A PYTHIA-8 Underlying Event Tune from RHIC to the LHC

Isaac Mooney for the STAR Collaboration

isaac.mooney@wayne.edu

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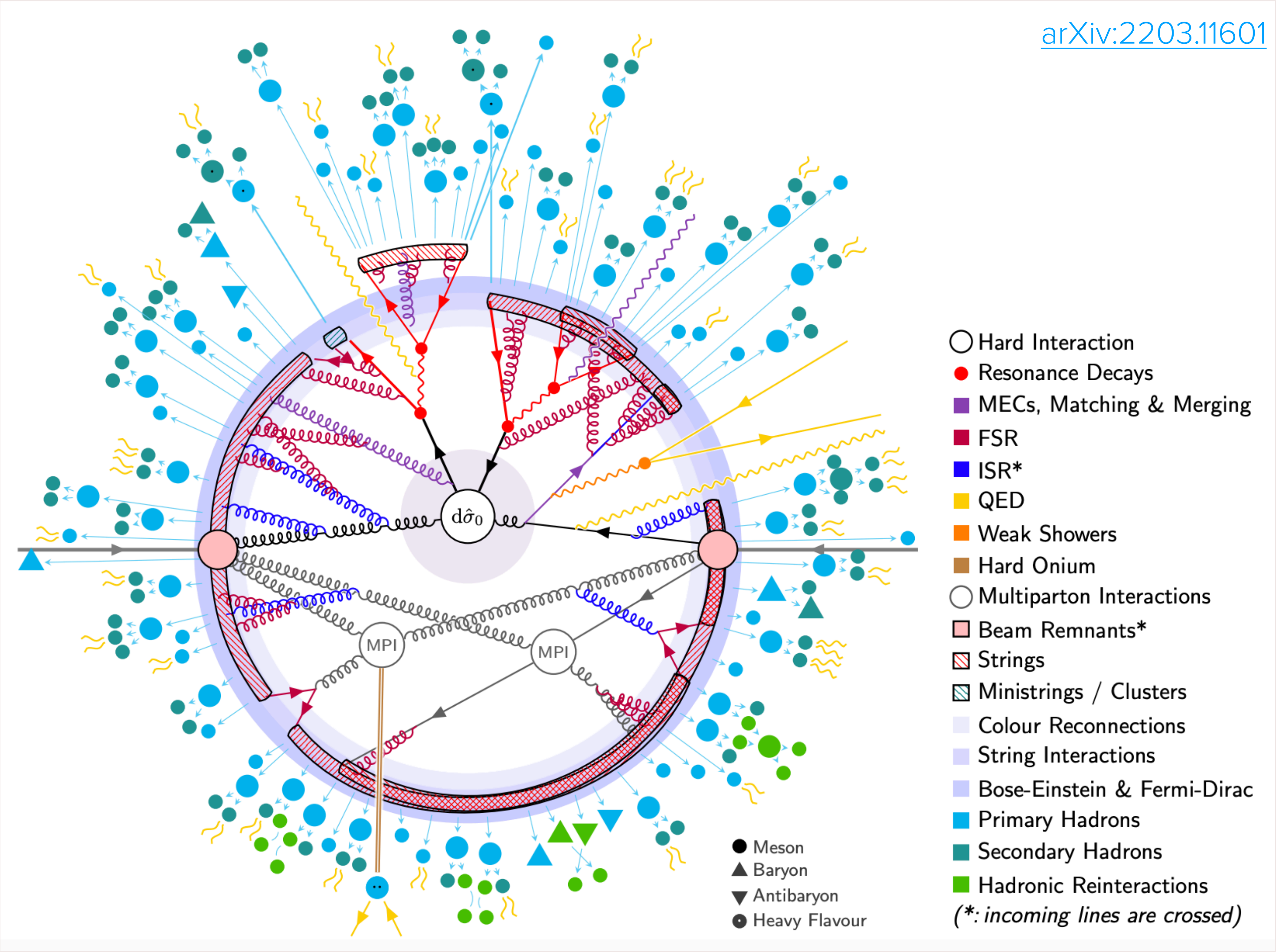
STAR

WAYNE STATE UNIVERSITY

Monte Carlo event generators



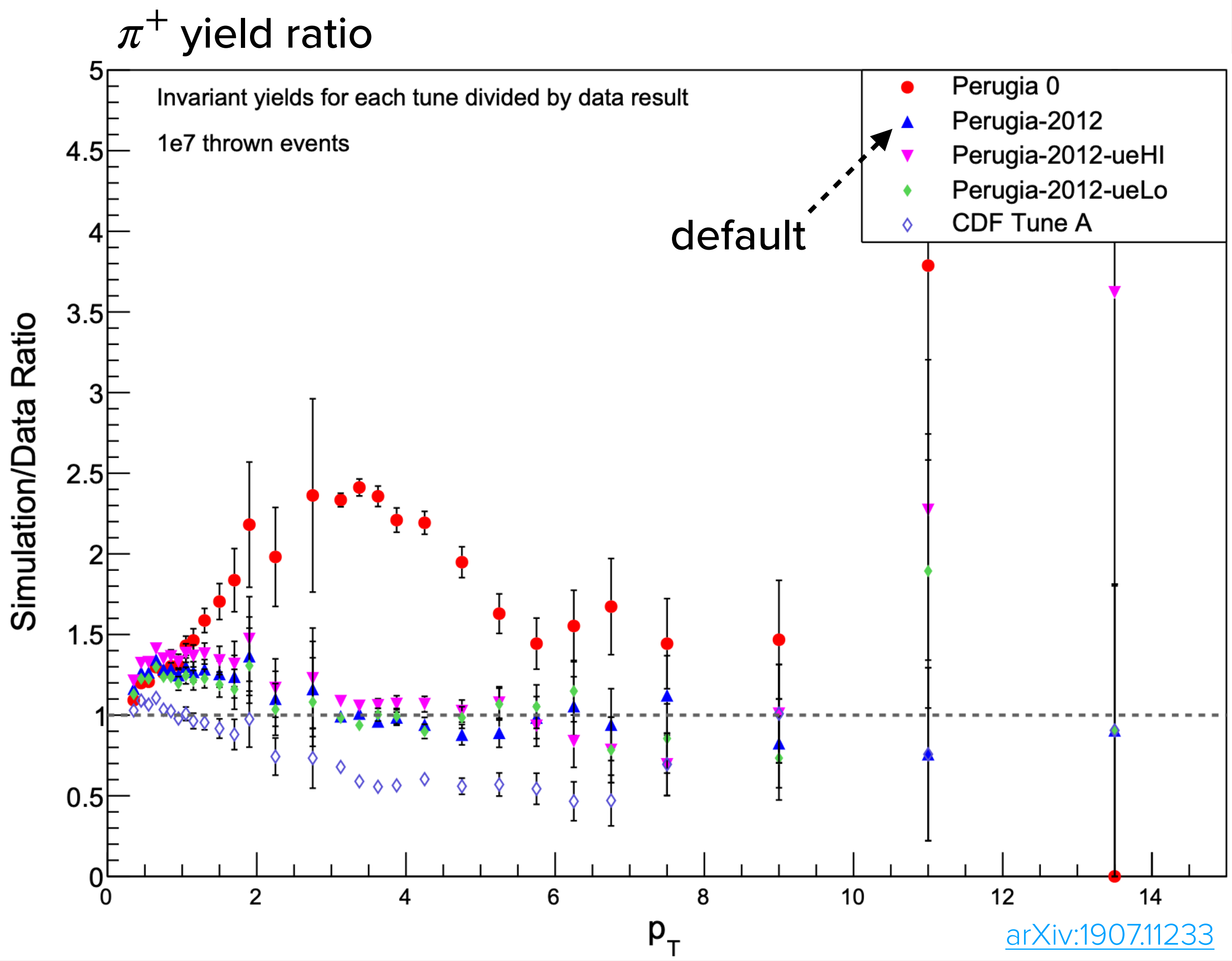
Image

Full picture of pp collision including soft underlying event is complicated!
Universal applicability requires extrapolation between kinematic regimes →

PYTHIA: $p_{\mathrm{T},0} = p_{\mathrm{T},0}^{\mathrm{ref}}\left(\sqrt{s}/\sqrt{s}_{\mathrm{ref}}\right)^{\mathrm{ecmPow}}$ — phenomenological low-p_T MPI regularizer

Universal?

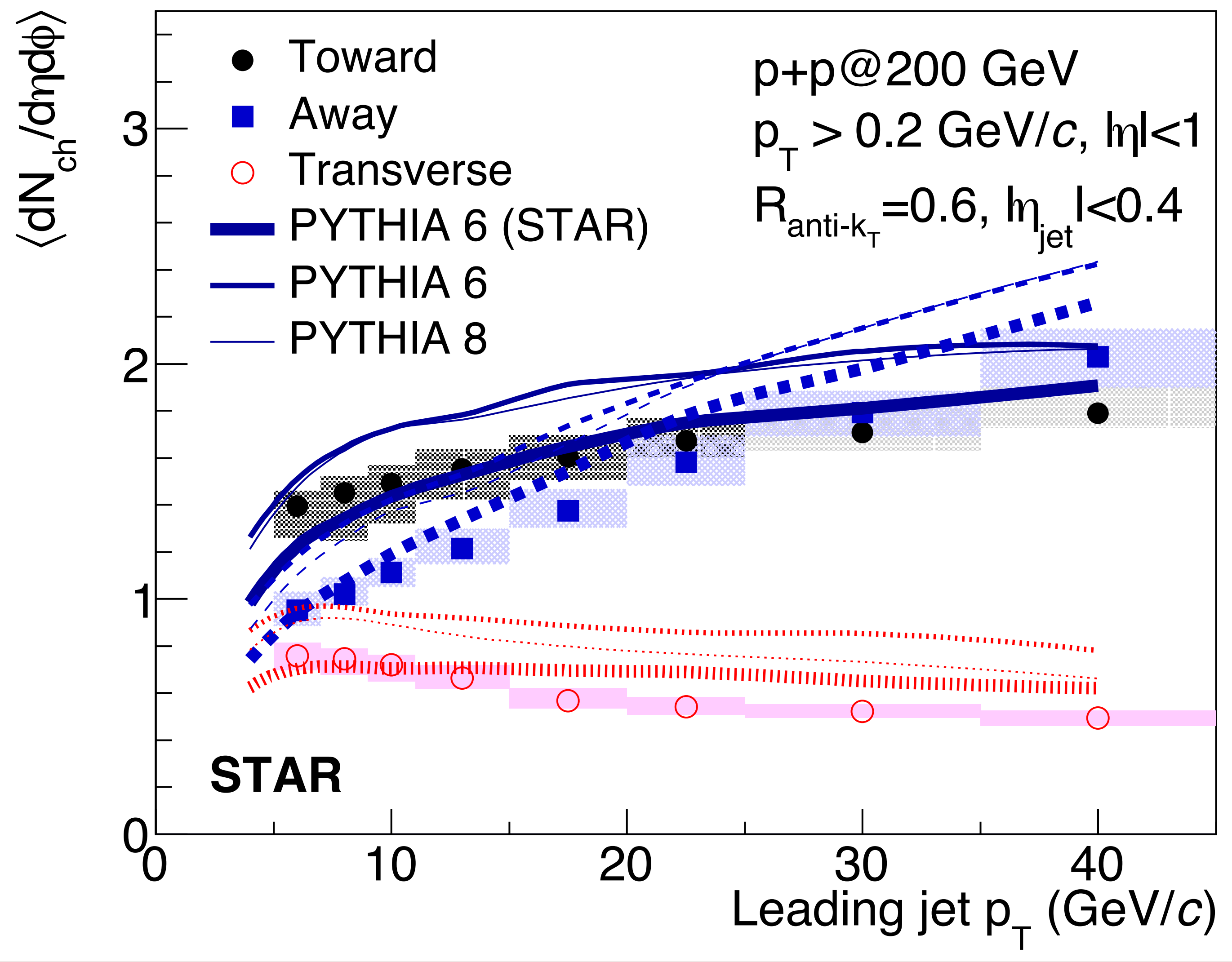
Confronting with RHIC data



Before ecmPow adjusted: PYTHIA-6 default tune disagreed with STAR pion yields by up to 30%

STAR-tuned PYTHIA-6

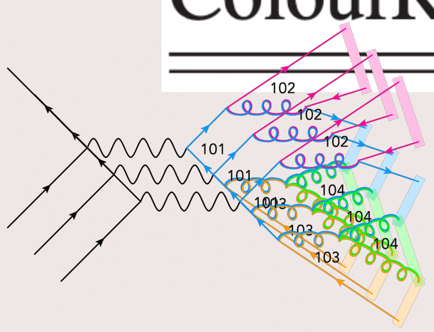
STAR, PRD 101 (2020) 5, 052004



After: "STAR-tuned" PYTHIA-6 (ecmPow: 0.240 → 0.213) in excellent agreement with underlying event (UE) observables (better than PYTHIA-8!)

PYTHIA-8 tuning parameters

Setting	Monash	New
PDF:pSet	NNPDF 2.3	NNPDF 3.1
MultipartonInteractions:ecmRef	7 TeV	200 GeV
MultipartonInteractions:bprofile	exp overlap	double Gauss
Tuning Parameter	**Monash**	**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	.0–9.0



Image

Tuned exclusively using MPI parameters

$\sqrt{s}_{ref}$ set to RHIC energy, for minimal extrapolation

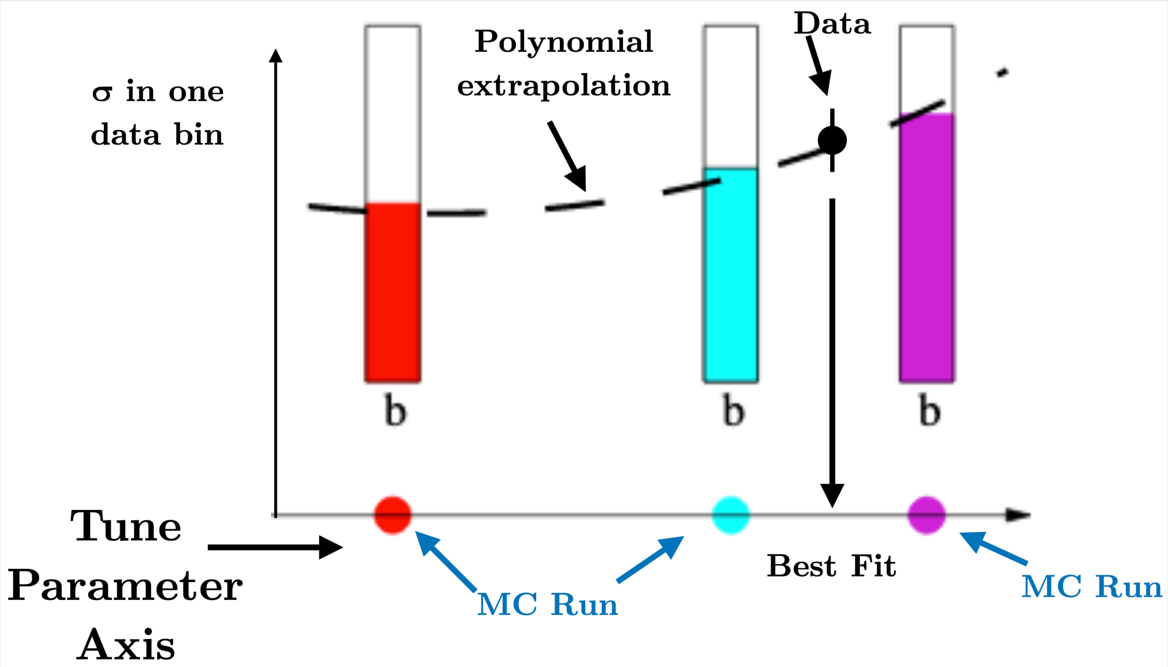
Images: Farnsworth, Pythia

Buckley, Hoeth, Lacker, Schulz, von Seggern, EPJC 65 (2010) 331-357

Tuning procedure

PROFESSOR

Image (modified by Matt Kelsey)



Randomly sample param. values → run event gen. → histograms for all observables

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

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

[1]Bierlich et al., SciPost Phys. 8 (2020) 026

Data used for tuning

Experiment	$\sqrt{s}$ (GeV)	Observable	Reference
STAR	200	$\pi^{\pm}$ cross sections vs p_T	PLB 637 (2006) 161-169
PHENIX	200	Dimuon pairs from Drell-Yan vs di-muon p_T	PRD 99 (2019) 7, 072003
STAR	200	Average charged particle multiplicities and p_T vs leading jet p_T in the forward, transverse, and away regions	PRD 101 (2020) 5, 052004
CDF	300, 900, 1960	Charge particle density and $\sum p_T$ vs leading hadron p_T in transverse region	PRD 92 (2015) 9, 092009
STAR	200	SoftDrop groomed jet substructure (z_g and R_g)	PLB 811 (2020) 135846
STAR	200	Inclusive and groomed jet mass	PRD 104 (2021) 5, 052007

A representative sample of hard and soft physics observables from RHIC and Tevatron energies

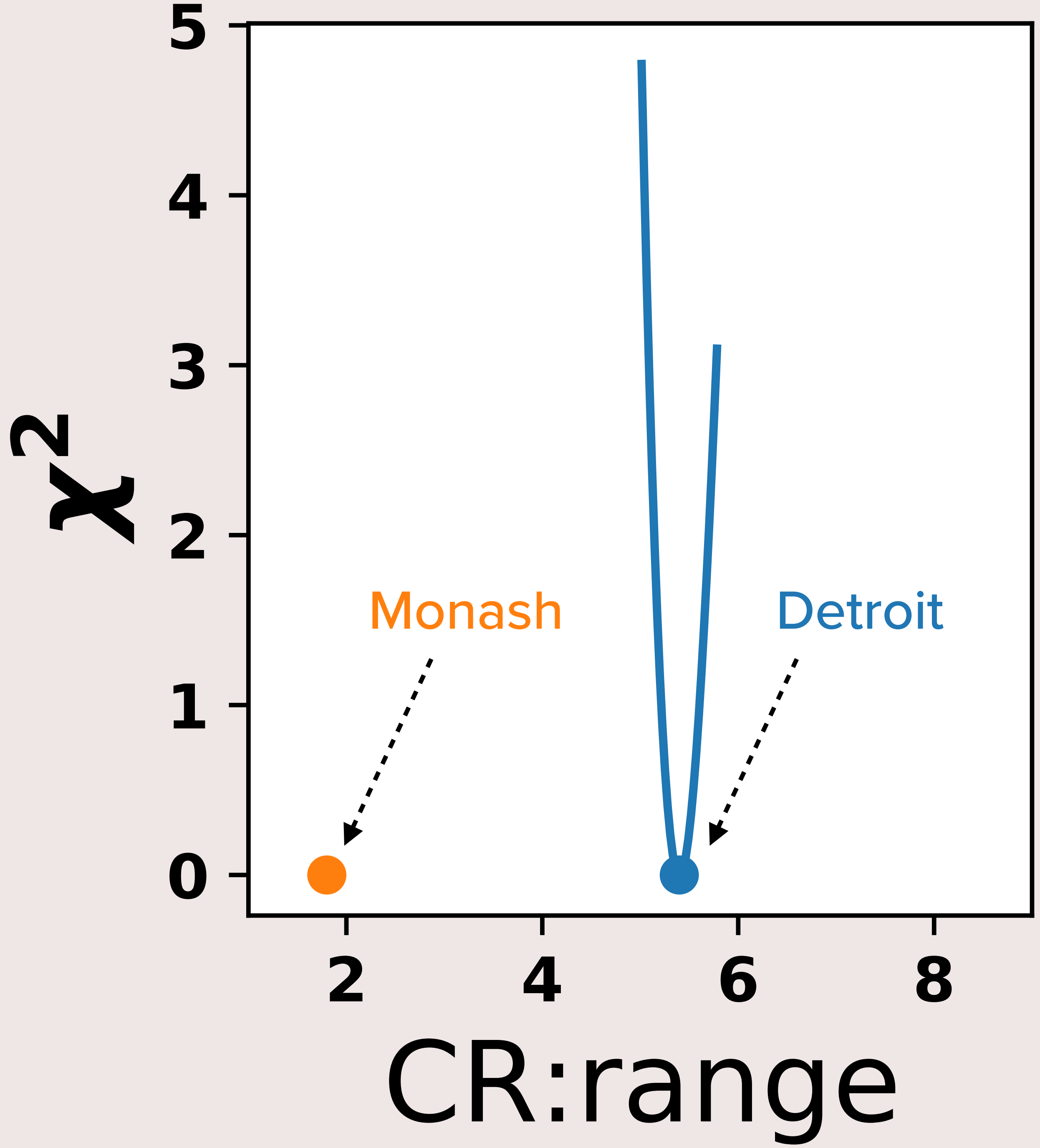
STAR analyses now included in RIVET[1]!

https://github.com/star-bnl/star-PYTHIA8-tune

https://github.com/mjk655/DetroitTuneOnRCF

Introducing the “Detroit” Tune

Aguilar, Change, Kunnawalkam Elayavalli, Fatemi, He, Ji, Kalinkin, Kelsey, IAM, Verkest, PRD 105 (2022) 1, 016011



ColourReconnection:range
1.8 → 5.4

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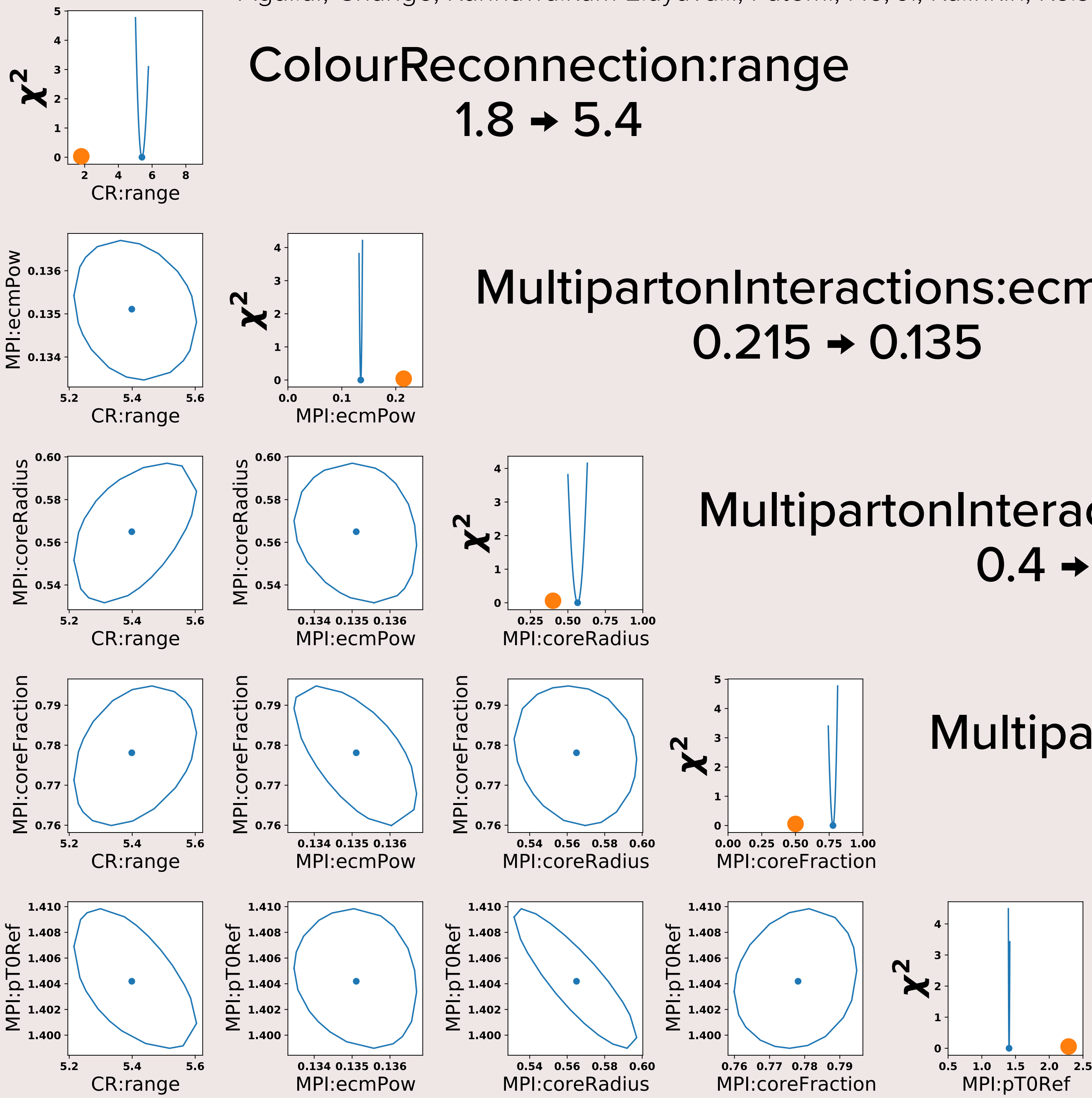

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1.8 → 5.4

Global $\chi^2/\mathrm{ndf} = 611/493$

MultipartonInteractions:ecmPow
0.215 → 0.135

MultipartonInteractions:coreRadius
0.4 → 0.56

MultipartonInteractions:coreFraction
0.5 → 0.78

MultipartonInteractions:pT0Ref
2.28 → 1.40 GeV

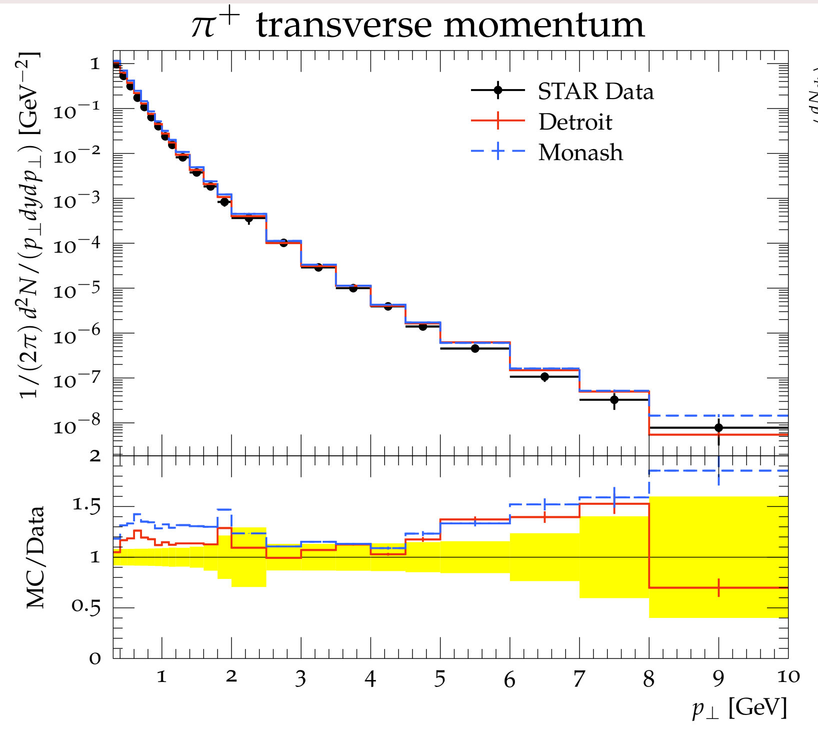
Image (modified)

representative sample

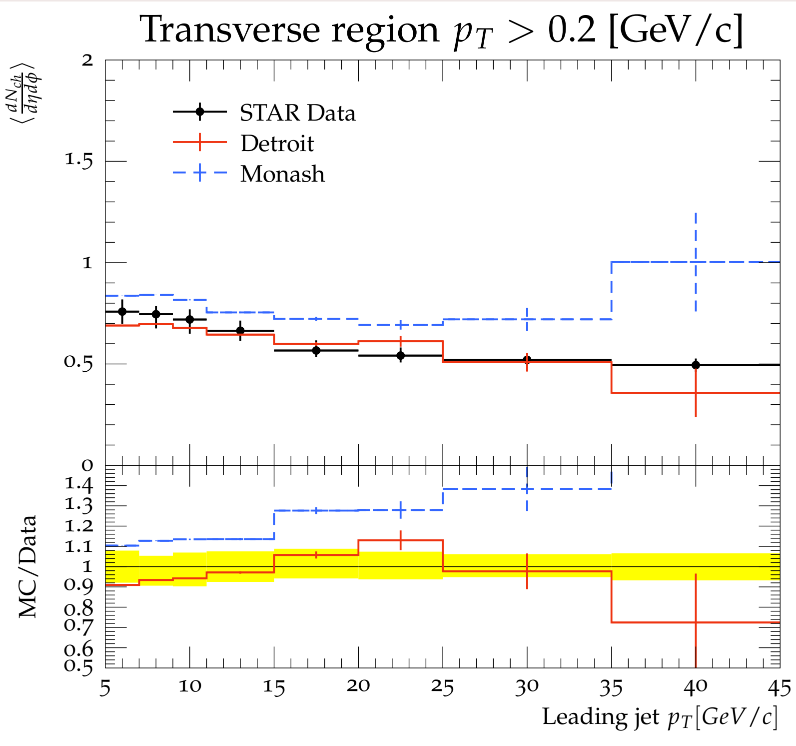
Comparison to data

RHIC — 200 GeV

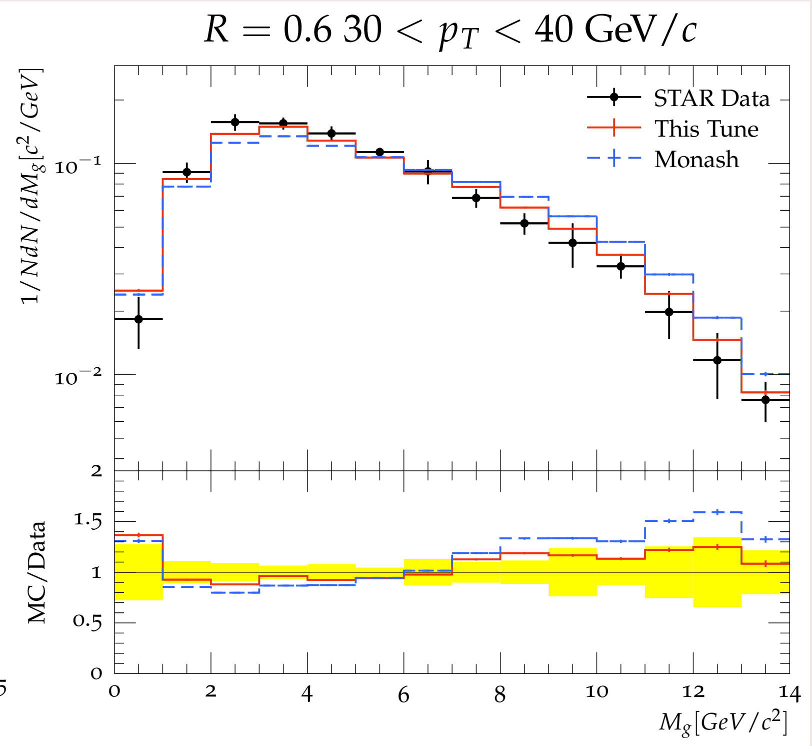
STAR, PLB 637 (2006) 161-169



STAR, PRD 101 (2020) 5, 052004



STAR, PRD 104 (2021) 5, 052007



Detroit outperforms Monash consistently for UE observables and low-p_{T} yields as expected, but also for jet substructure observables

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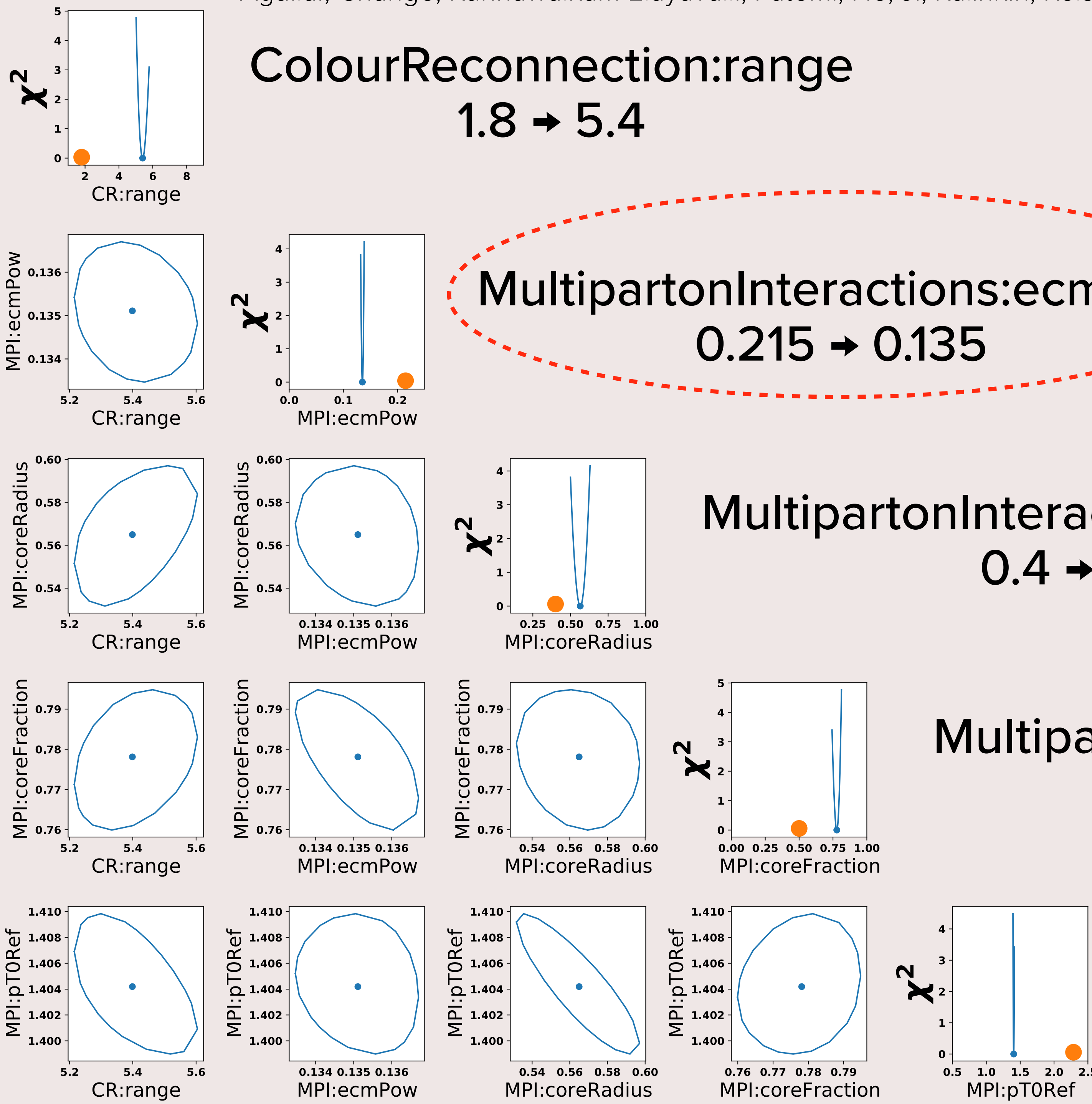

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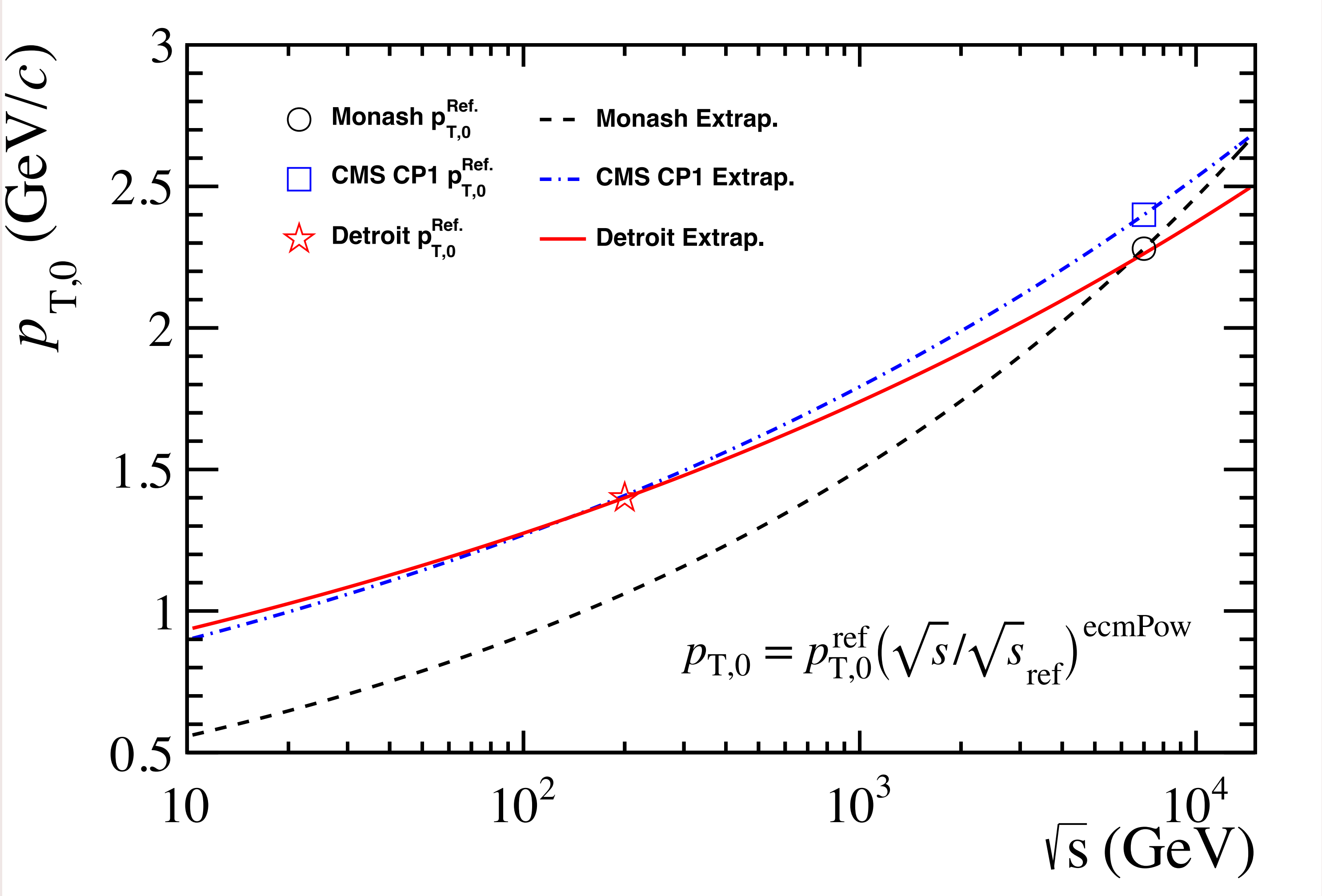
Energy extrapolation

Aguilar, Change, Kunnawalkam Elayavalli, Fatemi, He, Ji, Kalinkin, Kelsey, IAM, Verkest, [PRD 105 (2022) 1, 016011]

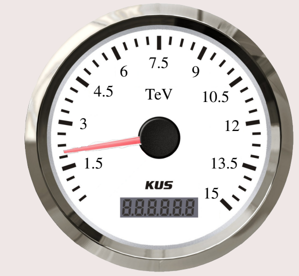


Disagreement with Monash ∼ 30% at 200 GeV/c

CMS CP1 tune's $p_{T,0}$ varies more rapidly with energy

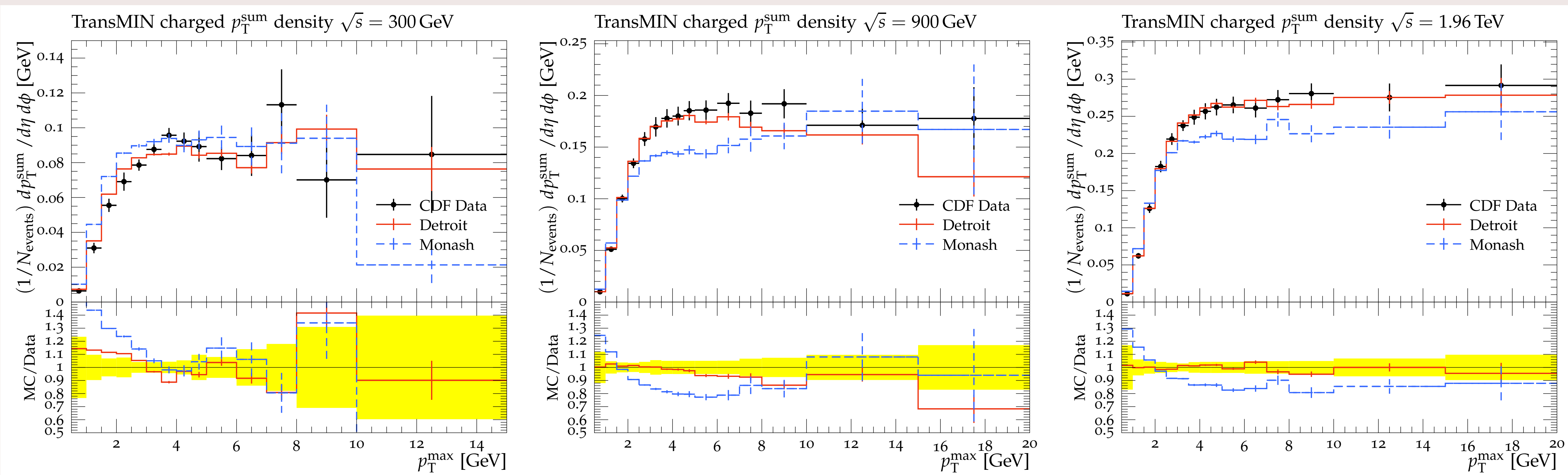
UE observables

Comparison to data



Tevatron — 0.3 to 1.96 TeV

CDF, PRD 92 (2015) 9, 092009

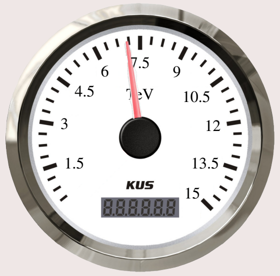


Detroit: excellent agreement with CDF data across wide range of energy

Monash: disagreement at, respectively, low-, mid-, and high-p_T^{max} as $\sqrt{s}$ increases

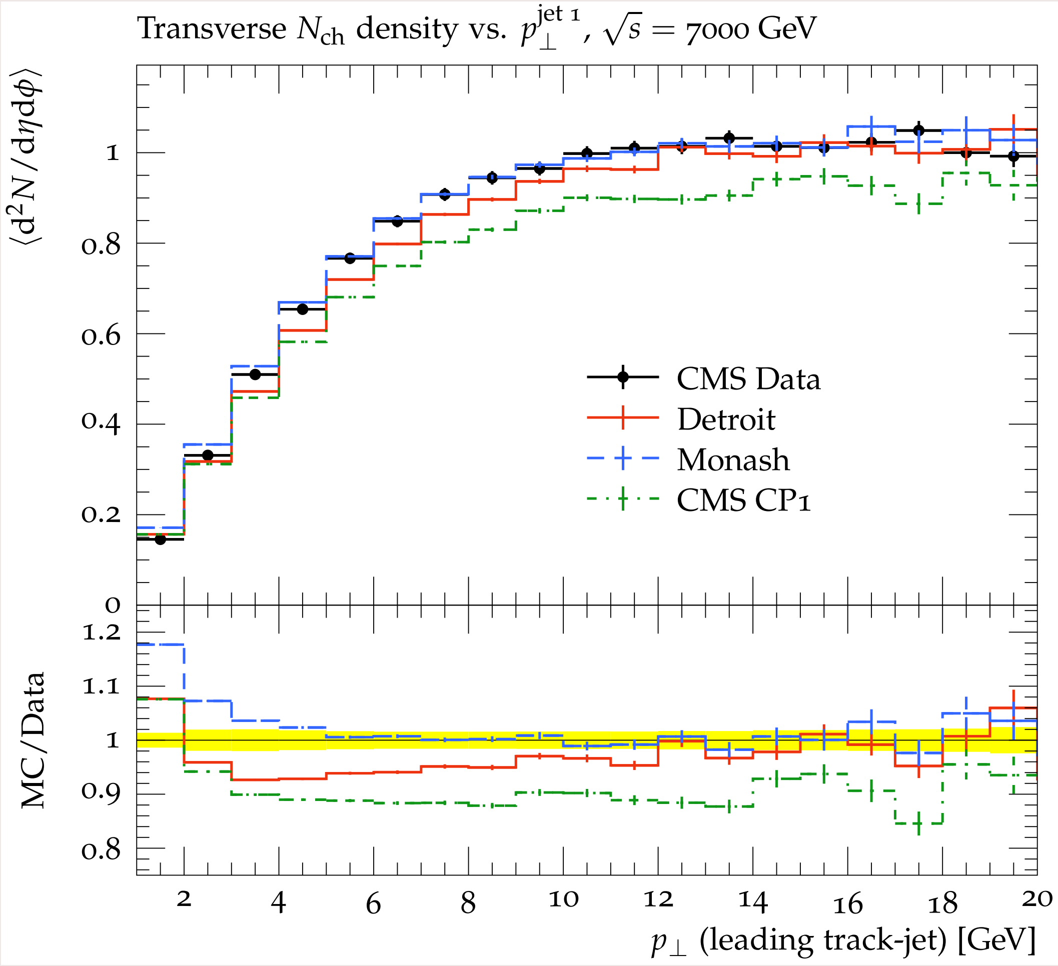
UE observables

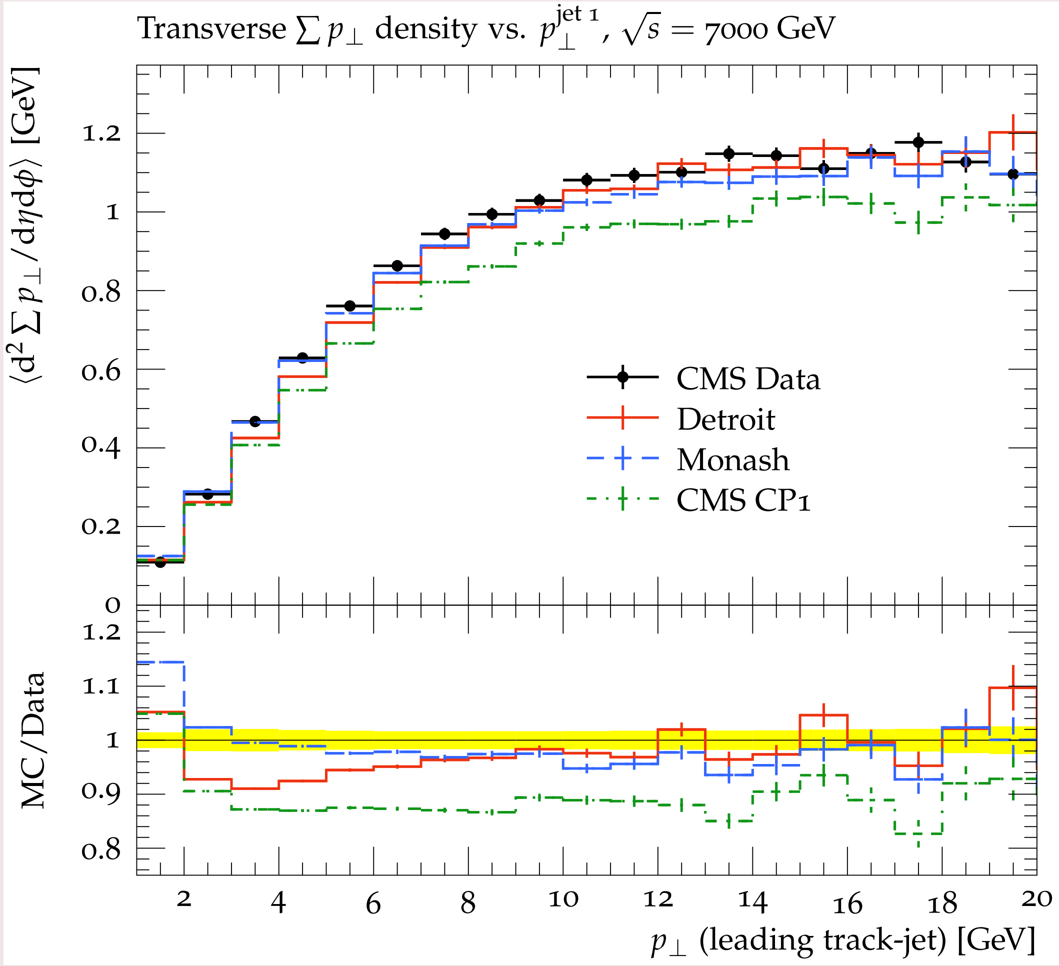
Comparison to data



LHC — 7 TeV

CMS, JHEP 09 (2011) 109





Monash tune gives best description of UE data for low p_T

For higher p_T, Detroit is consistent with data

CMS CP1[1] underpredicts the data for all p_T

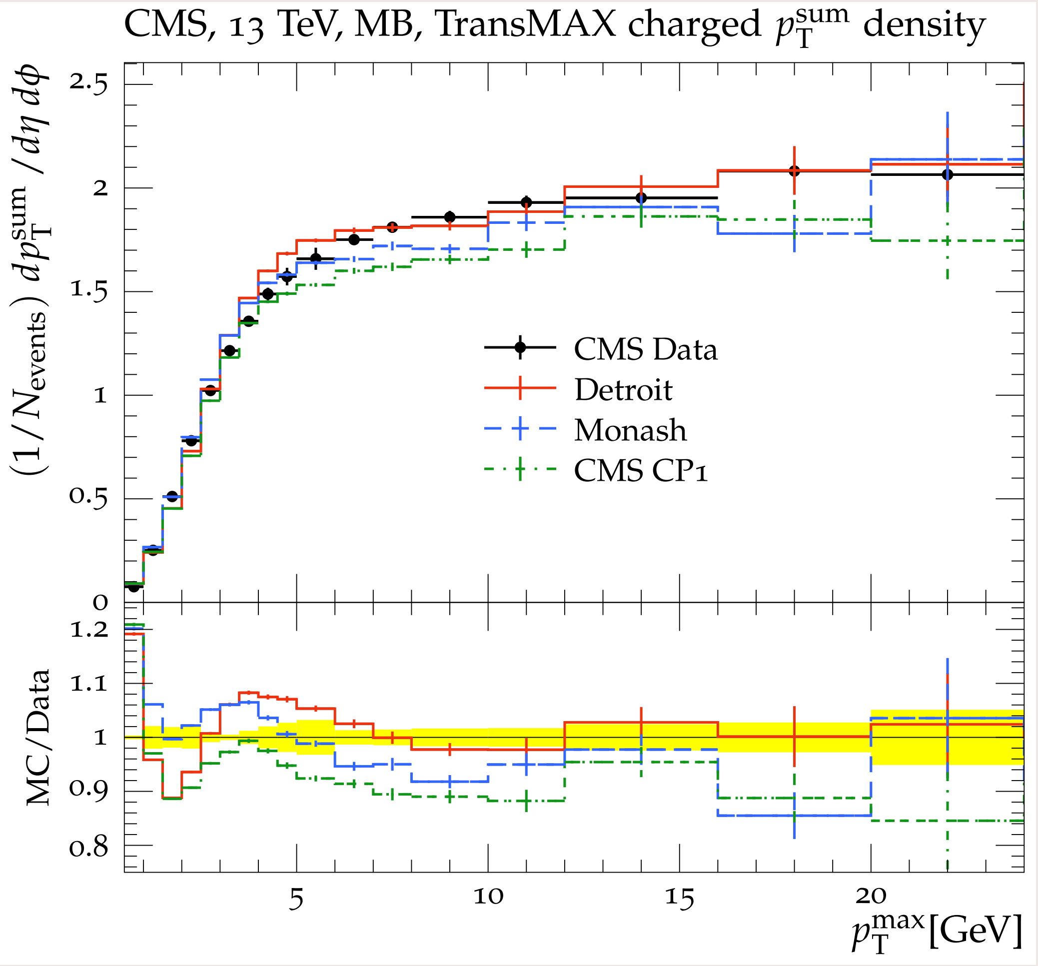
[1]CMS, EPJC 80 (2020) 1, 4

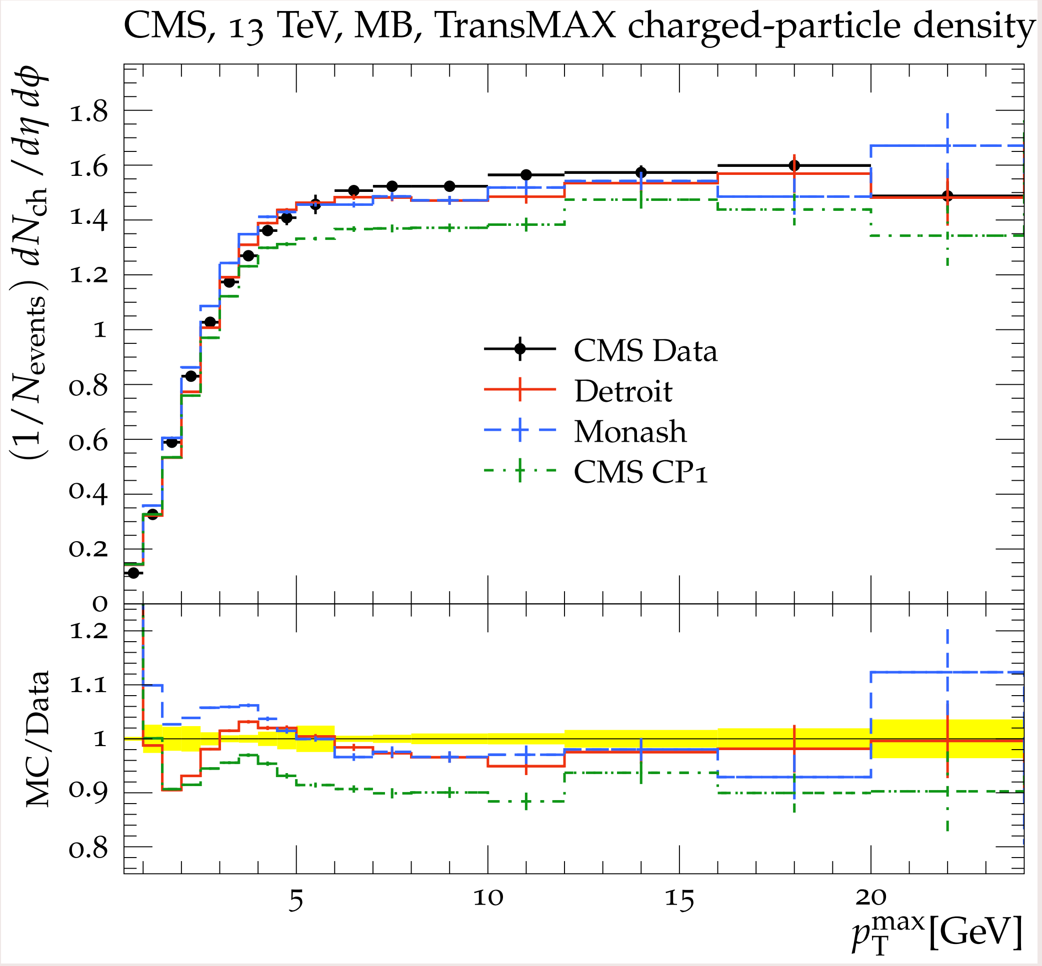
UE observables

Comparison to data

LHC — 13 TeV

CMS-PAS-FSQ-15-007





At high-p_T^{max}, Detroit performs better than or equal to Monash
At low-p_T^{max}, Detroit shape varies more due to proton shape function used
CMS CP1 still underpredicts the data significantly

Summary

Tuning at low energies where UE effects are relatively more important, and then extrapolating to high energies seems to work better than the reverse!

Detroit tune:

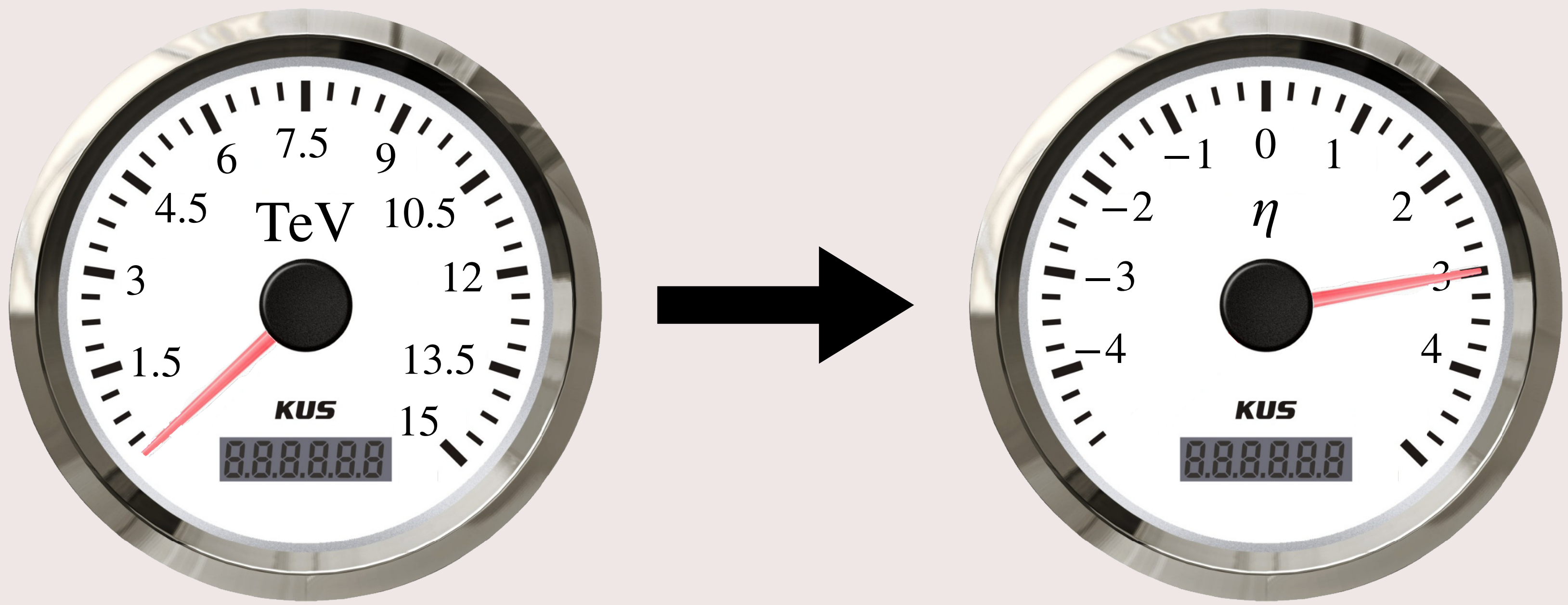
https://github.com/mjk655/DetroitTuneOnRCF

adjusted *MPI/UE* parameters + updated *PDFs*

➡ improved agreement, compared to Monash, with RHIC + Tevatron data (UE, jet substructure, etc.) at mid-rapidity

Predictions for some LHC data are better than CMS CP1 and at least as good as Monash at higher-p_{T}

Performance at large rapidity

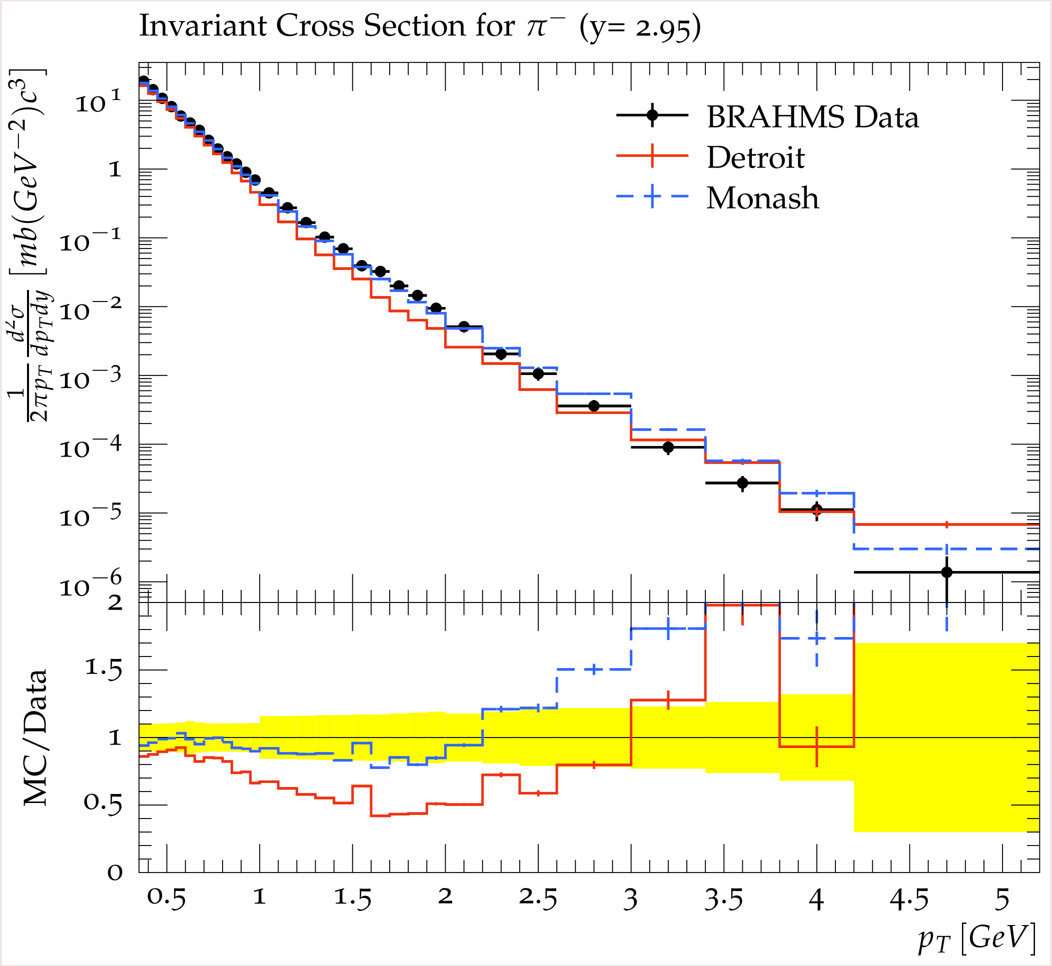


pion yields

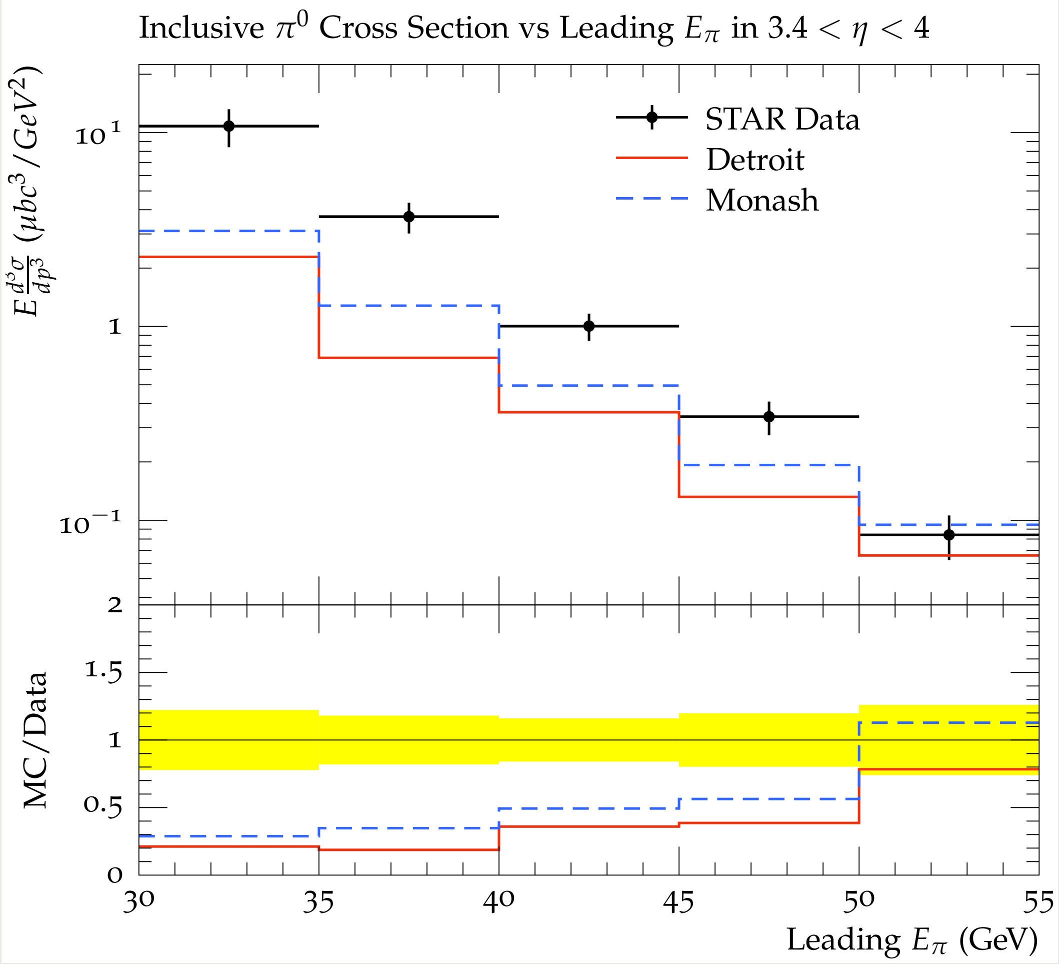
Comparison to data

Forward rapidity (200 GeV)

BRAHMS, PRL 98 (2007) 252001



STAR, PRL 92 (2004) 171801



Detroit underpredicts BRAHMS and STAR pion yields at large rapidities
Better agreement from Monash at low-p_T

Summary

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But for the future, it will be important to simultaneously describe forward and mid-rapidity RHIC data (STAR 2022 forward upgrade; EIC), which is currently not possible!

Backup