Validating Monte Carlo simulations for the EIC

H. Jung (DESY)

- Framework for comparison and validation
  - HZTool, Rivet, RivetHZTool
- Repository for ep results
- Tuning and all that
  - an older study :)

Framework for validation and theory comparison

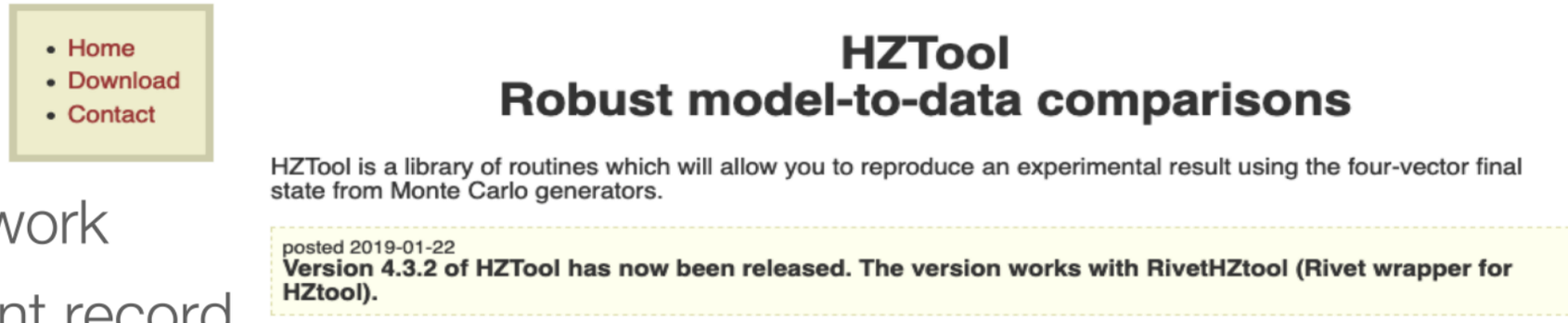
- store experimental results in HEPDATA – analyze them with Rivet
  - effort of unifying storing systematic uncertainties and to be able to use them in data MC/theory comparisons
    - proposal from LHC EW WG to LHC experiments
      - to be presented at meeting 2-3 July 2019
      - example:

```
dependent_variables:
- header:
    name: $d\sigma / d(H_{T})$
  units: pb/GeV
values:
- errors:
  - label: sys,JET_GroupedNP_1
    symerror: 9.6549e-07
  - label: stat,Data_statistics
    symerror: 2.5347e-06
  - label: sys,DY_TH_Scale_uncertainty
    symerror: 9.6354e-08
  value: 3.9537e-05
```

- Experiment and generator independent analysis frame for comparison of measurements with theory predictions
  - experiment and analysis independent software
    - sounds trivial, but is not: several analyses at LHC are not yet in HEPDATA

Validation and theory comparison at HERA

- HZTool frame



- Fortran based framework
  - reads HEPEVT event record
  - interfaces to different MC generators
- each experimental publication has its own subroutine (if implemented)
  - applies analysis cuts, as in publication for corrected data
  - fills histograms/distributions corresponding to each figure in the publication
  - **measurements are included inside subroutines** as data statements

- Most of HERA I and some of HERA II analyses are implemented and validated by experiments

Snapshot of analyses inside HZTool

Snapshot of analyses inside HZTool (cont'd)

Snapshot of analyses inside HZTool (cont'd)

- Issues with HZTool
  - makes use of generator dependent information
    - example: definition of scattered electron, definition of virtual photon etc
  - event record in HEPEVT format expected (not in HEPMC)
  - using many CERNlib subroutines, especially HBOOK for histogramming
  - No possibility foreseen to fit and to treat correlated systematics !

➔ Need something more !

Examples of HZTool runs

Andersen, J. R. and others (2004). Small x phenomenology: Summary and status 2002, Eur. Phys. J., C35(), 67-98

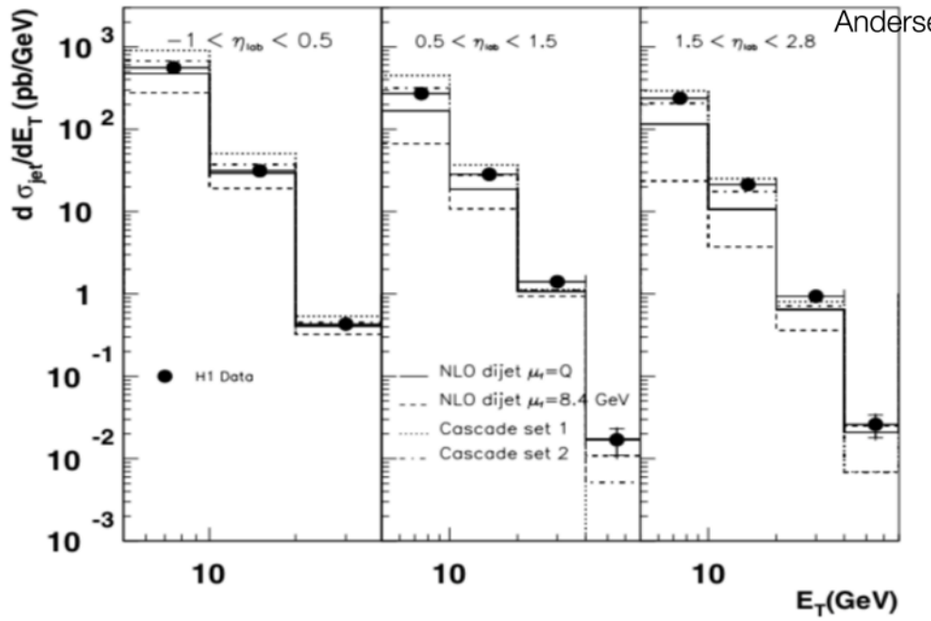


Fig. 19. Inclusive jet cross section $\mathrm{d}\sigma_{\mathrm{T,jet}}/\mathrm{d}E_{\mathrm{T}}$ in different ranges of η_{lab}, integrated over the region $5 < Q^2 < 100\,\mathrm{GeV}^2$ and $0.2 < y < 0.6$. The data are compared to NLO dijet calculation (DISENT) and to the predictions from CASCADE

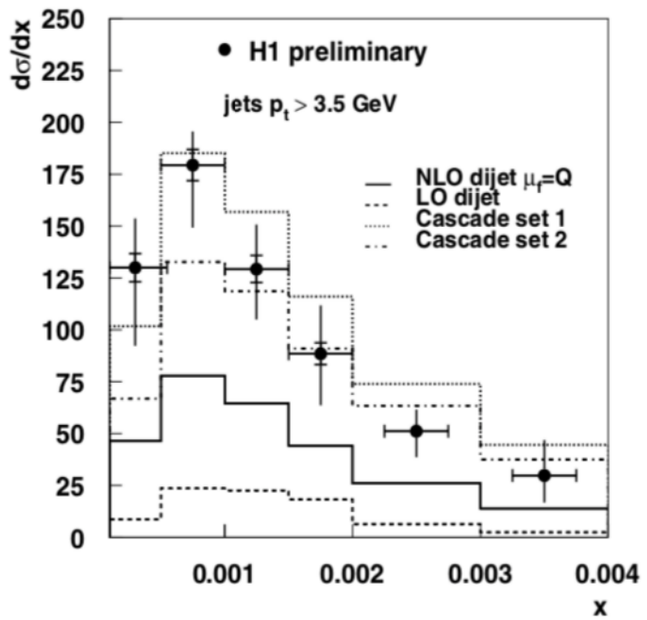


Fig. 26. The cross section for forward jet production [149] at the hadron level, as a function of x for $E_{\mathrm{T,jet}} > 3.5\,\mathrm{GeV}$. Also shown are the predictions from LO and NLO dijet calculations as well as predictions from CASCADE

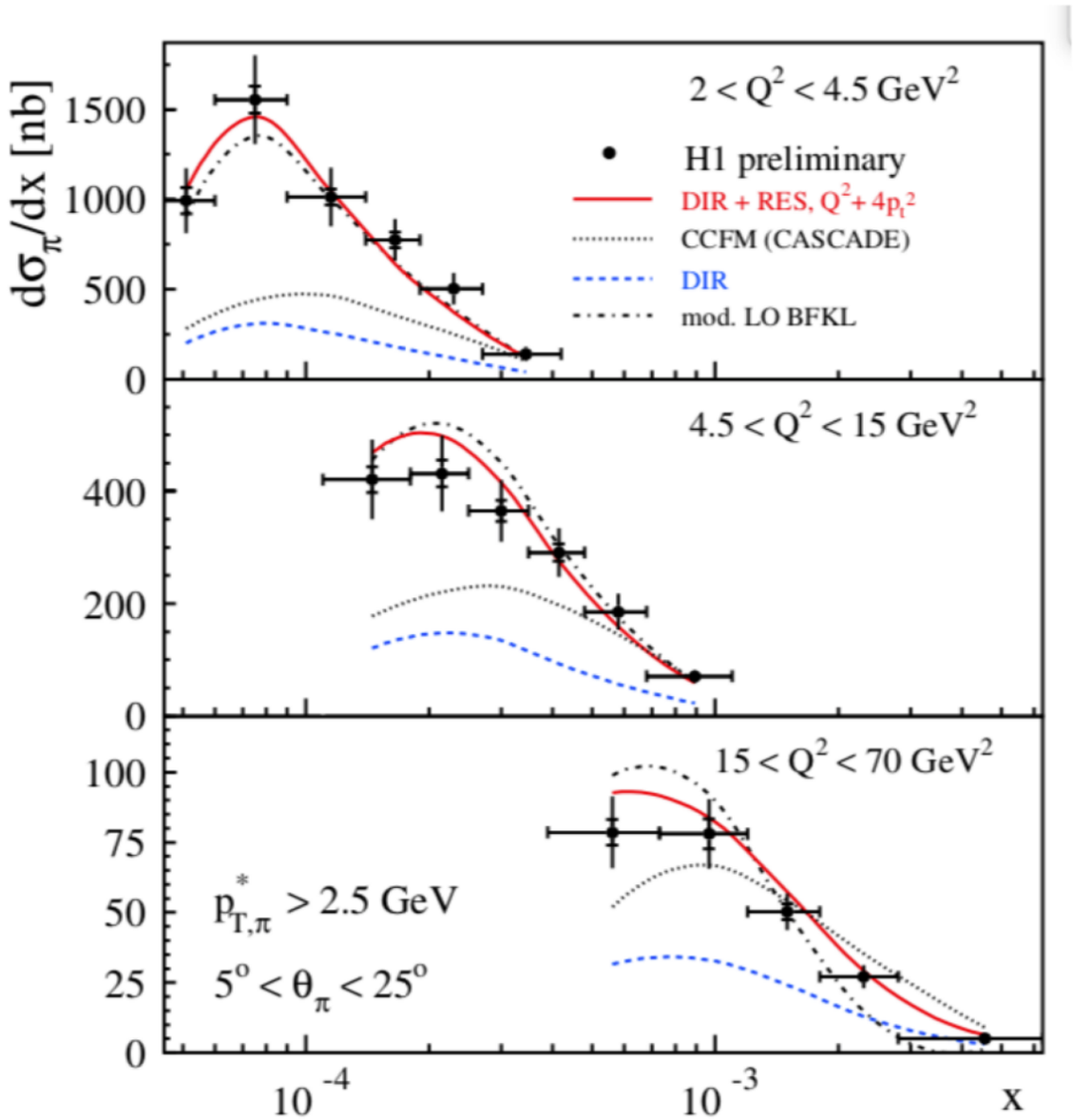


Fig. 31. The cross section for forward π^0 production as a function of x for $p^{\star}_{\mathrm{T},\pi^0} > 2.5\,\mathrm{GeV}$. Also shown are the predictions from various Monte Carlo calculations

Validation and theory comparison at LHC

Rivet

Rivet link

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 400 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

- includes χ^2 estimates
- can be used for fits – PROFESSOR tuning. NEW treatment of systematics

Rivet analysis coverage

Rivet analysis coverage

Rivet analyses exist for 324/5731 papers = 6%. 185 priority analyses required.

Total number of Inspire papers scanned = 7216, at 2019-05-21

Breakdown by identified experiment (in development):

Key	ALICE	ATLAS	CMS	LHCb	B-factories	HERA	LEP	Other
Rivet wanted (total):	200	264	354	161	1498	446	1418	1066
Rivet REALLY wanted:	35	42	74	10	2	14	7	1
Rivet provided:	**20/220 = 9%**	**149/413 = 36%**	**77/431 = 18%**	**11/172 = 6%**	**14/1512 = 1%**	**8/454 = 2%**	**38/1456 = 3%**	**7/1073 = 1%**

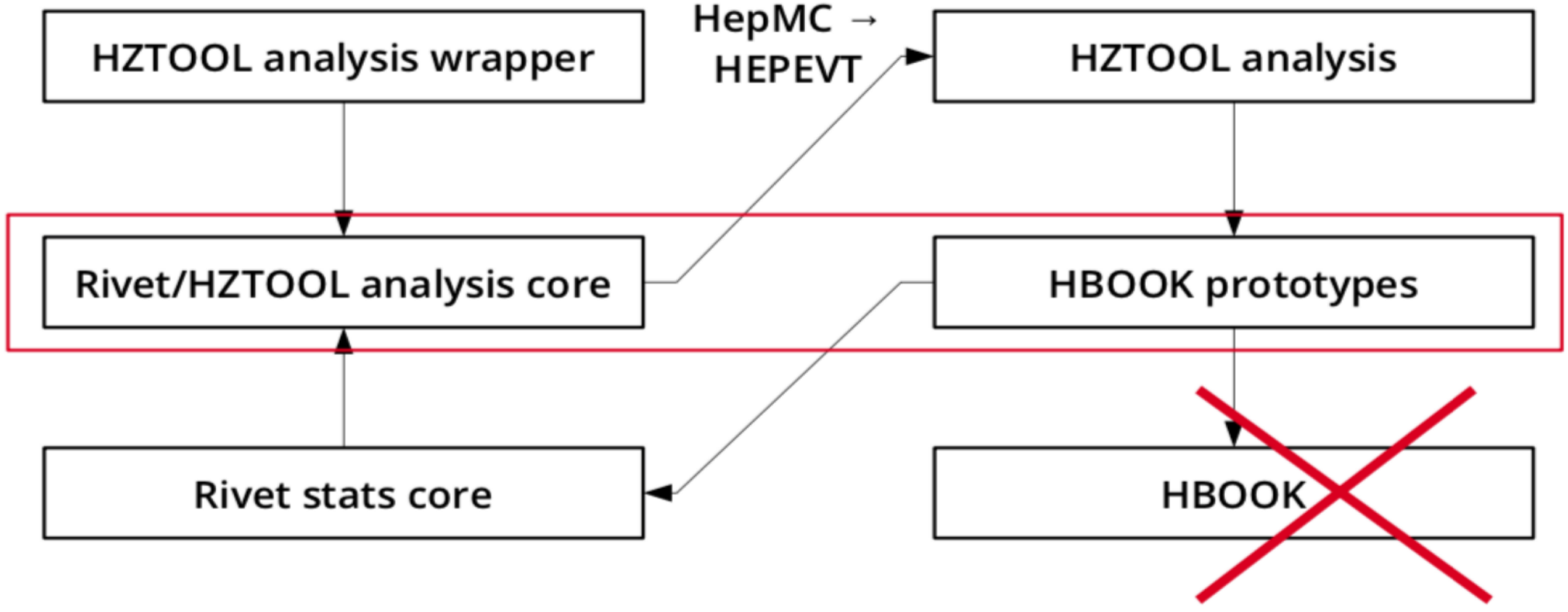
Importing knowns into the new frame: RivetHZTool

- Make use of the analyses already coded in HZTool: wrap HZTool to Rivet

Make as many analyses available at the least workload.
Wrap HZTOOL into Rivet to use existing workflows as easy as possible.
Generator-unspecific, i.e. operational, definitions for new generators.

S. Plaetzer: Rivet ep workshop, Feb 2019, DESY

Look & feel as before: **rivet -a HZ01064 ...**



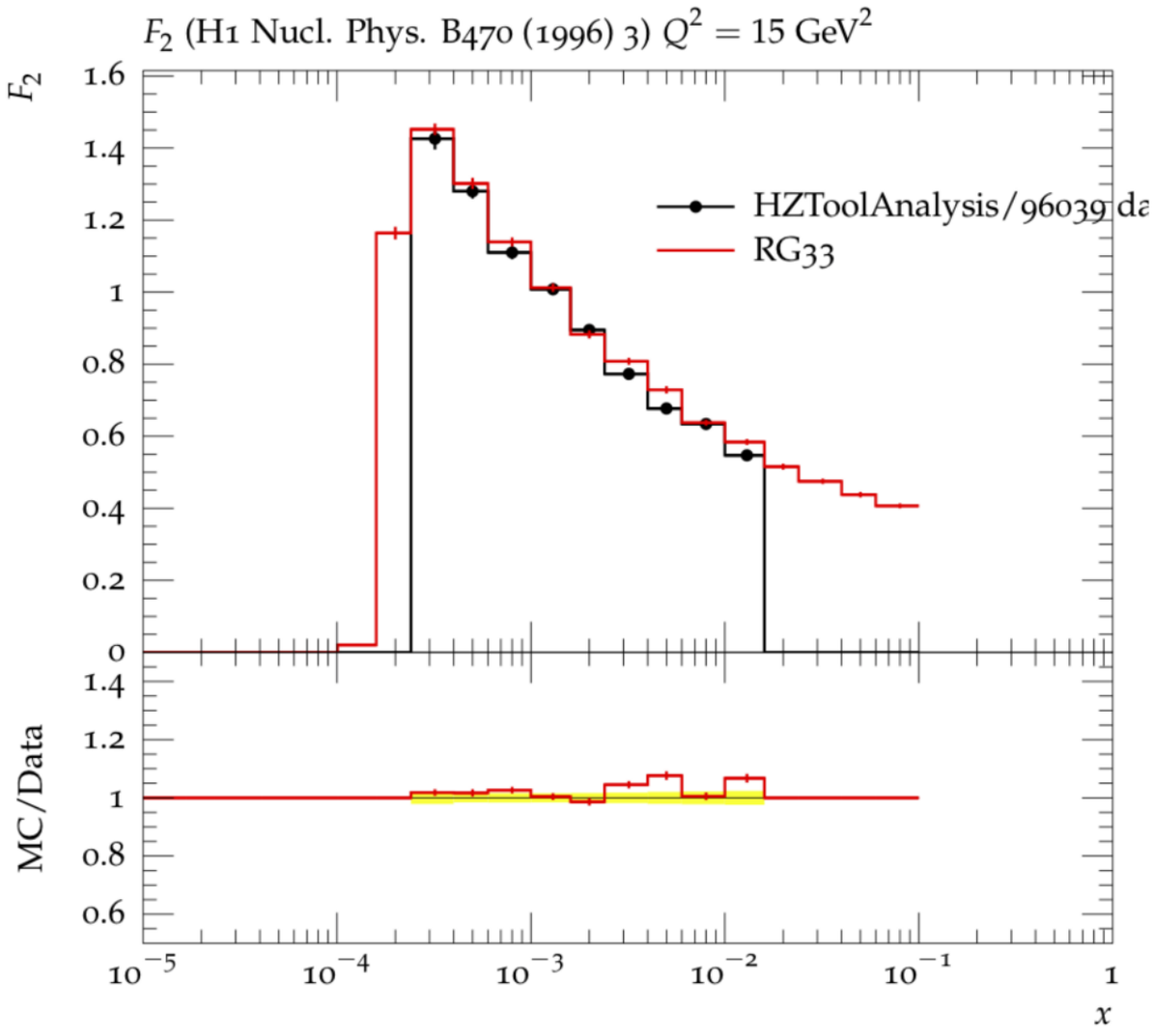
- NEW: RivetHZTool ported to Rivet 2.7.0
  - using tools from Rivet: DIS kinematics etc

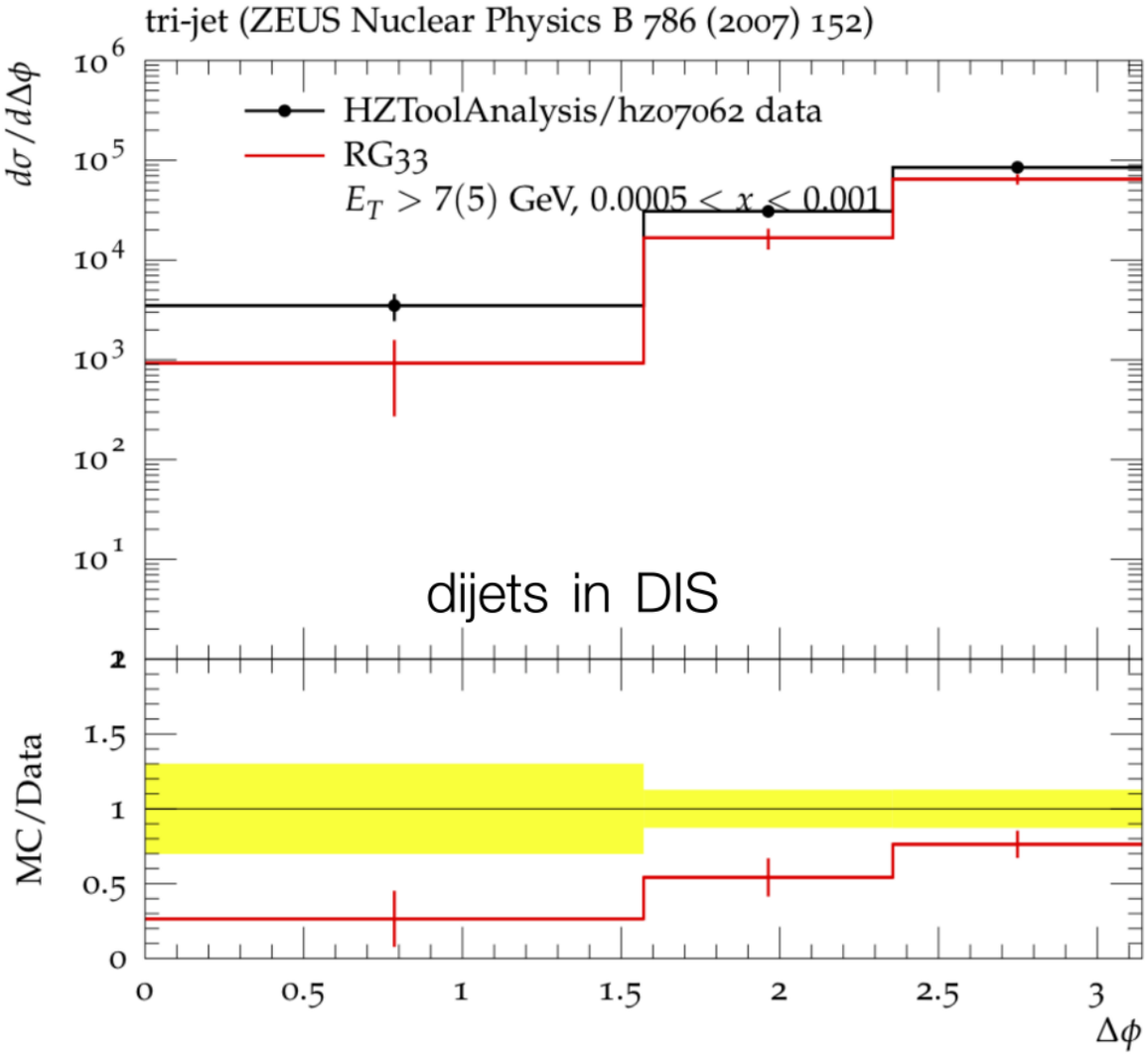
Rivet 2.7.1: ep analyses

- Presently implemented Rivet analyses
  - H1_1994_S2919893 – H1 energy flow and charged particle spectra in DIS — RivetHZTool: HZ94033
  - H1_1995_S3167097 – Transverse energy and forward jet production in the low-x regime at H1 — RivetHZTool: HZ95108
  - H1_2000_S4129130 – H1 energy flow in DIS — RivetHZTool: HZ99091
  - H1_2007_I746380 – Tests of QCD Factorisation in the diffractive production of dijets in deep-inelastic scattering and photoproduction at HERA
  - H1_2015_I1343110 – Diffractive dijets in DIS and photoproduction
  - ZEUS_2001_S4815815 – Dijet photoproduction analysis — RivetHZTool: HZ01220
  - ZEUS_2008_I763404 – Diffractive photoproduction of dijets
  - ZEUS_2012_I1116258 – Inclusive-jet photoproduction at HERA and determination of the strong coupling

- Need a systematic validation with RivetHZTool – volunteers ?

Examples results from RivetHZTool



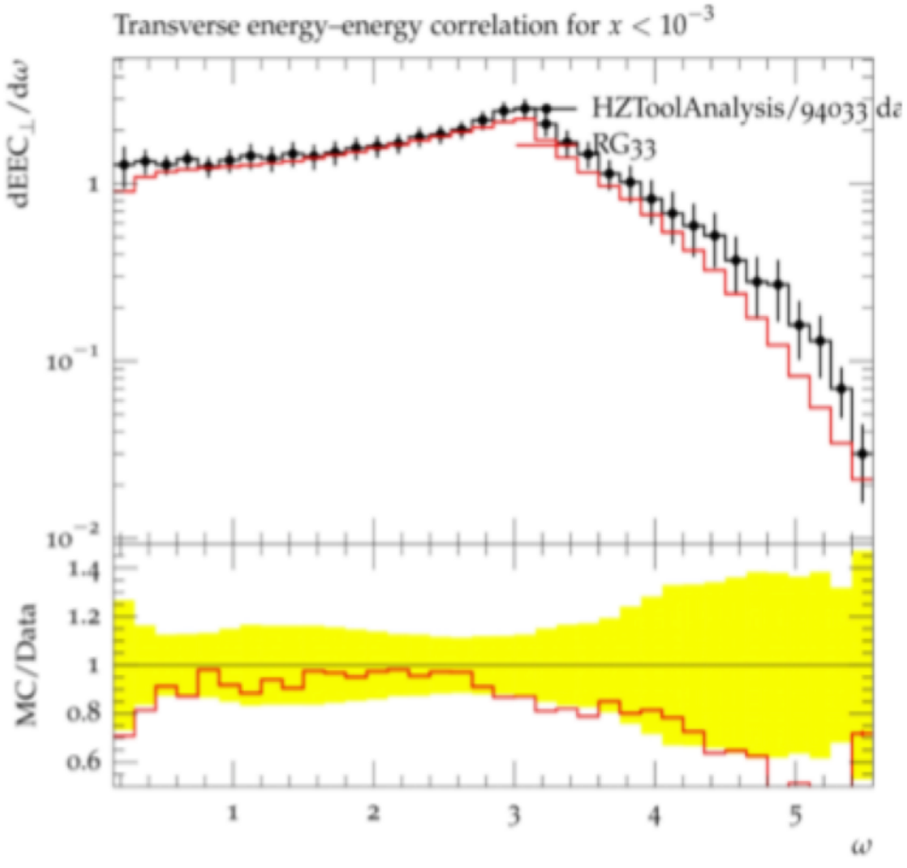


- Checks for inclusive x-sections: F_2
- Can be used for benchmarking

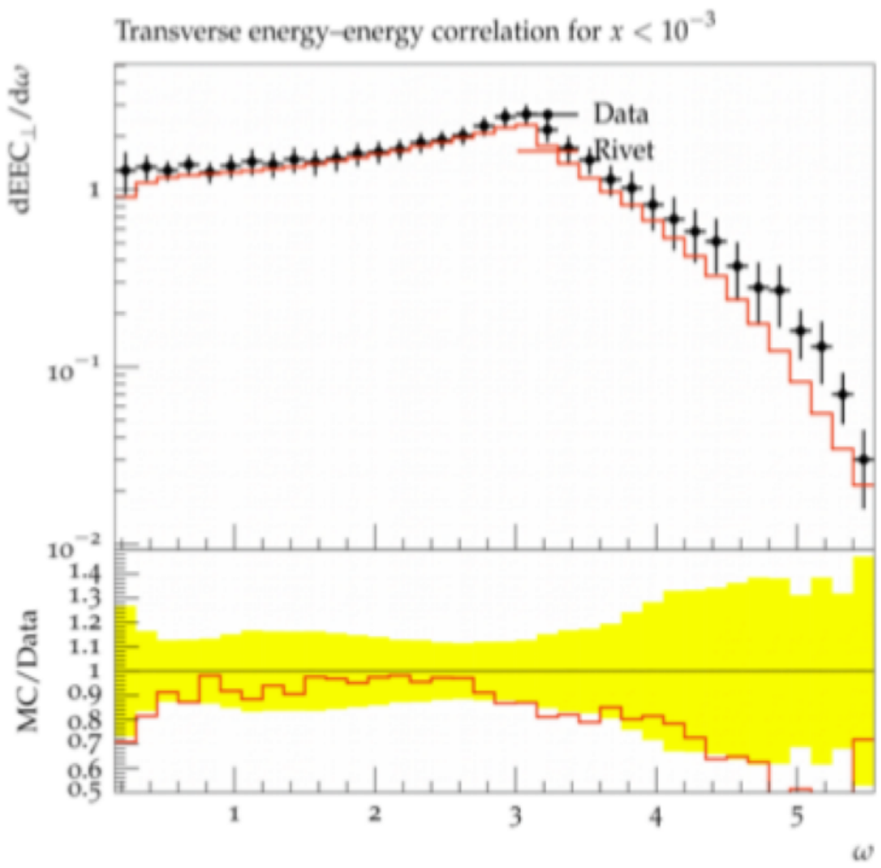
Compare RivetHZTool with plain Rivet

Transverse energy-energy correlation in DIS

HZ94033



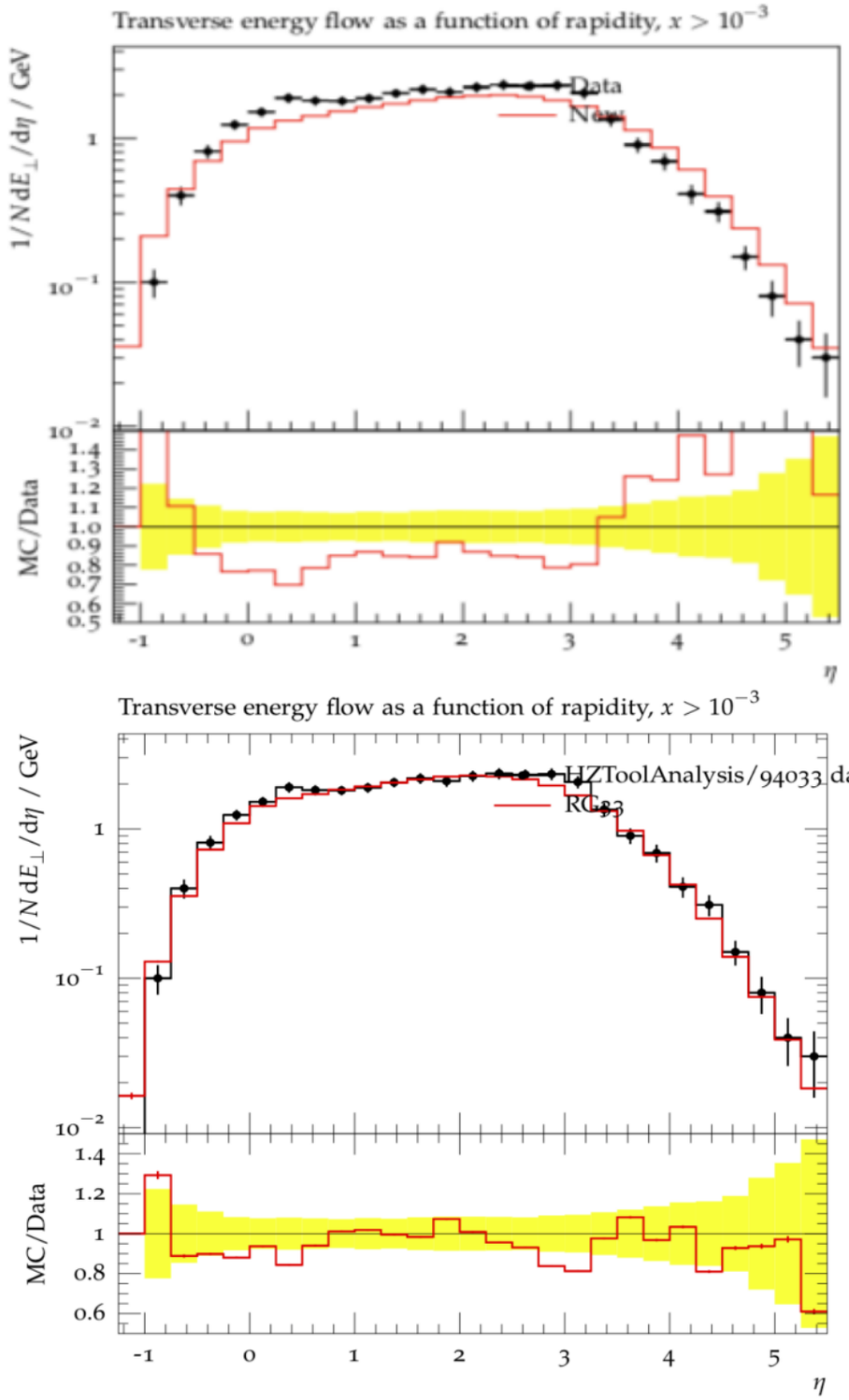
H1_1994_S2919893

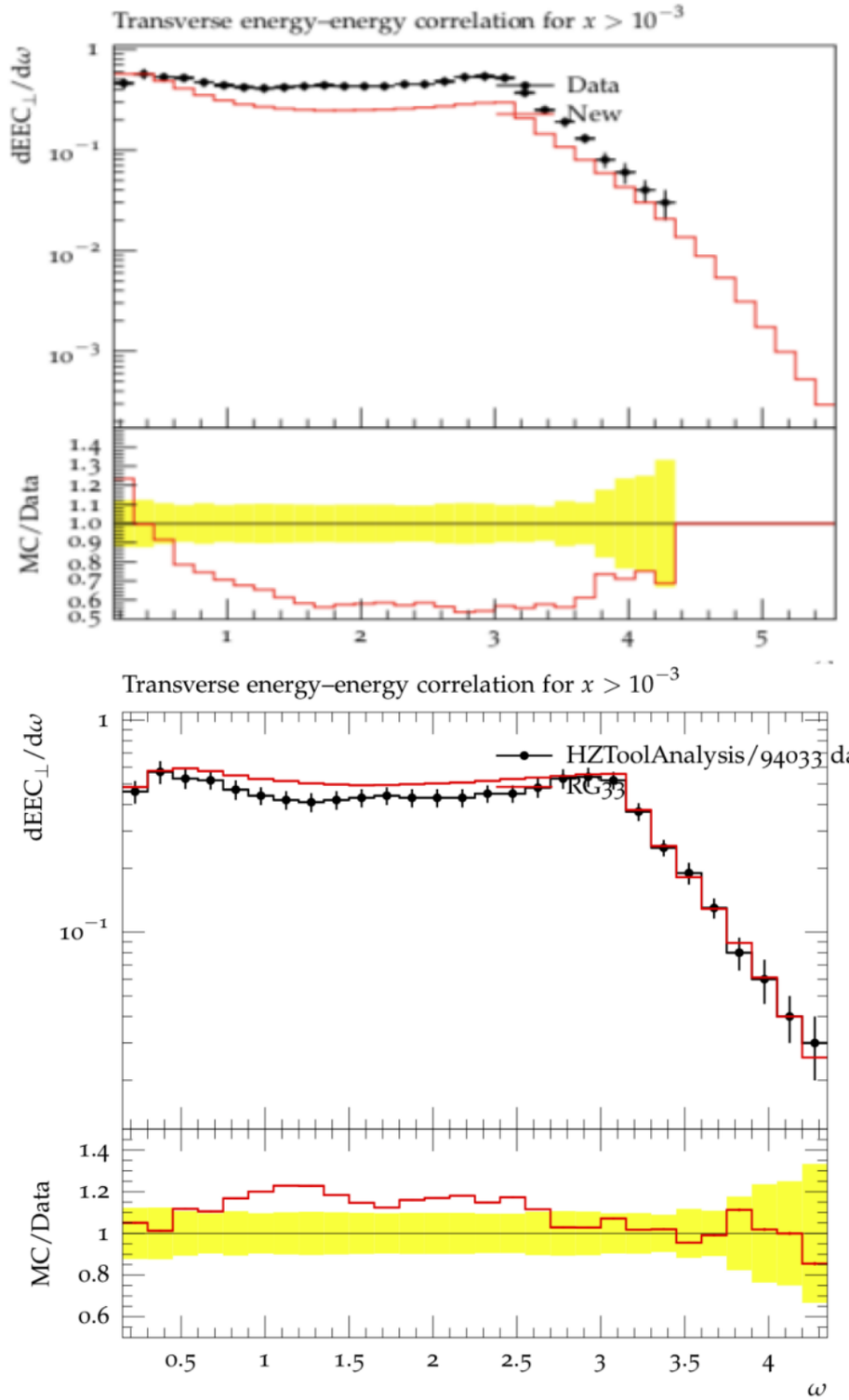


- Validation of Rivet implementation: ok
- RivetHZTool and plain Rivet give same results
  - ➔ use RivetHZTool for already available analyses

Comparison with ep generators: PYTHIA8 - RAPGAP

Transverse energy-energy correlation in DIS





PYTHIA 8

Lkka Helenius
Rivet eo meeting DESY 2019

RAPGAP33

- Comparison of ep generators
  - why is there a difference ?

A repository of comparisons for HERA

- Create repository of Rivet/RivetHZTool comparisons for HERA analyses
  - Web based, for easy comparison (with input cards for generators)
    - MCplots already existing, but using interfaces and not easy to update :)

December 2017 - P. Skands , A. Karneyeu

Reference: Eur Phys J C74 (2014) 1 (arXiv:1306.3436)

  - Develop light-weight version as repository and benchmarks
    - using RivetHZTool and Rivet for HERA analyses
    - using HERA generators for benchmarking
      - and add new generators for comparison
    - structure:
      - plot directly from Rivet plots, using `rivet-mkhtml`
    - need to be developed, starting with summer-student at DESY
      - help is welcome

What is missing ?

- RivetHZTool:
  - some functionality of HBook operations need to be implemented for yoda histograms
  - official release with documentation
  - final validation
- To Be Discussed:
  - will RivetHZTool be part of official Rivet package ?
    - need appropriate fortran compiler
- Rivet – ep:
  - DIS kinematics implemented
    - further validation with QED radiation needed
  - Diffractive selections implemented
    - detailed validation needed
    - x-check with RivetHZTool for LRG finder etc
  - implement new HERA analyses into Rivet:
    - Jets, particle spectra etc
    - some are ready and need to be released
      - but many are still missing

Benchmarks and tuning with HERA data

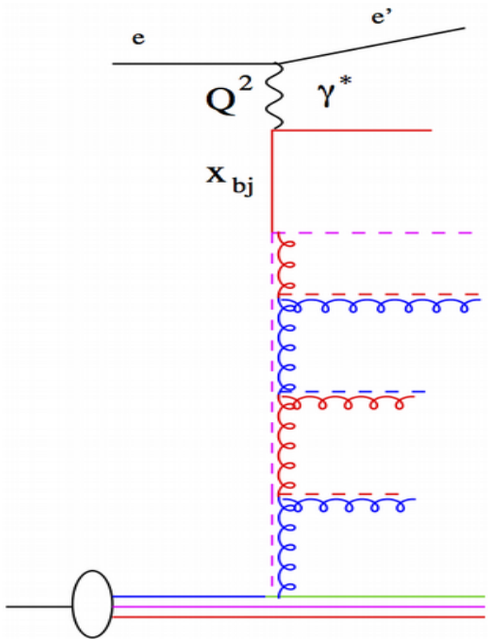
- Top priority:
  - description of total ep DIS xsection – including everything: ME corrections, parton shower, hadronization with consistent pdf set: α_s , scales etc
  - investigate QED radiation
- investigate hard ME corrections:
  - multijet events in central region
- investigate Parton Shower/Hadronization
  - charged particle spectra –examples on sensitivity on next slides

Charged particle spectra in DIS as example

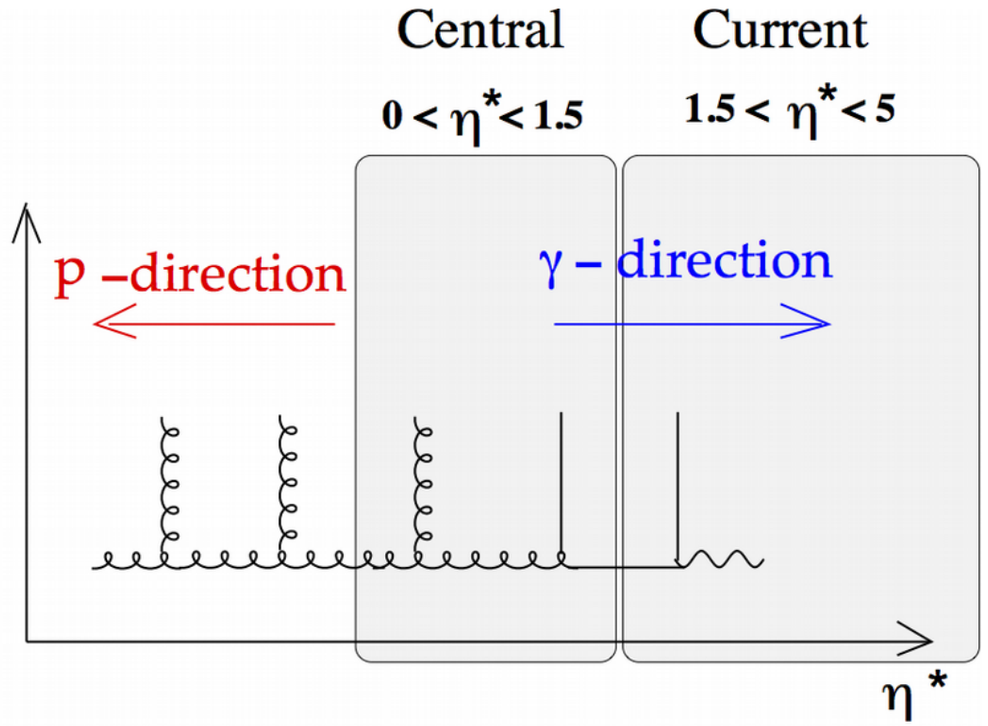
- kinematic range: $ep \to e'X$

e : 26.7 GeV; p : 920 GeV; $\sqrt{s} = 319$ GeV

$$5 < Q^2 < 100 \text{ GeV}$$
$$0.05 < y < 0.6$$
$$0.0001 < x_{bj} < 0.01$$

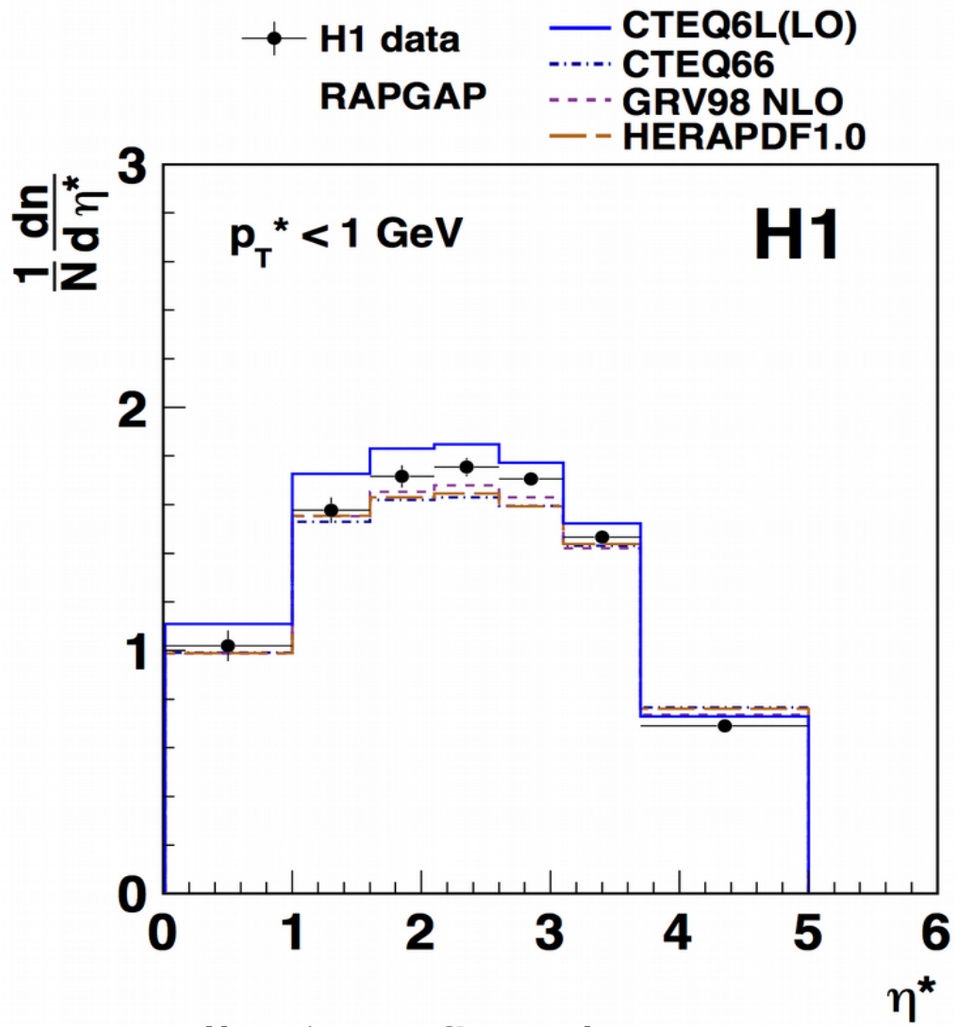


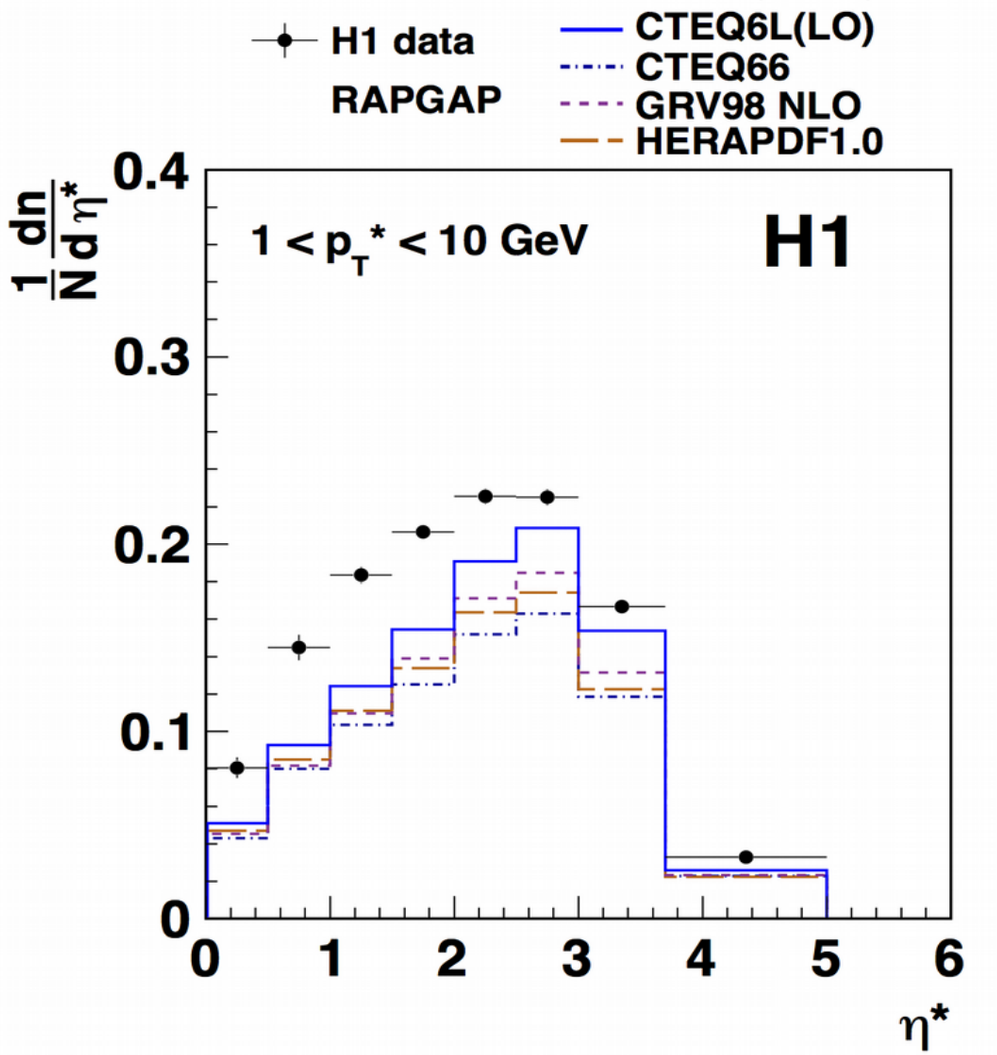
- tracks -2 < η < 2.5, p_t > 0.150 (0.5) GeV in lab-frame
- measurement in hadronic center-of-mass frame:
  - η^* and p_t^*
    - ➔ $\eta^* < 0$: target (p-remnant) hemisphere
    - ➔ $\eta^* > 0$: γ - hemisphere
      - central: $0 < \eta^* < 1.5$
      - current: $1.5 < \eta^* < 5$



Charged particle spectra in DIS

H1 Coll. EPJC 73 (2013) 2406



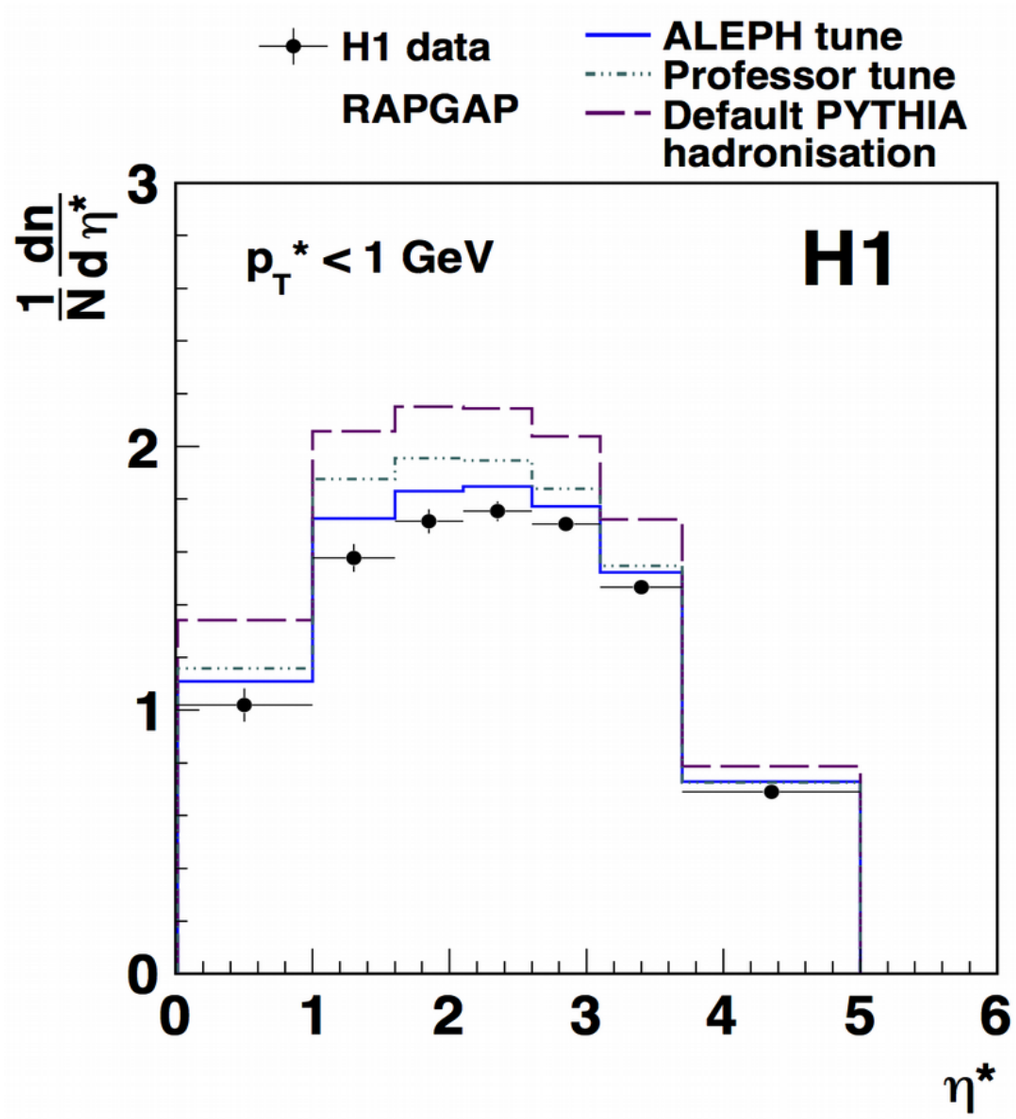


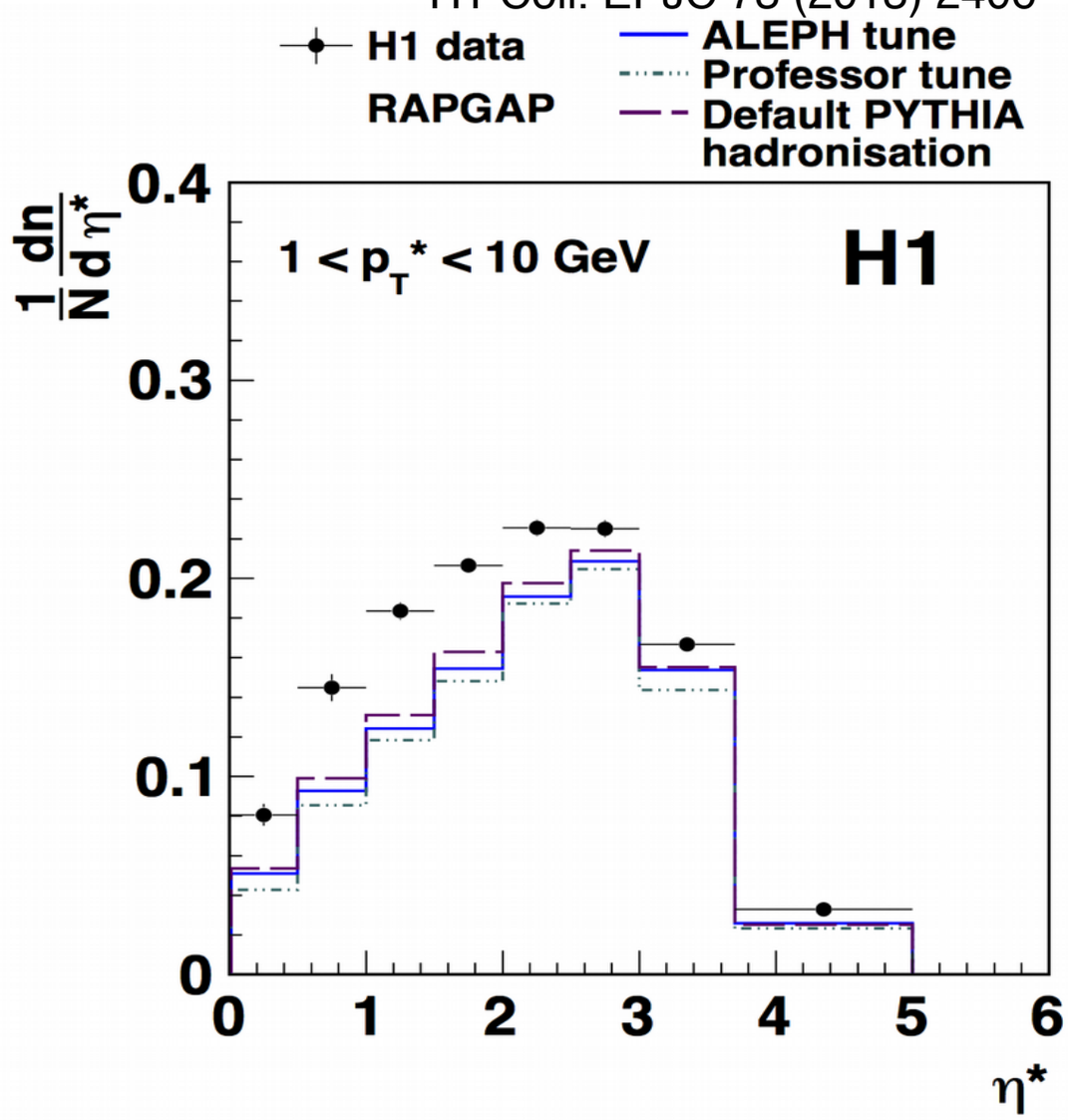
- at small p_t^* : ~ flat plateau
  - ➔ hadronization Nj described by MC
- at large p_t^* : rising towards photon (hard scale)
  - ➔ parton shower cascade Nj not described by MC

➔ dependence on parton densities

Charged particle spectra in DIS

H1 Coll. EPJC 73 (2013) 2406





- dependence on hadronization parameters
  - at small p_t^*:

    hadronization: sensitivity to tune
  - at large p_t^*:

    hadronization plays smaller role

Charged particle spectra in DIS

- dependence on parton shower model:
  - RAPGAP: virtuality ordered collinear PS (a la PYTHIA/LEPTO)
  - DJANGOH: PS from Color Dipole Model (ARIADNE)
  - HERWIG++: angular ordered collinear PS
  - CASCADE: angular ordered small-x improved CCFM PS

➔ for $p_t^* < 1$ GeV

➔ sensitivity on PS (except CASCADE) Nj sensitive to hadronization

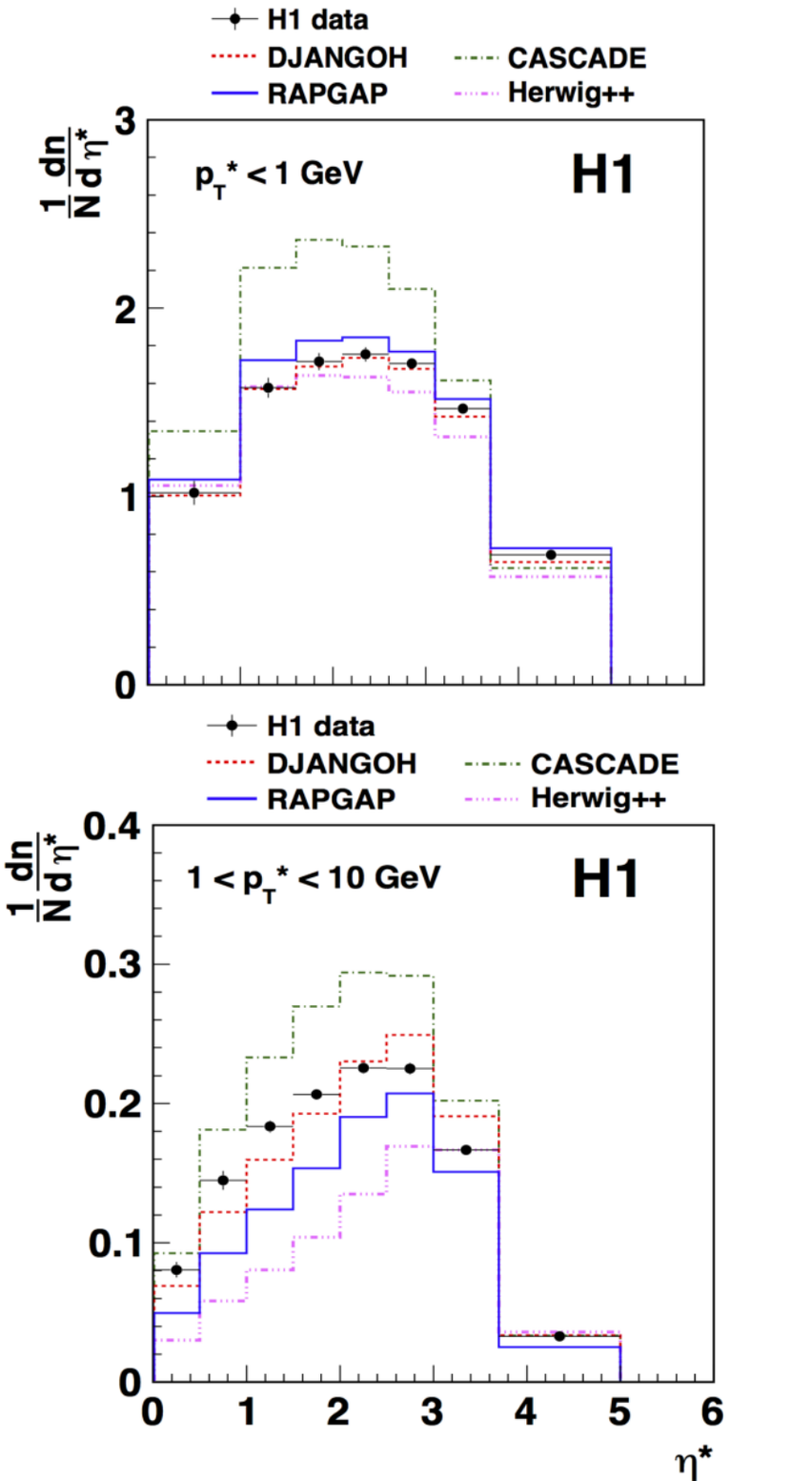
➔ for $p_t^* > 1$ GeV

➔ collinear parton shower (RAPGAP & HERWIG++) below data

➔ Color Dipole Model best

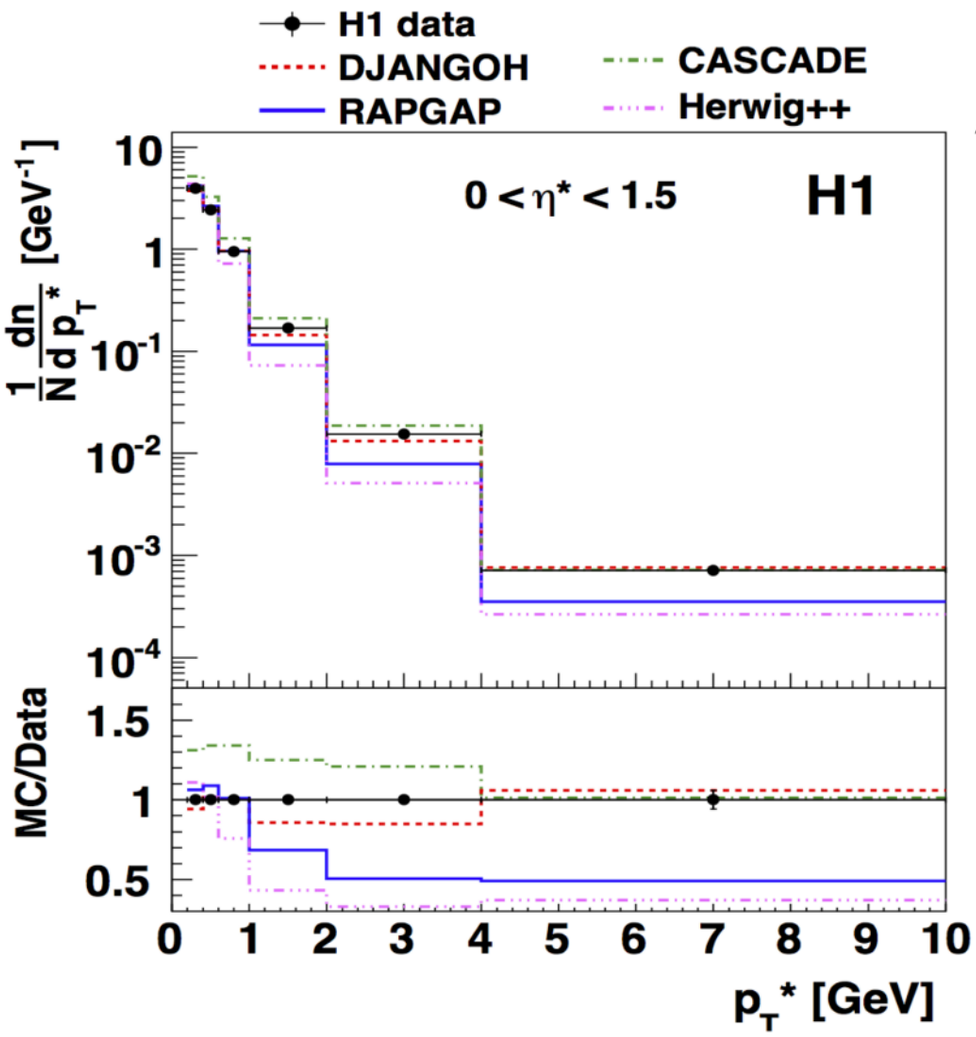
➔ small x improved CCFM shower to high

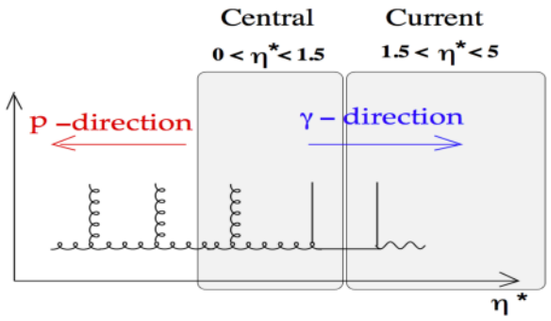
H1 Coll. EPJC 73 (2013) 2406

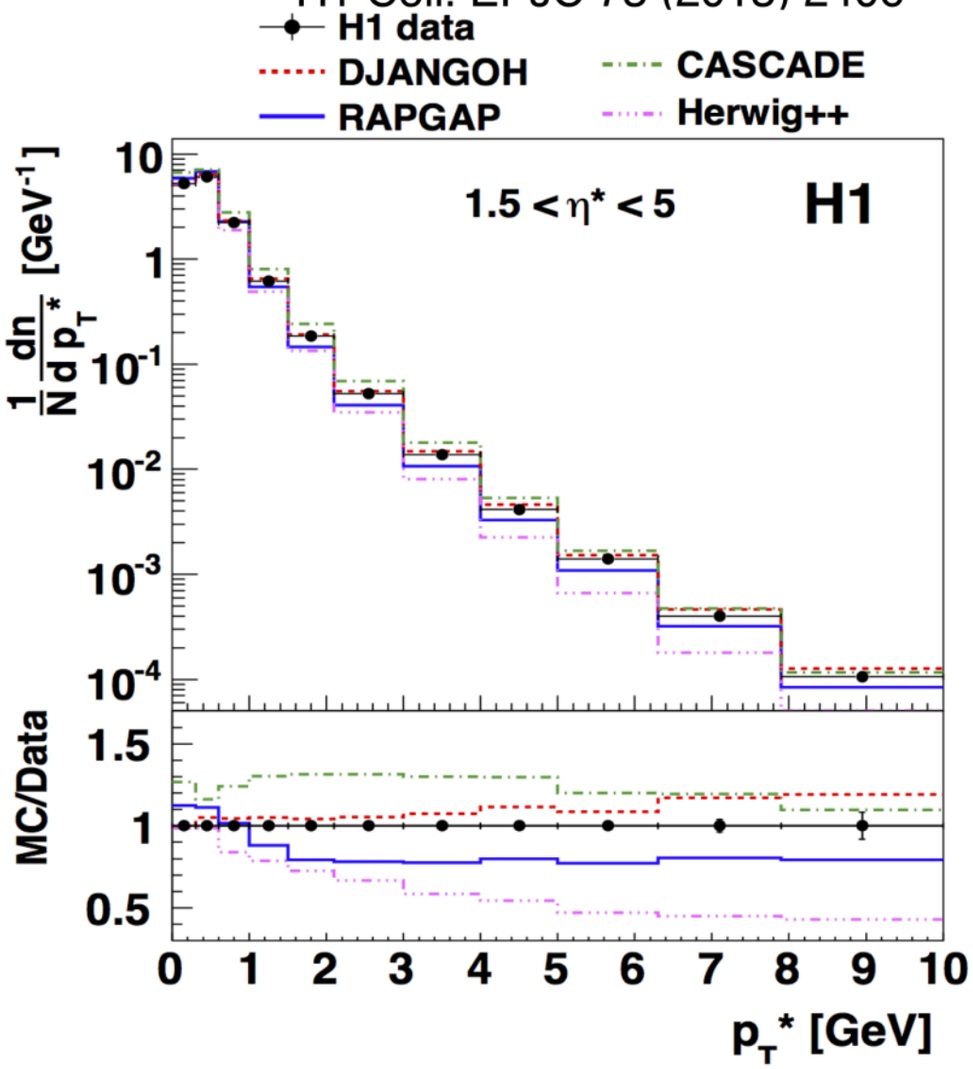


charged particle spectra in 2 regions of η^*

H1 Coll. EPJC 73 (2013) 2406







- $0 < \eta^* < 1.5$:
  - region sensitive to higher order radiation (parton shower)

  ➔ data not described by collinear parton shower models

- $1.5 < \eta^* < 5$
  - region sensitive to hard scattering

  ➔ at large p^*_t Nj data significantly larger than collinear shower predictions

Conclusion

- Rivet and RivetHZTool are appropriate tools for comparison of theory predictions of MC generators with measurements
  - DIS options implemented in Rivet
  - RivetHZTool is working with latest Rivet releases

- New analysis from new colliders and new analyses from HERA to be implemented in Rivet
  - Needs:
    - validation of Rivet plugins with RivetHZTool
    - new analyses to be coded – help needed

  - Validation and benchmarking
    - Repository of HERA generator predictions for HERA analyses (as used in publication)
    - Compare new generators for ep (with the known ones) !
    - Investigate tuning of free parameters (be careful not to over-tune interesting physics)