Pythia 8: Physics and usage

Saariselkä Midsummer School 2024

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UNIVERSITY OF JYVÄSKYLÄ

Research Council of Finland

Centre of Excellence in Quark Matter

Outline

Lecture 1:

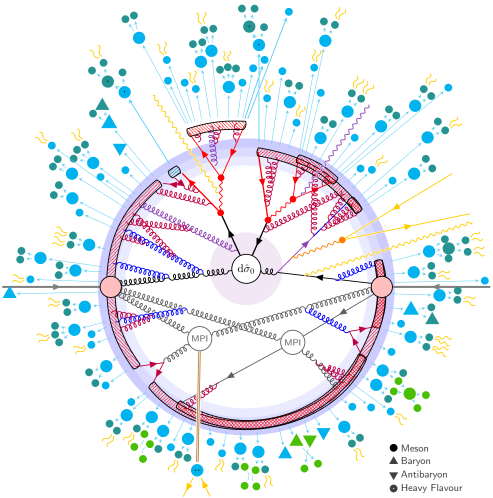
- History of Pythia
- Monte Carlo techniques
- Hard-process sampling

Lecture 2:

- Multiparton interactions
- Parton showers

Lecture 3:

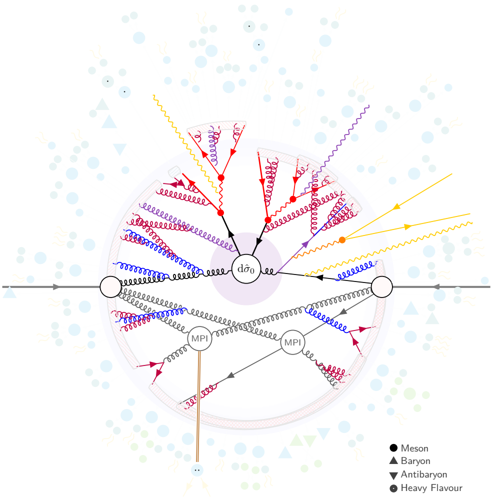
- Hadronization
- Beam configurations



[figure by P. Skands]

Outline

Lecture 3:



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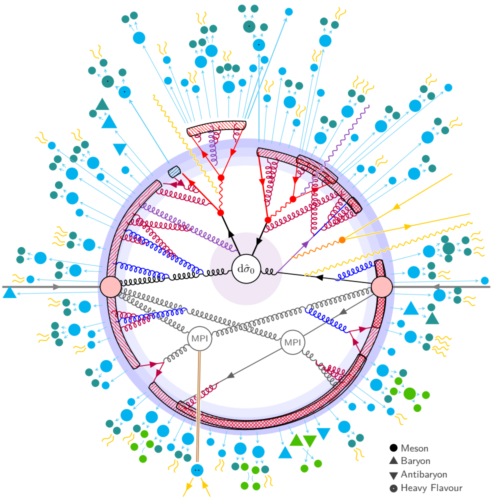
Outline

Lecture 3:

- Hadronization



[figure by P. Skands]

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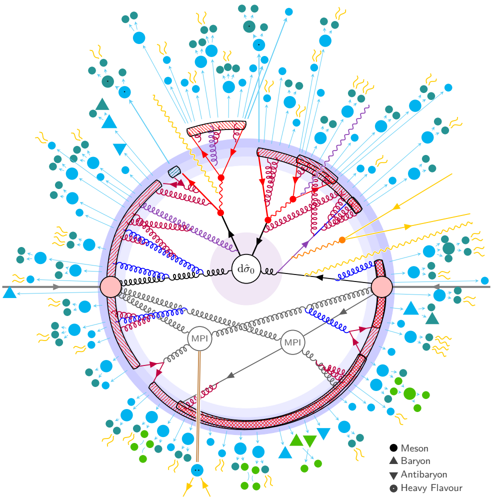
Lecture 3:

- Hadronization
- Beam configurations



[figure by P. Skands]

Hadronization

Lund string model

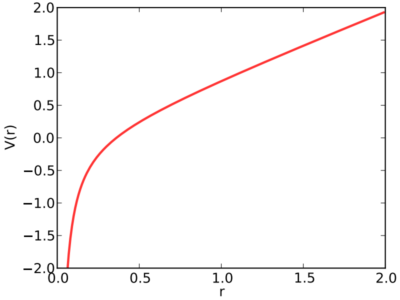
QCD potential between two colour charges

- String with a constant tension
  $\Rightarrow$ Linearly increasing potential

$$F(r) = \kappa \Rightarrow V(r) \approx \kappa r,$$

  where $\kappa \approx 1\,\mathrm{GeV/fm}$

- Stretching a colour string will lead to breaking of the string
  $\Rightarrow$ Will form a new $q\bar{q}$ pair



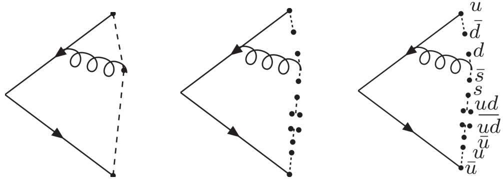
Lund string model

Where does the string break?

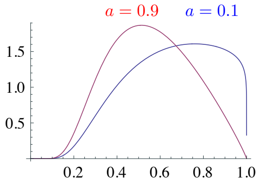
- String breaks causally disconnected
- Can proceed in arbitrary order
  $\Rightarrow$ Left-right symmetry

Lund symmetric fragmentation function ansatz

$$f(z) \propto \frac{(1-z)^a}{z} \exp\left[-\frac{bm^2}{z}\right]$$

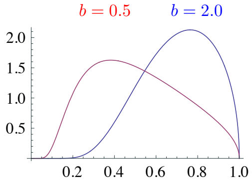


The a parameter



$b = 1\,\mathrm{GeV}^{-2}$, $m_\perp = 1\,\mathrm{GeV}$

The b parameter



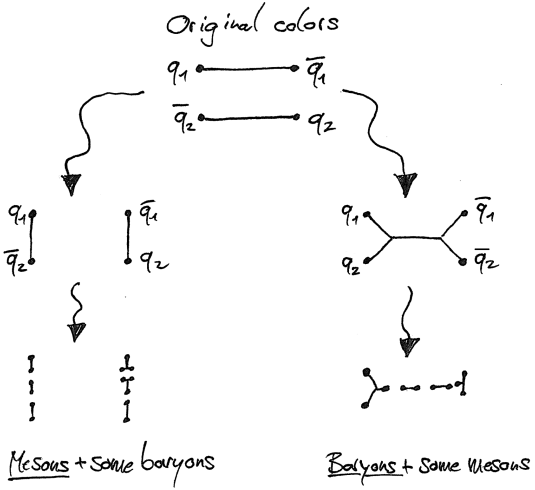
$a = 0.5$, $m_\perp = 1\,\mathrm{GeV}$

Colour reconnection (CR)

- Parton-shower splittings provide an initial colour configuration
- Reconnecting the coloured partons might reduce the total string tensoin

  ⇒ Junctions can lead to baryon enhancement

  ⇒ Larger effects at high multiplicities



[Figure by S. Prester]

Exercise V: Hadron production in e^+e^- at LEP

Exercise Va:

- Set beams and process

```
Beams:idA = 11
Beams:idB = -11
Beams:eCM = 91.18760
WeakSingleBoson:ffbar2gmZ = on
```

- Make Z boson to decay to $q\bar{q}$ only

```
23:onMode = off
23:onIfAny = 1 2 3 4 5
PDF:lepton = off
SpaceShower:QEDshowerByL = off
```

ALEPH_1995_I382179

- $\pi^{\pm}$, $K^{\pm}$ and $p(\bar{p})$ fragmentation functions at Z mass peak, $\sqrt{s} = m_Z$

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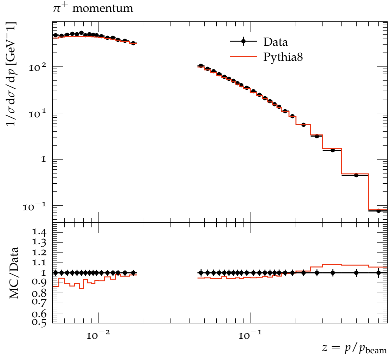


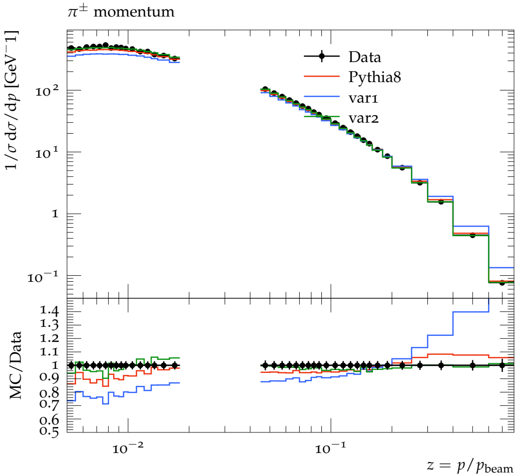
[ALEPH: Z.Phys. C66 (1995) 355-366]

Exercise Vb:

- Vary the Lund fragmentation function parameters *a* and *b*

```
StringZ:aLund = 0.68
StringZ:bLund = 0.98
```

- Compare to data



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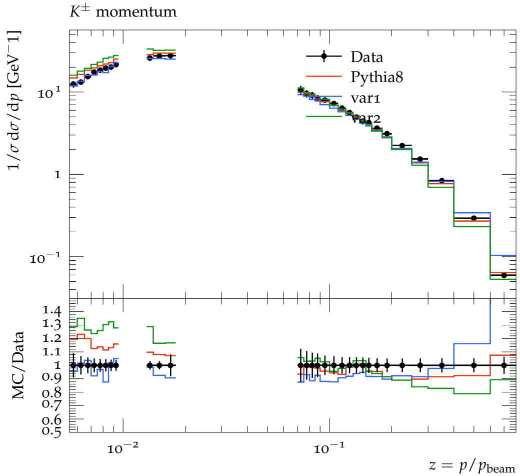

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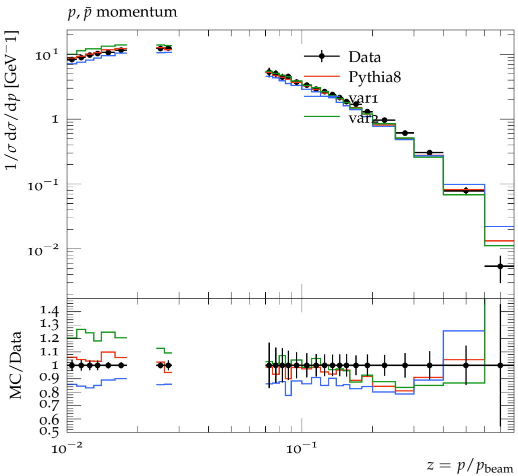
```

- Compare to data
- Important to consider several particles (and observables!)



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Beam configurations

Available beam configurations in Pythia 8

Hadronic collisions

- p-p: hard, soft and low-energy processes
- *h*-p, where $h = \pi^{\pm,0}, \mathrm{K}^{\pm,0}, \phi^0, \ldots$

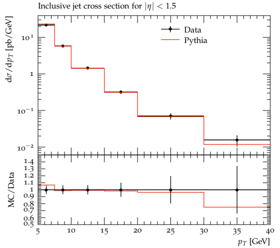
Collisions with leptons

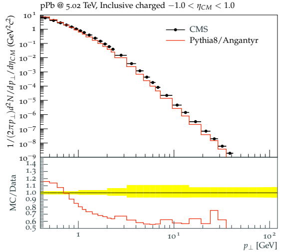
- $\mathrm{e}^+\mathrm{e}^-$, including $\gamma\gamma$ (also in p-p)
- e-p: (neutrino) DIS, photoproduction with soft and hard QCD processes

Heavy-ion collisions with Angantyr

- *A*-*A*, p-*A* and *h*-*A*
- UPCs with proton target, also VMD-*A*
- Some cosmic-ray related processes

[OPAL: PLB 658 (2008) 185-192]





[C. Bierlich, G. Gustafson, L. Lönnblad, H. Shah: JHEP10(2018)134]

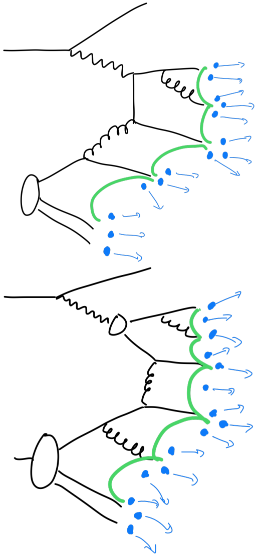
Exercise VI: Dijet photoproduction at HERA

ZEUS_2001_I568665

- Dijet photoproduction in e+p collisions
  $E_{\text{proton}} = 820$ GeV
  $E_{\text{electron}} = 27.5$ GeV
- Electron emits a (quasi-)real photon
- At least two jets with
  $p_T^{\text{jet1}} > 14$ GeV $\quad p_T^{\text{jet2}} > 11$ GeV

Two contributions

- Direct: Photon initiator for the hard process
- Resolved: Parton-from-photon-from-electron
  $\Rightarrow$ Generate events in separate runs



Exercise VI: Dijet photoproduction at HERA

Set up beams for HERA

```
Beams:idA = 2212
Beams:idB = 11
Beams:frameType = 2
Beams:eA = 820.
Beams:eB = 27.5
PDF:beamB2gamma = on
```

Process and settings

- Direct processes

```
PhotonParton:all = on
```

- Resolved processes

```
HardQCD:all = on
```

- Phase-space cuts

```
PhaseSpace:pTHatMin = 8.
```

- Modify $p_{\mathrm{T},0}^{\mathrm{ref}}$

```
MultipartonInteractions:
   pT0Ref = 3.
```

Exercise VI: Dijet photoproduction at HERA

- Direct part (PhotonParton:all)

```
$ pythia8-main93 -c main93.
   cmnd -o ep-direct
```

- Resolved part (HardQCD:all)

```
$ pythia8-main93 -c main93.
   cmnd -o ep-resolved
```

- Combine samples

```
$ rivet-merge -o ep-merged.
   yoda ep-direct.yoda ep-
   resolved.yoda
```

Exercise VI: Dijet photoproduction at HERA

- Direct part (PhotonParton:all)

```
$ pythia8-main93 -c main93.
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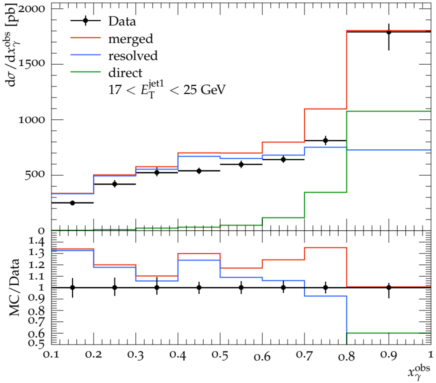


[ZEUS: EPJC 23 (2002) 615]

Exercise VI: Dijet photoproduction at HERA

Hadronization corrections

- Turn off the hadronization and generate a combined sample

```
HardQCD:all = on
PhotonParton:all = on
HadronLevel:all = off
```

- Compare to previous result with hadronization

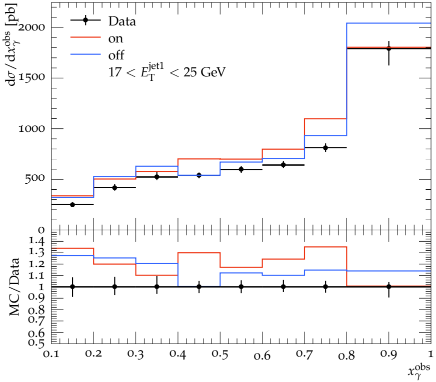
Exercise VI: Dijet photoproduction at HERA

Hadronization corrections

- Turn off the hadronization and generate a combined sample

```
HardQCD:all = on
PhotonParton:all = on
HadronLevel:all = off
```

- Compare to previous result with hadronization
- Hadronization shifts dijet events to lower x_γ



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Bonus exercise

Jet production in $\gamma\gamma$ collisions

- Study the online manual how to set up $\gamma\gamma$ in e^+e^-
- Check the configuration of OPAL_2008_I754316
- Generate events and compare to data

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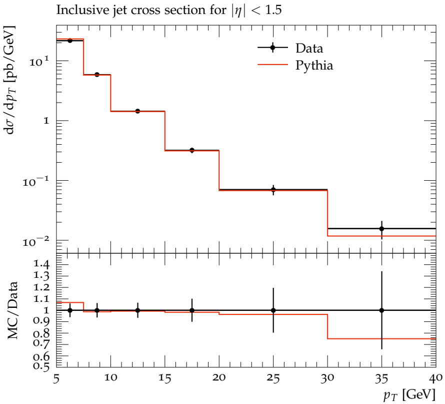

Summary

Pythia 8

- Long history with solid background
- Actively developed and maintained
- Not just a black box that sprays particles around

Further resources

- SciPost Phys. Codebases 8-r8.3 (2022)
- `https://pythia.org`
- `https://gitlab.com/Pythia8/releases`
- Contact: `authors@pythia.org`
- http://mcplots.cern.ch/
- https://rivet.hepforge.org