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

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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]


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Review

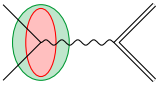
Quest for precision in hadronic cross sections at low energy: Monte Carlo tools vs. experimental data

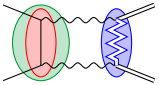
Working Group on Radiative Corrections and Monte Carlo Generators for Low Energies

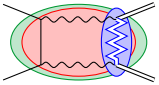
- improve SM precision tests at low energy
- ... but of course also provide input for $(g-2)$
- a lot has happened since 2009, $2 \to 2$ NNLO & NLL is standard @ LHC
- apply this to low-energy physics

WP1:	QED for leptons at NNLO
WP2:	Form factor contributions at $\mathrm{N^3LO}$
WP3:	Processes with hadrons
WP4:	Parton showers / YFS
WP5:	Experimental input

$ee \to \pi\pi$







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- 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 $ee \to ee, \mu\mu, \pi\pi$, $\sqrt{s} = 0.7\,\mathrm{GeV}$ — link
- KLOE $ee \to \{ee, \mu\mu, \pi\pi\} + \gamma$, $\sqrt{s} = 1.02\,\mathrm{GeV}$:
  - large angle (tagged photon) — link
  - small angle (untagged photon) — link
- BESIII $ee \to \{ee, \mu\mu, \pi\pi\} + \gamma$, $\sqrt{s} = 4\,\mathrm{GeV}$ — link
- generic B factory $ee \to \{ee, \mu\mu, \pi\pi\} + \gamma$, $\sqrt{s} = 10\,\mathrm{GeV}$ — link

see GitLab for details & reference implementations

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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