Latest developments in event generators

Keith Hamilton

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What to talk about

- Feed author lists of PYTHIA 8, HERWIG 7, SHERPA, POWHEG, MG5_aMC@NLO, HEJ, DEDUCTOR, GENEVA into iNSPIRE

- Select > 2017, primarch hep-ph, deselect proceedings

- 70 articles

- Pull out those focusing on & implementing SM event generator developments
  [heavy ions not in ATLAS SM analysis group]

- 17 articles [too many → see also backups]

- Soft QCD, NLO EW, [N]NLOPS, Parton Showers, Misc

Soft QCD

- PYTHIA 8

  Models for total, elastic and diffractive cross sections

  Christine Rasmussen, Torbjörn Sjöstrand

  The Space-Time Structure of Hadronization in the Lund Model

  Silvia Ferreres-Solé, Torbjörn Sjöstrand

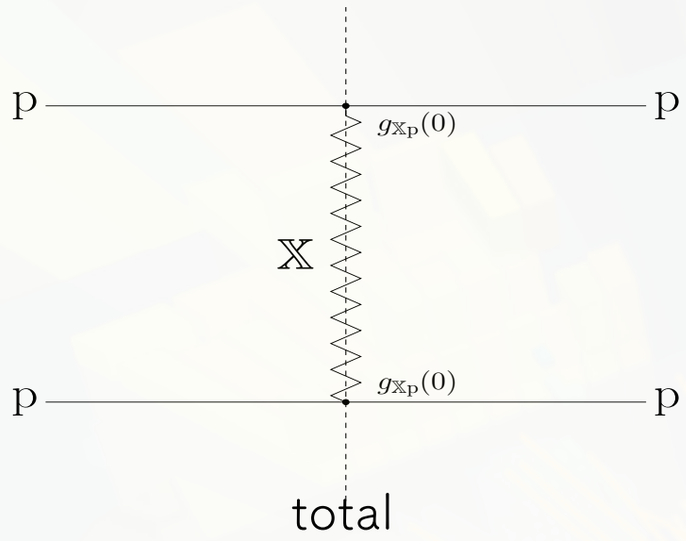
- HERWIG 7

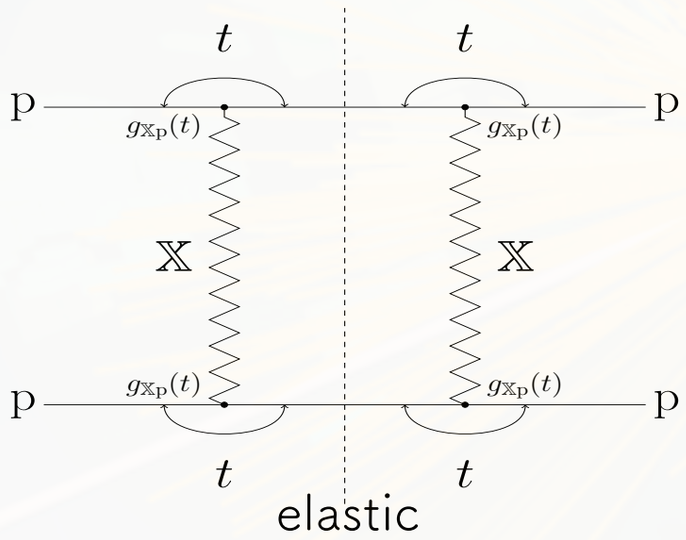
  Colour Reconnection from Soft Gluon Evolution

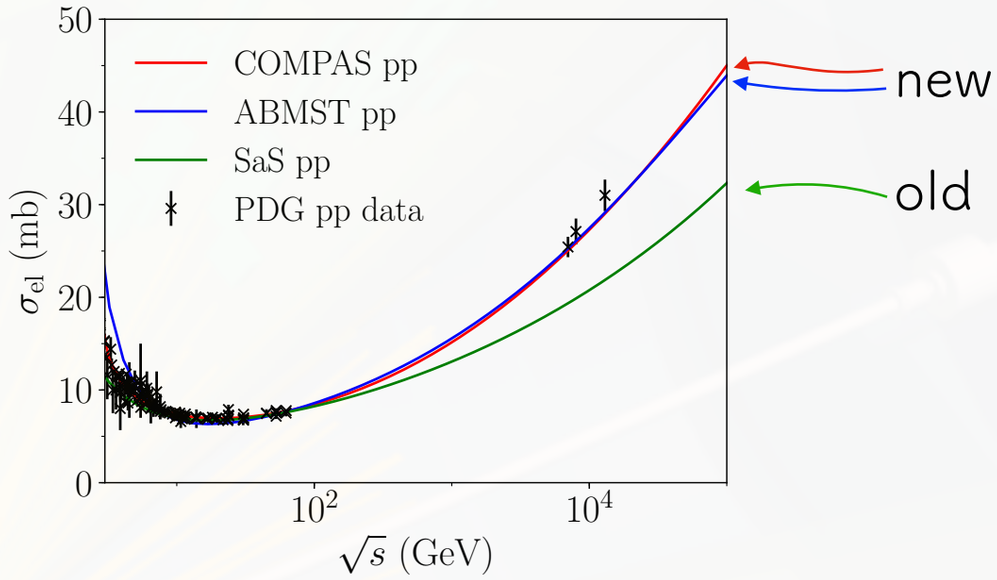
  Stefan Gieseke, Patrick Kirchgaeßer, Simon Plätzer, Andrzej Siodmok

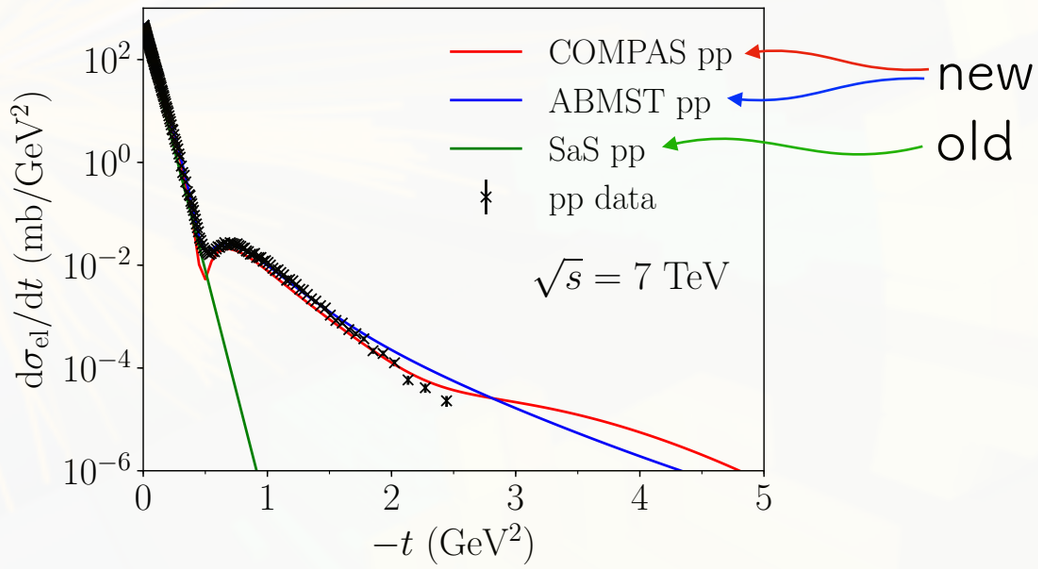
Soft QCD : Improved total, elastic & diffractive xsec models in Pythia8

Squared MEs







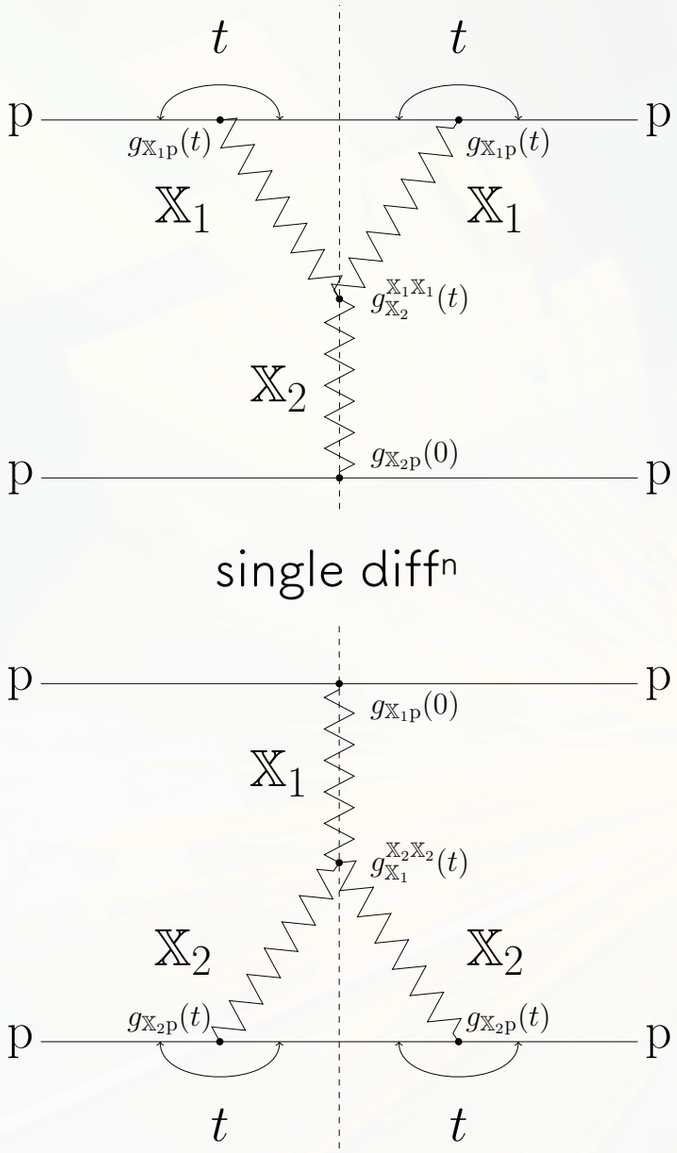


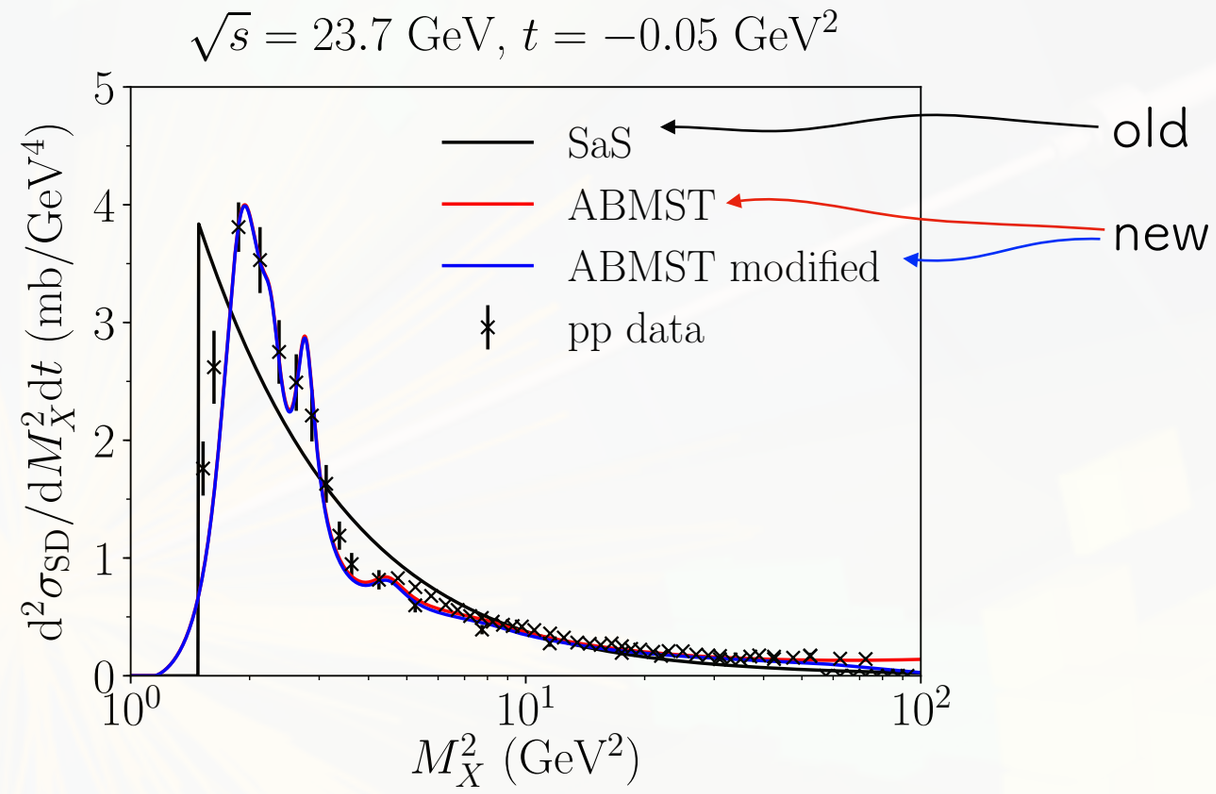
- Pythia 8 total & elastic xsecⁿ descⁿ based on single Pomeron/Reggeon exchange [SaS in plot] updated to modern parametrizations [ABMST, COMPAS] with more sophistication in terms of exchanges X: much improved description of LHC data

Christine Rasmussen, Torbjörn Sjöstrand

Soft QCD : Improved total, elastic & diffractive xsec models in Pythia8

Squared MEs



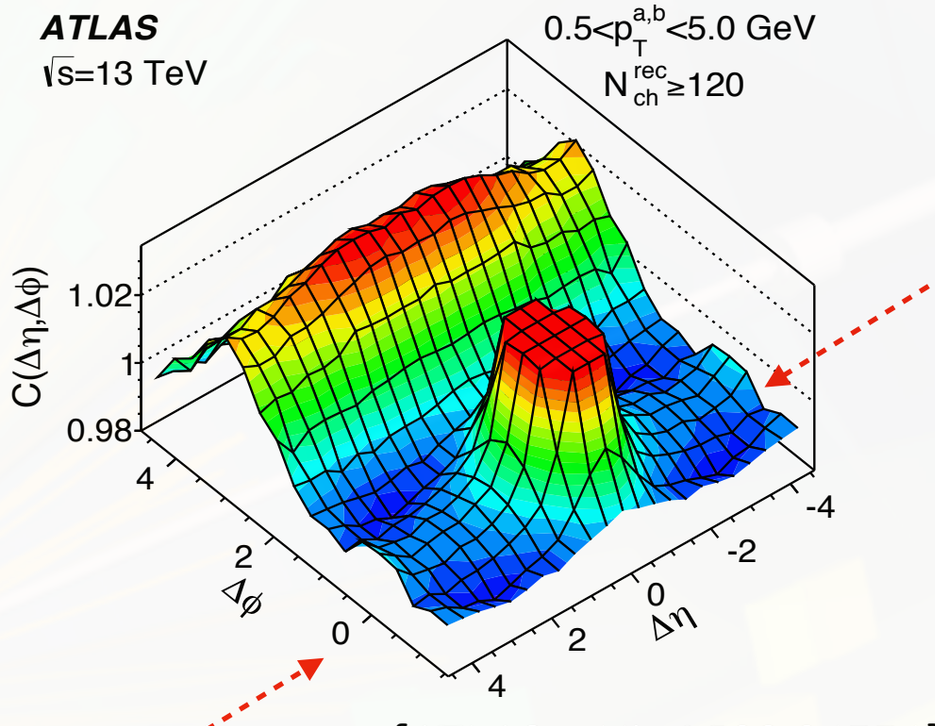


- Diffraction also subject to significant update based on ABMST model with important additions [double & central diffaction] & modifications [high energy]
- Improved description including also resonance shape in low-mass region

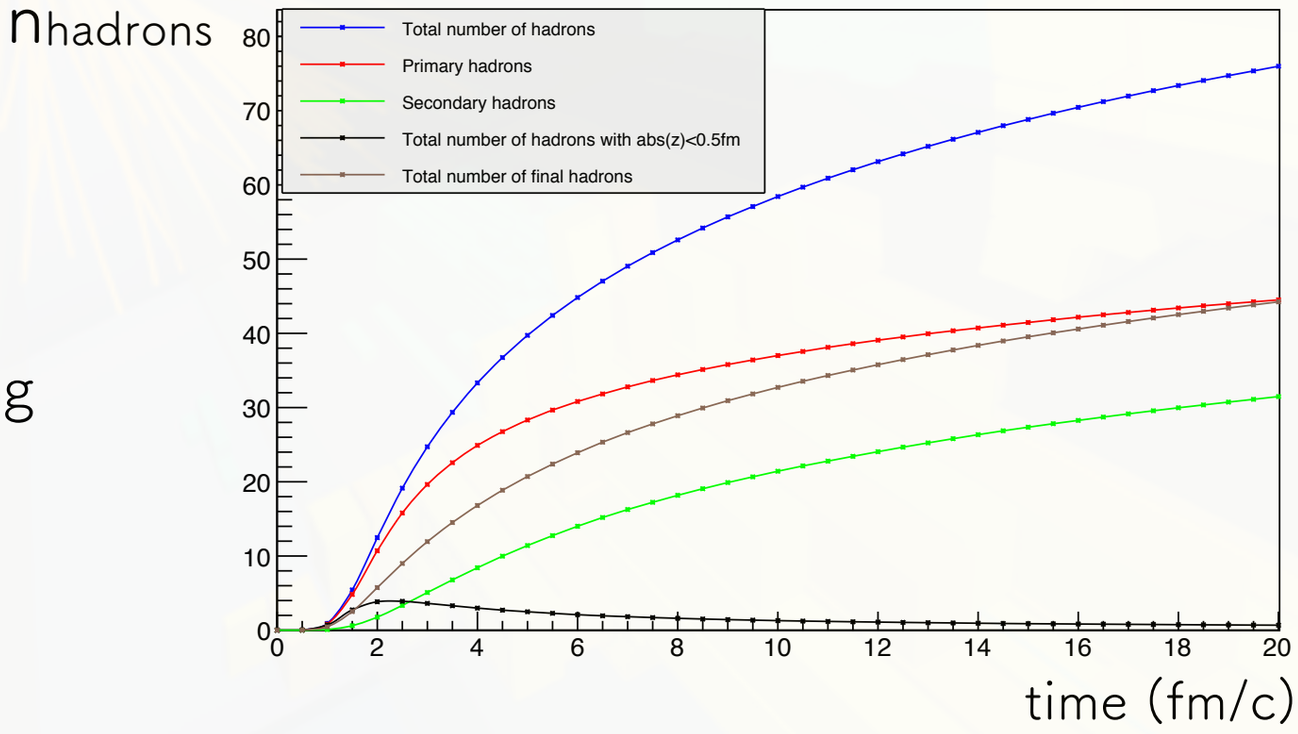
Christine Rasmussen, Torbjörn Sjöstrand

Soft QCD : Space-Time Structure of Hadronization in Pythia 8

- High multiplicity pp collisions display characteristics resembling heavy-ions
- E.g. two-particle correlⁿs as fⁿ of $\Delta\eta$, $\Delta\phi$ exhibit `ridge' at $\Delta\phi \sim 0$
- Models of collective phenomena based on QGP and/or densely packed QCD flux tubes all introduce a space-time picture of the collisions
- Recently Pythia8 took first steps in implementing a space-time picture of hadronization to facilitate model building in this context, with a view to help exploring e.g. which phenomena require invoking a QGP and which do not



[ATLAS arXiv:1509.04776]



Silvia Ferreres-Solé, Torbjörn Sjöstrand

NLO EW

- SHERPA

  Multi-jet merged top-pair production including electroweak corrections

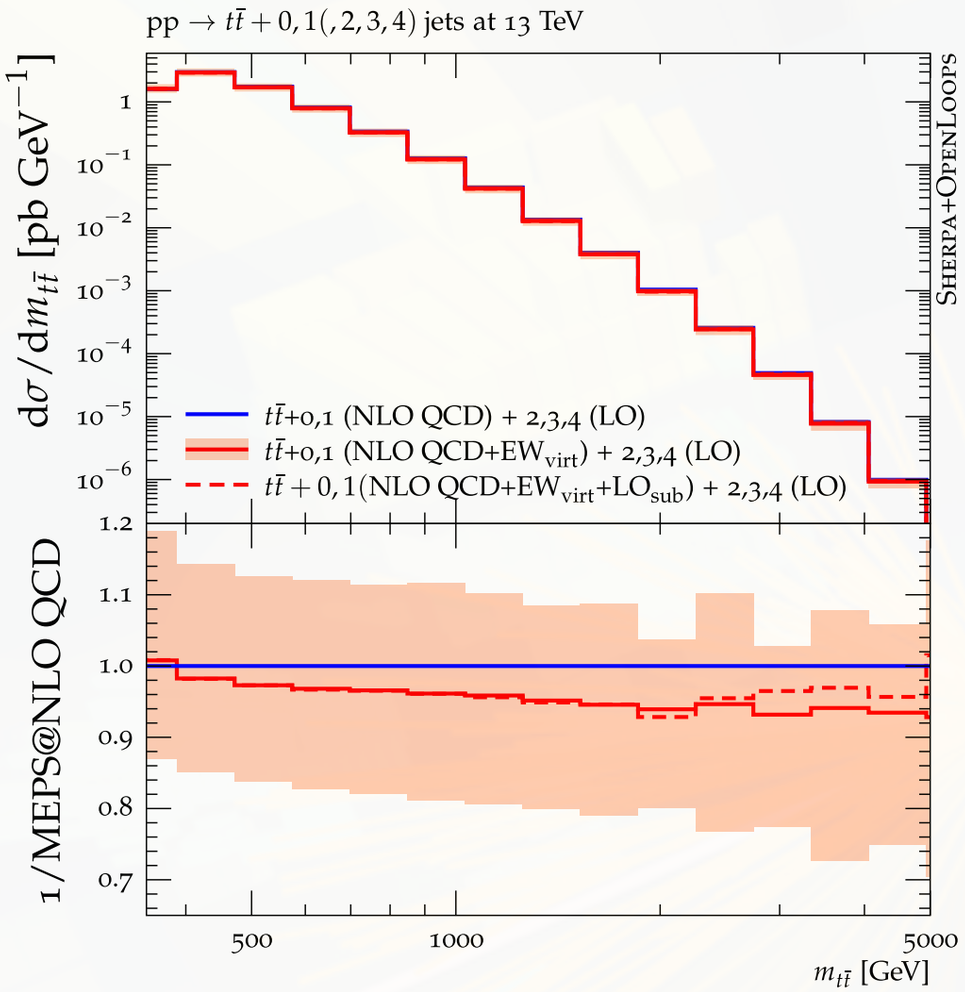
  Christian Gütschow, Jonas Lindert, Marek Schönherr

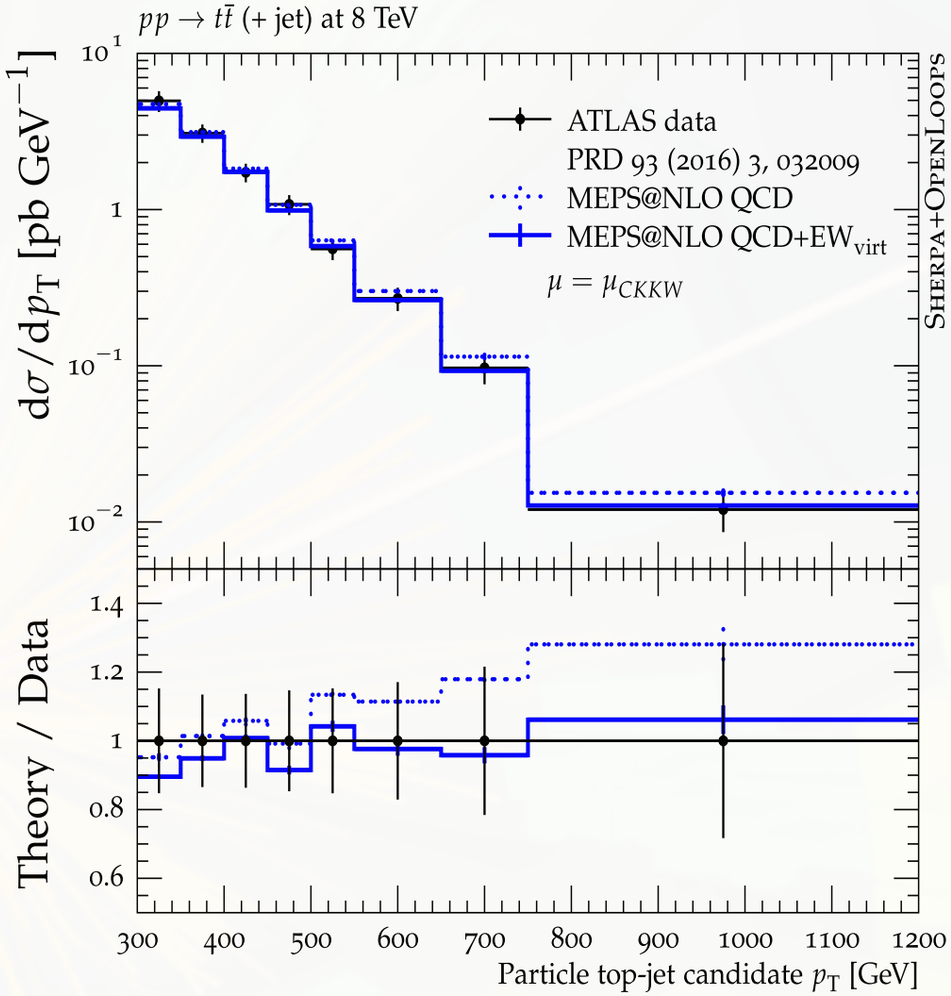
- MadGraph5_aMC@NLO

  The automation of next-to-leading order electroweak calculations

  R. Frederix, S. Frixione, V. Hirschi, D. Pagani, H.-S. Shao, M. Zaro

NLO EW : Multi-jet merged top-pair production with EW corrections





- tt and tt+jet predictions at NLO QCD + EW_{virt} accuracy
- Include 1-loop + integrated approximate real EW effects on top of LO QCD
- Approximate real EW corrⁿs later dressed back on via a QED PS
- Merge results of applying calcⁿ procedure separately to tt & tt+jet processes

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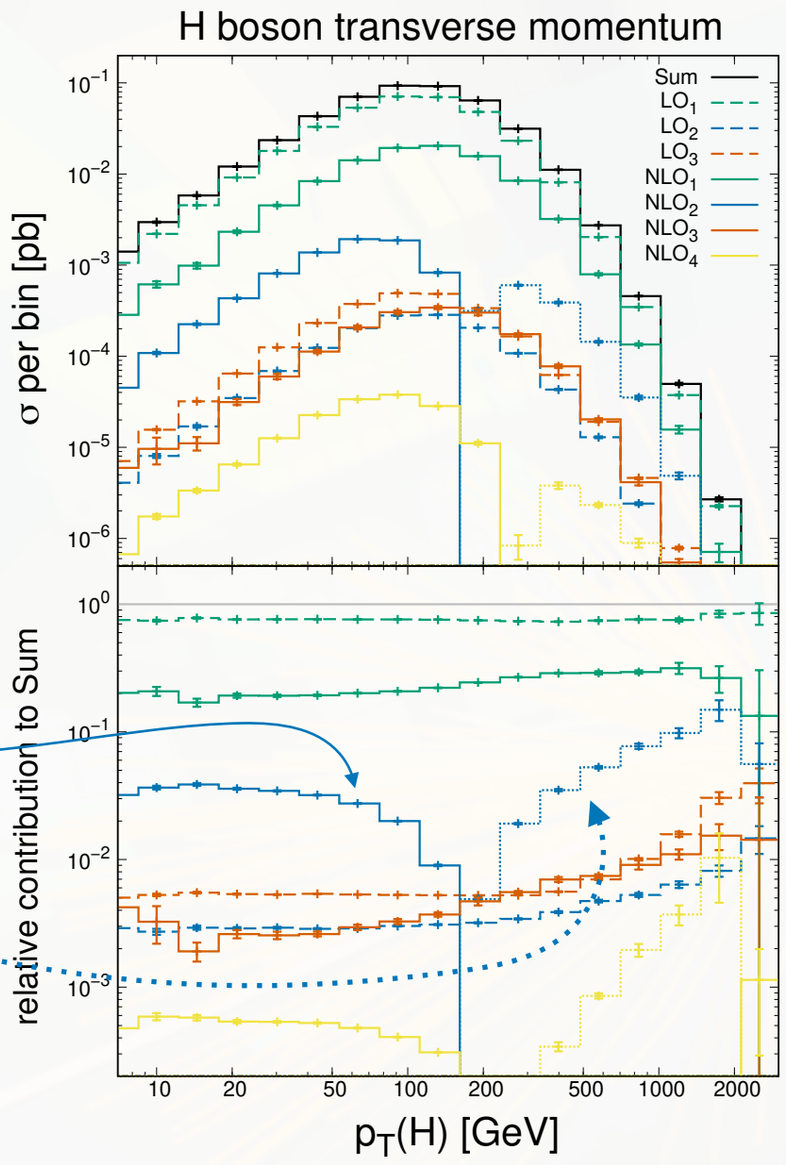
Christian Gütschow, Jonas Lindert, Marek Schönherr

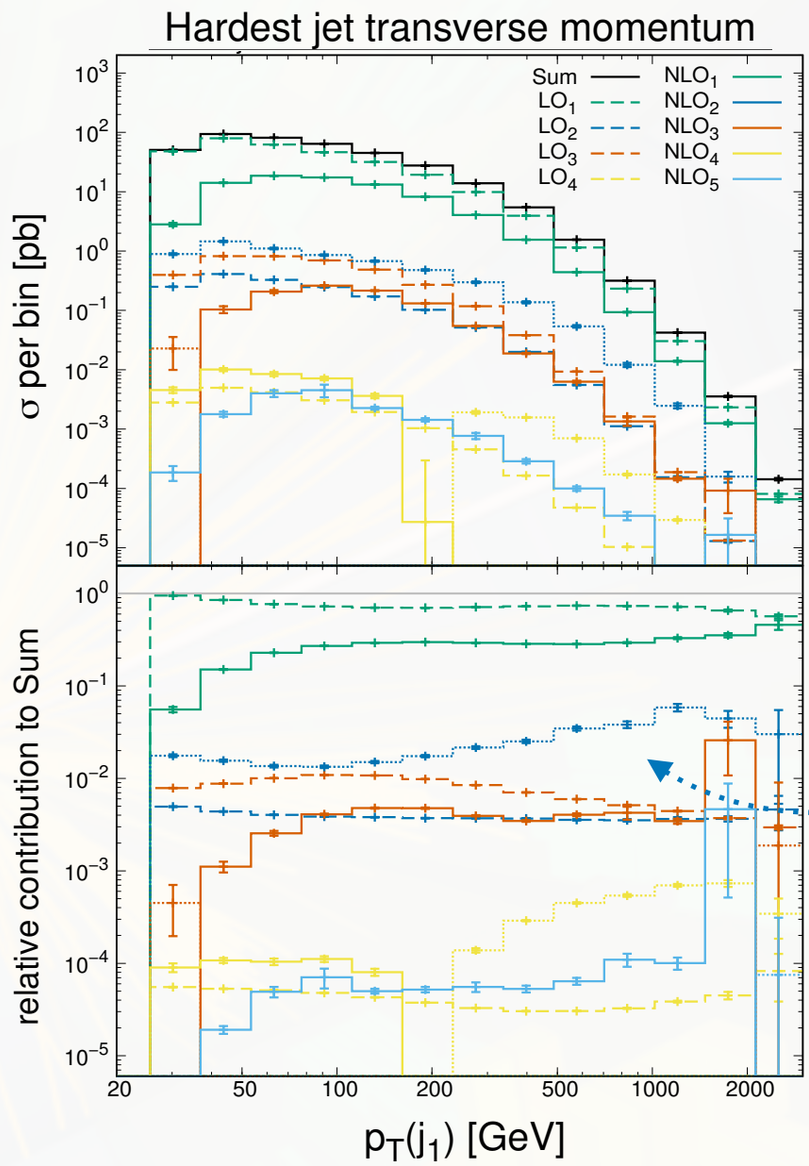
NLO EW : Automation of NLO EW calculations

pp → ttH

+ve NLO EW contribⁿ

-ve NLO EW p_T>150 GeV





pp → ttj

-ve NLO EW contribⁿ

- Public tour-de-force framework for automatic fixed order NLO QCD+EW calcⁿs
- FKS NLO subtraction extended to EW sector, implemented, automated
- Finite width effects in automated complex mass scheme at tree & 1-loop level
- QED shower counterterms done, public release of NLOPS part pending further study

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R. Frederix, S. Frixione, V. Hirschi, D. Pagani, H.-S. Shao, M. Zaro

Parton Showers

- HERWIG 7

  Colour Rearrangement for Dipole Showers

  Johannes Bellm

  Spin Correlations in Parton Shower Simulations

  Peter Richardson, Stephen Webster

  Color matrix element corrections for parton showers

  Simon Plätzer, Malin Sjodahl, Johan Thorén

- SHERPA

  Leading-Color Fully Differential Two-Loop Soft Corrections to QCD Dipole Showers

  Falko Dulat, Stefan Höche, Stefan Prestel

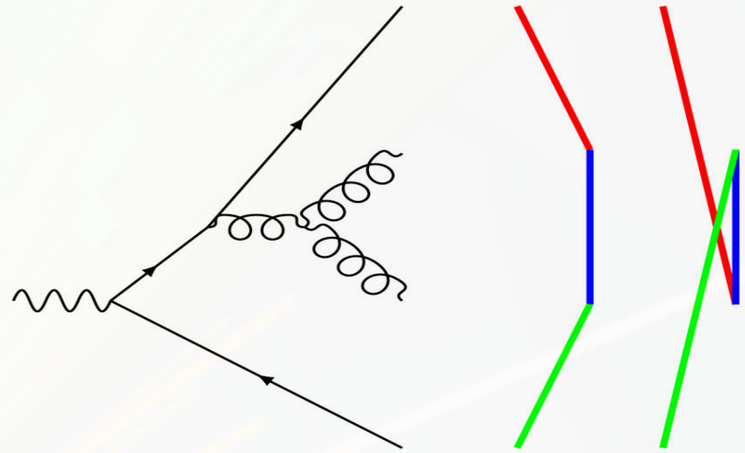
- Dasgupta & Co

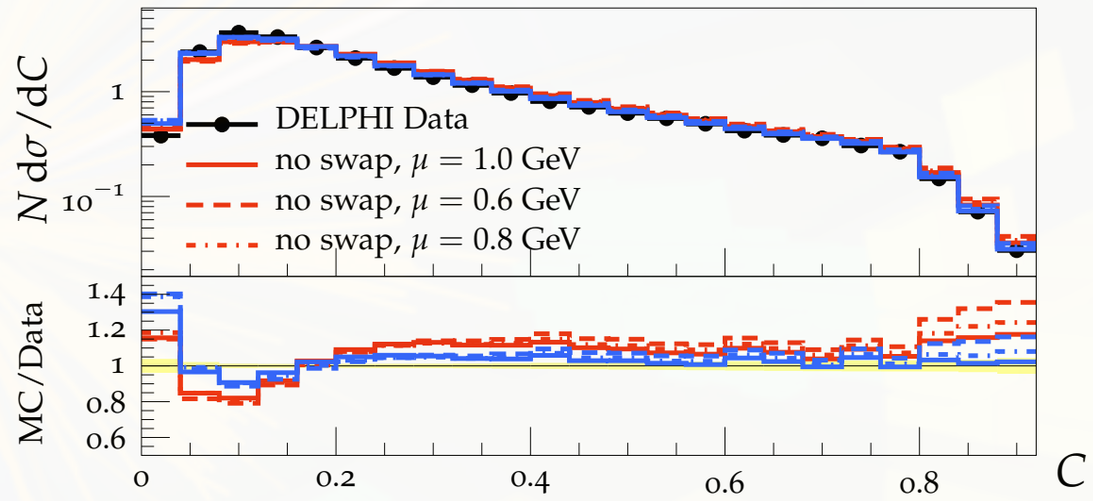
  Logarithmic accuracy of parton showers: a fixed-order study

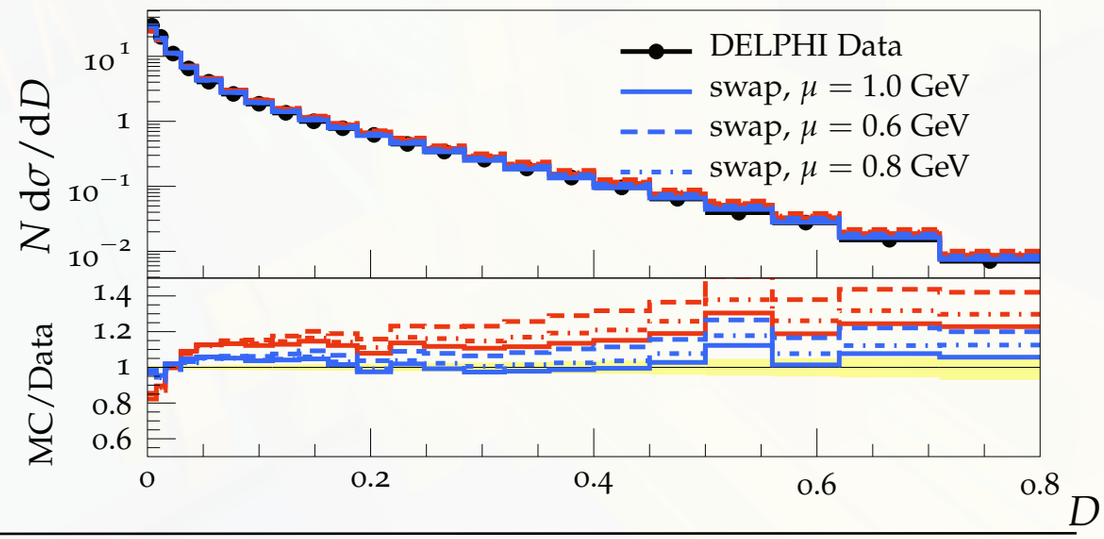
  Mrinal Dasgupta, Frédéric Dreyer, Keith Hamilton, Pier Monni, Gavin Salam

Parton Showers : Colour Rearrangement for Dipole Showers

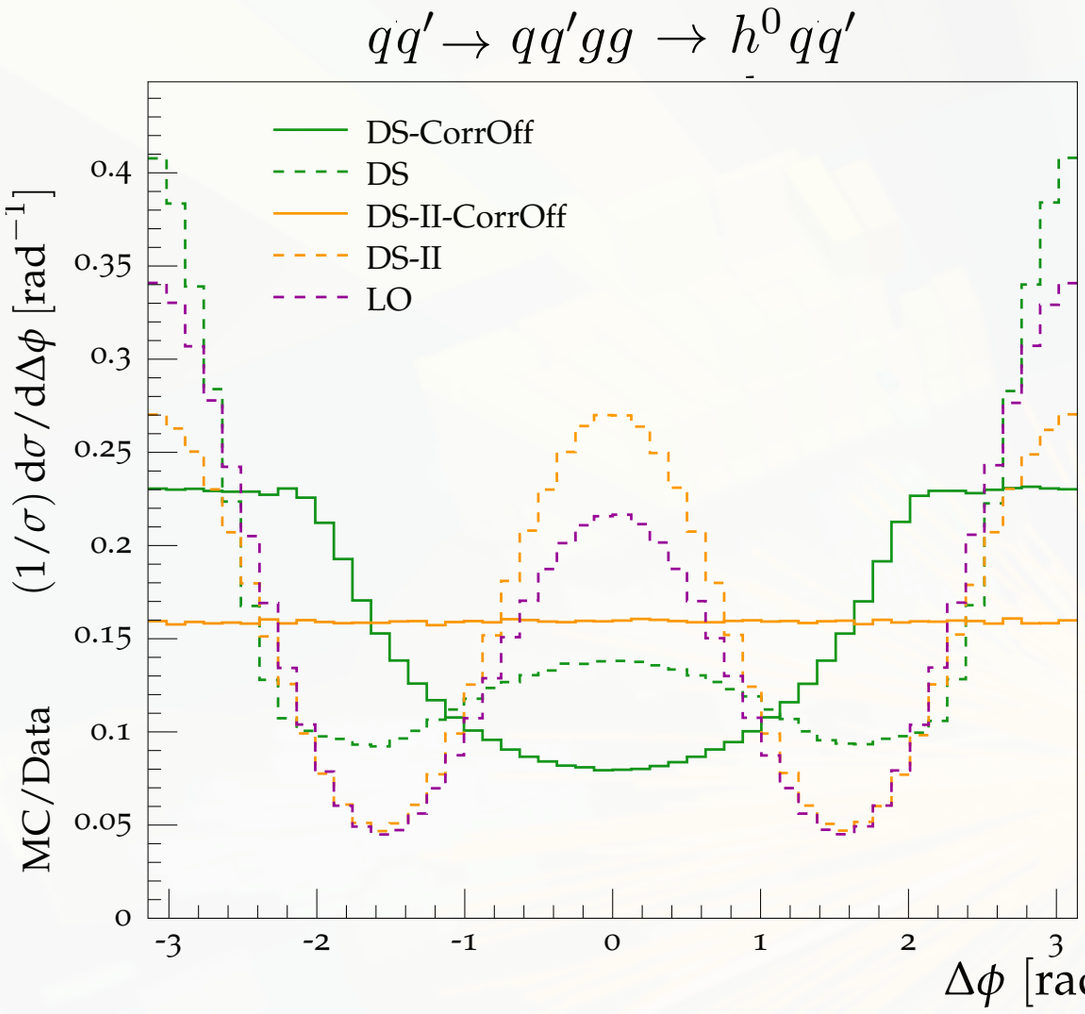
- Colour and kinematics are assigned in colour-anti-colour dipole showers based on large-N_C limit
- All the different colour-anti-colour dipoles don't talk to each other
- Author modifies this procedure to try to include `longer-range' correlation effect of `nearest-neighbour' dipole on the colour assignment
- Like an `in-shower' colour reconnection but all based [rightly] on pQCD
- Gives rise to lower mass colour strings & better agreement with data

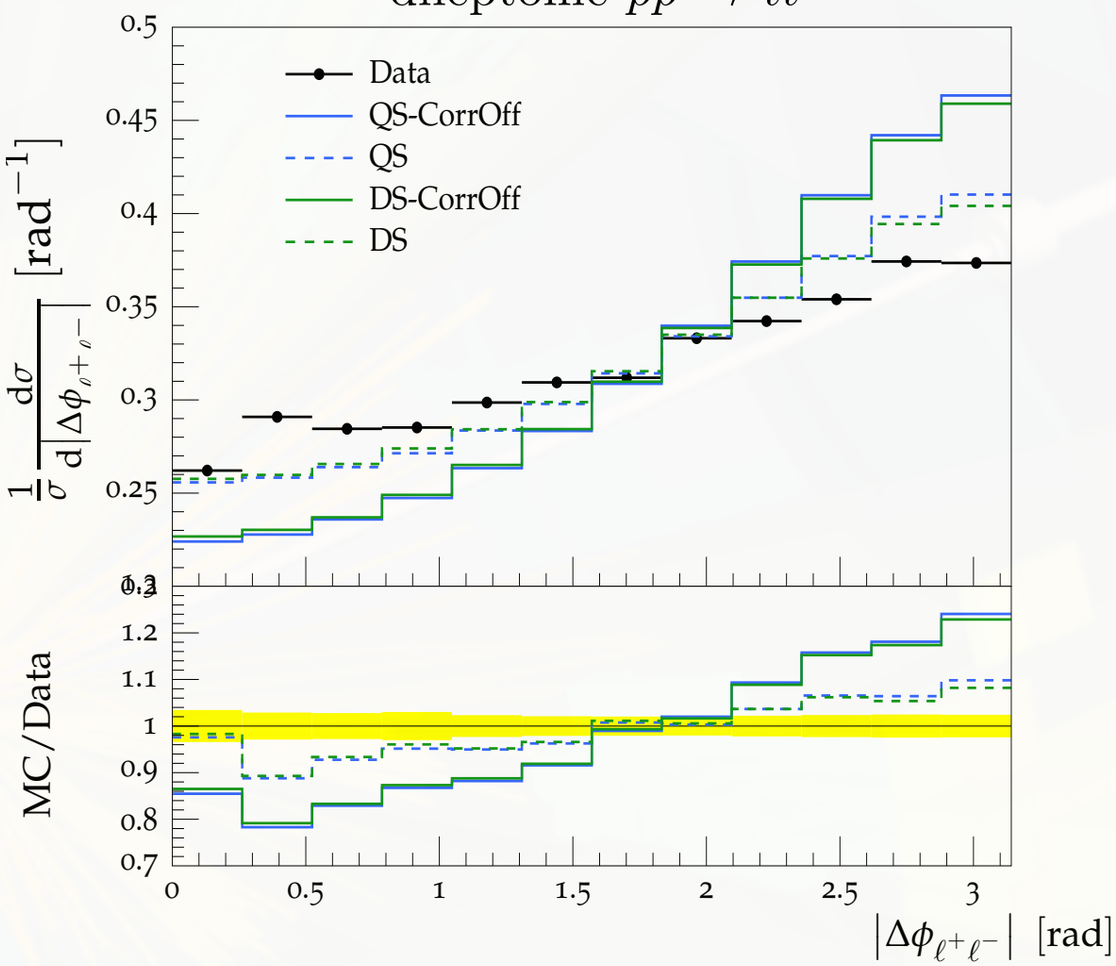






Parton Showers : Spin Correlations in Parton Shower Simulations





- Spin correlⁿs implemented between parton shower splittings in Herwig v7.2
- Included in both std angular order Herwig shower & Herwig's dipole shower
- Effect of these azimuthal correlⁿs in shower evolⁿ is typically v.small
- Most important spin correlⁿ effects already carried by MEs [prodⁿ → decays]
- Spurious azimuthal correlⁿ effect induced by recoil found in dipole shower

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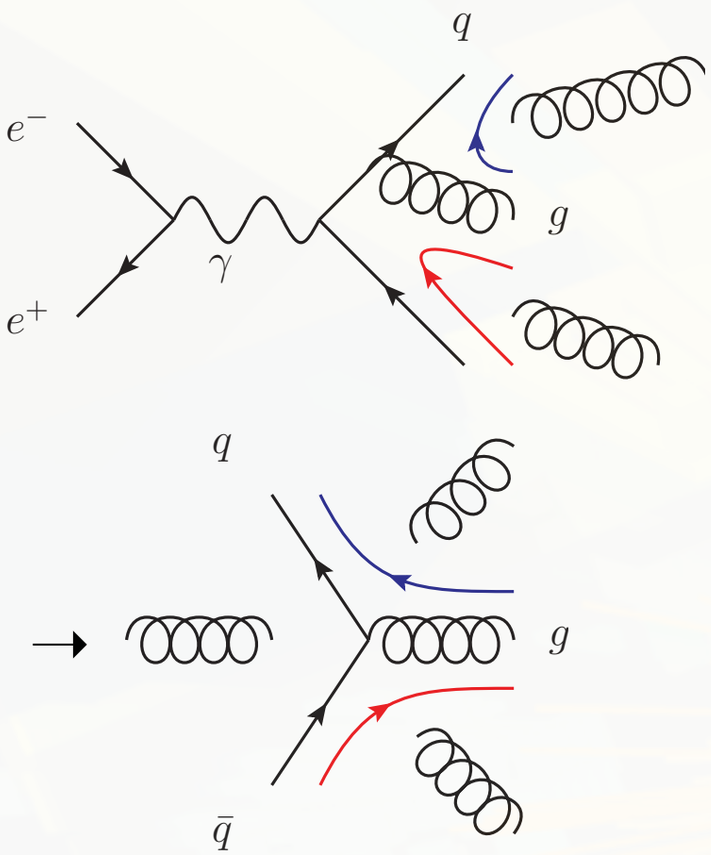
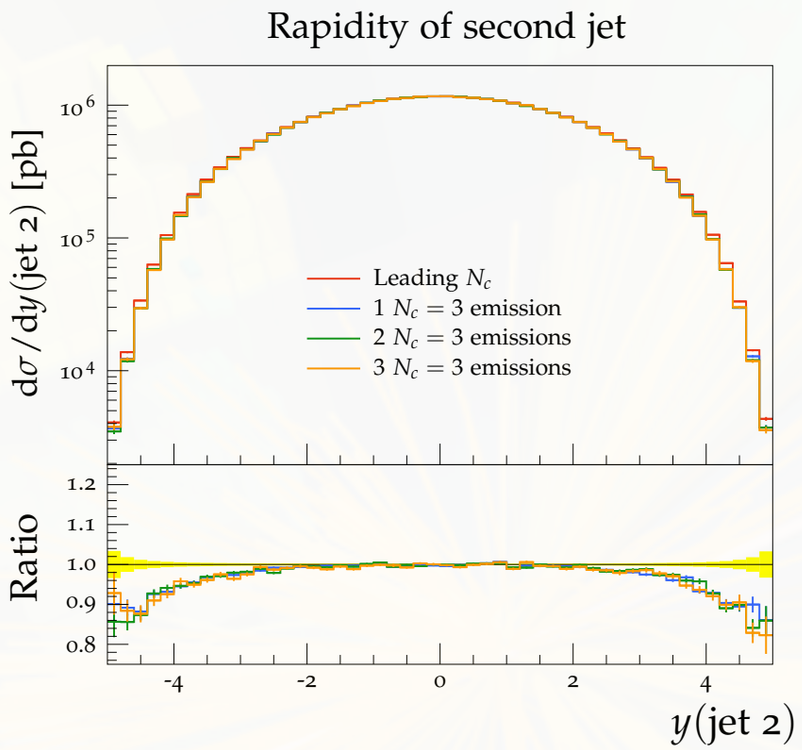
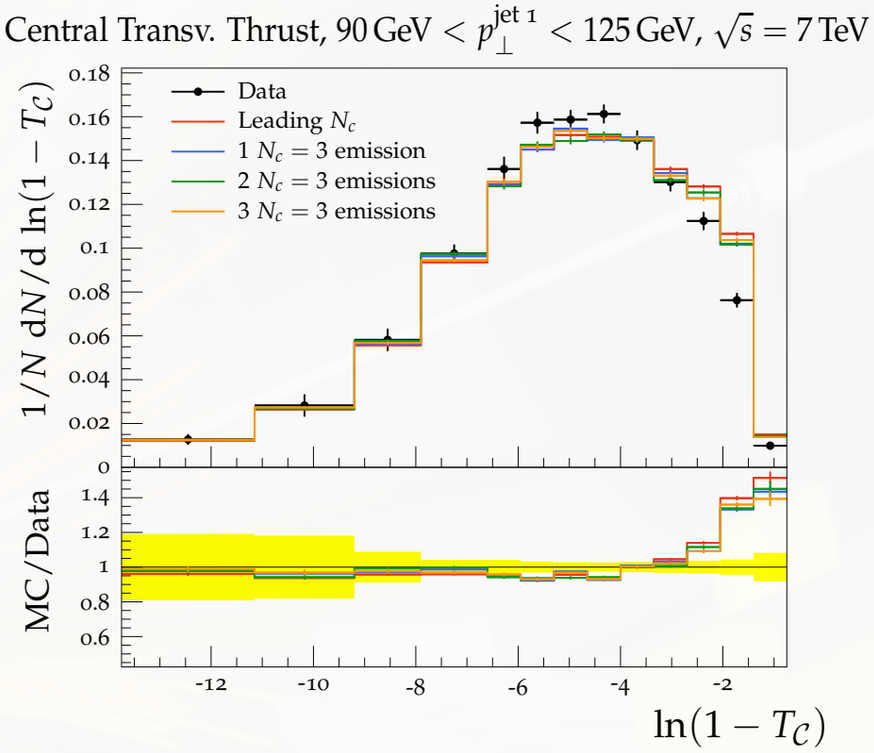
Peter Richardson, Stephen Webster

Parton Showers : Color matrix element corrections for parton showers



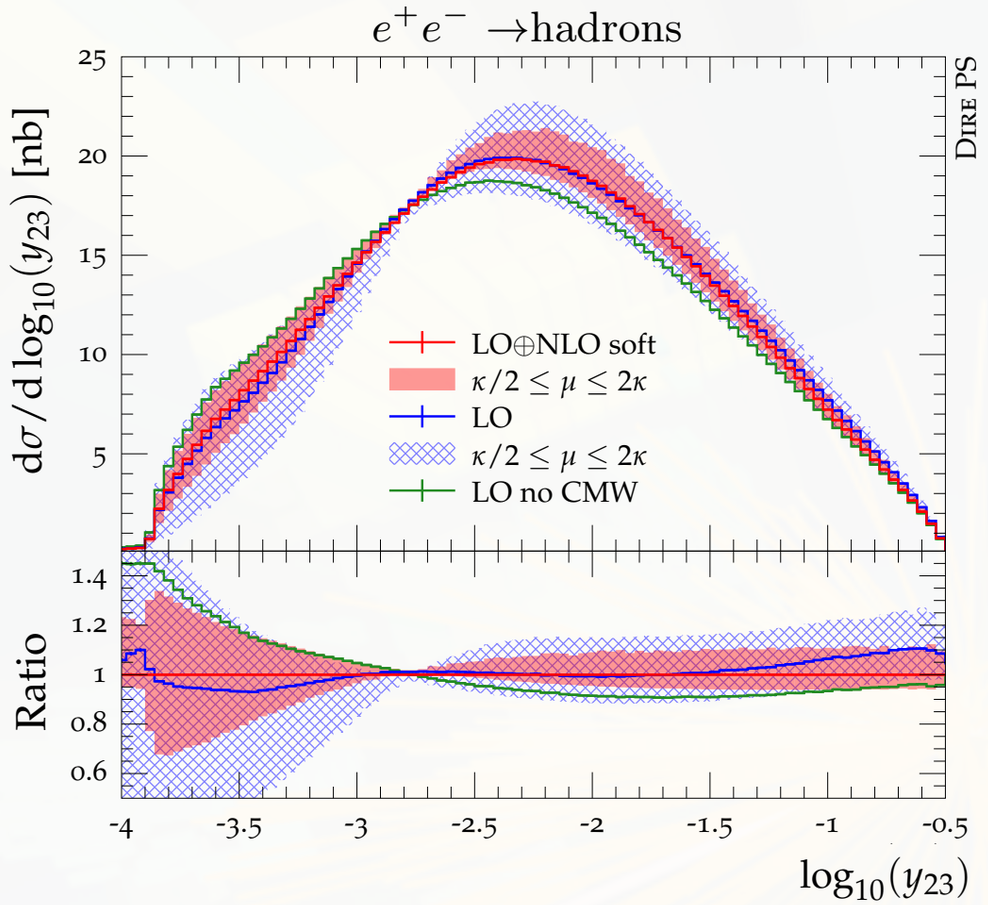


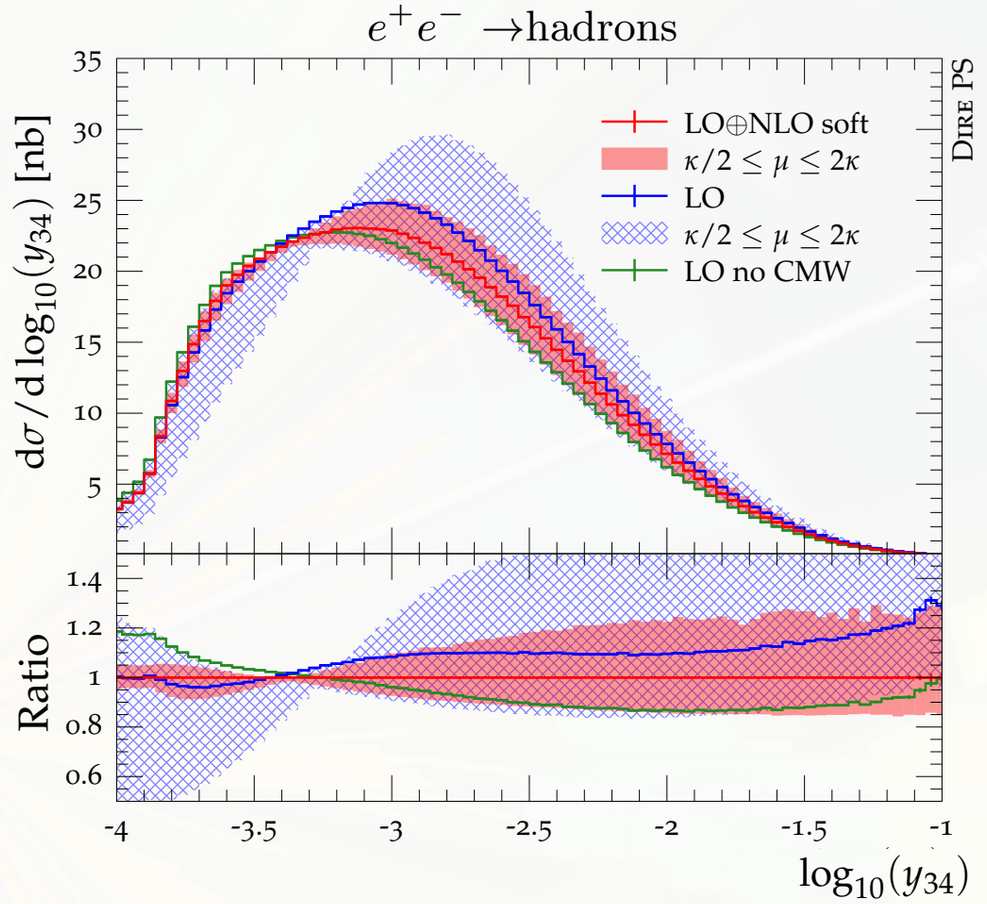


- Generally parton showers operate in the large Nc approximation
- Beyond leading Nc approximation is hard: shower emission probability involves exponentiation of arbitrarily large colour structure matrices
- Authors improve shower's real radⁿ distⁿ to full-Nc for first 2/3 emissions ; virtual effects on colour structure & subleading Nc effect in Sudakov neglected
- Generally small differences ~few % ; how much does MEPS/NLOPS already get?

Simon Plätzer, Malin Sjodahl, Johan Thorén

Parton Showers : Fully Differential Two-Loop Soft Corrections to Dipole Showers





- Part of goal to extend DIRE to an `NLO shower' adding in higher order corrⁿs
- Include double soft `splitting fⁿ' & 1-loop corrⁿ to single soft `splitting fⁿ'
- Essentially do shower as an `MC@NLO' for every parton shower emission
- Strong reduction in uncertainty estimates
- What's log accuracy of this PS? More understanding & validation desirable

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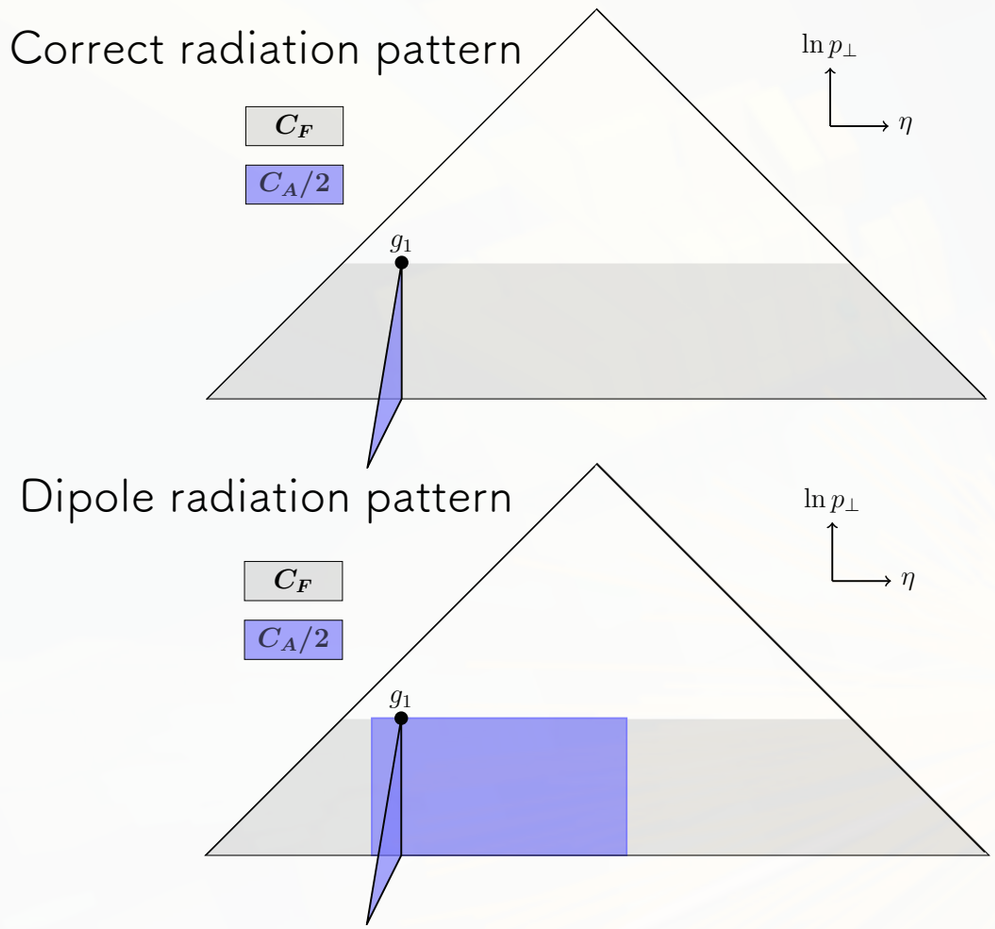
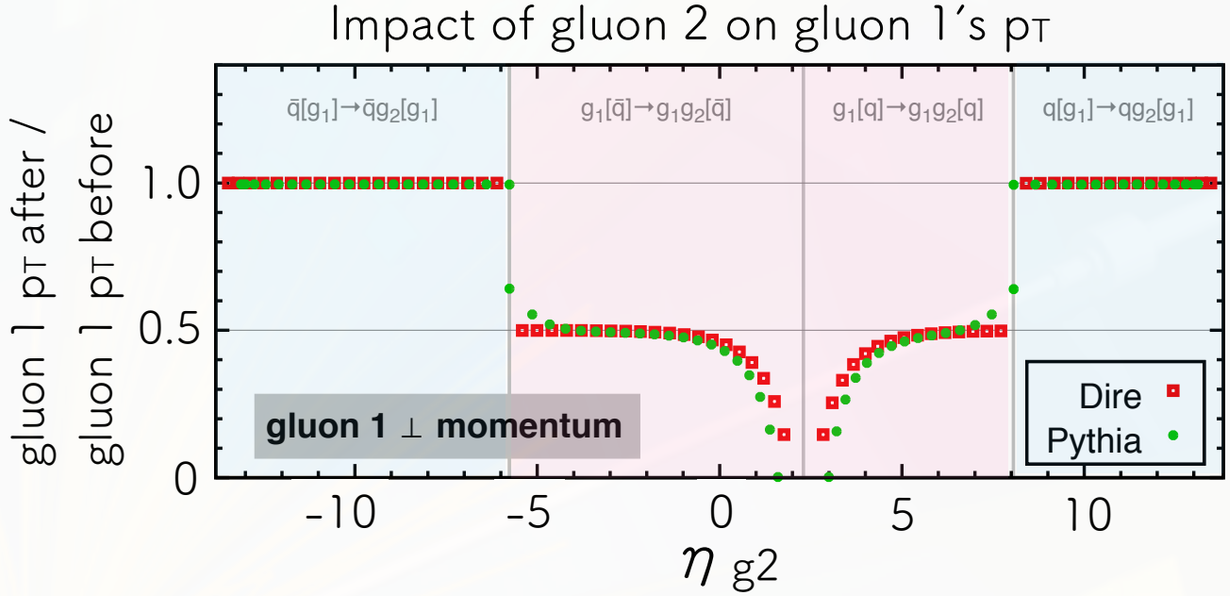
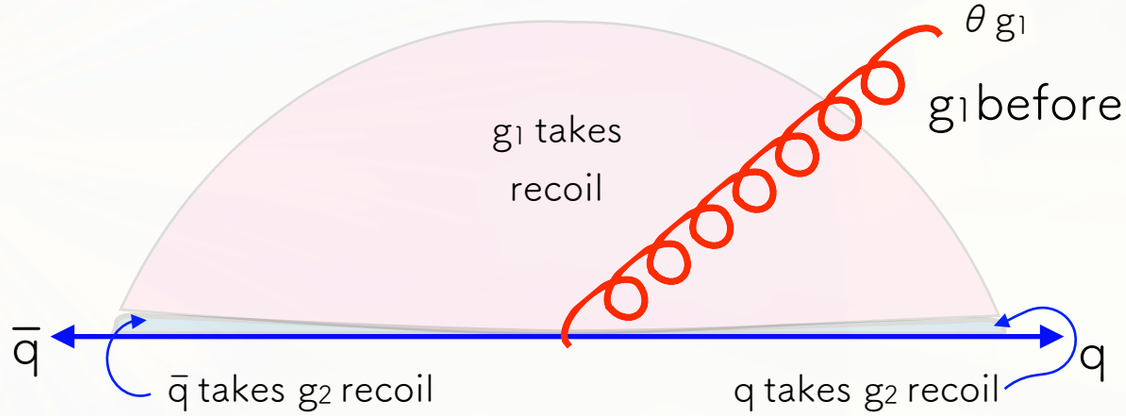
Falko Dulat, Stefan Höche, Stefan Prestel

Parton Showers : Logarithmic accuracy of parton showers: a fixed order study







- Basic fixed order analysis of two FS dipole showers in Pythia 8 & DIRE [@LO]
- `Later' gluons attributed to emission off `earlier' ones even if closer in angle to $q\bar{q}$
- Effective matrix element of parton showers different to known analytic result
- Find leading logs generally correctly resummed only in leading-Nc approx [CF=CA/2]
- Next-to-leading logs at leading-Nc generally incorrect due to recoil attribution

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Mrinal Dasgupta, Frédéric Dreyer, Keith Hamilton, Pier Monni, Gavin Salam

[N]NLOPS

- SHERPA

  Resonance-aware subtraction in the dipole method
  Stefan Höche, Sebastian Liebschner, Frank Siegert

- POWHEG

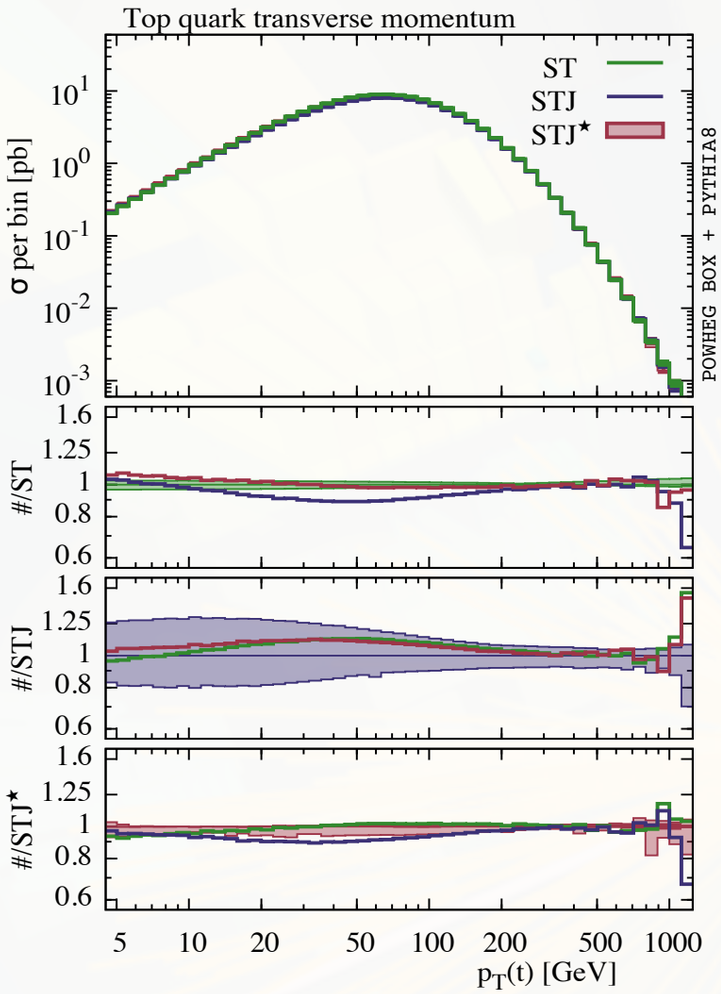
  New NLOPS predictions for tt+b-jet production at the LHC
  Tomáš Ježo, Jonas M. Lindert, Niccolo Moretti, Stefano Pozzorini

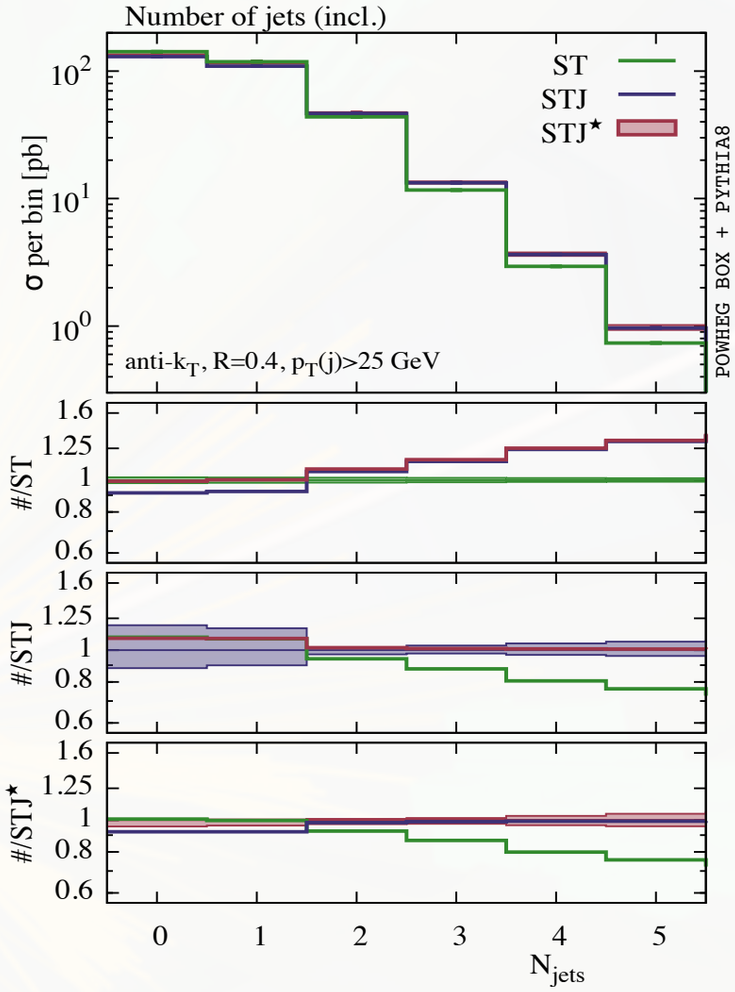
  MINLO t-channel single-top plus jet
  Stefano Carrazza, Rikkert Frederix, Keith Hamilton, Giulia Zanderighi

  NNLOPS accurate predictions for WW production
  Emanuele Re, Marius Wiesemann, Giulia Zanderighi

  NNLOPS accurate associated HZ production with NLO decay H→bb
  William Astill, Wojciech Bizon, Emanuele Re, Giulia Zanderighi

nNLOPS: MINLO t-channel single-top plus jet

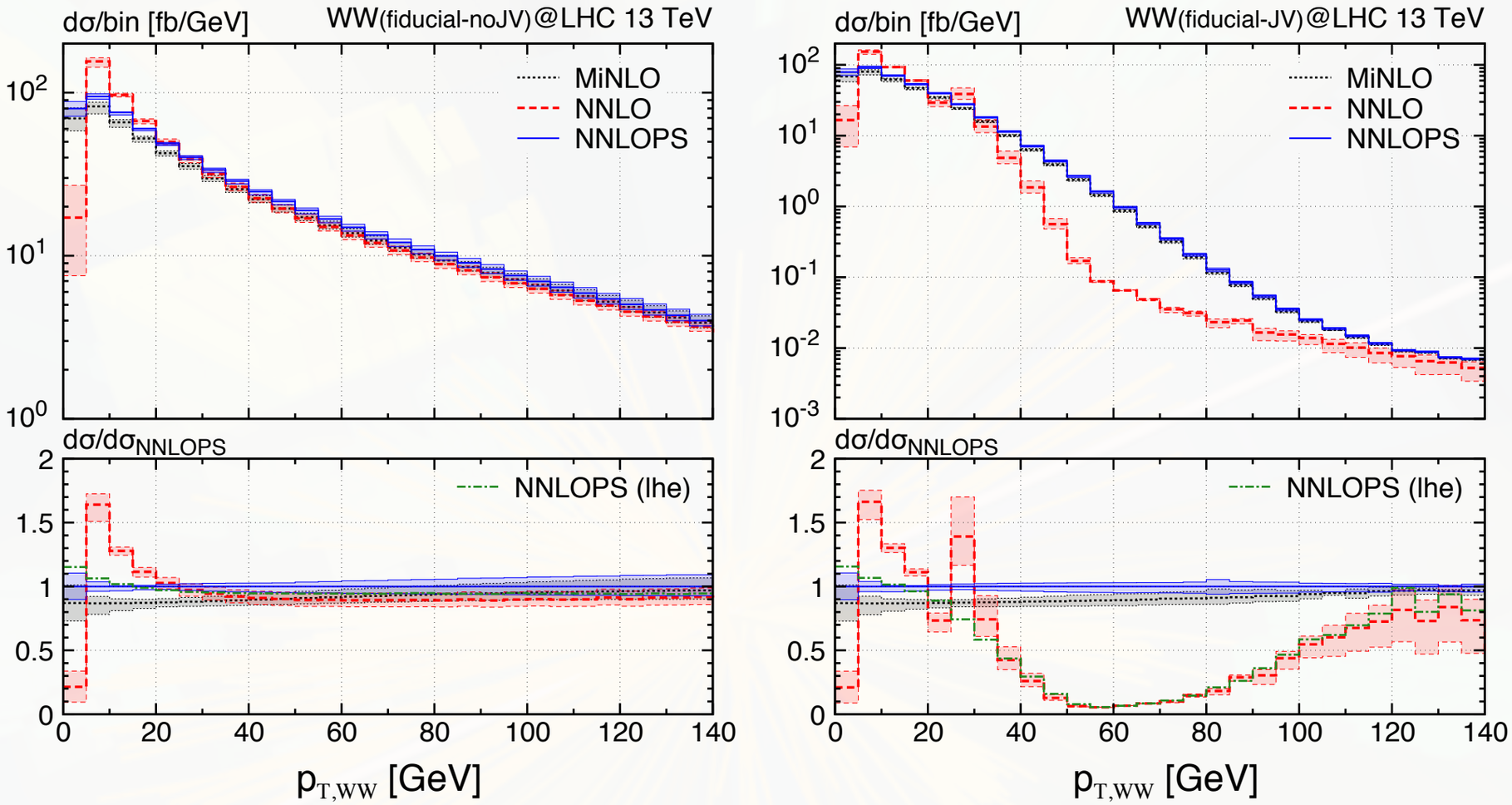




- Multiscale Improved NLO, aka MiNLO, method extended to MiNLO′ for colour singlet+jet production HJ / VJ / HVJ / WWJ
- MiNLO′ means above calcⁿs become simultaneously NLO for H / V / HV / WW
- Extended to complex process [HJJ] in proof-of-concept work [Frederix, KH]
- Proof-of-concept refined into public code for MiNLO′ single-top+jet [STJ*]

Stefano Carrazza, Rikkert Frederix, Keith Hamilton, Giulia Zanderighi

NNLOPS: NNLOPS accurate predictions for WW production

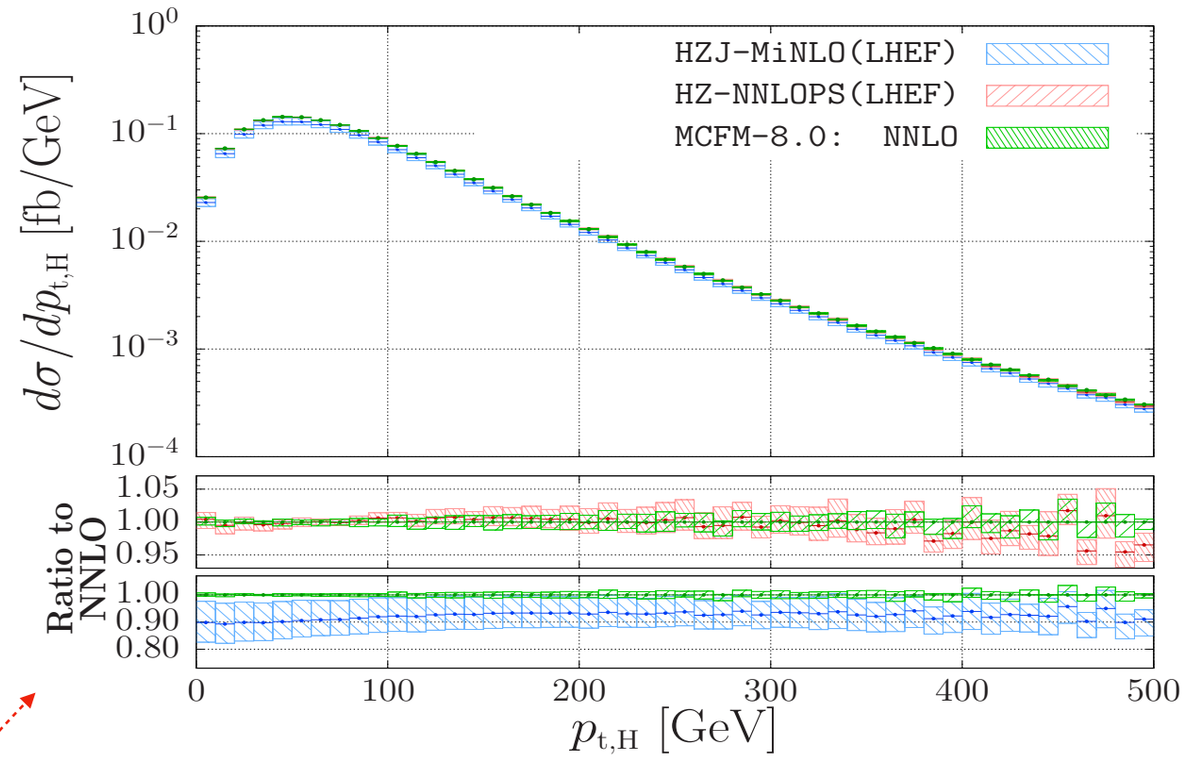


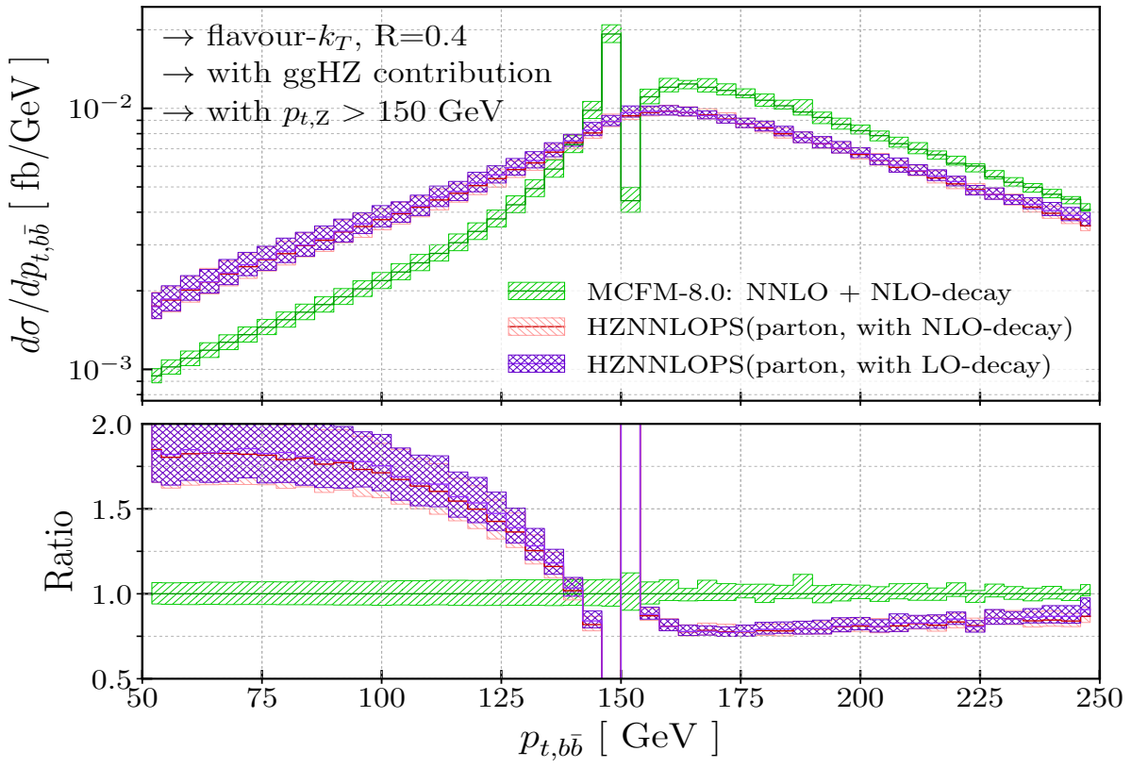
- Building on original NNLOPS proposal WWJ MiNLO′ code can be reweighted differentially to [MATRIX] NNLO in 9D Born phase space to yield NNLOPS
- 9D reweighting reduced to 9x9 copies 3D grids [no-W-decays] phase space by decomposing angular distⁿ of each decay in terms of 9 spherical harmonics
- Supplements NNLO with resummation & real-life output. Code now public.

Emanuele Re, Marius Wiesemann, Giulia Zanderighi

NNLOPS: NNLOPS accurate HZ production with NLO decay H→b$\bar{\text{b}}$

- Same NNLOPS methodology as WW case but here for HZ production
- Simulation includes also NLO corrections to H→bb decay
- Inclusive quantities agree perfectly with NLO
- NNLOPS resums important multiple emission effects NNLO misses
- Public code available





William Astill, Wojciech Bizon, Emanuele Re, Giulia Zanderighi

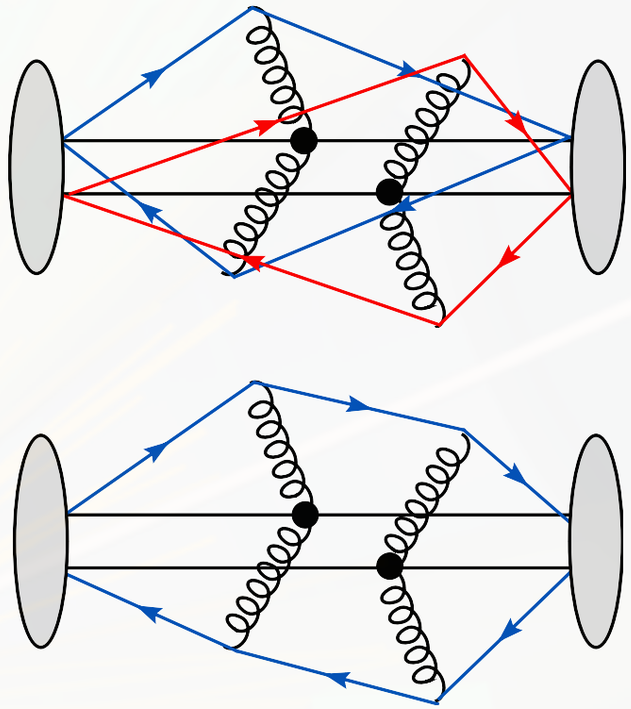
Summary

- Soft QCD
  - Substantially improved modelling of LHC total, elastic, diffractive in Pythia8
  - Start of platform to explore collective effects in Pythia8: spacetime pic of hadronizatⁿ
- NLO EW
  - Semi-automatised NLO QCD+EW in SHERPA with approx PS matching
  - Full NLO EW automation in MG5_aMC framework, public QCD+EW NLOPS to follow
- Parton showers
  - Improvements re inclusion of spin & colour correlations though effects look small
  - Work towards `NLO showers' by DIRE [Hoeche, Prestel & Co]
  - Nuts+bolts analysis of dipole showers w.r.t resummation initiated by Dasgupta & Co
- [N]NLOPS
  - Handful of public NNLOPS processes by now developed by Re, Zanderighi & Co
  - Proof-of-concept extending MiNLO' to complex procs no longer proof-of-concept
- Misc
  - Promising neural network approach to obtaining fast parton shower uncertainties
  - Much faster matching of HEJ generator, based on high energy factorization, to NLO

Soft QCD : Colour Reconnection from Soft Gluon Evolution

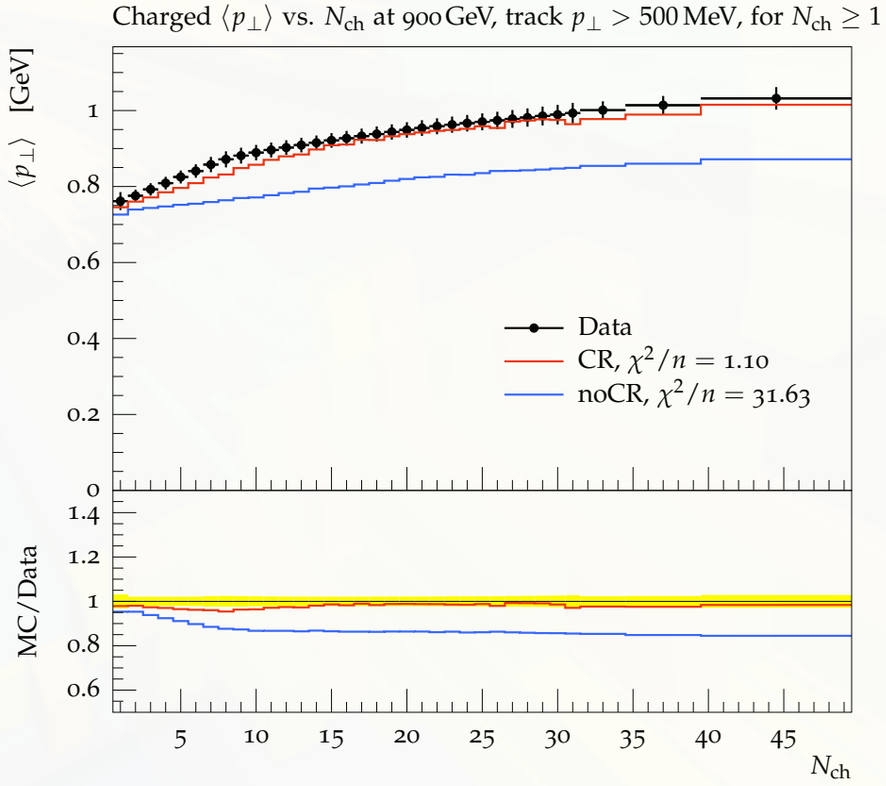
- Colour reconnection rearranges parton colour assignments prior to hadronizatⁿ minimizing string lengths

- Important at LHC where it's not clear how colour flows between MPI scatterings relate to one another



Long colour strings to proton remnants generate excess of N_{ch} per event, making <p_T> vs N_{ch} too flat

- Important also for W mass, top mass analysis, and better descⁿ of SM bkgs



Stefan Gieseke, Patrick Kirchgaeßer, Simon Plätzer, Andrzej Siodmok

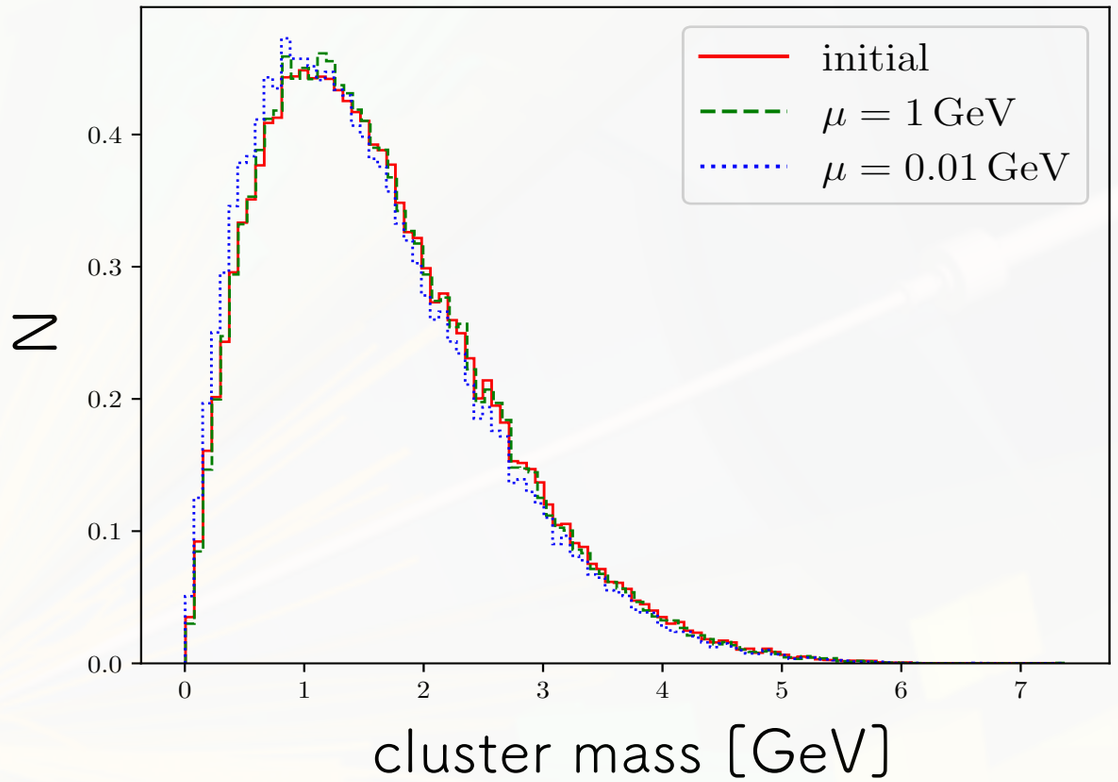
Soft QCD : Colour Reconnection from Soft Gluon Evolution

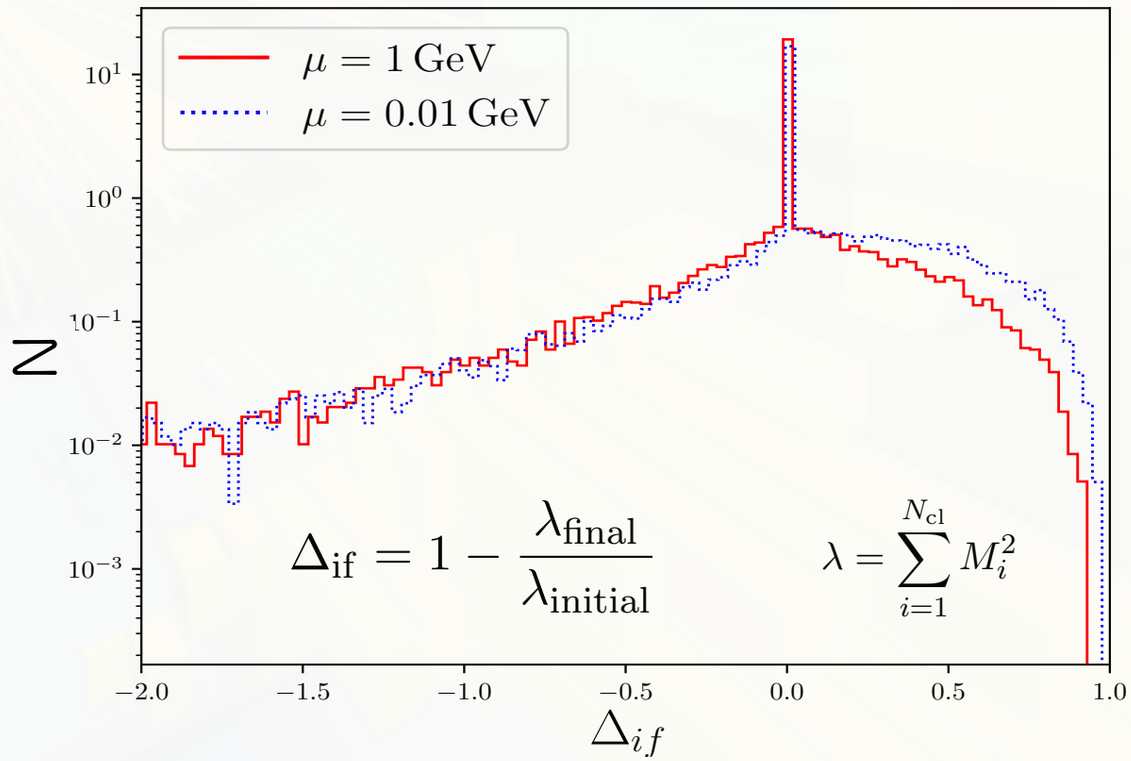
- Most colour reconnection models based on brute force minimization by comparing cluster masses

- New proposal to carry out full colour parton shower evolution of cluster model cluster constituents exchanging only **virtual** gluons

- Perturbative take on NP physics

- Still experimental but behaves like conventional CR models: reduced cluster mass and colour length drop

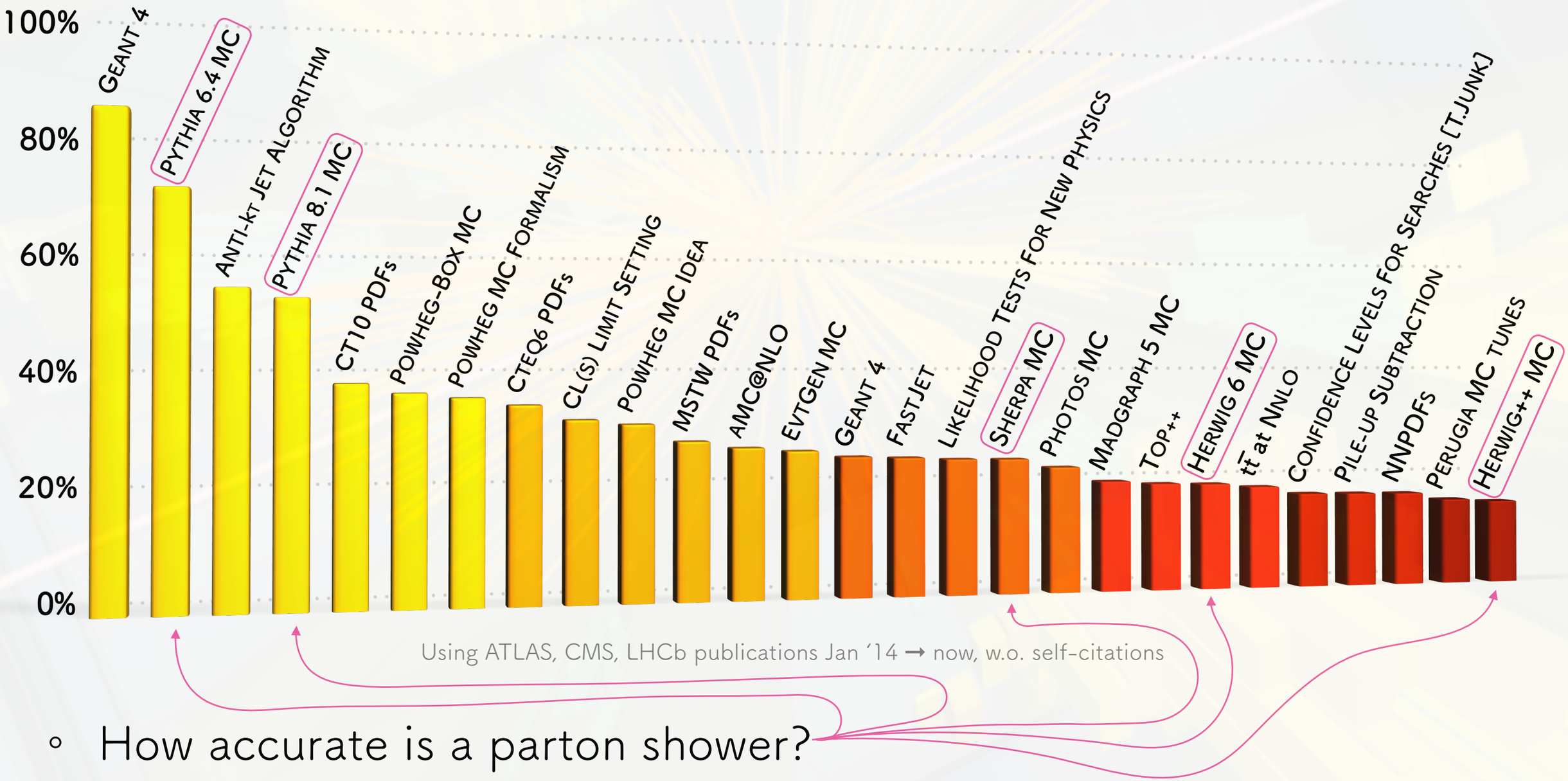




Stefan Gieseke, Patrick Kirchgaeßer, Simon Plätzer, Andrzej Siodmok

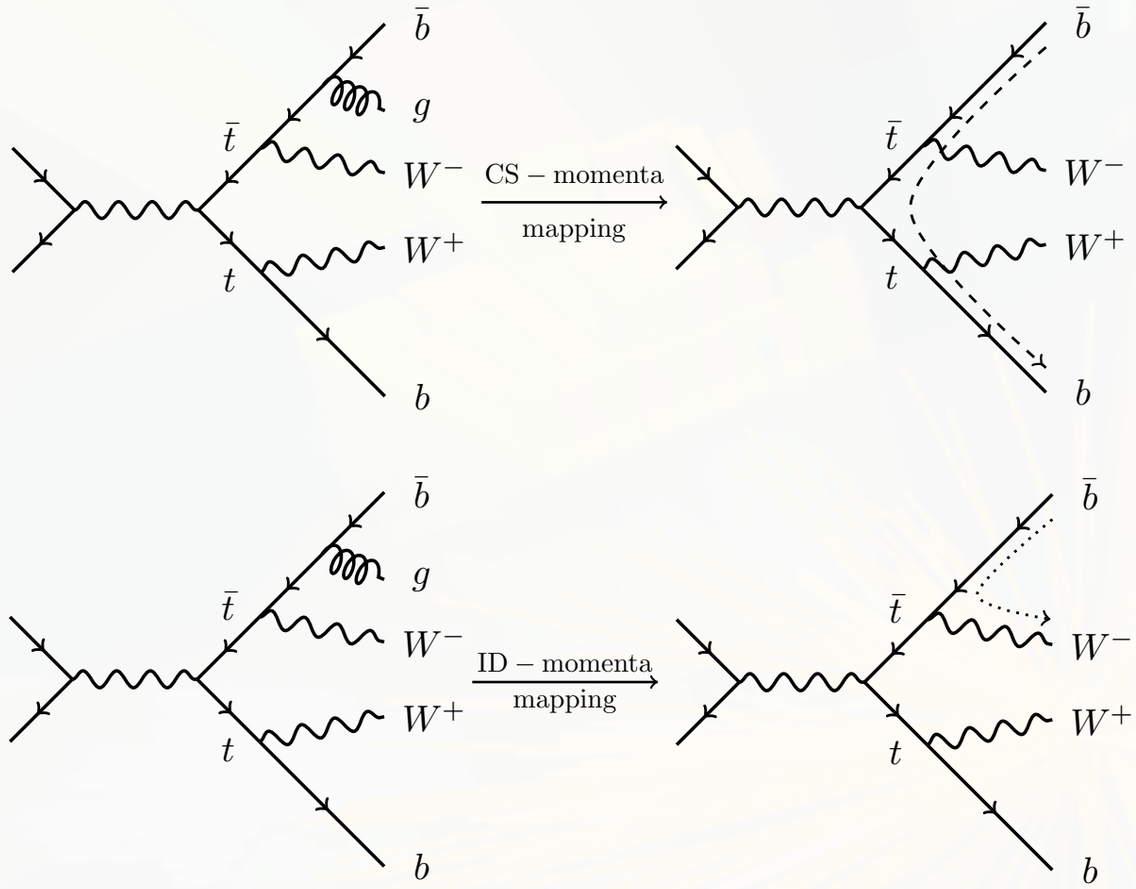
Parton Showers

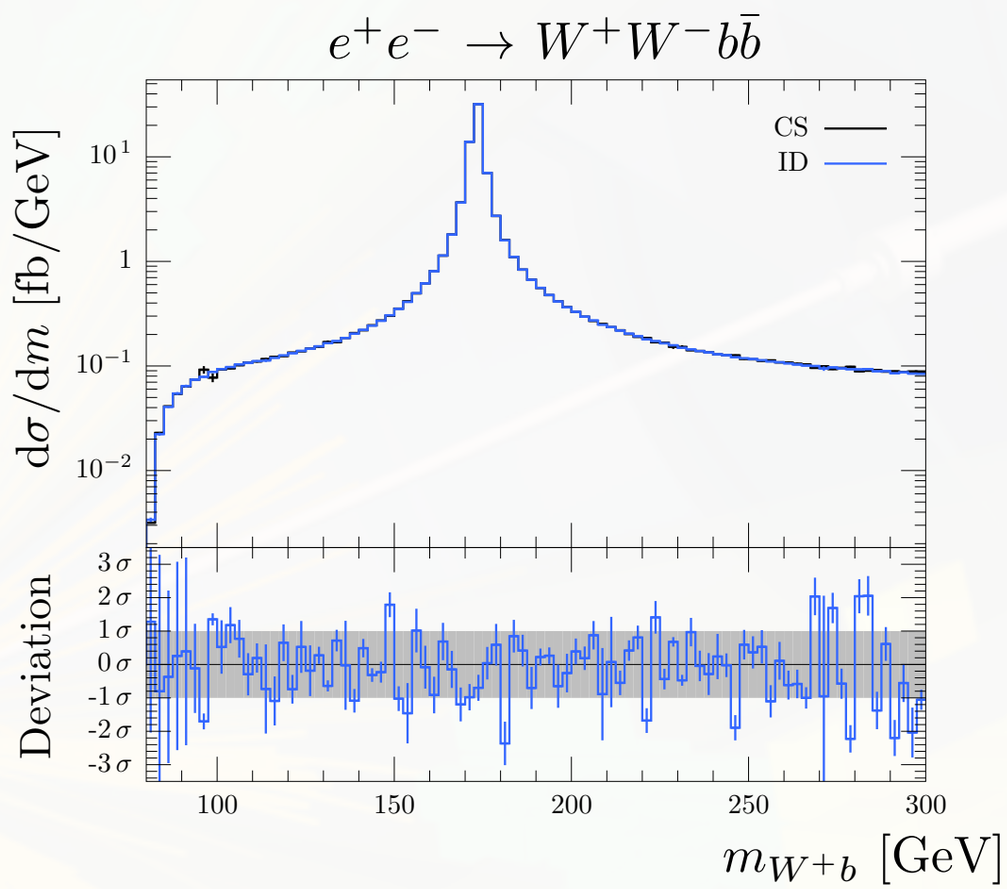
Percentage of ATLAS, CMS, LHCb publications citing a given article



- How accurate is a parton shower?

NLOPS: Resonance-aware subtraction in the dipole method





- Momentum map in dipole subtraction only sees external particles
- Map from Real to Born can throw on-shell intermediates off-shell & vice versa
- Answer still finite, unchanged, but subtraction prone to be inefficient/unstable
- Problem first noticed and addressed by Ježo & Nason in FKS subtraction
- Reformulate dipole subtraction for better convergence & stability in application to processes with intermediate resonances

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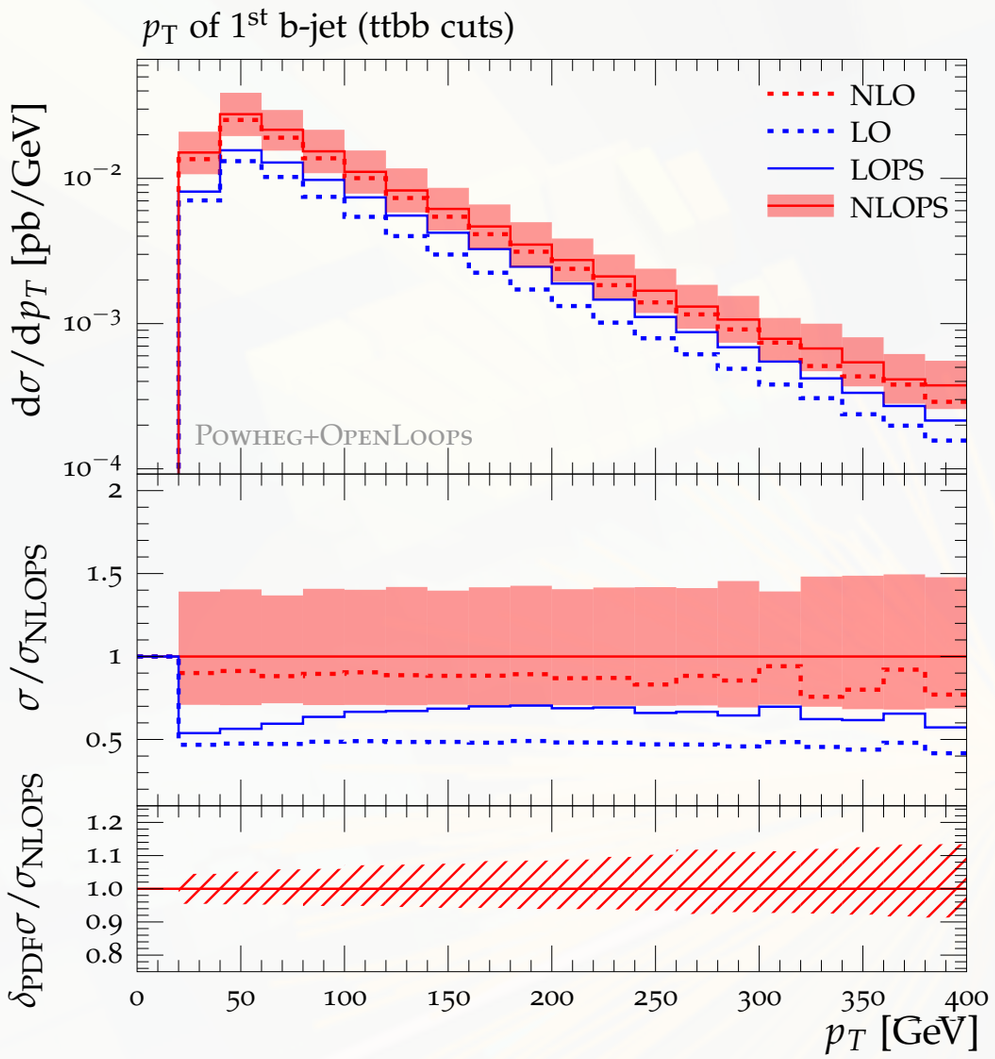
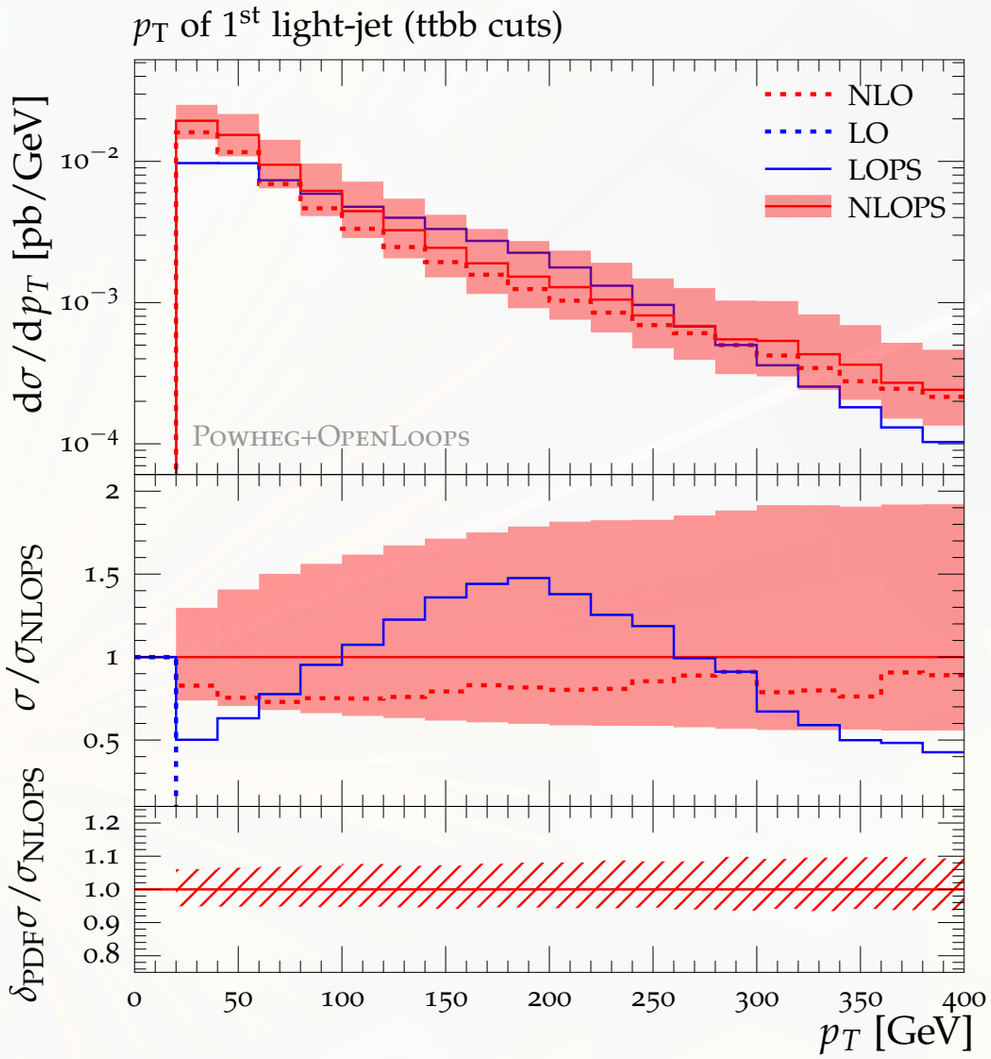
Stefan Höche, Sebastian Liebschner, Frank Siegert

NLOPS: New NLOPS predictions for tt+b-jet production at the LHC





- $t\bar{t}b\bar{b}$ important background for $t\bar{t}H$
- New POWHEG ttbb generator in 4FS [massive b's] ; public release soon
- LO process is α_S^4 process and multiscale → NLO badly needed
- Expect large scale var^{n}s etc
- Future work proposed to study more advanced scale setting procedures

$$\mu_F = \xi_F \frac{H_T}{2} = \xi_F \frac{1}{2} \sum_{i=t,\bar{t},b,\bar{b},j} E_{T,i}$$

$$\mu_{t\bar{t}} = \sqrt{E_{T,t} E_{T,\bar{t}}}$$

$$\mu_{b\bar{b}} = \sqrt{E_{T,b} E_{T,\bar{b}}}$$

$$\mu_R = \xi_R \sqrt{\mu_{t\bar{t}}\, \mu_{b\bar{b}}}$$

Tomáš Ježo, Jonas M. Lindert, Niccolo Moretti, Stefano Pozzorini

Misc

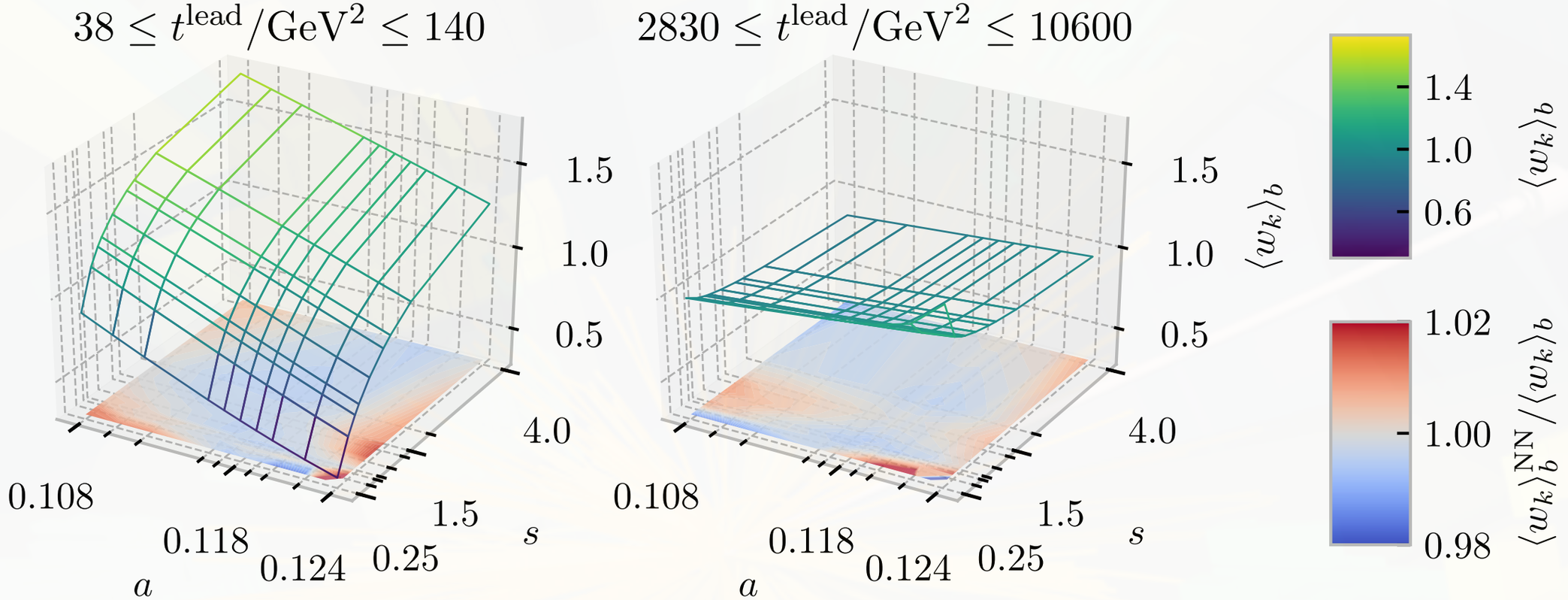
- SHERPA

  Reweighting a parton shower using a neural network: the final-state case
  Enrico Bothmann, Luigi Del Debbio

- HEJ

  Merging High Energy with Soft and Collinear Logarithms using HEJ and PYTHIA
  Jeppe Andersen, Helen Brooks, Leif Lönnblad

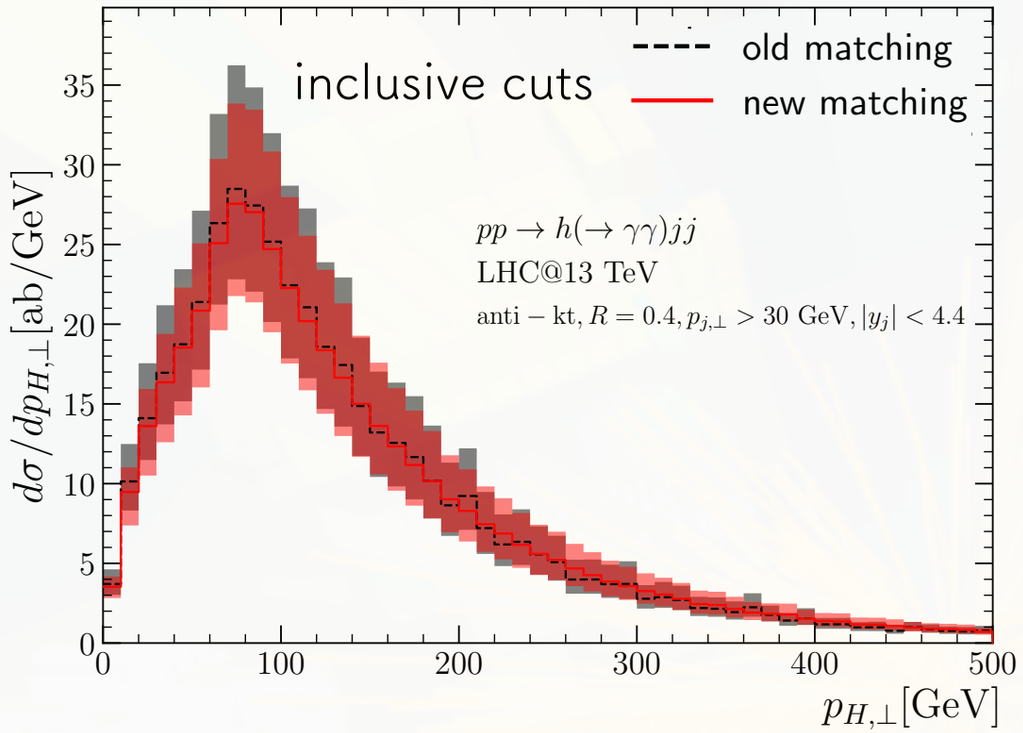
Misc: Reweighting a PS using a NN: the final-state case

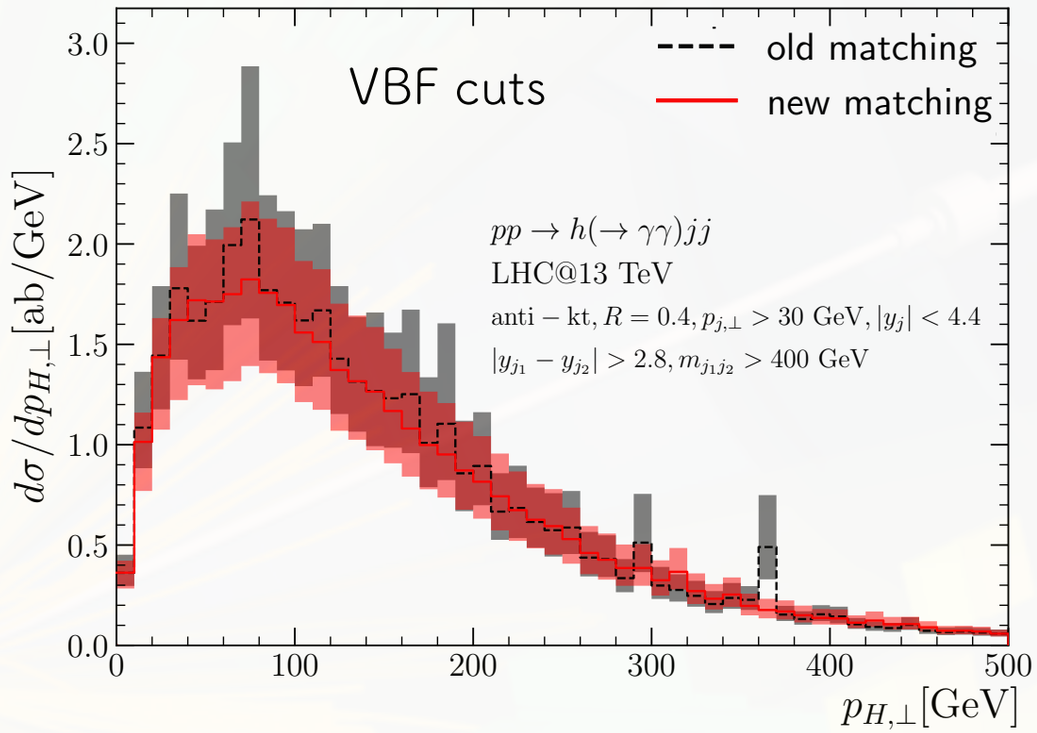


(a) leading emission scale t^{lead}

- Prohibitive to use shower MC in PDF fits due to computational cost associated to re-evaluating observables for every variation in the PDF
- Usual interpolation methods getting around this in fixed order calcⁿs not applicable in context of all orders resummations
- Authors start investigation of feasibility of NN to predict observables subject to variations in the parton shower : start with final-state showers

Misc: Higgs+Dijets: Higher-Order Matching for HEJ





- New fixed order matching procedure developed for HEJ event generator
- Identical results to before, but far greater MC convergence and stability
- Studied H+jets with VBF cuts, observed NLO xsec^n < NLO+HEJ by factor 1.5
- How does picture change with more sophisticated scale choices and showering?
- Proof-of-concept merging HEJ to Pythia8 for real-life simulation shown in 2017

Jeppe R. Andersen, Tuomas Hapola, Marian Heil, Andreas Maier, Jennifer M. Smillie