Generatori Monte Carlo e uso in simulazioni di DPS

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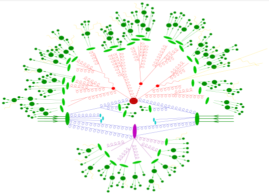


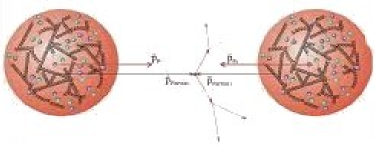
KEEP
CALM
AND
CARRY
A TUNE

To simulate proton-proton collisions, physicists generally use

Monte Carlo event generators

Ingredients of the hard scattering

→ Factorization theorem
→ Parton distribution functions
→ Matrix element calculation
..starting from lowest order in α_S but might include additional real and virtual corrections



$$\sigma_{ab\to F}(Q^2) = \int dx_1 dx_1' \; f_a^1(x_1, Q^2) \; f_b^2(x_1', Q^2) \; \hat{\sigma}_{ab}(x_1, x_1', Q^2)$$

Total Cross Section

Parton Distribution Functions

Partonic Cross Section

with x = longitudinal proton momentum fraction carried by the parton
Q^2 = scale of the scattering

MC generator types

Pure matrix element (ME) simulation:

MC integration of cross section & PDFs, no hadronization
(recall: cross section = $|\text{matrix element}|^2 \otimes$ phase space)

Useful for theoretical studies, no exclusive events generated

[Example: MCFM (http://mcfm.fnal.gov); many LHC processes up to NLO]

Event generators:

Combination of ME and parton showers ...

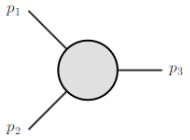
Typical: generator for leading order ME
combined with leading log (LL) parton shower MC

Exclusive events ➛ useful for experimentalists ...

MC generator types

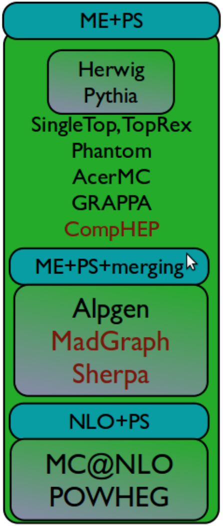
Type I : Leading order matrix element & leading log parton shower

LO ME for hard processes
[2→1 or 2→2]



Parton Shower:
Re-summation of leading logarithms ...

[Examples: Pythia, Herwig]



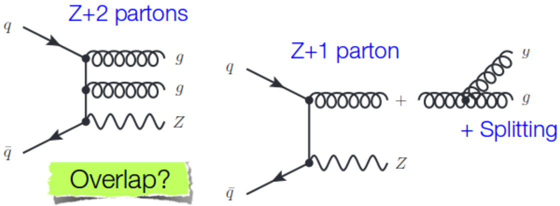
[F. Maltoni]

Type II : Leading order matrix element, parton shower & merging

i.e.: MEs for 2 ➛ n processes (e.g. W/Z + jets)
PS with LO generator [Pythia or Herwig]

Examples: ALPGEN, MadGraph, Sherpa

Challenge: Remove overlap between jets from ME and jets from parton shower [MLM matching, CKKW]



ME+PS

Herwig
Pythia
SingleTop, TopRex
Phantom
AcerMC
GRAPPA
CompHEP

ME+PS+merging

Alpgen
MadGraph
Sherpa

NLO+PS

MC@NLO
POWHEG

[F. Maltoni]

MC generator types

Type III: Next-to-leading order ME & leading-log parton shower

hard processes simulated to NLO accuracy including real & virtual corrections ...

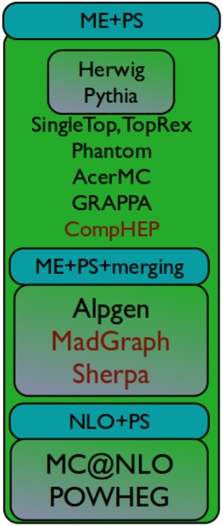
➛ improved description of cross sections & kinematic distributions

Remove phase-space overlap between jets from NLO ME and leading log PS ...

Mechanism: subtraction of PS emissions already generated in hard process at NLO ...

Fairly recent development,
but heavily used in ATLAS and CMS ....

Examples:
MC@NLO (since 2002), POWHEG (since 2007)



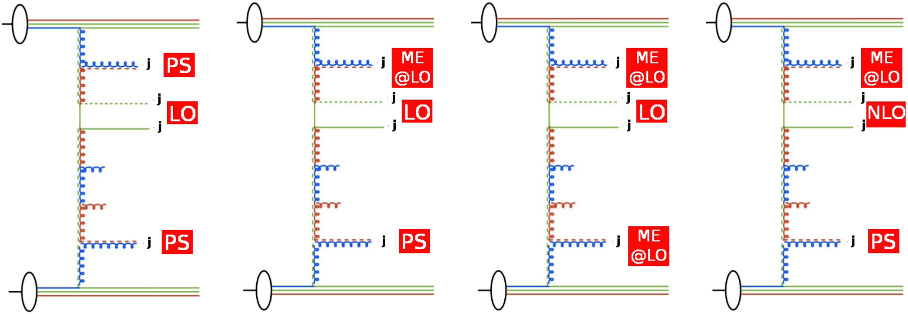
[F. Maltoni]

Details of the Monte Carlo generators

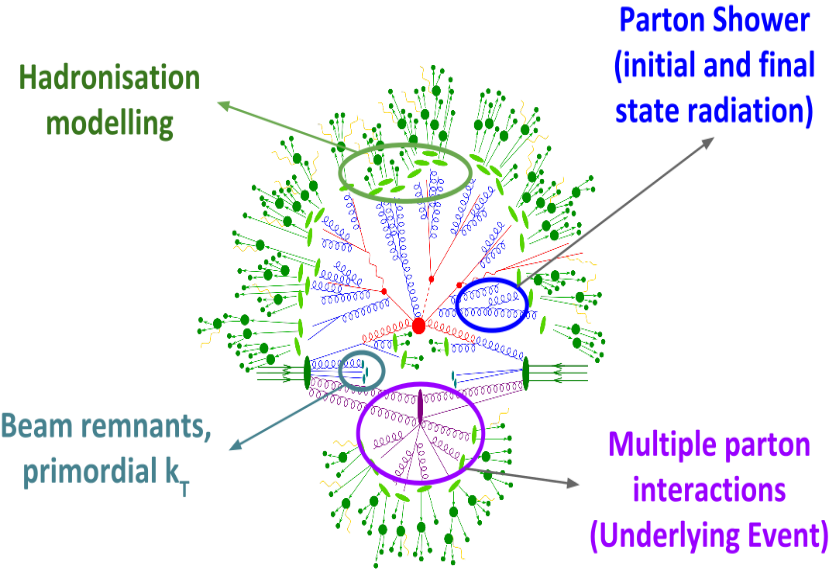
AIM: Comparison between data and various MC generators

- PYTHIA8 and HERWIG++: LO MC generators with extra jets from PS & MPI
- SHERPA, MADGRAPH: matrix element with N-jets (extra real emission)
- POWHEG: matrix element with a hard emission @ NLO (real & virtual)

PYTHIA, HERWIG | SHERPA | MADGRAPH | POWHEG

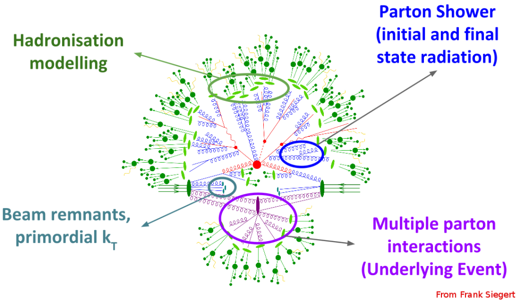


The underlying event at the LHC



From Frank Siegert

The underlying event at the LHC



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)

$$\sigma_{AB} = \frac{m}{2}\sigma_A \frac{\sigma_B}{\sigma_{eff}} \rightarrow \sigma_{eff} \approx 15\text{-}20 \text{ mb}$$

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)

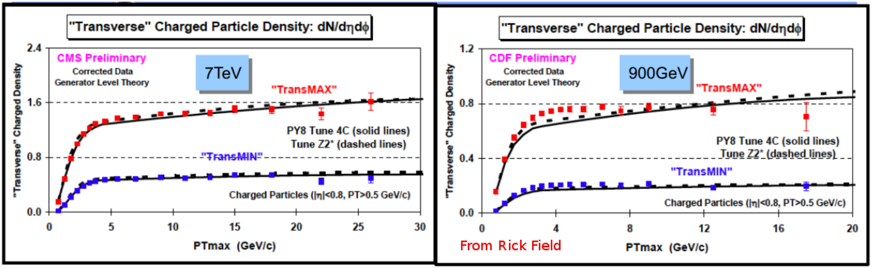
	PYTHIA 8 Monash	HERWIG++ UE-EE-5C
(soft) MPI	UE pp($\bar{p}$) data at various $\sqrt{s}$	UE pp($\bar{p}$) data at various $\sqrt{s}$ Value of measured σ_{eff}
Primordial k_T	p_T spectrum of lepton pair from Z decays in hadronic collisions	p_T spectrum of Z boson in hadronic collisions
Parton shower	Event 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

N.B. For the DPS simulation, generators normally use parameters of soft MPI and extrapolate to harder scales

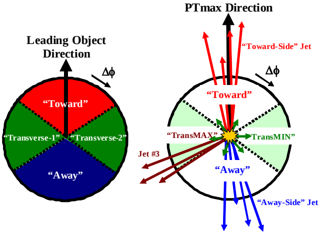
Can they be refined?

How well do they describe observables at different energy?



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

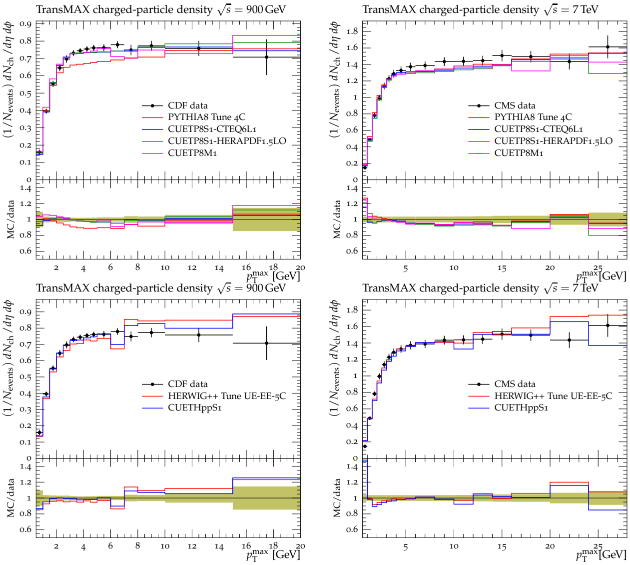
- TRANS MIN: sensitive to MPI
- TRANS MAX: sensitive to MPI and PS
- TRANS DIF: sensitive to PS
- TRANS AVE: sensitive to MPI and PS



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)

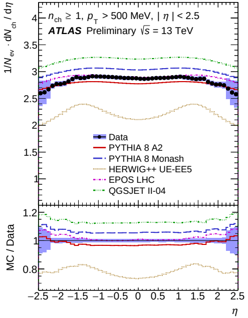
with various PDFs

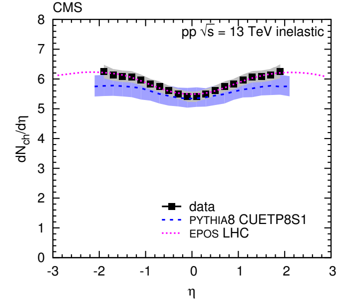
Better constrain of the energy extrapolation
CR changes with the choice of the PDF

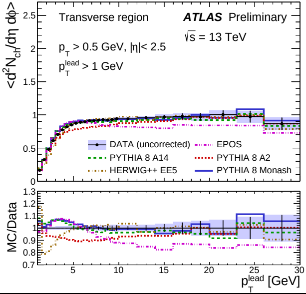
Rising part and plateaux region are well predicted by the new tunes

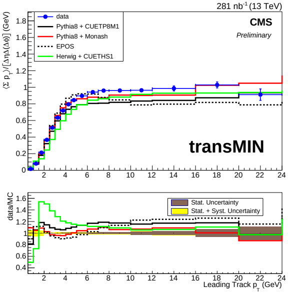
(arXiv 1512.00815)

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

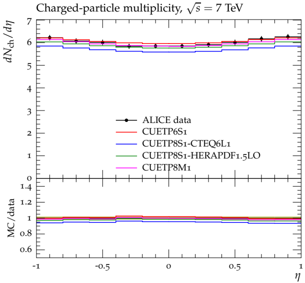
None of the tunes reproduce the data perfectly!

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

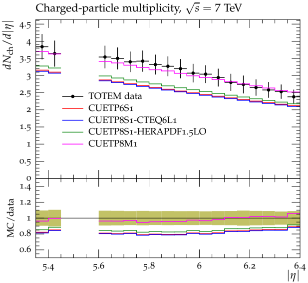
$$p_T^0 = p_T^{ref} \cdot (E/E_{ref})^{\epsilon}$$

What about other observables? (arXiv 1512.00815)

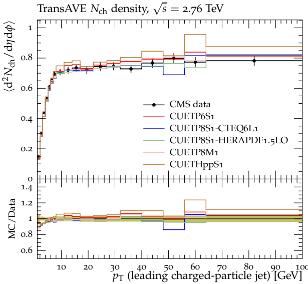
Min. Bias observables ✓



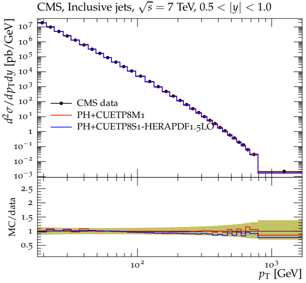
Forward region ✓



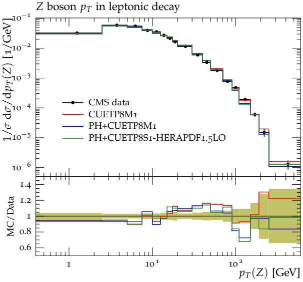
UE vs p_T^{jet} ✓



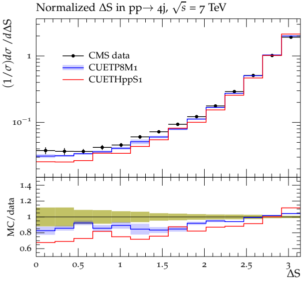
Incl. jet cross sections ✓



Z-boson observables ✓



DPS observables X

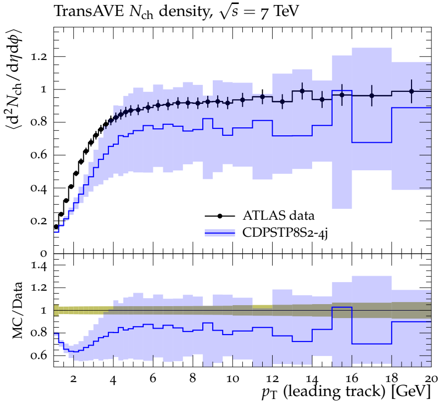


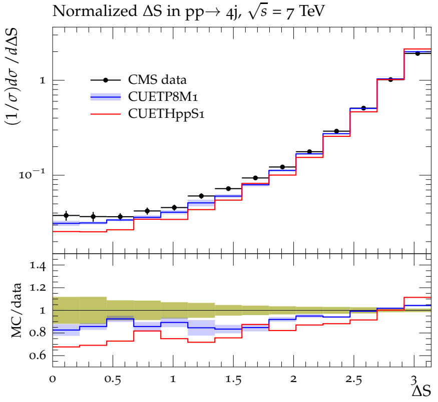
Further look at UE/DPS comparisons (arXiv 1512.00815)

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

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

Possible solutions?

- Use of the same approach and finding new generators/strategies:
  - inclusion of higher-order effects
  - accounting for different parameters
- Including partonic correlations within a Monte Carlo simulation

Combined fits to DPS measurements

Fitting measurements separately..

Fitted measurements	σ_{eff} value (mb)	Reference
4j	$\mathbf{19.0}^{+4.7}_{-3.0}$	arXiv 1512.00815
W2j	$\mathbf{25.8}^{+8.2}_{-4.2}$	arXiv 1512.00815
2b2j	$\mathbf{23.2}^{+3.3}_{-2.5}$	DESY-THESIS-15-010

What happens if we try to fit more measurements at the same time?

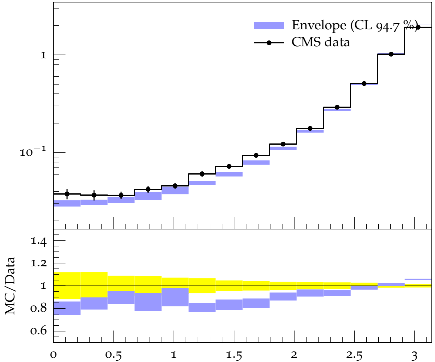
Fitted measurements	σ_{eff} value	χ^2
4j+2b2j	**24.37 mb**	0.631
W2j+2b2j	**25.32 mb**	0.807
W2j+4j	**23.20 mb**	0.948
2b2j+W2j+4j	**22.57 mb**	0.876

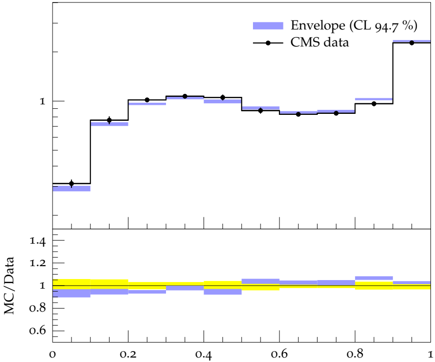
It works! But..we might wash out DPS dependences..

What about tuning other parameters?

Tuned parameter	Variation range
α_S (hard scattering)	0.1 – 0.15

LEFT: ΔS, RIGHT: $\Delta^{rel} p_T$





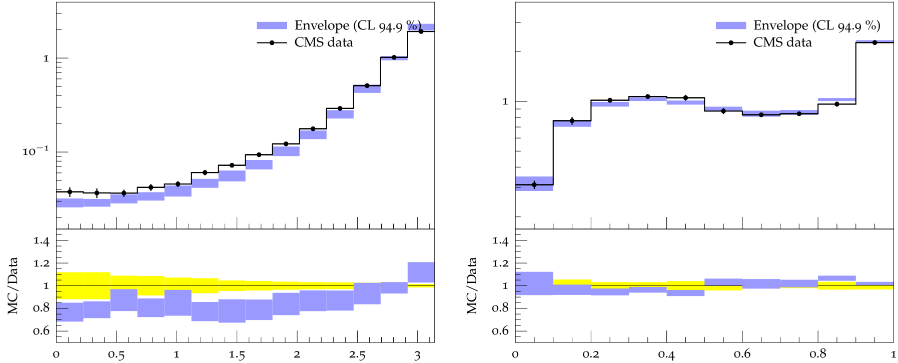
By changing the strong coupling of the hard-scattering matrix element, we do not get a good description of these data

The shape of the ΔS observable does not depend strongly on α_S^{hard}

What about tuning other parameters?

Parameter name	Variation range
α_S (initial-state radiation)	0.1 – 0.15
α_S (final-state radiation)	0.1 – 0.15

LEFT: ΔS, RIGHT: $\Delta^{rel} p_T$



By changing the strong coupling of the parton shower, we do not get a good description of these data

The shape of the ΔS observable does not depend strongly on α_S^{PS}

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

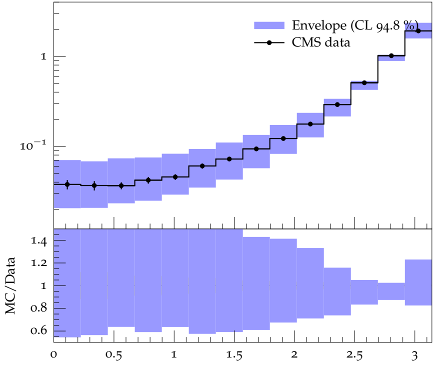
ATL-PHYS-PUB-2014-021

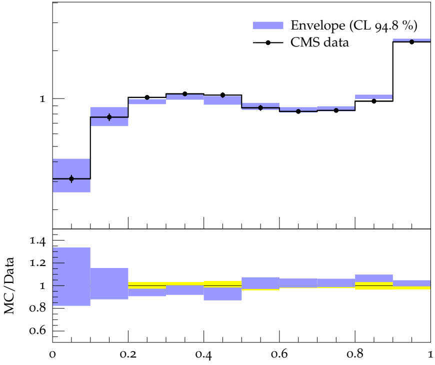
Same tune for DPS?

Parameter name	Variation range
α_S (final-state radiation)	0.1 – 0.15
α_S (initial-state radiation)	0.1 – 0.15
Primordial k_T	1.5 – 2.0
MPI p_T regulator	1.5 – 3.5
Overlap matter distr.	0.5 – 3.0
ISR p_T regulator	0.75 – 2.5
α_S (MPI)	0.1 – 0.15

LEFT: ΔS,
RIGHT: $\Delta^{rel} p_T$

Full tune in "ATLAS style":
ATL-PHYS-PUB-2014-021





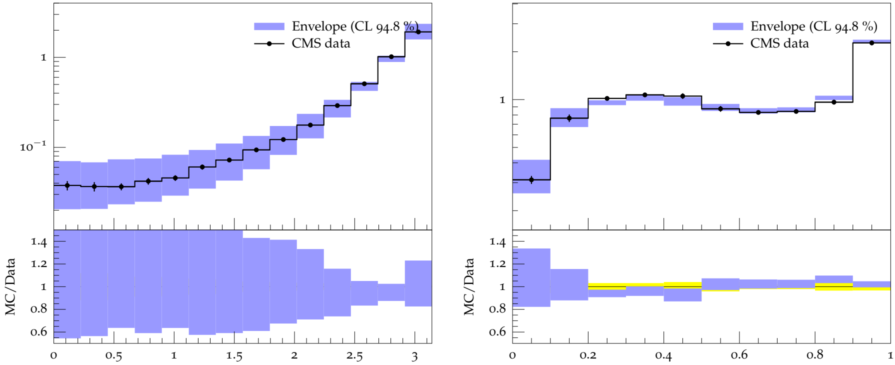
Same tune for DPS?

Parameter name	Fit value
α_S (final-state radiation)	0.146
α_S (initial-state radiation)	0.121
Primordial k_T	1.6529
MPI p_T regulator	2.55
Overlap matter distr.	1.79
ISR p_T regulator	0.936
α_S (MPI)	**0.1454**

χ^2**/Ndf = 3.10e-01**

σ_{eff} **= 24.78 mb**

LEFT: ΔS,
RIGHT: $\Delta^{rel} p_T$

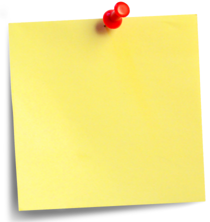


Riassunto e conclusioni

La fisica delle alte energie si basa su simulazioni con programmi Monte Carlo

- Molti tunes disponibili che danno una buona descrizione dei dati in una vasta gamma di energie
- Fino ad ora, non siamo in grado di ottenere un fit che descriva ad un buon livello interazioni partoniche in tutto lo spazio delle fasi
- E' possibile ottenere un fit consistente con molte misure di DPS a 7 TeV..**MA..non vengono considerate le correlazioni partoniche**
- Introducendo correlazioni, la situazione sembra migliorare

Problema aperto: simulazioni piú sofisticate aiuterebbero in questa direzione



Riassunto e conclusioni

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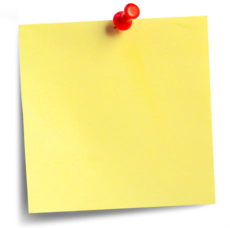


GRAZIE PER L'ATTENZIONE

BACKUP SLIDES

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

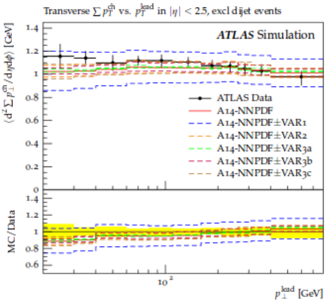
→ How to reduce the numbers of eigentunes?

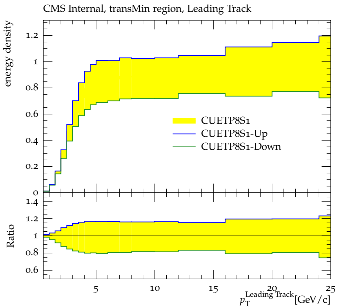
ATLAS strategy ATL-PHYS-PUB-2014-021

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?

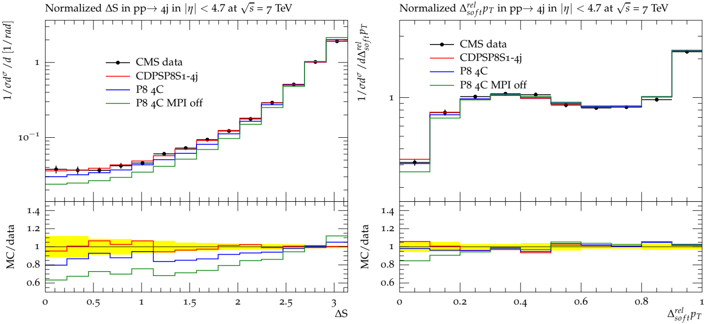
Effective cross section in the four-jets channel (I)

Tuning the four-jet distributions in the tuning range [0.8,2.5]

Parameter	New Tune	4C
MultipleInteractions:expPow	1.160	2.0
+Unc	1.2096	-
-Unc	1.1109	-
Goodness of fit	0.751	-

$$\sigma_{eff} = 21.3^{+1.2}_{-1.6}\ \text{mb}$$

$\rightarrow \sigma_{eff}$ (Tune 4C) $\sim$ 30.2 mb



Improved agreement with the new tune

New set of parameters: CDPSP8S1-4j

LEFT: ΔS

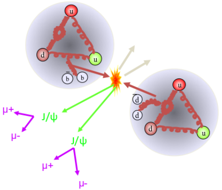
RIGHT: $\Delta^{rel}_{soft} p_T$

CMS-GEN-14-001

Cross section measurements sensitive to DPS

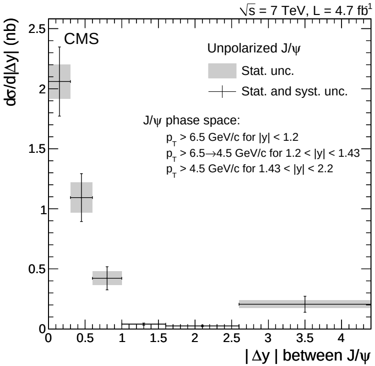
Event selection

Presence of two pairs of same-sign muons in $|\eta| < 2.2$; the two pairs must have invariant mass close to J/ψ



$\sigma(J/\psi J\psi + X)$

$1.49 \pm 0.07 \pm 0.13$ nb



Correction and phase-space extrapolation assuming unpolarized production

SPS background should dominate the fall at low Δy

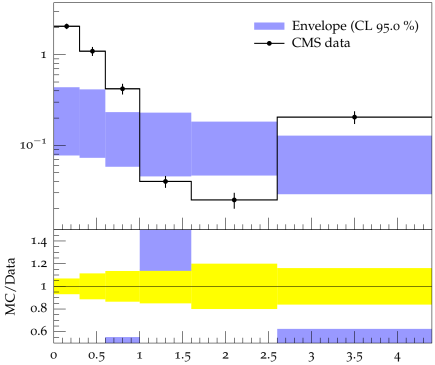
DPS expected to fill the high Δy region

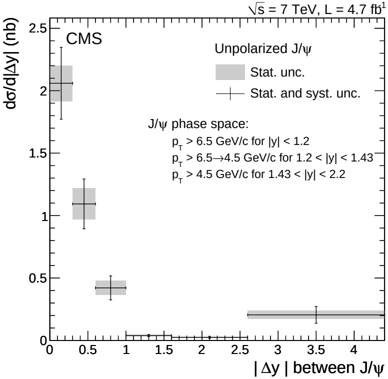
Useful baseline for building reliable models of J/ψ production before extracting DPS signal

Tuning other measurements?

Parameter name	Variation range
MPI p_T regulator	1.5 – 3.5
Overlap matter distr.	0.5 – 3.0

DPS signal expected at high rapidity separation



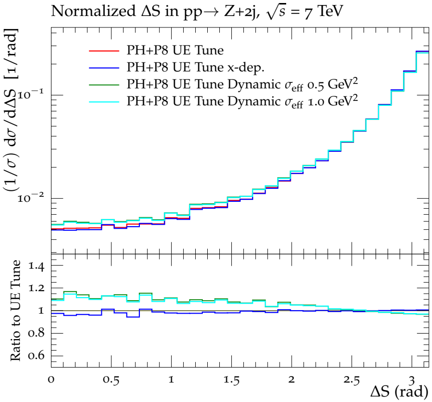


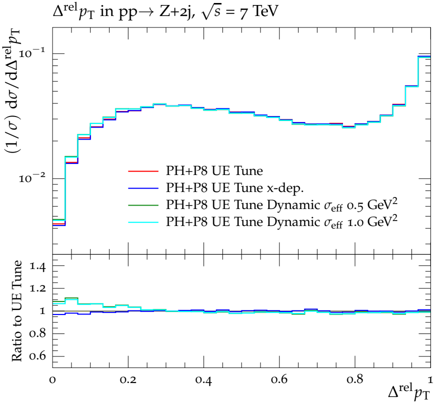
Clearly we need a better model to describe double J/ψ observables

This measurement will not be accounted for in the global DPS fit

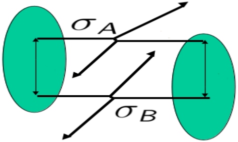
Comparison with DPS measurements in Z+jets

LEFT: ΔS, RIGHT: $\Delta^{rel} p_T$





A double parton scattering (DPS)



- Two different x values for the two partons in each proton
- Impact parameter b

$$\sigma^{DPS}_{A,B} = \frac{m}{2} \int dx_1 dx'_1 \hat{\sigma}_A(x_1, x'_1) \int dx_2 dx'_2 \hat{\sigma}_B(x_2, x'_2) \int d^2b\, f(x_1, x_2, b)\; f(x'_1, x'_2, b)$$

DPS Cross Section

Double parton distribution functions

Partonic cross sections

If the partons are assumed to be uncorrelated:

$$f(x_1, x_2, b) = f(x_1) f(x_2) F(b)$$

The two scatterings factorize in the cross section formula:

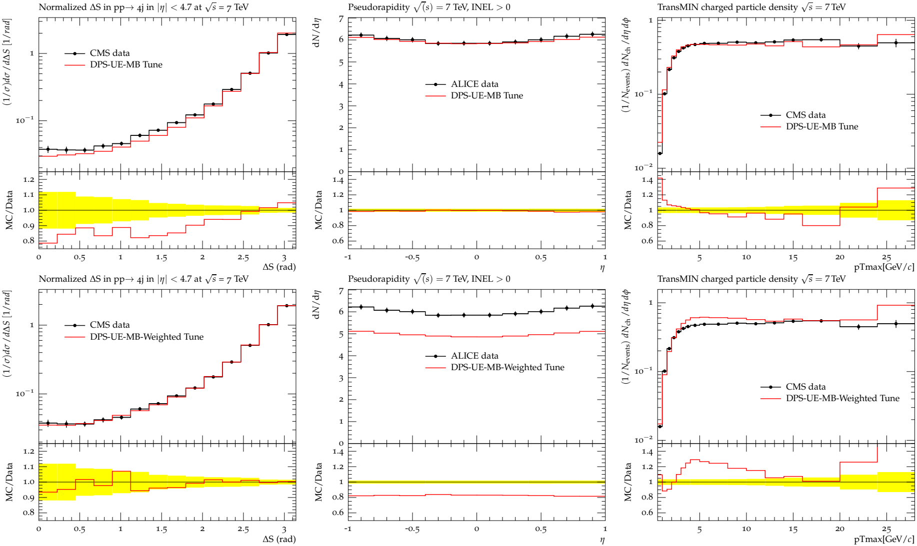
$$\sigma^{DPS}_{AB} = \frac{m}{2} \int dx_1 dx'_1 \hat{\sigma}_A f(x_1) f(x'_1) \int dx_2 dx'_2 \hat{\sigma}_B f(x_2) f(x'_2) \int d^2b\, [F(b)]^2$$

It is thus defined:

$$\sigma_{eff} = \frac{1}{\int d^2b\, [F(b)]^2}$$

Combined fits to whole MPI spectrum

Combined fits of observables sensitive to soft, semi-hard and hard MPI



No hope to get the measurements well described altogether

What about possible correlations included? (I)

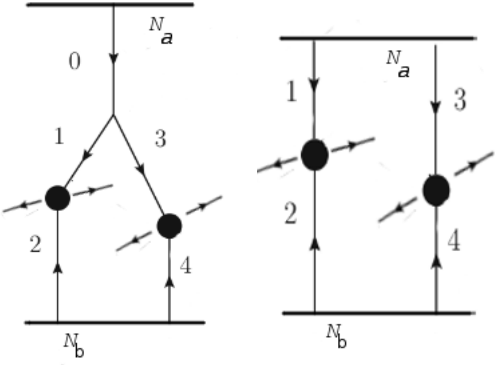
Current status of MPI simulation

MPI are simulated in an interleaved way, treated in the same way as ISR and FSR

Whole machinery is based on single PDFs

The so-called 1×2 and 2×2 mechanisms also contribute to MPI processes

The 1×2 mechanisms lead to a signicant transverse-scale dependence of MPI cross sections



EPJC75 (2015) 6 282, arXiv 1510.07436

BUT ... No Monte Carlo simulation available with such model

A bit more details..

$$\frac{1}{\sigma_{eff}} \equiv \int \frac{d^2\vec{\Delta}}{(2\pi)^2}[\ _{[2]}G_2(x_1, x_3, Q_1^2, Q_2^2; \vec{\Delta})_{[2]}G_2(x_2, x_4, Q_1^2, Q_2^2; -\vec{\Delta})$$

$$+\ _{[1]}G_2(x_1, x_3, Q_1^2, Q_2^2; \vec{\Delta})_{[2]}G(x_2, x_4, Q_1^2, Q_2^2; -\vec{\Delta})$$

$$+\ _{[1]}G_2(x_2, x_4, Q_1^2, Q_2^2; \vec{\Delta})_{[2]}G_2(x_1, x_3, Q_1^2, Q_2^2; -\vec{\Delta})].$$

x-dependence:

$$\frac{1}{\sigma^0_{eff}} = \frac{1}{2\pi} \frac{1}{\sum_i f(log[x_0/x_i^{-1}])}$$

Q^2 dependence:

$$R(Q_1^2, Q_2^2, Q_0^2)$$

REMARKS:

→ Inputs of the models are the standard single PDF, and the gluon form factors which are obtained from J/ψ photoproduction measurements in ep collisions

→ R functions are calculated by solving iteratively the nonlinear evolution equations, and the only one free parameter Q_0 is the separation between soft and hard scales

What about possible correlations included? (III)

How is it practically done? - PYTHIA 8

- The "underlying" UE tune is provided by fitting charged particle observables at low scales
- A value of σ_{eff} is calculated through functions obtained from electron-proton collision data
- Reweight the PYTHIA events on an event-by-event basis

Key formula for amount of DPS:

$$\sigma_{eff} = \frac{\sigma^0_{eff}(x_i)}{1+R(Q_j^2)}$$

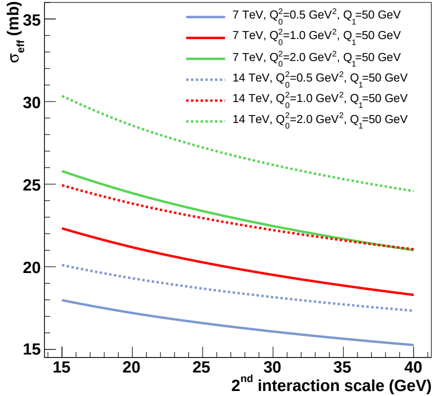
1. UE Tune: no σ_{eff} reweight
2. UE Tune - Q^2-dep: reweighting vs parton scales
3. UE Tune - x-dep: reweighting vs parton x
4. UE Tune - dynamic σ_{eff}: reweighting vs parton scales and x

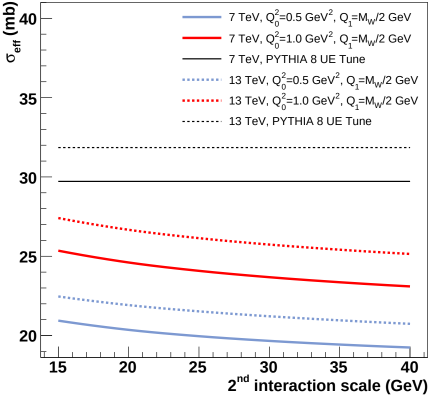
N.B. There is no modification on kinematics of the outgoing partons, but only on the DPS cross section

Dynamic values of σ_{eff} implemented

Different partonic initial states:
gluon-gluon interaction in 4j
quark-quark interaction in Wj

LEFT: four-jet, RIGHT: W+jets
EPJC75 (2015) 6 282, arXiv 1510.07436





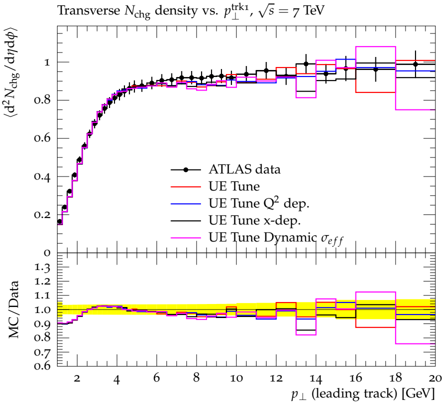
Lower values obtained for gluon-initiated final states

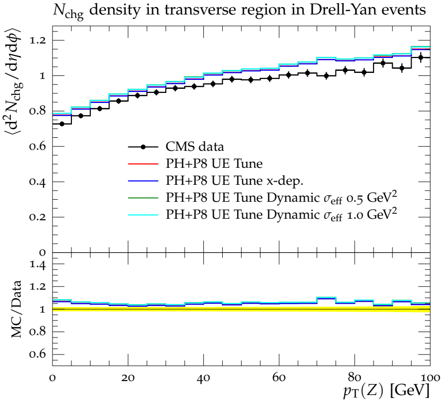
σ_{eff} ranging between 15-25 mb at 7 TeV

Comparison with UE measurements

UE parameters obtained by fitting the low p_T region of observables in hadronic events

Charged particle multiplicity in hadronic (LEFT) and Drell-Yan (RIGHT) events
EPJC75 (2015) 6 282, arXiv 1510.07436





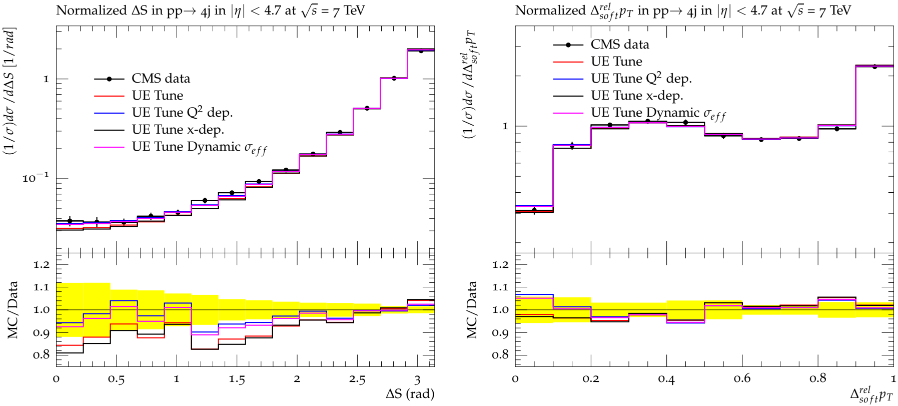
Very good description of both sets of data with all settings

Soft MPI are not sensitive to σ_{eff} variations

Comparison with DPS measurements in four jets

UE parameters obtained by fitting the low p_T region of observables in hadronic events

LEFT: ΔS, RIGHT: $\Delta^{rel} p_T$
EPJC75 (2015) 6 282



Introducing a dynamic σ_{eff} dependence brings the predictions closer to the data

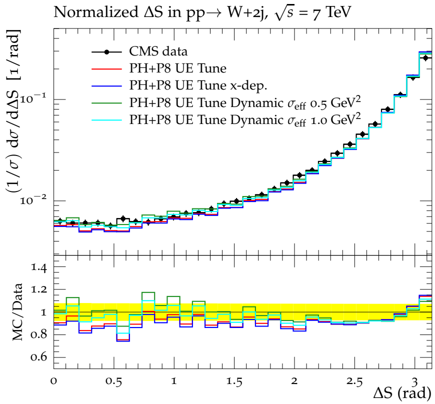
Improvement of 10% for ΔS with respect to standard predictions

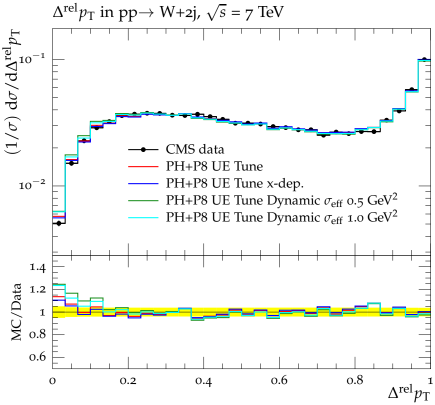
Comparison with DPS measurements in W+jets

UE parameters obtained by fitting the low p_T region of observables in hadronic events

LEFT: ΔS, RIGHT: $\Delta^{rel} p_T$

arXiv 1510.07436





Introducing a dynamic σ_{eff} dependence has a relatively small effect but describes well the measurements