



# Future plans in Sherpa

RadioMonteCarLow2 Working Group Meeting

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15th November 2024

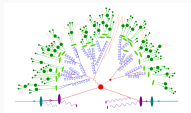
University of Liverpool & Jagiellonian University

## General features

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# Currently: Sherpa 3.0

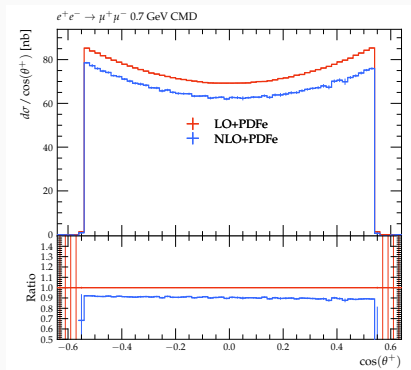
- Analytic  $2 \rightarrow 2$  matrix elements, plus two fully automated tree-level ME generators:
  - AMEGIC
  - COMIX
- Interfaces to one-loop providers OPENLOOPS, RECOLA, MADLOOP, MCFM
- UFO interface for BSM models
- Intuitive YAML input structure, efficient integration and event generation, fully parallelisable
- Lots of recent developments for future lepton colliders (see backup)



## Fixed-order methods

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- Full NLO EW fixed-order integration/event generation for any SM process [Schönherr '17](#)
- Catani-Seymour subtraction
- Automated identification & subtraction of QCD and QED divergences
- External photons can be treated as resolved or unresolved



Preliminary

## YFS methods

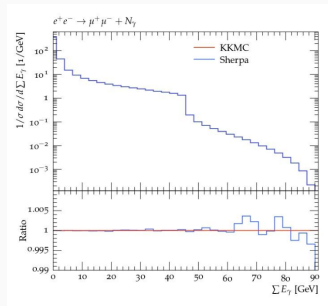
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# Initial-state YFS

- Photon radiation from initial state through YFS

Krauss, Price, Schönherr '22

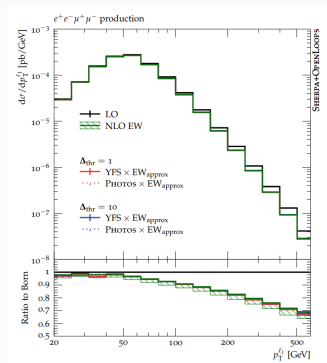
- Supplemented with collinear logs up to  $\mathcal{O}(\alpha^3 L^3)$  in the EEX framework
- Complete treatment of multi-photon kinematics and phase space
- Explicit photons created
- Also for **polarised** lepton beams!
- Included in SHERPA 3.x soon: full NLO
  - Automated NLO using IR subtraction from YFS module



$\gamma$  energy validation at LEP

# Final-state YFS

- YFS for decays (including hadron decays) [Krauss, Schönherr '08](#)
- Includes NLO QED, soon NNLO [Krauss, Lindert, Linten, Schönherr '18](#)
- Includes all-orders LL effect of photon splittings into leptons and light hadrons [LF, Schönherr '22](#)
  - Coming soon: splittings of photons emitted from IS



[Schönherr, Gütschow '20](#)



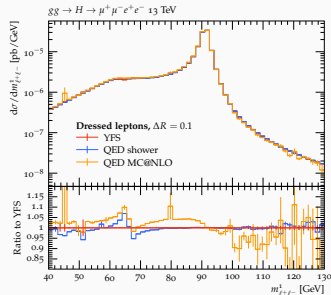
# Parton shower methods

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- Photon radiation (and optionally charged particle production) from all external legs
- QCD shower paradigm: evolution outwards from amplitude
- Allows for equal treatment of ISR, FSR and interference
- Backward evolution a challenge for IS leptons due to integrable divergence
- Currently: implementing solution using weighted veto algorithm
- Watch this space

# Automated NLO parton shower matching

- QED extension of MC@NLO method  
[Frixione, Webber '02](#)
- Can match QCD and QED emissions to full NLO QCD+EW
- Once QED shower finished, we get this “for free”
- Treatment of Born photons not implemented yet – Marek’s new PhD student



Flower '24 (PhD thesis)

## Other plans

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## Detailed study with KKMC

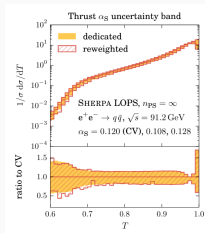
- Compare KKMC YFS+CEEX to SHERPA YFS+EEX and SHERPA (NLO matched) parton shower
- How important is initial-final interference?
- How many collinear logs do we need?

## Pion cross sections

- New: pion XS in F $\times$ sQED at LO (+ IS YFS)
- In future: NLO corrections to pions
- Validate pion form factor & HVP implementations

# Integration with existing features

- More flexibility in form factor and HVP choices
- Capture HVP and form factor uncertainties without re-running
- **On-the-fly variations** [Bothmann, Schönherr, Schumann '16](#)

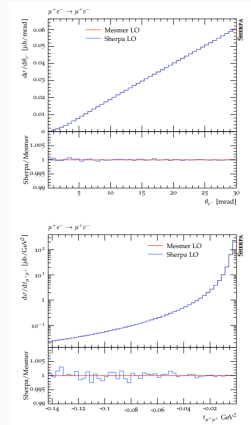


# Sherpa for MUonE

- New fixed-target mode
- Event generation tested against MESMER – proof of concept
- YFS+EEX precise enough, just need higher order input
- i.e. N<sup>3</sup>LO...

$\mu^+e^- \rightarrow \mu^+e^-$	LO	YFS <sup>Born</sup>	YFS <sup>EEX</sup>
SHERPA	245.034(3)	261.296(9)	256.315(8)
	LO	NLO	NNLO
Mesmer	245.038910(1)	255.8437(5)	256.092(1)

Table 1: Total cross-sections for  $\mu^\pm e^- \rightarrow \mu^\pm e^-$  in  $\mu b$ .



# Conclusions

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# In the (near) future, we hope to have...

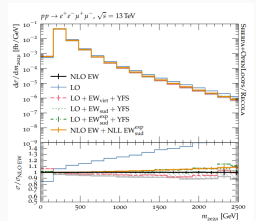
- Full YFS@NLO+EEX framework for precision low-energy
- QED parton shower for  $e^+e^-$  and automated NLO matching
- Event generation setup for MUonE at YFS@NLO+EEX
- Low-energy hadronic physics improvements
  - Pion form factor
  - Hadronic VP
  - Treatment of radiation off pions and NLO corrections
- On-the-fly uncertainty estimates for parametric uncertainties

Thanks for listening!



# Backup: Developments in high-energy $e^+e^-$

- Automated EW Sudakov corrections  
Bothmann, Napoletano '20
- Cross sections for polarised intermediate EW bosons Hoppe, Schönherr, Siegert '23
- Combined QED ISR (YFS+EEX) with QCD FSR (MEPs@NLO and Mc@NLO)
- New NLL QCD parton shower: ALARIC Herren et al. '21
- Photoproduction at NLO HÖche, Krauss, Meinzinger '23
  - Single or double
  - Resolved or direct



Bothmann et al. '21