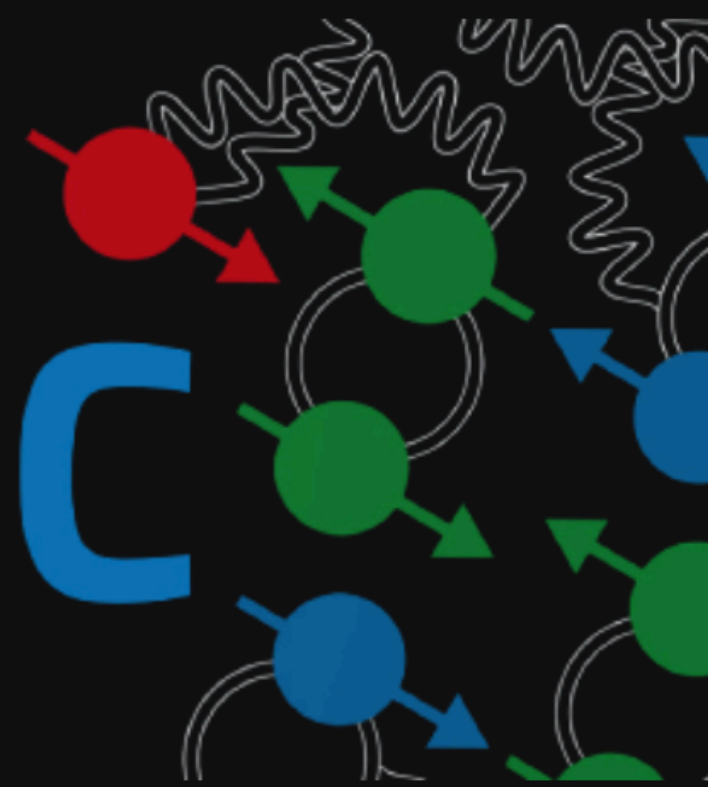


12th MPI at LHC



12th International workshop on Multiple Partonic Interactions at the LHC

11-15 October 2021
LIP Lisbon

A PYTHIA 8 Underlying Event Tune for RHIC Energies

Matthew Kelsey (for the STAR Collaboration)

Wayne State University

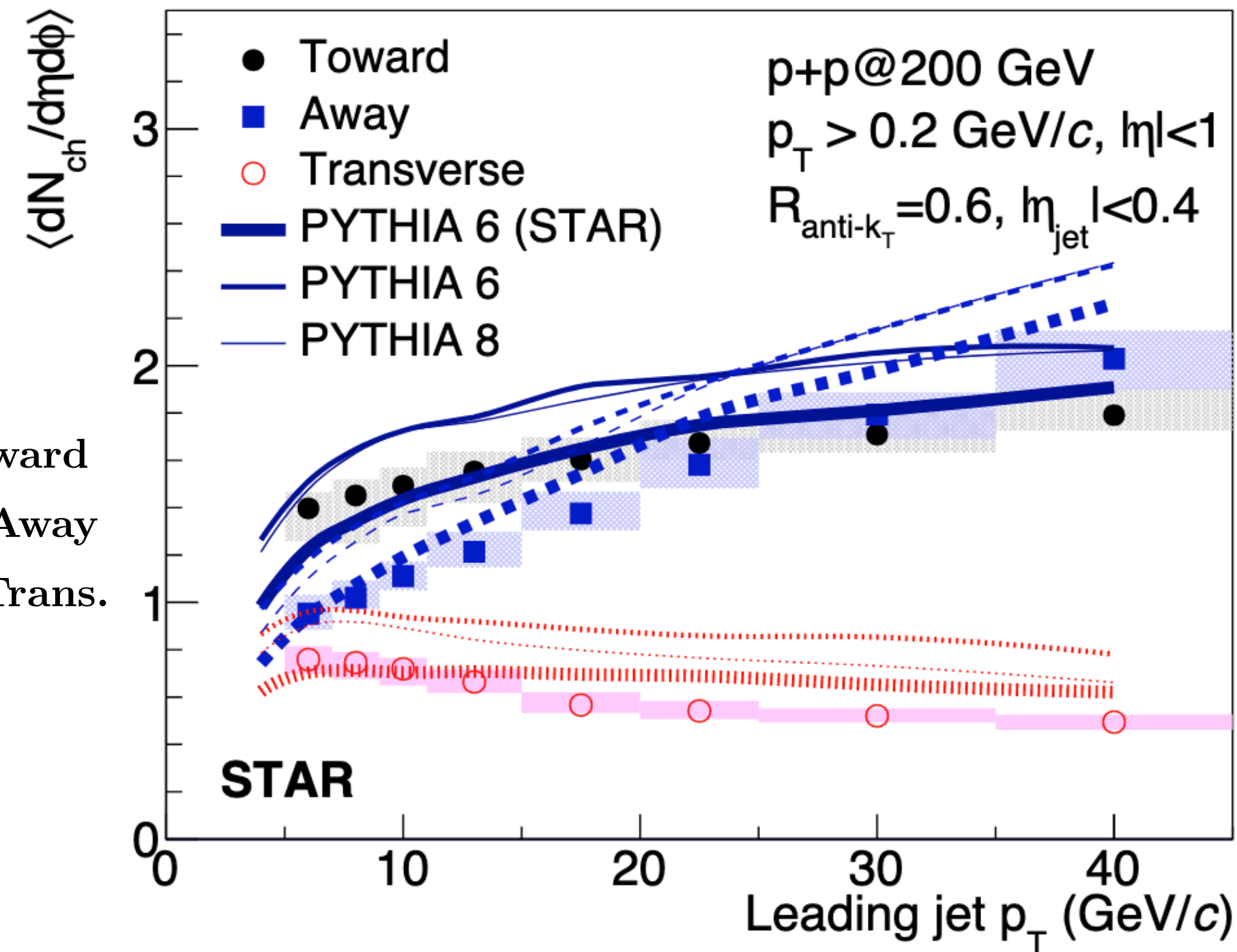


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ENERGY

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Science



STAR Phys. Rev. D 101, 052004 (2020)



$$p_{T,0} = p_{T,0}^{Ref} \left(\frac{\sqrt{s}}{\sqrt{s_{Ref}}} \right)^{ecmPow}$$

PYTHIA 6 “STAR” tune adjusted power law extrapolation parameter (PARP(90)=0.24 → 0.213) to match low- p_T π^\pm yields
STAR Phys. Rev. D100, 052005 (2019)

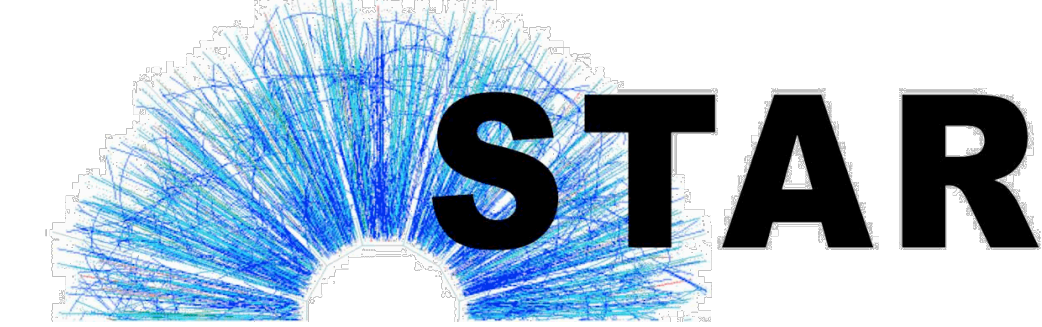
Modeling of Multi-Parton Interactions (MPI) in PYTHIA essential to simulate underlying event (UE) in hadron collisions

- Key component: Regularization parameter $p_{T,0}$

Collision energy extrapolation of $p_{T,0}$ follows power law function

- Reference energy usually 7 TeV; accurate extrapolation down to 200 GeV is not easy (see also*)

Tuning Strategy



Parametrization-based tuning methodology: *Professor* toolkit

(professor.hepforge.org)

- Polynomial parameterization of generated Monte Carlo (MC) data w/ parameter variation
- χ^2 min. w.r.t. data



$p \equiv$ tunable parameter space

$$MC_b(\mathbf{p}) \approx f^{(b)}(\mathbf{p}) = \alpha_0^{(b)} + \sum_i \beta_i^{(b)} p'_i + \sum_{i \leq j} \gamma_{ij}^{(b)} p'_i p'_j$$

MC response in one data bin b

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

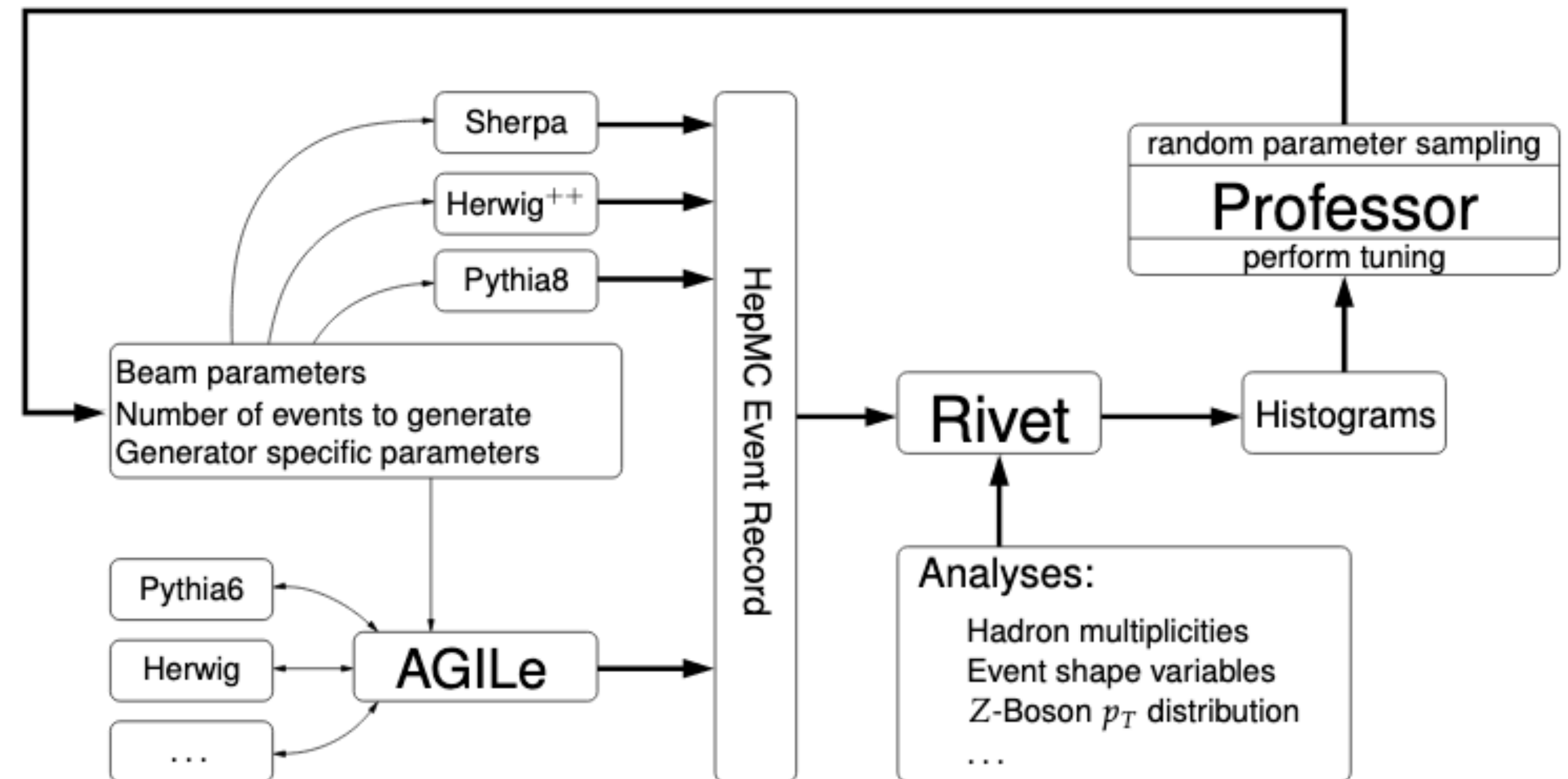


Image credit: Holger Schulz's Thesis
professor.hepforge.org/diplomathesis_h_schulz.pdf

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](https://arxiv.org/abs/2011.03422)

....

Tuning Parameters and Observables



Starting point is PYTHIA 8.303 with
prepackaged Monash* tune

NNPDF 2.3 → NNPDF 3.1

- Leading order, $\alpha_s(m_Z) = 0.130$

Reference energy switched to 200 GeV

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

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

Experiment	\sqrt{s} (GeV)	Observable	Reference
STAR	200	π^\pm cross sections vs. p_T	Physics Letters B 637, 161 (2006)
PHENIX	200	Di-muon pairs from Drell-Yan vs. di-muon p_T	Phys. Rev. D 99, 072003 (2019)
STAR	200	Average charged particle multiplicities and p_T vs. leading jet p_T in the forward, transverse, and away regions	Phys. Rev. D 101, 052004 (2020)
CDF	300, 900, 1960	Charge particle density and $\sum p_T$ vs. leading hadron p_T in transverse region	Phys. Rev. D 92, 092009 (2015)
STAR	200	SoftDrop groomed jet sub-structure (z_g and R_g)	Physics Letters B 811, 135846 (2020)
STAR	200	Inclusive and groomed jet mass	Phys. Rev. D 104, 052007 (2021)

New From
STAR

Included in
RIVET

Degrees of Freedom = 493

*P. Skands *et al.* Eur. Phys. J. C74, 3024 (2014)

Tune Results: The ‘Detroit’ Tune STAR

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

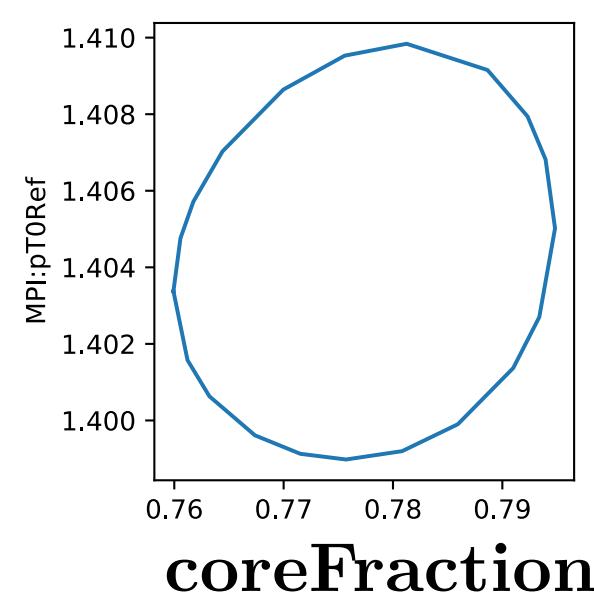
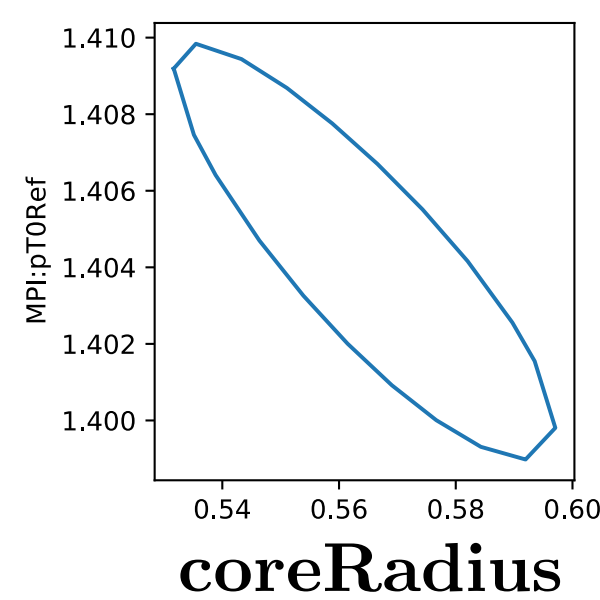
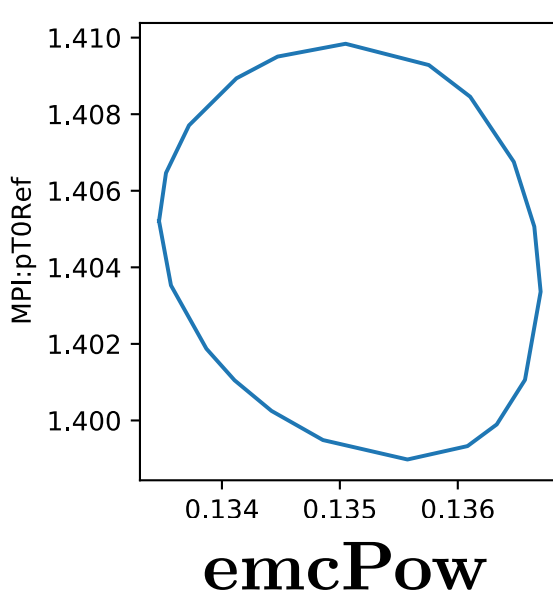
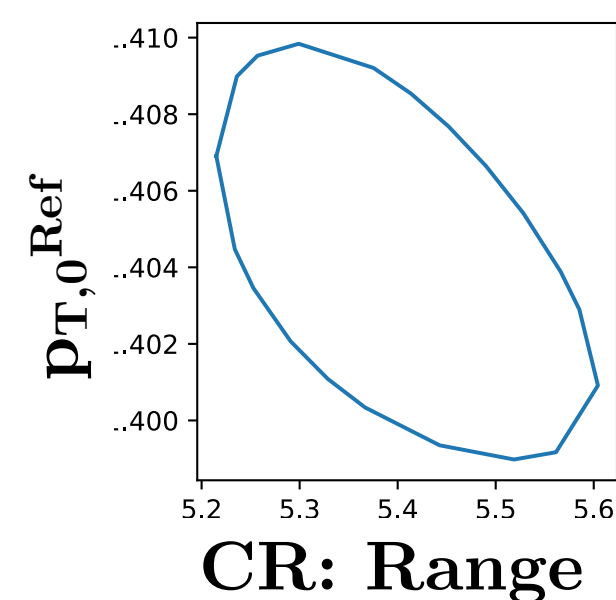
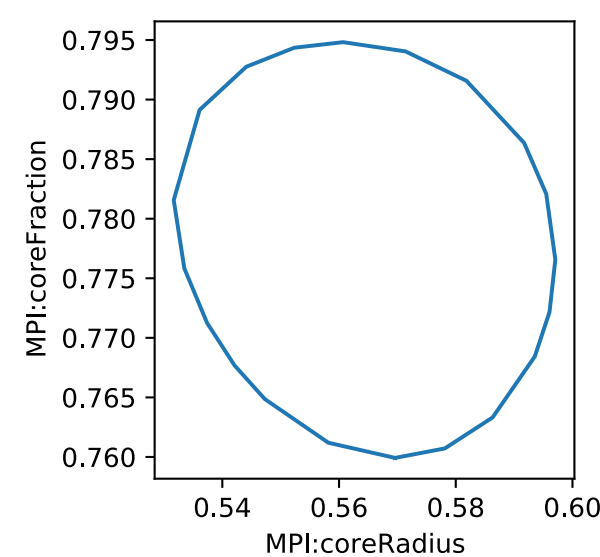
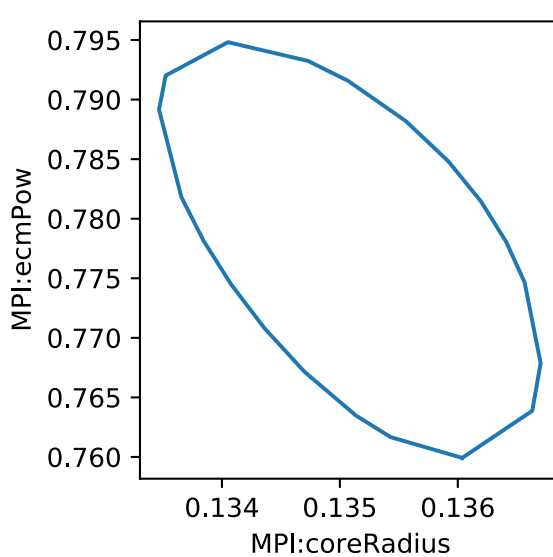
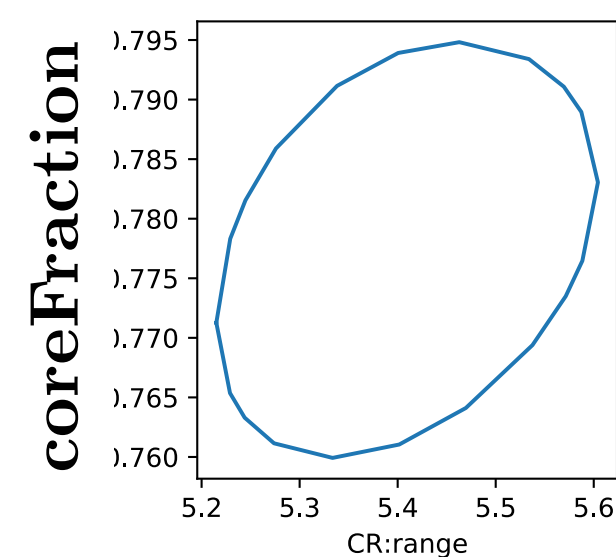
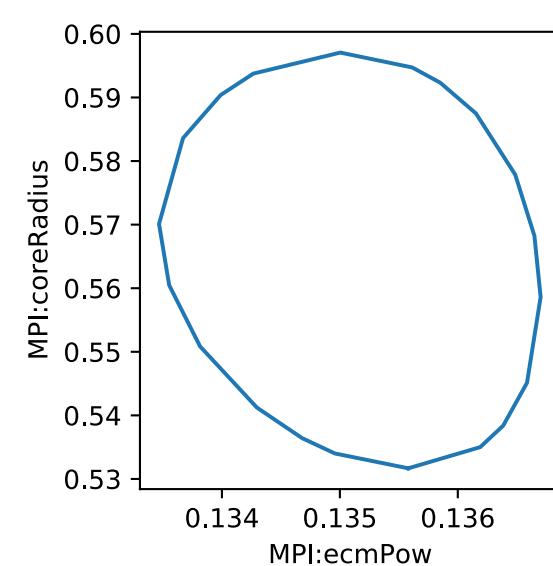
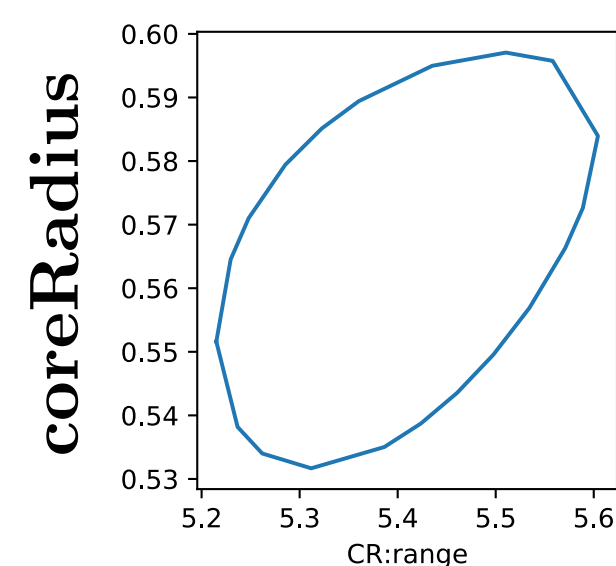
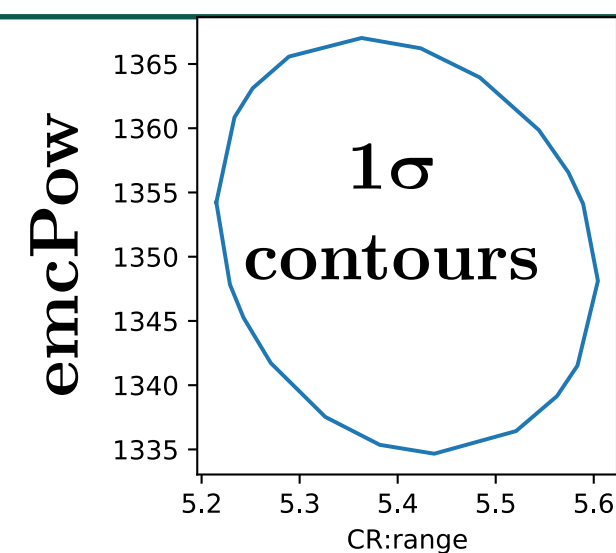
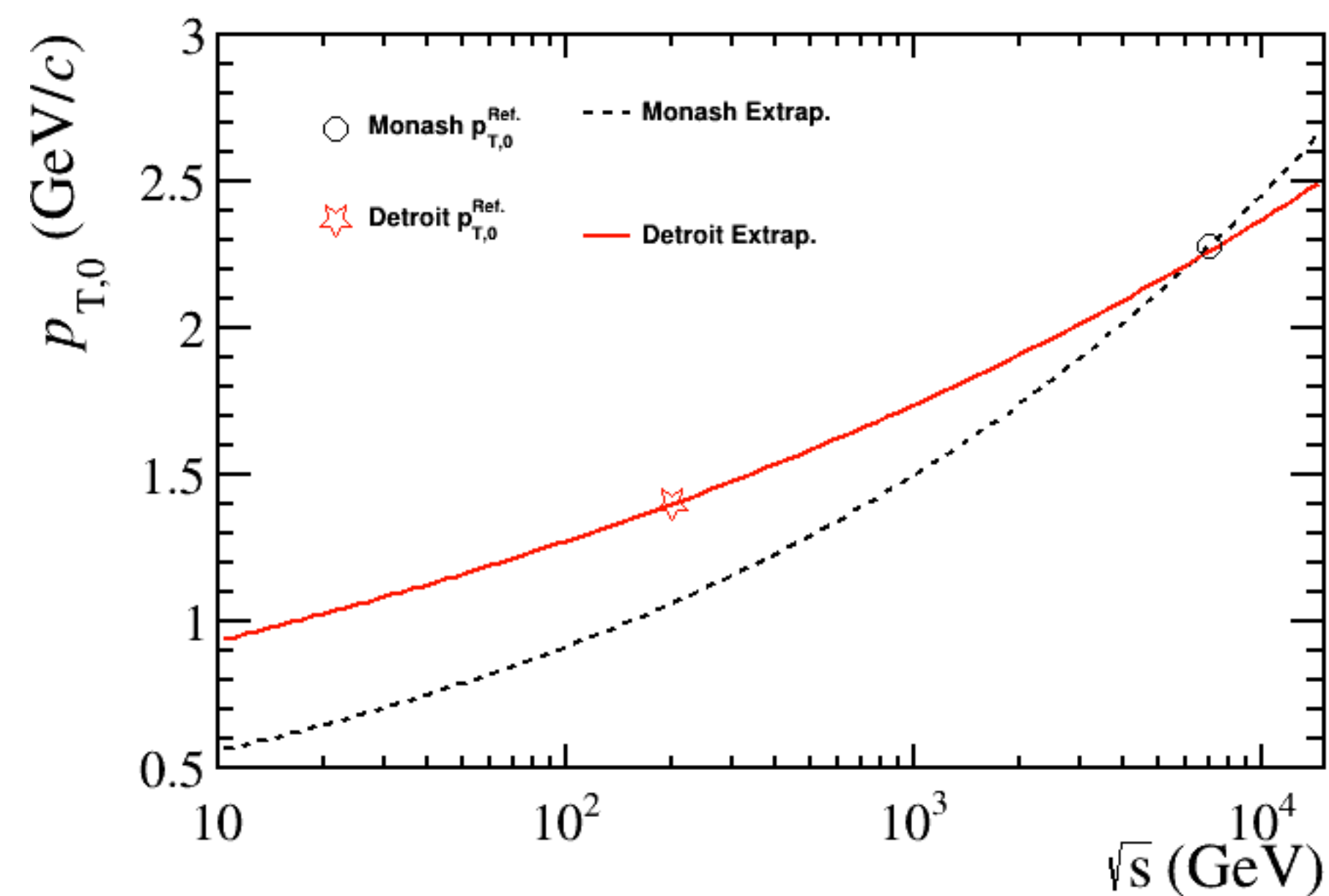


TABLE III. PYTHIA 8 tuned parameters.

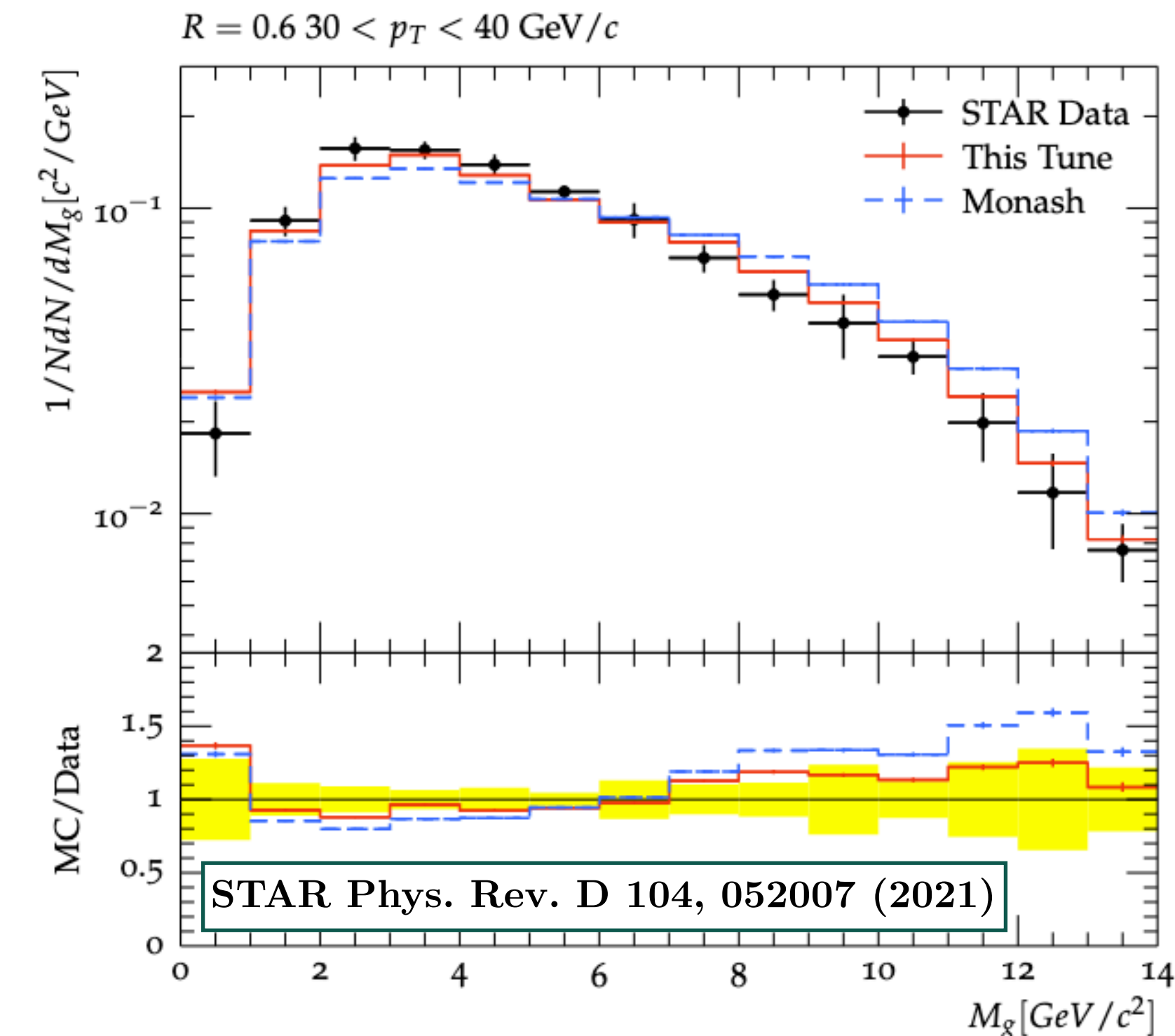
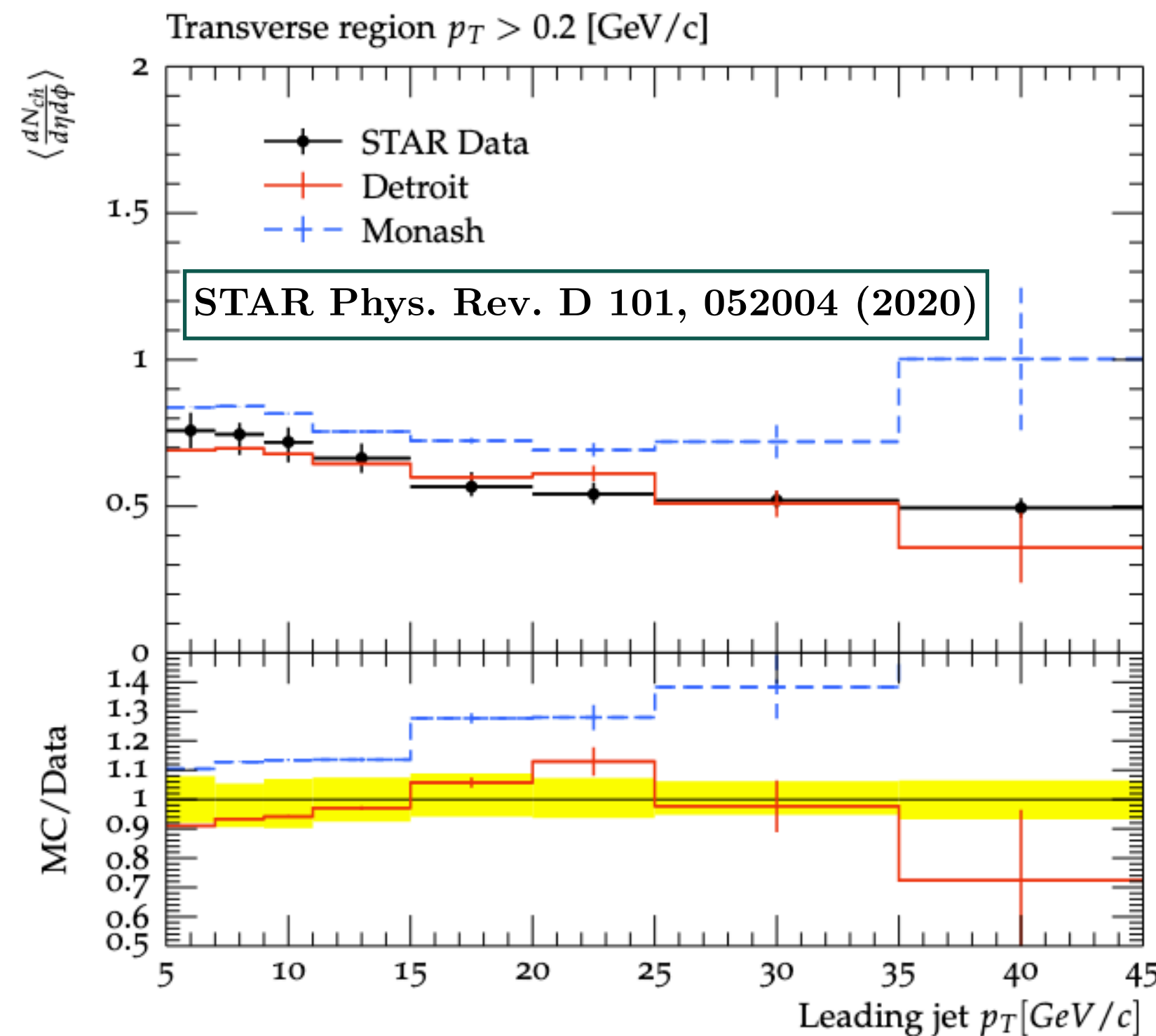
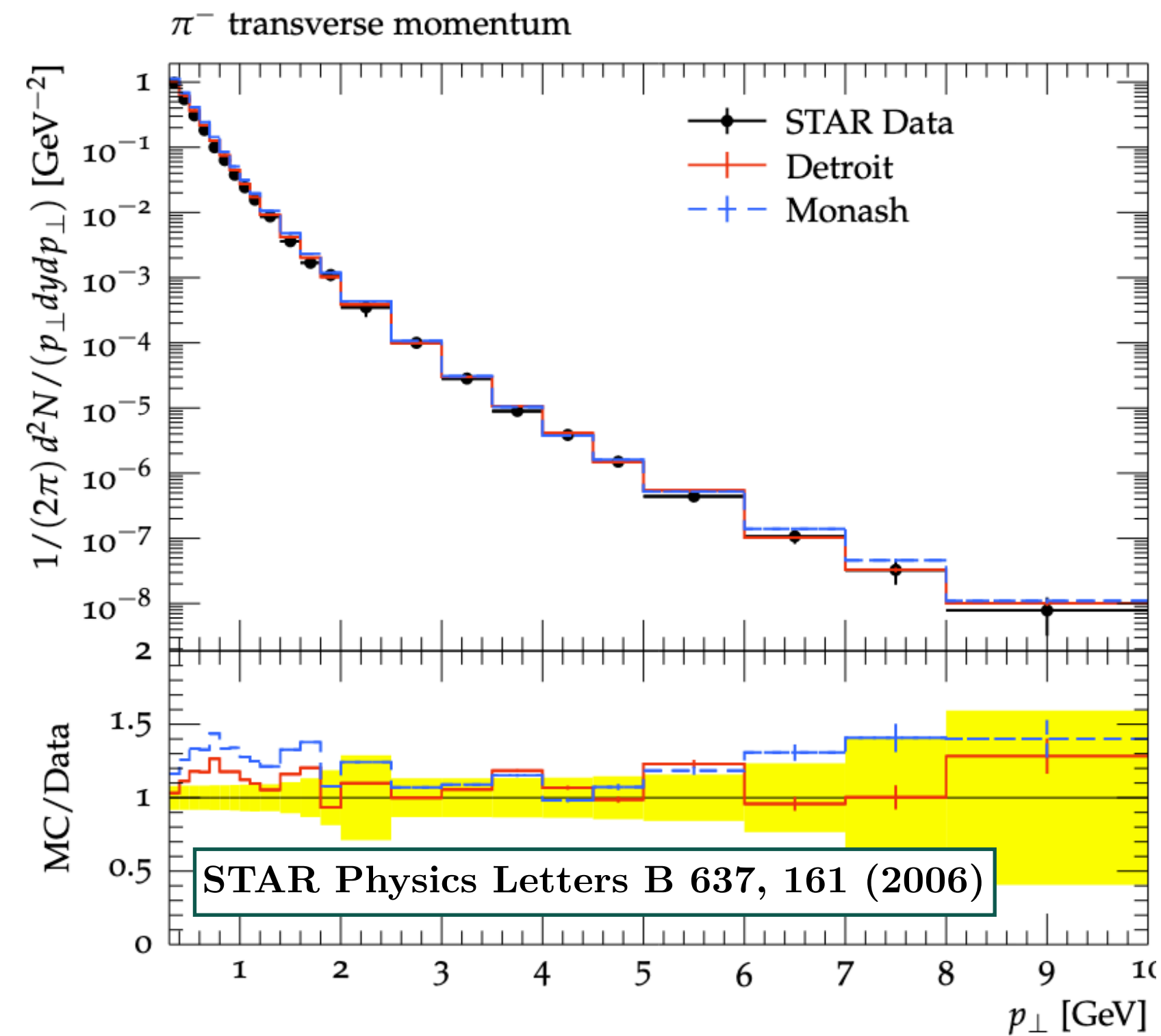
Tuning Parameter	Default	New
MultipartonInteractions:pT0Ref	2.28 GeV	1.40 GeV
MultipartonInteractions:ecmPow	0.215	0.135
MultipartonInteractions:coreRadius	0.4	0.56
MultipartonInteractions:coreFraction	0.5	0.78
ColourReconnection:range	1.8	5.4



New PYTHIA 8 Performance



Representative plots (see backup)



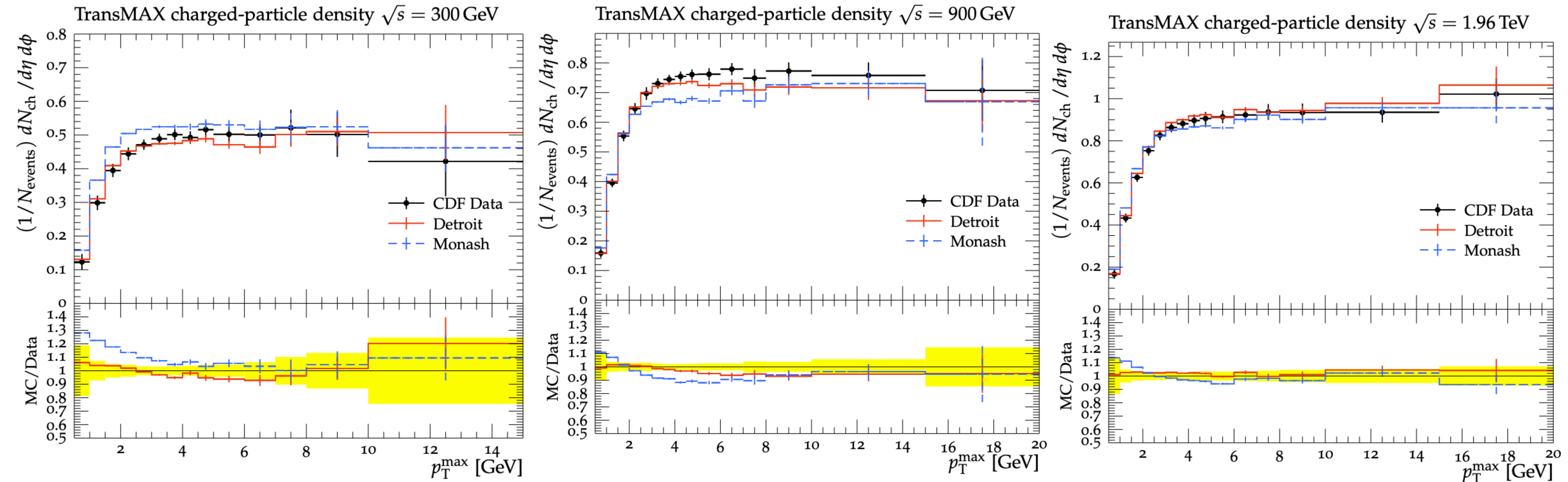
Significant improvement of pion spectrum and underlying event description @ 200 GeV

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

Yellow bands show data uncertainties only

Energy Dependence: 300-1960 GeV

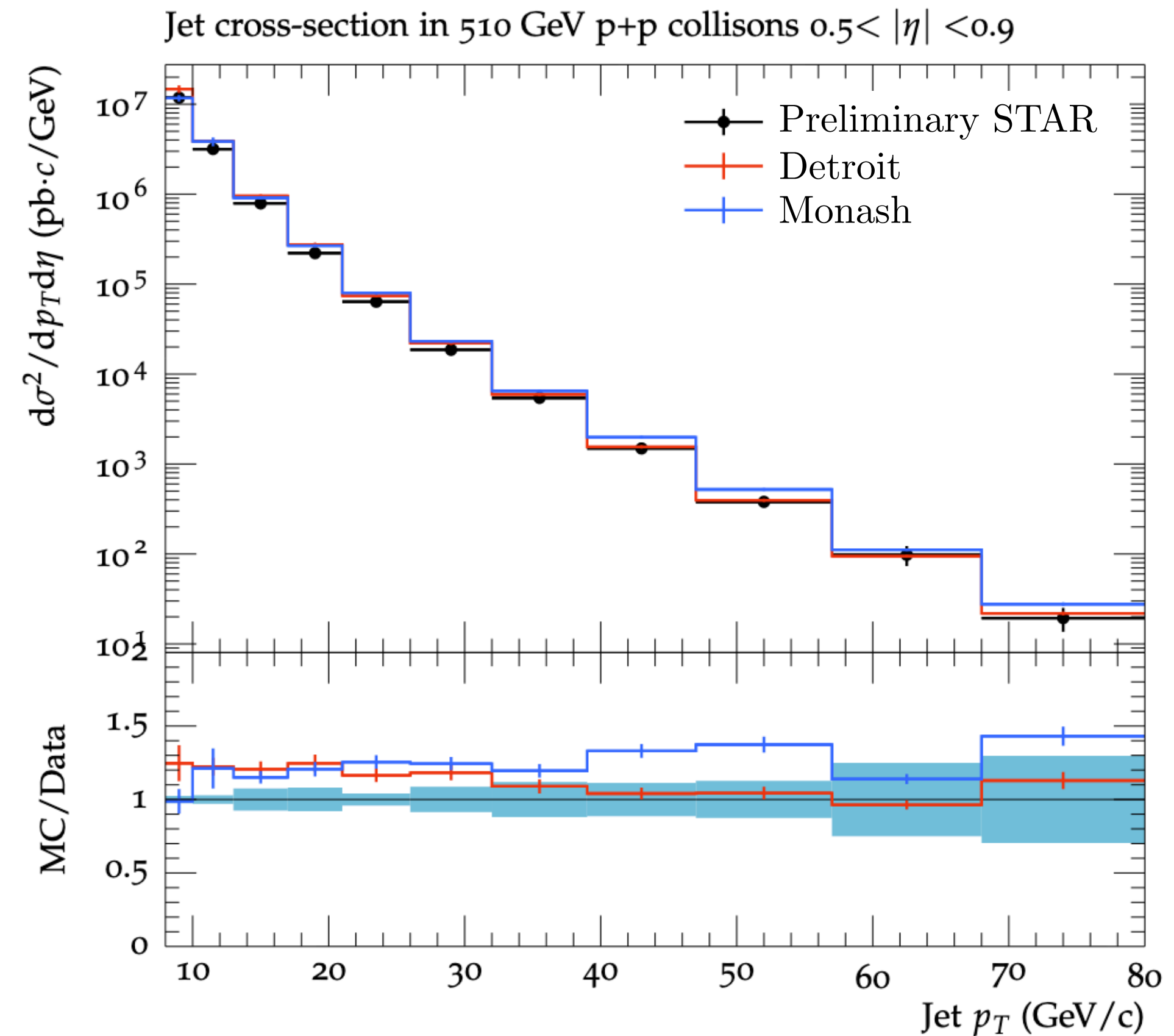
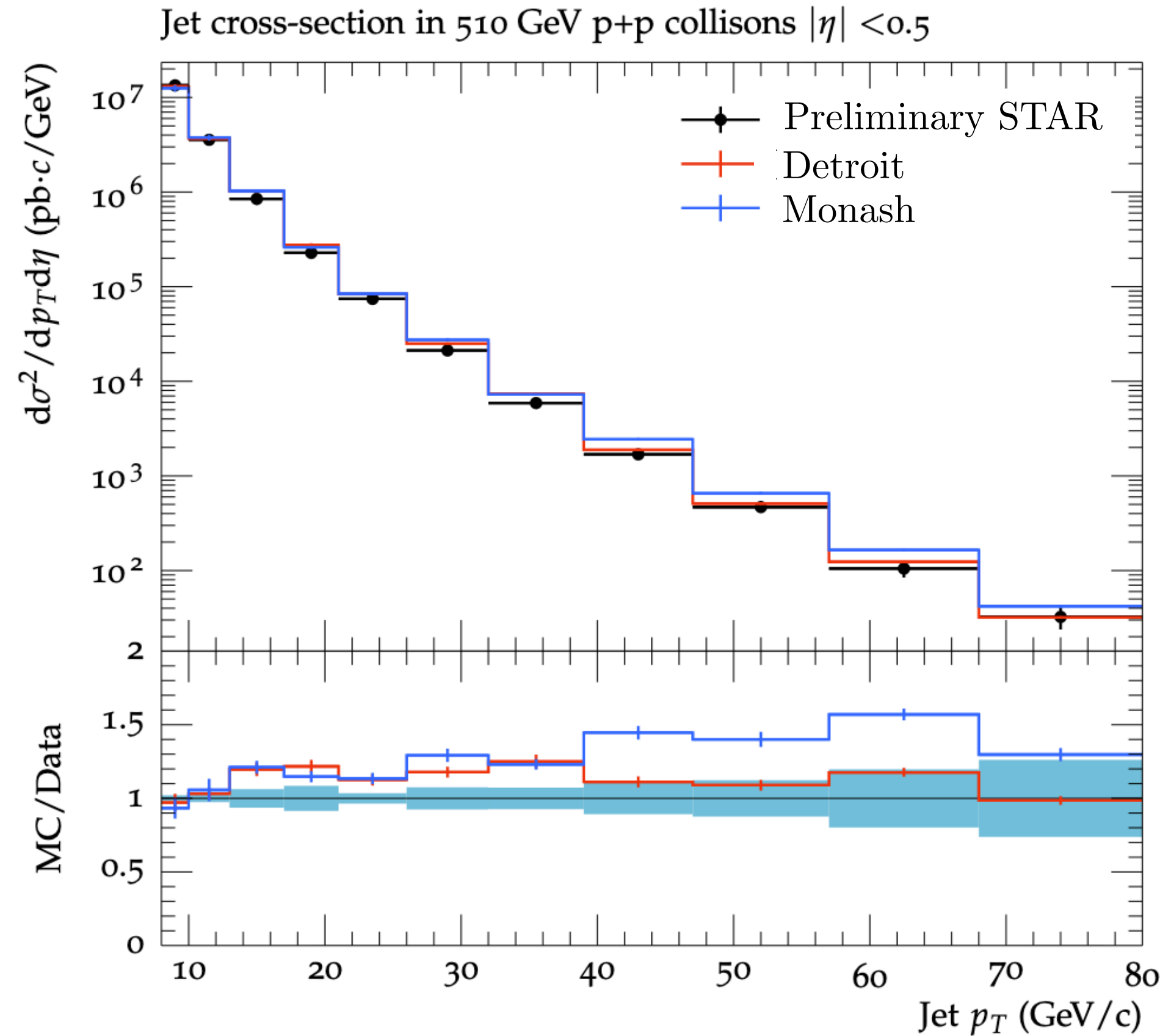
CDF Phys. Rev. D 92, 092009 (2015)



Representative plots at each energy; similar comparisons for p_{T} sum and transMIN

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

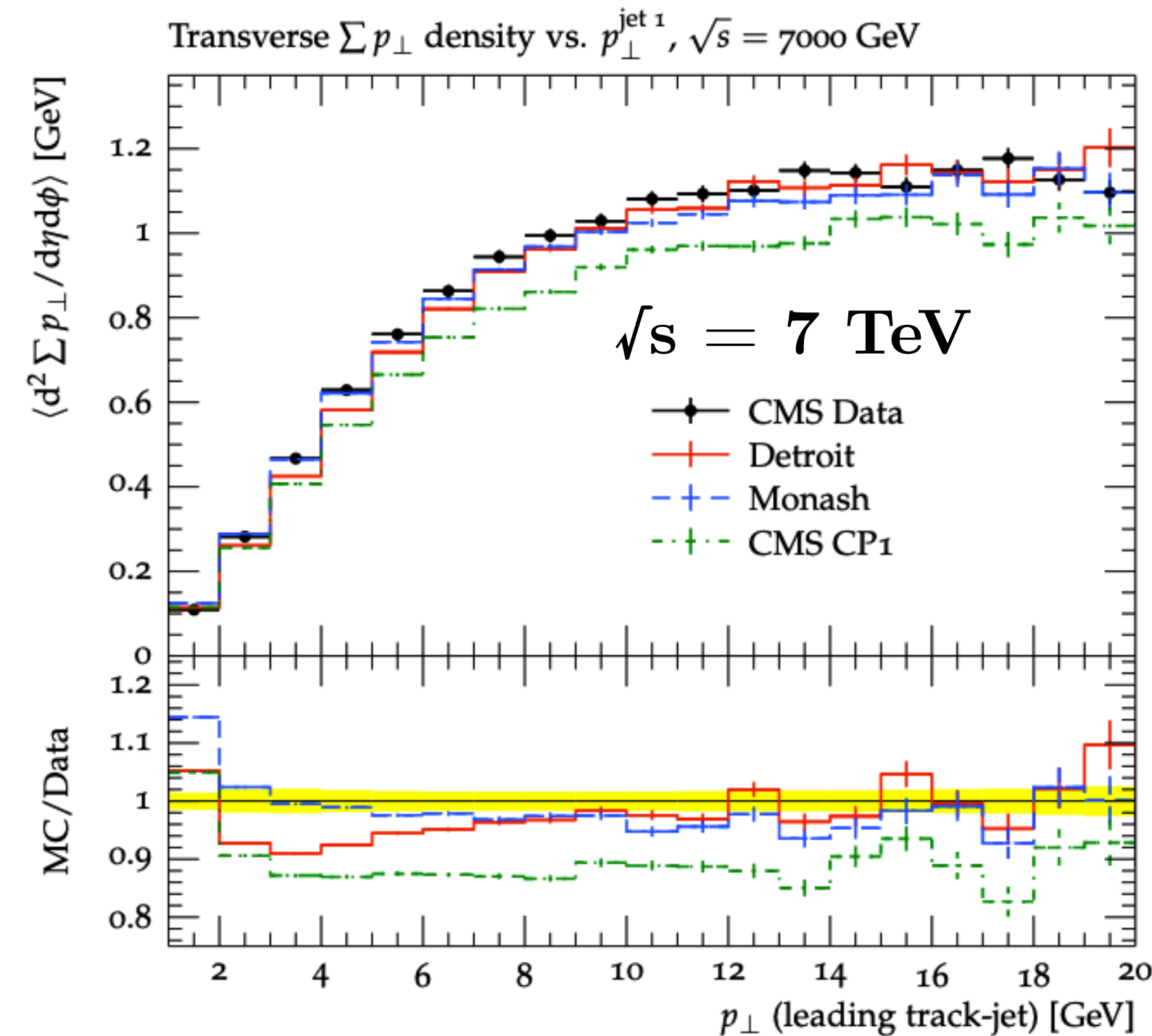
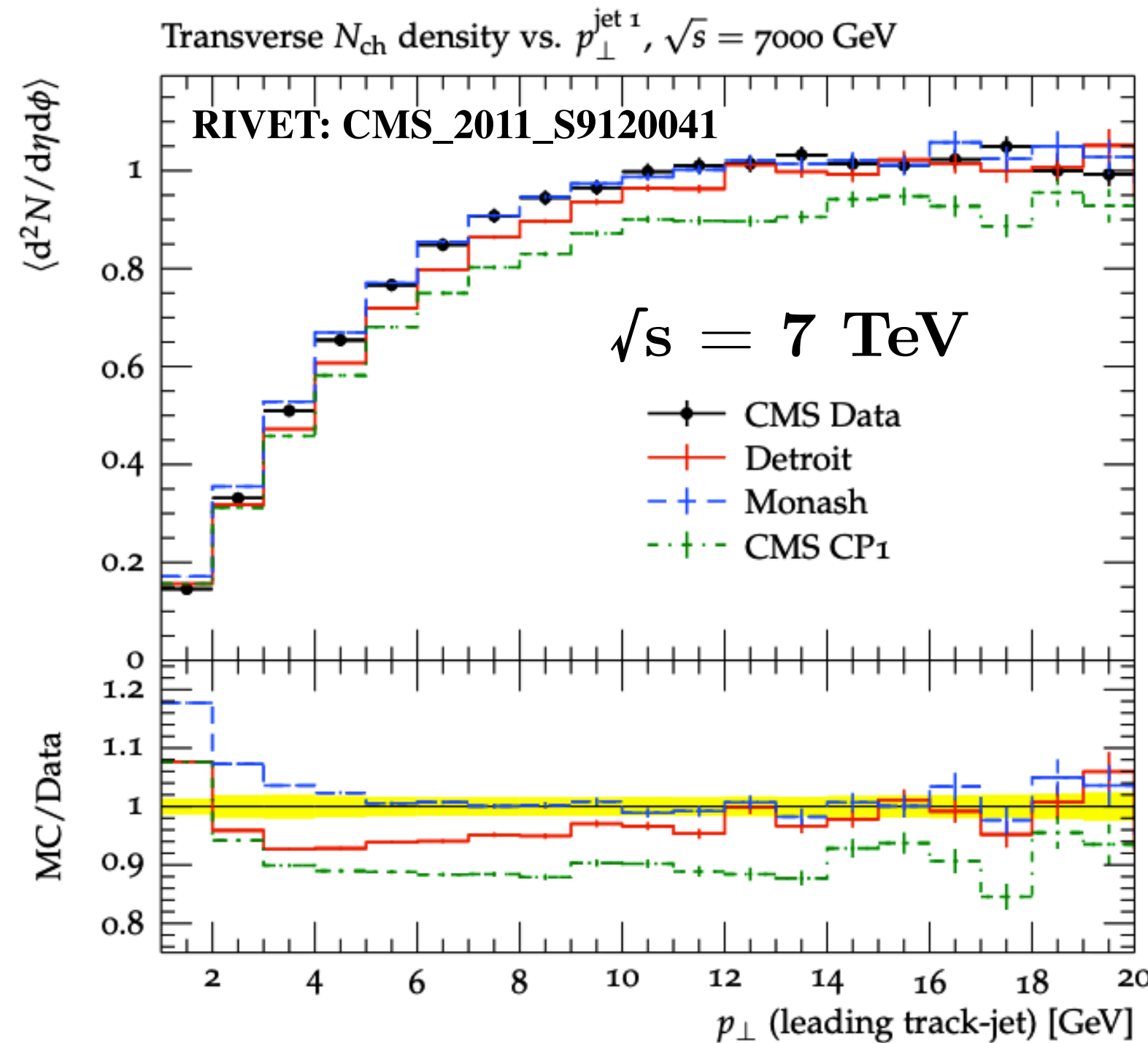
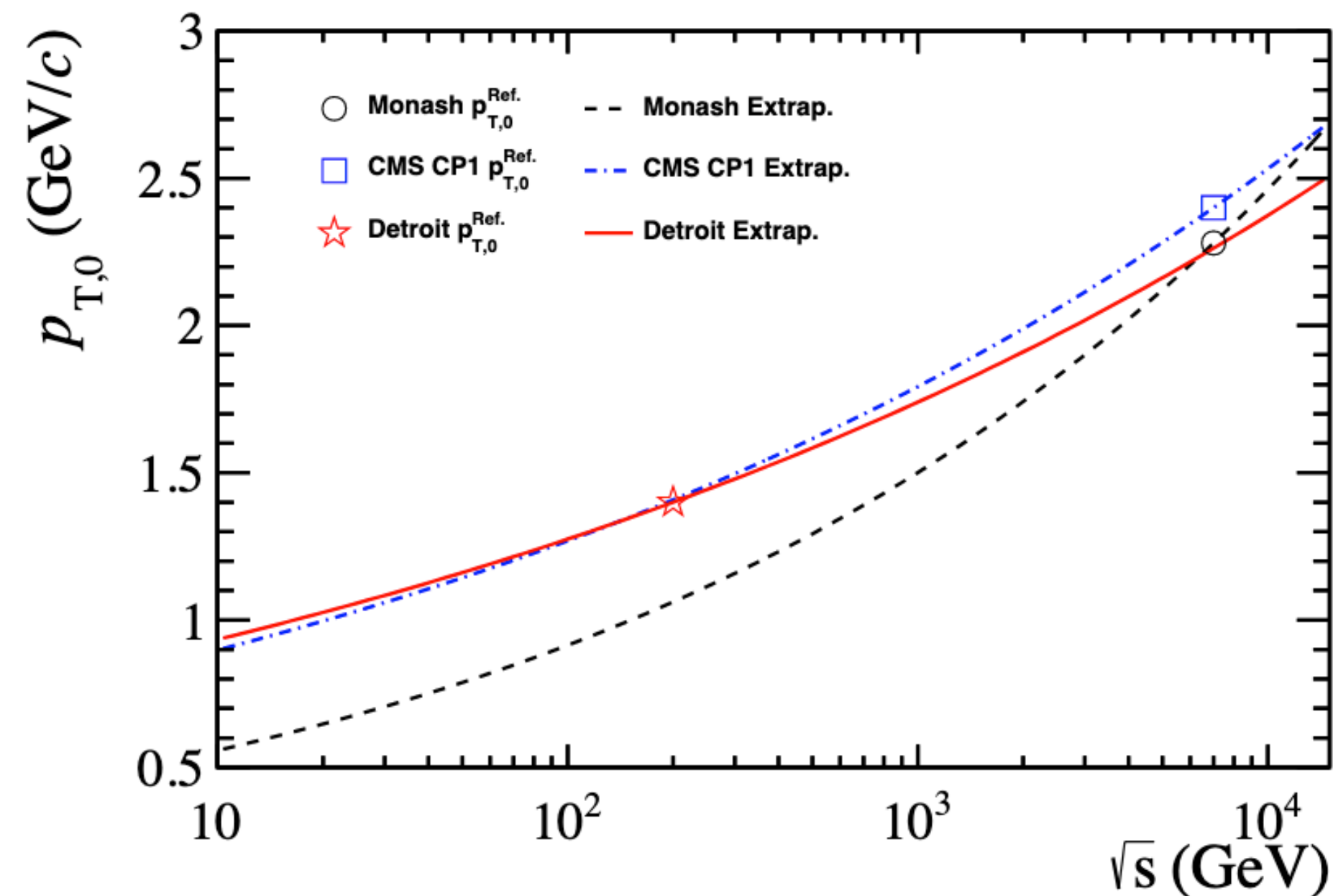
Energy Dependence: $\sqrt{s} = 510$ GeV



Comparisons with preliminary STAR inclusive jet spectra at 510 GeV improved in shape and scale - largely driven by new proton PDFs

Comparisons at LHC Energies: 7 TeV

CMS Journal of High Energy Physics 2011, 109 (2011)

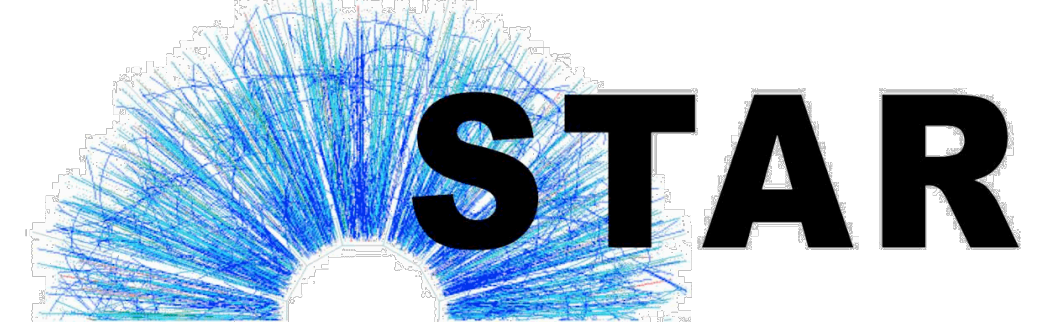


CMS CP tunes follow similar strategy as this exercise (European Physical Journal C 80, 4 (2020))

Extrapolation curve for Detroit tune less steep than Monash and CMS CP1 tunes

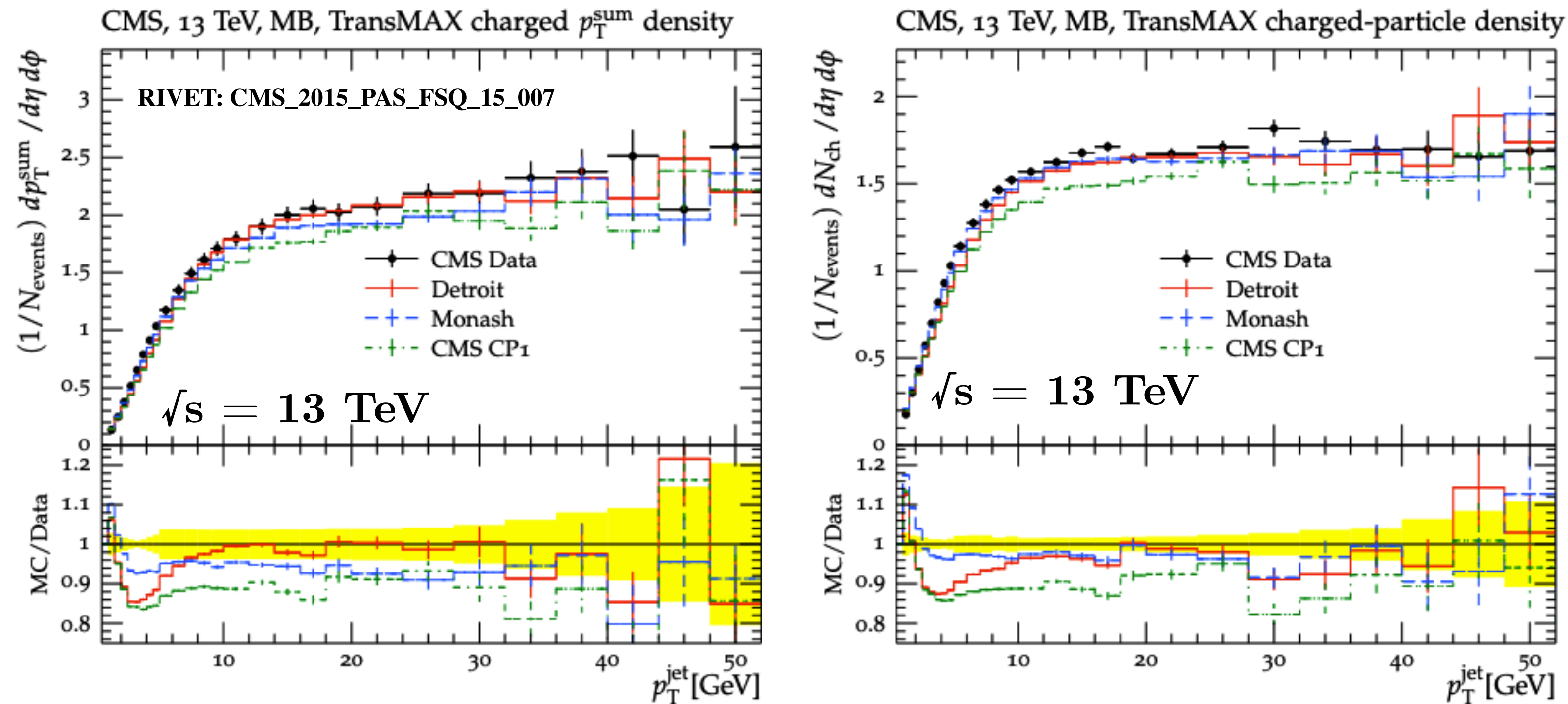
High leading track-jet p_T : Comparable to CMS underlying event data at 7 TeV, and Monash tune; deviations at low p_T

Comparisons at LHC Energies: 13 TeV



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

Representative plots
(see backup)



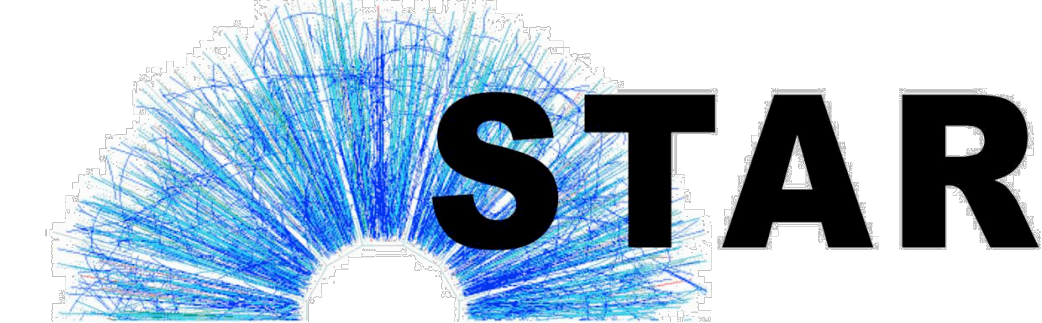
Comparable or better than Monash tune at high p_T ; deviations with data at low p_T

- Likely driven by different proton shape function used

High p_T region significantly impacted by long-lived decays in MC

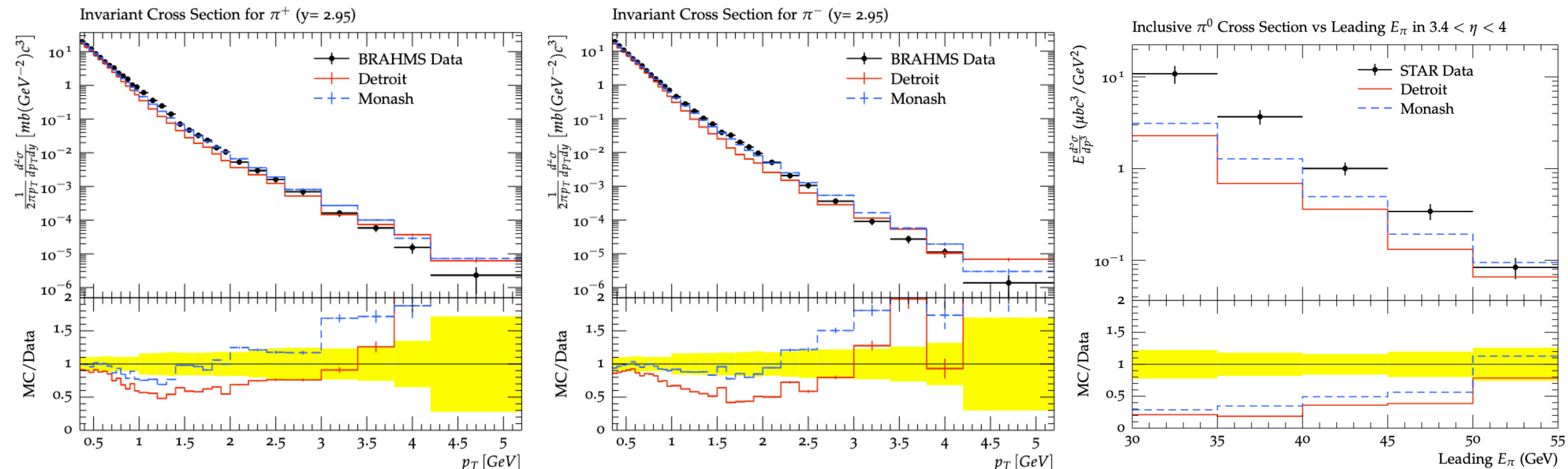
- Explicitly turned off here; could resolve CMS CP1 discrepancy

Forward Rapidity Comparisons



BRAHMS Phys. Rev. Lett. 98, 252001 (2007)

Phys. Rev. Lett. 92, 171801 (2004)



Both Monash and Detroit tunes can't describe forward pion spectra from BRAHMS or STAR

- New tune does worse than Monash...
- Simultaneous tune with mid-rapidity and larger tune-able phase space (ISR) unable to recover MC/data agreement

Desirable to resolve for RHIC programs starting in 2022 (forward STAR upgrade), and future Electron-Ion Collider program

PYTHIA 8 tuned to underlying event data at $\sqrt{s} = 200\text{-}1960$ GeV:

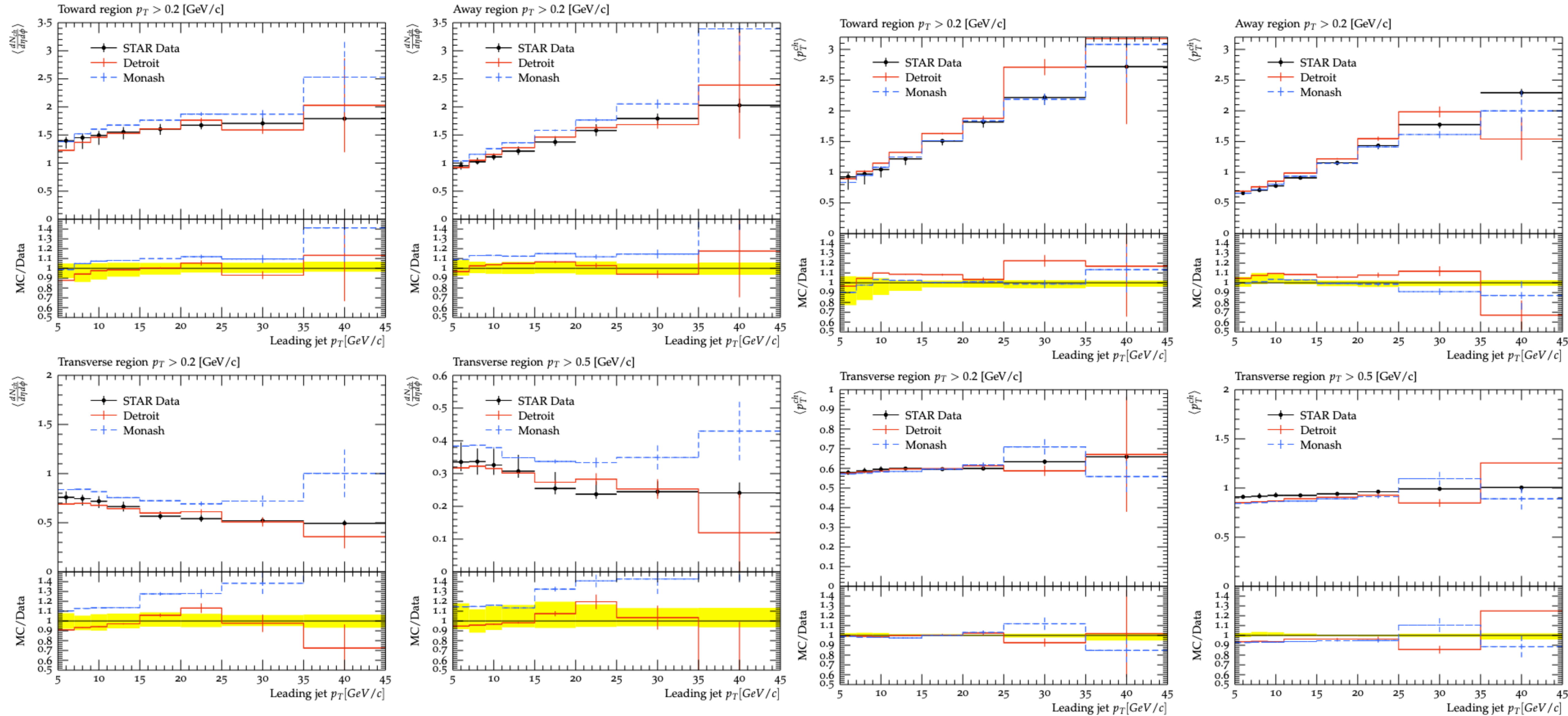
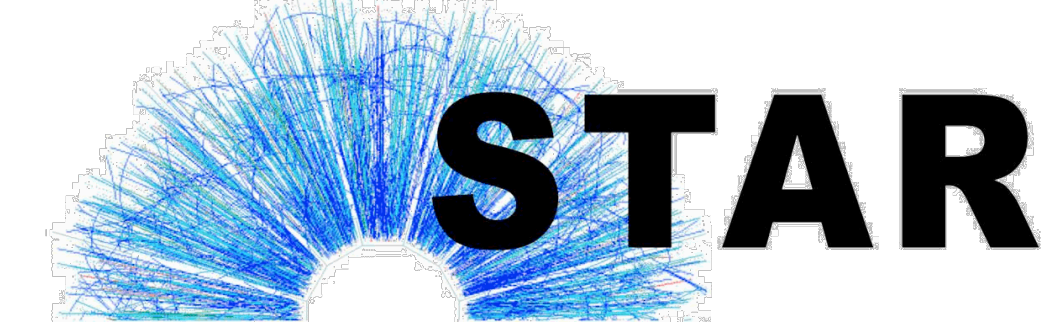
The 'Detroit' Tune

- Significant improvement in the description of data at all energies used in tuning
- Underlying event observables vs. leading particle/jet at high p_T described at $\sqrt{s} = 7$ and 13 TeV; Comparable or better than Monash tune
- Manuscript in preparation... stay *tuned!*

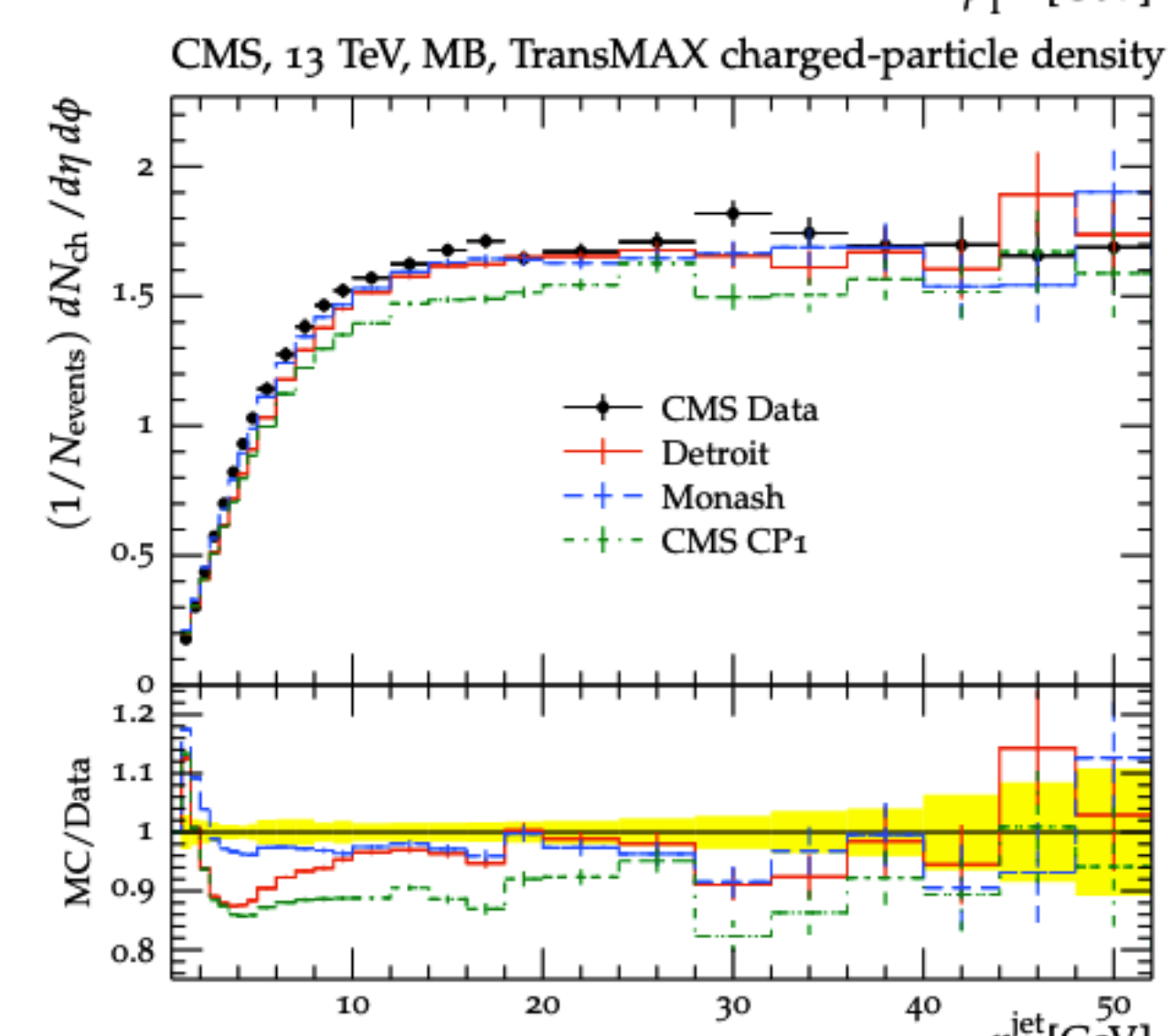
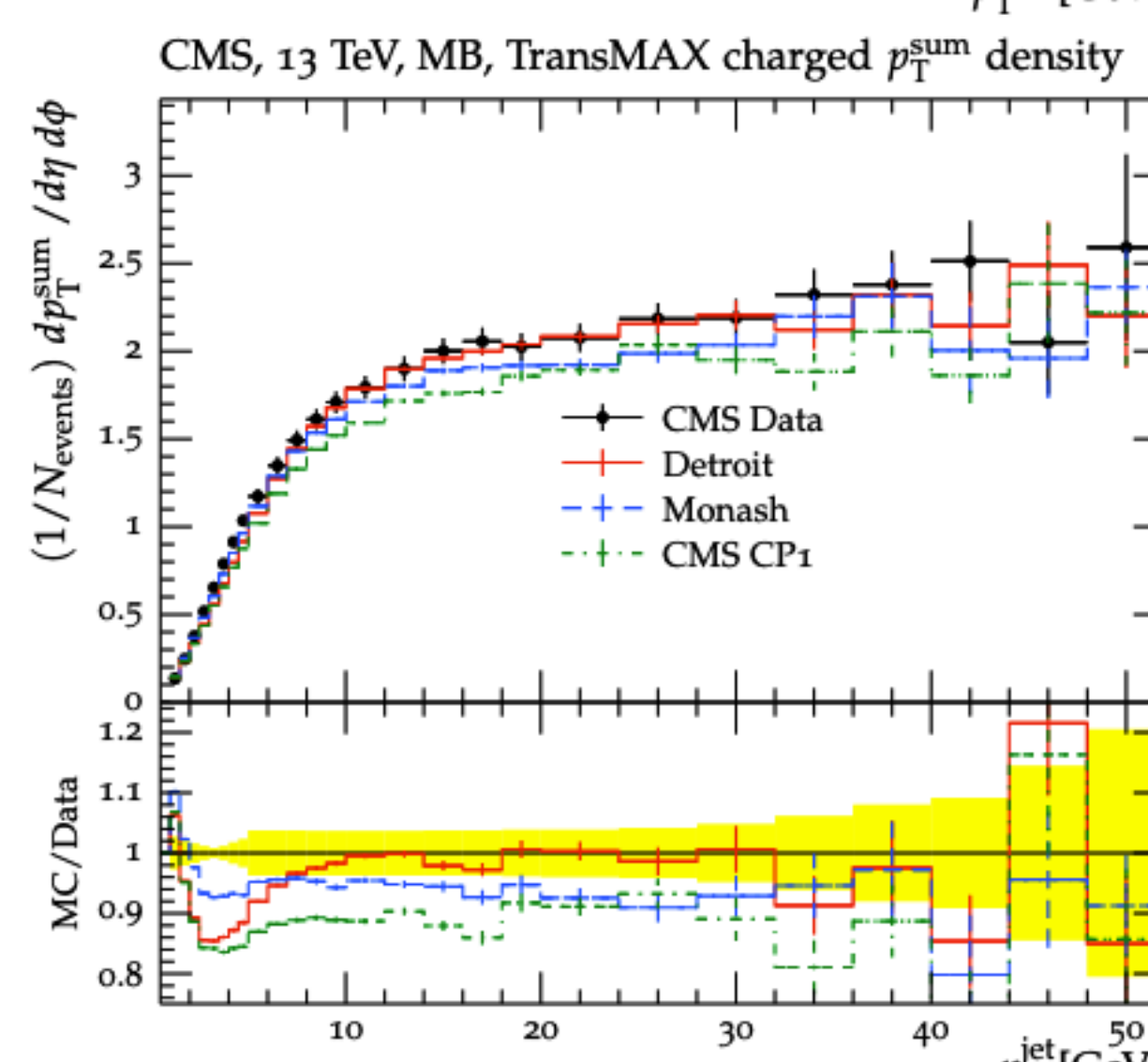
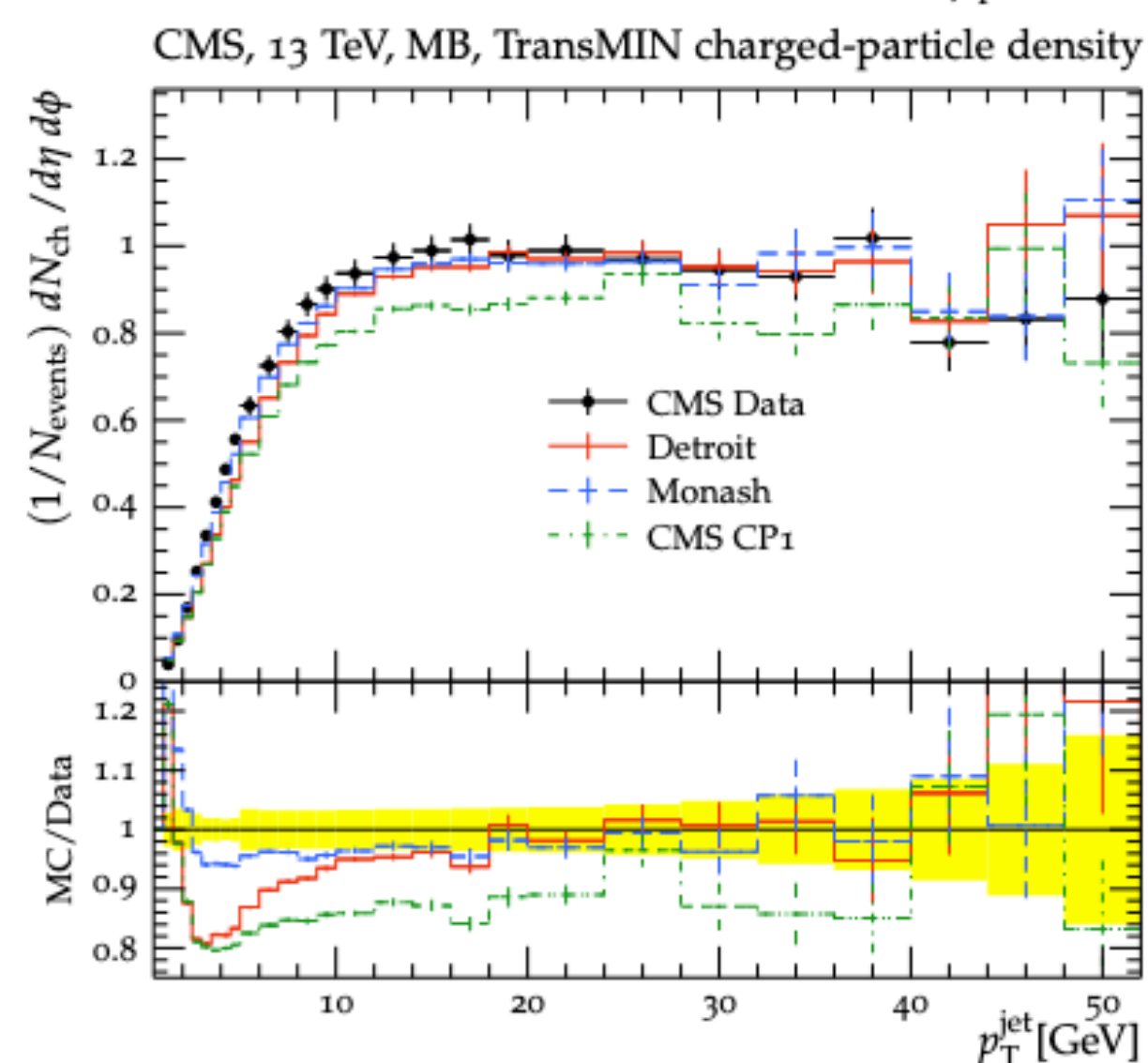
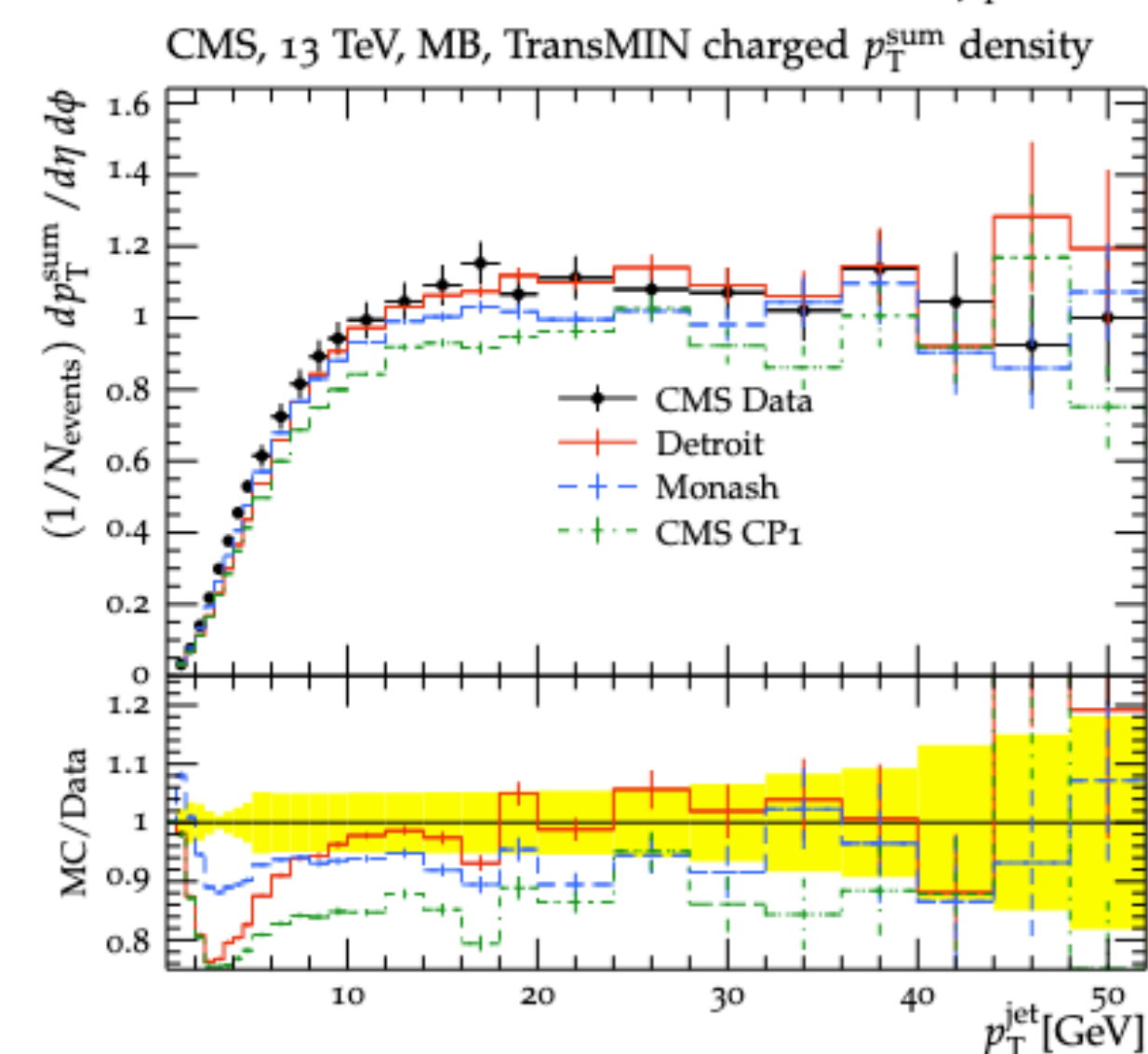
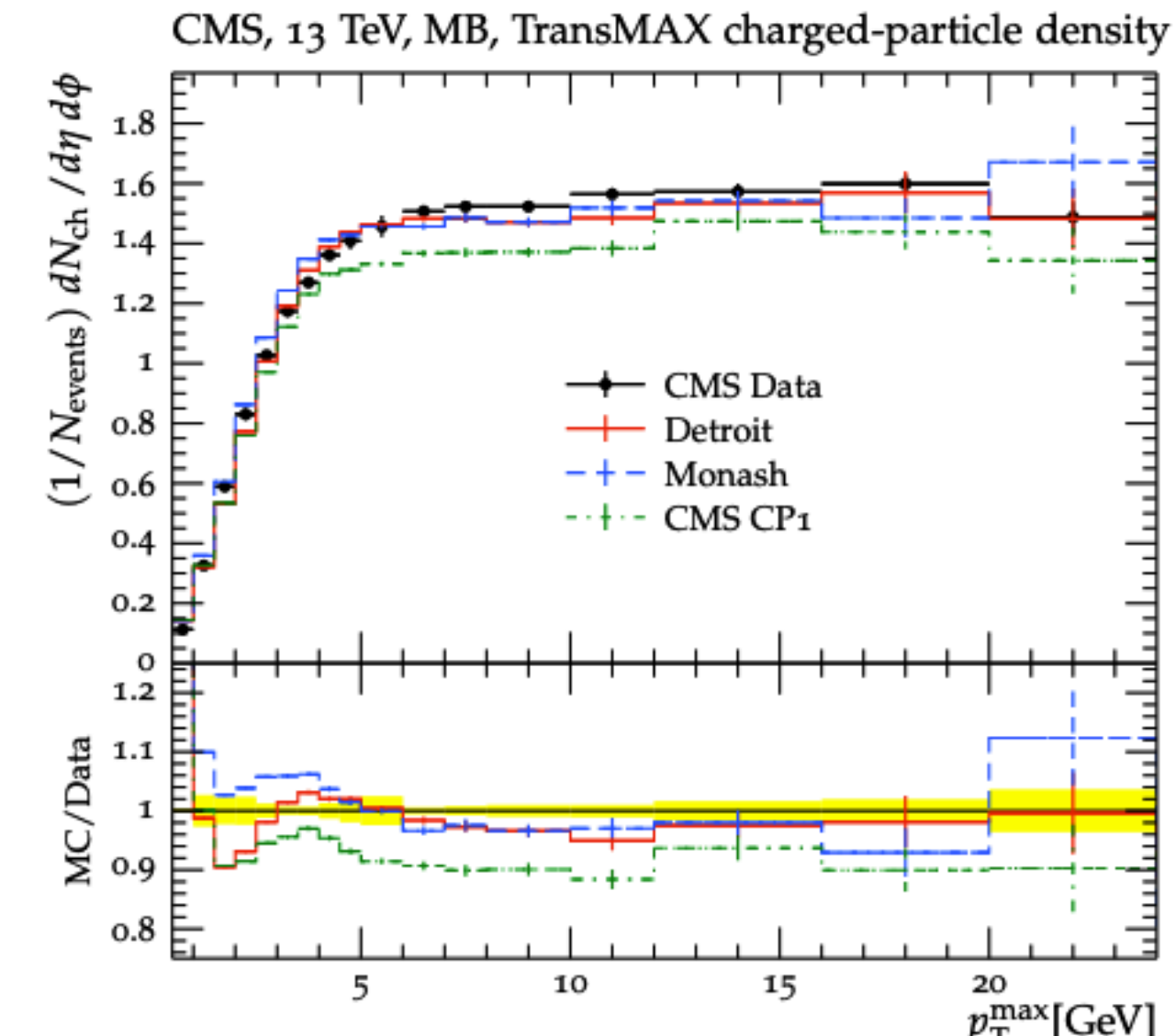
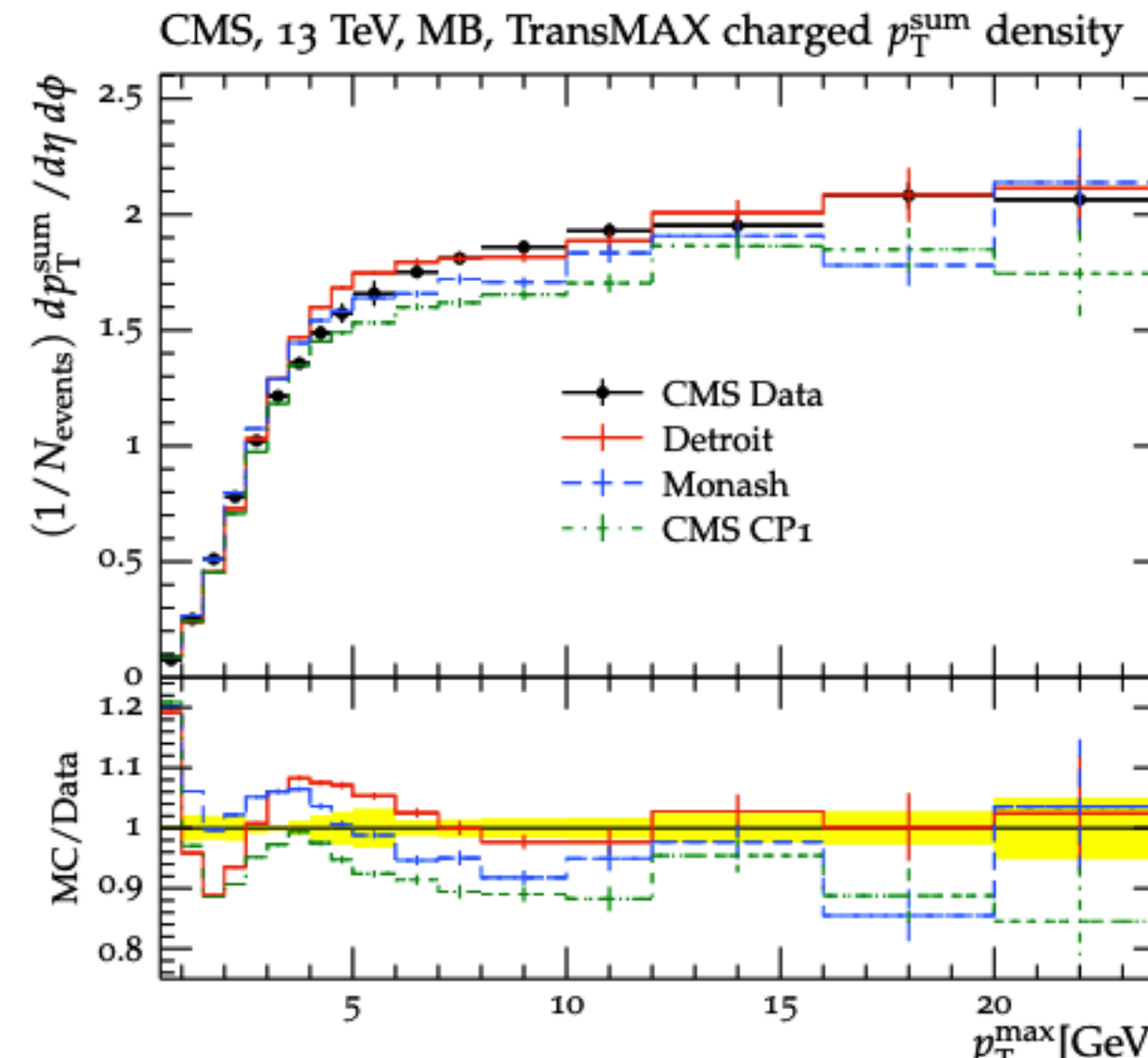
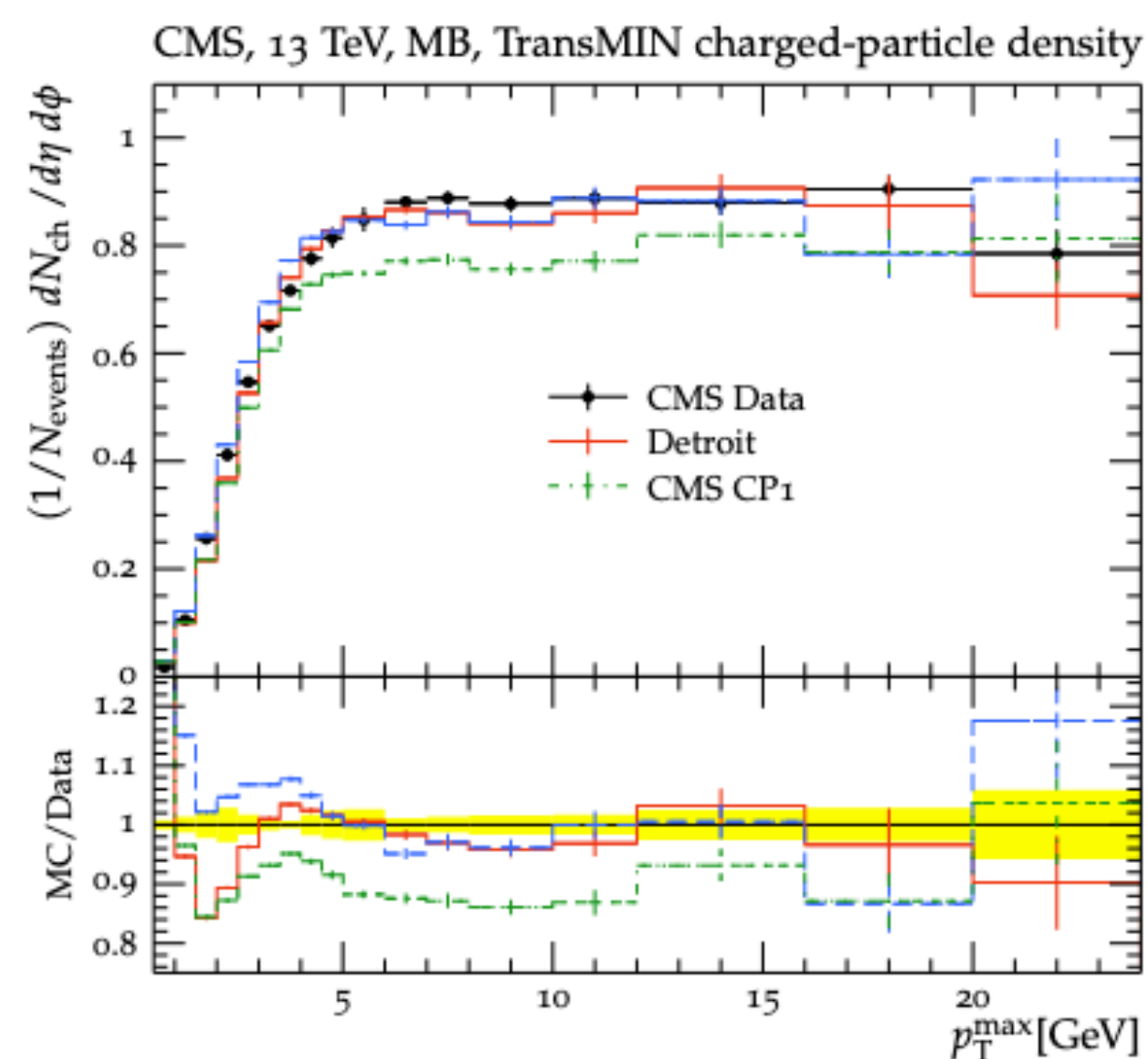
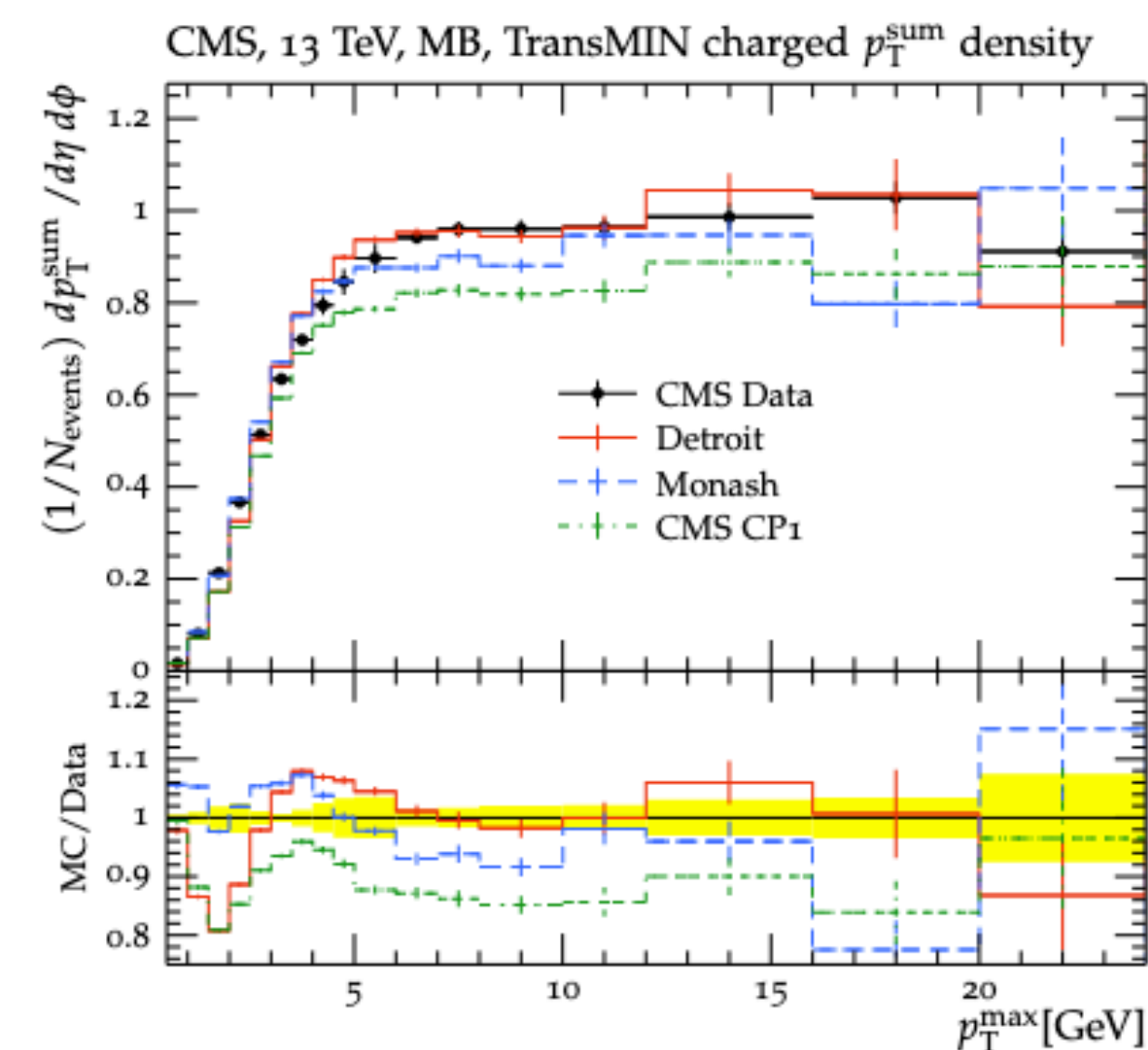
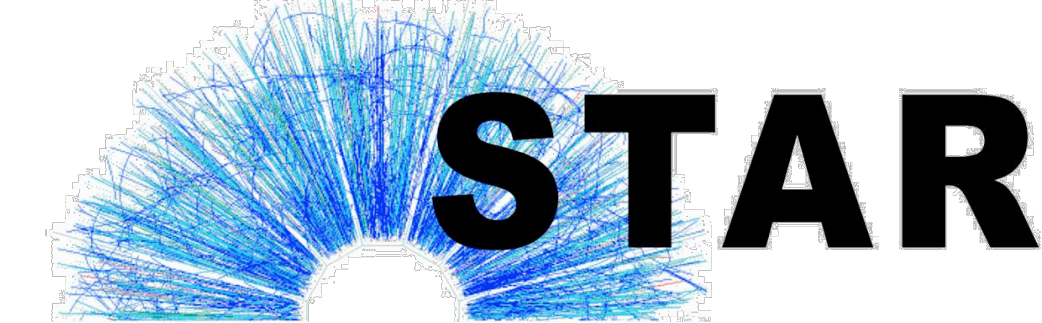
Simultaneous description of both mid- and forward-rapidity data currently not achievable → **Highly desired for upcoming (2022+) STAR forward upgrade data!**

Backup Slides Follow

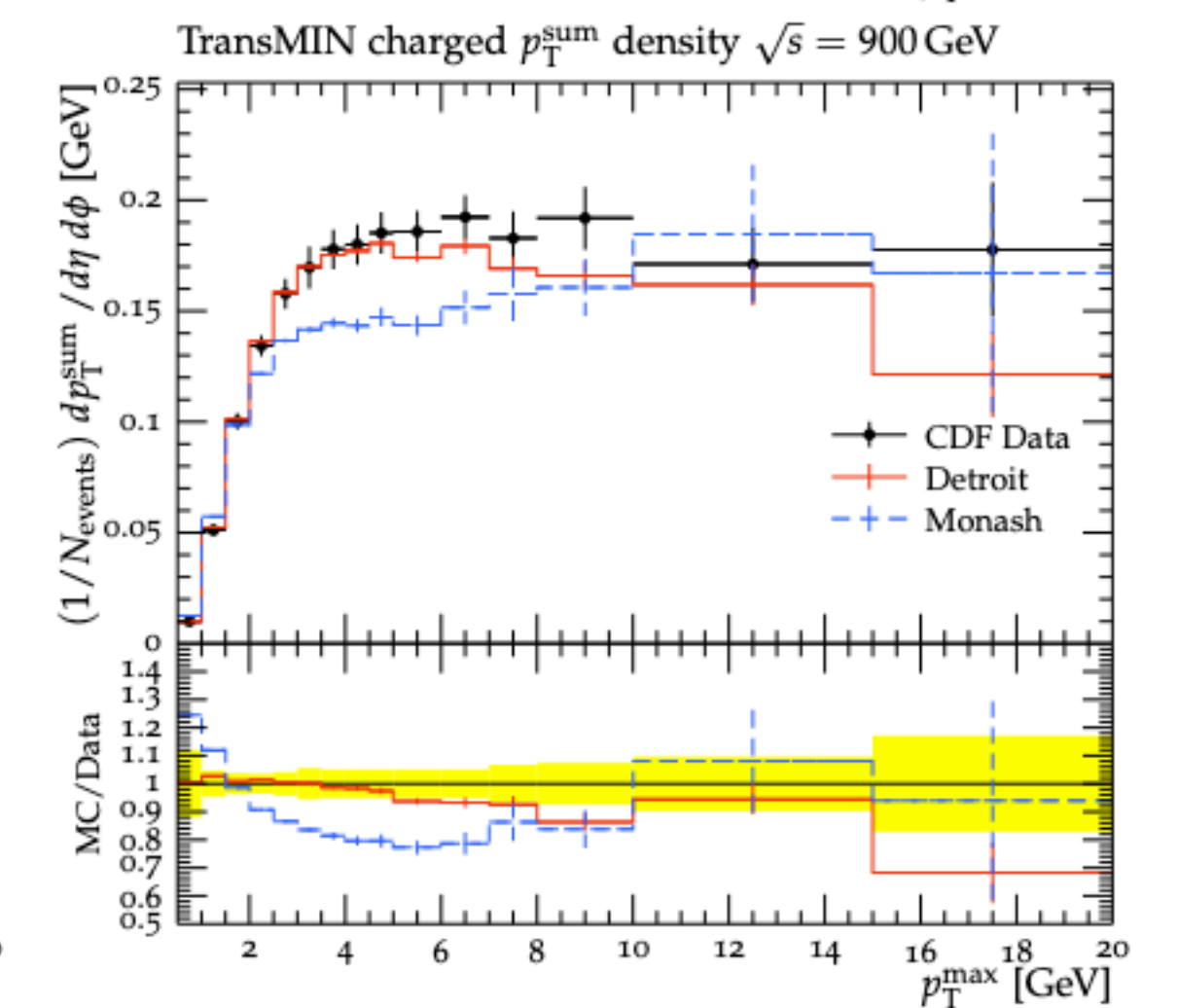
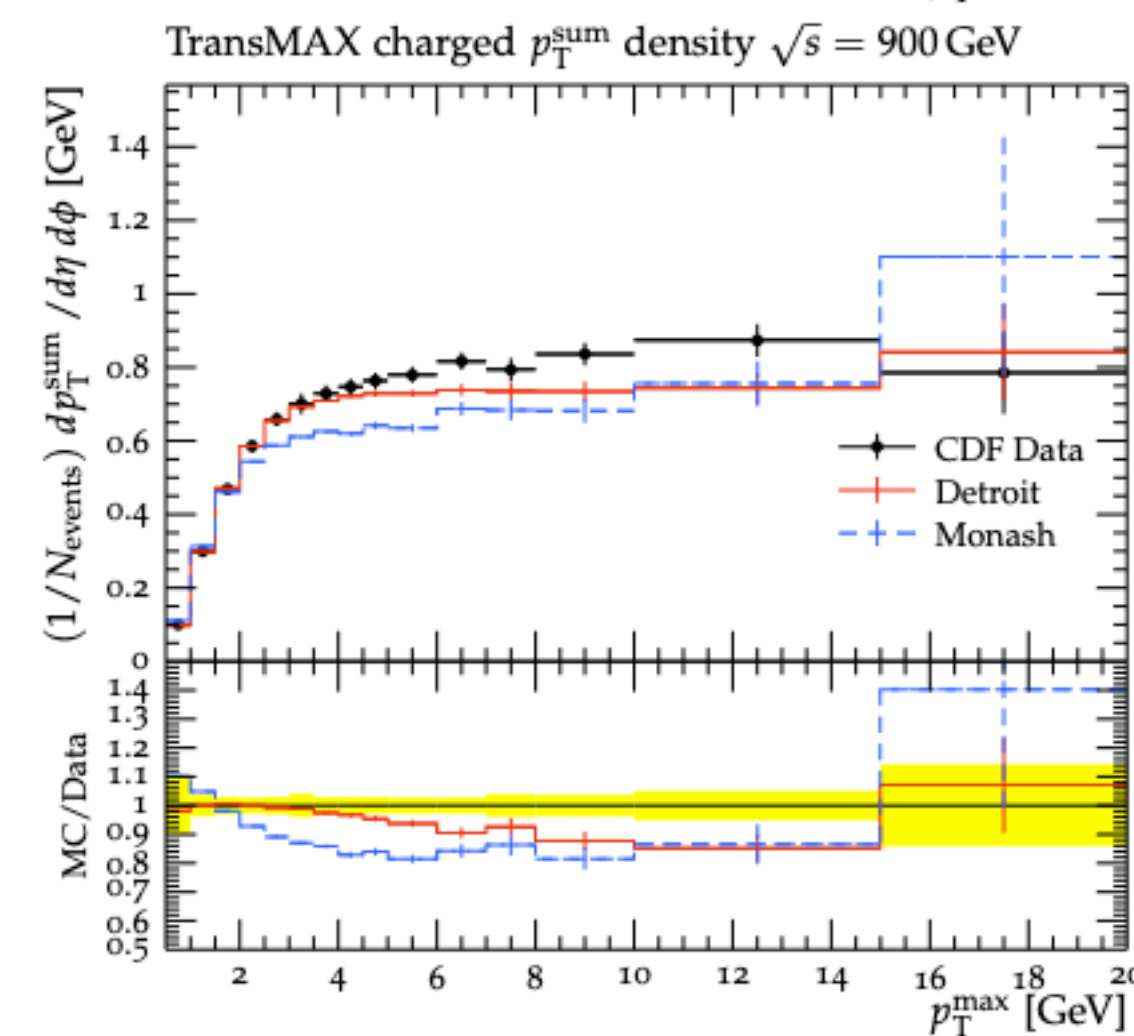
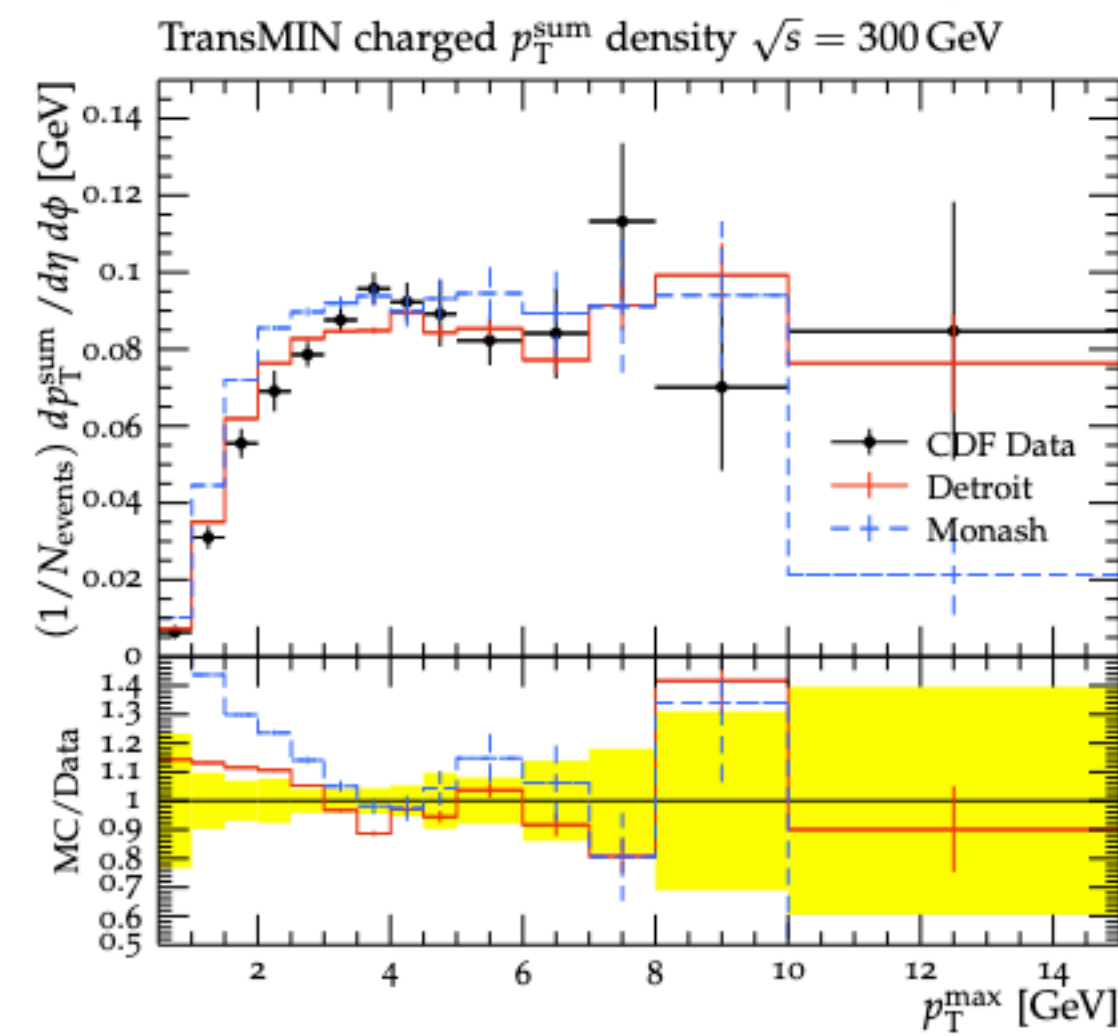
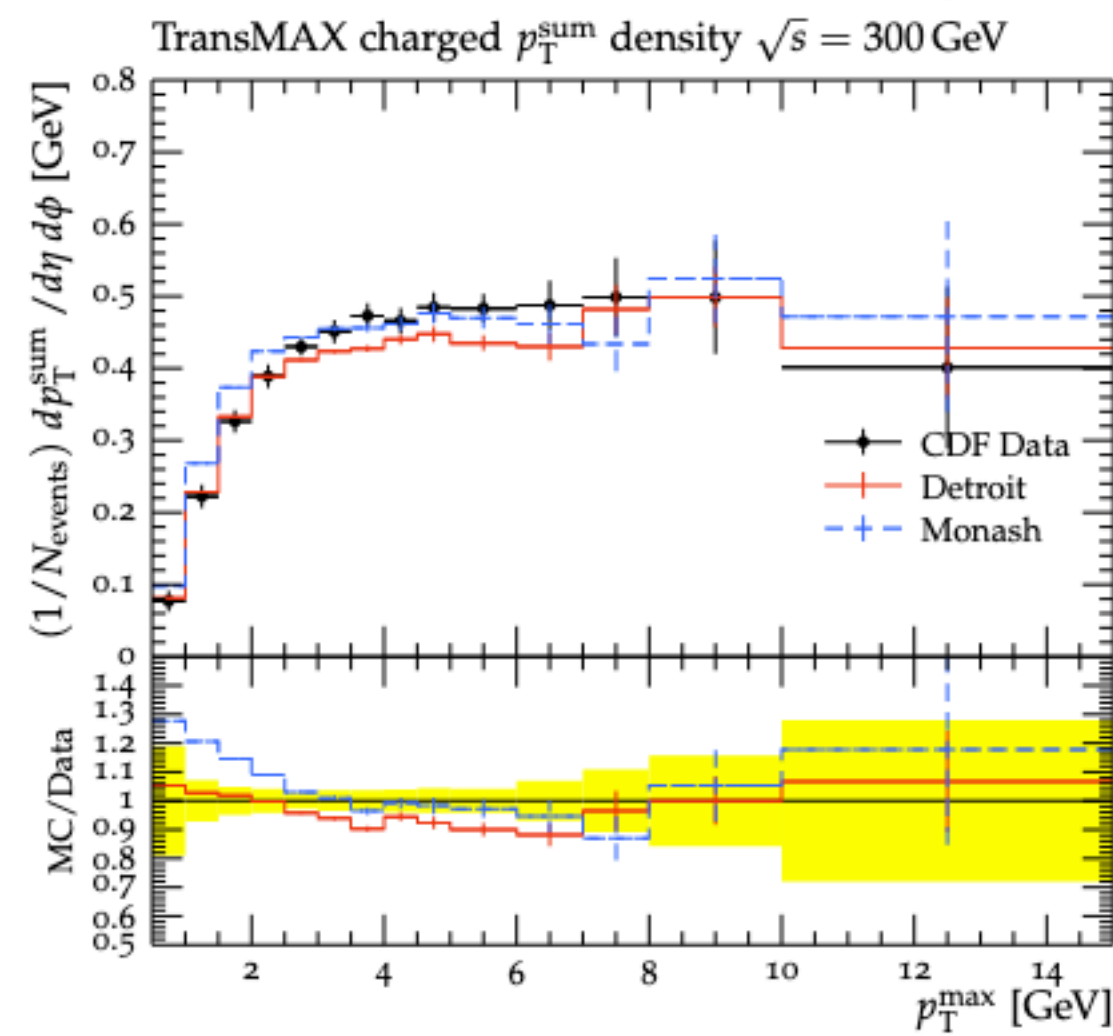
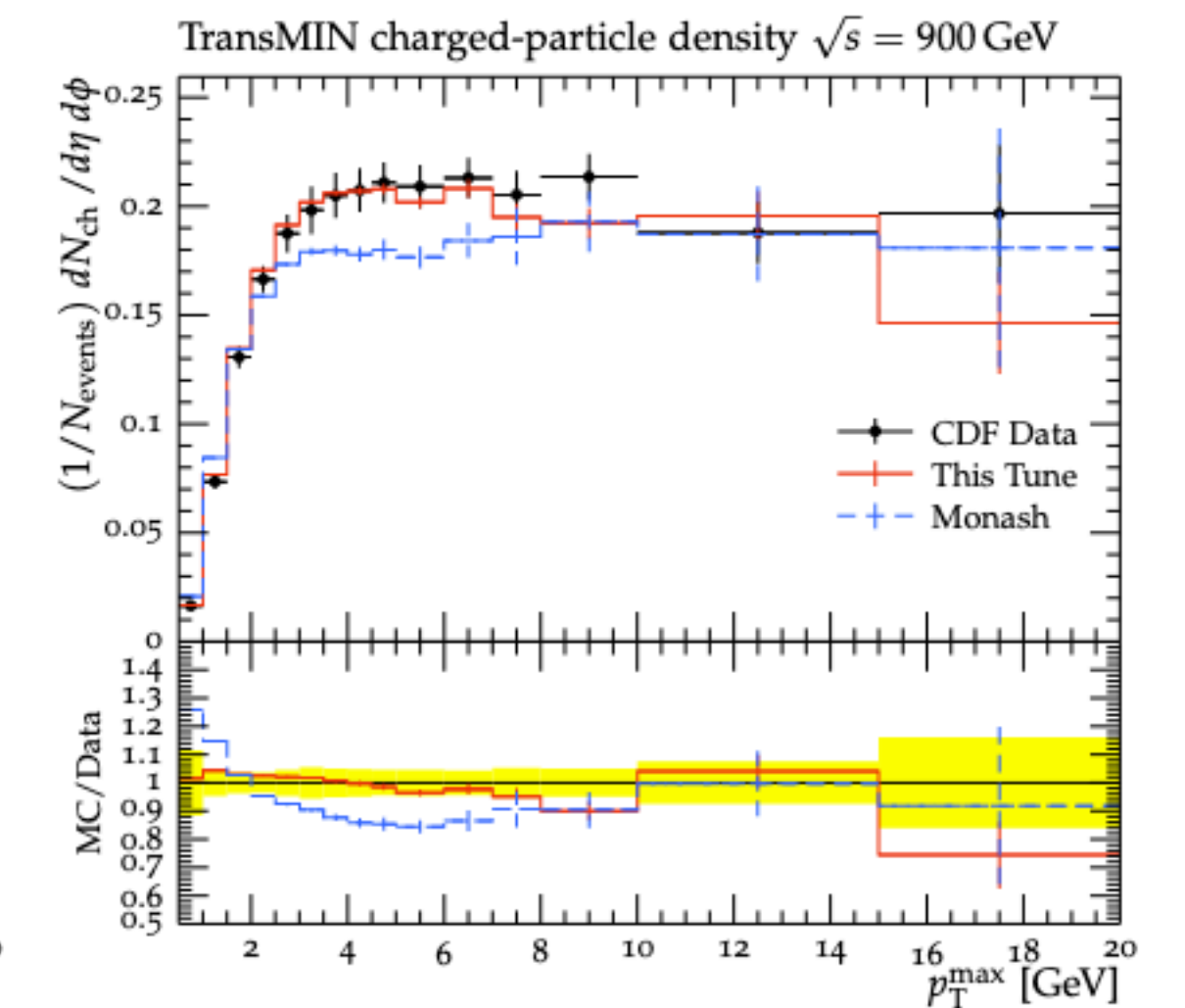
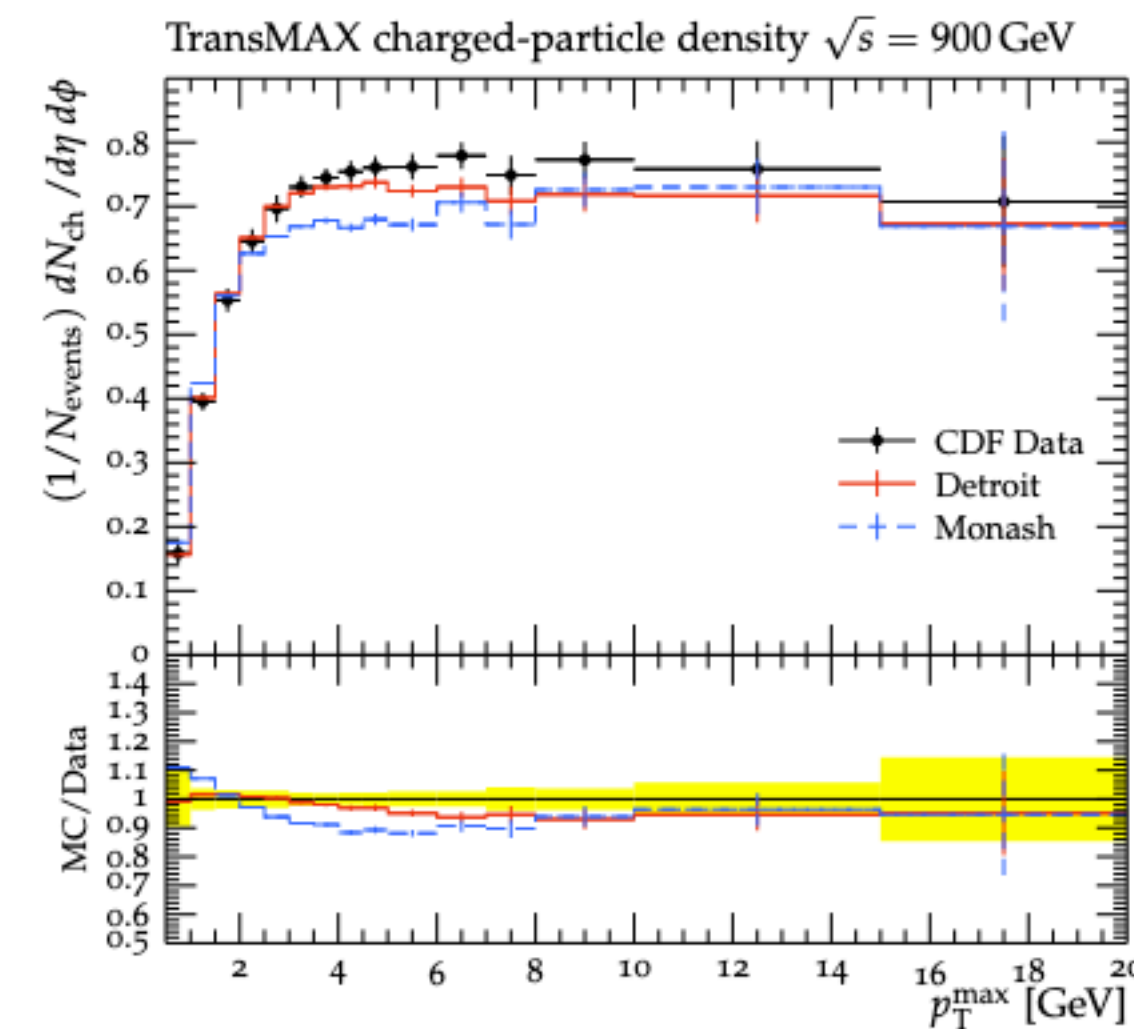
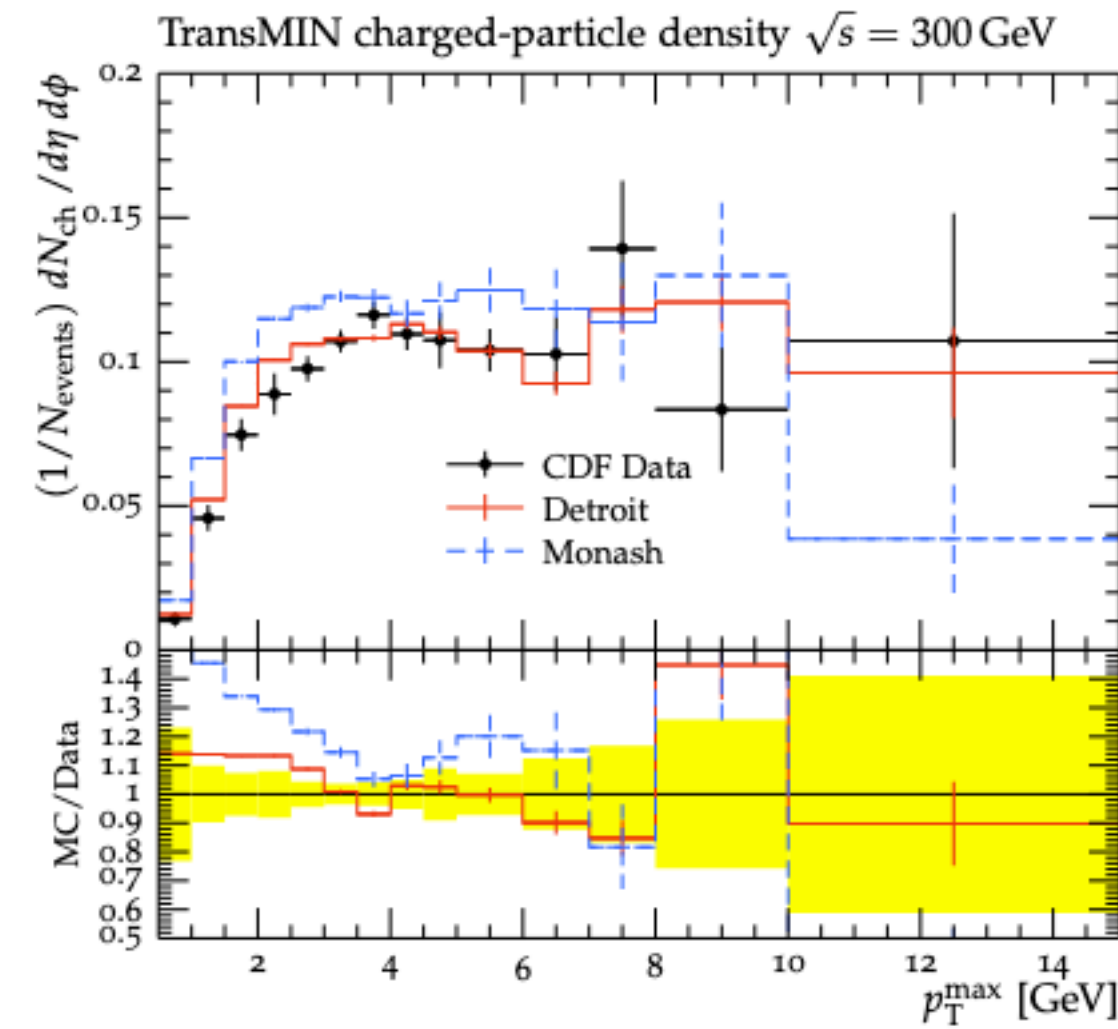
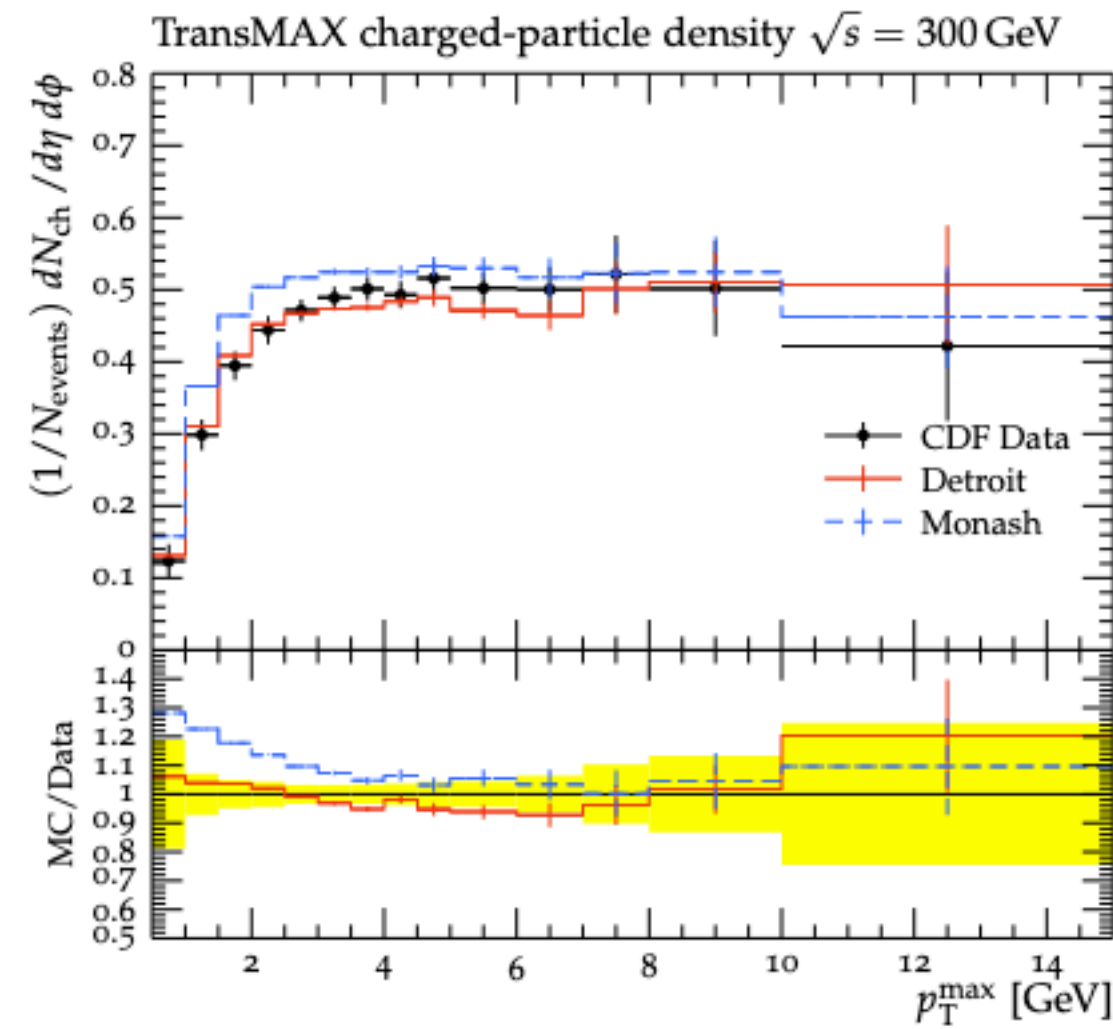
Underling Event @ 200 GeV



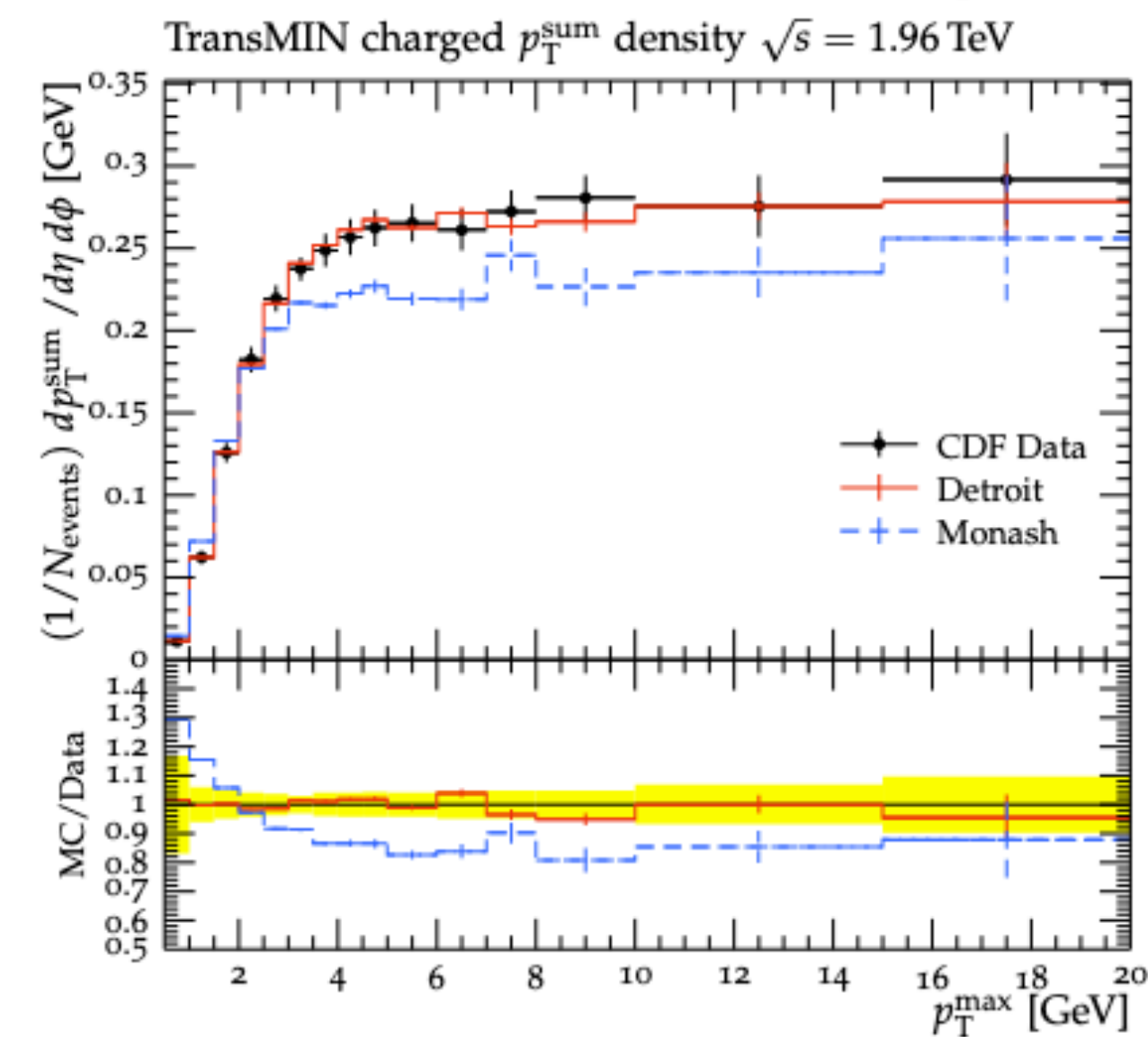
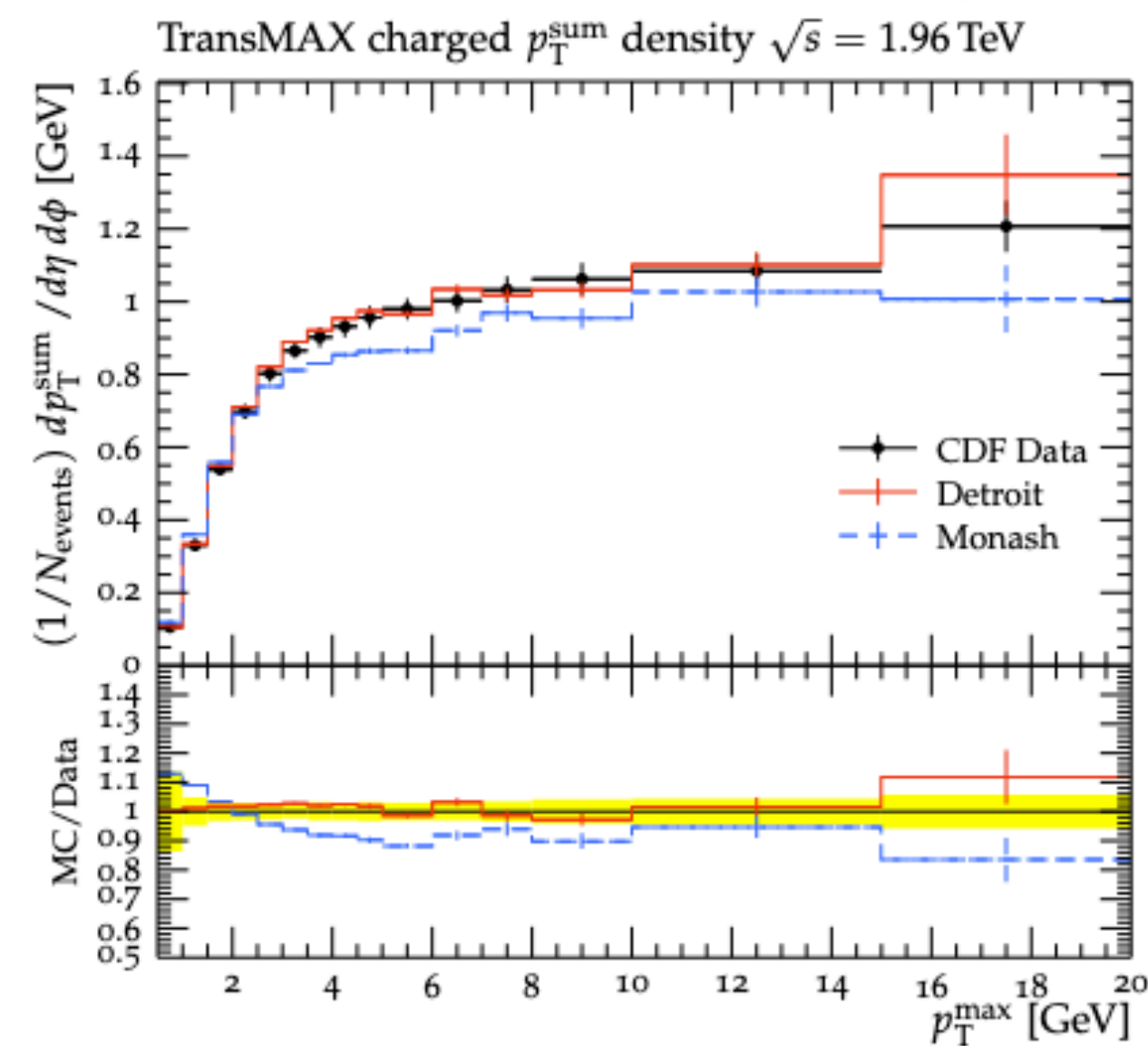
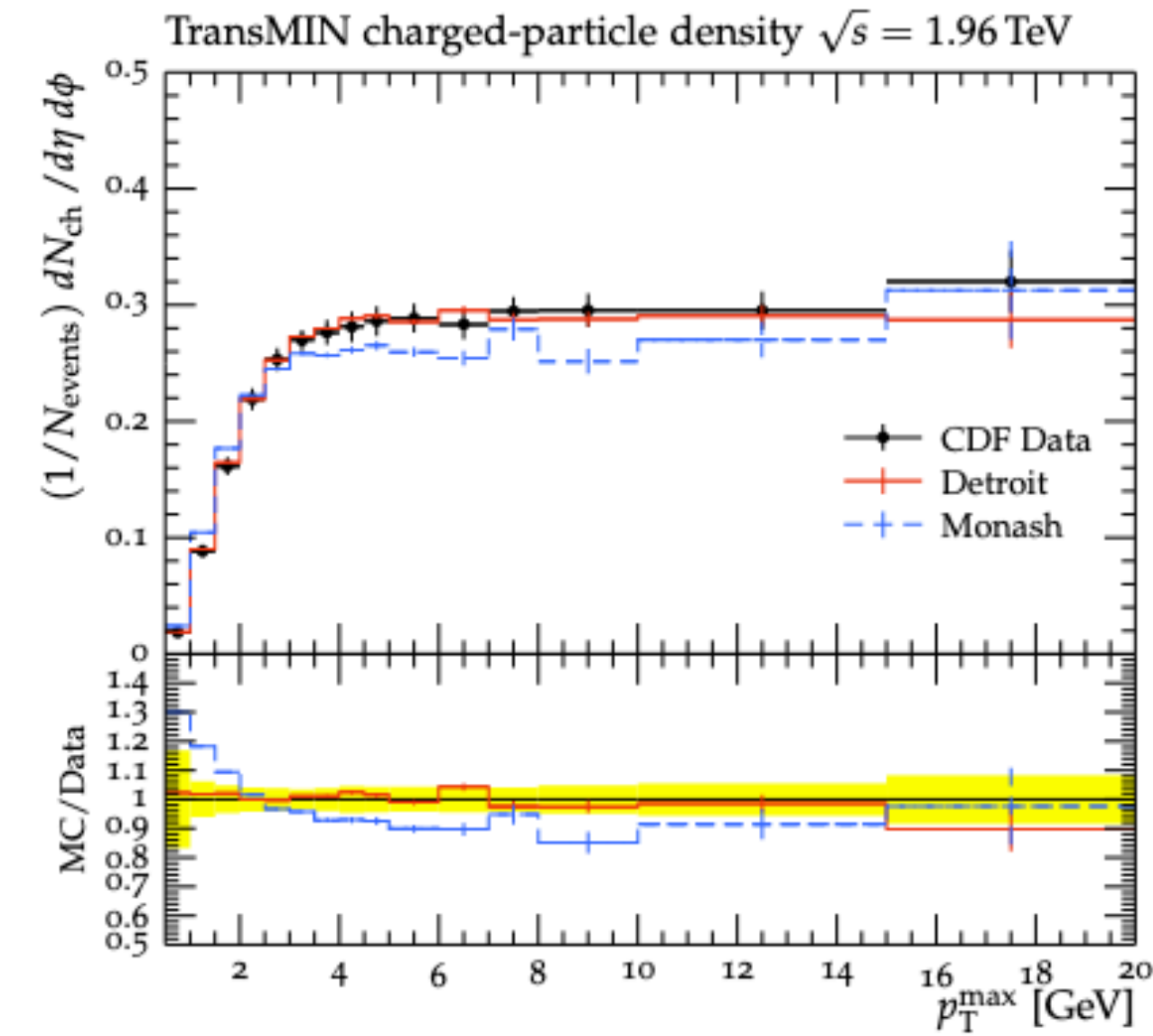
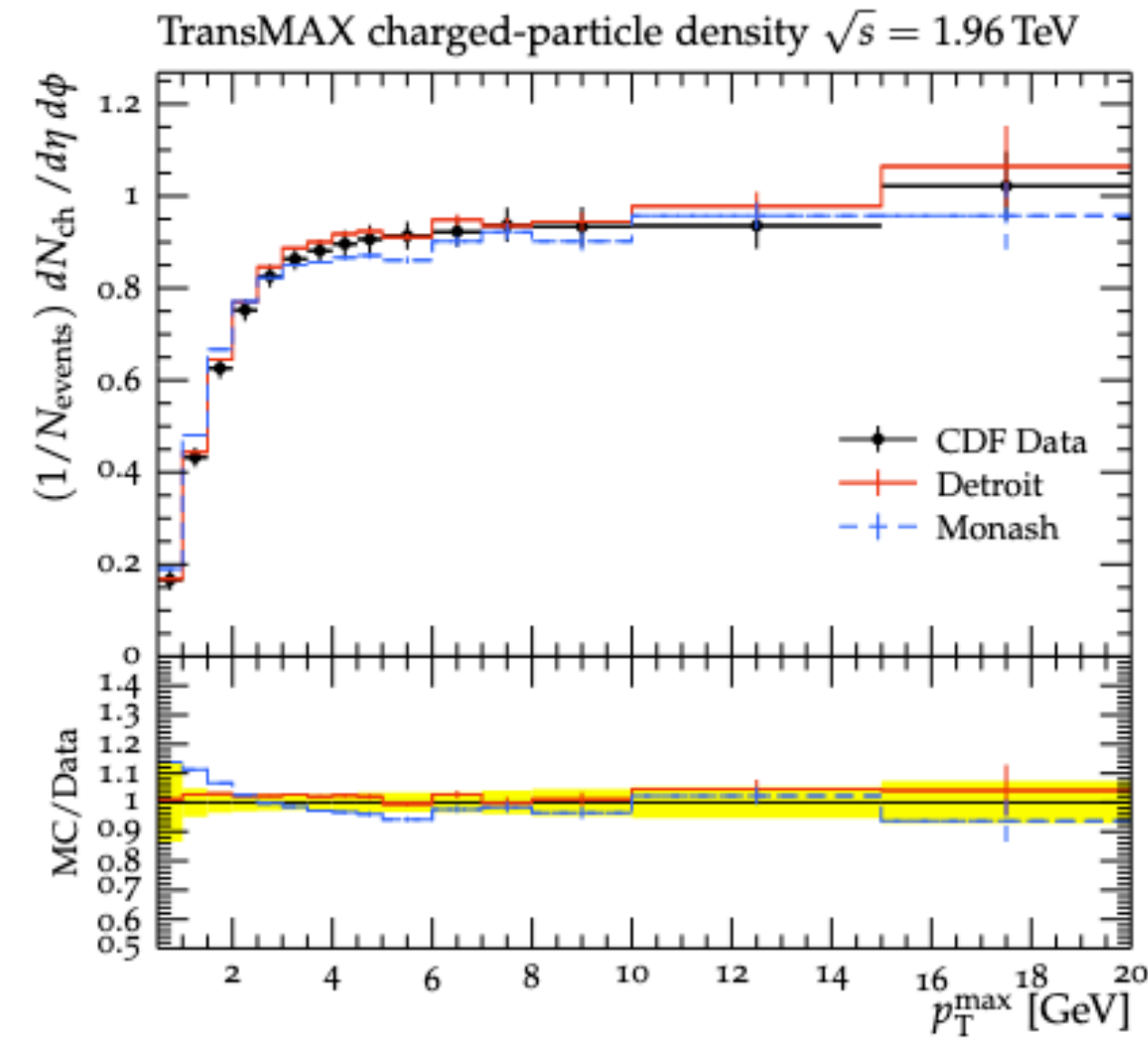
Underling Event @ 13 TeV

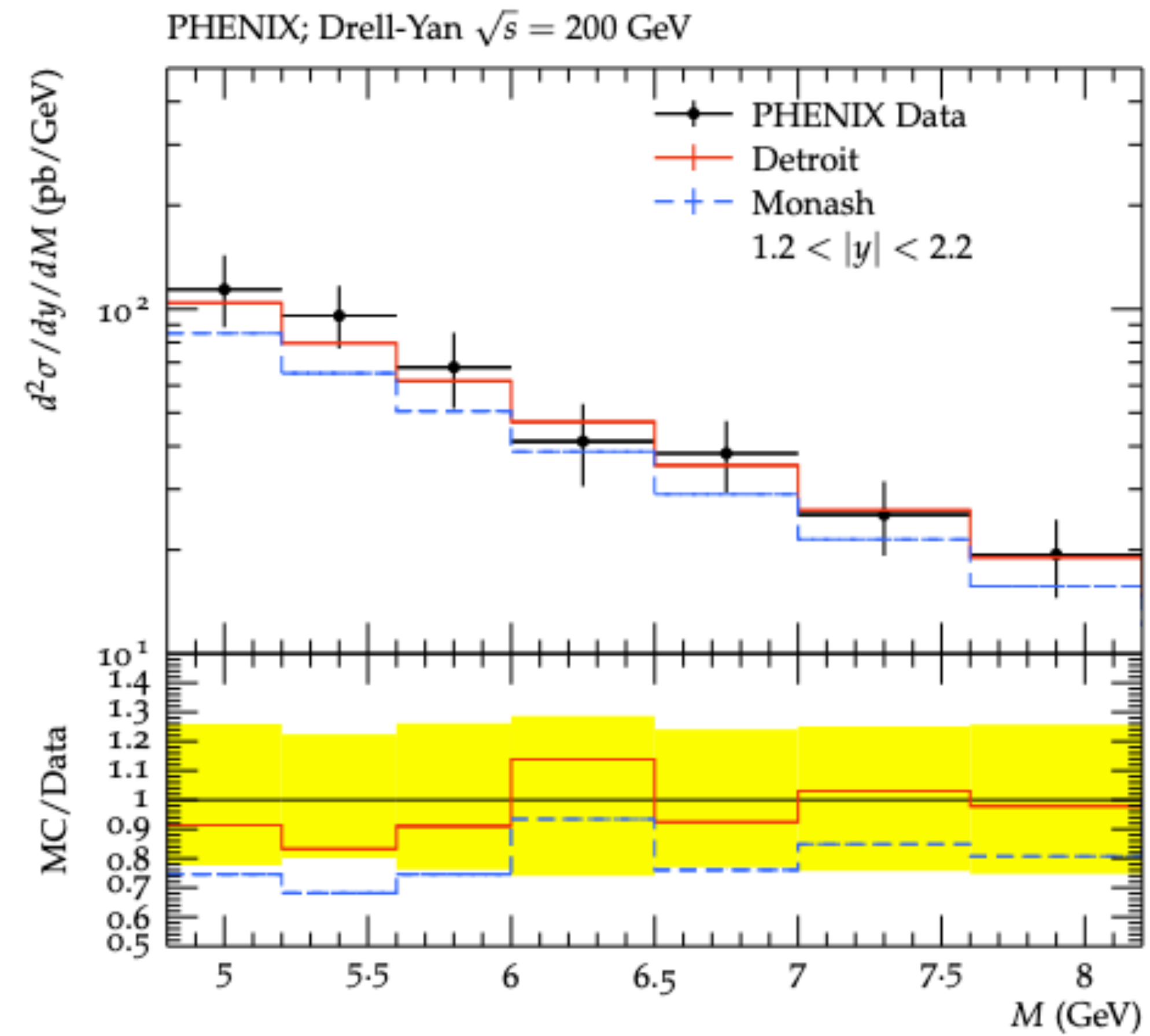
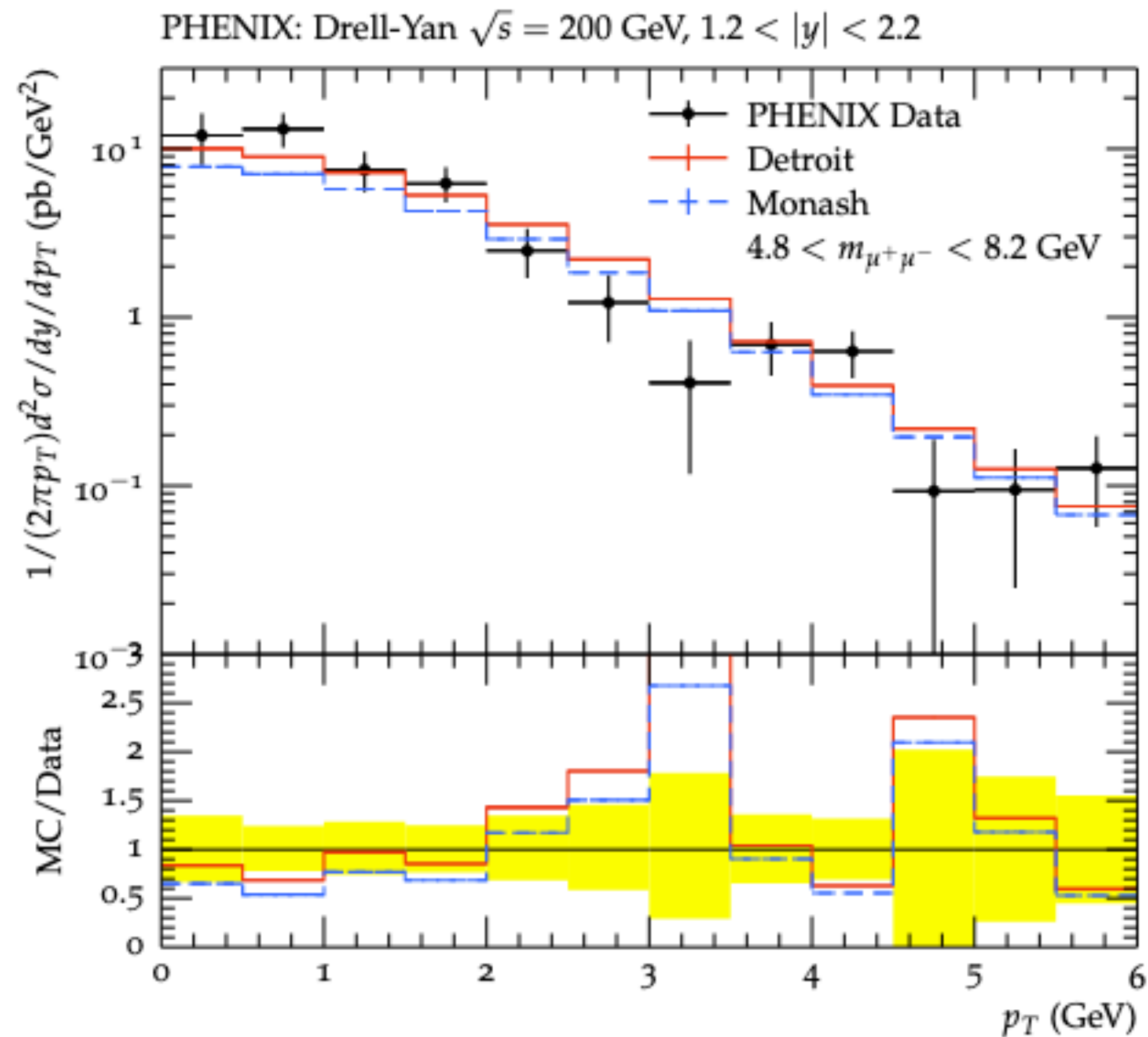


Underling Event: CDF

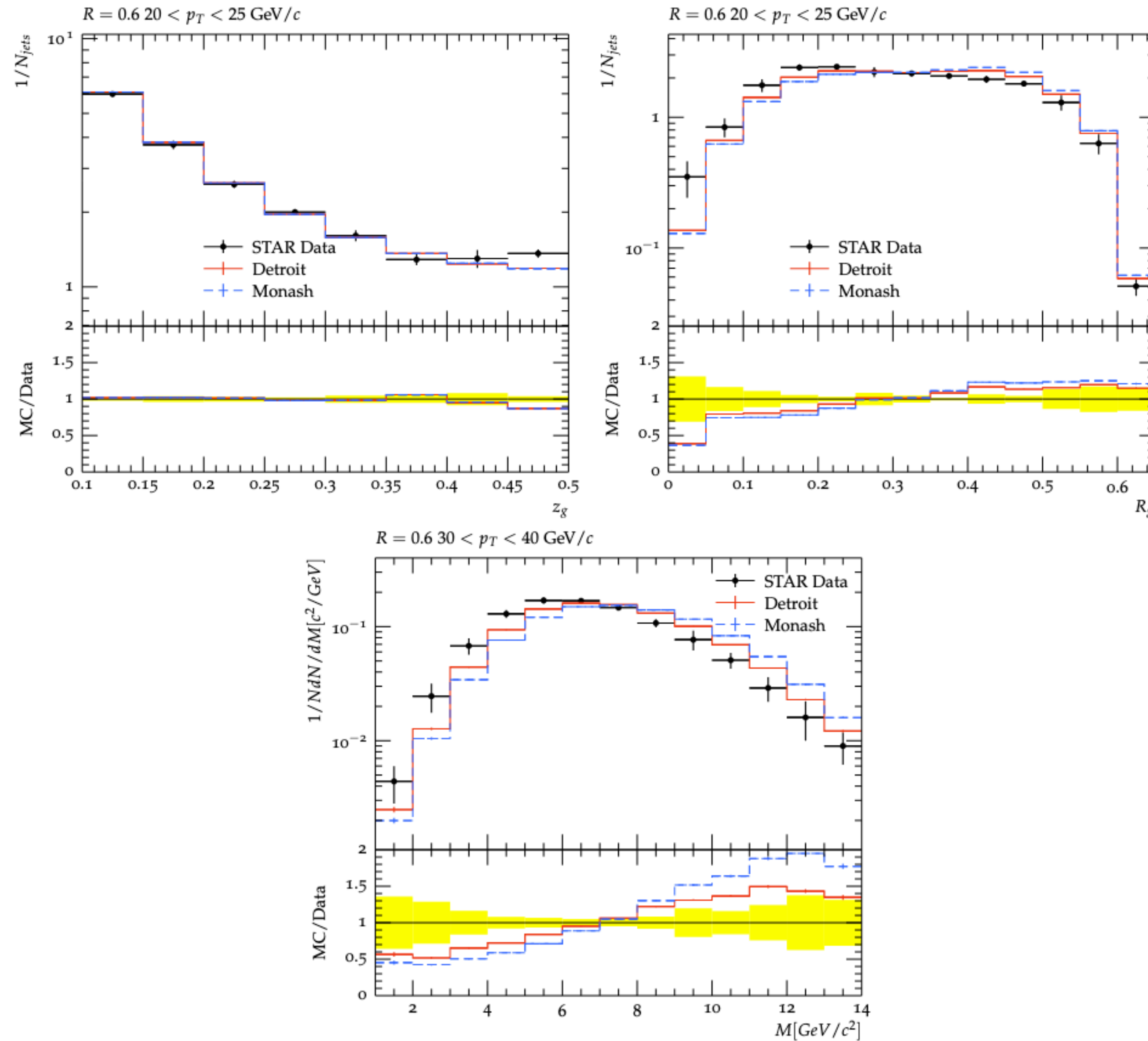
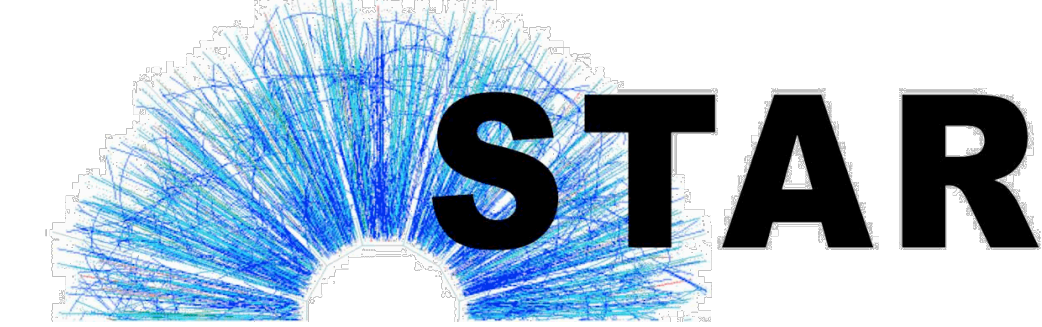


Underling Event: CDF cont.





More Jet Observables



MC Errors: Eigentunes

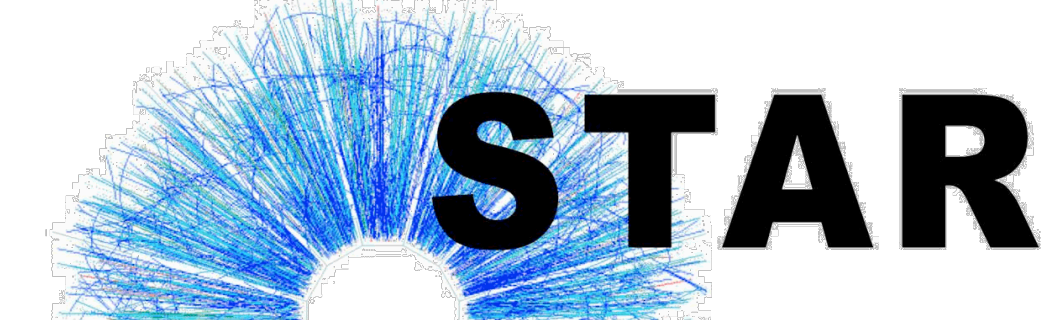


TABLE IV. PYTHIA 8 tune parameter variations for each eigentune.

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

