LHC data confront Monte Carlo predictions

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Outline

1. Introduction: why minimum bias events?
2. Models for soft particle production
3. A potpourri of results from Tevatron to LHC
4. A snapshot of **one** new development
5. Conclusions

Introduction: why minimum bias events?

The bird's eye view

- Name suggests: most complete view of physics

  (at the LHC or any other experiment)

- As such: intellectual challenge to grasp complete picture:
  Up to now no complete model based on first principles including all facets - elastic scattering, diffractive events & hard jets - on the same footing;
  instead: phenomenological models with many choices & parameters.
- First day physics at the LHC
  new energy regime to challenge our understanding of soft particle production and the corresponding tunes of the event generators.
- Intimate connection of minimum bias physics to underlying event

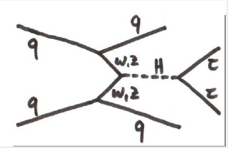
  (Although underlying event $\neq$ minimum bias event)

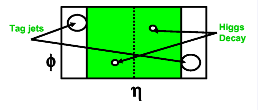
- Therefore: Immediate impact on some searches for new physics (see below), jet physics (e.g. jet energy scale, relation of hadrons $\leftrightarrow$ partons, . . .) etc..

Importance of particle production: Rapidity gaps

As an example consider Higgs physics at the LHC.

- Important channels for Higgs searches: VBF
- Signature: two forward jets + rapidity gap, filled by Higgs decay
- Essential for S/B: rapidity gap (and its survival rate)
- Typical manifestation of gap: central jet veto.
- Also discussed: track based rapidity gaps.

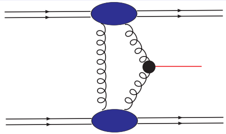




- Typically, the requirement of central gap effectively suppresses perturbative QCD-driven backgrounds (hadrons produced along colour exchange between *pp*)
- Obvious: Underlying event/soft particle production beyond perturbation theory may spoil this picture.

Rapidity gaps, once again

- Another daring idea: elastic Higgs production
- Signature: two intact protons in the forward direction, only Higgs in central detector.
- Again: rapidity gap (suppresses background)



- Rare process: very few events.
- If possible to trigger on forward protons: super clean signature, full control over FS kinematics.
- Most likely not a discovery channel, but due to spin-selection (only $J^{PS} = 0^{++}$ possible) a great chance to measure the quantum numbers of H.
- Need a straw-man to check calculations: central diffractive production.

Models for soft particle production

Reminder: Eikonals

- Optical theorem relates total cross section $\sigma_{\rm tot}$ with elastic scattering amplitude $\mathcal{A}(s,t)$ through

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

- Rewrite $\mathcal{A}(s,t)$ as $a(s,b_\perp)$ in impact parameter space

$$\mathcal{A}(s,t=-\vec{q}_\perp^{\,2}) = 2s\int {\rm d}^2 b_\perp e^{i\vec{q}_\perp\cdot\vec{b}_\perp} a(s,\vec{b}_\perp)$$

and introduce eikonal Ω (guarantees unitarity of cross sections)

$$a(s,\,\vec{b}_\perp) = \frac{e^{-\Omega(s,\vec{b}_\perp)}-1}{2i}.$$

- Total cross section now reads:

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

and similar expressions for elastic & inelastic cross sections.

Formulation of models based on eikonals

- Typical procedure: Write eikonals as sum of soft and hard part:

$$\Omega(s,\vec{b}_\perp) = \Omega_S(s,\vec{b}_\perp) + \Omega_{\rm H}(s,\vec{b}_\perp)$$

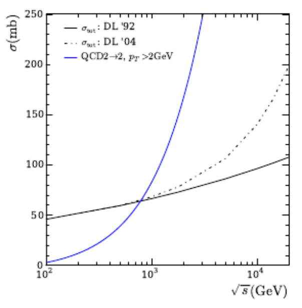
- Use perturbative QCD for hard part:

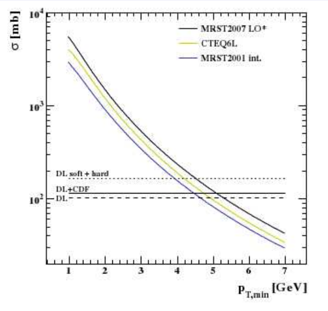
$$\Omega_{\rm H}(s,\vec{b}_\perp) = \frac{1}{2}\,\rho(\vec{b}_\perp)\,\hat{\sigma}_{2\to 2}(s)$$

  Here:
  - $\rho(\vec{b}_\perp)$ = spatial distribution of partons, parametrised with form factors;
  - $\hat{\sigma}_{2\to 2}(s)$ parton-parton cross section from QCD, typically collinear factorisation (see next slide).
- Can fix Ω_S as constant to reproduce anticipated total *pp*-xsec from fits, set it to 0, or give some dynamics based on Regge-physics or similar.
- Produce hard and soft interactions according to their eikonals, typically as a Poissonian distribution with argument like $\Omega/\sigma_{\rm tot}$.

The hard part: $\Omega_{\rm QCD}$

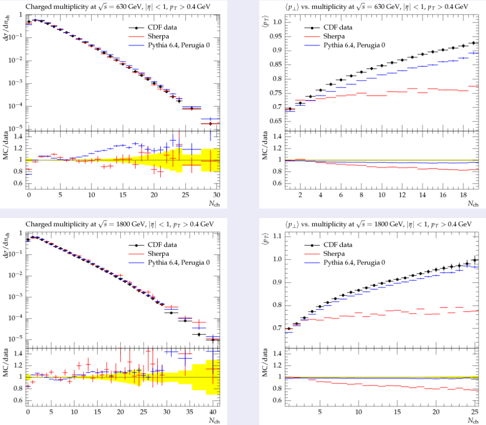
- For low $p_{\perp,\min} \approx 5$ GeV, $\sigma_{ij}(s) > \sigma_{\rm tot}(s)$ interpretation: multiple scattering



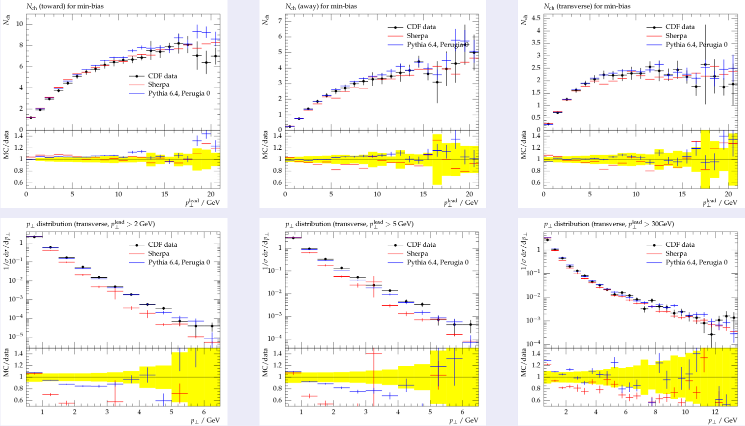


- Note: strong dependence on $p_{\perp,\min}$ (parton xsec $\propto 1/p^4_{\perp,\min}$)
- Can be tamed by replacing $p_\perp^2 \longrightarrow p_\perp^2 + p_{\perp,0}^2$ everywhere (in ME and in argument of α_S).

MC vs. Tevatron, 630 & 1800 GeV, inclusive data

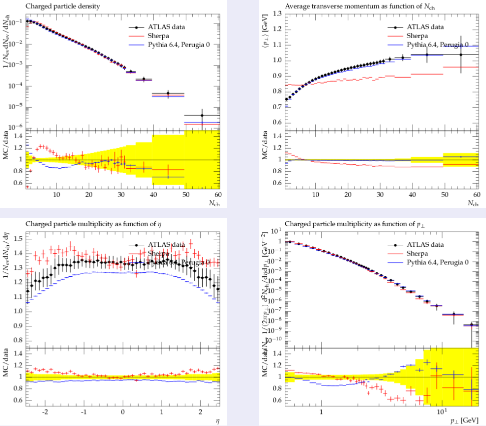


MC vs. underlying event at Tevatron, Run I

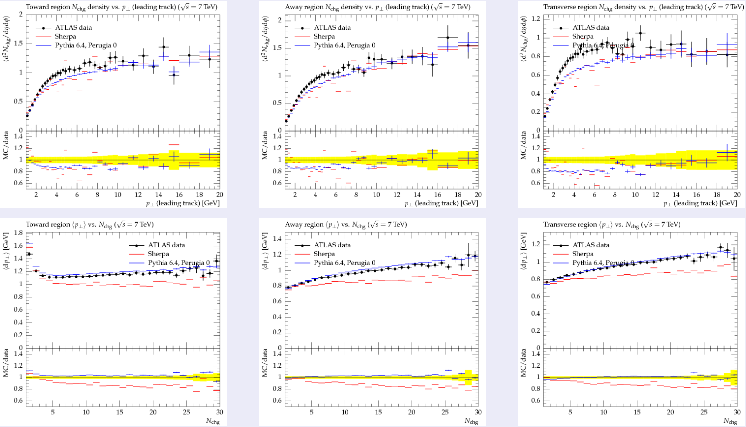


MC vs. ATLAS, 900 GeV

- Charged particles only, analysis track-based, corrected to particle level.
- Trigger: at least one particle with $p_\perp > 500$ MeV, $|\eta| < 2.5$



MC vs. underlying event at ATLAS, 7 TeV



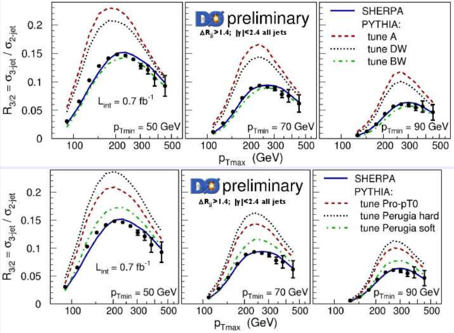
Why I did not show any CMS/ALICE data

- I wanted to show some results of tuned SHERPA and PYTHIA and not just regurgitate the plots shown by the collaborations.
- Main problem of CMS data: Not corrected for detector effects - this makes it nearly impossible to run your MC and draw any conclusion from the comparison with data.
- ALICE is an even sadder story:
    - In their first publication, ALICE corrected (with Monte Carlo) on "non-single diffractive" events. This selection is based on rapidity gaps, which however, may also occur as fluctuation, due to hadronisation etc., of "proper" inelastic events.
    - In addition, they filled the region outside their acceptance (especially the low $p_\perp$-region) with MC.

Therefore it is hard to see how you can test MCs with this data in an unbiased fashion.

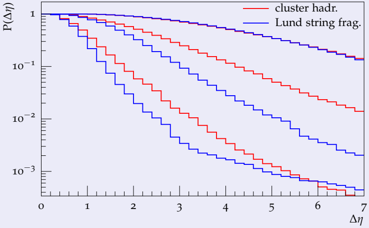
A remark on tuning

- Tuning can help a model to describe a limited subset of data - but deficiencies of the model will show up at other places.
- Always try to check for the overall picture.
- Measure R_{32} the three-to-two jet ratio.
- Fairly independent of PDFs, allows to test running of α_S at hadron colliders.
- Receives contributions from hadronisation and underlying event activity.
- Two parameters:
  $p_\perp^{\max}$ = minimal $p_\perp$ of 1st jet
  $p_\perp^{\min}$ = scale of other jets



Rapidity gaps from fluctuations - a remark on diffraction

- Often, diffractive events are identified by a rapidity gap of a certain size.
- Nearly always the effect of fluctuations, where perturbative events produce rapidity gaps due to hadronisation effects, are ignored.
- It is hard to estimate the probability for this to happen from first principles or a Monte Carlo simulation, see below.
- Figure to the right:
  - SHERPA simulation with native cluster and Lund fragmentation, both tuned to LEP data.
  - Figure shows probability to find a rapidity gap of a given size, with different $p_\perp$-thresholds (bottom to top: 100 MeV, 500 MeV, 1000 MeV) at a c.m.-energy of 7 TeV.

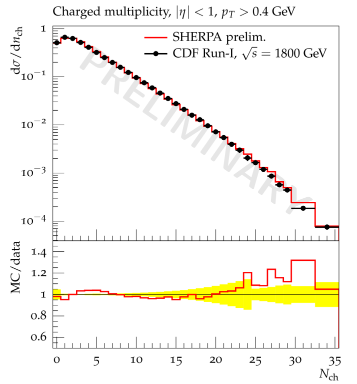


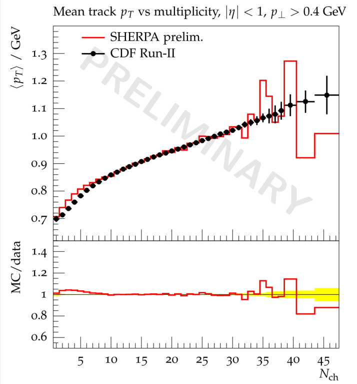
A new model for Minimum Bias (and the underlying event)

Underlying ideas

- Multi-channel eikonal approach (decompose proton in more than one diffractive eigenstate, one eikonal for each pair of states): allows for natural description of low-mass diffraction.
- Rooted in unitarisation by exponentiating eikonals.
- BFKL-inspired interpretation: exchange of "ladders" (cut pomerons) between hadrons yields eikonal.
- Ladders described by evolution equations in rapidity y, with form factor as starting condition at $y = \pm``\infty"$; evolution for both hadrons coupled through rescattering/absorption in effective description.
- Number of ladders $\propto$ eikonal, partons emitted by ladder according to differential equation.
- Naturally incorporates diffraction/diffractive parts in ladder dynamics.
- Work in progress, expect model in $\approx$ 4 weeks.

Some appetisers





Conclusions

- There are two classes of models currently used for describing minimum bias/ soft particle production data: Regge-based and PQCD-based.
- The former (implemented e.g. in PHOJET) have some difficulties describing Tevatron data, energy extrapolation, and perturbative QCD - I did not discuss it here.
- The latter (implemented in standard MCs such as PYTHIA and SHERPA) do somewhat better - they're still far from being perfect, and very susceptible to tuning. PDF effects also play a substantial role.
- None of the models manages to describe all data satisfactory.
- In my opinion this shows that we have not understood minimum bias physics.