TECHNISCHE UNIVERSITÄT DRESDEN
Fakultät Physik Institut für Kern- und Teilchenphysik

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft DFG

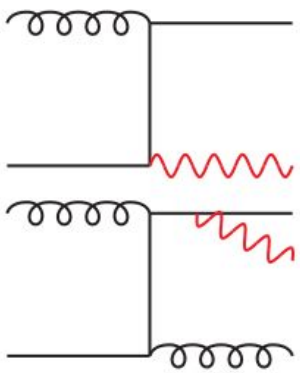
Event generators for prompt photon production

Frank Siegert

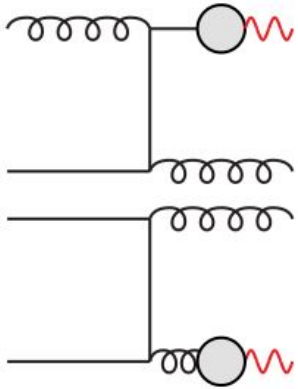
Photon Physics Workshop, June 2019, Frascati

Photon production at fixed order

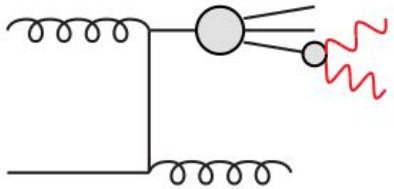
Direct Photons



Fragmentation



(Non-prompt)

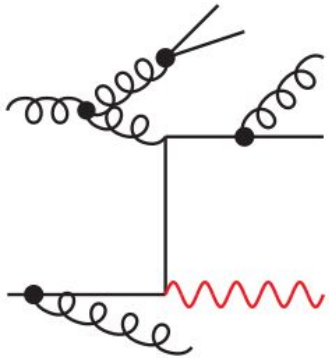


- Separation between direct & fragmentation depends on order of calculation
- Equivalents in parton shower programs?
  - parton shower goes beyond fixed-order → no exact identification of these

But let's try ...

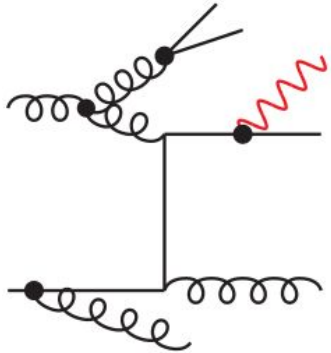
Photon production in traditional parton showers

Direct Photons



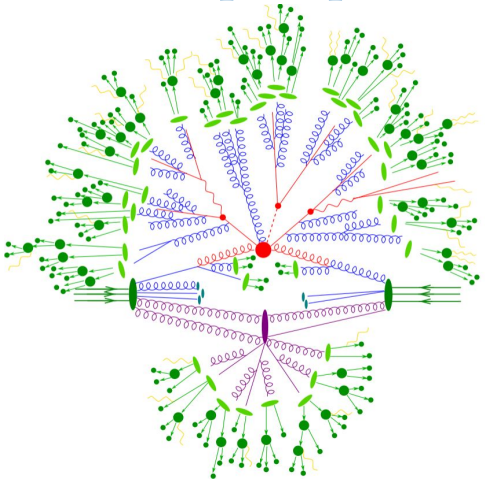
- LO matrix elements for **photon** production
- Dressed with **softer QCD** shower emissions

Fragmentation



- LO matrix elements for **jet** production
- Dressed with **softer QED** shower emissions

Non-prompt



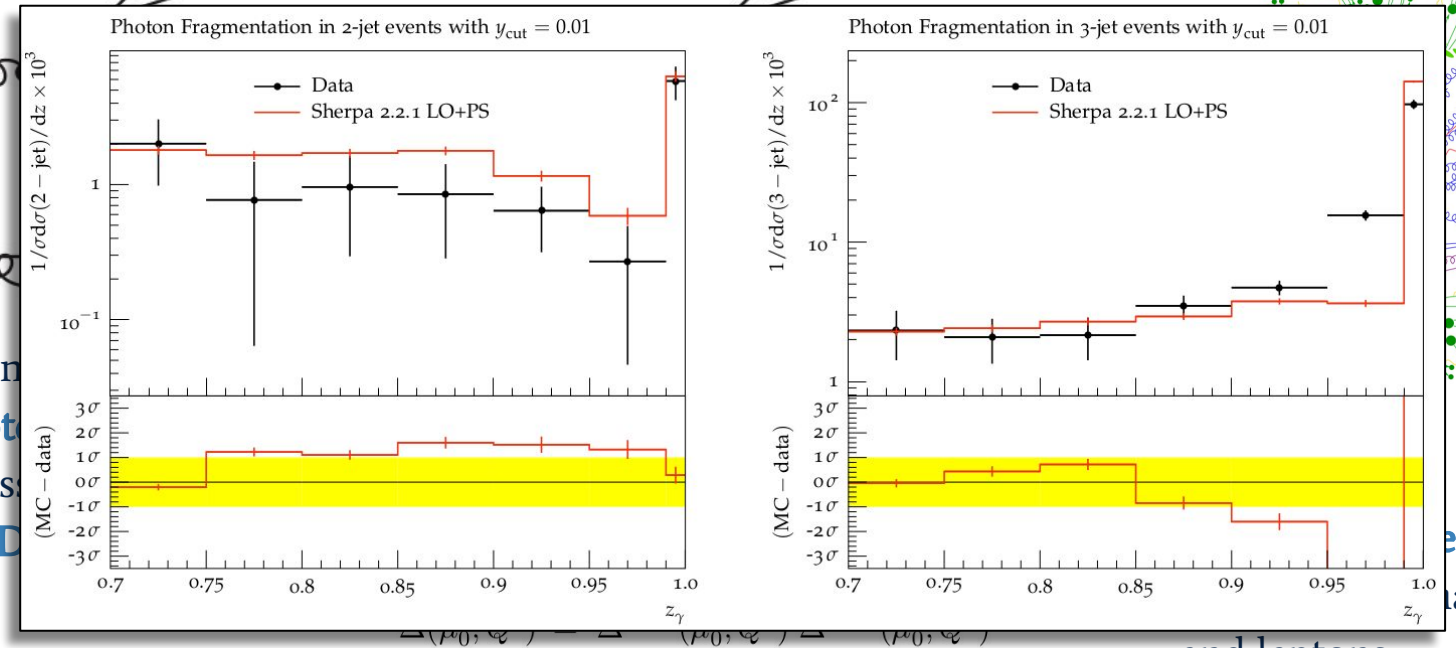
- Hadron decays ($\pi^0 \to \gamma\gamma$)
- **QED final state radiation** from charged hadrons and leptons

$$\Delta(\mu_0^2, Q^2) = \Delta^{\mathrm{QCD}}(\mu_0^2, Q^2)\, \Delta^{\mathrm{QED}}(\mu_0^2, Q^2)$$

$$\Delta^{\mathrm{QED}}(\mu_0^2, Q^2) = \exp\left\{ -\int_{\mu_0^2}^{Q^2} \frac{\mathrm{d}t}{t} \int \mathrm{d}z \sum_i \frac{1}{2} \mathcal{K}_i^{\mathrm{QED}}(z,t) \right\}$$

Photon production in traditional parton showers

Direct Photons **Fragmentation** **Non-prompt**



- LO n
  phot
- Dres
  QCD

($\pi^0 \to \gamma\gamma$)
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and leptons

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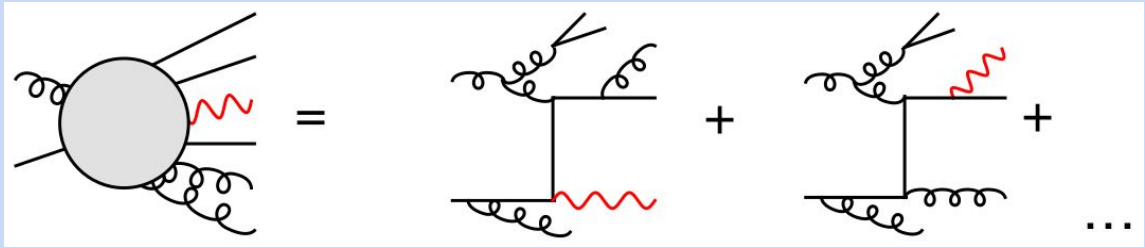
QCD multi-jet merging

Direct Photons

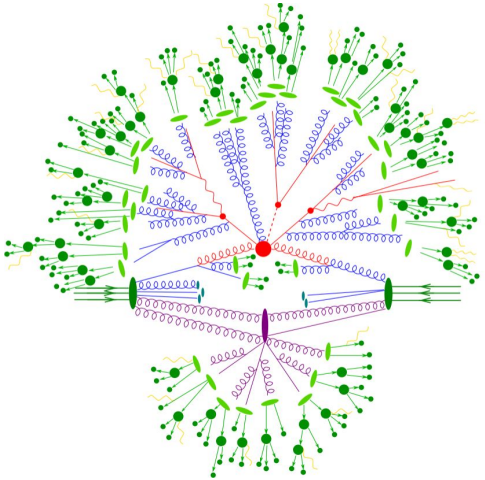
Fragmentation

Non-prompt

- QCD multi-jet merging:
  - Hard QCD emissions from higher-order MEs
  - Soft QCD emissions from shower
- **Relevant for photon production:**
  Multi-jet matrix elements contain direct and fragmentation-like configurations!



- Introduces dependence on photon isolation



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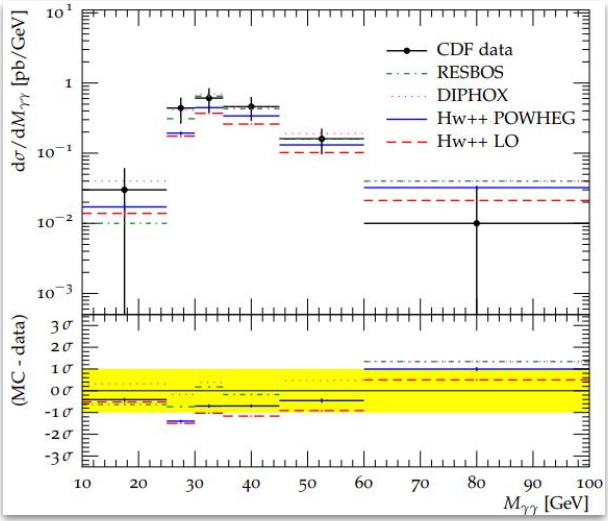
NLO corrections

- NLO+PS matching methods (e.g. POWHEG, MC@NLO):
  Inclusion of NLO matrix elements into parton shower predictions
  - inclusive observables with better normalisation and lower scale unc's
  - first emission LO correct

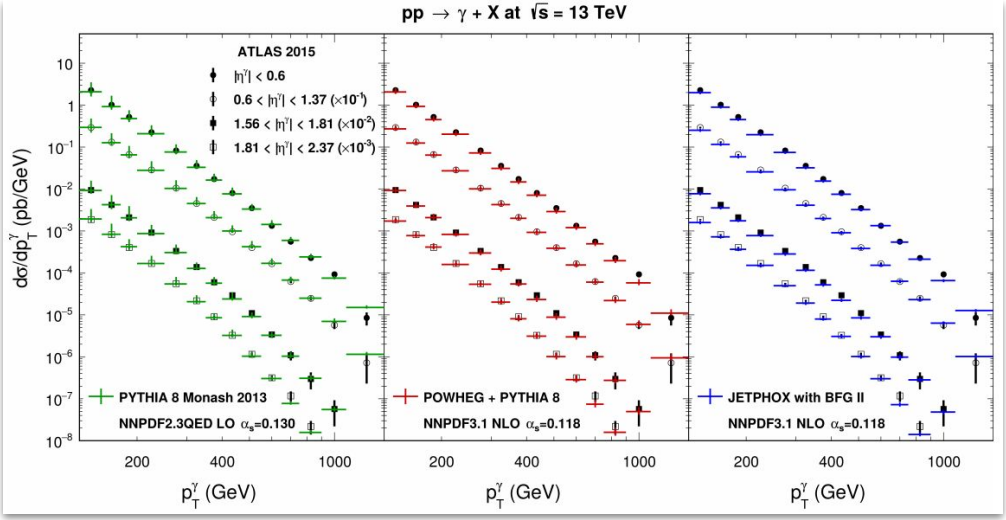
γγ in Herwig++

[D'Errico, Richardson 1106.3939]



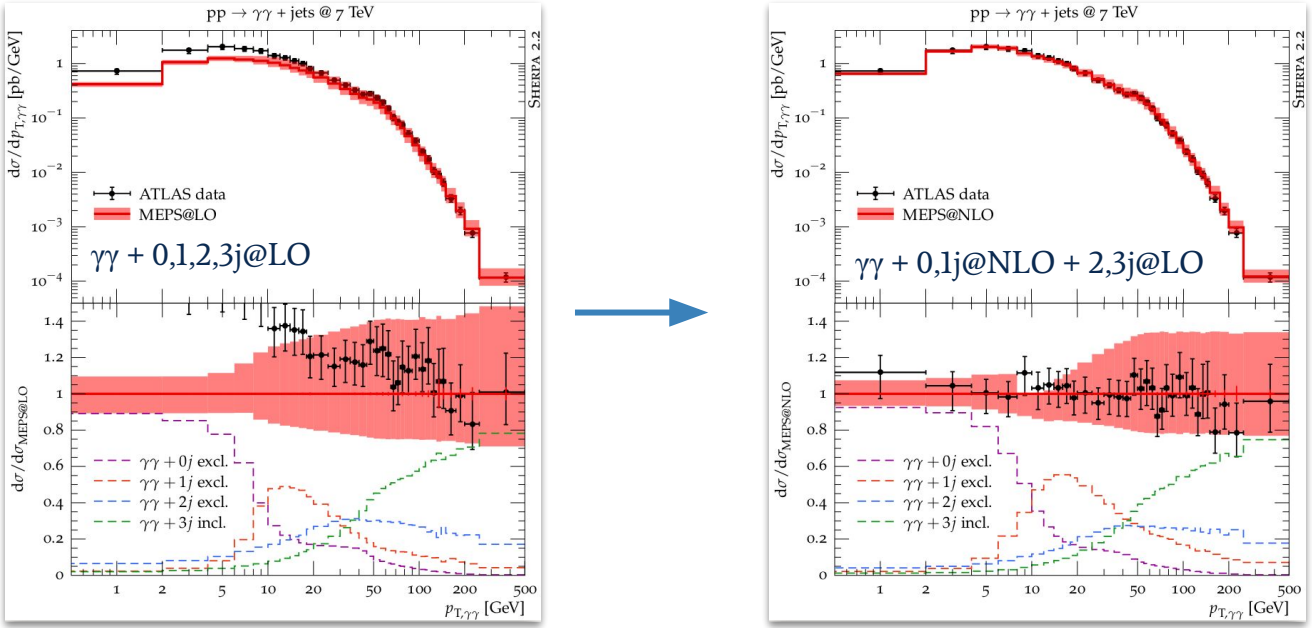
γ+jet in PowhegBox

[Klasen, Klein-Bösing, Poppenborg 1709.04154]



MEPS@NLO: Combining multi-leg and NLO

- MEPS@NLO procedure in Sherpa well-established for other processes
  - LO+PS → NLO+PS for each jet multiplicity in multi-leg merging
  - For highest multiplicities not feasible → LO+PS retained
- Applied e.g. in γγ + 0, 1 jets @ NLO + 2, 3 jets @ LO with Sherpa [FS 1611.07226]



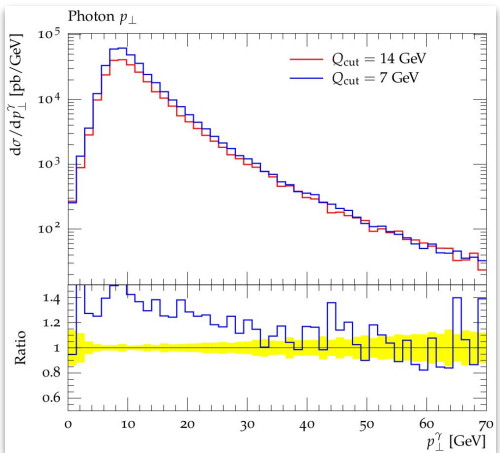
Two practical problems in QCD MEPS@(N)LO

Despite success: 2 problems of MEPS@(N)LO compared to QCDxQED shower

1. Fragmentation component incomplete

[FS 1611.07226]

- factorisation scale (e.g. $\mu_F = p_\perp(\gamma)$) can become lower than merging cut
  $\Rightarrow$ shower (and thus factorised xs) does not fill phase space up to merging cut Q_{cut}
  $\Rightarrow$ misses part of fragmentation component
- in many processes this is not a problem due to large μ_F
- here even relevant for higher $p_\perp(\gamma)$ generated from further emissions



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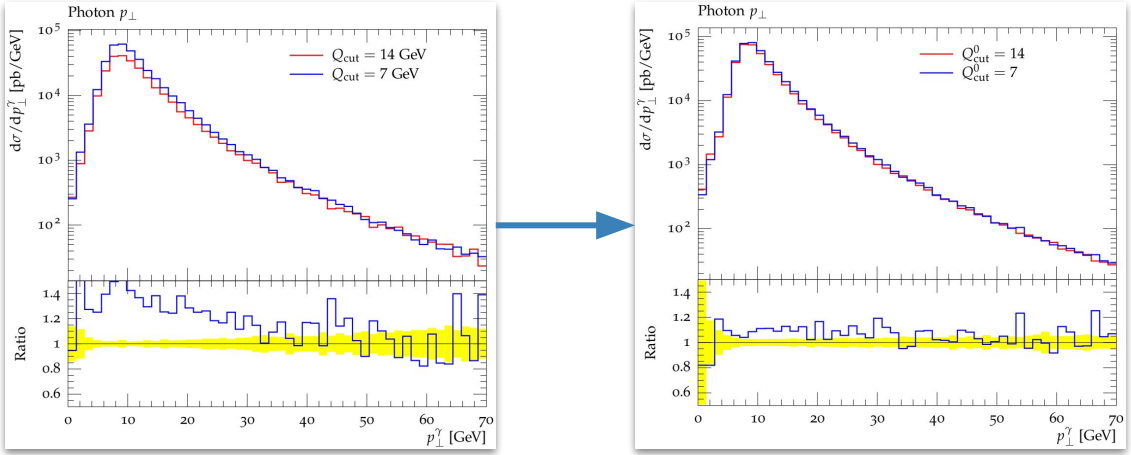
Solution:

- Dynamical merging cut

$$Q_{\text{cut}} = \left[\frac{1}{\bar{Q}^2_{\text{cut}}} + \frac{1}{S^2\,\mu_F^2} \right]^{-1/2}$$

- Similar to DIS situation
  [Carli, Gehrmann, Höche 0912.3715]



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2. **Photon isolation needed in multi-jet matrix elements**
   - Regularises collinear q-γ singularities
   - If isolation cut too loose: logs would need to be resummed, ME results unreliable

   → MC samples potentially not inclusive enough for expt needs!

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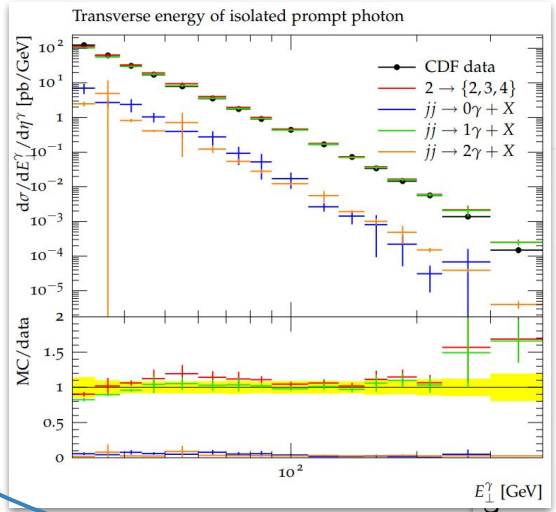

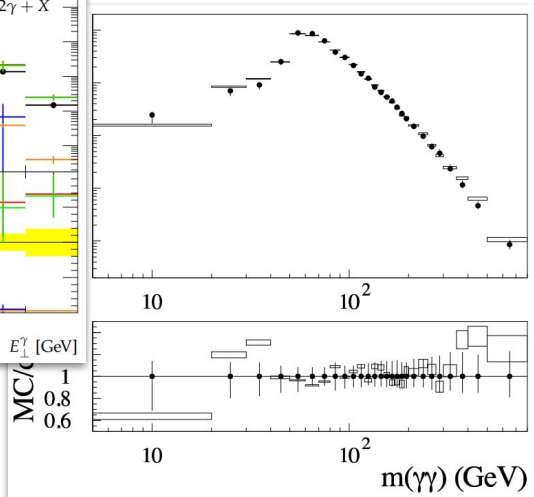

Solution:

- Combined QCDxQED merging
  [Höche, Schumann, FS 0912.3501] (Sherpa)
  [Odaka, Kurihara 1607.00204] (Gr@ppa)
- **Only available in LO so far :-(**

Conclusions

- **Event generation for prompt photon production important but difficult!**

Tasks for the future:

- Revisit combined QCDxQED multi-jet merging using MEPS@NLO
  - Would provide **full inclusivity** with respect to γ-isolation (see discussion later)
  - For complete solution this would need a **QED NLO+PS** implementation (so far exists **only for W/Z** production, not for γγ/γj/jj)
  - Maybe soon: **pragmatic solutions** to combine MEPS@LO for QED with MEPS@NLO for QCD?
  - also needs **practicability features** to generate "shower component" with high enough efficiency
    - » adapting ME+PS merging cut parameters to typical experimental criteria
    - » weighted/enhanced parton shower for q→qγ splittings
- **NNLO+PS** for γγ? (and γj??) (within NLO multi-jet merging???)