Flavour-aware lepton dressing algorithms in the presence of photon splittings

Lois Flower

Institute for Particle Physics Phenomenology
Durham University

lois.flower@durham.ac.uk

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Introduction

- We are in an era of precision phenomenology in experiment and in theory
- Object definitions that are convenient both theoretically and experimentally are crucial
- Traditional cone-dressed leptons with photons are convenient until photons are further resolved

YFS and photon splittings

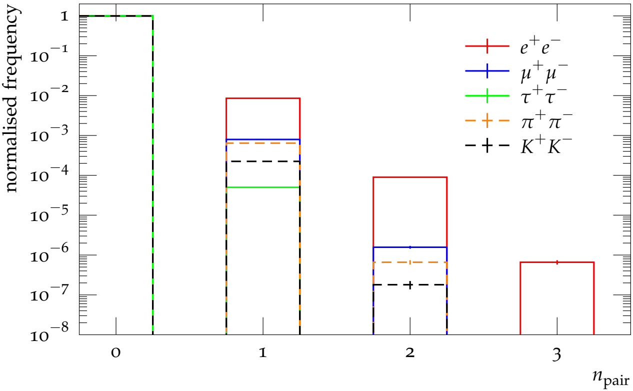
- Photons are usually produced as QED corrections to a process
- If these photons are further resolved, we should reevaluate lepton dressing procedures
- Here we use the YFS soft-photon resummation as implemented in SHERPA for photon production

Yennie, Frautschi, Suura '61

Krauss, Schönherr '08

- We implemented a photon splitting algorithm which allows $\gamma \to \mathrm{f}\bar{\mathrm{f}}$ to occur, where $\mathrm{f} = e, \mu, \tau, \pi, K$

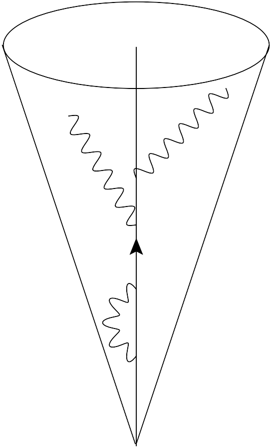
Secondary flavour distribution for $Z \to e^+e^-$



Lepton definitions

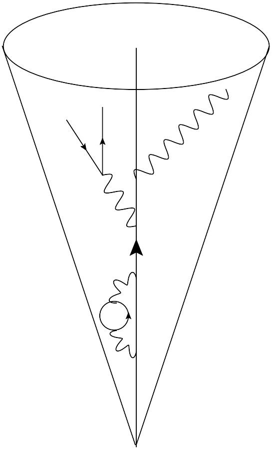
- Massive bare leptons are IR safe but experimentally difficult for electrons
- Electromagnetic calorimeter measures electrons and photons very similarly, though a magnetic field decouples their trajectories
- Usual practice: define a cone around a primary lepton, absorb all photons within its radius
- We will show this is very sensitive to higher-order corrections, especially $\gamma \to e^+e^-$ which gives the largest mass enhancements

Lepton definitions cont'd



- For massless leptons, cone dressing with only photons is problematic
- Because we exclude real $\ell^+\ell^-$, there is nothing to cancel the virtual collinear singularity
- For massive leptons, there are contributions $\sim \log(m_\ell)$

Lepton definitions cont'd



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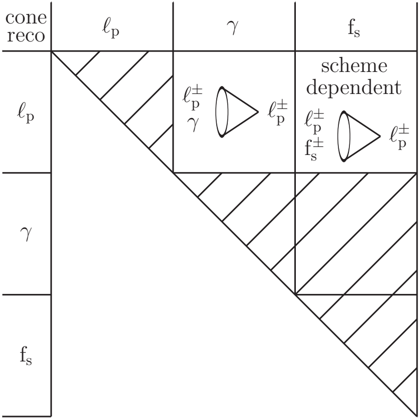
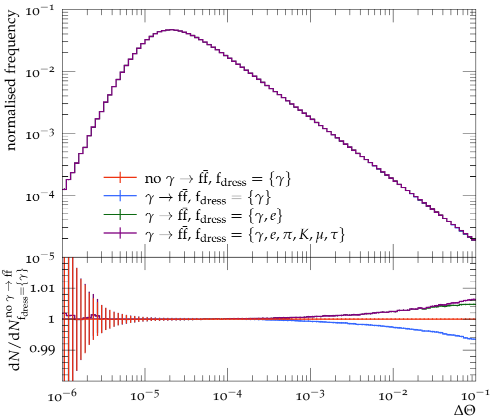
Lepton dressing II



We consider the following schemes:

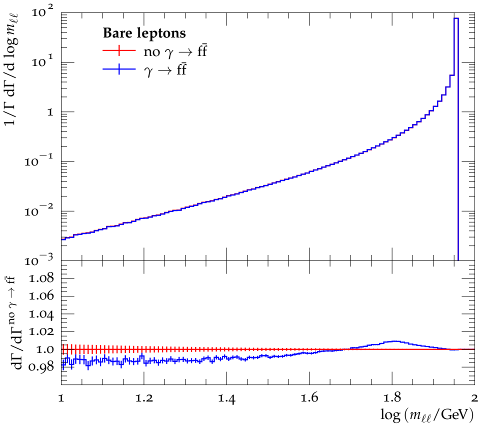
- $f_{dress} = \{\gamma\}$
- $f_{dress} = \{\gamma, e\}$
- $f_{dress} = \{\gamma, e, \pi, K\}$
- $f_{dress} = \{\gamma, e, \pi, K, \mu, \tau\}$

Dressed lepton structure

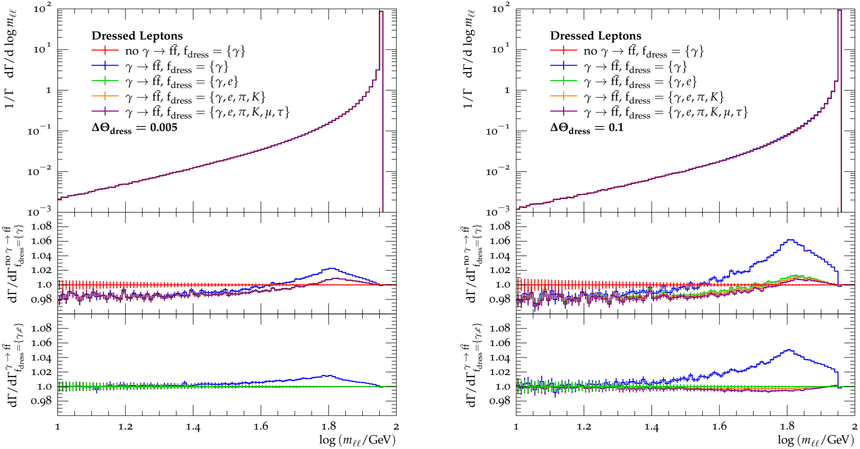


- On-shell $Z \to e^+e^-$
- For IR safety, $E_\gamma > 0.1$MeV
- At small $\Delta\Theta$, no difference in multiplicity
- At larger $\Delta\Theta$, more inclusive f_{dress} recoups loss of DL constituents due to photon splitting
- Including electrons as well as photons already reincorporates most constituents

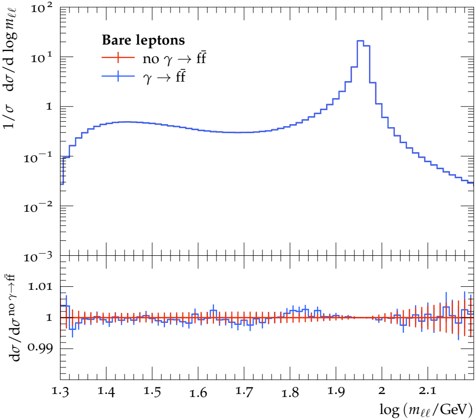
Dilepton invariant mass for on-shell $Z \to e^+e^-$



Dilepton invariant mass for on-shell $Z \to e^+e^-$



Dilepton invariant mass for $pp \to e^+e^-$ (preliminary)



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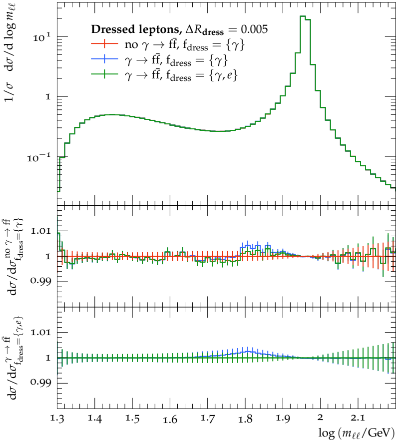

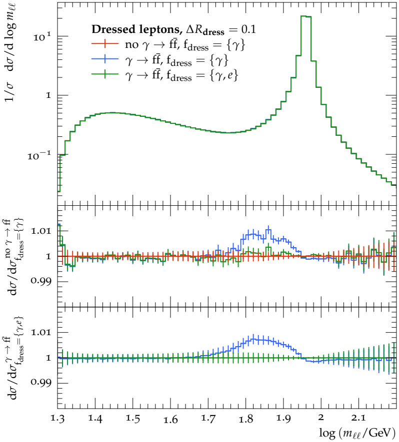

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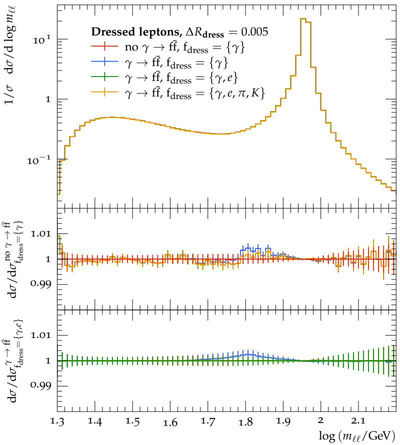
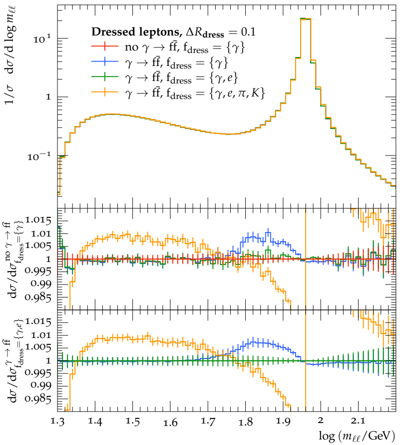
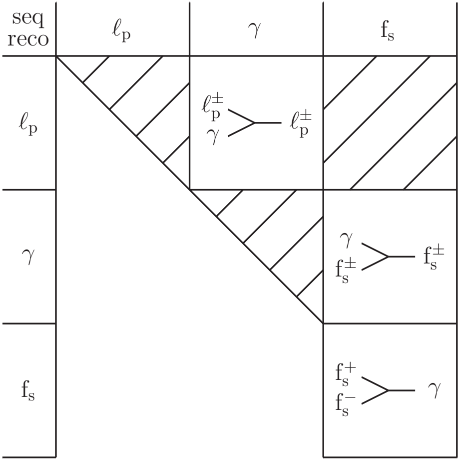




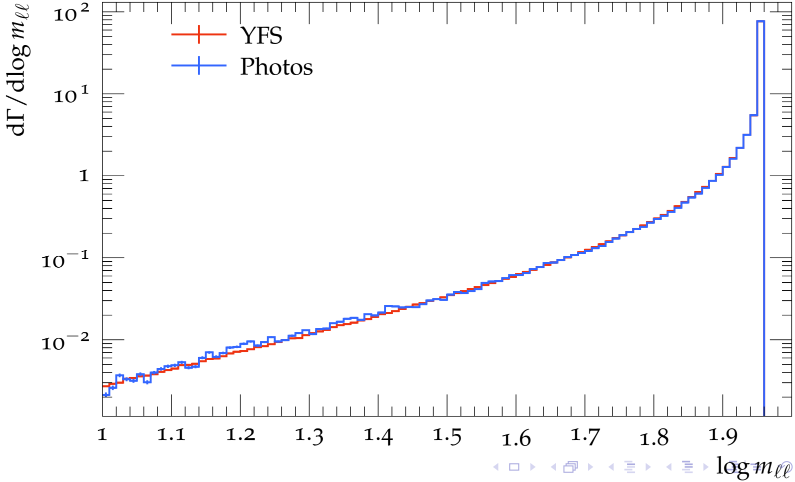
Conclusions and outlook

- We introduced a novel set of lepton dressing strategies which can be used theoretically in conjunction with QED corrections
- Results were presented for on-shell Z decay to leptons and Drell-Yan lepton production
- Flavour-aware dressing can be used when massless leptons are produced by photon splitting to ensure cancellation of collinear singularities
- What do we consider a reasonable definition of a dressed lepton?

Backup: Sequential recombination dressing



Backup: Comparison with Photos: $Z \to e^+e^-$



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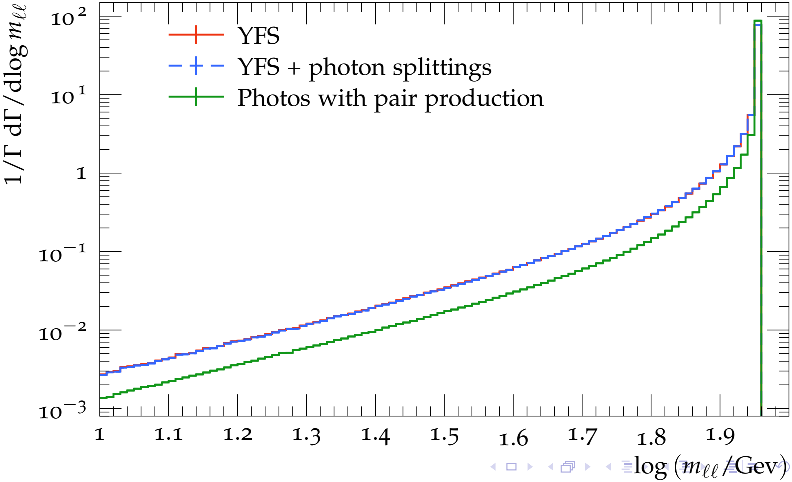

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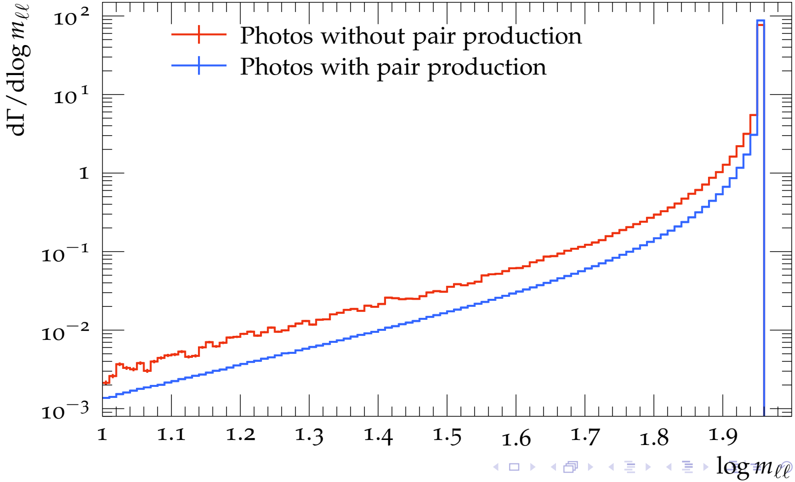
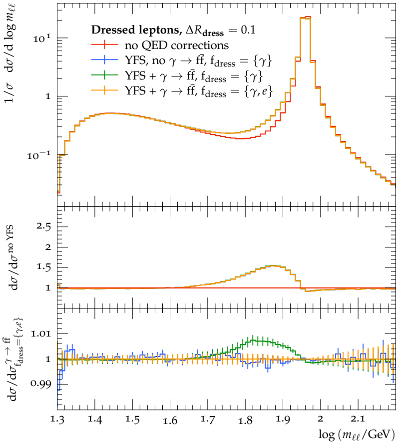
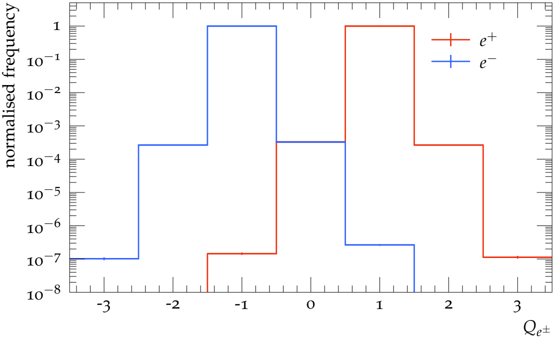


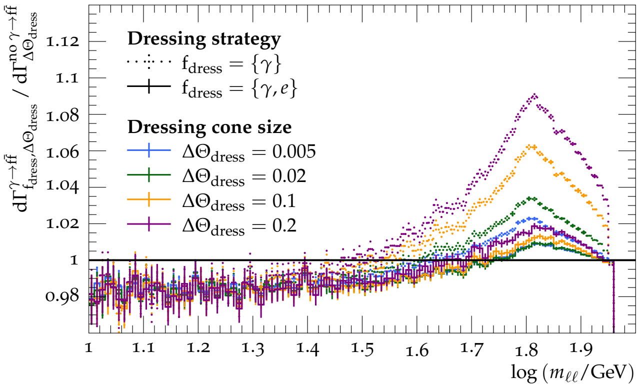
Backup: Dilepton invariant mass for $pp \to e^+e^-$



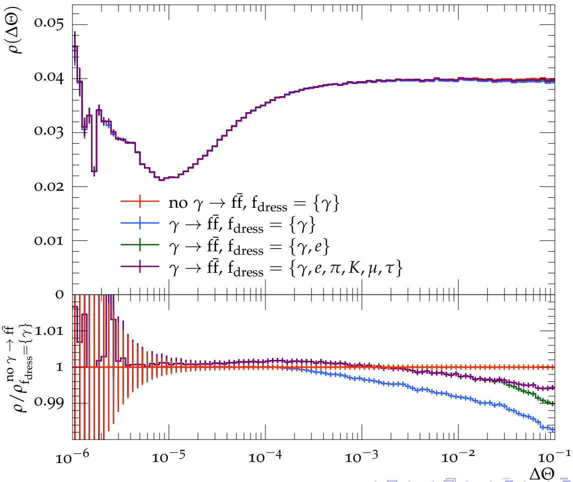
Backup: Dressed lepton charge



Backup: Dressing cone size dependence



Backup: Energy density of a dressed lepton



Backup: The YFS soft-photon resummation

$$\mathrm{d}\Gamma^{\mathsf{YFS}} = \mathrm{d}\Gamma_0 \cdot e^{\alpha Y(\omega_{\mathsf{cut}})} \cdot \sum_{n_\gamma=0}^{\infty} \frac{1}{n_\gamma!} \left[\prod_{i=1}^{n_\gamma} \mathrm{d}\Phi_{k_i} \cdot \alpha\, \tilde{S}(k_i)\, \Theta(k_i^0 - \omega_{\mathsf{cut}}) \cdot \mathcal{C} \right]$$

- $Y(\omega_{\mathrm{cut}})$ is the YFS form factor containing soft-photon logarithms
- $\tilde{S}$ is the eikonal (soft emission effects)
- $\mathcal{C}$ corrects for hard-emission effects up to a given order
- YFS contains no description of charged particle production, $\gamma \to \mathrm{f\bar{f}}$

Backup: Photon splitting algorithm

- One-step parton shower - subsequent emissions factorise when ordered in a scale variable t
- Input: primary charged particles and coherently emitted soft photons
- We reconstruct the scale t_{start} (GeV^2) from the input
- Then calculate probabilities for each photon to split and let all possible splittings compete

Backup: Splitting functions

$$S_{s_{\widetilde{\imath\jmath}}(\tilde{k})\to s_i\gamma_j(k)} = -\, Q^2_{\widetilde{\imath\jmath}\tilde{k}}\,\alpha\left[\frac{2}{1-z+zy} - \frac{\tilde{v}_{\widetilde{\imath\jmath},\tilde{k}}}{v_{ij,k}}\left(2+\frac{m_i^2}{p_ip_j}\right)\right]$$

$$S_{f_{\widetilde{\imath\jmath}}(\tilde{k})\to f_i\gamma_j(k)} = -\, Q^2_{\widetilde{\imath\jmath}\tilde{k}}\,\alpha\left[\frac{2}{1-z+zy} - \frac{\tilde{v}_{\widetilde{\imath\jmath},\tilde{k}}}{v_{ij,k}}\left(1+z+\frac{m_i^2}{p_ip_j}\right)\right]$$

$$S_{\gamma_{\widetilde{\imath\jmath}}(\tilde{k})\to s_i\bar{s}_j(k)} = S_{\gamma_{\widetilde{\imath\jmath}}(\tilde{k})\to f_i\bar{f}_j(k)} = -\,Q^2_{\widetilde{\imath\jmath}\tilde{k}}\,\alpha\left[1-2z(1-z)-z_+z_-\right]$$

Catani et al. '02, Dittmaier et al. '08, Schumann, Krauss '08

Backup: Leptonic W decay

- The W is charged and the neutrino is not, so instead of an FF dipole we have an FI dipole $W - \ell$
- Large W mass suppresses photon emissions, so neglect it as an emitter
- Modify kinematic variables and splitting functions – we keep the W eikonal term

Basso et al. '16