The Strong2020 and Radio MonteCarLow activities

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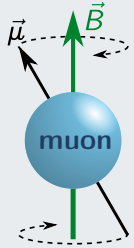
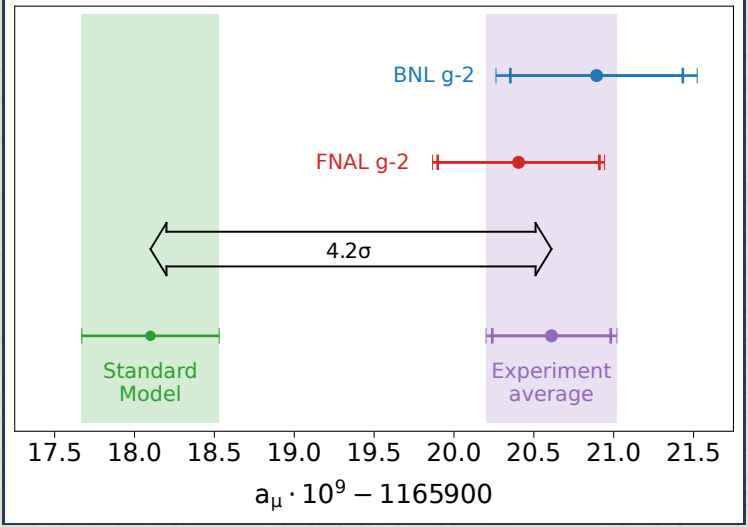
Introduction

Muon spin precession

muon magnetic moment measured 0.46 ppm observing muon spin precession in magnetic field does not match Standard Model theory prediction (similarly precise)

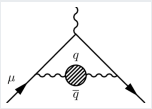


Muon magnetic anomaly discrepancy, April 2021



Introduction

- theory uncertainty dominated by incalculable hadronic QCD contribution to the photon propagator (HVP,LO = Hadronic Vacuum Polarization, Leading Order)



$a_\mu^{\mathrm{HVP,LO}}$ computation

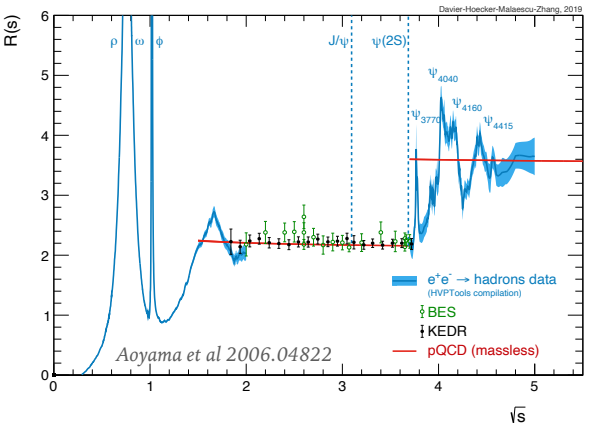
$$a_\mu^{\mathrm{HVP,LO}} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{m_\pi^2}^{\infty} \frac{\hat{K}(s)}{s^2} R(s) ds$$

$$R(s) = \frac{\sigma^0(e^+e^- \to \mathrm{hadrons}(\gamma))(s)}{\sigma^0(e^+e^- \to \mu^+\mu^-(\gamma))(s)}$$

cross sections $\sigma^0(\ldots(\gamma))$

- inclusive of higher order radiative processes
- subtracted of HVP contribution to photon propagator
- $\Delta a_\mu^{\mathrm{HVP,LO}} = 0.57\%$ now
  but 0.23% desirable in near future

$R(s)$ as measured by experiments



Introduction

Radio MonteCarLoW

- Radiative Corrections and Monte Carlo Generators for Low Energies Working Group
- goal: provide best radiative corrections and Monte Carlo generators for low energy e^+e^- data and τ-lepton decays
- http://www.lnf.infn.it/wg/sighad/
- operative since 2006
- highly referenced report in 2010, "Quest for precision in hadronic cross sections at low energy: Monte Carlo tools vs. experimental data", Eur.Phys.J.C66:585-686, 2010

Strong 2020 – PrecisionSM

- EU Horizon 2020 grant agreement n. 824093
- "The strong interaction at the frontier of knowledge: fundamental research and applications"
- http://www.strong-2020.eu/
- Work Package 21, RA3-PrecisionSM: "Precision Tests of the Standard Model"
- goal: annotated database for low-energy hadronic cross sections in e^+e^- collisions
- https://precision-sm.github.io/
- started in 2019
- Proceedings of 2021 Virtual Workshop, arXiv:2201.12102 [hep-ph]

RadioMonteCarLow 2010 report

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

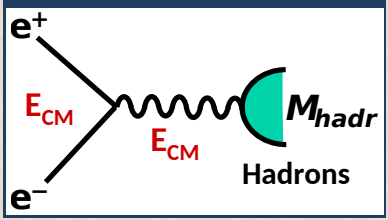
Working Group on Radiative Corrections and Monte Carlo Generators for Low Energies

S. Actis[28], A. Arbuzov[9,e], G. Balossini[32,33], P. Beltrame[13], C. Bignamini[32,33], R. Bonciani[14], C.M. Carloni Calame[35], V. Cherepanov[25,28], M. Czakon[1], H. Czyż[19,a,f,i], A. Denig[22], S. Eidelman[25,26,g,k], G.V. Fedotovich[25,26,c,k], 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,d,l], A. Kalinowski[29], W. Kluge[17], A. Korchin[30], J.H. Kühn[18], E.A. Kuraev[9], P. Lukin[25], P. Mastrolia[14], G. Montagna[32,33,b,i], S.E. Müller[22,f], F. Nguyen[34,e], O. Nicrosini[33], D. Nomura[36,h], G. Pakhlova[24], G. Pancheri[13], 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,b], 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,d], M. Worek[40,19], C.Z. Yuan[2]

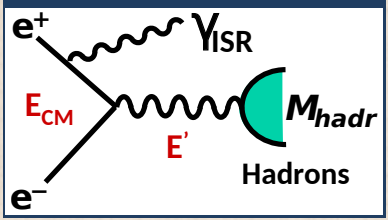
5 sections with overview of experimental results and status of Monte Carlo generators:

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. tau physics
5. calculation of vacuum polarization with emphasis on the hadronic contributions

energy scan measurement



radiative return measurement



RadioMonteCarLow meetings from the web site

20. Meeting 2.03.2019 at the Budker Institute of Nuclear Physics Novosibirsk
19. Meeting 30.06.2017 at Institute for Nuclear Physics Mainz
18. Meeting 19/20.05.2016 at LNF Frascati
17. Meeting 20/21.04.2015 at LNF Frascati
16. Meeting 18/19.09.2014 at LNF Frascati
15. Meeting 11.04.2014 at Mainz
14. Meeting 13.09.2013 at LNF Frascati
13. Meeting 11/12.04.2013 at ECT* Trento
12. Meeting 27/28.09.2012 in Mainz
11. Meeting 16/17.04.2012 in Frascati
10. Meeting 23.06.2011 in Novosibirsk
9. Meeting 28/29.03.2011 in Frascati
8. Meeting 18/19.09.2010 in Liverpool
7. Cancelled Meeting 19/20.04.2010 in Frascati
6. Meeting 17.10.2009 in Beijing
5. Meeting 06.04.2009 - 07.04.2009 in Frascati
4. Meeting 09.10.2008 - 11.10.2008 in Beijing
3. Meeting 11.04.2008 in Frascati
2. Meeting 25.06.2007 - 26.06.2007 in Frascati
1. Meeting 15.10.2006 - 16.10.2006 in Frascati

Additional meetings very related to RadioMonteCarLow

recent meetings

- STRONG2020 (Virtual) meeting, 24-26 November 2021 (https://agenda.infn.it/event/28089/)
- N^3LO kick-off workstop / thinkstart 3-5 August 2022, IPPP Durham (https://conference.ippp.dur.ac.uk/event/1104/)

planned meetings

- WorkStop on "Radiative corrections and Monte Carlo tools for low-energy hadronic cross sections in e+e- collision", 05-09 June 2023, Zurich University

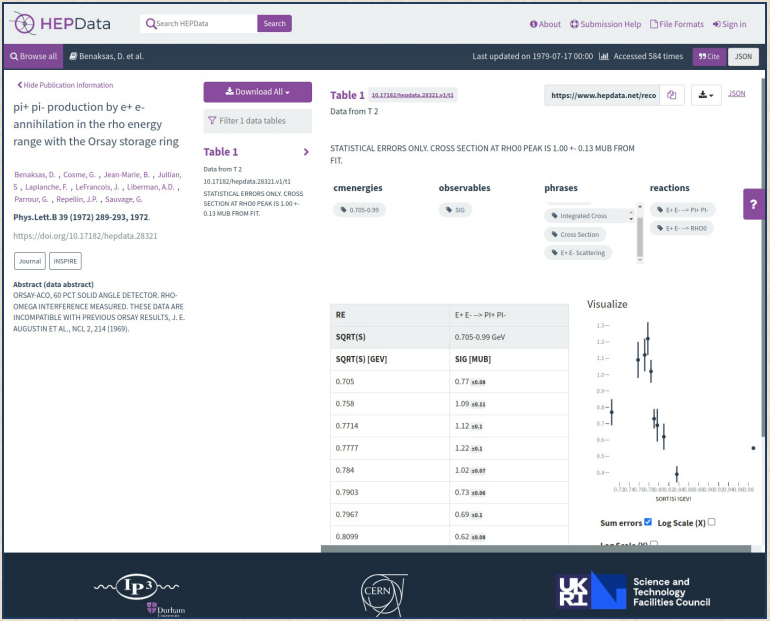
Strong 2020 / PrecisionSM activities

- collect low energy hadronic cross-section measurements in HEPDATA
- maintain annotated database of hadronic cross-section measurements for computation of the HVP,LO contribution to muon magnetic anomaly
- annotated database rendered on dedicated web site, with hyperlinks
- document, with examples, how to use measuremente stored in HEPDATA
- responsive plots of measurements of hadronic cross-sections

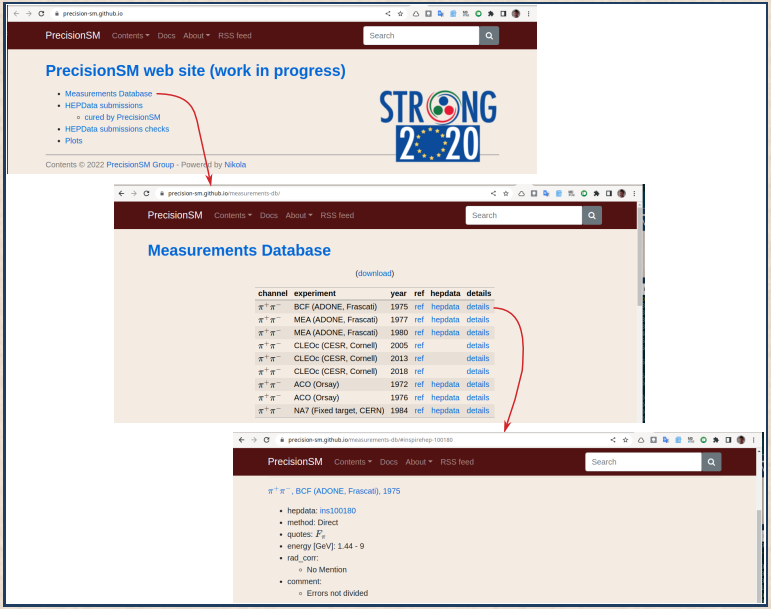
HEPData.net

- HEP data public storage web site, mainly used by LHC experiments
- well defined submission data format, functionally adequate for our data of interest
- uses YAML and JSON, can export to Root format and other formats
- measurements on HEPData.net link their InspireHEP.net publication and InspireHEP.net back-links HEPData.net
- possible to download data and metadata programmatically
- submissions are done by authorized contact persons of collaborations
- submissions have now quite higher quality and reliability than past ones
- some experiments are quite active in promptly uploading their published data

HEPData: example of stored hadronic cross-section measurement



Precision SM: annotated database rendered on web site



PrecisionSM measurement database in YAML text file

- standard text format for numeric and text data
- easy to edit manually
- easily "versioned" in git repository
- easily read/write in Python, C++, etc.

example measurement entry in YAML DB

```
inspirehep-100180:
  channel: $\pi^+\pi^-$
  experiment: BCF (ADONE, Frascati)
  year: 1975
  reference: https://inspirehep.net/literature/100180
  inspirehep: '100180'
  hepdata: ins100180
  method: Direct
  quotes:
  - - $F_\pi$
    - tot
    - stat
    - syst
  E_lo: 1.44
  E_hi: 9.0
  rad_corr:
  - No Mention
  comment:
  - Errors not divided
```

PrecisionSM web site, example of responsive plot

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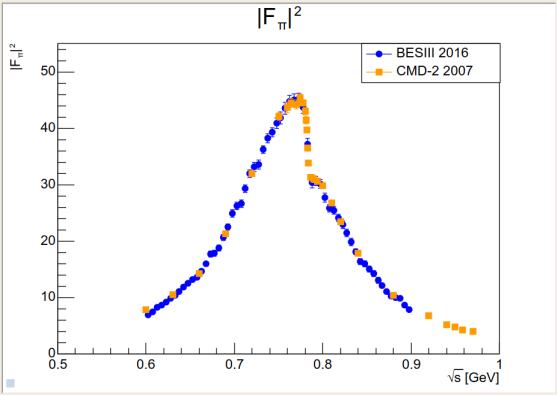
PrecisionSM Group — 2020-09-06 14:36

Example responsive plot

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



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PrecisionSM web site, read HEPData measurements & prepare responsive plot

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Prepare Root Plot with data from HEPData

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get two cross-section measurements from HEPData and plot them

- e+ e- -> pi+ pi- BES-III 2016 https://www.hepdata.net/record/ins1385603
- e+ e- -> pi+ pi- CMD-2 2007 https://www.hepdata.net/record/ins728302

In [1]:

```
from math import *
import re
from pprint import pprint
import urllib.request
from requests.utils import requote_uri
from array import array
import json
import yaml
import itertools
import ROOT
from ROOT import TCanvas, TFile, TProfile, TNtuple, TH1F, TH2F, TLegend
from ROOT import TGraph, TGraphErrors, TGraphAsymmErrors
from ROOT import gROOT, gBenchmark, gRandom, gSystem, gStyle, gPad
```

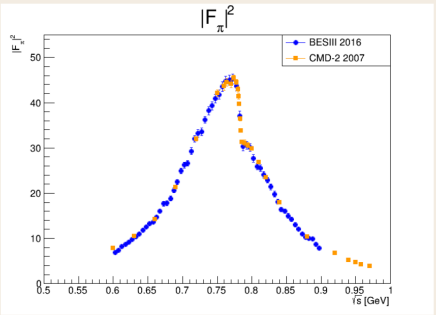
```
Welcome to JupyROOT 6.22/08
```

In [2]:

```
##
## iterator generator using outer product of two lists
## - first list is inner and second one is outer
## - also able to return nth elements of iterator
## - iterator never ends but folds
##
class iterprod2:
  def __init__(self, arr1, arr2):
    self.arr1, self.arr2 = arr1, arr2
  def __iter__(self):
    self.i1 = 0
    self.i2 = 0
    return self
  def __next__(self):
```

In [15]:

```
leg = TLegend(0.65, 0.80, 0.90, 0.90)
leg.SetTextSize(0.035)
leg.AddEntry(ins1385603_gr, ins1385603_gr.GetTitle(), "LP")
leg.AddEntry(ins728302_gr, ins728302_gr.GetTitle(), "LP")
leg.Draw()
canvas.Draw()
```



In [16]:

```
rfile = TFile("precsm-resp-plot-example.root", "recreate")
canvas.Write("F_pip_pim")
rfile.Close()
```

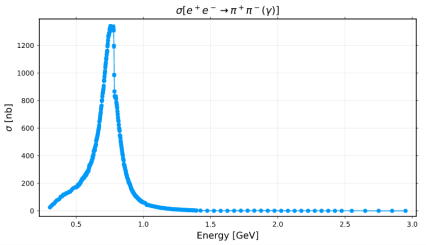
PresisionSM web site, read BaBar $e^+e^- \to \pi^+\pi^-(\gamma)$ and make plots

cross-section

In [56]:

```
##
## plot cross-section vs. energy (stat. unc. only)
##
curpl = @df sigma_df plot(
  :E,
  :sigma_val,
  yerror = :sigma_unc,
  title = L"$\sigma[e^+e^- \rightarrow \pi^+\pi^-(\gamma)]$",
  xlabel = "Energy [GeV]",
  ylabel = L"$\sigma$ [nb]",
  markerstrokecolor = :auto,
  legend = false
)
## mysavefig(curpl, "curpl.pdf")
## display(curpl)
```

Out[56]:

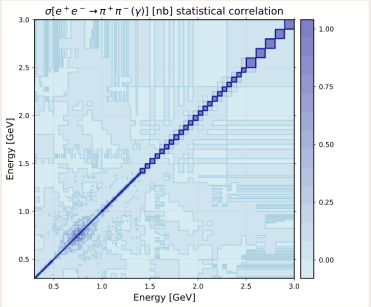


correlation

In [65]:

```
##
## plot statistical correlation contour plot
##
curpl = @df sigma_df contourf(
  range(extrema(vcat(:E_l, :E_h))..., length=500),
  range(extrema(vcat(:E_l, :E_h))..., length=500),
  sigma_stat_corr,
  ## clims = sigma_stat_corr_clims,
  color = :blues,
  title=L"$\sigma[e^+e^- \rightarrow \pi^+\pi^-(\gamma)]$ [nb] statistical correlation",
  xlabel="Energy [GeV]",
  ylabel="Energy [GeV]",
  size=(600, 500)
)
```

Out[65]:



PrecisionSM web site: collaborative framework on github.com

- measurement data base and source web site files on Github repository
- Nikola static web generator generates website (= HTML, CSS and javascript)
- simple procedure to publish on Github Pages at https://precision-sm.github.io/
- web pages are edited in simplified markup languages like Markdown
  - but HTML, CSS and Javascript can be used if desired
- collaborators can be added as editors of Github repository
- git repository keeps tracks of all changes and resolves editing conflicts

Summary

- precision tests of the Standard Model require collection, sophisticated analysis and elaboration of large number of hadronic cross-section measurement
- RatioMonteCarLoW project coordinated development of a variety of tools for the analysis and elaboration of low energy hadronic cross-sections
- Strong2020 PrecisionSM project is assembling an annotated database of hadronic cross-section measurements with a web site that also documents how to use the data