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

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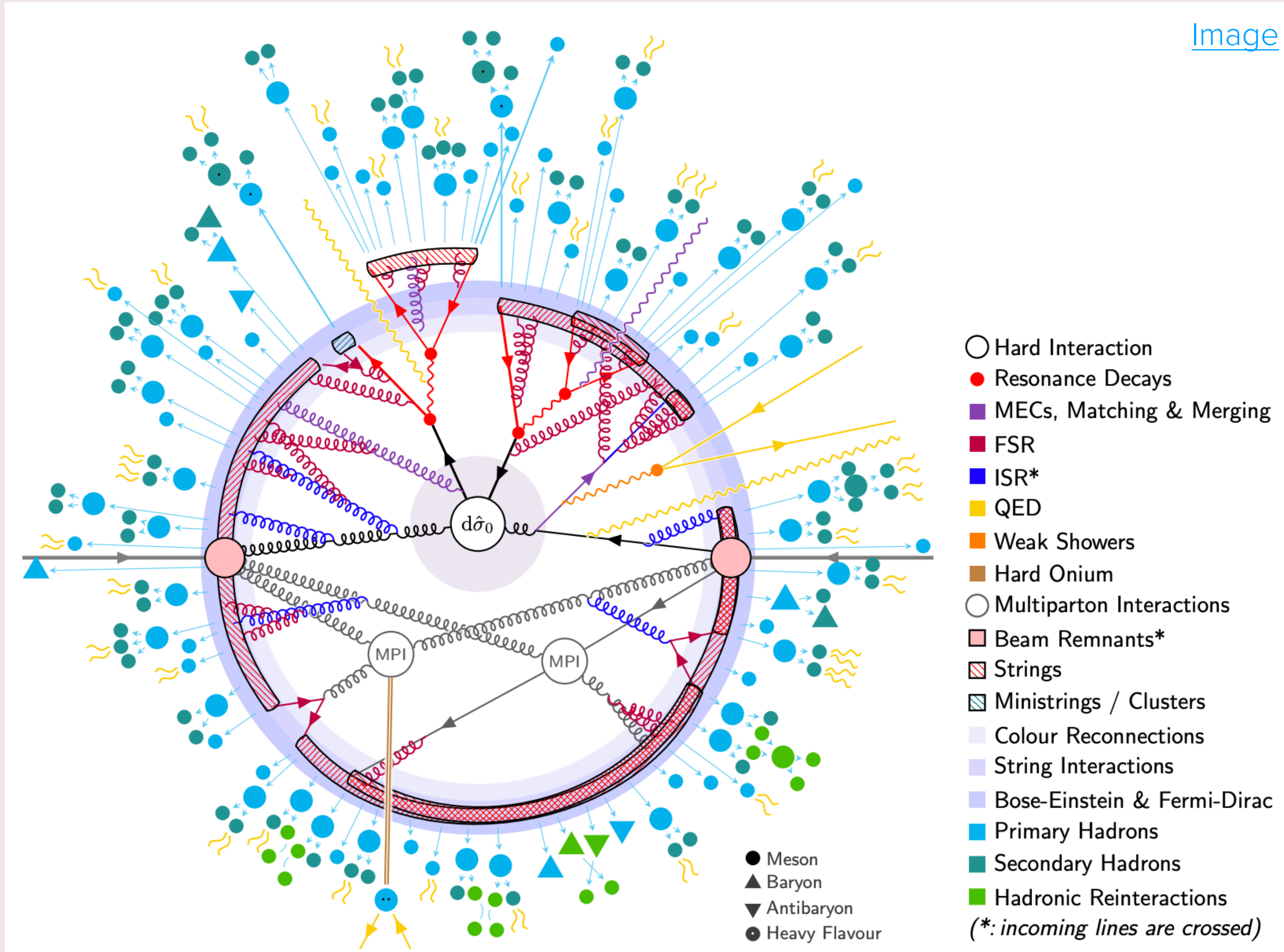
Monte Carlo event generators

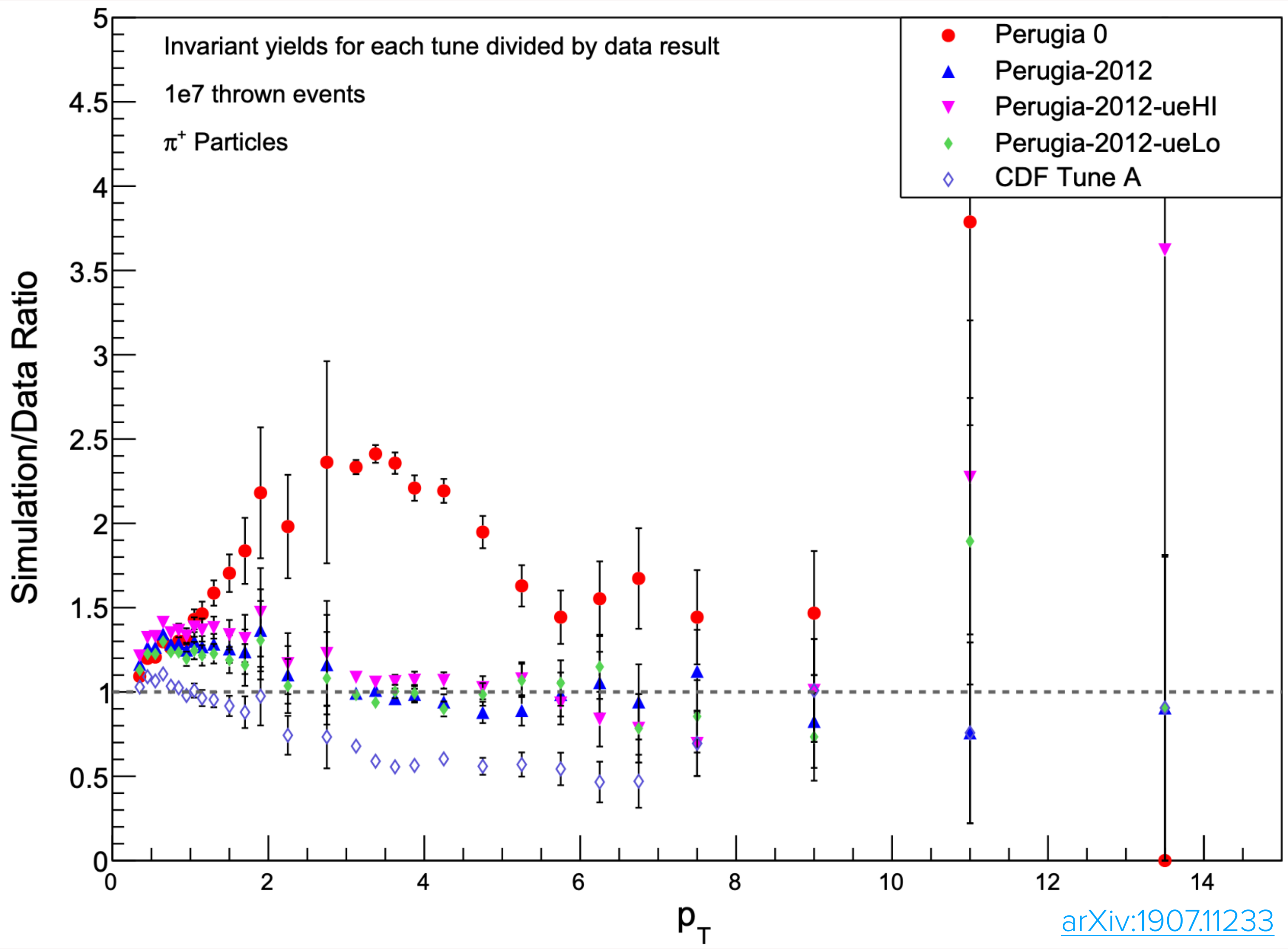


Full picture of pp collision including soft underlying event is complicated!
Universal applicability requires extrapolation between kinematic regimes ➔

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



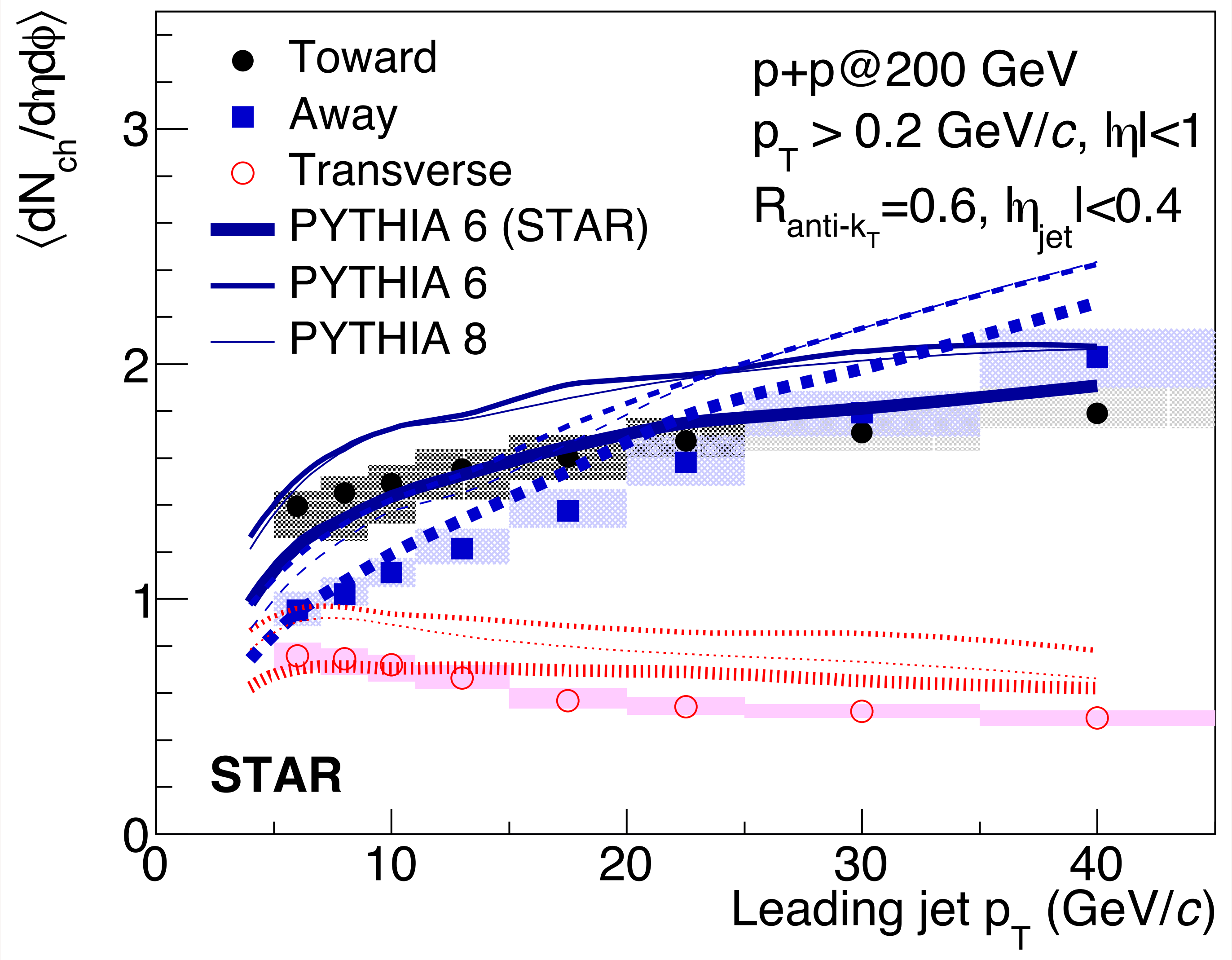
arXiv:1907.11233

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

Universal?

Confronting with RHIC data

STAR, PRD 101 (2020) 5, 052004

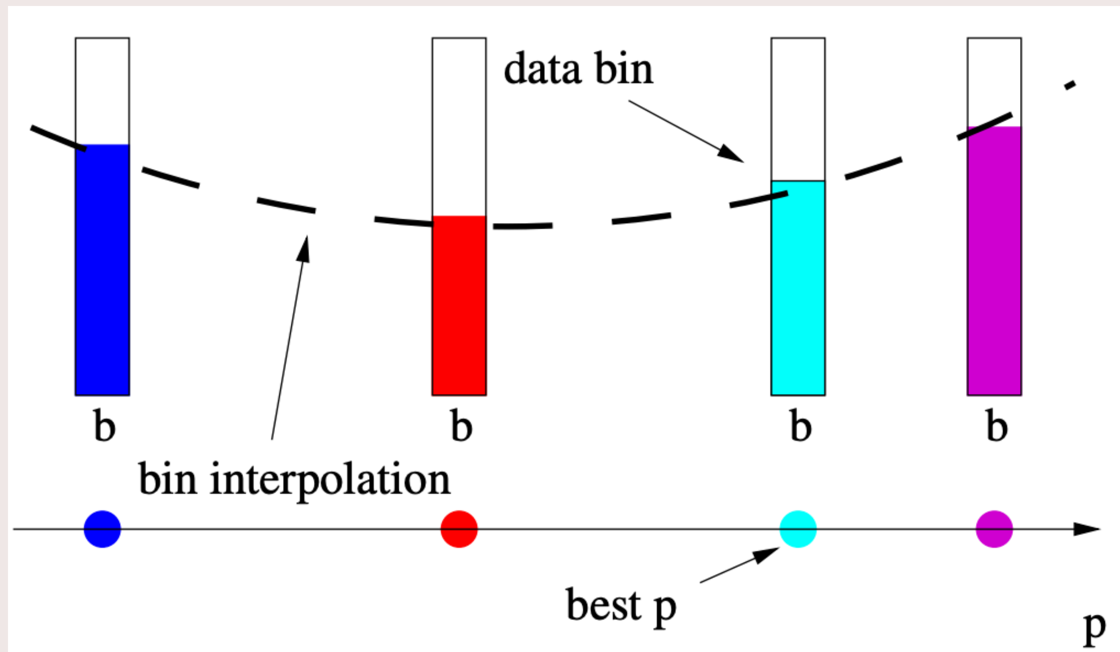


After: "STAR-tuned" PYTHIA-6 in excellent agreement with underlying event (UE) observables (better than PYTHIA-8!)

PYTHIA-8 tuning procedure

PROFESSOR

Image



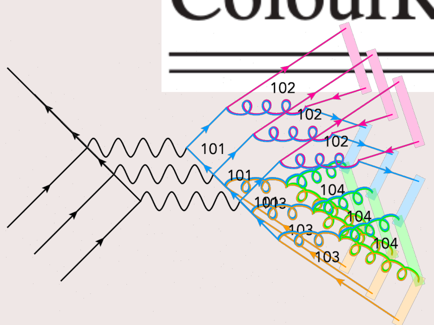
Randomly sample parameter values → run event generator → produce histograms for all observables

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

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



Tuned exclusively using MPI parameters

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

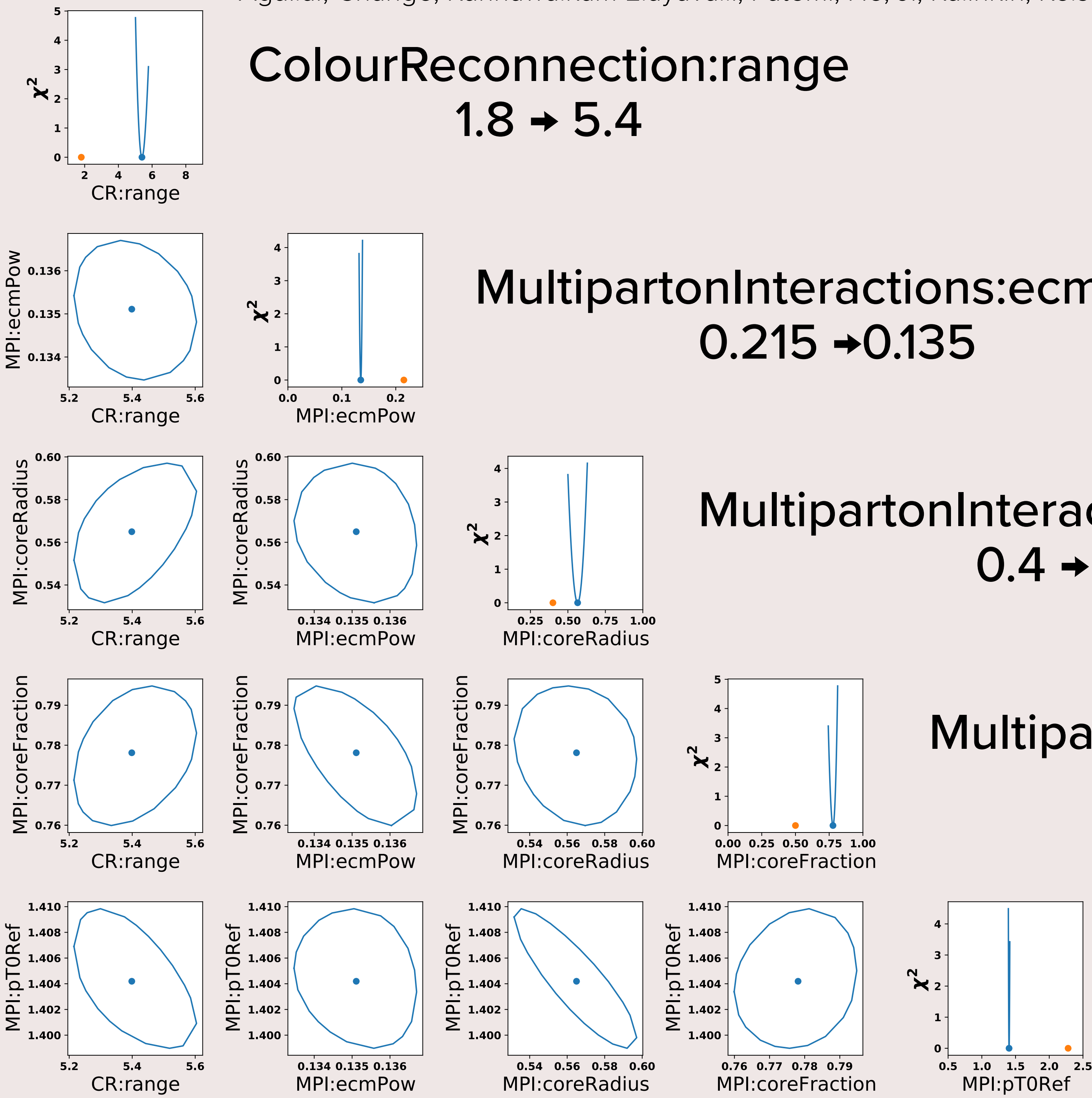
Tuning data

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

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

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

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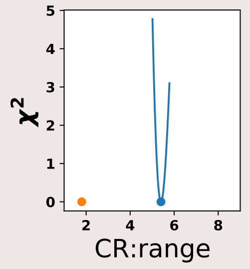

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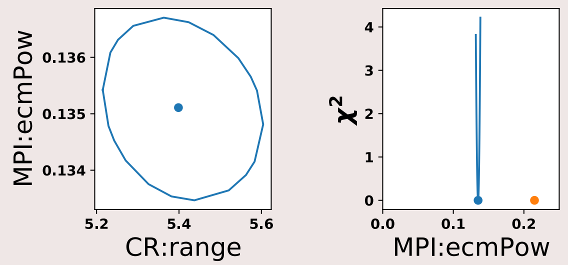

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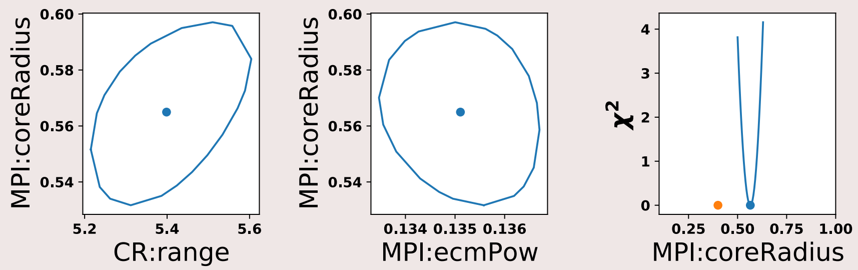

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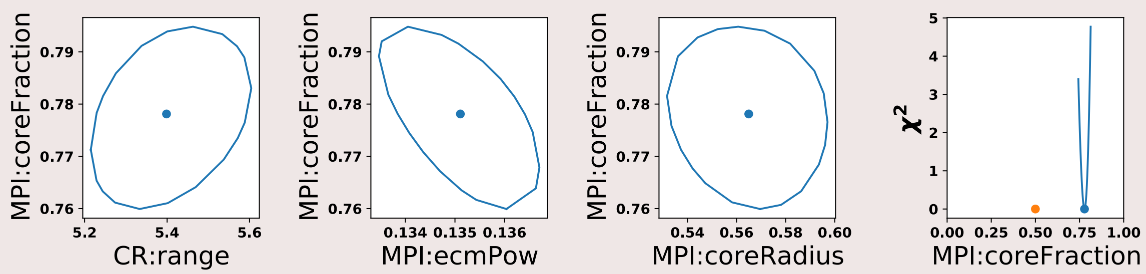

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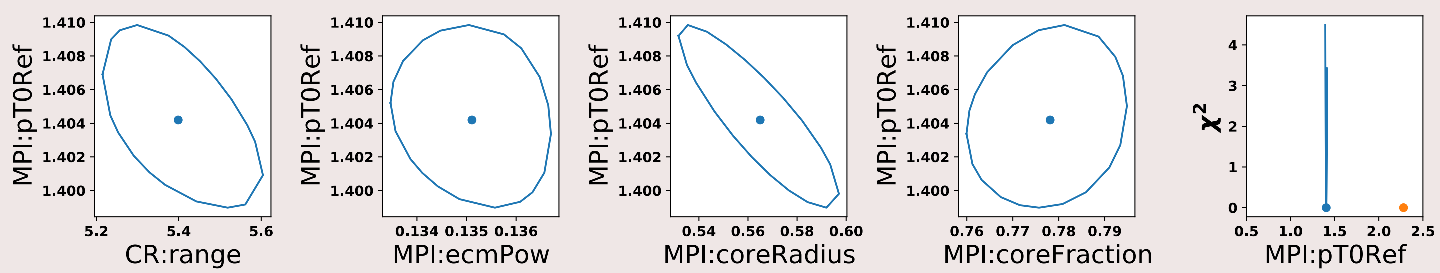

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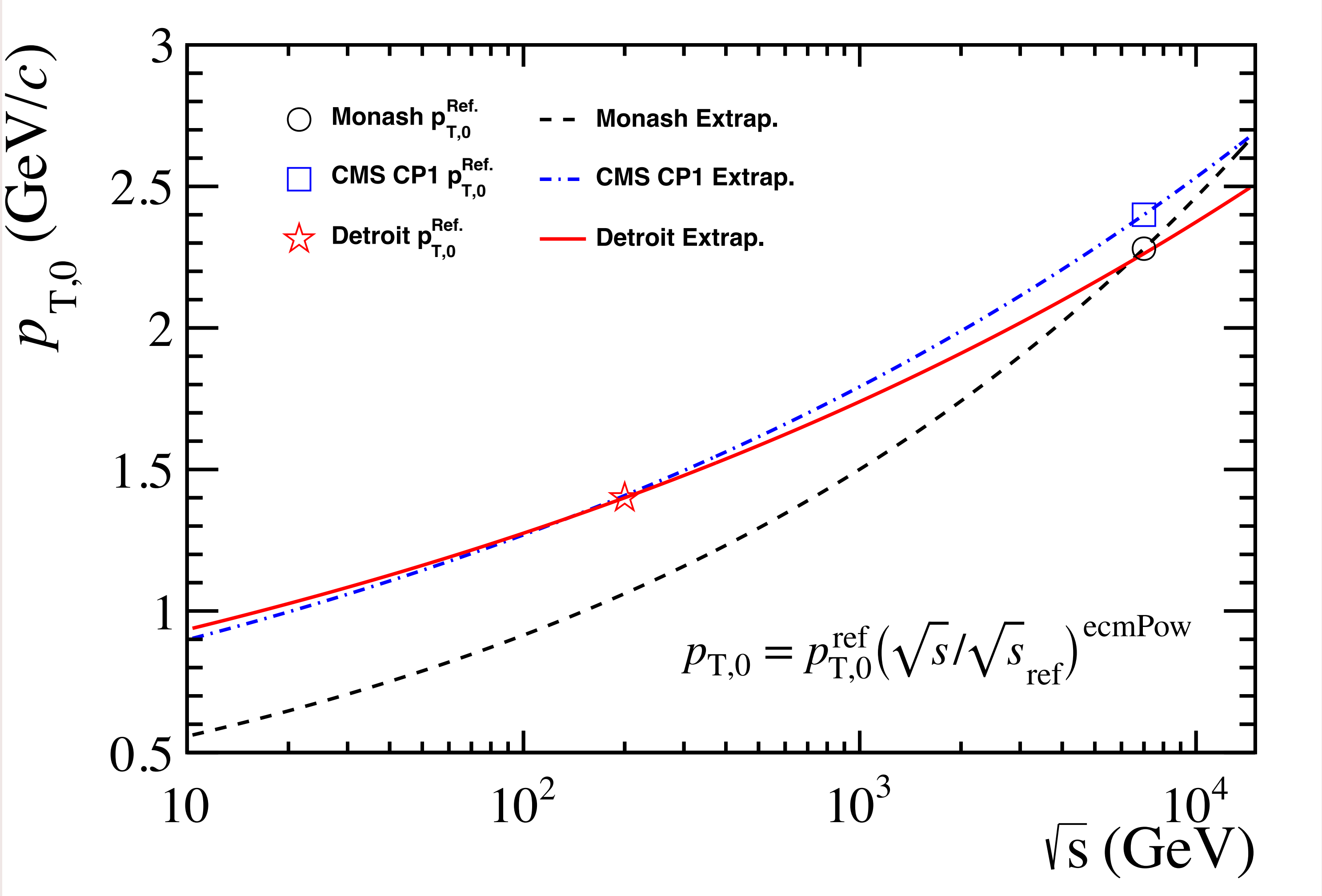


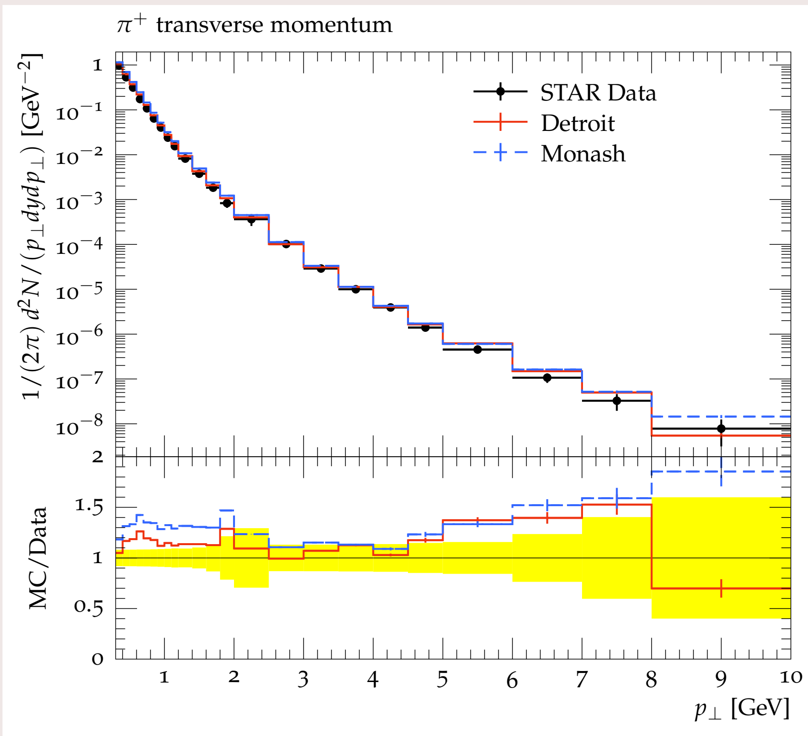
Disagreement with Monash ~ 30% at 200 GeV/c

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

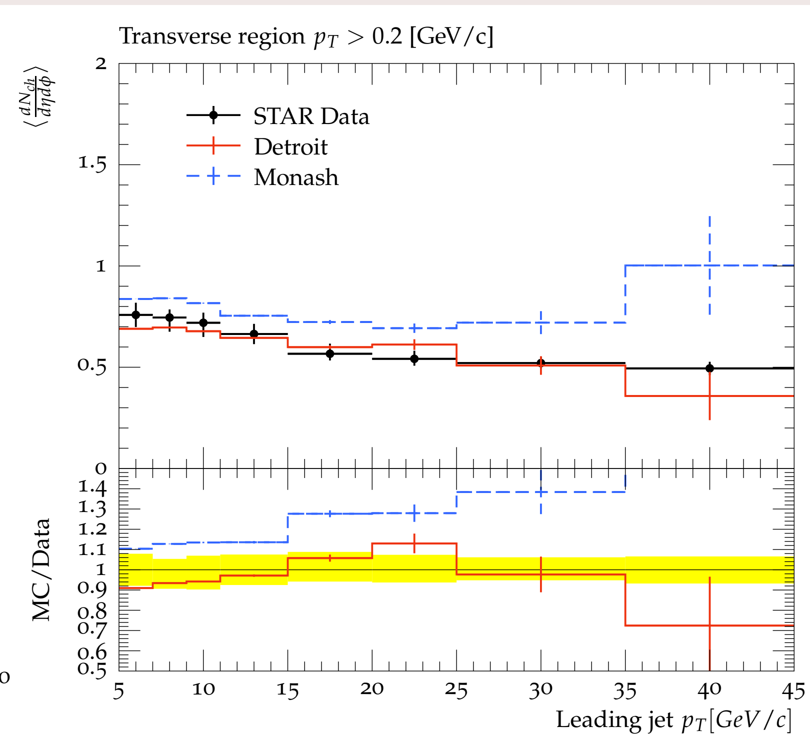
Comparison to data

RHIC — 200 GeV

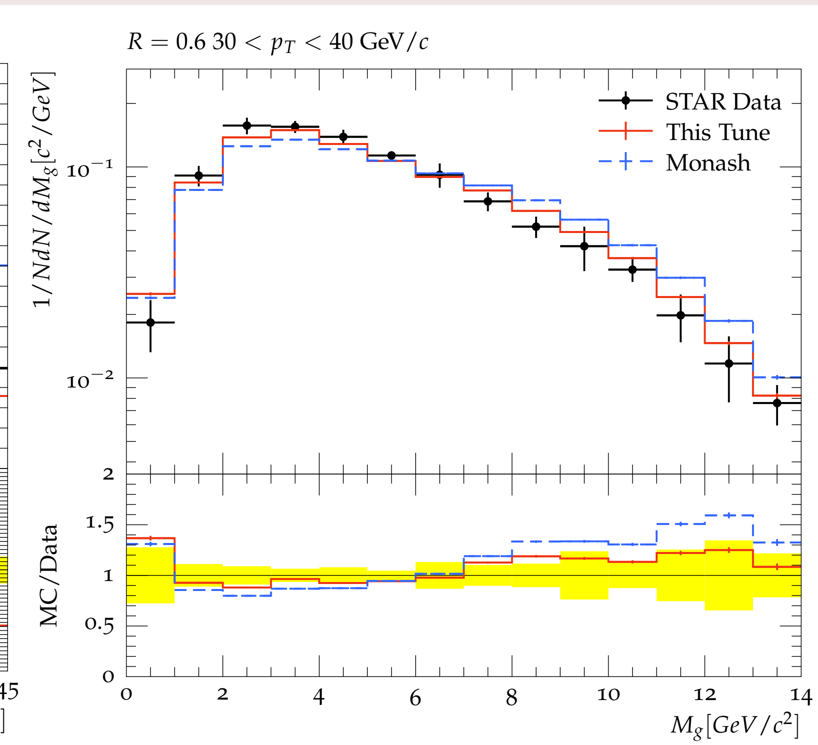
STAR, PLB 637 (2006) 161-169



STAR, PRD 101 (2020) 5, 052004



STAR, PRD 104 (2021) 5, 052007

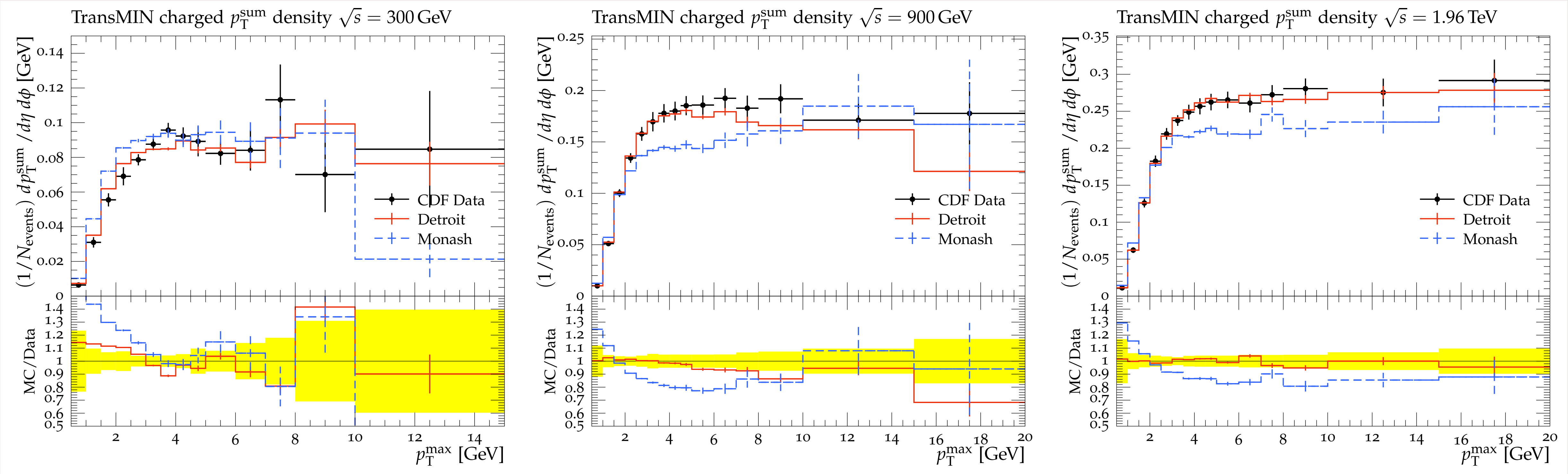


Detroit outperforms Monash consistently for UE observables and low-p_{T} yields as expected, but also for jet substructure observables

Comparison to data

Tevatron — 0.3 to 1.96 TeV

CDF, [PRD 92 (2015) 9, 092009]



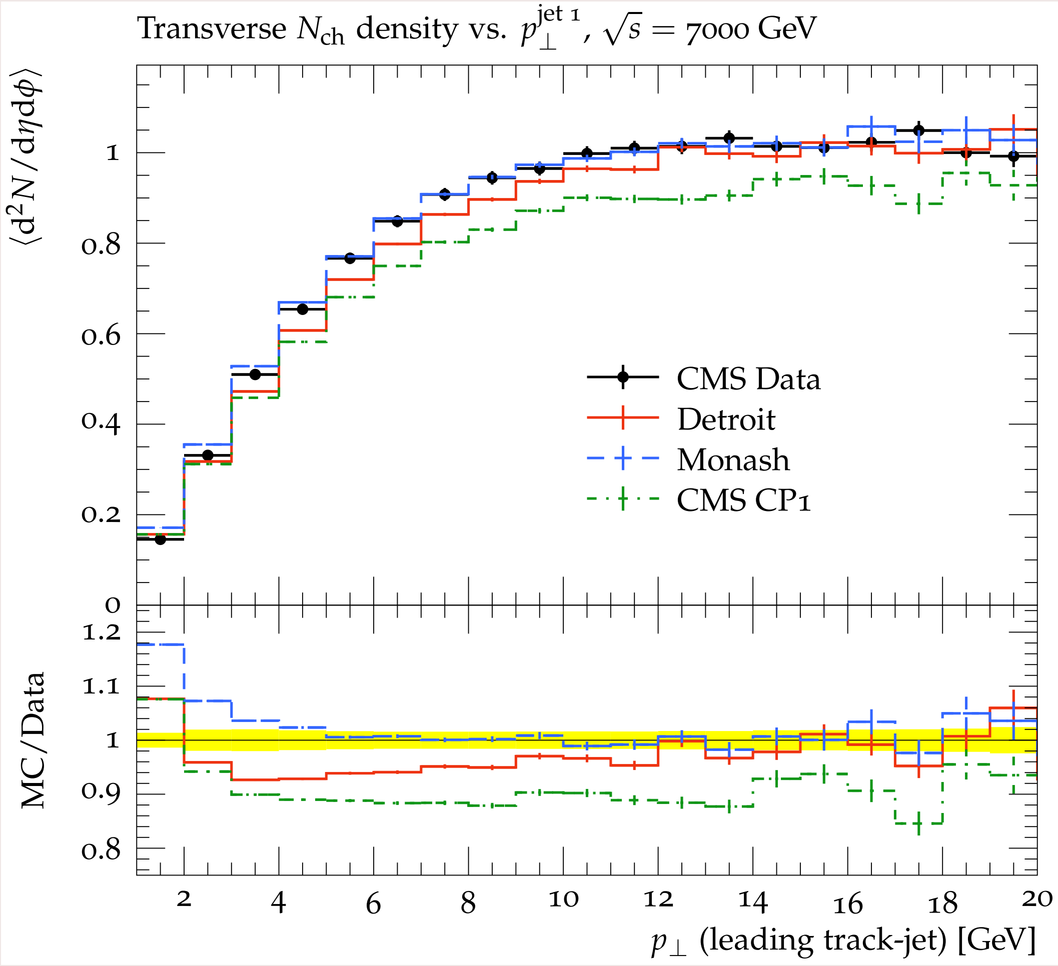
Detroit: excellent agreement with CDF data across wide range of energy

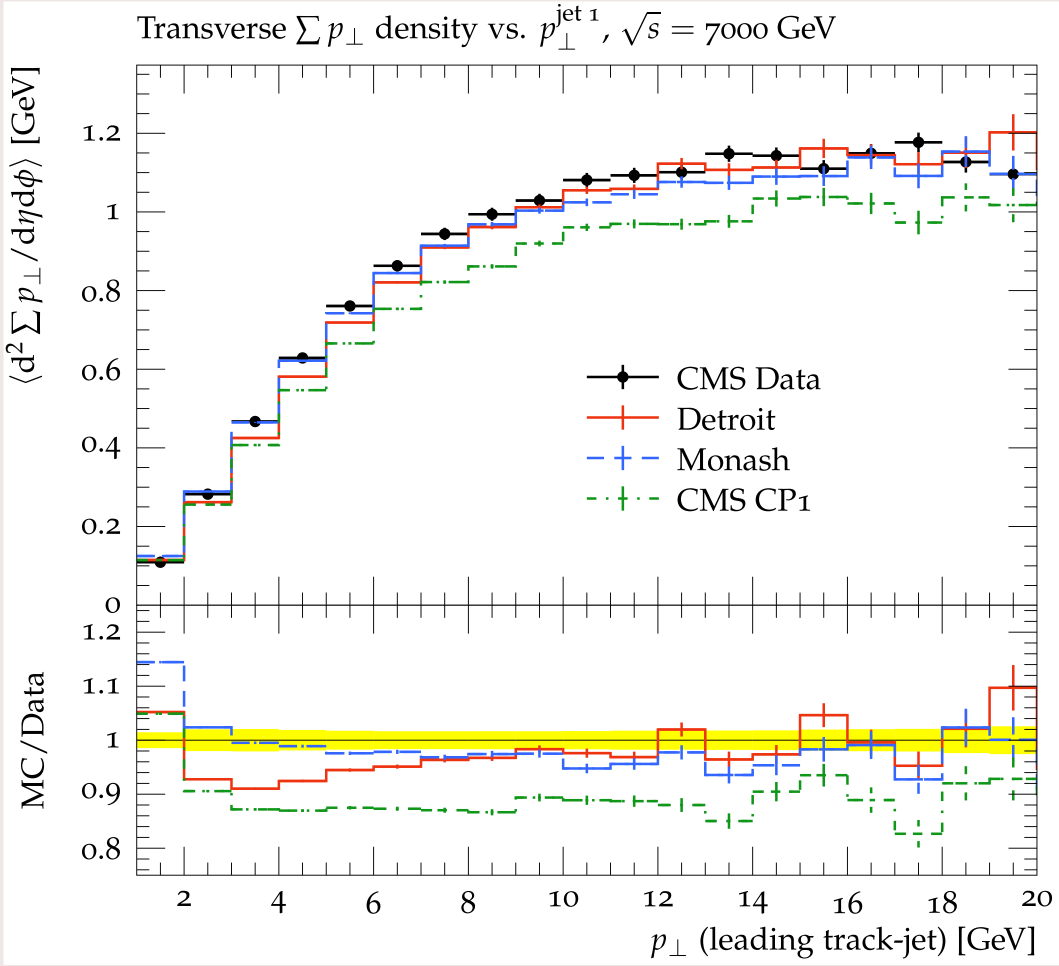
Monash: disagreement at, respectively, low-, mid-, and high-p_T^{max} as $\sqrt{s}$ increases

Comparisons to data

LHC — 7 TeV

CMS, JHEP 09 (2011) 109



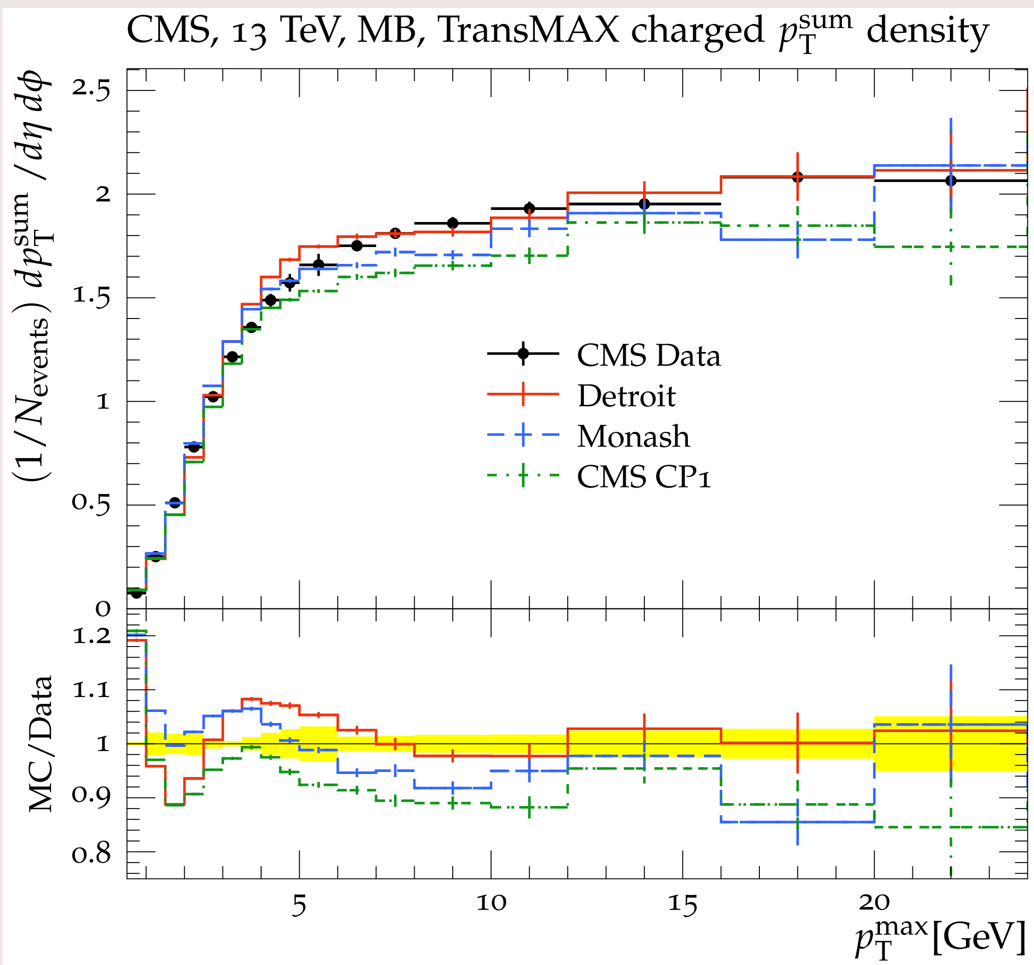


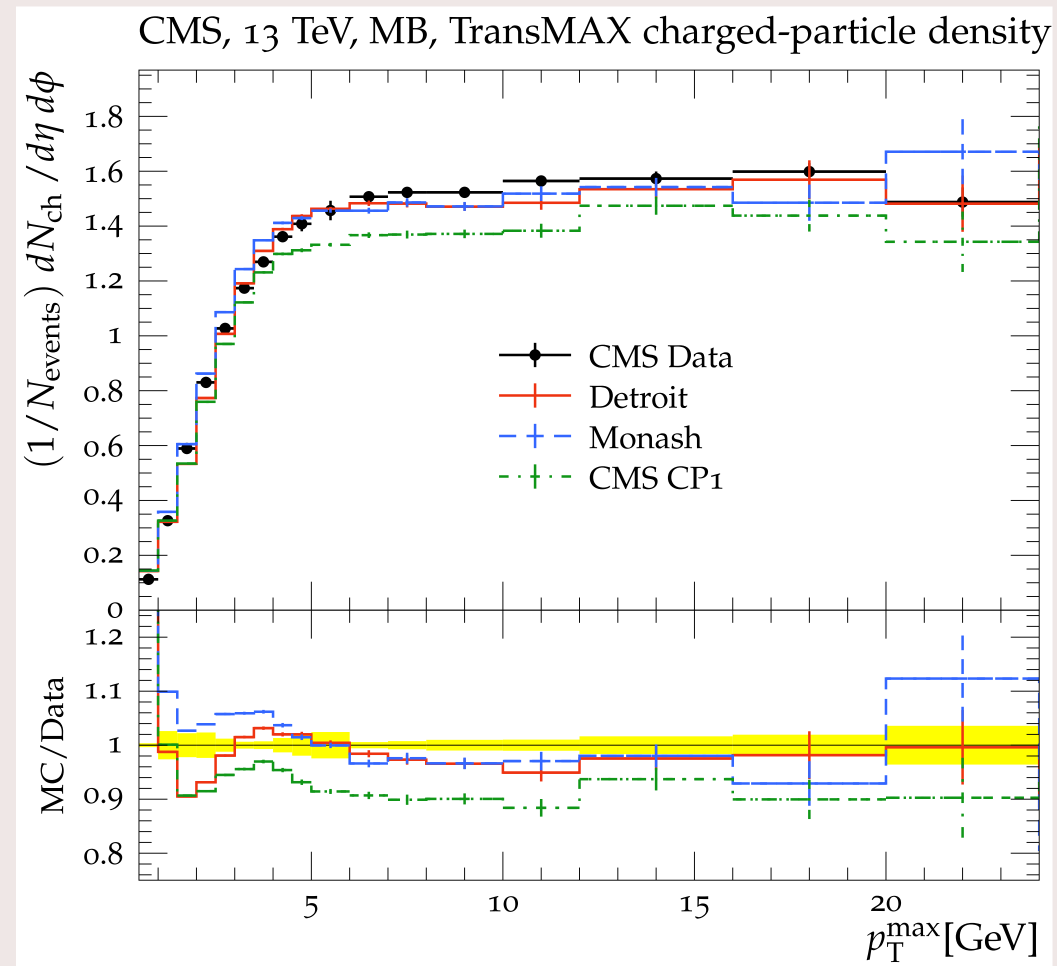
Monash tune gives best description of UE data for low p_T
For higher p_T, Detroit is consistent with data
CMS CP1 underpredicts the data for all p_T

Comparisons to data

LHC — 13 TeV

CMS-PAS-FSQ-15-007



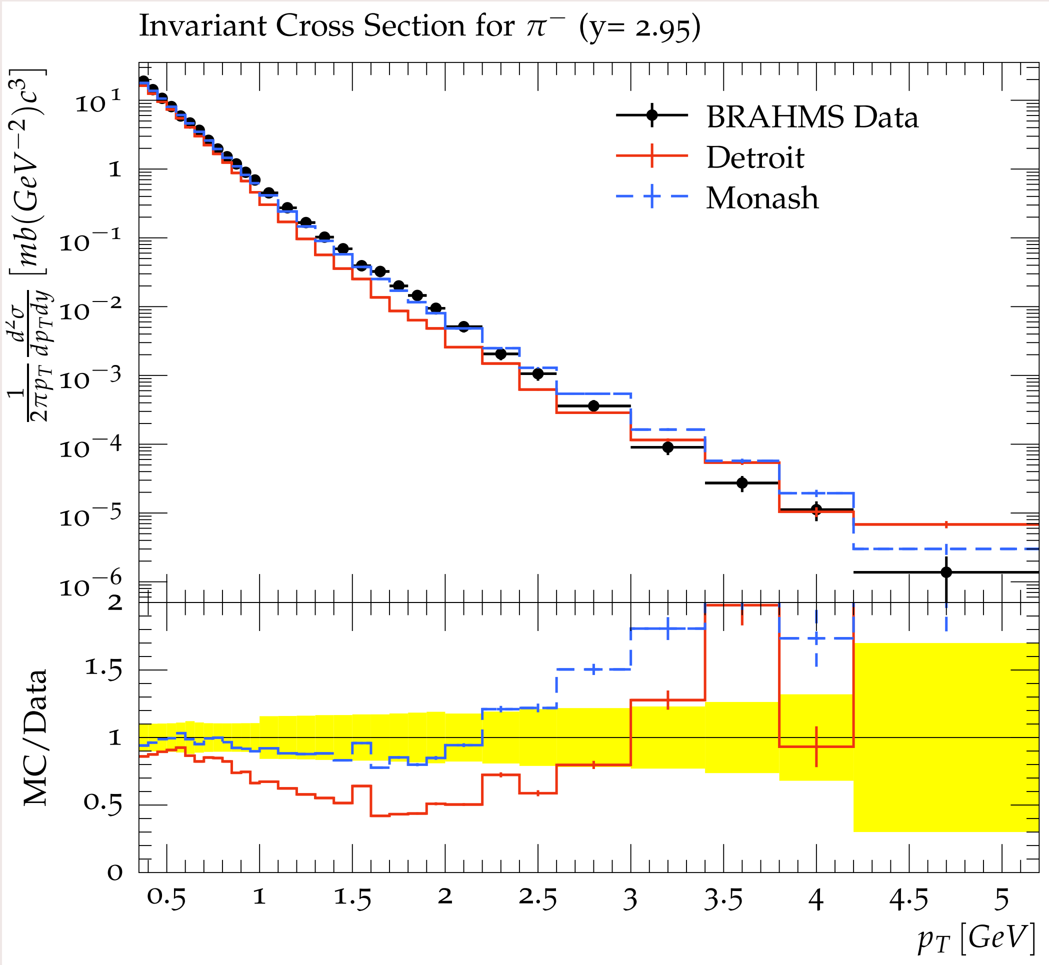


At high-p_T^{max}, Detroit is consistent with data to at least the level of Monash
At low-p_T^{max}, Detroit shape varies more due to proton shape function used
CMS CP1 still underpredicts the data significantly

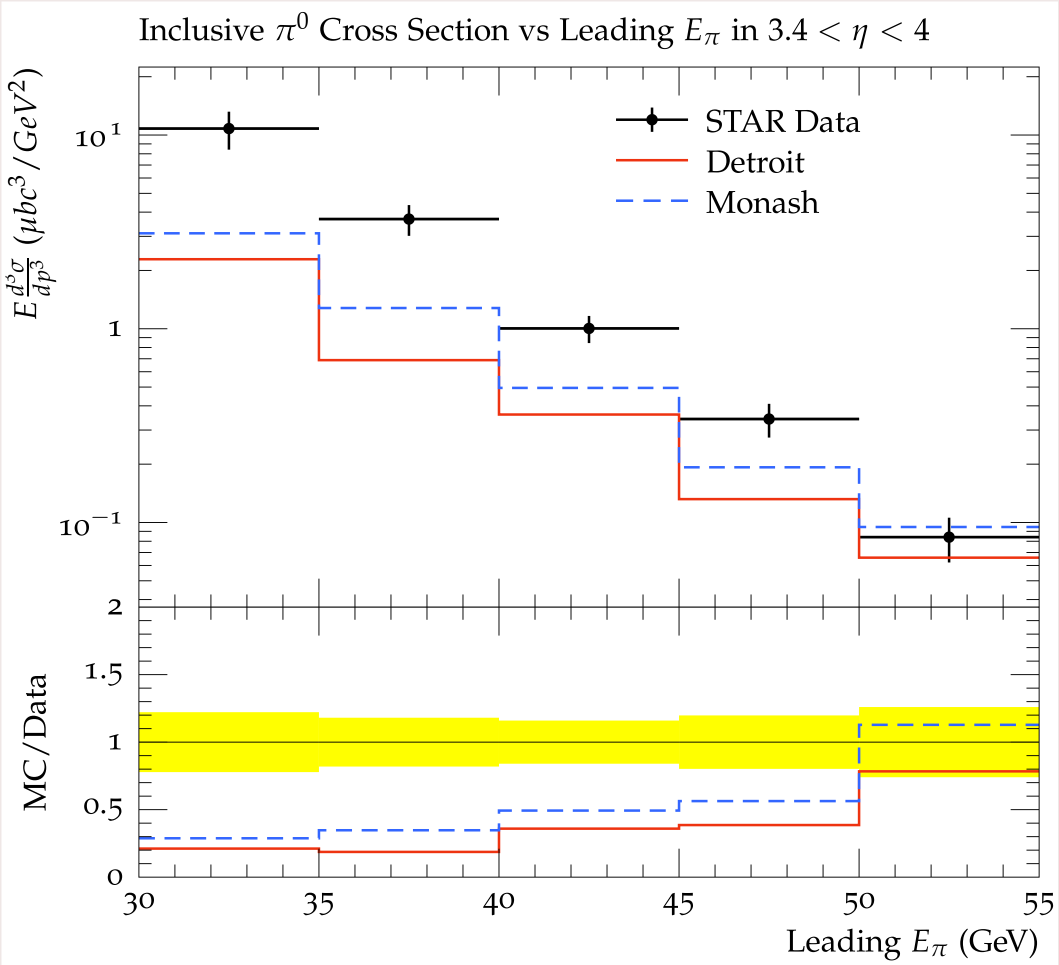
Comparisons to data

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 with Monash at low-p_T

Summary

Detroit tune:

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

➡ improved agreement, compared to Monash (and CMS CP1), with RHIC + Tevatron data (UE, jet substructure, etc.) at mid-rapidity

Predictions for some LHC data are at least as good as Monash at higher-p_{T}

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

Backup