Early Data for Monte Carlo Simulations

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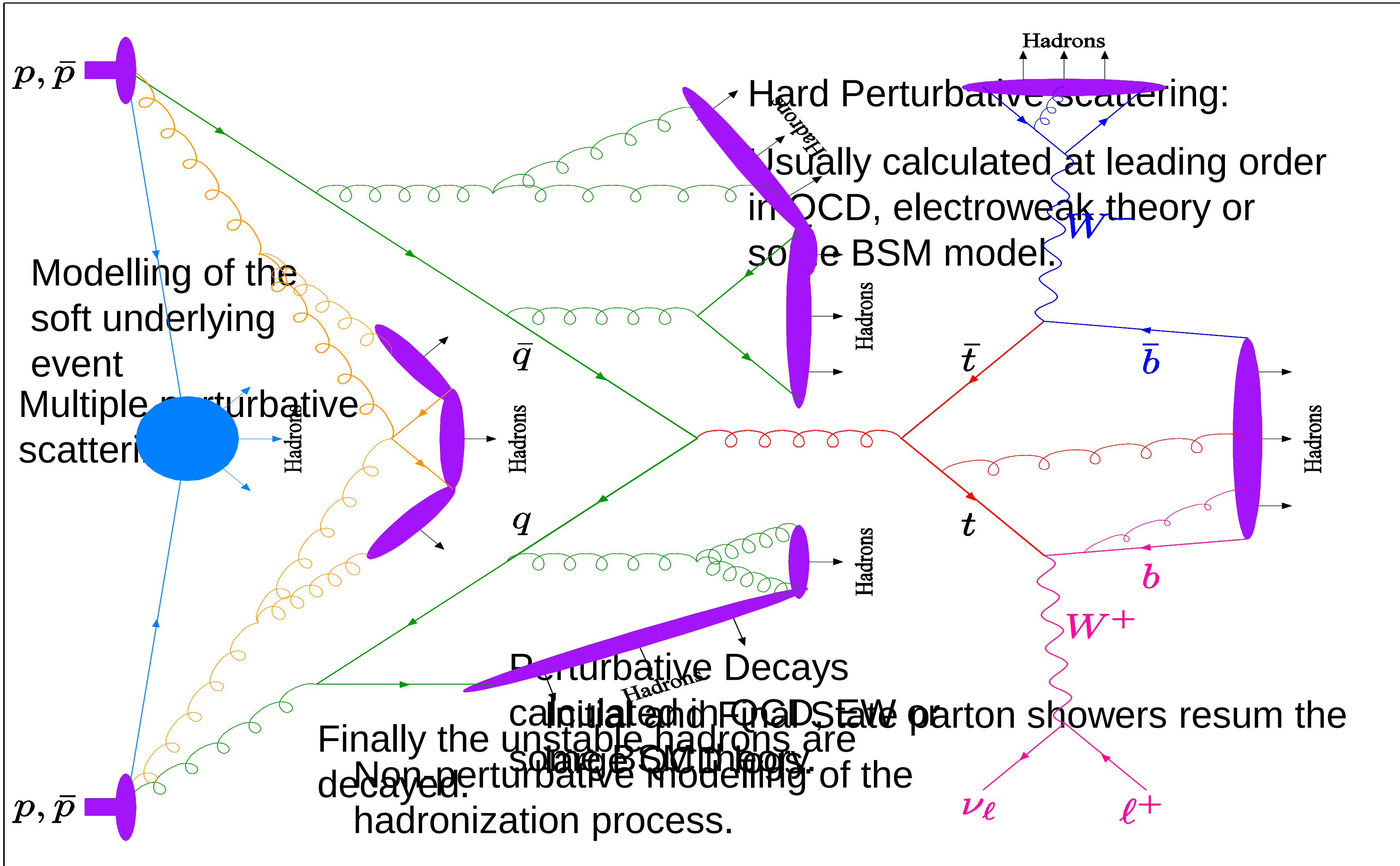
Summary

- Introduction
- Basics Of Monte Carlo Event Generation
- Multiple Parton-Parton Scattering
- Current Results
- Near Future
- Conclusions

Introduction

- Monte Carlo event generators are designed to simulate hadron collisions using a combination of
  - Fixed order perturbative calculations
  - Resummation of large QCD logarithms
  - Phenomenological Models
- Currently these models are tune at a range of experimental data, primarily from LEP, HERA and the Tevatron, although some earlier e^+e^- and hadron collision data are also used.

A Monte Carlo Event



Hard Perturbative scattering:

Usually calculated at leading order in QCD, electroweak theory or some BSM model.

Modelling of the soft underlying event

Multiple perturbative scattering.

Perturbative Decays calculated in QCD, EW or some BSM theory.

Initial and Final State parton showers resum the large QCD logs.

Finally the unstable hadrons are decayed.

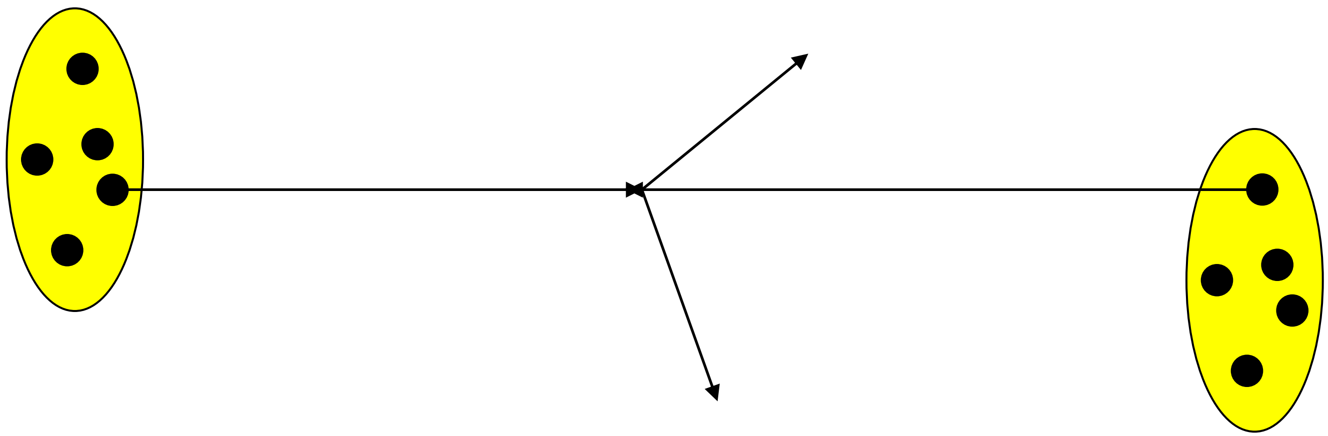
Non-perturbative modelling of the hadronization process.

Introduction

- The different models are generally tuned to different types of data:
  - Parameters relating to the final-state parton shower and hadronization are tuned to LEP data;
  - Parameters relating to initial-state parton showers and multiple parton-parton interactions are tuned to data from the Tevatron and UA5.
- The big change with the current LHC data is better measurements at 900 GeV and the first results at 7 TeV.

The Underlying Event

- Protons are extended objects.
- After a parton has been scattered out of each in the hard process what happens to the remnants?



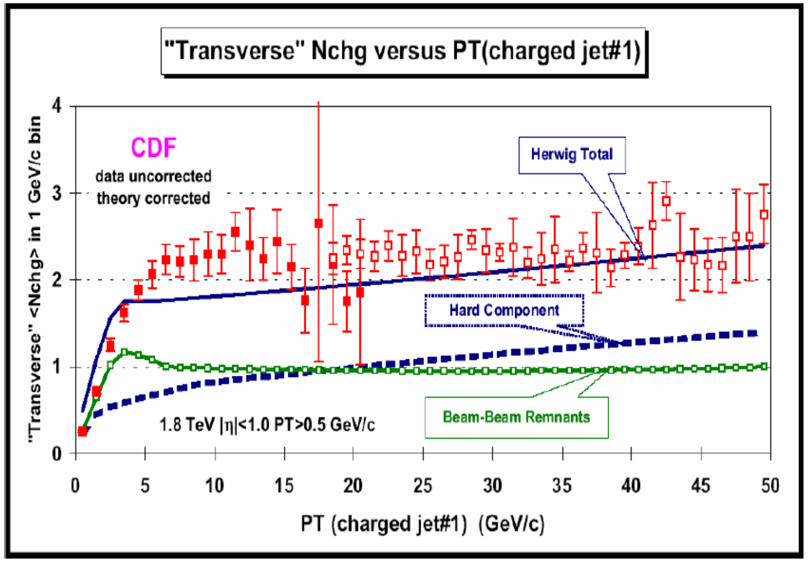
Two Types of Model:

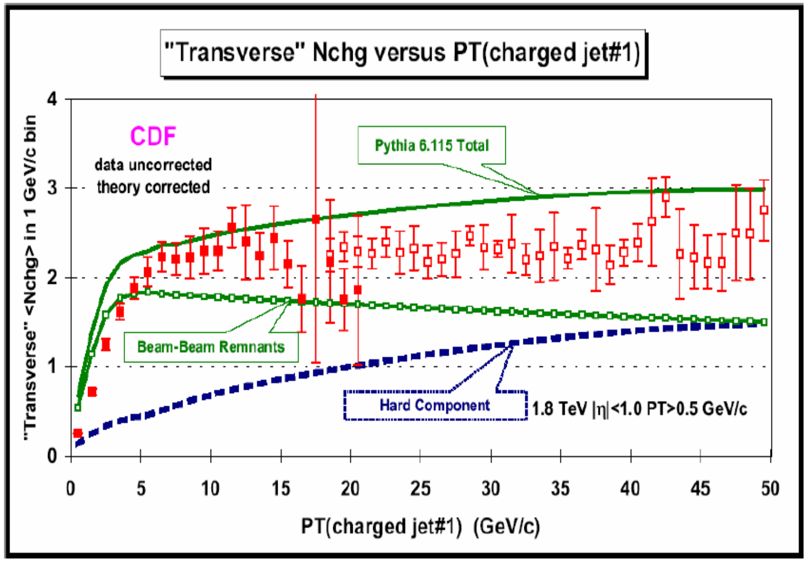
1) Non-Perturbative: Soft parton-parton cross section is so large that the remnants always undergo a soft collision.

2) Perturbative: 'Hard' parton-parton cross section is huge at low p_T, dominates the inelastic cross section and is calculable.

Minimum Bias and Underlying Event

- Not everyone means the same thing by “underlying event”
- The separation of the physics into the components of a model is of course dependent on the model.
- Minimum bias tends to mean all the events in hadron collisions apart from diffractive processes.
- Underlying event tends to mean everything in the event apart from the collision we are interested in.

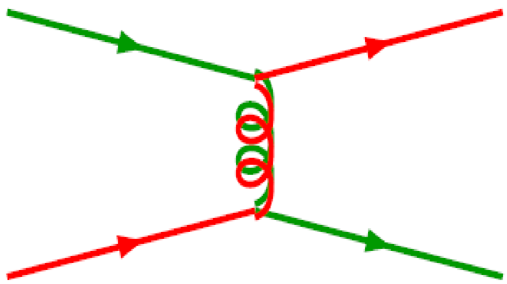




Underlying Event

- This is one of the main problems in comparing the results of modern Monte Carlo simulations with old data.
- The data has generally been corrected using some obsolete model to remove single and/or double diffractive events.
- General problem with many experimental results in that there seems to be a reluctance to publish what was actually measured.
- This has been one of the major improvements with the recent LHC results.

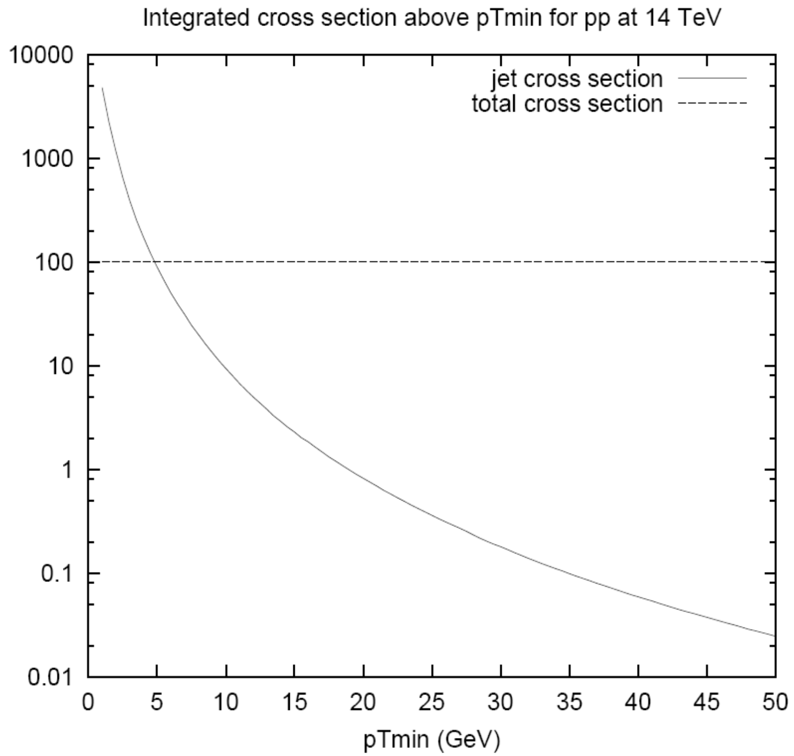
Multiparton Interaction Models



- The cross-section for 2→2 scattering is dominated by t-channel gluon exchange.
- It diverges like

$$\frac{d\sigma}{dp_\perp^2} \approx \frac{1}{p_\perp^4} \quad \text{for} \quad p_\perp \to 0$$

- This must be regulated used a cut of p_{Tmin}.
- For small values of p_{Tmin} this is larger than the total hadron-hadron cross section.
- More than one parton-parton scattering per hadron collision

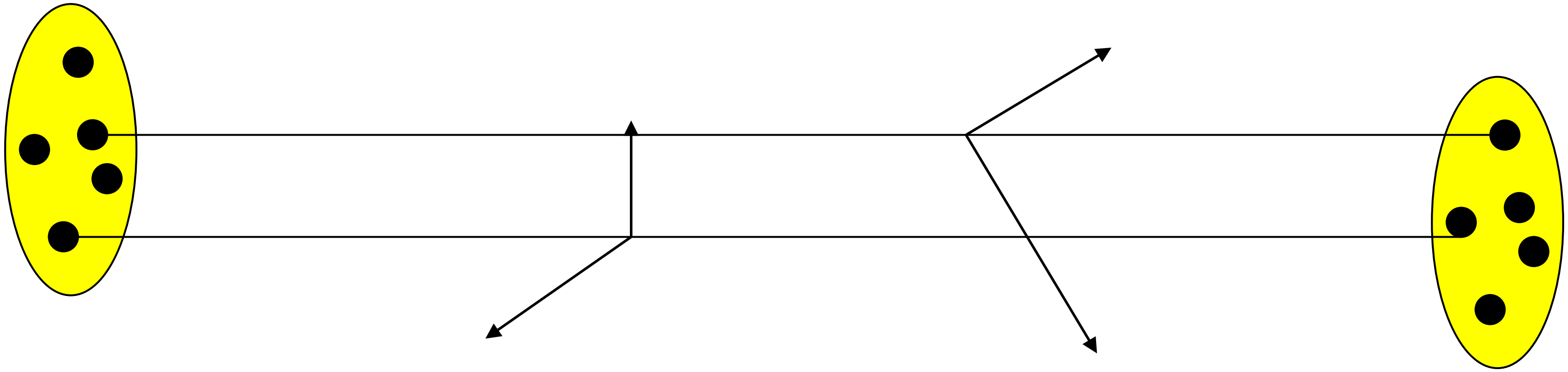


Multiparton Interaction Models

- If the interactions occur independently then follow Poissonian statistics

$$P_n = \frac{\langle n \rangle^n}{n!} e^{-\langle n \rangle}$$

- However energy-momentum conservation tends to suppressed large numbers of parton scatterings.



- Also need a model of the spatial distribution of partons within the proton.

Multiparton Interaction Models

- In general there are two options for regulating the cross section.

$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_\perp^2} \propto \frac{\alpha_s^2(p_\perp^2)}{p_\perp^4} \to \frac{\alpha_s^2(p_\perp^2)}{p_\perp^4}\theta(p_\perp - p_{\perp\min}) \quad \text{simpler}$$

$$\text{or} \to \frac{\alpha_s^2(p_\perp^2 + p_{\perp 0}^2)}{(p_\perp^2 + p_{\perp 0}^2)^2} \quad \text{more complicated}$$

  where $p_{\perp\min}$ or $p_{\perp 0}$ are free parameters of order 2 GeV.
- Typically 2-3 interactions per event at the Tevatron and 4-5 at the LHC.
- However tends to be more in the events with interesting high p_T ones.

Simple Model

- T. Sjostrand, M. van Zijl, PRD36 (1987) 2019.
- Sharp cut-off at p_{Tmin} is the main free parameter.
- Doesn't include diffractive events.
- Average number of interactions is

$$\langle n \rangle = \sigma_{\text{int}}(p_{\perp \min}) / \sigma_{\text{non-diffractive}}$$

- Interactions occur almost independently, i.e. Poisson $P_n = \langle n \rangle^n e^{-\langle n \rangle} / n!$
- Interactions generated in ordered p_T sequence
- Momentum conservation in PDF's reduces the number of collisions.

More Sophisticated

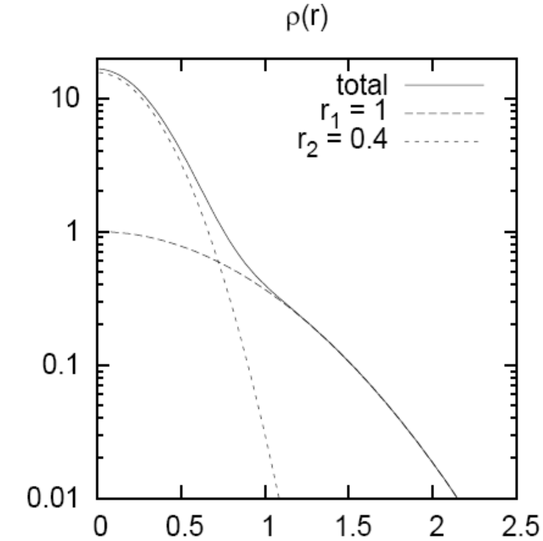
- Use a smooth turn off at p_{T0}.
- Require at least 1 interaction per event
- Hadrons are extended objects, e.g. double Gaussian ("hot spots"):

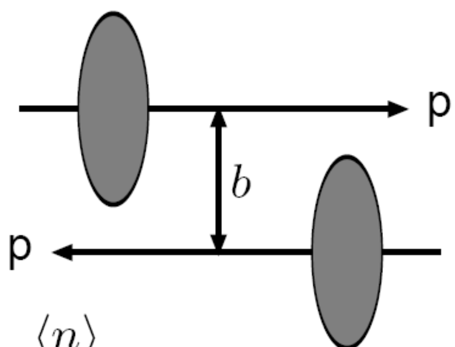
$$\rho_{\text{matter}} = N_1 \exp\left(-\frac{r^2}{r_1^2}\right) + N_2 \exp\left(-\frac{r^2}{r_2^2}\right)$$

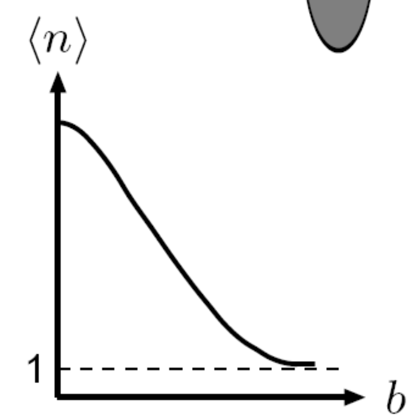
  where $r_2 \neq r_1$ represents "hot spots"
- Events are distributed in impact parameter *b*.
- The hadrons overlap during the collision

$$O(b) = \int d^3x\, dt\, \rho_{1,\text{matter}}^{\text{boosted}}(x,t)\, \rho_{2,\text{matter}}^{\text{boosted}}(x,t)$$

- Average activity at b proportional to O(b).
  - Central collisions normally more active
  - more multiple scattering.





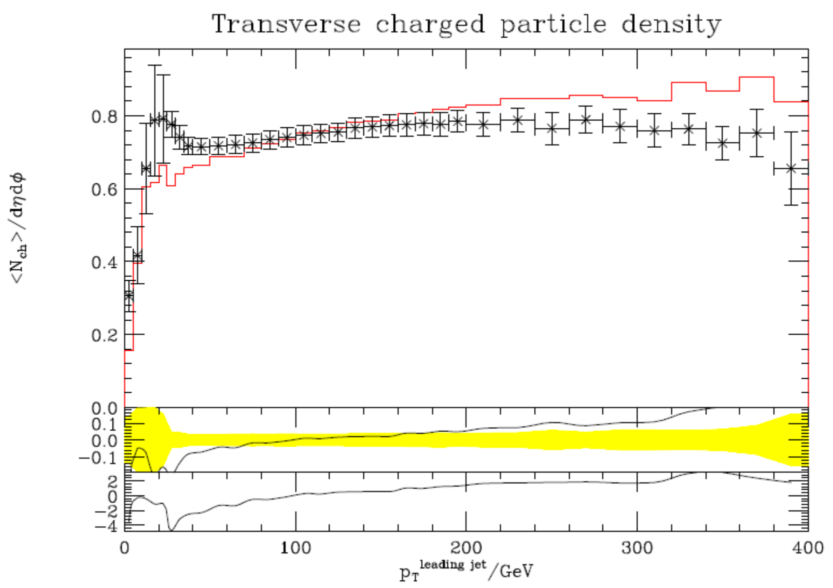


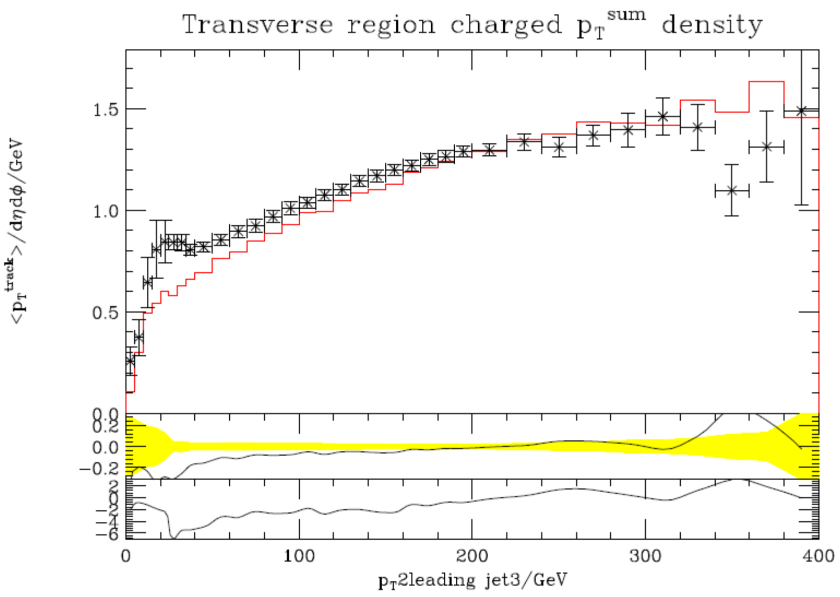
Prior to LHC

- Before the LHC data from:
  - UA5 experiment;
  - CDF at both 630, 1800 and 1960 GeV.

  were used to constrain the parameters of the underlying event model.
- The data at the higher Tevatron energies is the best for tuning the parameters at specific energy.
- Need the other points to extrapolate the parameters to LHC energies.

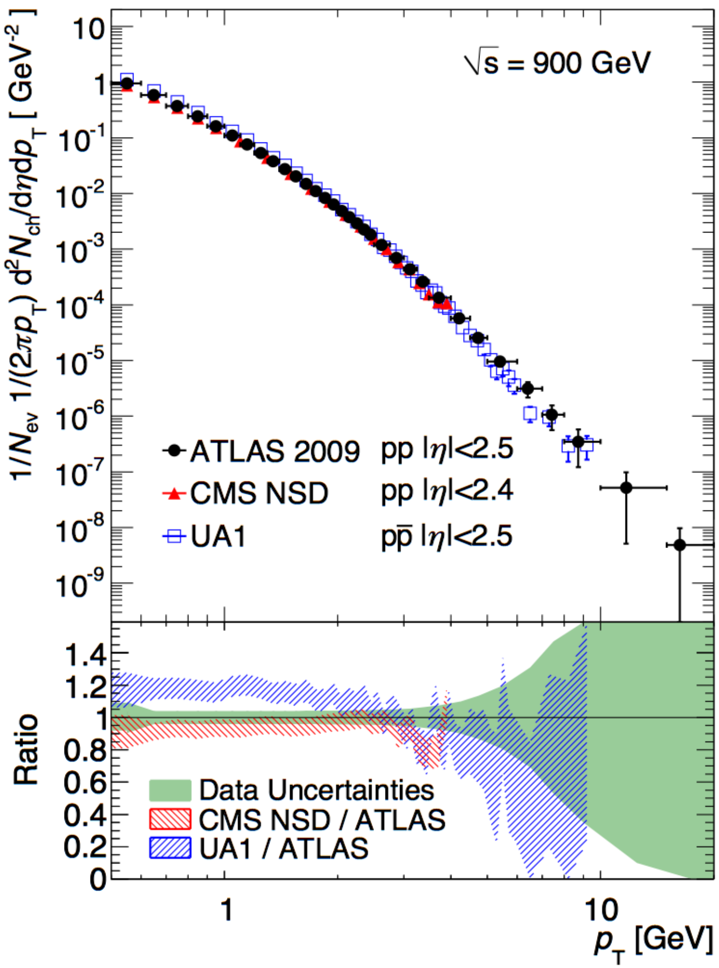
Underlying Event

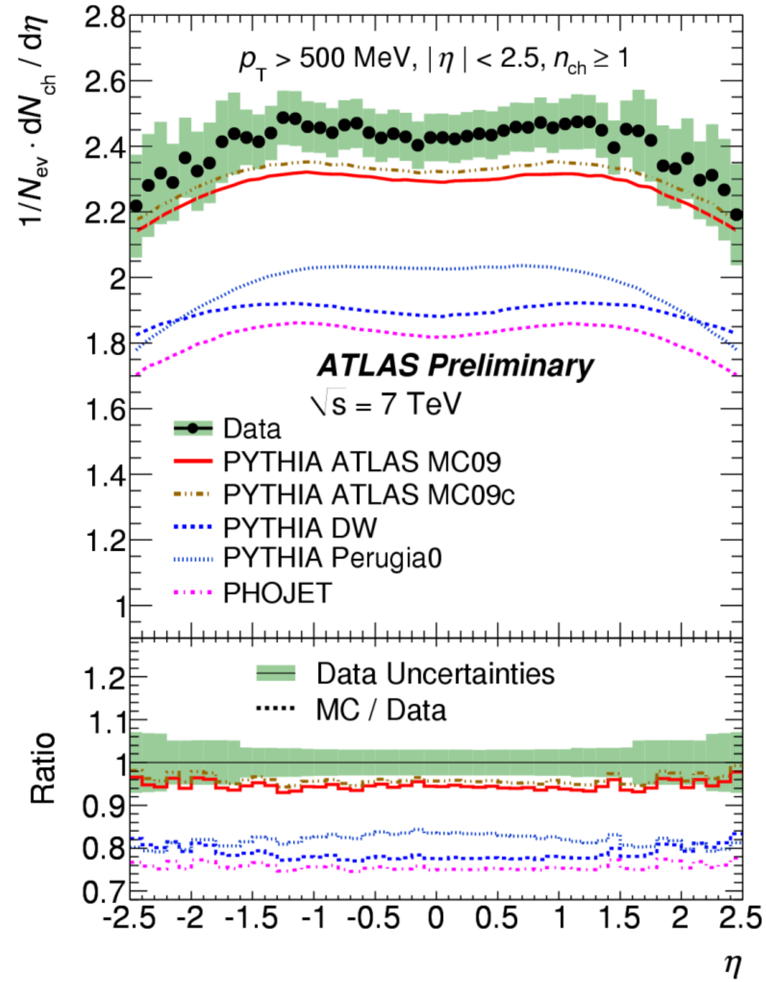




Herwig++ compared to CDF data

Charged Particle Multiplicities at √s=0.9, 7 TeV



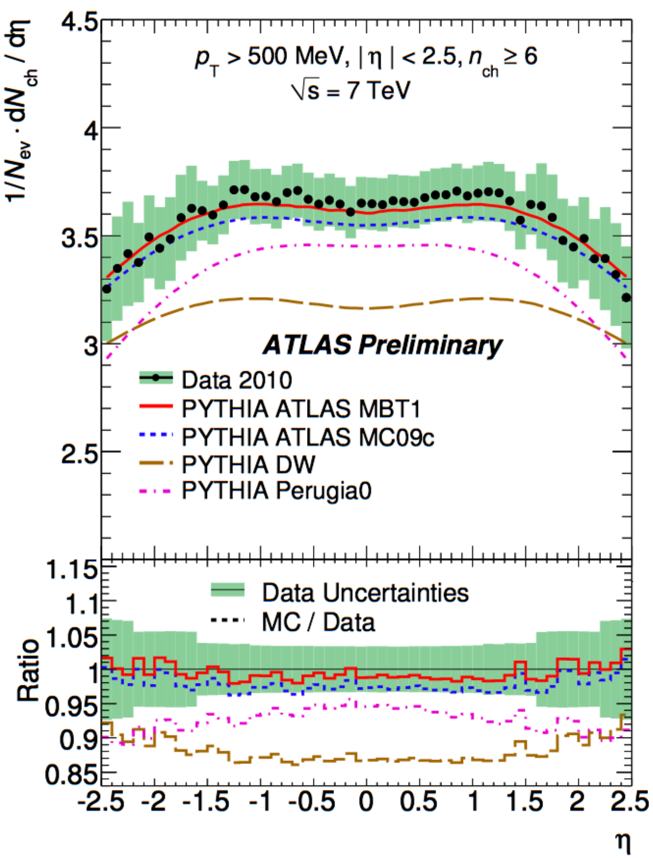


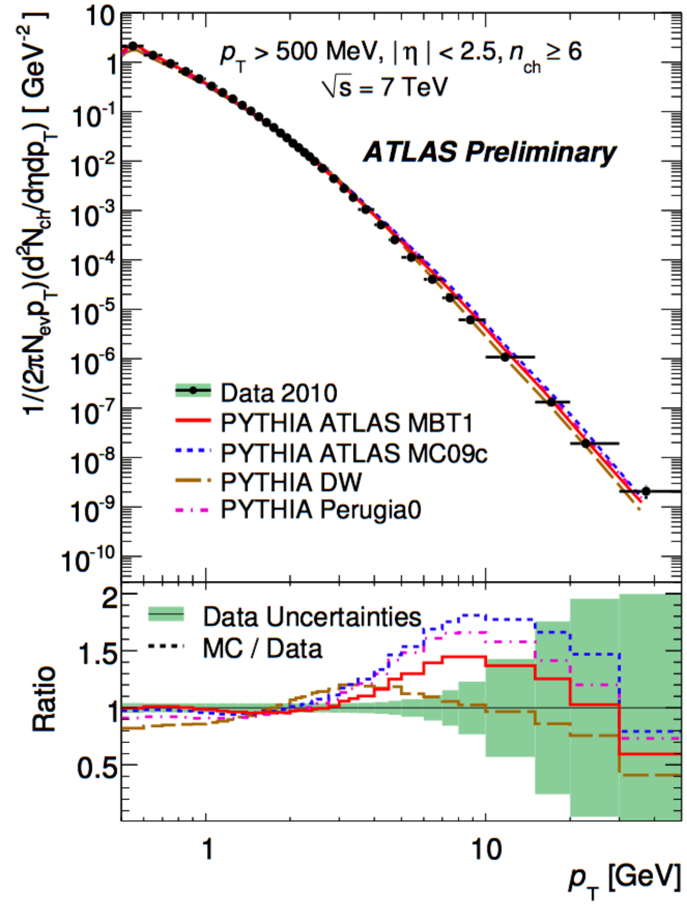
Monte Carlo underestimates the track multiplicity seen in ATLAS

Pythia Tune to ATLAS MinBias and Underlying Event

Used for the tune

ATLAS UE data at 0.9 and 7 TeV
ATLAS charged particle densitites at 0.9 and 7 TeV
CDF Run I underlying event analysis (leading jet)
CDF Run I underlying event "Min-Max" analysis
D0 Run II dijet angular correlations
CDF Run II Min bias
CDF Run I Z pT





Result

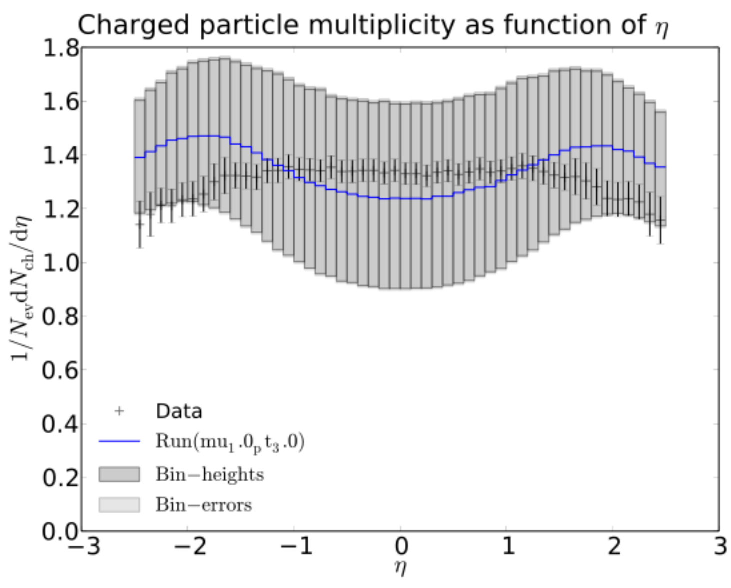
This tune describes most of the MinBias and the UE data
Significant improvement compared to pre-LHC tunes
Biggest remaining deviation in → $\frac{1}{N_{\rm ev}} \cdot \frac{1}{2\pi p_{\rm T}} \cdot \frac{d^2 N_{\rm ch}}{d\eta dp_{\rm T}}$
These deviations could not be removed
Needs further investigtions

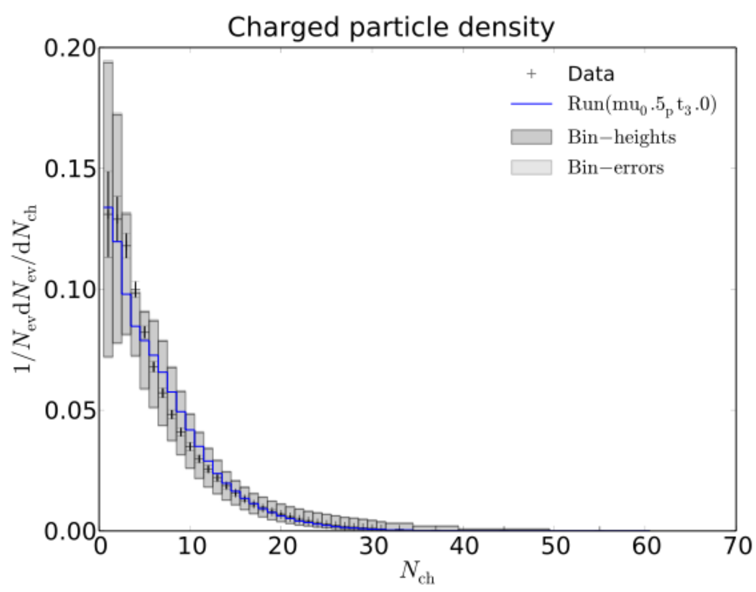
Minimum Bias

- Completely new in Herwig++

  hard + soft multi-parton interaction model

  First comparison with ATLAS data looks promising…





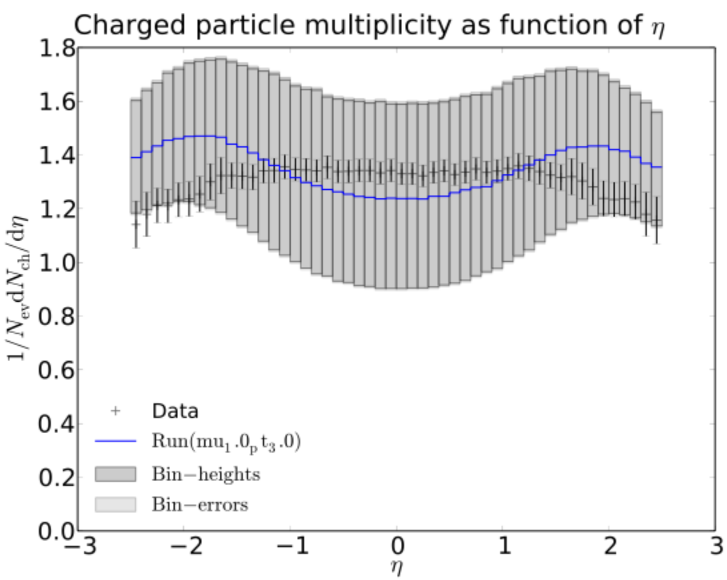
Minimum Bias

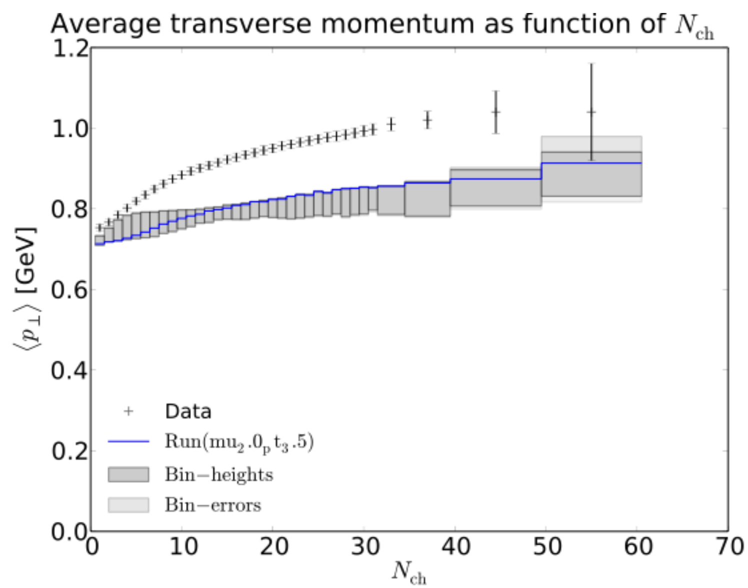
- Completely new in Herwig++

  hard + soft multi-parton interaction model

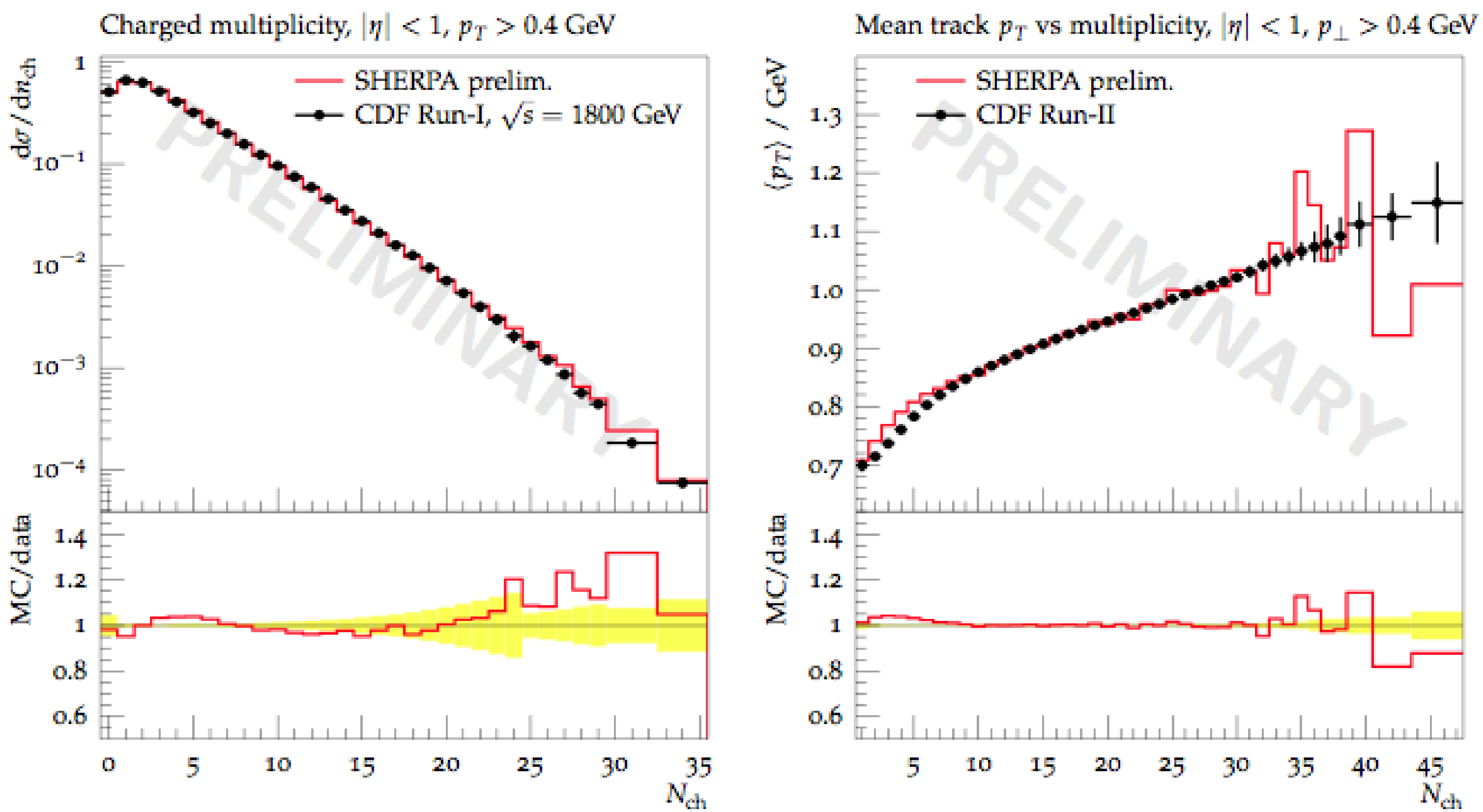
  First comparison with ATLAS data looks promising…

  but still work to do…





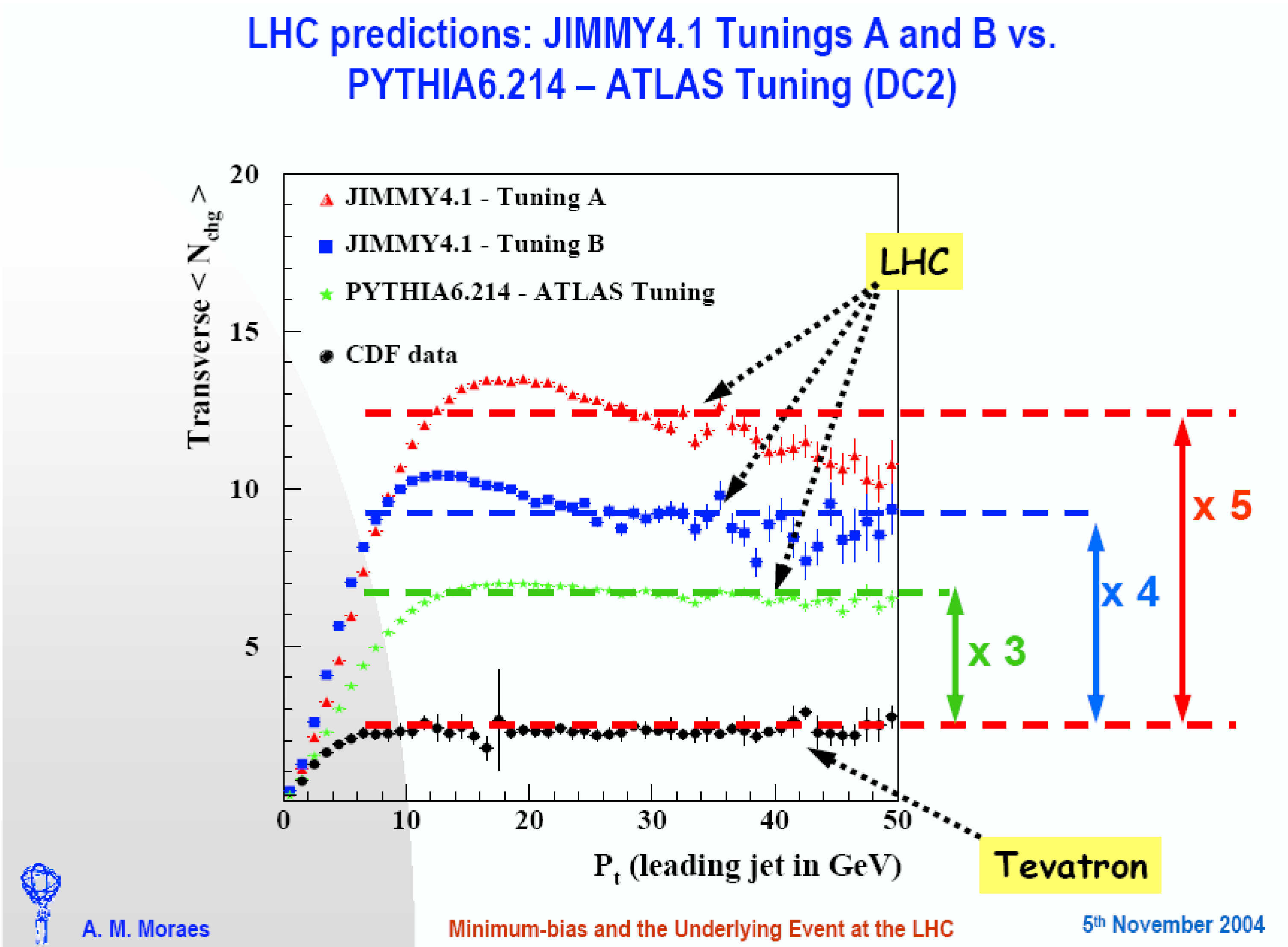
New MinBias model: First preliminary results



Phys.Rev.D65:072005,2002 Phys.Rev.D79:112005,2009

Multiple Parton Scattering

- Results are encouraging.
- The results of the tunes made before data taking don’t exactly agree with the data but aren’t orders of magnitude off.
- Including the new results in the fitting gives good agreement.
- The models therefore seem reasonable, perhaps some theoretical tweaking needed, but not a major rethink of the whole approach.


LHC predictions: JIMMY4.1 Tunings A and B vs.
PYTHIA6.214 – ATLAS Tuning (DC2)
Transverse < N_chg >
P_t (leading jet in GeV)
JIMMY4.1 - Tuning A
JIMMY4.1 - Tuning B
PYTHIA6.214 - ATLAS Tuning
CDF data
LHC
Tevatron
x 5
x 4
x 3
20
15
10
5
0
10
20
30
40
50
A. M. Moraes
Minimum-bias and the Underlying Event at the LHC
5th November 2004

The Rest

- The modelling of the underlying event is the thing that was most uncertain:
  - model not firmly based on perturbative QCD;
  - parameters had to be extrapolated.
- The parameters for the simulation of QCD radiation in the parton shower should be universal.
- We assume that having used the parton shower to evolve from high to low energy scales the hadronization parameters are also universal.

Jets

- There are results on:
  - jet shapes;
  - azimuthal decorrelations;
  - a lot of results on the production of jets in association with W/Z;

  from the Tevatron
- However most of the measurements of pure jet production are very inclusive and not a lot of use for tuning the generators.
- Given the new energy regime we are beginning to enter this should be checked.

Jets

- The simulation of jet production usually starts from a 2→2 matrix element.
- So the distribution of the two leading jets is dominated by the hard matrix element.
- The shower gives the shape of the jet, azimuthal decorrelations and some changes in p_T and rapidity.
- The third and subsequent jets are radiated in the shower.

Jets

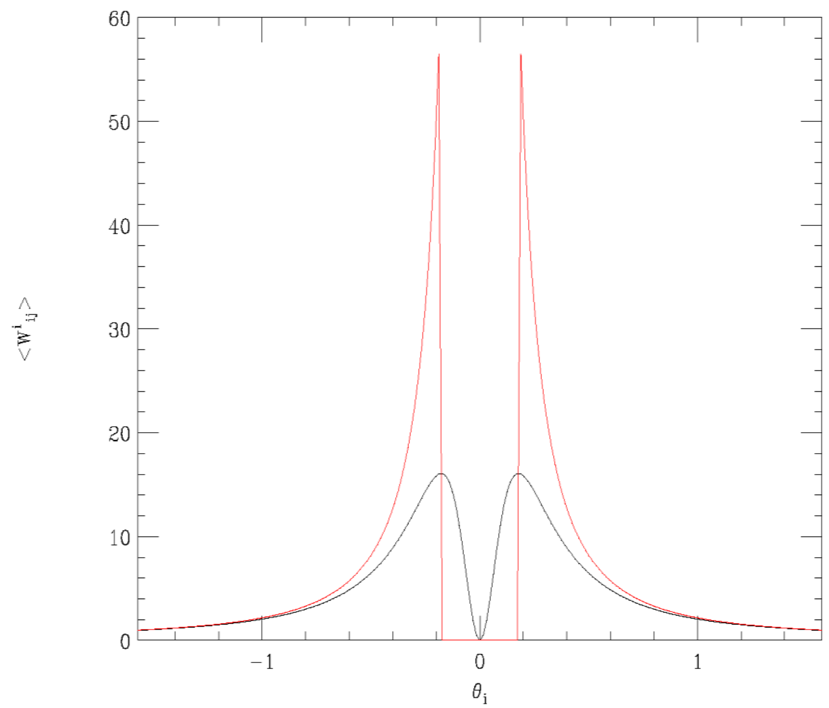
- There has been little work looking at jet structure in hadron collisions with the new generation of matrix element matching approaches (CKKW, MLM).
- CKKW at least works well with LEP observables, but things are different in hadron collisions where there's more energy.

Boosted Objects

- As we've spend many years simulating LEP events the simulation of the radiation in the decay of a colour neutral boosted object should be pretty reliable.
- However we have a lot less experience with simulating radiation from heavy coloured particles.
- There's only the top and due to the C.M.S. energy it doesn't radiated much at the Tevatron.

Dead-Cone

- For massive particles radiation with angle less than m/E is suppressed, the "dead-cone".
- In FORTRAN HERWG made an extreme approximation which leads to problems in physical distributions.



Soft radiation pattern from a top quark with 1 TeV energy.

Top

- The parton shower is based on the collinear and soft approximations.
- The treatment of mass effects has improved theoretically over the years:
  - different evolution variables;
  - quasi-collinear splitting functions.
- However only really tested for bottom quark production.
- Any results on radiation in top events will be interesting.

Summary

- We've spent a long time developing a new generation of simulations for the LHC.
- We've done a lot to compare and tune the results to existing data.
- However as we enter the new energy regime of the LHC some things we will need to:
  - retune parameters;
  - improve the perturbative physics.
- So far things look O.K. but that may well change as statistics improve.