

PrecisionSM: an annotated database for low-energy e^+e^- hadronic cross sections



LEVERHULME
TRUST

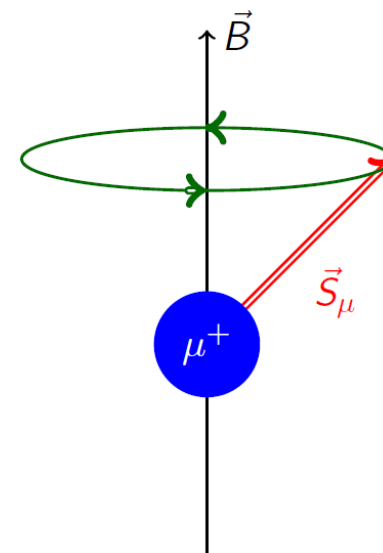
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08/07/2025: EPS-HEP, MARSEILLE



Outline

- Current status of the muon $g - 2$
- RadioMonteCarLow 1 and 2 and STRONG2020 activities
- Specific goal: database for low energy e^+e^- hadronic cross section
 - Input data
 - Procedure to create entries
 - Plots
 - Future work

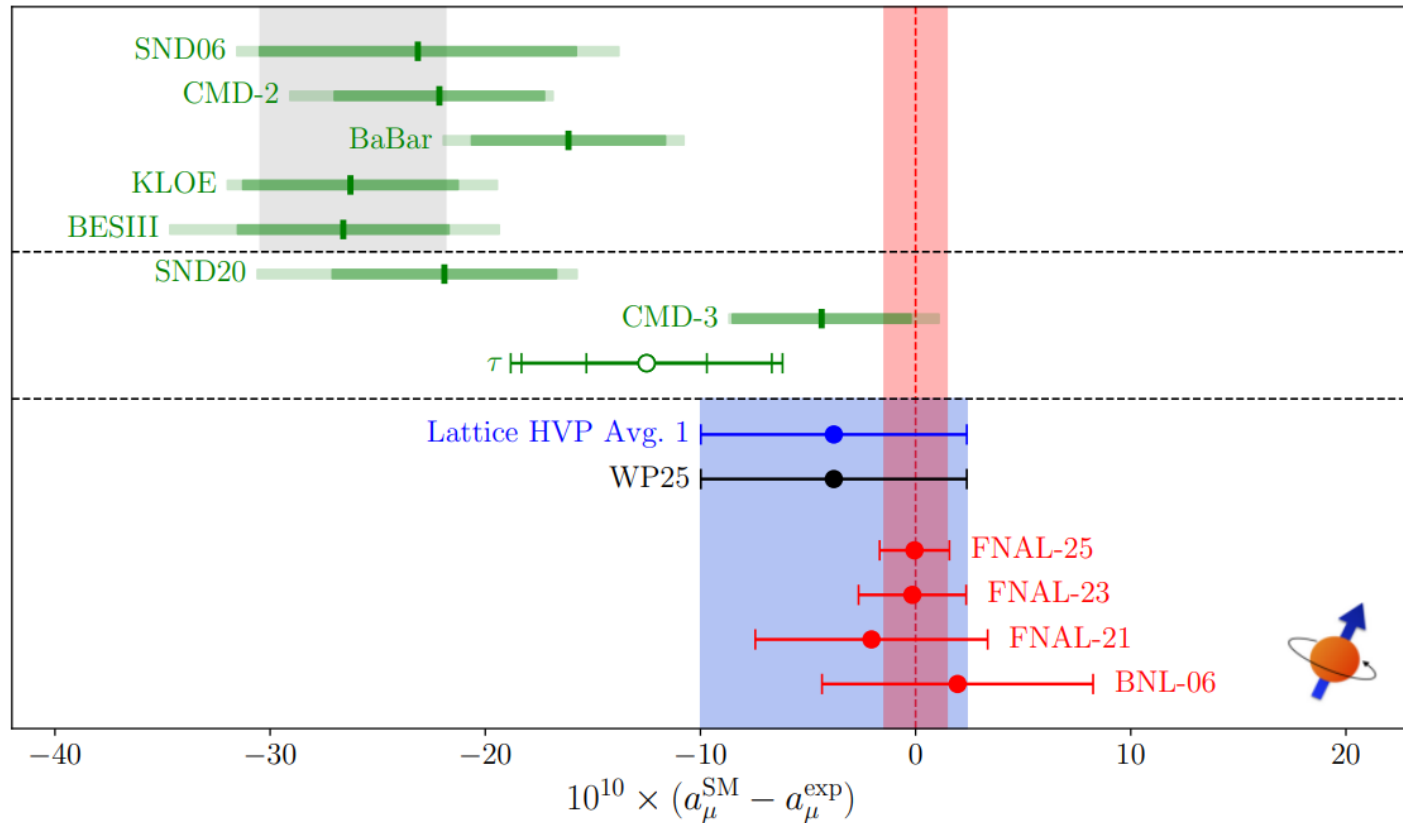


$$\vec{\mu} = g \frac{e}{2m} \vec{S}$$

$$a_{\mu} = \frac{g - 2}{2}$$

Muon $g - 2$: theory vs experiment

Theory Initiative White Paper 2025. [hep-ph/arXiv:2505.21476](https://arxiv.org/abs/2505.21476)



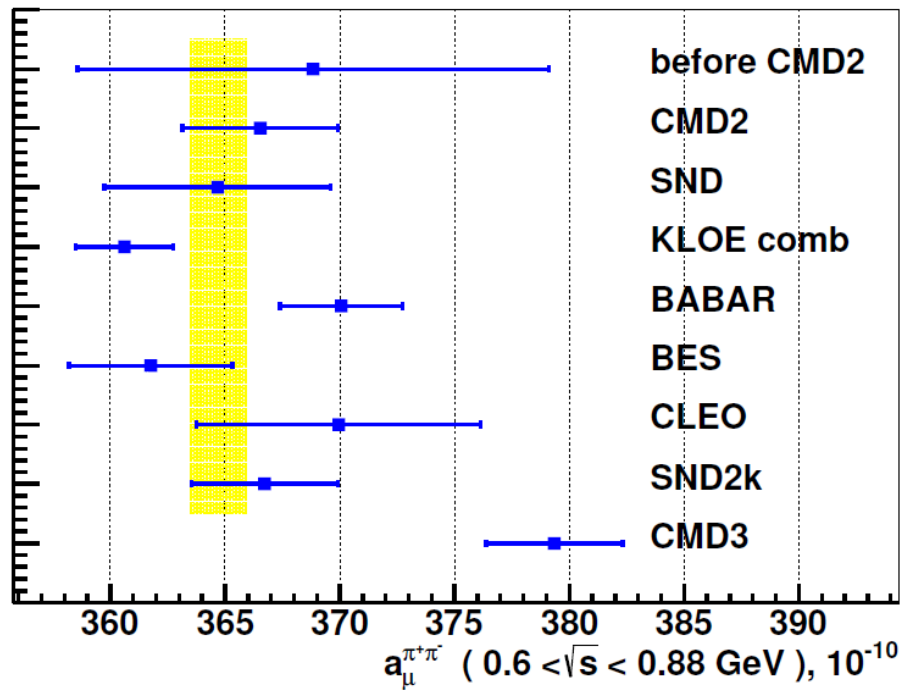
Used for previous White Paper of the Theory Initiative (WP2020), based on data-driven dispersive approach (input from $e^+e^- \rightarrow \text{hadrons}$ experimental data)

Several talks on all of these updates at this conference!

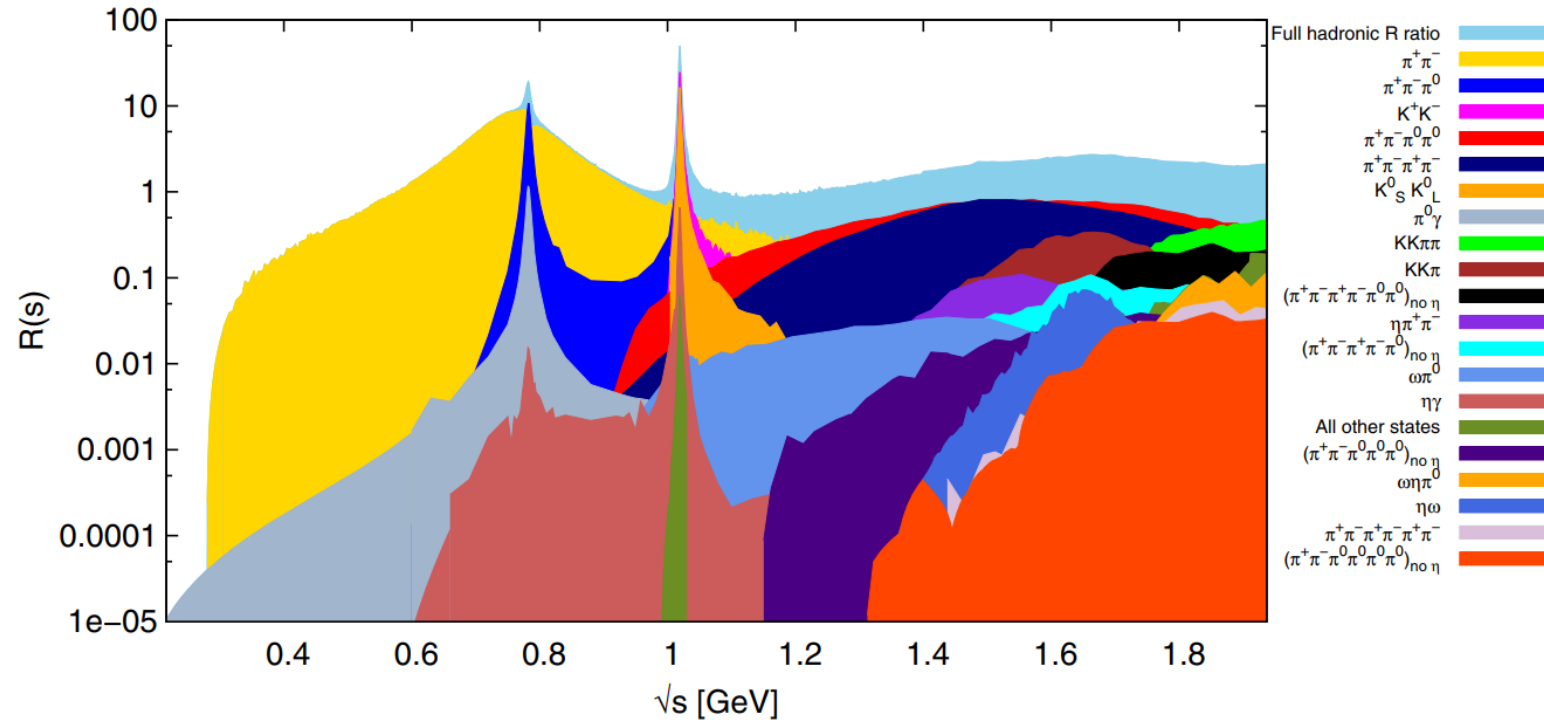
The error on the prediction of a_μ is dominated by the theoretical error on the leading order Hadronic Vacuum Polarization (HVP-LO)

Tensions in the data-driven HVP calculation

Phys. Rev. D 109, 112002 (2024)



Phys. Rev. D 97, 114025 (2018)
Hadronic R-ratio divided by channel



Experimental data from $e^+e^- \rightarrow \text{hadronic channels}$ are used as an input

Activities on low energy e^+e^- data

RadioMonteCarLow



<https://www.lnf.infn.it/wg/sighad/>

- Active from 2006 to 2019
- Report in 2010 on Eur. Phys. J. C

RadioMonteCarLow2

<https://radiomontecarlow2.gitlab.io/>



- Continuation of previous project, see [talk](#)
- Phase I started in 2022, Phase II in 2024
- Phase I report published in SciPost

STRONG2020 Project



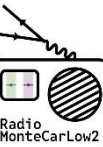
<http://www.strong-2020.eu/>

Completed in 2024

- Work Package under the EU Horizon 2020 grant agreement n. 824093
- Specific goal within the project: create an annotated database, PrecisionSM, for low-energy hadronic e^+e^- cross sections
- PrecisionSM DB is online:

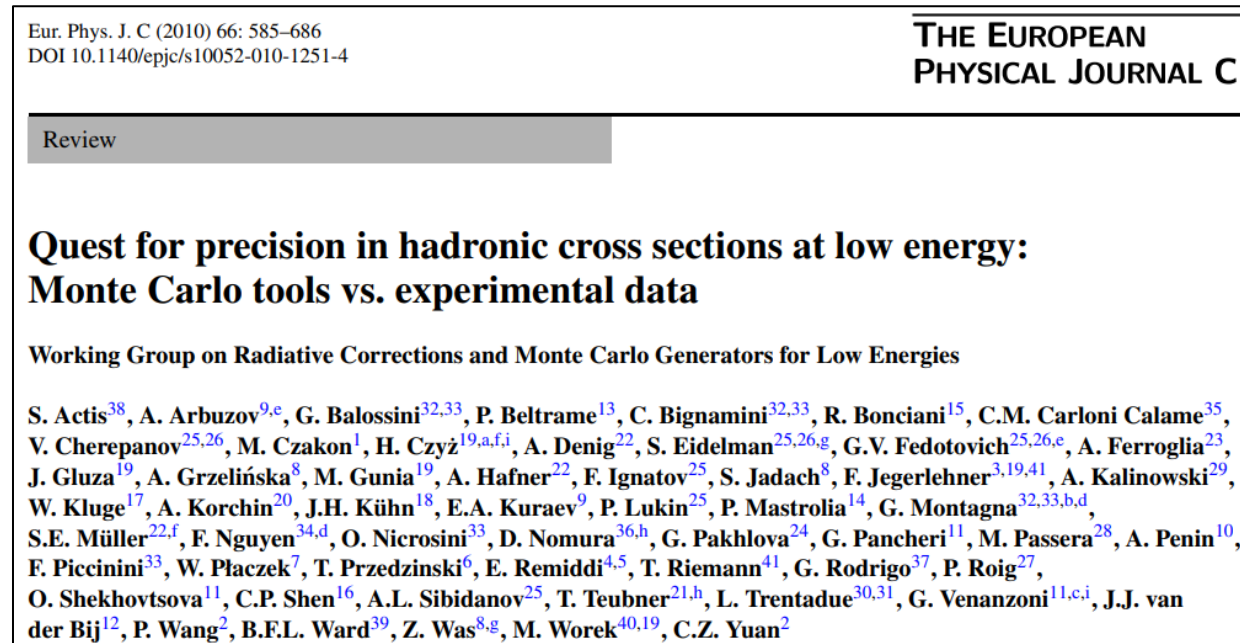
<https://precision-sm.github.io/>

Important for the HVP-LO contribution to a_μ and for running of α_{em}



RadioMonteCarLow activities

- 20 meetings between theorists and experimentalists from 2006 to 2019
- Efforts to develop MC generators for luminosity, $e^+e^- \rightarrow$ hadrons and leptons (+ γ from ISR), τ -lepton production and decays
- Final report, divided into 5 subjects:
 1. Luminosity measurements at low energies (up to B-factories energy)
 2. R(s) measurement with energy scan
 3. R(s) measurement with radiative return
 4. τ -lepton physics
 5. Calculation of vacuum polarization with emphasis on the hadronic contributions



Eur.Phys.J.C 66 (2010) 585-686

More details [HERE](#)



RadioMonteCarLow2 Working Group

- See previous talk by [J. Paltrinieri at this conference](#)
- Efforts from theorists and experimentalists aimed at improving our knowledge of low-energy e^+e^- collisions
- 4 sections in Phase I report:
 1. Review of experiments that provided e^+e^- data for HVP in the dispersive approach
 2. Computational setup: overview of all tools and contributions to theoretical prediction
 3. Review of 7 MC codes used for comparisons in Phase I
 4. Comparisons of MC codes in realistic scenarios
- Phase II launched in 2024

Radiative corrections and Monte Carlo tools for low-energy hadronic cross sections in e^+e^- collisions

• Riccardo Aliberti¹, • Paolo Beltrame², • Ettore Budassi^{3,4},
• Carlo M. Carloni Calame⁴, • Gilberto Colangelo⁵, • Lorenzo Cotrozzi²,
• Achim Denig¹, • Anna Driutti^{6,7}, • Tim Engel⁸, • Lois Flower^{2,9},
• Andrea Gurgone^{3,6,7}, • Martin Hoferichter⁵, • Fedor Ignatov²,
• Sophie Kollatzsch^{10,11}, • Bastian Kubis¹², • Andrzej Kupś^{13,14*},
• Fabian Lange^{10,11}, • Alberto Lusiani^{7,15}, • Stefan E. Müller¹⁶, • Jérémy Paltrinieri²,
• Pau Petit Rosàs², • Fulvio Piccinini⁴, • Alan Price¹⁷, • Lorenzo Punzi^{7,15},
• Marco Rocco^{10,18}, • Olga Shekhovtsova^{19,20}, • Andrzej Siódmok¹⁷,
• Adrian Signer^{10,11*}, • Giovanni Stagnitto²¹, • Peter Stoffer^{10,11},
• Thomas Teubner², • William J. Torres Bobadilla²,
• Francesco P. Ucci^{3,4}, • Yannick Ulrich^{2,5*} and • Graziano Venanzoni^{2,7*}
(RadioMonteCarLow 2 working group)

SciPost Phys. Comm. Rep. 9 (2025)

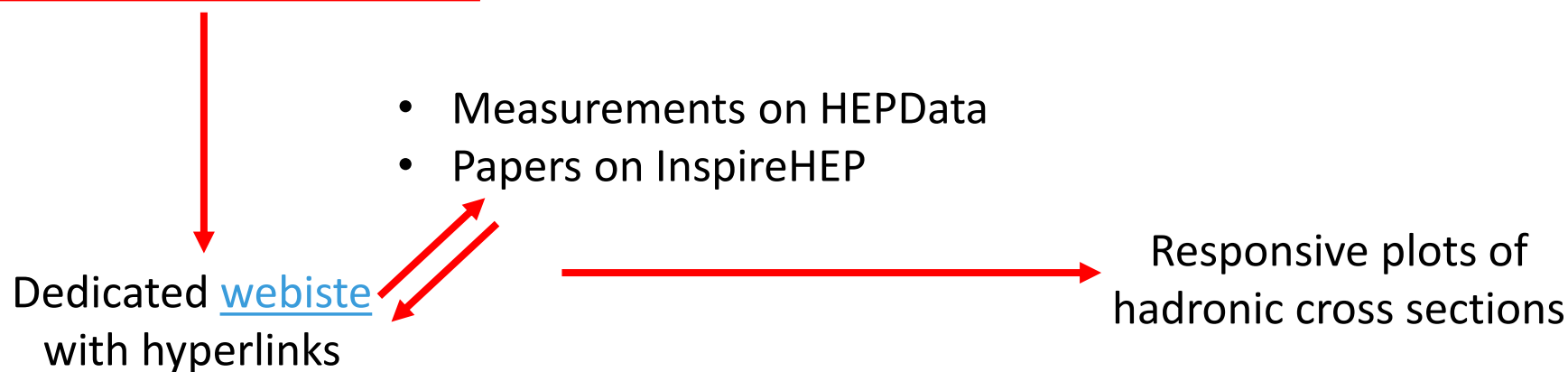
More details [HERE](#) (second half of slides)



Overview of STRONG2020 project



- EU project to study strong interactions
- PrecisionSM “Hadron Physics for Precision Tests of the Standard Model” with several goals:
 - Combine theory and experiment for BSM precision tests (R(s) measurements, Radiative corrections and MC generators)
 - Compile an annotated database for low-energy hadronic cross sections in e^+e^- collisions



PrecisionSM annotated database ([link](#))

PrecisionSM Contents Docs About RSS feed

Search

Low energy e^+e^- channels database

- Measurements Database:
 - $e^+e^- \rightarrow \pi^+\pi^-$
 - $e^+e^- \rightarrow \pi^+\pi^-\pi^0$
 - $e^+e^- \rightarrow \pi^0\gamma$
- HEPData submissions
 - cured by PrecisionSM
- HEPData submissions checks
- Plots

Contents © 2025 PrecisionSM Group - Powered by Nikola

Database for $e^+e^- \rightarrow \pi^+\pi^-$ channels

Experiment	Year	Reference (link to INSPIRE-HEP)	Link to Hepdata	Details	Status
BESIII (BEPC, Beijing)	2016	Phys.Lett.B 753(2016) 629-638 [errata: Phys.Lett.B 812 (2021) 135982]	ins1385603	details	Finalized
BaBar (SLAC, Stanford U.)	2012	Phys.Rev.D 86 (2012) 032013	ins1114155	details	Finalized
CLEO (CESR, Cornell U.)	2018	Phys.Rev.D 97 (2018) 3, 032012	ins1643020	details	Finalized
CLEO (CESR, Cornell U.)	2013	Phys.Rev.Lett. 110 (2013) 2, 022002	ins1189656	details	Finalized
CLEOc (CESR, Cornell U.)	2005	Phys.Rev.Lett. 95 (2005) 261803	ins693873	details	Finalized
KLOE (DAΦNE, Frascati)	2017	JHEP 03 (2018) 173		details	In Preparation
KLOE (DAΦNE, Frascati)	2017	JHEP 03 (2018) 173		details	In Preparation

Input data

KLOE (DAΦNE, Frascati), 2017



- status: **in preparation**
- hepdata: 1634981
- method: Direct
- quotes:
 - $d\sigma/dQ^2(\pi^+\pi^-\gamma)$ (stat, syst)
 - $\sigma_{\pi^+\pi^-}$ (stat, syst)
 - F_π (stat, syst)
- energy[GeV]: 0.32 - 0.97
- radiative corrections:
 - VP corr. updated to 'alphaQED16.tar.gz' package by F. Jegerlehner (2016)
 - Remaining are in inspirehep-797438, inspirehep-859660, inspirehep-1208095
- comment:
 - combination of KLOE08, KLOE10 and KLOE12 data;
 - updates for inspirehep-797438, inspirehep-859660, inspirehep-1208095

Annotate:

- available data (cross section, form factor, matrices, etc)
- energy ranges **in GeV**
- treatment of Radiative Corrections
- any other information needed to use the data properly

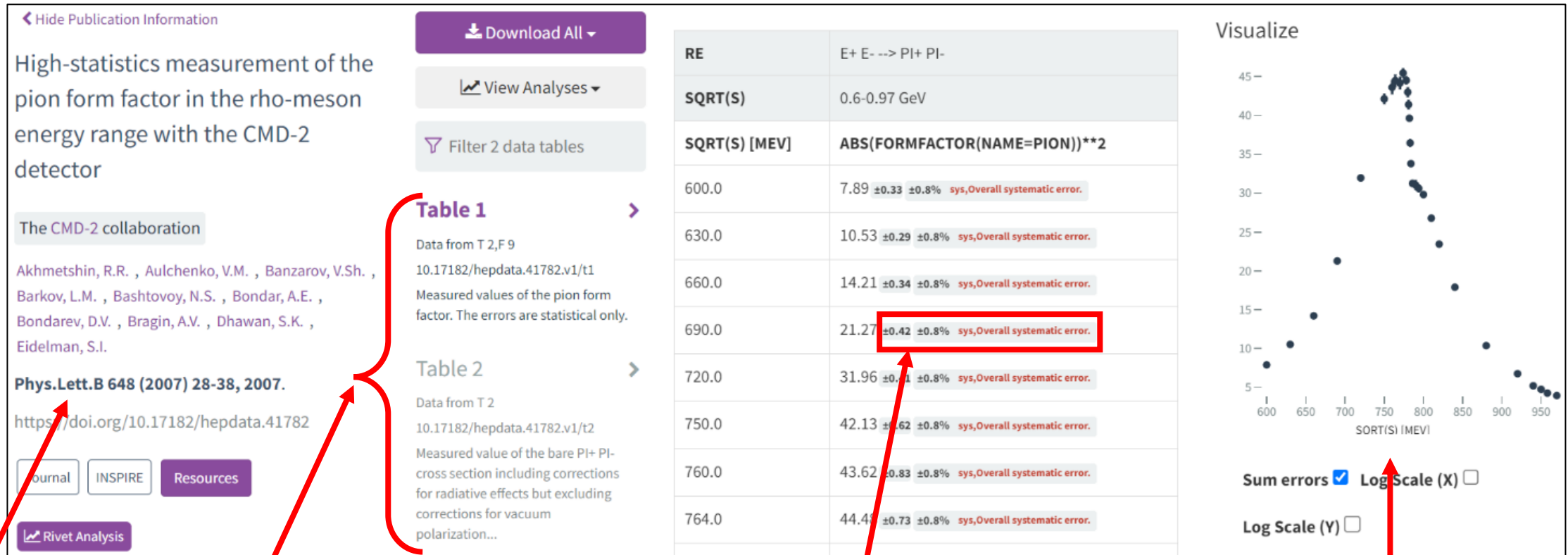
3 channels currently maintained: $\pi^+\pi^-$ ($\sim 75\%$ of total contribution); $\pi^+\pi^-\pi^0$; $\pi^0\gamma$

Steps to create the database

1. **DATA COLLECTION:** inputs of hadronic (starting from $\pi^+\pi^-$) e^+e^- data from published experiments (see next slide)
2. **UPLOAD DATA IN PUBLIC REPOSITORY**  HEPData.net  InspireHEP.net
 - Collaboration point-of-contact (or STRONG2020 coordinator) submits data
 - Reviewer appointed for cross-checks: no mistakes, HEPData.net prescriptions
 - If validated: data is posted, can be catalogued and used
3. **CATALOGUE DATA IN ACCESSIBLE WAY:** precision-sm.github.io
 - Website files on GitHub
 - Created with Nikola static website generator
4. **PROVIDE TOOLS TO ELABORATE DATA** (see following slides)

Available e^+e^- data

- For each dataset, a member of the collaboration provided relevant data: BABAR, BESIII, KLOE, Belle-II, CERN-NA007, CLEO, experiments at Novosibirsk, ADONE, and Orsay. «**Finalized**» entries appear on HEPData.net



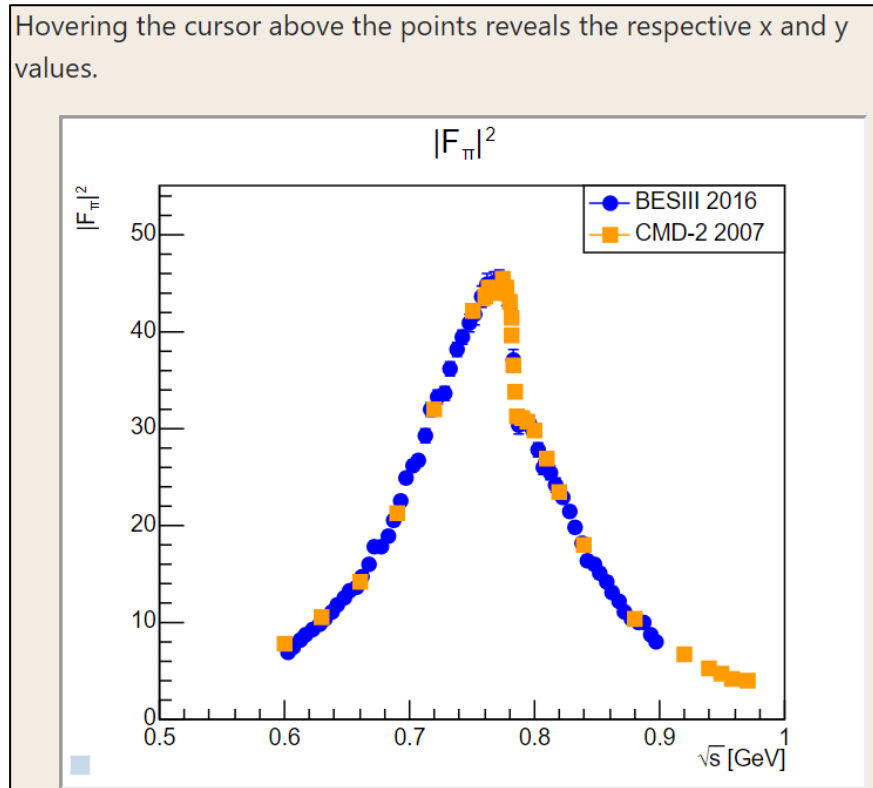
Paper on
Inspire

Tables of
available data

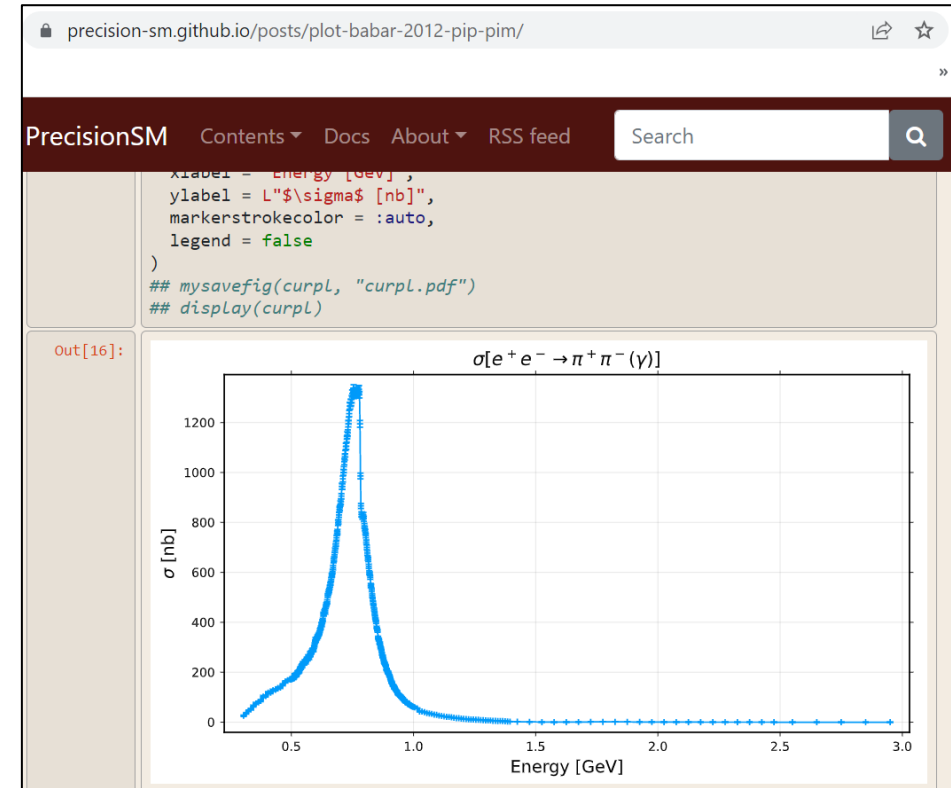
Statistical and systematic
errors, with comments

User-friendly plot

Examples of notebooks and responsive plots



Pion Form Factor

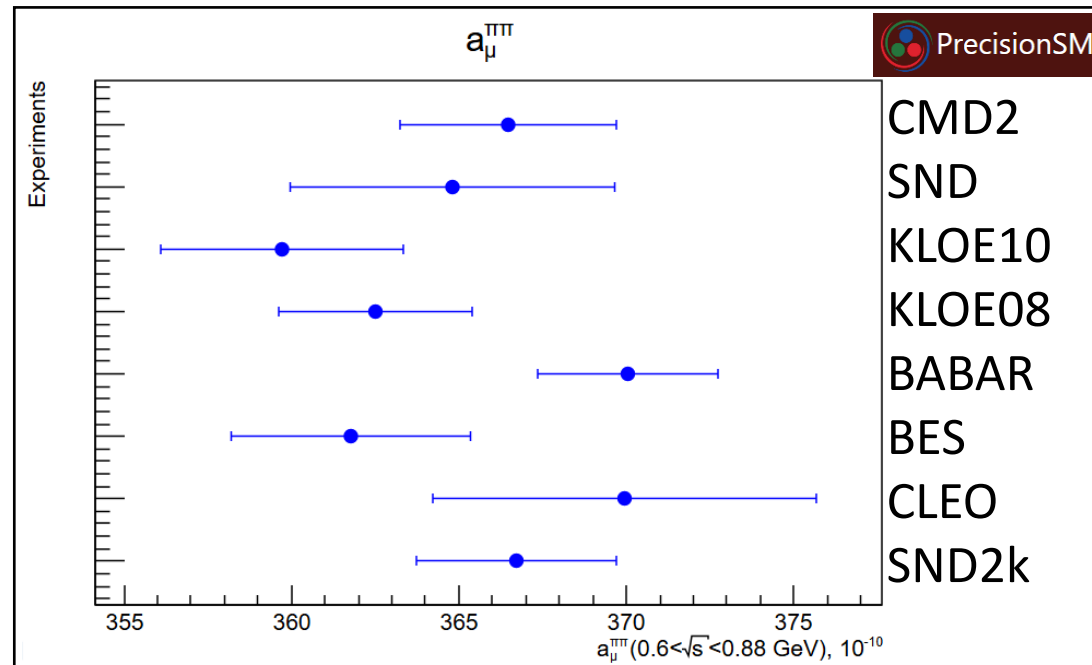


BABAR $\sigma(e^+e^- \rightarrow \pi^+\pi^-(\gamma))$

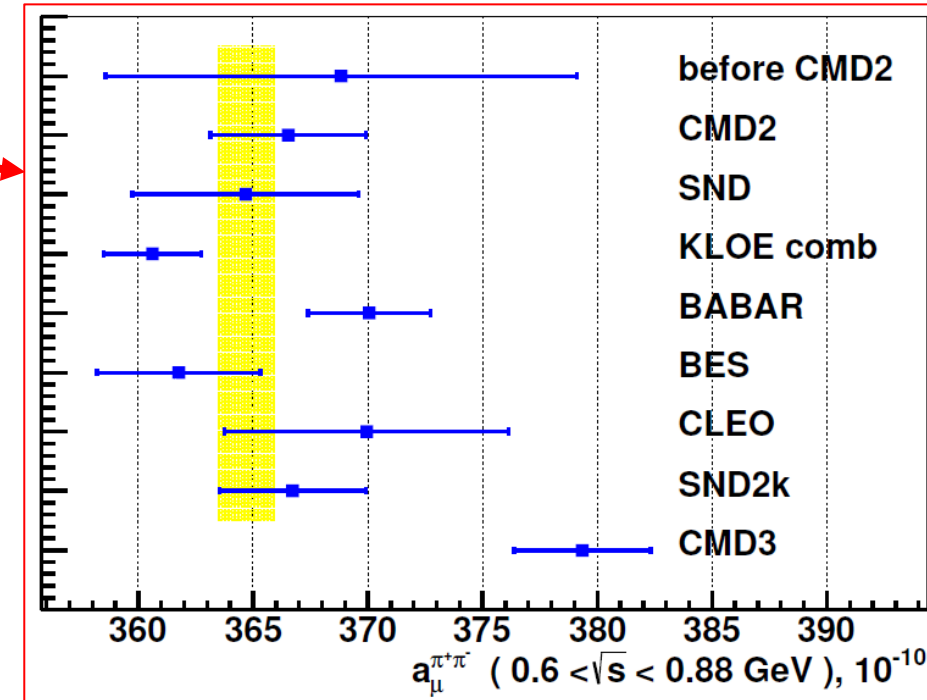
These are all meant as **tools** to work on the database

Work in progress: plot of contributions to $a_\mu^{HVP,LO}$

- Goal to reproduce integrals: from cross section to $a_\mu^{\pi\pi}$ contribution, like this plot
- They should include at least the following energy range: $[\sim 0.6, \sim 0.9]$ GeV, which contributes the most to the cross section



Phys. Rev. D 109, 112002 (2024)



← We started from the most recent experiments that were available on HEPData

How the plot currently works: example

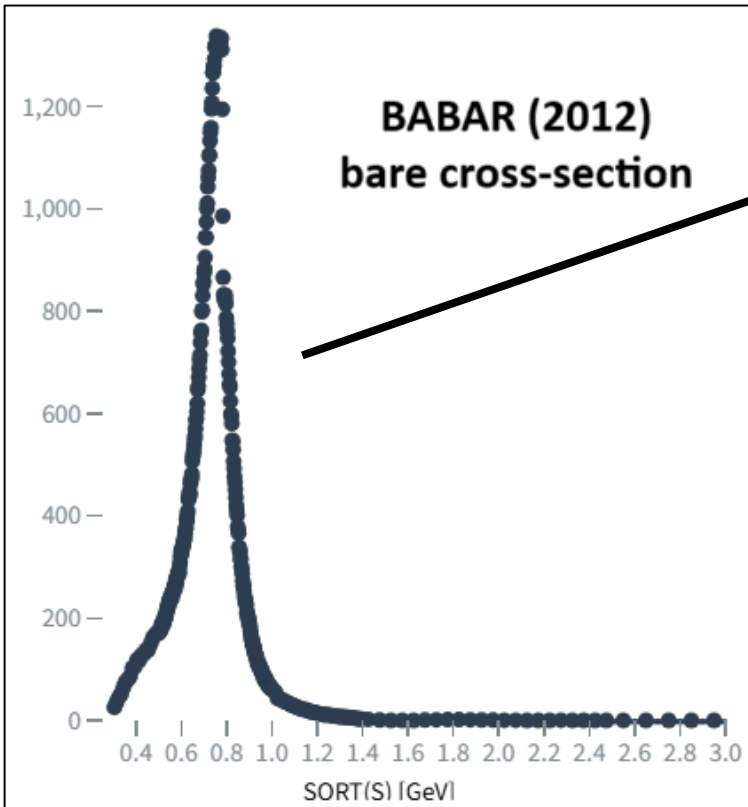
Use JavaScript ROOT to:

1. Take json file from «Bare cross-section» table on HEPData
2. If needed: convert to cross-section versus s (square of \sqrt{s}) in GeV^2
3. Perform HVP dispersive integral with trapezoidal integration

$$a_{\mu}^{HVP,LO} = \left(\frac{\alpha m_{\mu}}{3\pi}\right)^2 \int_{s_1}^{s_2} ds \frac{\hat{K}(s)}{s^2} R_{had}(s)$$

- $\hat{K}(s)$ being the kernel function (see WP25), $R_{had}(s)$ the hadronic R-ratio
- s_1 and s_2 currently set at $(0.6 \text{ GeV})^2$ and $(0.88 \text{ GeV})^2$, respectively

4. Covariance matrices for errors are used when available



Work in progress

1. **Use all experiments**, also those that don't provide the bare cross section directly but, for instance, only the pion form factor.
2. **Make this user-friendly**: the user can choose which experiments to include and which energy range to integrate over.
3. **Display errors** separately between statistical and systematic.
4. **Complete the plot with all channels** available – with proper weights – to produce the hadronic cross section observable.

List of previous talks, posters and proceedings



Now available [here](#)

List of Past Presentations

July 2024: [42nd International Conference on High Energy Physics \(ICHEP 2024\) - Prague, Czech Republic.](#)

- Title: "PrecisionSM: an annotated database for low-energy positron-electron hadronic cross sections"
- Contribution: [Poster](#)
- Proceeding: [PoS ICHEP2024 \(2025\) 578](#)

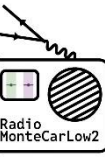
August 2023: [2023 European Physical Society Conference on High Energy Physics \(EPS-HEP2023\) - Hamburg, Germany.](#)

- Title: "PrecisionSM: an annotated database for low-energy positrons-electrons into hadrons"
- Contribution: [Poster](#)
- Proceeding: [PoS EPS-HEP2023 \(2024\) 376](#)

4 presentations, 3 posters, 6 proceedings

Summary, conclusion and acknowledgements

- Efforts for more than 20 years within [RMCL1](#) and [RMCL2](#), important for evaluating $\alpha_{\mu}^{HVP,LO}$ and for fits to Standard Model (running of α_{em})
- Reliable estimates of $\alpha_{\mu}^{HVP,LO}$ and fits to SM depend on the correctness of data and on the correct treatment of radiative corrections
- We are contributing with a database for low-energy hadronic cross sections with relevant information (RC treatment, systematic errors, ...): over 60 database entries among 3 channels (there will be ~ 200 entries in total). Stay tuned for updates on <https://precision-sm.github.io/>!
- This work was supported by the European Union STRONG2020 project under Grant Agreement Number 824093
- We thank the collaborations for providing us with the relevant data!!

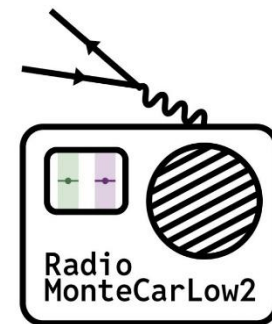


THANK YOU VERY MUCH FOR YOUR ATTENTION!



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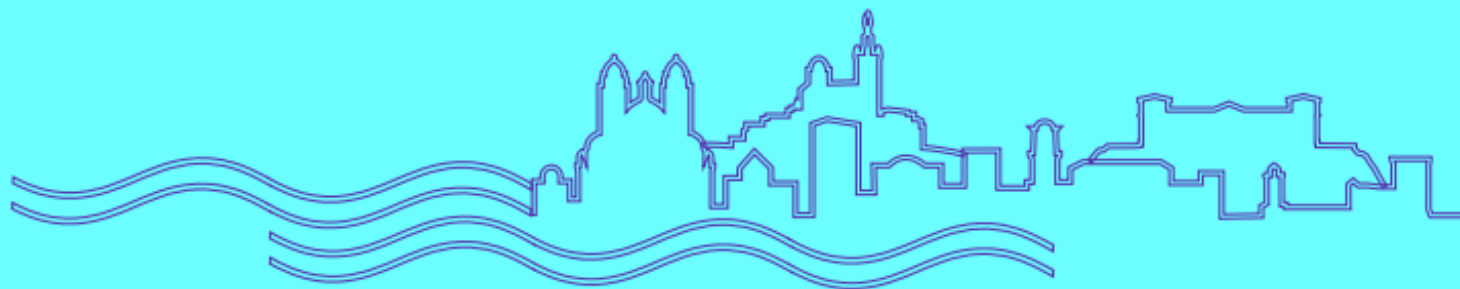


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BACKUP SLIDES