

# Pythia 8: Physics and usage

Saariselkä Midsummer School 2024

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June 29, 2024



# Outline

## Lecture 1:

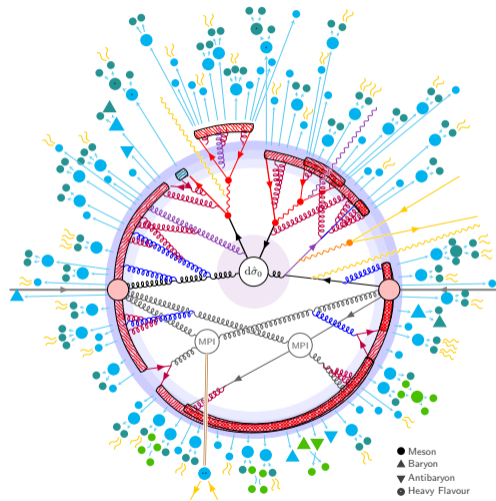
- History of Pythia
- Monte Carlo techniques
- Hard-process sampling

## Lecture 2:

- Multiparton interactions
- Parton showers

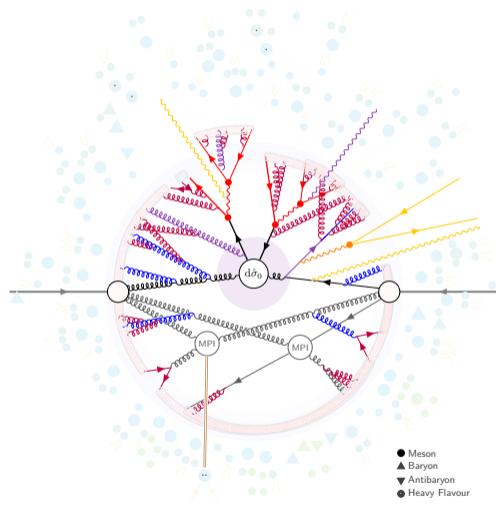
## Lecture 3:

- Hadronization
- Beam configurations



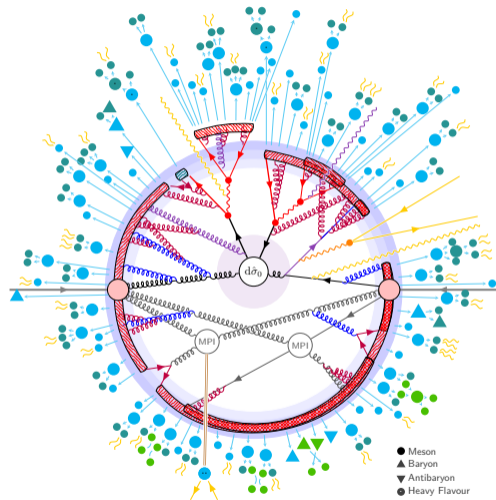
[figure by P. Skands]

## Lecture 3:



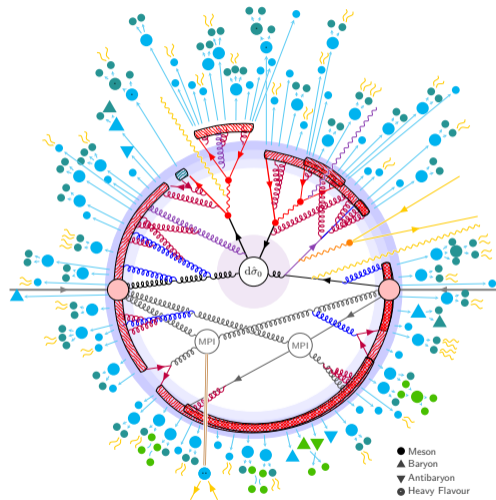
## Lecture 3:

- Hadronization



## Lecture 3:

- Hadronization
- Beam configurations



# Hadronization

# Lund string model

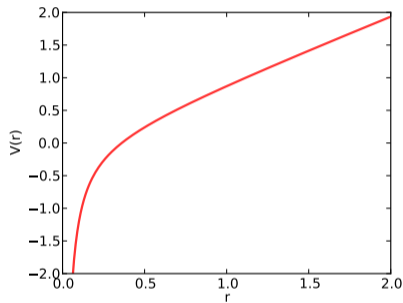
## QCD potential between two colour charges

- String with a constant tension  
⇒ Linearly increasing potential

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

where  $\kappa \approx 1 \text{ GeV/fm}$

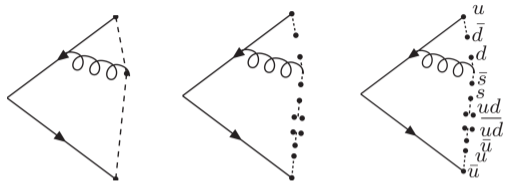
- Stretching a colour string will lead to breaking of the string  
⇒ Will form a new  $q\bar{q}$  pair



# Lund string model

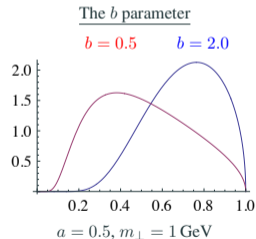
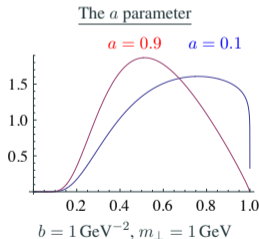
## Where does the string break?

- String breaks causally disconnected
- Can proceed in arbitrary order  
⇒ Left-right symmetry



Lund symmetric fragmentation function ansatz

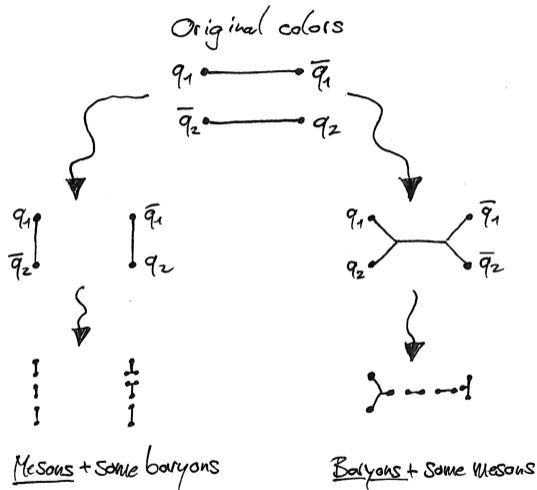
$$f(z) \propto \frac{(1-z)^a}{z} \exp\left[-\frac{bm^2}{z}\right]$$





# Colour reconnection (CR)

- Parton-shower splittings provide an initial colour configuration
- Reconnecting the coloured partons might reduce the total string tension
  - ⇒ 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,  $\sqrt{s} = m_Z$

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

## Exercise Va:

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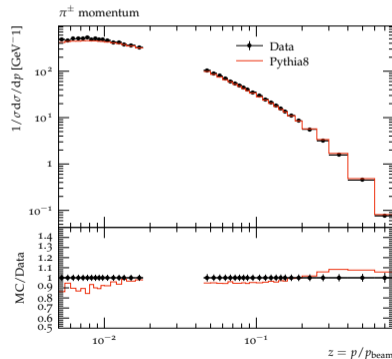
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[ALEPH: Z.Phys. C66 (1995) 355-366]

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

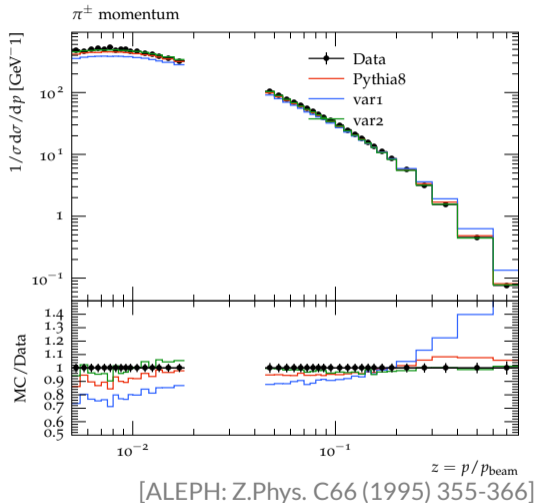
## Exercise Vb:

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

```
StringZ:aLund = 0.68
```

```
StringZ:bLund = 0.98
```

- Compare to data



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

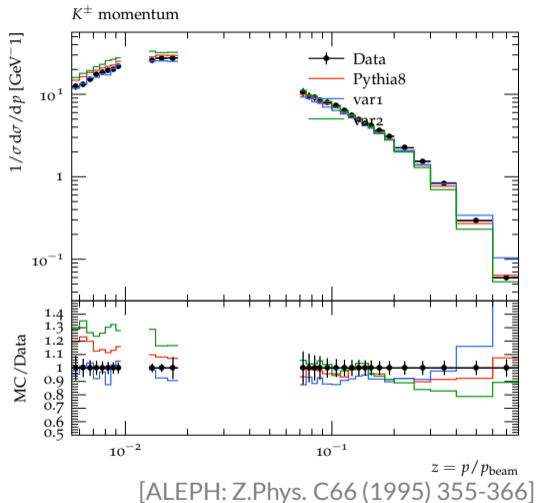
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# Exercise V: Hadron production in $e^+e^-$ at LEP

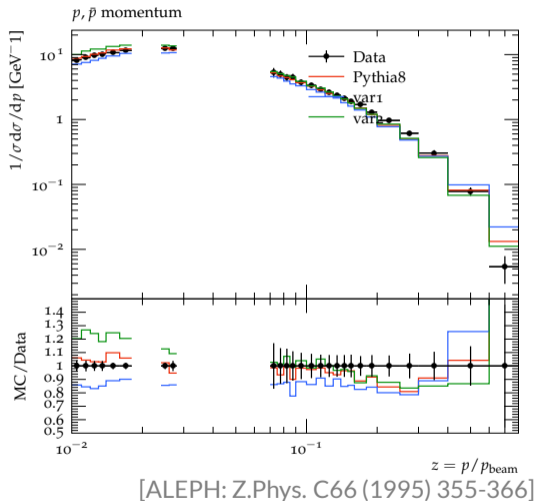
## Exercise Vb:

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

```
StringZ:aLund = 0.68
```

```
StringZ:bLund = 0.98
```

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



# Beam configurations

# Available beam configurations in Pythia 8

## Hadronic collisions

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

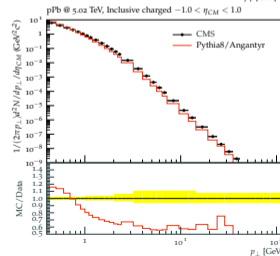
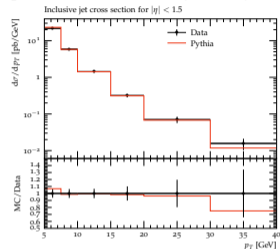
## Collisions with leptons

- $e^+e^-$ , 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

$$E_{\text{proton}} = 820 \text{ GeV}$$

$$E_{\text{electron}} = 27.5 \text{ GeV}$$

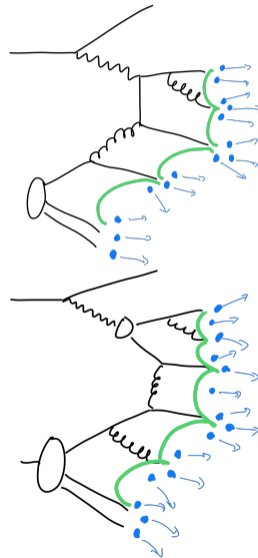
- Electron emits a (quasi-)real photon

- At least two jets with

$$p_{\text{T}}^{\text{jet1}} > 14 \text{ GeV} \quad p_{\text{T}}^{\text{jet2}} > 11 \text{ GeV}$$

### Two contributions

- Direct: Photon initiator for the hard process
- Resolved: Parton-from-photon-from-electron  
⇒ 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  $p_{T,0}^{\text{ref}}$

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

## Exercise VI: Dijet photoproduction at HERA

- Direct part (PhotonParton:all)

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

- Resolved part (HardQCD:all)

```
$ pythia8-main93 -c main93.  
  cmd -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)

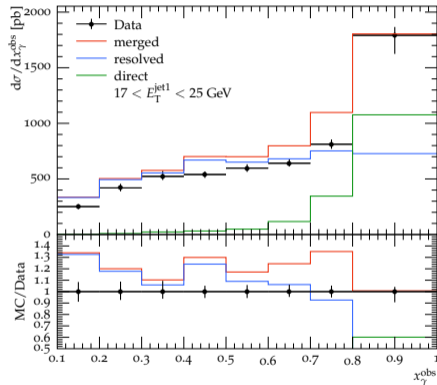
```
$ pythia8-main93 -c main93.  
  cmd -o ep-direct
```

- Resolved part (HardQCD:all)

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

- Combine samples

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



[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

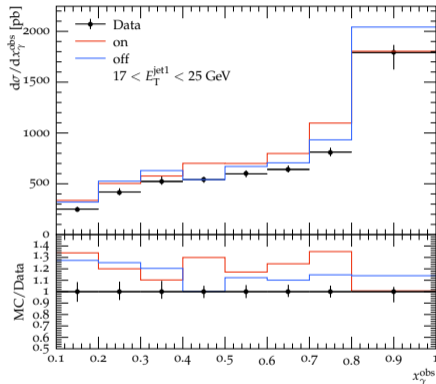
# Exercise VI: Dijet photoproduction at HERA

## 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  $x_\gamma$



[ZEUS: EPJC 23 (2002) 615]

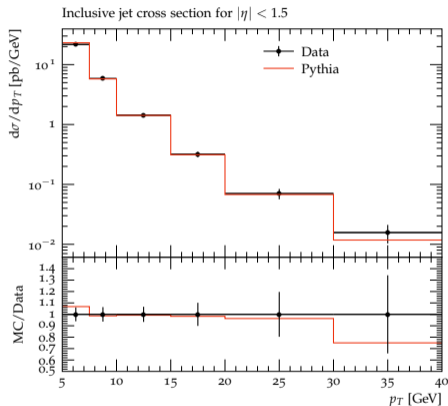
### Jet production in $\gamma\gamma$ collisions

- 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

## 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





# 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](mailto:authors@pythia.org)
- <http://mcplots.cern.ch/>
- <https://rivet.hepforge.org>

