Status and Progress of Pythia8

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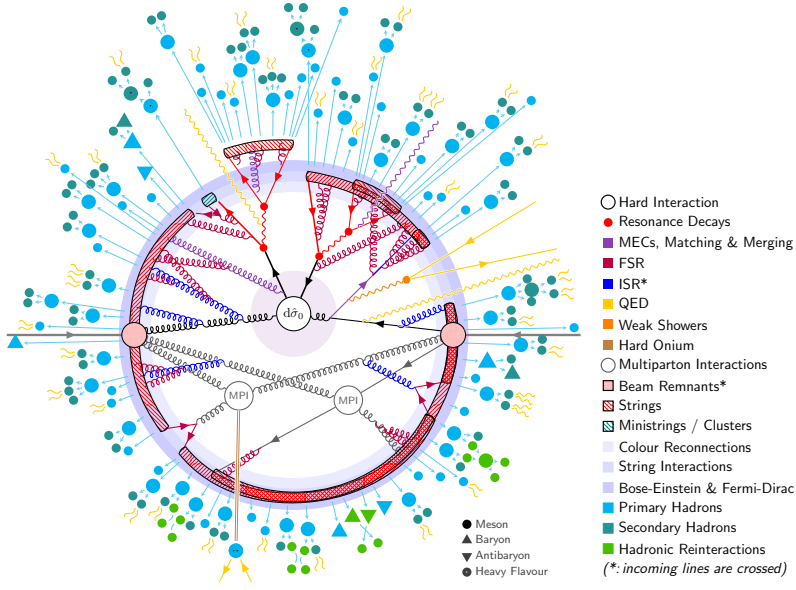
Parton Showers and Resummation 2023, Milan
June 6th to 8th, 2023

LUND
UNIVERSITY

MCnet

An event in PYTHIA 8 [Bierlich, Chakraborty, Desai, LG, et al. (2022)]



Introduction: Status and Progress

- Current series: PYTHIA 8.3. New manual: [Bierlich, Chakraborty, Desai, LG, et al. (2022)]
- Broad rather than deep overview, reflects broad interests within collaboration

General Overview

- Heavy ion physics: Angantyr
- Hadronization: string interactions
- Rescattering & Cosmic rays
- ...

PS and Related

- Dire & Vincia
- Automated variations
- $2 \to 4$ splittings
- Matching & merging
- Interleaved resonance decays
- Sector showers
- ...

Technical and Organizational

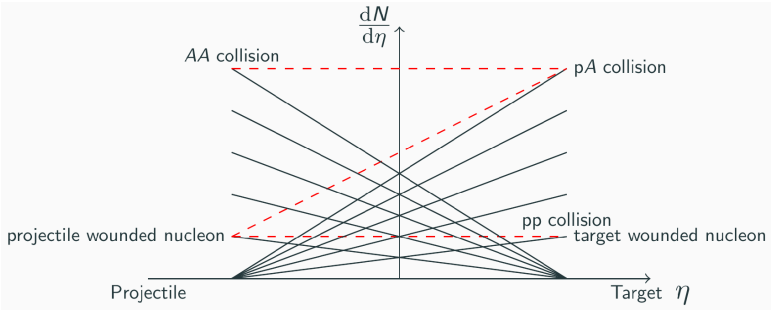
- Python interface
- Pythia8 contrib
- Gitlab & issue desk
- Distributed management
- ...

- Not a complete list, apologies to those not mentioned

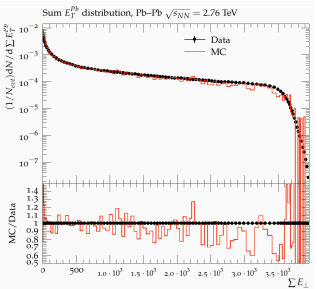
A Broad Overview

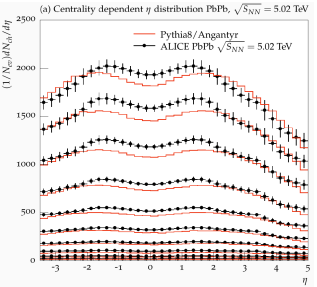
Angantyr

- Framework for heavy ion collisions
  - Glauber calculation decides which nucleons hit each other
  - Pythia pp, pn & nn events stacked on top of each other
  - A clean baseline for adding collective effects, no QGP



[Bierlich, Gustafson, Lönnblad, Shah (2018)]





String Interactions and CR

- Extending Lund strings' abilities: interactions between strings
- String shoving generates flow
- Rope hadronization increases strangeness and baryons
- Intention: alternative to QGP models
- Extension to AA ongoing

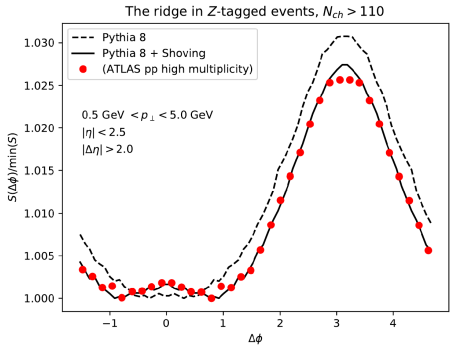
[Bierlich, Gustafson, Lönnblad (2018)]

[Bierlich (2019)] [Bierlich (2019)]

[Bierlich, Chakraborty, Gustafson, Lönnblad (2021)]

- Spatially constrained QCD color reconnection in pp, pA, AA

[Lönnblad, Shah (2023)]



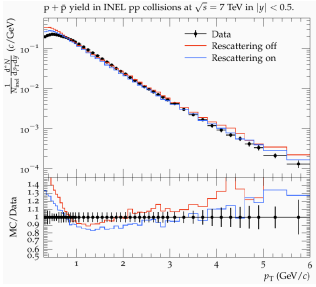
Hadronic Rescattering

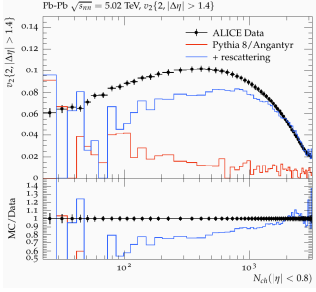
- Allow hadrons to scatter again in final state
- Some effects in pp, very important in ion collisions
- Requires knowledge of production vertices
- Comes with new framework for low energy QCD cross sections

[Ferreres-Solé, Sjöstrand (2018)] [Sjöstrand, Utheim (2020)] [Bierlich, Sjöstrand, Utheim (2021)]

- Low energy QCD framework can be used for atmospheric cascades of cosmic rays

[Sjöstrand, Utheim (2022)]





Parton Showers and Related Aspects

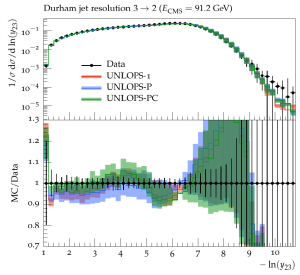
Automated Variations: Shower and Merging

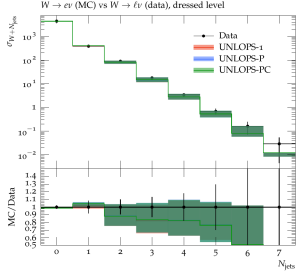
- Expanding on automated scale and pdf variations in parton showers

[Mrenna, Skands (2016)]

- Automatic consistent renormalization scale variation in different merging schemes
- Scheme variations for unitary NLO multi-jet merging
- Help improve error estimation and save runtime

[LG, Prestel (2020)]

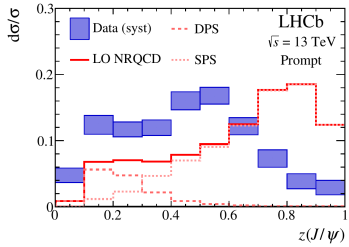


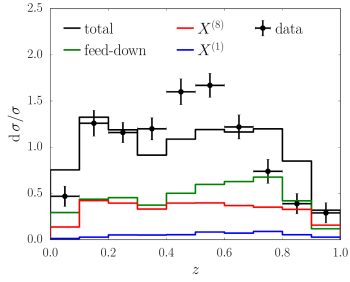


Quarkonia Production in the Parton Shower

- Production of heavy flavor mesons in parton shower
- Based on NRQCD LDMEs
- Color singlet & octet quarkonia implemented

[Cooke, Ilten, Lönnblad, Mrenna (coming soon)]



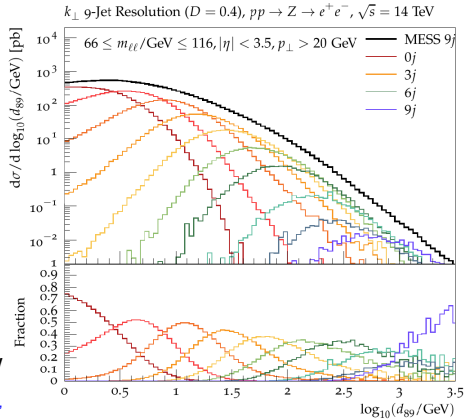


Vincia

- Alternative parton shower, based on antenna formalism
- Fully incorporated in Pythia since 8.3
- Fully coherent soft interference for QED
- Includes model for electroweak shower, with interleaved resonance decays
- Sector shower to facilitate high multiplicity jet merging
- Work towards NNLO matching

⇒ Dedicated presentation by Christian Preuss tomorrow

[Brooks, Skands (2019)] [Skands, Verheyen (2020)] [Brooks, Preuss, Skands (2020)] [Brooks, Preuss (2021)] [Brooks, Skands, Verheyen (2022)] [Campbell, Höche, Li, Preuss, Skands (2023)]



Dire

- Fully incorporated Dire shower in Pythia 8.3
- Dipole-like parton shower, evolution symmetric in emitter and spectator
- Partial fractioned eikonal à la Catani-Seymour
- Focus on higher order corrections to kernels
- Facilitates merging and matrix-element corrections
- QCD and QED shower with automatic uncertainties
- Some study of QCD/QED interference and contributions beyond LC
- Allows for dark matter emissions in shower

[Höche, Prestel (2015)] [Höche, Prestel (2017)] [Dulat, Höche, Prestel (2018)] [LG, Höche, Prestel (2022)] [LG, Prestel, Spannowsky (2022)]

Double Soft and Triple Collinear Emissions

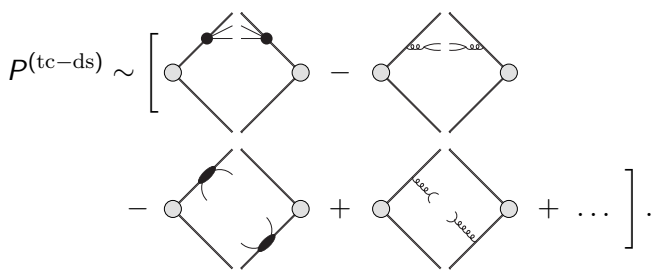
- Inclusion of double soft and triple collinear effects into NLO parton shower treated separately in [Höche, Prestel (2017)] and [Dulat, Höche, Prestel (2018) [hep-ph]]
- Two structurally different approximations. Implemented in shower as additional kernel, avoiding double counting with LO shower by subtracting iterated LO shower

$$P^{(\mathrm{tc})} \sim \left[\quad - \quad \right] ,$$

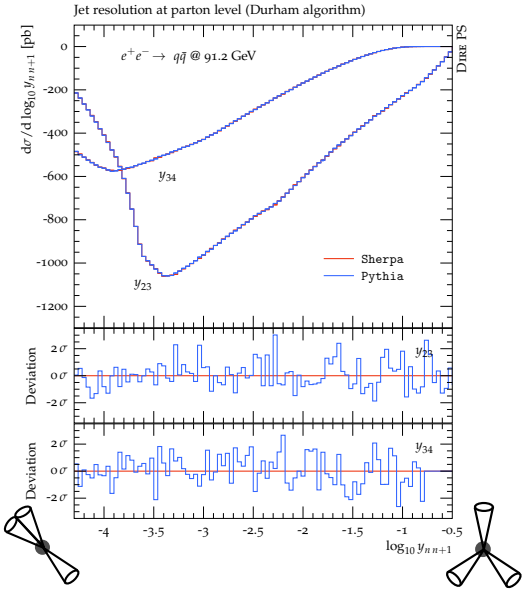
$$P^{(\mathrm{ds})} \sim \left[\quad - \quad + \cdots \right] ,$$

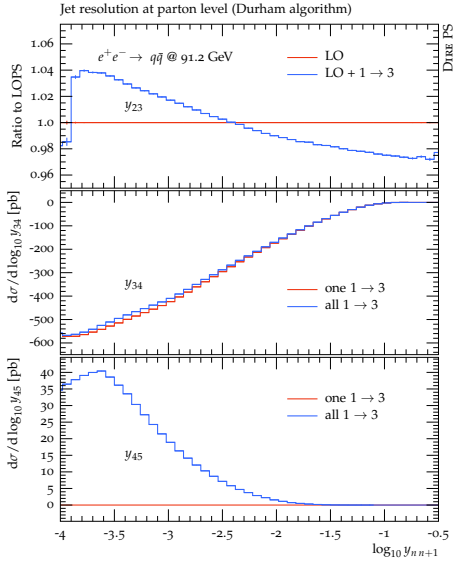
Combining Double Soft and Triple Collinear Emissions

- Need both double soft and triple collinear emissions in full NLO shower, needed for NNLL/NNDL accuracy
- Remove overlap: include double soft, and subtract corresponding contribution from each triple collinear kernel [LG, Höche, Prestel (2022)]



Validation and impact of soft-subtracted triple-collinear splittings



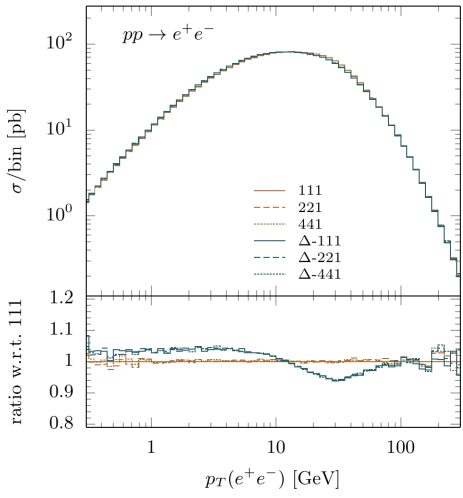


MC@NLO-Δ

- New NLO-accurate matching prescription
- Reduces number of negative-weight events
- Implemented in MadGraph5_aMC@NLO and Pythia 8.3 (runtime interface)
- Drawback: increased runtime

⇒ See Rikkert's talk for more details!

[Frederix, Frixione, Prestel, Torrelli (2020)]



Higher Order Matching

- TOMTE: N3LO+PS
  - Consistent combination of N3LO+PS
  - Proof-of-principle code using Pythia+Dire+Apfel available
  - Based on UN^{2}LOPS

[Prestel (2021)] [Bertone, Prestel (2022)]

- Fully differential NNLO+PS
  - Extension of POWHEG philosophy to NNLO
  - Born-local NNLO K-factor
  - Hardest-emission spectrum of PS given by NLO result (real-virtual and double-real corrections)
  - Proof-of-concept worked out for $e^+e^- \to 2j$
  - $\Rightarrow$ Christian's talk

[Campbell, Höche, Li, Preuss, Skands (2023)]

Technical and Organizational Developments

Technical Developments

- Better ME interfacing
- Transition to c++11
- Based on gitlab.com (formerly svn)
  - Enhanced collaboration and code review
  - Automated tests
  - Issue desk for user questions and feedback, also via authors@pythia.org
- PowhegHooks for all shower models
- Python interface
- PythiaParallel
- Pythia8 contrib coming soon
  - Interface for user-contributed code
  - UserHooks, and much much more!
- HPC compatibility
- Much more...

The PYTHIA Collaboration

- Distributed management: Codemaster, Spokesperson, Webmaster
- Developments driven by individual's interests
  - Christian Bierlich; Lund; HI, hadronization. **Webmaster**
  - Nishita Desai; Tata Inst; SUSY, SLHA, BSM.
  - LG; Lund; Uncertainties, matching/merging, showers.
  - Ilkka Helenius; Jyväskylä; Photoproduction, $\gamma - \gamma$, diffraction. **Spokesperson**
  - Philip Ilten; Cincinatti; τ's, onia, LHCb. **Codemaster**
  - Leif Lönnblad; Lund; HI, hadronization.
  - Stephen Mrenna; Fermilab; SUSY, matching/merging, CMS.
  - Christian Preuss; Zürich; Vincia, extME, matching/merging.
  - Torbjörn Sjöstrand; Lund; SM, parton showers, MPIs, CR, hadronization, core structure.
  - Peter Skands; Monash; VINCIA, MPIs, CR, tuning, hadronization. **Deputy spokesperson**
  - Marius Utheim; Jyväskylä; Hadronic rescattering, HI. **Deputy codemaster**
  - Rob Verheyen; UCL; Weak showers, VINCIA.

Summary

- PYTHIA general purpose event generator with diverse applications
- General developments: Heavy Ions, string interactions, rescattering, ...
- PS and matching: VINCIA and DIRE, variations, towards higher order matching...
- Many technical developments, distributed management
- Check new manual, comprehensive overview of physics and usage
  [Bierlich, Chakraborty, Desai, LG, et al. (2022)]