

December 2017
MPI@LHC 2017
Shimla (India)



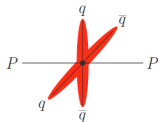
Tuning of color reconnection models with CMS data at 13 TeV

Paolo Gunnellini
on behalf of the CMS Collaboration

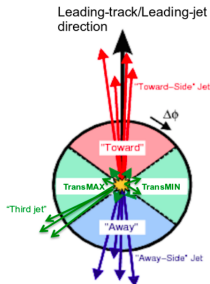
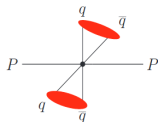


- Introduction
- Colour reconnection and models
- Tuning colour reconnection models in PYTHIA 8
- Colour reconnection in top physics
- Summary

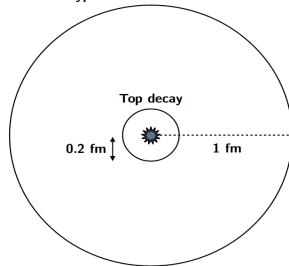
Before colour reconnection



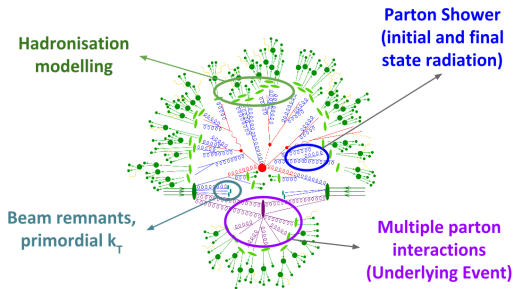
After colour reconnection?



Typical hadronization scale



The underlying event at the LHC

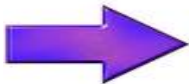


From Frank Siegert

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
- Beam Remnants
- Multiple Parton Interactions (MPI)
- Hadronization

These contributions are not always calculable in pert. QCD



Governed by free phenomenological parameters to determine

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)
 - Correct estimation of uncertainties
 - Models are not "allowed" to fail
- ② **Good physics predictions**
 - Correct evaluation of physics effects
 - Models are "allowed" to fail

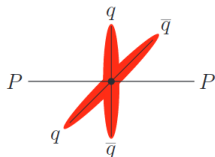


The danger is overtuning!

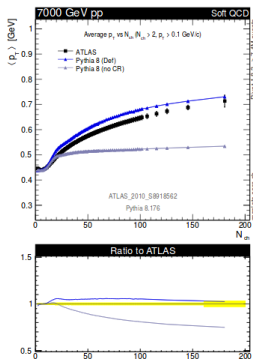
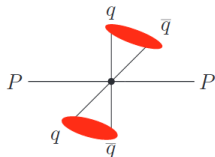
What is colour reconnection?

Colour reconnection addresses the problem of how the colour fields rearrange themselves after the collision

Before colour reconnection



After colour reconnection?



Experimentally driven in order to describe the rise of average transverse momentum as a function of number of particles

Source: mcplots.cern.ch

Monte Carlo event generators (e.g. PYTHIA 8) have various model to implement such arrangements:

MPI-based

QCD-inspired

Gluon-move

Colour reconnection in Pythia8 (QCD-based model)

String beyond leading colour (J.Christiansen, P.Skands)

JHEP08 (2015) 003

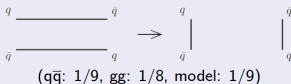
(SOME) FEATURES:

- Include more rigorously the QCD colour rules
- Include additionally a space-time casual connection between strings
- Include in the effects of "higher orders" in colour connections
- Describe observables in the strange sector which are not described with the simple CR model

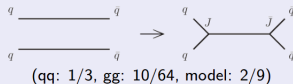
QCD-based
model based
on string
minimization

It includes also
"junction"
reconnections

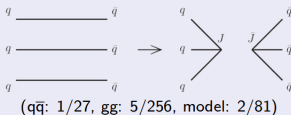
Ordinary string reconnection



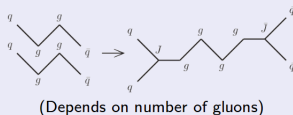
Double junction reconnection



Triple junction reconnection



Zippering reconnection



String beyond leading colour (J.Christiansen, P.Skands)

JHEP08 (2015) 003

(SOME) FEATURES:

- Include more rigorously the QCD colour rules
- Include additionally a space-time casual connection between strings
- Include in the effects of "higher orders" in colour connections
- Describe observables in the strange sector which are not described with the simple CR model

QCD-based
model based
on string
minimization

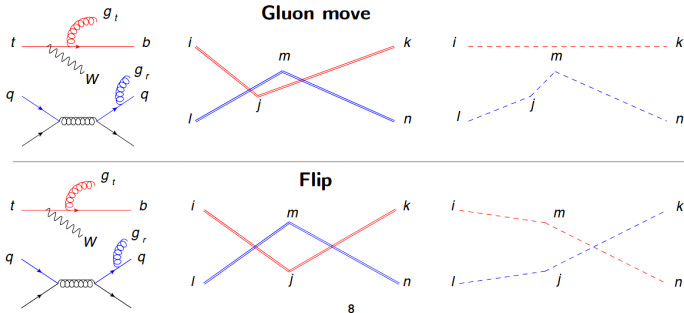
It includes also
"junction"
reconnections

PARAMETERS RULING THE MODEL:

- m_0 : variable used in the measure of the string length
- timeDilationPar: minimal time of two strings to resolve each other between formation and hadronization
- junctionCorrection: extraparameter for controlling junction production

Colour reconnection in Pythia8 (gluon-move model)

**Gluon-move model also based on the minimization of string length
..but with different mechanisms**



→ M2LAMBDA: represents an approximate hadronic mass-square scale
(in the λ measure)

→ FRACGLUON: probability of gluons to move

→ DLAMBDA CUT: minimal amount of λ reduction allowed for gluon
moves and colour flips

T. Sjöstrand, J. Christiansen (arXiv:1506.09085)

Baseline: CUETP8M2T4 - top-specific tune
($\alpha_S^{ISR} = 0.1108$, NNPDF30LO PDF set)

See talk from Deniz and CMS-PAS-TOP-16-021

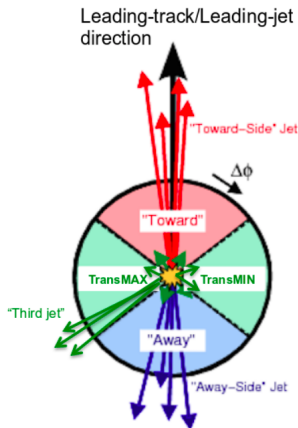
$\rightarrow p_T^0 - [1.0 - 3.0]$
 $\rightarrow \text{expPow} - [0.4 - 10.0]$

- QCD-inspired model
 - junctionCorrection - [0.05 - 9.0]
 - timeDilationPar - [0 - 90]
 - m0 - [0.2 - 4.5]
- Gluon-move model
 - m2Lambda - [0.25,16]

OBSERVABLES:

p_T^{sum} and N_{ch} in the TransMIN and MAX regions
and $dN/d\eta$ at 13 TeV

Low p_T part excluded from the fit ($p_T^{max} < 3$),
possible contributions from diffractive processes

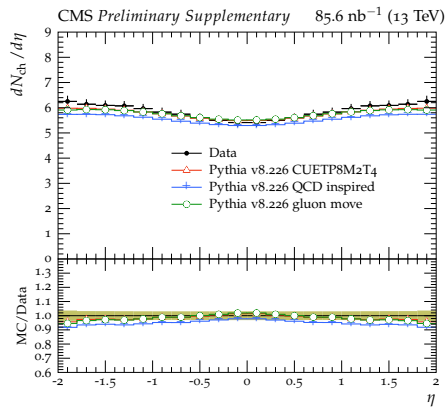
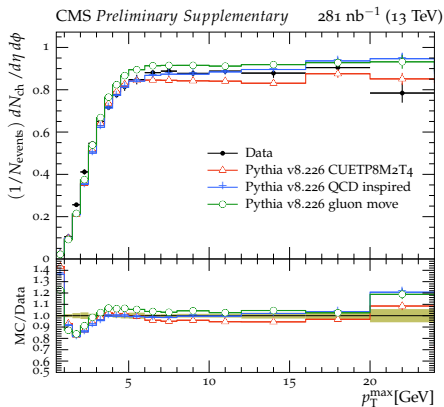


Parameters	CUETP8M2T4	QCD inspired	gluon move
MultipartonInteractions: pT0Ref	2.20	2.17	2.30
MultipartonInteractions: expPow	1.60	1.31	1.35
MultipartonInteractions: ecmRef	7000	7000*	7000*
MultipartonInteractions: ecmPow	0.25	0.25*	0.25*
ColourReconnection: range	6.59	-	-
ColourReconnection: junctionCorrection	-	0.12 (1.20)	-
ColourReconnection: timeDilationPar	-	15.9 (0.18)	-
ColourReconnection: m0	-	1.2 (0.3)	-
ColourReconnection: m2lambda	-	-	1.9 (1.0)
ColourReconnection: fracGluon	-	-	1.0* (1.0)
ColourReconnection: dLambdaCut	-	-	0.0* (0.0)
PDF set	NNPDF30_LO [JHEP 04 (2015)]	NNPDF30_LO	NNPDF30_LO
SpaceShower:alphaSvalue	0.1108*	0.1108*	0.1108*
Goodness of fit/dof	1.89 [CMS-PAS-TOP-16-021]	1.06	1.69
* = value kept fixed in the fit			

Remarks:

- Need for including also MPI parameters for a converging fit
- High value of COLOURRECONNECTION:RANGE value for MPI-based model
- Big changes in the parameters of the QCD inspired model wrt default values
 - Gluon-move mass not significantly different from default
 - Goodness of fit (reduced χ^2) is ~ 1 -2 for all tunes

Published as supplementary material in CMS-TOP-17-007



Remarks:

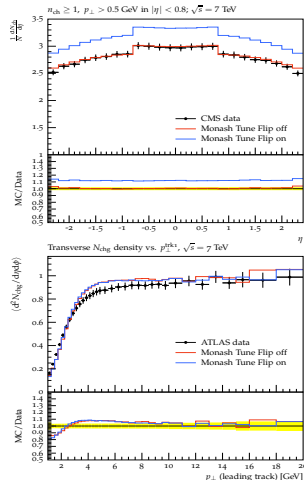
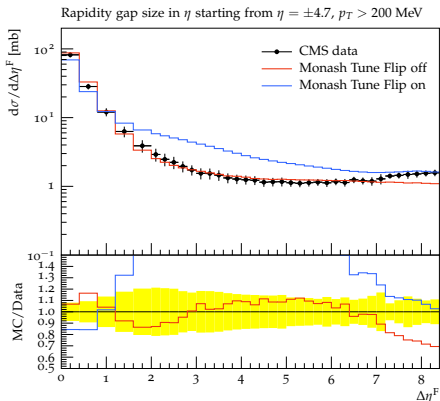
→ Very difficult to describe the rising part of the spectrum at 13 TeV

Flip mechanism effect (gluon-move model)

Soft-physics observables at 7 TeV

(Monash tune - gluon-move CR model with flip mechanism on and off)

(left) rapidity gap, (top right) charged-particle multiplicity vs η , (bottom right) average charged-particle multiplicity vs p_T^{max}



Dramatic effect of the flip mechanism (mainly in single diffractive events)

→ It was decided to switch off the flip mechanism in our tune settings

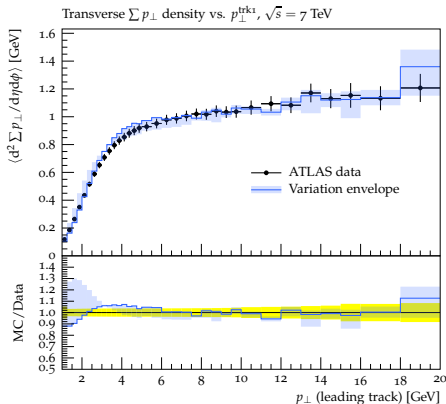
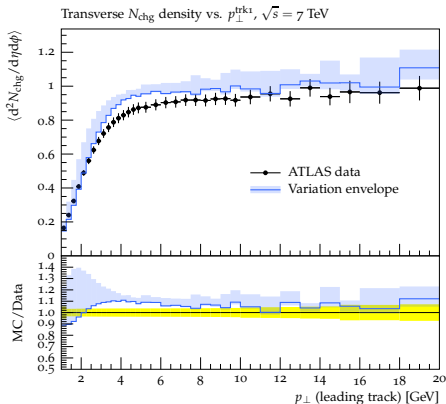
PRD92 (2015), 012003, CMS-PAS-QCD-10-024, PRD83 (2011), 112001

Parameter sensitivity (gluon move model)

Soft-physics observables at 7 TeV

(Monash tune, with gluon-move CR model for variations of parameter dLAMBDA CUT)

(left) average charged-particle multiplicity vs p_T^{max} , (right) average p_T vs p_T^{max}



Changes (10%) on average number of particles but not in average p_T
(The curve with $\text{dLAMBDA CUT}=0$ is on the lower side of the envelope)

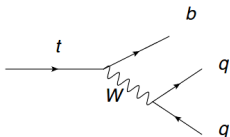
→ It was decided to fix the dLAMBDA CUT parameter in the tune

PRD83 (2011), 112001

Colour reconnection in top physics

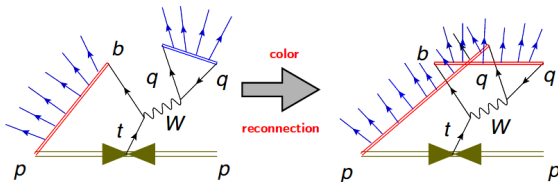
Colour reconnection in top physics

Direct m_{top} measurement (lepton+jets channel)



$$\hat{m}_{\text{top}}^2 = (p_b + p_{j1} + p_{j2})^2$$

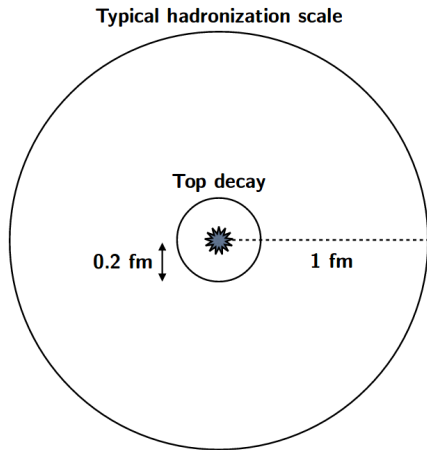
Color reconnection affects the reconstruction of the top system



Ambiguity in the definition of the top mass: $m_{\text{top}}^2 \neq (p_b + p_{j1} + p_{j2})^2$

Credits: Spyros Argyropoulos
JHEP11 (2014) 043

Colour reconnection in top physics



Colour reconnection in top is different from QCD events

- Top decays before hadronization
- Both the top quark and its decay products might colour-reconnect

What happens in PYTHIA 8?

Early Resonance Decay (ERD)
option for top quark

- ERD = off: top quark can colour reconnect to other partons
- ERD = on: the decay products of the top quark can colour reconnect to other partons

The reality should be somewhere in between!

→ Use tuned colour reconnection models to provide better understood uncertainty

- Run-I strategy: compare same UE tune with and without CR effects
- Run-II strategy: compare default CR model with alternative "QCD based" and "gluon move" + compare effects of different choices of "ERD" option

	2D approach		1D approach	Hybrid	
	δm_t^{2D} (GeV)	δJSF^{2D}	δm_t^{1D} (GeV)	δm_t^{hyb} (GeV)	$\delta \text{JSF}^{\text{hyb}}$
""QCD inspired"" (both ERD on)	-0.11	-0.001	-0.19	-0.13	-0.001
""gluon move"" (both ERD on)	+0.34	-0.001	+0.23	+0.31	-0.001
def. ERD off to def. ERD on	-0.22	+0.008	+0.42	-0.03	+0.005

CMS-PAS-TOP-17-007

→ Uncertainties from CR are larger than ERD and than the ones from Run-1

8 TeV (PRD 96, 032002 (2017))	δM_t^{2D}	δJSF^{2D}	δM_t^{1D}	δM_t^{hyb}
CR on to CR off	± 0.06	± 0.001	± 0.15	± 0.13

BUT THEY ARE BASED ON PHYSICS!

- New tunes (both from CMS and from ATLAS) have been obtained for the two alternative colour reconnection models implemented in PYTHIA 8: QCD-inspired and gluon-move models
- They are based on 13 TeV data and describe simultaneously observables sensitive to soft and semi-hard processes
- Gluon flip seems to be disfavoured by soft-physics observables
- Very useful input for a more "physical" estimation of model uncertainties in top physics

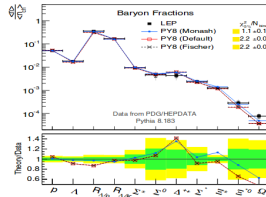
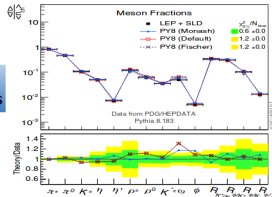
- New tunes (both from CMS and from ATLAS) have been obtained for the two alternative colour reconnection models implemented in PYTHIA 8: QCD-inspired and gluon-move models
- They are based on 13 TeV data and describe simultaneously observables sensitive to soft and semi-hard processes
- Gluon flip seems to be disfavoured by soft-physics observables
- Very useful input for a more "physical" estimation of model uncertainties in top physics

THANKS FOR YOUR ATTENTION!

Back to Strangeness

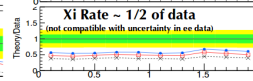
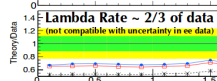
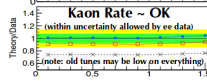
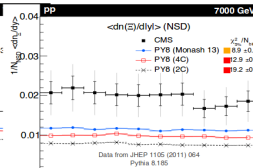
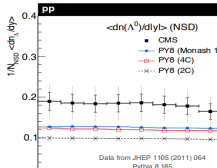
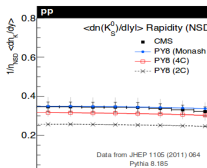
Plots from the Monash tune paper
Eur.Phys.J. C74 (2014) no.8, 3024

Z Decays



This is the data used to tune the models

CMS

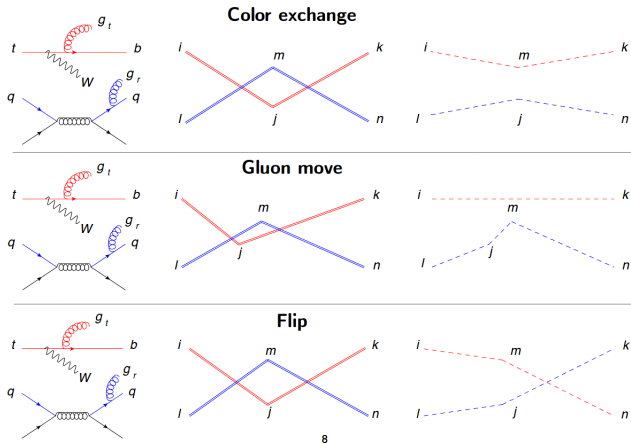


- Beyond-leading-colour effects are expected to be less relevant for LEP measurements
- For pp collisions, they start to contribute with effects up to 50% for identified hadrons

Colour reconnection in Pythia8 (gluon-move model)

In the gluon-move model, the move and the flip mechanisms can be included

Ways to perform a reconnection



From Spyros Argyropoulos' slides based on arXiv:1407.6653