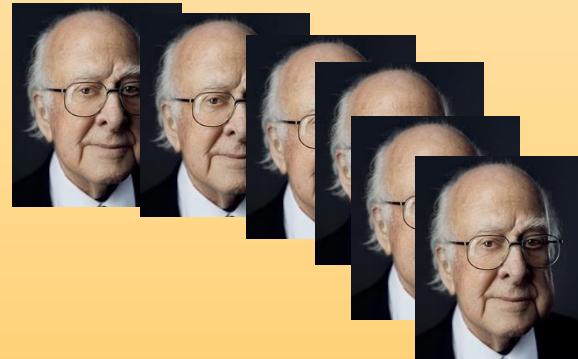


Higgs Reloaded

João P. Silva

DF & CFTP (IST)



Physics is an experimental science

- Where is data coming from?

LHC

(Atlas + CMS ~4066 publ in 2016-18)

- What have we learned?

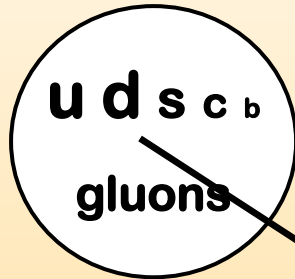
There is a fundamental spin 0 particle :

the Higgs

| | | |
|---------------|------------------------------|-------------|
| mass: | 125 GeV | |
| width: | < ~ 1 GeV (direct) | [SM ~4 MeV] |
| elmg charge: | none | |
| color charge: | none | |

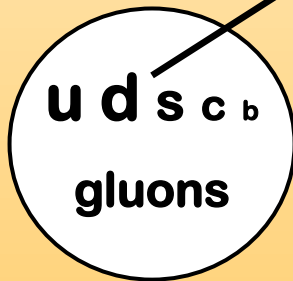
Higgs is difficult to produce

proton



$$\left(\frac{m_u}{m_H} \right) \sim \left(\frac{2 \text{ MeV}}{125 \text{ GeV}} \right) \sim 10^{-5}$$

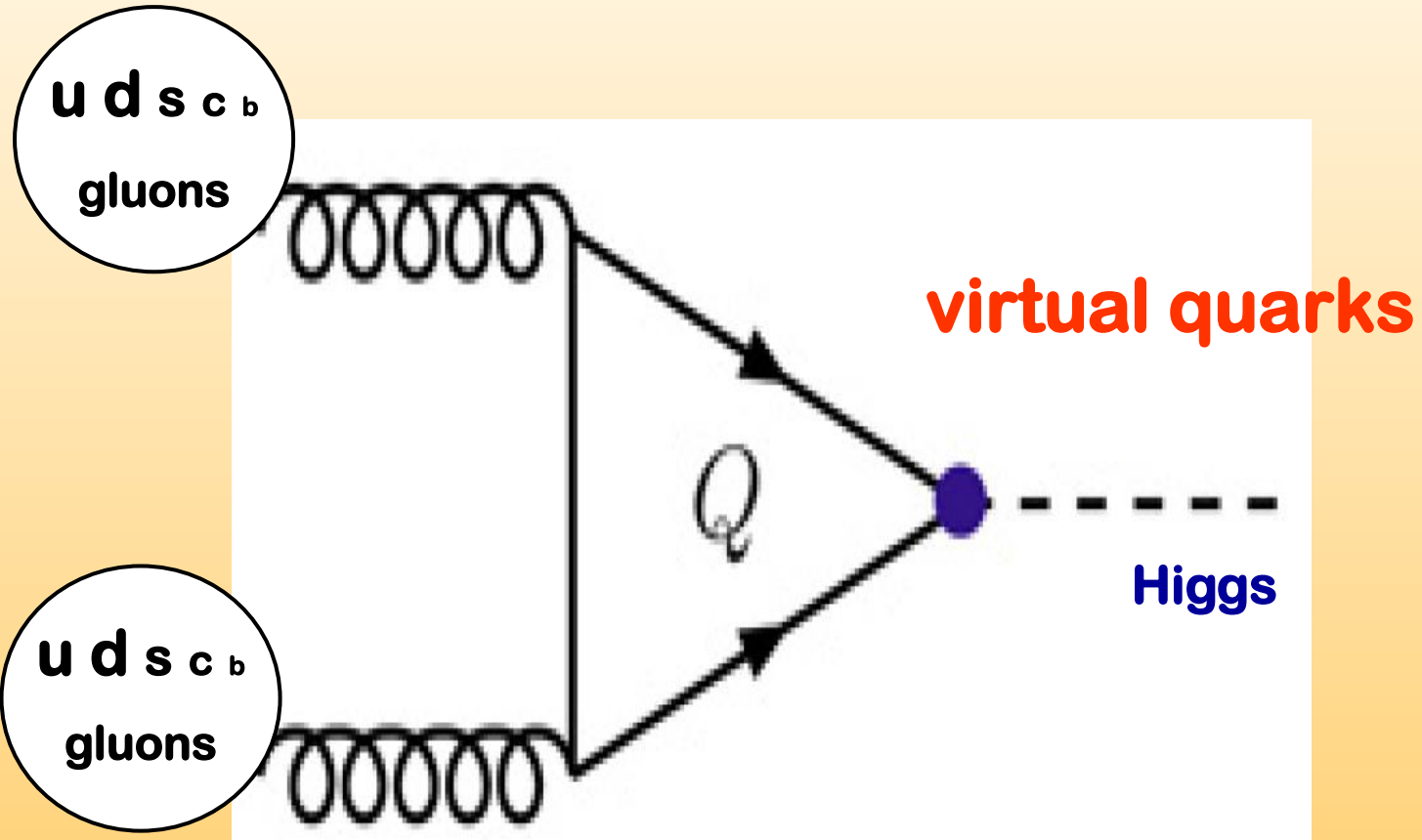
Higgs



proton

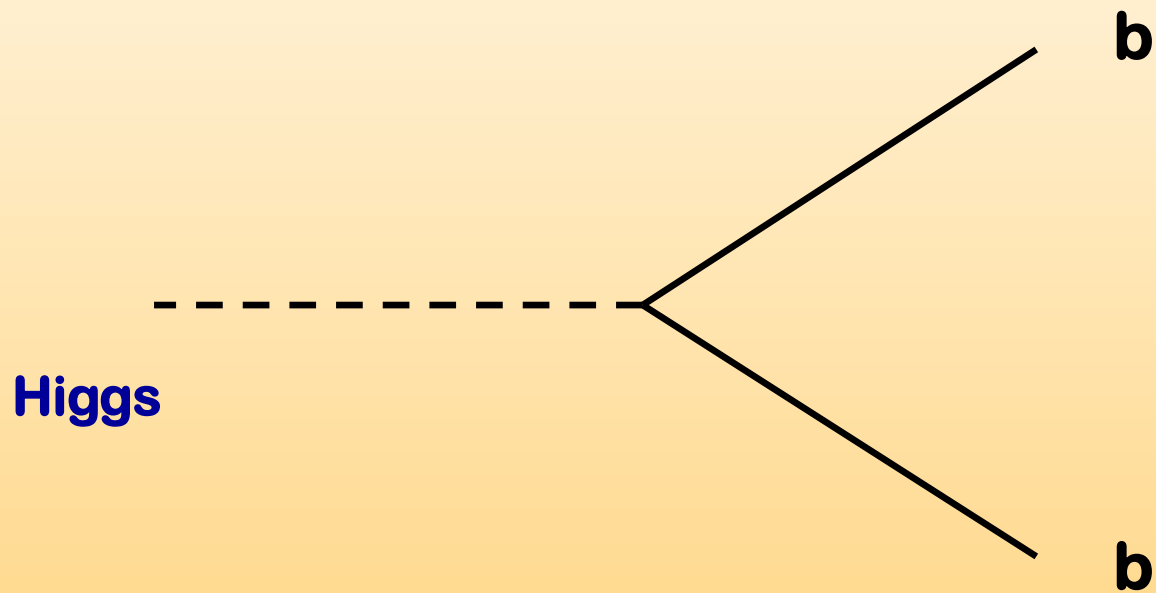
Higgs is difficult to produce

proton

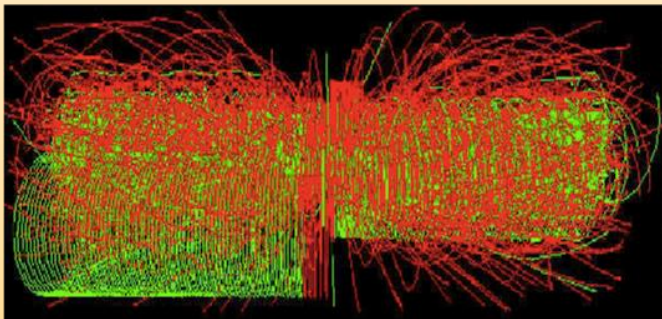
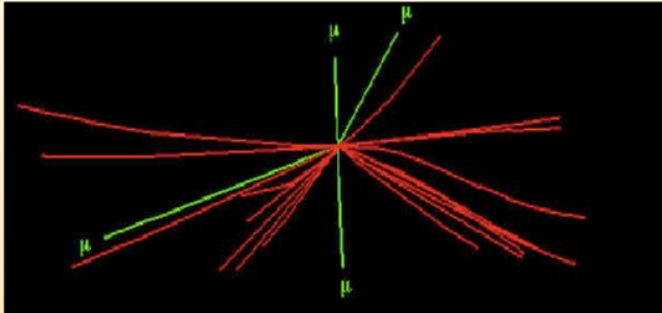


proton

Higgs is difficult to detect

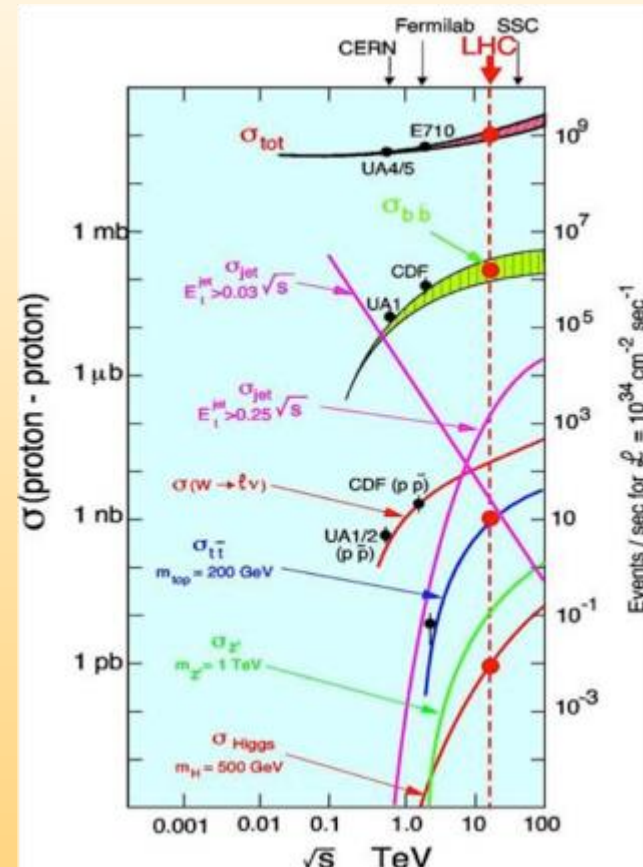


Higgs is difficult to detect



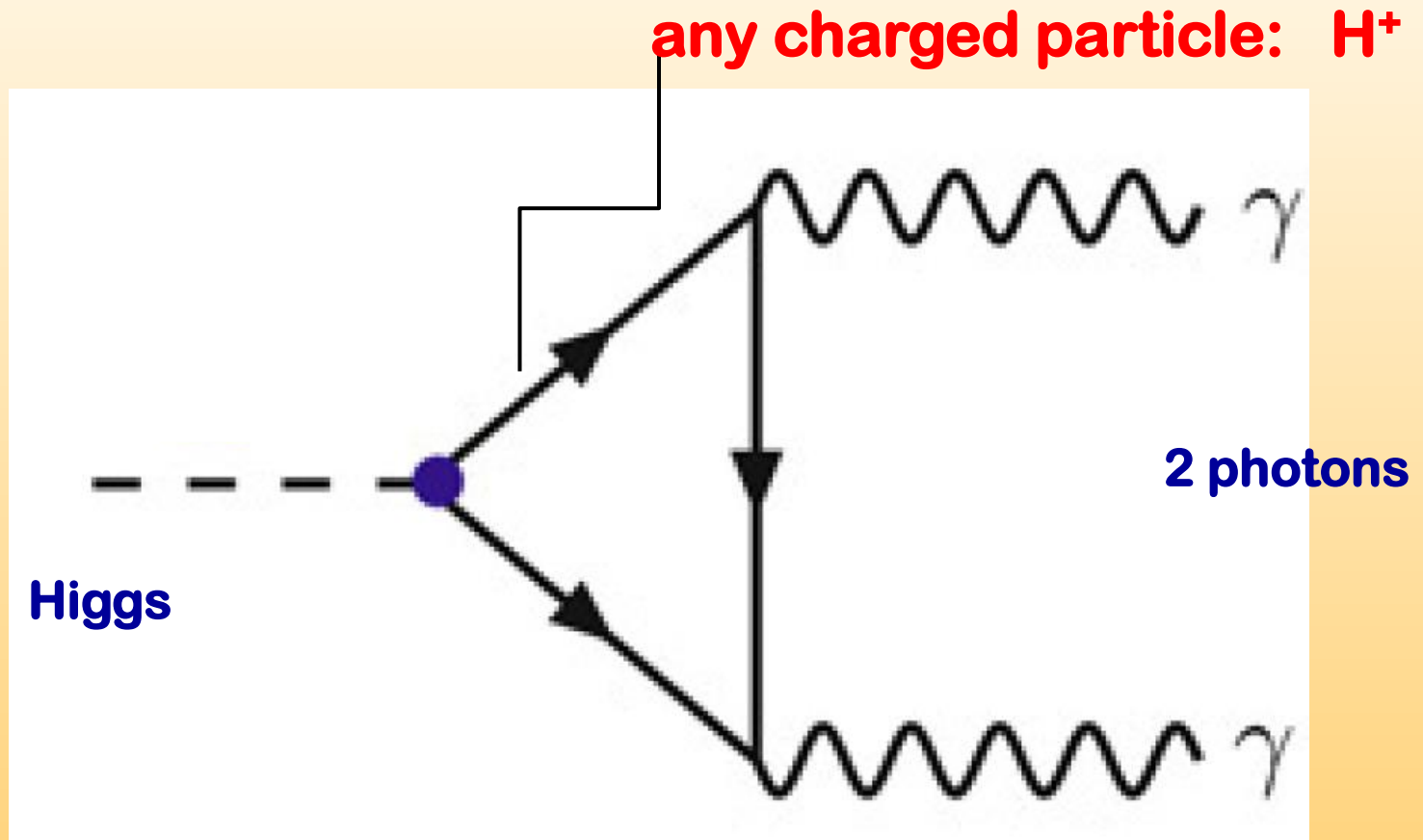
ATLAS

- $\sim 300 \times 10^{12}$ collisions
- ~ 1300 Higgs created
- ~ 450 h $\rightarrow \gamma\gamma$



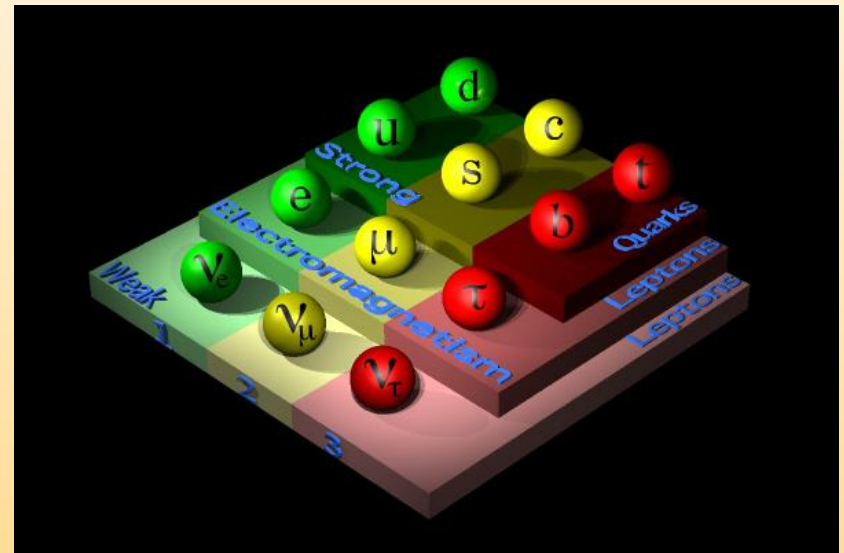
thanks to: Ricardo Gonalo

Higgs is difficult to detect



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

Comercial break



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

Unitarity bounds for any number of Higgs

- **MEFT student – Miguel Bento**



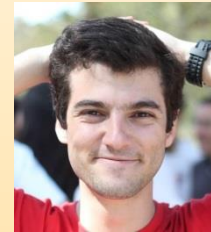
1. JHEP 1711, 095 (2017) (67 pages!)
2. JHEP 1810, 143 (2018)

Multi-Higgs doublet models: physical parametrization, sum rules and unitarity bounds

Miguel P. Bento,^a Howard E. Haber,^b J.C. Romão^a and João P. Silva^a

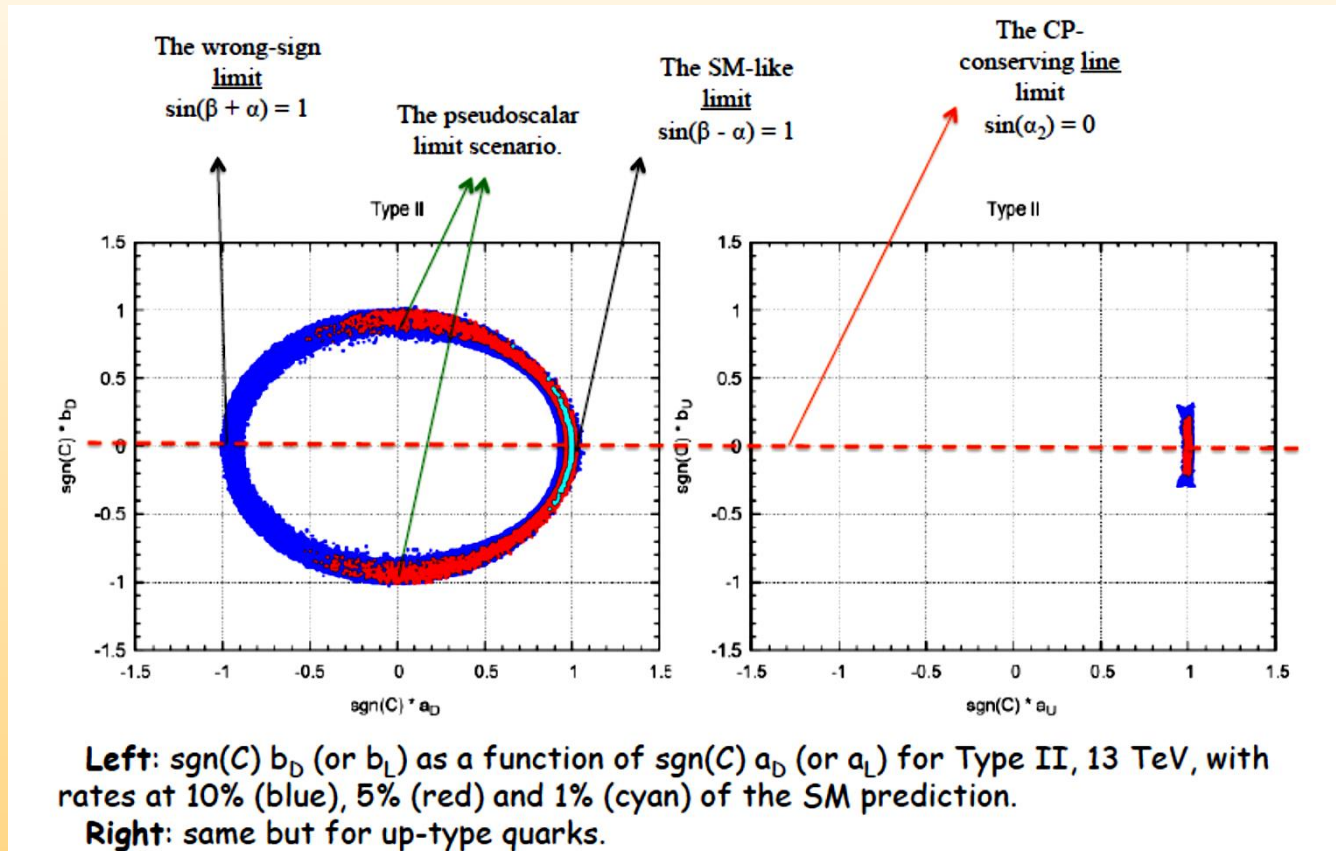
A most interesting possibility: Higgs with large pseudoscalar content

- **MEFT → PhD student – Duarte Fontes**



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. Deciphering the Nature of the Higgs Sector (>500 citations)
6. Eur. Phys. J. C77 (2017) no.3, 176 (EFT)
7. JHEP 1804, 002 (2018) (EFT)
8. JHEP 1802, 073(2018)

Higgs pseudoscalardness?



Fontes, Romão, R. Santos, JPSilva : Toyama

Multi-Higgs Workshops

**Workshop on
Multi-Higgs Models**

4-7 September 2018

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.

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:

| | |
|-----------------------------|-----------------------------------|
| Jorge Romão, CFTP | International Advisory Committee: |
| João P. Silva, CFTP | F.J. Botella |
| Rui Santos, ISEL & CFTC | G.C. Branco |
| Pedro Ferreira, ISEL & CFTC | H. Haber |
| Luís Lavoura, CFTP | B. Grzadkowski |
| | P. Osland |



**Workshop on
Multi-Higgs Models**

September 2016

Lisbon - Portugal

together those interested in the theory of Multi-Higgs models. The program is 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.

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**Workshop on
Multi-Higgs Models**

September 2014

Lisbon - Portugal

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**Workshop on
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September 2012

Lisbon - Portugal

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September 2009

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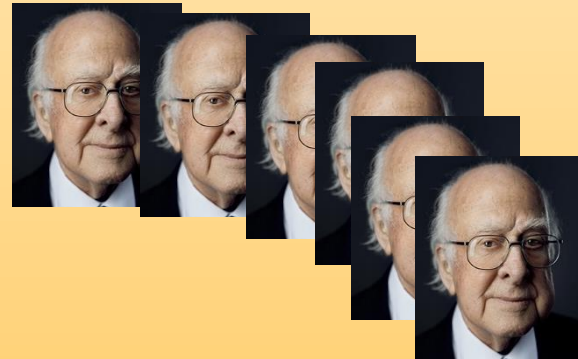
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- **Very active field**
- **Many experimental results**
- **Many interesting theoretical features**
- **Strong international impact**



END