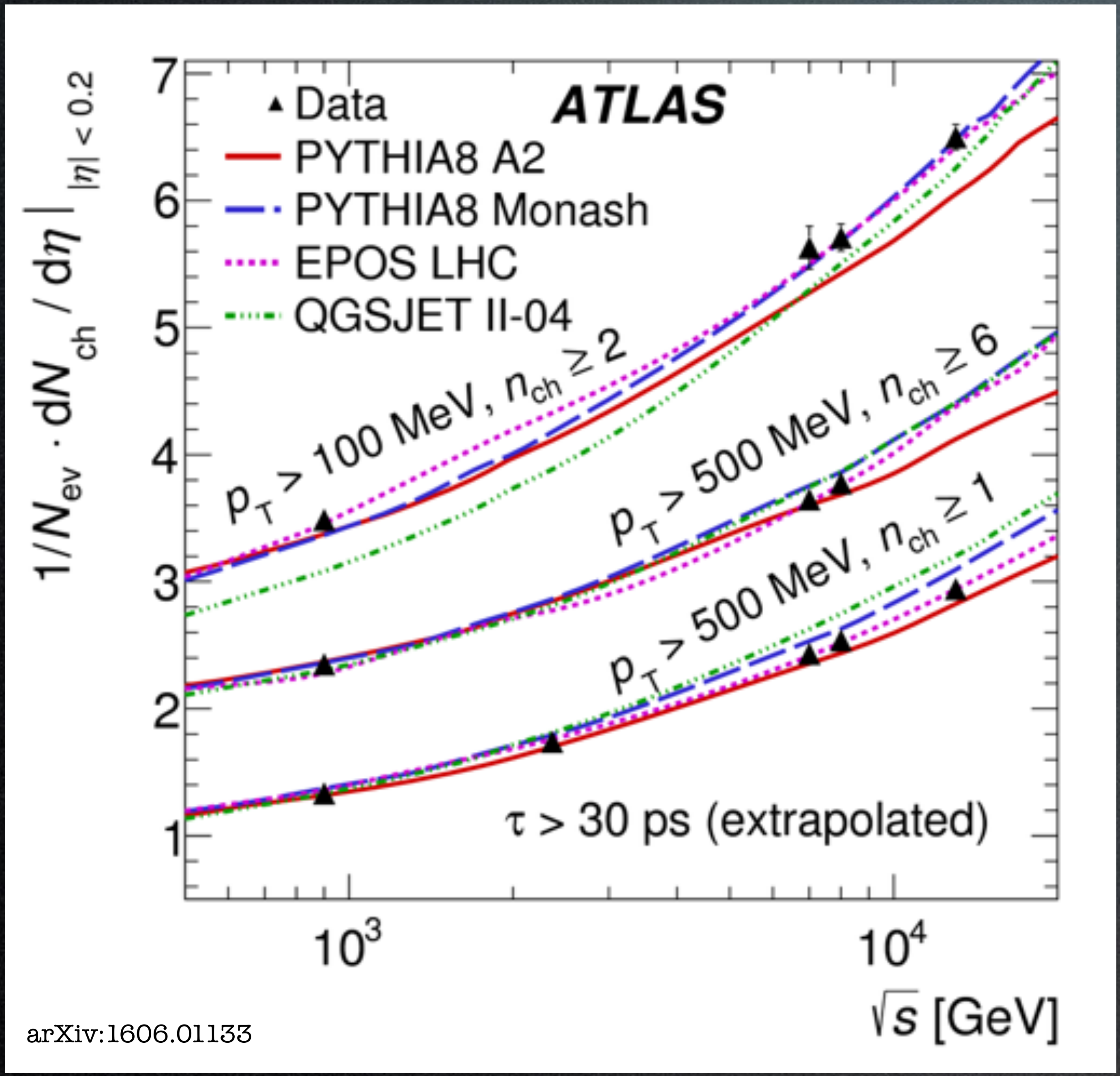
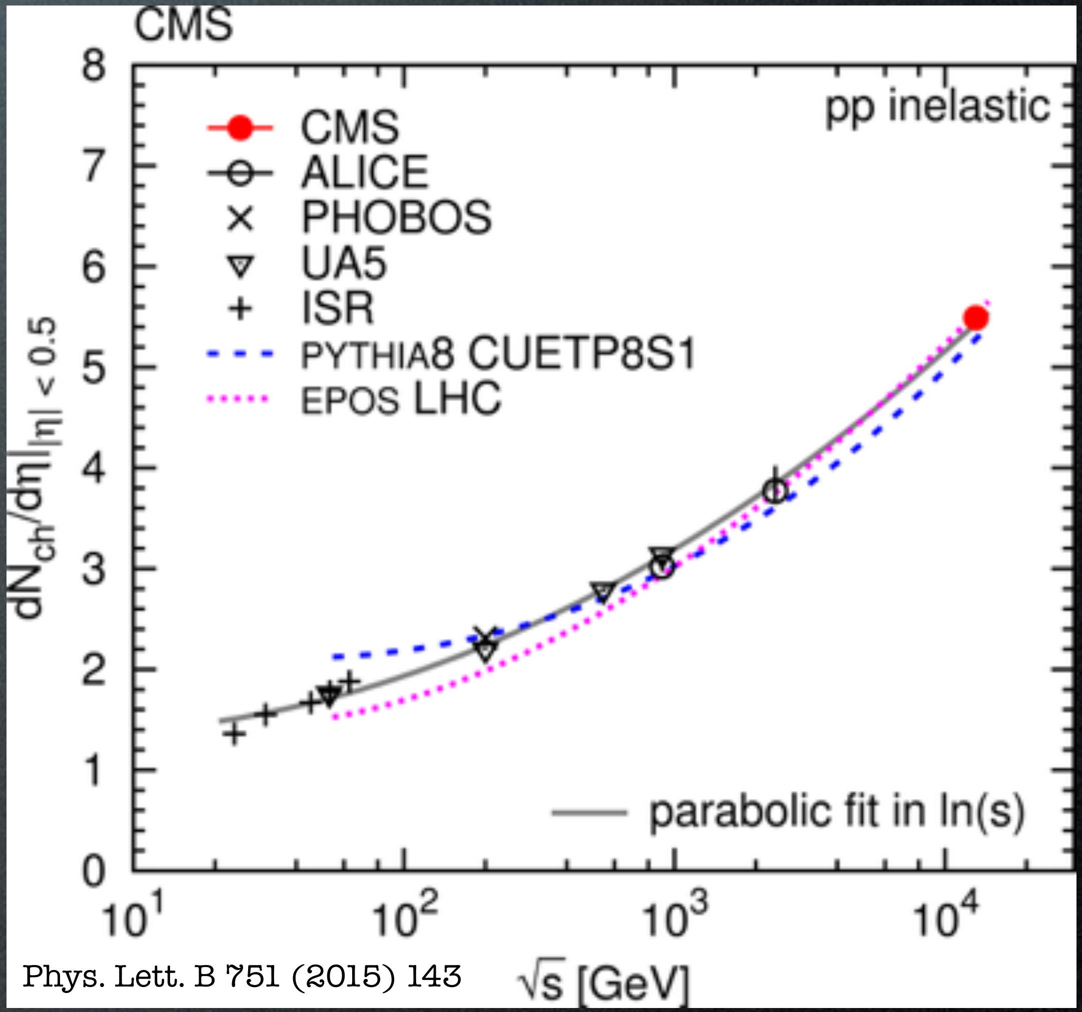
- Models show discriminating power
- Results available for different phase spaces

Dependence on E.C.M





Most models get the energy extrapolation trend right

About 20% increase from going from 7 to 13 TeV

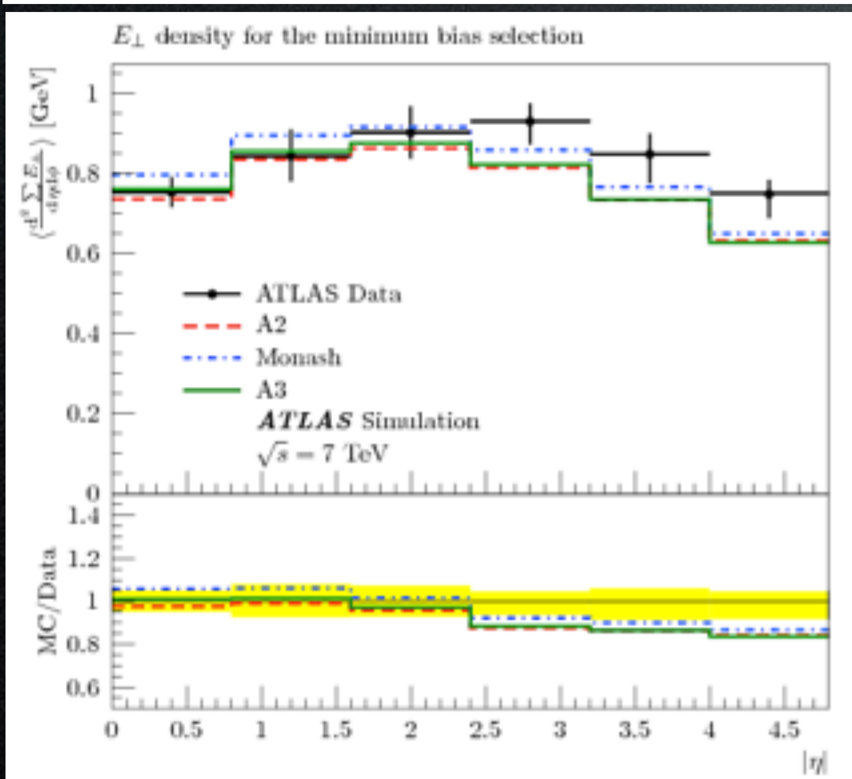
Pythia8 A3 Tune

New

Tom Sykora's Talk

	ATLAS data (mb)	SS (mb)	A3 (mb)
At $\sqrt{s} = 13$ TeV	68.1 ± 1.4	74.4	69.9
At $\sqrt{s} = 7$ TeV	60.3 ± 2.1	66.1	62.3

Using Donnachie-Landshoff diffractive model and NNPDF2.3LO



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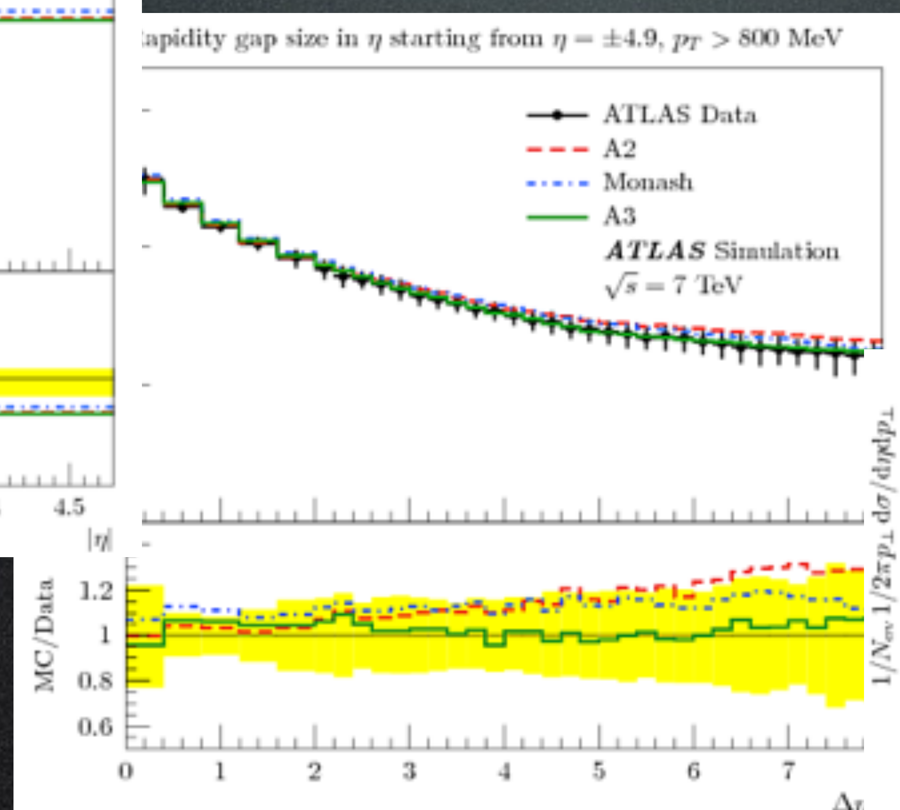
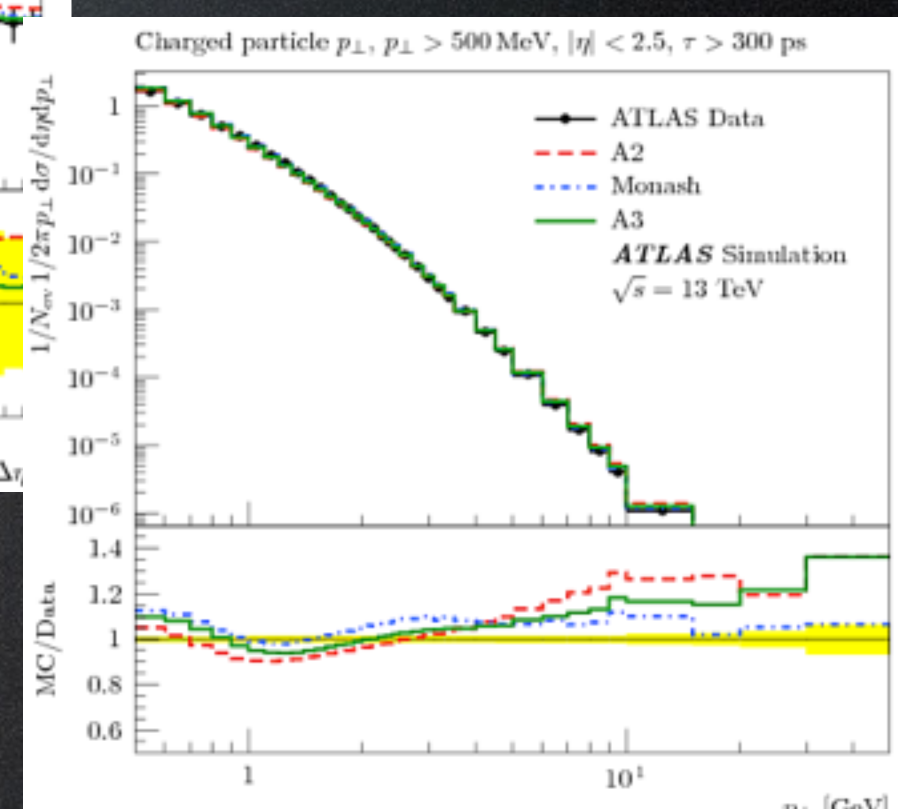


Much improved total inelastic cross section prediction



Mostly similar level of agreement with Minbias observables

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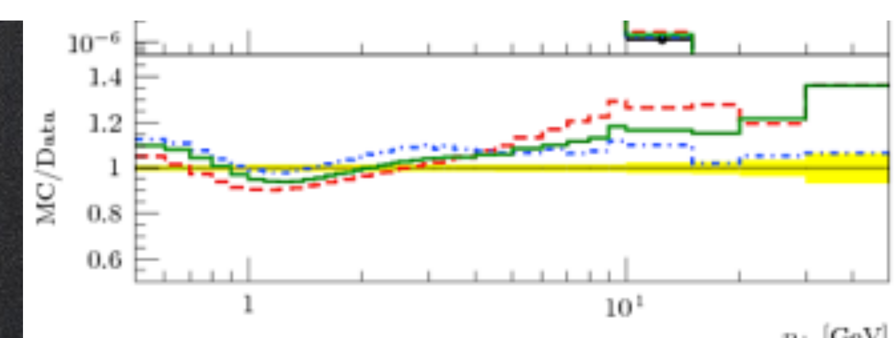
Using Donnachie-Landshoff diffractive model and NNPDF2.3LO

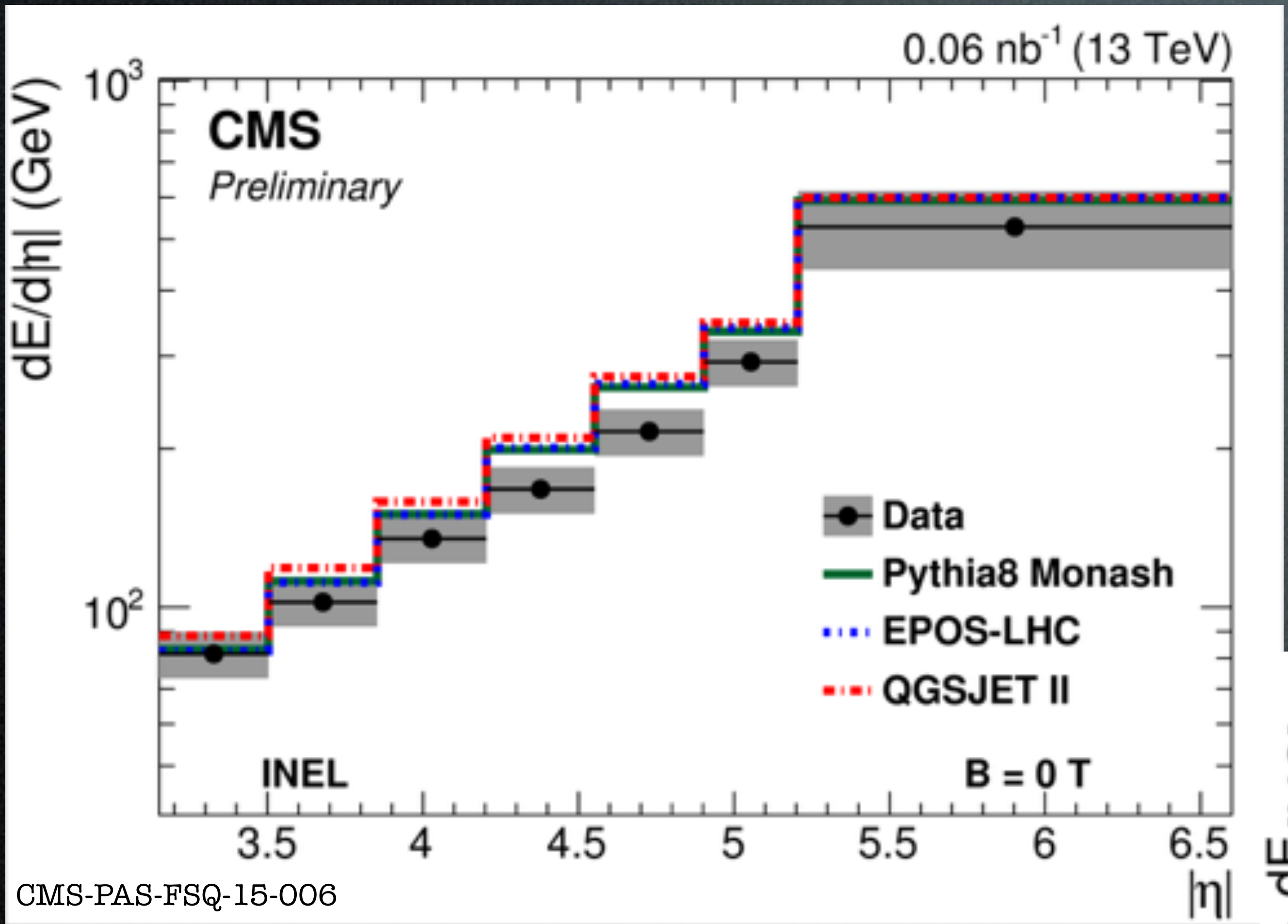
Parameter	A3 value	A2 value	Monash value
`MultipartonInteractions:pT0Ref`	2.45	1.90	2.28
`MultipartonInteractions:ecmPow`	0.21	0.30	0.215
`MultipartonInteractions:coreRadius`	0.55	-	-
`MultipartonInteractions:coreFraction`	0.90	-	-
`MultipartonInteractions:a1`	-	0.03	-
`MultipartonInteractions:expPow`	-	-	1.85
`BeamRemnants:reconnectRange`	1.8	2.28	1.8
`Diffraction:PomFluxEpsilon`	0.07 (0.085)	-	-
`Diffraction:PomFluxAlphaPrime`	0.25 (0.25)	-	-

Mostly similar level of agreement with Minbias observables



Forward Energy Flow

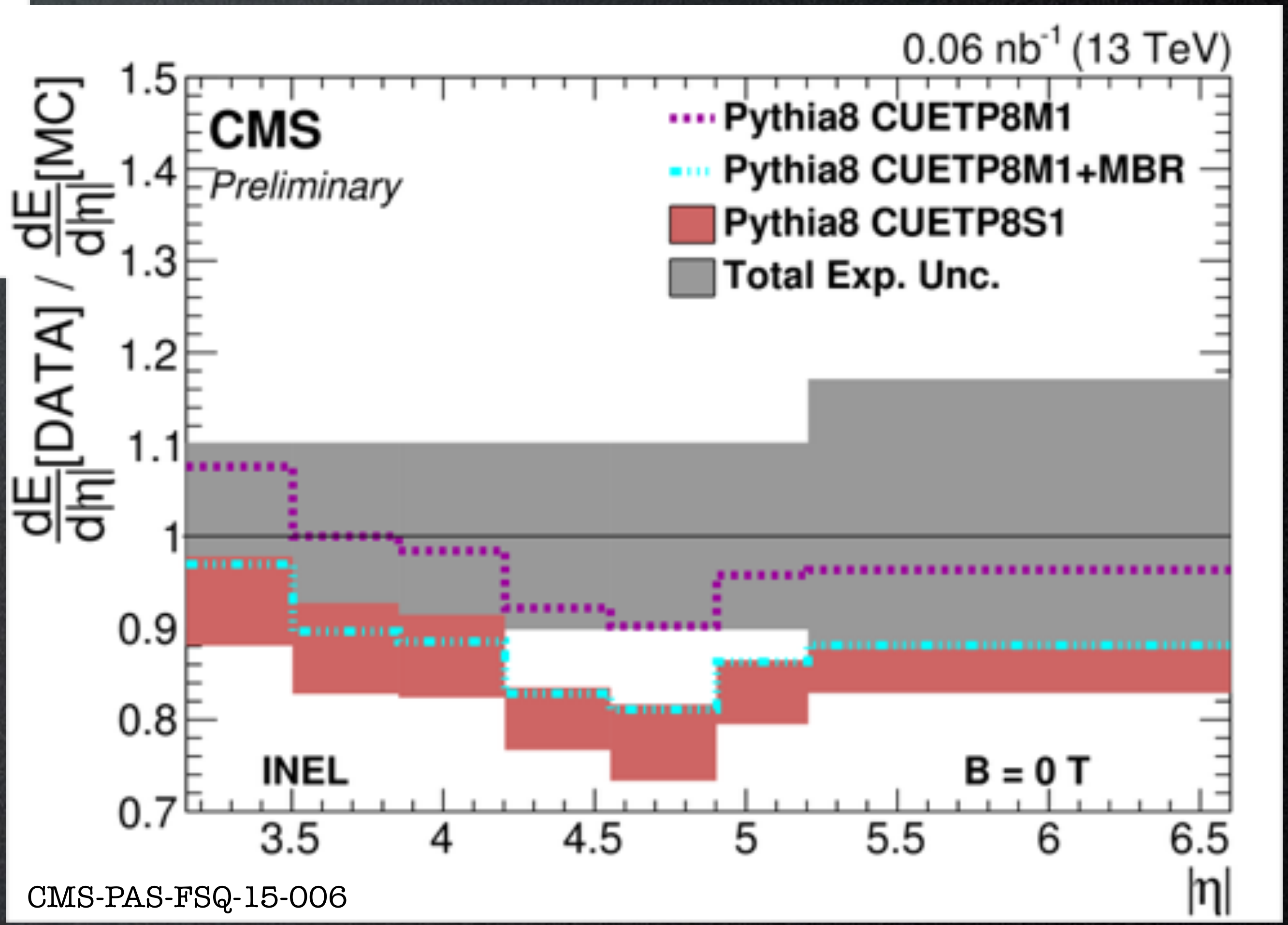
Measured in 3.15 < |η| < 6.6



Models in general perform worse in more forward region

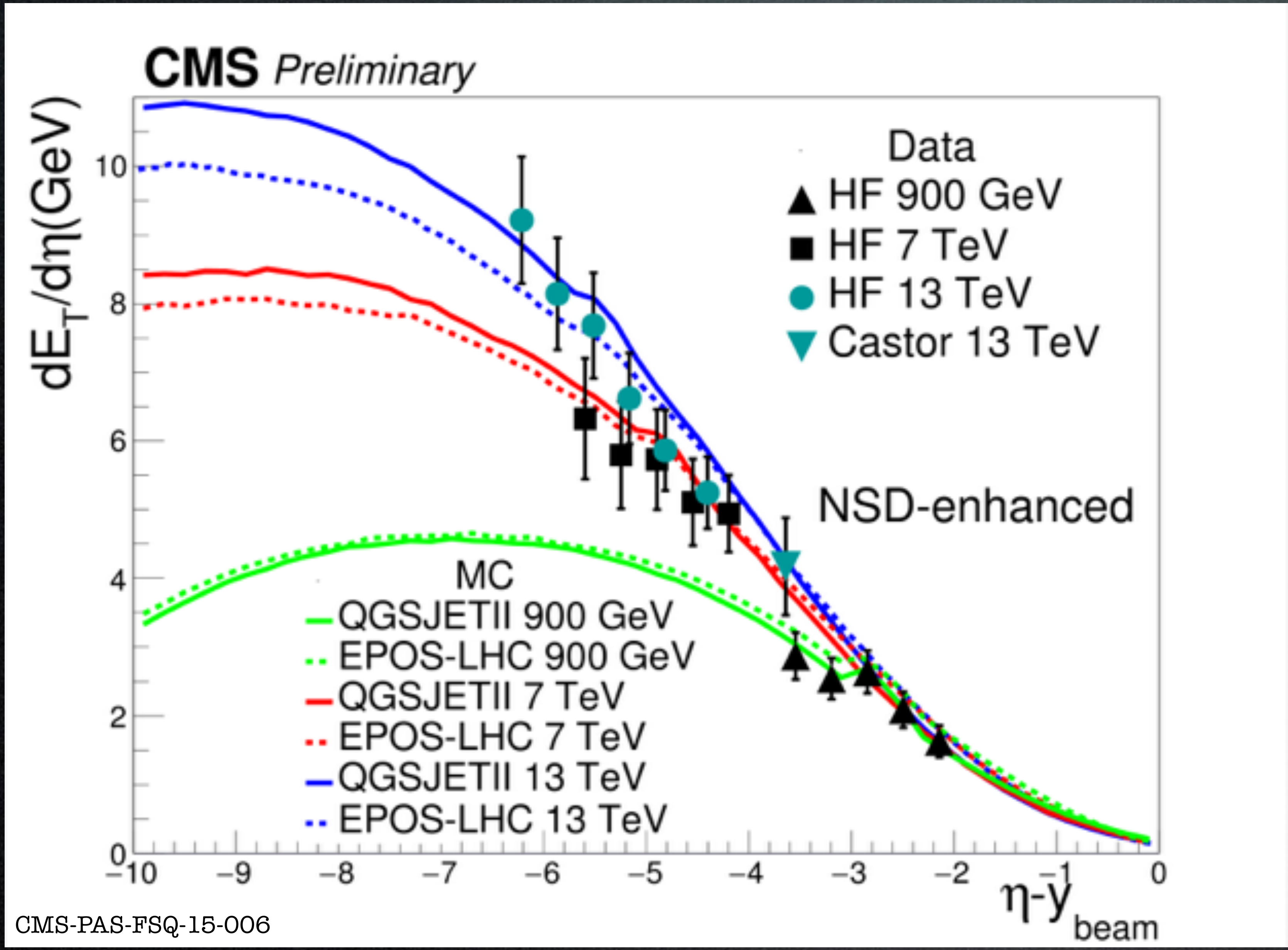
Large spread in predictions

Also measured in non-single diffractive events, where models tend to do better



Forward Energy Flow

Measured in $3.15 < |\eta| < 6.6$

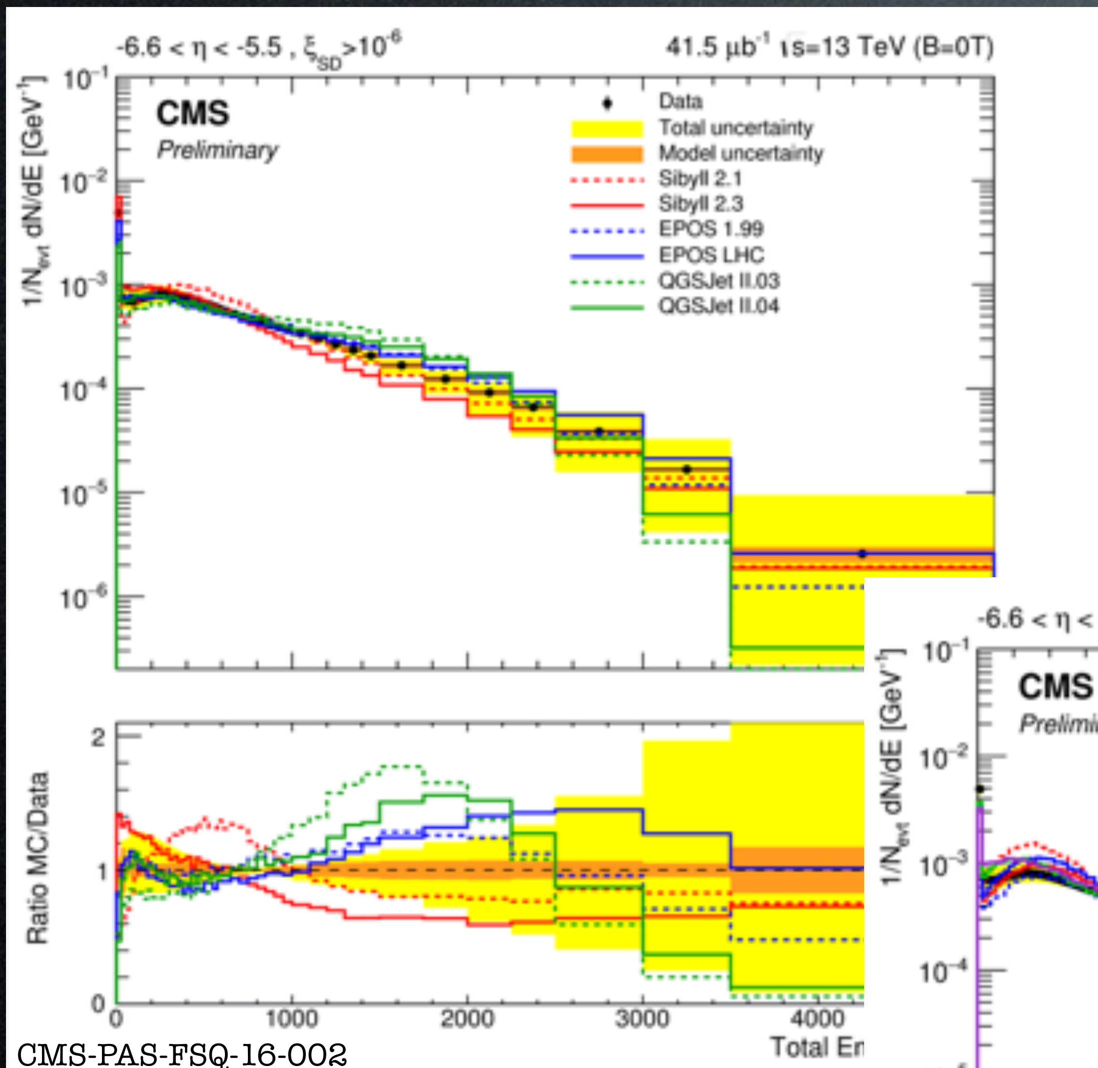


At least two charged particles in the range $3.9 < |\eta| < 4.4$
At least one on each side with respect to the interaction point

Transverse energy flow as a function of shifted pseudorapidity

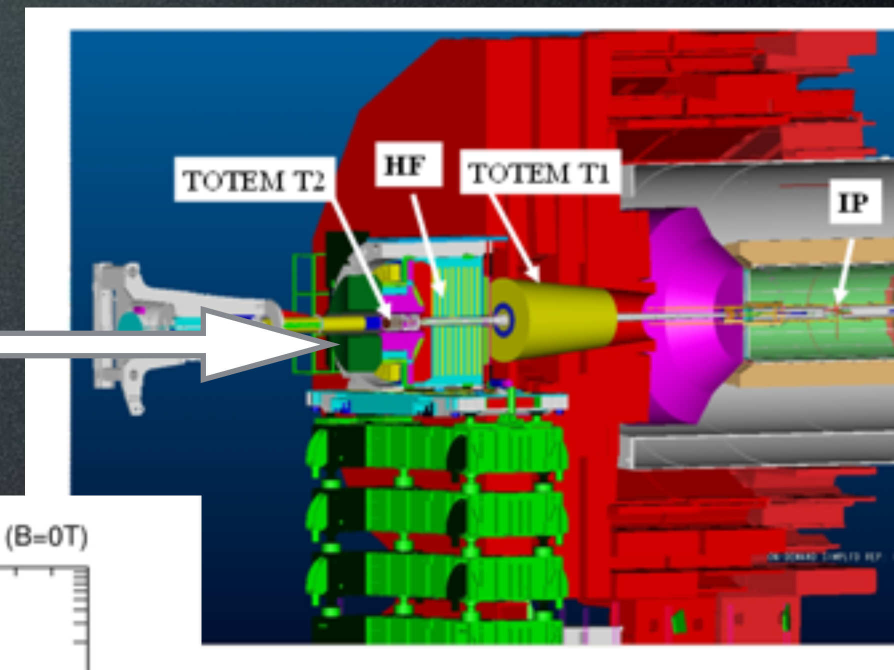
Consistent across wide range of collision energies

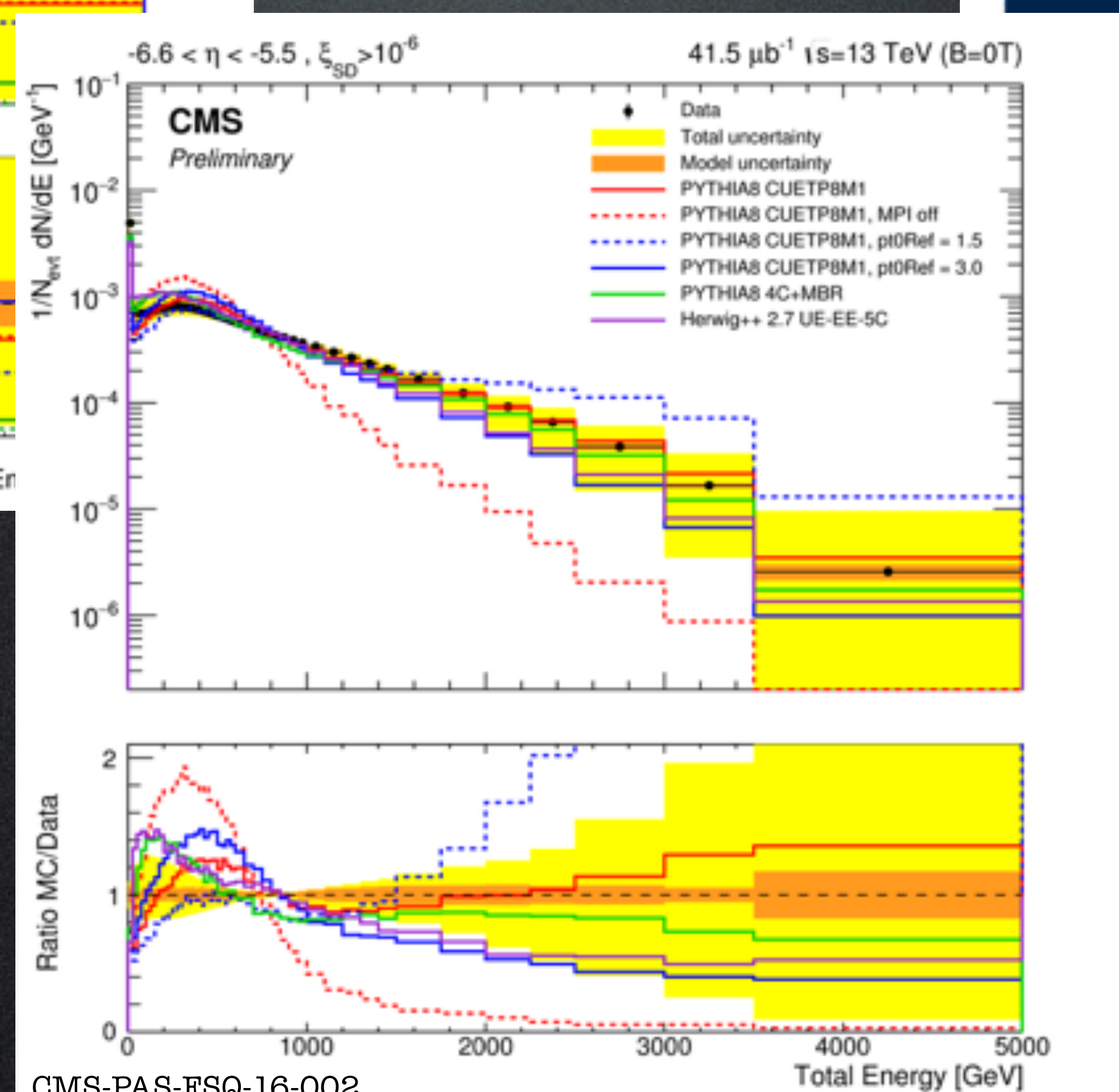
Very Forward Energy Flow



Castor

$-5.2 < \eta < -6.6$



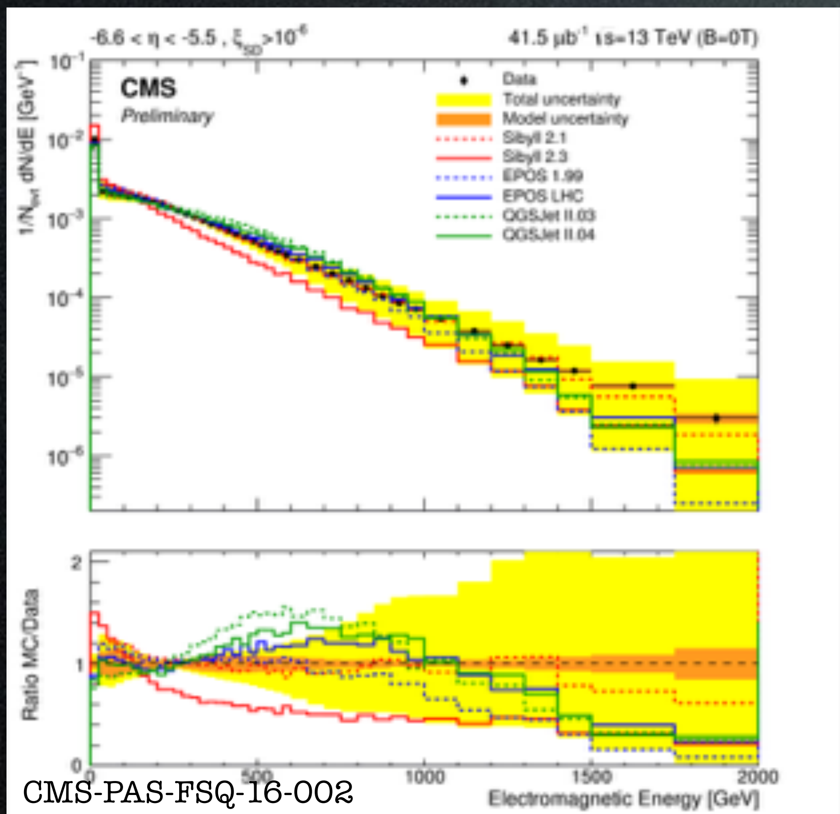


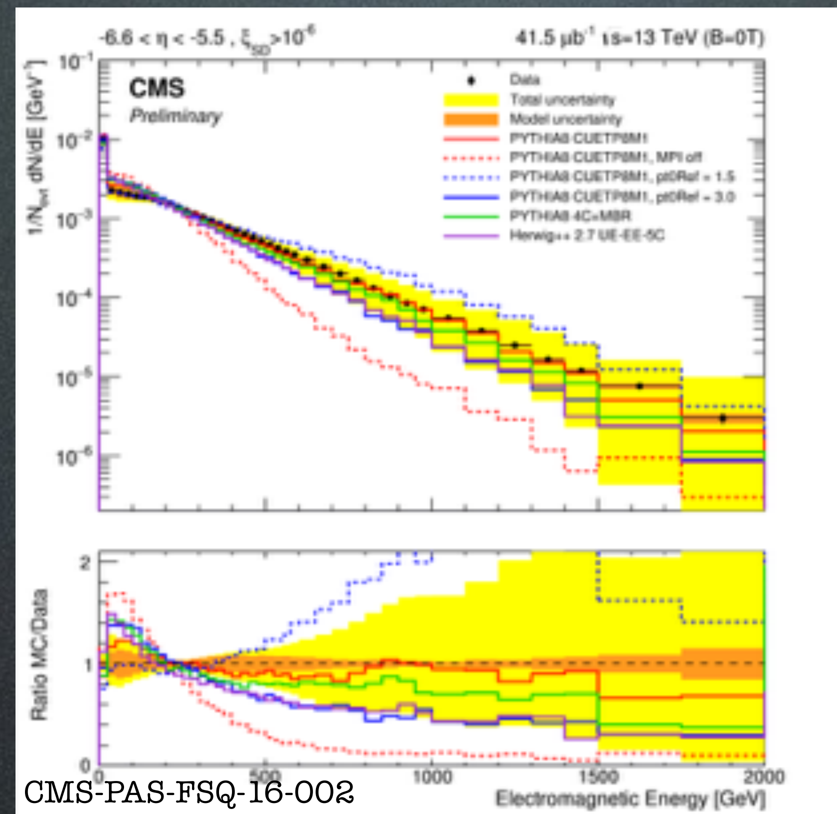
Discriminating power between the models

Generally worse at the soft part of the spectrum

Bump at ~200 GeV, then steeply falling

Very Forward Energy Flow





Electromagnetic

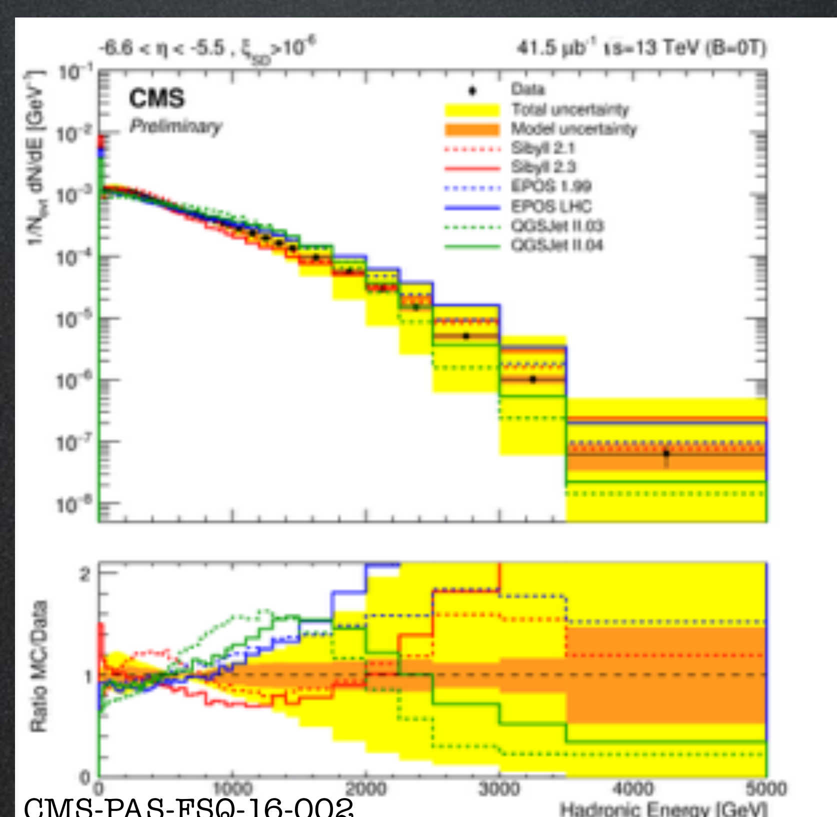
Models overall perform better

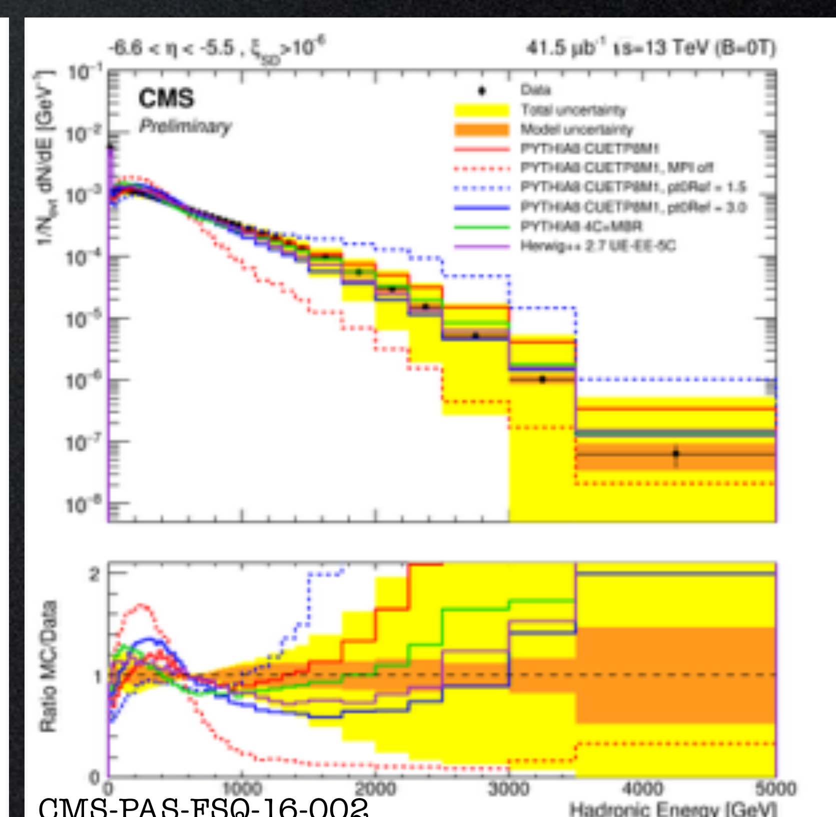
Sensitive to MPI

Hadronic

The bump comes from hadronic spectrum

Cosmic shower models better, but none predicts the entire shape well





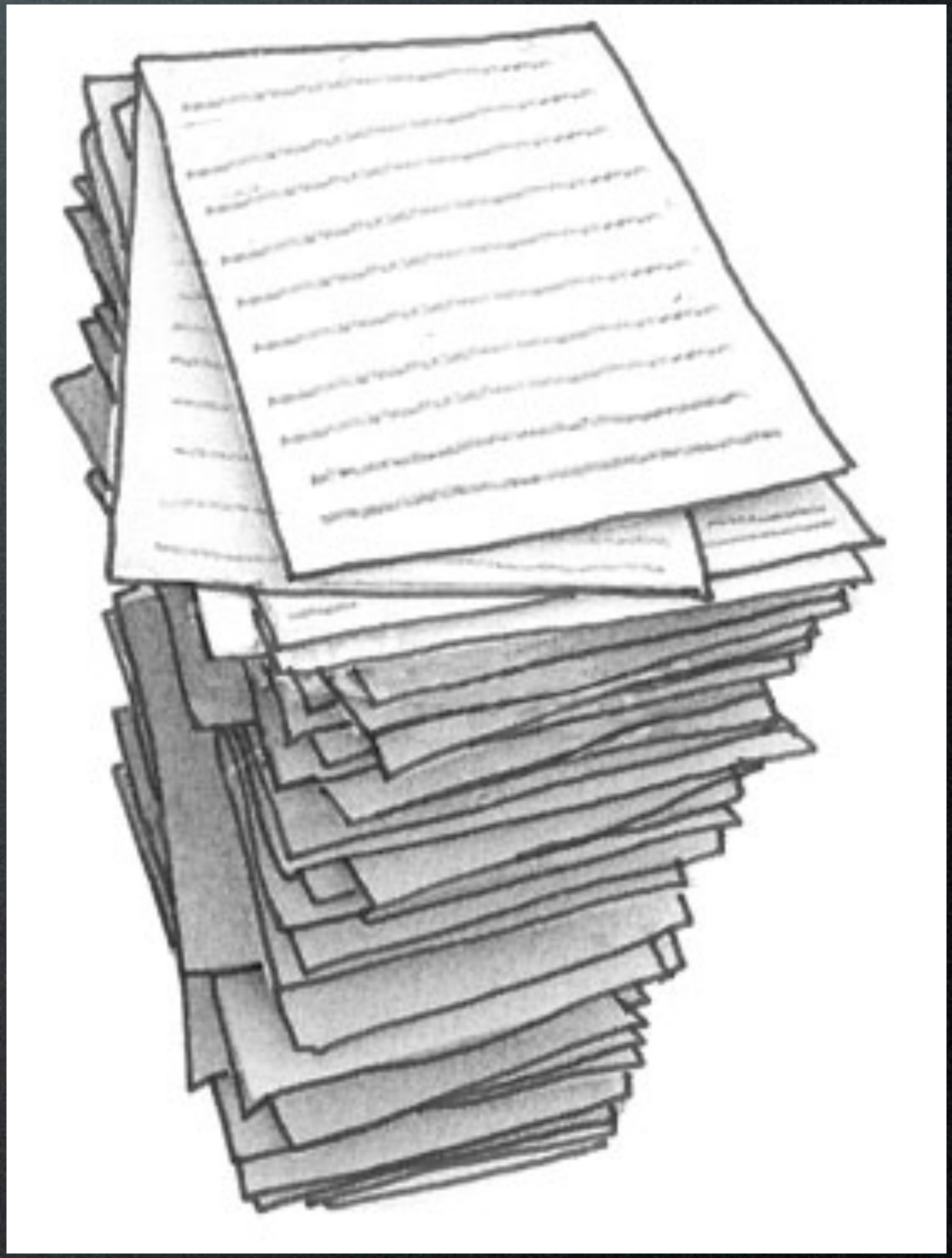
Summary

- A wide range of minbias measurements, both with charged and neutral particles have been performed with LHC Run 2 data.
- While none of the models considered is perfect for all observables and full ranges, many do a reasonable job.
- Energy evolution of Multiple Parton Interactions is historically a poorly understood parametrisation, but most models seem to perform well at this new highest collision energy.
- Important for pileup modelling, and constraining the Monte Carlo event generators.

References

- CMS MB: Phys. Lett. B 751 (2015) 143
- ATLAS 13 TeV MB: Physics Letters B (2016), Vol. 758, pp. 67-88
- ATLAS 13 TeV low-pT MB: arXiv:1606.01133
- ATLAS 8 TeV MB: Eur. Phys. J. C (2016) 76: 403.
- ATLAS A3 Tune: ATL-PHYS-PUB-2016-017
- CMS forward energy flow: CMS-PAS-FSQ-15-006
- CMS/Totem very forward energy flow: CMS-PAS-FSQ-16-002

Supporting Material



NEW PREDICTIONS (10 years)

1. QCD tests & applications will greatly improve, incorporating NLO, NNLO,...and a theory of fragmentation and hadronization.
2. Atlas and CMS will discover a candidate Higgs particle.
3. There will be convincing evidence for Susy particles.
4. Plans will be underway to build a LC (at Cern) to explore the superworld and the US will join CERN.
5. There will be direct detection of the Dark Matter wind.
6. Alice will see a crossover to the perturbative quark-gluon plasma.
7. Some new Z mesons will be discovered.
8. Gravitational waves and B modes will be observed.
9. String theory will start to be a **theory** with predictions.
10. We will have a plausible explanation of why Λ is so small.

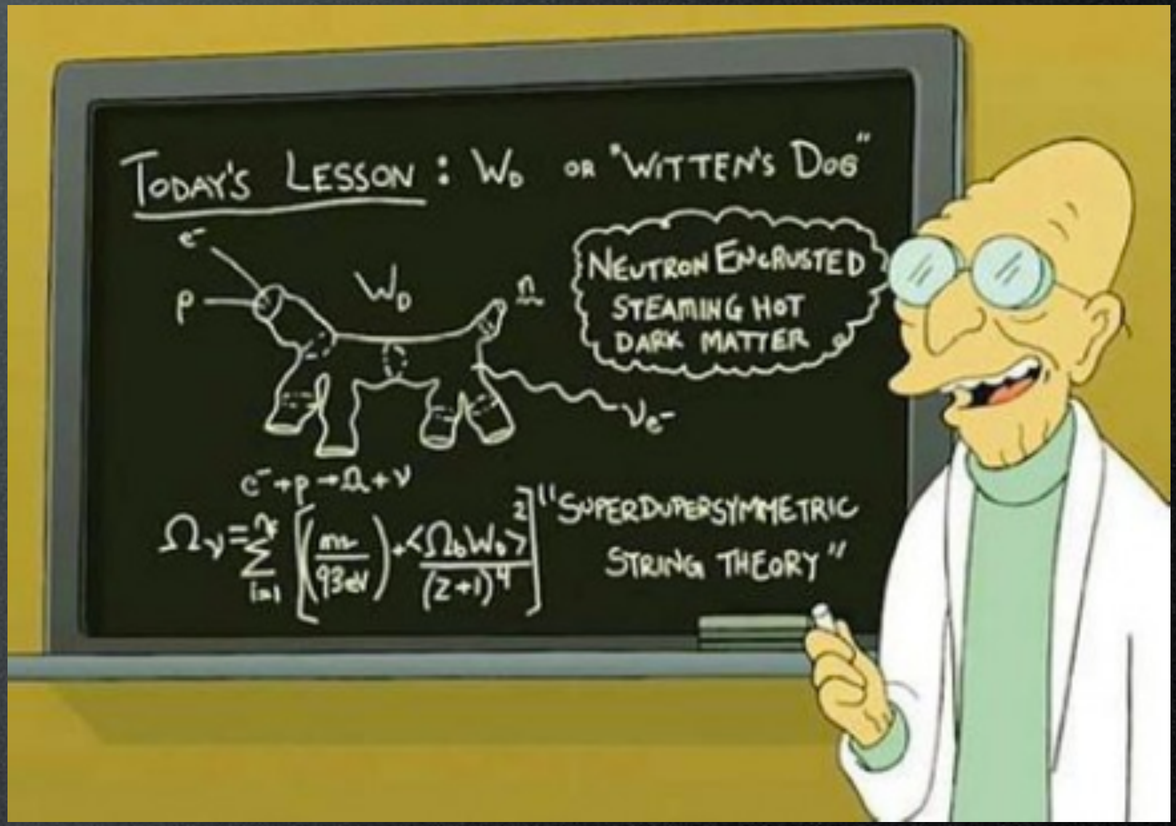
David Gross at EPS 2011

Detour: Event Generators

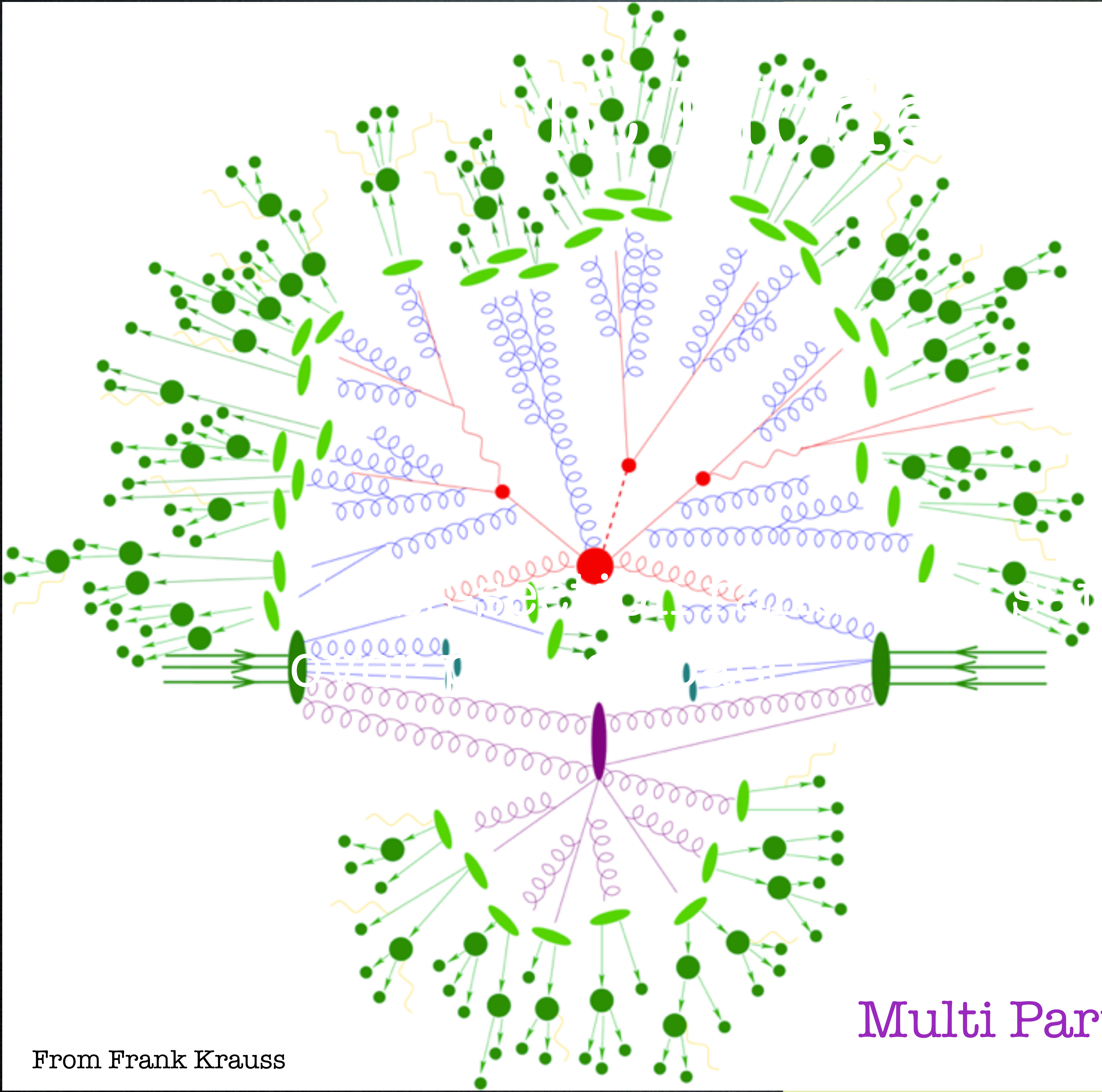
- We want realistic simulation of the collision events. To devise analysis strategy, background model, study/remove detector effect, etc.

- The hard scattering part can be calculated theoretically (in some order) .

- The soft part is not calculable, so we use phenomenological models implemented in Monte



Actually two step process, but not going to discuss detector simulation!



Hard Process

Parton Shower

Hadronization

Decays

Multi Parton Interaction

From Frank Krauss

Monte Carlo Models

- Leading order/Parton shower models: Trying to build up a complex 2->N final state by showers.
- Pieces of a Parton-Shower MC Generator: (2->2 hard scattering), ISR, FSR, MPI, Fragmentation, Hadronization.
- Examples: Pythia, Herwig family.
- Higher order/Multileg generators: Sherpa, Alpgen, MC@NLO, Madgraph, Powheg ...
- Generators used mostly for a specific process: Phojet (diffraction), HIJING (heavy ion), AcerMC (top), JHU (spin and polarization information)...

Tuning

- Ultimate goal: models need to describe real data.
- "Free" parameters control all these aspects of the models, which cannot be derived analytically.
- A bunch of correlated (or anti-correlated) parameters describe one aspect, so have to change them simultaneously.

Tune: A particular optimized parameter setting in a particular MC generator to match the simulation with available data. Differ according to which datasets are included.

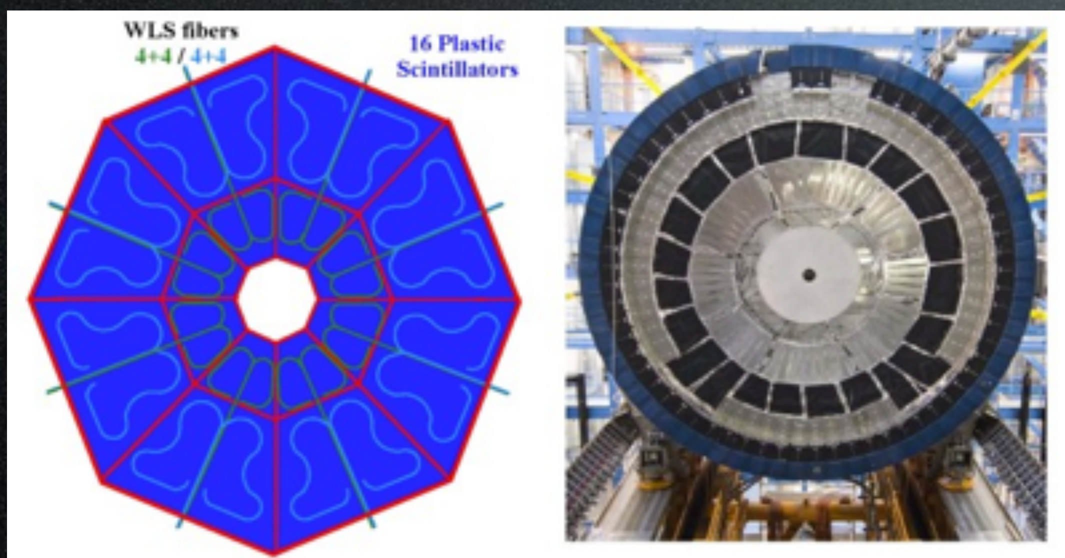
A Note on the Models

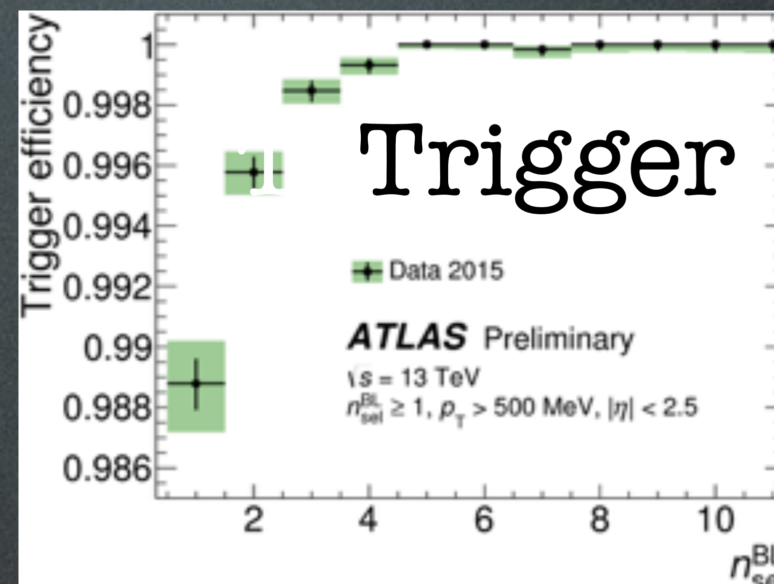
"The predictions of the model are reasonable enough physically that we expect it may be close enough to reality to be useful in designing future experiments and to serve as a reasonable approximation to compare to data. We do not think of the model as a sound physical theory . . . "

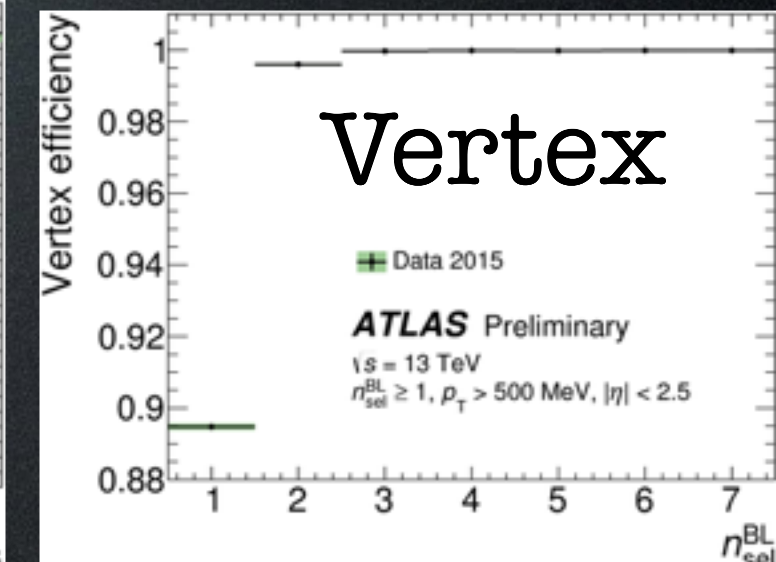
– Richard Feynman and Rick Field, 1978

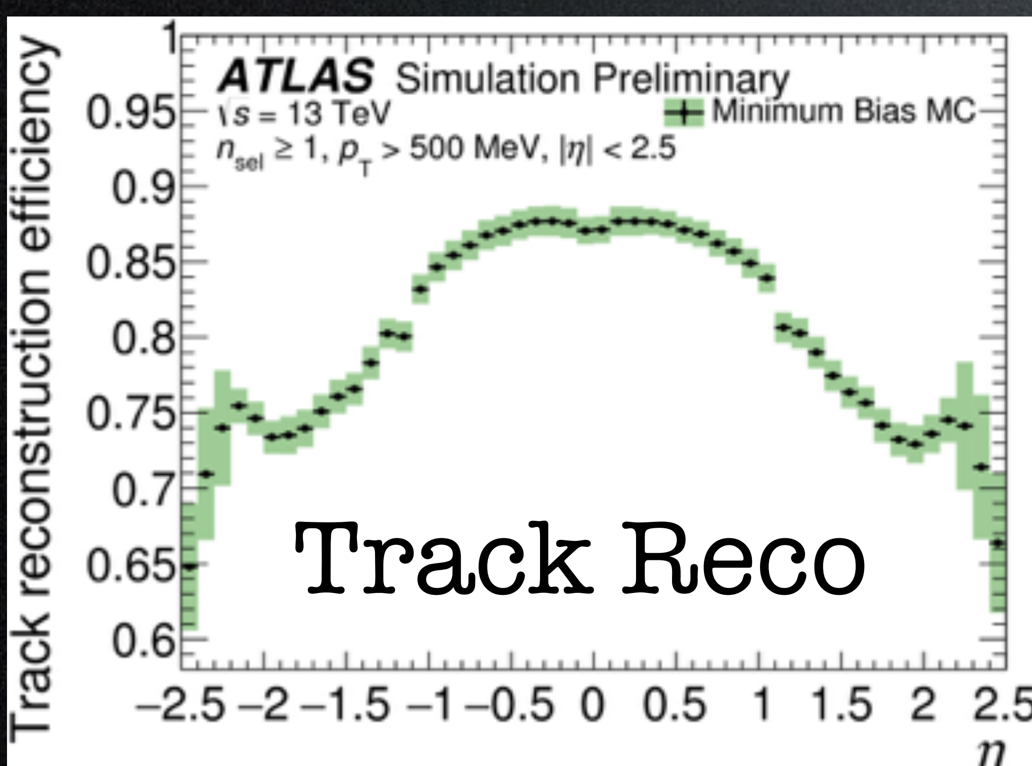
Charged Particle Distributions

MBTS - single side hit required









About 10M events, using low μ run

Tracks with p_T > 0.5 GeV and |η| < 2.5

Remove primary charged particles with 30 < τ < 300 ps (strange baryons)

Glossary

- Minimum-bias (MB): Pretty much everything, exact definition trigger dependent.
- Underlying event (UE): background to events with an identified hard scatter (more like the actual interesting events we want to look at)
- Pileup (PU): (uncorrelated) separate collisions within the same/different bunch crossing we can’t differentiate because of our finite detector resolution (more like “isotropic” min-bias events).