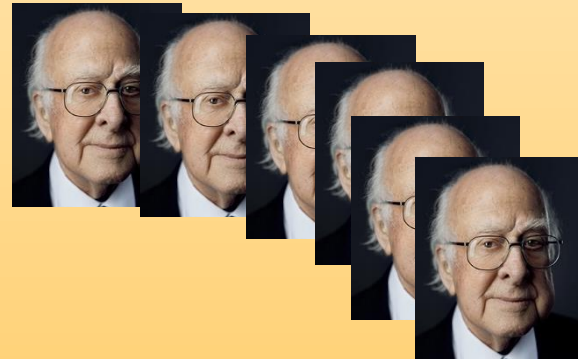


Higgs Reloaded

**João P. Silva
& Jorge Romão**

DF & CFTP (IST)



jpsilva@tecnico.ulisboa.pt

Physics is an experimental science

- Where is data coming from?

LHC

(Atlas + CMS ~ 6500 publ in 2016-22)

- What have we learned?

There is a fundamental spin 0 particle :

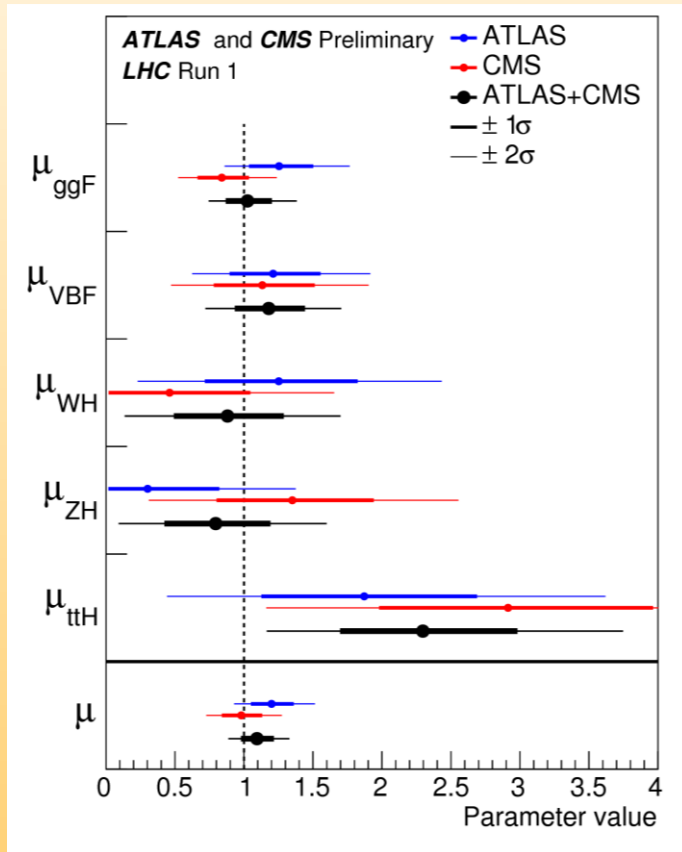
the Higgs

mass:

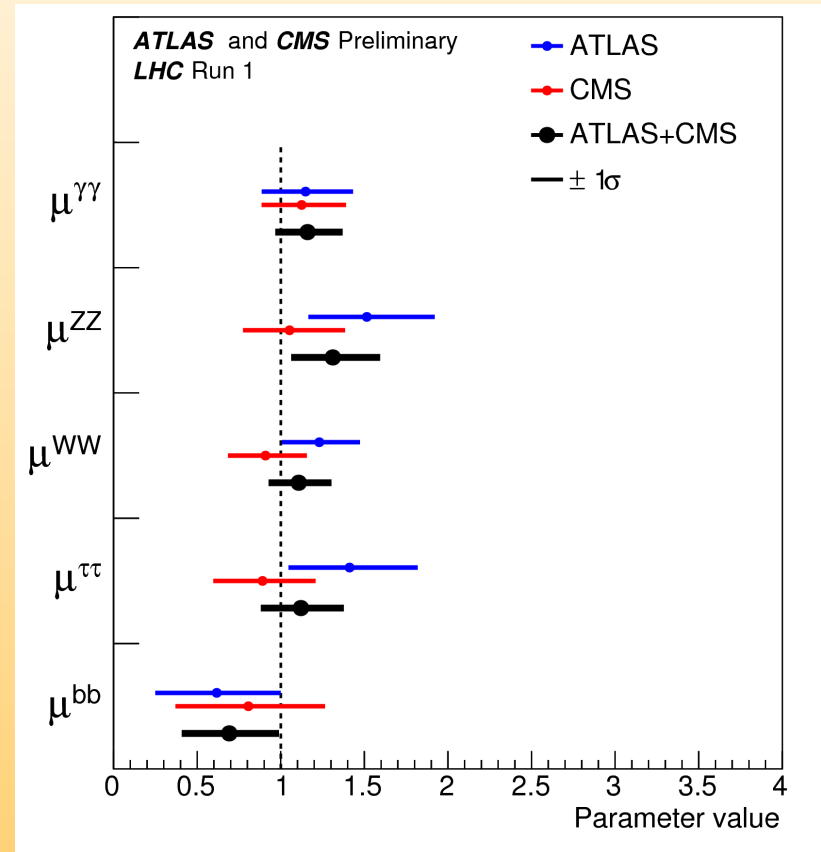
125 GeV

Physics is an experimental science

SM BRs assumed

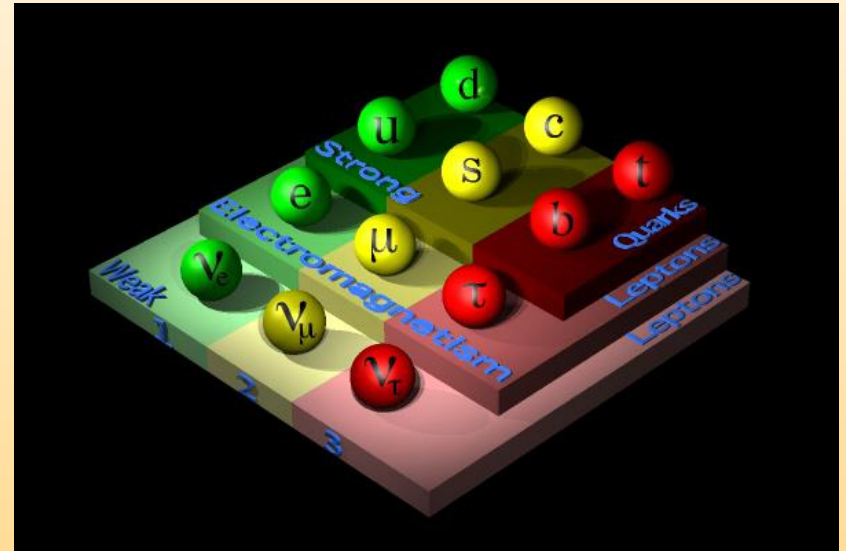


SM production assumed



Why 1 Higgs?

- # Spin 1 fixed by gauge group:
 $SU(3) \times SU(2) \times U(1) \Rightarrow W^\pm, Z^0, \gamma, g_{1..8}$
- Nothing fixes # Spin 1/2:
Settled by experiment



- Nothing fixes # Spin 0:
MUST be settled by experiment

Novelties in Multi-Higgs

- **Multiple spin-0 particles**
 - **Neutral:**
 - Scalar (**h, H**)
 - Pseudoscalar (**A**)
 - Mixed (**h_1, h_2, h_3**)
 - **Charged (H^\pm)**
- **Rich vacuum structure**
 - **May have charge breaking minimum**
 - **May have two local minima of unequal depths**

Novelties in Multi-Higgs

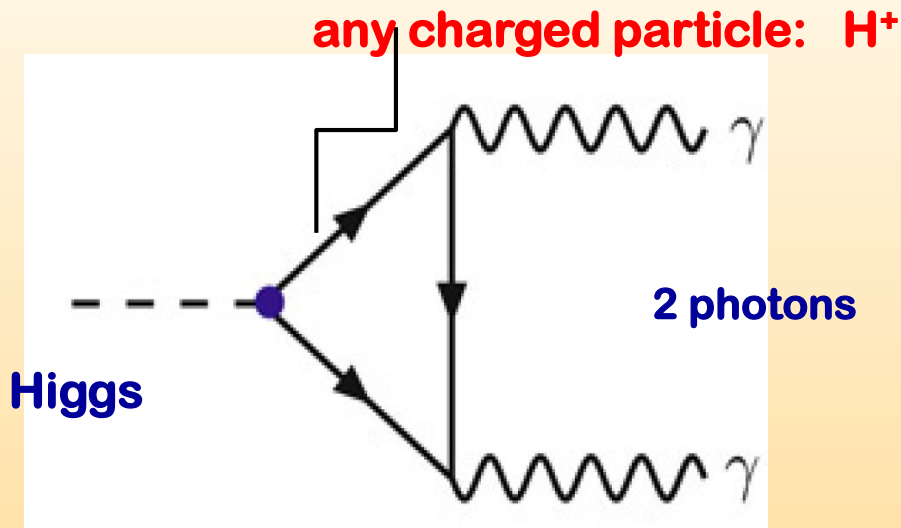
- **CP violation in the Higgs sector**

- **Theory:** **Explicit**
 Spontaneous
- **Experiment:** **Scalar-pseudoscalar mixing**
 Mixing of charged Higgs
 Diagonal coupling to fermions
 Off-diagonal coupling to fermions **(FCNSI)**

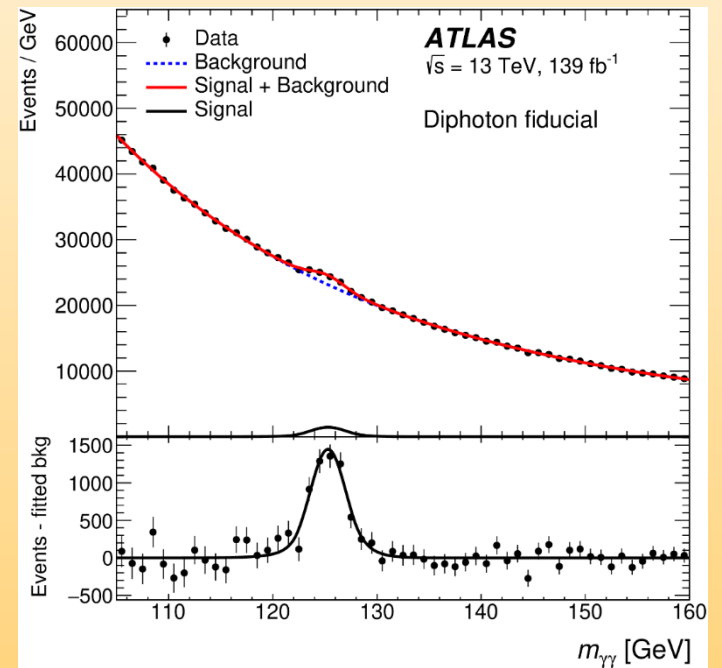
- **Possible Cosmological implications**

- **Baryogenesis / Higgsogenesis**
- **Candidates for Dark Matter**

Higgs decays



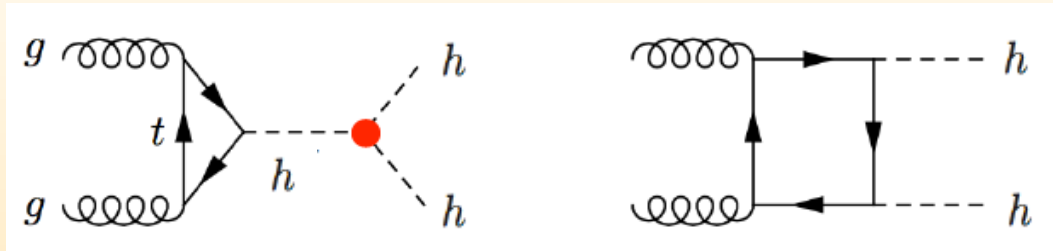
ATLAS: 9300 $h \rightarrow \gamma\gamma$



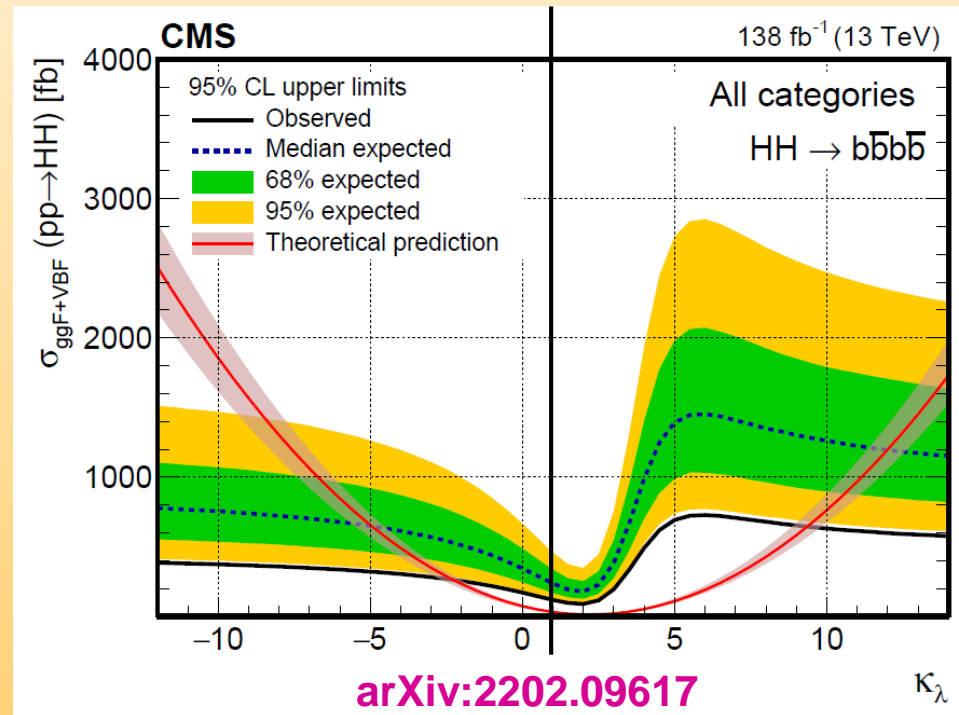
thanks to: Patricia Conde Muño

Higgs pair production

SM

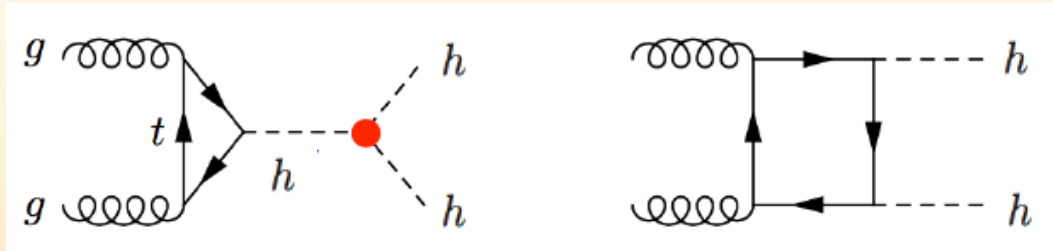


$-2.3 < \kappa_\lambda < 9.4$ (95% CL)

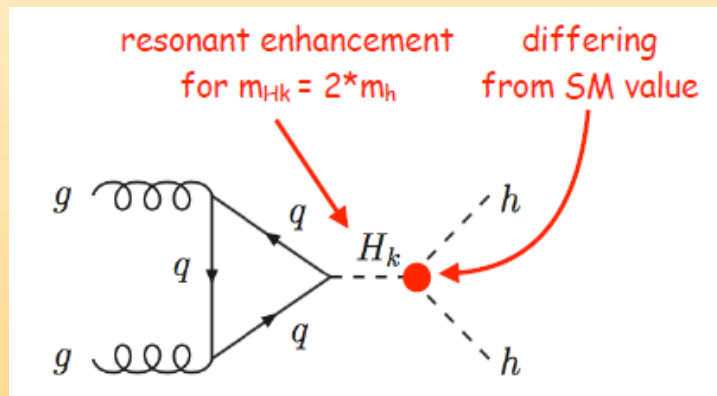


Higgs pair production

SM



New states



M.M.Mühlleitner, Talk at Higgs 2020

Theoretical constraints



- **MEFT– Sérgio Carrôlo → PhD Max Planck**

1. PRD 103, 075026 (2021)
2. EPJC 82, 749 (2022)
3. EPJC 83, 292 (2023)

Eur. Phys. J. C (2023) 83:292
<https://doi.org/10.1140/epjc/s10052-023-11463-5>

THE EUROPEAN
PHYSICAL JOURNAL C



Regular Article - Theoretical Physics

Eur. Phys. J. C (2022) 82:749
<https://doi.org/10.1140/epjc/s10052-022-10712-3>

THE EUROPEAN
PHYSICAL JOURNAL C



Regular Article - Theoretical Physics

atrices

Conditions for global minimum in the A_4 symmetric 3HDM

venida Rovisco Pais 1, 1049 Lisbon, Portugal

Sergio Carrolo^a, Jorge C. Romão^b, João P. Silva^c

PHYSICAL REVIEW D **103**, 075026 (2021)

Symmetry and decoupling in multi-Higgs boson models

Sergio Carrolo,^{*} Jorge C. Romão,[†] João P. Silva^{b,‡} and Francisco Vazão[§]
*CFTP, Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa,
Avenida Rovisco Pais 1, 1049 Lisbon, Portugal*

(Received 3 March 2021; accepted 22 March 2021; published 23 April 2021)

Unitarity bounds for any number of Higgs

- **MEFT → PhD student – Miguel Bento**



1. JHEP 1711, 095 (2017) (67 pages!)
2. JHEP 1810, 143 (2018)
3. JHEP 21, 229 (2020)
4. JHEP 05, 146 (2021) (single author!)
5. JHEP 08, 273 (2022)

The invariant space of multi-Higgs doublet models

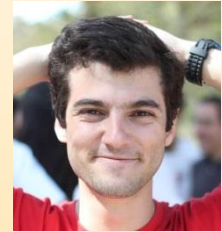
M.P. Bento

JHEP05

A most interesting possibility: Higgs with large pseudoscalar content

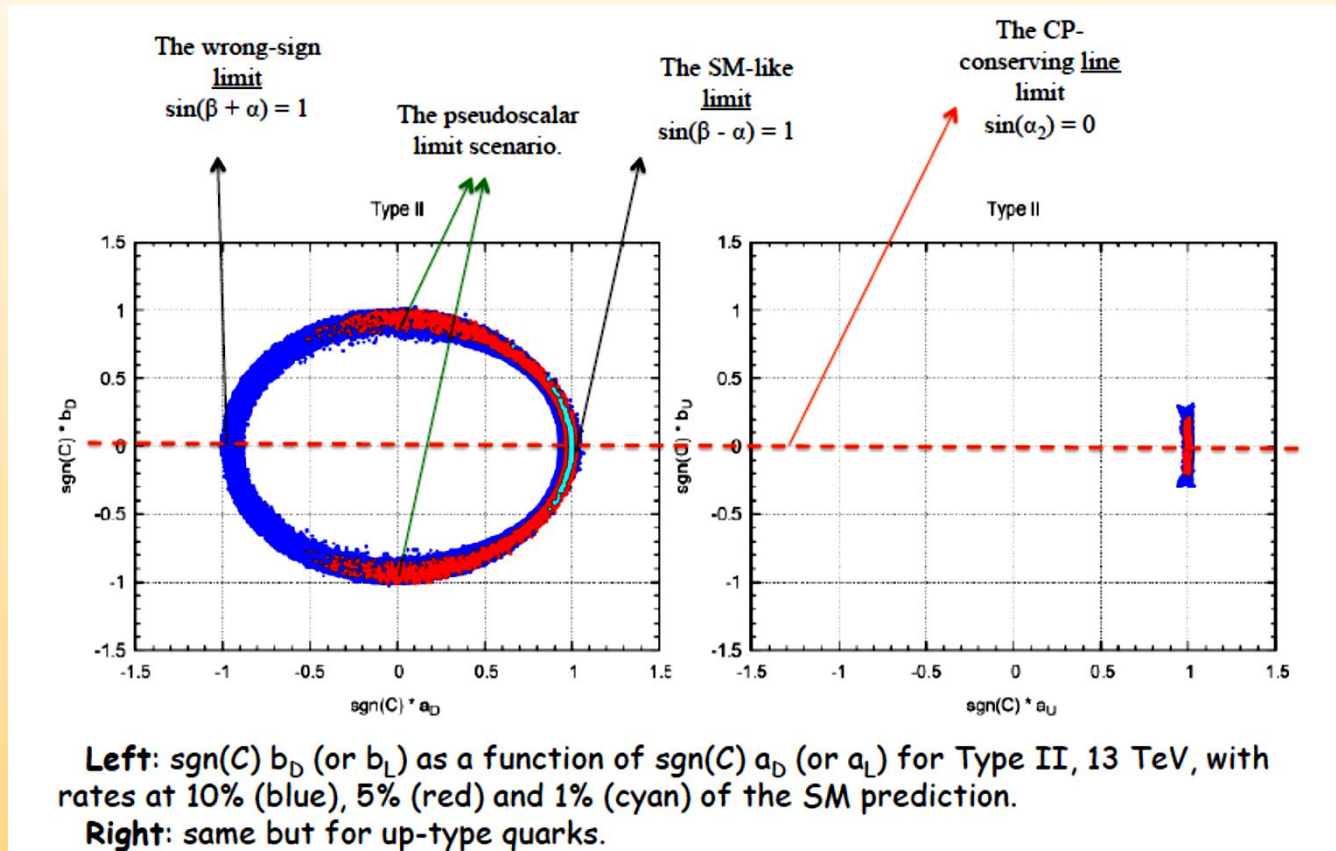
Duarte Fontes

MEFT → PhD → PostDoc (Brookhaven National Lab.)



1. Phys. Rev. D90, 015021 (2014)
2. JHEP 1412, 043 (2014)
3. JHEP 1506, 060 (2015)
4. Phys. Rev. D92, 055014 (2015)
5. Handbook of LHC Higgs Cross Sections: 4. (>1600 citations)
6. Eur. Phys. J. C77 (2017) no.3, 176 (EFT)
7. JHEP 1804, 002 (2018) (EFT)
8. JHEP 1802, 073 (2018)
9. JHEP 1910, 245 (2019)
10. **FEYNMASTER**
11. Nucl.Phys.B 958 (2020) 115131
12. Eur.Phys.J.C 81 (2021) 6, 541
13. JHEP 06 (2021) 016
14. JHEP 03 (2022) 144

Higgs pseudoscalardness?



Fontes, Romão, R. Santos, JPSilva : Toyama

Multi-Higgs Workshops

Workshop on Multi-Higgs Models

30Ago - 2Sept 2022

Lisbon - Portugal

This Workshop brings together those interested in the theory and phenomenology of Multi-Higgs models. The program is designed to include talks given by some of the leading experts in the field, and also ample time for discussions and collaboration between researchers. A particular emphasis will be placed on identifying those features of the models which are testable at the LHC and DM searches.

For registration and/or to propose a talk, send an email to:

2hdmwork@cftp.tecnico.ulisboa.pt

Web Page : <http://cftp.tecnico.ulisboa.pt/~2hdmwork/>

Organizing Committee:

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João P. Silva, CFTP
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International Advisory Committee:

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G.C. Branco
H. Haber
B. Grzadkowski
S. Kanemura
P. Osland



Workshop on
Multi-Higgs Models
September 2018
Lisbon - Portugal

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Workshop on
Multi-Higgs Models
October 2016
Lisbon - Portugal

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Workshop on
Multi-Higgs Models
November 2014
Lisbon - Portugal

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Workshop on
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December 2012
Lisbon - Portugal

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Workshop on
Multi-Higgs Models
January 2009
Lisbon - Portugal

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Workshop on
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February 2009
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- **Very active field**
- **Many experimental results**
- **Many interesting theoretical features**
- **Strong international impact**

**João P. Silva
& Jorge Romão
DF & CFTP (IST)**

