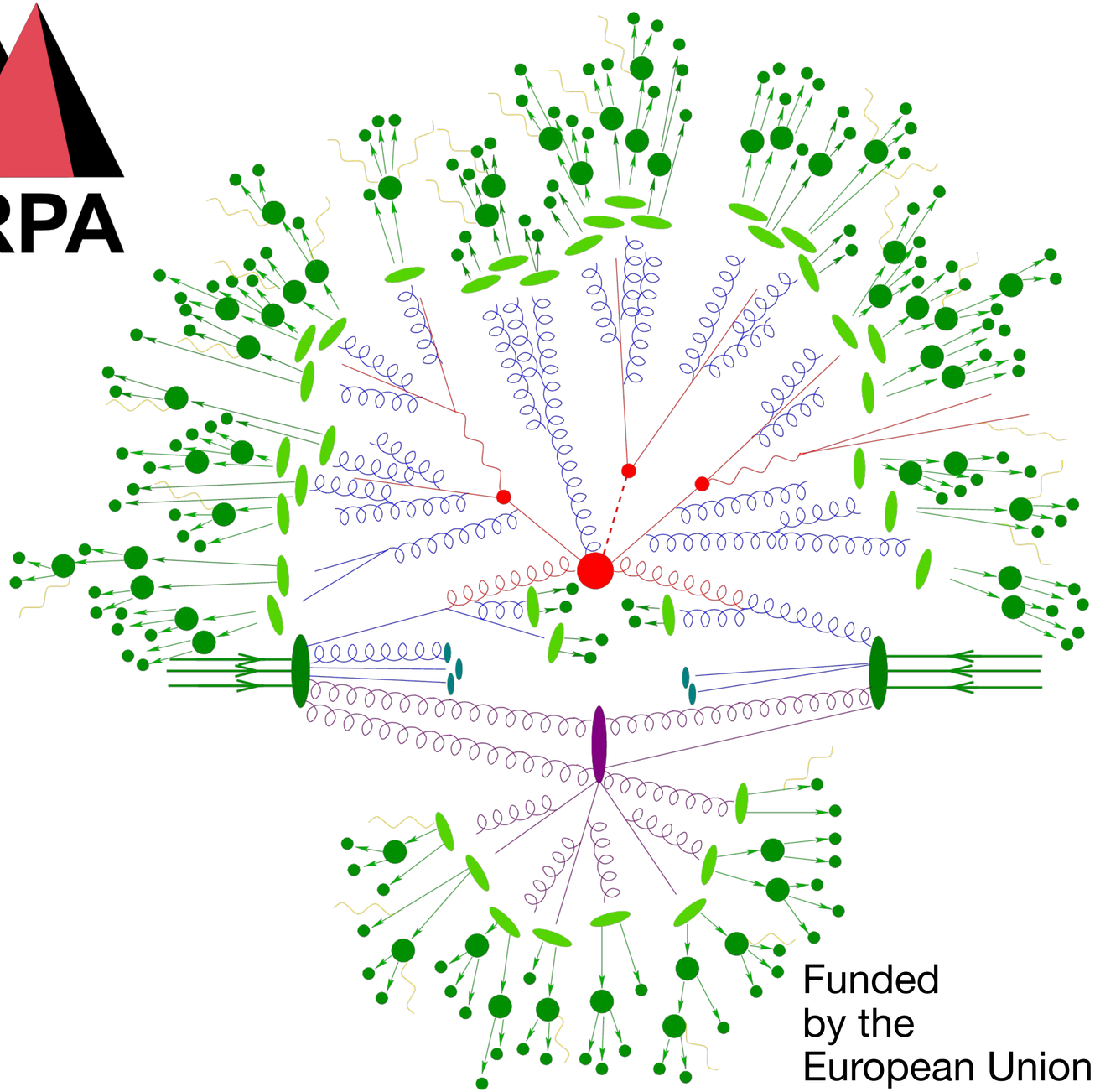
Incorporating QED effects in SHERPA parton showers for the EIC



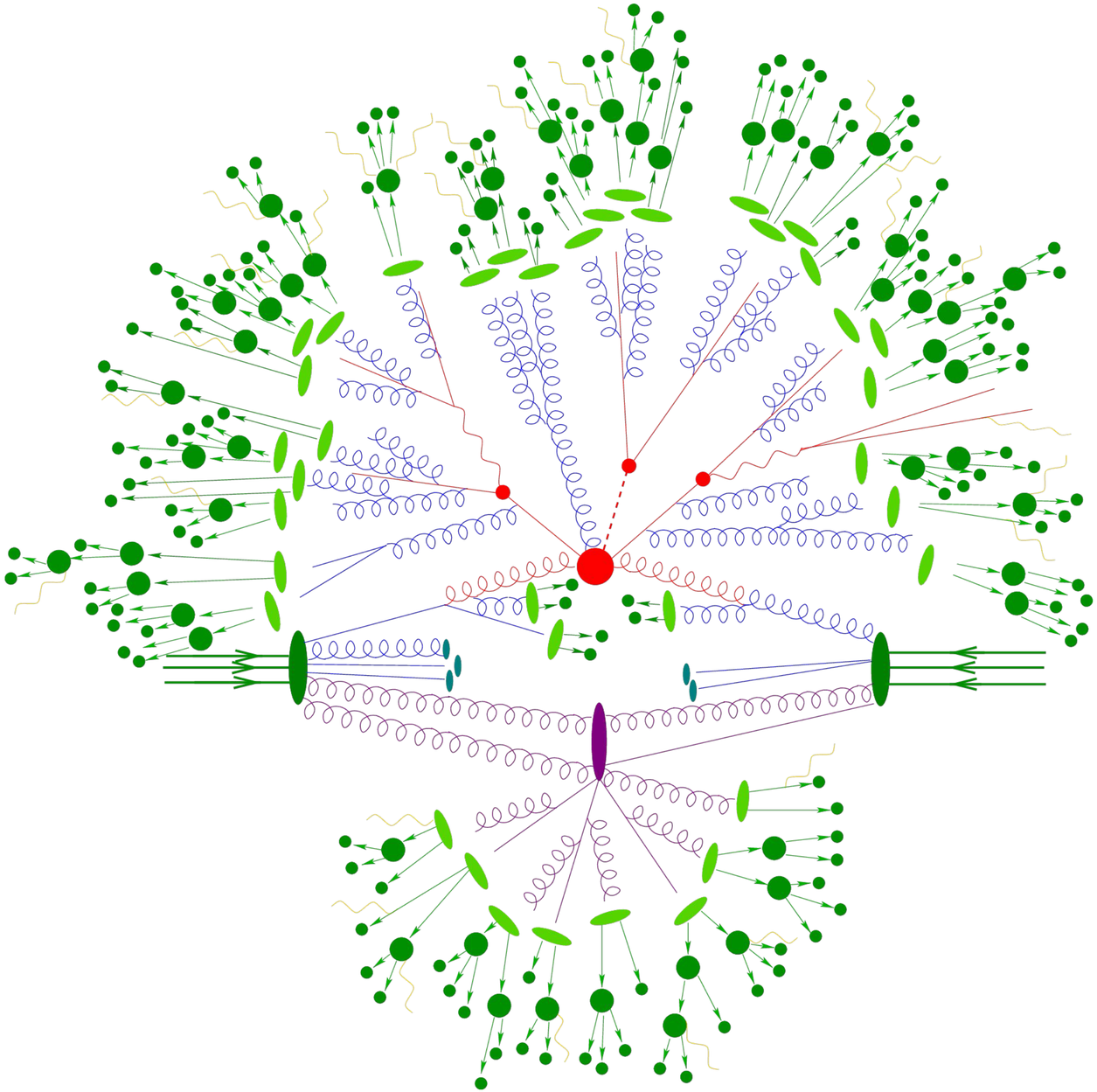
MC4EIC 2025

Daniel Reichelt

Funded by the European Union

Theorist view on collider events

- Event simulation factorised into
  - Hard Process
  - Parton Shower
  - PDF/Underlying event
  - Hadronisation
  - QED radiation
  - Hadron Decays



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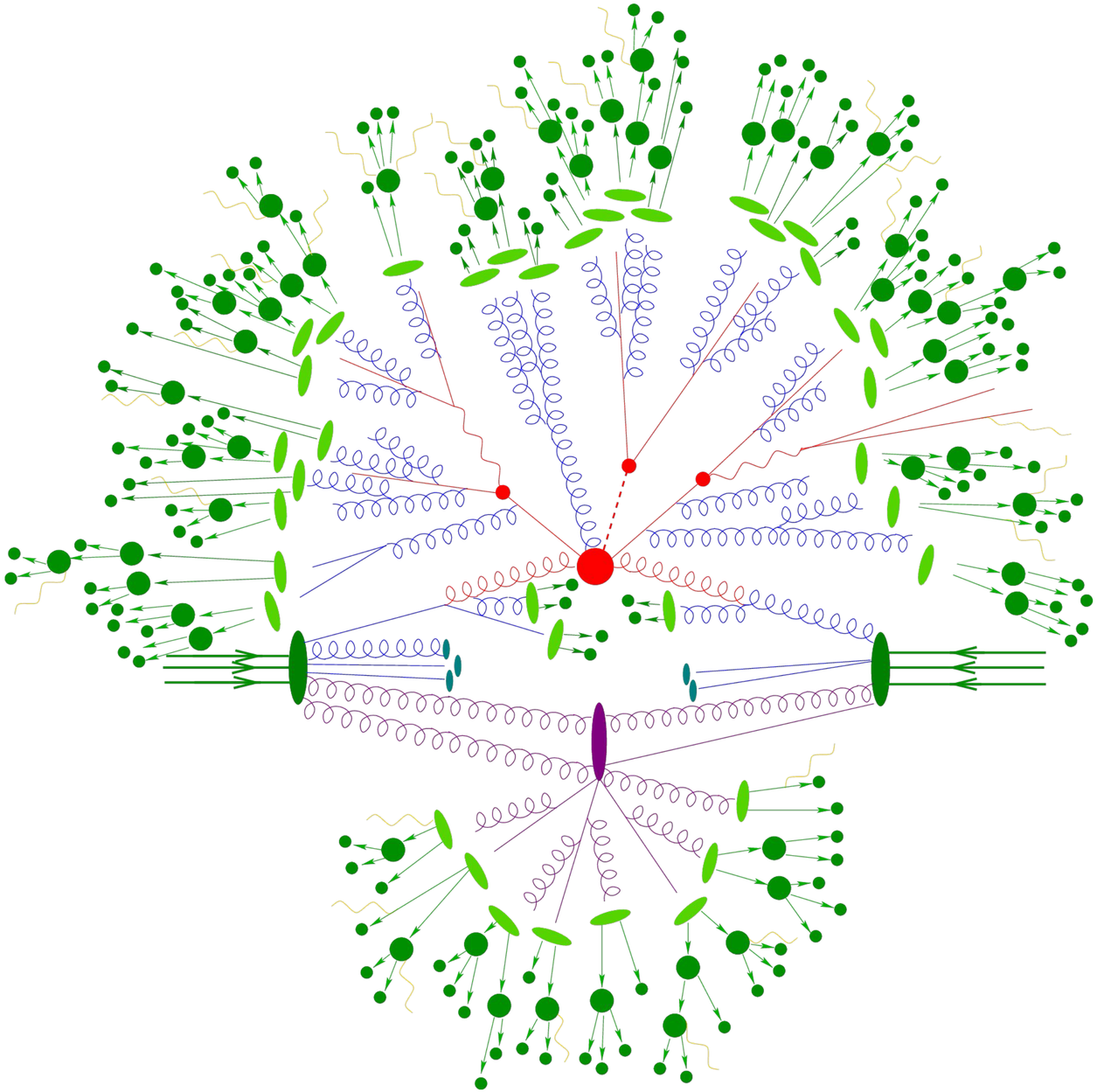
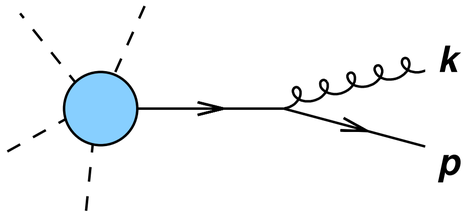


Parton shower approach principles

- we know how dominant corrections to higher orders behave:



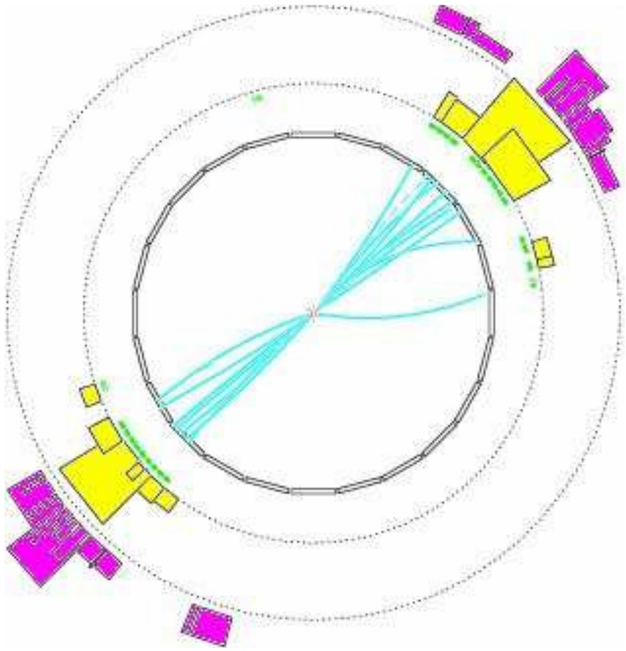
$$\simeq \quad \frac{2\alpha_s C_F}{\pi}\frac{dE}{E}\frac{d\theta}{\theta}$$

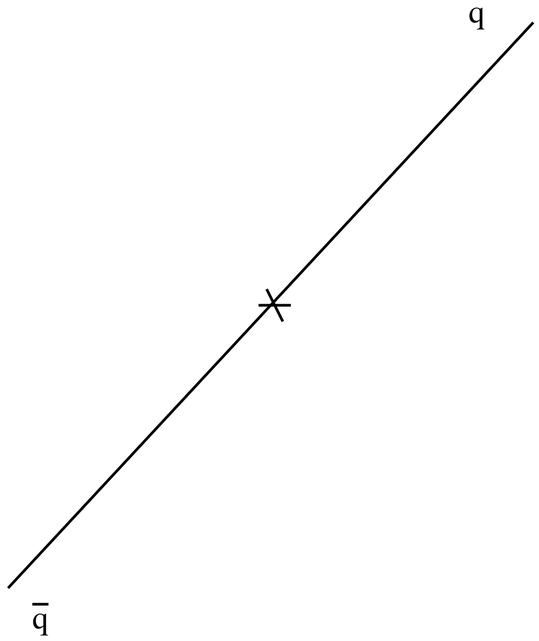
- picture: emission of additional gluons/photons from emitter, same divergence structure, only different colour factor

- repeats at all orders → we can iteratively generate emissions from the hard process + from subsequent emissions

Parton Shower Evolution

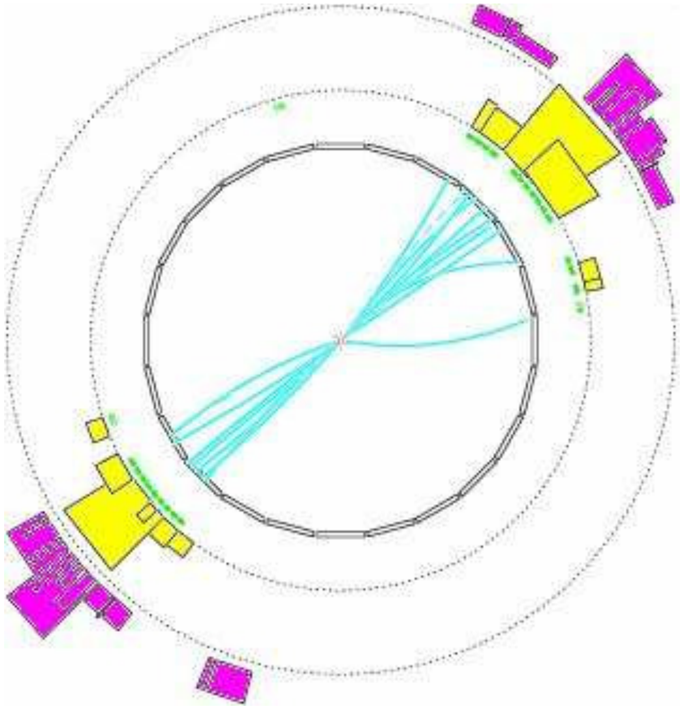
- Start from Born type event

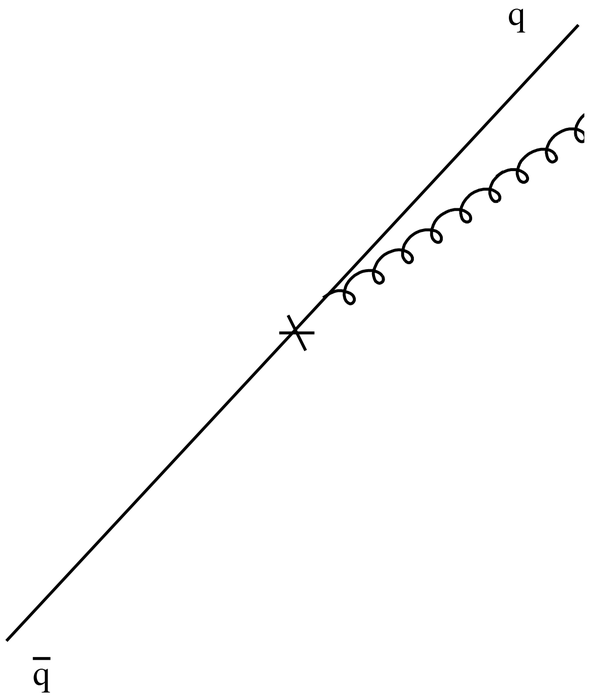




Parton Shower Evolution

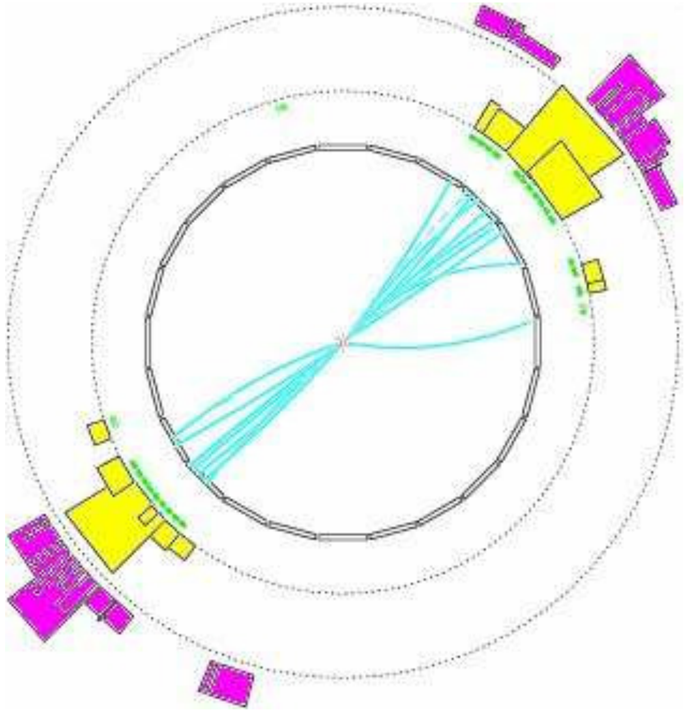
- Start from Born type event
- add radiation from hard particles according to universal IR limits

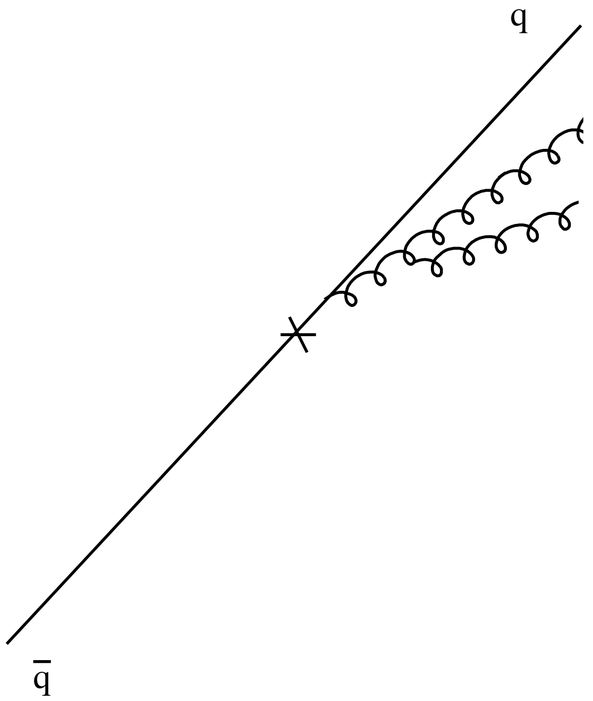




Parton Shower Evolution

- Start from Born type event
- add radiation from hard particles according to universal IR limits
- iterate to build up fully differential radiation pattern





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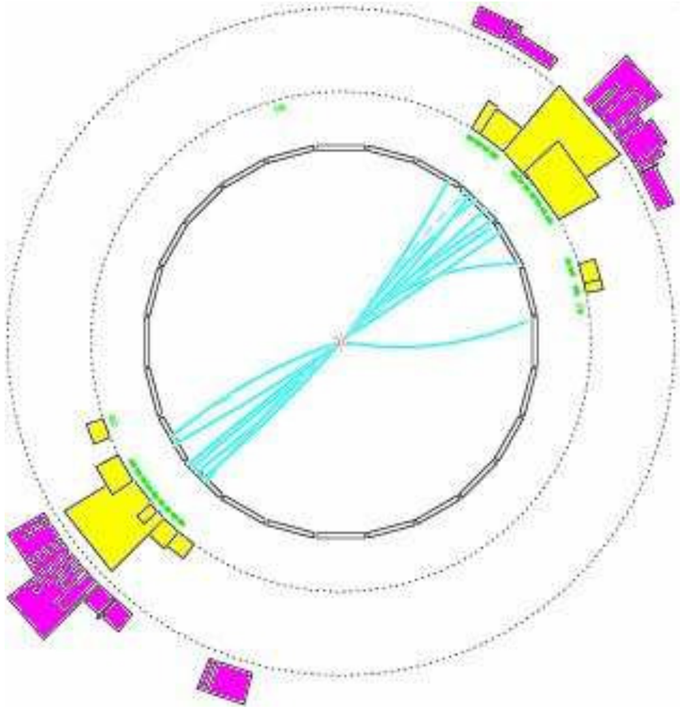

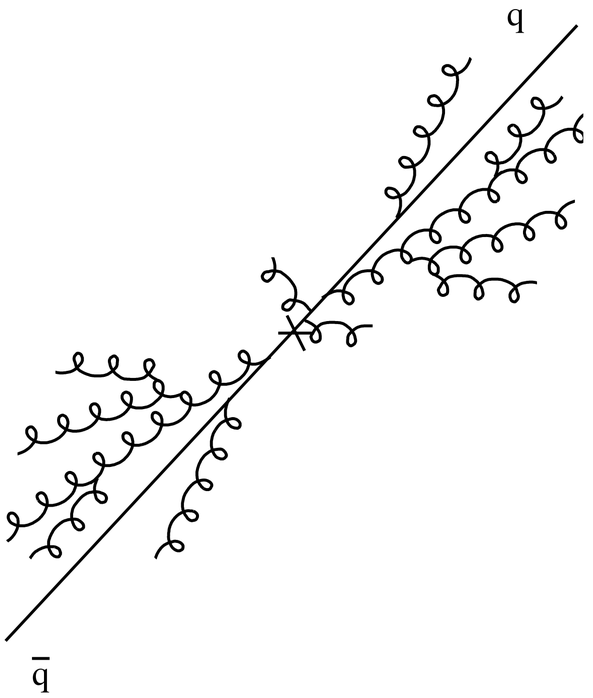

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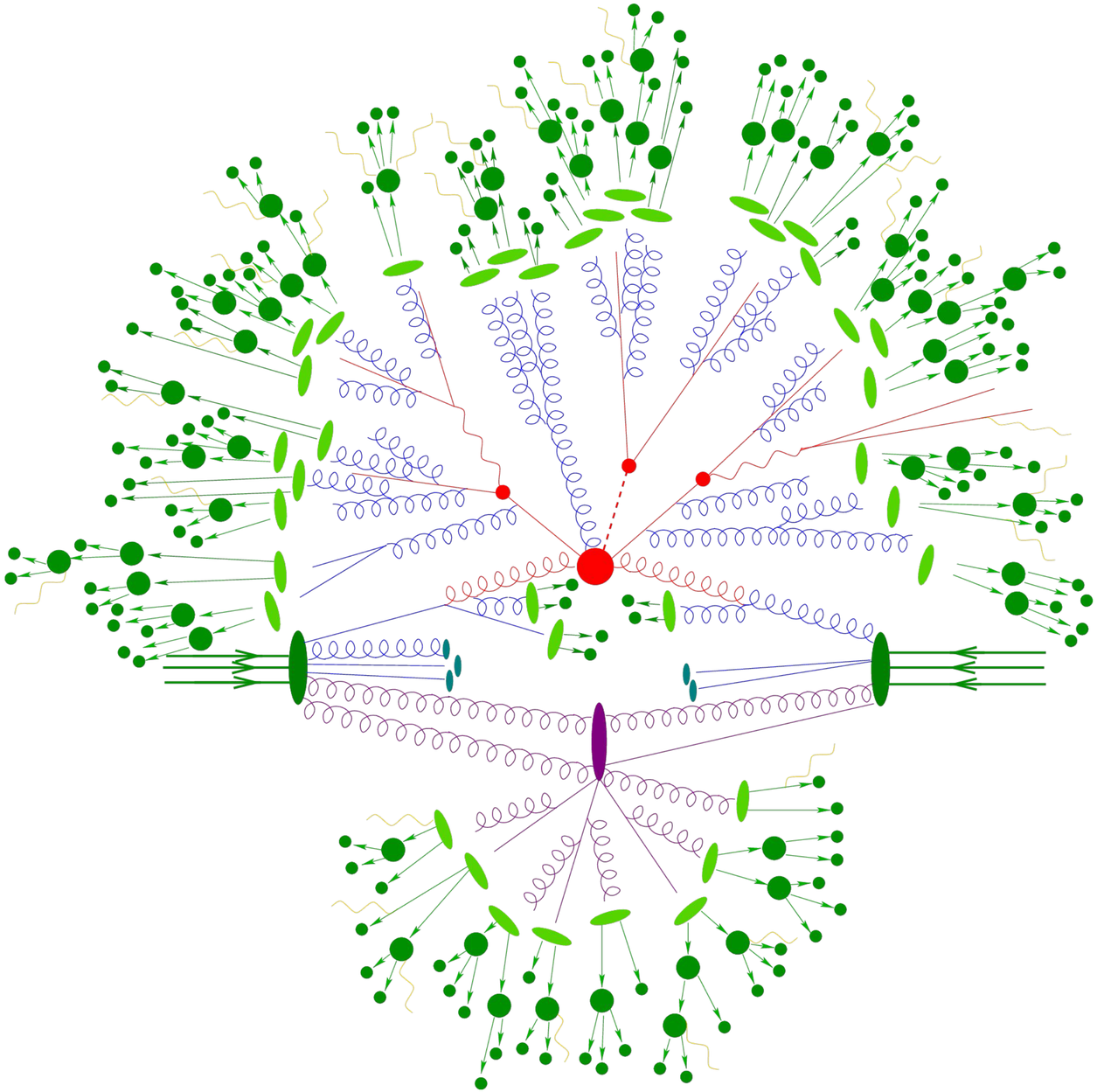

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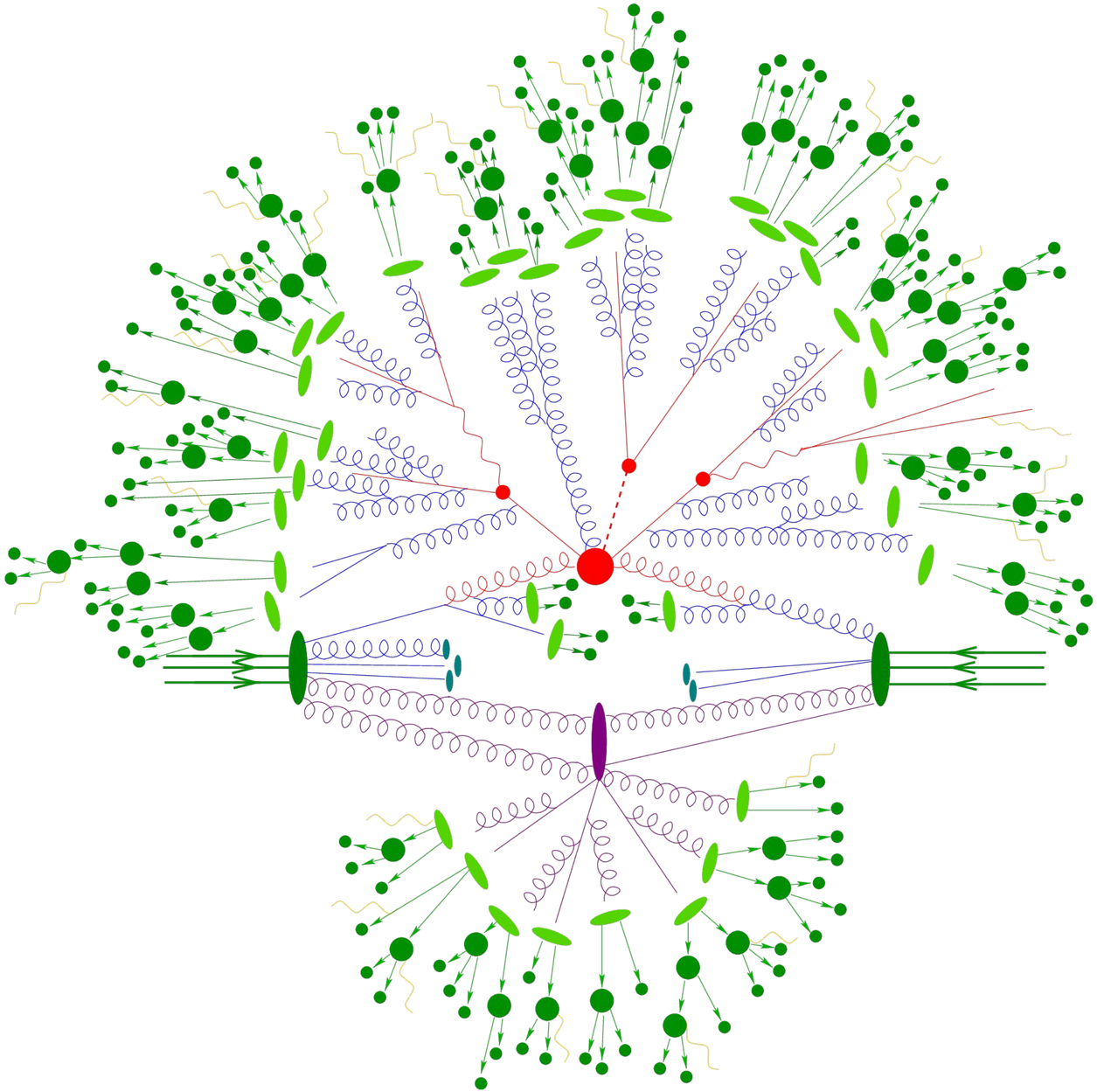
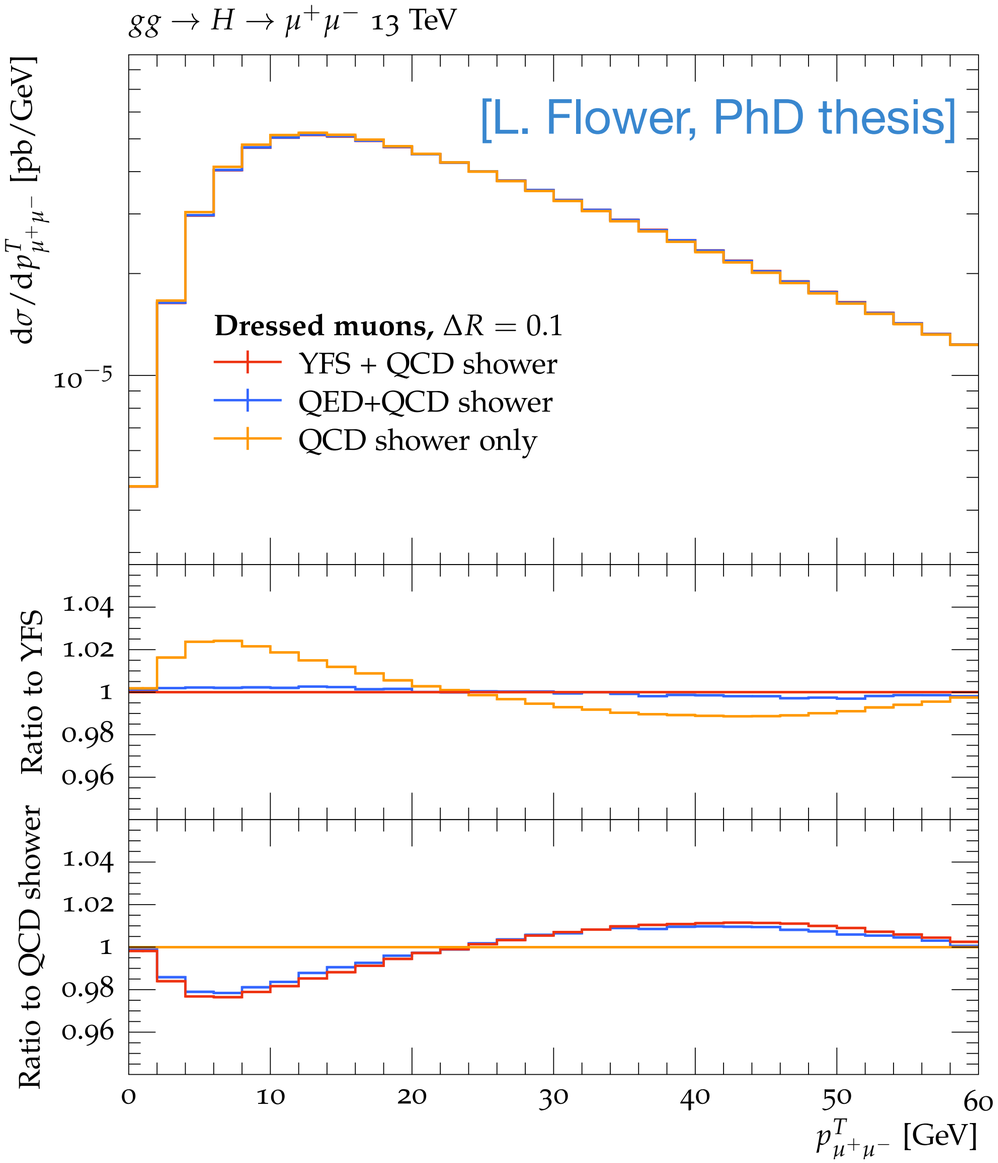


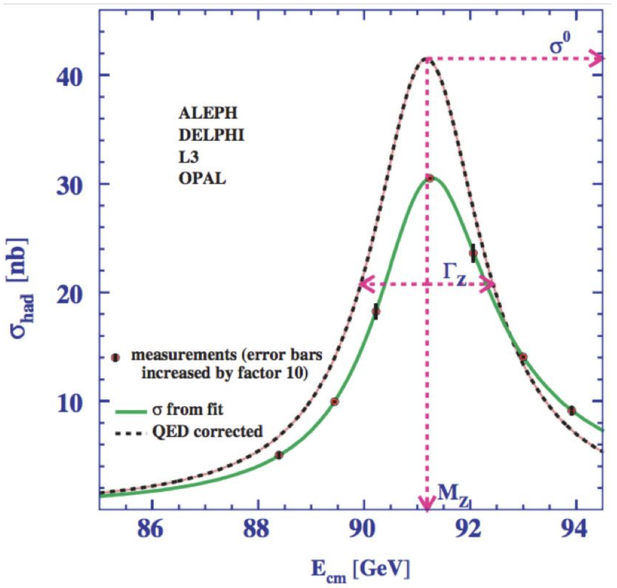
Methods for fully differential predictions

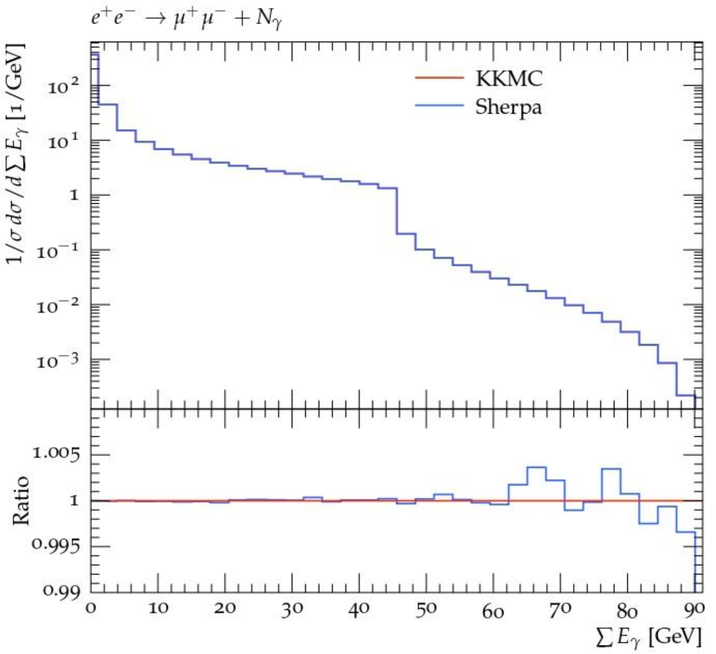
- Include at fixed order (see e.g. Djangoh+Heracles at HERA)
  - calculate $e^- p \to e^- \gamma p$ with IR cuts, combine with Born process and virtual + soft corrections
- The YFS procedure
  - based on all order QED treatment, very successful for example for LEP
- Use a QED parton showers
  - Regularly applied for QED corrections to charged final states

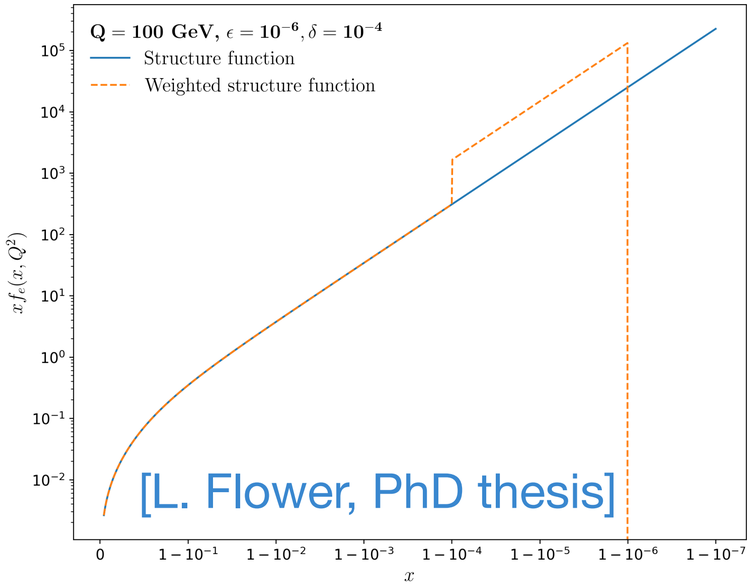


Initial state QED radiation

- Initial-initial lepton case:
  - classic application of YFS as used by LEP experiments
  - new implementation available in Sherpa
  - Structure function: inclusive treatment, resuming (next-to) leading logarithms
  - QED Showers: in principle applicable, but problems overestimating pdfs





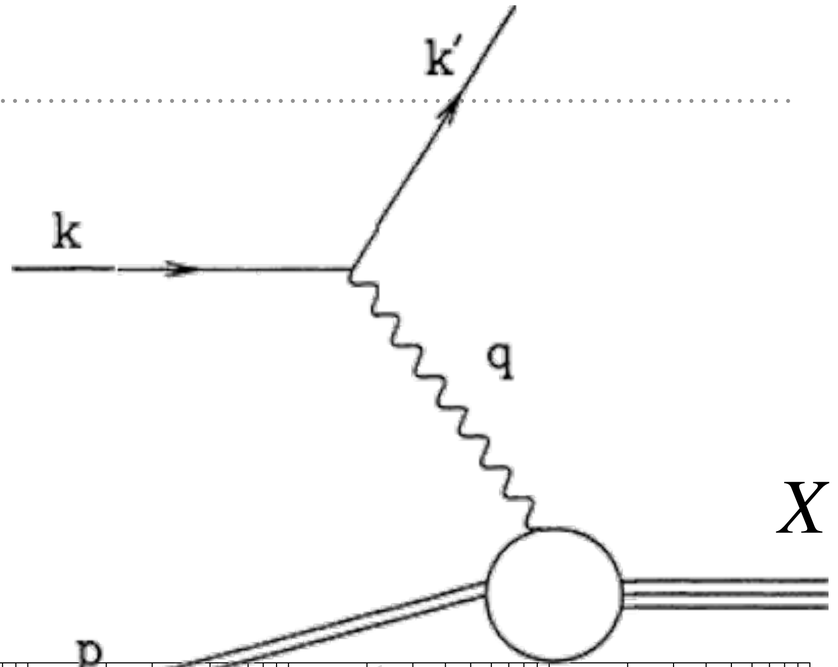


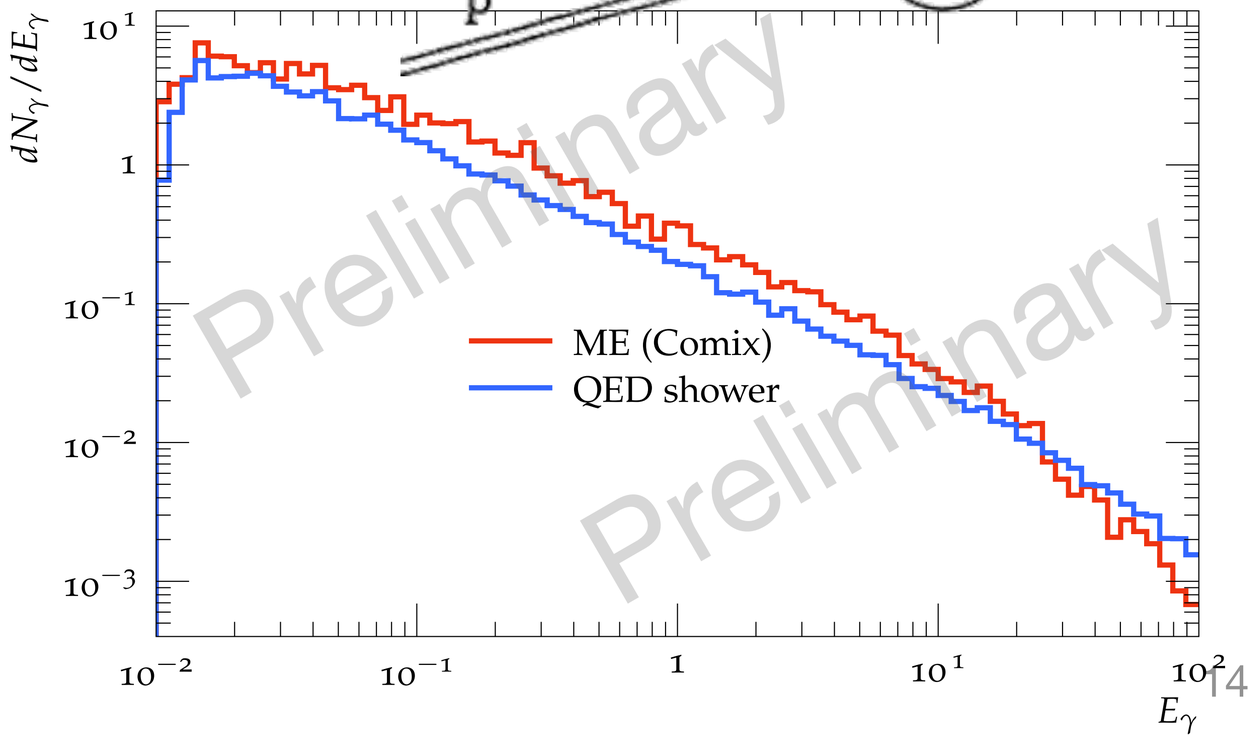
Initial-Final QED showers

- DIS case
  - one lepton in initial, one in final state
    - no clear separation in dipole shower picture
  - several stumbling stones for solutions
    - “Full” QED shower: need practical solution for structure function treatment in backward evolution
    - YFS: need massive leptons everywhere, develop IF case
    - both with technical problems to solve, focus of current developments II (and lesser extent FF) case

Structure functions + FS shower approach

- Idea: IS radiation is dominated by collinear photons ⇒ use **structure function** for that
- Combine with **FS shower**, based on collinear splitting function, recoil against hadronic final state X (i.e. don't touch initial electron)
- Test: ignore quark charges and fix their energy (i.e. $e^-\nu_\mu \rightarrow e^-\nu_\mu$) for unambiguous **ME comparison**





Preliminary results

- **First results** for generic observables related to radiated photons, in $e^- p \to e^- p$ with 1 photon emission from the QED shower

- "Reasonable" (?) behavior

- **Community question:**
  - define **relevant benchmarks**?
  - i.e. what plot/comparison would you want to see?