Monte Carlo

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UK HEP Forum “LHC first results and outlook”

www.ippp.dur.ac.uk

Outline

- Part I: What we've learnt so far
  - Modelling Minimum Bias and the Underlying Event
  - Pythia confronting first ATLAS data
  - Some remarks on MC tuning

- Part II: further improving the MC's
  - Herwig++: Status
  - Sherpa: Status and future plans

Part I: What we've learnt so far

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

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

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

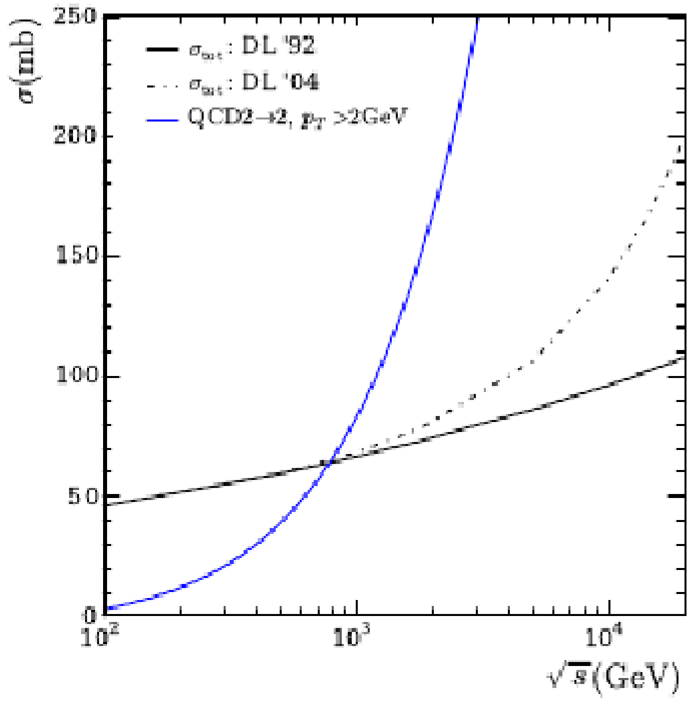
$$\sigma_{\rm tot}(s) = 2\int {\rm d}^2 b_\perp [1 - e^{-\Omega(s,\vec{b}_\perp)}]$$

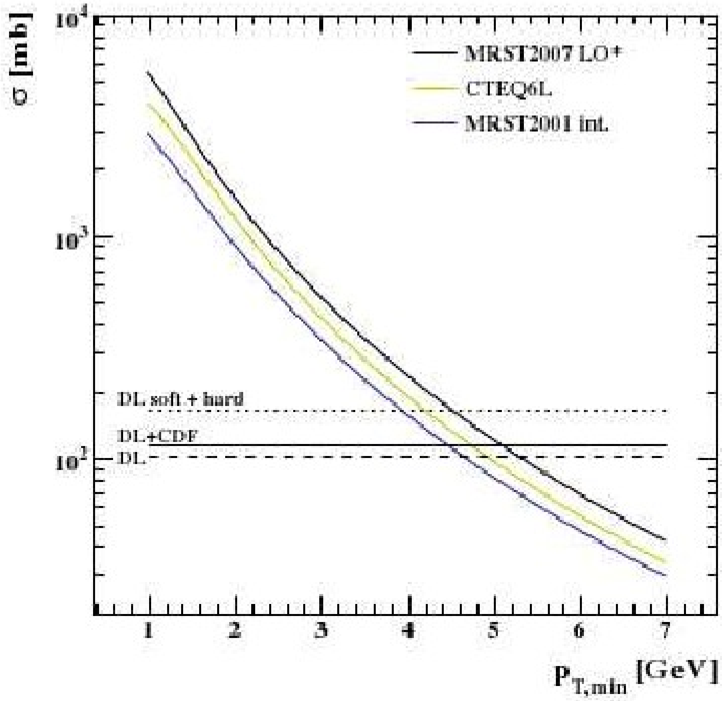
- Write eikonal as sum of soft and hard part: $\Omega(s,\vec{b}_\perp) = \Omega_S(s,\vec{b}_\perp) + \Omega_{\rm H}(s,\vec{b}_\perp)$
- Write hard part as $\Omega_{\rm H}(s,\vec{b}_\perp) = \frac{1}{2}\,\rho(\vec{b}_\perp)\,\hat{\sigma}_{2\to 2}(s)$
- Take $\hat{\sigma}_{2\to 2}(s)$ from pert. QCD (including 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 α_s, should be systematically treated.



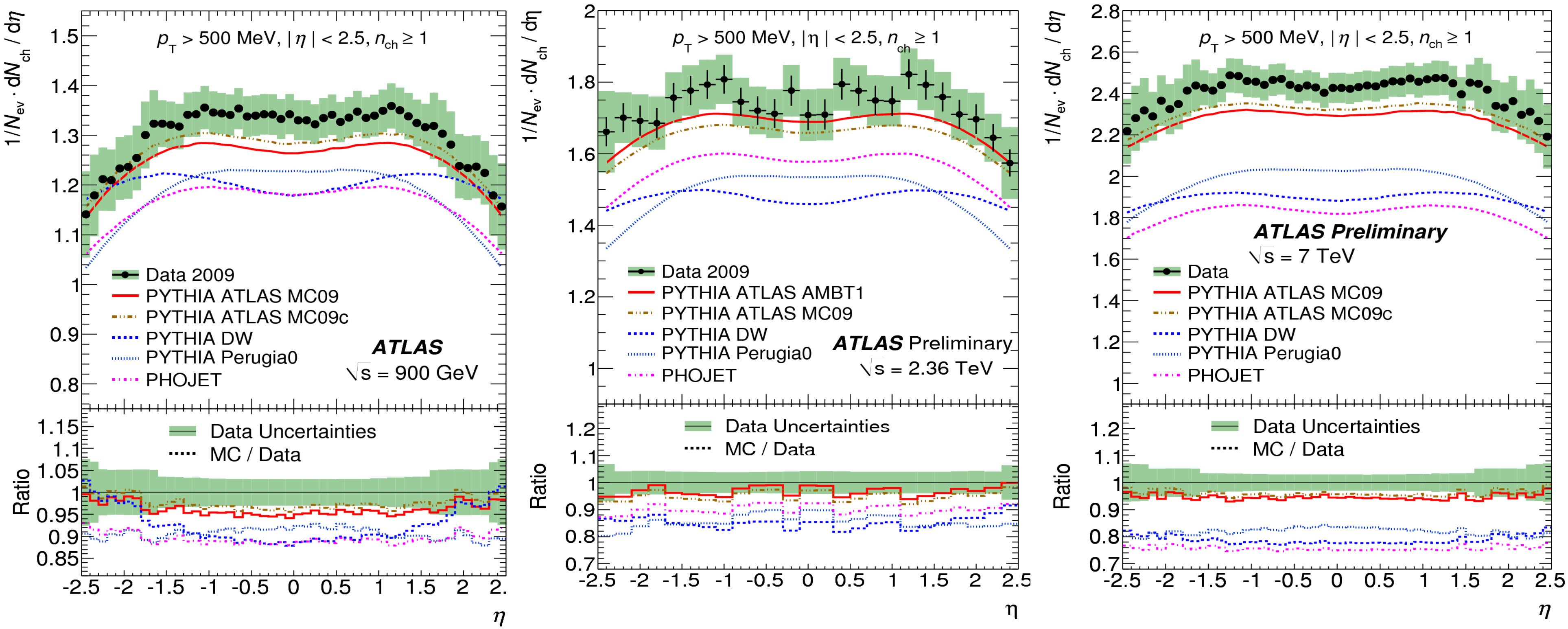


- Stress: **Changing cut-off or PDF or strong coupling will ruin the tune!**

(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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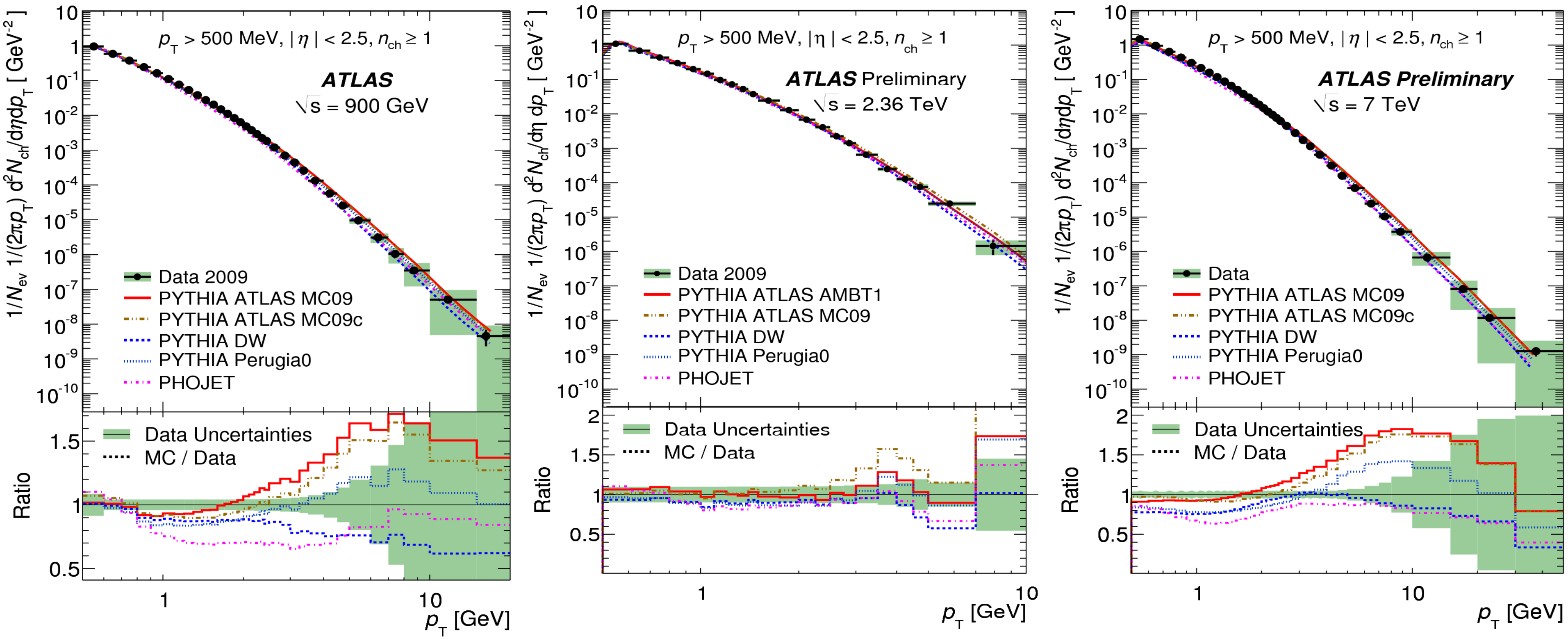

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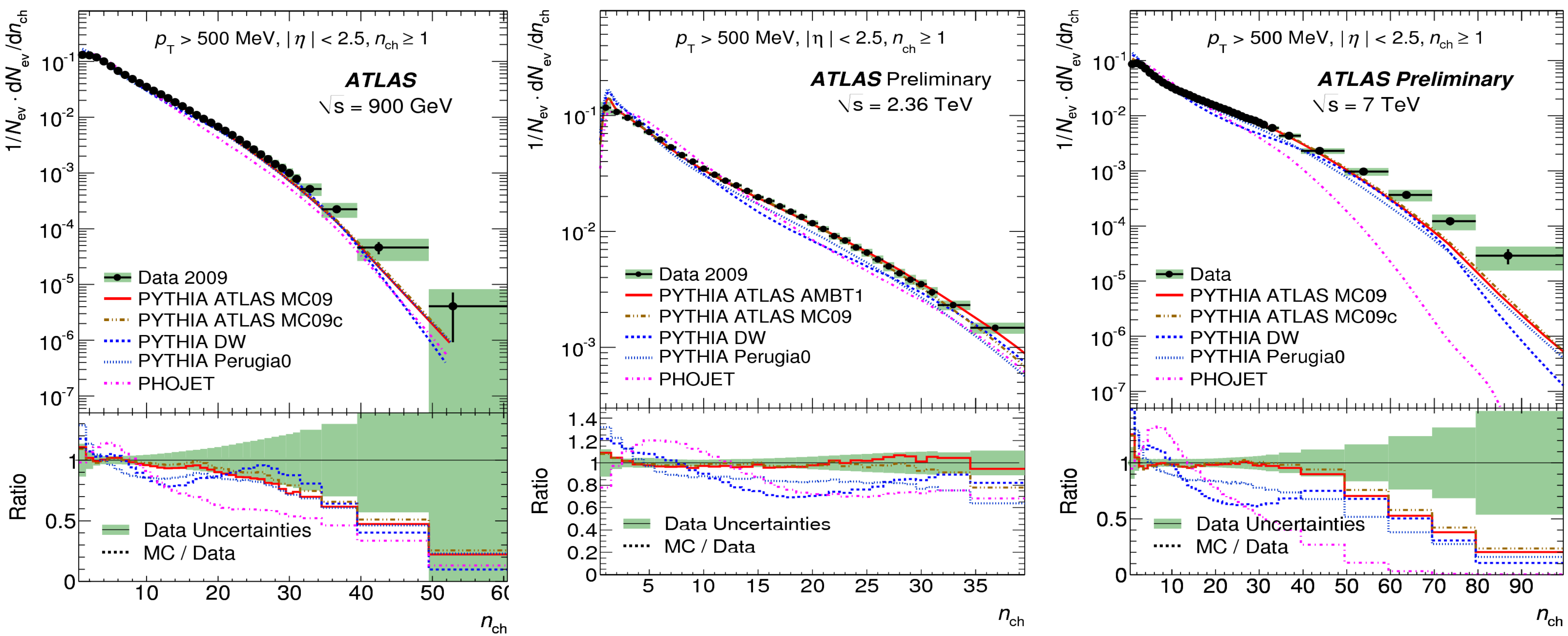

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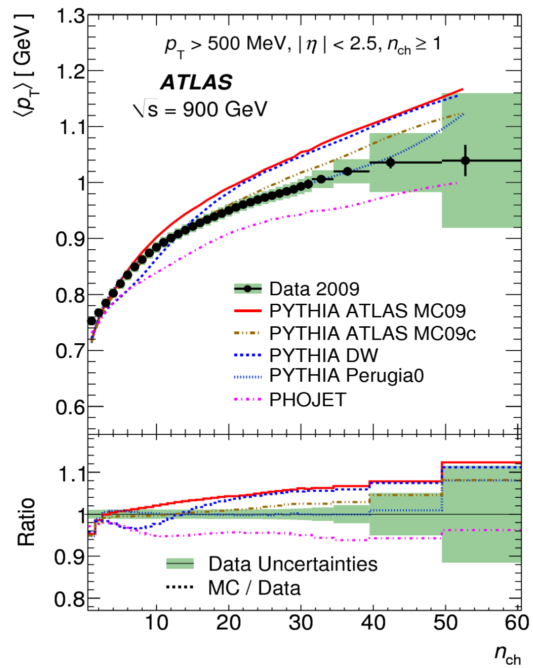
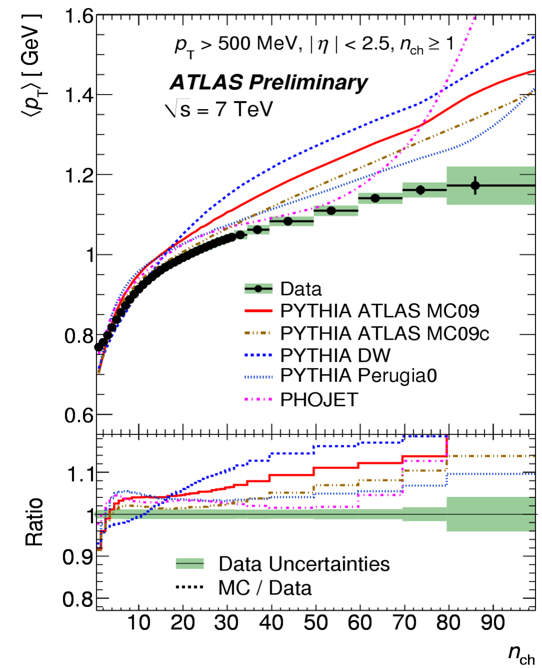
Performance of pre-LHC tunes in Min Bias - Summary

- 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

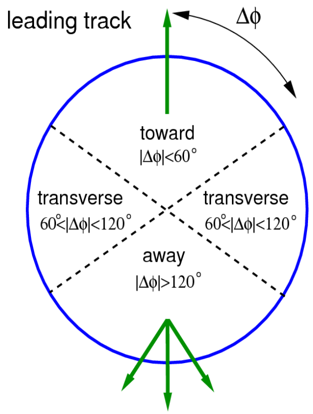


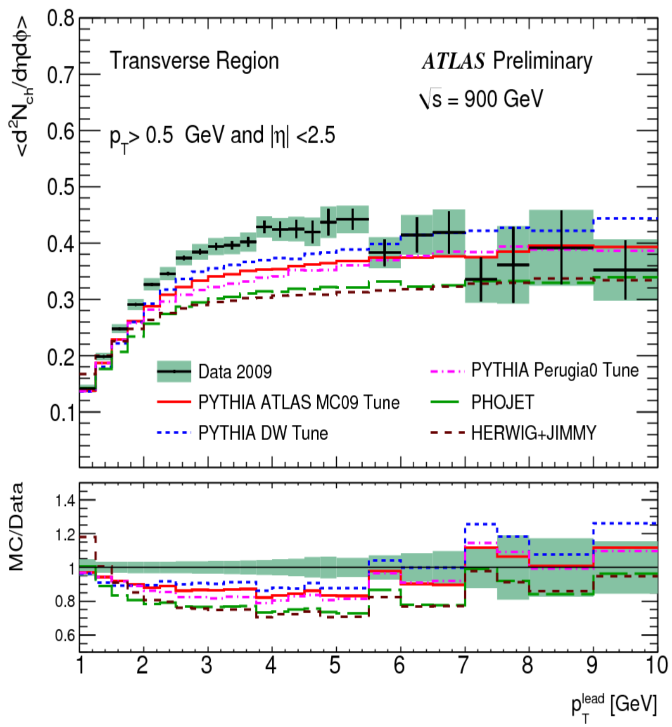


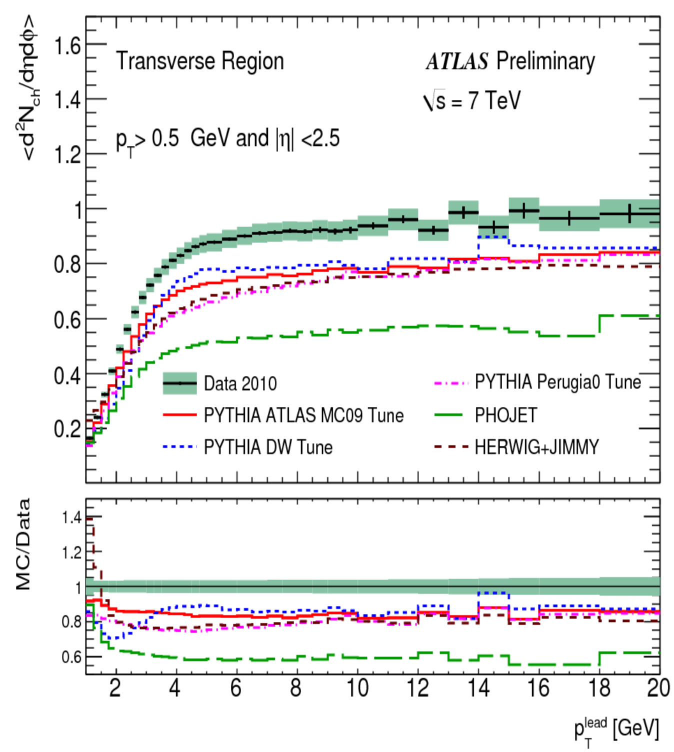
- Typically undershooting multiplicities by few % - 20% (Perugia)
- ATLAS MC09 Tunes perform best, but some shape in p_T distributions – overshooting at around 10 GeV (by around 50%), with a slight dip at around 1 GeV.
- Surprising since 900 GeV data well in STAR→Tevatron extrapolation
- Common feature: 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, $|\eta|$<2.5
  - Particularly interesting: Transverse regions, multiplicity densities and total momentum transverse momentum
  - Towards and away test jet fragmentation







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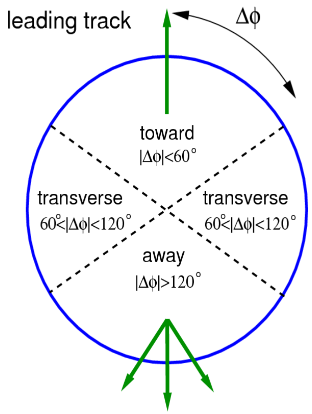
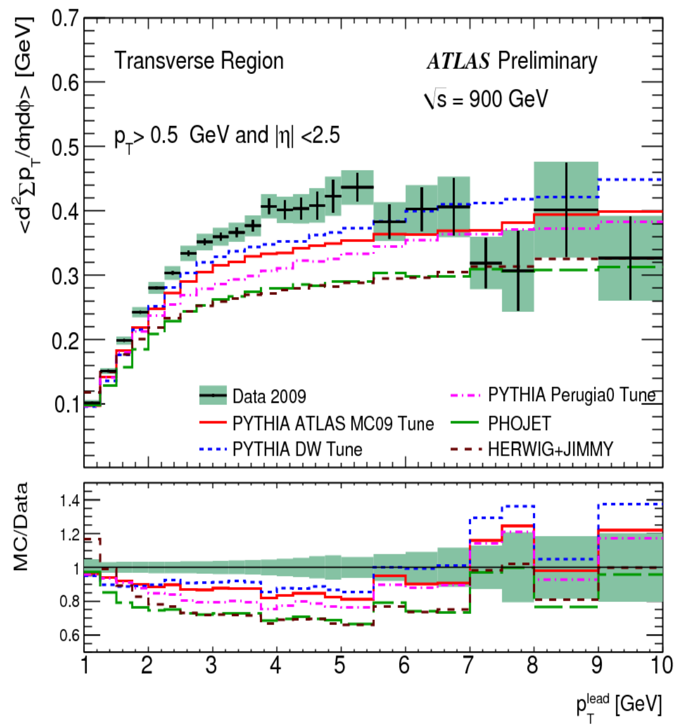
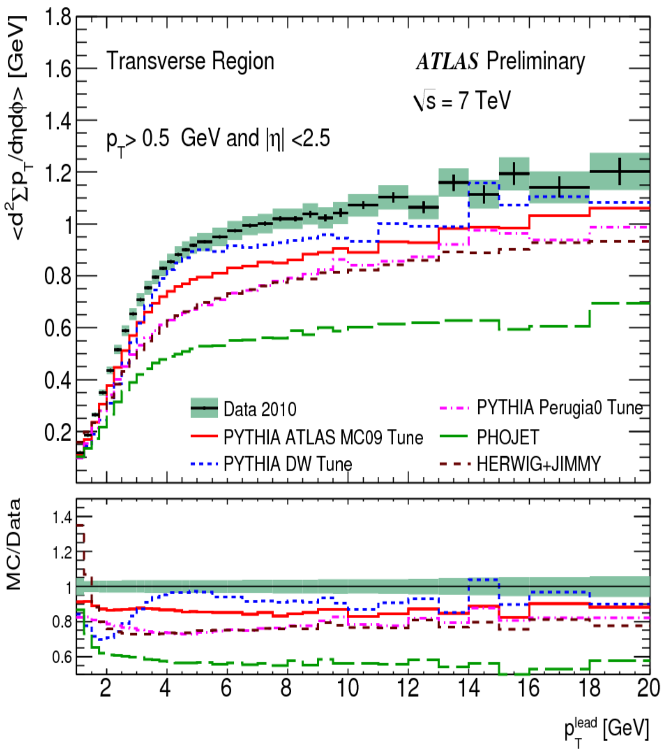
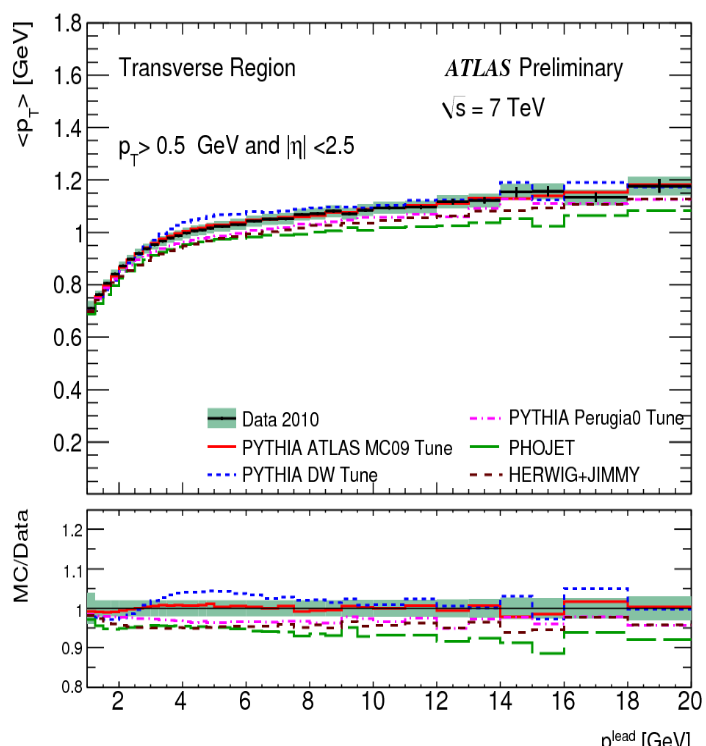


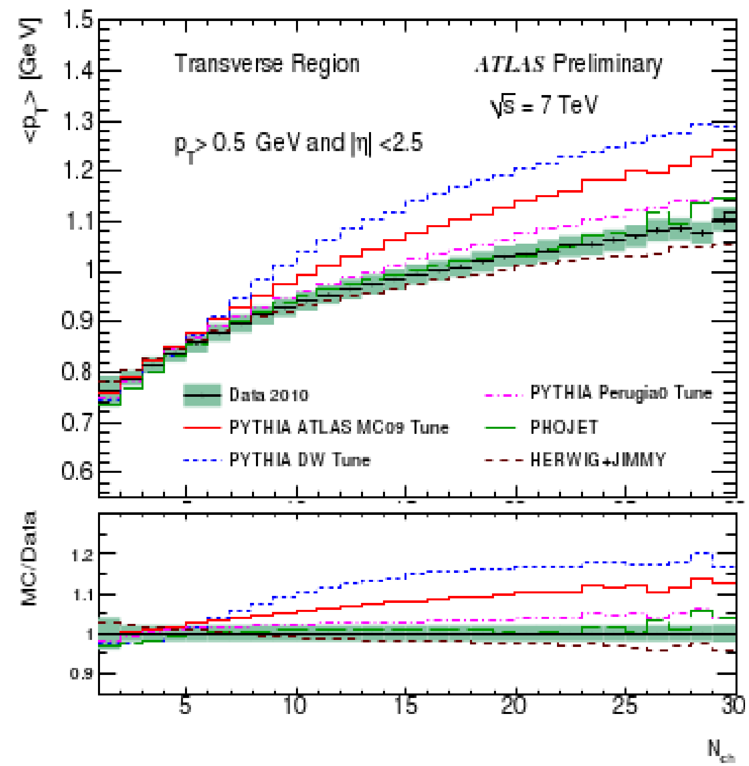




Performance of pre-LHC tunes in Underlying Event - Summary:

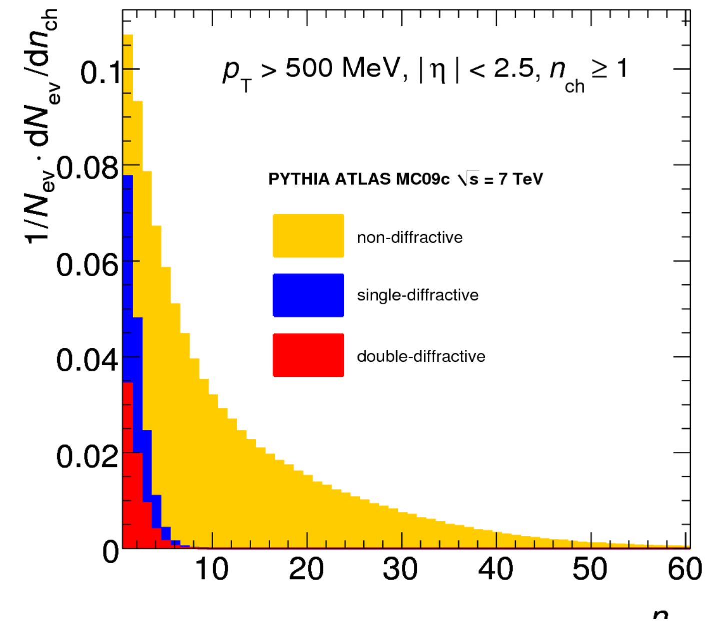
- Consistent picture: AMBT performs slightly better than Perugia, but roughly on the same footing as DW (in MinBias, DW was significantly worse).
- Again: Undershooting multiplicities and summed transverse momentum in transverse region by up to 20% (AMBT)
- Again: mean transverse momentum increases too 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

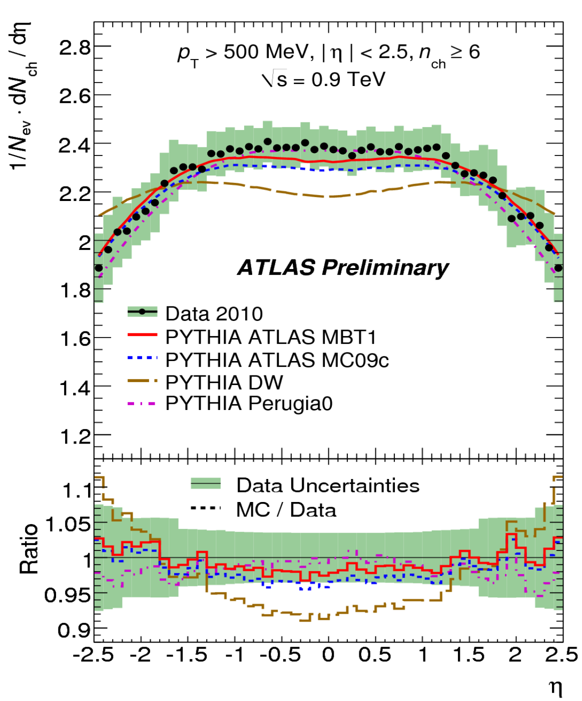


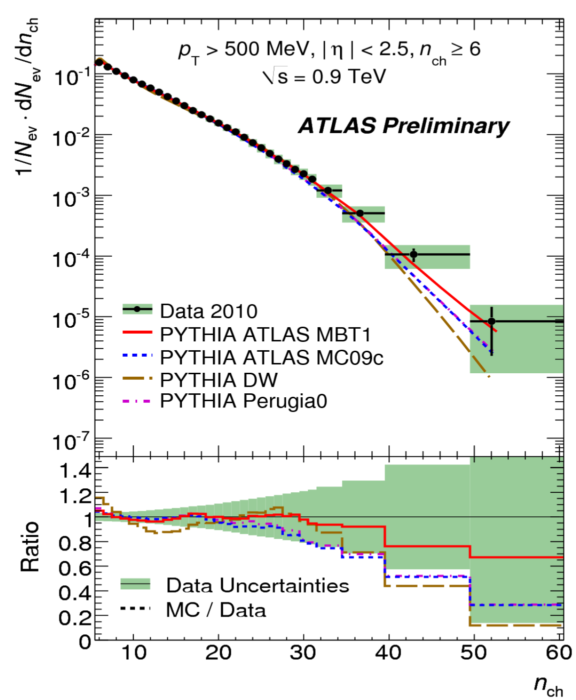


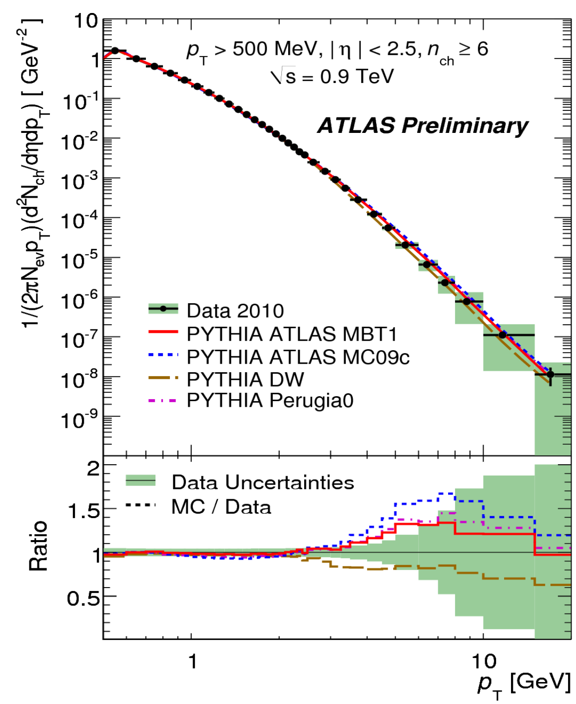
Improving the tuning with LHC data:

- 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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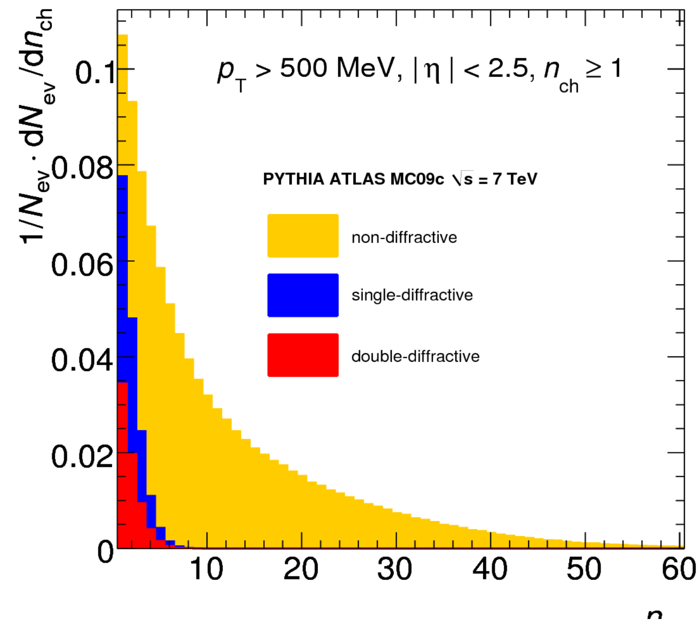
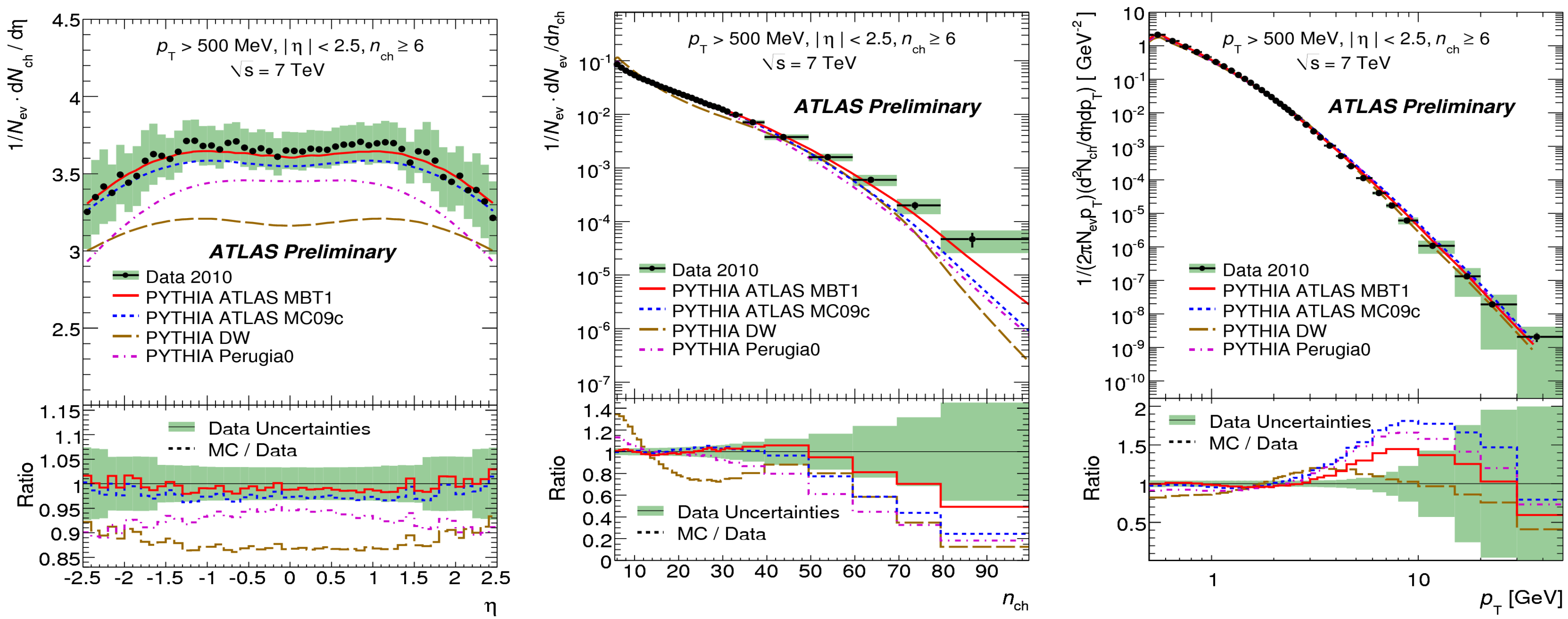
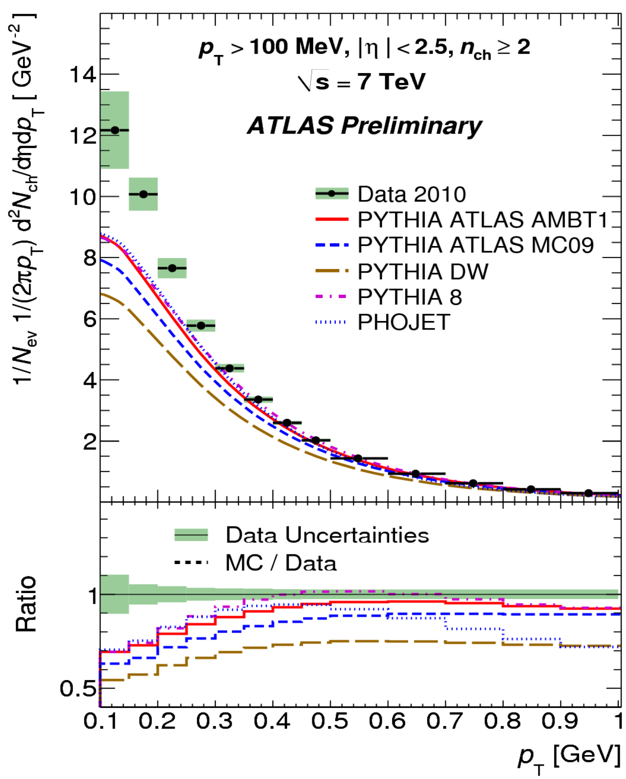
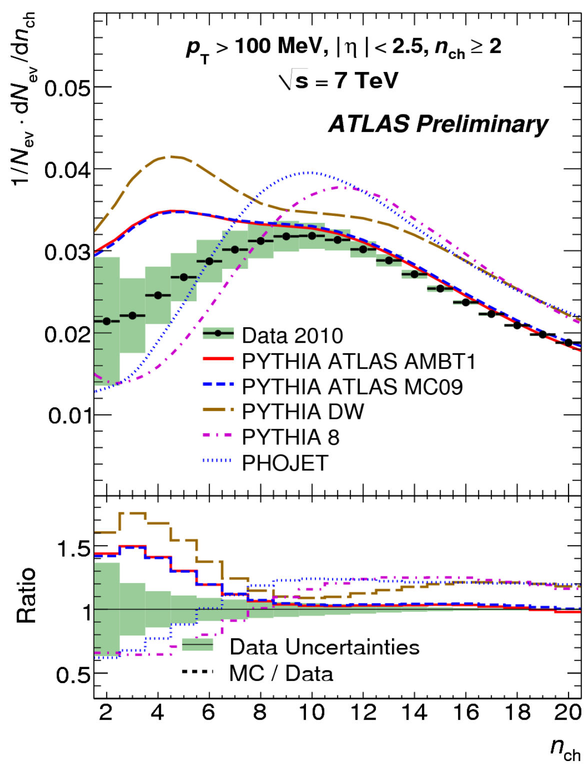


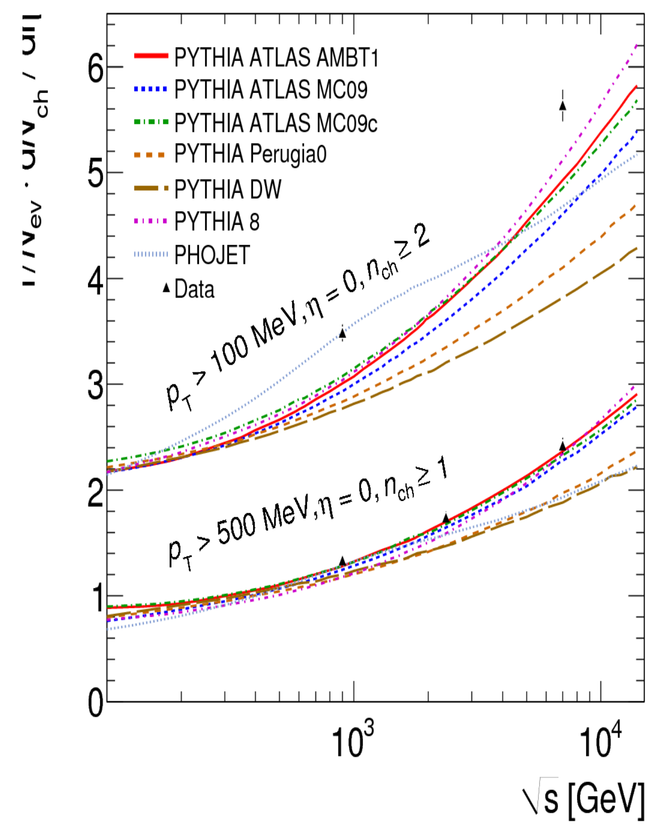


Performance of tunes in MinBias with changed sample:

- 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)

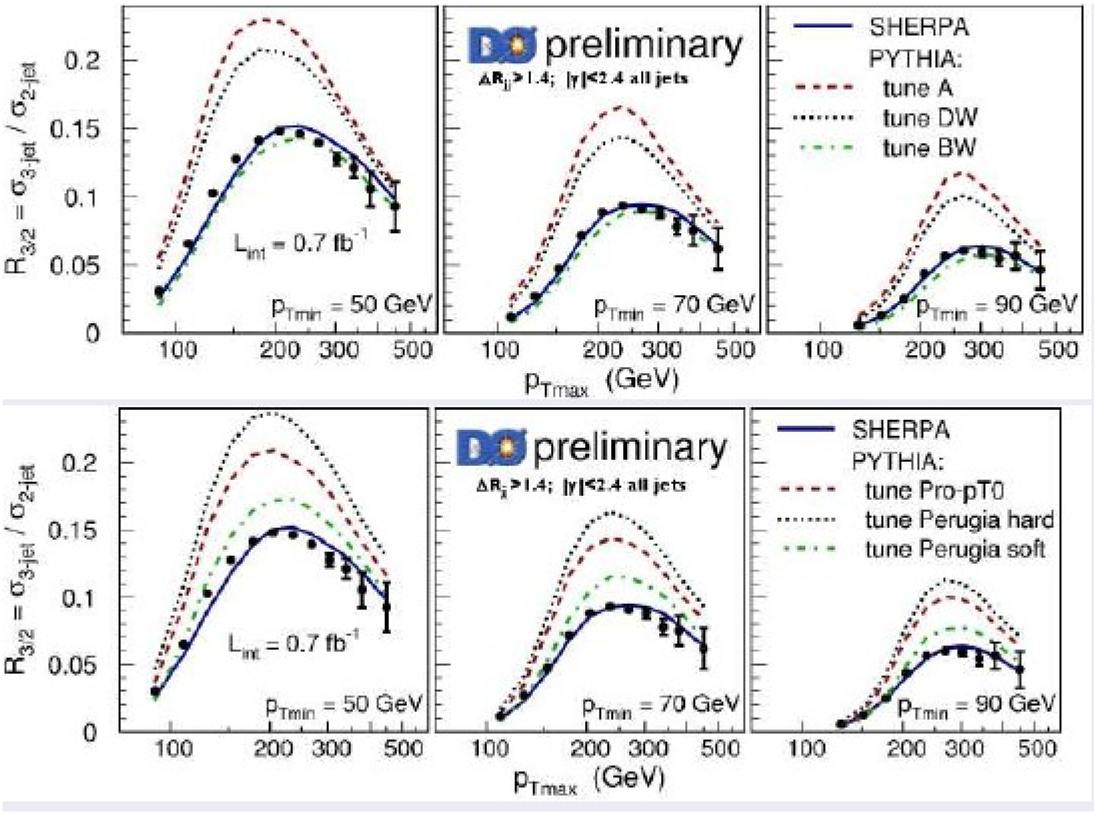






Some general remarks on tuning:

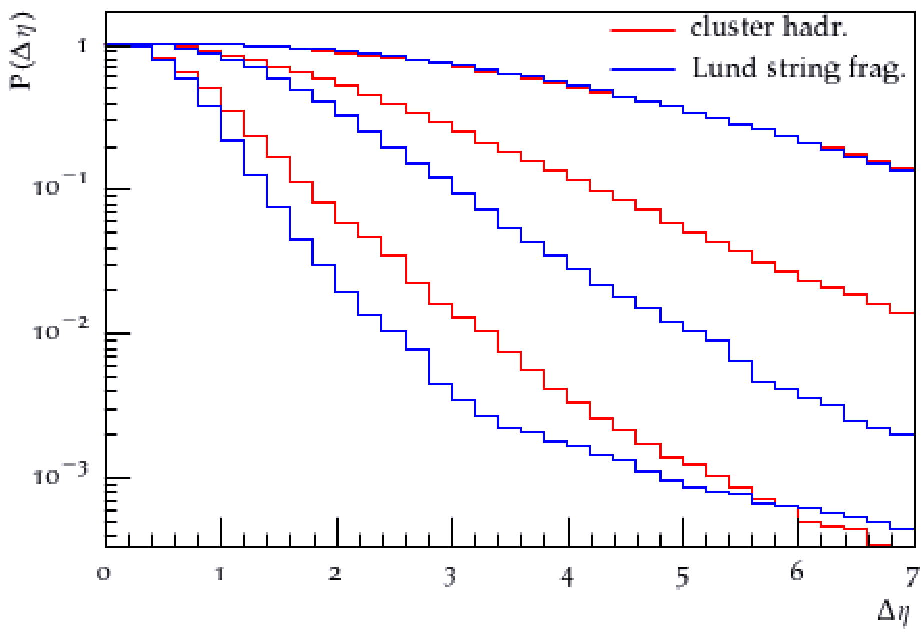
- Clearly, with enough parameters, expert tuning can significantly improve description of some subsets of data – but it will have implications on other data sets.
- As an example consider R_{32}, the three-to-two jet rate at D0.
- Two parameters: $p_{T,max}$ of leading jet and minimal jet transverse momentum $p_{T,min}$
- In Pythia tunes strong coupling gets modified (in fact, Pythia has more than one α_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



Part II: Further improving the MCs

(with my UK, IPPP & Sherpa hats on)

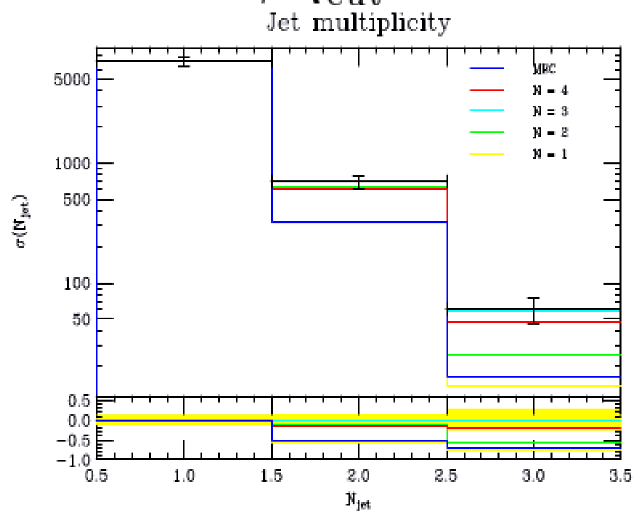
Herwig++ status:

- Construction started around 2002, based on Fortran Herwig
- Incorporated new, better parton shower with improved AO variables
- Improved cluster fragmentation and greatly improved hadron decays + QED radiation
- Jimmy-like model for Underlying Event fully embedded, replaced old UA5 one.
- Added soft eikonal part to C++ version of original Jimmy model
- Extension: Hot-spot model
- Work on multijet merging started, some first results for hadronic collisions available
- Matrix elements provided by link to LHA event files.
- Established Powheg method for a couple of processes with simple colour configs, at the moment shipping with $hh \rightarrow \gamma/Z$, W, H, WH, and ZH
- More processes (VV', VBF) under construction – will come in the near future.

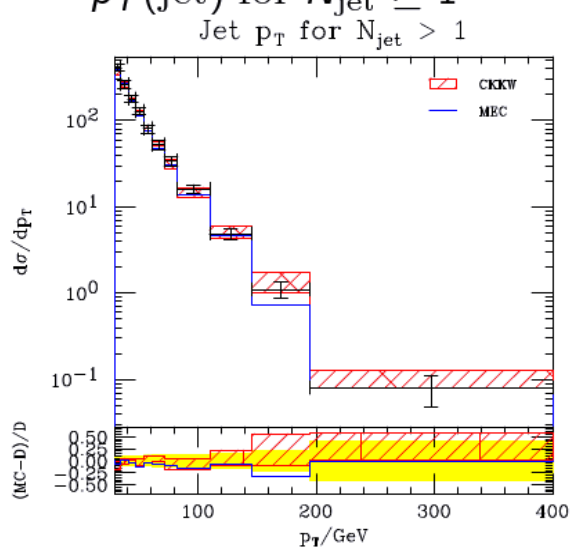
Multijet merging in Herwig++:

- Employ Sudakov form factors from parton shower (same in Sherpa's new version)
- Must truncate the shower due to mismatch of hardness scale (transverse momentum) and ordering parameter in parton shower (angles) – this resolves the problems apparent in the old Fortran Herwig-based studies by Mrenna and Richardson.
- In release up to now: ee annihilations only, results below for DY at Tevatron (CDF)

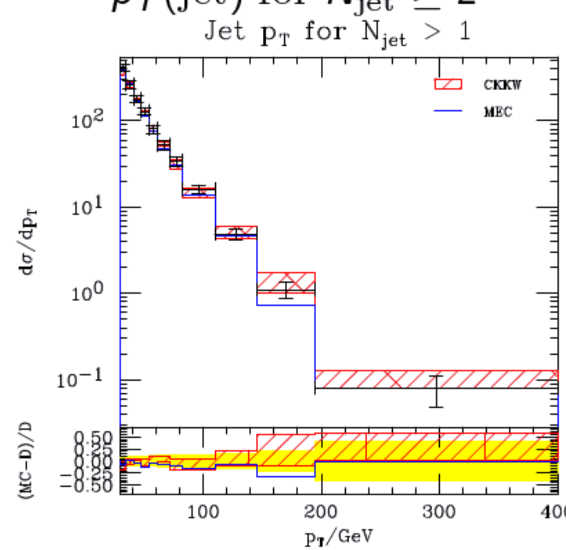
HERWIG++, $Q_{\mathrm{cut}} = 30$ GeV



$p_T(\mathrm{jet})$ for $N_{\mathrm{jet}} \geq 1$

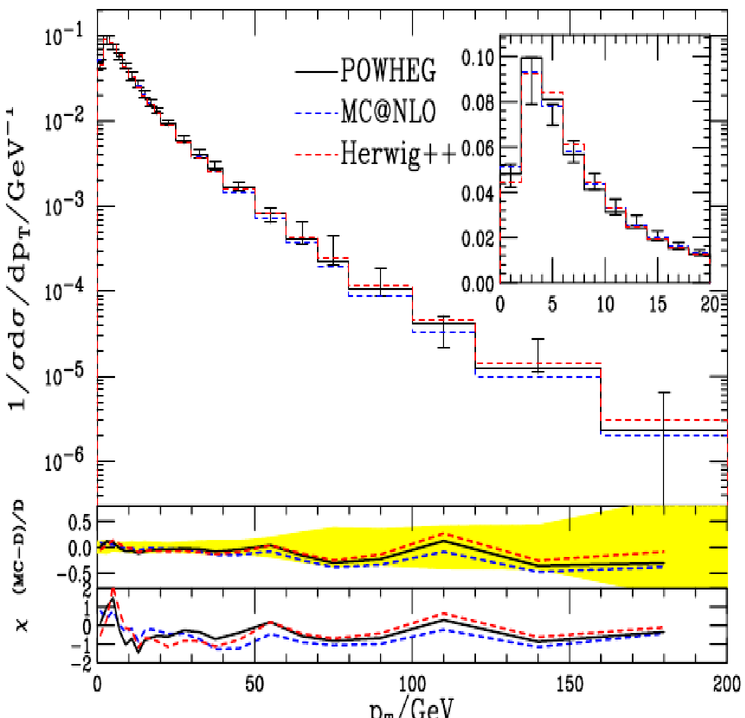


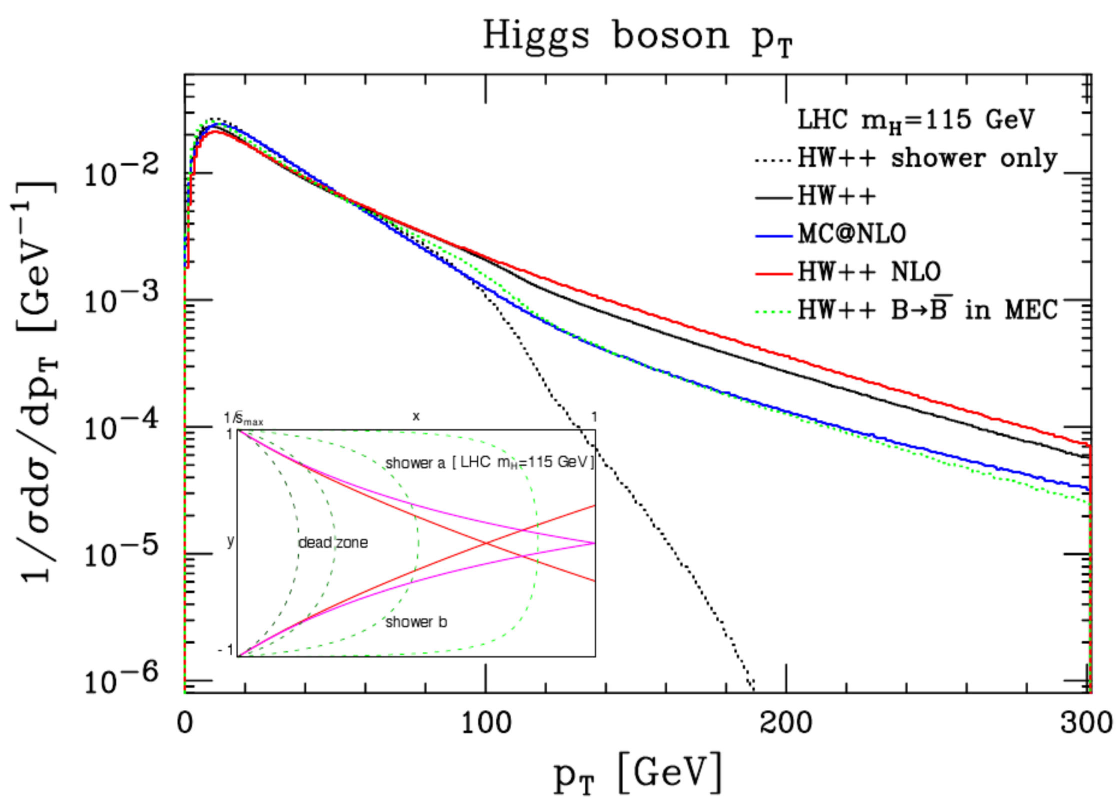
$p_T(\mathrm{jet})$ for $N_{\mathrm{jet}} \geq 2$



Powheg method in Herwig++:

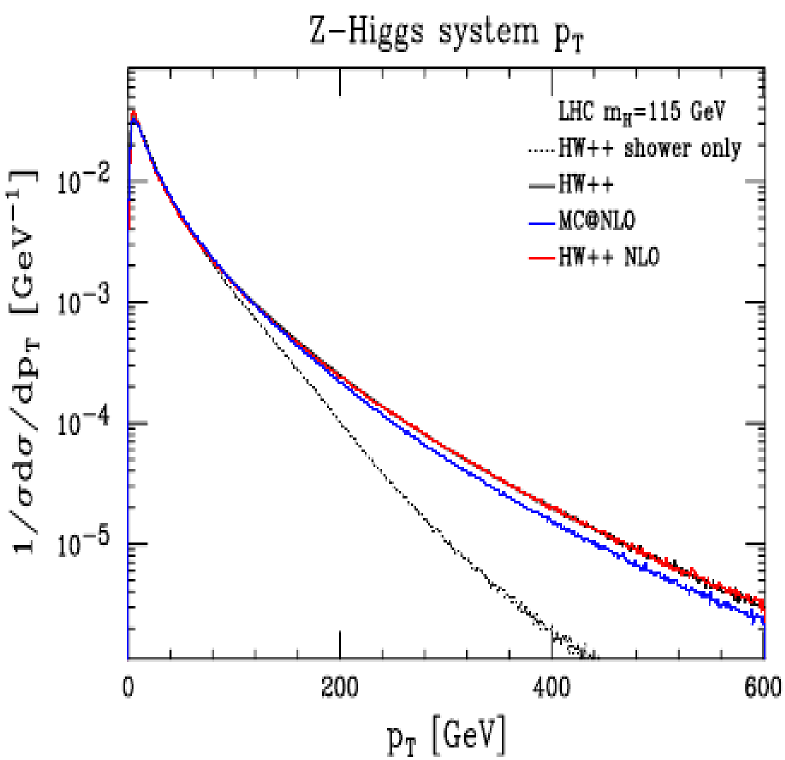
- Aim of Powheg method:
  - Generate unweighted events with weight = 1 with NLO cross section.
  - Generate first emission according to real-emission matrix element
- To achieve this, need some tricks – will skip this.
- Some example results: transverse momentum of W and H

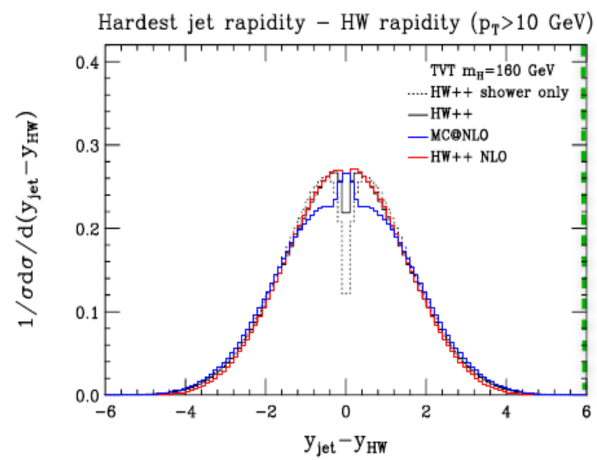


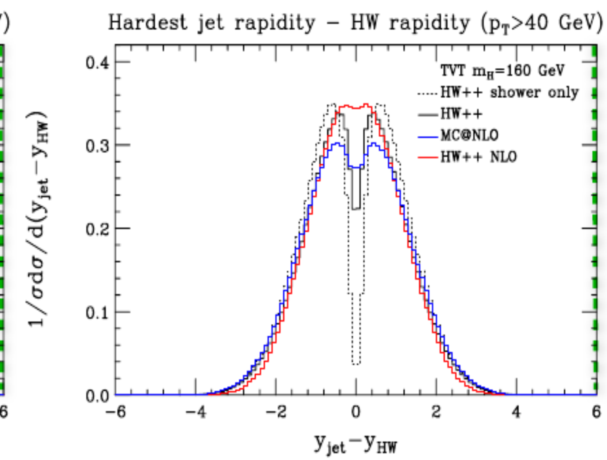


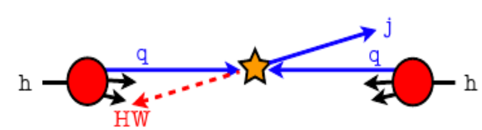
Powheg method in Herwig++:

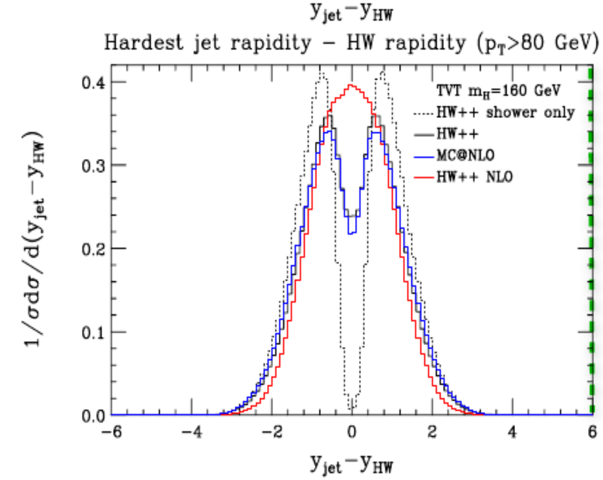
- Powheg method cures some phase-space issues in Herwig++ shower/MC@NLO:
  - Example: ZH production











Sherpa status:

- Construction started in late 1990's, mainly through diploma and PhD theses.
- Up to date: 7 PhD theses and 12 diploma theses finished, in total around 50 man-years of code development and physics improvement.
- First release in 2002: Proof-of-concept version Sherpa 1.0.ά, by now 1.2.3 in prep.
- Structure very modular, essentially bottom-up as design principle.
- From the beginning: Focus on perturbative aspects, especially multi-jet merging.
- By now: Two independent matrix element generators, a new shower (old Pythia-like shower to be disbanded in next release, 1.3), an independent version of cluster hadronization, an independent implementation of Pythia's old UE model, elaborate hadron decays, and QED final state radiation.
- Only recently: own fragmentation model, hadron decays, and QED radiation, interface to Pythia 6 kept for systematic checks and backward compatibility.
- Current main focus: NLO accuracy in multijet merging.
- In addition: New, independent Minimum Bias and Underlying Event model under active development.

Matrix elements in Sherpa:

Three kinds of matrix elements:

- Since 1.2.0: Comix - mainly SM, can handle up to 8-10 final state particles

  (implementations for BSM-relevant methods have low priority in Comix.)
- Amegic++ - SM & BSM generator, up to 6 final state particles

  (development stalled, will eventually move to Comix.)
- Specific, hard-coded ME's at LO and NLO.
- Using Comix makes Sherpa even easier to handle:
  - no more libraries written out to be compiled in intermediate step.
- Sherpa/Amegic++ support FeynRules
  - a tool to generate Feynman rules directly from Lagrangians

    (a new standard to propagate BSM models?)
- No support for to read in LHA event-files - considered pointless by Sherpa

  (tools to write out such files may become available some day – ask S.Schumann.)

Some NLO stuff in Sherpa:

- Sherpa was the first code to automate Catani-Seymour subtraction kernels
  - A method to isolate infrared divergences in real-emission part of NLO correction (consists of two parts: the actual subtraction term, acting on the real emission bit, and the term to be added to the virtual bit)
- B now extensively used by the Blackhat collaboration, some state-of-the-art results (W+3,4 jets and Z+3 jets) done as Blackhat+Sherpa
- Nice connection to parton shower: Sherpa's new default shower bases on the same phase-space mappings

  (just forward, unfolding the extra emission, rather than backward, undoing it in the subtraction procedure)
- This made the automation of the Powheg method in Sherpa quite straightforward

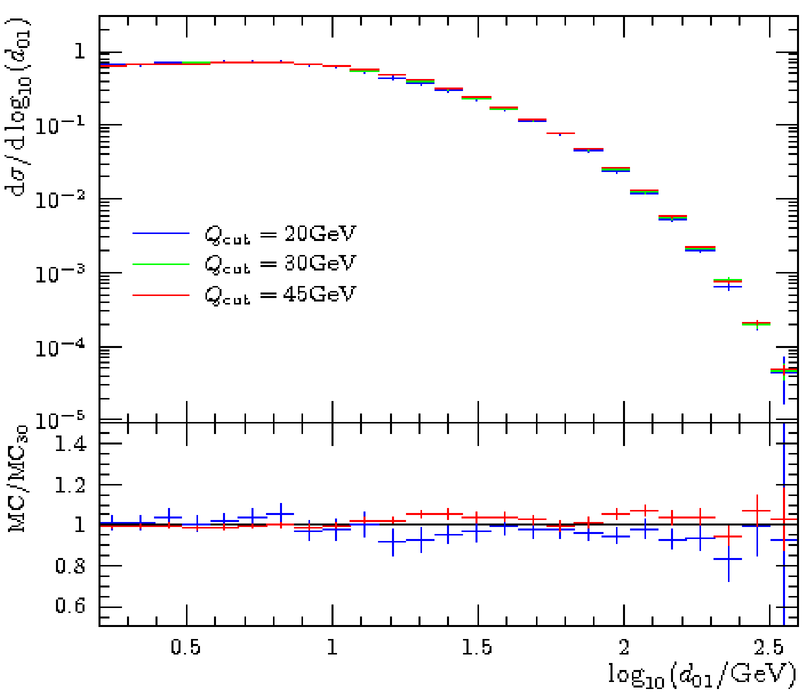
  (Expect a release Sherpa 2.0.ά in the next few months)

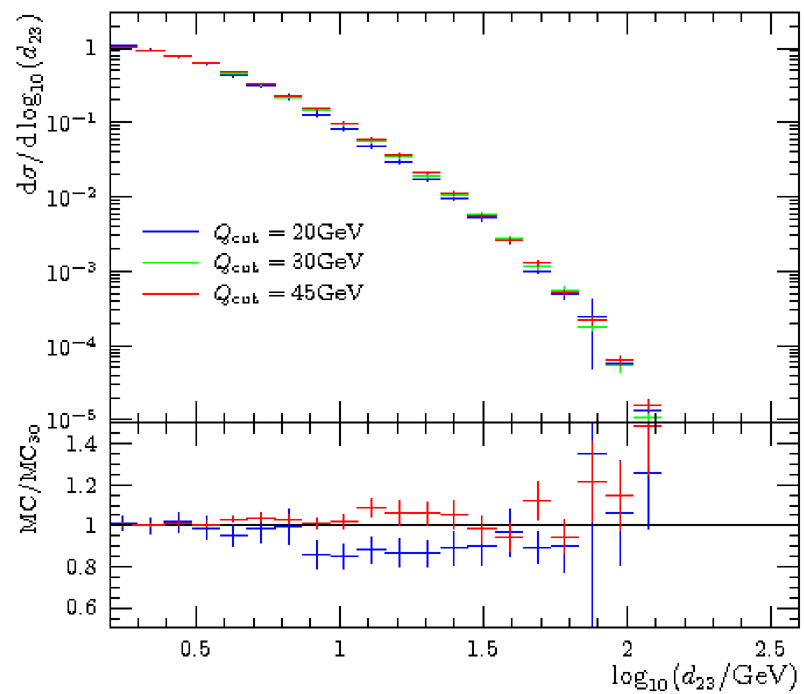
Multijet merging in Sherpa:

- New improved formalism, greatly reduced merging systematics

  (<15% for Q_{cut} [20, 50] GeV, Sherpa 1.1 was better than 40% in extreme bins)

- Shown to preserve formal accuracy of parton shower, i.e. shower logarithms are correctly accounted for; (MLM algorithm does not do that)

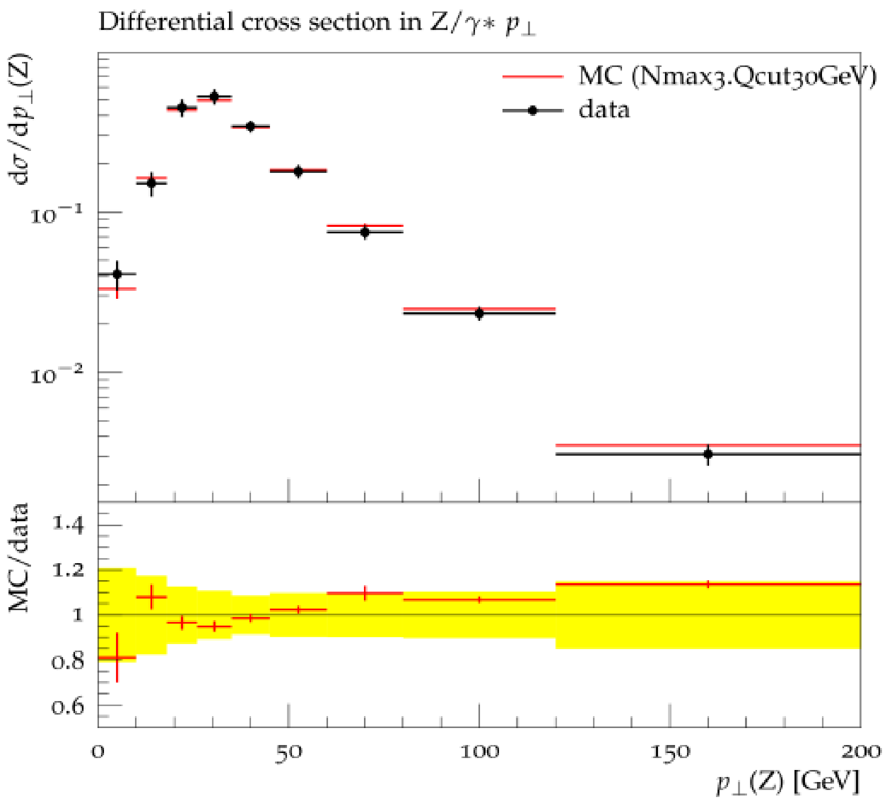


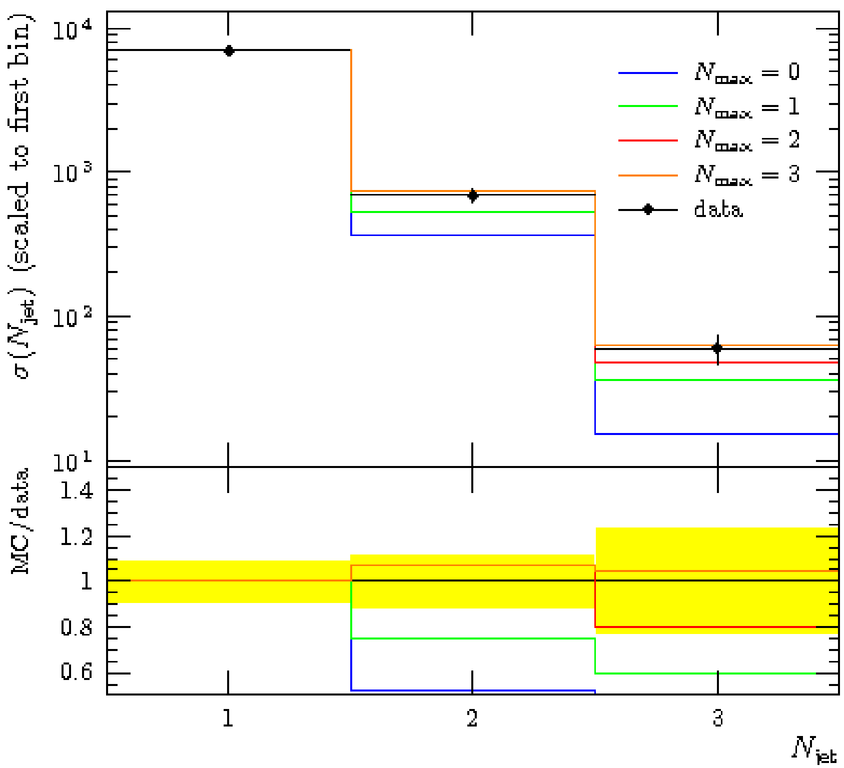


- Similar approach in Herwig++ - up to now available for ee-annihilations, hadronic collisions work in progress (see previous slides).

Multijet merging in Sherpa:

- Typically, Sherpa 1.2 describes Tevatron data very well:

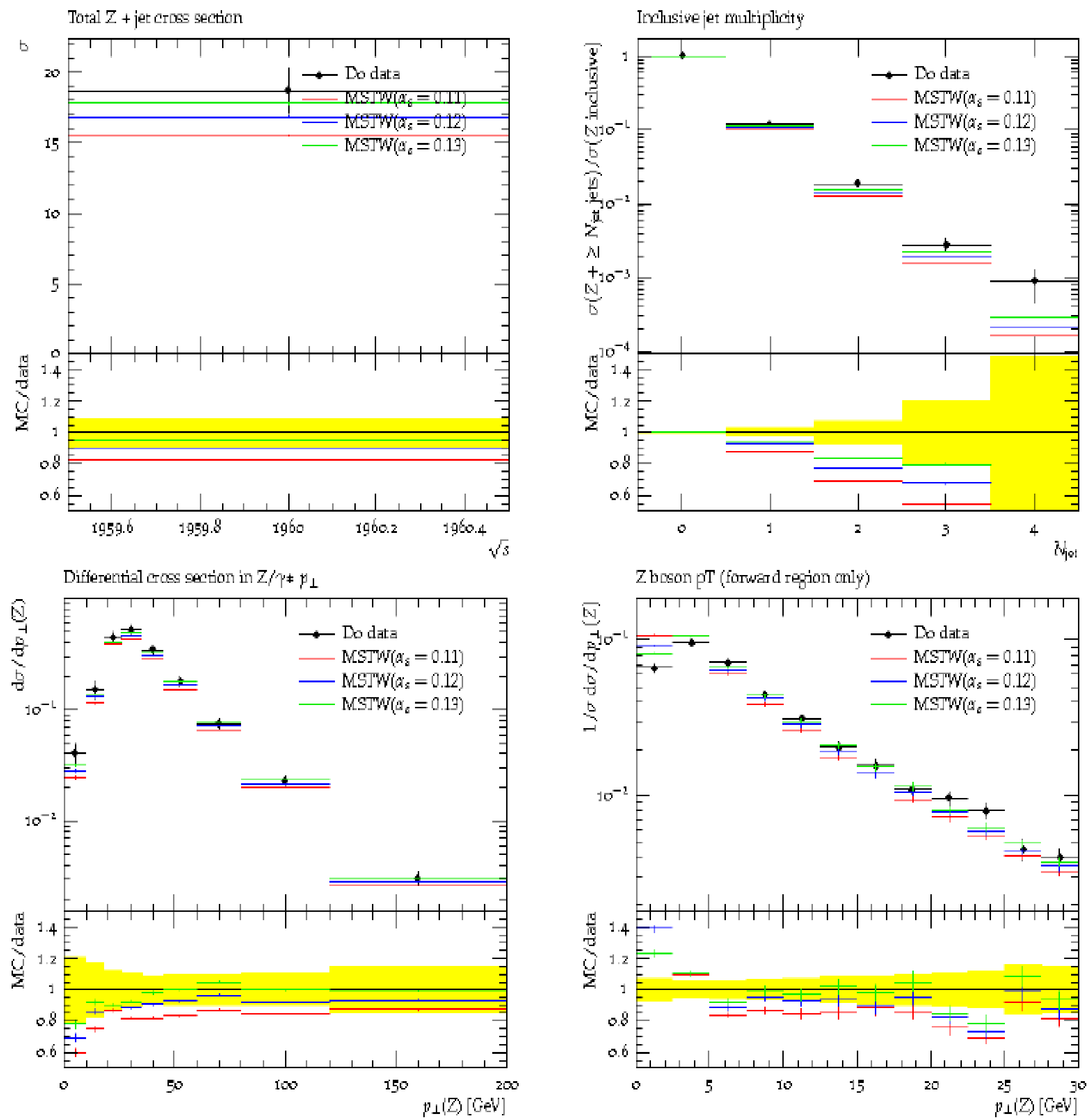




- Similar quality also for other observables and processes like W+jets.

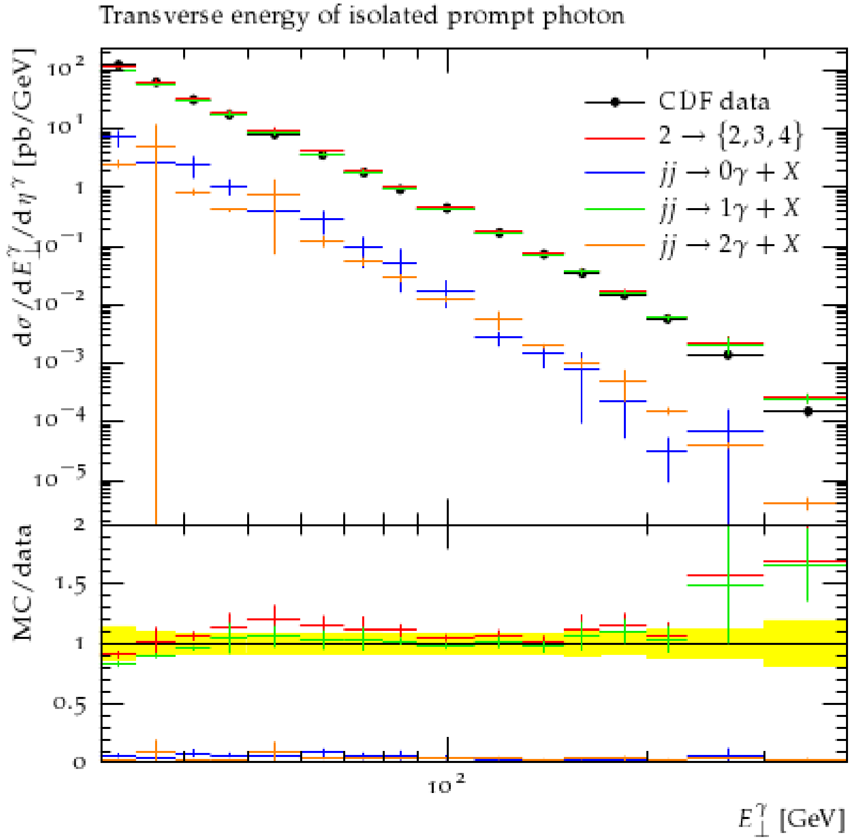
Merging in Sherpa – Impact of α_s

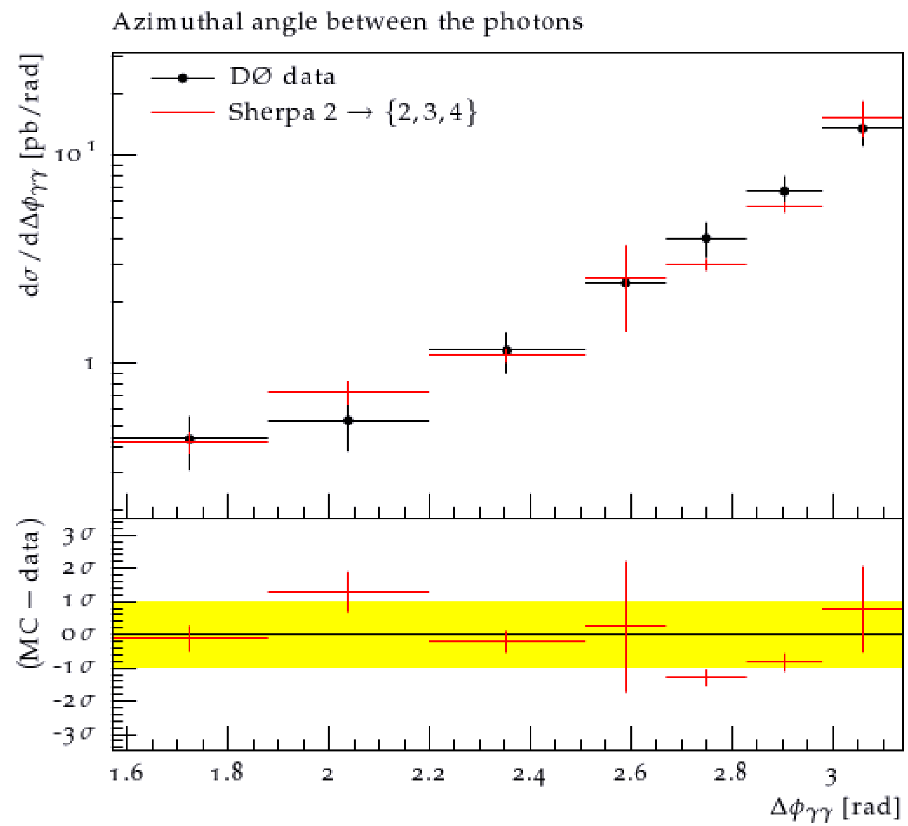
- In contrast to Pythia, there is only one strong coupling constant in Sherpa, fixed by the PDF.
- I believe this is the only truly consistent choice, especially in view of treating higher order corrections in multijet merging and NLO matching.
- Therefore: Clear and immediate impact on observables.
- Therefore: Will provide tunes for different PDFs, including those with different values of strong coupling; this will allow for meaningful systematic error estimates



Multijet merging with photons:

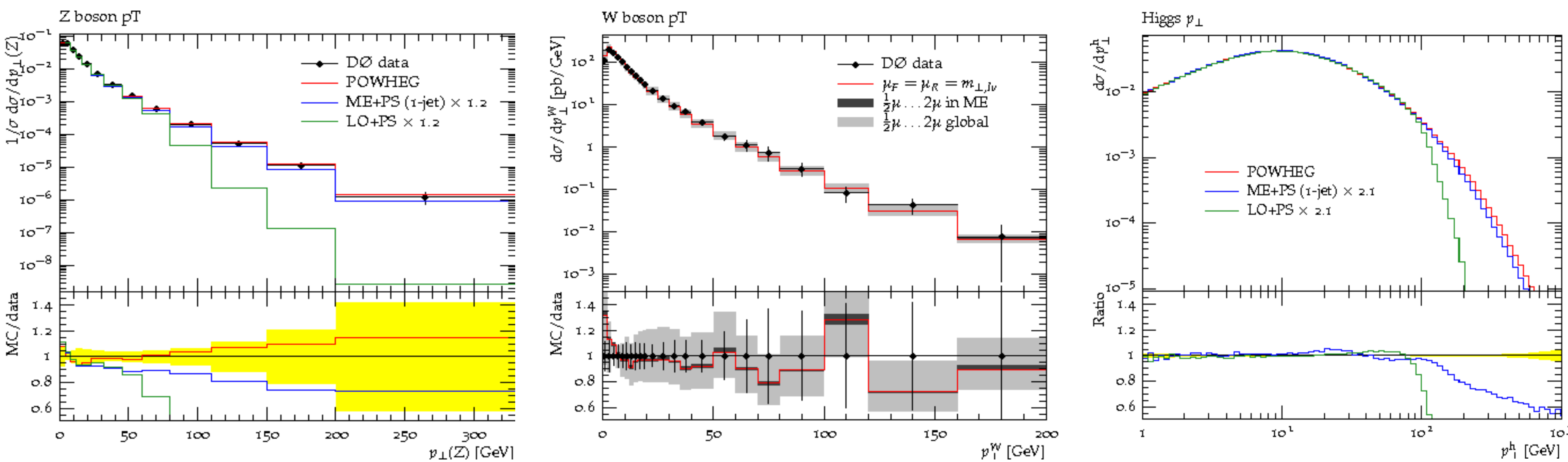
- Recently extended method also to photons.
- Example results:





Automation of Powheg method:

- Method pioneered by Nason et al., implemented in Powheg-box and Herwig++: Aims to include NLO accuracy for total rate and some inclusive observables.
- Automated for simple processes (one colour line: ee, DIS, DY, VV', gg→H) in Sherpa, non-trivial processes to follow very soon.
- Example results (Z-pt, W-pt at Tevatron, Higgs-pt at 14 TeV LHC):

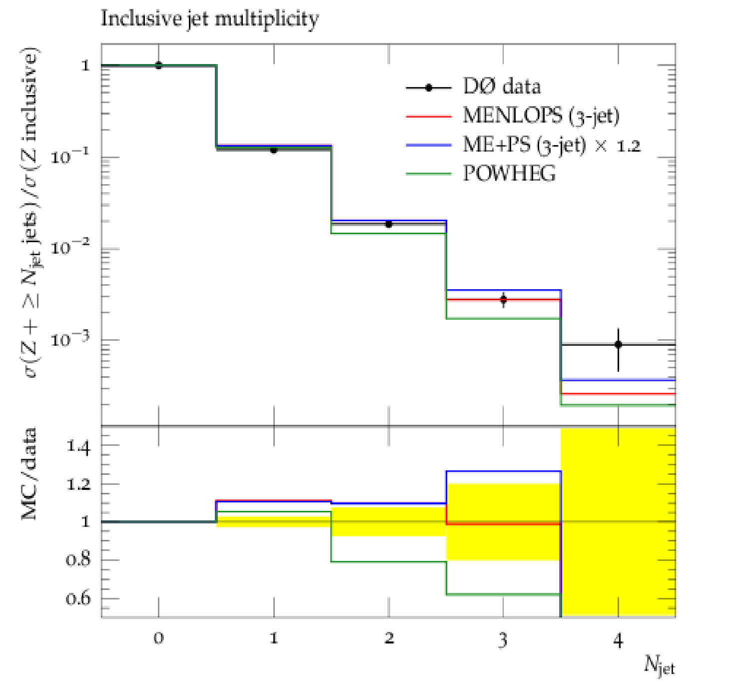


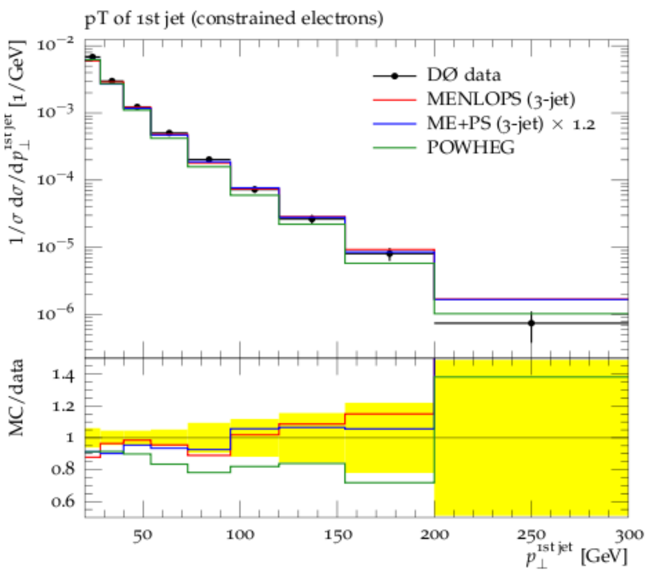
- Performed many checks on implementation, lots of plots in paper.

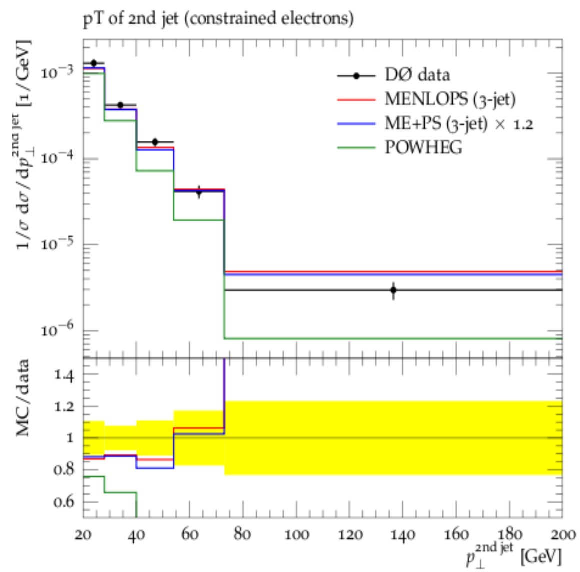
MENLOPS in Sherpa:

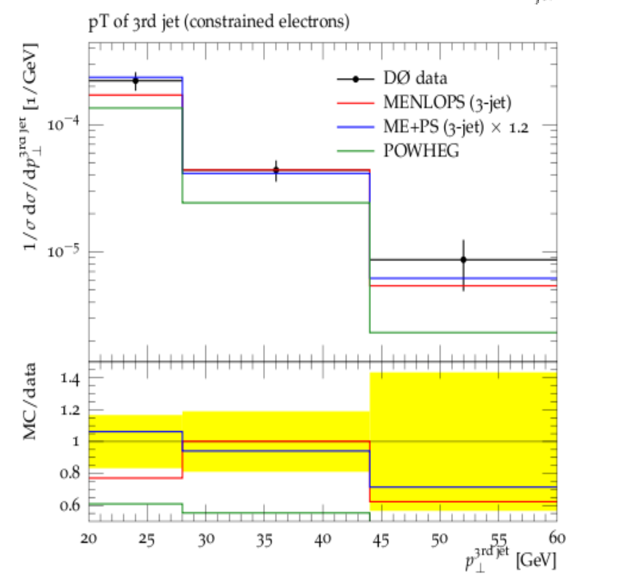
- Based on Powheg, can add multijet-merging on top – yields an inclusive sample with NLO cross section and ME+PS accuracy in all jet shapes

(development in parallel with Hamilton and Nason, identical formalism in both, but different implementation: H+N use Powhegbox+Madgraph+Pythia)









Conclusions and Outlook:

- Please present data detector corrected, 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.

  (I still fail to understand why ATLAS does not hand out the numbers – please explain!)

- 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.
- UK-based event generators Herwig++ and Sherpa made huge progress towards embedding HO accuracy in a systematic way – please use them! (Especially as UK experimenters – in the end you want us to discuss with you, offer advise and, in general, give theoretical support)
- MENLOPS method will become the standard for simulations, incorporating the best of both worlds (merging and matching).