



@IPARCOS-UCM

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IPARCOS

Science Advisory Board Meeting: TH1 - High-energy particle physics

Juan José Sanz Cillero (speaker)

IPARCOS March 6th 2023
Universidad Complutense de Madrid



Effective field theories for LHC

Felipe J.
Llanes Estrada



Juan José
Sanz Cillero



Antonio Dobado

- **New national grant approved:**

Teorías Efect., Part. Elem. y Sim. y Comput. Avanzadas.

[2023-26] PID2022-137003NB-I00. 66.300 € (direct costs)

- **Previous national grants:**

Teorías Efectivas en Física de Partículas y Cosmología.

[2020-23] PID2019-108655GB I00. 47.000 € (direct costs)

Efectivas en Física de Partículas y Cosmología.

[2017-19] FPA2016-75654-C02-01. 86.000 € (direct costs)

PhD students in the HEP group:

Directly work on the EFT@LHC research line:

Carlos Quezada Calonge (ongoing PhD)

Alexandre Salas Bernárdez (**doctorate 2023**)

Javier Martínez Martín (ongoing PhD)

Work with us on other research lines

Eva Lope Oter (**doctorate 2023**) [grav]

Adrián Casado Turrión (**doctorate 2023**) [grav/cosmo]

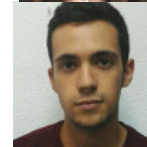
Clara Álvarez Luna (**doctorate 2023**) [grav]

Juan J. Gálvez Viruet (ongoing PhD) [quant. comput.QCD]



Msc students:

Adriana Bariego



Pablo Navarro

Internal collaborators:



→ *Internal collaborators in other IPARCOS groups:*

Clara Peset, Aneta Wojnar, José A.R.Cembranos

External collaborators:

Some external collaborations from last years:

Raquel Gómez Ambrosio (INFN Torino) and *Rafael Delgado* (U.P. Madrid)

Sally Dawson (Brookhaven) and *Duarte Fontes* (Brookhaven)

Reinhard Alkofer (U. Graz)

Toni Pich (U. Valencia) and *Ignasi Rosell* (CEU-Cardenal Herrera)

Álvaro de la Cruz Dombriz (U. Salamanca)

Víctor González Sebastián (Wayne State) and *Noe Demazure* (ENS Lyon)

Olga Shekhovtsova (Kharkov KIPT)

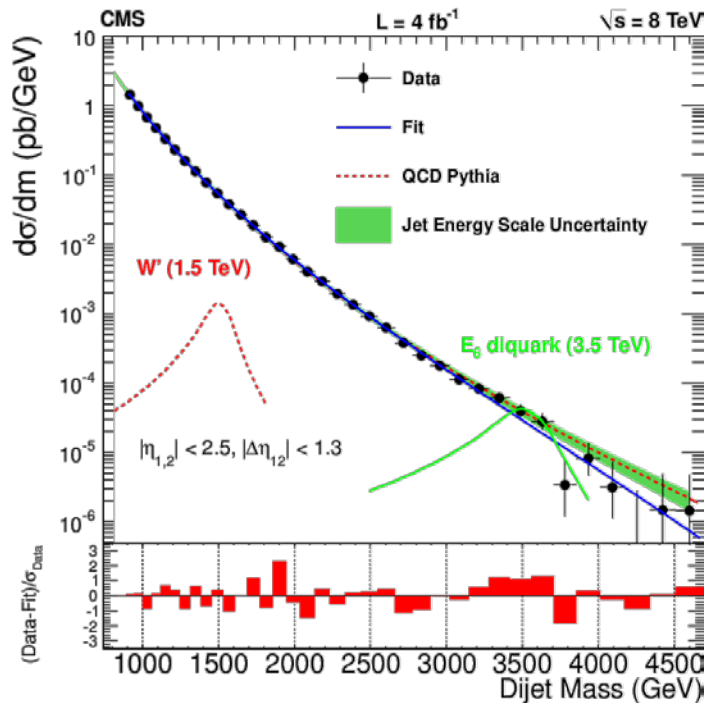
Alejandro Jiménez-Cano (U.Tartu) and *Francisco J. Maldonado* (U.Tartu)

Higgs Effective Field Theory @ LHC



RCOS

No new particles?



Let's look for new forces!

New physics? $>$ few TeV

GAP

— H (125.9 GeV, PDG 2013)

== W (80.4 GeV), Z (91.2 GeV)

Higgs Effective Field Theory @ LHC: SMEFT vs HEFT

What is the proper effective theory to extend the **SM**?

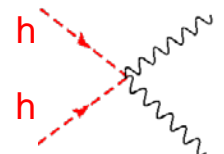
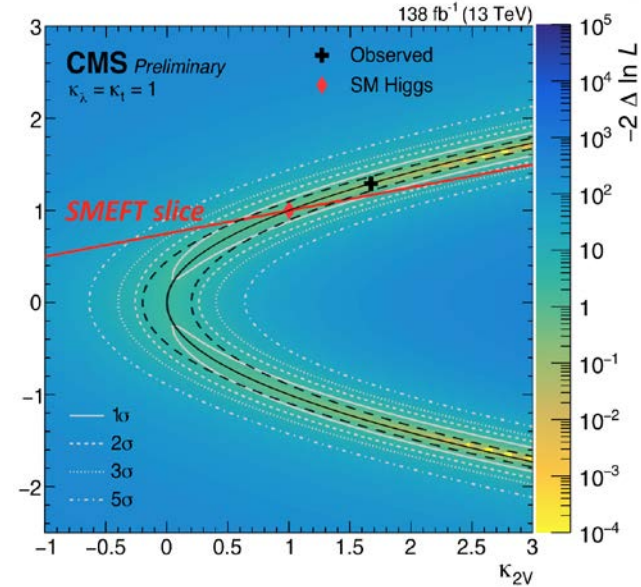
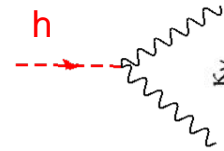
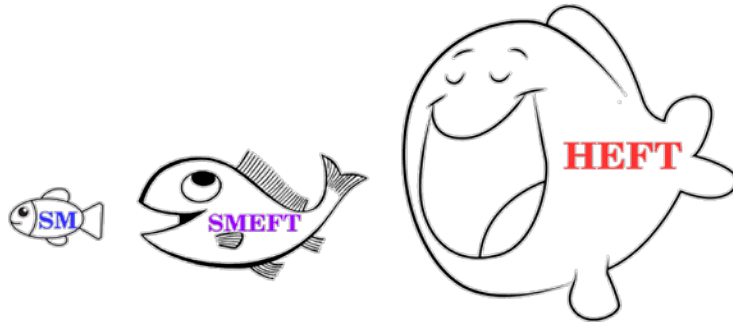
SMEFT

(H doublet, linear rep)

or

HEFT

(Non-linear)



Higgs Effective Field Theory @ LHC: top loops



All you always wanted to know about...

Top loops in WW scattering

-Boson contributions
proportional to

$$\mathcal{O}(s^2/v^4)$$

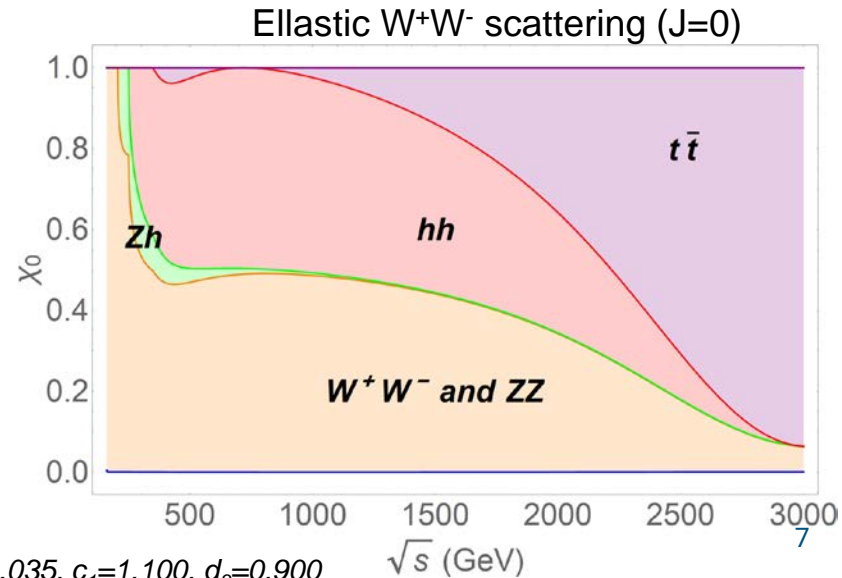
-Fermion contributions
proportional to

$$\mathcal{O}(M_{\text{Fer}}^2 s/v^4)$$

Relevance of fermions vs bosons quantified by

$$R_J = \frac{\text{Fer}_J}{\text{Bos}_J + \text{Fer}_J}$$

HEFT \longrightarrow new interactions



Example of HEFT coefficients yielding large fermion contributions: $a=1.008$, $b=1.035$, $c_1=1.100$, $d_3=0.900$

Other research lines...



There are several other research lines in the project [[Grav/Cosmo](#)]:

- **[Grav/Cosmo] Galactic rotation curves & dark matter:**

Description in terms of “dark matter cigars” [elongated (rather than spherical) DM halos]

- **[Grav] Equations of state for matter in neutron stars:**

Searching for 1st order phase transitions from neutron to quark matter through rotating stars

- **[Grav] $f(R)$ & metric-affine theories as generalizations of General Relativity:**

Viability in describing compact objects, collapse and gravitational waves

- **[Grav/HEP] gravity and spontaneous symmetry breaking:**

Coleman-Weinberg effective potential mechanism applied to gravity

Other research lines...

There are several other research lines in the project [**Hadr/QCD** & **other**]:

- **[Hadr/QCD] Spin of fermion pairs** produced in QCD when a hadron decays:
Comparison with electrodynamics in an intense field
- **[Hadr/QCD] Heavy ion collisions:**
Identify Resonances as, there, triangle kinematic singularities are rapidly erased
Anticorrelations between baryons & potential deficiency in Monte Carlo programs
- **[Hadr] Inverse Amplitude Method** (unitarization):
Analysis of systematic uncertainties
- **Other:** Fragmentation funct, inform. & entropy, hadr. spectroscopy,
 γ -ray propagation between galaxies, symmetry-breaking in QFT

By the numbers

[2020 - Present]

InspireHep



- Number of peer-reviewed articles: **32**
1 ProgPNP, **11** PRD, **4** JHEP, **3** JCAP, **13** (others: EPJC, PLB, PRC, NPB, etc.) + **7** preprints
- Number of conference proceedings: **29** (PoS, EJJ Web Conf, NPPP, etc.)
- Regular participations [2020-...]:
 - International Conf:** APS, EPS-HEP, ICHEP, HIGGS, Confinement, etc.
 - International WG:** LHC-HXS-WG, LHC-EFT-WG, CEPC, VBScan COST
 - National meetings:** Red LHC, CPAN, RSEF Biennial, @FlipPhysics, etc.
- Organization [2020-...]: RSEF Biennial [A. Dobado], **2** workshops [FJ.Llanes]

By the numbers

[2022 - Present]

InspireHep



- Number of peer-reviewed articles: **26**
9 PRD, **4** JHEP, **3** JCAP, **10** (others: EPJC, PLB, PRC, NPB, etc.) + **7** preprints
- Number of conference proceedings: **18** (PoS, EJJ Web Conf, NPPP, etc.)
- Regular participations [2020-...]:
 - International Conf:** APS, EPS-HEP, ICHEP, HIGGS, Confinement, etc.
 - International WG:** LHC-HXS-WG, LHC-EFT-WG, CEPC, VBScan COST
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Ongoing work...



Multiquark states: Hartree-Fock up to $6t\ 6\bar{t}$ [FJ. Llanes, C.Peset, students]



Constrain EFT parameters involving tops?

2DHM (extra H doublet or other scalars) [JJS.Cillero, S.Dawson, D. Fontes, students]

+ matching to a low-energy EFT

2nd quantization + QCD on a quantum computer [FJ.Llanes, JJ.Gálvez]

Any sort of new resonances and unitarization, always interesting

New national MICINN grant: $\approx 20\ k\text{€}/y$ funding for next years

Final words: **gender balance**



- Effort in the gender balance of the team:
 - **PID2022-137003NB-I00** [2023-26] Work team → Female **6** Male **7**
(Permanent Research Team → F **0** M **3**)
 - **PID2019-108655GB-I00** [2020-23] Work team → Female **3** Male **4**
(Permanent Research Team → F **0** M **3**)
- Supporting participation in **@FlipPhysics**
(The @FlipPhysics initiative seeks to bring together female researchers in the area of nucl. & part.phys)
- **UCM gender balance acts:** Phys. gender eq. group, Mentoriza-1-Fut-Científica... 13



IPARCOS

BACKUP

By the numbers

[2020 - Present]



Citation Summary

InspireHep source [d>2019]

Exclude self-citations ?

Citeable ?

Published ?

Papers

69

29

Citations

267

197

h-index ?

8

8

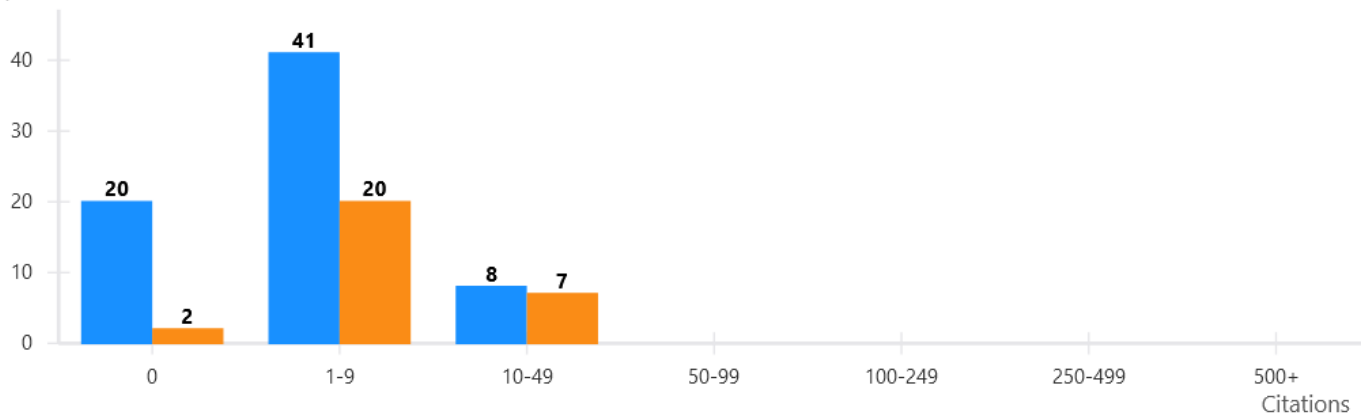
Citations/paper (avg)

3.9

6.8

Papers

— Citeable — Published



By the numbers

[2020 - Present]



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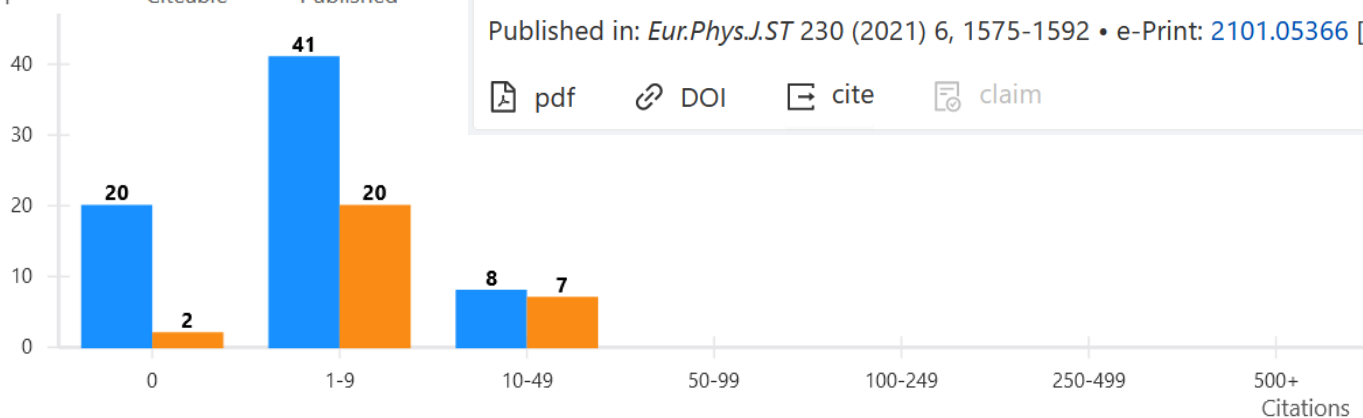
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Citations/paper (avg)

Papers

— Citeable — Published



Glueballs as the Ithaca of meson spectroscopy: From simple theory to challenging detection #1

Felipe J. Llanes-Estrada (Madrid U.) (Jan 10, 2021)

Published in: *Eur.Phys.J.ST* 230 (2021) 6, 1575-1592 • e-Print: [2101.05366](#) [hep-ph]

pdf

DOI

cite

claim

reference search

23 citations

By the numbers

[2020 - Present]



Citation Summary

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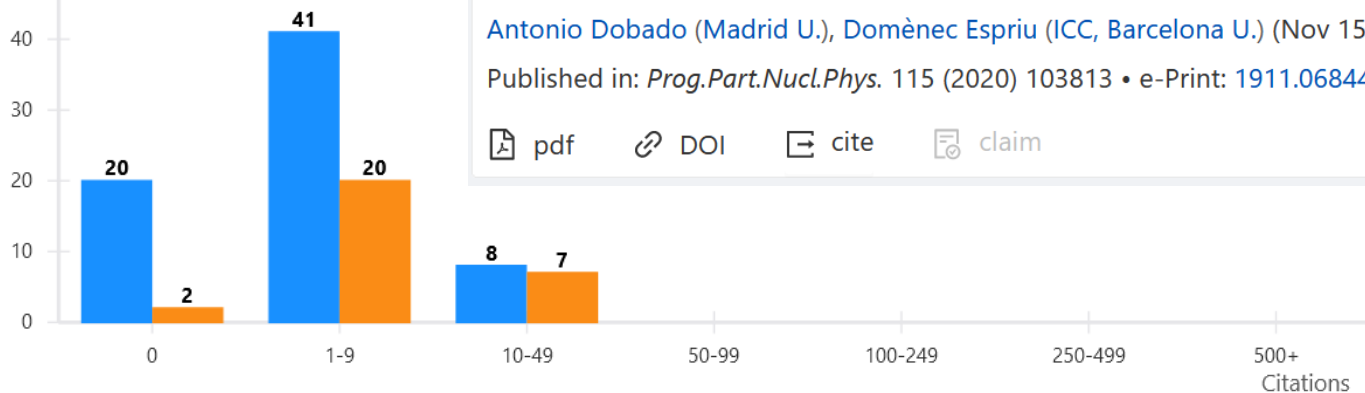
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Citations/paper (avg)

Papers

— Citeable — Published



Glueballs as the Ithaca of meson spectroscopy: From simple theory to challenging detection

#1

Strongly coupled theories beyond the Standard Model

#2

Antonio Dobado (Madrid U.), Domènec Espriu (ICC, Barcelona U.) (Nov 15, 2019)

Published in: *Prog.Part.Nucl.Phys.* 115 (2020) 103813 • e-Print: [1911.06844](#) [hep-ph]

pdf

DOI

cite

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reference search

23 citations

By the numbers

[2020 - Present]



Citation Summary

InspireHep source [d>2019]

Exclude self-citations [?]

Citeable [?]

Published [?]

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69

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Citations

267

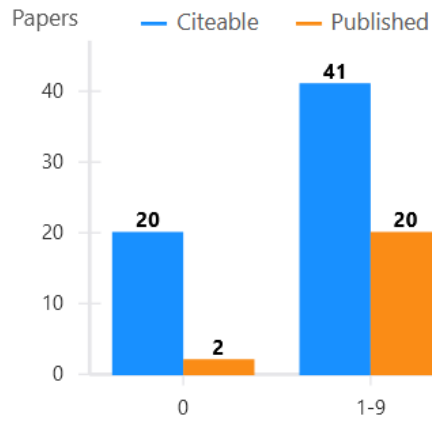
197

h-index [?]

8

8

Citations/paper (avg)



Glueballs as the Ithaca of meson spectroscopy: From simple theory to challenging detection #1

Strongly coupled theories beyond the Standard Model #2

Systematizing and addressing theory uncertainties of unitarization with the Inverse Amplitude Method #3

[Alexandre Salas-Bernárdez \(Madrid U.\)](#), [Felipe J. Llanes-Estrada \(Madrid U.\)](#), [Juan Escudero-Pedrosa \(Madrid U.\)](#), [Jose Antonio Oller \(Murcia U.\)](#) (Oct 26, 2020)

Published in: *SciPost Phys.* 11 (2021) 2, 020 • e-Print: [2010.13709](#) [hep-ph]

pdf

DOI

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reference search

23 citations

By the numbers

[2020 - Present]



Citation Summary

InspireHep source [d>2019]

Exclude self-citations ?

Citeable ?

Published ?

Papers

69

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Citations

267

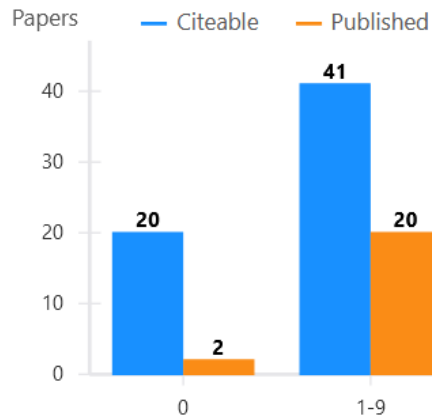
197

h-index ?

8

8

Citations/paper (avg)



Glueballs as the Ithaca of meson spectroscopy: From simple theory to challenging detection

#1

Strongly coupled theories beyond the Standard Model

#2

Systematizing and addressing theory uncertainties of unitarization with the Inverse Amplitude

#3

Quantum Information Science and Technology for Nuclear Physics. Input into U.S. Long-Range Planning, 2023

#4

Douglas Beck, Joseph Carlson, Zohreh Davoudi, Joseph Formaggio, Sofia Quaglioni et al. (Feb 28, 2023)

e-Print: [2303.00113](#) [nucl-ex]



reference search



19 citations

10-49

50-99

100-249

250-499

500+

Citations

By the numbers

[2020 - Present]



Citation Summary

InspireHep source [d>2019]

Exclude self-citations [?](#)

Citeable [?](#)

Published [?](#)

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69

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267

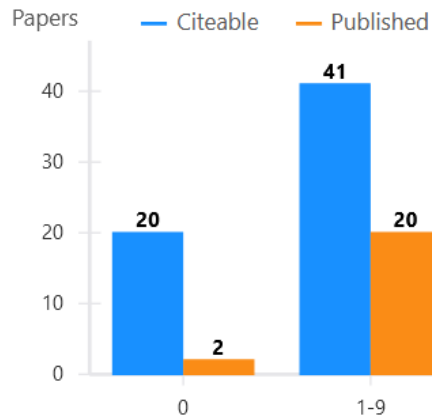
197

h-index [?](#)

8

8

Citations/paper (avg)



Glueballs as the Ithaca of meson spectroscopy: From simple theory to challenging detection

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#3

Quantum Information Science and Technology for Nuclear Physics. Input into U.S. Long-Range

#4

Distinguishing electroweak EFTs with $W_L W_L \rightarrow n \times h$

#5

Raquel Gómez-Ambrosio (Milan Bicocca U. and INFN, Milan Bicocca), Felipe J. Llanes-Estrada (Madrid U.), Alexandre Salas-Bernárdez (Madrid U.), Juan J. Sanz-Cillero (Madrid U.) (Apr 4, 2022)

Published in: *Phys.Rev.D* 106 (2022) 5, 053004 • e-Print: [2204.01763](#) [hep-ph]

pdf

DOI

cite

claim

reference search

16 citations

By the numbers (according to [2020-23] PID2019-108655GB-I00 report):



- Number of peer-reviewed articles [2020-23]: **36**
1 ProgPNP, **9** PRD, **4** JHEP, **4** JCAP, **4** EPJC, **15** (others: PLB, PRC, NPA, EPJA, etc.)
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- Organization [2020-23]: RSEF Biennial [A. Dobado], **2** workshops [FJ.Llanes]

Other research lines: gravity and spont. sym. breaking

All you always wanted to know about...

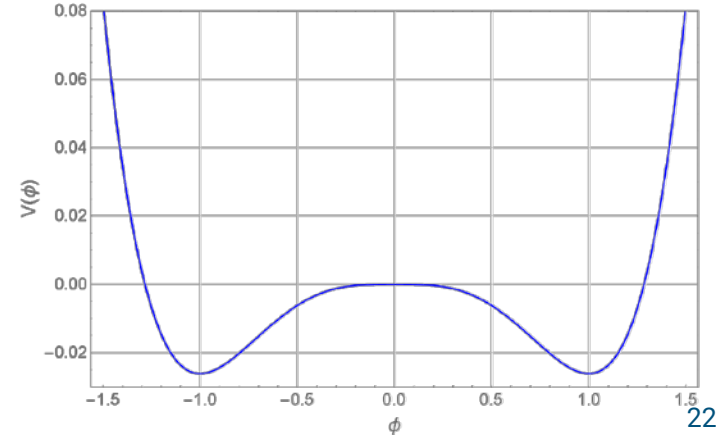
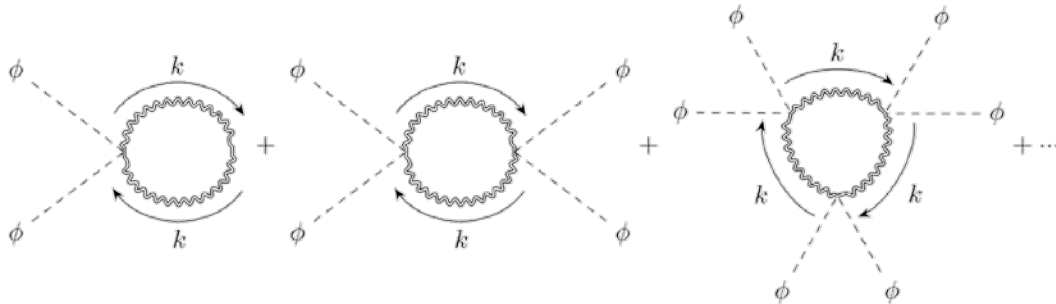
Coleman-Weinberg mechanism applied to gravity

$$\sqrt{|\det g|} \mathcal{L} = \sqrt{|\det g|} \left[\frac{1}{2} (\partial_\mu \phi_1)^2 + \frac{1}{2} (\partial_\mu \phi_2)^2 - V_0(\phi_1, \phi_2) + \frac{R^2}{6f_0^2} + \frac{\frac{1}{3}R^2 - R_{\mu\nu}^2}{f_2^2} - \frac{1}{2}R(\xi_1\phi_1^2 + \xi_2\phi_2^2) \right]$$

$$V_0(\phi_1, \phi_2) = \frac{1}{4!} (\lambda_{11}\phi_1^4 + \lambda_{22}\phi_2^4 + 2\lambda_{12}\phi_1^2\phi_2^2)$$

$\downarrow \langle \phi \rangle$
 M_{Pl}^2

Renormalization magic: scaleless Lagr + quantization scale



Zero-point energy of graviton field affects the scalar



SMEFT vs. HEFT

$$|H|^2 = \frac{(v+h)^2}{2},$$
$$(\partial|H|^2)^2 = (v+h)^2 (\partial h)^2 = 2|H|^2 (\partial h)^2.$$

$$\mathcal{L}_{\text{SMEFT}} = \underbrace{|\partial H|^2}_{=\mathcal{L}_{SM}} + \underbrace{\frac{1}{2} \left[\left(\frac{1}{v} (F^{-1})' [\sqrt{2|H|^2/v^2}] \right)^2 - 1 \right]}_{=\Delta\mathcal{L}_{BSM}} \frac{(\partial|H|^2)^2}{2|H|^2}.$$

Higgs Effective field theories @ LHC: theory



All you always wanted to know about...

The right effective theory to modify the Standard Model, **SMEFT** vs. **HEFT**

