Calculation of $\alpha_\mu^{(\pi^+\pi^-,LO)}$ with the use of a phenomenological dispersive method

Master's Internship

Eirini Lymperiadou

HISKP (Theory), Universität Bonn

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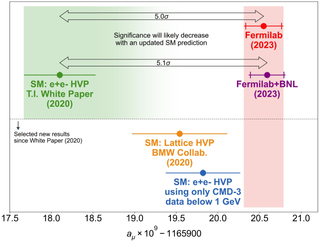
Motivation

- Tension between experiment - SM theory
- Improve errors for α_μ^{had}-result

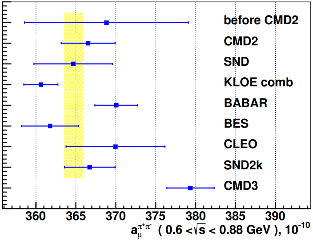
  $\hookrightarrow$ HVP-term: $\alpha_\mu^{\pi\pi,LO}$ ($\sim$ 60%)
- **In SM theory**: higher CMD3 result



[Aguillard D.P. et al., 2023]

Primary topic:

- Use standard dispersion method for $\alpha_\mu^{\pi\pi,LO}$ calculation
- Use of phenomenological $F_\pi^V(s)$ functions to test/reproduce this deviation
- Comparison of BaBar - CMD3 data results
- Use fit parameters for $\mathcal{B}(\omega \to \pi\pi)$ and $\mathcal{B}(\phi \to \pi\pi)$ calculation



[Ignatov F.V. et al., 2023]

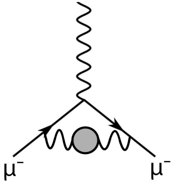
Dispersive method

2.1: Dispersive method for α_μ^{HVP}

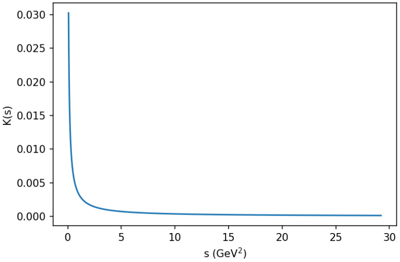
- Use of cross section data for calculation [De Troconiz J.F. & Ynduráin F.J., 2002]:

(LO) HVP Anomalous magnetic moment contribution

$$\alpha_\mu^{\mathrm{HVP},LO} = \frac{1}{4\pi^3}\int_{s_{th}}^{\infty} ds\, \sigma_{(e^+e^-\to\gamma^*\to hadrons)} \cdot \mathrm{K}(s)$$



$\rightarrow$ Analytical kernel function $\mathrm{K}(s)$:

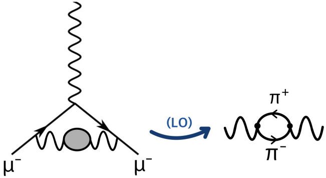


$$\mathrm{K}(s) = \frac{\left(1+x^2\right)(1+x)^2}{x^2}\left(\log(1+x) - x + \frac{x^2}{2}\right) + \frac{x^2}{2}\left(2-x^2\right) + \frac{1+x}{1-x}x^2\log(x)$$

$$x = \frac{1-\sigma_\mu(s)}{1+\sigma_\mu(s)} \quad , \quad \sigma_\mu(s) = \sqrt{1-\frac{4m_\mu^2}{s}}$$

- With respect to the 2-pion vector form factor (VFF):

$$\alpha_\mu^{\pi\pi,LO} = \frac{\alpha^2}{12\pi^2}\int_{4M_\pi^2}^{\infty} ds\, \frac{\beta_\pi^3 \cdot \mathrm{K}(s) \cdot |F_\pi^V(s)|^2}{s}$$



→ Pion velocity : $\beta_\pi = \sqrt{1 - 4\frac{m_\pi^2}{s}}$, α : fine-structure constant [Review of Particle Physics, 2022]

- Due to the analytic structure of $F_\pi^V(s)$ → Dispersion representation of VFF

$$F_\pi^V(s) = \frac{1}{\pi}\int_{4M_\pi^2}^{\infty} \frac{ds'}{s'-s} \cdot \mathrm{Im}F_\pi^V(s')$$

2.2: Omnès function

- Solution constructed analytically → Consider special solution: Omnès function $\Omega(s)$

$$\boxed{F_\pi^V(s) = \Omega(s) \quad \text{with} \quad \Omega(0) = 1}$$

Then:

$$\Omega(s + i\epsilon) = \left|\Omega(s)\right| e^{i\delta(s)}$$
$$\Omega(s - i\epsilon) = \left|\Omega(s)\right| e^{-i\delta(s)}$$

$$\Rightarrow \operatorname{disc} \log \Omega(s) = \log \Omega(s + i\epsilon) - \log \Omega(s - i\epsilon) = 2i\delta(s)$$

for $\delta(s \to \infty) \to$ *constant*, the once-subtracted dispersion relation for $\log \Omega(s)$:

$$\log \Omega(s) = \log \Omega(0) + \frac{s}{\pi} \int_{4M_\pi^2}^{\infty} ds' \, \frac{\delta(s')}{s'(s'-s)} \Rightarrow \Omega(s) = exp\left\{\frac{s}{\pi} \int_{4M_\pi^2}^{\infty} ds' \, \frac{\delta(s')}{s'(s'-s)}\right\}$$

$$\Omega(s) = exp\left\{\frac{s}{\pi} \int_{4M_\pi^2}^{\infty} dx \, \frac{\delta(x)}{x(x-s)}\right\} = exp\left\{\frac{s}{\pi} \int_{4M_\pi^2}^{\infty} dx \, \frac{\delta(x)-\delta(s)}{x(x-s)} + i\delta(s) - \frac{\delta(s)}{\pi} \log\left(\frac{4M_\pi^2 - s}{4M_\pi^2}\right)\right\}$$

where $\delta(s)$: the (elastic) phase shift

Phenomenological model

- **In this project:**

$$F_\pi^V(s) = P(s) \cdot \Omega(s)$$

for the "polynomial" P(s): [1]

- **FF1-type:** $F_\pi^V(s) = \left(1 + \alpha \cdot s + \frac{\epsilon_{\rho\omega} \cdot s}{M_\omega^2 - s - iM_\omega \Gamma_\omega^{tot}}\right) \cdot \Omega(s)$

[1] marked are the fit parameters in each case

3.1: The 2-pion vector form factor

- **In this project:**

$$F_\pi^V(s) = P(s) \cdot \Omega(s)$$

for the "polynomial" P(s): [1]

- **FF1-type:** $$F_\pi^V(s) = \left(1 + \alpha \cdot s + \frac{\epsilon_{\rho\omega} \cdot s}{M_\omega^2 - s - iM_\omega \Gamma_\omega^{tot}}\right) \cdot \Omega(s)$$

- **FF2-type:** $$F_\pi^V(s) = \left(1 + \alpha \cdot s + \frac{\epsilon_{\rho\omega} \cdot s}{{M_\omega}^2 - s - iM_\omega \Gamma_\omega^{tot}}\right) \cdot \Omega(s)$$

[1] marked are the fit parameters in each case

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- **FF2-type:** $$F_\pi^V(s) = \left(1 + \alpha \cdot s + \frac{\epsilon_{\rho\omega} \cdot s}{{M_\omega}^2 - s - iM_\omega \Gamma_\omega^{tot}}\right) \cdot \Omega(s)$$

- **FF3-type:** $$F_\pi^V(s) = \left(1 + \alpha \cdot s + \frac{\epsilon_{\rho\omega} \cdot s}{M_\omega^2 - s - iM_\omega \Gamma_\omega^{tot}} + \frac{\epsilon_\phi \cdot s}{M_\phi^2 - s - iM_\phi \Gamma_\phi^{tot}}\right) \cdot \Omega(s)$$

[1] marked are the fit parameters in each case

- **In this project:**

$$F_\pi^V(s) = P(s) \cdot \Omega(s)$$

for the "polynomial" P(s): [1]

- **FF1-type:** $$F_\pi^V(s) = \left(1 + \alpha \cdot s + \frac{\epsilon_{\rho\omega} \cdot s}{M_\omega^2 - s - iM_\omega \Gamma_\omega^{tot}}\right) \cdot \Omega(s)$$

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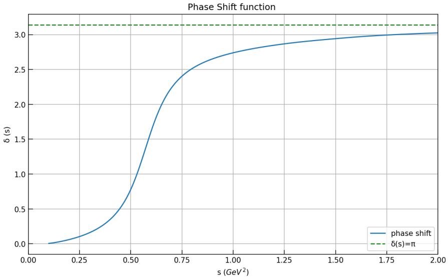
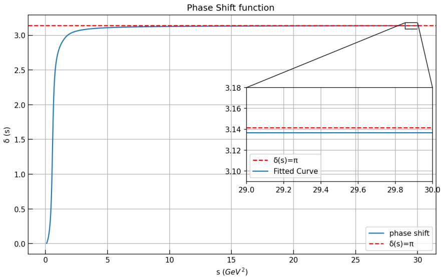
- **FF4-type:** $$F_\pi^V(s) = \left(1 + \alpha \cdot s + \frac{\epsilon_{\rho\omega} \cdot s}{M_\omega{}^2 - s - iM_\omega \Gamma_\omega^{tot}} + \frac{\epsilon_\phi \cdot s}{M_\phi{}^2 - s - iM_\phi \Gamma_\phi^{tot}}\right) \cdot \Omega(s)$$

[1] marked are the fit parameters in each case

$$\delta(s) = \begin{cases} \text{Interpolated function from isospin 1 P-wave phase shift values (Bern)} & \text{, for } \quad 4M_\pi^2 \le s \le s_0 \\ \pi + (\delta(s_0) - \pi)\left(\dfrac{\lambda_0^2 + s_0}{\lambda_0^2 + s}\right) & \text{, for } \quad s \ge s_0 \end{cases}$$

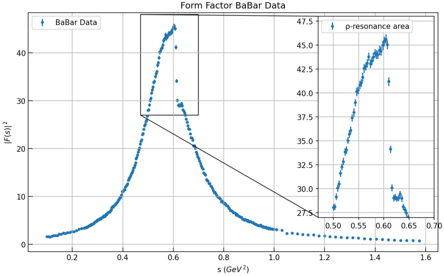
with $s_0 = 25\,(GeV)^2$ and $\lambda_0 =$const.



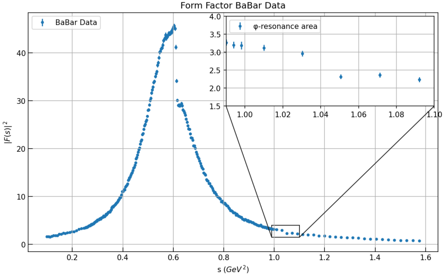


Fits & Results

- BaBar data from measurements of $e^+e^- \to \pi^+\pi^-(\gamma)$ cross section with the Initial-State Radiation (IRS) method [Lees J.P. et al., 2012]

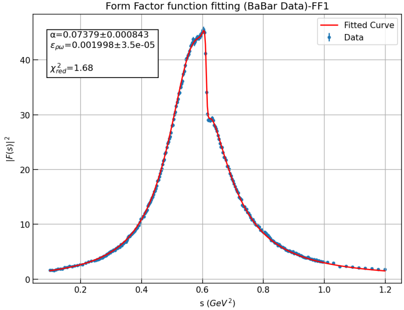


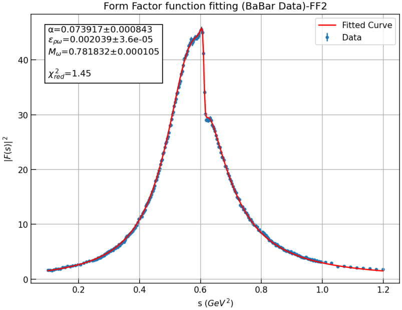
BaBar data with zoom in the behaviour exhibited due to the ω,ρ-mixing.

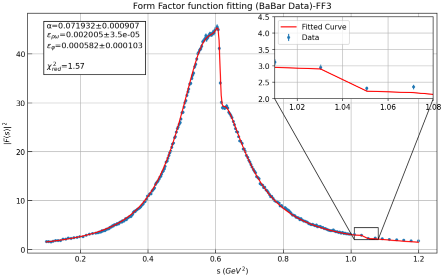


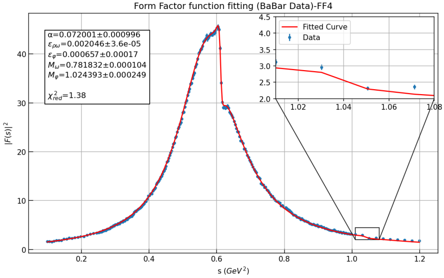
BaBar data with zoom in the behaviour exhibited due to the ϕ-resonance.

4.2: BaBar fits

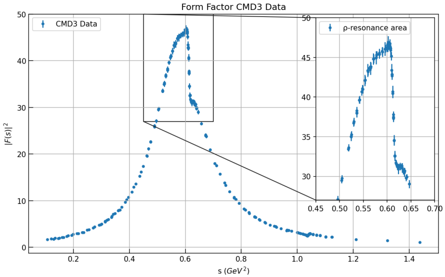




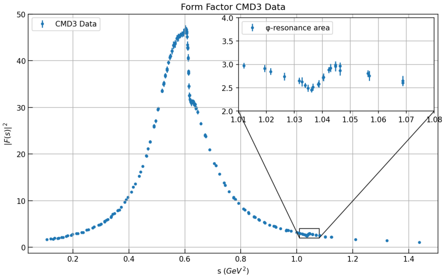




- CMD3 data from measurements of $e^+e^- \to \pi^+\pi^-$ cross section with energy-scan measurement method [Ignatov F.V. et al., 2023]

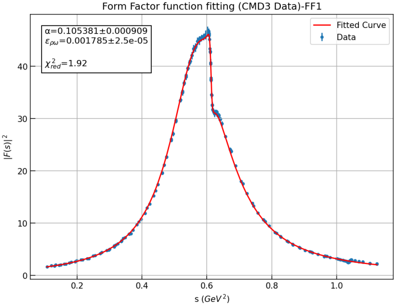


CMD3 data with zoom in the behaviour exhibited due to the ω, ρ-mixing.

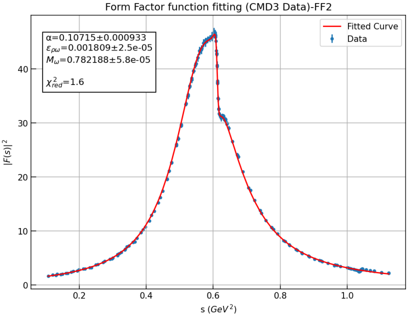


CMD3 data with zoom in the behaviour exhibited due to the ϕ-resonance.

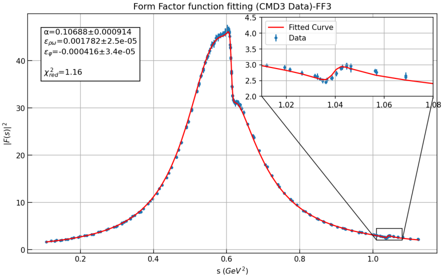
4.4: CMD3 fits



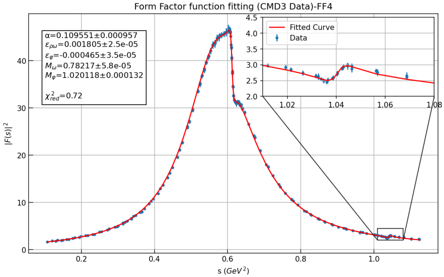
Form Factor function fitting (CMD3 Data)-FF1
α=0.105381±0.000909
$\epsilon_{\rho\omega}$=0.001785±2.5e-05
χ^2_{red}=1.92
Fitted Curve
Data
$|F(s)|^2$
s (GeV^2)



Form Factor function fitting (CMD3 Data)-FF2
α=0.10715±0.000933
$\epsilon_{\rho\omega}$=0.001809±2.5e-05
M_{ω}=0.782188±5.8e-05
χ^2_{red}=1.6
Fitted Curve
Data
$|F(s)|^2$
s (GeV^2)



Form Factor function fitting (CMD3 Data)-FF3
α=0.10688±0.000914
$\epsilon_{\rho\omega}$=0.001782±2.5e-05
ϵ_{φ}=-0.000416±3.4e-05
χ^2_{red}=1.16
Fitted Curve
Data
$|F(s)|^2$
s (GeV^2)

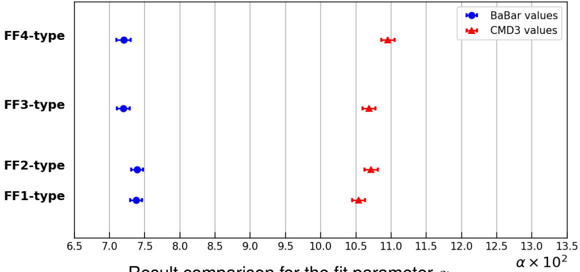


Form Factor function fitting (CMD3 Data)-FF4
α=0.109551±0.000957
$\epsilon_{\rho\omega}$=0.001805±2.5e-05
ϵ_{φ}=-0.000465±3.5e-05
M_{ω}=0.78217±5.8e-05
M_{φ}=1.020118±0.000132
χ^2_{red}=0.72
Fitted Curve
Data
$|F(s)|^2$
s (GeV^2)

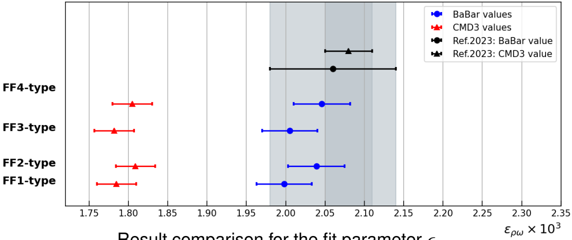
4.5: Results for fit parameters

$F_\pi^V(s)$ type	Data set ($\leq$1.2GeV^2)	$\alpha \times 10^{-2}$	$\epsilon_{\rho\omega} \times 10^{-4}$	M_ω(MeV)	$\epsilon_\phi \times 10^{-4}$	M_ϕ (MeV)	χ^2_{red}
FF1-type	**BaBar**	7.38 (±0.08)	19.98 (±0.35)	-	-	-	**1.68**
	CMD3	10.54 (±0.09)	17.85 (±0.25)	-	-	-	**1.92**
FF2-type	**BaBar**	7.39 (±0.08)	20.39 (±0.36)	781.833 (±0.105)	-	-	**1.45**
	CMD3	10.72 (±0.09)	18.09 (±0.25)	782.188 (±0.058)	-	-	**1.60**
FF3-type	**BaBar**	7.19 (±0.09)	20.05 (±0.35)	-	5.82 (±1.03)	-	**1.57**
	CMD3	10.69 (±0.09)	17.82 (±0.25)	-	-4.16 (±0.34)	-	**1.16**
FF4-type	**BaBar**	7.2 (±0.10)	20.46 (±0.36)	781.832 (±0.104)	6.57 (±1.70)	1024.393 (±0.249)	**1.38**
	CMD3	10.97 (±0.10)	18.05 (±0.25)	782.168 (±0.058)	4.68 (±0.35)	1020.118 (±0.131)	**0.76**

Results for the fit parameters for each form factor function and data set

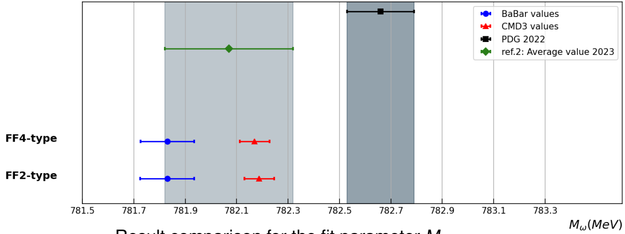


Result comparison for the fit parameter α.



Result comparison for the fit parameter $\epsilon_{\rho\omega}$.

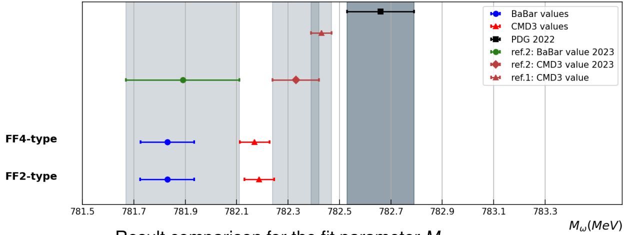
Ref.2023 BaBar, CMD3 values: [Colangelo G., Hoferichter M. & Stoffer P., 2023]



Result comparison for the fit parameter M_ω.

ref.2, Average value 2023: [Colangelo G., Hoferichter M. & Stoffer P., 2023]

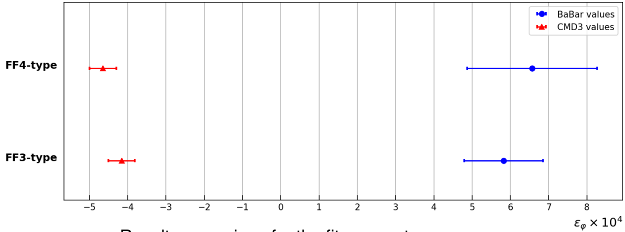
Review of Particle Physics, Average value (2022): [Review of Particle Physics, 2022]



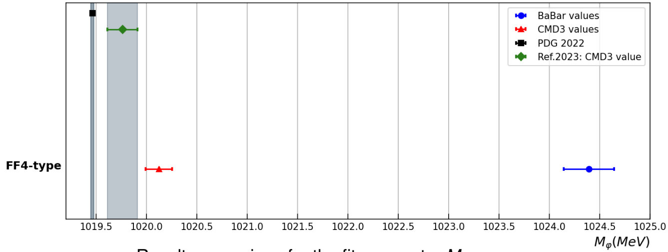
Result comparison for the fit parameter M_ω.

ref.1, CMD3 value: [Ignatov F.V. et al., 2023]

ref.2 BaBar, CMD3 values 2023: [Colangelo G., Hoferichter M. & Stoffer P., 2023]



Result comparison for the fit parameter ϵ_ϕ.



Result comparison for the fit parameter M_ϕ.

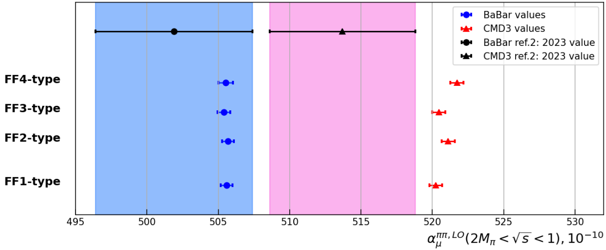
PDG Average value (2022): [Review of Particle Physics, 2022)]

Ref.2023 CMD3 value: [Ignatov F.V. et al., 2023]

$\alpha_\mu^{\pi\pi,LO} \times 10^{-10}$						
	BaBar			**CMD3**		
$F_\pi^v(s)$ type	$(2M_\pi - 1)$ GeV	$(0.6 - 0.88)$ GeV	$(0.327 - 1.2)$ GeV	$(2M_\pi - 1)$ GeV	$(0.6 - 0.88)$ GeV	$(0.327 - 1.2)$ GeV
FF1-type	505.58±0.41	372.15±0.34	509.38±0.43	520.23±0.44	383.99±0.36	524.50±0.45
FF2-type	505.67±0.41	372.23±0.34	509.47±0.43	521.11±0.46	384.72±0.37	525.41±0.47
FF3-type	505.39±0.46	371.94±0.37	509.13±0.43	520.45±0.45	384.22±0.37	524.78±0.45
FF4-type	504.06±0.52	371.69±0.42	509.27±0.43	520.32±0.47	384.94±0.38	526.09±0.48

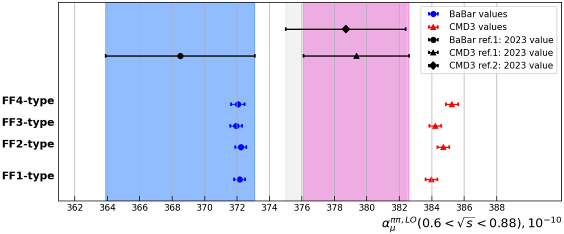
Results for the HVP contribution of the (2π,LO) to the anomalous magnetic moment of the muon

- The result comparison [2] for $\sqrt{s} \in [2M_\pi, 1]$ GeV :

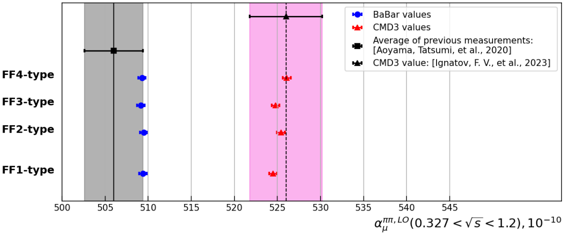


[2] BaBar ref.2, CMD3 ref.2: 2023 value: [Colangelo G., Hoferichter M. & Stoffer P., 2023]

- The result comparison [3] [4] for $\sqrt{s} \in [0.6, 0.88]$ GeV:



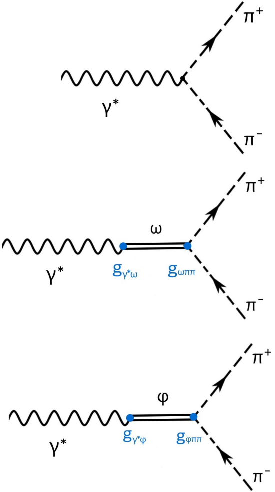
- The result comparison for $\sqrt{s} \in [0.327, 1.2]$ GeV:



[3] BaBar ref.1, CMD3 ref.1: 2023 values: [Ignatov F.V. et al., 2023]

[4] CMD3 ref.2: 2023 value [Colangelo G., Hoferichter M., & Stoffer P., 2023]

Branching ratios



$$\kappa_1 = g_{\gamma^*\omega} \cdot g_{\omega\pi\pi} = \epsilon_{\rho\omega}$$
$$\kappa_2 = g_{\gamma^*\phi} \cdot g_{\phi\pi\pi} = \epsilon_{\phi}$$

- Use of known decay widths [a] to calculate $g_{\gamma^*\omega}$ and $g_{\gamma^*\phi}$:

$$\Gamma(\omega \to e^+e^-) = \frac{4\pi\alpha_{em}^2}{3} {g_{\gamma^*\omega}}^2 M_\omega$$

$$\Gamma(\phi \to e^+e^-) = \frac{4\pi\alpha_{em}^2}{3} {g_{\gamma^*\phi}}^2 M_\phi$$

[a] [Hanhart C. et al., 2018]

• Use of fit parameters $\epsilon_{\rho\omega}/\epsilon_{\phi}$ to calculate the couplings $g_{\omega\pi\pi}$ and $g_{\phi\pi\pi}$ and then the branching ratios [5]:

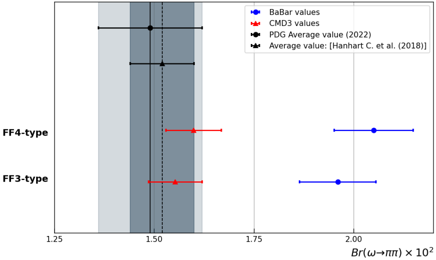
$$\mathcal{B}\left(\omega \to \pi^+\pi^-\right) = \frac{\Gamma(\omega \to \pi^+\pi^-)}{\Gamma_\omega^{tot}} = \frac{{g_{\omega\pi\pi}}^2}{48\pi} \frac{\left(M_\omega^2 - 4M_\pi^2\right)^{3/2}}{M_\omega^2} \left|\Omega\left(M_\omega^2\right)\right|^2 \cdot \frac{1}{\Gamma_\omega^{tot}}$$

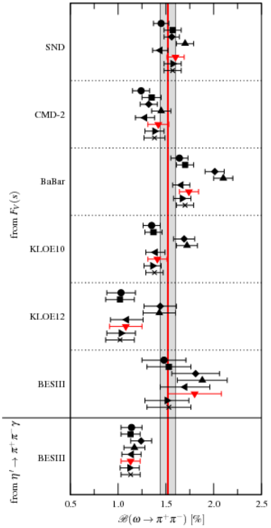
$$\mathcal{B}\left(\phi \to \pi^+\pi^-\right) = \frac{\Gamma(\phi \to \pi^+\pi^-)}{\Gamma_\phi^{tot}} = \frac{{g_{\phi\pi\pi}}^2}{48\pi} \frac{\left(M_\phi^2 - 4M_\pi^2\right)^{3/2}}{M_\phi^2} \left|\Omega\left(M_\phi^2\right)\right|^2 \cdot \frac{1}{\Gamma_\phi^{tot}}$$

$F_\pi(s)$ type	Data set	$\lvert g_{\omega\pi\pi}\rvert \times 10^{-2}$	$\lvert g_{\phi\pi\pi}\rvert \times 10^{-2}$	$\mathcal{B}(\omega \to \pi\pi) \times 10^{-2}$	$\mathcal{B}(\phi \to \pi\pi) \times 10^{-2}$
FF3-type	**BaBar**	3.42 (±0.08)	0.78(±0.14)	1.96 (±0.90)	0.029 (±0.010)
	CMD3	3.04 (±0.07)	0.56 (±0.05)	1.55 (±0.07)	0.015 (±0.003)
FF4-type	**BaBar**	3.49 (±0.08)	0.88 (±0.23)	2.05 (±0.10)	0.036 (±0.019)
	CMD3	3.08 (±0.07)	0.63 (±0.05)	1.60 (±0.07)	0.019 (±0.003)

[5] [Hanhart C. et al., 2018]

- The branching ratio result comparison for the mode $(\omega \to \pi\pi)$ [a] :

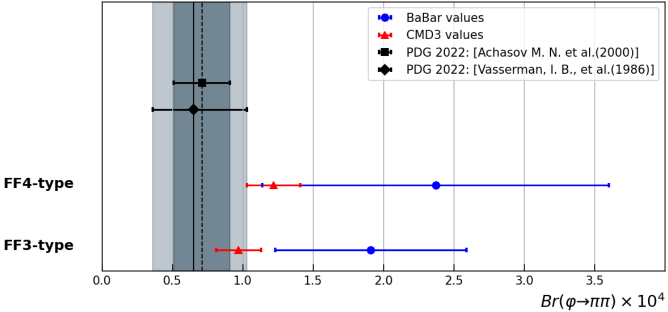




[Hanhart C. et al., 2018]

[a] PDG Average value (2022): [Review of Particle Physics, 2022]
Average value including corrected BaBar data: [Hanhart C. et al., 2018]

- The Branching ratio result comparison for the mode $(\phi \to \pi\pi)$ [6] :



Branching ratio results for the mode $(\phi \to \pi\pi)$

[6] PDG 2022 values: [Review of Particle Physis, 2022]

Summary & Conclusions

Summary of results

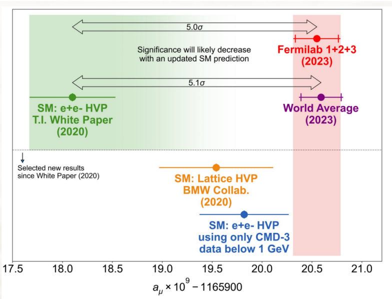
Fit of **four** phenomenological functions of $F_\pi^V(s)$ on data from BaBar and CMD-3:

- **Calculated $\alpha_\mu^{\pi\pi,LO}$ for $\sqrt{s} \in [2M_\pi, 1]$, $[0.6, 0.88]$ and $[0.327, 1.2]$GeV**
  - $\hookrightarrow$ Results within the limits for BaBar and in relative agreement for CMD-3
  - $\hookrightarrow$ **Reproduced** and **confirm the deviation** between the values for BaBar and CMD-3
- **Used $\epsilon_{\rho\omega}$ and ϵ_ϕ for the isospin-breaking processes**
  - $\hookrightarrow$ Calculated branching ratios for ($\omega \to \pi^+\pi^-$, $\phi \to \pi^+\pi$)
  - $\hookrightarrow$ Values from CMD-3 data analysis closer or in agreement with reference values

Conclusions

Primary concerns:

- CMD-3 produce higher values than all previous experiments
  - $\hookrightarrow$ inconsistencies between results
  - $\hookrightarrow$ add to the uncertainty for the α_μ^{HVP}
- Using only CMD3 data for $\alpha_\mu^{e^+e^-,\,\text{HVP}}$
  - $\hookrightarrow$ eliminate large deviation from experiment
  - $\hookrightarrow$ deviation from previous evaluations



[Ignatov F. et al., 2023.]

Future goals:

- ▶ Further study of experimental & calculation methods → determine the source of discrepancy
- ▶ Results from future experiments → obtain more values for a more accurate picture

Thank you for your attention!
Any questions?

References

References I

[1] Aguillard, D. P., et al. ”Measurement of the Positive Muon Anomalous Magnetic Moment to 0.20 ppm.” arXiv preprint arXiv:2308.06230 (2023).

[2] Ignatov, F. V., et al. ”Measurement of the $e^+e^- \to \pi^+\pi^-$ cross section from threshold to 1.2 GeV with the CMD-3 detector.” arXiv preprint arXiv:2302.08834 (2023).

[3] Ignatov, F. V., et al. ”Measurement of the pion formfactor with CMD-3 detector and its implication to the hadronic contribution to muon (g-2).” arXiv preprint arXiv:2309.12910 (2023).

[4] Lees, J. P., et al. ”Precise measurement of the $e^+e^- \to \pi^+\pi^-(\gamma)$ cross section with the initial-state radiation method at BABAR.” Physical Review D 86.3 (2012): 032013.

[5] De Troconiz, J. F., & Ynduráin, F. J. (2002). Precision determination of the pion form factor and calculation of the muon g 2. Physical Review D, 65(9), 093001.

[6] Particle Data Group, et al. ”Review of particle physics.” Progress of theoretical and experimental physics 2022.8 (2022): 083C01.

[7] Colangelo, G., Hoferichter, M., & Stoffer, P. (2023). Puzzles in the hadronic contributions to the muon anomalous magnetic moment. arXiv preprint arXiv:2308.04217.

[8] Hanhart, C., et al. ”The branching ratio $\omega \to \pi^+\pi^- \omega \to \pi + \pi-$ revisited.” The European Physical Journal C 77 (2017): 1-13.

[9] Vasserman, I. B., et al. ”Measurement of the $\to +$ branching ratio.” Physics Letters B 99.1 (1981): 62-65.

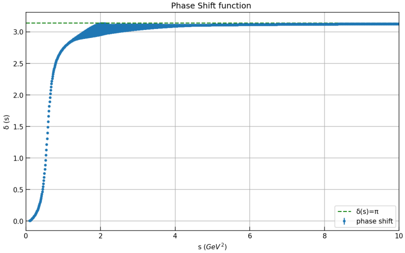
[10] Achasov, M. N., et al. ”Decay $\to +$.” Physics Letters B 474.1-2 (2000): 188-193.

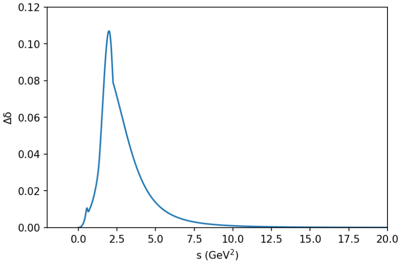
[11] Aoyama, Tatsumi, et al. ”The anomalous magnetic moment of the muon in the Standard Model.” Physics reports 887 (2020): 1-166.

[12] Ignatov F., “Recent $e^+e^- \to \pi^+\pi^-$ measurement with the CMD-3 detector”, The Sixth Plenary Workshop of the Muon g-2 Theory Initiative, Bern, 4 Sept. 2023.https://indico.cern.ch/event/1258310/contributions/5515288/attachments/2707763/4701189/pipiFinal_4Sept2023_TI.pdf

B.1: Alternative to error analysis

- Include the error-data of phase shift $\delta \pm \Delta\delta(s)$:





- Extrapolate the errors at higher energy so that it goes to 0:

$$\Delta\delta(s) = \begin{cases} \text{Interpolated function from Bern error values} & , \text{for} \quad 4M_\pi^2 \leq s \leq s_0 \\ \Delta\delta\,(s_0) \cdot \left(\dfrac{\lambda_0^2 + s_0^4}{\lambda_0^2 + s^4} \right) & , \text{for} \quad s \geq s_0 \end{cases}$$

with $s_0 = 2.25\,(GeV)^2$.

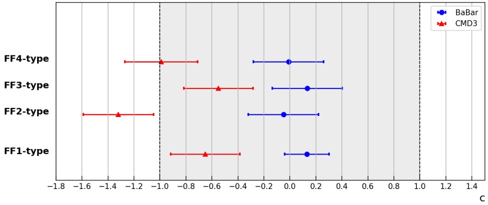
- Use exponential form of $\Omega(s)$ and add another fit parameter:

$$\Omega[\delta \pm \Delta\delta] = \Omega[\delta] \cdot \Omega[\pm\Delta\delta] = \Omega[\delta] \cdot (\Omega[\Delta\delta])^{c}$$

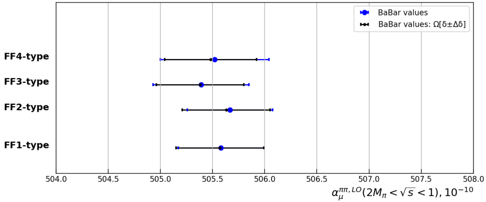
$$F_\pi^V(s) = P(s) \cdot \Omega[\delta(s)] \cdot \Omega[\Delta\delta(s)]^{c}$$

- Fit result comparison:

χ^2_{red}				
	BaBar		**CMD3**	
F-type	**without $\Delta\delta$**	**with $\Delta\delta$**	**withoutwithout $\Delta\delta$**	**with $\Delta\delta$**
FF1	1.68	1.67	1.92	1.89
FF2	1.45	1.44	1.60	1.49
FF3	1.57	1.57	1.16	1.14
FF4	1.38	1.37	0.72	0.65



- Result comparison for BaBar:



- Result comparison for CMD-3: