NNLOPS

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UCL

Outline

- Motivation [just time for one of several good ones]
- NNLOPS

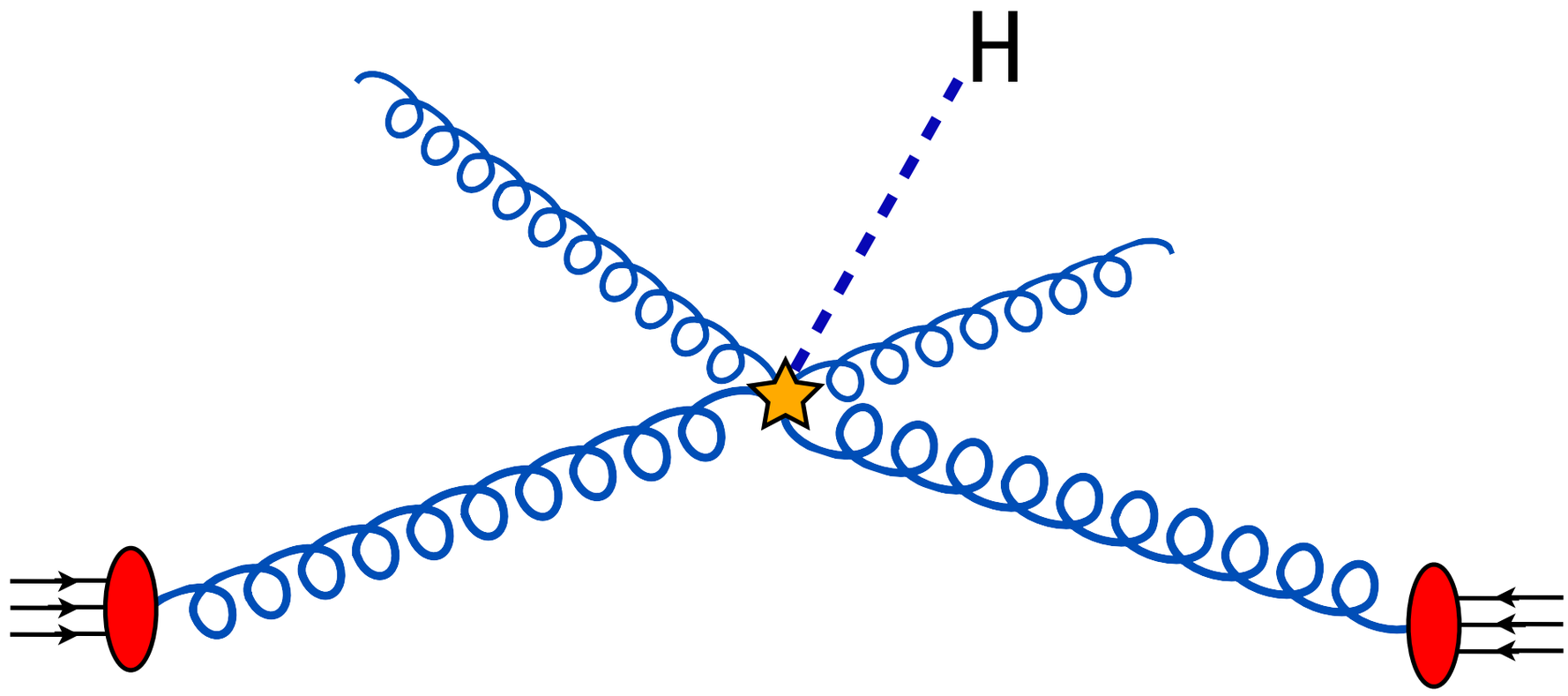
  Nason, Zanderighi, Re, k.h. - JHEP 1310/JHEP 1505

  Karlberg, Re, Zanderighi - JHEP 1409

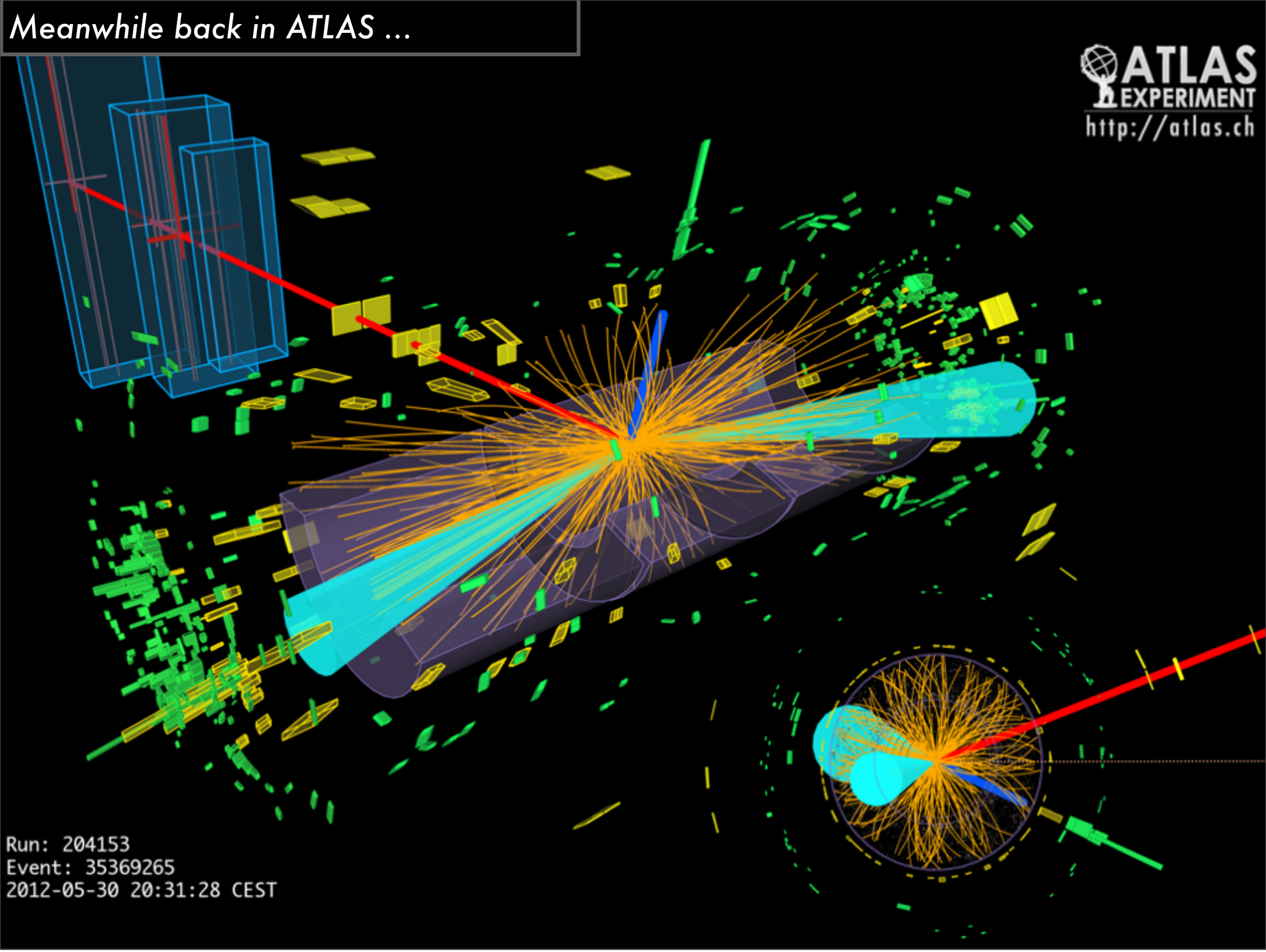
  Astill, Bizoń, Re, Zanderighi - JHEP 06[2016]154
- Status
- Prospects

NNLOPS Motivation: for %-level predⁿs should worry about everything

- Description of highest multiplicity events in e.g. NNLO gg → Higgs, is

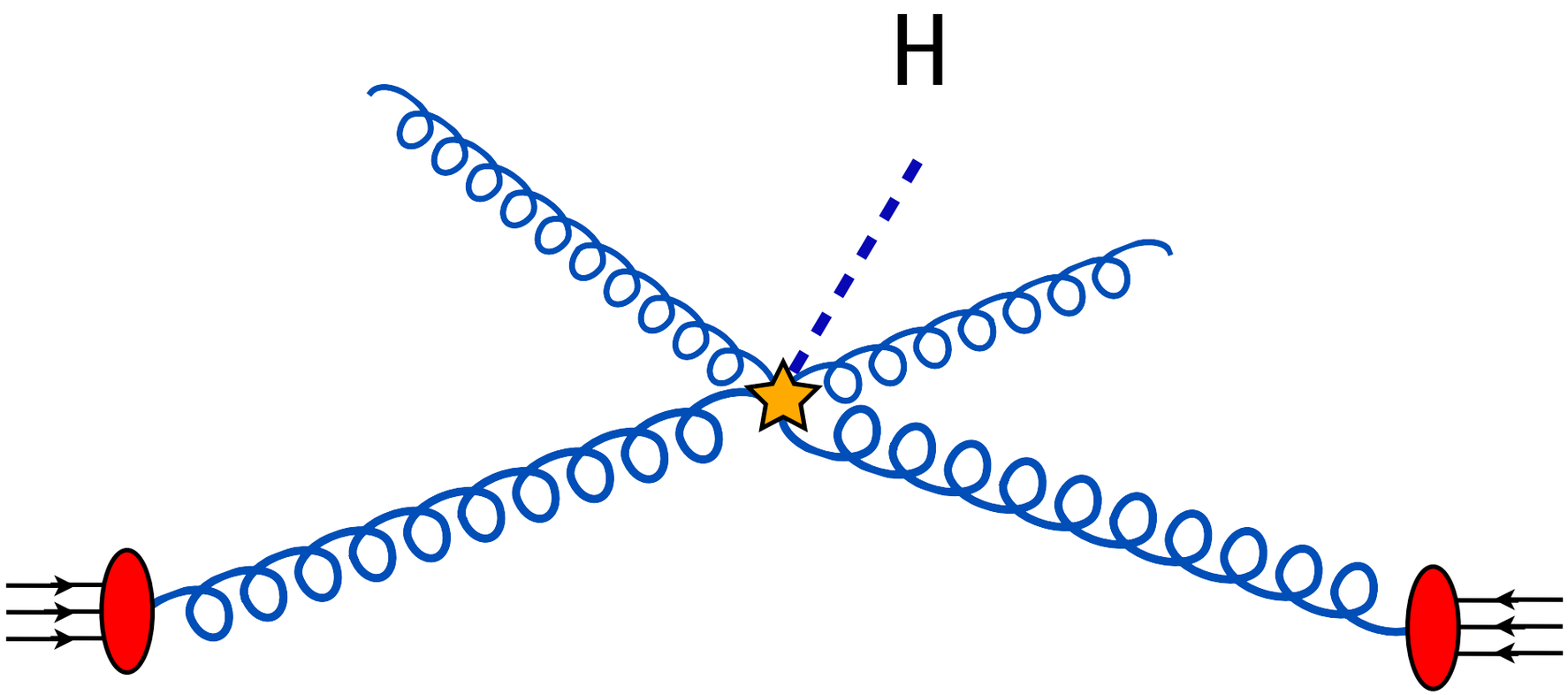


Meanwhile back in ATLAS ...



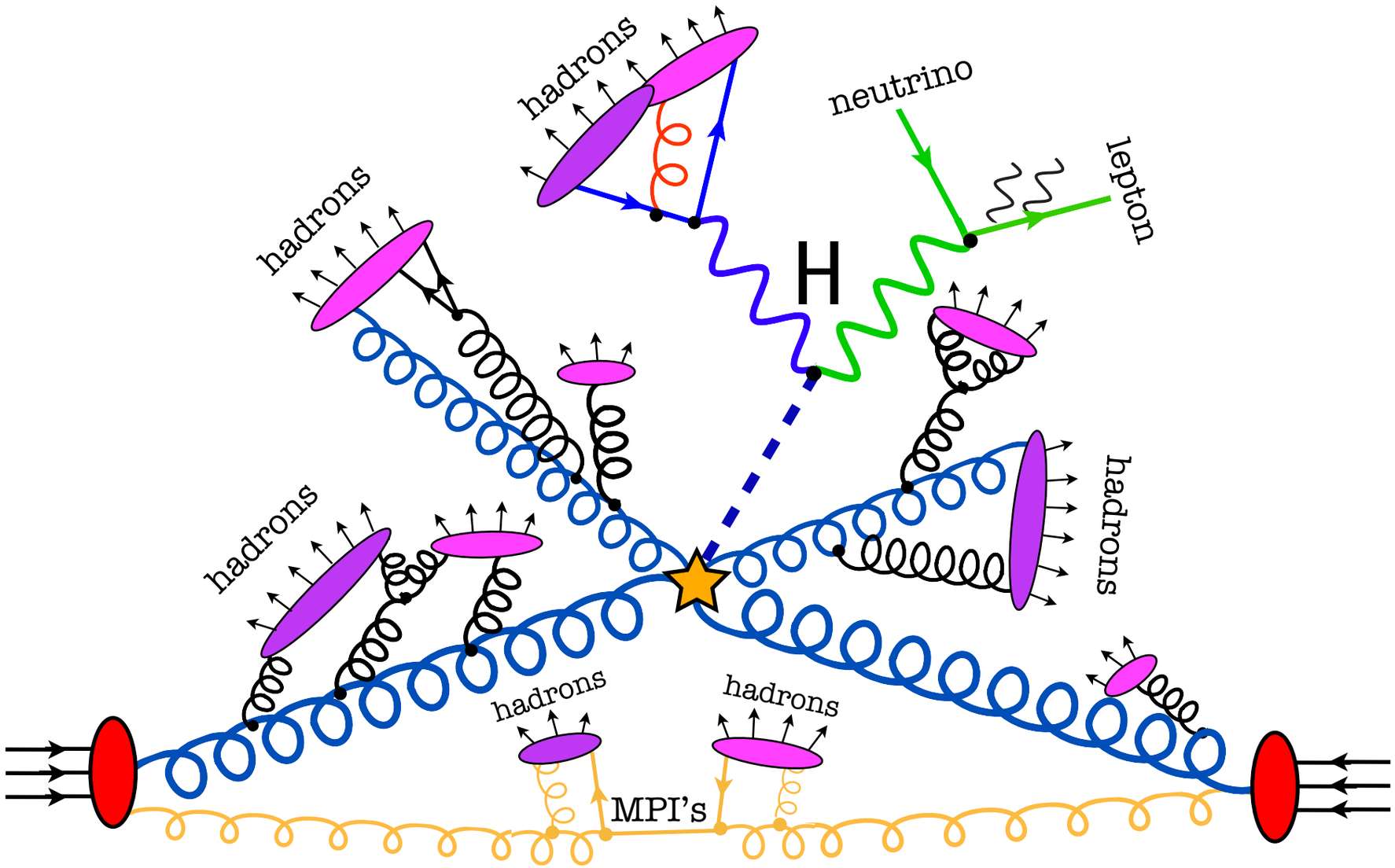
NNLOPS Motivation: for %-level predⁿs should worry about everything

- NNLOPS takes fixed order NNLO as input ...



NNLOPS Motivation: for %-level predⁿs should worry about everything

- NNLOPS outputs NNLO+[N]LL resummed, hadronized, fully exclusive, particle-level, unweighted events, with MPI, with QED ...



- No need for extrapolations, acceptance corrⁿs, effy corrⁿs, shower corrⁿs, non-perturbative corrⁿs, MPI, QED ...

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- STATUS

- PROSPECTS

NNLOPS

- HJ NLO:
  - Unphysical 0-jet obs
  - NLO 1-jet obs
  - LO 2-jet obs
  - 0 everything else

- HJ-MiNLO′ [NLO x NLO]:
  - NLO 0-jet obs
  - NLO 1-jet obs
  - LO 2-jet obs
  - 0 everything else

- HJ-MiNLO′ + PS for $q<q_0$:
  - NLO 0-jet obs
  - NLO 1-jet obs
  - LO 2-jet obs
  - PS everything else

- NNLOPS:
  - NNLO 0-jet obs
  - NLO 1-jet obs
  - LO 2-jet obs
  - PS everything else

- Achieved by NNLO/NLO rwgting the NLO x NLO version of HJ-MiNLO

Nason, Oleari, Zanderighi, k.h. 2012 JHEP 1305 Nason, Re, Zanderighi, k.h. JHEP 1310

vanilla Higgs NNLOPS

- In its most basic form:

  $d\sigma_{NNLOPS} = d\sigma_{MiNLO'} \times W(y_H)$ with $W(y_H) = \dfrac{\frac{d\sigma_{NNLO}}{dy_H}}{\frac{d\sigma_{MiNLO'}}{dy_H}}$

- Since $\frac{d\sigma_{MiNLO'}}{dy_H} = \frac{d\sigma_{NNLO}}{dy_H}$ at NLO ⟶ $W(y_H) = 1+O(\alpha_S^2)$

  so $W(y_H)$ factor only affects $d\sigma_{MiNLO}$ by NNLO terms

- So multiplying $d\sigma_{MiNLO'}$ by the $W(y_H)$ factor for NNLO accuracy

  doesn't spoil NLO accuracy already in $d\sigma_{MiNLO'}$ for ≥ 1 jet obs!

- If $\frac{d\sigma_{MiNLO'}}{dy_H} \neq \frac{d\sigma_{NNLO}}{dy_H}$ at NLO $W(y_H)$ spoils NLO of $d\sigma_{MiNLO'}$ for ≥ 1 jet obs

- Two bottlenecks: i) someone needs to do the NNLO calcⁿ for us;

  ii) we need to figure out how to make the NLO x NLO MiNLO′ calcⁿ

HNNLO is fixed order NNLO code of Catani, Grazzini, Sargsyan 2007/2013 PRL 98/JHEP 1309]

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- Status
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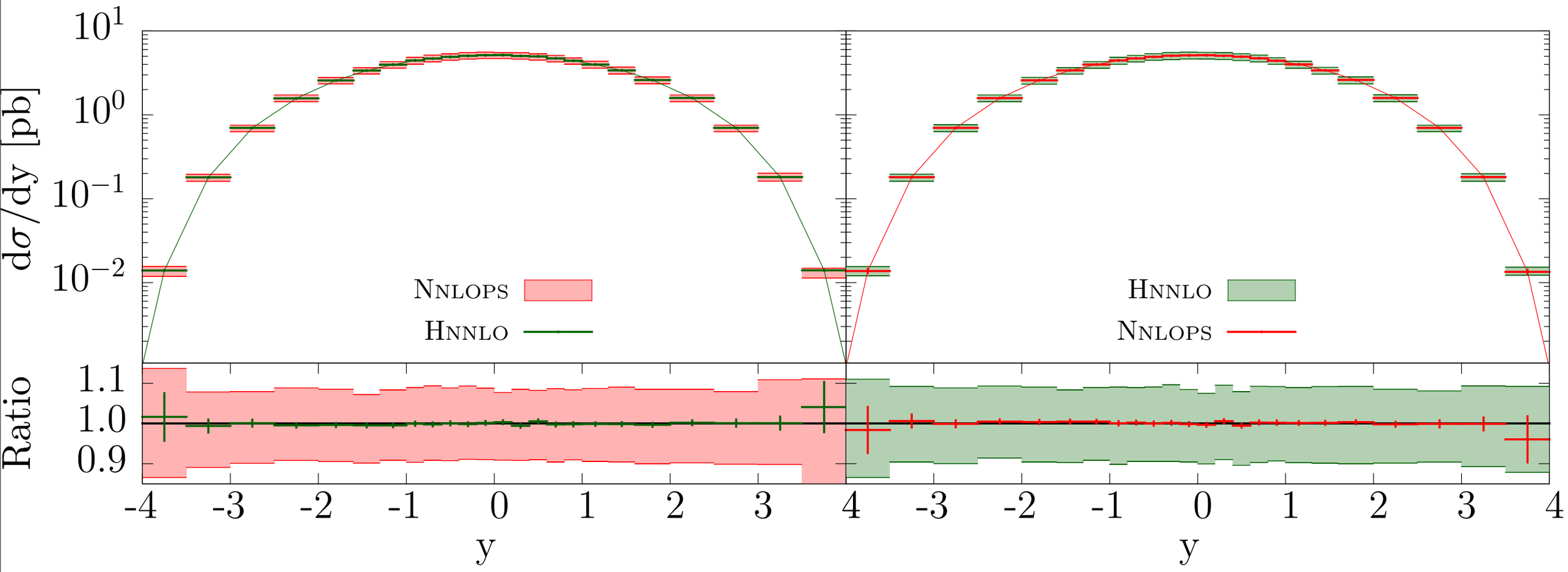
Higgs rapidity: HNNLOPS vs NNLO

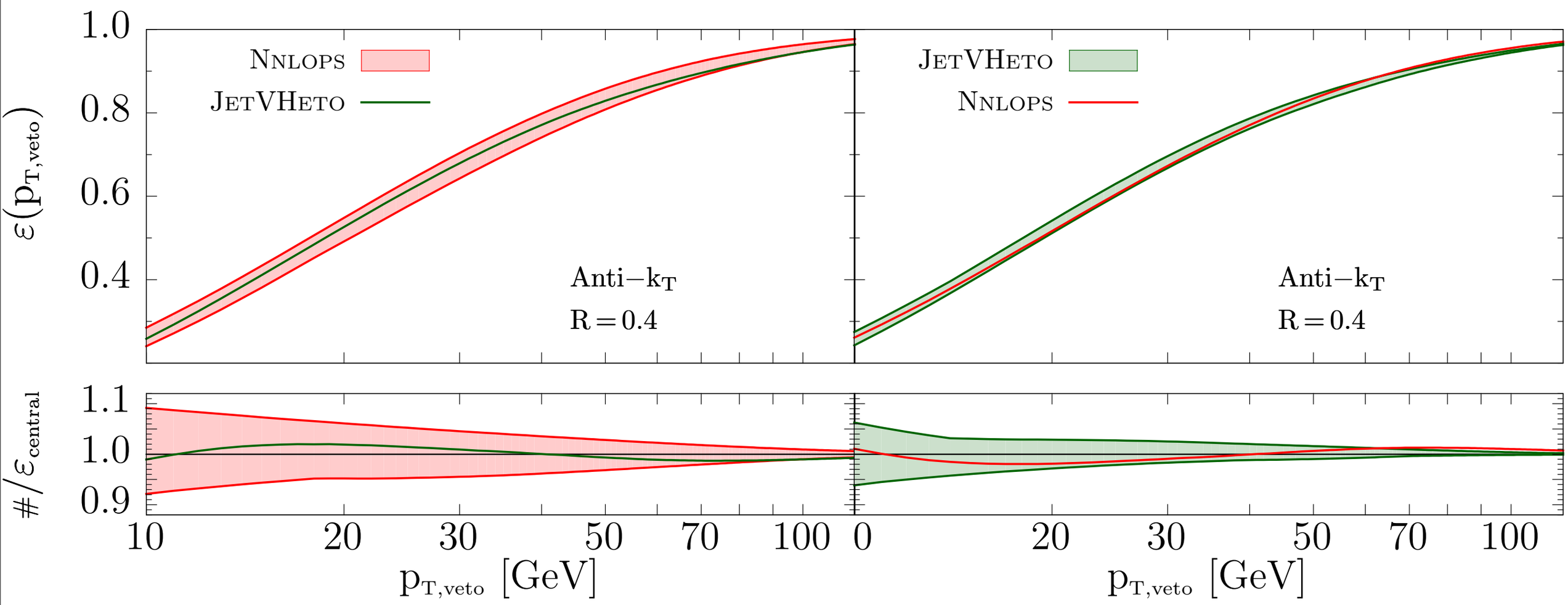


- HNNLO: state-of-the-art fixed order Higgs production calculation [Catani, Grazzini, Sargsyan 2007/2013 PRL 98/JHEP 1309]

- HNNLOPS: as above but with resummed, parton showered, fully exclusive, realistic, hadron level, final-states

Nason, Re, Zanderighi, k.h. JHEP 1310

Jet veto efficiency: HNNLOPS vs NNLO+NNLL

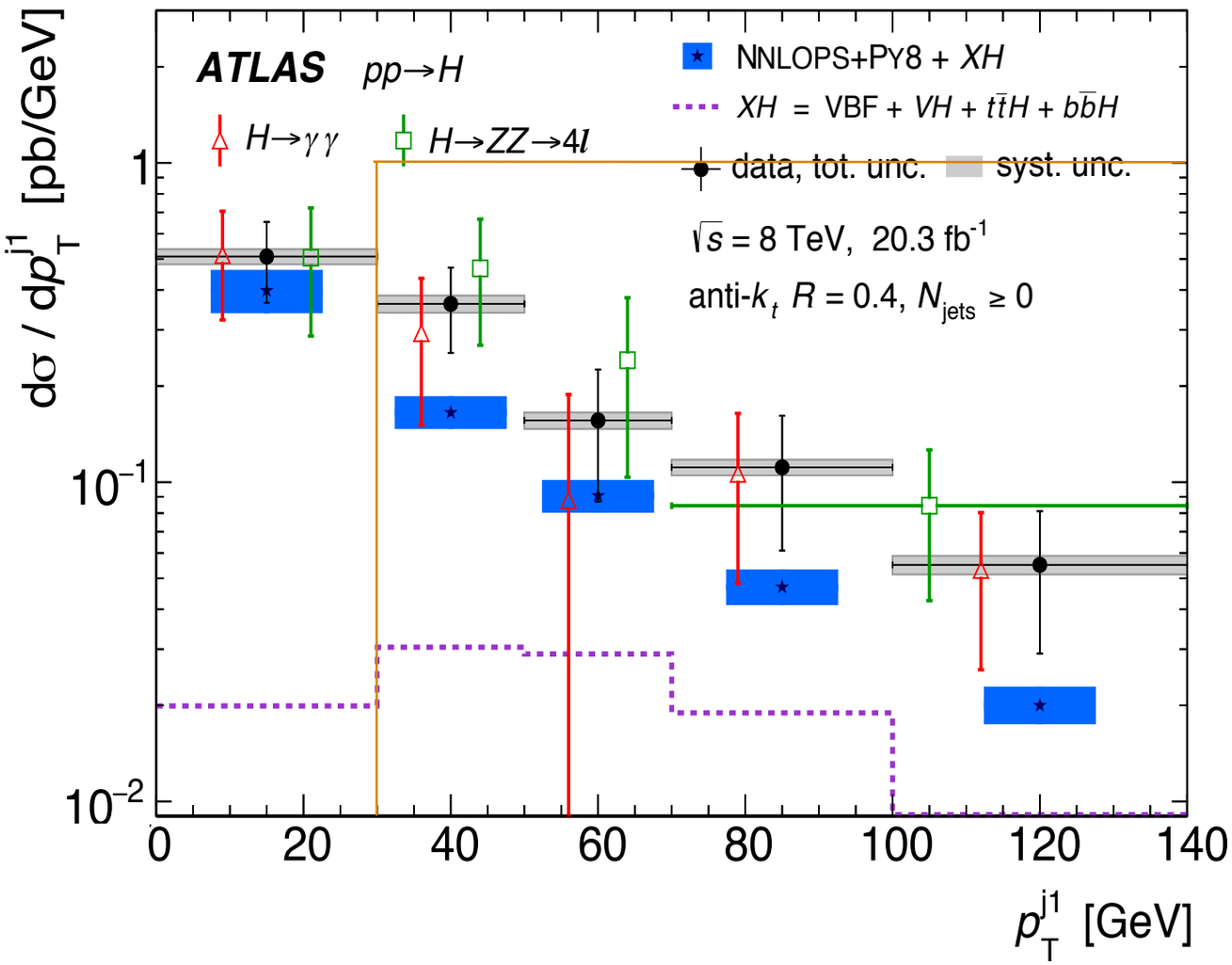


- 0-jet xsec efficiency: $\varepsilon(p_{T,veto}) = \sigma(p_{T,veto}) / \sigma_{tot}$
- JETVHETO: NNLO+NNLL 0-jet xsec effy
  [Banfi, Monni, Salam, Zanderighi 2012 PRL 109]
- HNNLOPS: agreement at level of ≤ 3% everywhere

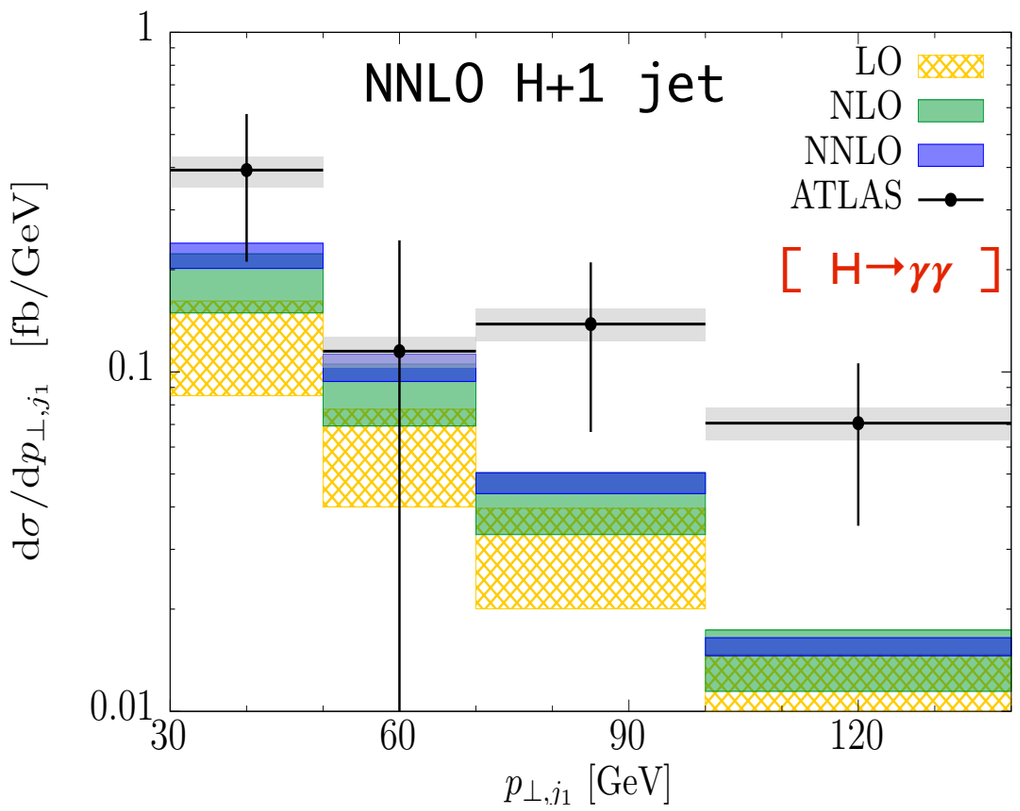
Nason, Oleari, Zanderighi, k.h. 2012 JHEP 1305 Nason, Re, Zanderighi, k.h. JHEP 1310

Jet p_T : HNNLOPS vs ATLAS data

ATLAS PRL 2015



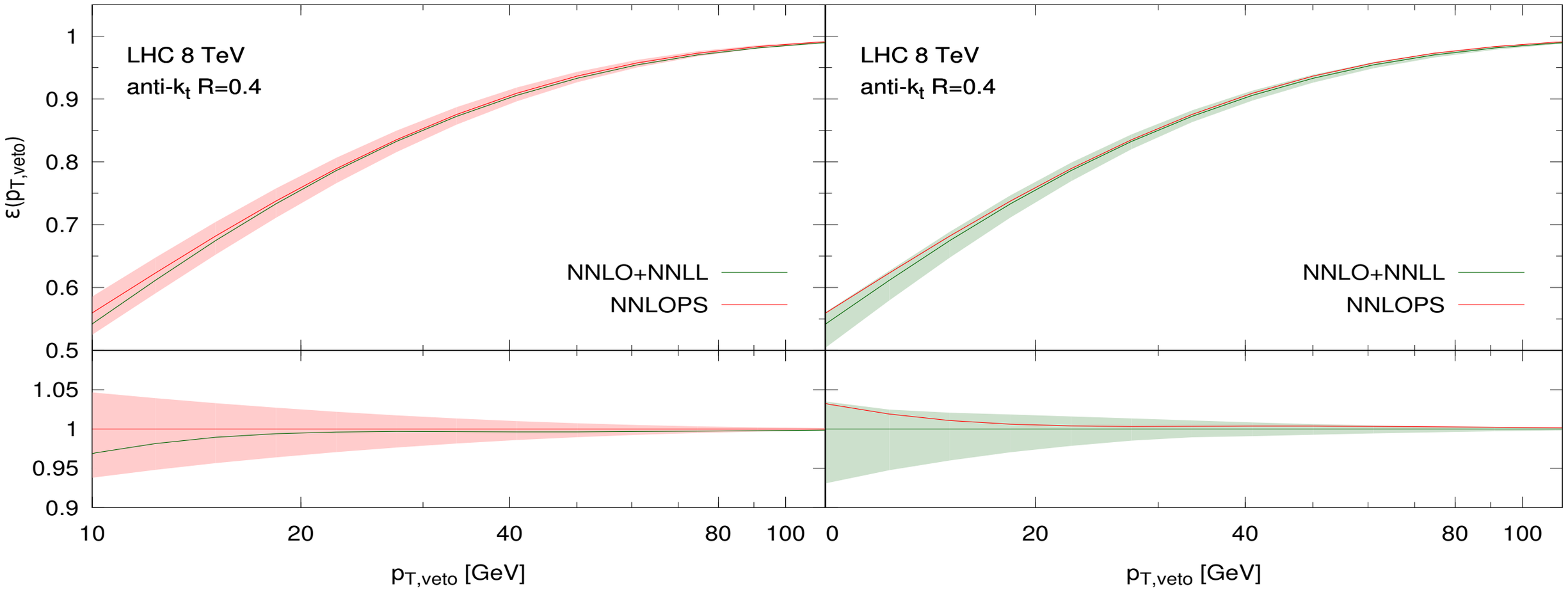
Caola, Melnikov, Schulze
ATLAS JHEP 1409



- Left : NNLOPS vs 20.3 fb^{-1} ATLAS PRL 2015, H → $\gamma\gamma$ △, H → ZZ □, H → ZZ ⊕ $\gamma\gamma$ ⌖
- Right : NNLO H+1 jet vs 20.3 fb^{-1} ATLAS JHEP 1409 H → $\gamma\gamma$
- HNNLOPS [= NLO+resummation for this qty] & state-of-the-art NNLO H+1 jet calc^{n} agree well

Left ATLAS & Nason, Re, Zanderighi, k.h. JHEP 1310 Right: Caola, Melnikov, Schulze arXiv:1508.02684

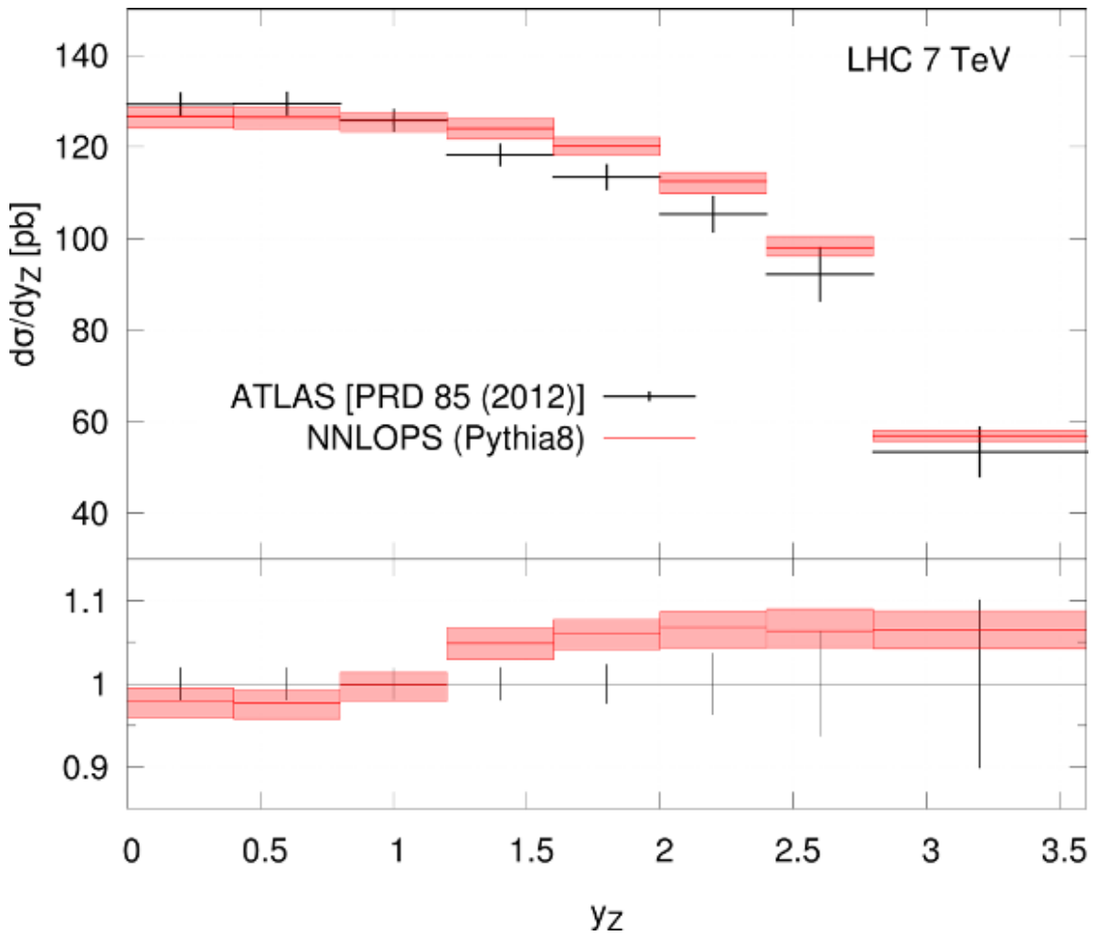
Jet veto efficiency: DYNNLOPS vs NNLO+NNLL

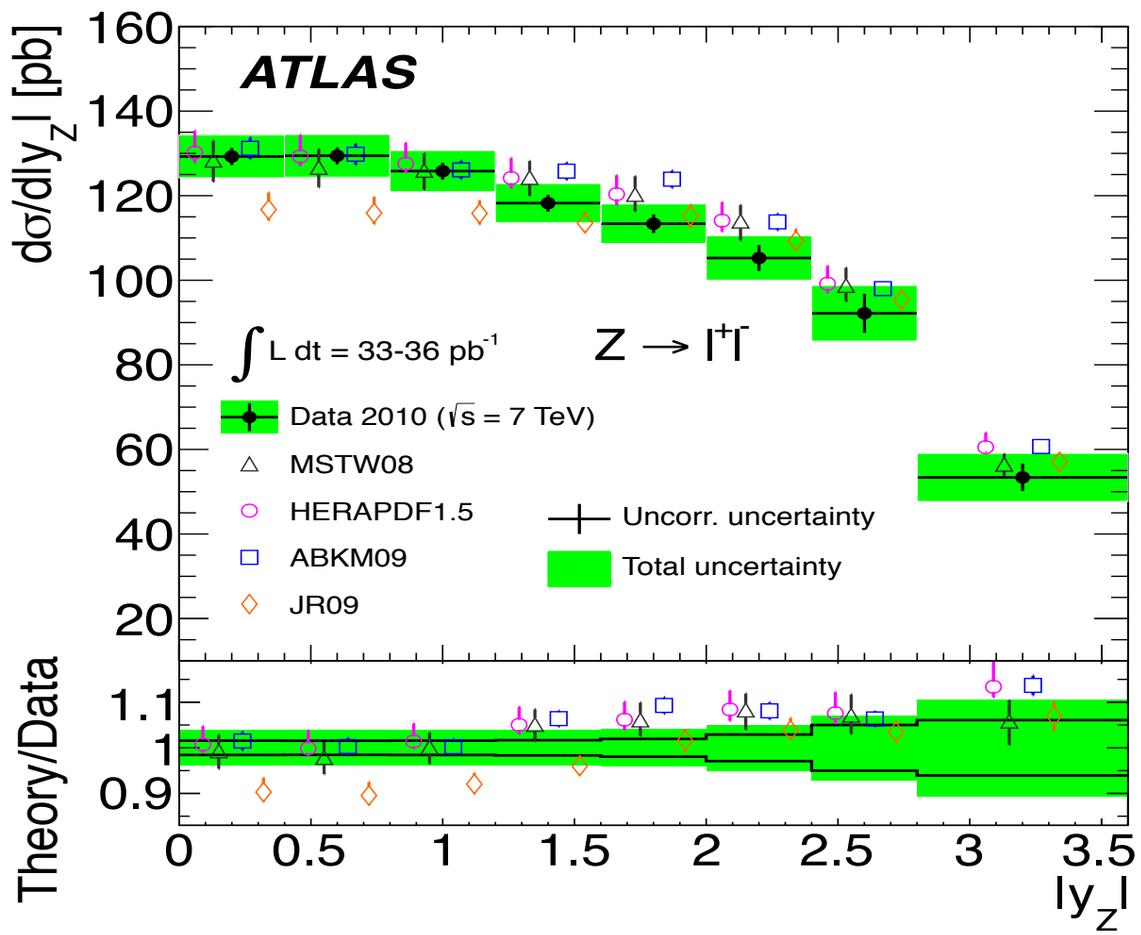


- 0-jet xsec efficiency: $\varepsilon(p_{T,veto}) = \sigma(p_{T,veto}) / \sigma_{tot}$
- JetVHeto: state-of-the-art NNLO+NNLL 0-jet xsec effy
  [Banfi, Monni, Salam, Zanderighi 2012 PRL 109]
- DYNNLOPS: agreement at level of ≤ 3% everywhere [as for HNNLOPS]

Karlberg, Re, Zanderighi 2014 JHEP 1409

Z rapidity: DYNNLOPS on ATLAS data

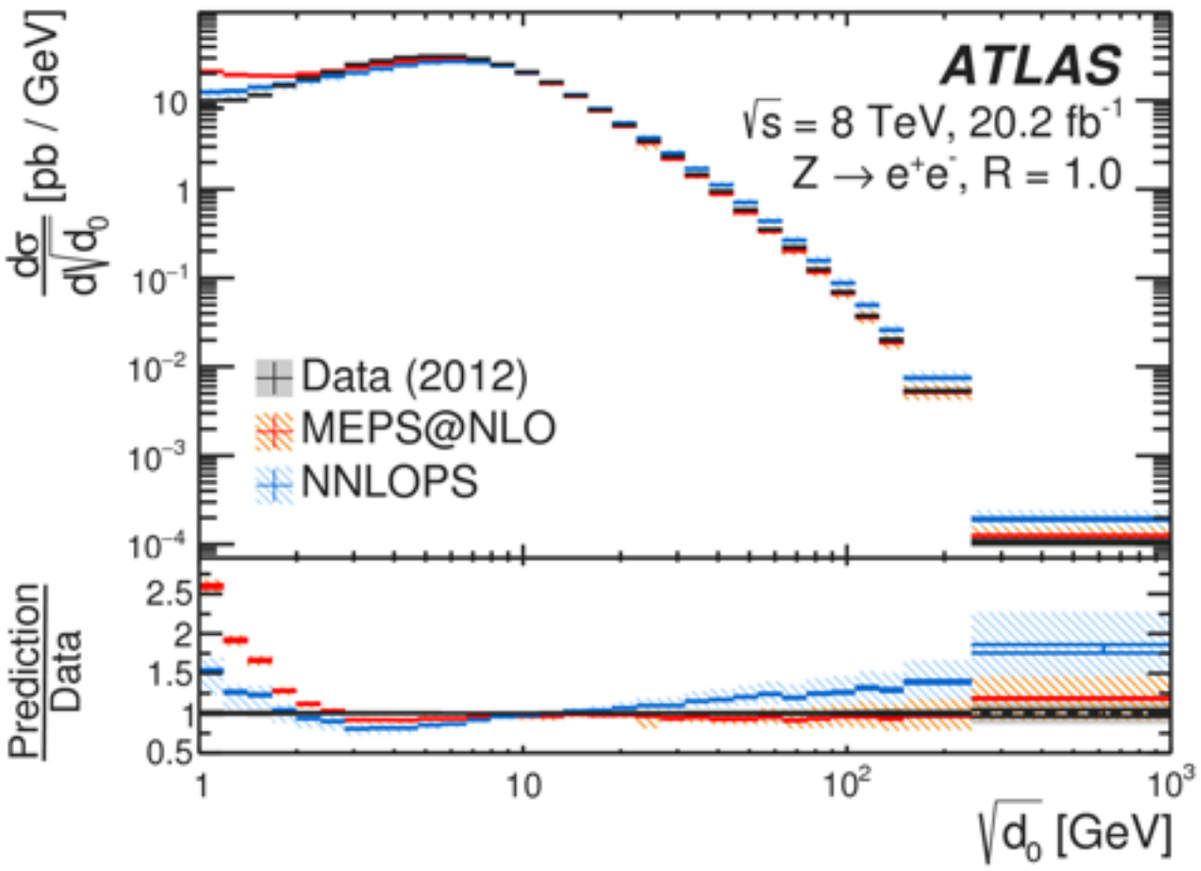


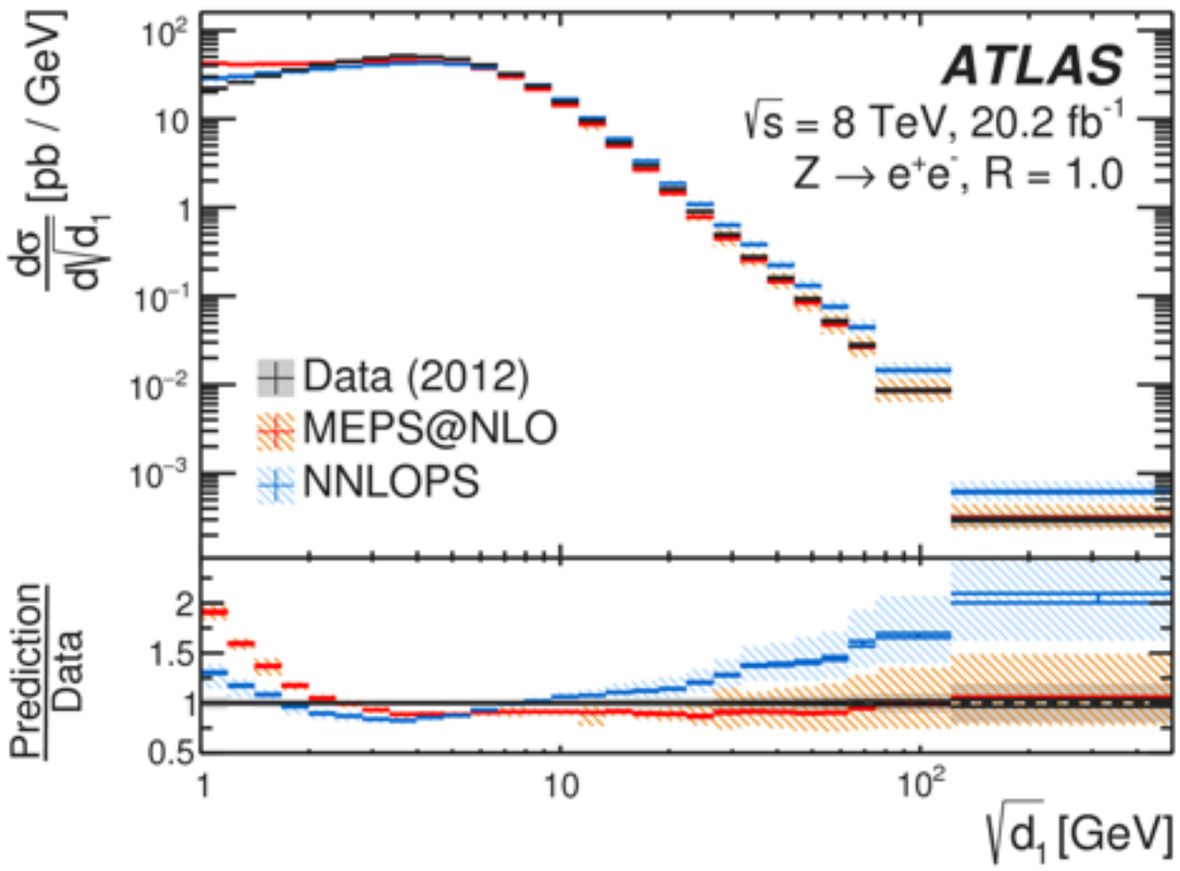


- ATLAS late 2011 incl. Z analysis PRD 85
- Left: DYNNLOPS v data. Right: FEWZ with various PDFs v data ...
- Good agreement for central region, less so at high $|y_Z|$
- DYNNLOPS v.compatible with independent fixed order FEWZ NNLO

Karlberg, Re, Zanderighi 2014 JHEP 1409 ATLAS 2011 PRD 85

k_T splittings scales: DYNNLOPS on 8 TeV ATLAS data

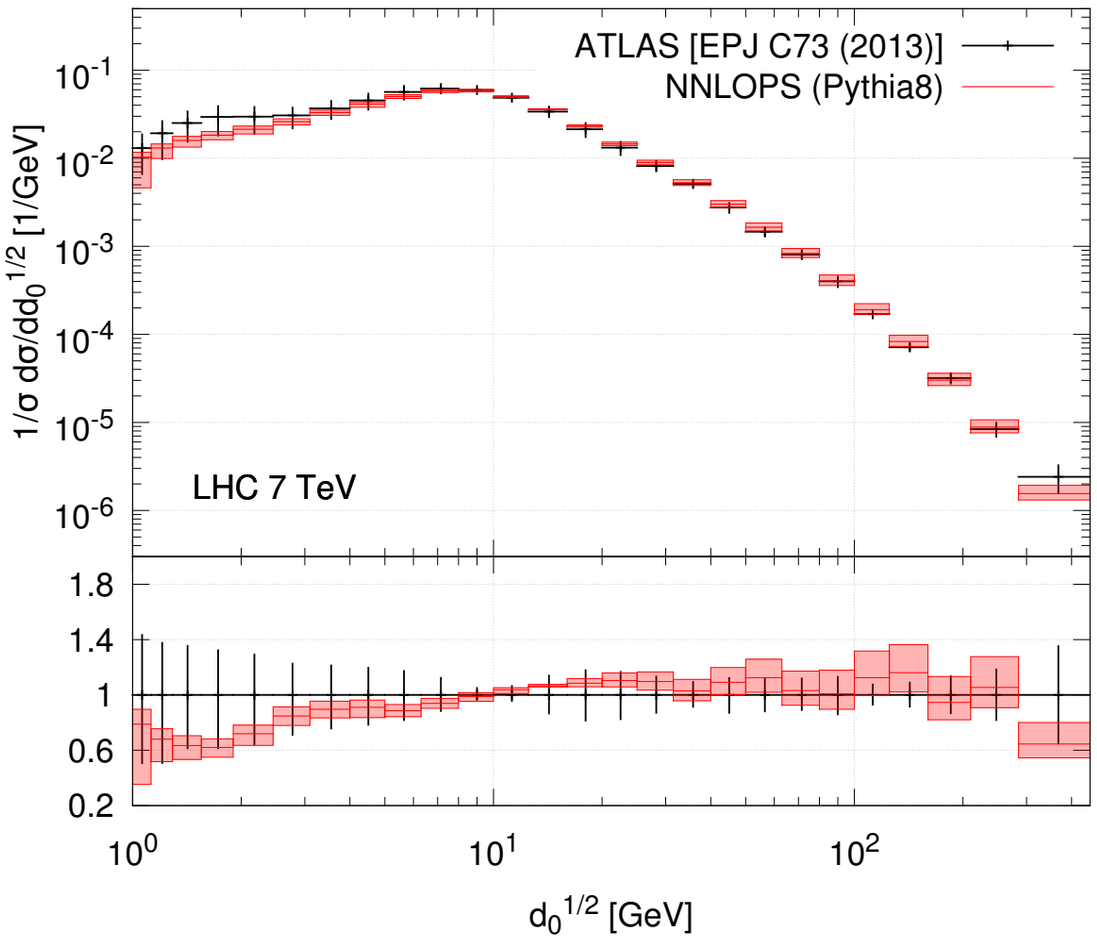


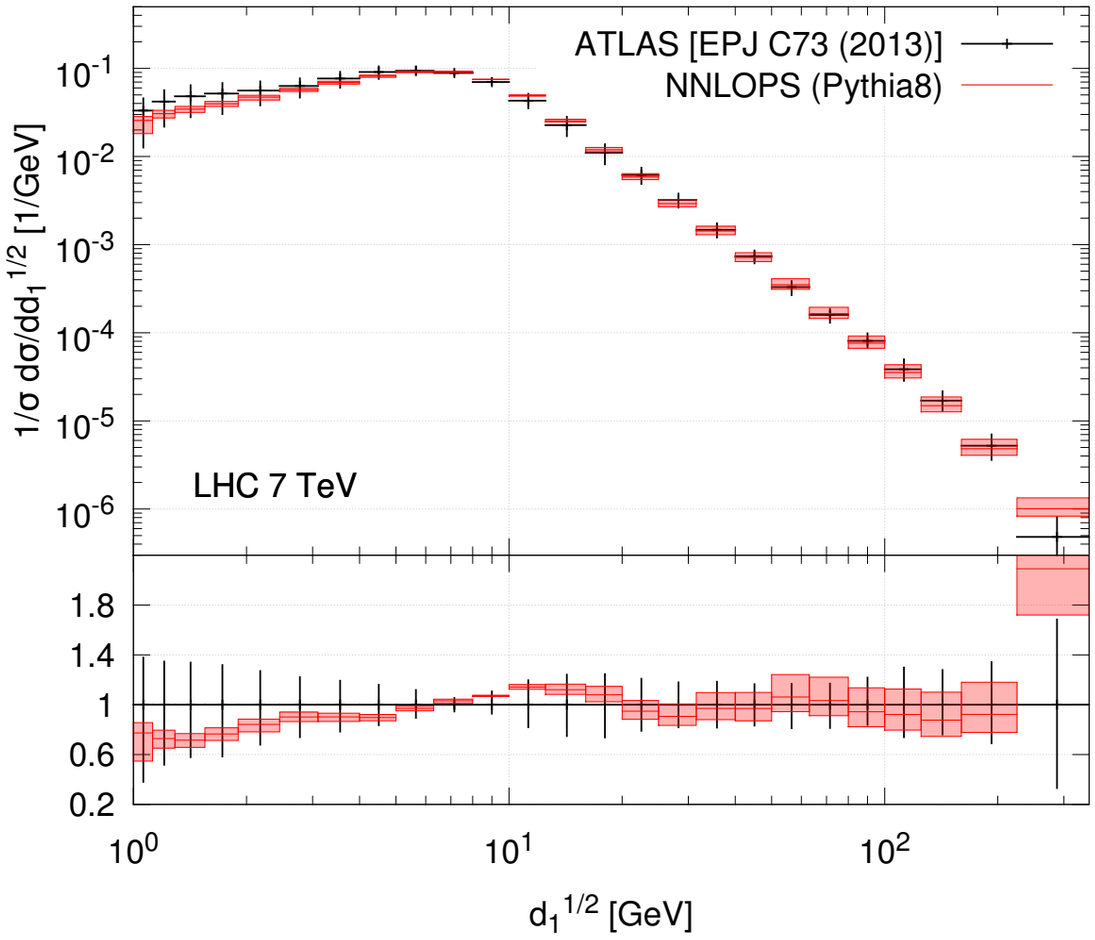


- Recent 8 TeV ATLAS 2017 k_T jet rates [R=1.0, not normalised]
- DYNNLOPS+PYTHIA8 blue, SHERPA MEPS@NLO red
- DYNNLOPS+PYTHIA8 high for $\sqrt{d_0} \gtrsim 150$ GeV and $\sqrt{d_1} \gtrsim 30$ GeV ...

ATLAS collaboration 2017 arXiv:1704.01530
Submitted to JHEP

k_T splittings scales: DYNNLOPS on 7 TeV ATLAS data





- Older 7 TeV W+jets ATLAS 2013 k_T jet rates [R=0.6, normalised]
- DYNNLOPS+PYTHIA8 looking fine here, no sign of 8 TeV issues
- Not like-4-like: Z/W, 7/8 TeV, unnormalised/normalised, R=1/R=0.6
- Now investigating why W+jets 7 TeV comp. OK, but not Z+jets 8 TeV

Karlberg, Re, Zanderighi 2014 JHEP 1409

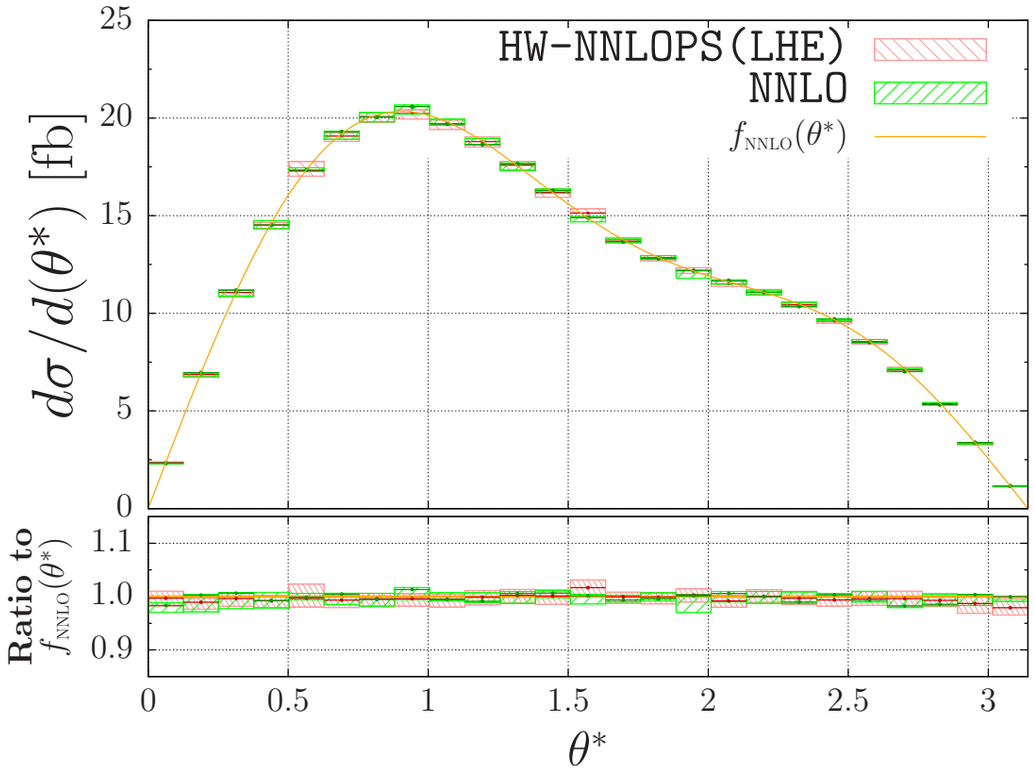
ATLAS collaboration 2013 arXiv:1302.1415

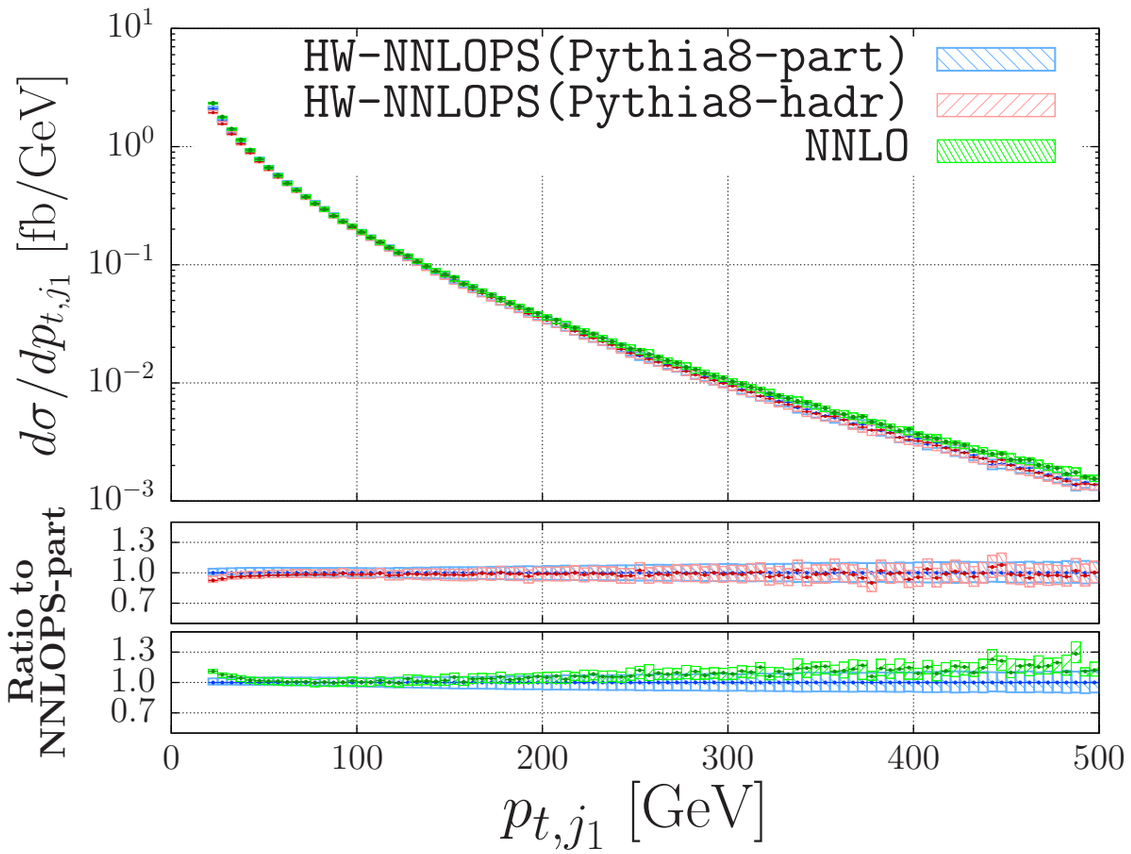
WH NNLOPS

To reweight, use $(y_{\mathrm{HW}}, \Delta y_{\mathrm{HW}}, p_{t,\mathrm{H}})$ + Collins-Soper angles

$$\frac{d\sigma}{d\Phi_B} = \frac{d\sigma}{dy_{\mathrm{HW}}\, d\Delta y_{\mathrm{HW}}\, dp_{t,\mathrm{H}}\, d\cos\theta^* d\phi^*}$$

$$= \frac{3}{16\pi}\left(\frac{d\sigma}{d\Phi_{\mathrm{HW}^*}}(1+\cos^2\theta^*) + \sum_{i=0}^{7} A_i(\Phi_{\mathrm{HW}^*}) f_i(\theta^*,\phi^*)\right)$$





- left plot: angular dependence in slice of y_{HW}
- right plot: hardest-jet spectrum

Will Astill, Wojciech Bizoń, Emanuele Re, Giuia Zanderighi 2016 JHEP 06 (2016) 154

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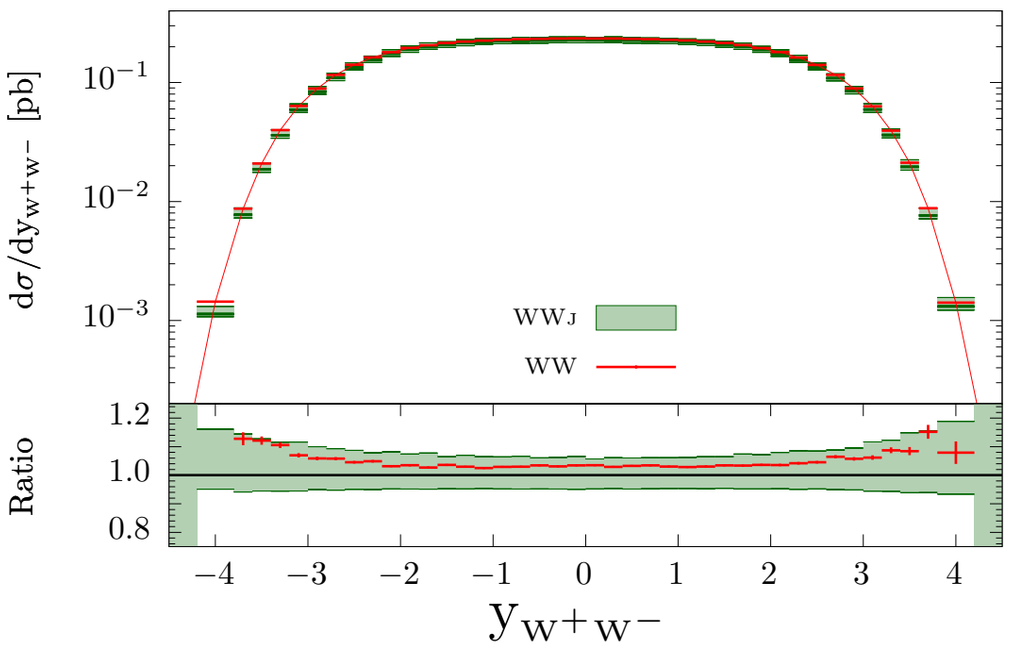
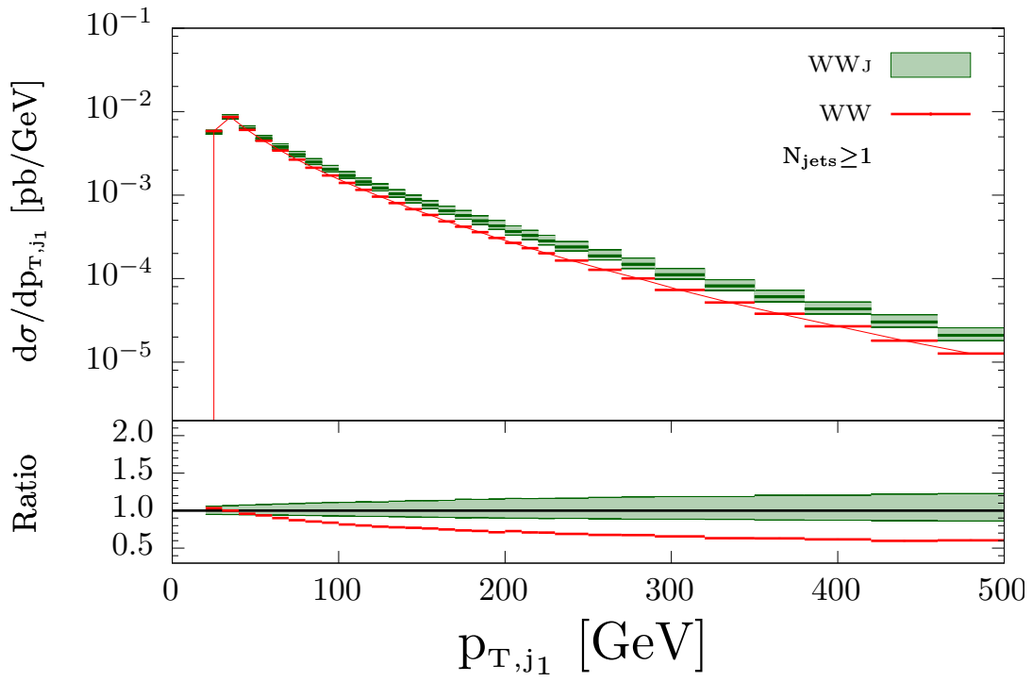
- STATUS
- PROSPECTS

PROSPECTS: VVNNLOPS

- WWJ-MiNLO′ code produced last year
- Formalism extended from 2 → 1 colourless to 2 → 2 colourless:
- Process dependent Drell-Yan/Higgs B_2 Sudakov coeffs are just numbers while for VV it's a function of VV Born kinematics
- WWJ-MiNLO′ simultaneously NLO for WW and WWJ w.o. any merging scale





- If there is demand VVNNLOPS can follow by rwgting VV kinematics of VVJ-MiNLO′ with analogous NNLO predictⁿs of the Zurich group.

Tom Melia, Pier Monni, Emanuele Re, Giulia Zanderighi, k.h. 2016 JHEP 09(2016)057

PROSPECTS: NNLOPS shortcomings & improvements

- Not easy to run: need separate [long] run of HNNLO/DYNNLO/ MATRIX/... followed by feeding-in of that output to rwgt MiNLO'

  - Embed specialised reweightings in MiNLO' codes: select these perturbative "tunes" in input file

- Reweighting code is crude: bins not optimised, selection of Born variables not optimised, no interpolation

  - Use Neural Net techniques for reweighting

- Resummation only guaranteed to be NLL_σ despite sometimes extremely nice accidental agreement with NNLL codes

  - Rwgt to <u>differential</u> NNLO+NNLL

    e.g. MiNLO+MRT, [MiNLO+MATRIX??]

Pier Monni, Emanuele Re, Paolo Torrielli

Massimiliano Grazzini, Stefan Kallweit, Stefano Pozzorini, Dirk Rathlev, Marius Wiesemann

PROSPECTS: Extending the MiNLO method

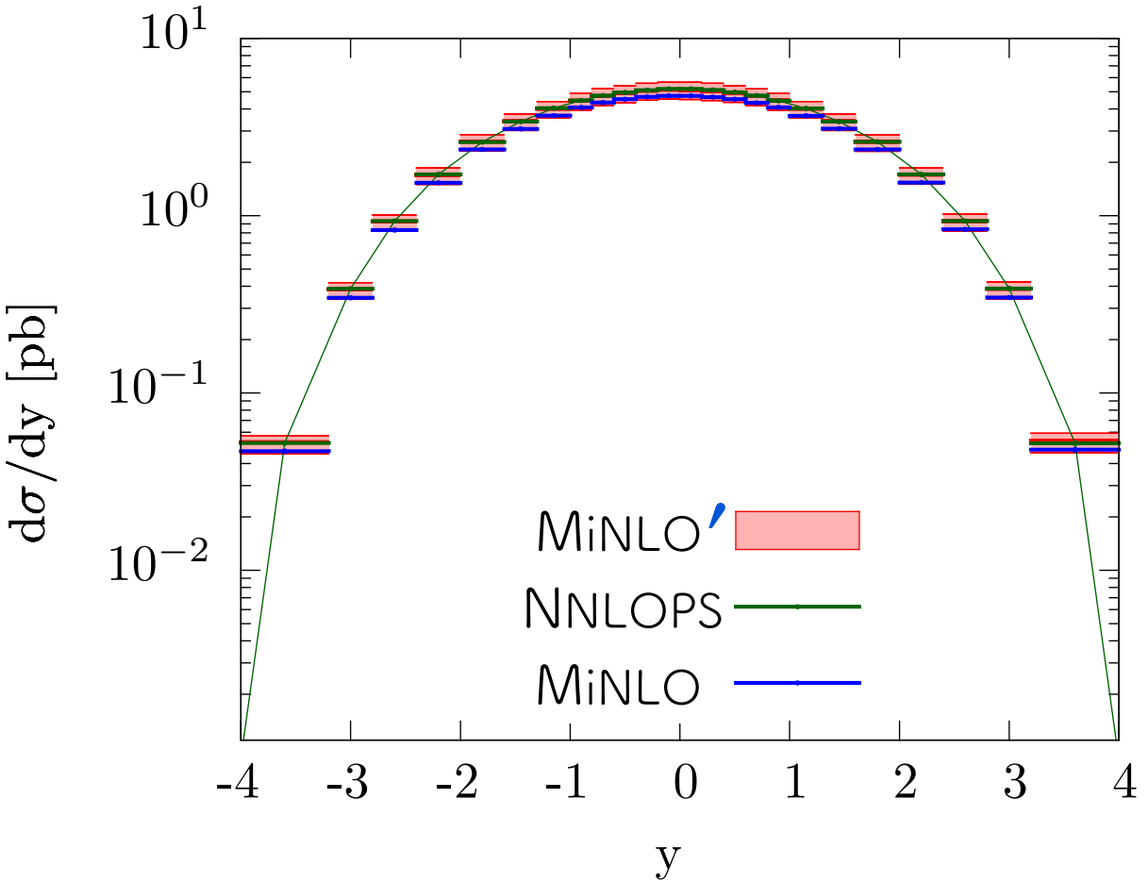
- NNLOPS relies on having related MiNLO′ simulation
- MiNLO′ means NLO for Born AND NLO for the ‘Born-of-the-Born’
- Achieved by precise analytic knowledge of needed MiNLO Sudakov FF’s
- Only known for very limited no. of procs and clustering variables

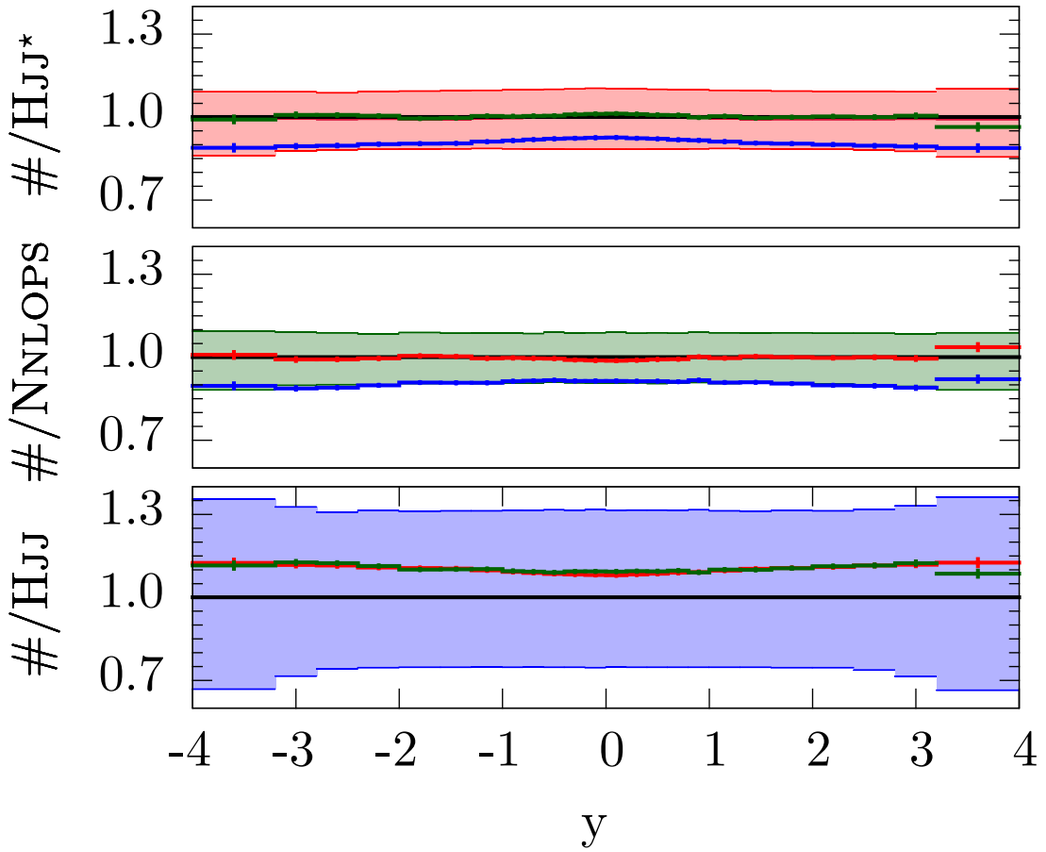
- Proposal: use well-known NLO for ‘Born-of-the-Born’ to fit very well-unknown Sudakov factors
- Tried out to make HJJ-MiNLO into HJJ-MiNLO′
- Good results despite quick & dirty implementation

Rikkert Frederix, k.h. JHEP 1605 (2016) 042

PROSPECTS: Extending the MiNLO method

Higgs rapidity



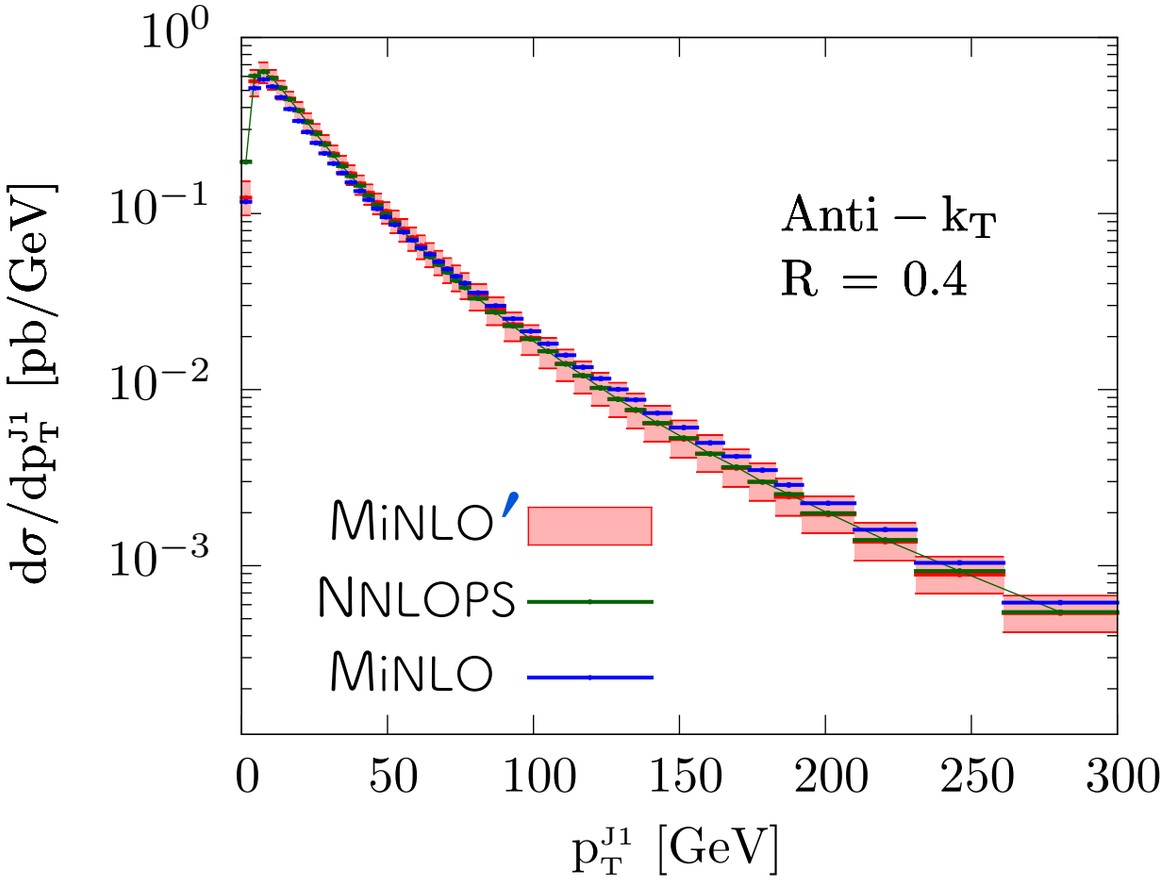


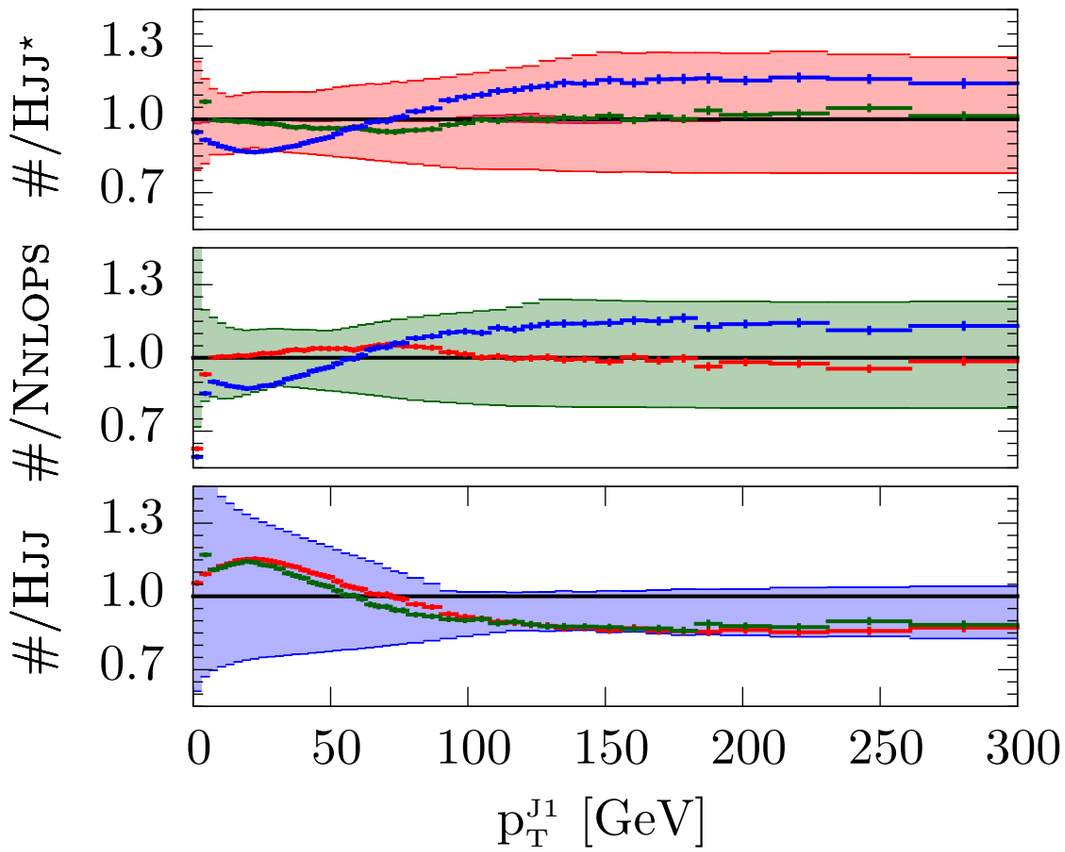
- MiNLO′ H+2-jets: red, formally NNLO
- HNNLOPS: green, formally NNLO
- MiNLO H+2-jets: blue, formally not quite LO

Rikkert Frederix, k.h. JHEP 1605 (2016) 042

PROSPECTS: Extending the MiNLO method

Leading jet transverse momentum





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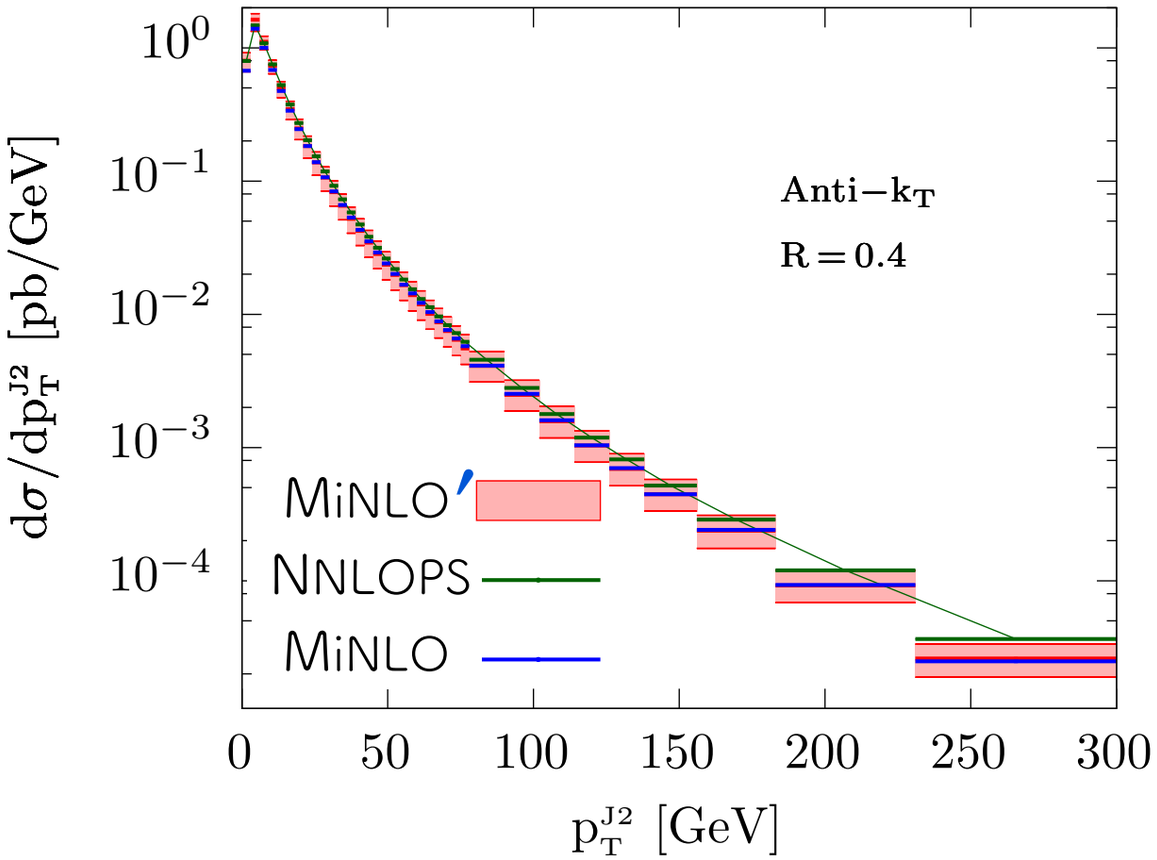
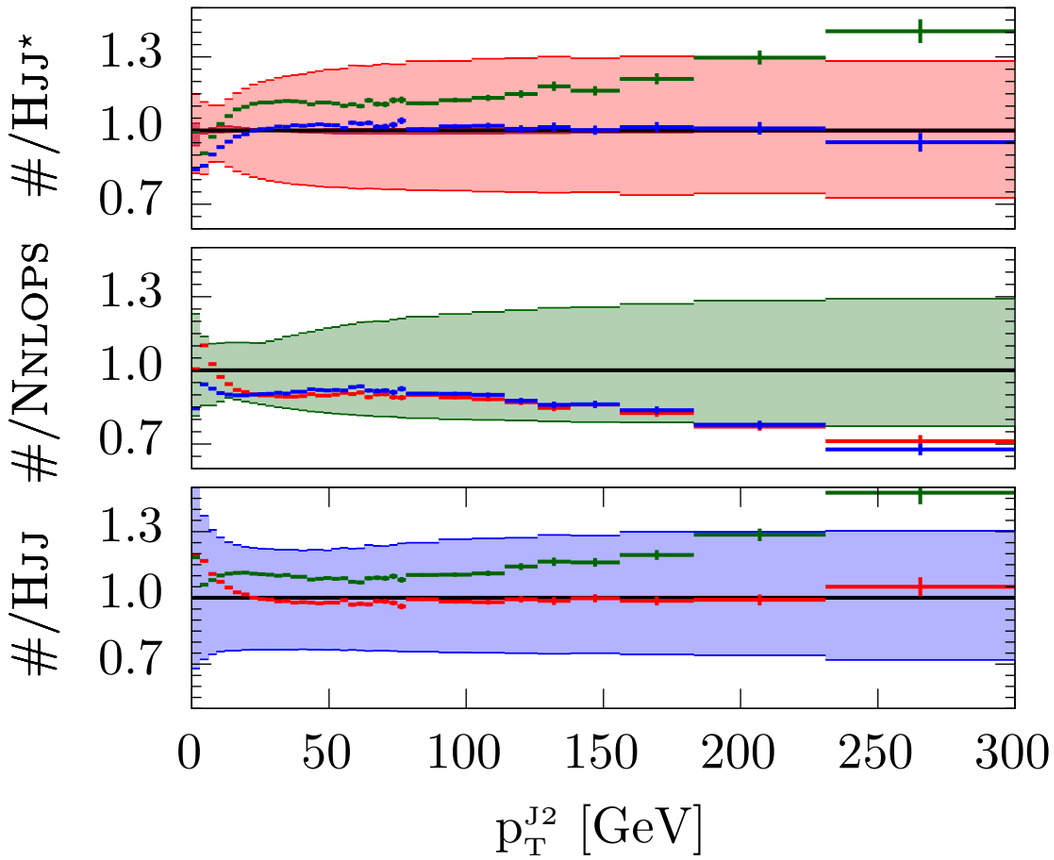
Rikkert Frederix, k.h. JHEP 1605 (2016) 042

PROSPECTS: Extending the MiNLO method

Second jet transverse momentum





- MiNLO′ H+2-jets: red, formally NLO
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Rikkert Frederix, k.h. JHEP 1605 (2016) 042

PROSPECTS: Extending the MiNLO method

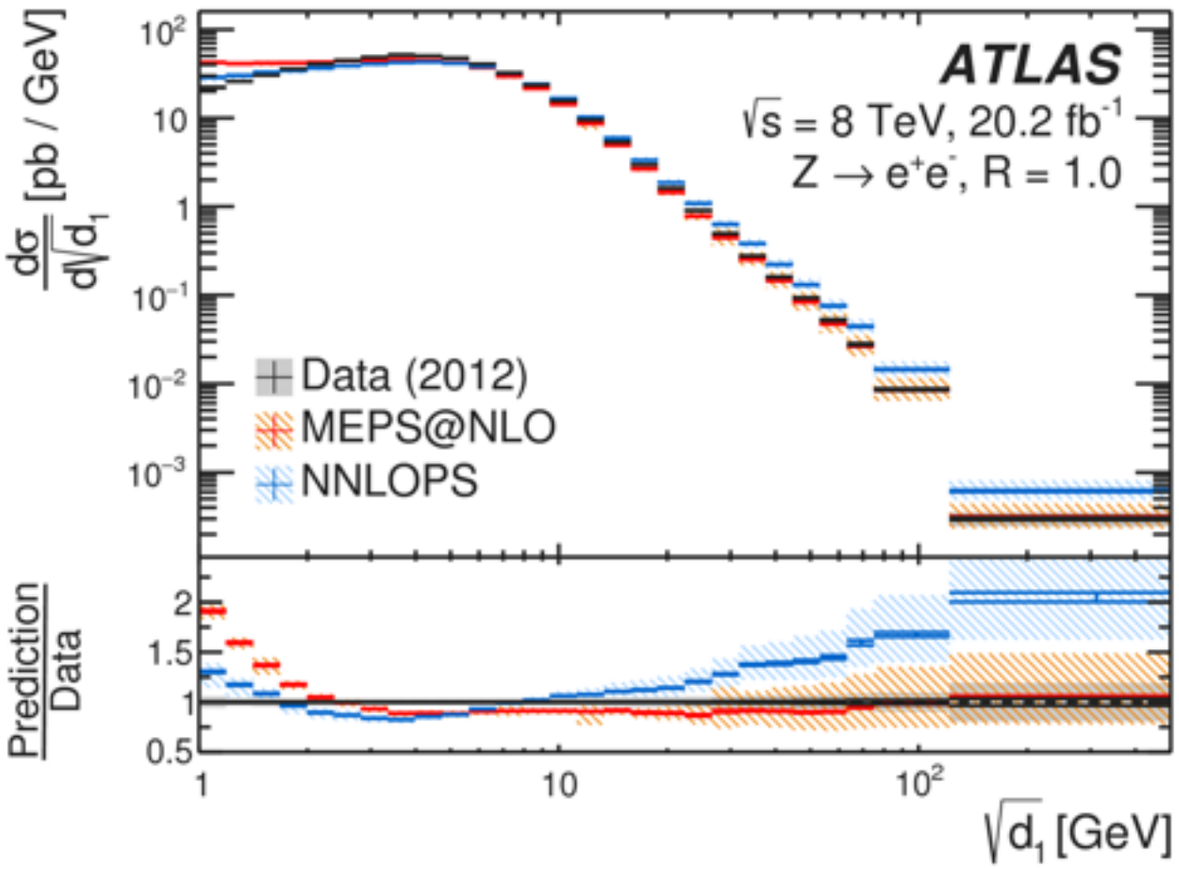
- Going from MiNLO′ H+2-jets to NNLOPS H+1-jet should be a matter of reweighting to NNLO H+1-jet Born kinematics

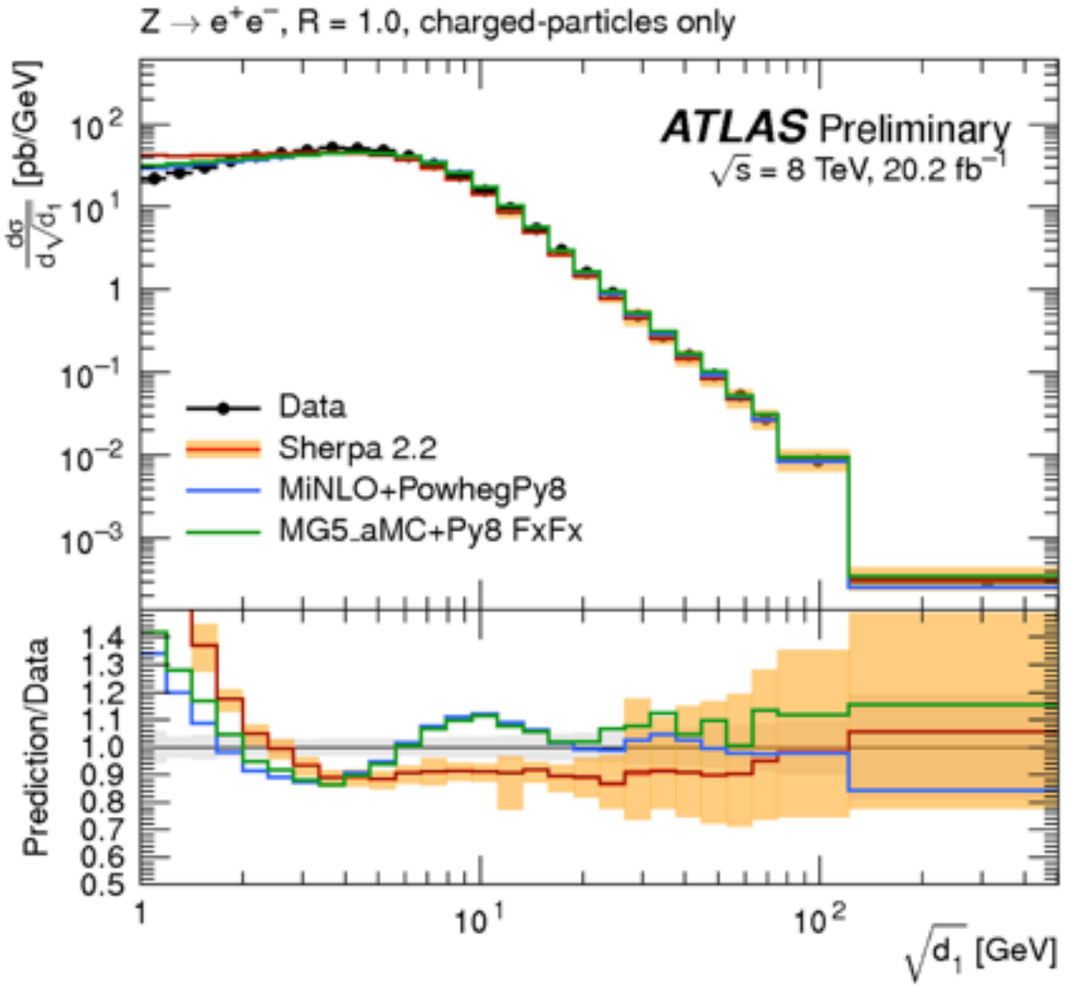
- Will do after the general improvements to NNLOPS infrastructure

- NNLOPS W/Z+jet is just the same but numerics will prove HARD due to SMALL NNLO uncertainties & higher dimensional ph.space

Rikkert Frederix, k.h. JHEP 1605 (2016) 042

k_T splittings scales: DYNNLOPS on 8 TeV ATLAS data





- Left ATLAS collaboration 2017 arXiv:1704.01530
- Right ATL-PHYS-PUB-2017-006
- By default NNLOPS rwgting is constructed to leave $p_{T,J1} \gtrsim m_Z$ description of ZJ-MiNLO′ phase space totally unchanged

ATLAS collaboration 2017 arXiv:1704.01530
Submitted to JHEP