SHERPA for EIC

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6.6.2024 – MC4EIC – IPPP Durham

- introduction
- multijet merging
- SHERPA for DIS
- ALARIC: a new parton shower for SHERPA
- Recent use by H1
- Forthcoming attractions

instead of an introduction

(executive summary)

SHERPA overview

SciPost Phys.7 (2019) 3, 034; new release (v3.0.0) imminent

- automated matrix element generators: COMIX & AMEGIC++
  JHEP 12 (2008) 039; JHEP 02 (2002) 044
- interfaces to loop generators: MCFM, OPENLOOPS & RECOLA
  Eur.Phys.J C81 (2021) 12, 1117; Eur.Phys.J C79 (2019) 10, 866; Eur.Phys.J C77 (2017) 492
- multijet merging at LO & NLO — JHEP 11 (2001) 063; JHEP 04 (2013) 027
- parton showers: CSSHOWER & ALARIC — JHEP 03 (2008) 038; JHEP 10 (2023) 091
- cluster fragmentation: AHADIC & interface to string fragmentation (PYTHIA 8) — SciPost Phys. 13 (2022) 019; Comput.Phys.Commun. 191 (2015) 159
- colour reconnection model — work in progress
- hadron and τ decays: HADRONS++ — no separate publication (yet?)
- MPI model according to Sjostrand-van der Zijl — Phys.Rev.D 36 (1987) 2019
- interface to RIVET — SciPost Phys. 8 (2020) 026

multijet merging

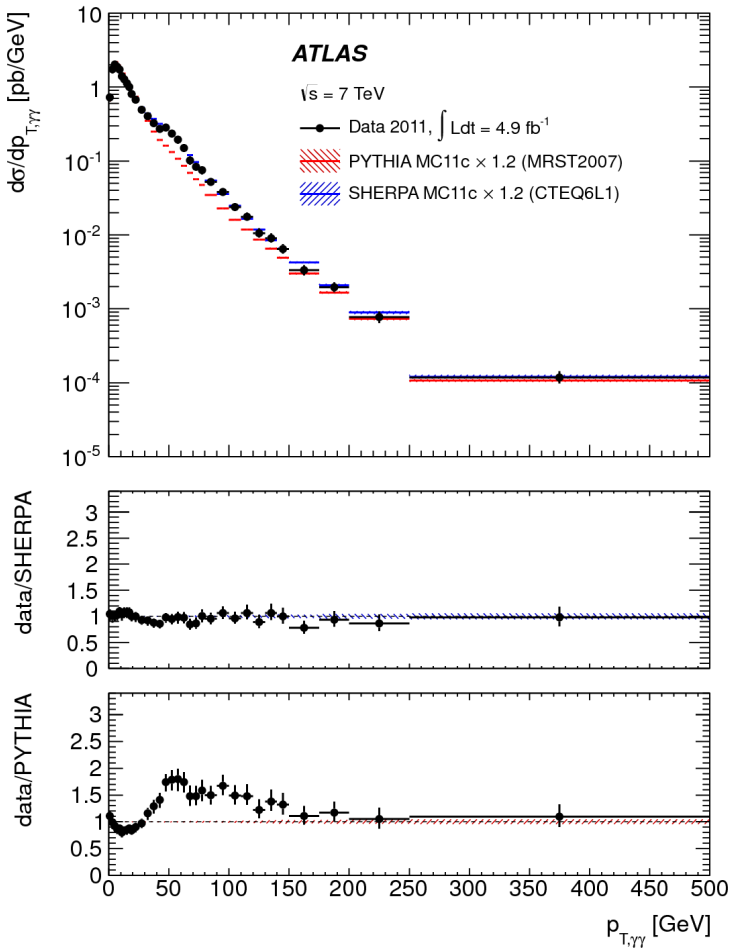
(principles & examples applications LHC)

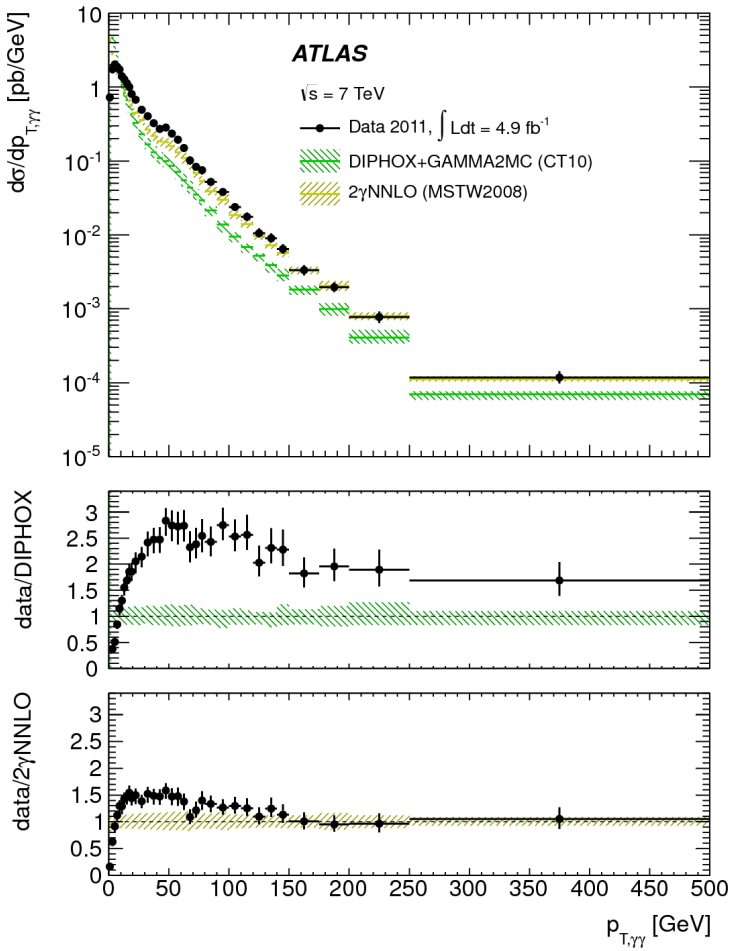
underlying idea

- matrix elements (ME) good for jet production
- parton showers (PS) good for jet production
- want the best of both worlds:
  combine them **without double counting**
- logic:
  - reweight MEs with Sudakov form factors & appropriate scales in α_S,
  - veto unwanted (=hard jet) emissions in PS

propaganda: $p_{\perp,\gamma\gamma}$ LHC in MEPS@LO vs. NNLO

(JHEP 01 (2013) 086)





multijet-merging at NLO

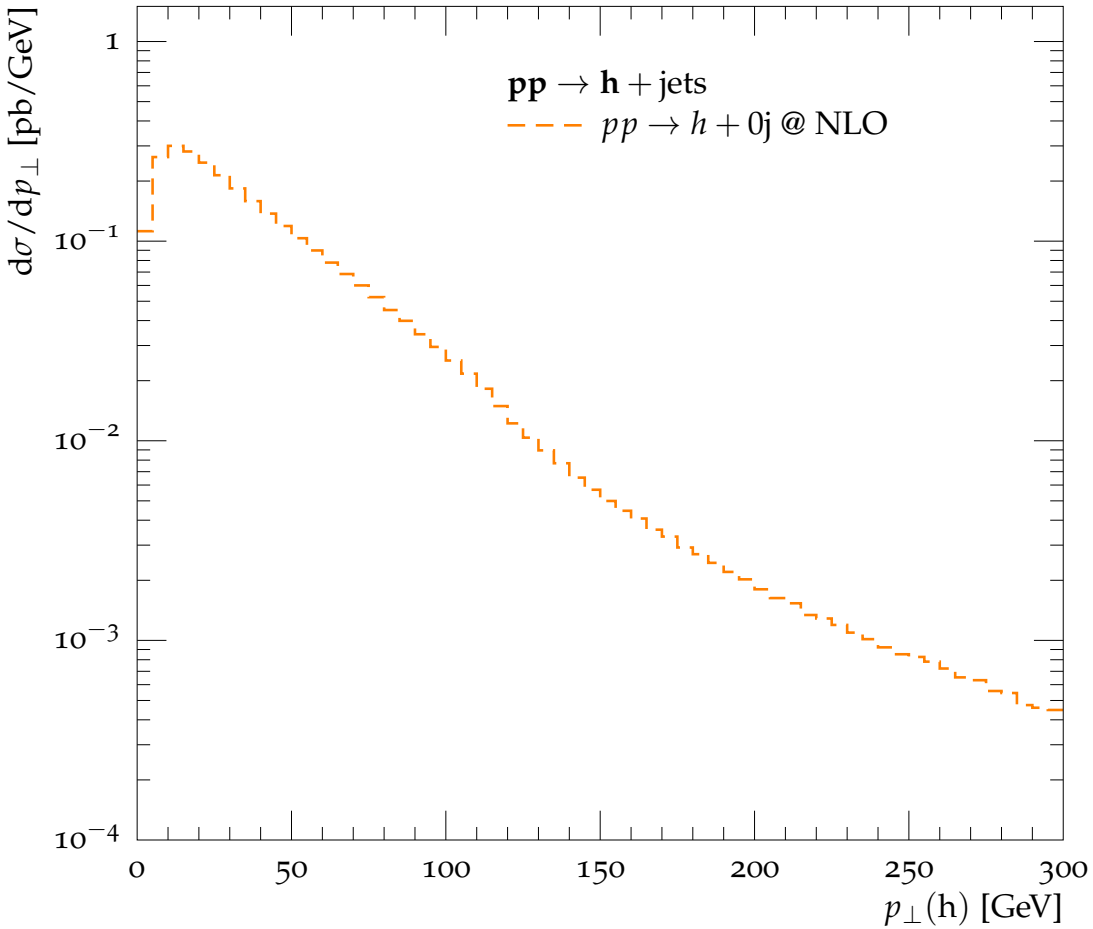
- sometimes "more legs" wins over "more loops"
- basic idea like at LO: towers of MEs with increasing jet multi
  (but this time at NLO)
- combine them into one sample, remove overlap/double-counting
- maintain NLO and LL accuracy of ME and PS
- effectively merging MC@NLO simulations,
  further supplemented with LO simulations for even higher FS multiplicities
- different implementations, parametric accuracy not always clear

  (MEPS@NLO, FXFX, UNLOPS)

- can extend to/include EW corrections

  (e.g. JHEP 06 (2022) 064; JHEP 10 (2020) 159; Phys.Rev.D 89 (2014) 11, 114006)

illustration: $p_\perp^H$ in MEPS@NLO



- first emission by MC@NLO

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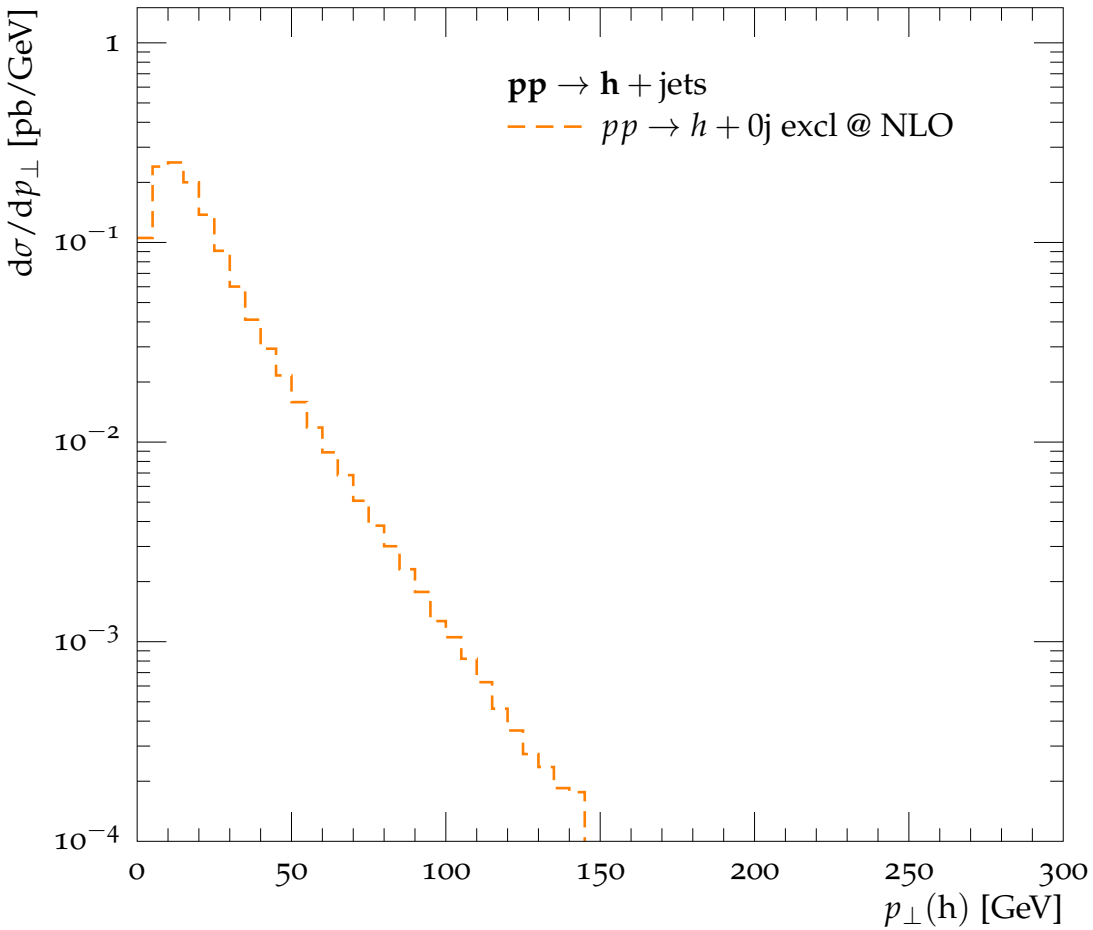

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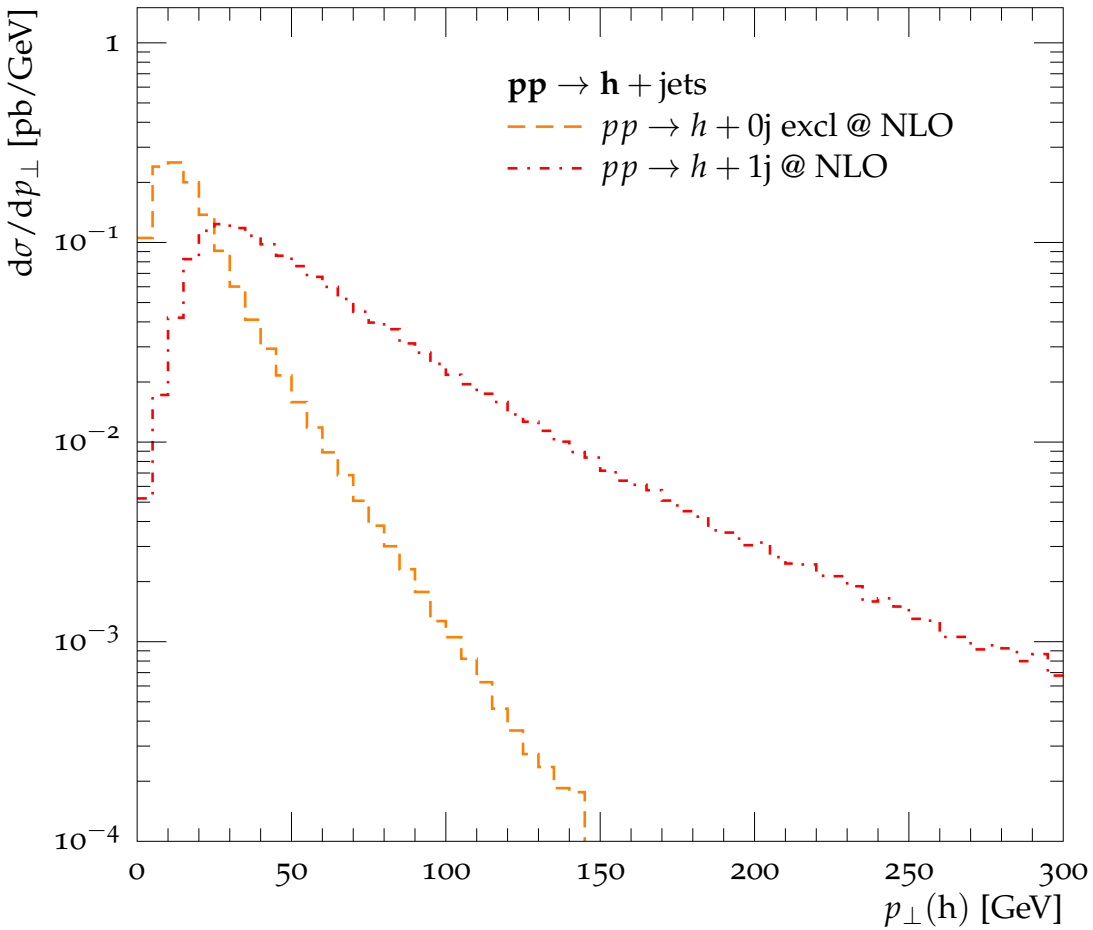

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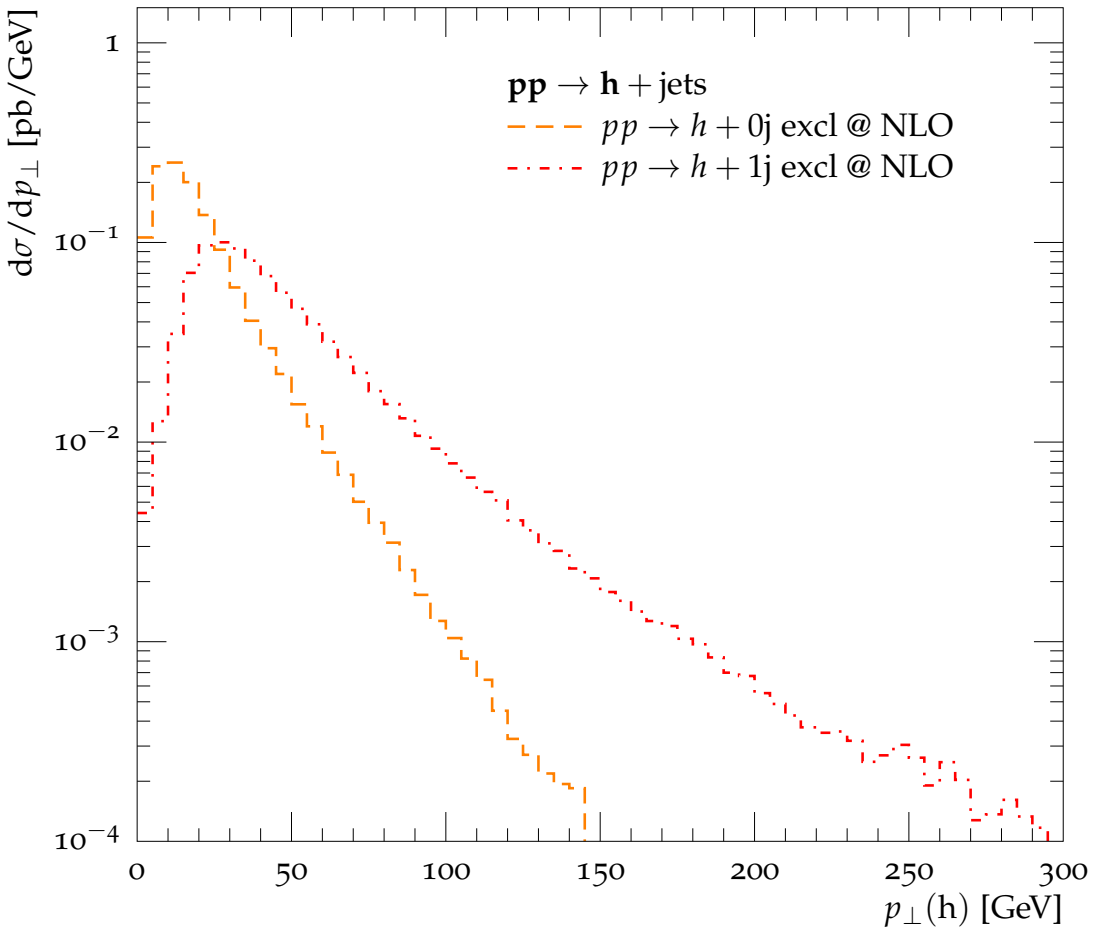

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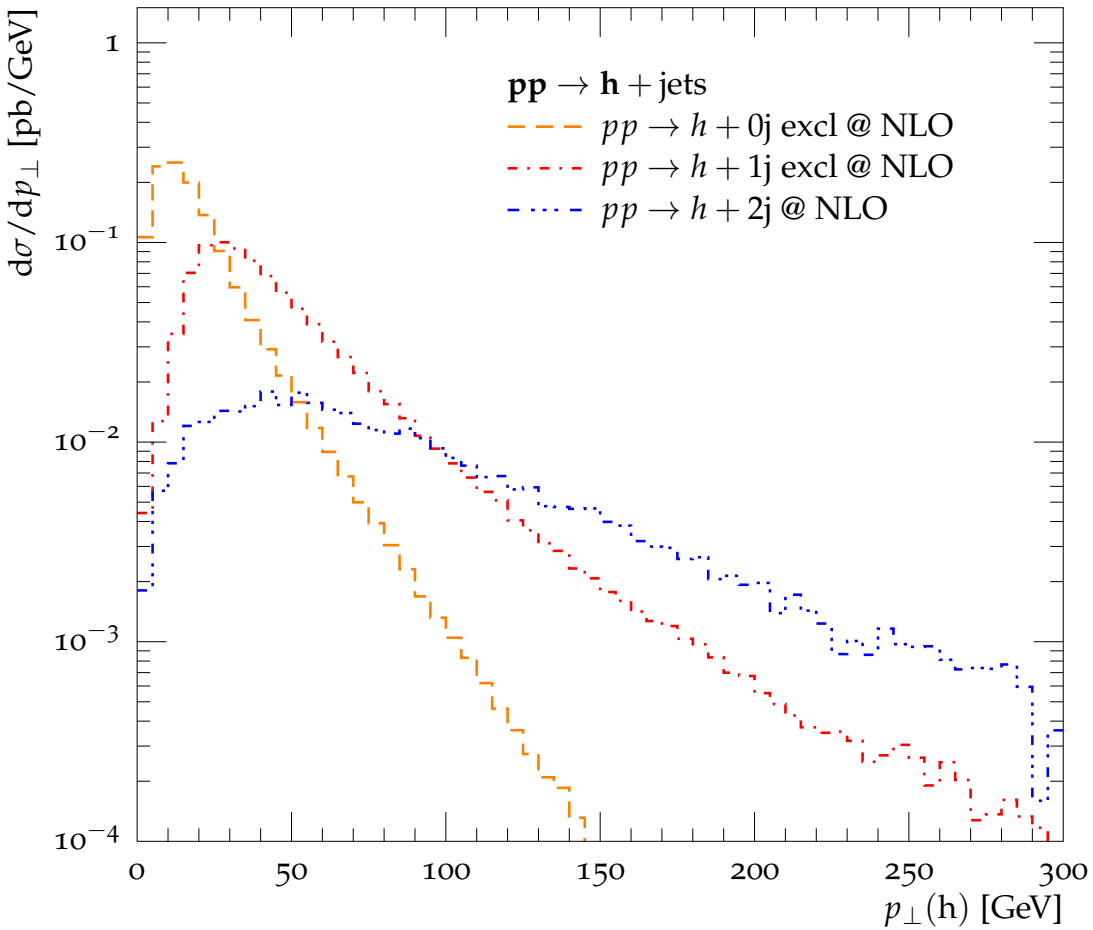

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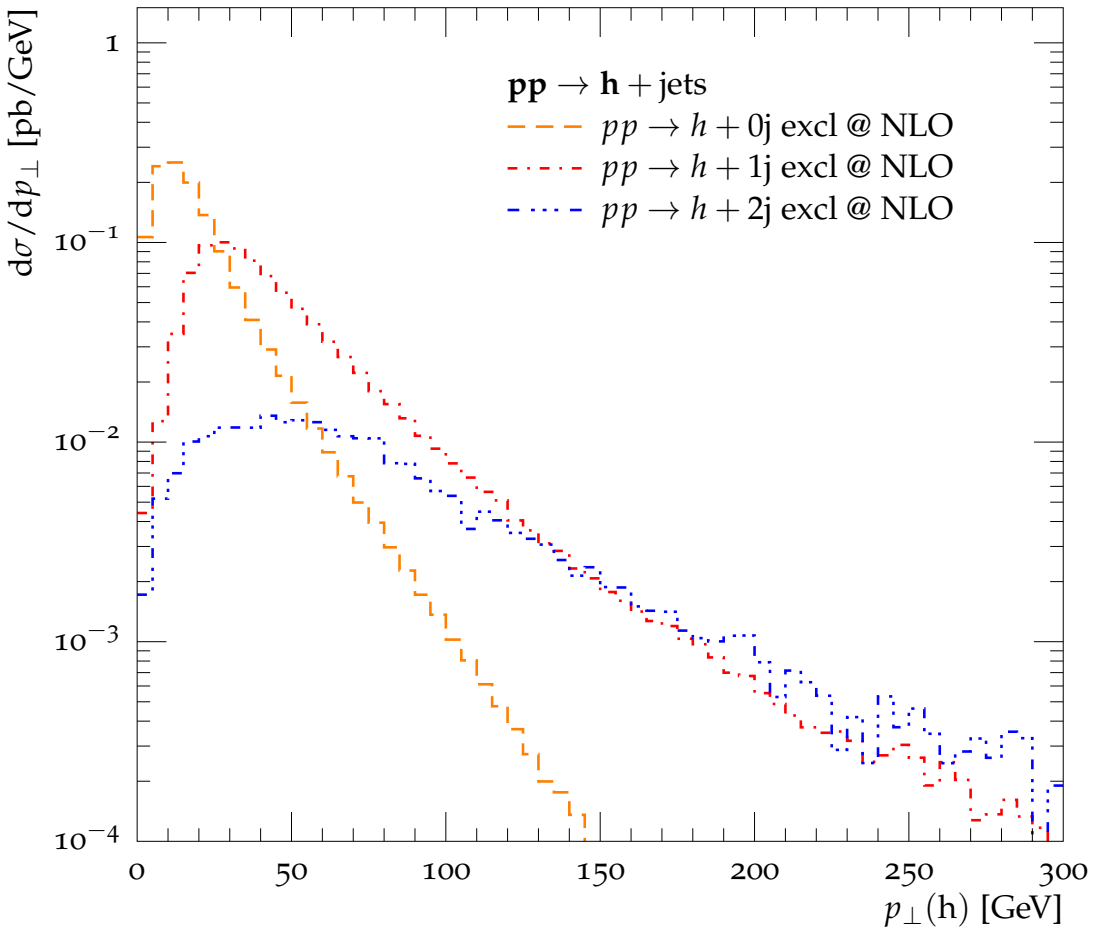

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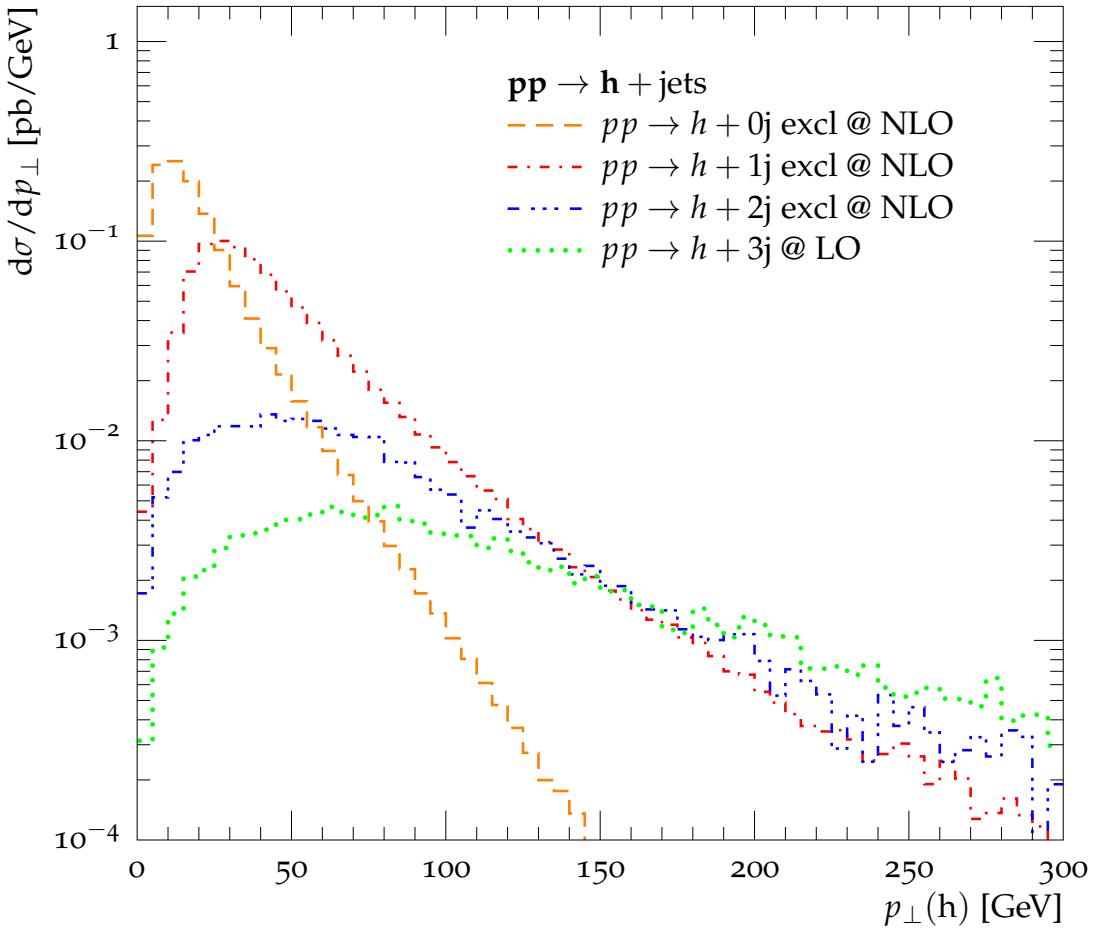

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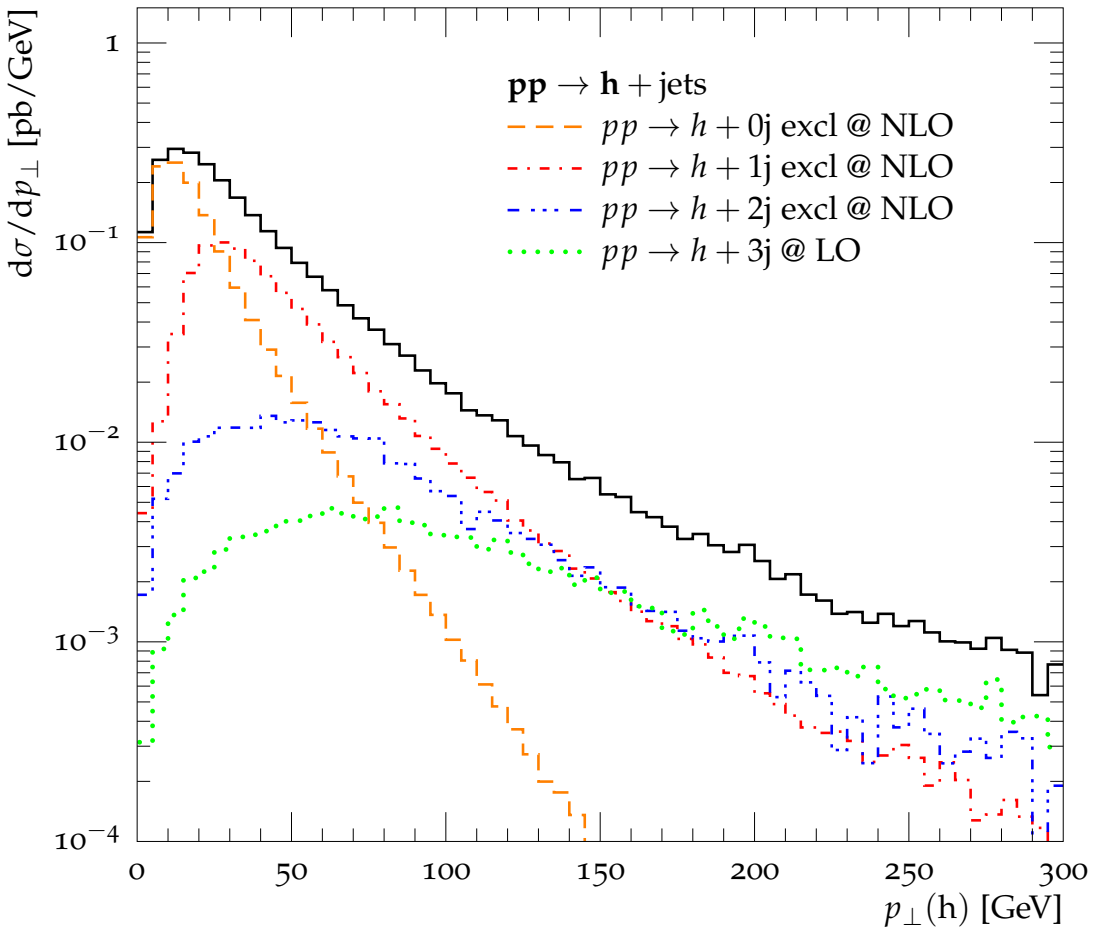

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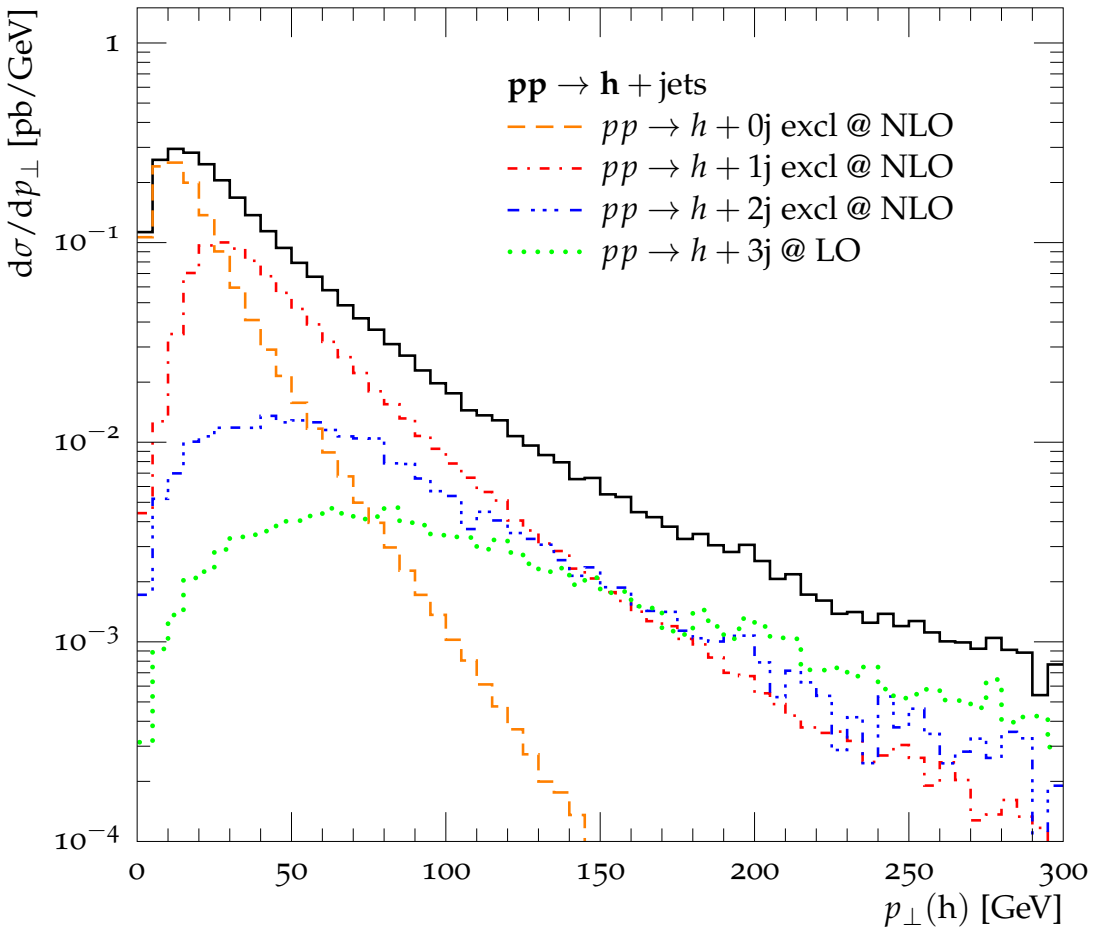

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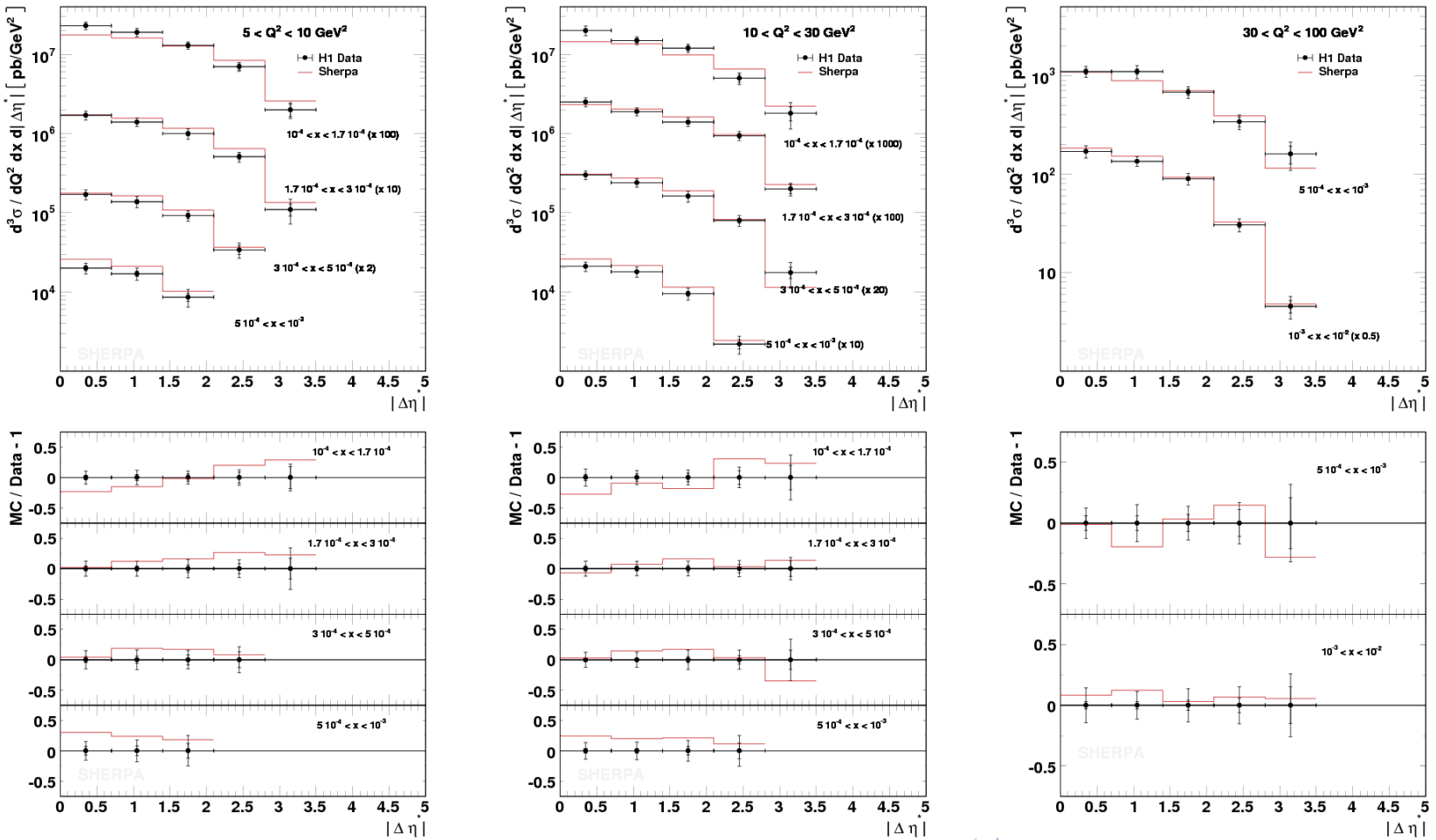
- MC@NLO $pp \to h + 2\mathrm{jets}$ for $Q_{n+2} > Q_{\mathrm{cut}}$
- iterate
- sum all contributions
- eg. $p_\perp(h)$>200 GeV has contributions fr. multiple topologies

SHERPA for DIS

(some examples)

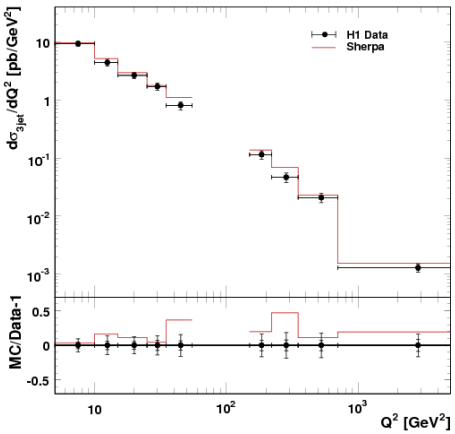
leading order example: di-jet production at HERA

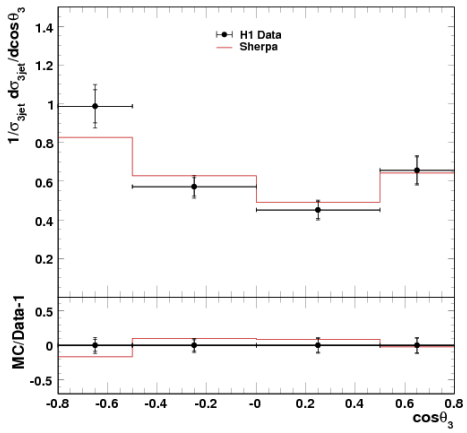
(Eur.Phys.J.C 67 (2010) 73, data from Eur.Phys.J.C33 (2004), 477)

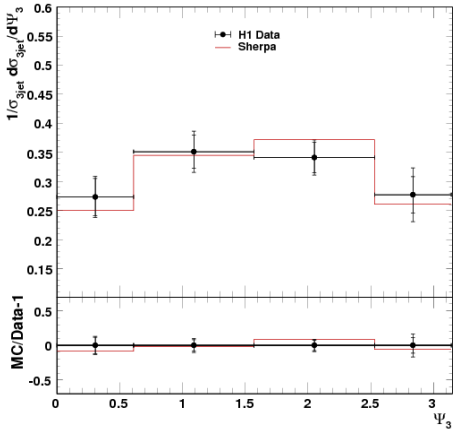


leading order example: three-jet production at HERA

(Eur.Phys.J.C 67 (2010) 73, data from Phys.Lett.B515 (2001) 17)

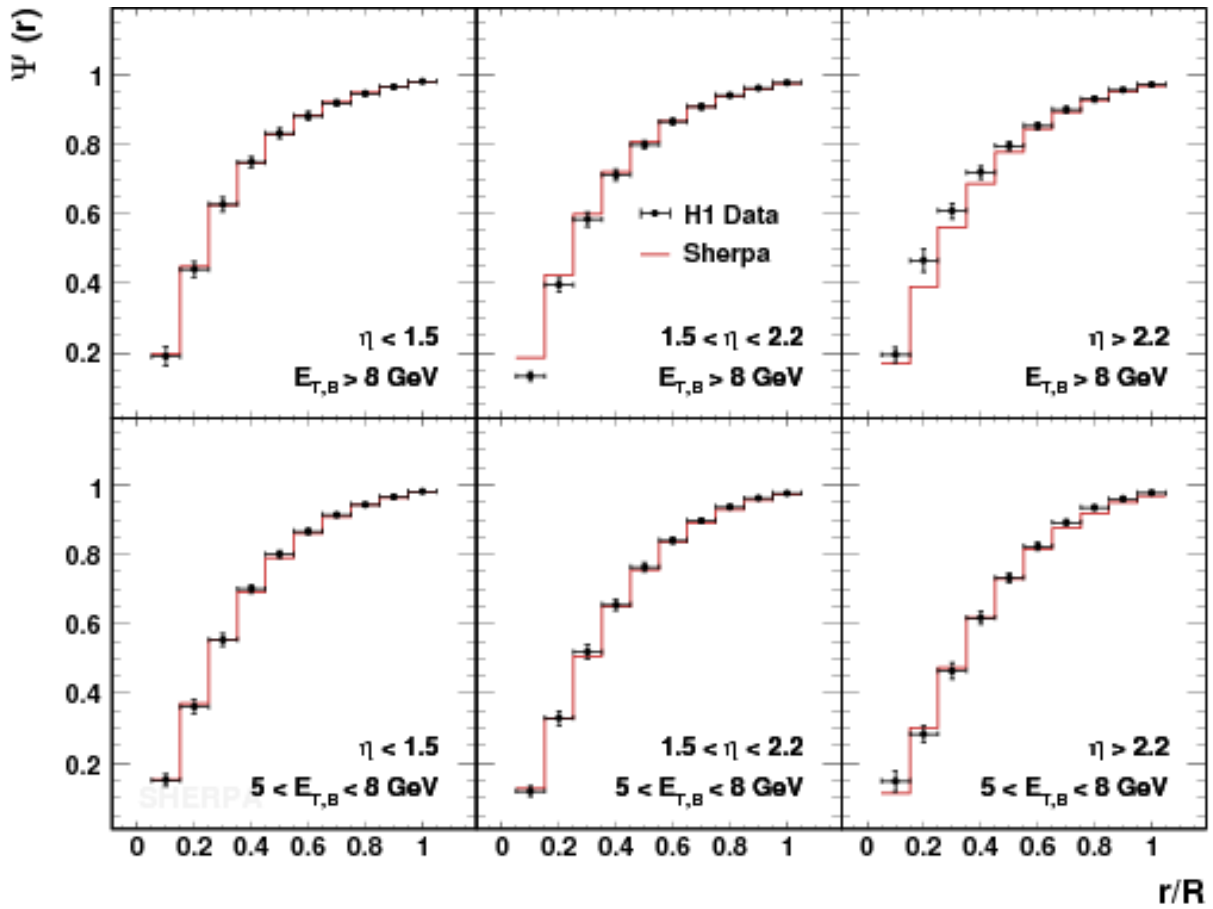






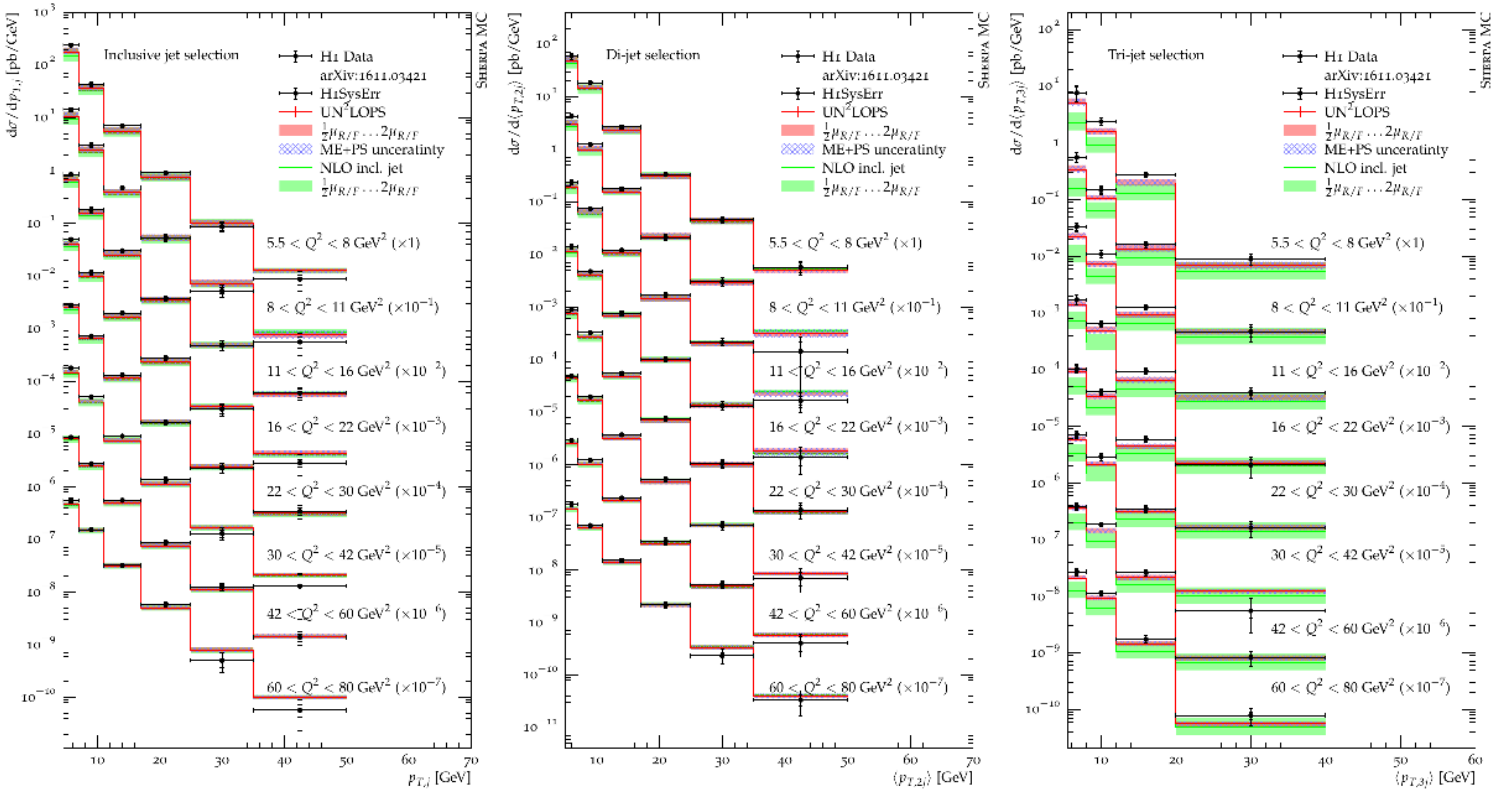
leading order example: jet shapes at HERA

(Eur.Phys.J.C 67 (2010) 73, data from Nucl.Phys.B545 (1999) 3)



inclusive NC-DIS at NNLO

(Phys.Rev.D 98 (2018) 11, 114013; data from Eur.Phys.J.C75 (2015) 65)



ALARIC

(a new parton shower for SHERPA)

motivation

- currently used parton showers (CSSHOWER, DIRE) not NLL correct

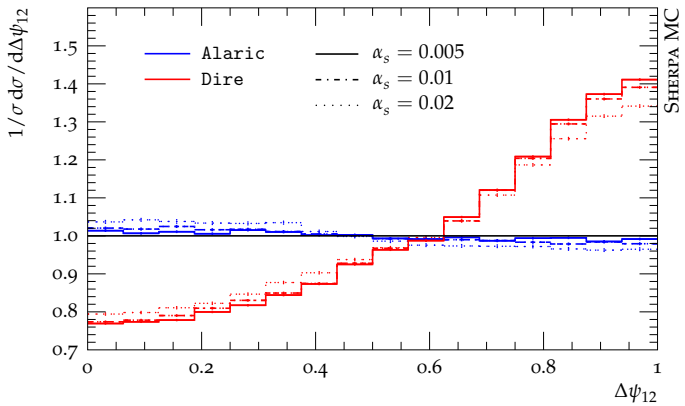
  (Phys.Rev.Lett. 125 (2020) 5, 052002)

  due to issues with kinematics of subsequent emissions
  $\longrightarrow$ have to go back to drawing board
- results (condensed in ALARIC): (JHEP 10 (2023) 091)
  - revisited eikonal factorisation $\rightarrow$ reformulated angular ordering
  - disentangled colour spectator and recoil partner
  - new kinematics mapping, full event for recoil
  - new role of color spectator: only fixing directions
  - analytic proof of NLL accuracy

set-up of numerical tests

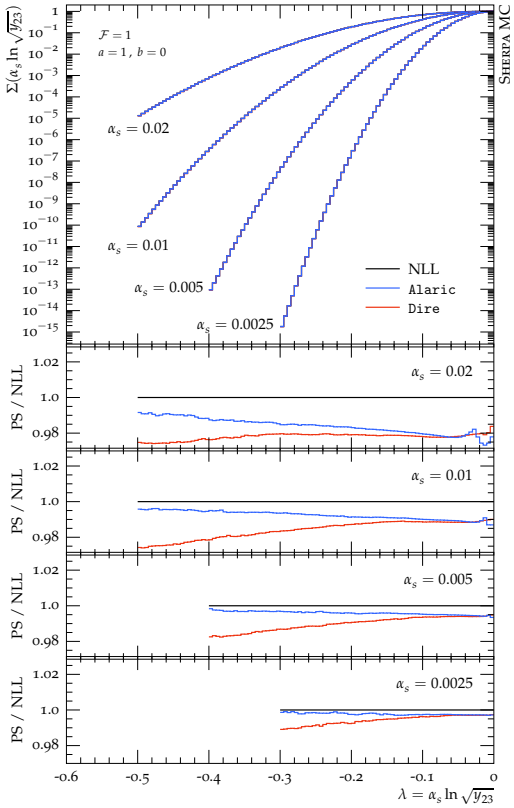
- compare results in $\alpha_S \to 0$ limit with NLL result
- set-up for checks
  - fixed α_S
  - leading colour $C_A = 2C_F = 3$
  - all partons massless
- example: azimuthal angle between two leading Lund-plane declusterings

(should be $\Delta\Psi_{12} = 0$)

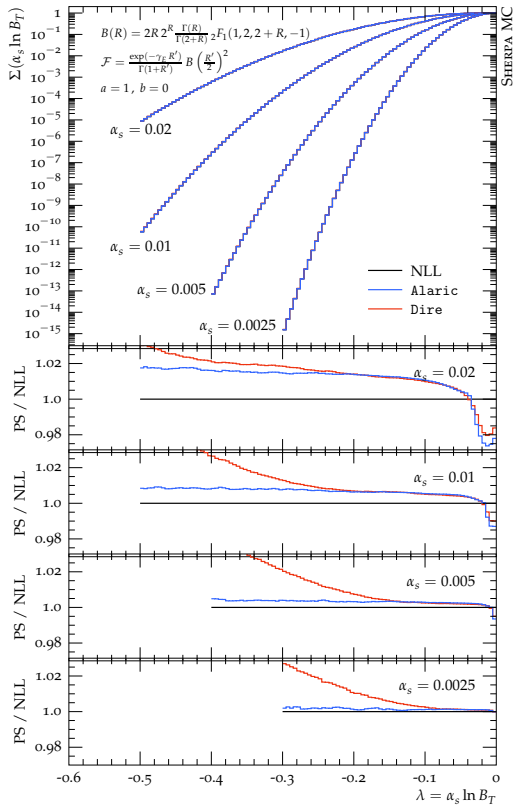


numerical checks

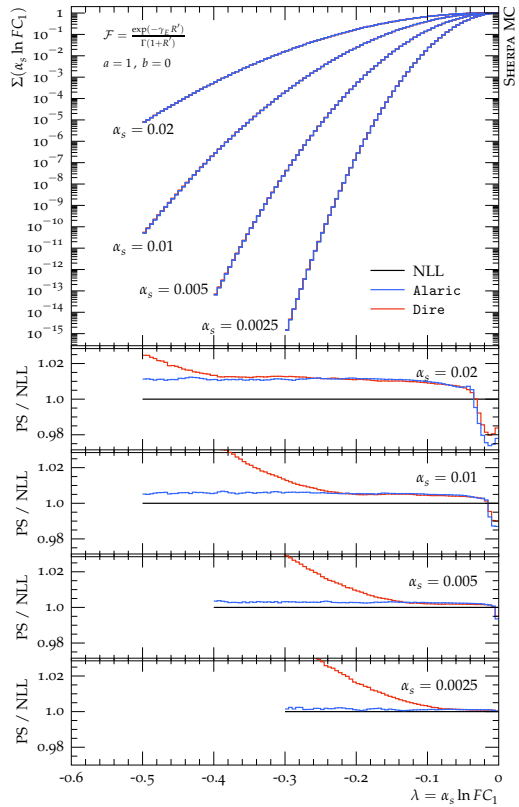
y_{23}



B_T

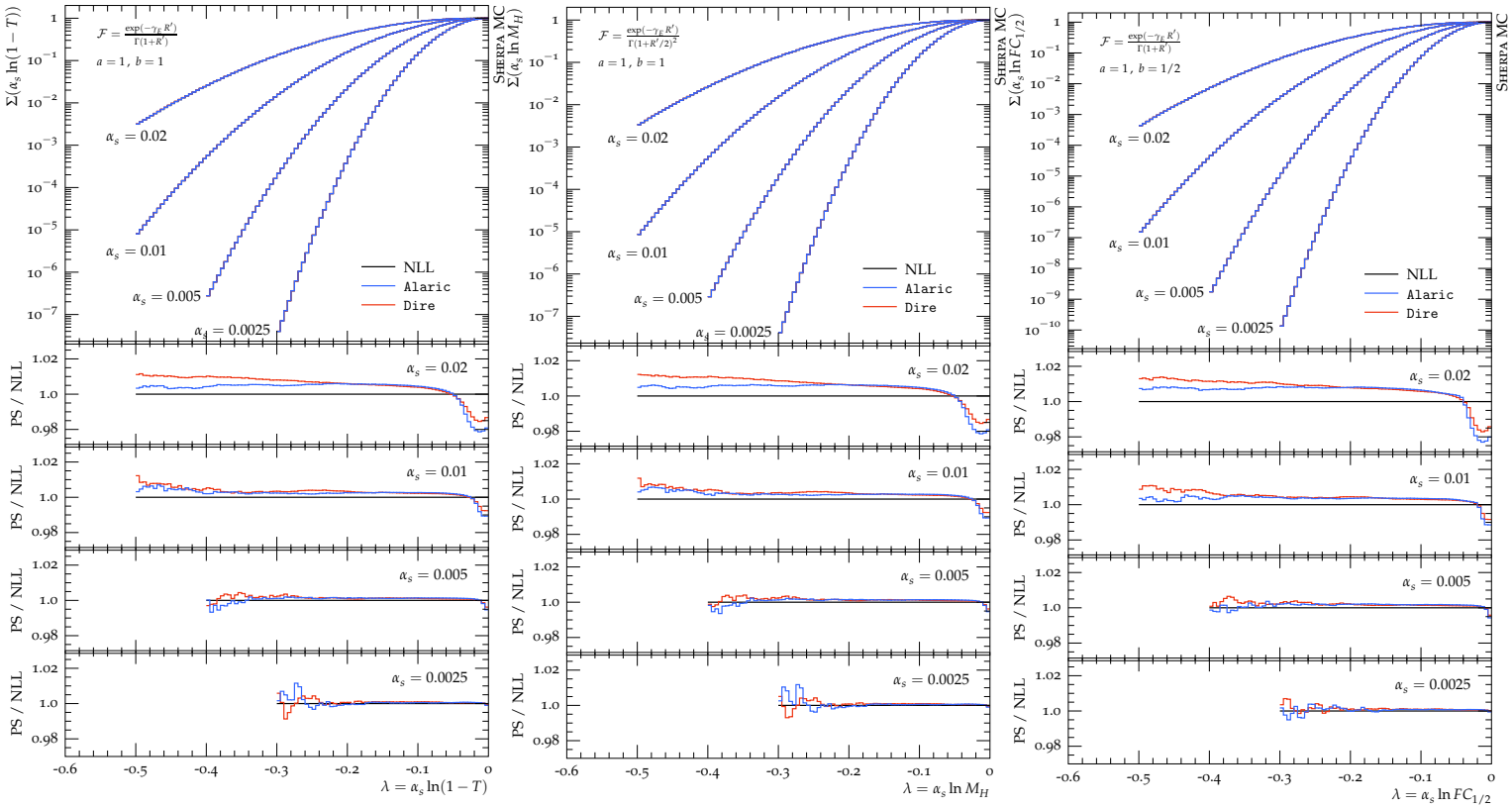


FC_1



numerical checks

$1-T$ M_H $FC_{1/2}$



set-up of data comparison with LEP 1

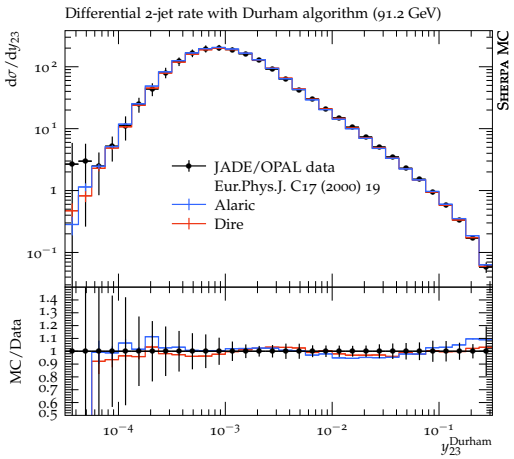
- compare hadron-level results with LEP data
- perturbative set-up
  - no higher orders (no matching or merging)
  - running two-loop α_S with $\alpha_S(M_Z) = 0.118$
  - use CMW scheme for soft eikonal parts
  - all partons massless, masses emulated through simplistic thresholds
  - leading colour $C_A = N_c = 3$, $C_F = \frac{N_c^2-1}{2N_c}$
- non-perturbative set-up
  - need to use PYTHIA hadronization

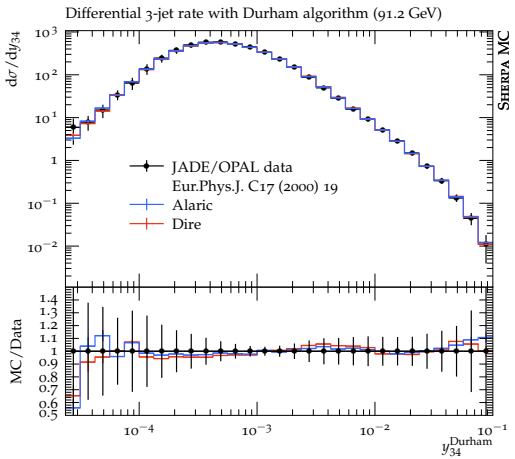
(ALARIC not yet ready for heavy hadron decays)

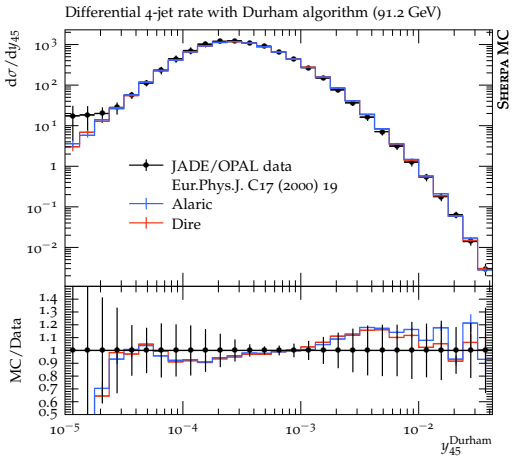
  - default parameters of PYTHIA 6.4, but

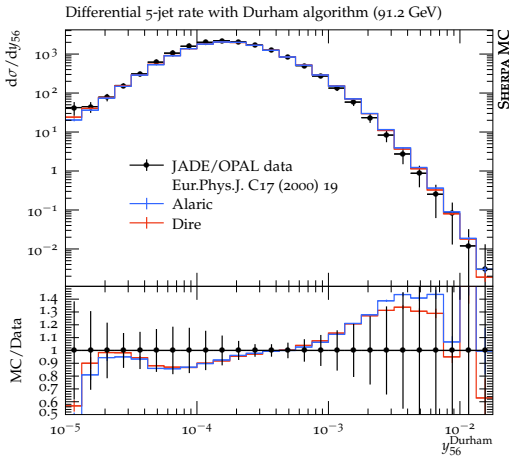
PARJ(21) = 0.3, PARJ(41) = 0.4, PARJ(42) = 0.36(ALARIC)/0.45(DIRE)

data comparison at LEP 1









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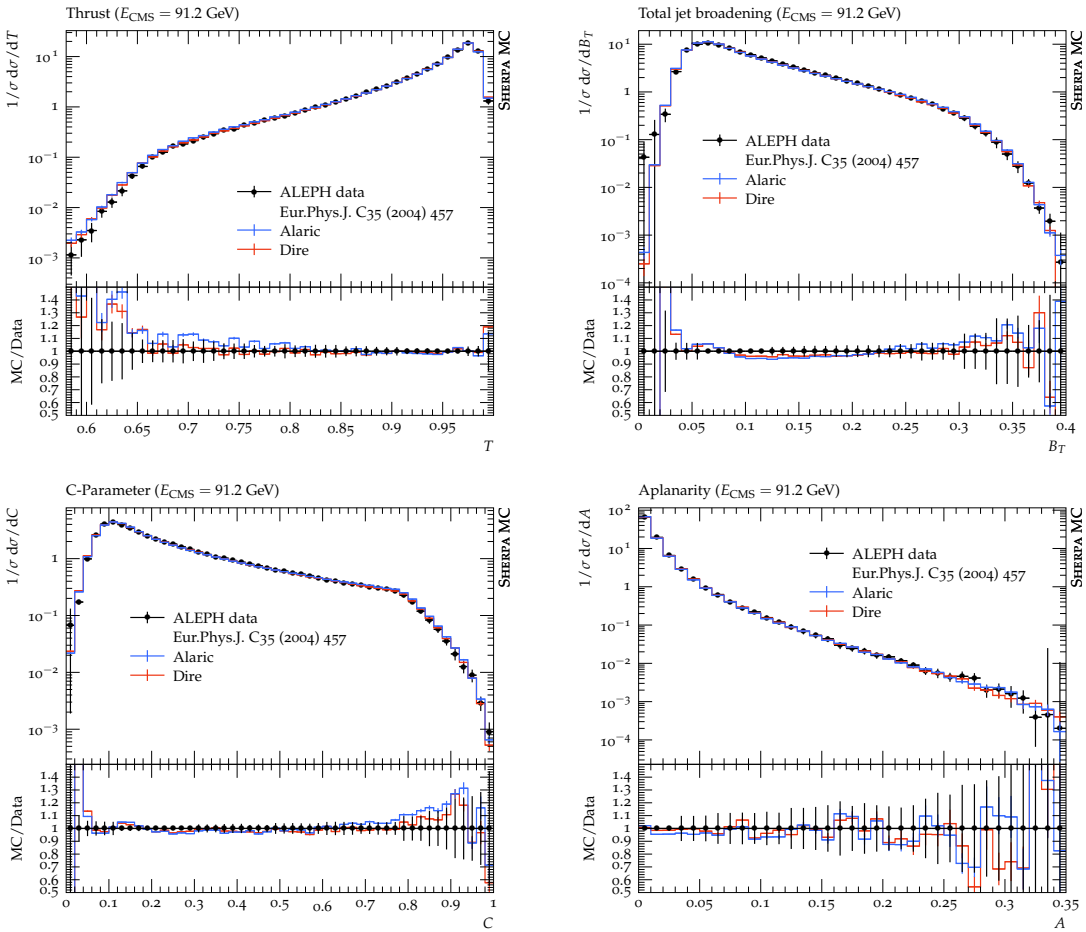
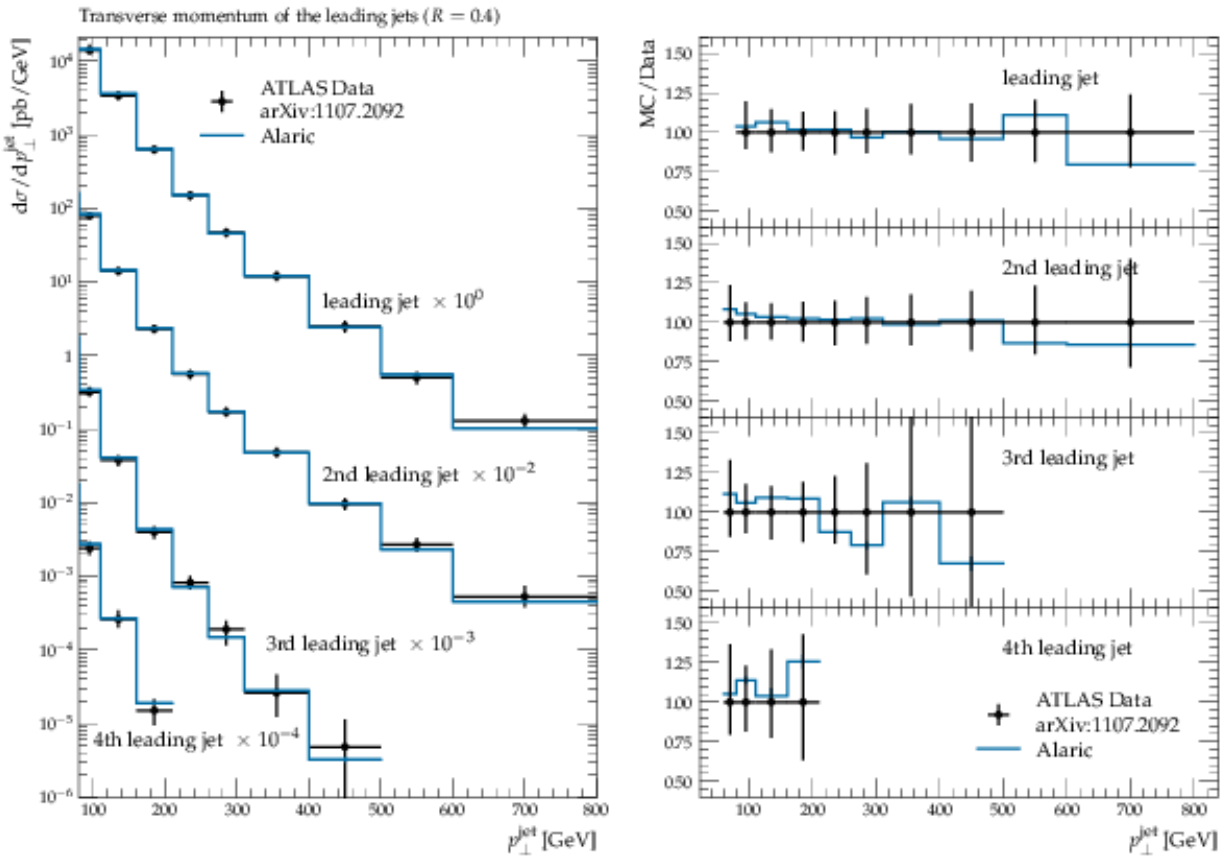


data comparison at LHC: QCD events

(2404.14360, data from Eur.Phys.J.C 71 (2011) 1763 & Eur.Phys.J.C 74 (2014) 11)



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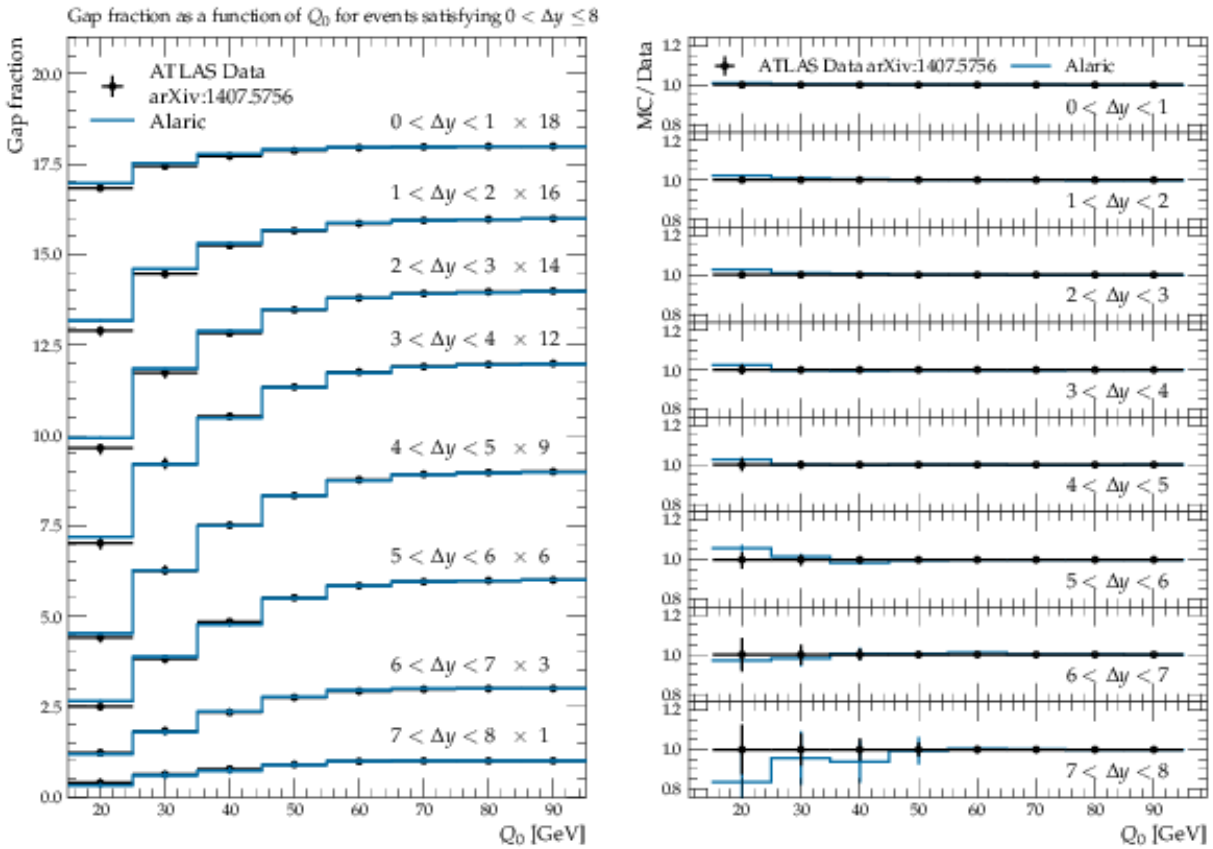
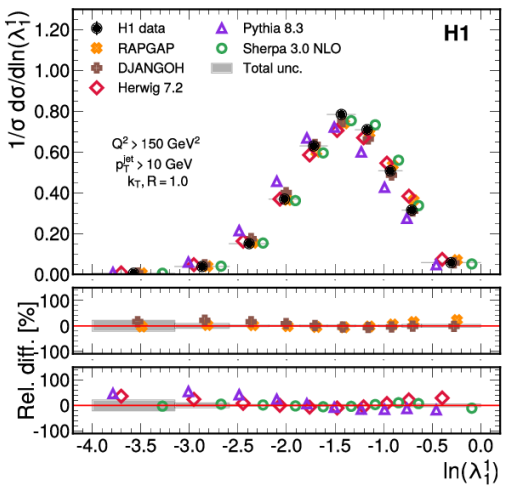


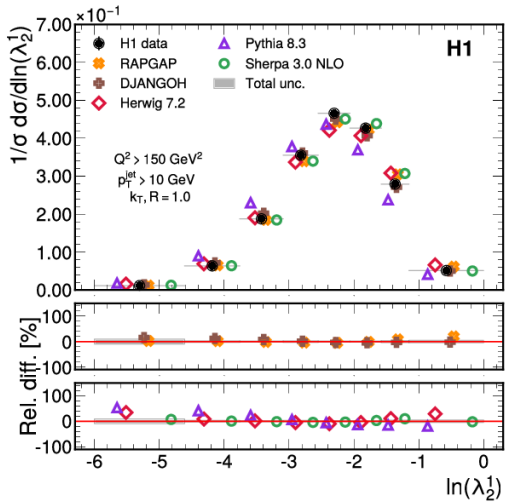
SHERPA @ H1

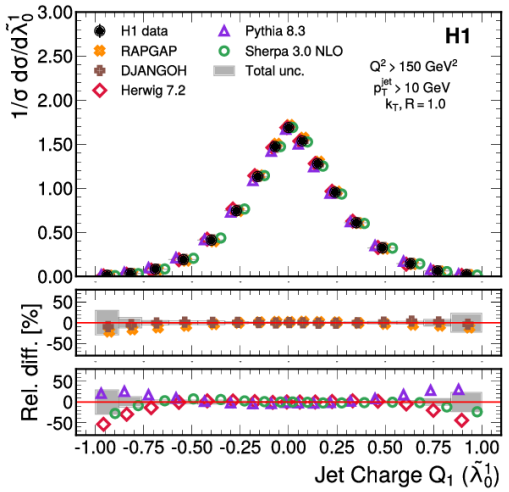
(recent use)

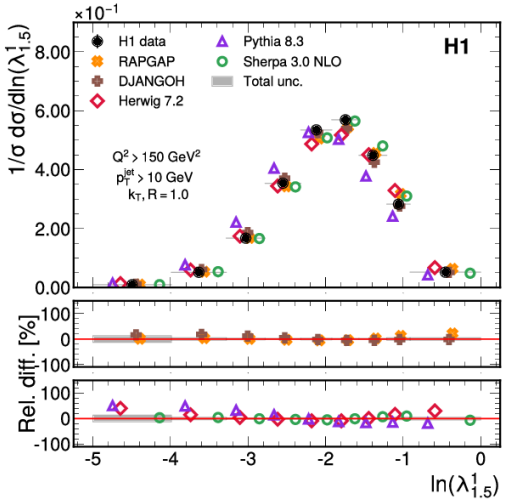
jet substructures at H1

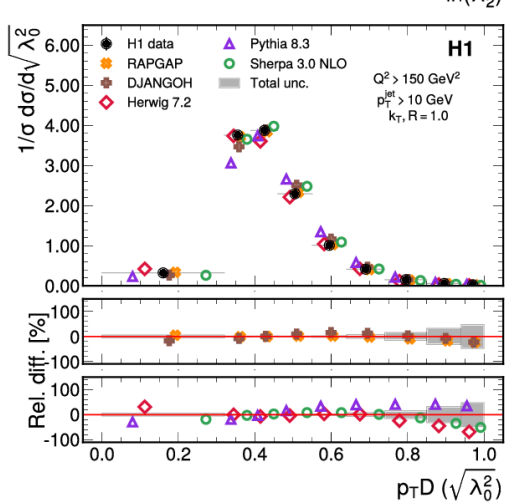
(Phys.Lett.B 844 (2023) 138101)

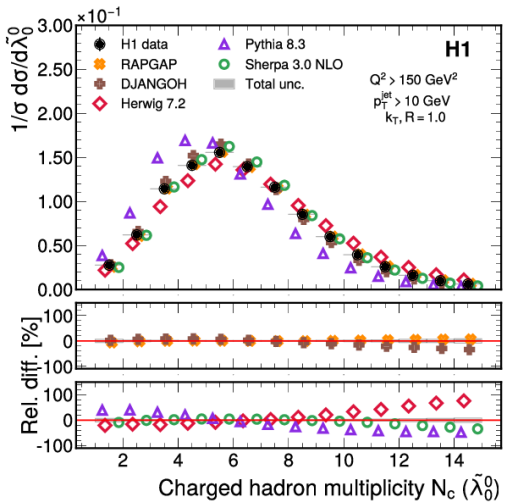






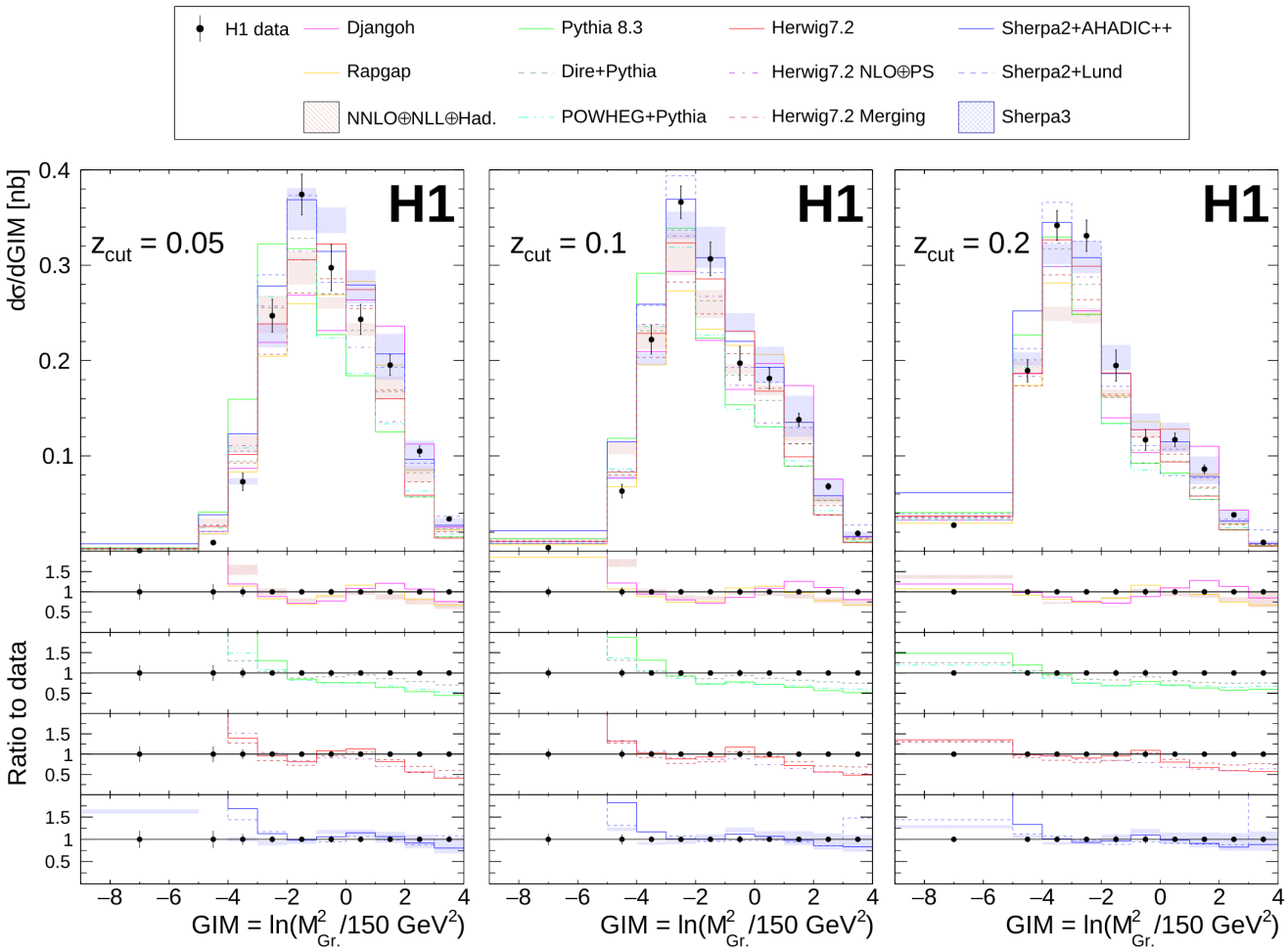






groomed event shapes at H1

(2403.10134 [hep-ex])



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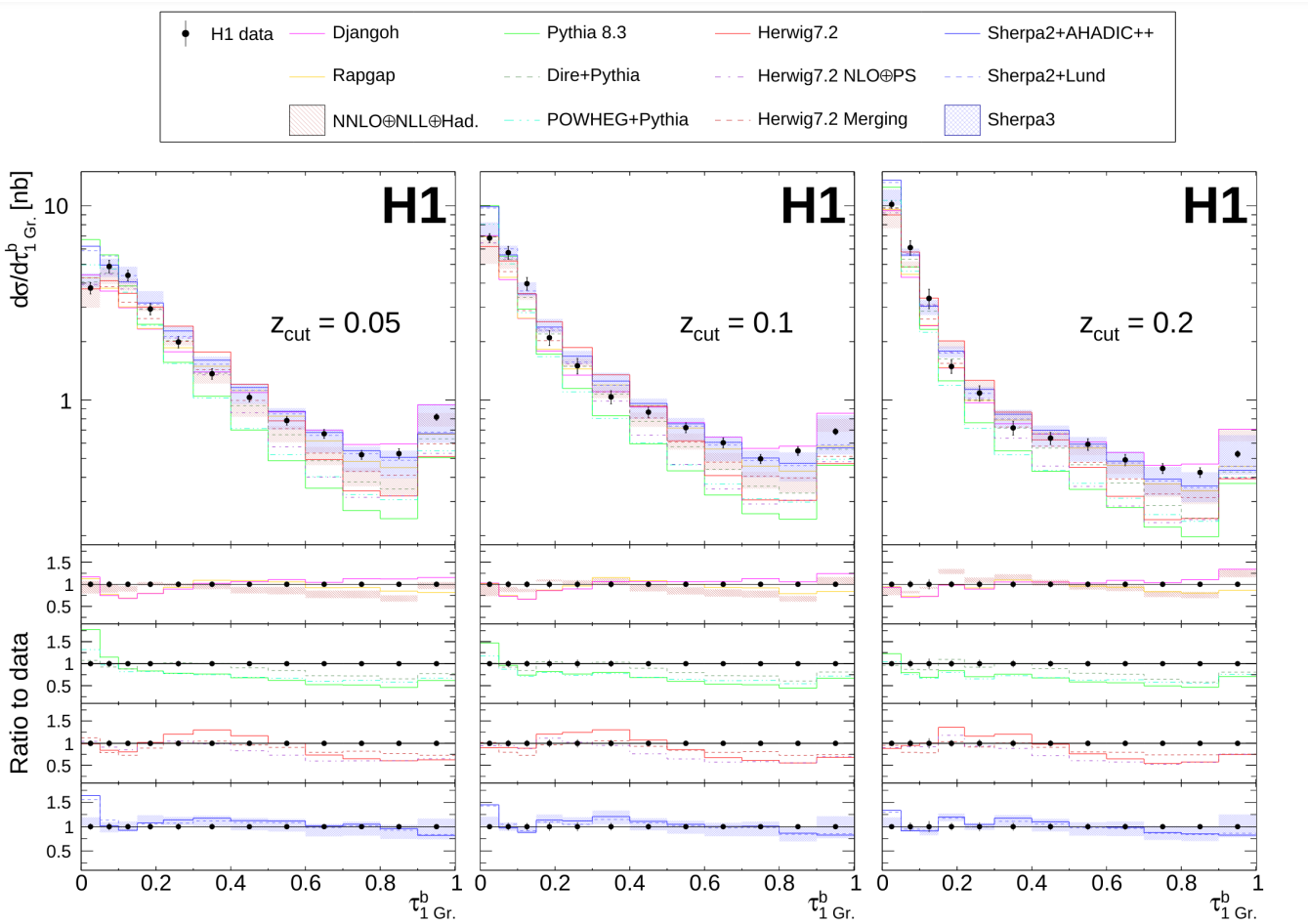


summary & outlook

summary

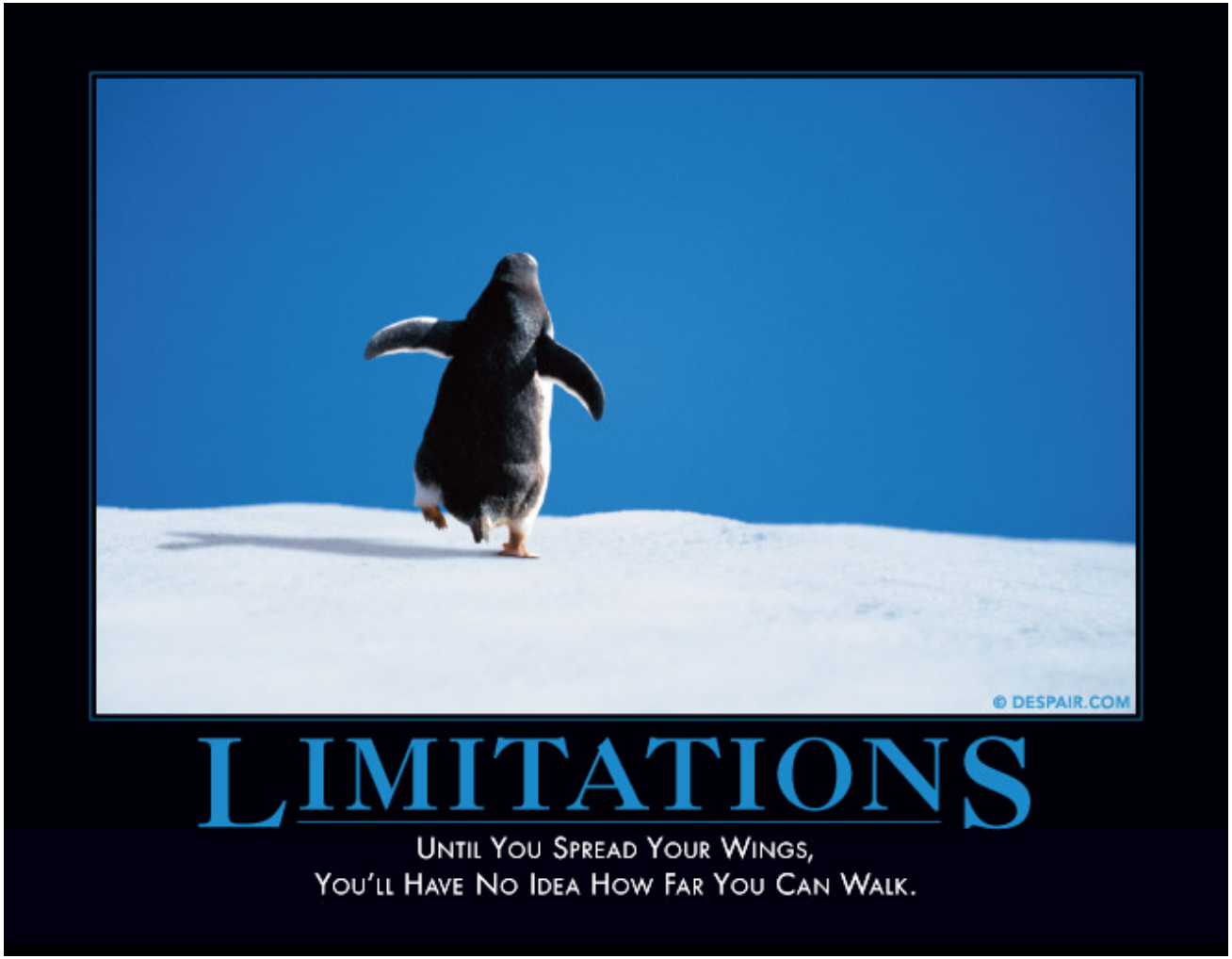
- SHERPA one of the frontrunners in precision simulations @ LHC
  $\longrightarrow$ in the process of porting/adapting technology for EIC:
  - NC/CC DIS with MEPS@NLO and NNLOprecision available
  - photoproduction in EPA with different PDFs @ MEPS@NLO (available in new 3.0)
  - MPI model for photoproduction (needs tuning) (see talk by Ilkka)
  - modelling of hard diffraction started (see talk by Peter)
  - heavy use of HERA data for bootcamp/validation/tuning

forthcoming attractions

- SHERPA 3.0.0 to be released next week (hopefully):
  - improved run-card handling
  - massively increased generation efficiency
- beyond 3.0.0:
  - ALARIC: new parton shower with increased (NLL+) precision

    ((N)NLO matched & merged)
  - tuned cluster hadronization (and tuning Lund for SHERPA)
  - tuned MPI model, adapted for photoproduction

    (and also adapted for "rescattering")
  - new colour reconnection model
  - long term: YFS QED simulation for DIS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LIMITATIONS
UNTIL YOU SPREAD YOUR WINGS,
YOU'LL HAVE NO IDEA HOW FAR YOU CAN WALK.