First results on Higgs boson searches and prospects from CMS

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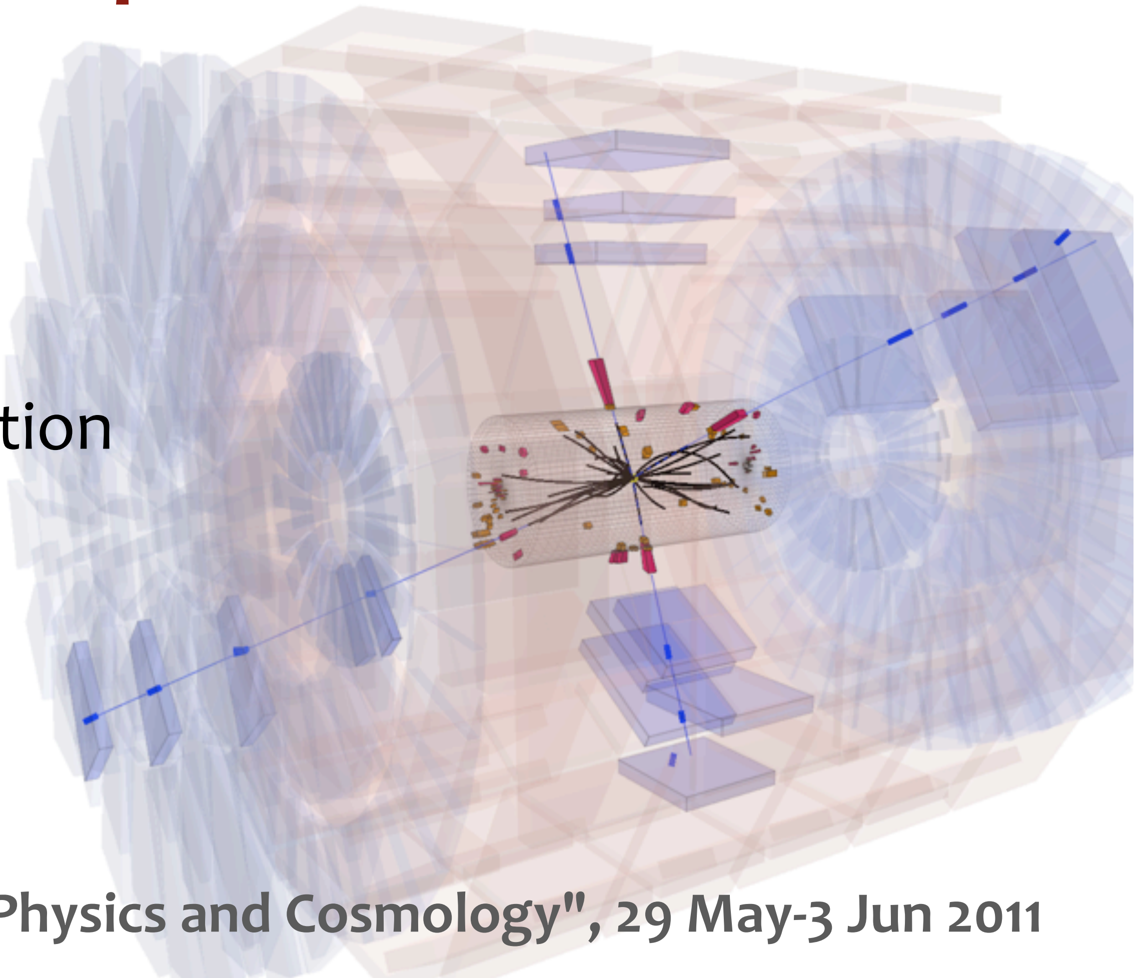
on behalf of the CMS collaboration

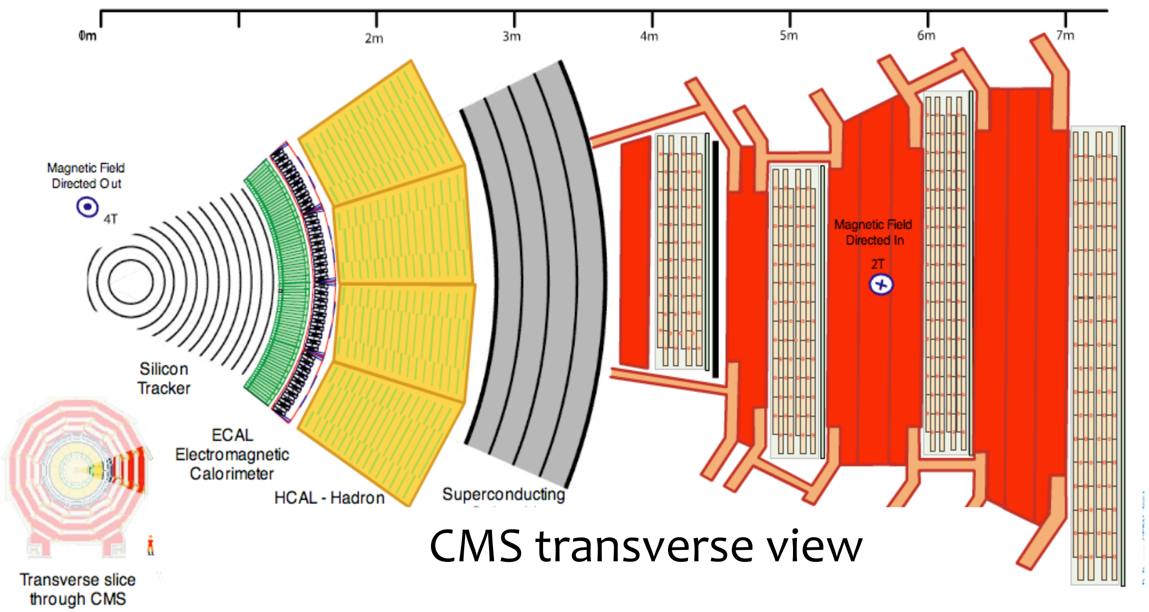


23rd Rencontres de Blois on "Particle Physics and Cosmology", 29 May-3 Jun 2011

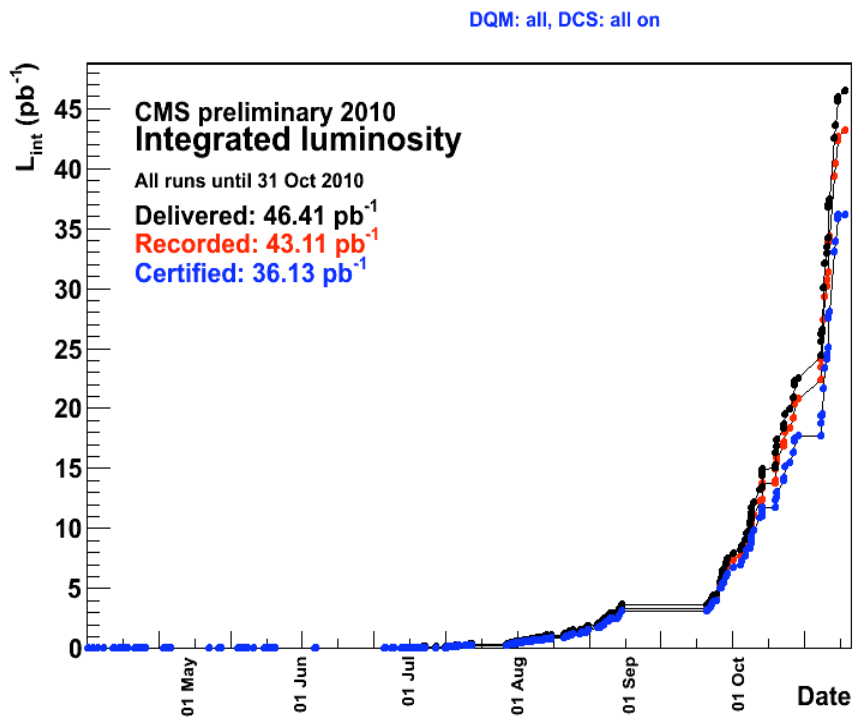
Outline

- CMS' Path to the Higgs
- Hunting the Higgs with the 2010 data
  - status of CMS' searches
- Projections
  - how and when we can discover the SM Higgs or prove it doesn't exist

CMS detector

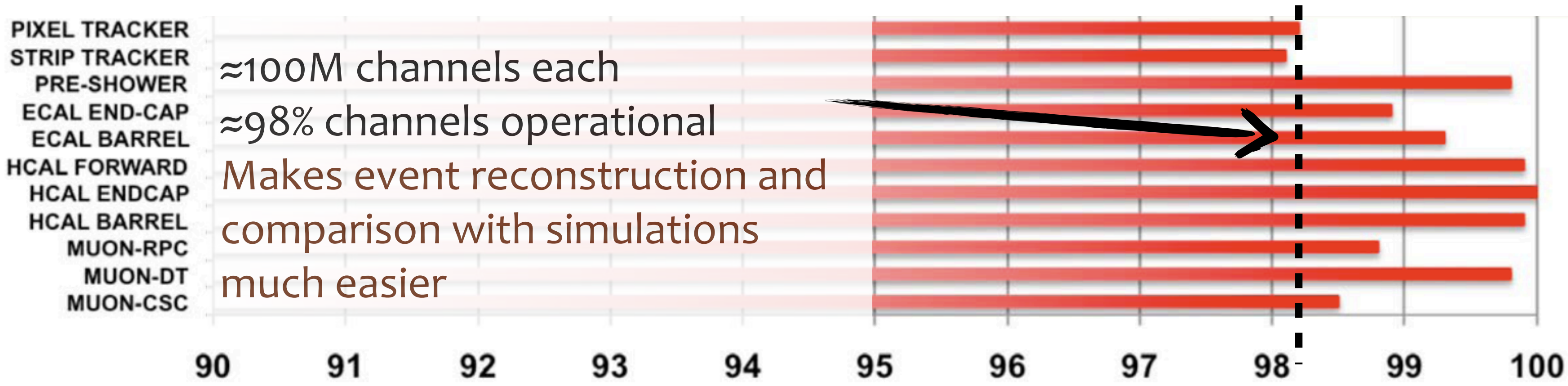


CMS transverse view



Luminosity uncertainty < 4% already!

Good understanding of machine

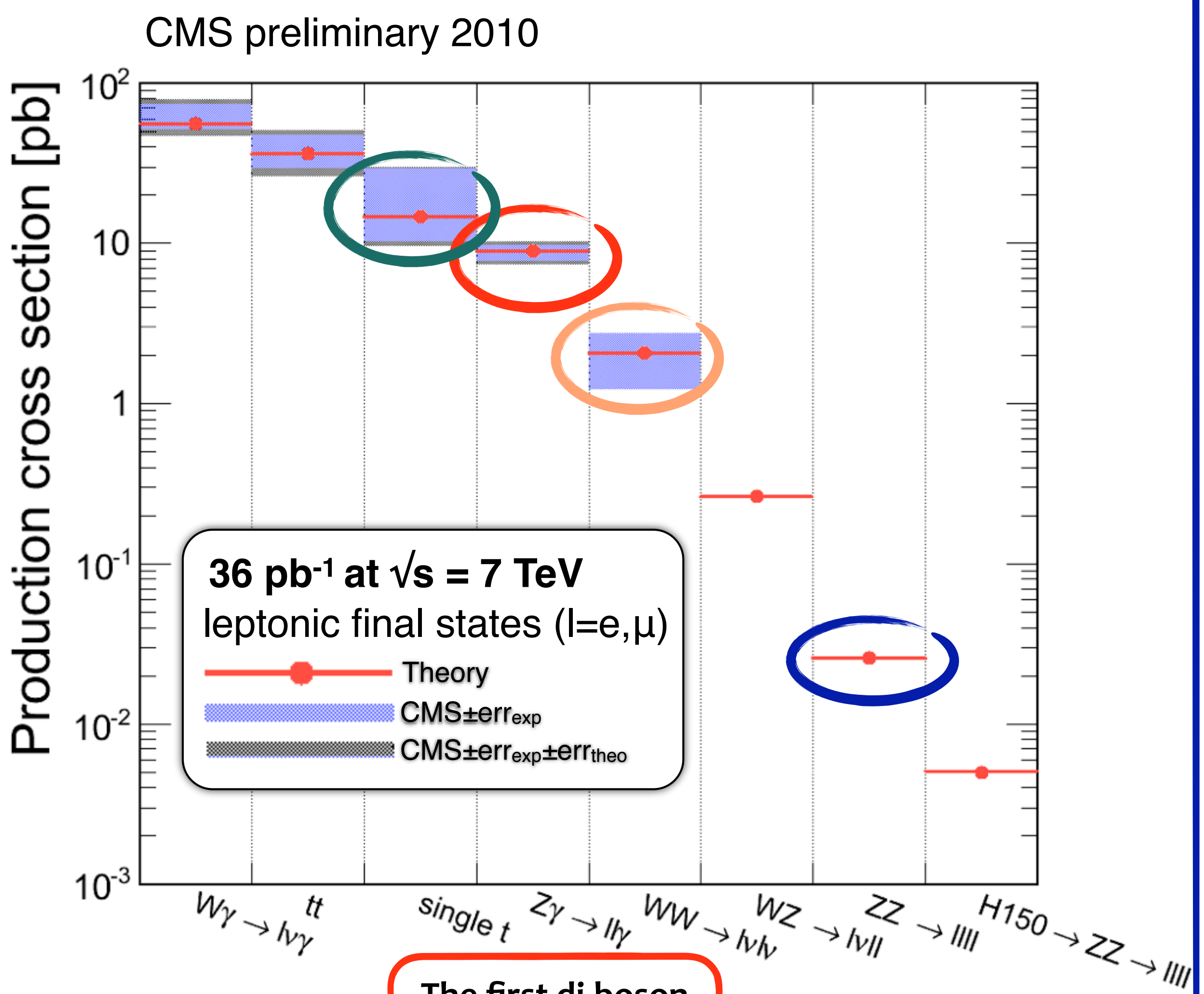


≈100M channels each

≈98% channels operational

Makes event reconstruction and comparison with simulations much easier

CMS' path to the Higgs



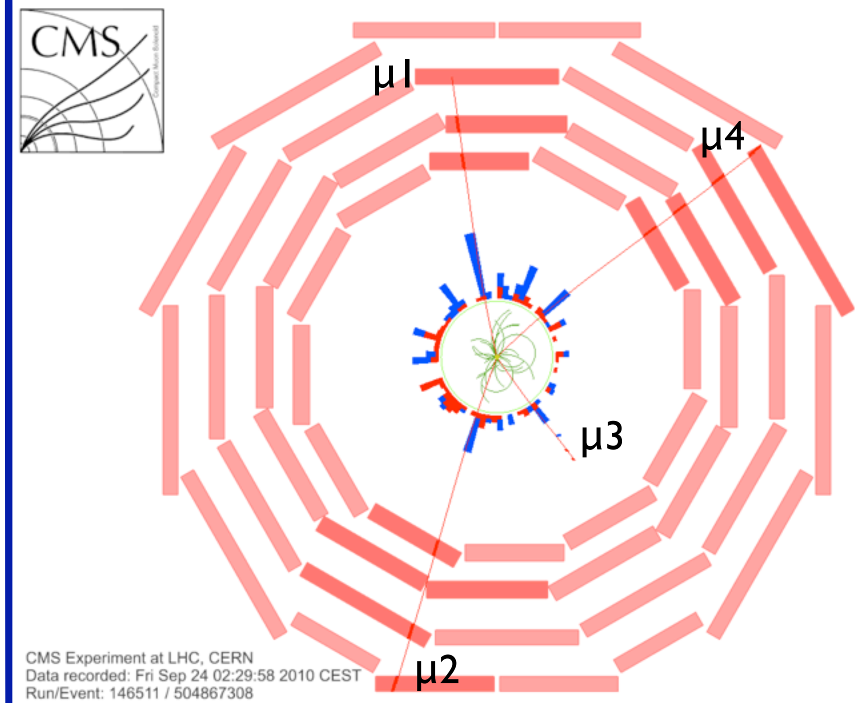
The first di-boson observation

An example of finding tiny signal with leptons, MET, b-tag & jets

The hunt is starting ...

ZZ observation

A beautiful event observed in data (walked in early !)



$P_T^{\mu 1}$ = 48.1GeV/c
$P_T^{\mu 2}$ = 43.4GeV/c
$P_T^{\mu 3}$ = 25.9GeV/c
$P_T^{\mu 4}$ = 19.6GeV/c

$M_{\mu 1 \mu 2}$ = 92.15 GeV/c^2
$M_{\mu 3 \mu 4}$ = 92.15 GeV/c^2
$M_{4\mu}$ = 201 GeV/c^2

Probability of observing a pp$\to$ ZZ $\to$4μ event in **36 pb^{-1}** is ~ 20%

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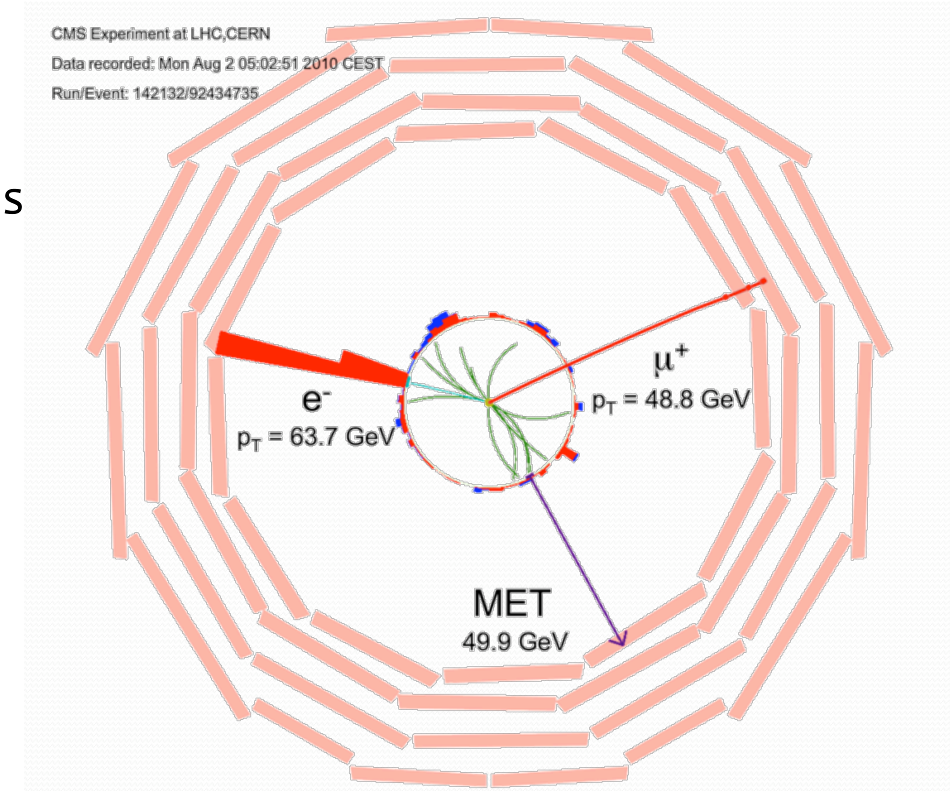
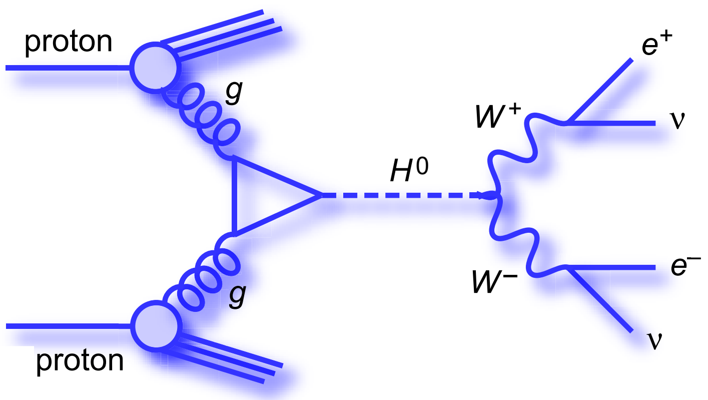
how and when we can discover the SM Higgs
or prove it doesn’t exist

$gg \rightarrow H \rightarrow WW^* \rightarrow l\nu l\nu$



- **The signature**
  - 2 opposite charged- isolated- hight p_t leptons
  - large missing transverse energy
  - no jet activity

- **The backgrounds**
  - real or fake sources of leptons and MET
    W+jets and QCD, DY, tt, tW
  - irreducible WW



- No narrow mass
  peak can be reconstructed
- Count excess
  - cut based analysis
  - multivariate approach

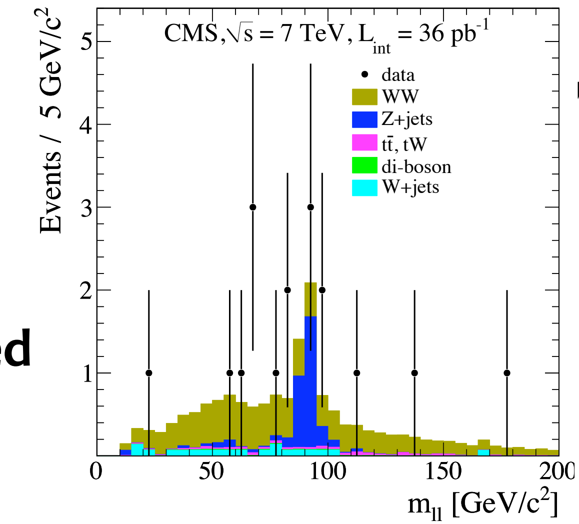
arXiv:1102.5429, accepted by PLB for publication

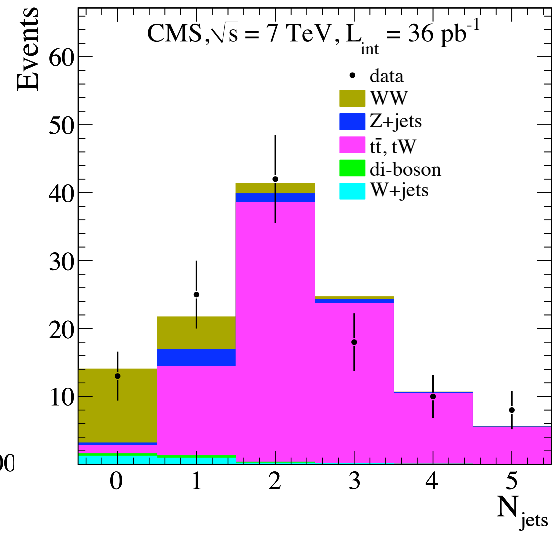
Selection

WW EWK selection

- "projected MET" cut
- and Z-veto and $m_{l^+l^-} > 12$ Gev/c^2
- JetVeto & b-jet tag
- additional lepton veto

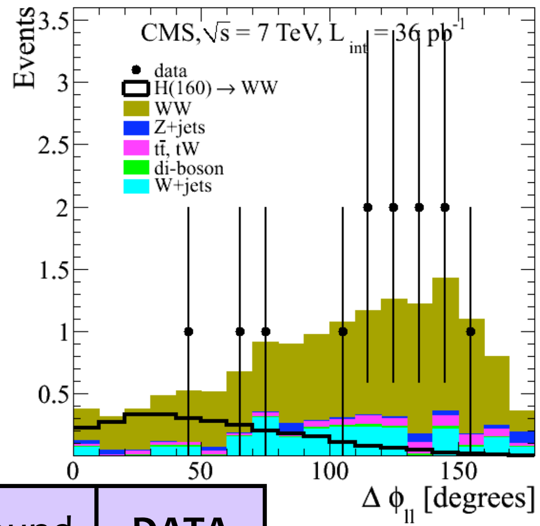
13 evt selected with 36 /pb

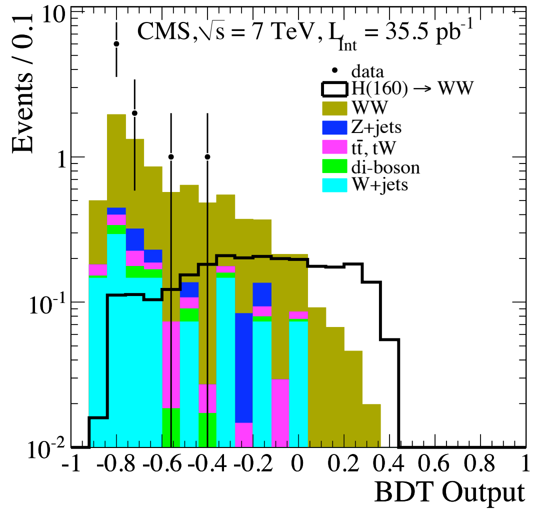




Higgs WW selection

- optimize cuts as a function of m_H
- cut based approach variables:
  - m_{ll}, $p_{T,l}^{max}$, $p_{T,l}^{min}$, $\Delta\varphi_{ll}$
- multivariate approach, BDT





Cut Based final yields

M_H	SM Higgs	4th Gen	Background	**DATA**
130	0.3 ± 0.01	1.73 ± 0.04	1.67 ± 0.10	1
160	1.23± 0.02	10.35 ± 0.16	0.91 ± 0.05	0
200	0.47 ± 0.01	3.94 ± 0.07	1.47 ± 0.09	0

MVA gives ~15% better sensitivity

Background control & Systematics

Bkg control

Reducible bkg

- QCD and W+jets background (fake leptons)

estimated from fake rate on a jet dominated sample

- Top background

estimated from MC due to lack of statistics
(100% uncertainty)
strategy on top-enriched sample for the future

- DY/γ* background

extrapolation from Z peak in signal region

Irreducible WW

- data-driven
  - control region: invert m_{ll} cut
  - extrapolated in the signal region
  - ~50% uncertainty with $L=36pb^{-1}$

Signal Efficiency

Source	Relative uncertainty (%)
Luminosity	11
Trigger ε	1,5
Muon ε	0,7
Electron ε	2,4
Momentum scale	1,3
pu	0,5
Jet veto ε	5,5
PDF	3,0

Jet Veto

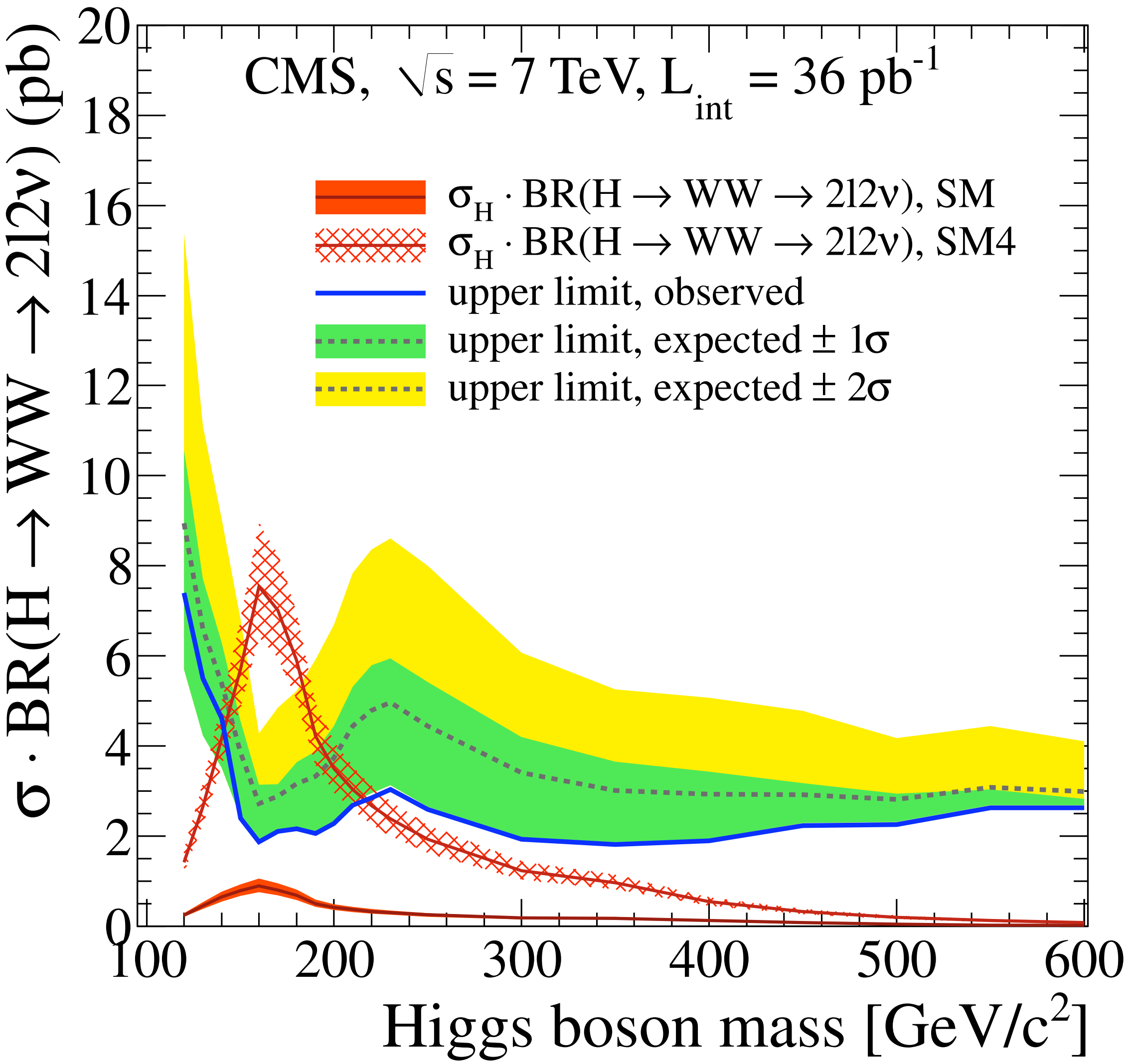
- most delicate ingredient of the analysis
- estimate from data as a ratio:

$$\varepsilon^{data}_{H\to WW} = \varepsilon^{MC}_{H\to WW} \left(\varepsilon^{data}_{Z}/\varepsilon^{MC}_{Z}\right)$$

- $\varepsilon^{MC}_{H\to WW}/\varepsilon^{MC}_{Z}$ mainly affected by the theoretical uncertainty due to higher order corrections
- experimental uncertainties cancel out

- Uncertainty computed compare different generators

Results



- Not yet sensitivity to SM Higgs (× **2.1** @ m_H =160 GeV/c^2)

- In a 4^{th} generation model with infinite quark masses (conservative), Higgs mass excluded in range **[144-207]** GeV/c^2 at 95% C.L.

- Competitive with TeVatron limits (m_H = [131-204] GeV/c^2 with 4.8+5.4 fb^{-1})

stat interpretation: Bayesian interference results from multivariate approach

MSSM $\varphi \to \tau\tau$

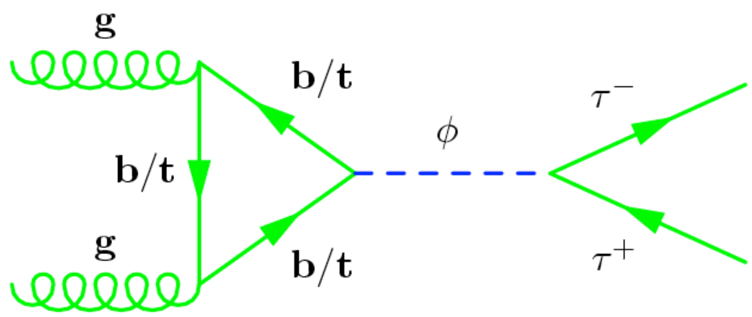
Looking beyond the SM the Higgs sector becomes much richer: MSSM

- 2 doublets of Higgs scalar fields, 5 Physical Higgs Bosons: h, H, A, H^+, H^-
- depending on the regime φ = h, H, A masses are degenerate

  m_φ : sum of (pseudo-scalar + scalar) Higgs of about same mass
- couplings of the neutral φ to down-type quarks and leptons are enhanced at high $\tan\beta$:

  cross section increases and BR($\varphi \to \tau\tau$) enhanced (cleaner signature then bb decay)

Search for $gg \to \varphi(bb) \to \tau\tau$



Three decay channels considered:

$\varphi(bb) \to \tau\tau \to \mu + \tau h$ (τh=hadronic decay)

$\varphi(bb) \to \tau\tau \to e + \tau h$ (τh=hadronic decay)

$\varphi(bb) \to \tau\tau \to e + \mu$

arXiv:1104.1619, accepted by PRL for publication

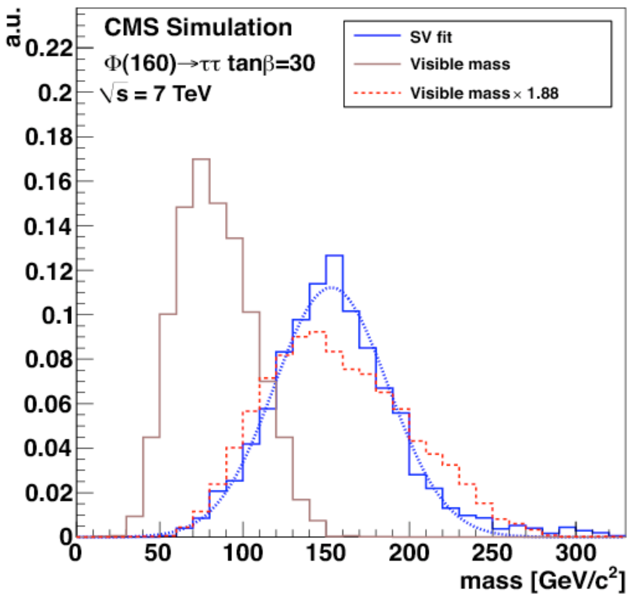
Selection

Selection

- isolated, P_t>15 electrons/muons
- analysis makes use of Particle Flow techniques to identify hadronic taus
  - HPS reconstructs the individual resonances of the τ decays
  - The jet fake rate is 1% while achieving an efficiency of 50%
- cut on the M_T (lepton and E_T^{miss}) + other leptons veto

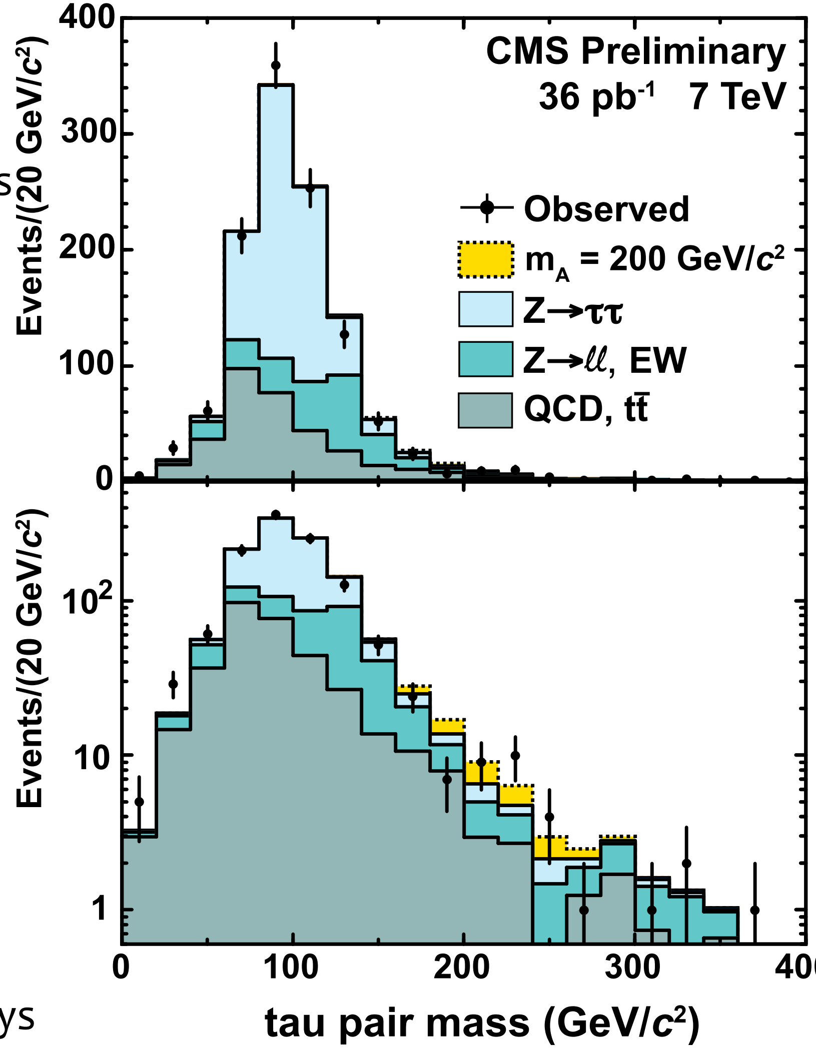
Main bkg: QCD, tt and Z->ll

- control via OS-SS normalization, jet-to-tau fake rate



ττ mass reconstruction

- Likelihood fit of momenta of visible decay products and of neutrinos produced in τ decays

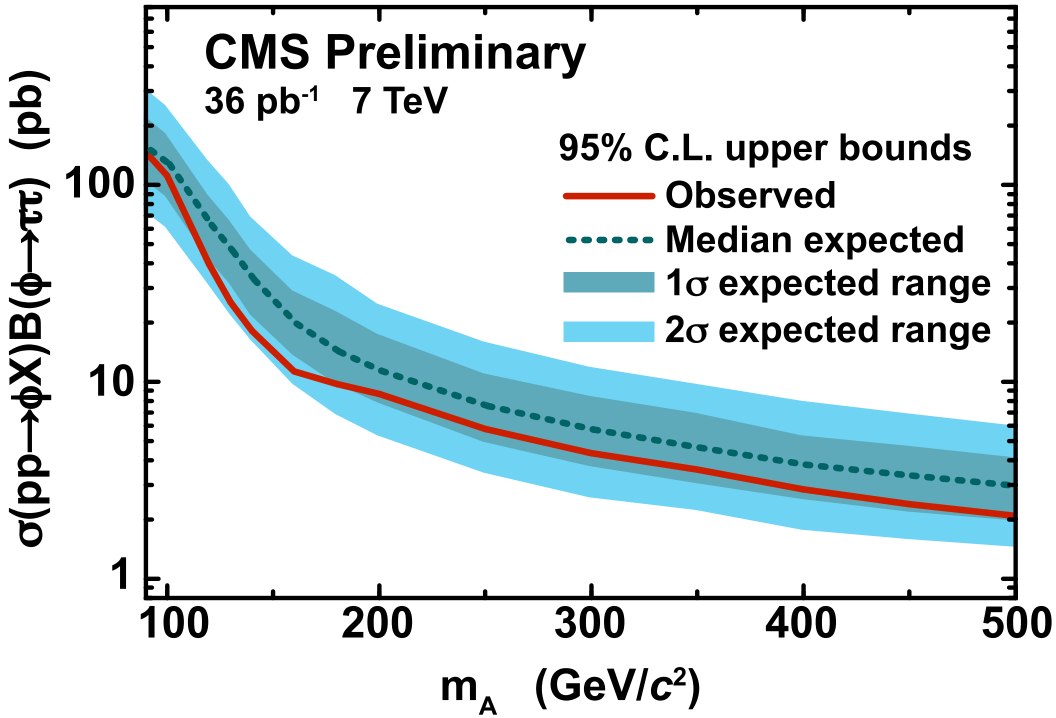


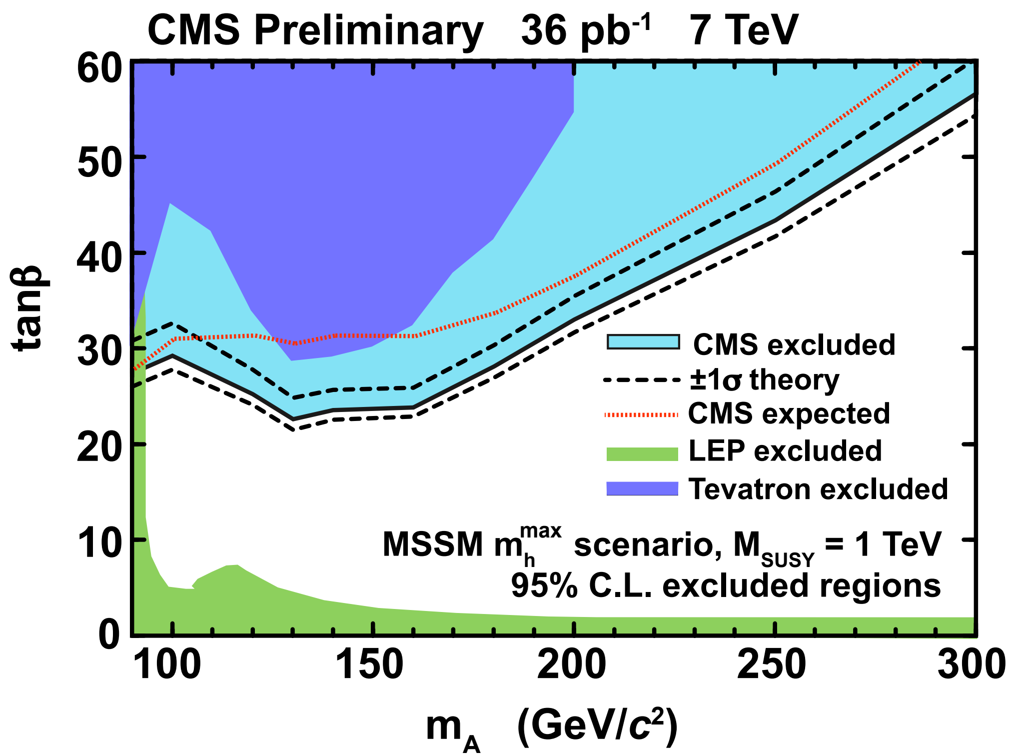
Results

Xsections and BR for MSSM $\varphi \to \tau\tau$ from:

LHC cross section working group yellow report: arXiv:1101.0593

(5FS adopted)



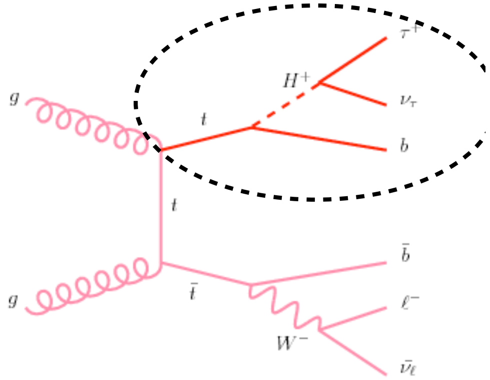


- No signal excess observed
  - Set upper limits on σxBR for different m_A hypothesis (assuming tgβ = 30)
  - observed limit agrees with expected sensitivity
  - the results can be interpreted in MSSM parameter space of tgβ vs m_A, choosing a benchmark scenario: m_h^{max}
  - **we significantly extended previous limits**

Charged Higgs

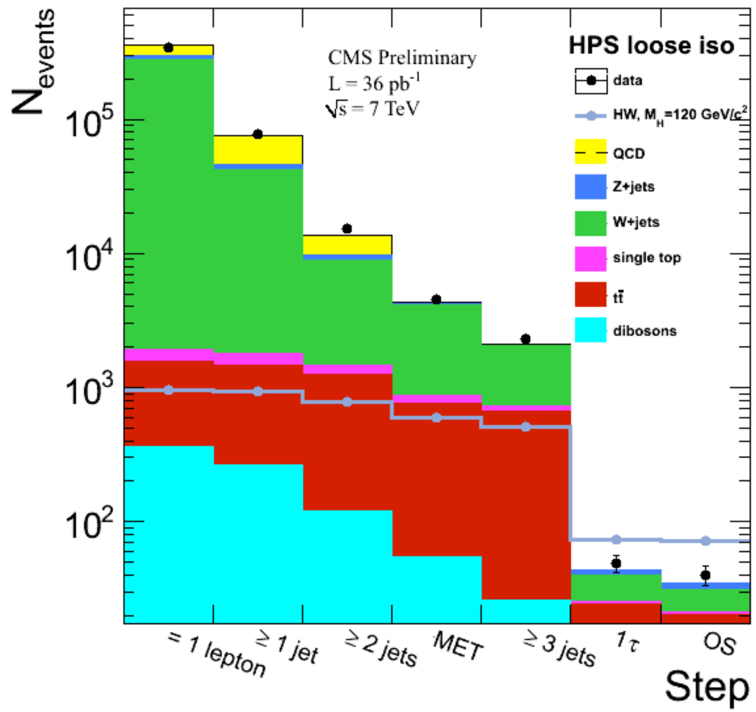
Charged $H^{\pm}$ boson can contribute to ttbar decays

- search for ttbar events with $H^{\pm}$ that sostitute $W^{\pm}$ in ttbar decays
- if exists it alters the SM predictions in τ lepton production in ttbar decays



Selection

- the same as for ttbar cross section measurement
- 2 di-lepton channel considered: **$e\tau$** and **$\mu\tau$**
  - One muon (electron) with $p_T > 20$ (30) GeV/c
  - Hadronic τ with $p_T > 20$ GeV/c, HPS identification
  - At least two jets $p_T > 30$ GeV/c
  - MET > 40 GeV



No signal excess observed

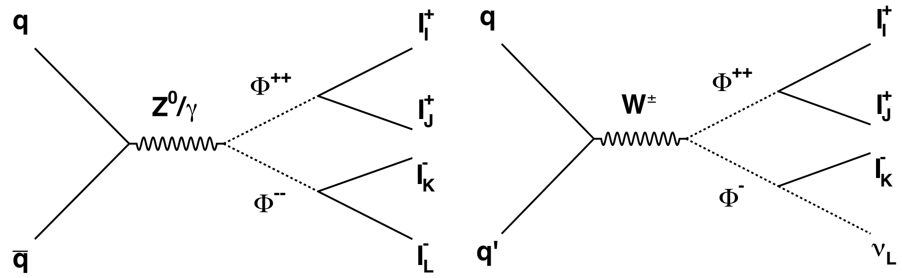
- upper limit on the BR ($t \rightarrow H^{\pm} b$) assuming BR($H^+ \rightarrow \tau^+ \nu$)=1
  ~0.25-0.30 for 80 GeV/c² < m_{H+} < 140 GeV/c²
- limit already comparable with Tevatron results

CMS-PAS-HIG-11-002

Doubly Charged Higgs

Possible extension of the SM adding scalar triplet ($\Phi^{\pm\pm}, \Phi^{\pm}, \Phi^{0}$)

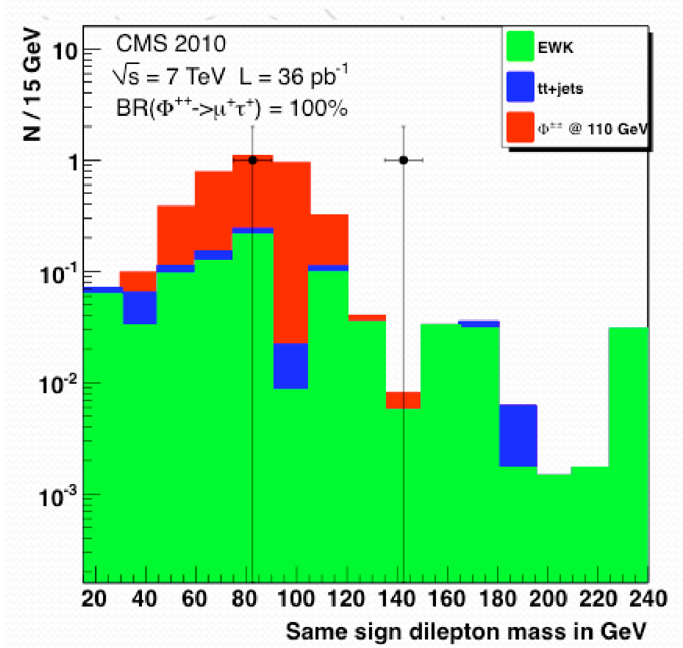
- triplet Yukawa coupling responsible for the neutrino masses



Strategy

- search for events with 3 or 4 isolated charged leptons any flavour, and look for resonance peaks in SS dilepton mass distribution
- sensitivity in the Φ mass range where $\Phi \to W^+W^-$ is kinematically forbidden
- BRs for a different $l_1 l_2$ pairs depend on the neutrino mass hierarchy and phase

Normal Hierarchy / Inverse Hierarchy / Degenerate State



No signal excess observed

- lower limit at 95% C.L. are set on the $\Phi^{\pm\pm}$
  - of 156 GeV in the $\mu\mu$ (BR $\Phi^{\pm\pm} \to \mu\mu$ =100%)
  - of 154 GeV in the $e\mu$ (BR $\Phi^{\pm\pm} \to e\mu$ =100%)
  - (116-131) GeV for the defined benchmark points (type II seesaw model)
- $\Phi^{\pm\pm}$ is excluded in mass ranges beyond those set previously by LEP and Tevatron

CMS-PAS-HIG-11-001

Outline

CMS's Path to the Higgs

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status of CMS' searches

Projections for 2011-2012

Projections

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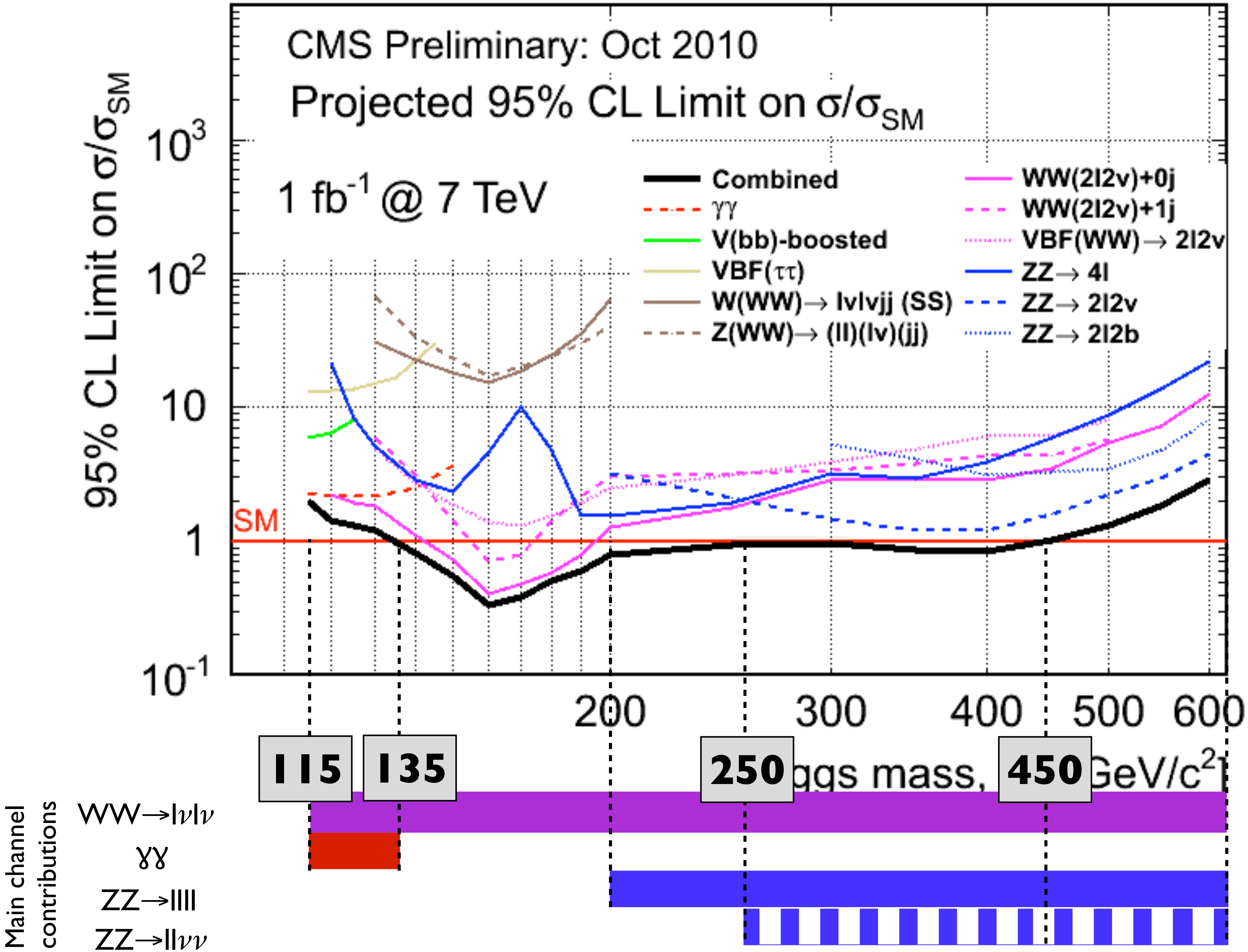
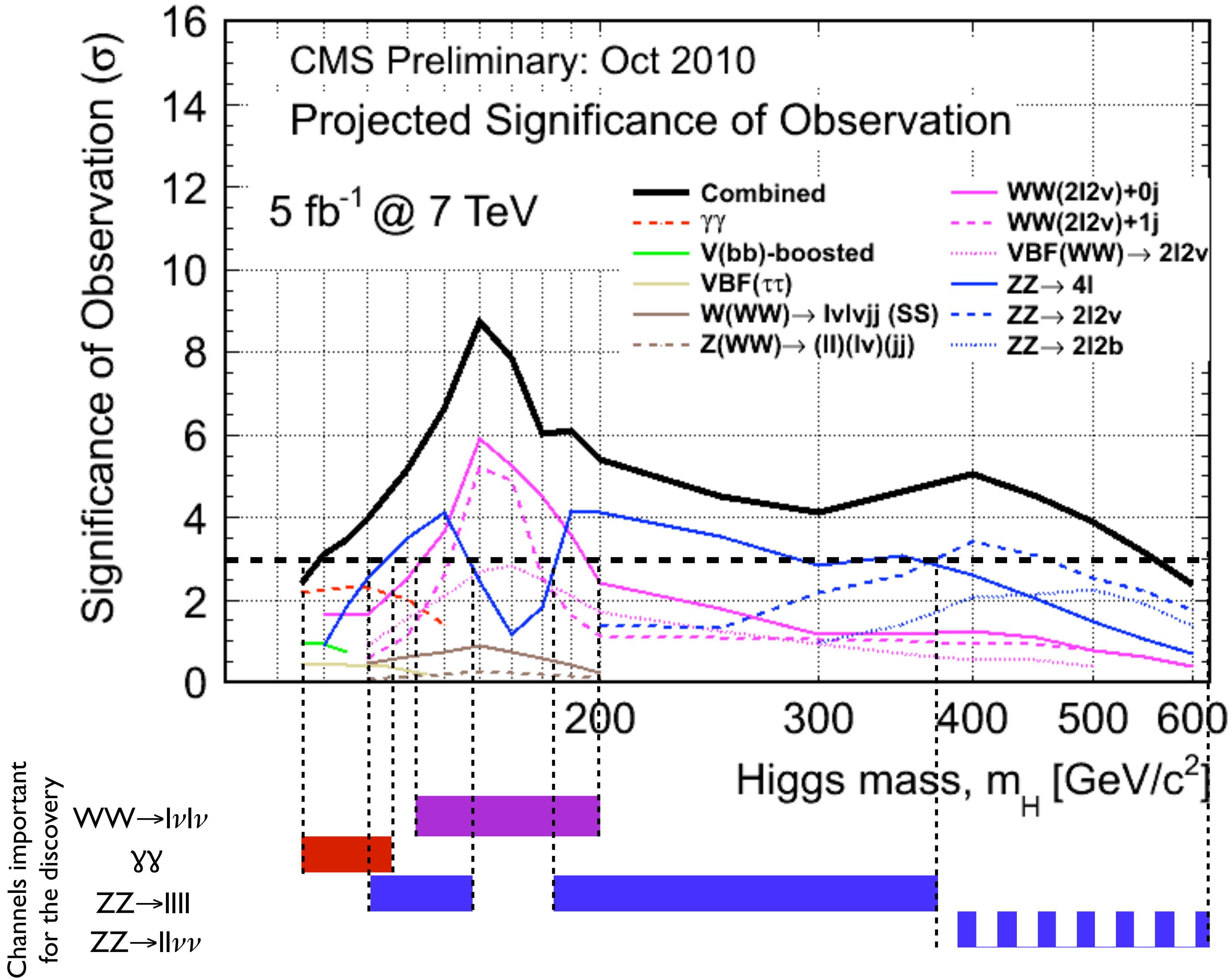
SM Higgs Exclusions: $1fb^{-1}$@ 7 TeV



Significance of Observation: 5 fb^{-1}@ 7 TeV



Conclusions

- The CMS experiment has revisited the Standard Model in a new regime at record centre-of-mass energy of 7 TeV for p-p collisions and a **solid ground** has been established, with EWK boson candles, first di-bosons, di-top and single top measurements, on the route towards the Higgs boson(s)

- A SM-Higgs boson with mass in **144-207 GeV/c^2** range in an extension of the Standard Model with 4-fermion generations is excluded

- New territories are being explored for **extending Higgs sector** (e.g. MSSM)

- An **exclusion** of the SM-Higgs is possible at the **95% CL** for and integrated luminosity of **1fb^{-1}** for masses between **135-450 GeV/c^2**

- A **3σ observation** for the SM-Higgs bosons is possible for integrated luminosity of **5 fb^{-1}** and masses above **120-550 GeV/c^2**

- A **5σ discovery** for the SM-Higgs bosons is possible for integrated luminosity of **5 fb^{-1}** and masses above **140-220 GeV/c^2**

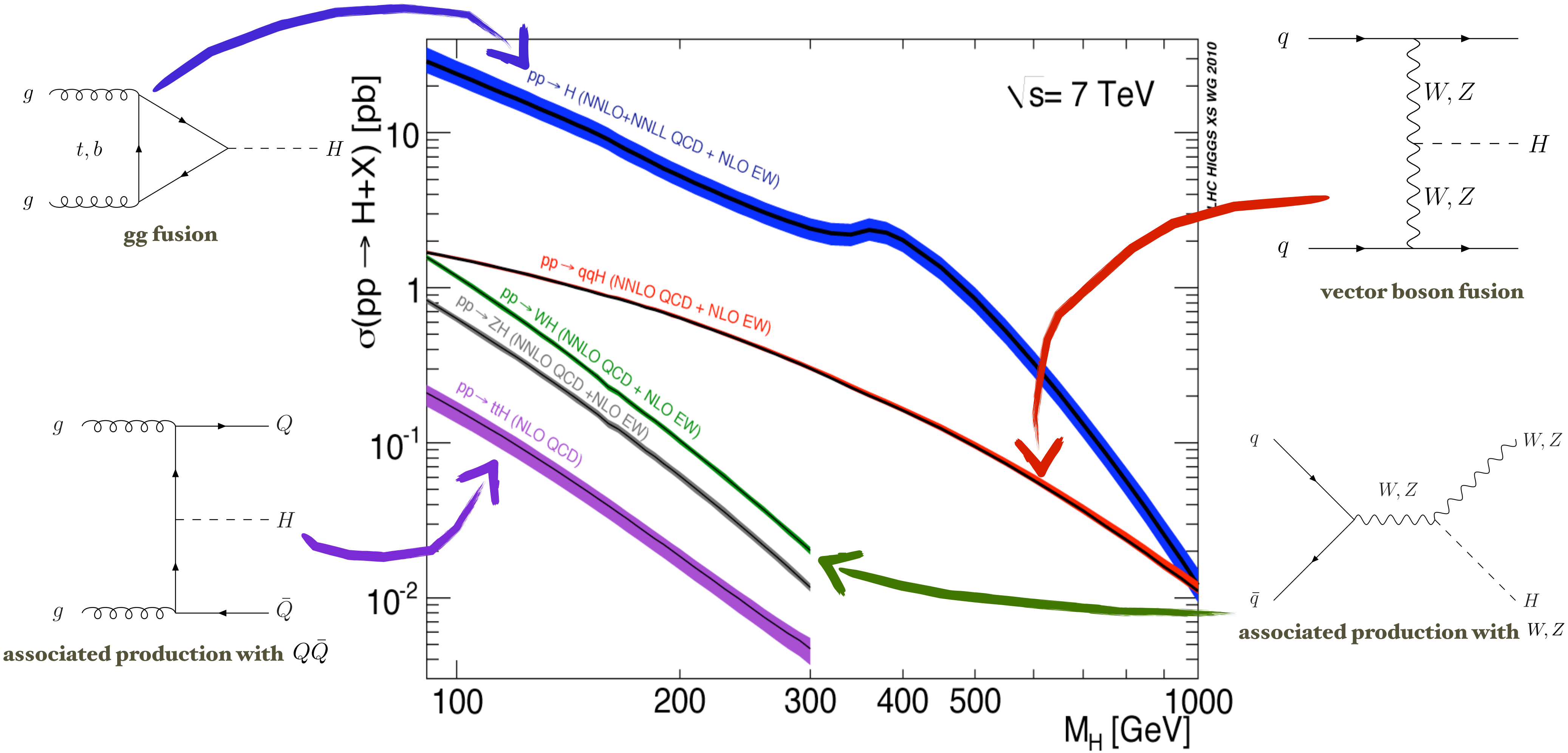
- Very low masses **115 < M_H < 130 GeV/c^2** will require the highest integrated luminosity and relay for a discovery mostly on H in 2 gamma and H in ZZ* (+possibly boosted Higgs in bb)

Wide range of searches underway with novel techniques

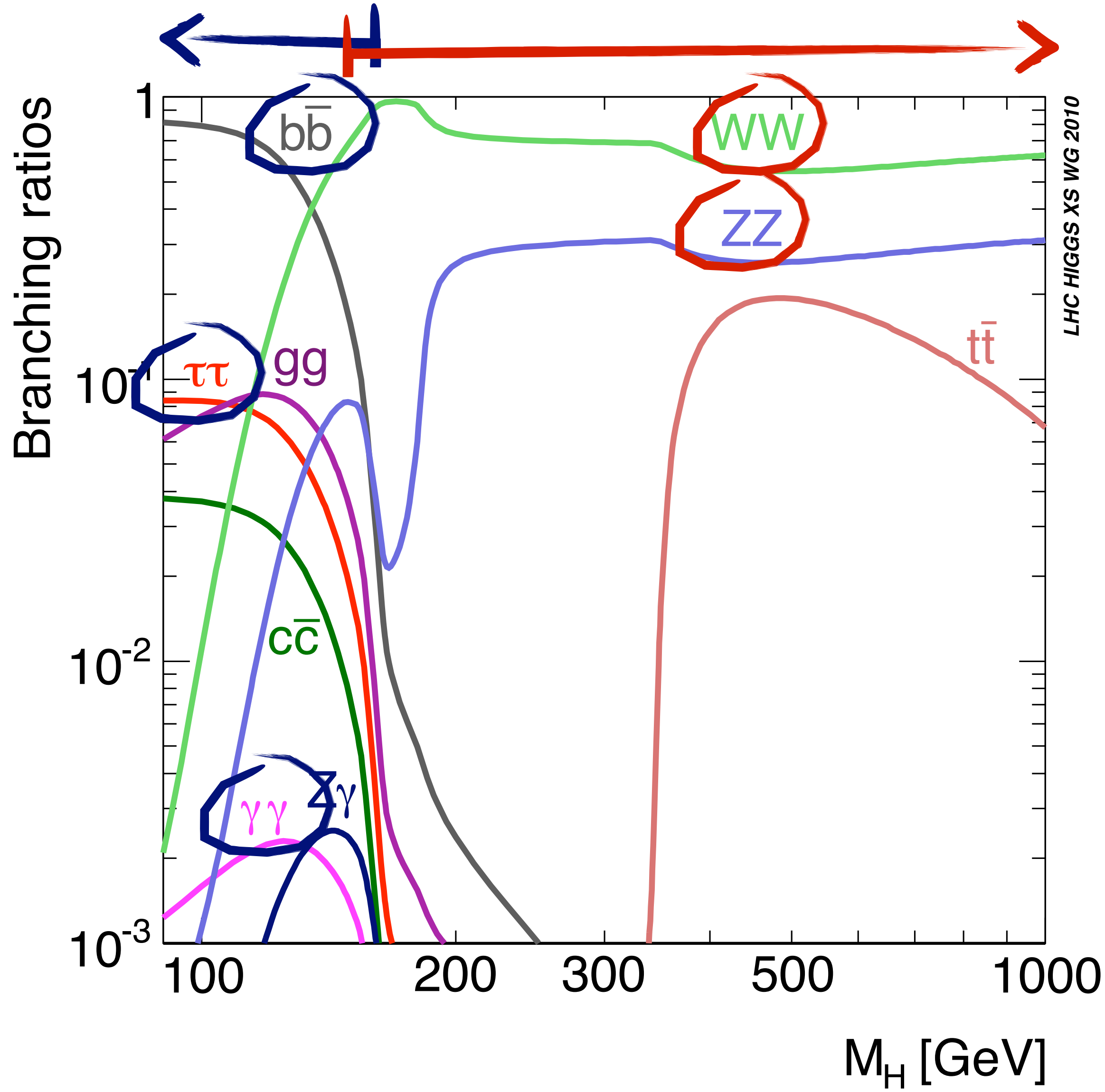
Backup

LHC cross section working group

CERN-2011-002 arXiv:1101.0593



LHC cross section working group



CERN-2011-002 arXiv:1101.0593

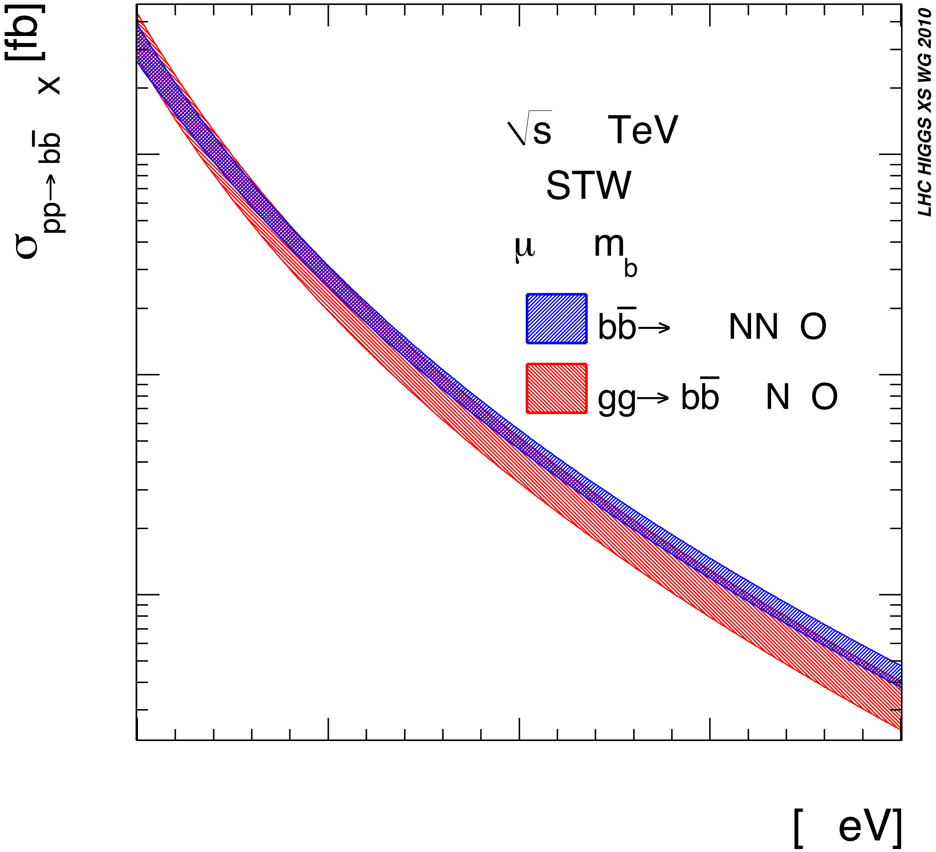
Low mass regime:
$m_H < 140$ GeV/c²

- ✓ $H \rightarrow b\bar{b}$
  - ✓ associated production, VBF
- ✓ $H \rightarrow \tau\tau$
  - ✓ VBF
- ✓ $H \rightarrow \gamma\gamma$
  - ✓ extremely low B.R.

Intermediate-High mass regime:
$m_H > 130$ GeV/c²

- ✓ $H \rightarrow WW$
  - ✓ no mass peak
- ✓ $H \rightarrow ZZ$
  - ✓ discovery channel

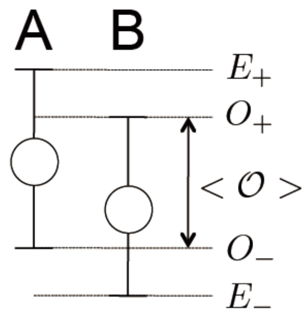
Xsections for MSSM $\varphi \rightarrow \tau\tau$



$\sigma(bbA)$: Theoretical Uncertainties					
4FS calculation			5FS calculation		
M_A (GeV)	scale	PDF+α_s	M_A (GeV)	scale	PDF+α_s
100	24%	-	100	5%	3%
300	24%	-	300	2%	6%
500	26%	-	500	2%	8%
1000	30%	-	1000	1%	2%

Comparison of the 4-flavour NLO and 5-flavour NNLO bbHiggs cross section for a pseudo-scalar Higgs.

Discussion within the LHC cross section working group. Envelope method for higher masses?



m_h^{max} scenario for MSSM $\varphi \to \tau\tau$

It is customary to discuss searches for MSSM Higgs bosons in terms of benchmark scenarios where the lowest-order input parameters $\tan\beta$ and M_A are varied, while the other SUSY parameters entering via radiative corrections are set to certain benchmark values. In this study the $m_h^{\max}$ benchmark scenario is considered, which in the on-shell scheme is defined as

$$M_{SUSY} = 1\text{TeV}, \; X_{PQt} = 2M_{SUSY}, \; \mu = 200\text{GeV}, \; M_{\tilde{g}} = 800\text{GeV}, \; M_2 = 200\text{GeV}, \; A_b = A_t, \quad (1)$$

where M_{SUSY} denotes the common soft-SUSY-breaking squark mass of the third generation, $X_t = A_t - \mu/\tan\beta$ the stop mixing parameter, A_t and A_b the stop and sbottom trilinear couplings, respectively, μ the Higgsino mass parameter, $M_{\tilde{g}}$ the gluino mass, and M_2 the SU(2)-gaugino mass parameter. M_1 is fixed via the GUT-relation $M_1 = 5/3 M_2 \sin\theta_w / \cos\theta_w$.

Projections

- Used state of the art cross-sections
  - signal NNLO for gg, NLO for VBF,VH
  - background processes at NLO
- Full GEANT based detector simulation
- Simple cut-based analysis, mostly counting events:
  - no SHAPE analysis used (can improve sensitivity by ~(20-100)%)
- Validation from 2010 data:
  - **excellent agreement between data and detector simulation**
  - detector performance close to design in most cases
  - measured production rates of background processes in good agreement with expectations (5-30 % uncertainties)
- In general, analyses with data more sensitive than the simulation based studies used in the projections…and will continue to improve!

Projections are indicative not predictive !