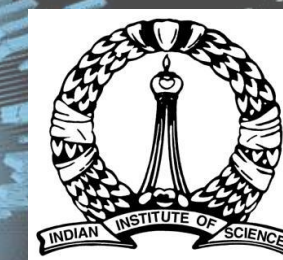




WG Report: Experimental Group



**2nd workshop
 of the
 Indo-French Network
 in High Energy Physics**



Suzanne GASCON-SHOTKIN
IPN Lyon (IN2P3-CNRS)/Université Claude Bernard Lyon 1
Seema SHARMA
IISER-Pune

IISR-Pune
 February 26, 2018



The Experimental WG: Current/potential members (30!)



- Lyon Node:
 - Senior: M. Lethuillier, S. Gascon-Shotkin, M. Gouzevitch
 - Postdoc: L. Finco Students: C. Camen, S. Zhang
- Saclay Node:
 - Senior: M. Besançon, P. Gras
- Bangalore/Chennai Node:
 - Senior: J. Komaragiri
 - Students: P. Chandra, L. Panwar
- Mumbai/Pune Node:
 - Senior: S. Dube, S. Sharma, A. Thalapillilil, (IISER) M. Guchait, G. Majumder, K. Mazumdar , R. Sharma (TIFR)
 - Students: S. Chauhan, V. Hegde, B. Kansal, A. Kapoor, K. Kotheekar, S. Pandey, A. Rane, A. Rastogi (IISER)
- Kolkata Node:
 - Senior: S. Bhattacharya (SINP), P. Mal, B. Mohanty (NISER)
 - Students: A. Purohit, P.K. Rout (SINP)



Activities of the Experimental WG since the Bangalore kickoff (May 2016)



1 of 2

CEFIPRA Kickoff meeting

Bangalore May, 2nd-4th 2016

- Initial brainstorming in Bangalore...

EWorking Group (CMS-Experiment)

Participants to the working group meeting May, 3rd 2016 2.45pm

Suzanne GASCON-SHOTKIN (IPN Lyon)
 Amina ZGHICHE (CEA Saclay)
 Satyaki Bhattacharya (SINP, Kolkata)
 Seema Sharma (IISER, Pune)
 Prolay Kumar Mal (NISER Bhubaneswar)
 Manoranjan Guchait (TIFR, Mumbai)
 Somnath Choudhury (IISc, Bengaluru)
 Jyothsna Rani Komaragiri (IISc, Bengaluru)

Identified topics and participating Institutes:

Analyses

H->gammagamma, either $m_H=125$ GeV or $m_H<125$ GeV (IISc-Bangaluru, IPN-Lyon, TIFR-Mumbai, SINP-Kolkata, CEA-Saclay)
 (including collaboration with theorists on interpretations of search results)

H->bb (IISc-Bangaluru, CEA-Saclay)

Double HIGGS:HH->gamma gamma b bar (IISc-Bangaluru, IPN-Lyon, TIFR-Mumbai, CEA-Saclay) also including collaboration with theorists for interpretation(SINP)

2 of 2

CEFIPRA Kickoff meeting

Bangalore May, 2nd-4th 2016

Top physics+MET(IPN-Lyon, IISER-Mumbai, NISER-Bhubaneswar)

Monophoton+DM(SINP-Kolkata, CEA-Saclay)

And possibly

H->TauTau(IISc-Bangaluru, CEA-Saclay)

Sub-detector oriented topic

ECAL(IPN-Lyon, SINP-Kolkata, CEA-Saclay)

As for the Upgrade part:

Si strips+HGAL would be the common topics

Communication

CMS e-group

Meetings-Workshops including PhD students: one day before or after CMS weeks or Physics weeks

- Informal coffee meeting during June 2016 CMS Week @ CERN → Planning of INFRE-HEPNET 'satellite' meeting for Nov. 2016 CMS Week @TIFR...

3



Activities of the Experimental WG since the Bangalore kickoff



Indo – French Meet@TIFR

19th November, 2016

AGENDA
Venue : AG 66

Time	Title	Speaker
9:00 – 9:10	Scope of Indo-French project at TIFR	Sourendu Gupta
9:10 - 9:35	A new variable for Jet Quenching	Rishi Sharma
9:35 – 10:00	Light Higgs boson signal in Diphoton channel	Jacky Kumar
10:00 – 10:25	TBA	Sreerup Raychaudhury
10:25 – 10:50	Phenomenology of Bulk Higgs at the LHC	Ushoshi Maitra
10: 50 : 11:15	Tea/Coffee	
11:15 – 11:40	Search for two low mass Higgs bosons ($m_h < 110$ GeV) decaying to two photons in CMS, with 2HDM interpretation and perspective for Indo-French collaboration.	Marc Besancon
11:40 - 12:05	Search for HH production in the $b\bar{b}g\gamma\gamma$ channel at 13 TeV.	Susan Shotkin Gascon-Shotkin
12:05 – 12:30	TBA	Arnab Purohit/Satyaki Bhattacharya
12:30 – 13:00	Discussion	
13:00 – 14:00	LUNCH	
14:00 – 16:00	CMS Internal Meeting	

- The ‘satellite’ meeting including:
 - guest talks by TIFR theory colleagues in the AM
 - CMS internal session in the PM
- took place on Nov. 19 2016

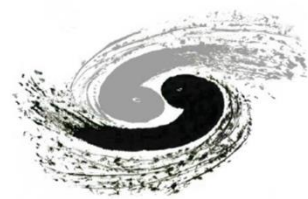


Status of concrete projects in the Experimental WG



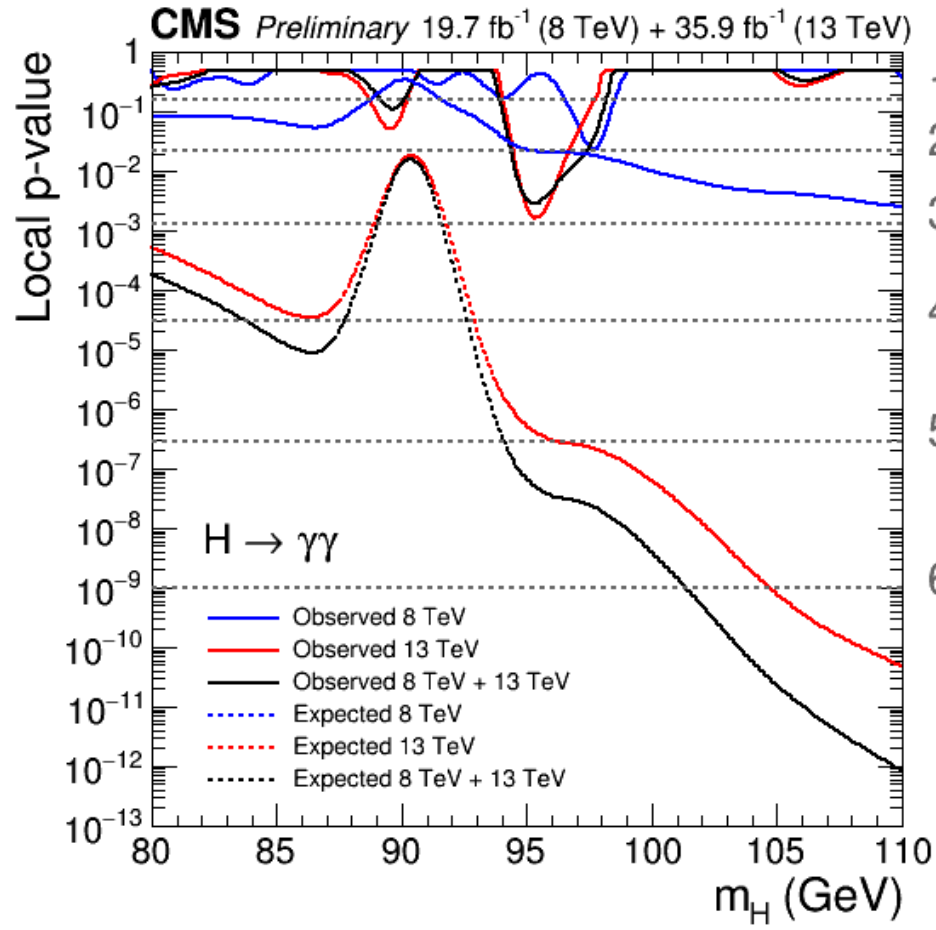
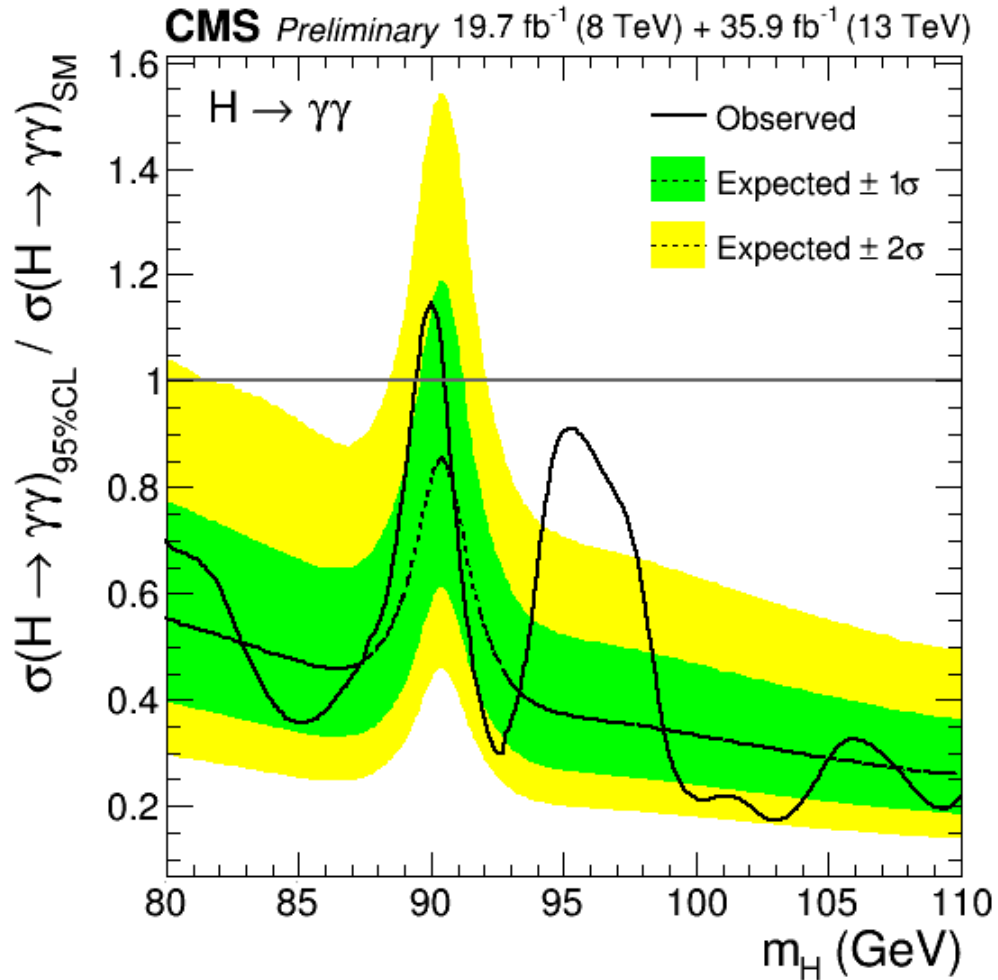
- One project begun during the Nov. 2016 CMS Week @Mumbai: **SINP** group joins **IPN Lyon**/IHEP-Beijing collaboration on the **CMS low-mass ($m < 125$ GeV) $h \rightarrow \gamma\gamma$ search**
- Team: IPN Lyon: S. G-S, M. Lethuillier, L. Finco, C. Camen IHEP-Beijing: G. Chen, J. Tao, A. Shahzad, S. Zhang SINP Kolkata: S. Bhattacharya, K. Mondal, A. Purohit, P. K. Rout
- Team leads/holds responsibility for this field in CMS since 2013: Public Run 1 (CMS-HIG-14-037) and Run 2 preliminary results (2016 13 TeV data + combination with 2012 8 TeV data) released Sept. 2017 (CMS-HIG-17-013), paper in preparation (internal CMS review)[see next slide]
- Without the SINP-IPNL partnership we would still probably not have public Run 2 results today. Only LHC results to date using 13 TeV data
- One project in its infancy stage: **TIFR Mumbai** joins **IPN Lyon** and other CMS groups on **HH \rightarrow bb $\gamma\gamma$**
- Team: IPN Lyon: M. Gouzevitch TIFR Mumbai: K. Mazumder, N. Sahoo, A. Ray
- Leading role in most sensitive HH results to date (2 publications)

Low-mass $h \rightarrow \gamma\gamma$ (70/80-110 GeV)



CMS PAS HIG-17-013

Public preliminary result Sept. 2017, paper in preparation (internal CMS review)



8TeV+13 TeV
 Combination: Excess
 with $\sim 2.8 \sigma$ local (1.3σ
 global) significance
 at $m=95.3$ GeV

More data are
 required to ascertain
 the origin of this
 excess. No 13 TeV
 ATLAS result yet

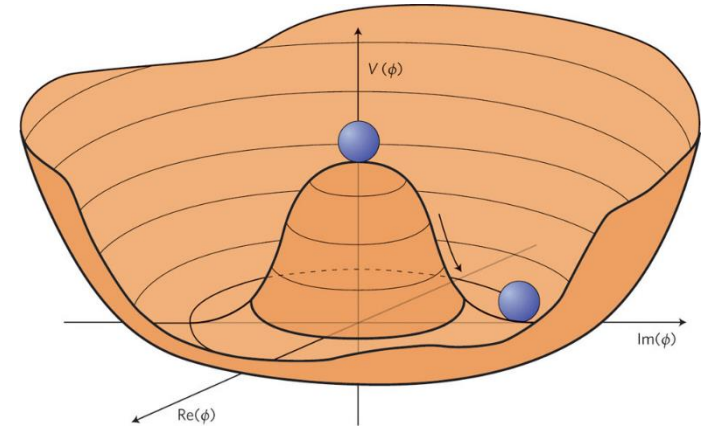
See following
 dedicated talk by
 Arnab Purohit
 (SINP)

- Combined 8 TeV+13 TeV $\sigma \times \text{BR}$ limit normalized to SM expectation (production processes assumed in SM proportions).

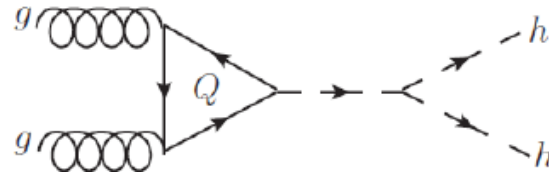
- Expected and observed local p-values for 8 TeV, 13 TeV and their combination

HH → bbyγ (1)

- Shape of the Higgs potential
 - postulated not taken from first principles.
 - indirectly constrained within SM.
- HH production sensitive to the quartic term, but the cross section is too small.



$$\lambda_{hhh} \equiv \eta = \frac{m_H^2}{2v^2}$$



$$\mathcal{L}^h = \frac{1}{2} m_h^2 h^2 + \eta v h^3 + \frac{\eta}{4} h^4$$

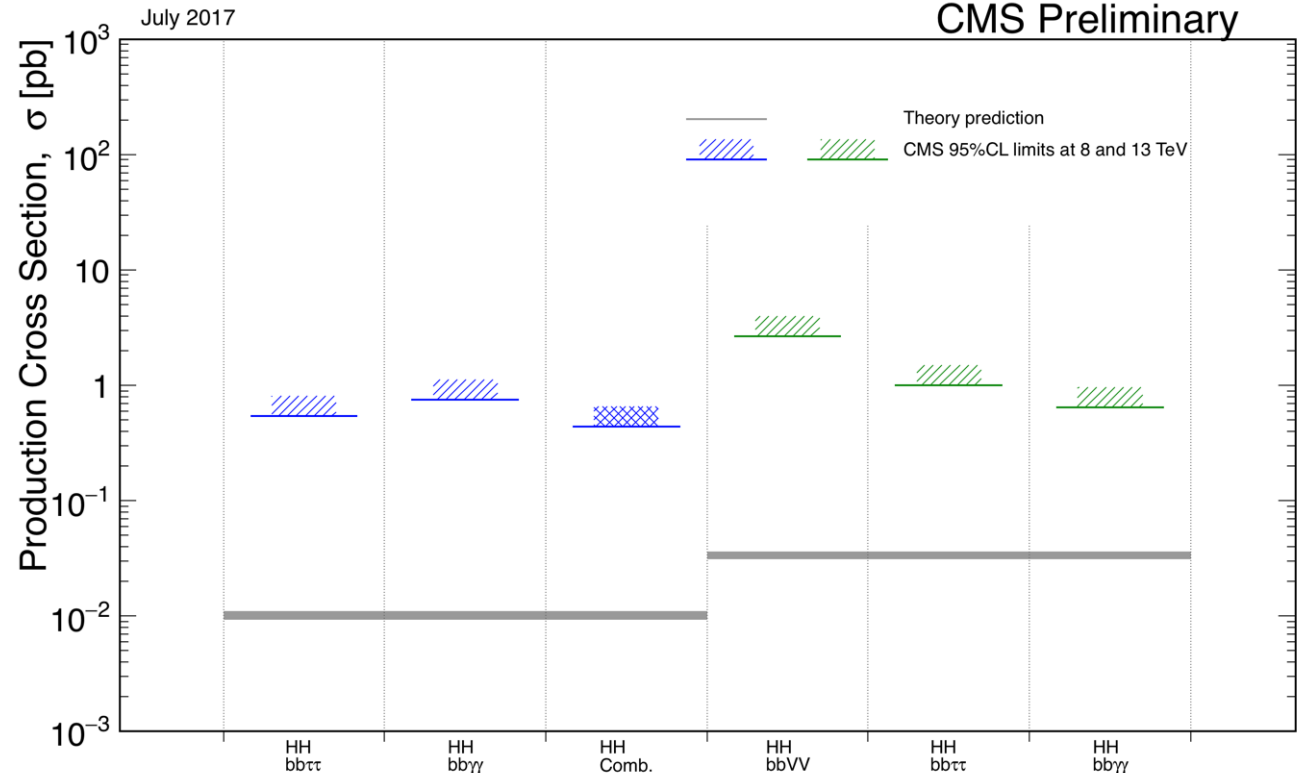
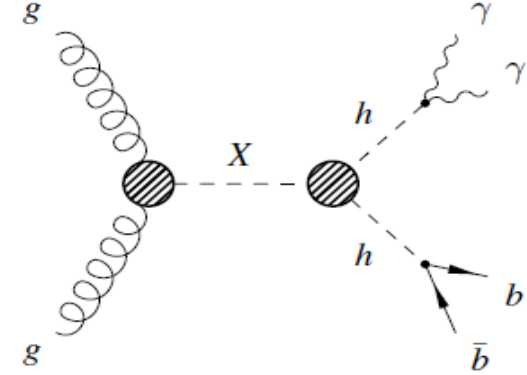
- Since Run I we have searched for anomalous production and try to provide a precise estimate of what HL-LHC can bring us:
 - The HH channel appears in almost all the HL-LHC TDR of CMS.
 - ~ 10 publications from the different channels



HH → bbγγ (2)



- The most sensitive channel is HH → 2b2γ.
 - Excellent H → resolution and high H → bb branching.
- Below an example of the sensitivity to SM-like production.





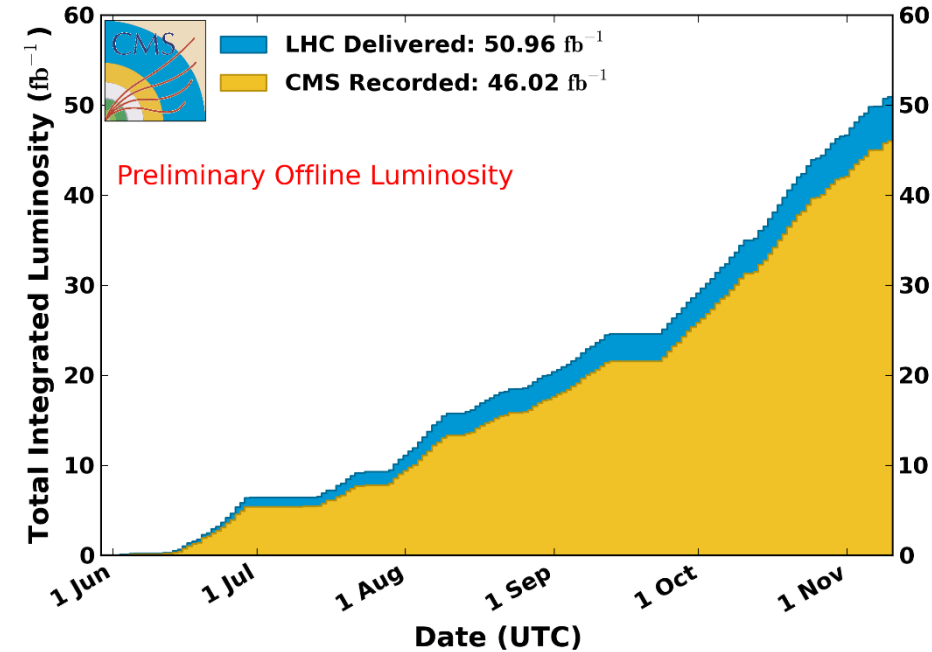
Short-term (≤ 2019) perspectives: Current projects



- Priority: Analyze the 2017 data ($>40 \text{ fb}^{-1}$, slightly bigger dataset than 2016) and then the 2018 data (last year of Run 2): $\sim 70 \text{ fb}^{-1}$ expected
- For low-mass $H \rightarrow \gamma\gamma$, this data could be conclusive. New publications for both projects
- Both projects will participate in HL/HE LHC 'CERN Yellow Report' for end of 2018 (input to European Strategy)
- Will discuss plans for 2018 visit requests (current call) during the parallel session
- Try to develop additional new projects

CMS Integrated Luminosity, pp, 2017, $\sqrt{s} = 13 \text{ TeV}$

Data included from 2017-05-30 08:43 to 2017-11-10 14:09 UTC



- Continue efforts for exp-th collaborations (next slide)

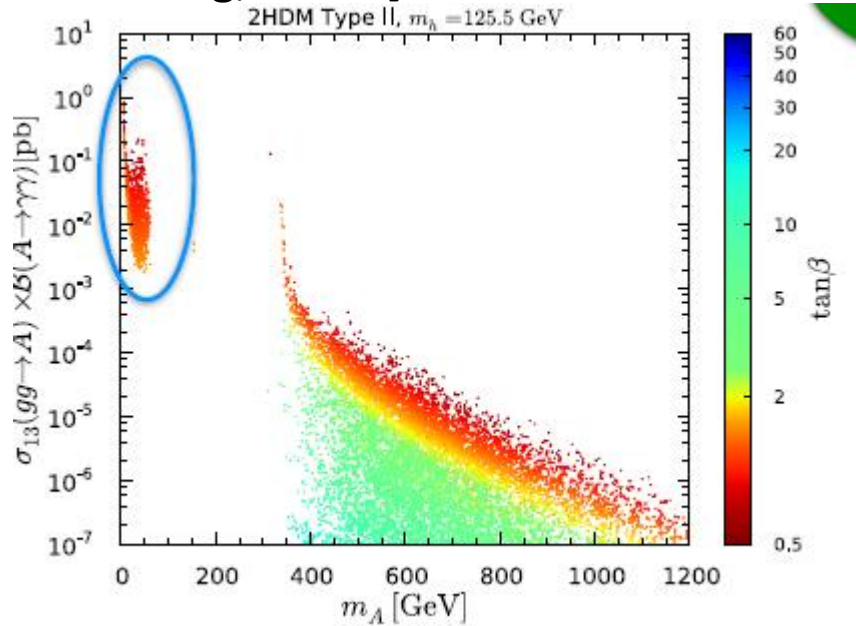


Short-term (≤ 2019) perspectives: Potential new projects/synergy with theorists/other WG



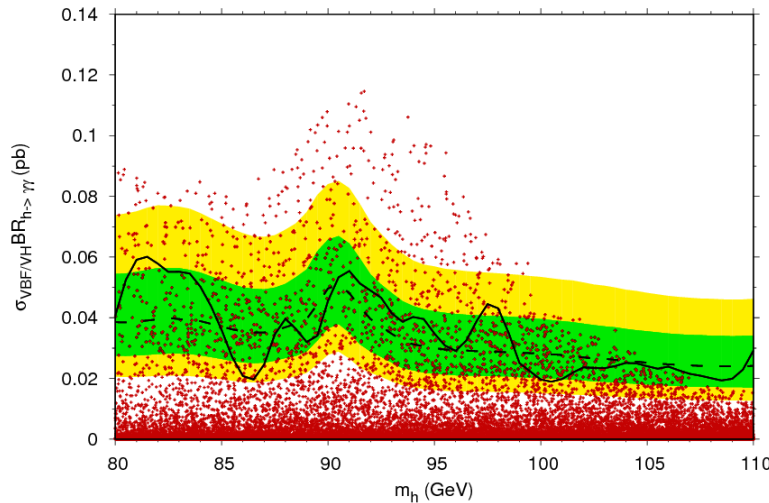
- ~Example: $h \rightarrow \gamma\gamma$ with $m_h < 110\text{GeV}$: Many network members already working on cases of:

A of 2HDM Type 2 (Alignment Lim)[Bernon, Gunion, Haber, Jiang, **Kraml**]



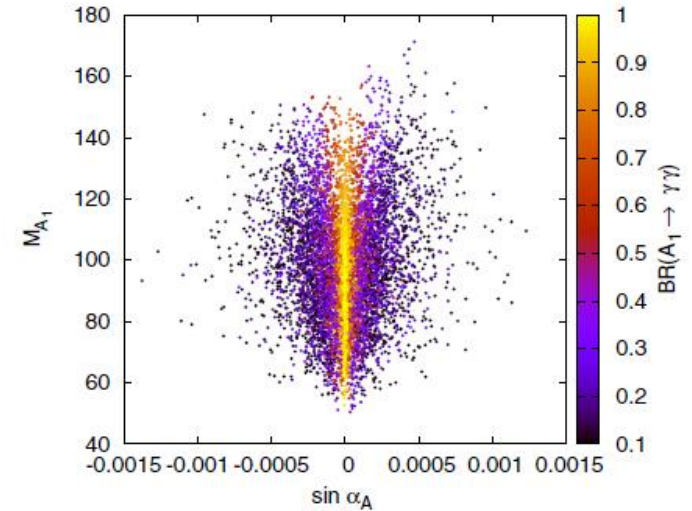
1507.00933, Phys. Rev. D 92, 075004 (2015)

h of 2HDM Type 1
[**Deandrea, Cacciapaglia, G-S, LeCorre, Lethuillier, Tao**]



1607.0865, JHEP12(2016)068

A_1 of NMSSM [**Guchait, J. Kumar**]



1608.05693, Phys. Rev. D 95, 035036

- Also light radion [**S. Bhattacharya, G. Moreau**..], h_1 of NMSSM [**Bélanger, Ellwanger, Djouadi**..], DM[Bannerjee, **Bélanger** et al], Higgs Compositeness [**Cacciapaglia** et al] \rightarrow DM, ExtraDimensions, Tools/reinterpretation/presentation of results [**Kraml, Boudjema**] WG



Global/long-term perspectives and Conclusions



- Possible areas for new projects (inter-exp and exp-th): CMS Phase 2 Upgrades (example: HGCAL), Run 3 and HL/HE LHC preparation
- The Experimental working group still has a vocation, needs to increase synergy with theorists/other WG

- Thank you for your attention!

Acknowledgements

- A big THANK YOU to S. Sharma, S. Dube, and the other members of the organization staff of the Pune meeting!
- CEFIPRA INFRE-HEPNET





Additional Material

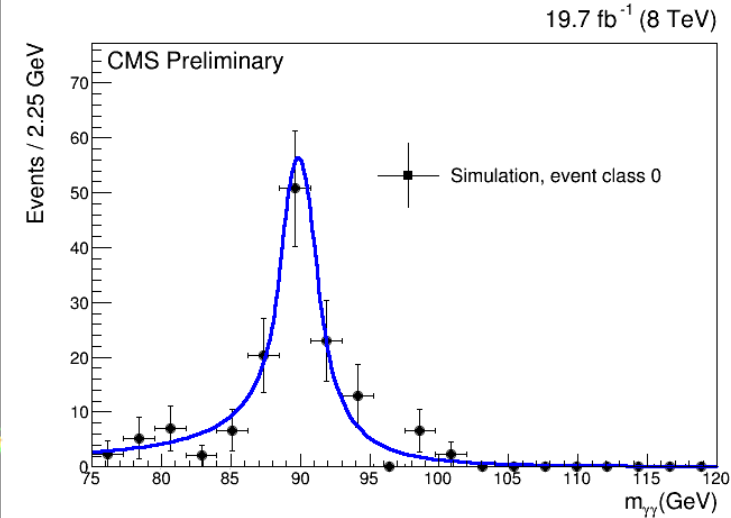
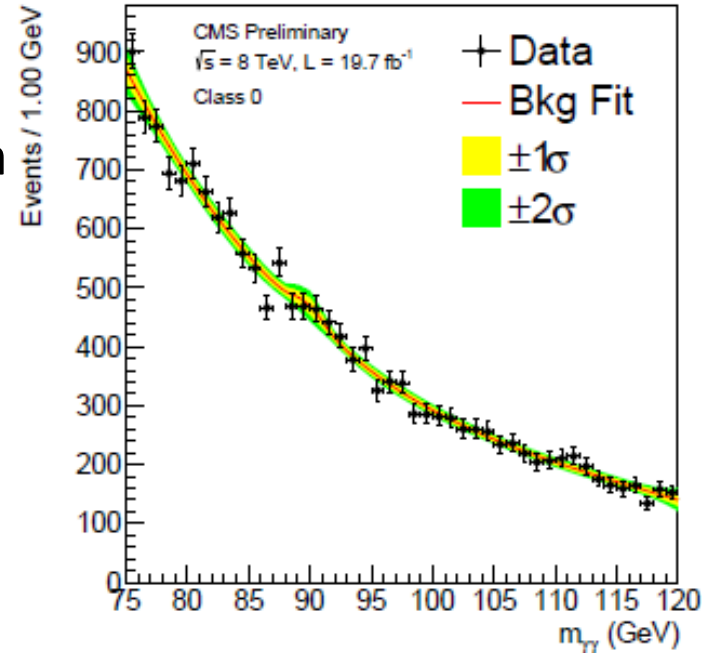


Run 1 $h \rightarrow \gamma\gamma$ Search (80-110 GeV)



CMS PAS HIG-14-037

- Joint effort by the IPN Lyon (C. Carrillo, B. Courbon, J. Fan, S. G-S, M. Lethuillier, D. Sabes, L. Sgandurra) and IHEP-Beijing (G. Chen, M. Chen, Y. Shen, J. Tao, S. Zhang) team
- Many analysis elements inherited from the SM $H \rightarrow \gamma\gamma$ 'legacy' analysis (see Arnab's talk)
- Analysis specifics wrt SM analysis:
 - Search range: $80 \text{ GeV} < m_h < 110 \text{ GeV}$ (cut on $m_{\gamma\gamma}$ at Trigger-level)
 - 4 inclusive event classes (output of diphoton boosted decision tree [BDT] with photon identification and kinematic inputs)
 - Background model: Two-component background model (relic Z peak modeled by double-sided Crystal Ball (DCB) function on top of monotonically decreasing polynomial)



- More stringent electron veto applied (no hits in pixel detector)
- DCB shape parameters determined from Drell-Yan Monte Carlo, contributes additional systematic error
- Relic $Z \rightarrow ee$ normalization left floating

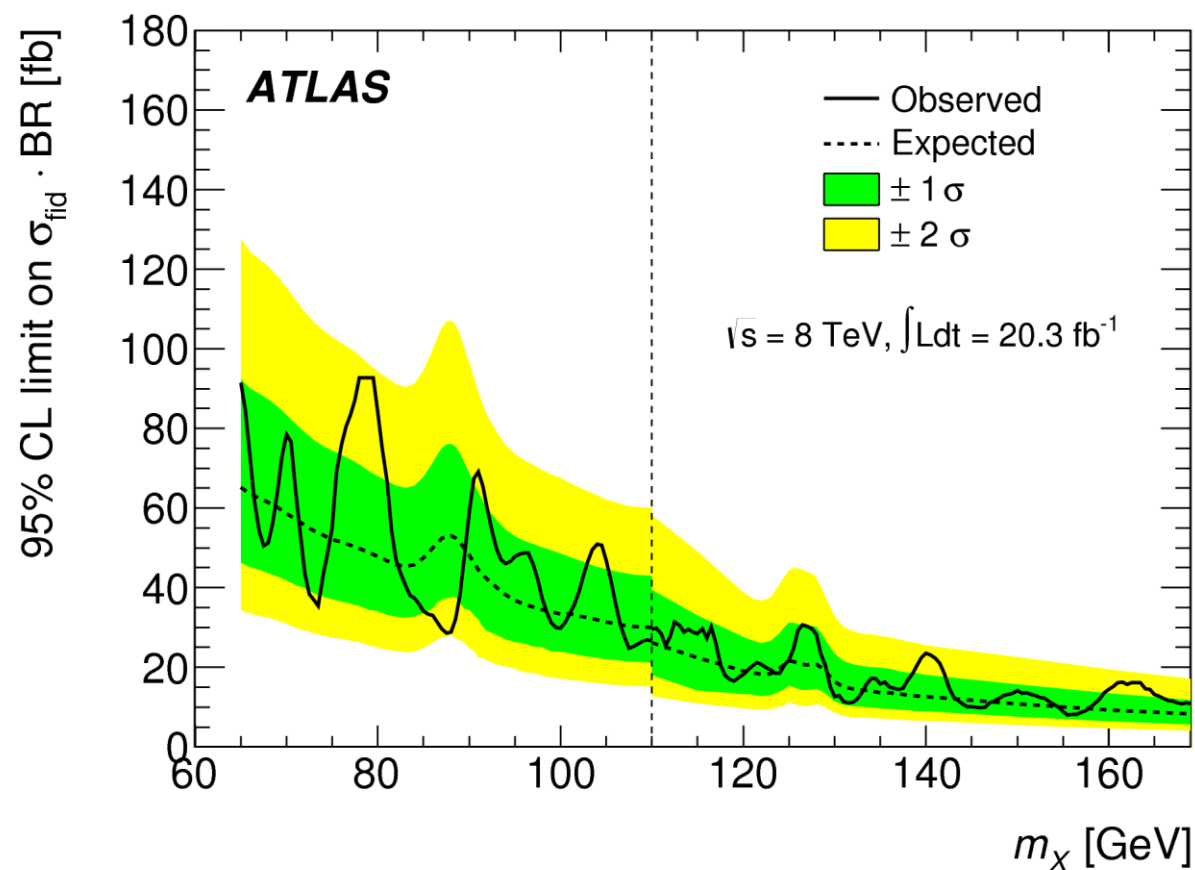
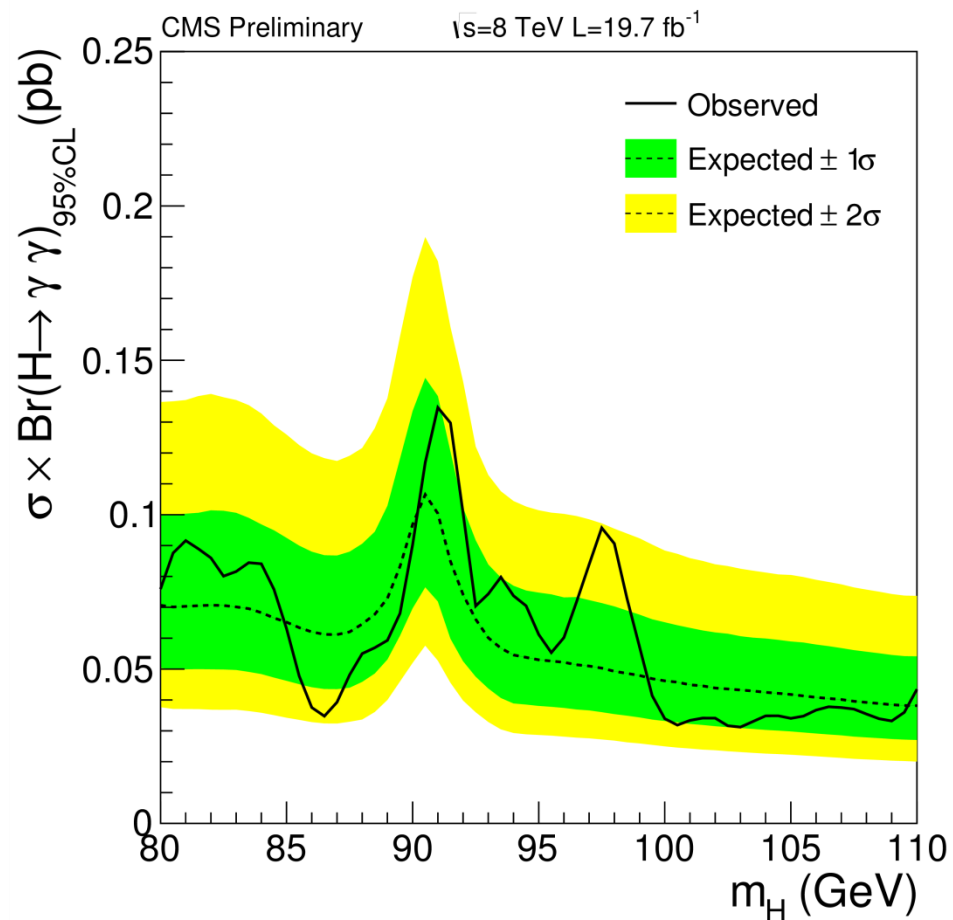


$h \rightarrow \gamma\gamma$ Run 1: CMS and ATLAS



CMS PAS HIG-14-037

PRL 113 171801 (2014)



• $\sim 2\sigma$ excursion @ ~ 97.5 GeV

• $\sim 2\sigma$ excursion @ ~ 80 GeV

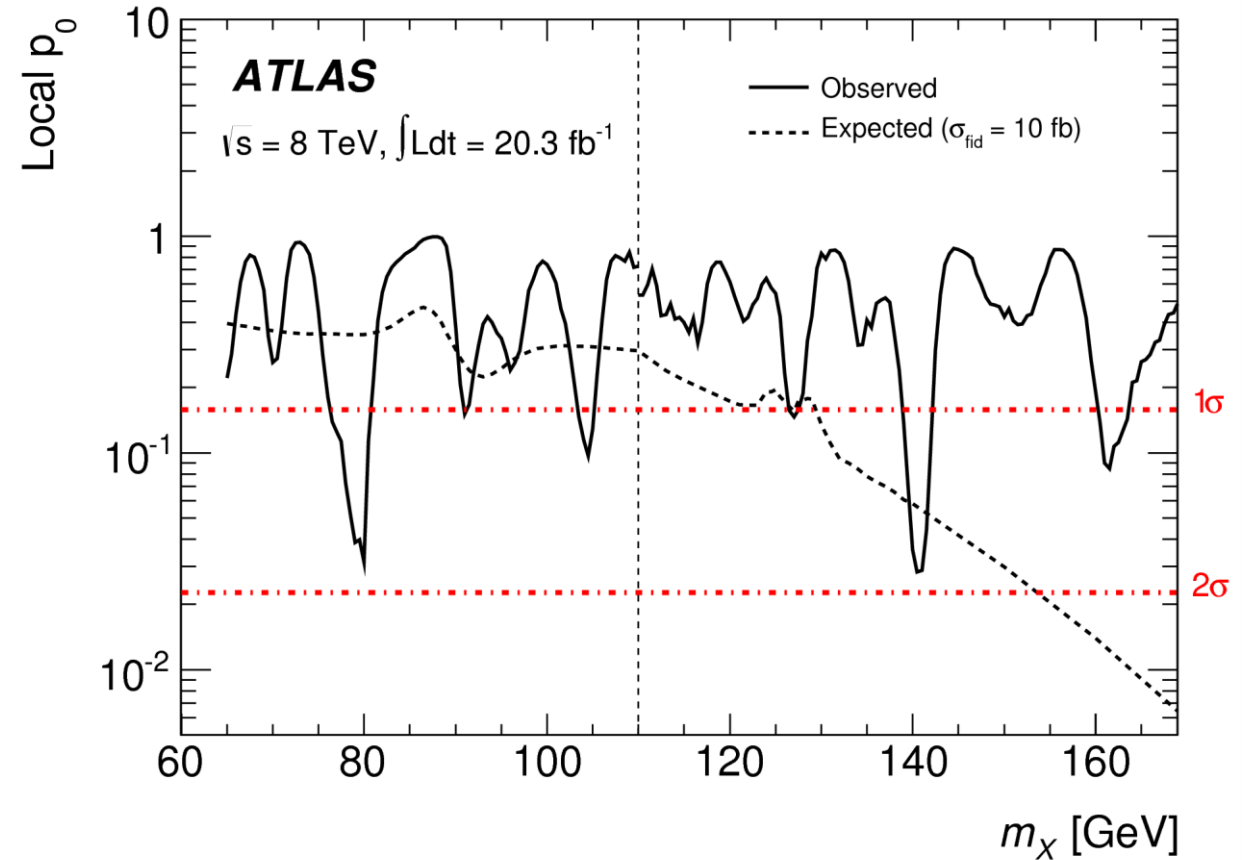
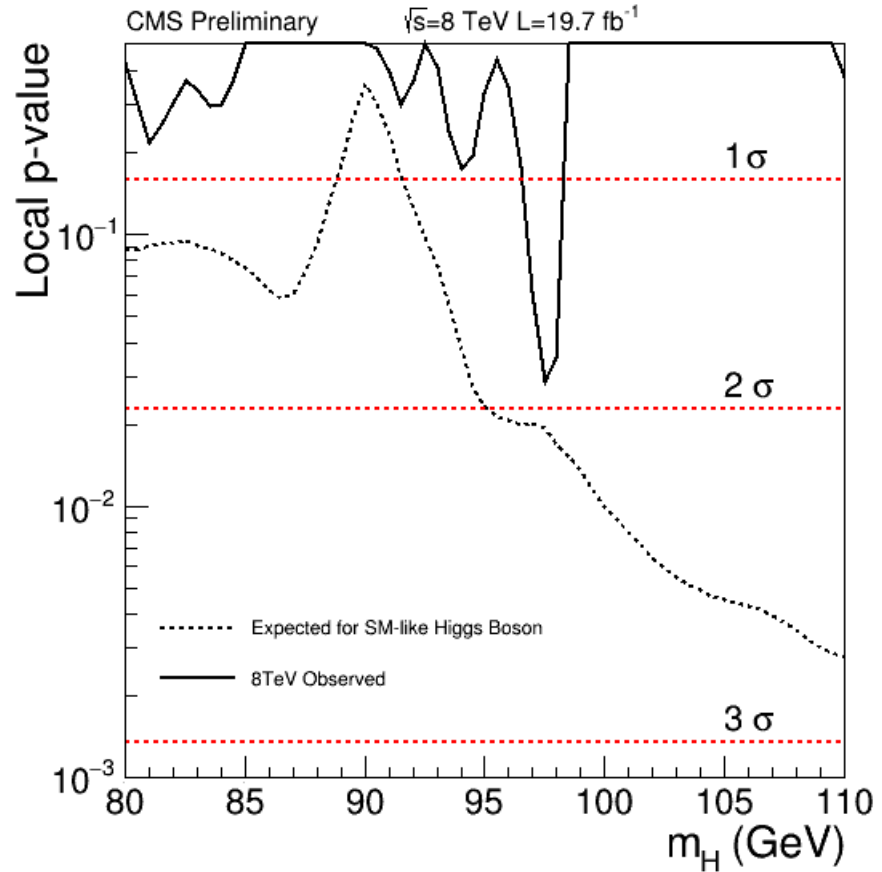


$h \rightarrow \gamma\gamma$ Run 1: CMS and ATLAS



CMS PAS HIG-14-037

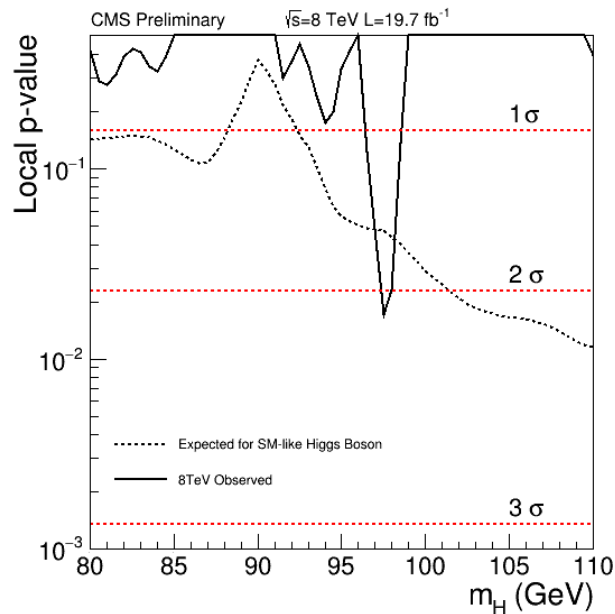
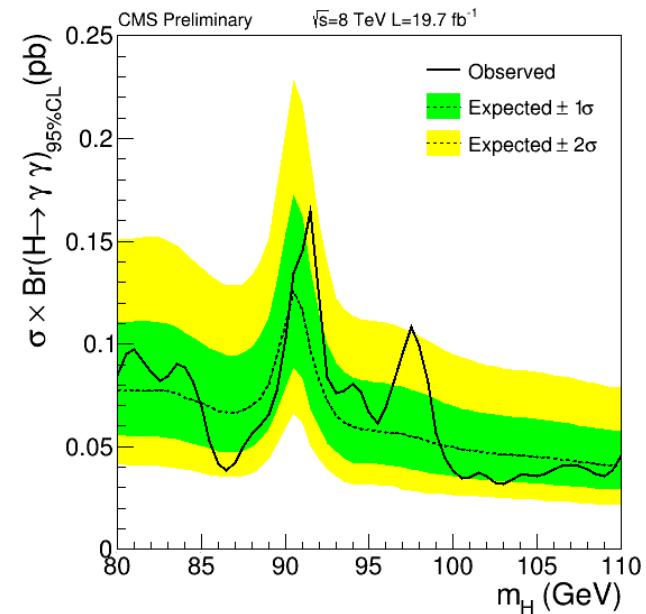
PRL 113 171801 (2014)



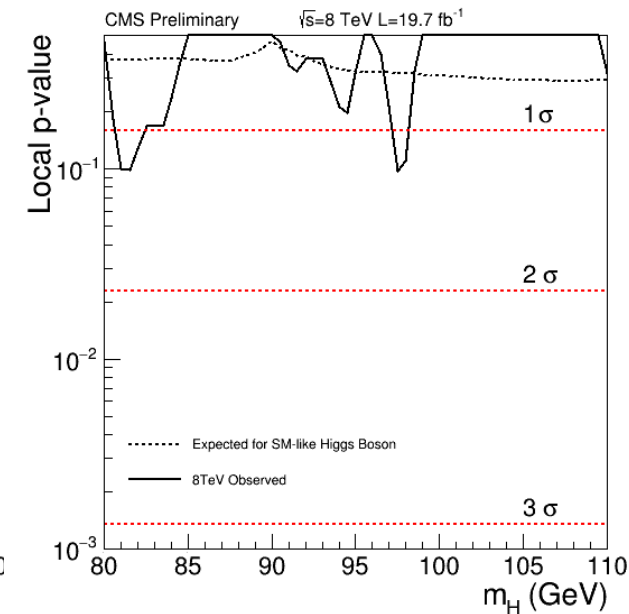
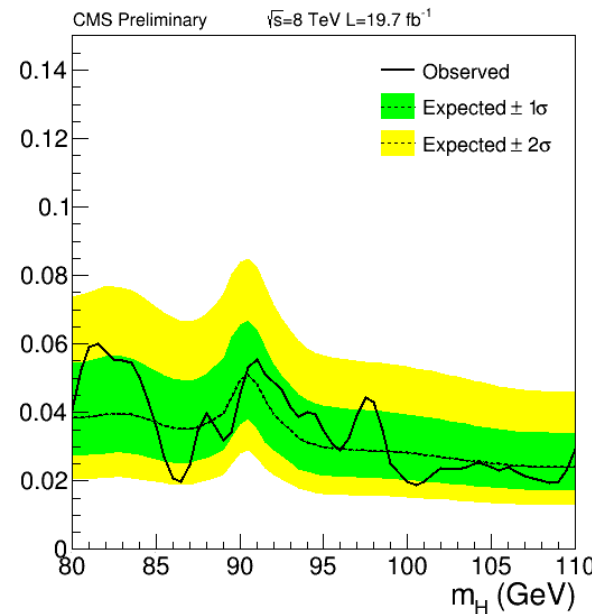
- Local p-values



$h \rightarrow \gamma\gamma$ Run 1: by production process



• Gluon fusion+ $tt\bar{t}h$



• VBF + VH

$h \rightarrow \gamma\gamma$: 2HDM Interpretation of CMS Run 1 results

arXiv:1607.08653,
 subm. JHEP

Work done with IPNL theorists: G. Cacciapaglia, A. Deandrea, S. Le Corre

Computation of the $\sigma \times BR_{h \rightarrow \gamma\gamma}$

- Branching ratios and widths:** computed with 2HDMC.

[Eriksson, Rathsmann, Stal; arXiv:0902.0851v2]

$$\kappa_g^2 = \frac{\Gamma_{ggh}^{2HDM}}{\Gamma_{ggh}^{SM}}, \quad \kappa_V^2 = \frac{\Gamma_{WW}^{2HDM}}{\Gamma_{WW}^{SM}} = \sin^2(\beta - \alpha)$$

2HDM	Type I	Type II	Flipped (Type Y)	Lepton Specific (Type X)
Up-type quark	ϕ_2	ϕ_2	ϕ_2	ϕ_2
Down-type quark	ϕ_2	ϕ_1	ϕ_1	ϕ_2
Leptons	ϕ_2	ϕ_1	ϕ_2	ϕ_1

- Cross sections:** computed with the “kappa trick”.

[Cacciapaglia, Deandrea, Drieu La Rochelle, Flament; arXiv:1311.5132v2]

$$\sigma_{ggh}^{2HDM} \simeq \kappa_g^2 \times \sigma_{ggh}^{SM}, \quad \sigma_{VBF+VH}^{2HDM} \simeq \kappa_V^2 \times \sigma_{VBF+VH}^{SM}$$

SM cross section taken from LHCHSWG [CERN-2013-004], [arXiv:1307.1347].

- Cross-checked with SusHi [Harlander, Liebler, Mantler; sushi.hepforge.org/manual/SusHi150.pdf] for gluon fusion mode, agreement at ~3% level

$h \rightarrow \gamma\gamma$ (65-110 GeV): 2HDM Interpretation of CMS Run 1 results

arXiv:1607.08653,
subm. JHEP

(Cacciapaglia, Deandrea, G-S, Le Corre, Lethuillier, Tao)

m_h (GeV)	m_H (GeV)	m_A (GeV)	m_{H^\pm} (GeV)	$\sin(\beta - \alpha)$	$\tan \beta$	m_{12}^2 (GeV) ²
[80;110]	125	[60;1000]	[80;1000]	[-1;1]	[1/50;50]	$[-(300)^2;+(200)^2]$

- Initial 1M-point scan, apply cumulative constraints:

- **Indirect constraints:**

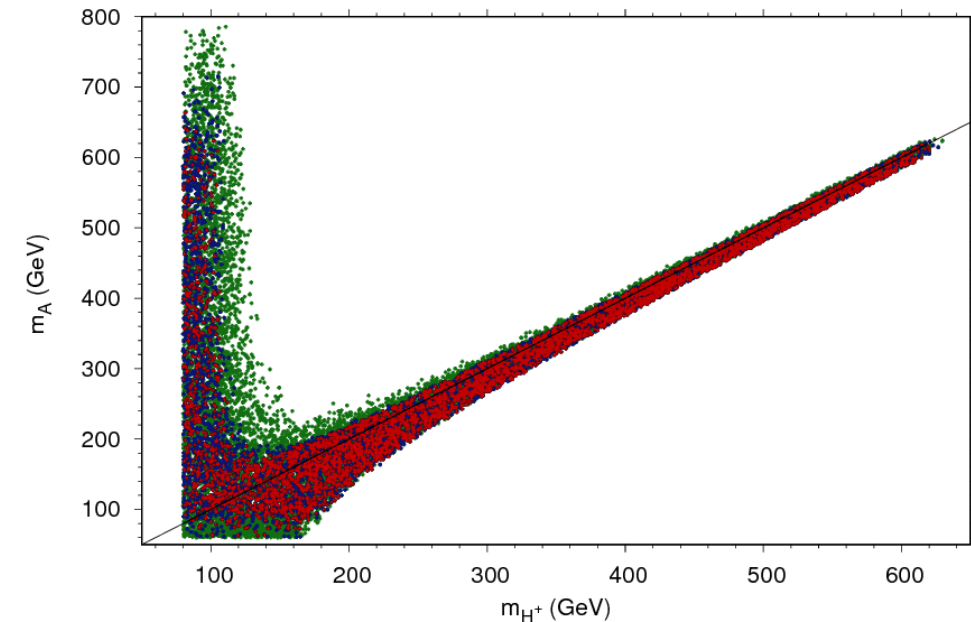
- Electroweak precision tests (S, T, U parameters);
- Stability, unitarity and perturbativity constraints;
- Flavor constraints ($B \rightarrow X_s \gamma$, $B_s \rightarrow \mu\mu$, $\Delta_0(B \rightarrow K^* \gamma)$, ΔMd)
(SuperIso [Mahmoudi, arXiv:0808.3144])

- **LEP constraints** (HiggsBounds [Bechtel et al., arXiv:0811.4169])
Including limits on scalar and pseudo-scalar Higgs bosons and light charged Higgs bosons

- **LHC constraints** on the 125 GeV Higgs boson (Run I Legacy combination).

[ATLAS-HIGG-2015-07; CMS-HIG-15-002], [arXiv:1606.02266]

m_A vs m_{H^\pm}



Type 1

$h \rightarrow \gamma\gamma$ (65-110 GeV): 2HDM Interpretation of CMS Run 1 results

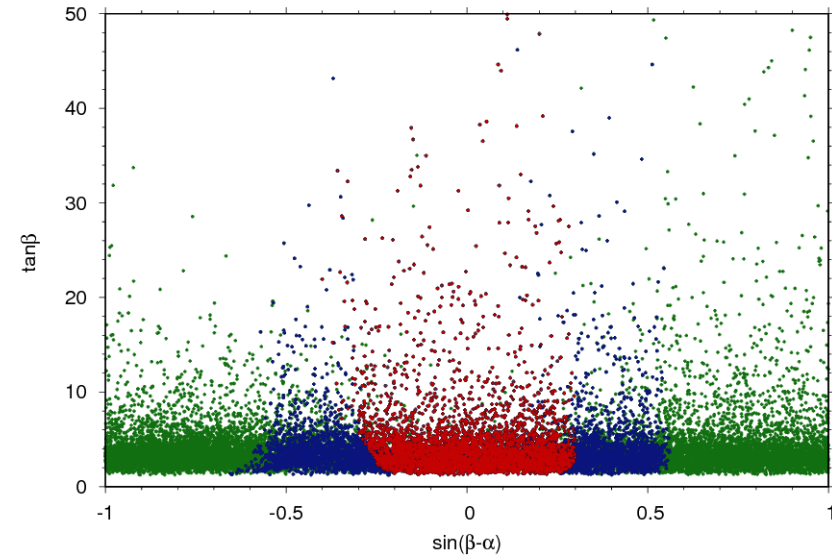
arXiv:1607.08653,
subm. JHEP

(Cacciapaglia, Deandrea, G-S, Le Corre, Lethuillier, Tao)

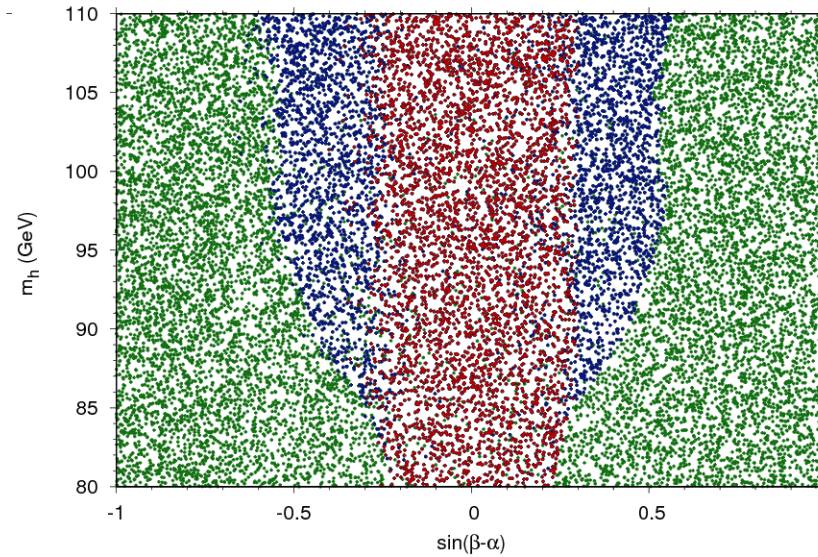
m_h (GeV)	m_H (GeV)	m_A (GeV)	m_{H^\pm} (GeV)	$\sin(\beta - \alpha)$	$\tan \beta$	m_{12}^2 (GeV) ²
[80;110]	125	[60;1000]	[80;1000]	[-1;1]	[1/50;50]	[-(300) ² ;+(200) ²]

- Initial 1M-point scan, apply cumulative constraints to refine ranges (shown: Type 1)

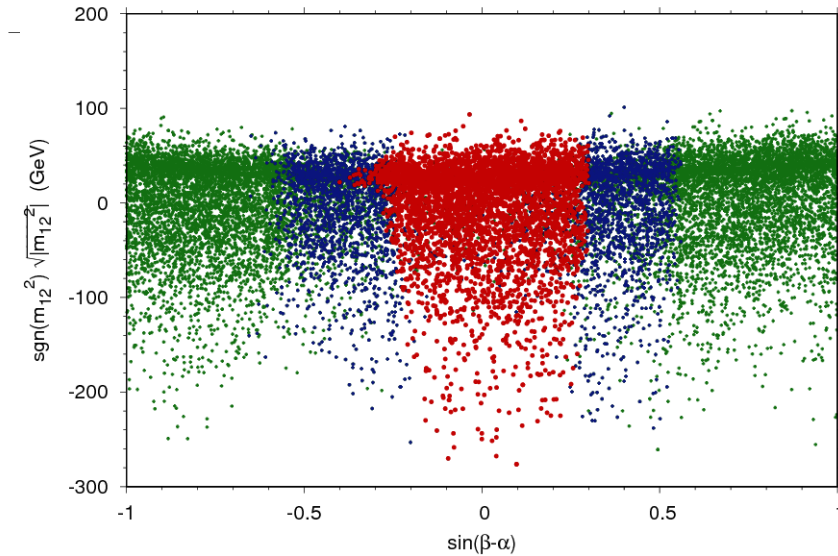
$\tan \beta$ vs $\sin(\beta - \alpha)$



m_h vs $\sin(\beta - \alpha)$



m_{12} vs $\sin(\beta - \alpha)$



$h \rightarrow \gamma\gamma$ (65-110 GeV): 2HDM Interpretation of CMS Run 1 results

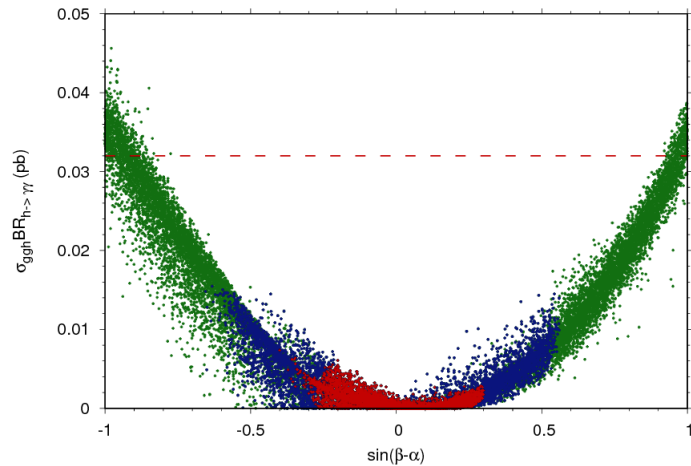
arXiv:1607.08653,
 subm. JHEP

(Cacciapaglia, Deandrea, G-S, Le Corre, Lethuillier, Tao)

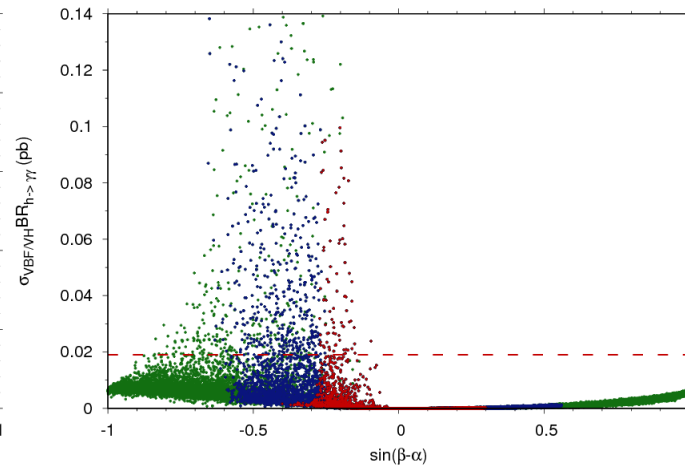
m_h (GeV)	m_H (GeV)	m_A (GeV)	m_{H^\pm} (GeV)	$\sin(\beta - \alpha)$	$\tan \beta$	m_{12}^2 (GeV) ²
[80;110]	125	[60;1000]	[80;1000]	[-1;1]	[1/50;50]	[-(300) ² ;+(200) ²]

- Initial 1M-point scan, apply cumulative constraints:

$\sigma \times BR_{h \rightarrow \gamma\gamma}$ vs $\sin(\beta - \alpha)$ (Type I)

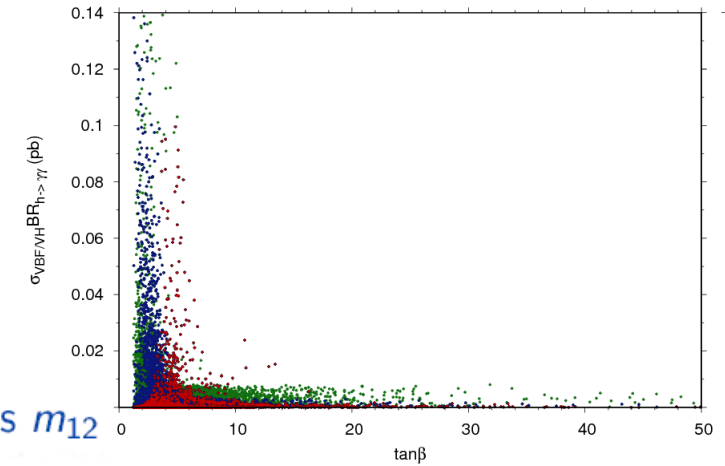


Gluon fusion

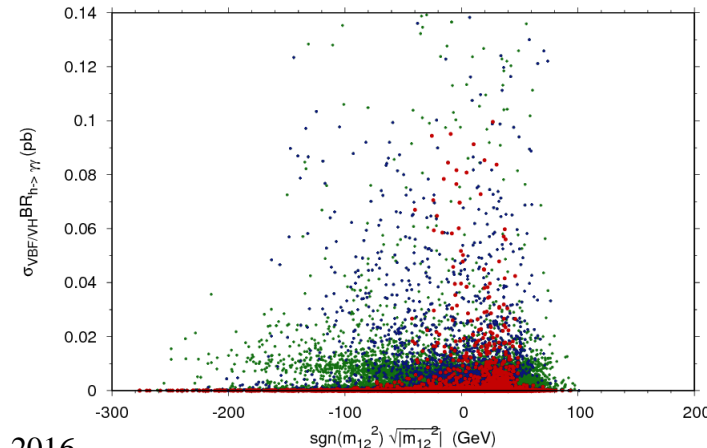


VBF+VH

$\sigma_{VBF/VH} \times BR_{h \rightarrow \gamma\gamma}$ vs $\tan \beta$



$\sigma_{VBF/VH} \times BR_{h \rightarrow \gamma\gamma}$ vs m_{12}



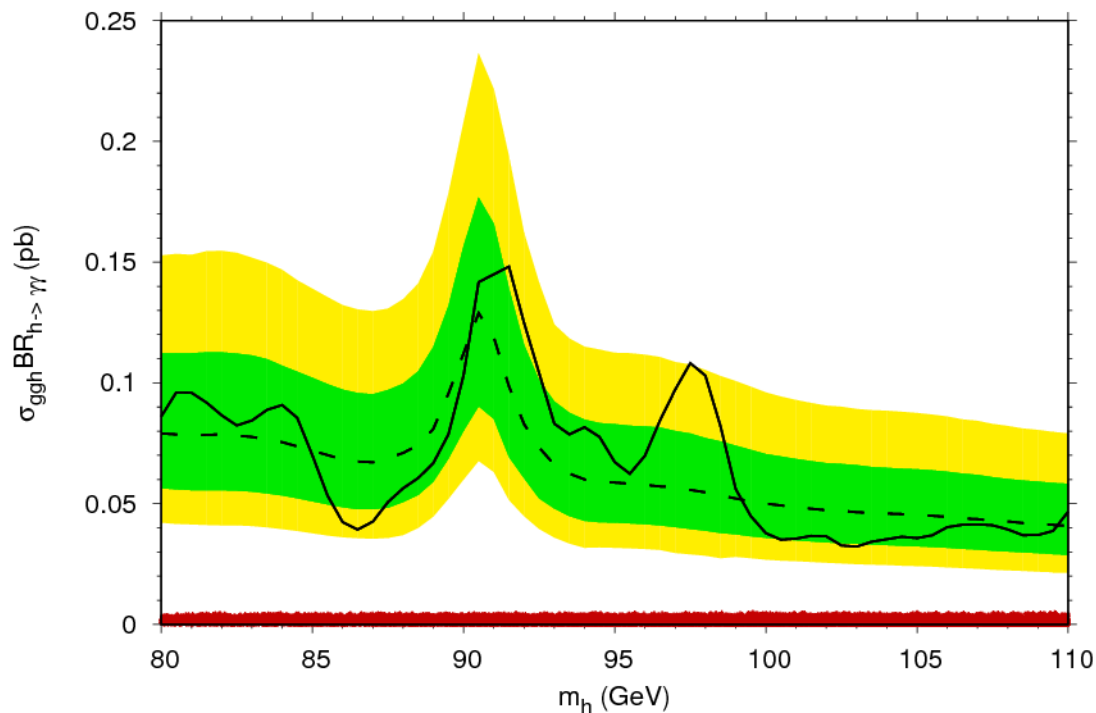
- Further refine ranges targeting points within 'shooting distance' of CMS maximal sensitivity (>0.01 pb)

$h \rightarrow \gamma\gamma$ (65-110 GeV): 2HDM Interpretation of CMS Run 1 results

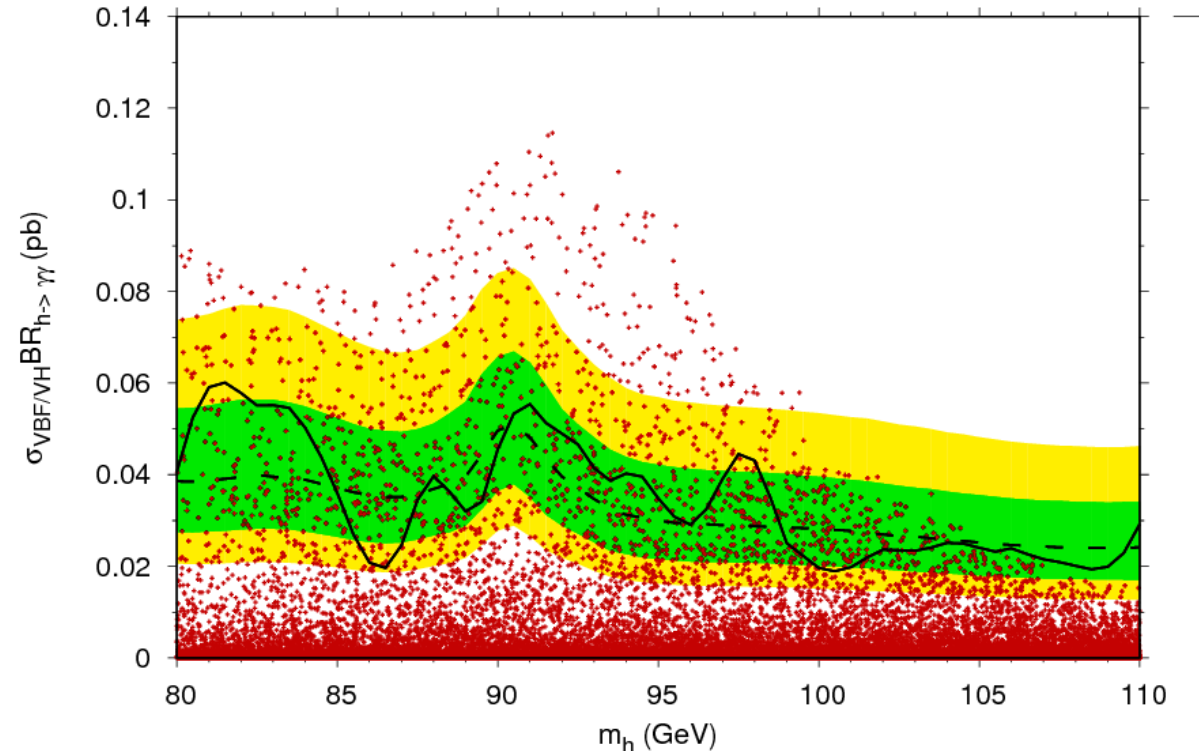
m_h (GeV)	m_H (GeV)	m_A (GeV)	m_{H^\pm} (GeV)	$\sin(\beta - \alpha)$	$\tan \beta$	m_{12}^2
[80;110]	125	[60;650]	[80;630]	[-0.3;-0.05]	[2;12]	$[-(100)^2;+(100)^2]$

arXiv:1607.08653,
 subm. JHEP

Table 8: Allowed range of variation for the free parameters.



Gluon fusion

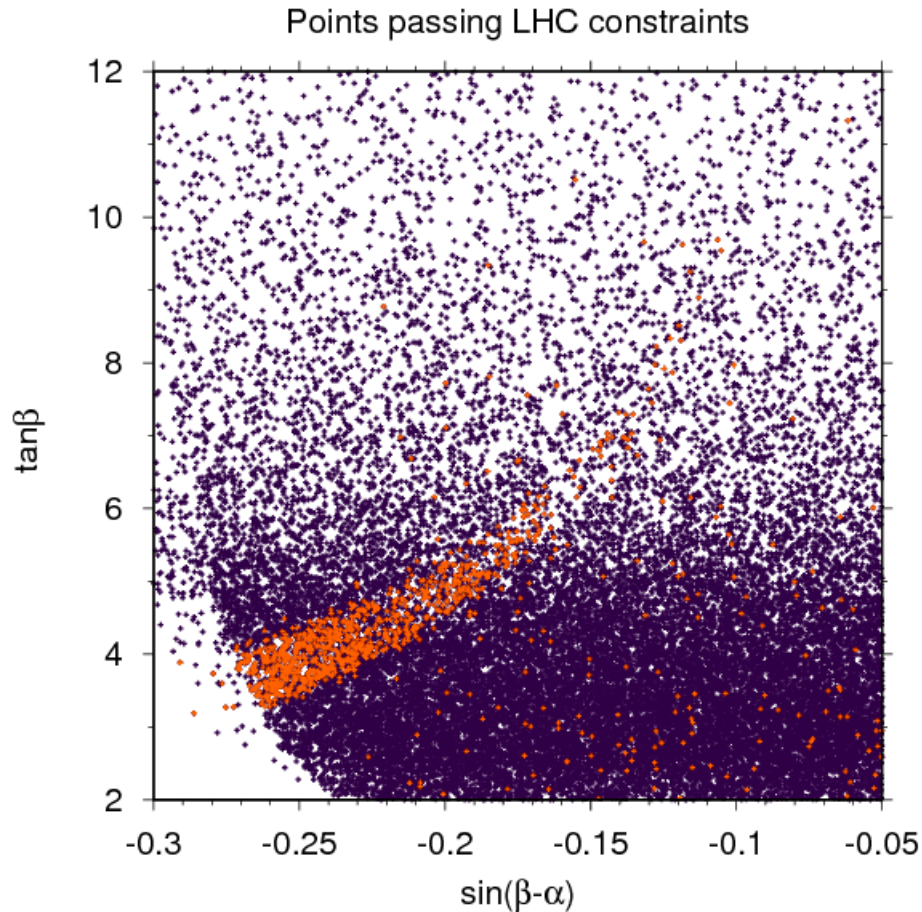


VBF+VH

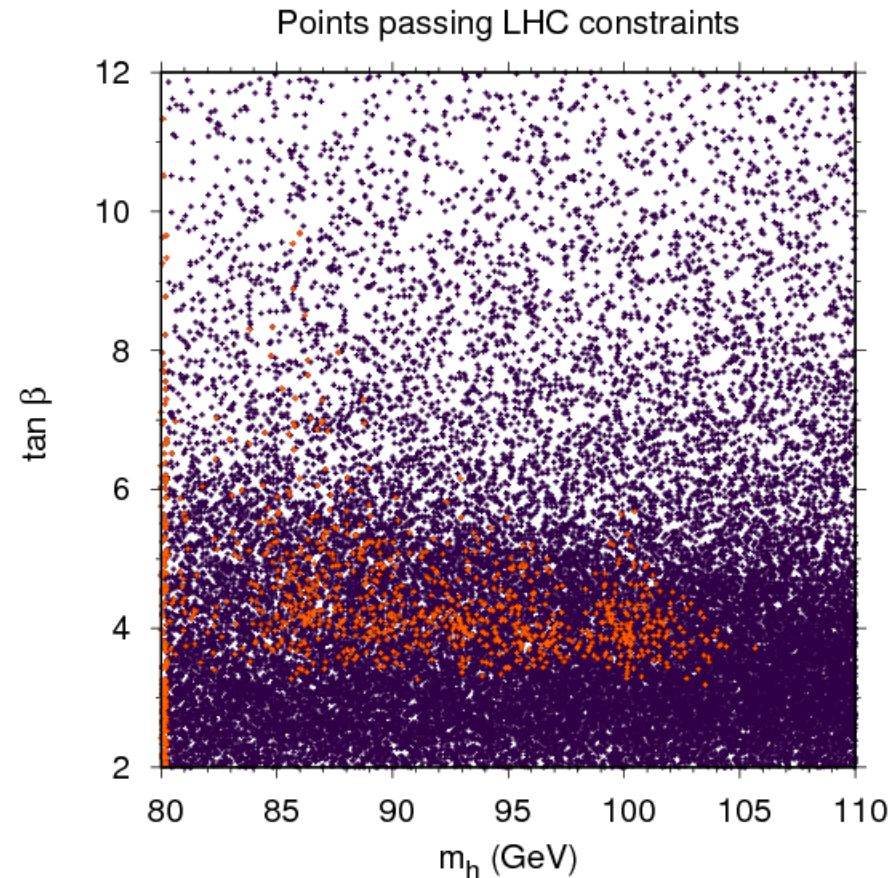
- Results of new 1M-point scan with new ranges: Some exclusion possible with VBF + VH, $m_h \sim < 105$ GeV

$h \rightarrow \gamma\gamma$ (65-110 GeV): 2HDM Interpretation of CMS Run 1 results

$\tan \beta$ vs $\sin(\beta - \alpha)$



$\tan \beta$ vs m_h



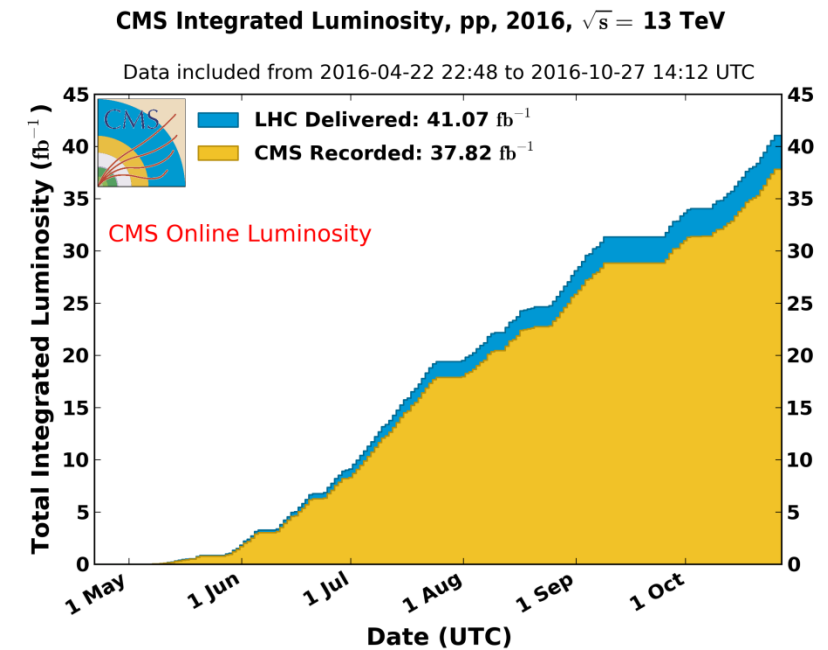
arXiv:1607.08653,
subm. JHEP

- Projections of **red** points on previous slide \rightarrow **orange** if $\sigma_{\text{XBR}} > \text{CMS observed limit}$ $\leftarrow \rightarrow$ excluded (**violet** otherwise) [but caveat...]



$h \rightarrow \gamma\gamma$ with $m_h < 110\text{GeV}$: Conclusions/Perspectives

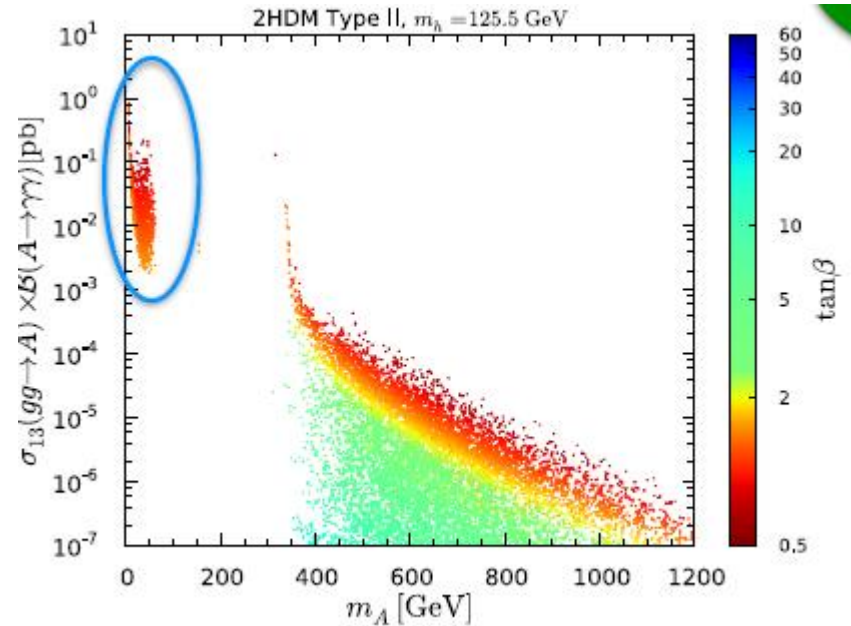
- Run 2: Analysis of 2015, 2016 data in progress ($>35\text{fb}^{-1}$) with new IPNL group members L. Finco and B. Marques
- New trigger paths have been developed to extend lower bound of search range below $m_{\gamma\gamma} < 80\text{ GeV}$
- We are very pleased to be able to start a collaboration with the SINP group (S. Bhattacharya, K. Mondal, A. Purohit, P. K. Rout) beginning with some crucial elements for the analysis (see Arnab's talk): Photon preselection + identification efficiency scale factors and associated systematics
- Later possibility: Fix rather than float normalization of relic $Z \rightarrow ee$ background for increased sensitivity near m_Z (requires detailed dielectron to diphoton fake rate study.)
- Another $\sim 45\text{fb}^{-1}$ hoped for 2017, $\sim 100\text{fb}^{-1}$ by end Run 2



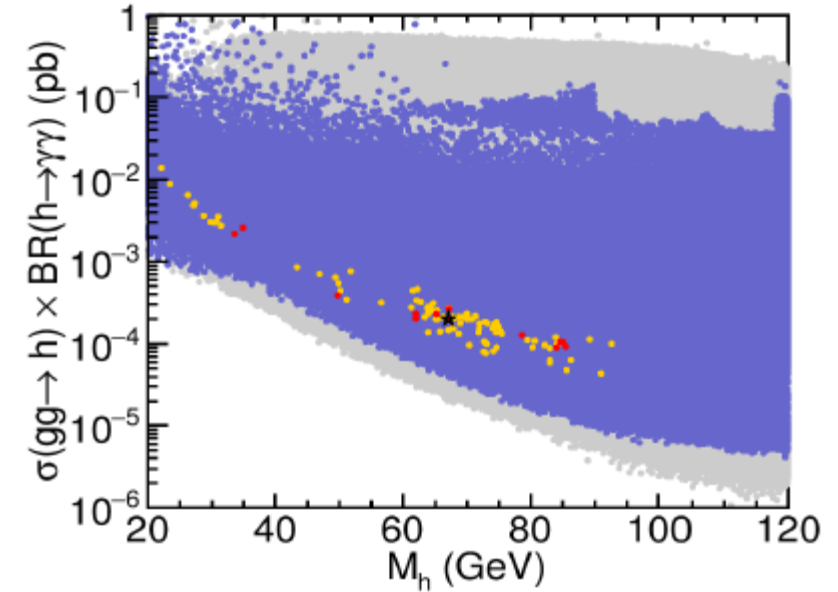
$h \rightarrow \gamma\gamma$ with $m_h < 110\text{ GeV}$: Perspectives on interpretations

- Continuation with interpretations as h_1 in NMSSM and 2HDM on future Run 2 results (already some exclusion in Run 1)
- Interpretations as pseudoscalar a ($\sim 50\text{ GeV} < m_a < 100\text{ GeV}$)
 - NMSSM A_1 (M. Guchait, J. Kumar 1608.05693, see Jacky's talk earlier)
 - S. Bhattacharya et al.
 - 2HDM Type II in $gg \rightarrow H, A \rightarrow \gamma\gamma$ in alignment limit (J. Bernon, J. Gunion, H. Haber, Y. Jiang, S. Kraml)

arXiv:1507.00933



(Bechtle, Haber, Heinemeyer, Stal, Stefaniak, Weiglein, Zeune)



arXiv:1608.00638

- Interpretations as h in MSSM still possible (Bechtle et al, 1608.00638)

Introduction/Motivation: Is there a second Higgs boson with $m < 125$ GeV?

- The LHC Standard Model $H \rightarrow gg$ discovery analyses explored a mass range between 110 and 150 GeV

- Several models like the NMSSM or in general Two-Higgs-Doublet-Models (2HDM) postulate the existence of additional light Higgs bosons and even admit the possibility that the observed $H(125)$ is only the next-to-lightest

- Subject of this talk: **CMS** searches during **LHC Run 1** for additional scalars/pseudoscalars with $m < 110$ GeV, in the diphoton decay channel by definition in a BSM context.

- Perspectives for Run 2 and interpretations

- Final LEP SM Higgs boson search results: $>2\sigma$ excess at $m_H = 98$ GeV. Has contributed to sustained interest by both theorists and experimentalists in the possibility of additional low-mass (pseudo-) scalars

LEPHWG, Phys. Lett. B565:61-75,2003

