Ongoing CMS tuning efforts

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on behalf of the CMS collaboration

Outline

Generator tunes in CMS Run3

Current snapshot

- ❖ GEN-22-001: **Intrinsic k_T tune** with DY data in a range of mass and center-of-mass energies Natasa Raicevic's talk
- ❖ Extraction of HERWIG7 and PYTHIA8 **DPS tunes** from CMS multi-jet measurements

Studies to cross-check the tunes' validity & possible improvements

- ❖ Tune with **jet substructure** analyses to fix the Data/MC discrepancies observed in some jet-substructure measurements
- ❖ Tune for **NNPDF4.0**
- ❖ Include **Sherpa** in the tuning study

Current generator tunes in CMS Run3

Generators	❖ Madgraph5_aMC@NLO: **2.9.X** ❖ Other versions of Madgraph5_aMC@NLO are supported ❖ **Pythia: 8.306** ❖ **Herwig: 7.X**
PDF	❖ **NNPDF3.1** (unchanged from Ultra Legacy Run2) ❖ Alternate sets will mostly contain NNLO PDFs including NNPDF4.0
Tune	❖ **CPX** family for **Pythia8** (GEN-17-001) ❖ **CHX** family for **Herwig7** (GEN-19-001) ❖ Intrinsic-k_T tune introduced for Drell-Yan processes
HEPMC	❖ **HEPMC2** (unchanged from Ultra Legacy Run2)

CPX and **CHX** families are recommended for Run3 samples

CP5 and **CH3** tunes are the most commonly used in Run3

Intrinsic-k_T tune is used in Run3 NLO **DYJets** and **WJets** production

Double Parton Scattering (DPS)

SPS and **DPS** show different topologies in the final state

DPS cross section is suppressed w.r.t SPS

$$\frac{\sigma_{DPS}}{\sigma_{SPS}} \sim \frac{\Lambda^2}{Q^2}$$

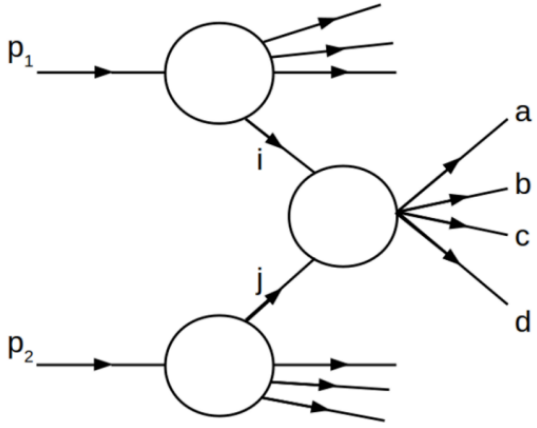
(Hadronic scale ~1GeV)

(Hard interaction scale)

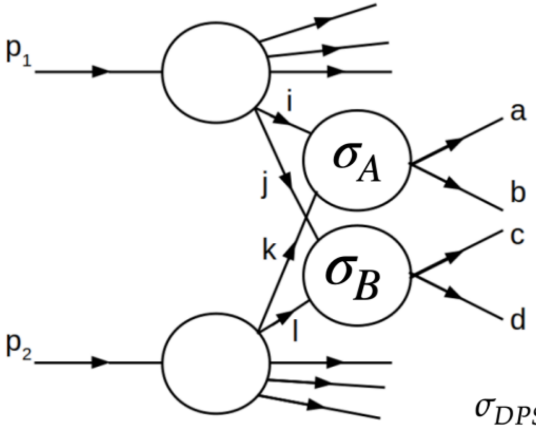
- DPS becomes more important as the collider energy grows. Larger density of partons at small-x values
- DPS can become competitive with SPS when SPS is hindered by small couplings; e.g. same-sign WW production
- …

At the LHC, DPS has been studied in multiple final-states such as

- 4 jets, 4 jets with b-jets, γ+3 jets, W(→$l\nu$)+dijet, Z(→l^+l^-)+J/ψ, J/ψ+J/ψ, same sign WW, etc



Single Parton scattering (SPS)
One hard scattering in a single pp collision. Final states particles are correlated.



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

Double Parton scattering (DPS)
Two separate hard interactions in a single pp collision. Two pairs of partons from the incoming hadrons interact independently with each other.

DPS sensitive observables: 4 jets example

DPS sensitive observables

- The difference in azimuthal angle between the light jet pair

$$\Delta\phi = |\phi(j_1) - \phi(j_2)|$$

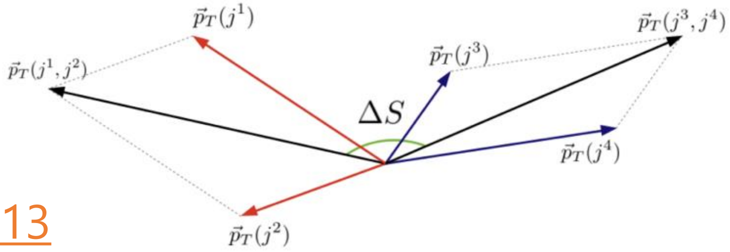
- The balance in p_T of the two light jets

$$\Delta p_T = \frac{|p_T(j_1) + p_T(j_2)|}{(||p_T(j_1)| + |p_T(j_2)||)}$$

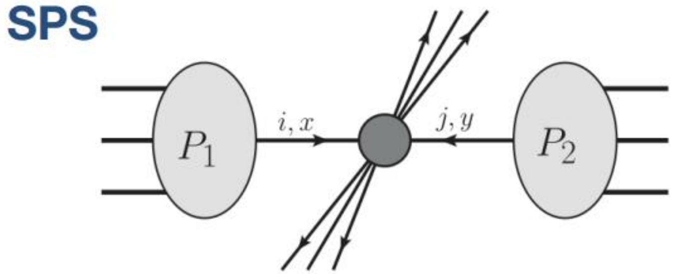
(Soft jets are expected to be produced by a 2nd scattering)

- The azimuthal angle between the two dijet pairs

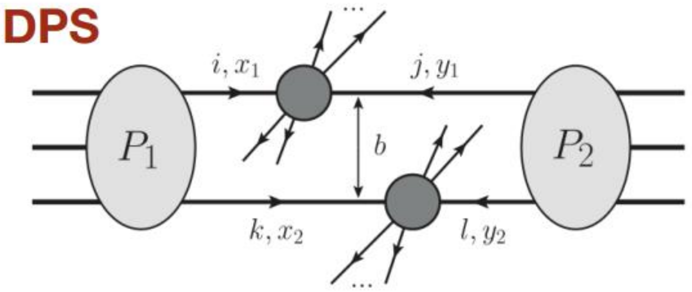
$$\Delta S = \frac{(p_T(j_3, j_4) \cdot p_T(j_1, j_2))}{(|p_T(j_3, j_4)| + |p_T(j_1, j_2)|}$$



Phys. Rev. D **97**, 035013



correlated topologies, back-to-back jets



Uncorrelated topologies, back-to-back jets only for each of the independently produced jet pairs

Description of DPS observables

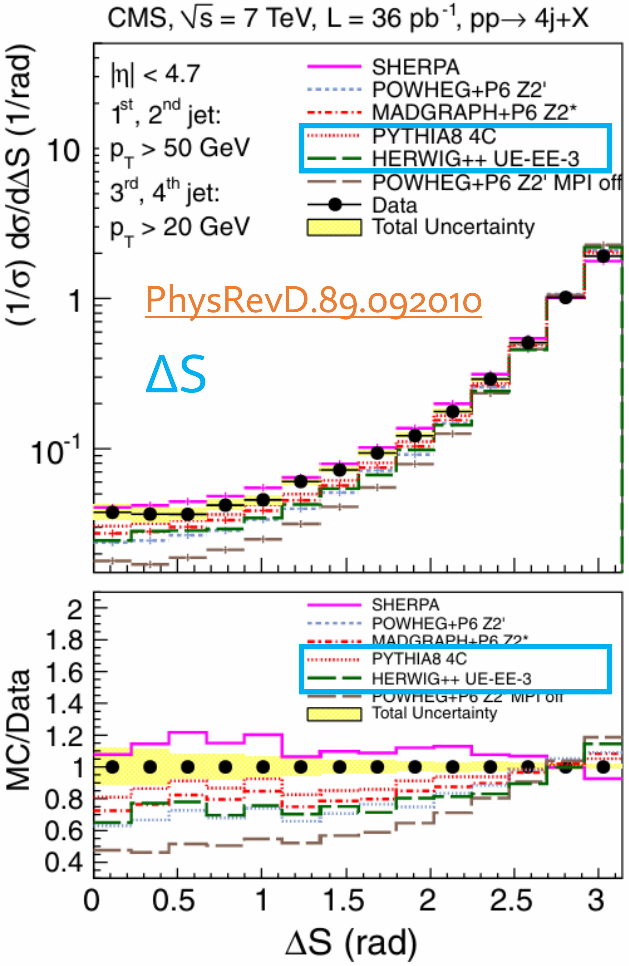
CP5 and CH3 tunes fail at describing DPS observables from CMS multi-jet

Studies ongoing to get a better description of these variables

- Multi-parton interaction (MPI) parameters are obtained through a fit to multi-jet measurements data collected by the CMS experiment at $\sqrt{s}$ = 7 TeV [1,2]

Relevant parameters

- **PYTHIA8**
  - pT0Ref
  - coreFraction
  - coreRadius
- **HERWIG7**
  - ColourReconnector:ReconnectionProbability
  - MPIHandler:InvRadius
  - MPIHandler:Power
  - MPIHandler:pTmin0



The PYTHIA8 and HERWIG7 have similar behavior in CP5 and CH3

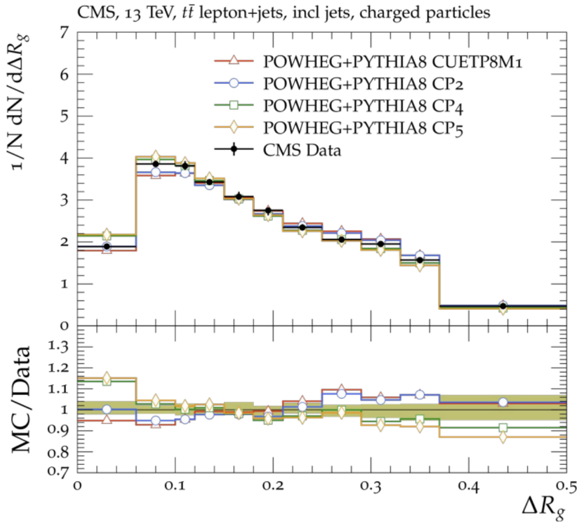
Description of jet substructure

Standard CP5 and CH3 are tunes of 4~5 minimum-bias and color reconnection parameters

- No focus on jet substructure (mostly sensitive to shower development (FSR) & hadronization effects)

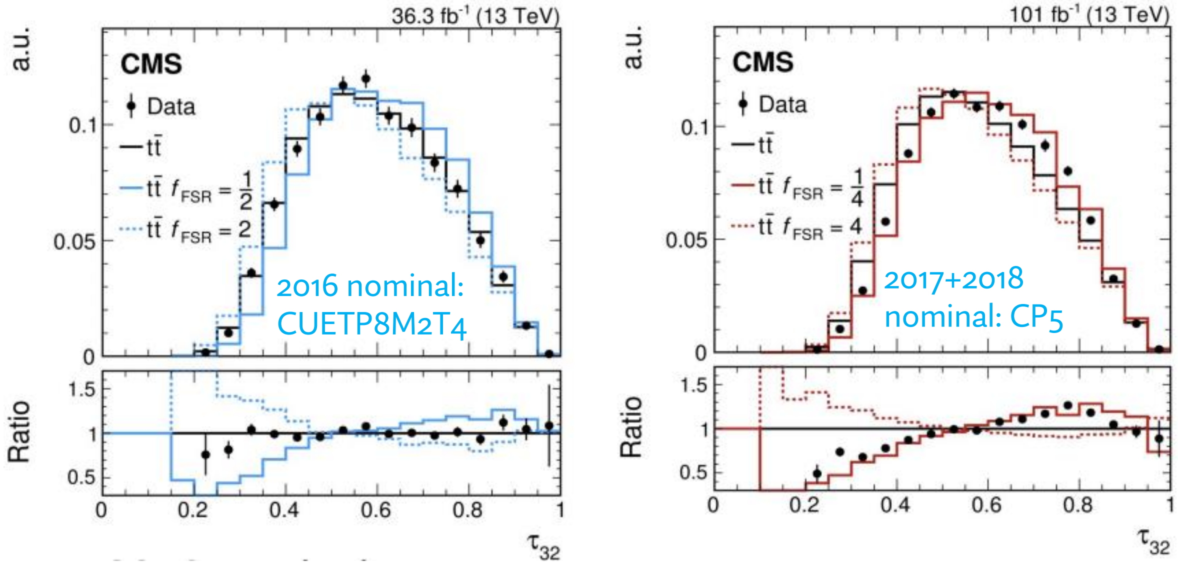
Jet substructure in ttbar TOP-17-013

- **Angle between two groomed subjets** GEN-17-001, data from TOP-17-013



Boosted top quark jet substructure TOP-21-012

- **N-subjettiness ratio**

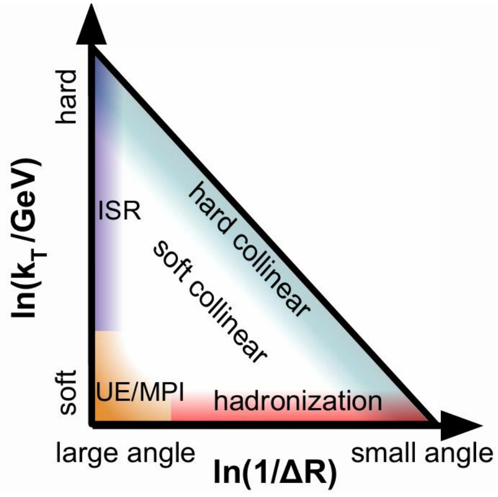


Measurements show jet substructure is not well modeled by simulation

Description of jet substructure

Lund plane: 2D representation of QCD radiation

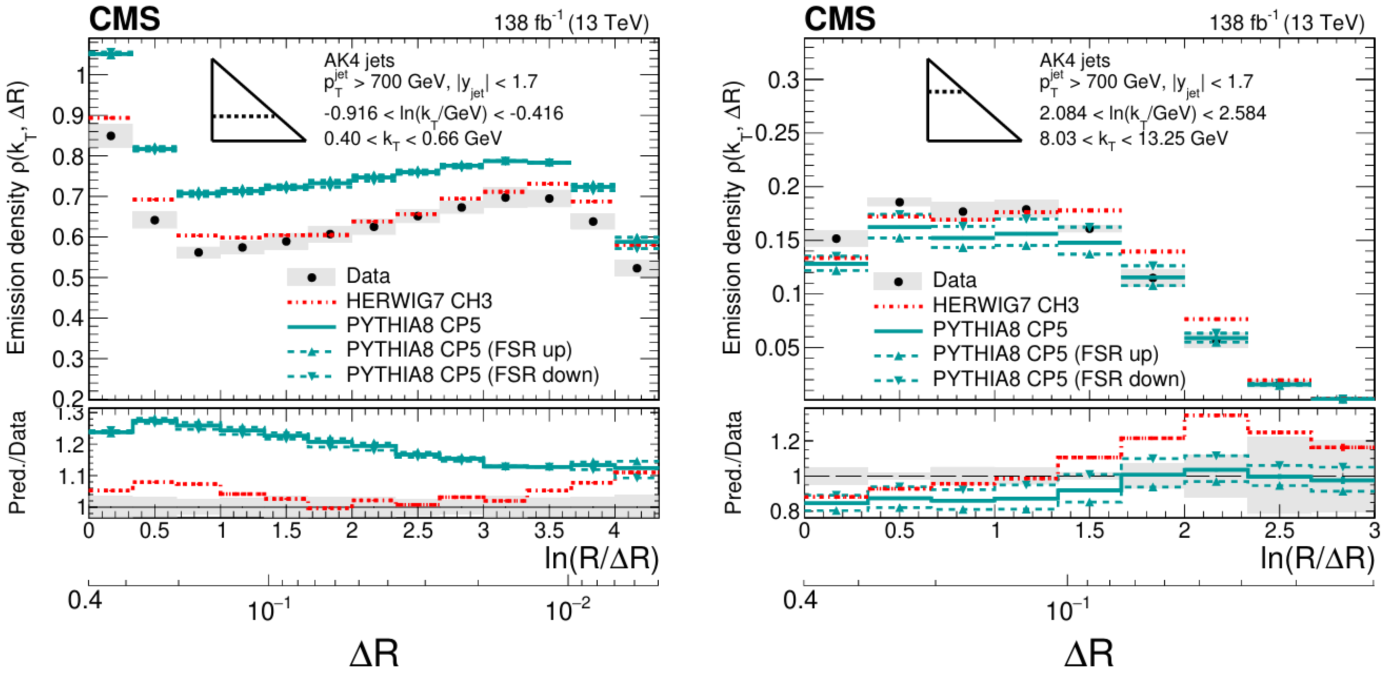
❖ A given jet is represented as a number of points in the Lund plane



SMP-22-007 Measurement of the primary Lund jet plane density in pp collisions at 13 TeV

Neither CP5 nor CH3 describe data well everywhere

❖ 10–20% differences across phase space



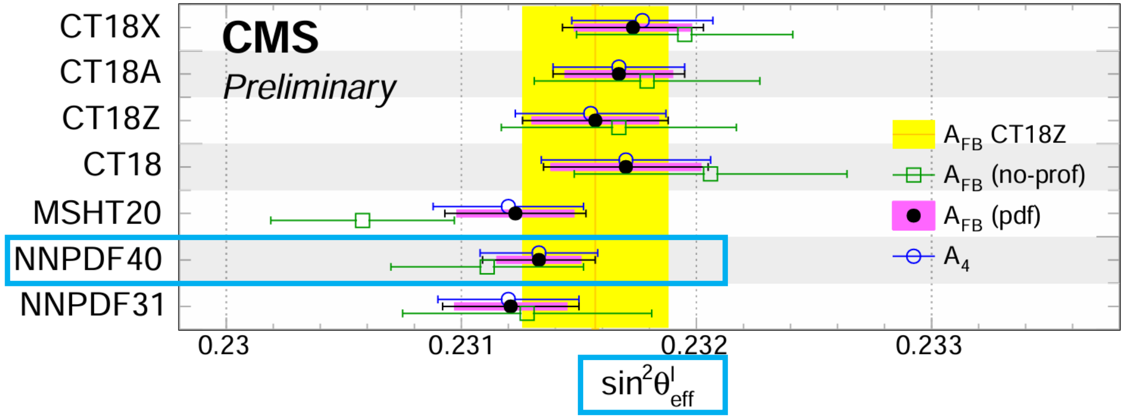
NNPDF4.0 in CMS

NNPDF4.0 was published with outstanding uncertainties (around 1% at the most x)

- NNPDF4.0 was already included in Run3 sample production
- Corresponding tune is in development

CMS GEN group got several queries about how to use it

- Measurement of the weak mixing angle with DY: SMP-22-010 tested NNPDF4.0 (details in Rhys Taus' talk)



NNPDF4.0 shows the best performance

NNPDF4.0 in CMS

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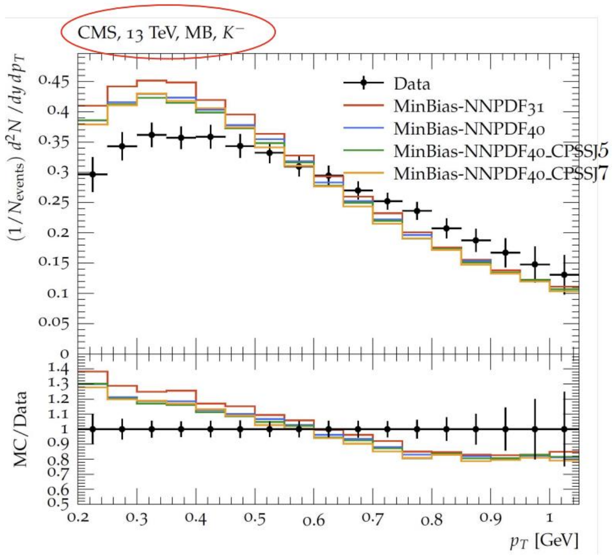
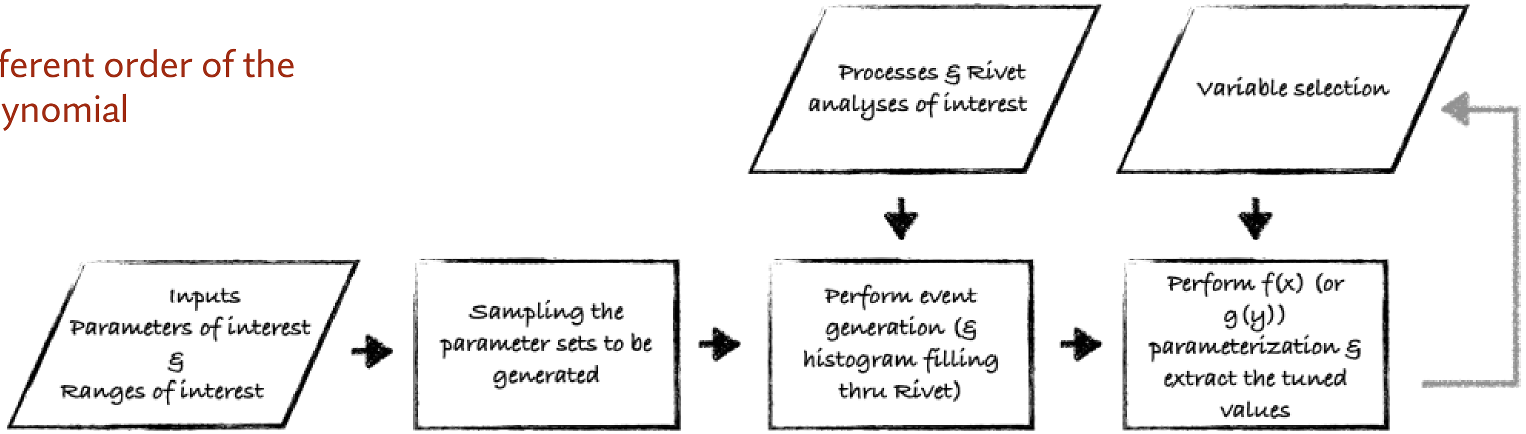
Need a new tune for NNPDF4.0: chance to have a common automated workflow for tunning

- Tuning tool itself is applicable to different event generators, use NNPDF4.0 as a demonstration



Different order of the polynomial



Plots from Sitian Qian

Test of the Sherpa cluster hadronization tune

Cluster Hadronization tune in Sherpa

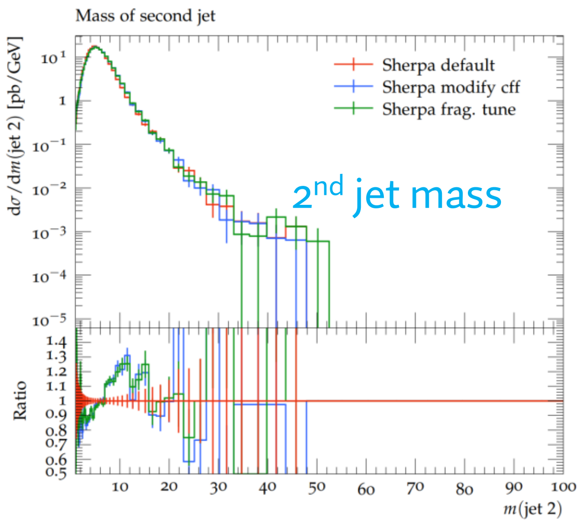
- ❖ Reference: https://arxiv.org/abs/2203.11385
- ❖ Tuned Hadronization Parameters google doc

Sherpa v2.2.15 is current CMS recommendation

- ❖ ME and PS, Hadronization are separate in Sherpa
- ❖ Possible to tune Sherpa in the current CMS workflow (tested with the cluster Hadronization tune)
  - ❖ Once cross sections integrated (compressed as **Sherpack** in CMS), could rerun the shower with new parameter values

Sherpa Tune

Parameters in 2.2.11 sherpa/AHADIC++/Tools/Hadronisation_Parameters.C	**Default**	**Tuned CSS**	**Tuned Dire**
STRANGE_FRACTION	0.6049	0.535	0.513
BARYON_FRACTION	1.0	1.48	1.49
DECAY_OFFSET	1.202	1.29	1.39
DECAY_EXPONENT	2.132	3.03	3.18
P_qs_by_P_qq	0.3	0.26	0.153
P_ss_by_P_qq	0.01	0.012	0.005
P_di_1_by_P_di_0	1.0	0.93	0.51
G2QQ_EXPONENT	1.08	0.60	1.02
PT_MAX	1.0	1.48	1.37
PT_MAX_FACTOR	1.0	1.34	1.48
SPLIT_EXPONENT	0.1608	0.24	0.23
SPLIT_LEADEXPONENT	1.0	1.49	1.41
SPECT_EXPONENT	1.739	1.49	1.21
SPECT_LEADEXPONENT	8	10.32	4.04



Sherpa default:
- ❖ **Sherpack** with **default** parameters
- ❖ **Default** parameters in the **configuration**

Sherpa modify cff:
- ❖ **Sherpack** with **default** parameters
- ❖ **Cluster hadronization tune** parameters in the **configuration**

Sherpa frag. tune:
- ❖ **Sherpack** with **cluster hadronization tune** parameters
- ❖ **Cluster hadronization tune** parameters in the **configuration**

Summary

CPX and **CHX** families are recommended for Run3 in CMS

- **CP5** and **CH3** tunes are the most commonly used

Ongoing studies to improve current tunes

- Intrinsic-k_T tune: fix the discrepancy between the CP5 tune and data in the low p_T DY spectrum
- New tune sets to improve the discrepancies shown (such as: DPS variables, jet substructure, …)

New opportunities

- Common automated workflow development for tunning