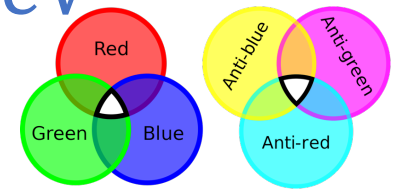
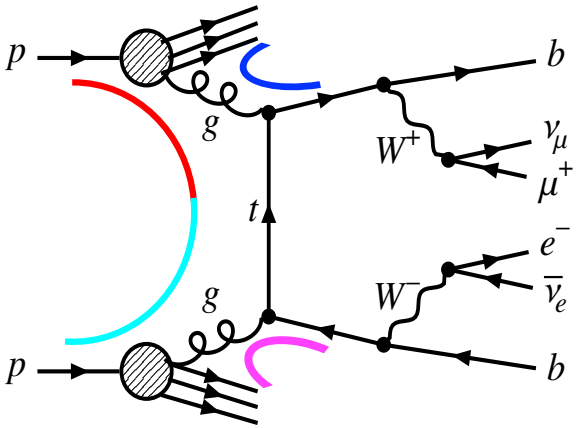
Measurement of observables sensitive to colour reconnection in $t\bar{t}$ events with the ATLAS detector at $\sqrt{s} = 13$ TeV



arXiv:2209.07874



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TOP 2022 - Durham
September 6, 2022

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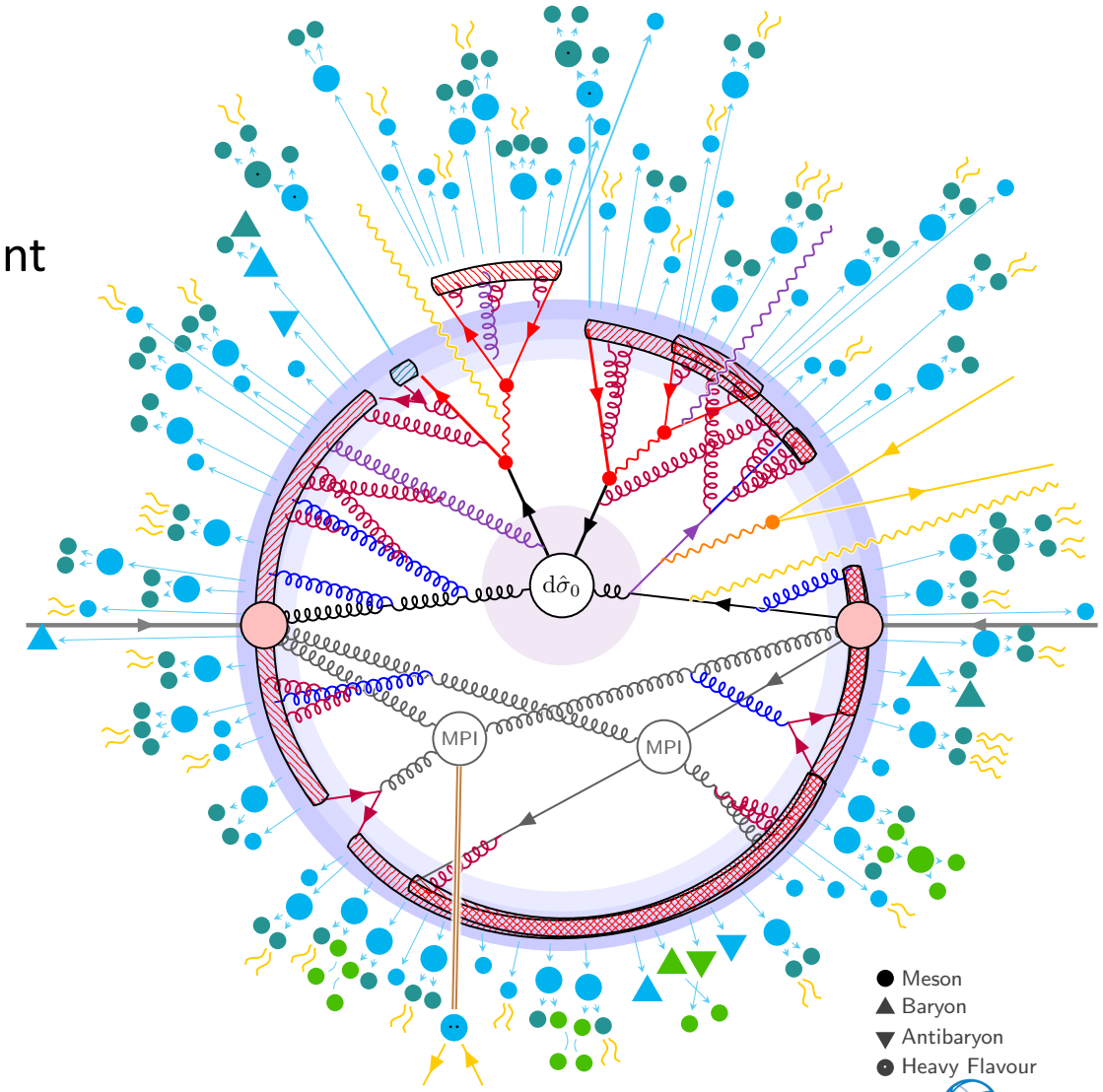
Event simulation

- Perturbative methods
  - Hard process/Matrix element
  - Parton shower
- Non-perturbative models
  - Hadronisation and decay
  - The underlying event
  - Colour reconnection



Hard Interaction
Resonance Decays
MECs, Matching & Merging
FSR
ISR*
QED
Weak Showers
Hard Onium
Multiparton Interactions
Beam Remnants*
Strings
Ministrings / Clusters
Colour Reconnections
String Interactions
Bose-Einstein & Fermi-Dirac
Primary Hadrons
Secondary Hadrons
Hadronic Reinteractions
(: incoming lines are crossed)*

arXiv:2203.11601

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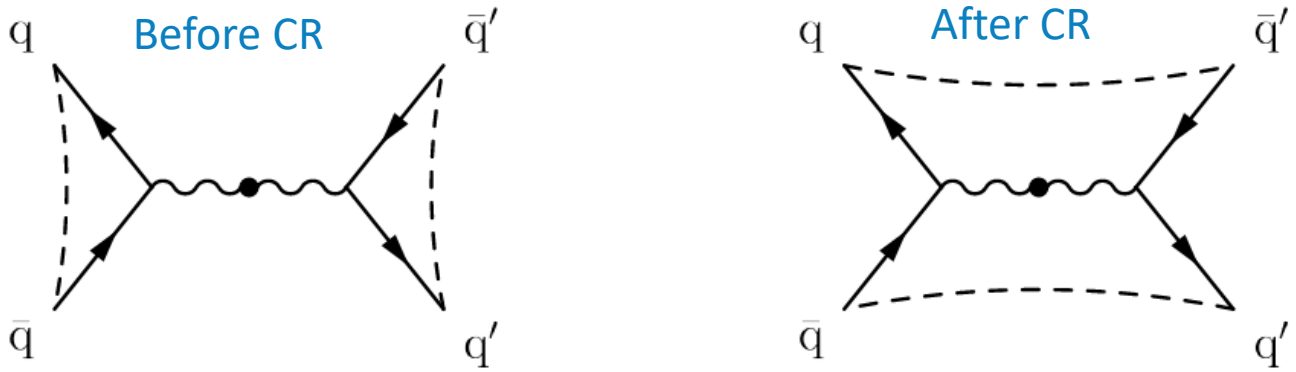
Colour reconnection mechanism

Rearranging colour connections between partons during the hadronisation

- Connections other than the predefined ones according to the simple leading colour (LC) approximations
  - In the LC approximations each successively emitted parton is colour connected to its parent
  - CR allows colour lines to be formed between partons also from different interactions



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Colour reconnection mechanism

- The simulation of the CR mechanism is poorly understood
  ↪ several phenomenological models are available
  - Models come with many free parameters

- In Pythia 8, there are currently more than 16 models
  - taking them into account in top-quark mass measurements
    ↪ leads to large uncertainties
  - most of new models predict a shift in m_{top} to lower values
  - prescription to estimate this uncertainty is not well defined

	m_{top} [GeV]
Result	172.63
Statistics	0.20
Method	0.05 ± 0.04
Matrix-element matching	0.35 ± 0.07
Parton shower and hadronisation	0.08 ± 0.05
Initial- and final-state QCD radiation	0.20 ± 0.02
Underlying event	0.06 ± 0.10
Colour reconnection	0.29 ± 0.07
Parton distribution function	0.02 ± 0.00
Single top modelling	0.03 ± 0.01
Background normalisation	0.01 ± 0.02
Jet energy scale	0.38 ± 0.02
b-jet energy scale	0.14 ± 0.02
Jet energy resolution	0.05 ± 0.02
Jet vertex tagging	0.01 ± 0.01
b-tagging	0.04 ± 0.01
Leptons	0.12 ± 0.02
Pile-up	0.06 ± 0.01
Recoil effect	0.37 ± 0.09
Total systematic uncertainty (without recoil)	0.67 ± 0.05
Total systematic uncertainty (with recoil)	0.77 ± 0.06
Total uncertainty (without recoil)	0.70 ± 0.05
Total uncertainty (with recoil)	0.79 ± 0.06

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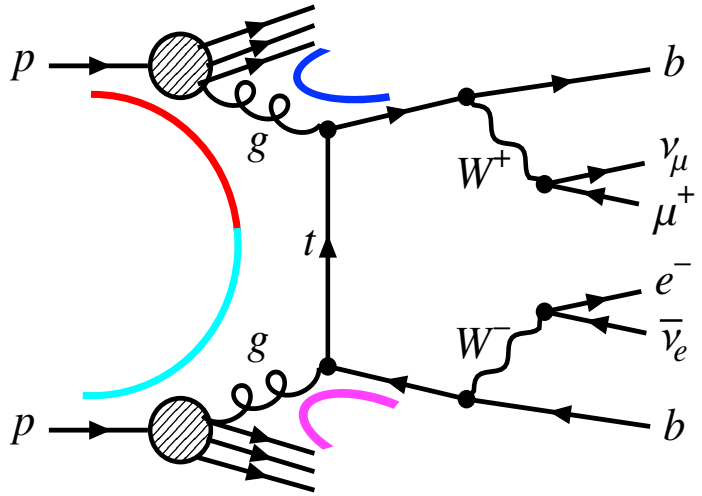
Selection and observables definition

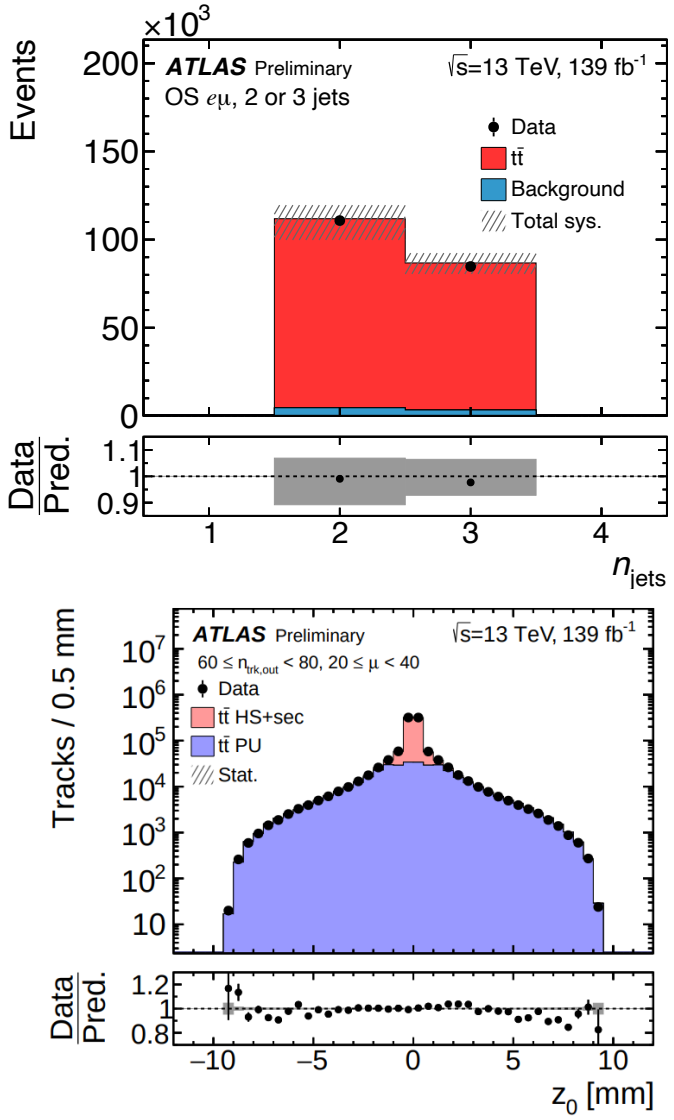


- Select $t\bar{t}$ events in the dileptonic $e\mu$ channel

- Measure three observables:
  - Charged particle multiplicity (n_{ch})
  - Scalar sum of charged-particles transverse momenta ($\sum_{n_{ch}} p_{\mathrm{T}}$)
  - $\sum_{n_{ch}} p_{\mathrm{T}}$ in bins of n_{ch}

- The observables use tracks outside jets
  ↪ tracks inside jets does not contribute significantly to the discrimination power between CR models

Analysis strategy

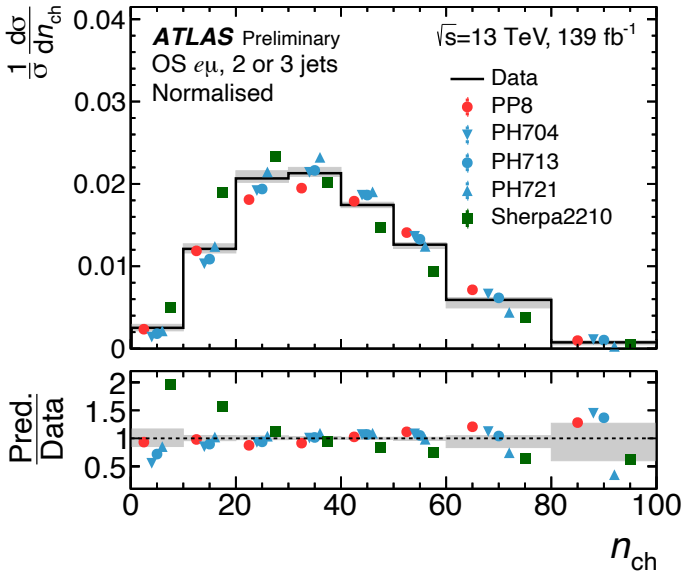


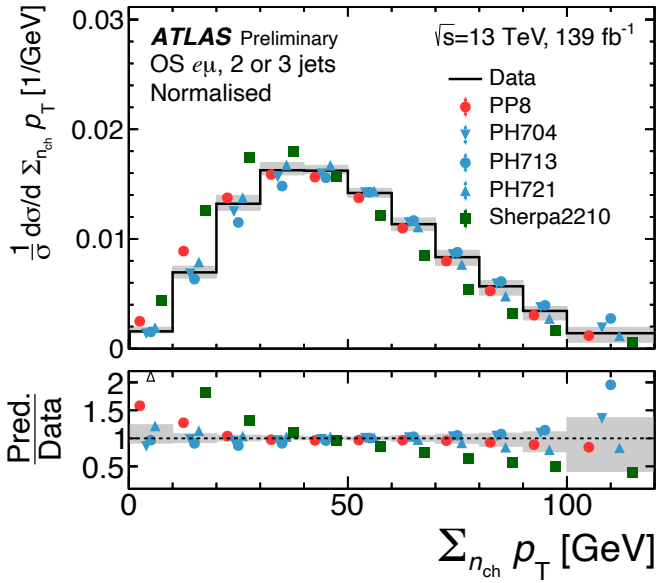
Estimate various background contributions

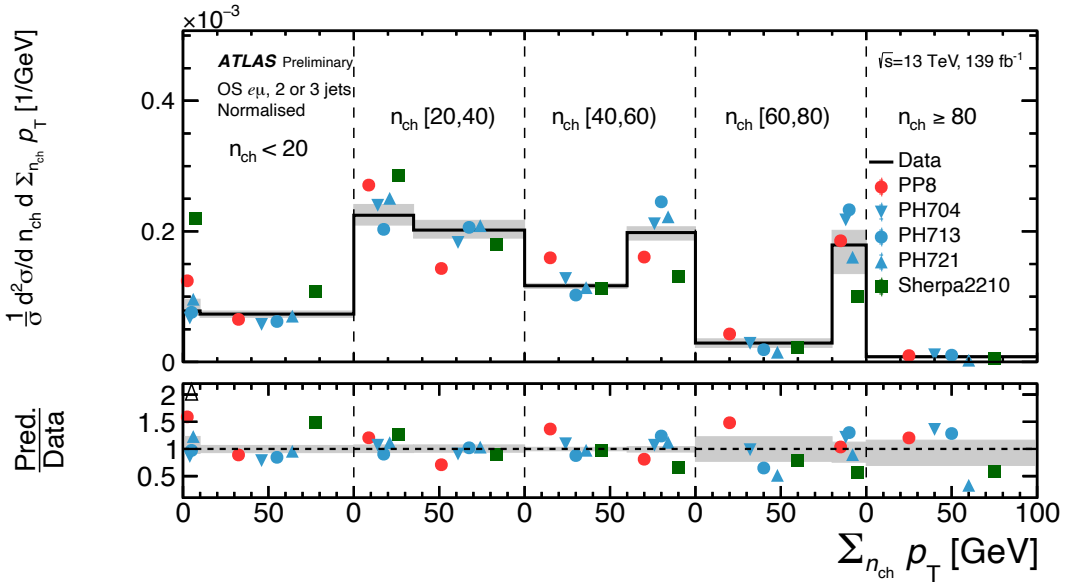
- Backgrounds to $t\bar{t}$ events (single top tW, fake-leptons, $t\bar{t}V$, $\mathrm{Z}+\mathrm{jets}$, $\mathrm{diboson}$)
- Backgrounds to primary hard-scatter tracks
  - Estimate and subtract the pile-up and secondary particle tracks contamination
    - in a stochastic way based on a method using MC templates
    - account for Data-MC mismodelling by estimating scale factor
- Observables are unfolded to particle-level, using IBU
- Compare unfolded data to several MC predictions

Results

- Measured normalised differential cross-sections are compared to the prediction from different generators
- Dominant uncertainties are signal modelling uncertainties, i.e. parton shower and hadronization model



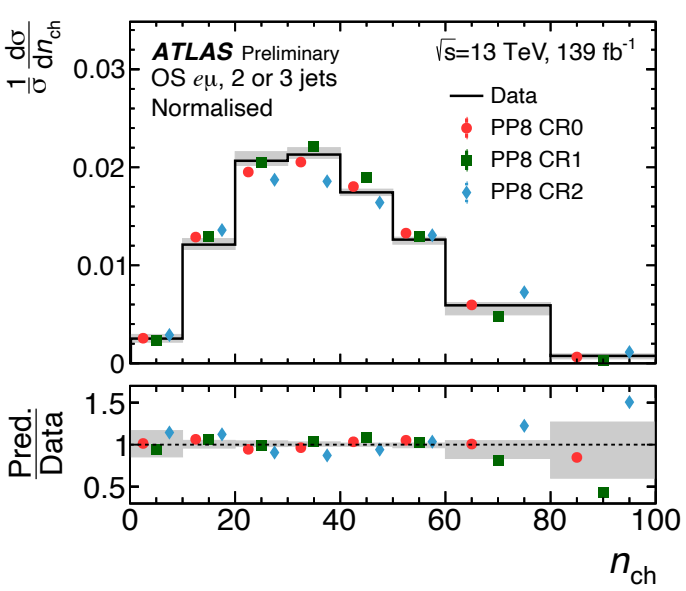


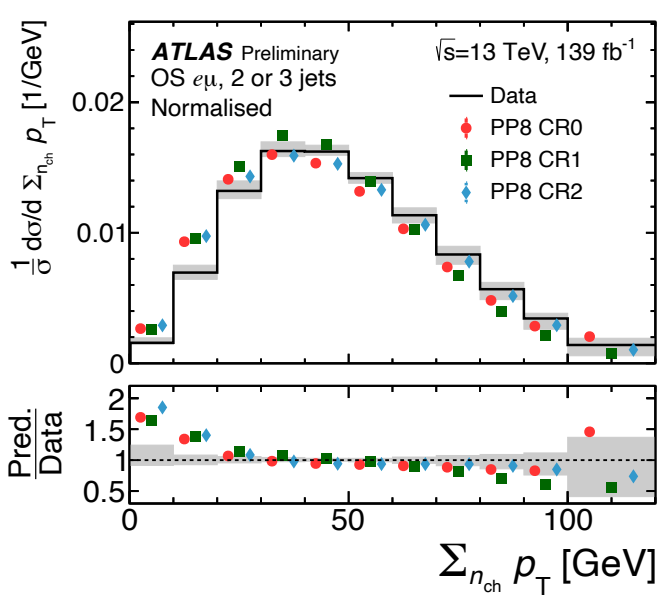


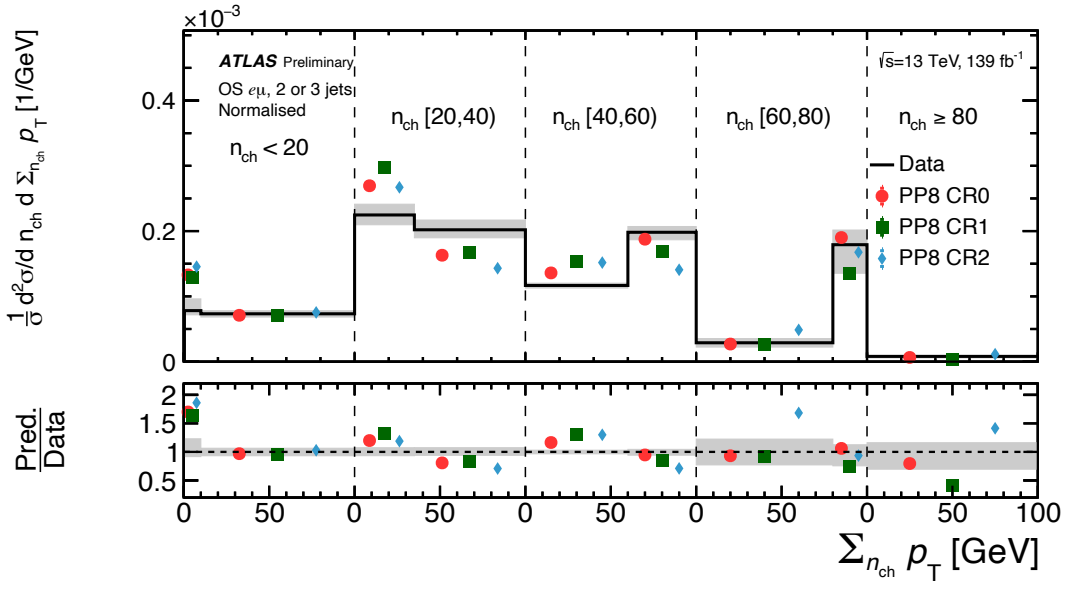
- Measured data disagree with the predictions from Sherpa 2, which does not include CR effects
- The n_{ch} measured cross-section is approximately equally well described by Pythia 8 and Herwig 7
- The $\sum_{n_{ch}} p_{\mathrm{T}}$ has a better agreement for Herwig 7, especially in the lower part of the distribution
- The distribution of $\sum_{n_{ch}} p_{\mathrm{T}}$ in bins of n_{ch} is best described by the three versions of Herwig 7

Results

- Measured normalised differential cross-sections are compared to the prediction from tuned CR models in Pythia8 generators (ATL-PHYS-PUB-2017-008)







- n_{ch} and $\sum_{n_{ch}} p_{\mathrm{T}}$ in bins of n_{ch} are best described by the CR0 model
- For the $\sum_{n_{ch}} p_{\mathrm{T}}$ none of the models can describe the lower part of the distribution well

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Conclusion

- Presented a measurement of three observables sensitive to colour reconnection
  - n_{ch} charged particle multiplicity
  - $\sum_{n_{ch}} p_T$ scalar sum of charged-particles transverse momenta
  - $\sum_{n_{ch}} p_T$ in bins of n_{ch} scalar sum of charged-particles transverse momenta
- The result can be used as input for future tuning of MC generators for both CR and MPI parameters
- Public page is available here: arXiv:2209.07874