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

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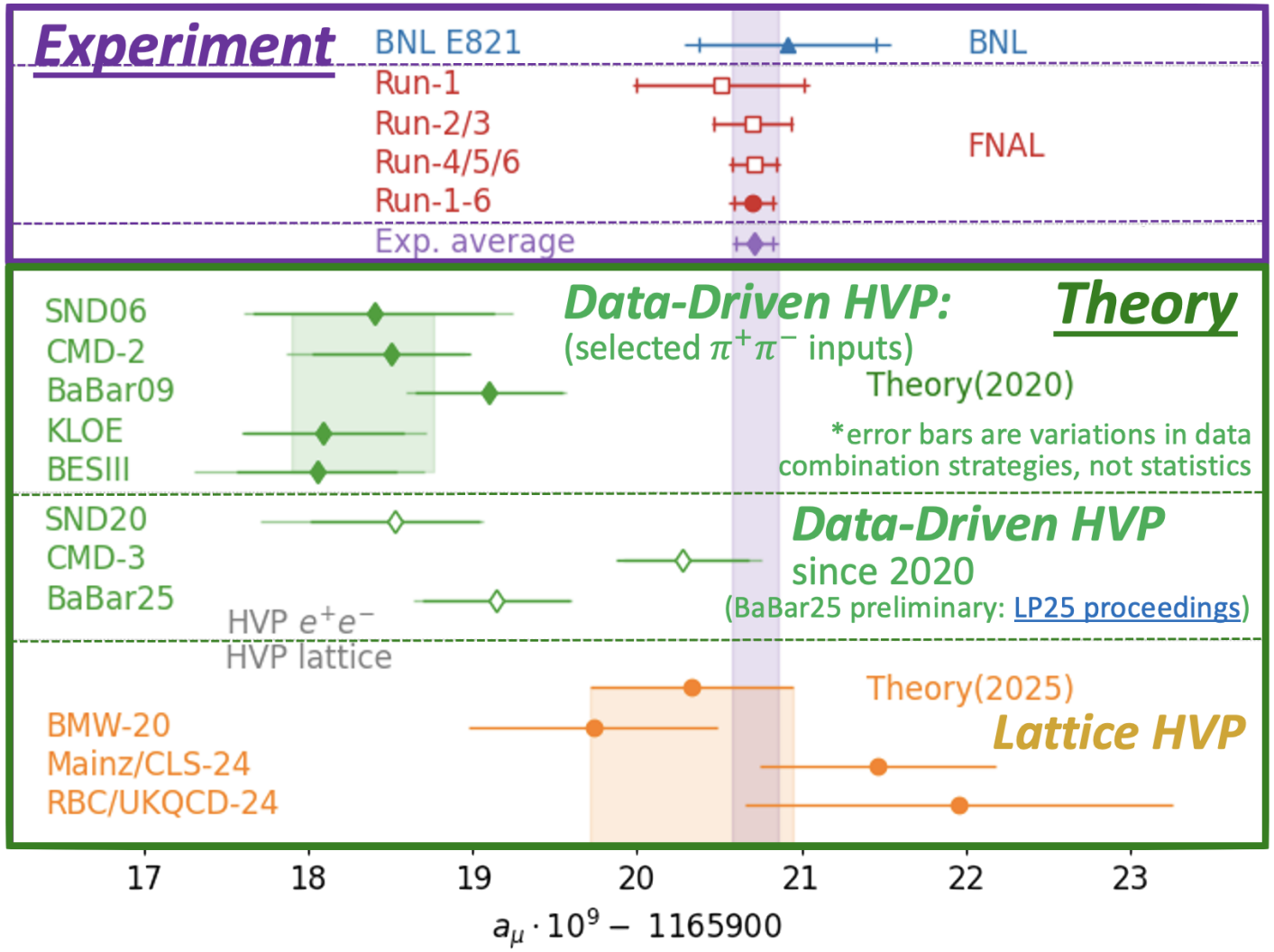
Muon $g-2$: theory vs experiment



Experimental Measurements:

Decades of measurements at CERN, BNL, and FNAL culminate in the 2025 experimental world average, achieving an unprecedented precision of 124 ppb.

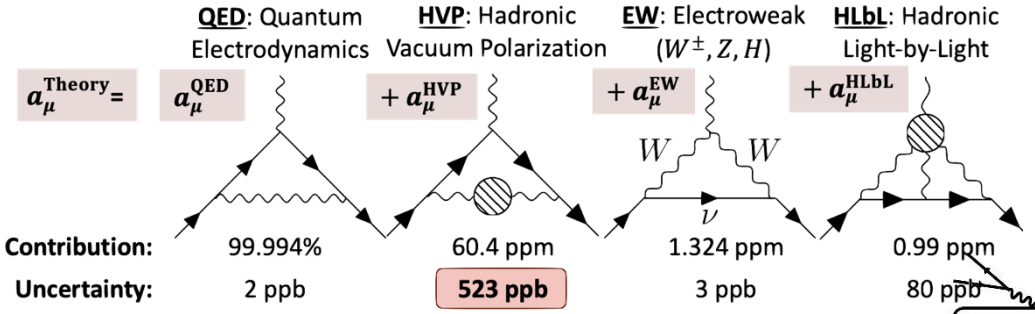
🏅 **Breakthrough Prize 2026 in Fundamental Physics**.

[Phys. Rev. Lett. 135, no.10, 101802 (2025)]

Theoretical Calculation:

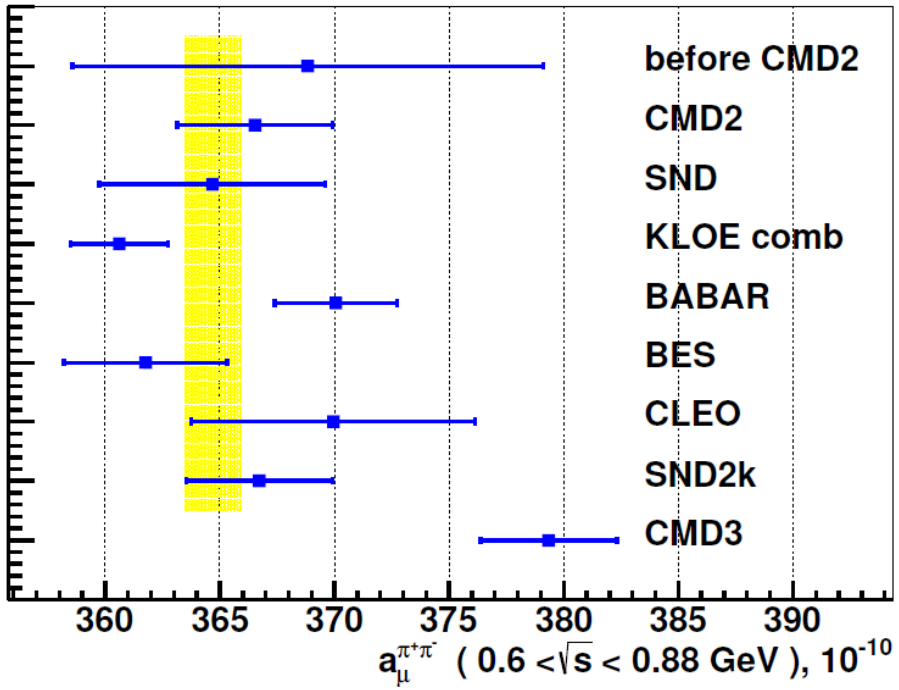
Uncertanty on the prediction of a_μ is dominated by the theoretical uncertanty on the leading order Hadronic Vacuum Polarization (HVP-LO)

[Phys. Rept. 1143, 1-158 (2025)]

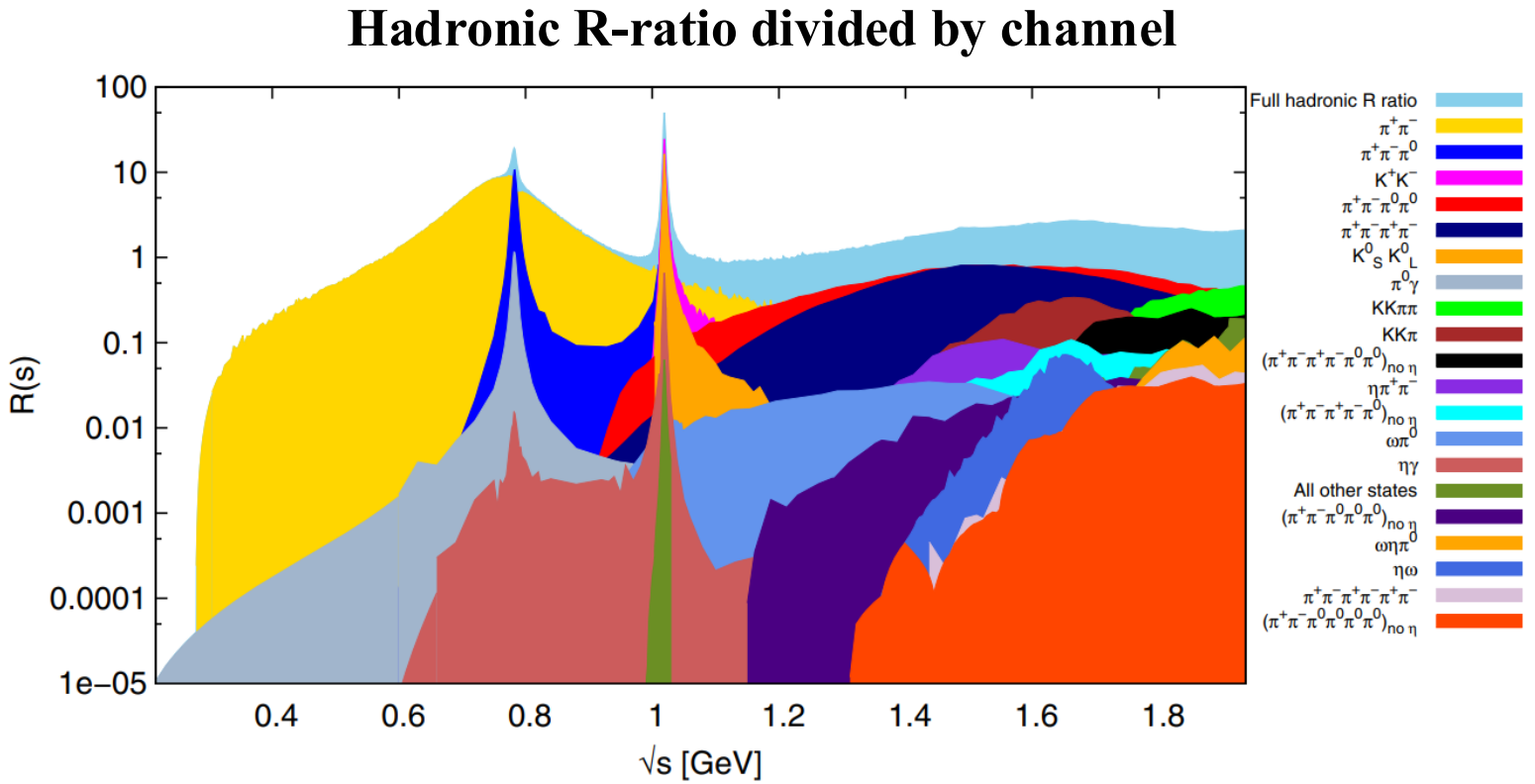


Tensions in the data-driven HVP calculation

Data-Driven HVP requires precise inputs from $e^+e^- \rightarrow hadrons$



[Phys. Rev. D 109, 112002 (2024)]



[Phys. Rev. D 97, 114025 (2018)]

Radio MonteCarLow2

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
- 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 ($+\gamma$ 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 (2010) 66: 585–686
DOI 10.1140/epjc/s10052-010-1251-4

THE EUROPEAN PHYSICAL JOURNAL C

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

S. Actis[38], A. Arbuzov[9,e], G. Balossini[32,33], P. Beltrame[13], C. Bignamini[32,33], R. Bonciani[15], C.M. Carloni Calame[35], V. Cherepanov[25,26], M. Czakon[1], H. Czyż[19,a,f,i], A. Denig[22], S. Eidelman[25,26,g], G.V. Fedotovich[25,26,e], A. Ferroglia[23], J. Gluza[19], A. Grzelińska[8], M. Gunia[19], A. Hafner[22], F. Ignatov[25], S. Jadach[8], F. Jegerlehner[3,19,41], A. Kalinowski[29], W. Kluge[17], A. Korchin[20], J.H. Kühn[18], E.A. Kuraev[9], P. Lukin[25], P. Mastrolia[14], G. Montagna[32,33,b,d], S.E. Müller[22,f], F. Nguyen[34,d], O. Nicrosini[33], D. Nomura[36,h], G. Pakhlova[24], G. Pancheri[11], M. Passera[28], A. Penin[10], F. Piccinini[33], W. Płaczek[7], T. Przedzinski[6], E. Remiddi[4,5], T. Riemann[41], G. Rodrigo[37], P. Roig[27], O. Shekhovtsova[11], C.P. Shen[16], A.L. Sibidanov[25], T. Teubner[21,h], L. Trentadue[30,31], G. Venanzoni[11,c,i], J.J. van der Bij[12], P. Wang[2], B.F.L. Ward[39], Z. Was[8,g], M. Worek[40,19], C.Z. Yuan[2]

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

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

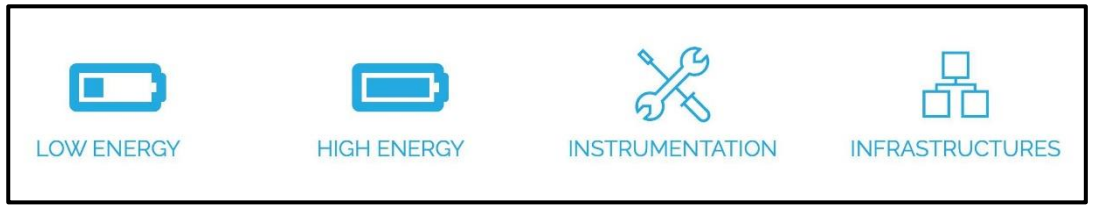
Radiative corrections and Monte Carlo tools for low-energy hadronic cross sections in e^+e^- collisions

Riccardo Aliberti[1], Paolo Beltrame[2], Ettore Budassi[3,4], Carlo M. Carloni Calame[4], Gilberto Colangelo[5], Lorenzo Cotrozzi[2], Achim Denig[1], Anna Driutti[6,7], Tim Engel[8], Lois Flower[2,9], Andrea Gurgone[3,6,7], Martin Hoferichter[5], Fedor Ignatov[2], Sophie Kollatzsch[10,11], Bastian Kubis[12], Andrzej Kupść[13,14⋆], Fabian Lange[10,11], Alberto Lusiani[7,15], Stefan E. Müller[16], Jérémy Paltrinieri[2], Pau Petit Rosàs[2], Fulvio Piccinini[4], Alan Price[17], Lorenzo Punzi[7,15], Marco Rocco[10,18], Olga Shekhovtsova[19,20], Andrzej Siódmok[17], Adrian Signer[10,11⋆], Giovanni Stagnitto[21], Peter Stoffer[10,11], Thomas Teubner[2], William J. Torres Bobadilla[2], Francesco P. Ucci[3,4], Yannick Ulrich[2,5⋆] and Graziano Venanzoni[2,7⋆]
(RadioMonteCarLow 2 working group)

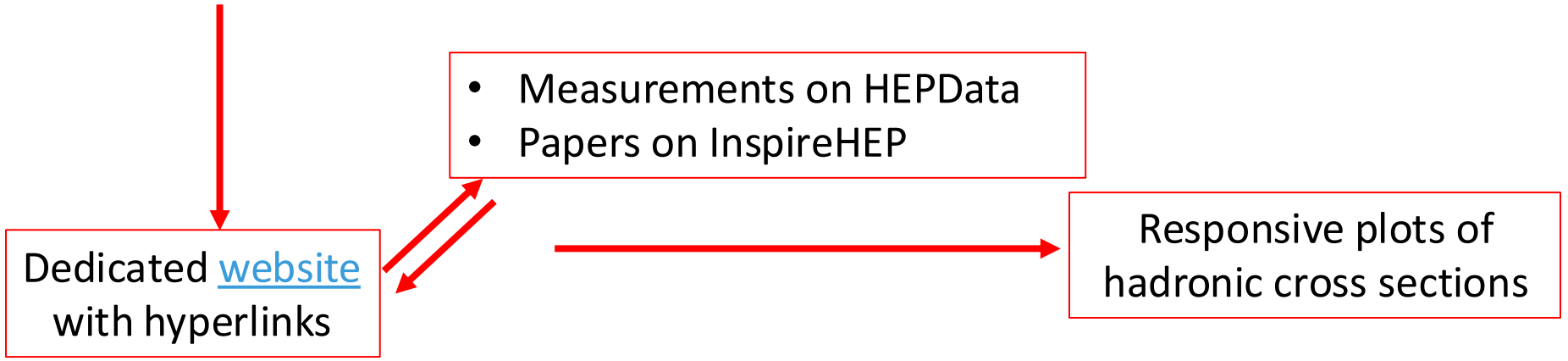
[SciPost Phys. Comm. Rep. 9 (2025)]

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



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**

PrecisionSM annotated database (link)

PrecisionSM Contents Docs About RSS feed Search

Low energy e^+e^- channels database

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

Contents © 2025 PrecisionSM Group - Powered by Nikola

Input data

Database for $e^+e^- \to \pi^+\pi^-$ 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 (DAPHNE, Frascati)	2017	JHEP 03 (2018) 173		details	In Preparation
					In

KLOE (DAPHNE, 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: $\pi^+\pi^-$ (~75% of total contribution); $\pi^+\pi^-\pi^0$; $\pi^0\gamma$

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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

Hide Publication Information

High-statistics measurement of the pion form factor in the rho-meson energy range with the CMD-2 detector

The CMD-2 collaboration

Akhmetshin, R.R. , Aulchenko, V.M. , Banzarov, V.Sh. , Barkov, L.M. , Bashtovoy, N.S. , Bondar, A.E. , Bondarev, D.V. , Bragin, A.V. , Dhawan, S.K. , Eidelman, S.I.

Phys.Lett.B 648 (2007) 28-38, 2007.

https://doi.org/10.17182/hepdata.41782

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Table 1

Data from T 2,F 9

10.17182/hepdata.41782.v1/t1

Measured values of the pion form factor. The errors are statistical only.

Table 2

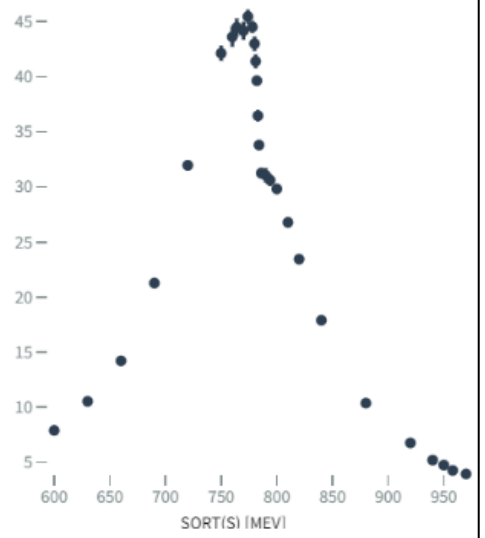
Data from T 2

10.17182/hepdata.41782.v1/t2

Measured value of the bare PI+ PI- cross section including corrections for radiative effects but excluding corrections for vacuum polarization...

RE	E+ E- --> PI+ PI-
SQRT(S)	0.6-0.97 GeV
SQRT(S) [MEV]	ABS(FORMFACTOR(NAME=PION))**2
600.0	7.89 ±0.33 ±0.8% sys,Overall systematic error.
630.0	10.53 ±0.29 ±0.8% sys,Overall systematic error.
660.0	14.21 ±0.34 ±0.8% sys,Overall systematic error.
690.0	21.27 ±0.42 ±0.8% sys,Overall systematic error.
720.0	31.96 ±0.[illegible] ±0.8% sys,Overall systematic error.
750.0	42.13 ±0.62 ±0.8% sys,Overall systematic error.
760.0	43.62 ±0.83 ±0.8% sys,Overall systematic error.
764.0	44.4[illegible] ±0.73 ±0.8% sys,Overall systematic error.

Visualize



Sum errors ☑ Log Scale (X) ☐

Log Scale (Y) ☐

Paper on Inspire

Tables of available data

Statistical and systematic errors, with comments

User-friendly plot

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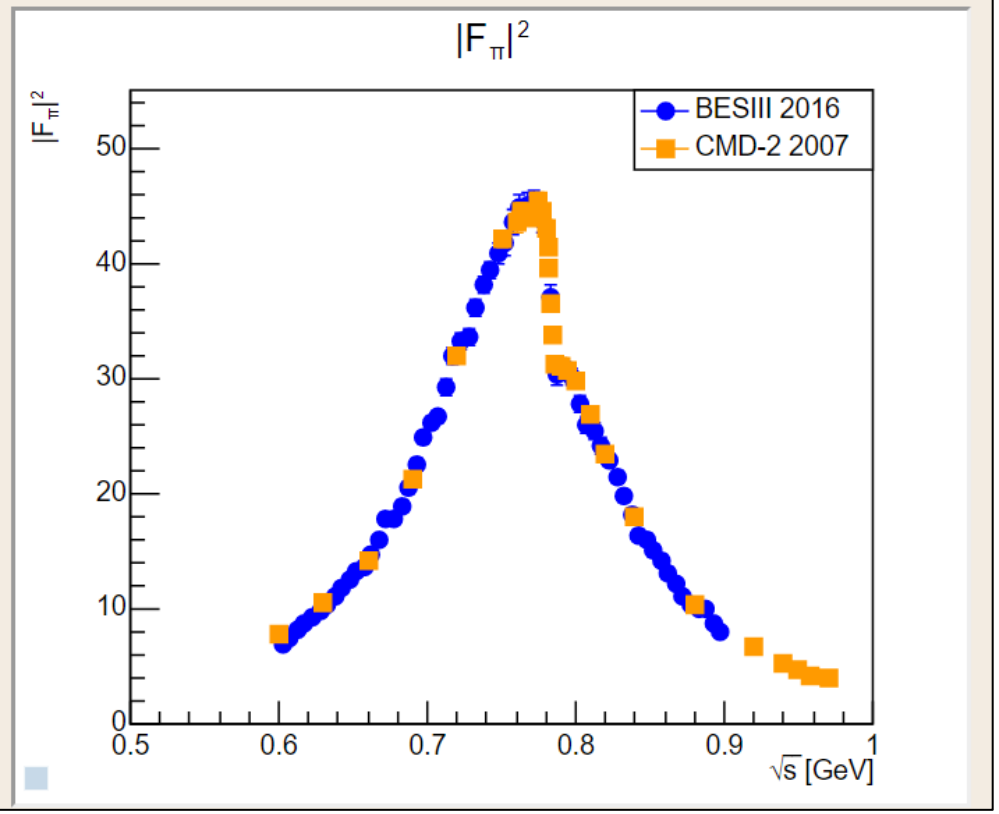
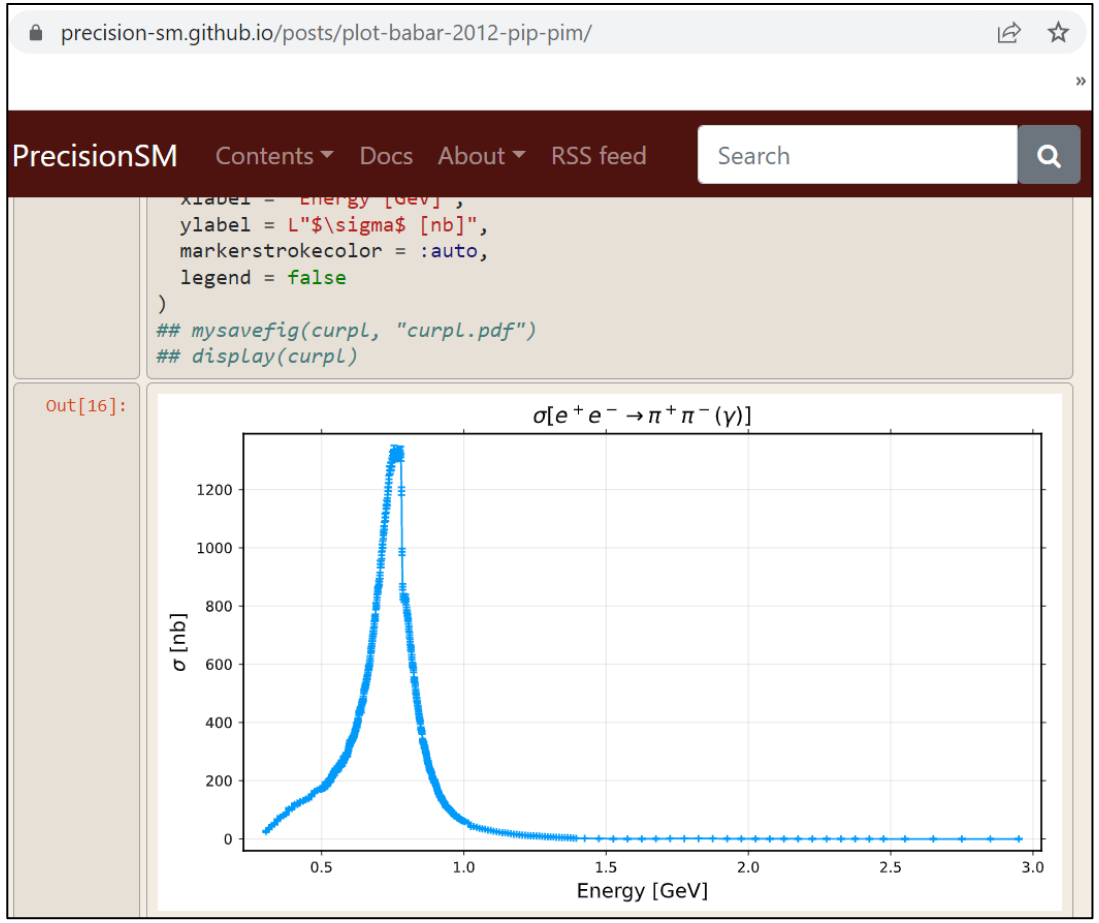
Examples of notebooks and responsive plots

Pion Form Factor

Hovering the cursor above the points reveals the respective x and y values.



BABAR $\sigma\left(e^+e^- \to \pi^+\pi^-(\gamma)\right)$



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

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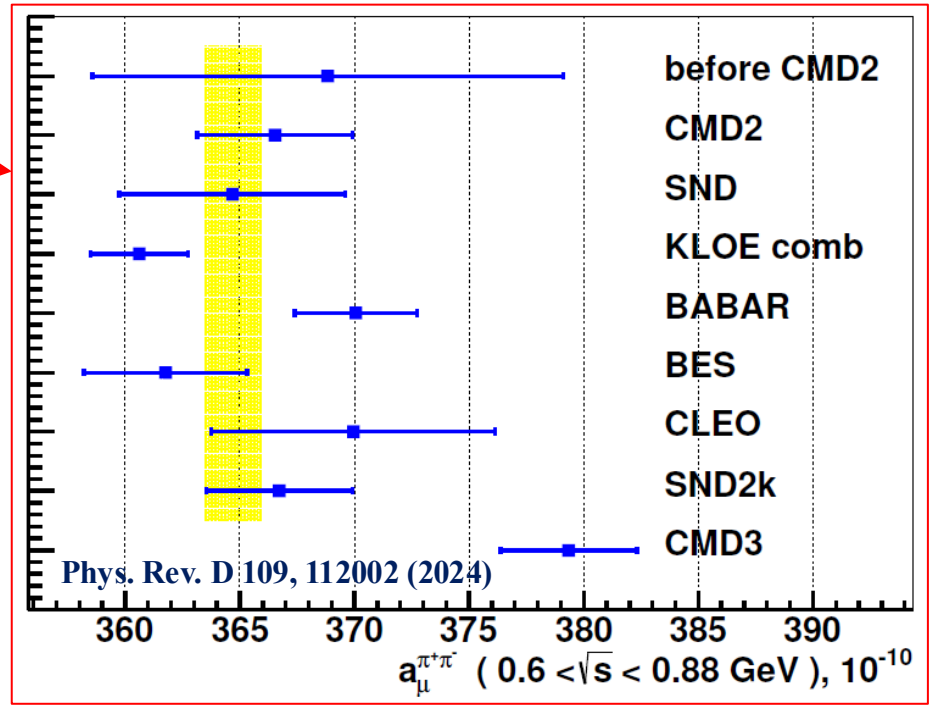
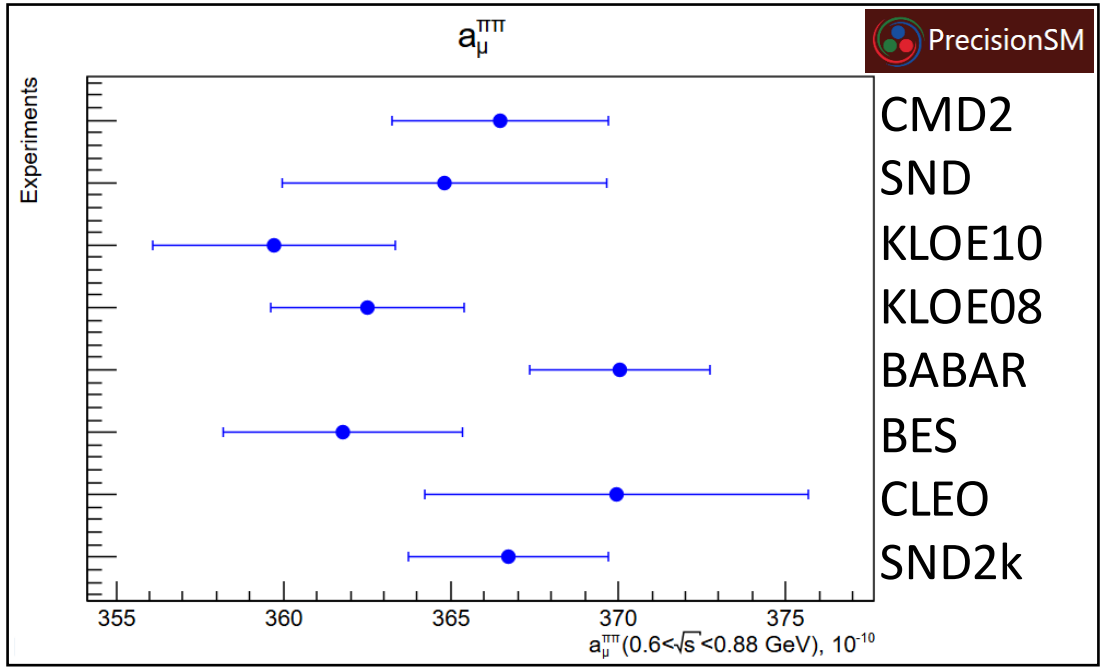
Work in progress: plot of contributions to $a_\mu^{HVP,LO}$

- 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: [~0.6, ~0.9] GeV, which contributes the most to the cross section



NEW!



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

List of previous talks, posters and proceedings

Now available here

List of Past Presentations

June 2026: 14th International Workshop on e^+e^- collisions from Phi to Psi (PhiPsi26) - Pisa, Italy.

- Title: "PrecisionSM: an annotated database for low-energy positron-electron hadronic cross sections"
- Contribution: Presentation
- Proceeding: In preparation

July 2025: 2025 European Physical Society Conference on High Energy Physics (EPS-HEP2025) - Marseille, France.

- Title: "PrecisionSM: an annotated database for low-energy positron-electron hadronic cross sections"
- Contribution: Presentation
- Proceeding: PoS EPS-HEP2025 (2026) 287

6 presentations, 4 posters, 8 proceedings

Radio MonteCarLow2

Summary, conclusion and acknowledgements

- Efforts for more than 20 years within RMCL1 and RMCL2, important for evaluating $a_\mu^{HVP,LO}$ and for fits to Standard Model (running of α_{em})
- Reliable estimates of $a_\mu^{HVP,LO}$ 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!

Stay tuned for updates on https://precision-sm.github.io/!