Search for a Higgs boson in Diboson Channels with CMS

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LHC: next years

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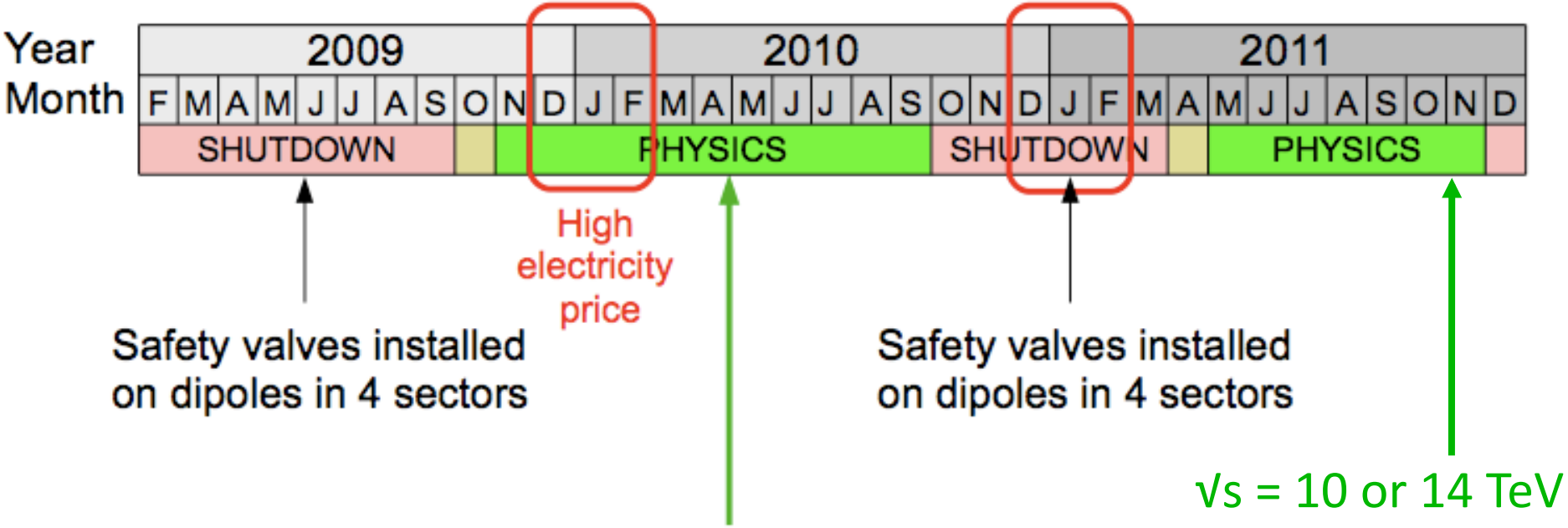
Schedule announced on 9 February 2009

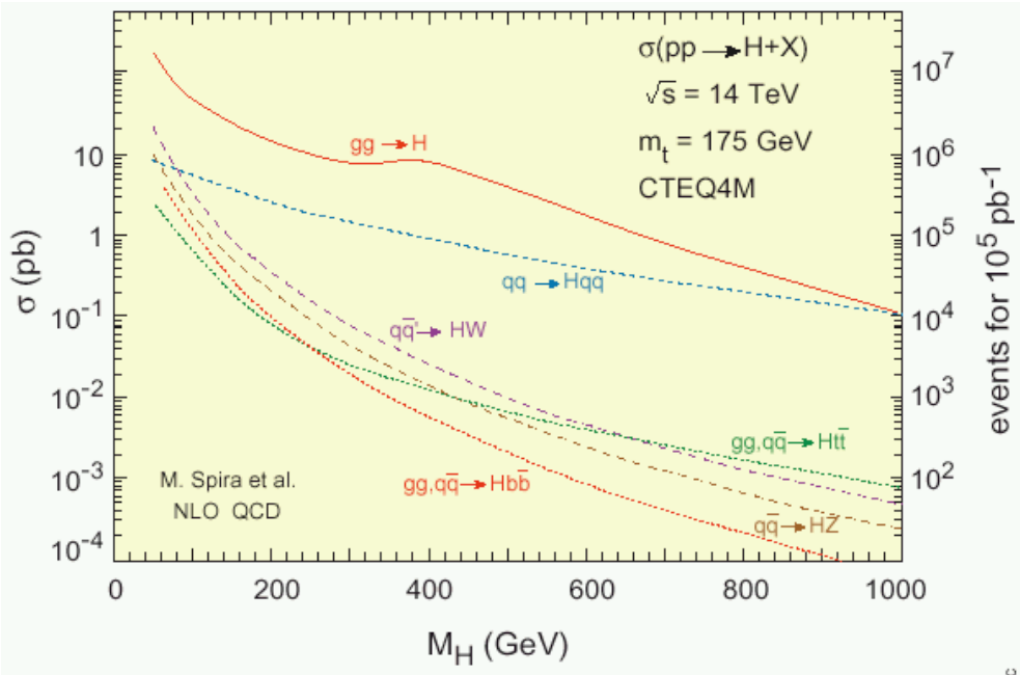


$\sqrt{s}$ = 10 or 14 TeV
~ few x 1 fb^{-1} (?)

$\sqrt{s}$ = 8-10 TeV
Peak luminosity ~ 2 x 10^{32} $cm^{-2}s^{-1}$
Integrated luminosity ~ few x 100 pb^{-1} (?)

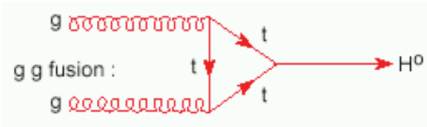
Higgs boson production

- Inclusive production

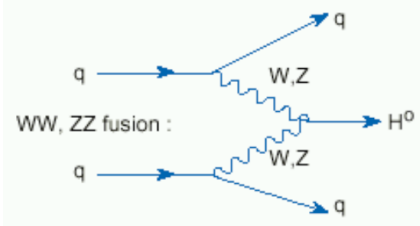


A. Djouadi

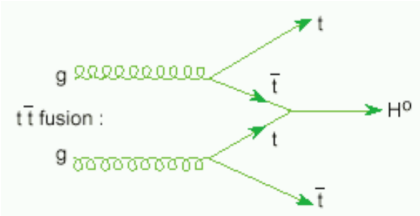
- gg fusion



- vector boson fusion



- $t\bar{t}$ fusion



- associated production (W,Z)

Higgs boson mass range

- Lower bound from LEP
  - $M_H > 114.4$ GeV
- SM unitarity bound
  - $M_H < 780$ GeV
- Consistency fit (95% CL)

(knowing that $M_H > 115$ GeV)

  - $M_H < 182$ GeV

SM search mainly in the range: 115-200 GeV

Other models suggest $M_H > 200$ GeV

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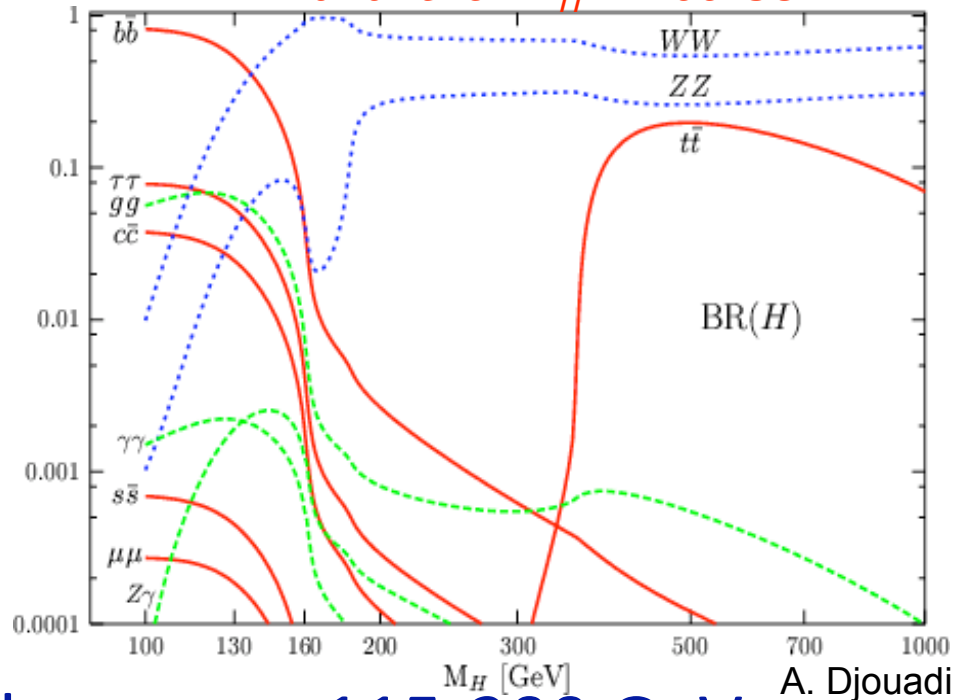
Lower masses: H → $\gamma\gamma$, $\tau\tau$

Higher masses: H → WW, ZZ

~ invariant for $M_H > 200$ GeV



A. Djouadi

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Other models suggest $M_H > 200$ GeV

Higgs boson decays

- Diboson decays
  - $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$

    $e^+e^-e^+e^-$, $\mu^+\mu^-\mu^+\mu^-$, $e^+e^-\mu^+\mu^-$ (x2)

  - $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$

    $e^+e^-\nu_e\bar{\nu}_e$, $\mu^+\mu^-\nu_\mu\bar{\nu}_\mu$, $e^+\mu^-\nu_e\bar{\nu}_\mu$, $\mu^+e^-\nu_\mu\bar{\nu}_e$

=> Detection of isolated electrons and muons

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Main backgrounds: $t\bar{t}$, $Zb\bar{b}$, ZZ Fakes: Z+jets, W+jets, WZ+jets

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Main backgrounds: (Wt, WZ, ZZ), DY, $t\bar{t}$, WW Fakes: W+jets, Z+jets

=> Detection of isolated electrons and muons

Higgs boson decays

- Diboson decays
  - $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$

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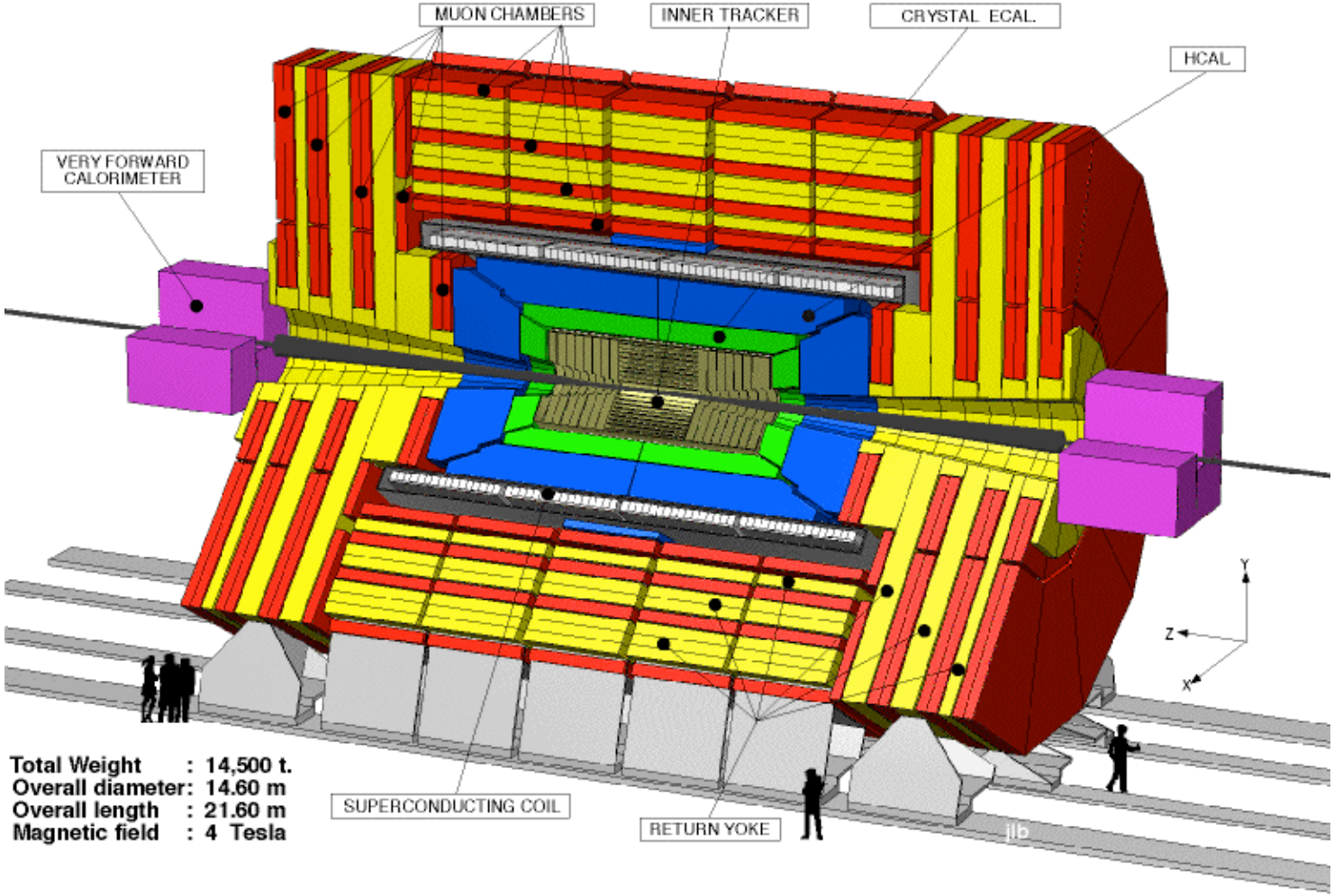
Main backgrounds: (Wt, WZ, ZZ), DY, $t\bar{t}$, WW Fakes: W+jets, Z+jets

Higgs boson masses considered for analyses:

115-200 GeV; 250 GeV

Lepton reconstruction

e/μ detection with CMS



e/μ detection with CMS

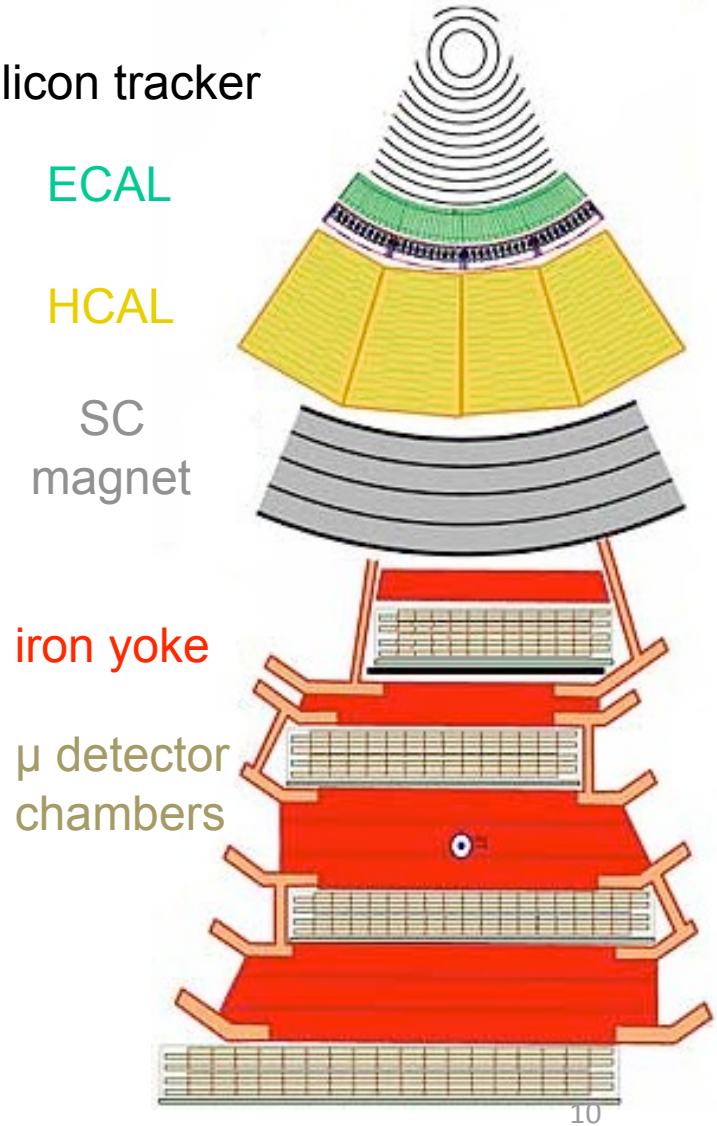
- Electrons
  - Track in the silicon tracker
  - Energy clusters in the ECAL

  (Si tracker: $|\eta| < 2.5$, ECAL: $|\eta| < 3$)

- Muons
  - Inner (silicon tracker) and Outer (muon chambers) tracks

  (μ chambers: $|\eta| < 2.4$)

Efficiency control via $Z \rightarrow \ell\ell$ measurements



e reconstruction with CMS

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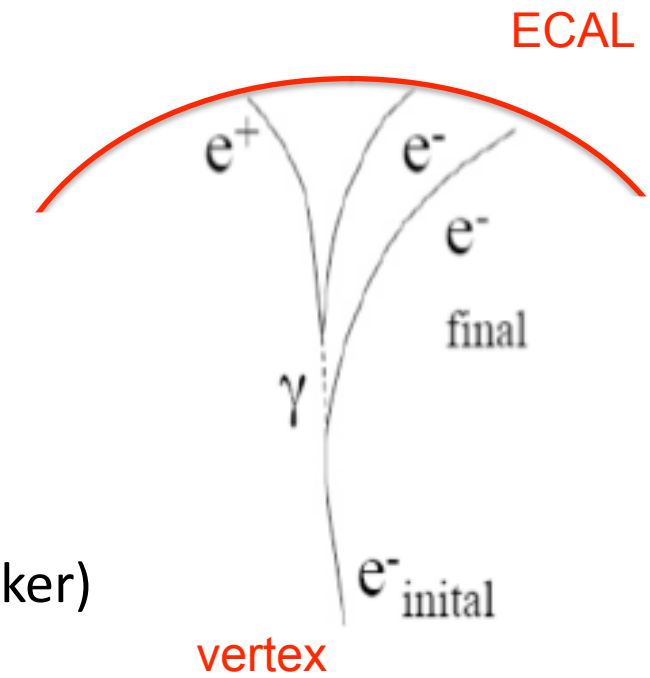
- ECAL-driven reconstruction

Si tracker: a lot of material budget
=> complicated tracks



- energy deposit in the ECAL crystals
- supercluster

(whole energy of the initial e in ECAL)

- Track seed (innermost layers of Si tracker)
- Track (Si tracker)

Preselection (Track - SC concordance)

=> creation of an electron candidate

Efficiency:
85% at p_T=10 GeV
90% at p_T=10 GeV, $|\eta|$< 1.1
90% at p_T=35 GeV
95% at p_T=35 GeV, $|\eta|$< 1.1

μ reconstruction with CMS

- Muon Chambers driven reconstruction
  (~ 95 - 99% efficiency except at crack level)
  - Fast trigger chambers (RPC)
    < 10 ns time resolution -- set off the mechanism
  - High resolution tracking detectors (CSC, DT)
    reconstruction of the outer tracks
  - Combination with the inner detector
  - Small energy deposits in the ECAL and HCAL

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$WW^{(*)}$ and $ZZ^{(*)}$ channels

$WW^{(*)}$ channel strategy

- Preselection
  - exactly 2 leptons of opposite charge *(WZ, ZZ)*
  - Lower cuts for p_T, E_T^{miss}, $m_{\ell\ell}$, isolation *($t\bar{t}$, Wt, W+jets, DY)*

- Further selection *($t\bar{t}$, DY+jets)*
  - Central jet veto, angular correlation ($\Delta\Phi_{\ell\ell'}$), tightening

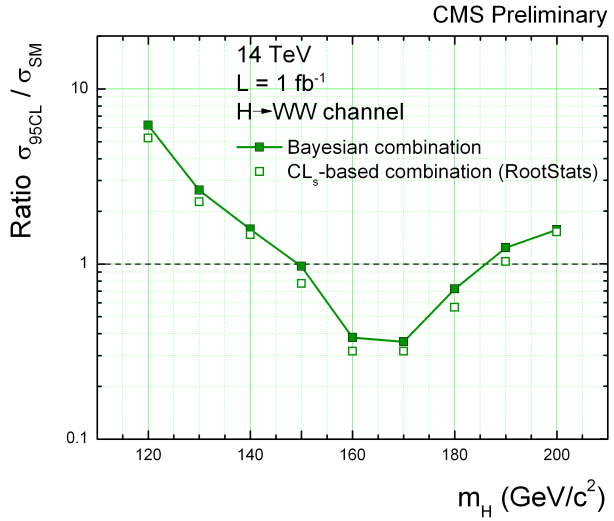
Cut sequence, or multivariate analysis

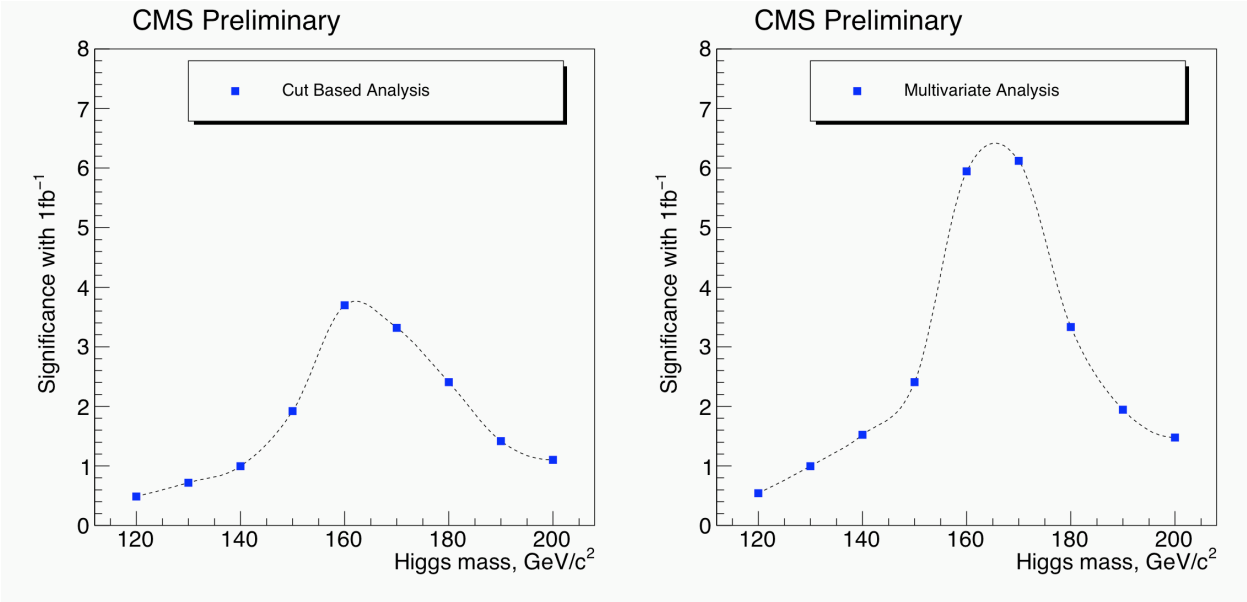
- Control of background rates from data
  - Relaxing/inverting some cuts *($t\bar{t}$, WW)*
  - « fake » probability from jet triggers *(W+jets)*

$WW^{(*)}$ results

14 TeV

1 fb^{-1}





Exclusion at 95% CL
for 150 GeV < M_H < 190 GeV

Multivariate analysis :
Discovery at 5σ for
155 GeV < M_H < 175 GeV

$WW^{(*)}$ results

- Exciting expectations already at 14 TeV, 1 fb^{-1}
- Expected results of projection at 200 pb^{-1}, 10 TeV
  ~ already comparable to current TeVatron results
- A very powerful channel, but E_T^{miss}
  => No identifiable peak
  Background control is crucial

$ZZ^{(*)}$ channel strategy

- Preselection *(QCD, Z/W+jets)*
  - *at least* 2 pairs of opposite charge, matching flavour leptons
  - Lower cuts on p_T^{ℓ}, $m_{\ell+\ell-}$, $m_{4\ell}$; loose isolation
  - Identification of the « Z pair » and the « Z* pair » [exactly 4ℓ]

- Further selection *(Z+jets, $t\bar{t}$, Zbb)*
  - isolation, $p_T^{\ell\,\mathrm{lowest}}$, impact parameter
  - Restrictions on the reconstructed « m_Z » and « m_{Z*} »

- Systematics and control from data *(ZZ)*
  - Efficacity measurement with Z production
  - Normalization ZZ/Z
  - Random cone technique

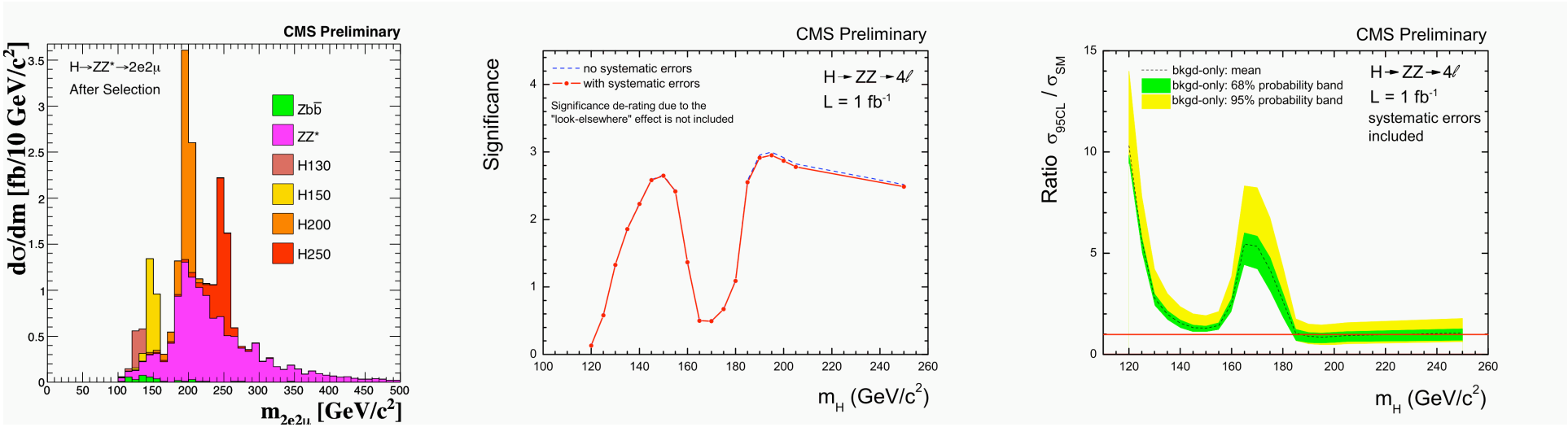
$ZZ^{(*)}$ channel results

14 TeV

1 fb^{-1}

look-elsewhere effects

need to substract ~ 1σ in the significance



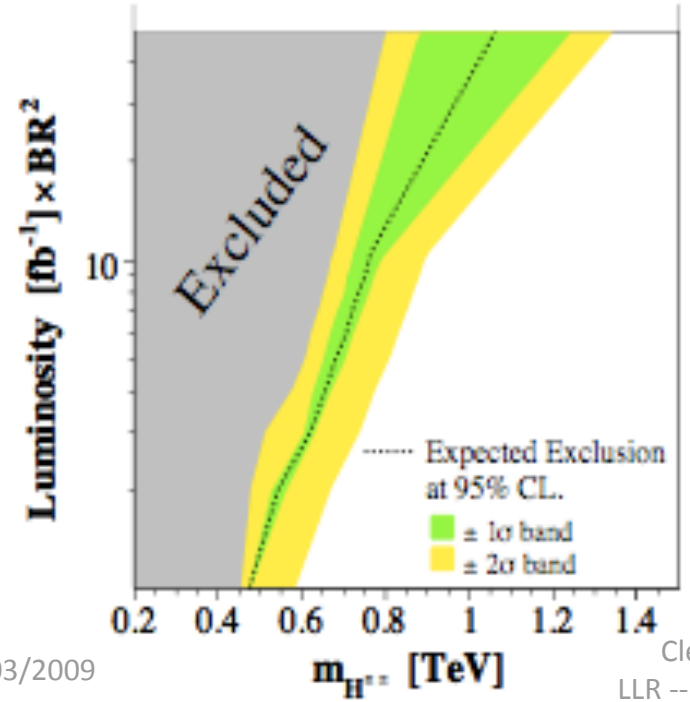
Not enough luminosity for a discovery

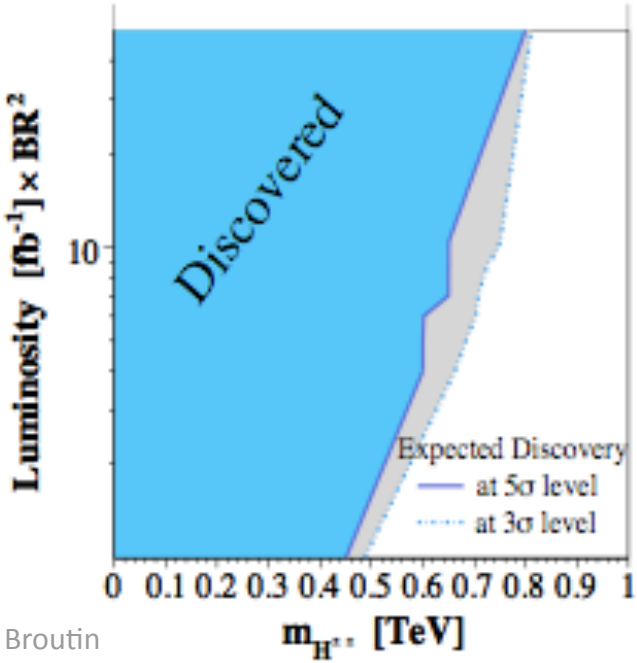
~ exclusion for $M_H \gtrsim 185$ GeV

$WW^{(*)}$, $ZZ^{(*)}$: other results

- Relaxing flavour, charge cuts *($ZZ^{(*)}$)*
  - Control of background (bkg/data ratio…)
  - Finding more exotic signal (doubly charge Higgs, …)

$$pp \rightarrow H^{++} H^{--} + X \rightarrow \ell_1^+ \ell_2^+ \ell_3^- \ell_4^- + X$$





$WW^{(*)}$, $ZZ^{(*)}$: other results

- Higgs decays into neutralinos *(SUSY)*

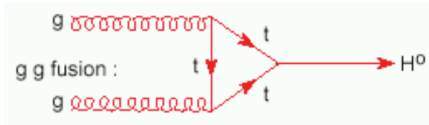
  $A^0, H^0 \rightarrow 2\chi_2^0 \rightarrow 4\ell\, 2\chi_1^0$

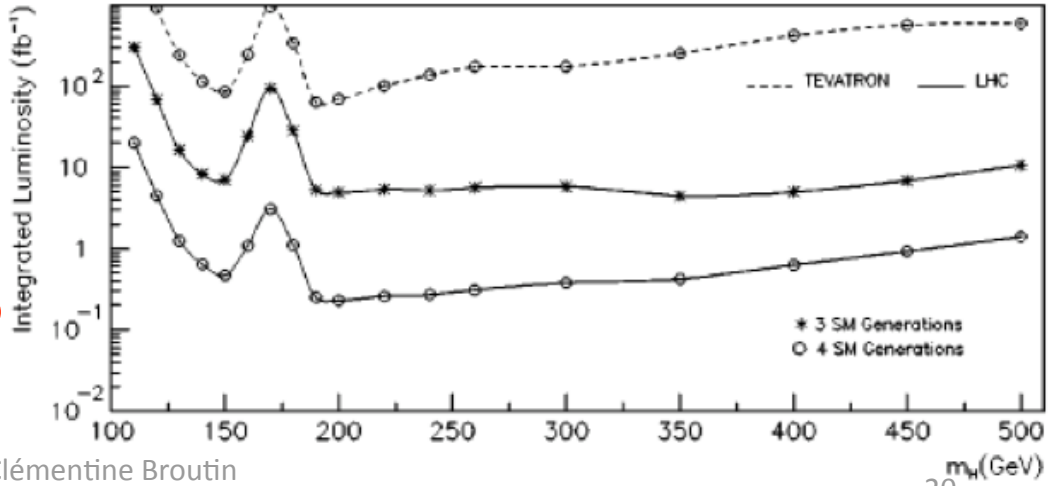
- Fourth generation of fermions

  More intermediate quark loops in gg fusion diagram

  → higher production rate

  Changes Branching Ratios





=> Early discovery?

Combined $WW^{(*)}$ and $ZZ^{(*)}$ channels

- Improves the sensitivity
- Correlations of systematics?
- 2 different analyses

  different statistical models, different hypotheses on correlations

Bayesian exclusion limits

- Likelihood function $\mathcal{L}(r)$ normalized to 1
- r : s.t. $\sigma_{obs} = \sigma_b + r\,\sigma_s$
- partial integral = 0.95

Modified Frequentist CL_s excl. limits

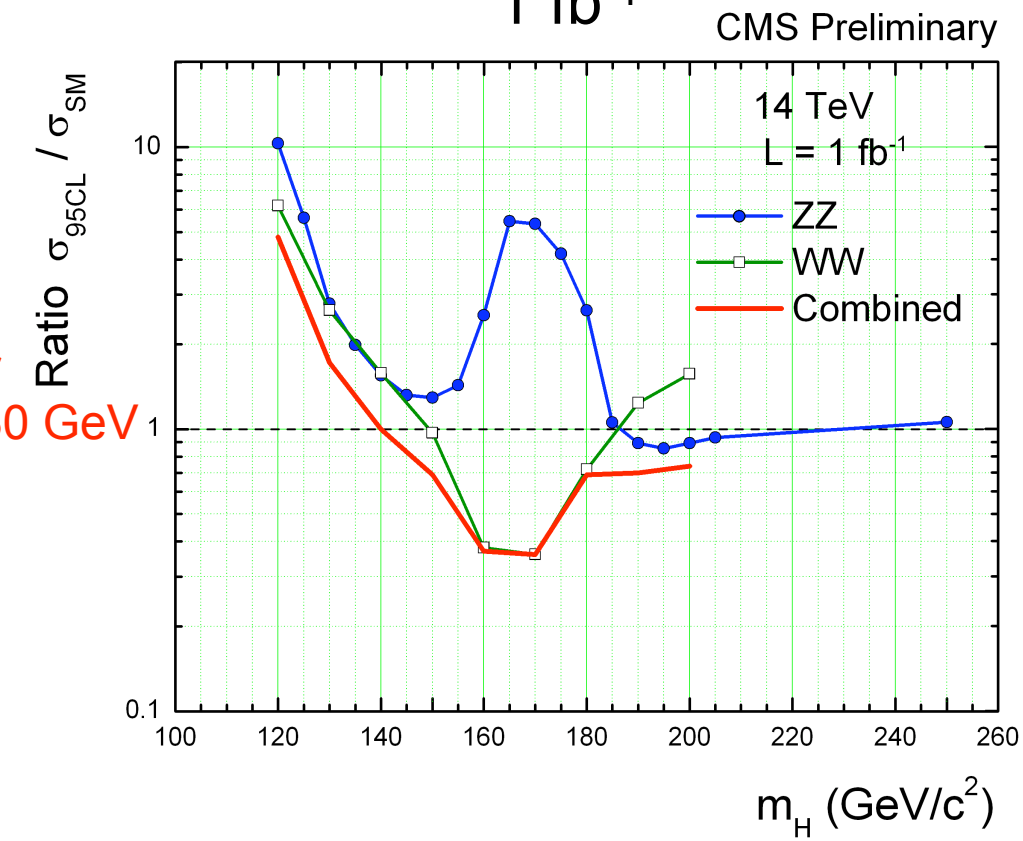
- log. likelihood ratios Q
- ratio $CL_{sb} / CL_b < 0.05$

Very similar results

Combined $WW^{(*)}$ and $ZZ^{(*)}$ channels

14 TeV

1 fb^{-1}



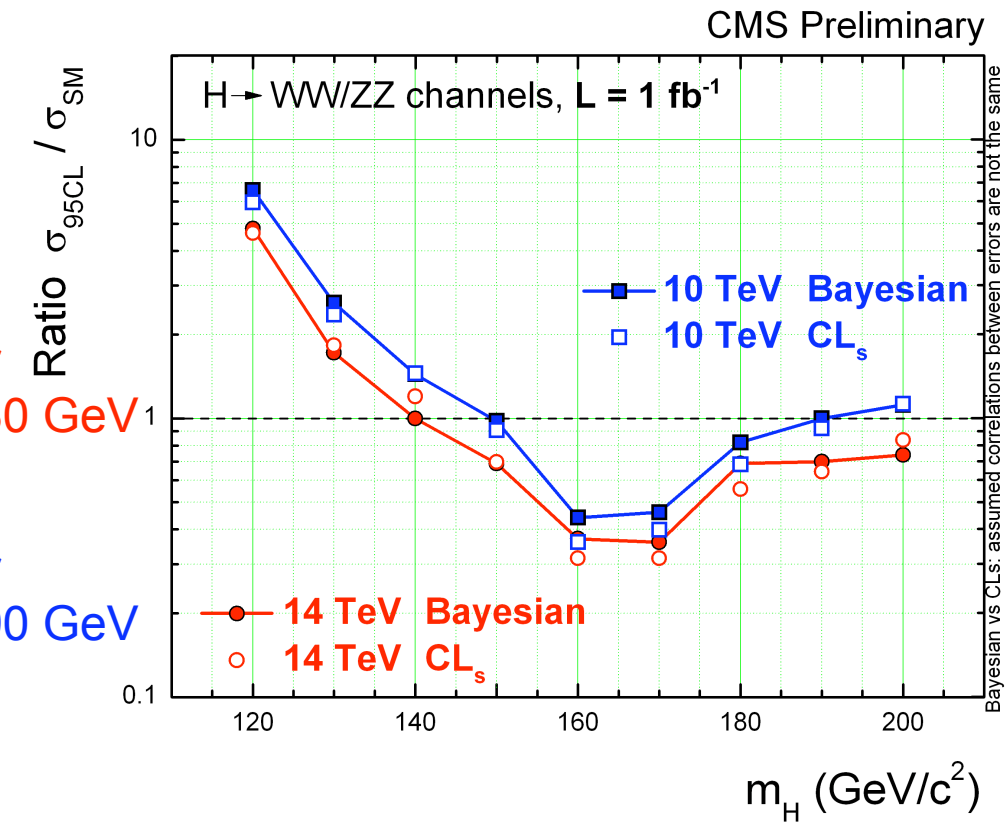
14 TeV
Exclusion for
140 GeV < M_H < 230 GeV

Combined $WW^{(*)}$ and $ZZ^{(*)}$ channels

Projection at 10 TeV (1 fb^{-1})

14 TeV
Exclusion for
140 GeV < M_H < 230 GeV

10 TeV
Exclusion for
150 GeV < M_H < 190 GeV



~ Autumn 2011 ?

Sensitivity divided by a factor ~ 1.5

Conclusion

- Expecting solid results at 14 TeV, 1 fb^{-1}
  - Possibility of exclusion (95% CL) on a main mass range
  - Already a possibility of discovery at 5σ around $2M_W$

- First year at LHC: 10 TeV, 200 pb^{-1} *
  - first exclusion results in the SM Higgs boson search
  - possibility of very interesting surprises

* Specific tuning at 10 TeV, low int. luminosity to come soon

Including the cross section of the diboson background gg → ZZ , gg → WW.

Back-up Slides

Publications

$H \rightarrow WW^{(*)} \rightarrow 4\ell$ at 14 TeV, $1fb^{-1}$

CMS AN-2008/039

CMS PAS HIG-08-006

$H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ at 14 TeV, $1fb^{-1}$

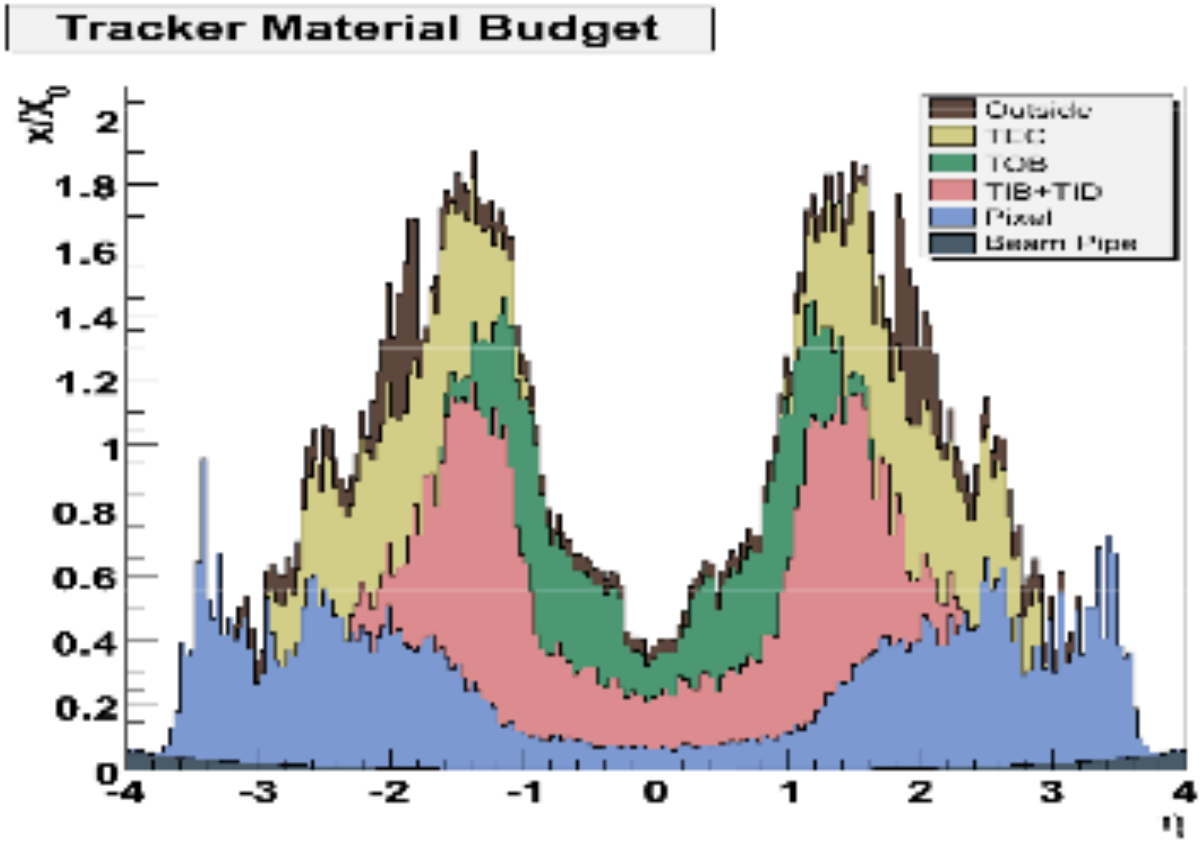
CMS AN-2008/050

CMS PAS HIG-08-003

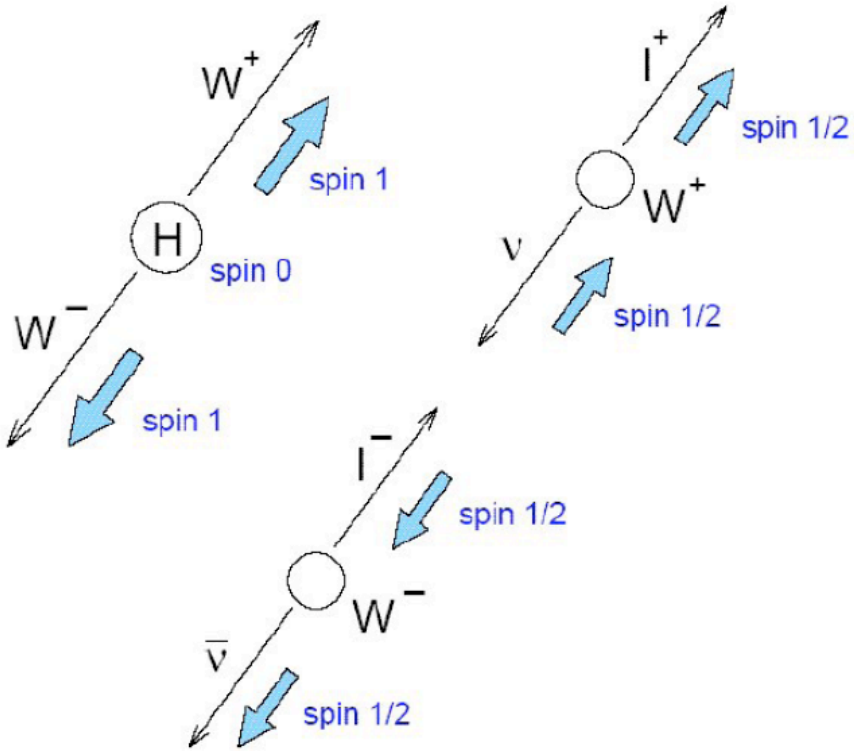
Combined channels and projection to 10 TeV, $1fb^{-1}$

CMS AN-2009/020

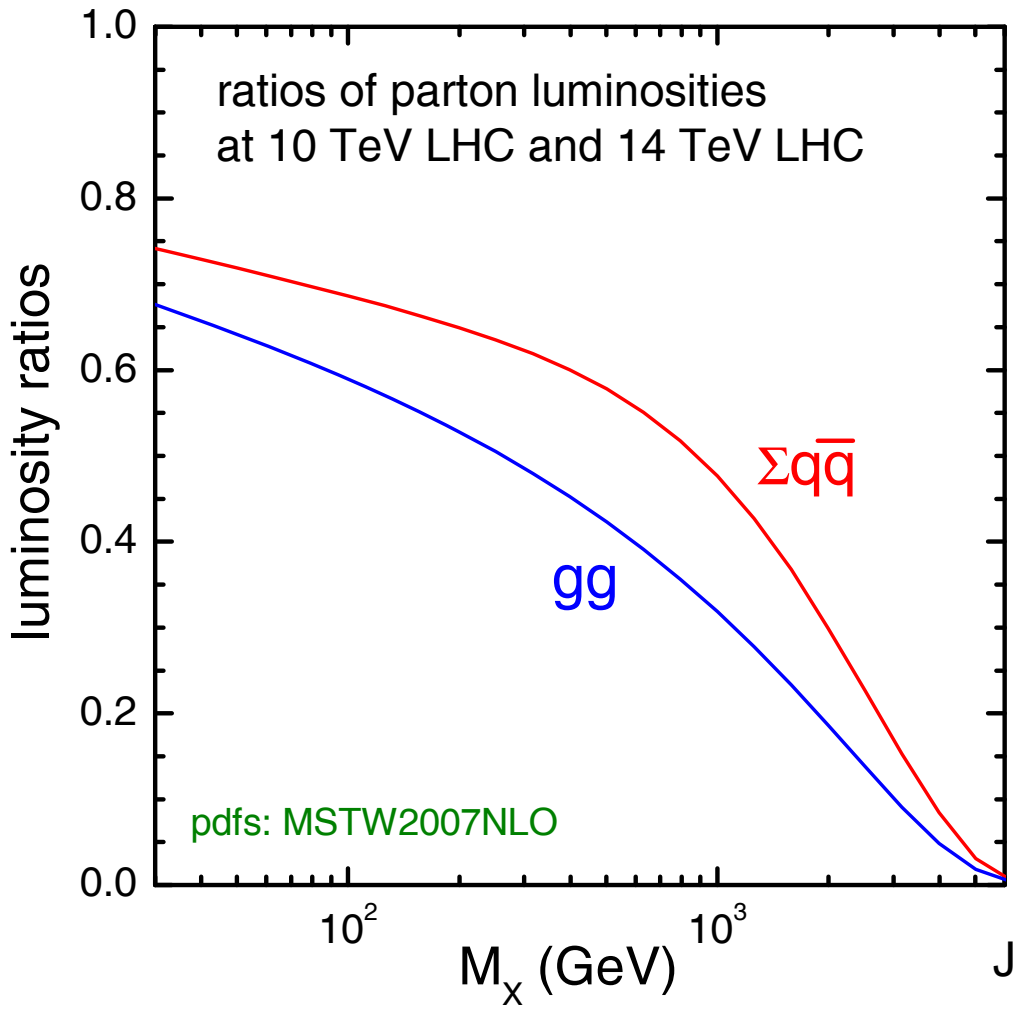
e reconstruction: impact of material budget



$WW^{(*)}$ channel: angular correlation

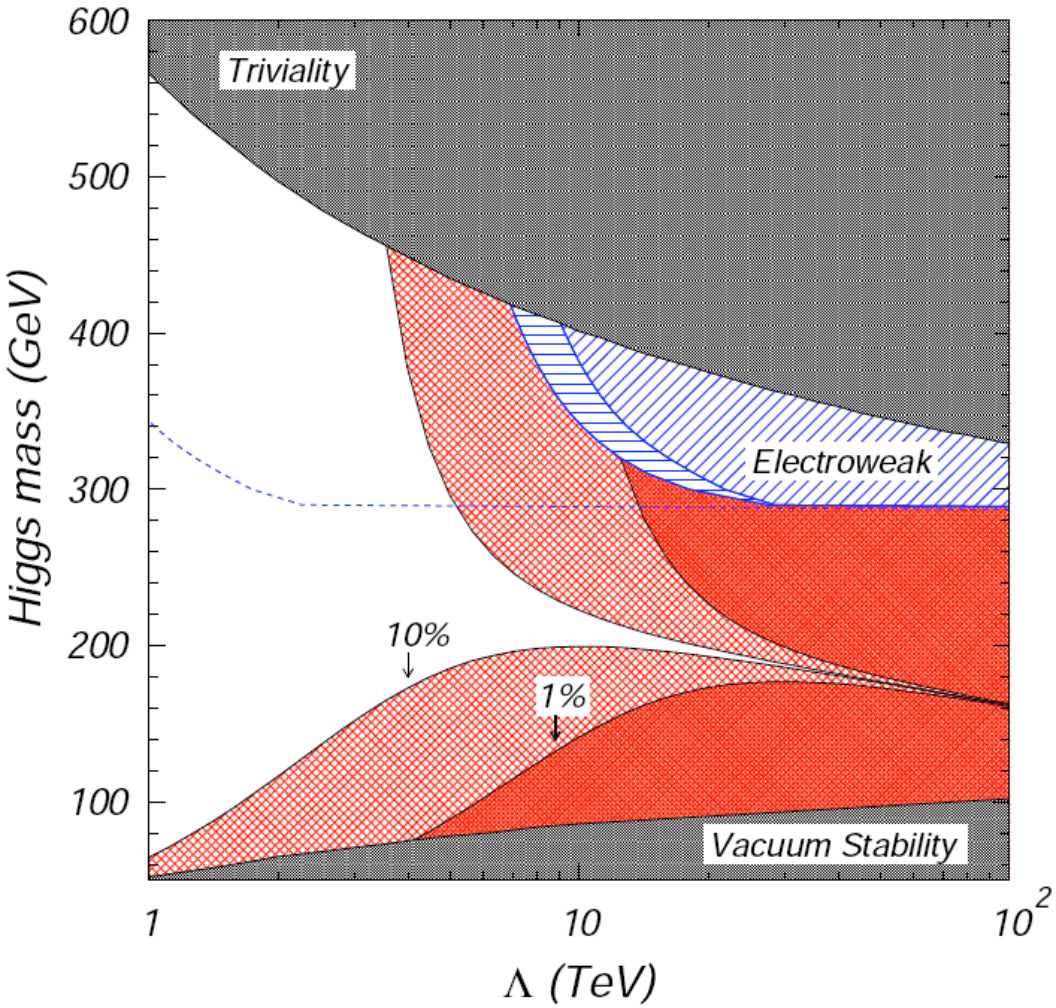


10 TeV to 14 TeV ratio



James Stirling

Constraints on a SM Higgs mass



The CMS detector