Status of NLO electroweak corrections in SHERPA+OPENLOOPS

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Introduction

Electroweak correction come in two variants: virtual corrections and real emission correction.

Most observables driven by either

- virtual corrections, often studied in the context of vector boson or jet production at large $p_\perp$ (EW-Sudakov suppression)
  $\rightarrow$ **NLO EW calculation**
- real photon emission/bremsstrahlung, very important for most lepton observables, less important for quarks as drowned in QCD bremsstrahlung
  $\rightarrow$ **NLO EW matched to resummation**
- real weak boson emissions, constitutes separately finite process, depending on decay channel and analysis different signature
  $\rightarrow$ **add as separate LO process**

Resummation of genuine weak corr. important if scale $\gg m_V$ present

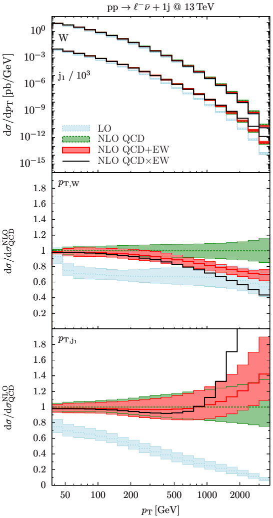
Next-to-leading order electroweak corrections

Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2015)012, JHEP04(2016)021

- fixed-order next-to-leading order electroweak corrections
- automated implementation, independent cross checks:
  - OpenLoops for virtual corrections
    cross checked against other private generator
  - Sherpa for Born, real em., subtraction and phase space int.,
    cross checked against Munich (MEs from OpenLoops)
- combine QCD and EW corrections as:
  QCD+EW: $\sigma_{\text{NLO QCD+EW}} = \sigma_{\text{LO}}\,(1 + \delta_{\text{QCD}} + \delta_{\text{EW}})$
  QCD×EW: $\sigma_{\text{NLO QCD}\times\text{EW}} = \sigma_{\text{LO}}\,(1 + \delta_{\text{QCD}})\,(1 + \delta_{\text{EW}})$
- already studied a range of processes:
  - $pp \to V + 1, 2(, 3)$ jets production
  - $pp \to t\bar{t}h$ for LH'15
  - $pp \to Zj/pp \to \gamma j$ ratio for LH'15
  - $pp \to Vh$ for FCC report

$pp \to Wj$ @ 13 TeV

Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021



- NLO QCD to $p_{\mathrm{T}}^{j_1}$ dominated by hard dijet topologies
  $\to$ LO, no EW corr.
  Rubin, Salam, Sapeta JHEP09(2010)084
  $\to$ need merging
- remove dijet configs through $\Delta\phi_{j_1 j_2} < \frac{3}{4}\pi$
  $\to$ EW Sudakov recovered

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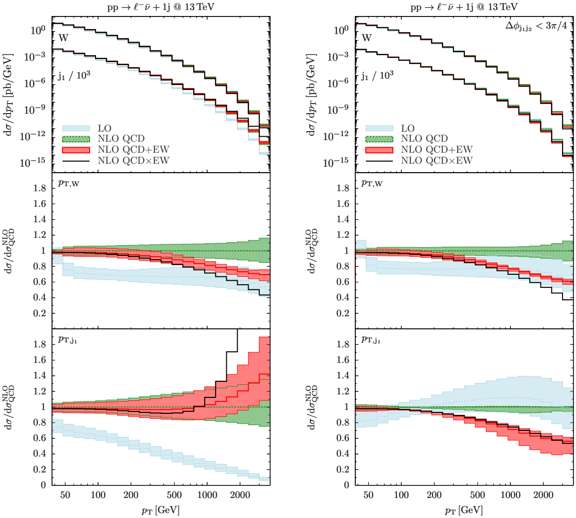

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$pp \to Wj\,/\,Wjj\,/\,Wjjj$ @ 13 TeV

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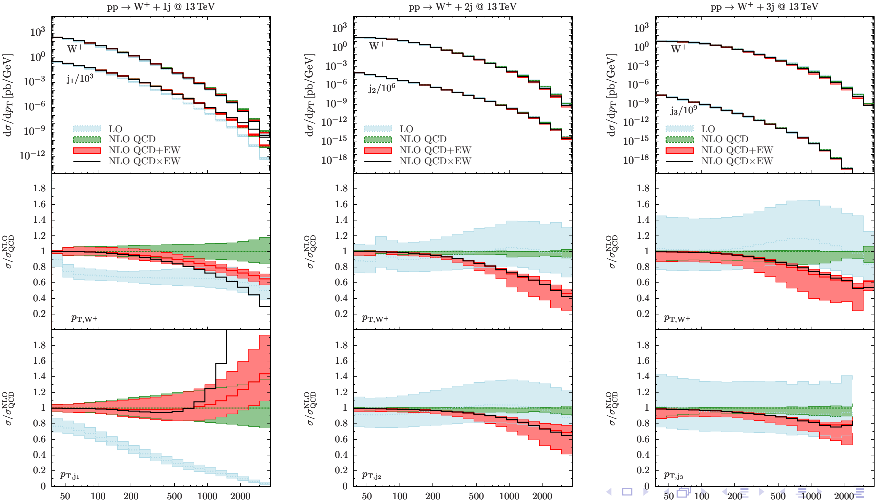
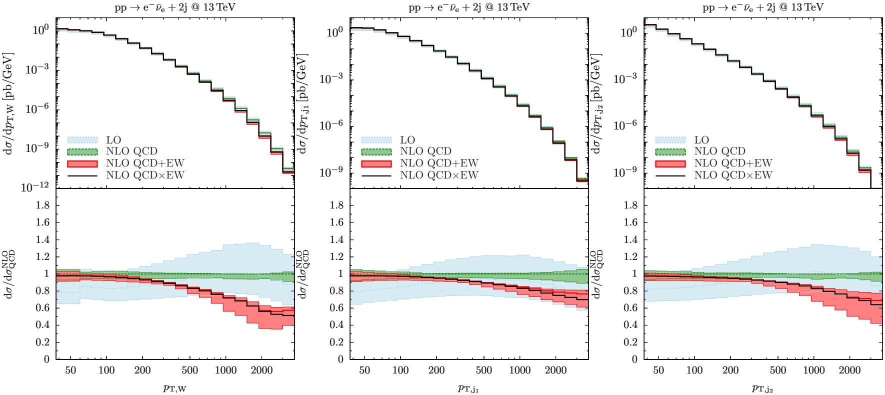


$pp \to Wjj$ @ 13 TeV

Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021



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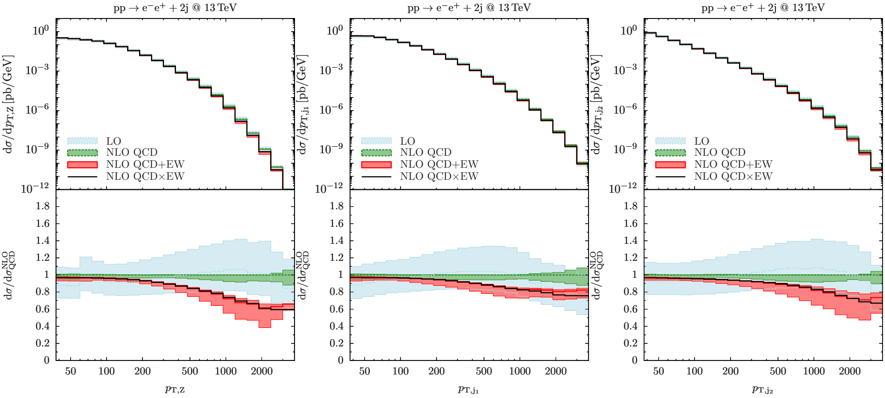

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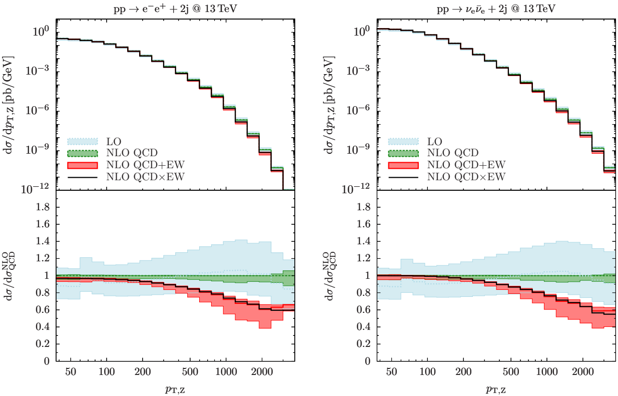
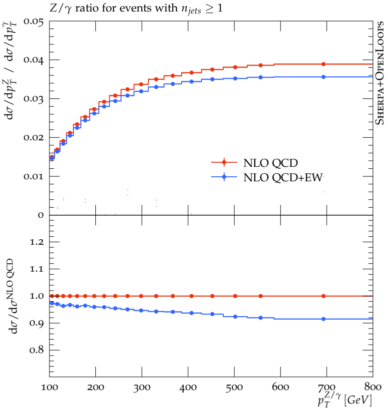


→ EW corrections independent of the decay mode

Z/γ ratio @ 8 TeV



Kallweit, Lindert, Pozzorini, MS for LH'15

- use this ratio to get handle on $p_\perp^Z$ in $Z \to \nu\bar{\nu}$ for NP searches
- test how well data is described in $Z \to \ell\ell$

$\Rightarrow$ NLO EW improves data description

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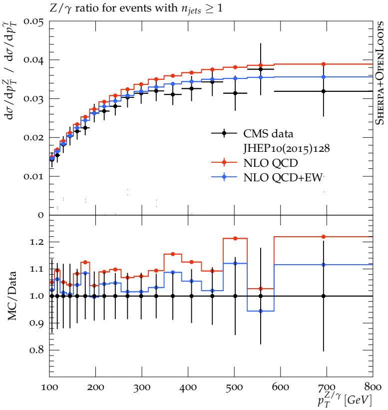

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Inclusion of virtual electroweak corrections

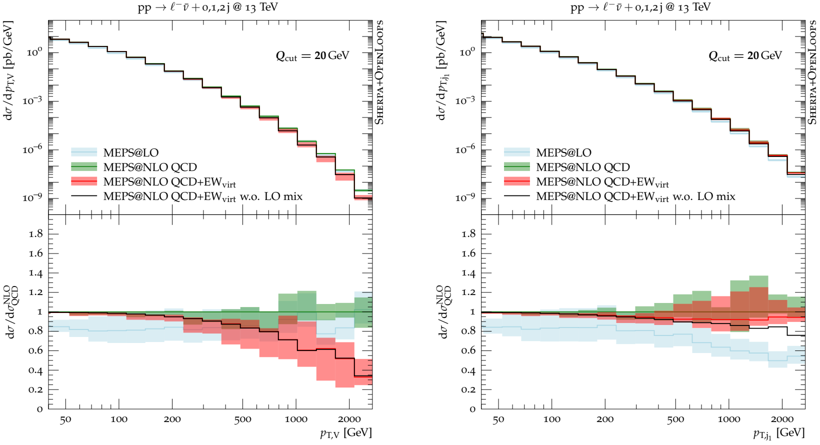
- incorporate approximate electroweak corrections in NLO QCD multijet merging (MEPS@NLO)
- modify MC@NLO $\tilde{\mathrm{B}}$-function to include NLO EW virtual corrections and integrated approx. real corrections
  $\rightarrow$ optionally also subleading Born configurations

$$\tilde{\mathrm{B}}_{n,\mathrm{QCD+EW_{virt}}}(\Phi_n) = \tilde{\mathrm{B}}_n(\Phi_n) + \mathrm{V}_{n,\mathrm{EW}}(\Phi_n) + \mathrm{I}_{n,\mathrm{EW}}(\Phi_n) + \mathrm{B}_{n,\mathrm{mix}}(\Phi_n)$$

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

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

Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021



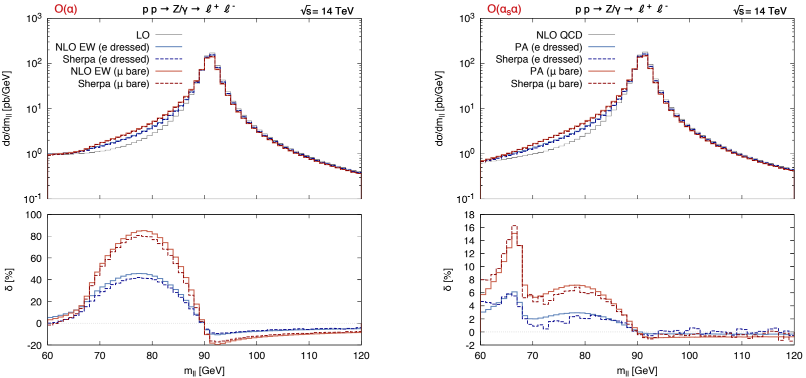
⇒ particle level events including dominant EW corrections

Soft photon resummation

- YFS soft-photon resummation default for higher-order QED corrections in SHERPA — Yennie, Frautschi, Suura Annals Phys.13(1961)379-452; MS, Krauss JHEP12(2008)018
- factorised from higher-order QCD corrections
- universal soft eikonal supplemented with universal hard collinear corrections
- process specific corrections can be easily incorporated where known
  $\rightarrow$ NLO QED accuracy in $W \rightarrow \ell\nu$ and $Z \rightarrow \ell\ell$
  and other important resonant decay channels
  $\rightarrow$ generic resonance identification in multibody final states
  invariant masses are preserved
  important in e.g. VV etc.

Accuracy in $pp \to \ell\ell$

Huss, MS for LH'15



- $\mathcal{O}(\alpha)$ and $\mathcal{O}(\alpha_s\alpha)$ electroweak corrections well reproduced
- residual difference due to multi-photon emissions
- genuine weak corrections very small

Accuracy in $pp \to \ell\ell$

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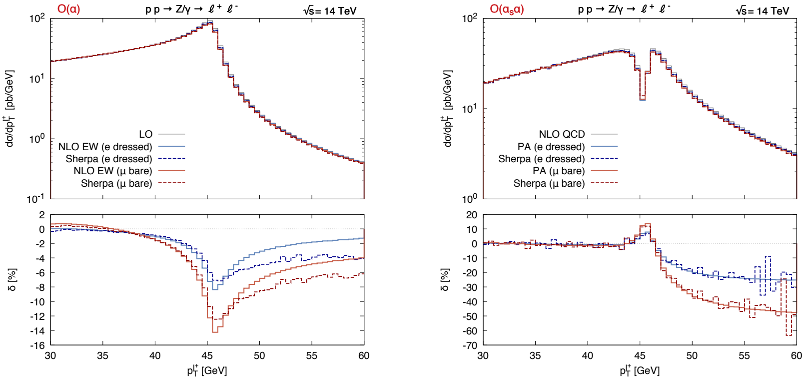

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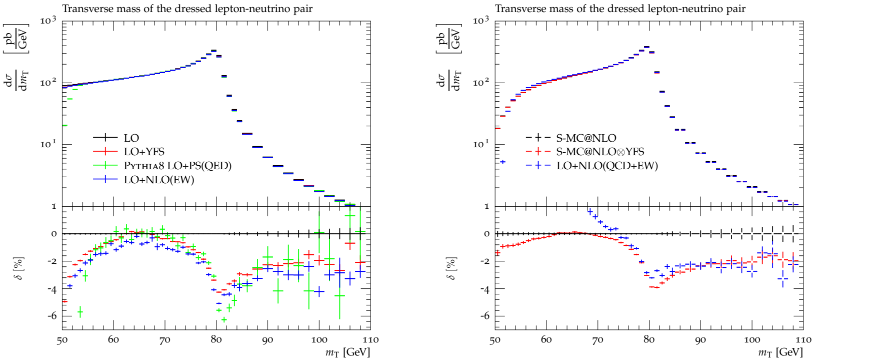
- for $p_\perp^\ell > \frac{1}{2}m_Z$ driven by ISR (not in YFS), but $\ll$ QCD ISR
- genuine weak corrections sizeable only at large $p_\perp^\ell$

Accuracy in $pp \to \ell\nu$

Höche, Prestel, MS for EW report



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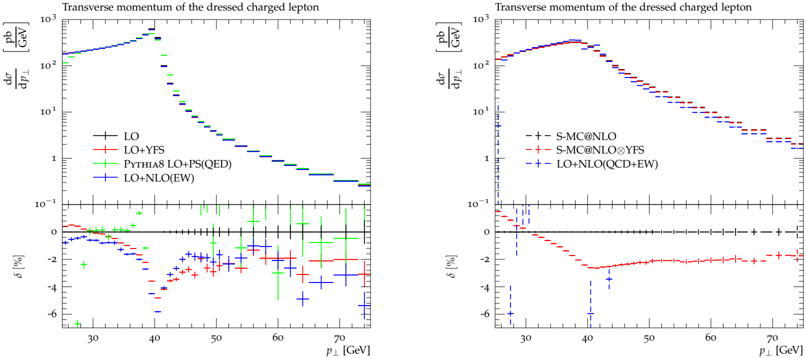

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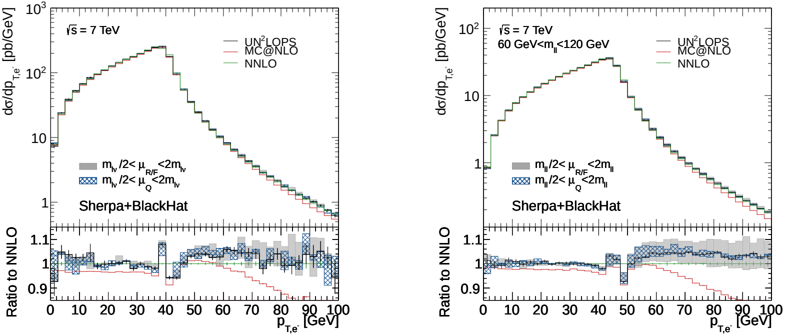
Highest precision description



$pp \to \ell\nu$ $pp \to \ell\ell$

- NNLOPS in UN^{2}LOPS scheme Höche, Li, Prestel PRD91(2015)074015
- YFS soft-photon resummation applied to boson decay

$\Rightarrow$ NNLO+PS$\otimes$YFS

Conclusions

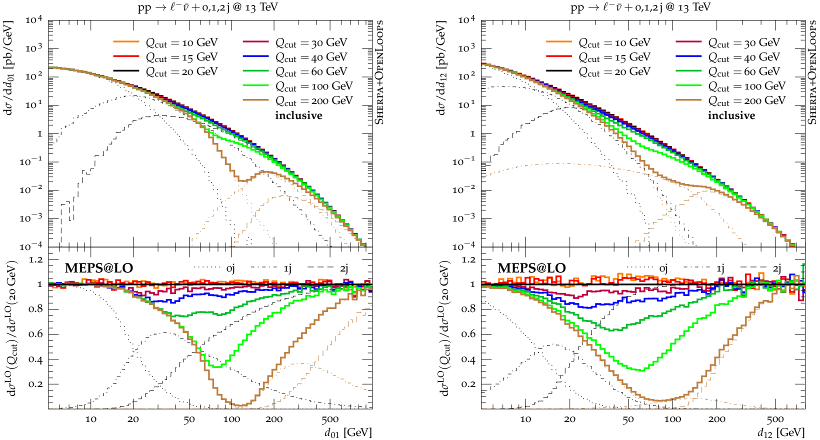
- NLO EW automated in SHERPA+OPENLOOPS framework
  → programs will become public soon
- no matching of NLO EW to parton shower available yet
  → in the works
- YFS-type soft-photon resummation gives precise results for bremsstrahlung dominated observables
  → no EW Sudakov-type corrections
  → no ISR corrections (usually negligible)
- implementation orthogonal to higher-order QCD corrections
  → complements LOPS, NLOPS (MC@NLO), NNLOPS (UN^{2}LOPS) and MEPS, MEPS@NLO simulations

Thank you for your attention!

Backup

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

Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021



$\Rightarrow$ dead zones in incl. obs. if Q_{cut} too high

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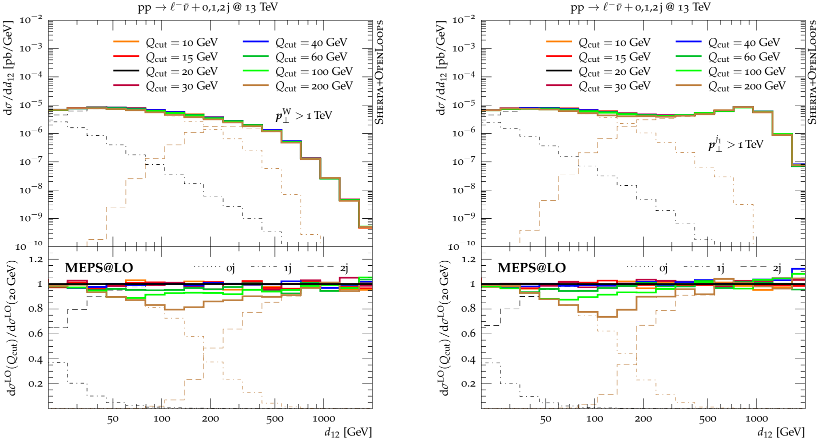

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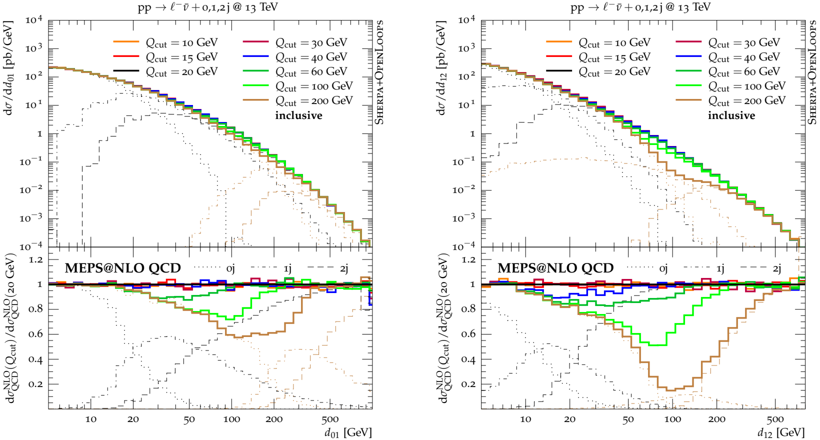

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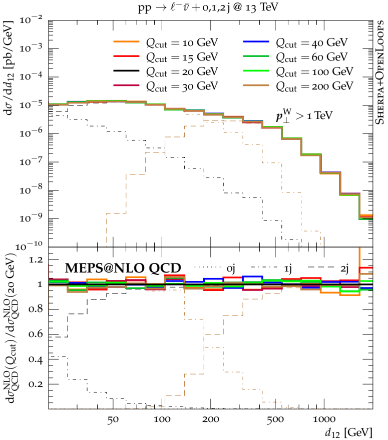

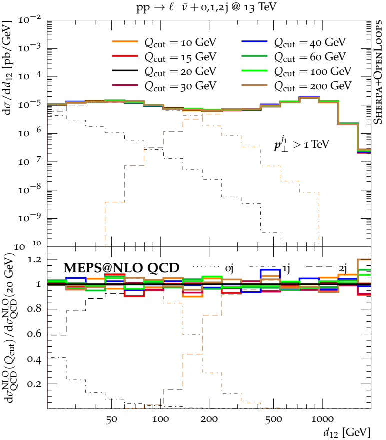

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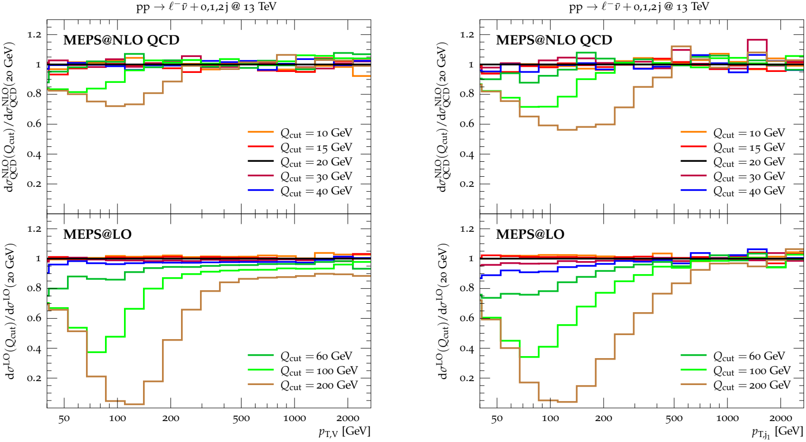

$\Rightarrow$ TeV region stable ($\lesssim 5\%$), $Q_{\text{cut}} = 20\,\text{GeV}$ suitable for whole range