Background Material for Tuning Discussion

Stephen Mrenna
Fermilab

April 13, 2021

Some CMS Tuning Activities

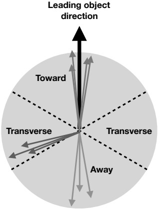
- ⋆ Both ATLAS and CMS have dedicated tuning groups
- ⋆ Review process tends to be long and tedious
- ⋆ Production of new tunes driven by disagreements with data either in UE-observables or some high-p_{T}matched samples
- ⋆ Slides shown here from CMS talk at DIS2019

15 Second Overview

- CUETP8M1: Monash + PDF change
- One parameter tweaks:
  - CUETP8M2T4: $\alpha_s(ISR) \neq \alpha_s(FSR)$
  - Jet substructure: $\alpha_s(FSR) < 0.13$
- 6-parameter CPX tunes: match PDF and α_s in ME

Comparisons of predictions for UE observables from previous tunes to 13 TeV data

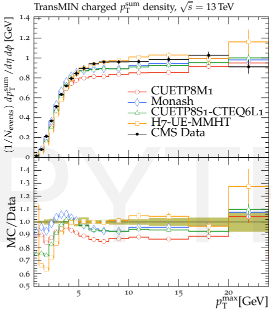
arXiv:1903.12179

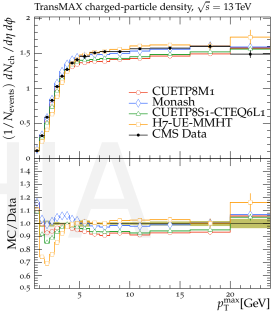


$p_T > 0.5\ GeV$

$|\eta| < 0.8$

$p_T^{max} = max(p_T^{trk,i})$

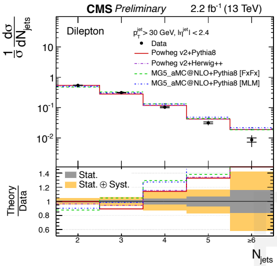




- Main CMS tune (CUETP8M1 based on Monash tune) used until 2017 analyses does not describe well the central values of the data at 13 TeV. EP JC 76 (2016) 155
- CUETP8M1: α_s and shower parameters kept as in Monash → $\alpha_s^{ISR/FSR}$=0.1365 despite the prefered values of 0.130 in LO and 0.118 in NLO matrix elements/ PDF sets.
  - α_s^{FSR} in Monash → by fitting Pythia8 predictions to LEP event shapes and α_s^{ISR} is just assumed to be the same as α_s^{FSR}.
  - α_s^{MPI} = 0.130 set to the value prefered in the LO PDF set.

Revisiting Shower Parameters and Tunes

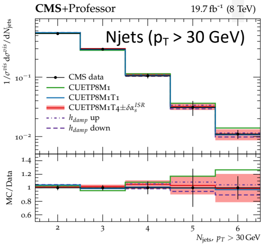
- Starting from parton shower in ttbar events [CMS-PAS-TOP-16-021]
  → CUETP8M2T4 tune ($\alpha_s^{ISR} \sim 0.11$)
- UE in ttbar events at 13 TeV [EPJC 79 (2019) 123]
  → α_s^{FSR}~0.118 agrees better with data.
- Jet substructure in ttbar events at 13 TeV [PRD98 (2018) 092014]
  → α_s^{FSR}~0.115.
- New CMS tunes using (N)(N)LO PDF sets in PS [arXiv:1903.12179]
  → CPX tunes (consistent treatment of PDF+α_s in matrix element and parton shower)
- UE in Z+jets events at 13 TeV [JHEP07 (2018) 032] and [arXiv:1903.12179]



CUETP8M2T4 Event Tune

CMS-PAS-TOP-16-021

- CUETP8M1 not only bad in describing the UE but its predictions overshoot the data for large jet multiplicities when out of the box parameters are used (in Monash-based tunes: α_s^{ISR}=0.1365)
- Effect also observed with 8 TeV data.



Tune α_s^{ISR} using 8 TeV ttbar Njets (using the parton-shower dominated region) and ttbar jet pT data →

$$\alpha_s^{ISR} = 0.1108^{+0.0145}_{-0.0142}$$
$$h_{damp} = 1.581^{+0.658}_{-0.585} m_t$$

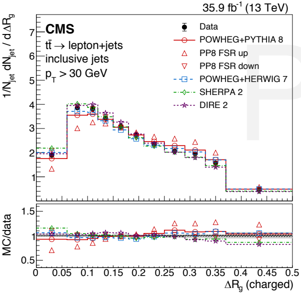
SpaceShower:RapidityOrdering=on

→ Significantly lower α_s^{ISR} cures the overshoot of CUETP8M1 at high jet multiplicities.
→ UE event tune starting with fixed lower α_s^{ISR} describes the UE & min-bias (and top quark) significantly data better.

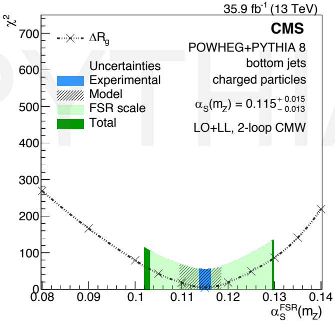
α_s^{FSR} from jet substructure in ttbar l+jets events

- Measured using charged+neutral and with only charged jet constituents (particle pT > 1 GeV).
- b, light, or gluon jet enriched samples.

PRD98 (2018) 092014



Angle between groomed subjets at particle level (correlated to jet width)



Angle between groomed subjets at particle level.

Pythia8:
CUETP8M2T4 for ttbar
CUETP8M1 for the rest.

None of the default tunes yield a good overall description of the data.

Powheg+Pythia8 with LO+LL, 2-loop :

$$\alpha_s^{FSR}(M_Z) = 0.115^{+0.015}_{-0.013}$$

New CMS Tunes using LO PDF

arXiv:1903.12179

PYTHIA8 parameter	CP1	CP2	
PDF Set	NNPDF3.1 LO	NNPDF3.1 LO	Fixed inputs
$\alpha_S(m_Z)$	0.130	0.130	
`SpaceShower:rapidityOrder`	off	off	
`MultipartonInteractions:EcmRef` [GeV]	7000	7000	
$\alpha_S^{\mathrm{ISR}}(m_Z)$ value/order	0.1365/LO	0.130/LO	
$\alpha_S^{\mathrm{FSR}}(m_Z)$ value/order	0.1365/LO	0.130/LO	
$\alpha_S^{\mathrm{MPI}}(m_Z)$ value/order	0.130/LO	0.130/LO	
$\alpha_S^{\mathrm{ME}}(m_Z)$ value/order	0.130/LO	0.130/LO	
`MultipartonInteractions:pT0Ref` [GeV]	2.4	2.3	Fitted parameters
`MultipartonInteractions:ecmPow`	0.15	0.14	
`MultipartonInteractions:coreRadius`	0.54	0.38	
`MultipartonInteractions:coreFraction`	0.68	0.33	
`ColorReconnection:range`	2.63	2.32	
χ^2/dof	0.89	0.54	

PYTHIA

New CMS Tunes using (N)NLO PDFs

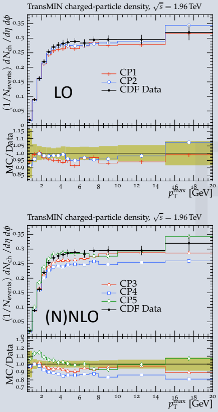
arXiv:1903.12179

PYTHIA8 parameter	CP3	CP4	CP5	
PDF Set	NNPDF3.1 NLO	NNPDF3.1 NNLO	NNPDF3.1 NNLO	Fixed inputs
$\alpha_S(m_Z)$	0.118	0.118	0.118	
`SpaceShower:rapidityOrder`	off	off	on	
`MultipartonInteractions:EcmRef` [GeV]	7000	7000	7000	
$\alpha_S^{ISR}(m_Z)$ value/order	0.118/NLO	0.118/NLO	0.118/NLO	
$\alpha_S^{FSR}(m_Z)$ value/order	0.118/NLO	0.118/NLO	0.118/NLO	
$\alpha_S^{MPI}(m_Z)$ value/order	0.118/NLO	0.118/NLO	0.118/NLO	
$\alpha_S^{ME}(m_Z)$ value/order	0.118/NLO	0.118/NLO	0.118/NLO	
`MultipartonInteractions:pT0Ref` [GeV]	1.52	1.48	1.41	Fitted parameters
`MultipartonInteractions:ecmPow`	0.02	0.02	0.03	
`MultipartonInteractions:coreRadius`	0.54	0.60	0.76	
`MultipartonInteractions:coreFraction`	0.39	0.30	0.63	
`ColorReconnection:range`	4.73	5.61	5.18	
χ^2/dof	0.76	0.80	1.04	

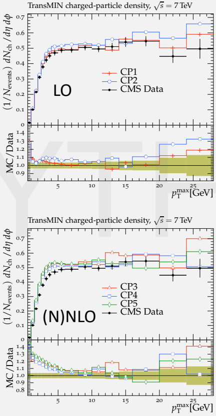
PYTHIA

CPX and Energy Dependence

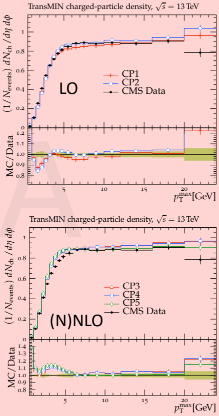
√s=1.96 TeV



√s=7 TeV



√s=13 TeV



- All predictions reproduce well the central values of UE observables at 1.96, 7, and 13 TeV.
- LO-PDF tunes slightly better in describing the energy dependence.

CPX and Z+Jets

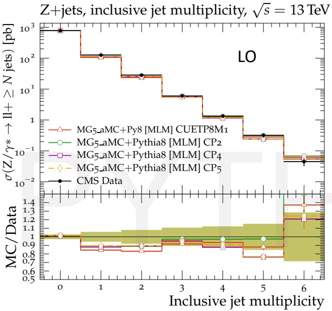
arXiv:1903.12179

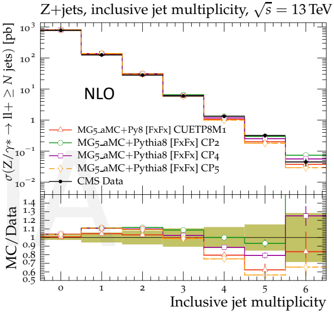
Matrix elements:

- LO: ≤ 3 partons
- NLO: ≤ 2 parton at NLO 3[rd] at LO
- NNPDF3.1 NNLO $\alpha_s(m_Z)$=0.118 for both cases

$$p_T^{\ell\ell} > 20\ GeV,\ |y^{\ell\ell}| < 2.4,\ |m^{\ell\ell} - 20| < 91\ GeV$$

$$p_T^{jet} > 30\ GeV,\ |y^{jet}| < 2.4$$





- Little sensitivity to the tune for low multiplicities.
- All tunes describe the central values of Njets reasonably well.
- CP2 has a slightly better description of the central values.
- CUETP8M1 and CP5 undershoot the data at the PS dominated region with at least 4 jets.

Not Mentioned here

Still internal stuff, including

- ⋆ CR tunes
- ⋆ *in situ* fit to b-fragmentation in $t\bar{t}$
- ⋆ . . .

ATLAS A14

6.5 years old!

- ★ 10 parameter tune
- ★ Roughly 10 classes of data, 400+ histograms, 7000-ish bins
- ★ Used Professor framework: built surrogate model (polynomial) of Pythia8 predictions based on smallish number of parameter samples
- ★ Aimed at standalone Pythia8 tune good enough for search limits
- ★ Used weighting procedure to adjust importance of various distributions to arrive at certain behavior: very tedious and crying out for automation
- ★ Provided eigentunes
- ★ Fairly well-documented, and even some of the Yoda files were still around

BROOD: Bilevel and Robust Optimization and Outlier Detection for Efficient Tuning of High-Energy Physics Event Generators

https://arxiv.org/abs/2103.05751

- Output of a SciDAC project with the thought of doing tuning on HPCs
- However: this work did not rely on that
- Bottom line:
  - One can develop several bi-level algorithms that select weights, minimize, and then iterate
  - These can produce tunes that are comparable or outperform expert tunes
- Evolution of Professor to Apprentice See: https://arxiv.org/abs/2103.05748
  - more choices of optimizers
  - rational approximation surrogate models

Rest is thoughts and comments

WHAT DO WE WANT AN UNCERTAINTY TUNE TO BE?

Can we constructively criticize eigen-tune method and develop an alternative?

What is really χ^2 distributed anyways?

What are the correct degree of freedom? or is it meaningful or necessary to introduce them?

I am pragmatic – don't care about mathematical proofs as long as method is useful and not too conservative

UTOPIAN TUNES

Fit one histogram at a time (yes, even sometimes where $N_{\text{bins}} \sim N_{\text{params}}$)

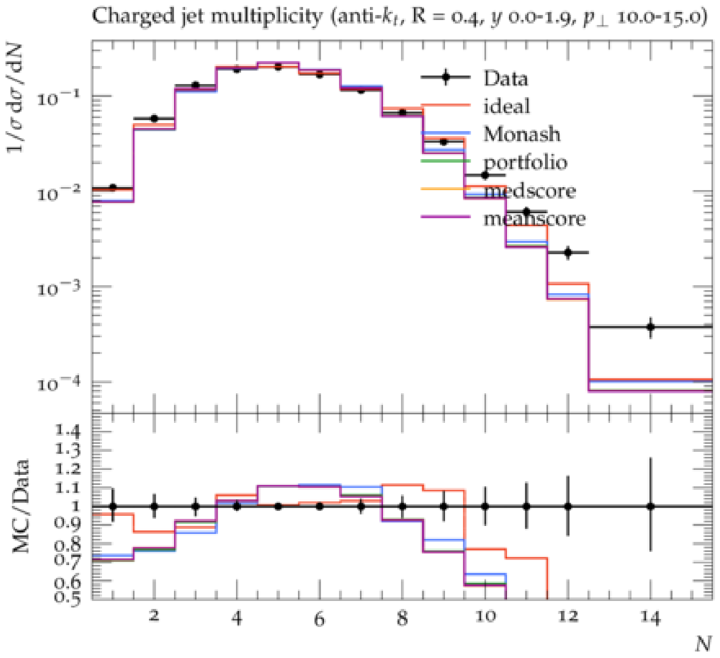
Surprisingly, this happens. So what?

There is a gap between the prediction and data

Build a model of the gap using ML

Can be used to supplement predictions and provide additional uncertainty estimate

Could be expressed symbolically to develop new models


Charged jet multiplicity (anti-k_t, R = 0.4, y 0.0-1.9, $p_\perp$ 10.0-15.0)
$1/\sigma\, d\sigma/dN$
Data
ideal
Monash
portfolio
medscore
meanscore
MC/Data
N

No bounds

With surrogate models and HPCs, we can expand the number of parameters we vary at the LHC

Can/should try to tune hadronization parameters using LHC data

ALICE flavor and hadronization measurements

https://arxiv.org/abs/1709.08522v1 (no Rivet analysis) Fig 1
https://arxiv.org/abs/1802.09145v1 (no HepData) Fig 7
https://arxiv.org/abs/1708.08745v1 (HepData and Rivet available)
https://arxiv.org/abs/1807.11186 (no HepData)
https://arxiv.org/abs/1807.11321 (no HepData)
https://arxiv.org/abs/1811.01535

arXiv:1011.5531 [pdf, other] Charged particle multiplicities in pp interactions at sqrt(s) = 0.9, 2.36, and 7 TeV

arXiv:1012.5104 [pdf, ps, other]Charged-particle multiplicities in pp interactions measured with the ATLAS detector at the LHC

arXiv:1307.1094 [pdf, ps, other] Multiplicity dependence of the average transverse momentum in pp, p-Pb, and Pb-Pb collisions at the LHC

Concluding Remarks

- ⋆ I think we should be in the business of making tunes
- ⋆ We have expertise on many fronts, including contacts in the relevant experiments
- ⋆ We can make some use of the tools and computational resources from my SciDAC project
- ⋆ Providing tunes that fit into the HL-LHC is my primary interest