ATLAS-CMS selected Higgs results and Run-II perspective

Camilo Carrillo

on behalf of the CMS and ATLAS collaborations

8th France China Particle Physics Laboratory (FCPPL) Workshop

Institute de physique Nuclear de Lyon (IPNL)

08/04/2015

Table of contents

The Large Hadron Collider Run-I, pp collisions at $\sqrt{s}$ = 7 TeV and 8 TeV


- LHC excellent performance in 2011 and 2012
- $\int L\,dt \approx 25\,fb^{-1}$ at $\sqrt{s}$ = 7 and 8 TeV
- Peak Instant Luminosity: L = 7.7 $\times$ 10^{-33} cm^{-2}s^{-1}
- World record in energy and instantaneous luminosity
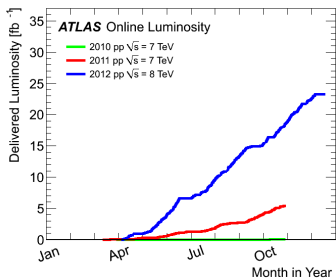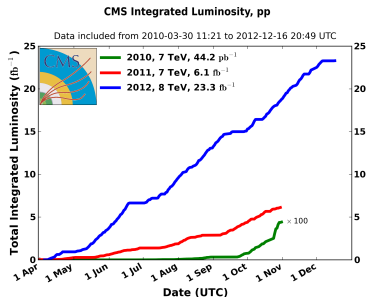
ATLAS-CMS

- Big collaborations ($\approx$4000/experiment)
- Multi purpose experiments
- LHC data efficiency recording (used for analysis) > 90% during Run-I.
- Robust Muon systems and $e\gamma$-calorimeters (crystals(CMS) and liquid argon(ATLAS)).
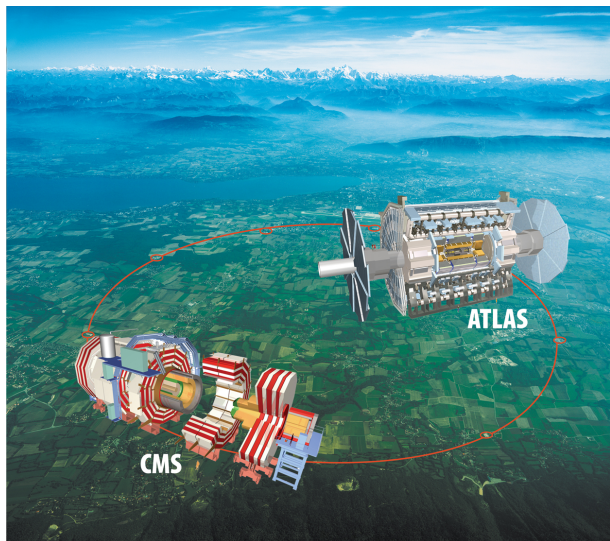
## Multiple collisions per bunch crossing, a challenge for the experiments

- Due to the increase in luminosity, more than one collision happen during a bunch-crossing in the LHC, this is called pile up (PU).

- 2011 average PU $\approx$ **10**, for 2012 average PU $\approx$ **20**.

- Particle flow algorithm helps a lot in high PU events.

- Less energy resolution for e and γ

- Central jet veto and VBF jet tagging affected.

- **For LHC Run-II at $\sqrt{s} = 13\,TeV$ are expected PU $\approx$ 40**

- Experiments request to LHC PU<50.
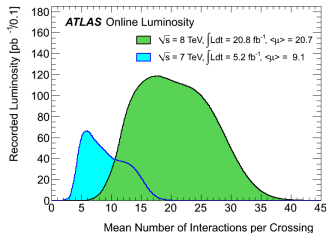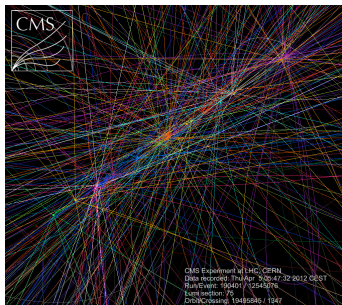
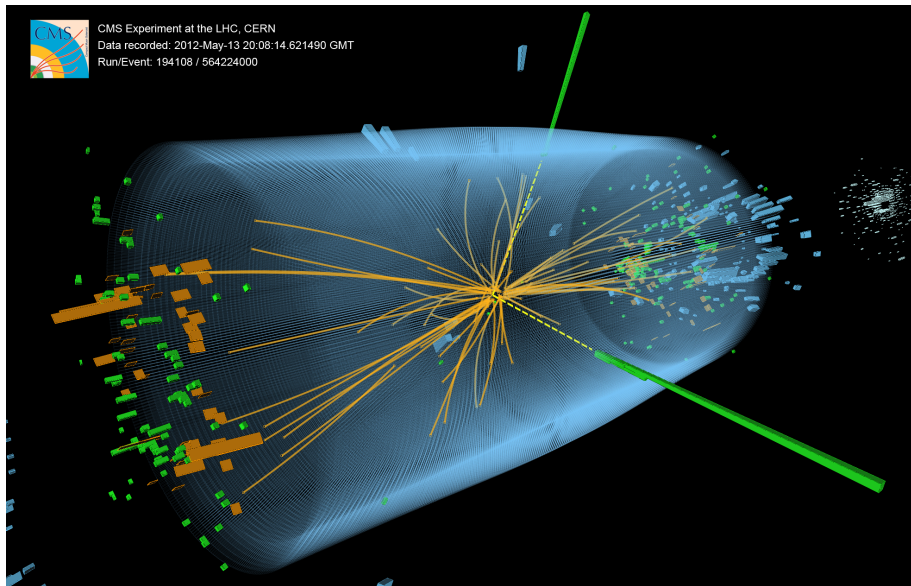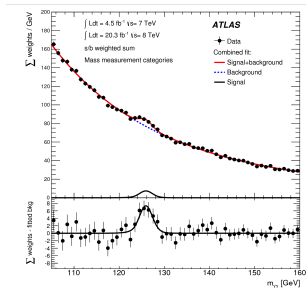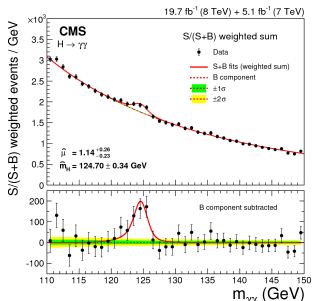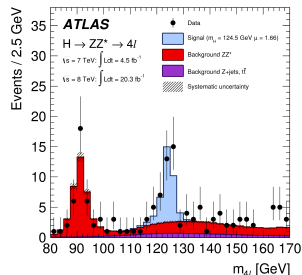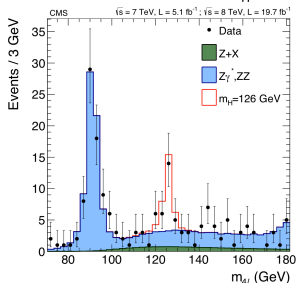# Selected Higgs results (Run-I) Standard Model

Higgs production modes
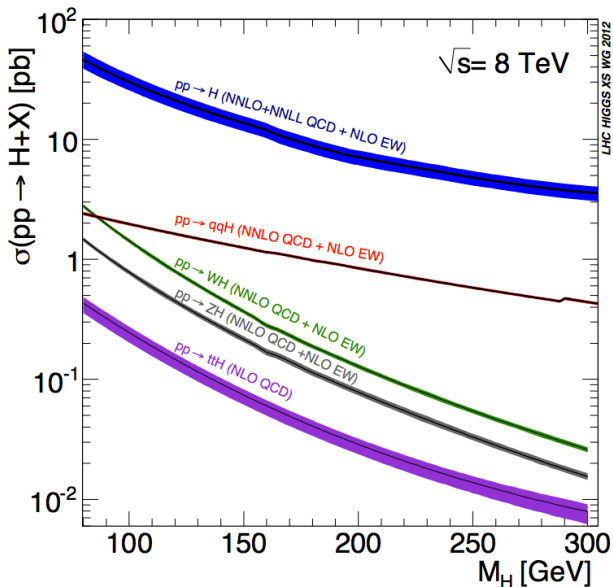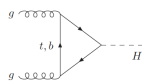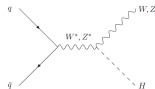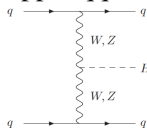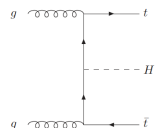
Higgs Decays, branching ratios
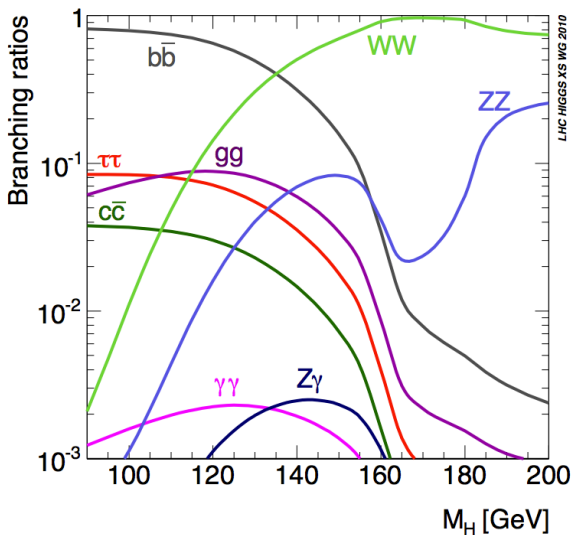
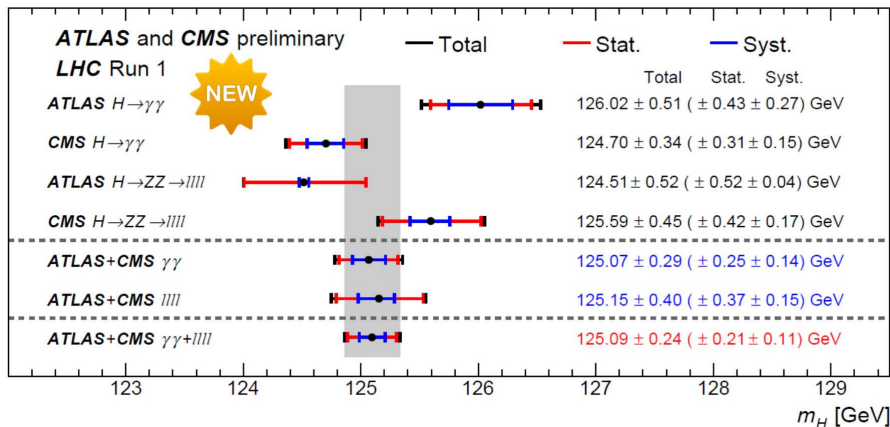# An event display, $m_{\gamma\gamma} = 125.9\,GeV$

Higgs Mass combination CMS-ATLAS, $m_H = 125.09 \pm 0.24$ GeV

$H \to \gamma\gamma$

$H \to ZZ \to 4l$

A detailed view for the mass measurements

ATLAS and CMS preliminary
LHC Run 1

	Total	Stat.	Syst.
ATLAS $H \to \gamma\gamma$	126.02 ± 0.51	$(\pm 0.43$	$\pm 0.27)$ GeV
CMS $H \to \gamma\gamma$	124.70 ± 0.34	$(\pm 0.31$	$\pm 0.15)$ GeV
ATLAS $H \to ZZ \to llll$	124.51 ± 0.52	$(\pm 0.52$	$\pm 0.04)$ GeV
CMS $H \to ZZ \to llll$	125.59 ± 0.45	$(\pm 0.42$	$\pm 0.17)$ GeV
ATLAS+CMS $\gamma\gamma$	125.07 ± 0.29	$(\pm 0.25$	$\pm 0.14)$ GeV
ATLAS+CMS $llll$	125.15 ± 0.40	$(\pm 0.37$	$\pm 0.15)$ GeV
ATLAS+CMS $\gamma\gamma + llll$	125.09 ± 0.24	$(\pm 0.21$	$\pm 0.11)$ GeV

— Total   — Stat.   — Syst.

m_H [GeV]

Tension in the experiments measurements. Not in-between experiments

Analysis Overview

|	H→γγ	H→ZZ	H→WW	H→ττ	H→bb	H→Zγ	H→μμ
gg→H	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS		ATLAS CMS	ATLAS CMS
VBF	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS		ATLAS CMS	ATLAS CMS
VH	ATLAS CMS	ATLAS CMS	ATLAS CMS	- CMS	ATLAS CMS	ATLAS CMS	- CMS
ttH	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS		

A

comprehensive coverage of all Higgs/SM physics cases

Higgs Signal Strength

Signal Strength decay
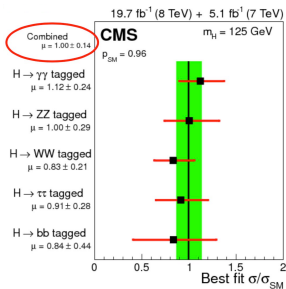
Signal Strength production
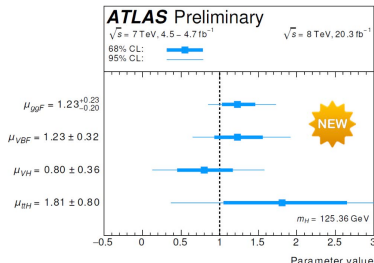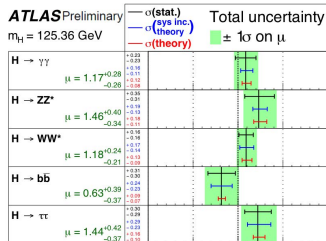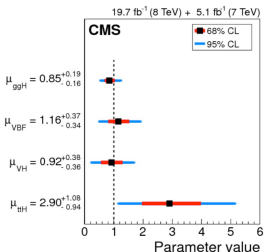
Selected Higgs results (Run-I) Beyond Standard Model

Search for additional Higgs Beyond the Standard Model (2HDM)

- The addition of doublet in the Higgs sector is one of the simplest possible extensions
- 2HDMs and the MSSM are fully compatible with a SM-like Higgs boson with mass $\approx$125 GeV

- 5 Higgs bosons

CP-even Higgses (*)   CP-odd Higgs (*)   Charged (*)
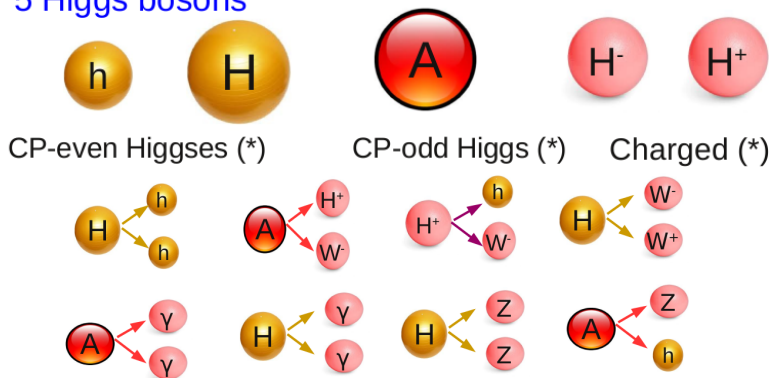
Search for additional Higgs Beyond the Standard Model

Direct Searches for additional Higgs Bosons: $H \to hh, H/A \to \tau\tau, A \to Zh$ and low mass Higgs.

In 2HDM models:

- 5 Higgs Bosons:
  - h - SM like Higgs Boson
  - H - CP even
  - A - CP odd
  - H$^{\pm}$ - Charged

- Free parameters:
  - 4 Higgs masses
  - tan β – ratio of vevs
  - α – mixing angle of h and H

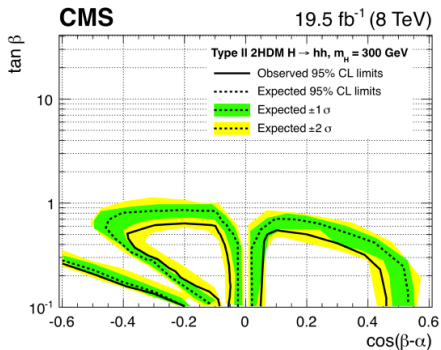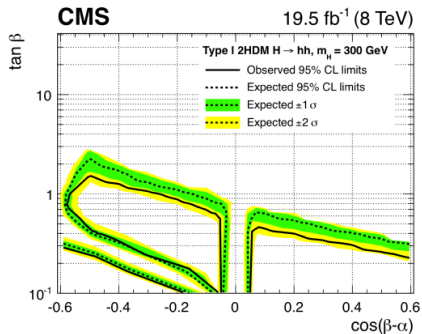- Yukawa couplings arranged in 4 different model 'types'
  - MSSM is based on a Type II
  - Alignment limit cos(β-α)=0 : h has SM couplings

H Coupling scale factor: 2HDM/SM

	Type I	Type II	Lepton Specific	Flipped
κ_V	sin(β-α)	sin(β-α)	sin(β-α)	sin(β-α)
κ_u	cos(α)/sin(β)	cos(α)/sin(β)	cos(α)/sin(β)	cos(α)/sin(β)
κ_d	cos(α)/sin(β)	-sin(α)/cos(β)	cos(α)/sin(β)	-sin(α)/cos(β)
κ_l	cos(α)/sin(β)	-sin(α)/cos(β)	-sin(α)/cos(β)	cos(α)/sin(β)

$H \rightarrow hh$

- Look at multi-lepton (h→WW,ZZ,ττ)+h→γγ final states

- Best direct limit on H at low tan β and low mass
- High tan β covered by H→ττ
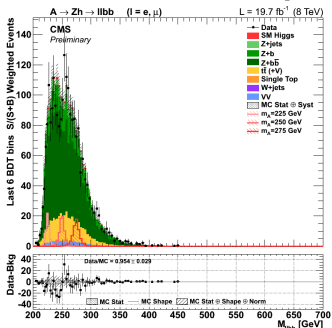- Searches with decays h→bb also being persued (ATLAS+CMS)

$H/A \to \tau\tau$
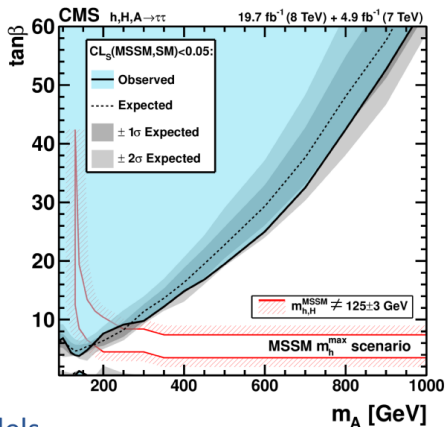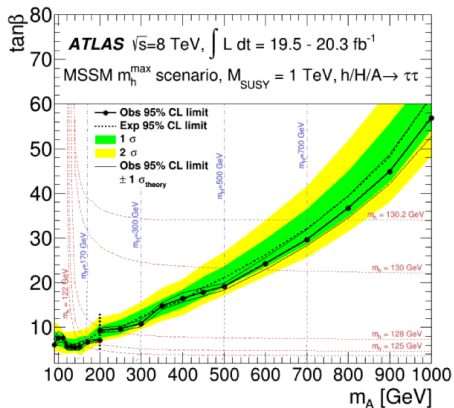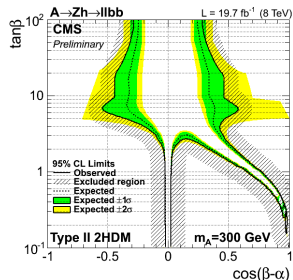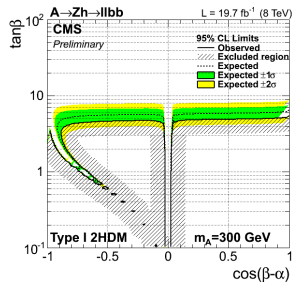

- Analysed in MSSM (type II) models
- Best exclusion at high tan β up to large masses

$A \to Z\,h$ (CMS)

- Analyzed with decays:
  $h \to bb$, $h \to ZZ$ and $h \to WW$
- Very good mass resolution
- Best limits at $m_A < 2m_{top}$ and low $\tan\beta$

Example $h \to bb$
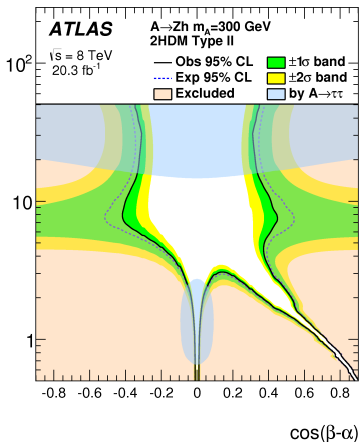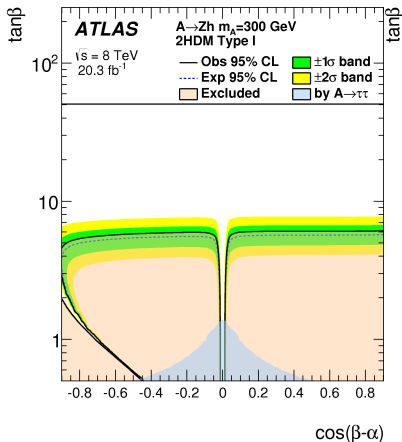
$A \rightarrow Z\,h$ (**ATLAS**)

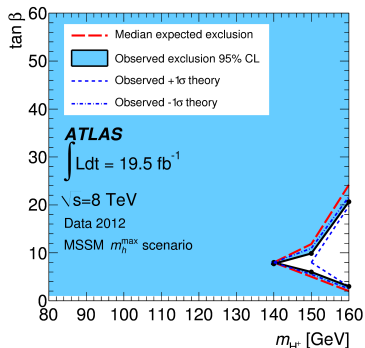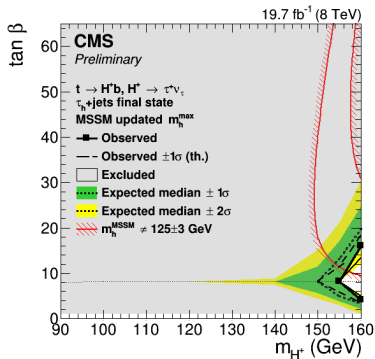*Zh* analyzed in:

- $Z \rightarrow (ee, \mu\mu)$ and $h \rightarrow \tau\tau$ / $Z \rightarrow (ee, \mu\mu, \nu\nu)$ and $h \rightarrow bb$
- All τ decays considered for both decays

$H^{\pm}$: (m_{H^+} < m_{top})

- Production: $gg \to tbH^{\pm}$, $gb \to tH^{\pm}$, $gg \to tt \to WbH^{\pm}b$: ($m_{H^{\pm}} < m_t$)
- Decays: $H^{\pm} \to \tau^{\pm}\nu$ (ATLAS/CMS) and $H^{\pm} \to cs$ / $H^{\pm} \to tb$ (CMS)
- All τ decays considered for both decays

$H^{\pm}$: $(m_{H^{\pm}} > m_{top})$
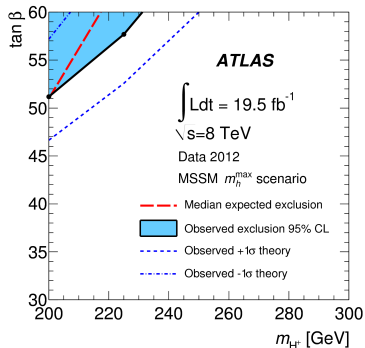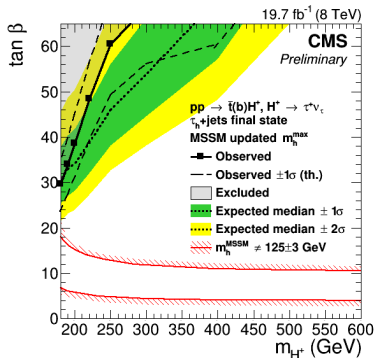
- Search in $tH^{\pm}$ or $btH^{\pm}$ mode
- Little phase space covered so far: Lots of room for discovers during LHC-Run-II

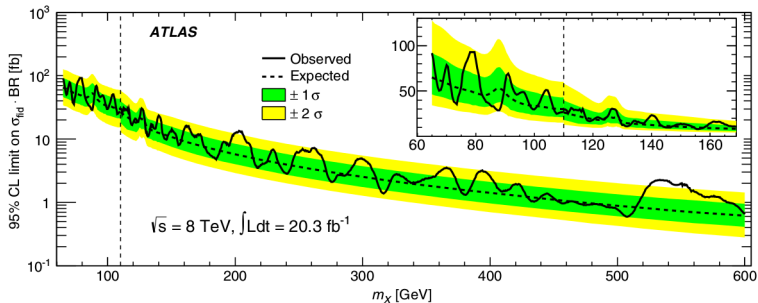## Low mass Higgs in $\gamma\gamma$ resonances

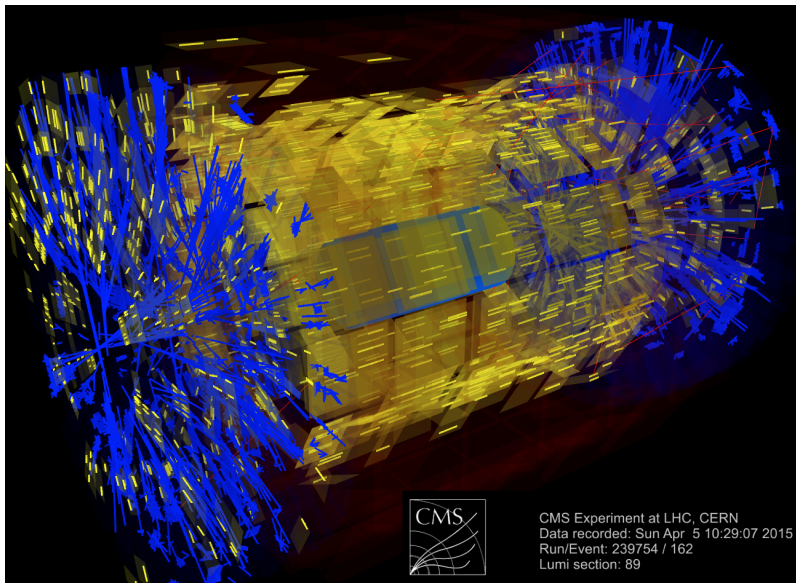Additional Higgs at a lower mass (down to $m_H = 60$ GeV)

- Few words about this search in this presentation.
- Presentation about Run-I $\approx$ Fan Jiawei (IPNL/IHEP) today.
- For Run-II, a High Level Trigger selections are being implemented in CMS to extend our search during run-II.

ATLAS results:
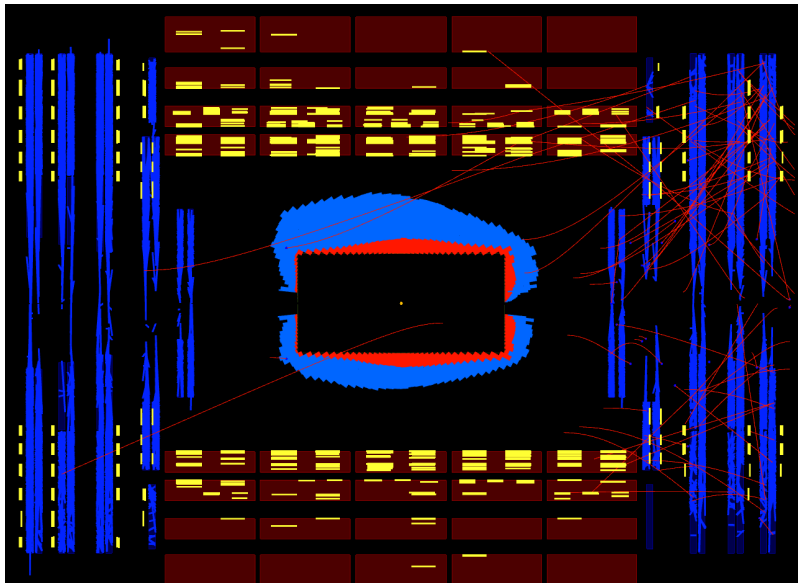
Higgs Perspectives for Run-II
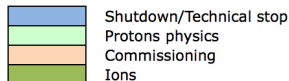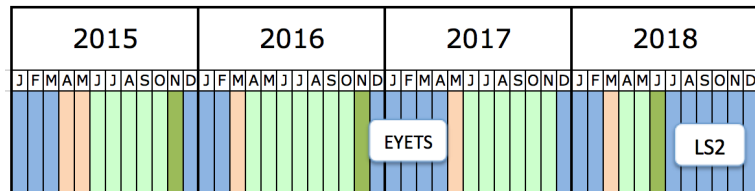
LHC Run-II is imminent, last Sunday (source BBC)

CMS Experiment at LHC, CERN
Data recorded: Sun Apr 5 10:29:07 2015
Run/Event: 239754 / 162
Lumi section: 89

LHC Run-II is imminent, LHC is back, last Sunday

# Expected Integrated luminosity for run-II 2015 $\approx$ 10 fb^{-1}

- Conservative β^* to start
- Conservative bunch population
- Assuming same machine availability as 2012

	Nc	Beta*	ppb	EmitN	Lumi [cm^{-2}s^{-1}]	Days (approx)	Int lumi	Pileup
50 ns	1300	80	1.2e11	2.5	4.8e33	21	~1 fb^{-1}	25
2015.1	2592	80	1.1e11	2.5	7.6e33	30	3 fb^{-1}	21
2015.2	2592	40	1.1e11	2.5	1.2e34	48	8 fb^{-1}	34

2015	2016	2017	2018
J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D

EYETS

LS2

- Shutdown/Technical stop
- Protons physics
- Commissioning
- Ions

A little bit further into the future

ATLAS Simulation Preliminary

$\sqrt{s}$ = 14 TeV: $\int$Ldt=300 fb^{-1} ; $\int$Ldt=3000 fb^{-1}
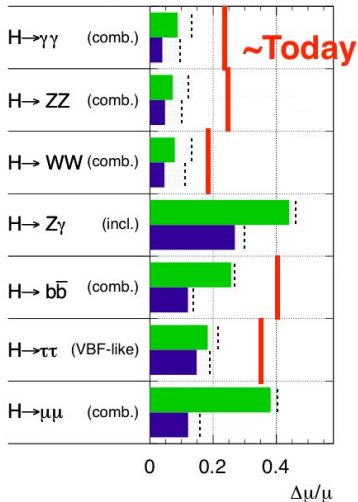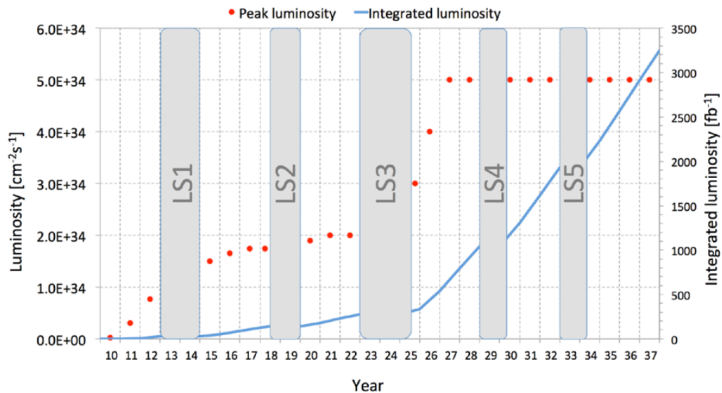

- This could be the window to new physics.
- Reducing $\dfrac{\Delta\mu}{\mu}$ could show as a deviations from the SM

Run-II year by year ($\approx 100fb^{-1}$)

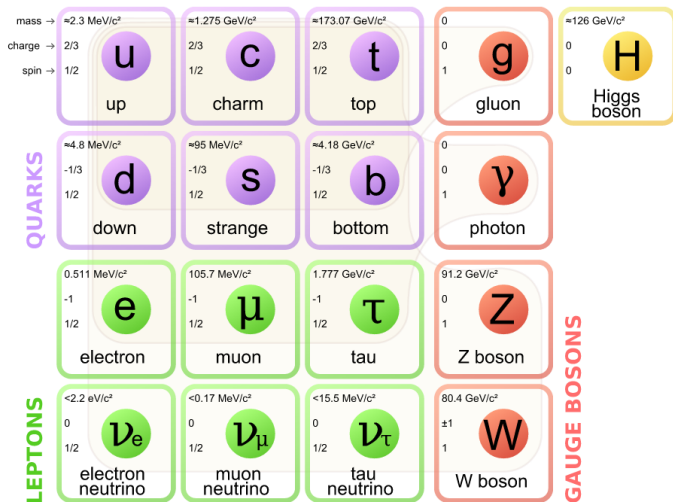|	Peak lumi E34 cm^{-2}s^{-1}	Days proton physics	Approx. int lumi [fb^{-1}]
2015	1.3	100	10
2016	1.5	160	35
2017	1.7	160	45
2018	1.7	40	10

Perspective for the LHC during the next 10 years

- Run-I center of mass energy is just $\approx \frac{1}{2}$ of the designed for the LHC
- Run-I is a small portion of the expected integrated luminosity for the life-time of the LHC.
- Nevertheless we have a discovery!

Conclusions

| mass →	≈2.3 MeV/c²	≈1.275 GeV/c²	≈173.07 GeV/c²	0	≈126 GeV/c²
charge →	2/3	2/3	2/3	0	0
spin →	1/2 **u**	1/2 **c**	1/2 **t**	1 **g**	0 **H**
	up	charm	top	gluon	Higgs boson

The Standard Model "free-parameters" are now known!

Conclusions

- Combined ATLAS+CMS measurement of the Higgs boson mass: **m_H = 125.09 $\pm$ 0.24GeV**
- Combinations of Run 1 measurements in each experiment have been done for a majority of results
- Combination of ATLAS+CMS Higgs coupling strength in preparation
- Extensive search for deviations from the SM prediction in:
  - Higgs production kinematics
  - WW and ZZ Higgs decay kinematics
  - Signal strength in all categories of all observable final states and Higgs coupling strength
- Extensive BSM searches have been made in ATLAS and CMS
- Searches for CP even(H),odd(A) and charged $H^{\pm}$ Higgs in a variety of decay modes
- All results show consistency within errors with the Standard Model Hypothesis
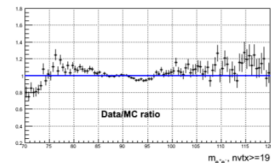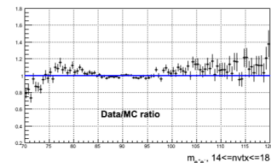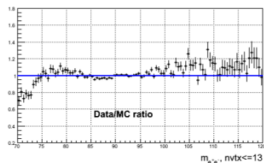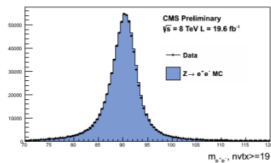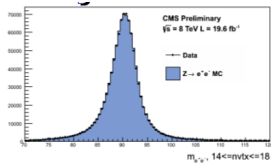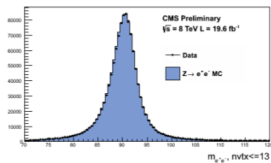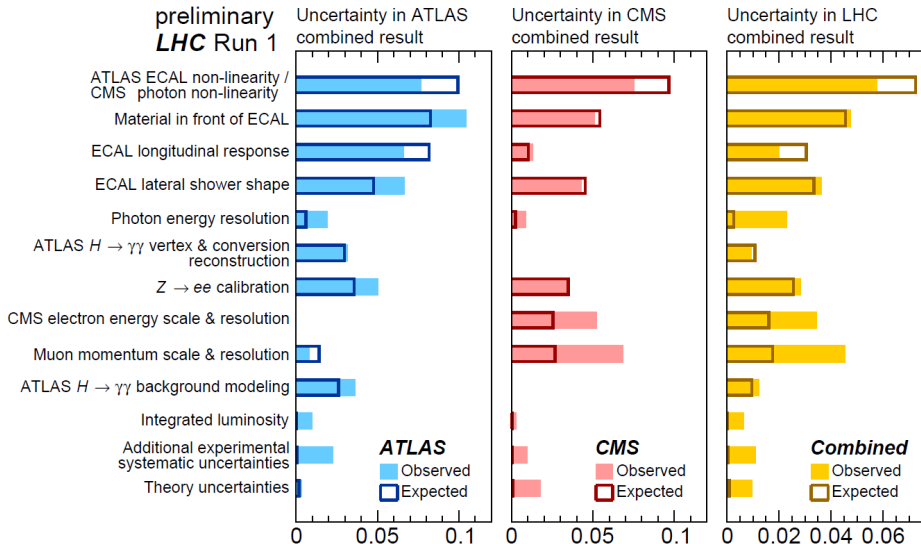- Looking forward for Run-II

Backup

BACKUP
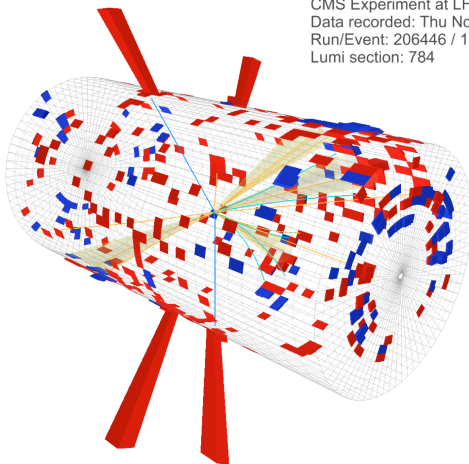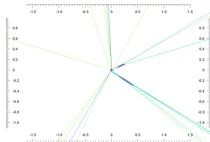
Lepton momentum scale
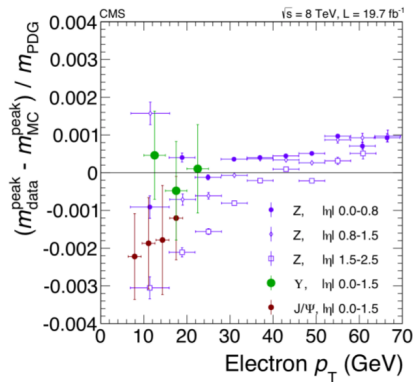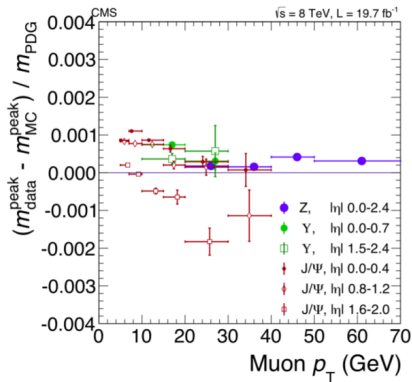
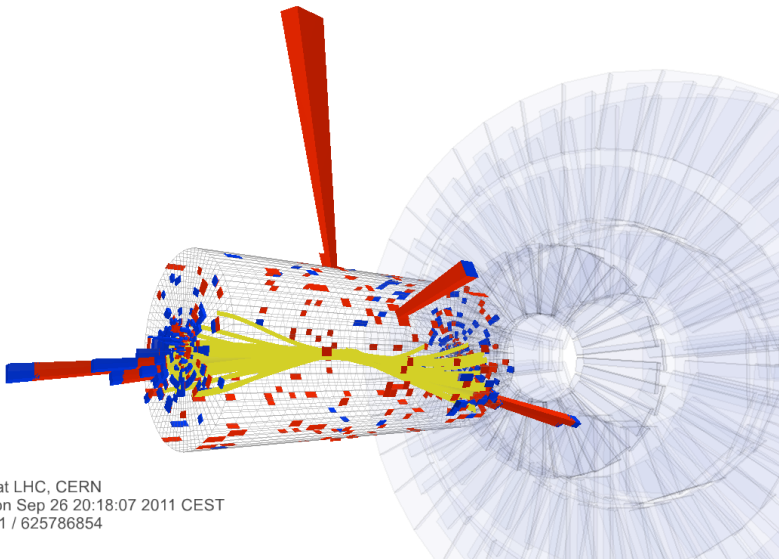# e γ energy reconstruction stability

systematics $\gamma\gamma$

ATLAS and *CMS* preliminary LHC Run 1

event display tth

CMS Experiment at LHC, CERN
Data recorded: Thu Nov 1 02:13:01 2012 CEST
Run/Event: 206446 / 1072391444
Lumi section: 784

event display vbf

CMS Experiment at LHC, CERN
Data recorded: Mon Sep 26 20:18:07 2011 CEST
Run/Event: 177201 / 625786854
Lumi section: 450