Underlying event and multiple parton interaction tunes

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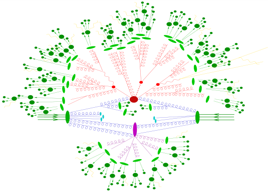
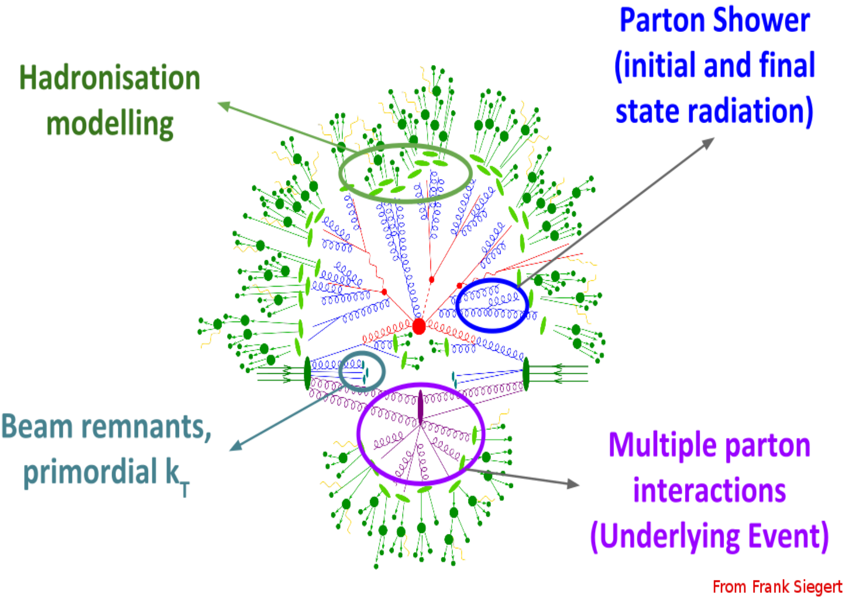
1. **Introduction**
   - Underlying event
   - Tuning MC generators
2. **Current tuning efforts:**
   - General tunes
   - Energy dependence
   - Forward region understanding
3. **Tune uncertainties**
4. **Extrapolation to higher collision energies**
5. **Summary and conclusions**



The underlying event at the LHC



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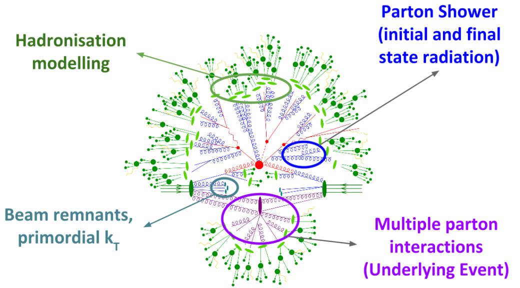


From Frank Siegert

A hard *pp*-collision at the LHC can be interpreted as a hard scattering between partons, accompanied by the underlying event (UE) consisting of:

- Initial and final state radiation
- Multiple Parton Interactions (MPI)
- Beam Remnants
- Hadronization

Many processes are included in the nomenclature "UE" at different scales

Diffractive processes
Semi-hard multiparton interactions
Double Parton Scattering (DPS)

How do we deal with that?

Montecarlo event generators (PYTHIA, HERWIG, SHERPA..)

Parameters need to be adjusted (tuned) to describe data

- MPI — e.g. $p_T^0 = p_T^{ref} \cdot (E/E_{ref})^\epsilon$
  Proton matter distribution profile
  Colour reconnection
- Primordial k_T — e.g. Width of the gaussian used for modelling the parton primordial k_T inside the proton
- Hadronization — e.g. Length of fragmentation strings
  Strange baryon suppression
- Parton shower — e.g. Strong coupling value
  Regularization cut-off
  Upper scale

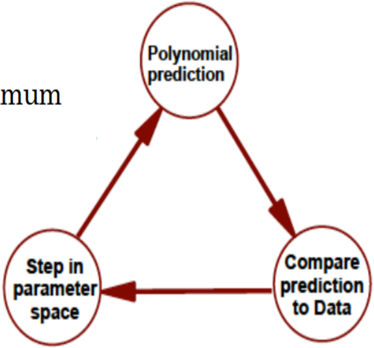
How does one tune all these?

- Choice of parameter ranges and sensitive observables
- Predictions for different parameter choices and interpolation of the MC response
- Data-MC difference and minimisation over parameter space

RIVET AND PROFESSOR

- building a MC grid parameter space
- grid points are calculated simultaneously
- parameterize the MC parameter space with a polynomial
- tune polynomial to data

- determination of minimum in parameter space



Not only for fun!

1. Correct description of the data
   - Pile-up simulation
   - Evaluation of detector effects and unfolding
   - Estimation of background (in MC-driven approach)
   - Models are not "allowed" to fail
2. Good physics predictions
   - Correct evaluation of physics effects
   - Models are "allowed" to fail

The danger is overtuning!

Some "official" tunes from the authors..

- PYTHIA 8 **Monash Tune - PDF: NNPDF2.3LO** (EPJ C74 (2014) 8)
- HERWIG++ **UE-EE-5C - PDF: CTEQ6L1** (JHEP 1310 (2013) 113)

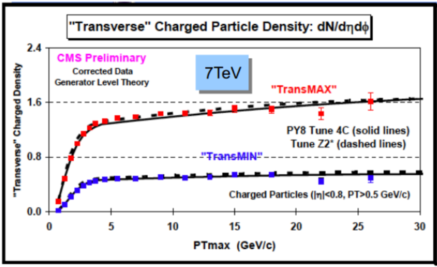
	PYTHIA 8 Monash	HERWIG++ UE-EE-5C
MPI	UE pp($\bar{\text{p}}$) data at various $\sqrt{s}$	UE pp($\bar{\text{p}}$) data at various $\sqrt{s}$ Value of measured σ_{eff}
Primordial k_T	p_T spectrum of lepton pair from Z decays in hadronic collisions	p_T spectrum of Z boson in hadronic collisions
Hadronization	Particle multiplicities in hadronic Z decays in e^+e^- collisions	Particle production at various colliders
Parton shower	Event shapes in p$\bar{\text{p}}$ interactions (taken from previous tune)	Jet multiplicity, jet rates and shapes at various colliders

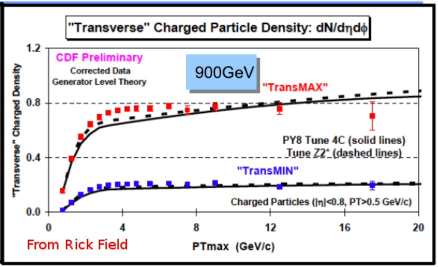
General approach is a "factorized" tuning procedure with only some of the components investigated

Many other tunes available focussing on one or more components, different features or observables!

Can they be refined?

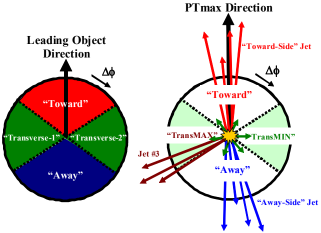
How well do they describe observables at different energy?





→ N_{ch} and p_T^{sum} as a function of the leading charged particle

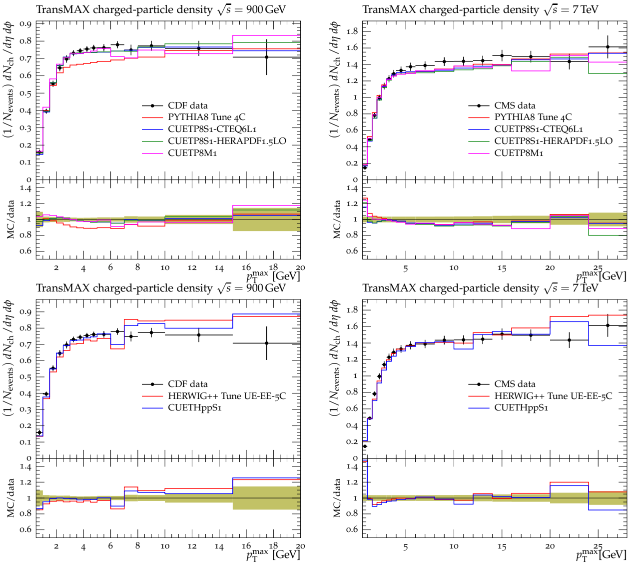
- TRANS MIN: sensitive to MPI
- TRANS MAX: sensitive to MPI and PS
- TRANS DIF: sensitive to PS
- TRANS AVE: sensitive to MPI and PS



PURPOSE: Tuning MPI and colour reconnection parameters

Results of the energy-dependence tuning

Charged particle mult. in the MAX reg. @ 0.9 (left) and 7 (right) TeV



CMS tunes!

- PYTHIA 8 (CUETP8)
- HERWIG++ (CUETHpp)

with various PDFs

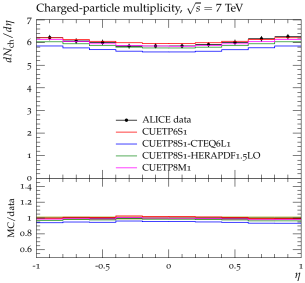
Better constrain of the energy extrapolation
CR changes with the choice of the PDF

Rising part and plateaux region are well predicted by the new tunes

(arXiv 1512.00815)

What about other observables? (arXiv 1512.00815)

Min. Bias observables ✓



Forward region

UE vs p_T^{jet}

Incl. jet cross sections

Z-boson observables

DPS observables

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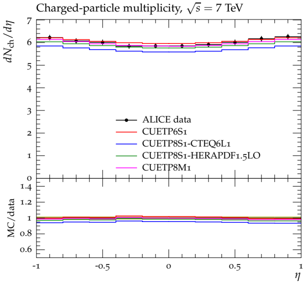

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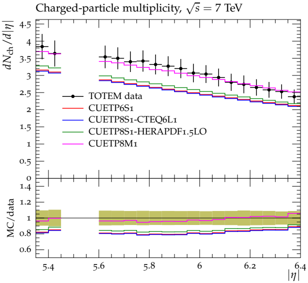

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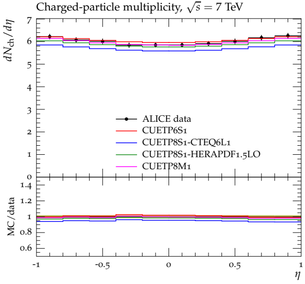

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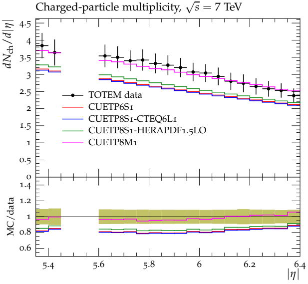

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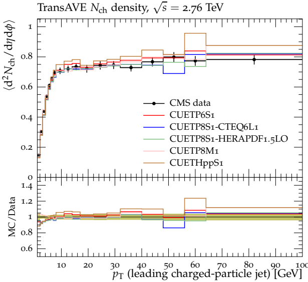

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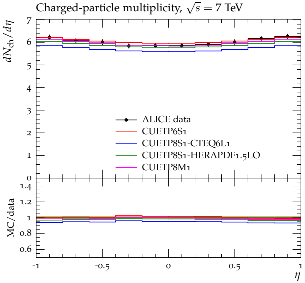

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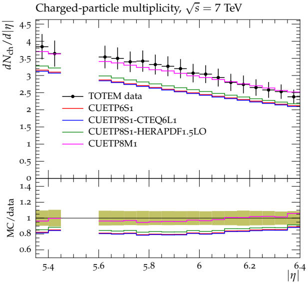

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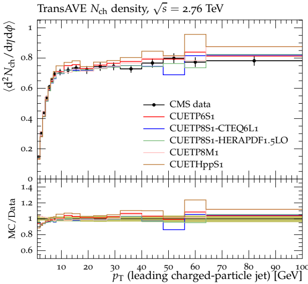

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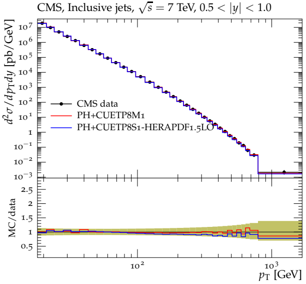

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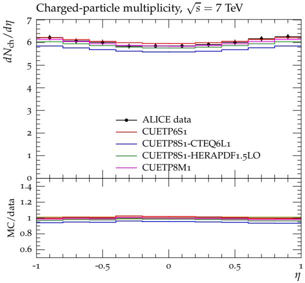

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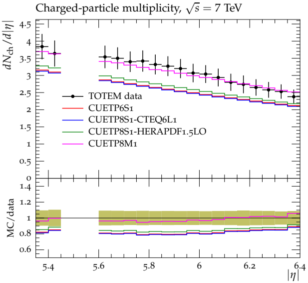
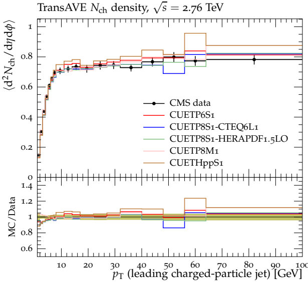


UE vs p_T^{jet} ✓



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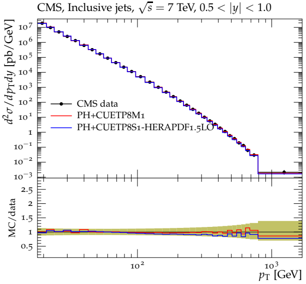

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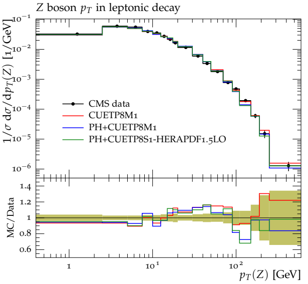

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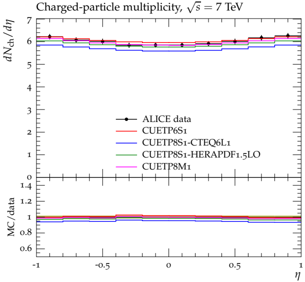

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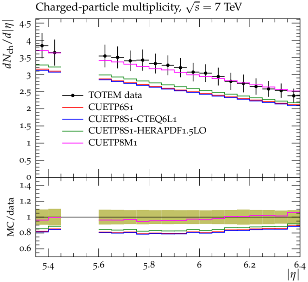

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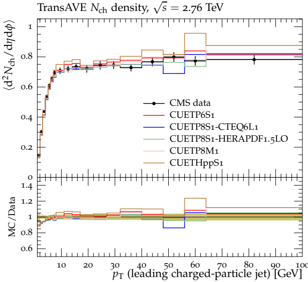

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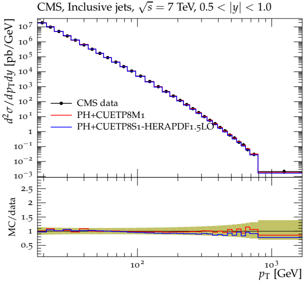

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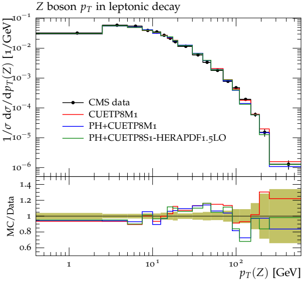
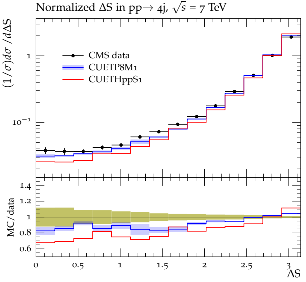
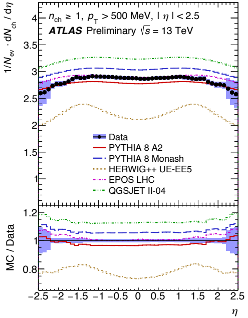
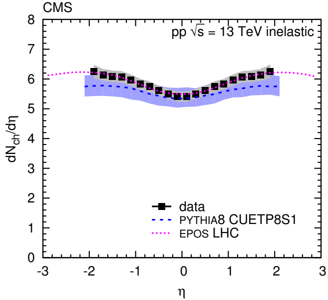


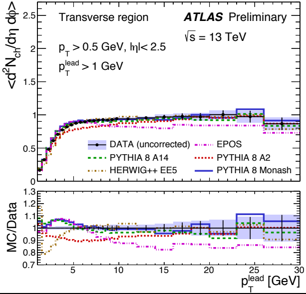
DPS observables X

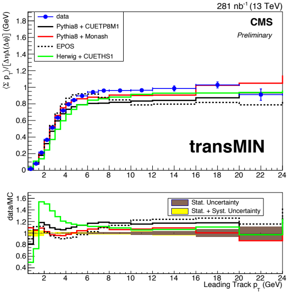


Tune performance at the new energy









$\sqrt{s} = 13$ TeV

TOP: $dN/d\eta$

ATLAS-CONF-2015-028, PLB751 (2015)

BOTTOM: N_{ch} vs p_T^{lead}

ATLAS-PHYS-2015-019, CMS-FSQ-15-007

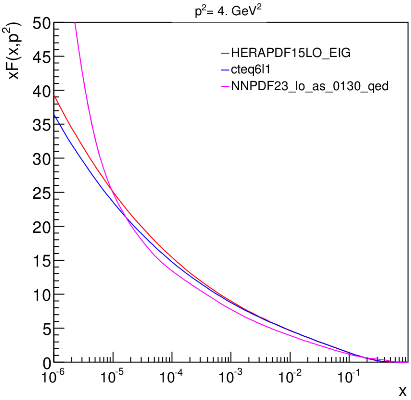
None of the tunes reproduce the data perfectly!

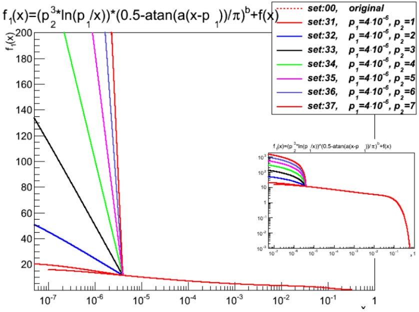
Is the energy dependence of the MPI to be improved in the generators?

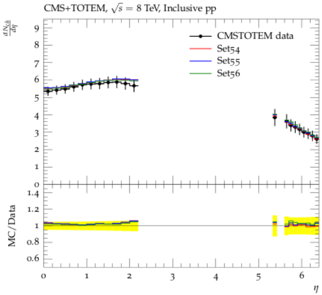
$$p_T^0 = p_T^{ref} \cdot (E/E_{ref})^{\epsilon}$$

Zoom on behaviour in the forward region

Main difference among the tunes, it is the low-x PDF behaviour!







By (artificially) modifying the PDF at low x, the agreement in the forward region improves!

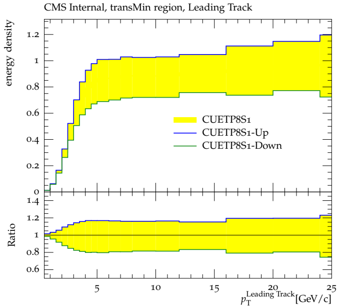
Tune uncertainties (I)

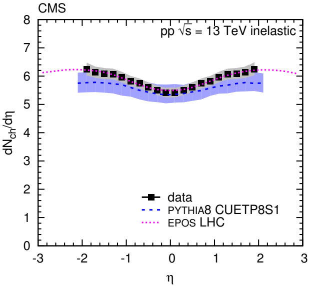
Nominal tune uncertainty: Set of (MANY) eigentunes obtained from Professor

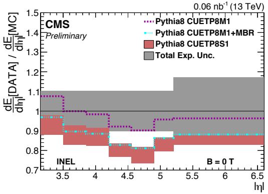
→ How to reduce the numbers of eigentunes?

CMS strategy arXiv 1512.00815

Fit of the upper and the lower part of the UE predictions at 13 TeV obtained with full set of eigentunes → The new pair of tunes is assigned as uncertainty

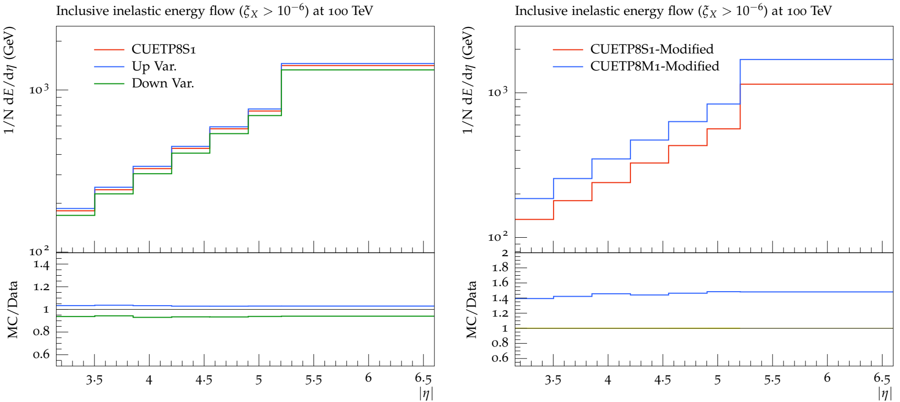






Fundamental question: how can one cover all (most of) physics effects?

Going to (much) higher energy..



Very small tune uncertainties ($\sim$ 5-10%)

Difference between tunes
using different PDFs becomes bigger ($\sim$ 40%)!

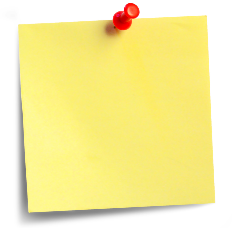
DISCLAIMER: gymnastics done with the simulation to remove the energy dependence of the MPI scale

MC tuning is necessary for any kind of physics studies

- Huge effort from theorists and experiments in achieving a good understanding of the tools and the best description of the data
- Tunes able to describe a wide range of measurements and well performing in matched MC event generators
- Some corners of the phase space are still not well reproduced
- PDF in the low-x regime plays (and will play) a very important role on many observables

Watch out the overtune!

(what might be a possible sign of overtuning?)



Allow the models to fail!

Summary and Conclusions

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THANKS FOR YOUR ATTENTION