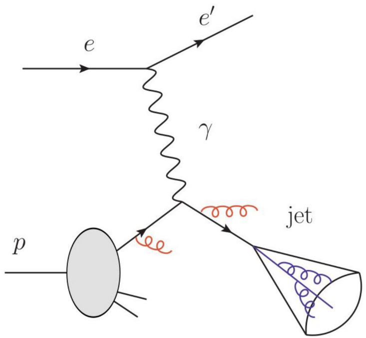
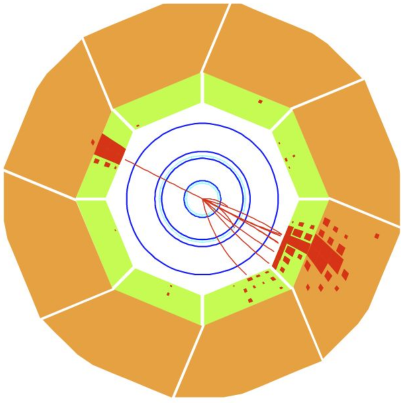
Multi-differential Jet Substructure Measurement in High Q^2 DIS Events with HERA-II Data

Vinicius M. Mikuni, on behalf of the H1 Collaboration

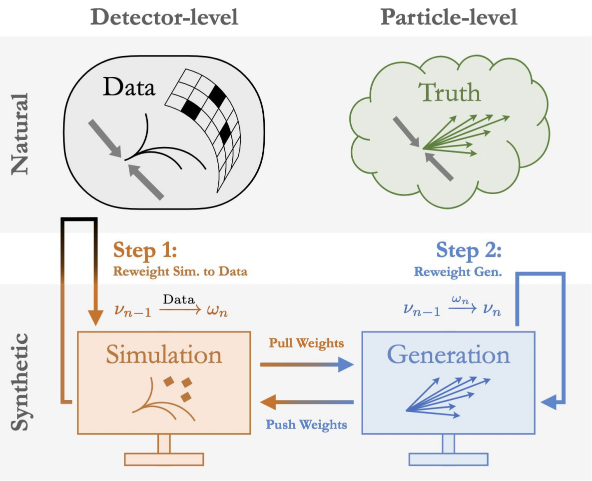
Review

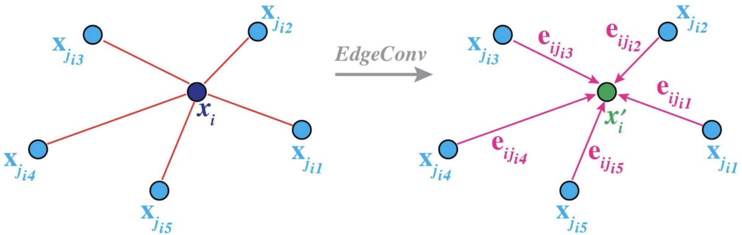
1: Definition of measure observables



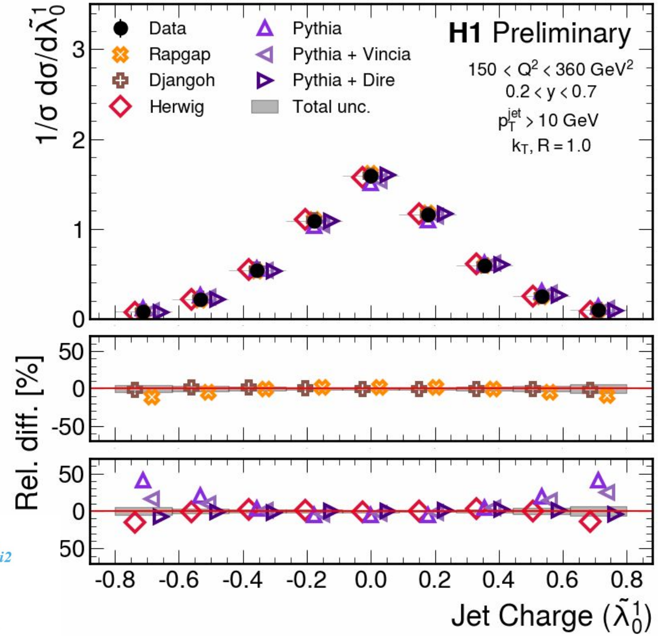


2: Unfolding methodology





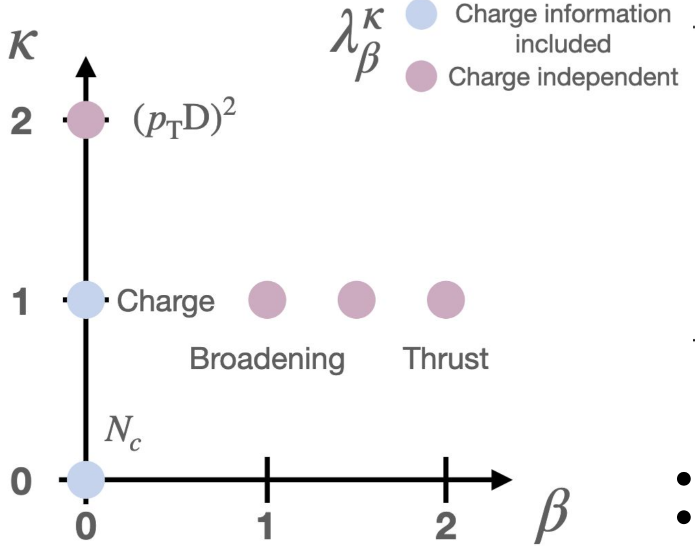
3: Multi-differential cross section results

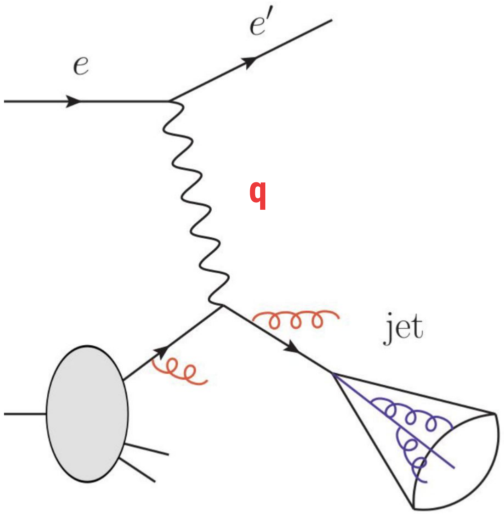


Jet angularities

Use jet observables to study different aspects of QCD physics:

- IRC safe λ^1_a, a = [0,0.5,1] and unsafe $p_T D$ angularities
- Charge dependent observables: Q_j and N_c
- Study the evolution of the observables with energy scale $Q^2 = -q^2$



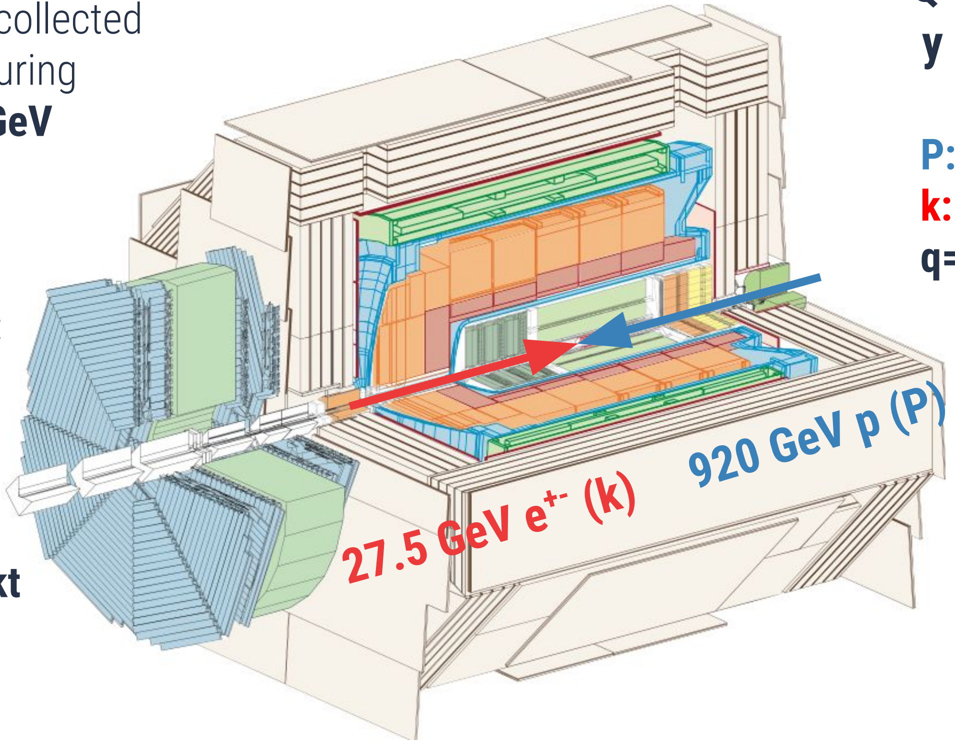


- z_i: longitudinal momentum fraction
- q_i: charge
- R_i distance from jet axis in (eta,phi)

$$\lambda^\kappa_\beta = \sum_{i \in \text{jet}} z_i^\kappa \left(\frac{R_i}{R_0}\right)^\beta \qquad \tilde{\lambda}^\kappa_0 = Q_\kappa = \sum_{i \in \text{jet}} q_i \times z_i^\kappa .$$

Experimental setup

Using **228 pb^{-1}** of data collected by the **H1 Experiment** during **2006** and **2007** at **318 GeV center-of-mass energy**



$Q^2 = - q^2$
$y = Pq / pk$

P: incoming proton 4-vector
k: incoming electron 4-vector
q=k-k' : 4-momentum transfer

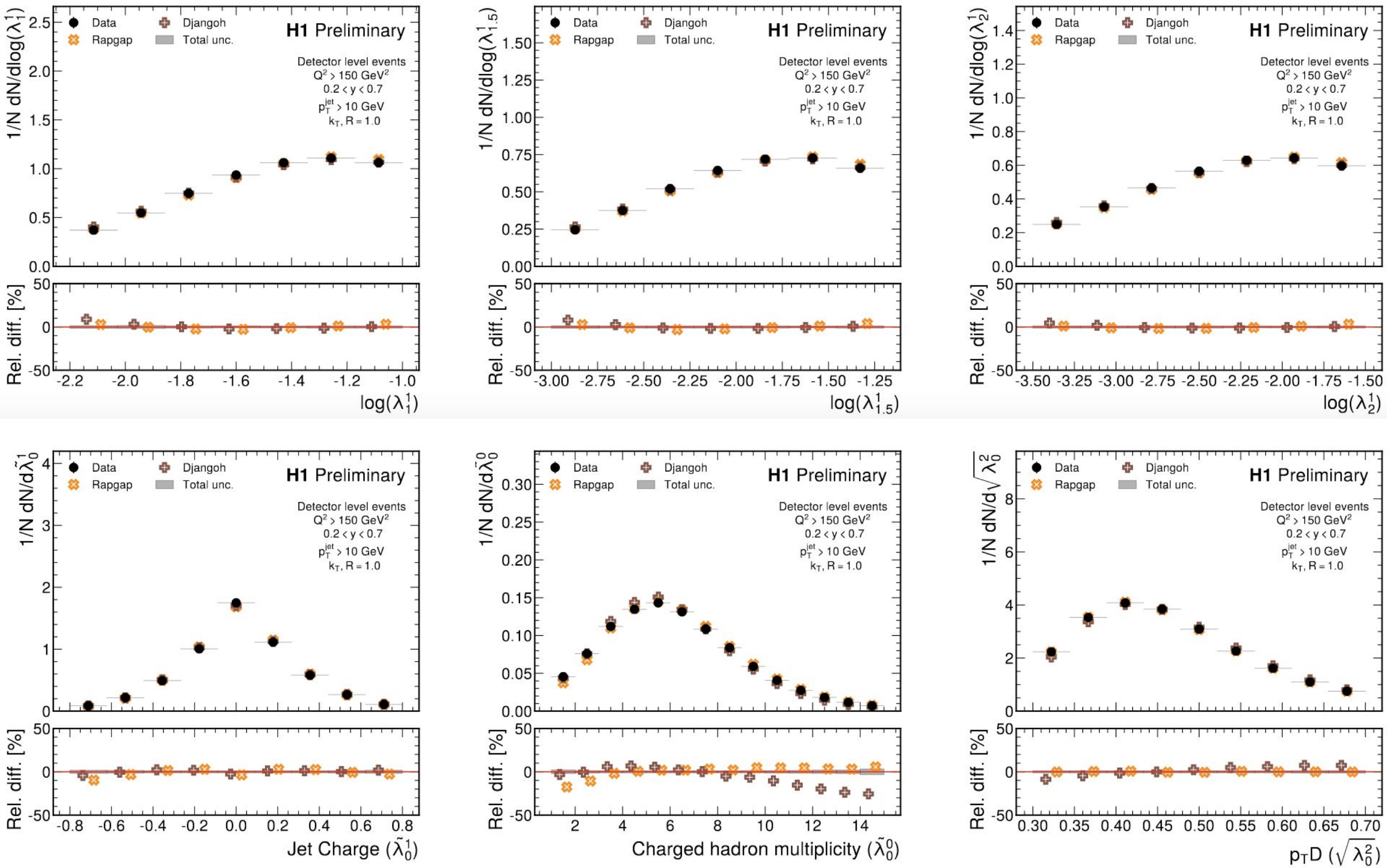
Phase space definition:

- $0.2 < y < 0.7$
- $Q^2 > 150$ GeV^2
- Jet $p_T > 10$ GeV
- $-1 < \eta_{lab} < 2.5$

Jets are clustered with **kt** algorithm with **R=1.0**

Reconstructed hadrons using combined detector information: **energy flow algorithm**

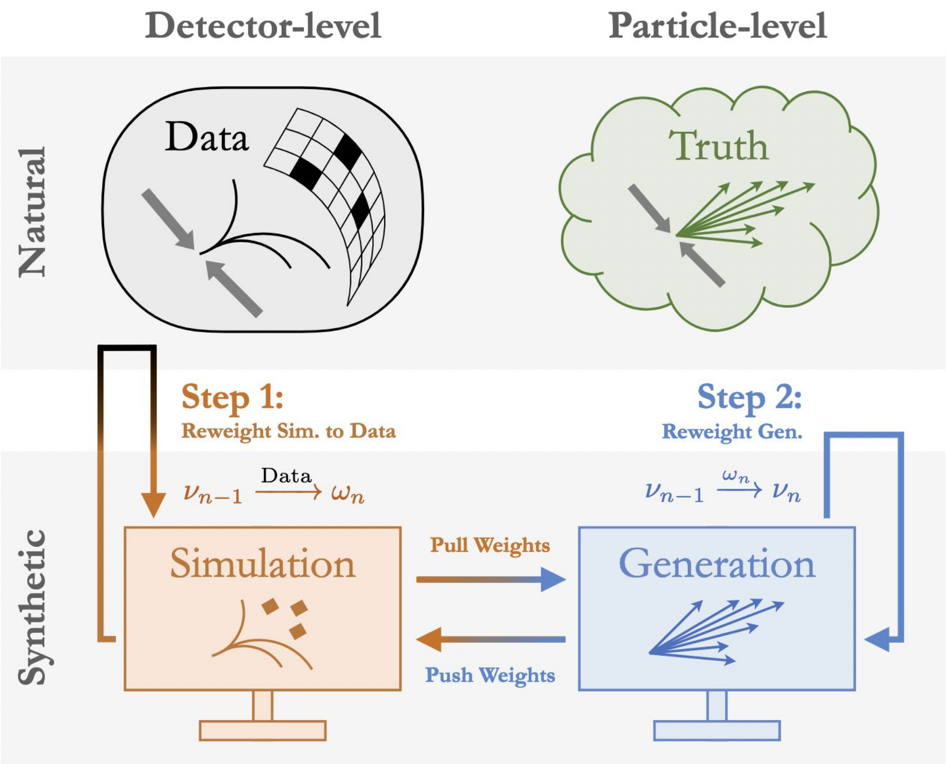
Total experimental uncertainty at reconstruction level at the **% level**!



Part 2

Unfolding strategy

Omnifold*



2 step iterative approach

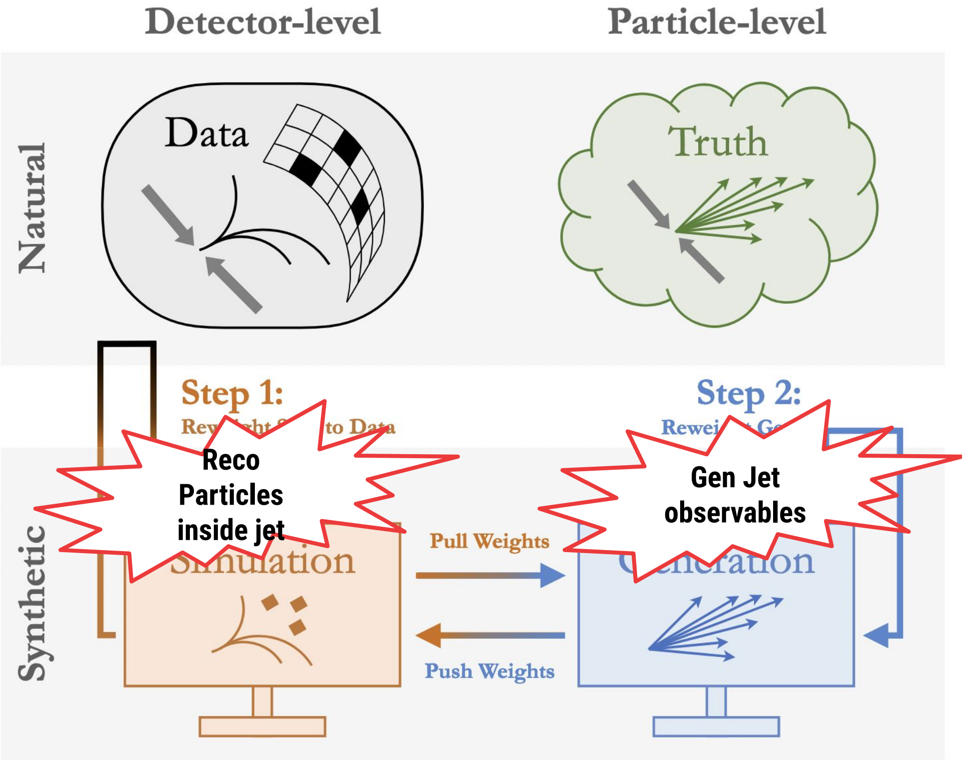
- Simulated events after detector interaction are reweighted to match the data
- Create a "new simulation" by transforming weights to a proper function of the generated events

Machine learning is used to approximate **2** likelihood functions:

- **reco MC to Data** reweighting
- **Previous** and **new Gen** reweighting

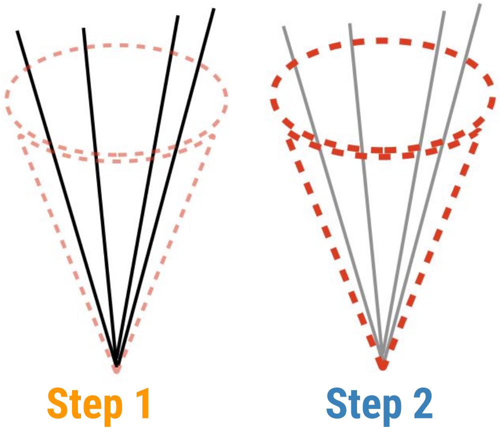
* Andreassen et al. PRL 124, 182001 (2020)

Omnifold



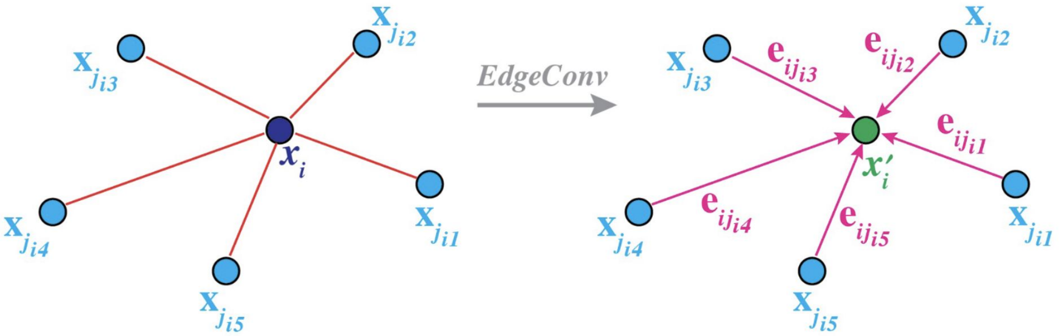
Different input levels for each step

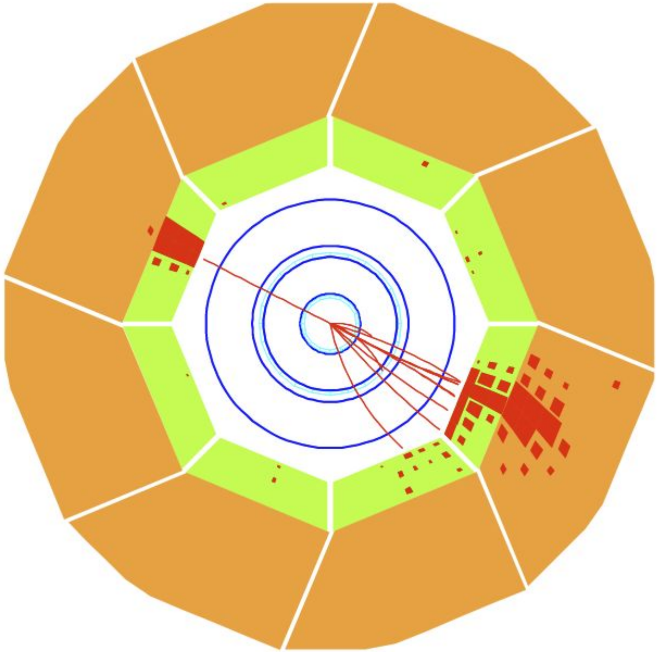
- **Step 1** particles are used as inputs
- **Step 2** uses the set of observables planned to unfold



Extracting particle information

- Particle information is extracted using a **Point cloud transformer*** model
- Model takes **kinematic properties** of particles and use the distance between particles in η-φ to learn the relationship between particles
- Built in symmetries: **permutation invariance**
- Consider up to **30** particles per jet

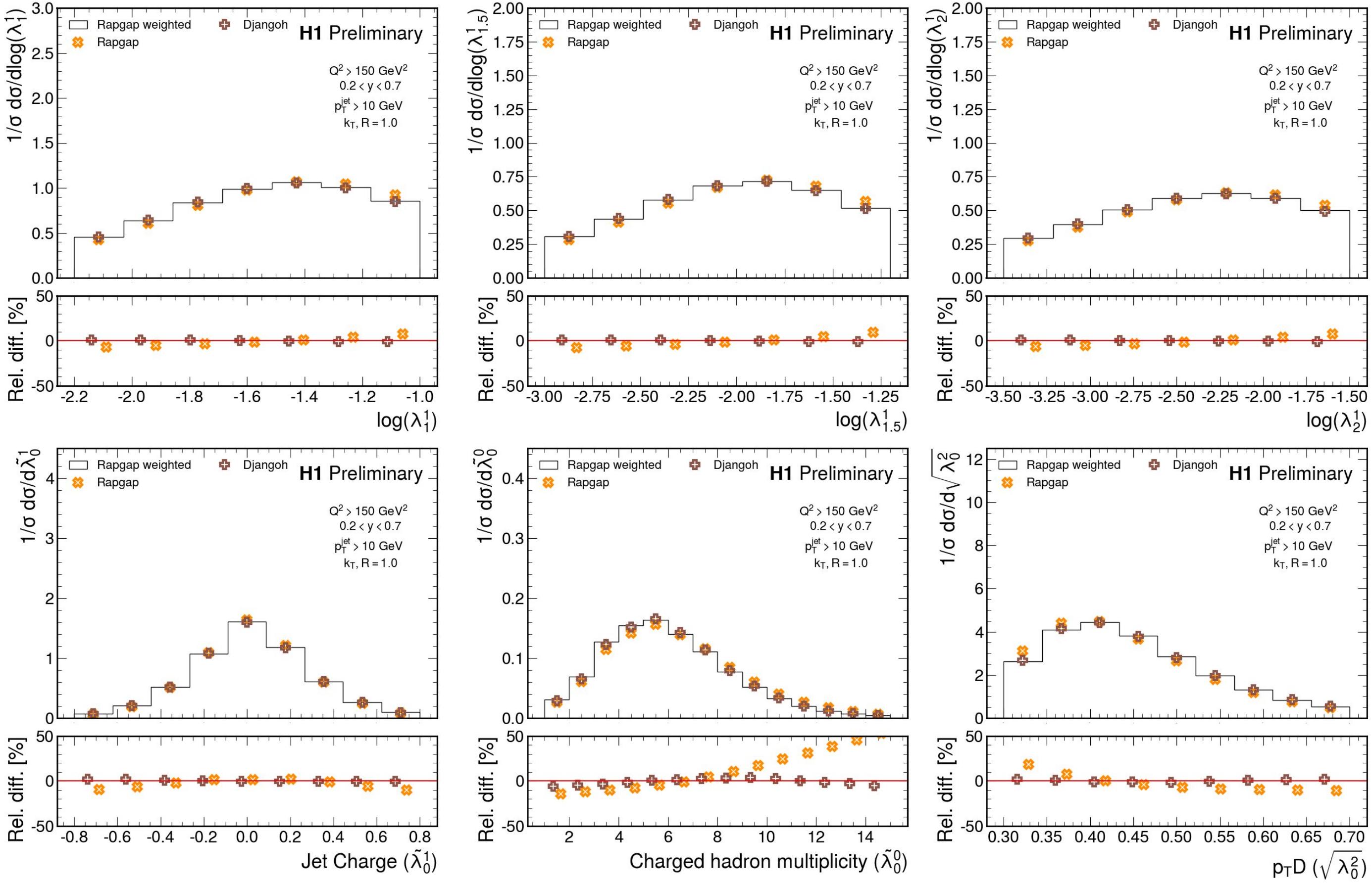




* V. Mikuni and F. Canelli 2021 *Mach. Learn.: Sci. Technol.* **2** 035027

Closure test

All distributions are unfolded **simultaneously without binning and without jet substructure information used at reco level!**



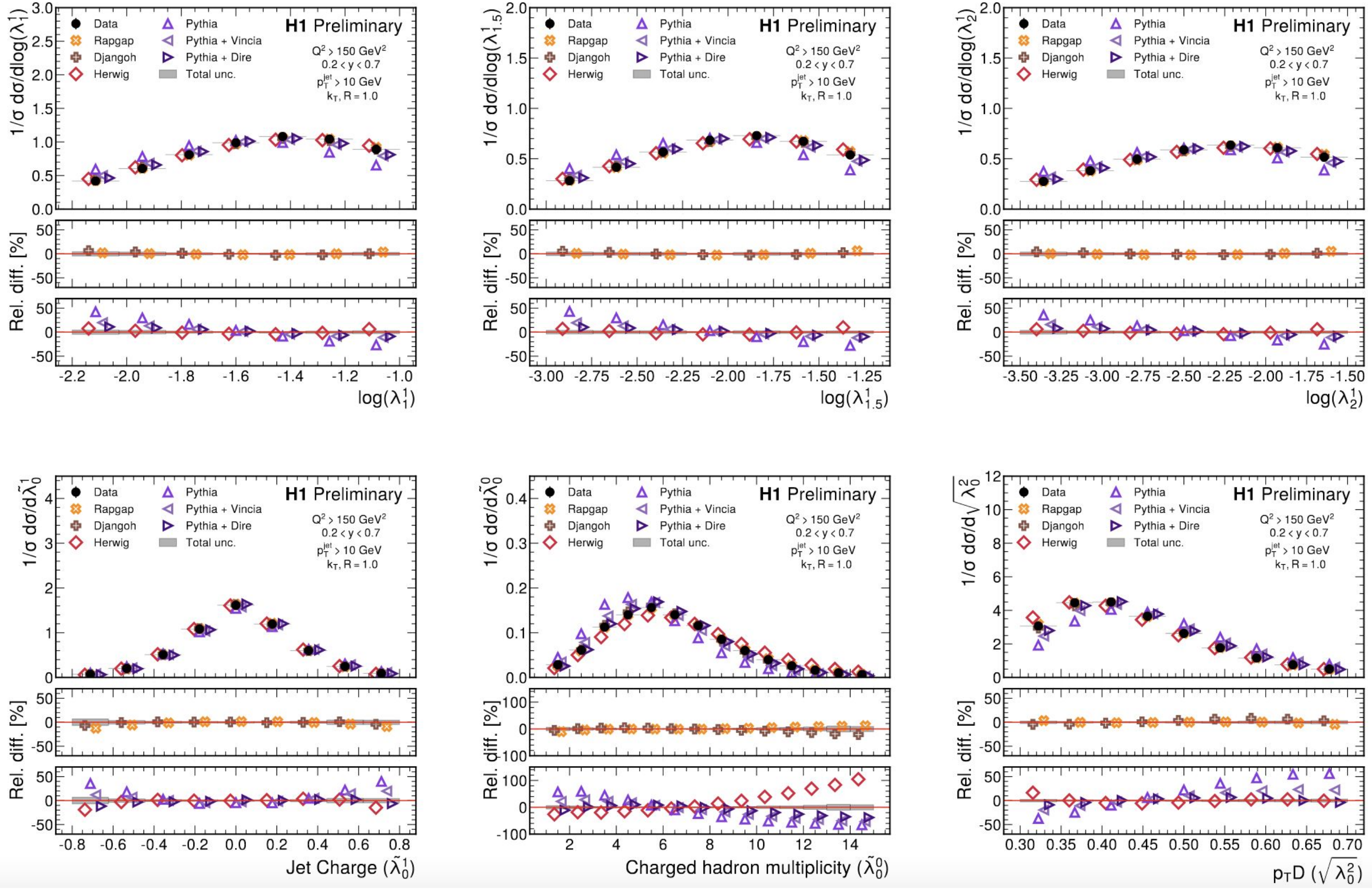
Verify the model **consistency**: start from the **Rapgap** simulation and unfold the response based on the **Djangoh** simulation

Total of **6 iterations** used to derive the main results

Part 3

Unfolded results

Inclusive

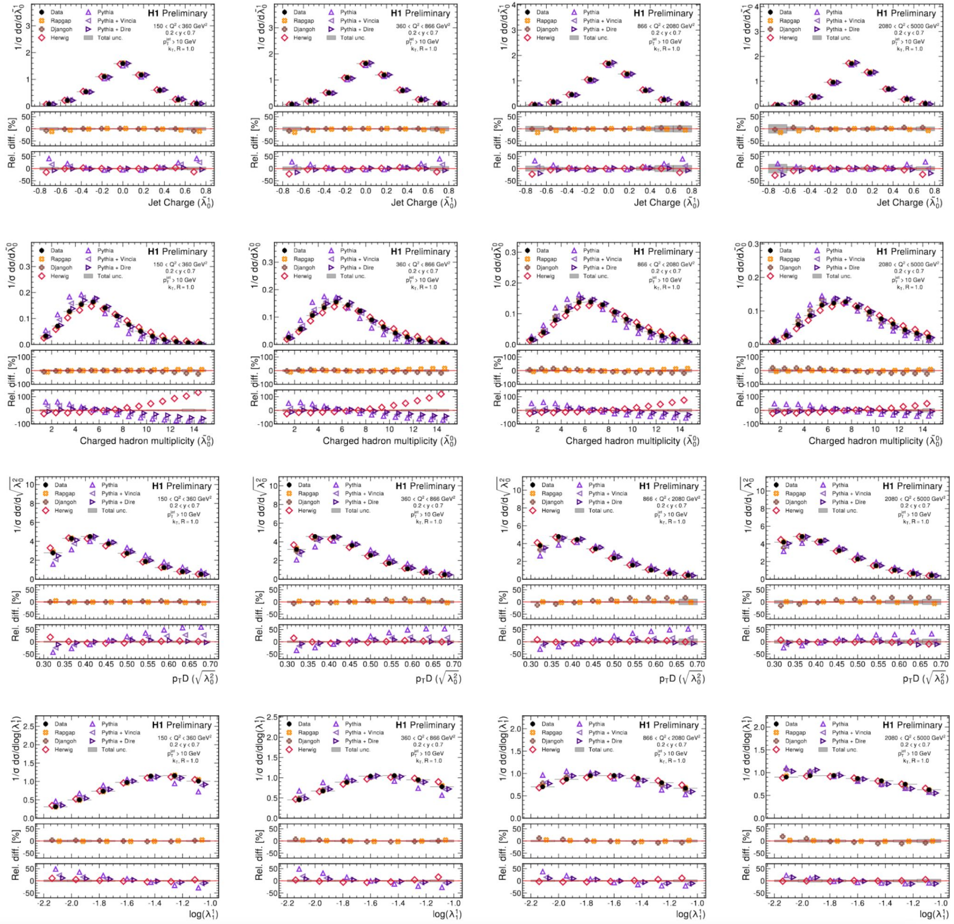


Dedicated DIS generators do a good job **everywhere**, especially **Rapgap**

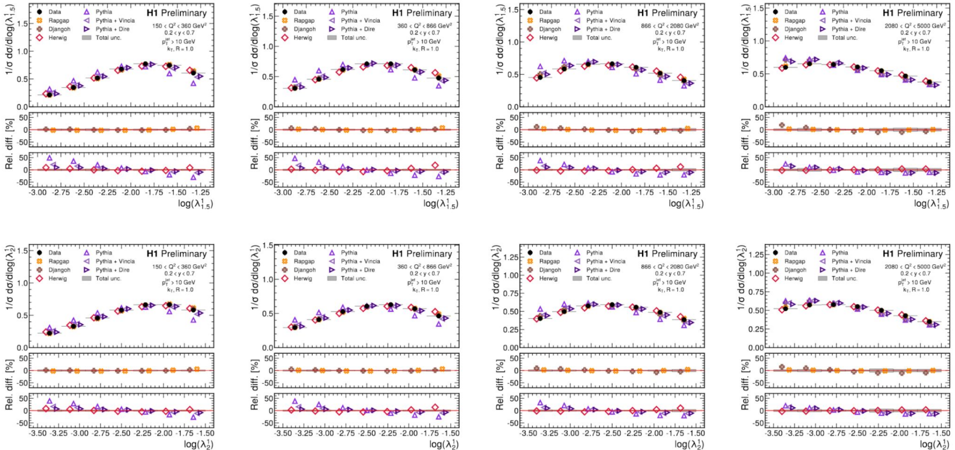
Herwig does a good job for all distributions besides charge particle multiplicity

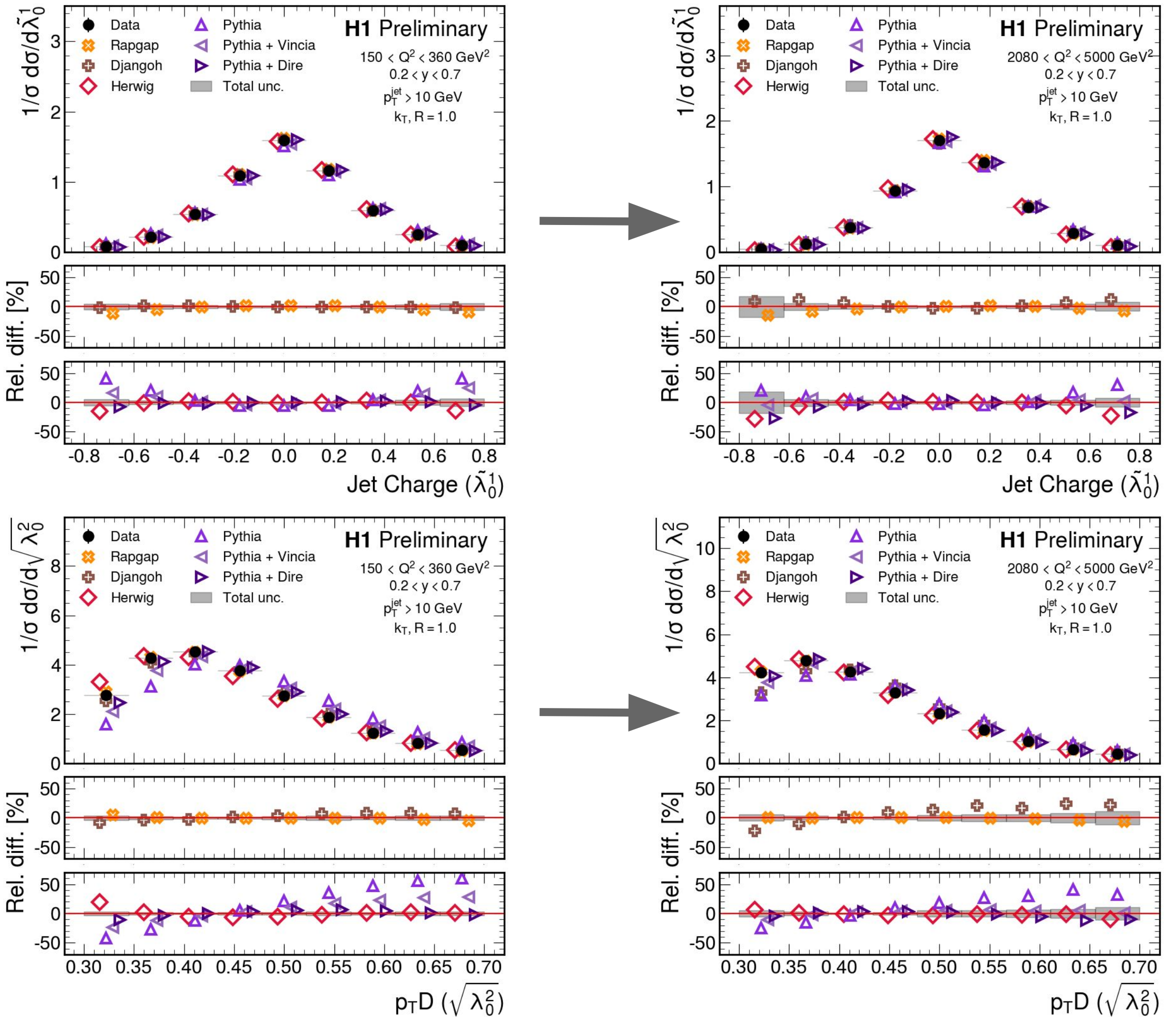
Alternative parton showers for **Pythia** do better than nominal, specially **Dire**

Multi-differential

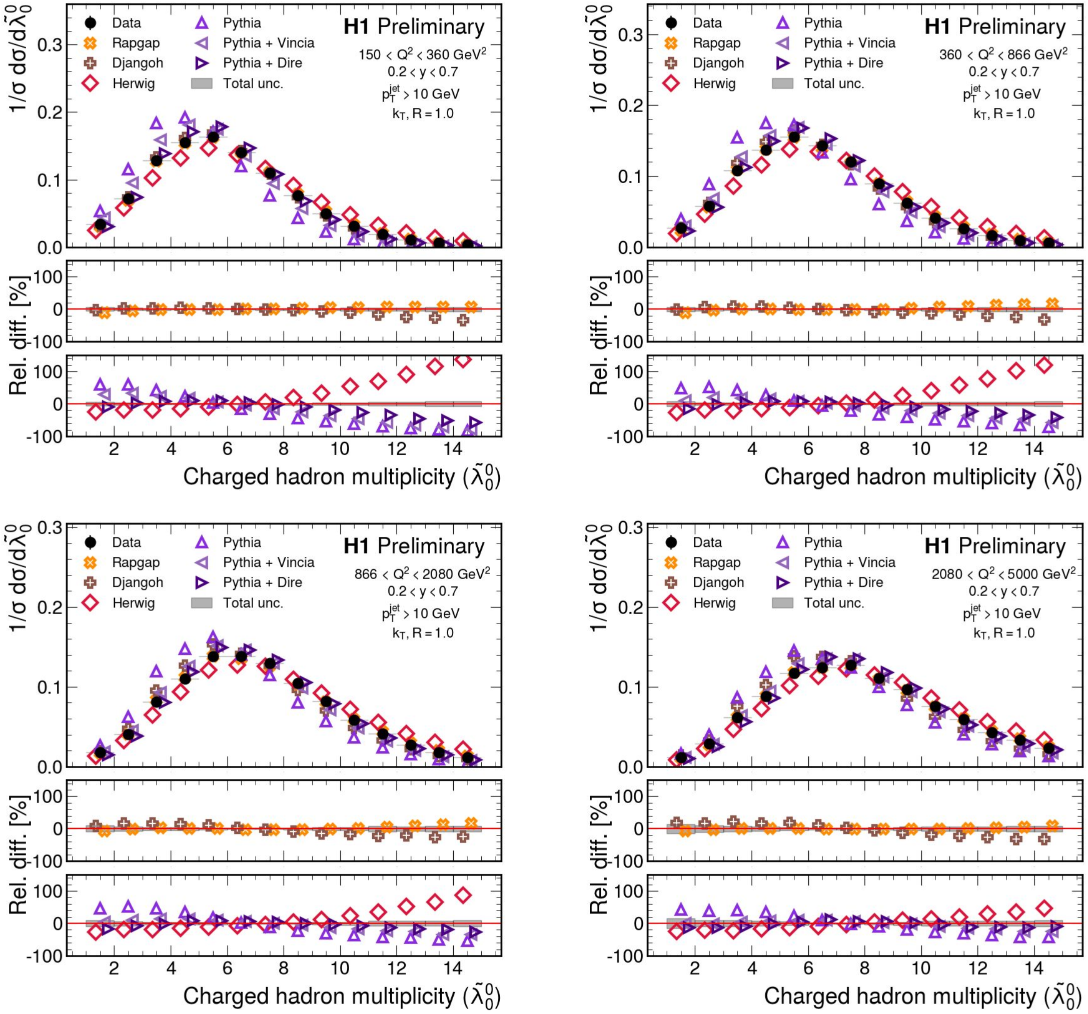


Q^2 distribution is simultaneously unfolded
with the other jet substructure distributions





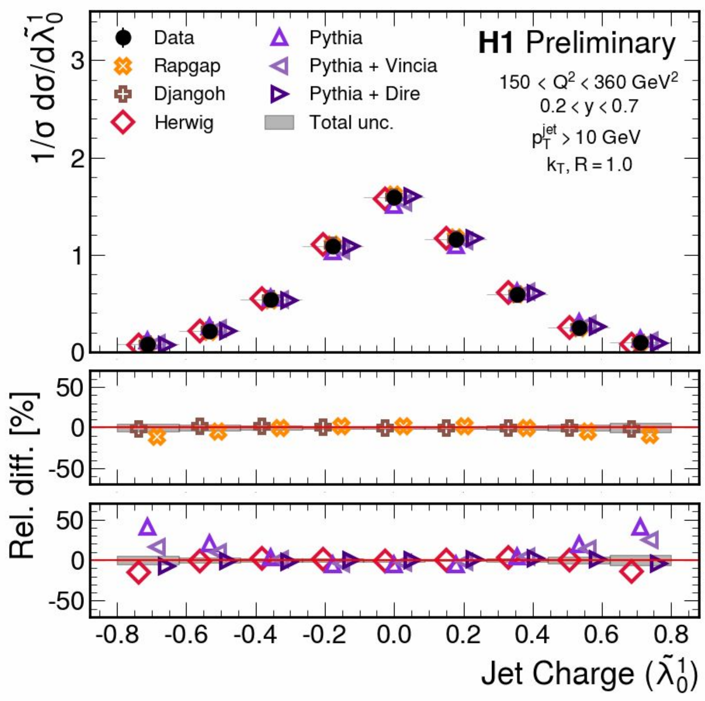
More quark-like distributions as Q^2 increases



Agreement between general purpose generators **improve** at higher Q^2

Conclusions

Conclusions and prospects



- Jet observables are an unique laboratory to study **QCD properties**
- **Energy scale** evolution for each jet observable measured in multiple **Q^2 intervals from 150 to 5000 GeV^2**
- Detector effects are corrected using the **Omnifold method** with particles as inputs using **graph neural networks**
  - Unbinned and simultaneous unfolding
- Good agreement for dedicated DIS generators, **Herwig** described all distributions besides track multiplicity while **Dire** parton shower has the best agreement for the **Pythia** implementations
- First step towards unfolding **any** jet observable in one go
- Preliminary results available at: H1prelim-22-034

THANKS!

Any questions?

Backup

Systematic uncertainties

Systematic uncertainties currently considered

- **HFS energy scale:** +- 1%
- **HFS azimuthal angle:** +- 20 mrad
- **Lepton energy:** +- 0.5% (mainly affects Q^2)
- **Lepton azimuthal angle:** +- 1 mrad (mainly affects Q^2)
- **Model uncertainty:** differences in unfolded results between Djangoh and Rapgap
- **Non-closure uncertainty:** Differences between the expected and obtained values of the closure test
- **QED uncertainty**: Use the variation of measured quantities when radiation is turned off in the simulation
- **Statistical uncertainty:** Standard deviation of 100 bootstrap samples with replacement

MC Generators

Lund string hadronization model and **CTEQ6L** PDF set

- **Djangoh:** Dipole model from Ariadne
- **Rapgap**: PS from leading log approximation

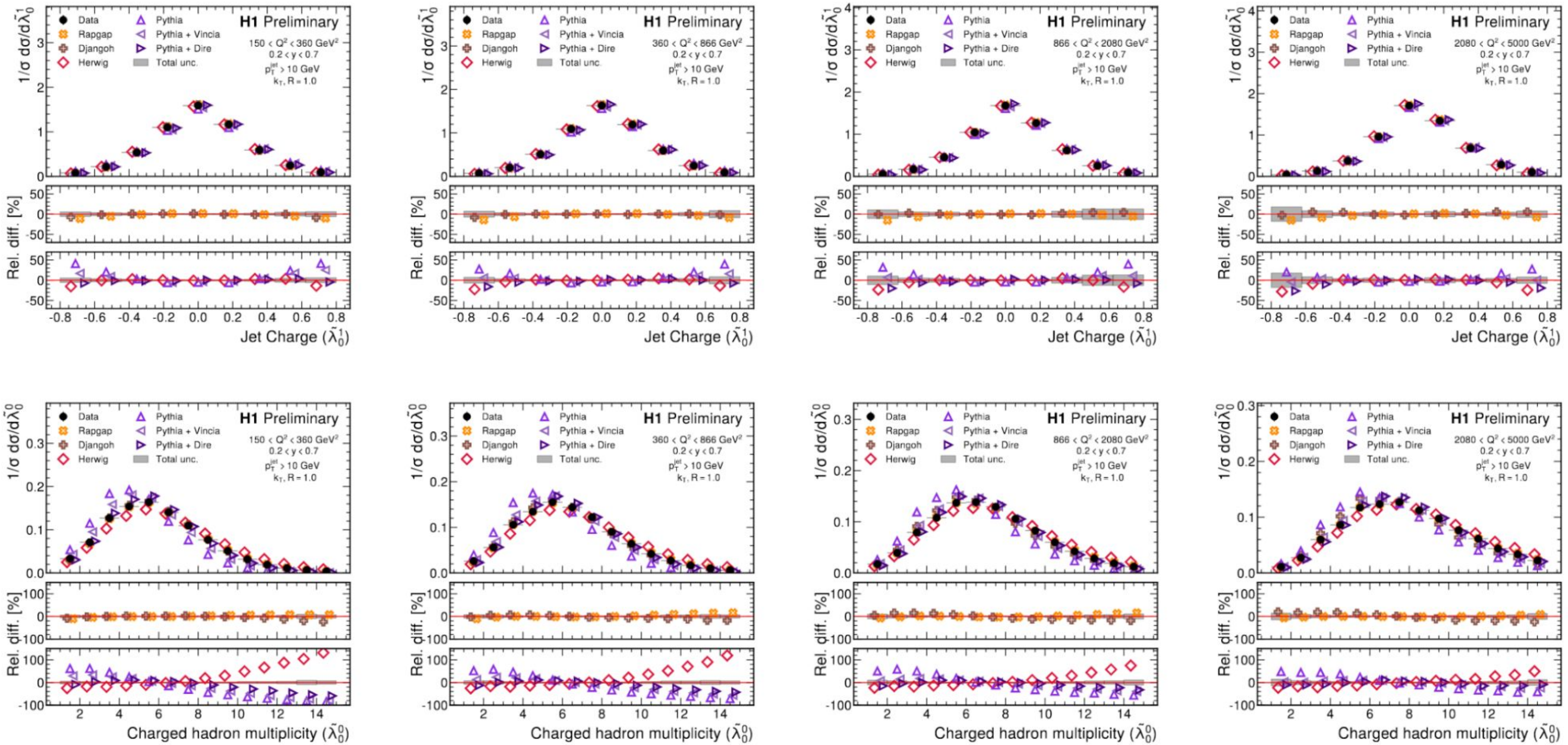
Pythia 8.3: default NNPDF3.1 PDF

- **Vincia**: p_T ordered antenna and NNPDF3.1 PDF
- **Dire**: dipole model, similar to Ariadne and MMHT14nlo68cl PDF

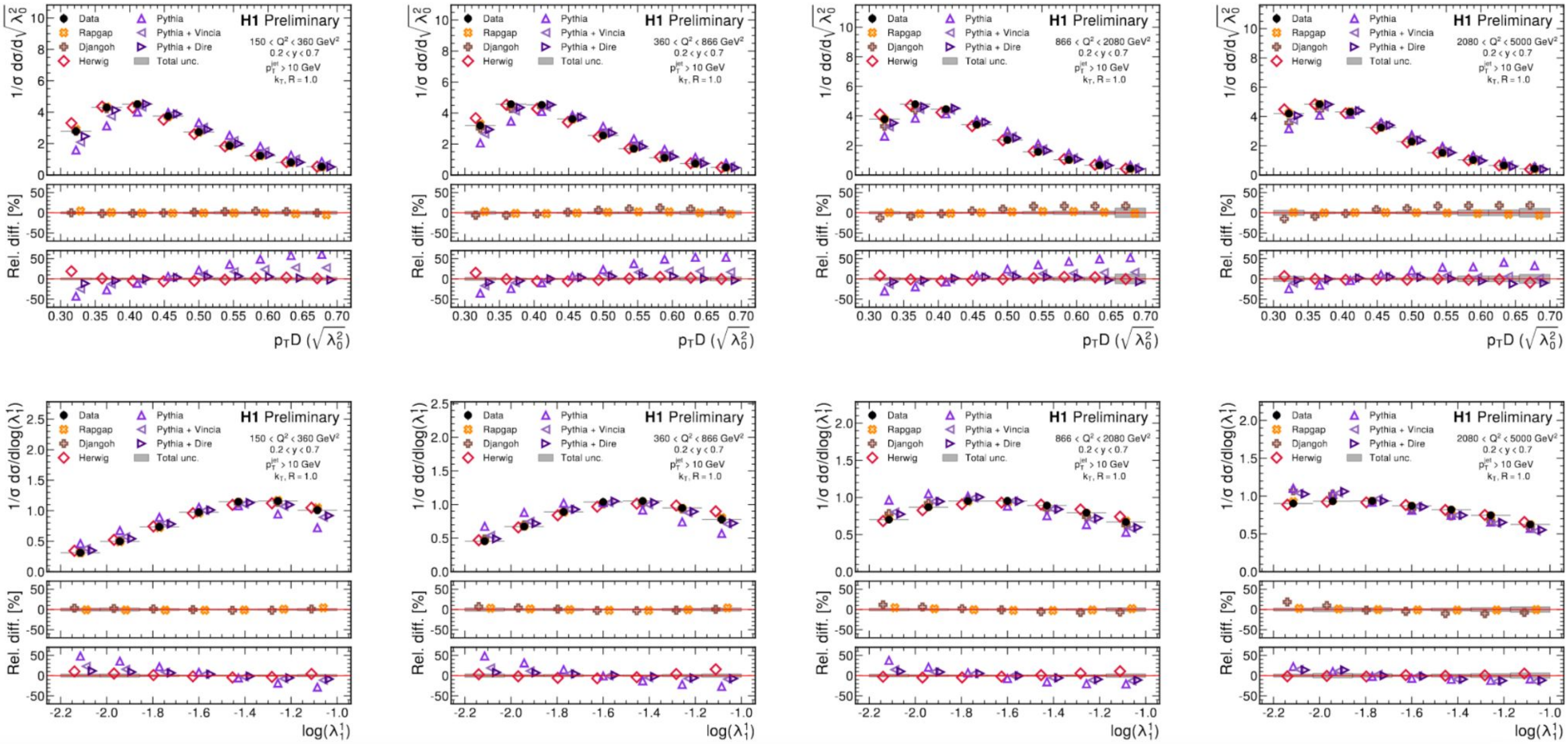
Herwig 7.2: Cluster hadronization and CT14 PDF set

More details on Ilkka's talk:

Multi Differential



Multi Differential



Multi Differential