MC Tuning

Minimum bias physics

Underlying event

Parton Shower

Motivation for MC tuning

MC generators important tools to

- Derive resolution and accepetance corrections
- Estimate backgrounds
- Design detectors
- Provide theoretical interpretation of the results

➢ Need good description of ALL aspects of high energy interaction

➢ Check and tune models with available data

"The experience gained with the model, in failures as well as successes, could be used as a guideline in the evolution of yet more detailed models." [T.Sjoestrand, 1987]

Observables and the partonic picture

Hard interactions

Jets
Leptons

Radiation effects

Inner jet structure
Small angle lepton distributions

Soft QCD

Soft charged particles
Energy flow

Short distance physics
- Small alpha_s
- Perturbative calculations

Factorisation

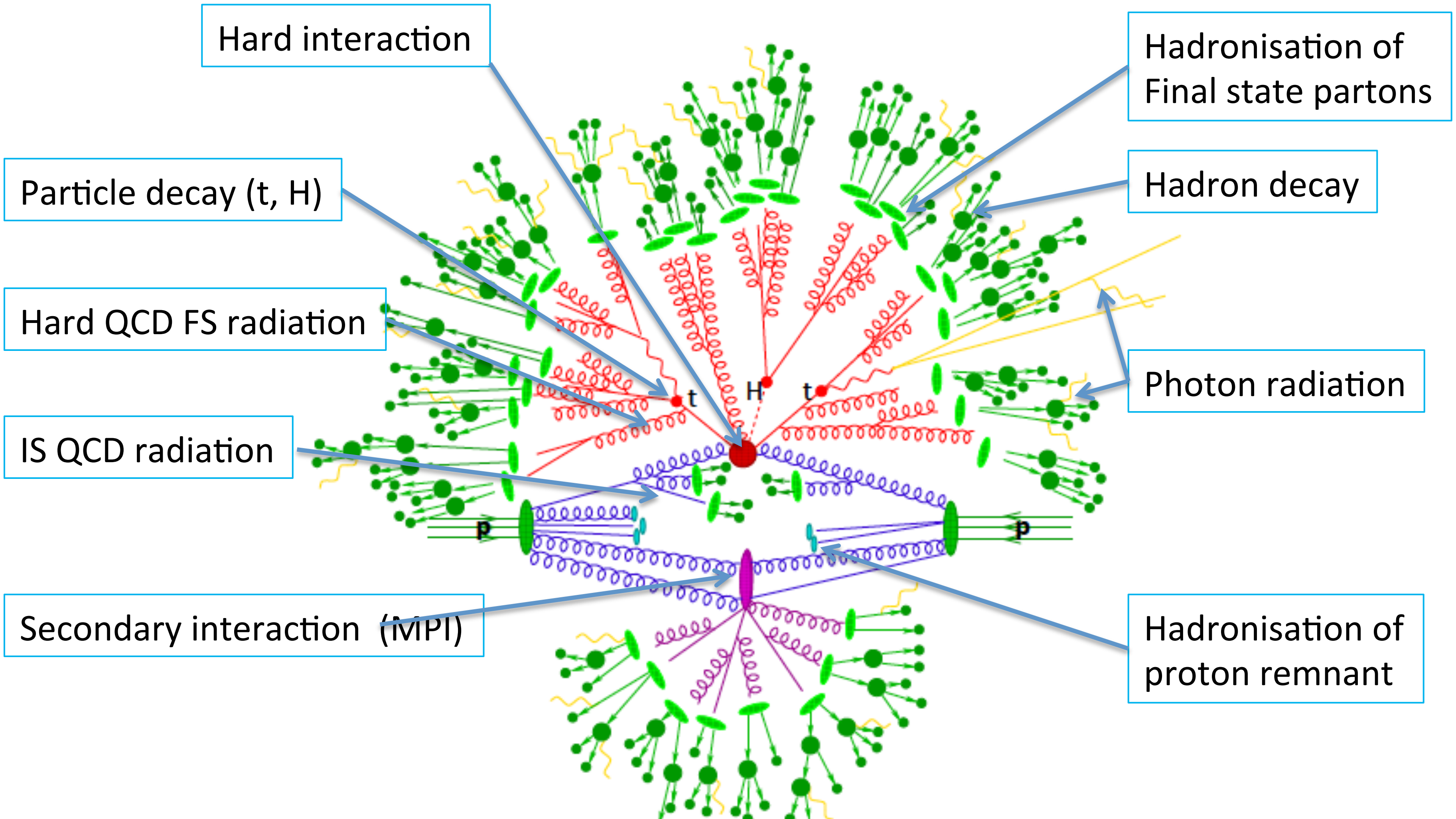
Large distance physics
- Large alpha_s
- Phenomenological models
- Univeraslity

Universality of phenomenological models

Underlying assumption: non-perturbative dynamics independent of the hard scattering process

- use of the same parameters for the predictions of different observables
- Simultaneous Tunes to different observables
- Validation of models and tunes in direct comparison with different data sets

QCD in MC



Up to ~30 tuneable parameters in MC codes

MC Tuning Method

- Assumption: each parameter controls only a relatively small & exclusive detail of the event generation
  - Allows tuning of small amount of parameters for a particular component to suitable observables
  - However, observables usually also weakly dependent on other parameters & components
  - Iterative tuning
- Typical tuning sequence:
  1. Fragmentation and parts of parton shower tuned to LEP data
  2. Soft QCD models tuned to hadron collider data
- Probe scaling of models by tuning / comparing to different cms energies (Tevatron, LHC 900 GeV, 7 TeV, 8 TeV)

Tuning methods (1)
Manual tunes

- Generate predictions for a parameter set within the validity range of the model & optimise according to human judgement
- Strength: comprehensible & stable results
- Limitations: correlated and many parameters -> very time consuming
- Examples: Pythia6 and Pythia8 author (Skands, Sjoestrand) tunes (Perugia Tunes, Monash Tunes, C4, C4x…), tune A, Z1, Z2, (Rick Field)

Tuning method (2) analytical approximations

- Approximate the parameter dependence of the physical observable on the model parameters by an analytical function, typically a 2nd or 3rd order polynomial
- Optimise tuning of a large number of parameters simultaneously
- Personal judgement enters via weights of observables
- Examples: ATLAS tunes (pythia AMBT1, AZ, AUET, fHerwig), CUET tunes, recent Herwig++ and Sherpa tunes

Uncertainties
on models & optimised parameters

- tuning to different but redundant observables or different ranges of observable spectra (AZ tunes)
- Allow limited deviations from the measurements (see Perugia tunes)
- Perform “eigentunes” of the analytical approximation: calculate chi2 variations of the diagonalised covariance matrix used in the minimisation (see ATLAS tunes)

Software & Tools

- HepMC : output format for event generators
- Rivet (HZTool): analysis libraries for LHC, LEP (HERA) to extract physical observables corresponding to experimental measurements
- MCPLOTS (http://mcplots.cern.ch/) web-accessible repository of theoretical predictions from various MC generators for experimental data
- Professor (Proffit): tuning tool using analytical approximations interfaced to Rivet

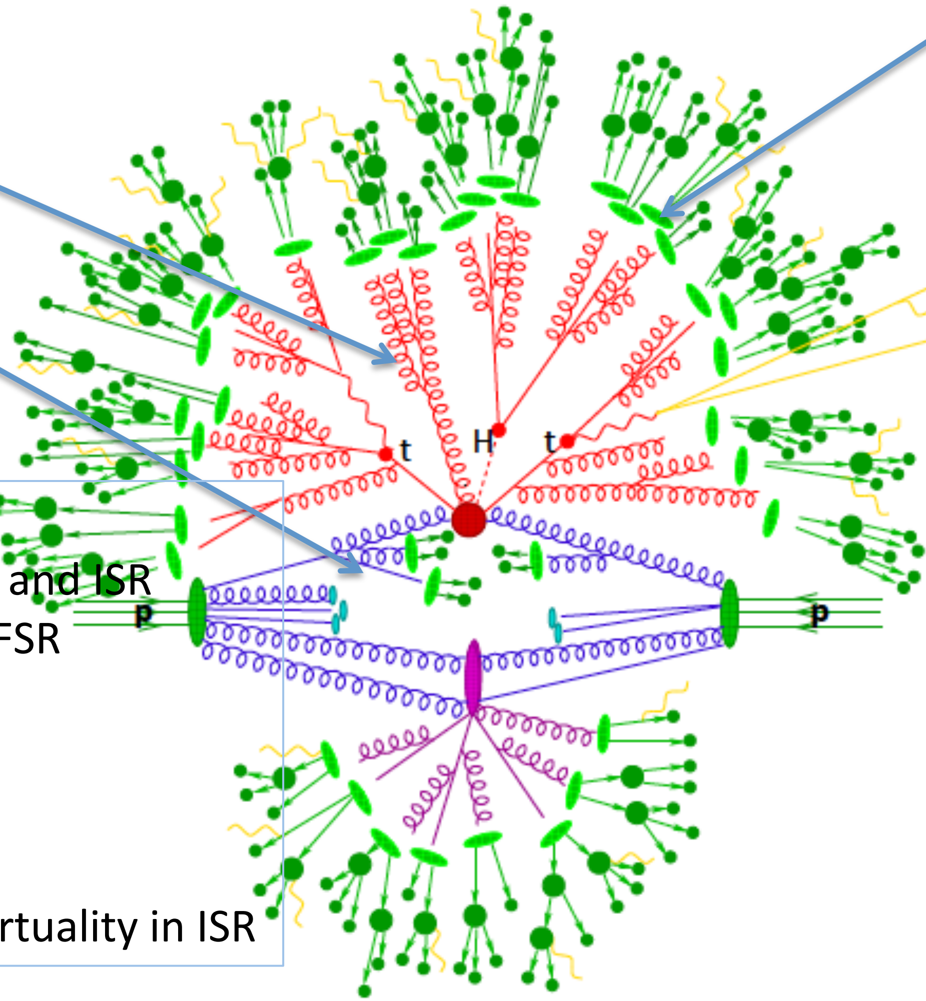
Tuning parton shower and fragmentation

Hadronisation of
Final state partons

Lund string model
Cluster fragmentation

QCD FS radiation

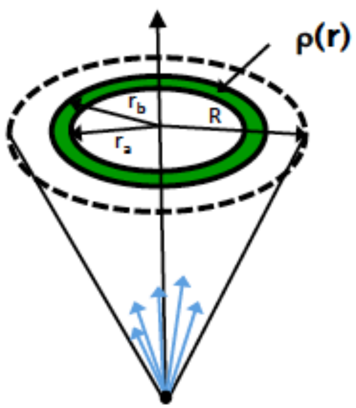
IS QCD radiation

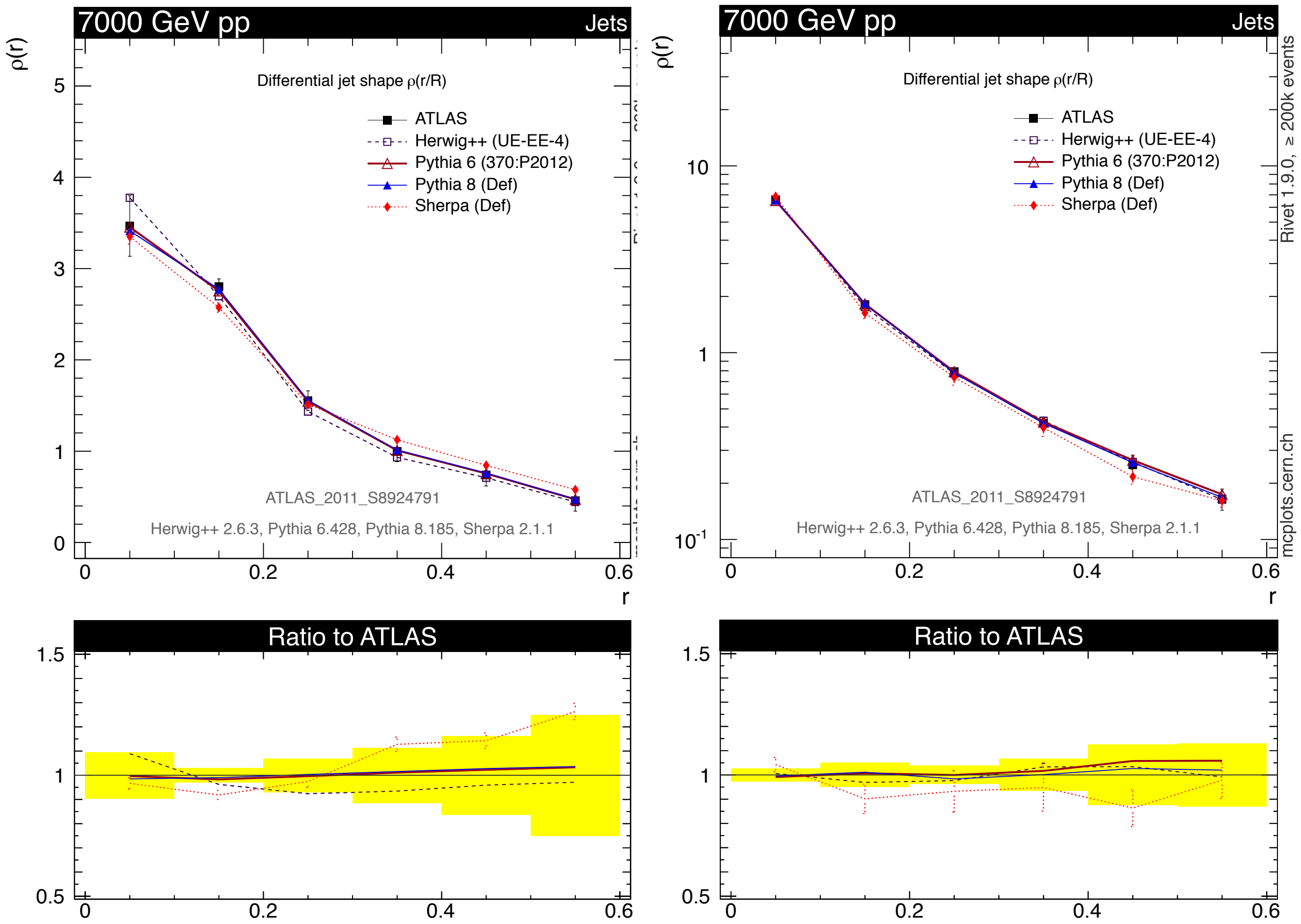


Tuned to LEP data:
- particle multiplicity
- Event shape variables
- Momentum spectra

Shower parameters:
Low Q0 cut-off for FSR and ISR
a_s (lambda_QCD) for FSR
Mean intrinsic kT
PYTHIA:
a_s for ISR
a_s for FSR off ISR
Max. allowed parton virtuality in ISR

FSR Observables: Jet shapes





$$\rho(r) = \frac{1}{\delta r} \cdot \frac{1}{N_{jets}} \cdot \sum_{jets} \frac{p_T(r_a, r_b)}{p_T(0, R)}$$

+ b-jet shapes, jet shapes from Tevatron

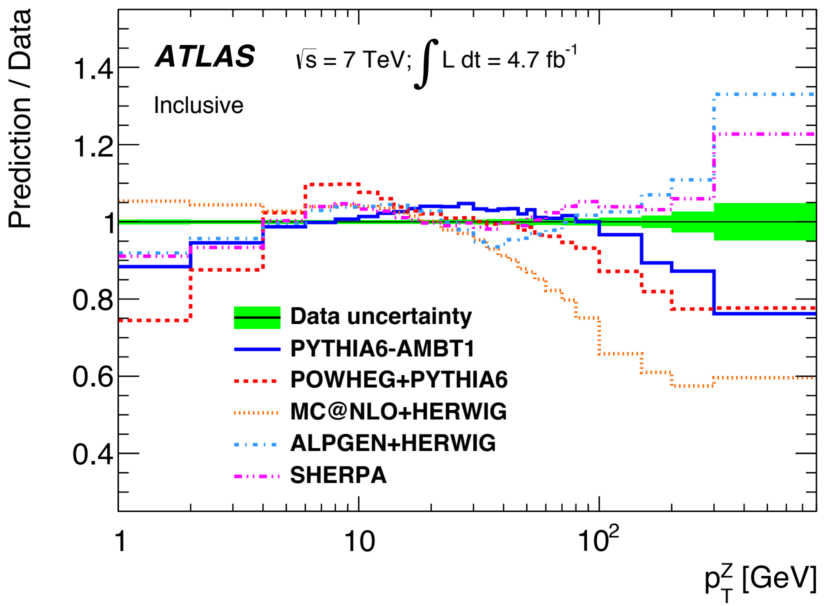
ISR Observables: Drell Yan

q q -> Z -> e e

Zpt and phi* $\phi^*_\eta \equiv \tan(\phi_{acop}/2) \cdot \sin(\theta^*_\eta)$

Intrinsic kt:
kT of partons inside incoming protons
Fermi motion ~200 MeV
“sum of unresovled effect below shower cut-off”

ISR Q_0 cut-off
Alpha_s



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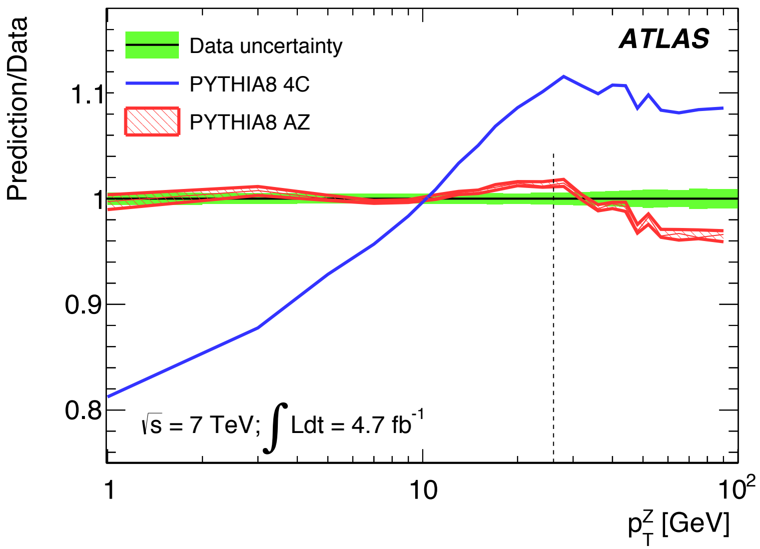
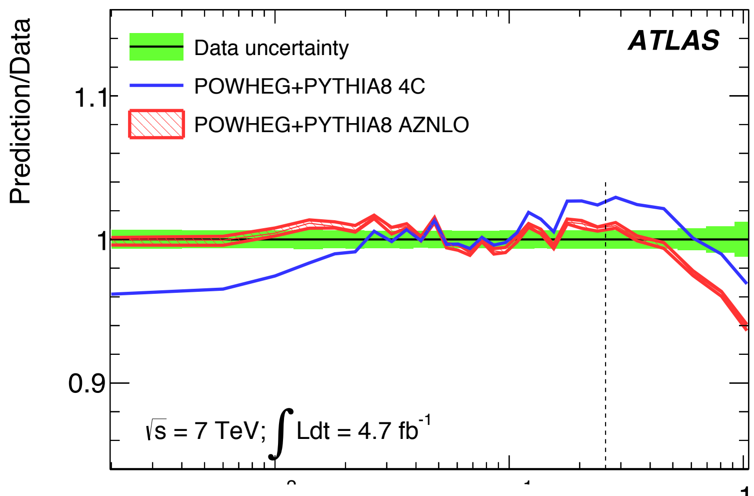
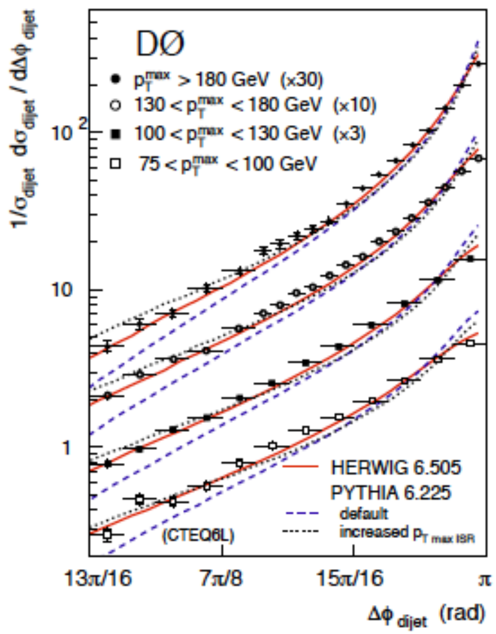


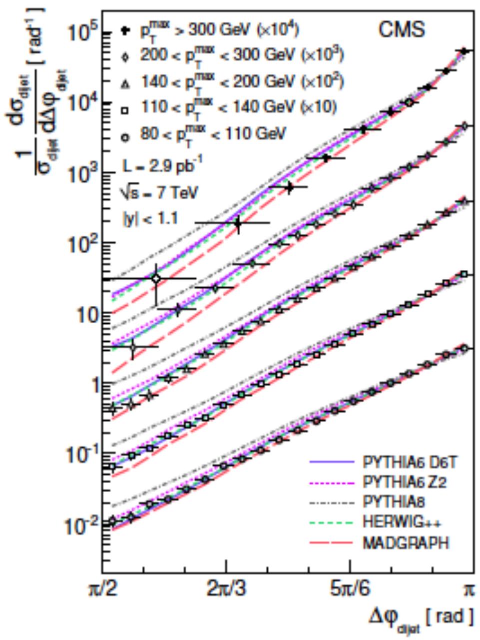


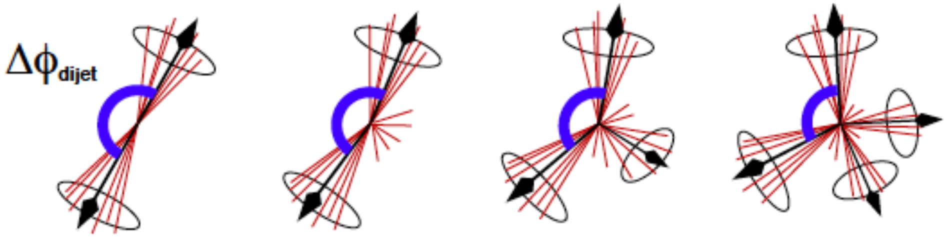
$$\phi^*_\eta \equiv \tan(\phi_{\rm acop}/2) \cdot \sin(\theta^*_\eta)$$

PS in dijet decorrelation

Probe hard and soft emission without explicit separation

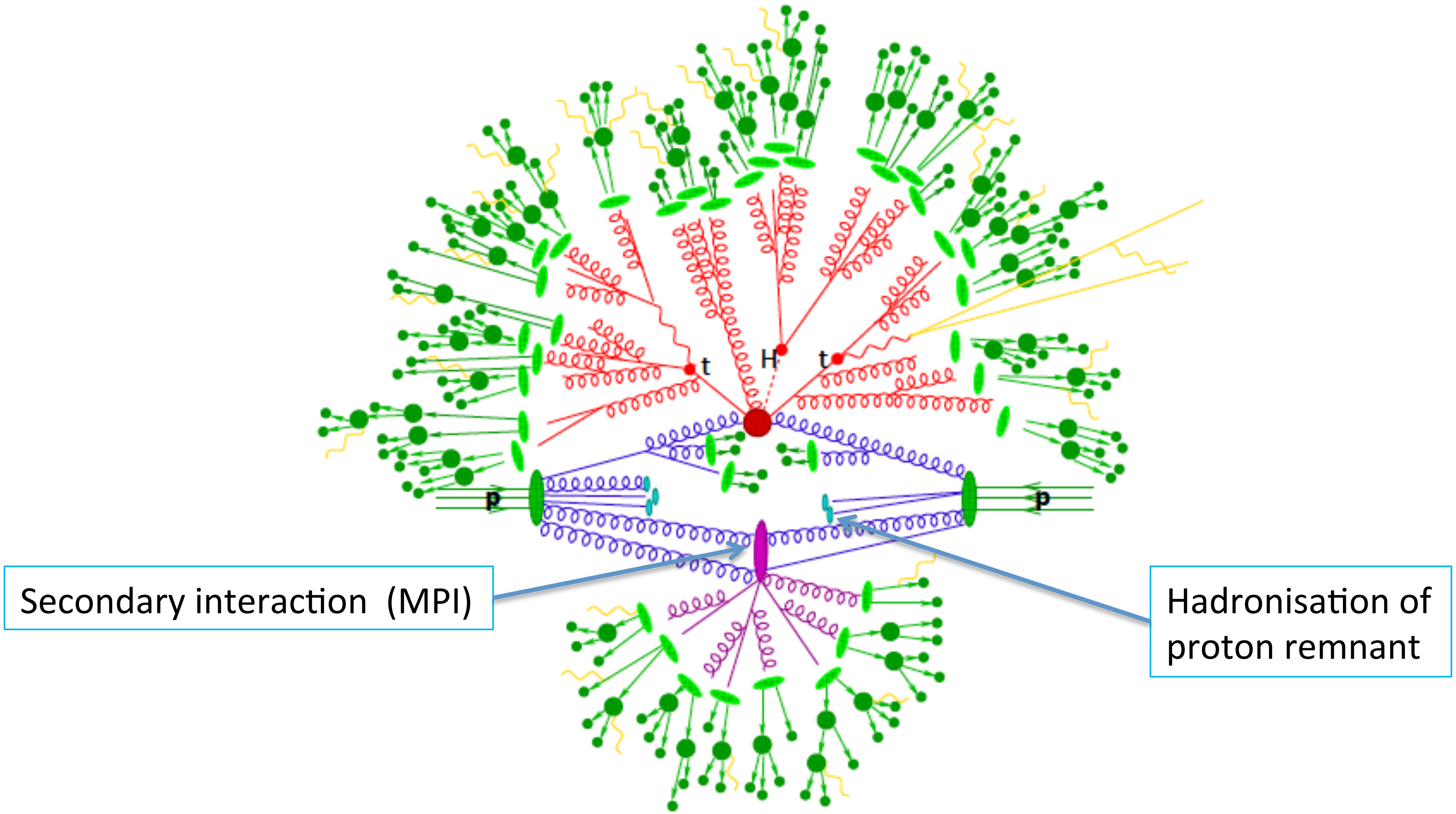




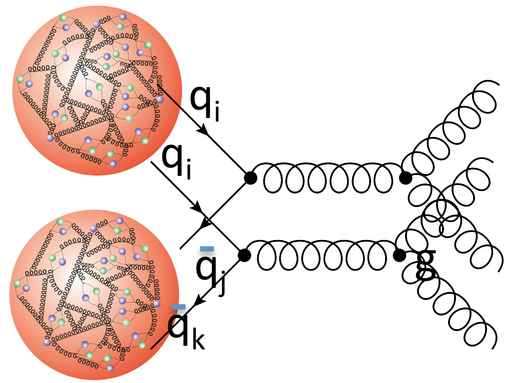


Sensitive to max. allowed parton virtuality

MPI and Colour Reconnection



MPI



- Secondary interaction between remnant partons
- Modeled by perturbative parton-parton scattering framework

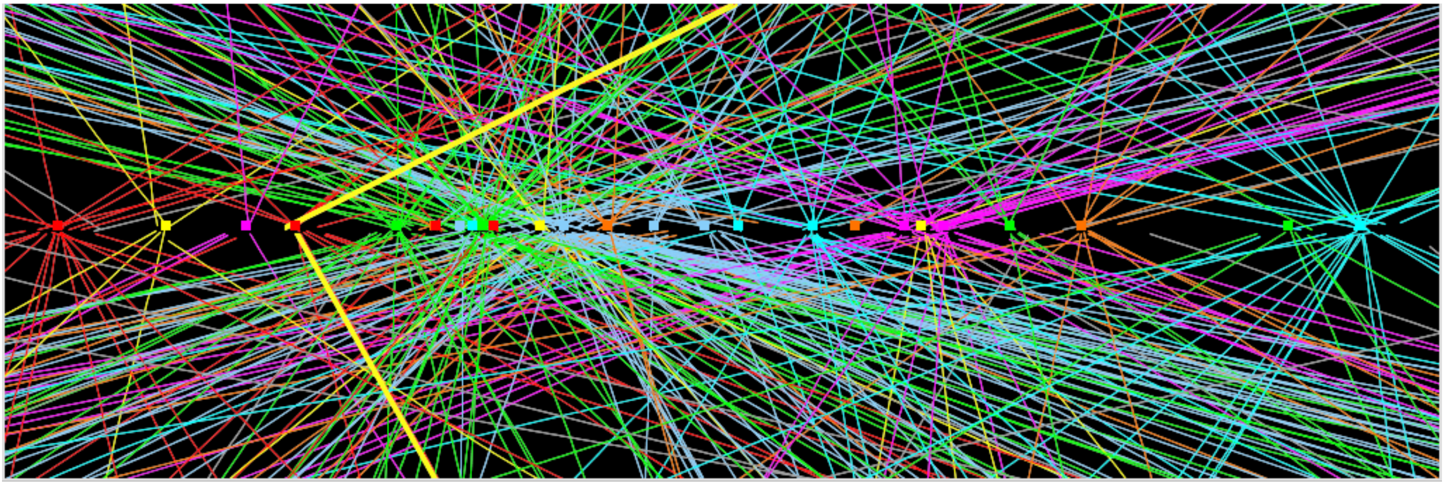
  -> rising towards low p_T

  -> dominated by t-channel gluon exchange

  -> parton shower and hadronise
- Hard MPI observed gamma+2jet (Tevatron), W+ 2jets (LHC)
- Soft MPI: major source of soft particle production in min.bias events and underlying event in hard scatter processes

Reminder:
Minimum bias abundantly

Pile-up at LHC



2012 data (8 TeV): <mu> ~ 21

Run 2 (13-14 TeV): <mu> ~ 40

Color reconnection

- Rearrangement of the final state parton connections due to the colour structure of the scattering
- Includes modeling of MPI scatters and colour flow in beam-beam remnant
- Various models exist, e.g. reorder hadrons to minimise string length or cluster mass
- Modifies the relation between <pT> and number of charged particles in hadron collisions
- May also affect top mass (one of the dominant uncertainties!)

MPI model & parameters

$$\sigma_{hard}(p_{T,min}) = \int_{p_{T,min}^2}^{s/4} \frac{d\sigma}{dp_T^2} dp_T^2.$$

- Exceed total cross section at 1-2 GeV due to high parton densities
  - Limit rise of partonic cross section via
    N(Parton-parton) = sigma(hard)/sigma(non-diff) -> matter overlap
- Divergent for pT->0 : introduce cut-off pTmin

Do we have this right for LHC at 13 TeV?

$$p_{T,min}(\sqrt{s}) = p_{T,min,0} \cdot (\frac{\sqrt{s}}{E_0})^b$$

PDF dependent!

Tuneable paramters

Observables for MPI & CR

Mean nr of charged particles (Ncharged) : ptmin,0

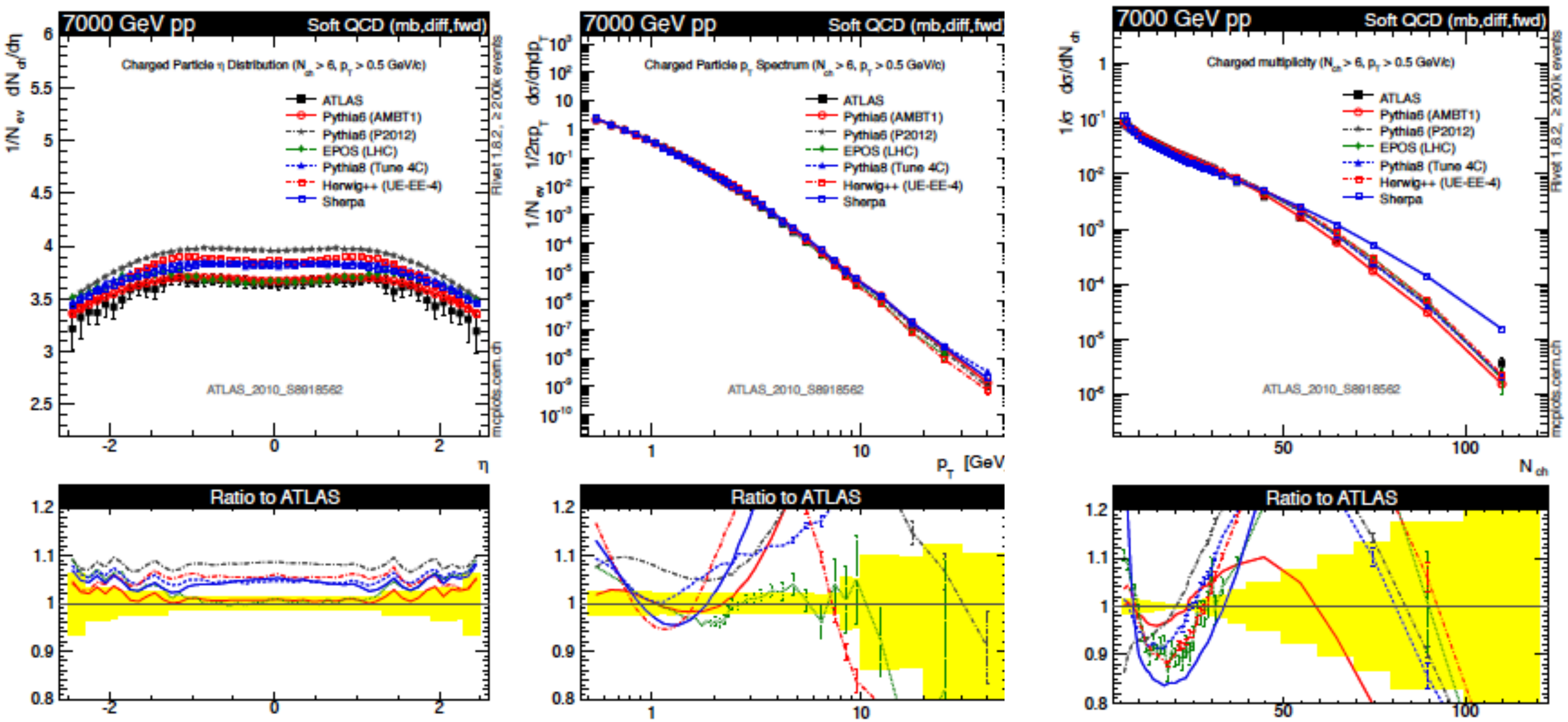
Charged particles at different sqrt(s) : b

Probability distribution of charged particle multiplicity: matter distribution

<pt> vs Ncharge : color reconnection

Measured at LHC, Tevatron, SPS in minimum bias and hard scatter events

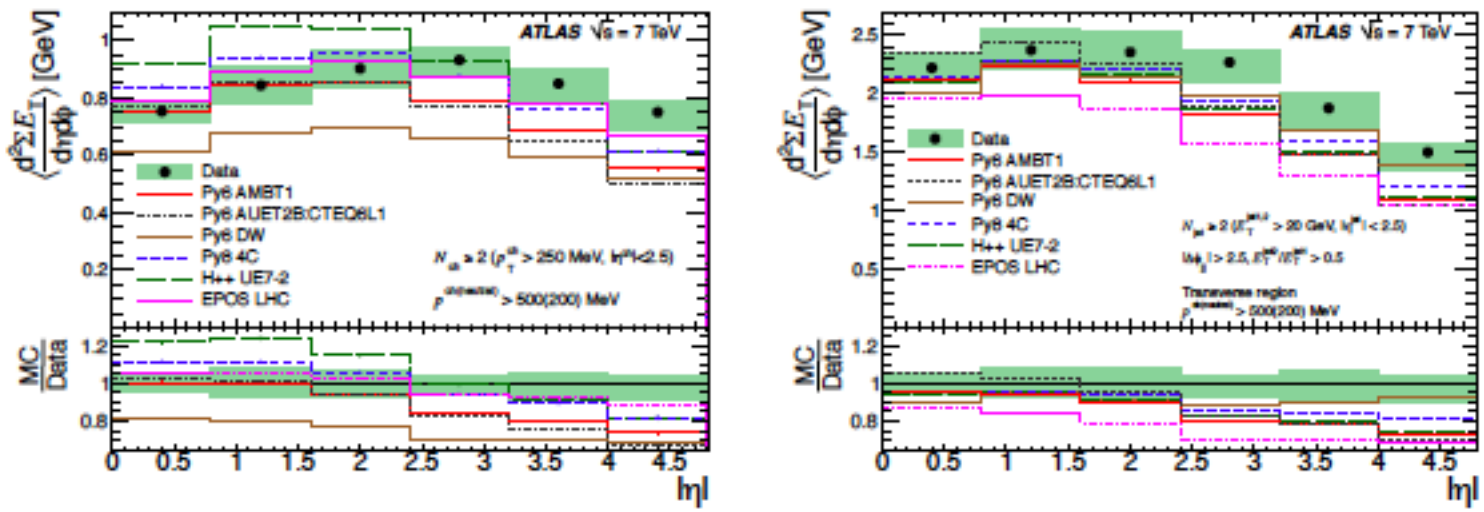
Minimum Bias Measurements (1) charged particle distributions



Manageable to describe inclusive production but difficult to get the details right

- Problems to extrapolate to softer particle production, chemical composition, Tevatron …

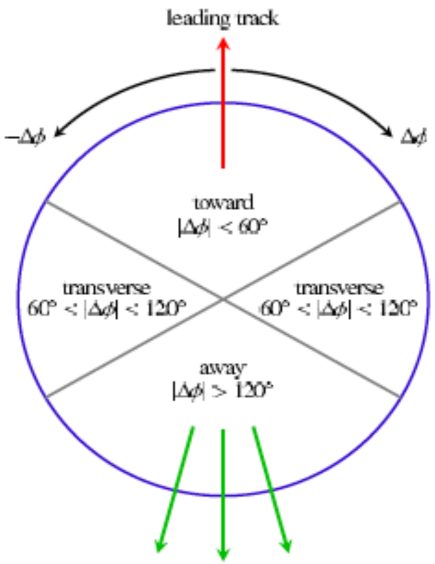
Minimum bias observables (2)
Forward energy flow

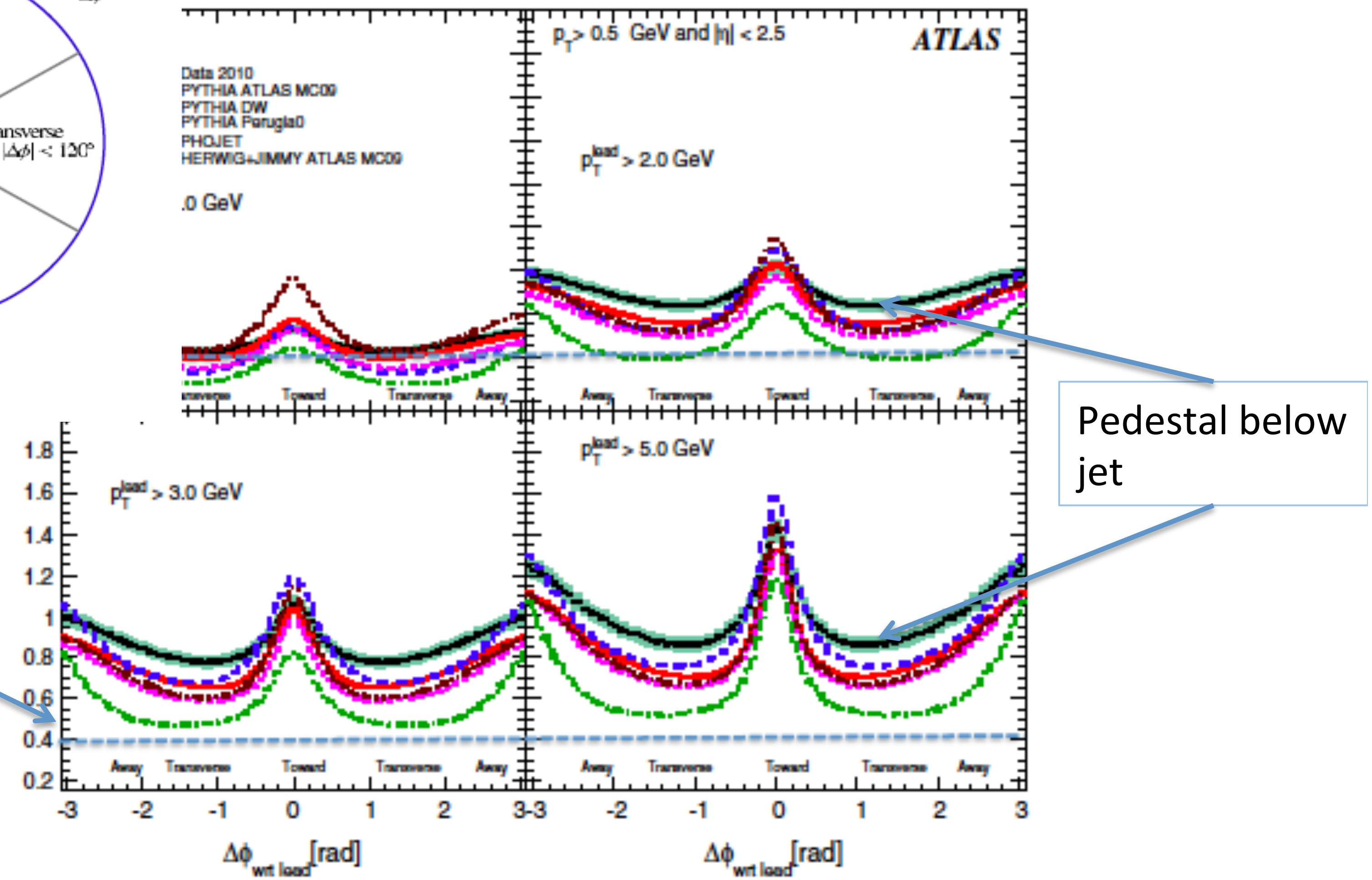


Hard to get right!

Would be nice to have for Etmiss and Cosmic rays……

Pedestal effect

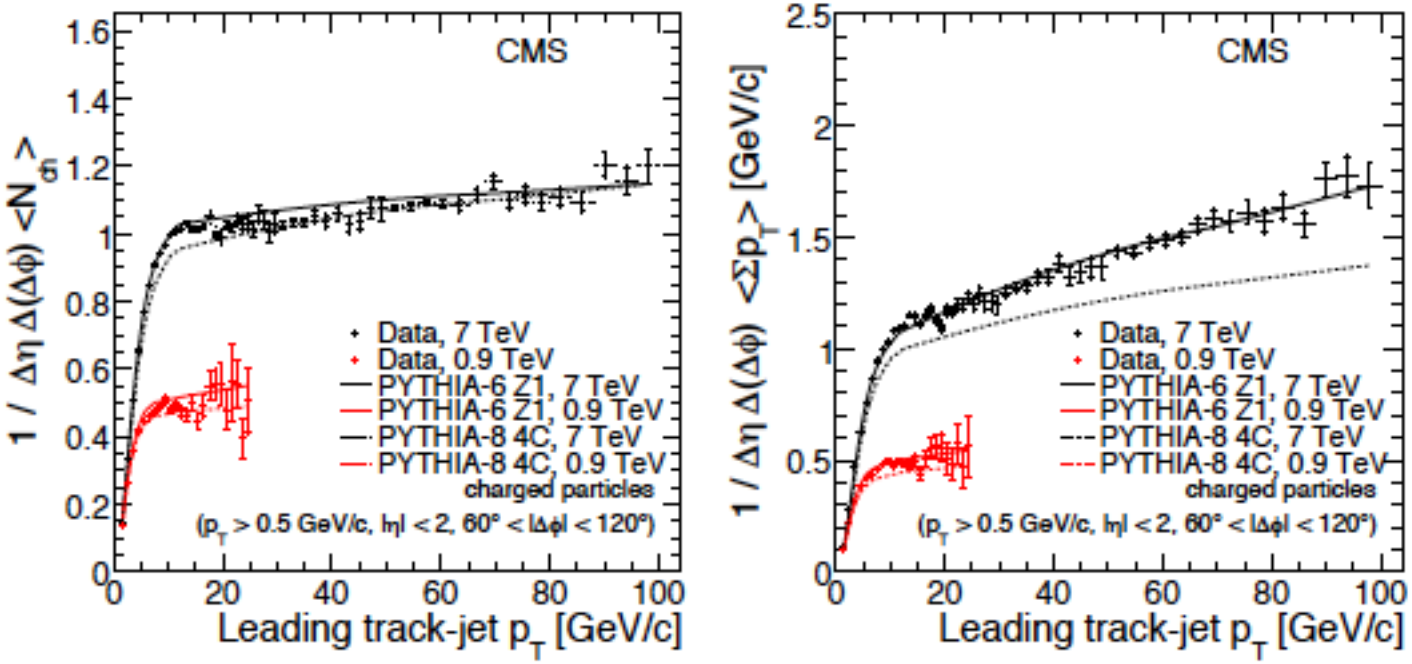




Charged particle production with respect to the leading jet

Underlying event observables

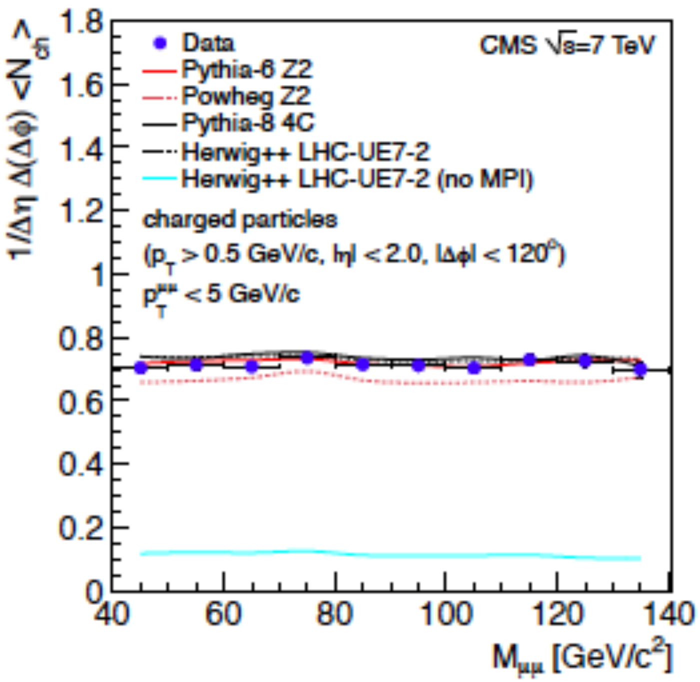
Measure charged particle density and energy density



Good description achievable with LHC data at different CMS energies
Tension with Tevatron data

Will this work also for 13 TeV?

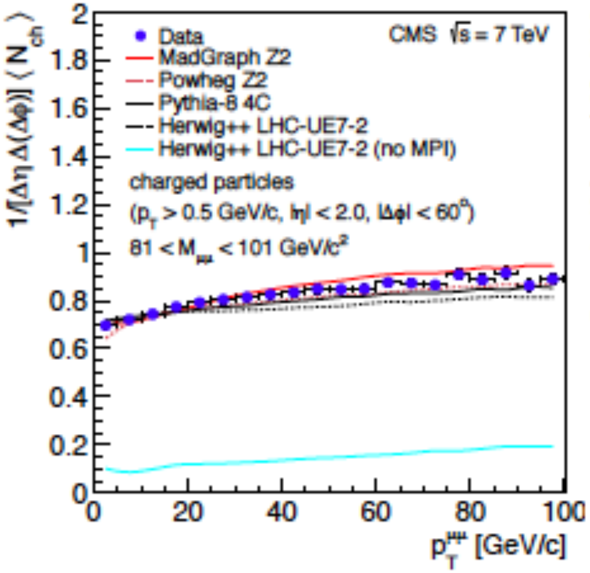
Disentangle ISR and MPI? UE in DY (1)



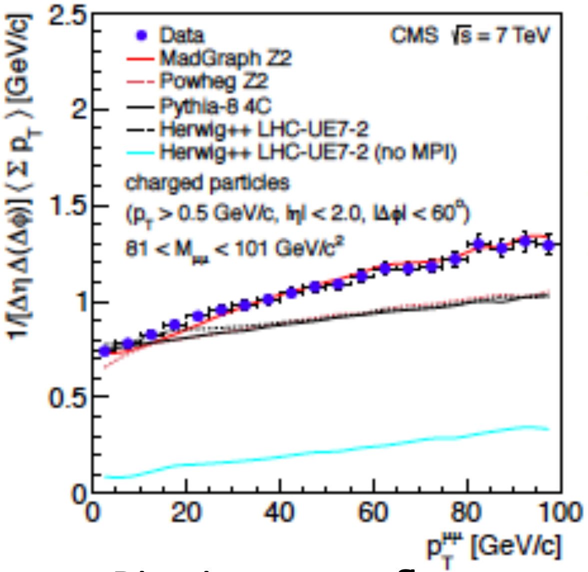
Ideal case to study MPI!

Disentangle ISR and MPI?
UE in DY (2)

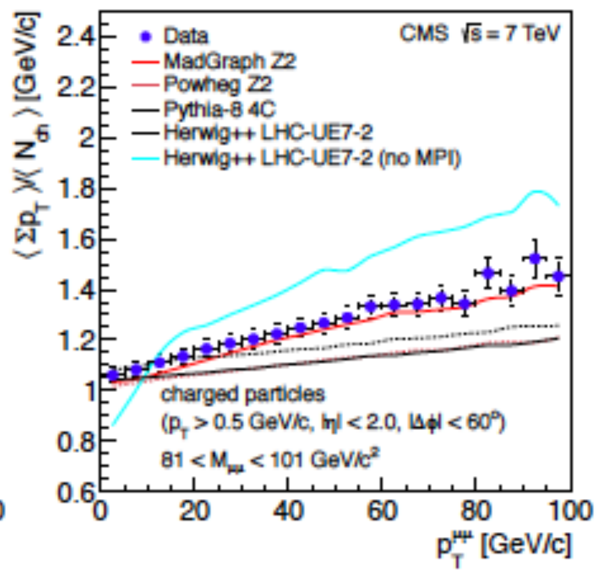
particle density



energy density



ratio of energy and particle densities

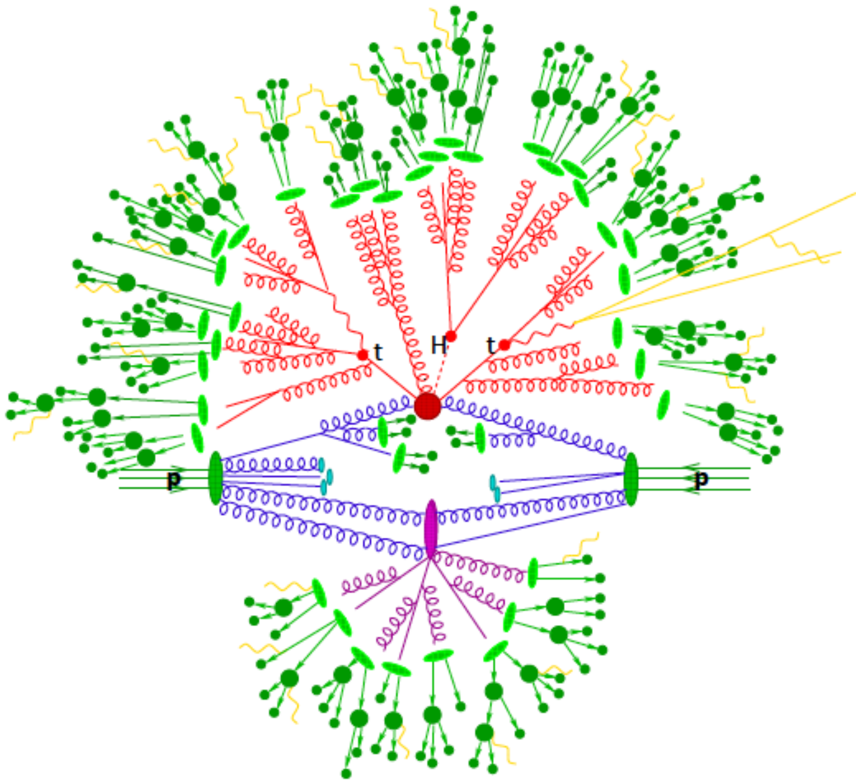


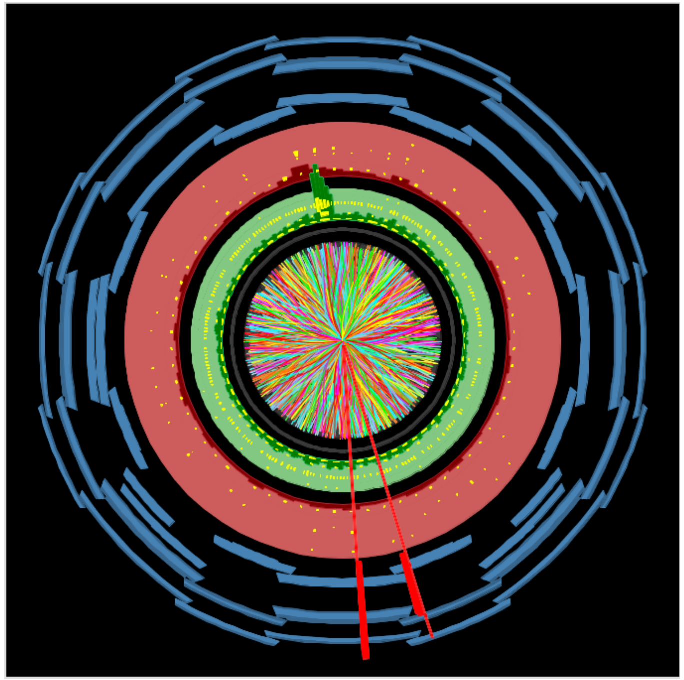
~stable particle production

Rise in energy flow

Significant contribution from ISR to UE

Summary





Adjust theory to agree with experiment essential to perform high precision measurements at LHC

Lot's of work ahead with the upcoming 13 TeV run