(Groomed) 1-jettiness in neutral current DIS

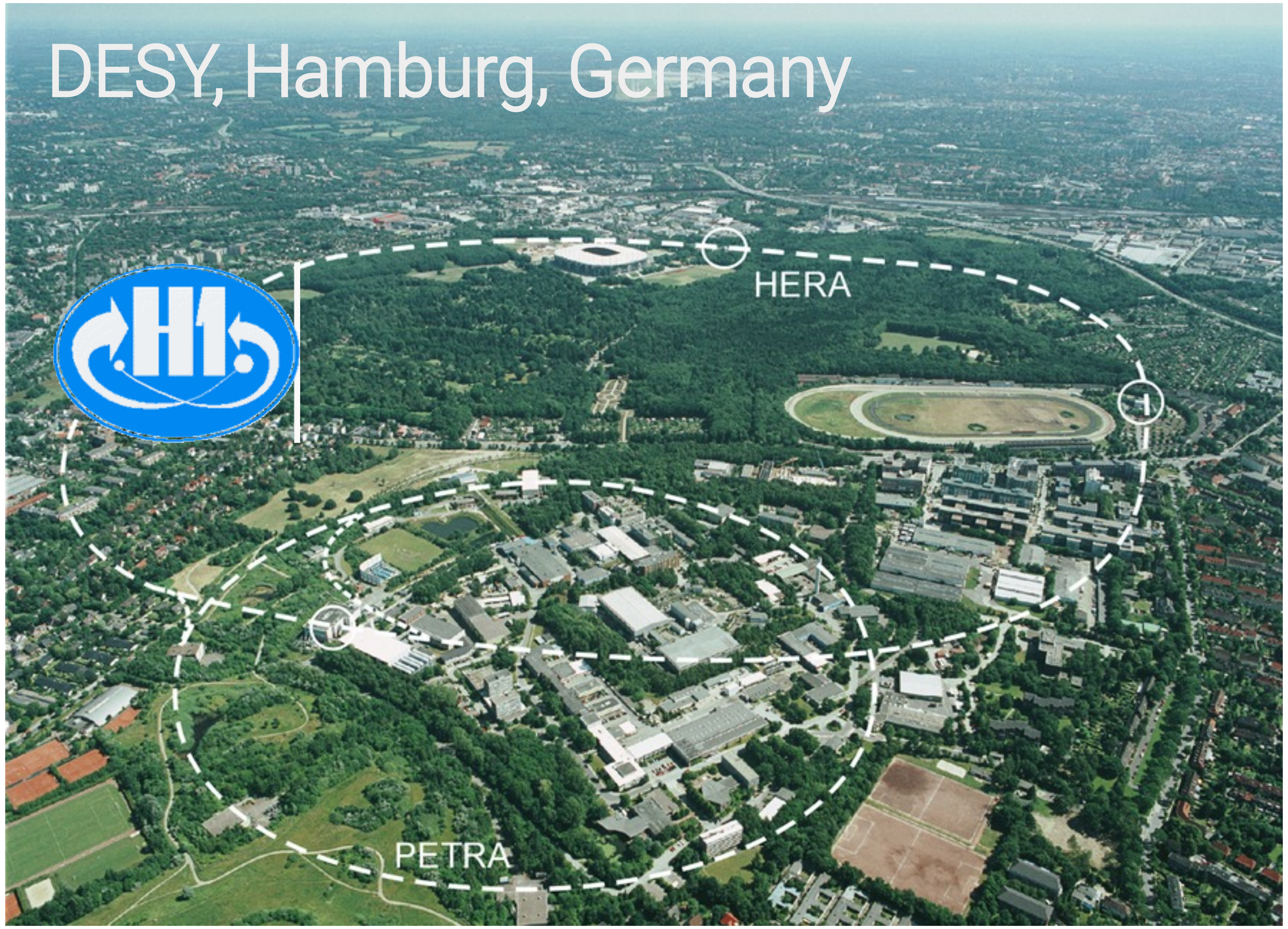
QCD@LHC 2023, 6 September 2023

[H1prelim-21-032], [H1prelim-22-033], [arXiv:2306.17736]

Daniel Reichelt, work with Max Knobbe, Steffen Schumann and the H1 collaboration

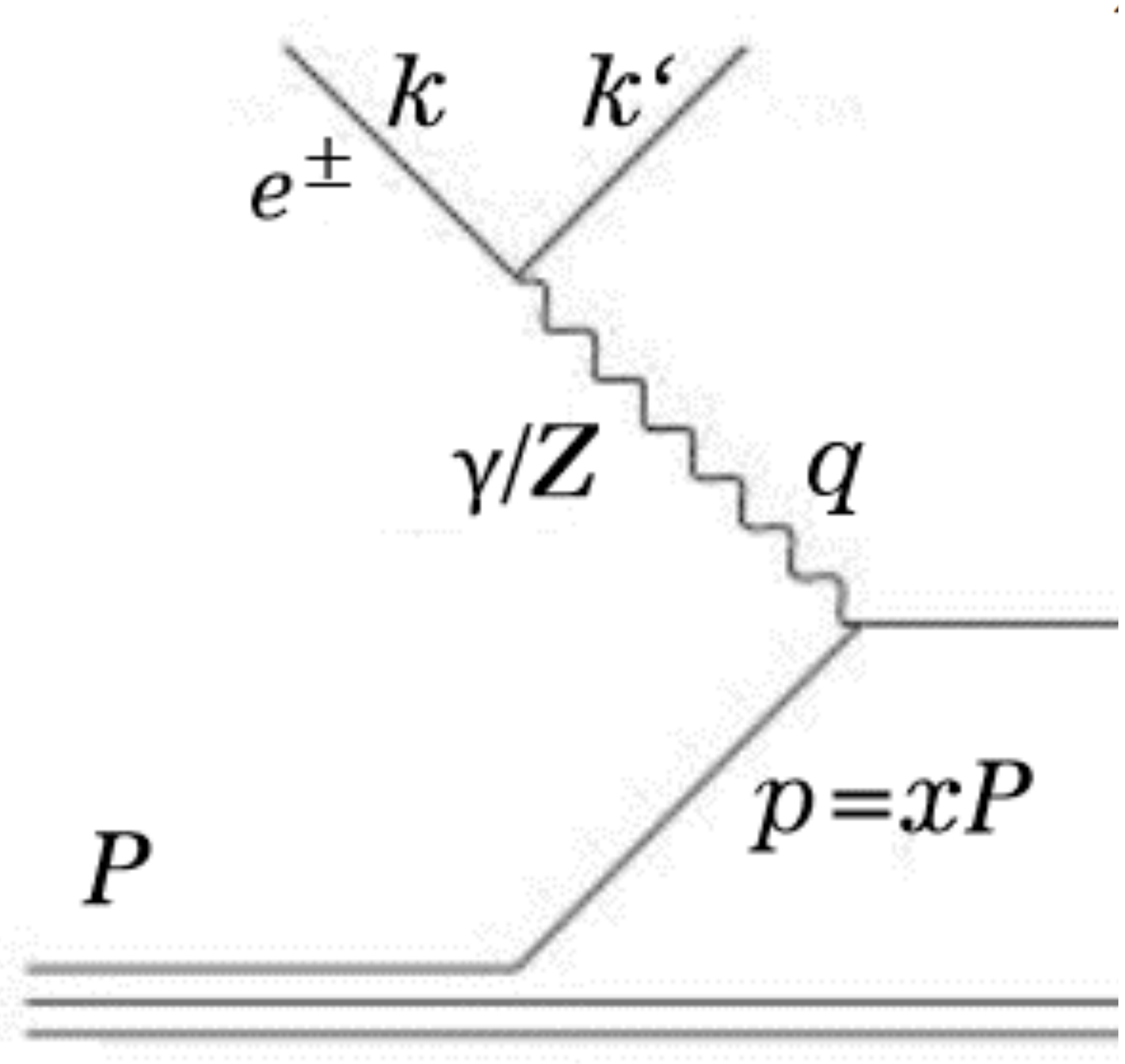
H1 setup

- electron proton collisions from HERA at $\sqrt{s} = 319\ \text{GeV}$
  $E_e = 27.6\ \text{GeV}$,
  $E_p = 920\ \text{GeV}$
- data shown here recorded in 2003-2007, corresponding to $\mathscr{L} = 351.6\ \text{pb}^{-1}$
- focus on higher $Q^2 > 150\ \text{GeV}^2$ range



DIS kinematics

- Photon virtuality $Q^2 = -q^2$
  - scale of perturbative process
- Bjorken $x_B = \dfrac{Q}{2P \cdot q}$
  - momentum fraction (infinite momentum frame) of proton
- Inelasticity $y = \dfrac{P \cdot q}{P \cdot k}$
  - energy fraction (proton rest frame) transferred from electron to parton



Breit frame

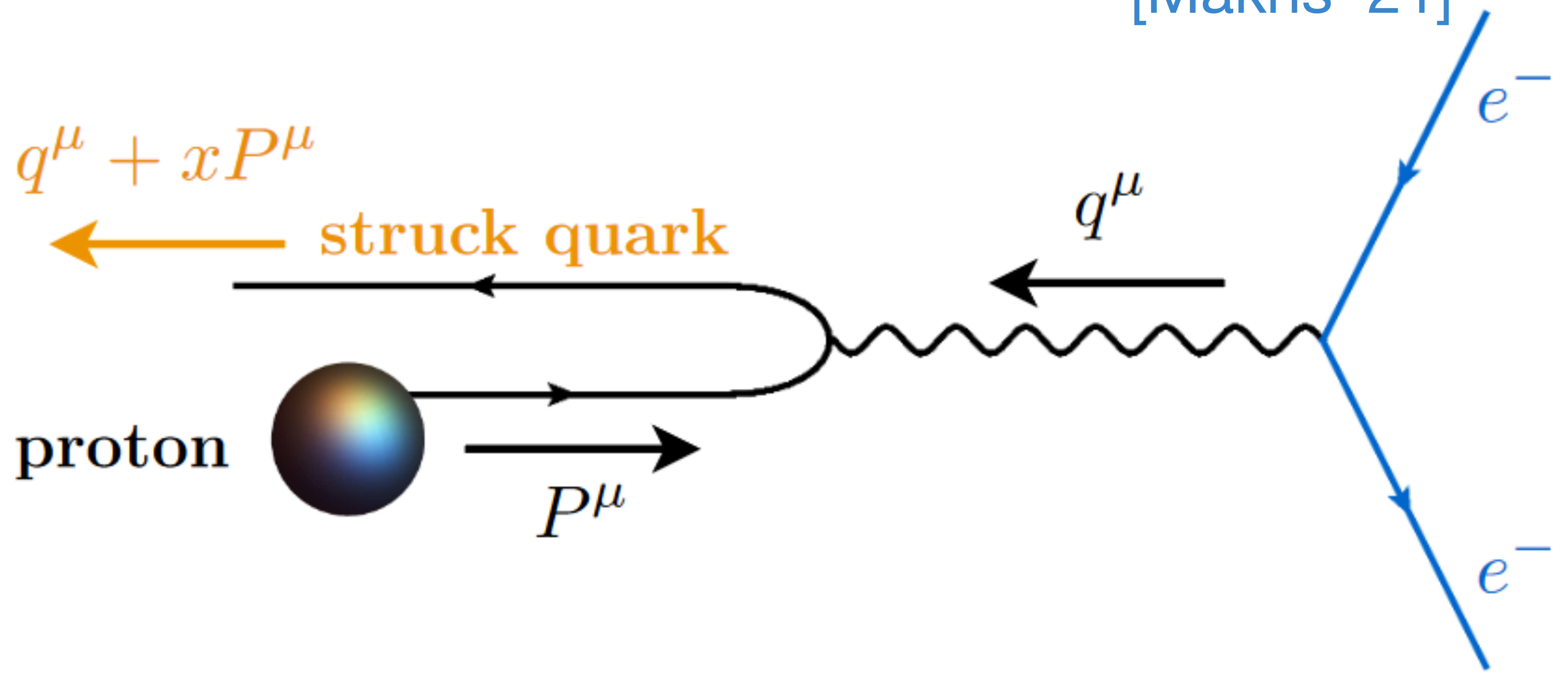
- define by $q^\mu = (0,0,0,-Q)$
- reference vectors

  $n_+ = (1,0,0,1)$

  $n_- = (1,0,0,-1)$

- two hemispheres (analogous to thrust hemispheres in e^+e^-):
  - $\mathscr{H}_C$ current hemisphere $\quad p_i \cdot n_+ > p_i \cdot n_-$
  - $\mathscr{H}_B$ beam hemisphere $\quad p_i \cdot n_+ < p_i \cdot n_-$

[Makris '21]

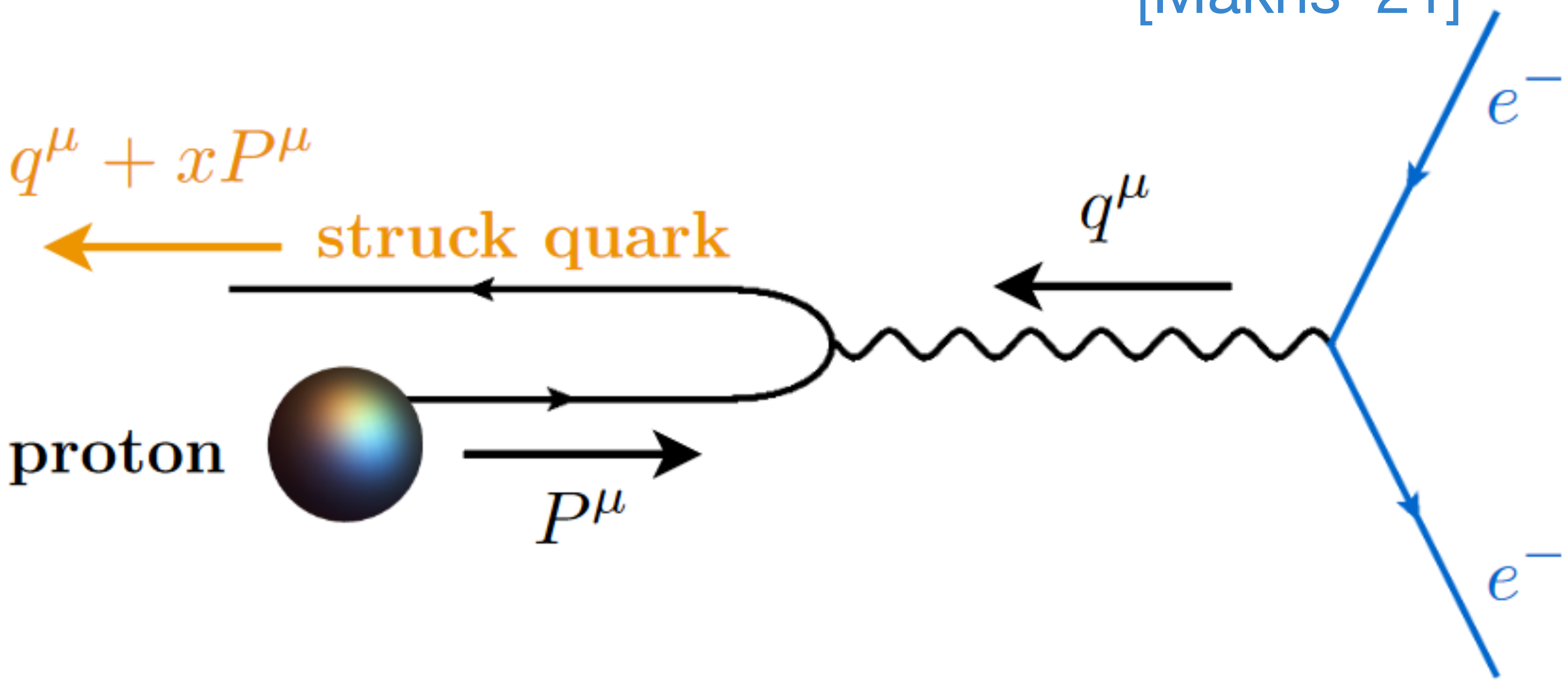


1-jettiness

- $\tau^1 = \frac{1}{Q}\sum \min(p_i \cdot n_+, p_i \cdot n_-)$

see also [Stewart, Tackmann, Waalewijn '10]
[Kang, Mantry, Qiu '12]
[Kang, Liu, Mantry '13]

[Makris '21]



- equivalently $\tau^1 = 1 - \frac{2}{Q}\sum_{i \in \mathscr{H}_C} p_{z,i}$

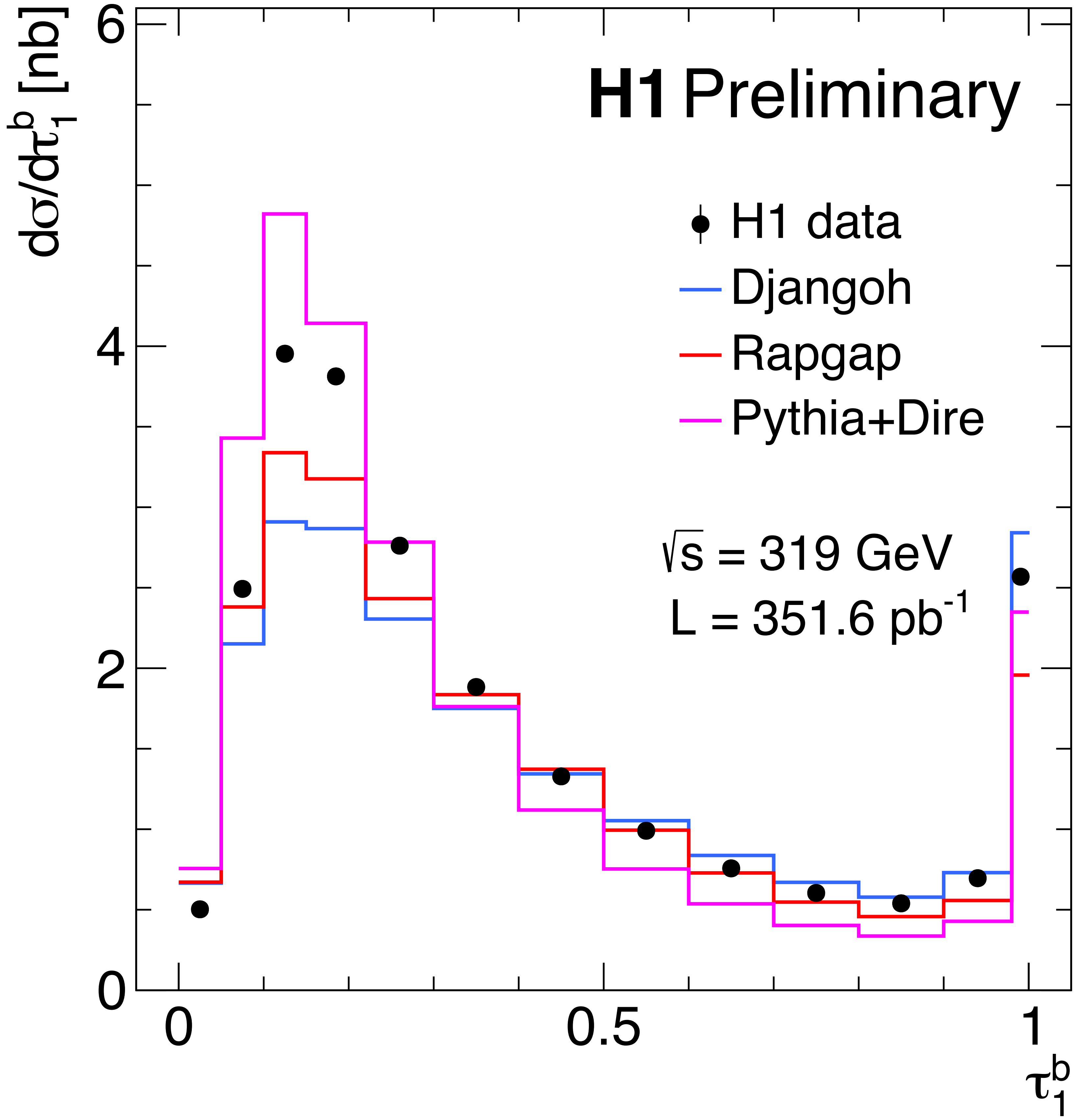
(in Breit frame) → thrust in DIS

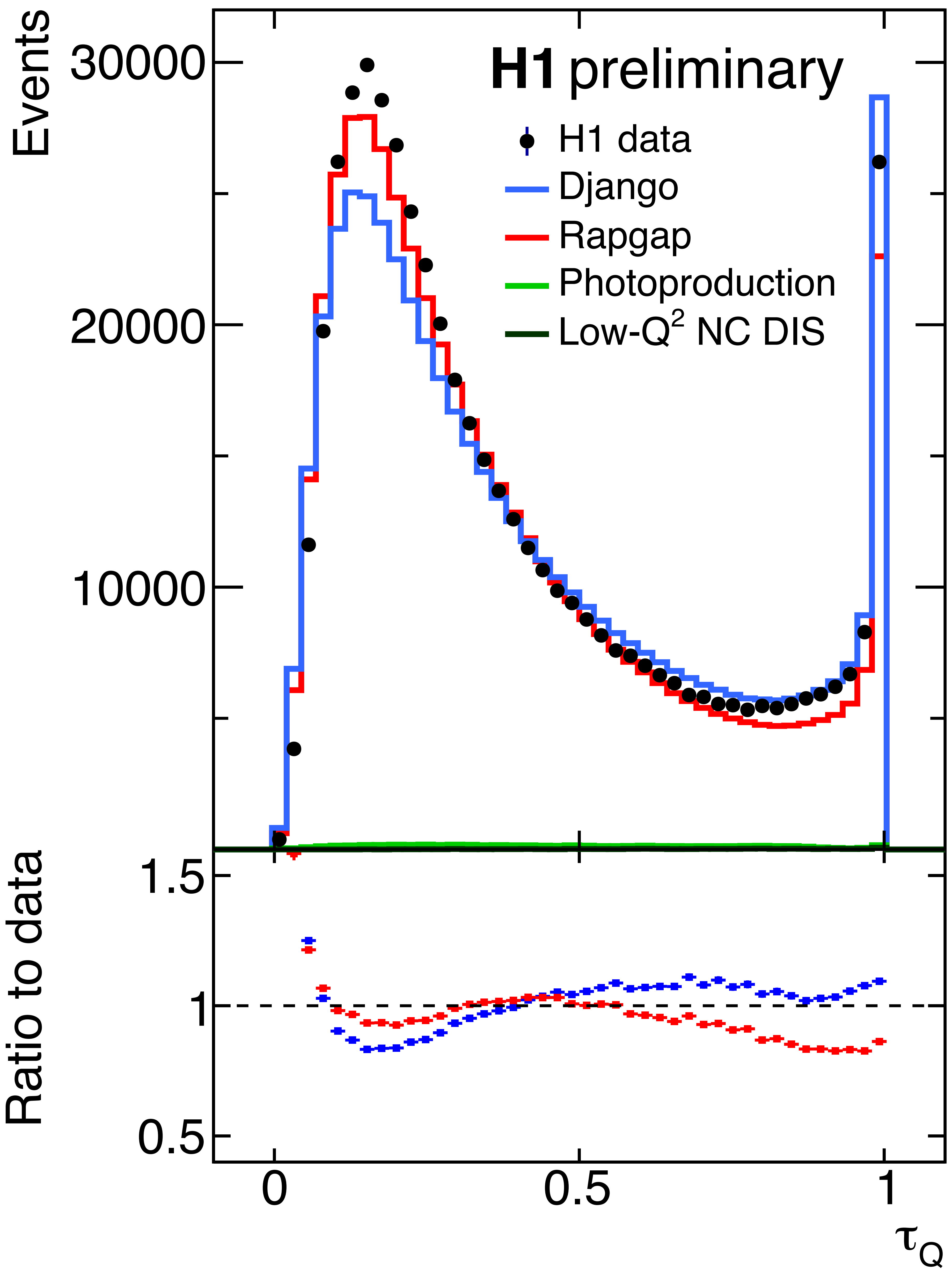
see also [Antonelli, Dasgupta, Salam '00],
[Dasgupta Salam '02]

- manifestly global (sensitive to radiation everywhere in phase space)
- equivalency allows measurement based on current hemisphere particles

H1 results

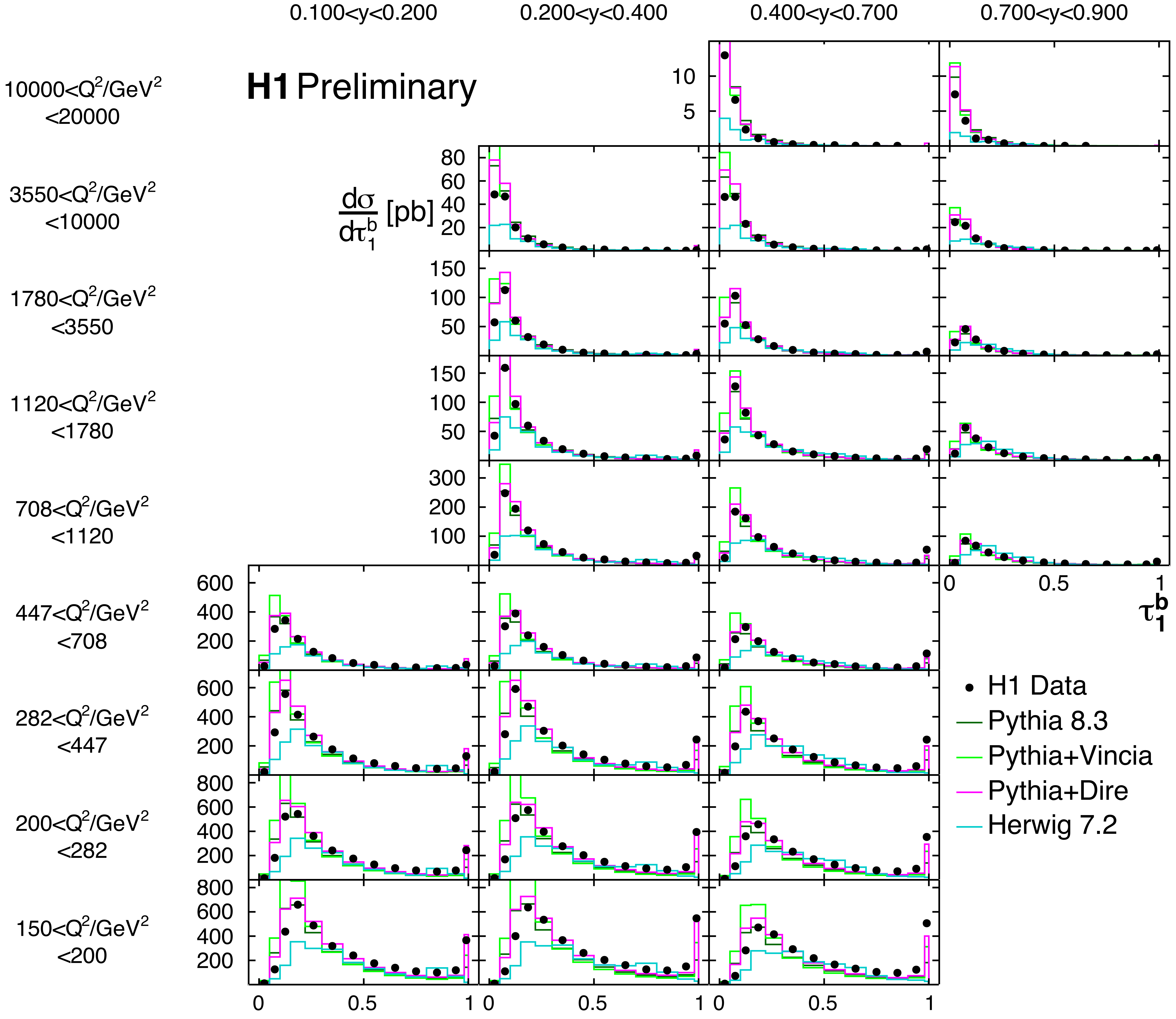
- initial comparison to DIS signal Monte Carlo genrators Django and Rapgap
- unfolded measurement, compared to Pythia





H1 results

- measured distributions in several Q^2, y bins
- initial comparison to several parton shower MCs
- none provide a perfect description everywhere
- goal of [arXiv:2306.17736]: provide (matched) NLL results, and parton shower matching + merging



Calculation setup - Cliff notes

- CAESAR formalism for soft gluon resummation at NLL [Banfi, Salam, Zanderighi ’04]
- available as implementation in Sherpa [Gerwick, Höche, Marzani, Schumann ’15] [Baberuxki, Preuss, DR, Schumann ’19]
- multiplicative matching (⇒ NLL’ accurate)
- necessary extensions for jet observables… :
  - modified wide angle behaviour [Dasgupta, Khelifa-Kerfa, Marzani, Spannowski ‘12] [Caletti, Fedkevych, Marzani, DR, Schumann, Soyez, Theeuwes ’21] [DR, Caletti, Fedkevych, Marzani, Schumann, Soyez ‘22]
  - non-global logs [Dasgupta, Salam ’01]
- … and for soft drop grooming [Larkoski, Marzani, Soyez, Thaler ’14]
  - CEASAR style formulas available [Baron, DR, Schumann, Schwanemann, Theeuwes ‘20]

Calculation setup - details

- master formula for rIRC save observable: [Banfi, Salam, Zanderighi '04]

$$\Sigma^{\delta}_{\rm res}(v) = \int d\mathcal{B}_\delta \frac{d\sigma_\delta}{d\mathcal{B}_\delta} \exp\left[-\sum_{l\in\delta} R_l^{\mathcal{B}_\delta}(L)\right] \mathcal{P}^{\mathcal{B}_\delta}(L)\mathcal{S}^{\mathcal{B}_\delta}(L)\mathcal{F}^{\mathcal{B}_\delta}(L)\mathcal{H}^{\delta}(\mathcal{B}_\delta)$$

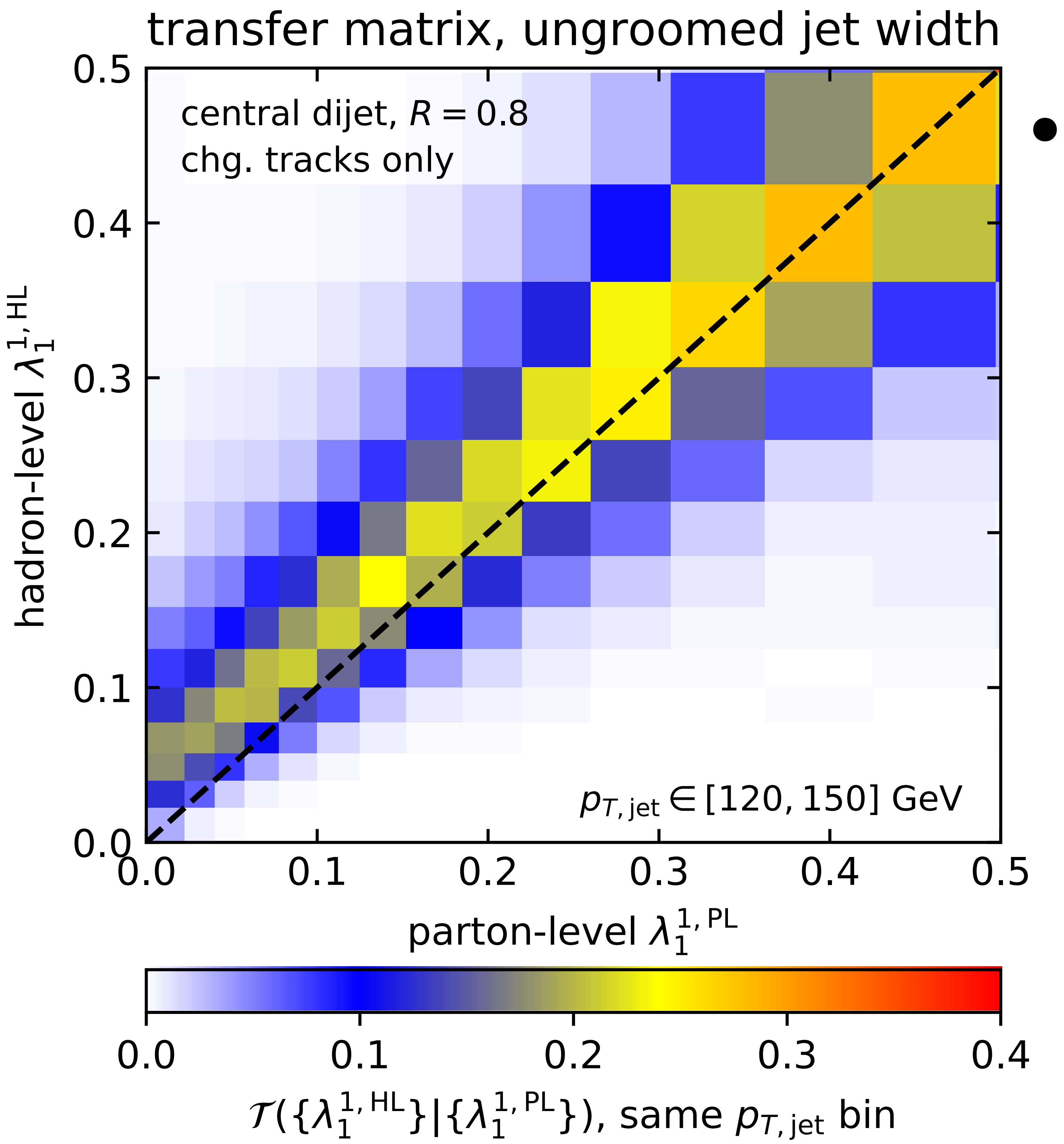
- ingredients known analytically in this case
- matching: $\Sigma_{\rm matched} = \Sigma_{\rm res}\left(1 + \frac{\Sigma^{(1)}_{\rm fo} - \Sigma^{(1)}_{\rm res}}{\sigma^{(0)}} + \frac{\Sigma^{(2)}_{\rm fo} - \Sigma^{(2)}_{\rm res}}{\sigma^{(0)}} - \frac{\Sigma^{(1)}_{\rm res}}{\sigma^{(0)}} \frac{\Sigma^{(1)}_{\rm fo} - \Sigma^{(1)}_{\rm res}}{\sigma^{(0)}}\right)$
- note $\Sigma^{(2)}_{fo}$ included → using "projection to Born" technique in Sherpa

[Höche, Kuttimalai, Li '18]

  - cross sections / normalisation correct to NNLO, distributions at NLO

    → overall label as (N)NLO

Non-perturbative corrections



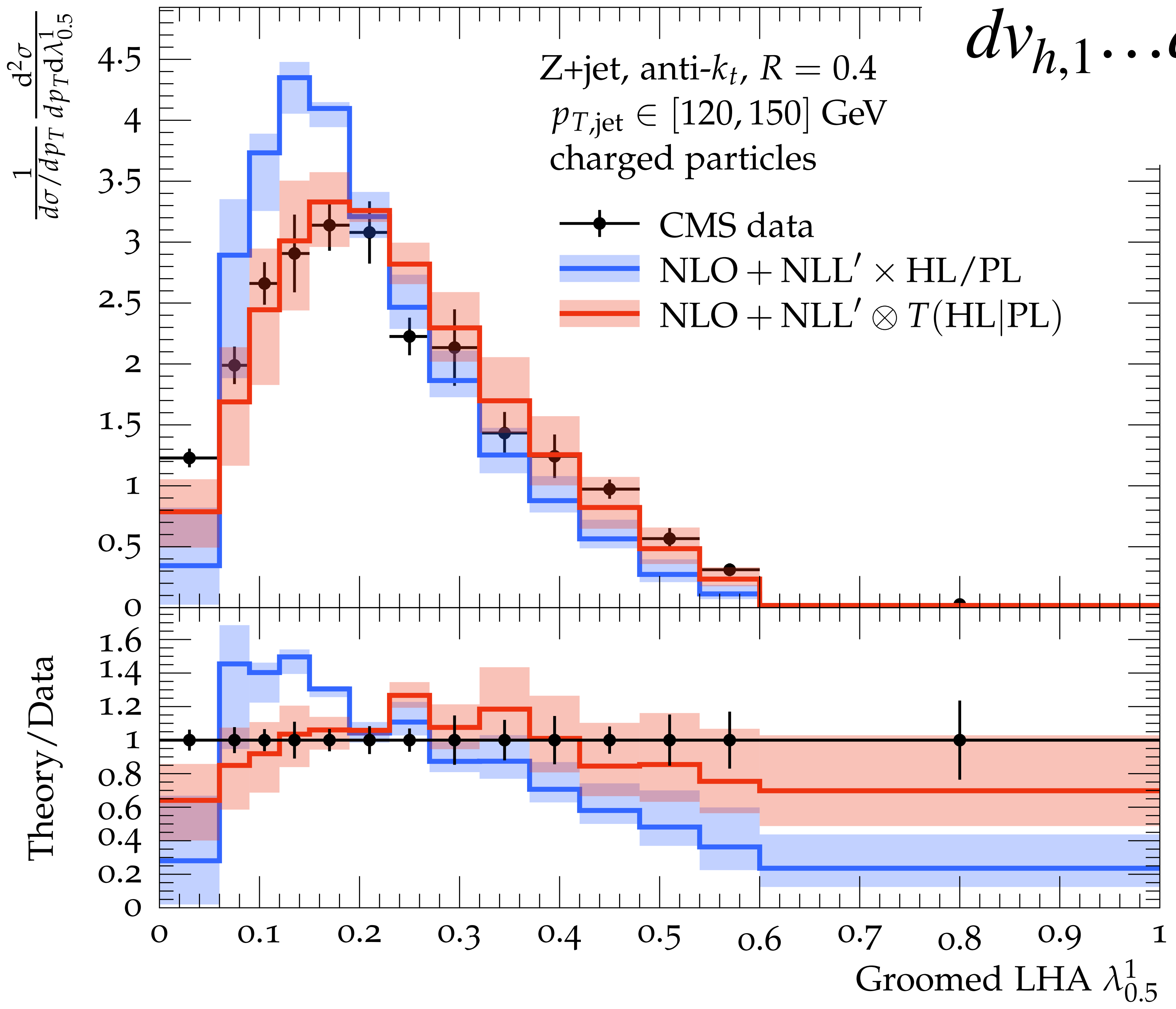
examples from [DR, Caletti, Fedkevych, Marzani, Schumann, Soyez '22]

- earlier approach:

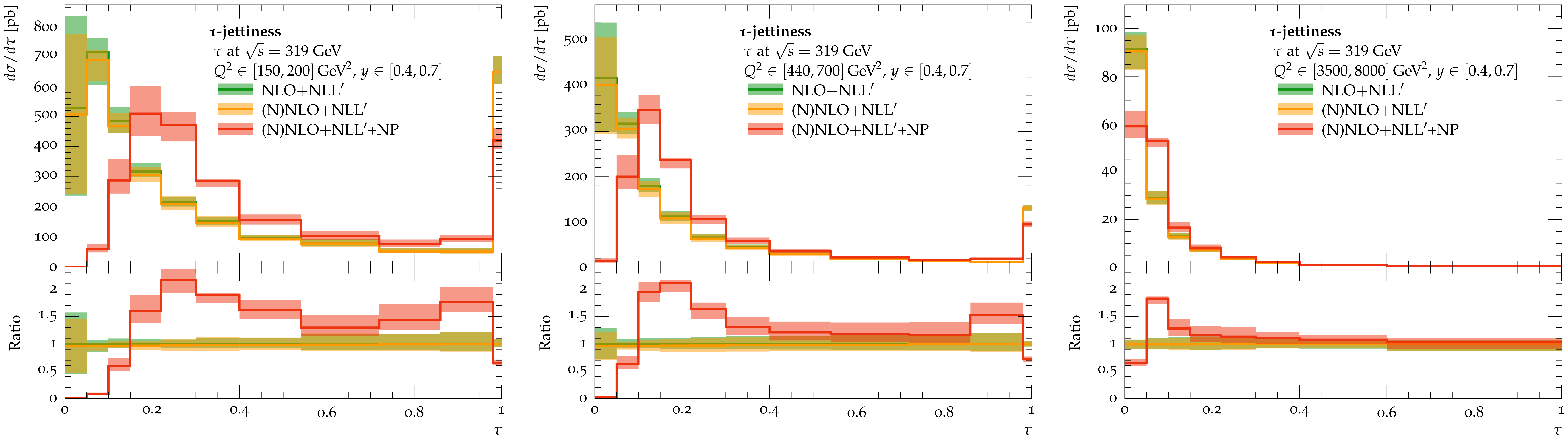
$$\frac{d\sigma^{\mathrm{HL}}}{dv} = \frac{d\sigma^{\mathrm{MC,HL}}/dv}{d\sigma^{\mathrm{MC,PL}}/dv}\frac{d\sigma^{\mathrm{PL}}}{dv}$$

- here, extract transition matrix between parton- and hadron level bins in p_T and observable v

$$\frac{d^m\sigma^{\mathrm{HL}}}{dv_{h,1}\ldots dv_{h,m}} = \int d^m\vec{v}_p\ \mathcal{T}(\vec{v}_h|\vec{v}_p)\frac{d^m\sigma^{\mathrm{PL}}}{dv_{p,1}\ldots dv_{p,m}}$$



(N)NLO+NLL'+HAD results



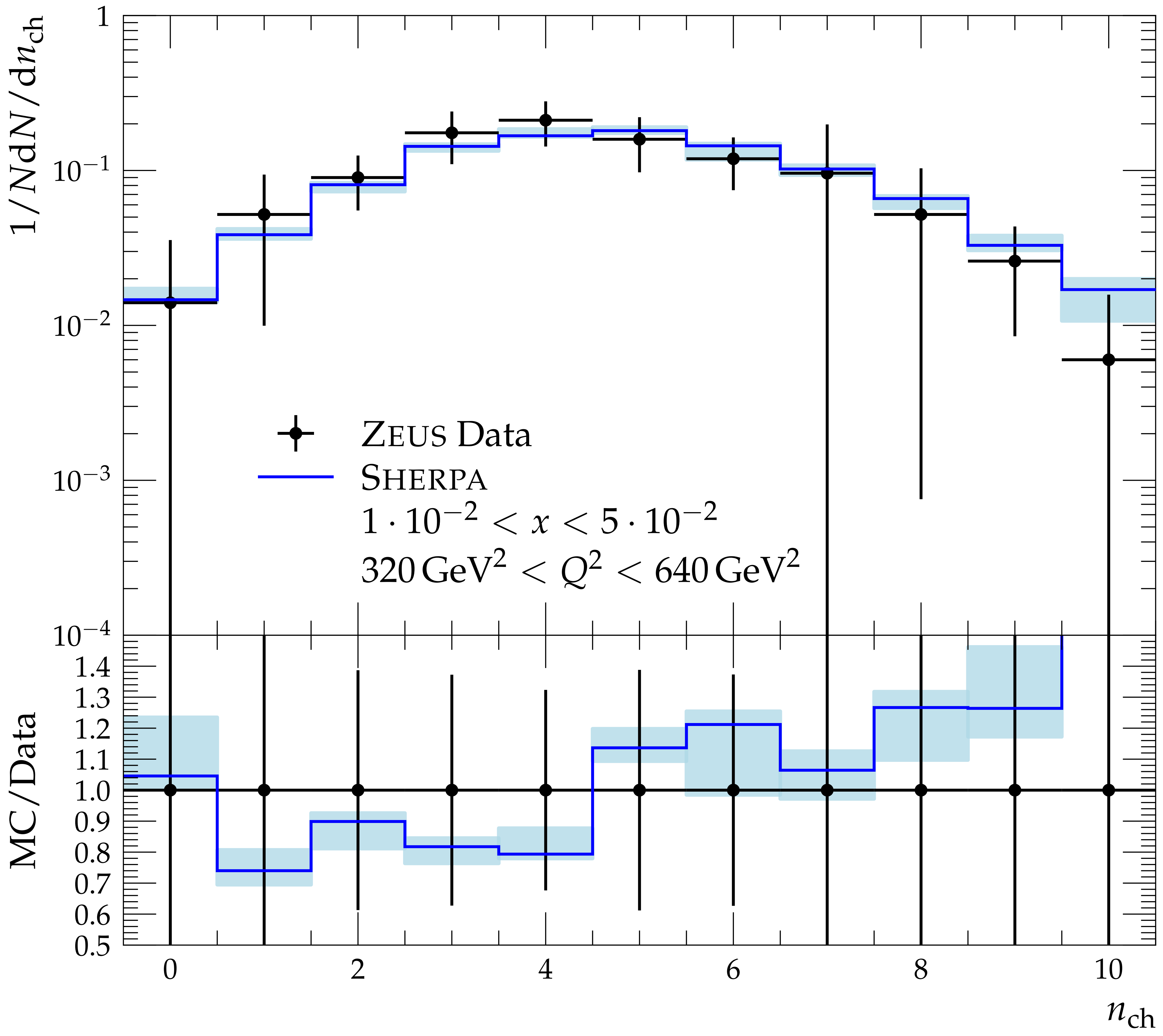
- 1-jettiness with $0.4 < y < 0.7$ at “low”, mid and high Q^2
- small corrections from NNLO normalisation
- large non-perturbative corrections!

Sherpa MEPS@NLO - setup

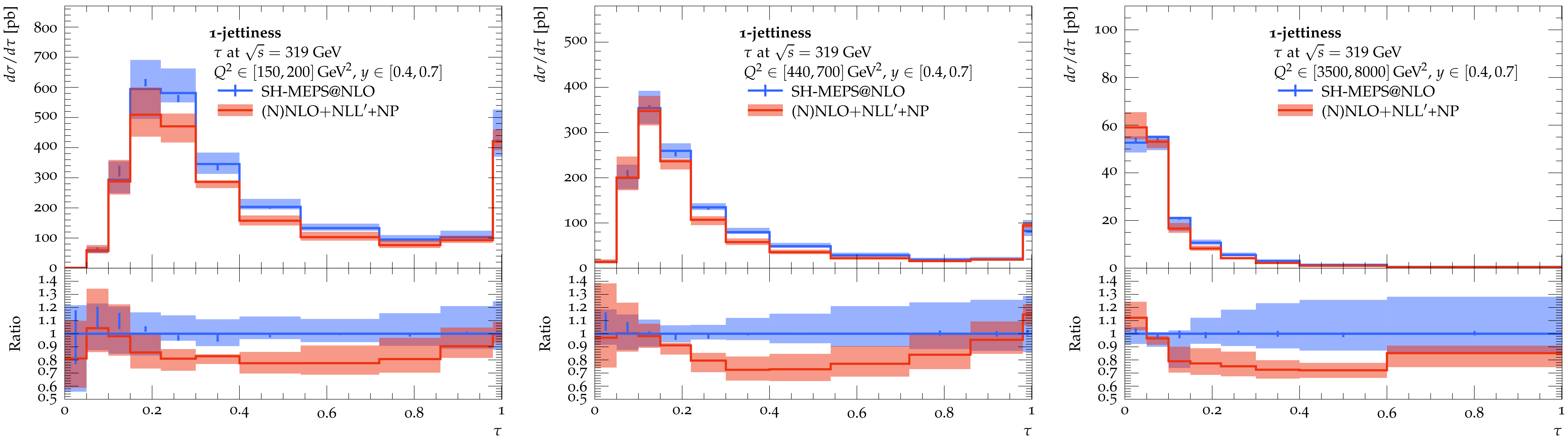
- using Sherpa 3.0.0β
- MC@NLO matching, CKKW merging to include

$$e^- p \to e^- + 1, 2\, j \,@\, \mathrm{NLO} + 3, 4\, j \,@\, \mathrm{LO}$$

- tuning of beam-fragmentation parameters in DIS
- replica tunes to estimate related uncertainty

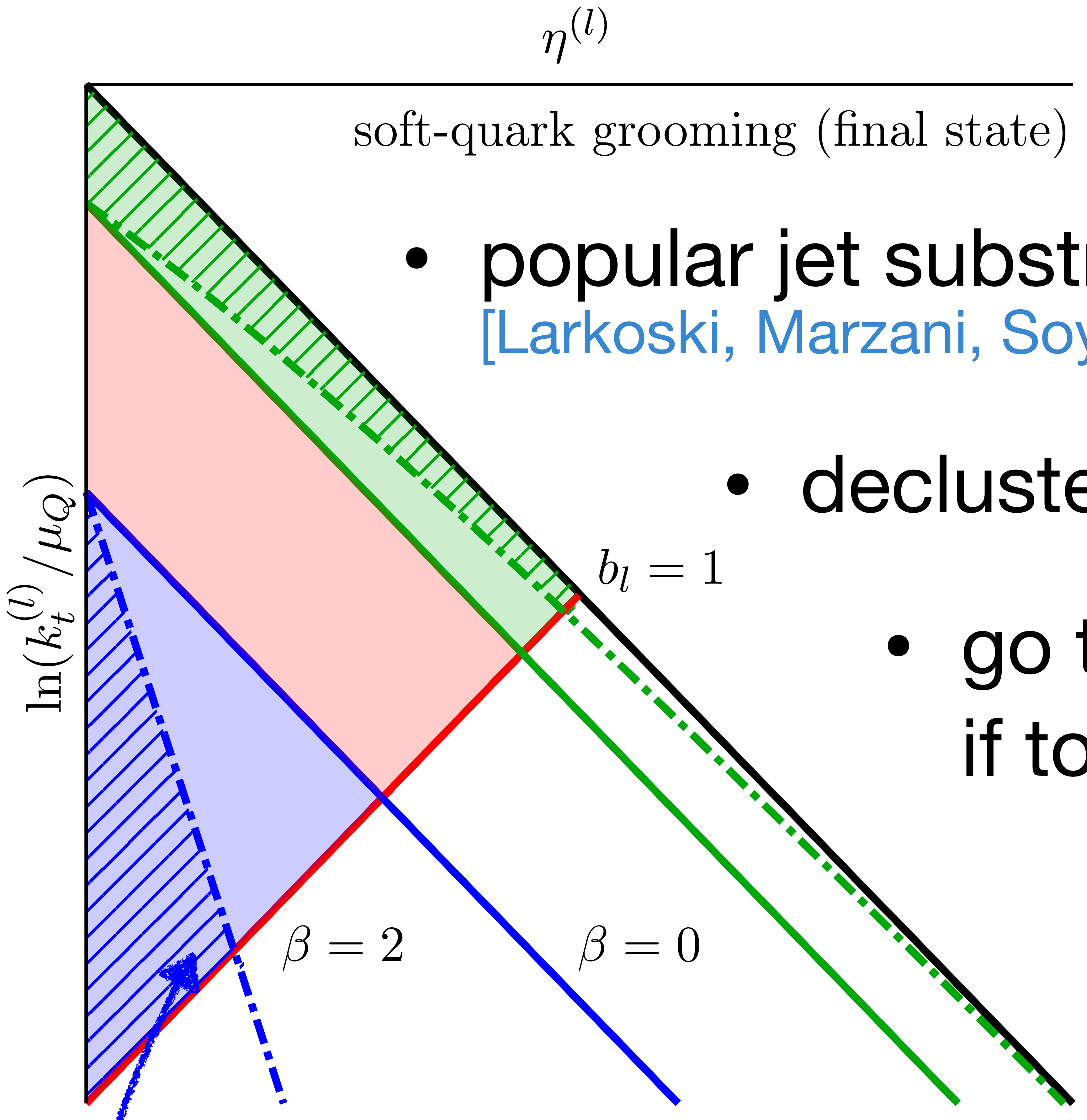


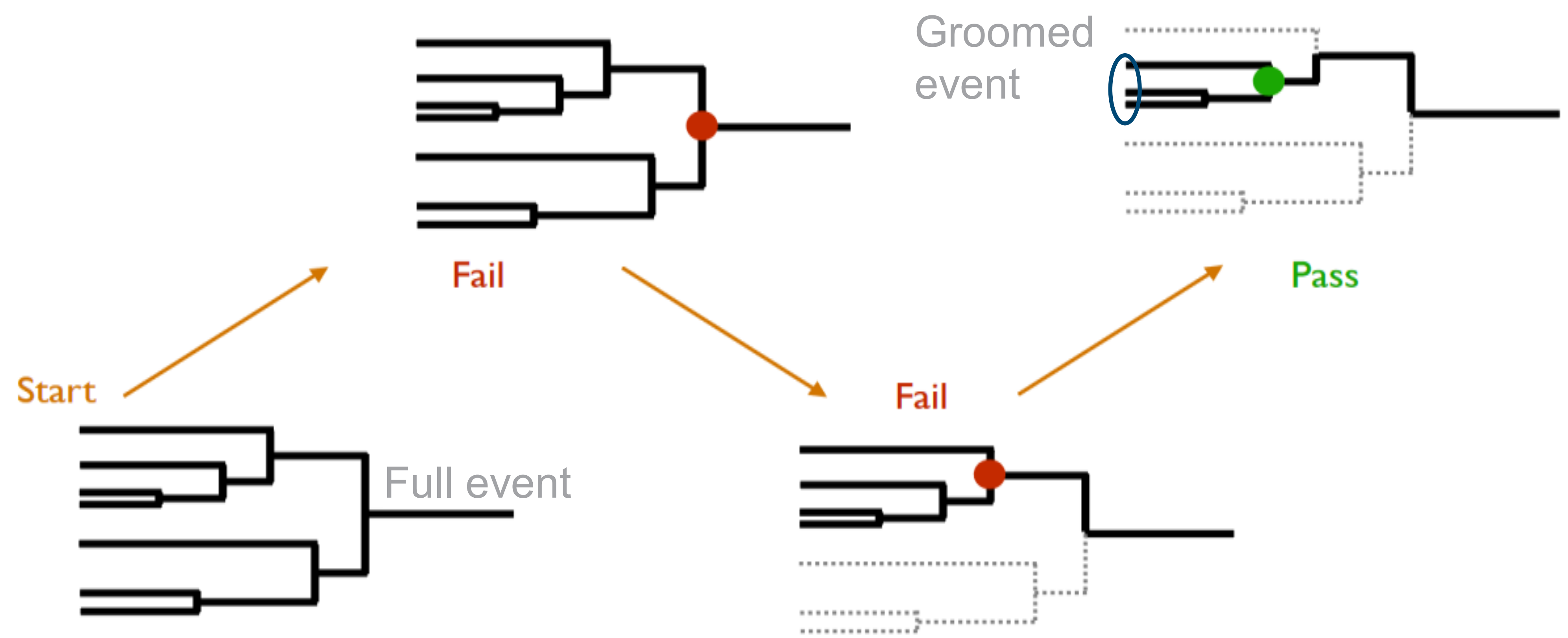
Sherpa MEPS@NLO - results



- compared to resummed results (see previous slide)
- agreement in soft and very hard regions, differences in “interpolation region”

Soft drop method



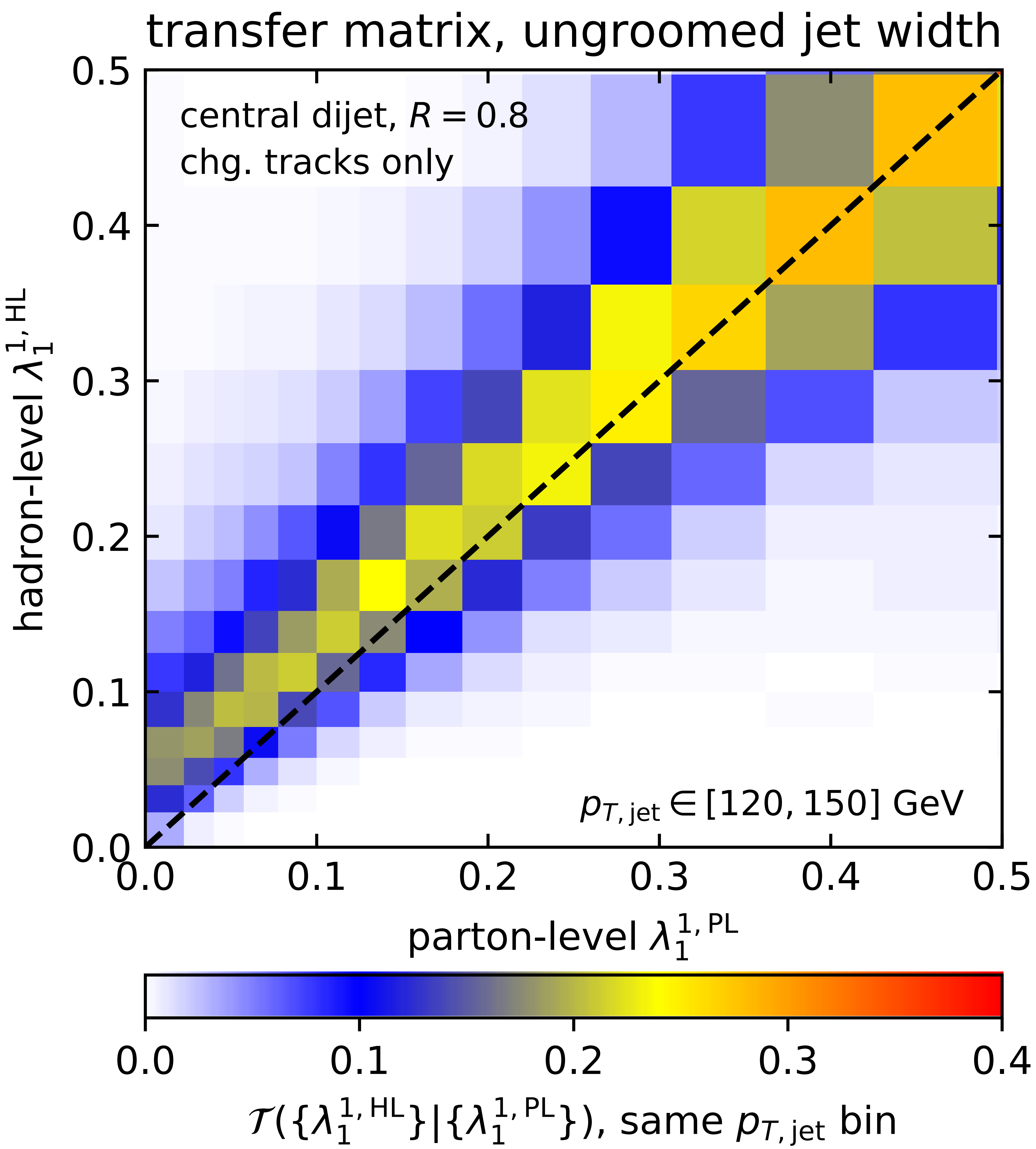


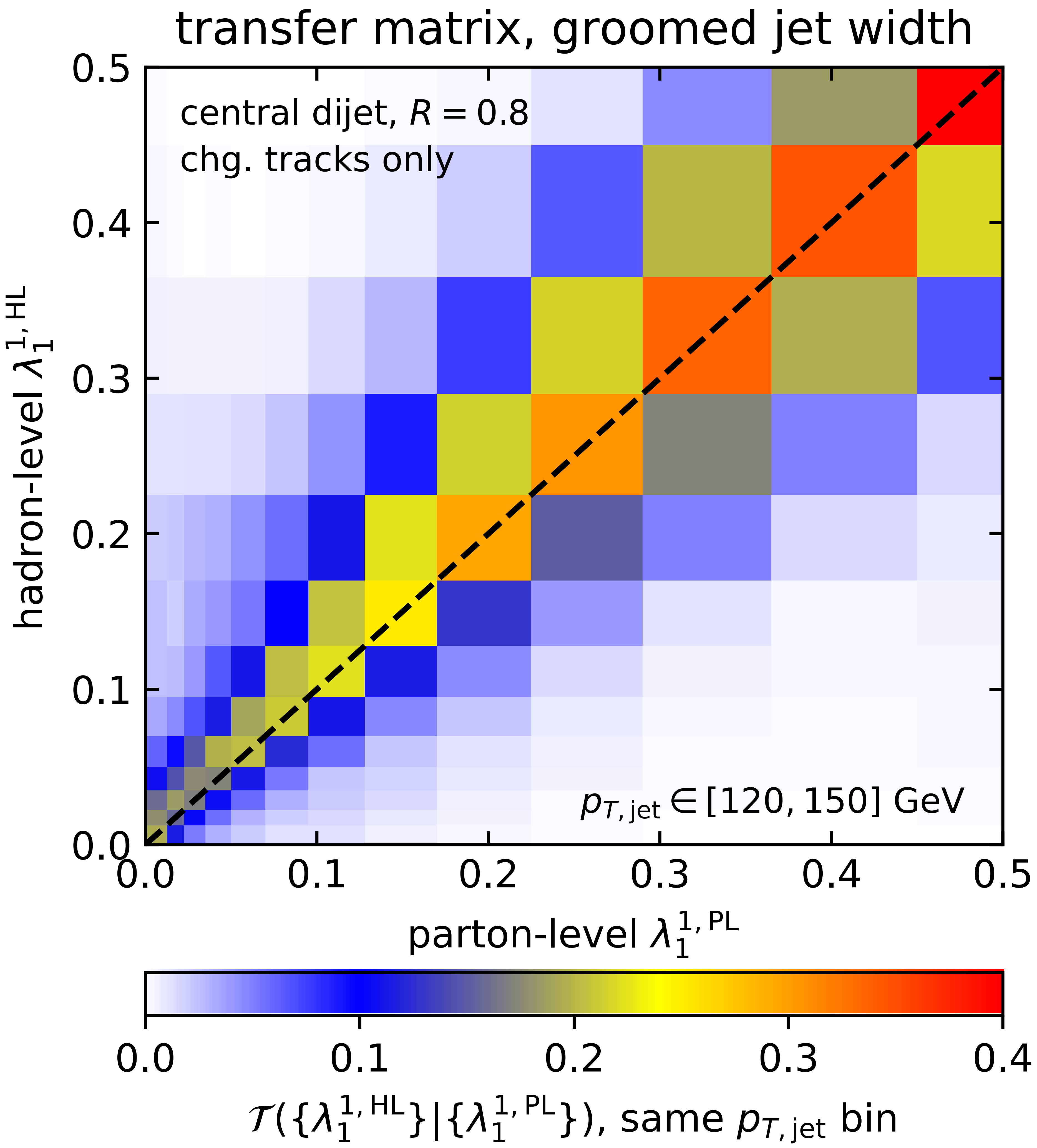
- popular jet substructure technique:
  [Larkoski, Marzani, Soyez, Thaler '14]
  - decluster given jet
    - go through sequence, remove softer branch if too soft (relative to parameter $z_{\rm cut}$)

idea: avoid soft wide-angle phase space

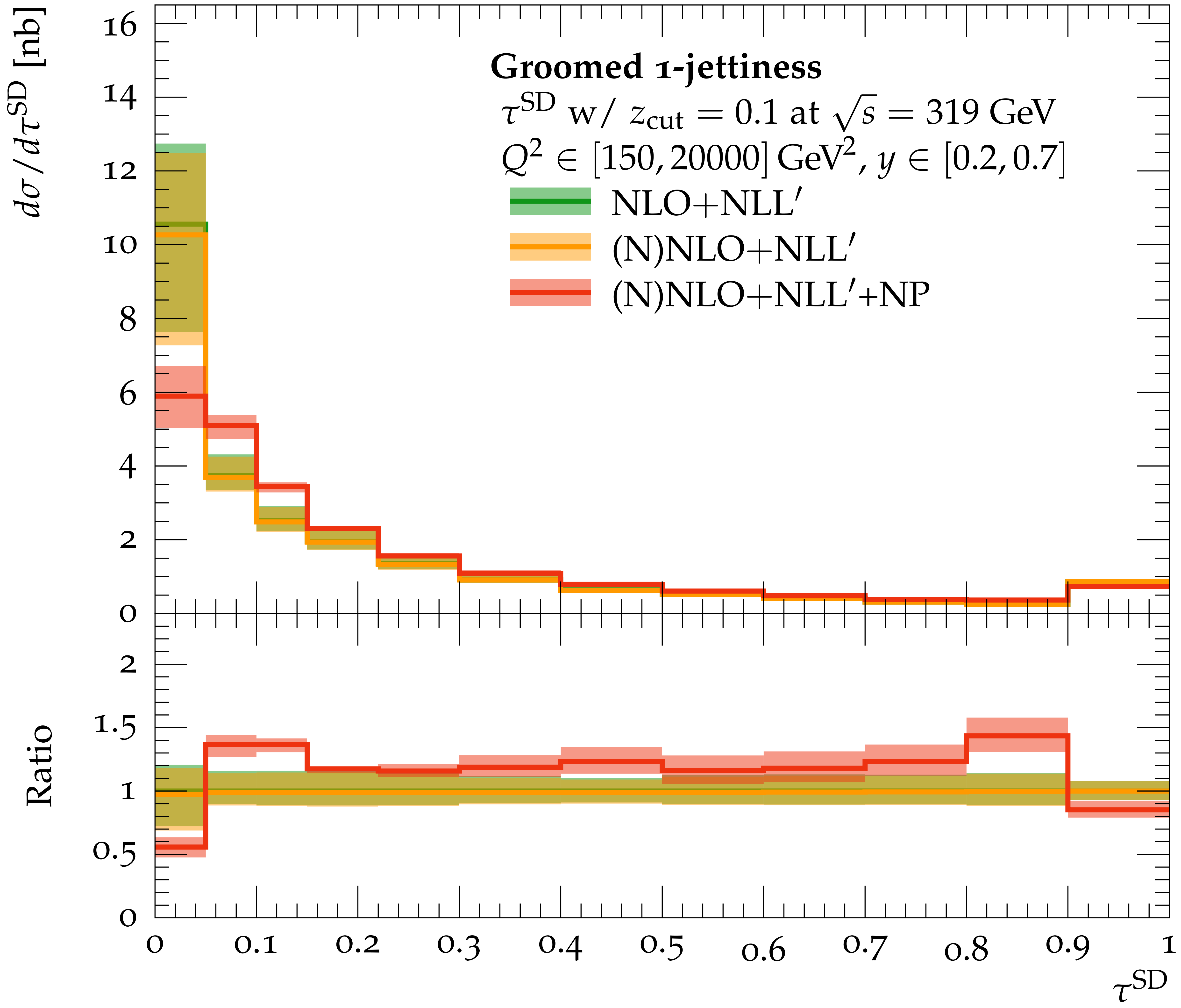
- extended to DIS in [Makris '21]
- based on Centauro jet measure [Arratia, Makris, Neill, Ringer, Sato '21]
- calculation based on implementation in [Baron, DR, Schumann, Schwanemann, Theeuwes '21]

Non-perturbative corrections with SD

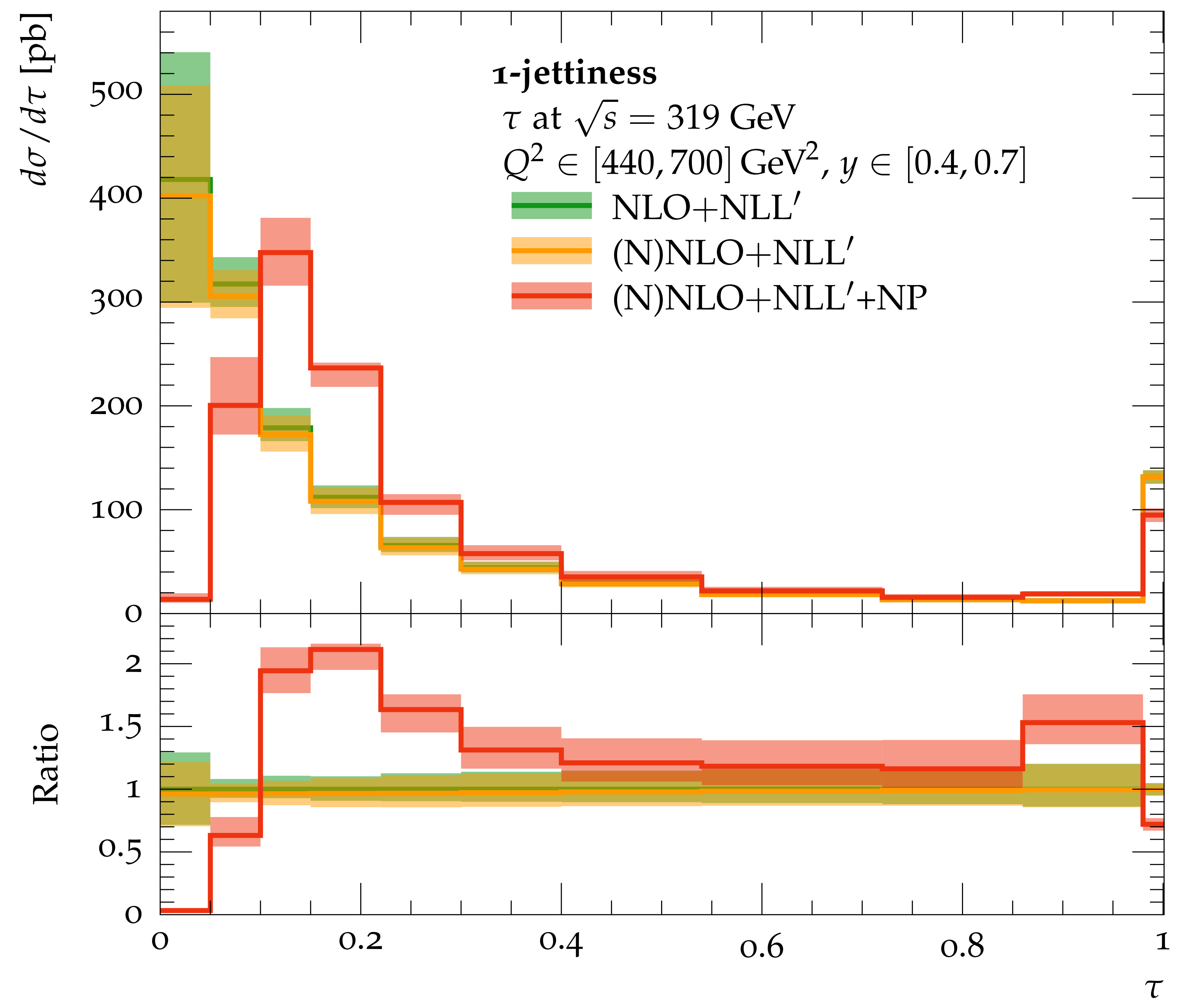




(N)NLO+NLL'+HAD results

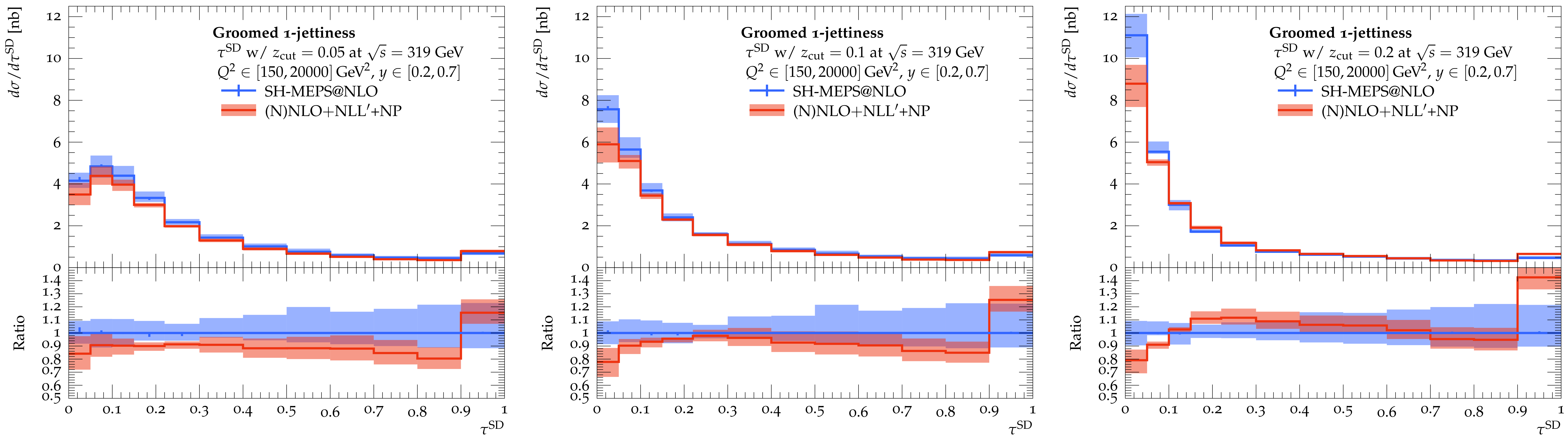


Reminder: without grooming



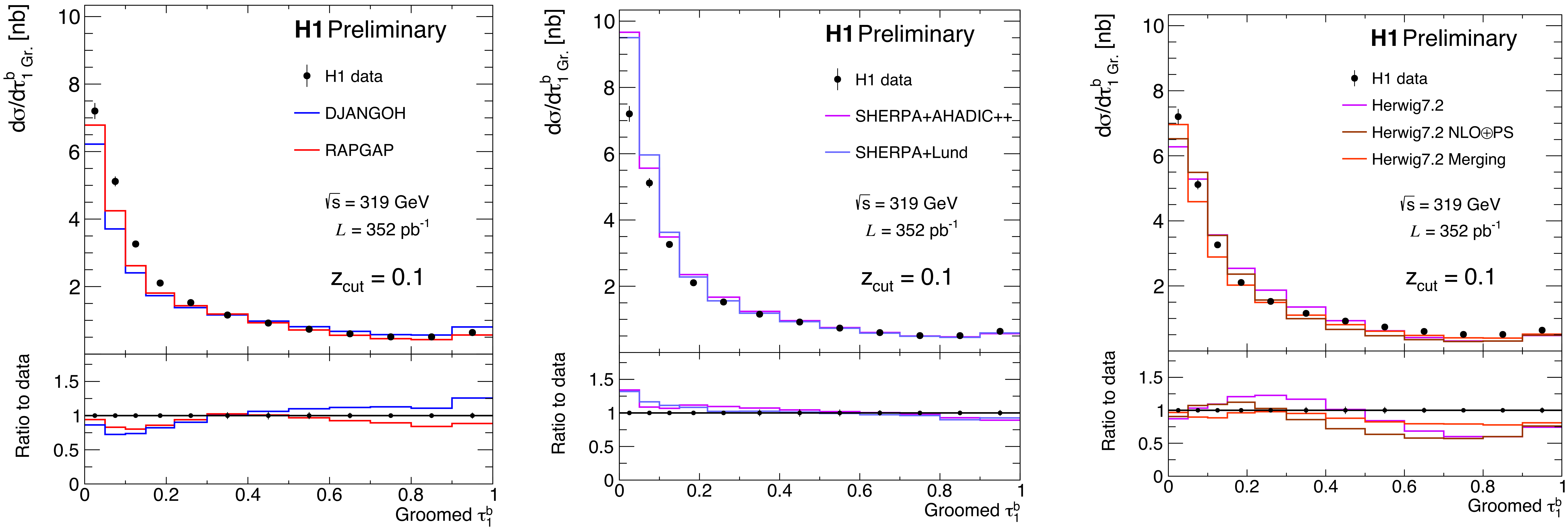
Grooming achieves significant reduction of non-perturbative corrections!

Sherpa MEPS@NLO results with SD



- differences significantly reduced compared to ungroomed case → agreement within uncertainties for most τ values
- some discrepancies appearing around transition point for larger z_{cut}

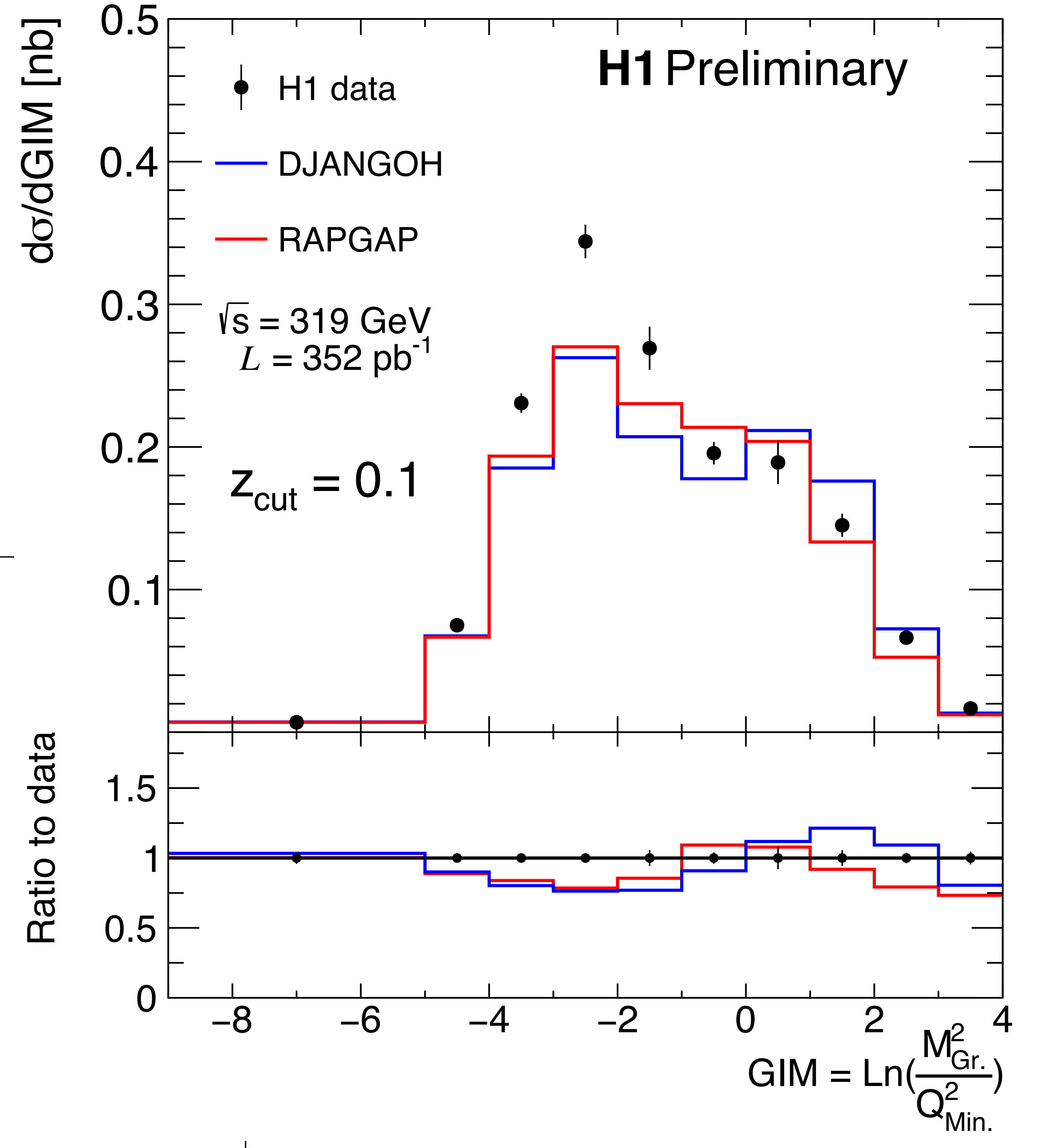
H1 results

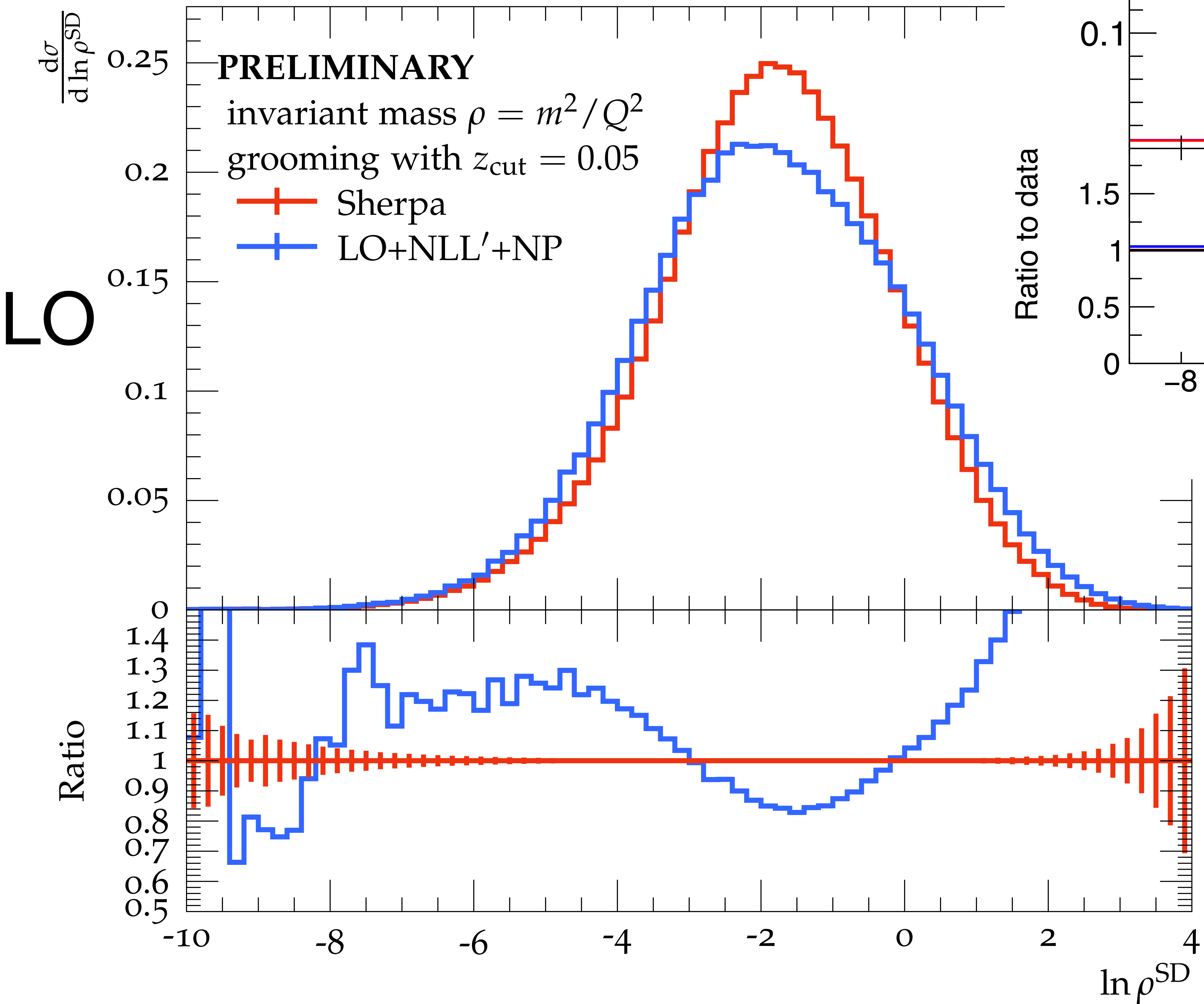


- groomed 1-jettiness, measured in larger y, Q^2 range
- comparison agains several MC generators

Outlook - groomed mass

- further measurements:
  - mass of groomed Centauro jet
  - same techniques apply for calculation
  - new transfer matrices, NLO calculation necessary
    → work in progress with Steffen Schumann, Leon Stöcker





Summary

- Presented preliminary measurements of 1-jettiness and groomed 1-jettiness with the H1 detector at $\sqrt{s} = 319\ \mathrm{GeV}$
- New calculations
  - state-of-the art Monte Carlo predictions with Sherpa at MEPS@NLO accuracy: $e^- p \to e^- + 1,2\,j\,@\,\mathrm{NLO} + 3,4\,j\,@\,\mathrm{LO}$
  - (N)NLO+NLL’+HAD predictions from Sherpa+CAESAR
- renewed interest, both experimentally and theoretically in light of upcoming EIC and proposals like LHeC, FCC-eh

see also [Banfi, Ravviso, Jäger, Karlberg, Reichenbach, Zanderighi ’23]