PROCEEDINGS OF SCIENCE

PrecisionSM: an annotated database for low-energy electron-positron into hadrons

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PrecisionSM (precision Standard Model) is an annotated database for low-energy electron-positron into hadrons data developed within the European Project STRONG2020. The database relies on a custom made website that contains an up-to-date list of the published measurements with links to their HEPData locations and some examples of tools to elaborate them. The database contains information about the datasets, the systematic uncertainties and the treatment of radiative corrections. Such information is important for precision tests of the Standard Model like the calculation of anomalous magnetic moment of the muon whose accuracy relies on the quality of $e^+e^- \rightarrow hadrons$ data. This proceeding describes the status of the PrecisionSM annotated database, and shows examples on how the information are displayed in the webpage.

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1. Introduction

The measurements of low-energy positrons-electrons collisions into hadrons ($e^+e^- \rightarrow hadrons$) are fundamental to investigate some physics effects not yet explained by the Standard Model (SM) of particle physics. In particular, they are a key ingredient in the precision test of the SM performed by comparing the experimental measurement and theoretical calculations of the muon anomalous magnetic moment $a_\mu = (g-2)/2$, where g is the gyromagnetic factor of the muon. In fact, since a_μ comprises terms from the QuantumElectroDynamics (QED), ElectroWeak (EW) and Quantum-ChromoDynamics (QCD) theories, it is a key observable for precisely probing the SM. Recently there have been improvements on the knowledge of the anomalous magnetic moment of the muon in both experimental and theoretical fronts.

In the experimental side, the new world average experimental value of the muon anomalous magnetic moment, obtained combining the experimental measurements from the Fermilab experiment published in 2021 (first result [1]) and in 2023 (twice-precise second result [2]), and from the BNL experiment published in 2006 [3], is $a_\mu^{Exp} = 116592059(22) \times 10^{-11}$, which has a precision of 190 ppb (parts-per-billion).

In the theory side, the Muon $g-2$ theory initiative published in 2020 an updated theoretical calculation of the muon anomalous magnetic moment, a_μ^{SM}, (referred as White Paper, WP, calculation) with 370 ppb precision [4], which differs by 5.1σ from the experimental value a_μ^{Exp}. The major contribution to the uncertainty on the SM calculation is the HVP-LO (Hadronic Vacuum Polarization - Leading Order) QCD-term *i.e.*, the term that accounts for the vacuum fluctuations involving strong interactions between particles. This term cannot be reliably calculated using the perturbative QCD and in [4] has been calculated with a time-like data-driven approach that uses the dispersion relation *i.e.*, Eq. 1:

$$a_\mu^{HVP-LO} = \frac{\alpha^2}{3\pi^2} \int_{m_\pi^2}^{\infty} K(s) \, \frac{R_{had}(s)}{s} \, ds \tag{1}$$

where α, m_π, $K(s)$ are the fine structure constant, the pion mass and, the kernel function respectively; while $R_{had}(s)$ is the ratio of the total $e^+e^- \rightarrow hadrons$ and the Born $e^+e^- \rightarrow \mu^+\mu^-$ cross-sections in the muon mass equal to zero limit (point-like approximation). Hence, to compute $R_{had}(s)$, $e^+e^- \rightarrow hadrons$ experimental data are needed.

In 2021, the BMW collaboration published an alternative calculation of a_μ^{HVP-LO} [5] based on the lattice QCD. This calculation shows a $2.1\,\sigma$ tension with the prediction from the dispersive approach used in [4]. If the lattice QCD prediction for the $HVP-LO$ part of a_μ^{SM} is used instead of the value in Eq. 1, the theoretical value results closer to the experimental value.

Many efforts are ongoing in order to clarify the origin of the discrepancy between the latest theoretical and experimental values and also between the two theoretical calculations of the a_μ^{HVP-LO} term, one of them is to build the Precision Standard Model annotated DataBase (PrecisionSM DB). This project is also reviving part of the efforts of the Radio MonteCarLow working group [6], which in the past focused on the radiative corrections and the Monte Carlo generators for low-energy experiments combining the expertises in the low-energy e^+e^- and τ physics of theoreticians and experimentalists.

2. The Precision Standard Model DataBase

The calculation of a_μ^{HVP-LO} with the dispersion integral of Eq. 1 depends on the ratio $R_{had}(s)$, which is the hadrons-to-muons cross-section ratio for the e^+e^- annihilation processes at energies up to few GeV. These cross-sections comprise many final states channels ($e.g.$, $\pi^+\pi^-$, $\pi^+\pi^-\pi^0$, ...) from several experiments ($e.g.$, SND, CLEO, BES, KLOE, BaBar, ...). Therefore, recently the STRONG2020 [7] project, which is a EU project that aims to study strong interactions combining knowledge from many frontiers (*i.e.*, high and low energy physics, instrumentation and research infrastructures), promoted an activity called JRA3-PrecisionSM which focuses on precise tests of the SM such as the high precision determination of: the muon anomalous magnetic moment a_μ, the CKM matrix element V_{ud} from beta decay, and the weak mixing angle from parity violating electron scattering [8]. Within this activity one of the goals is to produce an annotated database that collects all the low-energy hadronic cross-sections that are available in literature [9].

In particular, the steps for the construction of the annotated Precision SM DataBase for the low-energy cross sections in $e^+e^- \to hadrons$, are:

1. Collecting all published measurements from all experiments. In this phase, with the help of experts, a full list of the published low energy experimental measurements that should be included in the R-ratio is made. The list is then divided in sublists, one for each final state.

2. Uploading the measurements in the public repository HEPData [10]. We ask to each experiment to identify a person to be the expert point-of-contact. This expert uploads the data in the repository and appoints a reviewer for a cross-reference validation.

3. Cataloguing the measurements in the PrecisionDB Website at the following address: `https://precision-sm.github.io`. All the data are indexed in the PrecisionSM website. For each final state a webpage with a table that contains all the measurements is created. In this table for each measurements are indicated: experiment, paper and year of the publication (linked to the publication page in INSPIRE-HEP website [11]), link to the results uploaded in HEPData and their status (validated or in preparation). In the table there is also a link (under the "details" column) to the lower part of the webpage where for each publication are annotated comments regarding the measurement, such as information about the radiative corrections applied.

4. Preparing examples on how to read HEPData measurements and make responsive plots. The website contains multiple examples on how to submit and visualize the data, see webpages linked in Ref. [12].

At present all the $e^+e^- \to \pi^+\pi^-$ measurements are catalogued as shown in figure 1 where the table of the website page containing the "Database for the $e^+e^- \to \pi^+\pi^-$ channel" information is reported.

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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.)	2016	Phys.Rev.D 86 (2012) 032013		details	In Preparation
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		details	In Preparation
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
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: Picture of the PrecisionSM website page showing the full list of the $e^+e^- \to \pi^+\pi^-$ measurements. Link to the webpage.

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3. Conclusions

The Strong2020 Working Group has the goal of facilitating the collaboration between the experimental and theoretical groups involved in the study of the strong interaction for fundamental research and applications. One of the objectives is to provide an annotated database for low-energy $e^+e^- \to hadrons$ cross-section data (the PrecisionSM DB), which is relevant for understanding the tensions in the Standard Model predictions and with the experimental measurement of the muon anomalous magnetic moment. These efforts have also been recently revitalized by the new high-precision measurement of the anomalous magnetic moment of the muon at Fermilab [2].

4. Acknowledgements

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References

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[7] STRONG2020 Webpage: `http://www.strong-2020.eu`.

[8] Link to STRONG2020 JRA3-PrecisionSM Webpage.

[9] Mini-Proceedings of the STRONG2020 Virtual Workshop on *"Space-like and Time-like determination of the Hadronic Leading Order contribution to the Muon g-2"*, arXiv:2201.12102 [hep-ph].

[10] HepData Webpage: `https://www.hepdata.net`

[11] INSPIRE-HEP Webpage: `https://inspirehep.net`

[12] Precision Standard Model Database Webpages: Example of submission to HEPData; Example on how display data with responsive plots; Example of $e^+e^- \to \pi^+\pi^-$ cross-section plots.