Boson(s) de Higgs dans l'expérience CMS au LHC

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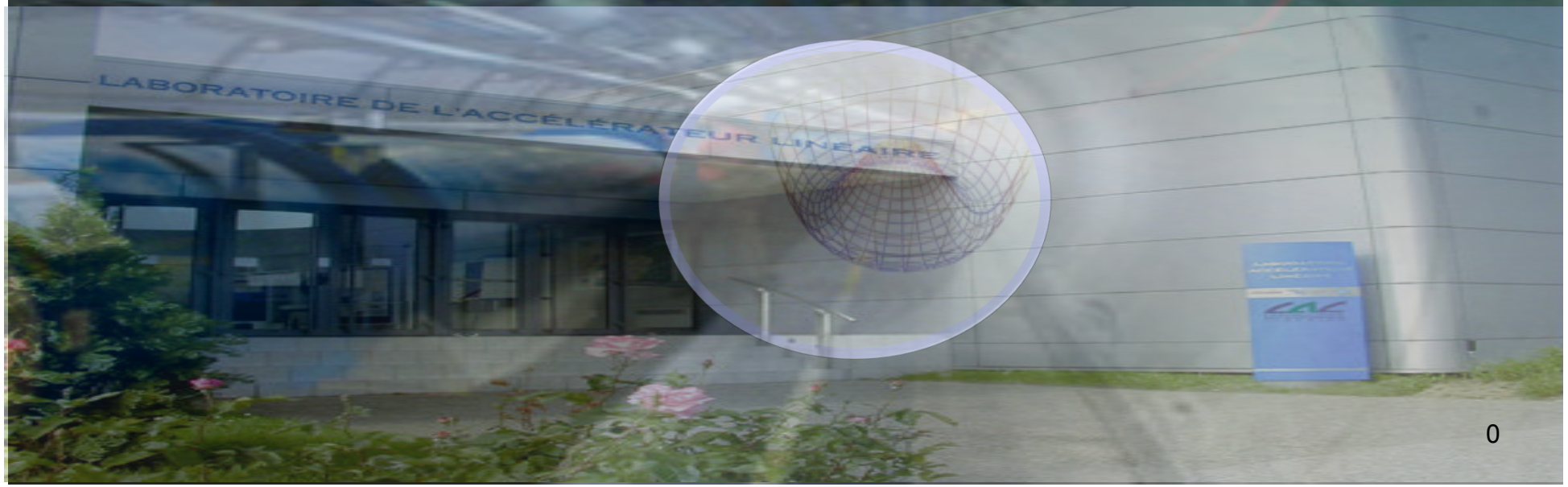
Séminaire LAL, 20 Janvier 2012



Introduction

Scientific Objectives at the LHC

Origin of Masses

Electroweak symmetry breaking – particle masses, Higgs boson(s)
supersymmetry – dark matter, ...

Hierarchy and Unification of Forces

Supersymmetry, new gauge symmetries, extra-dimensions, ...

Structure of elementary matter

Three fermion families (« replica »), flavour changing weak interactions (CKM et PMNS), CP violation and matter-antimatter asymmetry

Propriétés de la soupe primitive de matière

Plasma de Quarks Gluons, confinement de la couleur,
masse hadronique, ...

The essential physics motivations remain as they were at the birth of the project in 1989

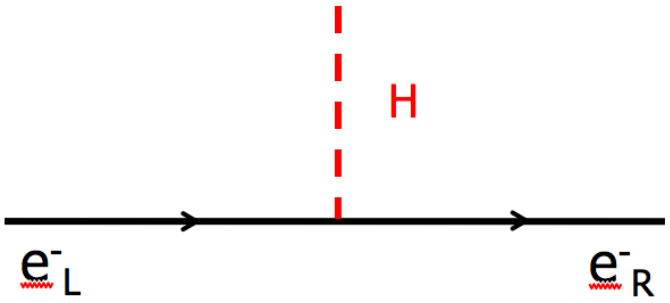
Electroweak Symmetry Breaking

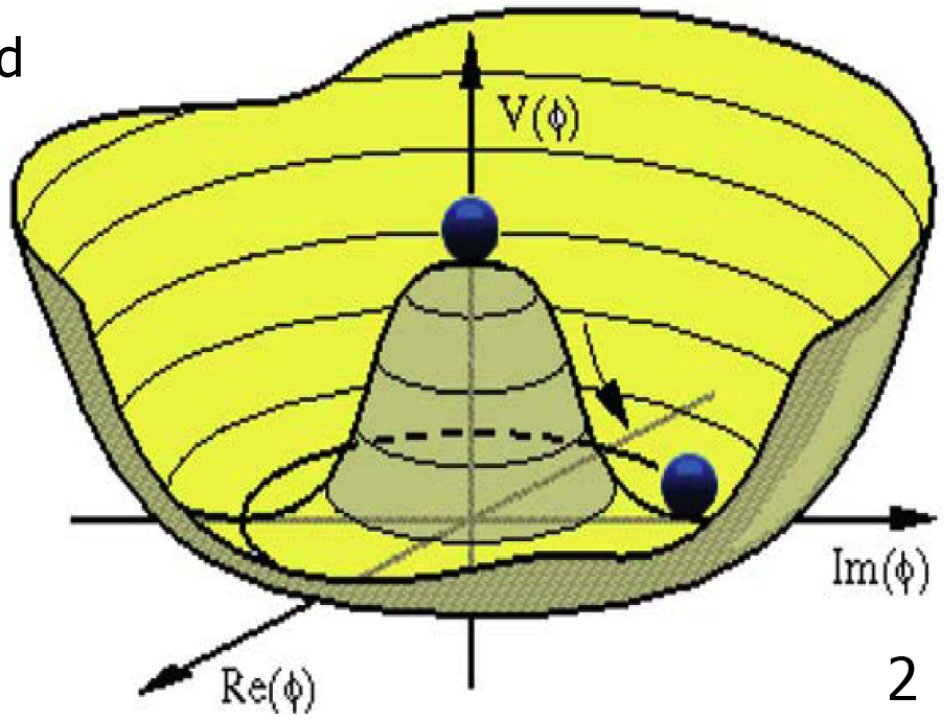
There exist a scalar field present in the whole universe, which appeared $\sim 10^{-12}$ s after the Big Bang

This field is responsible for the spontaneous breaking of electroweak symmetry

The Z^0 et $W^{\pm}$ acquire a mass

Elementary fermions interact with the field and acquire mass





2

There exist at least one scalar boson associated to the field: the Higgs boson

The Higgs Boson

Recall: 1 doublet of Higgs fields ⇒ 1 physical boson (CP-even)
M_H is a free parameter $\quad M_H^2 = 2\lambda v^2$; $v \sim 246$ GeV

Theory Constraints:

Unitarity: $A\left(W_L^+W_L^- \to Z_L Z_L\right) = \frac{G_F E^2}{8\sqrt{2}\pi}\left(1 - \frac{E^2}{E^2 - m_H^2}\right)$

$$M_H < 700 - 800\ GeV/c^2$$

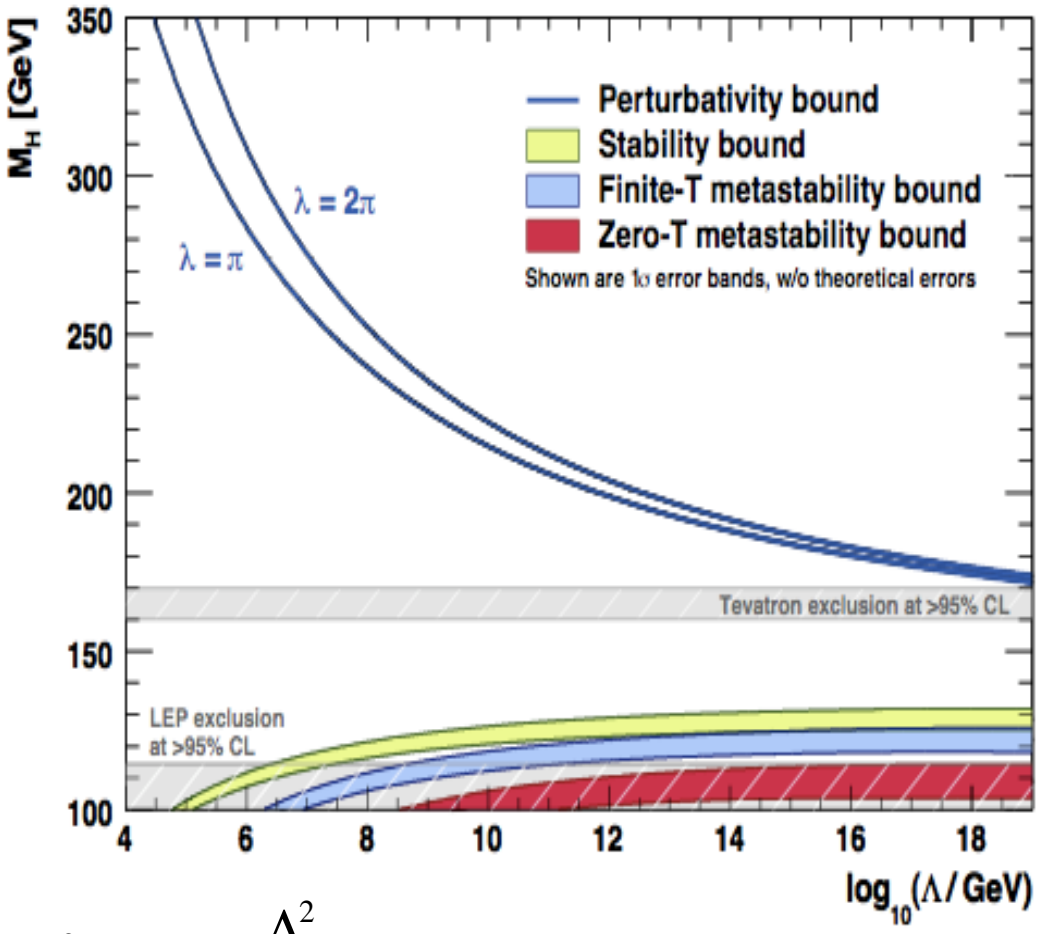
"Triviality" (Higgs self-coupling remains finite :)

$$M_H^2 < \frac{4\pi^2 v^2}{3\ln(\Lambda/v)}$$

"Stability" of vacuum:

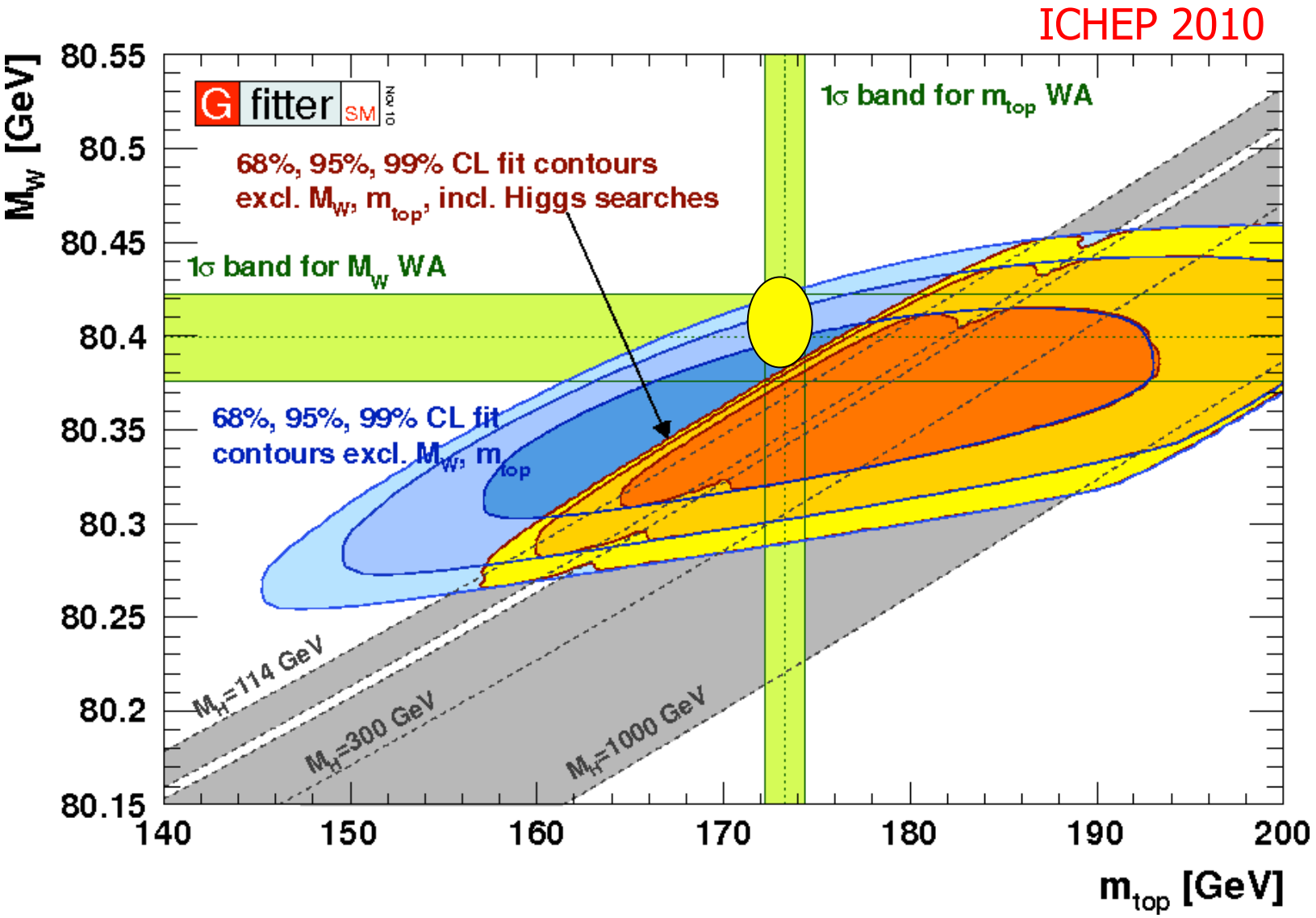
$$M_H^2 > \frac{4m_t^4}{\pi^2 v^2}\ln(\Lambda/v)$$

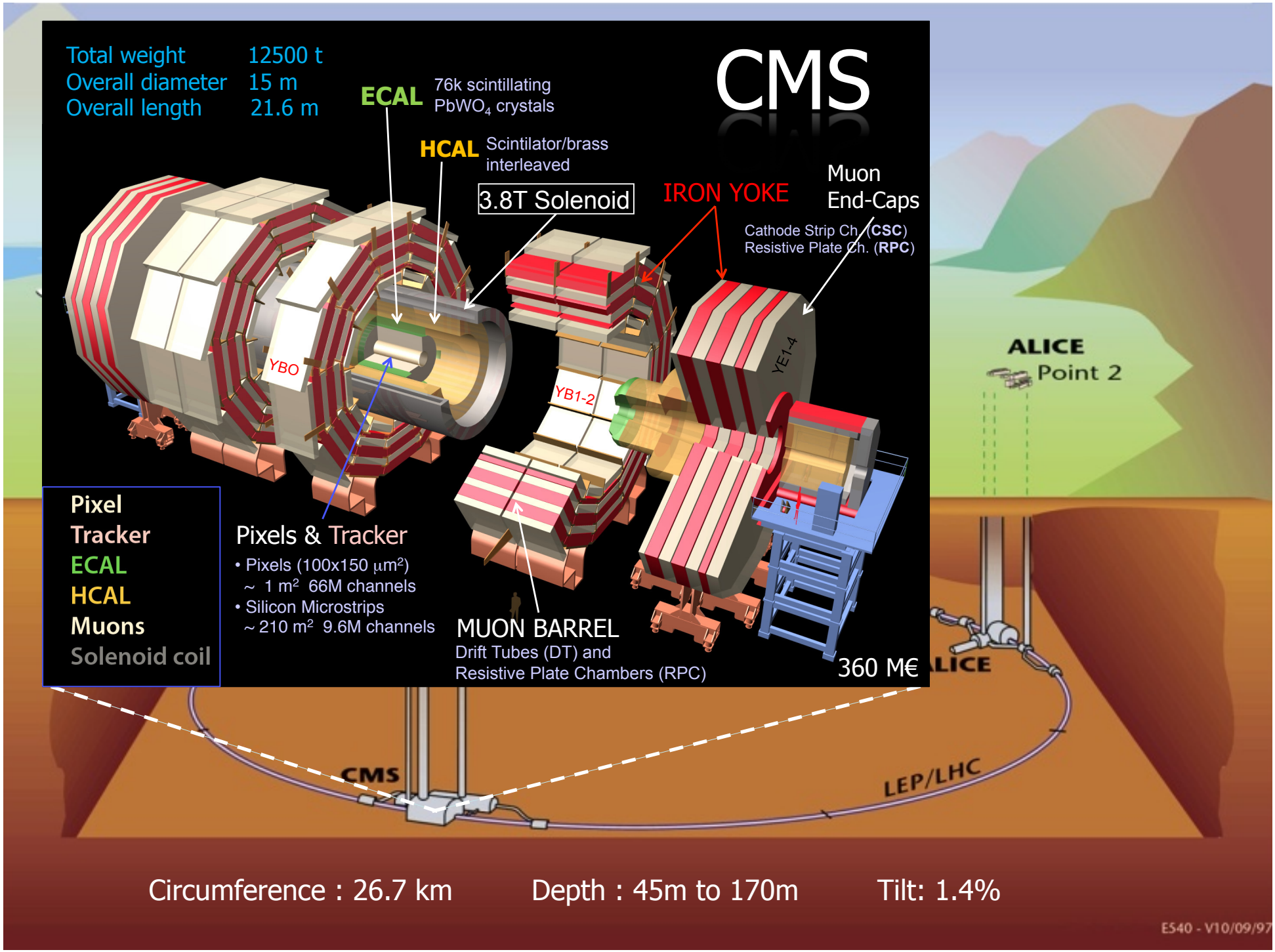
Λ = cut-off scale



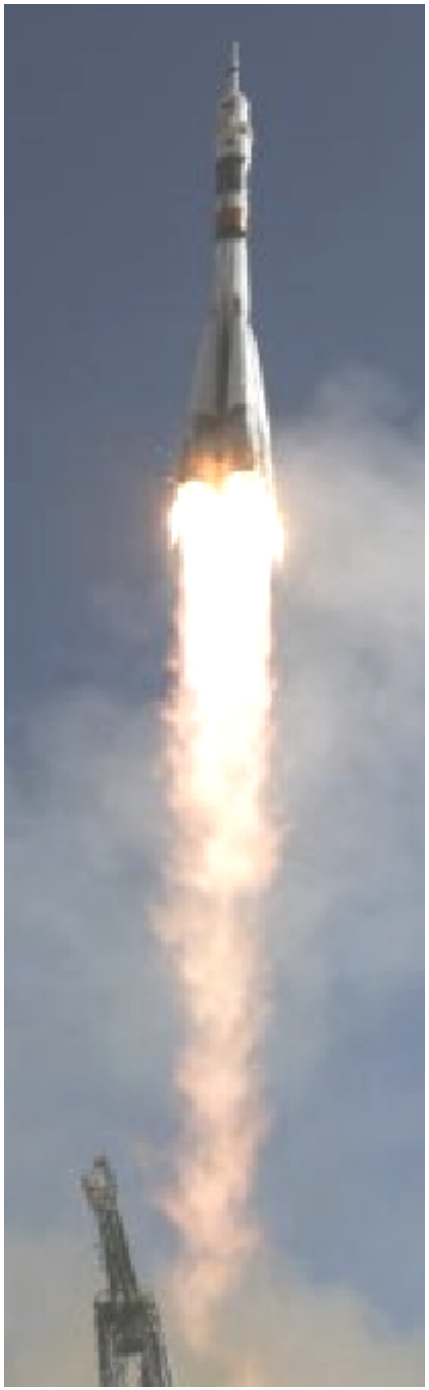
⚠ quadratic divergencies: $m^2 = m_0^2 + \alpha\lambda\frac{\Lambda^2}{16\pi^2}$

Electroweak fit and Mass Constraints




CMS
Total weight 12500 t
Overall diameter 15 m
Overall length 21.6 m
ECAL 76k scintillating $PbWO_4$ crystals
HCAL Scintilator/brass interleaved
3.8T Solenoid
IRON YOKE
Muon End-Caps
Cathode Strip Ch. (CSC)
Resistive Plate Ch. (RPC)
YBO
YB1-2
YE1-4
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm²) ~ 1 m² 66M channels
• Silicon Microstrips ~ 210 m² 9.6M channels
MUON BARREL
Drift Tubes (DT) and Resistive Plate Chambers (RPC)
360 M€
ALICE
Point 2
CMS
LEP/LHC
Circumference : 26.7 km
Depth : 45m to 170m
Tilt: 1.4%
E540 - V10/09/97

CMS Physicists



The LHC : HEP in acceleration

PbPb Physics Runs $\sqrt{s}$ = 2.8 TeV : ~ 150 μb^{-1}/exp.

pp Physics Runs $\sqrt{s}$ = 7 TeV : ~ 5 fb^{-1}/exp.

EPS/LP 2011

2011
pp Physics Runs $\sqrt{s}$ = 7 TeV

$\mathcal{L}$ ~ 1-2 fb^{-1} / exp.

Quark Matter 2011

November – December 2010
PbPb – First Heavy Ion Runs

Moriond 2011

July - December 2010
pp Physics Runs $\sqrt{s}$ = 7 TeV

$\mathcal{L}$ ~ 35 pb^{-1} / exp.

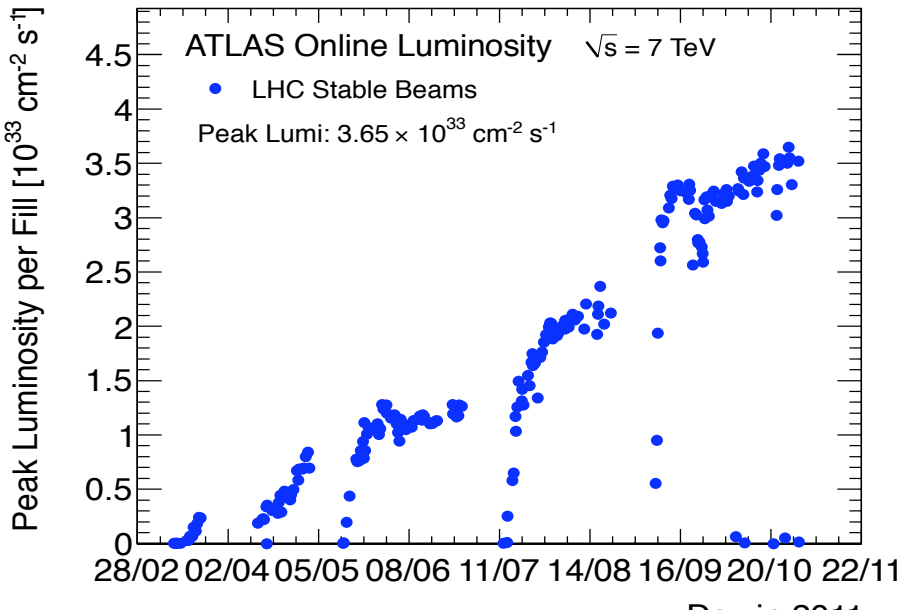
ICHEP 2010

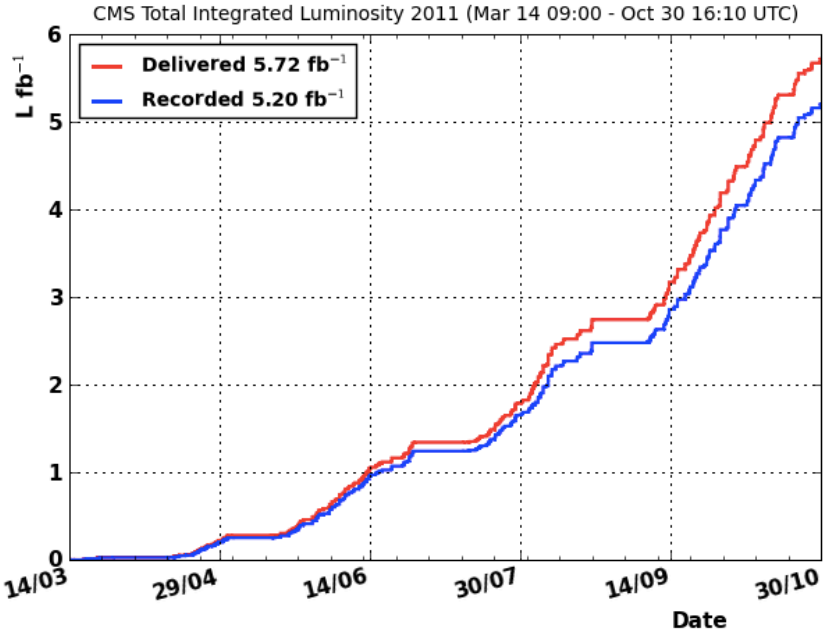
April - July 2010
Start-up Runs $\sqrt{s}$ = 7 TeV

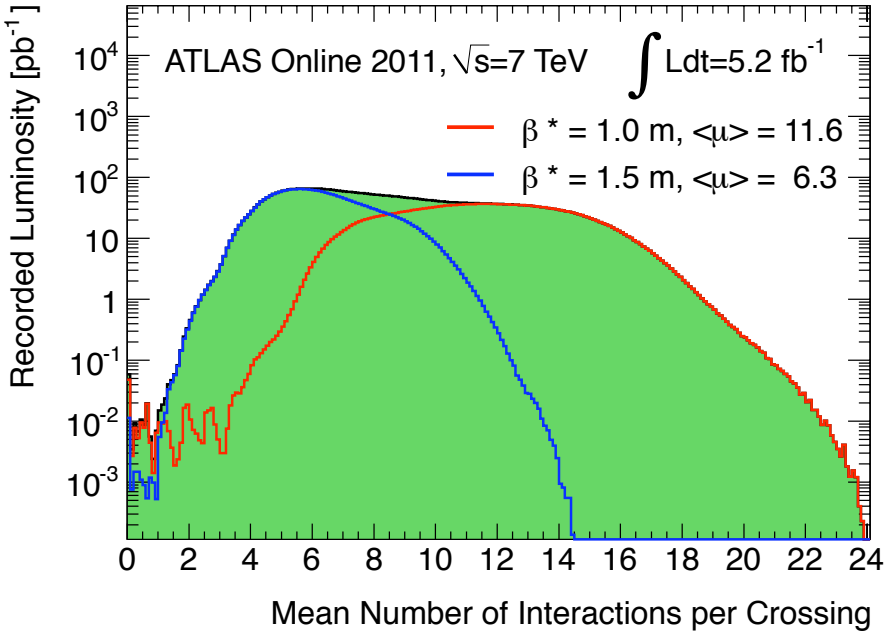
$\mathcal{L}$ ~ 3 pb^{-1} / exp.

December 2009
Pilot runs $\sqrt{s}$ = 0.9 & 2.36 TeV

Collisions pp à √s = 7 TeV en 2011







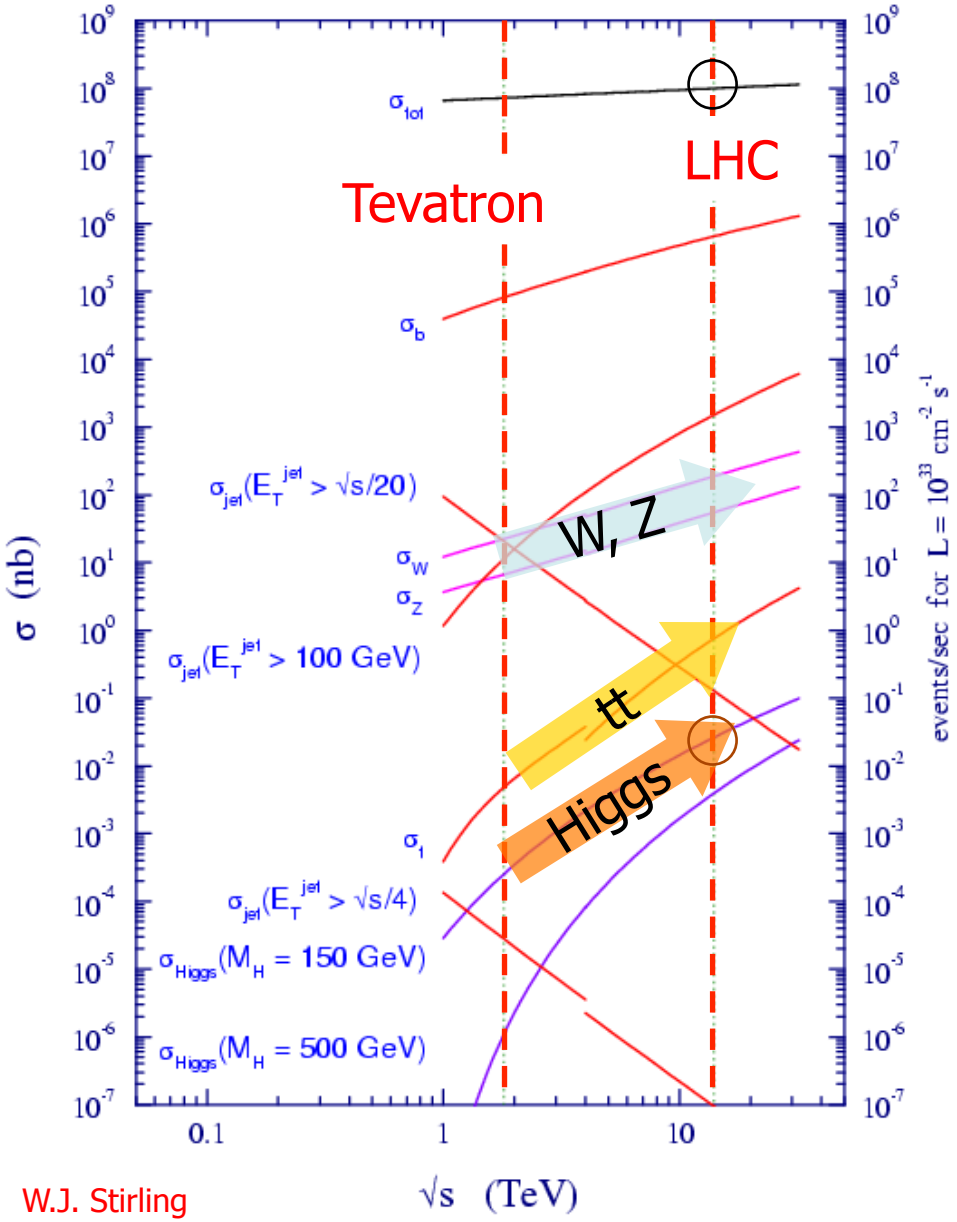
L instantanée ↑ 3.6 x 10^{33} $cm^{-2}s^{-1}$

$\mathcal{L}$ intégrée > 5 fb^{-1} / expérience

Un nombre d'empilement très élevé !

140 x L_{2010} !!!

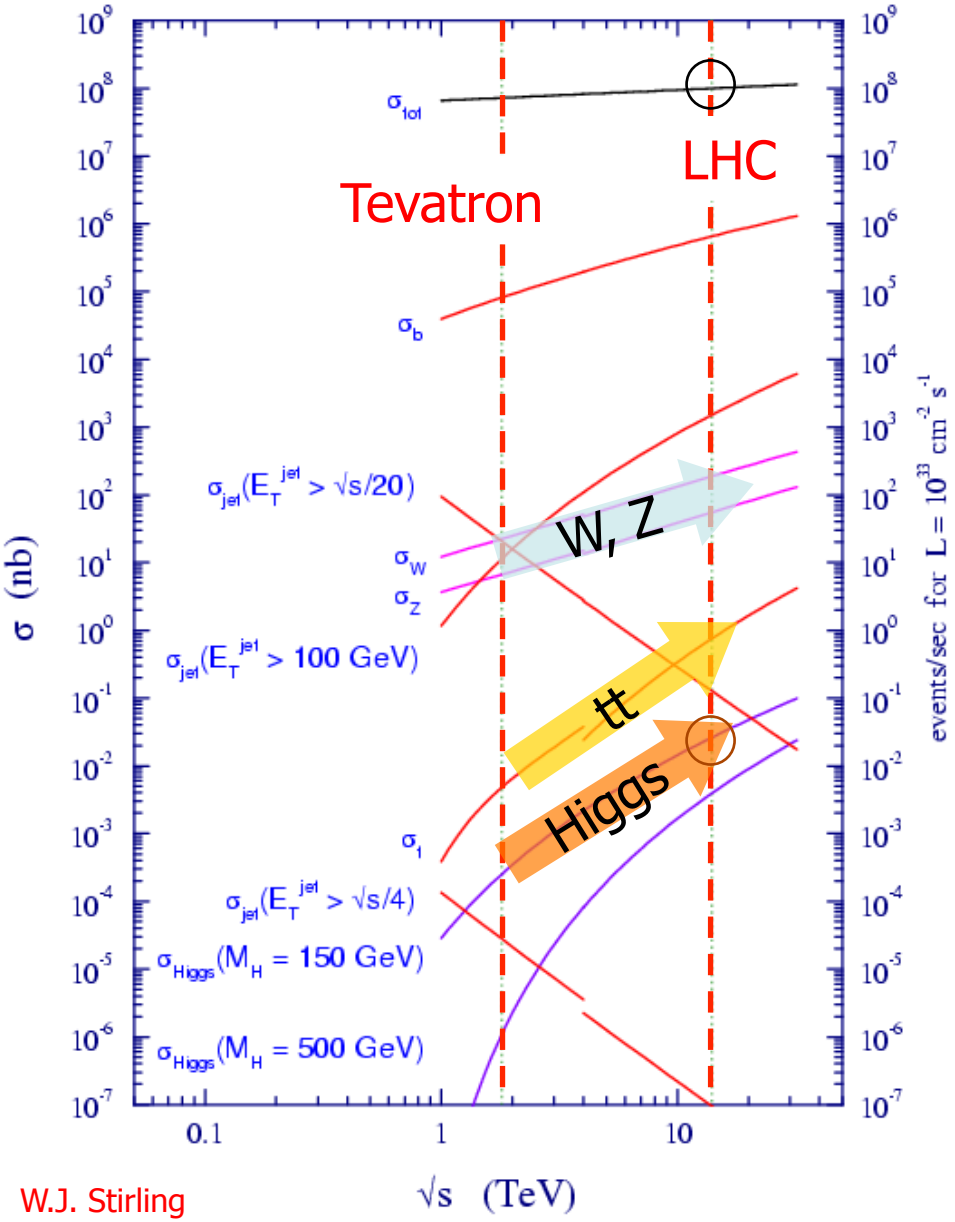
Evolution of the Cross-Sections



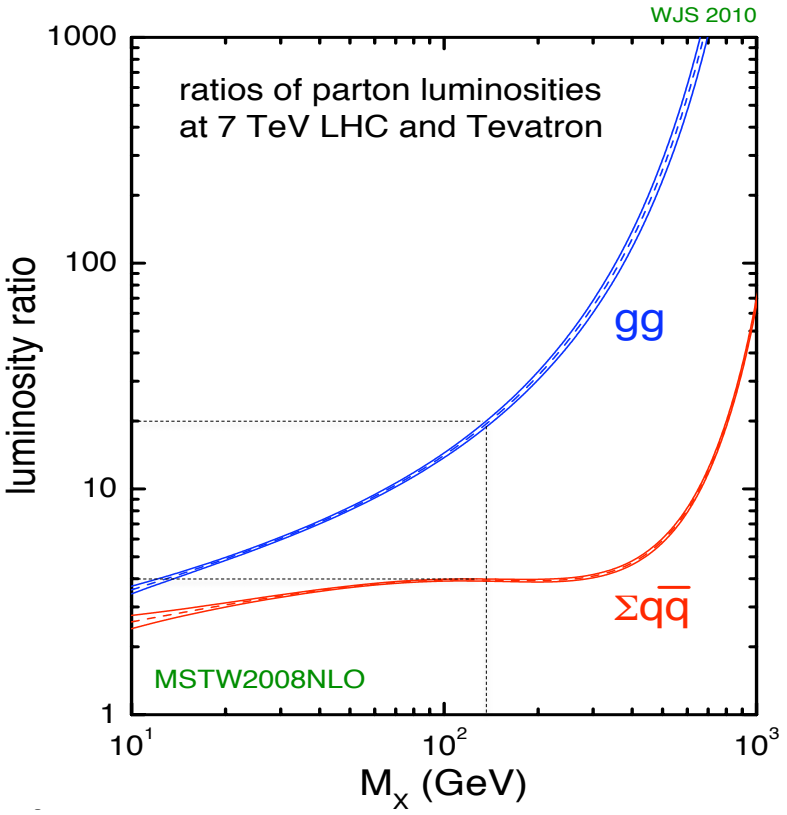
- Gain in cross-section increase with increasing mass !
- Ratio of EW cross-sections to QCD favorable ! [background "candles"]
- Ratio of Higgs to EW cross-sections favorable !

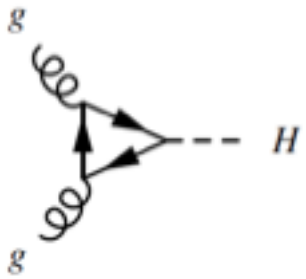
W.J. Stirling

Evolution of the Cross-Sections

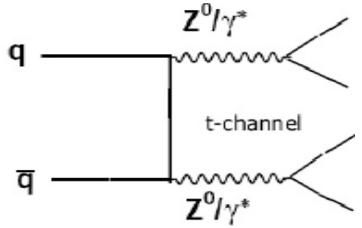


W.J. Stirling





× 20



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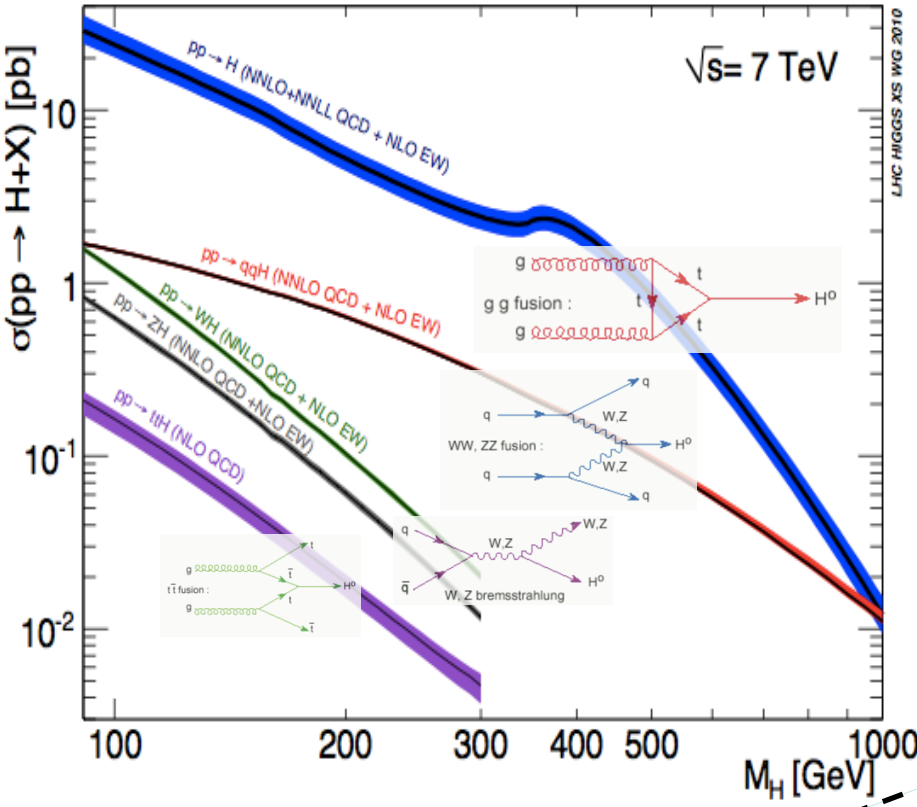
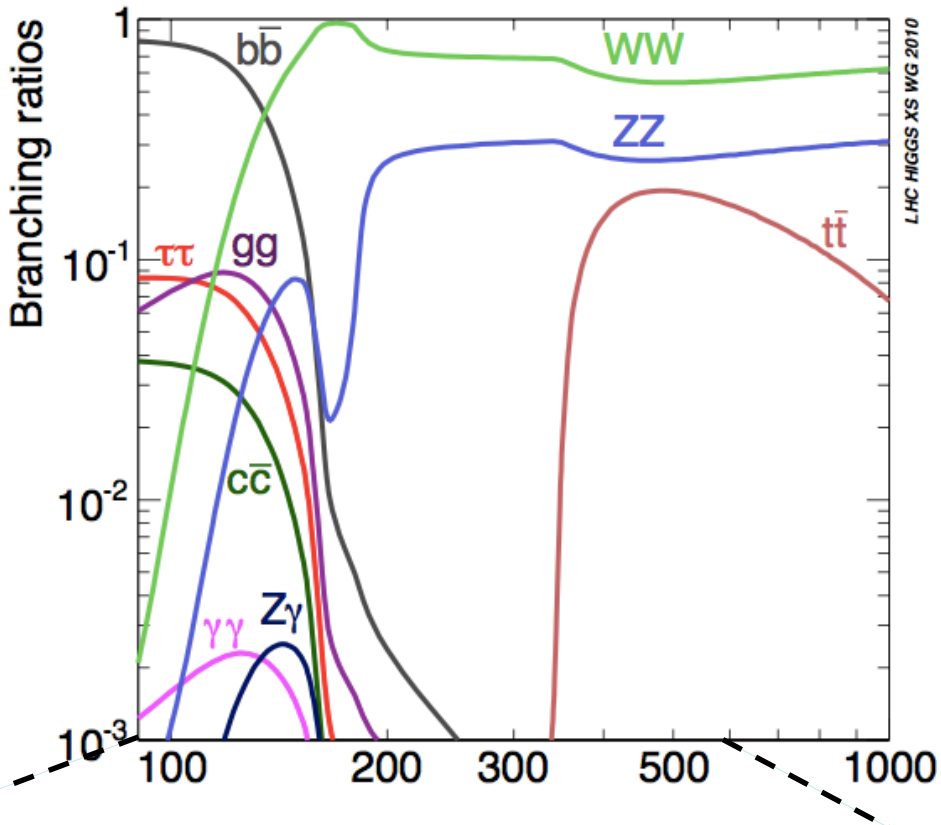
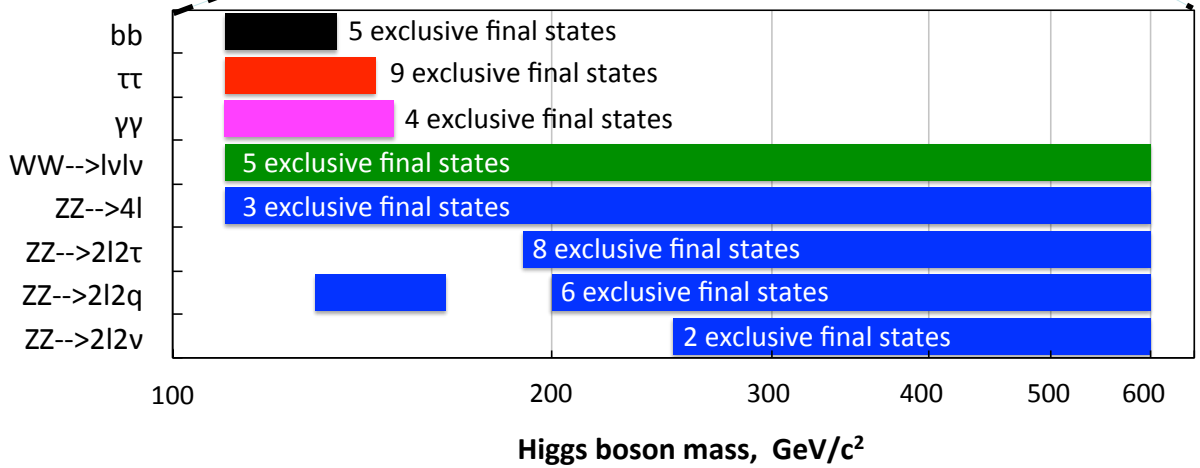
Production and Decay at the LHC

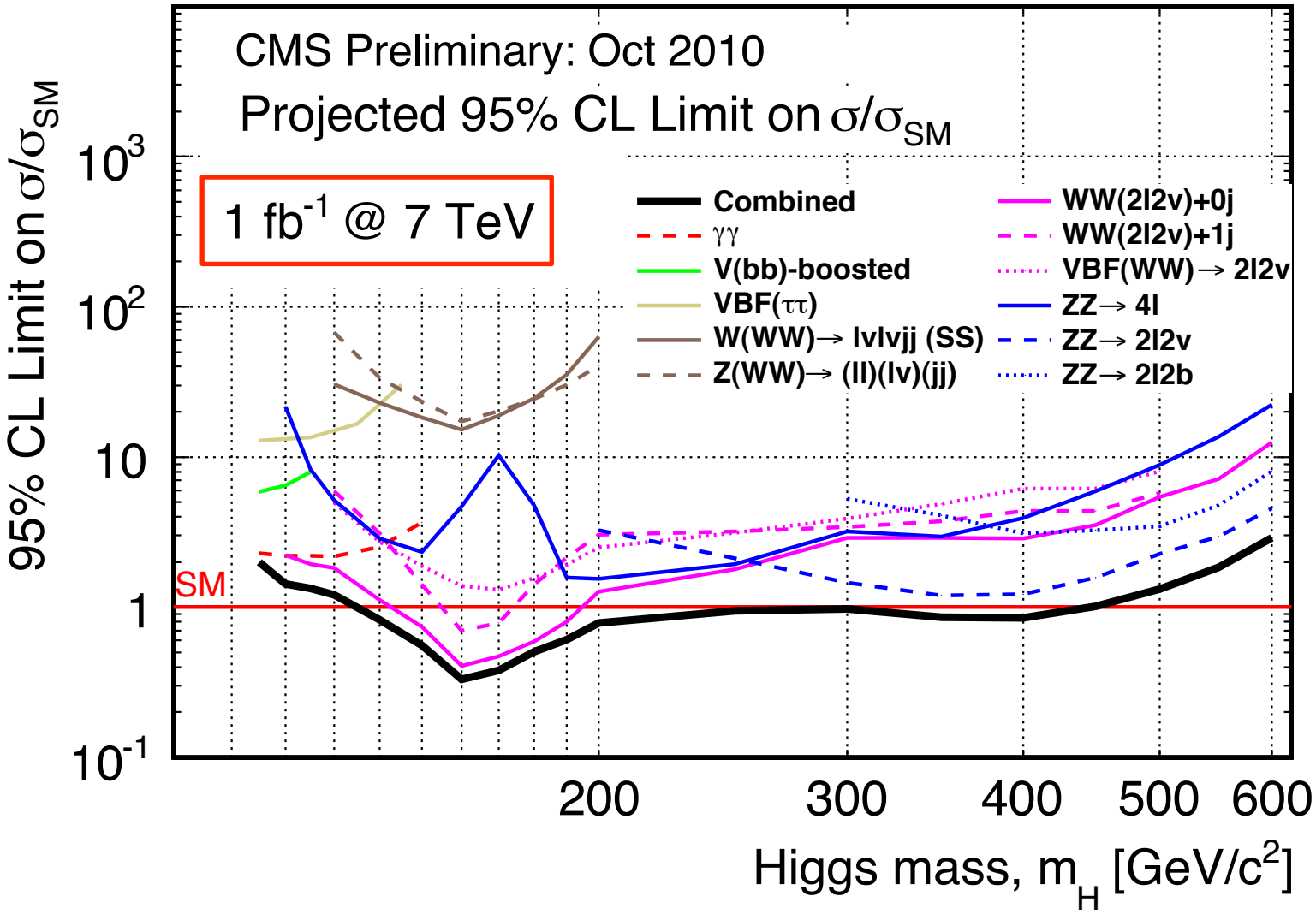




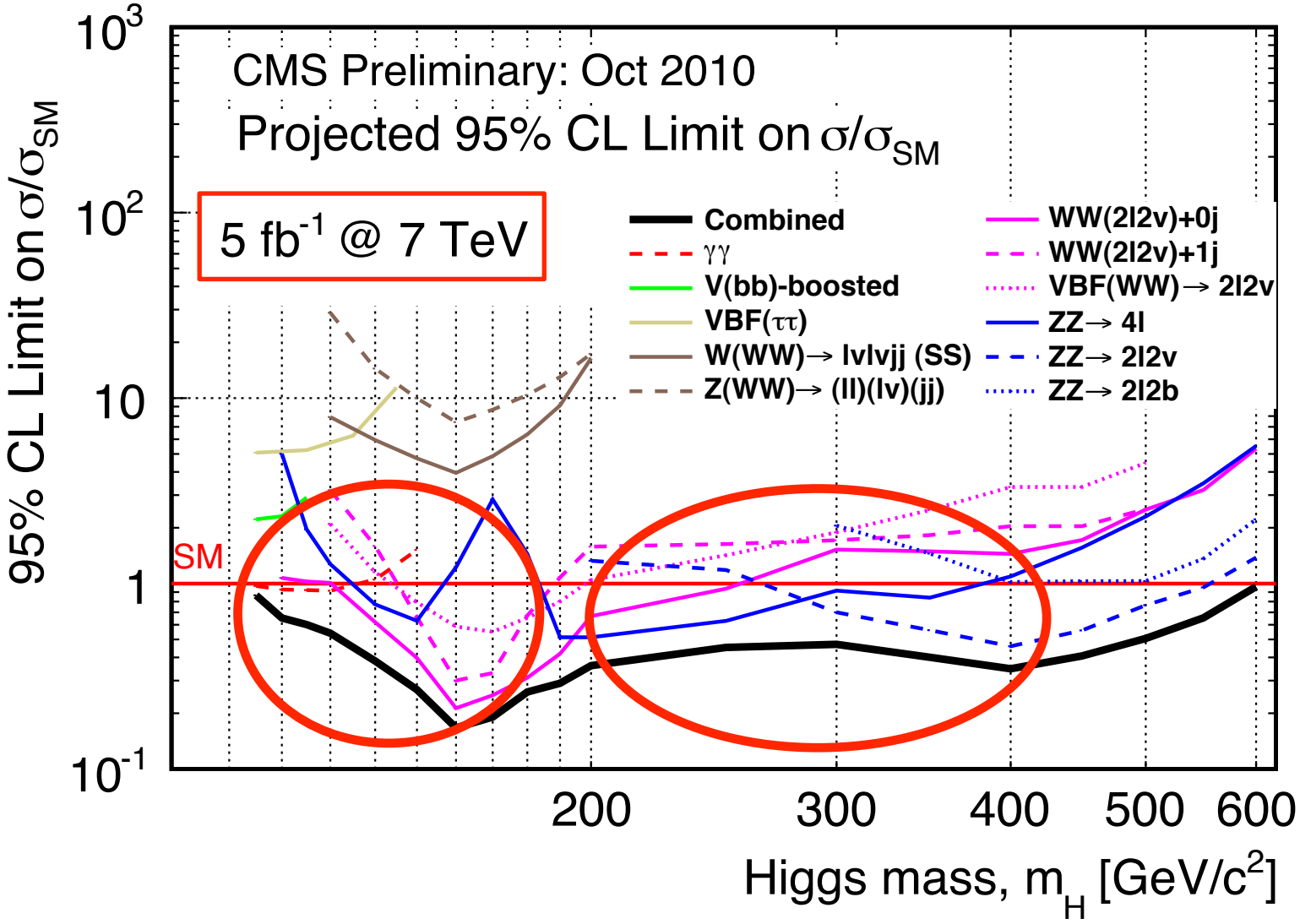


Higgs Boson Searches in CMS

Prospective (… from the past)



Prospective (... from the past)



Summary

SM Higgs Boson Searches in CMS

Channel	m_H Range	Lumi	Sub-Channels	m_H Resolution	Main Background	Expected sensitivity	Number of signal events after cuts
$H\to\gamma\gamma$	110-150	4.7	4	1-3%	$\gamma\gamma$ γj jj	1.5-2	~70
$H\to\tau\tau$	110-145	4.6	9	20%	$Z\to\tau\tau$ *W+jet QCD*	2-3	40-90
$H\to bb$	110-135	4.7	5	10%	*V+jet Vbb tt*	3-6	0.5-2
$H\to WW\to l\nu l\nu$	110-600	4.6	5	20%	*WW DY tt*	0.7-7	25-180
$H\to ZZ\to llll$	110-600	4.7	3	1-2%	ZZ *Z+jets tt Zbb*	0.5-10	1.-16
$H\to ZZ\to ll\tau\tau$	190-600	4.7	8	10-15%	ZZ *Z+jets tt*	3-12	0.5-2
$H\to ZZ\to ll\nu\nu$	250-600	4.6	2	7%	ZZ WZ *Z+jets*	0.6-2	3-20
$H\to ZZ\to llqq$	130-164 200-600	4.6	6	3%	*Z+jets tt*	5-15 1-5	~15 17-70

Background derived from Data

Signal MC: POWHEG, reweighted at NNLO

Background: PYTHIA, MadGraph, etc reweighted at NLO

HIG-11-024

$H \rightarrow WW \rightarrow 2\ell\, 2\nu$

$H \rightarrow WW \rightarrow 2\ell\, 2\nu$

Signature:

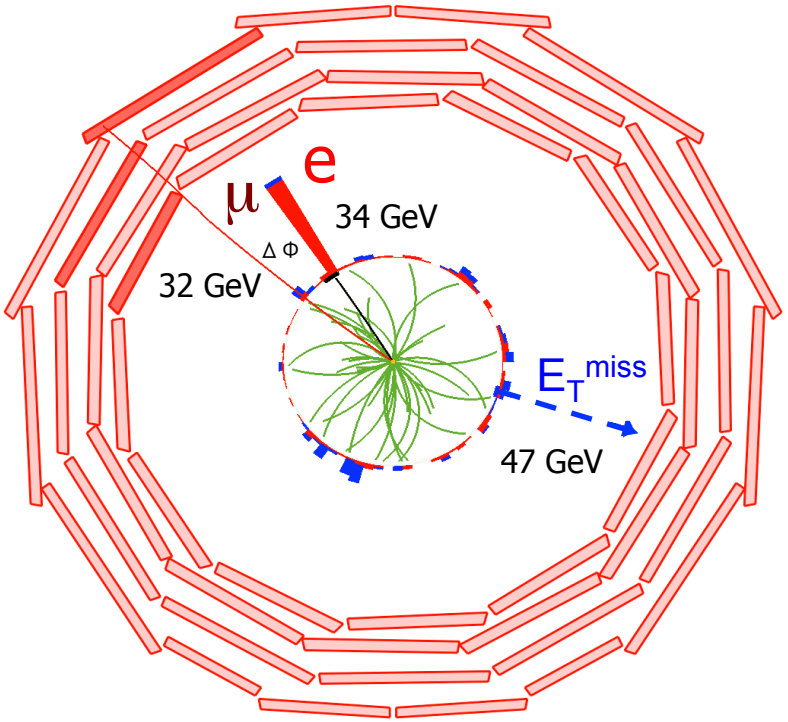
Excess of events with two leptons of opposite signs, and missing E_T

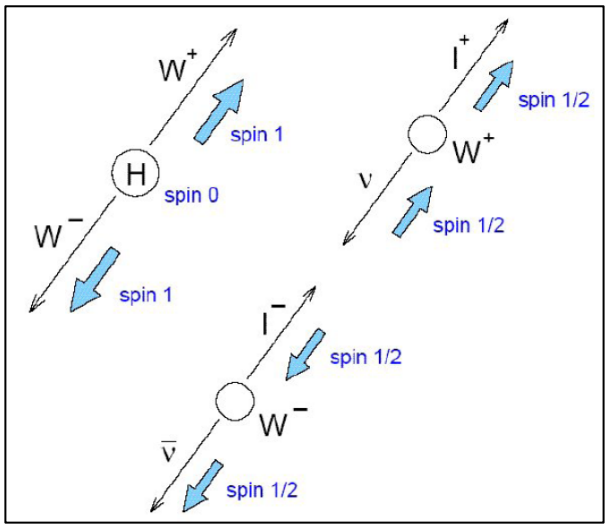
Five categories with different S/B and B composition:

0 or 1 jet, with SF or OF leptons

2 jets optimized for VBF

9 exclusive final states



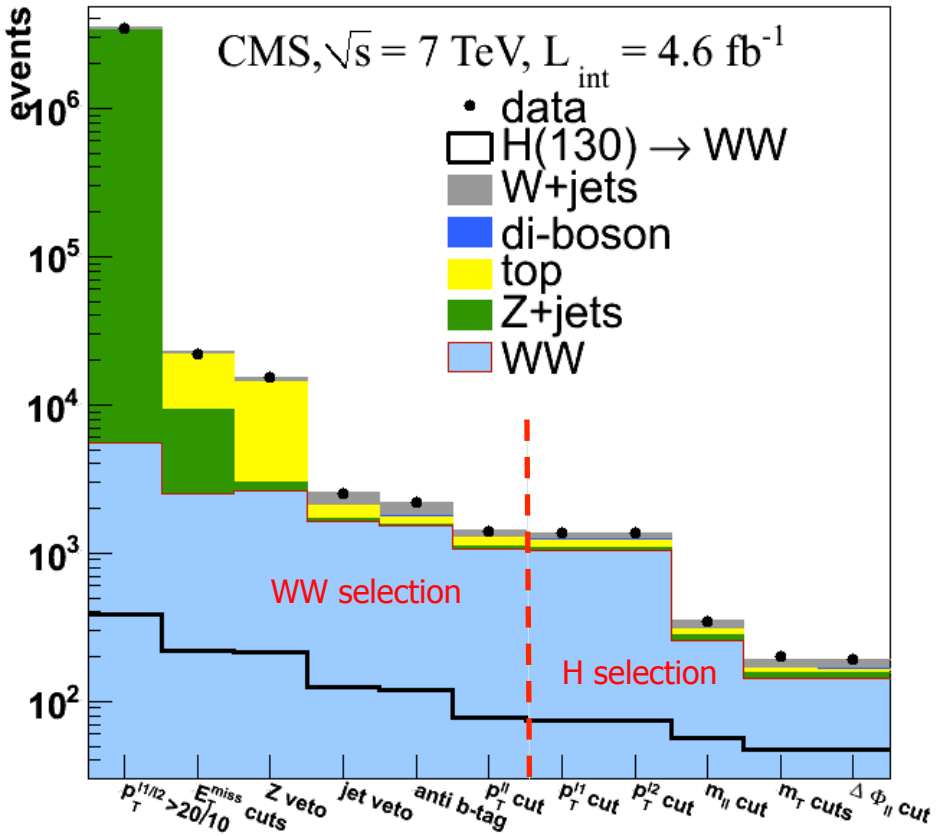


Scalar boson decay to vector bosons + V-A structure of EWK interaction

[exploited especially for $M_H >> 2 \times M_W$]

H → WW offers best sensitivity for exclusion at low $\mathcal{L}$ over a wide mass range

Event Selection



- Single or double lepton triggers
- Exactly 2 identified isolated $\ell^+ \ell'^-$ from primary vertex
  P_T > 20 GeV/c for leading lepton
  P_T > 10 (15) GeV/c for trailing lepton in OF (SF) events

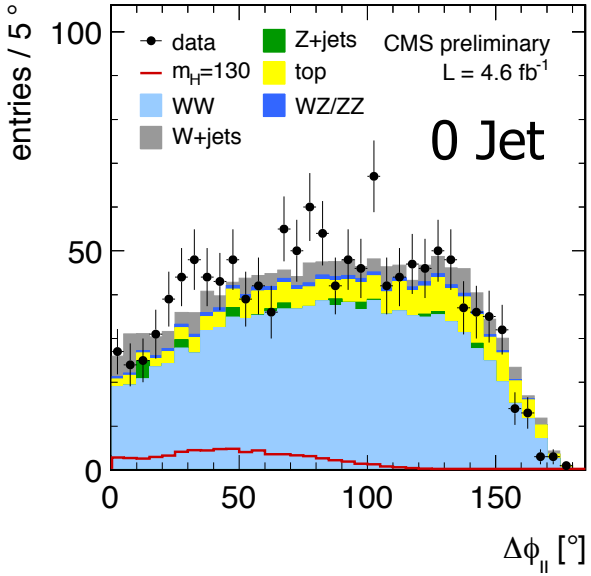
"WW" selection (= pre-selection)

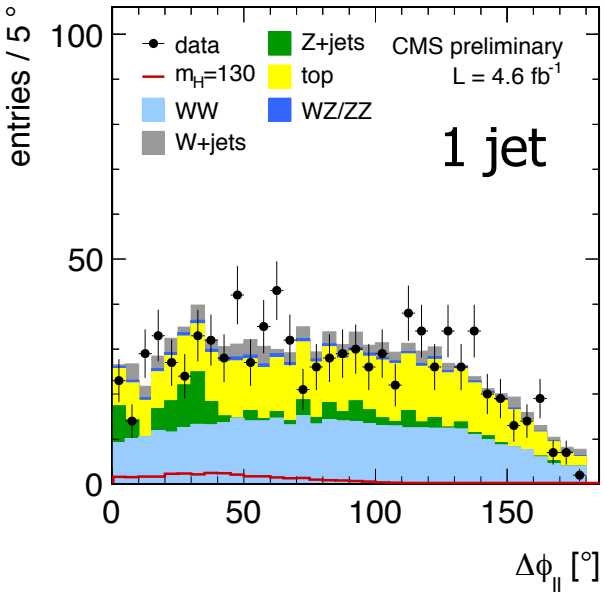
- Z veto: $|M_{ll}-M_Z|>15$ GeV
- SF: Min $E_t^{miss} > 37+0.5\ N_{vtx}$;
  OF: Min $E_T^{miss} > 20$ GeV/c^2
- Anti top-tagging
- Jet counting: $p_T>30$, $|\eta|<5$
- $\Delta\phi$(jet,di-lepton) < 165 (jet $p_T>15$, SF only)
- Lepton kinematics:
  di-lepton pT>45, $M_{ll}>20$ GeV/c^2

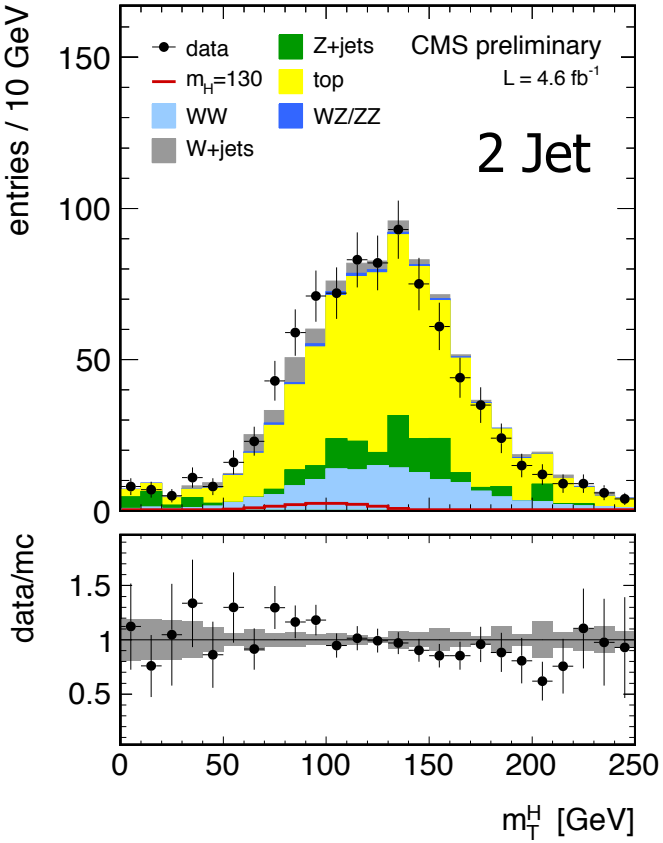
"Higgs" selection

- f(M_H) cuts for cut-based extraction
- Same observables used in BDT with also ΔR, $M_T^{\ell 1}$ Etmiss, $M_T^{\ell 2}$ Etmiss
- VBF Selection: $|\Delta\eta_{J1J2}| > 3.5$, $M_{J1J2} > 450$ GeV/c^2

WW Selection Level

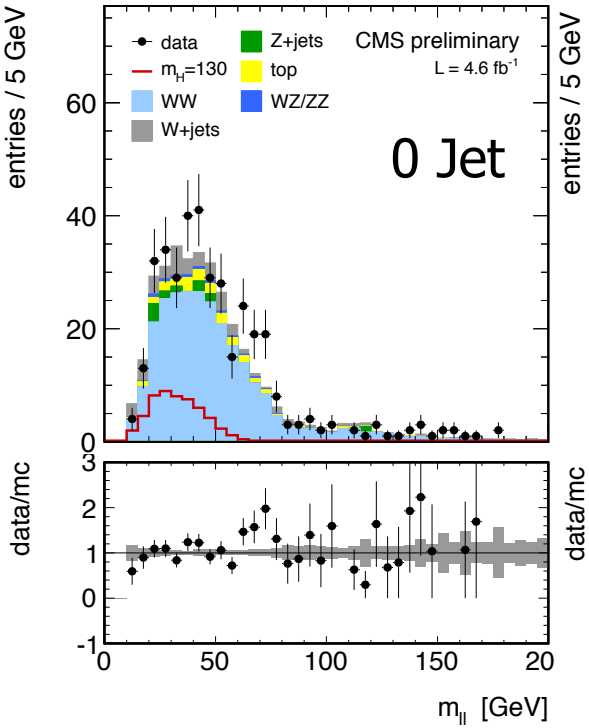


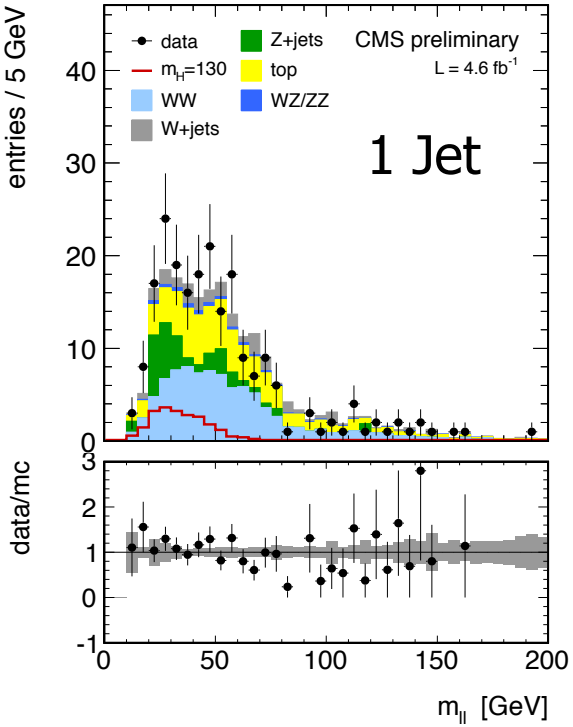


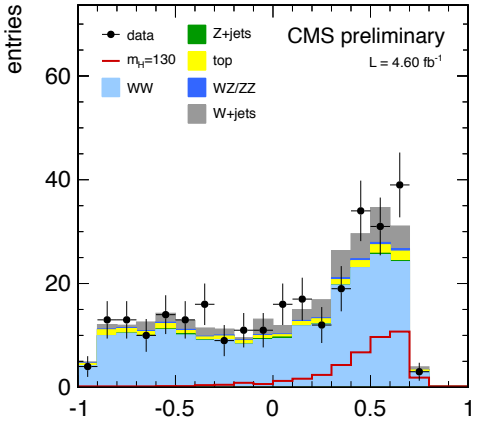


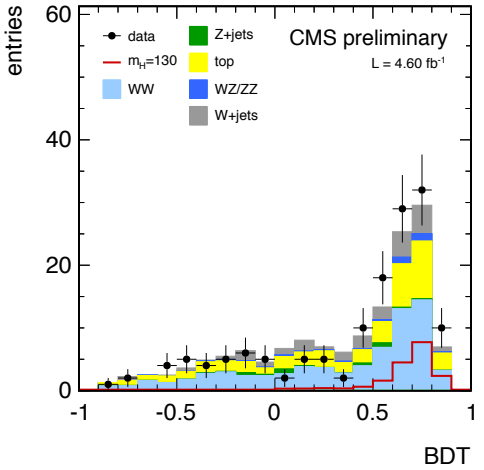
	data	all bkg.	$qq \to W^+W^-$	$t\bar{t}$+tW
0-jet	1359	1364.8 ± 9.3	980.6 ± 5.2	147.3 ± 2.5
1-jet	909	951.4 ± 9.8	416.8 ± 3.6	334.8 ± 3.0
2-jet	703	714.8 ± 13.5	154.7 ± 2.2	413.5 ± 2.7

Higgs Selection Level



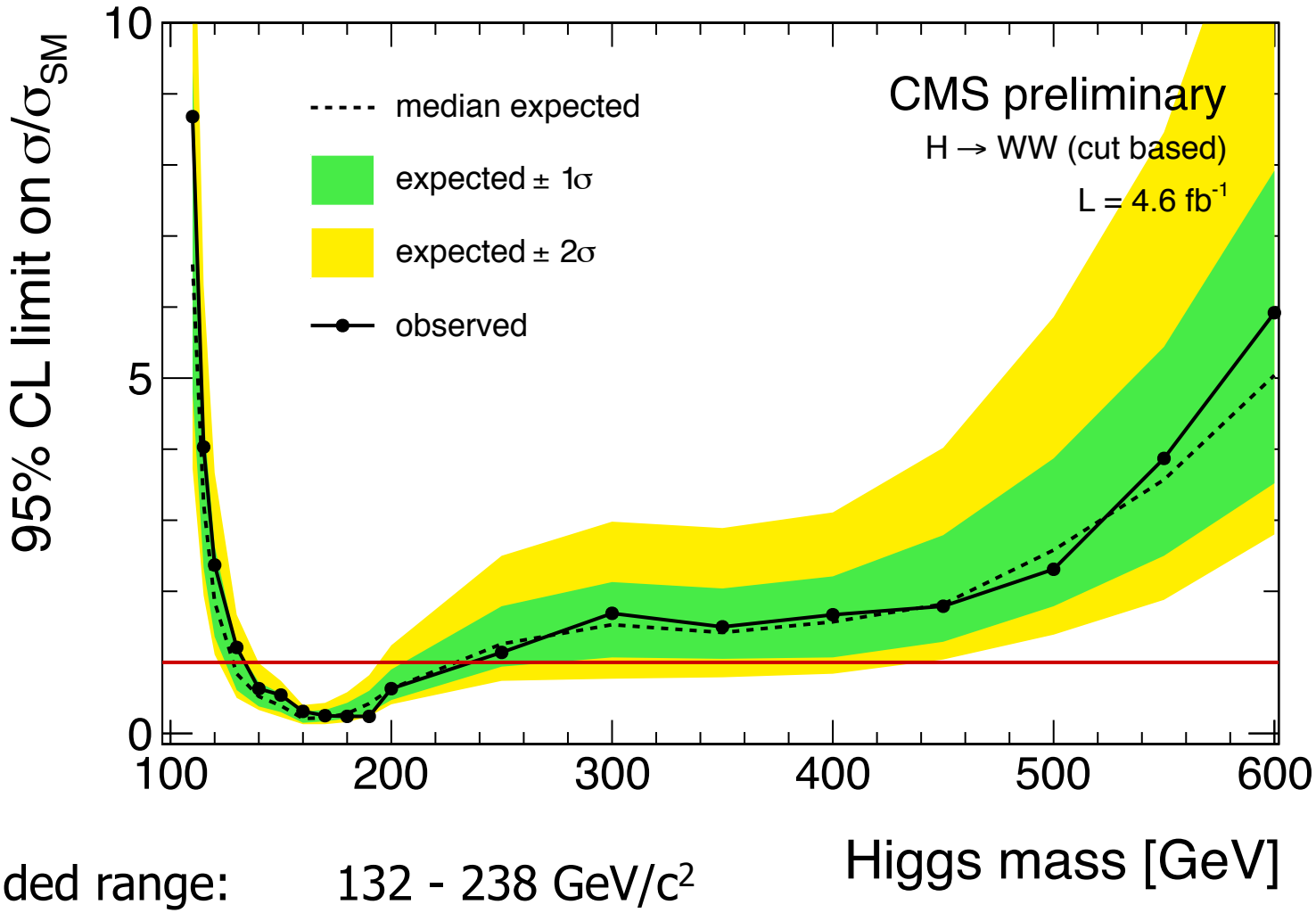






m_H	all bkg.	$H \to W^+W^-$	data	all bkg.	$H \to W^+W^-$	data	all bkg.	$H \to W^+W^-$	data
	0 jet category			1 jet category			2 jets category		
120	136.7 ± 12.7	15.7 ± 0.8	136	59.5 ± 5.9	6.5 ± 0.3	72	11.3 ± 3.6	1.1 ± 0.1	8
130	191.5 ± 14.0	45.2 ± 2.1	193	79.9 ± 7.7	17.6 ± 0.8	105	13.3 ± 4.0	2.7 ± 0.2	10
160	101.7 ± 6.8	122.9 ± 5.6	111	70.8 ± 6.0	60.2 ± 2.6	86	15.9 ± 4.6	12.2 ± 0.7	12

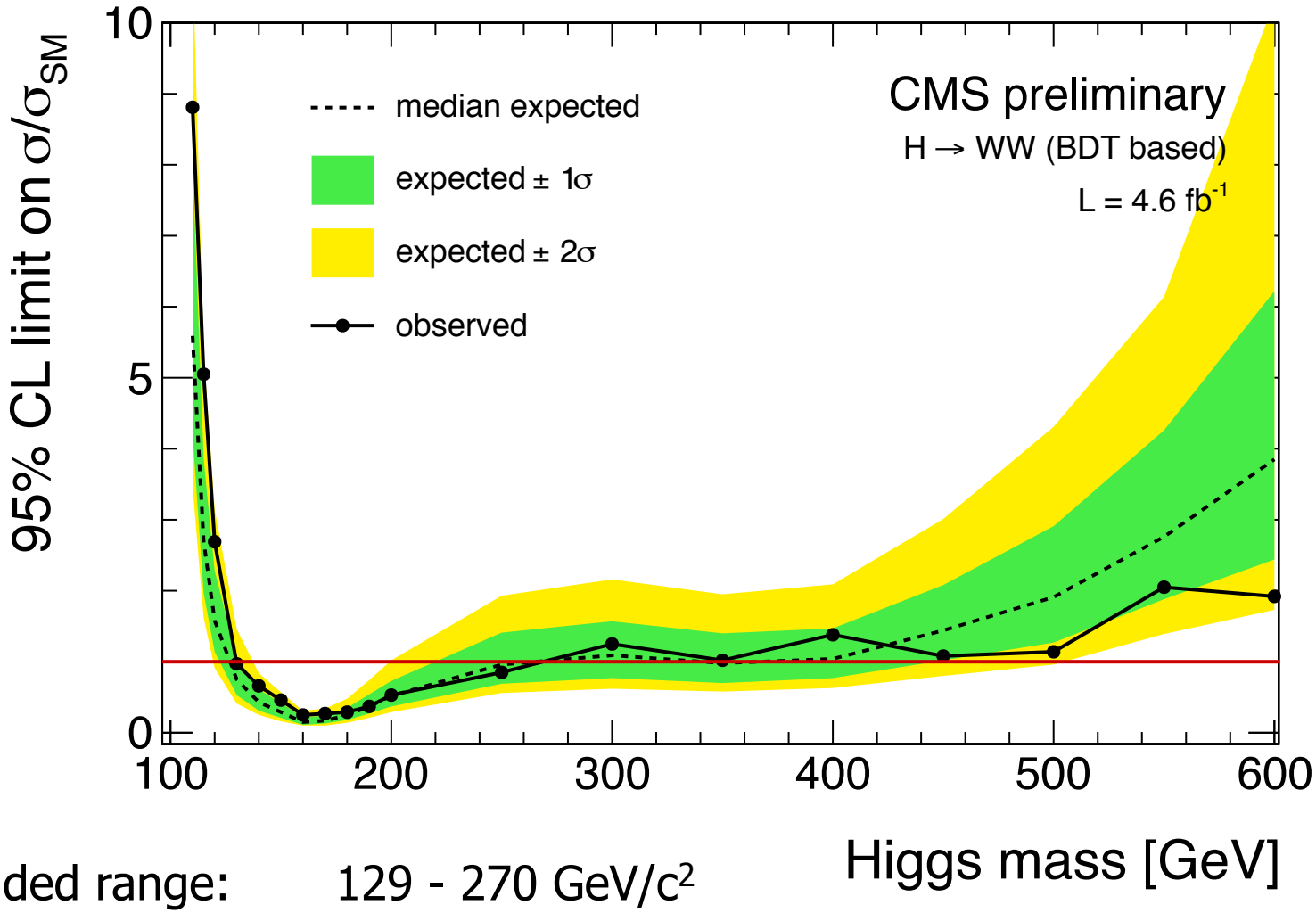
Exclusion Limits



Excluded range: 132 - 238 GeV/c^2

Expected sensitivity: 129 - 236 GeV/c^2

Exclusion Limits



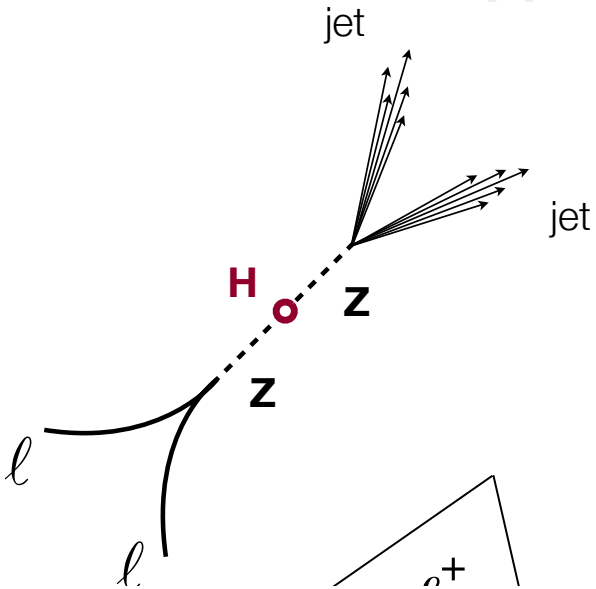
Excluded range: 129 - 270 GeV/c^2

Expected sensitivity: 127 - 270 GeV/c^2

HIG-11-027

$H \rightarrow ZZ \rightarrow 2\ell\ 2\text{jets}$

$H \to ZZ \to 2\ell\, 2jets$



Signature:

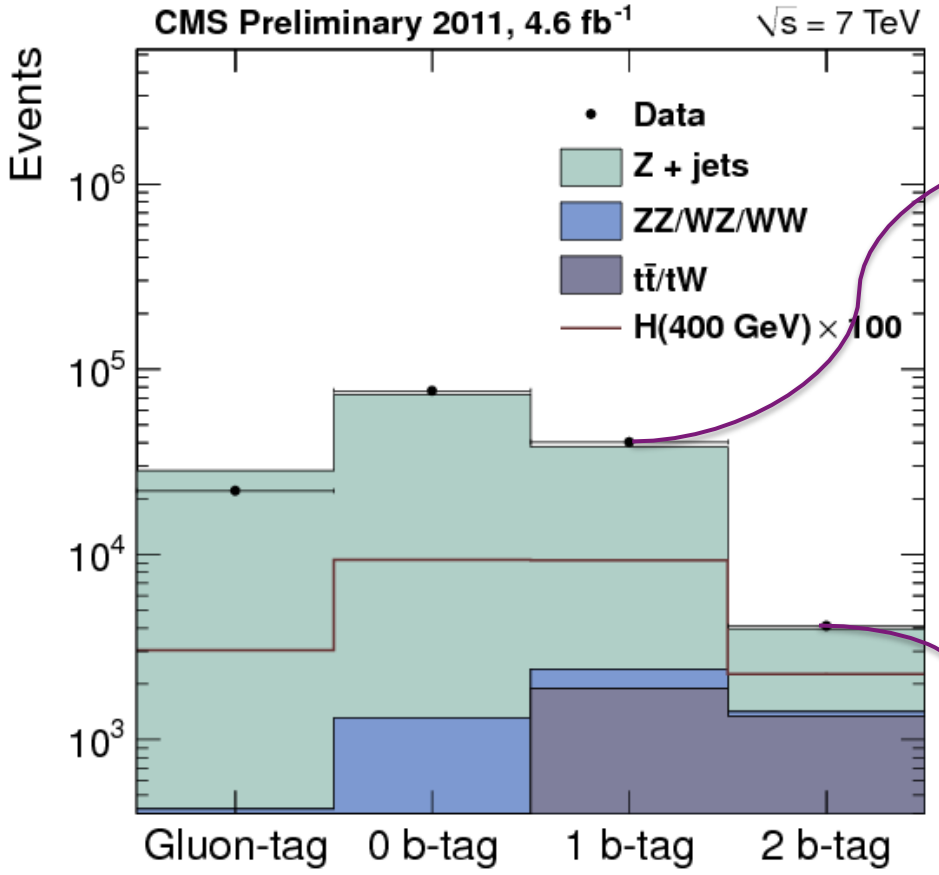
Excess of events around $m_{2\ell 2j}$
+ $\ell^+\ell^-$ lepton SF pair and 2 jets

3 categories depending on $N_{b\text{-tagged}}$ jets:
2 b tags, 1 b tag or no b-tag

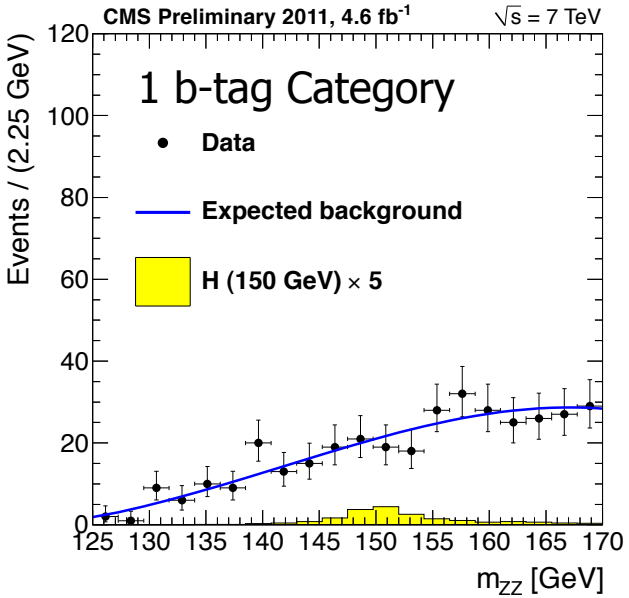
6 exclusive final states

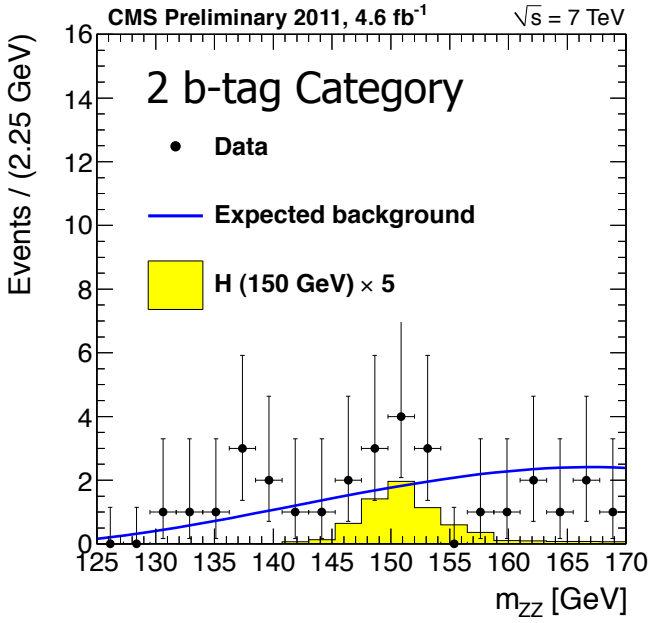
	preselection		
$p_T(\ell^\pm)$	lowest $p_T > 20(10)$ GeV, highest $p_T > 40(20)$ GeV		
p_T(jets)	> 30 GeV		
$\lvert\eta\rvert(\ell^\pm)$	$e^\pm < 2.5$, $\mu^\pm < 2.4$		
$\lvert\eta\rvert$(jets)	< 2.4		
	0 b-tag	1 b-tag	2 b-tag
b-tag	none	one loose	medium & loose
angular LD	$> 0.55 + 0.00025\, m_{ZZ}$	$> 0.302 + 0.000656\, m_{ZZ}$	> 0.5
quark-gluon LD	> 0.10	none	none
$2 \ln \lambda(\not{E}_T)$	none	none	< 10 ($\not{E}_T < 50$ GeV)
m_{jj}	$\in$ [75, 105] GeV		
$m_{\ell\ell}$	$\in$ [70, 110] ($<$80) GeV		
m_{ZZ}	$\in$ [183, 800] ($\in$ [125, 170]) GeV		

Event Selection

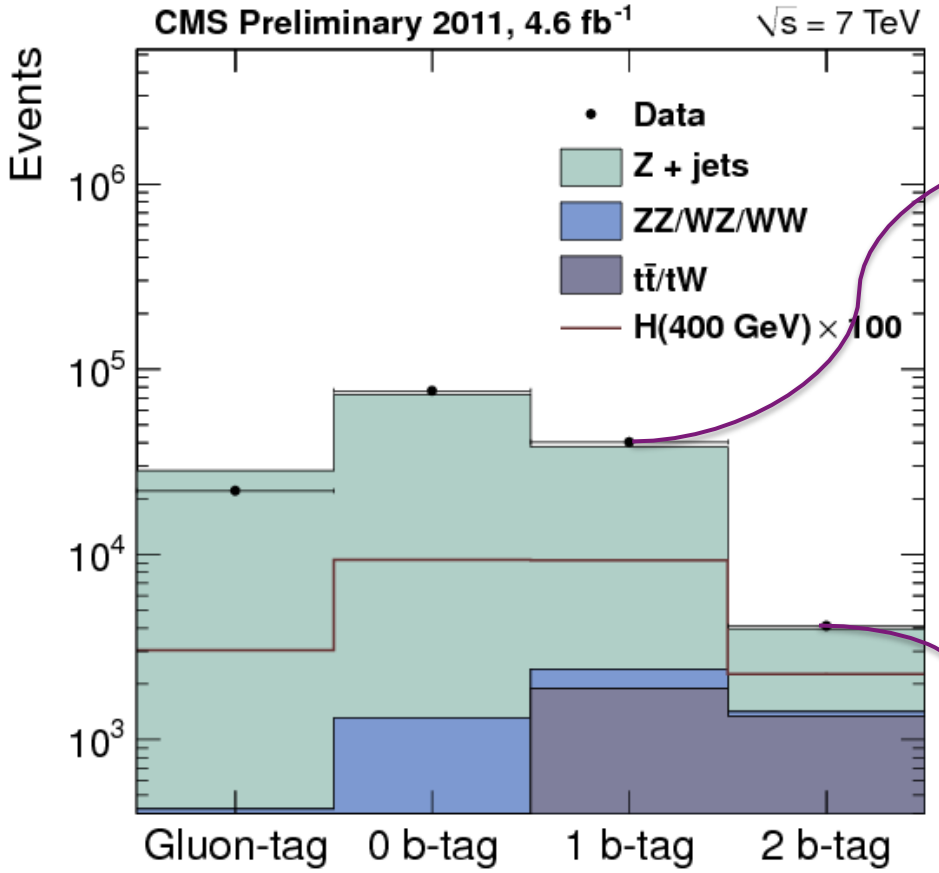


Low Mass Results

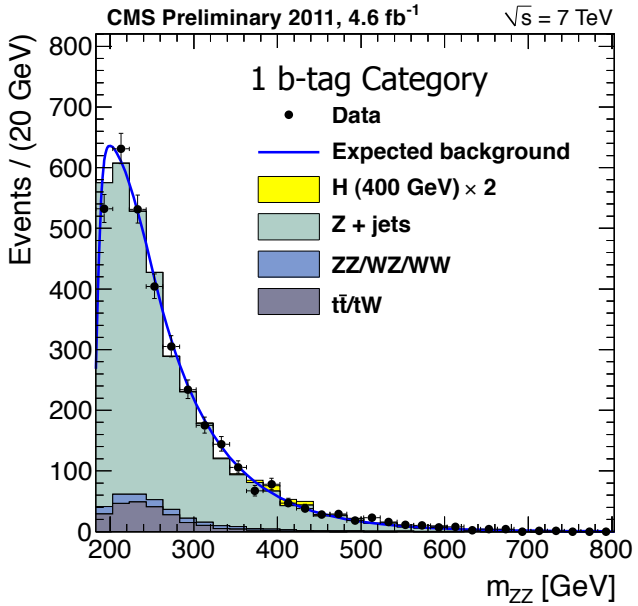


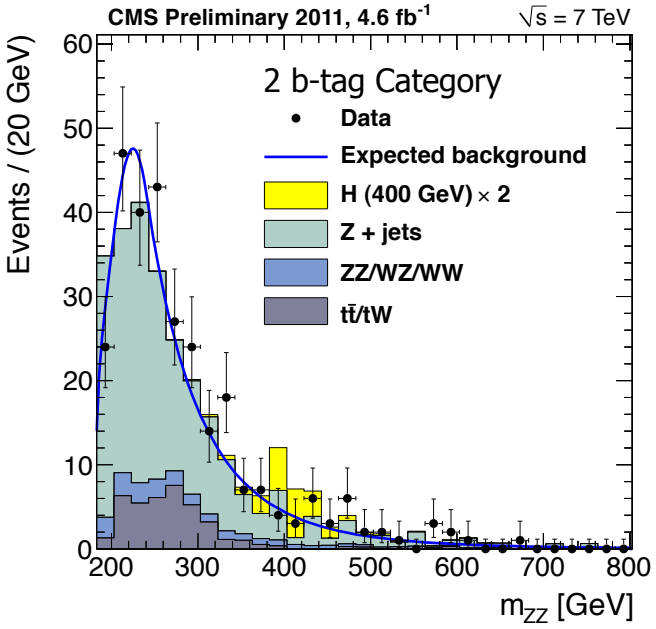


Event Selection

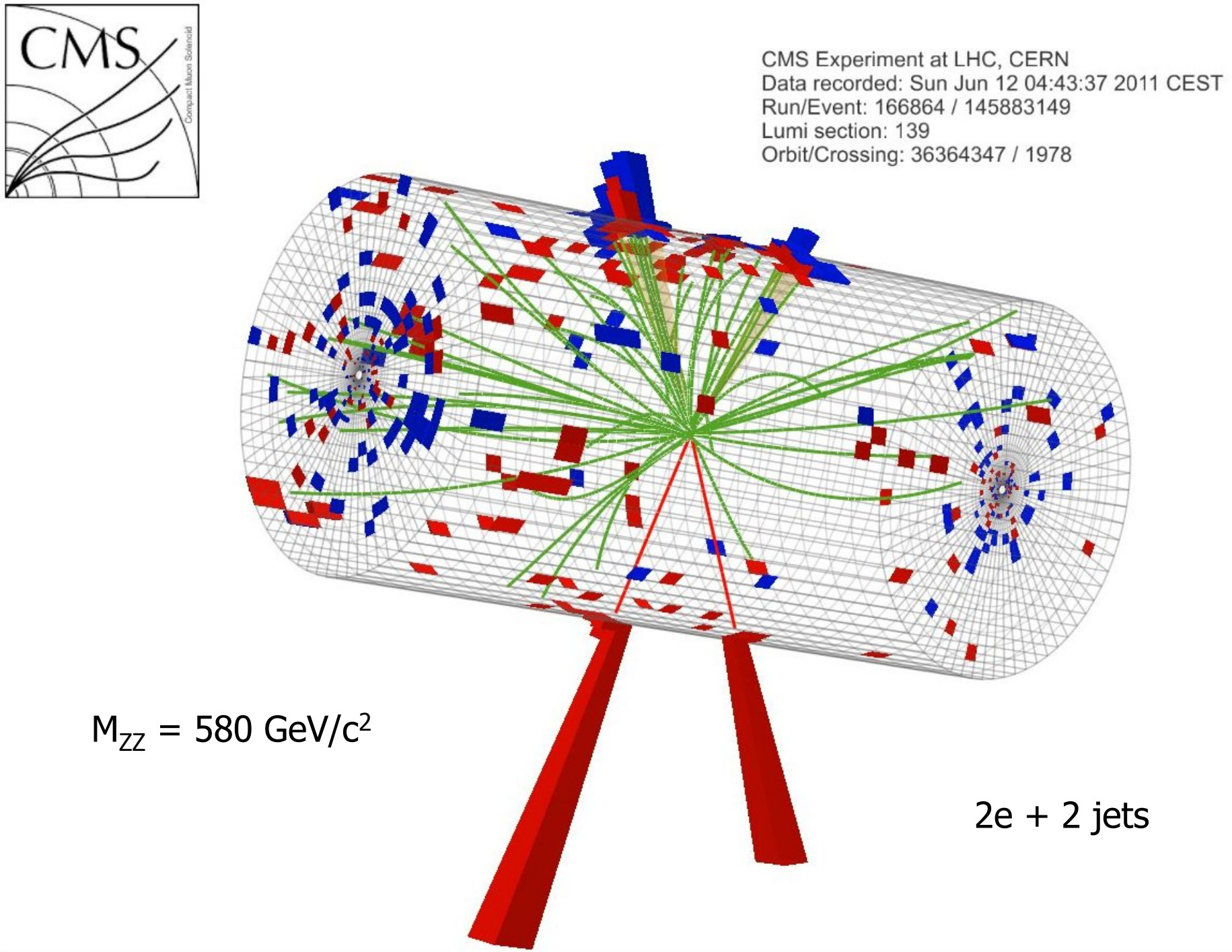


High Mass Results

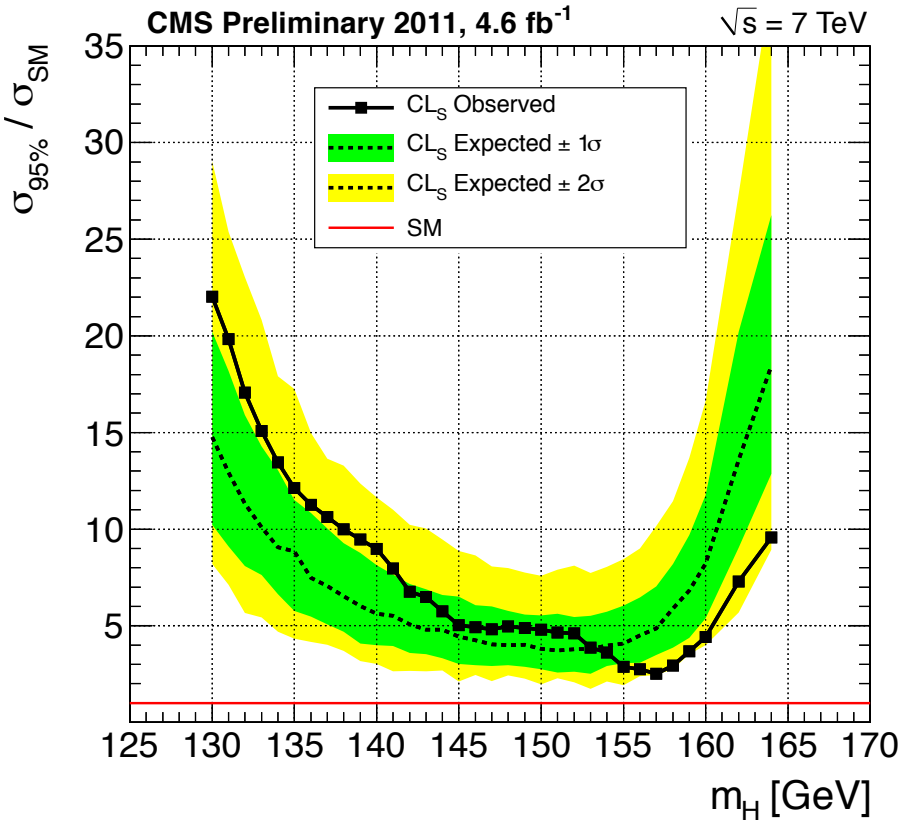


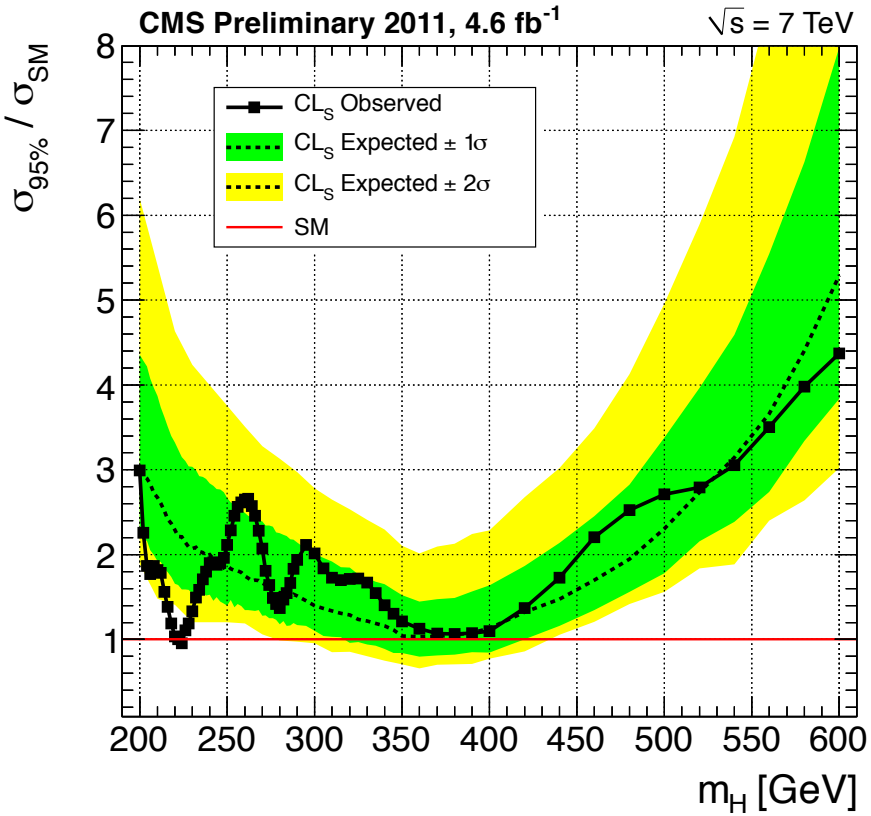


Most sensitivity from the
2 b-tag category !


CMS
Compact Muon Solenoid
CMS Experiment at LHC, CERN
Data recorded: Sun Jun 12 04:43:37 2011 CEST
Run/Event: 166864 / 145883149
Lumi section: 139
Orbit/Crossing: 36364347 / 1978
M_{ZZ} = 580 GeV/c^2
2e + 2 jets

Exclusion Limits





HIG-11-028

$H \rightarrow ZZ \rightarrow 2\ell\, 2\tau$

τ

$H \to ZZ \to 2\ell\, 2\tau$

Signature:

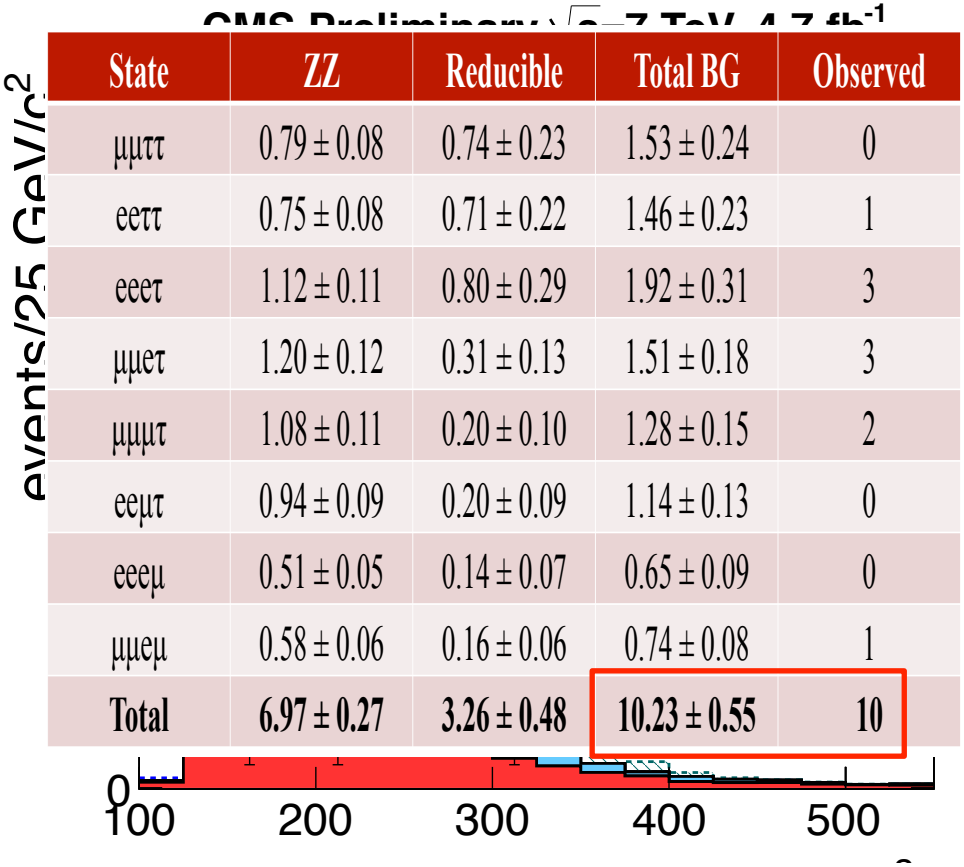
Excess in the visible mass distribution for events with one $\ell^+\ell^-$ lepton pair forming a on-shell Z boson and a $\tau^+\tau^-$ pair in the $e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$ final states

8 exclusive final states

Selection:

- a leading $Z \to \ell^+ \ell'^-$ with
  $P_{T\,l1} > 20$ GeV/c & $P_{T\,l2} > 10$ GeV/c
- two τ_h with $P_T > 20$ GeV/c

Particle flow used for lepton isolatior and τ_{ID} ("hadron + strip" algorithm)



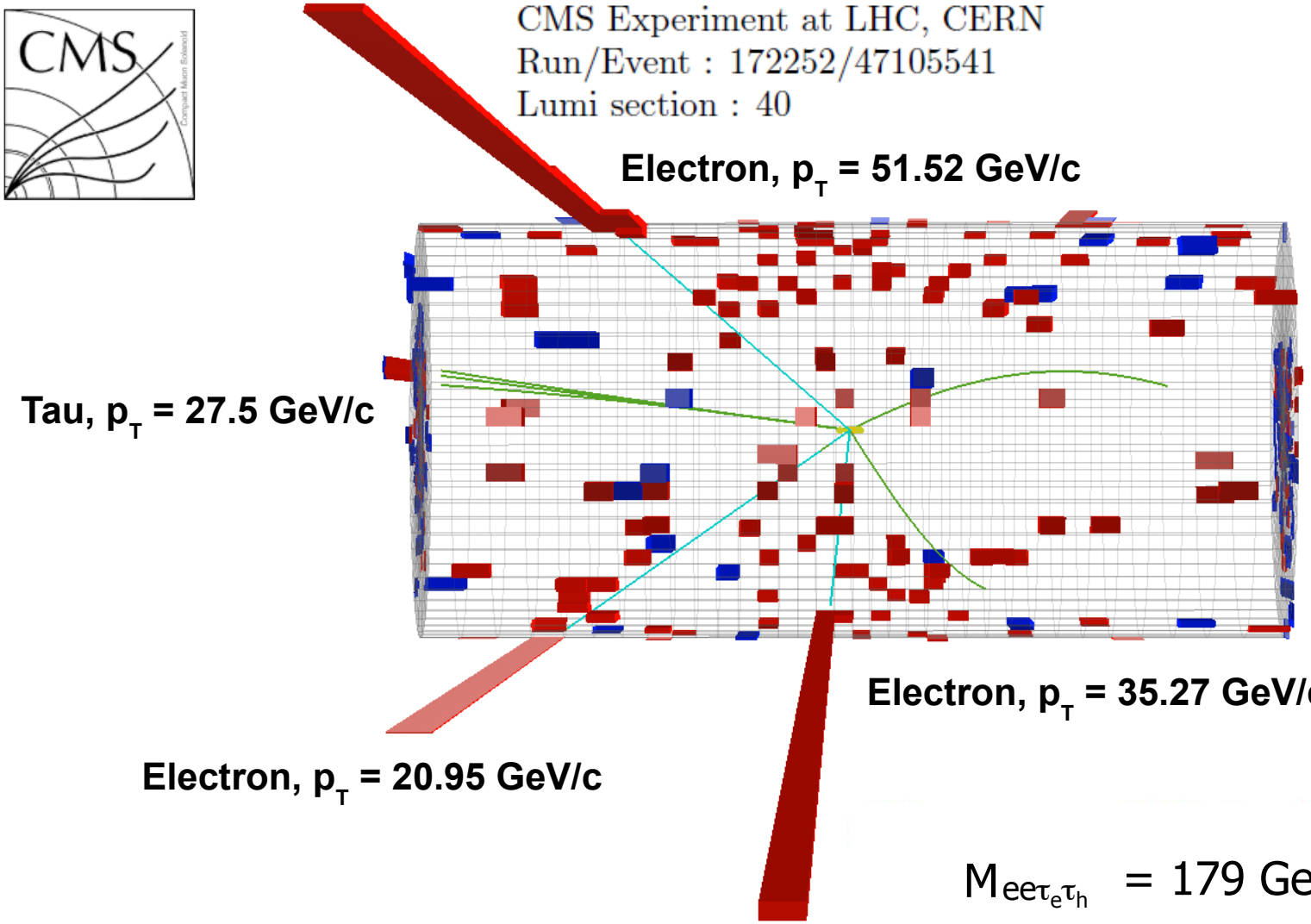
State	ZZ	Reducible	Total BG	Observed
μμττ	0.79 ± 0.08	0.74 ± 0.23	1.53 ± 0.24	0
eeττ	0.75 ± 0.08	0.71 ± 0.22	1.46 ± 0.23	1
eeeτ	1.12 ± 0.11	0.80 ± 0.29	1.92 ± 0.31	3
μμeτ	1.20 ± 0.12	0.31 ± 0.13	1.51 ± 0.18	3
μμμτ	1.08 ± 0.11	0.20 ± 0.10	1.28 ± 0.15	2
eeμτ	0.94 ± 0.09	0.20 ± 0.09	1.14 ± 0.13	0
eeeμ	0.51 ± 0.05	0.14 ± 0.07	0.65 ± 0.09	0
μμeμ	0.58 ± 0.06	0.16 ± 0.06	0.74 ± 0.08	1
Total	6.97 ± 0.27	3.26 ± 0.48	10.23 ± 0.55	10

Expected Higgs yields:

1.49 events for $M_H = 200$ GeV/c²

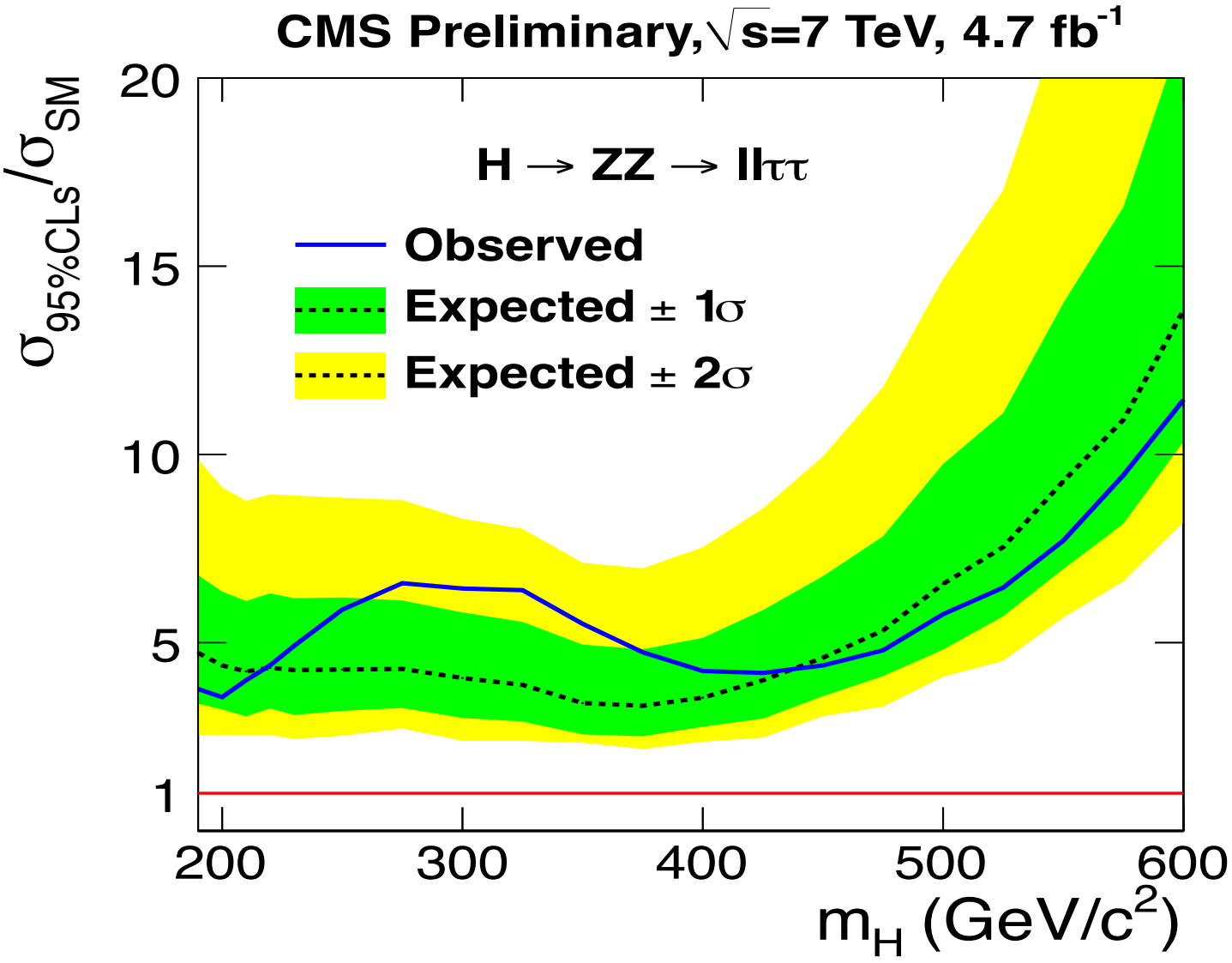
1.39 events for $M_H = 400$ GeV/c²

$ZZ \rightarrow 2\ell\, 2\tau$
$\rightarrow ee\tau_e\tau_h$



$M_{ee\tau_e\tau_h}$ = 179 GeV/c^2

Exclusion Limits



HIG-11-026

$H \rightarrow ZZ \rightarrow 2\ell\, 2\nu$

τ

$H \rightarrow ZZ \rightarrow 2\ell\, 2\nu$

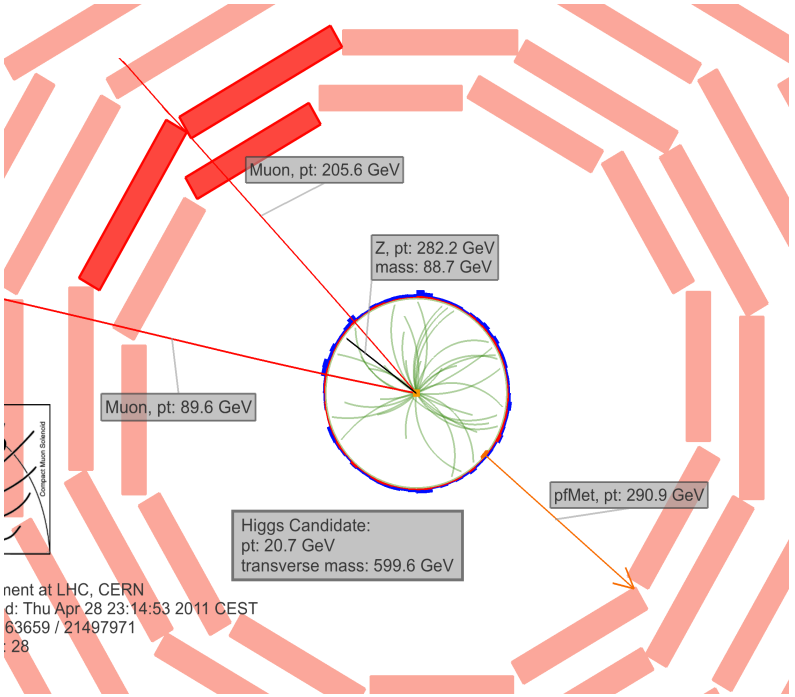
Signature:

Broad excess in the transverse mass distribution m_T for events with one $\ell^+\ell^-$ lepton pair (forming a on-shell Z boson) and a large missing E_T

2 exclusive final states

Selection:

- a leading $Z \rightarrow \ell^+ \ell'^-$ with two isolated leptons with small parameter
- large $P_{T\,\ell\ell}$
- large E_T^{miss}
  (not aligned with jets or leptons)



Backgrounds:

Z+jets ⇒ from data (γ + jets)

tt, WW, W+jets ⇒ from data (off Z peak)

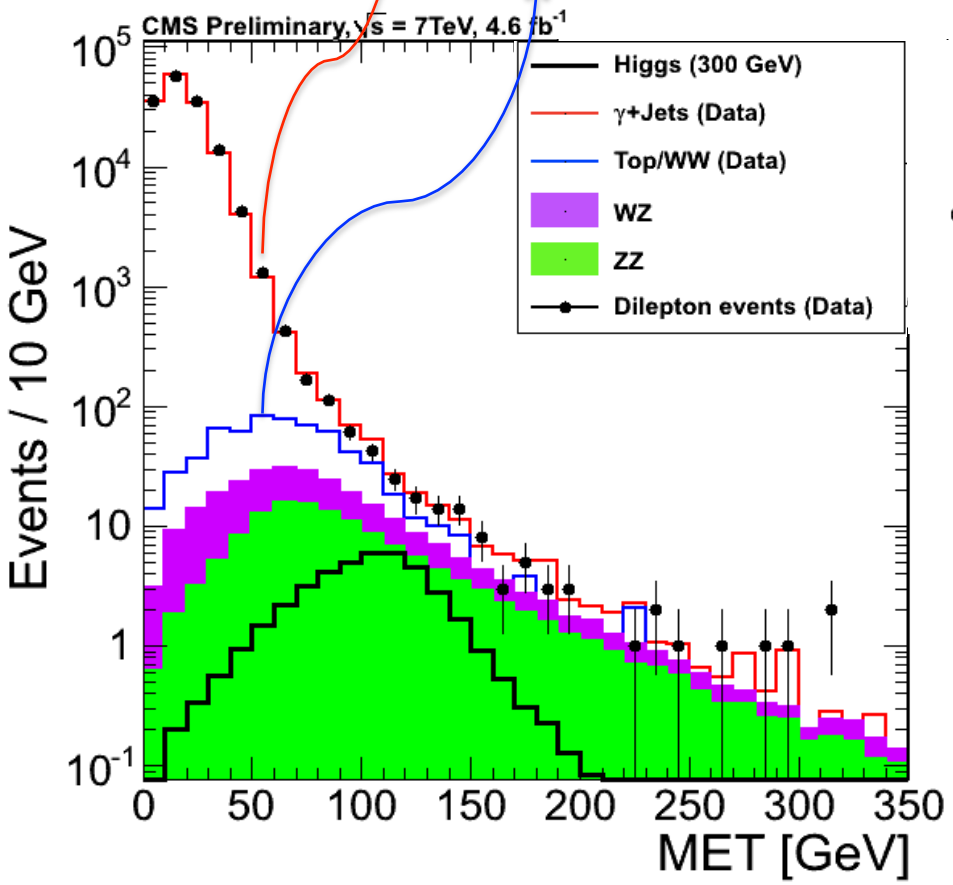
WZ, ZZ ⇒ from MC

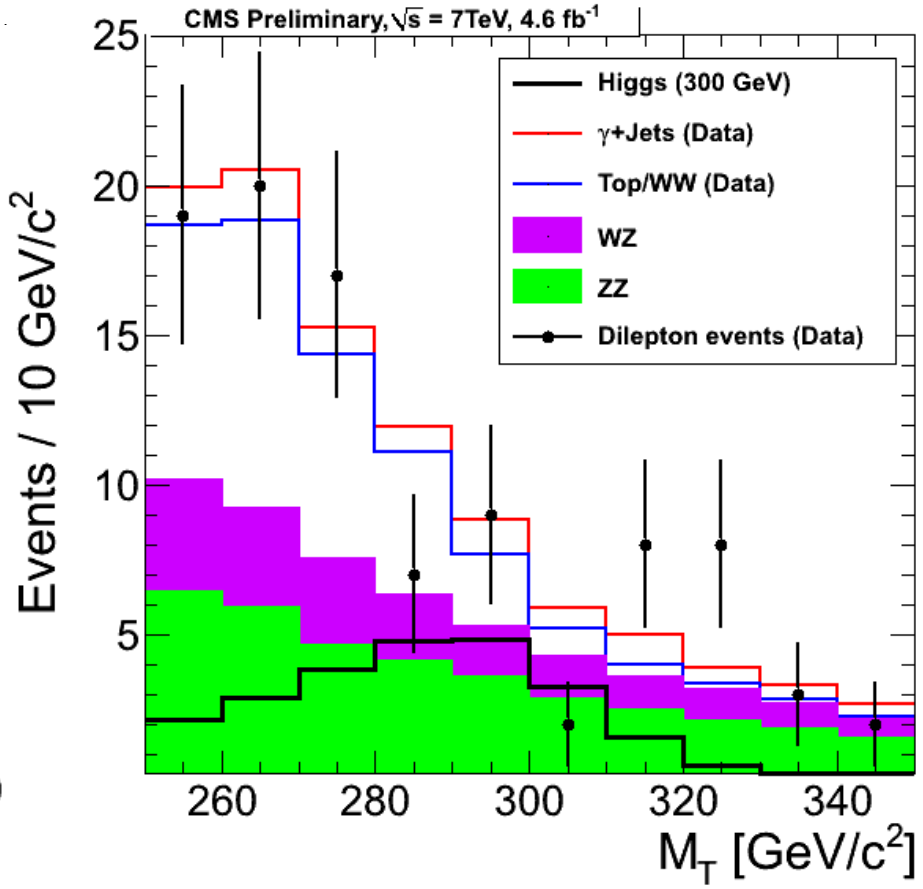
Measured Spectra

Data-driven prediction for Z+jets using γ + jets events

Data-driven prediction for tt/WW using using sidebands

Mass spectra after $E_T^{miss} > 95$ GeV/c^2



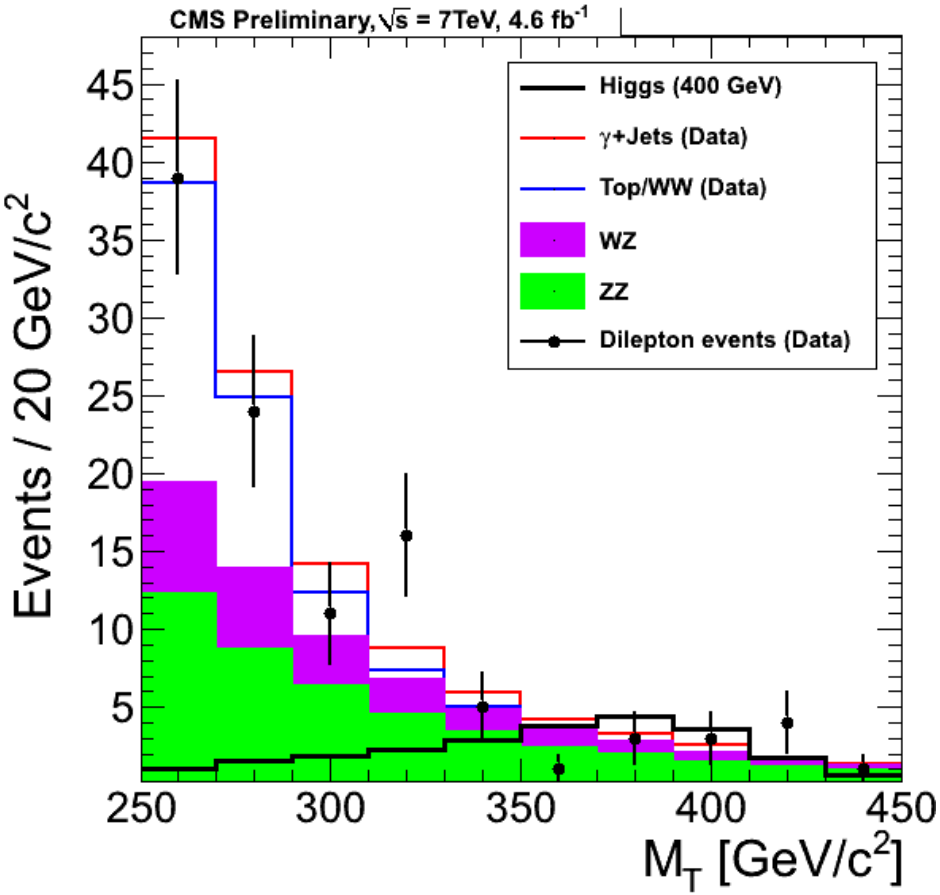


Event Selection

M_H dependent
M_T and Et^{miss} cuts

m_H GeV/c²	Total	Signal	Data
250	$140 \pm 3.8 \pm 16$	22 ± 2.1	142
300	$60 \pm 1.1 \pm 7.3$	21 ± 2	64
350	$29 \pm 0.25 \pm 4.4$	21 ± 2.3	26
400	$19 \pm 0.19 \pm 2.9$	17 ± 1.6	18
500	$11 \pm 0.14 \pm 1.5$	7.4 ± 0.76	14
600	$5.3 \pm 0.095 \pm 0.7$	2.9 ± 0.31	5

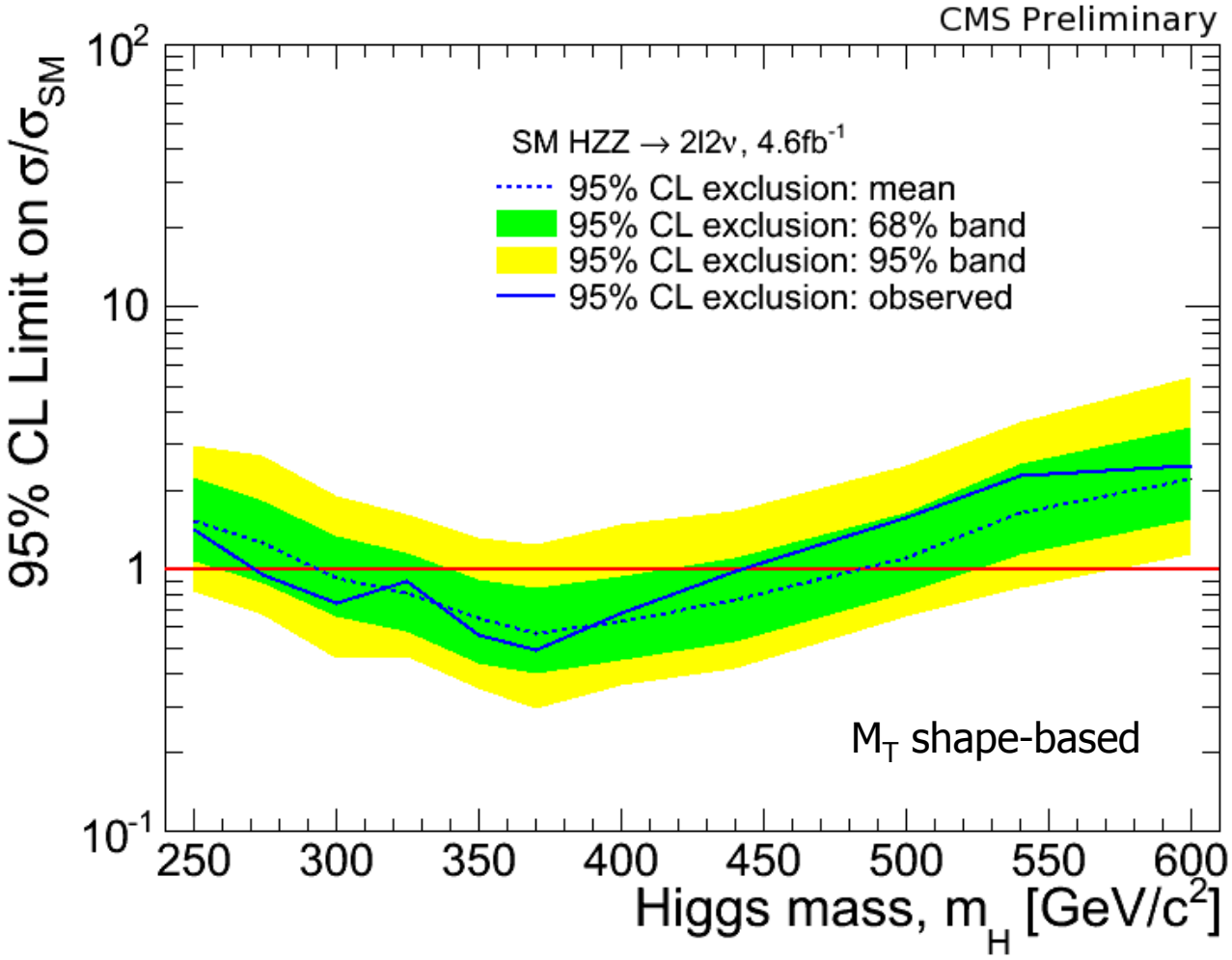
Mass spectra after
$E_T^{miss} > 115$ GeV/c²



Exclusion Limits

Similar results using cut-based and M_T shape-Based analyses

Excluded:
310 – 465 GeV/c^2
(cut-based)
270 - 440 GeV/c^2
(shape-based)



HIG-11-025

$H \rightarrow ZZ \rightarrow 4\ell$

$H \rightarrow ZZ \rightarrow 4\ell$

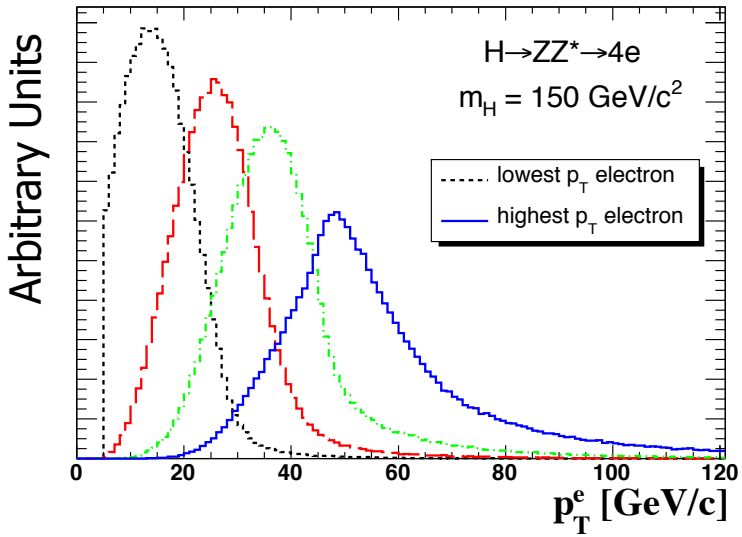
Signature:

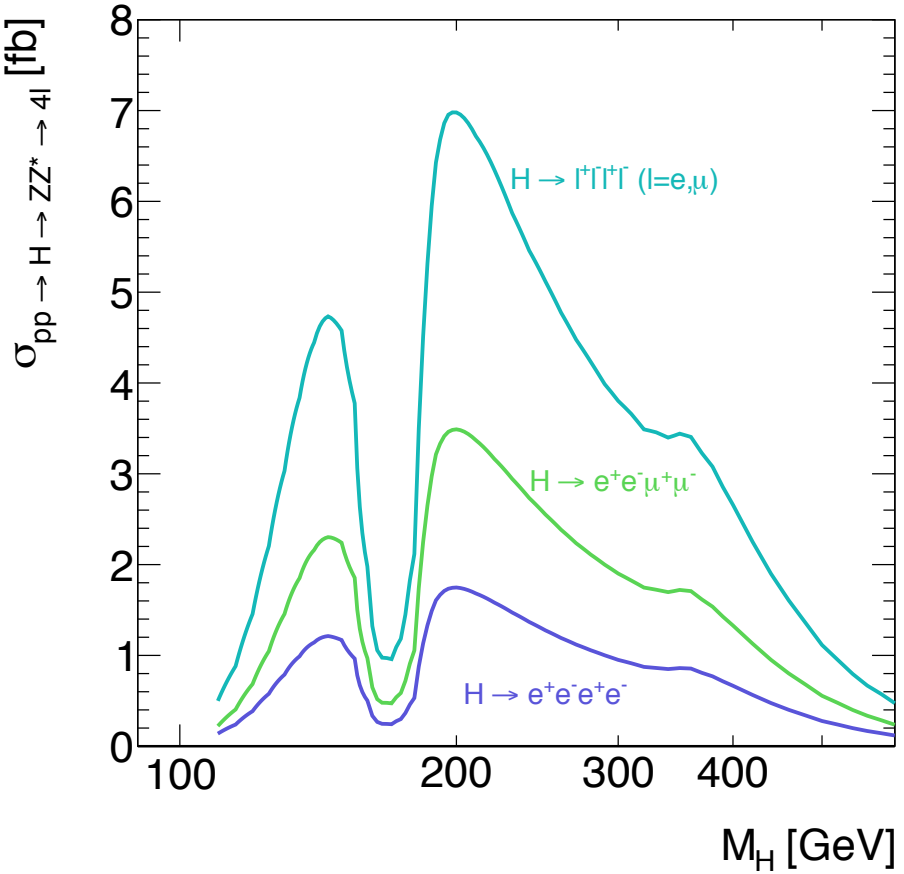
The "golden" channel

Narrow peak over a locally flat background continuum

Allows to measure M_H, S_{CP}, …

3 exclusive final states





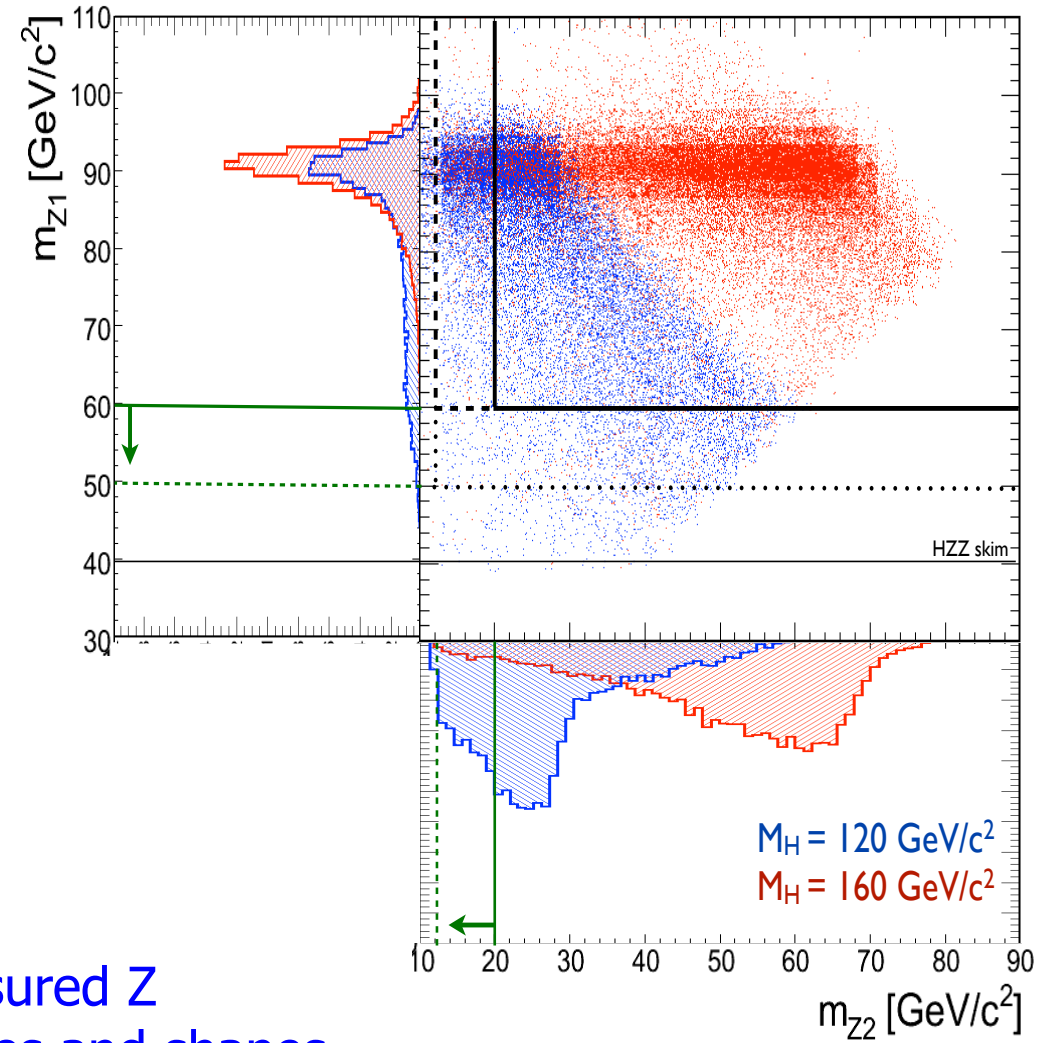
⚠ Need to preserve highest efficiencies ℓ_{ID}, ℓ_{Iso}, Kinematics

Event Selection

Selection:

- 4 isolated leptons with small impact parameter to primary vertex
- $P_{T\,1,2,3} > 20, 10, 7$ GeV/c
- $P_{T\,4} > 5$ (μ) or 7 (e) GeV/c
- $50 < M_{Z1} < 120$ GeV/c^2 ***
- $12 < M_{Z2} < 120$ GeV/c^2
- at least three $\ell^+\ell^-$ combinations with $M_{ll} > 12$ GeV/c^2 (4e, 4μ)

*** Improved acceptance at low MH

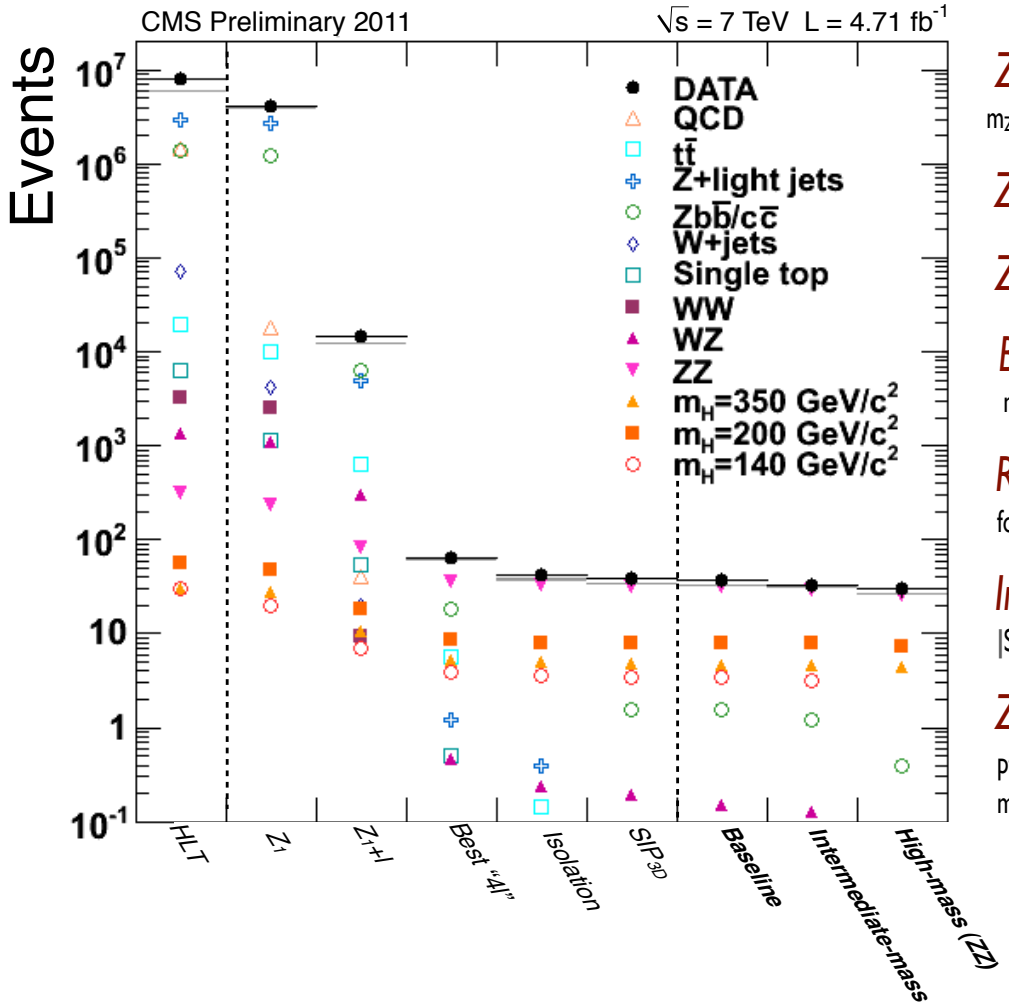


Backgrounds:

ZZ $\Rightarrow$ from MC ZZ/Z and measured Z

Z+jets, Zbb, tt $\Rightarrow$ from fake rates and shapes

Selection Steps



Z_1, at least one quality Z candidate

m_{Z1}>50 GeV/c^2 + $p_{T,1}$ > 20 GeV/c + $p_{T,2}$ > 10 GeV/c + ($Rel_{Iso,1}$ + $Rel_{Iso,2}$) < 0.35 + $|SIP_{3D}|_{1,2}$ < 4

Z_1 + 1lepton

Z_1 + 2leptons of matching flavor and opposite sign

Best 4l candidate / Z_1 , Z_2 assignments

m_{Z2}>12 GeV/c^2 + m_{Z1Z2}>100 GeV/c^2 + 3/4 l^+l^- combinations have m_{ll} >12 GeV/c^2 (4e/4μ only)

Relative isolation for selected leptons

for any leptons combination ($Rel_{Iso,i}$ + $Rel_{Iso,j}$) < 0.35

Impact parameter for selected leptons

$|SIP_{3D}|$ < 4

Z and Z$^{(*)}$ kinematics

$p_{T,1}$ > 20 GeV/c $p_{T,2}$ > 10 GeV/c $p_{T,3,4}$ > 7(e),5(μ) GeV/c +
m_{Z1MIN} < m_{Z1} < 120 GeV/c^2 + m_{Z2MIN} < m_{Z2} < 120 GeV/

ℓ Reconstruction and Identification

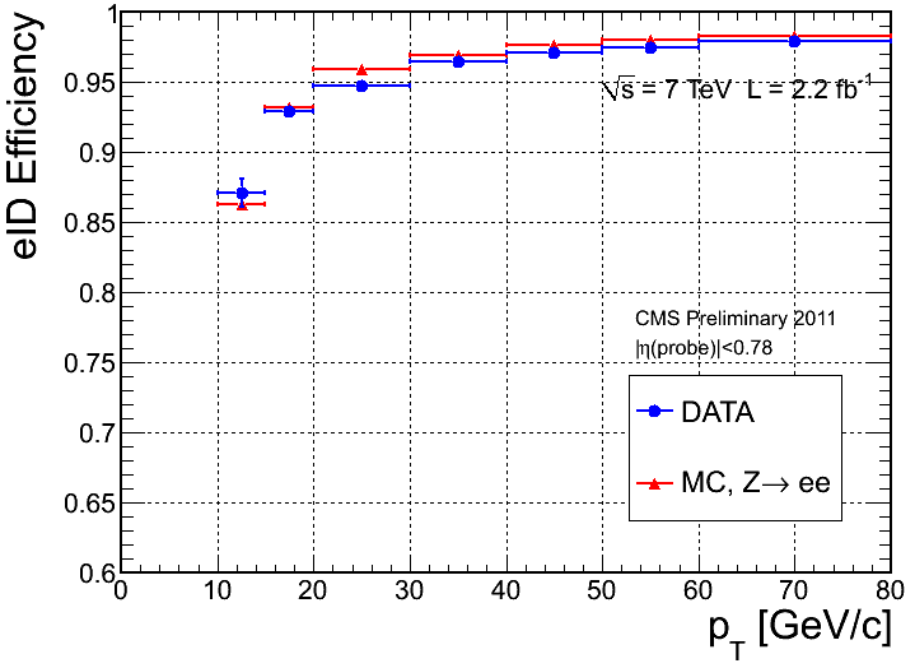
Muons: fit to inner + outer track (> 10 hits)

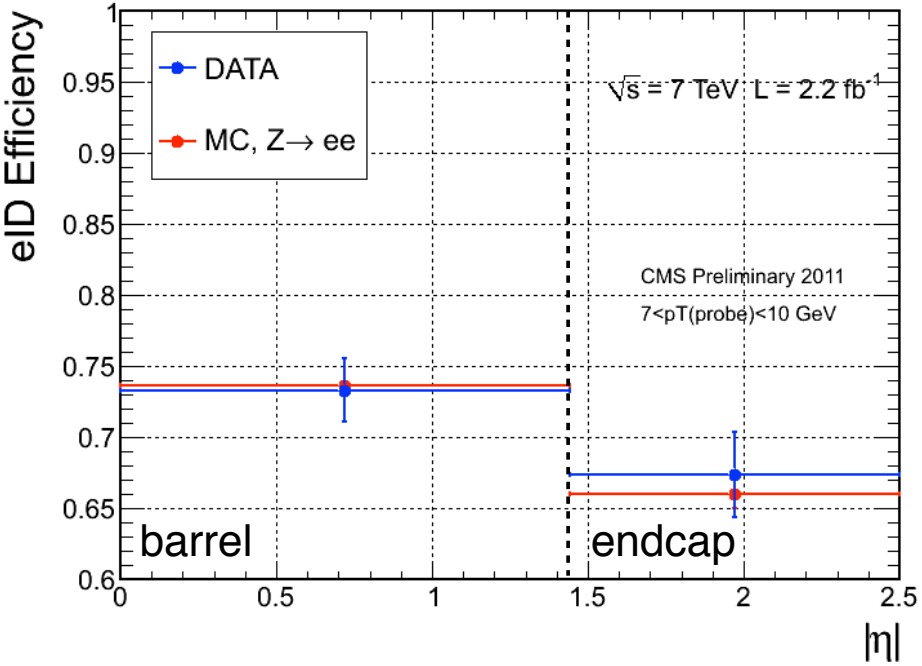
Electrons: "GSF" electrons (seeding ECAL-driven + tracker-driven)

P_T, $|\eta|$ dependent Id. using cut-in-categories function of f_{Bremss},

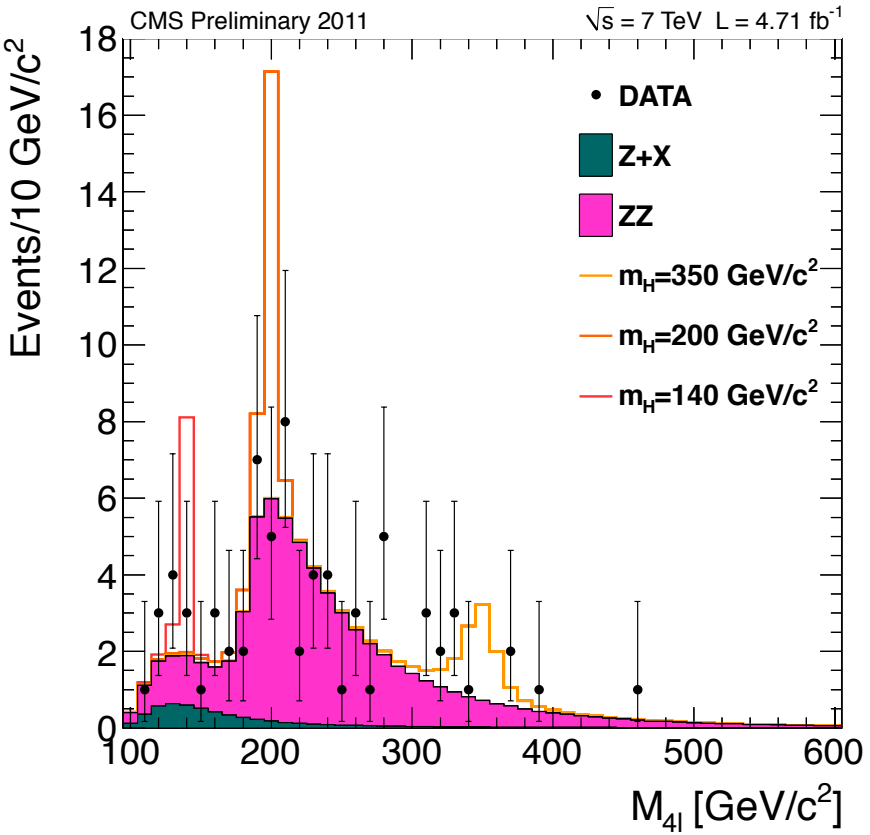
Efficiencies from data from tag-and-probe on the Z (for e,μ) and J/ψ (for low P_T μ)

Fake rates from Z+1 / Z+2 SS





Mass Spectrum



Baseline Selection

$50 < M_{Z1} < 120$ GeV/c^2

$12 < M_{Z2} < 120$ GeV/c^2

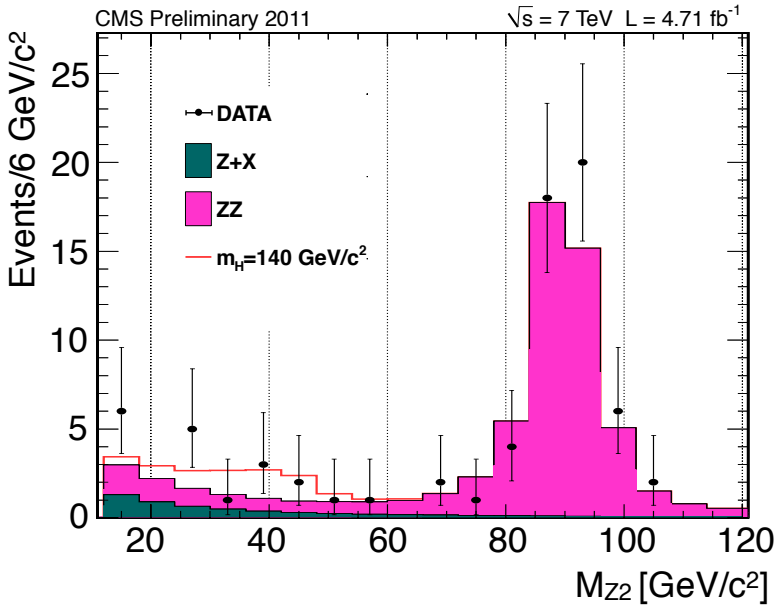
Event Yields:

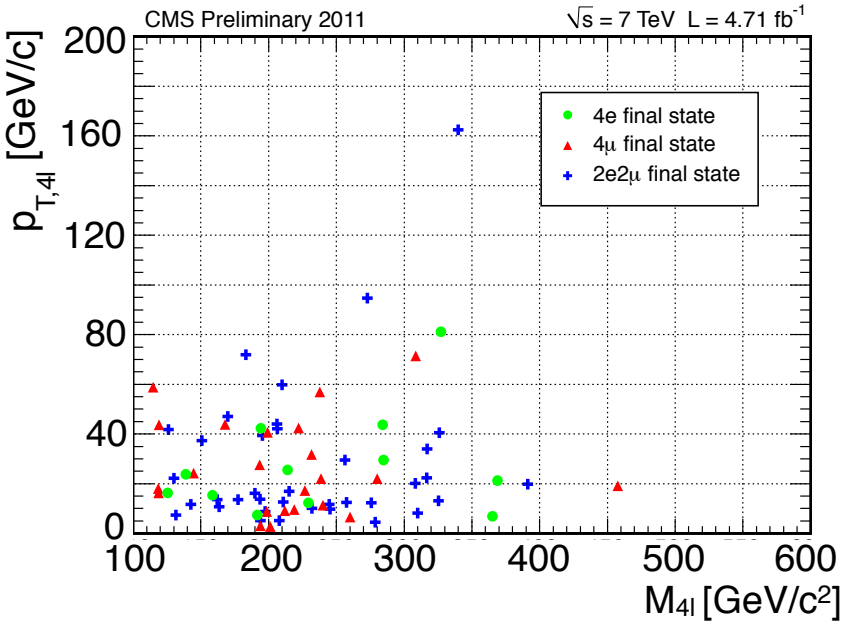
Baseline	$4e$	4μ	$2e2\mu$
ZZ	12.27 ± 1.16	19.11 ± 1.75	30.25 ± 2.78
Z+X	1.67 ± 0.55	1.13 ± 0.55	2.71 ± 0.96
All background	13.94 ± 1.28	20.24 ± 1.83	32.96 ± 2.94
$m_H = 120\,\mathrm{GeV}/c^2$	0.25	0.62	0.68
$m_H = 140\,\mathrm{GeV}/c^2$	1.32	2.48	3.37
$m_H = 350\,\mathrm{GeV}/c^2$	1.95	2.61	4.64
Observed	12	23	37

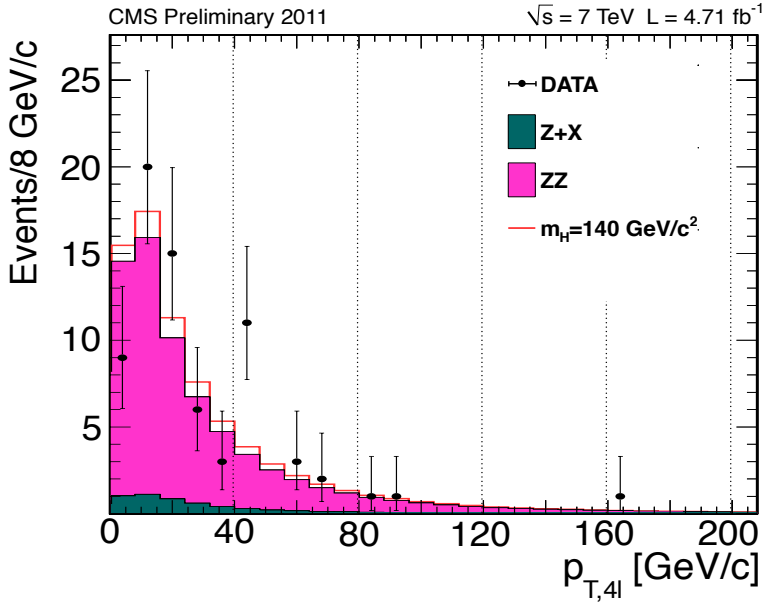
$M_{4\ell} > 100$ GeV/c^2 Observed: 72 Expected: 67.1 ± 6.0 events

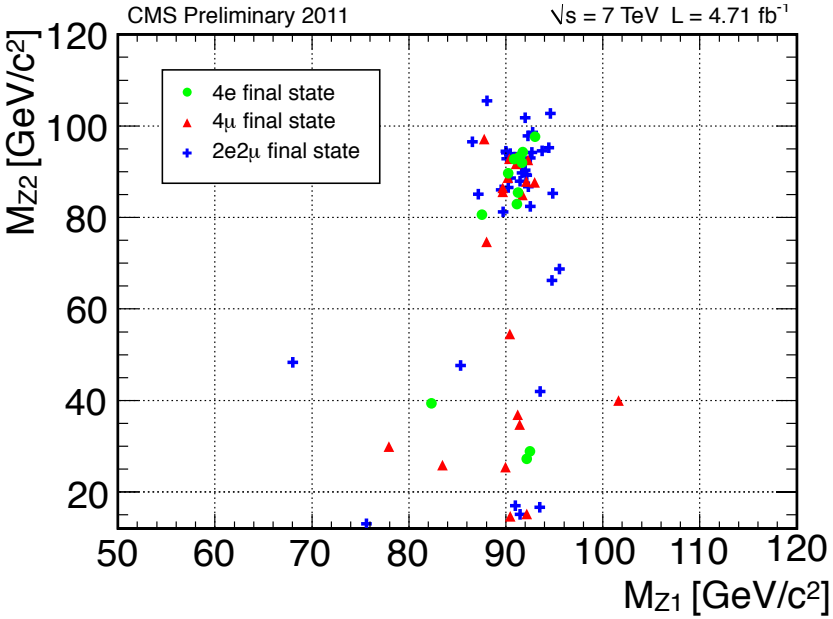
$H \rightarrow ZZ \rightarrow 4\ell$

Kinematics

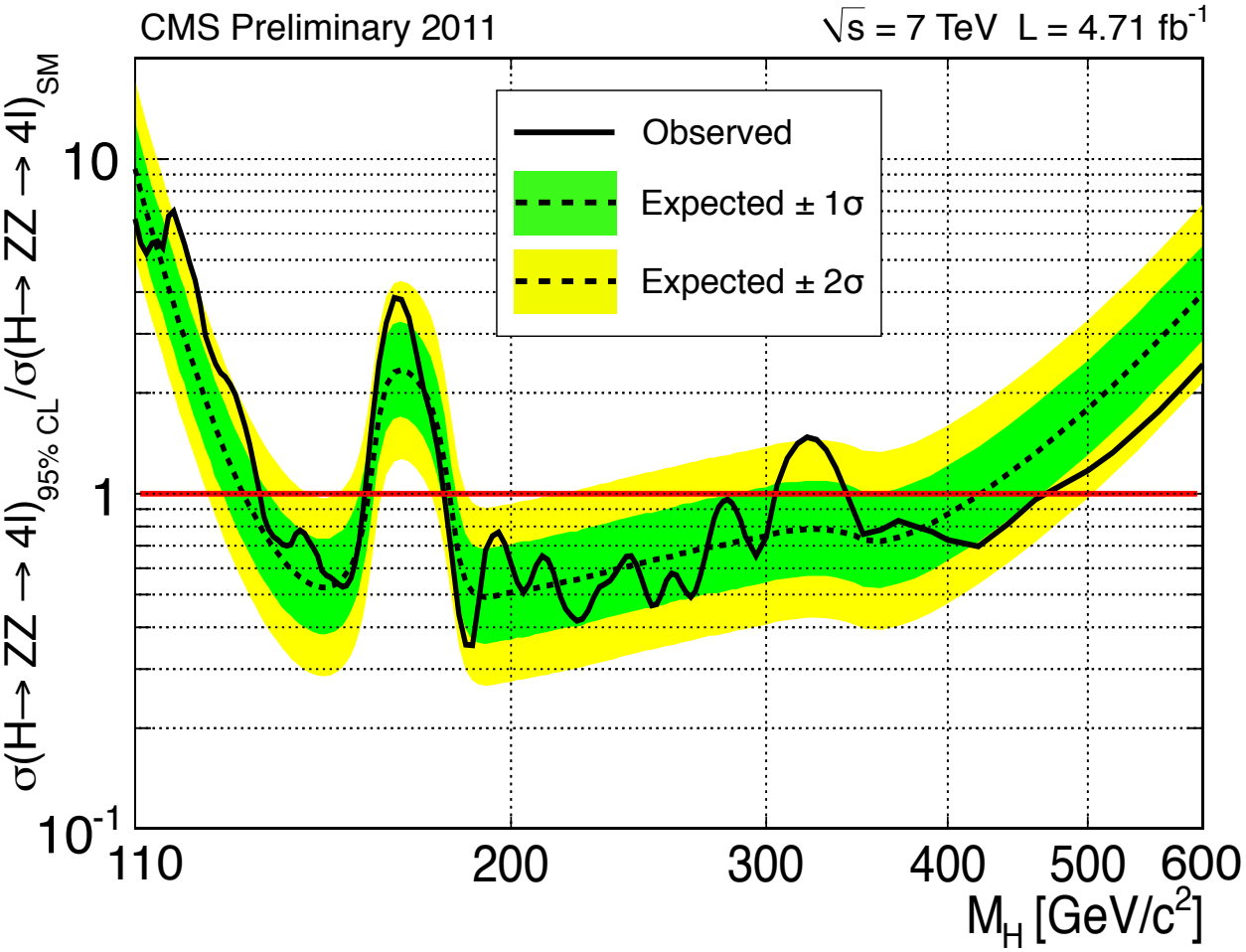








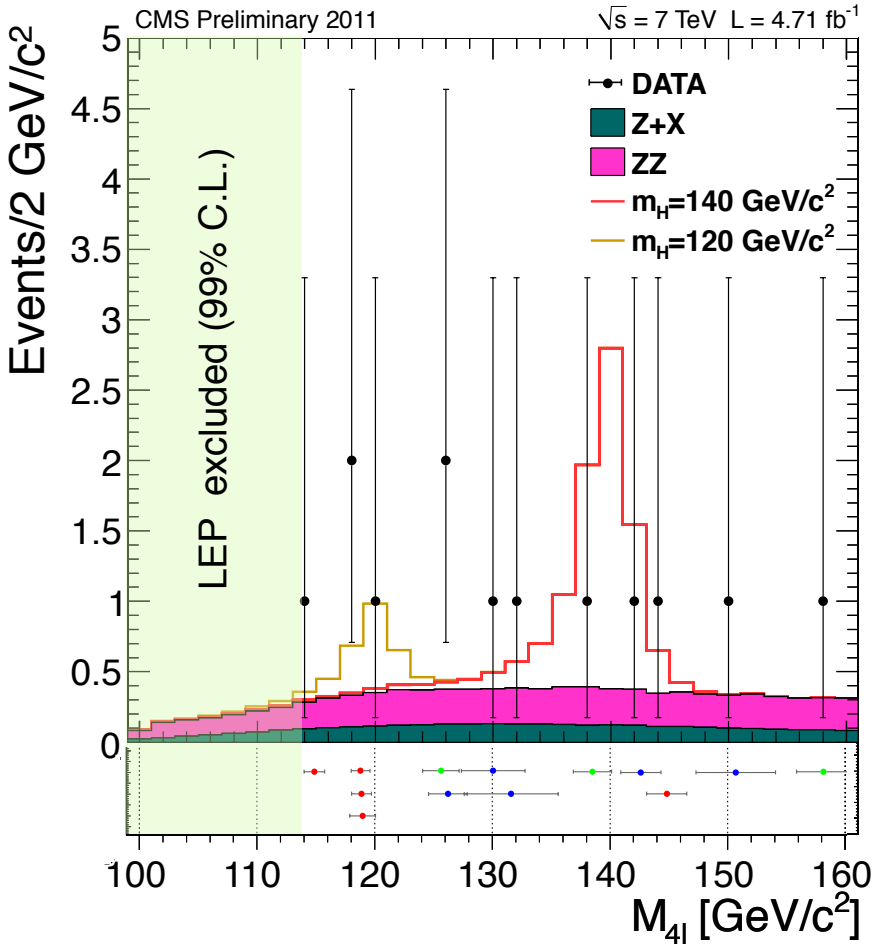
Exclusion Limits



Excluded:

134 – 158; 180 – 305 ; 340 – 465 GeV/c^2

Low Masses



Baseline Selection

$50 < M_{Z1} < 120$ GeV/c^2

$12 < M_{Z2} < 120$ GeV/c^2

$\varepsilon(M_H \sim 120) \sim 20\%$ (4e), 40% (4μ), 25% (2e2μ)

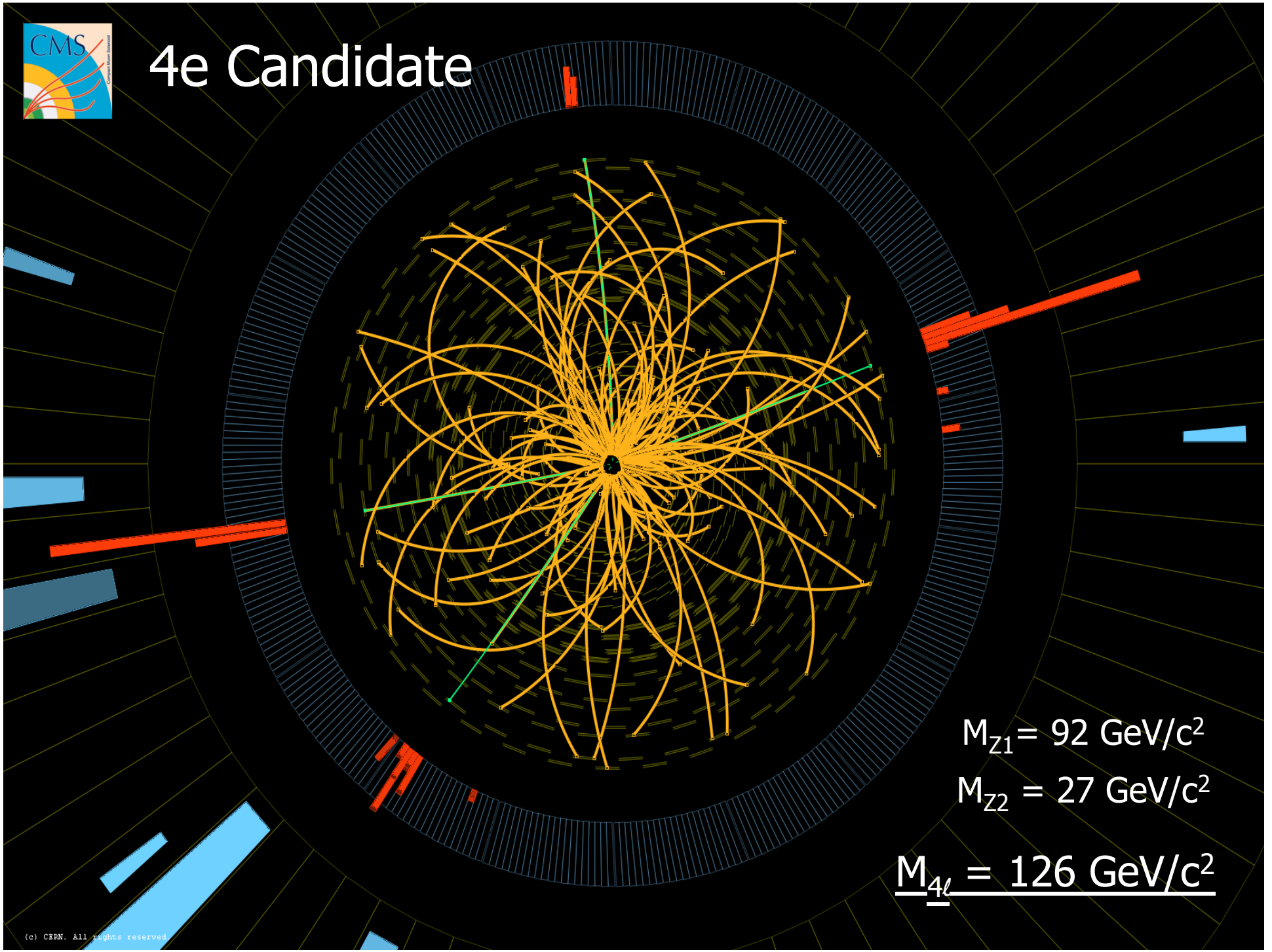
$\varepsilon(M_H \sim 160) \sim 42\%$ (4e), 75% (4μ), 55% (2e2μ)

Event Yields:

Final state:	4e	4μ	2e2μ
Obs. events:	3	5	5
Exp. events:	1.7	3.3	4.5

$100 < M_{4\ell} < 160$ GeV/c^2 Observed: 13 Expected: 9.5 ± 1.3 events

4e Candidate

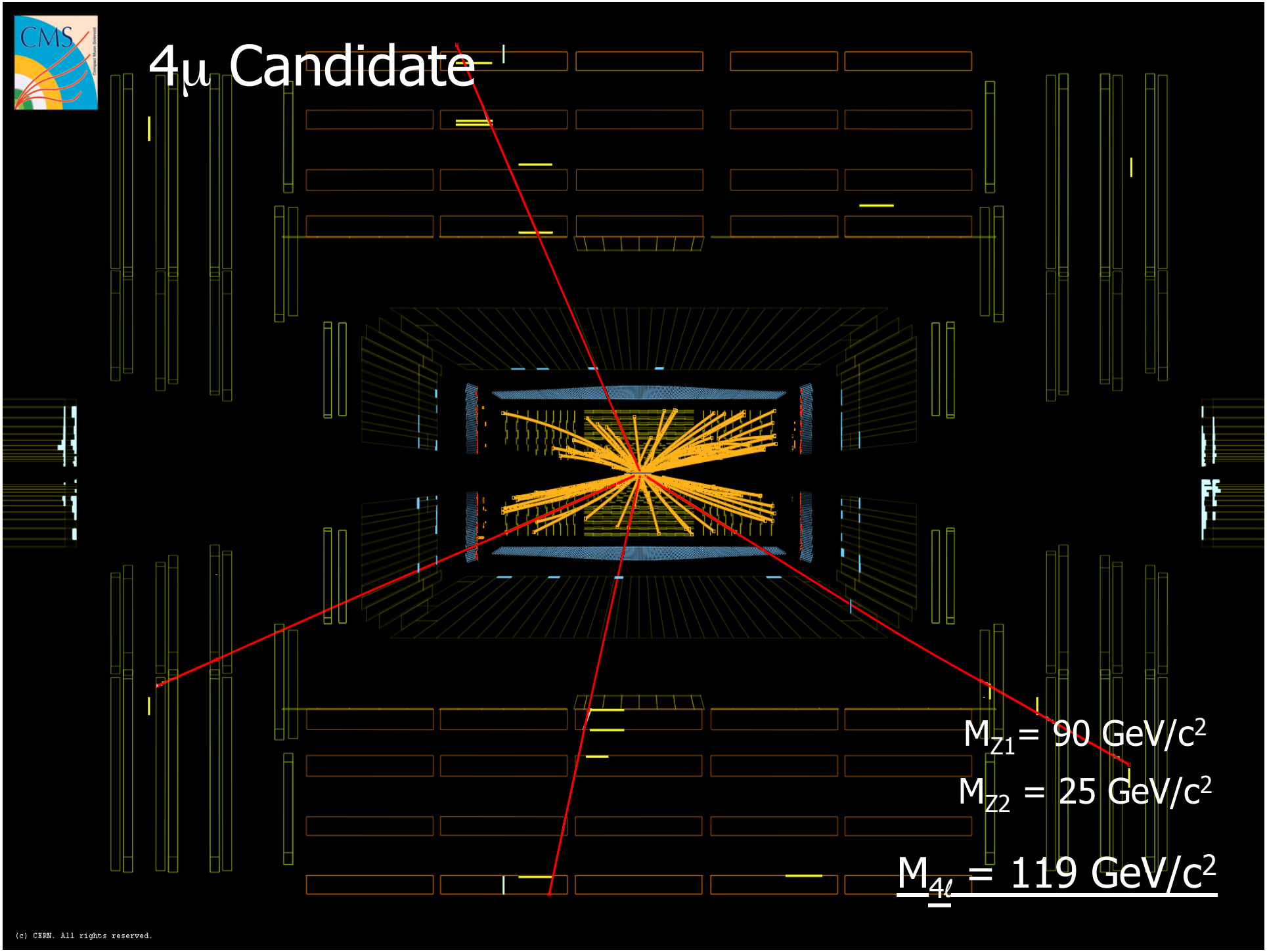


M_{Z1} = 92 GeV/c^2

M_{Z2} = 27 GeV/c^2

$M_{4\ell}$ = 126 GeV/c^2

4μ Candidate

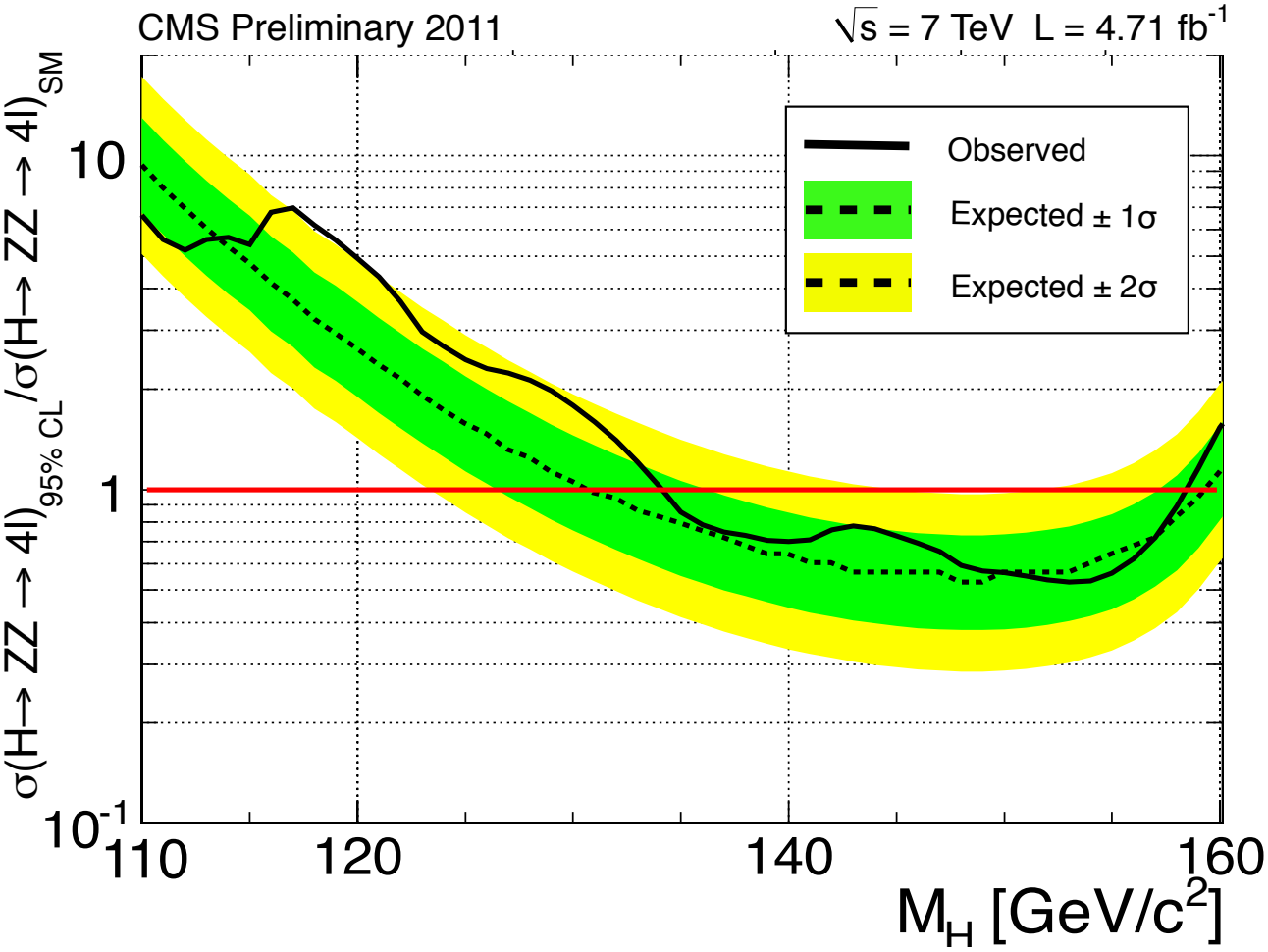


M_{Z1} = 90 GeV/c^2

M_{Z2} = 25 GeV/c^2

$M_{4\ell}$ = 119 GeV/c^2

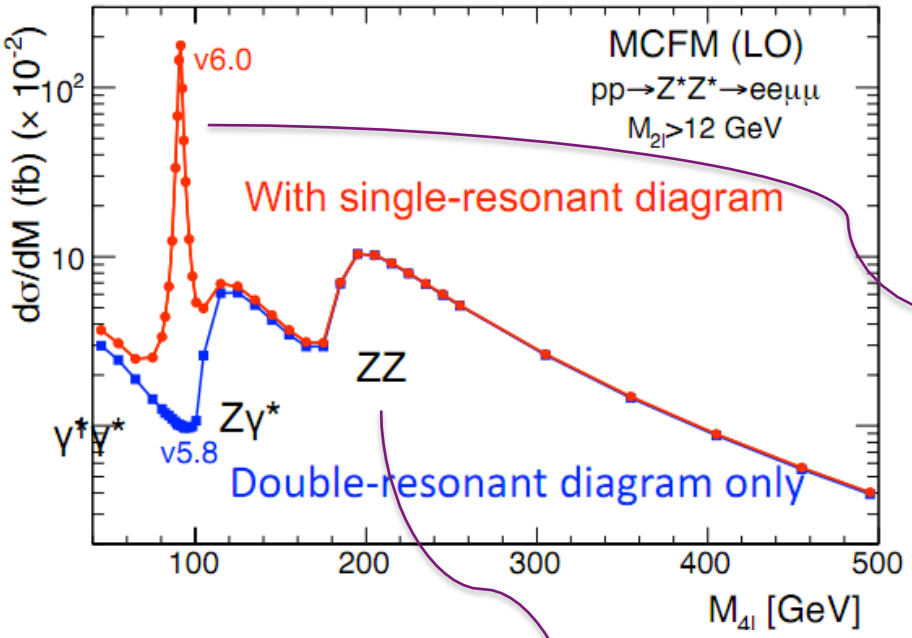
Exclusion Limits: Low Mass

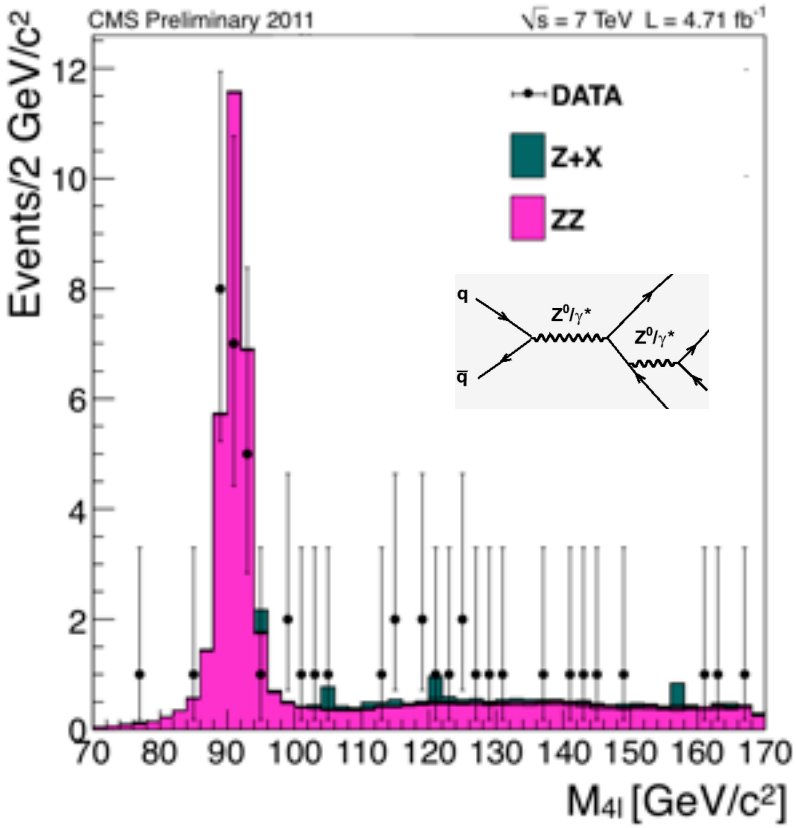


Excluded: $M_H > 134$ GeV/c^2

Expected sensitivity: 130 GeV/c^2

Other pp → 4ℓ Measurements





Measurement of the ZZ cross section with both Z on shell (60<MZ<120):

$$\sigma(pp \to ZZ + X) \times \mathcal{B}(ZZ \to 4\ell) = 28.1^{+4.6}_{-4.0}(\text{stat.}) \pm 1.2(\text{syst.}) \pm 1.3(\text{lumi.})\ \text{fb}$$

To be compared with the SM XS = 27.9 +- 1.9 fb

HIG-11-030

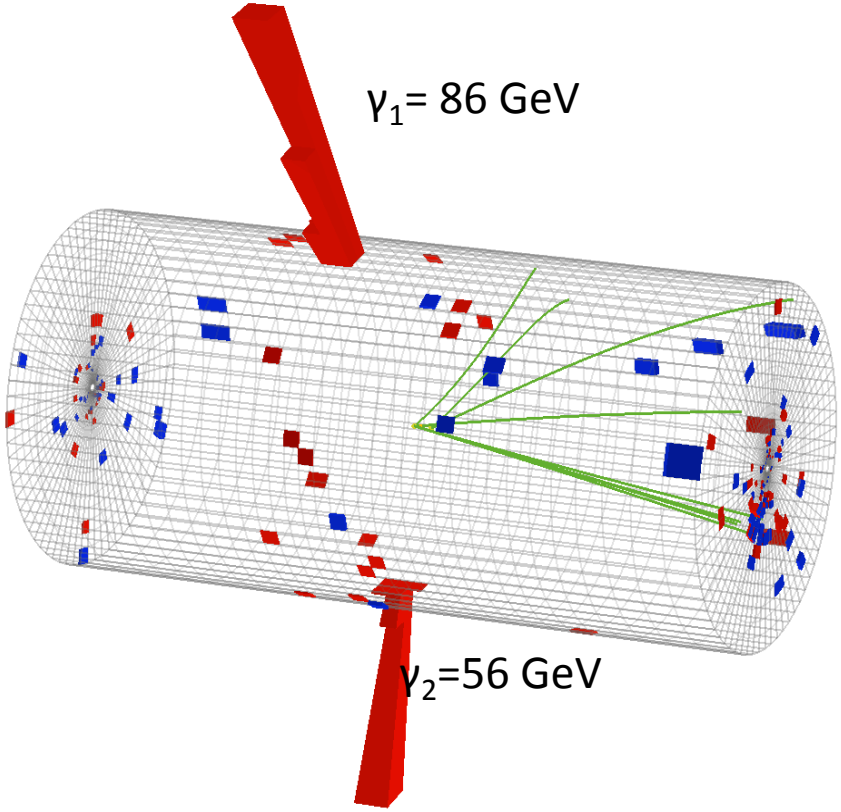
$H \rightarrow \gamma\gamma$

$H \rightarrow \gamma\gamma$

Signature:

Narrow peak in di-photon mass distribution

Four categories with different S/B:
- γ in central (ECAL barrel) or forward (ECAL endcaps)
- γ leading to compact or broad showers as expected from non-converted and converted photons respectively

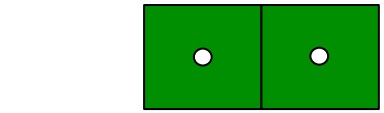


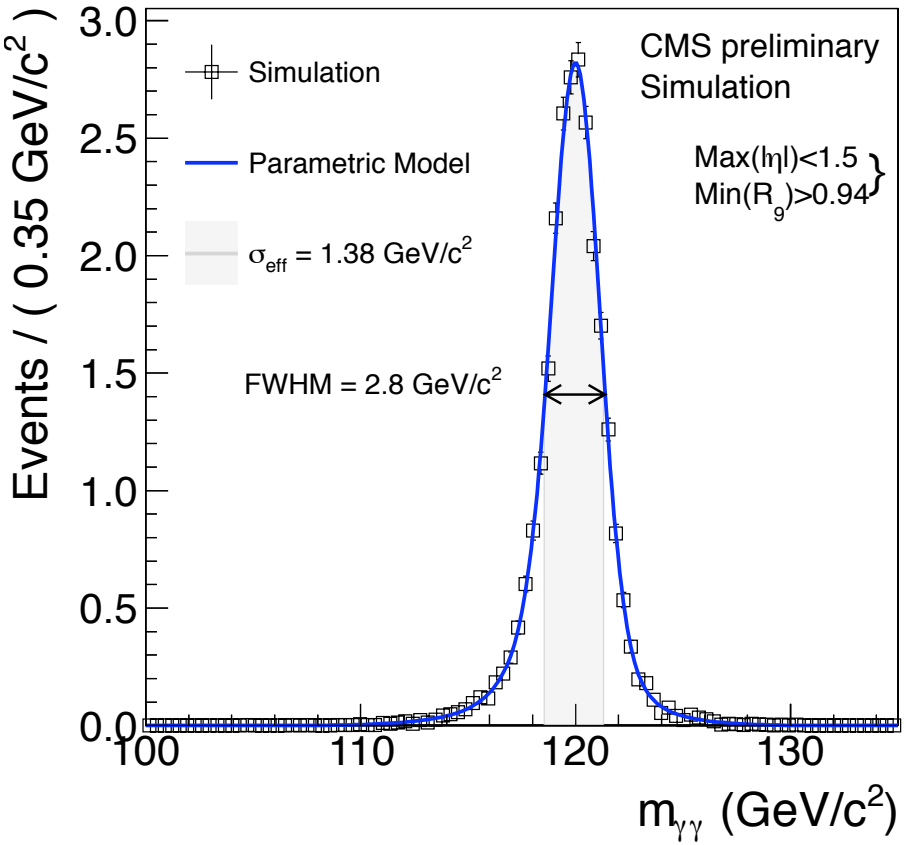
Total: 4 "exclusive" final states

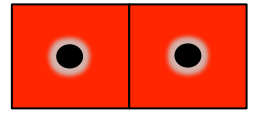
Selection:
photons with $P_T^{\gamma 1} > m_{\gamma\gamma}/3$ and $P_T^{\gamma 2} > m_{\gamma\gamma}/4$

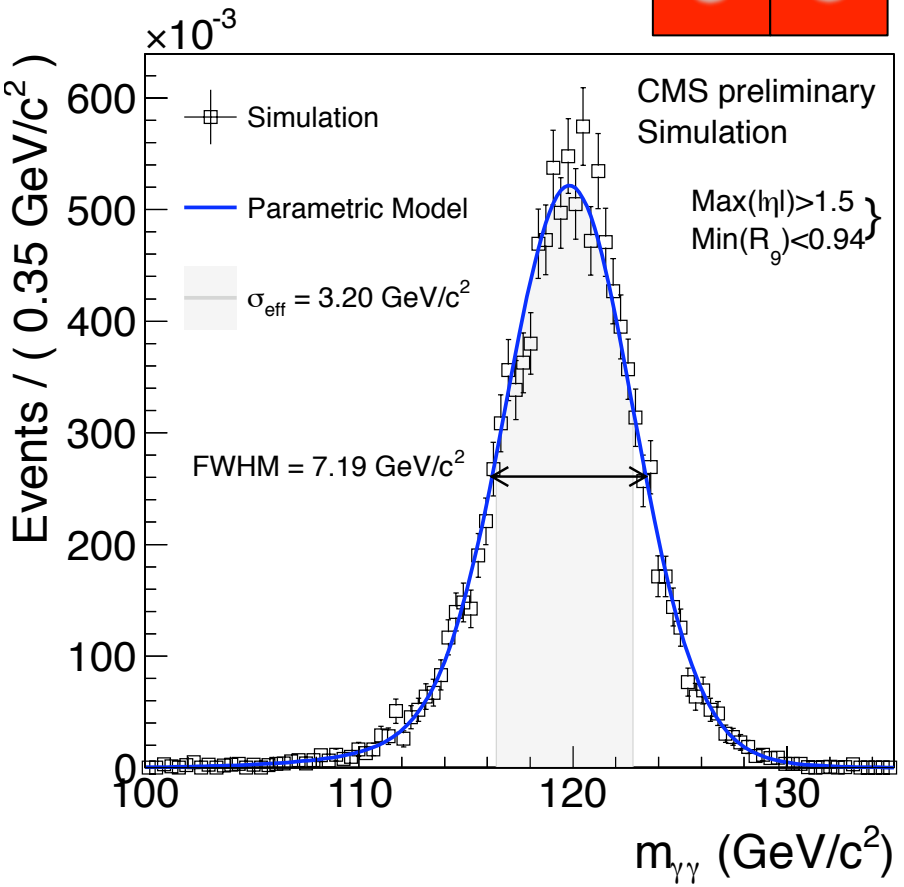
Backgrounds: from sidebands

Energy Resolution



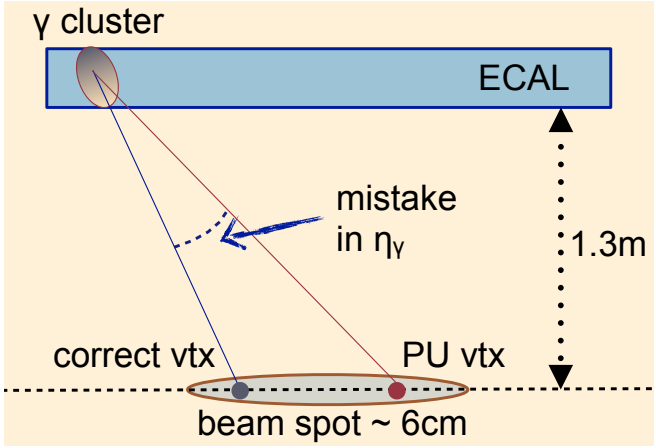




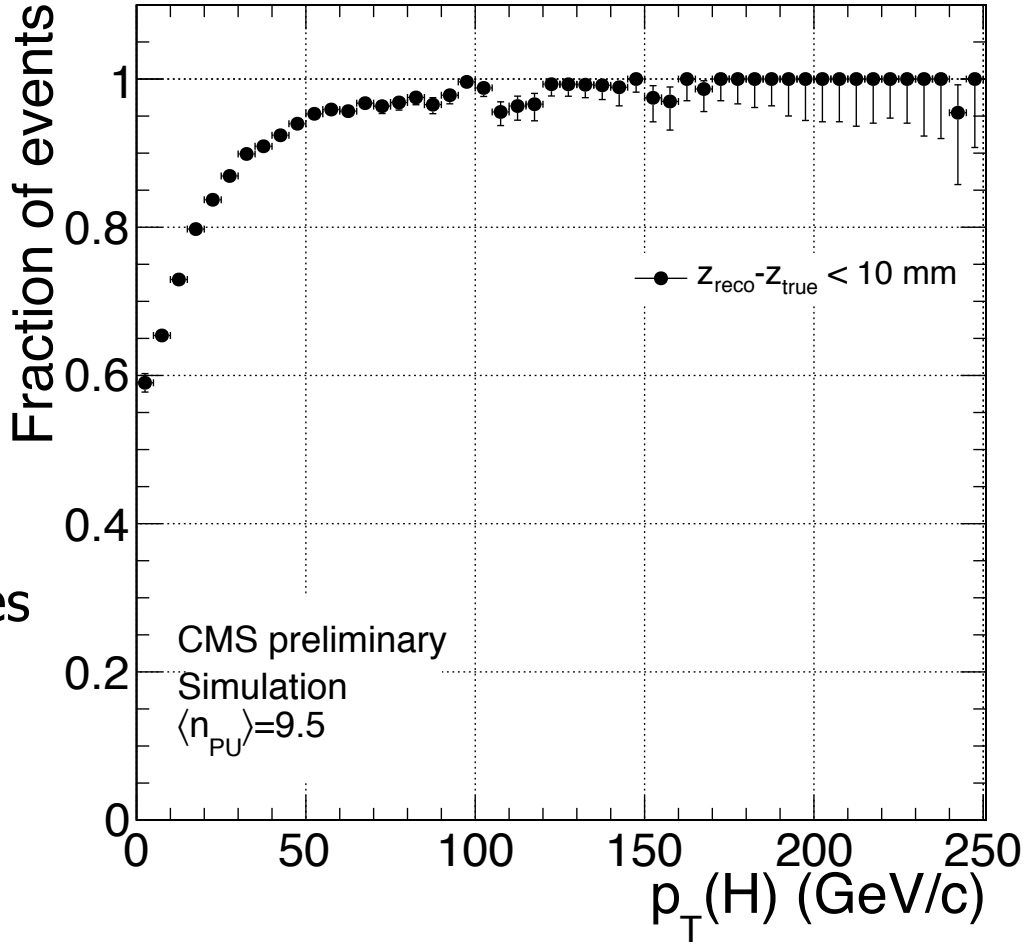


+ use BDT regression technique trained on γ+jet MC to correct raw super-cluster energies (use cluster position and shower shape) 10% gain in resolution
+ correct residual MC-Data differences on DY peak

Vertex Reconstruction



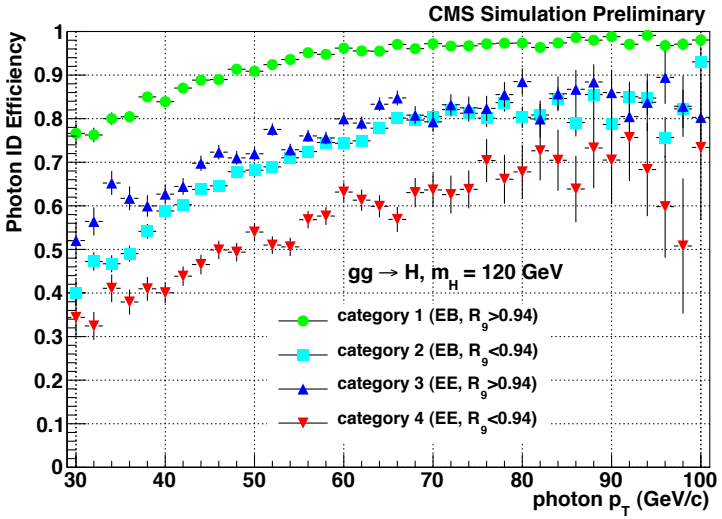
Fraction of Higgs boson vertices found within 10 mm of their true location

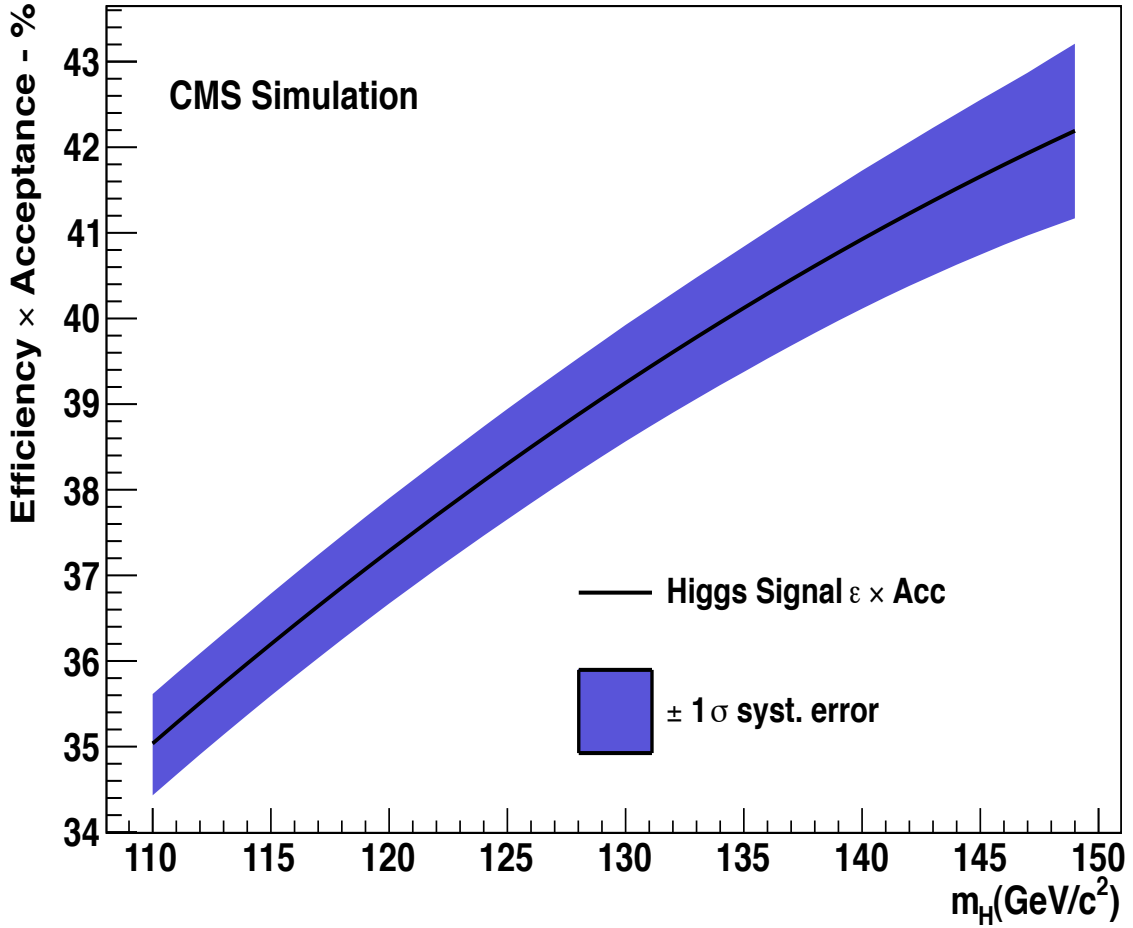


Vertex:

BDT Trained using input variables computed from track momenta (tracks recoiling against the γγ and/or converted γ's) and photon kinematics

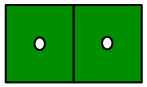
Efficiencies

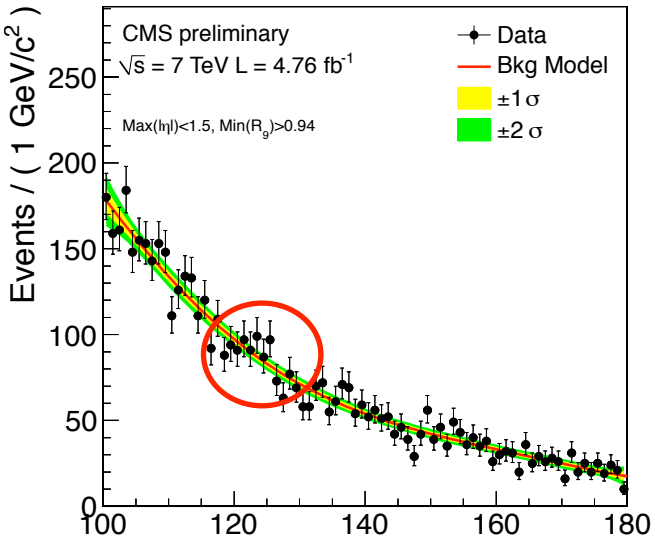


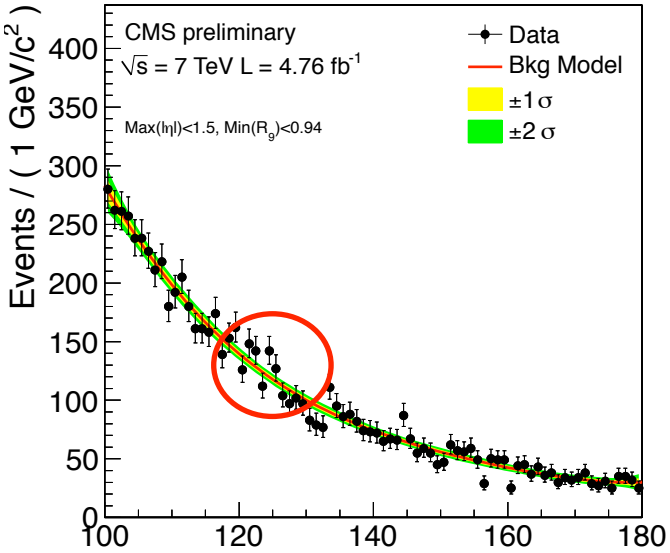


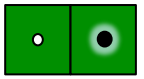
H → γγ

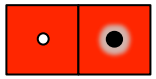
Mass Spectra

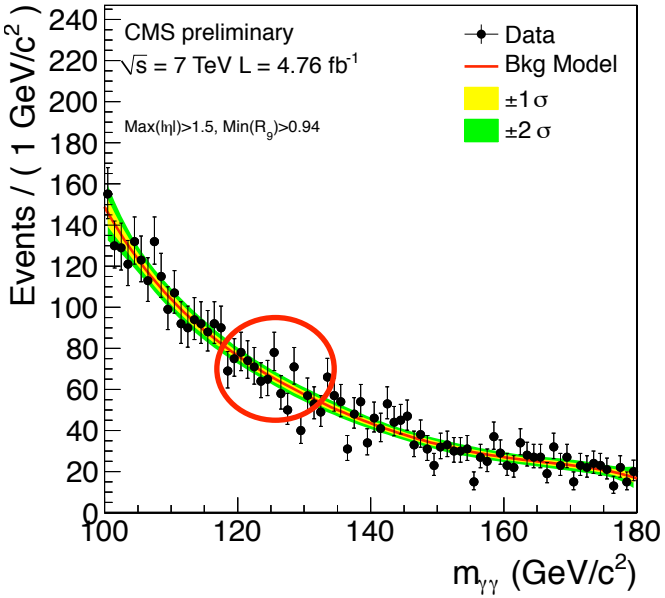


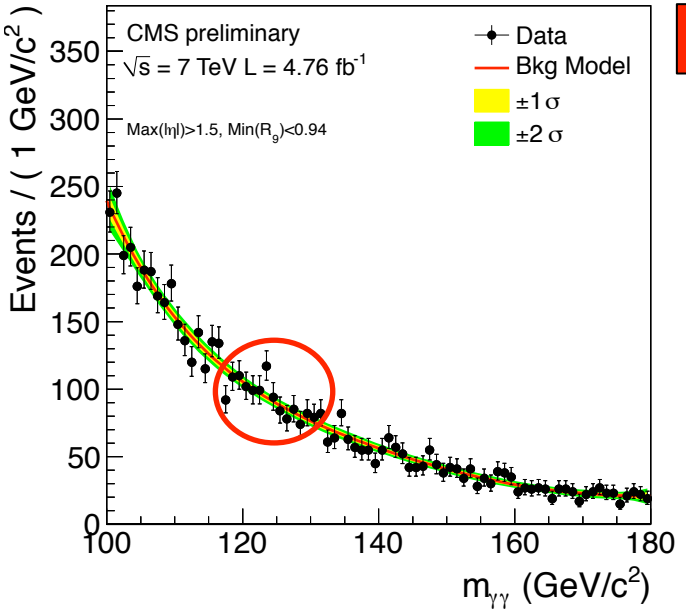


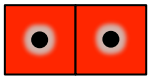




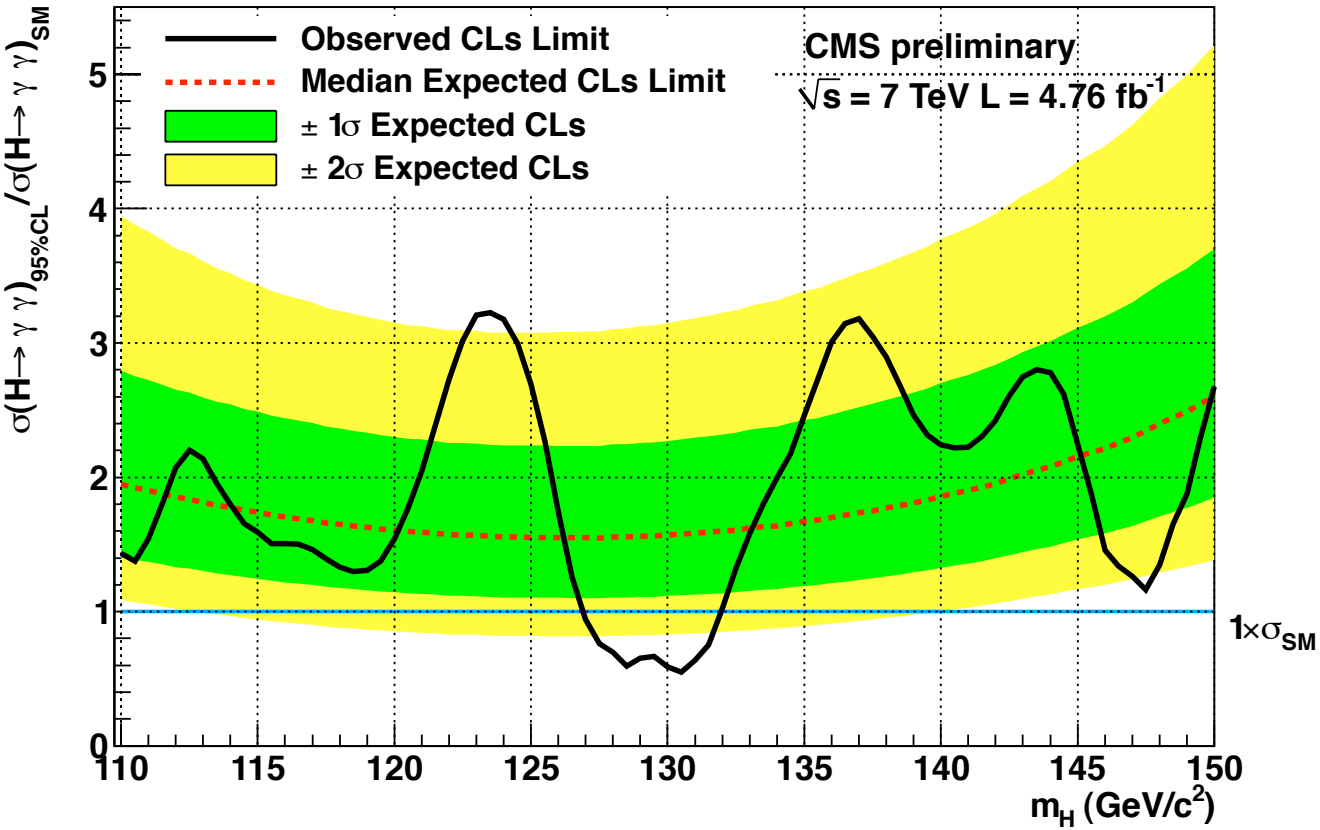








Exclusion Limits



Largest upward fluctuation at 123.5 GeV/c^2

HIG-11-029

$H \rightarrow \tau\tau$

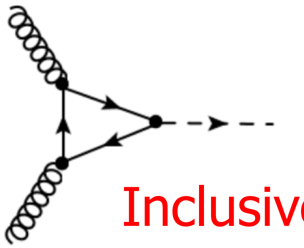
$H \rightarrow \tau\tau$

Signature:

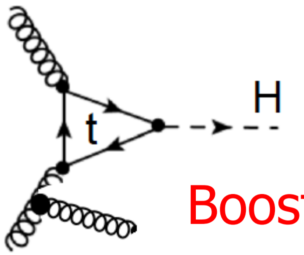
Broad excess in $m_{\tau\tau}$ distribution in the $e\mu$, $e\tau_h$ and $\mu\tau_h$ final states

Three categories with different S/B and B composition:
0 high E_T jet, 1 high E_T jet or 2 jets optimized for VBF

Total: 9 exclusive final states

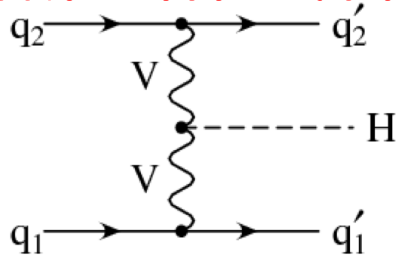


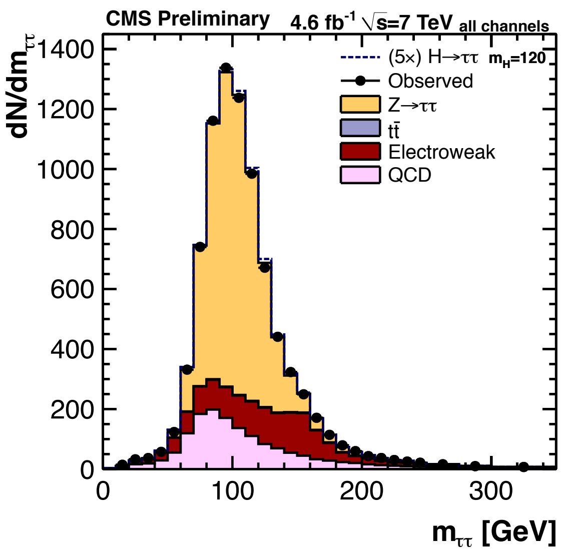
Inclusive

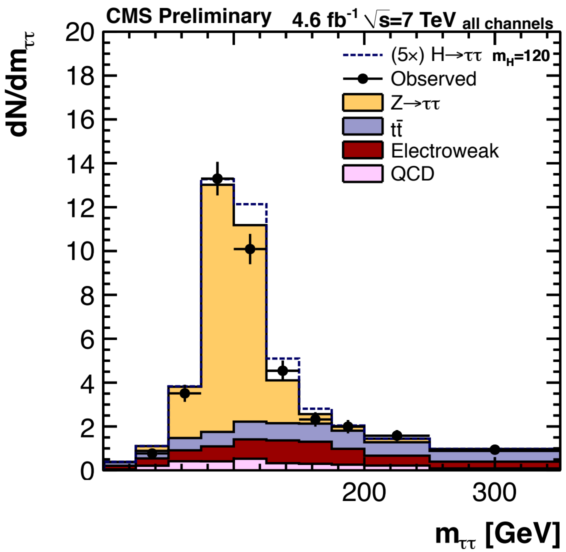


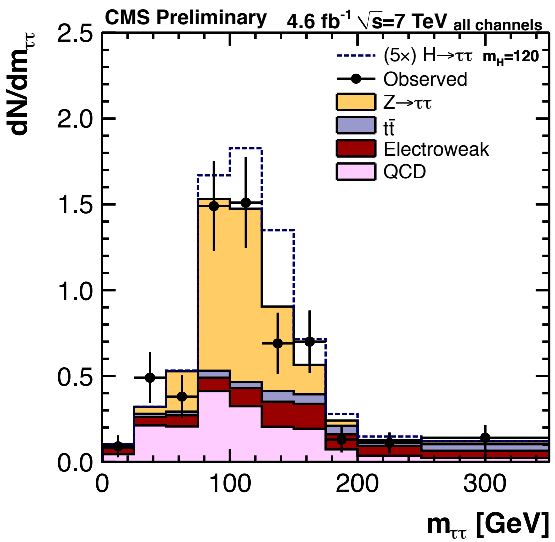
Boosted

Vector Boson Fusion

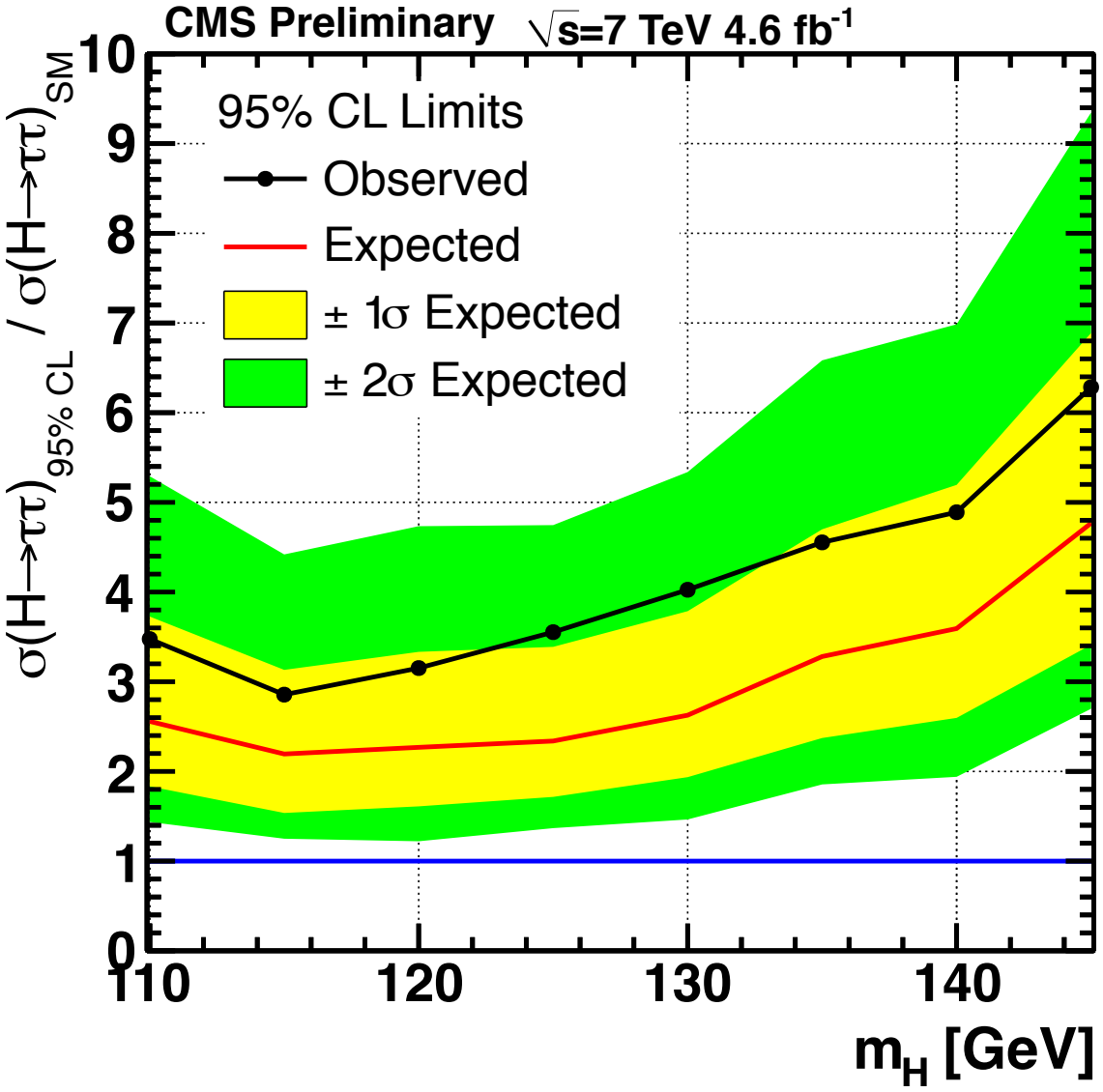




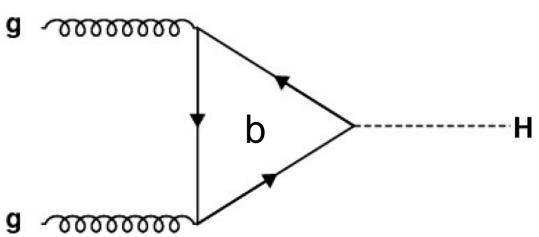




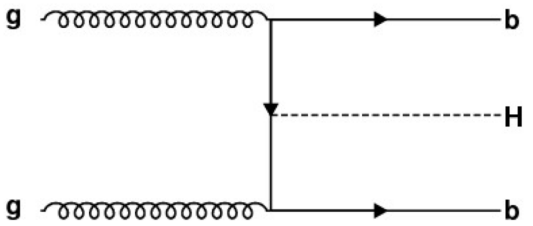
Exclusion Limits



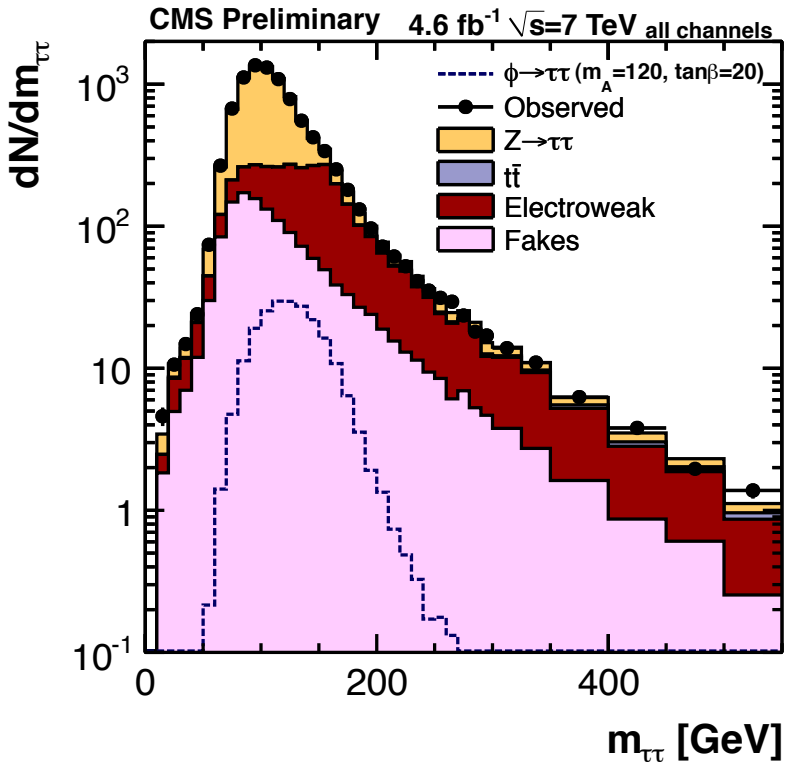
MSSM: $H \rightarrow 2\tau$ Search Modes

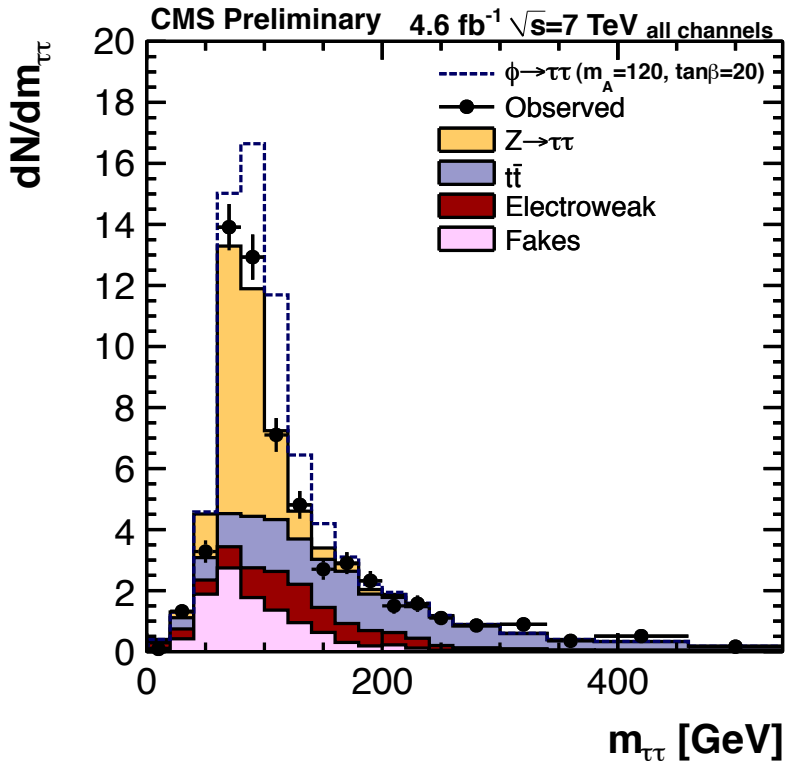


Inclusive

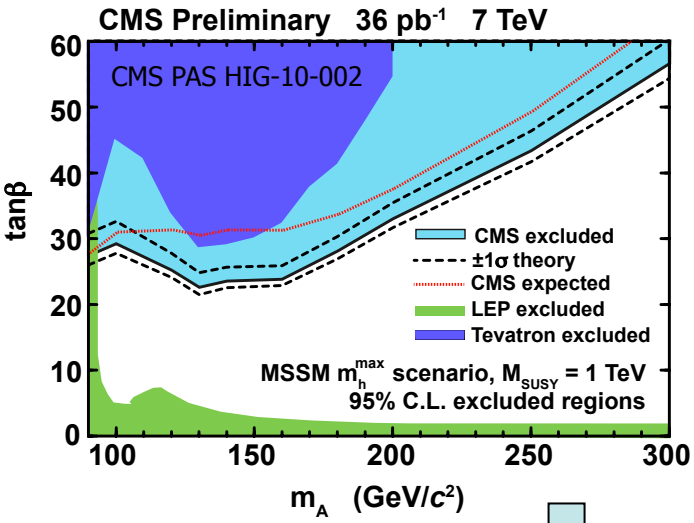


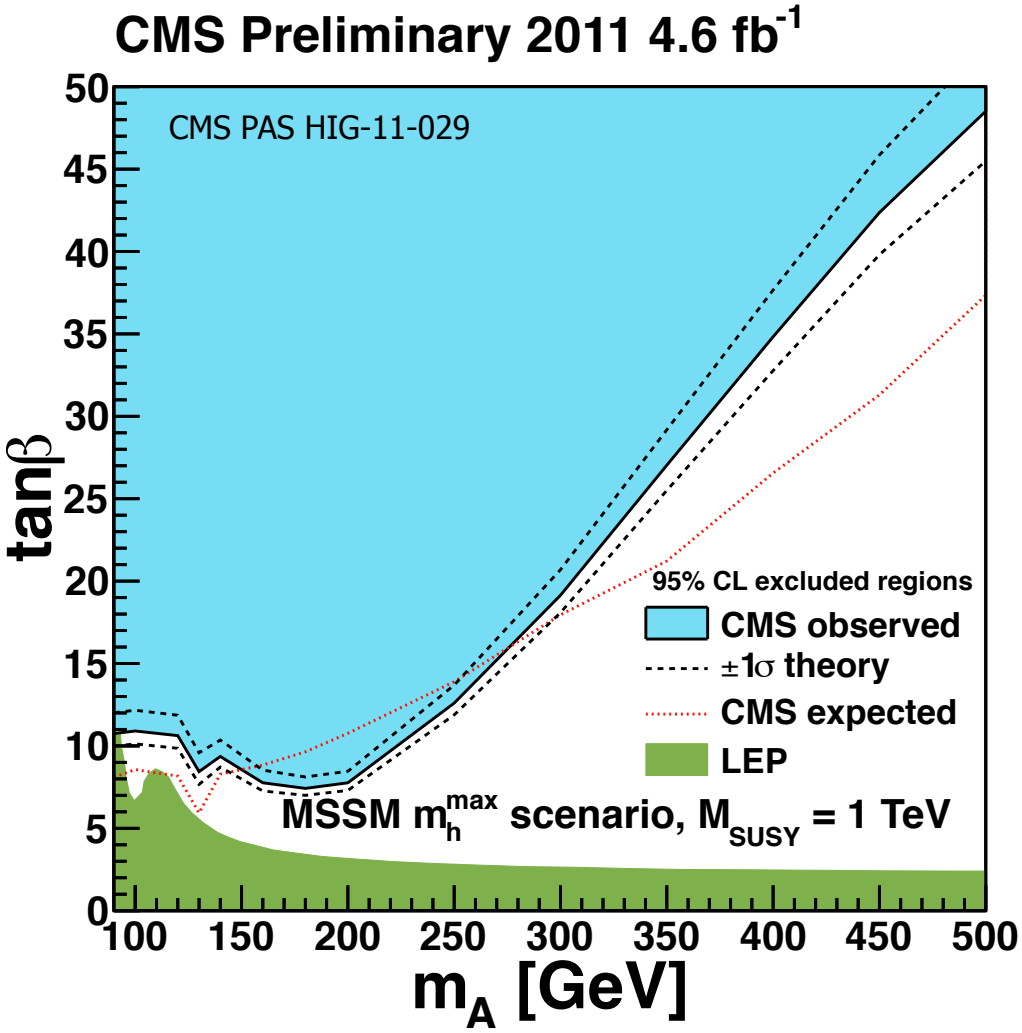
Associated production





MSSM Constraints from H → 2 τ Decay





HIG-11-031

$H \rightarrow bb$

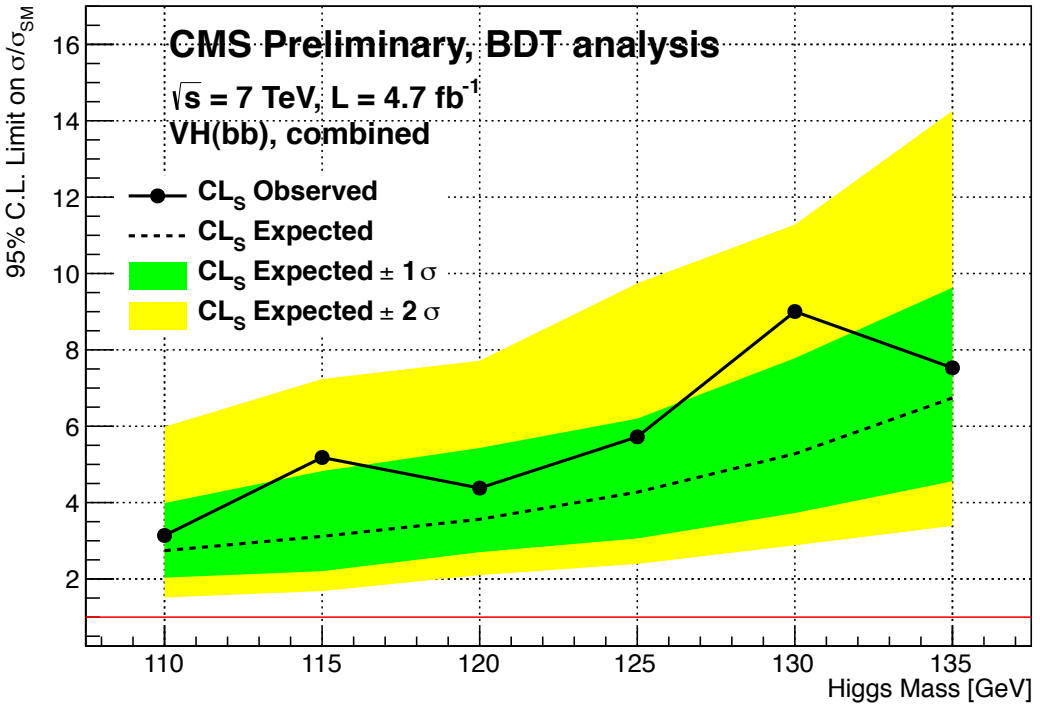
VH; H → bb

Signature:

W+jets or Z+jets with
W → eν, μν and Z → ℓℓ; ℓ = e , μ , ν

Two b tagged jets boosted
in the transverse plane

Total: 5 exclusive final states



Combination and Interpretation


Combination
WORD LOCK
S T A T S
H I G G S
C O M B I
L A S E R

SM Higgs Search: CMS Combination

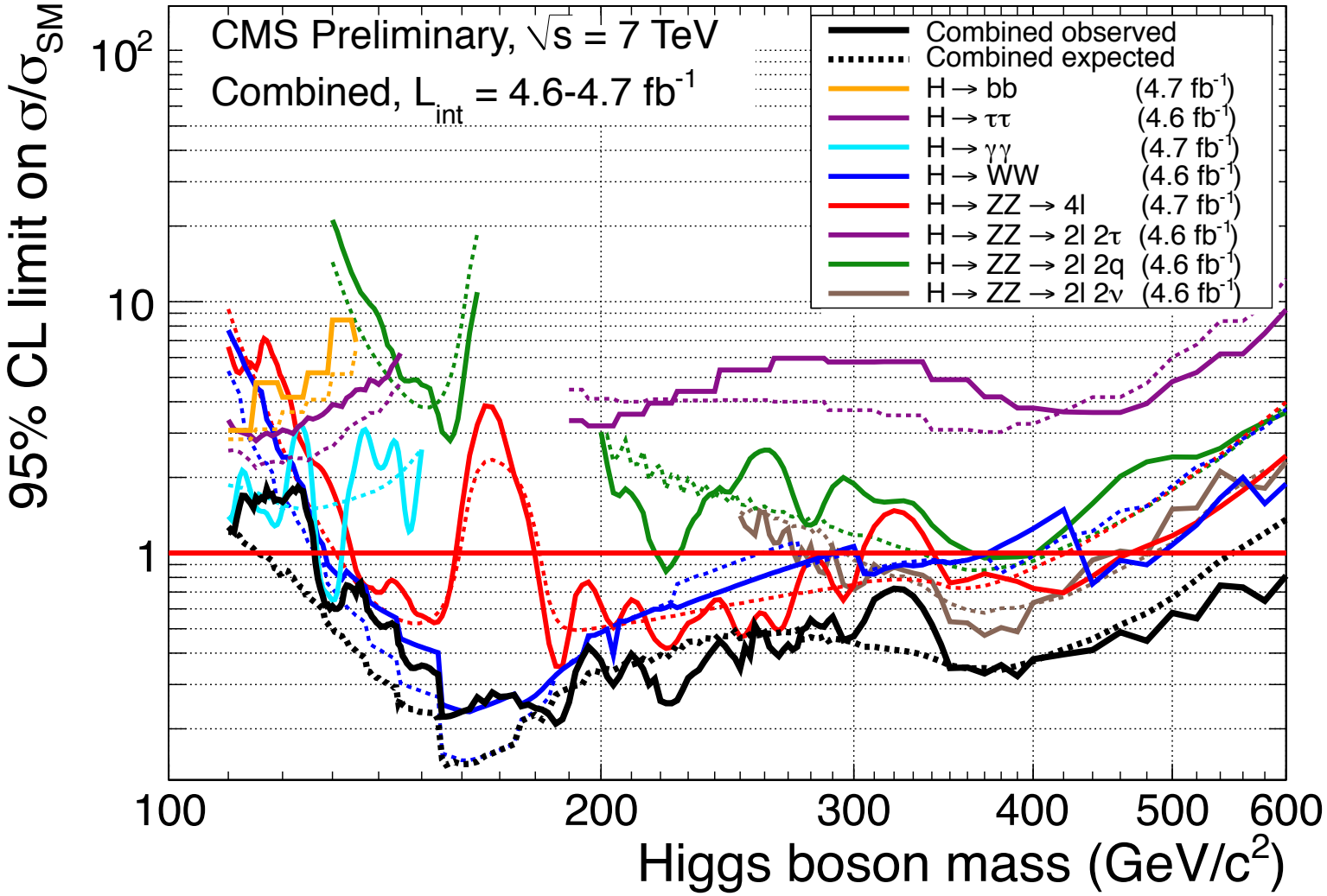
Channel	m_H range (GeV/c^2)	Lumi (fb^{-1})	sub-channels	m_H resolution
$H \to \gamma\gamma$	$110 - 150$	4.7	4	1–3%
$H \to \tau\tau$	$110 - 145$	4.6	9	20%
$H \to bb$	$110 - 135$	4.7	5	10%
$H \to WW \to \ell\nu\ell\nu$	$110 - 600$	4.6	5	20%
$H \to ZZ \to 4\ell$	$110 - 600$	4.7	3	1–2%
$H \to ZZ \to 2\ell 2\tau$	$190 - 600$	4.7	8	10–15%
$H \to ZZ \to 2\ell 2\nu$	$250 - 600$	4.6	2	7%
$H \to ZZ \to 2\ell 2q$	$\begin{cases} 130 - 164 \\ 200 - 600 \end{cases}$	4.6	6	3%

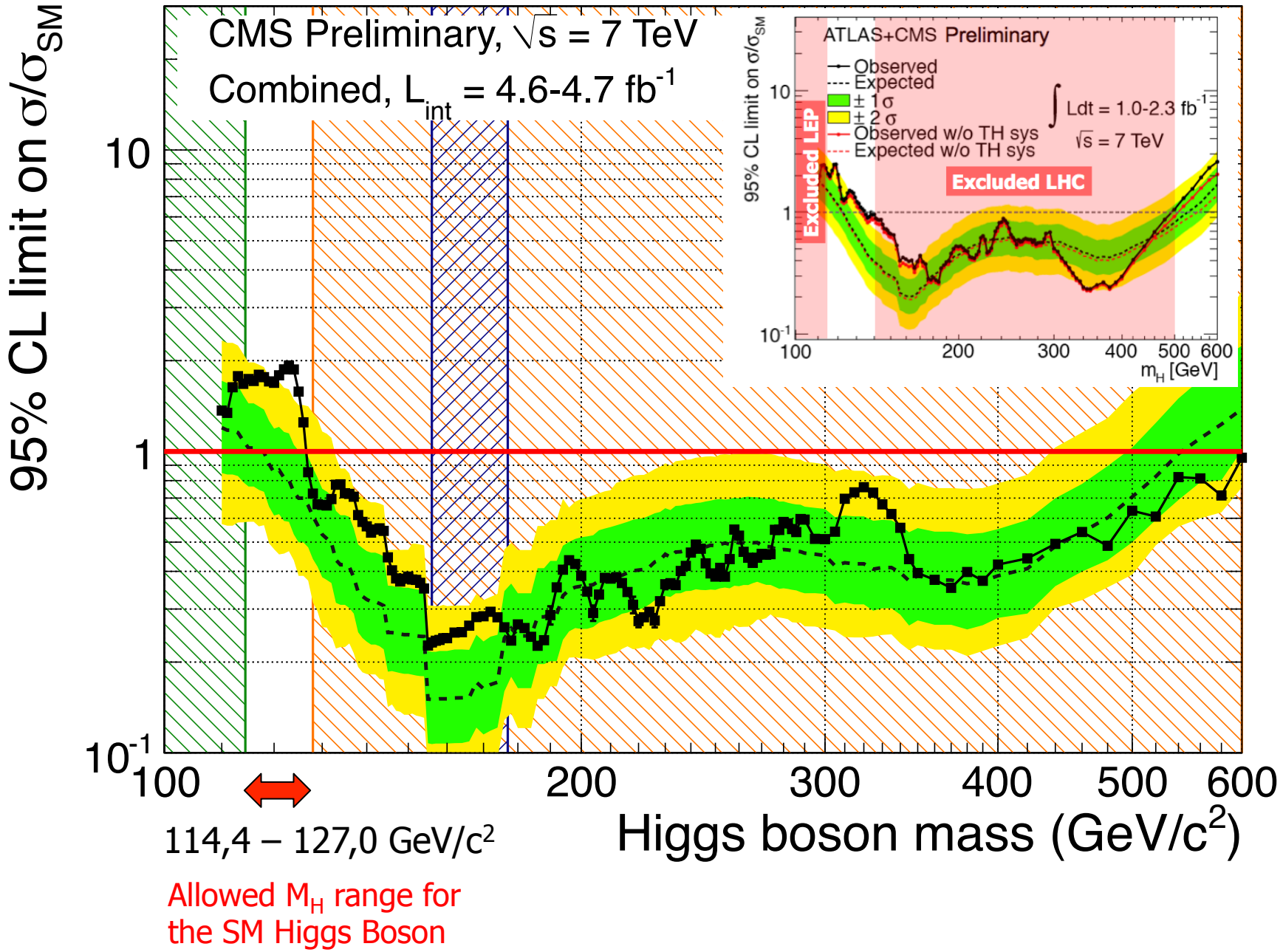
42 exclusive final states
About 200 nuisance parameters

CMS Combination: Uncertainties

group	nuisance	comments
cross section (pdf)	gg	$gg \to H, t\bar{t}H, VQQ, t\bar{t}, tW, tb$ (s-channel), $gg \to VV$
	qqbar	VBF $H, VH, V, VV, \gamma\gamma$
cross section (QCD scales)	ggH	total inclusive $gg \to H$
	ggH1in	inclusive $gg/qg \to H+ \geq 1$ jets
	ggH2in	inclusive $gg/qg \to H+ \geq 2$ jets
	qqH	VBF H
	VH	associate VH
	ttH	$t\bar{t}H$
	VV	WW, WZ, and ZZ up to NLO
	ggVV	$gg \to WW$ and $gg \to ZZ$
Higgs BR	ZZ	Branching ratio BR($H \to ZZ$)
phenomenology	UE & PS	modeling of underlying event (UE) and parton showering (PS)
luminosity	lumi	uncertainties in integrated luminosity
efficiencies	muon	prompt muon efficiency (includes reconstruction, isolation)
	electron	prompt electron efficiency (includes reconstruction, isolation)
	tau	reconstruction efficiency of prompt hadronicly decaying tau
	b-tag	b-tag efficiency for b-jets (anti-correlated with b-jet veto)
p_T scales	muon	prompt muon p_T-scale
	electron	prompt electron p_T-scale
	tau	p_T scale for prompt hadronicly decaying tau
	jets	jet energy scale
p_T resolutions	electron	prompt electron p_T-resolution
fake rates	lepton	determination of fake lepton rates in data
trigger efficiencies	muon	prompt muon efficiency (includes trigger, reconstruction, isolation)
	electron	prompt electron efficiency (includes trigger, reconstruction, isolation)

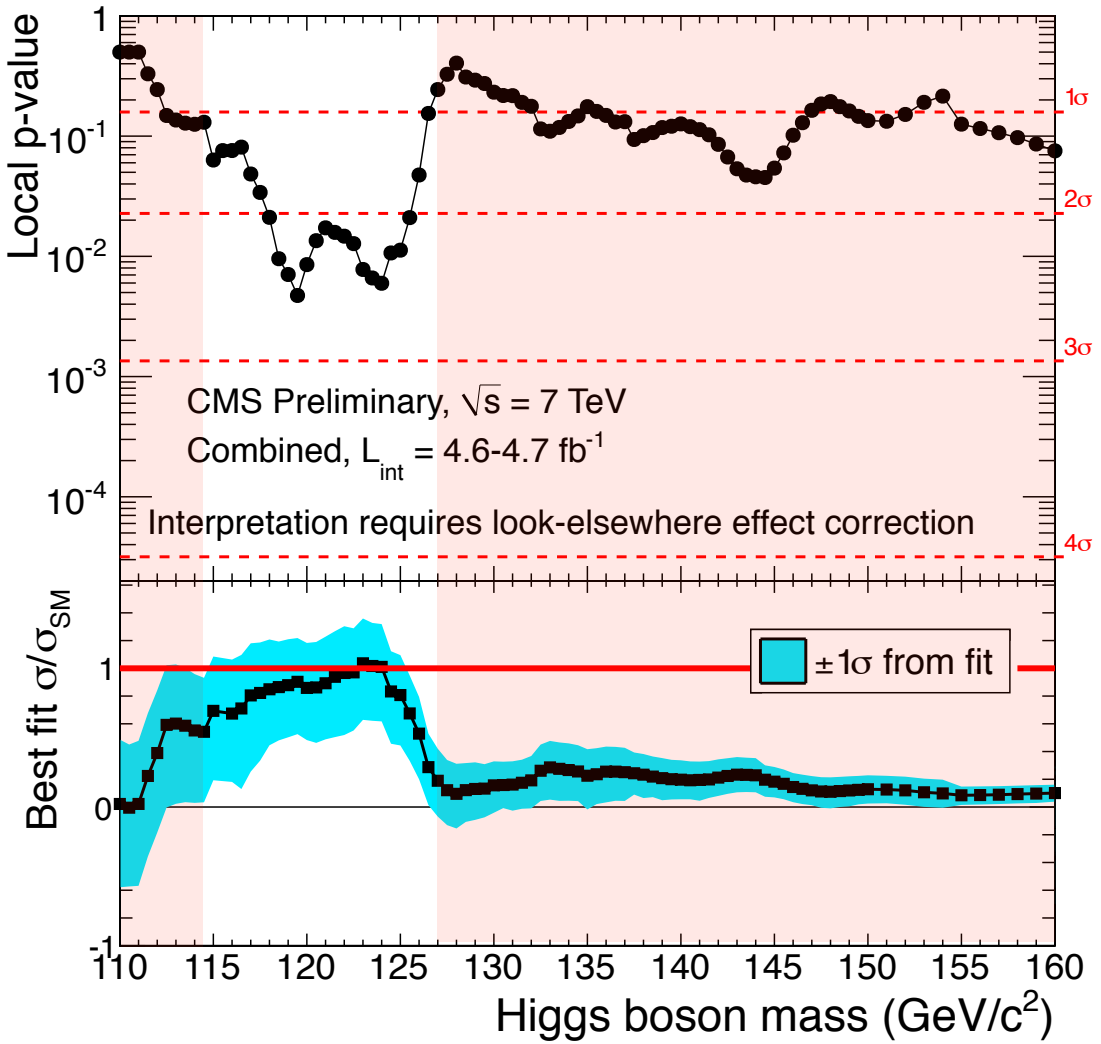
Exclusion Limits: Interplay of Channels





Allowed M_H range for the SM Higgs Boson

Low Mass Excess



Local Significance

P_{min} = 0.005

Z_{max}= 2.6σ

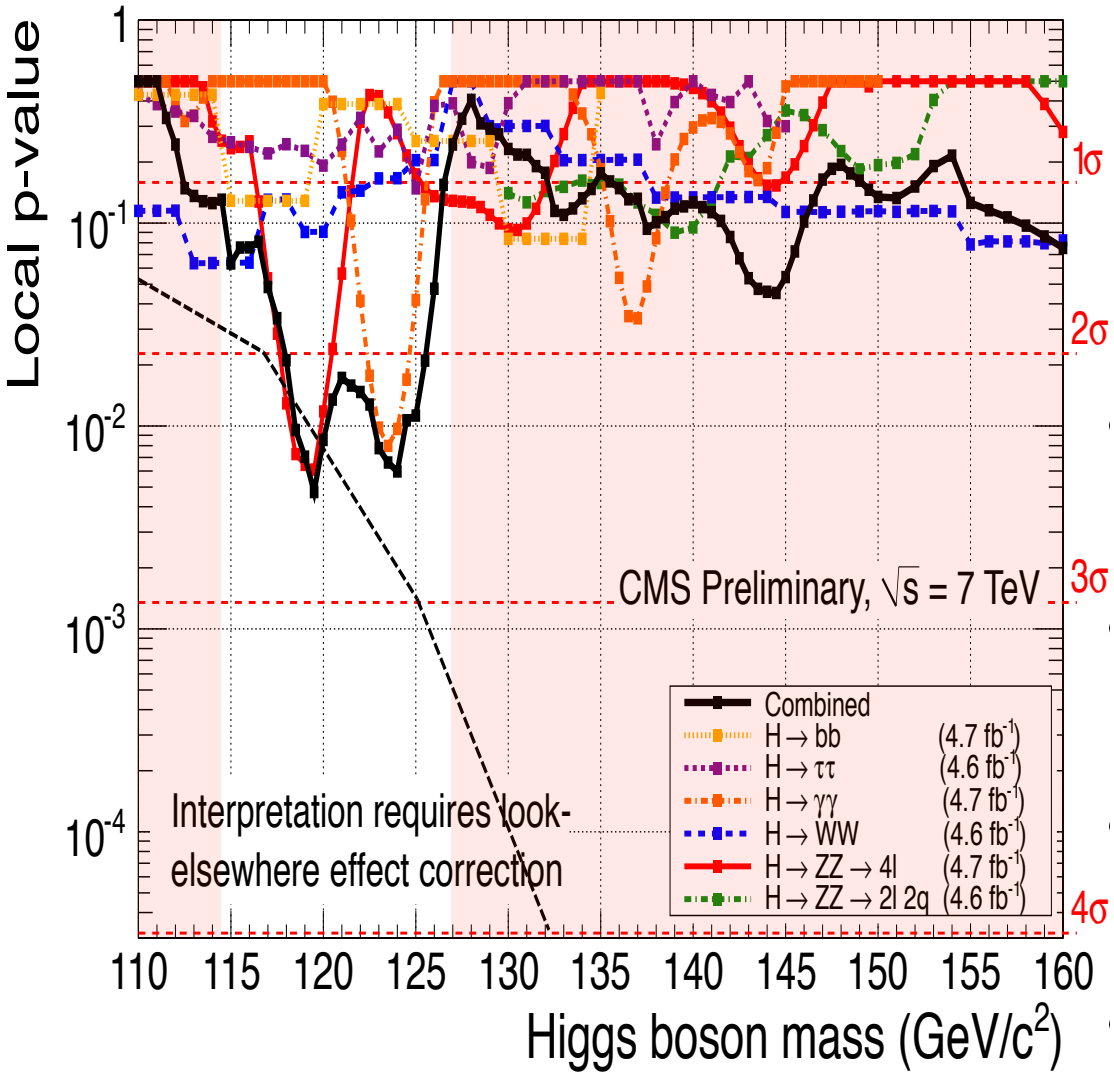
Global Significance
Full range
110-600 GeV/c^2

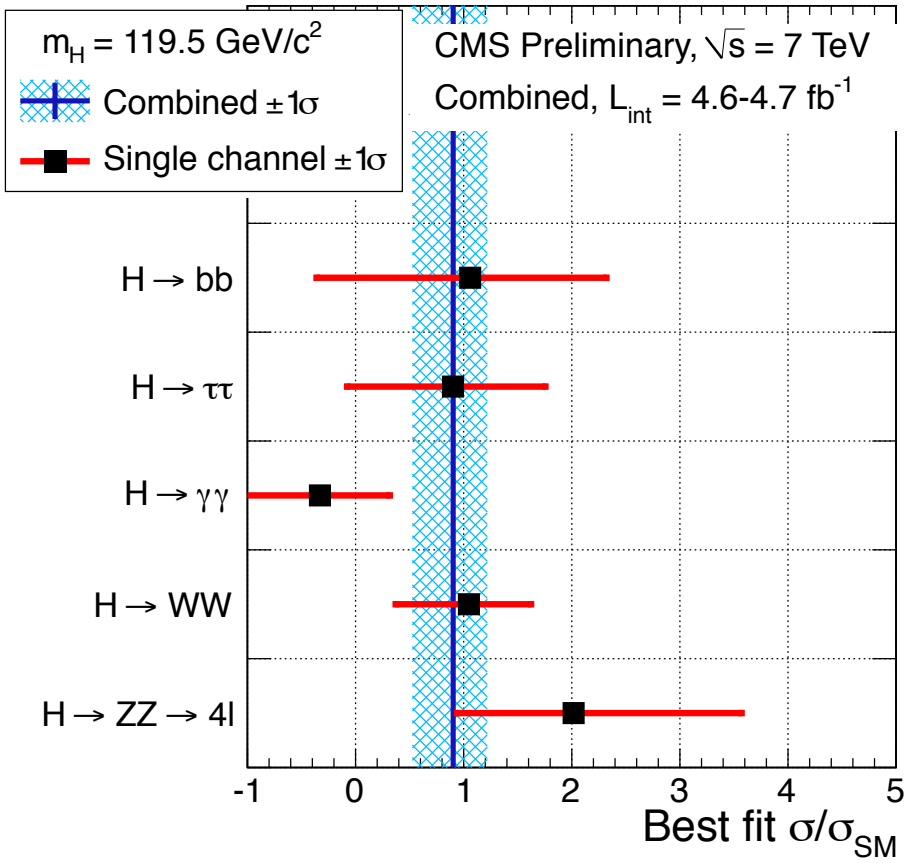
Z_{max}= 0.6σ

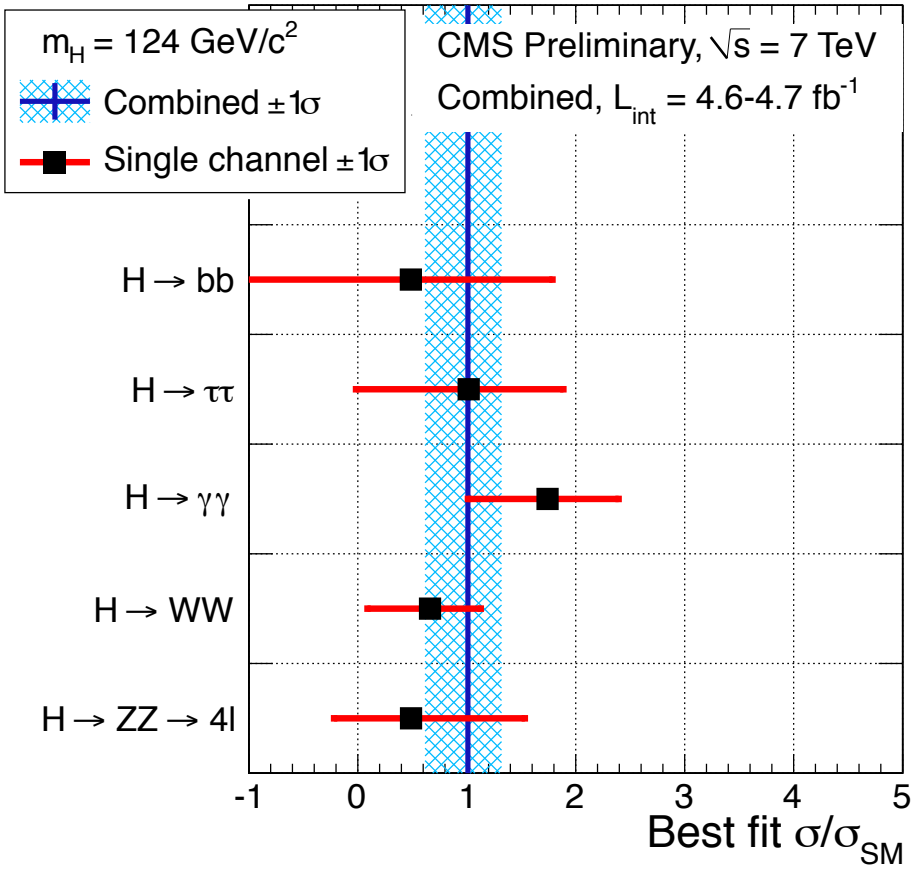
Restricted range
110-145 GeV/c^2

Z_{max}= 1.9σ

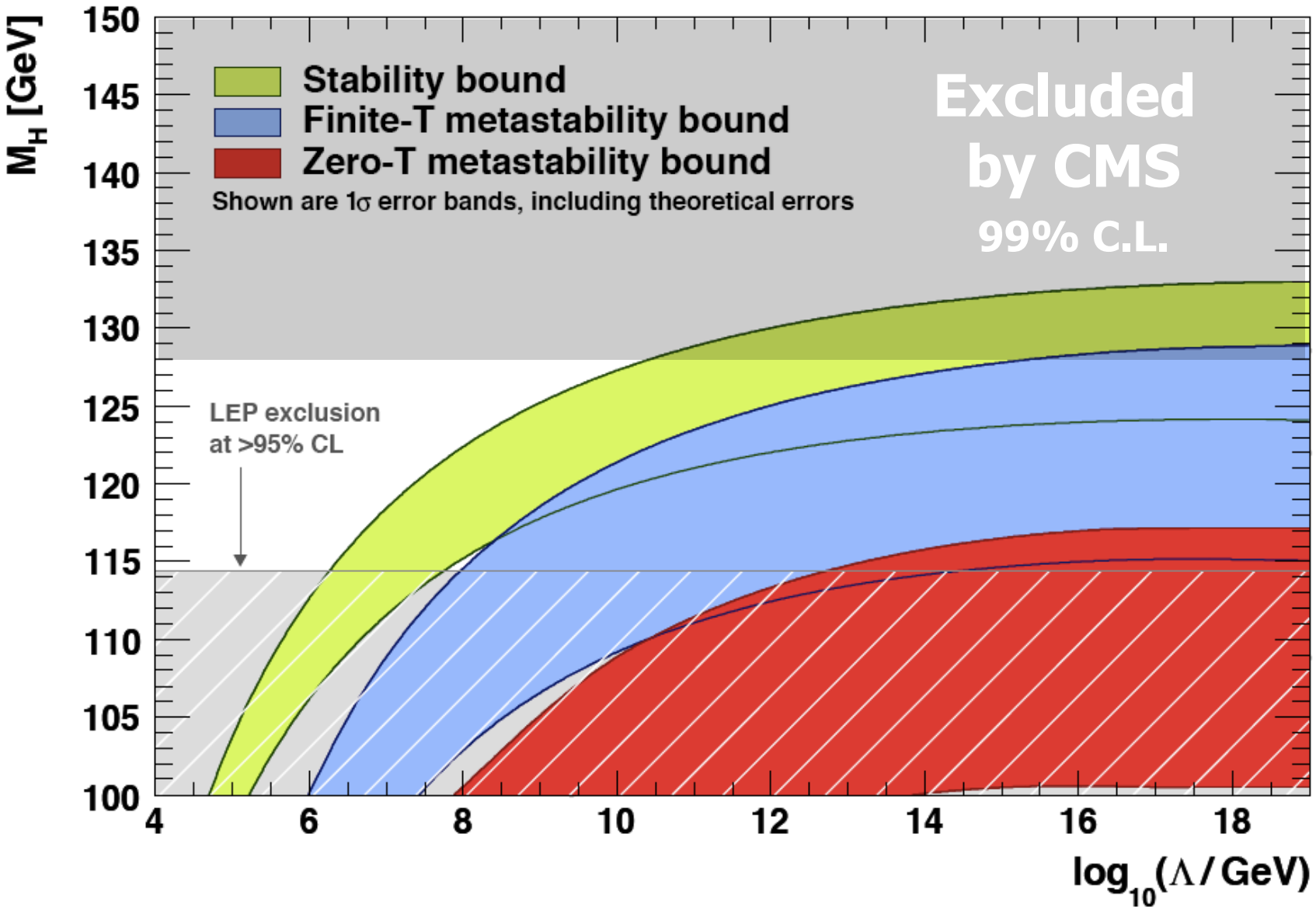
Low Mass Excess



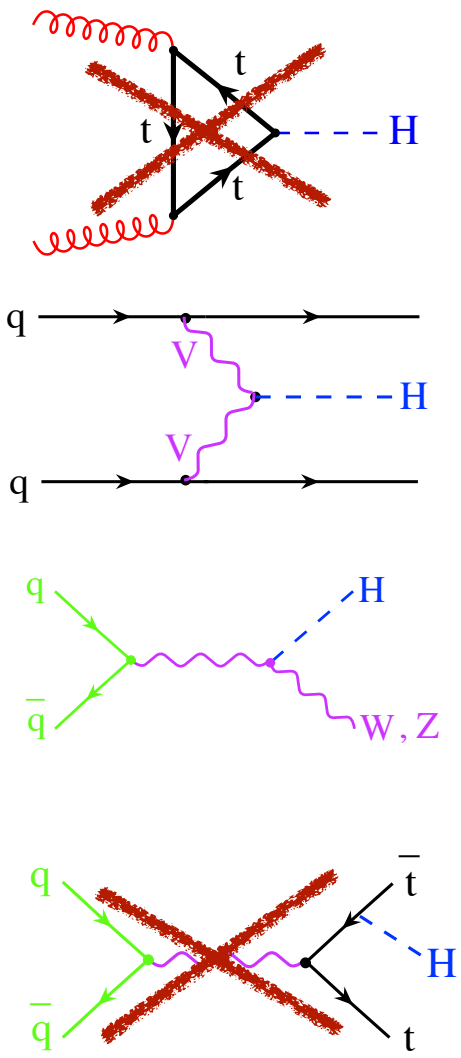

m_H = 119.5 GeV/c^2
Combined ±1σ
Single channel ±1σ
CMS Preliminary, $\sqrt{s}$ = 7 TeV
Combined, L_{int} = 4.6-4.7 fb^{-1}
H → bb
H → ττ
H → γγ
H → WW
H → ZZ → 4l
-1
0
1
2
3
4
5
Best fit σ/σ_{SM}

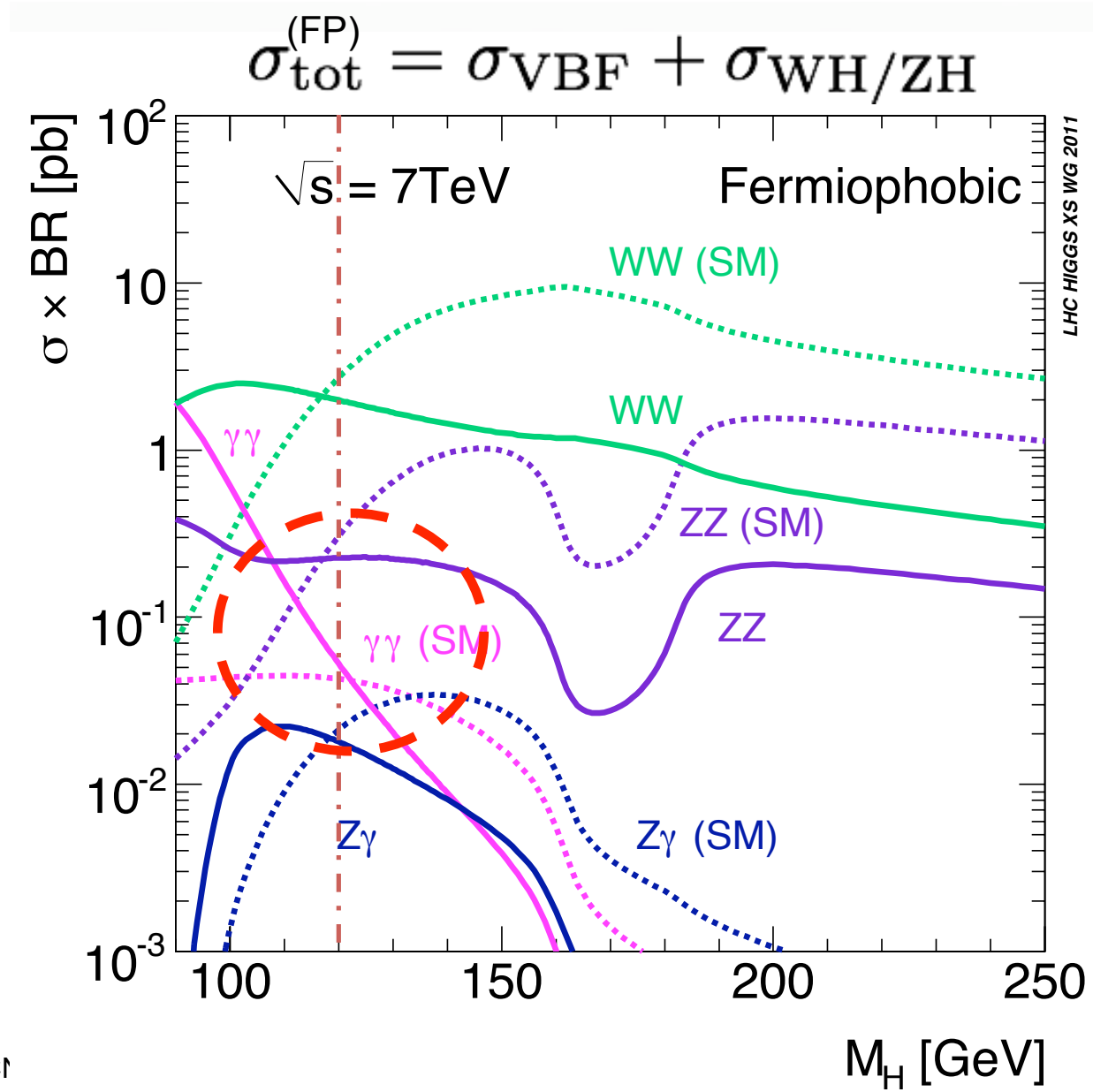

m_H = 124 GeV/c^2
Combined ±1σ
Single channel ±1σ
CMS Preliminary, $\sqrt{s}$ = 7 TeV
Combined, L_{int} = 4.6-4.7 fb^{-1}
H → bb
H → ττ
H → γγ
H → WW
H → ZZ → 4l
-1
0
1
2
3
4
5
Best fit σ/σ_{SM}

Outlook and Conclusions


Stability bound
Finite-T metastability bound
Zero-T metastability bound
Shown are 1σ error bands, including theoretical errors
Excluded by CMS
99% C.L.
LEP exclusion at >95% CL
M_H [GeV]
log10(Λ / GeV)
150
145
140
135
130
125
120
115
110
105
100
4
6
8
10
12
14
16
18

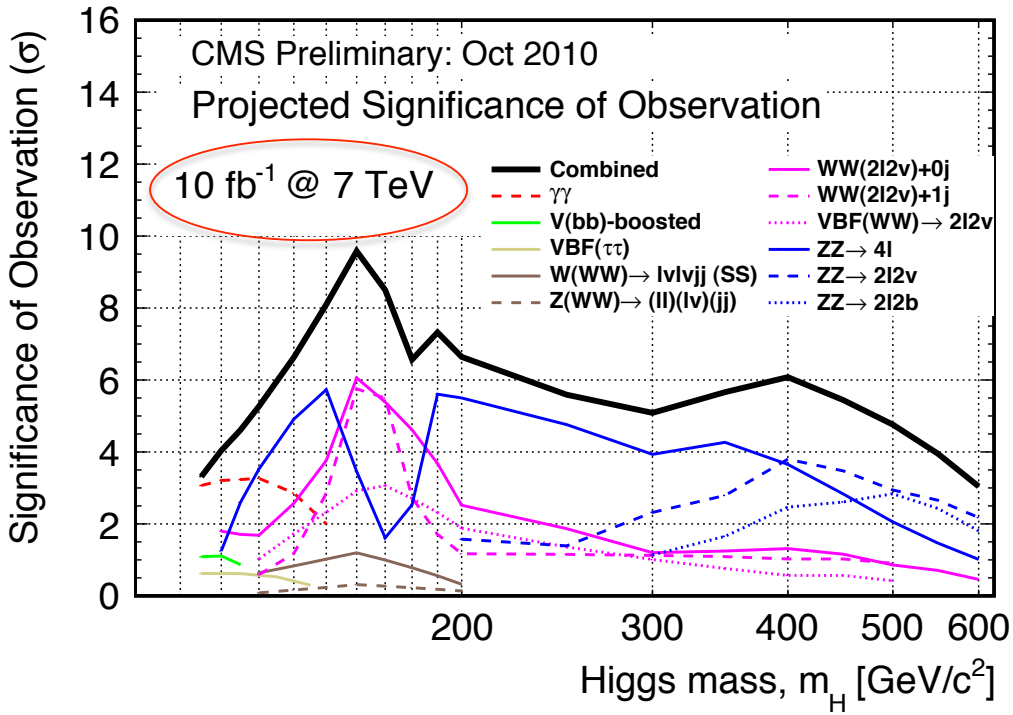
Modèle Standard ou Fermiophobique ?

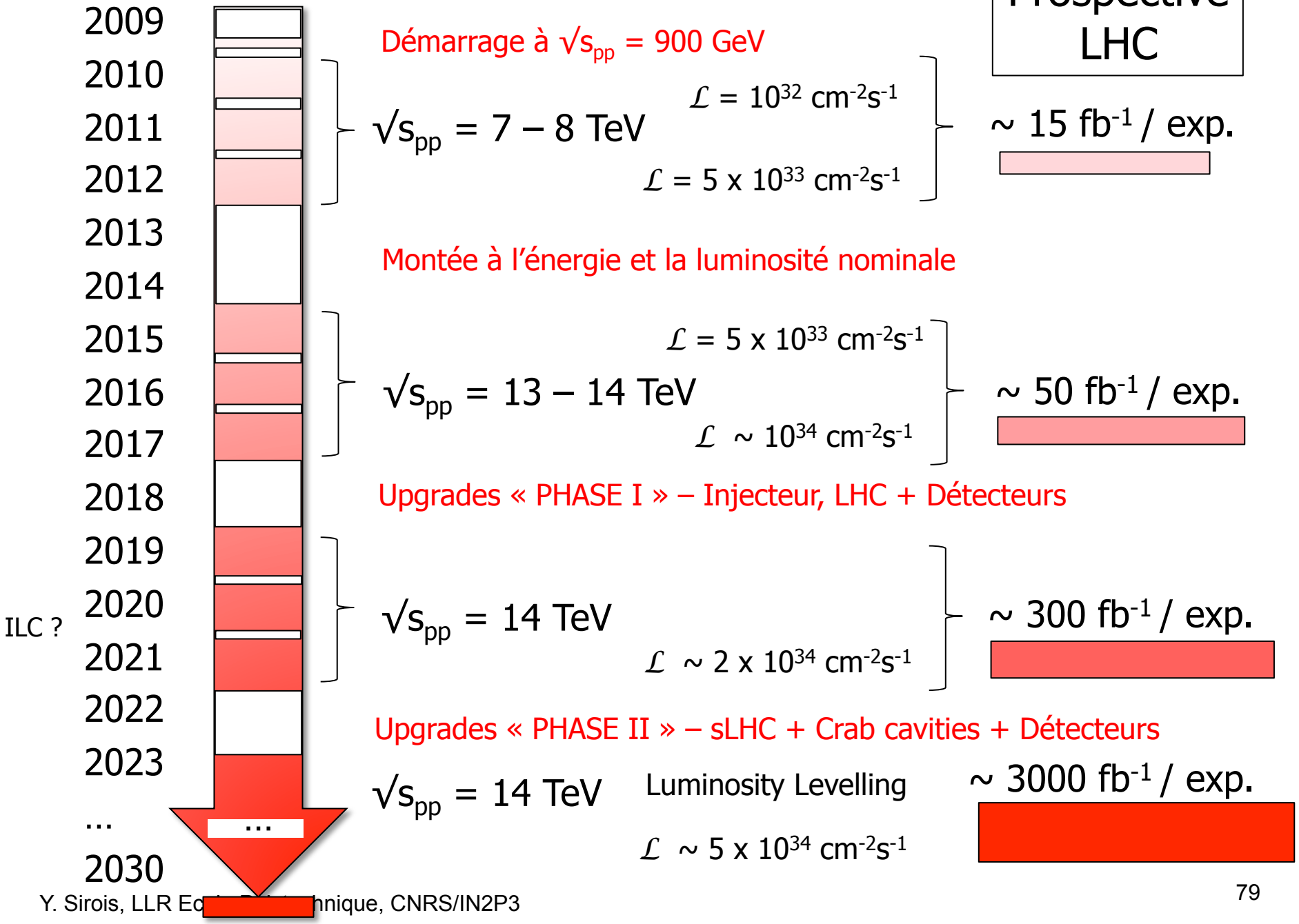


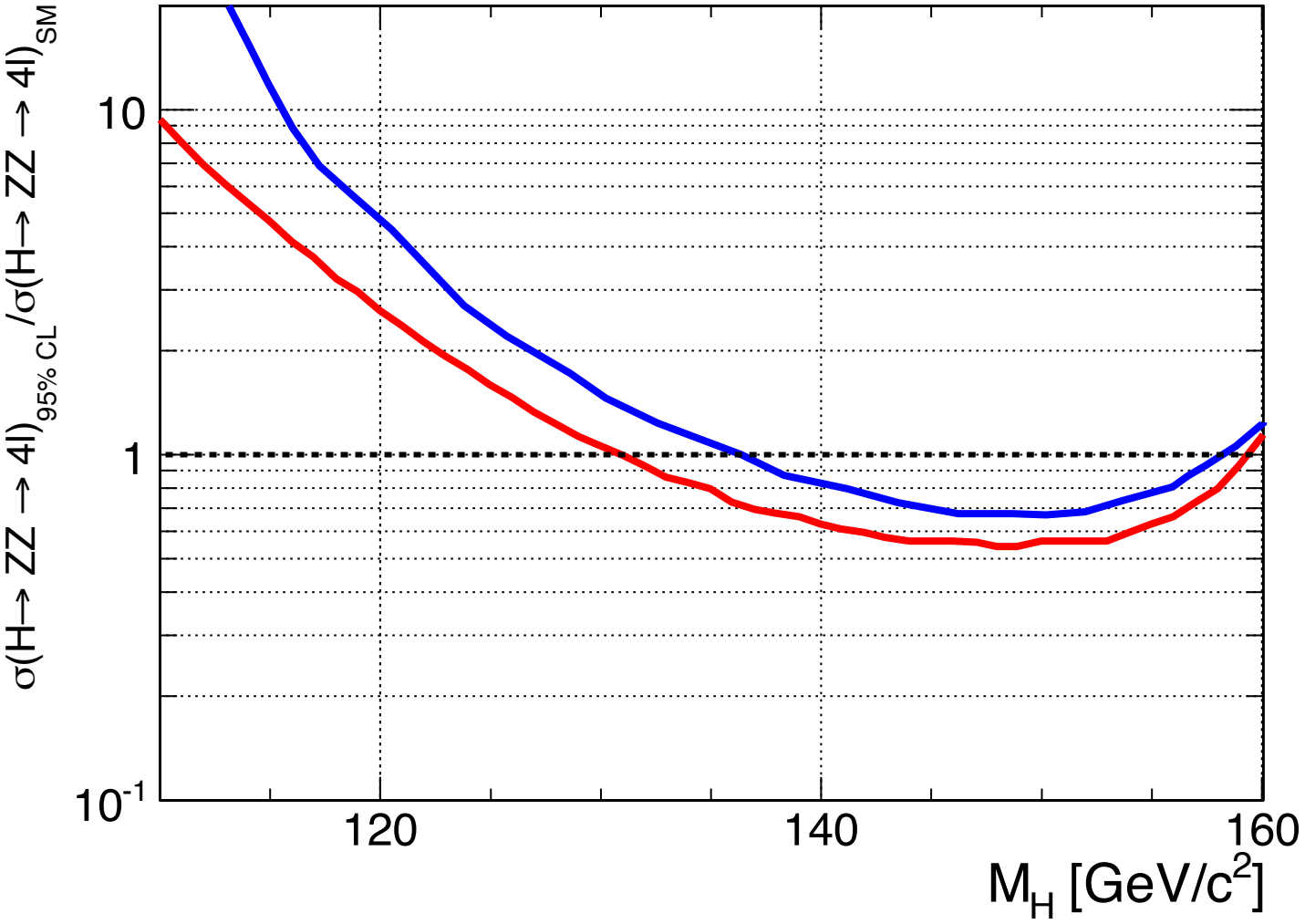


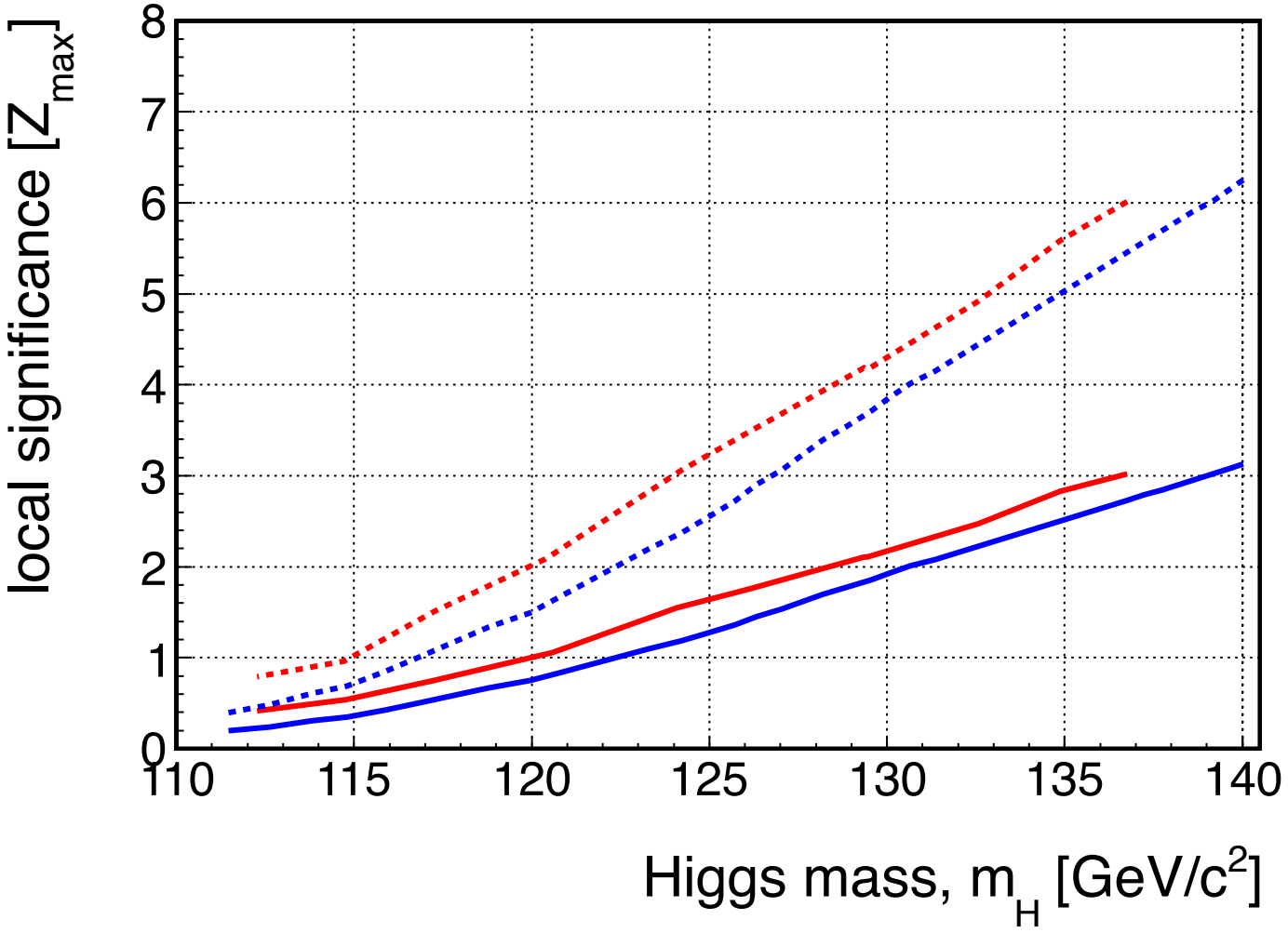
Conclusions

- The 2010-2012 has brought major analysis developments and results in the Higgs sector at the LHC
- Only a very narrow mass range [114.4 – 127 GeV/c^2] remains compatible in CMS with the existence of the SM Higgs boson
- An excess of events is observed, most significant in the 4ℓ and $\gamma\gamma$ channels, in the range 119 – 125 GeV
- 2012 data is very likely to be decisive




Prospective LHC
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
...
2030
ILC ?
Démarrage à √spp = 900 GeV
√spp = 7 – 8 TeV
ℒ = 10^32 cm^-2s^-1
ℒ = 5 x 10^33 cm^-2s^-1
~ 15 fb^-1 / exp.
Montée à l'énergie et la luminosité nominale
√spp = 13 – 14 TeV
ℒ = 5 x 10^33 cm^-2s^-1
ℒ ~ 10^34 cm^-2s^-1
~ 50 fb^-1 / exp.
Upgrades « PHASE I » – Injecteur, LHC + Détecteurs
√spp = 14 TeV
ℒ ~ 2 x 10^34 cm^-2s^-1
~ 300 fb^-1 / exp.
Upgrades « PHASE II » – sLHC + Crab cavities + Détecteurs
√spp = 14 TeV
Luminosity Levelling
ℒ ~ 5 x 10^34 cm^-2s^-1
~ 3000 fb^-1 / exp.


$\sigma(H\to ZZ\to 4l)_{95\%\,CL}/\sigma(H\to ZZ\to 4l)_{SM}$
10
1
10^{-1}
120
140
160
M_H [GeV/c^2]


local significance [Z_{max}]
0
1
2
3
4
5
6
7
8
110
115
120
125
130
135
140
Higgs mass, m_H [GeV/c^2]