UNIVERSITY OF LIVERPOOL

Hadron Physics in Horizon Europe

RadioMonteCarLow2++

Yannick Ulrich

(he/him)

University of Liverpool

1 July 2025

- VA project to improve theory for low-energy hadron physics processes and their connection to experiments
- lead by Carlo Carloni Calame (Pavia, TH), Achim Denig (Mainz, EXP), Franziska Hagelstein (Mainz, TH), Andrzej Kupsc (Uppsala, EXP), Yannick Ulrich (Liverpool, TH), Graziano Venanzoni (Liverpool, EXP)
- supported by members of 16 institutes
- continuation and extension of the RadioMonteCarLow2 project lead by Andrzej, Graziano, myself and Adrian Signer

who? `radiomontecarlow2.gitlab.io`

- group of 35 theorists and experimentalists from 22 institutions trying to improve theory for low-energy e^+e^-
- meetings in 2023 (Zurich), 2024 (Liverpool), and 2025 (Pisa)
- review just published `10.21468/SciPostPhysCommRep.9`

when?

- Phase I: review state-of-the-art for $ee \to \mu\mu(+\gamma)$, $ee \to \pi\pi(+\gamma)$ in 7 MC codes
- Phase II: improvements (NNLO for $2 \to 3$, N^{3}LO for $2 \to 2$, dispersive $ee \to \pi\pi$, ...)

what now?

- join forces with lepton-scattering community
- provide state-of-the-art MC tools for hadronic physics

goals of VA RadioMonteCarLow2++

- *support the improvement of MC tools*
- *collate and maintain existing codes in a common repository.*
- *support the integration of MC tools into experimental analyses and feasibility studies.*

goals of VA RadioMonteCarLow2++

- *support the improvement of MC tools*
  - extend RadioMonteCarLow2 physics coverage to $\ell p \to \ell p$, $e\mu \to e\mu$ and others
  - scientific exchange between MC developers through internships & workshops
- *collate and maintain existing codes in a common repository.*
- *support the integration of MC tools into experimental analyses and feasibility studies.*

goals of VA RadioMonteCarLow2++

- *support the improvement of MC tools*
- *collate and maintain existing codes in a common repository*.
  - idea: archive all codes, provide runcards, example analyses, results etc.
  - existing partial storage of MC codes on `radiomontecarlow2.gitlab.io`
  - physics results are online but code repository is incomplete
  - make complete, easier to use & streamline process
  - possibly integrate with data, cf. `PrecisionSM` of Strong2020
- *support the integration of MC tools into experimental analyses and feasibility studies*.

goals of VA RadioMonteCarLow2++

- *support the improvement of MC tools*
- *collate and maintain existing codes in a common repository.*
- *support the integration of MC tools into experimental analyses and feasibility studies.*
  - provide examples, advice & training to experimentalist
  - develop common interface between codes and analysis, cf. `rivet`
  - make swapping of codes easier to benefit directly from theory improvements

any experiment that is studying $ee \to \{\mu\mu, \pi\pi, ee, \gamma\gamma\} + n\gamma$, $\ell p \to \ell p$, $e\mu \to e\mu$

- CERN
  - MUonE $e\mu \to e\mu$ for $(g-2)_\mu$ HVP
  - AMBER $\ell p \to \ell p$ for proton structure
- Mainz (MAMI, MESA) $eN \to eN$
  - $N \in \{\mathrm{Ar}, \mathrm{O}, \mathrm{C}\}$ for neutrino input
  - $N = {}^{12}\mathrm{C}$ (Hoyle state)
  - P2 for weak charge of the proton
  - MAGIX for nuclear structure
- LNF
  - KLOE $ee \to \pi\pi\gamma$ for e.g. F_π^V
  - PADME $ee \to \gamma\gamma$ for $ee \to \gamma A'$
- JLAB
  - PRad2 $ep \to ep$ / DRad $eD \to eD$ for charge radii
  - Ce$^+$BAF $ee \to ee$ for dark searches
- non-TA facilities
  - Belle II $ee \to \tau\tau$ for $(g-2)_\tau$
  - BES III $ee \to \pi\pi\gamma$ for e.g. F_π^V
  - CMD $ee \to \pi\pi$ for F_π^V
  - ULQ2 $eN \to eN$ for charge radii
  - ...

right now, switching to (or even trying) a new theory code is very time consuming!

- this is very bad as experiments cannot benefit from improvements easily
- all of the 7 MC codes in Phase I used different conventions etc.
- usage requires a fair bit of knowledge of the internals
- n experiments, m applicable codes $\rightarrow$ $n \times m$ implementations (35 in Phase I)
- not always clear which version of which code to use

the plan: common interface & examples in repository

- with a common interface: $n + m$ implementations (12 in Phase I)
- some tailoring will still be required $\rightarrow$ examples as a starting point
- clear which version is "canonical"

timeline

- repository
  - 1st year: design interface from codes & examples in current repo
  - 2nd year: collect missing codes, provide documentation
  - after: keep repo up-to-date with member postdocs
- scientific exchange to support MC development for full duration of project

resources

- $\geq$ 2 postdoc-years to build the repository ($\approx 160k$€)
- workshop travel funds ($\approx 10k$€)
- 3×4 internships ($\approx 60k$€ total)

timeline

- repository
- scientific exchange to support MC development for full duration of project
  - 2 workshops a year for wider exchange & community engagement
  - 3 internships a year for specific exchange between groups

resources

- $\geq$ 2 postdoc-years to build the repository ($\approx 160k$€)
- workshop travel funds ($\approx 10k$€)
- 3×4 internships ($\approx 60k$€ total)

timeline

- repository
- scientific exchange to support MC development for full duration of project

resources

- $\geq$ 2 postdoc-years to build the repository ($\approx 160k$€)
  - constructing interface, collating & documenting codes, develop examples takes time & expertise
  - high impact for the users as it simplifies their work
- workshop travel funds ($\approx 10k$€)
- 3×4 internships ($\approx 60k$€ total)

timeline

- repository
- scientific exchange to support MC development for full duration of project

resources

- $\geq$ 2 postdoc-years to build the repository ($\approx 160k$€)
- workshop travel funds ($\approx 10k$€)
  - funded externally, worked for RadioMonteCarLow2
  - some travel support for ECRs who could not otherwise attend
- 3×4 internships ($\approx 60k$€ total)

timeline

- repository
- scientific exchange to support MC development for full duration of project

resources

- $\geq$ 2 postdoc-years to build the repository ($\approx 160k$€)
- workshop travel funds ($\approx 10k$€)
- 3×4 internships ($\approx 60k$€ total)
  - improvements of MC codes are done by their developers
  - cross-pollination between different groups would speed this up!
  - encourage $\mathcal{O}(4\text{weeks})$ internships in other groups