

Underlying event and multiple parton interaction tunes

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Outline

① Introduction

- Underlying event
- Tuning MC generators

② Current tuning efforts:

- General tunes
- Energy dependence
- Soft and hard multiparton interactions
- Parton shower and matched generators

③ Tune uncertainties

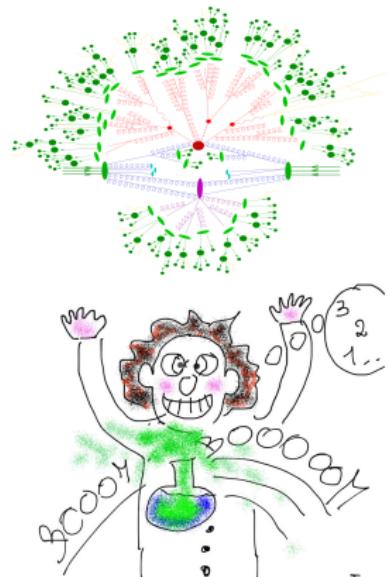
④ Gluon- and quark-induced processes

⑤ Summary and conclusions

Much more not covered in this presentation:

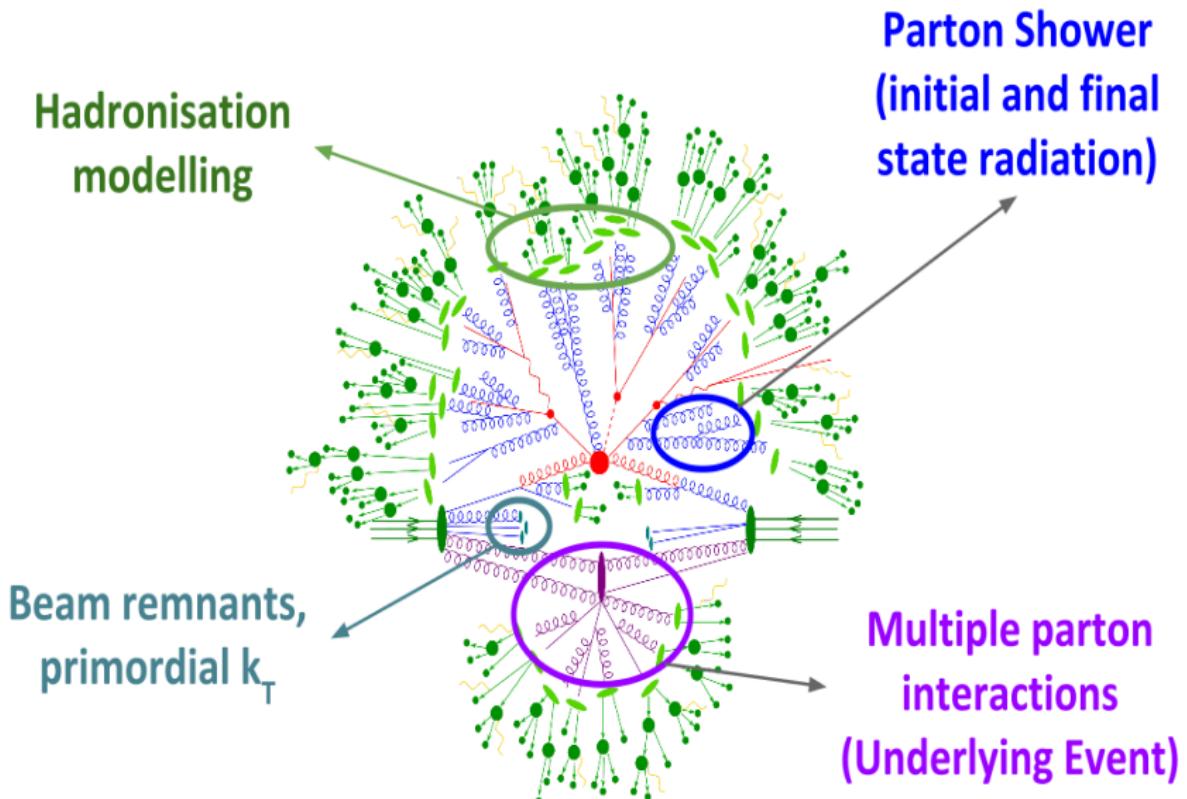
- heavy-flavour fragmentation
- estimation of uncertainties of non-perturbative corrections
- parton correlations for description of UE and DPS observables

ATL-PHYS-PUB-2012-003, EPJ C75 (2015), arXiv 1510.07436



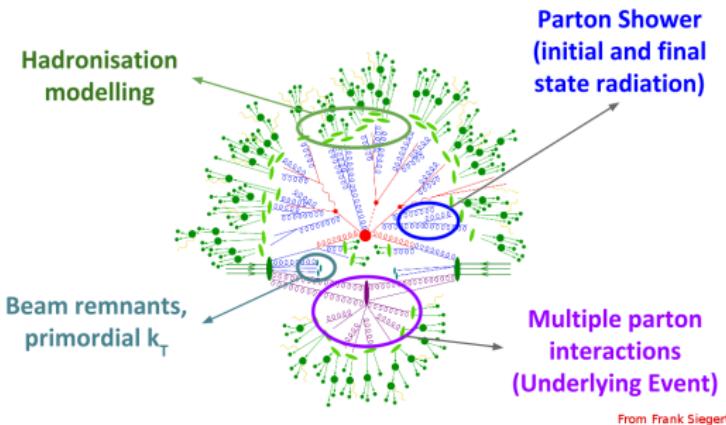
KEEP
CALM
AND
CARRY
A TUNE

The underlying event at the LHC



From Frank Siegert

The underlying event at the LHC

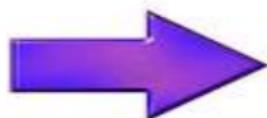


From Frank Siegert

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

In general the UE is a softer contribution but... some MPIs can be even hard!



Double Parton Scattering (DPS)

$$\sigma_{AB} = \frac{m}{2} \sigma_A \frac{\sigma_B}{\sigma_{eff}}$$

$$\rightarrow \sigma_{eff} \approx 15-20 \text{ mb}$$

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
- Parton shower
 - e.g. Strong coupling value
Regularization cut-off
Upper scale
- Hadronization
 - e.g. Length of fragmentation strings
Strange baryon suppression

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

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](#))

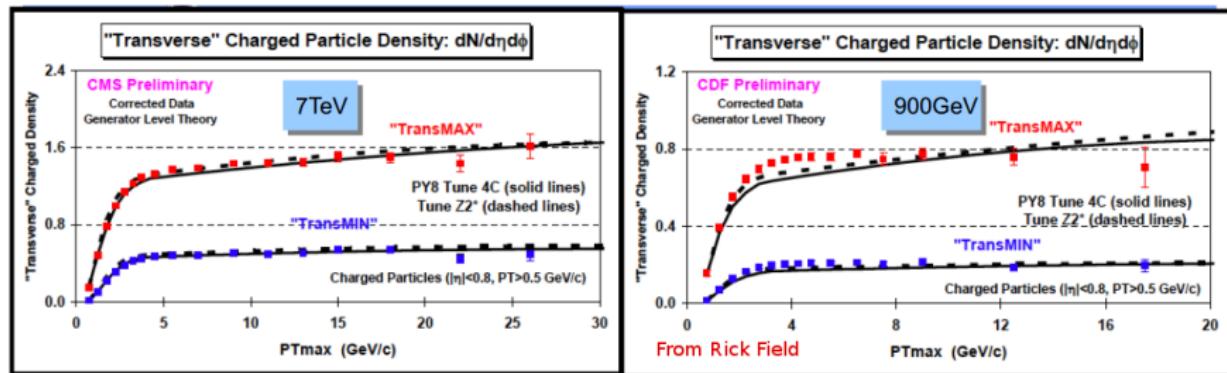
	PYTHIA 8 Monash	HERWIG++ UE-EE-5C
MPI	UE pp(\bar{p}) data at various \sqrt{s}	UE pp(\bar{p}) data at various \sqrt{s} Value of measured σ_{eff}
Primordial k_T	p_T spectrum of lepton pair from Z decays in hadronic collisions	p_T spectrum of Z boson in hadronic collisions
Parton shower	Event shapes in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

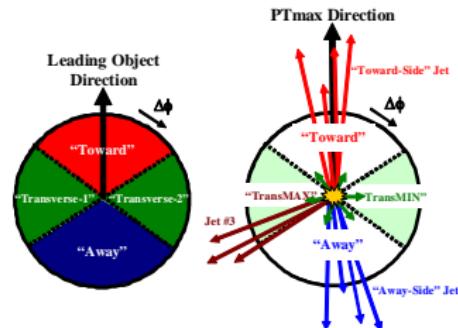
How well do they describe observables at different energy?



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

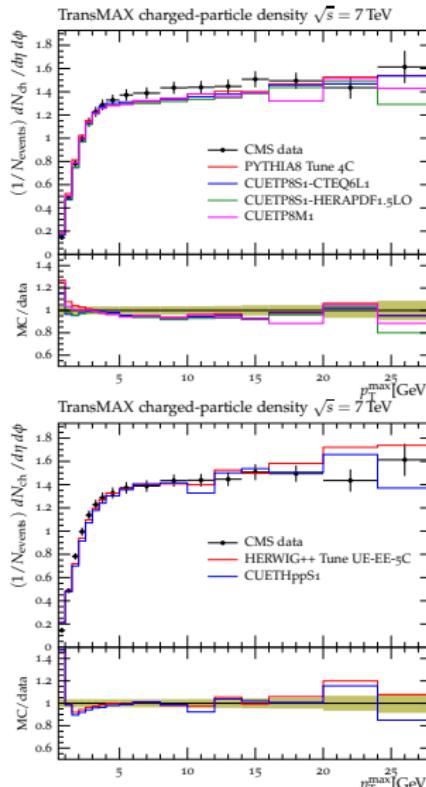
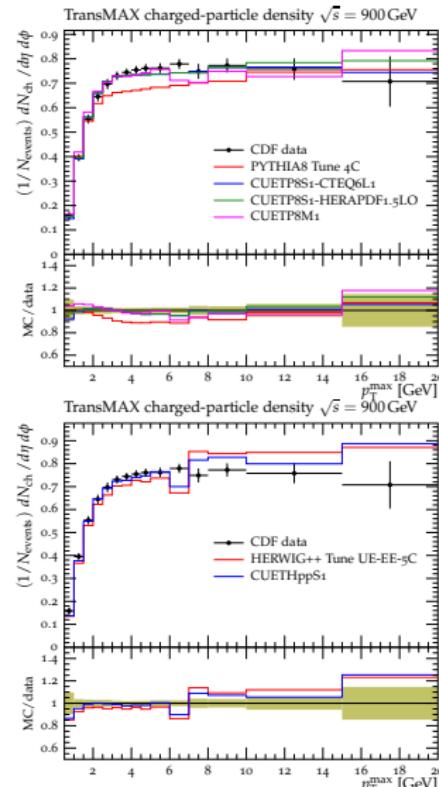
- TRANS MIN: sensitive to MPI
- TRANS MAX: sensitive to MPI and PS
- TRANS DIF: sensitive to PS
- TRANS AVE: sensitive to MPI and PS

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



New tunes!

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

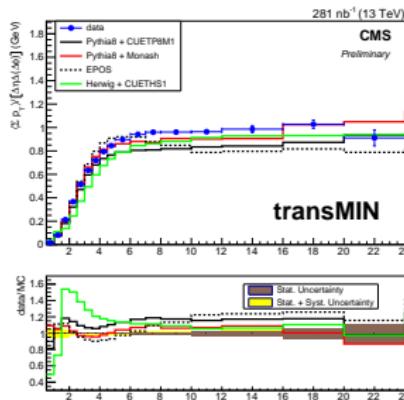
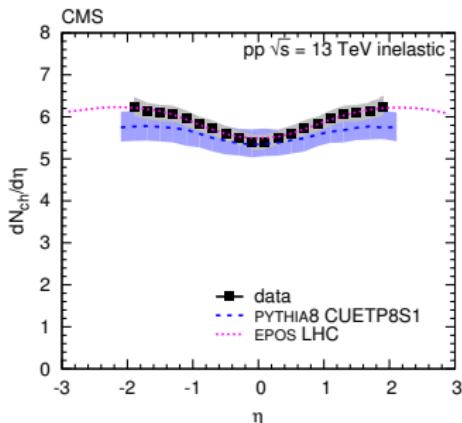
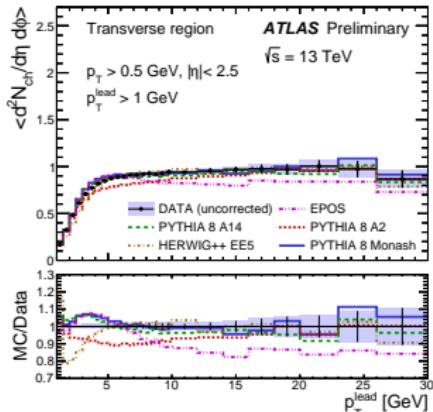
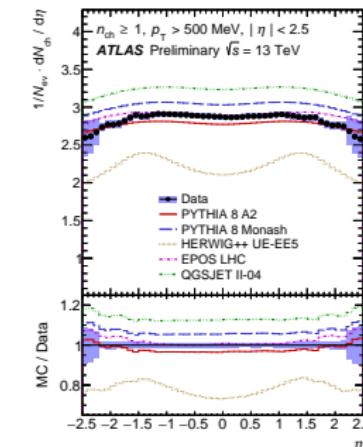
with various PDFs

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)

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

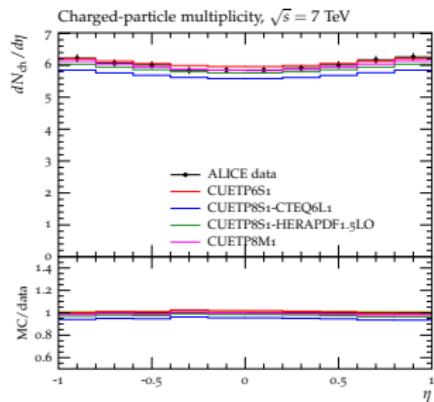
None of the tunes reproduce the data perfectly!

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

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

What about other observables? (arXiv 1512.00815)

Min. Bias observables ✓



Forward region

UE vs p_T^{jet}

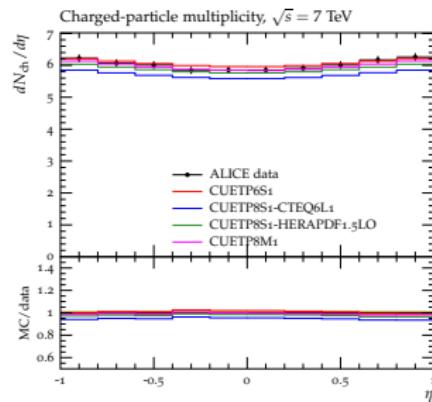
Incl. jet cross sections

Z-boson observables

DPS observables

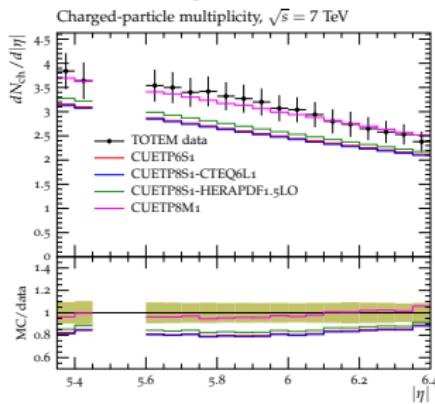
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Forward region ✓



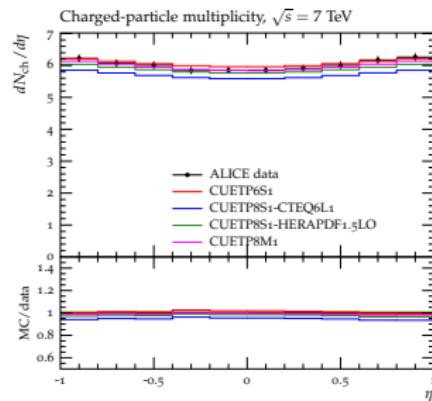
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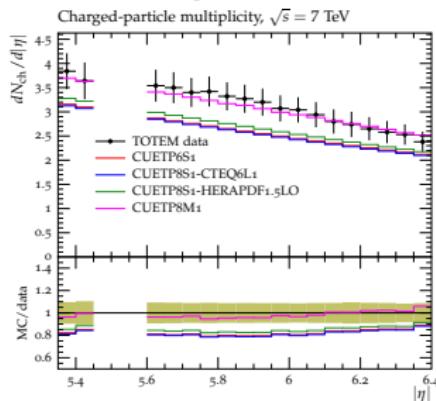
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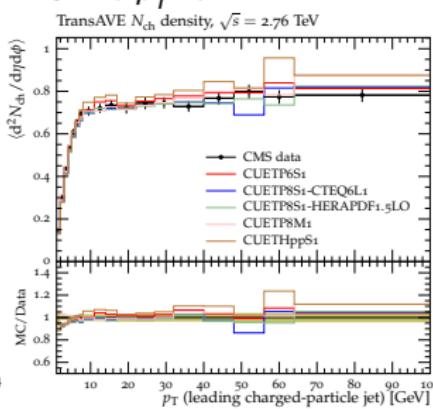
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Forward region ✓



Z-boson observables

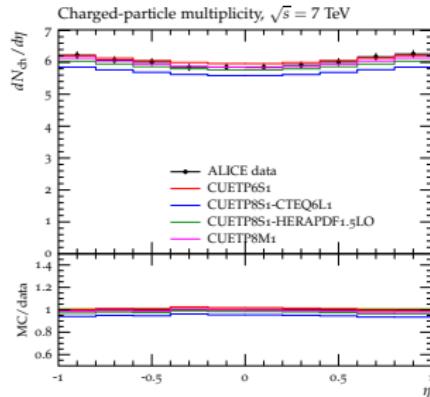
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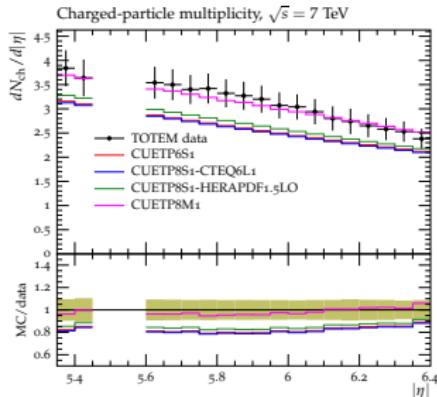
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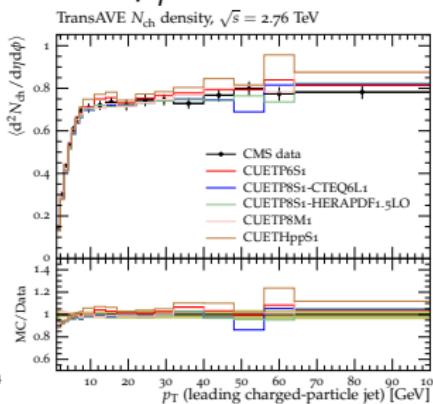
Min. Bias observables ✓



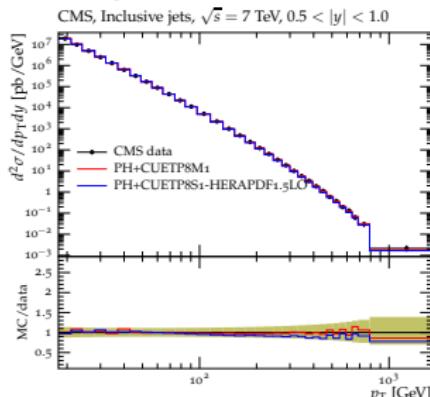
Forward region ✓



UE vs p_T^{jet} ✓



Incl. jet cross sections ✓

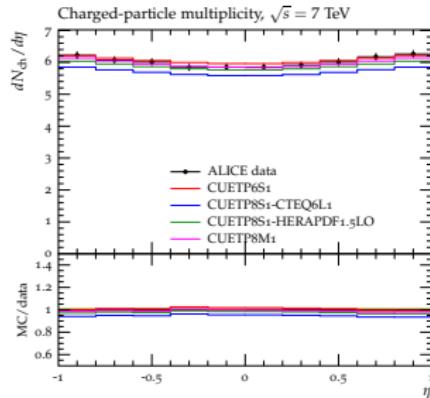


Z-boson observables

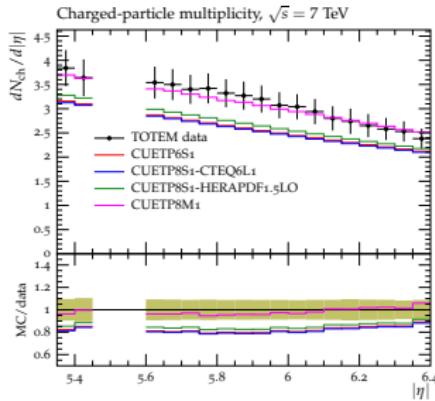
DPS observables

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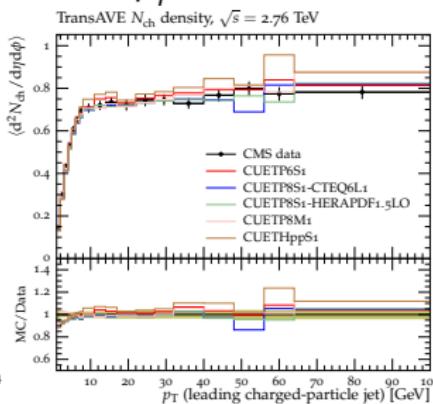
Min. Bias observables ✓



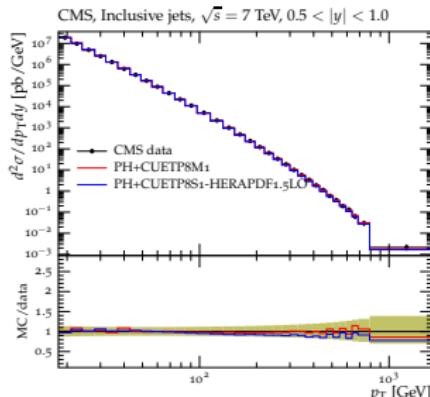
Forward region ✓



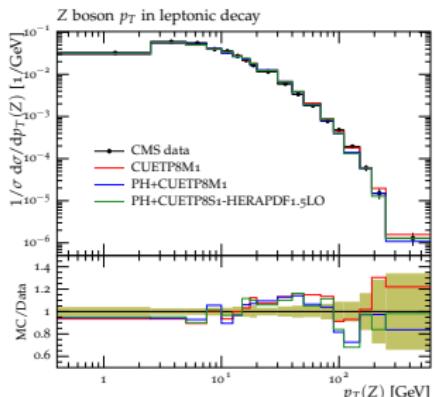
UE vs p_T^{jet} ✓



Incl. jet cross sections ✓



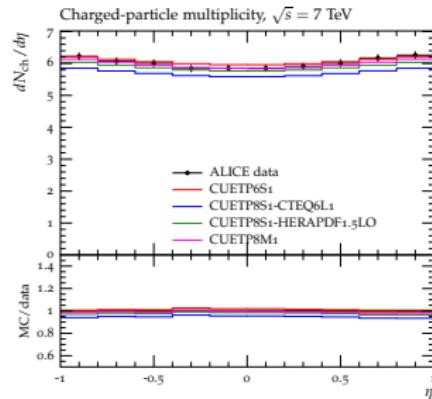
Z-boson observables ✓



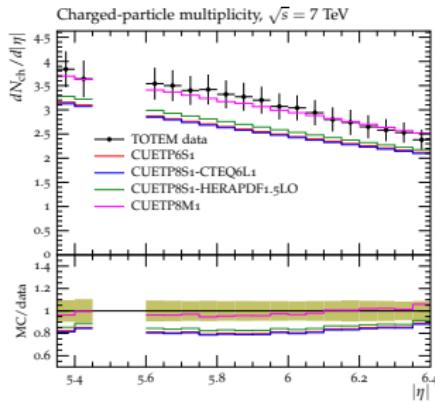
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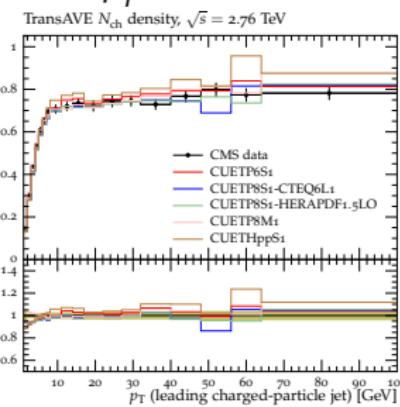
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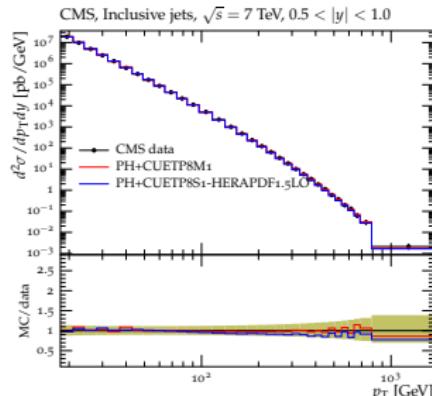
Forward region ✓



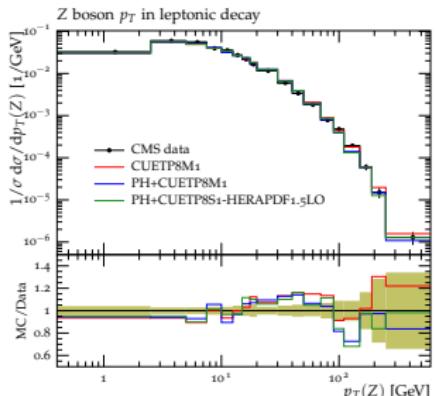
UE vs p_T^{jet} ✓



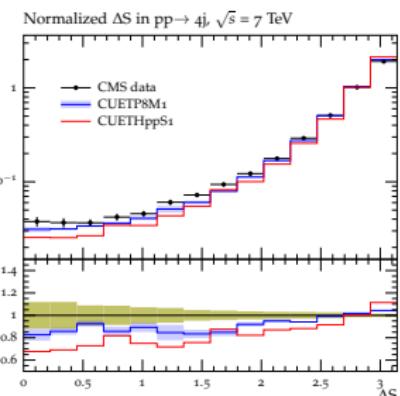
Incl. jet cross sections ✓



Z-boson observables ✓

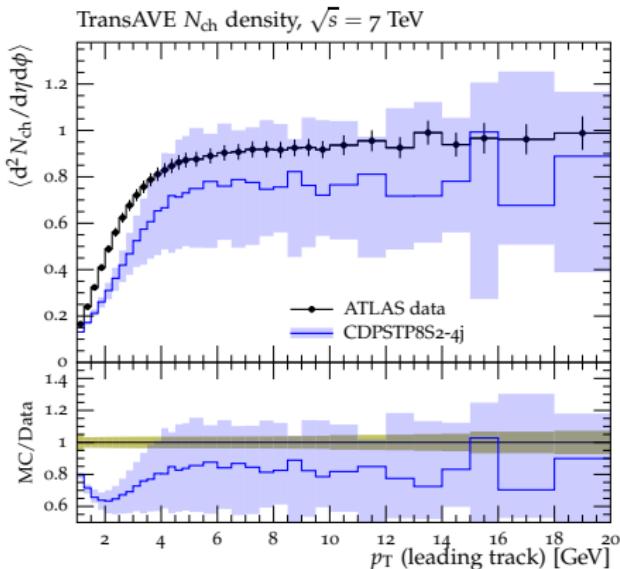


DPS observables X



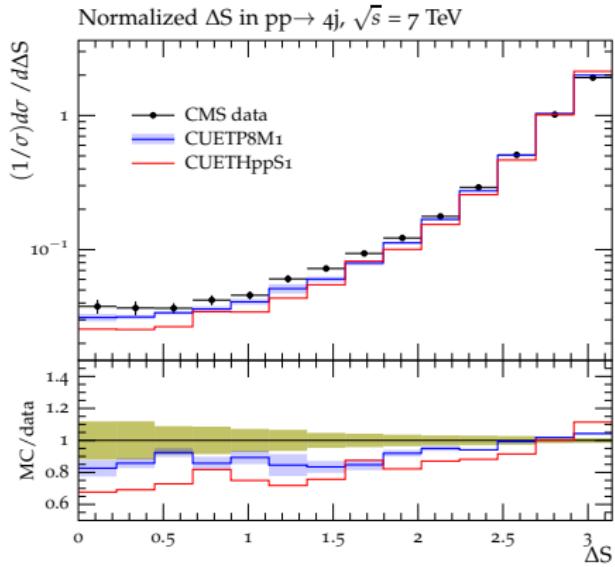
Further look at UE/DPS comparisons (arXiv 1512.00815)

Tune name	σ_{eff} value (mb)
CUETP8M1	$26.0^{+0.6}_{-0.2}$
CUETHppS1	$15.2^{+0.5}_{-0.6}$



Dedicated tune to DPS-sensitive observables in four-jet final state

$$\text{CDPSTP8S2} \rightarrow \sigma_{\text{eff}} = 19.0^{+4.7}_{-3.0} \text{ mb}$$



Not able to describe both UE and DPS observables at with the same set of tunes
Indication for need of a refinement of the current MPI model?

Parton shower and MPI tuning

TUNING OF PYTHIA 8 TO OBSERVABLES MEASURED IN DIFFERENT PROCESSES

Study of the interplay between MPI and parton shower
Various PDF sets investigated

Observables
Track jet properties
Jet shapes
Dijet decorrelations
Multijets
Z boson p_T
$t\bar{t}$ gap and jet shapes
Track-jet and jet UE

SigmaProcess:alphaSvalue	The α_S value at scale $Q^2 = M_Z^2$
SpaceShower:pT0Ref	ISR p_T cutoff
SpaceShower:pTmaxFudge	Mult. factor on max ISR evolution scale
SpaceShower:pTdampFudge	Factorisation/renorm scale damping
SpaceShower:alphaSvalue	ISR α_S
TimeShower:alphaSvalue	FSR α_S
BeamRemnants:primordialKThard	Hard interaction primordial k_\perp
MultipartonInteractions:pT0Ref	MPI p_T cutoff
MultipartonInteractions:alphaSvalue	MPI α_S
BeamRemnants:reconnectRange	CR strength

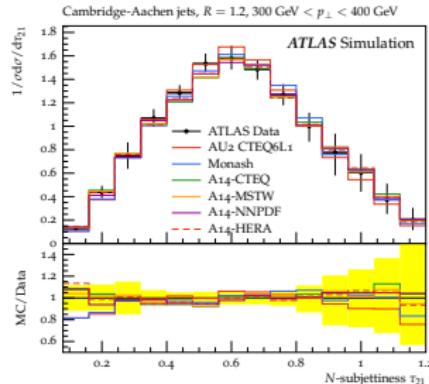
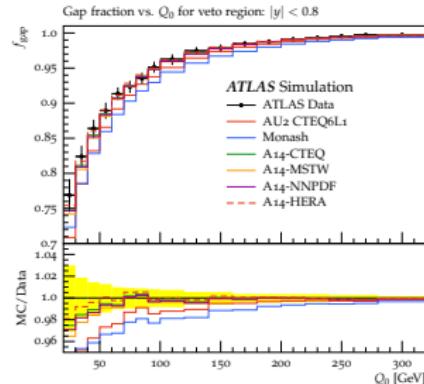
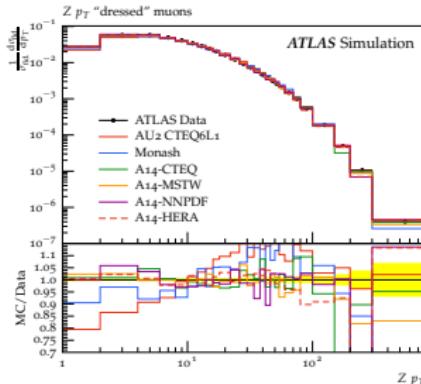
Extremely important for:

- testing the universality of the parton shower in leptonic and hadronic collisions
- testing the performance of UE simulation for different hard scattering processes

ATL-PHYS-PUB-2014-021

Parton shower and MPI tuning

Significant improvement of description of observables in:
Drell-Yan (left), top-antitop (center) and jet substructure (right) sectors



- α_s values are similar for all PDF used
 - quite high for the hard processes
 - lower for initial- and final-state radiation
 - significantly lower than Monash tune for ISR and FSR
- damped shower needed to describe gap fraction in t \bar{t} events and p_T^Z simultaneously

Tuning higher-order ME matched to parton showers

OBSERVABLES: gap fraction, jet shapes and jet multiplicity in $t\bar{t}$ events

GENERATORS: PYTHIA 8 standalone, MADGRAPH_aMC@NLO and
POWHEG + PYTHIA 8

Different steps of tuning:

- tuning of ISR and FSR separately, then simultaneous tune to account for their interplay
- application of tune for the matched generators
- tune of the matched MADGRAPH_aMC@NLO + PYTHIA 8

(Some of the) Outcomes

- Significant improvement in the description of $t\bar{t}$ observables
- Parameters of simultaneous ISR-FSR tune do not differ much from the separate tunes
- Tune of matched MADGRAPH+PYTHIA 8 has similar parameters to standalone PYTHIA 8

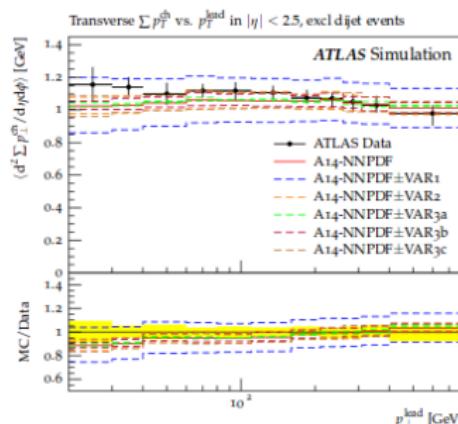
ATL-PHYS-PUB-2015-007, ATL-PHYS-PUB-2015-048

Tune uncertainties

Nominal tune uncertainty: Set of (MANY) eigentunes obtained from Professor
→ How to reduce the numbers of eigentunes?

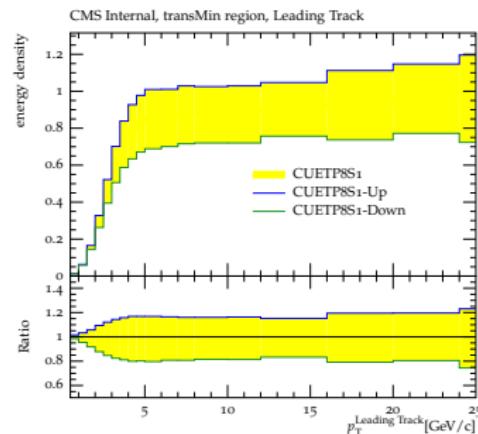
ATLAS strategy ATL-PHYS-PUB-2014-021

Only the pair of eigentunes showing the maximal variation for the considered observables is considered for the uncertainty → procedure repeated for different observables



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

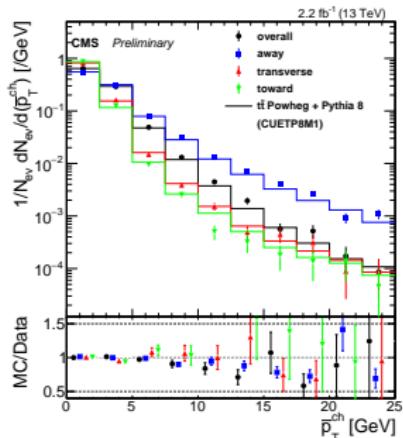
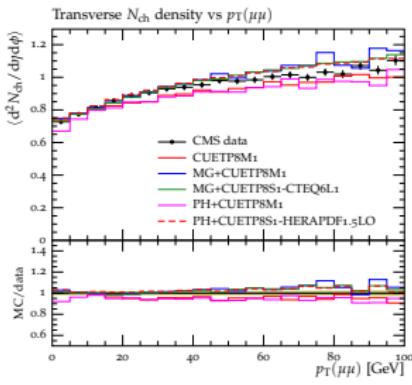
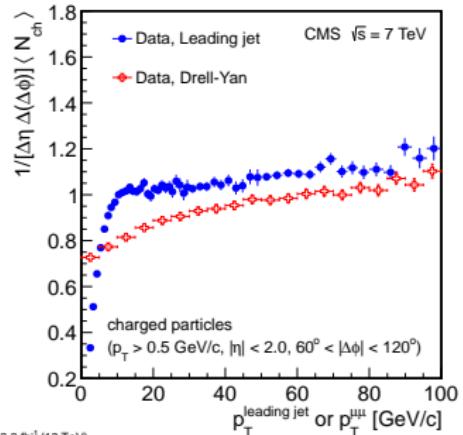
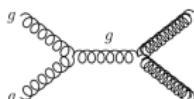
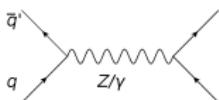


Fundamental question: how can one cover all (most of) physics effects?

Quark- and gluon-induced processes

Different UE activity expected for different initial states due to quark and gluon colour factors

Measurement in hadronic, Drell-Yan and $t\bar{t}$ events



At the current stage, available tunes are describing well UE activity induced by different initial states

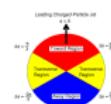
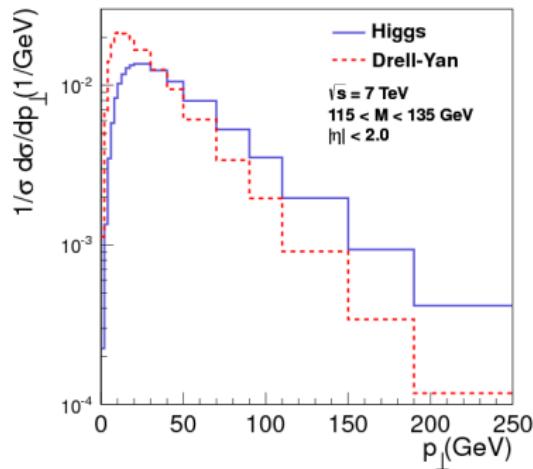
BUT..there might be more!

arXiv 1512.00815, CMS-TOP-15-017

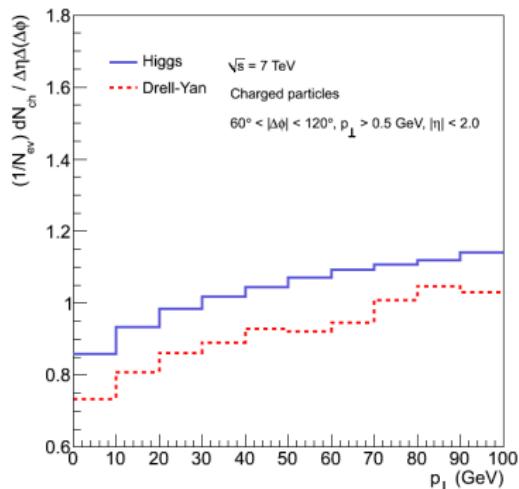
Quark- and gluon-induced processes

Striking comparison between UE activity in quark- and gluon-induced processes at the same scale can make use of Drell-Yan and Higgs production

Measurement of the inclusive boson p_T



Charged particle multiplicity in the transverse region



Possibility of further different features (correlations, scale dependence..) between quarks and gluons!

PRD 88, 097501

Summary and Conclusions

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
- Open issue related to tune uncertainties

Global tuning effort?

**Watch out the
overtune!**

(what might be a possible sign of overtuning?)



Allow the models to fail!

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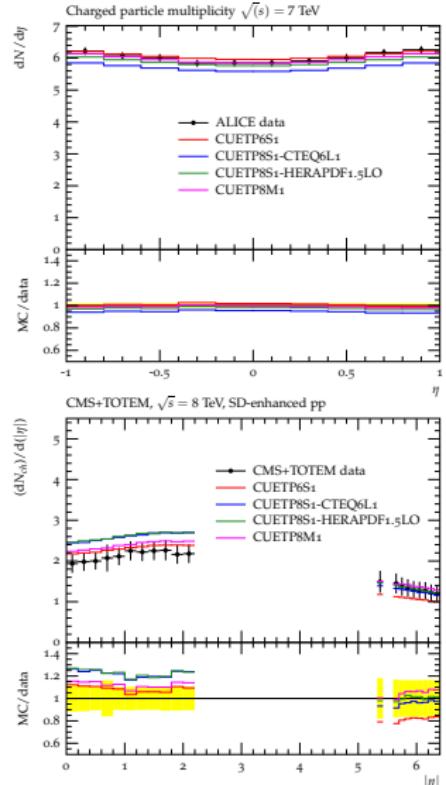
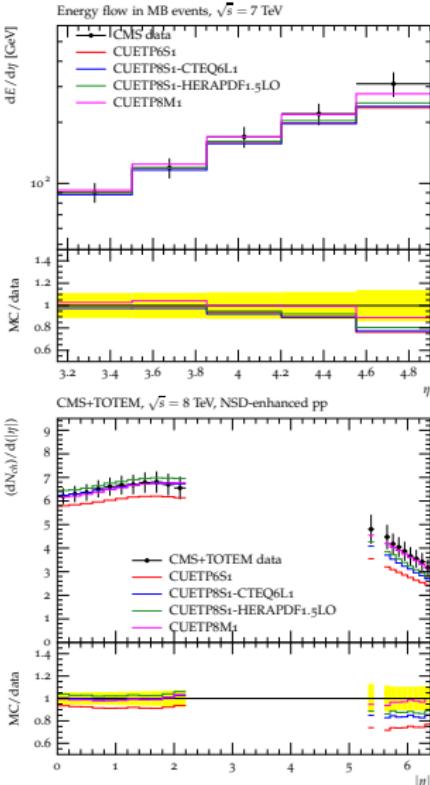
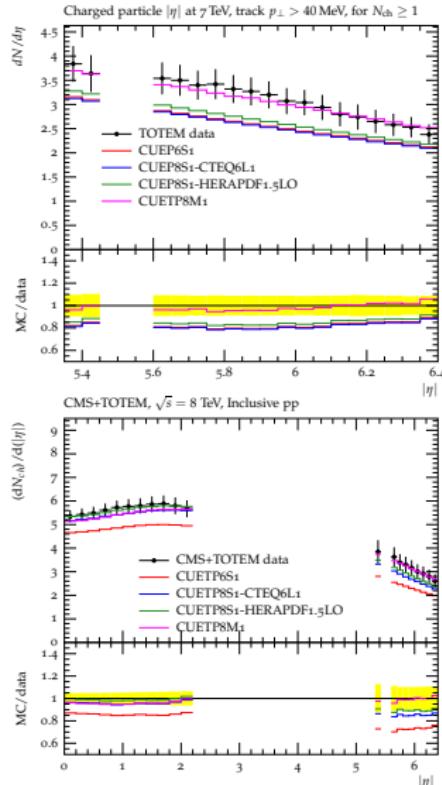


Allow the models to fail!

THANKS FOR YOUR ATTENTION

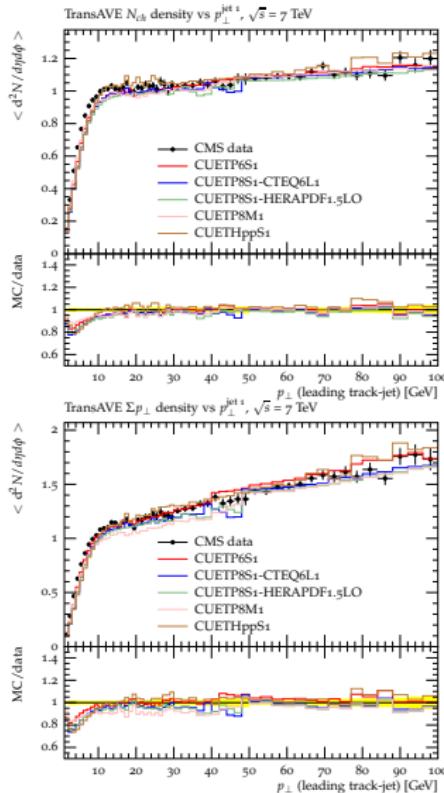
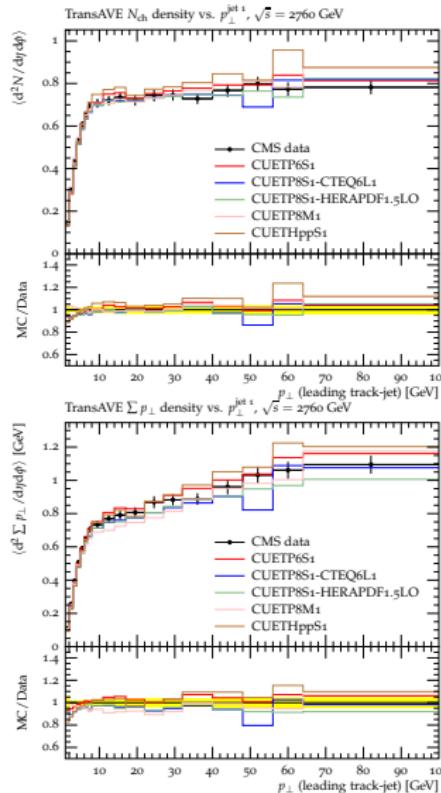
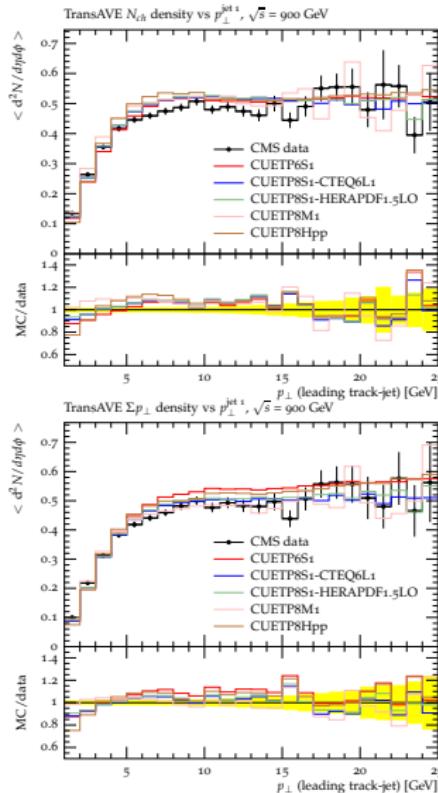
Validation plots (I): MB

$dN/d\eta$ at fwd and centr. region at 7,8 TeV and fwd energy flow in MB events



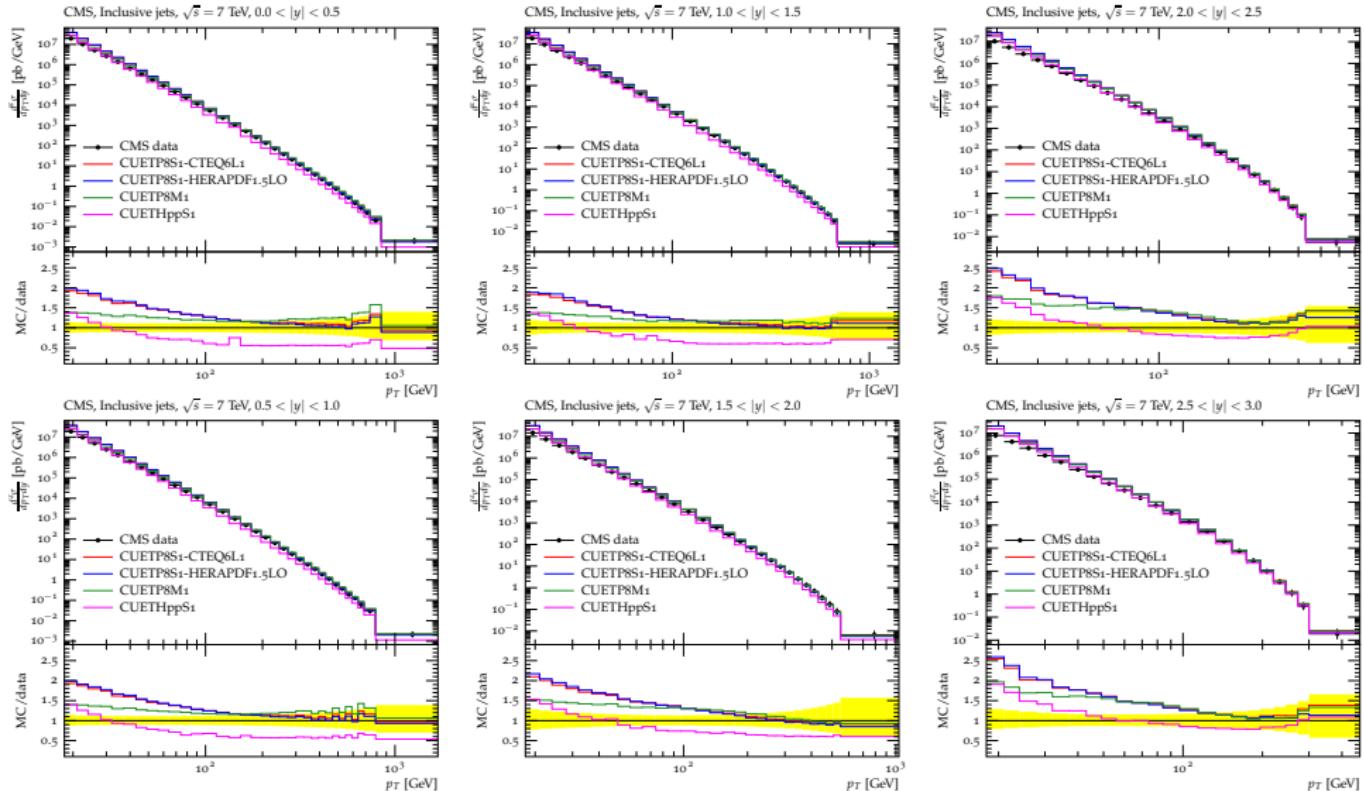
Validation plots (II): UE

Charged particle multiplicity and p_T sum measured by CMS in the transverse region as a function of the leading track jet p_T at 900, 2760 and 7000 GeV



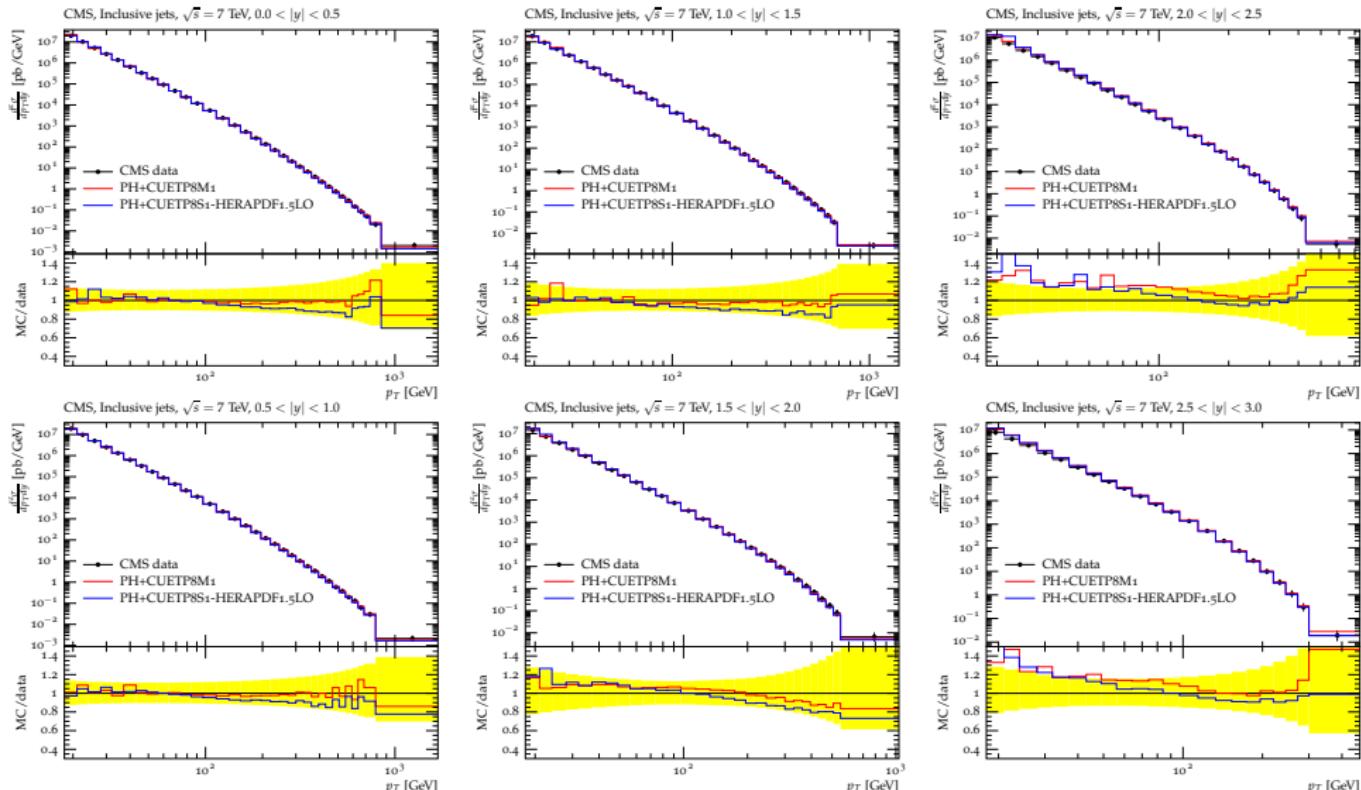
Validation plots (III): Jets

Inclusive jet cross sections measured by CMS in rapidity bins



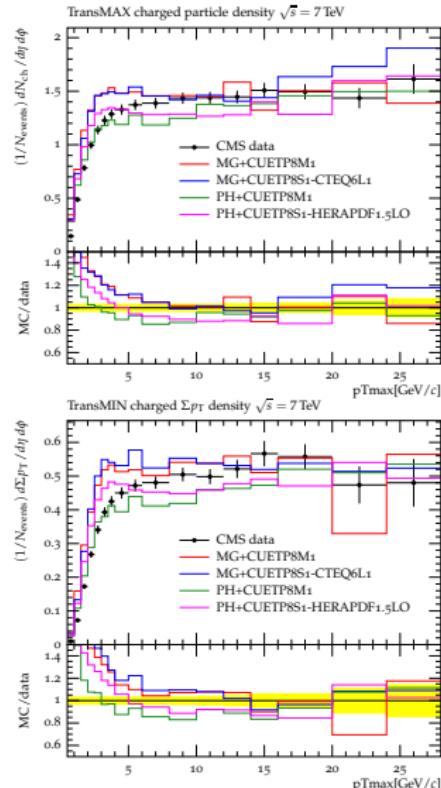
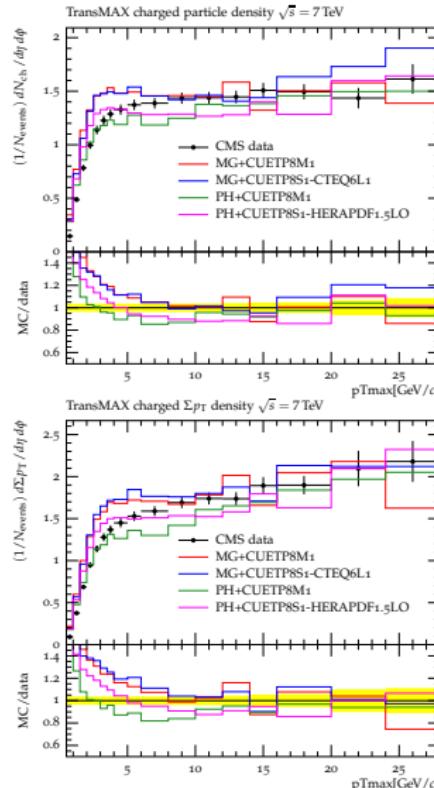
Interface with NLO matrix element (I): Jets

Inclusive jet cross sections measured by CMS in rapidity bins



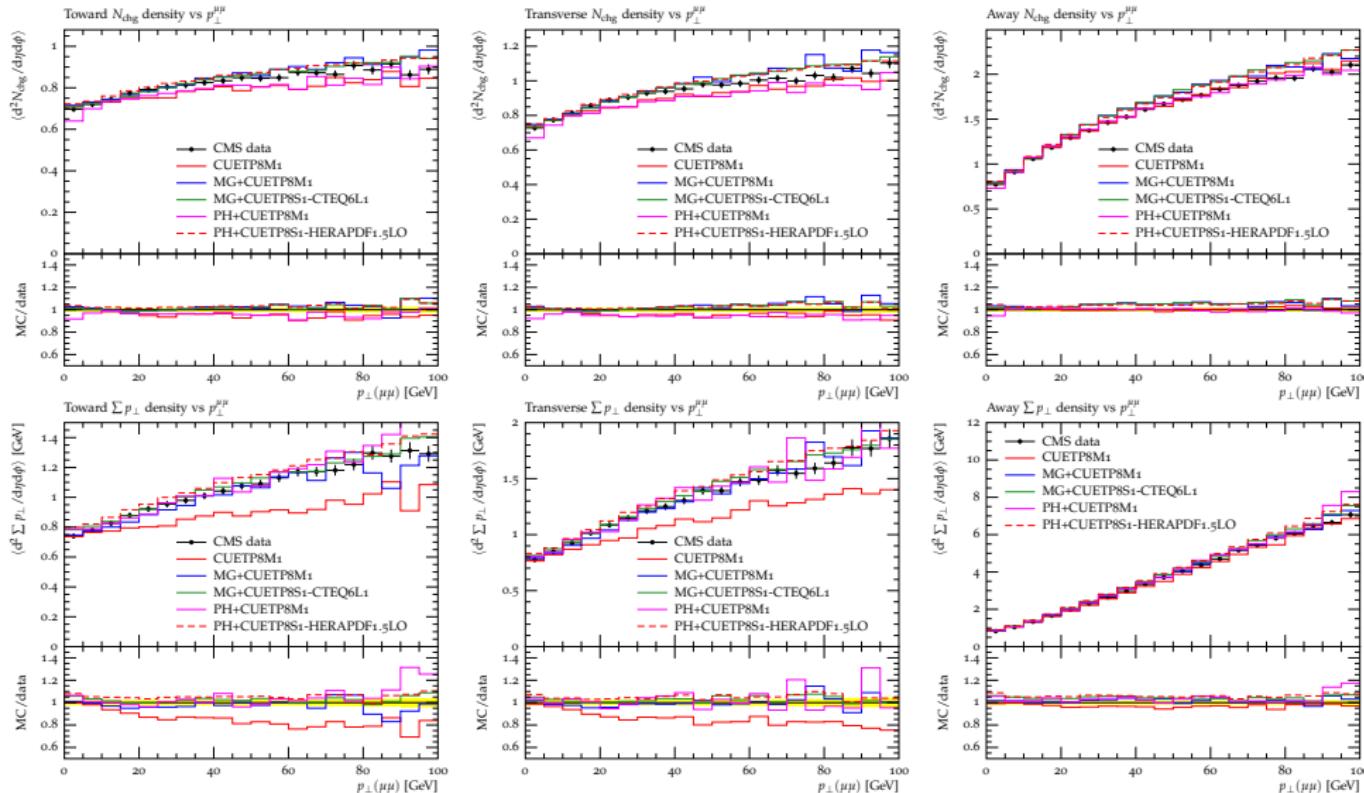
Interface with NLO and higher-order matrix elements (II)

Charged particle multiplicity and p_T sum in TransMAX and TransMIN at 7 TeV



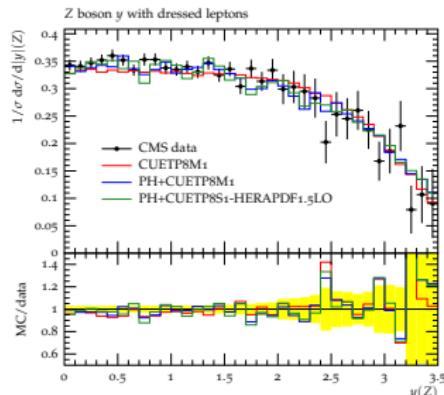
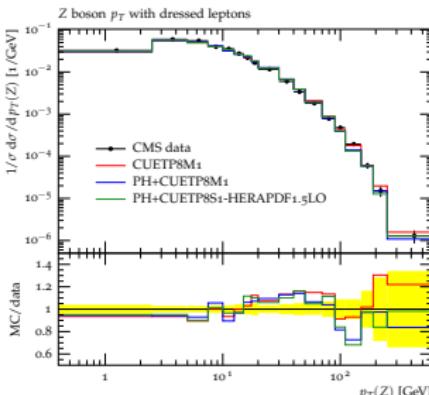
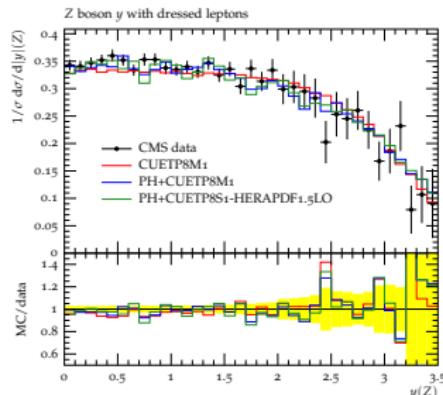
Interface with NLO and LO matrix elements (III): Drell-Yan

Charged particle multiplicity and p_T sum in Drell-Yan events



Interface with NLO matrix element (IV): Drell-Yan

Z-boson p_T and η at 7 TeV



Summary

- The new (standalone) tunes describe UE, MB observables but they have troubles in jet cross sections and Drell-Yan UE data
- Higher order LO matrix elements and NLO calculations interfaced with the new tunes describe all the previous observables **without need of retuning!**