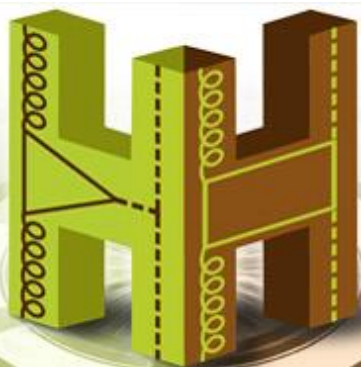


HH workshop : introduction



Workshop **HH** ATLAS
double Higgs production

January 18-20, 2016

Laboratoire de l'Accélérateur Linéaire, Orsay

-Happy new year 2016

-Thank you for your coming

Purpose of the workshop

During this period of LHC 'shut-down'

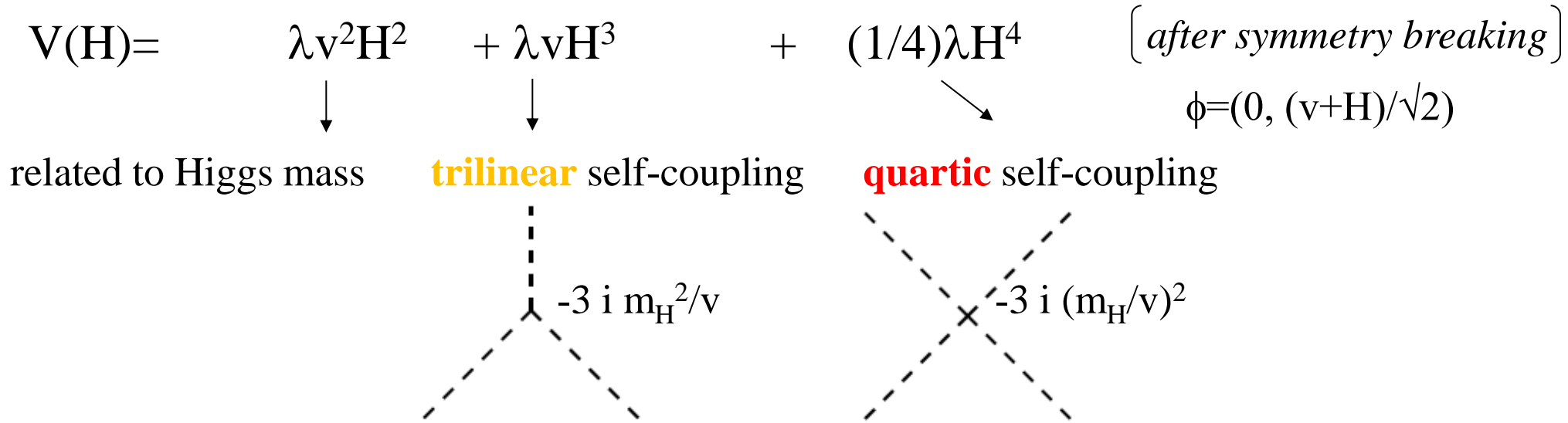
- Review / discuss analyses made on the purpose of HH of Run 1
- Learn the state of art from theoretical side

- Review the possible channels and analyses for Run 2
- Discuss the performance on objects, related to these analyses

The organization committee

A (non-exhaustive) piece of Higgs sector

Measurement of parameters of Higgs potential

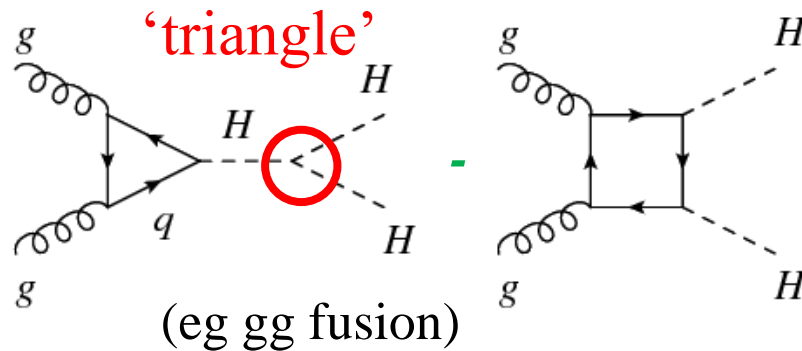


-**HHHH** : extremely difficult : requires huge luminosity
 even too small for future ee collider ($ee \rightarrow ZHHH$, $ee \rightarrow \nu\nu HHH$)

-**HHH** : HL-LHC conditions (3000 fb^{-1} ; $\sqrt{s}=14 \text{ TeV}$)
 → needs **Higgs pair production**

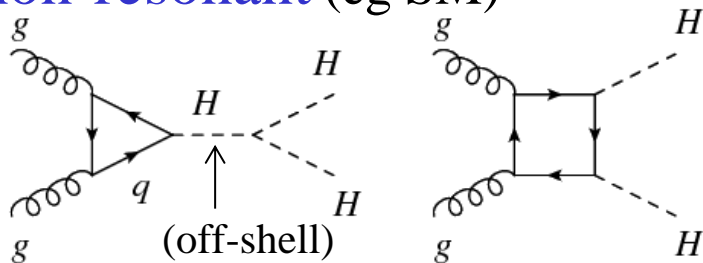
Double Higgs production

- Various prod. modes (gg fusion, W, Z fusion, double Higgs-strahlung, etc)
- various knowledge on perturbative order
- Destructive (in SM) interference between **self-coupling** and other diagrams

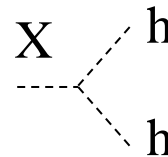


- Possible alterations of λ_{hhh} wrt SM
- Mechanisms of production for SM and BSM

non-resonant (eg SM)



resonant (eg : 2HDM : $H \rightarrow hh$)



- etc.

Double Higgs production : public session

- Before discussing theoretical aspects : review of **experimental searches**

Run 1 hh results

by C. Gwilliam, E. Etzion

- Then discussion state of art on the **theory side** ? In particular...

-on the cross-sections

hh in the LHC HXS WG and resonant (non-2HDM/MSSM) models by M. Slawinska

-on 2HDM $\begin{pmatrix} \cdot \\ \cdot \end{pmatrix} \begin{pmatrix} \cdot \\ \cdot \end{pmatrix}$ Type I Type II Type III Type IV
(MSSM)

2HDM theory/phenomenology and MG models by E. Vryonidou

-in particular for **MSSM**

MSSM hh theory/phenomenology by J. Quevillon

-on non-resonant aspects

SM and non-resonant BSM theory/phenomenology by Daniel de Florian

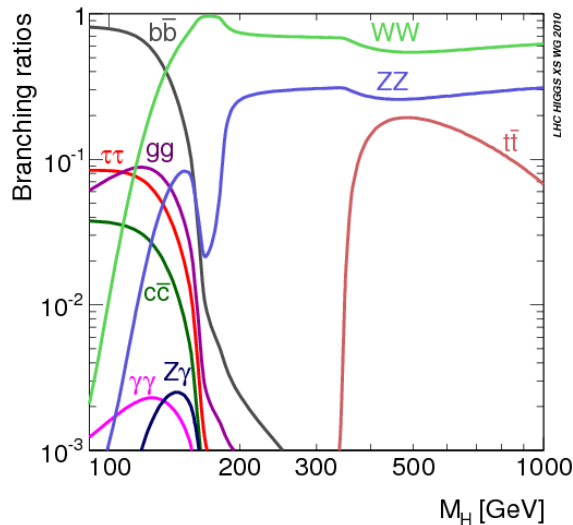
- Exhaustivity is not possible ($\text{Type 1, 2, 3, 4, } m_h^{\text{max}}, m_h^{\text{mod+}}, -, \text{light-stop, stau, tau-phobic, low-}m_H$, and many others, etc.

→ discussion, animated by L. Barak, R. Tanaka

Next days: ATLAS session : will focus on ATLAS analyses

Various channels

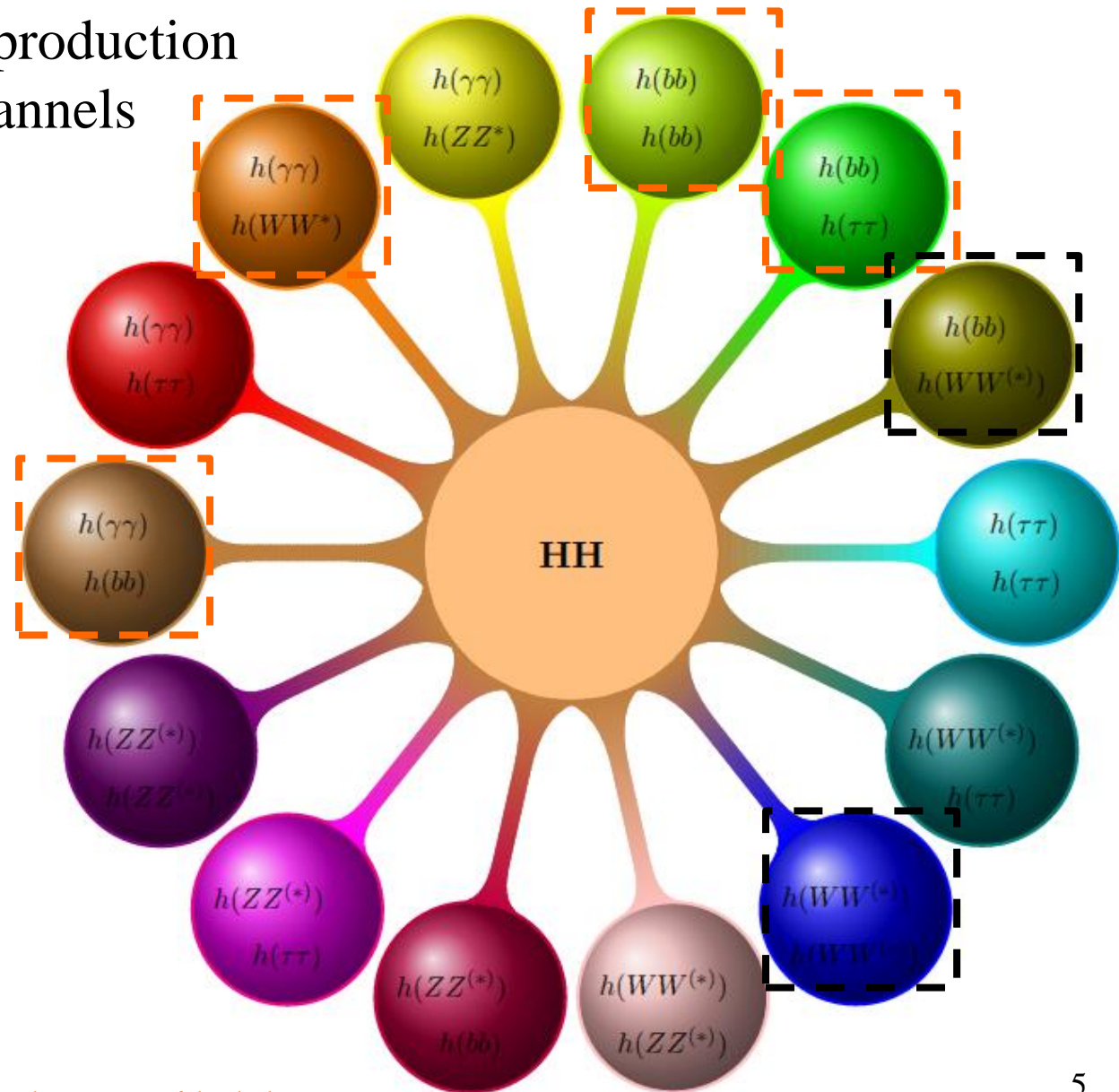
- Channels for double Higgs production
 \sim emerge from single Higgs channels



$$h \rightarrow \dots \quad \times \quad h \rightarrow \dots =$$

- $h(\gamma\gamma)$
- $h(bb)$
- $h(\tau\tau)$
- $h(WW^*)$
- $h(ZZ^*)$

Discussed in workshop



Results available at Run 1

Performance

- Signal is rare, so most pioneer studies consider channels where at least one Higgs decays to b quarks

→ important role of b-tagging

More generally : various channels and processes involved : signal, bkg

Various objects for reconstruction

→ Monte-Carlo and performance on reco/identification of objects

Monte-Carlo

by J. Robinson

b-tagging

by M. Kagan

non boosted

Combined performance on photons

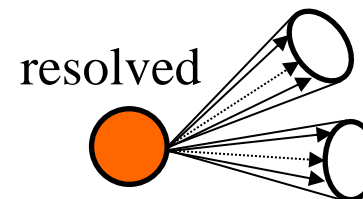
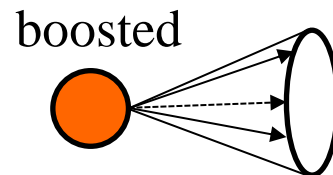
by J. Vasquez

Combined performance on (boosted) tau

by D. Kirchmeier

-high p_T : separate objects difficult

→ boosted configurations



Run 1 in a nutshell

non-resonant : using $m_H=125.4$ GeV

- $\gamma\gamma bb$

ATLAS, PRL 114, 081802 (2015)

Upper limits

-non resonant : σ : 2.2 pb (220xSM)

-resonant : σ : 0.7-3.5 pb

-limits 2HDM Type I

CMS, CMS-PAS-HIG-13-032

-resonant : $\sigma \times BR$: 0.1-10 fb ($f(\Lambda_R)$)

- $\gamma\gamma WW$

ATLAS, PRD 92, 092004 (2015)

Upper limits

-non resonant : σ : 11 pb (1150xSM)

-resonant : σ : 12-19 pb

- $bbbb$

ATLAS, EPJ C (2015) 75:412

Upper limits

-non resonant : σ : 0.62 pb (63xSM)

-resonant : $\sigma \times BR$: 3.2 fb (G_{KK}^* of 1 TeV)

- $bb\tau\tau$

ATLAS, PRD 92, 092004 (2015)

Upper limits

-non resonant : σ : 1.6 pb (160xSM)

-resonant : σ : 0.46-4.2 pb

CMS, CERN-PH-EP-2015-211

Upper limits

-resonant : $\sigma \times BR$: 0.2 pb

-limits MSSM plus Type II HDM

| **ATLAS** Combination : PRD 92, 092004 (2015)

| $h(bb)h(\tau\tau)$, $h(\gamma\gamma)h(WW^*)$, $h(\gamma\gamma)h(bb)$, $h(bb)h(bb)$

| Upper limits

| -non-resonant : σ : 0.69 pb (exp : 0.47 pb) \Leftrightarrow 70xSM

| $\{gg \rightarrow hh\}$ (48xSM)

| -resonant : σ : 2.1 pb at 260 GeV, 0.011 pb at 1000 GeV

| +various scenarios MSSM

(more details in *Run 1 hh results* by C. Gwilliam, E. Etzion)

Analyses reviewed

- $bb\gamma\gamma$, chairs : M. Chelstowska, N. Andari

Combined performance on photons

by J. Vasquez

hh \rightarrow bb $\gamma\gamma$ analysis

by L. Cerda

prospects

by R. Reed

- $bb\tau\tau$, chairs : K. Leney, H. Fox

- τ Decay : hadronic	64.79 %
leptonic	35.21 %

Combined performance on (boosted) tau

by D. Kirchmeier

hh \rightarrow bb $\tau\tau$ analysis : lep had

by A. Bethani

hh \rightarrow bb $\tau\tau$ analysis : had had

by K. Grimm

hh \rightarrow bb $\tau\tau$ analysis : boosted

by N. Ilic

prospects

by M. Donadelli

Analyses reviewed

- **bbbb**, chairs : M. Bellomo, A. Naip Tuna

hh → bbbb analysis: Resolved

by J. Alison

hh → bbbb analysis: Boosted

by T. Lazovich

Intepretation and Combination

by Q. Zeng

Prospects

by D. Wardrope

- **WW $\gamma\gamma$ /WWWW**, chair : A. Mc Carn

WW $\gamma\gamma$ analysis

by H. Zhang

WWWW preliminary studies

by Y. Fang

Analyses reviewed

- **bbWW**, chair : C. Gwilliam

bbWW analysis

by B. Di Micco

Future plans

by S. Shrestha

- **Combination and Conclusion**, chairs : A. Nisati, M. Escalier

hh combination

by X. Sun

Wrap-up/Conclusion

by P. Savard

Organisation and thanks

Thank you to everybody in the committee

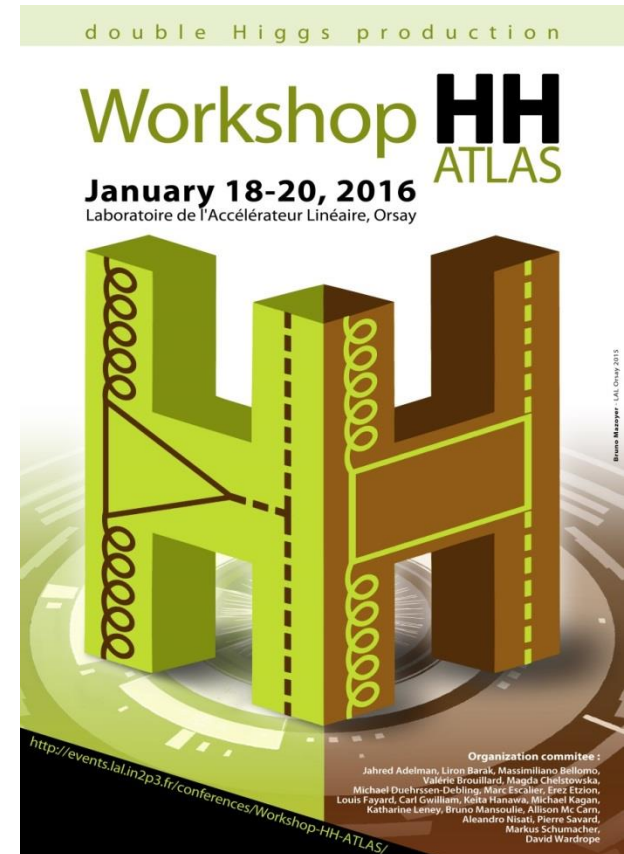
International Advisory Committee

J. Adelman	Northern Illinois University, USA
L. Barak	CERN, Switzerland
M. Bellomo	University of Massachusetts Amherst, USA
M. A. Chelstowska	University of Michigan, USA
M. Duehrssen-Debling	CERN, Switzerland
E. Etzion	Tel Aviv University, Israel
C. Gwilliam	University of Liverpool, UK
K. Hanawa	University of Tokyo, Japan
M. A. Kagan	SLAC, USA
K. Leney	University College London, UK
B. Mansoulié	CEA-Saclay, France
A. R. Mc Cam	University of Michigan, USA
P. Savard	University of Toronto, Canada
M. Schumacher	Freiburg, Germany
D. Wardrope	University College London, UK

Organising Committee

V. Brouillard	LAL-Orsay
M. Escalier	LAL-Orsay
L. Fayard	LAL-Orsay
A. Nisati	Roma, Italy

- Additional thanks :
Catherine Bourge (webmaster)
Valérie Brouillard (main contact+registration)
Bruno Mazoyer (poster) →
Gregory Perrin : vidyo/technicalities, etc.



Organisation

Lunch : local people will be courteous to show the place : just follow them
But just in case, a map below



Organisation

Rules of thumb for a workshop

- Keep in time (chairs and speakers)
- Keep being courteous (different point of view, etc.)
- don't monopolise discussion : allow various exchanges
- try to be pedagogic : everyone is completely ignorant at least in something

Next days sessions start at 9:00

Social events

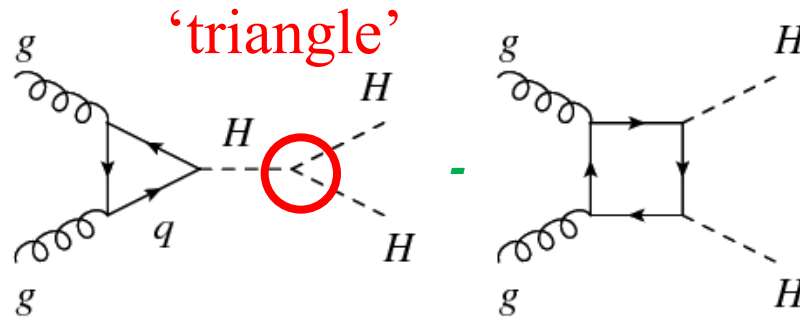
- Monday, 18:55 - 19:55, Welcome cocktail (in the main cafetariat of the lab)
- Tuesday, 19:00-20:00, Wine and cheese buffet dinner

BACKUP

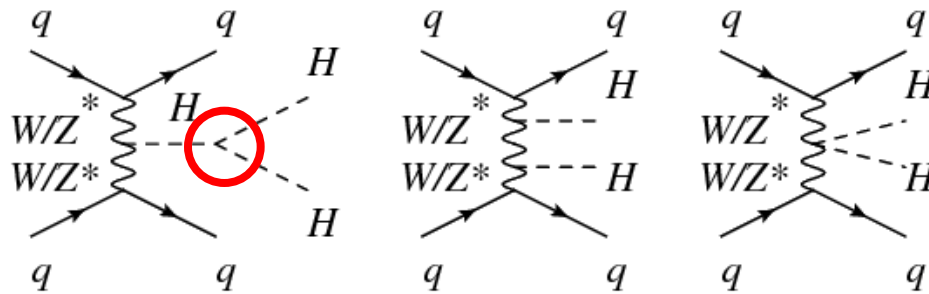
Double Higgs production

Double-Higgs production does not originate exclusively from the **self-coupling** : additional diagram that interferes **destructively**

• gluons fusion



• W or Z fusion



• Double Higgs-strahlung

