Hands-on Pythia 8.3 features: Photoproduction and UPCs

Pythia Week Spring 2021

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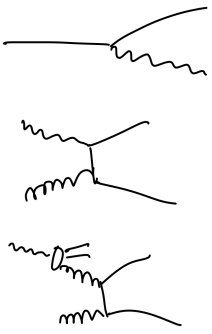
Photoproduction and ultra-peripheral collisions: Physics

A low-virtuality photon emitted by the beam particle (remains intact) interacts with the target hadron

1. May interact directly (direct)
   - Any photon-initiated process (e.g. $\gamma + \mathrm{g} \to q + \bar{q}$)
2. Or fluctuate into a hadronic state (resolved)
   - Non-pert. vector mesons or pert. $q\bar{q}$ states (PDFs)
   - Like any hadron-hadron collision with reduced $\sqrt{s}$
   - Any parton-initied process (e.g. $\mathrm{g} + \mathrm{g} \to q + \bar{q}$)
   - Soft QCD processes

- Relative importance depends on collision kinematics and considered final state



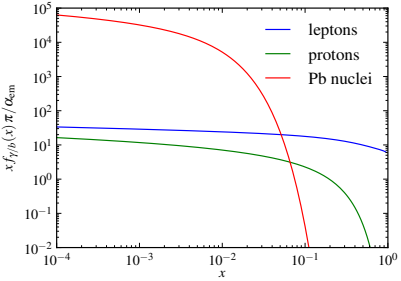
Implemented photon fluxes

Charged leptons for ep

- Standard Weizsäcker-Williams
- User-defined as a `PDFPtr`

Protons for pp

- Approximation by Drees and Zeppenfeld, Q^2 dependent
- Budnev et al., integrated in Q^2
- User-defined as a `PDFPtr`



Heavy nuclei for pA where A provides the photons, amplified by Z^2

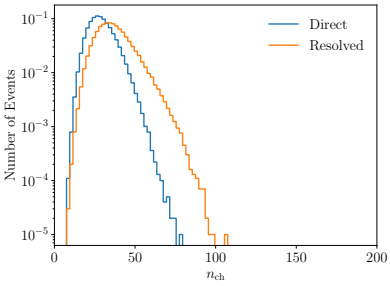
- Flux defined as a class derived from PDF, needs to be provided as a `PDFPtr`
- Relevant parameters depend on beam configuration

Exercise I: Multiplicities at HERA

- Use provided `test70.cc` to generate charged-multiplicity distributions for
  - Direct processes `PhotonParton:all = on`
  - Resolved processes `HardQCD:all = on`

  using `pTHatMin = 10.0` and `Wmin = 100.`
- Plot the distributions using the provided pytplot script `plot_multiplicity_HERA.py`

Expected result:

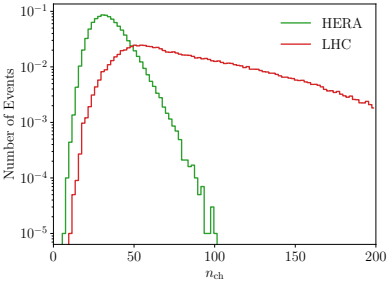


- Why is the multiplicity higher for Resolved events even though the $\sqrt{\hat{s}}$ is typically lower?

Exercise II: Multiplicities in pp at the LHC

- Generate both contributions simultaneously with `test70.cc` for HERA configuration
- Modify the code to do the same for $p \to \gamma + p$ at the LHC
  (Just comment out the HERA-specific beam configuration, leave `PDF:beamA2gamma = on`)

Expected result:

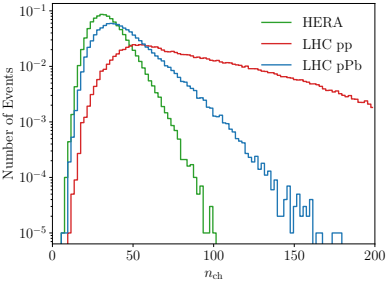


- Calculate also the averge number of MPIs in each case (`Info::nMPI()`)
- How does that compare with hadronic pp collisions?

Exercise IIIa: Heavy-ions at the LHC

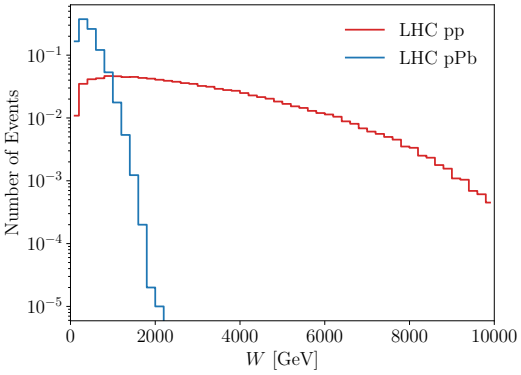
- Generate ultraperipheral pPb collisions for the same processes and kinematics as before
  - Construct a `Nucleus2gamma` object as a `PDFPtr`, defined in `PartonDistributions.h`
  - Adjust parameters as described in `PDF Selection` → `Photon fluxes` → `Nuclear beams` to suit pPb at $\sqrt{s} = 5.02$ GeV
  - Some guidance in example `main70.cc`
  - Calculate the multiplicity distribution and compare to previous results in ep and pp

Expected result:



Exercise IIIb: Heavy-ions at the LHC

- Why so much less multiplicity in pPb?
- Study also invariant mass distribution of γp system (`Info::eCMsub()`)



- Softer photon flux $\Rightarrow$ lower γp collision energy $\Rightarrow$ less multiplicity

Bonus (requires Rivet)

Tune $p_{\perp,0}^{\text{ref}}$ to HERA data

- Go to directory `rivet-analysis` (Supplement with a suitable `Makefile.inc`)
- Compile the Rivet analysis
- Compile and run test78.cc with a couple of values for $p_{\perp,0}^{\text{ref}}$
- Notice that the data is for $\gamma + \text{p}$ with $\sqrt{s_{\gamma\text{p}}} = 200$ GeV, i.e. the flux has been integrated out
- Try to match the Pythia result to the H1 low-p_{T} data

Expected result: