SHERPA status

Frank Krauss

Institute for Particle Physics Phenomenology
Durham University

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www.ippp.dur.ac.uk

MCnet

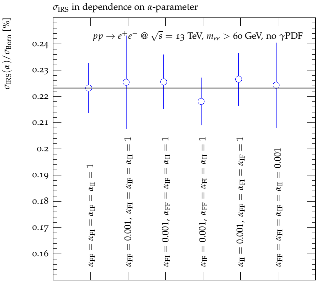
erc European Research Council

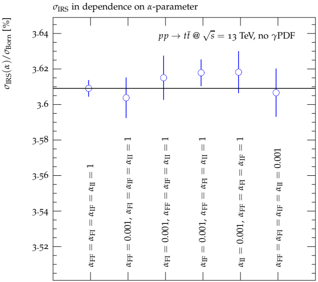
EW NLO corrections

NLO EW subtraction in SHERPA

- adapt QCD subtraction (spl. fns. and colour-/spin-correlated MEs)
- replacements: $\alpha_s \to \alpha,\ C_F \to Q_f^2,\ C_A \to 0,$
  $T_R \to N_{c,f}\, Q_f^2,\ n_f\, T_R \to \sum_f N_{c,f}\, Q_f^2,$

$$\frac{\mathbf{T}_{ij}\cdot\mathbf{T}_k}{\mathbf{T}_{ij}^2} \to \frac{Q_{ij}Q_k}{Q_{ij}^2}$$





inclusion of electroweak corrections in simulation

- incorporate approximate electroweak corrections in MEPS@NLO
  1. using electroweak Sudakov factors

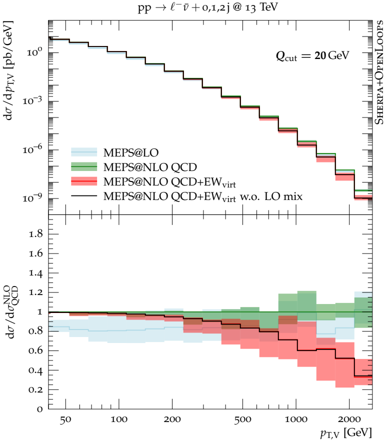
$$\tilde{\mathrm{B}}_n(\Phi_n) \;\approx\; \tilde{\mathrm{B}}_n(\Phi_n)\,\Delta_{\mathrm{EW}}(\Phi_n)$$

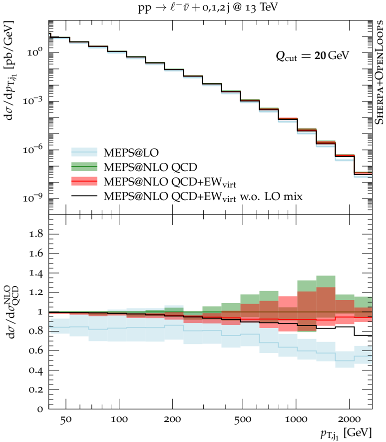
  2. using virtual corrections and approx. integrated real corrections

$$\tilde{\mathrm{B}}_n(\Phi_n) \;\approx\; \tilde{\mathrm{B}}_n(\Phi_n) + \mathrm{V}_{n,\mathrm{EW}}(\Phi_n) + \mathrm{I}_{n,\mathrm{EW}}(\Phi_n) + \mathrm{B}_{n,\mathrm{mix}}(\Phi_n)$$

- real QED radiation can be recovered through standard tools (parton shower, YFS resummation)
- simple stand-in for proper QCD$\oplus$EW matching and merging
  $\rightarrow$ validated at fixed order, found to be reliable,
  difference $\lesssim 5\%$ for observables not driven by real radiation

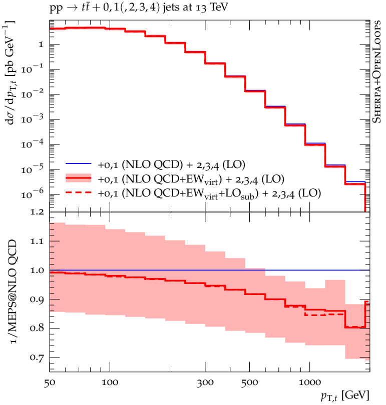
results: $pp \to \ell^- \bar{\nu} + \text{jets}$

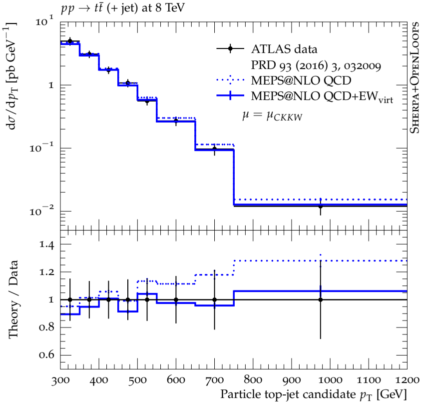




$\Rightarrow$ particle level events including dominant EW corrections

results: $pp \to t\bar{t}$

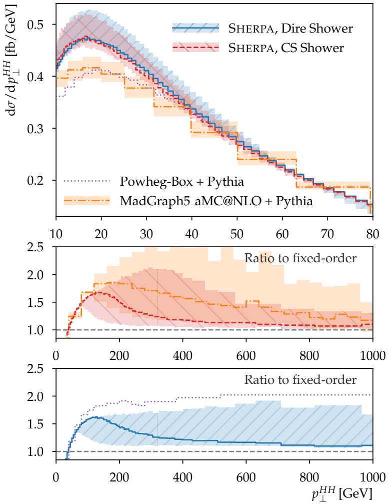




⇒ particle level events including dominant EW corrections

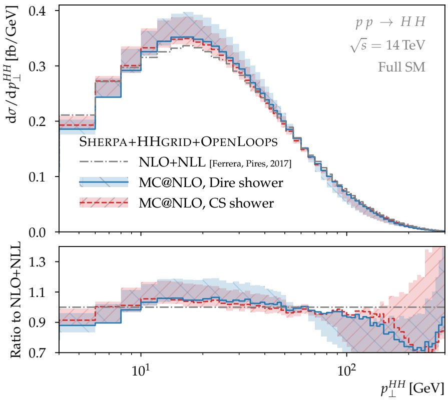
loop-induced processes: $gg \to HH$

comparison with literature: NLO+PS



- largest differences in peak region due to differences in algorithms beyond choice of $\mu_{\rm PS}$: 15%
- all NLO+PS results agree within uncertainties in tail region
- MADGRAPH uncertainties larger
- POWHEG: flat excess in tail known feature of matching method (somewhat suppressed through "damping factor" $h_{\rm damp} = 250$ GeV)

comparison with literature: analytic resummation

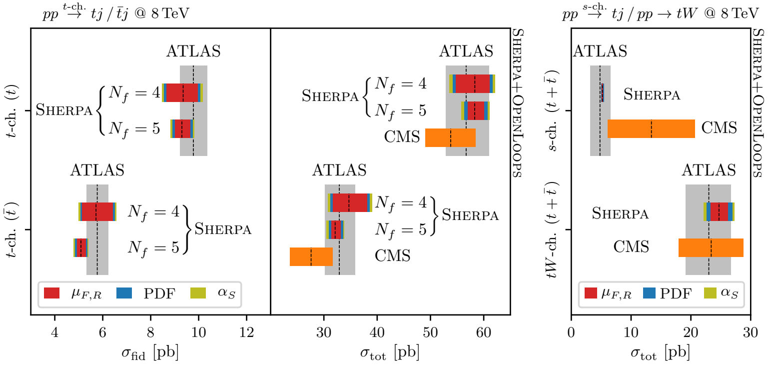


- next-to-leading log (NLL) parametrically equivalent to parton shower
- uncertainties on NLO+NLL:
  - 3% near $p_\perp^{HH} \approx 20$ GeV
  - 10% near $p_\perp^{HH} \approx 100$ GeV
- good agreement within uncertainties

example applications

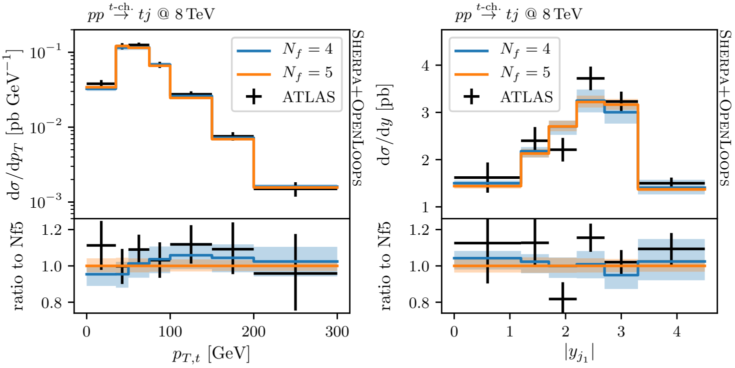
single-top production: rates

- MC@NLO
- $\mu^2 = \hat{t}, \hat{s}$ for t-/s-channel (by clustering to $2 \to 2$), tW: ${m_T^t}^2$
- comparison to ATLAS/CMS results:



single-top production: distributions

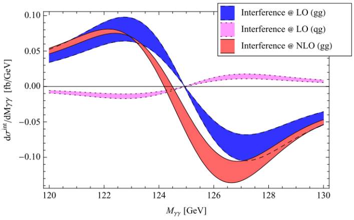
- comparison to [ATLAS 1702.02859]

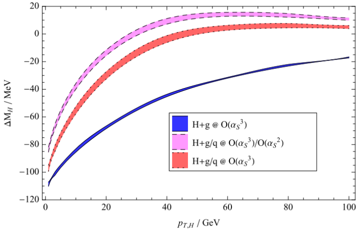


- good agreement for distributions, both with NF4 & NF5

interference-induced Higgs peak shift

- interference with background shifts Higgs diphoton peak [Martin 1208.1533]
- can infer Higgs decay width from peak shift [Dixon Li 1305.3854]
- with HL-LHC $3\,\text{ab}^{-1}$ $\Gamma_H/\Gamma_H^{\text{SM}} < 15$ at 95 % CL

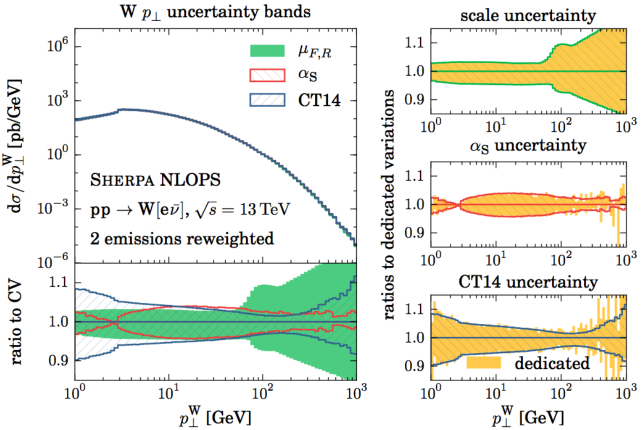




on-the-fly reweighting

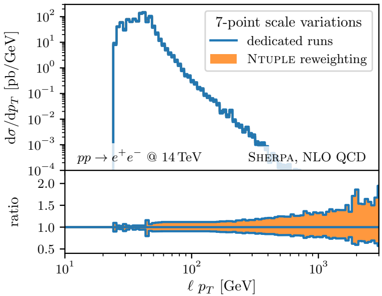
reweighting on-the-fly: NLOPS

- 110 variations in $pp \to W$ at MC@NLO
- two hardest emissions included in reweighting

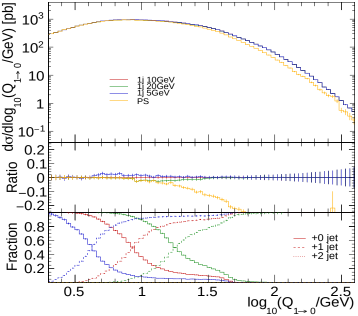


reweighting on-the-fly: $Q_{\rm cut}$ (recent news)

variation of NTUPLE samples



$Q_{\rm cut}$ variations in merging runs



- on-the-fly reweighting as the ubiquitous & default way to generate systematic uncertainty bands

implementing DGLAP @ NLO

towards higher logarithmic accuracy

- aim: reproduce DGLAP evolution at NLO

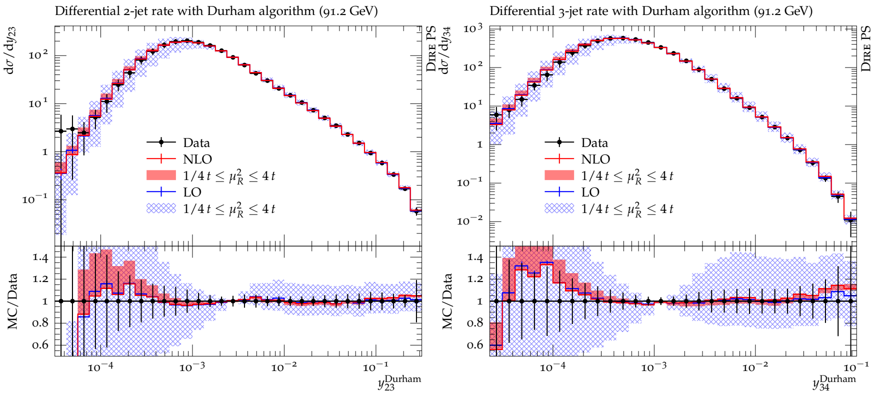
  include all NLO splitting kernels

- expand splitting kernels as

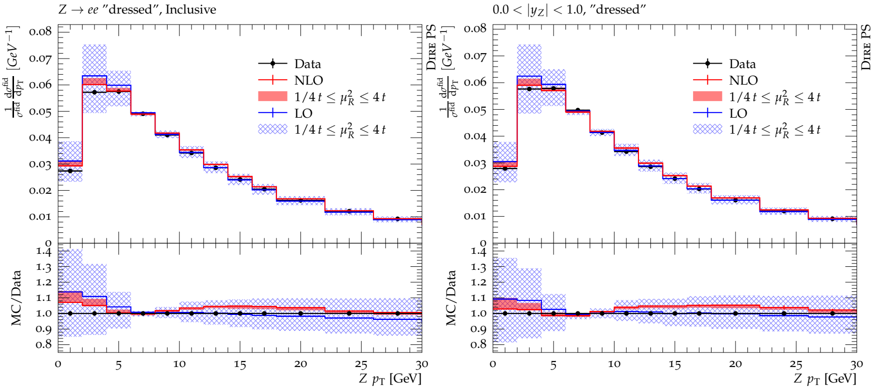
$$P(z,\,\kappa^2) \;=\; P^{(0)}(z,\,\kappa^2) + \frac{\alpha_S}{2\pi}\,P^{(1)}(z,\,\kappa^2)$$

- three categories of terms in $P^{(1)}$:
  - cusp (universal soft-enhanced correction) (already included in original showers)
  - corrections to $1 \to 2$
  - new flavour structures (e.g. $q \to q'$), identifed as $1 \to 3$
- new paradigm: two independent implementations

physical results: $e^-e^+ \to$ hadrons



physical results: DY at LHC



parton shower accuracy

how to assess formal precision?

- PS proven to be NLL accurate for simple observables, provided

  Catani,Marchesini,Webber, NPB349(1991)635

  - soft double-counting removed ($\nearrow$ before) and
  - 2-loop cusp anomalous dimension included
- not entirely clear what this means numerically, because
  - parton shower is momentum conserving, NLL is not
  - parton shower is unitary, NLL approximations break this
- differences can be quantified by
  - designing an MC that reproduces NLL exactly
  - removing NLL approximations one-by-one
- employ well-established NLL result as an example
  - observable: Thrust in $e^+e^- \to$hadrons
  - method: Caesar Banfi,Salam,Zanderighi, hep-ph/0407286
- this discussion is technical, but it is needed to show that equivalence at NLL does not mean identical numerics

differences between pure NLL and parton shower

Hoeche, Reichelt, Siegert, arXiv:1711.03497

- isolated differences in terms of resolved/unresolved splitting probability:

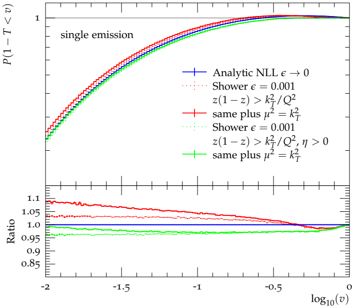
$$R'_{\lessgtr v}(\xi) = \frac{\alpha_s^{\lessgtr v,\mathrm{soft}}\left(\mu^2_{\lessgtr}\right)}{\pi}\int_{z^{\min}}^{z^{\max}_{\lessgtr v,\mathrm{soft}}} dz\,\frac{C_\mathrm{F}}{1-z} - \frac{\alpha_s^{\lessgtr v,\mathrm{coll}}\left(\mu^2_{\lessgtr v}\right)}{\pi}\int_{z^{\min}}^{z^{\max}_{\lessgtr v,\mathrm{coll}}} dz\, C_\mathrm{F}\,\frac{1+z}{2}$$

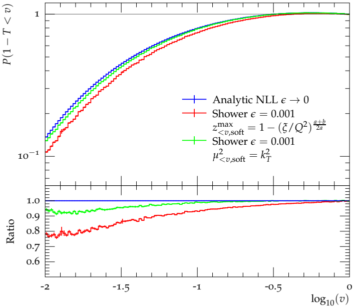
	NLL	Parton Shower
$z^{\max}_{>v,\mathrm{soft}}$	$1-(\xi/Q^2)^{\frac{a+b}{2a}}$	
$\mu^2_{>v,\mathrm{soft}}$	$\xi(1-z)^{\frac{2b}{a+b}}$	
$\alpha_s^{>v,\mathrm{soft}}$	2-loop CMW	
$z^{\max}_{<v,\mathrm{soft}}$	$1-v^{\frac{1}{a}}$	$1-(\xi/Q^2)^{\frac{a+b}{2a}}$
$\mu^2_{<v,\mathrm{soft}}$	$Q^2 v^{\frac{2}{a+b}}(1-z)^{\frac{2b}{a+b}}$	$\xi(1-z)^{\frac{2b}{a+b}}$
$\alpha_s^{<v,\mathrm{soft}}$	1-loop	2-loop CMW

	NLL	Parton Shower
$z^{\max}_{>v,\mathrm{coll}}$	1	$1-(\xi/Q^2)^{\frac{a+b}{2a}}$
$\mu^2_{>v,\mathrm{coll}}$	ξ	$\xi(1-z)^{\frac{2b}{a+b}}$
$\alpha_s^{>v,\mathrm{coll}}$	1-loop	2-loop CMW
$z^{\max}_{<v,\mathrm{coll}}$	0	$1-(\xi/Q^2)^{\frac{a+b}{2a}}$
$\mu^2_{<v,\mathrm{coll}}$	n.a.	$\xi(1-z)^{\frac{2b}{a+b}}$
$\alpha_s^{<v,\mathrm{coll}}$	n.a.	2-loop CMW

- can cast pure NLL into PS language by using NLL expressions in PS
- can study each effect in detail by reverting changes back to PS

Local momentum conservation and unitarity

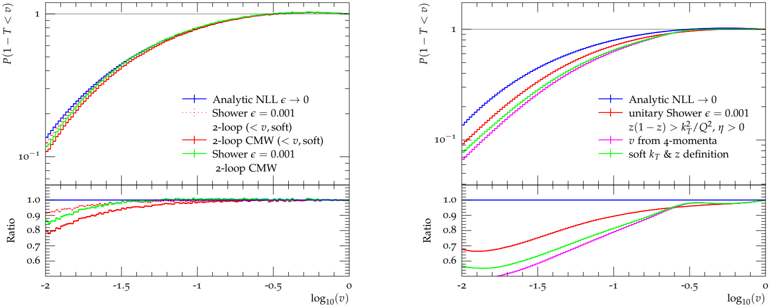




- NLL→PS in $z_{\mathrm{min/max}}$ (4-momentum conservation)
- NLL→PS in $z^{\mathrm{coll}}_{>v,\mathrm{max}}$ (phase-space sectorization)
- NLL→PS in $\mu^2_{>v,\mathrm{coll}}$ (conventional)

- NLL→PS in $z^{\mathrm{soft}}_{<v,\mathrm{max}}$ (from PS unitarity)
- NLL→PS in $\mu^2_{<v,\mathrm{soft}}$ (from PS unitarity)

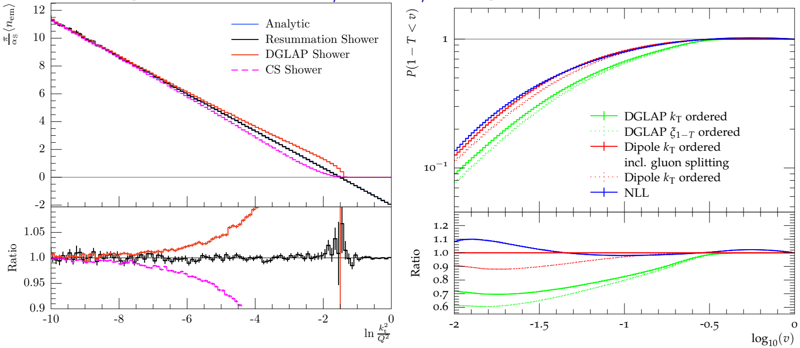
Running coupling and global momentum conservation



- NLL→PS in 2-loop CMW $< v$, soft (from PS unitarity)
- NLL→PS in 2-loop CMW overall (conventional)

- NLL→PS in observable (use experimental definition)
- NLL→PS in evolution variable

Overall comparison NLL / PS / Dipole Shower



- Tuned comparison of differences between formally equivalent calculations
- Simplest process and simplest observable, but still large differences
- Origin of differences traced to treatment of kinematics & unitarity
- At NLL accuracy, none of the methods is formally superior
  $\rightarrow$ Difference is a systematic uncertainty & needs to be kept in mind