Electroweak corrections to $V+$ jets production

Marek Schönherr

Universität Zürich

LoopFest, Buffalo, 16/08/2016

Universität Zürich[UZH]

FNSNF
FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION

Introduction

Electroweak corrections are important not only for precision observables, but also at at large transverse momenta.

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

$$\mathrm{d}\sigma^{\mathsf{NLO}} = \int \mathrm{d}\Phi_B \left[\mathrm{B}(\Phi_B) + \mathrm{V}_{\mathsf{EW}}(\Phi_B) + \mathrm{I}_{\mathsf{QED}}(\Phi_B)\right] + \int \mathrm{d}\Phi_R \left[\mathrm{R}_{\mathsf{EW}}(\Phi_R) - \mathrm{S}_{\mathsf{QED}}(\Phi_R)\right]$$

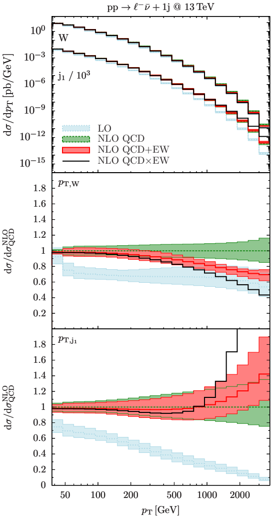
- automated implementation, independent cross checks:
  - OpenLoops for virtual corrections (Collier tensor ints) cross checked against independent private generator
  - Munich for phase space integration (MEs from OpenLoops), Sherpa for Born, real em., subtraction and phase space int.
- includes interferences of diagrams of different $\mathcal{O}(g_s^n e^m)$
- subleading Born contributions complete α_s renormalisation of NLO EW correction, can be non-negligible contribution

Next-to-leading order electroweak corrections

- generally NNPDF23_nlo_as_0118_qed (6 fl., neglect tiny top PDF)
- 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: $\sigma_{\text{NLO QCD}\times\text{EW}} = \sigma_{\text{LO}}\,(1 + \delta_{\text{QCD}})\,(1 + \delta_{\text{EW}})$
  $\Rightarrow$ use difference as indication of potential size of $\mathcal{O}(\alpha_s\alpha)$ corrs.
- already studied a range of processes:
  - $pp \to V + 0, 1, 2(, 3)$ jets
    Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2015)012, JHEP04(2016)021
    EW report arXiv:1606.02330
  - $pp \to t\bar{t}h$
    LH'15 arXiv:1605.04692
  - $pp \to Zj/pp \to \gamma j$ ratio
    Kallweit, Lindert, Maierhöfer, Pozzorini, MS arXiv:1505.05704
    LH'15 arXiv:1605.04692
  - $pp \to Vh$
    FCC report, arXiv:1607.01831
- dedicated comparisons in LH'15 against Recola $(Z + 2j)$ and MadGraph (tth) showed agreement

$pp \to Wj$ @ 13 TeV

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



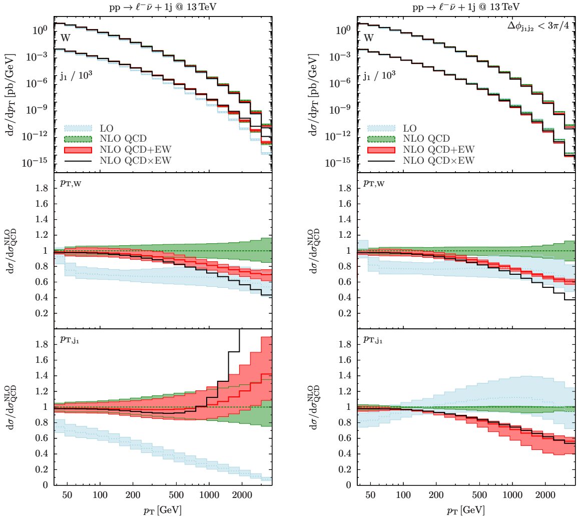
- NLO QCD to $p_T^{j_1}$ dominated by hard dijet topologies
  $\to$ LO, no EW corr.

  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

$pp \to Wj$ @ 13 TeV

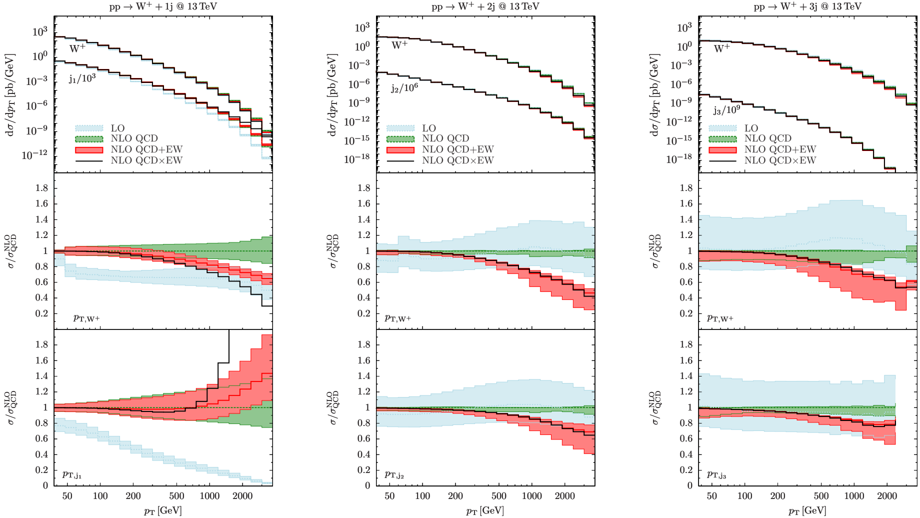
Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021



- 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

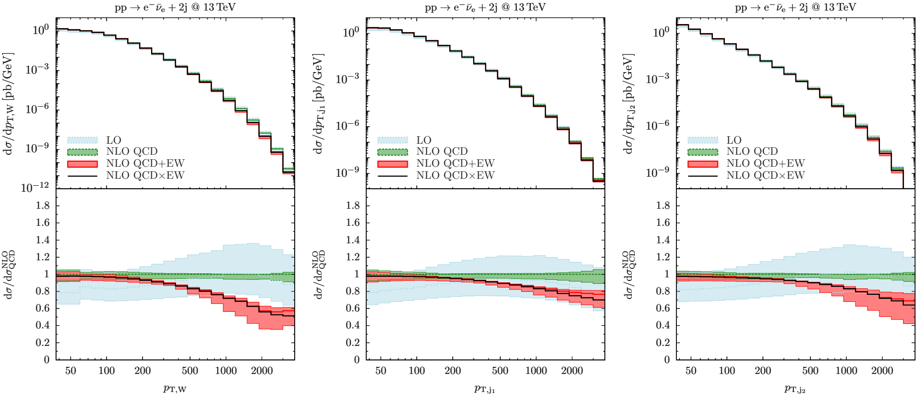
$pp \to Wj\,/\,Wjj\,/\,Wjjj$ @ 13 TeV

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



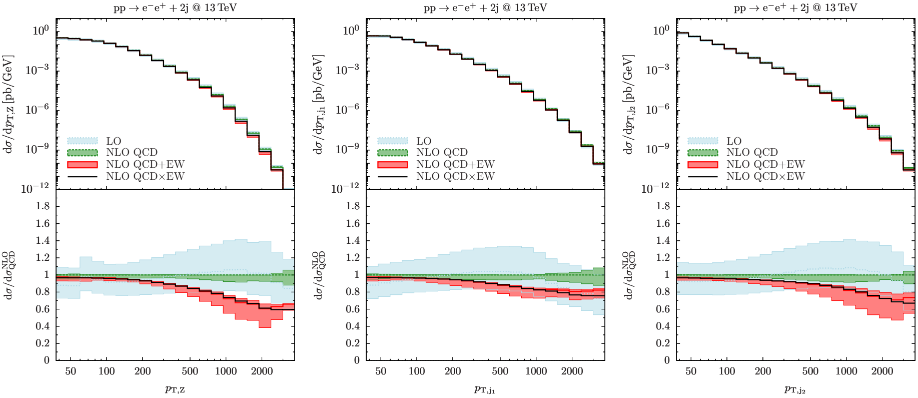
$pp \to Wjj$ @ 13 TeV

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



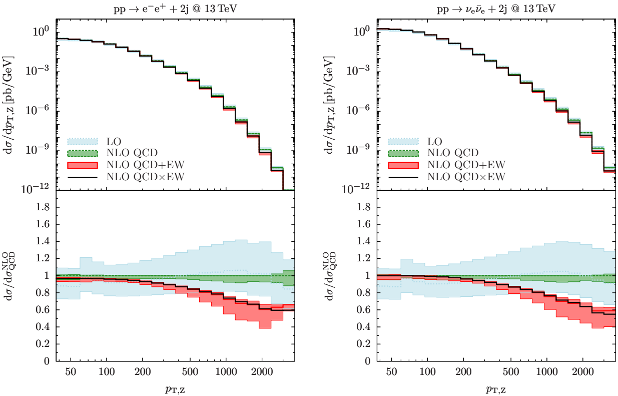
$pp \to Zjj$ @ 13 TeV

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



$pp \to Zjj$ @ 13 TeV

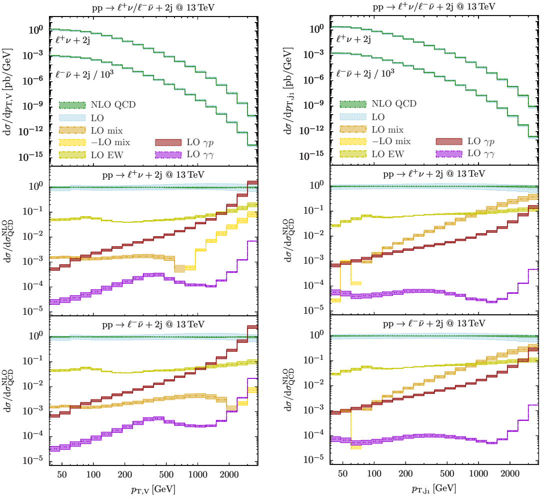
Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021



$\rightarrow$ EW corrections independent of the decay mode

$pp \to Wjj$ @ 13 TeV – subleading Born contributions

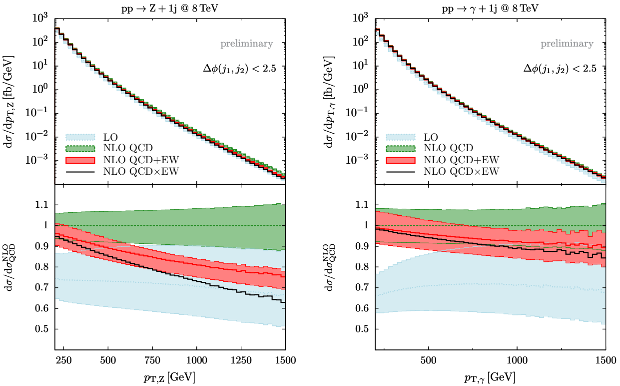
Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021



- LO dominated by gq IS
- either $4q$ procs (LO mix) or photon initiated
  $\rightarrow$ can be important in TeV range (large x)
- $4q$ interferences of diagrams of different $\mathcal{O}(g_s^n e^m)$
  $\rightarrow$ not pos. definite
- γPDF has $\mathcal{O}(1)$ unc.
  $\rightarrow$ high-$p_\perp$ data can be used as constraint

Z/γ ratio @ 8 TeV

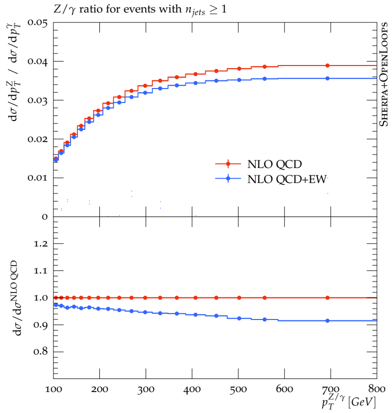
Kallweit, Lindert, Maierhöfer, Pozzorini, MS arXiv:1505.05704



→ EW corrections different for Z and γ

Z/γ ratio @ 8 TeV

Kallweit, Lindert, Pozzorini, MS for LH'15 [arXiv:1605:04692]

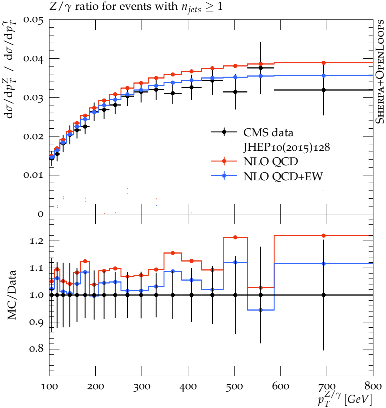


- use this ratio to get handle on $p_\perp^Z$ in $Z \to \nu\bar{\nu}$ for NP searches
- test how well data is described in $Z \to \ell\ell$

$\Rightarrow$ NLO EW improves data description

Z/γ ratio @ 8 TeV

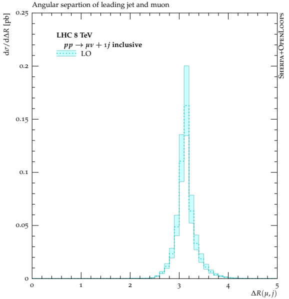
Kallweit, Lindert, Pozzorini, MS for LH'15 [arXiv:1605:04692]



- 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

NLO EW predictions for $\Delta R(\mu, j_1)$

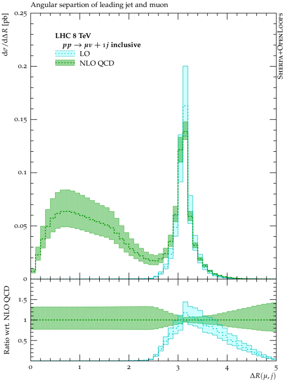


Measure coll. W emissions, simplified from Krauss, Petrov, MS, Spannowsky PRD89(2014)114006

LHC@8TeV, $p_\perp^{j_1} > 500\,\mathrm{GeV}$, central μ and jet

- LO $pp \to Wj$ with $\Delta\phi(\mu, j) \approx \pi$
- NLO corrections neg. in peak large $pp \to Wjj$ component opening PS
- subleading Born (γPDF) imp. at large ΔR
- restrict to exactly $1j$, no $p_\perp^{j_2} > 100\,\mathrm{GeV}$
- describe $pp \to Wjj$ @ NLO, use $p_\perp^{j_2} > 100\,\mathrm{GeV}$
- pos. NLO QCD, neg. NLO EW, $\sim$ flat
- subleading Born contribs positive
- sub^{2}leading Born (diboson etc) conts. pos. $\to$ possible double counting with BG
- merge using exclusive sums

NLO EW predictions for $\Delta R(\mu, j_1)$

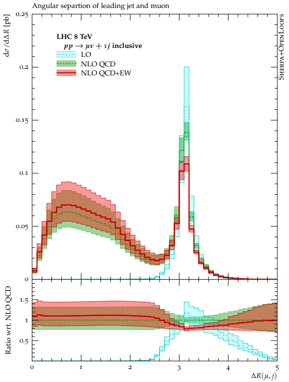


Measure coll. W emissions, simplified from
Krauss, Petrov, MS, Spannowsky PRD89(2014)114006

LHC@8TeV, $p_\perp^{j_1} > 500\,\mathrm{GeV}$, central μ and jet

- LO $pp \to Wj$ with $\Delta\phi(\mu, j) \approx \pi$
- NLO corrections neg. in peak
  large $pp \to Wjj$ component opening PS
- subleading Born (γPDF) imp. at large ΔR
- restrict to exactly $1j$, no $p_\perp^{j_2} > 100\,\mathrm{GeV}$
- describe $pp \to Wjj$ @ NLO,
  use $p_\perp^{j_2} > 100\,\mathrm{GeV}$
- pos. NLO QCD, neg. NLO EW $\sim$ flat
- subleading Born contribs positive
- sub^{2}leading Born (diboson etc) conts. pos.
  $\to$ possible double counting with BG
- merge using exclusive sums

NLO EW predictions for $\Delta R(\mu, j_1)$

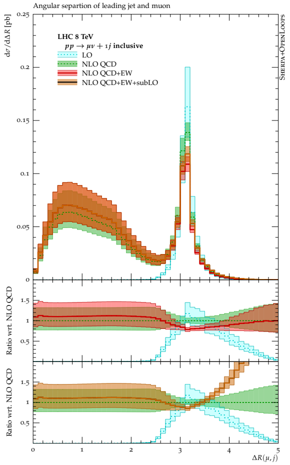


Measure coll. W emissions, simplified from
Krauss, Petrov, MS, Spannowsky PRD89(2014)114006

LHC@8TeV, $p_\perp^{j_1} > 500\,\mathrm{GeV}$, central μ and jet

- LO $pp \to Wj$ with $\Delta\phi(\mu, j) \approx \pi$
- NLO corrections neg. in peak
  large $pp \to Wjj$ component opening PS
- subleading Born (γPDF) imp. at large ΔR
- restrict to exactly $1j$, no $p_\perp^{j_2} > 100\,\mathrm{GeV}$
- describe $pp \to Wjj$ @ NLO,
  use $p_\perp^{j_2} > 100\,\mathrm{GeV}$
- pos. NLO QCD, neg. NLO EW, $\sim$ flat
- subleading Born contribs positive
- sub^{2}leading Born (diboson etc) conts. pos.
  $\to$ possible double counting with BG
- merge using exclusive sums

NLO EW predictions for $\Delta R(\mu, j_1)$

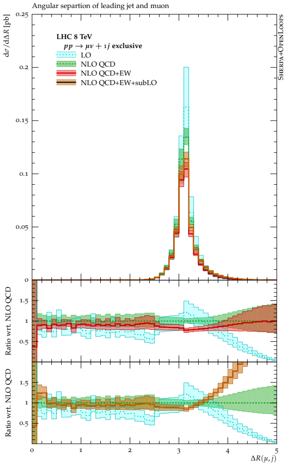


Measure coll. W emissions, simplified from
Krauss, Petrov, MS, Spannowsky PRD89(2014)114006

LHC@8TeV, $p_\perp^{j_1} > 500\,\mathrm{GeV}$, central μ and jet

- LO $pp \to Wj$ with $\Delta\phi(\mu, j) \approx \pi$
- NLO corrections neg. in peak
  large $pp \to Wjj$ component opening PS
- subleading Born (γPDF) imp. at large ΔR
- restrict to exactly $1j$, no $p_\perp^{j_2} > 100\,\mathrm{GeV}$
- describe $pp \to Wjj$ @ NLO,
  use $p_\perp^{j_2} > 100\,\mathrm{GeV}$
- pos. NLO QCD, neg. NLO EW, $\sim$ flat
- subleading Born contribs positive
- sub^{2}leading Born (diboson etc) conts. pos.
  $\to$ possible double counting with BG
- merge using exclusive sums

NLO EW predictions for $\Delta R(\mu, j_1)$

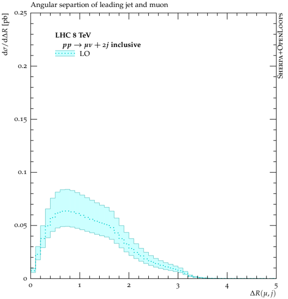


Measure coll. W emissions, simplified from
Krauss, Petrov, MS, Spannowsky PRD89(2014)114006

LHC@8TeV, $p_\perp^{j_1} > 500\,\mathrm{GeV}$, central μ and jet

- LO $pp \to Wj$ with $\Delta\phi(\mu, j) \approx \pi$
- NLO corrections neg. in peak
  large $pp \to Wjj$ component opening PS
- subleading Born (γPDF) imp. at large ΔR
- restrict to exactly $1j$, no $p_\perp^{j_2} > 100$ GeV
- describe $pp \to Wjj$ @ NLO,
  use $p_\perp^{j_2} > 100$ GeV
- pos. NLO QCD, neg. NLO EW, $\sim$ flat
- subleading Born contribs positive
- sub^{2}leading Born (diboson etc) conts. pos.
  $\to$ possible double counting with BG
- merge using exclusive sums

NLO EW predictions for $\Delta R(\mu, j_1)$

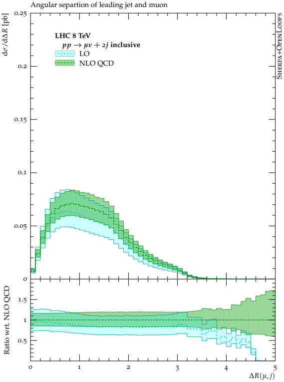


Measure coll. W emissions, simplified from
Krauss, Petrov, MS, Spannowsky PRD89(2014)114006

LHC@8TeV, $p_\perp^{j_1} > 500\,\mathrm{GeV}$, central μ and jet

- LO $pp \to Wj$ with $\Delta\phi(\mu, j) \approx \pi$
- NLO corrections neg. in peak
  large $pp \to Wjj$ component opening PS
- subleading Born (γPDF) imp. at large ΔR
- restrict to exactly $1j$, no $p_\perp^{j_2} > 100$ GeV
- describe $pp \to Wjj$ @ NLO,
  use $p_\perp^{j_2} > 100$ GeV
- pos. NLO QCD, neg. NLO EW, $\sim$ flat
- subleading Born contribs positive
- sub^{2}leading Born (diboson etc) conts. pos.
  $\to$ possible double counting with BG
- merge using exclusive sums

NLO EW predictions for $\Delta R(\mu, j_1)$

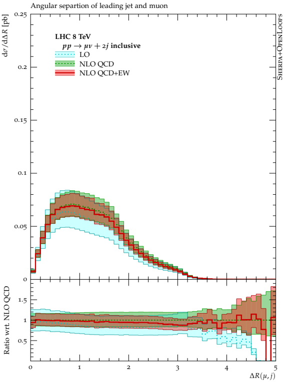


Measure coll. W emissions, simplified from Krauss, Petrov, MS, Spannowsky PRD89(2014)114006

LHC@8TeV, $p_\perp^{j_1} > 500\,\mathrm{GeV}$, central μ and jet

- LO $pp \to Wj$ with $\Delta\phi(\mu, j) \approx \pi$
- NLO corrections neg. in peak
  large $pp \to Wjj$ component opening PS
- subleading Born (γPDF) imp. at large ΔR
- restrict to exactly $1j$, no $p_\perp^{j_2} > 100$ GeV
- describe $pp \to Wjj$ @ NLO,
  use $p_\perp^{j_2} > 100$ GeV
- pos. NLO QCD, neg. NLO EW, $\sim$ flat
- subleading Born contribs positive
- sub^{2}leading Born (diboson etc) conts. pos.
  $\to$ possible double counting with BG
- merge using exclusive sums

NLO EW predictions for $\Delta R(\mu, j_1)$

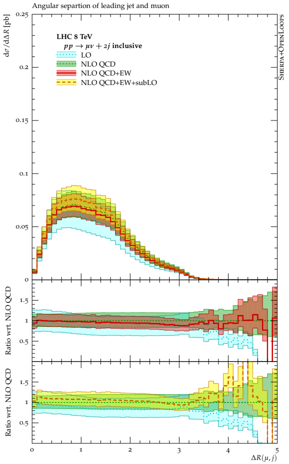


Measure coll. W emissions, simplified from
Krauss, Petrov, MS, Spannowsky PRD89(2014)114006

LHC@8TeV, $p_\perp^{j_1} > 500\,\mathrm{GeV}$, central μ and jet

- LO $pp \to Wj$ with $\Delta\phi(\mu, j) \approx \pi$
- NLO corrections neg. in peak
  large $pp \to Wjj$ component opening PS
- subleading Born (γPDF) imp. at large ΔR
- restrict to exactly $1j$, no $p_\perp^{j_2} > 100$ GeV
- describe $pp \to Wjj$ @ NLO,
  use $p_\perp^{j_2} > 100$ GeV
- pos. NLO QCD, neg. NLO EW, $\sim$ flat
- subleading Born contribs positive
- sub^{2}leading Born (diboson etc) conts. pos.
  $\to$ possible double counting with BG
- merge using exclusive sums

NLO EW predictions for $\Delta R(\mu, j_1)$

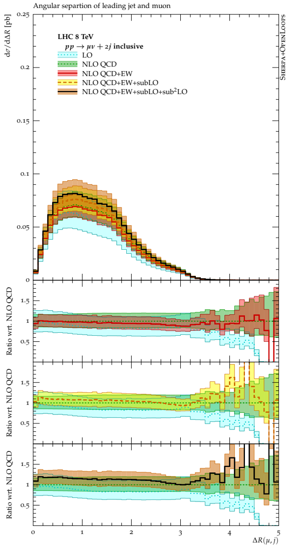


Measure coll. W emissions, simplified from
Krauss, Petrov, MS, Spannowsky PRD89(2014)114006

LHC@8TeV, $p_\perp^{j_1} > 500\,\mathrm{GeV}$, central μ and jet

- LO $pp \to Wj$ with $\Delta\phi(\mu, j) \approx \pi$
- NLO corrections neg. in peak
  large $pp \to Wjj$ component opening PS
- subleading Born (γPDF) imp. at large ΔR
- restrict to exactly $1j$, no $p_\perp^{j_2} > 100$ GeV
- describe $pp \to Wjj$ @ NLO,
  use $p_\perp^{j_2} > 100$ GeV
- pos. NLO QCD, neg. NLO EW, $\sim$ flat
- subleading Born contribs positive
- sub^{2}leading Born (diboson etc) conts. pos.
  $\to$ possible double counting with BG
- merge using exclusive sums

NLO EW predictions for $\Delta R(\mu, j_1)$

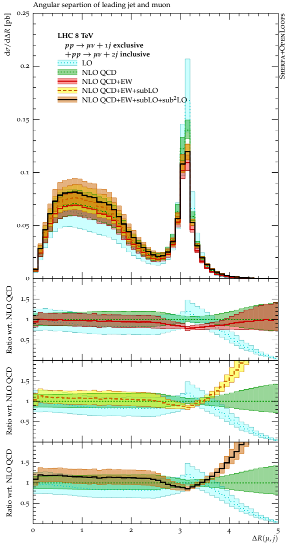


Measure coll. W emissions, simplified from
Krauss, Petrov, MS, Spannowsky PRD89(2014)114006

LHC@8TeV, $p_\perp^{j_1} > 500\,\mathrm{GeV}$, central μ and jet

- LO $pp \to Wj$ with $\Delta\phi(\mu, j) \approx \pi$
- NLO corrections neg. in peak
  large $pp \to Wjj$ component opening PS
- subleading Born (γPDF) imp. at large ΔR
- restrict to exactly $1j$, no $p_\perp^{j_2} > 100\,\mathrm{GeV}$
- describe $pp \to Wjj$ @ NLO,
  use $p_\perp^{j_2} > 100\,\mathrm{GeV}$
- pos. NLO QCD, neg. NLO EW, $\sim$ flat
- subleading Born contribs positive
- sub^{2}leading Born (diboson etc) conts. pos.
  $\to$ possible double counting with BG
- merge using exclusive sums

NLO EW predictions for $\Delta R(\mu, j_1)$

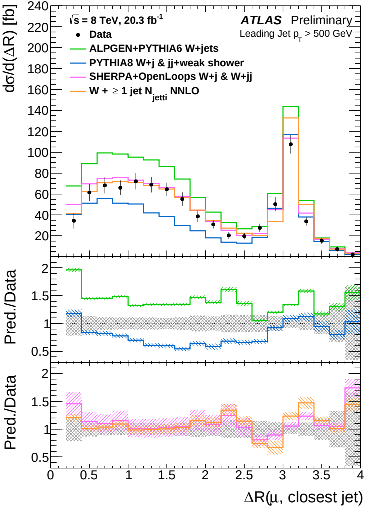


Measure coll. W emissions, simplified from
Krauss, Petrov, MS, Spannowsky PRD89(2014)114006

LHC@8TeV, $p_\perp^{j_1} > 500\,\text{GeV}$, central μ and jet

- LO $pp \to Wj$ with $\Delta\phi(\mu, j) \approx \pi$
- NLO corrections neg. in peak
  large $pp \to Wjj$ component opening PS
- subleading Born (γPDF) imp. at large ΔR
- restrict to exactly $1j$, no $p_\perp^{j_2} > 100\,\text{GeV}$
- describe $pp \to Wjj$ @ NLO,
  use $p_\perp^{j_2} > 100\,\text{GeV}$
- pos. NLO QCD, neg. NLO EW, $\sim$ flat
- subleading Born contribs positive
- sub^{2}leading Born (diboson etc) conts. pos.
  $\to$ possible double counting with BG
- merge using exclusive sums

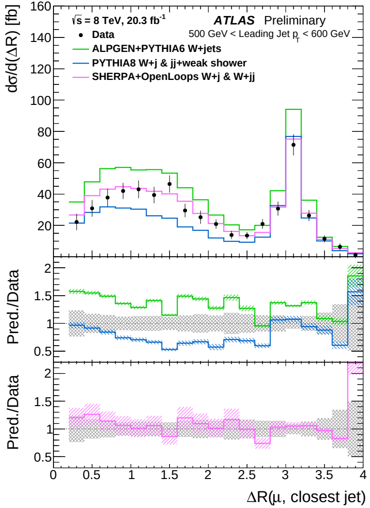
NLO EW predictions for $\Delta R(\mu, j_1)$



Data comparison M. Wu ICHEP'16

- ALPGEN+PYTHIA
  $pp \to W +$ jets MLM merged
  Mangano et.al. JHEP07(2003)001
- PYTHIA 8
  $pp \to Wj$ + QCD shower
  $pp \to jj$ + QCD+EW shower
  Christiansen, Prestel EPJC76(2016)39
- SHERPA+OPENLOOPS
  NLO QCD+EW+subLO
  $pp \to Wj/Wjj$ excl. sum
  Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021
- NNLO QCD $pp \to Wj$
  Boughezal, Liu, Petriello arXiv:1602.06965

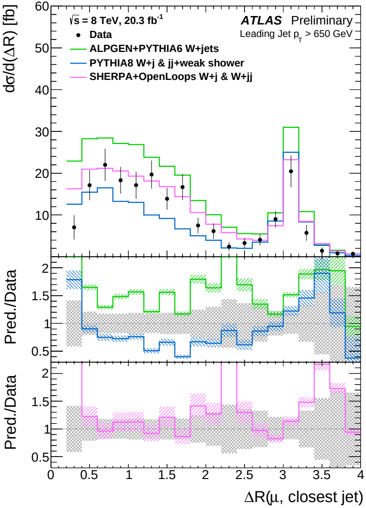
NLO EW predictions for $\Delta R(\mu, j_1)$



Data comparison   M. Wu ICHEP'16

- ALPGEN+PYTHIA
  $pp \to W+$jets MLM merged
  Mangano et.al. JHEP07(2003)001
- PYTHIA 8
  $pp \to Wj$ + QCD shower
  $pp \to jj$ + QCD+EW shower
  Christiansen, Prestel EPJC76(2016)39
- SHERPA+OPENLOOPS
  NLO QCD+EW+subLO
  $pp \to Wj/Wjj$ excl. sum
  Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021
- NNLO QCD $pp \to Wj$
  Boughezal, Liu, Petriello arXiv:1602.06965

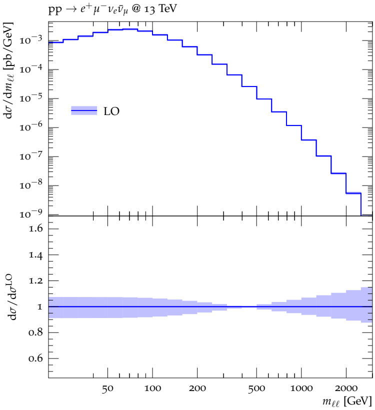
NLO EW predictions for $\Delta R(\mu, j_1)$



Data comparison M. Wu ICHEP'16

- ALPGEN+PYTHIA
  $pp \to W +$ jets MLM merged
  Mangano et.al. JHEP07(2003)001
- PYTHIA 8
  $pp \to Wj$ + QCD shower
  $pp \to jj$ + QCD+EW shower
  Christiansen, Prestel EPJC76(2016)39
- SHERPA+OPENLOOPS
  NLO QCD+EW+subLO
  $pp \to Wj/Wjj$ excl. sum
  Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021
- NNLO QCD $pp \to Wj$
  Boughezal, Liu, Petriello arXiv:1602.06965

$pp \to 2\ell 2\nu$ @ 13 TeV

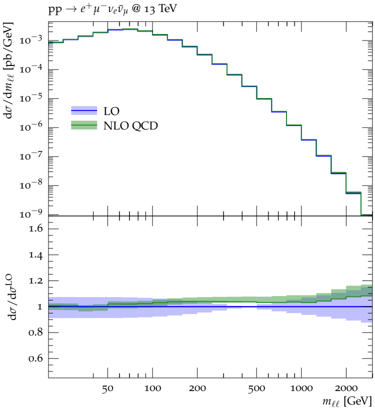


Kallweit, Lindert, Pozzorini, MS in prep.

$pp \to e^+\mu^-\nu_e\bar{\nu}_\mu$ @ 13 TeV

- $\mu = H_T^{\text{lep}} = \sum_{i\in\{e,\mu\}} p_{\perp,i} + \not{E}_T$
- analyses impose jet veto to control $t\bar{t}$-background $\to$ also reduces QCD corr.
- usual behaviour of NLO EW
- γ-induced LO large at high-x
- γPDF depedence huge similar in all obs. $\to$ ideal to measure γPDF

$pp \to 2\ell 2\nu$ @ 13 TeV

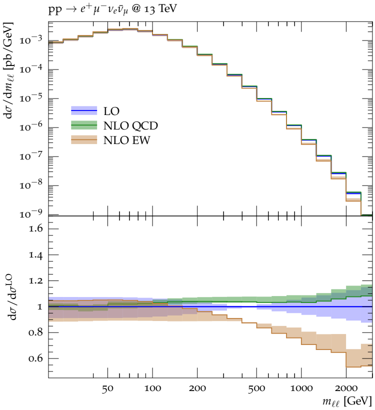


Kallweit, Lindert, Pozzorini, MS in prep.

$pp \to e^+\mu^-\nu_e\bar{\nu}_\mu$ @ 13 TeV

- $\mu = H_\mathrm{T}^\mathrm{lep} = \sum\limits_{i\in\{e,\mu\}} p_{\perp,i} + \not{E}_\mathrm{T}$
- analyses impose jet veto to control $t\bar{t}$-background
  $\to$ also reduces QCD corr.
- usual behaviour of NLO EW
- γ-induced LO large at high-x
- γPDF depedence huge
  similar in all obs.
  $\to$ ideal to measure γPDF

$pp \to 2\ell 2\nu$ @ 13 TeV

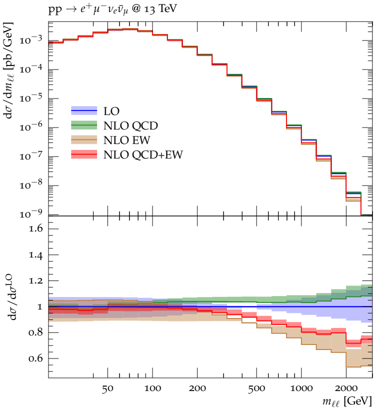


Kallweit, Lindert, Pozzorini, MS in prep.

$pp \to e^+\mu^-\nu_e\bar{\nu}_\mu$ @ 13 TeV

- $\mu = H_T^{\mathrm{lep}} = \sum_{i\in\{e,\mu\}} p_{\perp,i} + \not{E}_T$
- analyses impose jet veto to control $t\bar{t}$-background
  $\to$ also reduces QCD corr.
- usual behaviour of NLO EW
- γ-induced LO large at high-x
- γPDF depedence huge

$pp \to 2\ell 2\nu$ @ 13 TeV

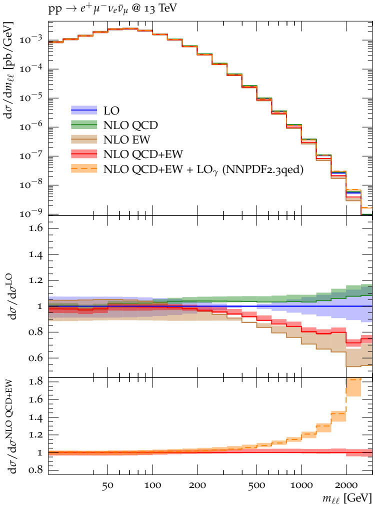


Kallweit, Lindert, Pozzorini, MS in prep.

$pp \to e^+\mu^-\nu_e\bar{\nu}_\mu$ @ 13 TeV

- $\mu = H_\mathrm{T}^{\mathrm{lep}} = \sum\limits_{i\in\{e,\mu\}} p_{\perp,i} + \not{E}_\mathrm{T}$
- analyses impose jet veto to control $t\bar{t}$-background
  $\to$ also reduces QCD corr.
- usual behaviour of NLO EW
- γ-induced LO large at high-x
- γPDF depedence huge

$pp \to 2\ell 2\nu$ @ 13 TeV

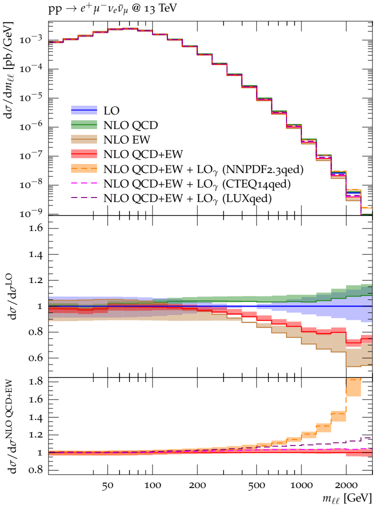


Kallweit, Lindert, Pozzorini, MS in prep.

$pp \to e^+\mu^-\nu_e\bar{\nu}_\mu$ @ 13 TeV

- $\mu = H_T^{\mathrm{lep}} = \sum\limits_{i\in\{e,\mu\}} p_{\perp,i} + \not{E}_T$
- analyses impose jet veto to control $t\bar{t}$-background → also reduces QCD corr.
- usual behaviour of NLO EW
- γ-induced LO large at high-x
- γPDF depedence huge

$pp \to 2\ell 2\nu$ @ 13 TeV

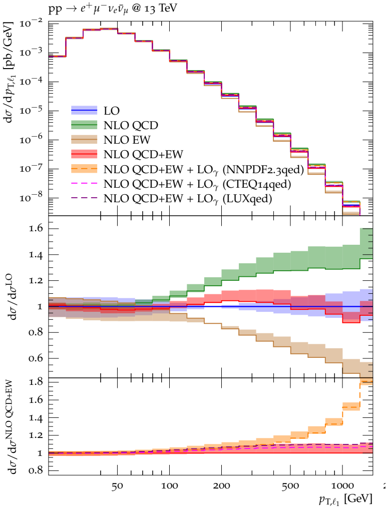


Kallweit, Lindert, Pozzorini, MS in prep.

$pp \to e^+\mu^-\nu_e\bar{\nu}_\mu$ @ 13 TeV

- $\mu = H_T^{\text{lep}} = \sum_{i\in\{e,\mu\}} p_{\perp,i} + \not{E}_T$
- analyses impose jet veto to control $t\bar{t}$-background
  $\to$ also reduces QCD corr.
- usual behaviour of NLO EW
- γ-induced LO large at high-x
- γPDF depedence huge
  similar in all obs.
  $\to$ ideal to measure γPDF

$pp \to 2\ell 2\nu$ @ 13 TeV



Kallweit, Lindert, Pozzorini, MS in prep.

$pp \to e^+\mu^-\nu_e\bar{\nu}_\mu$ @ 13 TeV

- $\mu = H_T^{\text{lep}} = \sum\limits_{i\in\{e,\mu\}} p_{\perp,i} + \not{E}_T$
- analyses impose jet veto to control $t\bar{t}$-background
  $\to$ also reduces QCD corr.
- usual behaviour of NLO EW
- γ-induced LO large at high-x
- γPDF depedence huge similar in all obs.
  $\to$ ideal to measure γPDF

Electroweak corrections in particle-level event generation

- incorporate approximate electroweak corrections in SHERPA's NLO QCD multijet merging (MEPS@NLO)
- modify MC@NLO $\overline{\mathrm{B}}$-function to include NLO EW virtual corrections and integrated approx. real corrections

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

- 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, diff. $\lesssim 5\%$ for observables not driven by real radiation

Electroweak corrections in particle-level event generation

- incorporate approximate electroweak corrections in SHERPA's NLO QCD multijet merging (MEPS@NLO)
- modify MC@NLO $\overline{\mathrm{B}}$-function to include NLO EW virtual corrections and integrated approx. real corrections

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

exact virtual contribution

- 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,
  diff. $\lesssim 5\%$ for observables not driven by real radiation

Electroweak corrections in particle-level event generation

- incorporate approximate electroweak corrections in SHERPA's NLO QCD multijet merging (MEPS@NLO)
- modify MC@NLO $\overline{\mathrm{B}}$-function to include NLO EW virtual corrections and integrated approx. real corrections

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

exact virtual contribution

approximate integrated real contribution

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

Electroweak corrections in particle-level event generation

- incorporate approximate electroweak corrections in SHERPA's NLO QCD multijet merging (MEPS@NLO)
- modify MC@NLO $\overline{\mathrm{B}}$-function to include NLO EW virtual corrections and integrated approx. real corrections

optionally include subleading Born

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

exact virtual contribution

approximate integrated real contribution

- 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,
  diff. $\lesssim 5\%$ for observables not driven by real radiation

Electroweak corrections in particle-level event generation

- incorporate approximate electroweak corrections in SHERPA's NLO QCD multijet merging (MEPS@NLO)
- modify MC@NLO $\overline{\mathrm{B}}$-function to include NLO EW virtual corrections and integrated approx. real corrections

optionally include subleading Born

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

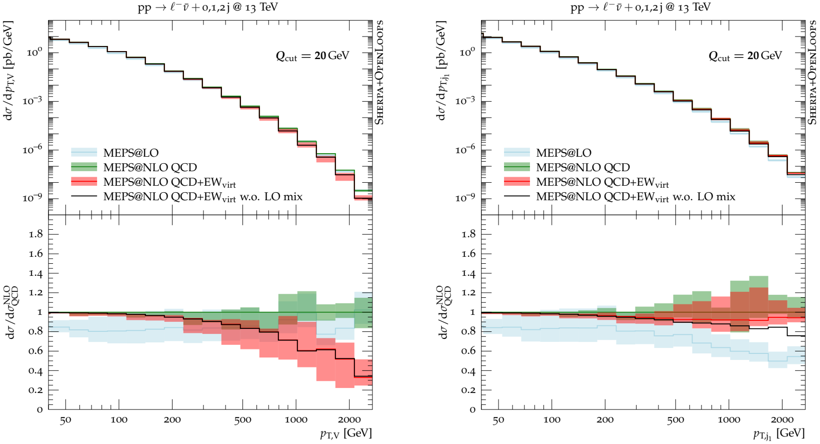
exact virtual contribution

approximate integrated real contribution

- 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,
  diff. $\lesssim 5\%$ for observables not driven by real radiation

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

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



$\Rightarrow$ particle level events including dominant EW corrections

Conclusions

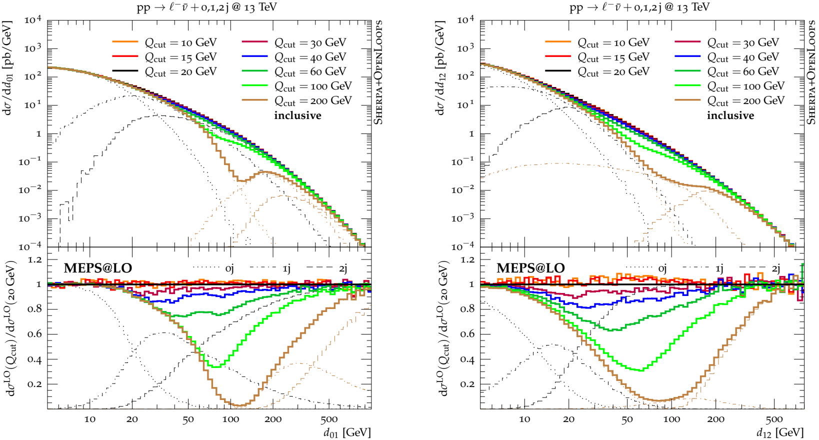
- electroweak effects are important at LHC at 13 TeV and beyond
- become large whenever the intrinsic scale is large compared to the electroweak scale (e.g. high-$p_\perp$)
  $\rightarrow$ improves data description in that region
- NLO EW automated in Sherpa/Munich+OpenLoops framework
  $\rightarrow$ programs will become public soon
- suitable approximation can be integrated in existing NLO QCD multijet merging methods
  $\rightarrow$ can be directly incorporated in particle level event generation
  $\rightarrow$ available as of Sherpa-2.2.1

Thank you for your attention!

Backup

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

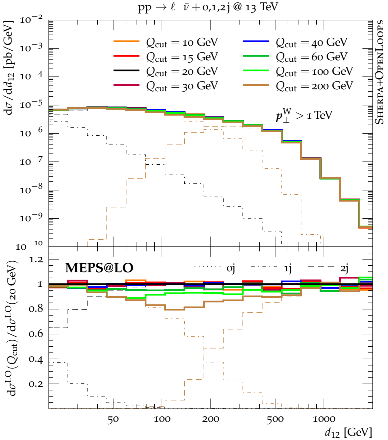
Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021

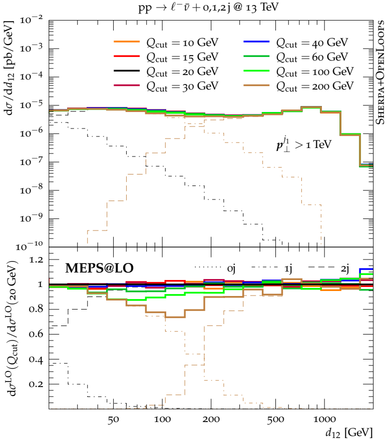


$\Rightarrow$ dead zones in incl. obs. if Q_{cut} too high

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

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

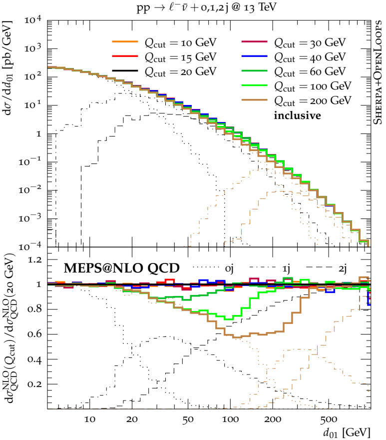




$\Rightarrow$ dead zones in incl. obs. if Q_{cut} too high

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

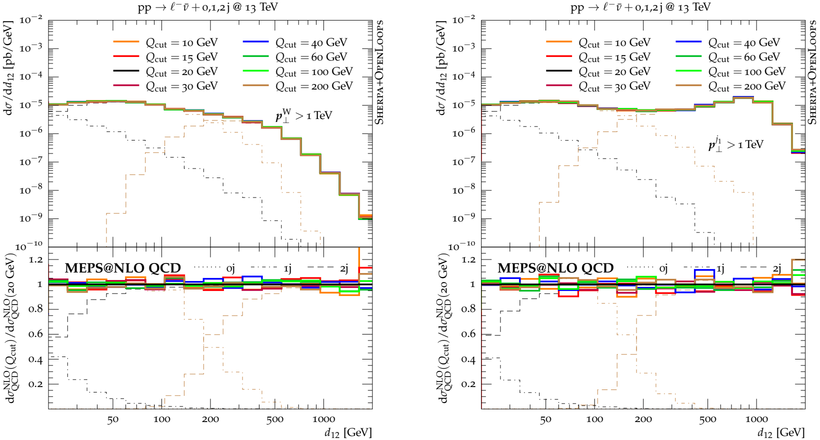
Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021



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

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

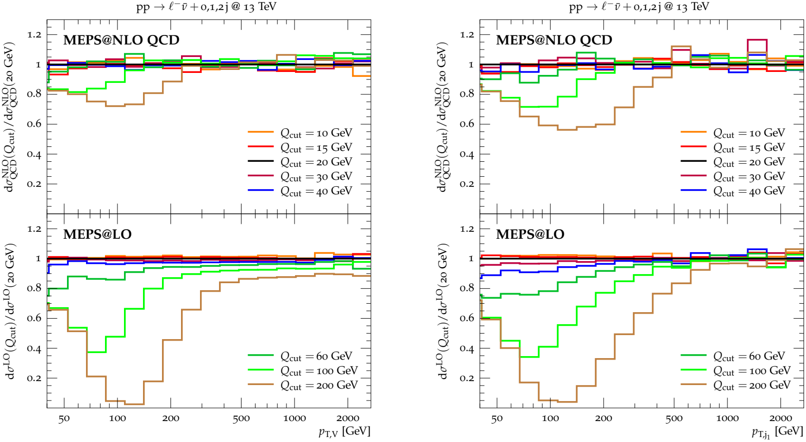
Kallweit, Lindert, Maierhöfer, Pozzorini, MS JHEP04(2016)021



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

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

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



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