PYTHIA 8 Tune Task Force Update

Matthew Kelsey
Wayne State University

Outline

1) **Task force logistics**
2) **Tuning methodology**
3) **Mid-rapidity tune results**
4) **Comparisons to forward rapidity pions**
5) **Paper plans**

Task Force Logistics

Formation: **Nov. 2020**

Charge:

Study PYTHIA8 event generator to attempt to determine a tune that better matches available RHIC data. Produce a writeup documenting these studies, results, and a "STAR tune" set of parameters. An initial report is expected in 3-6 months, and the final document in 6-12 months.

Addendum: **Investigate possible (additional) tune for forward-rapidity physics**

Task Force Logistics (cont.)

Chair: Matthew Kesley

Members: Raghav Kunnawalkam Elayavalli, Hanseul Oh, Yuanjing Ji, Jan Vanek, Qian Yang, Zilong Chang, Renee Fatemi, Manny Rosales Aguilar, Isaac Mooney, Veronica Verkest

Ex Officio: Jason Webb

Mailing list: star-tf-tunepy-l@lists.bnl.gov

Mattermost channel: https://chat.sdcc.bnl.gov/star/channels/pythia-8-tuning-task-force

Drupal page: https://drupal.star.bnl.gov/STAR/pwg/common/task-forces/tuning-pythia8

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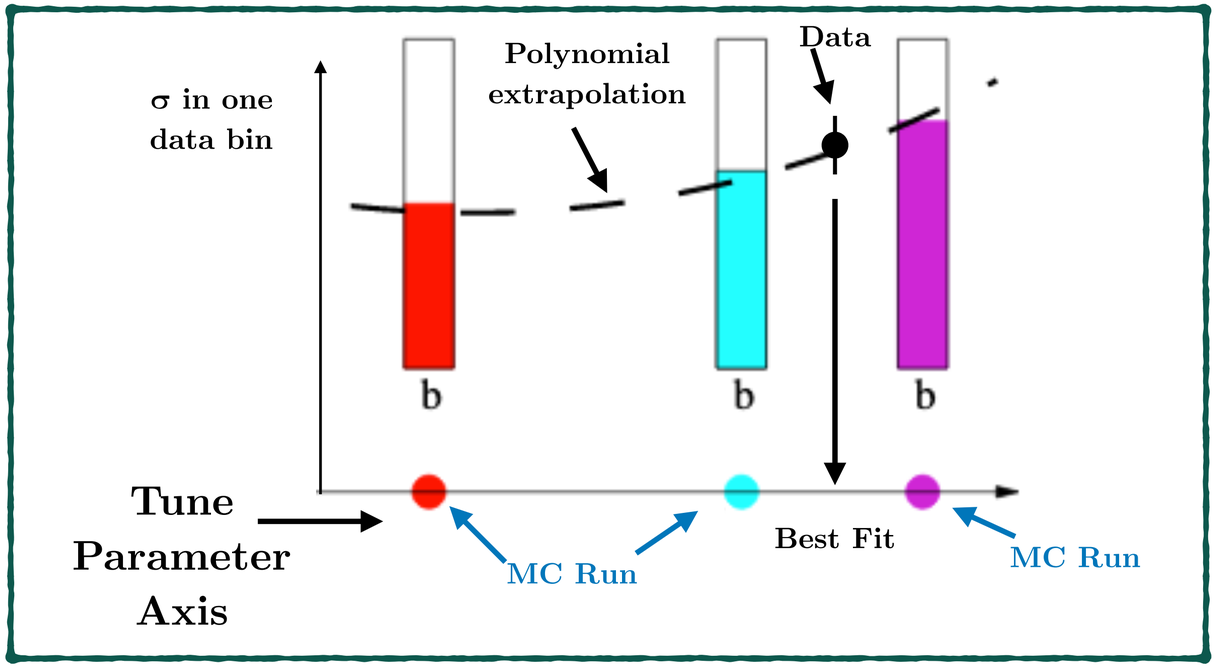
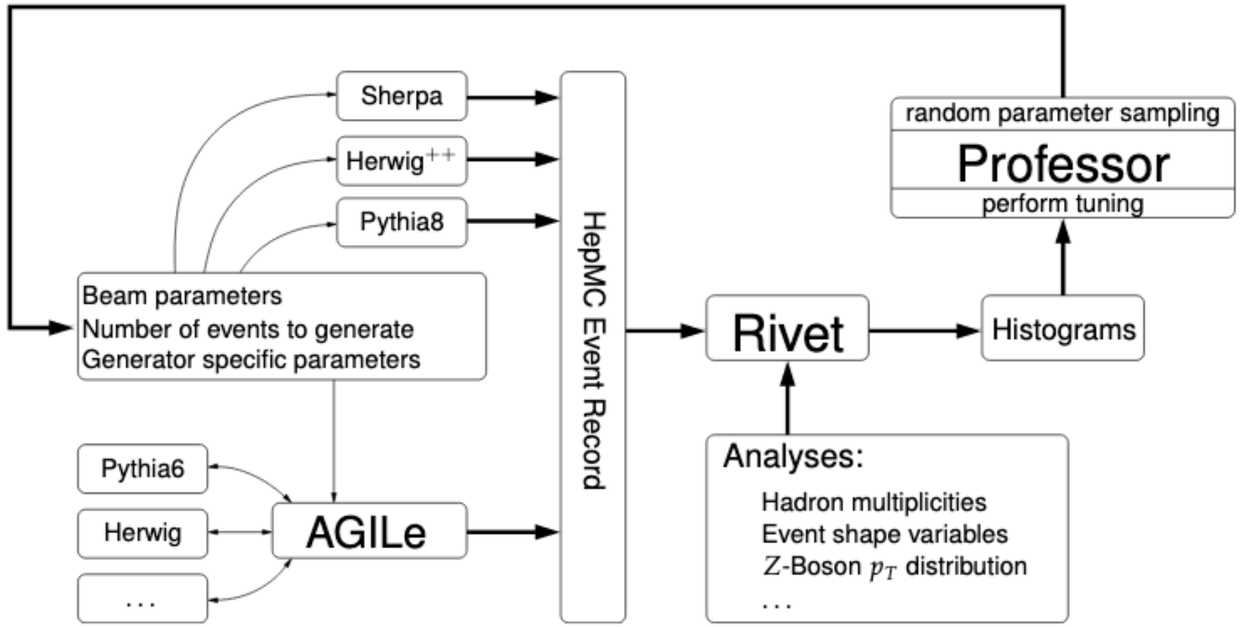
Tuning Strategy

Parametrization-based tuning methodology: *Professor* toolkit (professor.hepforge.org)

- Polynomial parameterization of MC variation response + χ^2 min. w.r.t. data





$$\mathrm{MC}_b(\boldsymbol{p}) \approx f^{(b)}(\boldsymbol{p}) = \alpha_0^{(b)} + \sum_i \beta_i^{(b)}\, p'_i + \sum_{i \le j} \gamma_{ij}^{(b)}\, p'_i\, p'_j$$

MC response in one data bin b

$p \equiv$ tunable parameter space

$$\chi^2(\boldsymbol{p}) = \sum_{\mathcal{O}} w_{\mathcal{O}} \sum_{b \in \mathcal{O}} \frac{(f^{(b)}(\boldsymbol{p}) - \mathcal{R}_b)^2}{\Delta_b^2}$$

Professor+PYTHIA6 Tune: https://doi.org/10.1140/epjc/s10052-009-1196-7

CMS PYTHIA6,8 Herwig++ Tune: https://doi.org/10.1140/epjc/s10052-016-3988-x

CMS Herwig 7 Tune: arXiv:2011.03422

Tuning Parameters and Observables

Starting point is PYTHIA 8.303 with prepackaged Monash tune

Updated PDFs (NNPDF 3.1)

Reference energy switched to 200 GeV

Proton shape and color reconnection length also optimized for low energy collisions

TABLE I. PYTHIA 8 settings and tuning parameters.

Setting	Default	New
PDF:pSet	13	17
MultipartonInteractions:ecmRef	7 TeV	200 GeV
MultipartonInteractions:bprofile	3	2
Tuning Parameter	**Default**	**Range**
MultipartonInteractions:pT0Ref	2.28 GeV	0.5-2.5 GeV
MultipartonInteractions:ecmPow	0.215	0.0-0.25
MultipartonInteractions:coreRadius	0.4	0.1-1.0
MultipartonInteractions:coreFraction	0.5	0.0-1.0
ColourReconnection:range	1.8	1.0-9.0

Provided by task force (& not limited to)

Included in RIVET

TABLE II. Mid-rapidity data used in the tuning procedure.

Experiment	$\sqrt{s}$ (GeV)	Observable	Reference
STAR	200	$\pi^{\pm}$ cross sections vs. p_T	[23]
PHENIX	200	Di-muon pairs from Drell-Yan vs. di-muon p_T	[24]
STAR	200	Average charged particle multiplicities and p_T vs. leading jet p_T in the forward, transverse, and away regions	[15]
CDF	300, 900, 1960	Charge particle density and $\sum p_T$ vs. leading hadron p_T in transverse region	[17]
STAR	200	SoftDrop groomed jet sub-structure (z_g and R_g)	[25]
STAR	200	Inclusive and groomed jet mass	[26]

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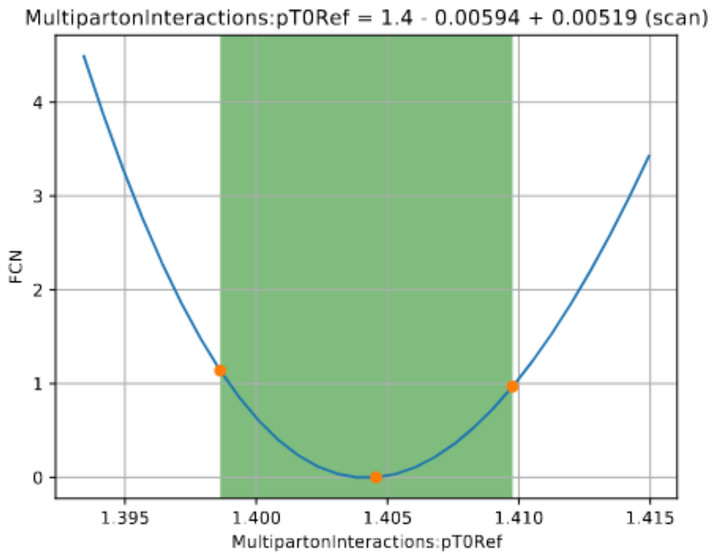
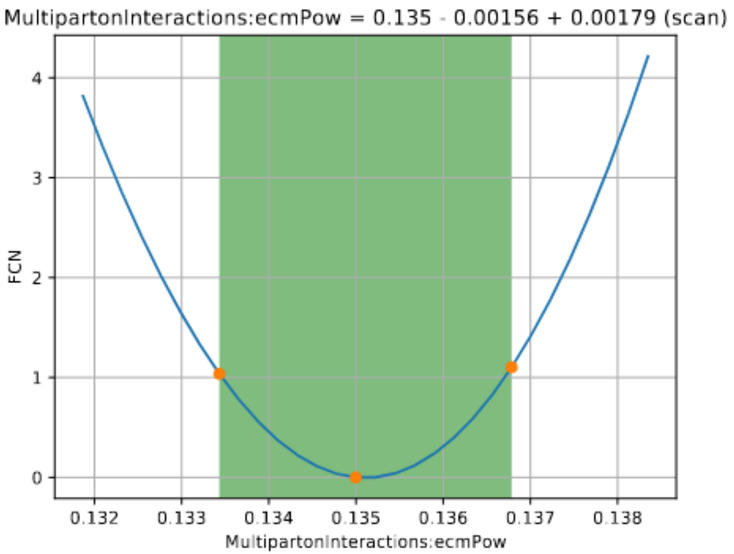
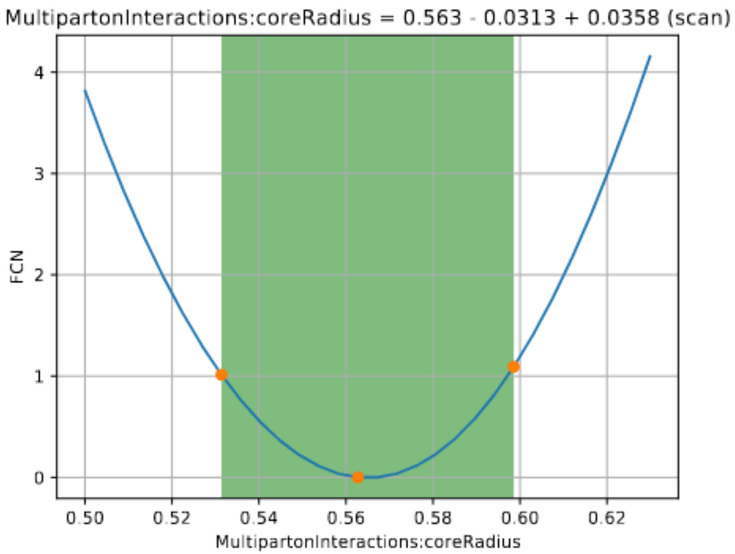
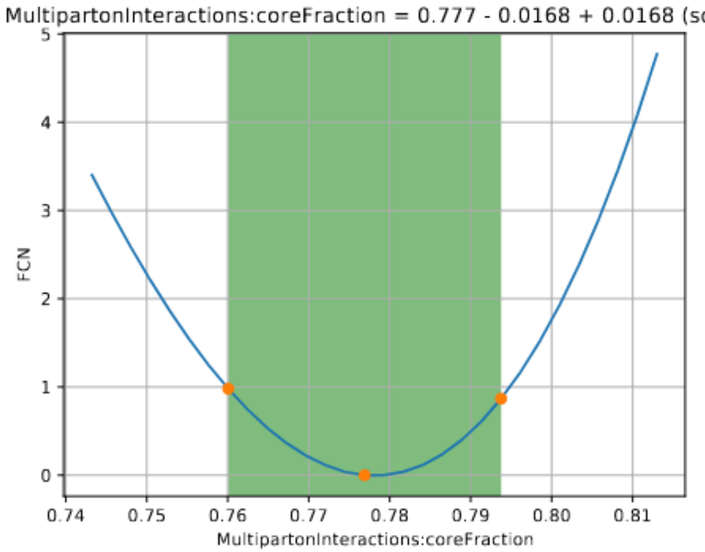
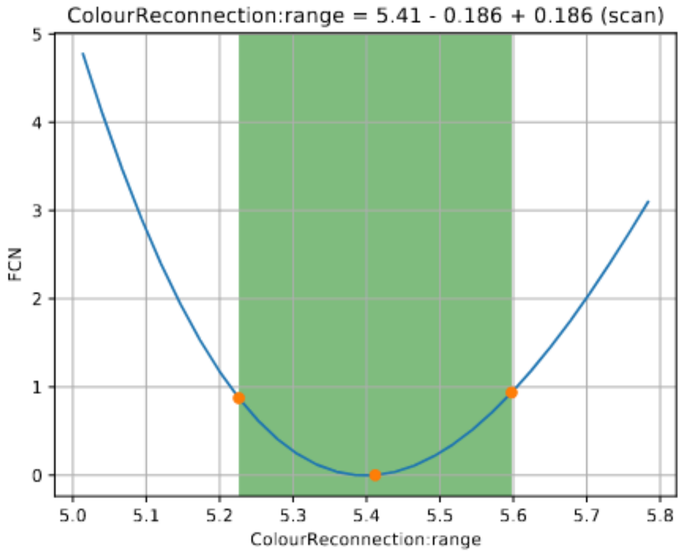
Final Tune Results











Global
$\chi^2/\text{n.d.f.} = 1.2$

Final Tune Results

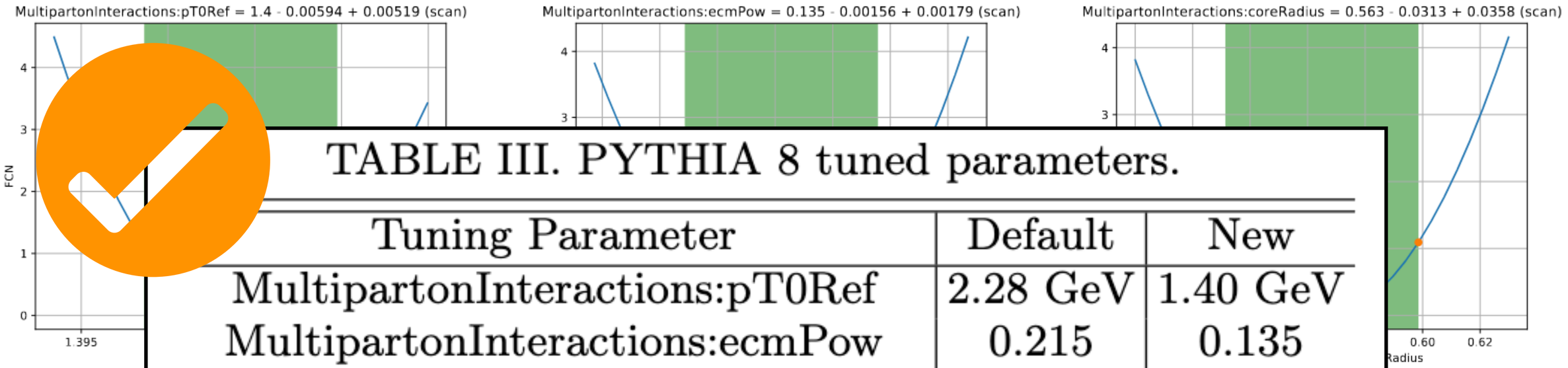
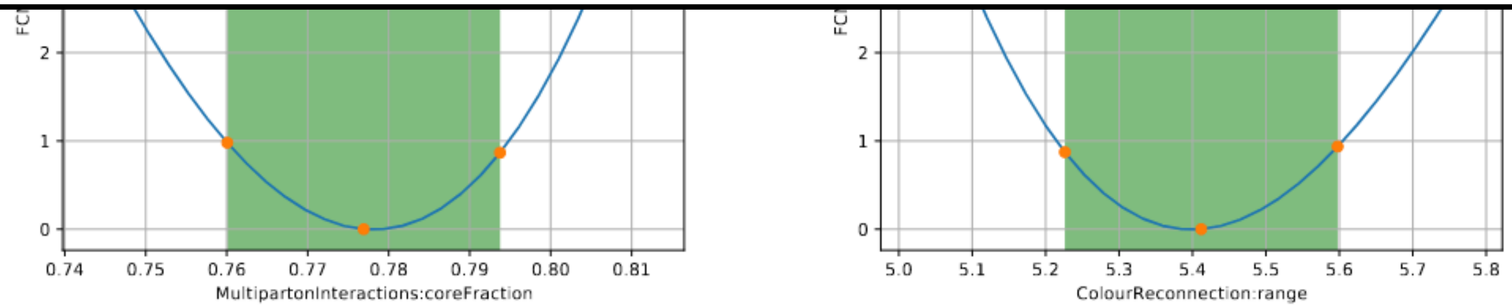


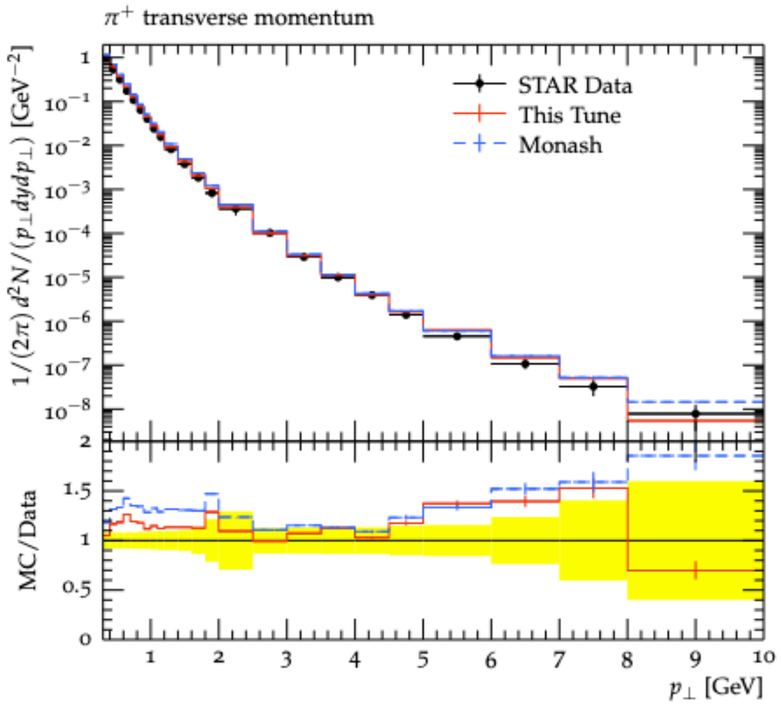
TABLE III. PYTHIA 8 tuned parameters.

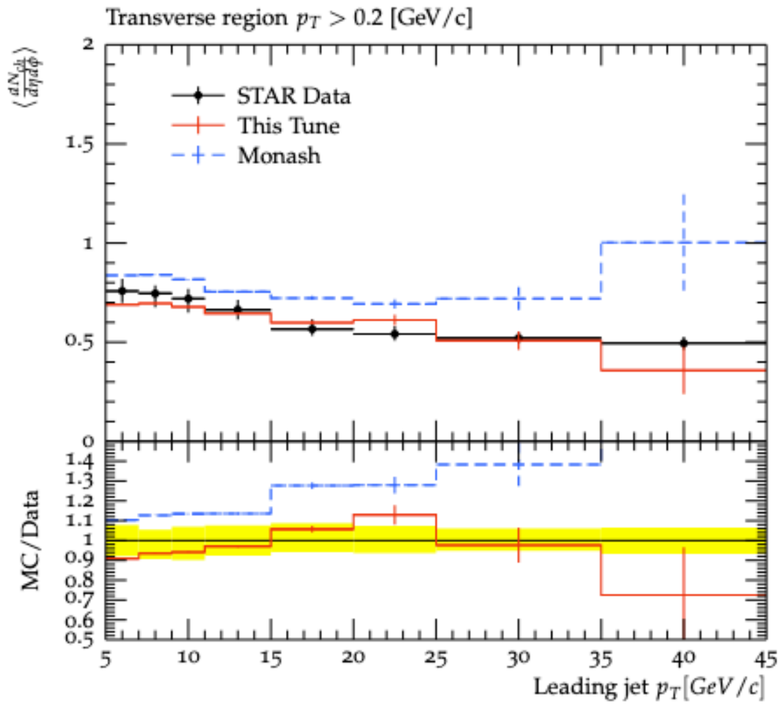
Tuning Parameter	Default	New
MultipartonInteractions:pT0Ref	2.28 GeV	1.40 GeV
MultipartonInteractions:ecmPow	0.215	0.135
MultipartonInteractions:coreRadius	0.4	0.56
MultipartonInteractions:coreFraction	0.5	0.78
ColourReconnection:range	1.8	5.4

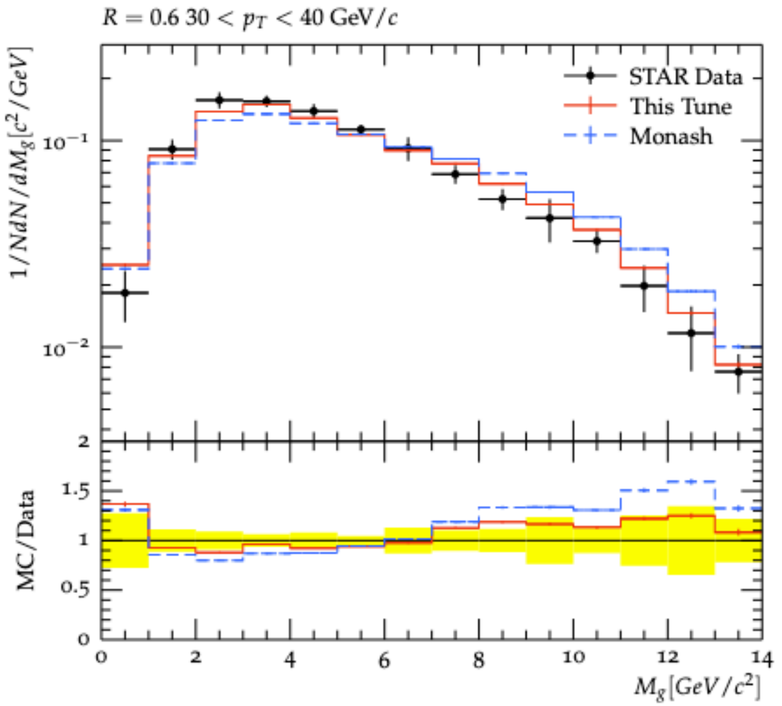


Global
χ^2 / n.d.f. = 1.2

New PYTHIA 8 Predictions



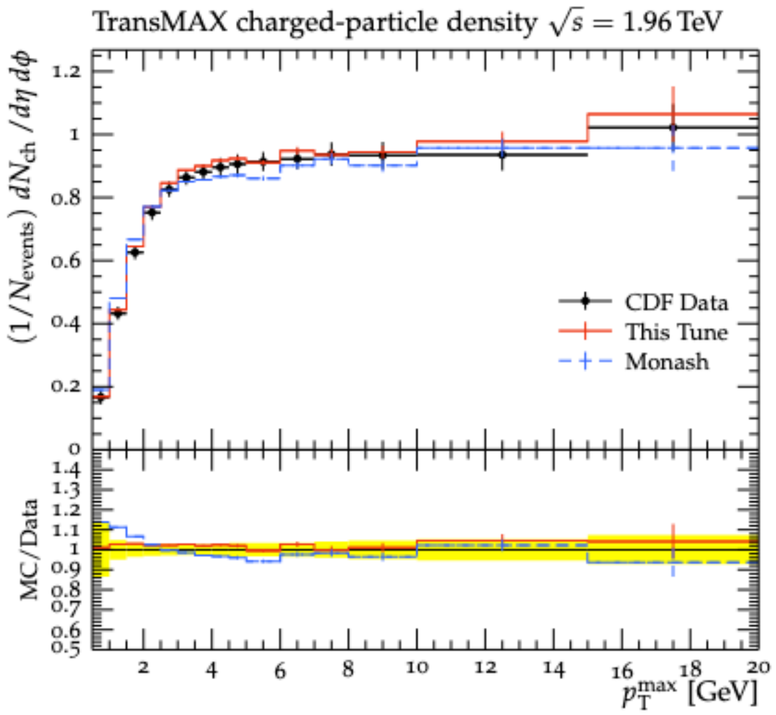


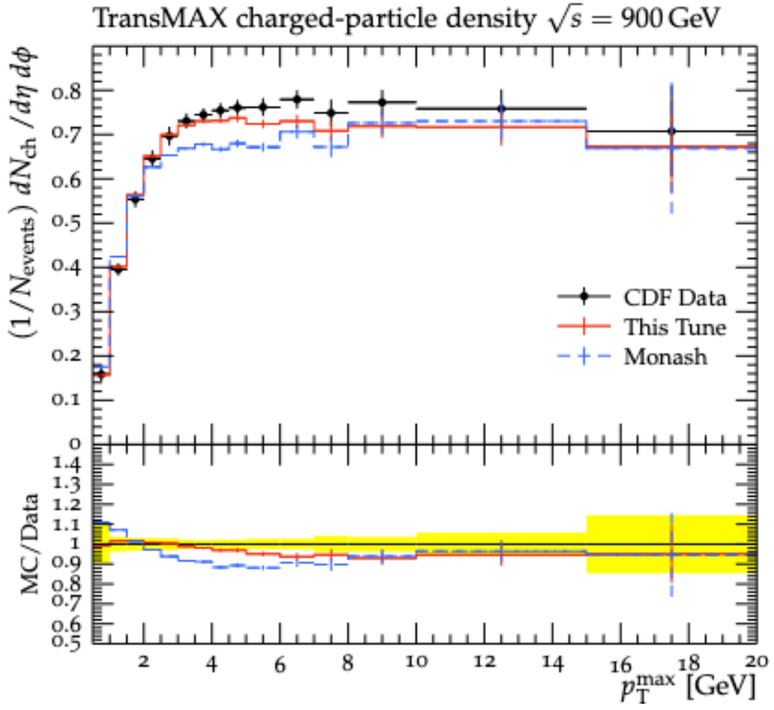


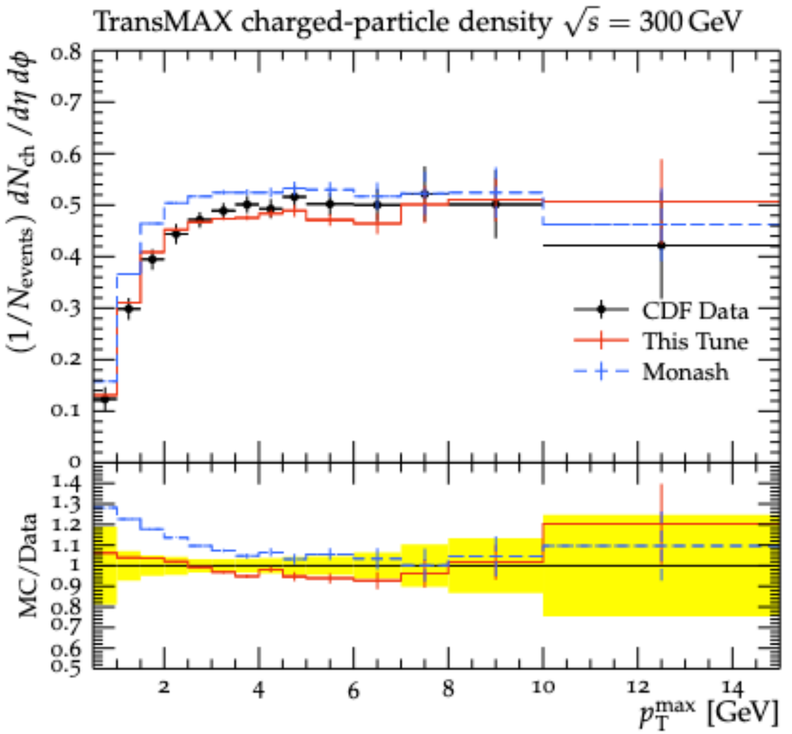
Significant improvement of mid-rapidity pion spectra and underlying event (UE) @ 200 GeV

Additional improvements in jet sub-structure and Drell-Yan (backup)

Energy Dependence: CDF UE 300-1960 GeV







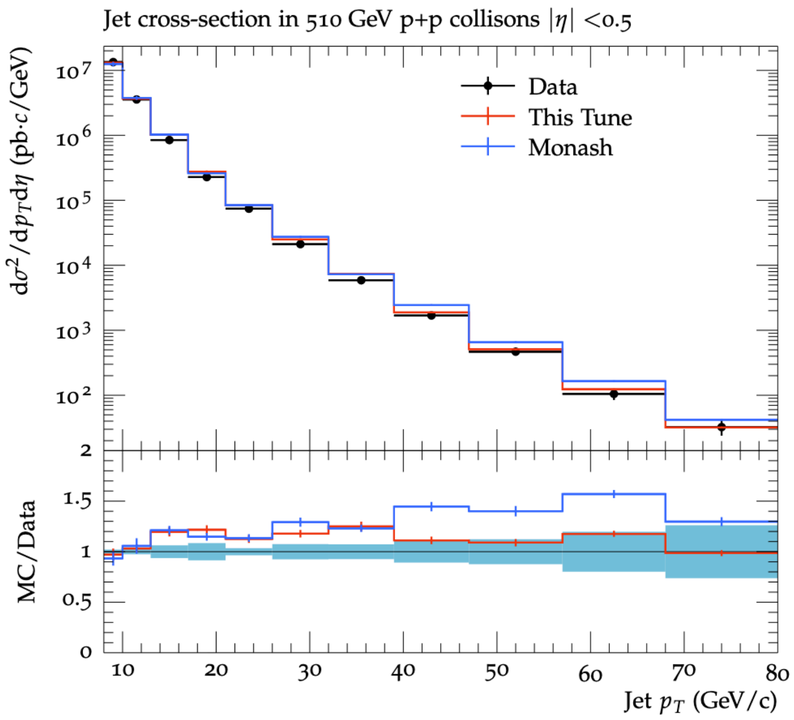
Representative plots at each energy; Similar comparisons for p_T sum and transMIN observable

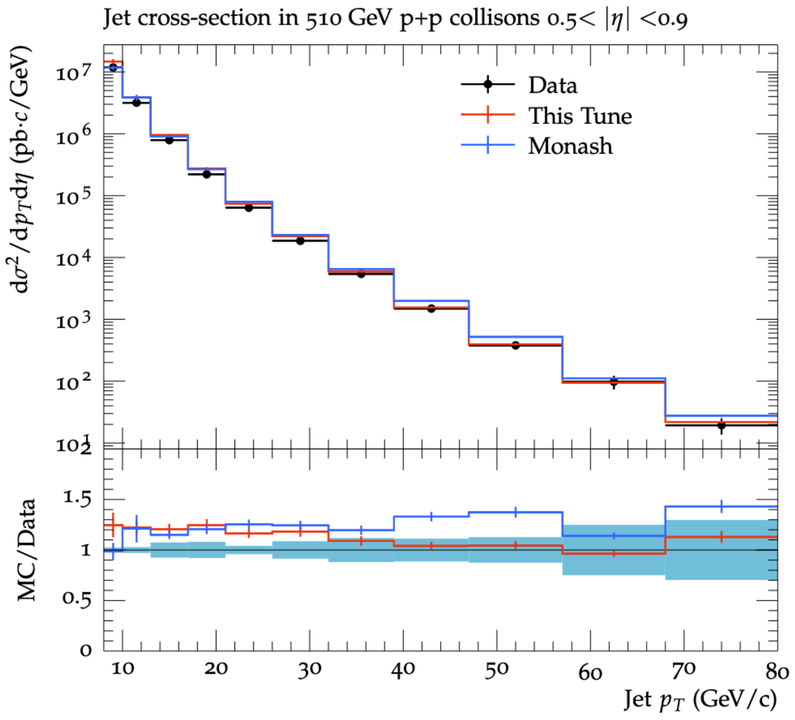
Agreement with data valid across all center-of-mass energies up to 1.96 TeV

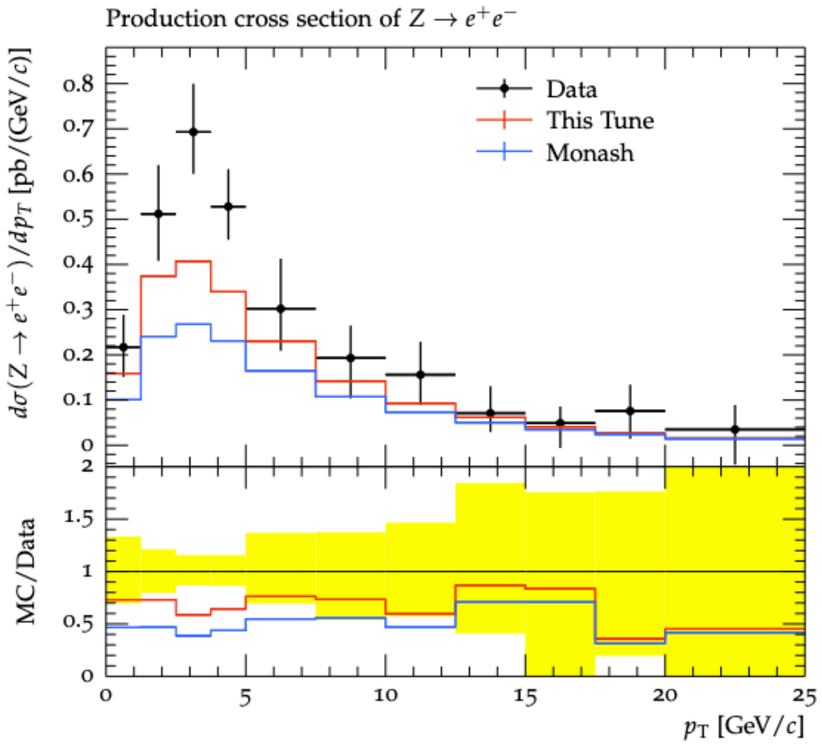
Energy Dependence: $\sqrt{s} = 510$ GeV

https://drupal.star.bnl.gov/STAR/blog/zchang/run12-pp510-jet-cross-seciton-preliminary-plot

https://drupal.star.bnl.gov/STAR/files/Fazio_DNP_Fall_OCT2020_v6.pdf



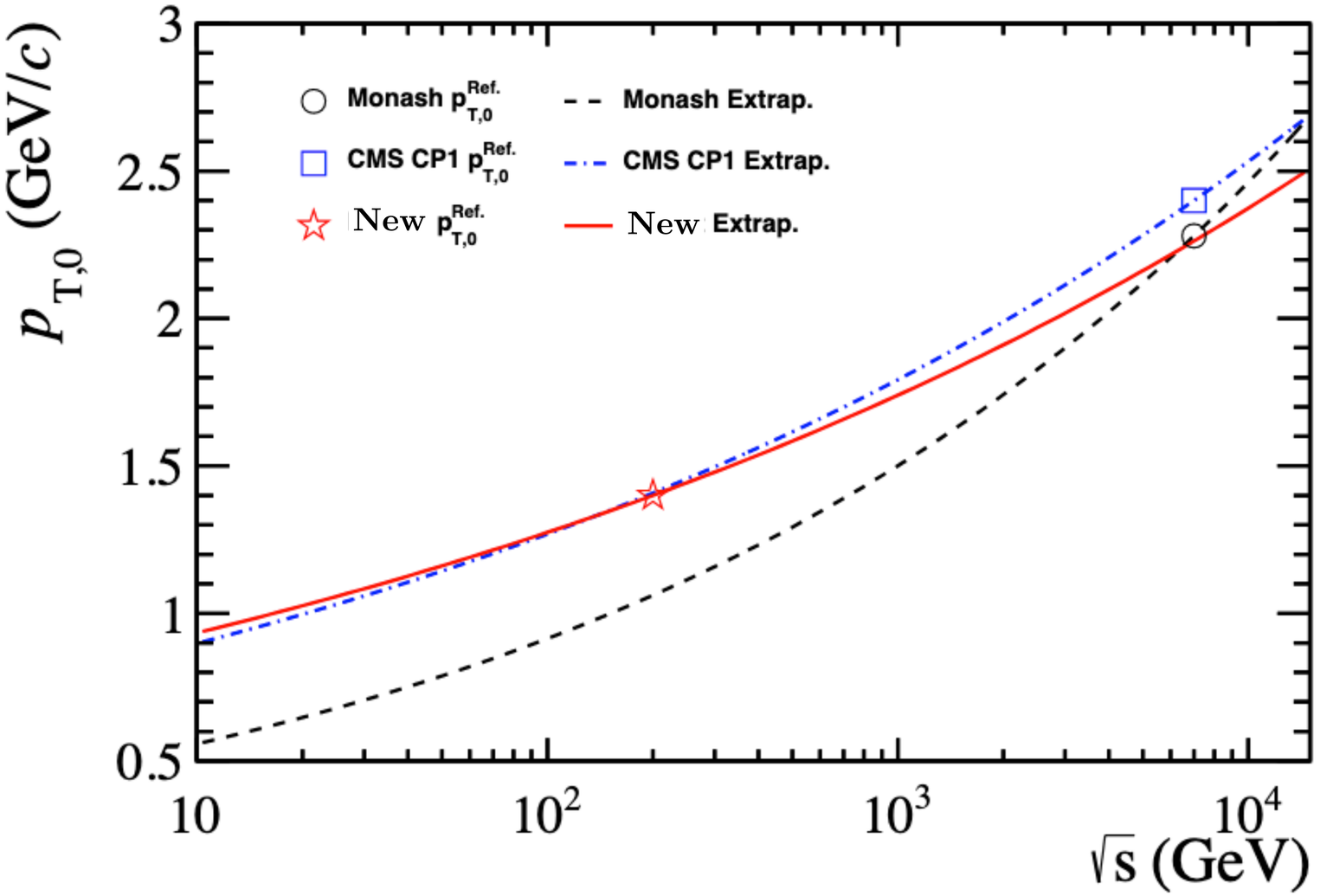




Preliminary data therefore not used in the tune

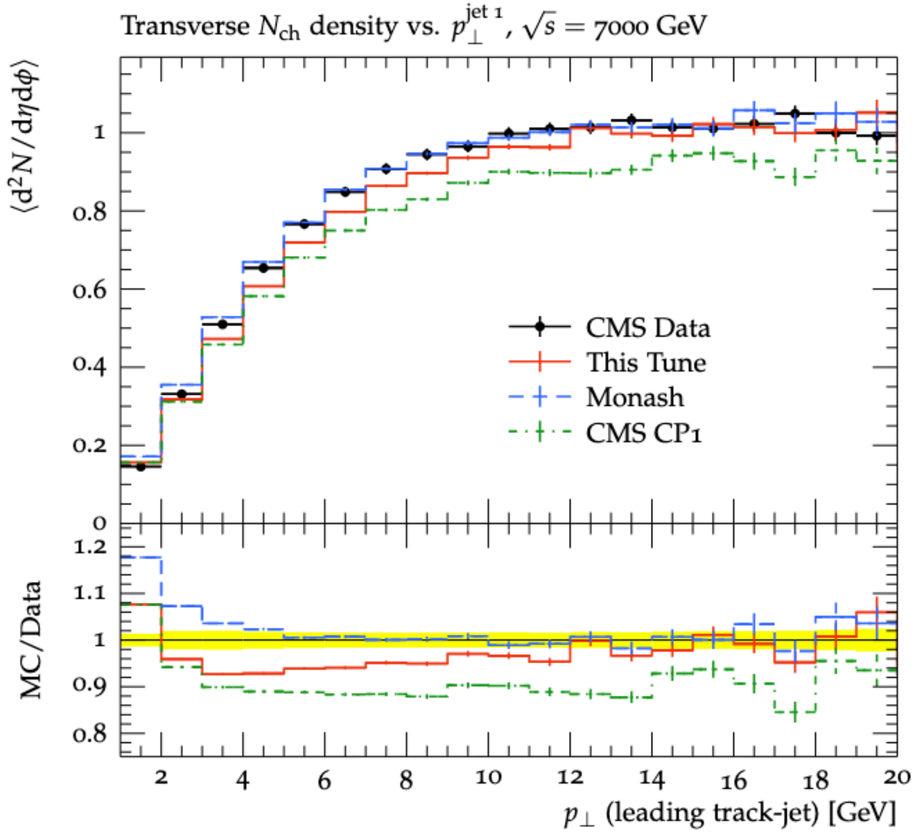
Improvements largely driven by new proton PDFs

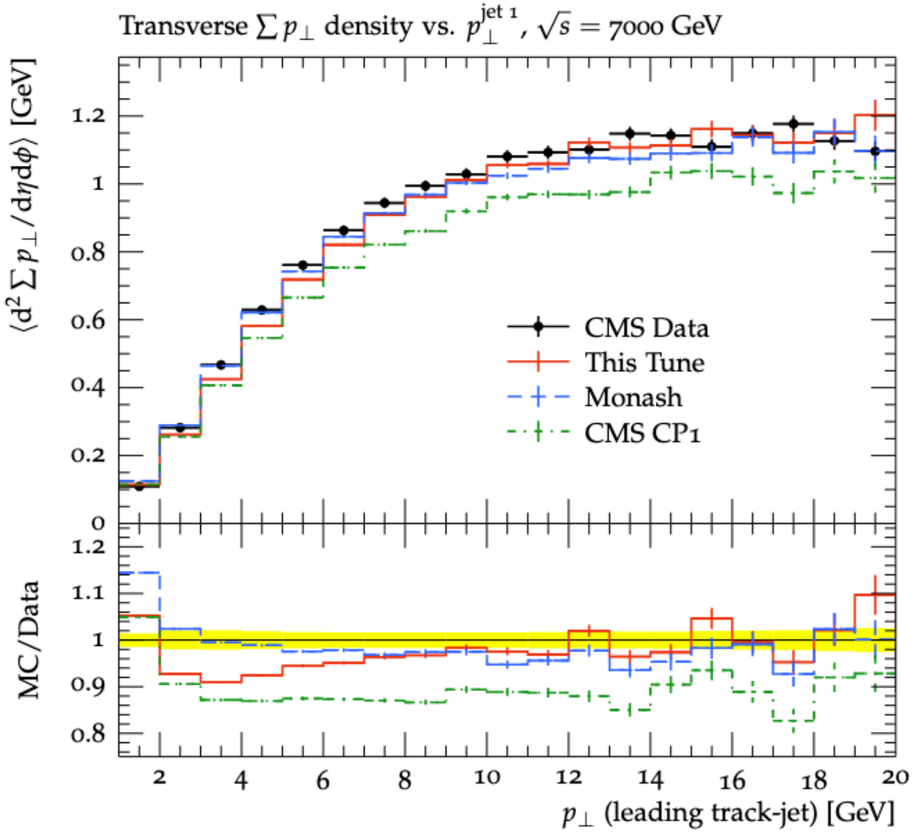
Comparisons at LHC Energies



CMS CP tunes follow similar strategy as this exercise (European Physical Journal C 80, 4 (2020))

Comparisons at LHC Energies cont.





CMS UE measurements at 7 and 13 TeV readily available in RIVET

Comparable to data Monash tune at high p_T; Deviations at low p_T

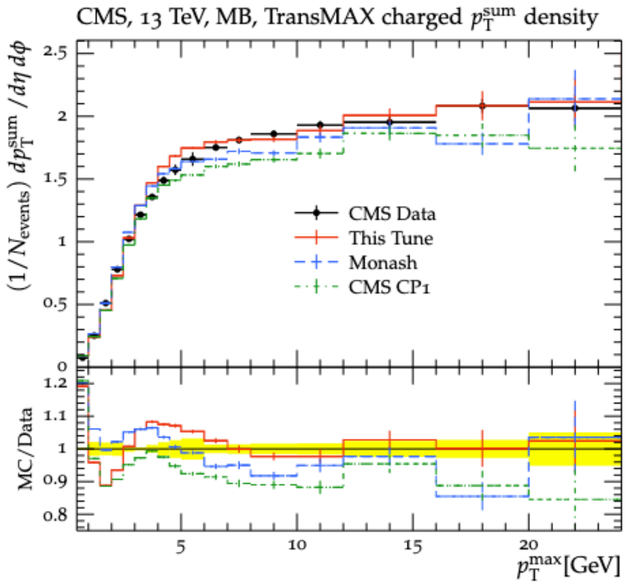
CMS 13 TeV: CDS CMS-PAS-FSQ-15-007

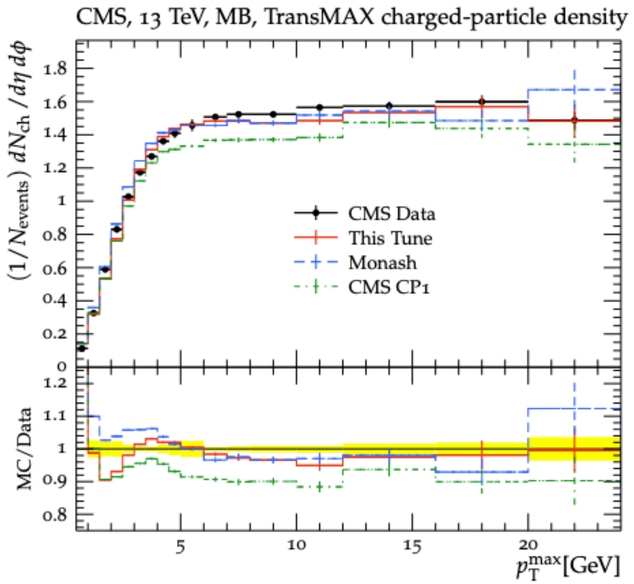
CMS 7 TeV: Journal of High Energy Physics 2011, 109 (2011)

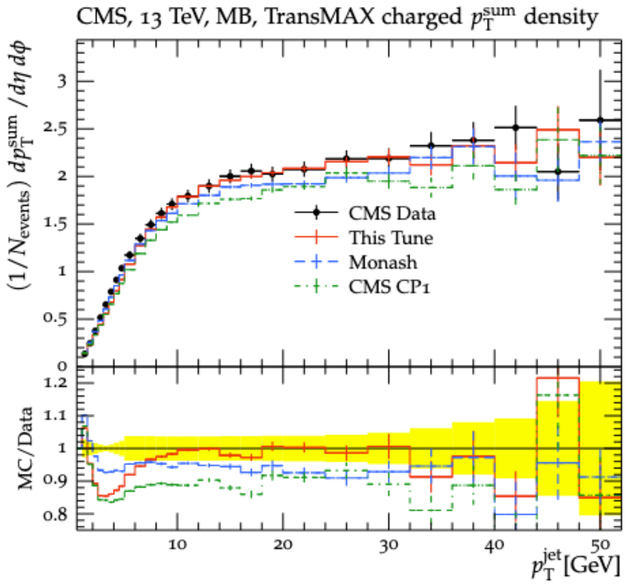
Comparisons at LHC Energies cont.

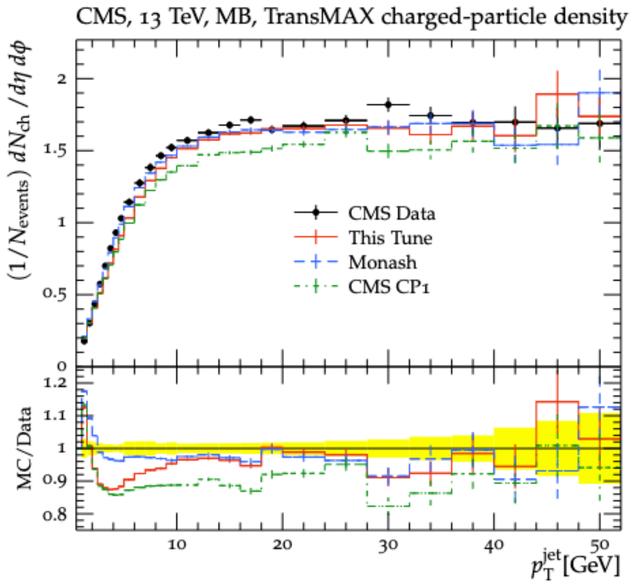
Comparable or better than Monash tune at high p_T; Deviations at low p_T

- Driven by proton shape/color reconnection optimized for low energies



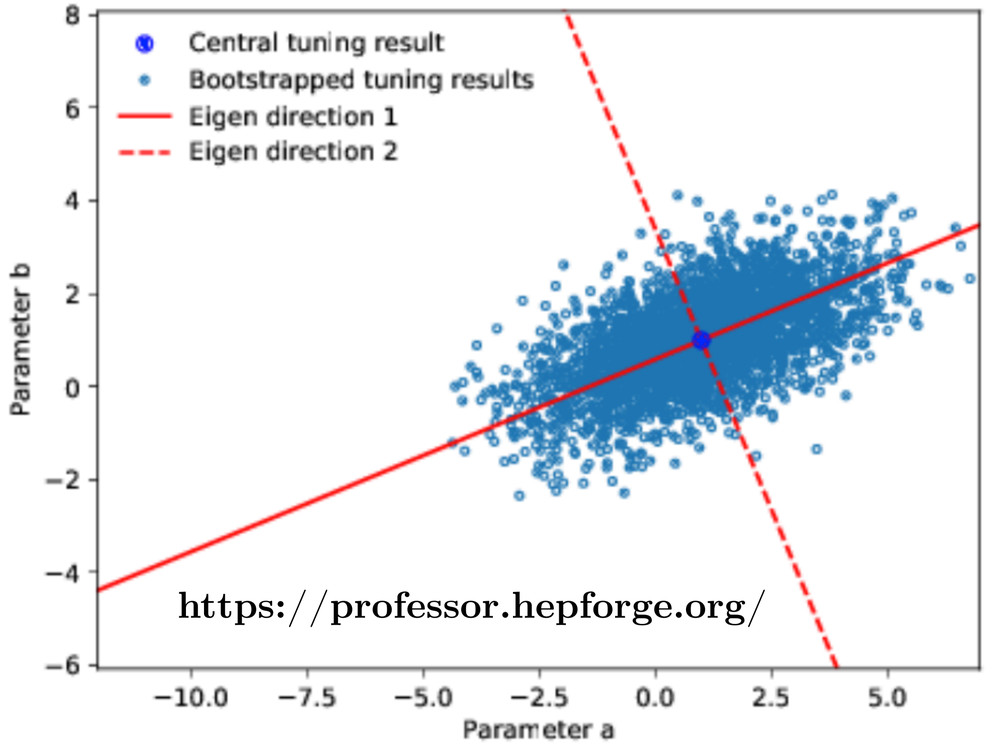


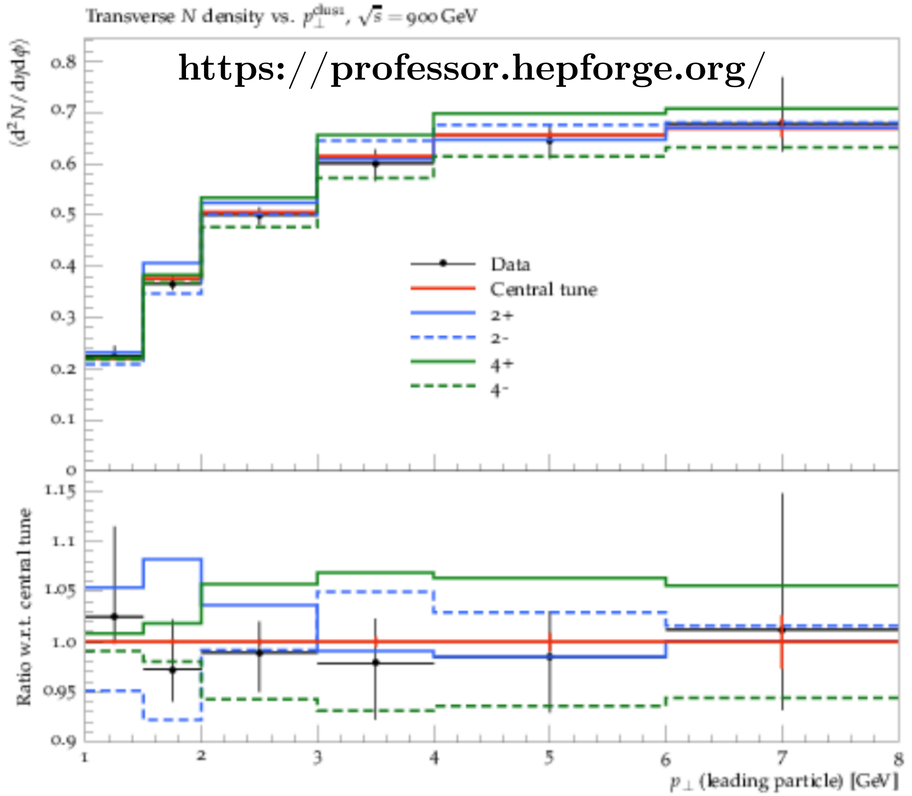




CMS 13 TeV: CDS CMS-PAS-FSQ-15-007
CMS 7 TeV: Journal of High Energy Physics 2011, 109 (2011)

Monte Carlo Errors





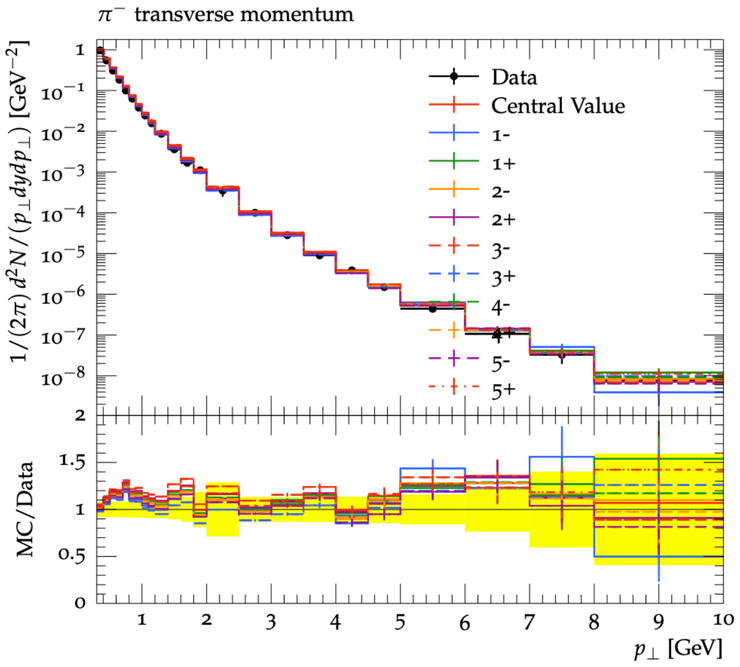
Functionality within Professor tool-kit to provide systematic errors on tune-ables as Minuit errors are very low ("Eigentunes")

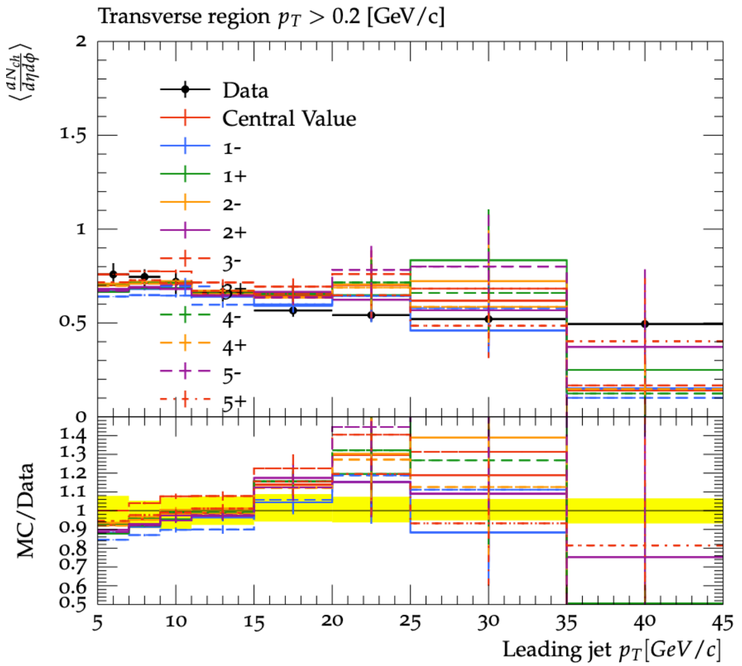
Diagonalize error matrix at best fit values and shift along principle axis for fixed tolerance $\Delta\chi^2$ (=n.d.f./2)

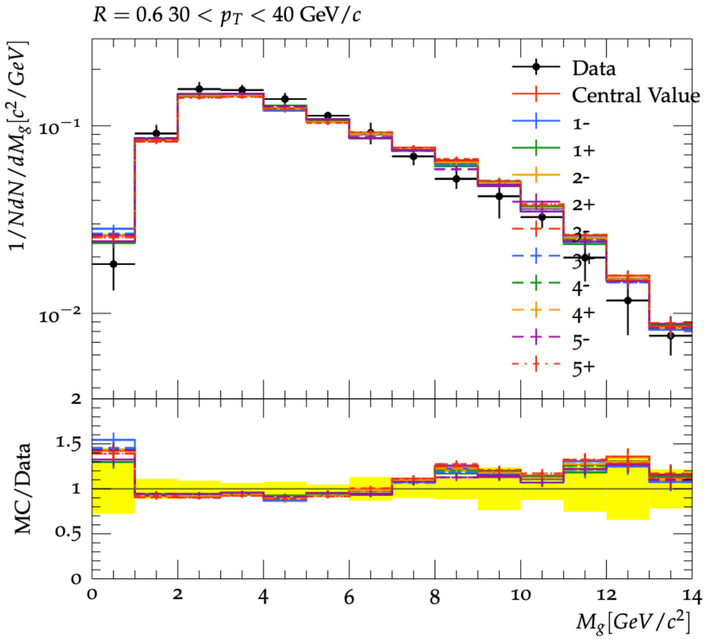
Eigentunes for Systematic Studies

TABLE IV. PYTHIA 8 tune parameter variations for each eigentune.

Tuning Parameter	1+	1-	2+	2-	3+	3-	4+	4-	5+	5-
MultipartonInteractions:pT0Ref (GeV)	1.37	1.43	1.38	1.42	1.44	1.37	1.41	1.40	1.40	1.41
MultipartonInteractions:ecmPow	0.132	0.138	0.135	0.135	0.119	0.150	0.145	0.126	0.148	0.125
MultipartonInteractions:coreRadius	0.74	0.41	0.77	0.41	0.57	0.56	0.57	0.56	0.51	0.60
MultipartonInteractions:coreFraction	0.84	0.72	0.72	0.82	0.78	0.78	0.78	0.78	0.60	0.90
ColourReconnection:range	7.50	3.61	5.38	5.41	5.40	5.40	5.40	5.40	5.41	5.40







For example analysts can do full eigentune variation or pick largest enveloping eigentunes (i.e., 3± for 200 GeV)

All data/MC comparisons available on task force Drupal page

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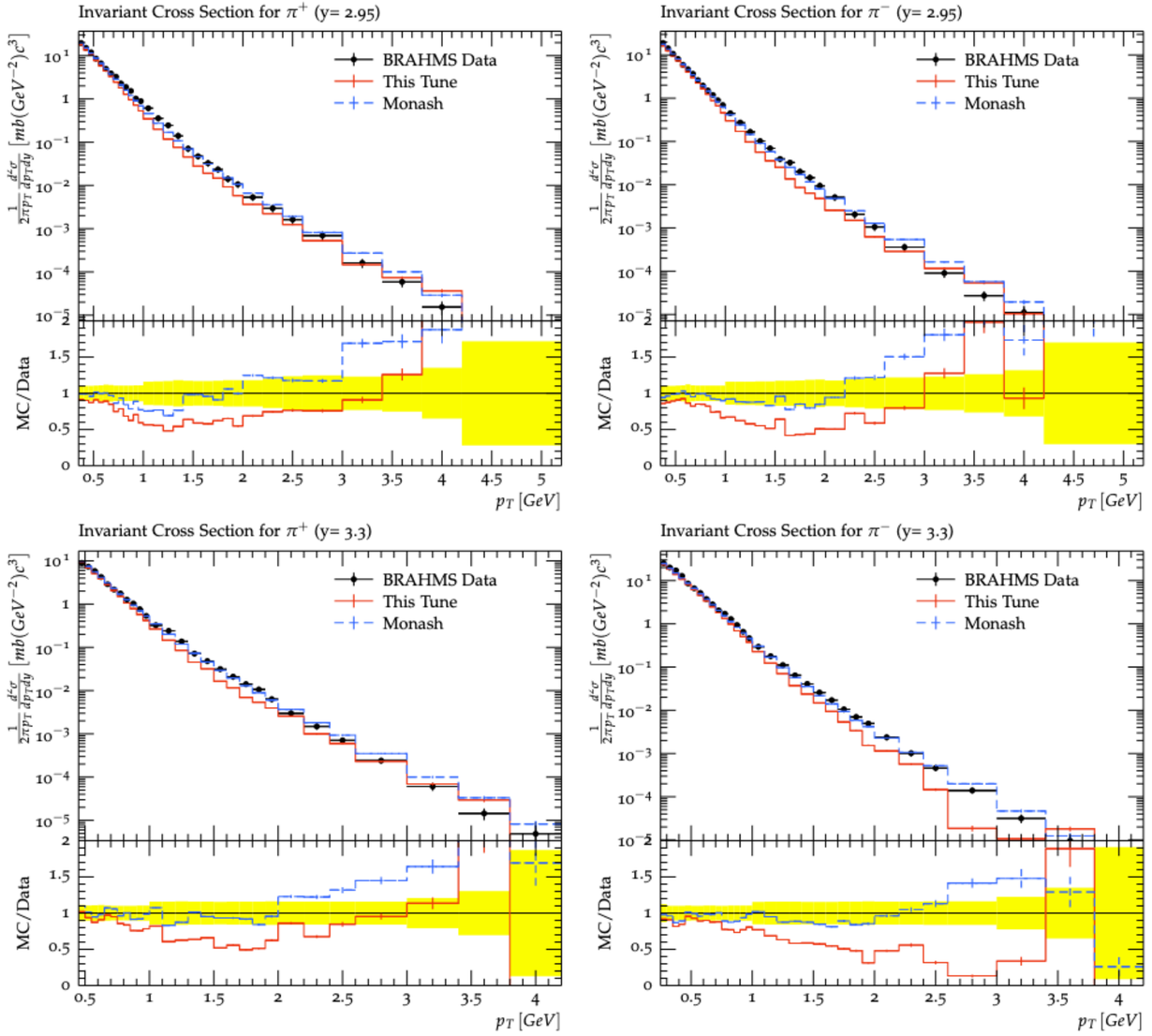
Forward Rapidity Comparisons

Both Monash and new tune can't describe forward pion spectra from BRAHMS

- New tune does worse than Monash

Simultaneous tune with mid-rapidity and larger tune-able phase space (ISR) unsuccessful



Forward Rapidity Comparisons

Both Monash and new tune can't describe forward pion spectra from BRAHMS

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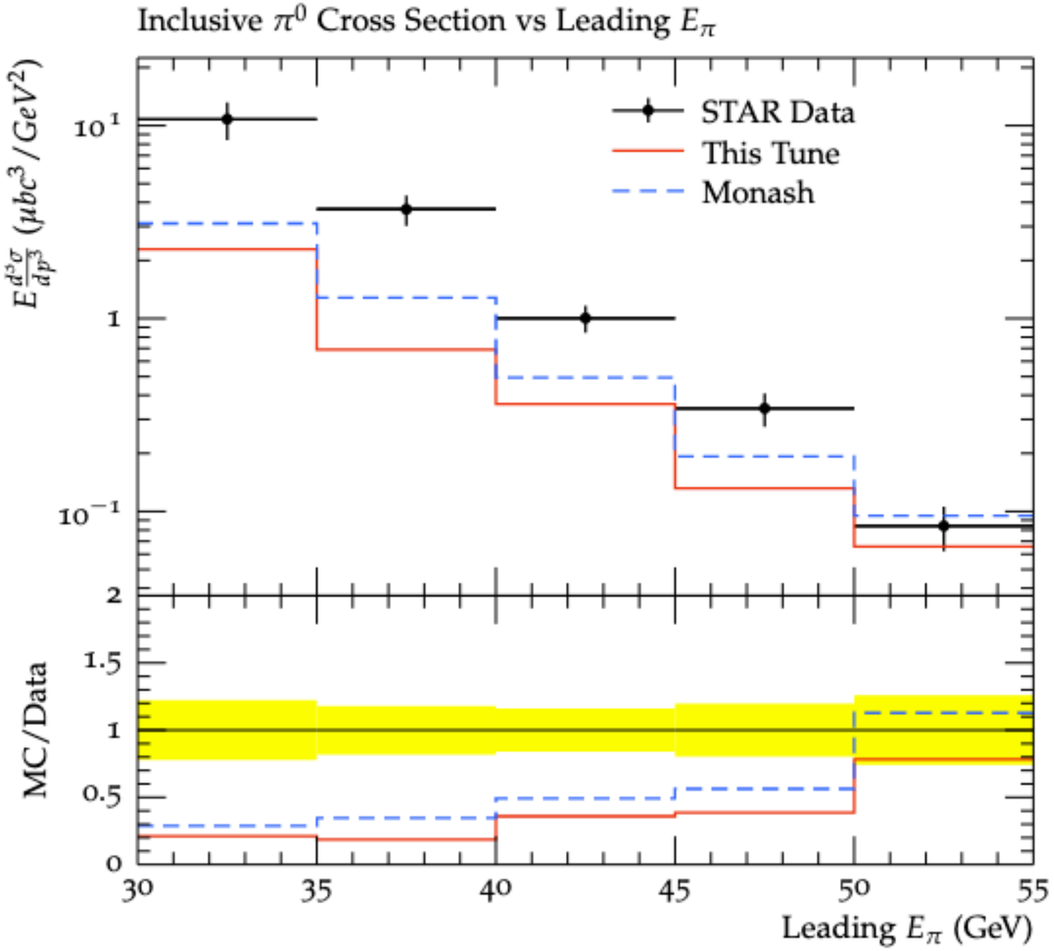
Simultaneous tune with mid-rapidity and larger tune-able phase space (ISR) unsuccessful

Additional check with STAR forward π^0 confirms disagreement

Gaining interest with PYTHIA collaborators!



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Proposal for Publication

Target journal: PRD

Timeline: 2nd week of Oct.

Abstract submitted
to MPI@LHC

A PYTHIA 8 Underlying Event Tune For RHIC Energies

Manny Rosales Aguilar,[1] Zilong Chang,[2] Raghav Kunnawalkam Elayavalli,[3,4] Renee Fatemi,[1] Yuanjing Ji,[5] Dmitry Kalinkin,[6] Matthew Kelsey,[7,*] Isaac Mooney,[7] and Veronica Verkest[7]

[1] *University of Kentucky, Lexington, Kentucky 40506, USA*
[2] *Brookhaven National Laboratory, Upton, New York 11973, USA*
[3] *Yale University, New Haven, CT 06517, USA*
[4] *Brookhaven National Laboratory, Upton, NY 11973, USA*
[5] *Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*
[6] *Indiana University, Bloomington, Indiana 47408, USA*
[7] *Wayne State University, Detroit, MI 48202, USA*

(Dated: September 21, 2021)

We report an underlying event tune for the PYTHIA 8 Monte Carlo event generator that is applicable for hadron collisions primarily at $\sqrt{s}$ ranges available at the Relativistic Heavy-Ion Collider (RHIC). We compare our new PYTHIA 8 tuned predictions to mid-rapidity inclusive $\pi^{\pm}$ spectra, jet sub-structure, Drell-Yan production, and underlying event measurements from RHIC and the Tevatron, as well as underlying event data from the Large Hadron Collider. With respect to the default PYTHIA 8 Monash Tune, the new 'Detroit' tune shows significant improvements in the description of the experimental data. Additionally, we explore the validity of PYTHIA 8 predictions for forward rapidity π in $\sqrt{s} = 200$ GeV collisions, where neither tune is able to sufficiently describe the data. We advocate for the new tune to be used at current and future RHIC experiments and discuss future tuning exercises at lower center of mass energies, where forward/backward kinematics are essential at the upcoming Electron-Ion collider.

Following similar naming convention used for Monash, Perugia tunes - The "Detroit" tune

Propose to follow same procedure as isobar methods paper

Summary

Mid-rapidity tune complete with errors for any potential systematic studies; Significant improvement in the description of data from 200-1960 GeV

Forward spectra data-MC disagreement persistent even after expanding tuning phase space

Proposed paper for PRD; Abstract submitted to MPI@LHC

Outlook

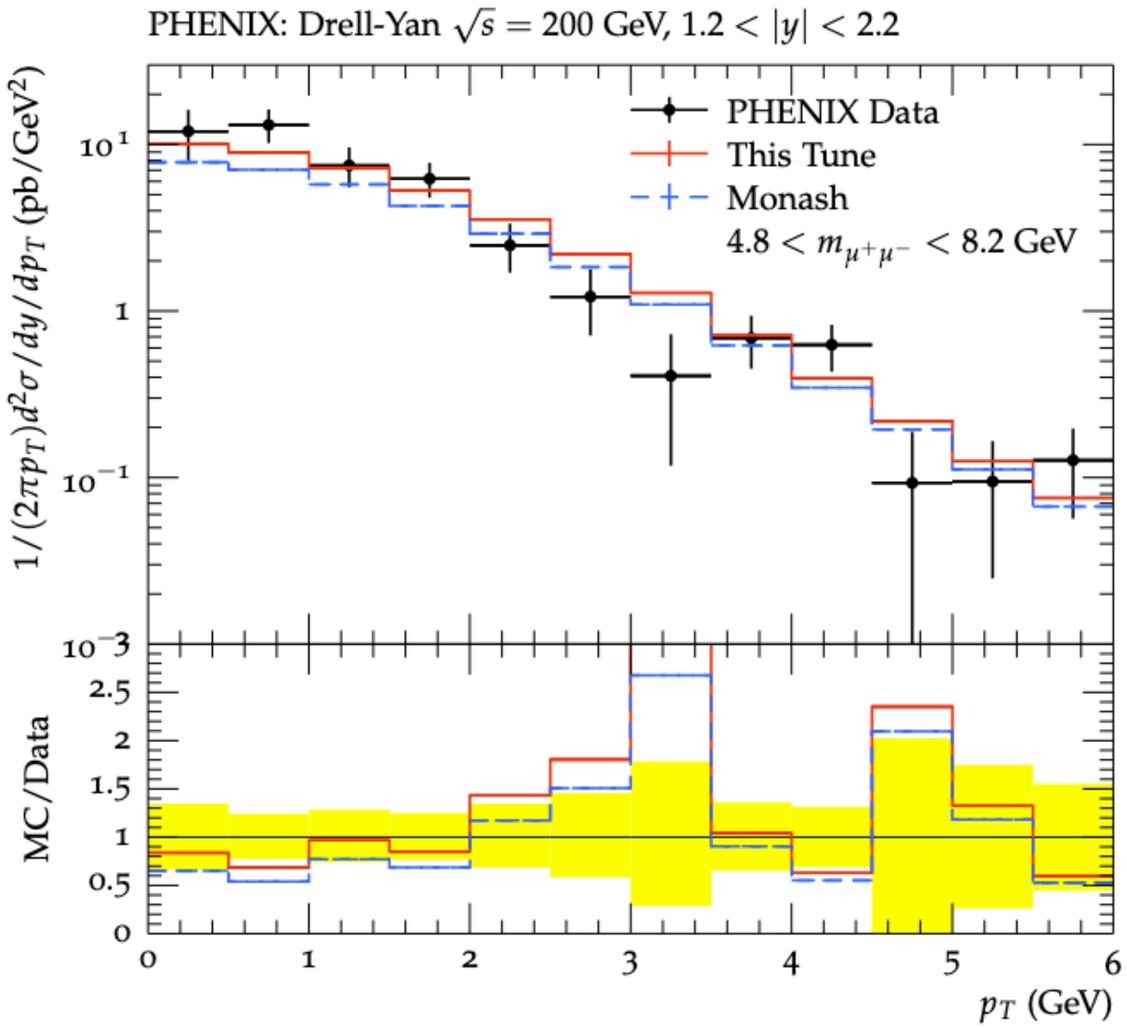
Discrepancy at forward rapidities attracting interest from PYTHIA collaborators; Will release RIVET analyses before paper submission

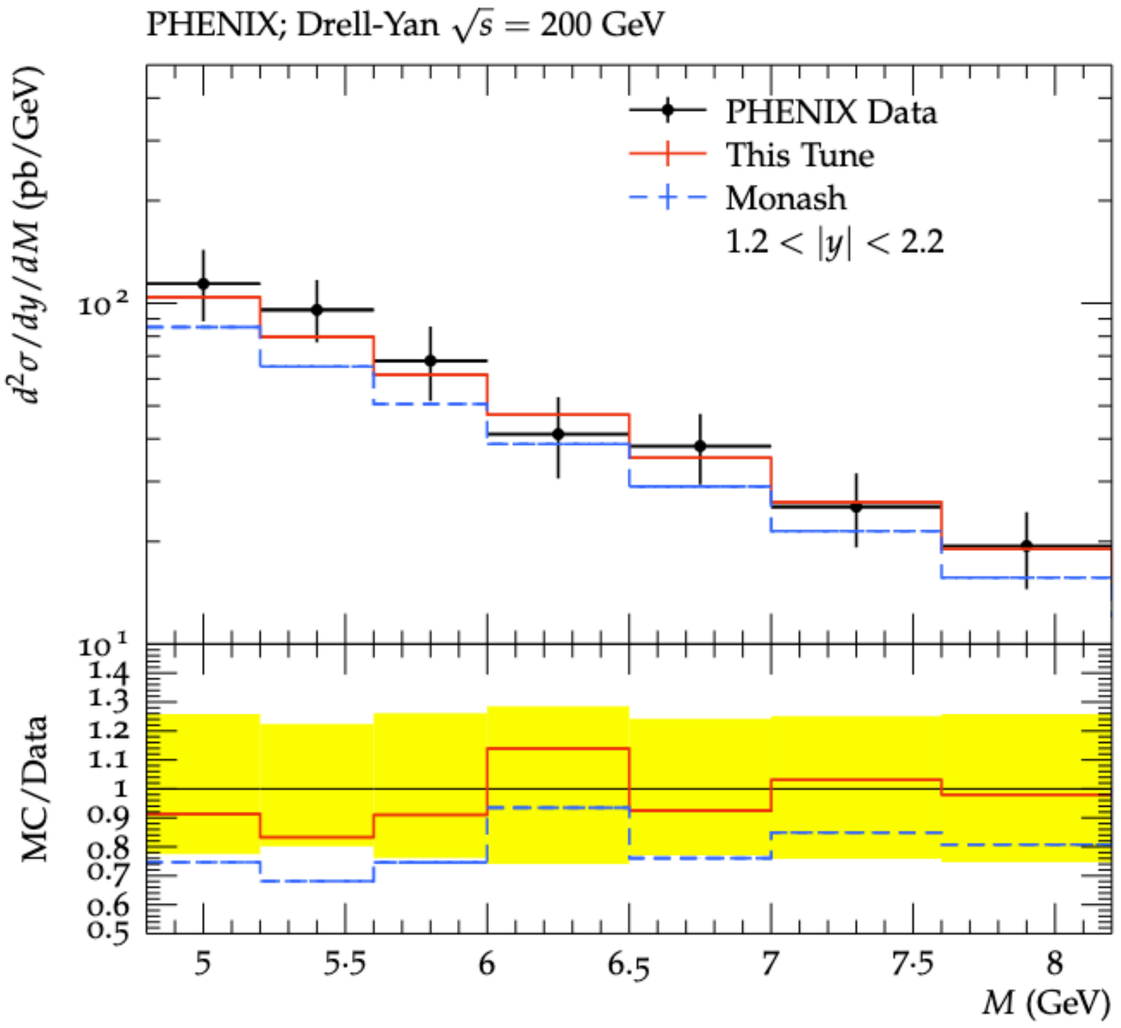
- Potential for sequential tuning with feedback from PYTHIA experts

Professor tuning infrastructure (+ needed MC generation manager) readily available for running on RCF; Anyone from STAR can run any PYTHIA 8 study

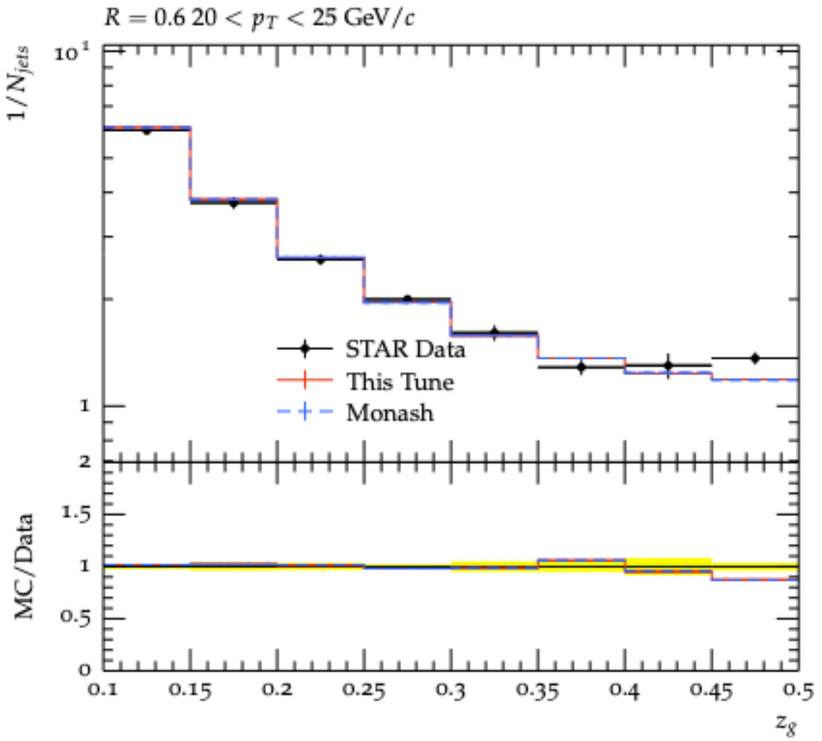
Backup Slides Follow

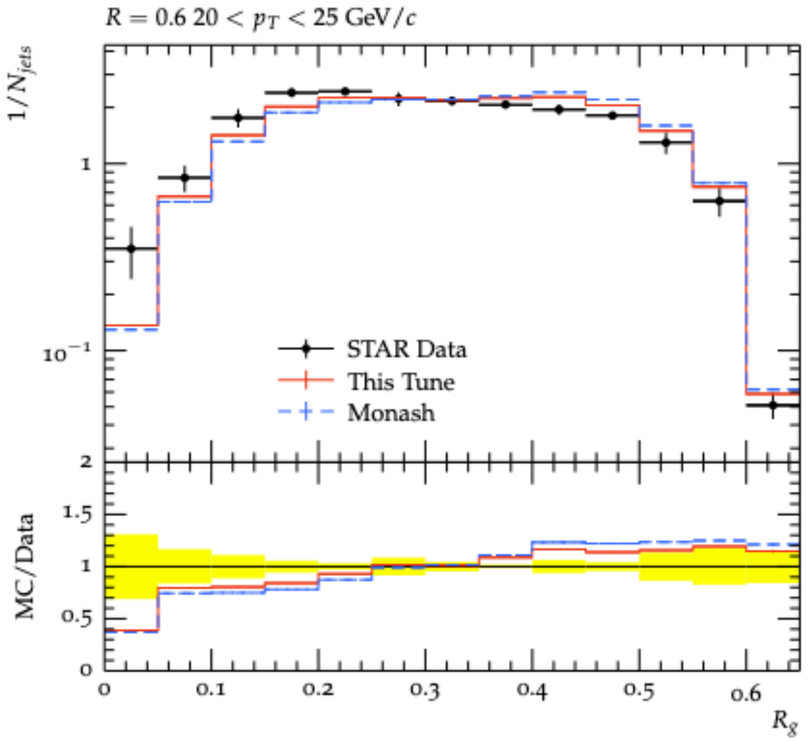
Drell-Yan

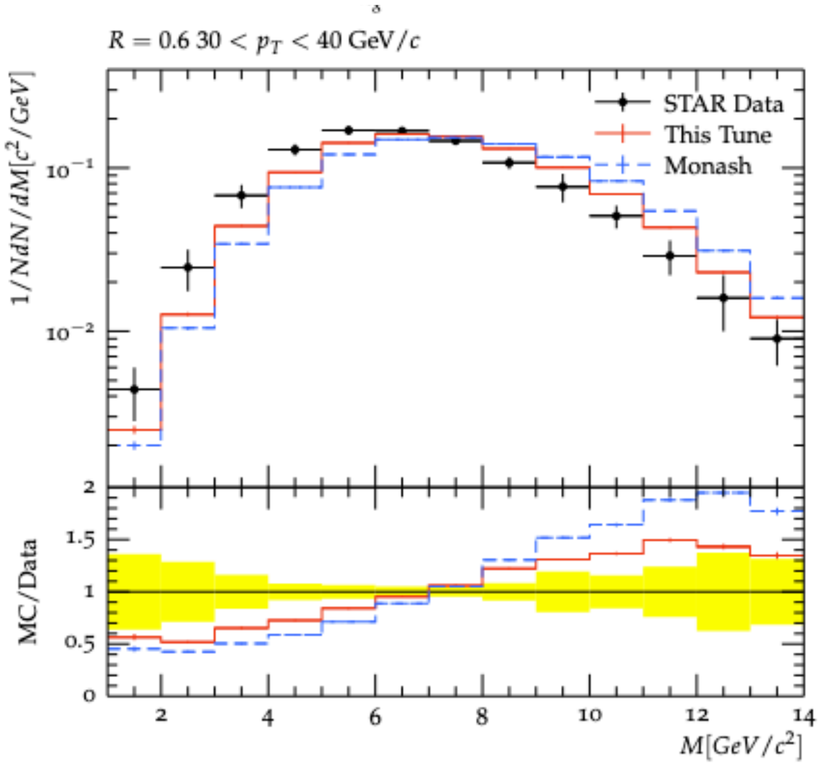

PHENIX: Drell-Yan $\sqrt{s} = 200$ GeV, $1.2 < |y| < 2.2$
PHENIX Data
This Tune
Monash
$4.8 < m_{\mu^+\mu^-} < 8.2$ GeV
$1/(2\pi p_T) d^2\sigma/dy/dp_T$ (pb/GeV^2)
MC/Data
p_T (GeV)


PHENIX; Drell-Yan $\sqrt{s} = 200$ GeV
PHENIX Data
This Tune
Monash
$1.2 < |y| < 2.2$
$d^2\sigma/dy/dM$ (pb/GeV)
MC/Data
M (GeV)

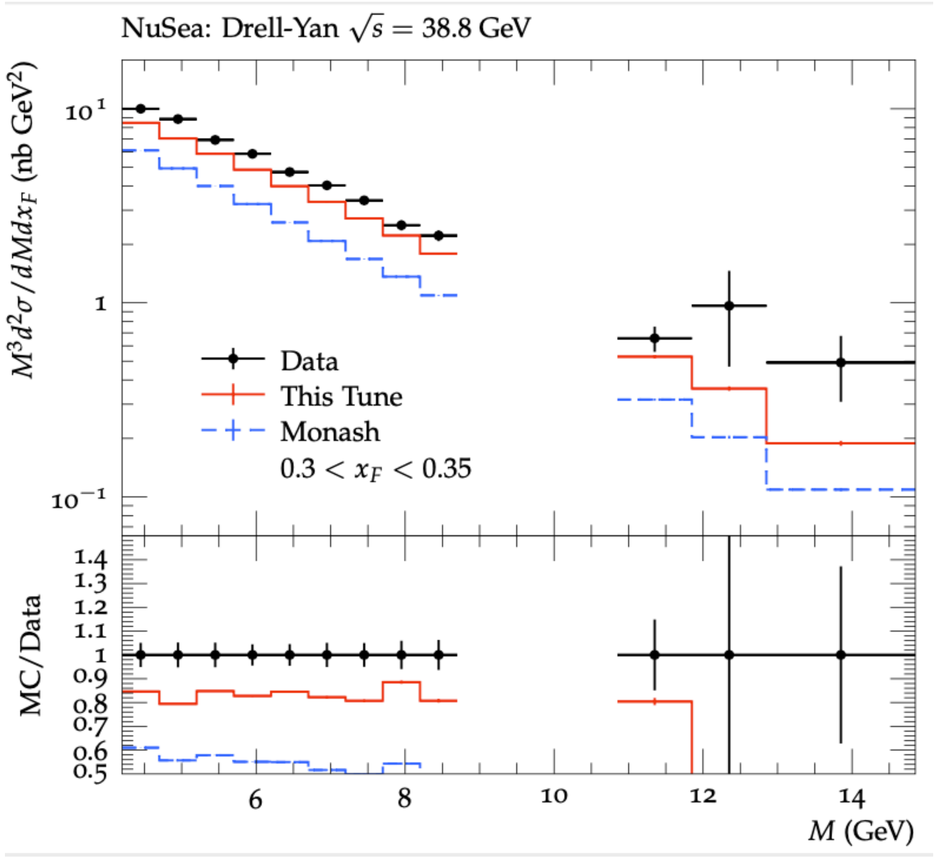
More Jet Observables

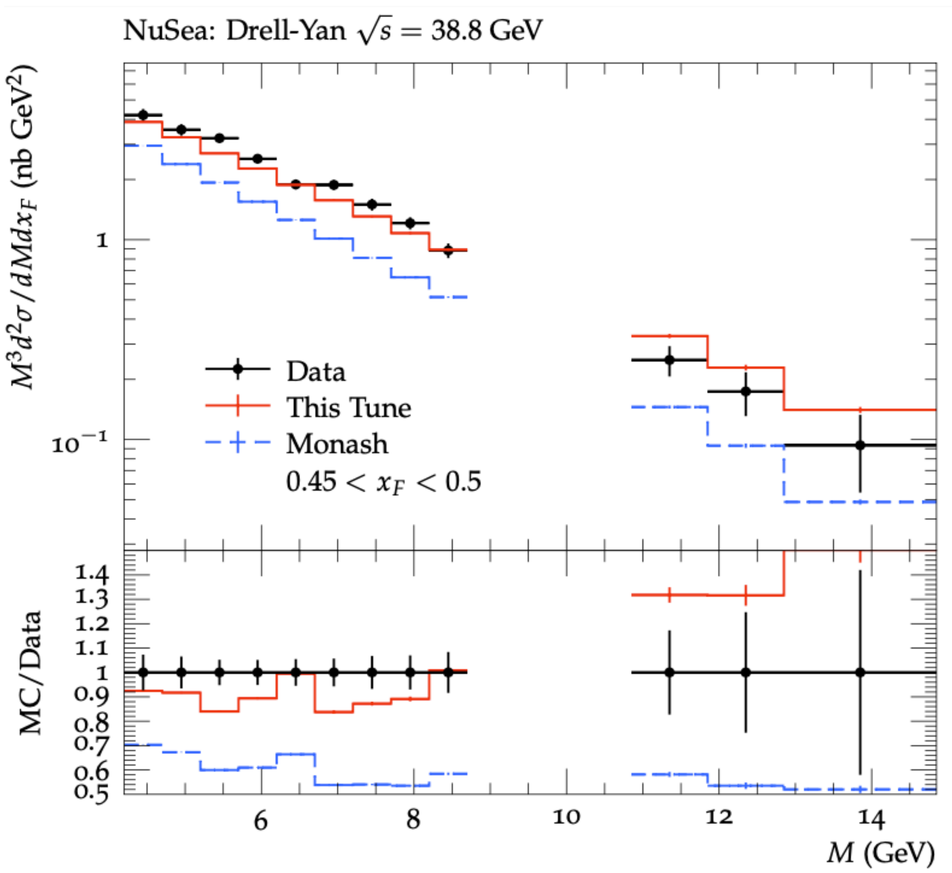






Energy Dependence: Low Energy





Representative plots from NuSea measurement @ COM = 38.8 GeV

Note not used in tuning

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