# Monte Carlo

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# Outline

- Modelling Minimum Bias and the Underlying Event
- Pythia confronting first ATLAS data
- Some remarks on MC tuning

# Modelling Minimum Bias and the Underlying Event

## Motivation

- Name suggests: most complete view on events at any experiment.
- As such an intellectual challenge to grasp complete picture: up to now no complete model, including total cross section, elastic scattering, diffraction, and inelastic particle production – instead phenomenological models with a plethora of parameters to tune.
- It's first day physics at the LHC, can put to test these models very quickly!
- Typically, there is an intimate connection between MB and UE (in MC's: same model, same parameters to be tuned to data – more later)
- Therefore: Immediate impact on jet physics, searches for new physics, etc.:
  - "Pollution" of jet signatures through UE
  - Rapidity gaps and their surviving probability in VBF production of Higgs bosons (huge impact from UE)
  - Rapidity gaps and their survival probability in central exclusive production of Higgs bosons (huge impact from soft particle production mechanisms)

# Models for MB and UE (in some formal language)

Typically based on eikonal picture:

- Optical theorem relates total cross section with elastic scattering amplitude

$$\sigma_{\mathrm{tot}}(s) = \frac{1}{s}\,\mathrm{Im}[\mathcal{A}(s, t=0)]$$

- Fourier transform of amplitude and rewriting FT $a(s,\,\vec{b}_\perp) = \frac{e^{-\Omega(s,\vec{b}_\perp)} - 1}{2i}$
- yields total cross section as function of eikonal (similar expressions for elastic scattering, low mass diffraction)

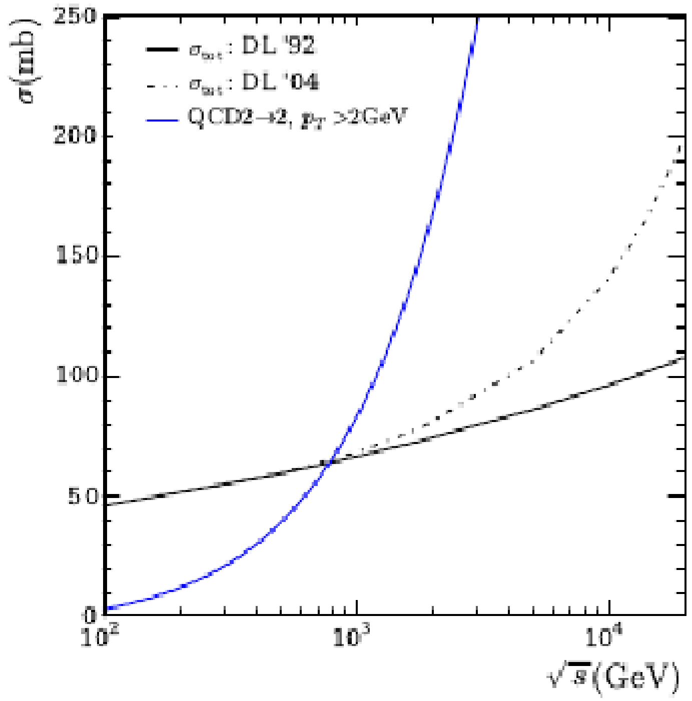
$$\sigma_{\mathrm{tot}}(s) = 2\int \mathrm{d}^2 b_\perp [1 - e^{-\Omega(s,\vec{b}_\perp)}]$$

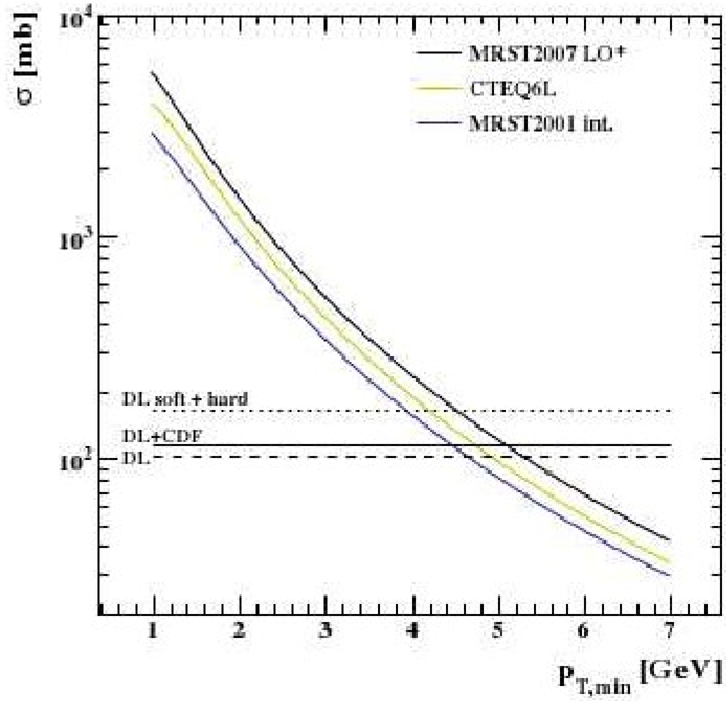
- Write eikonal as sum of soft and hard part: $\Omega(s,\vec{b}_\perp) = \Omega_S(s,\vec{b}_\perp) + \Omega_{\mathrm{H}}(s,\vec{b}_\perp)$
- Write hard part as $\Omega_{\mathrm{H}}(s,\vec{b}_\perp) = \frac{1}{2}\,\rho(\vec{b}_\perp)\,\hat{\sigma}_{2\to 2}(s)$
- Take $\hat{\sigma}_{2\to 2}(s)$ from pert. QCD (including PDF's, strong coupling constant), cut in phase space ($p_T$) to ensure cross section stays finite (see next slide).
  In Pythia this introduces at least two parameters: a cutoff $p_{T,0}$ at a reference scale and the energy extrapolation of it, typically of the form $p_T = p_{T,0}\exp[\eta\log(s/s_0)]$
- Parametrise parton density with form factors (another source of parameters)
- In Herwig: Add soft eikonal to add up to total cross section, below cutoff $p_{T,0}$

# Models for MB and UE (cont'd)

Realisation in Monte Carlo:

- For low $p_{T,0}$ (around 5 GeV at Tevatron and LHC), partonic cross section exceeds hadronic one: interpreted as multiple scattering.
- Create number of scatters as Poissonian in ratio of cross sections.
- Huge impact of cut-off, PDFs and of $\alpha_s$, should be systematically treated.



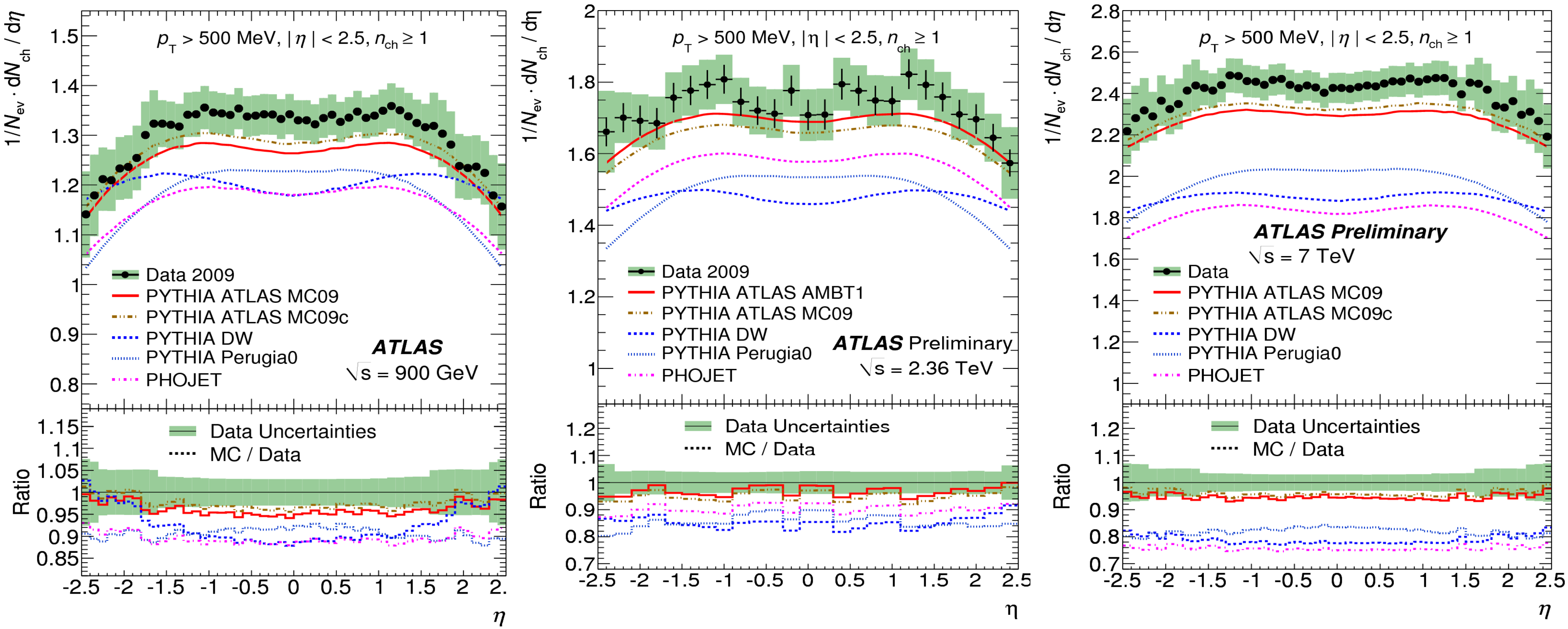




- Stress: **Changing cut-off or PDF or strong coupling will ruin the tune!**

(Disclaimer: I'll talk in the following mainly about Pythia and Atlas)

# Performance of pre-LHC tunes in MinBias:

- Typically based on Tevatron MB and UE data and on STAR pp data
- ATLAS MinBias data at 900 GeV, 2.36 TeV, and 7 TeV
- Cuts: $p_T$>500 MeV, 1 charged track in detector acceptance
- Rapidity distributions (Note: AMBT1 is ATLAS' new tune – see later):



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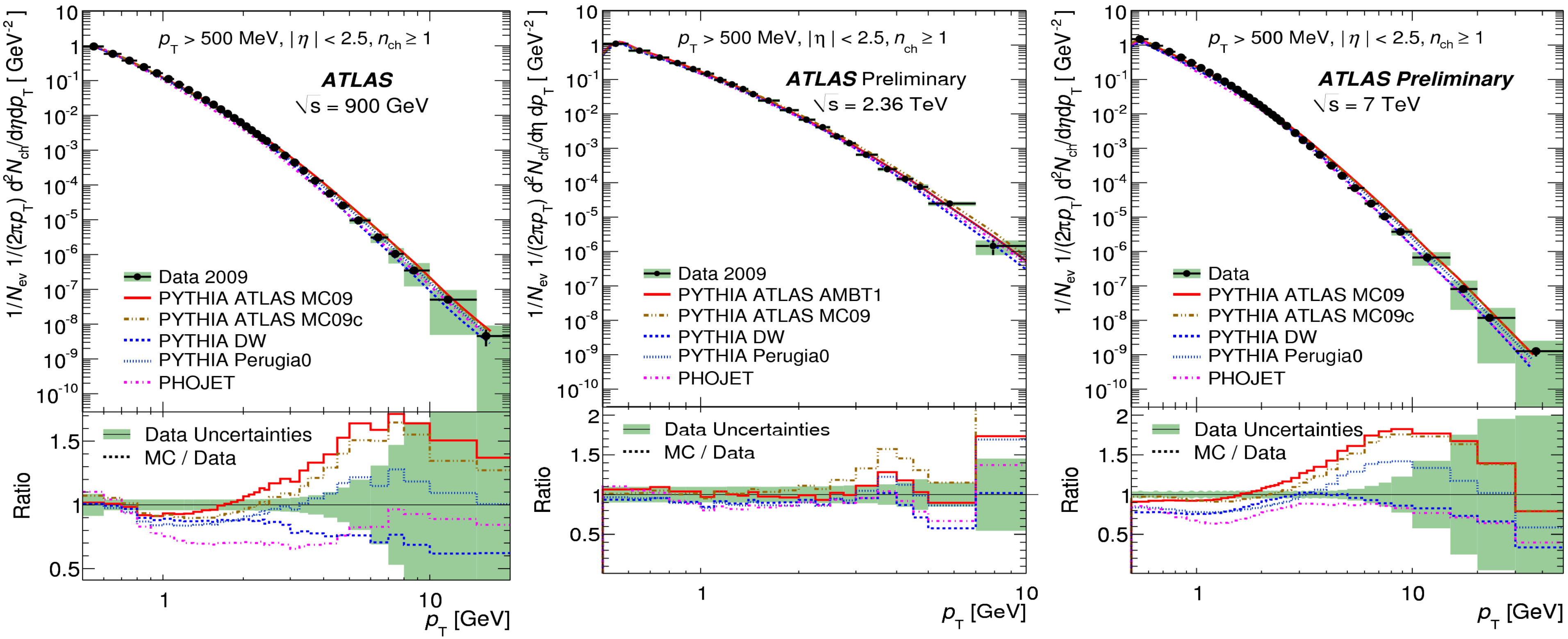

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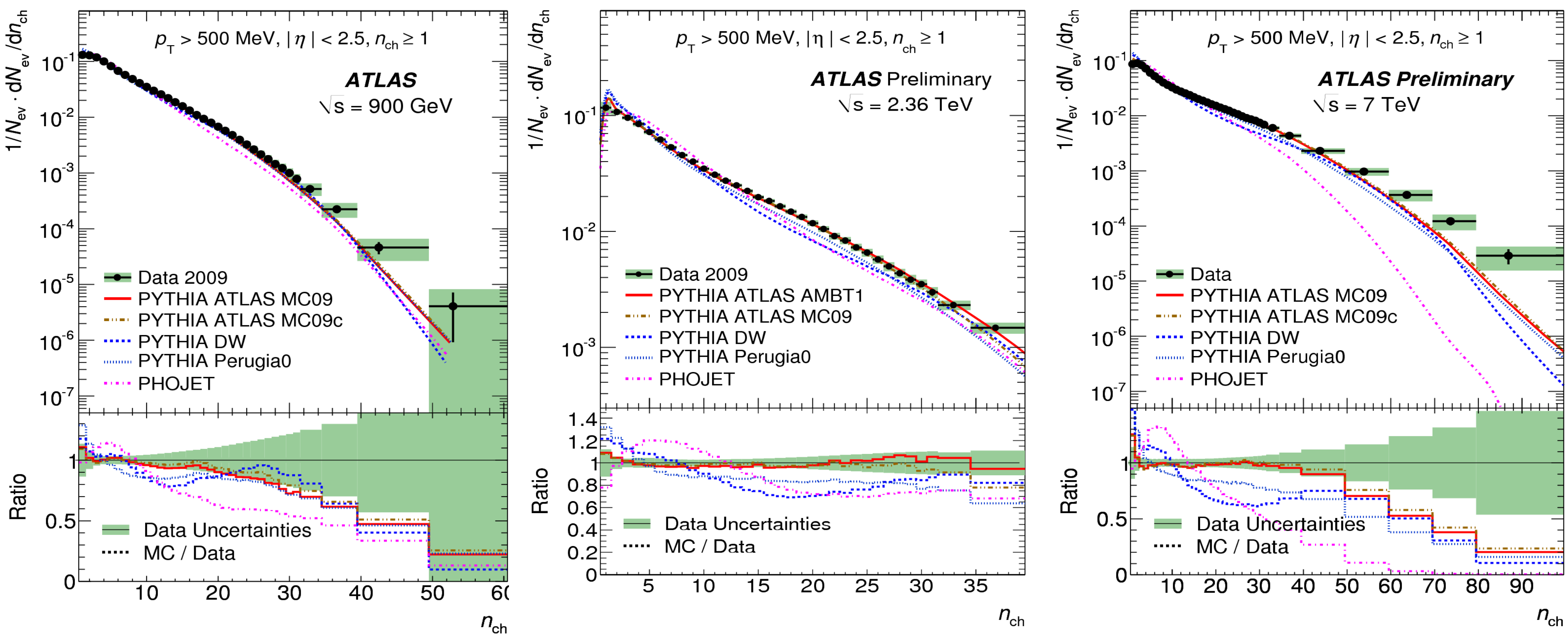

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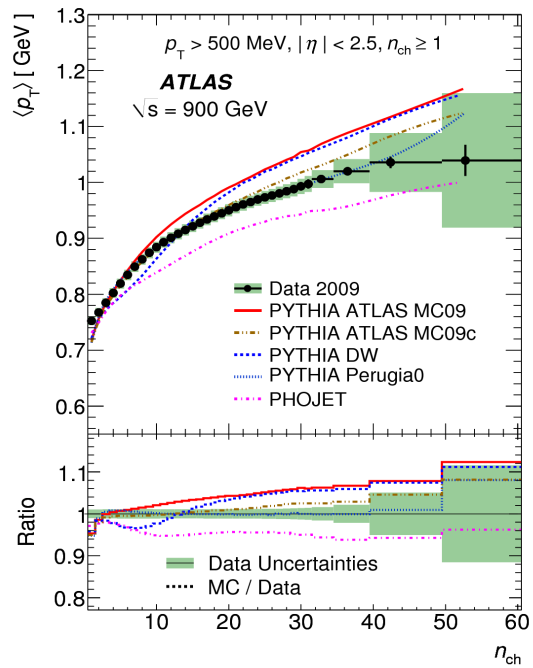
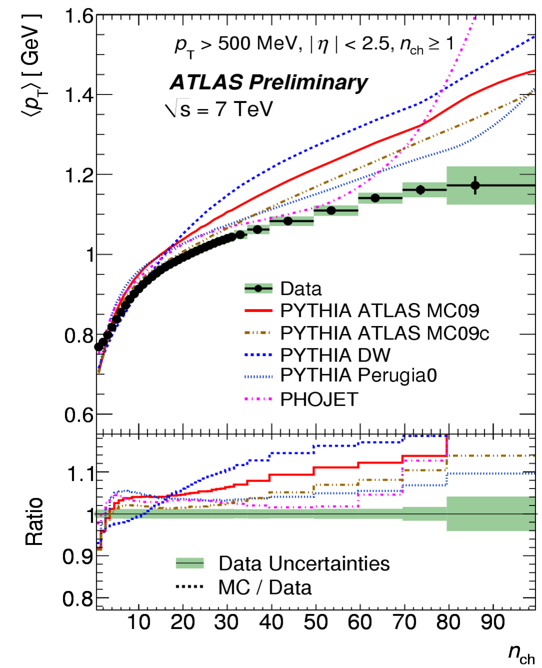
# Performance of pre-LHC tunes in Min Bias - Summary

- In high-multi events, the average transverse momentum tends to be too large
- Trend increases with hadronic c.m. Energy
- Very rapid increase seen with Phojet – model surprisingly seems to have problems with high c.m. energies

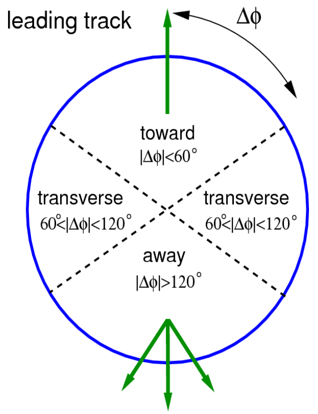


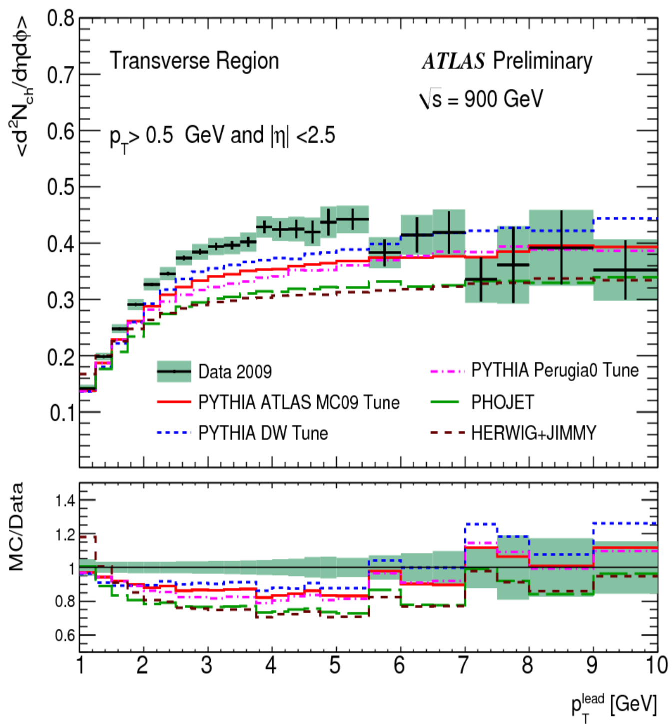



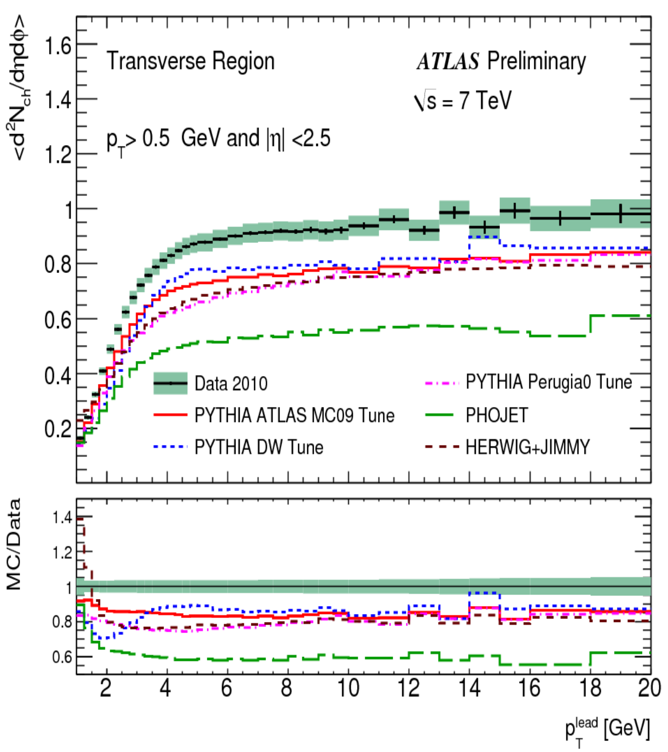

- Typically undershooting multiplicities by few % - 20% (Perugia)
- ATLAS MC09 Tunes perform best, but some shape in $p_T$ distributions – overshooting at around 10 GeV (by around 50%), with a slight dip at around 1 GeV.
- Surprising since 900 GeV data well in STAR→Tevatron extrapolation
- Common feature: overshoot of varying size at very low multiplicities (<5 or so): → must improve treatment of diffraction (not treated in the Pythia model)
- Phojet not very good – I wonder why anyone uses it, rather than, e.g. Herwig+Jimmy

# Performance of pre-LHC tunes in Underlying Event:

- Typical Tevatron-like Underlying Event analysis:
  - Orient events according to hardest track, with $p_{T,min}$ > 1 GeV
  - Use only particles with $p_T$>500 MeV, |η|<2.5
  - Particularly interesting: Transverse regions, multiplicity densities and total momentum transverse momentum
  - Towards and away test jet fragmentation



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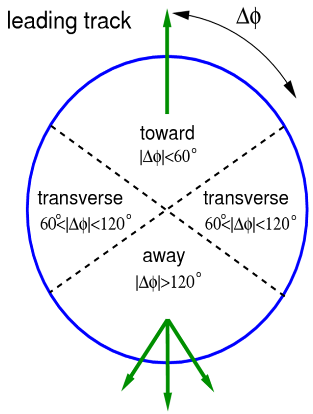
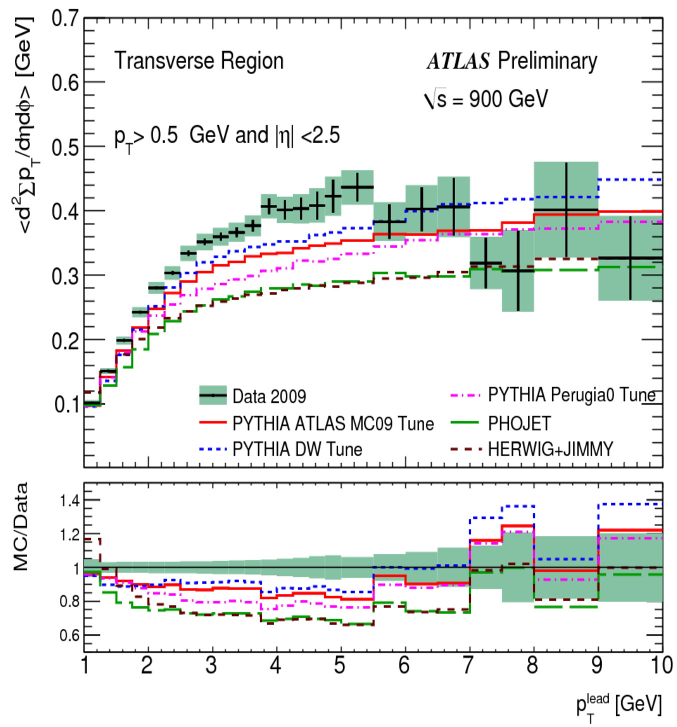
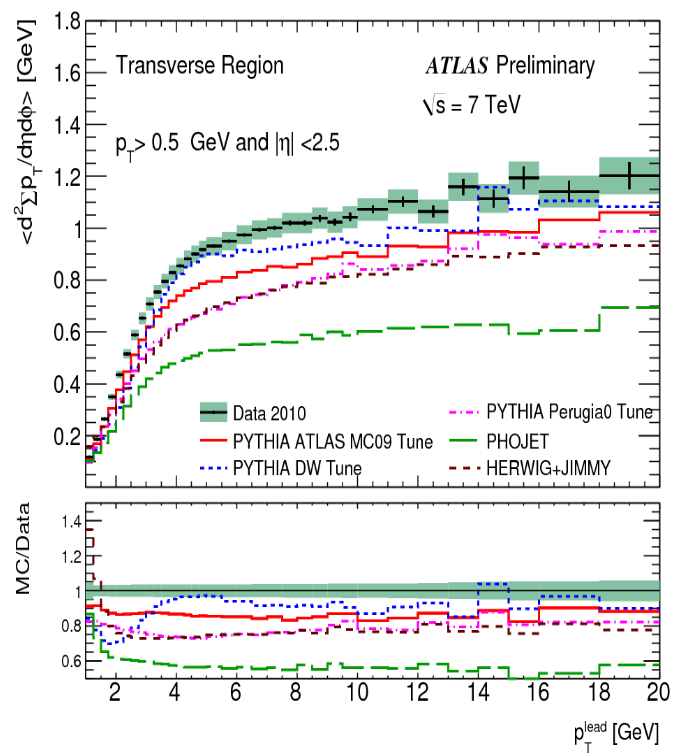
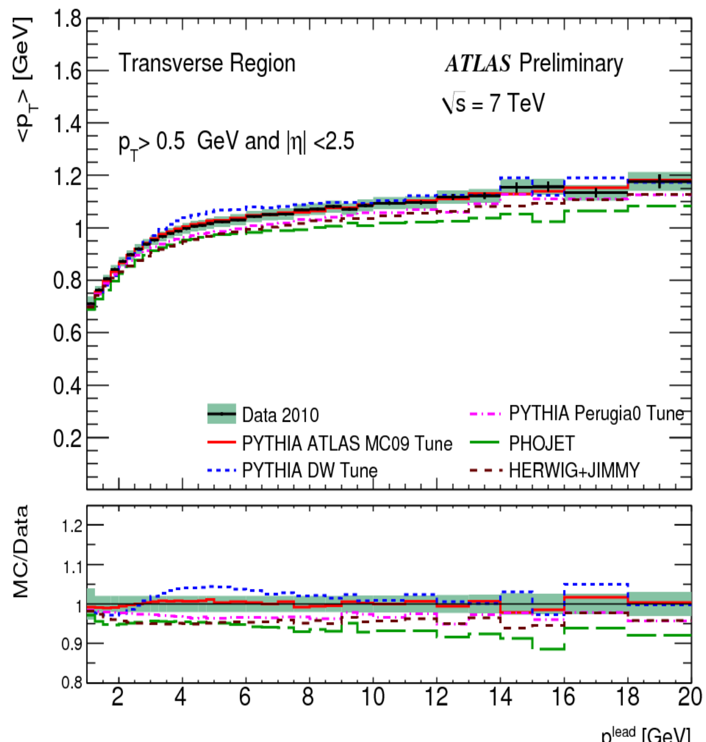


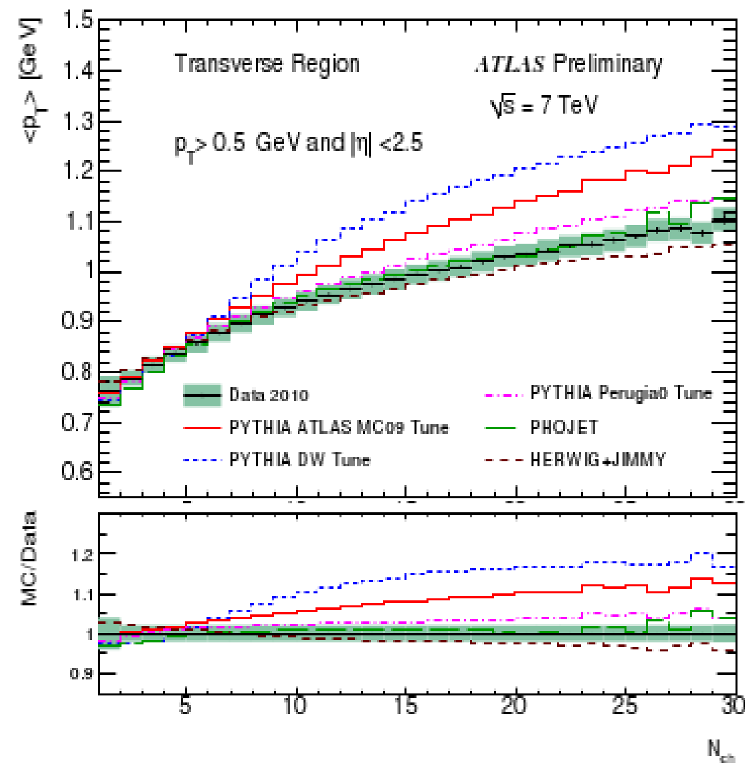



# Performance of pre-LHC tunes in Underlying Event - Summary:

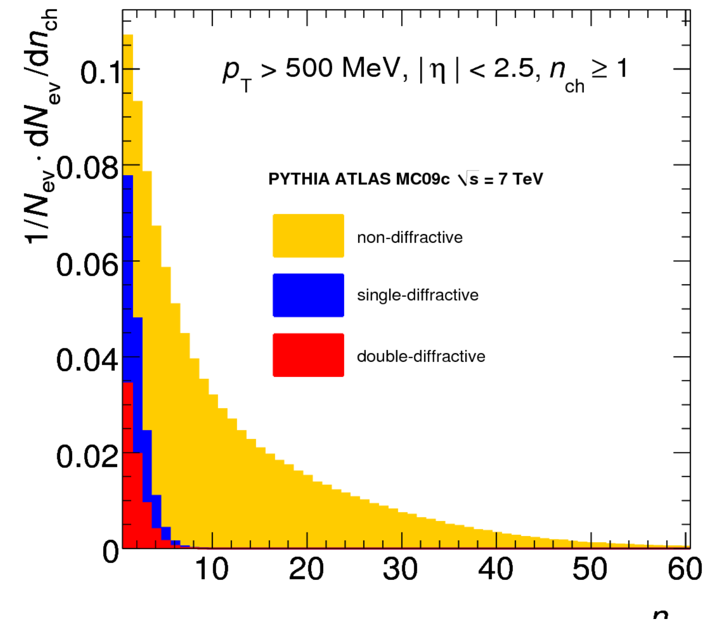
- Consistent picture: AMBT performs slightly better than Perugia, but roughly on the same footing as DW (in MinBias, DW was significantly worse).
- Again: Undershooting multiplicities and summed transverse momentum in transverse region by up to 20% (AMBT)
- Again: mean transverse momentum increases too fast with multiplicity, but, surprisingly, seems okay with leading track $p_T$
- Again: Phojet undershoot badly, both multi and $p_T$ at large c.m. energies

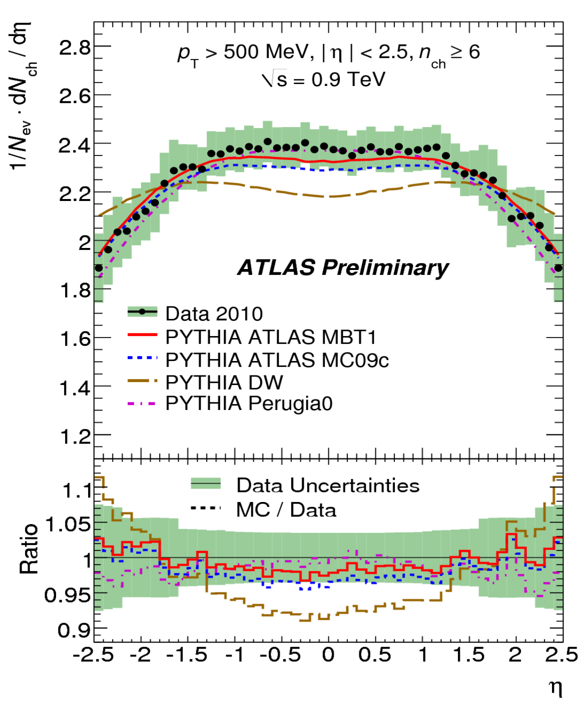


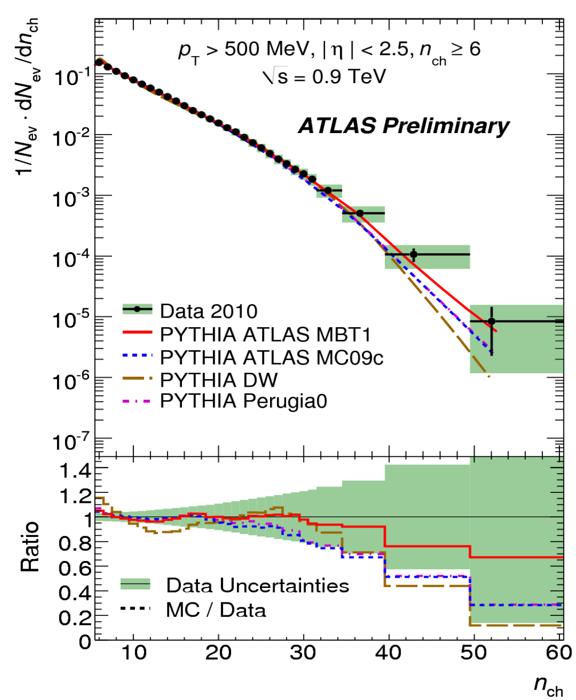



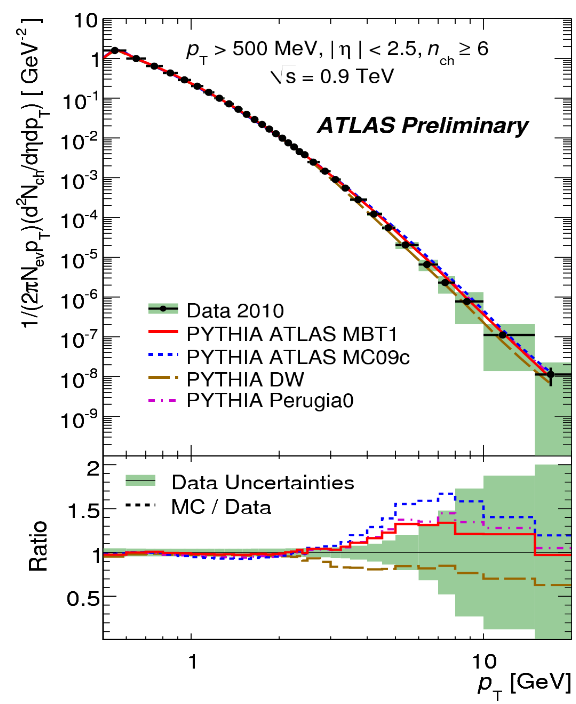
# Improving the tuning with LHC data:

- Realise that a good fraction of low multi events are diffractive – this is beyond the scope of the naïve Pythia and Herwig models, which base on perturbative QCD (hard eikonal).
- Therefore: Adapt cuts.
- ATLAS' choice in new tune: demand at least 6 charged tracks → AMBT1 tune
- Description improves significantly (900 GeV)



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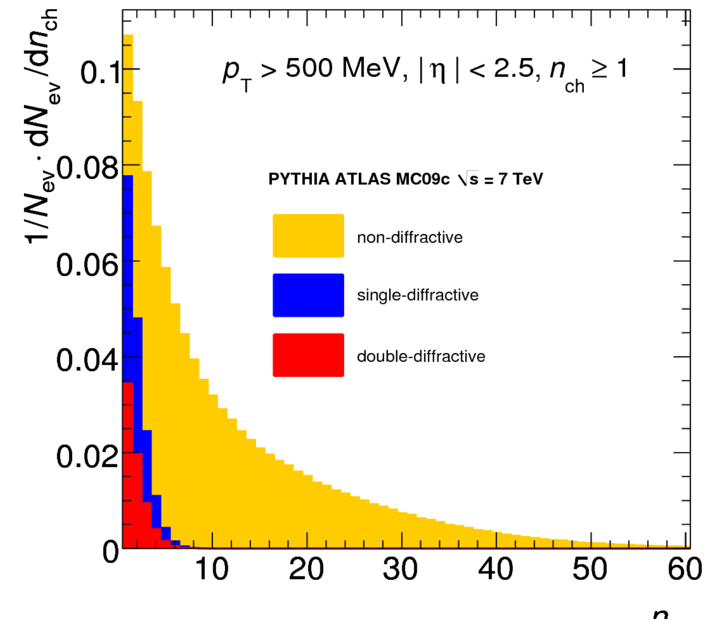
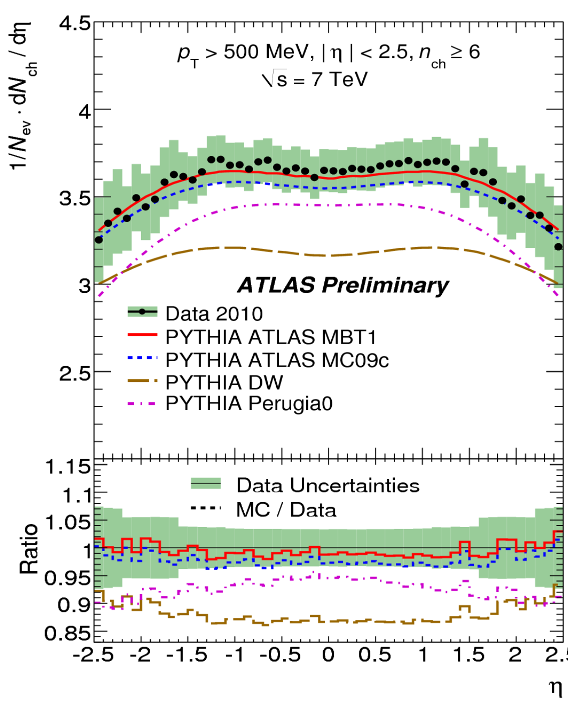
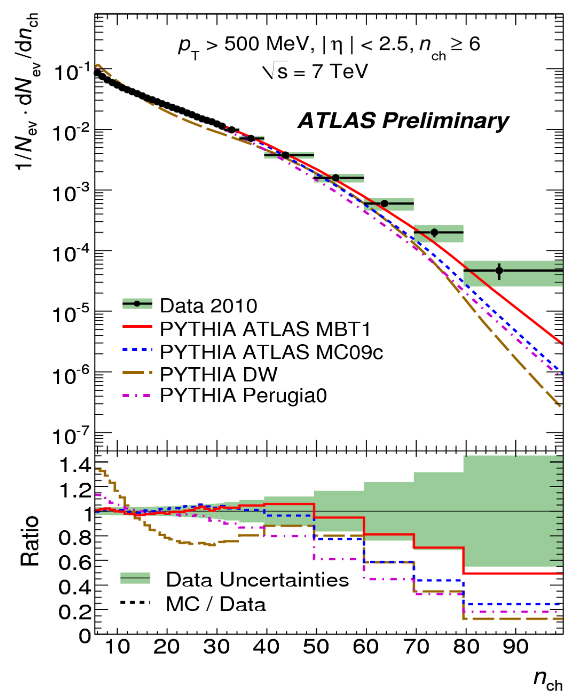
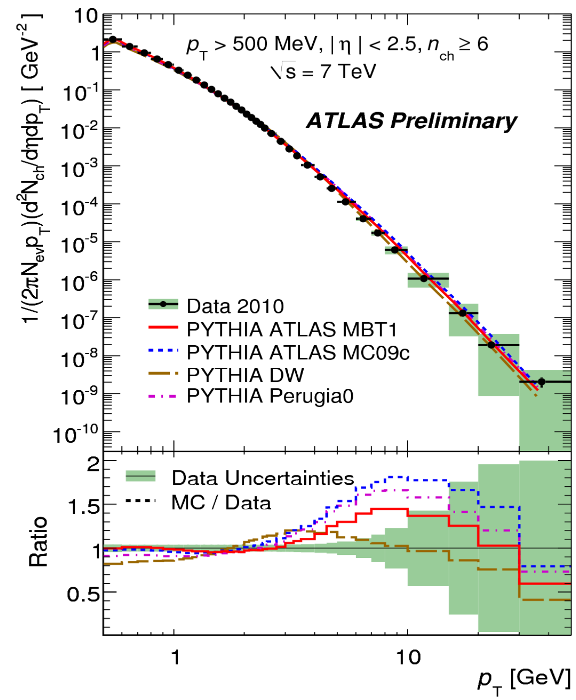


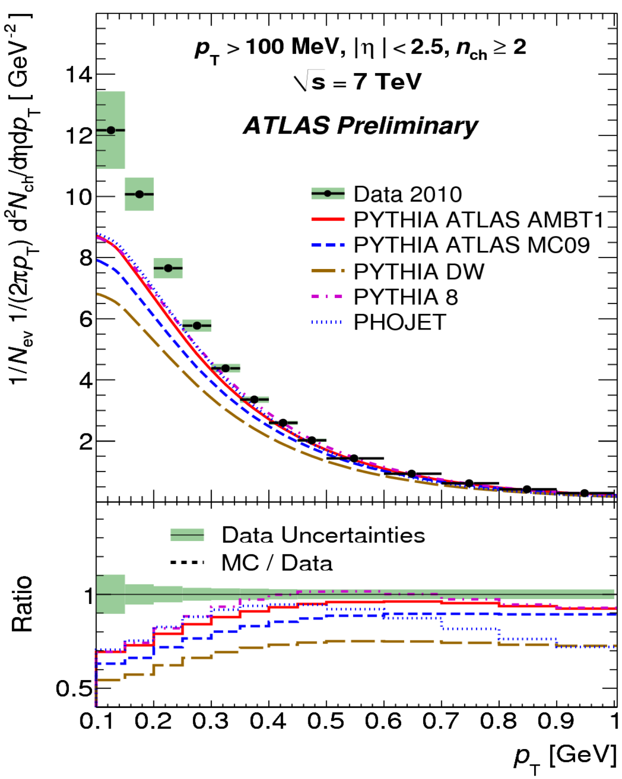



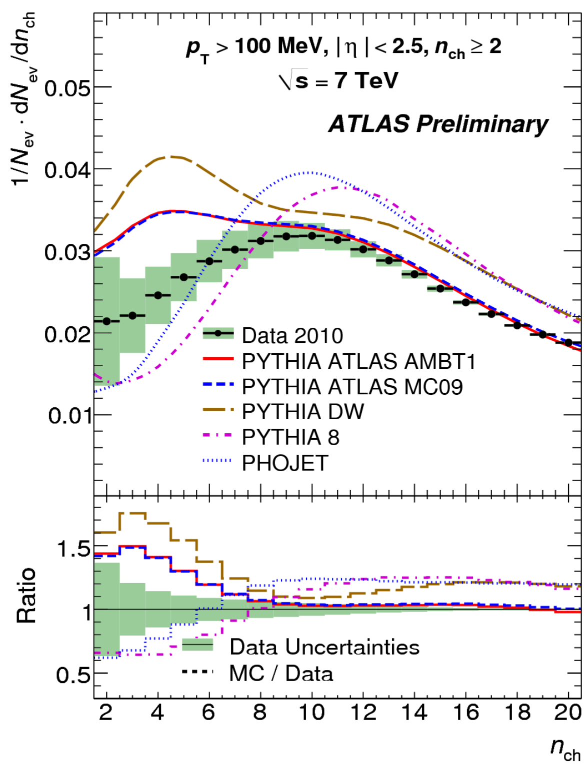



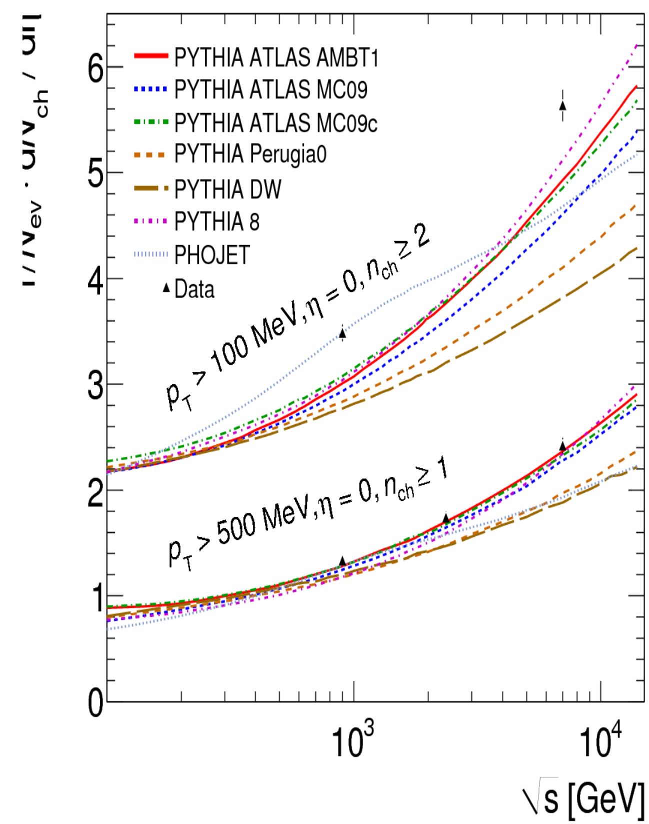



# Performance of tunes in MinBias with changed sample:

- Cuts: $p_T$>100 MeV, 2 charged tracks in detector acceptance
- $P_T$-spectrum too soft, some shapes in low multi bins, multiplicity undershoot worsens
- But still it seems as if new tune AMBT1 performs best (not perfect, but pretty good)

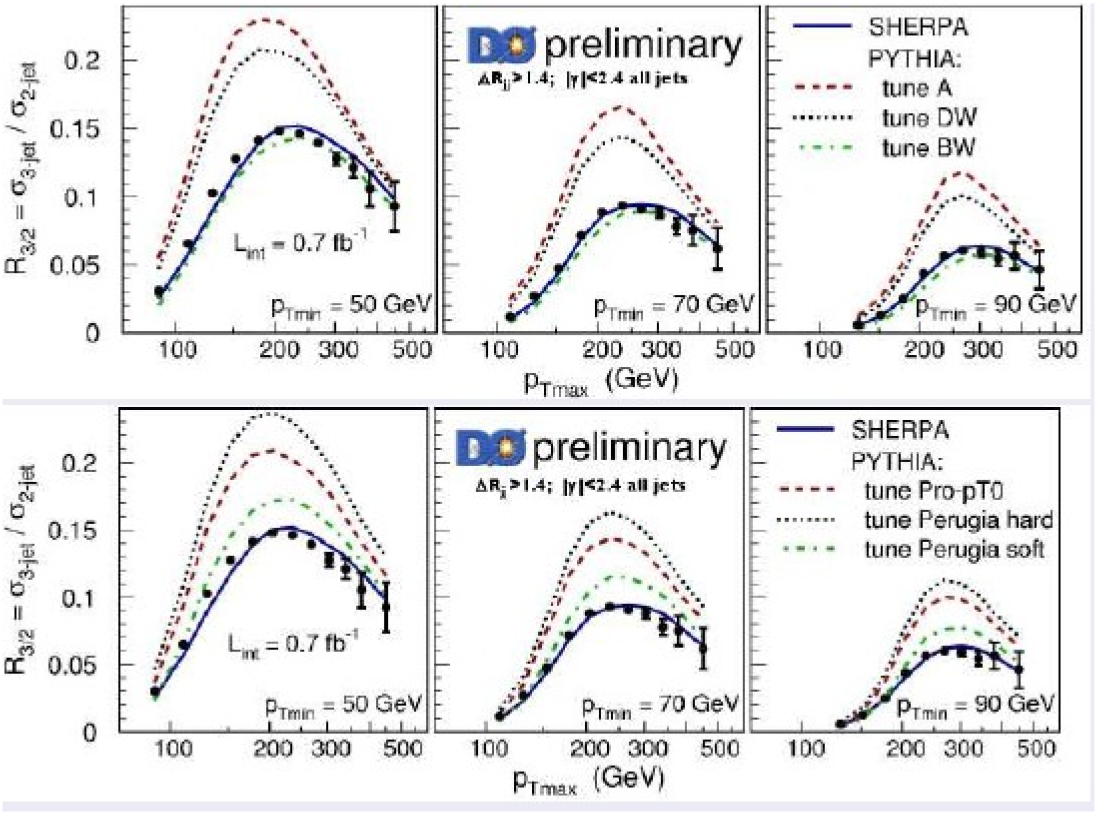


# Some general remarks on tuning:

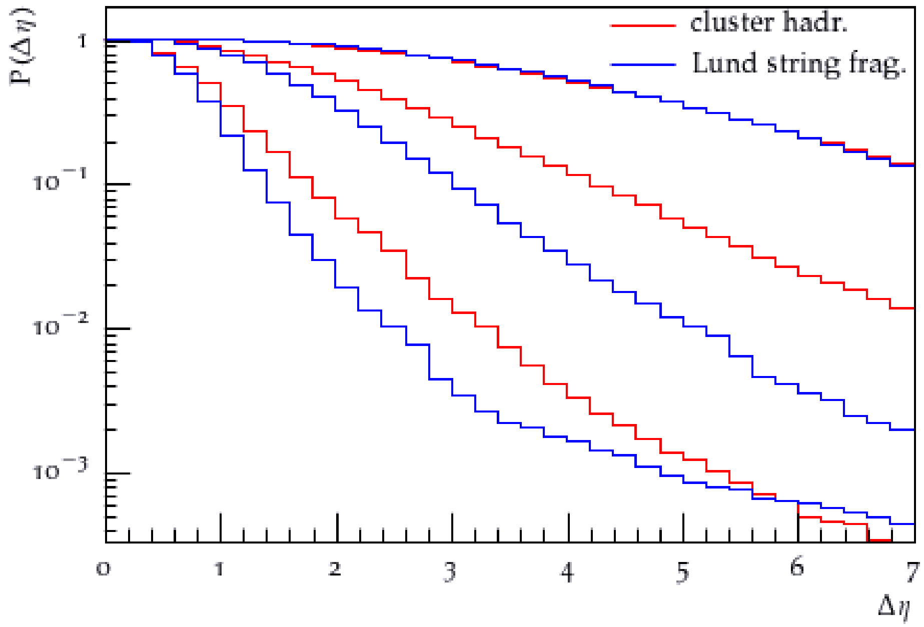
- Clearly, with enough parameters, expert tuning can significantly improve description of some subsets of data – but it will have implications on other data sets.
- As an example consider $R_{32}$, the three-to-two jet rate at D0.
- Two parameters: $p_{T,max}$ of leading jet and minimal jet transverse momentum $p_{T,min}$
- In Pythia tunes strong coupling gets modified (in fact, Pythia has more than one $\alpha_S$ floating around).
- In addition, various scale factors enter in the parton shower, enhancing phase space for various parts of the emission pattern
- This also impacts on merged samples, e.g. with Alpgen or Madgraph, leading to some inconsistencies (see talks at V+jets workshop in Durham)



# A remark on dealing with diffraction:

- Also note that there is some ambiguity in how diffraction is treated.
- Typically, inelastic cross sections are an order of magnitude or more above various diffractive ones.
- Due to fluctuations in hadronization, however, inelastic events can mimic diffraction.

- Figure to the right:
  - Sherpa simulation with Lund string and native cluster fragmentation, both tunes to LEP data.
  - Lund better describes LEP data, cluster is better for DIS at HERA.
  - Figure shows probabilities to find a rapidity gap in inelastic events, with no tracks above 100, 500 and 1000 MeV (bottom to top), at 7 TeV LHC



# Conclusions and Outlook:

- Please **present data**
  - detector corrected,
  - with clear, tractable and well-documented cuts
  - without any extrapolation

(Well done, ATLAS!)

- Please give numbers to Hepdata base – this will allow the MC authors to respond quickly, without wasting M.Whalley's time to read data off public conference notes.
- If possible, add your analysis to Rivet.
- The last word on modelling Minimum Bias and Underlying Event is not yet spoken – I still hope for a consistent model incorporating total xsecs, diffraction, and jets with few (less than 10) parameters.