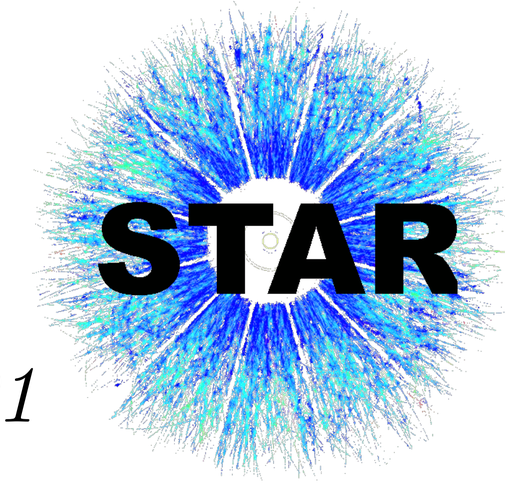
PYTHIA 8 Tuning Task Force Report

Matthew Kelsey
Wayne State University



STAR Collaboration Meeting March 1-12 2021

Outline

1) Task force logistics and tuning methodology

2) First tuning exercise using Professor method

3) Summary and 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 (+= Kolja Kauder, Renee Fatemi, Manny, Isaac Mooney, Veronica Verkest)**

Ex Officio: **Jason Webb**

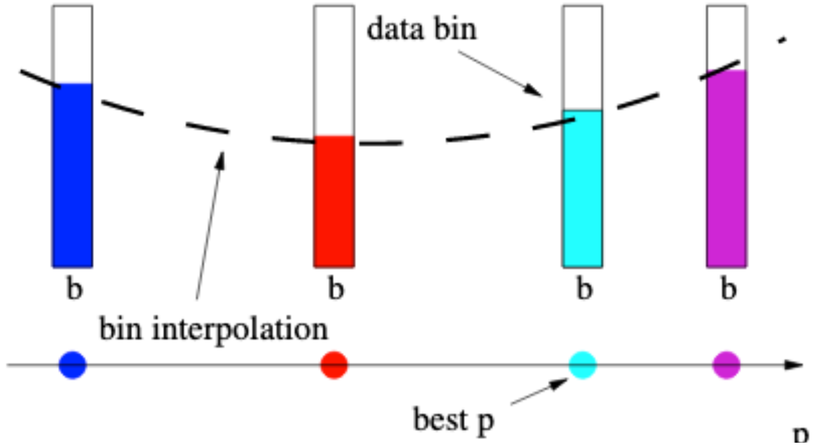
Mailing list: **star-tf-tunepy-l@lists.bnl.gov**

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**

Tuning Strategy

Parametrization-based tuning methodology: *Professor* method (professor.hepforge.org) - Polynomial parameterization of MC variation response + χ^2 min. w.r.t. data



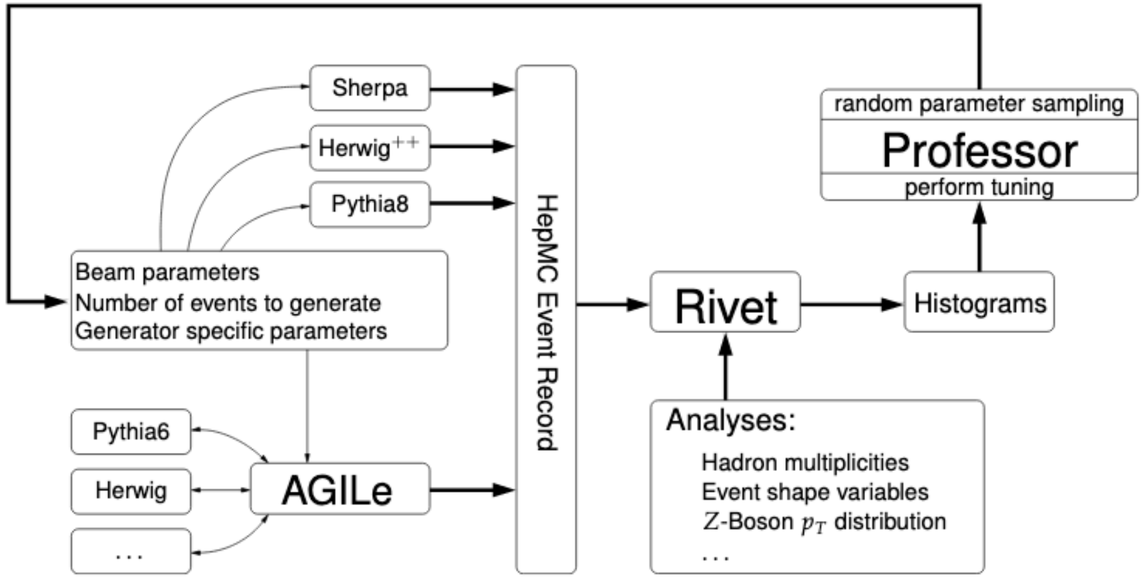
$$\mathrm{MC}_b(\boldsymbol{p}) \approx f^{(b)}(\boldsymbol{p}) = \alpha_0^{(b)} + \sum_i \beta_i^{(b)}\, p_i' + \sum_{i \le j} \gamma_{ij}^{(b)}\, p_i'\, p_j'$$

MC response in one data bin b

$p \equiv$ tunable parameter space

Quadratic+cubic options

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



Proposed Observables @ √s=200 GeV

First compilation of possible data

"Base" tune

- Single particle spectra + proton/pion ratio (https://arxiv.org/pdf/0808.2041.pdf, https://www.hepdata.net/record/ins930463)
- Jet cross section (https://drupal.star.bnl.gov/STAR/blog/zchang/run12-pp510-jet-cross-seciton-preliminary-plot)
- Jet mass (paper in collab.-wide review)
- Jet sub-structure (https://arxiv.org/pdf/2003.02114.pdf)
- Underlying event (https://arxiv.org/pdf/1912.08187.pdf)
- Drell-Yan (https://arxiv.org/pdf/1805.02448.pdf Tables XII + XIII)

Heavy Flavor:

- Open Charm spectra (https://arxiv.org/pdf/1404.6185.pdf)
- Heavy flavor decayed electron pt spectra (https://arxiv.org/pdf/1102.2611.pdf, https://arxiv.org/pdf/1102.2611.pdf)

Forward Physics:

- Charged particle rapidity depedence (https://arxiv.org/pdf/1011.1940.pdf)
- Identified hadron cross-section (https://arxiv.org/pdf/0908.4551.pdf)
- Proton/Pion ratio (https://arxiv.org/pdf/0910.3328.pdf)
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RIVET Complete

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First Tuning Exercise

Using (un-tuned) PYTHIA 8.303 out of the box

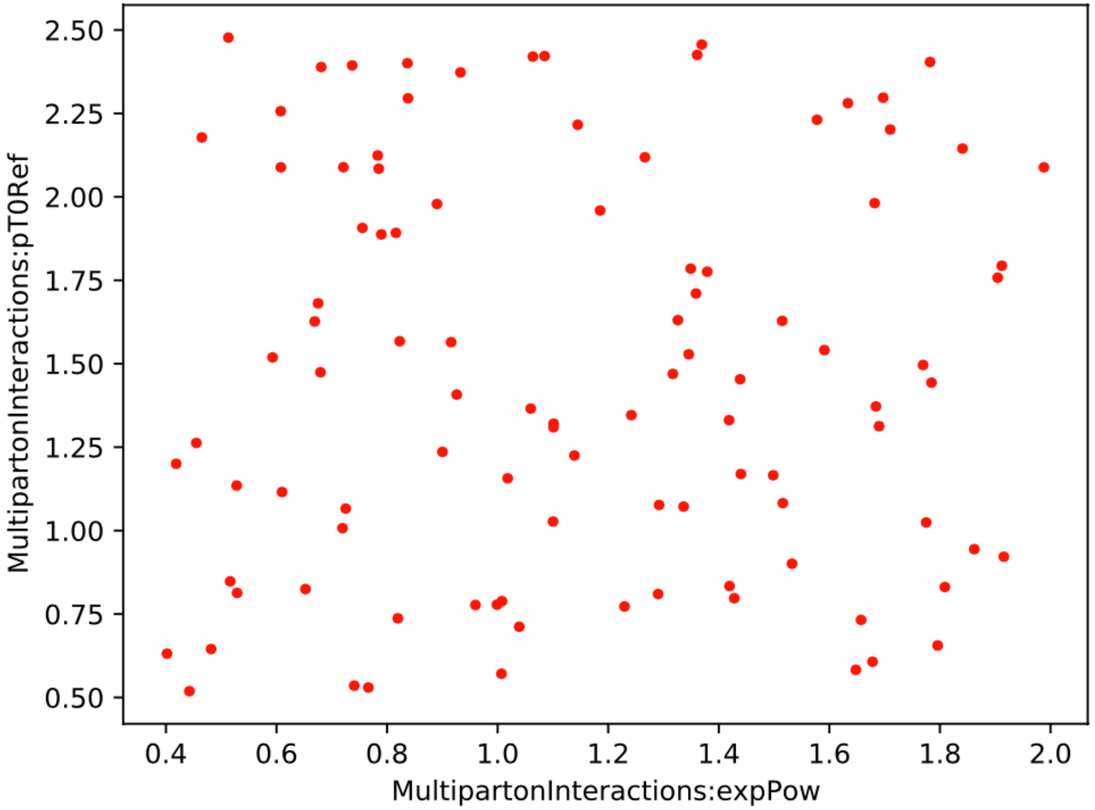
Tuning parameters (recommended by C. Bierlich):

- MultipartonInteractions:pT0Ref (def. = 2.28)
- MultipartonInteractions:expPow (def. = 1.85)
- (MultipartonInteractions:ecmRef = 200)
- (MultipartonInteractions:bProfile = 3)

Observables:

- UE event - $\langle N_{ch} \rangle + \langle p_T \rangle$, toward+away+transverse jet regions
- Jet mass - M + M_g
- Jet sub-structure - $R_g + z_g$
- Identified particle spectra (high-p_T)
- Total of 54 distributions (~475 NDOF)

Uniform sampling of pT0Ref and expPow (x100), produce 1M events per sample



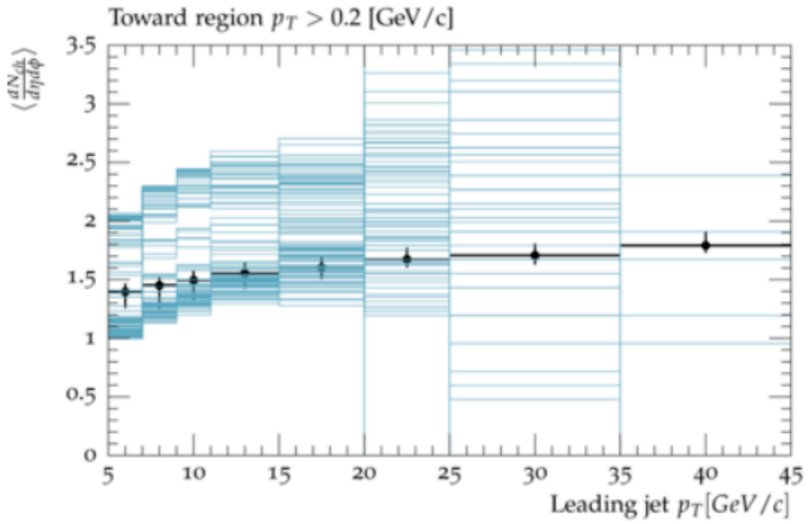
Ranges chosen to reflect that expected values are "probably" lower than LHC

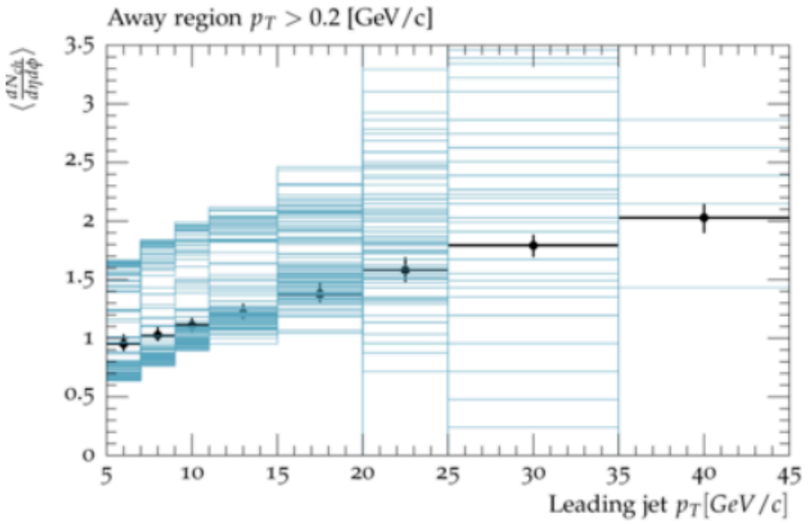
Observable Envelopes

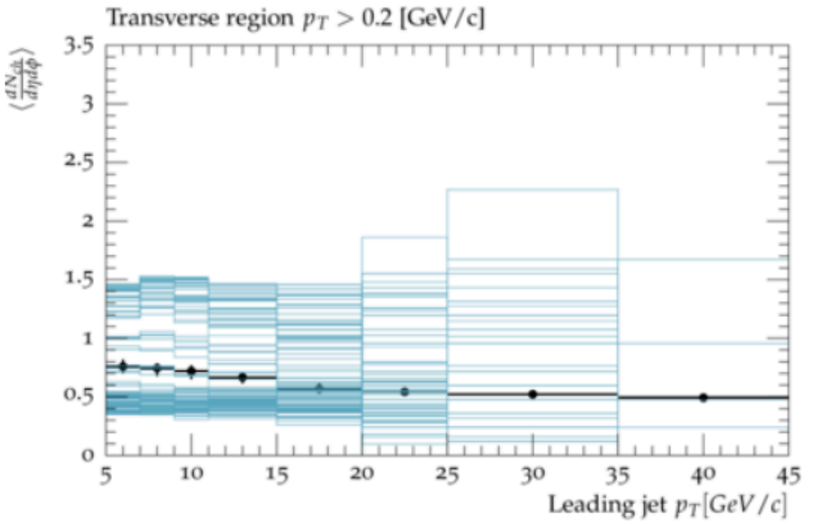
Note: Low statistics bins and regions of phase space far outside envelopes removed from later minimization

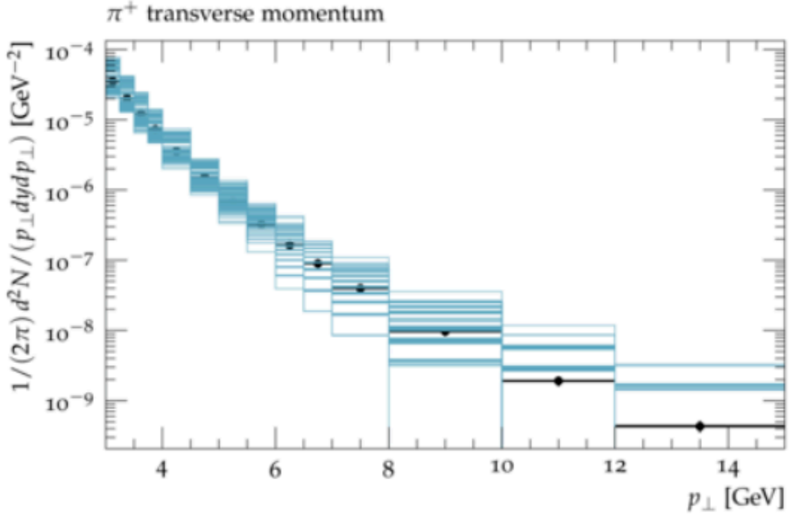
Every blue curve represents MC run with randomly sampled parameters - Want to see good coverage across all phase space

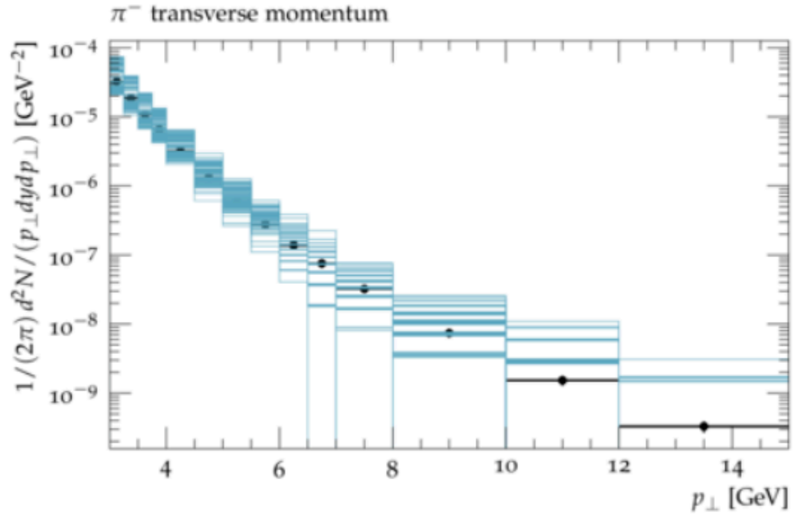
Large sensitivity seen in underlying event observables (expected)

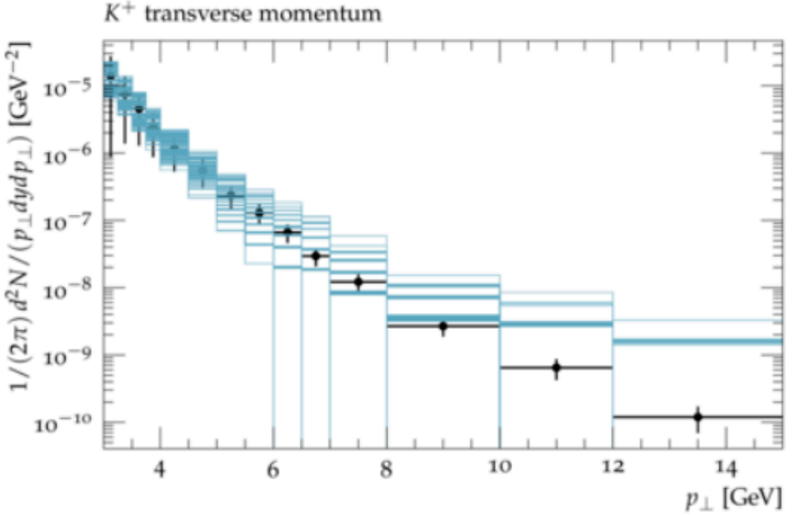












Observable Envelopes (cont.)

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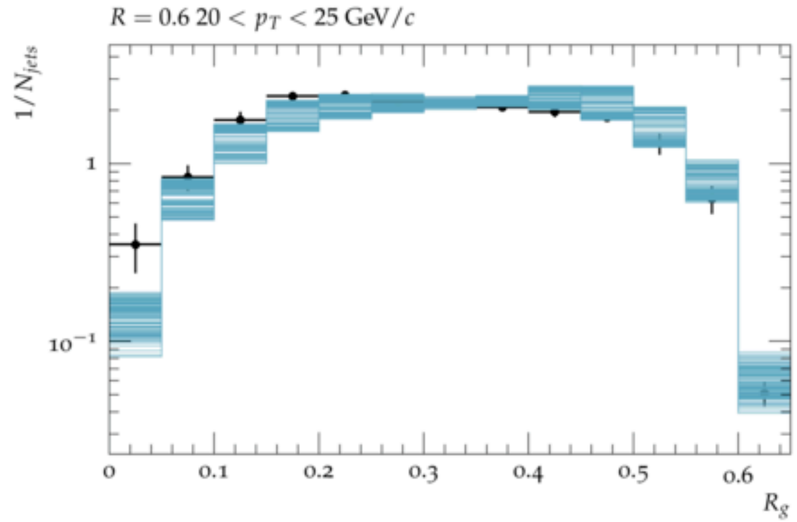
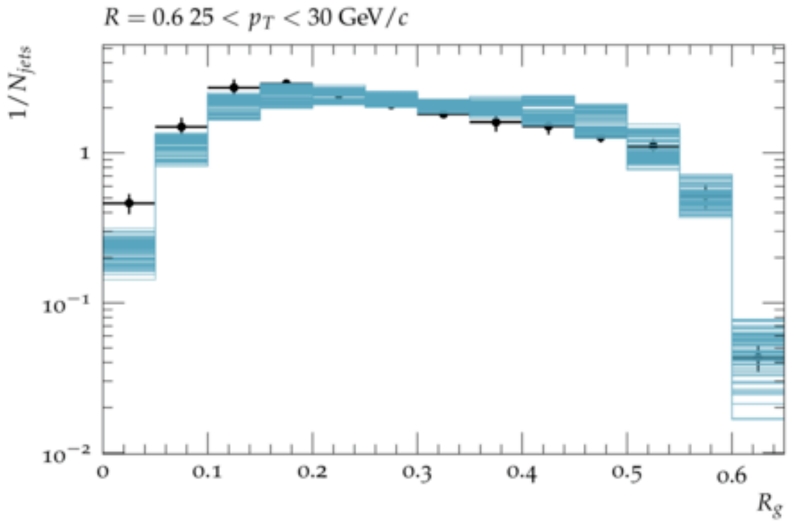
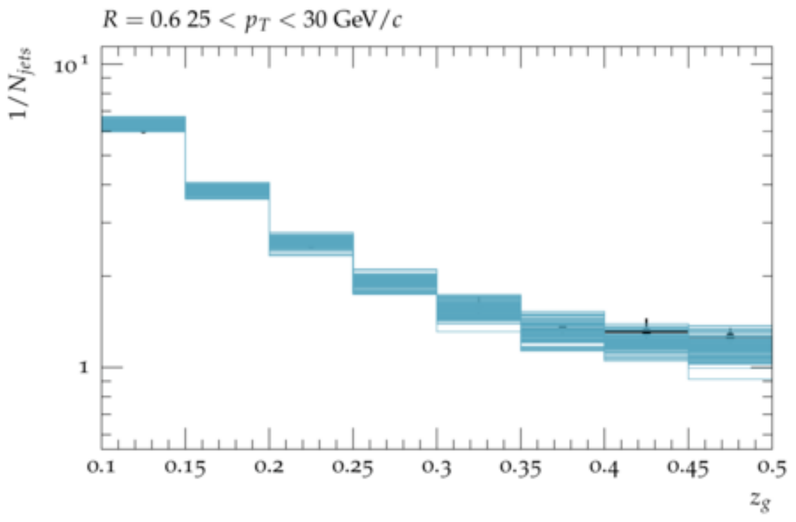
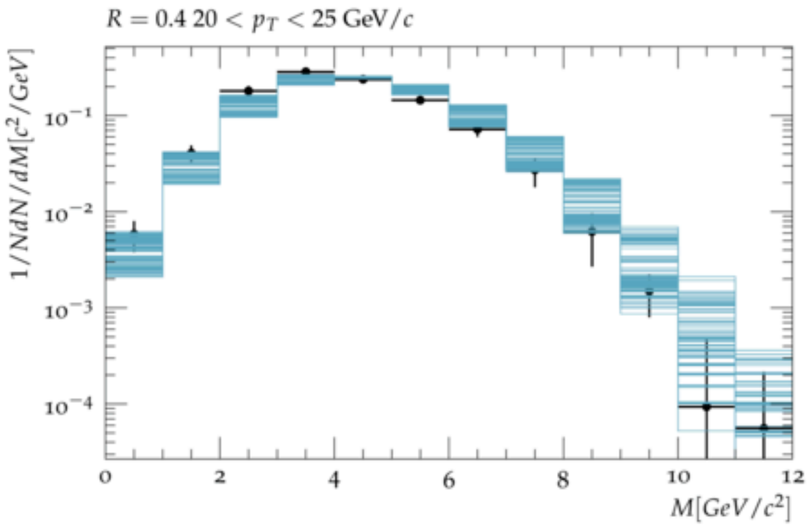
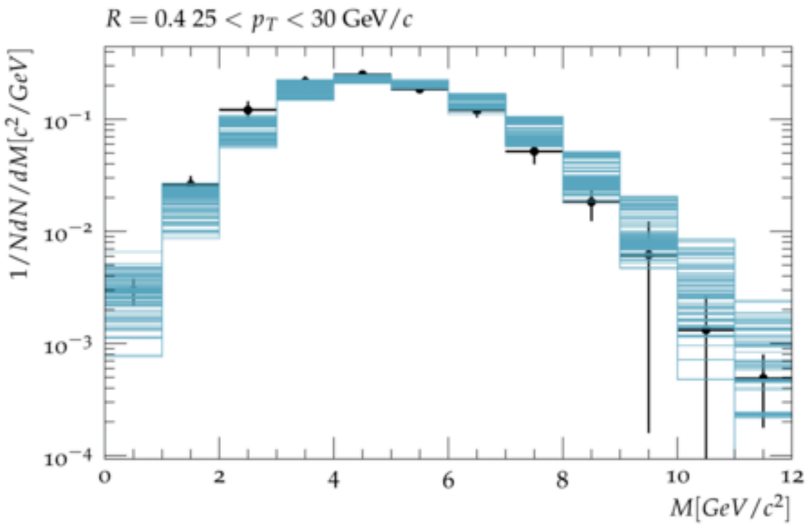
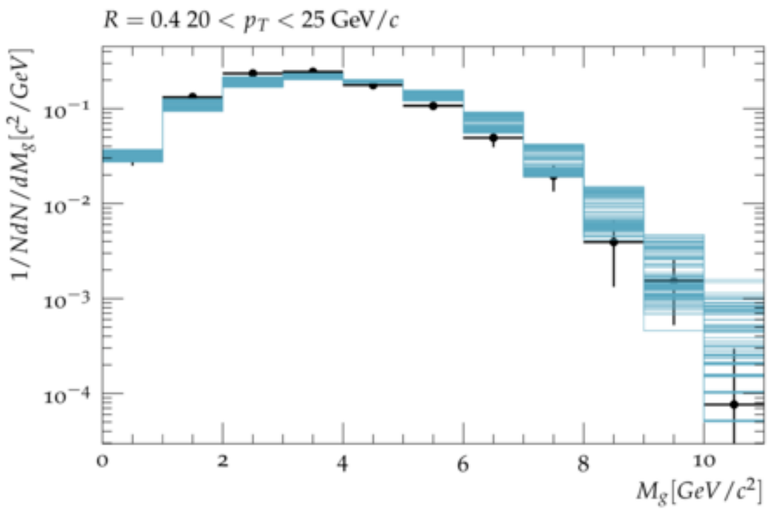




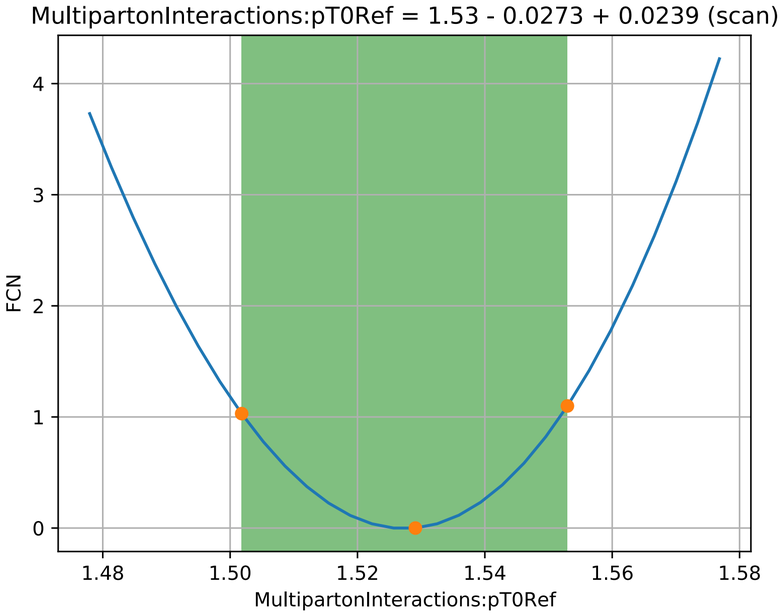


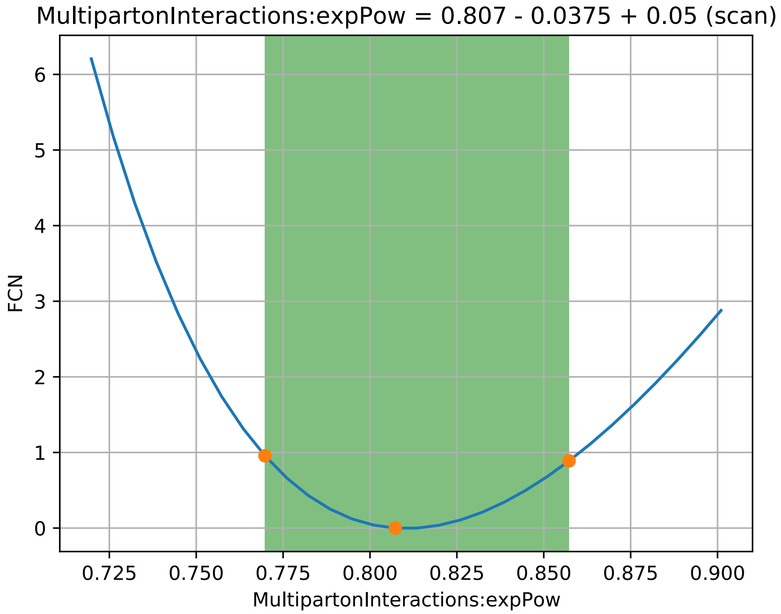


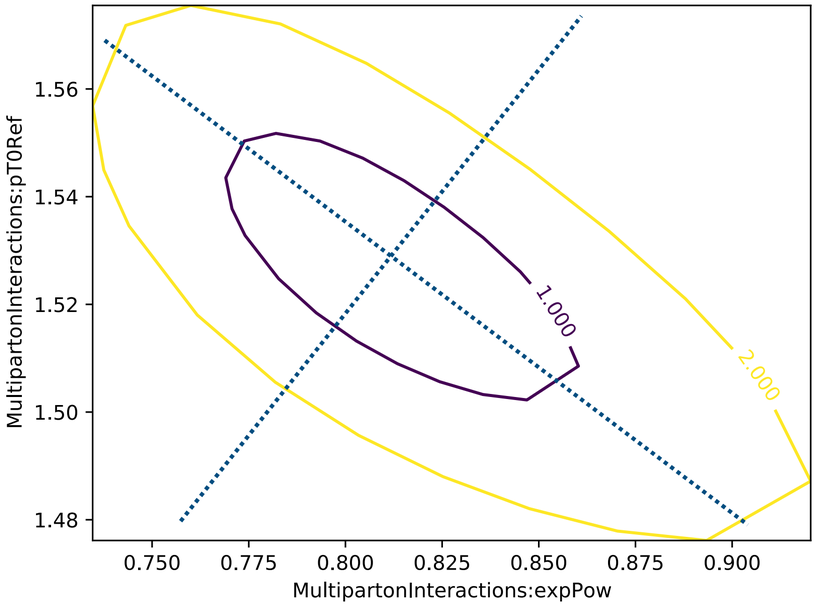




Best-Fit to Available Observables







Total χ^2 /NDOF = 436/464

MultipartonInteractions:pT0Ref = 1.53

MultipartonInteractions:expPow = 0.81

Eigentunes

(Deviations along maximally independent dimensions in parameter space)

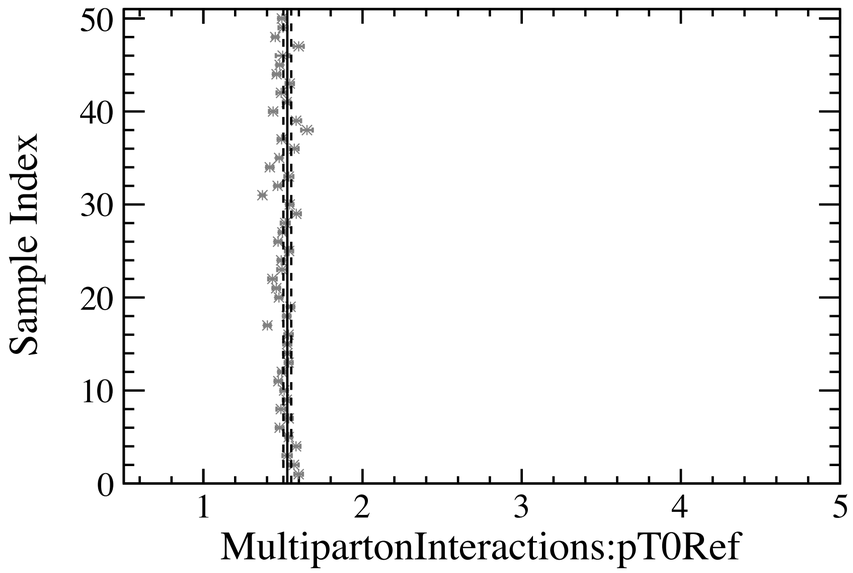
	1+	1-	2+	2-
pT0Ref	1.51	1.55	1.55	1.50
expPow	0.80	0.82	0.75	0.88

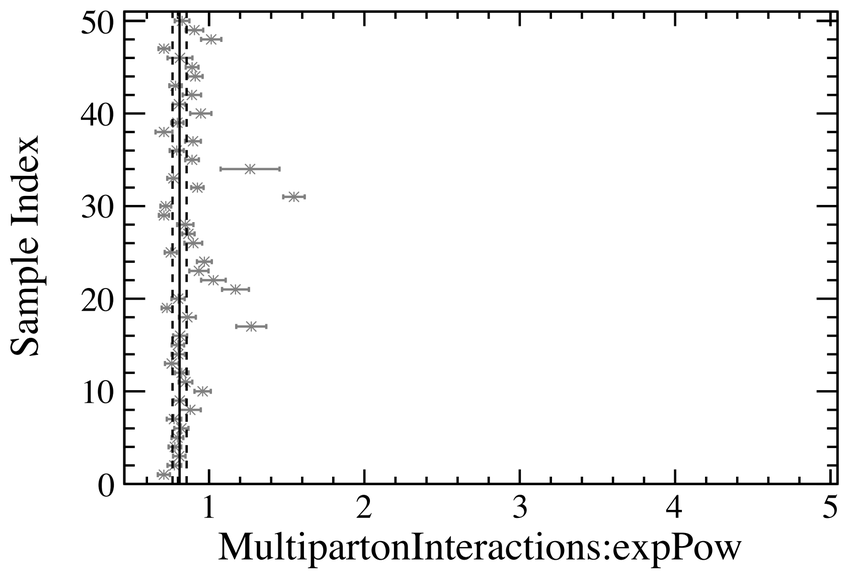
Note all values not final; just a first exercise

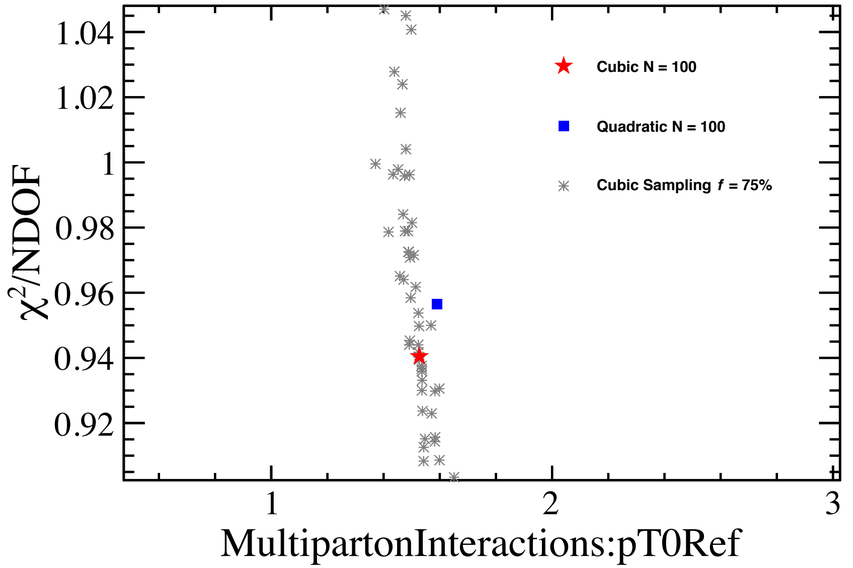
Tune Verification

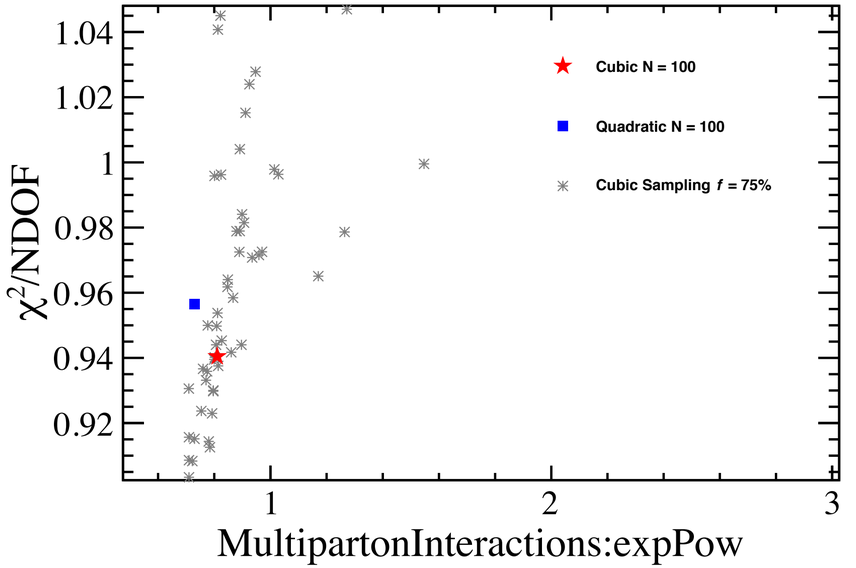
Randomly sample sub-set of MC runs to produce polynomial parameterizations

- Sampling fraction of total MC runs: 75%

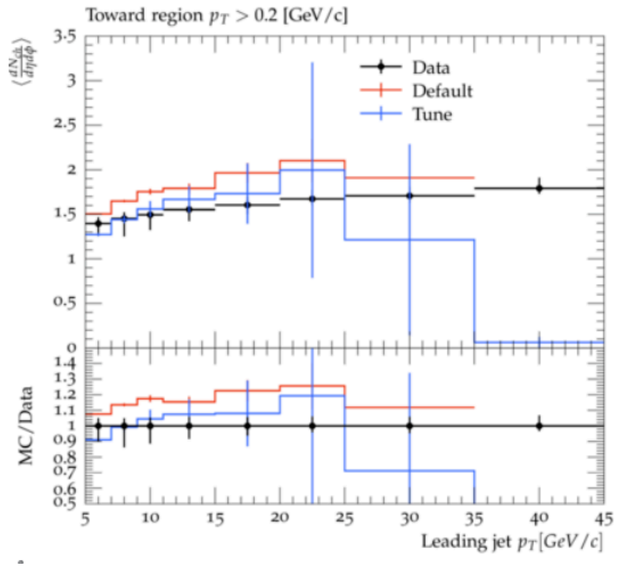


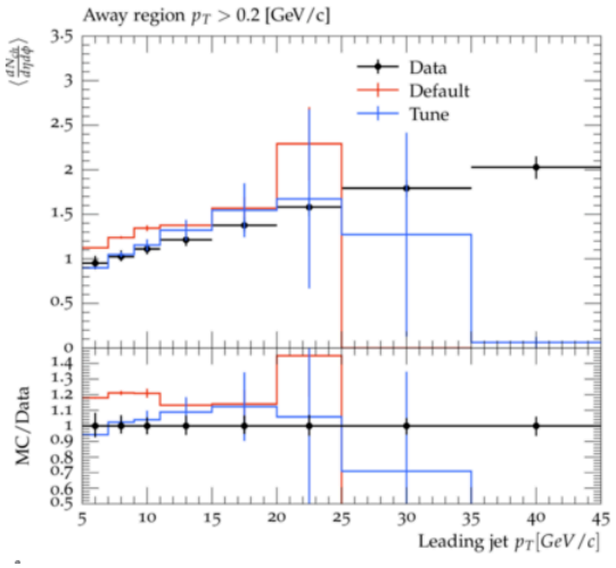


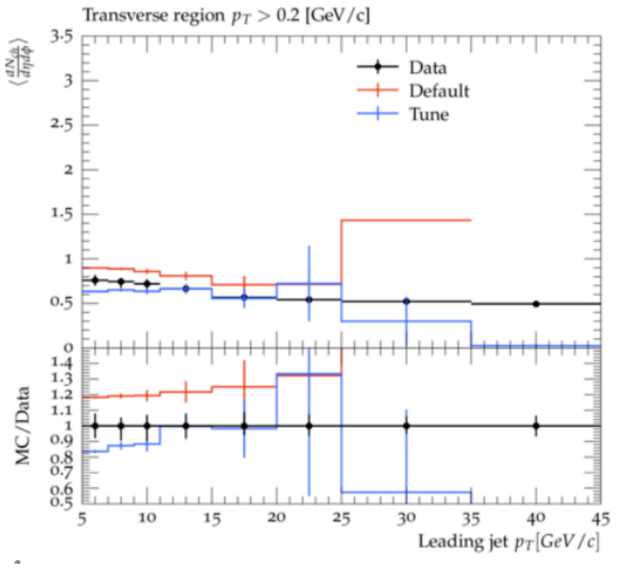


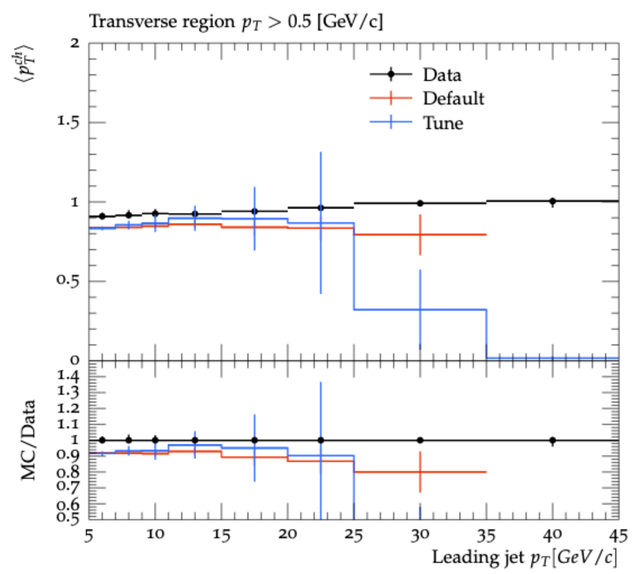


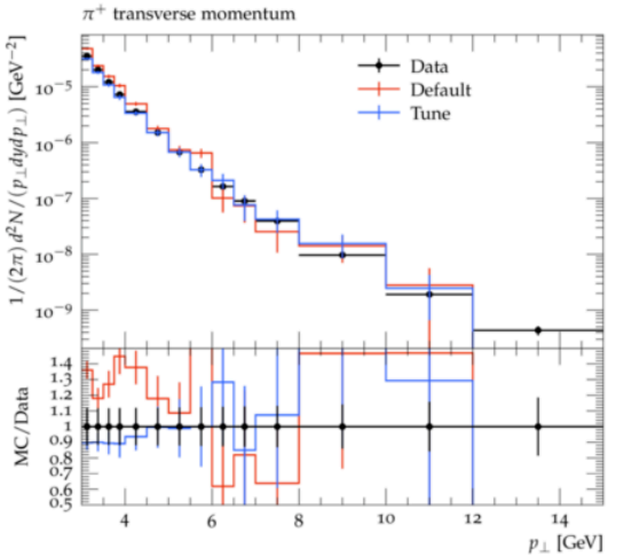
Comparisons to Un-tuned PYTHIA 8

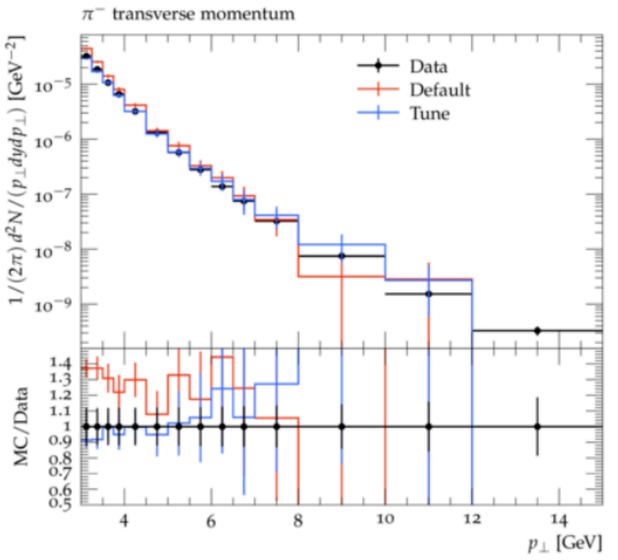


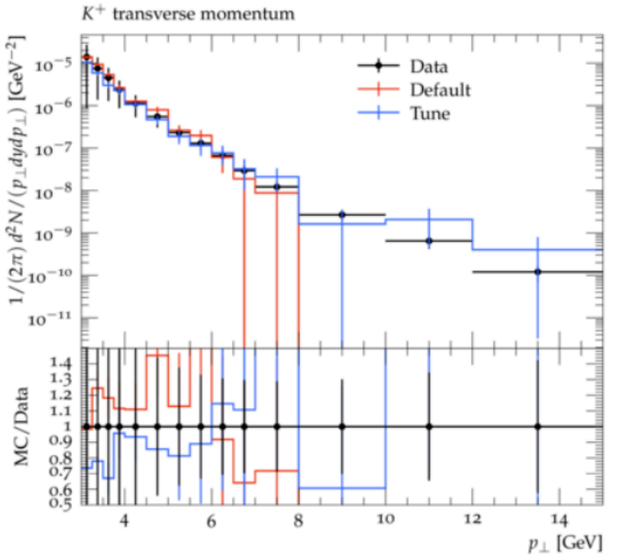


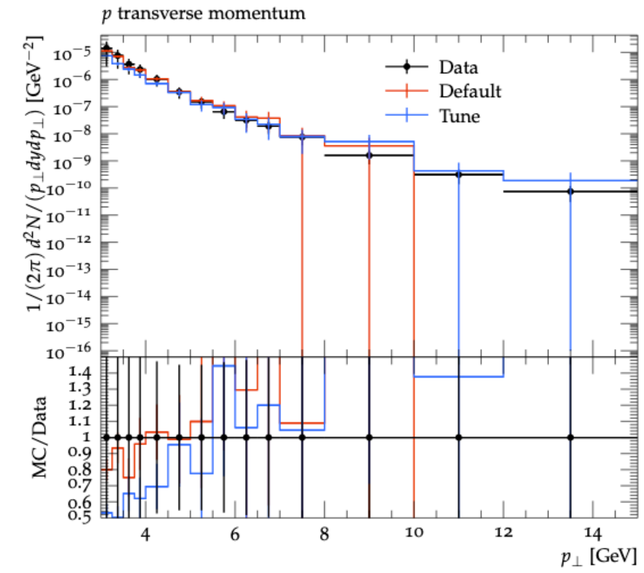












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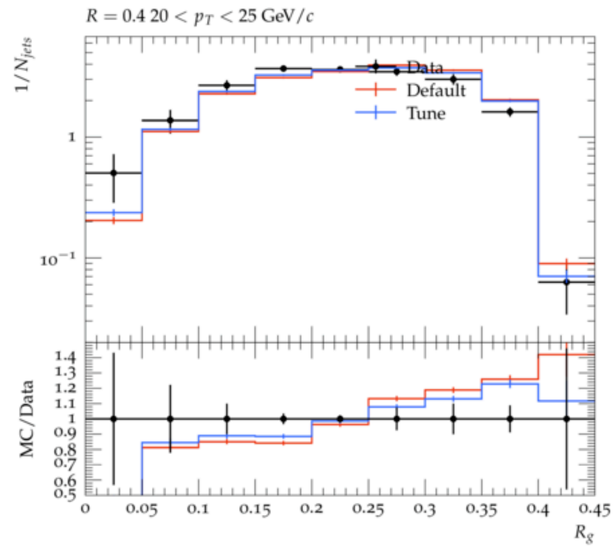

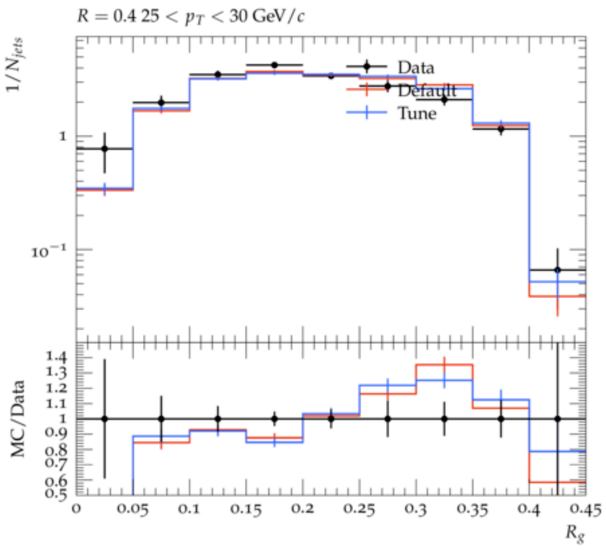

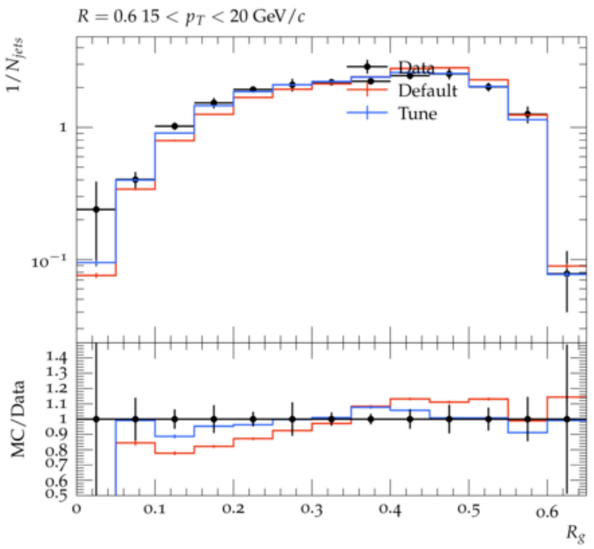

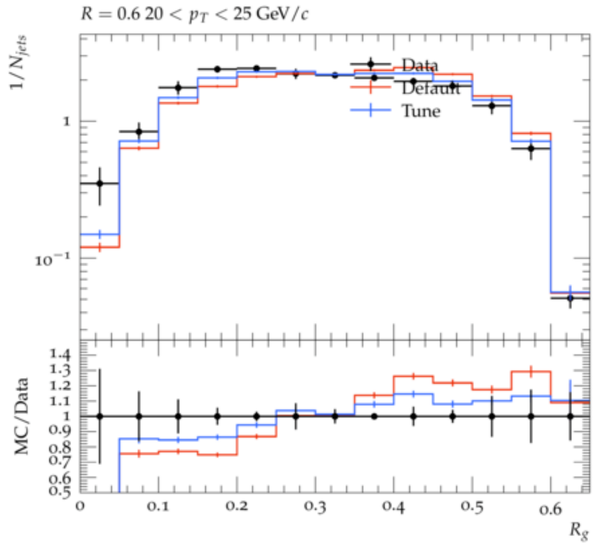

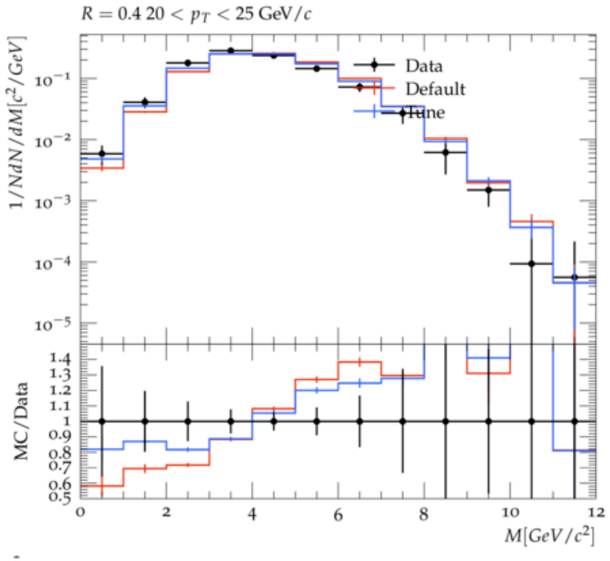

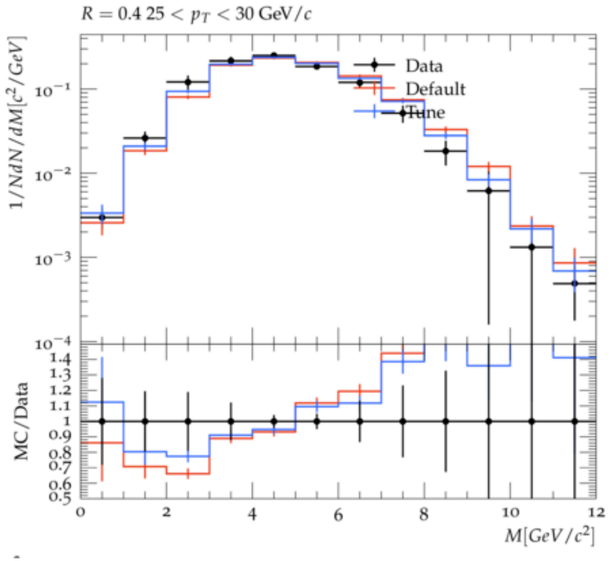

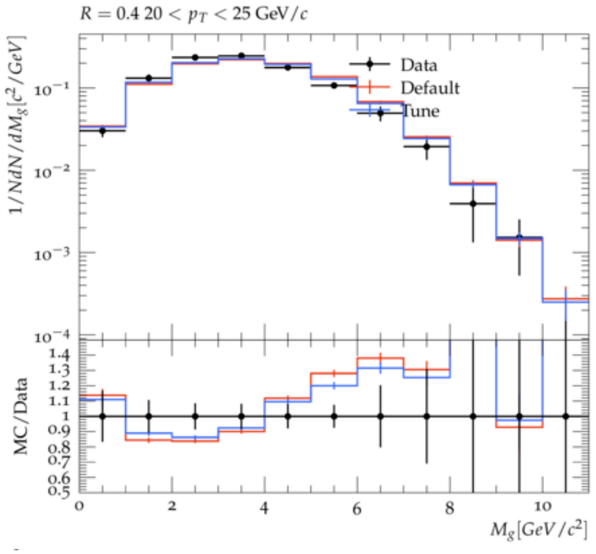

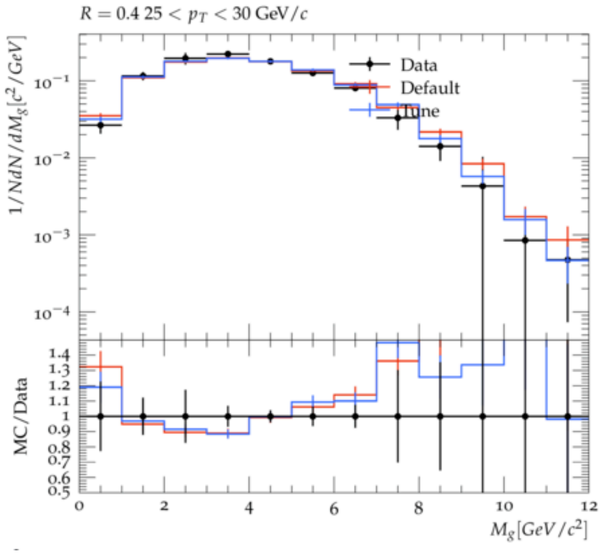

Summary

Excellent progress on producing RIVET analyses for tuning procedure

First exercise using Professor tuning method works, and produces stable results

- Improved MC description of data across the board
- Integration of final observables for finalization of "base" tune

Post-"base" tune plans

- Forward physics; RIVET analyses already being produced
- p+p @ $\sqrt{s}$=500 GeV
- ... Need RIVET analyses!

A full collection of plots (envelope, tuned results, etc.) can be downloaded from: https://drupal.star.bnl.gov/STAR/blog/mkelsey/pythia-8-tuning-plots

Backup Slides Follow

Observable Combinations in Minimization