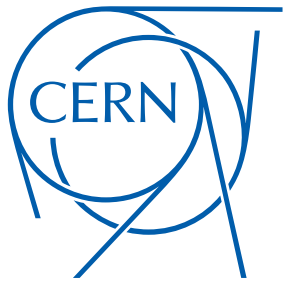
Electroweak corrections in event generators

Marek Schönherr

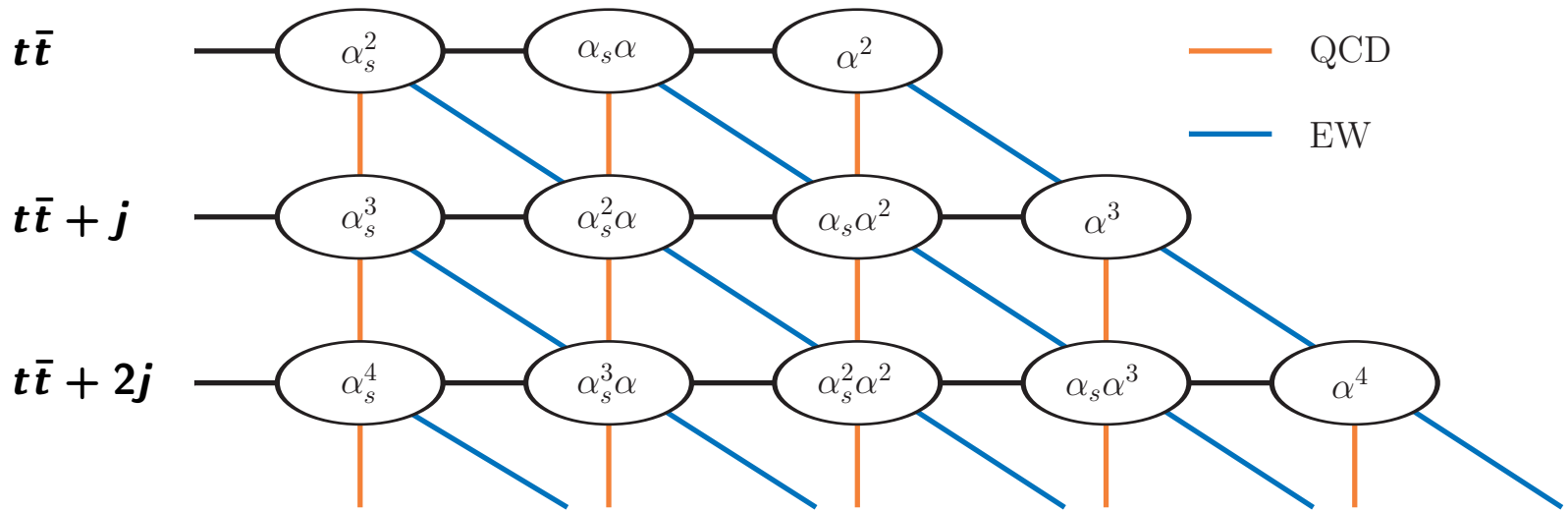
Parton Showers and Resummation Workshop – Lund, Sweden

06 Jun 2018



Anatomy of higher-order calculations – e.g. $t\bar{t}+$ jets

tree-level configuration



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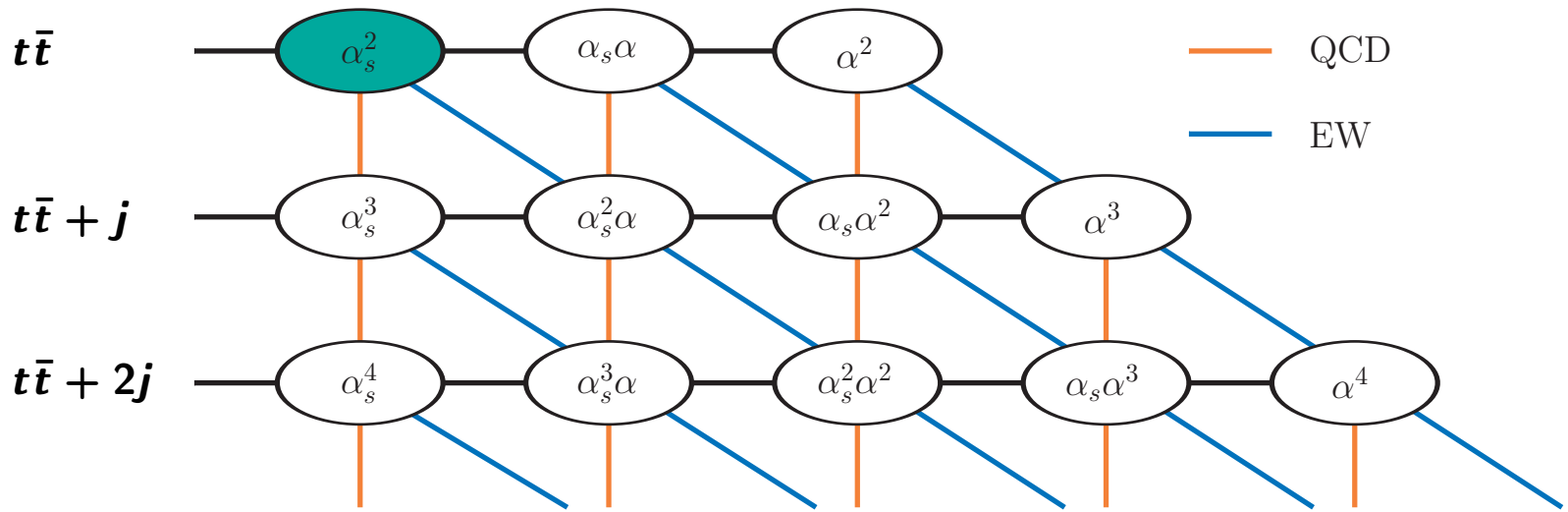

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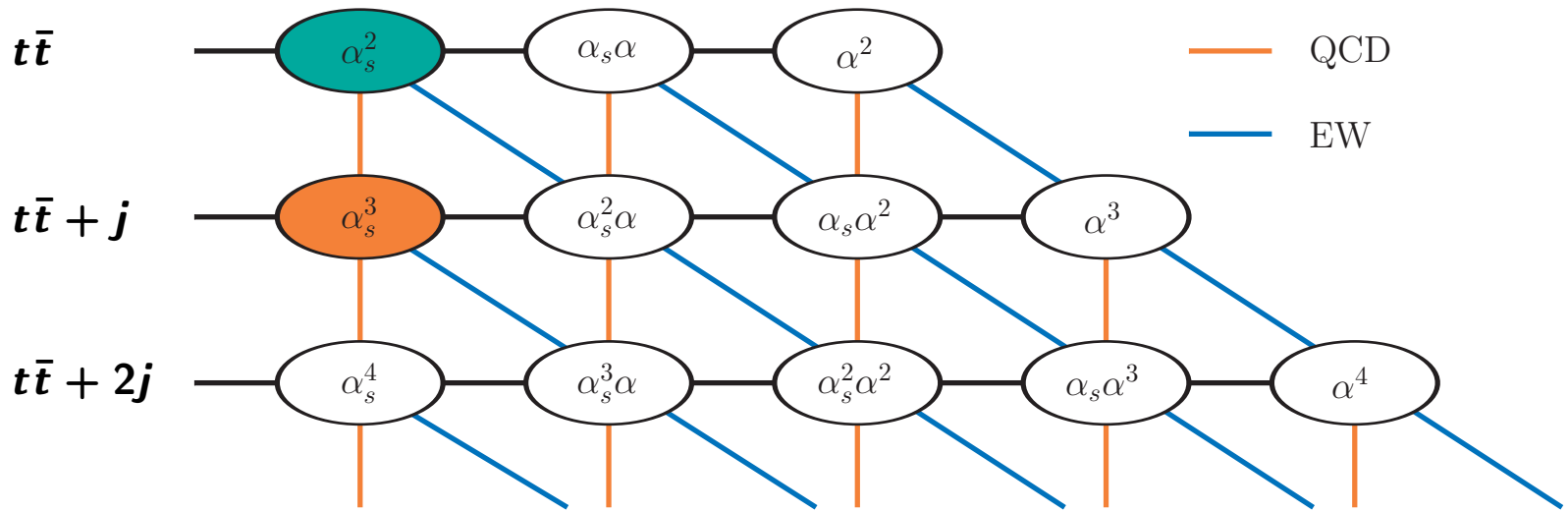

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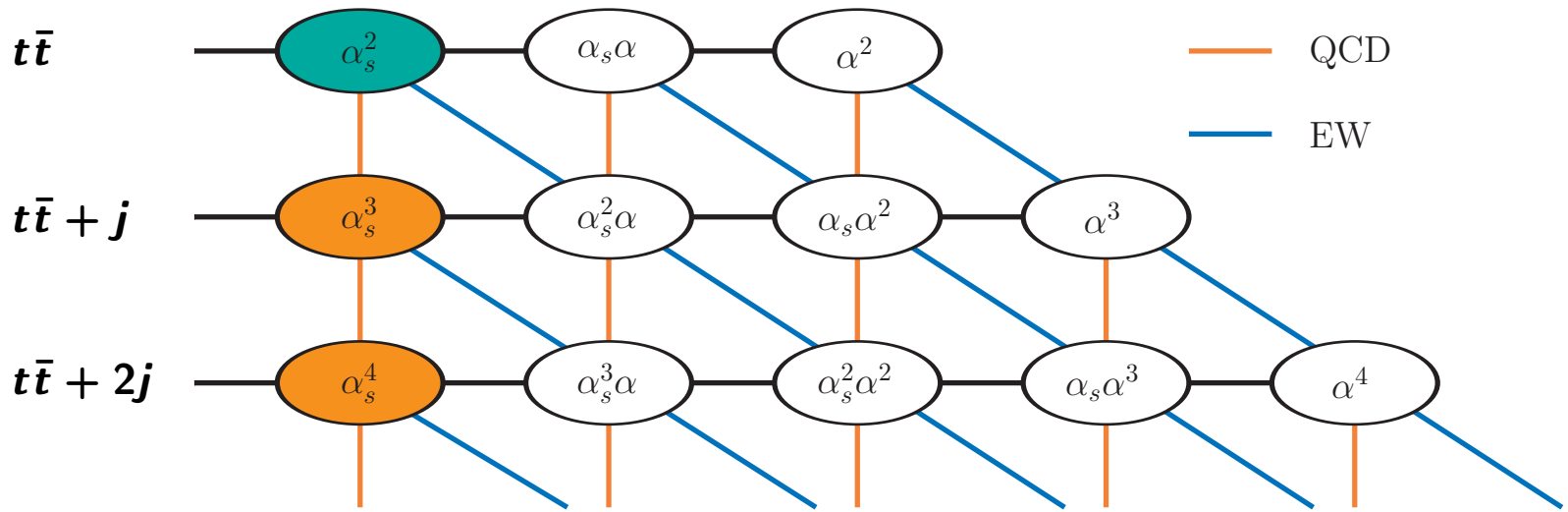

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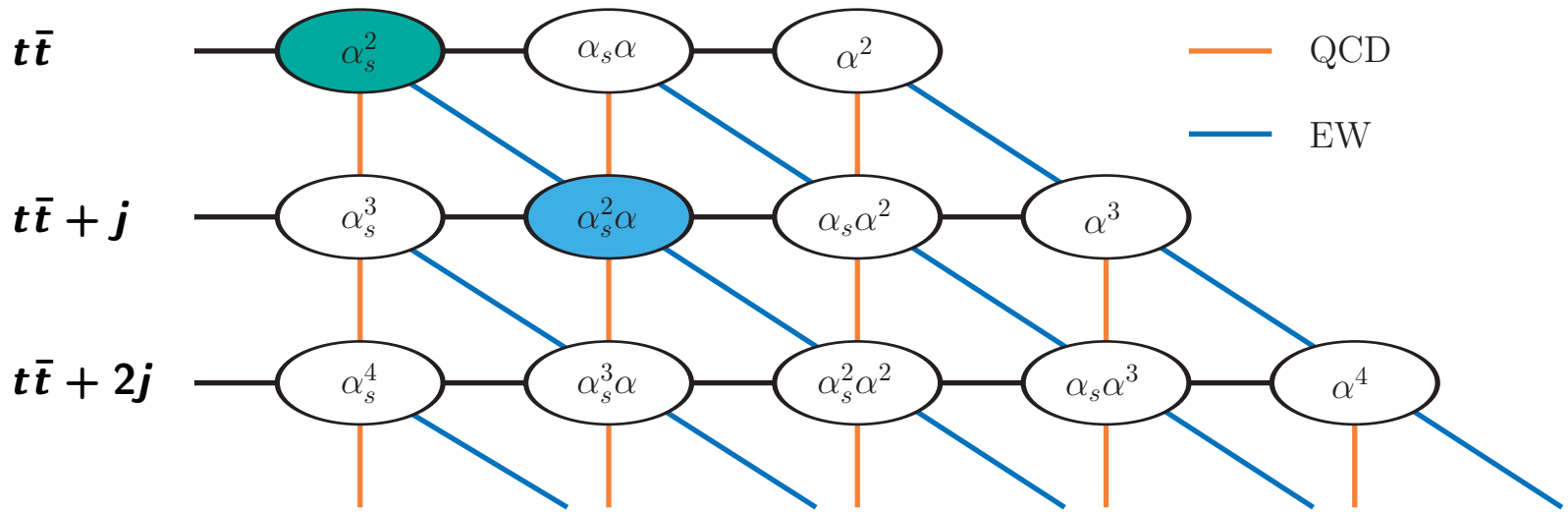

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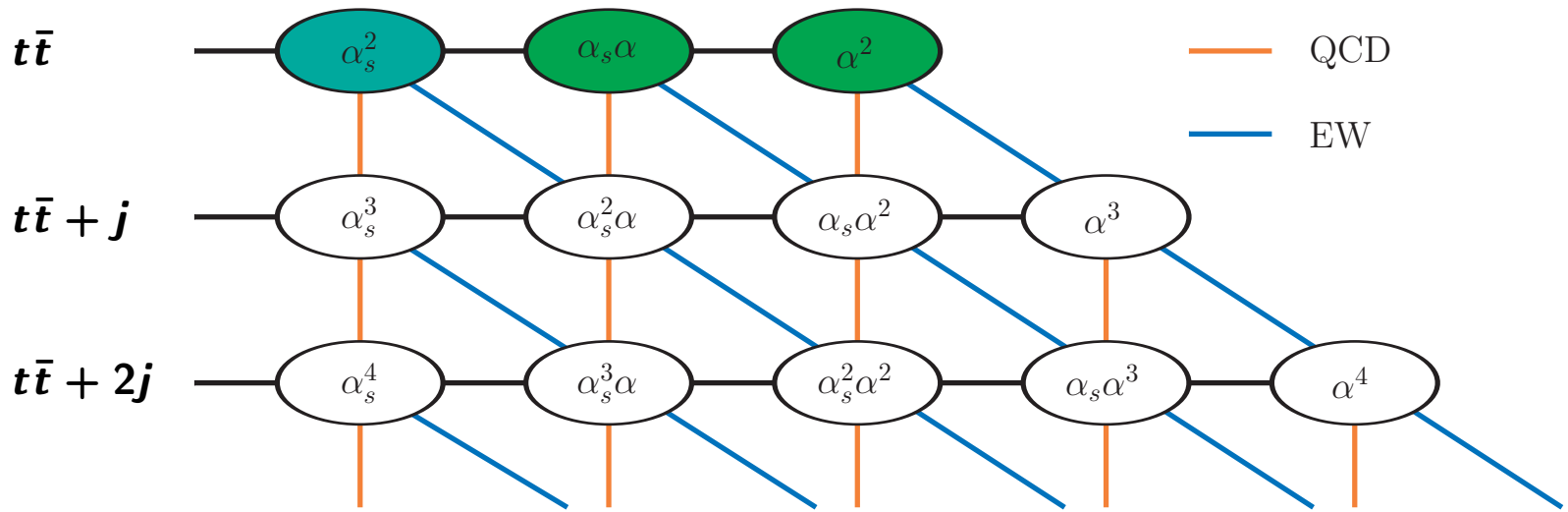

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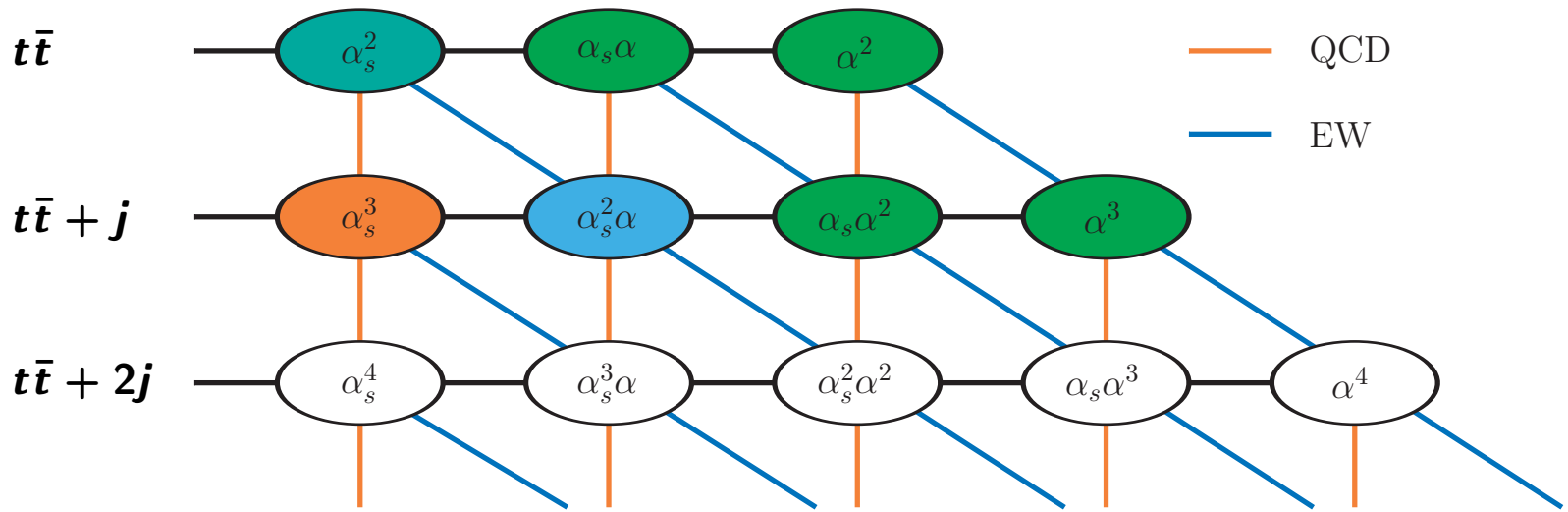

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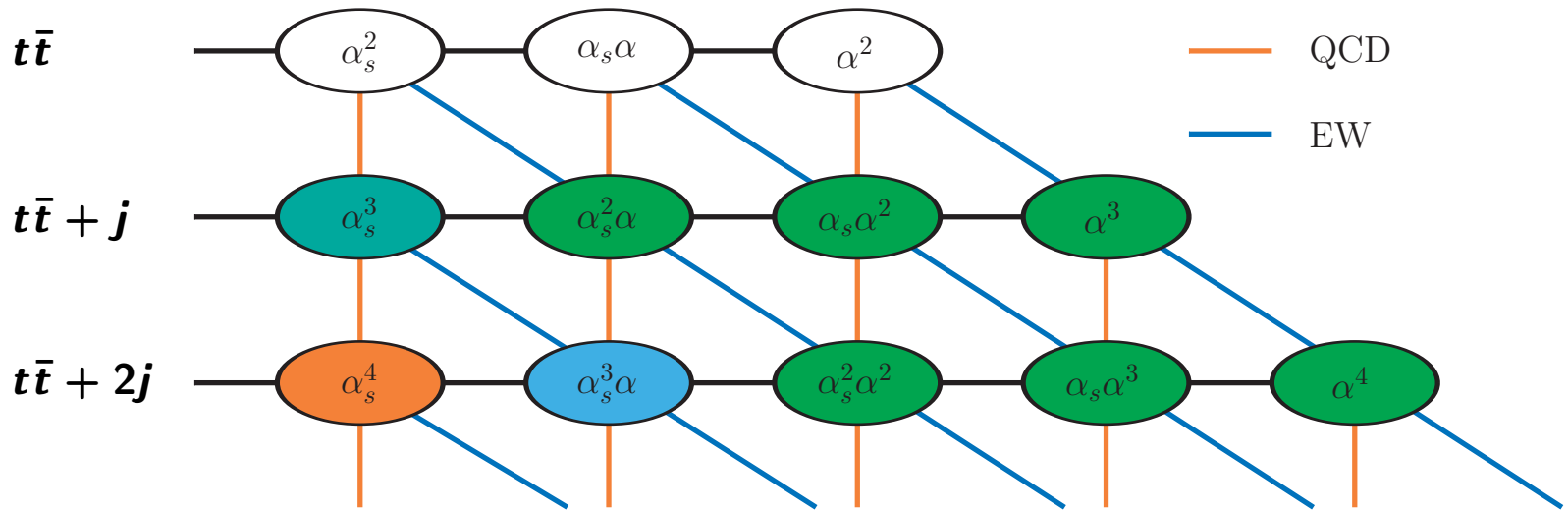

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Table of contents

NLO EW corrections

Setup

SHERPA+OPENLOOPS

- uses automated framework for general NLO calculations in SHERPA
  tree-level matrix elements, dipole subtraction,
  phase space integration, process management

  MS arXiv:1712.07975
- virtual corrections from OPENLOOPS

  Cascioli, Maierhöfer, Pozzorini arXiv:1111.5206

Parameters

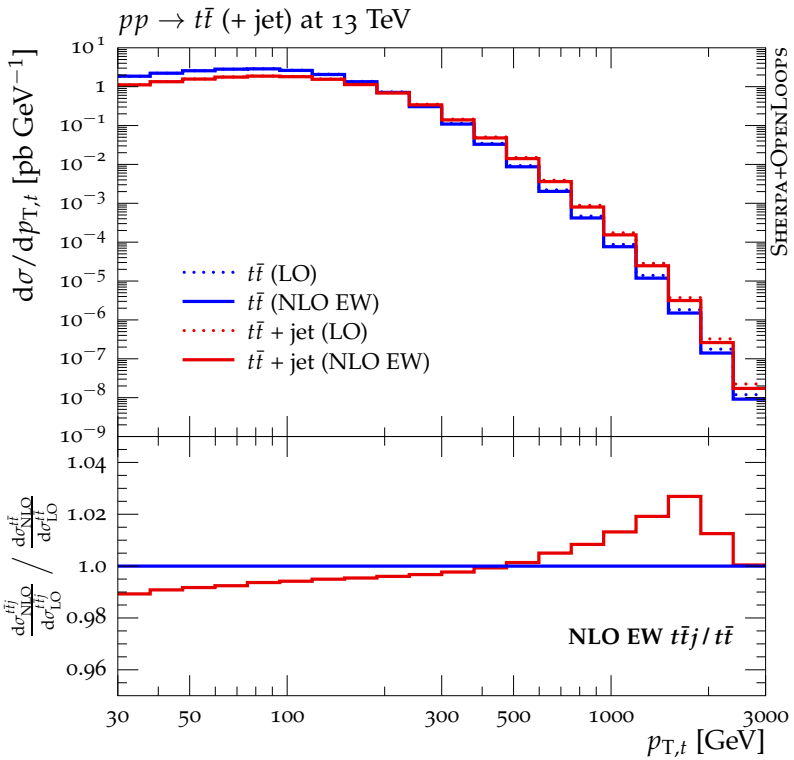
- $\mu_{R/F} = \frac{1}{2}\left(E_{\mathrm{T}}^{t} + E_{\mathrm{T}}^{\bar{t}}\right)$ in fixed-order calculation

  CKKW scale with $\mu_{\mathrm{core}} = \frac{1}{2}\left(\frac{1}{\hat{s}} + \frac{1}{m_t^2-\hat{t}} + \frac{1}{m_t^2-\hat{u}}\right)^{-\frac{1}{2}}$ in MEPS@NLO
- NNPDF3.0nnlo $\alpha_s = 0.118$, neglect γ-induced
- spin-correlated top decays, default tune for underlying event and hadronisation in data comparison

Setup

- SHERPA+OPENLOOPS:
  - $pp \to V + 0, 1, 2(, 3)$ jets — FCC report, arXiv:1607.01831; EW report arXiv:1606.02330; LH'15 arXiv:1605.04692; Kallweit,Lindert,Maierhöfer,Pozzorini,MS arXiv:1412.5157, arXiv:1511.08692
  - $pp \to Zj / pp \to \gamma j$ ratio — LH'15 arXiv:1605.04692; Kallweit,Lindert,Maierhöfer,Pozzorini,MS arXiv:1505.05704
  - $pp \to \gamma / \ell\ell / \ell\nu / \nu\nu + j$ — Lindert et.al arXiv:1705.04664
  - $pp \to Vh$ — FCC report, arXiv:1607.01831
  - $pp \to 2\ell 2\nu$ — Kallweit,Lindert,Pozzorini,MS, arXiv:1705.00598
  - $pp \to t\bar{t} / t\bar{t}j$ — Gütschow, Lindert, MS arXiv:1803.00950
  - $pp \to t\bar{t}h$ — LH'15 arXiv:1605.04692
- SHERPA+GOSAM
  - $pp \to \gamma\gamma + 0, 1, 2$ jets — Chiesa et.al. arXiv:1706.09022
  - $pp \to \gamma\gamma\gamma \,/\, \gamma\gamma\ell\nu \,/\, \gamma\gamma\ell\ell$ — Greiner, MS arXiv:1710.11514
  - $pp \to \gamma\gamma b\bar{b}$ — Greiner, MS in prep.
- SHERPA+RECOLA
  - $pp \to V + 0, 1, 2$ j, $pp \to 4\ell$, $pp \to t\bar{t}h$ — Biedermann et.al. arXiv:1704.05783
  - $pp \to 3\ell 3\nu$ — MS arXiv:1806.00307

Top pair production in association with jets



Gütschow, Lindert, MS arXiv:1803.00950

- $pp \to t\bar{t}$
  - LO: $\mathcal{O}(\alpha_s^2)$, $\mathcal{O}(\alpha_s\alpha)$, $\mathcal{O}(\alpha^2)$
  - include NLO corrections to subleading orders
- $pp \to t\bar{t}j$
  - LO: $\mathcal{O}(\alpha_s^3)$, $\mathcal{O}(\alpha_s^2\alpha)$, $\mathcal{O}(\alpha_s\alpha^2)$, $[\mathcal{O}(\alpha^3)]$
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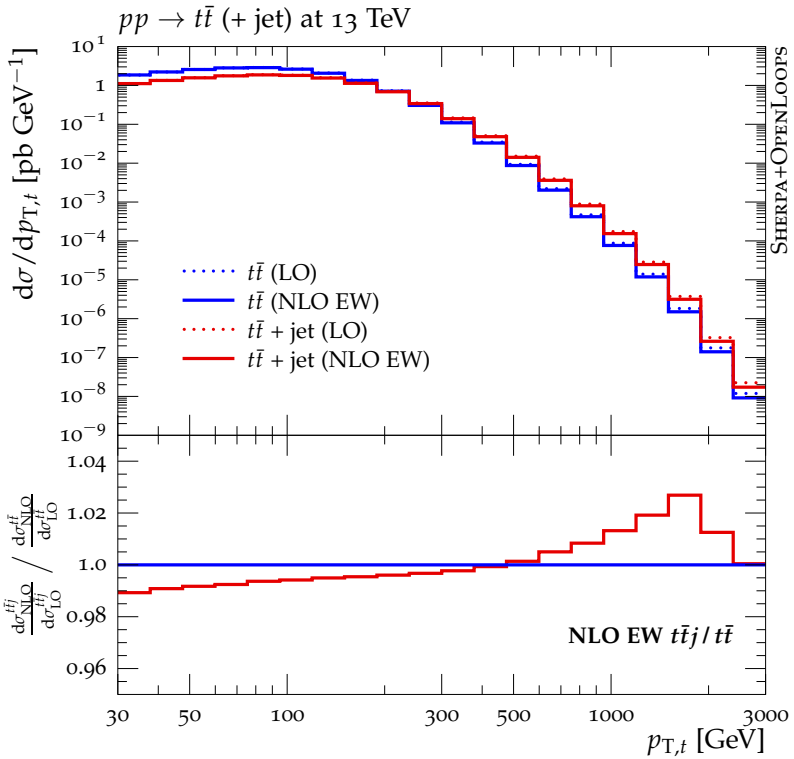

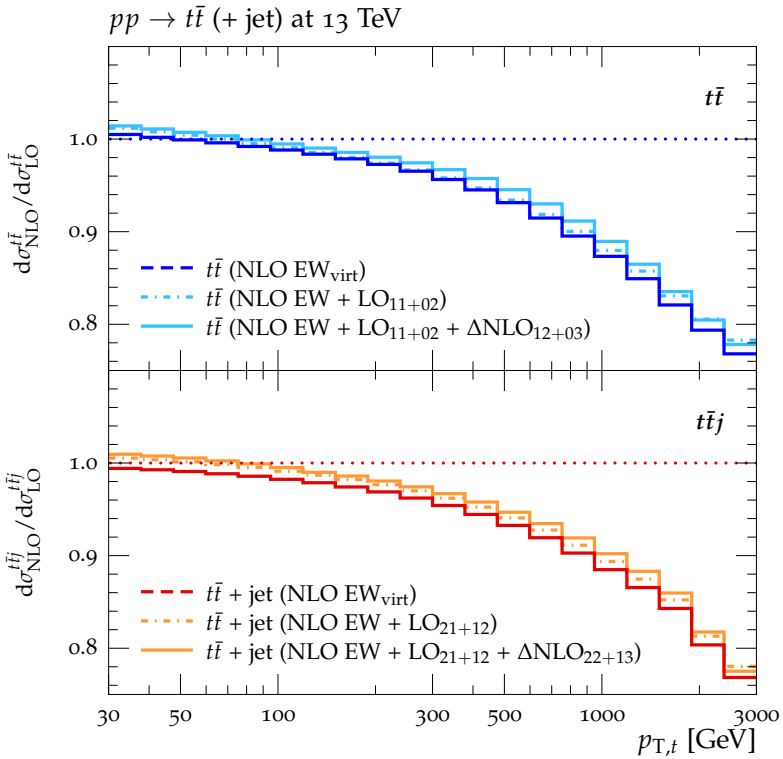

NLO EW factorises from additional jet activity

Top pair production in association with jets

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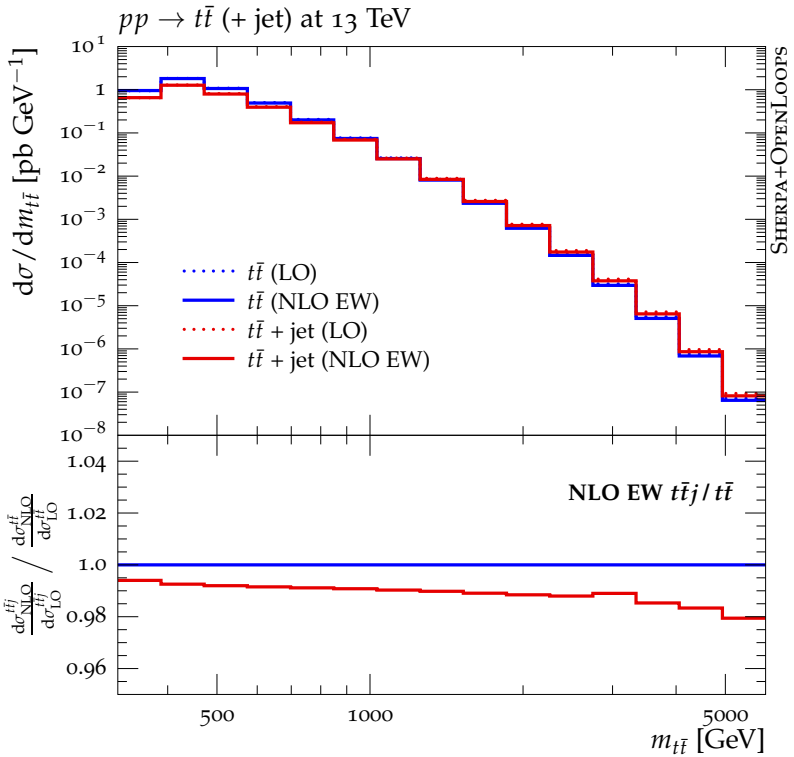

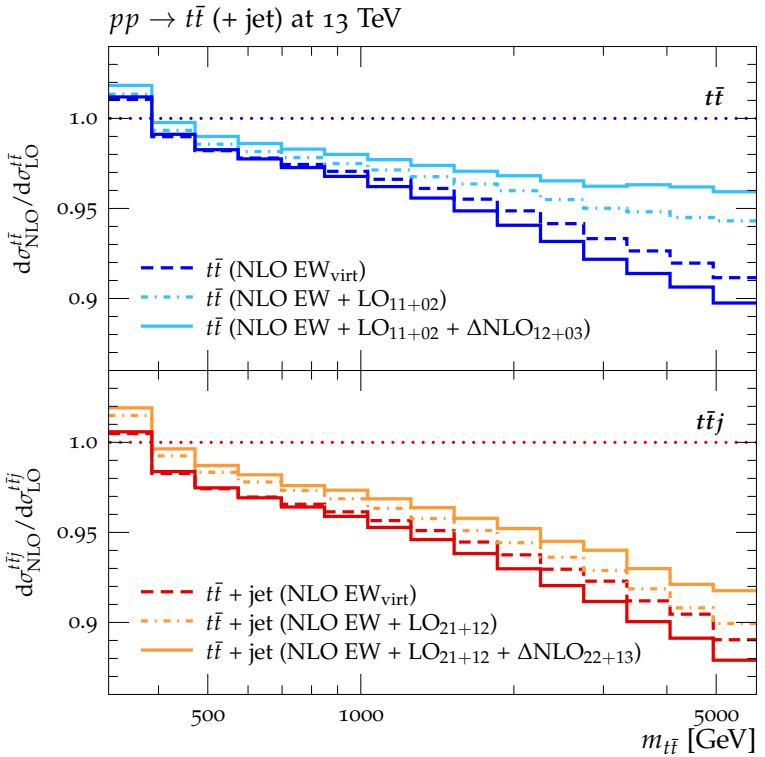

subleading orders important

Top pair production in association with jets

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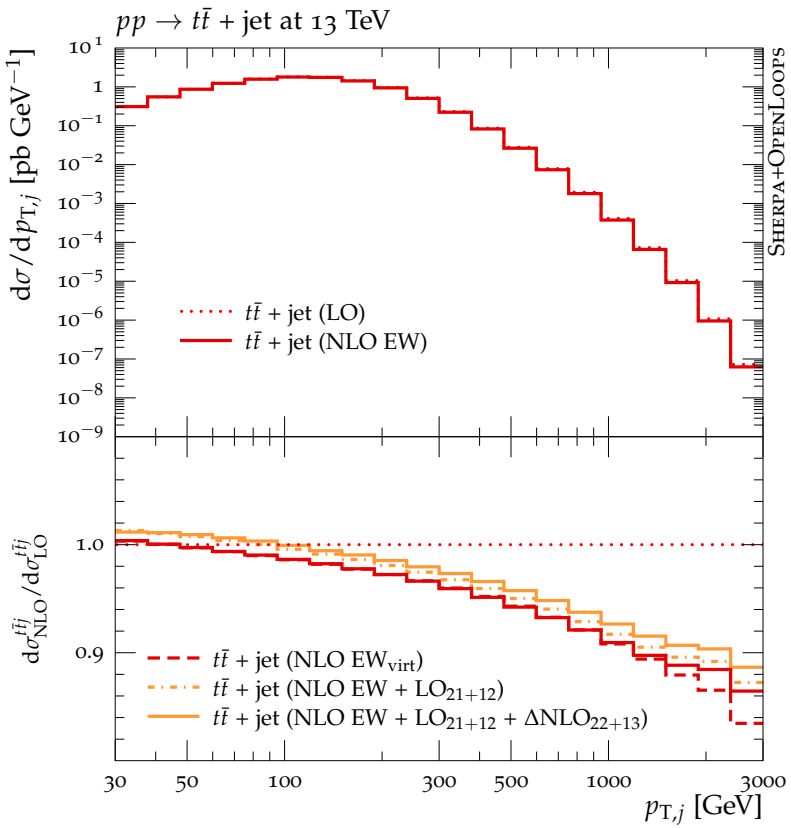
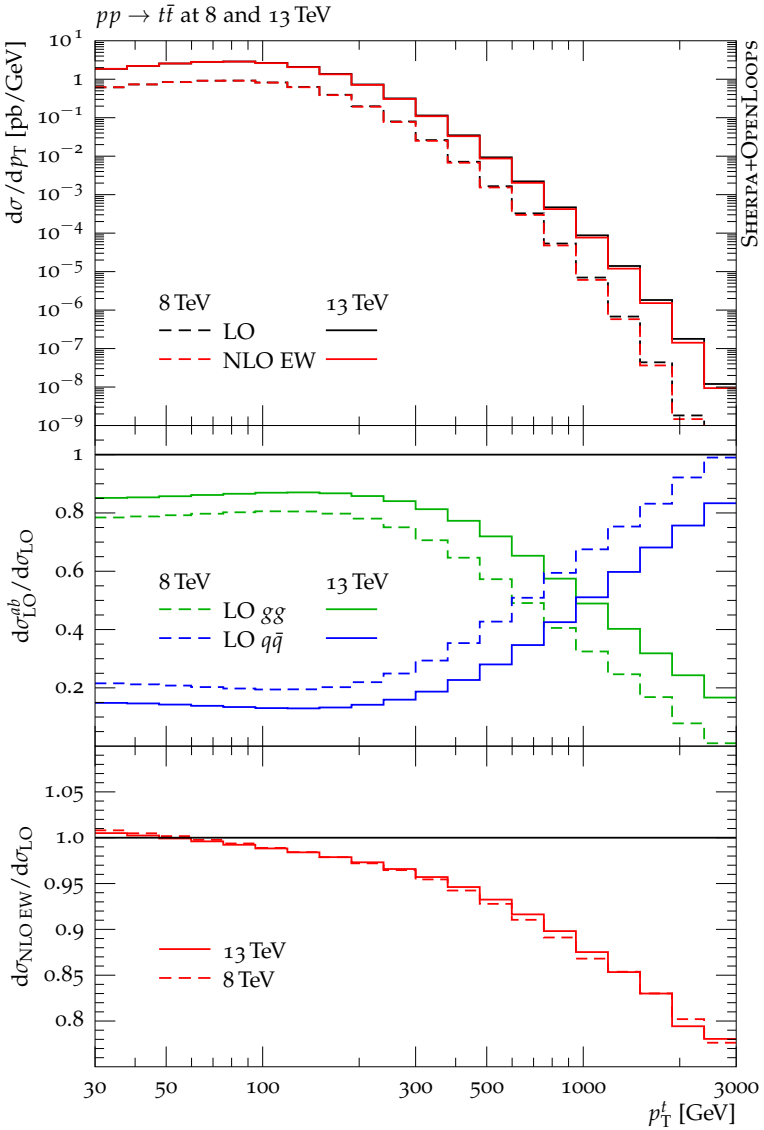


NLO EW corrections to $t\bar{t}$ at 8 and 13 TeV



- gg channel receives smaller EW corrections in Sudakov limit than $q\bar{q}$ channel, at 1 TeV:

$$\delta^{q\bar{q}}_{\text{EW,sud}} \approx 1.5\,\delta^{gg}_{\text{EW,sud}}$$

- composition of total from gg vs $q\bar{q}$ channels changes
  $\to$ NLO EW correction changes
  $\to$ effect still small

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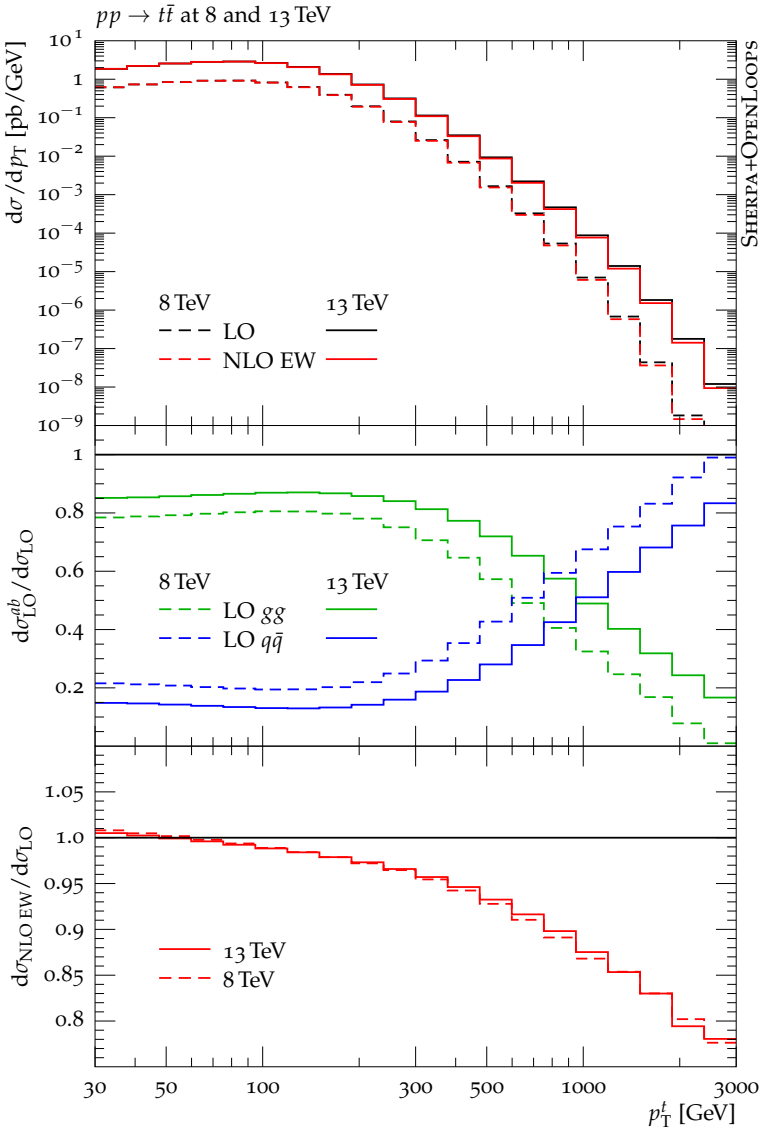
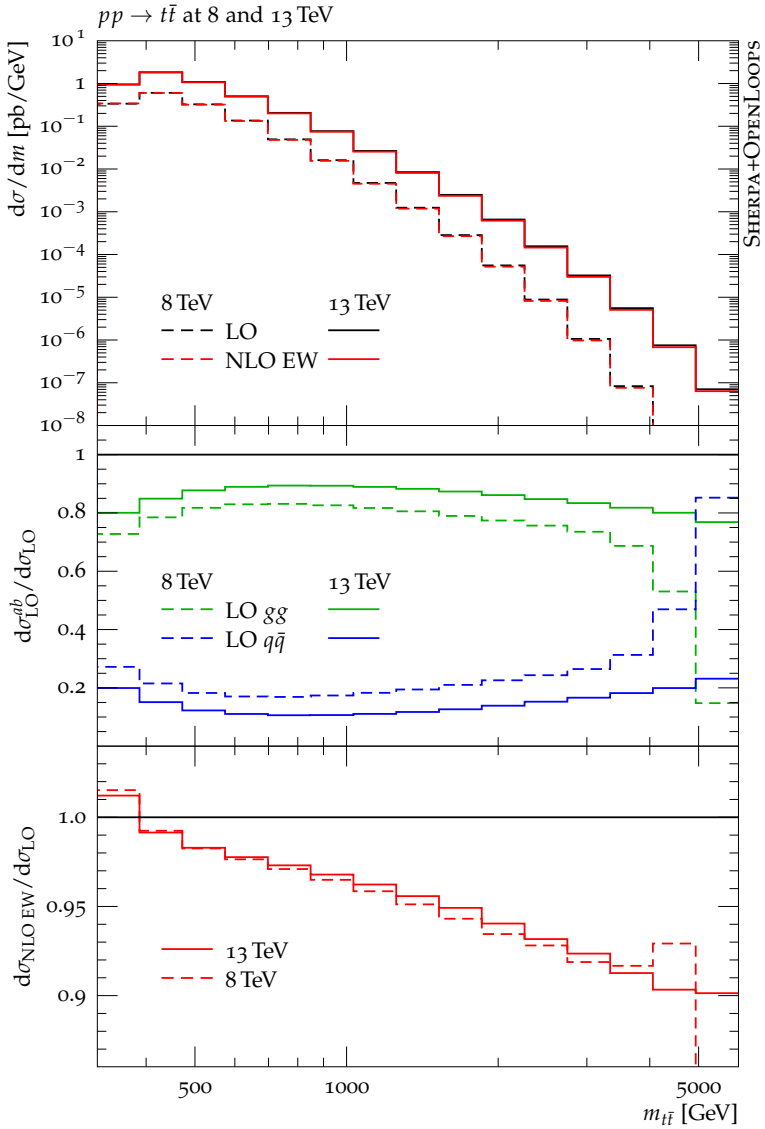
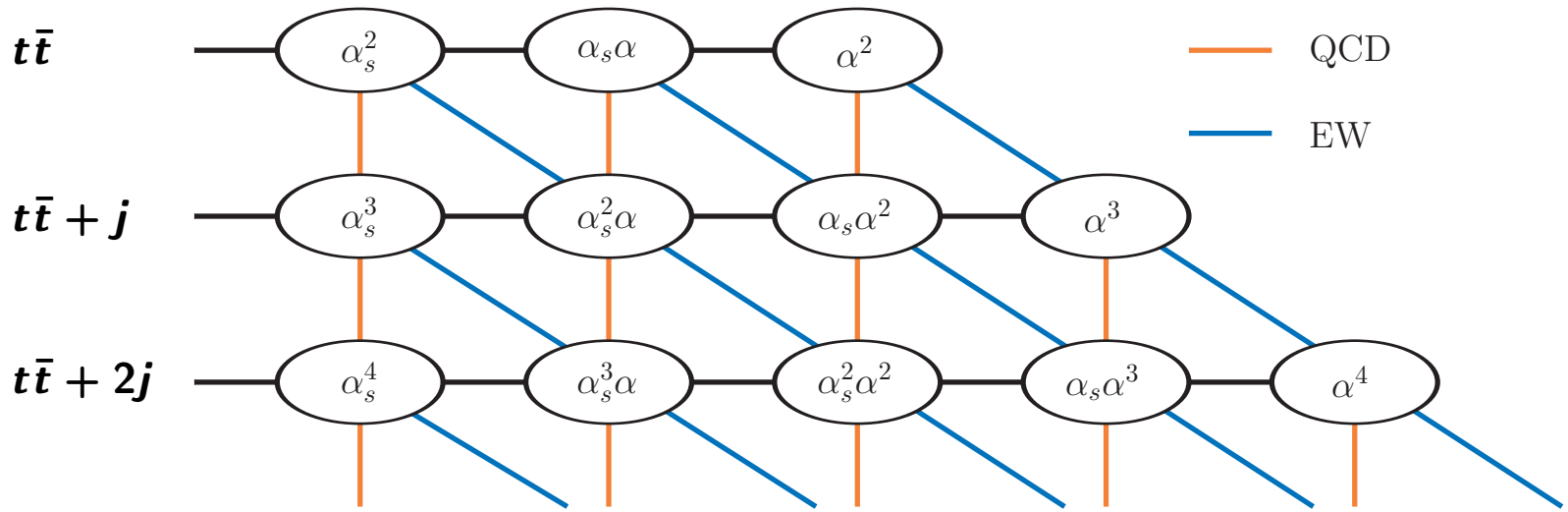




EW corrections in multijet merging

EW corrections in multijet merging – e.g. $t\bar{t}$

tree-level configuration



- extend NLO QCD multijet merging
- include approximate NLO EW corrections
- also include subleading tree-level corrections

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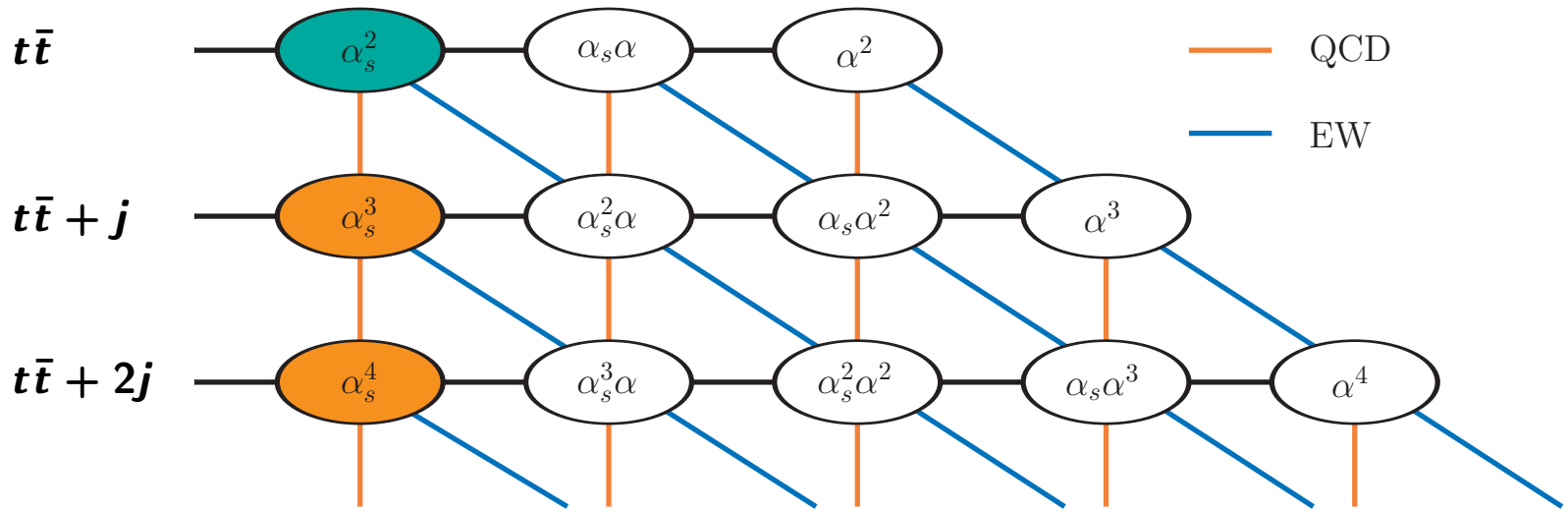

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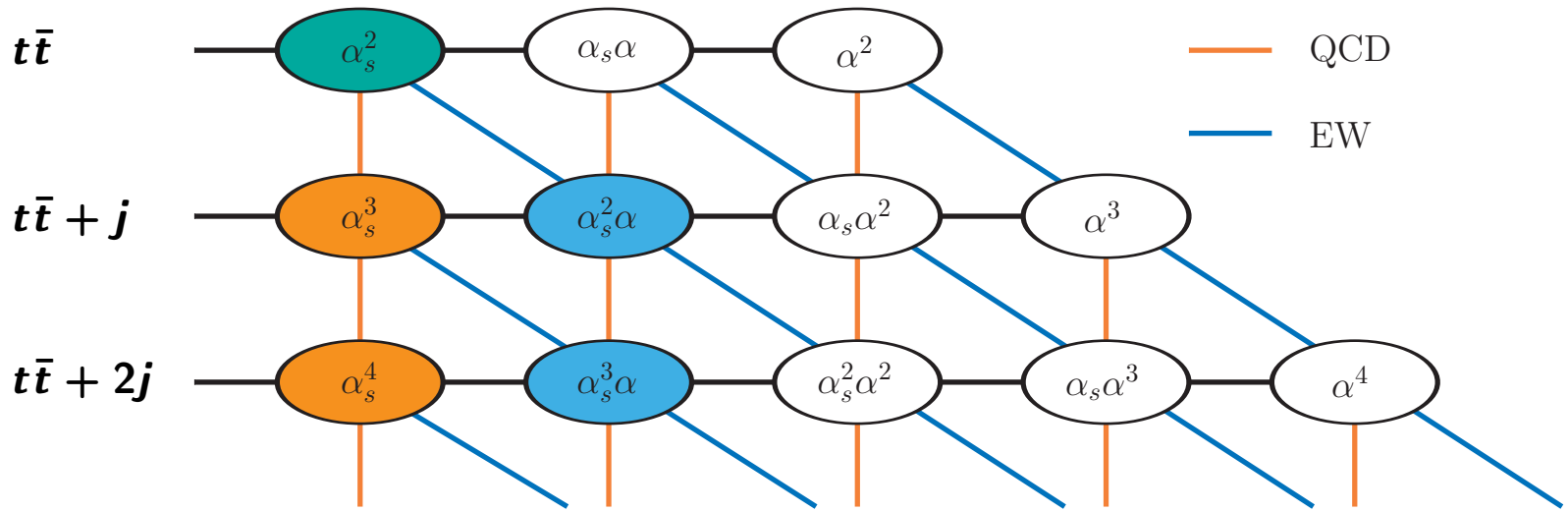

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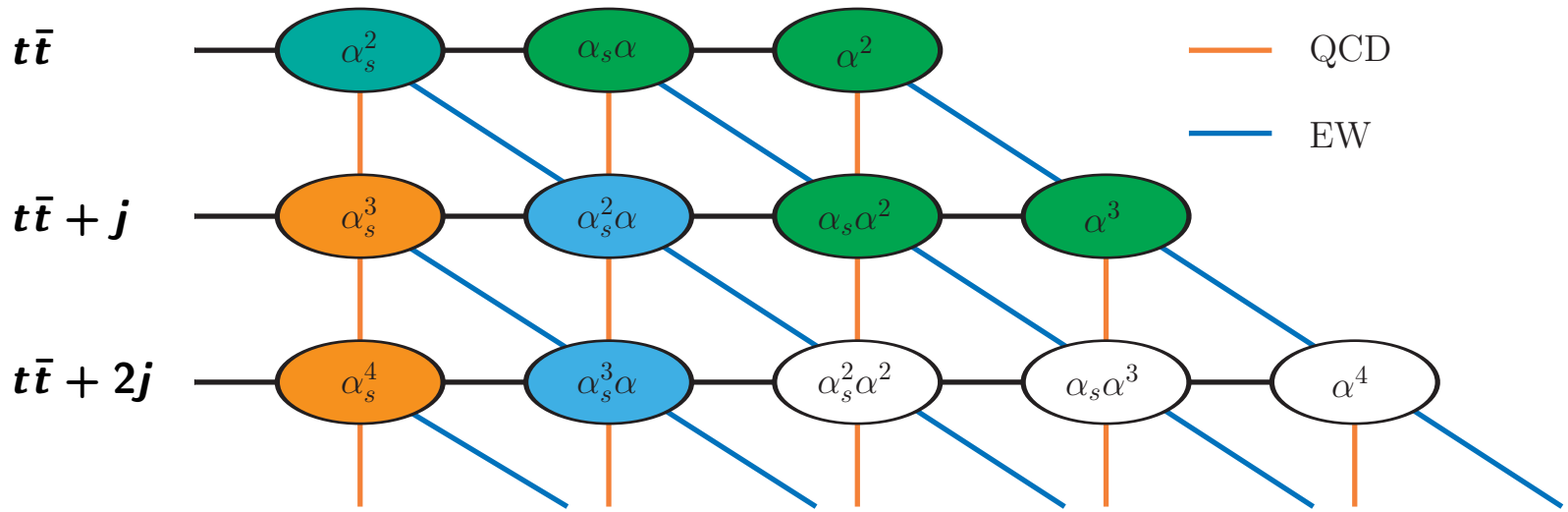

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EW corrections in multijet merging

- straight forward in Sudakov limit
  $\rightarrow$ modify weight of LO kinematics

  Denner, Pozzorini hep-ph/0010201, hep-ph/0104127
- LO $\times$ EW_{sud} in ALPGEN and HERWIG for selected processes

  Chiesa et.al. arXiv:1305.6837

  Gieseke, Kasprzik, Kühn arXiv:1401.3964
- at NLO, both additive and multiplicative combination possible
  NLO QCD+EW_{sud} vs. NLO QCD$\times\text{EW}_{\text{sud}}$
  - typically done on the histogram/observable level
    $\rightarrow$ not straight forward on event-by-event basis
  - choose additive approach for now

    Kallweit, Lindert, Maierhöfer, Pozzorini, MS arXiv:1511.08692

EW corrections in multijet merging

- 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

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

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

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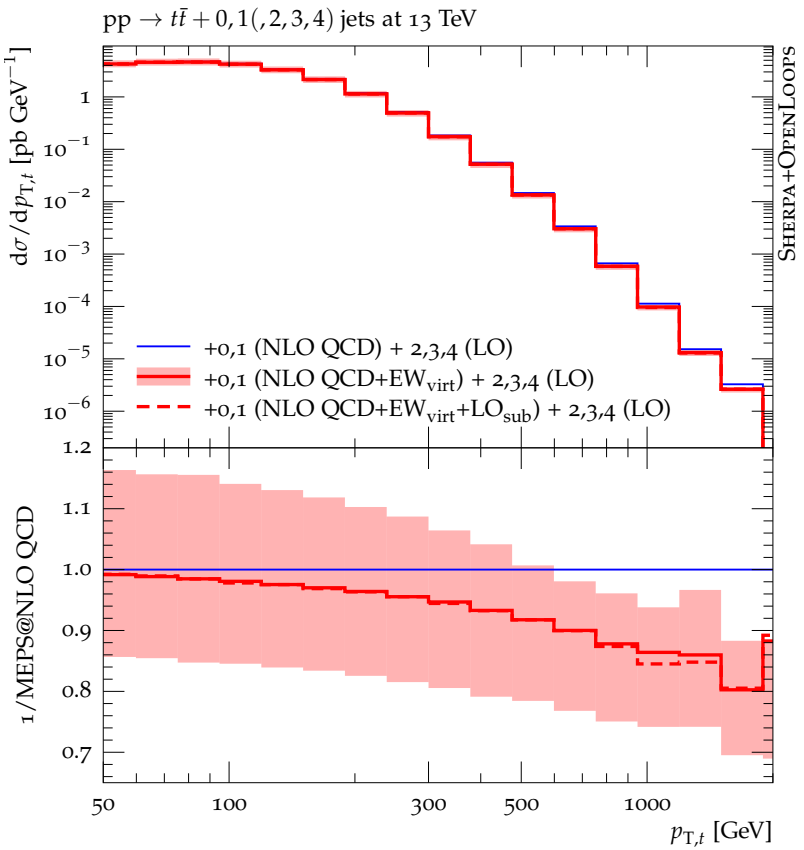
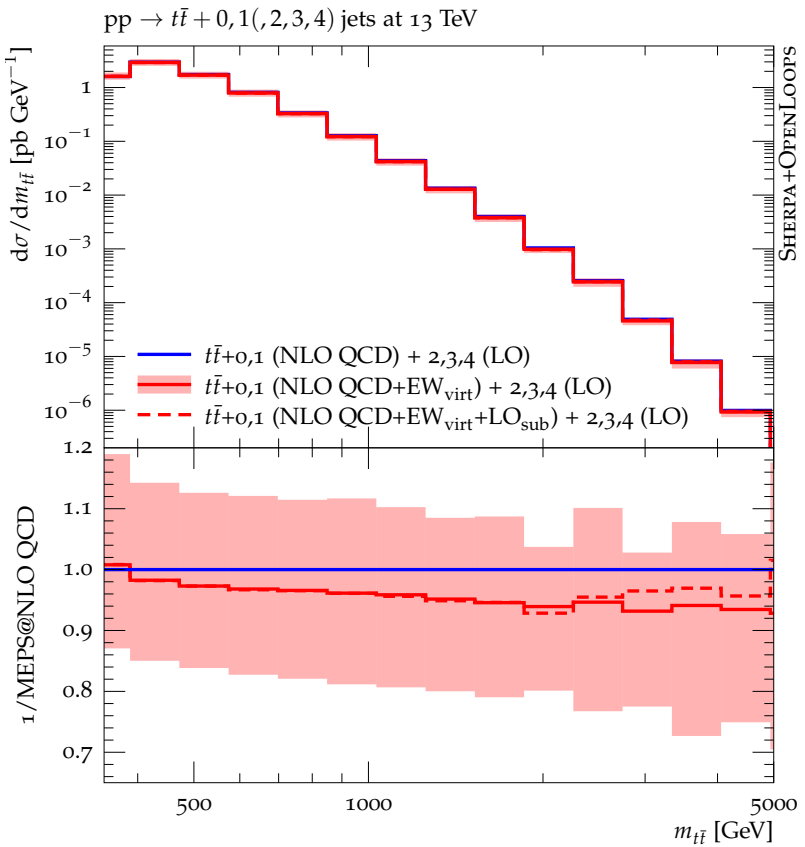
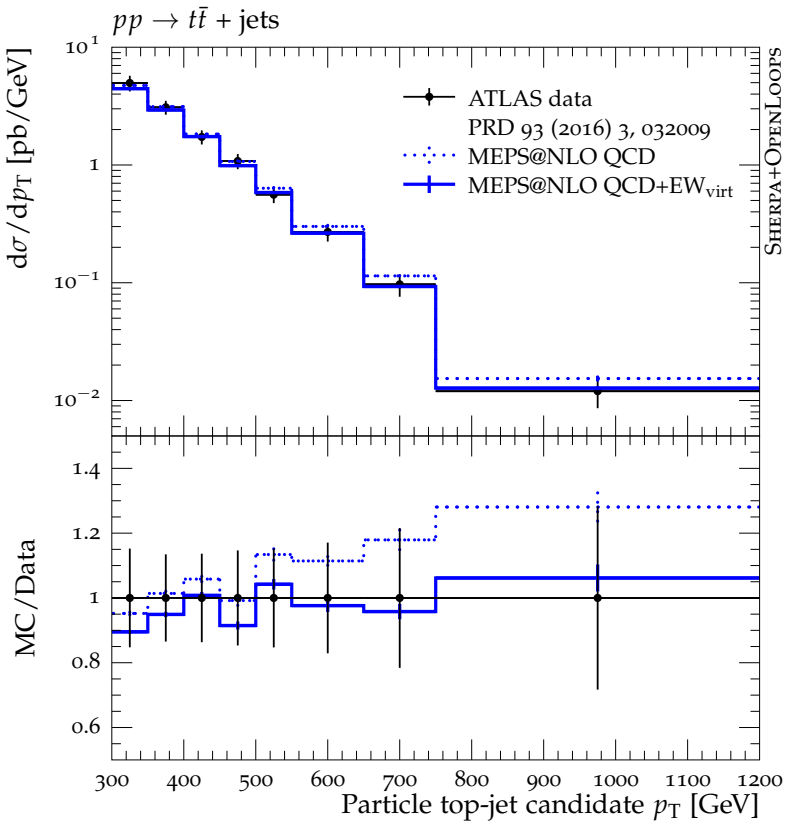
Results: $t\bar{t}$ + jets





reproduces well the corrections seen at fixed-order

Results: $t\bar{t}$ + jets at high p_T



Gütschow, Lindert, MS arXiv:1803.00950

- $pp \to t\bar{t} + 0, 1j$@NLO $+ 2, 3, 4j$@LO
- additional LO multiplicities inherit electroweak corrections through MENLOPS differential K-factor

  Höche, Krauss, MS, Siegert arXiv:1009.1127
- improved description of data

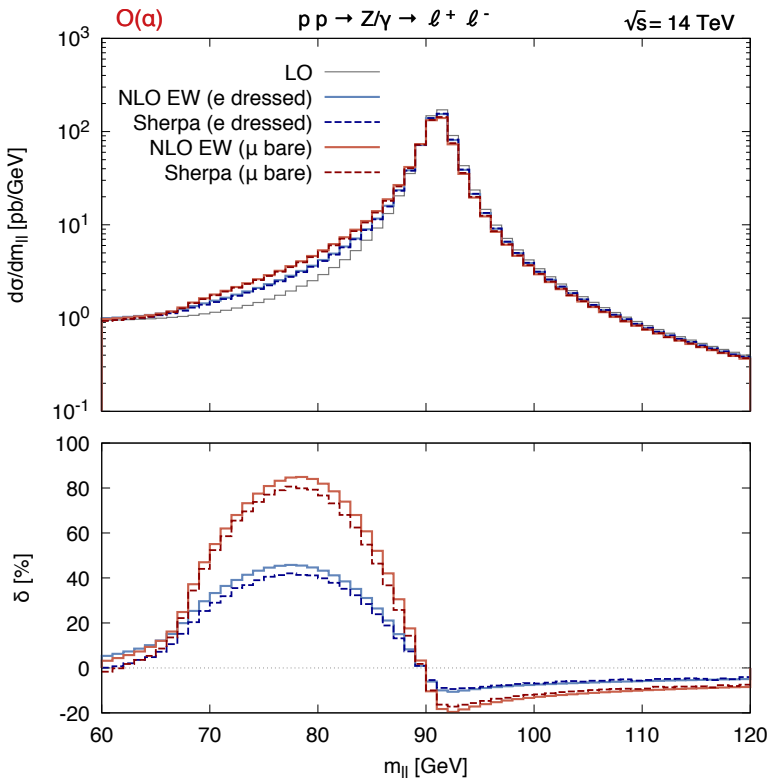
Soft-photon resummation

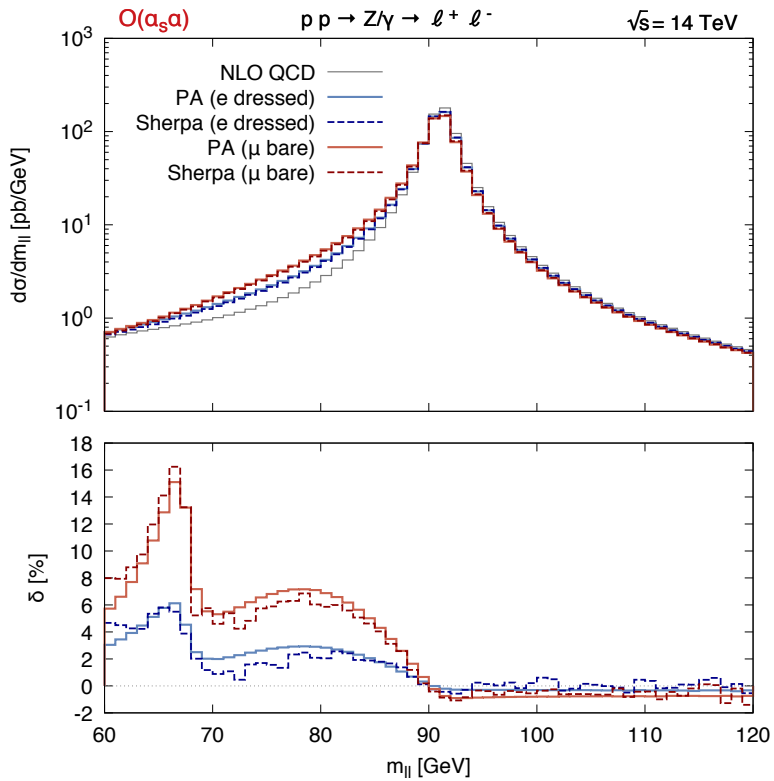
Soft-photon resummation

- 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
- coherent radiation off multipoles
- universal soft eikonal supplemented with universal hard collinear corrections
- process specific corrections can be easily incorporated where known
  → NLO QED accuracy in $W \to \ell\nu$ and $Z \to \ell\ell$
  and other important resonant decay channels
  → 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

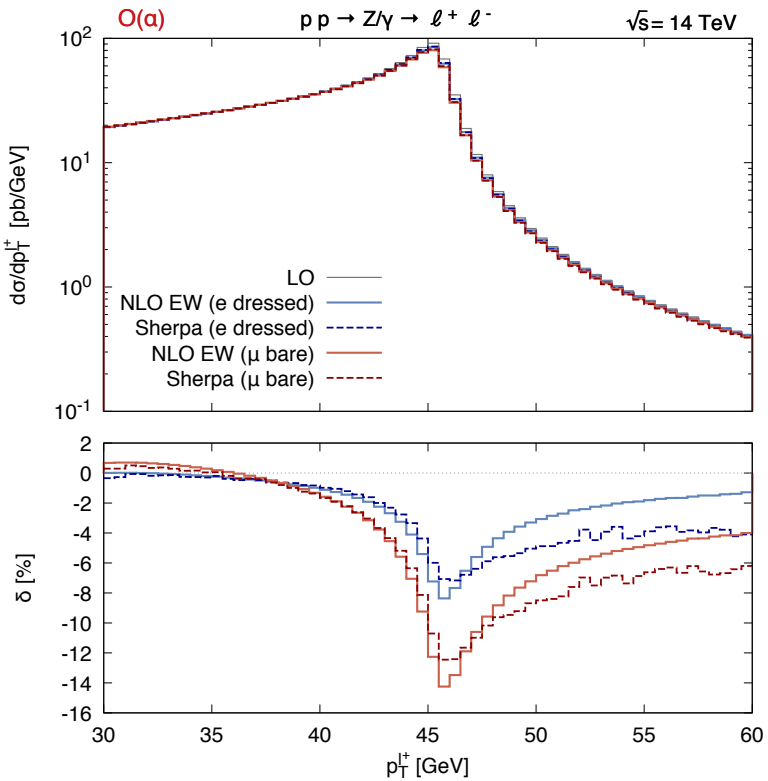


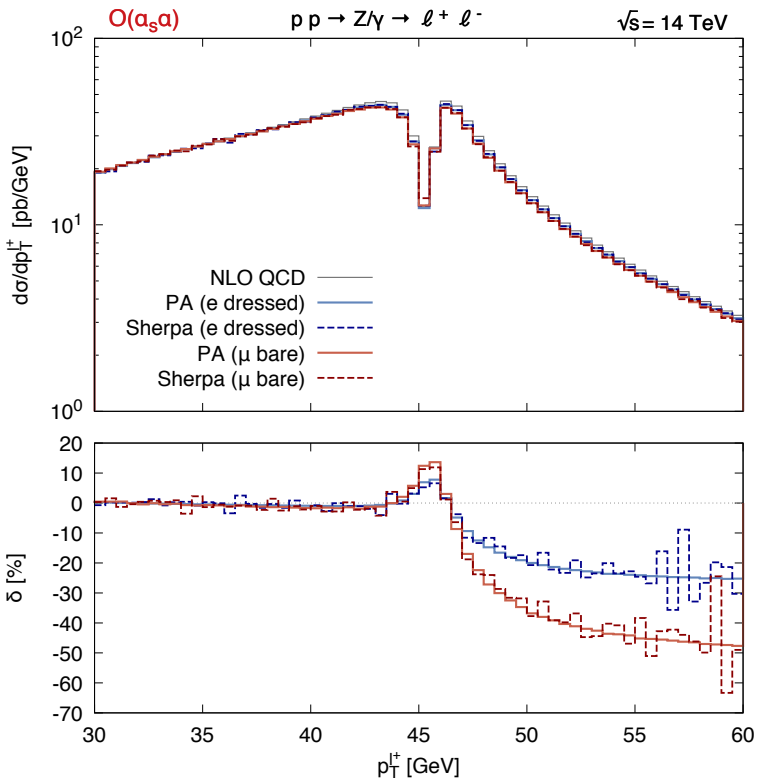


- $\mathcal{O}(\alpha)$ and $\mathcal{O}(\alpha_s\alpha)$ electroweak corrections well reproduced
- residual difference due to multi-photon emissions
- genuine weak corrections very small

Accuracy in $pp \to \ell\ell$

Huss, MS for LH'15

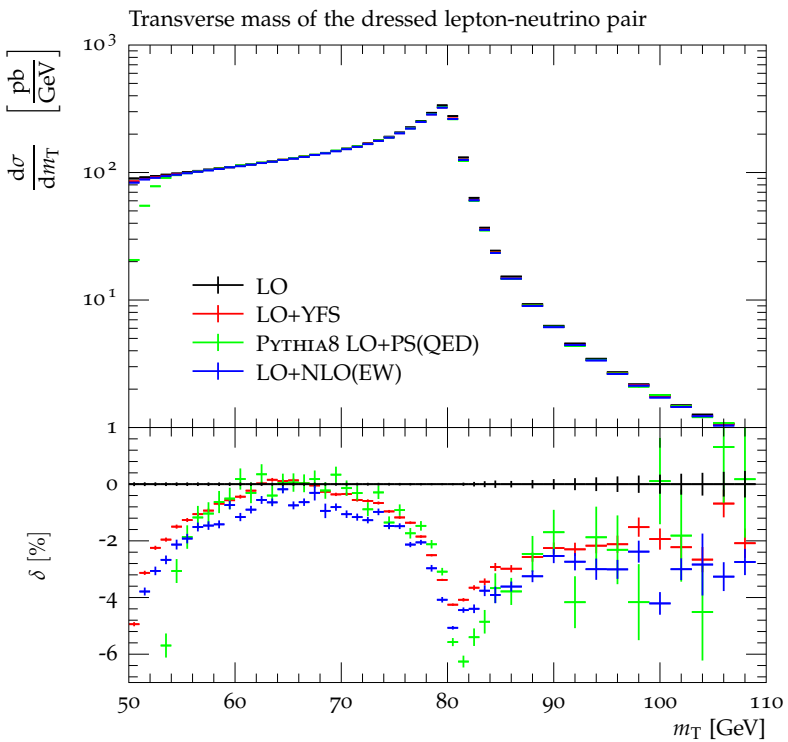


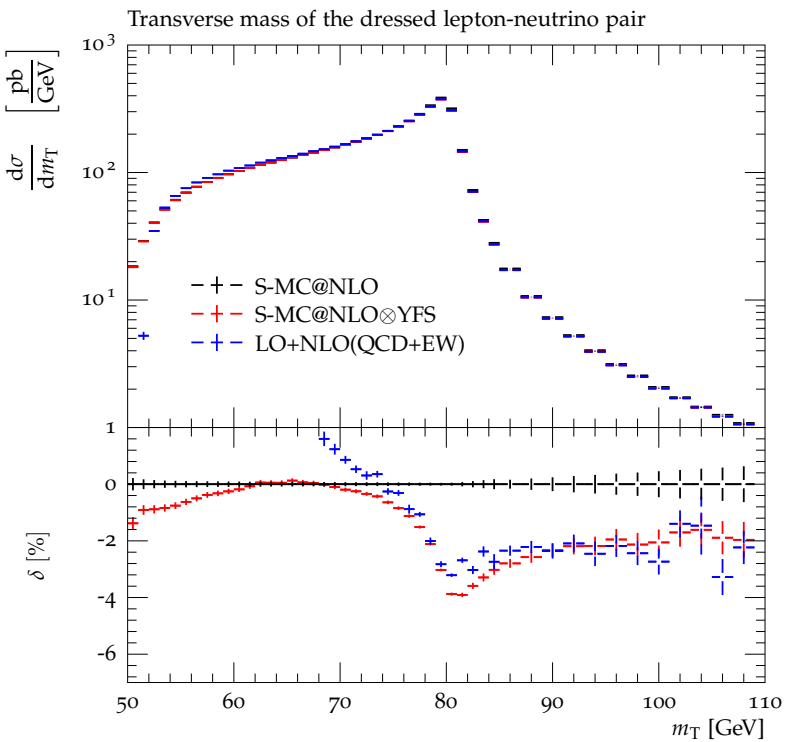


- $\mathcal{O}(\alpha)$ and $\mathcal{O}(\alpha_s\alpha)$ electroweak corrections well reproduced
- for $p_\perp^\ell > \frac{1}{2} m_Z$ driven by ISR (not in YFS), but $\ll$ QCD ISR
- genuine weak corrections sizeable only at large $p_\perp^\ell$

Accuracy in $pp \to \ell\nu$

Höche, Prestel, MS for EW report

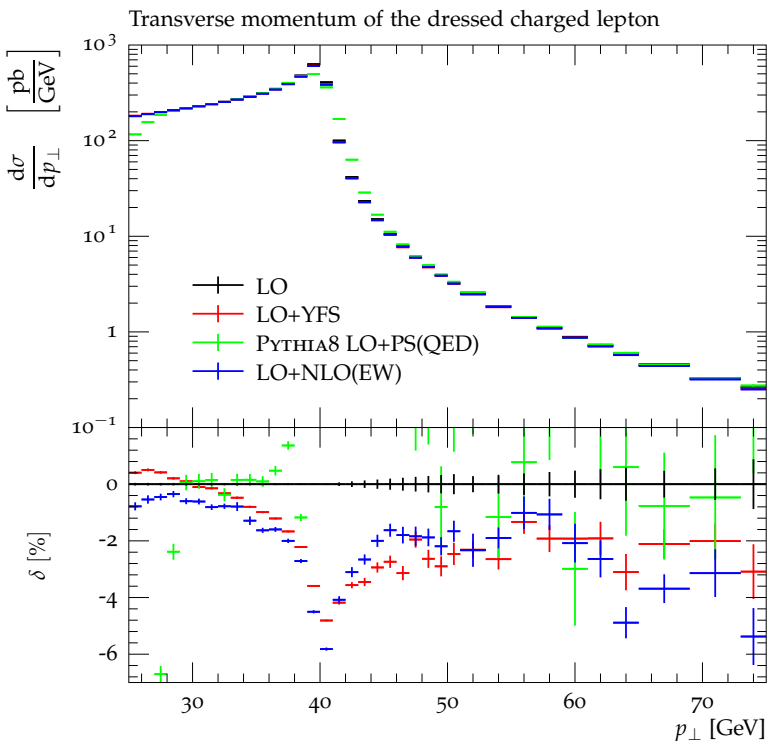


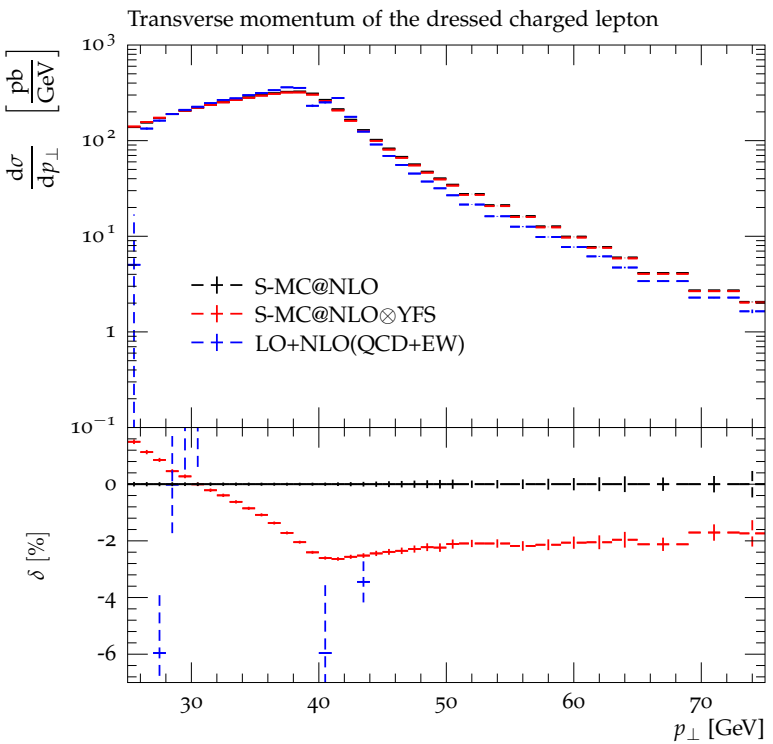


- $\mathcal{O}(\alpha)$ electroweak corrections well reproduced
- residual difference due to multi-photon emissions
- genuine weak corrections small

Accuracy in $pp \to \ell\nu$

Höche, Prestel, MS for EW report





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

Conclusions

- EW corrections in the Sudakov limit can easily be incorporated in LO and NLO QCD Monte-Carlo event generators
  - real photon emission effects can be recovered through DGLAP or soft-photon resummation (if matched to NLO QED better than fixed order description at NLO EW)
  - small finite corrections for inclusive distributions not exact to NLO EW
- inclusion of approximate EW corrections in MEPS@NLO available including important contributions from subleading orders
- improves data description at large transverse momenta
- publically available in SHERPA-2.2.5

Thank you for your attention!