Investigation of the underlying event in photon-initiated processes

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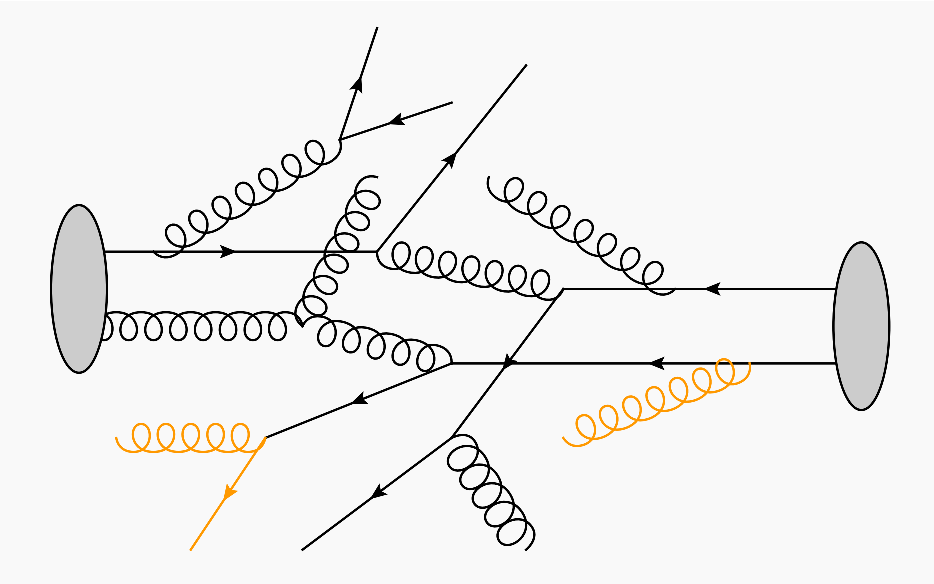
- Motivation
- Approach: use of Pythia, Rivet, MPI models and data
- Comparison to data from e^+e^- and *ep* collisions
- "Tunes" to data from e^+e^- and *ep* collisions
- Summary and outlook

Synergies between the EIC and the LHC, DESY — 14 December 2023

Motivation — high-energy hadronic interactions

- The underlying event or multi-parton interactions (MPIs) play a significant role in high-energy hadronic scattering.
- Much has been understood in proton−(anti)proton collisions through
  - Lots of data at different centre-of-mass energies, different kinematic regions, etc.
  - Dedicated measurements
  - Model development
  - Documentation and preservation of measurements
  - Tuning of models to data
  - Encapsulating our understanding in Monte Carlo simulations.

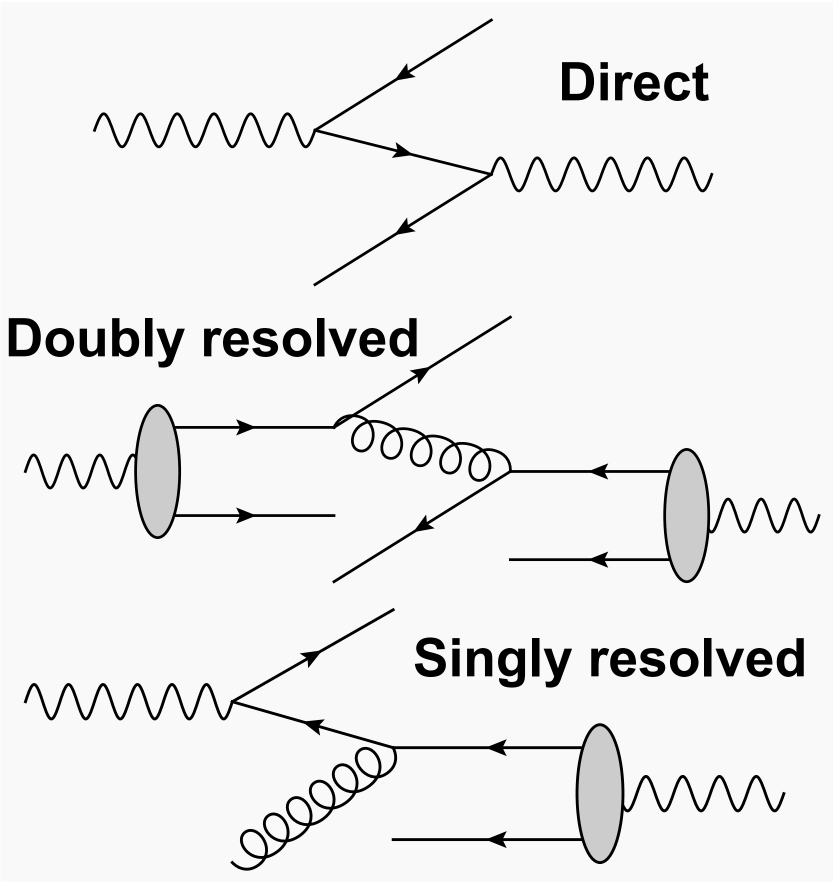


- What about photon-initiated processes ?

Motivation — high-energy photon interactions

- Collisions with photons do not just involve point-like photons
  - Direct processes
  - No MPIs.
- We can have photons which develop a structure
  - Resolved photons
  - Photons fluctuate to a hadronic state
  - Partonic content from photon PDFs
  - Can have MPIs in doubly-resolved processes.

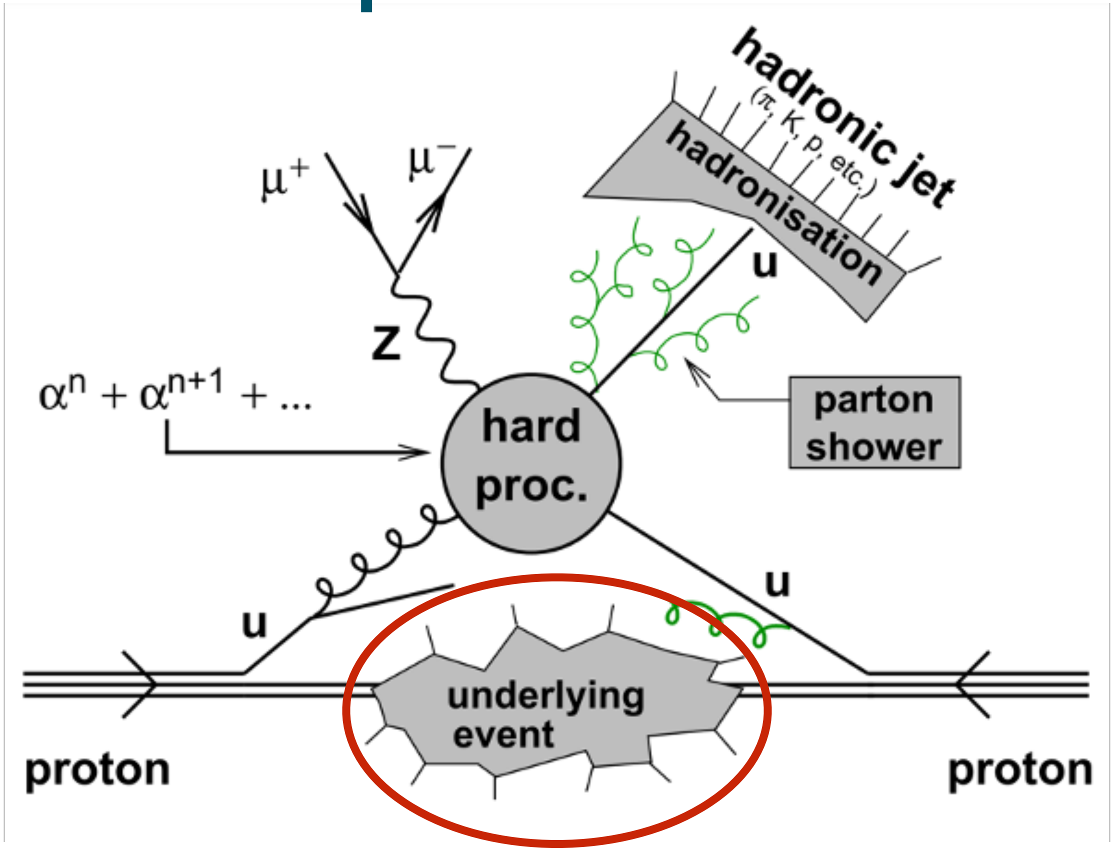
Photon−photon collisions



Motivation — high-energy photon interactions

- Understanding photon-initiated processes is important
  - $\gamma\gamma$ collisions in e^+e^- colliders
  - Photoproduction, γp, in *ep/A* collisions.
- We can learn a lot from LEP and HERA data
  - Various measurements sensitive to the underlying event
  - Models can be used to compare to the data.
- This can impact on our understanding for future e^+e^- colliders and future *ep/A* colliders like the EIC.
- Also relevant for $\gamma\gamma$ at the LHC.

Motivation — multi-parton interactions

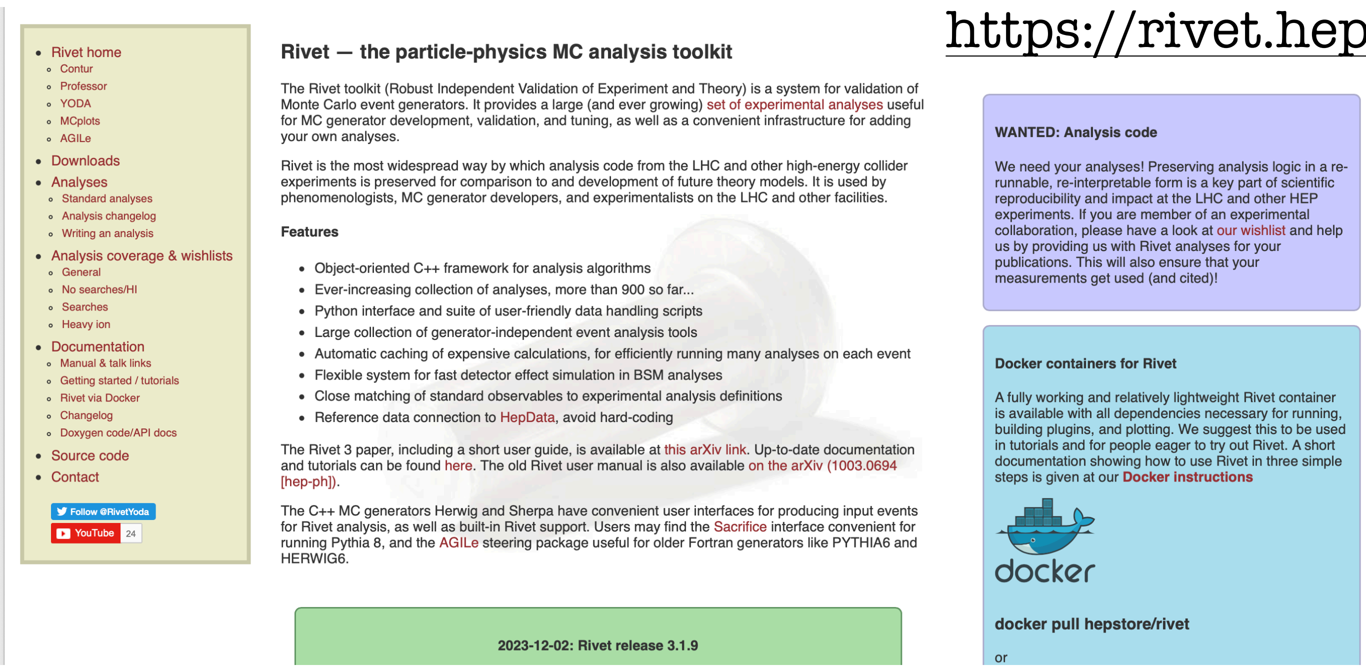


- MPIs contribute to the underlying event activity.
- Dominated by low transverse momentum, “soft”, process.
- Modelled with Monte Carlo generators, here using Pythia.
- What is the nature of multi-parton interactions in photon-initiated processes ?

Approach

- Many comparisons of MC models to *pp/p$\bar{p}$* data and tunes of parameters in the MPI model
  - Generally describe data well, including energy dependence.
  - How does the same model describe *γγ* and *γp* data?
- Use Pythia8 MC with MPI model.
- Use Rivet framework to access numerous results from data and compare with Pythia

https://rivet.hepforge.org/



- Rivet home
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  - Professor
  - YODA
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Rivet — the particle-physics MC analysis toolkit

The Rivet toolkit (Robust Independent Validation of Experiment and Theory) is a system for validation of Monte Carlo event generators. It provides a large (and ever growing) set of experimental analyses useful for MC generator development, validation, and tuning, as well as a convenient infrastructure for adding your own analyses.

Rivet is the most widespread way by which analysis code from the LHC and other high-energy collider experiments is preserved for comparison to and development of future theory models. It is used by phenomenologists, MC generator developers, and experimentalists on the LHC and other facilities.

Features

- Object-oriented C++ framework for analysis algorithms
- Ever-increasing collection of analyses, more than 900 so far...
- Python interface and suite of user-friendly data handling scripts
- Large collection of generator-independent event analysis tools
- Automatic caching of expensive calculations, for efficiently running many analyses on each event
- Flexible system for fast detector effect simulation in BSM analyses
- Close matching of standard observables to experimental analysis definitions
- Reference data connection to HepData, avoid hard-coding

The Rivet 3 paper, including a short user guide, is available at this arXiv link. Up-to-date documentation and tutorials can be found here. The old Rivet user manual is also available on the arXiv (1003.0694 [hep-ph]).

The C++ MC generators Herwig and Sherpa have convenient user interfaces for producing input events for Rivet analysis, as well as built-in Rivet support. Users may find the Sacrifice interface convenient for running Pythia 8, and the AGILe steering package useful for older Fortran generators like PYTHIA6 and HERWIG6.

2023-12-02: Rivet release 3.1.9

WANTED: Analysis code

We need your analyses! Preserving analysis logic in a re-runnable, re-interpretable form is a key part of scientific reproducibility and impact at the LHC and other HEP experiments. If you are member of an experimental collaboration, please have a look at our wishlist and help us by providing us with Rivet analyses for your publications. This will also ensure that your measurements get used (and cited)!

Docker containers for Rivet

A fully working and relatively lightweight Rivet container is available with all dependencies necessary for running, building plugins, and plotting. We suggest this to be used in tutorials and for people eager to try out Rivet. A short documentation showing how to use Rivet in three simple steps is given at our **Docker instructions**

docker

docker pull hepstore/rivet

or

Approach

- Including more routines in Rivet covering more *γγ* and *γp* analyses and wider phase space.
- Considered data:
  - Particle production at LEP
  - Dijet production at LEP
  - Particle production at HERA
  - Jet production at HERA, both low E_T and high E_T
- Considered several options for MPIs in Pythia.
- Detailed comparisons and some best descriptions, but not really “tuned”.

MPI models

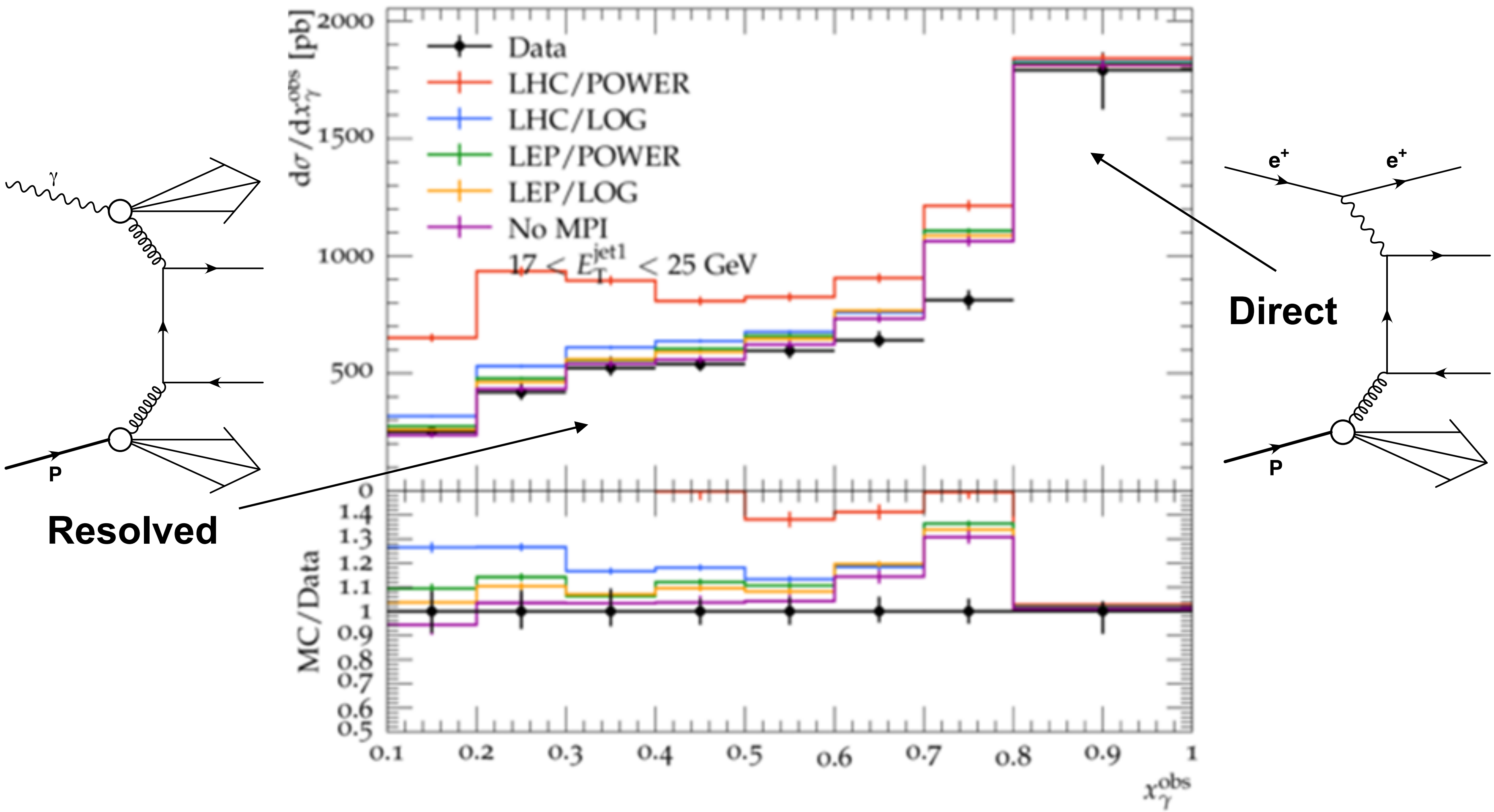
- LHC/POWER or Monash tune: default in Pythia for *pp* (and *ep*).
- LEP/LOG: default $\gamma\gamma$ tune.
- LHC/LOG: LHC/POWER but p_{T0} scaling law is logarithmic
- LEP/POWER: LEP/LOG but p_{T0} scaling law is power
- Detroit: tune to describe RHIC data, *pp* collisions at *200 GeV*
- 2C: tune to describe CDF data

$$p_{T0} = p_{T0}^{ref} + \alpha \ln \frac{\sqrt{s}}{\sqrt{s^{ref}}}$$

$$p_{T0} = p_{T0}^{ref} \left(\frac{\sqrt{s}}{\sqrt{s^{ref}}} \right)^{\alpha}$$

Parameter	LHC	LEP
p_{T0}^{ref}	2.28 GeV	1.54 GeV
$\sqrt{s^{ref}}$	7000 GeV	100 GeV
α	0.215	0.413
Scaling	Power	Logarithmic

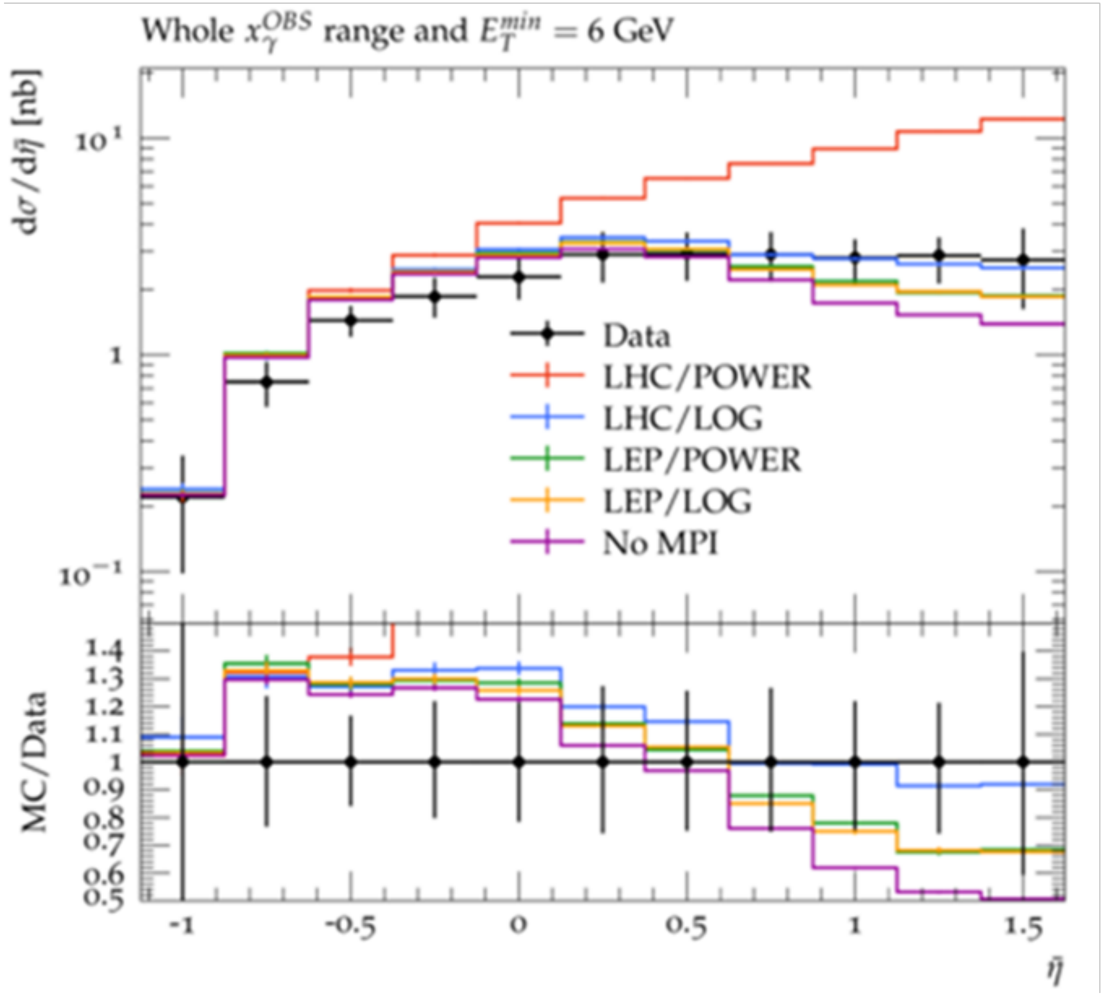
Default models compared to *ep* dijet data



Do not use the default Pythia LHC/POWER MPI model !

ZEUS Coll., EPJ **C23** (2002) 614

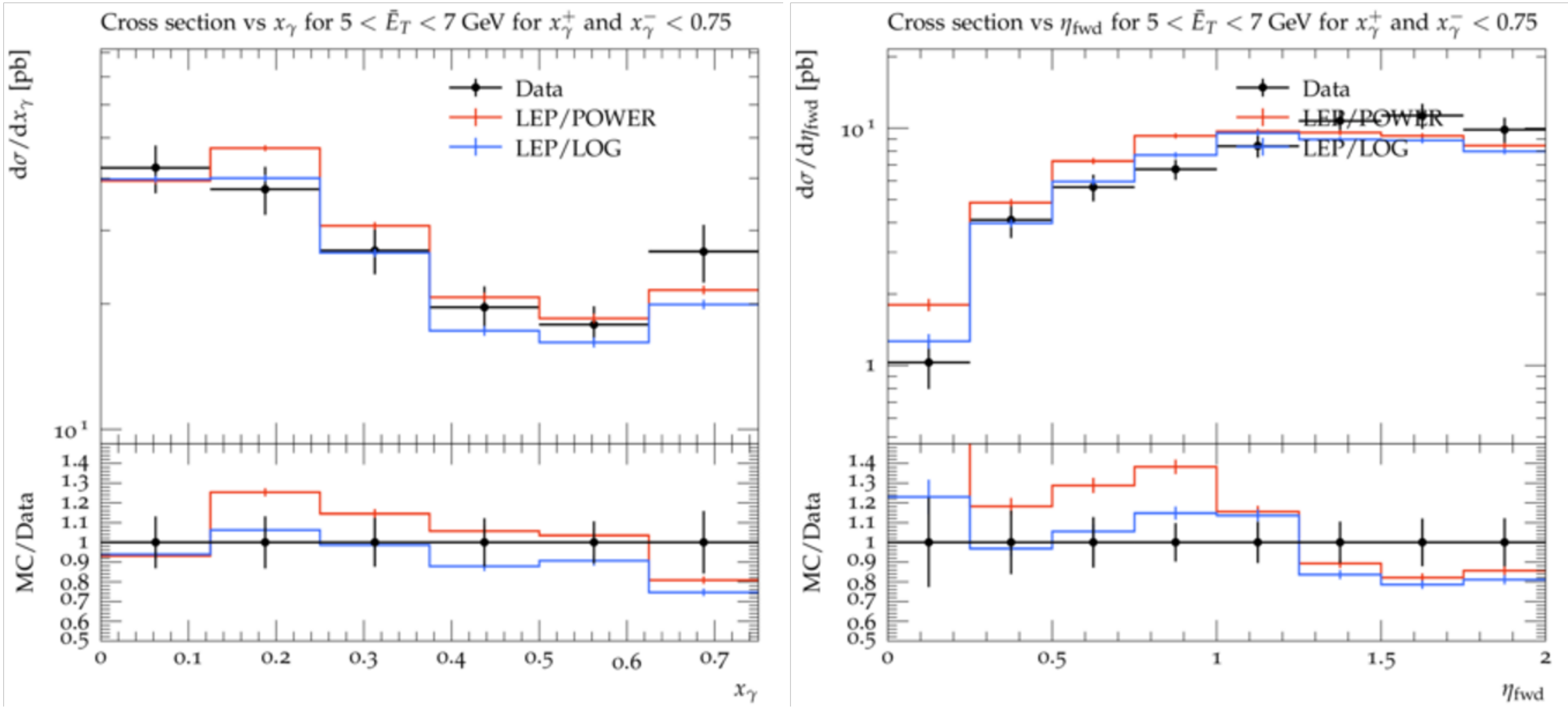
Default models compared to *ep* dijet data—lower E_T



LHC/POWER too high and No MPI too low.

ZEUS Coll., EPJ **C1** (1998) 109

Default models compared to $\gamma\gamma$ dijet data

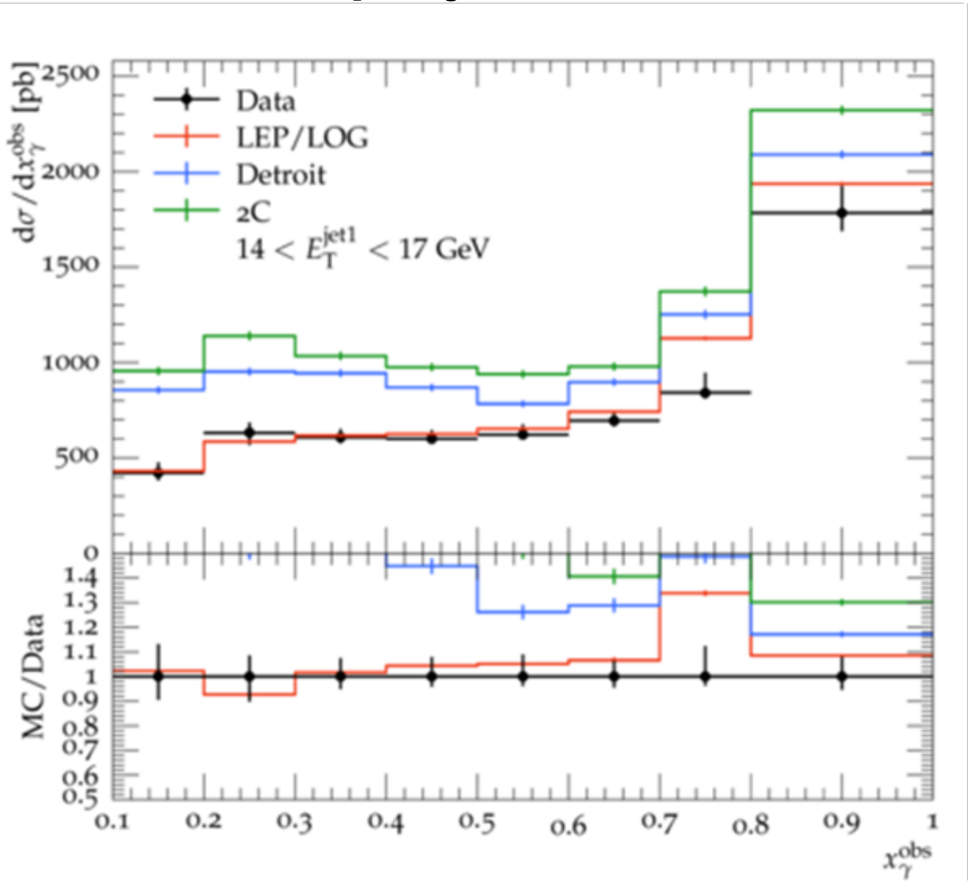


Doubly-resolved $\gamma\gamma$ data well described by LEP models and better by LEP/LOG

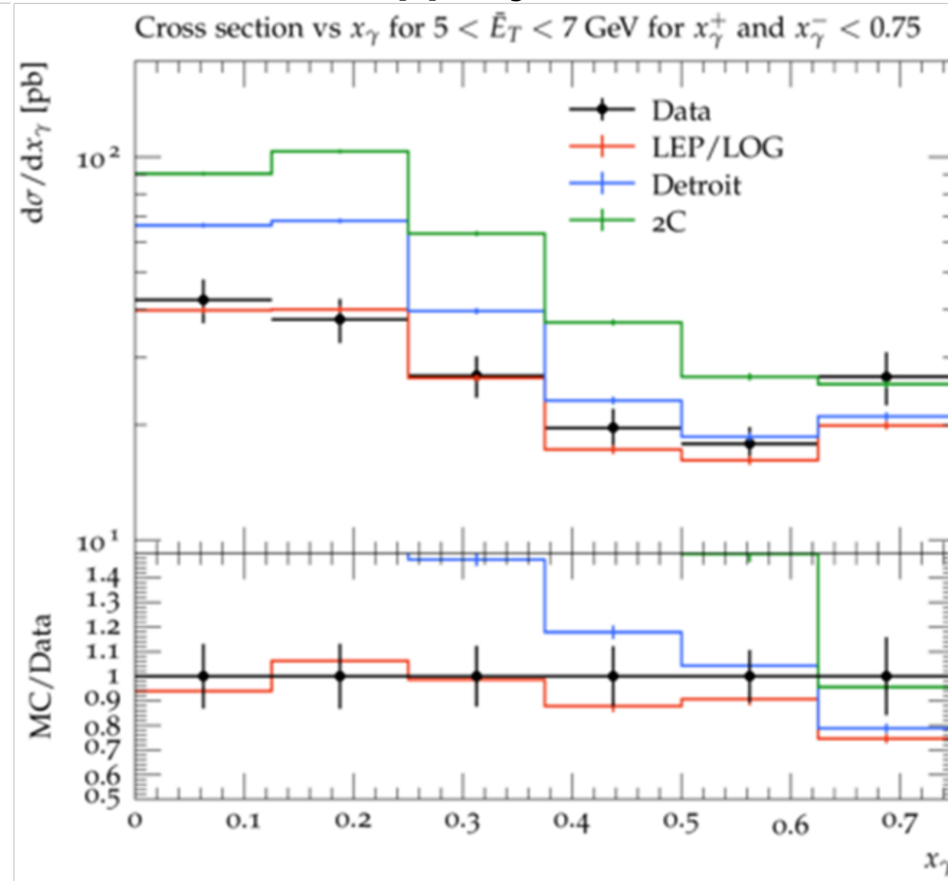
OPAL Coll., EPJ
C31 (2003) 307

Other models for low energy

***ep* dijet data**



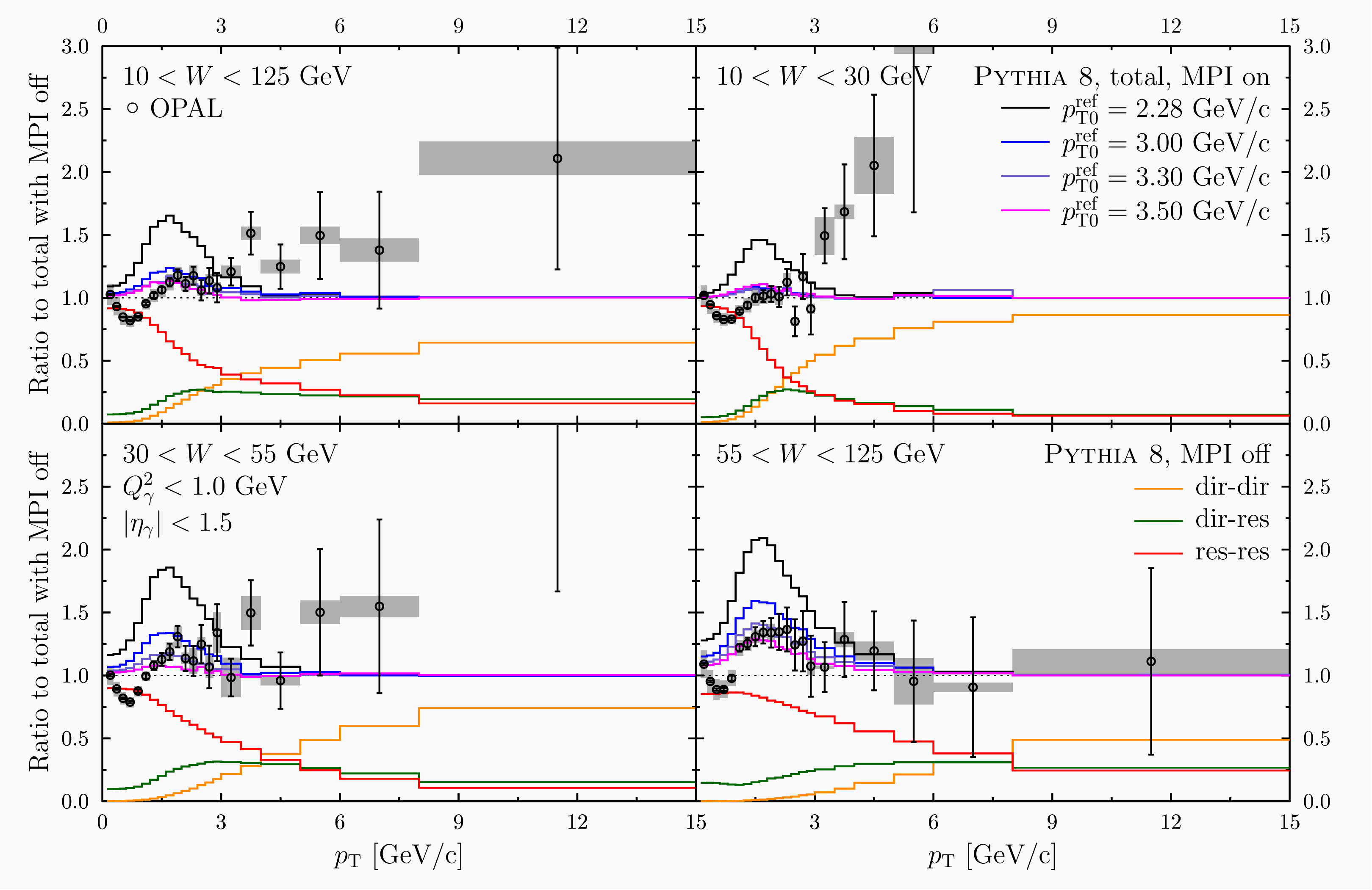
***γγ* dijet data**



Tunes specifically designed for *pp* data with √s ~ *200 − 300 GeV*. Do not describe HERA and LEP data of similar centre-of-mass energy.

"Tuning" to γγ data

I. Helenius,
arXiv:1708.09759



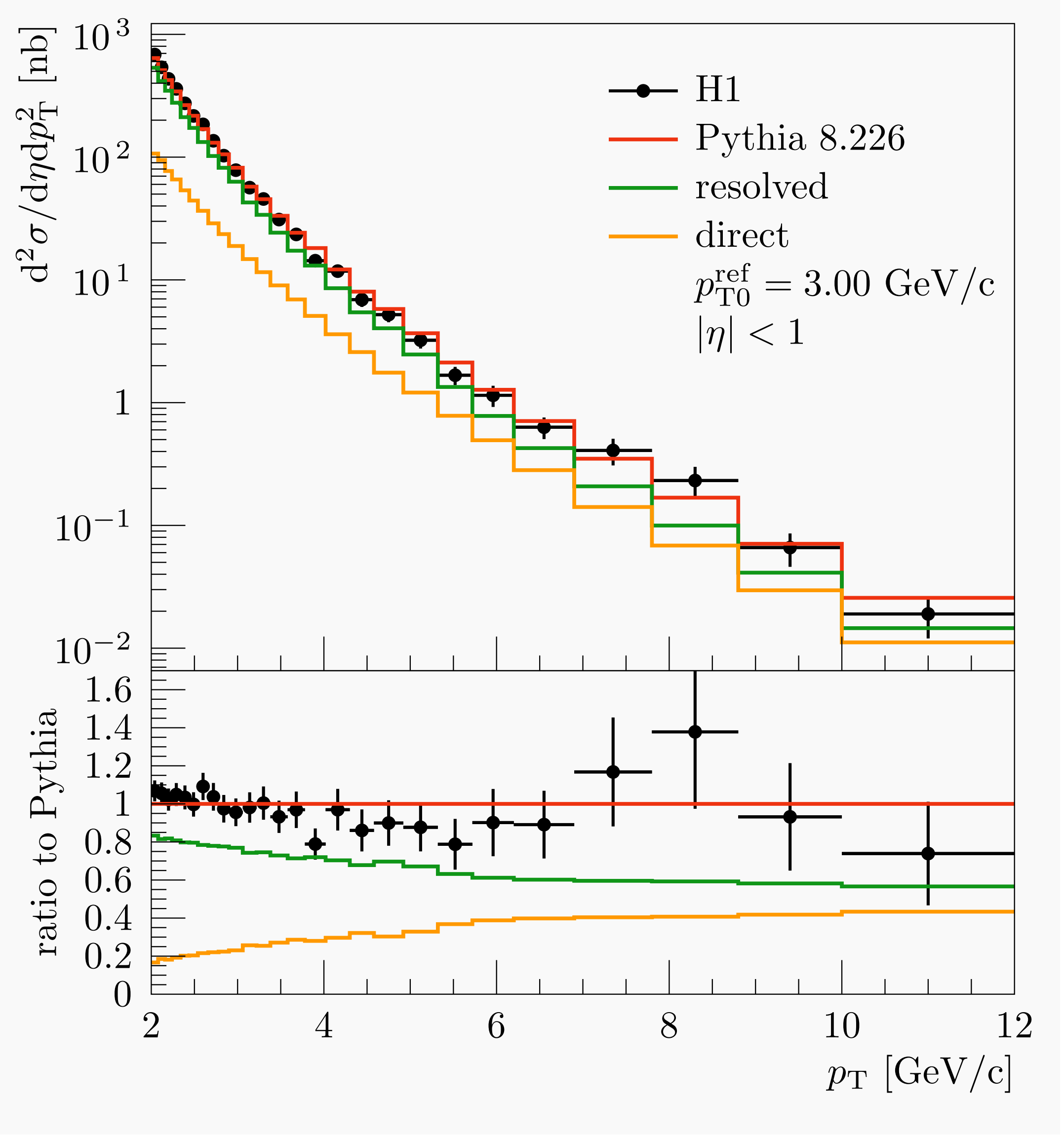
OPAL Coll., EPJ **C6** (1999) 253

- "Out of the box", default p_{T0}^{ref} = *2.28 GeV* too many hadrons
- Can "tune" and get a best description with p_{T0}^{ref} = *3.3 GeV*

“Tuning” to *ep* data

I. Helenius, arXiv:1708.09759

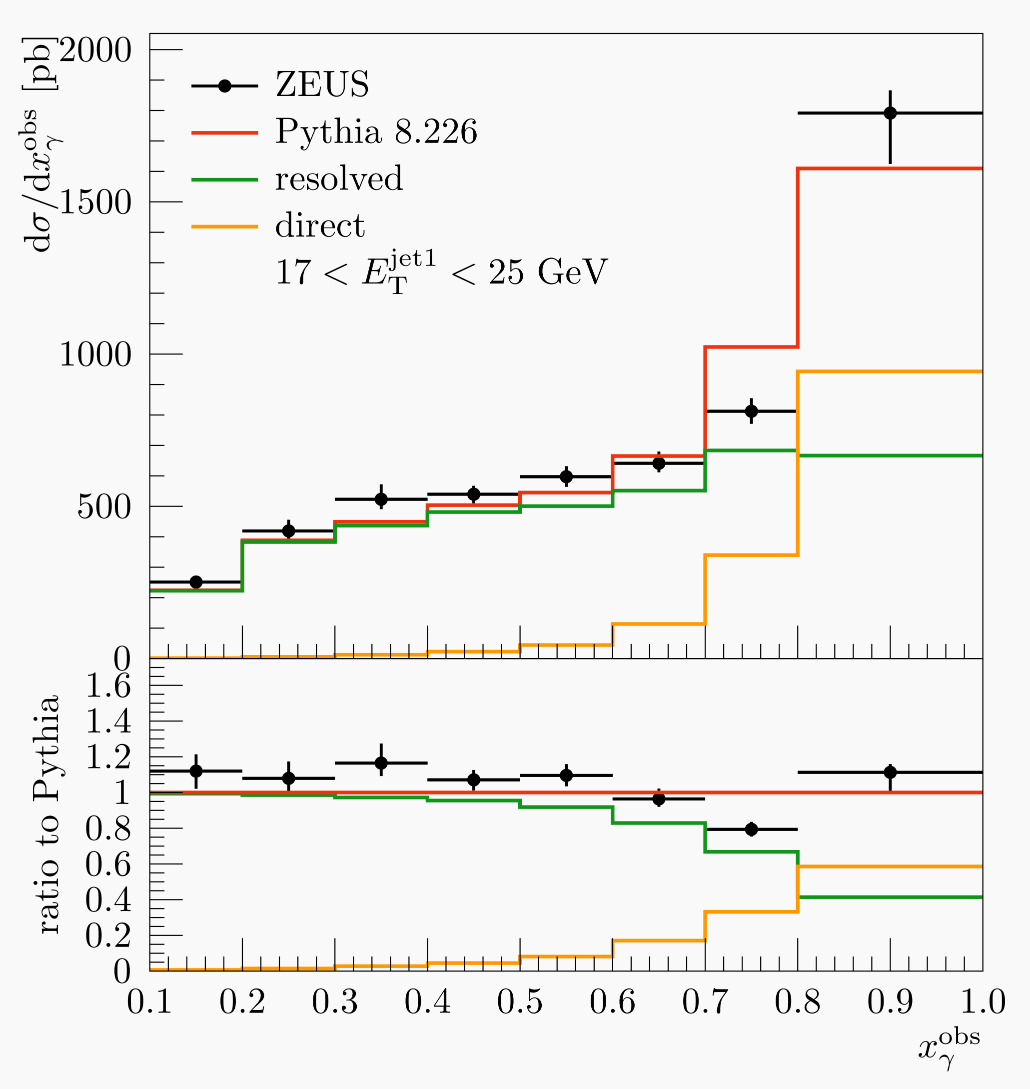
- Charged particle p_T spectra.
- Resolved contribution dominates.
- Data best described by p_{T0}^{ref} = *3 GeV**.
- Similar to $\gamma\gamma$ result.
- Got similar results tuning α instead, with α = 0.05 − 0.10 (cf. LHC, α = 0.215)



H1 Coll., EPJ **C10** (1999) 363

* See also: ZEUS Coll., JHEP **12** (2021) 102

“Tune” compared to *ep* dijet data



Good description of high-E_T jet data, similar to other models that do well.

Summary and conclusions

- Default *pp* tunes do not describe HERA data.
- Can describe all available HERA data with default LEP models and “tuned” models.
- Can get simultaneous tune/description of HERA and LEP data.
- Cannot get a simultaneous description of HERA/LEP and *pp* data, even using different settings tuned to pp data at the same centre-of-mass energy.
- Data favours fewer MPIs with photon-initiated processes than with protons.

Outlook

- Adding analysis routines (and knowledge) to Rivet.
- Do more detailed comparison/tune to all data—merging studies.
- Write a paper on findings and better understanding of photon-initiated processes.
- Provide better simulations of processes at future colliders with photons, e.g. the EIC and $\gamma\gamma$ collisions at the LHC.