

# Electroweak radiation in parton showers

Marek Schönherr

Institute for Particle Physics Phenomenology

CERN, 21/08/2012



LHCphenOnet



## 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

- 1 QED radiation
- 2 EW radiation – fixed order
- 3 EW radiation – parton shower
- 4 EW cluster histories in MEPS merging
- 5 Conclusions

# QED radiation

- usual suspects, most used tools:

- PHOTOS

- YFS-based QED resummation used in HERWIG++ and SHERPA

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

⇒ not considered

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

⇒ need interleaved evolution to get relative emission rates correct

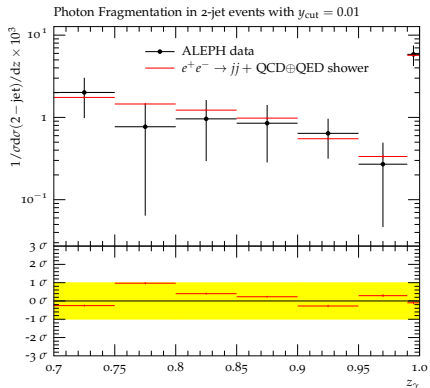
⇒ inclusion in conventional parton showers implies same ordering as QCD evolution

⇒ DGLAP resummation

# QED radiation

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

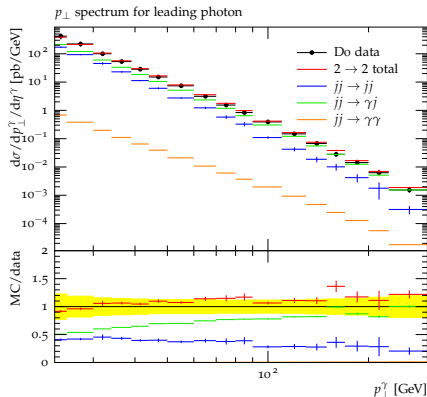
Höche, Schumann, Siegert  
Phys.Rev.D81(2010)034026



# QED-MEPS merging

- QED-merging works just like QCD-merging
  - introduce  $Q_{\text{cut}}$  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  
Phys.Rev.D81(2010)034026

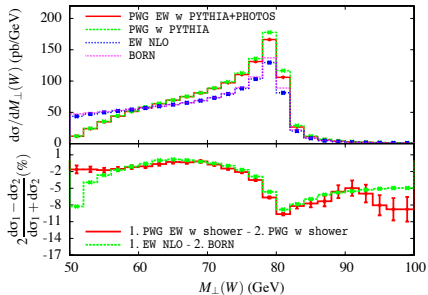


# QED-POWHEG matching

- NLO QCD and EW corrections for inclusive  $W$  production
- no real  $W/Z$  radiation  
→ 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, Wackerath arXiv:1201.4804



# EW radiation – fixed order

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

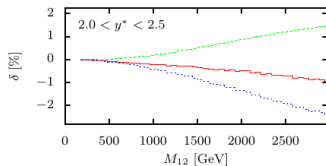
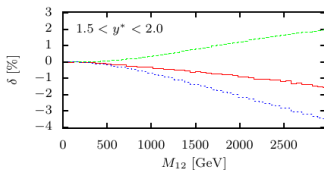
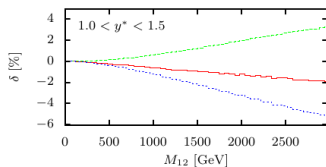
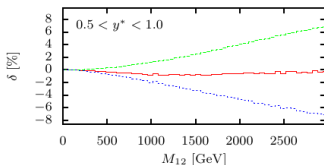
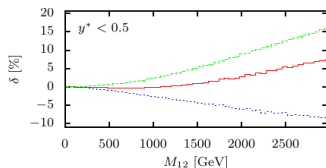
Dittmaier, Huss, Speckner arXiv:2012.1121

## Example: EW-NLO corrections in jet-production

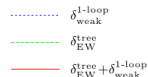
- due to  $W/Z$  mass real and virtual corrections involving  $W/Z$  bosons separately finite
- regard emission of real  $W/Z$  boson as separate identified final state  
→ do not include real emission corrections
- important: consistency of  $\mathcal{O}(\alpha_{\text{QED}})$  and  $\mathcal{O}(\alpha_s)$ 
  - 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

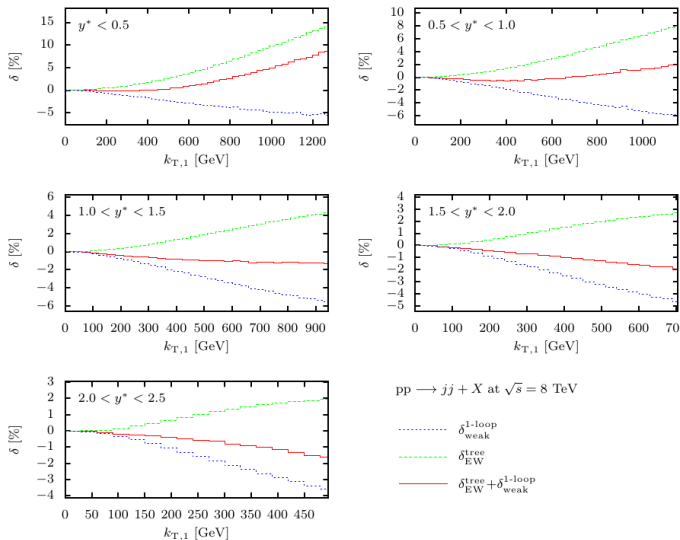


$pp \rightarrow jj + X$  at  $\sqrt{s} = 8$  TeV



# EW radiation – fixed order

Dittmaier, Huss, Speckner arXiv:2012.1121

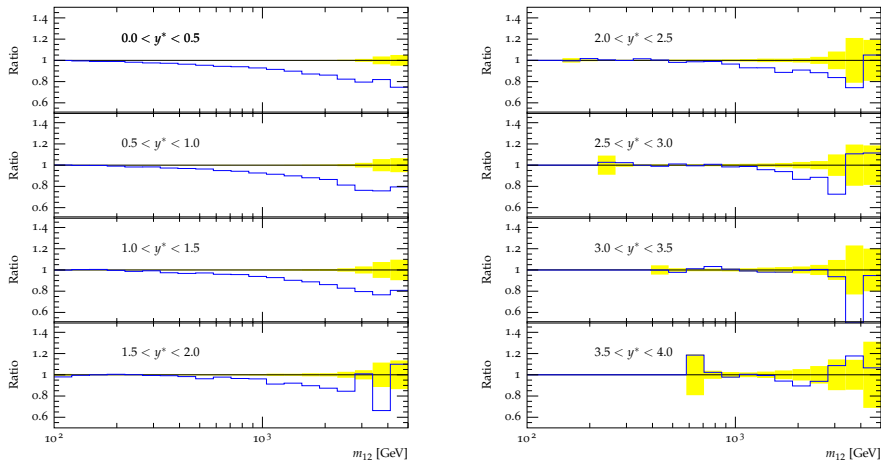


# EW radiation – parton shower

- EW W-emission from parton shower
- in principle, because  $ffW/ffZ$ -coupling is spin-dependent ( $ffW$  purely lefthanded) spin-correlated parton shower needed
- only transverse modes should be resummed due to equivalence theorem  
→ modification 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

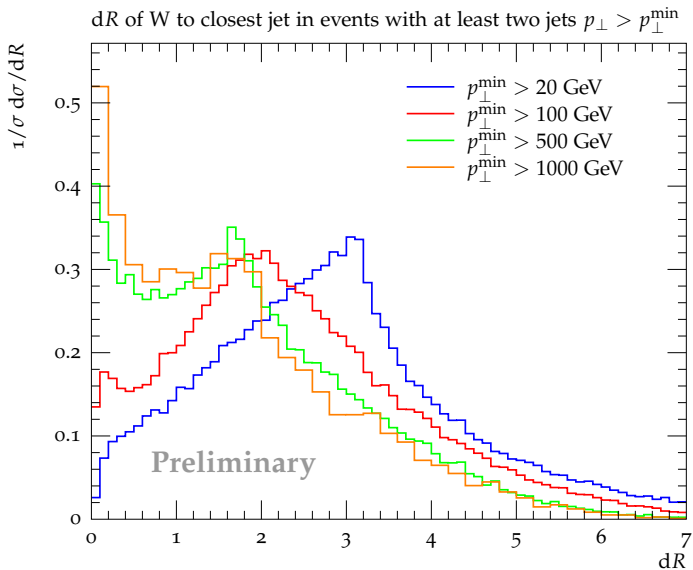
EW Sudakov corrections on dijet-masses (illustrational only!!)



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

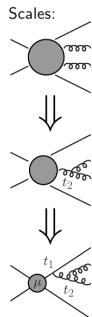
off by factor 2 because parton shower does not know helicity of the parton

# EW radiation – parton shower



# EW cluster histories in MEPS merging

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



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

# 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 (precision) 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!