Search for high mass Higgs boson production in final states with b-quarks with the LHC Run II data

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20/03/2018

Motivation for the BSM Higgs searches

- **13 TeV** measurements so far indicate **consistency of** the **h(125)** with the Standard Model (**SM**)
- However, several phenomena are not explained by the SM:
  - Dark matter and energy, gravity, neutrino masses…

BSM

- h(125) still can be only the one member of an **extended Higgs Sector:**
  - direct searches for **Heavy Higgs** bosons to check this!
- **Heavy neutral Higgs** bosons predicted by several **BSM** extensions:

Today

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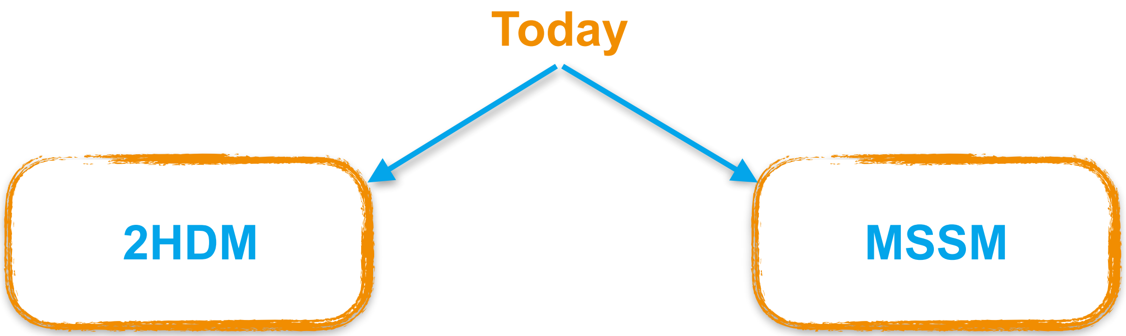


2HDM and MSSM

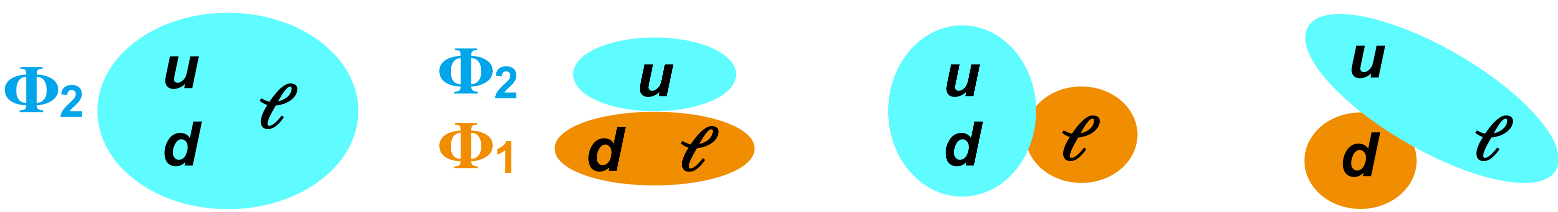
- Higgs sector of **Two Higgs Doublet Model** (2HDM):

2 doublets	CP-even	CP-odd	Charged	
Φ_2 Φ_1	h, H	A	$H^{\pm}$	(h, H, A) ≡ ϕ

  - **tan β** - ratio of vacuum expectation values ; **α** - **mixing** angle between h and H

- **4 types of 2HDM** with natural flavour and CP conservation, depending on how the 2 Higgs doublet fields couple to SM particles

Type I — Type II — Lepton Specific — Flipped



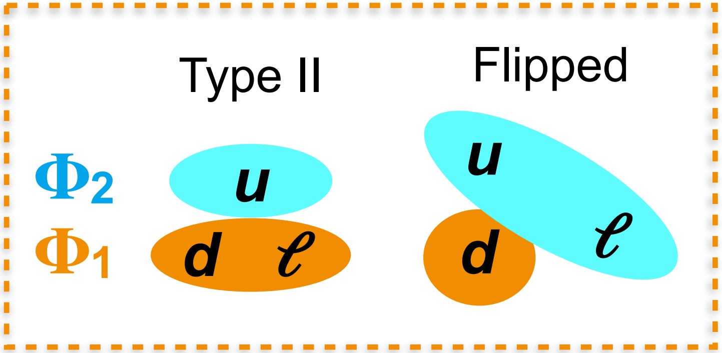
u - (u,c,t)
d - (d,s,b)
ℓ - (e,μ,τ)

all fermion couples to one Higgs boson — up v.s. down — quark v.s. lepton

- **Minimal Supersymmetric Standard Model** (MSSM) features same Higgs sector structure as in Type II:
  - **Two parameters at tree-level**: m_A and **tanβ**

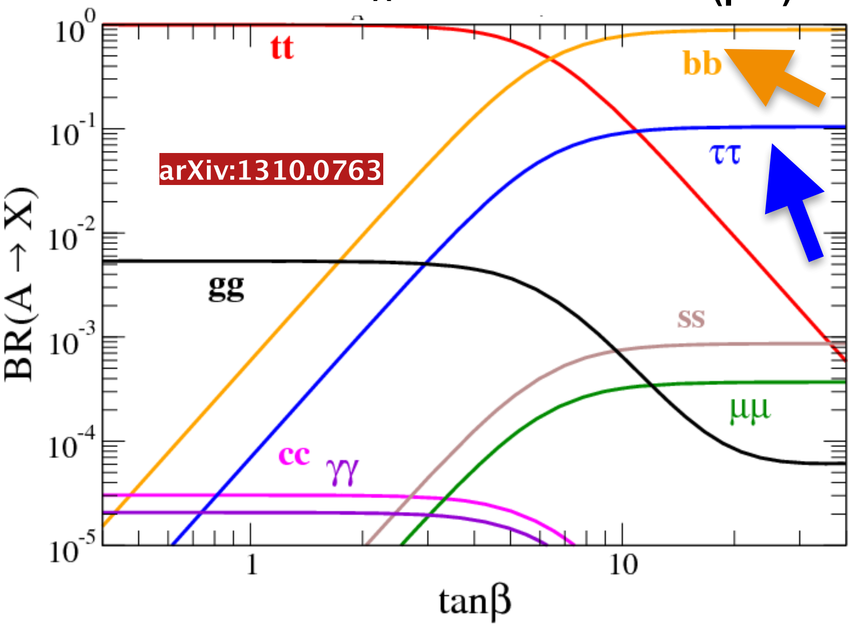
Heavy Higgs bosons and b-couplings

- **Enhanced b-couplings** in various scenarios within 2HDM and MSSM:
- Moreover in **Flipped** scenario **leptons** are **dis-favored**:
  - Low sensitivity of A/H→ττ
  - **2 decay channels dominate**: A/H → $b\bar{b}$, A → Zh(not shown here)



Type-II

A boson **m_A = 400 GeV** **cos(β-α) = 0**



Flipped

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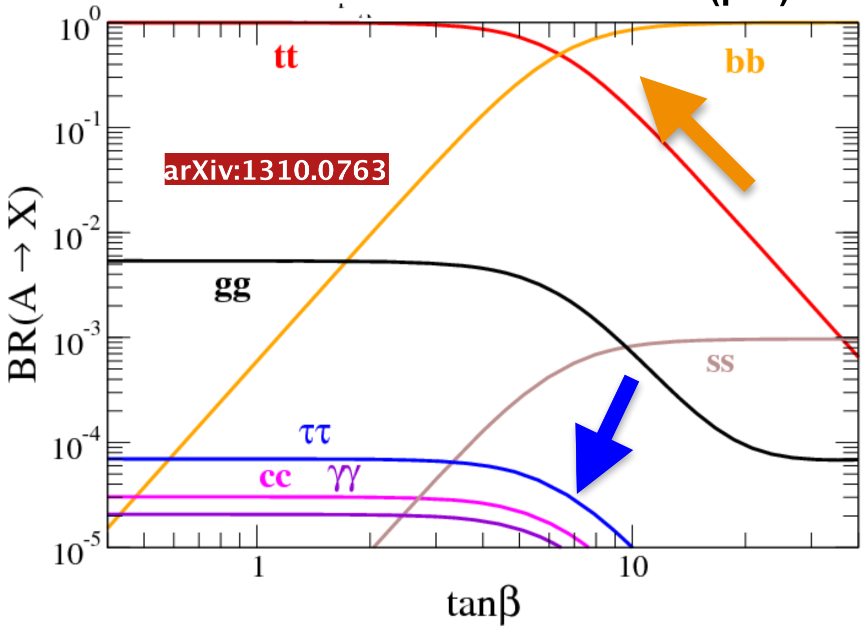
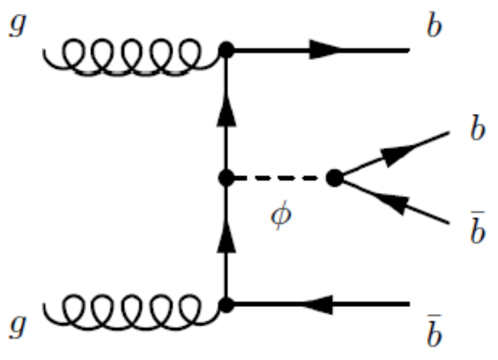
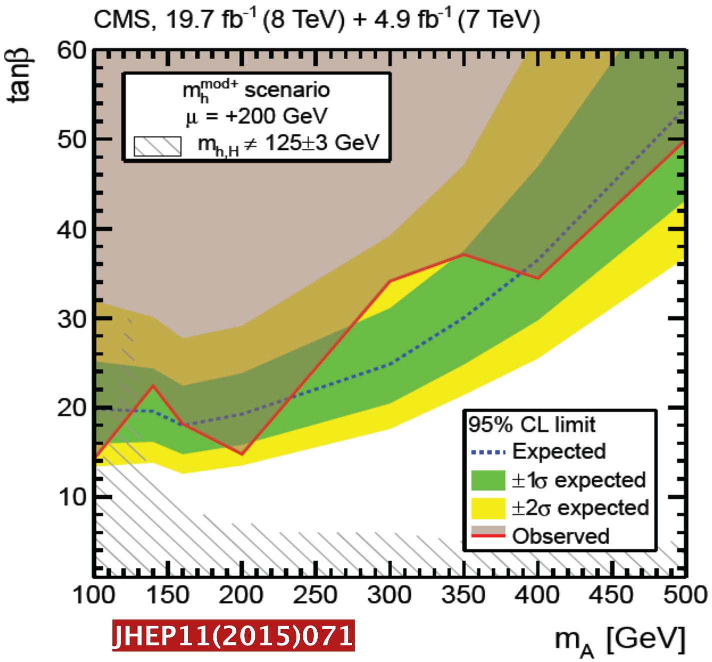


Acknowledgments: Stefan Liebler, Oscar Stal

$b\bar{b}$A/H, A/H→$b\bar{b}$ Analysis

- Search for the **b-associated** production of **degenerate H** and **A** in higher mass region:
  - cross-section enhanced up to ~ 2tan²β both in MSSM and 2HDM models;
  - better background control
- **Main challenge**: huge background rate from **QCD multi jet** production
  - dedicated trigger has been developed
- 7+8 TeV analysis achieved best sensitivity in this channel to date:
  - improve further with 13 TeV data

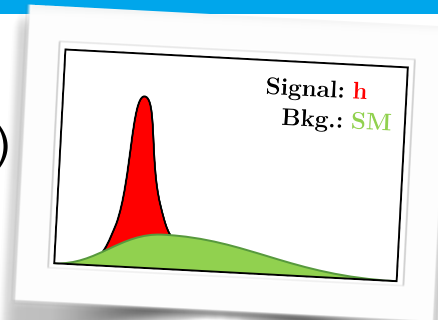




JHEP11(2015)071

13 TeV analysis overview

"**Bump hunting**"

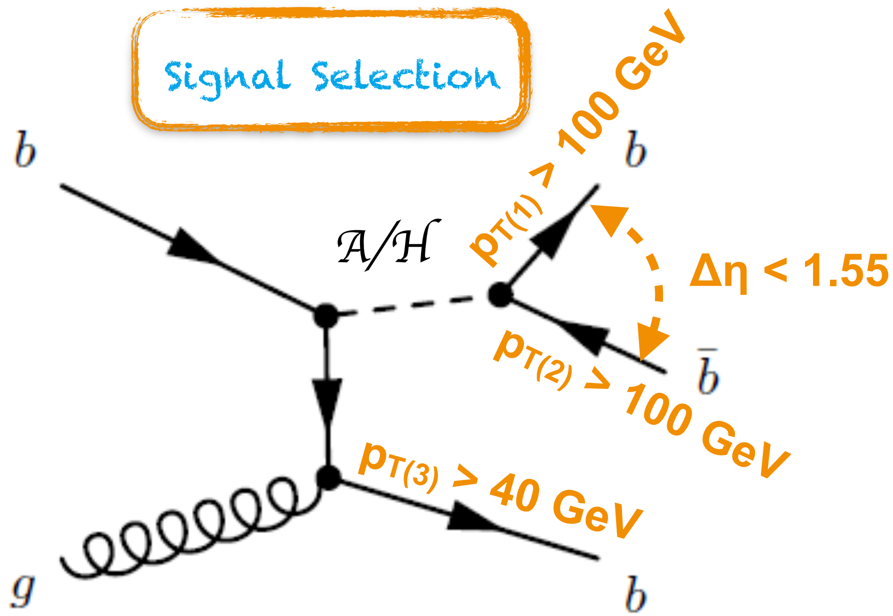


- Look for a peak in the invariant mass of the two leading b-jets (M_{12})

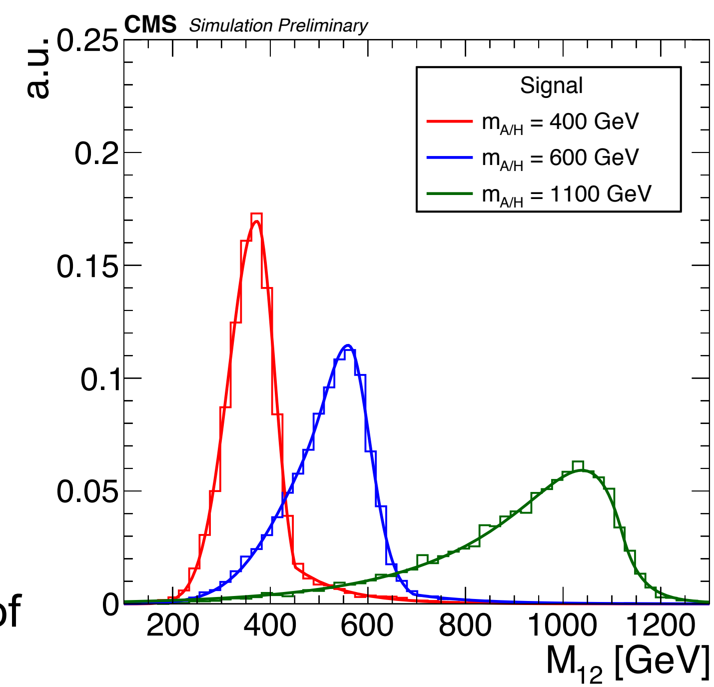
Dedicated Trigger	
Double jet with $p_T > 100$ GeV	reduce rate
$\lvert\Delta\eta_{12}\rvert < 1.6$	
double b tag (tight)	reduce non $b\bar{b}$ background

- **Data:** 2016 pp at 13 TeV, $\int L\,dt$: 35.7 fb^{-1}

Signal Selection



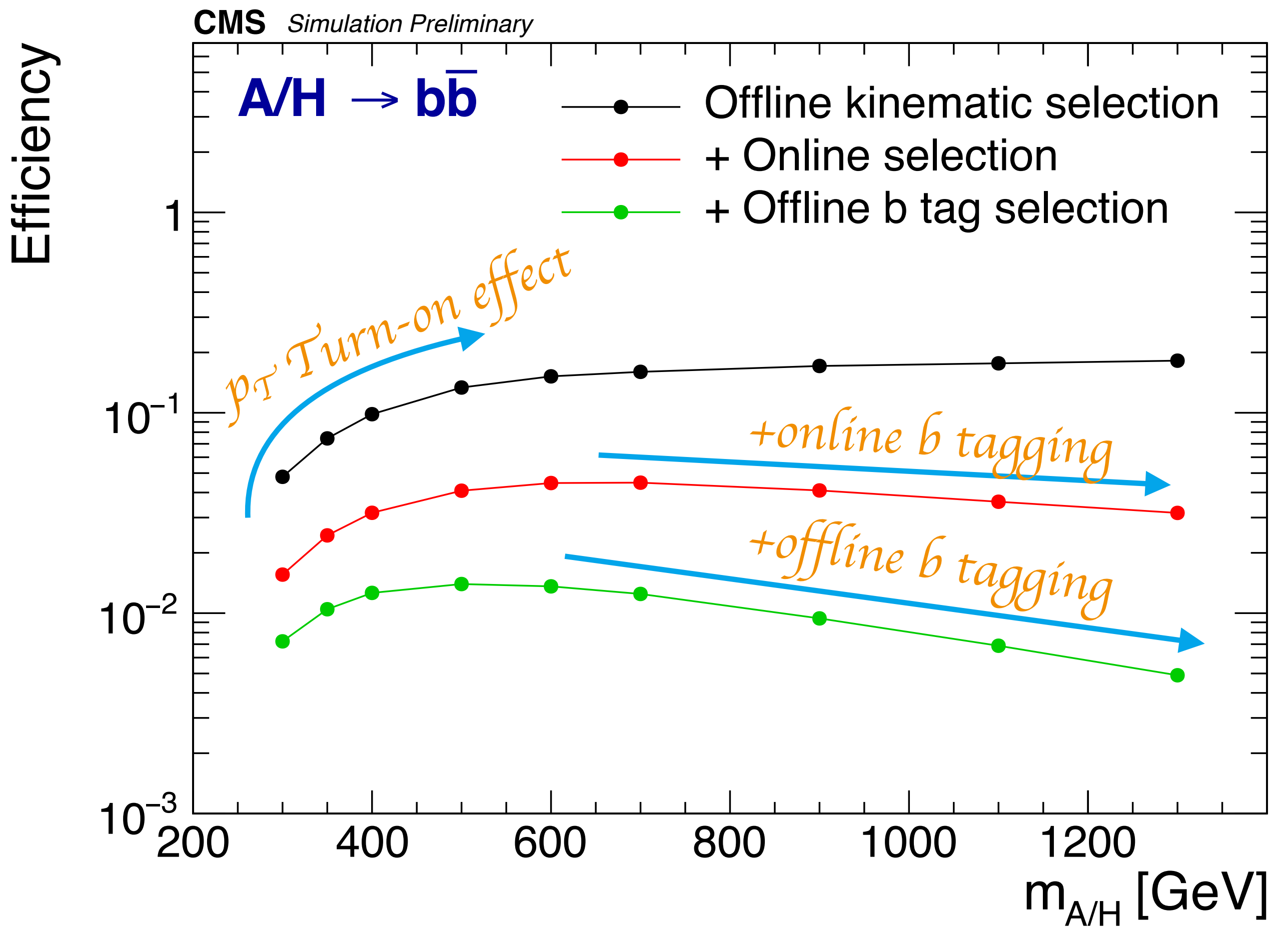
Expected Signal Shape



- **Sensitive** starting **from $M_{A/H}$ = 300 GeV**, because of the high p_T trigger threshold.

Signal Efficiency

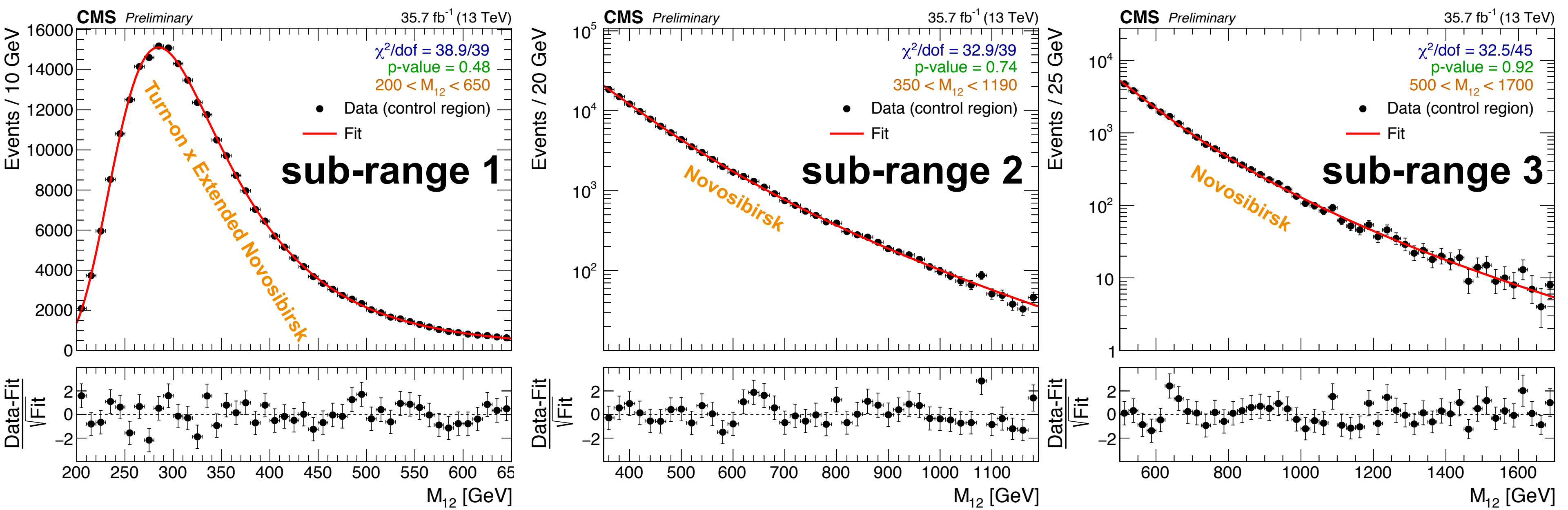
- Effect of the trigger p_T turn-on and b tagging



- **Efficiency** up to **1.5%** at 500 GeV mass point

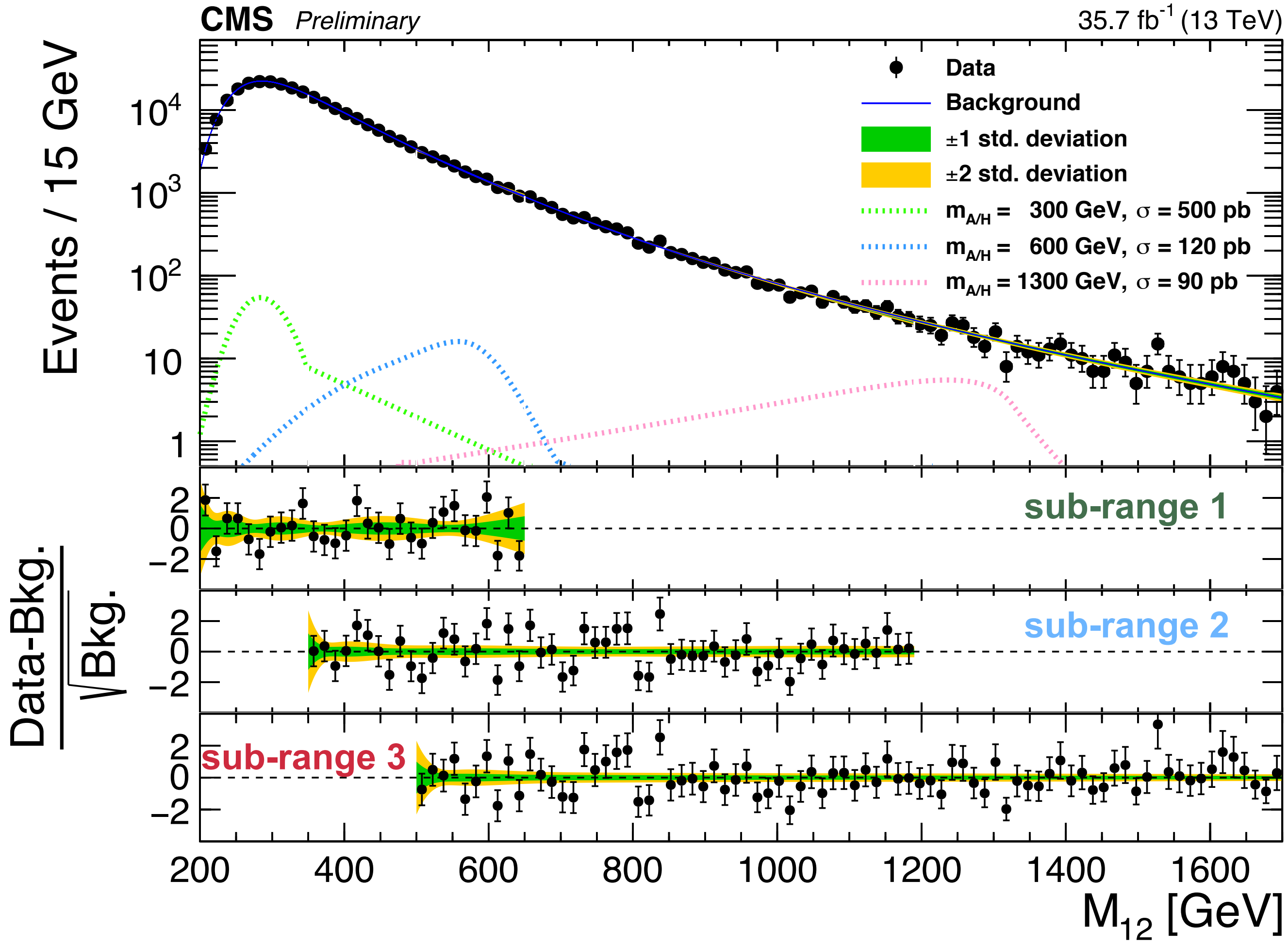
Background estimation: control region

- Model QCD background using **analytical function**
- Find **control region** with a shape of M_{12} similar to the signal region → validated in MC
  - "**Reverse b-tag CR**" has been selected
- Main **challenge**:
  - **precise fit** of a **large mass range** including the **background peak region**
- **Divide M_{12}** range into 3 **sub-ranges** to reduce the bias from the choice of the function and simplify the fitting procedure



Background estimation: signal region

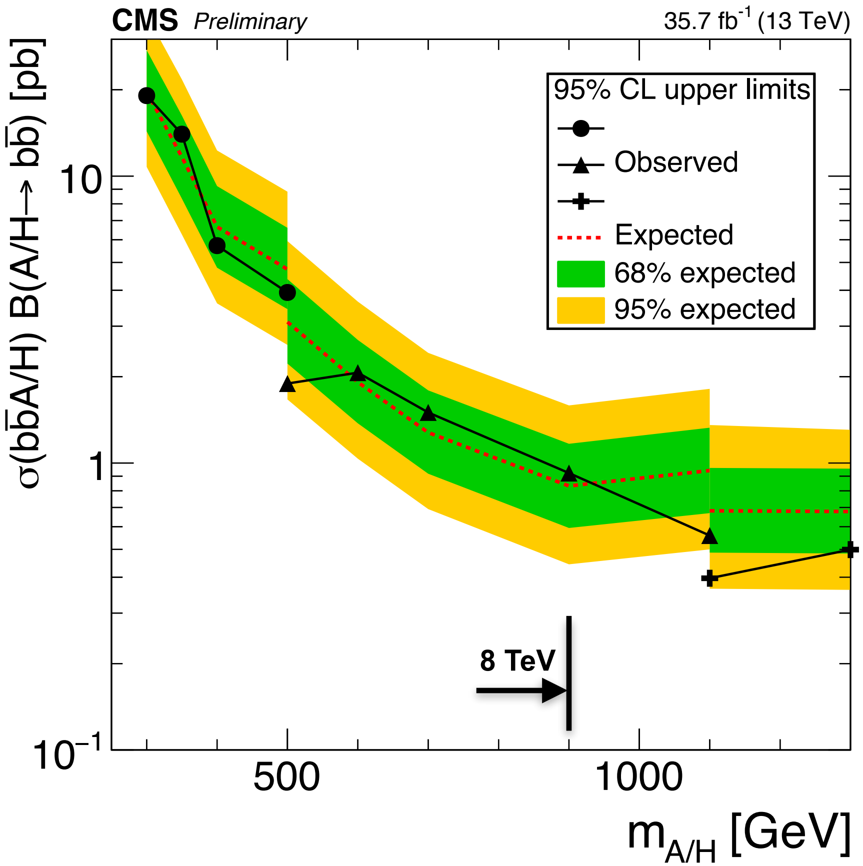
- Parameters of the background pdfs allowed to change between CR and SR:
- **Data** is **well fitted** with functions developed in the CR
- **No excess** found → compute **U**pper **L**imits



Model independent upper limits

systematic uncertainties	Size
kinematic trigger efficiency, p/jet	0 - 7 %
jet energy scale / resolution, p/jet	1 - 6 %
b-tag efficiency(b/c), p/jet	2 - 5 %
b-tag efficiency(udsg), p/jet	< 0.3 %
pileup	4,6 %
luminosity	2,5 %
online b-tag efficiency, p/jet	0.8-1.3 %
background specific, p/sub-range	100 %, 25 % ,20 %
pdf + α_s, mssm/2hdm cross-section	1 - 6 %
QCD scale, mssm/2hdm cross-section	1 - 10 %
NLO correction for the selection eff.	5 %

- The most prominent **systematic uncertainties**:
  - Offline b-tag efficiency, jet energy scale, bias

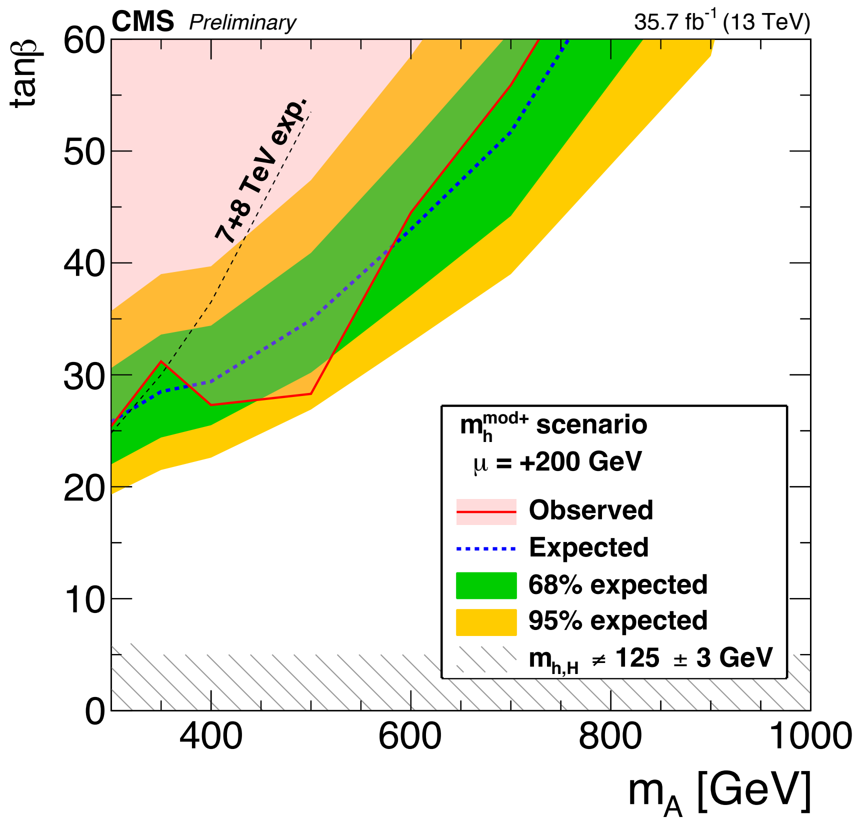


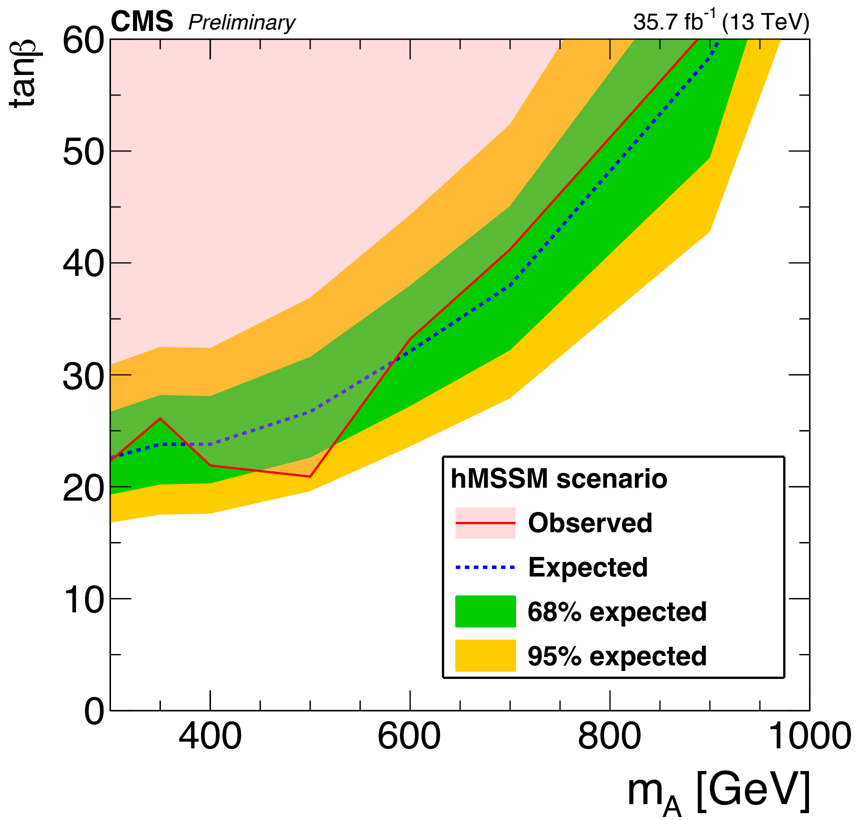
Main features

- Mass range is extended up to 1300 GeV in comparison to 8 TeV analysis;
- no significant excess found
- At 500/1100 GeV limits are calculated in adjoint sub-ranges

MSSM interpretation

- Observed **limits** are translated into exclusion limits **on MSSM** parameters - **tanβ** and **M_A**
- Interpretation within the **m_h^{mod+}** and **hMSSM** benchmark scenarios*.





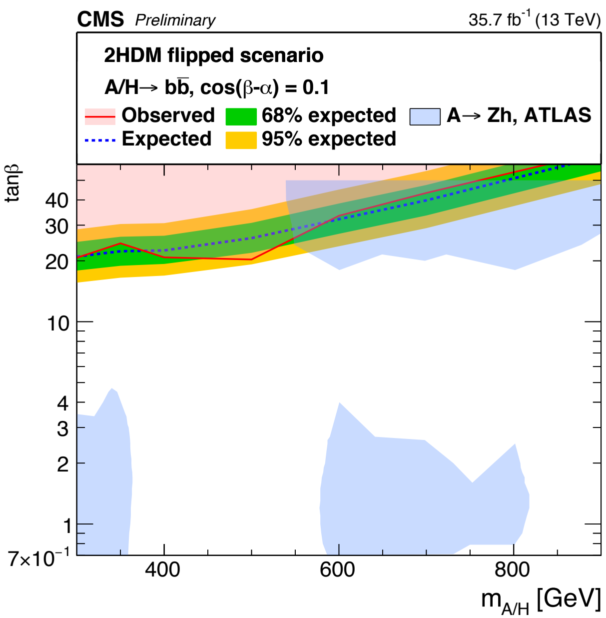
- In spite of higher trigger thresholds, 13 TeV limits for m_h^{mod+} are better than at 7 + 8 TeV everywhere except for the 300 GeV;
- **New** hMSSM interpretation: lower tanβ limits than m_h^{mod+} at large M_A

* - τ-phobic, light-$\tilde{t}$ and light-$\tilde{\tau}$ in the backup

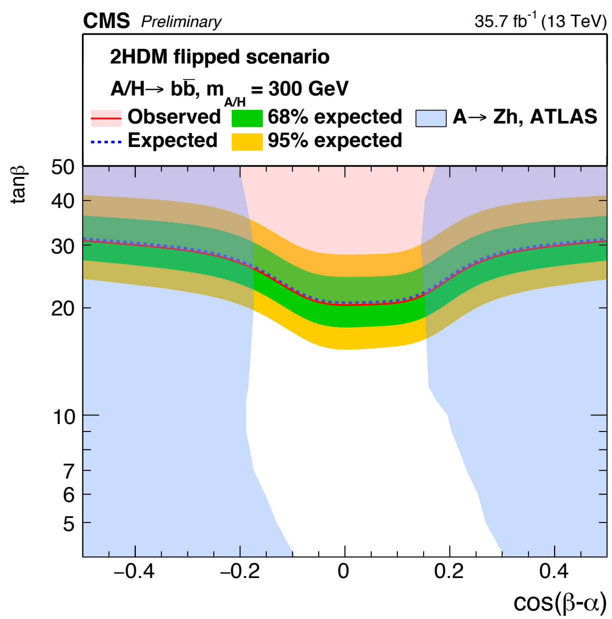
2HDM Interpretation: Flipped scenario

- **Exclusion limits** on **tanβ** vs **M_A** and **cos(β-α)** for 2HDM Flipped and Type-II models:
  - values of cos(β-α) = 0.1 and M_A = 300 GeV were chosen to compare with ATLAS A → Zh analysis [0]
- Our measurements are uniquely sensitive for small |cos(β-α)| (alignment limit) for high values of tanβ:
  - this is where h couplings are SM-like

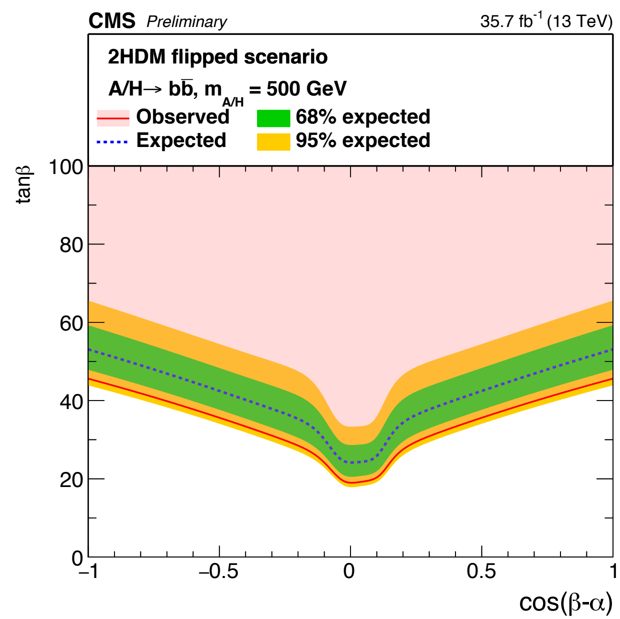
cos(β-α) = 0.1



M_A = 300 GeV



M_A = 500 GeV

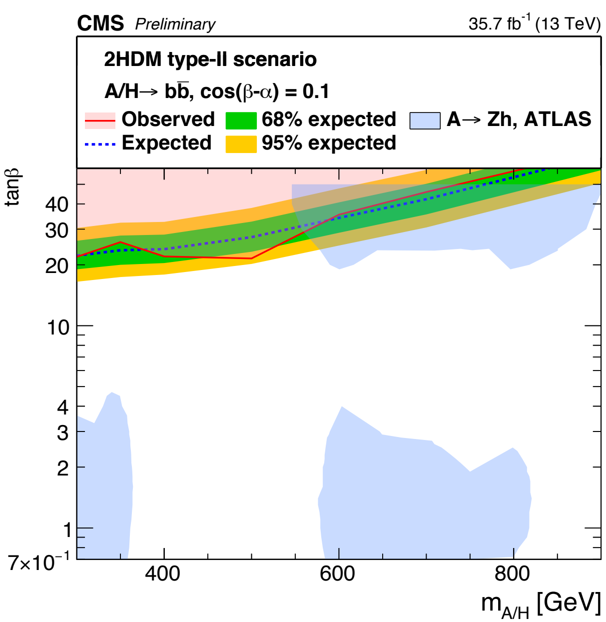


[0] - ATLAS collab., arXiv:1712.06518

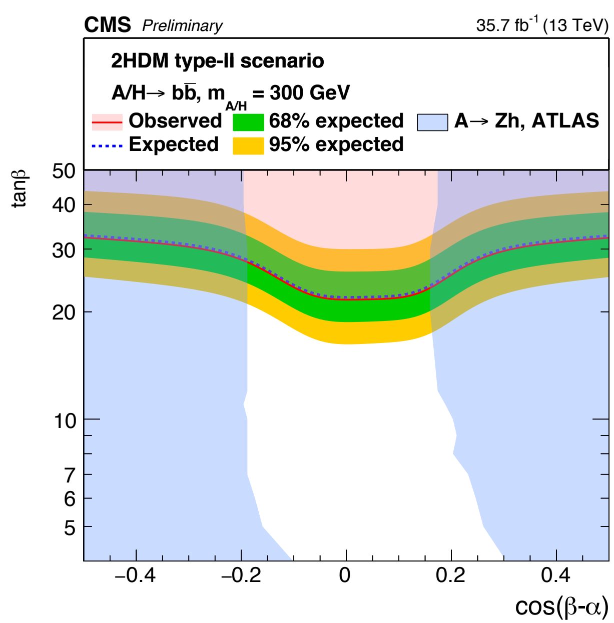
2HDM Interpretation: Type-II scenario

- **Exclusion limits** on **tanβ** vs **M_A** and **cos(β-α)** :
  - values of cos(β-α) = 0.1 and M_A = 300 GeV were chosen to compare with ATLAS A → Zh analysis [0]
- Our measurements are the only sensitive near the alignment limit for high values of tanβ:
  - where couplings are the most SM-like

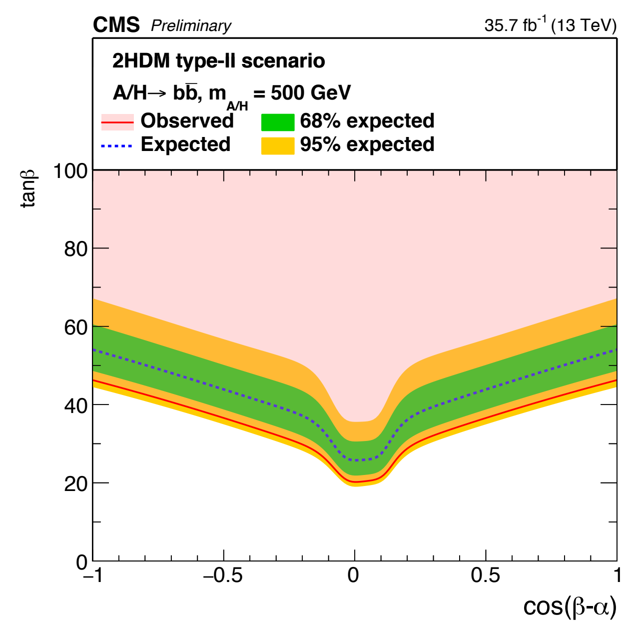
cos(β-α) = 0.1



M_A = 300 GeV



M_A = 500 GeV



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Summary

- A new search for **high mass Higgs** boson in **$b\bar{b}$ decay** channel in **association with b-quarks** was presented
  - unique analysis at LHC

- Results interpretations in context of **MSSM**:
  - **improved** limits in **m_h^{mod+}** and **new hMSSM** interpretation

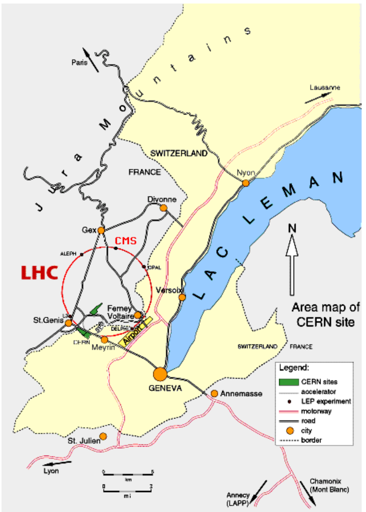
- Analysis put strong **constrains** on the relatively unexplored **«Flipped» 2HDM** scenario:
  - **Complements** ATLAS measurements of **$A \rightarrow Zh$**;
  - **Cover alignment limit** for large range of tanβ.

- Analysis to be **published soon**

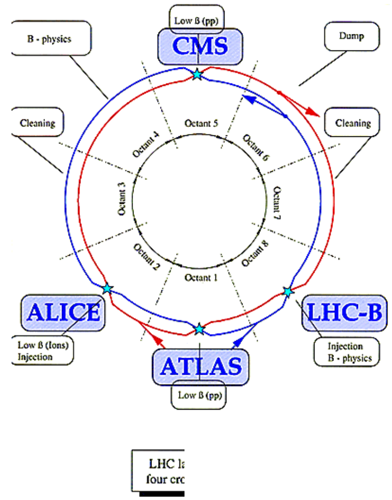
Текст заголовка

BACKUP

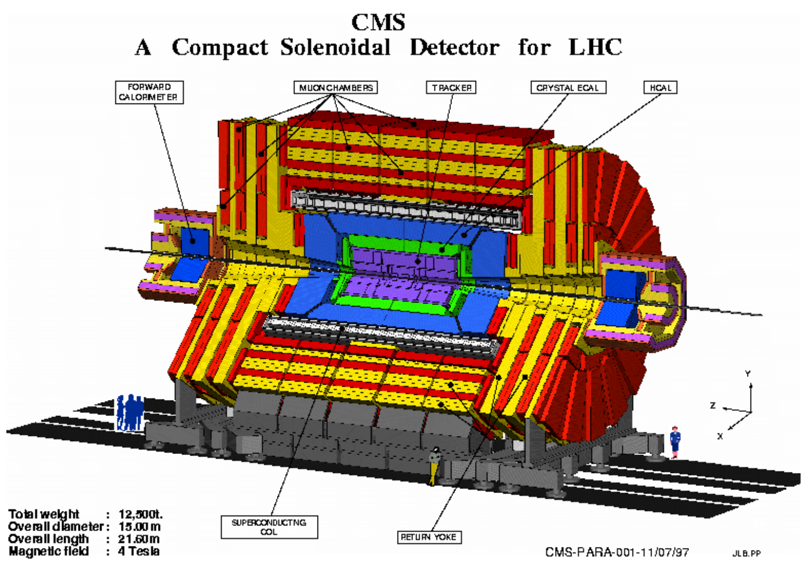
LHC and CMS



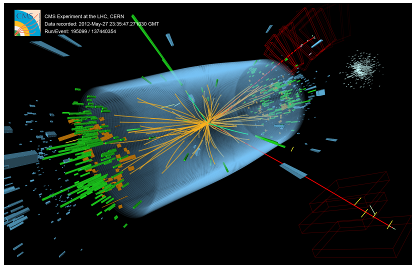
European Center for Nuclear Research (CERN)



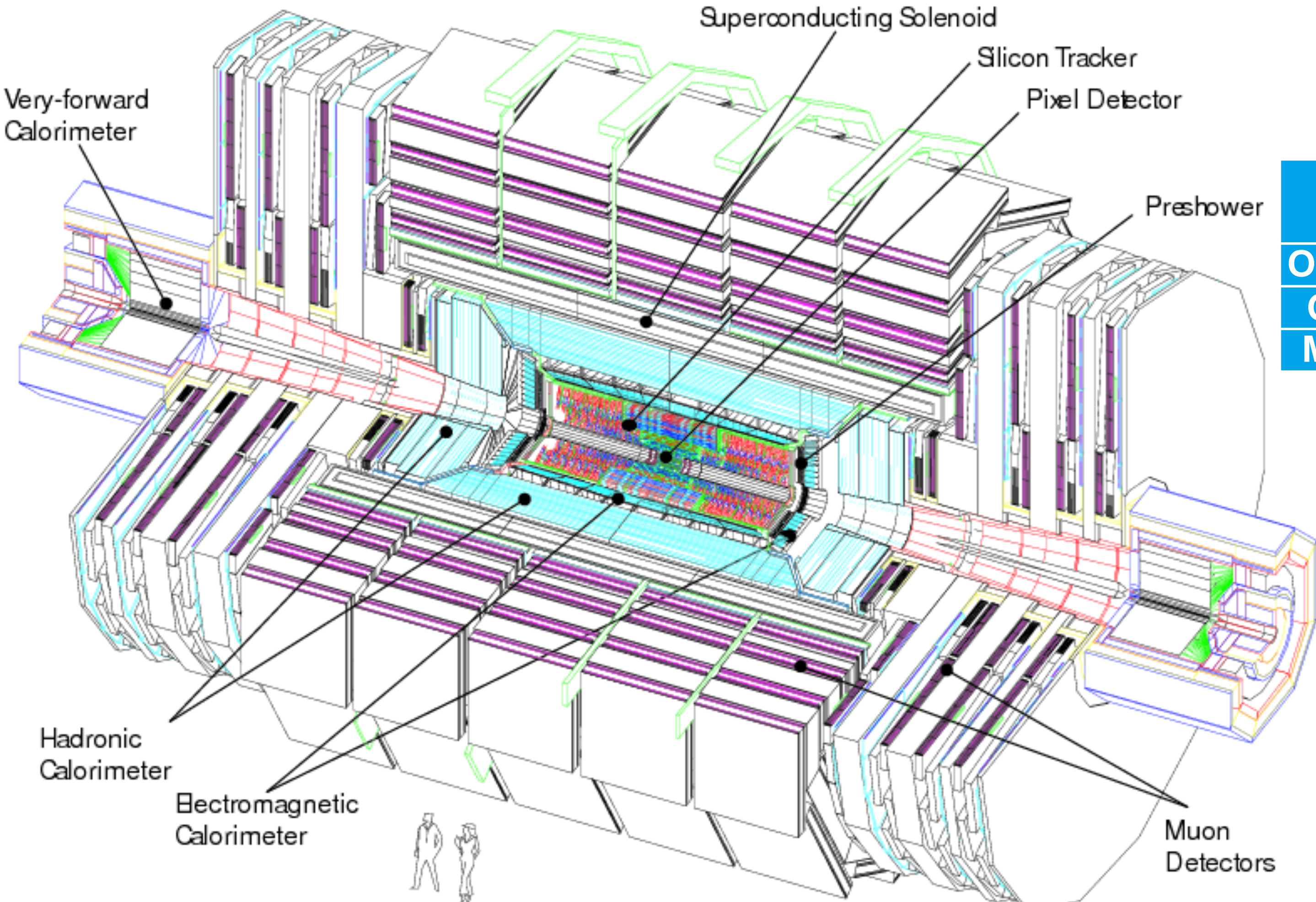
Large Hadron Collider (LHC)



Compact Muon Solenoid



Total weight	12.500 T
Overall diameter	15.0 m
Overall length	21.5 m
Magnetic Field	3.8 T



Compact Muon Solenoid

Two Higgs Doublet Model (2HDM)

- Higgs sector of **Two Higgs Doublet Model** (2HDM):

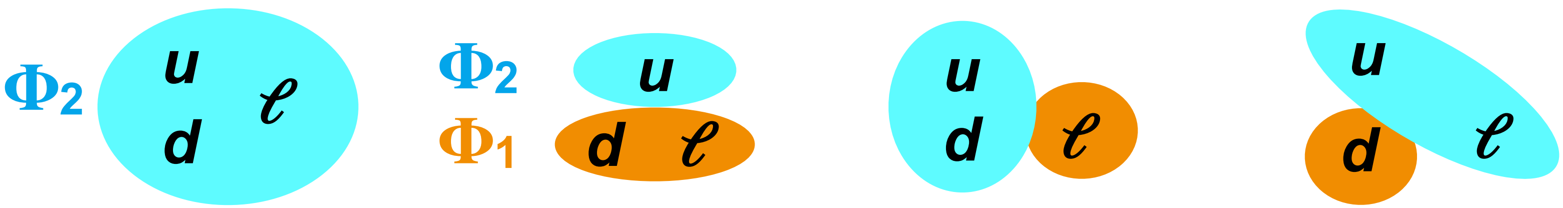
2 doublets	CP-even	CP-odd	Charged	
Φ_2 Φ_1	h, H	A	$H^{\pm}$	(h, H, A) ≡ ϕ

- **tan β** - ratio of vacuum expectation values ;
- **α** - **mixing** angle between h and H

\+ *other parameters*

- **4 types of 2HDM** with natural flavour and CP conservation, depending on how the 2 Higgs doublet fields couple to SM particles

Type I — Type II — Lepton Specific — Flipped



Type I: all fermion couples to one Higgs boson

Type II: up v.s. down

Lepton Specific: quark v.s. lepton

u - (u,c,t)
d - (d,s,b)
ℓ - (e,μ,τ)

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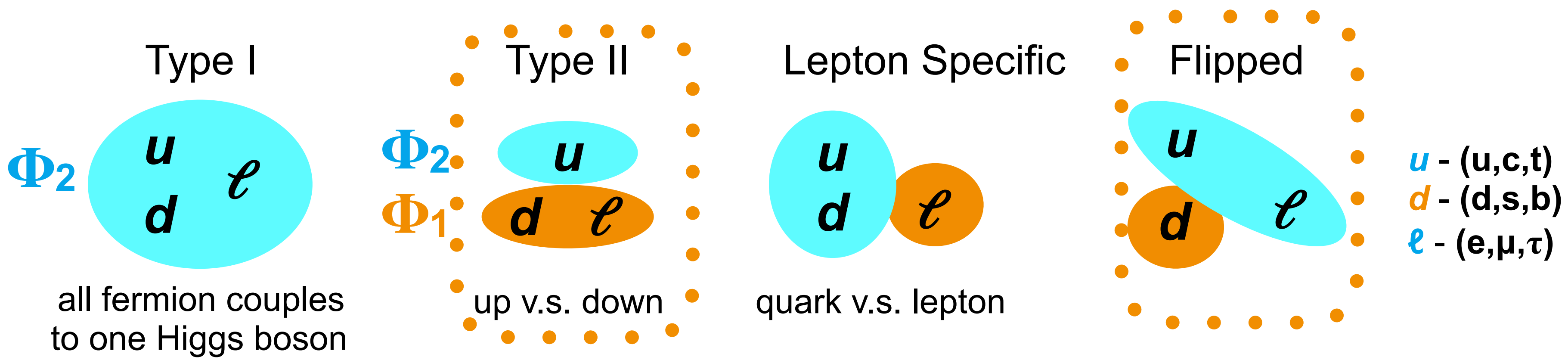
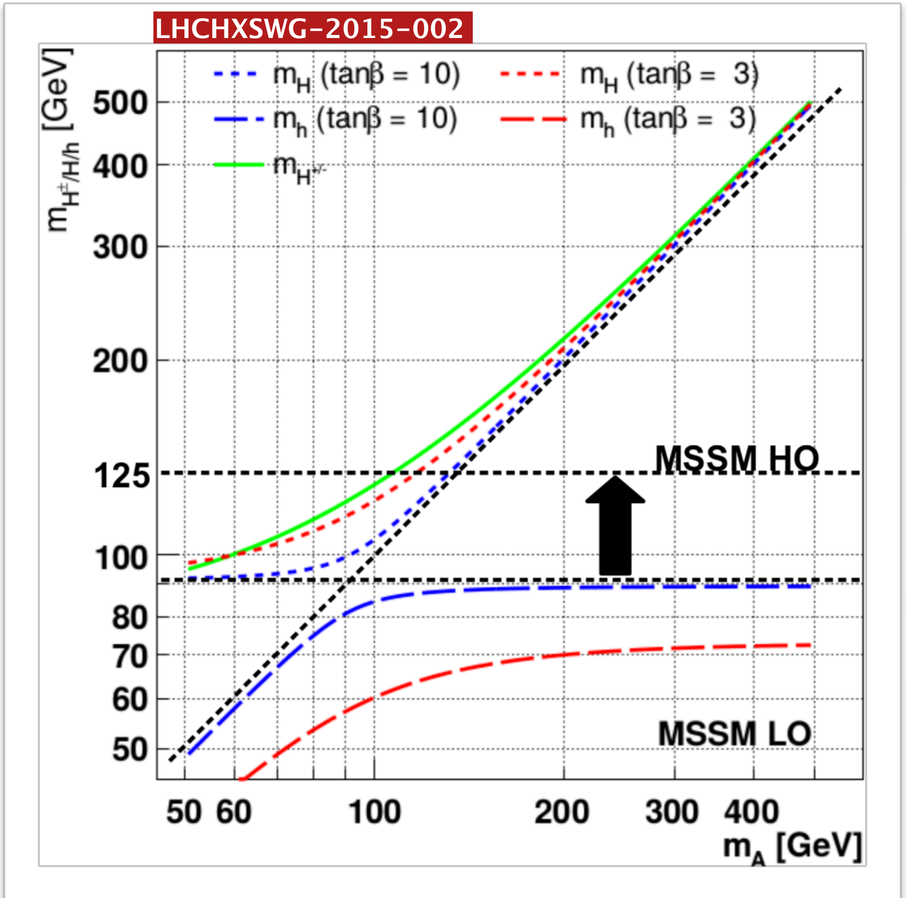


Minimal Supersymmetric Standard Model (MSSM)

- Features two complex Higgs doublets as in 2HDM.
  - **Two parameters at tree-level**:
    - m_A and **tanβ**



$$m^2_{H^\pm} = m^2_A + m^2_W$$
$$m^2_{H,h} = \frac{1}{2}(m^2_A + m^2_Z \pm \sqrt{(m^2_A + m^2_Z)^2 - 4m^2_A m^2_Z cos^2 2\beta})$$
$$tan\alpha = \frac{-(m^2_A + m^2_Z)sin2\beta}{(m^2_Z - m^2_A)cos2\beta + \sqrt{(m^2_A + m^2_Z)^2 - 4m^2_A m^2_Z cos^2 2\beta}}$$

- MSSM **features:**
  - Solve **hierarchy** problem
  - introduce **dark-matter candidate**
- **Compatibility with h(125)** achieved by the HO corrections:
  - **m_h increased** up to 30%
- Variety of **benchmark scenarios** to test different phase-space properties:
  - m_h^{mod+}; low-$\tilde{\tau}$, low-$\tilde{t}$, hMSSM… [0]

[0] - M. Carena et al., Eur. Phys. J. C 73 (2013) 2552

Novosibirsk and Extended Novosibirsk PDFs

- Function taken from H. Ikeda et al. NIM A441 (2000), p.401 (Belle Collaboration):

$$F(x) = N\exp(-\frac{1}{2\sigma_0^2}\ln^2(1 - \frac{x - x_p}{\sigma_E}\eta) - \frac{\sigma_0^2}{2})$$

$$\sigma_0 = (2/\xi)\sinh^{-1}(\eta\xi/2)(\xi = 2\sqrt{\ln 4} = 2.36)$$

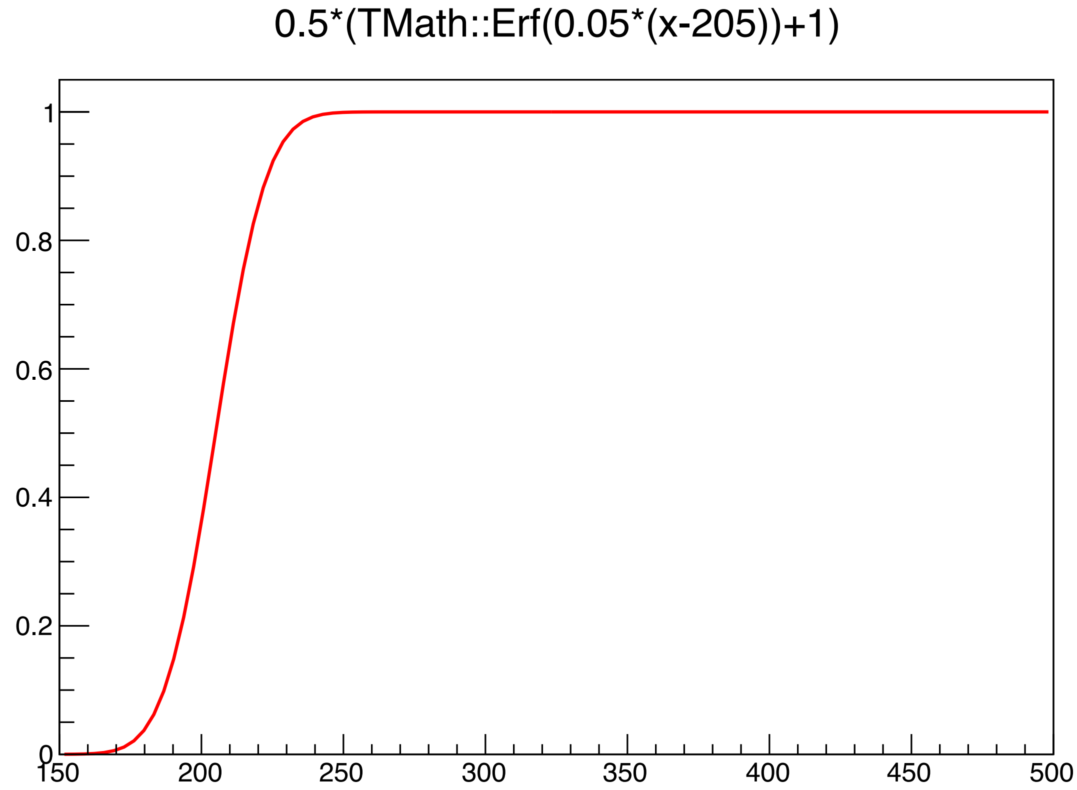
- where x_p = peak, σ_E = width
- Extended Novosibirsk PDF was introduced to give more flexibility to the function by adding one more “tail” term:

$$F(x) = N\exp(-\frac{1}{2\sigma_0^2}\ln^2(1 - \frac{x - x_p}{\sigma_E}\eta - \mathrm{p}_4\frac{(x - x_p)^2}{\sigma_E}\eta) - \frac{\sigma_0^2}{2})$$

- η = tail

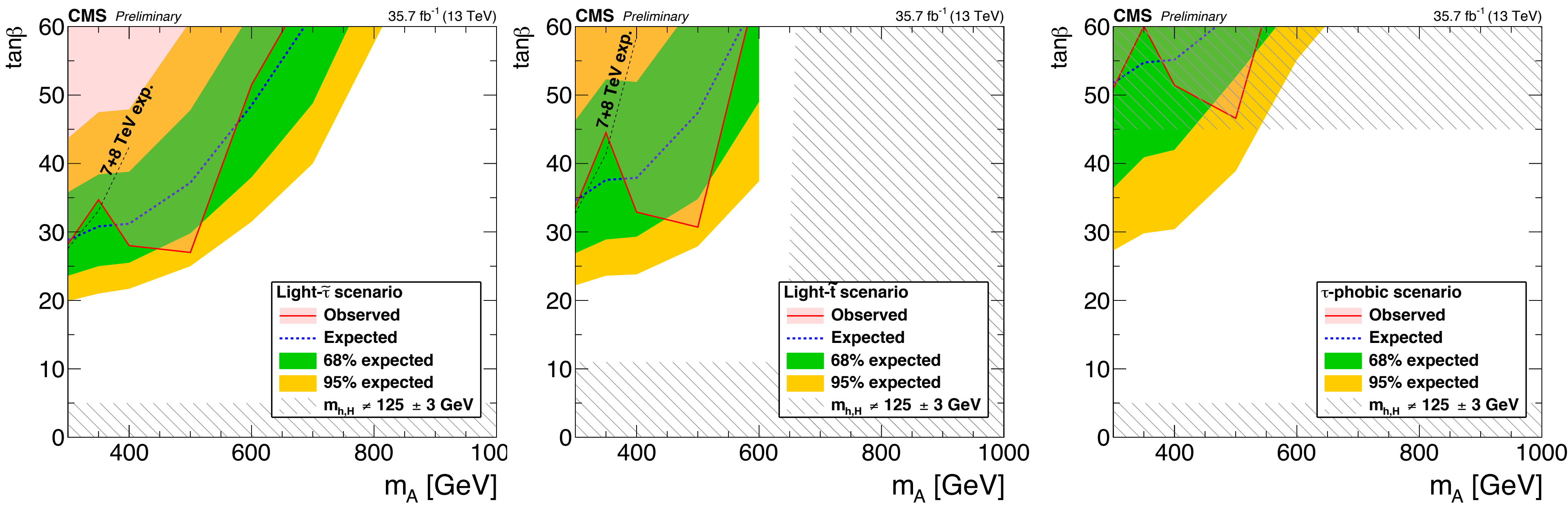
Turn-on functionn

- $F(x) = 0.5*Erf(P_0*(x-P_1))+1)$
  - where $Erf(x) = 2/\sqrt{\pi} * \int e^{-t^2} dt$ — integral between 0 to x
  - P_0 indicates slope of this turn-on function and P_1 is turn-on point



MSSM interpretation

- Expected **limits** are translated into exclusion limits **on MSSM** parameters - **tanβ** and **M_A**
- Interpretation performed using **NNLO** cross sections in the **Santander** matching within the **light-$\tilde{\tau}$** ,**light-$\tilde{t}$** and **τ-phobic** benchmark scenarios



- 13 TeV limits are better than at 7 + 8 TeV

Novosibirsk

- Standard Novosibirsk function has been extended to **Super**Novosibirsk function:

$$F(x) = N \cdot exp(-\frac{1}{2\sigma_0^2} ln^2(1 - \frac{\eta}{\sigma_E} \cdot (\sum_{i=1}^{n} p_{(i-1)} \cdot (x - x_p)^i) - \frac{\sigma_0^2}{2}))$$

$$\sigma_0 = (2/\epsilon) sinh^{-1}(\eta\epsilon/2)$$

$$\epsilon = 2\sqrt{ln4}) = 2.36$$

- $p_0 = 1$;
- η - tail parameter;
- σ_E - width;
- x_p - peak position