Electroweak radiation in parton showers

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Disclaimer

EW (W/Z) radiation (as opposed to QED radiation) in parton showers is not an active field of investigation in the field. The reason for will (hopefully) become clear during the talk. Non-published results shown cannot even be considered preliminary, but rather illustrational only.

Contents

QED radiation

- usual suspects, most used tools:
  - PHOTOS
  - YFS-based QED resummation used in HERWIG++ and SHERPA

  $\rightarrow$ high precission tools for pure QED situations, e.g. $Z \rightarrow \ell\ell$, hadron decays, ...

$\Rightarrow$ not considered

- consider QED radiation in the presence of QCD radiation, i.e. QED radiation off colour-charged particles

$\Rightarrow$ need interleaved evolution to get relative emission rates correct

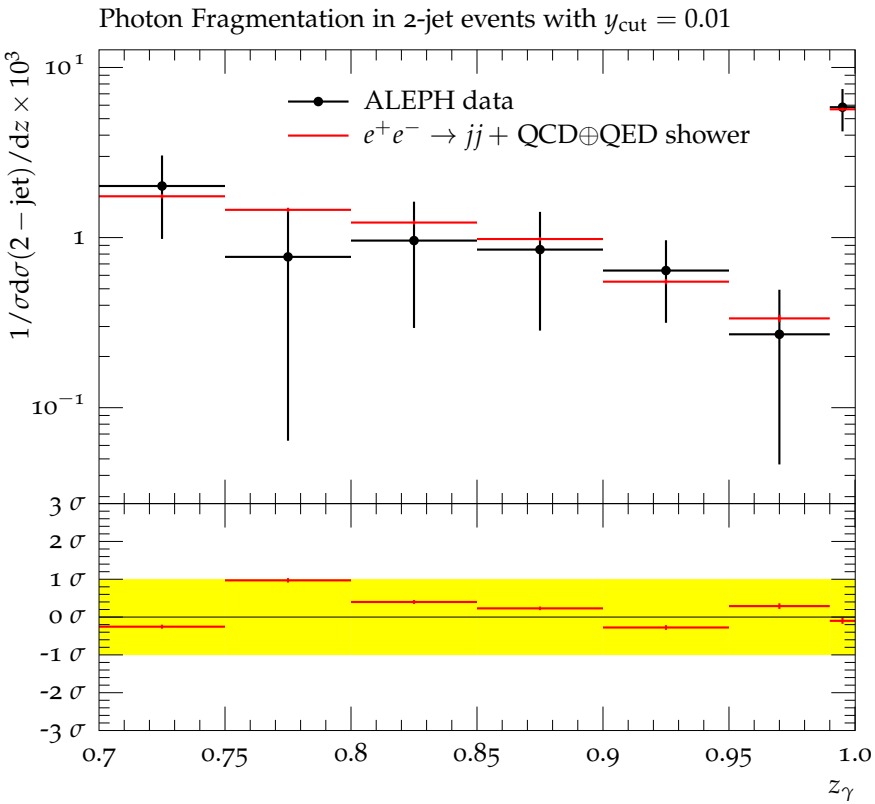
$\Rightarrow$ inclusion in conventional parton showers implies same ordering as QCD evolution

$\Rightarrow$ DGLAP resummation

QED radiation

- QED-splitting functions present in many parton showers
- same splitting functions as QCD: $\alpha_s \to \alpha_{\text{QED}}$, $C_F/T_R \to Q_i^2$ (but no $\gamma \to \gamma\gamma$)
- no leading colour approximation, coherence non-trivial to achieve $\to$ YFS
- plot for Drell-Yan vs. YFS
- very small scales possible, resummation necessary

Höche, Schumann, Siegert
Phys.Rev.D81(2010)034026



QED-MEPS merging

- QED-merging works just like QCD-merging
  - introduce Q_{cut} to separate ME and PS regions
  - apply QED-Sudakov to real emission ME
- problem: rare QED-splittings in co-evolving QCD and QED
- solved by weighted PS

Höche, Schumann, Siegert
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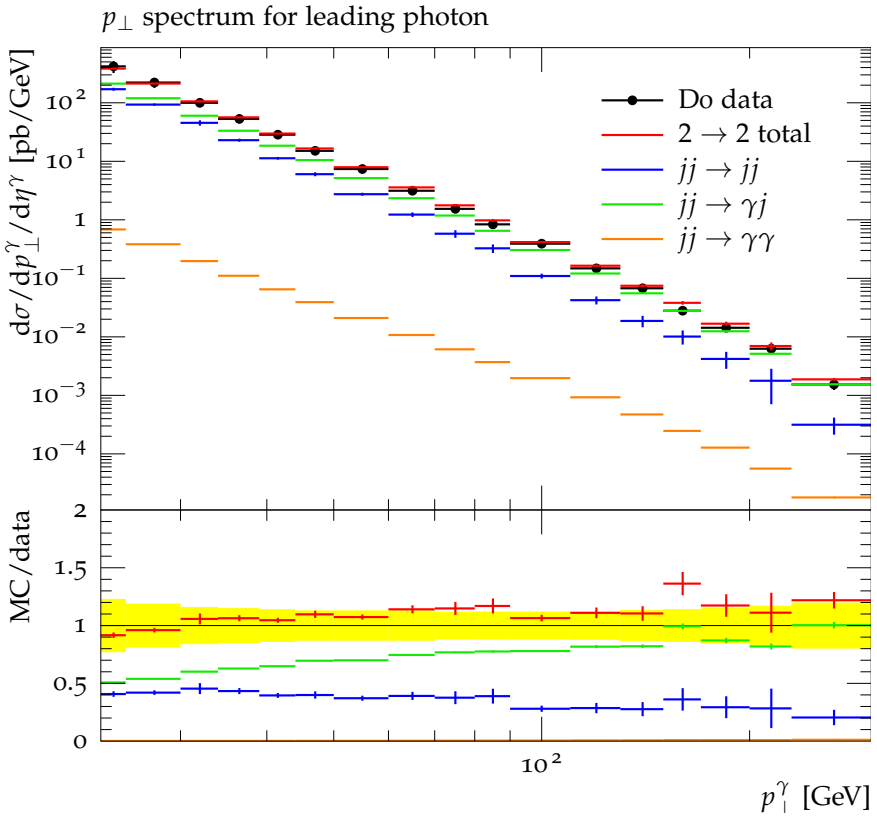
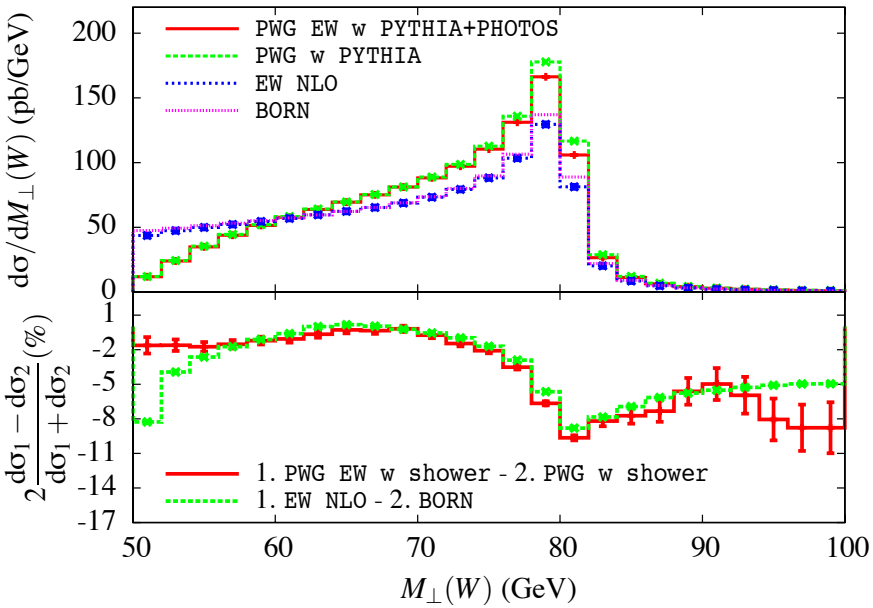


QED-POWHEG matching

- NLO QCD and EW corrections for inclusive W production
- no real W/Z radiation
  $\rightarrow$ parton shower matching for QCD and QED emissions
- further parton showering with PYTHIA
  further QED emissions of charged lepton
- since PHOTOS has no evolution/ordering special care has to be taken to ensure its not filling the phase space of the first emission again

Barze, Montagna, Nason, Nicrosini, Piccinini arXiv:1202.0465

Bernaciak, Wackeroth arXiv:1201.4804



EW radiation – fixed order

Moretti, Nolten, Ross Nucl.Phys.B759(2006)50-82

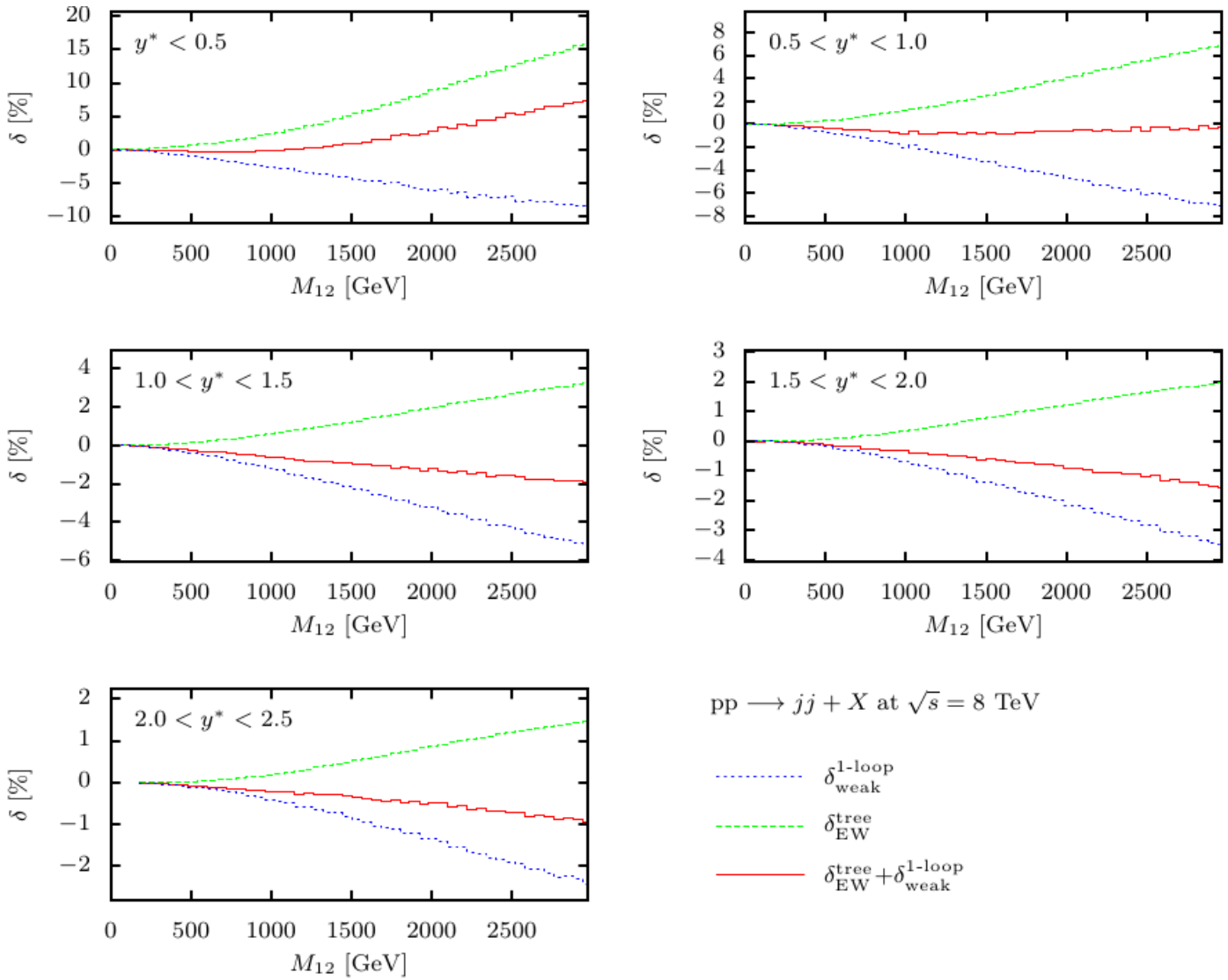
Dittmaier, Huss, Speckner arXiv:2012.1121

Example: EW-NLO corrections in jet-production

- due to W/Z mass real and virtual corrections involving W/Z bosons separatly finite
- regard emission of real W/Z boson as separate identified final state
  $\rightarrow$ do not include real emission corrections
- important: consistency of $\mathcal{O}(\alpha_{\text{QED}})$ and $\mathcal{O}(\alpha_s)$
  - tree-level QCD production $\mathcal{O}(\alpha_s^2)$,
    QCD NLO corrections $\mathcal{O}(\alpha_s^3)$, EW virtual corrections $\mathcal{O}(\alpha_s^2\alpha_{\text{QED}})$
  - interference of tree-level EW-production and QCD-production $\mathcal{O}(\alpha_s\alpha_{\text{QED}})$,
    QCD NLO corrections $\mathcal{O}(\alpha_s^2\alpha_{\text{QED}})$, EW virtual corrections $\mathcal{O}(\alpha_s\alpha_{\text{QED}}^2)$
  - tree-level EW-production $\mathcal{O}(\alpha_{\text{QED}}^2)$,
    QCD NLO corrections $\mathcal{O}(\alpha_s\alpha_{\text{QED}}^2)$, EW virtual corrections $\mathcal{O}(\alpha_{\text{QED}}^3)$

EW radiation – fixed order

Dittmaier, Huss, Speckner arXiv:2012.1121



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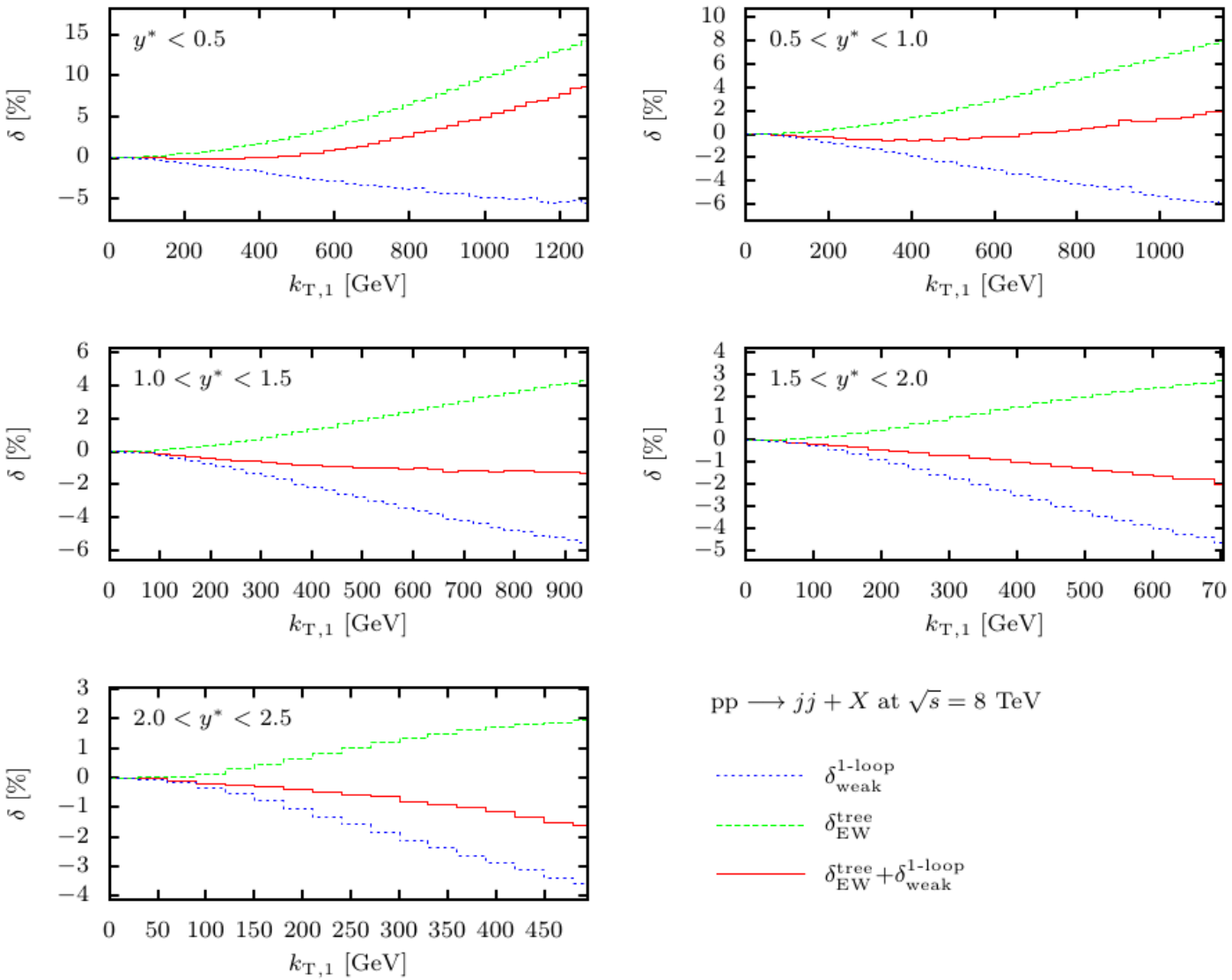
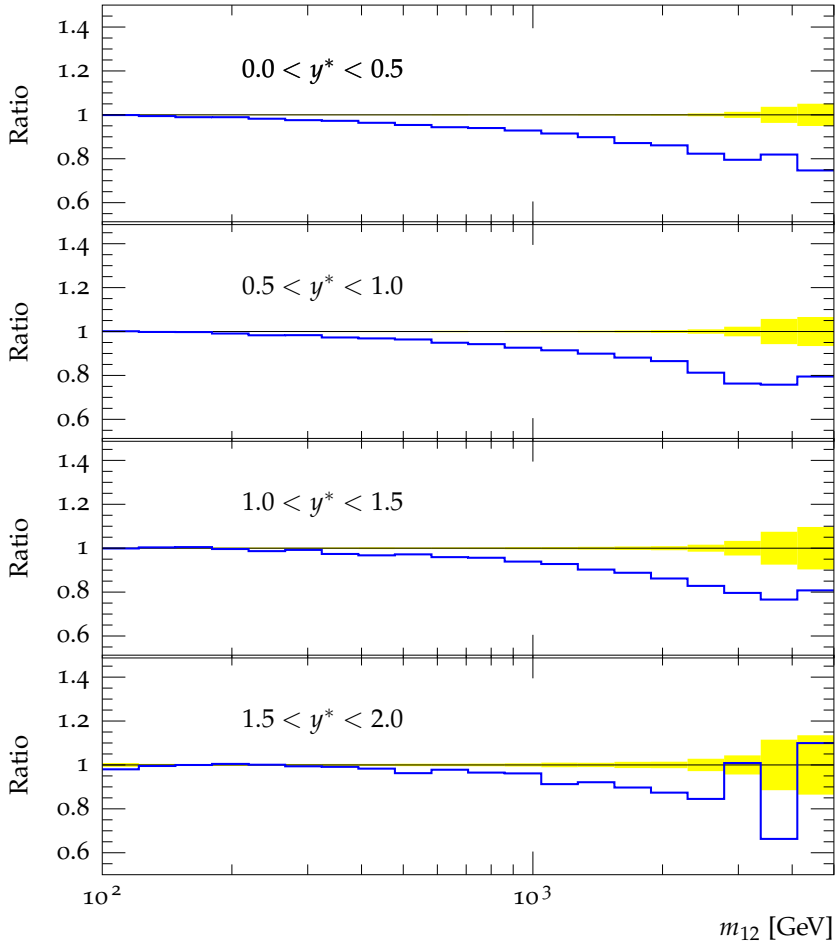


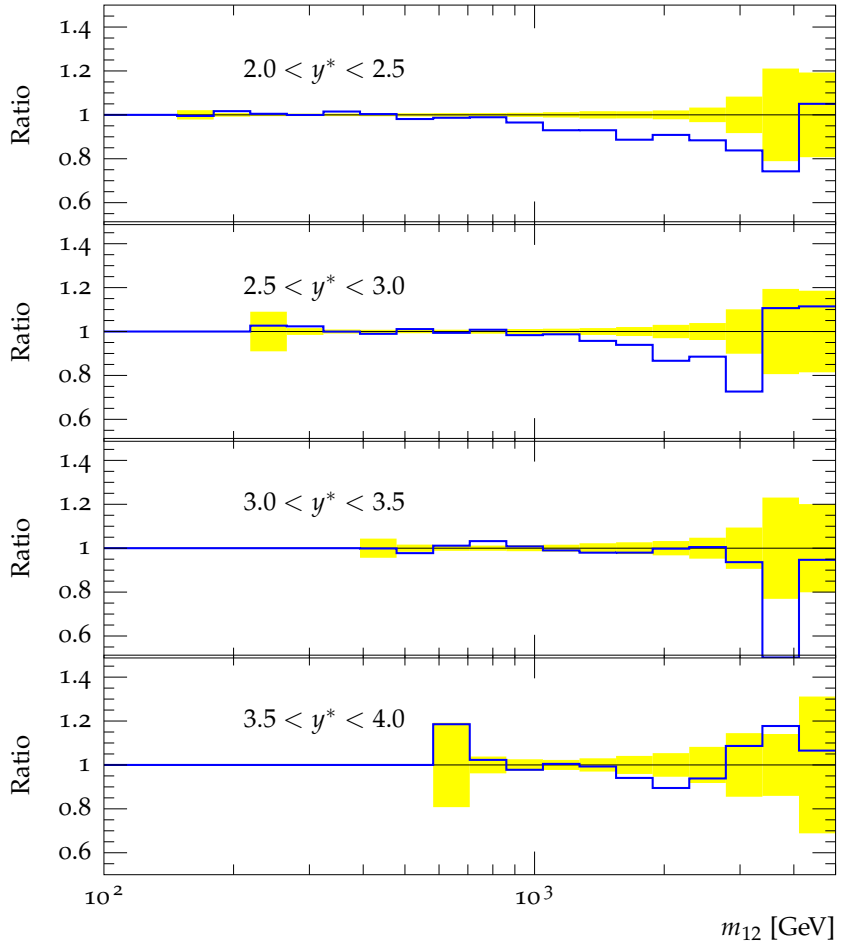
EW radiation – parton shower

- EW W-emission from parton shower
- in principle, because ffW/ffZ-coupling is spin-dependent (ffW purely lefthanded) spin-correllated parton shower needed
- only transverse modes should be resummed due to equivalence theorem $\rightarrow$ modifaction of splitting functions
- implementation in spin-summed parton shower can by definition only give rough estimate
- splitting functions available in CSSHOWER++ in SHERPA, but not used for evolution due to above limited correctness
  (also preliminary studies by J. R. Christiansen & T. Sjöstrand, see talk in "TH/LPCC Institute on SM at the LHC" October 2012)
- in general limited physics case for preferring spin-summed but resummed parton shower over fixed-order result because logarithms ($\sim \log \frac{p_\perp}{m_W}$) only large(ish) in extreme corners of the phase space

EW radiation – parton shower

EW Sudakov corrections on dijet-masses (illustrational only!!)

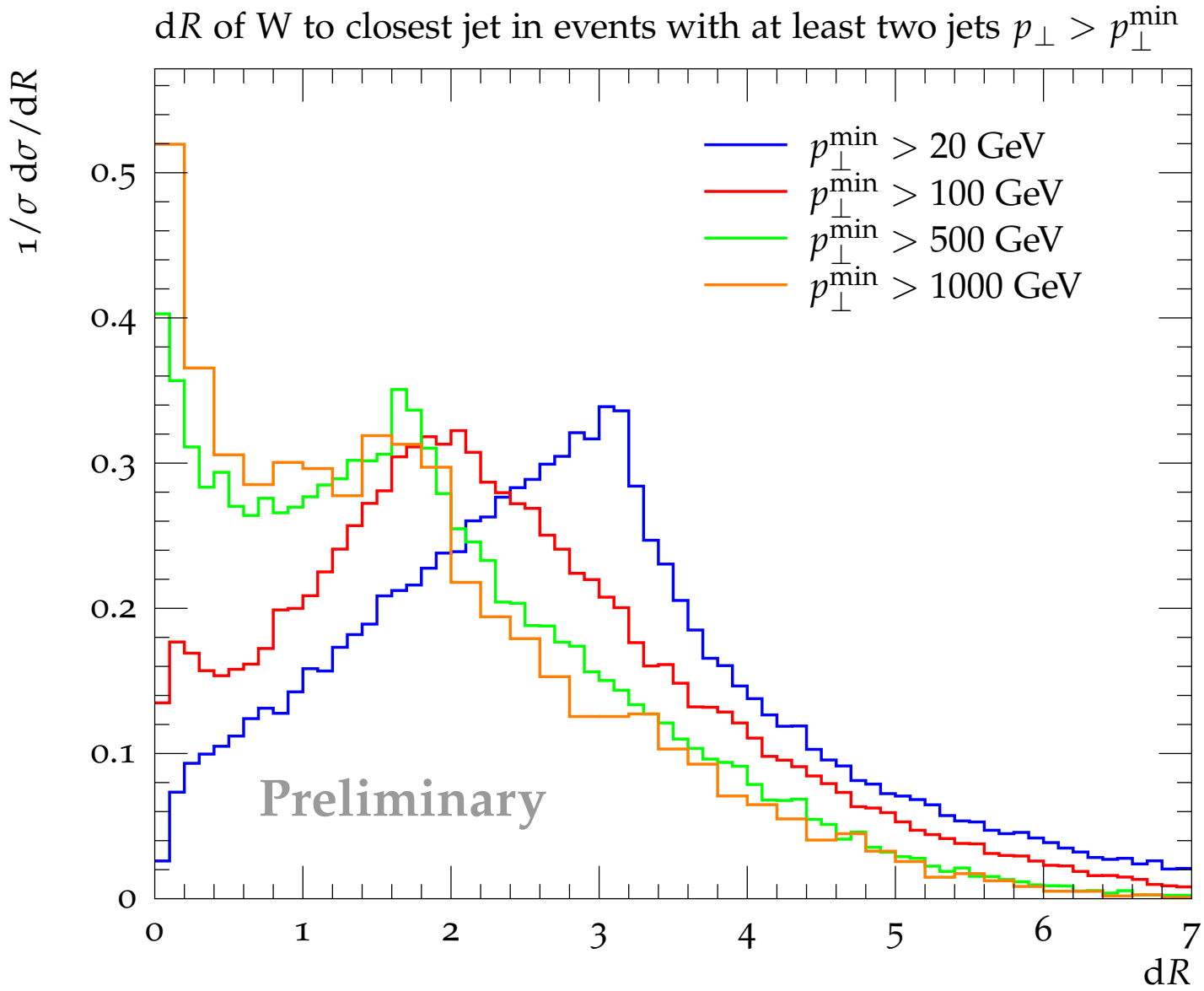




LO+PS(QCD) vs LO+PS(QCD +EW)

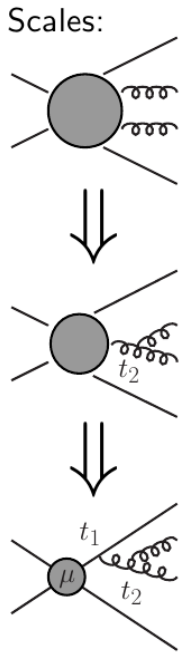
off by factor 2 because parton shower does not know helicity of the parton

EW radiation – parton shower



EW cluster histories in MEPS merging

- used for backwards clustering since SHERPA-1.2.0
  $\rightarrow$ determination of splitting scales and core scales
- example: W+2j regarded as EW correction to dijet production if
  - QCD-clusterings are forbidden, e.g. in $d\bar{d} \to c\bar{s}W^-$
  - EW splitting selected probabilistically
    $\rightarrow$ very likely in region where jets are hard and W is soft
- scales are then set appropriatly, e.g.
  - core $q\bar{q} \to \ell\nu$: $\mu = \hat{s}$
  - core $gg \to q\bar{q}$: $\mu = p_\perp(q)$



$$\alpha_s^{k+n}(\mu_{\text{eff}}) = \alpha_s^k(\mu)\,\alpha_s(t_1)\cdots\alpha_s(t_n)$$

Conclusions

- parton showering for QED available, used and validated
  for QED emissions off colour-charged line interleaved QED-QCD-evolution necessary
- W/Z should not be radiated from a helicity/spin summed shower
- generally no need for resummation, however, special cases exist
- nonetheless, NLO EW corrections are important for LHC (precission) measurements
- splitting functions exist in SHERPA since rel-1.2.0 and are used for backwards clustering, but generally not for forward evolution
  (may be switchable on demand in SHERPA-2.0.0)

Thank you for your attention!