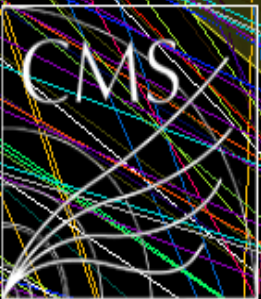


A large, circular visualization of particle tracks dominates the center of the slide. The tracks are represented by numerous thin, multi-colored lines (including red, green, blue, yellow, and purple) that radiate from a central point and curve outwards, creating a complex, web-like pattern. The tracks are set against a dark background and are enclosed within a thin green circular border. A red line with small square markers extends from the top and left edges towards the center of the tracks.

Status of the CMS SM Higgs Search

*Joe Incandela
UCSB/CERN
July 4, 2012*

CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35438125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295



Event
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35438125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295

Status of the CMS SM Higgs Search

*Raw $\Sigma E_T \sim 2$ TeV
14 jets with $E_T > 40$
Estimated PU ~ 50*

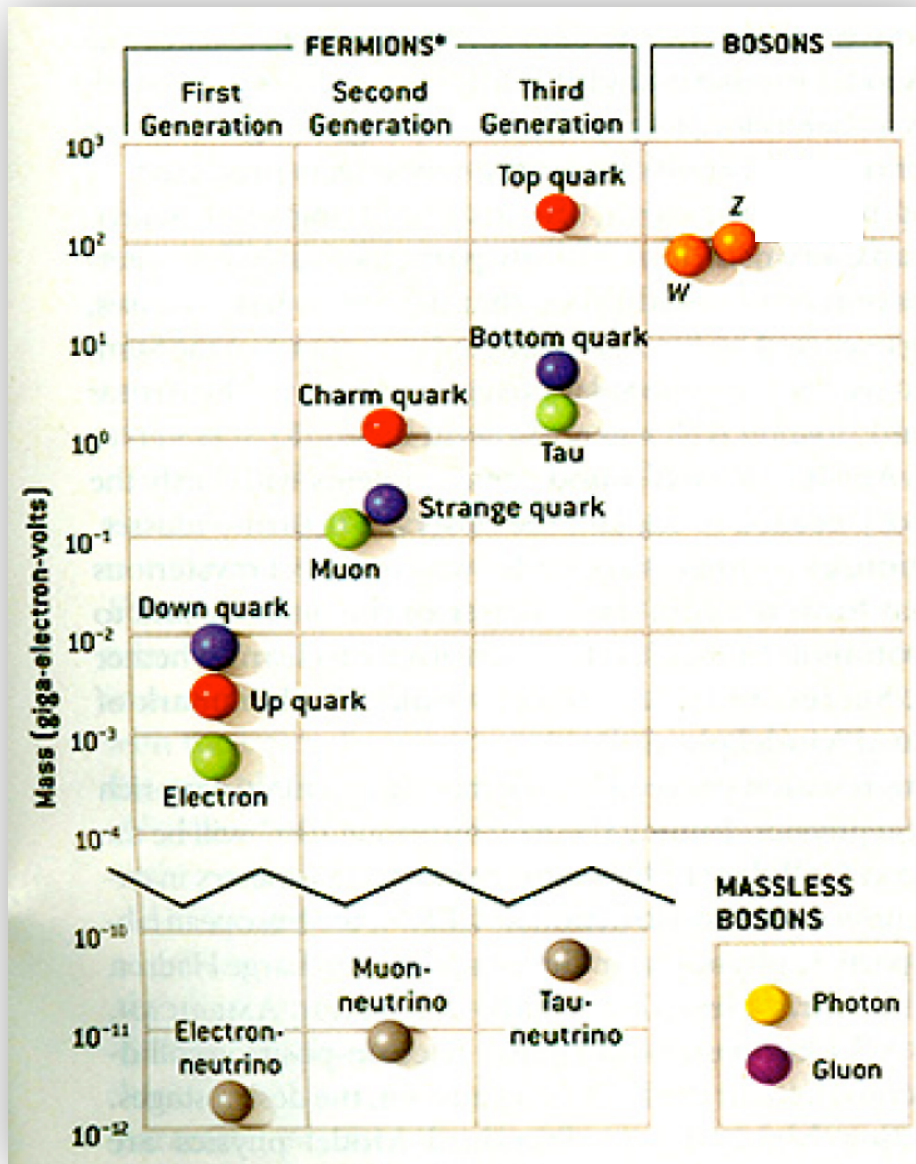
*Joe Incandela
UCSB/CERN
July 4, 2012*



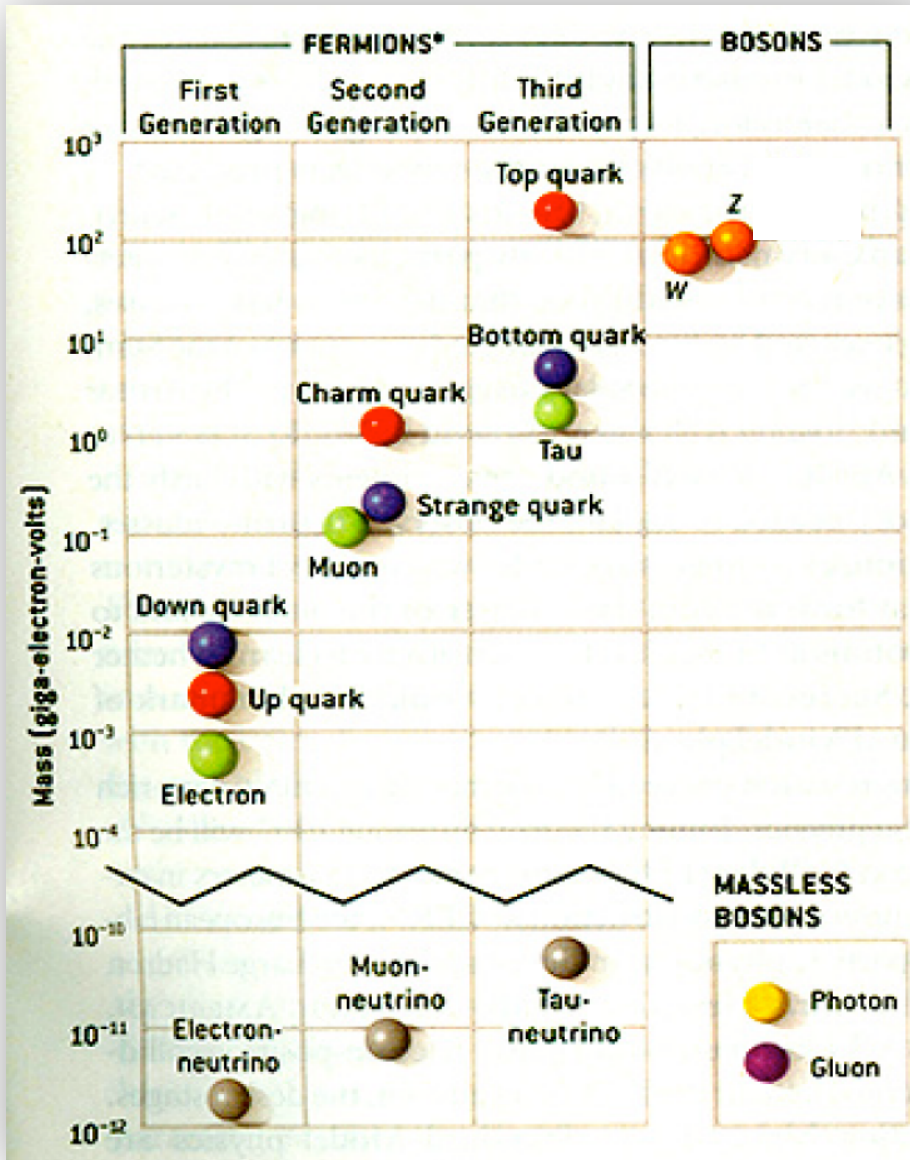
On behalf of the CMS Collaboration



The Standard Model



The Standard Model



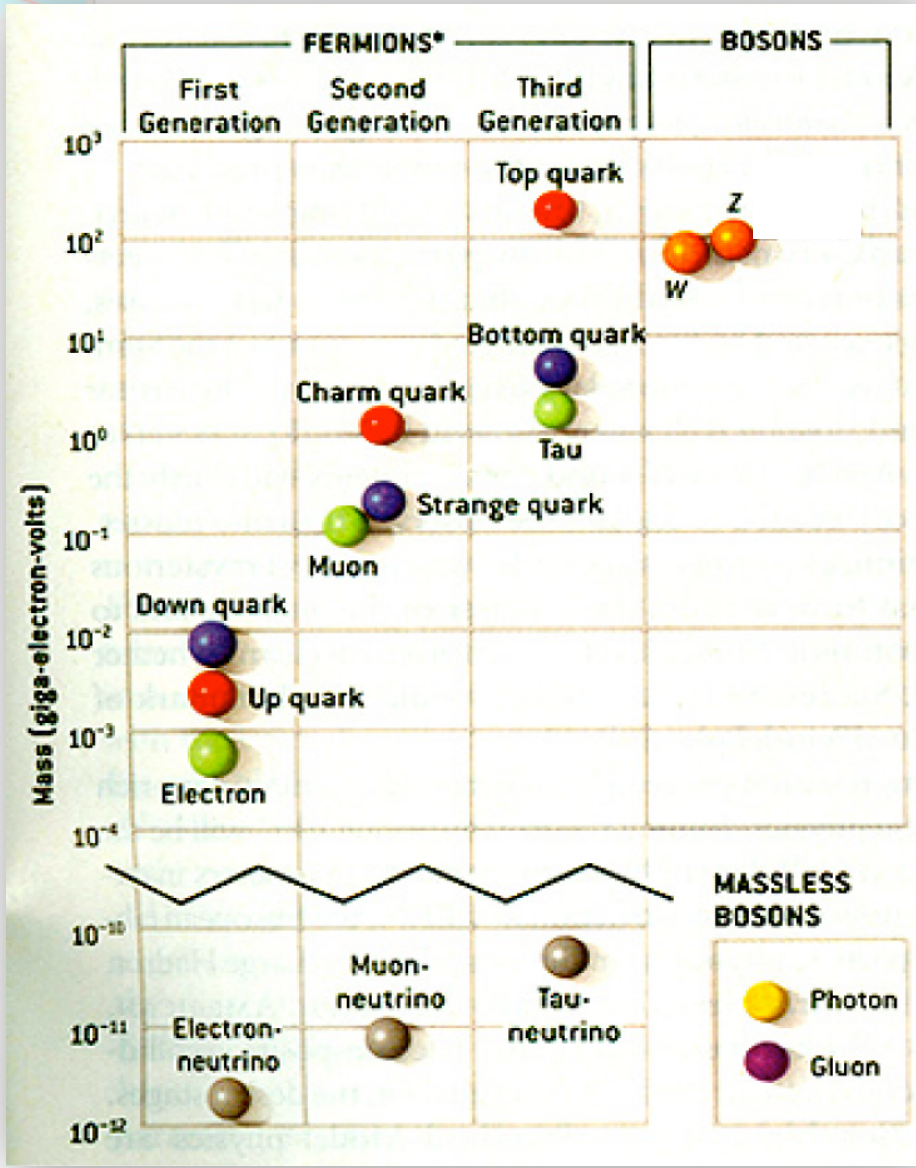
	Measurement	Fit	$10^{\text{meas}} - 0^{\text{fit}} / \sigma^{\text{meas}}$
$\Delta\alpha_{\text{had}}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02768	0.00010
m_Z [GeV]	91.1875 ± 0.0021	91.1874	-0.00010
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	0.00070
σ_{had}^0 [nb]	41.540 ± 0.037	41.479	-0.061
R_l	20.767 ± 0.025	20.742	-0.025
$A_{\text{fb}}^{0,l}$	0.01714 ± 0.00095	0.01645	-0.00069
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481	0.0016
R_b	0.21629 ± 0.00066	0.21579	-0.00050
R_c	0.1721 ± 0.0030	0.1723	0.00020
$A_{\text{fb}}^{0,b}$	0.0992 ± 0.0016	0.1038	0.0046
$A_{\text{fb}}^{0,c}$	0.0707 ± 0.0035	0.0742	0.0035
A_b	0.923 ± 0.020	0.935	0.012
A_c	0.670 ± 0.027	0.668	-0.002
$A_l(\text{SLD})$	0.1513 ± 0.0021	0.1481	-0.0032
$\sin^2\theta_{\text{eff}}^{\text{lept}}(Q_{\text{fb}})$	0.2324 ± 0.0012	0.2314	-0.0010
m_W [GeV]	80.399 ± 0.023	80.379	-0.020
Γ_W [GeV]	2.085 ± 0.042	2.092	0.007
m_t [GeV]	173.3 ± 1.1	173.4	0.1

July 2010



The Standard Model

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



	Measurement	Fit	$10^{\text{meas}} - 0^{\text{fit}} / \sigma^{\text{meas}}$
$\Delta\alpha_{\text{had}}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02768	~0.1
m_Z [GeV]	91.1875 ± 0.0021	91.1874	~0.001
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	~0.003
σ_{had}^0 [nb]	41.540 ± 0.037	41.479	~0.14
R_l	20.767 ± 0.025	20.742	~0.012
$A_{\text{fb}}^{0,l}$	0.01714 ± 0.00095	0.01645	~0.04
$A(P)$	0.1465 ± 0.0032	0.1481	~0.011
A_c	0.670 ± 0.027	0.668	~0.003
$A_l(\text{SLD})$	0.1513 ± 0.0021	0.1481	~0.15
$\sin^2\theta_{\text{eff}}^{\text{lept}}(Q_{\text{fb}})$	0.2324 ± 0.0012	0.2314	~0.008
m_W [GeV]	80.399 ± 0.023	80.379	~0.024
Γ_W [GeV]	2.085 ± 0.042	2.092	~0.003
m_t [GeV]	173.3 ± 1.1	173.4	~0.006

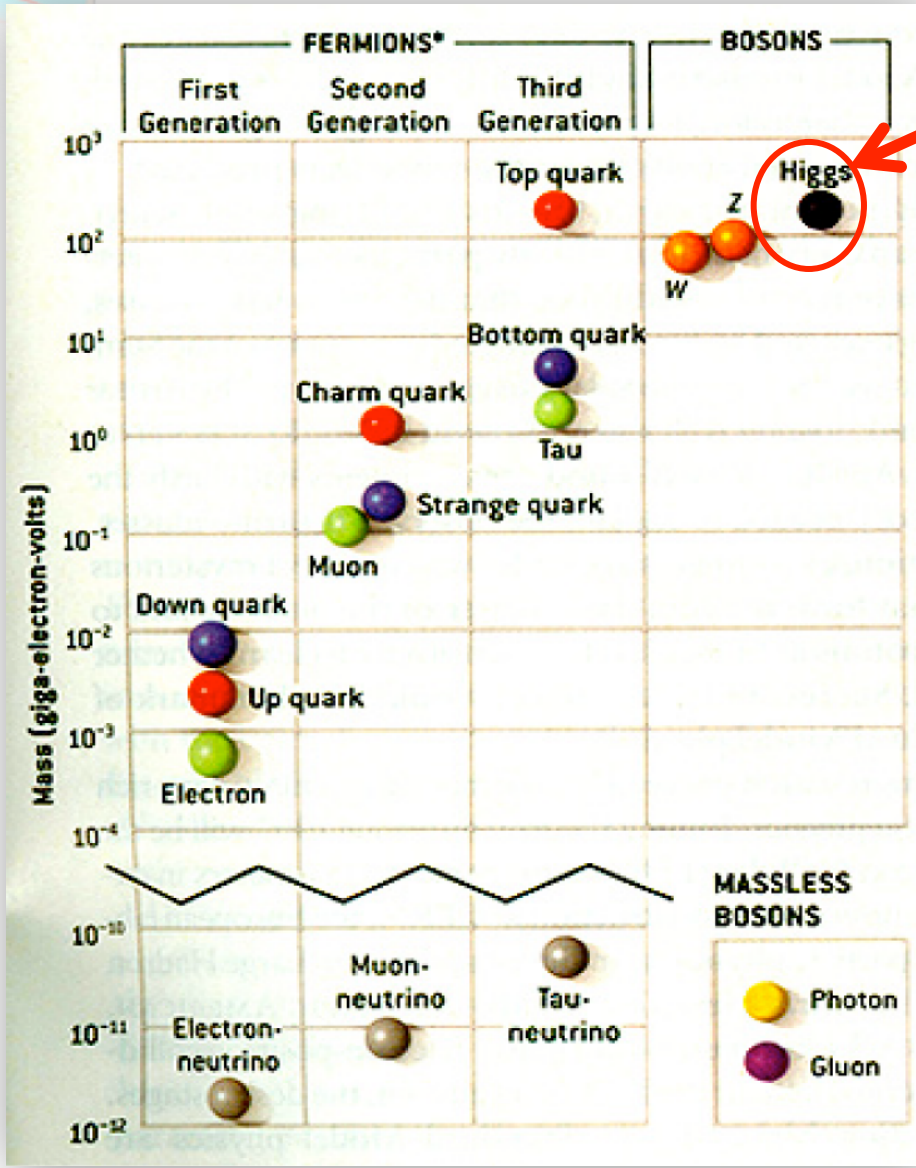
Confirmed to better than 1% uncertainty by 100's of precision measurements

July 2010



The Standard Model

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



1 Missing piece: Higgs

	Measurement	Fit	$10^{\text{meas}} - 0^{\text{fit}} / \sigma^{\text{meas}}$
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Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	0.3
σ_{had}^0 [nb]	41.540 ± 0.037	41.479	1.7
R_l	20.767 ± 0.025	20.742	1.0
$A_{\text{fb}}^{0,l}$	0.01714 ± 0.00095	0.01645	0.8
$A(P)$	0.1465 ± 0.0032	0.1481	0.5
A_c	0.670 ± 0.027	0.668	0.1
$A_1(\text{SLD})$	0.1513 ± 0.0021	0.1481	1.6
$\sin^2\theta_{\text{eff}}^{\text{lept}}(Q_{\text{fb}})$	0.2324 ± 0.0012	0.2314	0.9
m_W [GeV]	80.399 ± 0.023	80.379	0.2
Γ_W [GeV]	2.085 ± 0.042	2.092	0.3
m_t [GeV]	173.3 ± 1.1	173.4	0.1

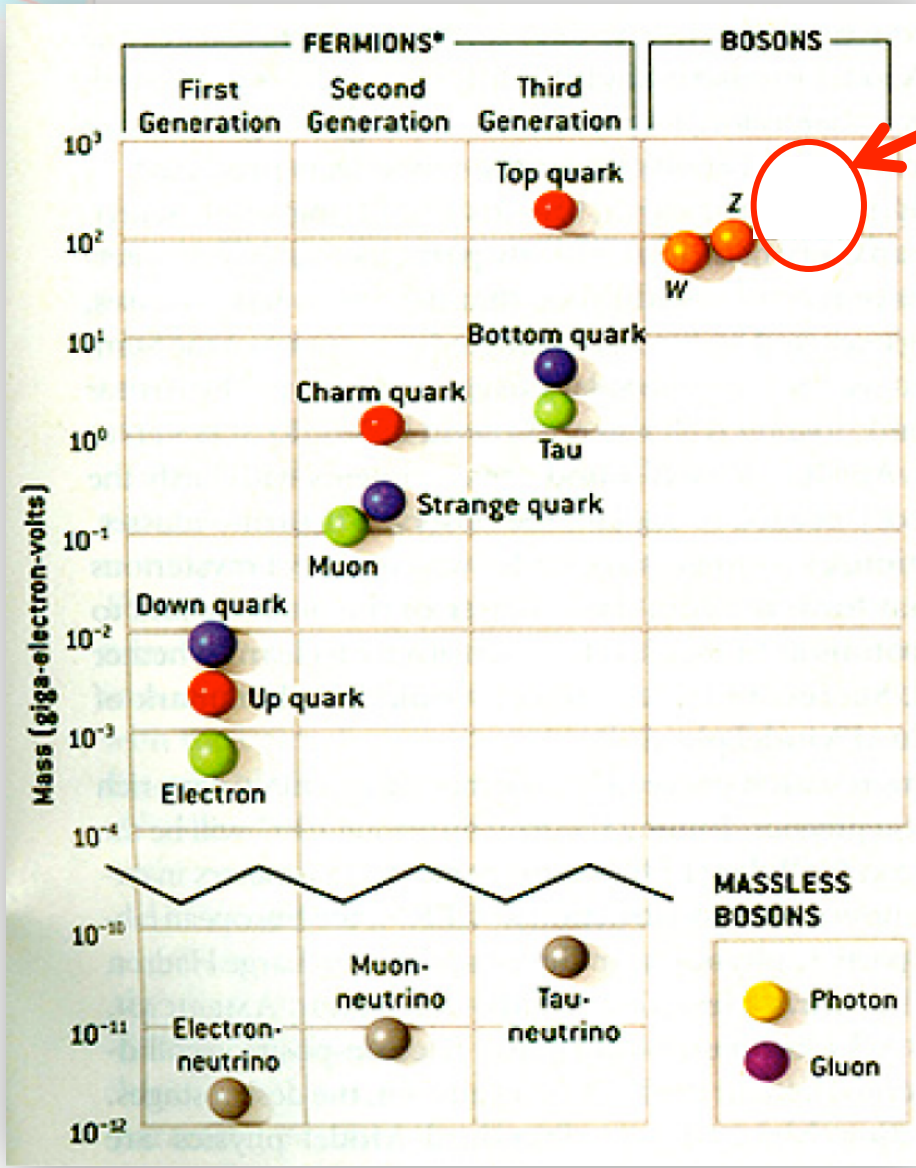
Confirmed to better than 1% uncertainty by 100's of precision measurements

July 2010



The Standard Model

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



1 Missing piece: Higgs

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Confirmed to better than 1% uncertainty by 100's of precision measurements

July 2010



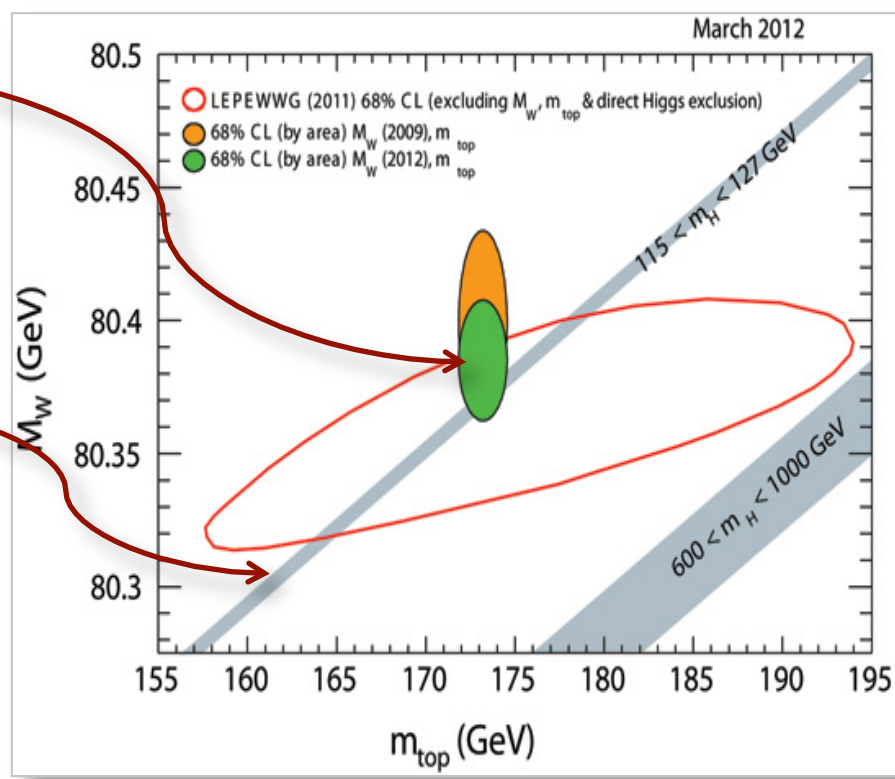
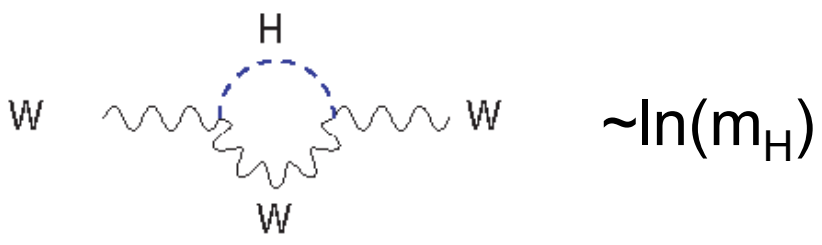
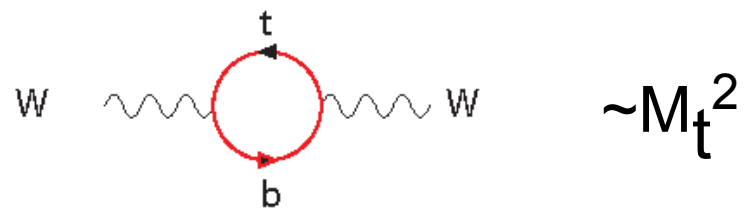
Where we stood last week

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

1. M_{top} vs. M_W

- Tevatron M_W *Tour de Force!!*
- $m_W = 80385 \pm 15$ MeV (World Ave - Mar 2012)
- Shifts for SM Higgs expectation

2. Colliders leave little space



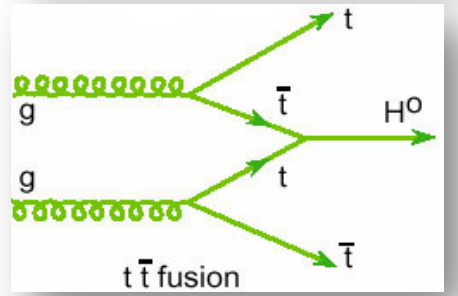
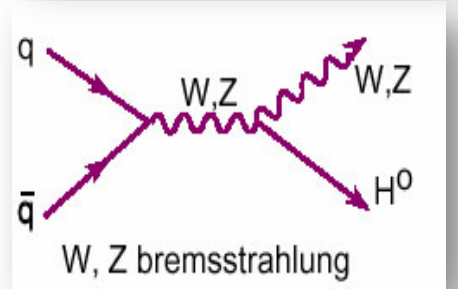
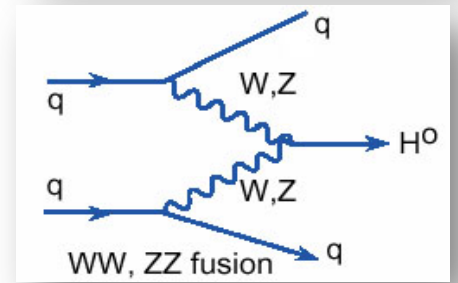
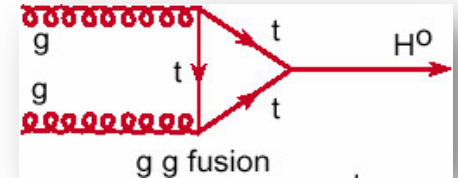
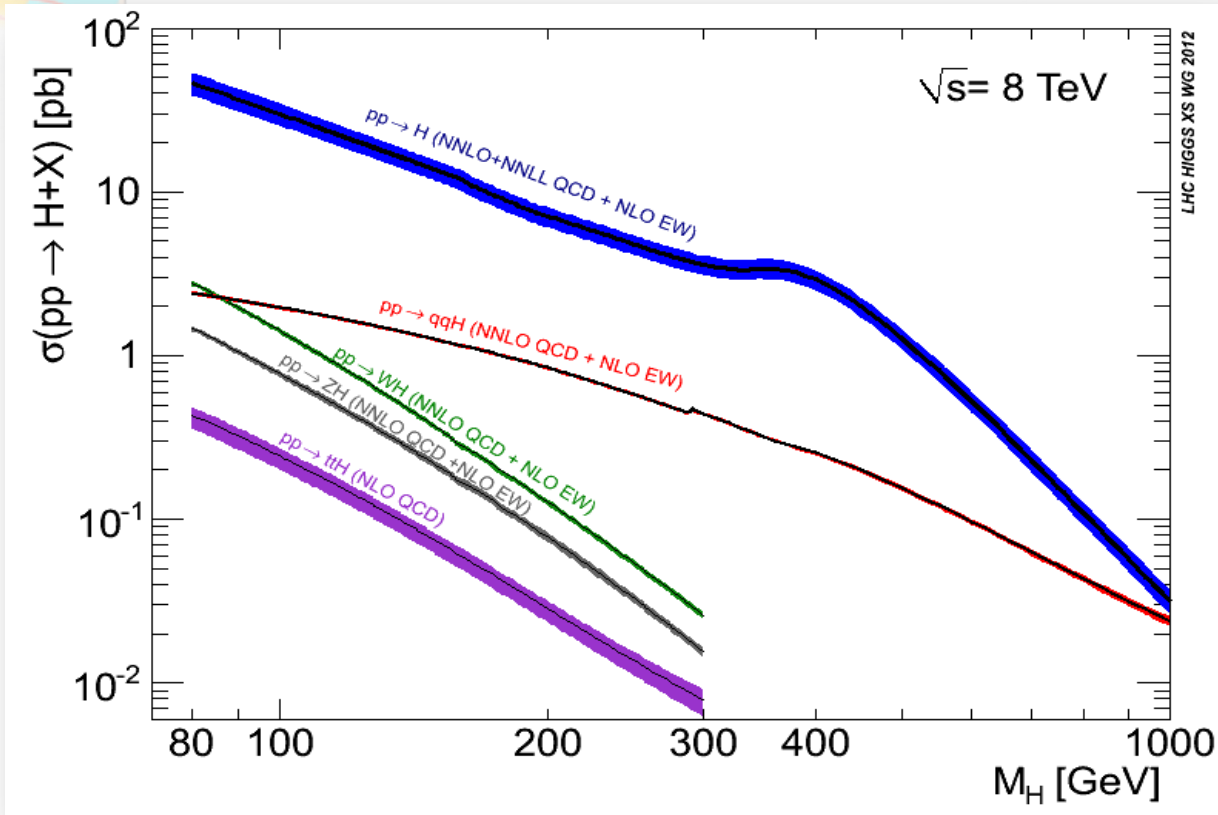
This is the main story of the past year

Eliminated ~475 GeV of the mass range.



Higgs boson production

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

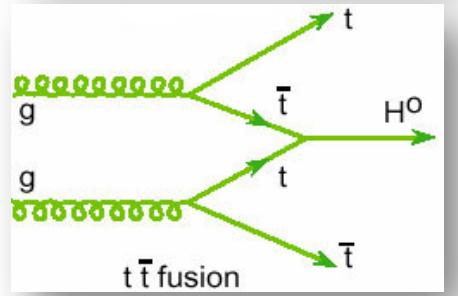
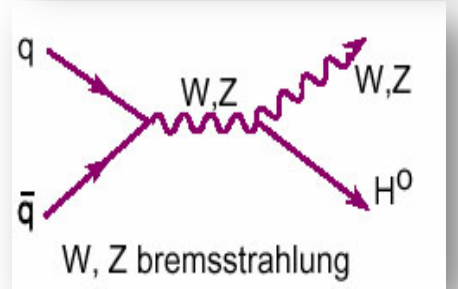
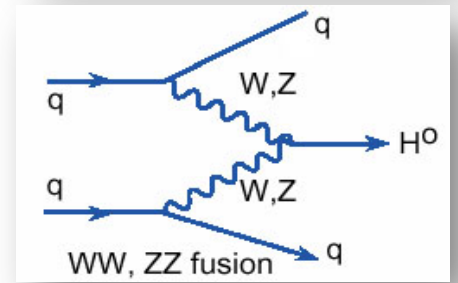
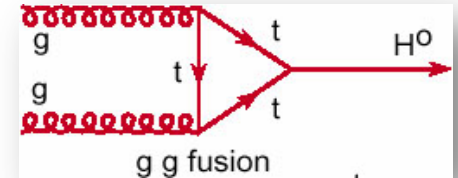
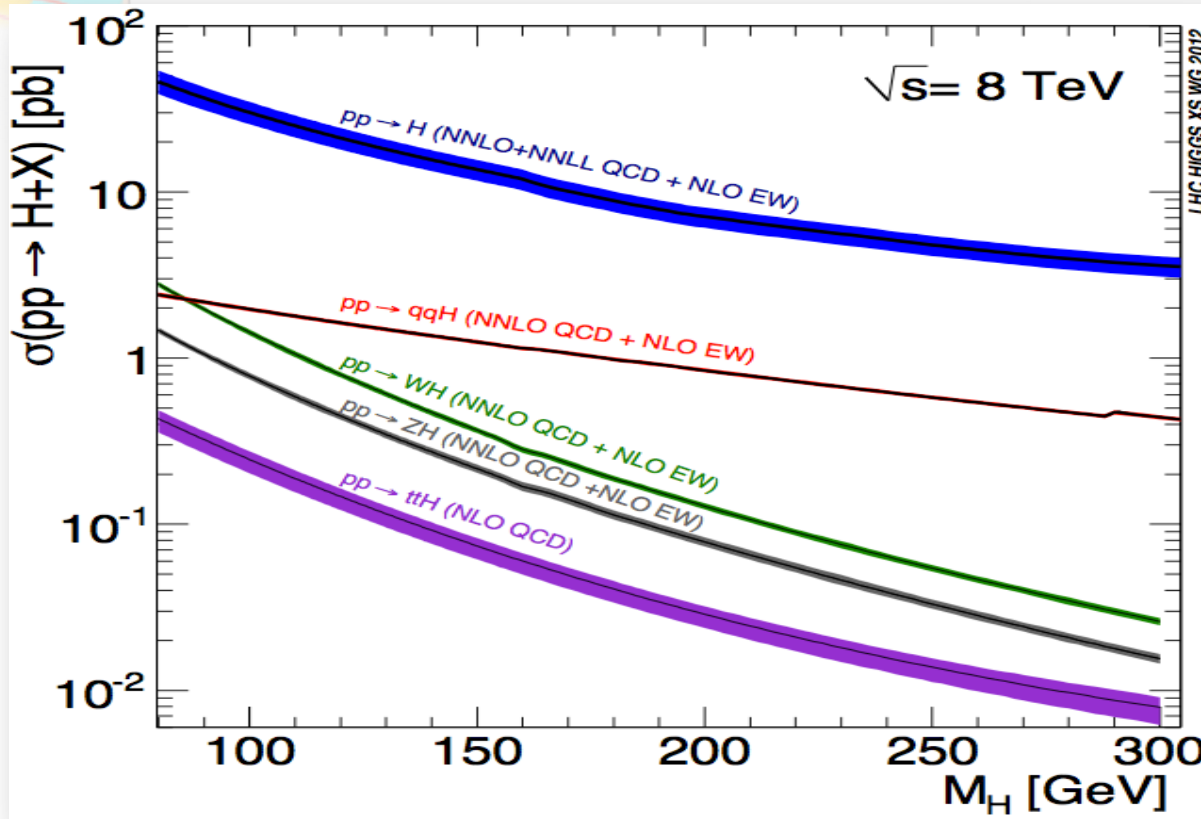


- $\sqrt{s}=8 \text{ TeV}$: 25-30% higher σ than $\sqrt{s}=7 \text{ TeV}$ at low m_H
- All production modes to be exploited
 - gg VBF VH ttH
 - Latter 3 have smaller cross sections but better S/B in many cases



Higgs boson production

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



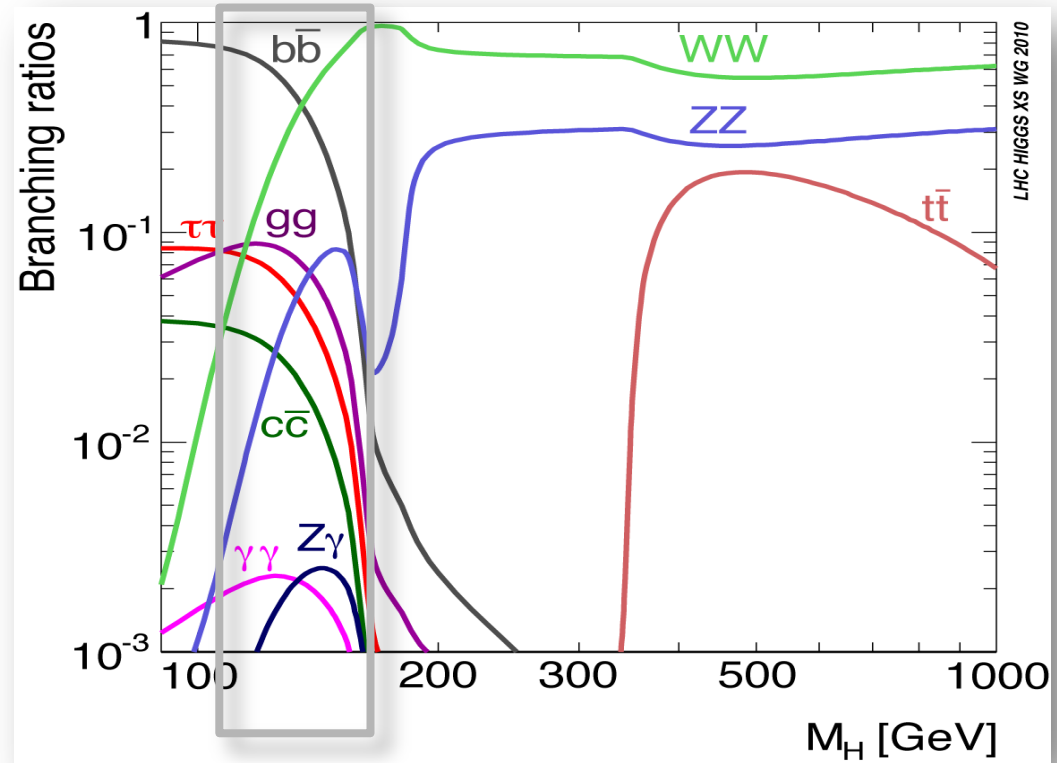
- $\sqrt{s}=8$ TeV: 25-30% higher σ than $\sqrt{s}=7$ TeV at low m_H
- All production modes to be exploited
 - gg VBF VH ttH
 - Latter 3 have smaller cross sections but better S/B in many cases



Higgs boson decays

5 decay modes exploited

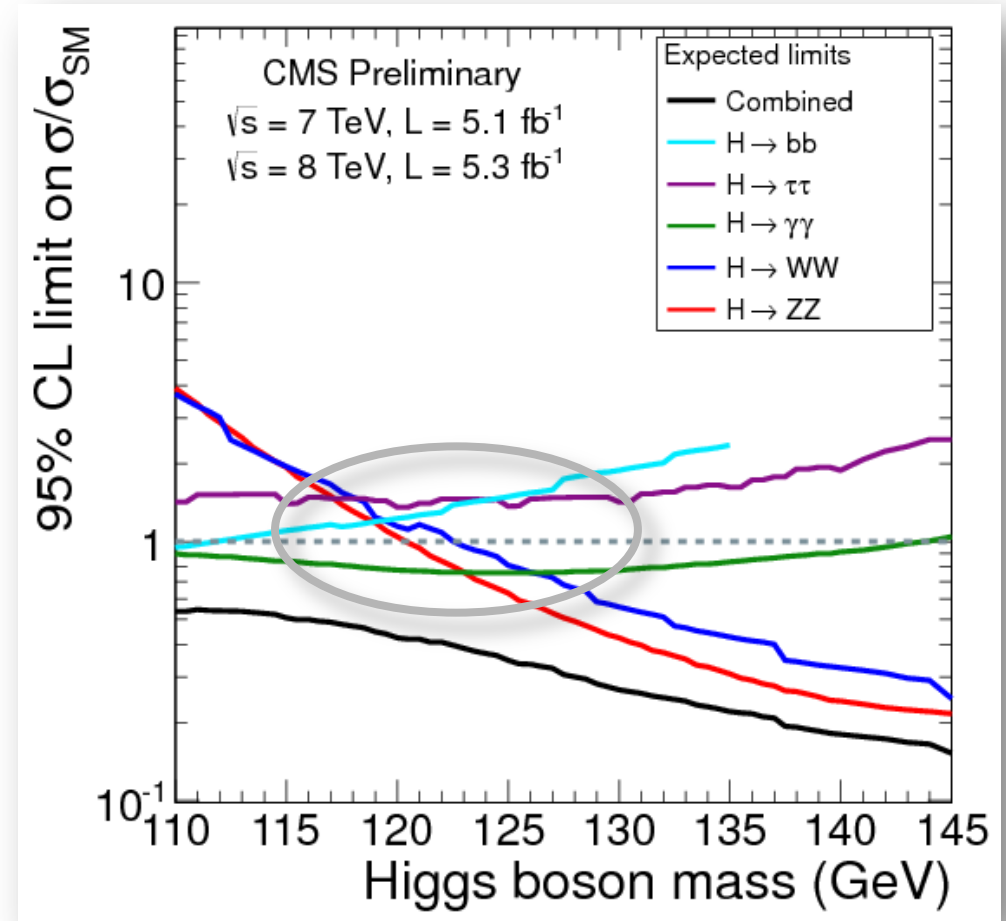
- High mass: WW, ZZ
- Low mass: $bb, \tau\tau, WW, ZZ, \gamma\gamma$
- Low mass region is very rich but also very challenging:
 main decay modes ($bb, \tau\tau$) are hard to identify in the huge background
- Very good mass resolution (1%): $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow 4l$





CMS Exclusion Potential

- Not-yet-excluded region:
~[115-130] GeV
- The five decay modes discussed today have comparable sensitivities for exclusion.
- Most analyses used in this combination have been re-optimized. In order to avoid the possibility of an unintended bias, all selection criteria in the analyses of the 2011 and 2012 data were fixed before looking at the result in the signal region.

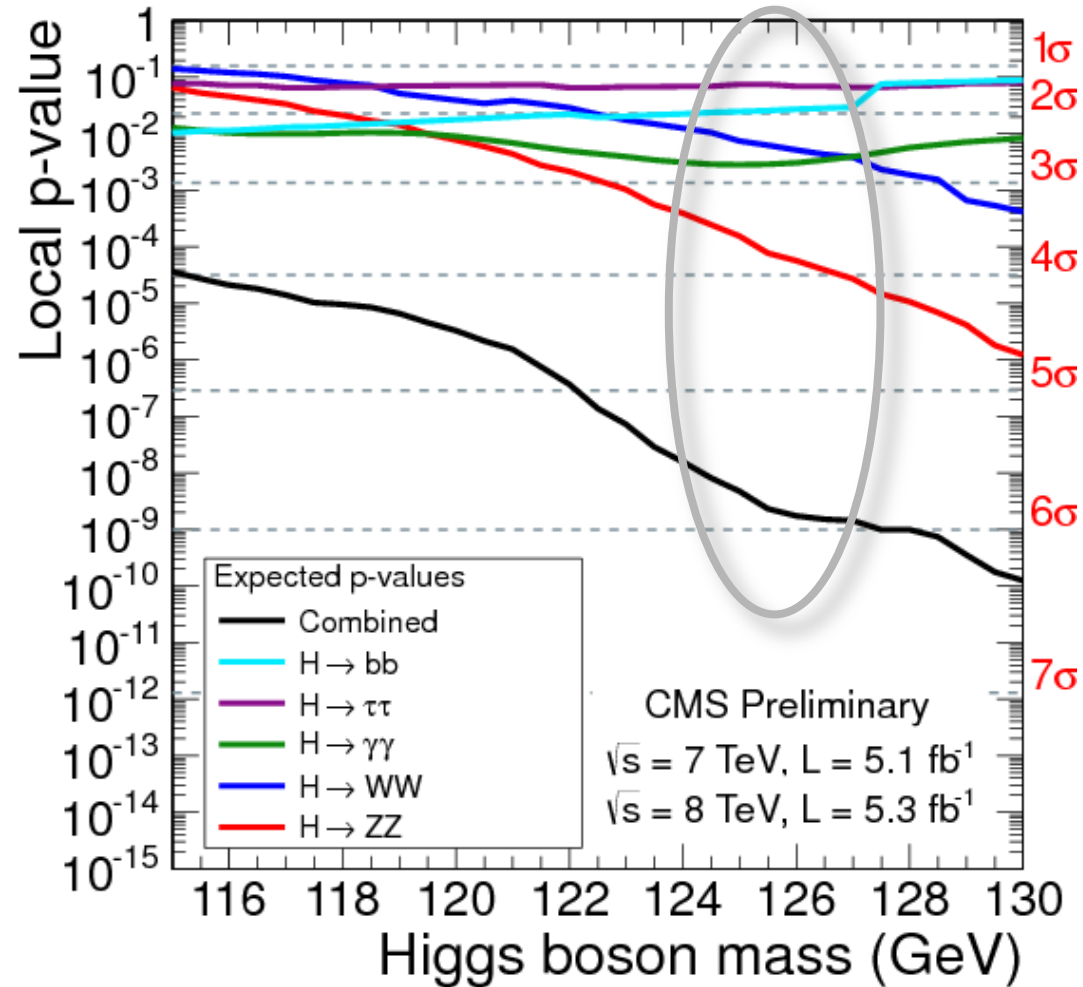




CMS Discovery potential

p-values

- Probability that background fluctuates to give an excess as large as the (average) signal size expected for a SM Higgs.
- Takes into account all analysis steps, estimated backgrounds, etc. for the 5 search channels indicated.
- Excellent prospects for exploring properties

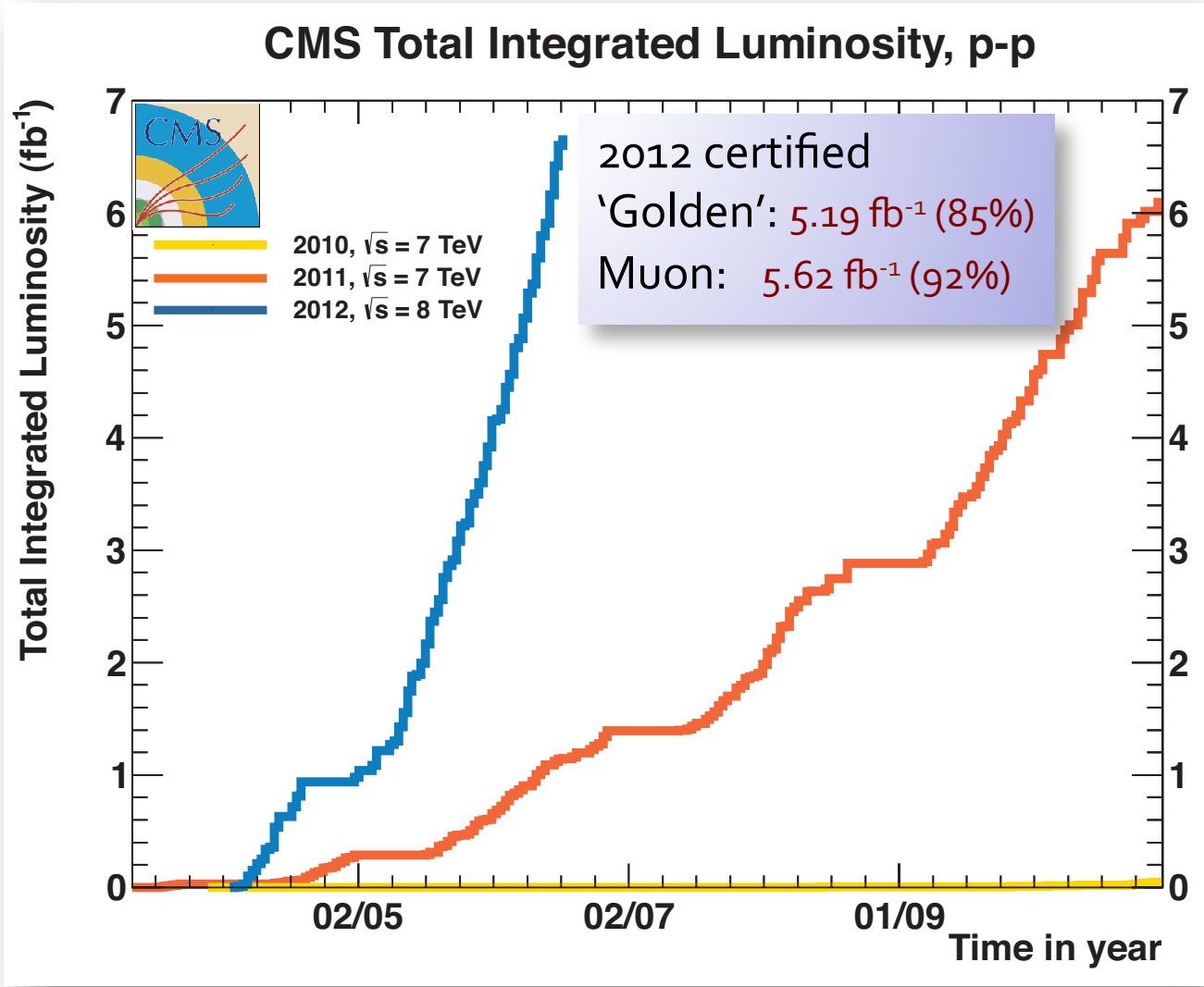




How is it possible to go so far so fast?

LHC performance: 2010-2011-2012

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



Stellar performance of the LHC enables all experiments to produce significant physics results

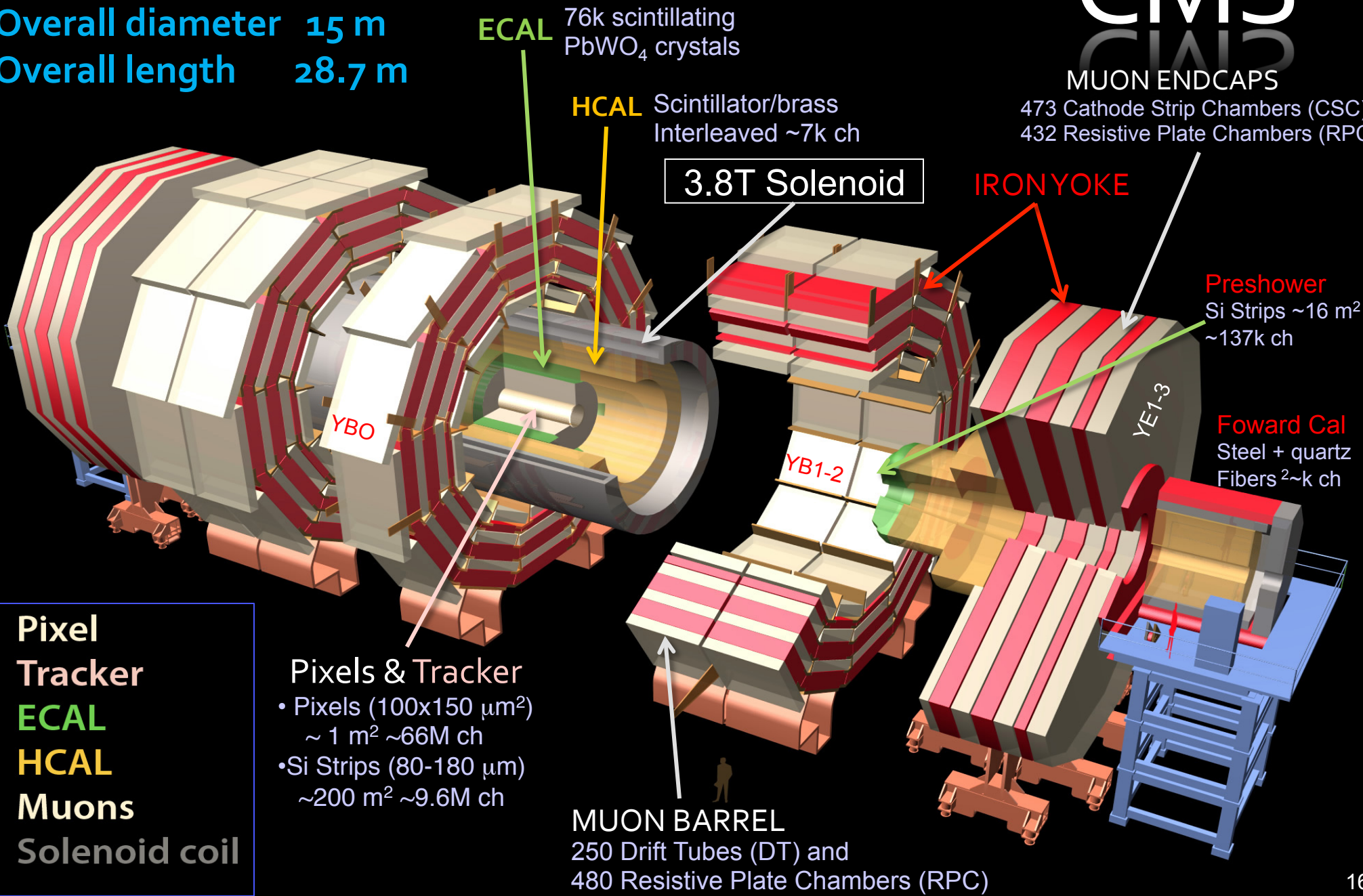
Many thanks to the LHC teams and the many others who made this possible!

CMS

Total weight 14000 t
Overall diameter 15 m
Overall length 28.7 m

MUON ENDCAPS

473 Cathode Strip Chambers (CSC)
432 Resistive Plate Chambers (RPC)



3.8T Solenoid

IRONYOKE

Preshower
Si Strips ~16 m²
~137k ch

Foward Cal
Steel + quartz
Fibers²~k ch

YBO

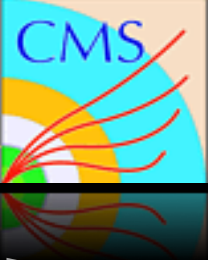
YB1-2

YE1-3

Pixel Tracker
ECAL
HCAL
Muons
Solenoid coil

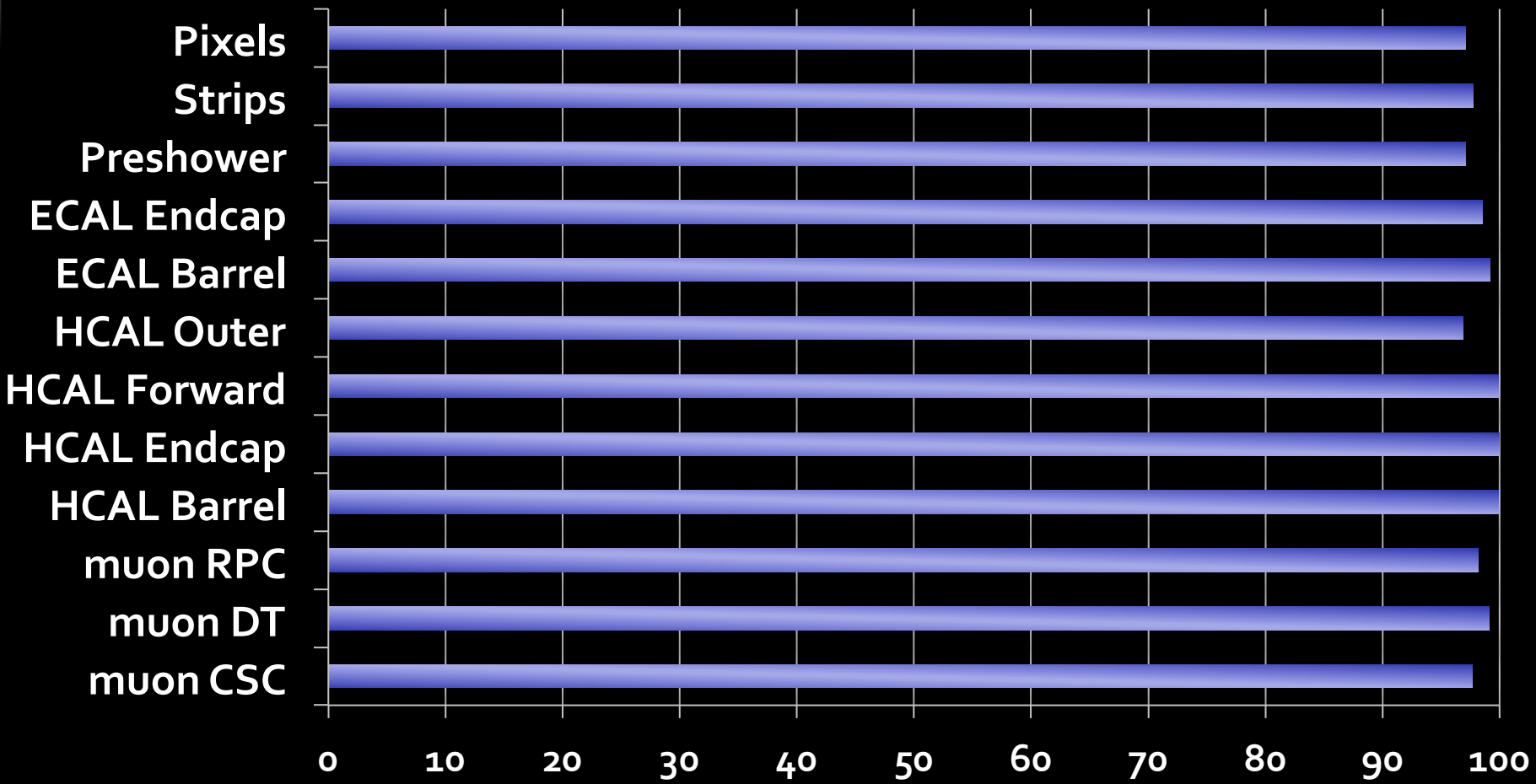
Pixels & Tracker
• Pixels (100x150 μm²)
~ 1 m² ~66M ch
• Si Strips (80-180 μm)
~200 m² ~9.6M ch

MUON BARREL
250 Drift Tubes (DT) and
480 Resistive Plate Chambers (RPC)



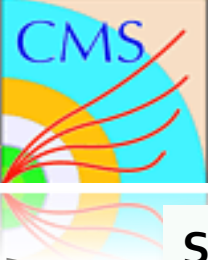
Current Operational Status*

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



Pixel Tracker	Strip Tracker	Preshower	ECAL Barrel	ECAL Endcaps	HCAL Barrel	HCAL Endcaps	HCAL Forward	HCAL Outer	Muon DT	Muon CSC	Muon RPC
97.1%	97.75%	97.1%	99.16%	98.54%	99.92%	99.96%	99.88%	96.88%	99.1%	97.67%	98.2%

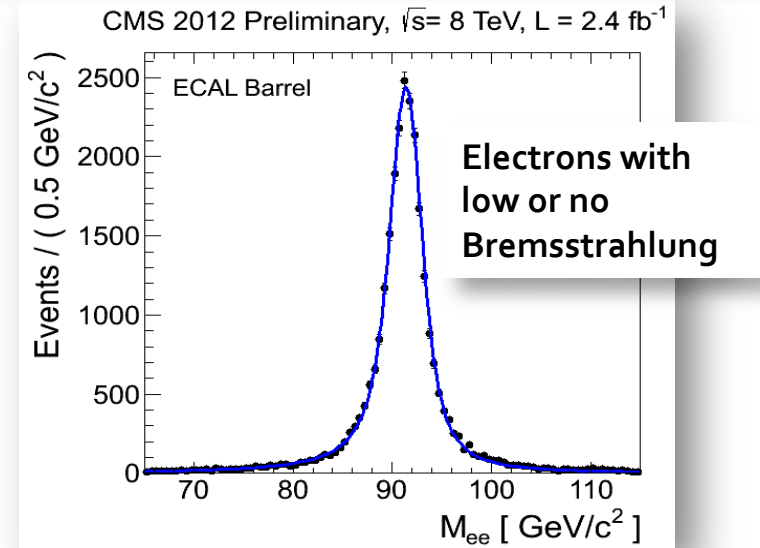
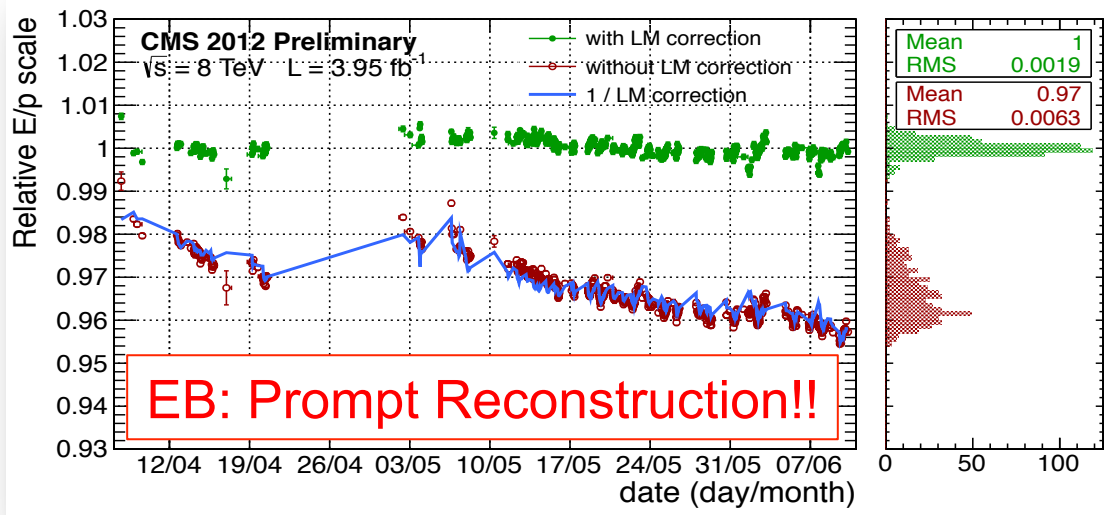
*As of June 15 2012 17



ECAL calibration, 2012 data

Single electron energy scale (E/p) stability in barrel measured with $W \rightarrow ev$ events

$Z \rightarrow ee$ invariant mass distribution for electrons measured in the barrel



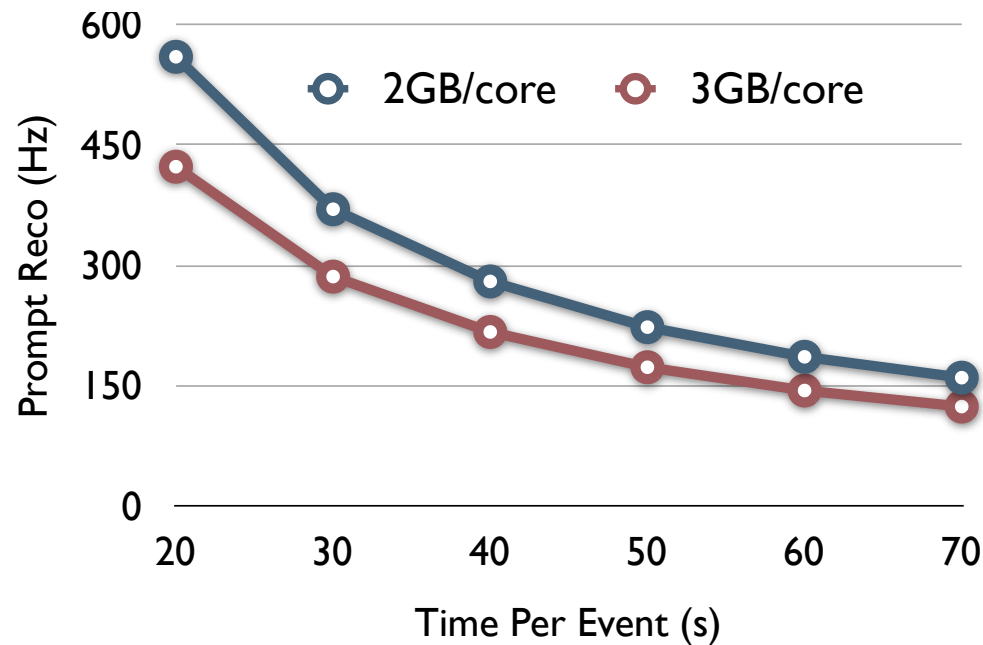
- $W \rightarrow ev$ E/p: Stable E scale during 2012 run after light monitoring (LM) corrections:
 - ECAL Barrel (EB): RMS stability after corrections 0.19%
- $Z \rightarrow ee$: Good resolution with preliminary energy calibration for 2012:
 - Instrumental resolution: 1.0 GeV in ECAL Barrel



CMS Preparations for 8 TeV and high PU in 2012

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

- Last Autumn
 - cpu time for high PU >40 sec/event
 - Memory usage well above 2 GB.
 - Means we cannot use all the cores!
 - Even 200 Hz looked hard!
- Task force started December
 - Major success!
- Improvements
 - A factor 2.5 in speed
 - Under ~15" per event on average
 - Much reduced memory use
 - Well under 2 GB
- Physics performance unchanged
 - Kept our AAA rating:
 - E.g. no explicit p_T threshold on tracks



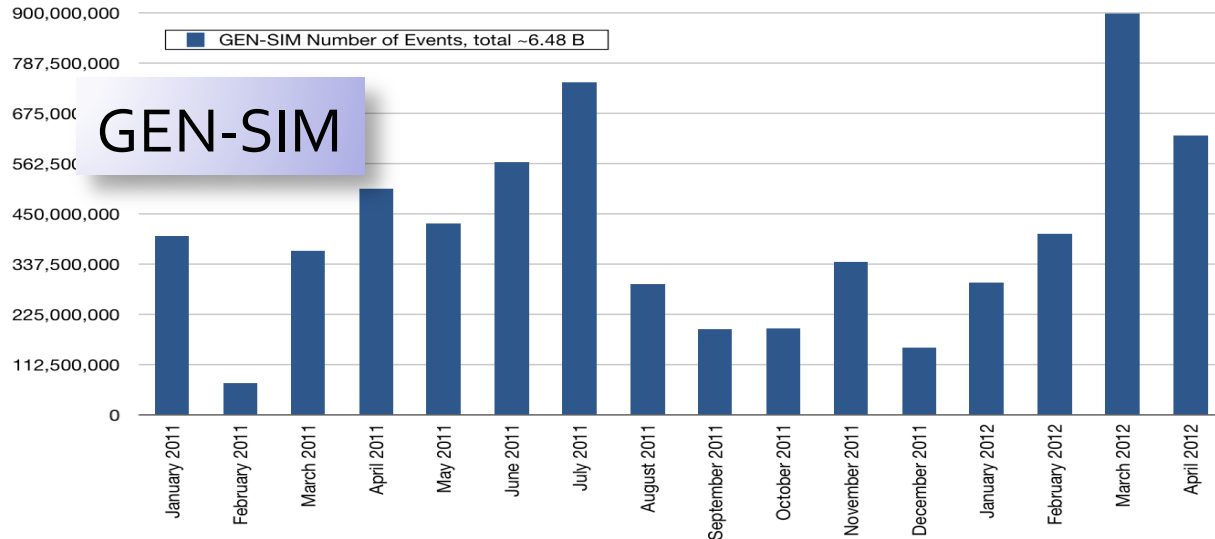
Prompt Reconstruction at Tier-0:
Limit on our data-taking rate versus event processing time for low and high memory use cases



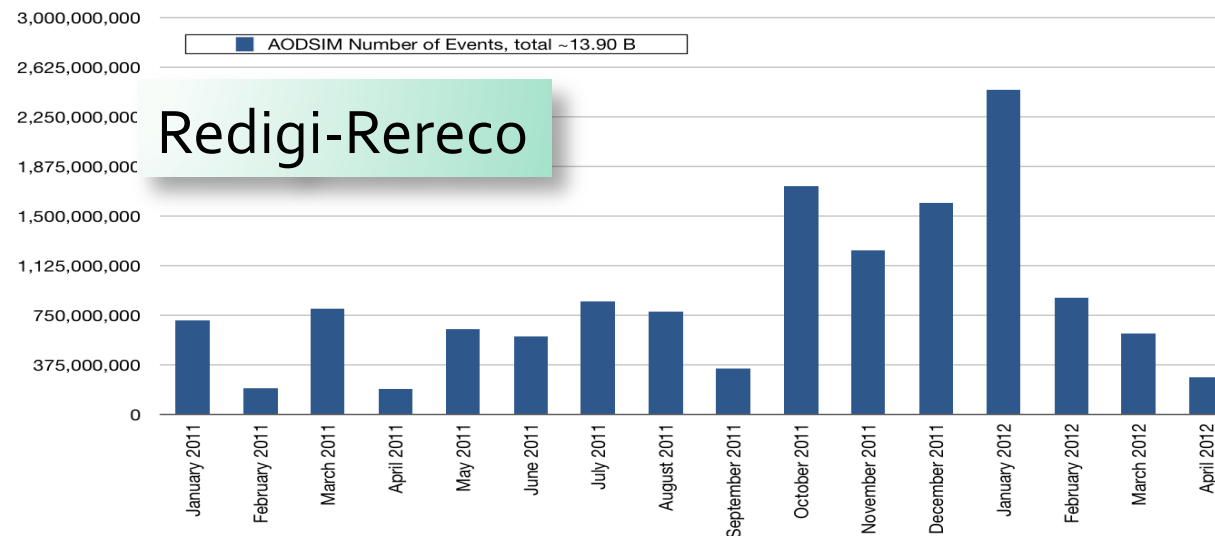
MC Production Capabilities

- Sustain 400M/Month
 - 900M, 600M past 2 months but had help from Tier-1's
- Sustain 1B/month
 - Peaks high as 2.3B

MC in 2011/2012: Number of Events per Month - GEN-SIM



MC in 2011/2012: Number of Events per Month - AODSIM

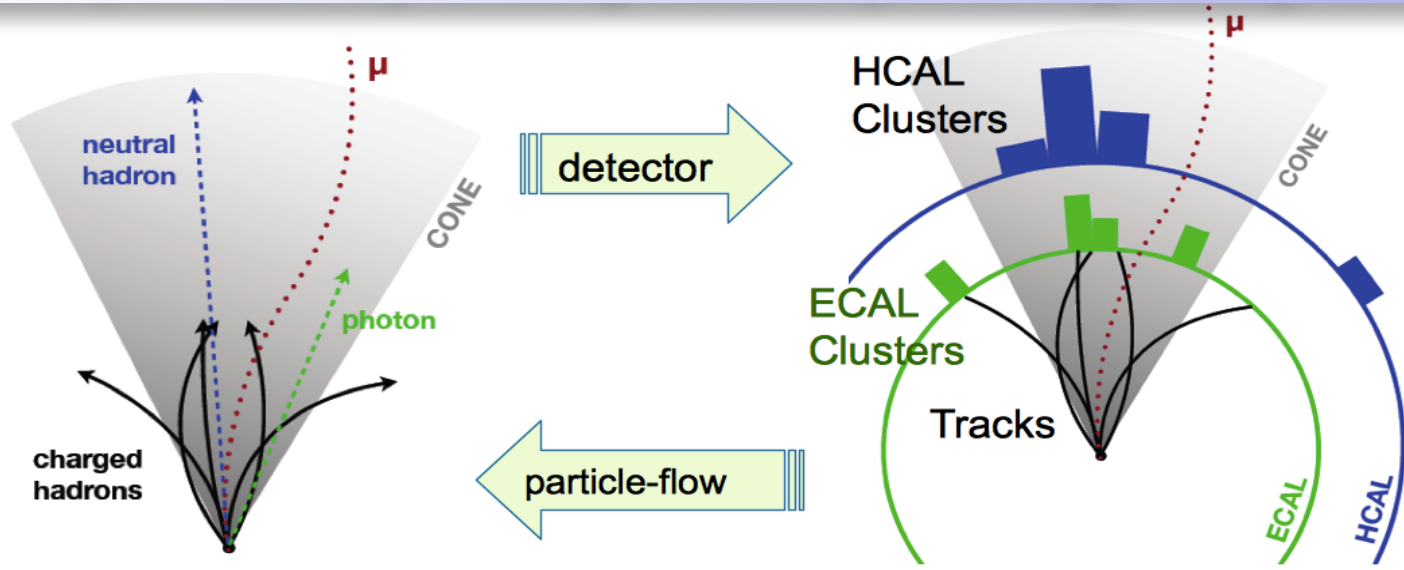


Reconstruction



Global Event Description (Pflow)

Made possible by CMS granularity and high magnetic field

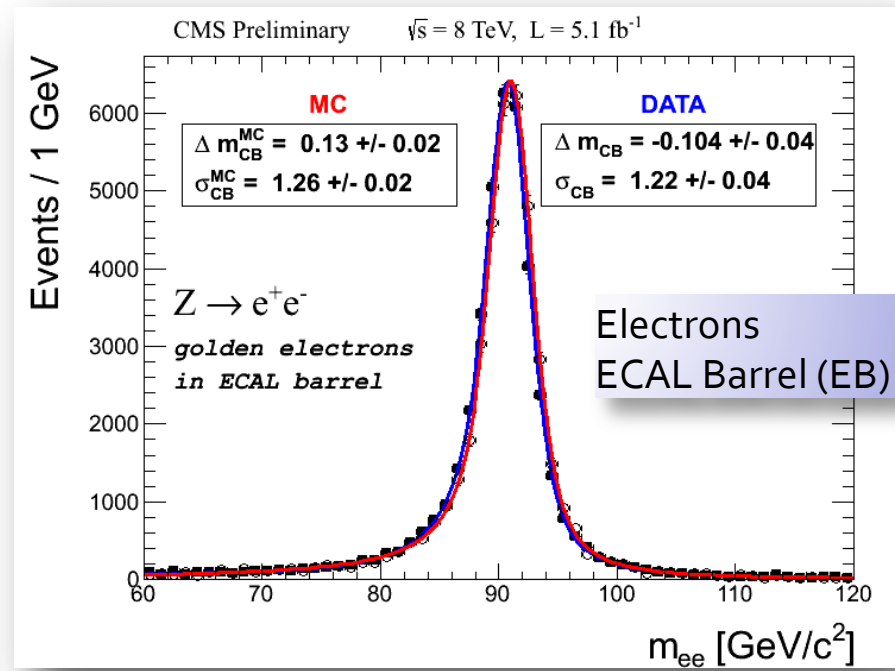
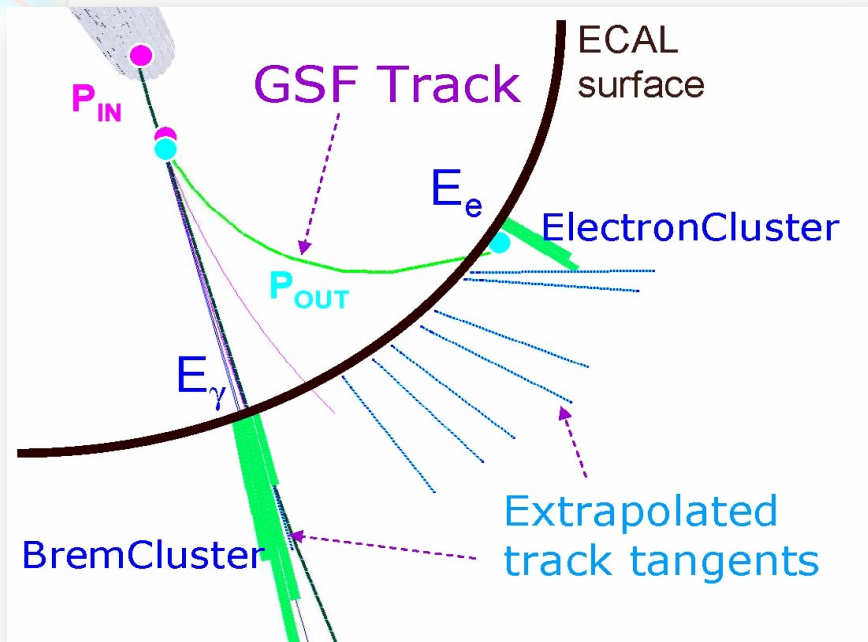


- Optimal combination of information from all subdetectors
- Returns a list of reconstructed particles
 - e, μ, γ , charged and neutral hadrons
 - Used in the analysis as if it came from a list of generated particles
 - Used as building blocks for jets, taus, missing transverse energy, isolation and PU particle identification



Electron/Photon reconstruction

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

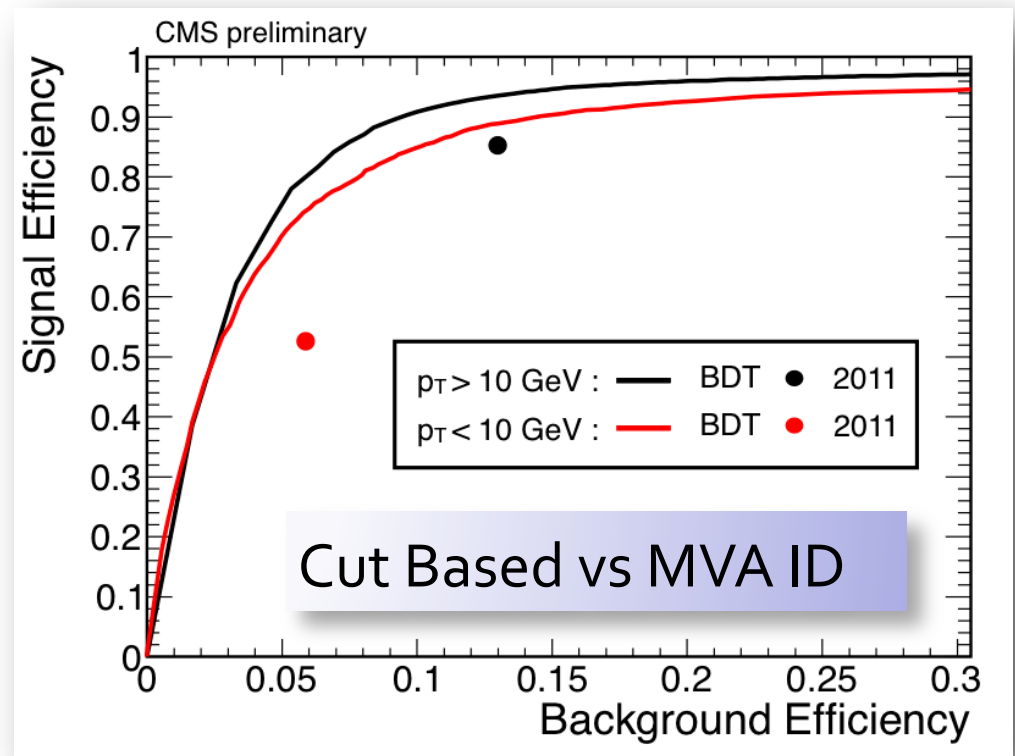
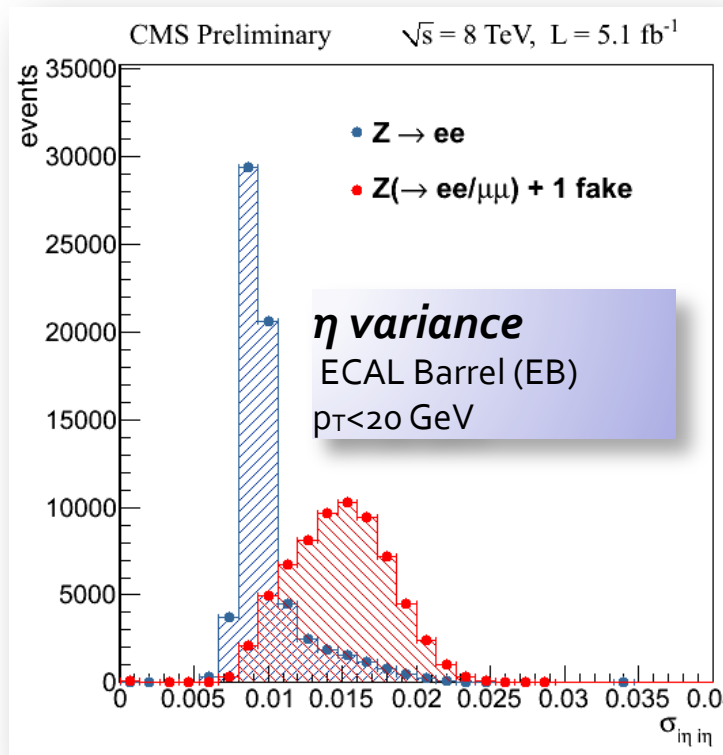


- Cluster reconstruction in ECAL
 - Common for both electrons and photons (Electrons also reconstructed as photons)
 - Designed to collect bremsstrahlung and conversions in extended phi region
- Dedicated track reconstruction for electrons
 - Gaussian Sum Filter allows for tracks w/large bremsstrahlung
- Photon identification specific to $H \rightarrow \gamma\gamma$
- Energy scale and resolution
 - Extensive control with Z and $J/\psi \rightarrow ee$ for both electrons and photons



Electron identification

- Multivariate e identification in 2012
 - ECAL, tracker, ECAL-tracker-HCAL matching, impact parameter
 - 30% efficiency improvement in $H \rightarrow ZZ \rightarrow 4e$ wrt cut based ID
- Multivariate training against background in data

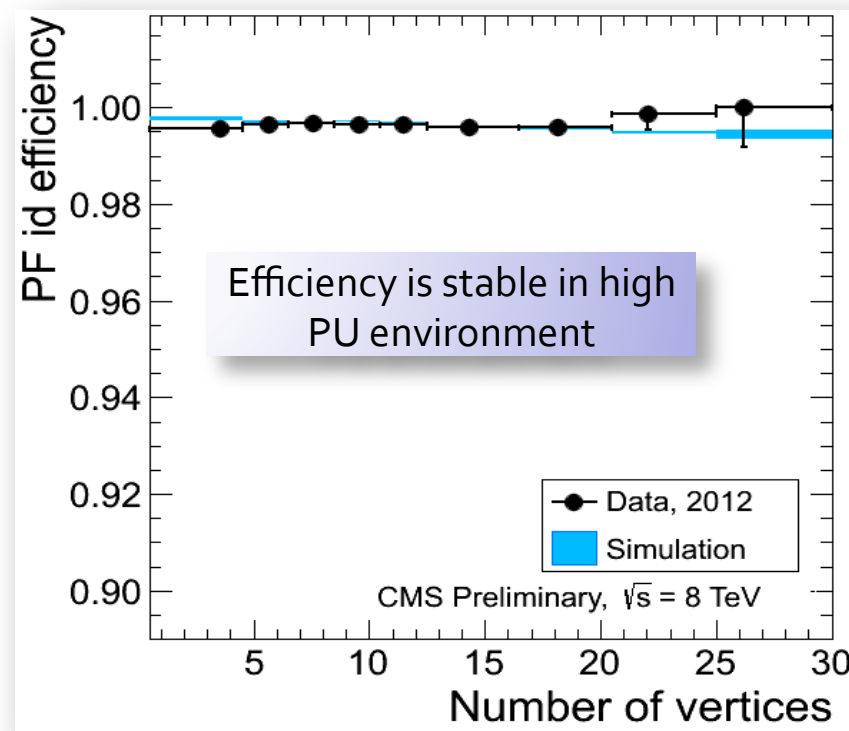
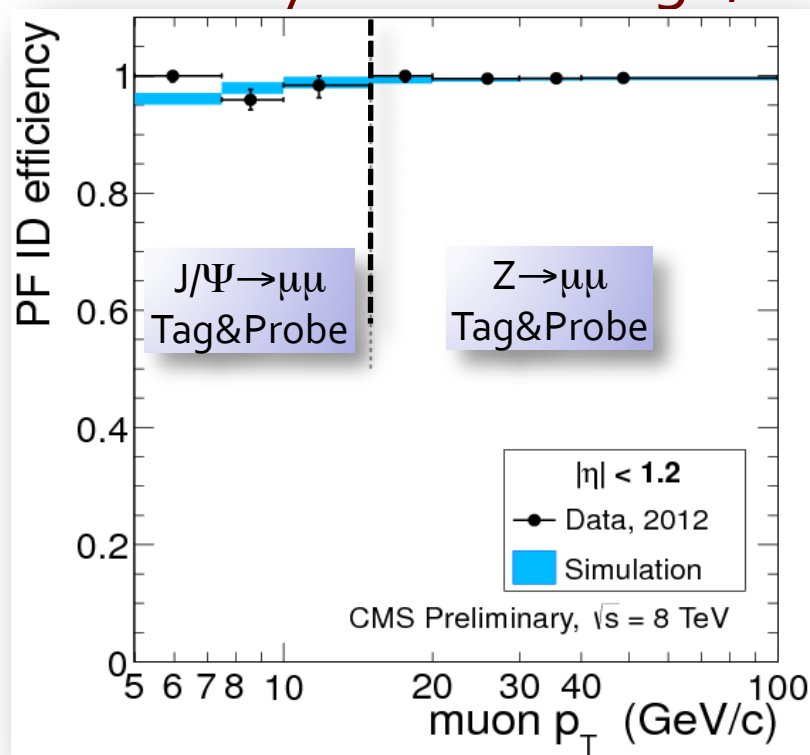




Muon reconstruction and identification

- Start with particle flow muons
- Efficiency above 96% down to $p_T = 5$ GeV
 - Above 99% efficiency for $p_T > 10$ GeV
 - Efficiency in data using J/Ψ and Z peak

Tighter quality criteria applied in some analyses



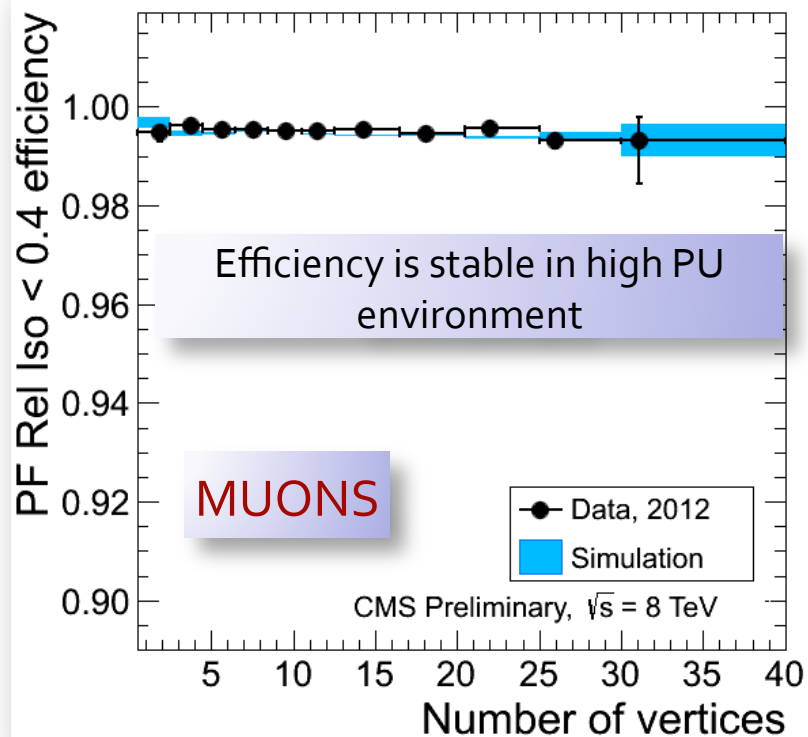


Particle-based isolation

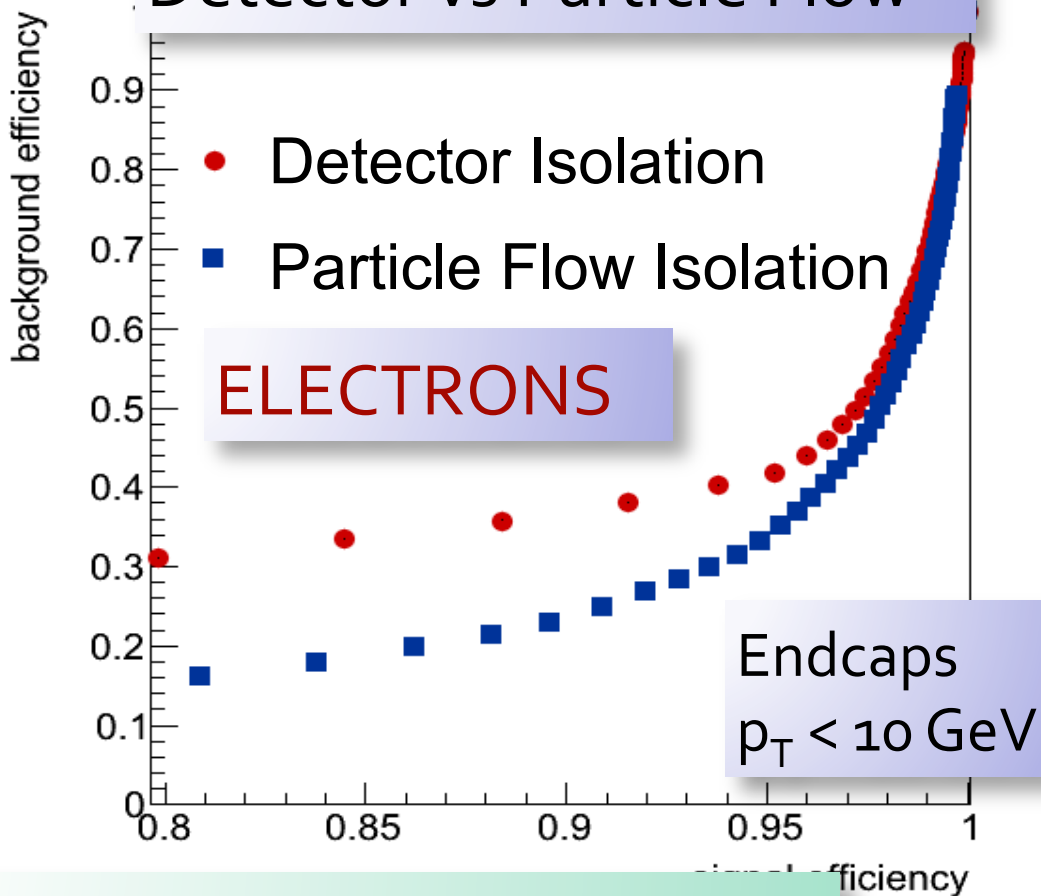
July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

Sum energy of particles in ΔR cone around the lepton

- Global event description eliminates double counting



Detector vs Particle Flow



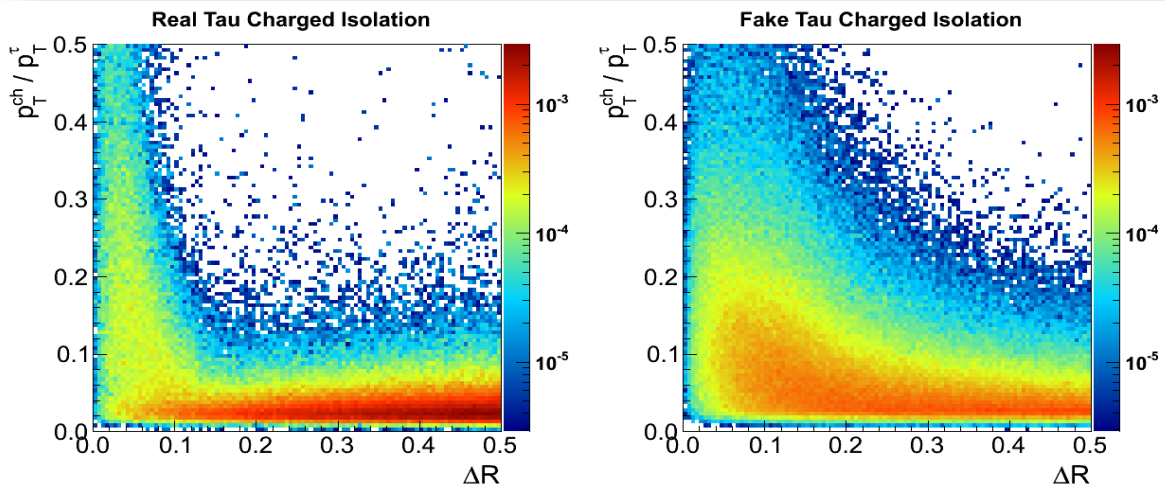
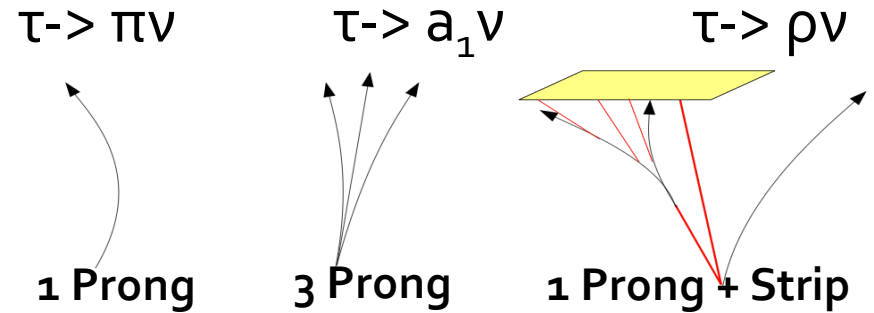
Pile-up contribution:

- Negligible for charged hadrons (vertexing)
- Neutrals corrected w/global energy density (ρ)



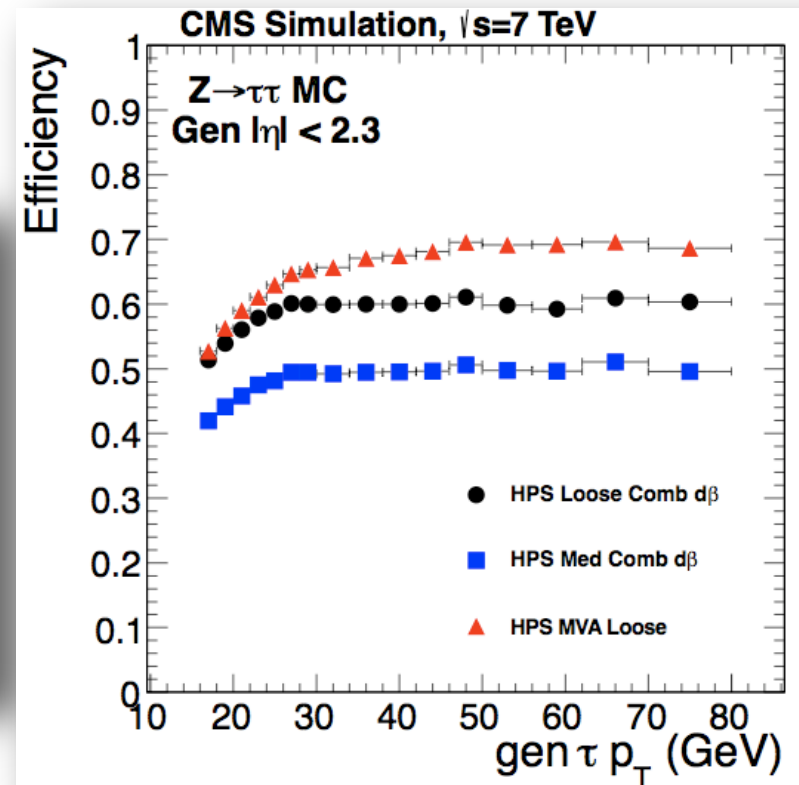
Tau Identification

- Tau identification:
 - Reconstruct individual decay modes
 - Charged hadrons + electromagnetic obj
 - EM strips account for material effects
- Tau isolation:
 - Multivariate discriminator using sum of energy deposits in dR rings around the tau



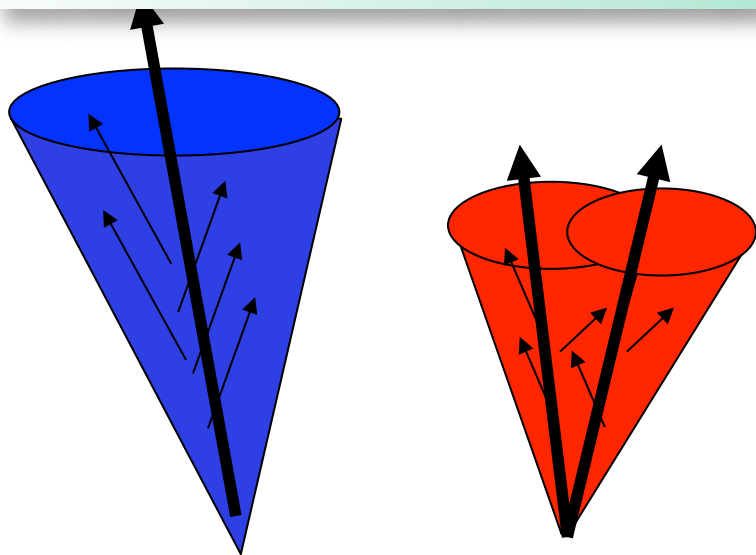
Real taus

Fake taus



Jet Identification

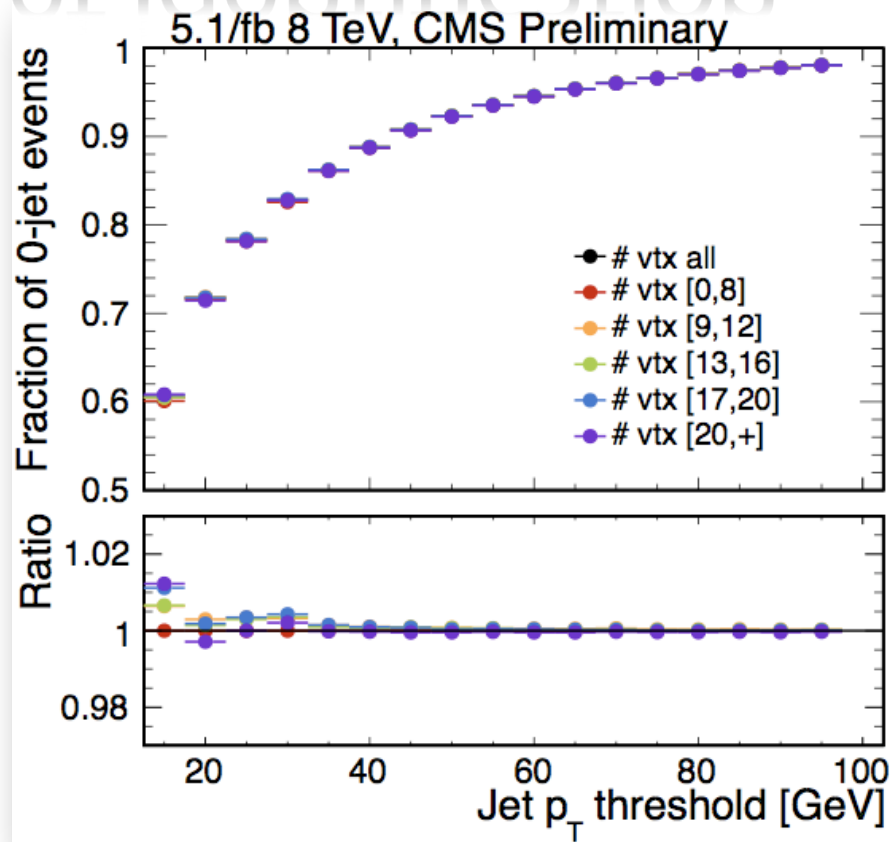
- Jet reconstruction
 - Reconstruction with particle flow objects



Typical jet

Pileup jet

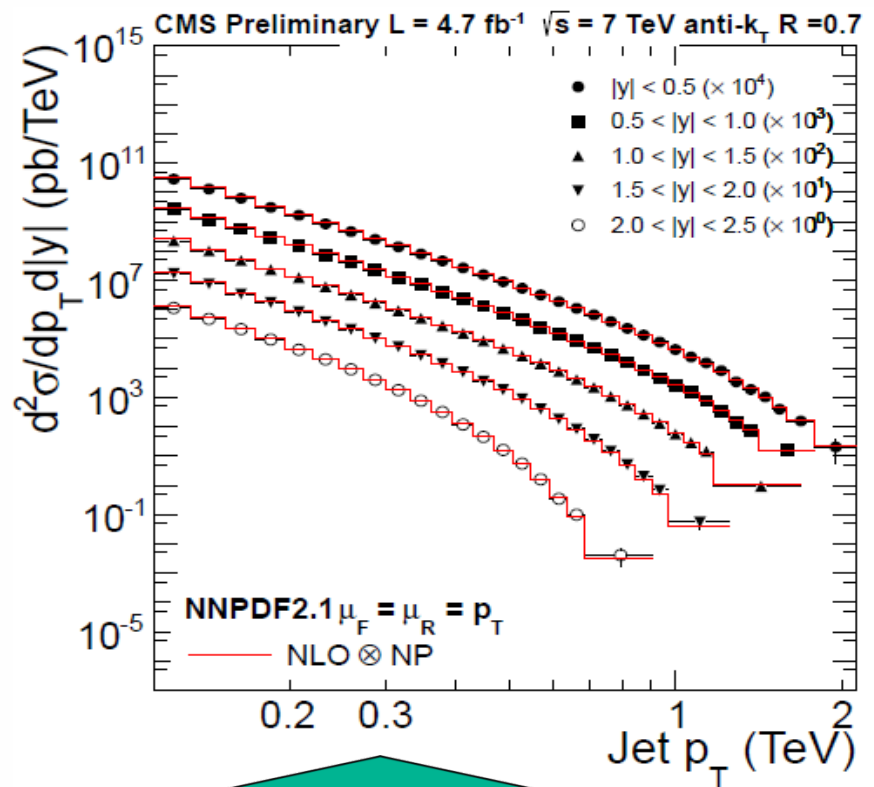
- Pileup jets structure differs wrt regular jets:
 - Pileup jets originate from several overlapping jets which merge together
 - Likelihood grows rapidly with high pileup
- Discriminant exploits shape and tracking variables
 - discrimination both inside and outside tracker acceptance



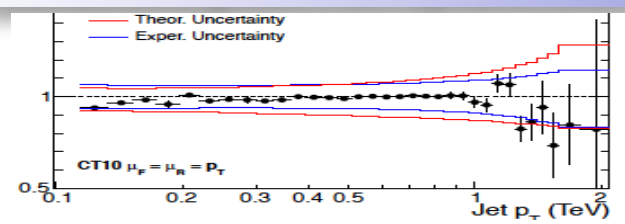


Standard Model: Precision Jets, W, and γ^*/Z

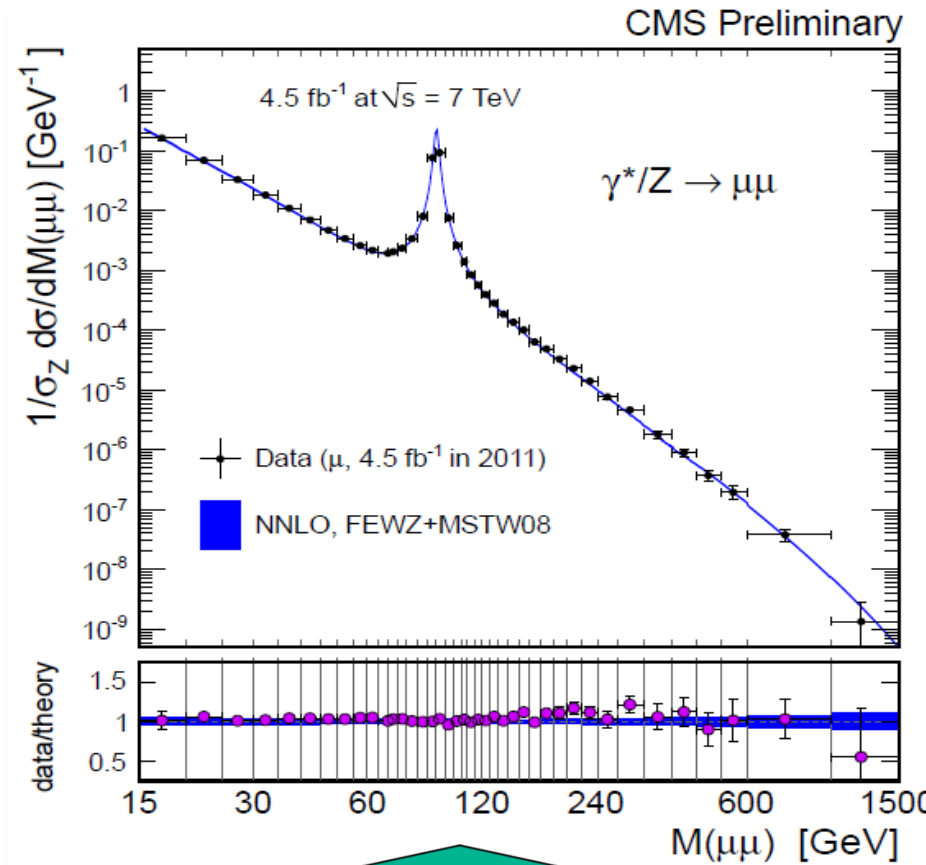
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Inclusive jet and dijets. 2-4% JES.
Constrains gluon PDF up to $x=0.6$



CMS-PAS-QCD-11-004



Differential Drell-Yan cross section: 2.5M $\mu\mu$ pairs tests NNLO cross sections and PDFs

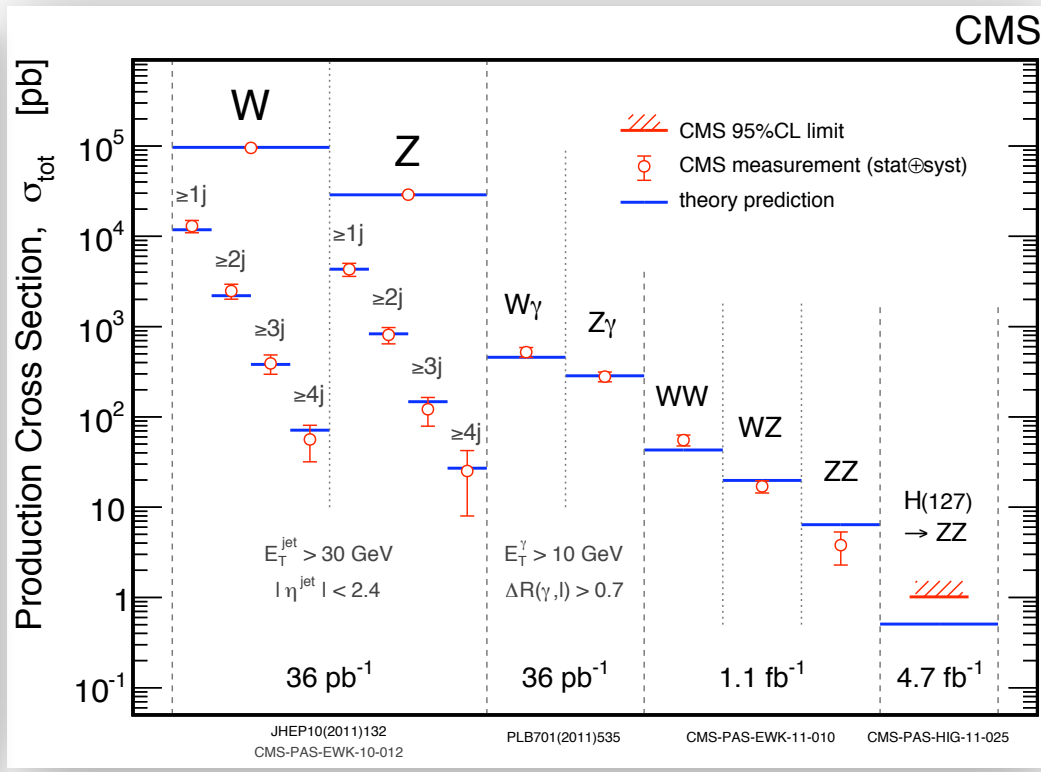
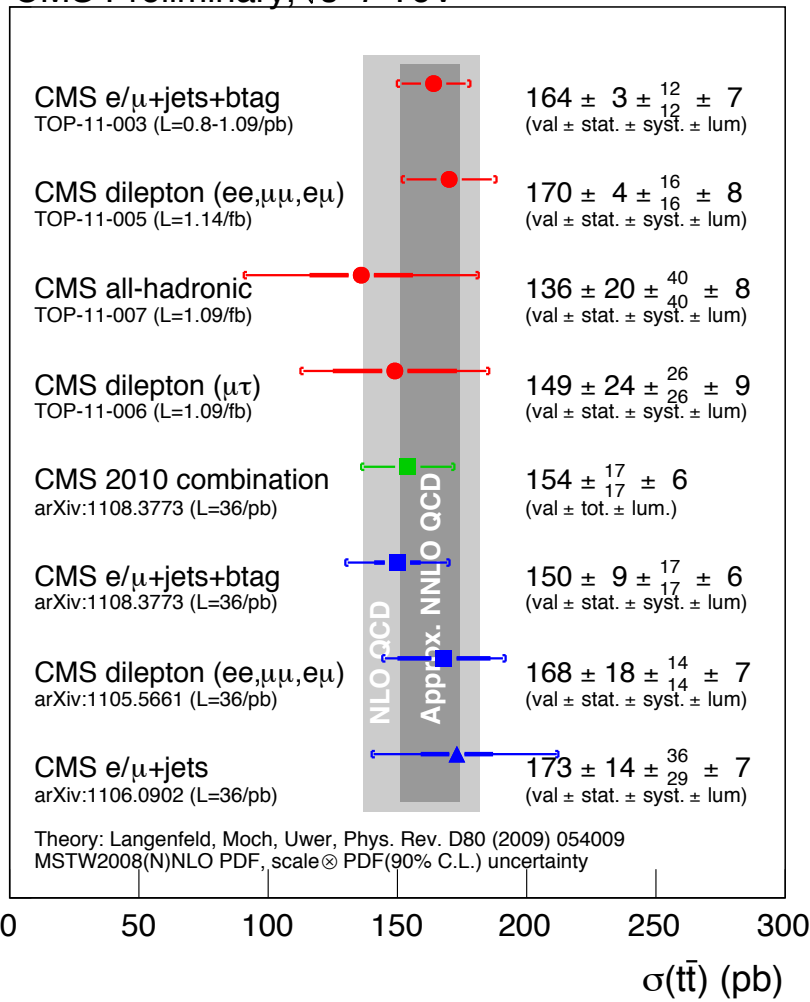
CMS-PAS-EWK-11-007



Standard Model at 7 TeV 2010-2011

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CMS Preliminary, $\sqrt{s}=7$ TeV



- Fabulous agreement
- Lots of data
- ... on to the Higgs...

$H \Rightarrow \gamma\gamma$

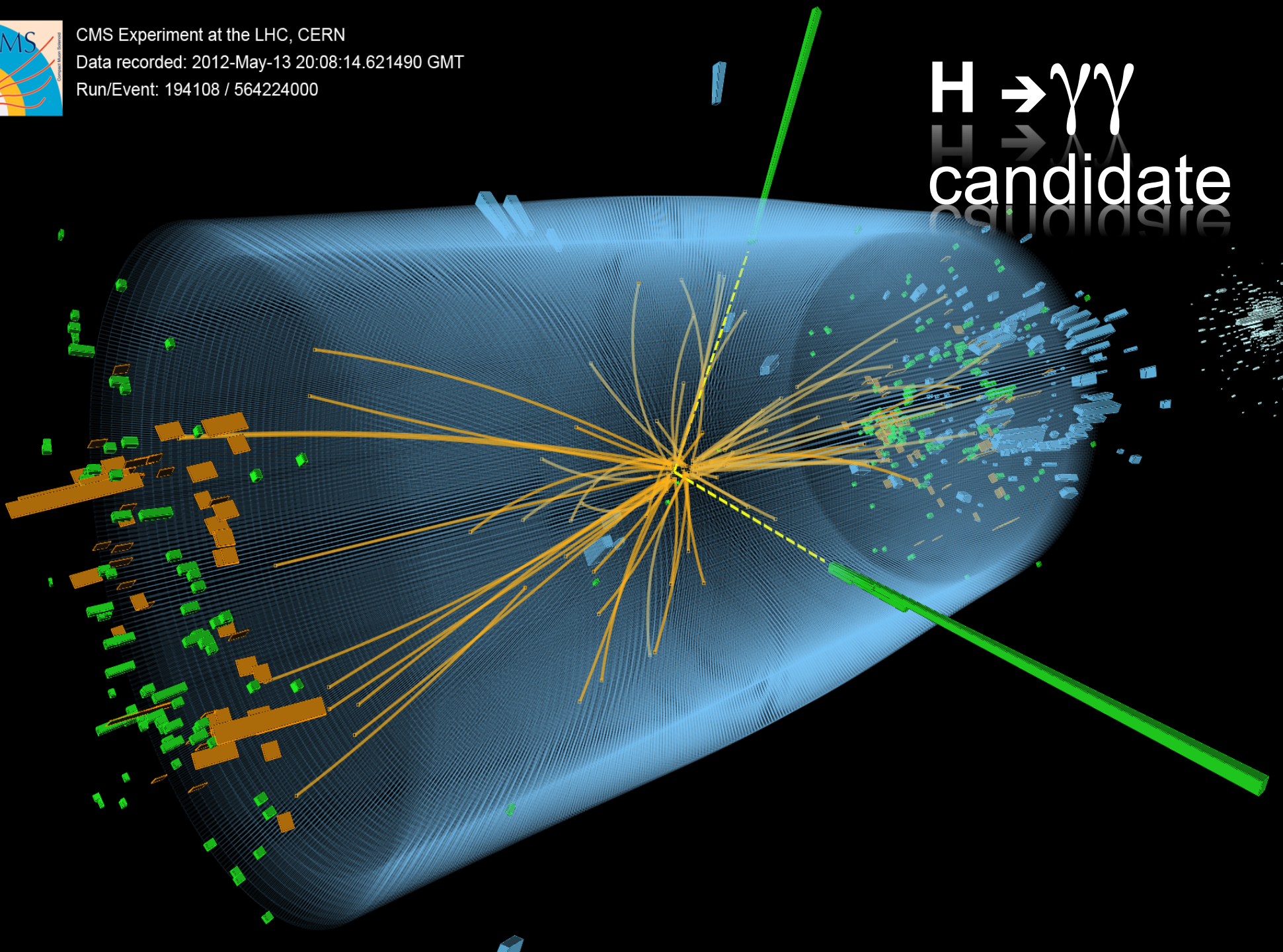


CMS Experiment at the LHC, CERN

Data recorded: 2012-May-13 20:08:14.621490 GMT

Run/Event: 194108 / 564224000

$H \rightarrow \gamma\gamma$
candidate





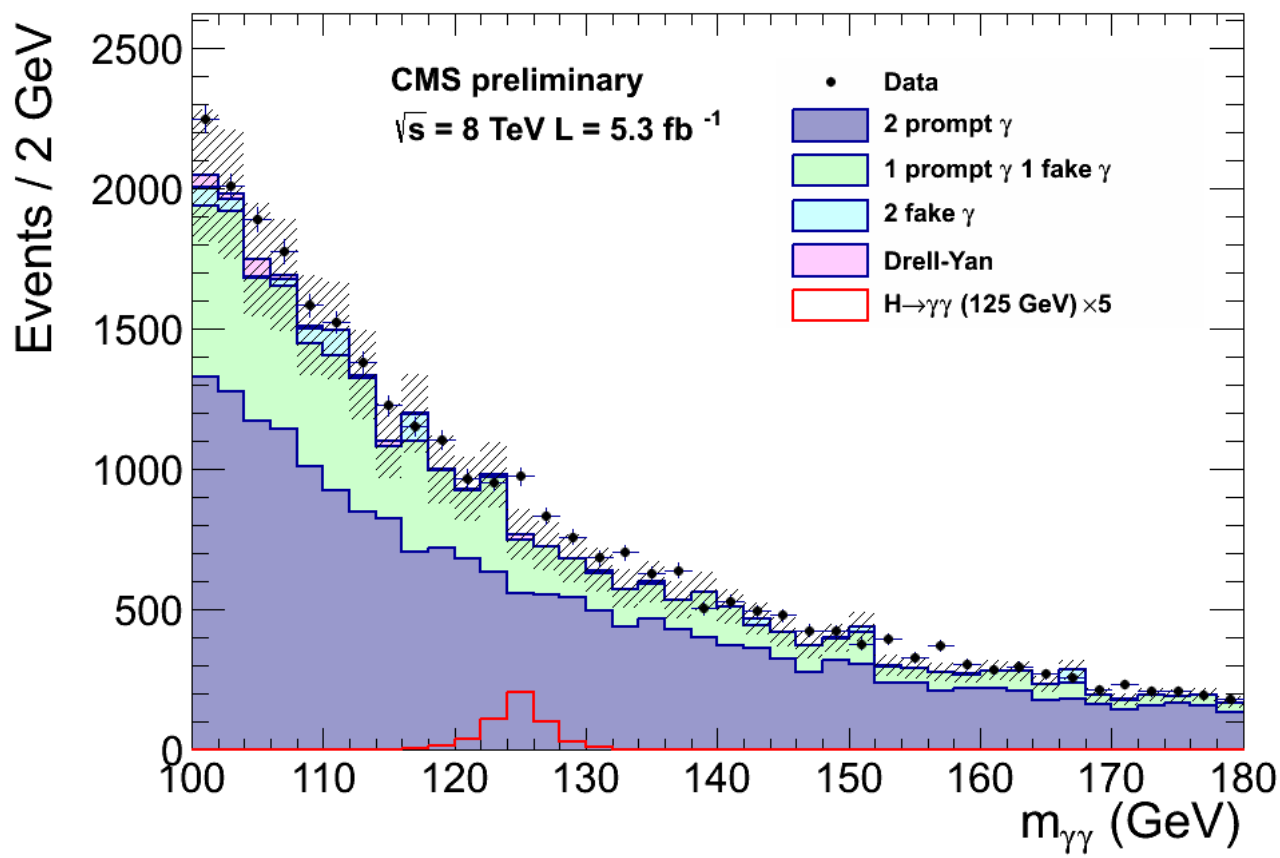
H \rightarrow $\gamma\gamma$ Overview

- Main analysis is a Multi-Variate-Analysis (MVA)
 - MVAs for photon ID and event classification
 - Fit mass distribution in 4 event classes based on a diphoton MVA output + 2 di-jet categories
 - Improvement in expected limit $\sim 15\%$ over cut-based analysis
 - **Cross-checked with an alternative background model extraction:**
 - Fit output of a 2nd MVA combining diphoton MVA and $m_{\gamma\gamma}$ using data in mass sidebands to construct the background model
- Also cross-checked with a cut based analysis
 - **Simple and robust**
 - Cut based photon ID and event classification
 - Fit data mass distribution in 2 rapidity x 2 shower shape = 4 categories with different Signal over Background (S/B) + 2 di-jet categories
 - **Published for 2011 data**
 - Phys.Lett. B710 (2012) 403-425 arXiv:1202.1487



Search for a narrow mass peak with two isolated high Et photons

2012 8 TeV

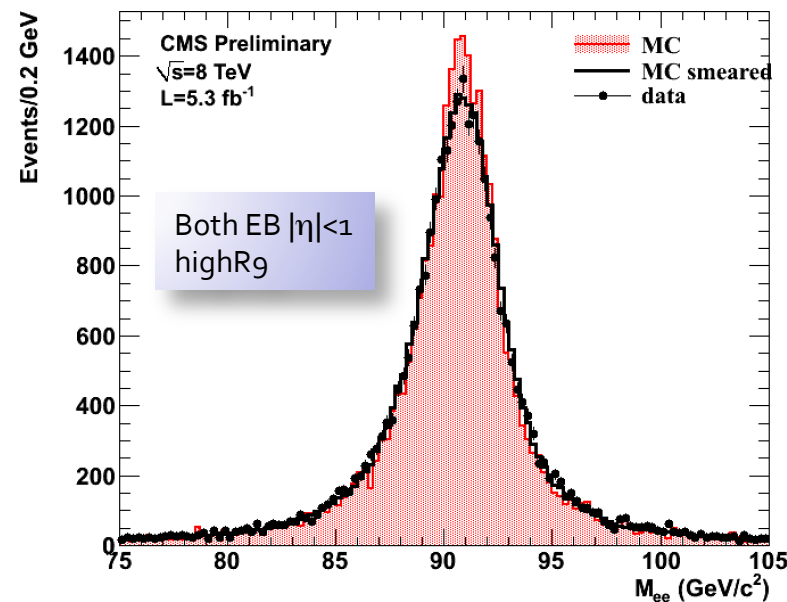
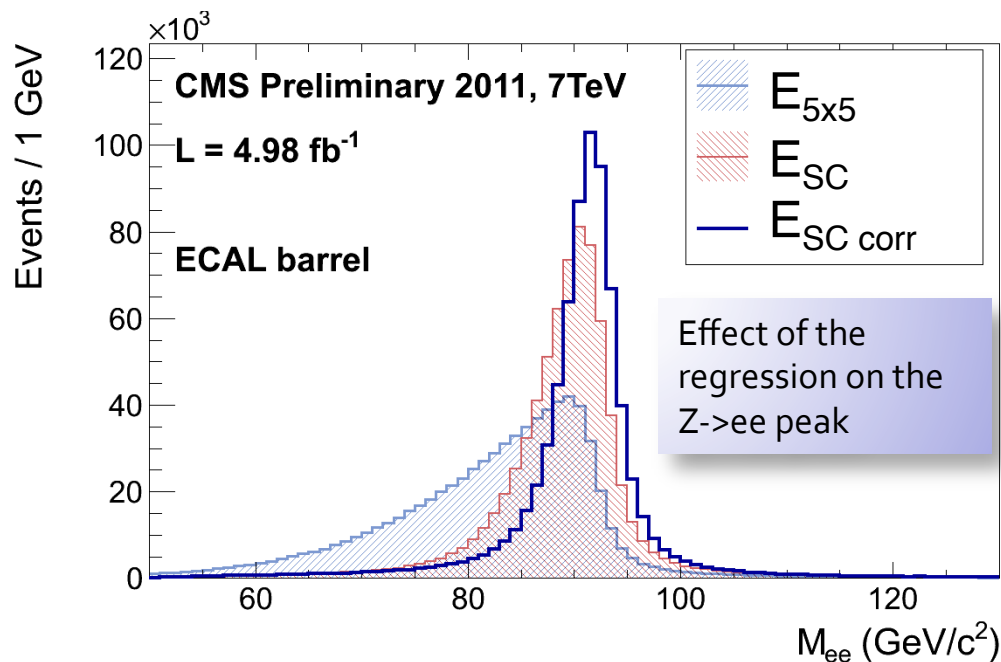


- Blind analysis in 2012
- Re-reco 2011 data into unchanged 2011 analysis
- Background MC only used for analysis optimization, $Z \rightarrow ee$ also to measure photon efficiencies and resolution with data



Photon Energy Scale and Resolution

- ECAL cluster energies corrected using a MC trained multivariate regression
 - Improves resolution and restores flat response of energy scale versus pileup
 - Inputs: Raw cluster energies and positions, lateral and longitudinal shower shape variables, local shower positions w.r.t. crystal geometry, pileup estimators
- Regression also used to provide a per photon energy resolution estimate
- To measure the Energy Scale and resolution: use $Z \rightarrow e^+e^-$

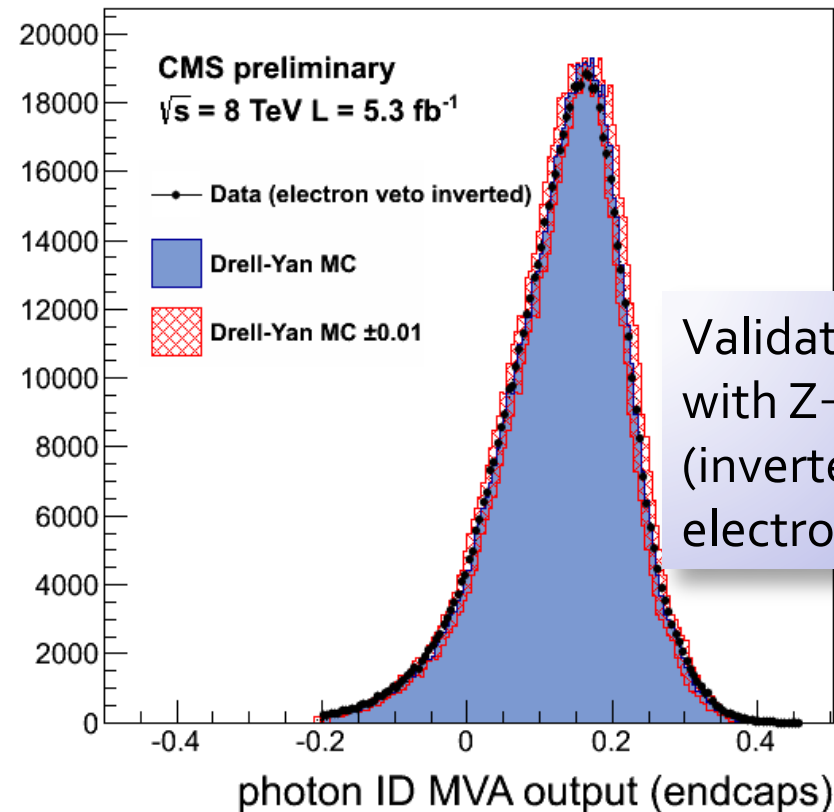
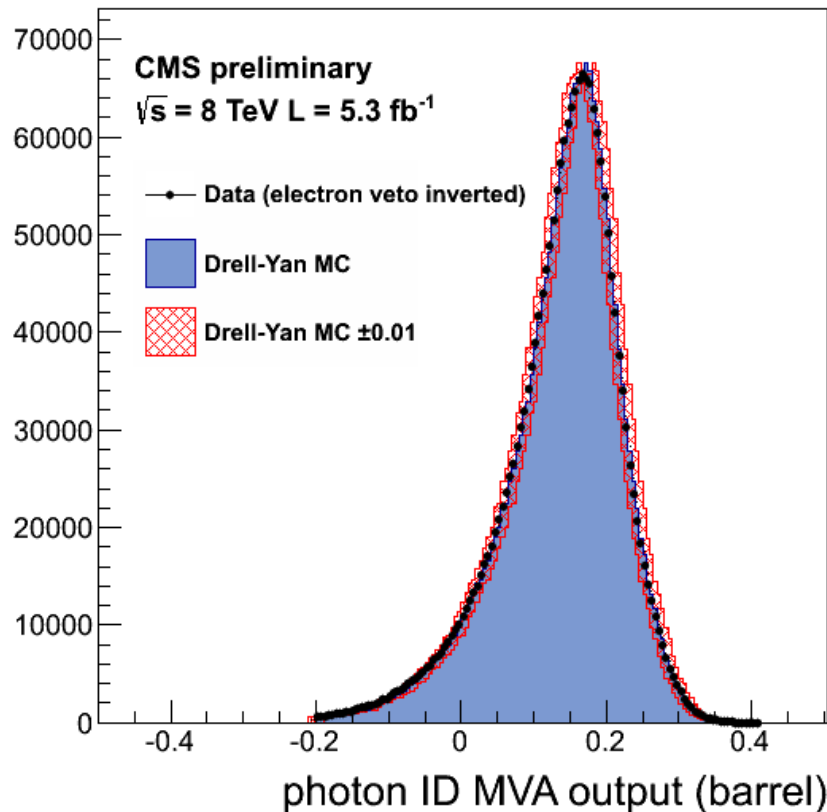


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Photon ID

- **Photon pre-selection:**
 - $E_{T\gamma 1}/m_{\gamma\gamma} > 3, E_{T\gamma 2}/m_{\gamma\gamma} > 4$
 - Photon ID a bit tighter than trigger selection and MC EM enrichment filters
 - Efficiency measured using tag and probe with $Z \rightarrow ee$
 - Electron veto: Efficiency measured using tag and probe with $Z \rightarrow \mu\mu\gamma$
- **MVA based photon ID discriminates photons from fakes:**
 - Inputs: isolation, shower shape, per event energy density, pseudorapidity

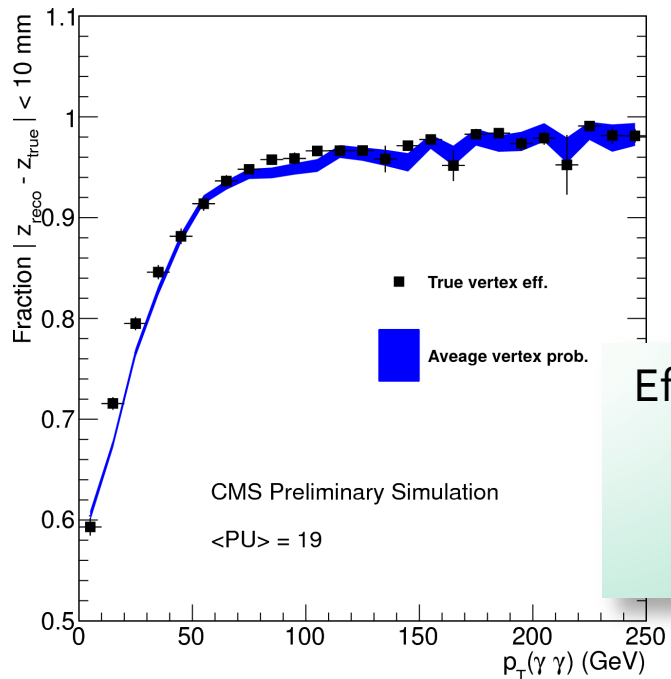


Validation with $Z \rightarrow ee$ (inverted electron veto)

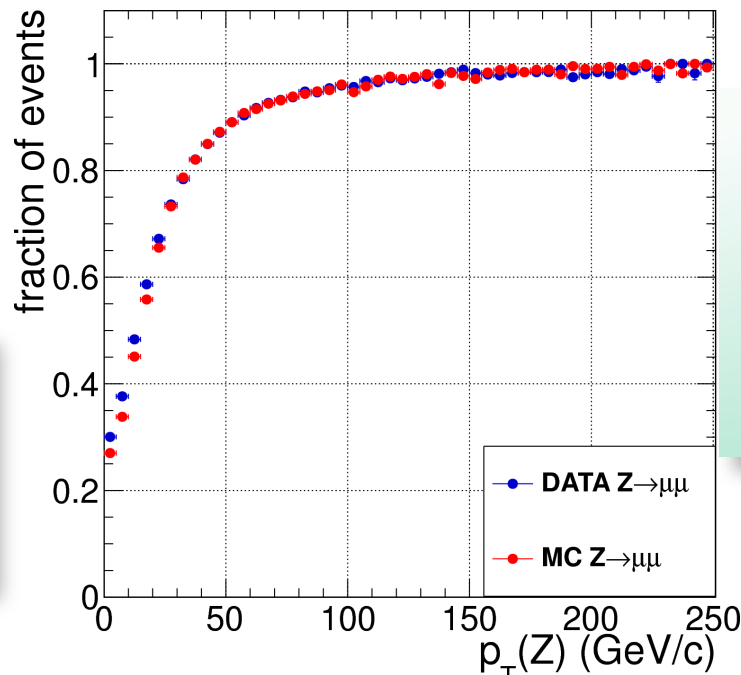


The $\gamma\gamma$ Vertex Choice

- Mass reconstruction
 - Depends on the correct position of the primary vertex
- Interaction vertex is identified using tracks from recoiling jets and underlying event plus conversions
 - correct in ~83% of cases for pileup in 2011 sample.
 - correct in ~80% of cases for pileup in 2012 sample.
- Vertex identification with a BDT
 - Input variables: Σp_t^2 , Σp_t projected onto the $\gamma\gamma$ transverse direction, p_t asymmetry and conversions
- Correct vertex finding probability also estimated using a BDT



Efficiency to identify correct vertex

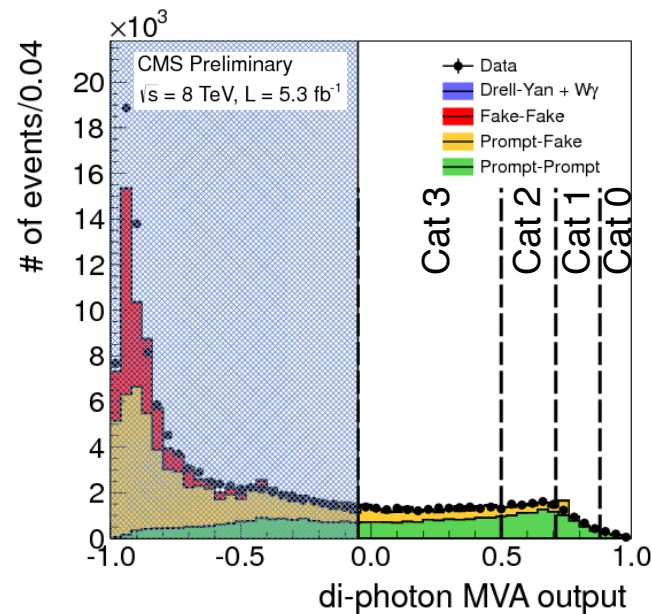
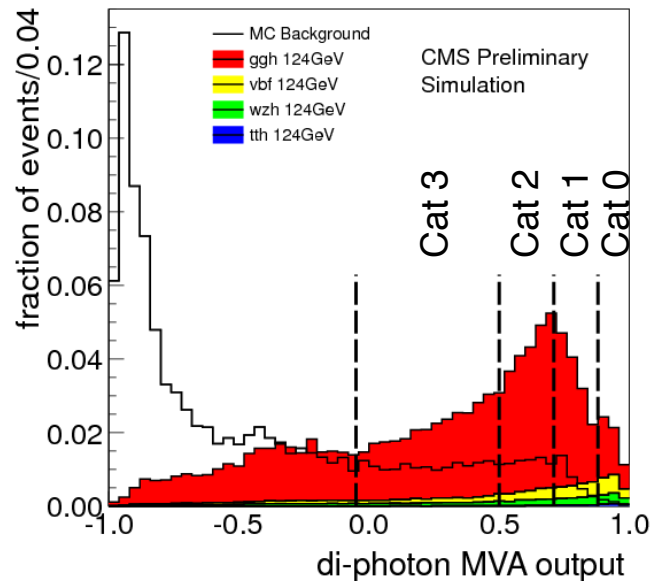


Data-MC efficiency for Z $\rightarrow \mu\mu$ After removing the μ tracks



Diphoton MVA

- Diphoton MVA trained on signal and background MC with input variables largely independent of $m_{\gamma\gamma}$
 - Kinematics: p_T and η of each photon, and $\cos\Delta\phi$ between the 2 photons
 - Photon ID MVA output for each photon
 - per-event mass resolution and vertex probability
- Encode all relevant information on signal vs background discrimination (aside from $m_{\gamma\gamma}$ itself) into a single di-photon MVA output to first order independent of $m_{\gamma\gamma}$



- Residual data-MC disagreement
 - For BG only make analysis sub-optimal
 - For signal would cause some category migration included in the systematic errors

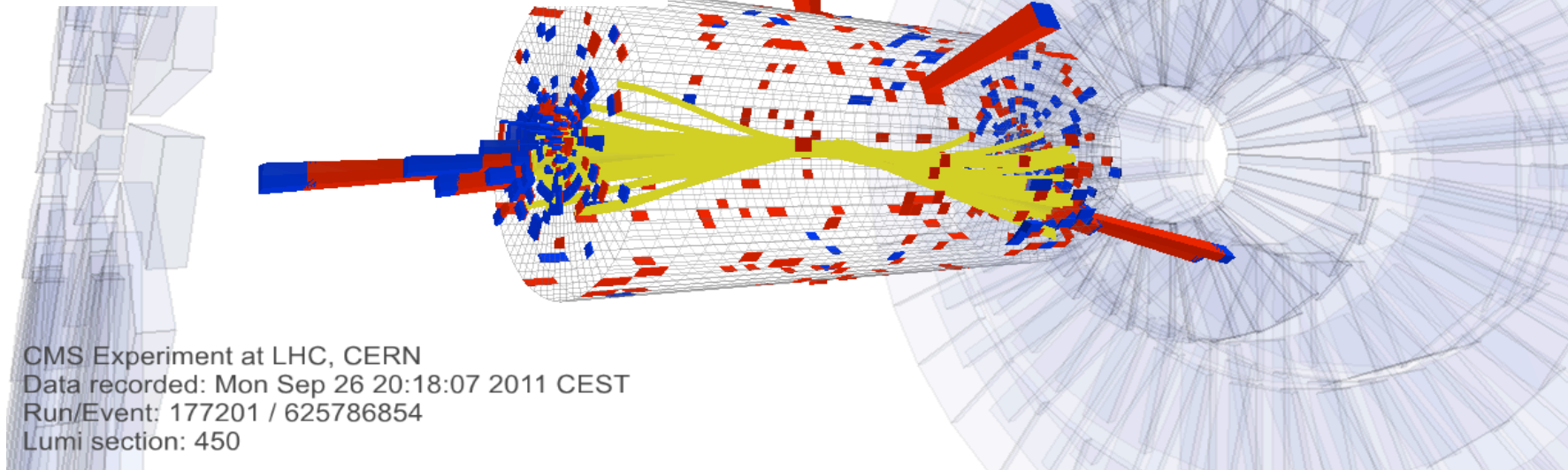


Di-jet Tagging

- Exclusive selection of di-photon events with VBF-like topology:
 - Two high p_T jets with large pseudo-rapidity difference and invariant mass
- High S/B
- ~80%-pure VBF events for large di-jet invariant masses

Di-jet event with:

- diphoton mass 121.9 GeV
- dijet mass 1460 GeV
- jet p_T : 288.8 and 189.1 GeV
- jet η : -2.022 and 1.860



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



Di-jet Tagging: Selection

Analysis improvements in 2012:

- Split di-jet tagged events in two categories based on M_{jj} and jet p_T
 - ~15% improvement in sensitivity for dijet category
 - better sensitivity to separate different Higgs production modes
- Removal of jets from pileup events
 - Based on the jet shape variables, tracks in jet and vertexing
 - Cross-checked using Z+jet and γ +jet events

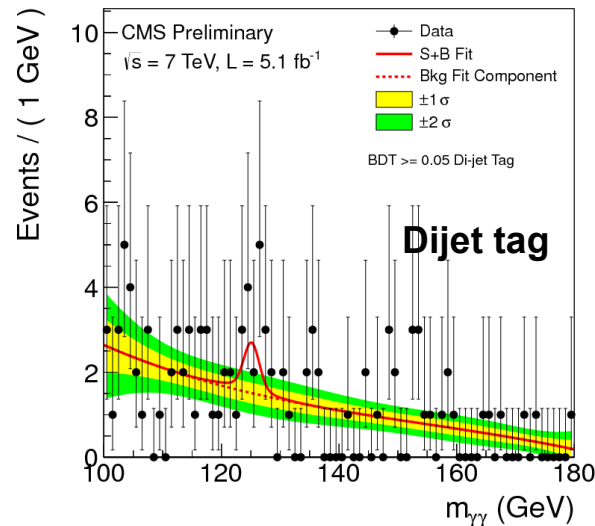
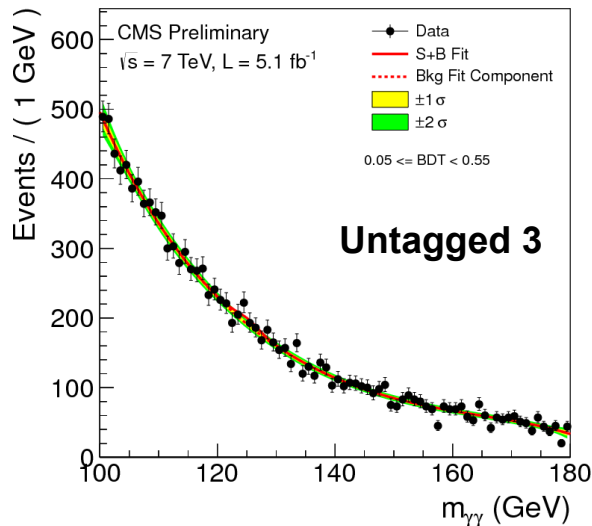
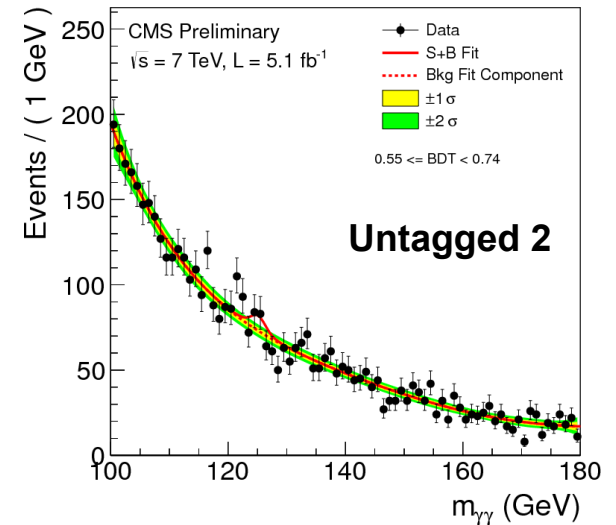
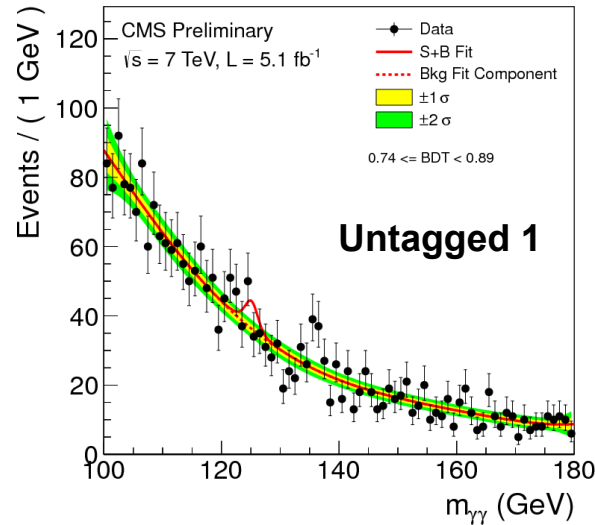
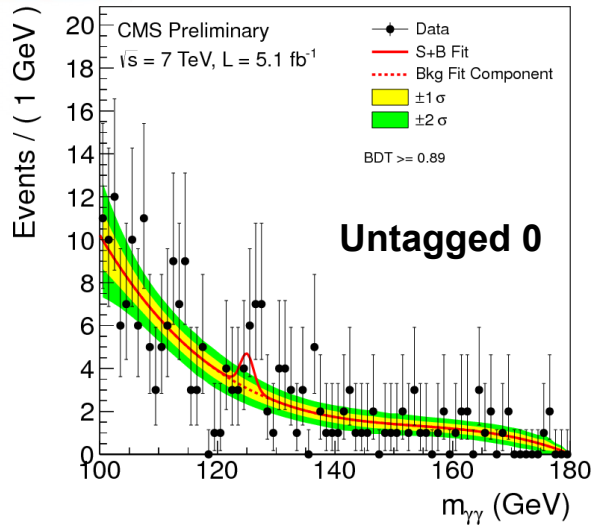
Dijet selection cuts

Variable	2011	2012	
		Loose	Tight
$p_T(j_1)$	> 30 GeV		
$p_T(j_2)$	> 20 GeV	> 30 GeV	
$\Delta\eta(j_1, j_2)$	> 3.5	> 3.0	
$ \eta_{\gamma\gamma} - \frac{1}{2}(\eta_{j1} + \eta_{j2}) $	< 2.5		
$\Delta\phi(jj, \gamma\gamma)$	> 2.6		
m_{jj}	> 350 GeV	> 250 GeV	> 500 GeV



7 TeV Mass Distribution in Categories

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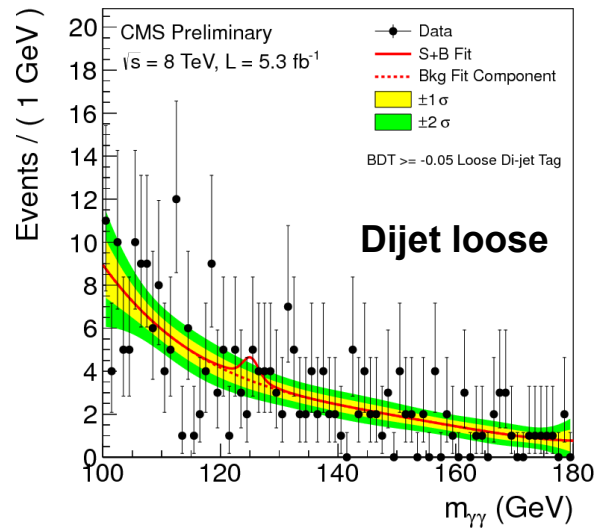
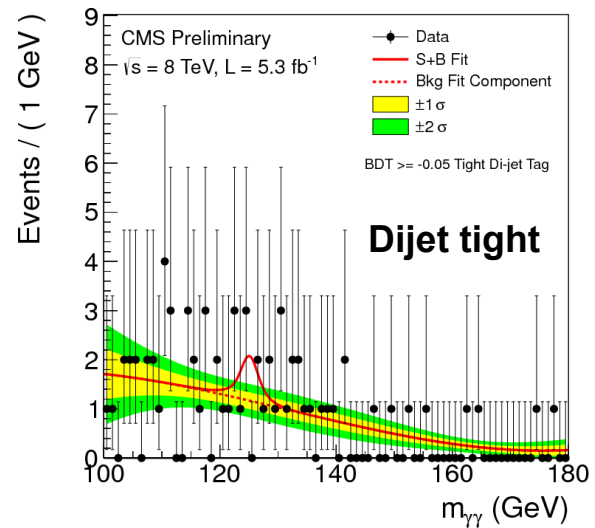
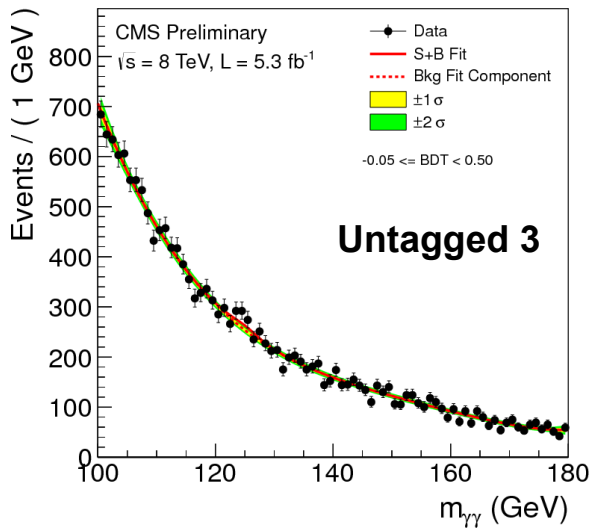
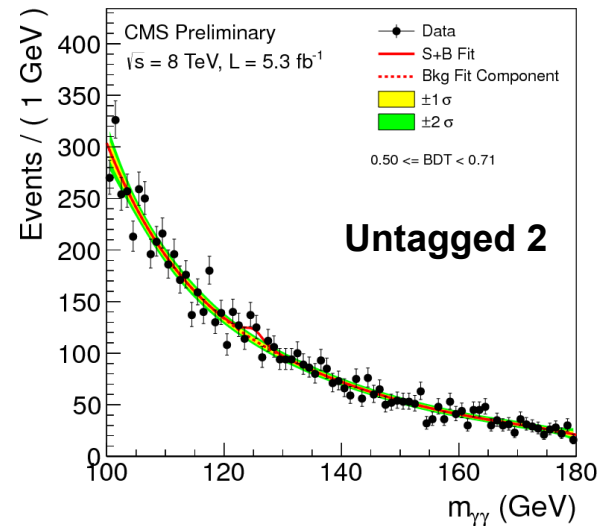
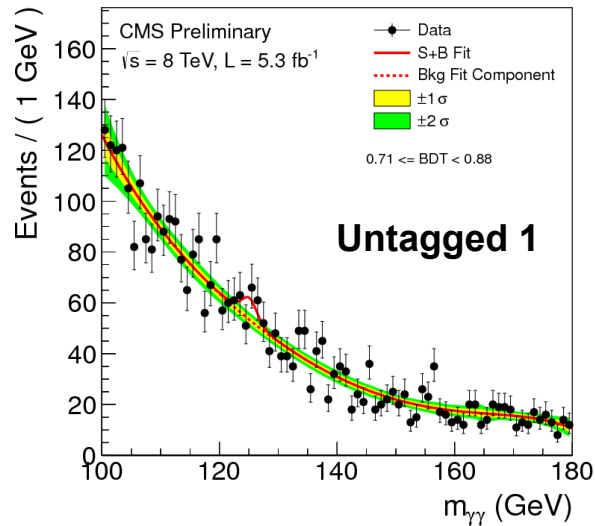
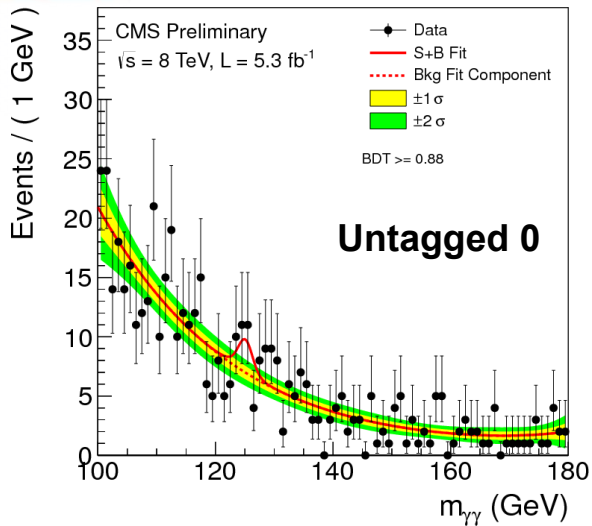


- Background model is entirely from data.
- Fit to mass distribution in each category with polynomial functions (3rd to 5th degree)
 - keep bias below 20% of fit error.
 - causes some loss of performance due to number of parameters in fit function.



8 TeV Mass Distribution in Categories

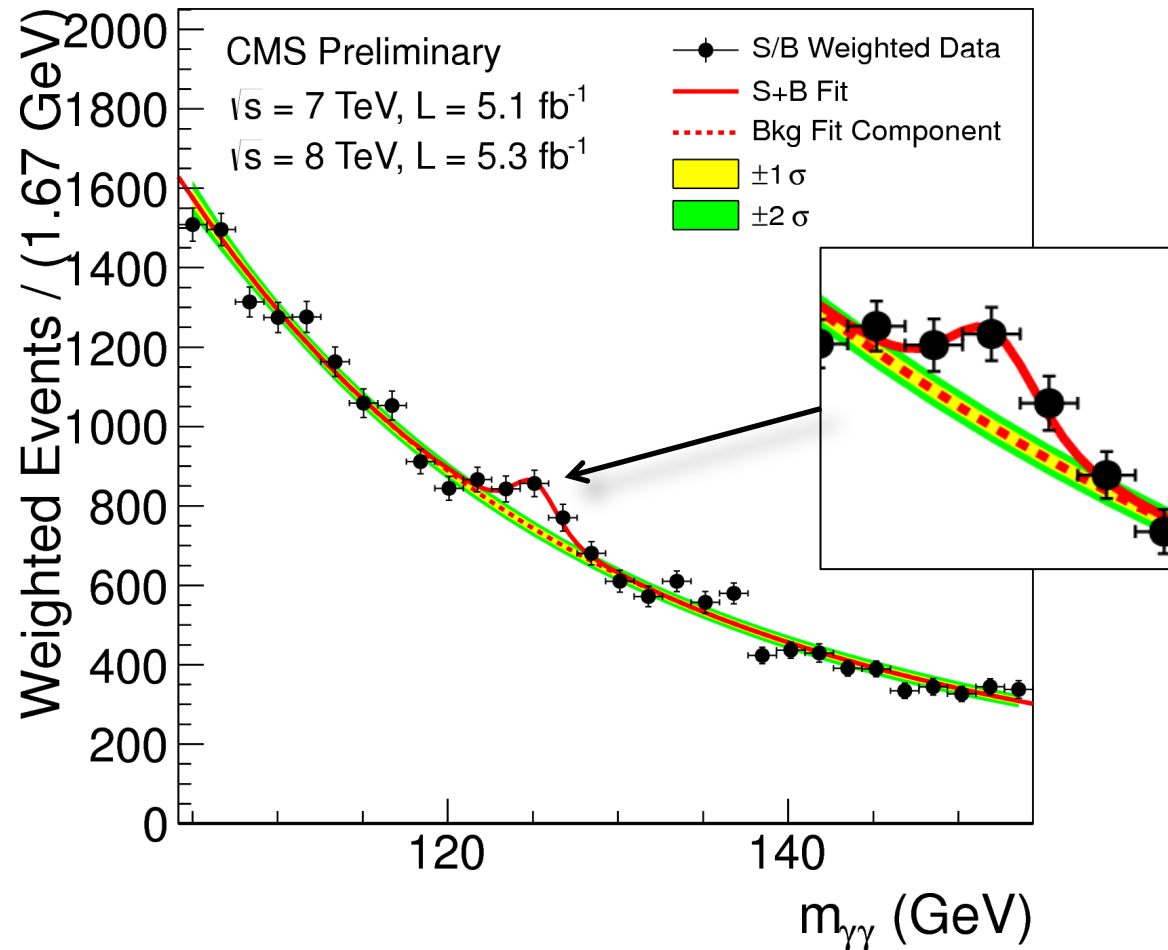
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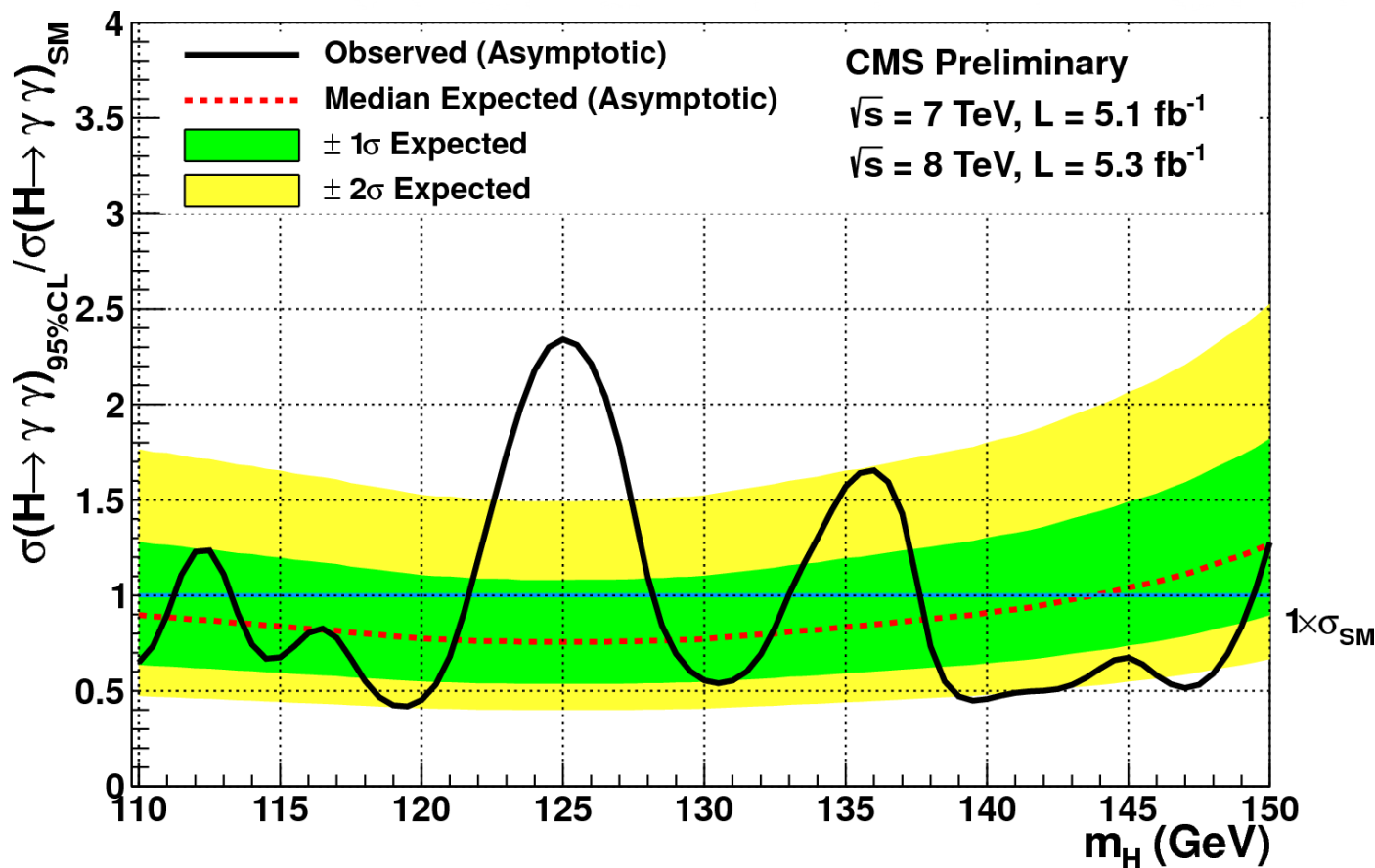
S/B Weighted Mass Distribution

- Sum of mass distributions for each event class, weighted by S/B
 - B is integral of background model over a constant signal fraction interval





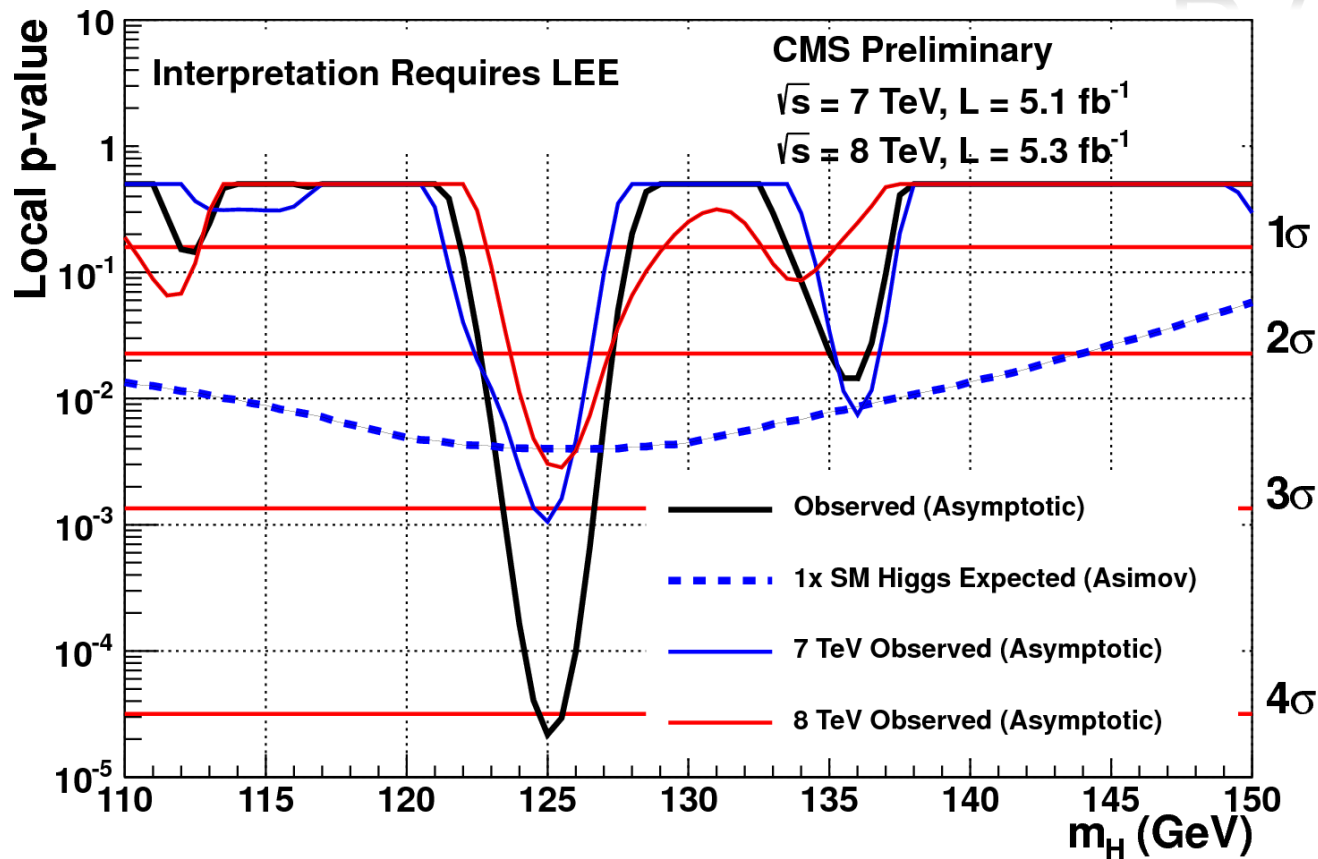
95% CL Exclusion for SM Higgs



- Expected 95% CL exclusion 0.76 times SM at 125 GeV
- Large range with expected excusion below σ_{SM}
- Largest excess at 125 GeV



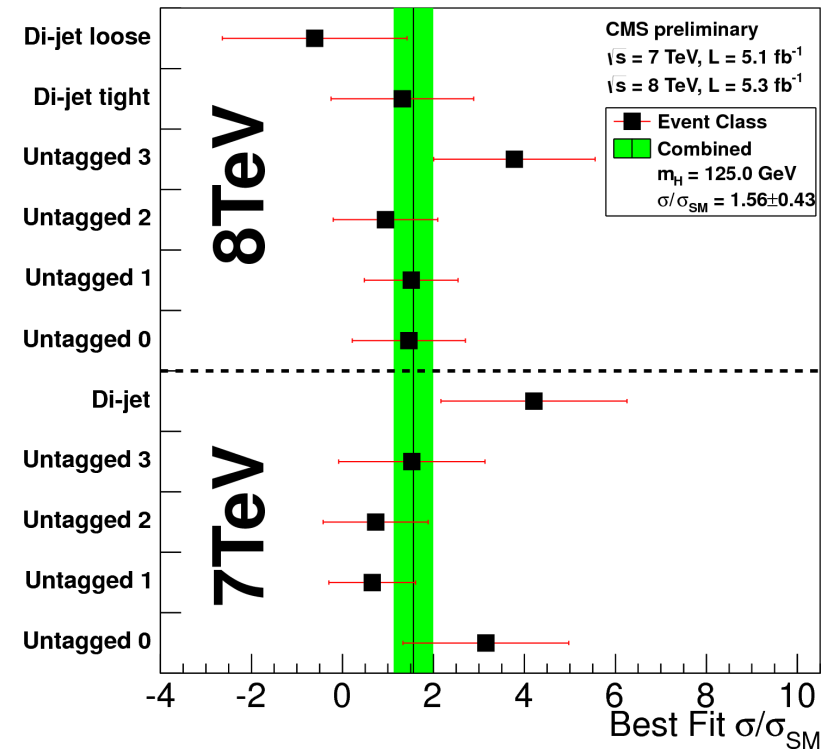
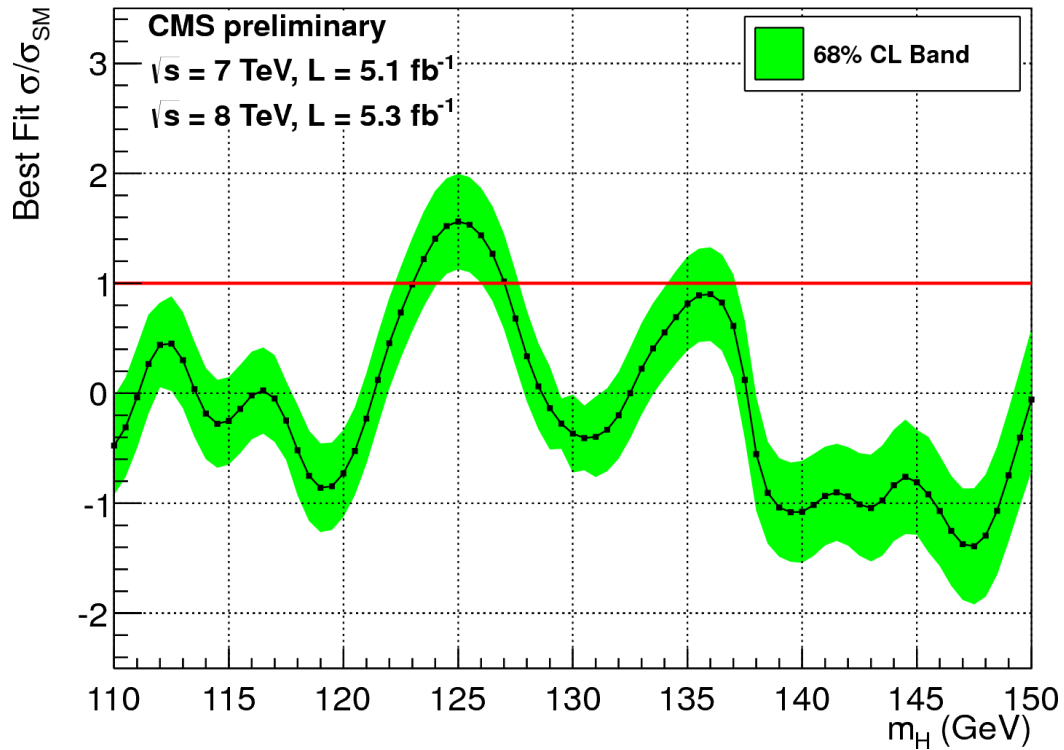
P-Values



- Minimum local p-value at 125 GeV with a local significance of 4.1σ
- Similar excess in 2011 and 2012
- Independent cross check analyses give similar results
- Global significance in the full search range (110-150 GeV) 3.2σ



Fitted Signal Strength



Combined best fit signal strength
 $\sigma/\sigma_{\text{SM}} = 1.56 \pm 0.43 \times \text{SM}$,
 consistent with SM.

Best fit signal strength
 consistent between
 different classes

$H \Rightarrow ZZ^*$



$H \rightarrow ZZ^{(*)} \rightarrow 4l$ ($l = e, \mu$): the golden channel

Clean signature: narrow peak, low background

Background: irreducible $ZZ^{(*)}$; reducible Z +jets, $t\bar{t}$, WZ

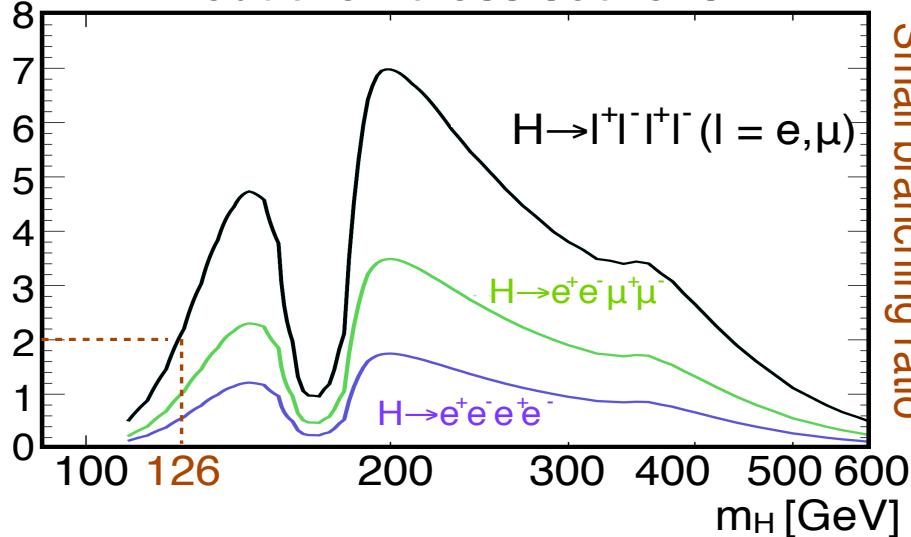
One of the best performing channels in the whole mass range ...

... but extremely demanding channel for selection, requiring the highest possible efficiencies (lepton Reco/ID/Isolation).

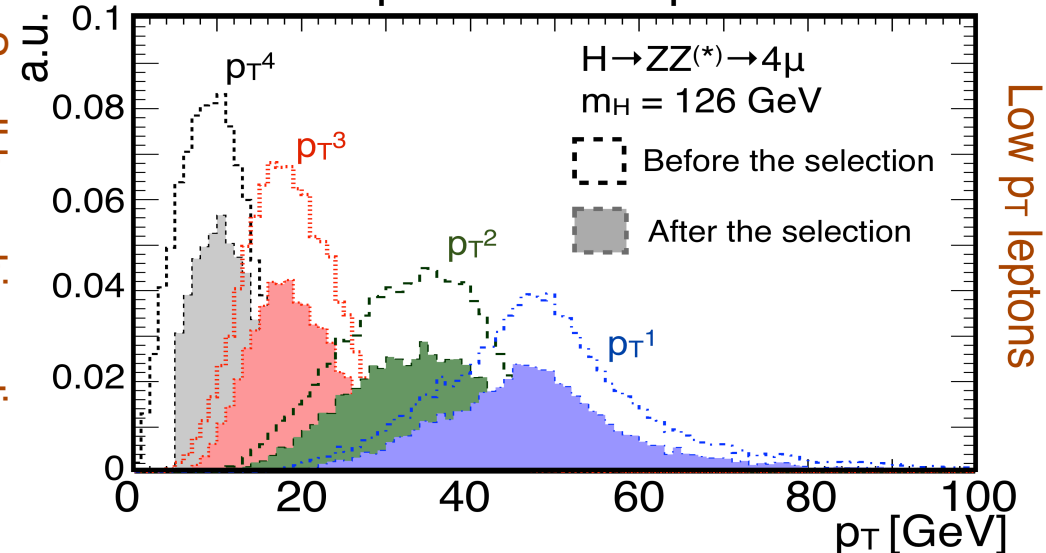
J. Incandela for the CMS COLLABORATION

July 4th 2012 The Status of the Higgs Search

Production cross sections



p_T of the 4 leptons





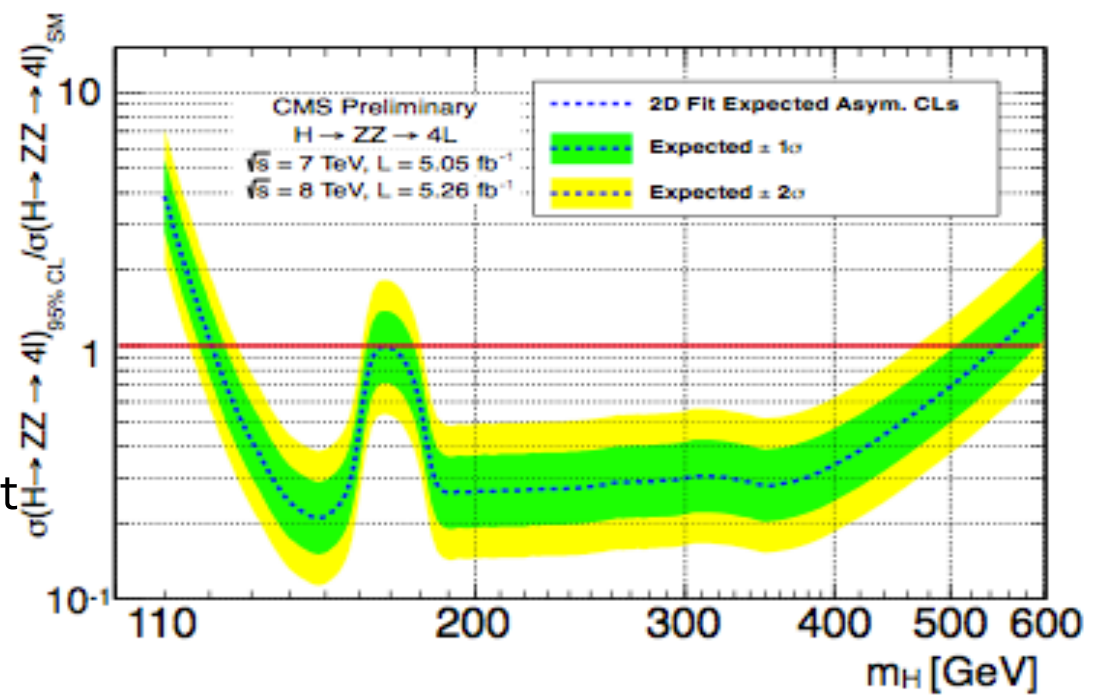
2012 analysis + improvements

Blinding policy: analysis optimized blindly for 2012, applied to 2011 reoptimization

Do NOT look at $110 < m_{4l} < 140$ GeV, and $m_{4l} > 300$ GeV

Main changes:

- New lepton ID (MVA + PFlow)
- New lepton PFlow isolation
- Final State Radiation (FSR) recovery
- 2D analysis: m_{4l} + Kinematic Discriminant



>20% improvement @ $m_H = 126$ GeV wrt 2011 analysis

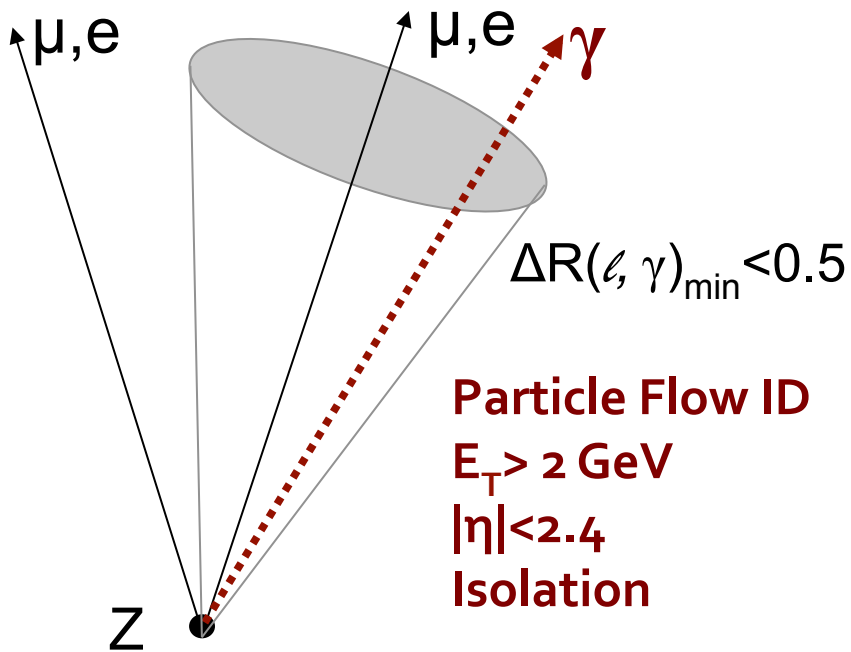
Expected exclusion range 121–540 GeV

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Final State Radiation recovery algorithm

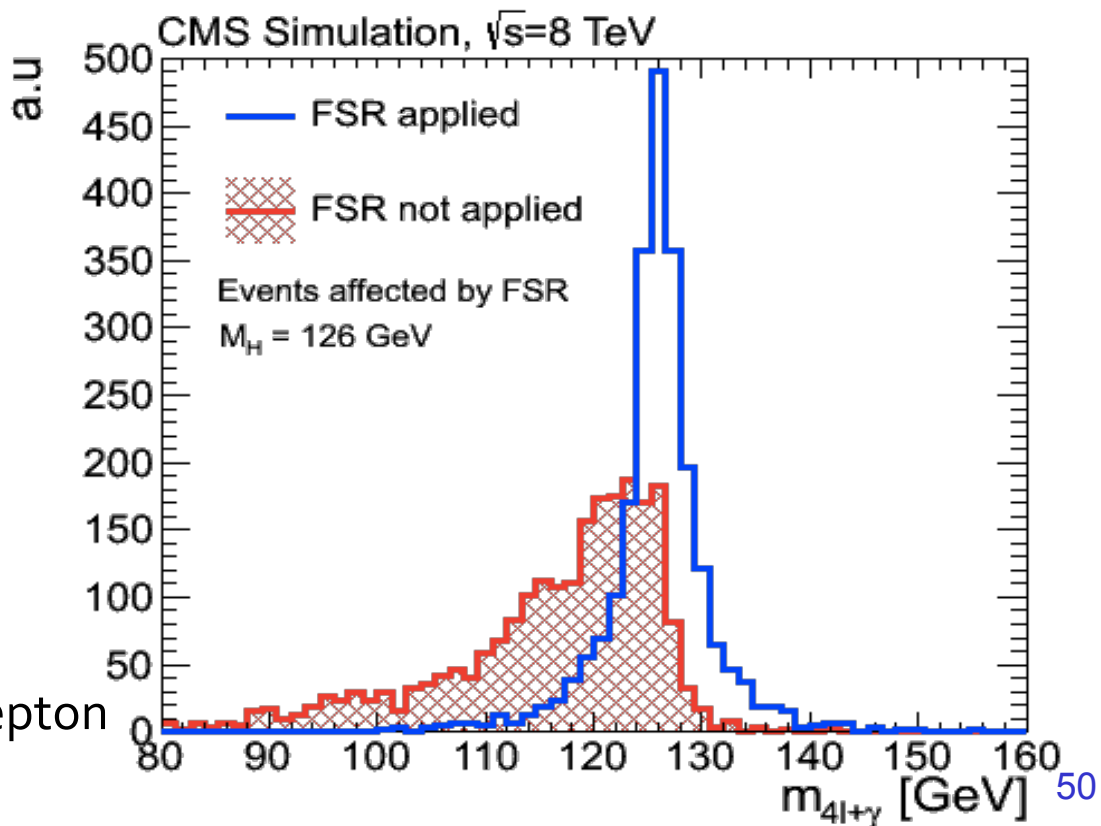
- Applied on each Z for photons near the leptons

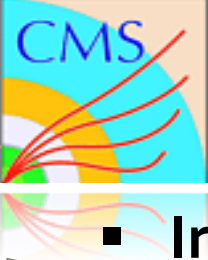


- Associates photon with Z if:
 - $M(\ell\ell+\gamma) < 100 \text{ GeV}$
 - $|M(\ell\ell+\gamma) - M_Z| < |M(\ell\ell) - M_Z|$
- Removes associated photons from lepton isolation calculation

Expected Performance for $M_H = 126 \text{ GeV}$

- 6% of events affected
- Average purity of 80%
- 2% added in analysis

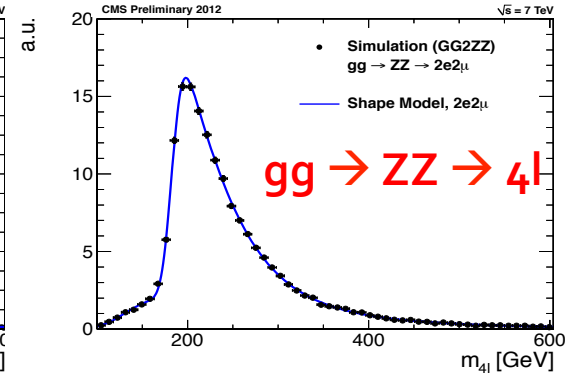
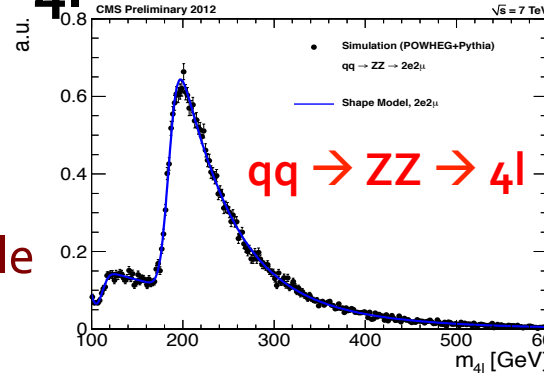




Background models

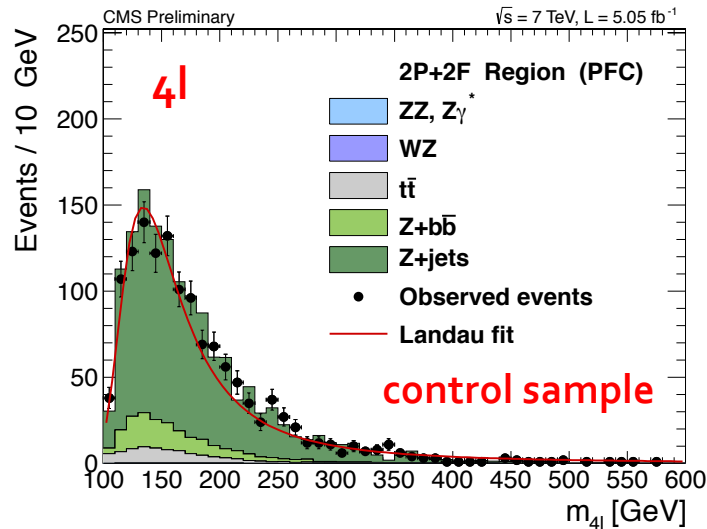
■ Irreducible background $ZZ \rightarrow 4l$

- Estimated using simulation
- Phenomenological shape models
- Corrected for data/simulation scale

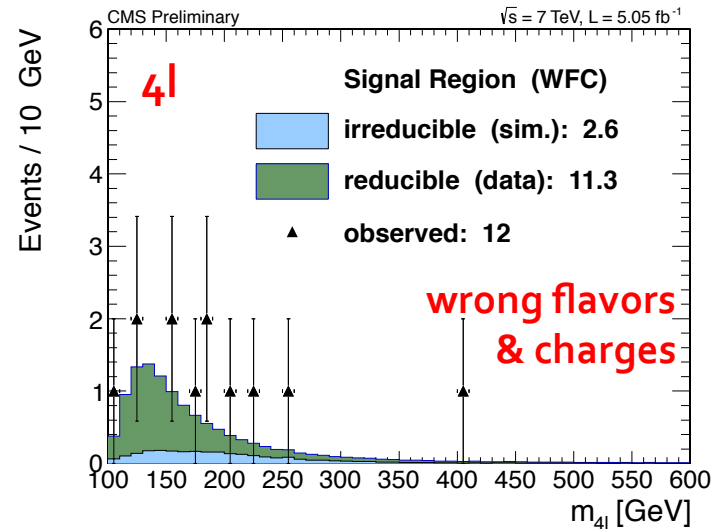


■ Reducible backgrounds estimated from data

- Extrapolation from control samples enriched with misidentified leptons
- Total uncertainty ~50%

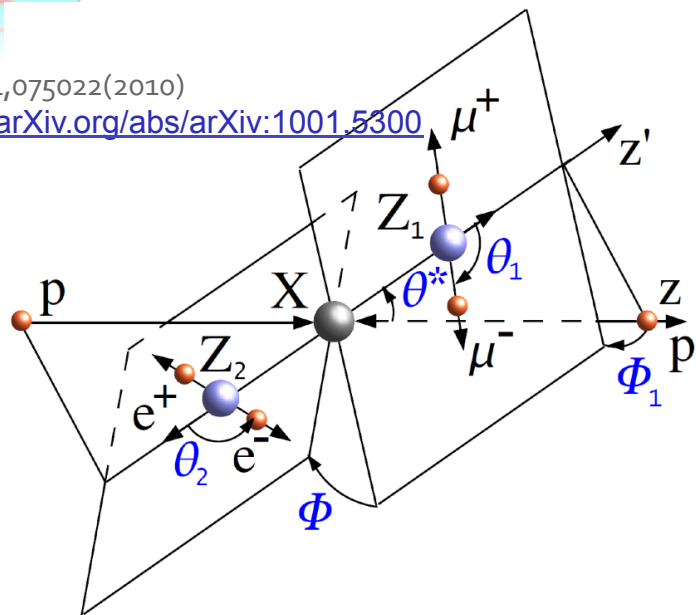


Validation in data





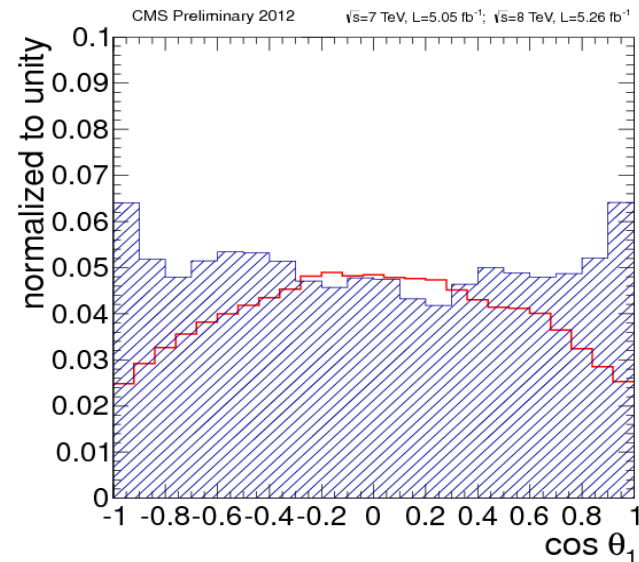
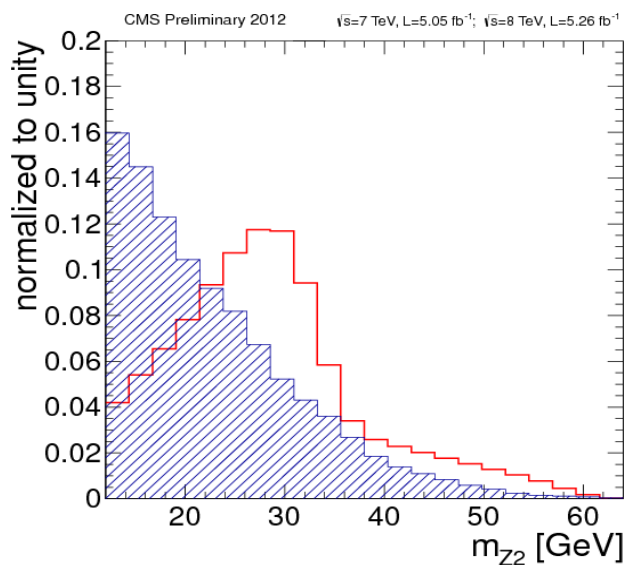
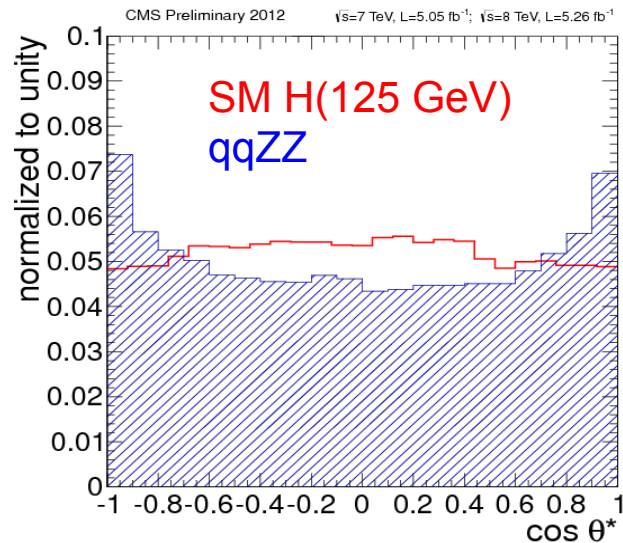
PRD81,075022(2010)
<http://arXiv.org/abs/arXiv:1001.5300>



Matrix Element Likelihood Analysis:
 uses kinematic inputs for
 signal to background discrimination

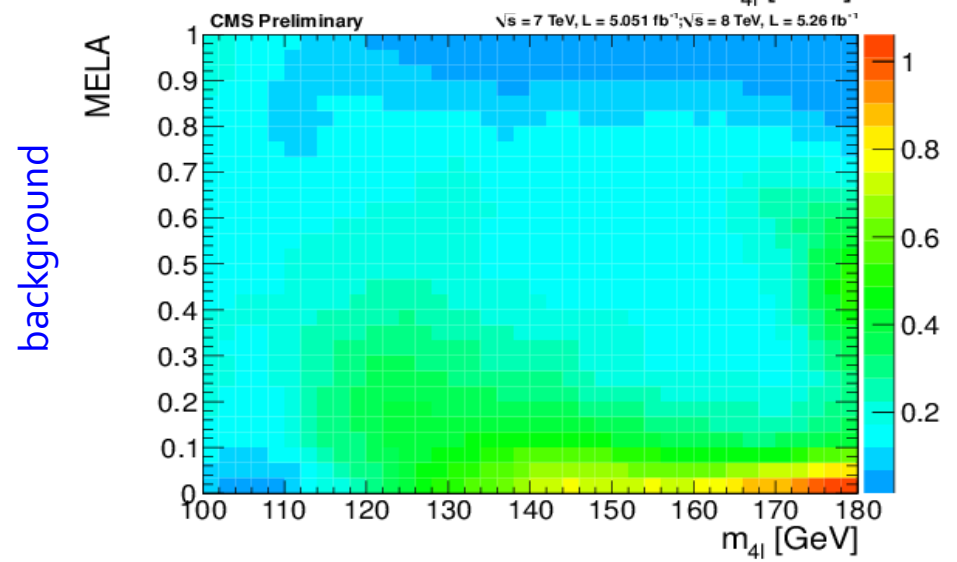
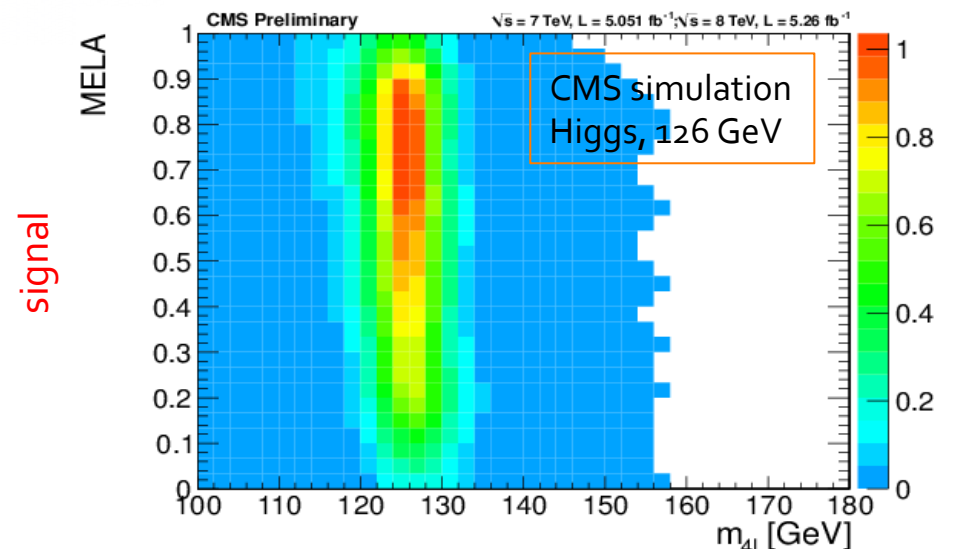
$$\{m_{1'}, m_{2'}, \theta_{1'}, \theta_{2'}, \theta^*, \Phi, \Phi_1\}$$

$$\text{MELA} = \left[1 + \frac{\mathcal{P}_{\text{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\text{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})} \right]^{-1}$$

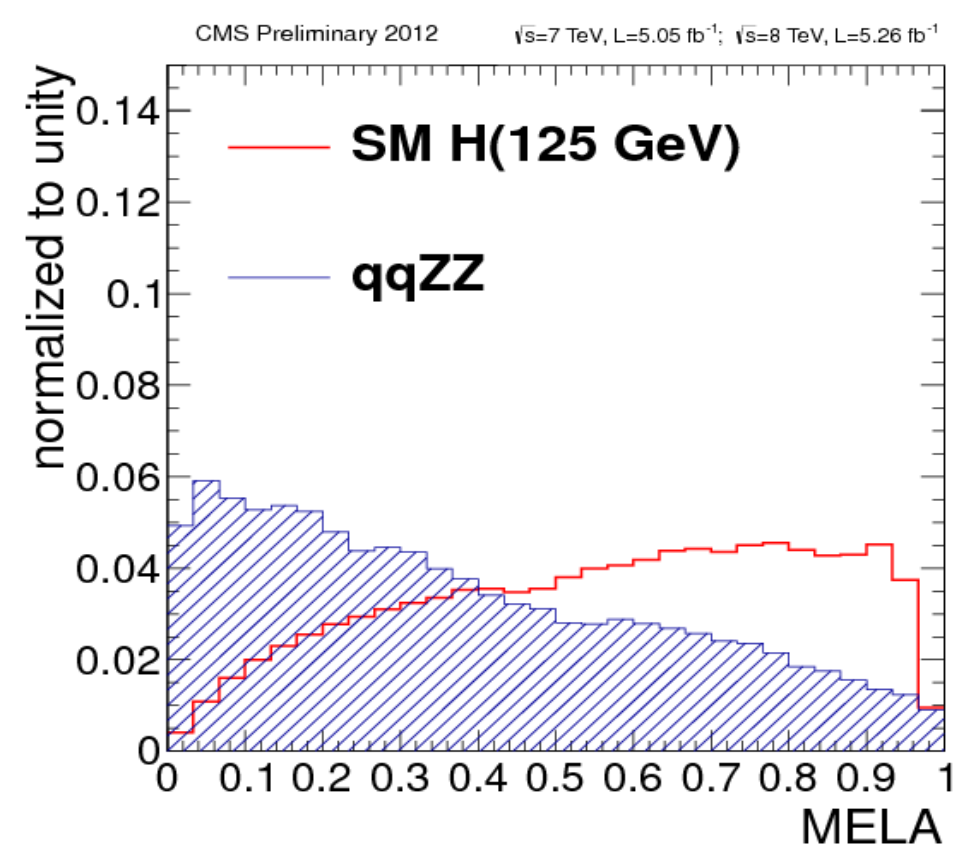




2D analysis using $\{m_{4l}, \text{MELA}\}$



MELA offers powerful discrimination of background



technique applicable for signal hypothesis testing

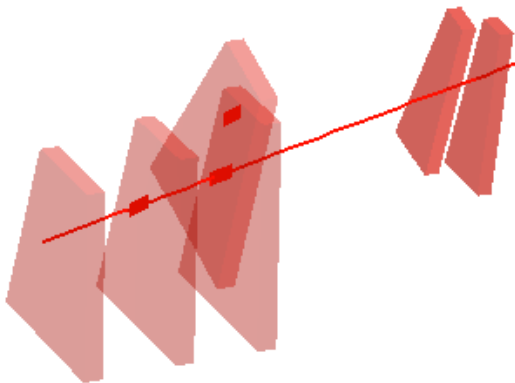


$\mu^+(Z_1) p_T : 43 \text{ GeV}$

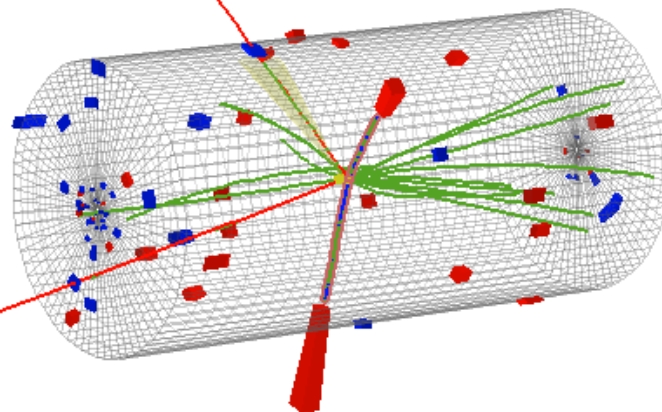
8 TeV DATA

4-lepton Mass : 126.9 GeV

$\mu^-(Z_1) p_T : 24 \text{ GeV}$



$e^-(Z_2) p_T : 10 \text{ GeV}$



$e^+(Z_2) p_T : 21 \text{ GeV}$

CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:35:47 2012 CEST
Run/Event: 195099 / 137440354
Lumi section: 115

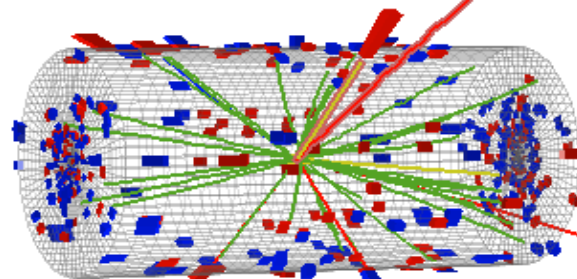


CMS Experiment at LHC, CERN
Data recorded: Thu Oct 13 03:39:46 2011 CEST
Run/Event: 178421 / 87514902
Lumi section: 86



$\gamma(Z_1) E_T : 8 \text{ GeV}$

$\mu^-(Z_1) p_T : 28 \text{ GeV}$



7 TeV DATA

4 μ + γ Mass : 126.1 GeV

$\mu^+(Z_2) p_T : 6 \text{ GeV}$

$\mu^-(Z_2) p_T : 14 \text{ GeV}$

$\mu^+(Z_1) p_T : 67 \text{ GeV}$



CMS Experiment at LHC, CERN
 Data recorded: Tue Oct 4 00:10:13 2011 CEST
 Run/Event: 177782 / 72158025
 Lumi section: 99

$\mu^-(Z_2) p_T : 15 \text{ GeV}$

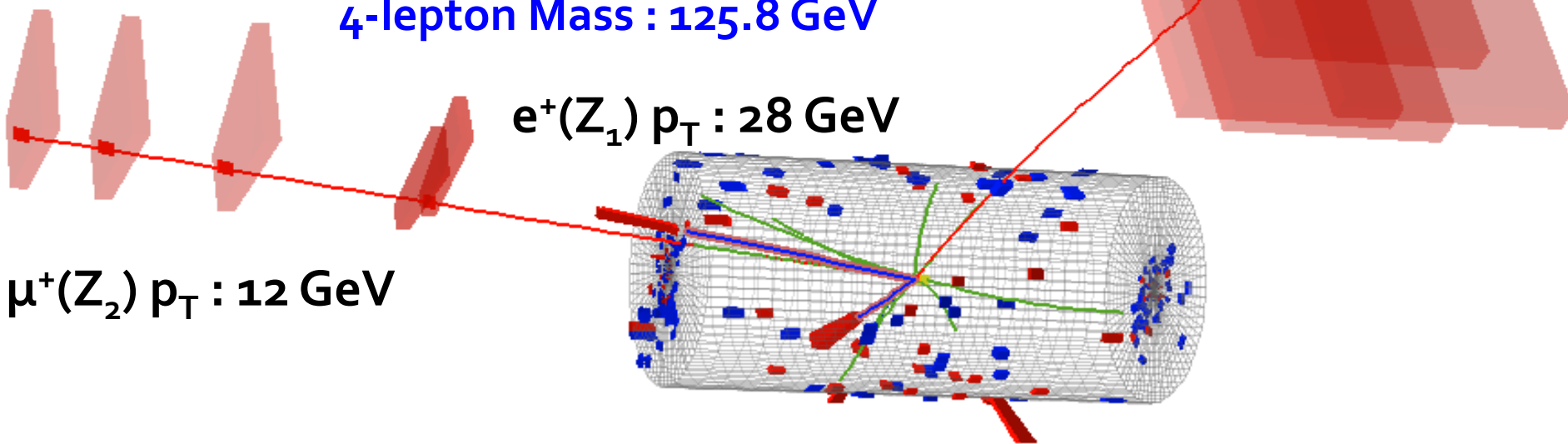
7 TeV DATA

4-lepton Mass : 125.8 GeV

$e^+(Z_1) p_T : 28 \text{ GeV}$

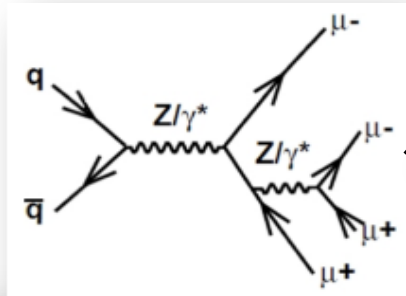
$\mu^+(Z_2) p_T : 12 \text{ GeV}$

$e^-(Z_1) p_T : 14 \text{ GeV}$

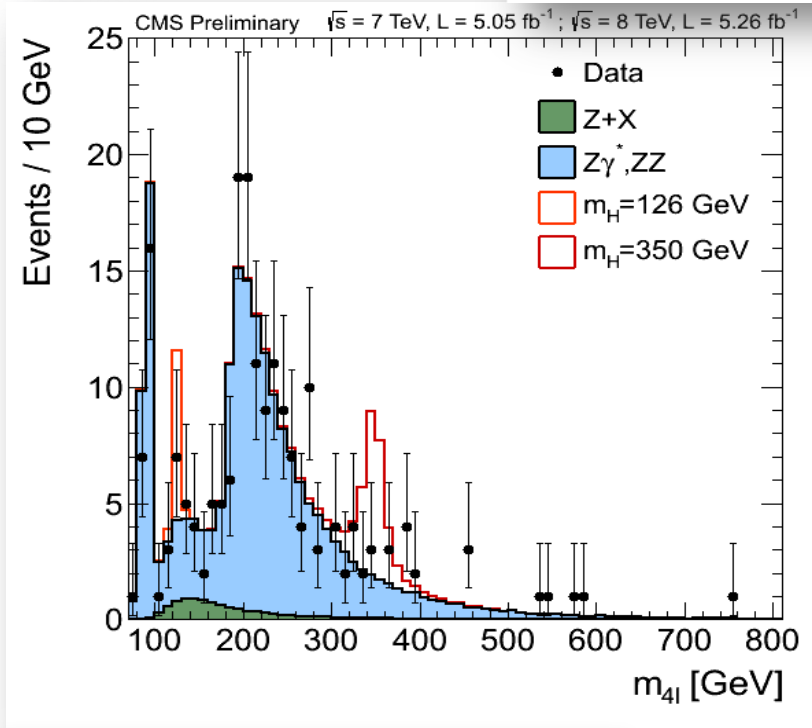




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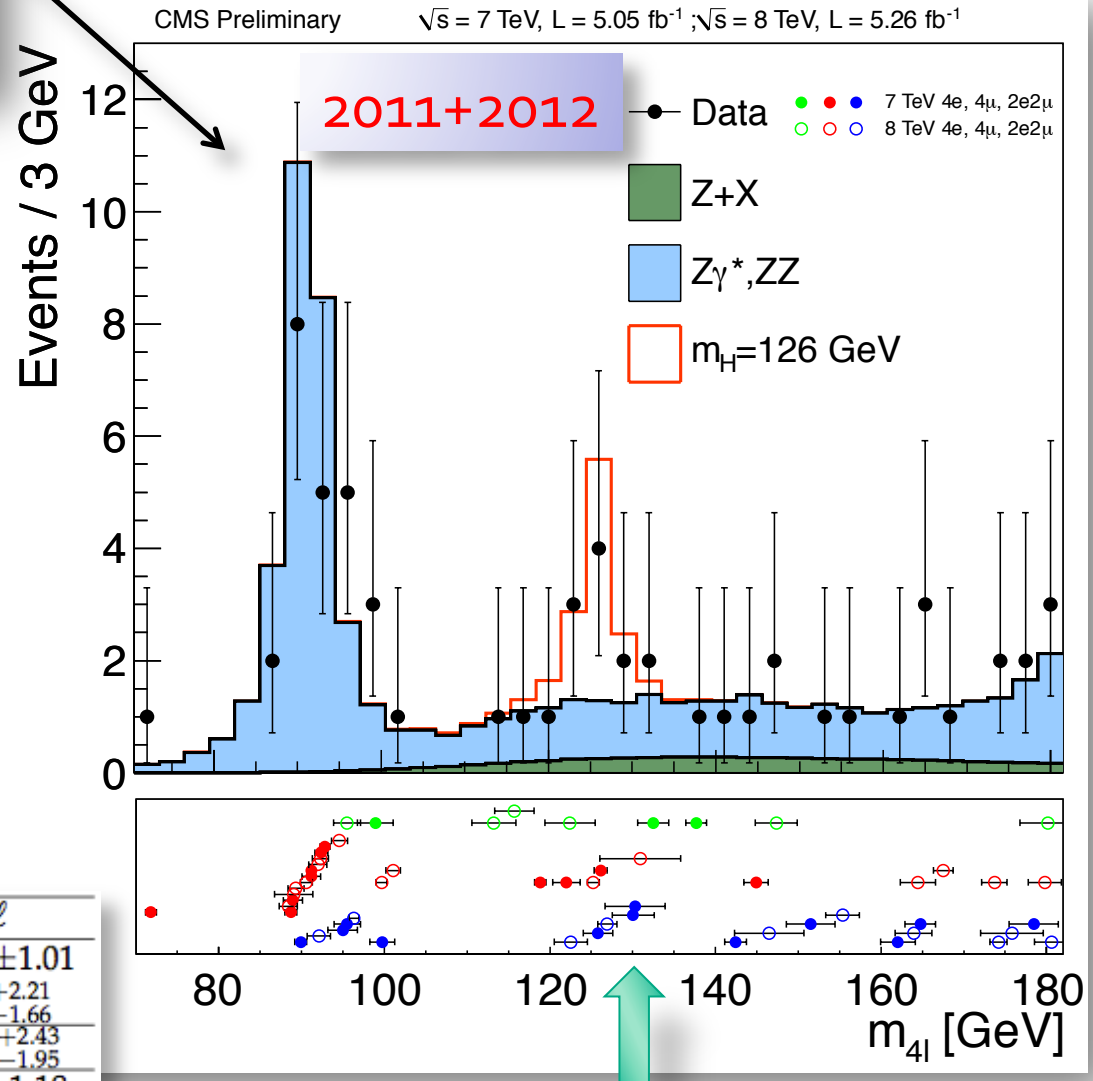
Results: $m(4l)$ spectrum



Yields for $m(4l) = 110..160 \text{ GeV}$

Channel	4e	4μ	2e2μ	4ℓ
ZZ background	2.65 ± 0.31	5.65 ± 0.59	7.17 ± 0.76	15.48 ± 1.01
Z+X	$1.20^{+1.08}_{-0.78}$	$0.92^{+0.65}_{-0.55}$	$2.29^{+1.81}_{-1.36}$	$4.41^{+2.21}_{-1.66}$
All backgrounds	$3.85^{+1.12}_{-0.84}$	$6.58^{+0.88}_{-0.81}$	$9.46^{+1.96}_{-1.56}$	$19.88^{+2.43}_{-1.95}$
$m_H = 126 \text{ GeV}$	1.51 ± 0.48	2.99 ± 0.60	3.81 ± 0.89	8.31 ± 1.18

164 events expected in [100, 800 GeV]
 172 events observed in [100, 800 GeV]



Event-by-event errors

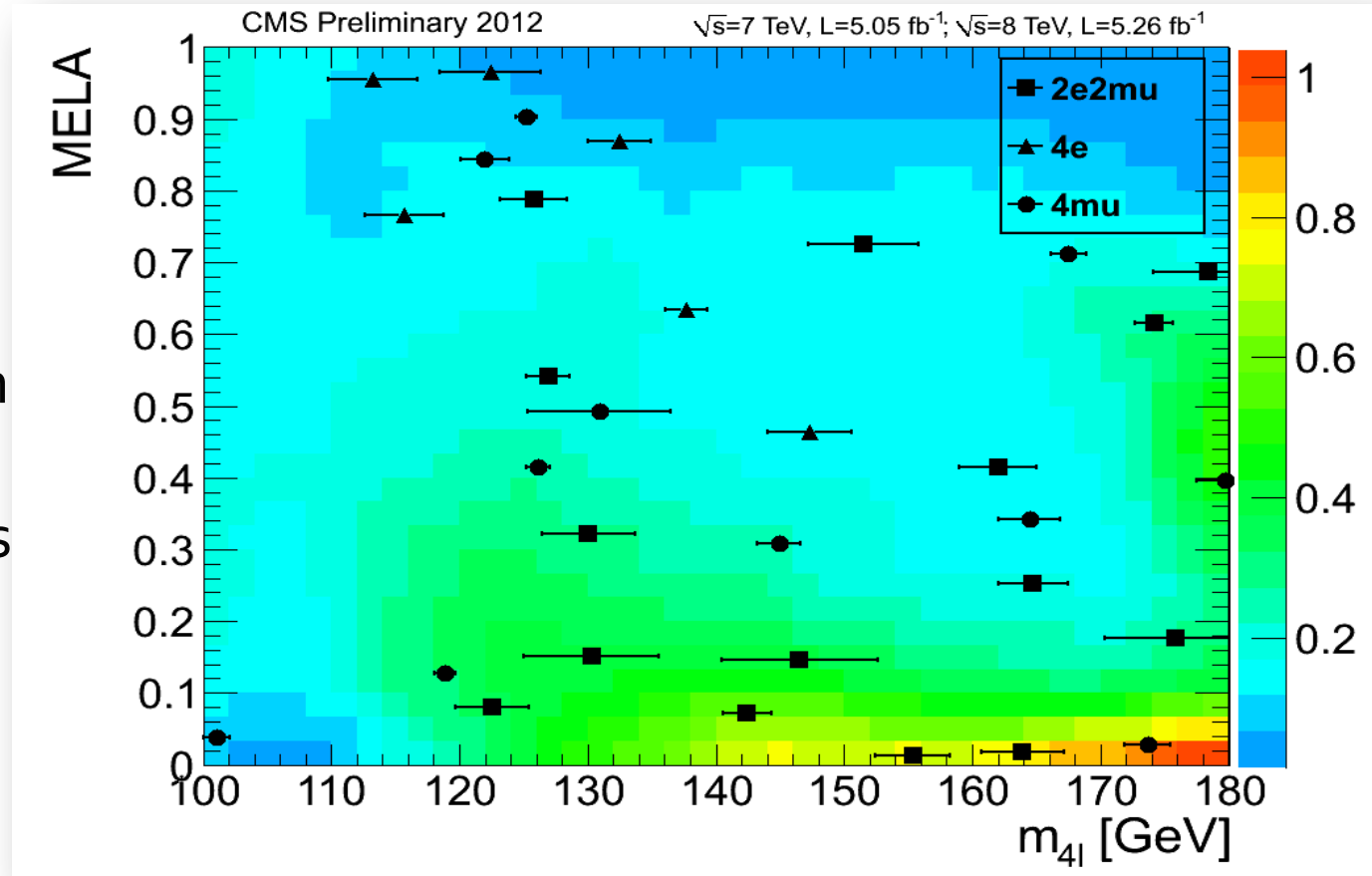
July 4



Results: MELA 2D plots

Perform 2D fit

- MELA discriminant versus m_{4l}
- Data points shown with per-event mass uncertainties



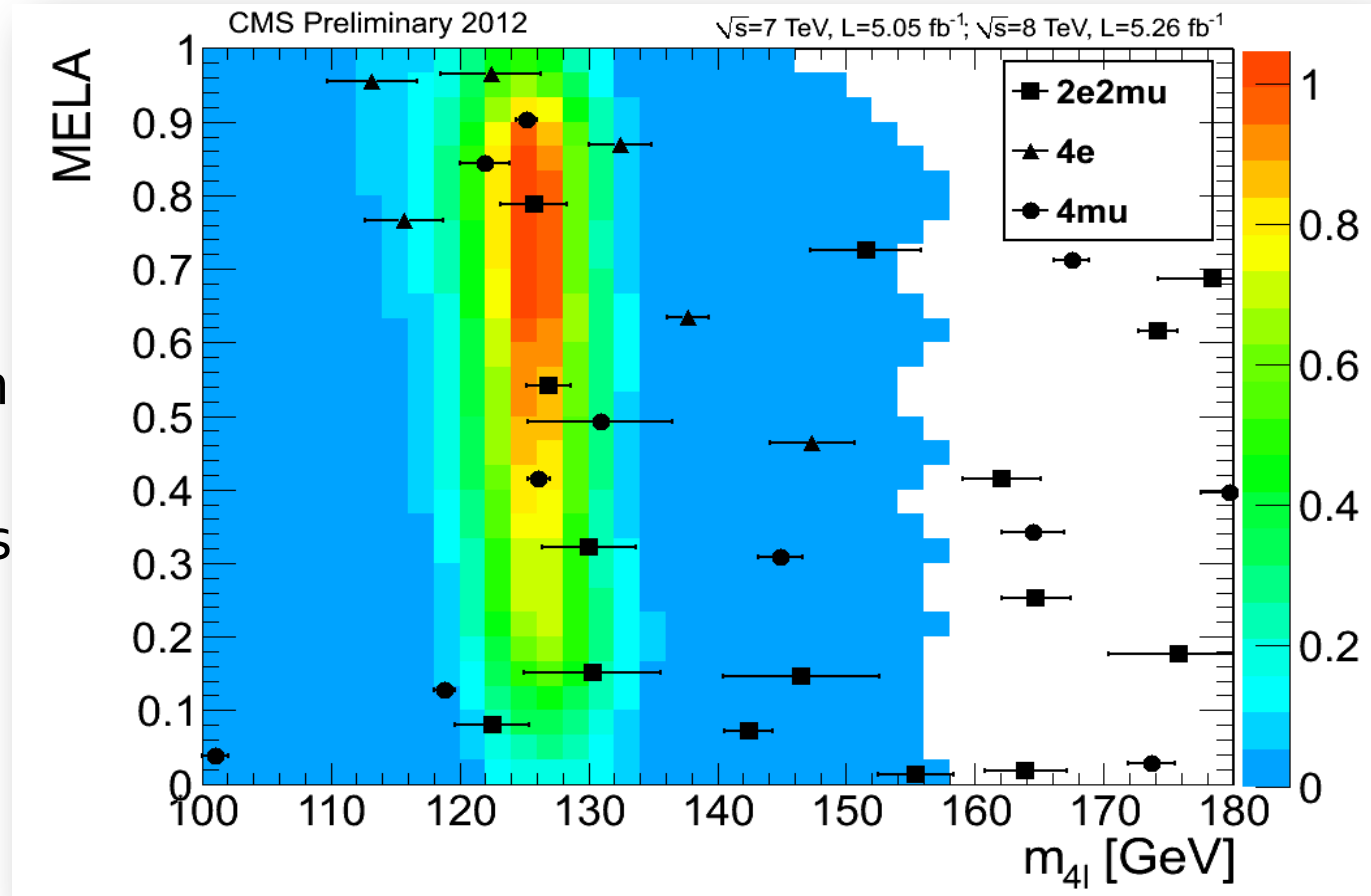
Data w.r.t. background expectation



Results: MELA 2D plots

Perform 2D fit

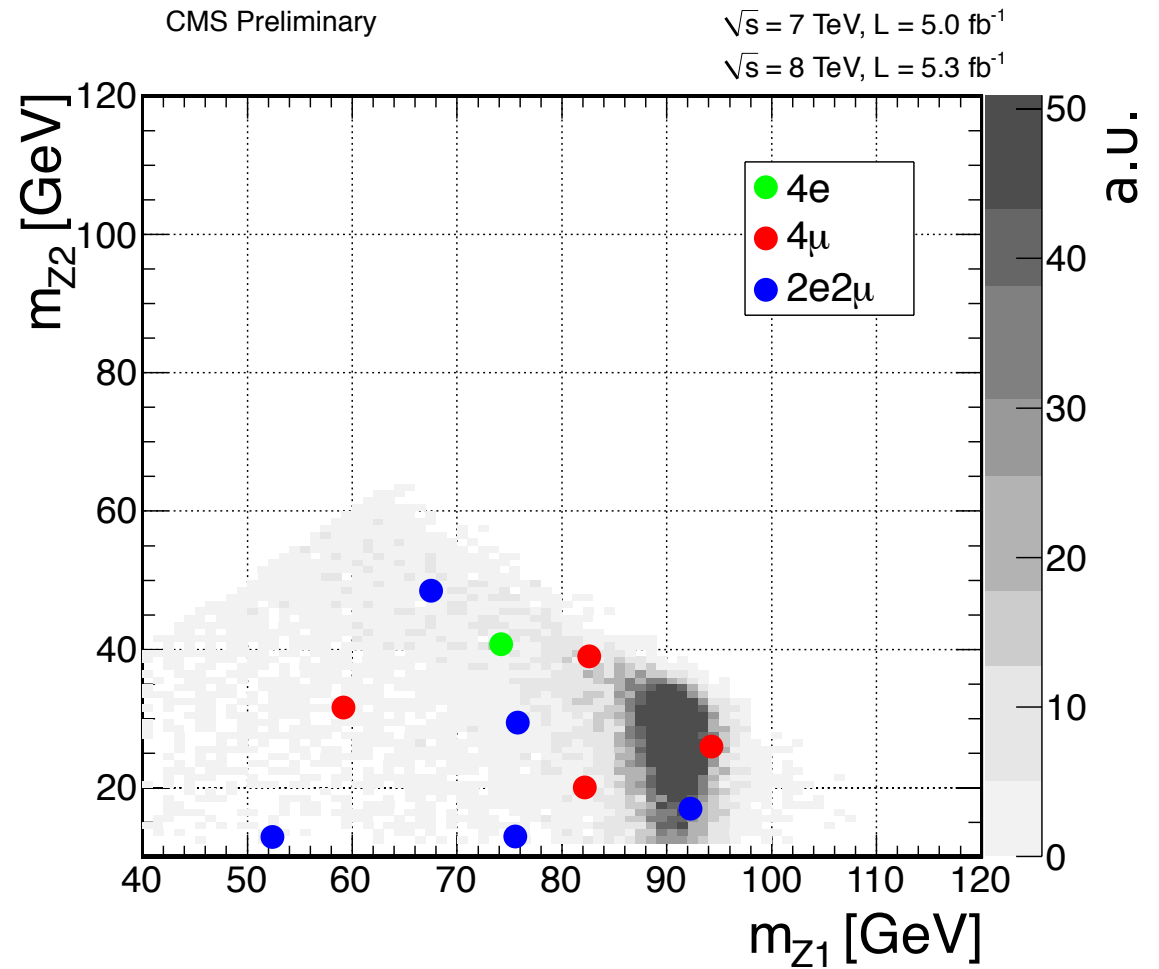
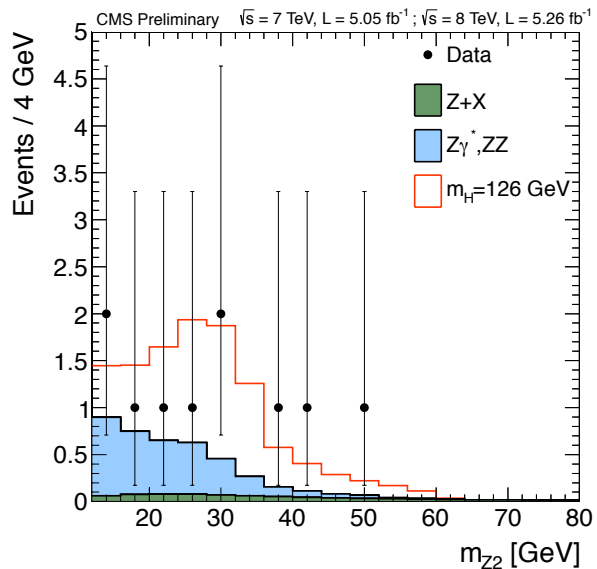
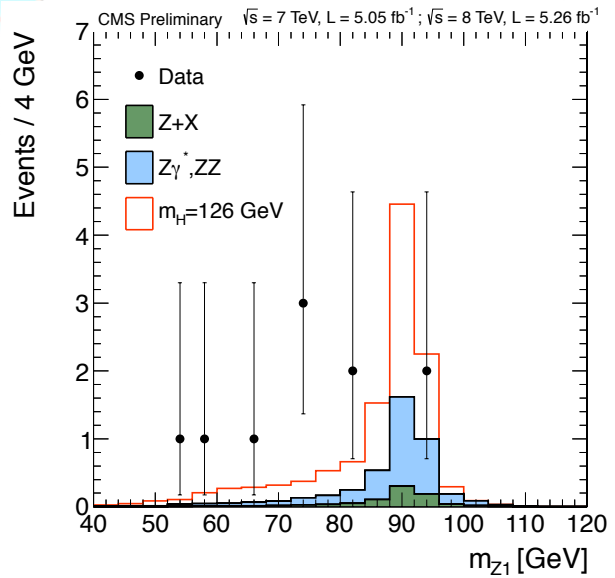
- MELA discriminant versus m_{4l}
- Data points shown with per-event mass uncertainties



Data w.r.t 126 GeV Higgs Expectation



Two-lepton invariant mass plots

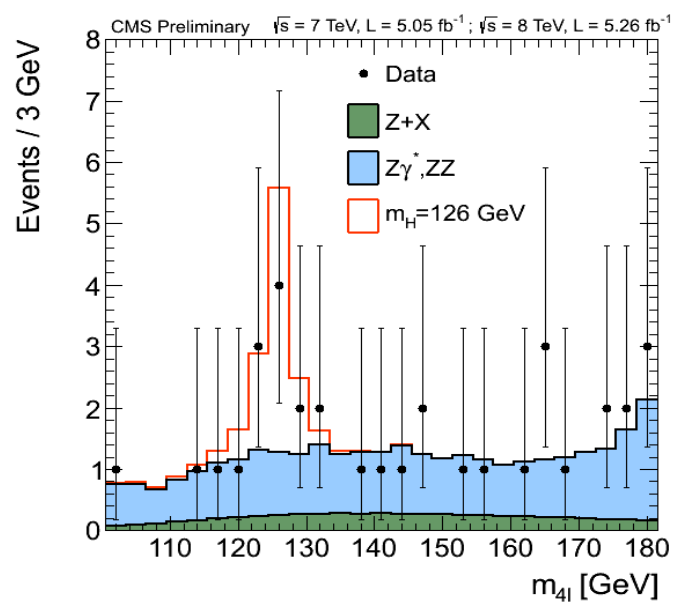


Grey – is simulation (expectation) for Higgs (126 GeV)

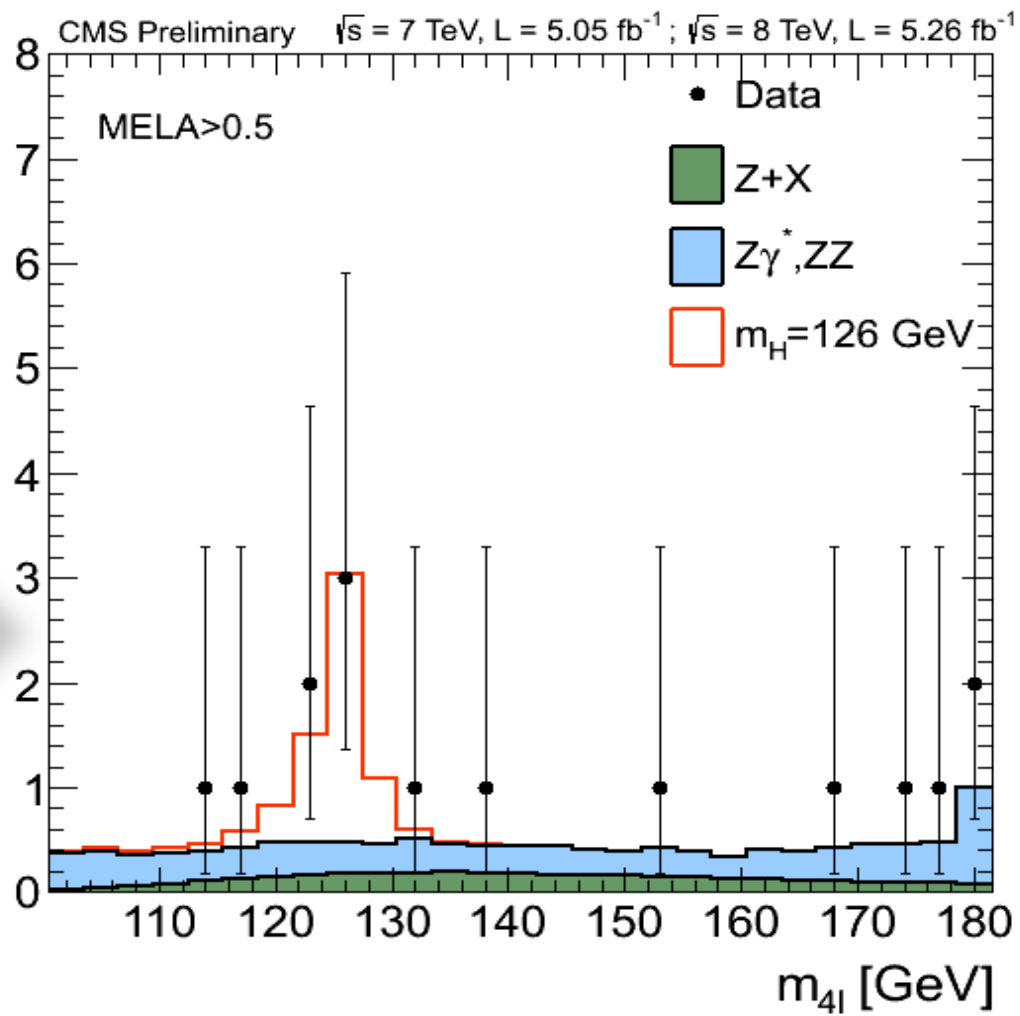


For illustration: Low mass region with MELA cut

- Enrich the signal content
 - Cut: $MELA > 0.5$
 - Cut value chosen such that signal probability > background probability



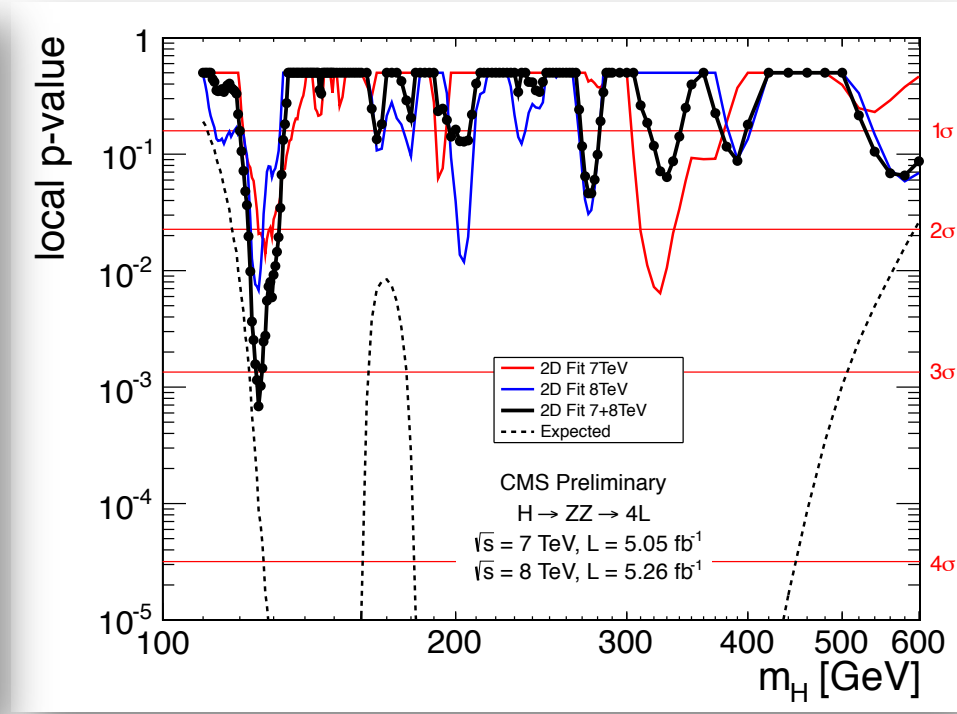
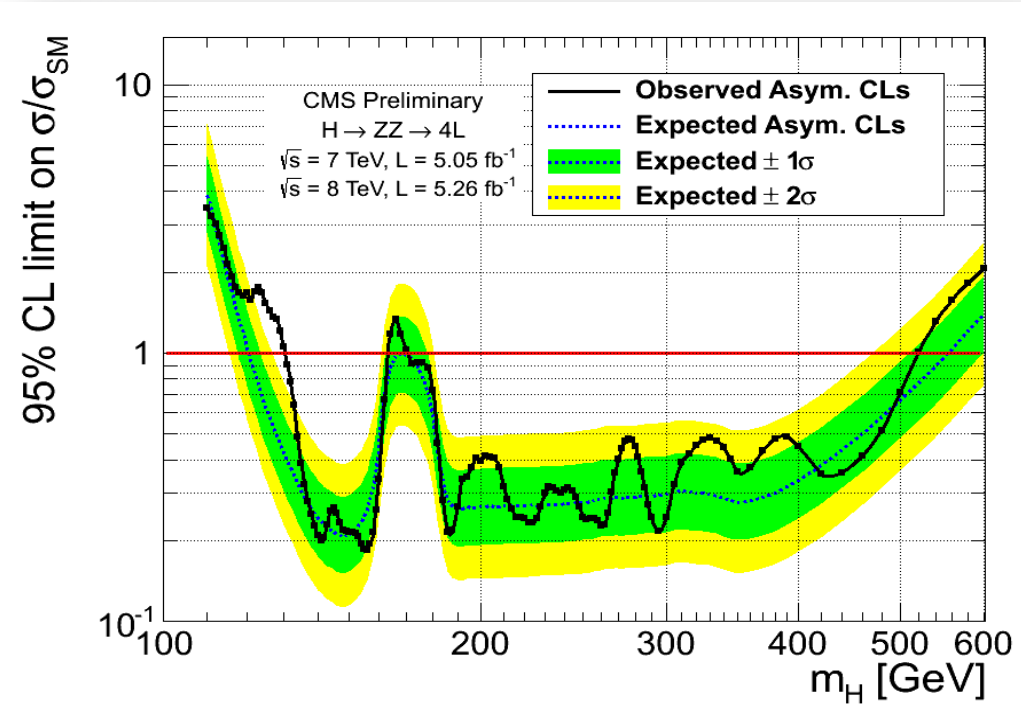
Events / 3 GeV





Limits and p-values

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



Expected exclusion at 95% CL :
121-550 GeV

Observed exclusion at 95% CL :
131-162 GeV and 172-530 GeV

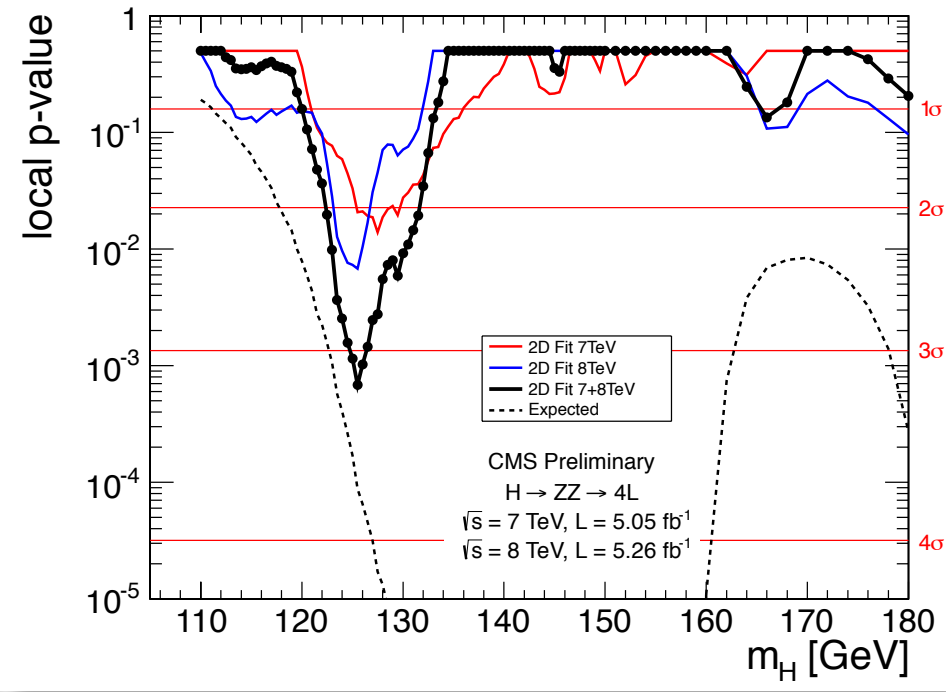
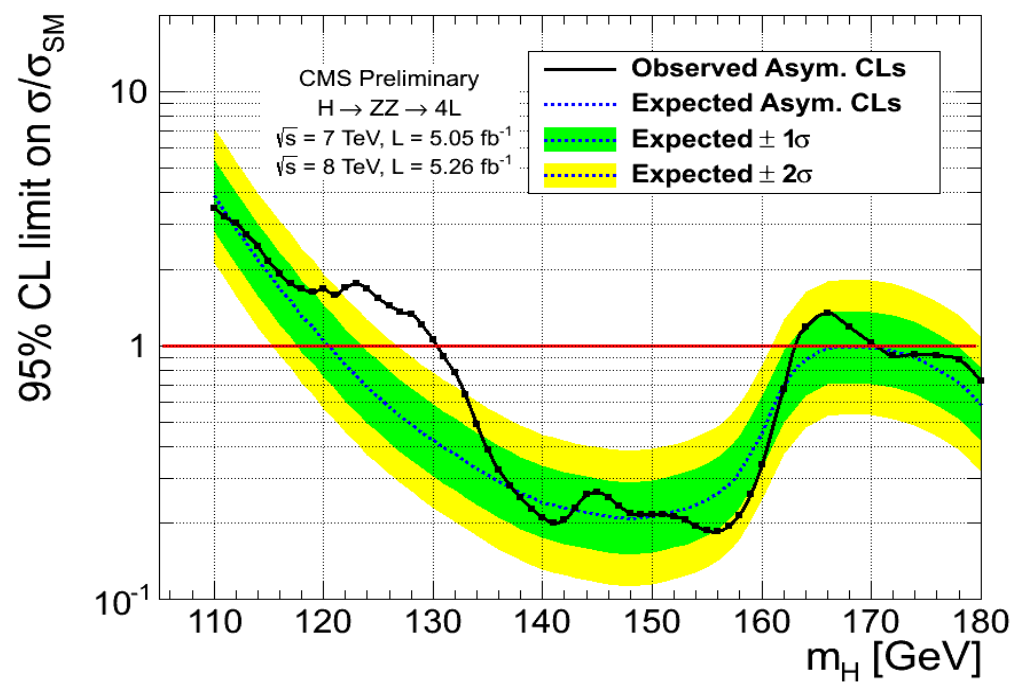
Expected significance at 125.5 GeV :
3.8 σ

Observed significance at 125.5 GeV:
3.2 σ



Limits and p-values

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



Expected exclusion at 95% CL :
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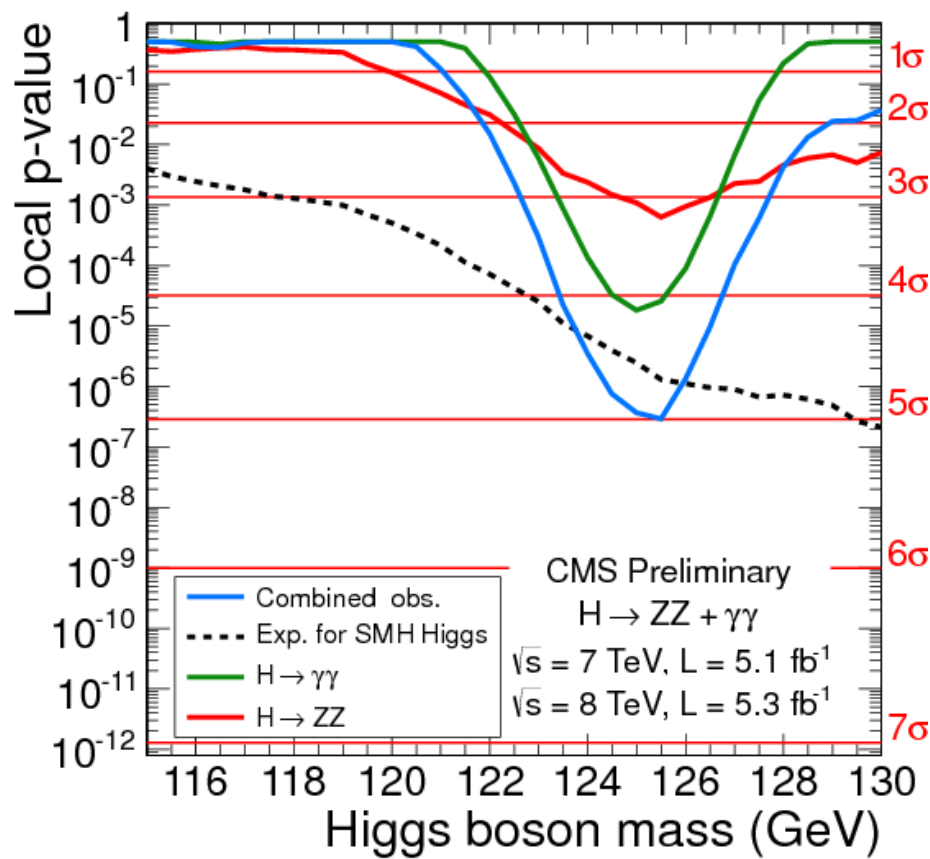
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3.8 σ

Observed significance at 125.5 GeV:
3.2 σ



Characterization of excess near 125 GeV

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



- high sensitivity, high mass resolution channels: $\gamma\gamma + 4l$
- $\gamma\gamma$: 4.1 σ excess
- 4 leptons: 3.2 σ excess
- near the same mass 125 GeV
- comb. significance: **5.0 σ**
- expected significance for SM Higgs: 4.7 σ

H → ***WWW*** → ***lvlv***



H → WW → lνlν Signature

μP_T
32 GeV

$e P_T$
34 GeV

ME_T
47 GeV

Signature:
2 high p_T leptons
large missing E_T

$qq \rightarrow WW + gg \rightarrow WW$
• Non-resonant

$H \rightarrow WW$
• Large BR
• Small $\Delta\phi(l\bar{l})$

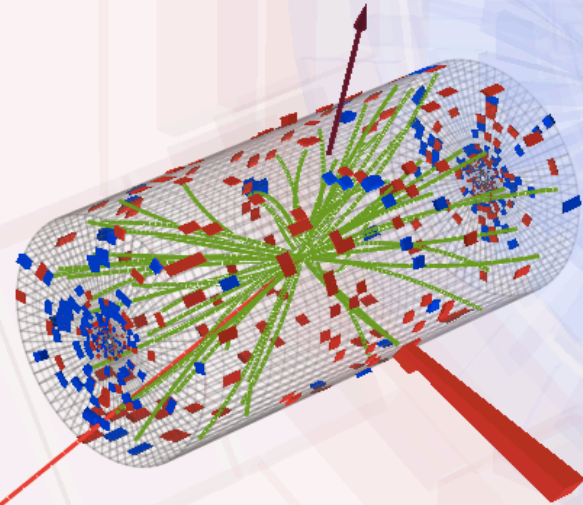
Main backgrounds:
WW, top
Other backgrounds:
W+jet, Z/ γ^* , WZ, ZZ, W γ



Analysis Strategies

Data-driven background estimation

- W+jets
Fake rate measured in QCD enriched data sample
- Z/ γ^*
Normalised in Z mass
- Top
b-tagging efficiency measured in top control region in data



Split in categories

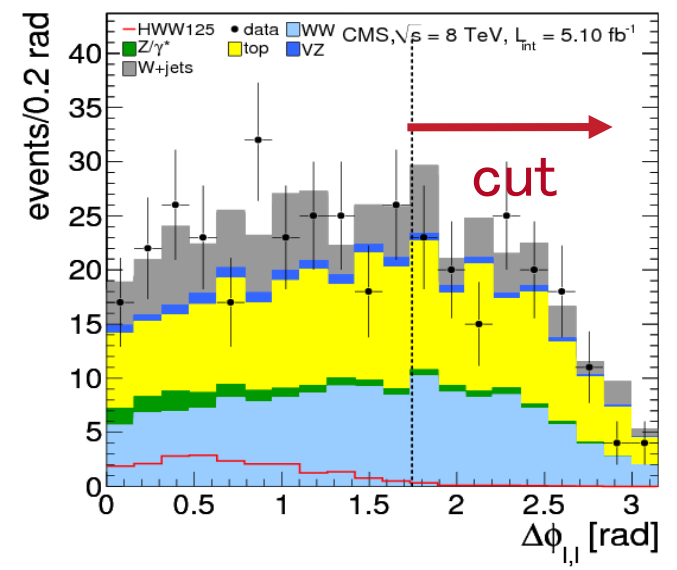
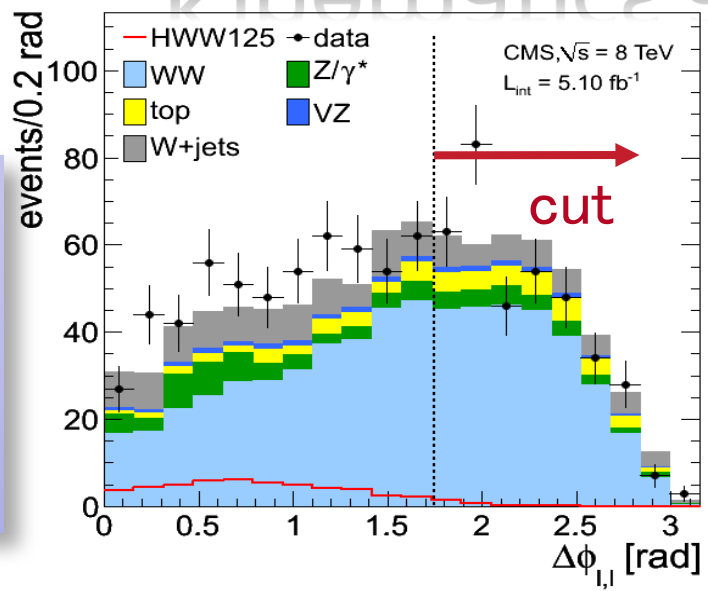
- 0/1-jet and VBF
 - Final state lepton flavors
- Cut-based approach for the first 2012 result



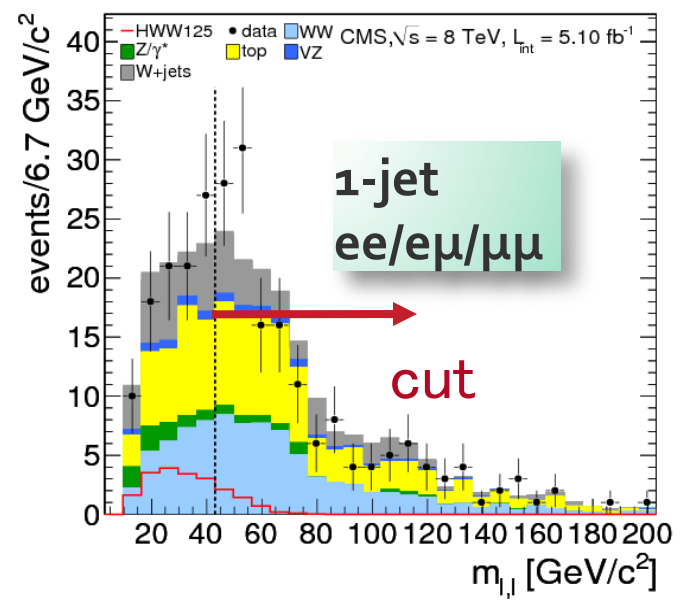
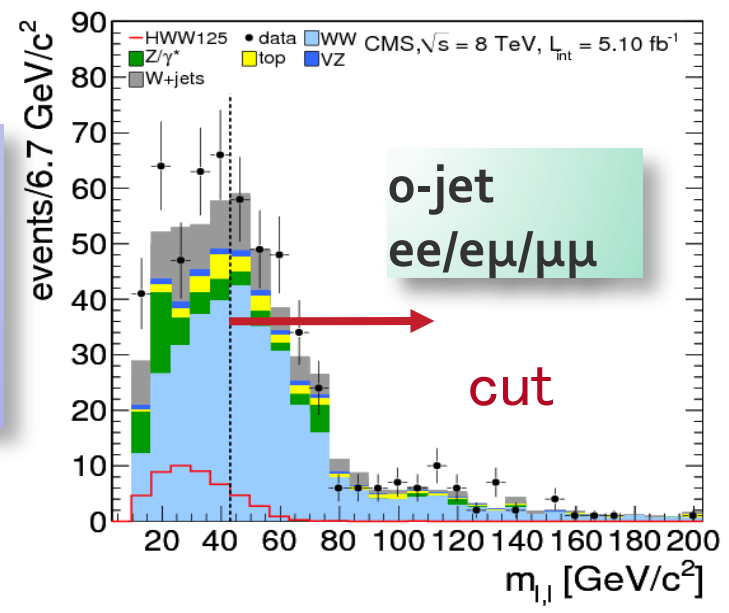
Kinematics at Final Selection

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

One step before the final selection (no cuts on $\Delta\phi(\ell\ell)$ and $m(\ell\ell)$)



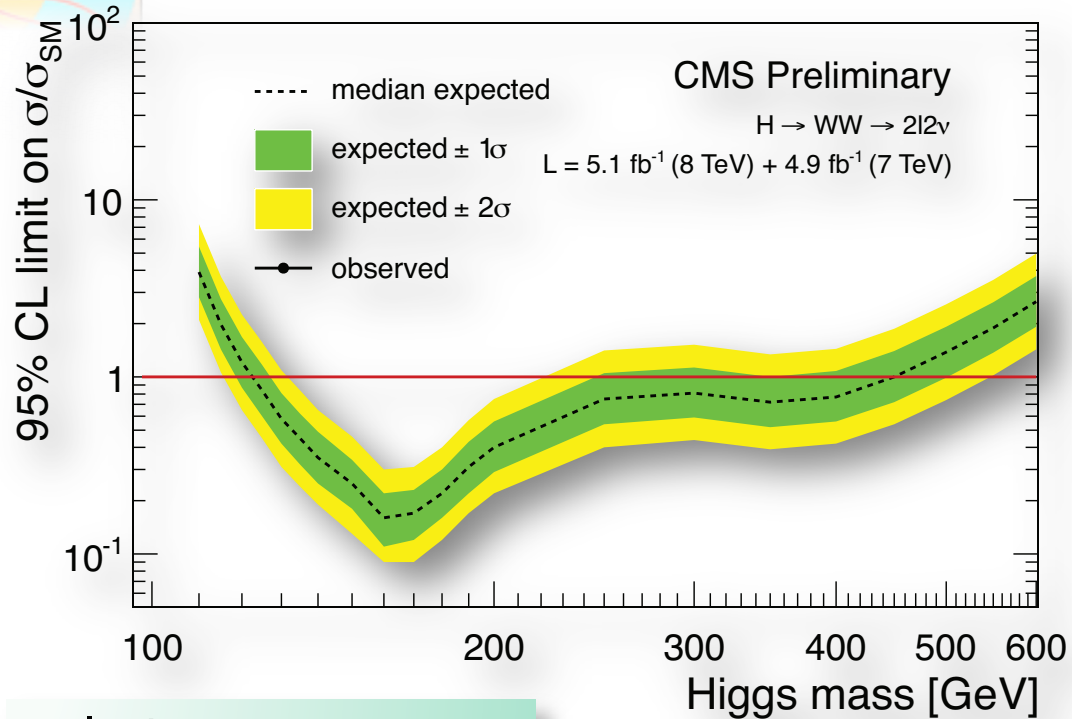
Final selection on $m(\ell\ell)$ (all other selection applied)



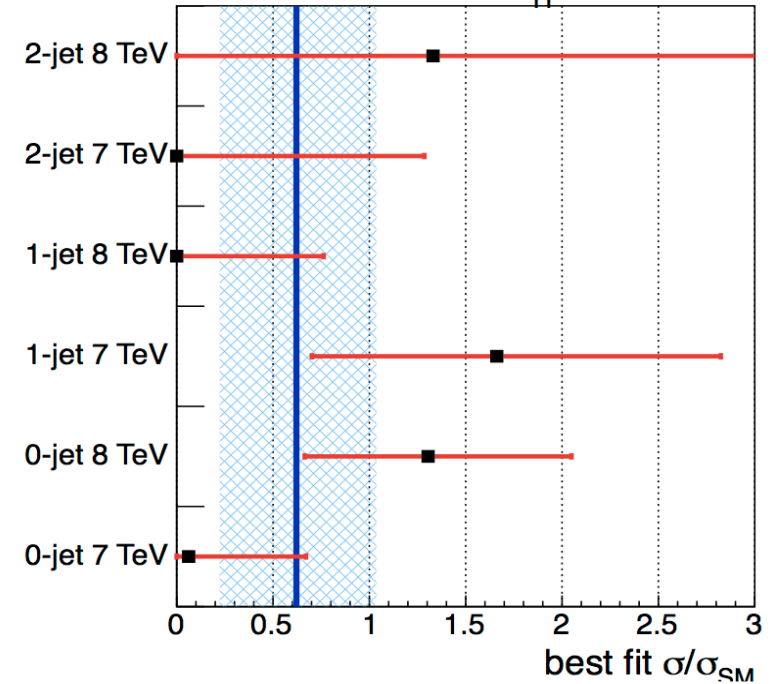


Combination of 7 TeV + 8 TeV

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



H → WW, $m_H = 125$ GeV

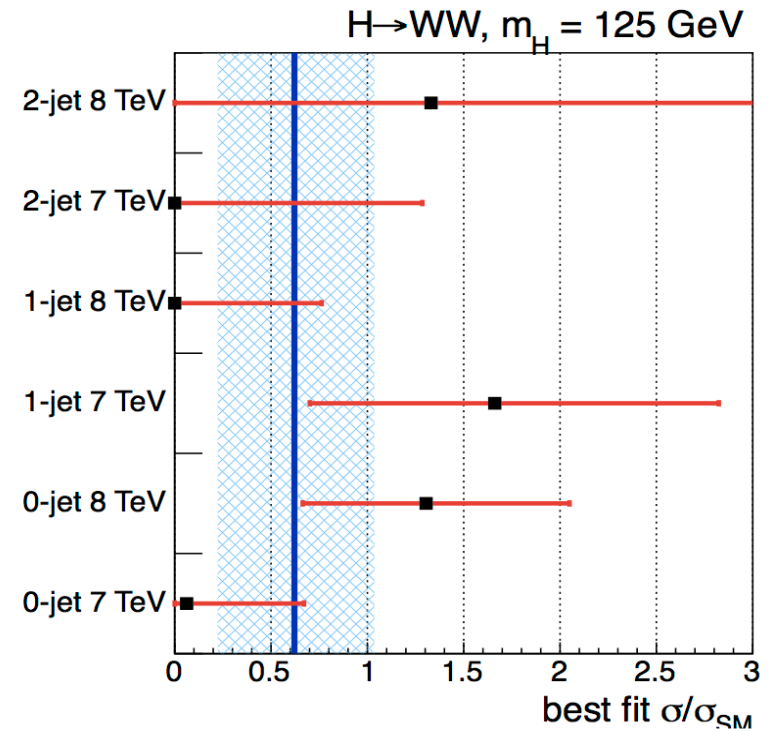
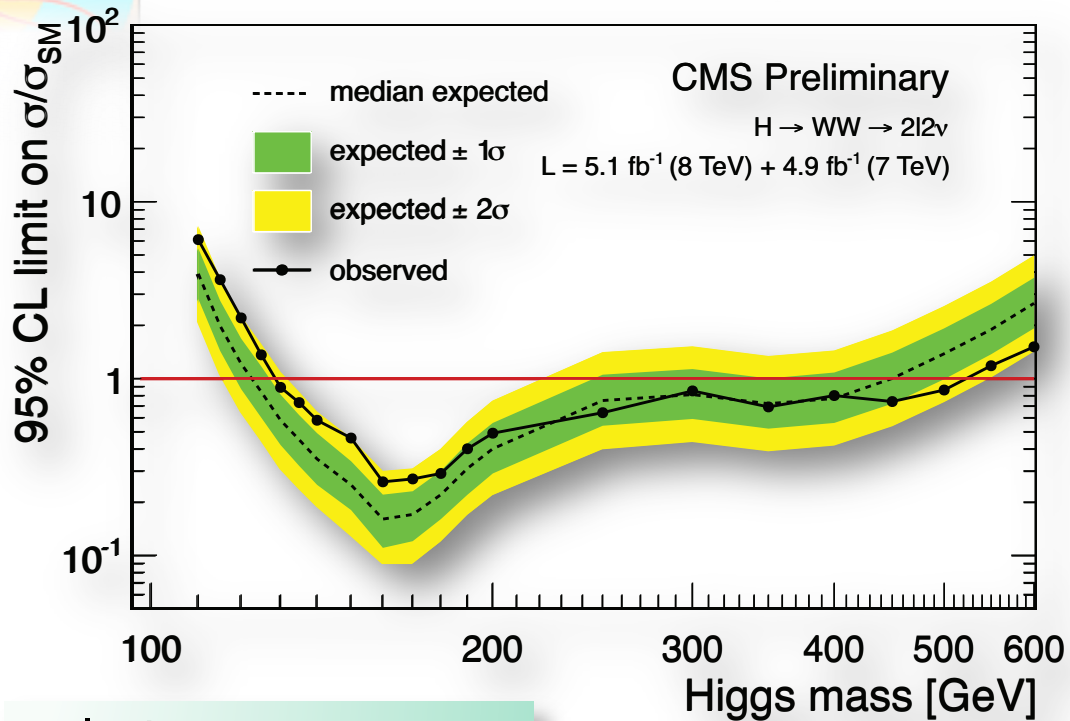


Exclusion range
 expected: 123-450 GeV
 observed: 129-520 GeV

- Combined limits from 2011 and 2012
 - 7 TeV result using a multivariate discriminant and updated with the final luminosity measurement
 - 2012 → 5% improvement in sensitivity coming from new object definitions and selection optimized for 2012 condition



Combination of 7 TeV + 8 TeV



Exclusion range

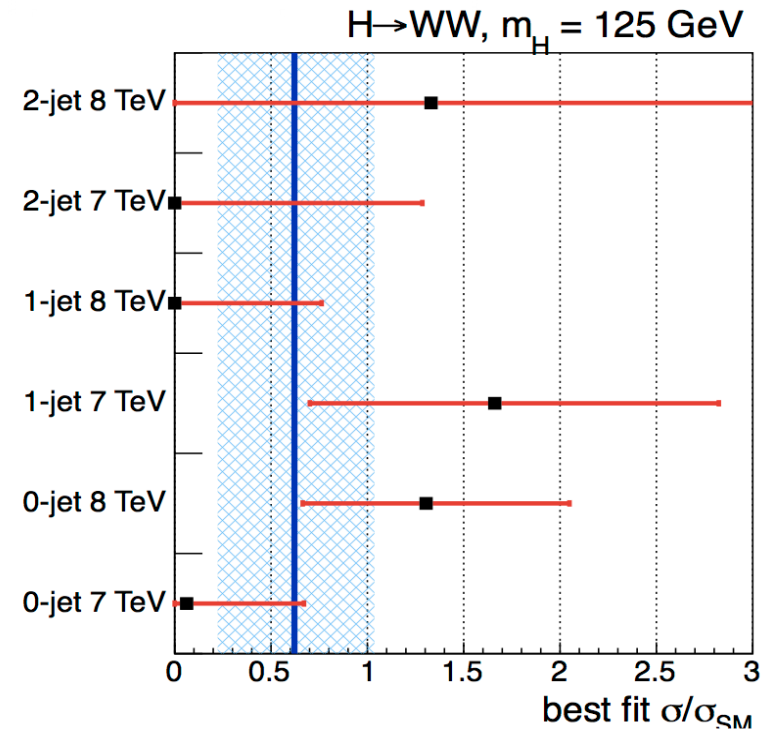
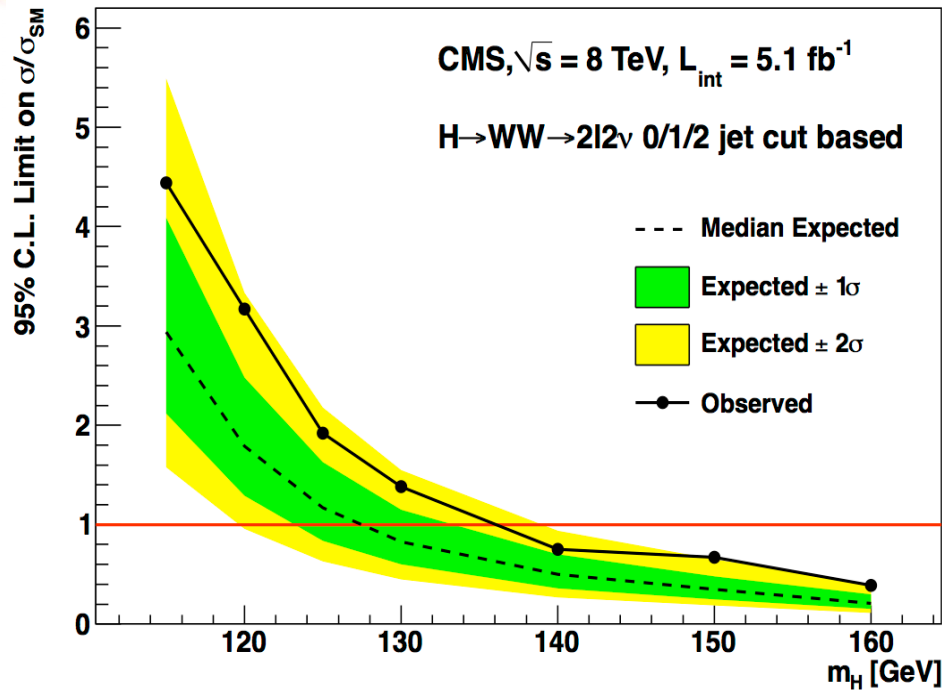
expected: 123-450 GeV

observed: 129-520 GeV

- Combined limits from 2011 and 2012
 - 7 TeV result using a multivariate discriminant and updated with the final luminosity measurement
 - 2012 \rightarrow 5% improvement in sensitivity coming from new object definitions and selection optimized for 2012 condition



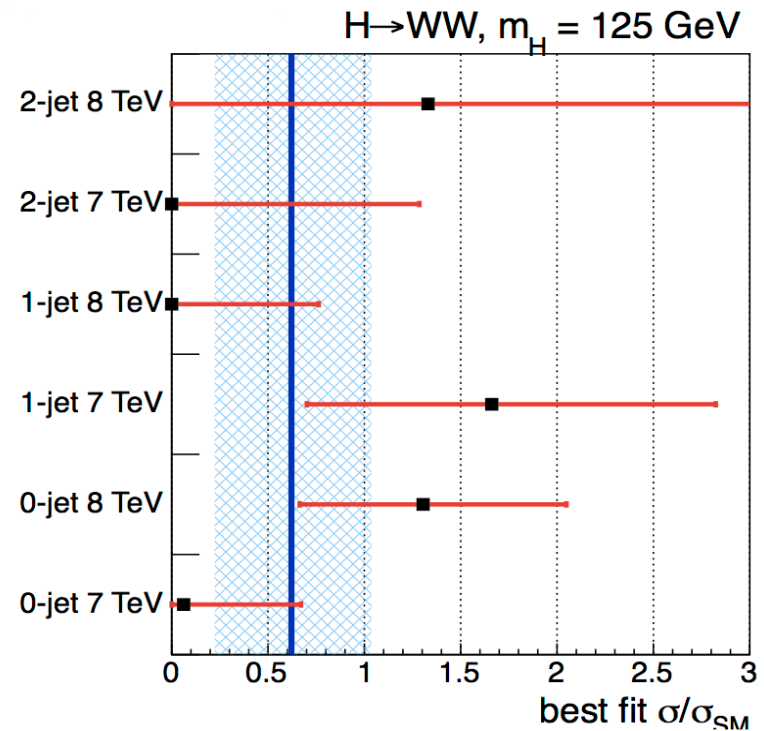
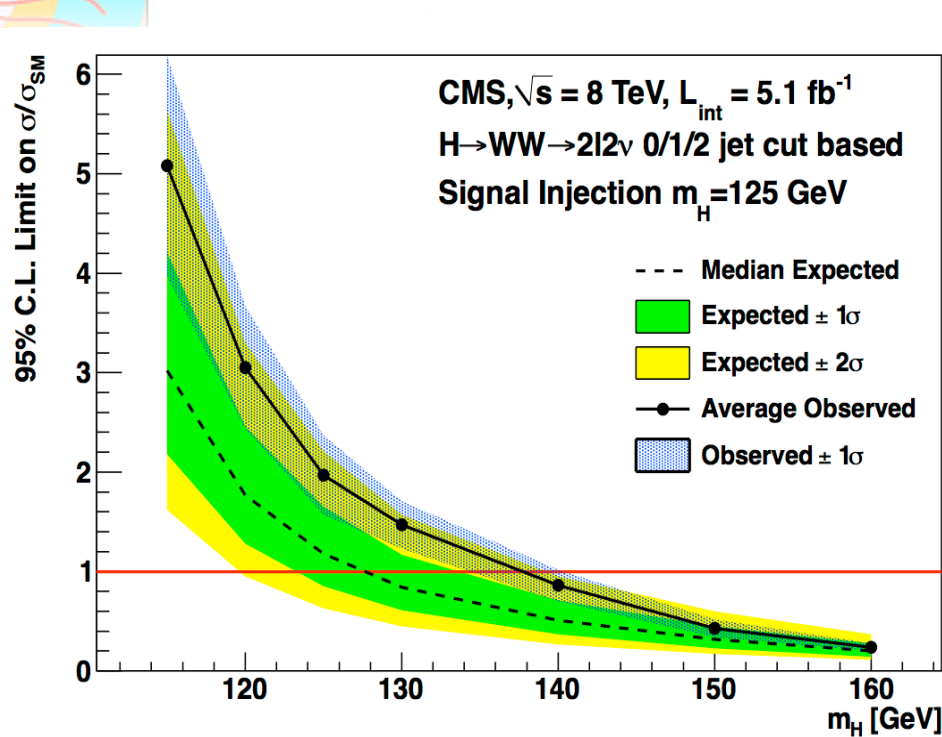
8 TeV – injected SM Higgs signal



- Signal injection using prediction at 5.1/fb 8 TeV
 - Average background prediction
 - Signal injection for $m_H = 125 \text{ GeV}$ with toys



8 TeV – injected SM Higgs signal



- Signal injection using prediction at 5.1/fb 8 TeV
 - Average background prediction
 - Signal injection for $m_H = 125 \text{ GeV}$ with toys

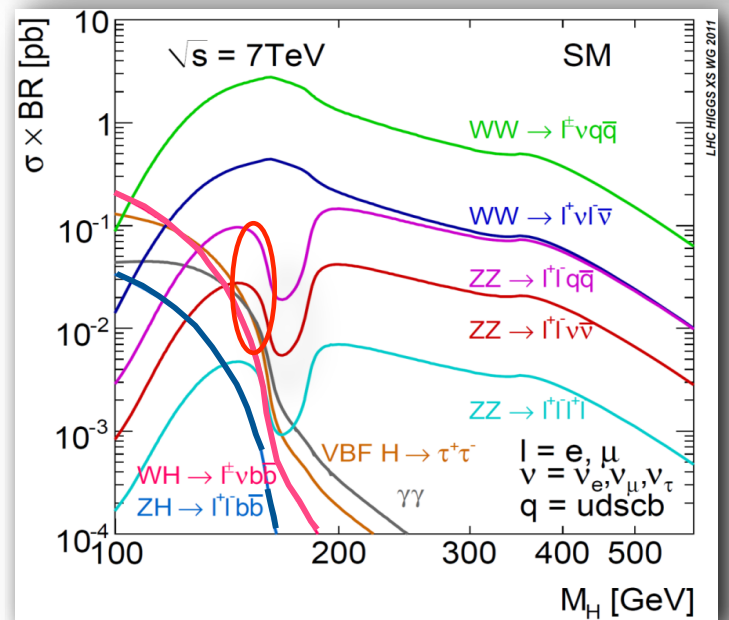
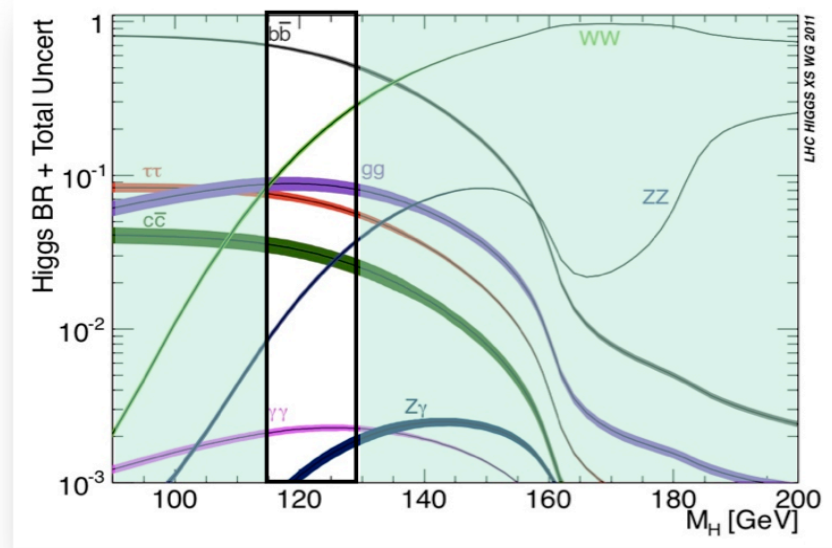
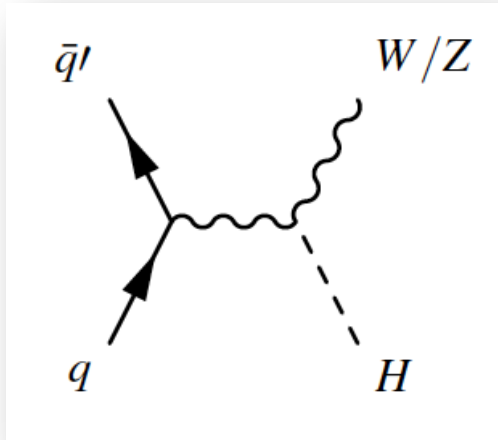
VH → Vbb
V → /v, /l, vv



VH → Vbb, V → lv, ll, νν

- Characteristics and importance
 - By far, largest BR for $m_H < 130$ GeV
 - Key piece of the observation puzzle
 - Tests specific production & decay couplings
- But $\sigma_{bb}(\text{QCD}) \sim 10^7 \sigma \times \text{BR}(H \rightarrow bb)$!

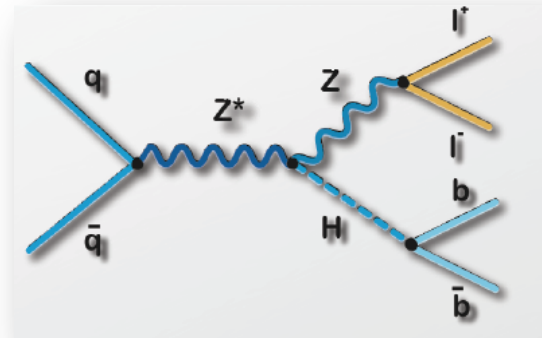
⇒ Search in associated production with W or Z





Analysis Strategy

Associated Production
=> final states with
leptons, MET and b-jets



5 channels

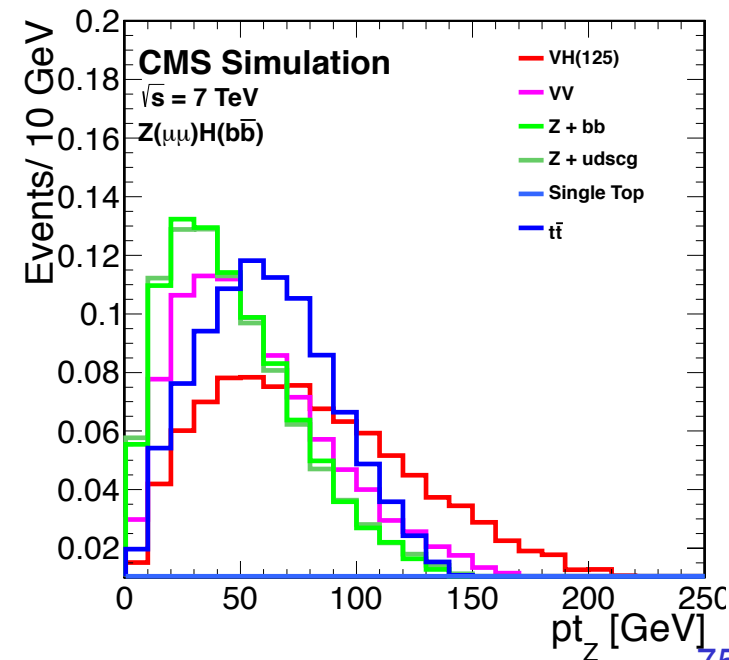
- Z(l \bar{l})H(bb)
- Z($\nu\nu$)H(bb)
- W(l ν)H(bb)

Reducible Backgrounds:
QCD, top, W/Z+ light jets

Less reducible:
V+bb, ZZ(bb), WZ(bb)

Boosted vector bosons:
 $p_T(V)$,
2 b-tagged jets (H \rightarrow bb)
Back-to-back V and H,
reconstruct m_{bb}

Main backgrounds
estimated from data in
control regions

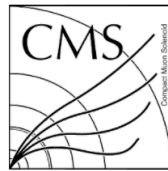
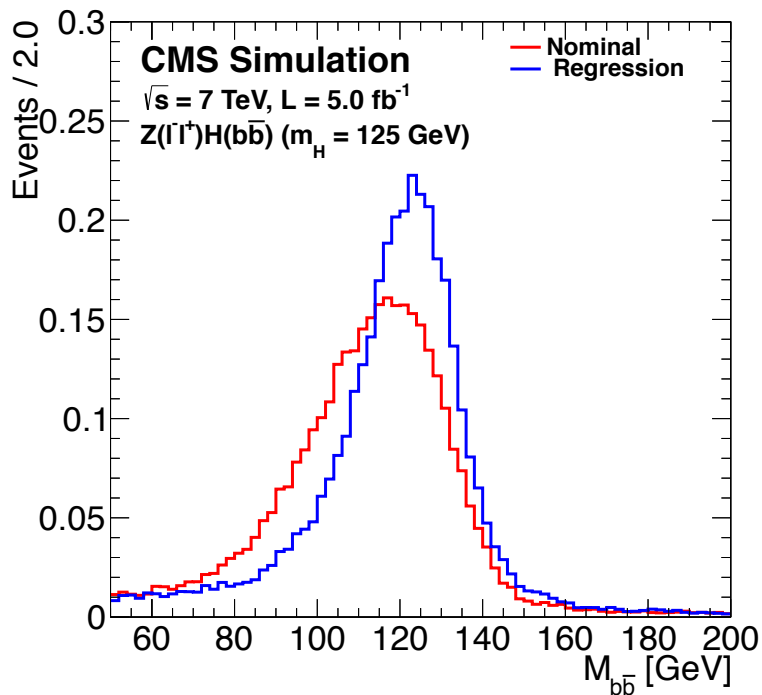




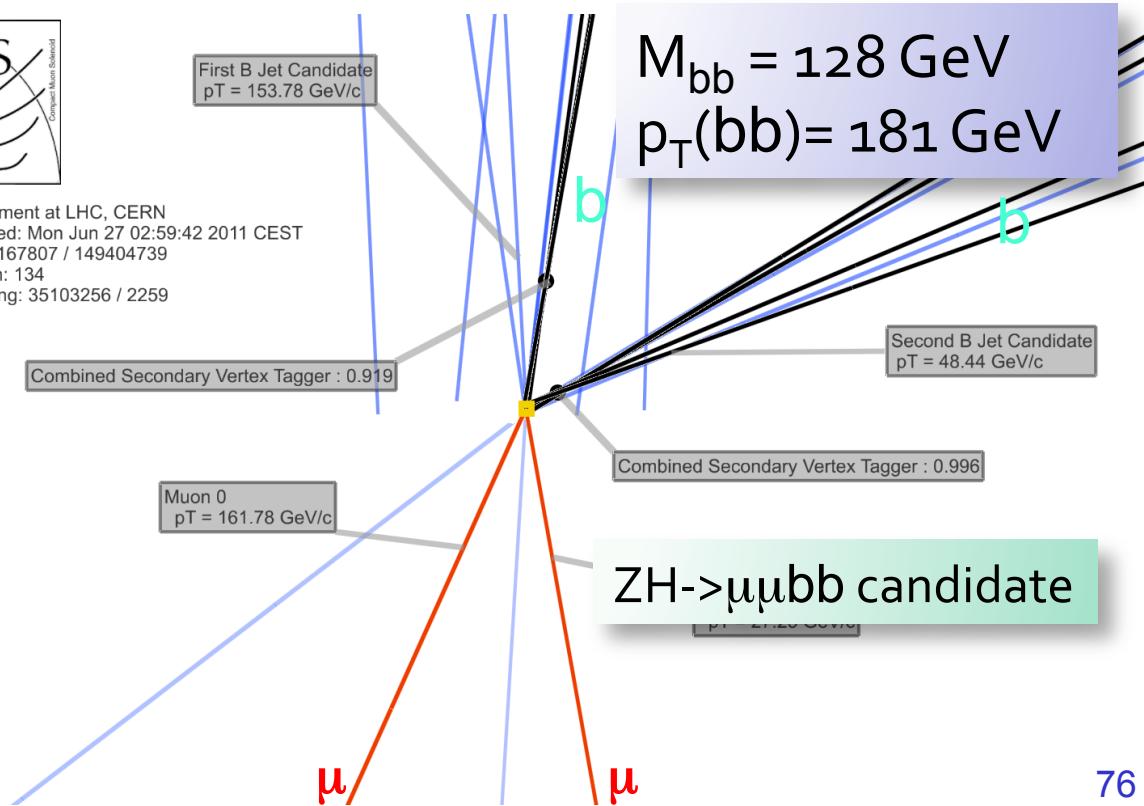
Event selection

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

- First CMS VHbb 2011 analysis: Phys. Lett. B 710(2012) 284-306
- Here 5 fb⁻¹ @ 7 TeV (2011) + 5 fb⁻¹ @ 8 TeV (2012)
 - Improvements OF ~ 50% in sensitivity:
 - Two Pt(V) bins: "low" and "high" – see backup
 - Fit the shape of the MVA output distribution (vs cut and count)
 - Improved b-jet energy resolution [MVA regression]



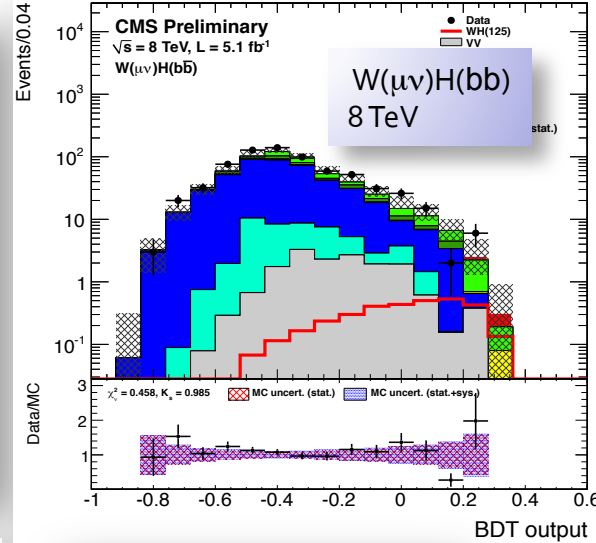
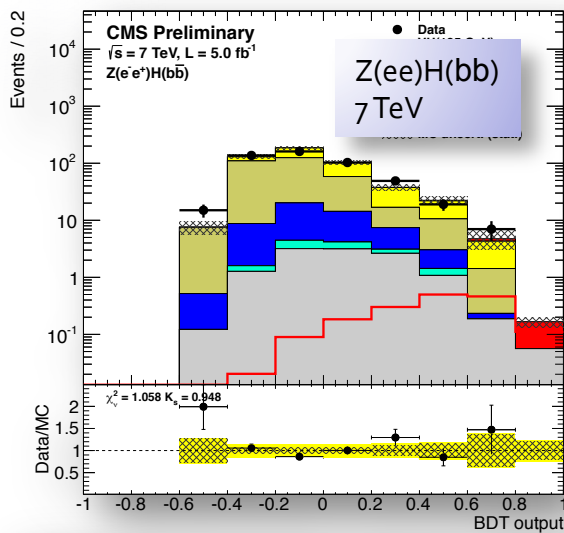
CMS Experiment at LHC, CERN
 Data recorded: Mon Jun 27 02:59:42 2011 CEST
 Run/Event: 167807 / 149404739
 Lumi section: 134
 Orbit/Crossing: 35103256 / 2259





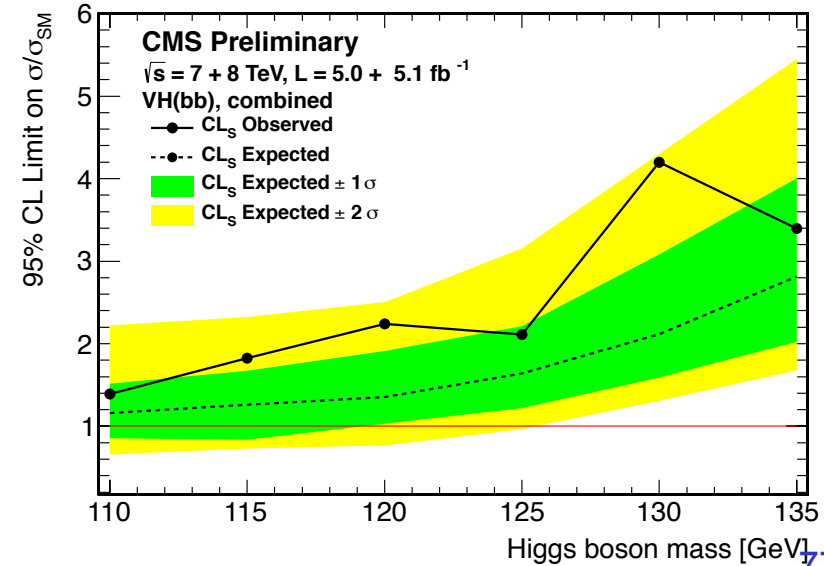
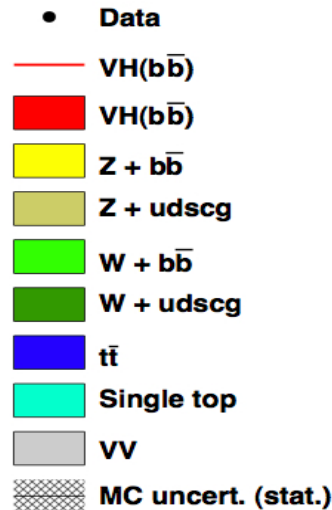
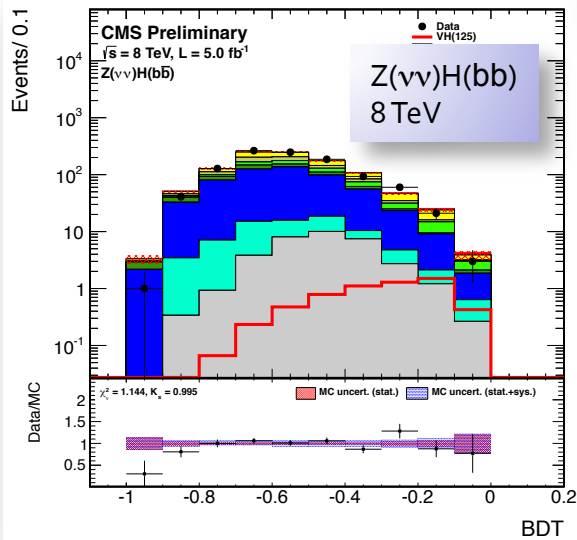
Examples of final MVA distributions

J. Incandela for the CMS COLLABORATION



- Observed limits:
 - Compatible with either background or signal from a 125 GeV Higgs

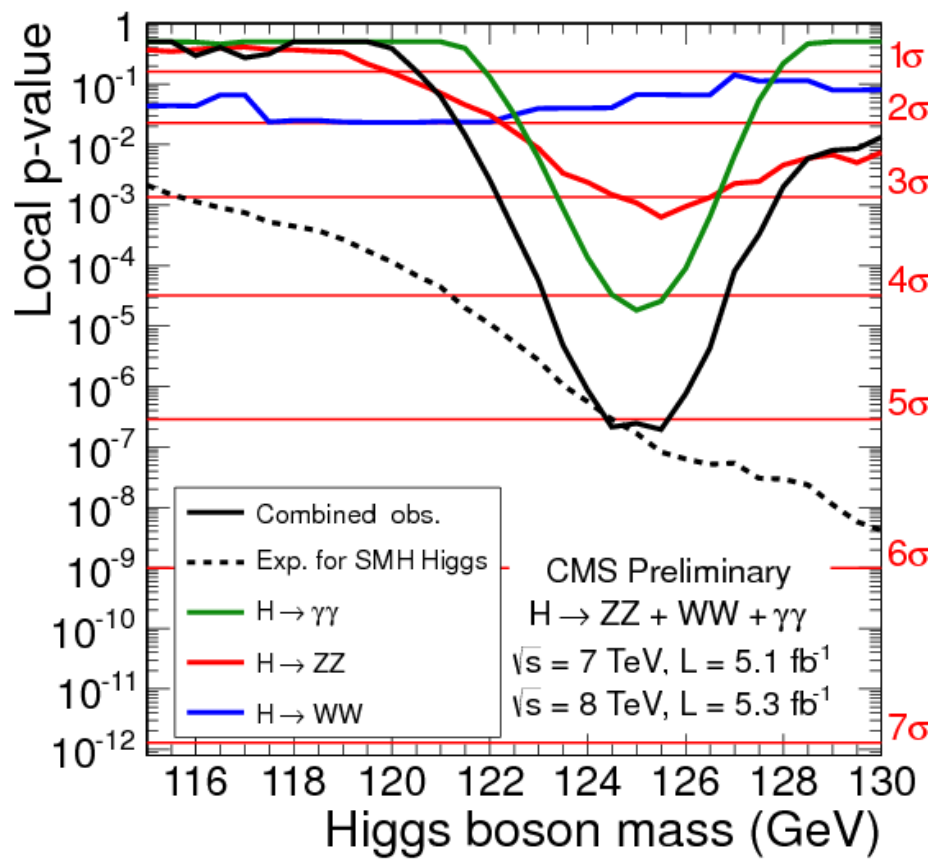
July 4th 2012 The Status of the Higgs Search





Characterization of excess near 125 GeV

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



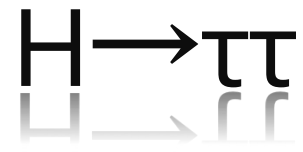
adding high sensitivity, but low mass resolution WW

comb. significance: **5.1 σ**

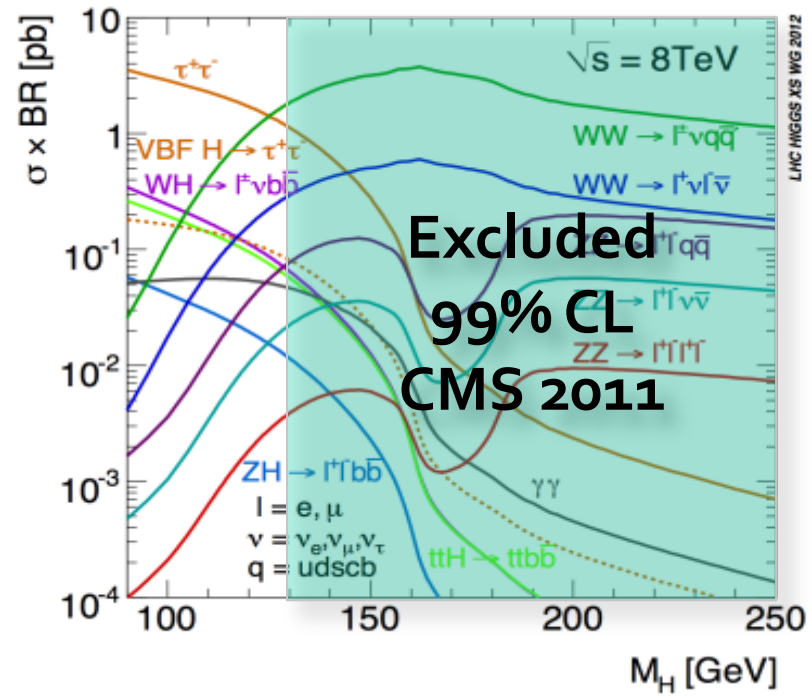
expected significance for SM Higgs: **5.2 σ**

H → TT

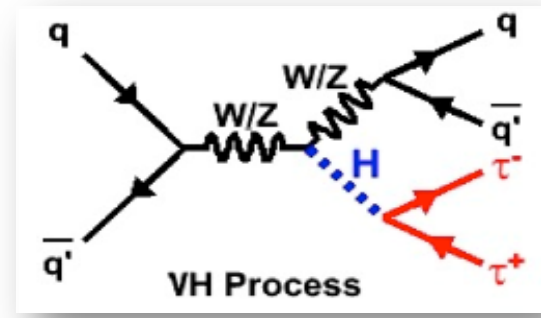
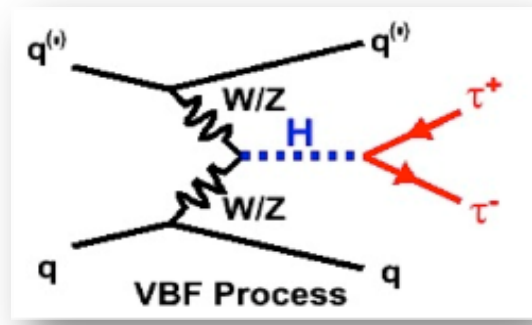
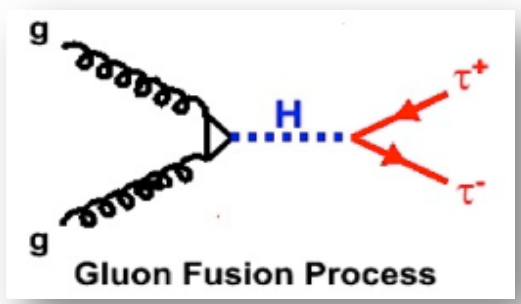
→ μτ_h, eτ_h, eμ, μμ



July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



- Characteristics
 - High $\sigma \cdot \text{BR}$ at low mass
 - Sensitive to all production modes
 - Probes coupling to leptons
 - Enhanced $\sigma \times \text{BR}$ in MSSM
 - Challenging large backgrounds:
 - $DY \rightarrow \tau\tau$, $W+\text{Jets}$, QCD

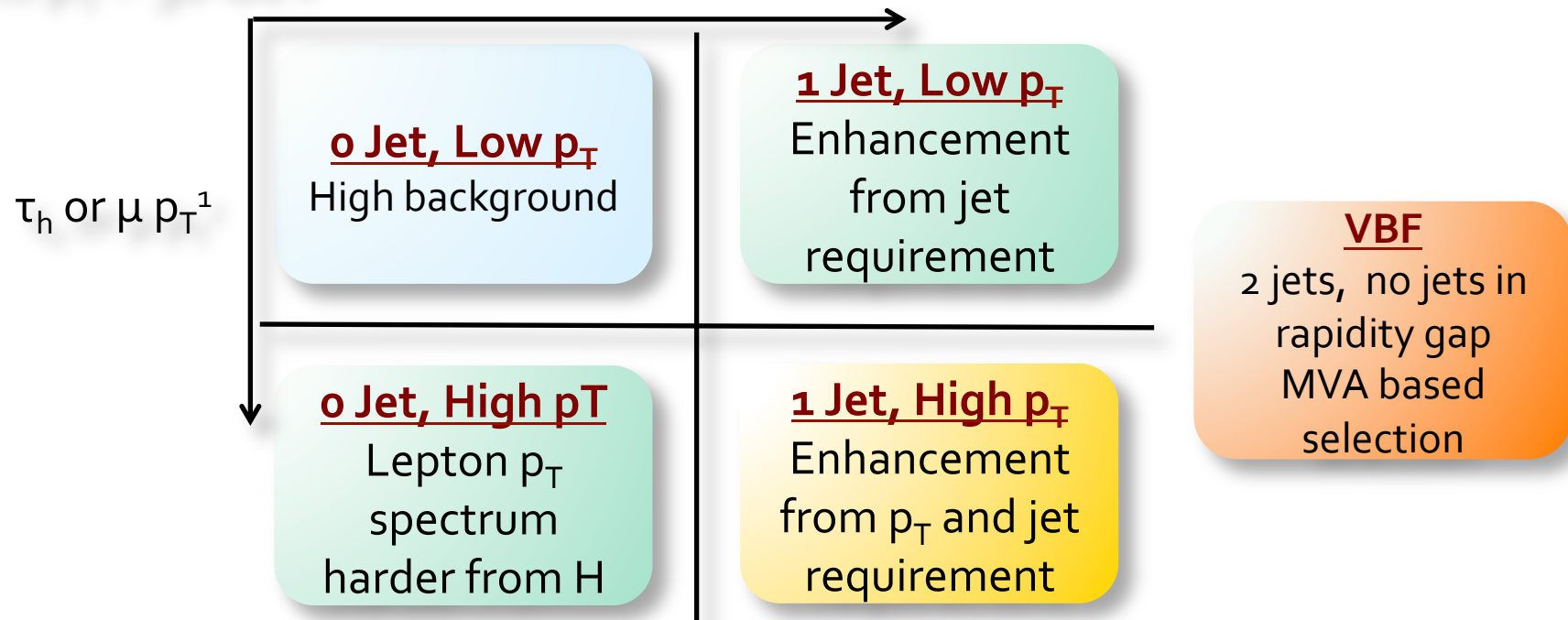




Analysis Strategy

- Search performed in 4 tau-pair final states: $\mu\tau_h$, $e\tau_h$, $e\mu$, $\mu\mu$
- Analysis divided into 5 categories: mass resolution, S/B
- All categories are fit simultaneously

Jets $p_T > 30$ GeV

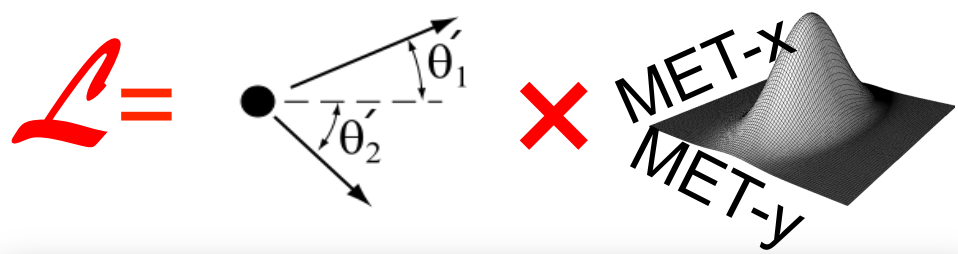


¹categorization based on $\tau_h p_T$ for $\mu\tau_h$, $e\tau_h$; μp_T for $e\mu$; leading μp_T for $\mu\mu$

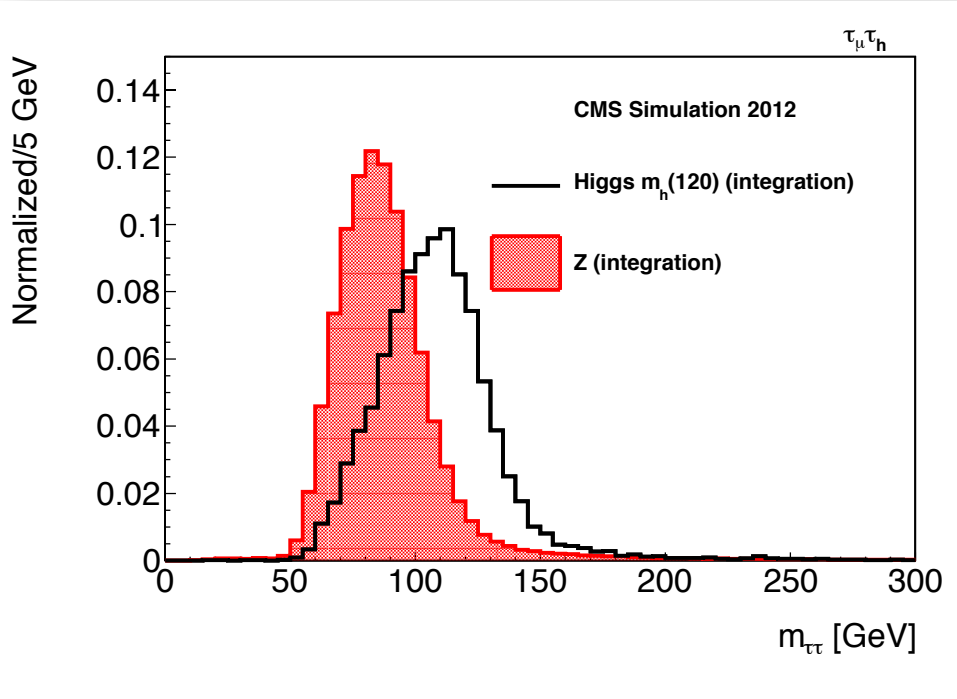


Full $m(\tau\tau)$ Reconstruction

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



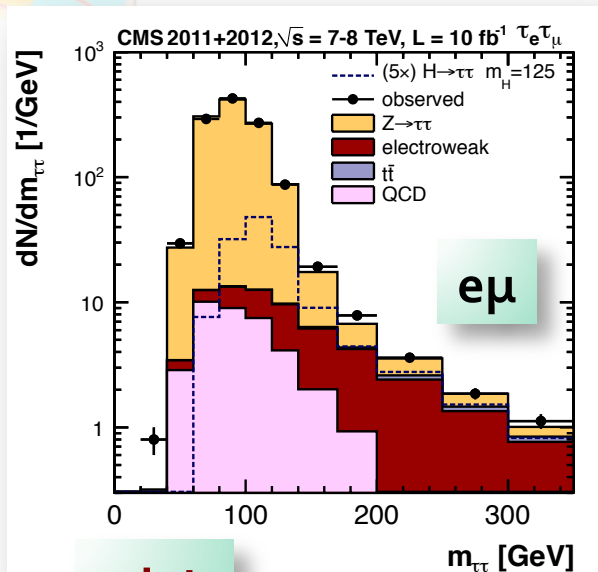
- SVFit
 - Event-by-event estimator of true $m(\tau\tau)$ likelihood
 - Matrix Element used for $\tau \rightarrow l\nu\nu$
 - Phase-Space is used for $\tau \rightarrow \pi$
 - Nuisance parameters are integrated out
- Mass peaks at true value
 - 20 % improved resolution
 - With respect to 2011
 - Better separation of H from Z





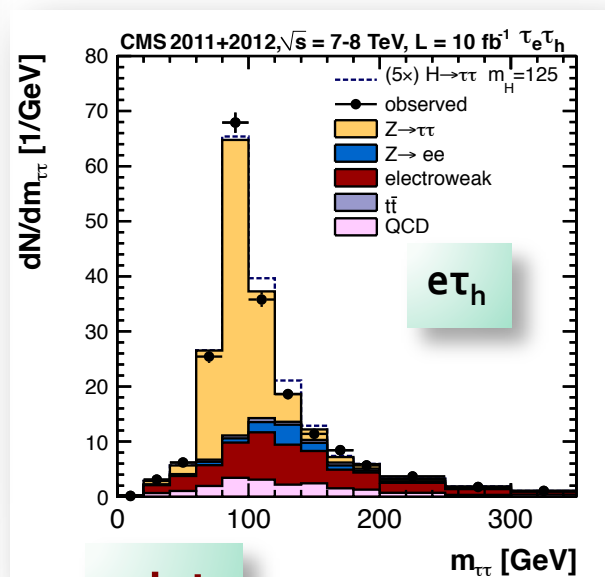
Mass Distributions in Event Categories

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



0 Jet

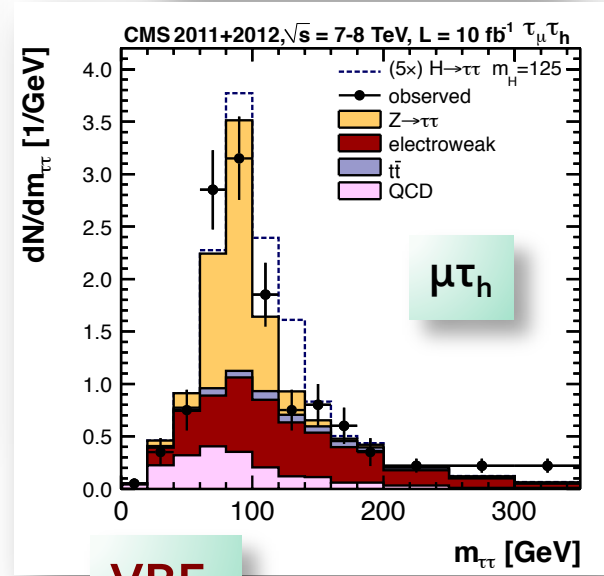
- Constrains energy scales and efficiencies
 - Large Drell-Yan background
 - Sensitivity boosted by low/high p_T split



1 Jet

- Enhanced sensitivity to gluon fusion
 - Improved mass resolution
 - Increased sensitivity by splitting into low and high p_T categories

..... (5x) $H \rightarrow \tau\tau$ $m_H = 125$ GeV
 —●— observed
 ■ $Z \rightarrow \tau\tau$
 ■ $t\bar{t}$
 ■ electroweak
 ■ QCD

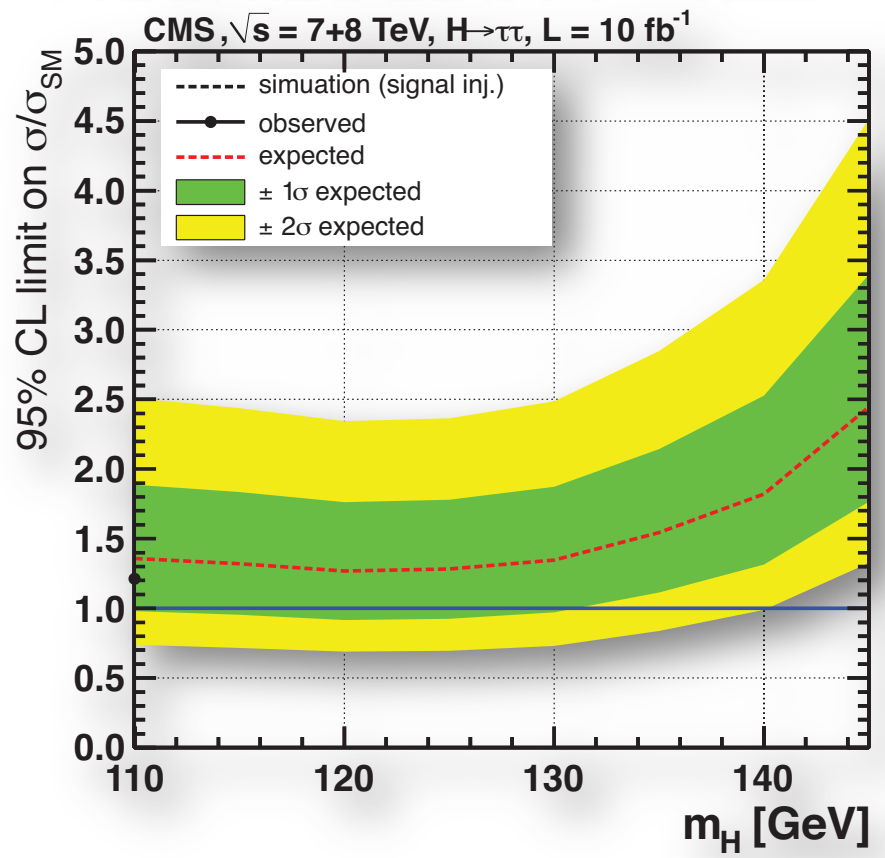
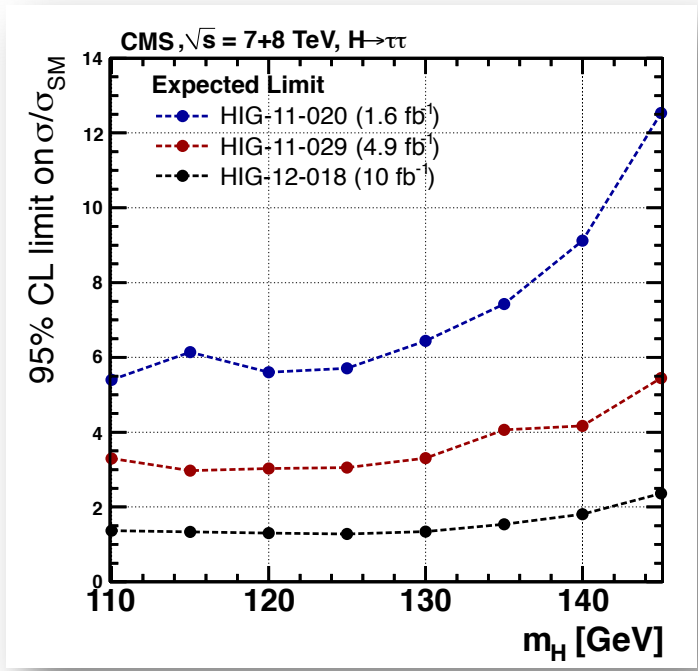


VBF

- Enhanced sensitivity to VBF production
 - Highest sensitivity for $m_H < 130$ GeV



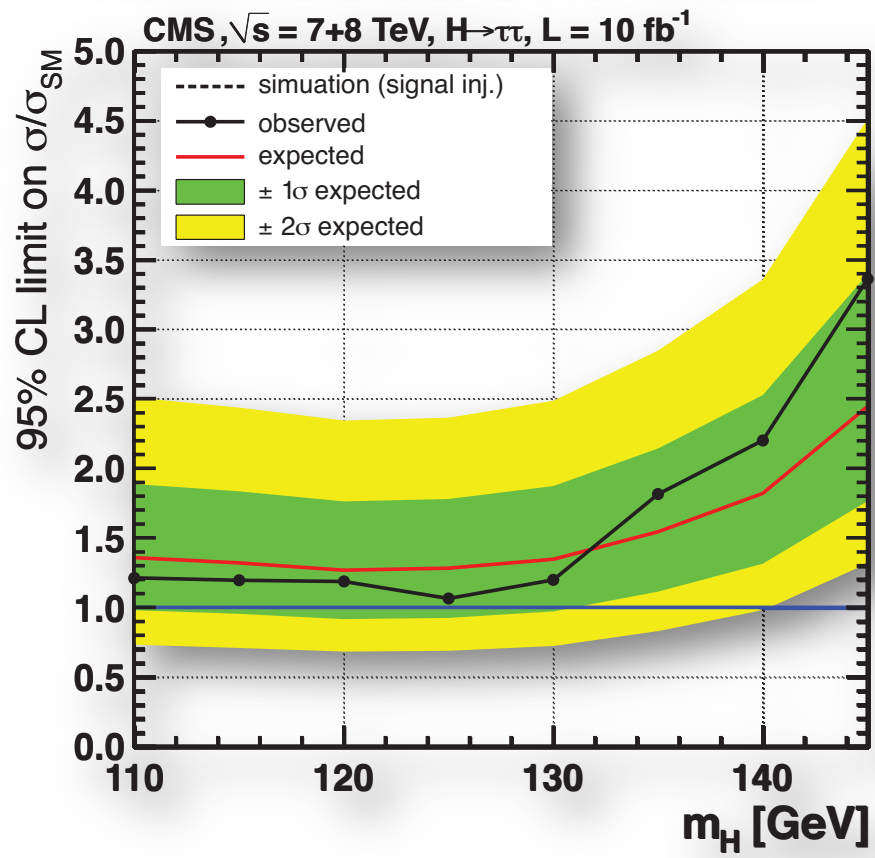
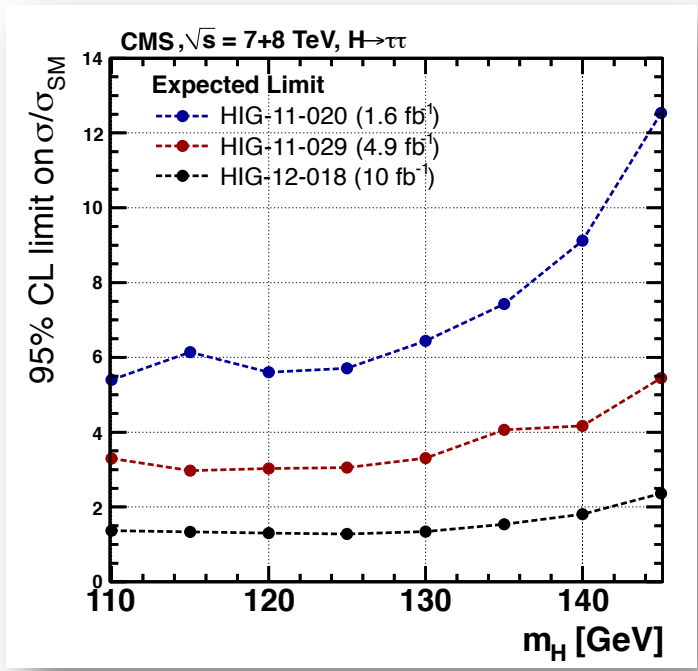
Results for $H \rightarrow \tau\tau$



- ~2x improvement in sensitivity in 2011 data alone
 - => 70% improvement in sensitivity on the same data
 - 40% improvement with the additional luminosity
- No significant departure from SM background-only expectation
 - Observed limit of 1.06 x SM at $m_H = 125$ GeV



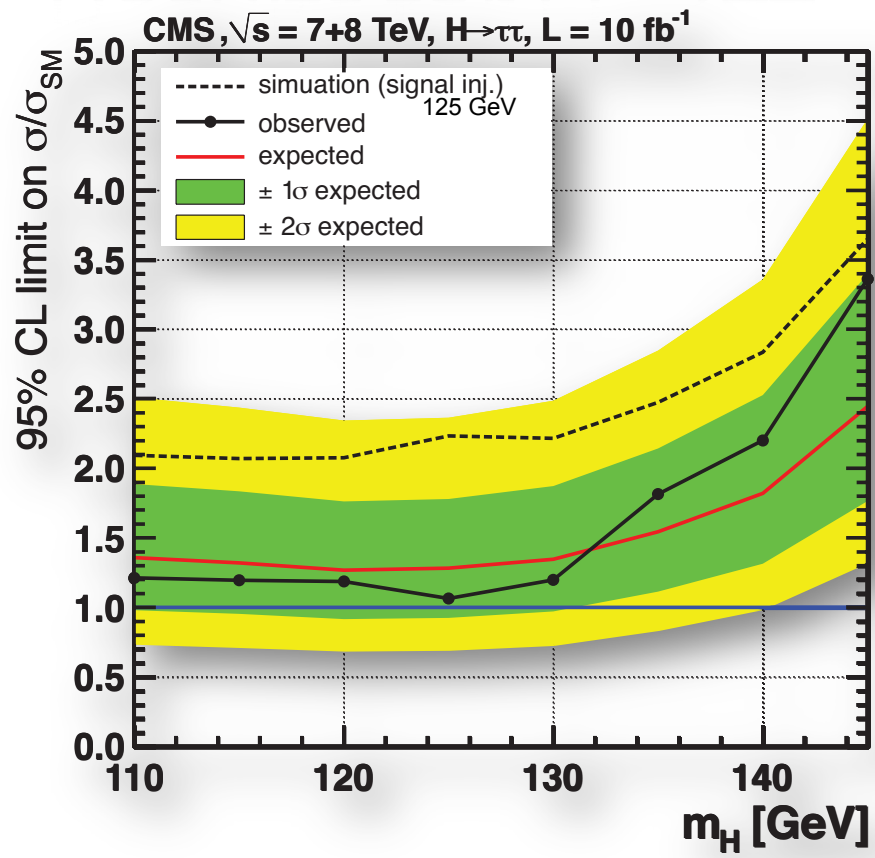
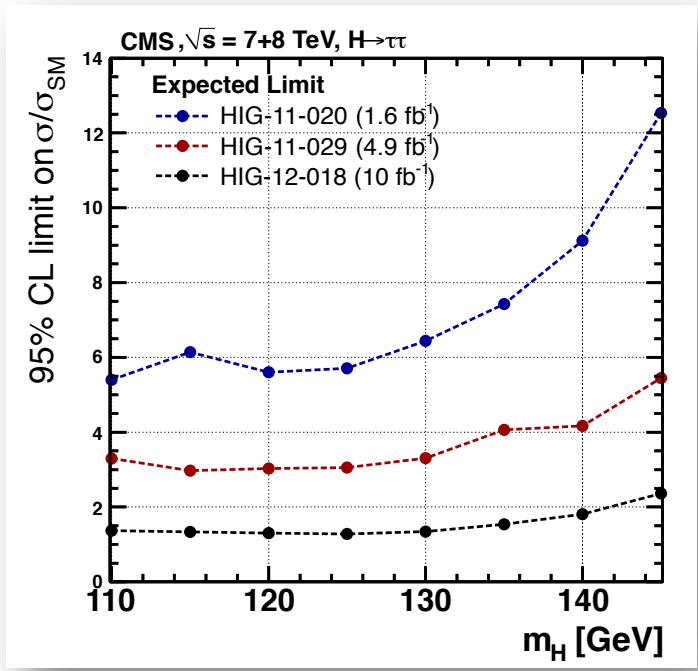
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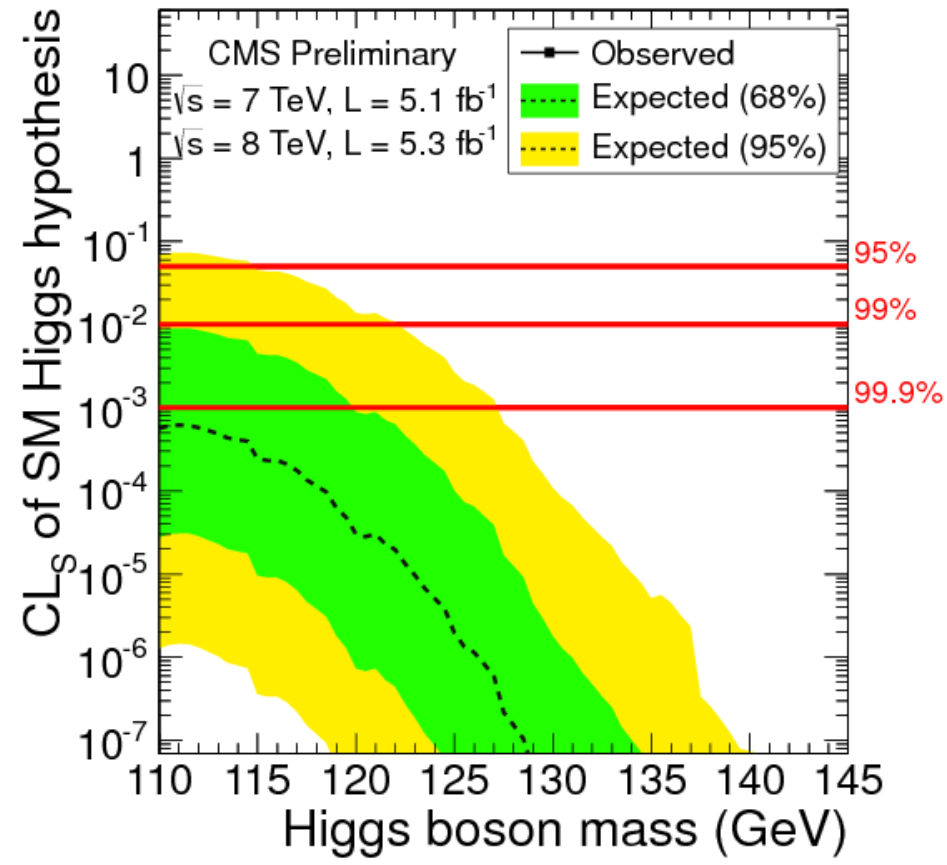
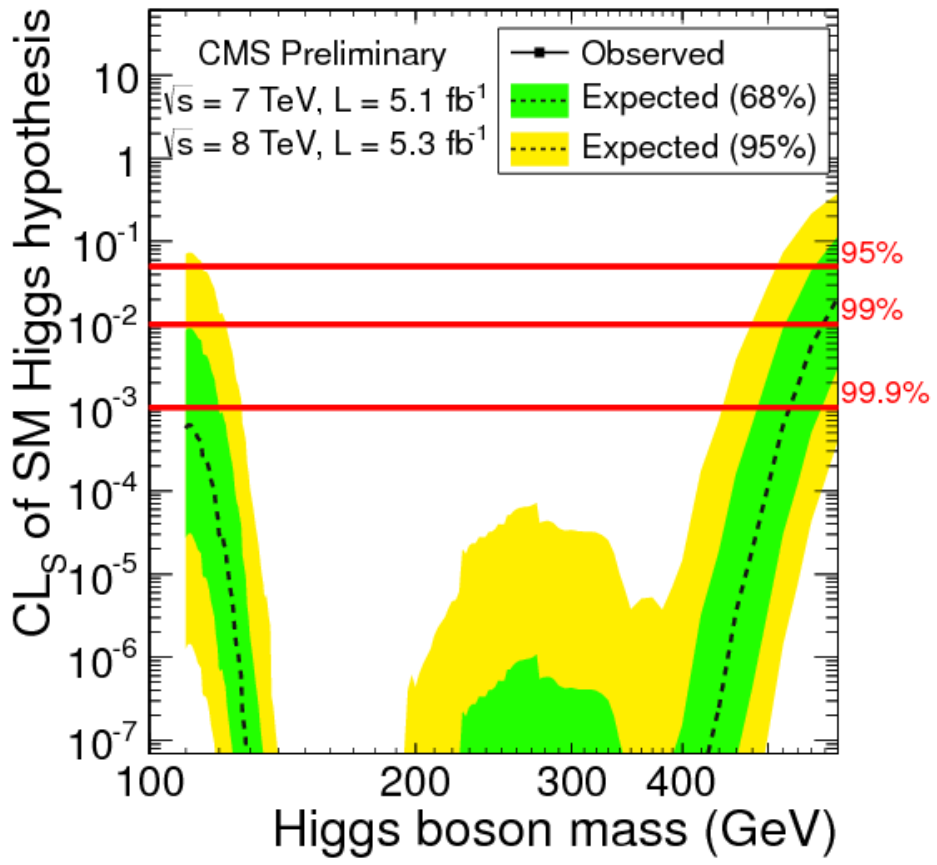
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Full result



SM Higgs exclusion: confidence level

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



Expected in absence of SM Higgs boson:

110 – 600 GeV at 95% CL

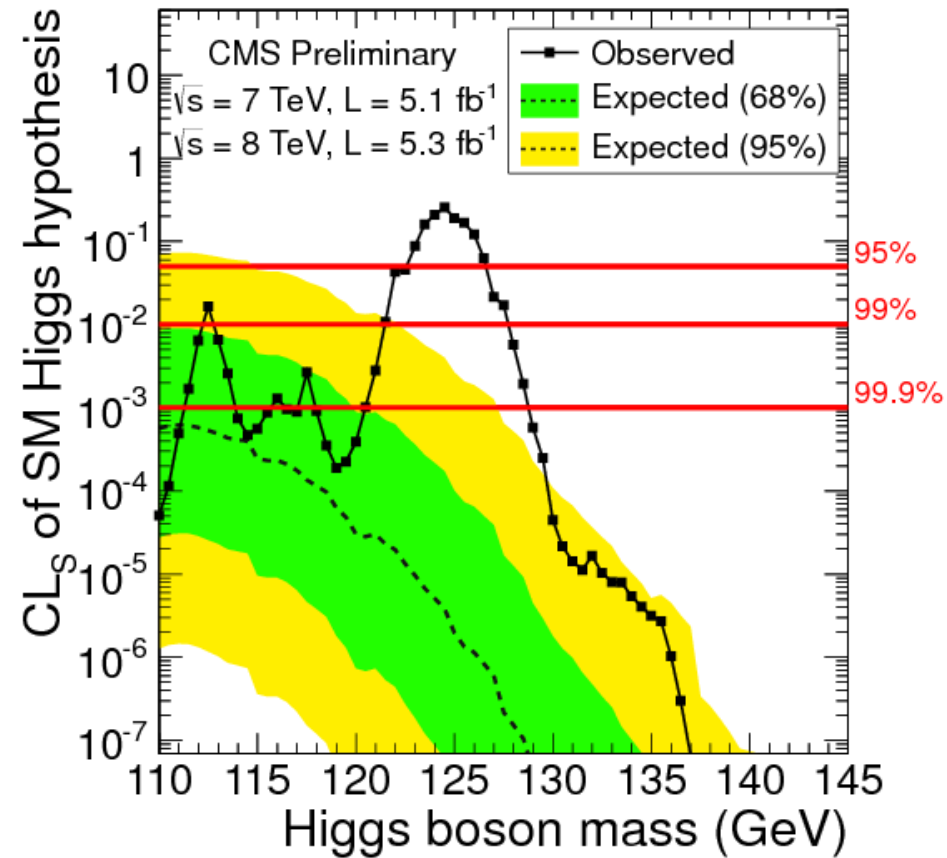
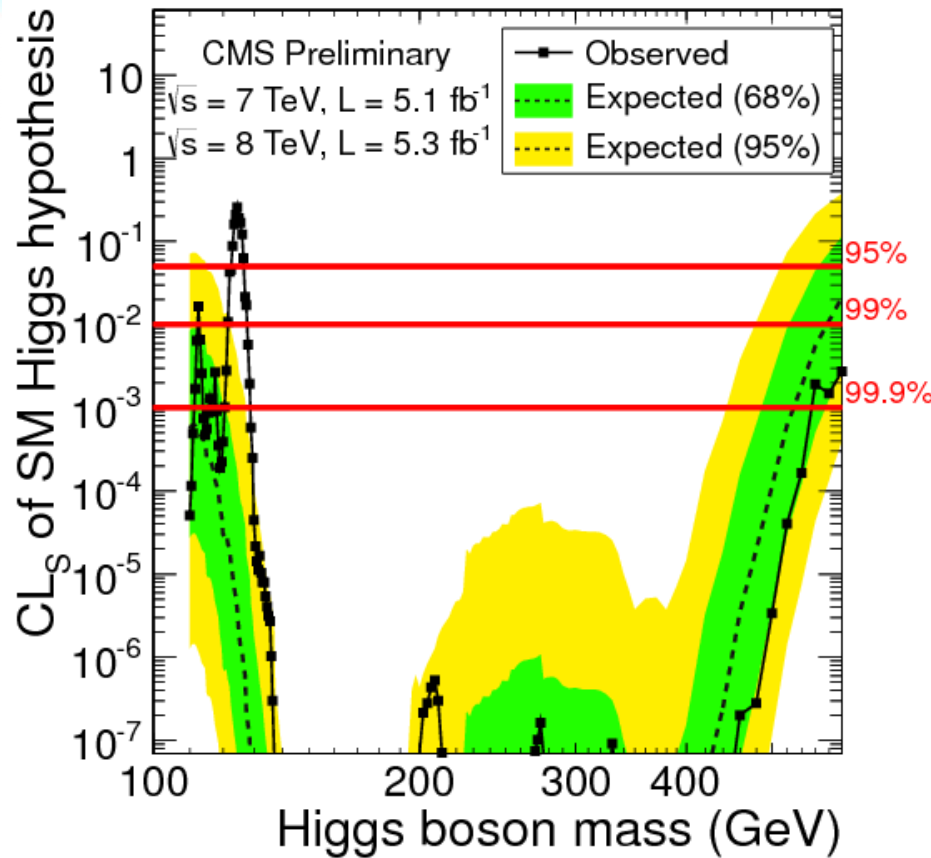
110 – 580 GeV at 99% CL

110 – 520 GeV at 99.9% CL



SM Higgs exclusion: confidence level

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

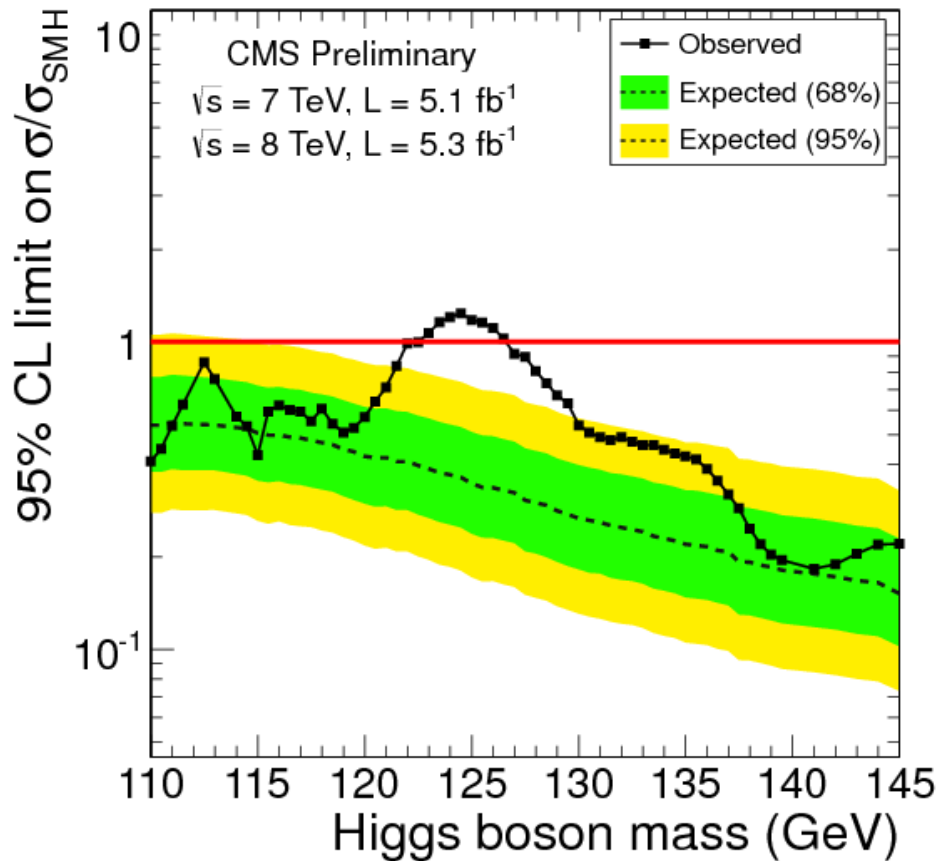
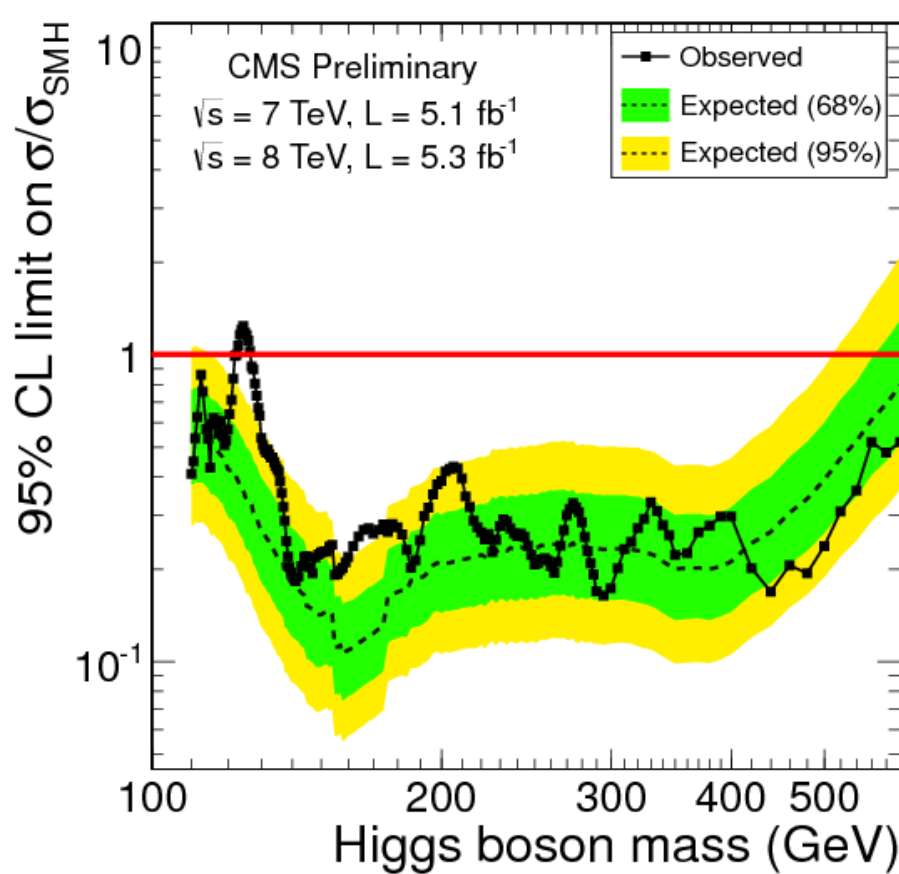


Observed: **110 – 122.5** [...] **127 – 600 GeV at 95% CL**
 110—112 .. 113 – 121.5 [...] **128 – 600 GeV at 99% CL**



SM Higgs exclusion: **signal strength**

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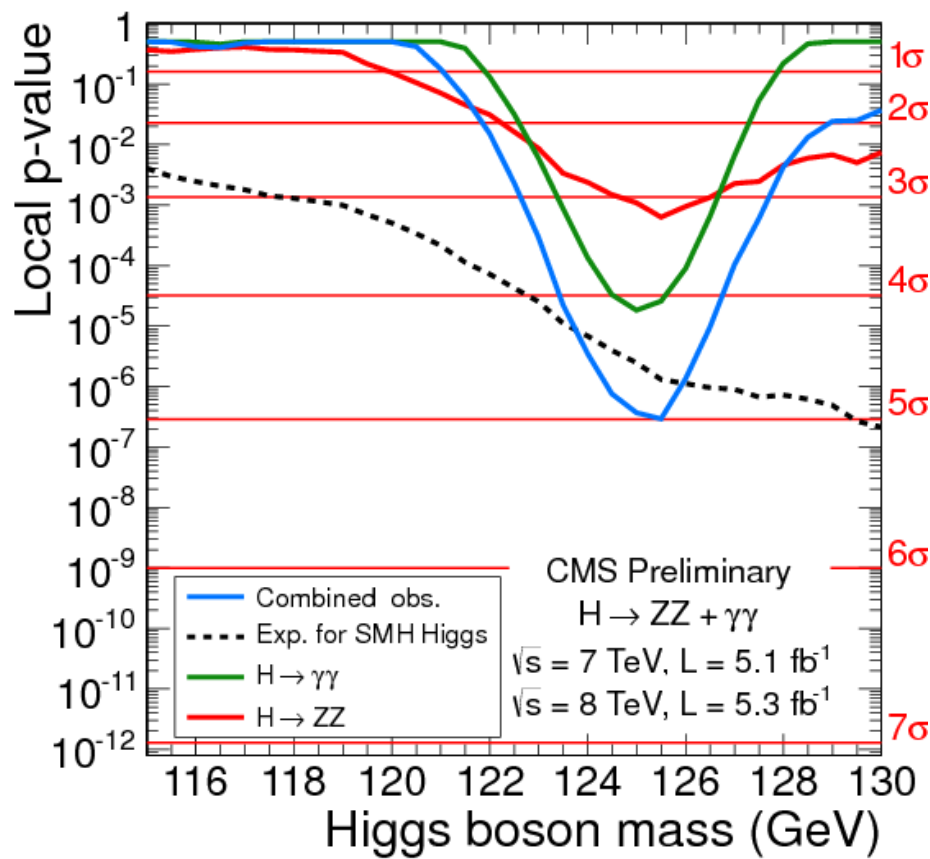


Observed: **110 – 122.5** **127 – 600 GeV at 95% CL**



Characterization of excess near 125 GeV

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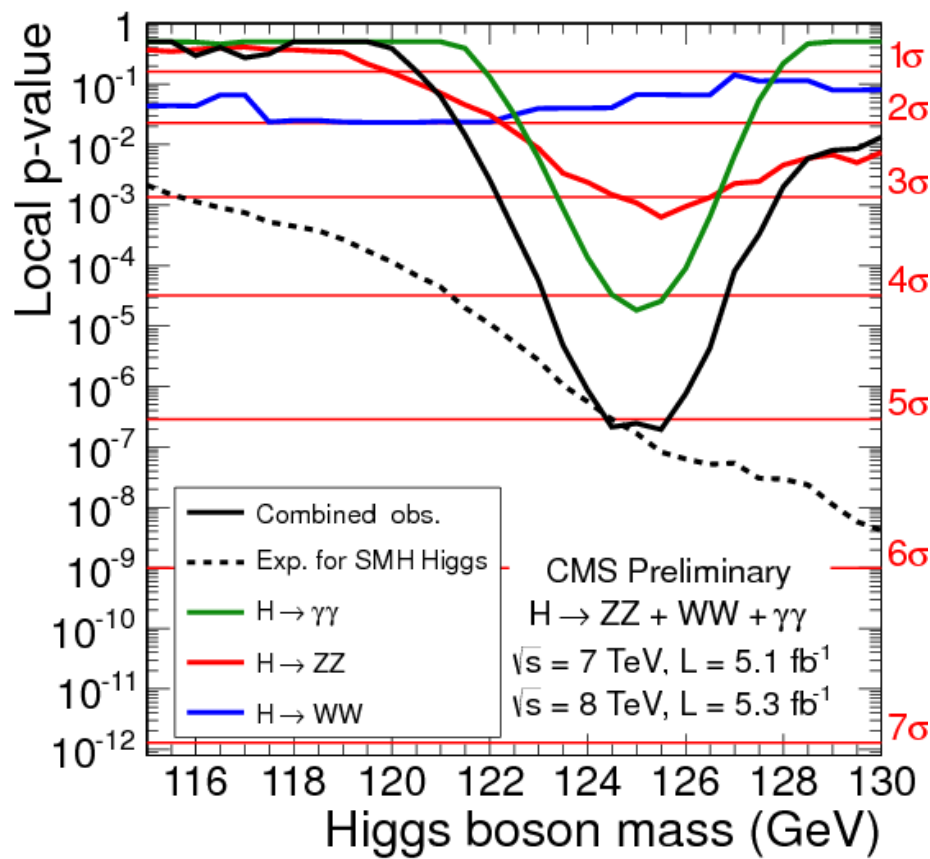


- high sensitivity, high mass resolution channels: $\gamma\gamma + 4l$
- $\gamma\gamma$: 4.1 σ excess
- 4 leptons: 3.2 σ excess
- near the same mass 125 GeV
- comb. significance: **5.0 σ**
- expected significance for SM Higgs: 4.7 σ



Characterization of excess near 125 GeV

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adding high sensitivity, but low mass resolution WW

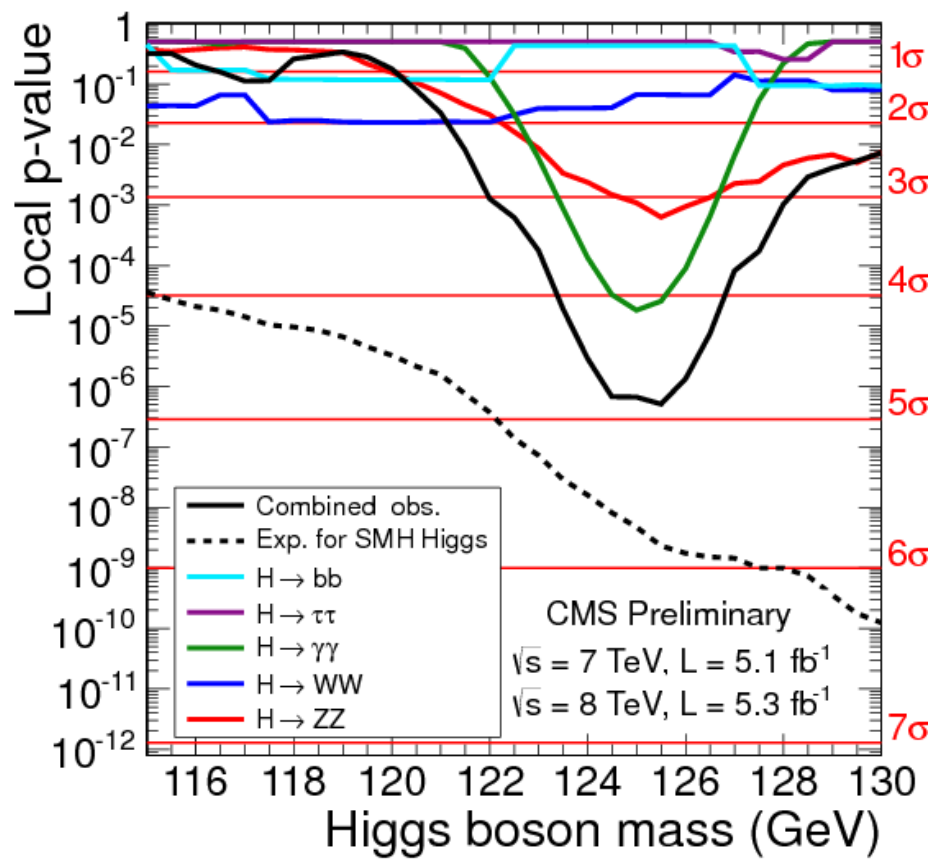
comb. significance: **5.1 σ**

expected significance for SM Higgs: **5.2 σ**



Characterization of excess near 125 GeV

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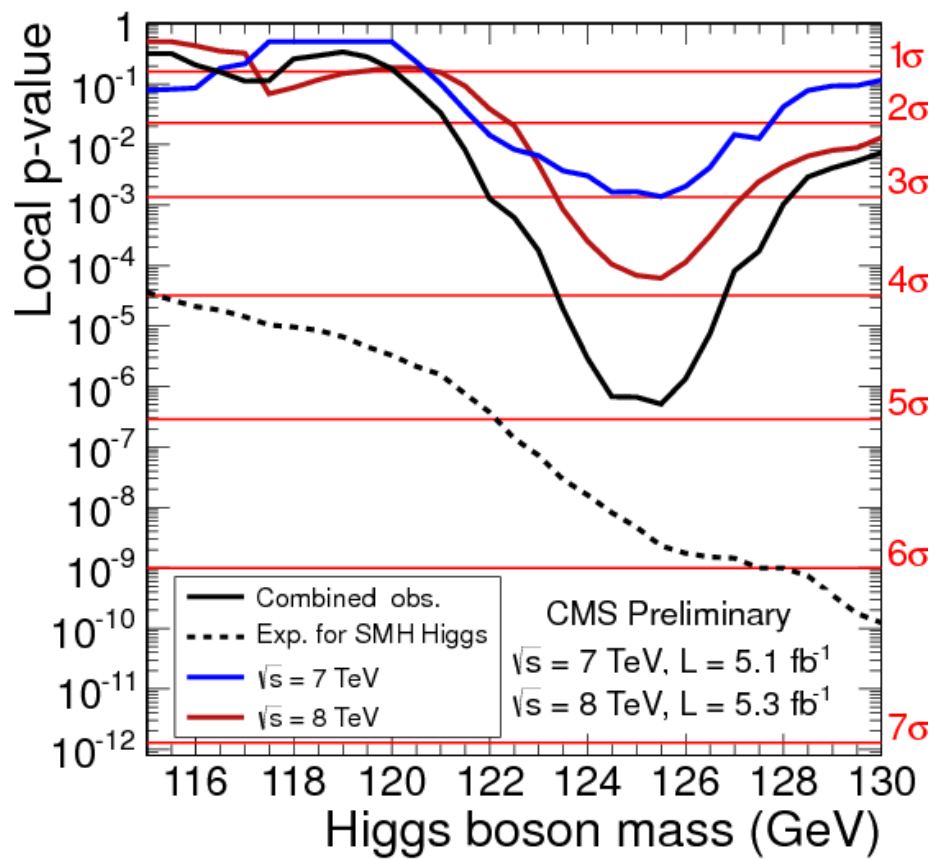
- all channels together:
comb. significance: **4.9 σ**

- expected significance
for SM Higgs: **5.9 σ**



Characterization of excess near 125 GeV

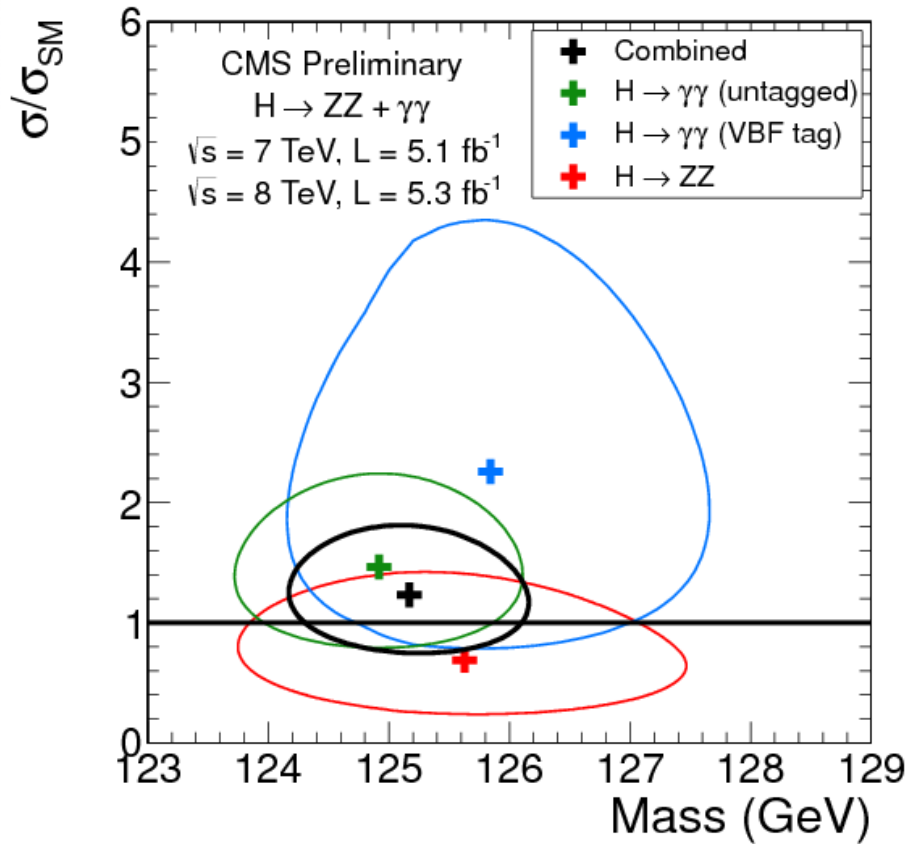
July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION



- Observed significance: **4.9 σ**
- Excess seen in both
 - 7 TeV data (3.0 σ)
 - 8 TeV data (3.8 σ)
 - near the same mass 125 GeV



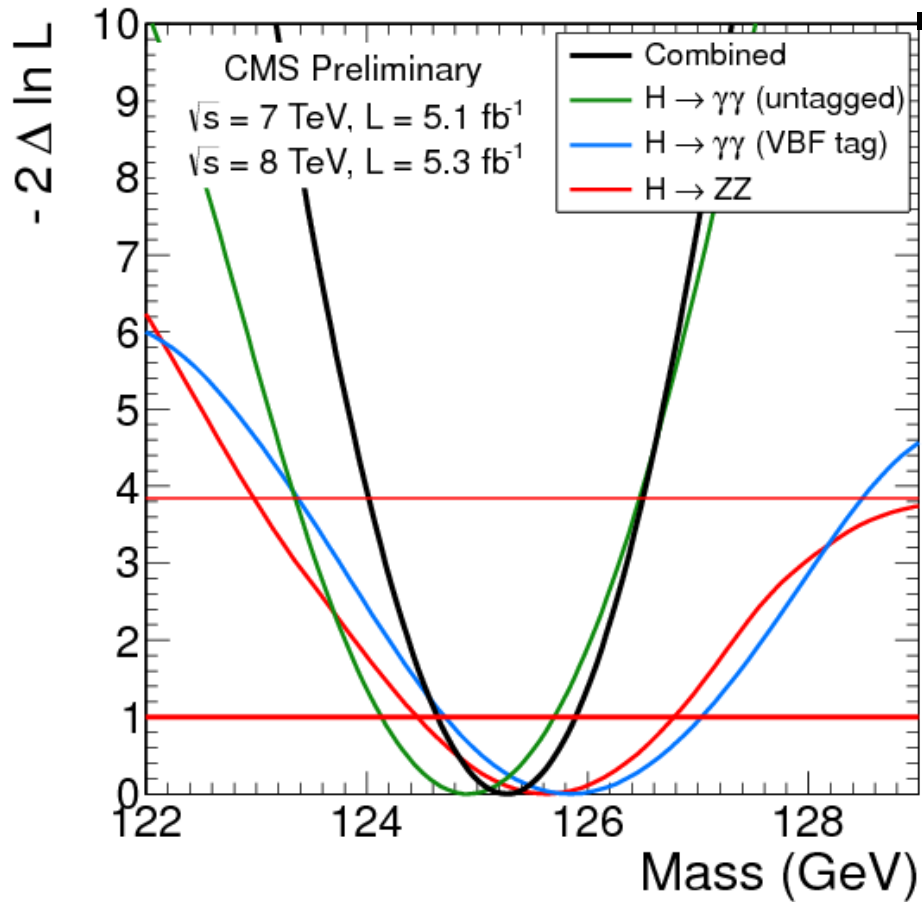
Characterization of the excess: **mass**



- Likelihood scan for mass and signal strength in three high mass resolution channels
- results are self-consistent and can be combined



Characterization of the excess: **mass**



To reduce model dependence, allow for free cross sections in three channels and fit for the common mass:

$$m_x = 125.3 \pm 0.6 \text{ GeV}$$

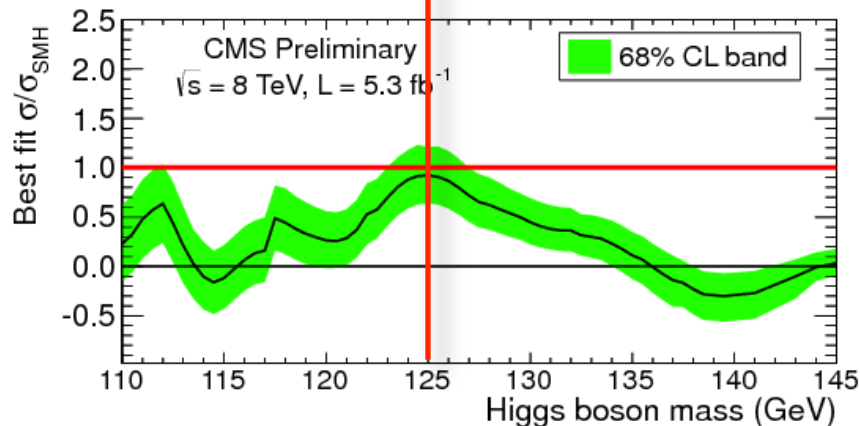
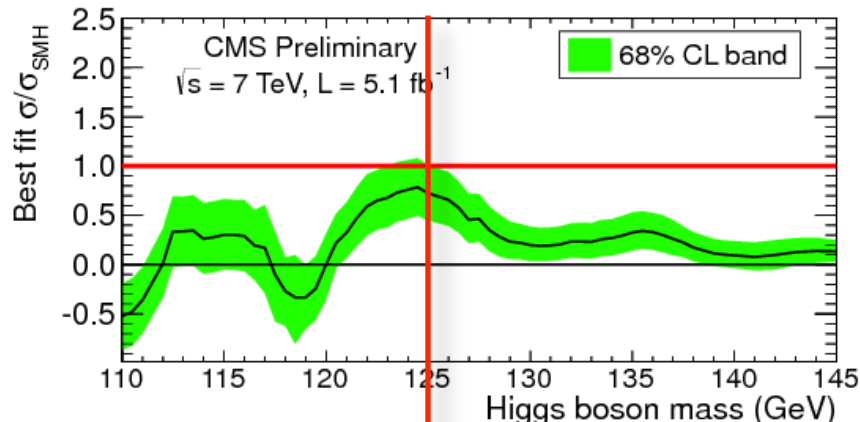
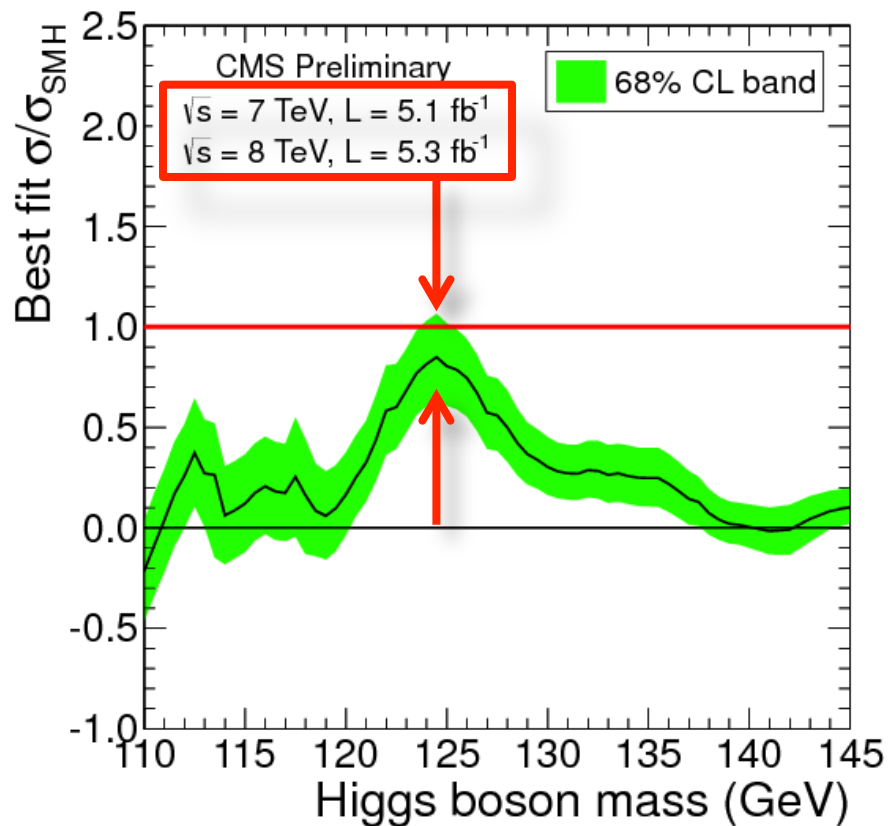


- We have observed a state decaying to di-photon and four-lepton final state with statistical significance of 5σ
- The observed state has mass near 125.3 ± 0.6 GeV
- Next we look at the extent to which the observed state is compatible, within the current uncertainties, with the SM Higgs boson



Compatibility with SM Higgs boson

Signal strength



- Overall best-fit signal strength in the combination:

$$\sigma/\sigma_{SM} = 0.80 \pm 0.22$$

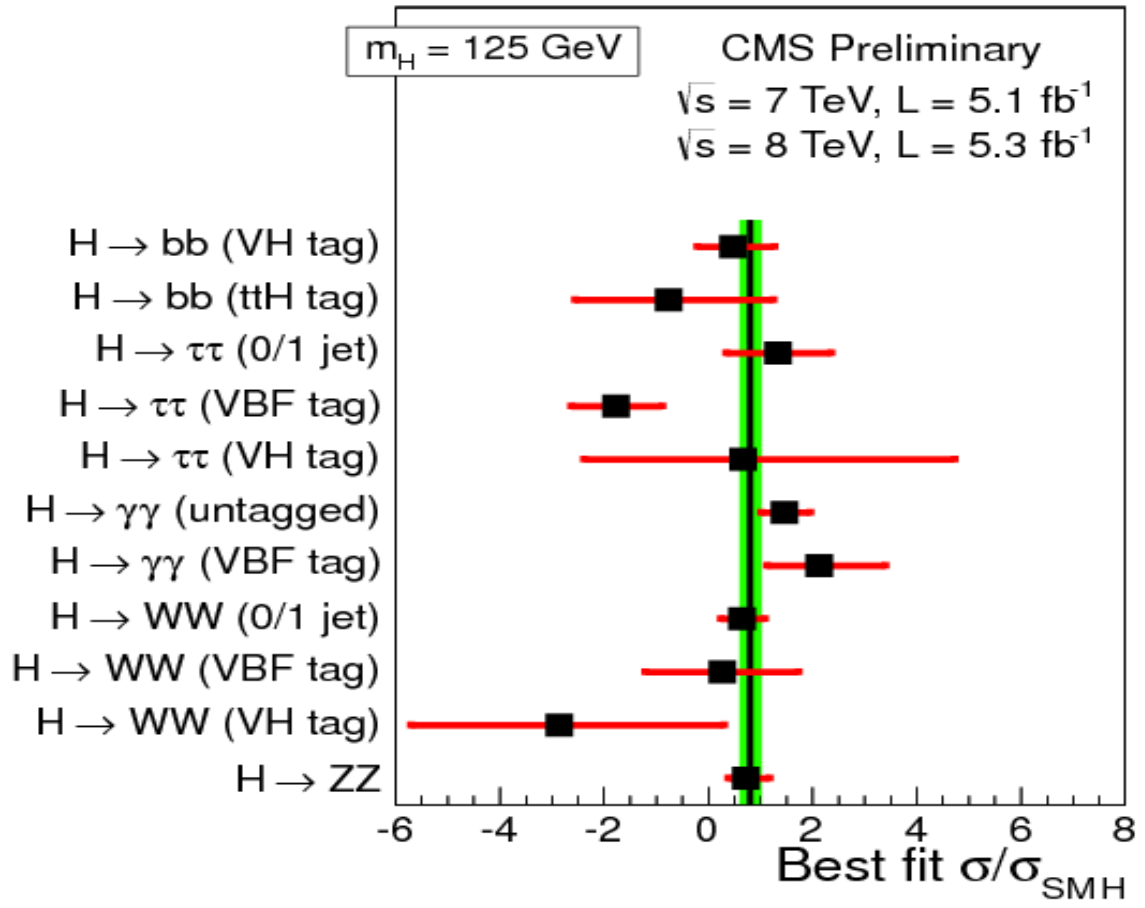
- Signal strength in 7 and 8 TeV data are self-consistent



Compatibility with SM Higgs boson event yields in different modes (1)

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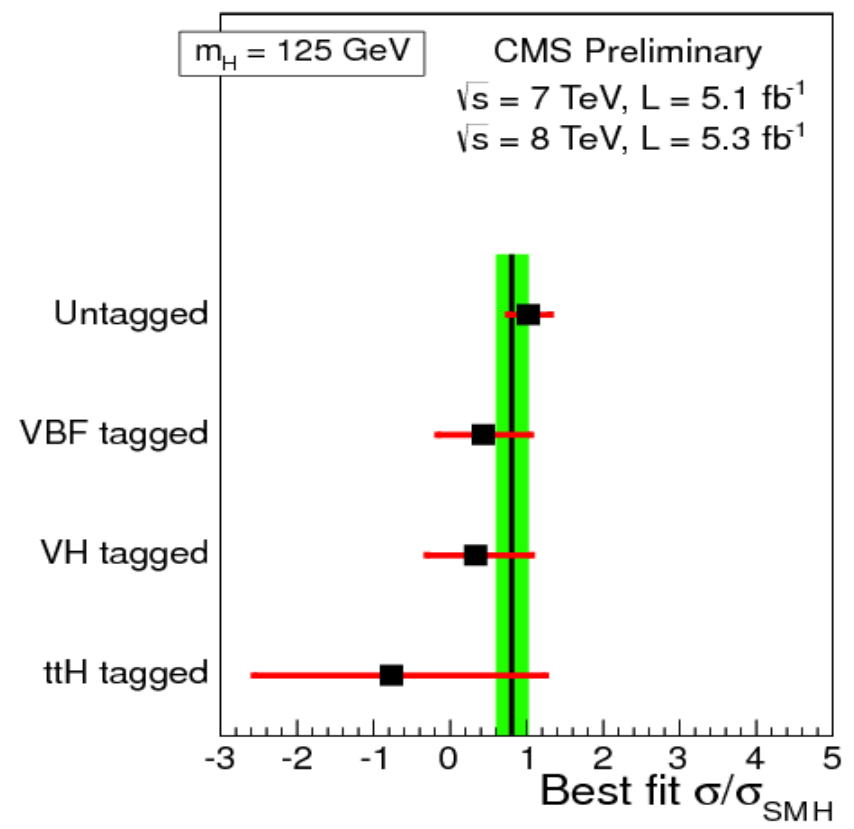
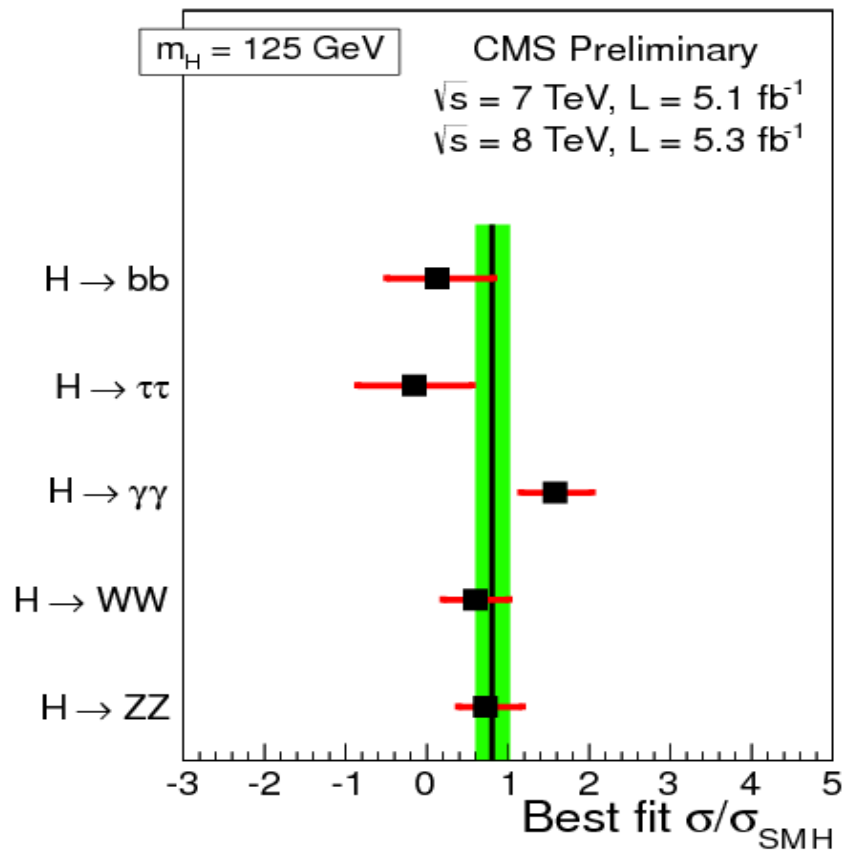
- Event yields in different production times decay modes are self-consistent
- albeit many modes have not yet reached sensitivity to distinguish SM from Background





Compatibility with SM Higgs boson event yields in different modes (2)

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- Event yields in different decay modes are self-consistent
- Event yields in different production topologies are self-consistent



Compatibility with SM Higgs boson custodial symmetry

- The measurement of the $H \rightarrow WW/H \rightarrow ZZ$ ratio is mostly driven by the ratio of the Higgs couplings to WW and ZZ , which is protected by custodial symmetry
- Combination of “inclusive” WW and ZZ yields gives

$$R_{ww/zz} = 0.9^{+1.1}_{-0.6}$$



Fit to C_V and C_F

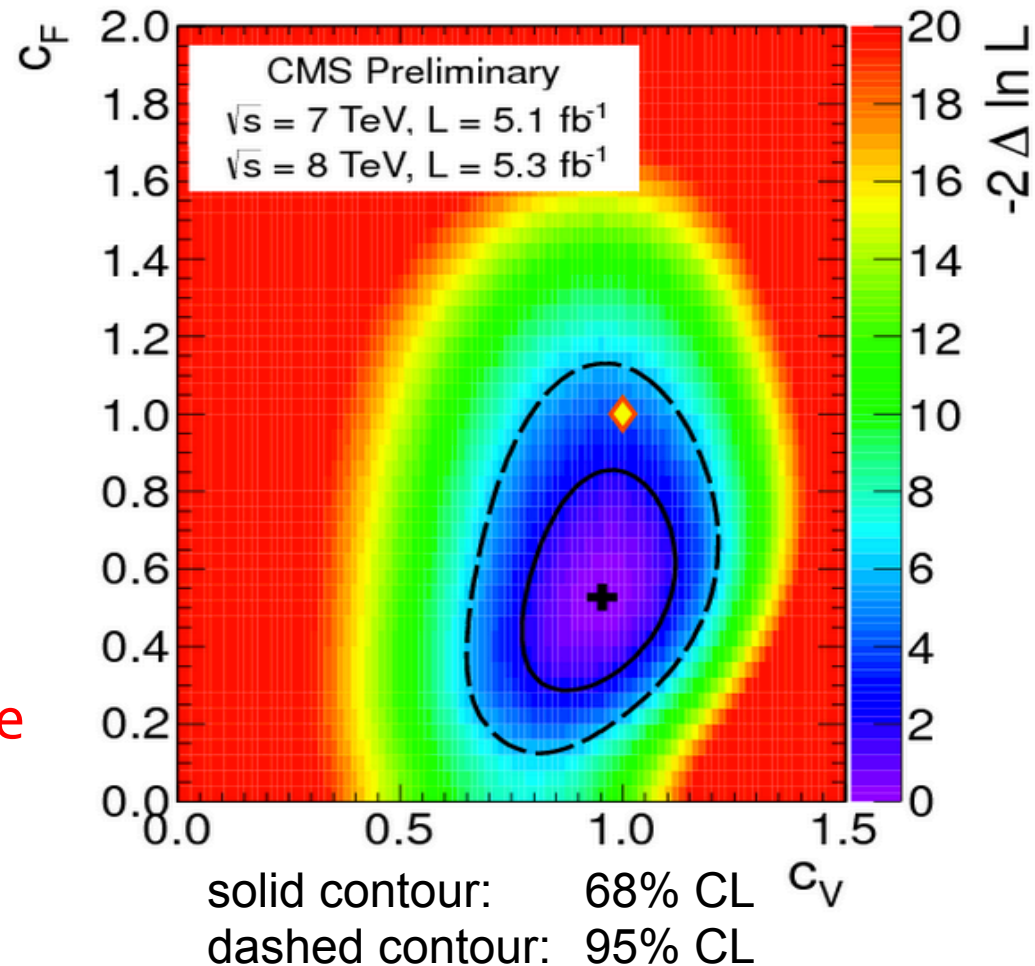
Group the Higgs couplings into “Vectorial” and “Fermionic” sets.

Attach a modifier to the SM prediction to each of those (C_V and C_F).

Use LO theoretical prediction for loop-induced $H \rightarrow \gamma\gamma$, $H \rightarrow gg$ couplings.

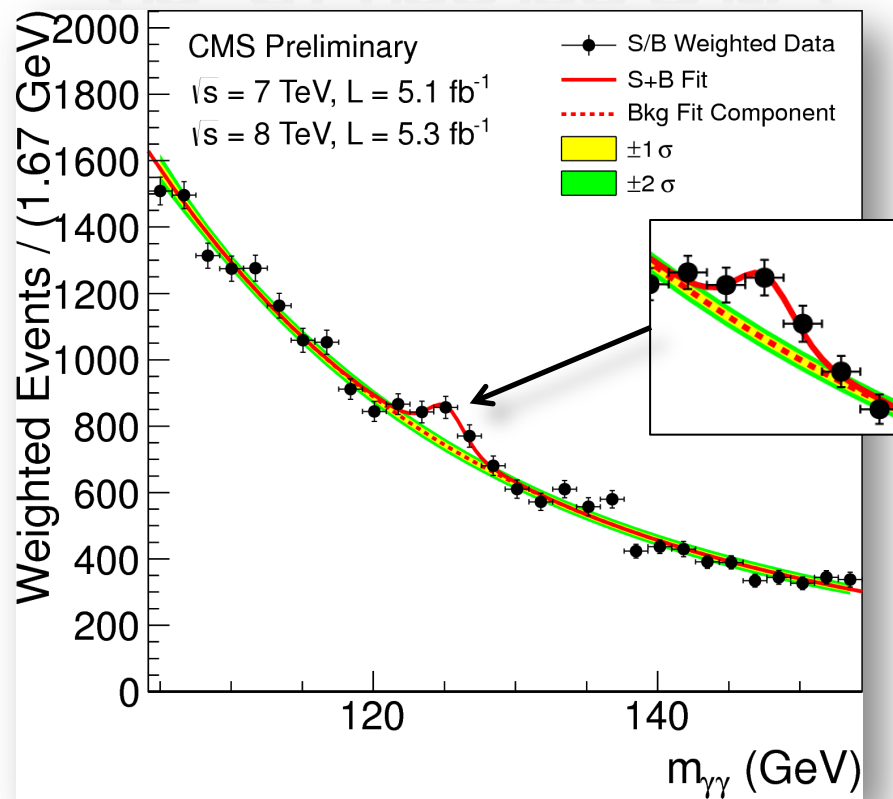
In agreement with the SM within the 95% confidence range

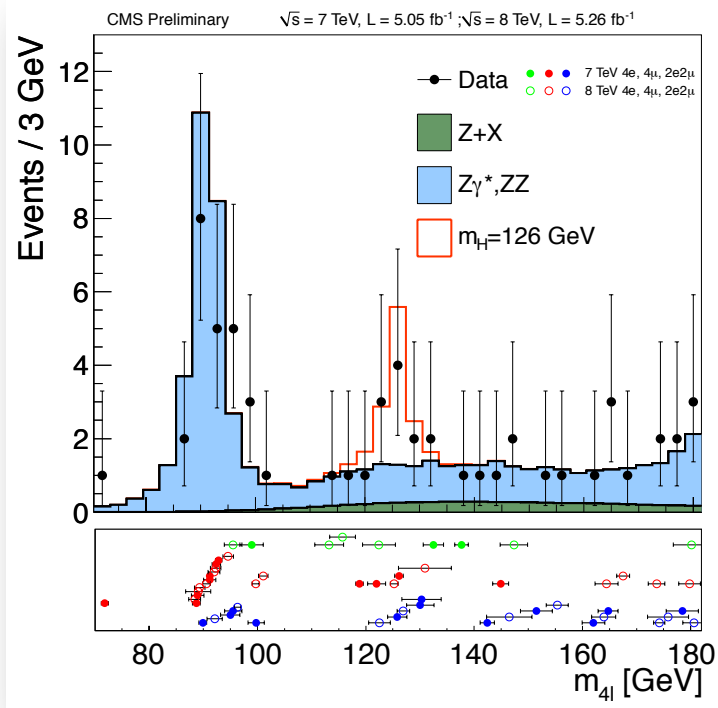
→ Need more data!



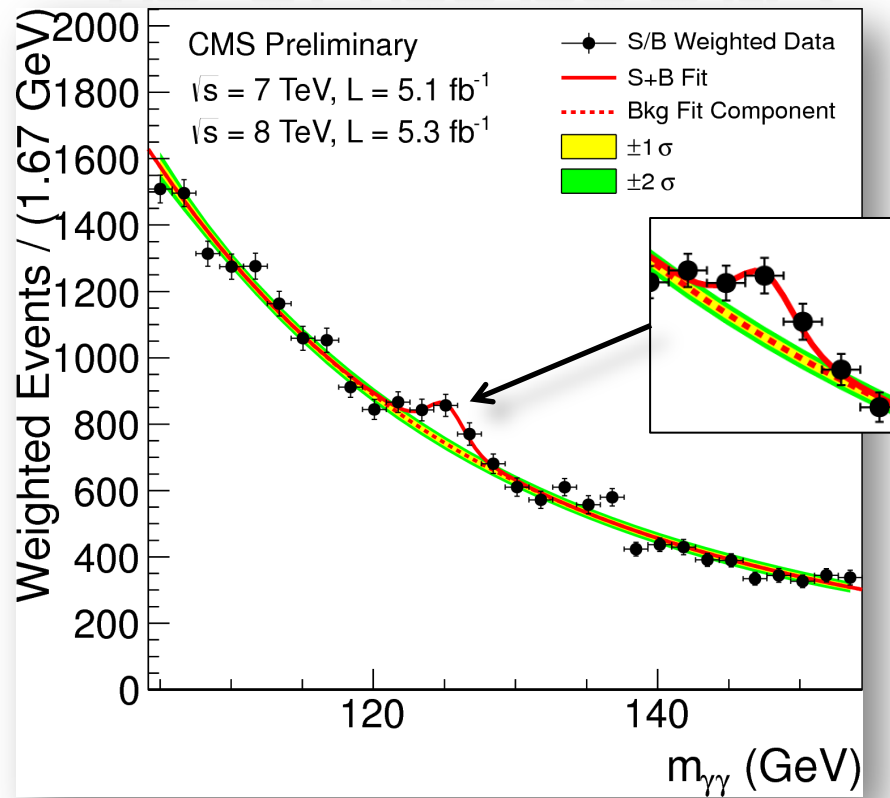


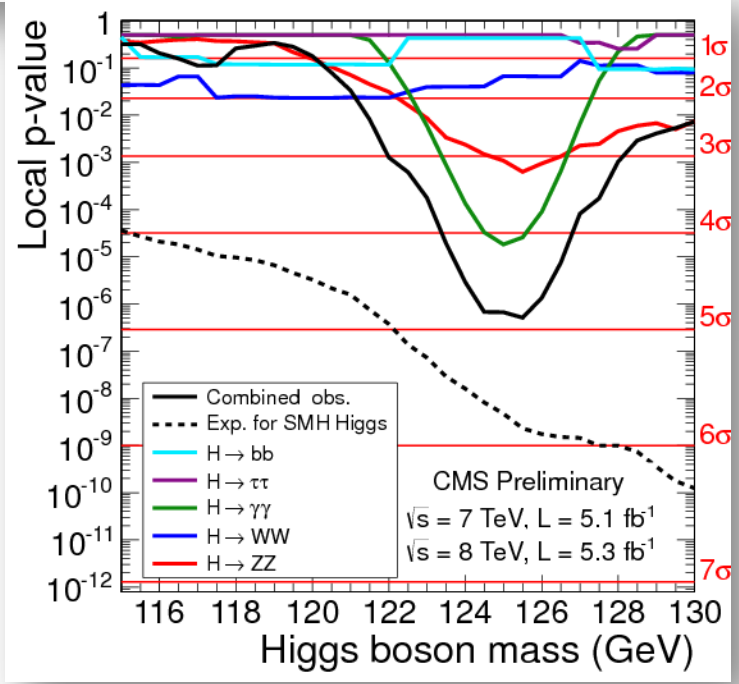
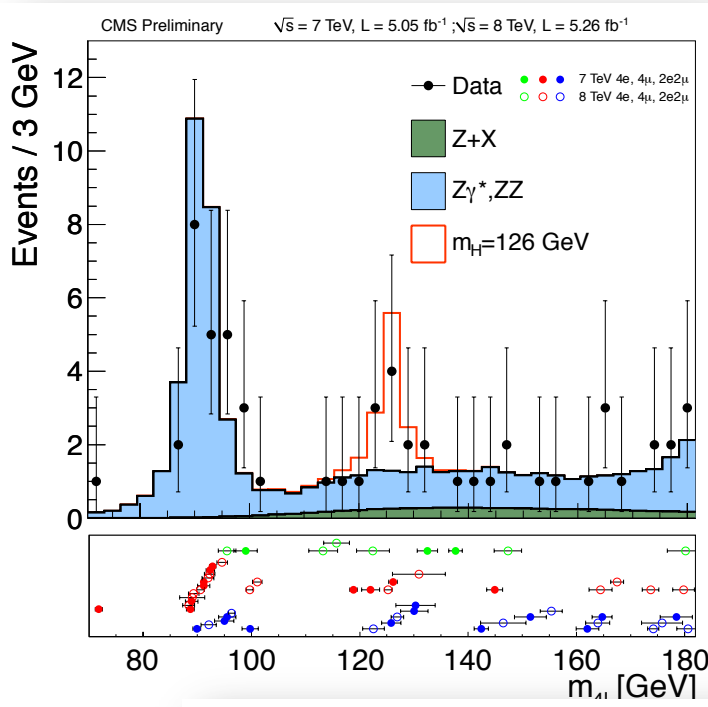
In summary



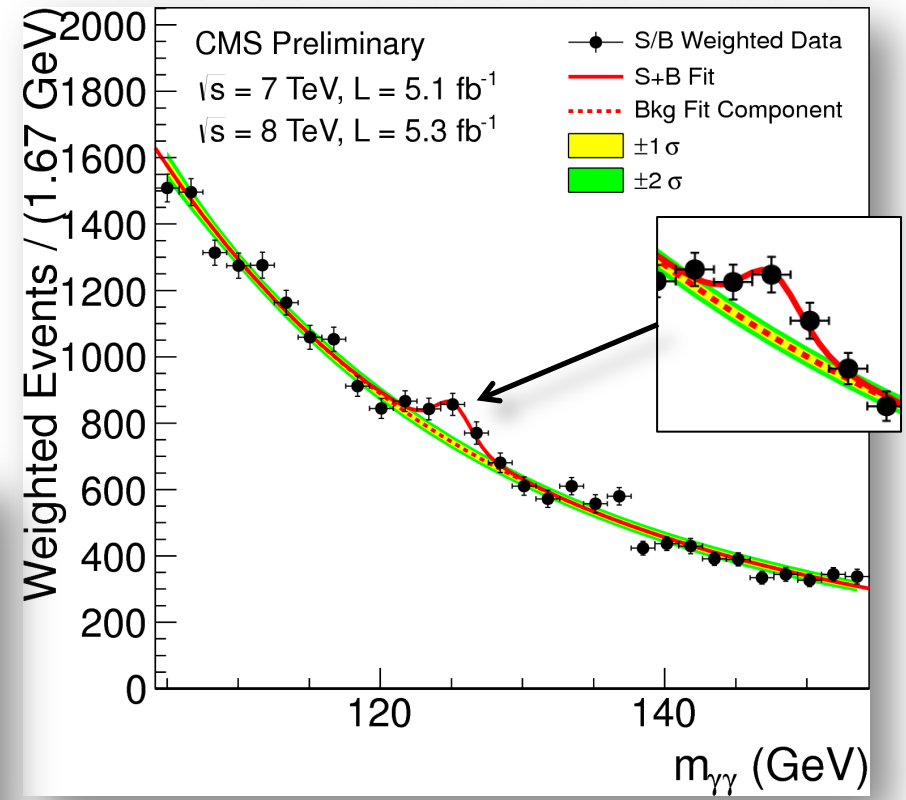


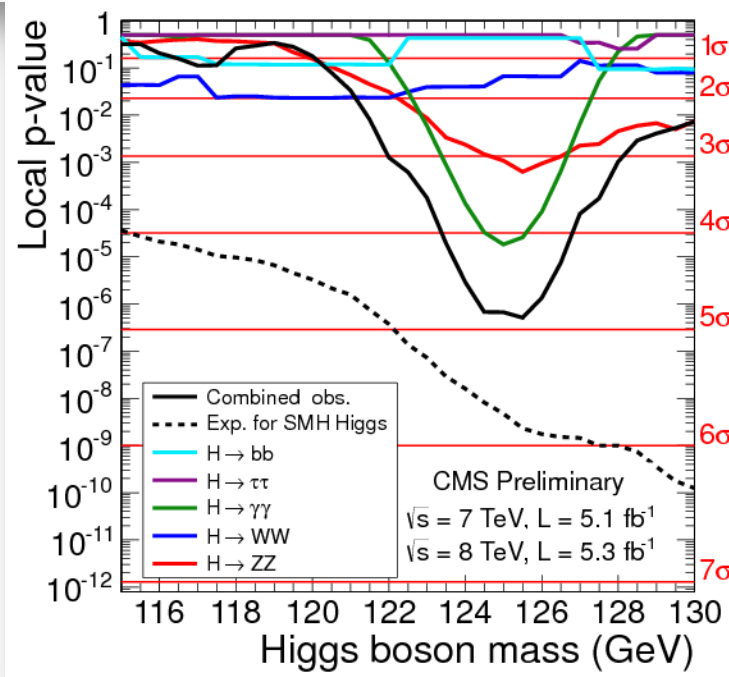
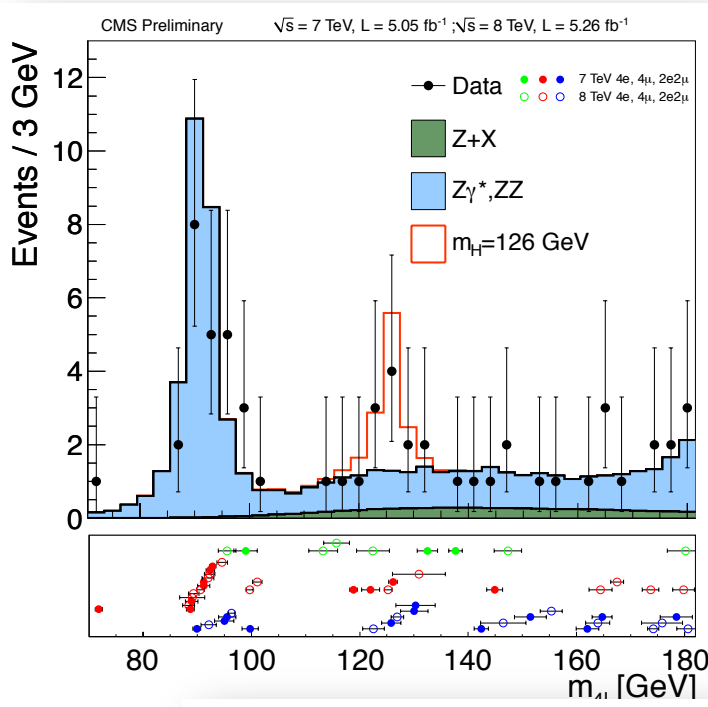
In summary



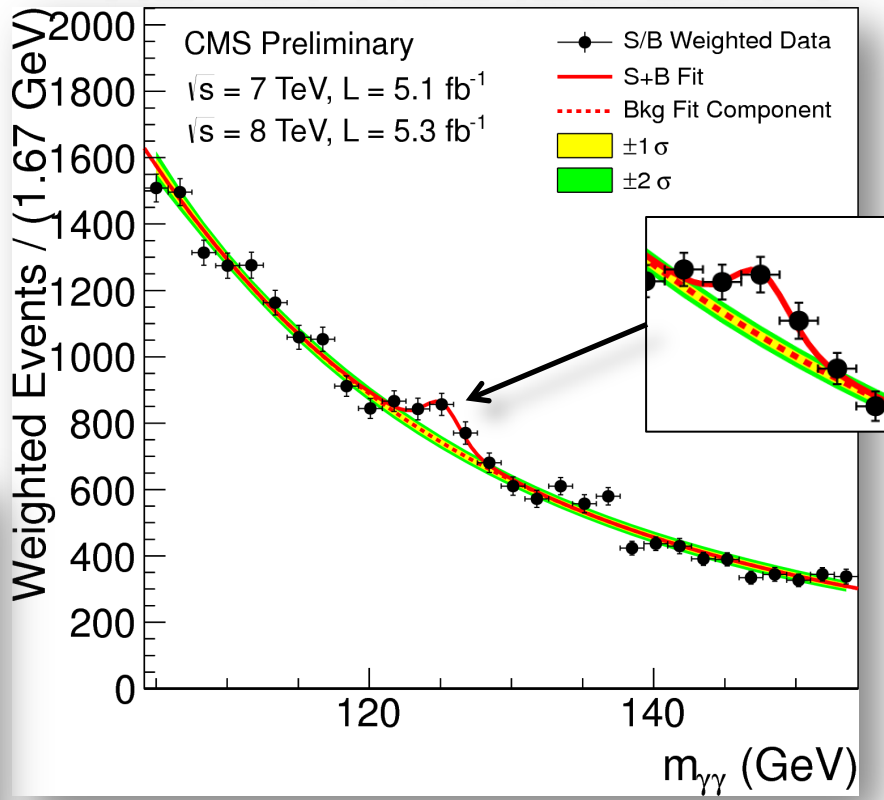


In summary





In summary



In summary

We have observed a new
boson with a mass of

$125.3 \pm 0.6 \text{ GeV}$

at

4.9σ significance !

Acknowledgements



Acknowledgements

- A very wide range of measurements have shown that SM predictions for known physics have been ~spot on.
 - A tribute to a large amount of work done by our theory colleagues along with the results from the other collider experiments at LEP, Tevatron, HERA, b-factories etc.
- And the Higgs cross section WG and all those theorists who prepared the way for today!

[1] S. Glashow, Nucl. Phys. 22 (1961) 579, doi:10.1016/0029-5582(61)90469-2.
[2] S. Weinberg, Phys. Rev. Lett. 19 (1967) 1264, doi:10.1103/PhysRevLett.19.1264.
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Electroweak Theory

Electroweak Symmetry Breaking

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10 September 2008: LHC inauguration day

First (single) beams circulating in the machine



Six CERN DGs, from conception to physics: Schopper, Rubbia, Llewellyn Smith, Maiani, Aymar, Heuer (from right to left) with 5-year terms!!





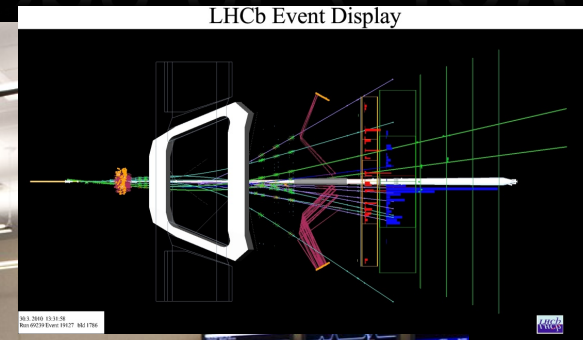
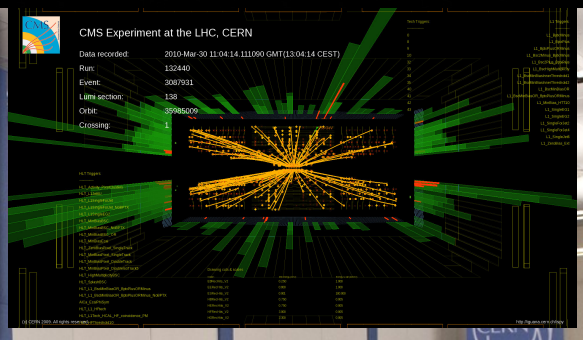
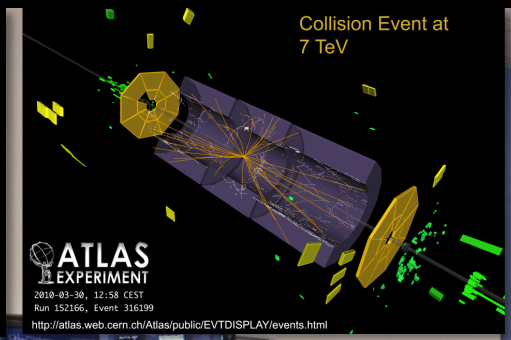
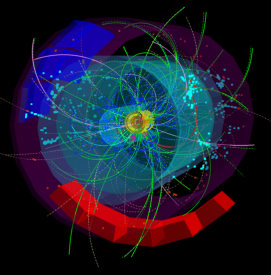
Acknowledgements

- The LHC Project (the accelerator, the experiments, and computing) have required a long and painstaking effort on a global scale encompassing the terms of 6 Director Generals, 3 LHC Project Leaders, and 6 Research Directors.
- The Project started in earnest in 1987 with Rubbia's Long Range Planning Committee recommending the LHC as the right choice for CERN's future.
- Great appreciation of the work of teams that built and now operate the magnificent LHC accelerator
- The CMS experiment is a tribute to the vision of its founders, the dedication of all of its thousands of collaborators in constructing and preparing the experiment in terms of hardware, software, computing, and physics analysis, and now the ones who operate and analyze the data (mostly young scientists!).



March 30 2010: 1st Collisions at 7 TeV

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A small fraction of the CMS Collaboration: June 2012





Thanks to all of the CMS institutes

AACHEN-1, AACHEN-3A, AACHEN-3B, ADANA-CUKUROVA, ALABAMA-UNIV, ANKARA-METU, ANTWERPEN, ATHENS, ATOMKI, AUCKLAND, BARI, BAYLOR-UNIV, BEIJING-IHEP, BOGAZICI, BOLOGNA, BOSTON-UNIV, BRISTOL, BROWN-UNIV, BRUNEL, BRUSSEL-VUB, BRUXELLES-ULB, BUDAPEST, CALTECH, CANTERBURY, CARNEGIE-MELLON, CATANIA, CCCS-UWE, CERN, CHANDIGARH, CHARLES-UNIV, CHEJU, CHICAGO, CHONNAM, CHUNGBUK, CHUNGLI-NCU, COLORADO, CORNELL, DEBRECEN-IEP, DELHI-UNIV, DEMOKRITOS, DESY, DONGSHIN, DUBLIN-UCD, DUBNA, EINDHOVEN, FAIRFIELD, FERMILAB, FIRENZE, FLORIDA-FIU, FLORIDA-STATE, FLORIDA-TECH, FLORIDA-UNIV, FRASCATI, GENOVA, GHENT, HAMBURG-UNIV, HEFEI-USTC, HELSINKI-HIP, HELSINKI-UNIV, HEPHY, IOANNINA, IOWA, IPM, ISLAMABAD-NCP, ISTANBUL-TECH, JOHNS-HOPKINS, KANGWON, KANSAS-STATE, KANSAS-UNIV, KARLSRUHE-IEKP, KHARKOV-ISC, KHARKOV-KIPT, KHARKOV-KSU, KONKUK-UNIV, KOREA-UNIV, KYUNGPOOK, LAPP, LAPPEENRANTA-LUT, LIP, LIVERMORE, LONDON-IC, LOUVAIN, LYON, LYON-CC, MADRID-CIEMAT, MADRID-UNIV, MARYLAND, MEXICO-IBEROAM, MEXICO-IPN, MEXICO-PUEBLA, MEXICO-UASLP, MILANO-BICOCCA, MINNESOTA, MINSK-INP, MINSK-NCPHEP, MINSK-RIAPP, MINSK-UNIV, MISSISSIPPI, MIT, MONS, MOSCOW-INR, MOSCOW-ITEP, MOSCOW-LEBEDEV, MOSCOW-MSU, MOSCOW-RDIPE, MUMBAI-BARC, MYASISHCHEV, NAPOLI, NEBRASKA, NICOSIA-UNIV, NORTHEASTERN, NORTHWESTERN, NOTRE DAME, NUST, OHIO-STATE, OVIEDO, PADOVA, PAVIA, PEKING-UNIV, PERUGIA, PISA, POLYTECHNIQUE, PRINCETON, PROTVINO, PSI, PUERTO RICO, PURDUE, PURDUE-CALUMET, RAL, RICE, RIE, RIO-CBPF, RIO-UERJ, ROCHESTER, ROCKEFELLER, ROMA-1, RUTGERS, SACLAY, SANTANDER, SAO PAULO, SEONAM, SEOUL-EDU, SEOUL-SNU, SINP, SHANGHAI-IC, SKK-UNIV, SOFIA-INRNE, SOFIA-ISER, SOFIA-UNIV, SPLIT-FESB, SPLIT-UNIV, ST-PETERSBURG, STRASBOURG, SUNY-BUFFALO, TAIPEI-NTU, TALLINN, TASHKENT, TBILISI-IHEPI, TBILISI-IPAS, TENNESSEE, TEXAS-TAMU, TEXAS-TECH, TIFR-EHEP, TIFR-HECR, TORINO, TRIESTE, UCDAVIS, UCLA, UCRIVERSIDE, UCSB, UCSD, UNIANDES, VANDERBILT, VILNIUS-ACADEMY, VILNIUS-UNIV, VINCA, VIRGINIA-TECH, VIRGINIA-UNIV, WARSAW-IEP, WARSAW-INS, WARSAW-ISE, WAYNE, WISCONSIN, WONKWANG, YEREVAN, ZAGREB-RUDJER, ZURICH-ETH, ZURICH-UNIV

**June 2012: 193 Institutions with ~3300 scientists and engineers
~ 2000 Signing Authors (including students)**



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The End

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