Hirsch FEST

Enrico Nardi

KBFI NICPB

HEP Group

INFN LNF

Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali di Frascati

[Subtle effects in high precision physics: the $(g-2)_\mu$ anomalies]

IFIC (Valencia) -- January 23-24, 2024

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In those years I was holding a professorship position at the UdeA in Medellín, Colombia.

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E. Nardi: Hirsch-1 Index = 2

However, there is a good explanation for this…

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Index	Domain	Meaning
Hirsch-0	Only applicable to Martin	No. of papers authored by Martin
Hirsch-1	Anyone	No. of papers coauthored with Martin by the researcher
Hirsch-2	Anyone	No. of papers coauthored with Martin by coauthors of the researcher
Hirsch-3	Anyone	No. of papers coauthored with Martin by coauthors of coauthors of the researcher
….		

E. Nardi: Hirsch-1 Index = 2

Quasi-Dirac neutrinos at the LHC

#1

G. Anamiati (Valencia U., IFIC), M. Hirsch (Valencia U., IFIC), E. Nardi (Frascati) (Jul 19, 2016)

Published in: *JHEP* 10 (2016) 010 • e-Print: 1607.05641 [hep-ph]

pdf DOI cite claim reference search 96 citations

Bounds on the tau and muon neutrino vector and axial vector charge radius

#2

Martin Hirsch (Valencia U., IFIC), Enrico Nardi (Frascati and Antioquia U.), Diego Restrepo (Antioquia U.) (Oct, 2002)

Published in: *Phys.Rev.D* 67 (2003) 033005 • e-Print: hep-ph/0210137 [hep-ph]

pdf DOI cite claim reference search 45 citations

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Quasi-Dirac neutrinos at the LHC #1

G. Anamiati (Valencia U., IFIC), M. Hirsch (Valencia U., IFIC), E. Nardi (Frascati) (Jul 19, 2016)

Published in: *JHEP* 10 (2016) 010 • e-Print: 1607.05641 [hep-ph]

pdf DOI cite claim reference search 96 citations

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Martin Hirsch (Valencia U., IFIC), Enrico Nardi (Frascati and Antioquia U.), Diego Restrepo (Antioquia U.) (Oct, 2002)

Published in: *Phys.Rev.D* 67 (2003) 033005 • e-Print: hep-ph/0210137 [hep-ph]

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However, my **Hirsch-2** index is remarkable:

E. Nardi: Hirsch-2 Index (partial, only UdeA) > 23

and there is a good explanation also for this...

At the end of the past millenium/beginning of the new one, in Colombia scientific isolation was affecting heavily scientific research, and high level formation of young researchers (Ph.D.)

- Internet seemed to run on a 56Kb modem for the whole UdeA (arXiv download only in the night)
- Only a few and outdated physics books in the Library
- Fragmentary collections of scientific journals (several years missing - almost useless)
- Administrative apparatus mainly oriented to handle teaching (unsuited for research needs)

[Example of a typical objections: 1 month leave of the absence to visit CERN = 1 month vacation in the Swiss ALPs]

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- Because of dangerous social conditions, very few colleagues willing to pay a visit to UdeA

Martin was one of those very few colleagues. From a backup CD, I have been able to trace:

- A 1st visit: 25 Nov - 11 Dec, 2000, during which he also acted as evaluator of the 1st thesis in HEP at UdeA.
- A 2nd visit: 10 Aug - 4 Sept 2002, during which I became **Hirsch-1 Index** = 1
- A 3rd visit: 26 Jan - 14 Feb 2004

Martin was always ready to comply with unusual requests:

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```
INBOX-NEW-  From enardi@naima.udea.edu.co Mon Nov 13 07:03:19 2000 -0500
INBOX-NEW:  Return-Path: <mahirsch@hep.phys.soton.ac.uk>
INBOX-NEW->
INBOX-NEW-> […] would it be possible that
INBOX-NEW-> I will ask amazon.co.uk to ship the
INBOX-NEW-> books to you, before November 25, and you will
INBOX-NEW-> bring them to us ?
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```
INBOX-NEW-  Hi Enrico,
INBOX-NEW-  Today I received 2 books from Amazon for you.
INBOX-NEW-  a.) Bailin and Love, Introduction to gauge field theory
INBOX-NEW-  b.) Gaisser, Cosmic Rays and Particle Physics.

INBOX-NEW-  Hi Enrico,
INBOX-NEW-
INBOX-NEW-  I received 5 more books from Amazon:
INBOX-NEW-  1. Lattice Gauge Theories: An introduction
INBOX-NEW-  2. Mathematical methods for physicists
INBOX-NEW-  3. Instantons in gauge theories
INBOX-NEW-  4. Modern Differential Geometry for Physicists
INBOX-NEW-  5. Dynamics of the SM
```

And also rather unusual non-academic requests (like importing coffee to Colombia !):

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```
Received-Feb-2004:  From mahirsch@ific.uv.es Fri Jan 23 10:52:06 2004
Received-Feb-2004-  Delivered-To: enardi@naima.udea.edu.co
Received-Feb-2004-  Hi Enrico,
Received-Feb-2004-
Received-Feb-2004-  > My Italian expresso coffee is finished :-(
Received-Feb-2004-  > And here in Medellin it is impossible
Received-Feb-2004-  > to find it, and therefore I am not sure
Received-Feb-2004-  > that I can make it until your arrival.
Received-Feb-2004-
Received-Feb-2004-  Hold on! Don't give up! Rescue is only a bit more than
Received-Feb-2004-  a week away...
Received-Feb-2004-
Received-Feb-2004-  > I order of preference, the brand could be :
Received-Feb-2004-  >
Received-Feb-2004-  > Illy
Received-Feb-2004-  > Lavazza Oro
Received-Feb-2004-  > Lavazza Rosso
Received-Feb-2004-
Received-Feb-2004-  ...I'll try to do my best.
```

Around mid 2000 a vacancy for a professorship position became available in UdeA. Martin responded positively to an inquiry about his possible interest in that position

```
NaimaInbox- On Mon, 14 Aug 2000, Diego Restrepo wrote:
NaimaInbox-
NaimaInbox-> Hola Martin,
NaimaInbox->
NaimaInbox-> Enrico me encomendo el preguntarte si tu estarias interesado en postular a
NaimaInbox-> una plaza vacante que hay en este momento en la Universidad de Antioquia o
NaimaInbox-> si conoces de alguien que podria estar interesado.
NaimaInbox->
NaimaInbox-> Hasta luego
NaimaInbox-> Diego

NaimaInbox- Date: Wed, 16 Aug 2000 00:04:57 +0200 (CET)
NaimaInbox: From: Martin Hirsch <mahirsch@nac11.ific.uv.es>
NaimaInbox- To: Diego Restrepo <restrepo@naima.udea.edu.co>
NaimaInbox- Subject: Re: Question
NaimaInbox-
NaimaInbox-  Hola Diego,
NaimaInbox-
NaimaInbox-  en principio puede ser que tengo interes. Sabes, que voy a inglatera
NaimaInbox-  on octubre, pero eso es solamente una position postdoctoral. Si tienes
NaimaInbox-  mas informaciones puedes enviar me lo? Si no, por favour, me escribiras
NaimaInbox-  el Email de Enrico...Gracias!
NaimaInbox-
NaimaInbox-  Hasta luego,
NaimaInbox-  Martin
```

UdeA colleagues where very excited to hear that Martin was willing to join the UdeA HEP group. But someone also moved some critiques…

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```
INBOX-NEW-  Date: Mon, 13 Nov 2000 22:44:53 +0100
INBOX-NEW-  From: Tatiana Fernandez Maya <taferma@alumni.uv.es>
INBOX-NEW-  To: enardi@naima.udea.edu.co
INBOX-NEW-
INBOX-NEW-  Me contaron por ahi las malas lenguas que dentro de unos dias llegara
INBOX-NEW-  alli Martin Hirsch (o algo asi) y que al parecer piensan ofrecerle el
INBOX-NEW-  puesto que dejo Luis Alberto; como puedes ser tan miserable que quieres
INBOX-NEW-  que Martin sufra todo lo que has sufrido? Que tienes contra el pobre
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How can you be so miserable that you want Martin to suffer all that you have suffered? What do you have against the poor man? He is a very good person.

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INBOX-NEW-  Date: Mon, 12 Feb 2001 02:30:10 +0000 (GMT)
INBOX-NEW:  From: Martin Hirsch <mahirsch@hep.phys.soton.ac.uk>
INBOX-NEW-  To: Enrico Nardi <enardi@naima.udea.edu.co>
INBOX-NEW-  Subject: Re: Time scale
INBOX-NEW-
INBOX-NEW-  Hi Enrico,
INBOX-NEW-  now it is final. PPARC send me a letter.
INBOX-NEW-  My contract here is till Sep.2002, but
INBOX-NEW-  there should be no problem quitting
INBOX-NEW-  earlier.
INBOX-NEW-  Cheers,
INBOX-NEW-  Martin
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So we opened the UdeA call, and Martin won it.
(With his academic records, basically no competitors)

But in the end Martin got a Ramon&Cajal and declined the UdeA position
(I guess, luckily for him, but in a sense also for us… you will see why…)

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Received-Sep-2001-  To:    Enrico Nardi <enardi@lnf.infn.it>
Received-Sep-2001-
Received-Sep-2001-  Hi Enrico,
Received-Sep-2001-
Received-Sep-2001-  this is going to be a bit difficult. I am in Valencia
Received-Sep-2001-  now for a short visit and news have just appeared that
Received-Sep-2001-  my name is on the list of eligible candidates for the
Received-Sep-2001-  Ramon y Cajal program. As I understand it right this
Received-Sep-2001-  moment this means that I have it, barring some unforeseen
Received-Sep-2001-  bureaucratic obstacle.
Received-Sep-2001-
Received-Sep-2001-  I hope you understand my situation and I am sorry if
Received-Sep-2001-  I caused trouble in Medellin. I will write to Nelson
Received-Sep-2001-  to explain the situation, because at present it seems
Received-Sep-2001-  that I will most likely not be able to accept the offer
Received-Sep-2001-  by the University of Antioquia.
Received-Sep-2001-
Received-Sep-2001-  It is really an embarrassing situation. For years I have
Received-Sep-2001-  tried to find something more permanent than a simple
Received-Sep-2001-  postdoc, and everything failed in the end.
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We have been lucky to have a contact in a strong HEP group in Europe, always ready to help: inviting students, helping with Ph.D. scholarships, supervising Ph.D. thesis:

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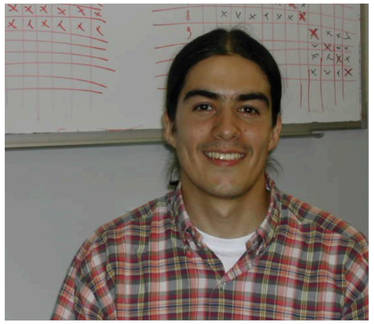

Diego Aristizabal Sierra (M.Sc. UdeA) Ph.D. U. Valencia 2007

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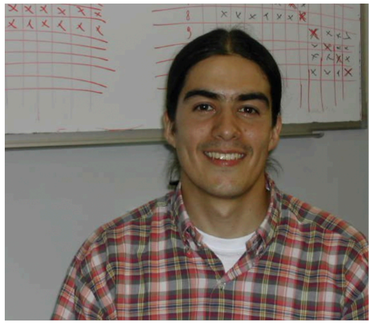

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Carolina Arbeláez (B.Sc. UdeA & UNAL-Med) Ph.D. U. Valencia 2014

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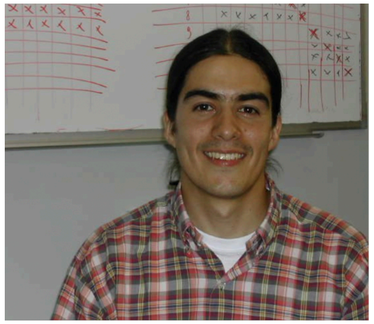

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Gaetana Animati (B.Sc. Unical) Ph.D. U. Valencia 2018

I think that my Hirsch-1 Index = 2 and Hirsch-2 Index > 23 can be now understood…

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Therefore, for all the episodes listed above, and for many more contributions not listed because of time/space constraints

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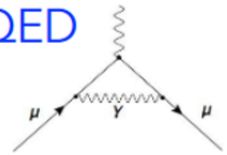
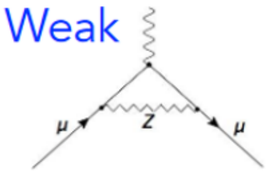
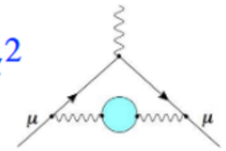
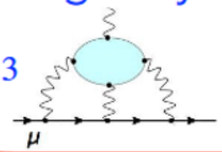
Thank you Martin !

Subtle effects in high precision physics: the $(g-2)_\mu$ anomalies

Based on:
L. Darmé, G. Grilli di Cortona, E. Nardi,
hep-ph/2112.09139 (JHEP)
hep-ph/2212.03877 (PRD)

SM WP20 prediction from the TI White Paper (0.37 ppm)

QED  +…	$116\,584\,718.9\,(1) \times 10^{-11}$	0.001 ppm
Weak  +…	$153.6\,(1.0) \times 10^{-11}$	0.01 ppm
Hadronic…		
…Vacuum Polarization (HVP)		
α^2  +…	$6845\,(40) \times 10^{-11}$ [0.6%]	0.34 ppm
…Light-by-Light (HLbL)		
α^3  +…	$92\,(18) \times 10^{-11}$ [20%]	0.15 ppm

➤ Uncertainty dominated by hadronic contributions, now **δ HVP > δ HLbL**

Subtle effects in high precision physics: the $(g-2)_\mu$ anomalies

Based on:
L. Darmé, G. Grilli di Cortona, E. Nardi,
hep-ph/2112.09139 (JHEP)
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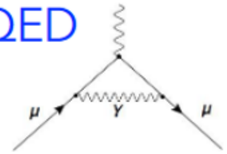
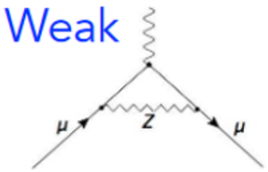
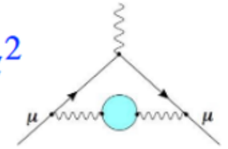
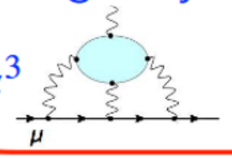
HPV is a non-perturbative contribution.

It can be estimated from data
(via dispersion relations)

or via non-perturbative methods
(lattice QCD)

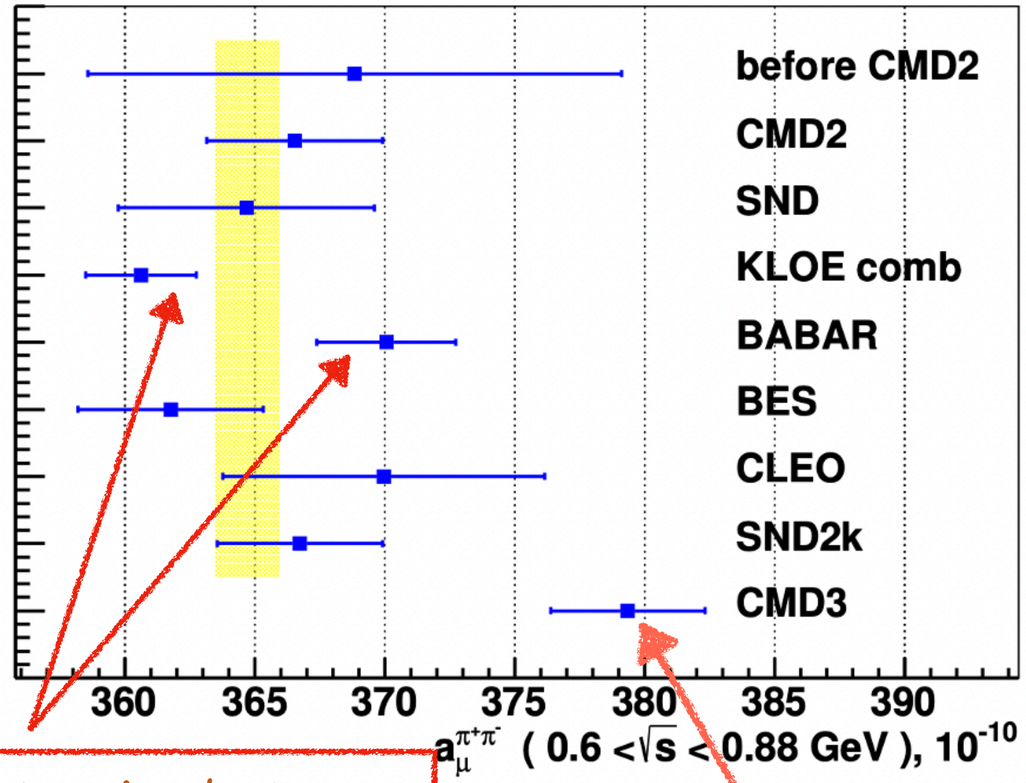
SM WP20 prediction from the TI White Paper (0.37 ppm)

QED  +…	$116\,584\,718.9\,(1) \times 10^{-11}$	0.001 ppm
Weak  +…	$153.6\,(1.0) \times 10^{-11}$	0.01 ppm
Hadronic…		
…Vacuum Polarization (HVP)	$6845\,(40) \times 10^{-11}$ [0.6%]	0.34 ppm
α^2  +…		
…Light-by-Light (HLbL)	$92\,(18) \times 10^{-11}$ [20%]	0.15 ppm
α^3  +…		

➤ Uncertainty dominated by hadronic contributions, now **δ HVP > δ HLbL**

Discrepancies in the different estimates of a_μ^{HVP}

$\sigma(e^+e^- \to \pi^+\pi^-)$ data



~ 3σ tension between KLOE and BaBaR

~ 5σ with CMD3 (2023)

Embarrassing disagreement

Discrepancies in the different estimates of a_μ^{HVP}

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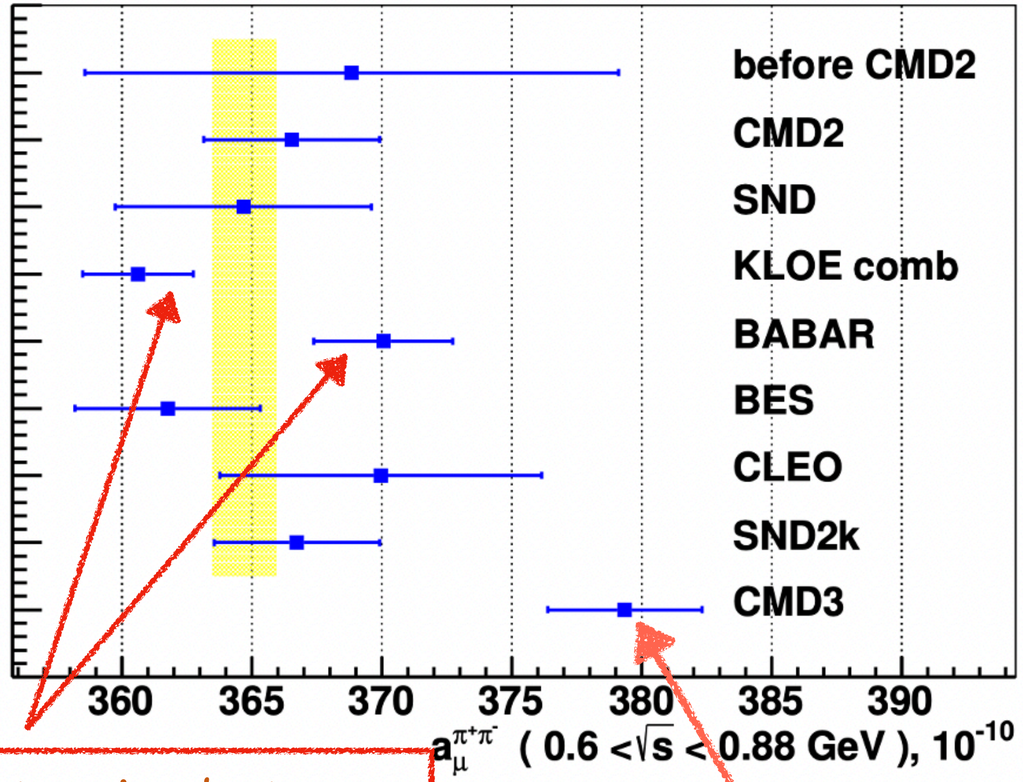

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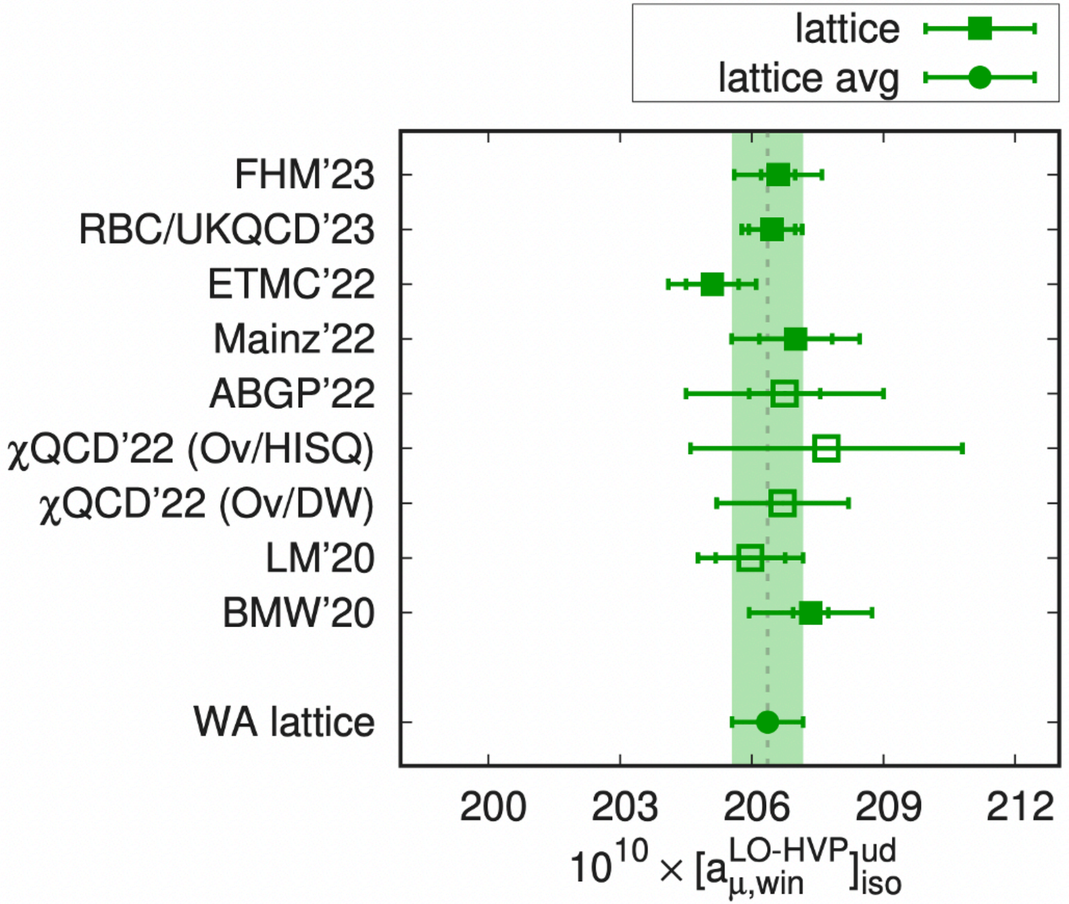
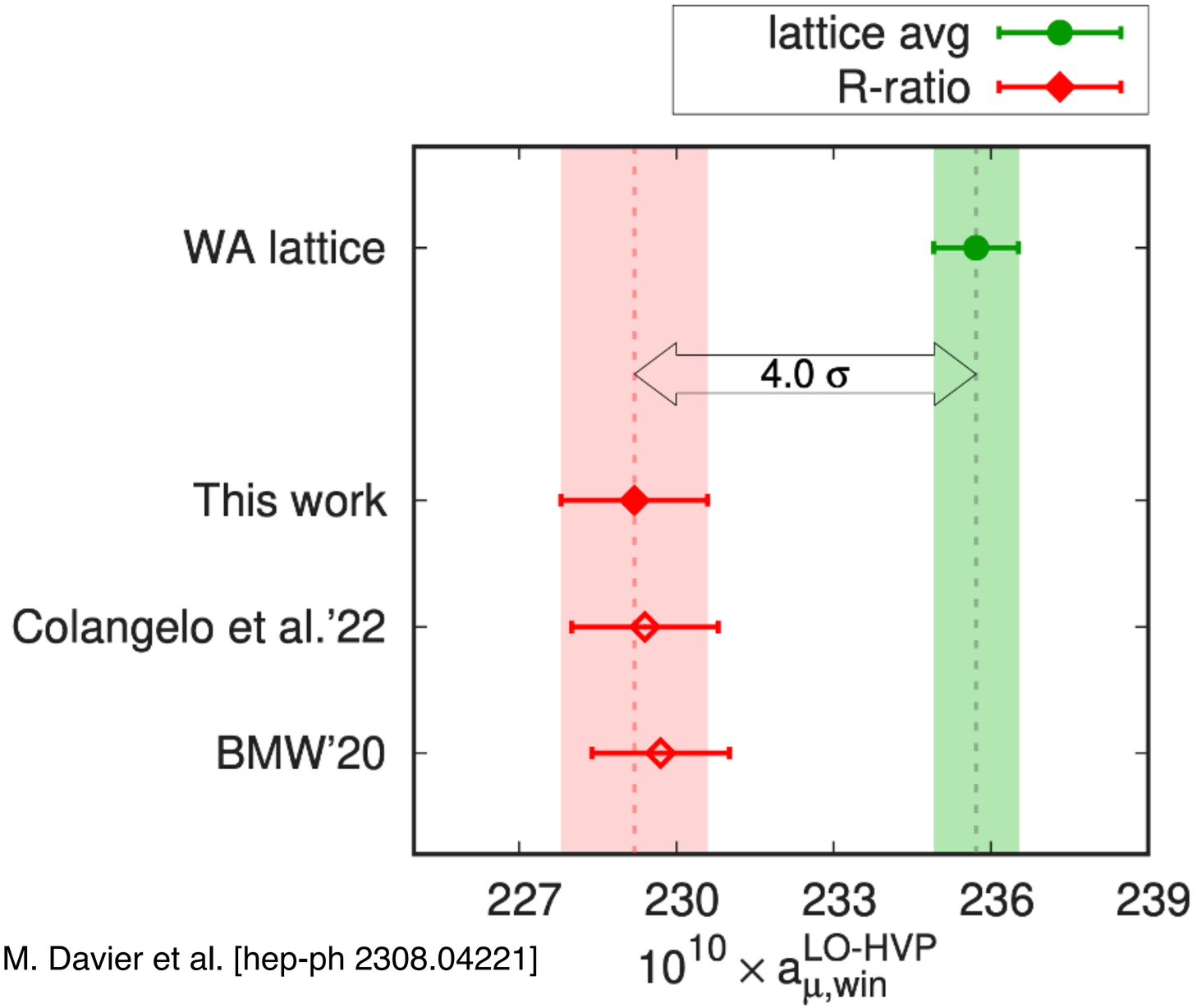


Very good agreement

Discrepancies in the different estimates of a_μ^{HVP}



M. Davier et al. [hep-ph 2308.04221]

Can it be possible to reconcile KLOE with BaBar with CMD3, Data driven a_μ^{HVP} with lattice, and explain $(g\text{-}2)^{exp}$ vs. $(g\text{-}2)^{th}$?

Measuring the Energy Dependence of the hadronic cross section $\sigma_{had}(s)$. Two strategies:

Radiative technique (KLOE, BaBar, BES)

$[e^+e^-](s) \rightarrow [e^+e^-](s') + \gamma_{ISR} \rightarrow had(s') + \gamma_{ISR}$

beams: $s = (E_b^+ + E_b^-)^2$ fixed

Scanning technique (KLOE, BaBar, BES)

$[e^+e^-](s) \rightarrow had(s)$

beams: $s = (E_b^+ + E_b^-)^2$ variable

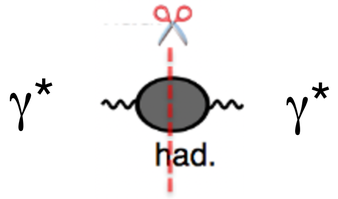
A Measurement of the hadronic cross section requires theoretical input

Luminosity dependent: $\sigma_{\rm had} \propto N_{\rm had}/\mathcal{L}_{e^+e^-}$ KLOE08, KLOE10

The luminosity is estimated by comparing high statistics measurements of $e^+e^- \to e^+e^-$ events with the SM prediction for Bhabha scattering:

$$\mathcal{L}^{\rm SM}_{e^+e^-} = \frac{N_{\rm Bha}}{\sigma^{\rm SM}_{\rm eff}}$$ <— Theory QED

If there are additional e^+e^- events from some NP: $\mathcal{L}_{e^+e^-} = \mathcal{L}^{\rm SM}_{e^+e^-} \frac{\sigma^{\rm SM}_{\rm eff}}{\sigma_{\rm eff}} < \mathcal{L}^{\rm SM}_{e^+e^-} \Rightarrow$ $\sigma_{\rm eff} = \sigma^{\rm SM}_{\rm eff}(1+\delta_R)$



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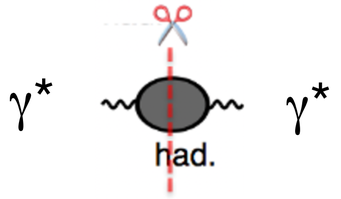
Luminosity independent: $\sigma^0_{\pi^+\pi^-} = \frac{N_{\pi^+\pi^-\gamma_{ISR}}}{N_{\mu^+\mu^-\gamma_{ISR}}}\,\sigma^0_{\mu^+\mu^-}$ BaBar, BESIII, KLOE12

Theory QED



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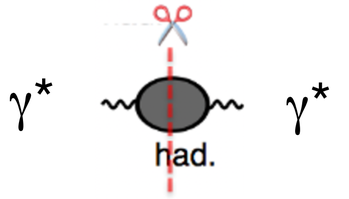


$$\sigma^0_{\pi^+\pi^-} \longrightarrow \sigma^{0\,(\gamma^*)}_{\pi^+\pi^-} \simeq \sigma^0_{\pi^+\pi^-}\,[1+\delta_\mu(s')]$$

If there are additional $\mu^+\,\mu^-$ X events from some NP (i.e. not from e^+e^- -> γ^* -> $\mu^+\,\mu^-$) mimicking $\mu^+\,\mu^-\,\gamma_{ISR}$ (X invisible) they must be subtracted out

$$\delta_\mu(s') \equiv \frac{\sigma^{NP}_{\mu\mu X}(s')}{\sigma_{\mu\mu}(s')}\frac{\epsilon^{NP}}{\epsilon^{SM}}$$

Now, which could be a useful model ? We need NP at 1 GeV !!

We have borrowed an iDM model

X = V Dark Photon

FEYNRULES

MadGraph5_aMC@NLO

Shifts: δ_R^{KLOE08} , δ_μ^{BESIII} , δ_μ^{KLOE12}

For KLOE08

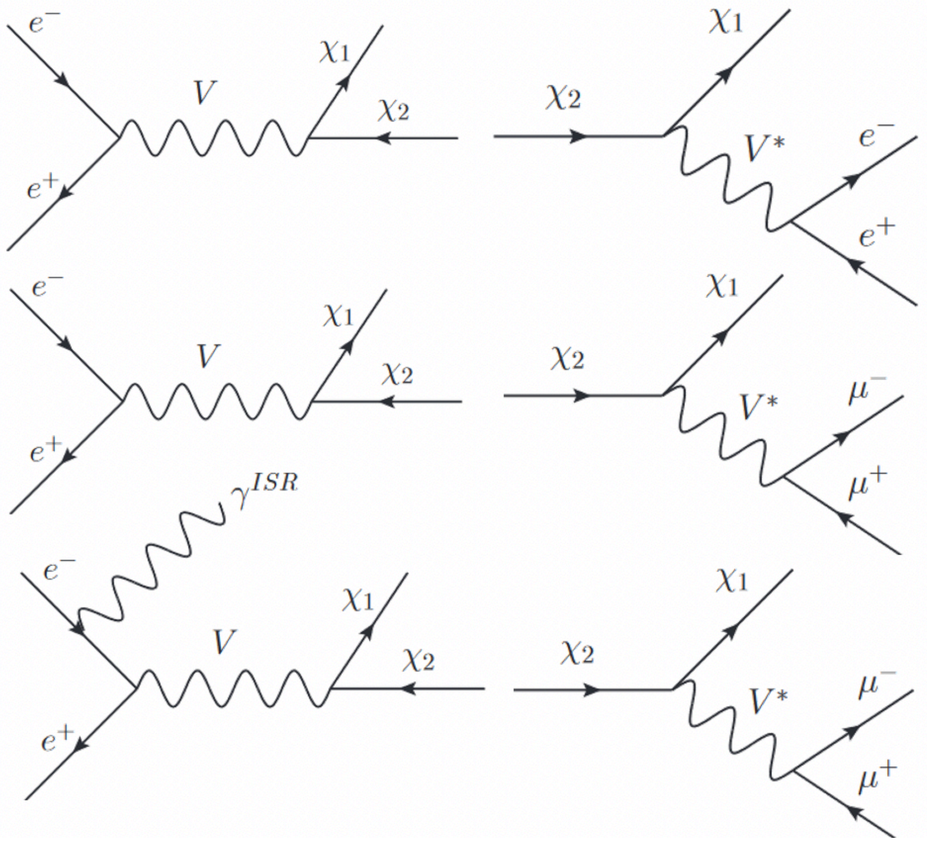
$e^+e^- \to e^+e^-\chi_1\,\chi_1$

For KLOE12

$e^+e^- \to \mu^+\mu^-\chi_1\,\chi_1$

For BESIII

$e^+e^- \to \mu^+\mu^-\gamma\,\chi_1\,\chi_1$



To hide NP at the GeV make the NP signature look like background of standard searches:

- No bumps in $(m_{e^+e^-})^2$ or $(m_{\mu^+\mu^-})^2$ invariant mass (multi-body final state)
- Evade searches based on missing energy with charged particles in the final state

The largest shift needed is in KLOE data. So assume new X resonance with $m_X \sim m_\varphi$ (we also assume $\Gamma_X \sim \Gamma_\varphi$). Three KLOE measurements

KLOE08: sqrt(s) = m_ϕ *Luminosity method*

KLOE10: sqrt(s) = m_ϕ - *4.5* Γ_ϕ *Luminosity method (in our model not affected by NP)*

KLOE12: sqrt(s) = m_ϕ *Luminosity* ***independent*** *method. Data fully correlated with KLOE08*

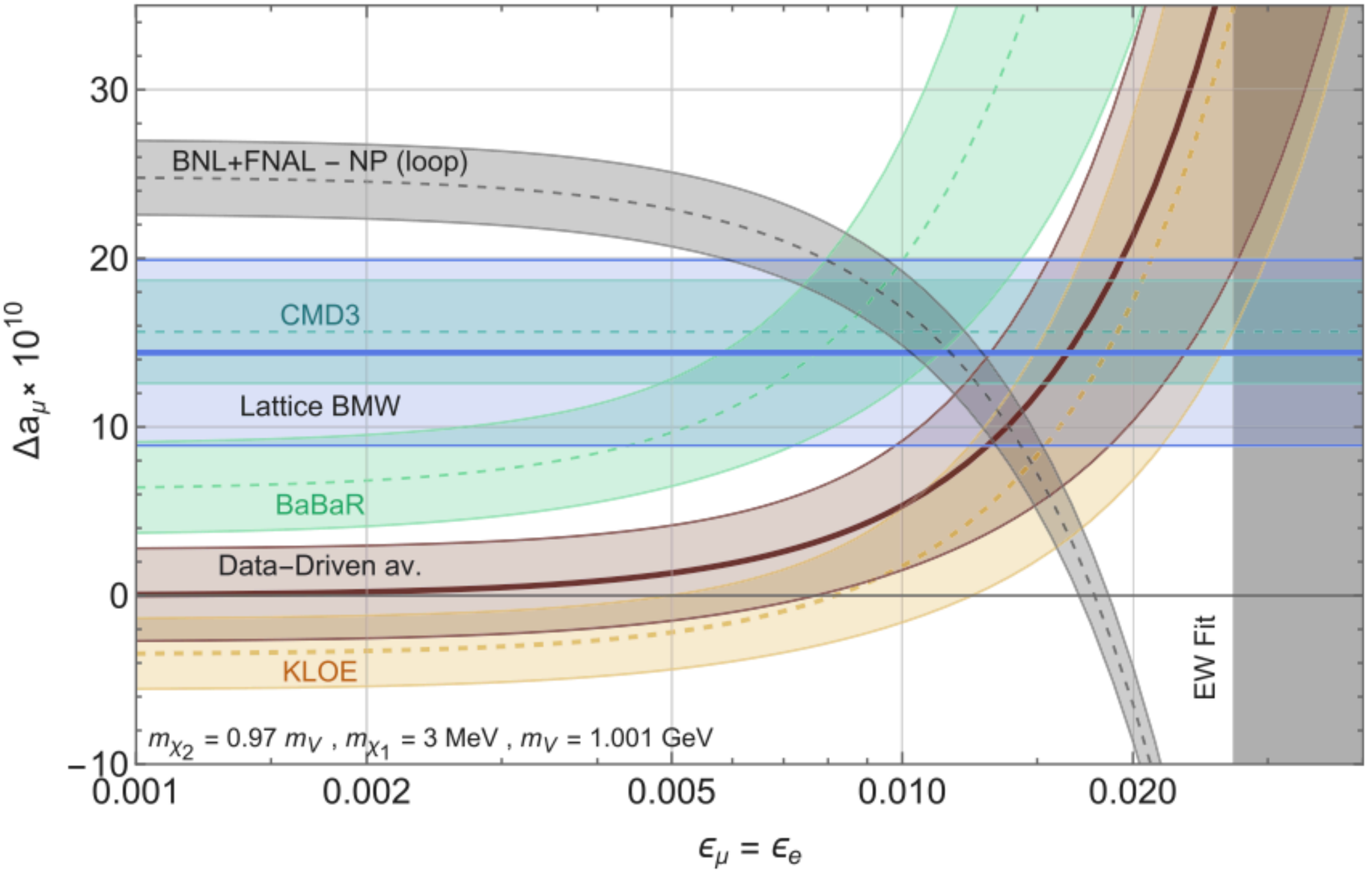
Although CoM far above m_φ, BaBar and BESIII also receive corrections

BaBar12: sqrt(s) = 10.6 GeV *Luminosity independent (μ) method.*

BESIII: sqrt(s) = 3.8 GeV *Luminosity independent (μ) method.*

Experiments that exploit the ISR method to scan s' will generally be affected whenever the CoM energy is above the resonance even if not particularly close to the pole. This is because ISR photon emission can downgrade the effective e^+e^- collision energy to the right value to excite the resonance. (In our analysis: Included in BESIII but not in BaBar)

Shifts in the prediction of the data-driven results



This idea was first put forth in
L. Darmé, G. Grilli di Cortona, E. Nardi, hep-ph/2112.09139 (JHEP)

The scenario (2021) predicted:

- No effects in scanning-method experiments $\sqrt{s} \lesssim 1$ GeV
- Lattice-Data driven discrepancy should not arise from the so called "short-distance window" (very roughly, for $\sqrt{s} \gtrsim 1$ GeV)

This is in nice agreement with (2023) results: [see hep-ph:2212.03877 (PRD)]

- The CMD3 result (Feb. 2023) [F.V. Ignatov et al., hep-ex:2302.08834.]
- The Fermilab Latt., HPQCD, and MILC; RBC/UKQCD (Jan. 2023) Lattice results
  [A. Bazavov et al. hep-lat:2301.08274 (PRD); T. Blum et al. [hep-lat:2301.08696] (PRD)]

Thanks for your attention !