PROCEEDINGS OF SCIENCE

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

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PrecisionSM is an annotated database that compiles the available data on low-energy cross sections of electron-positron collisions into hadronic channels. This database organizes and collects data samples from e^+e^- experiments, which are used as input for the data-driven theoretical evaluation of the muon anomalous magnetic moment, a_μ, serving as a precise test of the Standard Model when compared to the experimental measurements of a_μ. The database is accessible through a custom website (https://precision-sm.github.io) which contains details about the data samples, such as the treatment of radiative corrections, as well as links to papers on INSPIRE-HEP and to tables on HEPData.

The PrecisionSM database was developed within a Joint Research Initiative in the group application of the European hadron physics community, STRONG2020, and is now incorporated into the RadioMonteCarLow2 Working Group (RMCL2 WG) activities, which have the more general goal of improving the theoretical description of scattering processes at e^+e^- colliders. The results of Phase I of the new RMCL2 WG have been published in Ref. [1].

In this proceeding, we will report on the status of the PrecisionSM database, which currently contains a list of the dominant 2π channel as well as 3π and $\pi^0\gamma$, and on the ongoing work for the other channels and for responsive plots.

The European Physical Society Conference on High Energy Physics (EPS-HEP2025)
7-11 July 2025
Marseille, France

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1. Introduction

The measurements of low-energy hadronic cross sections in e^+e^- collisions are a key ingredient to probe the Standard Model (SM) of Particle Physics, and investigate any physical effects that are not yet explained by it. The $e^+e^- \to hadrons$ data can be used as input for the evaluation of the running of α_{em}, the electromagnetic coupling constant, and also for the determination of the hadronic contribution to the anomalous magnetic moment of the muon, a_μ, in the so-called "data-driven dispersive approach". The leading order hadronic contribution to a_μ is obtained through the integral in Eq. (1) [2, 3]:

$$a_\mu^{\mathrm{HLO}} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{s_{\mathrm{thr}}}^{\infty} ds \frac{\hat{K}(s)}{s^2} R_{\mathrm{had}}(s) \tag{1}$$

$$R_{\mathrm{had}}(s) = \frac{3s}{4\pi\alpha^2}\sigma^0 \left[e^+e^- \to \mathrm{hadrons}(+\gamma)\right], \tag{2}$$

where m_μ is the muon mass, $\alpha \equiv e^2/(4\pi)$ is the fine structure constant, $\hat{K}(s)$ is a kinematic kernel function and $R_{\mathrm{had}}(s)$ is the hadronic R-ratio, i.e. the total $e^+e^- \to$ hadrons cross section normalized to the Born cross section $e^+e^- \to \mu^+\mu^-$ in the point-like approximation. The superscript 0 in σ^0 indicates the *bare* cross section, "undressed" from Vacuum Polarization effects, to prevent double counting; in addition, the cross section used in the integral must be inclusive of final-state radiation of additional photons.

In 2020, the Muon $g-2$ Theory Initiative recommended a theoretical value for a_μ that was based on the dispersive approach for the leading-order hadronic contribution, with a total precision of 370 ppb [2]; this value was in 3.7 σ tension with the experimental value for a_μ at the time [4]. In 2021, the BMW collaboration published the first calculation of a_μ^{HLO} with sub-percent precision [5] based on an alternative approach, namely "lattice QCD". This result, when used for the calculation of a_μ, was closer to the experimental value for a_μ and in 2.2 σ tension with the value from the dispersive approach. Moreover, in 2023, the CMD-3 collaboration released new results for the $e^+e^- \to \pi^+\pi^-$ cross section which disagreed with all the previous measurements used as input to the 2020 recommendation, and which were less in tension with the experimental value when used individually for the HLO dispersive approach [6]. In 2025, the Muon $g-2$ collaboration at Fermilab published the final experimental value for a_μ, reaching the unprecedented precision of 124 ppb when combined with previous experimental results [7]; in the same year, the Muon $g-2$ Theory Initiative recommended a theoretical value for a_μ [3] which was based solely on lattice QCD for the evaluation of a_μ^{HLO}, and which implied no tension between the SM and experiment at the current level of precision. The persisting tensions within the e^+e^- hadronic cross section measurements used for the dispersive approach, as well as the increased a_μ experimental precision, motivated renewed efforts to shed light on the discrepancies and further improve the accuracy of the dispersive approach.

2. The STRONG2020 and RadioMonteCarLow2 activities

From 2006 to 2019, a community of experimentalists and theorists cooperated synergically within the RadioMonteCarLow Working Group (WG) with the goal of studying radiative corrections and

Monte Carlo generators. The WG produced a final report [8] which contained an overview and future prospects of the experimental results and status of Monte Carlo generators for each of the five sections: high-precision luminosity measurements at low energies meson factories; aspects of the direct R measurement performed at $e^+e^- \to hadrons$ experiments with energy scans; Initial State Radiation; τ-lepton physics; calculation of vacuum polarization with emphasis on the hadronic contributions. The efforts of this WG were recently revived with the publication of new theoretical and experimental inputs to a_μ. From 2020 to 2024, the European Union STRONG2020 Project (see http://www.strong-2020.eu/) incorporated parts of the RadioMonteCarLow WG, with the aim of studying strong interactions by combining knowledge from many frontiers: high and low energy physics, instrumentation and research infrastructures. The Project was concluded in 2024, and the activities of the former WG were incorporated in the newly established RadioMonteCarLow2 WG, which published its first report in 2024 [1, 9].

3. PrecisionSM: the Precision Standard Model Database

Within the STRONG2020 Project, the PrecisionSM database started as a specific goal of the JRA3-PrecisionSM activity, which focused on the precise determination of SM parameters, such as: the anomalous magnetic moment of the muon, a_μ; the CKM matrix element V_{ud} from β decay; the extraction of the weak mixing angle from parity-violating electron scattering [10].

PrecisionSM is an annotated database for low-energy hadronic e^+e^- cross sections available in literature, accessible through the following website: https://precision-sm.github.io, created by a Nikola static website generator (https://getnikola.com/), based on the files stored on the PrecisionSM GitHub repository. The database is divided by hadronic channels and for each channel it provides a list of the published experiments that measured the cross section, with annotated comments and links to the data.

The PrecisionSM database is built in the following steps:

1. **Data Collection.** In this phase, we make a list of all the experimental measurements that should be included in the input to the hadronic R-ratio, based on consultations with experts and on previously published reviews, such as the ones in Ref. [3, 11]. The list is divided into sublists based on the hadronic channel, and as a first step we started from the $\pi^+\pi^-$ final state, which accounts for most of the contribution to a_μ^{HLO} through Eq. (1). The following collected channels were $\pi^+\pi^-\pi^0$ and $\pi^0\gamma$, recently posted on the website.

2. **Upload of data in a public repository.** In this step, we communicate with the experimental collaborations to identify an expert point-of-contact. The expert submits the published data to the public repository HEPData (https://www.hepdata.net/) and appoints a reviewer, who will perform a cross-reference validation on the data based on the paper published on INSPIRE-HEP (https://inspirehep.net/).

3. **Catalogue data in an accessible way.** Once the entry on HEPData is validated and posted, it is then indexed on the PrecisionSM database. Fig. 1 shows, as an example, the table for

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
KLOE (DAPHNE, Frascati)	2012	Phys.Lett.B 720 (2013) 336-343		details	In Preparation
KLOE (DAPHNE, Frascati)	2010	Phys.Lett.B 700 (2011) 102-110	ins859660	details	Finalized
KLOE (DAPHNE, Frascati)	2008	Phys.Lett.B 670 (2009) 285-291	ins797438	details	In Review
KLOE (DAPHNE, Frascati)	2004	Phys.Lett.B 606 (2005) 12-24, 2005	ins655225	details	In Review
MEA (ADONE, Lab. Naz. Frascati)	1980	Lett.Nuovo Cim. 28 (1980) 337-342	ins158283	details	Finalized
MEA (ADONE, Lab. Naz. Frascati)	1977	Phys.Lett.B 67 (1977) 239-242	ins124109	details	Finalized
BCF (ADONE, Lab. Naz. Frascati)	1975	Lett.Nuovo Cim. 14 (1975) 418	ins100180	details	Finalized
NA007 (CERN)	1984	Phys.Lett.B 138 (1984) 454-458	ins195944	details	Finalized
ACO (Orsay)	1976	LAL-1287	ins109771	details	Finalized
ACO (Orsay)	1972	Phys.Lett.B 39 (1972) 289-293	ins73648	details	Finalized
DM2 (DCI, Orsay)	1989	Phys.Lett.B 220 (1989) 321-327	ins267118	details	Finalized
DM1 (DCI, Orsay)	1978	Phys.Lett.B 76 (1978) 512-516	ins134061	details	Finalized
SND (VEPP-2000, Novosibirsk)	2021	JHEP 01 (2021) 113	ins1789269	details	Finalized
SND (VEPP-2M, Novosibirsk)	2005	J.Exp.Theor.Phys. 101 (2005) 6, 1053-1070, Zh.Eksp.Teor.Fiz. 128 (2005) 6, 1201-1219 [errata: HEP-EX/0605013]	ins686349	details	Finalized
CMD3 (VEPP-2M, Novosibirsk)	2024	Phys.Rev.D 109 (2024) 11, 112002	ins2634277	details	In Preparation
CMD2 (VEPP-2M, Novosibirsk)	2007	Phys.Lett.B 648 (2007) 28-38	ins728302	details	Finalized
CMD2 (VEPP-2M, Novosibirsk)	2006	JETP Lett. 84 (2006) 413-417, Pisma Zh.Eksp.Teor.Fiz. 84 (2006) 491-495	ins728191	details	Finalized
CMD2 (VEPP-2M, Novosibirsk)	2005	JETP Lett. 82 (2005) 743-747, Pisma Zh.Eksp.Teor.Fiz. 82 (2005) 841-845	ins712216	details	Finalized
CMD2 (VEPP-2M, Novosibirsk)	2002	Phys.Lett.B 527 (2002) 161-172 [errata: HEP-EX/0308008]	ins568807	details	Finalized
OLYA (VEPP-2M, Novosibirsk)	1984	Nucl.Phys.B 256 (1985) 365-384	ins221309 Table 1	details	Finalized
CMD (VEPP-2M, Novosibirsk)	1983	Nucl.Phys.B 256 (1985) 365-384	ins221309 Table 2	details	Finalized
TOF (VEPP-2M, Novosibirsk)	1981	Yad.Fiz. 33 (1981) 709-714, Sov.J.Nucl.Phys. 33 (1981) 368-370	ins167191	details	Finalized
VEPP-2 (Novosibirsk)	1972	Phys.Lett.B 41 (1972) 205-208	ins75634	details	Finalized
VEPP-2 (Novosibirsk)	1971	Phys.Lett.B 34 (1971) 328-332	ins69313	details	Finalized
VEPP-2 (Novosibirsk)	1969	Yad.Fiz. 9 (1969) 114-119, Phys.Lett.B 25 (1967) 6, 433-435	ins57008	details	Finalized

Figure 1: Screenshot of the PrecisionSM table that lists all published measurements in the $e^+e^- \to \pi^+\pi^-$ channel. The up-to-date version of the table, accompanied by details on each experimental result, is accessible on the PrecisionSM website from the following link: https://precision-sm.github.io/2pi-db/.

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the $\pi^+\pi^-$ channel: each entry contains a link to the published paper on INSPIRE-HEP, to the data tables on HEPData, and the "details" link that points to notes on the bottom of the webpage. The additional information for each experiment includes: the range of energy for the cross section measurement; the treatment of radiative corrections and the Monte Carlo generators used; any other details on the experimental technique that might be of interest for any kind of comparisons among experiments.

As a last step, the PrecisionSM website provides templates for tools to read from HEPData tables and prepare user-friendly responsive plots, at the link in Ref. [12], with examples shown in Fig. 2. Currently, an additional plot is in preparation, that evaluates the $\pi^+\pi^-$ contribution to the integral of Eq. (1), for each of the published experiments that cover the energy range $[0.6, 0.88]$ GeV, with a calculation of the error bars that takes into account covariance matrices when provided.

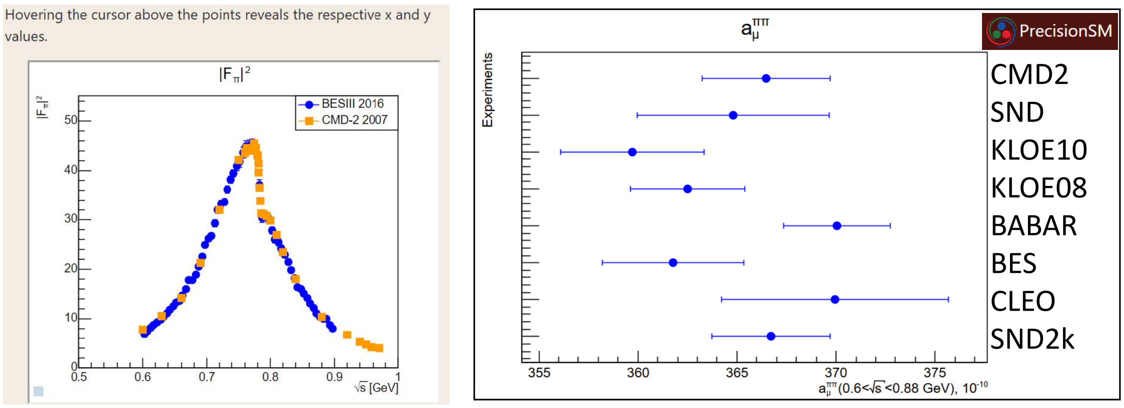

Figure 2: Example of responsive plots of hadronic measurements stored in HEPData [12]. The right-hand plot evaluates the integral of Eq. (1) for the 2π channel and is in preparation.

4. Conclusions

The STRONG2020 and RadioMonteCarLow(2) Working Groups have been facilitating the collaboration between the experimental and theoretical groups for 20 years, with the common goal of studying radiative corrections and Monte Carlo generators for low-energy hadronic e^+e^- processes. Within these projects, the PrecisionSM activity is contributing with an annotated database for low-energy hadronic cross sections that compiles relevant information (e.g. Radiative Corrections treatment and systematic errors) for previously published $e^+e^- \to hadrons$ results, with the possibility to interact with responsive plots that take HEPData tables as an input. The database currently contains more than 60 entries over three hadronic channels, and it will be expanded in order to list all the relevant channels. The information written in the PrecisionSM database are accessible to everyone and could be used, for example, by independent groups to calculate a_μ^{HLO} [1]. All of these efforts have recently been revived by the measurement of the $e^+e^- \to \pi^+\pi^-$ cross section with the CMD-3 detector [6] which is in tension with the previously published measurements, by the

[1]The authors of Ref. [13] plan to use the database to continue their work on Treed Gaussian processes to model the *R*-ratio.

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new sub-percent lattice QCD calculations of the leading-order hadronic contribution to the muon magnetic anomaly [3, 5], and by the final measurement from the Fermilab Muon $g-2$ collaboration of the anomalous magnetic moment of the muon with unprecedented precision [7].

Acknowledgments

This work was supported by the European Union STRONG2020 project under Grant Agreement Number 824093, and by the Leverhulme Trust, `LIP-2021-014`.

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