YFS and PHOTOS

–

QED FSR modelling in Drell-Yan and vector boson pair production

Marek Schönherr*

IPPP, Durham University

*in collaboration with C. Gütschow

YFS and PHOTOS

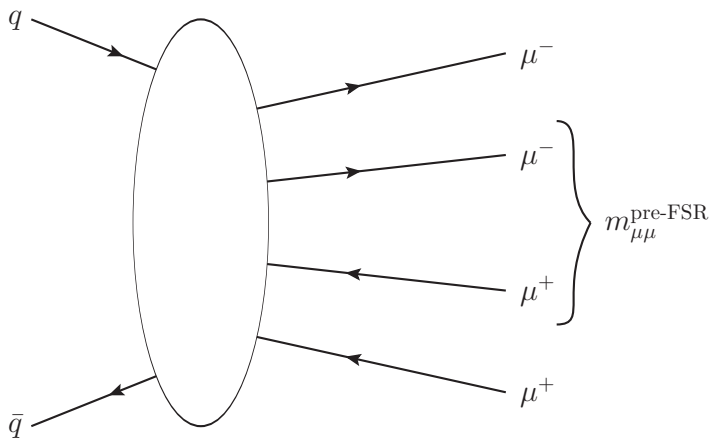
- compare two widely used QED FSR computations:
  1) YFS soft-photon resummation as implemented in SHERPA-2.2.6

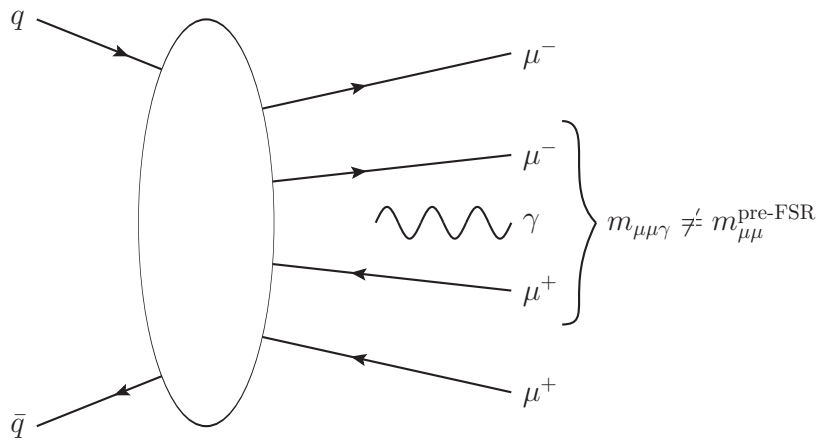
     Yennie, Frautschi, Suura Annals Phys. 13 (1961) 379-452
     MS, Krauss arXiv:0810.5071
  2) PHOTOS (v3.61 w/ C++ interface)

     Barberio, van Eijk, Wąs, Comput.Phys.Commun. 66 (1991) 115-128
     Davidson, Przedzinski, Wąs arXiv:1011.0937
- Both are interfaced to the same internal SHERPA event record
  - rough-hewn programmatic interface to PHOTOS
  - parameters (m_e, m_μ, $\alpha(0)$, ...) synchronised
- kinematic identification of resonances for the benefit of the QED FSR tools
  $\rightarrow$ application of higher-order corrections
  (YFS: NLO QED, PHOTOS NLO QED (?))
  $\rightarrow$ implication of choice of recoil partners

Resonance identification and preservation

Coherent emission from multiparticle final states (multipoles) changes invariant masses of subsystems.





Determine, which resonant structures to preserve with QED FSR.
Possible resonant structures given by contributing Feynman diagrams.
But: multiplie possibilities and contrast to non-resonant production.
Disentangle phase space point by phase space point, but ultimately incorporates some level of arbitrariness.

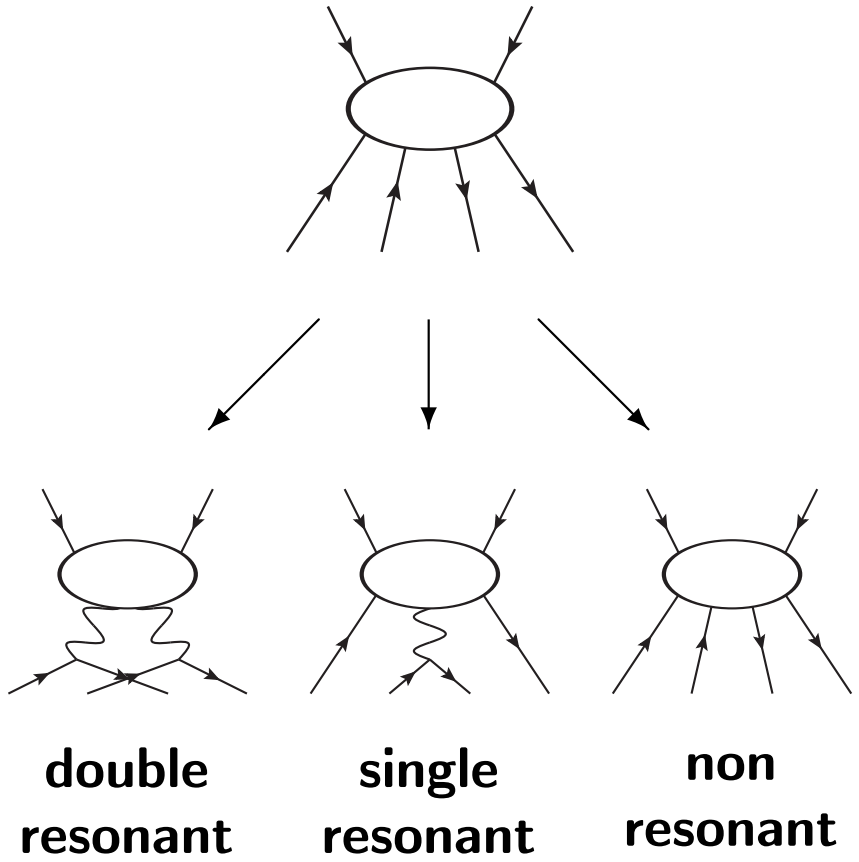
Resonance identification and preservation

Algorithm used in SHERPA:

- determine all

$$\Delta_{\mu_i^+\mu_j^-} = \frac{|m_{\mu_i^+\mu_j^-} - m_Z|}{\Gamma_Z}$$

- if $\Delta_{\mu_i^+\mu_j^-} > \Delta_{\text{thr}}$ classify as non-resonant
- identify resonant starting with smallest $\Delta_{\mu_i^+\mu_j^-}$, remove all other Δ using either μ_i^+ or μ_j^-, iterate
- apply QED FSR in identified subsystems, no interference across resonances



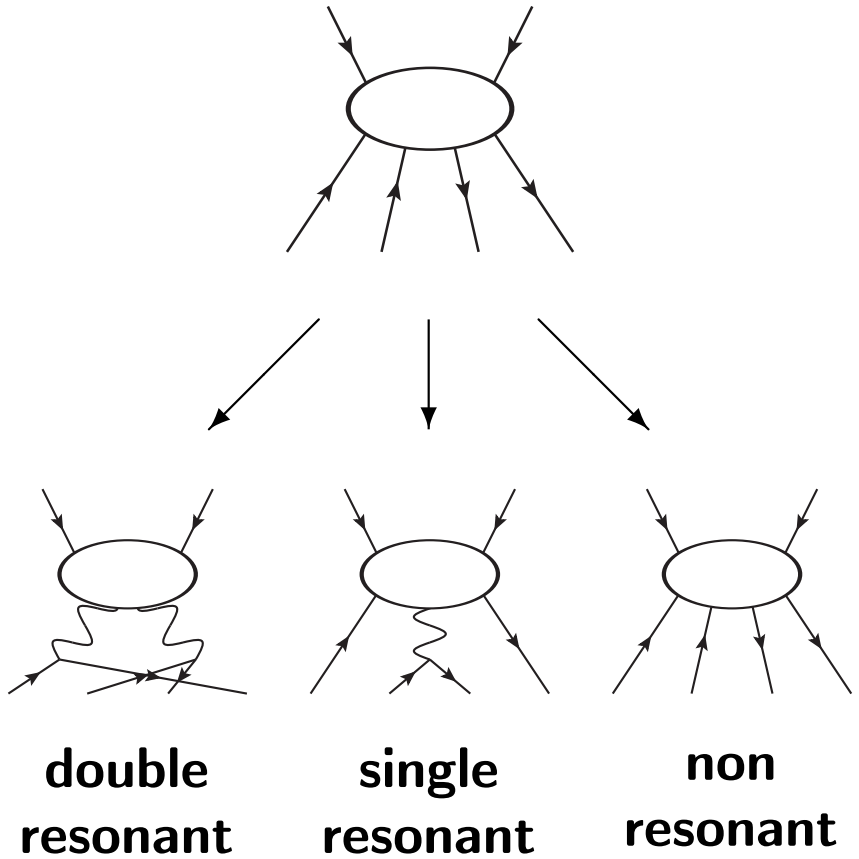
Resonance identification and preservation

Algorithm used in SHERPA:

- determine all

$$\Delta_{\mu_i^+\mu_j^-} = \frac{|m_{\mu_i^+\mu_j^-} - m_Z|}{\Gamma_Z}$$

- if $\Delta_{\mu_i^+\mu_j^-} > \Delta_{\text{thr}}$ classify as non-resonant
- identify resonant starting with smallest $\Delta_{\mu_i^+\mu_j^-}$, remove all other Δ using either μ_i^+ or μ_j^-, iterate
- apply QED FSR in identified subsystems, no interference across resonances



YFS and PHOTOS

Impact on lepton measurements

- the measurements of detector-corrected dressed, bare and Born leptons contains a theory dependence on the QED FSR modelling
- expect that dependence to be most pronounced for Born leptons because the concept is inherently ill-defined (and not just a consequence of perturbative truncation)
  - QED is IR-free
  - every accelerated, ie. interacting, charge radiates an infinite number of infinitely soft photons
  - measuring a Born lepton is akin to measuring a very light QCD parton in an arbitrary event record
    $\rightarrow$ functional definition of an observable can be found, with a **theory-dependent** conversion from meas. object to Born lepton

$\Rightarrow$ understand the theoretical uncertainty of the measured data, **or** to which extent the measured data is independent of the assumptions and approximation of the theory calculation

YFS and PHOTOS

Disclaimer
All of the following is work in progress,
some changes/corrections are to be expected.

QED FSR in Drell-Yan – preliminary

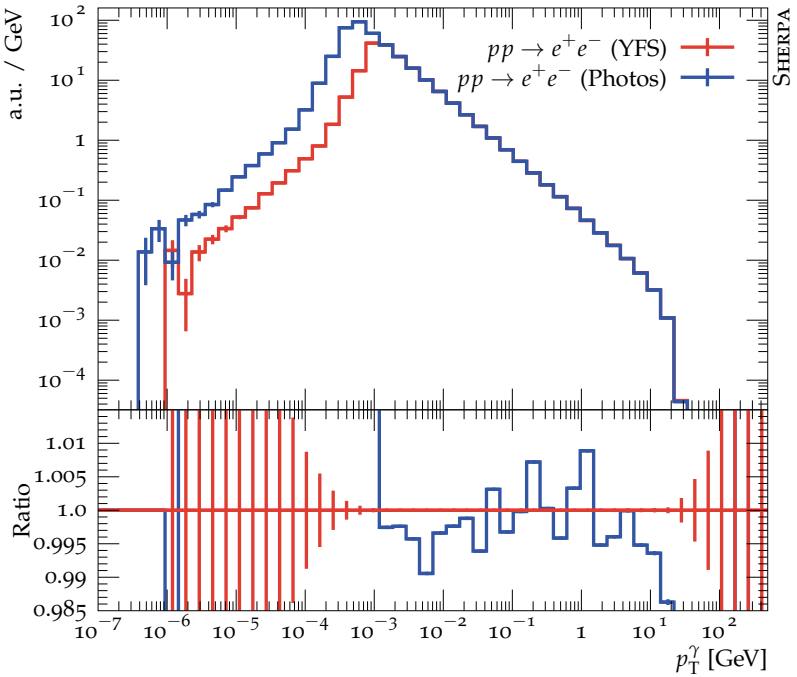
Very simple setup to not blur QED effects

- $q\bar{q} \to \ell^+\ell^-$ LO+QED FSR, no QCD corrections
- $|\eta(\ell)| < 2.4$,
  $p_{\mathrm{T}}(\ell) > 7\,\mathrm{GeV}$
- displayed uncertainties statistical only

QED FSR in Drell-Yan – preliminary

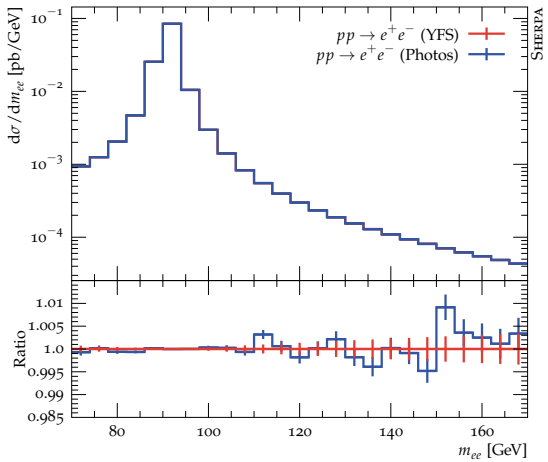
inclusive p_{T}^{γ} spectrum

- starts at $\mathcal{O}(\alpha)$
- difference in IR cutoff (in the range of MeV)
  $\rightarrow$ observables should be insensitive to even softer radiation at the investigated accuracy
- good agreement found, though YFS radiates slightly more throughout spectrum



inclusive p_{T}^{γ} spectrum

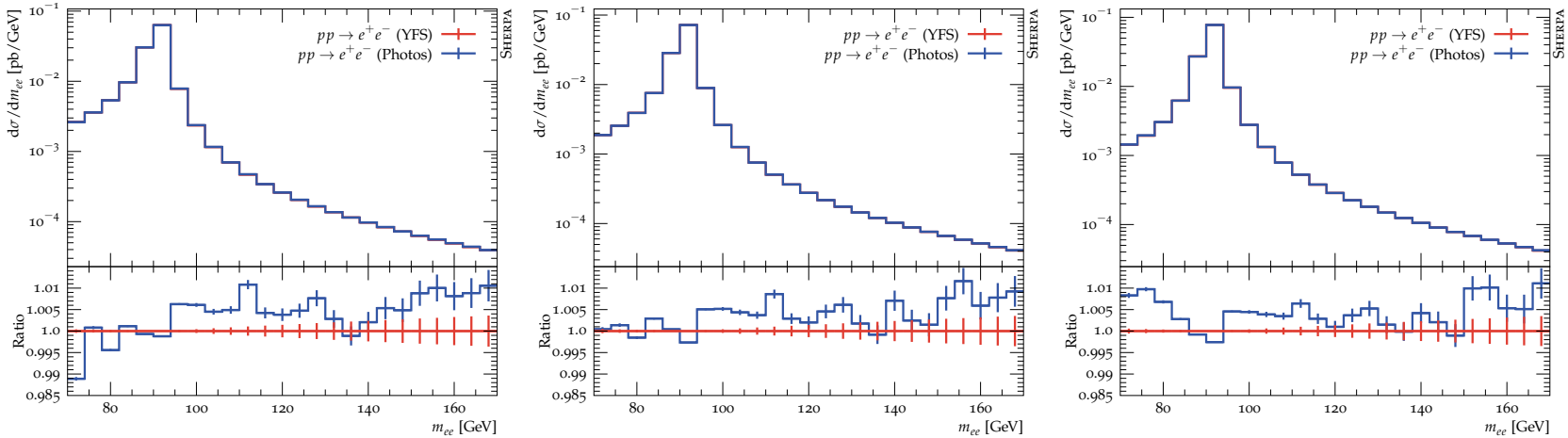
QED FSR in Drell-Yan – preliminary



Born leptons
(from event record)

- lepton-definition dependent level of agreement below the 0.5% level
  $\to$ slightly different radiation patterns
- except on-peak YFS predicts consistently lower cross sections,
  in-line with findings in incl. photon spectrum

QED FSR in Drell-Yan – preliminary



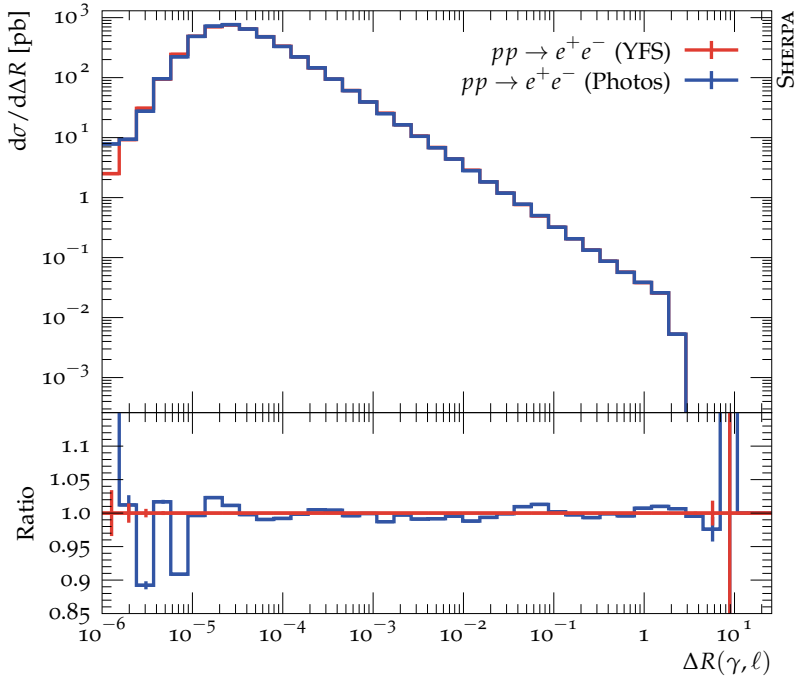
bare leptons | dressed leptons $\Delta R = 0.005$ | dressed leptons $\Delta R = 0.1$

- lepton-definition dependent level of agreement below the 0.5% level
  $\to$ slightly different radiation patterns
- except on-peak YFS predicts consistently lower cross sections,
  in-line with findings in incl. photon spectrum

QED FSR in Drell-Yan – preliminary

Investigate photon radiation pattern – $\Delta R(\gamma, \text{closest bare } \ell)$

- $p_{\mathrm{T}}^{\text{bare } \ell} > 7\,\text{GeV}$, $p_{\mathrm{T}}^{\gamma} > 10\,\text{MeV}$
- inclusive selection
- dead-cone (mass-suppression of ultra-collinear radiation) equally well described
- bulk of radiation well within dressing cones of 0.1 and 0.005

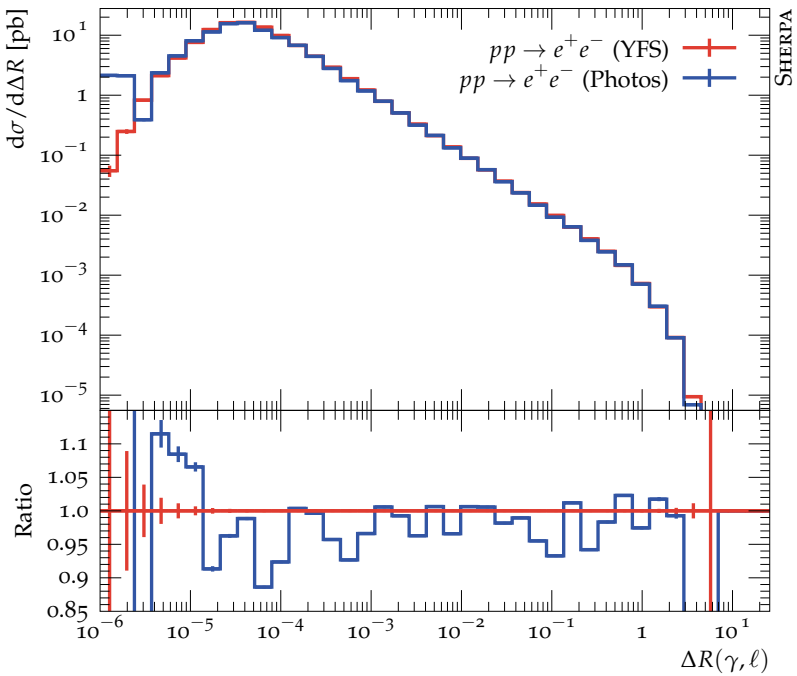


incl. lepton selection

QED FSR in Drell-Yan – preliminary

Investigate photon radiation pattern – $\Delta R(\gamma, \text{closest bare } \ell)$

- $p_{\mathrm{T}}^{\text{bare } \ell} > 7\,\text{GeV}$, $p_{\mathrm{T}}^{\gamma} > 10\,\text{MeV}$
- events with photons harder than the lepton
- small difference in ultra-collinear behaviour

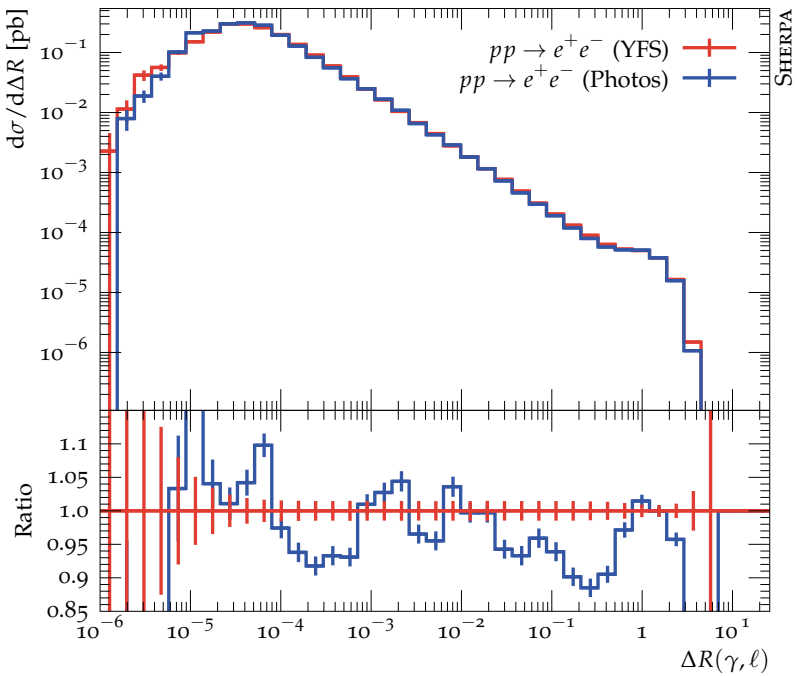


$$p_{\mathrm{T}}^{\gamma} > 1.5 \cdot p_{\mathrm{T}}^{\text{bare } \ell}$$

QED FSR in Drell-Yan – preliminary

Investigate photon radiation pattern – $\Delta R(\gamma, \text{closest bare } \ell)$

- $p_{\mathrm{T}}^{\text{bare } \ell} > 7\,\text{GeV}$, $p_{\mathrm{T}}^{\gamma} > 10\,\text{MeV}$
- events with photons harder than the lepton
- small difference in ultra-collinear behaviour

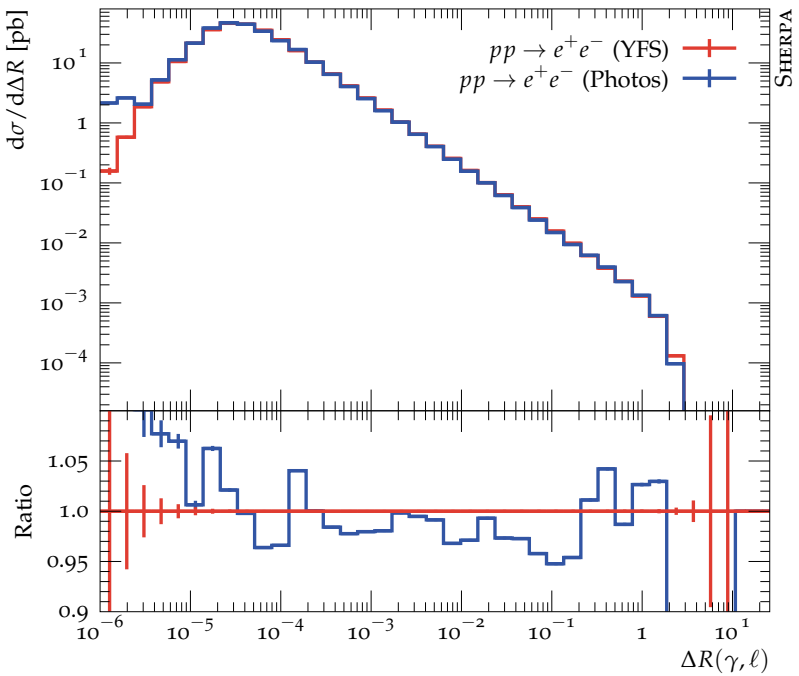


$$p_{\mathrm{T}}^{\gamma} > 2.2 \cdot p_{\mathrm{T}}^{\text{bare } \ell}$$

QED FSR in Drell-Yan – preliminary

Investigate photon radiation pattern – $\Delta R(\gamma, \text{closest bare } \ell)$

- $p_{\mathrm{T}}^{\text{bare } \ell} > 7\,\text{GeV}$, $p_{\mathrm{T}}^{\gamma} > 10\,\text{MeV}$
- events with significant radiative energy loss
- again largest difference in ultra-collinear region
- relevance for theory dependence of correction to Born leptons

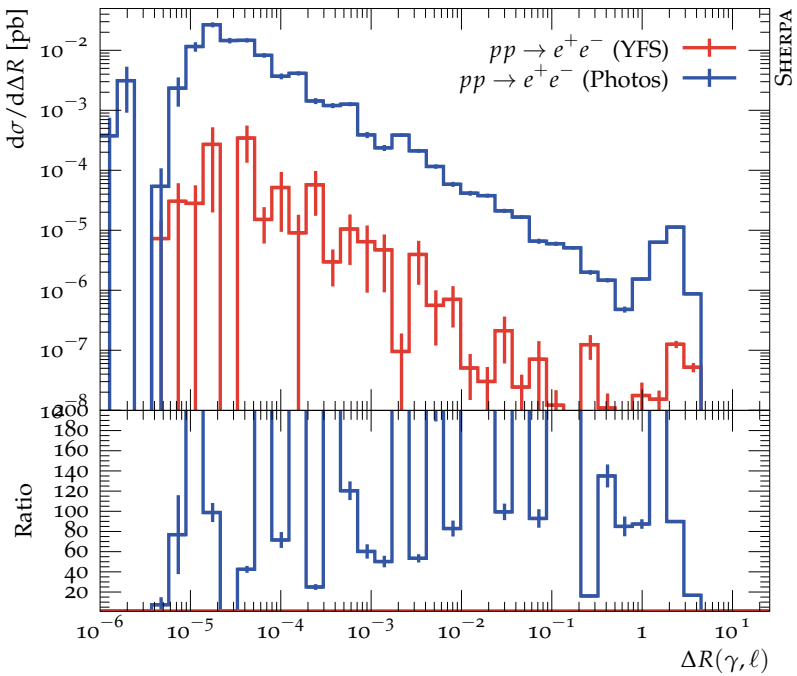


$$p_{\mathrm{T}}^{\text{bare } \ell} < 0.75 \cdot p_{\mathrm{T}}^{\text{Born } \ell}$$

QED FSR in Drell-Yan – preliminary

Investigate photon radiation pattern – $\Delta R(\gamma, \text{closest bare } \ell)$

- $p_{\mathrm{T}}^{\text{bare } \ell} > 7\,\text{GeV}$, $p_{\mathrm{T}}^{\gamma} > 10\,\text{MeV}$
- events where dressed lepton picked up energy from elsewhere
- very rare events, but $\mathcal{O}(100)$ difference
- relevance for theory dependence of correction to Born leptons



$$p_{\mathrm{T}}^{\ell+\gamma} > 1.25 \cdot p_{\mathrm{T}}^{\text{Born } \ell}$$

QED FSR in vector boson pair production

- comparison in $4e$, 4μ and $2e2\mu$ final states
- use exact NLO EW as impartial gauge
  $\rightarrow$ use approx. EW corrections for QED FSR comparison to compensate for weak virtual corrections

Kallweit,Lindert,Maierhöfer,Pozzorini,MS arXiv:1511.08692, arXiv:1705.00598
Gütschow, Lindert, MS in arXiv:1803.00950

$$\mathrm{B}(\Phi_B) \rightarrow \mathrm{B}(\Phi_B)\left(1 + \frac{\mathrm{V_{EW}}(\Phi_B) + \mathrm{I_{EW}}(\Phi_B)}{\mathrm{B}(\Phi_B)}\right)$$

- FSR dominated observables should be better described by resummations than by fixed order
- investigate dressing cone dependence, $\Delta R = 0.005, 0.02, 0.1, 0.2$

QED FSR in vector boson pair production

- comparison in $4e$, 4μ and $2e2\mu$ final states
- use exact NLO EW as impartial gauge
  $\rightarrow$ use approx. EW corrections for QED FSR comparison to compensate for weak virtual corrections

Kallweit,Lindert,Maierhöfer,Pozzorini,MS arXiv:1511.08692, arXiv:1705.00598
Gütschow, Lindert, MS in arXiv:1803.00950

$$\mathrm{B}(\Phi_B) \rightarrow \mathrm{B}(\Phi_B)\left(1 + \frac{\mathrm{V_{EW}}(\Phi_B) + \mathrm{I_{EW}}(\Phi_B)}{\mathrm{B}(\Phi_B)}\right)$$

exact virtual contribution

- FSR dominated observables should be better described by resummations than by fixed order
- investigate dressing cone dependence, $\Delta R = 0.005, 0.02, 0.1, 0.2$

QED FSR in vector boson pair production

- comparison in $4e$, 4μ and $2e2\mu$ final states
- use exact NLO EW as impartial gauge
  $\rightarrow$ use approx. EW corrections for QED FSR comparison to compensate for weak virtual corrections

Kallweit,Lindert,Maierhöfer,Pozzorini,MS arXiv:1511.08692, arXiv:1705.00598
Gütschow, Lindert, MS in arXiv:1803.00950

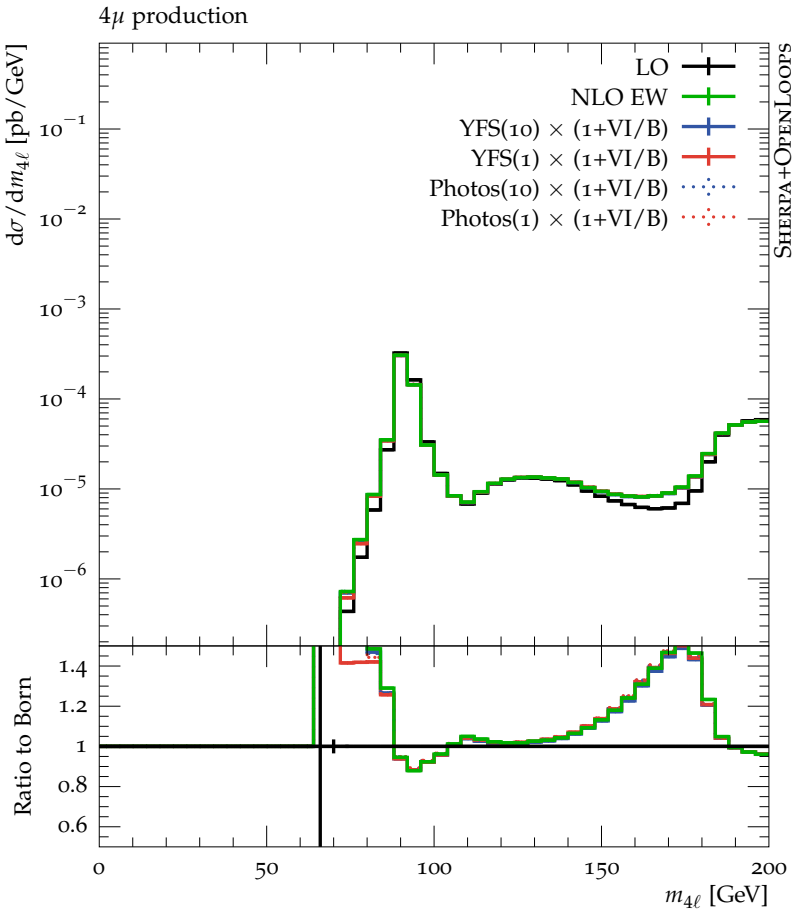
$$\mathrm{B}(\Phi_B) \rightarrow \mathrm{B}(\Phi_B)\left(1+\frac{\mathrm{V_{EW}}(\Phi_B)+\mathrm{I_{EW}}(\Phi_B)}{\mathrm{B}(\Phi_B)}\right)$$

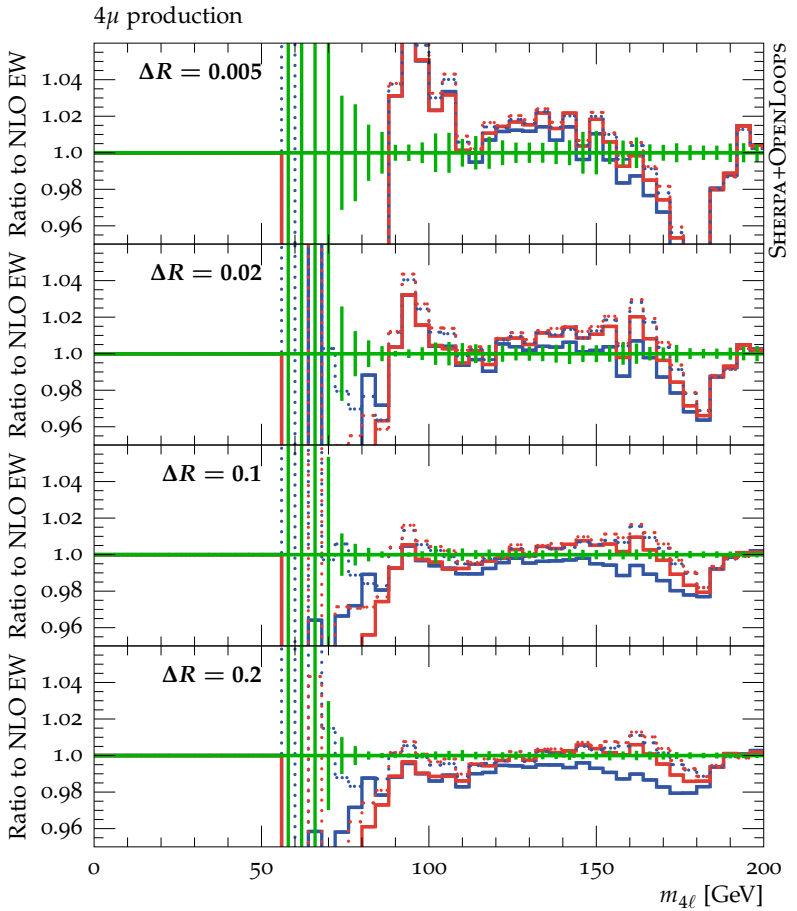
exact virtual contribution

approximate integrated real contribution

- FSR dominated observables should be better described by resummations than by fixed order
- investigate dressing cone dependence, $\Delta R = 0.005, 0.02, 0.1, 0.2$

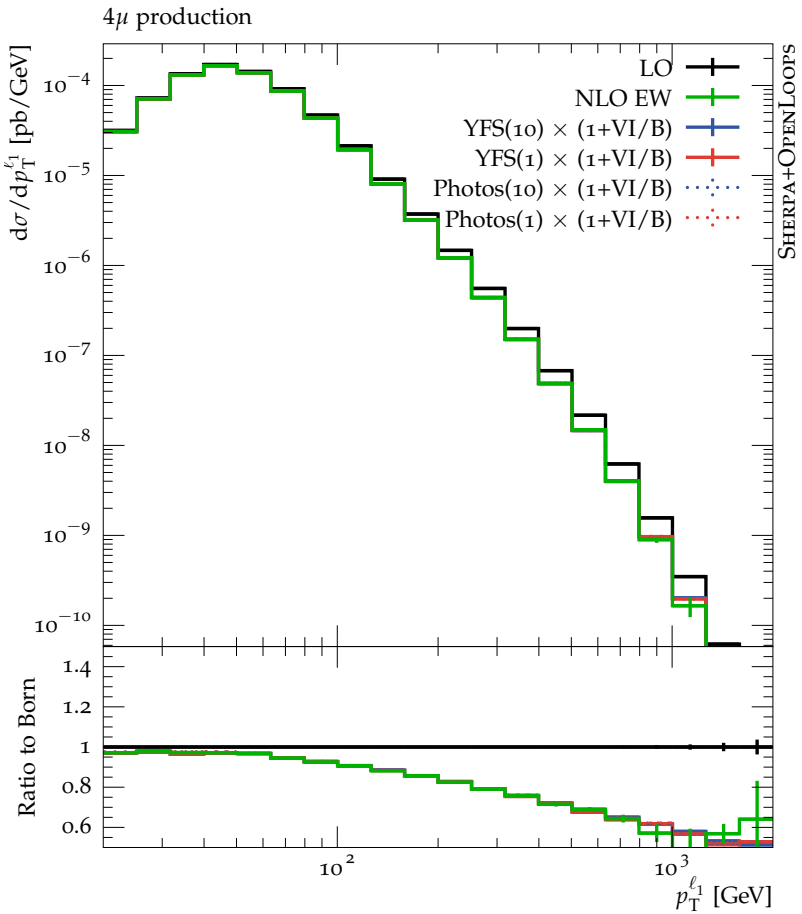
QED FSR in vector boson pair production – 4μ

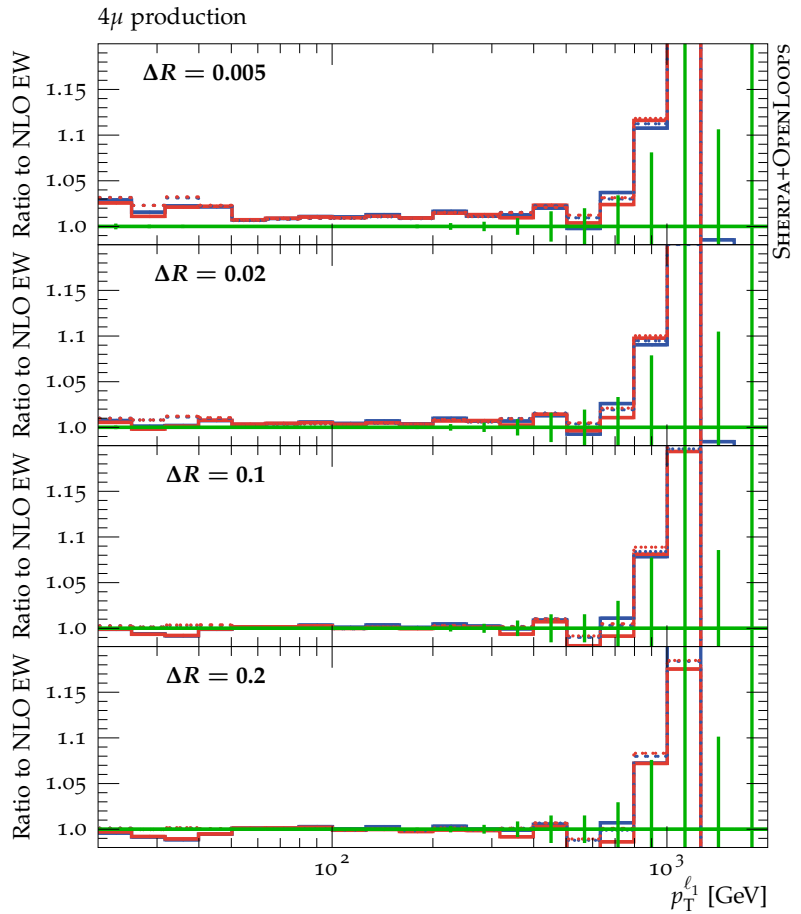




- agreement on percent level,
  except for regions where FSR correction are $\mathcal{O}(1)$

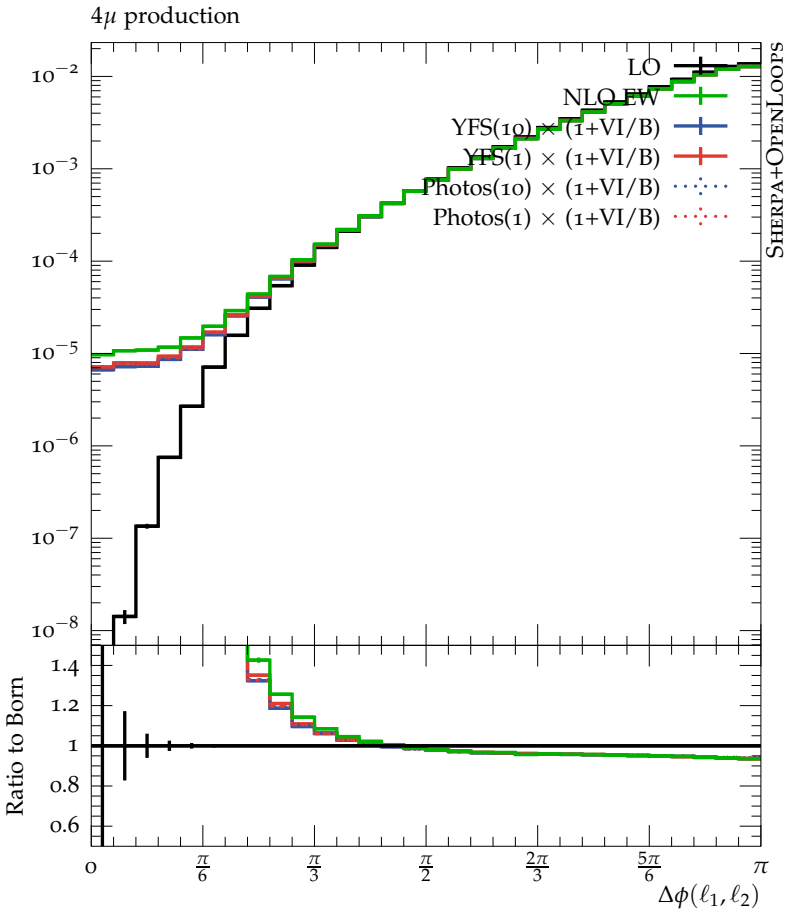
QED FSR in vector boson pair production – 4μ

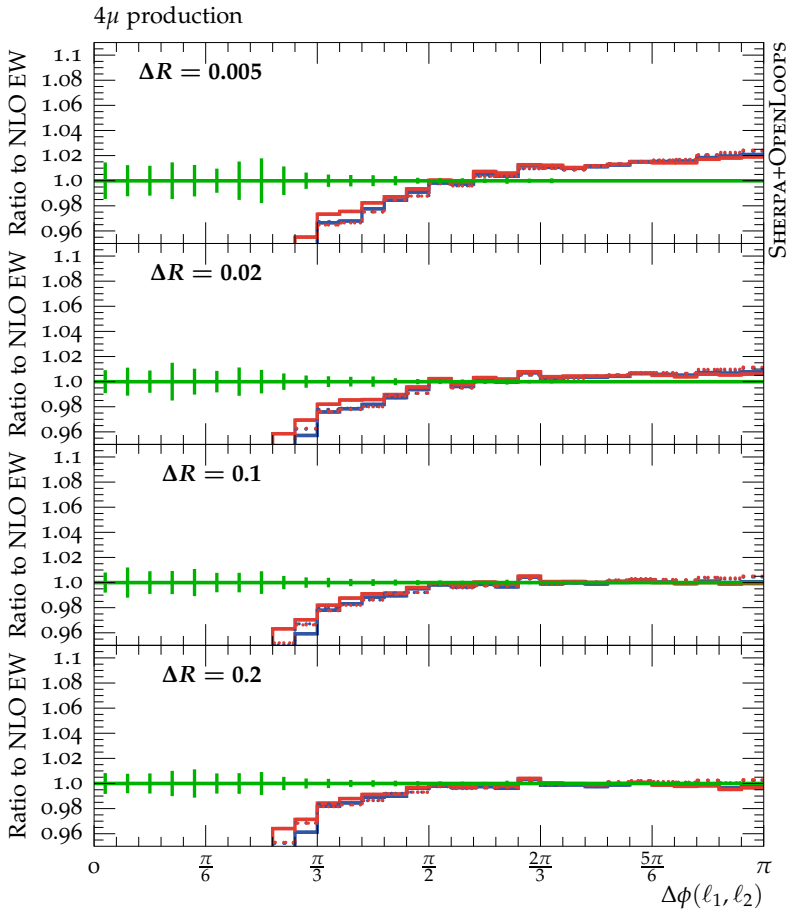




- very good agreement at large p_{T}
- at small p_{T}some dressing cone size dependence

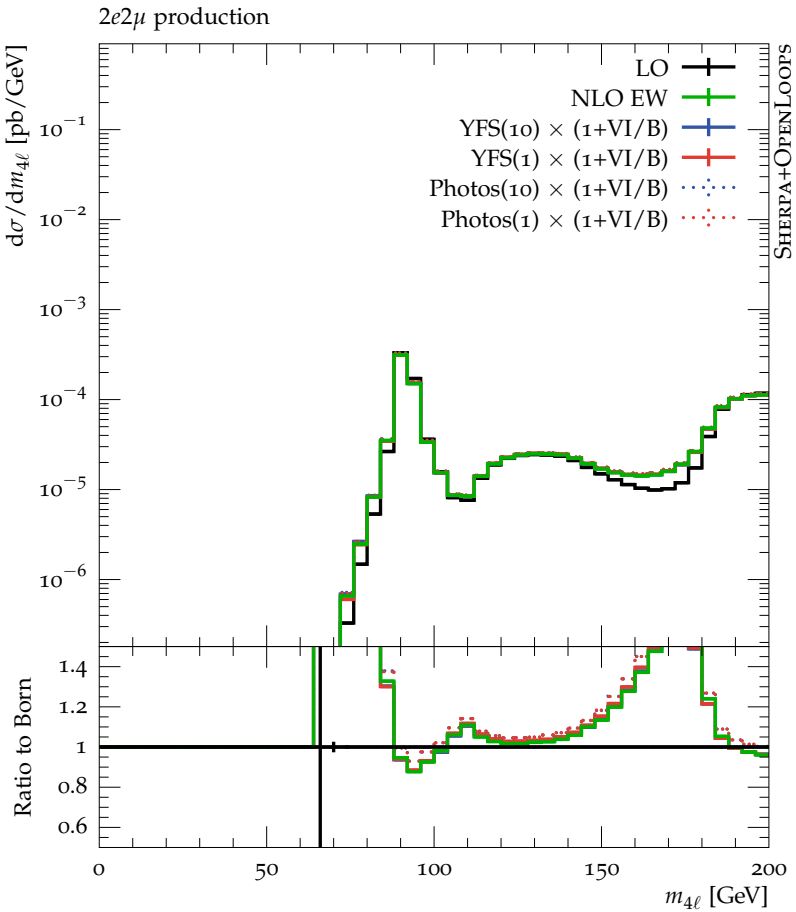
QED FSR in vector boson pair production – 4μ

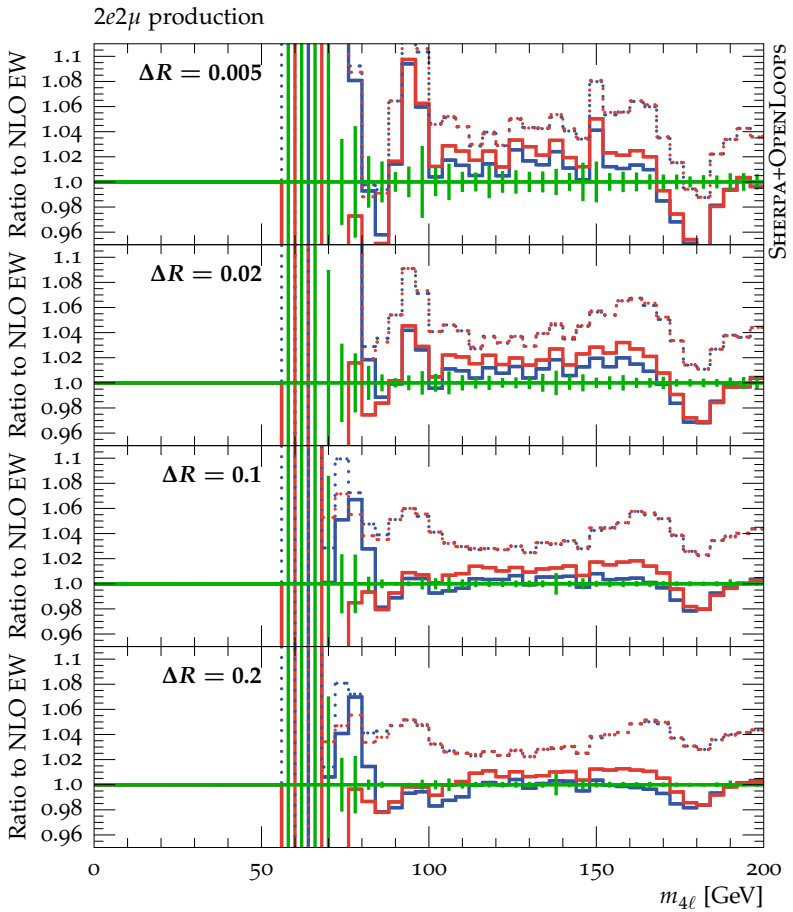




- large dressing cone size dependence
- low $\Delta\phi$ again receives large corrections at $\mathcal{O}(\alpha^2)$

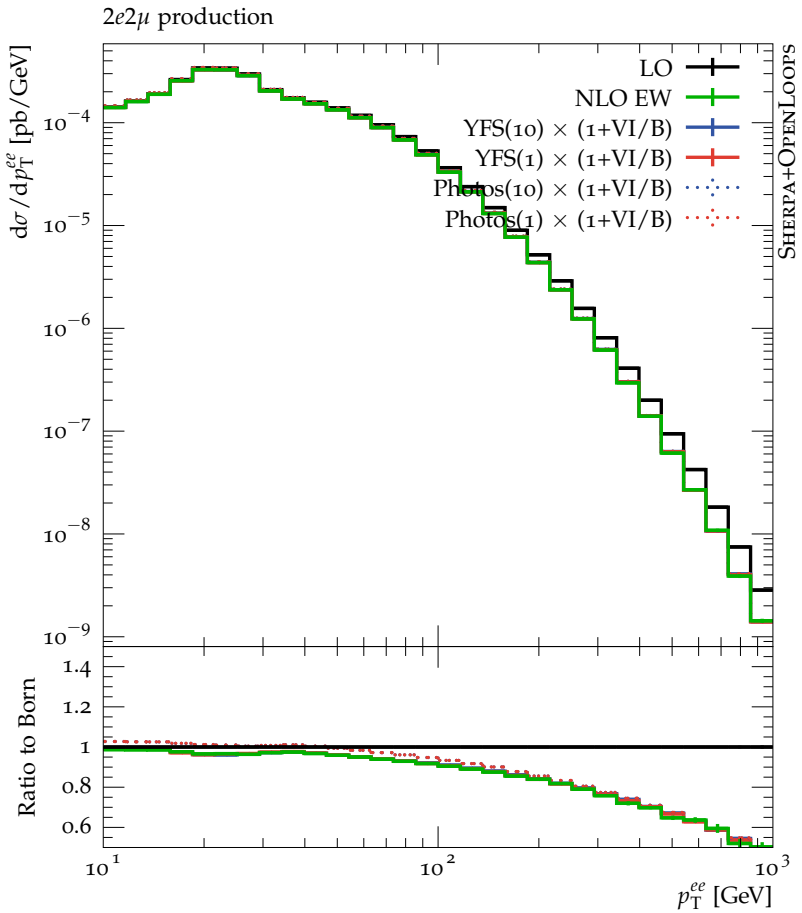
QED FSR in vector boson pair production – $2e2\mu$

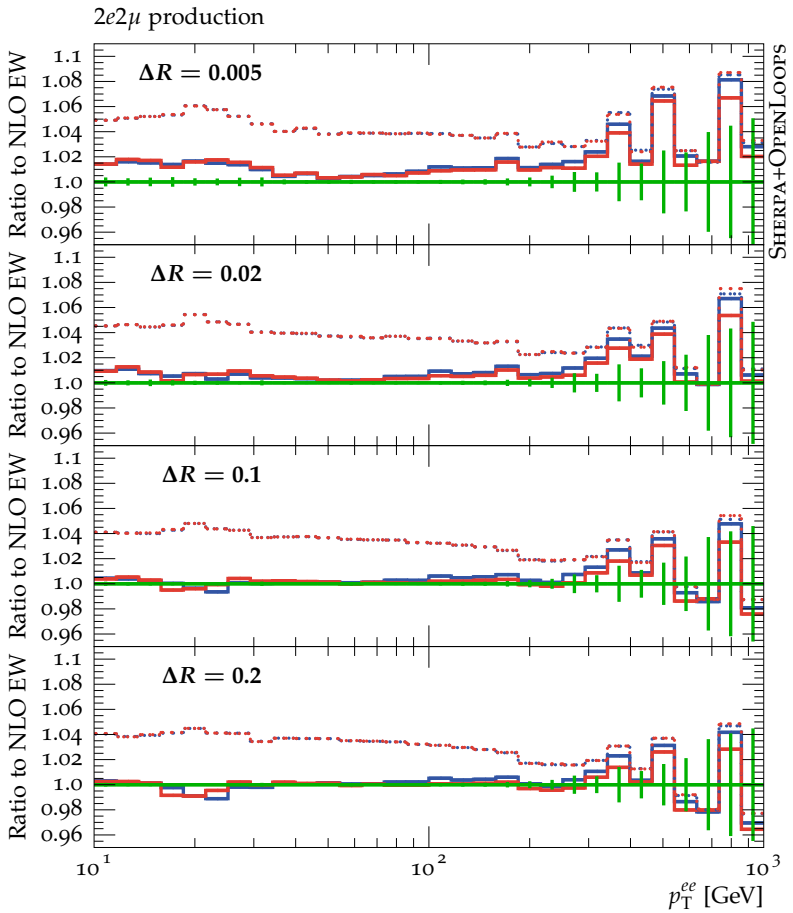




- using identical interface as before
- large difference to PHOTOS observed for all dressing cone sizes

QED FSR in vector boson pair production – $2e2\mu$





- using identical interface as before
- large difference to PHOTOS observed for all dressing cone sizes

Conclusions

- a detailed study of the theory dependence of the experimental data for various lepton definitions needed, most importantly measurements with Born lepton definitions
- initial study finds dependence on the resummation formalism on the order of $\sim 0.5\%$ for some inclusive observables
- more extreme phase space regions show larger dependence
- dependence on resonance identification depends on details of the resummation algorithms, but can be substantial
  $\rightarrow$ larger Δ_{thresh} supported by exact NLO EW

Thank you!

Backup