**Muon g-2 Theory Initiative Spring 2024 meeting**

# Monte Carlo generator comparison studies

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**for the Community Effort on low-energy $e^+e^-$ collisions**

**AEC, University of Bern**

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a community effort for theory improvement for $e^+e^- \to$ stuff for $\sqrt{s} \lesssim$ few GeV

- started in spring 2022, largely independently of $(g-2)_\mu$

- goal: state-of-the-art predictions (ie. NNLO+ for leptonic processes) for

$$e^+e^- \to \mu^+\mu^- + \gamma\{+\gamma\}$$
$$e^+e^- \to e^+e^- + \gamma\{+\gamma\}$$
$$e^+e^- \to \pi^+\pi^- + \gamma\{+\gamma\}$$

- other processes to remember

$$e^+e^- \to \gamma\gamma\{+\gamma\gamma\}$$
$$e^+e^- \to \pi^+\pi^-\pi^0$$
$$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$$
$$e^+e^- \to \pi^+\pi^-\pi^+\pi^-$$

... not (just) because of $(g-2)_\mu$

- inspired by [0912.0749]

Review

**Quest for precision in hadronic cross sections at low energy: Monte Carlo tools vs. experimental data**

Working Group on Radiative Corrections and Monte Carlo Generators for Low Energies

- improve SM precision tests at low energy

- ... but of course also provide input for $(g-2)$

- a lot has happened since 2009, $2 \to 2$ NNLO & NLL is standard @ LHC

- apply this to low-energy physics

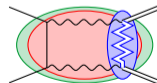$ee \to \pi\pi$

WP1:   QED for leptons at NNLO
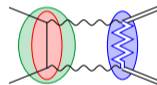
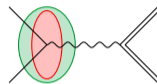WP2:   Form factor contributions at N³LO

WP3:   Processes with hadrons

WP4:   Parton showers / YFS

WP5:   Experimental input

- 2009: previous report
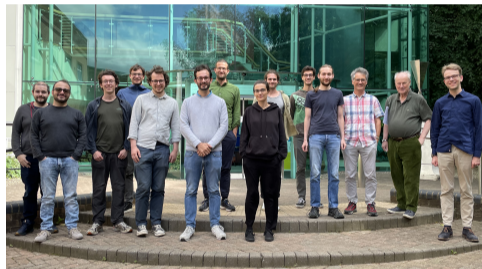- 2019: WP1 workstop on $e\mu \to e\mu$ in Zurich

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- summer 2023: workstop on WP1-5
- winter 2023/4: Monte Carlo comparison begins
- spring 2024: writing begins
- summer 2024: report on arXiv
- work continues

### which corrections are known? which matter?

- many different codes exist, all implement different corrections
  structure functions, YFS, Parton Shower, full radiative NLO, full NNLO, partial NNLO, …

- a priori unclear how important each of these are

- … will also depend on the kinematics

- what to focus on in the future?
  full radiative NNLO, ISR N$^3$LO ($ee \to \gamma^*$), FsQED-ish NNLO ($ee \to \gamma^*\gamma^*$), sNLL / cLL
  resummation, …

### our goal

- living: new results can be added at any point (though the paper cut-off has passed)

- reproducible & Open Science: all codes should be accessible and the runs documented

- collection of standard candles: future codes can be benchmarked against this

do not try to do an experimental analysis, do try to mimic what's relevant

- CMD $ee \to ee, \mu\mu, \pi\pi$, $\sqrt{s} = 0.7 \, \text{GeV}$    link

- KLOE $ee \to \{ee, \mu\mu, \pi\pi\} + \gamma$, $\sqrt{s} = 1.02 \, \text{GeV}$:

  - large angle (tagged photon)    link
  - small angle (untagged photon)    link

- BESIII $ee \to \{ee, \mu\mu, \pi\pi\} + \gamma$, $\sqrt{s} = 4 \, \text{GeV}$    link

- generic B factory $ee \to \{ee, \mu\mu, \pi\pi\} + \gamma$, $\sqrt{s} = 10 \, \text{GeV}$    link

see GitLab for details & reference implementations

$u^b$

7 different codes to be included for the paper

- AfkQED: ISR coll. + NLO photon in the boosted system + FSR with Photos

- Babayaga: NLO+QED PS

- KKMC: YFS

- MCGPJ: NLO + collinear structures

- McMule: full NNLO for leptonic $2 \to 2$, ISR for $ee \to \pi\pi$

- Phokhara: full NLO for $2 \to 3$

- Sherpa: LO + YFS

more codes / effects can be included later

- this is meant to be a living review

- contact yannick.ulrich@cern.ch if you want your code in the database
  (but not the paper, sorry)

what to expect in the next few years

- improved Monte Carlo codes for $ee \to \ell\ell\gamma$ (approximate NNLO + resummation)
- improved Monte Carlo codes for $ee \to \gamma^* \to \pi\pi$ (ISR NNNLO + resummation)

what to hope for in the next few years

- further dispersive input for building blocks
- better understanding when FsQED is (how) ok and when it fails completely

what we will habe by summer

- an updated report Radiative corrections and Monte Carlo tools for low-energy hadronic cross sections in $e^+e^-$ collisions
- a living review of Monte Carlo codes

... for Radiative Corrections & Monte Carlo tools for low energy $e^+e^-$ experiments

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