http://www.be-h.be

The H boson gateway to new physics

WP3: New scalar resonances

Christophe Delaere

Alberto Mariotti

Introduction

★*What is so special of the BEH boson?*

★*Are there new scalars?*

★*Unravel nature of EWSB !*

SUSY

2 Higgs Doublet Model

Singlet mixing with the BEH boson

Dark matter simplified models

Axion Like Particles

Work packages

From the BE.H proposal

- **WP 3.1: Theoretical aspects of an extended scalar sector**
  - Model building motivations
  - Accurate MC predictions and diff. distributions
  - Re-interpretation of LHC searches in different models
- **WP 3.2: Search for $H' \to A + Z$, $A \to H'/H + Z$.**
  - Exploration of both $llbb$ and $ll\tau\tau$ final states
- **WP 3.3: Search for $H' \to ZZ$**
  - Exploration of $ll\nu\nu$ final state
  - Possible impact also for dark matter models as $H' \to$ MET+Z

Team:

C. Delaere (UCL), F. Maltoni (UCL), A. Mariotti (VUB), M. Tytgat (ULB), P. Vanlaer (ULB)

Motivations (1)

Two Higgs doublet model (2HDM)

- **Economic extension of the scalar sector**
- **Two possible realizations depending on yukawa interactions**
- **Spectrum contains:** $h_{SM} \quad - \quad H \quad - \quad A$

- **Rich phenomenology (also connection with baryogenesis, inflation...)**

- **Couplings of Higgses compared to SM ones**

$$\hat{g}^h_{VV} = \sin(\alpha - \beta) \qquad \hat{g}^H_{VV} = \cos(\beta - \alpha) \qquad \hat{g}^A_{VV} = 0$$

$$g^{Ah}_Z = \cos(\beta - \alpha) \qquad g^{AH}_Z = -\sin(\beta - \alpha)$$

Small in decoupling limit

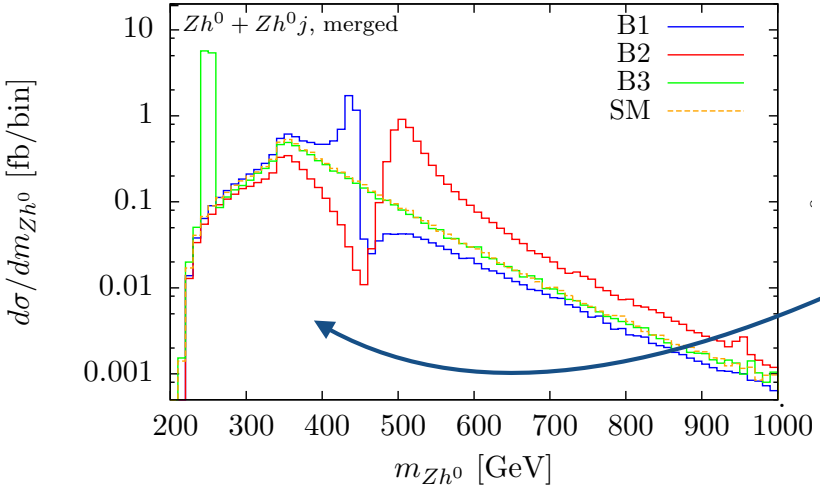
Large in decoupling limit

Resonant production @ LHC:

$$pp \to H \to AZ$$
$$pp \to A \to HZ \text{ or } hZ$$

Resonance production (H/A)

$pp \to A \to hZ$ *Hespel, Maltoni, Vryonidou '15*



★ *Features in diff. distributions*

- **Dip-Peak interference with SM**

Connection with SMEFT

★ *Signatures also of exotic models*

Axion Like Particles (ALP)

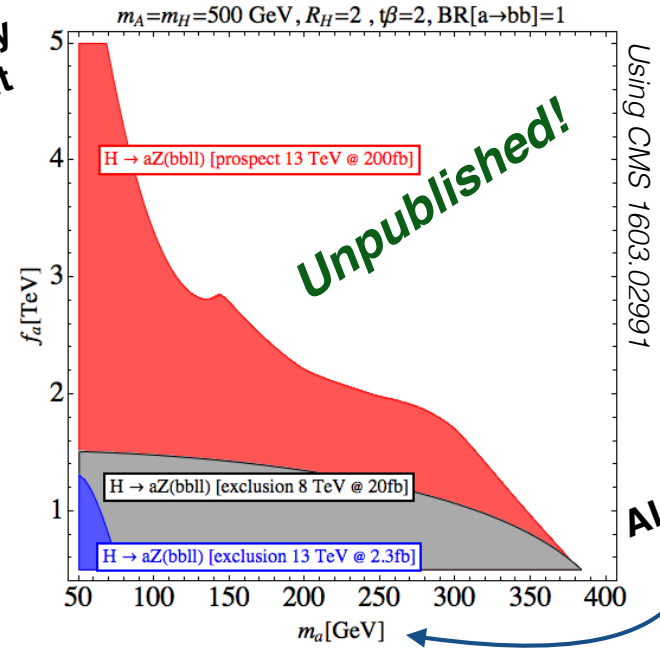
- **E.g.: R-axion**
  Bellazzini,Mariotti,Redigolo,Sala,Serra
- **LHC Signatures:** $H \to Za$

Can also be portal to dark sector (+MET signature)

$H \to Za \to Z\chi\chi$

On going with Pascal team

ALP decay constant



Unpublished!

ALP mass

Motivations (2)

Singlet extension of the SM

- **Minimal extension of the scalar sector**

$$\mathcal{L} \supset \lambda H H^\dagger S^2 + \mu H H^\dagger S + \ldots$$

- **Spectrum contains:** $h_{SM} - S$

- **Recurrent in naturalness (Neutral naturalness, Minimally extended SILH, ...)**
- **S can be *portal to dark sector, dark stops,* can induce EWBG, ...**
- **Phenomenology characterized by** $m_S\,,\ \sin\theta$

Mixing Angle

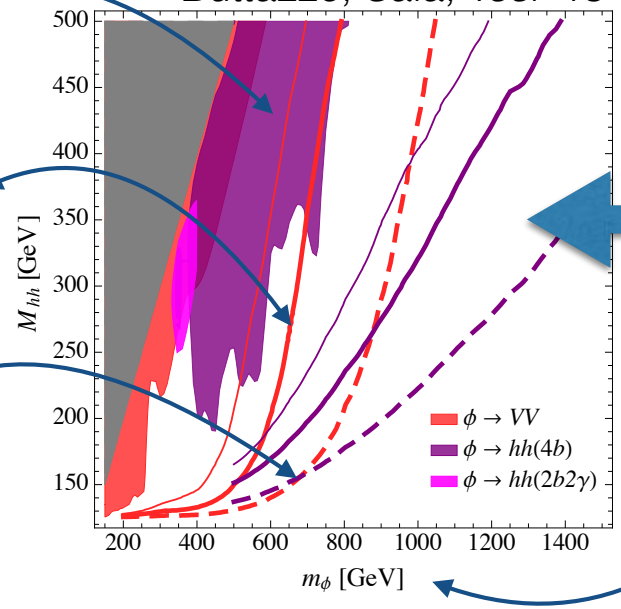
Constrained by Higgs coupling measurements

Resonant production @ LHC:

$$pp \to S \to VV \text{ or } hh \text{ or } t\bar{t}$$

Singlet signals

Buttazzo, Sala, Tesi '15



LHC exclusion

LHC14

LHC-HL

$$\sin\theta \sim \frac{M_{hh}}{m_\phi}$$

Singlet mass

★ Direct LHC signatures

★ Di-Bosons

★ Di-Higgs

★ (Di-Tops)

hh and VV final states are related by equivalence theorem

Singlet mixing with the Higgs generically give rise to di-higgs

Christophe will talk about this

$$pp \to S \to h(b\bar{b})h(l\nu l\nu)$$

CMS-PAS-HIG-17-006

★ Indirect signals at the LHC

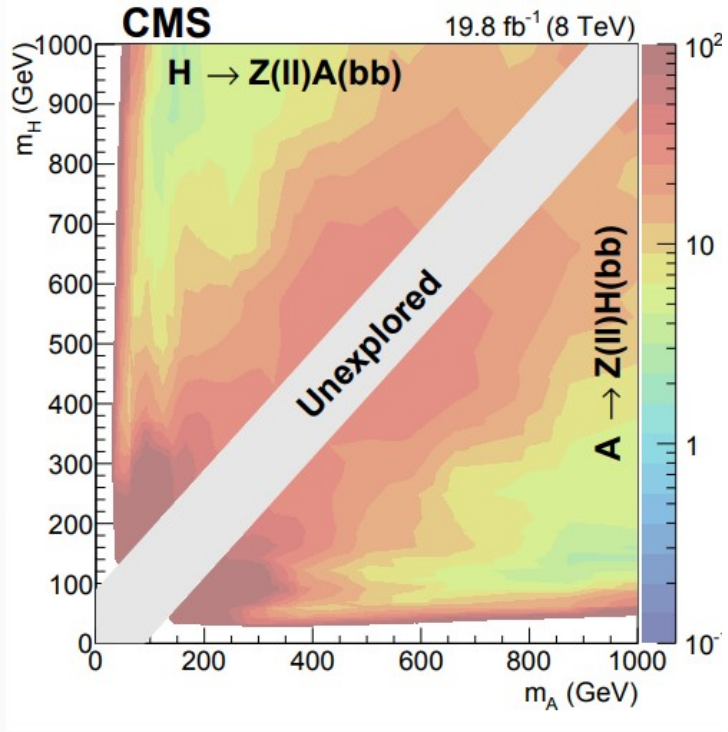
- ✳ Higgs coupling deviations
- ✳ Trilinear Higgs self-coupling deviations

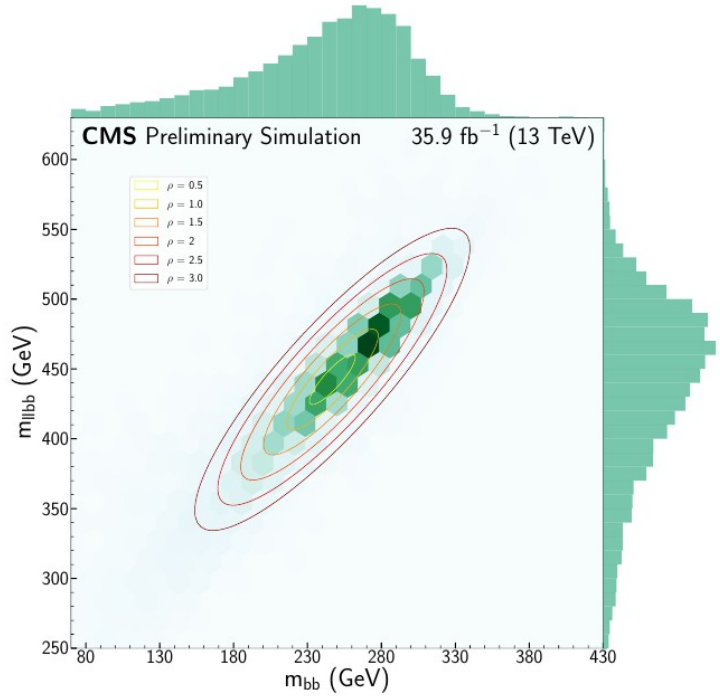
WP2

Complementary probes

ZA study (2HDM)

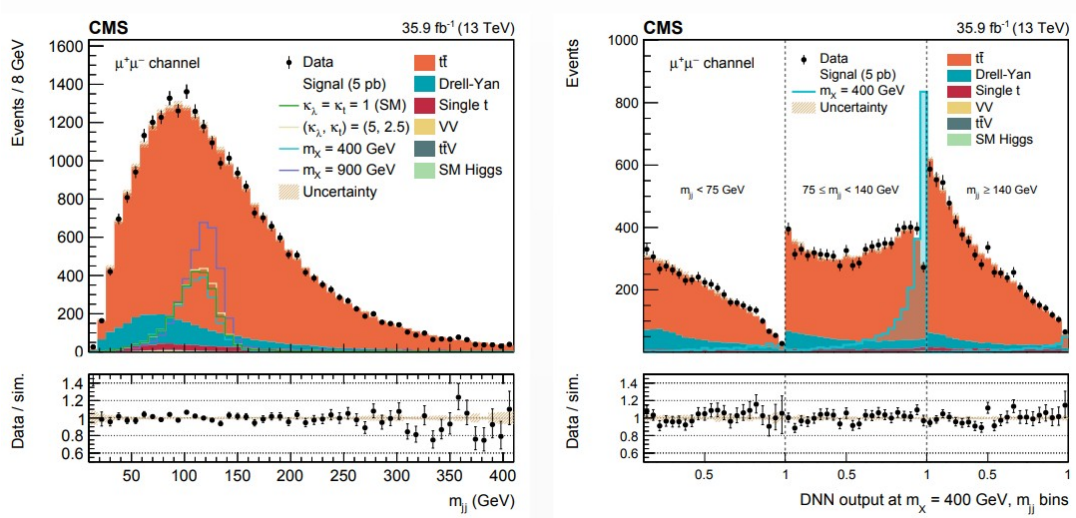
- Search for Heavy scalar (H) + pseudoscalar (A) in the H→Z(ll)→A(bb) decay
- Main backgrounds:
  - ttbar – extracted from the electron-muon control region
  - DY – obtained from simulation
- Model-independent approach where possible
- Study first performed with run 1 data, now being redone for 2016 with improved techniques



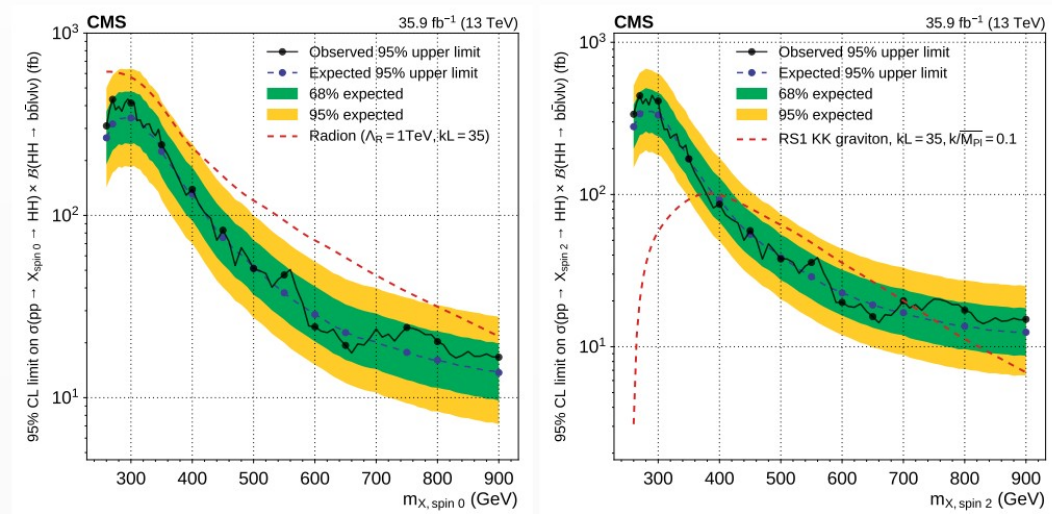


Di-Higgs study

- Study performed on 2016 data
- 1st use of Parametric DNN in CMS



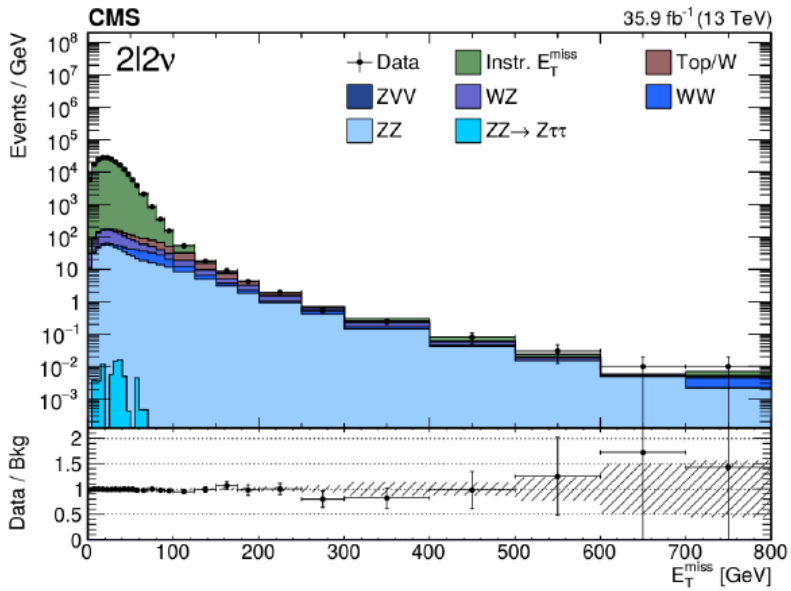
- Limits from the shape of a DNN+m_{jj} on generic spin 0 and spin 2 scenarios

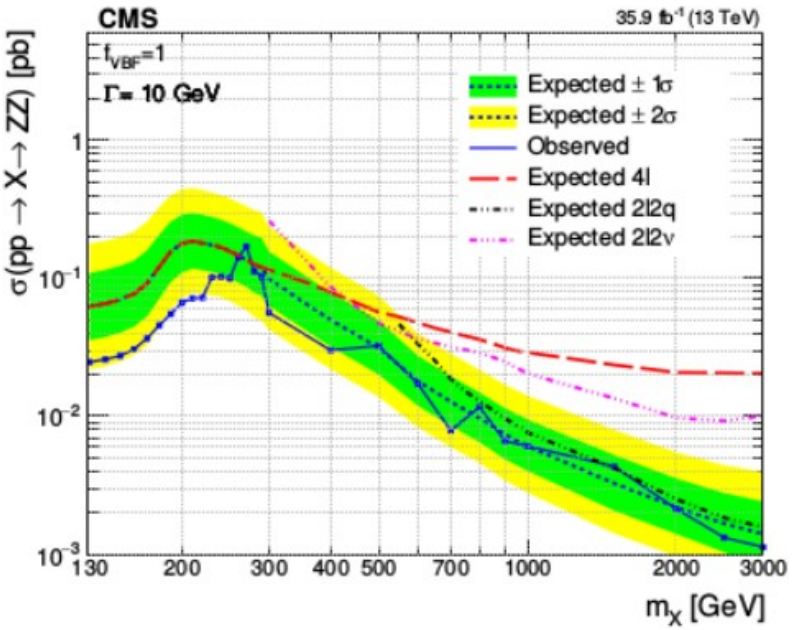


- Next: legacy run 2 analysis
  - Better electron ID
  - Improved DY estimate
  - Add semi-leptonic channel and ZZbb (tbc, CMS level)

H→ZZ→ll$\nu\nu$

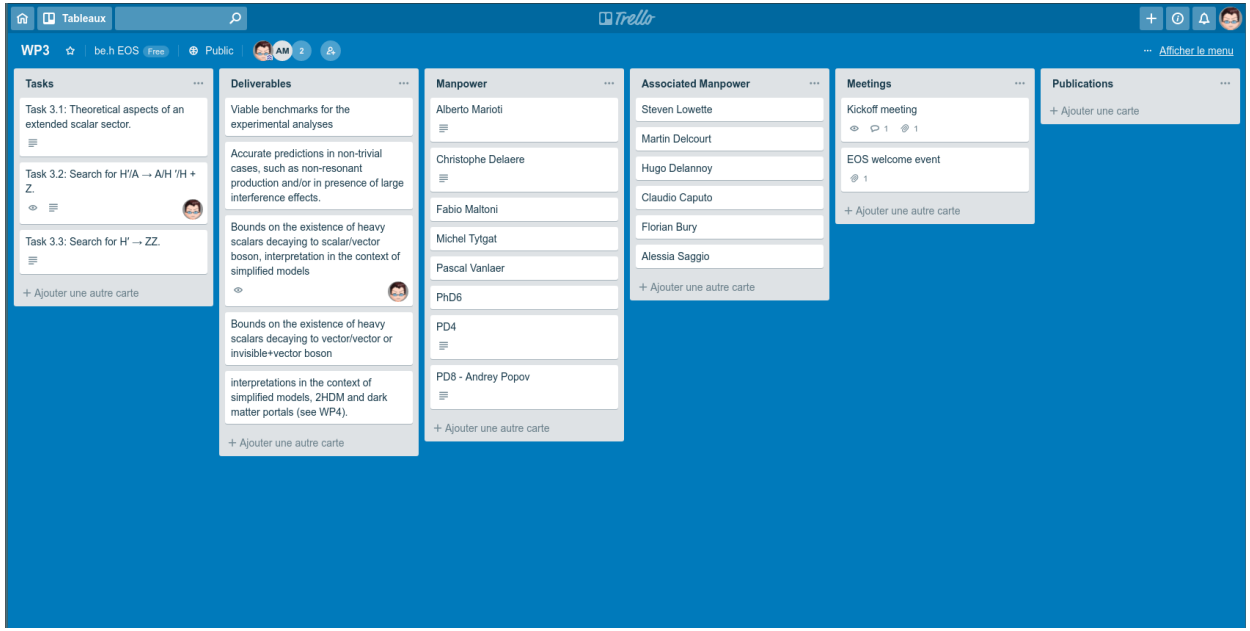
- Search for Heavy scalar (H) decaying in ZZ→ ll$\nu\nu$
- Main backgrounds:
  - Reducible background estimated from data (ttbar, tW, WW, W+jets, Z+jets)
  - Irreducible background estimated from MC (ZZ, WZ)
- Analysis already performed on 2016 data, to be extended. No excess found so far.
- Signal model:
  - 2 topologies: gg → H and qq → H + 2jets (VBF)
  - Look at a wide range of resonance masses, from 300 GeV to 3 000 GeV
  - Look at 3 different widths: Γ = 0 GeV, 10 GeV or 100 GeV
- H → ZZ → ll$\nu\nu$
  most sensitive around 500 − 700 GeV





Communication channels

- We created a CERN e-group for WP3
  - wp3-beh@cern.ch
  - Please use it for all communications across the WG.
- Slides will be collected on Indico
  - Access key “9720” will in principle be used for all our meetings
- We use a Trello board to centralize the information
  - Trello is a web-based project management application.
    - It has a variety of work and personal uses including software project management, bulletin boards, planning, …
    - an entry point to more detailed information: https://trello.com/b/rcntB91c/wp3
  - Content so far:
    - Tasks
    - Deliverables
    - Manpower
    - Meetings
    - Publications
    - ...
- Register to these channels if you are interested in WP3 activities..



Manpower

- EOS promoters:
  - Alberto, Christophe, Fabio, Michel, Pascal
- Hired personnel:
  - PhD6
    - UCL-based; H→ZA analysis
    - Job offer imminent; should start by the end of the year
  - PD4
    - UCL-based; WP2+WP3; Higgs potential through (in)direct measurements
    - Starts in 2020 – opened already with IISN funding for 2019
  - PD8
    - ULB-based; H→ZZ analysis
    - Andrey Popov hired recently
- EOS collaborators:
  - Anybody from the collaborating institutes involved in one of the WP3 topics.

Next...

Manpower

- Alberto Marioti
- Christophe Delaere
- Fabio Maltoni
- Michel Tytgat
- Pascal Vanlaer
- PhD6
- PD4
- PD8 - Andrey Popov

+ Ajouter une autre carte

Associated Manpower

- Steven Lowette
- Martin Delcourt
- Hugo Delannoy
- Claudio Caputo
- Florian Bury
- Alessia Saggio

+ Ajouter une autre carte

Next...

Manpower

- Alberto Marioti
- Christophe Delaere
- Fabio Maltoni
- Michel Tytgat
- Pascal Vanlaer
- PhD6
- PD4
- PD8 - Andrey Popov

+ Ajouter une autre carte

Associated Manpower

- Steven Lowette
- Martin Delcourt
- Hugo Delannoy
- Claudio Caputo
- Florian Bury
- Alessia Saggio

+ Ajouter une autre carte

Next...

Manpower

- Alberto Marioti
- Christophe Delaere
- Fabio Maltoni
- Michel Tytgat
- Pascal Vanlaer
- PhD6
- PD4
- PD8 - Andrey Popov

+ Ajouter une autre carte

Associated Manpower

- Steven Lowette
- Martin Delcourt
- Hugo Delannoy
- Claudio Caputo
- Florian Bury
- Alessia Saggio

Your name?

Andrey Popov

- Joining search for $\Phi \to ZZ \to \ell\ell\nu\nu$ at ULB
- Recent activity
  - Search for $\Phi \to tt$ (mostly in ℓ+jets)
    - Interference with SM tt gives signal complex peak–dip m_{tt} lineshape
  - Side project on jet calibration in multijet topology
- Expertise
  - Thorough experience with ℓ + ≥1b + jets final state
    - Including things like tt reconstruction and data-driven QCD
  - MVA, but need to catch up with the DNN revolution
  - Statistical analysis
- Physics objects
  - Worked with triggers, e, μ, (b-)jets, missing p_T
    - Insider's knowledge on jets

About Florian...

Curriculum Vitae

- Bachelors and Masters degree in UCLouvain
- CERN summer student 2017
- Ongoing PhD with C. Delaere

Projects

- CERN summer student project :

  Identification of long lived charginos in the CMS pixel tracker with a Deep Neural Network

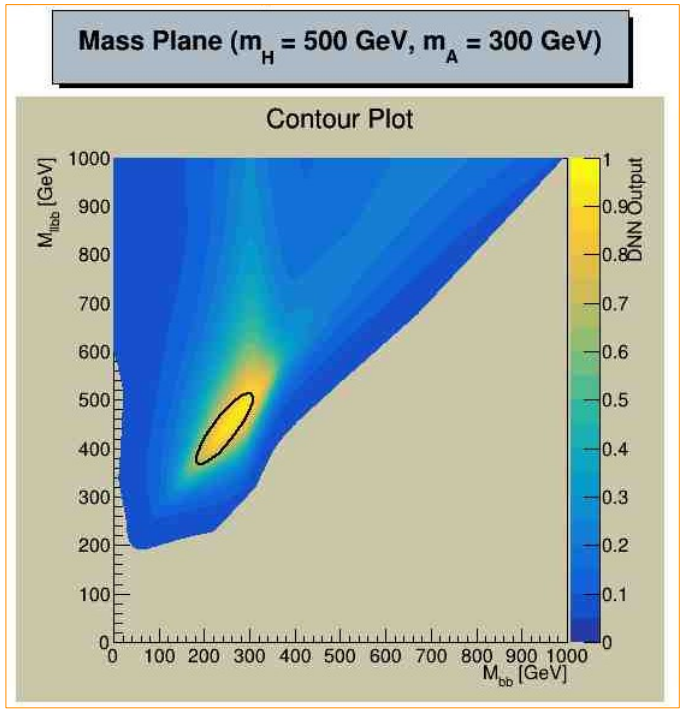
- Masters thesis :

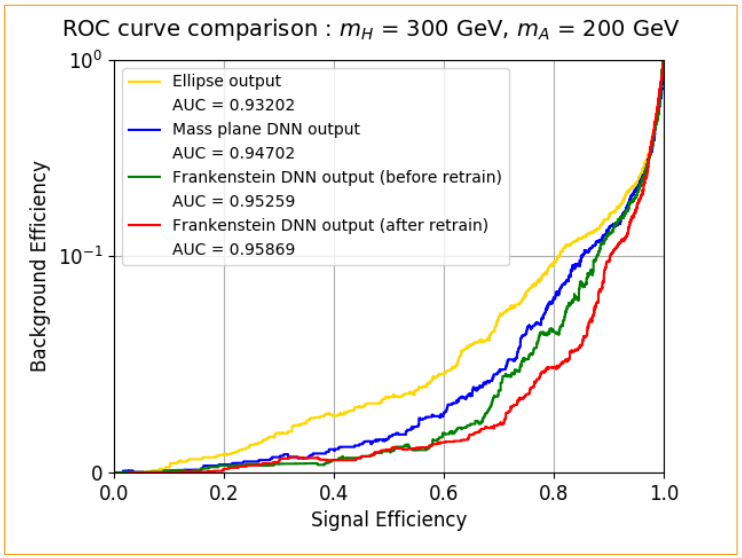
  Application of deep learning techniques in CMS data analysis

  - Search for a resonance in H→ZA→llbb channel
  - Use of a DNN to scan for a resonance in the (m_{bb},m_{llbb}) plane
  - Regression of the Matrix Element Method
  - Combination of the weights of the MEM and the mass plane discriminant inside a composite DNN

- PhD thesis :

  - Pursuing the same goals
  - CMS tracker update





"That's all Folks!"