WG1: Monte Carlo, MB, and UE

Armando Bermudez Martinez (DESY)

Arthur Moraes (CBPF)

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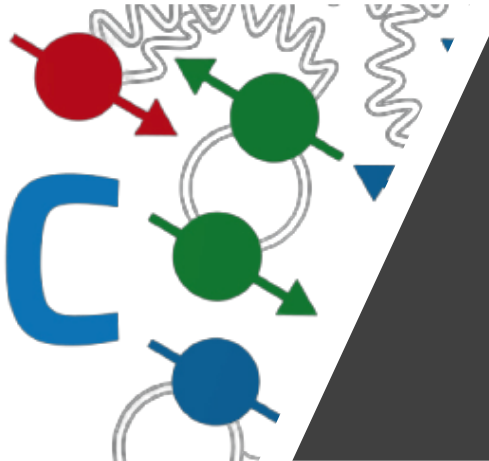

Lisbon, 11-15 October 2021

WG1: Minimum Bias, Underlying Event and Monte Carlo generators

- Monday (2 sessions) & Friday (1 session)
- 11 talks (10 WG1 + 1 shared WG1/WG4)
- Monte Carlo news and updates: PYTHIA8, HERWIG7, Geneva
- Experimental results & comparisons to MC: ALICE, ATLAS, CMS, LHCb, STAR (RHIC), H1 (HERA)

- Speakers: Simon Platzer, Smita Chakraborty, Matthew Kelsey, Marius Utheim, Chiara Oppedisano, Yuri Kulchitsky, Julian Alexander Boelhauve, Saptaparna Bhattacharya, Ben Nachman, Alessandro Gavardi, Mikel Mendizabal

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Lisbon, 11-15 October 2021

WG1: Minimum Bias, Underlying Event and Monte Carlo generators

Herwig 7 Overview

UNIVERSITÄT GRAZ
UNIVERSITY OF GRAZ

[Herwig collaboration – Eur.Phys.J. C76 (2016) 665]

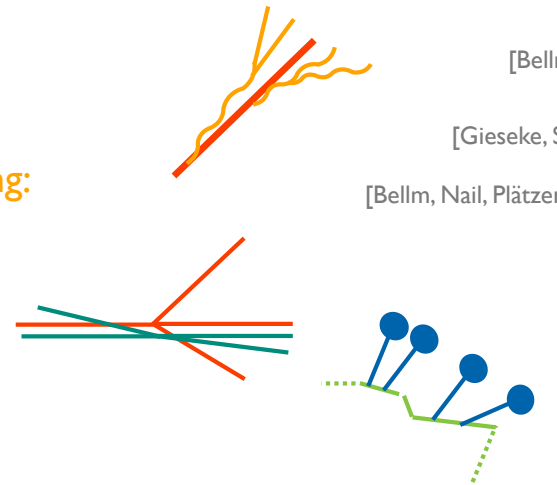
Hard partonic scattering:
NLO QCD routinely

[Plätzer, Gieseke – EPJ C72 (2012) 2187]
[Plätzer — JHEP 1308 (2013) 114]
[Bellm, Gieseke, Plätzer — EPJ C78 (2018) 244]

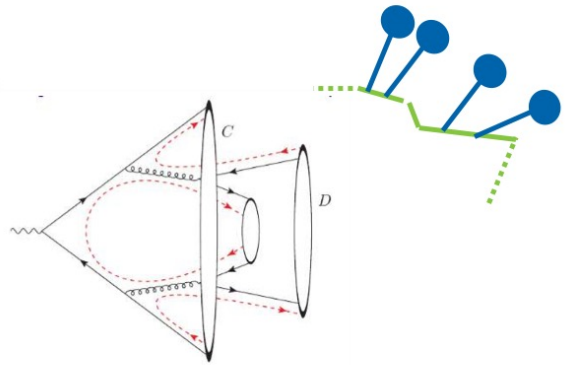
Jet evolution — parton branching:
NLL sometimes, mostly unclear

[Gieseke, Stephens, Webber – JHEP 0312 (2003) 045]
[Plätzer, Gieseke – JHEP 1101 (2011) 024]
[Bellm, Nail, Plätzer, Schichtel, Siodmok – EPJ C76 (2016) 665]

Multi-parton interactions
Hadronization



Eikonal MPI
Cluster Hadronization



Colour reconnection

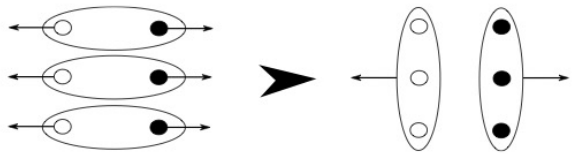
$$\mathrm{d}\sigma \sim \mathrm{L} \times \mathrm{d}\sigma_H(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{MPI} \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$

See Jo's talk on Thursday on double parton scattering.

Better understanding of showers, colour reconnection and hadronization connects to MPI modelling.

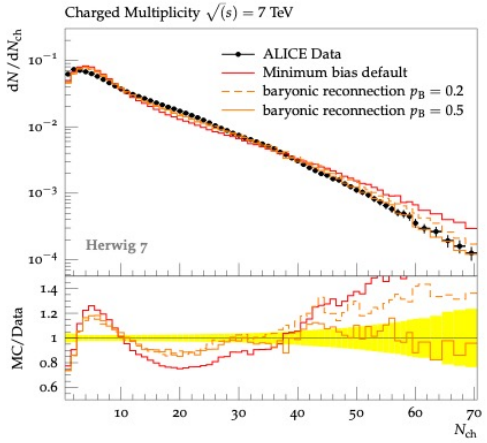
Colour reconnection

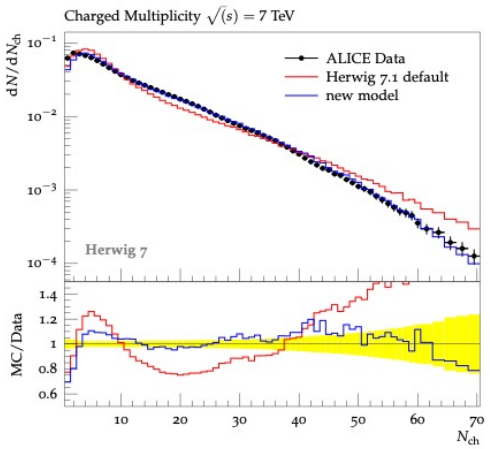
Generalize to geometric measure and baryonic systems



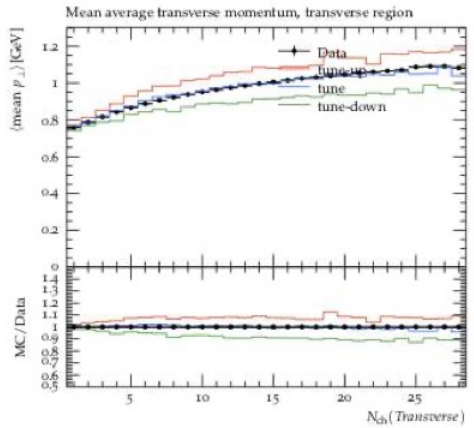
$$R_{q,qq} + R_{\bar{q},\bar{q}\bar{q}} < R_{q,\bar{q}} + R_{qq,\bar{q}\bar{q}}$$

[Gieseke, Kirchgaesser, Plätzer – EPJ C 78 (2018) 99]

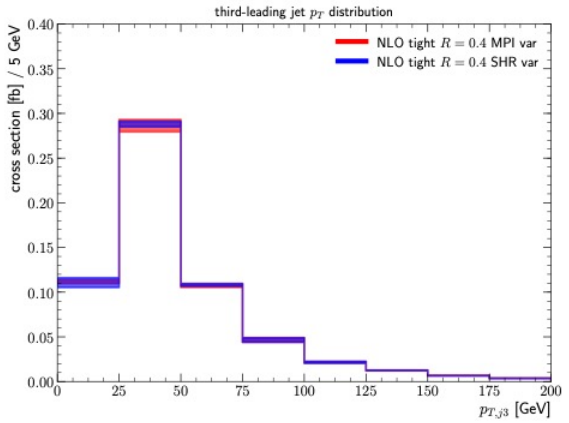


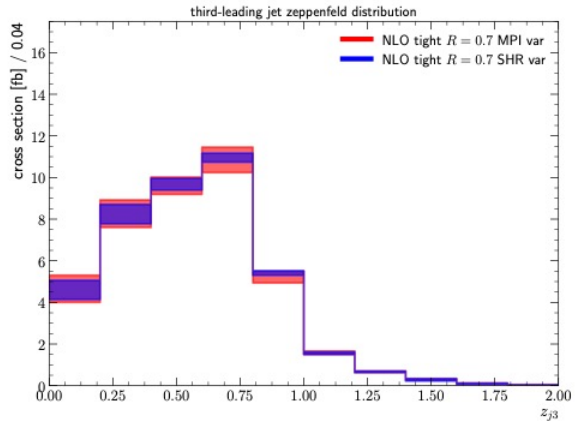


We know about the impact of multi-parton interactions, but what is the uncertainty?



Variations similar or even outrange the perturbative ones.

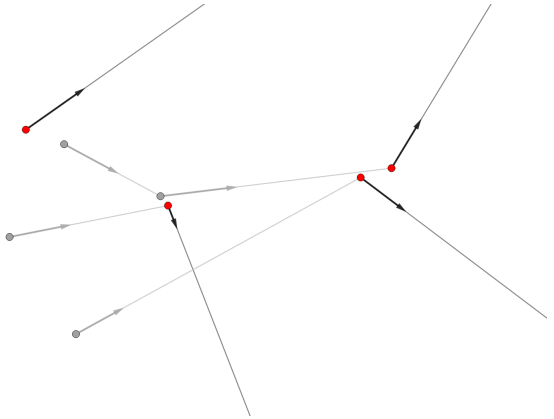




(see Simon Platzer's talk)

WG1 talks: Minimum Bias, Underlying Event and Monte Carlo generators

Hadronic rescattering



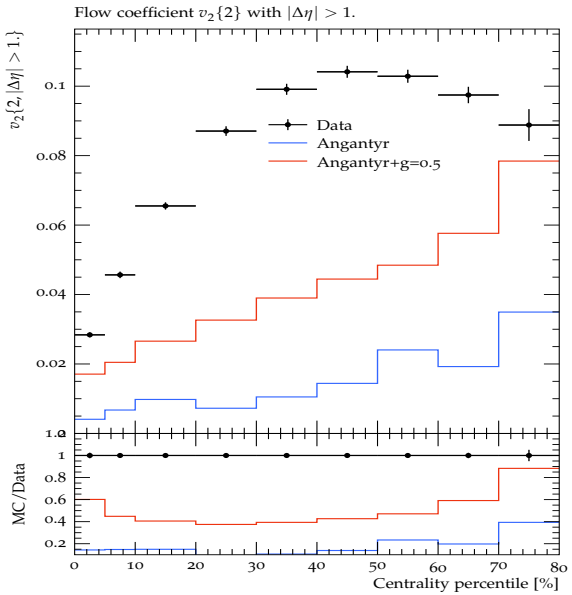
Using rescattering in PYTHIA

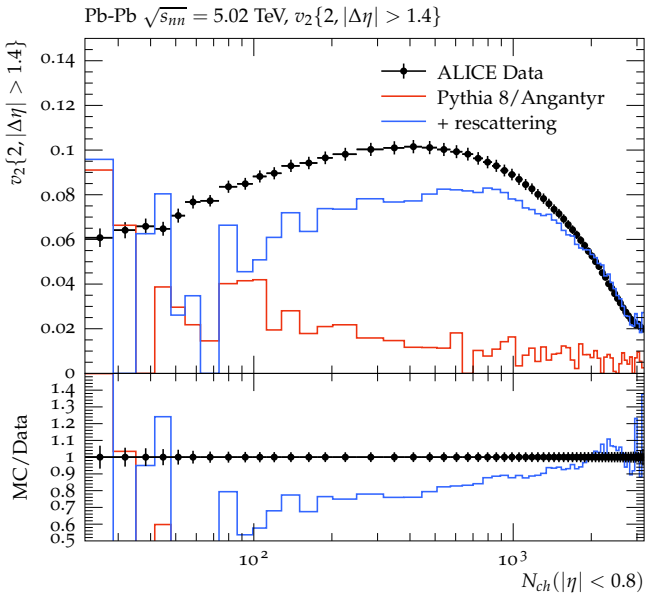
- `HadronLevel:Rescattering = on`
- To get correct multiplicity in pp collisions at 13 TeV, we use `MultipartonInteractions:pT0Ref = 2.345`
- Gives some significant effects, in particular a substantial amount of collective flow in Angantyr [`arXiv:2103.09665`]
- Can also be used for studies of specific resonances, such as exotic hadrons [`arXiv:2108.03479`], deuterons, $f_2(1270)$, etc., as alternative to coalescence models
- Simple to use, but relatively basic. For more sophisticated modelling, consider using e.g. the SMASH framework
- Open for future developments, but no specific features are currently in the works.

(see Marius Utheimr's talk)

WG1 talks: Minimum Bias, Underlying Event and Monte Carlo generators

$v_2\{2\}$ in Pb-Pb with shoving & rescattering





At $\sqrt{s_{NN}}$ =5.02 TeV, (left) $v_2\{2\}$ vs. centrality with only string shoving g = 0.5[†], (right) $v_2\{2\}$ vs $\langle N_{ch} \rangle$ with only rescattering[‡] (See talk by Marius Utheim on Monday afternoon)

[†]Bierlich, et. al., J. High Energ. Phys. 2021, 270 (2021), [‡]Bierlich, et. al., Eur.Phys.J.A 57 (2021) 7, 227.

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(see Smita Chakraborty's talk)

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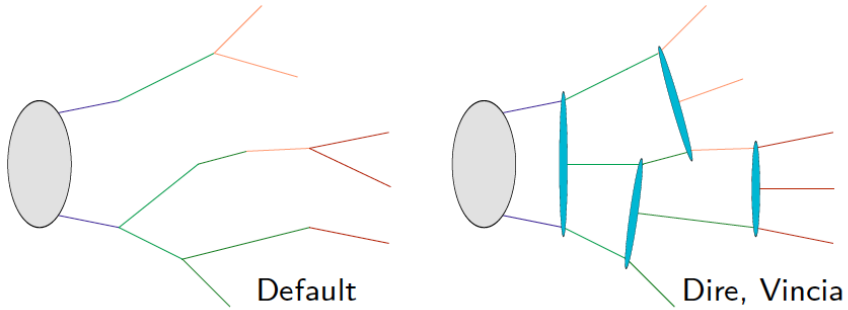
PYTHIA parton shower models

Starting from version 8.301, PYTHIA offers three built-in parton showers. Select which one by using the `PartonShowers:model` setting:

1. PYTHIA default
2. Vincia [`arXiv:2003.00702`]
3. Dire [`arXiv:1506.05057`]



Future: NNLO + Parton Shower matching is on the todo-list for both Vincia [arXiv:2108.07133] and Dire

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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

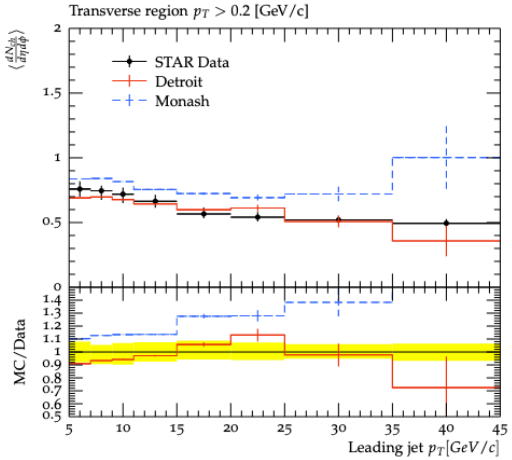
TABLE II. Mid-rapidity data used in the tuning procedure.

	Experiment	$\sqrt{s}$ (GeV)	Observable	Reference
New From STAR	STAR	200	$\pi^{\pm}$ cross sections vs. p_T	Physics Letters B 637, 161 (2006)
Included in RIVET	PHENIX	200	Di-muon pairs from Drell-Yan vs. di-muon p_T	Phys. Rev. D 99, 072003 (2019)
New From STAR	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)
Included in RIVET	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)
New From STAR	STAR	200	SoftDrop groomed jet sub-structure (z_g and R_g)	Physics Letters B 811, 135846 (2020)
New From STAR	STAR	200	Inclusive and groomed jet mass	Phys. Rev. D 104, 052007 (2021)

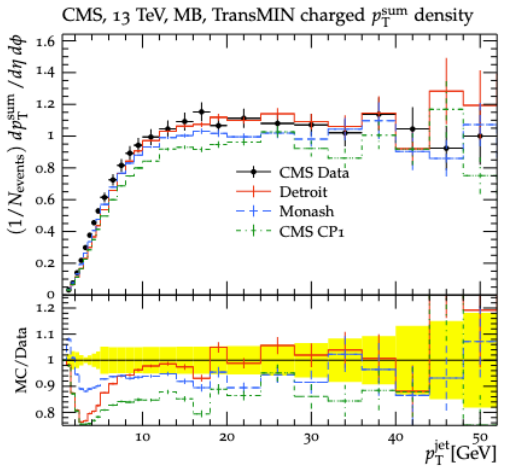
Degrees of Freedom= 493

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

UE@ √s=200GeV



UE@ √s=13TeV



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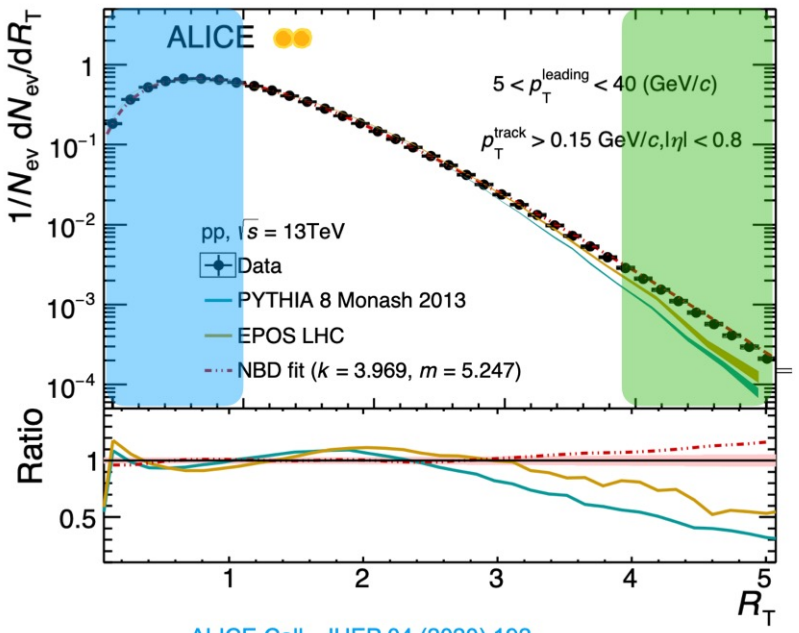
R_T estimator

$$R_T = \frac{N^{TR}}{\langle N^{TR} \rangle}$$

Relative Transverse activity classifier R_T: multiplicity in the TRANSVERSE REGION (p_T>5 GeV/c) normalised to MB

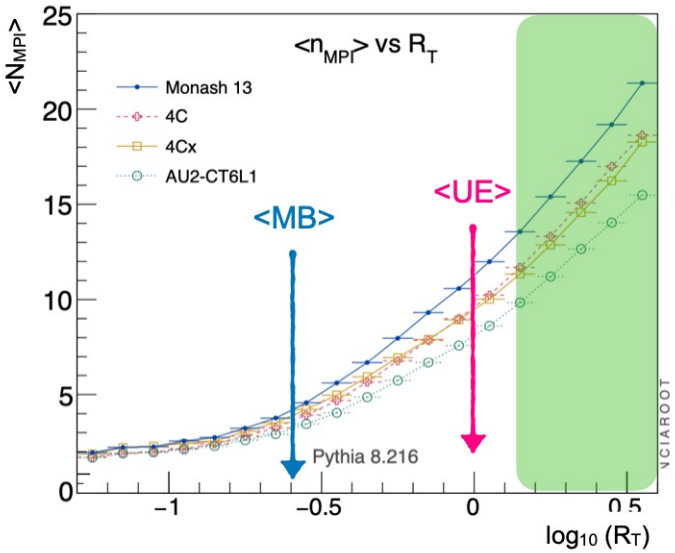
➧ study particle production as a function of UE activity



ALICE Coll., JHEP 04 (2020) 192

low-UE (R_T~0) ➧ low N_{MPI}, jet-dominated

high-UE (high R_T) ➧ high N_{MPI}



T. Martin et al., Eur. Phys. J. C76 5, (2016) 299

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(see C. Oppedisano's talk)

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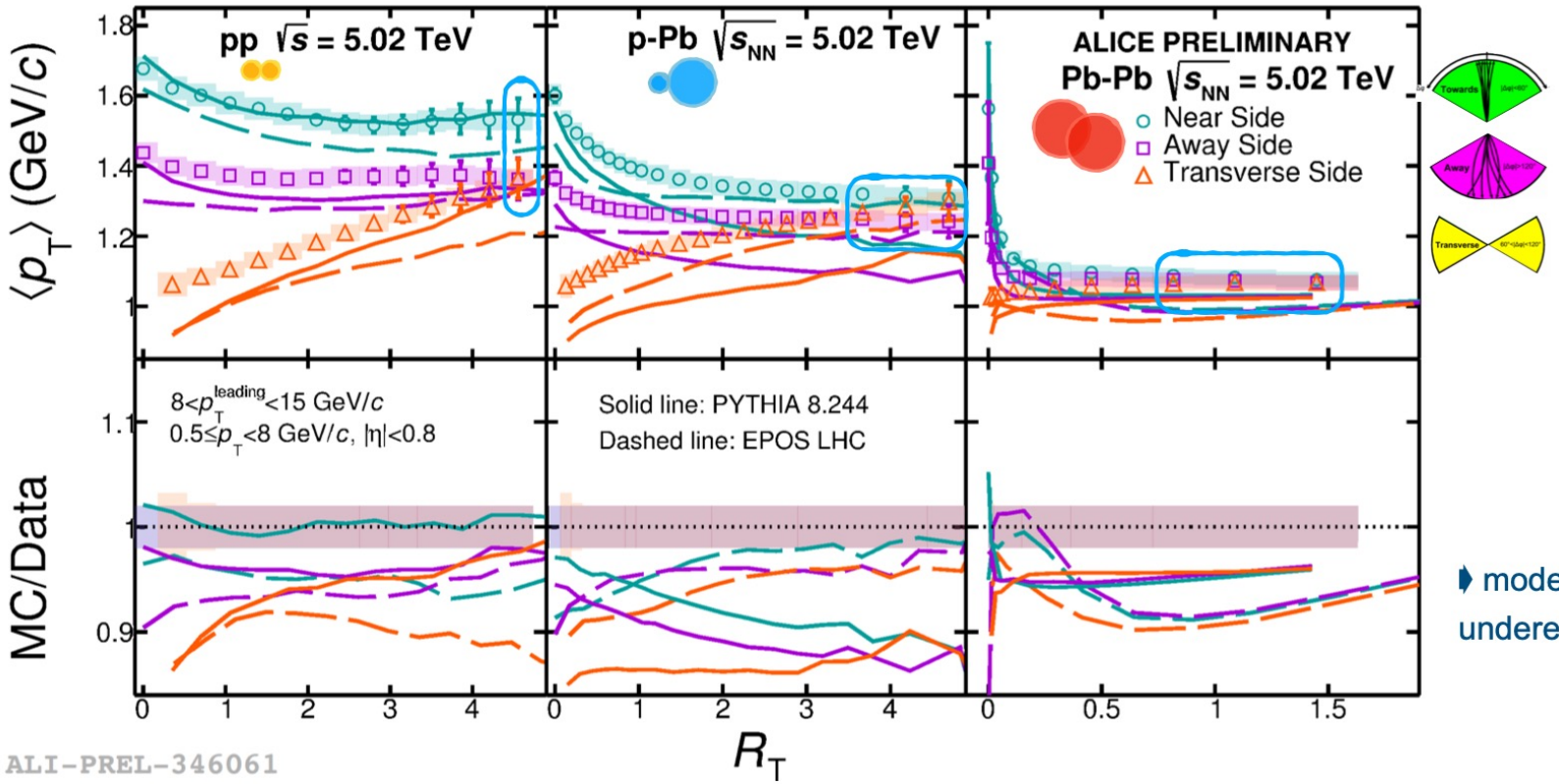
$\langle p_T \rangle$ vs. R_T



- models tend to underestimate $\langle p_T \rangle$

high R_T ➧ UE dominates ➧ similar $\langle p_T \rangle$ values in the 3 topological regions for each colliding system

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(see C. Oppedisano's talk)

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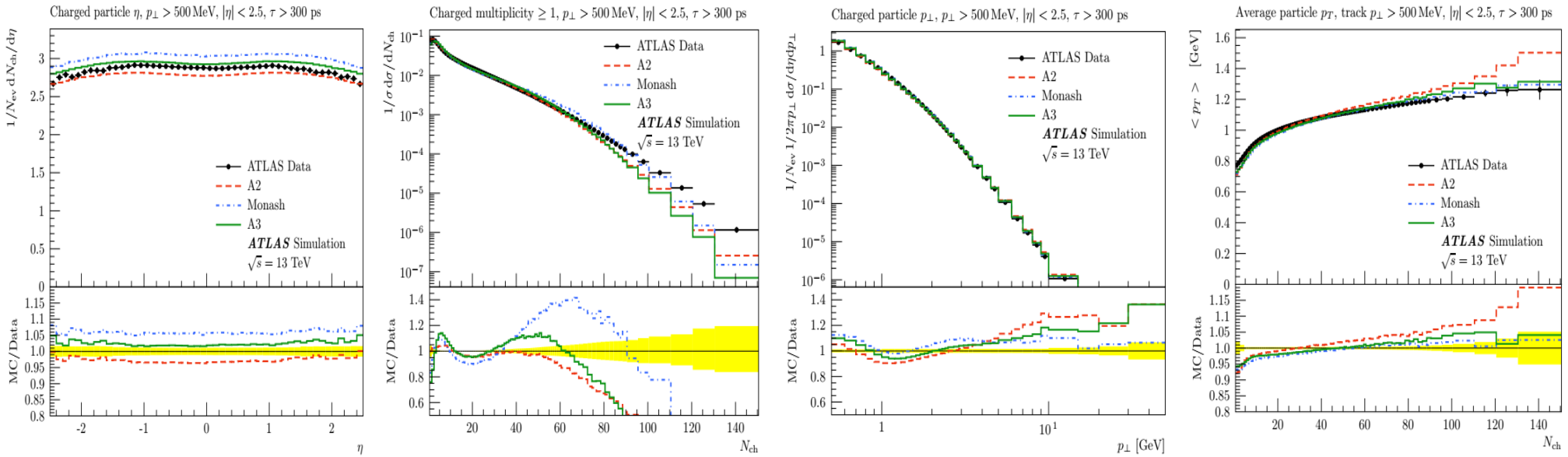
RUN 3: PLANS

ATL-PHYS-PUB-2016-017

- The typical variables used to study the soft phenomena using **MB** samples are usually tuned in event generators using these **MB** measurements, because there is a variability in modelling since non-perturbative QCD is used.
  - These variables for new collision energy will be measurement in **Run 3**
- The **MB/UE** results from **Run 2** are exploited for **Run 3:**
- The ***Pythia 8 A3 tune*** is suitable for inclusive QCD modelling for **Run 3** and it uses the ATLAS **Run 2** charged-particle distribution & inelastic cross section results in addition to the **Run 1** used for construction of ***MB tunes***



The ***Pythia 8 A3, A2 & Monash tune*** predictions compared with ATLAS charged particle distributions **at 13 TeV**

(see Yuri Kulchitsky*'s talk)*

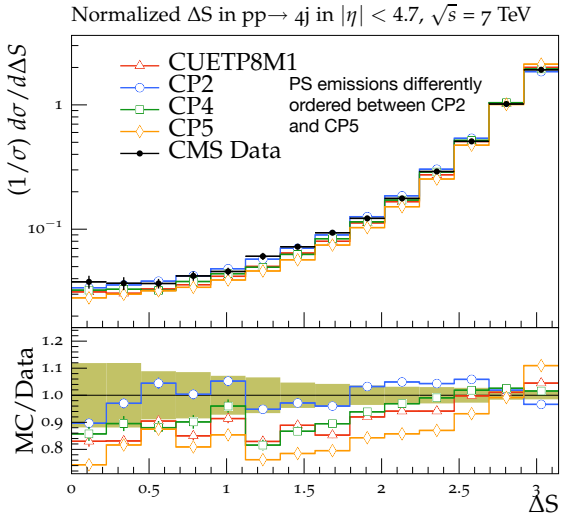
WG1 talks: Minimum Bias, Underlying Event and Monte Carlo generators

Skeletal Outline

- ☑ The LHC as a precision machine
  - ☑ Examples of analyses from the top and diboson final states
- ☑ The underlying event description and color reconnection modeling
- ☑ Color reconnection tunes
  - ☑ Performance of the color reconnection tunes in PYTHIA8 NEW
- ☑ Studies of double parton scattering NEW
- ☑ Going beyond DGLAP NEW

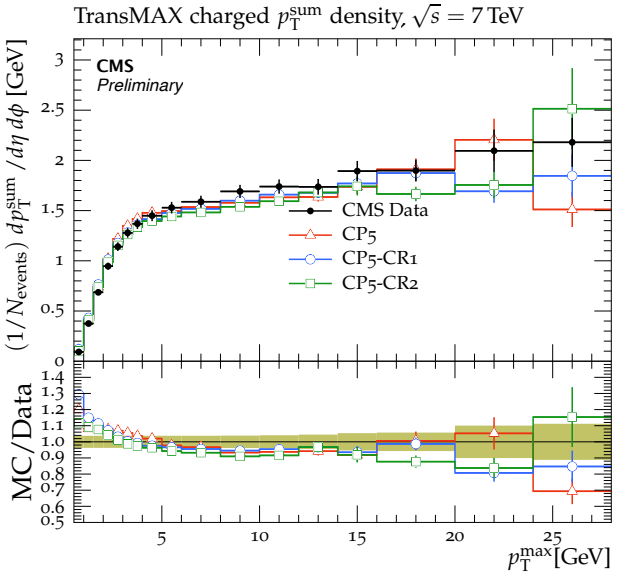
☑ Focused on recent results where possible
☑ Emphasis on exploration of novel regions of phase space

☑ Data shows preference for p_T ordered parton shower description (studies performed in GEN-17-001 in agreement)



Azimuthal angular difference between the hard and the soft jet pairs

$$\Delta S = \arccos\left(\frac{(\vec{p}_{T,1}+\vec{p}_{T,2})\cdot(\vec{p}_{T,3}+\vec{p}_{T}}{|\vec{p}_{T,1}+\vec{p}_{T,2}||\vec{p}_{T,3}+\vec{p}_{T,}}\right.$$



(see Saptaparna Bhattacharya*'s talk)*

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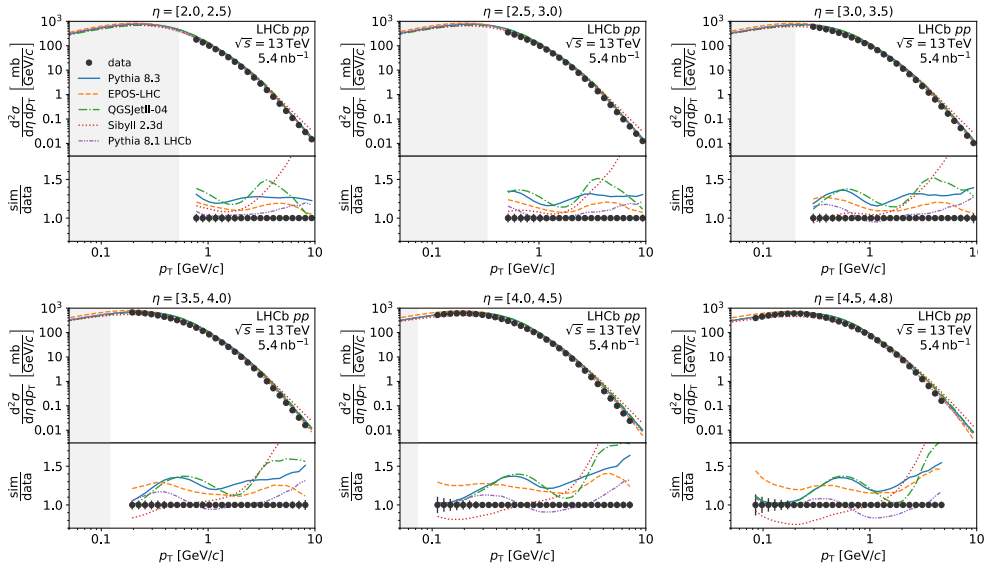
Prompt charged-particle production: Differential cross-section



- Deviations between $-26\,\%$ and $+170\,\%$
- Smallest overall deviation observed for EPOS-LHC

Plans for measurements in Run 3

- Hadron distributions in heavy-quark jets and jets produced in association with W or Z bosons
- Differential heavy-quarkonium production cross-sections
- Strangeness production
- Multiplicity-dependent cross-section ratios of prompt hadron production
- Prompt hadron production in proton-oxygen collisions as input to the Muon Puzzle

(see Julian Boelhauve's talk)

Discussion:

1. Monte Carlo models and tunes

2. Minimum bias measurements (Run 3)

3. The underlying event (Run 3)