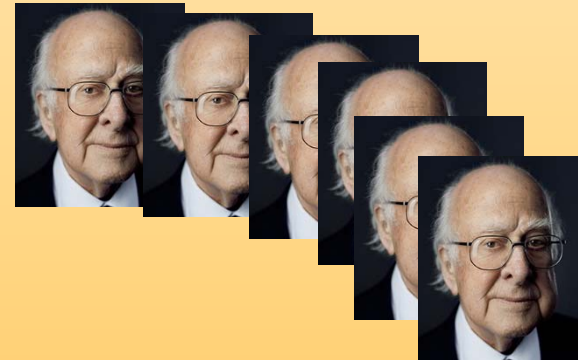


Higgs Reloaded

João P. Silva

DF & CFTP (IST)



Physics is an experimental science

- Where is data coming from?

LHC

(Atlas + CMS ~4698 publ in 2016-19)

- What have we learned?

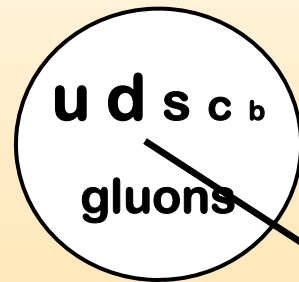
There is a fundamental spin 0 particle :

the Higgs

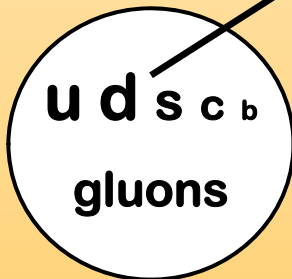
mass:	125 GeV	
width:	< ~ 1 GeV (direct)	[SM ~4 MeV]
elmg charge:	none	
color charge:	none	

Higgs is difficult to produce

proton



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

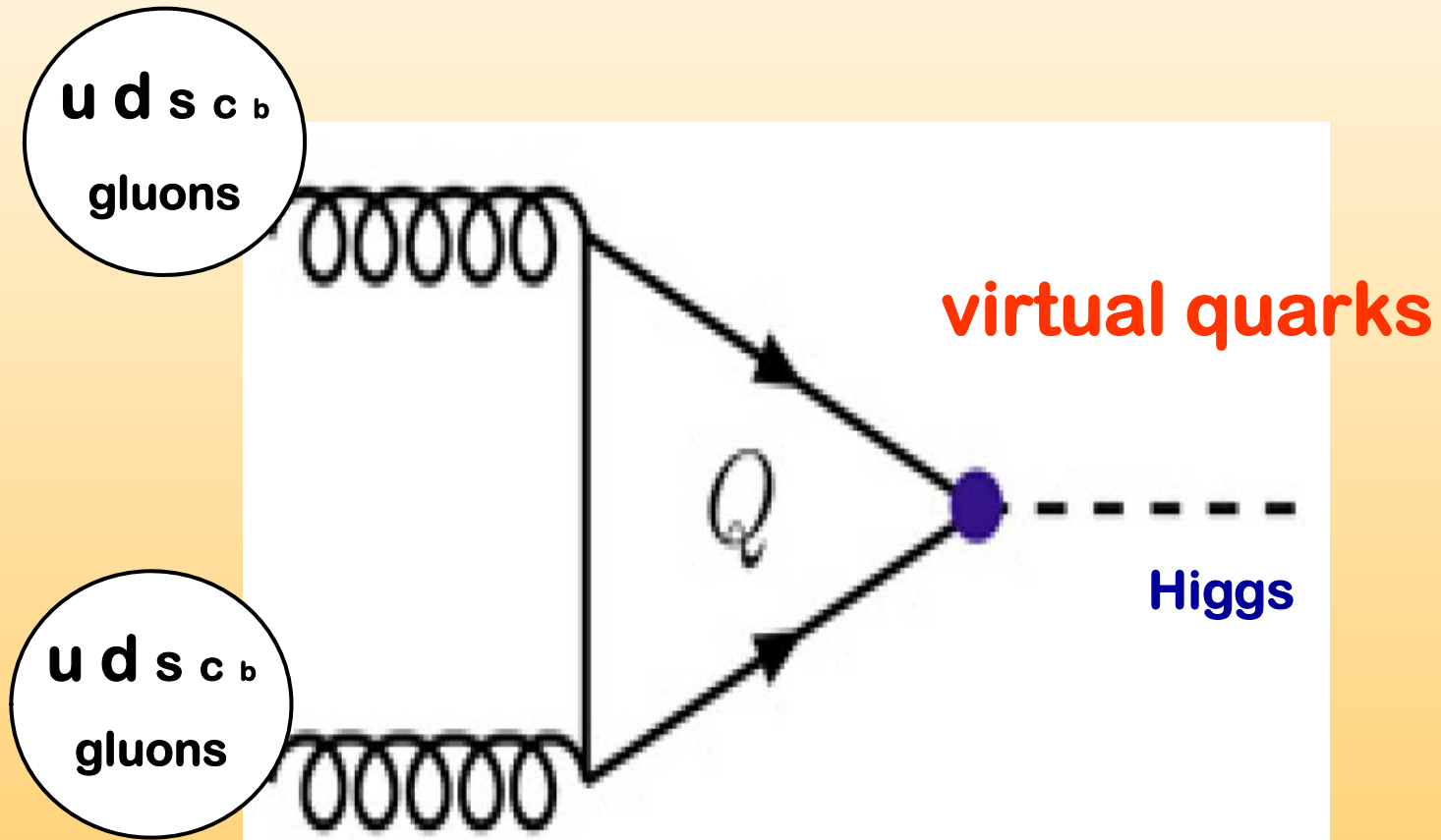


proton

Higgs

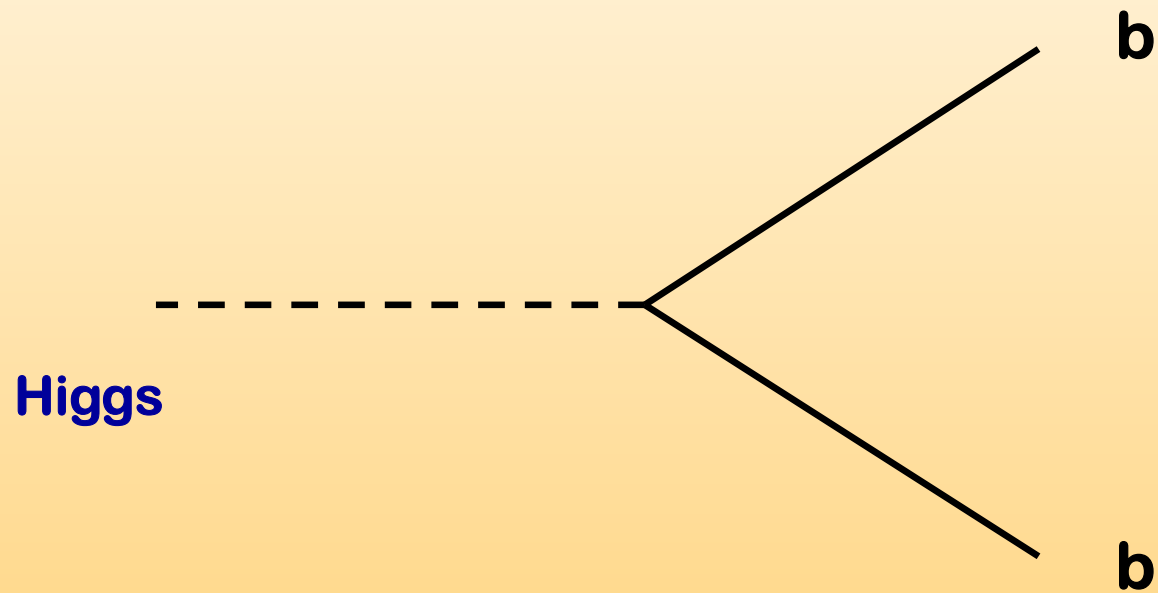
Higgs is difficult to produce

proton

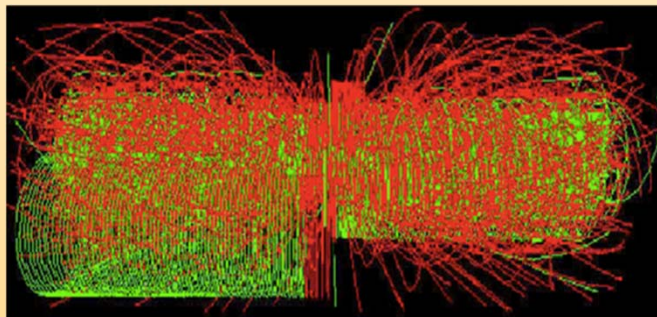
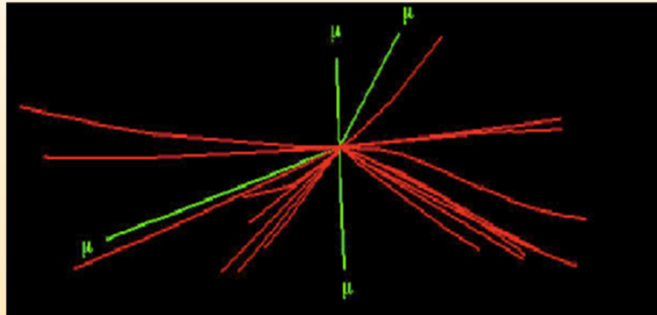


proton

Higgs is difficult to detect

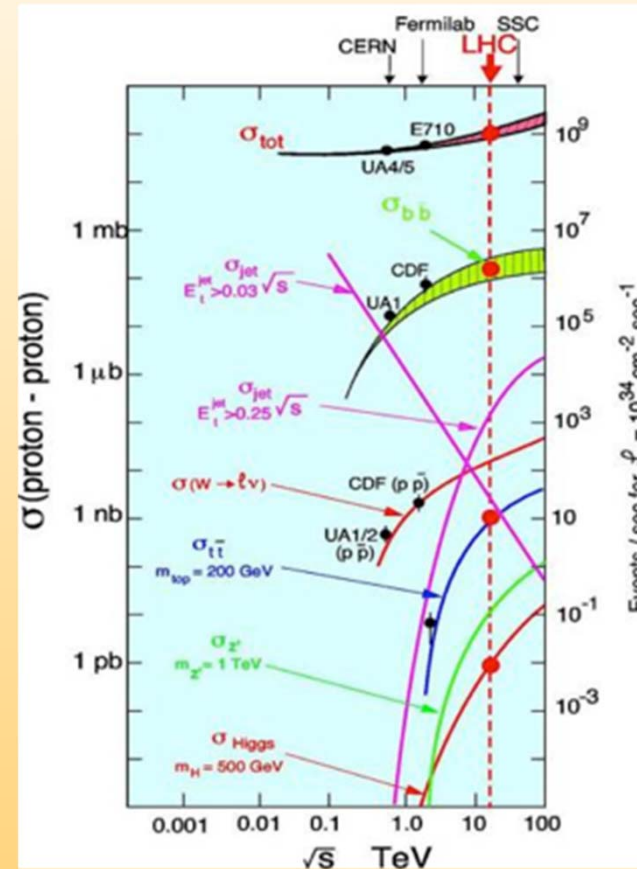


Higgs is difficult to detect



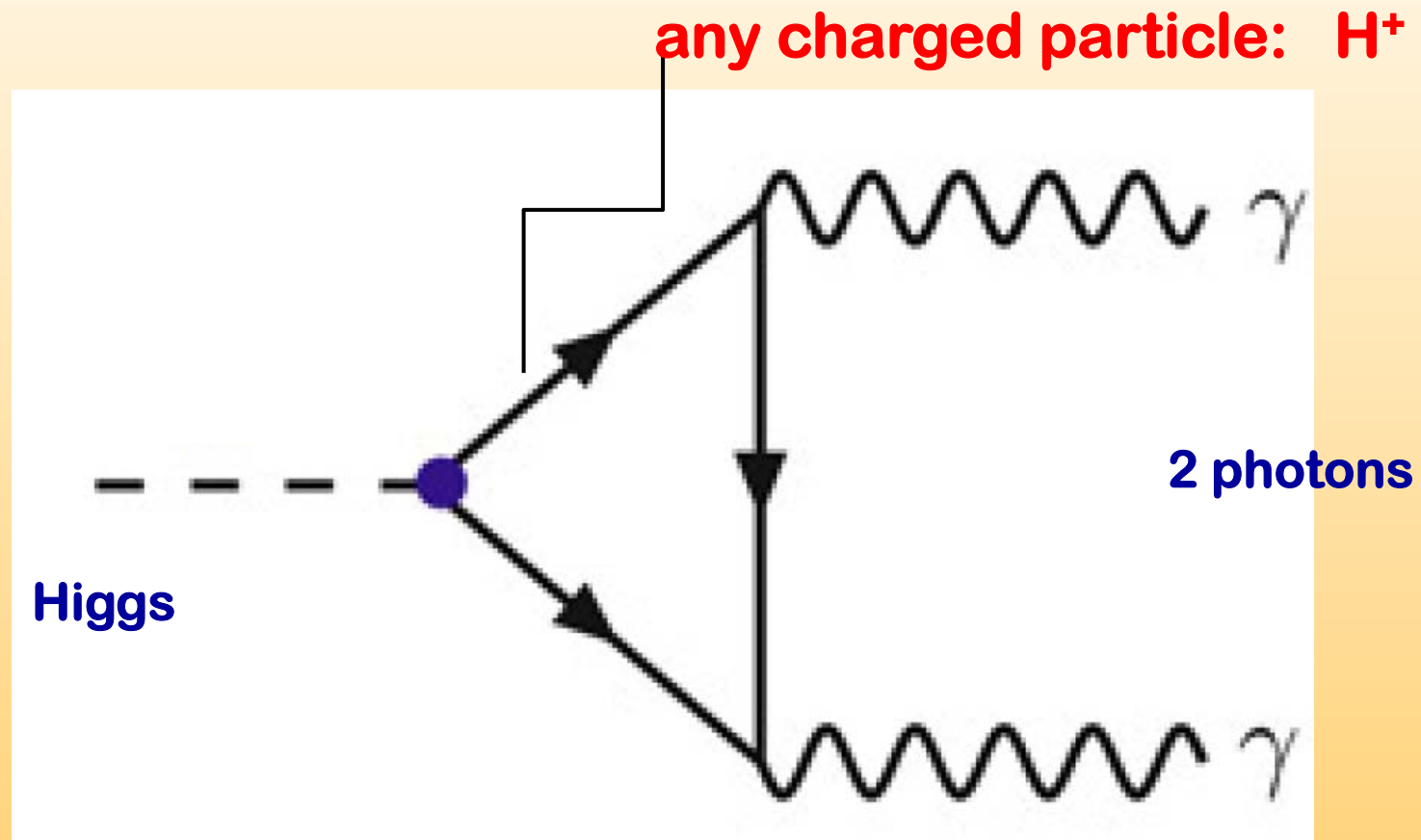
ATLAS

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



thanks to: Ricardo Gonalo

Higgs is difficult to detect

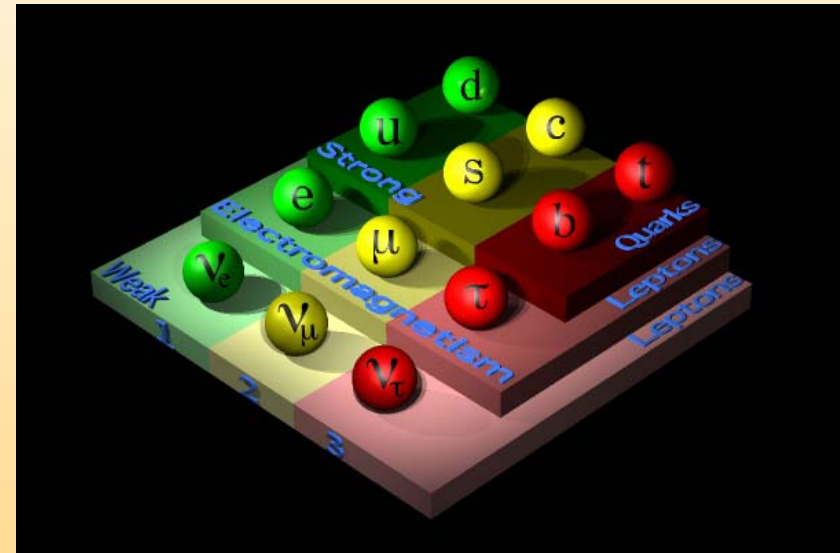


Comercial break



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 (h1, h2, h3)
 - **Charged (H[±])**
- **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**

Bounded from below

- **MEFT– Francisco Faro**



1. PRD 100, 035038 (2019)
2. to appear

PHYSICAL REVIEW D **100**, 035038 (2019)

Boundedness from below in the $U(1) \times U(1)$ three-Higgs-doublet model

Francisco S. Faro^{*} and Igor P. Ivanov[†]

*Centro de Física Teórica de Partículas, Departamento de Física, Instituto Superior Técnico,
Universidade de Lisboa, Lisboa 1049-001, Portugal*

Unitarity bounds for any number of Higgs

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



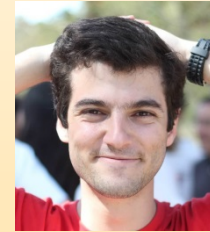
1. JHEP 1711, 095 (2017) (67 pages!)
2. JHEP 1810, 143 (2018)

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

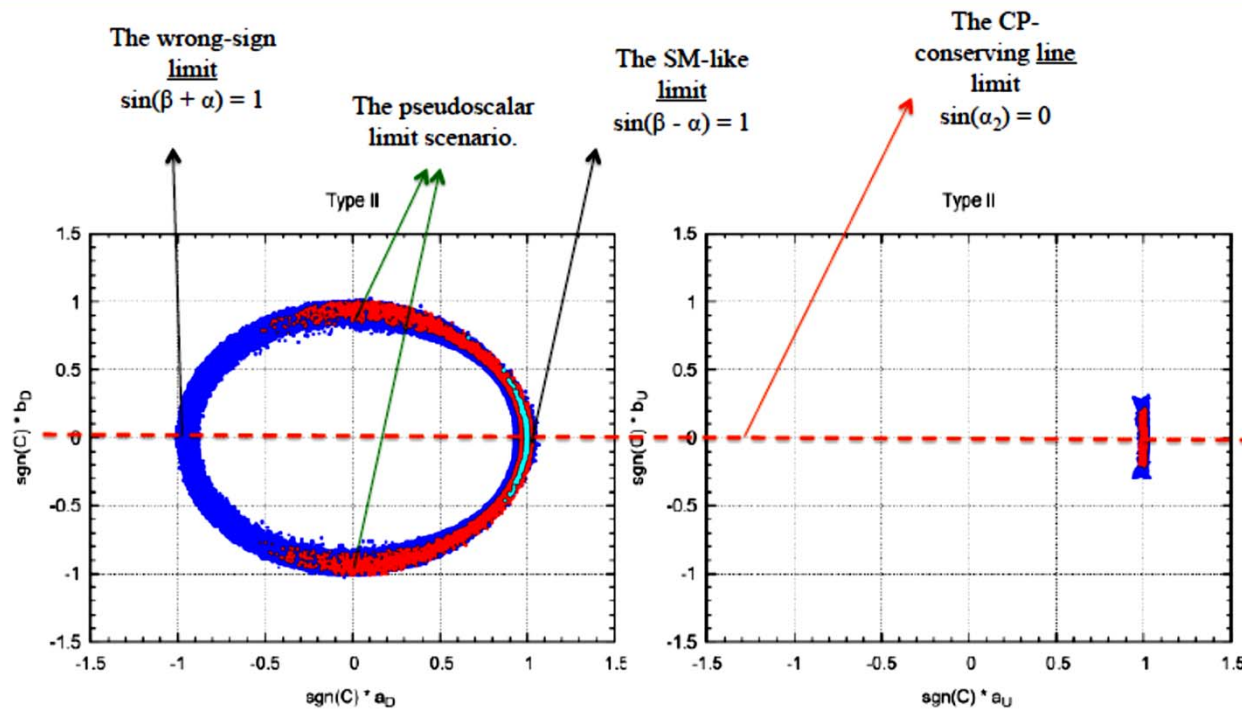
A most interesting possibility: Higgs with large pseudoscalar content

- **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 (>850 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**

Higgs pseudoscalardness?



Left: $\text{sgn}(C) b_D$ (or b_L) as a function of $\text{sgn}(C) a_D$ (or a_L) for Type II, 13 TeV, with rates at 10% (blue), 5% (red) and 1% (cyan) of the SM prediction.
Right: same but for up-type quarks.

Fontes, Romão, R. Santos, JPSilva : Toyama

Multi-Higgs Workshops

Workshop on Multi-Higgs Models

1-4 September 2020

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:

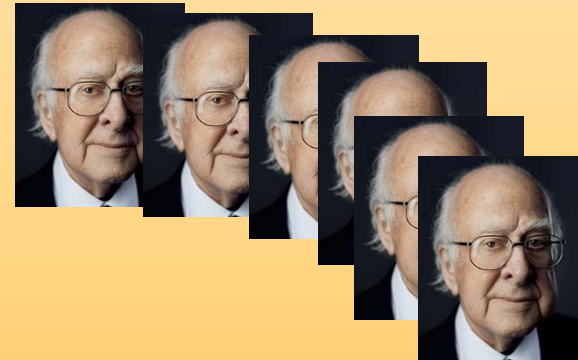
Jorge Romão, CFTP
 João P. Silva, CFTP
 Rui Santos, ISEL & CFTC
 Pedro Ferreira, ISEL & CFTC
 Luis Lavoura, CFTP

International Advisory Committee:

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

Join us

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



END