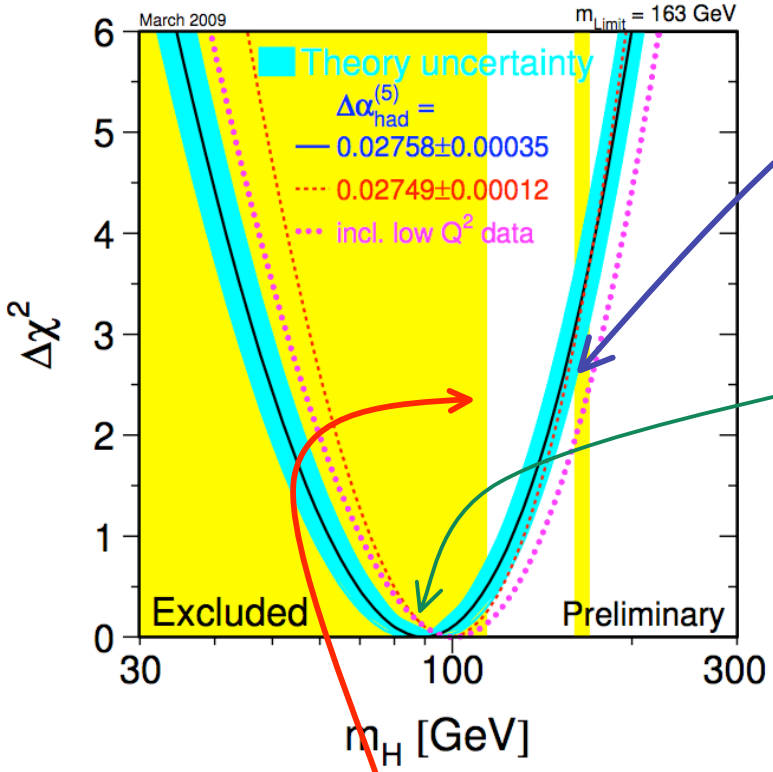
Photos from “URBAHN” web site

Prospects of CMS Higgs boson search

Chiara Mariotti, INFN Torino

FNAL 16-Jun-09

The Standard Model Higgs as of today!

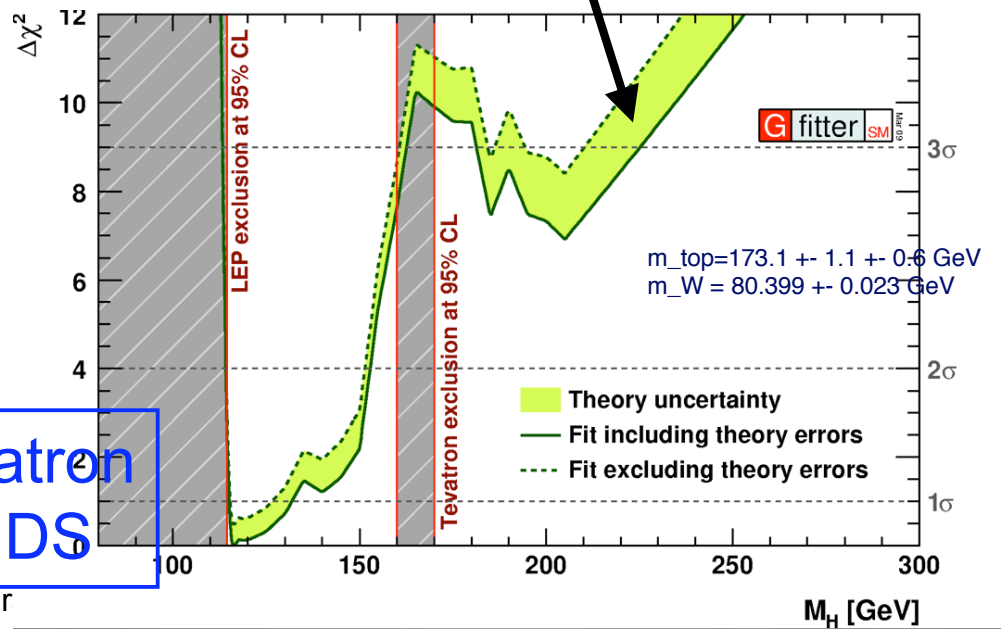


m(H)≤ 154 GeV/c² at 95% CL

EW precision measurements

m(H)= 84 $^{+34}_{-26}$ GeV/c²

Direct Search
m(H) ≥ 114.4 GeV/c²
at 95% CL



Plus Tevatron and LEP DS

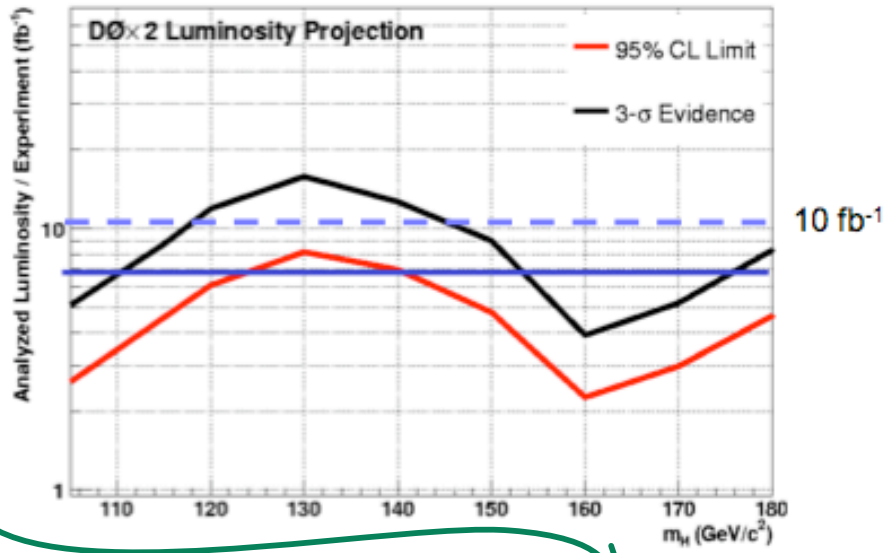
SM Higgs Prospects

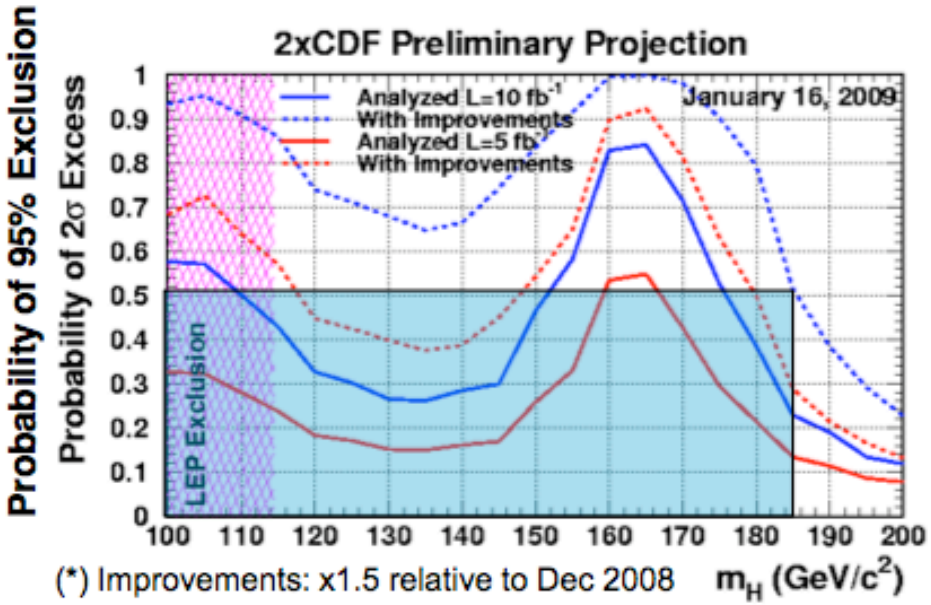
Aurelio Juste

- Median projected reach as a function of analyzed (=0.8 x delivered) integrated luminosity:

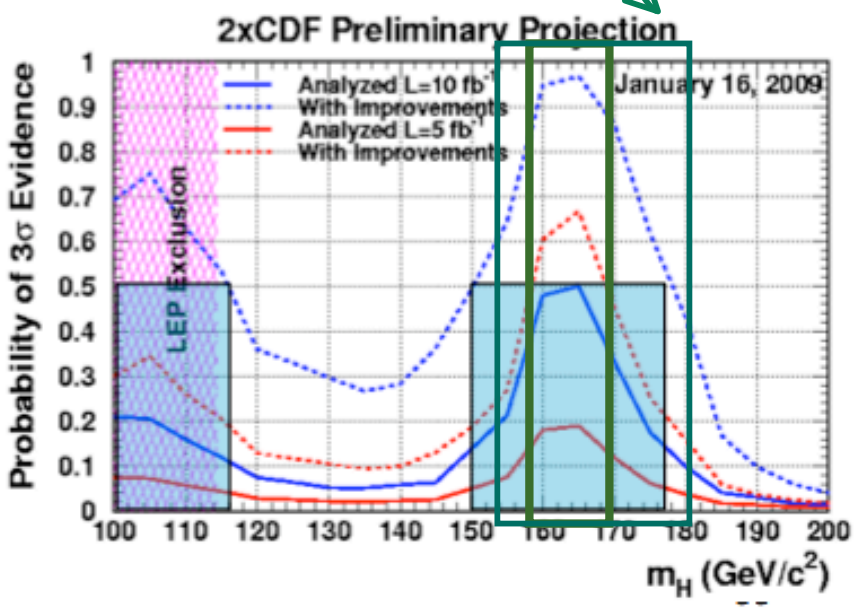
  ** Does NOT include current observed limit **

  With 10 fb^{-1} /experiment:
  - Exclude at 95% CL for m_H<185 GeV.
  - 3 evidence at low and high mass.
  - There is a band of possibilities around these lines.



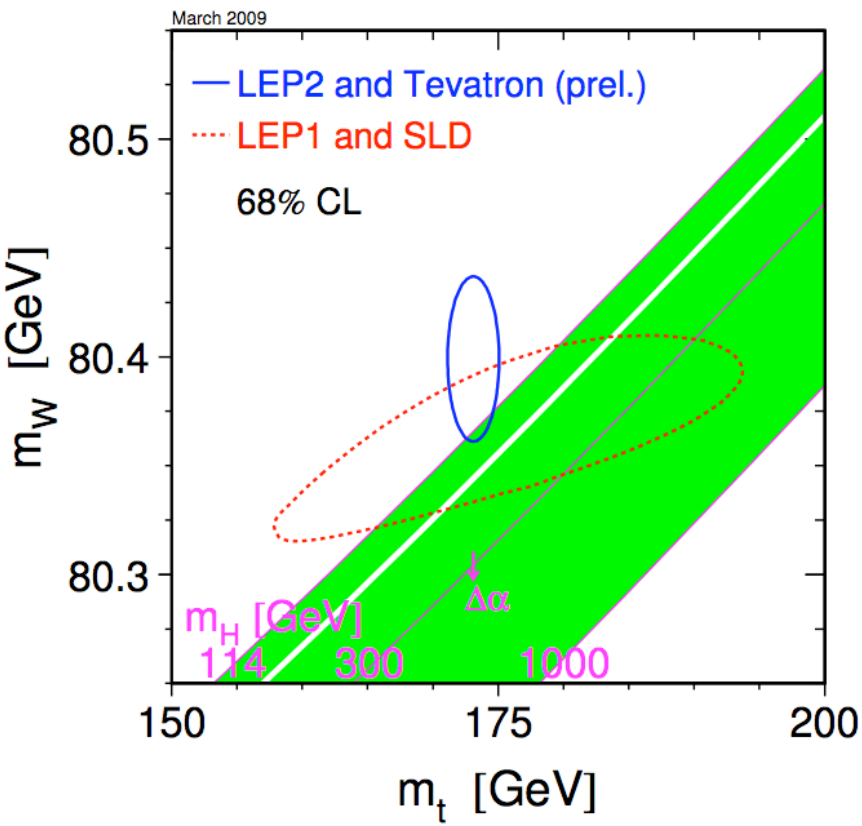


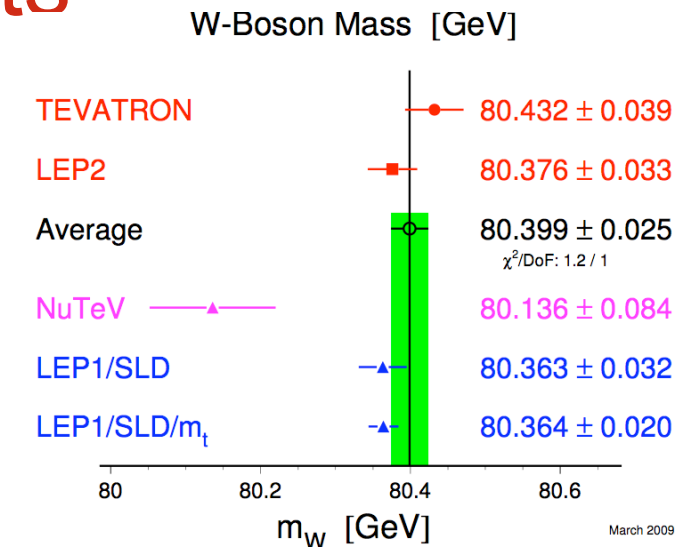
(*) Improvements: x1.5 relative to Dec 2008

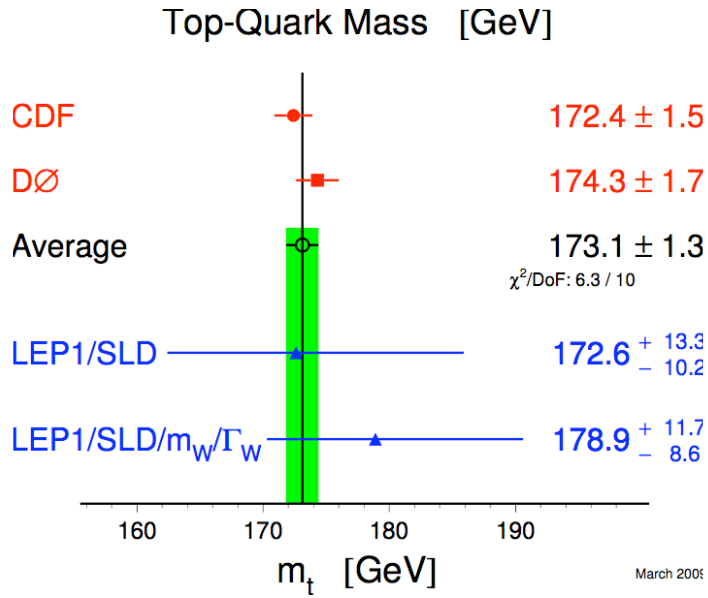


➔ Tevatron complements LHC at low mass.

Direct and Indirect m_W and m_t measurements



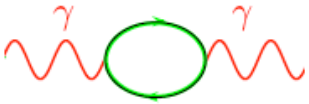




$$\Delta m_W = 0.7 \times 10^{-2}\, \Delta\, m_{top}$$

To get the same weight on the EW fit

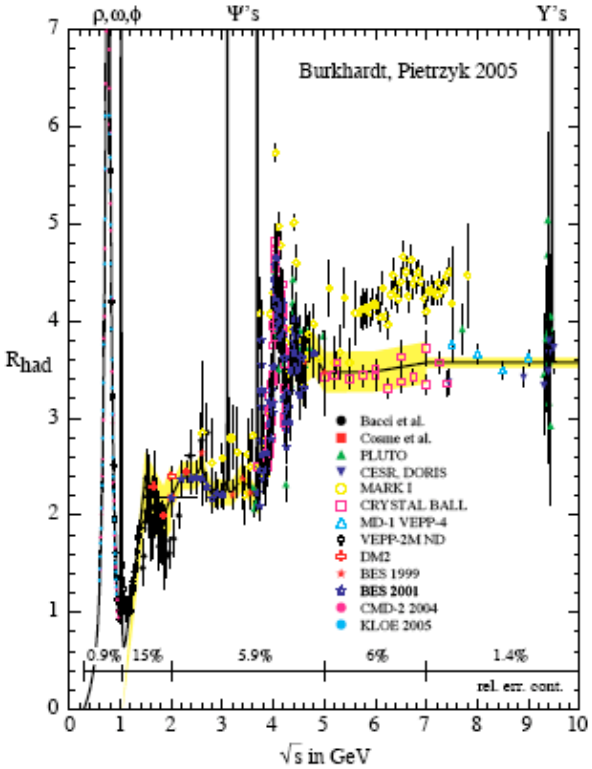
Knowledge of α_{EW} and $\sin\theta_{eff}$

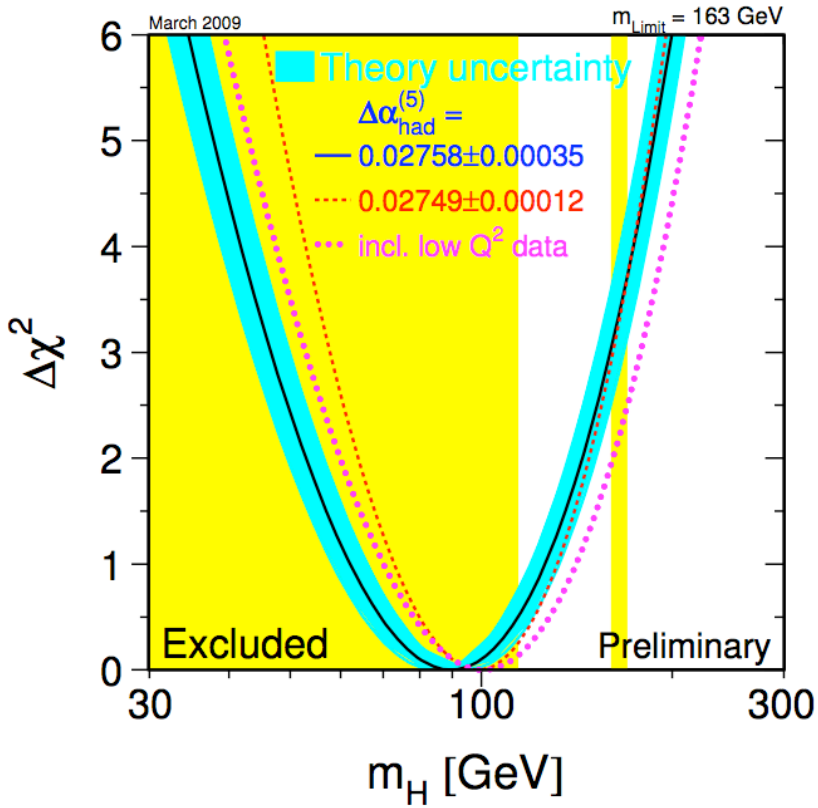


virtual pairs

$$\Delta\alpha_{\rm lept} = 0.031498 \quad (3-{\rm loop})$$
$$\Delta\alpha_{\rm had} = 0.02758 \pm 0.00035$$

$$\Delta\alpha_{\rm had} = -\frac{\alpha}{3\pi} M_Z^2 \,{\rm Re} \int_{4m_\pi^2}^{\infty} ds' \frac{R_{\rm had}(s')}{s'(s'-M_Z^2-i\epsilon)}$$





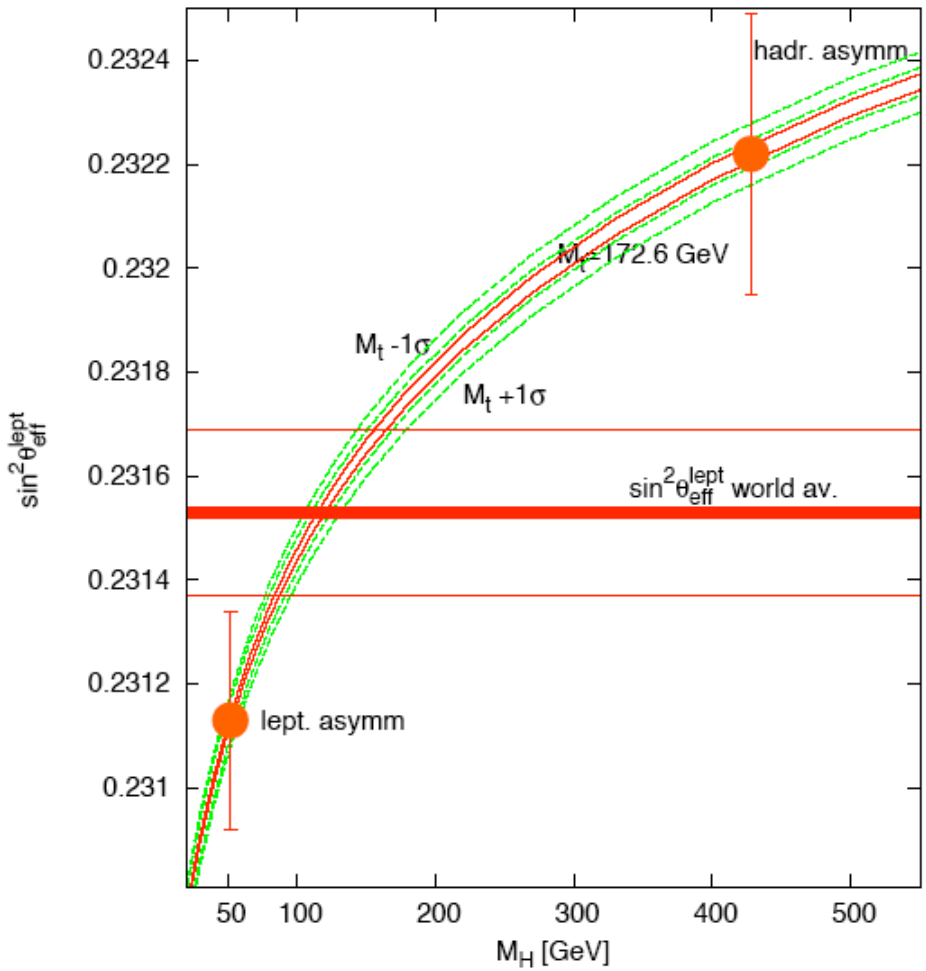
Knowledge of α_{EW} and $\sin\theta_{eff}$

$$\frac{\delta M_W}{M_W} \sim 0.23 \;\; \delta\Delta\alpha,$$

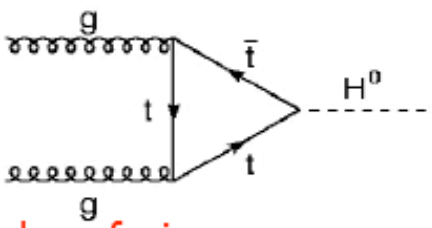
$$\frac{\delta \sin^2\theta}{\sin^2\theta} \sim 1.54 \;\; \delta\Delta\alpha$$

And α_{em}
is the least well measured
of the fundamental constant

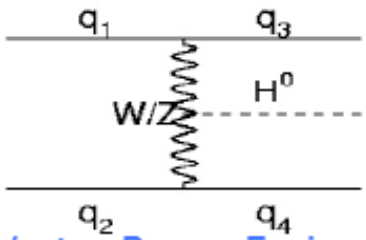
α_{em}	**3.1 x 10^{-4}**	**5%**
M(Z)	**2 x 10^{-5}**	**0.002 %**
G_F	**8.6 x 10^{-6}**	**0.0008%**
+		
α_s	**2.3 x 10^{-2}**	



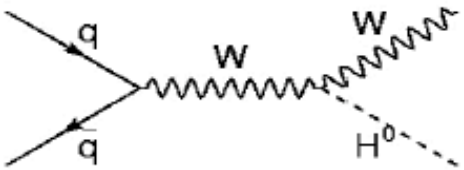
Higgs Production Cross Sections



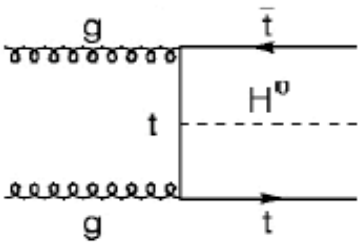
gluon fusion



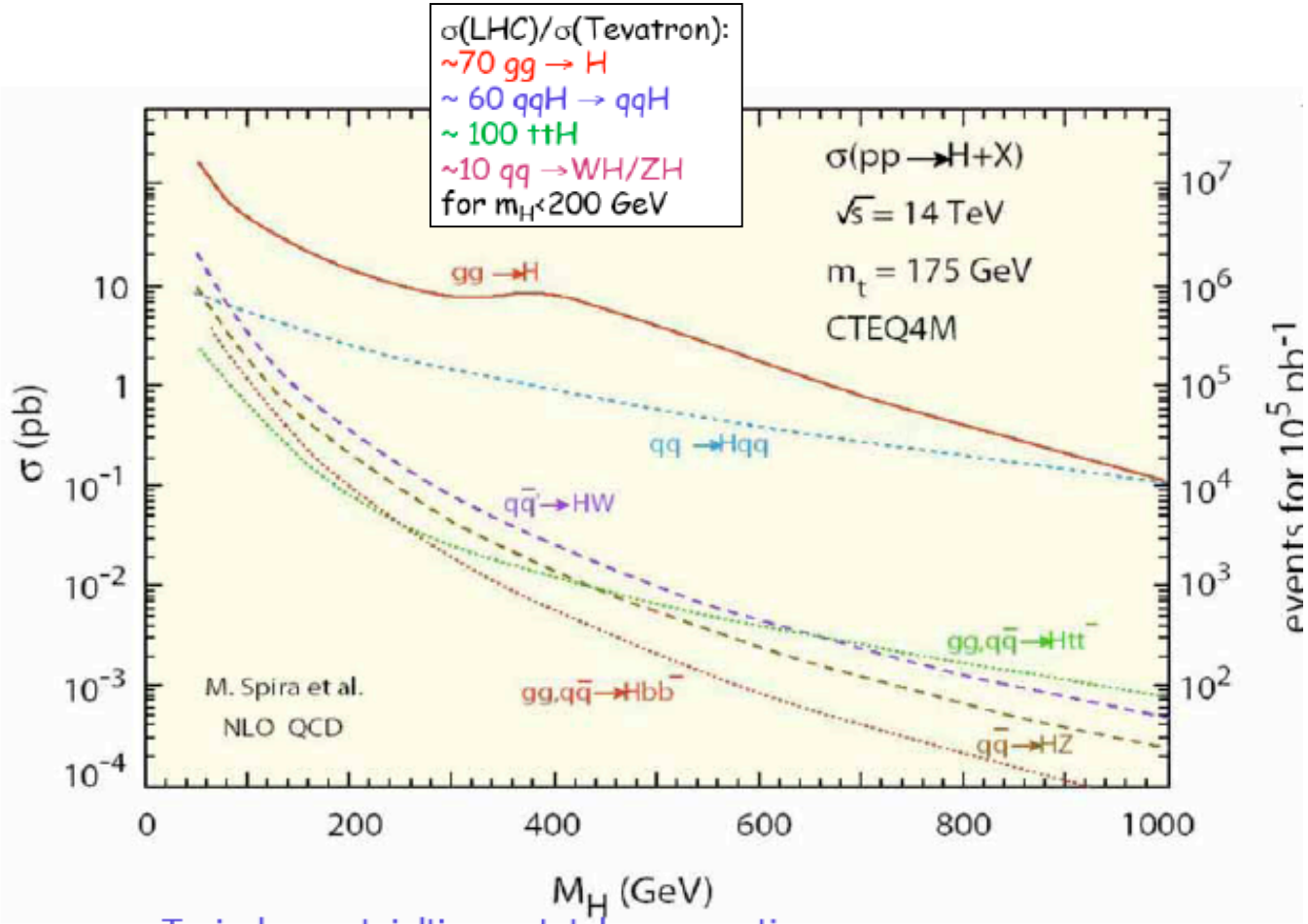
Vector-Boson-Fusion (VBF)



associated production (W, Z)



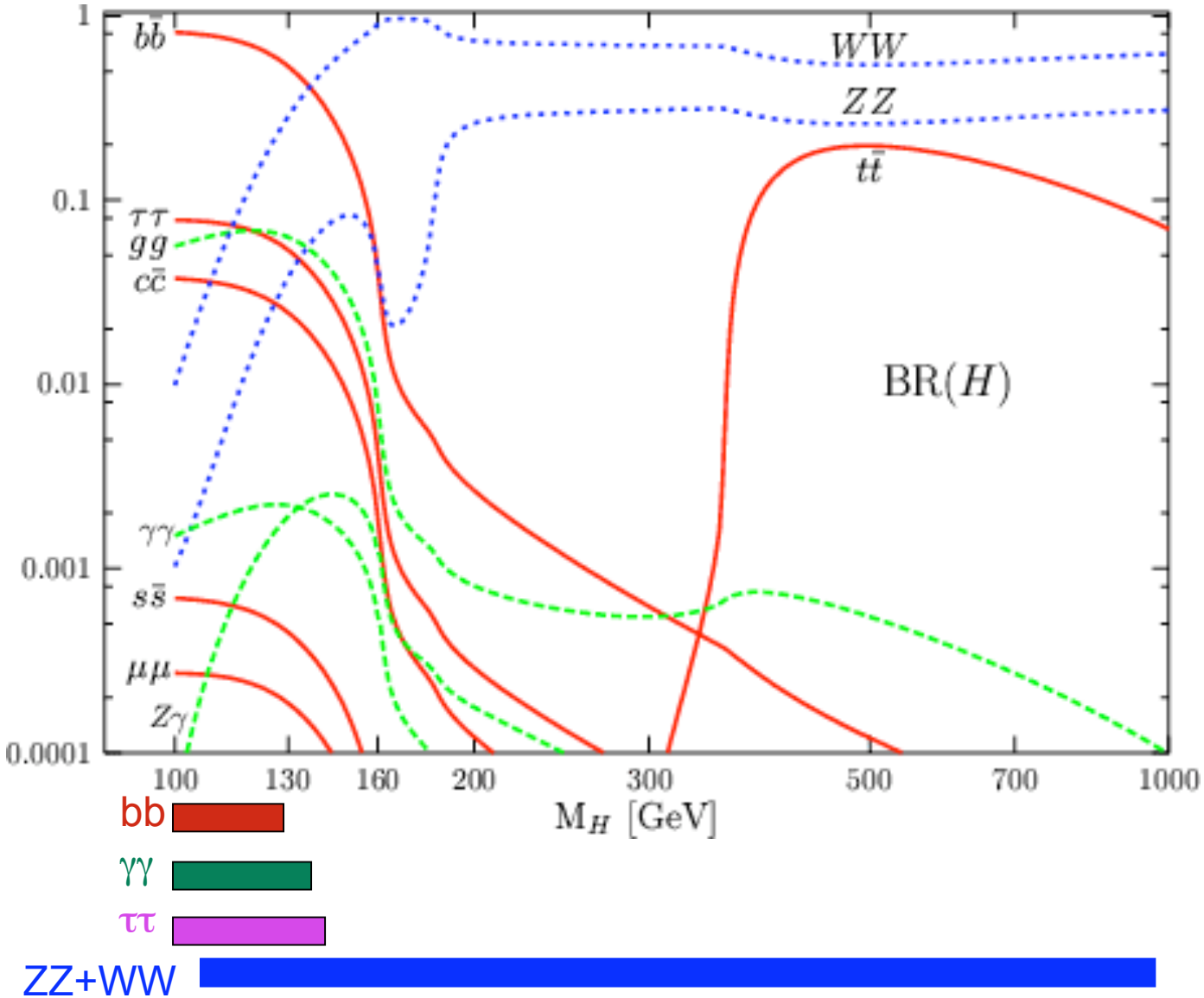
top fusion



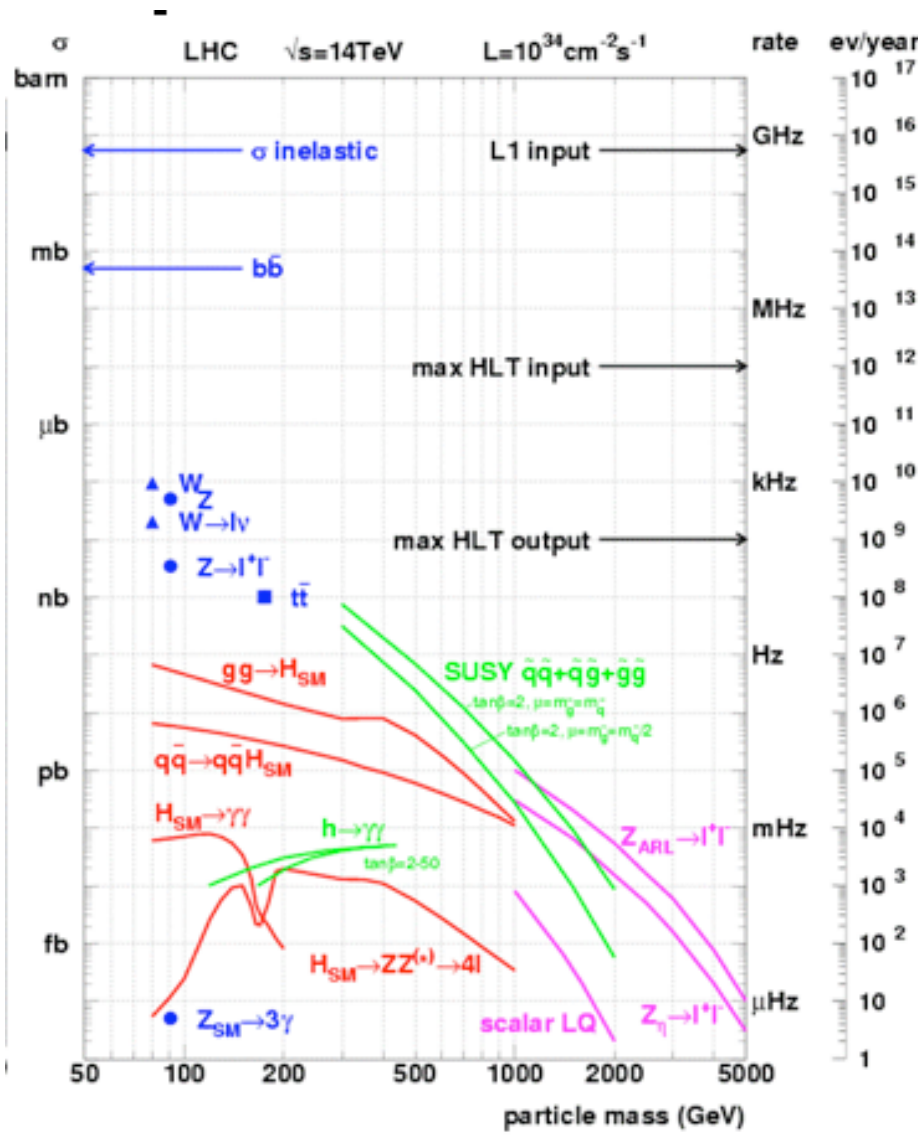
Typical uncertainlties on total cross-sections

gg	10%	NNnLO
VBF	5%	NLO
WH, ZH	5%	NNLO
ttH	15%	NLO

Higgs Branching Ratios



The Background

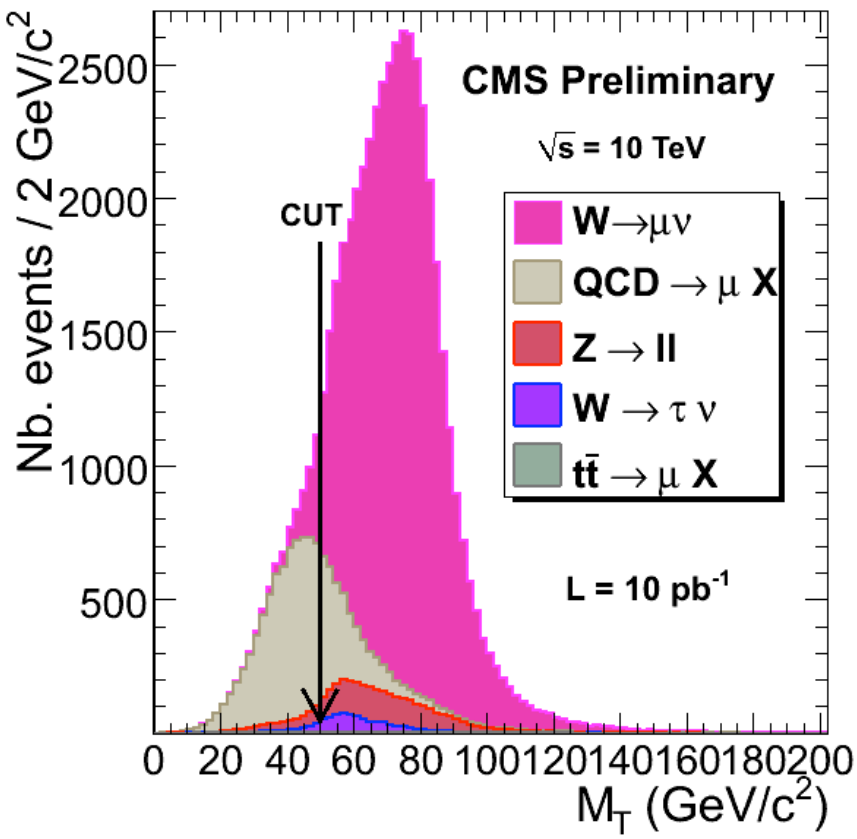


Process	Cross section	Events/s	Events/ year	Other machines
Total inel.	100 mb			
$\bar{b}b$	100 μb	10^5	10^7	10^8 Belle Babar
W->eν	20 nb	15	10^8	10^4LEP 10^7 TeV
Z->ee	2nb	1.5	10^7	10^7 LEP
g˜g˜	1pb	0.001	10^4	
H (200 GeV)	20 pb	0.01	10^5	
H(800 GeV)	1pb	0.001	104	

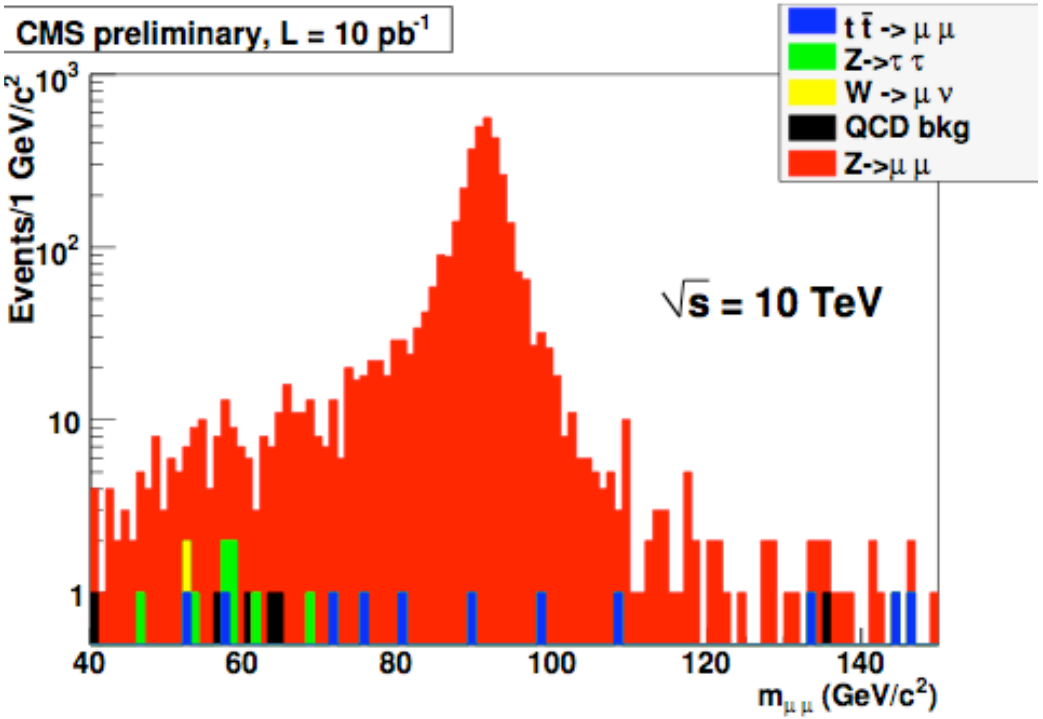
SM rediscovery

- The first data will allow us to re-discover the SM:
- CMS has to see again the Z and W, the tt production and the di-boson production.
- With these known processes it can establish the baseline to future discoveries.
- Data/MC should agree on known SM processes before claiming a new discovery
- It will not be trivial at all to have a good and tuned MC
- Data driven method should be used to control the background in order not to rely on the MC

SM: W and Z at 10 TeV with $10pb^{-1}$



Measurement of the Z and W cross section and of the Z line-shape -> (resolution and momentum scale)



If running at 6 TeV -> 0.6*sigma

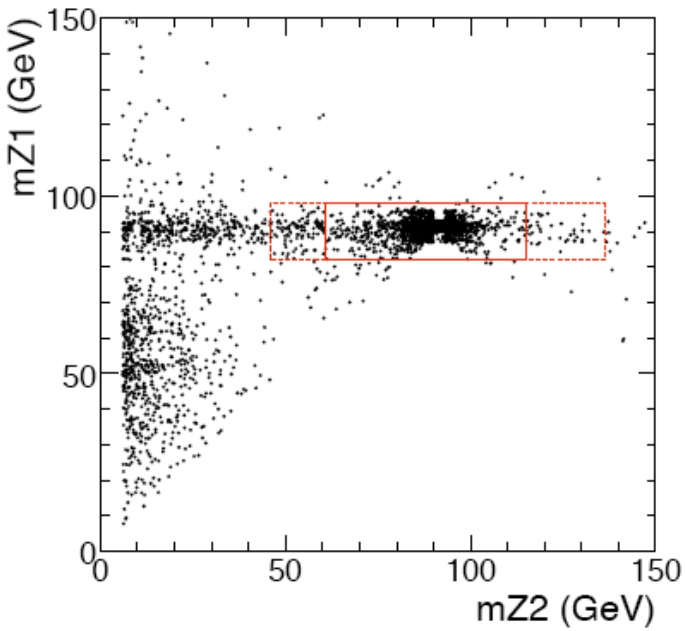
SM: observation of di-bosons at 10 TeV

- With 100 pb^{-1} at 10 TeV, 5σ observation of WW

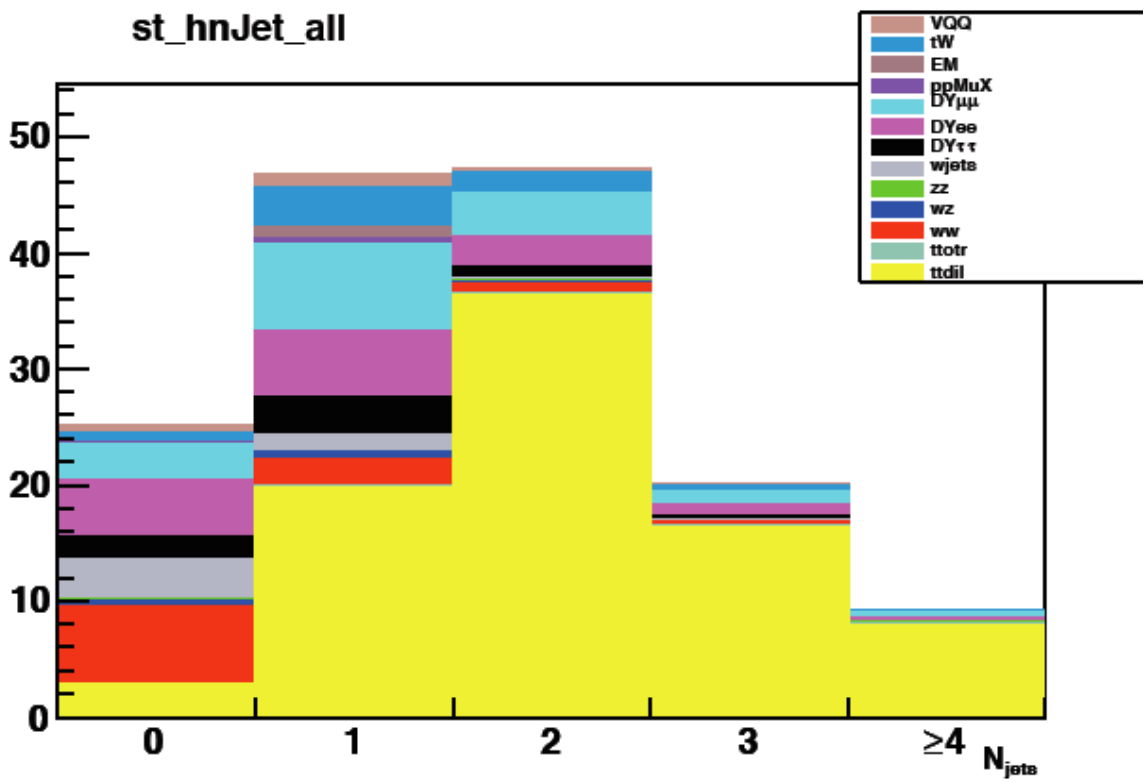
  σ(WW) ~ 74 pb -> Nevt ~ 35 Nbkg ~ 6

- With 133 pb-1 at 10 TeV, 5σ observation of ZZ

  σ(ZZ) ~ 18 pb -> Nevt ~ 3 Nbkg ~ 0.02



SM: Top at 10 TeV



Dilepton channel after 10pb-1

Cross section will be measured with the very first data

Higgs: Low Mass (M<130)

- The highest BR is into b-quarks
- Gamma-gamma has low BR, but is clean, provided a very good mass resolution (that CMS has!)
- WW and ZZ have lower BR but they will contribute!

	Tevatron Main Search Channels	LHC Main Search Channels
m_H ~115 GeV	WH→ lνbb ZH → ννbb, llbb	H → γγ, qqH → qqττ ttH→ lνbbX
m_H ~ 160 GeV	H →WW → lνlν	H → WW→ lνlν,H→ZZ*→4l, qqH→ qqWW→ qqlνlν

Large backgrounds at the LHC

Cross-sections too small at the Tevatron

H -> bb

- H->bb : it was studied in tt-associated-production but considered impossible for a discovery. Since then news ideas (yet to be studied):

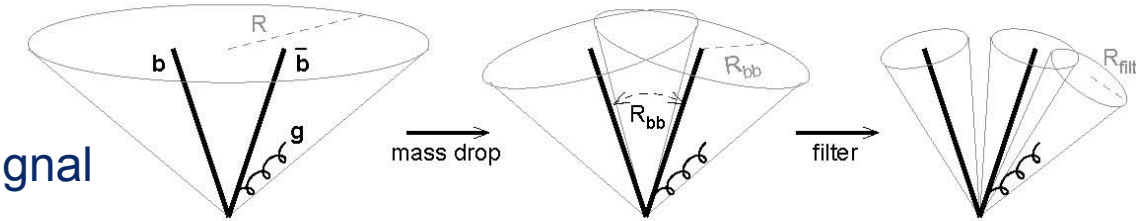
  HV, H->bb with pt(H) > 200 GeV

  VBF H , H->bb+γ/W for bb-coupling measurement

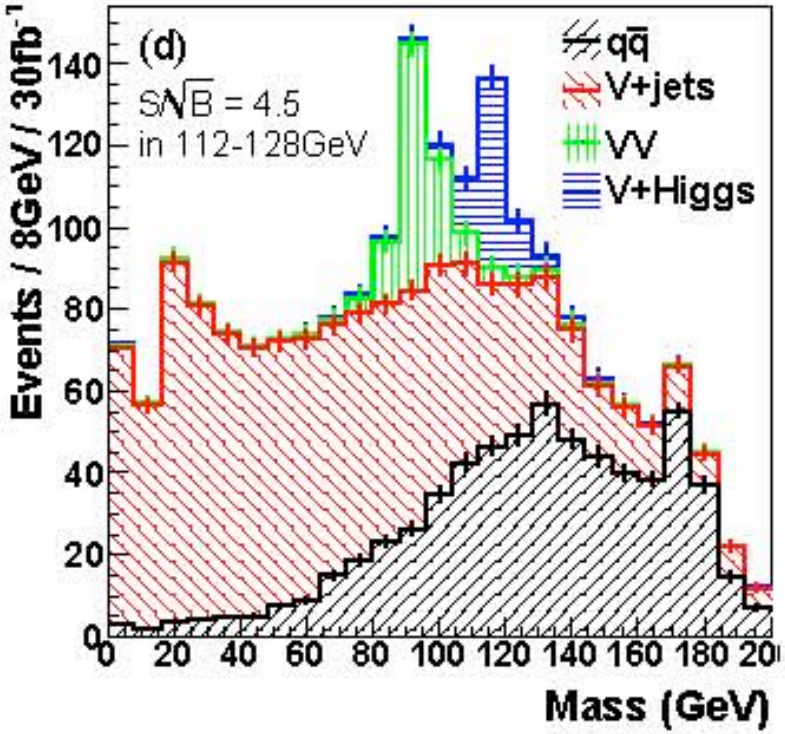
  bH, H->bb, bbb final state (under study in CMS)

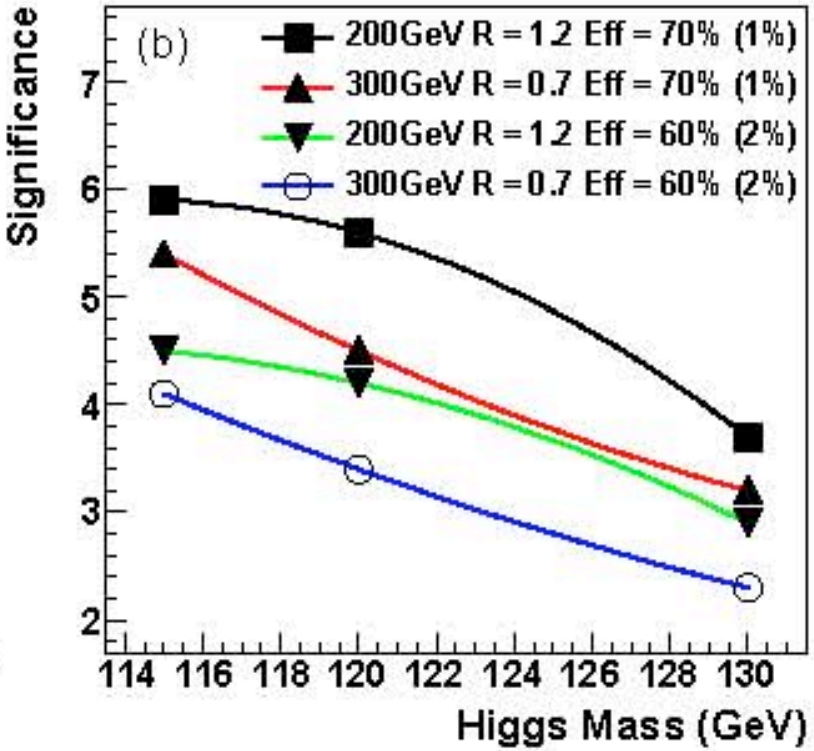
H->bb: WH, ZH Large Higgs p_T

- Proposed by J.M.Butterworth et al.
- WH,ZH H->bb
- M_H : 115-130 GeV
- p_t>200 GeV, retain ~5% of signal
- Generator level study
- Search for wide b-jet



IntL = 30 fb^{-1} at 14 TeV

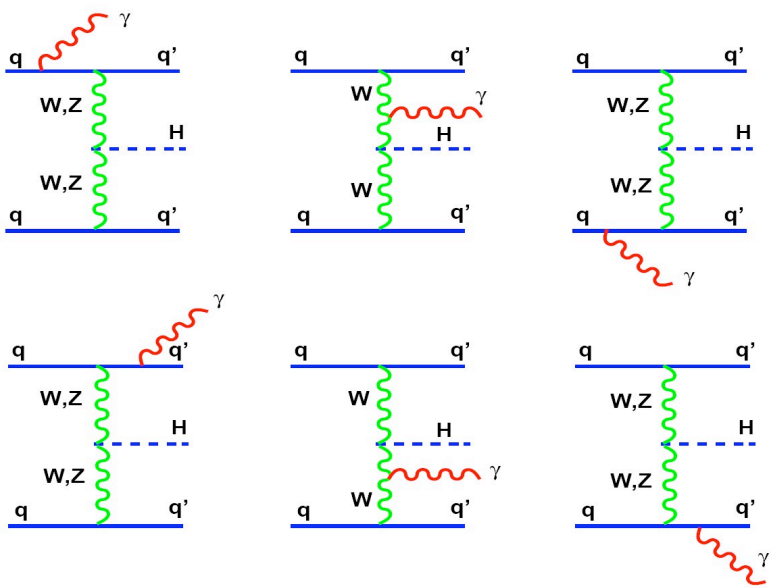




VBF H, H-> bb + γ/W

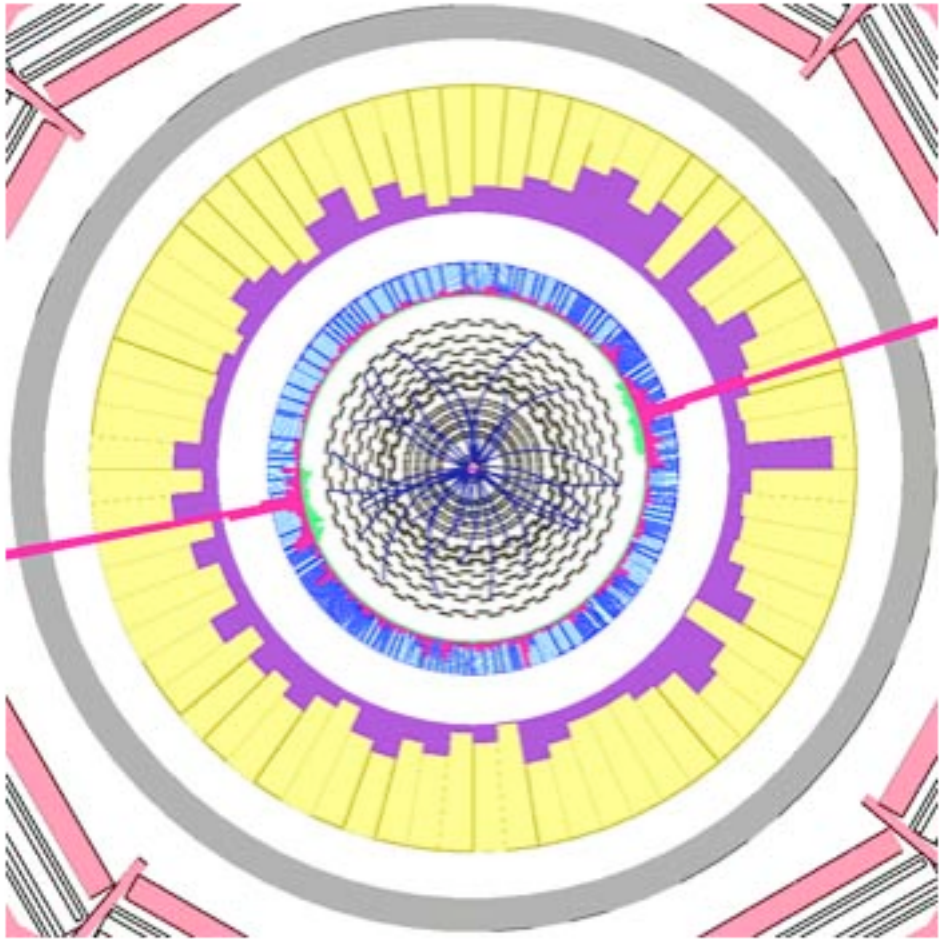
- qqH + additional W, W->lν, H->bb
  - initially proposed by D. Rainwater
  - recently re-analysed by A. Ballestrero et al.
- qqH + hard γ, H->bb
  - Gabrielli et al.

$S/\sqrt{B}$ increases by 10 when asking a hard γ
$S/\sqrt{B}$~3 with L=300 fb^{-1}



- Both the lepton from W and the hard γ make the trigger more efficient
- $P_{t\gamma}$>20 gev improves s/b because:
  - BG such as bbγjj have a large gluonic component
  - destructive interference for emitting central photons in BG
- Need full analysis by experiment before being confident that they are feasible

H -> $\gamma\gamma$



-look for $\gamma\gamma$ in all the Higgs production mode: gg, VBF, VH, ttH
-Higgs can be fermiophobic, thus could be seen with low luminosity

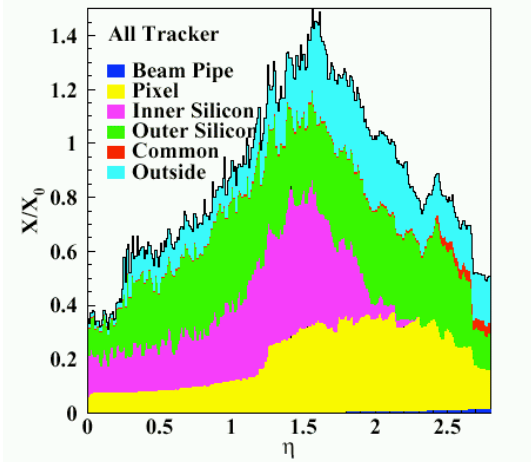
The challenge!

- The material budget

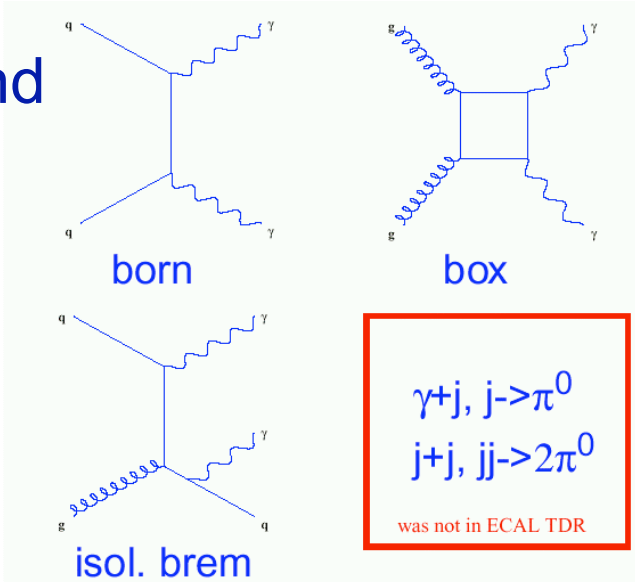
fraction of photons converting before ECAL

	Unconverted	Converted (Invisible)	Converted (Visible)
Barrel (ECAL TDR)	76.2 %	5.0 %	18.8 %
Barrel (present)	58.0 %	10.7 %	31.3 %
EndCap (ECAL TDR)	65.1 %	8.7 %	26.2 %
EndCap (present)	40.5 %	14.4 %	45.1 %

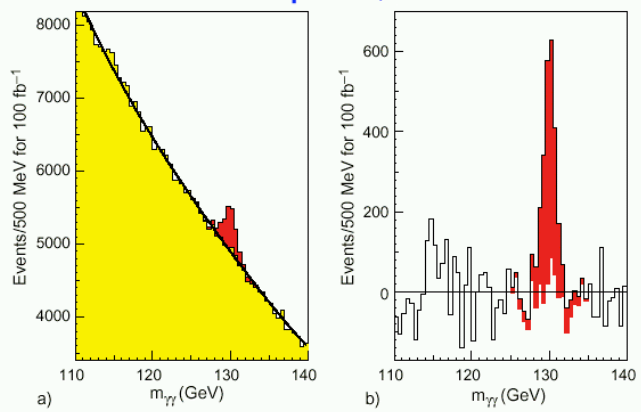
current design



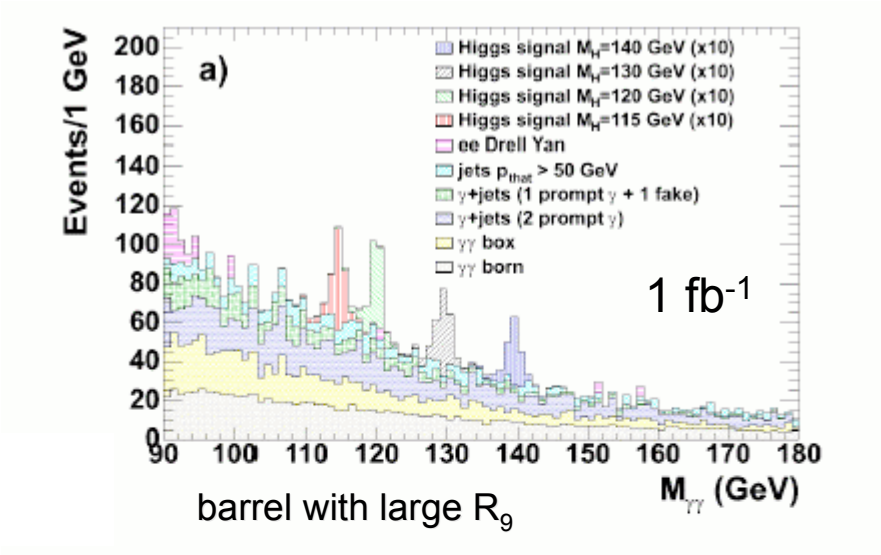
- The background



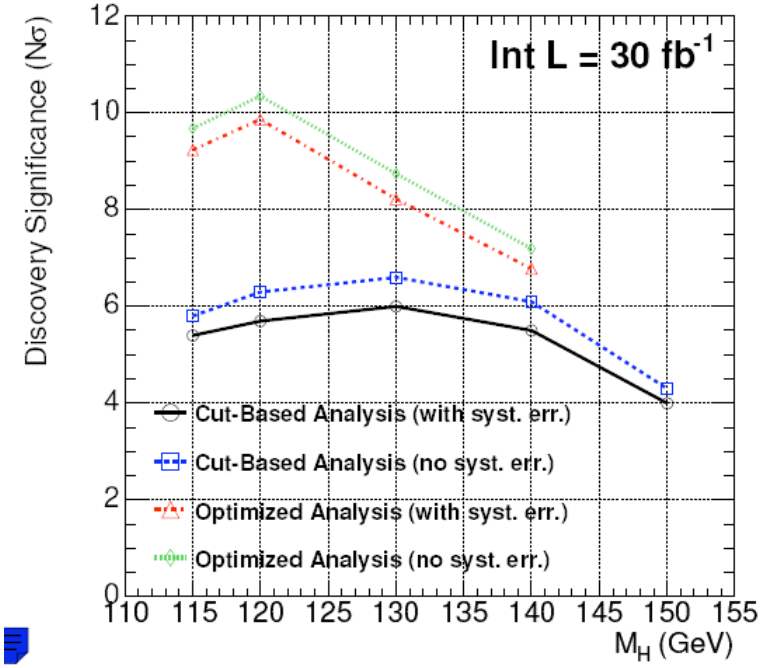
ECAL TDR plots, $L=10^{34}cm^{-2}s^{-1}$

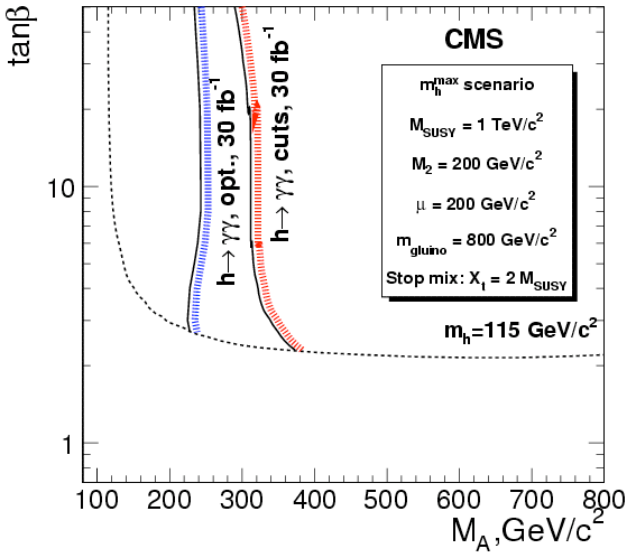


The performance at 14 TeV



barrel with large R_9

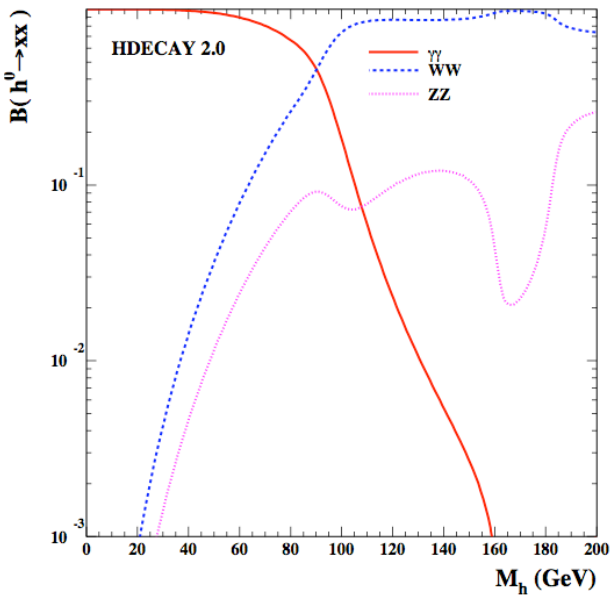




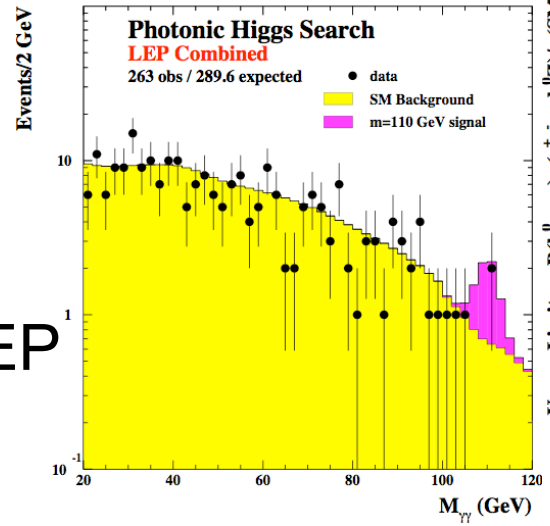
Significance for SM Higgs M_H=130 GeV for 30 fb^{-1}

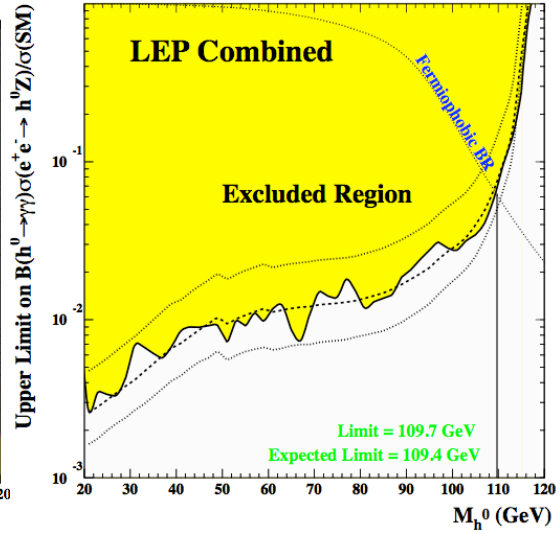
ECAL TDR	Phys TDR 2006	
count. exp	cut based	optimized
~ 7.5	6.0	8.2

Fermiophobic Higgs



LEP



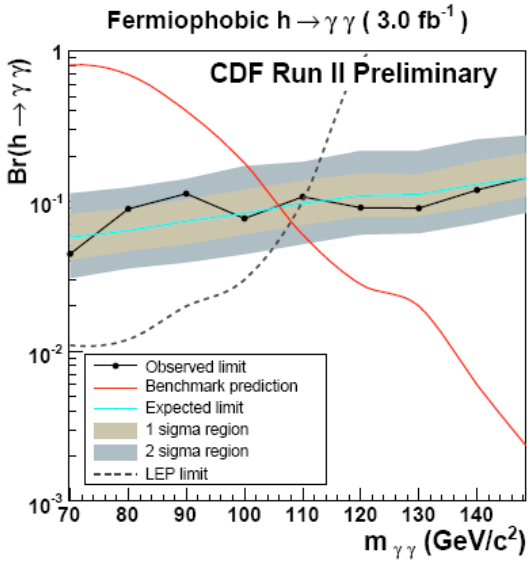


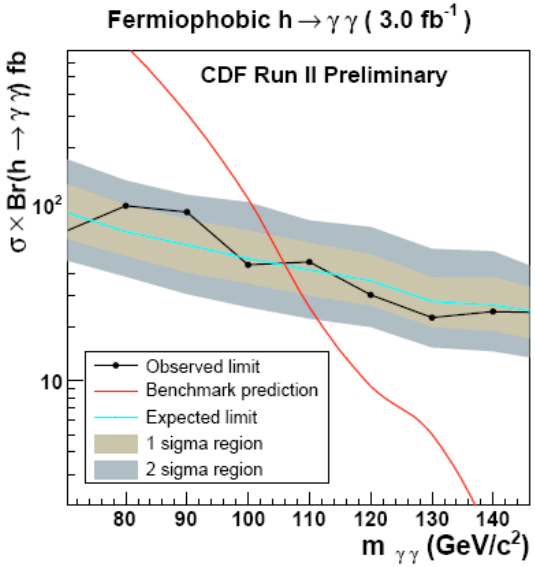
In 2HDM one Higgs couples to fermions $\propto \cos\alpha$

If $\alpha=\pi/2$ then it is suppressed.

Thus decays into WW,ZZ or $\gamma\gamma$

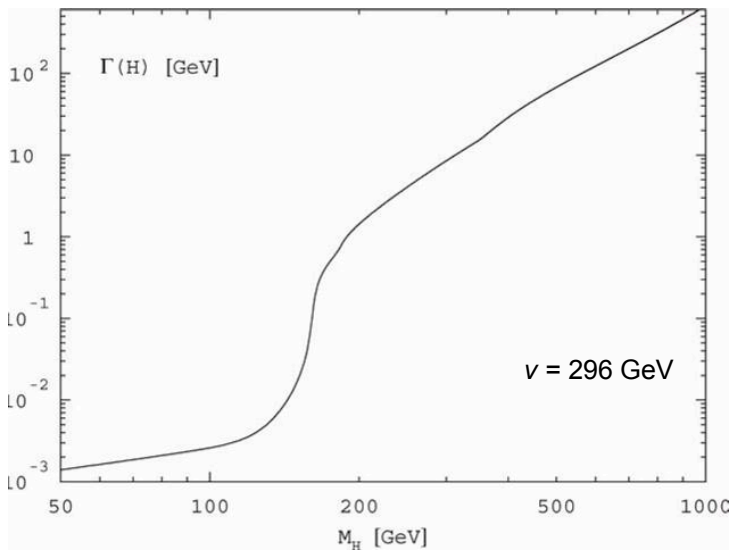
Limits from LEP and Tevatron!

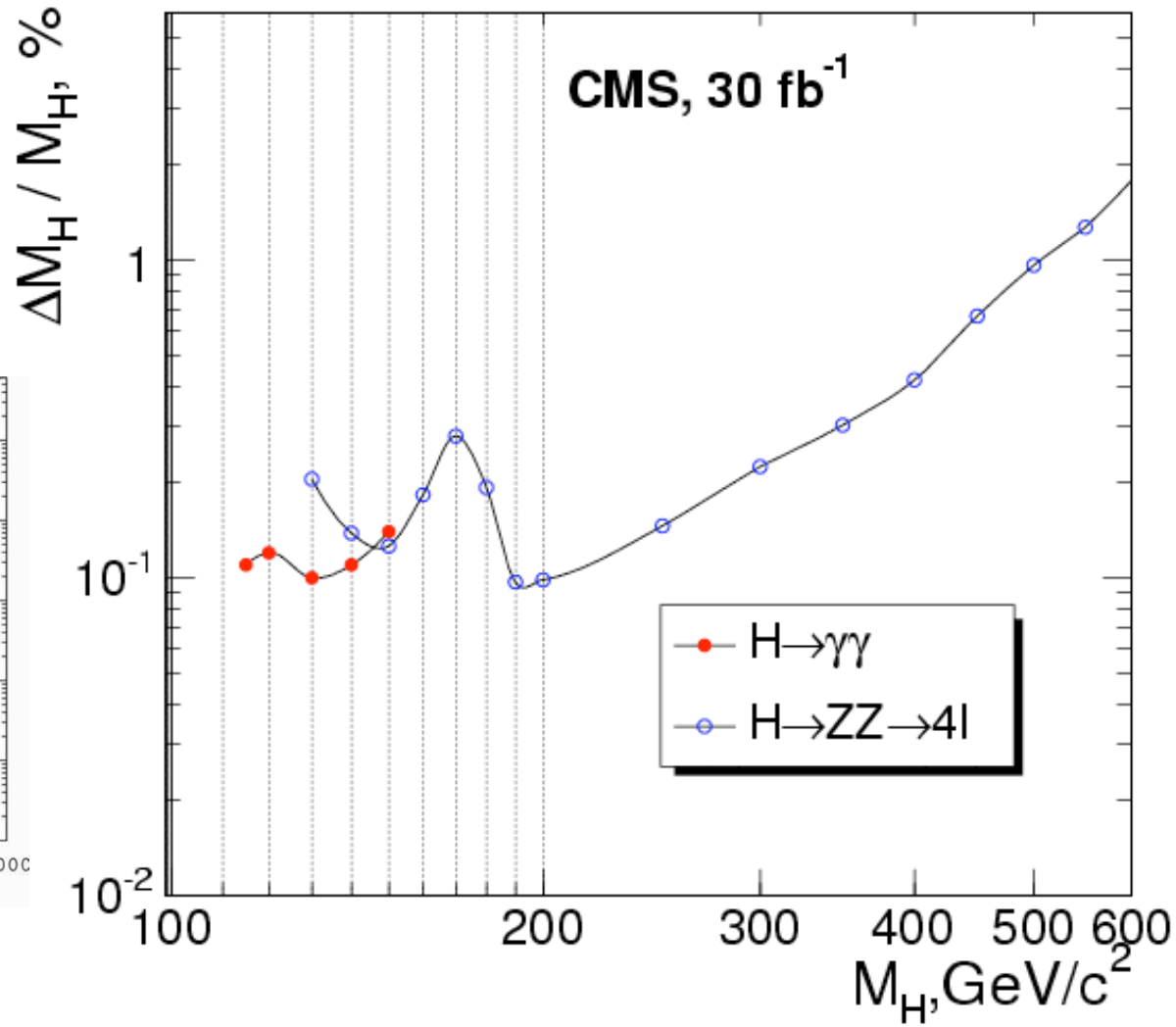




The Higgs Mass measurement

$$\Gamma_H(H \to VV) = \frac{3}{32\pi}\frac{m_H^3}{v^2}$$

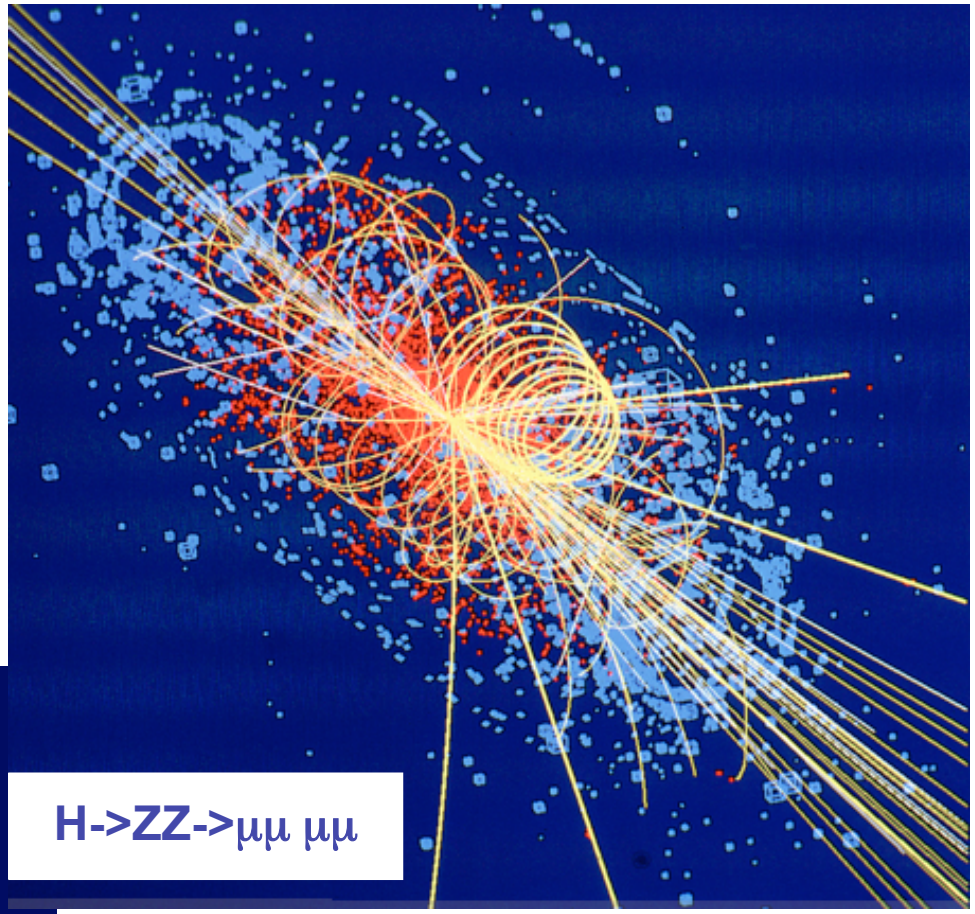


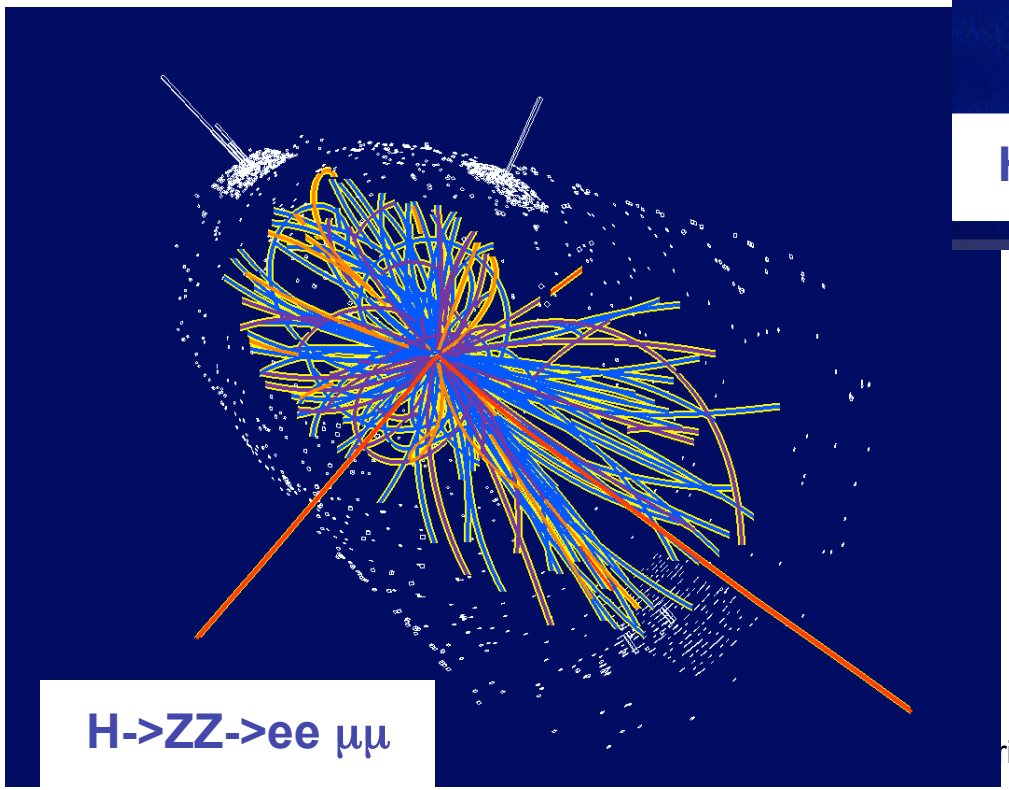


Higgs: ZZ and WW final state

- WW and ZZ decays will cover basically the full range (production via gg and VBF)
- H->WW: higher cross section and first channel at LHC!
- H->ZZ : very clean and very good mass resolution

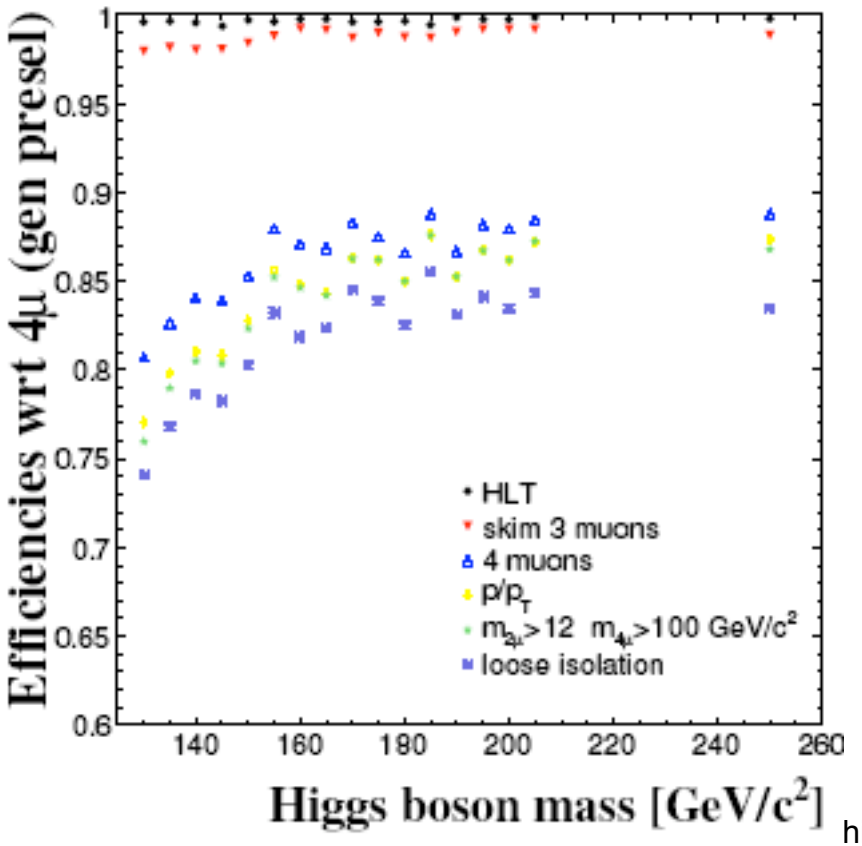
H->ZZ->4leptons

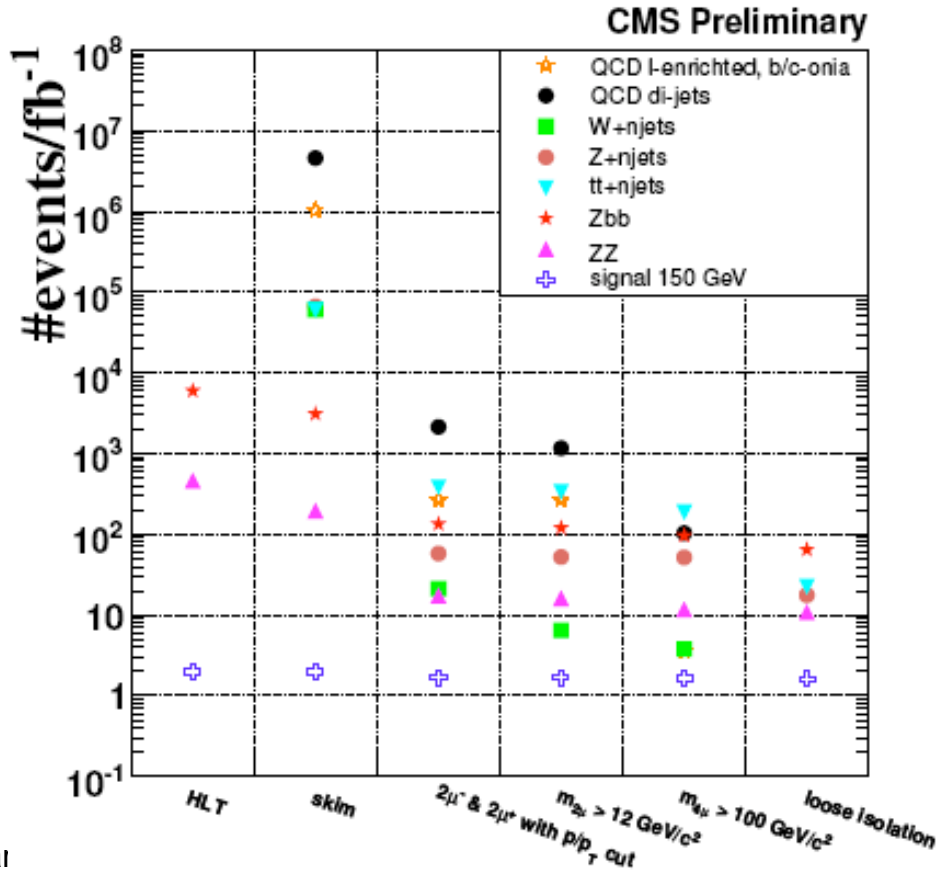




H->ZZ->4leptons

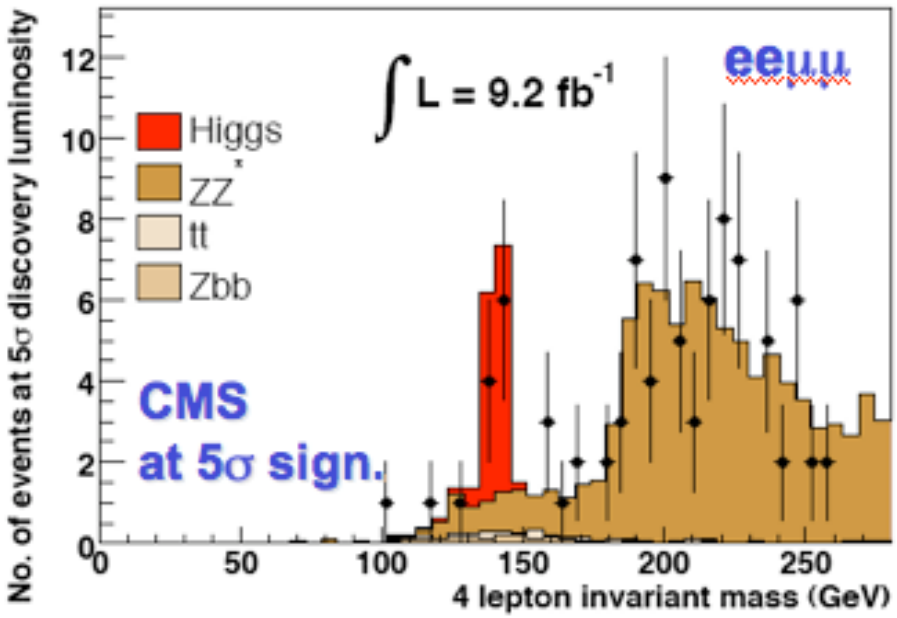
- Very clean final state: 4 isolated leptons of high p_T, coming from the primary vertex
- Background: QCD, V+jets, tt+jets, Zbb reducible
- EW ZZ irreducible!

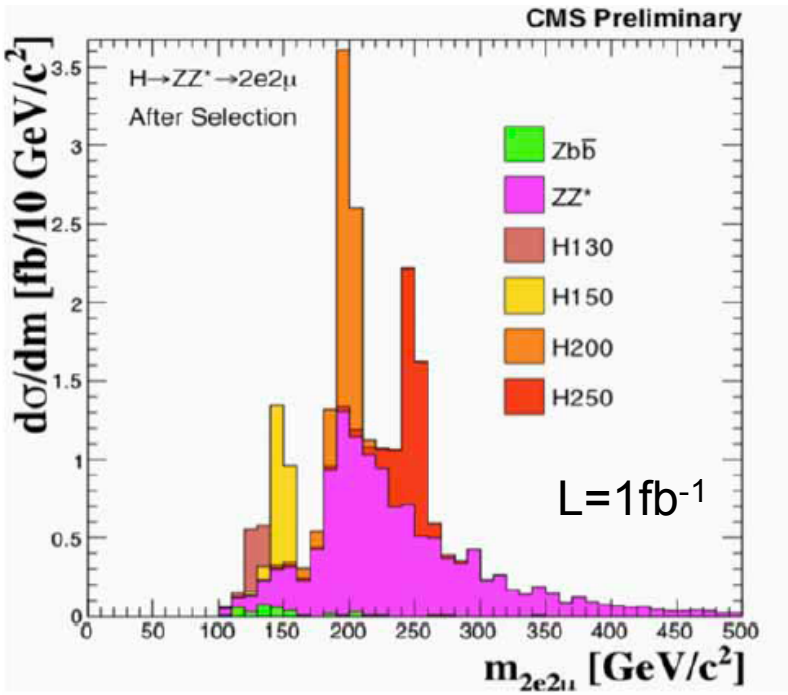




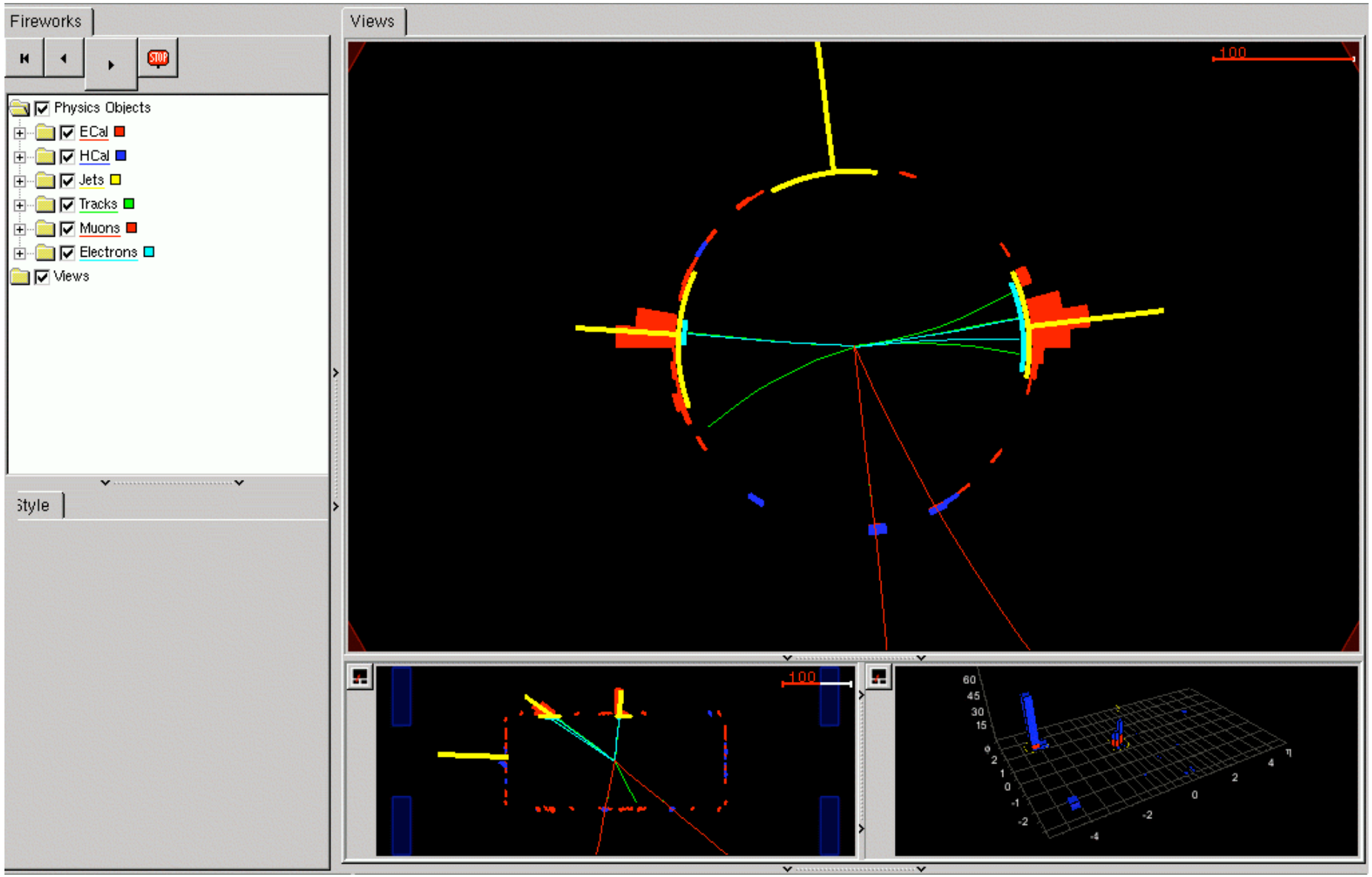
hiar

H->ZZ->4leptons

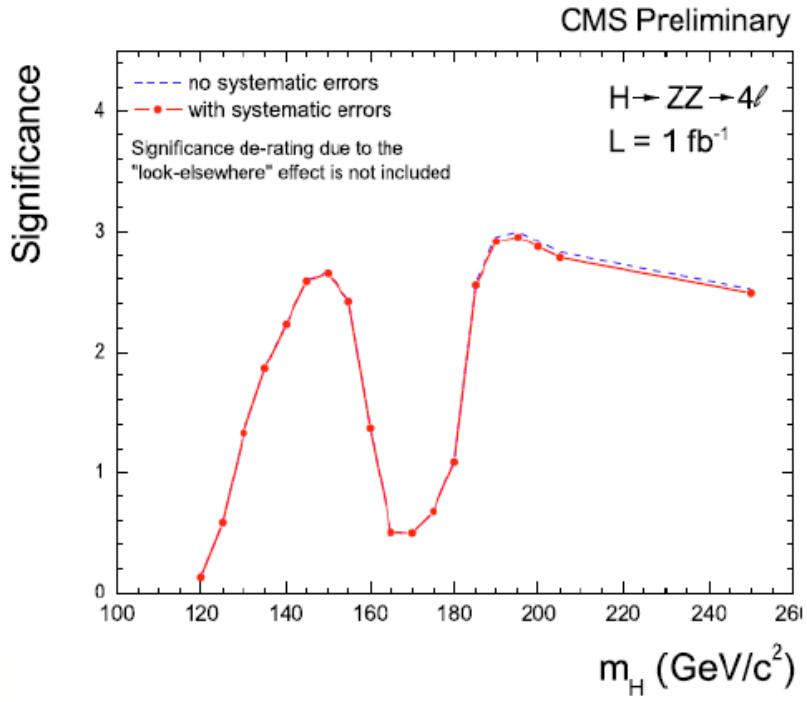


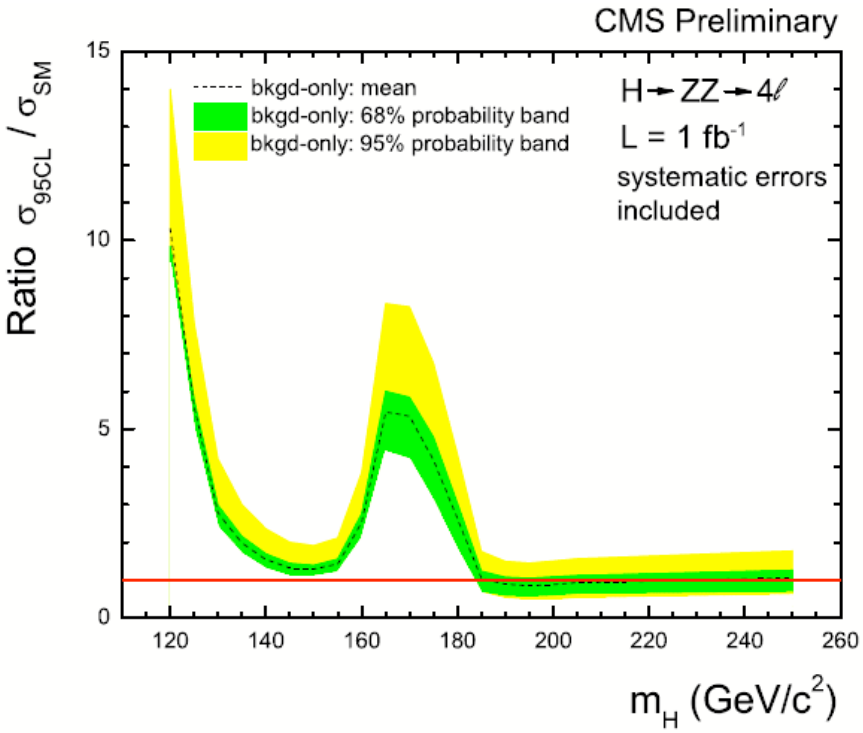


Is the background really reducible?

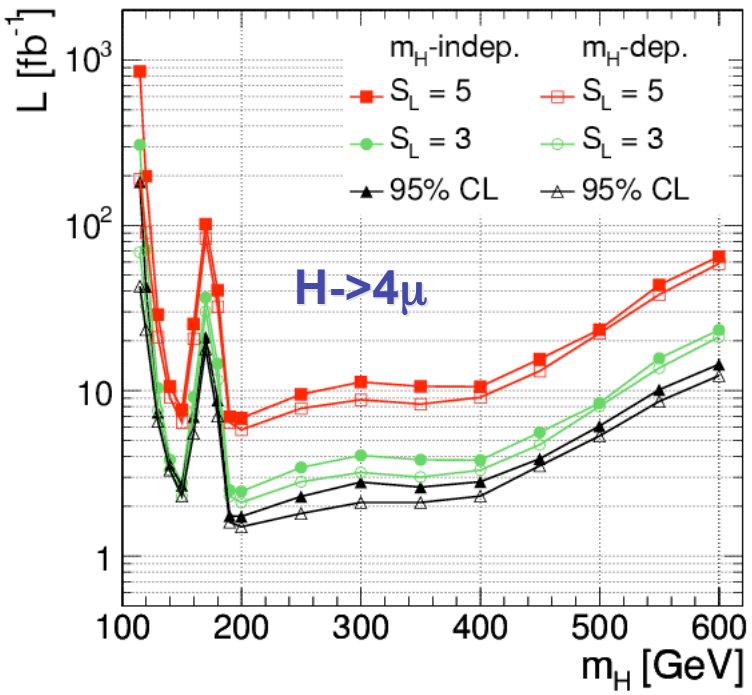


After L=1fb^{-1}





Then

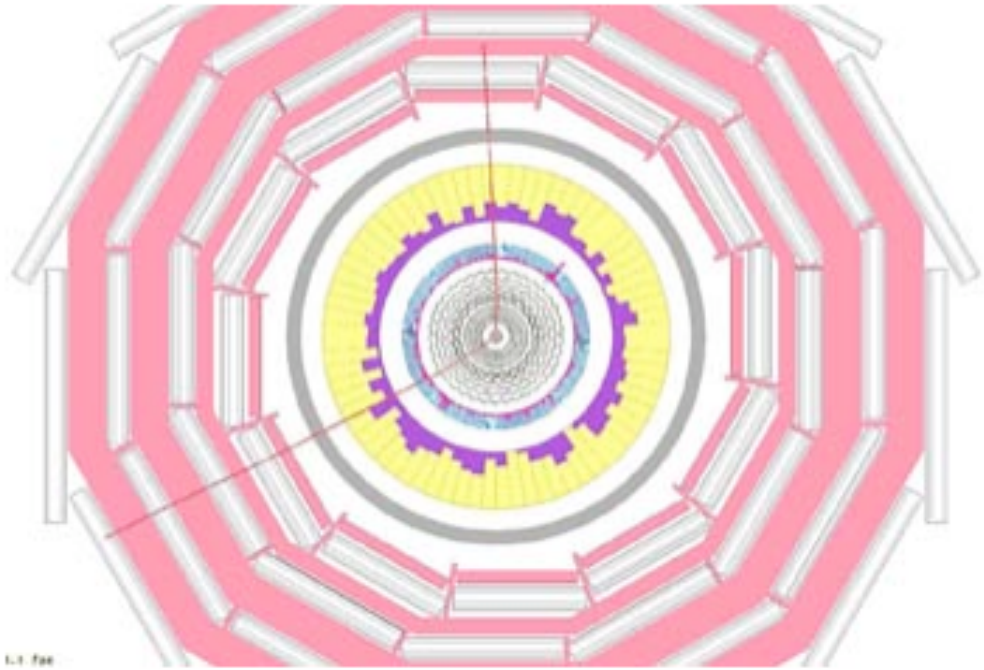


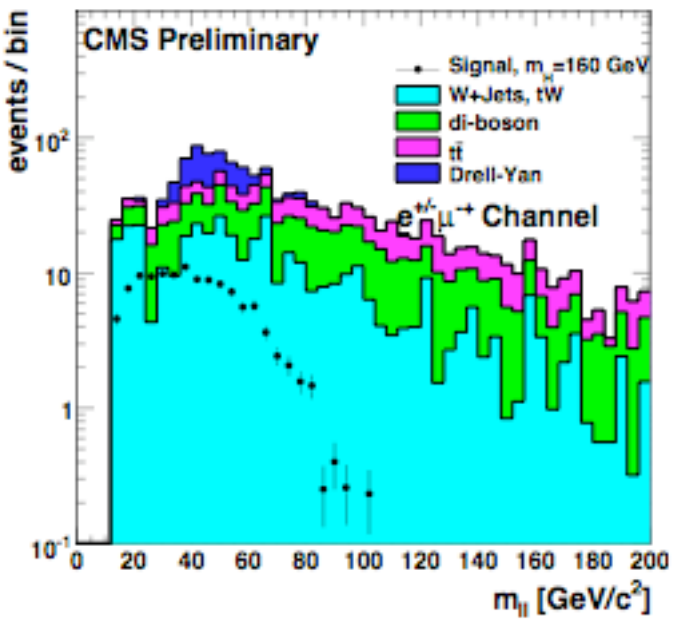
H->WW->ll$\nu\nu$

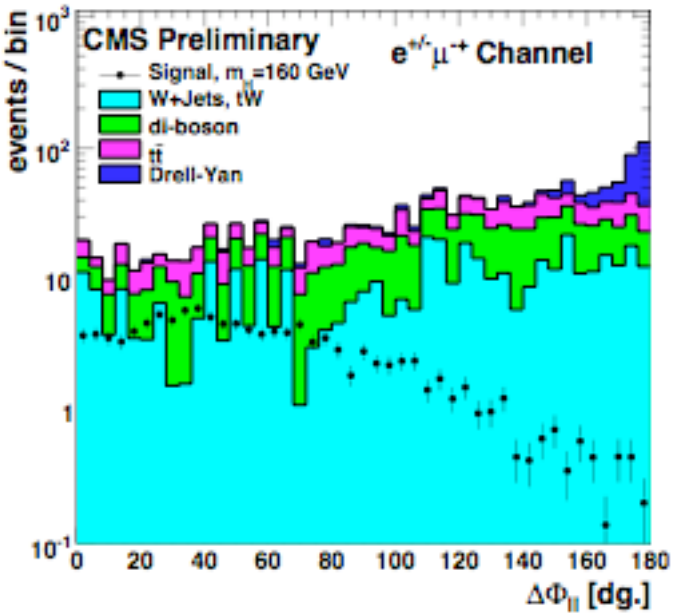
- H->WW->ll$\nu\nu$: no mass peak
- The control of the background is essential!

  CMS developed data driven methods to control the background
- Large cross section, so first exclusion/discovery channel!

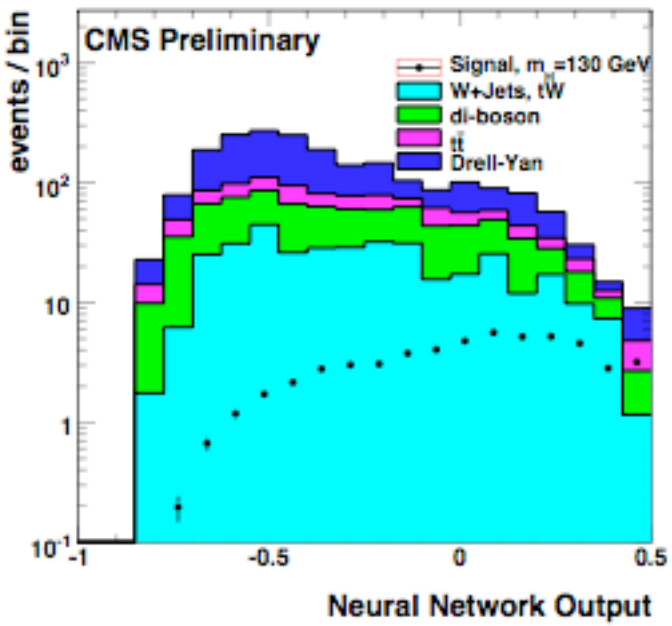
- Tevatron already covered the "easiest" region

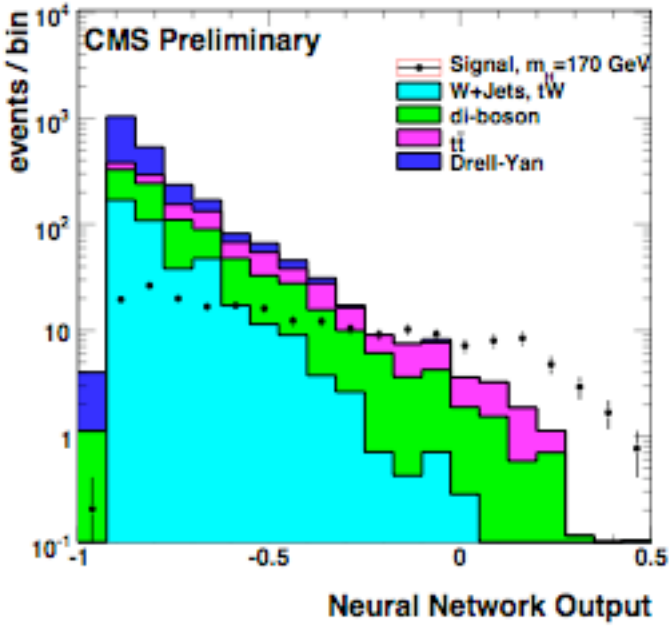






The 2 most discriminant variables m(ll), $\Delta\phi$(ll)





NN output for
M(H)=130 GeV
M(H)=170 GeV

Signal and Background and Systematic

	HWW (160 GeV)	*WW*	*WZ*	*ZZ*	*tW*	$t\bar{t}$	*W+jets*	*DY*
ee preselection	81	258	277	122	215	2472	150	15340
Final selection	20.1	13.7	1.7	0.0	0.0	4.3	2.0	1.0
$\mu\mu$ preselection	143	459	226	184	461	5128	177	39814
Final selection	21.0	10.0	0.1	0.0	0.3	6.0	0.1	0.6
$e\mu$ preselection	195	632	42	4	604	6008	453	471
Final selection	31.5	16.0	0.3	0.0	1.4	7.0	6.3	0.0

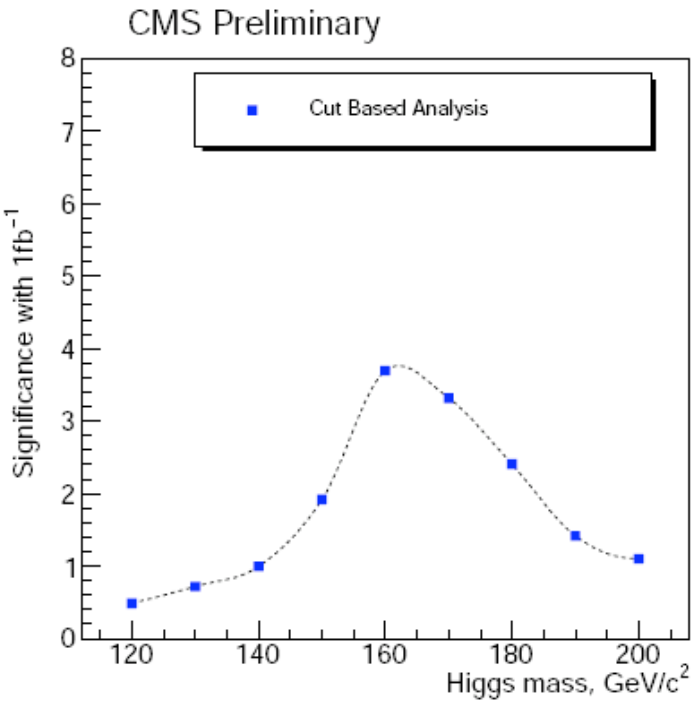
WW is the dominant bkgd

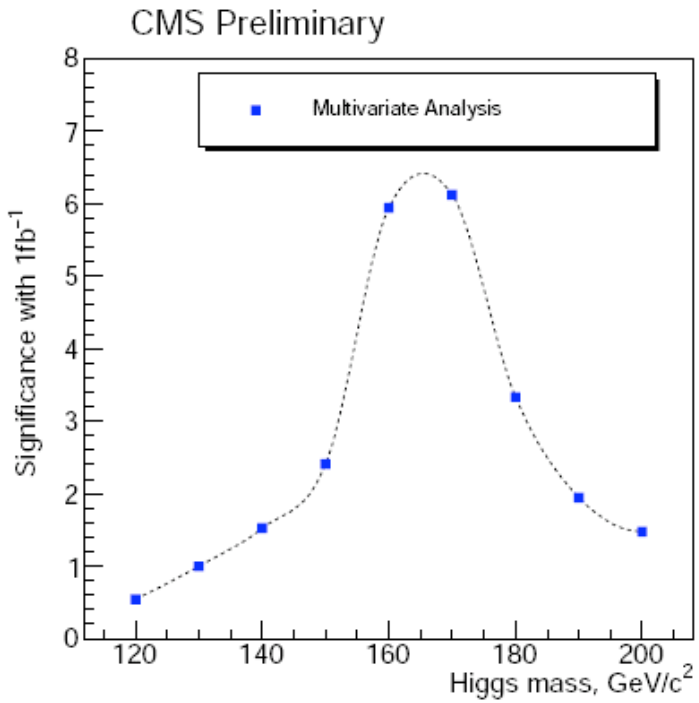
Source	Signal (%)	Background (%)
Luminosity	5	5
Lepton & trigger efficiencies	4	4
Muon miscalibration and misalignment	2	2
Electron miscalibration and misalignment	4	4
E_T^{miss} modeling	1	2
Jet reconstruction	3	8
PDF uncertainties	5	5
$t\bar{t}$ cross-section	—	18
WW cross-section	—	22
WZ/ZZ/W*t* cross-sections	—	10
DY cross-section	—	5
W+jets cross-sections (fakes)	—	100
MC statistics	5	10

Systematics estimated with data-driven methods

Significance at $1fb^{-1}$, 14 TeV

- Detector mis-alignment/mis-calibration
- more conservative bkg. systematic
- Optimized selections for each mass point

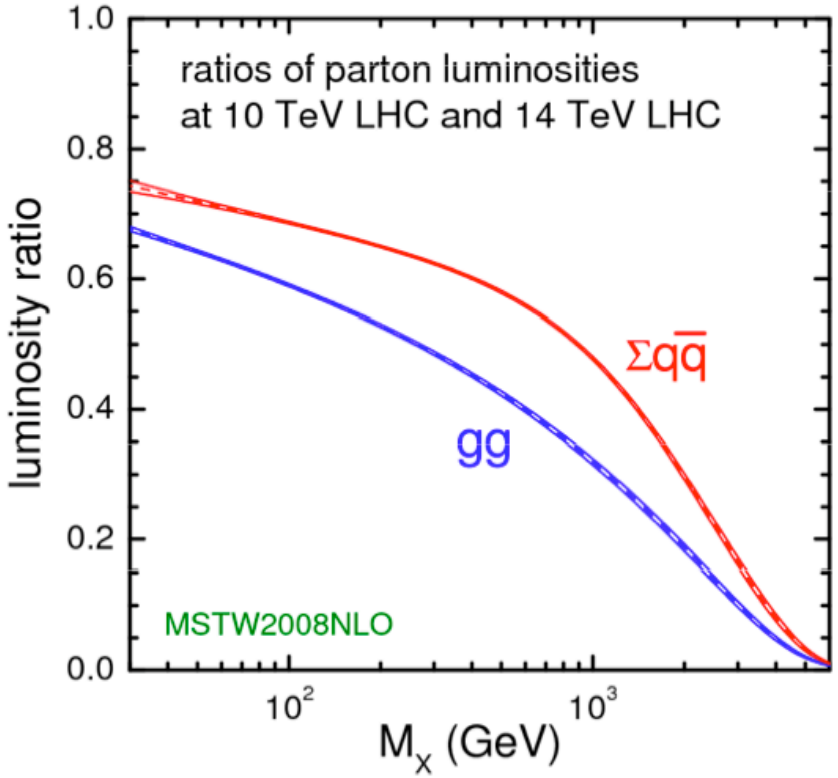


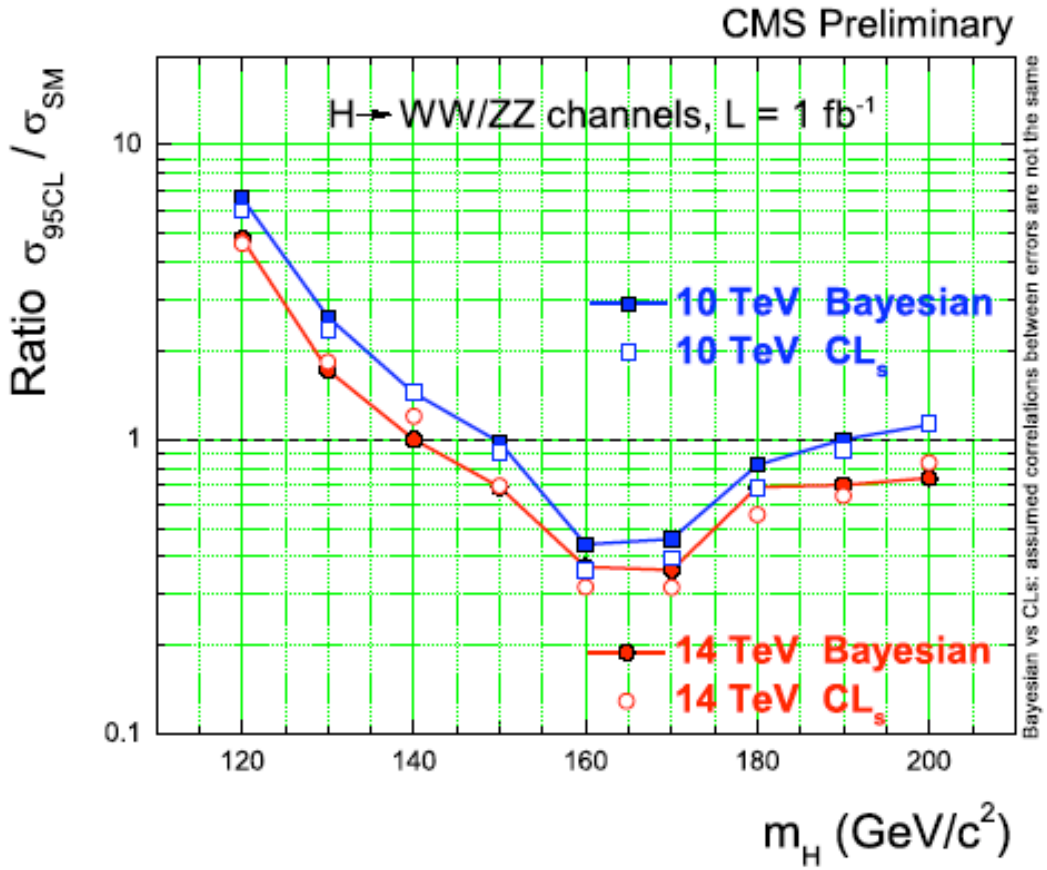


If taking data at 10 TeV

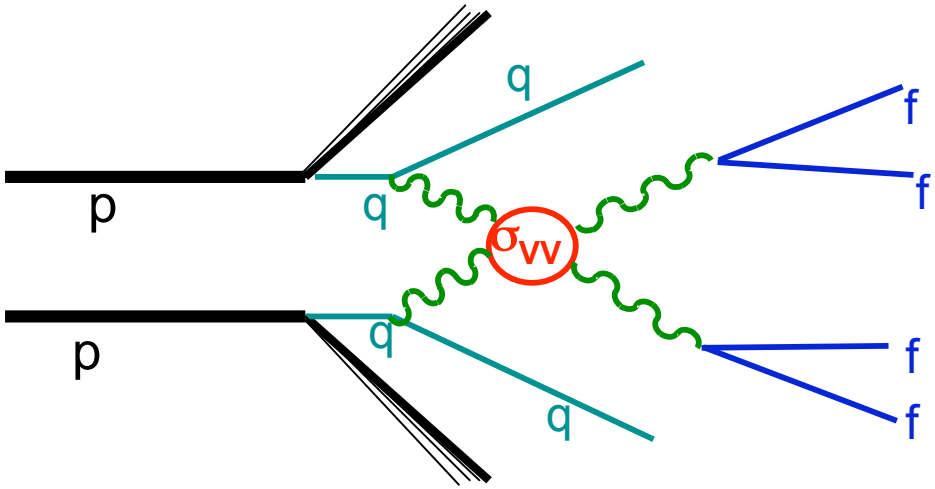
σ(@10 TeV) ~ 1/2 σ(@14 TeV)

We will need at least twice the luminosity





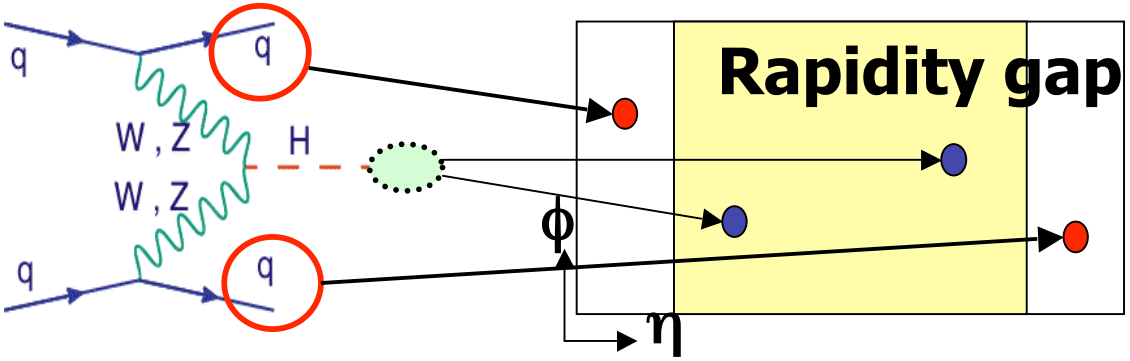
VBF: A probe to Symmetry Breaking



- If the Higgs exists a resonance will be observed in the M_{VV} spectrum at $M_H = M_{VV}$
- Without the Higgs, the V_L's interact strongly at high energy and the $V_L V_L$ cross-section violates the unitarity at $M_{VV} \sim$ 1-1.5 TeV → deviation from SM prediction
- Whether H exists or not, $V_L V_L$ should be studied in detail to verify if weak or/and strong interactions occur

WW scattering holds the key to EWSB

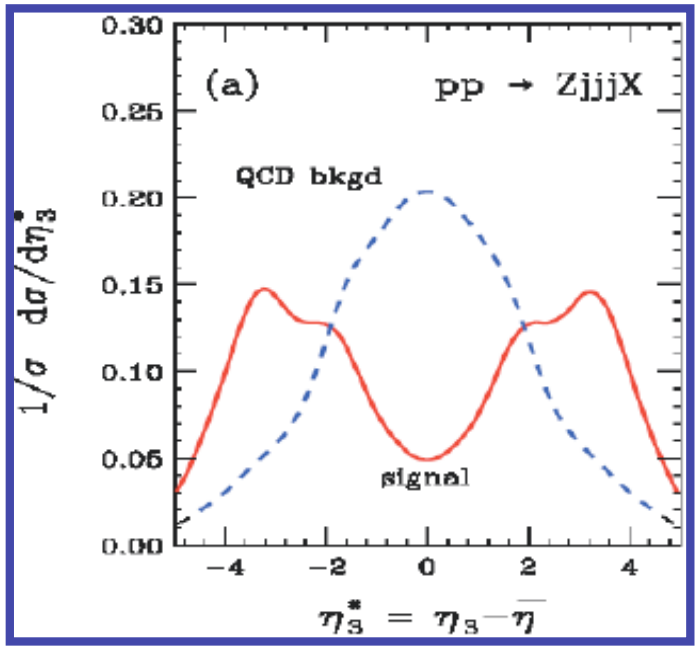
VBF: a peculiar signature



- Energetic jets in the forward/backward directions
- Higgs decay products between the tagging jets

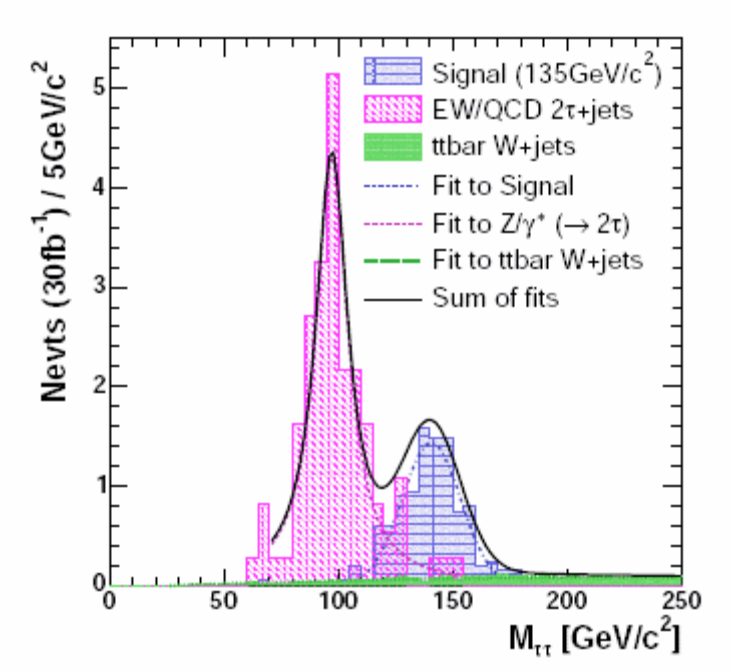
- Sparse gluon radiation in the central-rapidity region, due to colorless W/Z exchange -> central jet veto

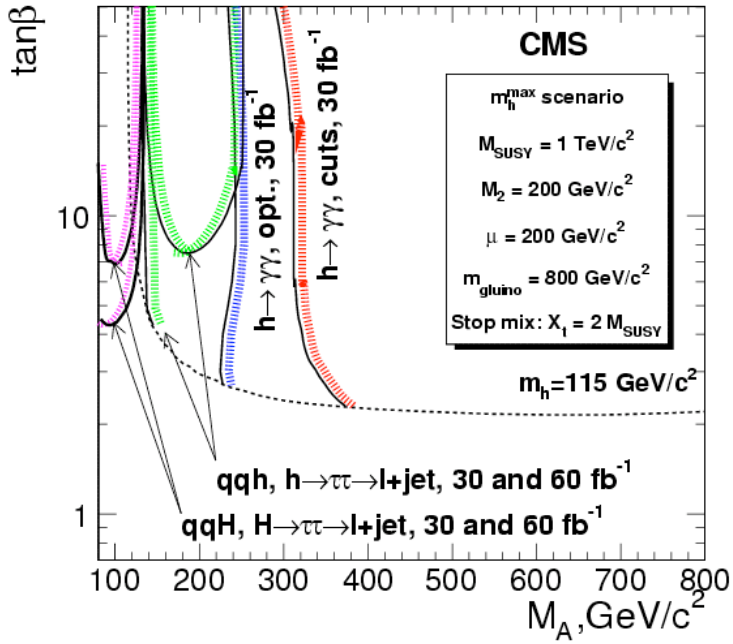
$$\eta_3^* = \eta_3 - \bar{\eta} = \eta_3 - \frac{\eta_j^{\text{tag1}} + \eta_j^{\text{tag2}}}{2}$$



born level distribution for Z + 3 jets
D. Zeppenfeld et al.,
Phys.Rev.D54:6680-6689,1996

First, full simulation analysis of qqH, H->ττ->l+jet



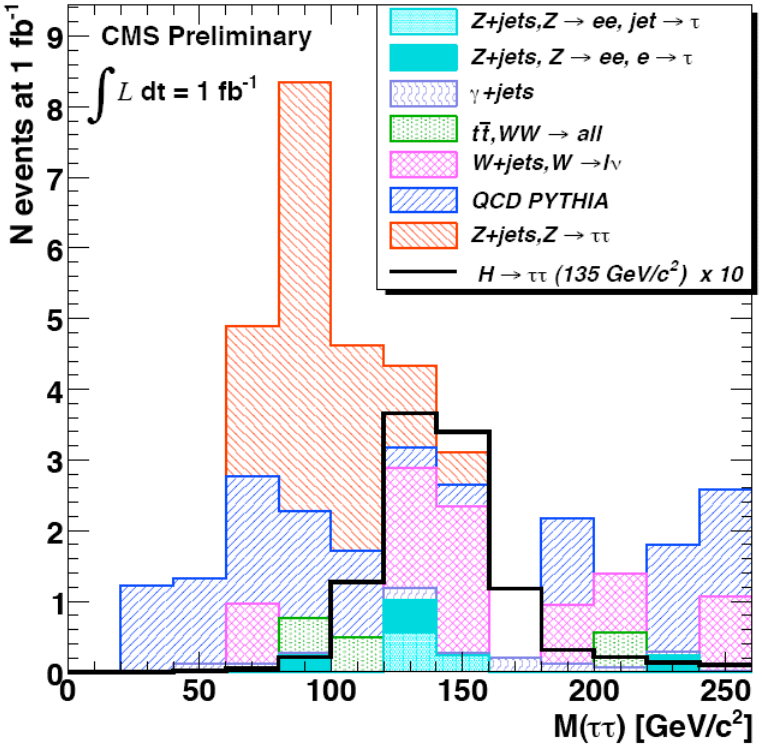


discovery light h in MSSM

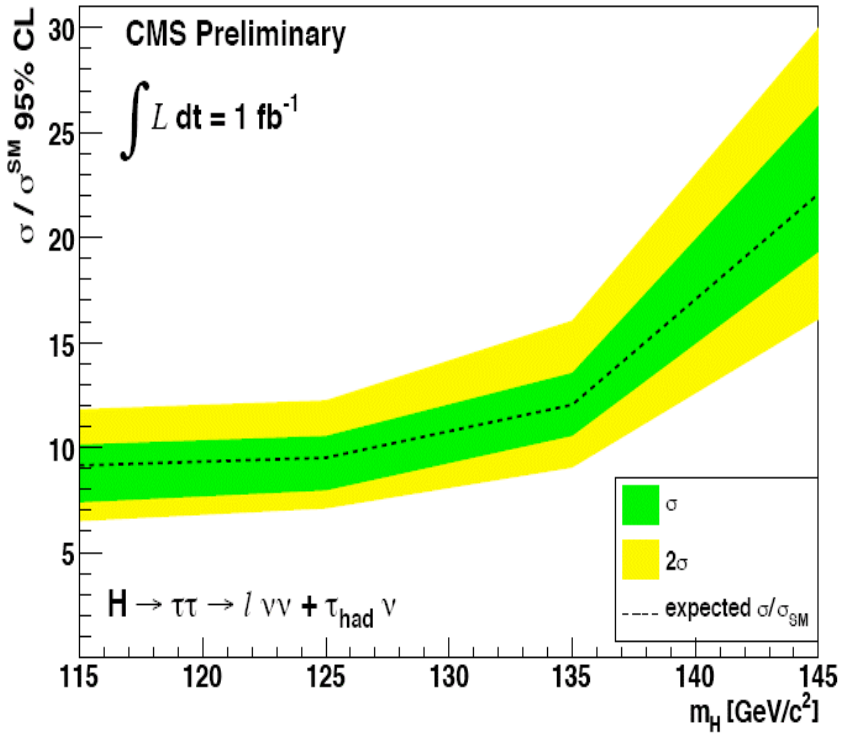
Discovery in Standard Model

M_H [GeV]	115	125	135	145
Production σ [fb]	4.65×10^3	4.30×10^3	3.98×10^3	3.70×10^3
$\sigma\times$BR(H$\rightarrow\tau\tau\rightarrow lj$) [fb]	157.3	112.9	82.38	45.37
N_S at 30 fb^{-1}	10.5	7.8	7.9	3.6
N_B at 30 fb^{-1}	3.7	2.2	1.8	1.4
Significance at 30 fb^{-1} ($\sigma_B = 7.8\%$)	3.97	3.67	3.94	2.18
Significance at 60 fb^{-1} ($\sigma_B = 5.9\%$)	5.67	5.26	5.64	3.19

CMS: "early" qqH, H->ττ-> l+j
1 fb^{-1}, 14 TeV, 2008

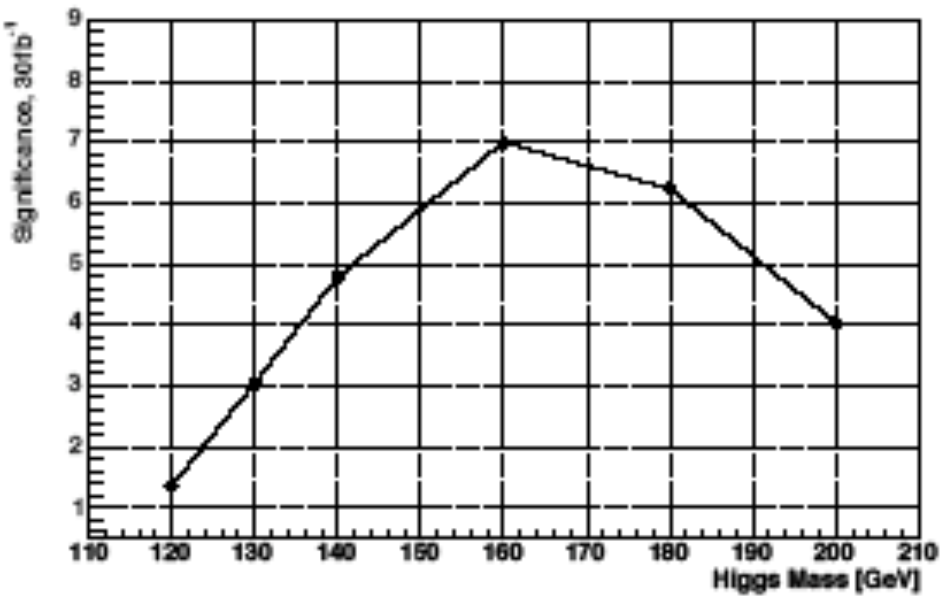


- Analysis in a nutshell:
  - ✓ Data driven approach to reproduce background shape
    - use similarity between Z→ ττ and Z→ μ μ
  - ✓ Advantage: accounts for E_T^{miss} effects from pile-up, underlying event and calorimetric response

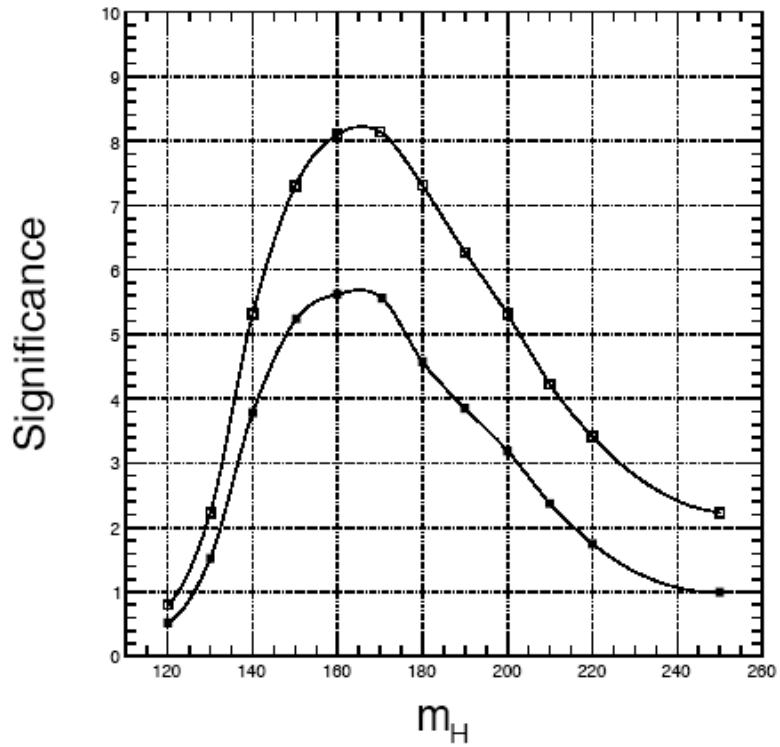


VBF H, H->WW->lνlν, lνjj

lνlν L=30fb^{-1}



lνjj (loose or tight jet veto) L= 30fb^{-1}

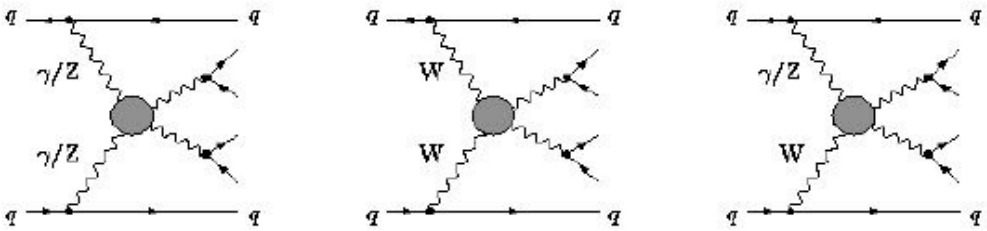


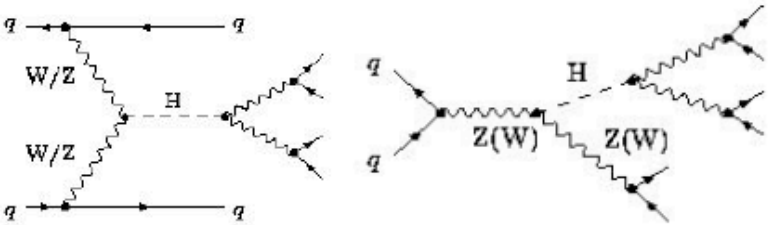
The background to VBF

The background: V+jets, VV+jets, t+jets, tt+jets

But also the irreducible QED background:

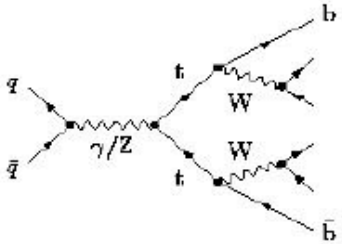
VV-fusion →



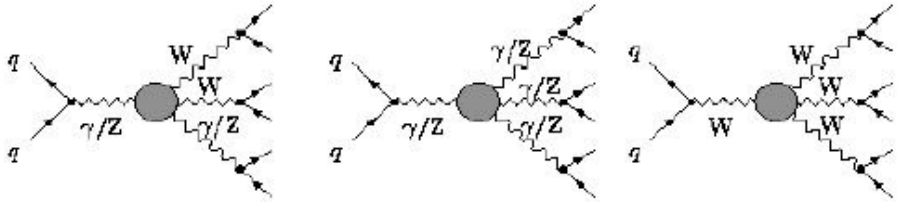


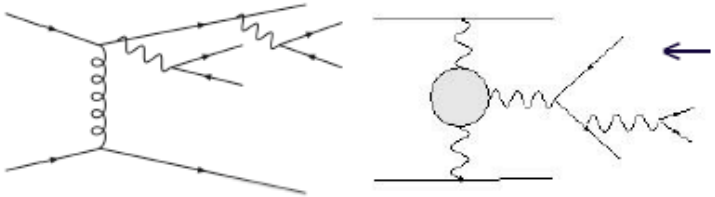
← Higgs

top-top →



TGC & QGC →





← VV non resonant

Phantom(Torino-I)

High mass region

- The cross section σ(qq->qqVV) and the V polarization depend on the presence of the Higgs:
  - V_T is independent of the Higgs presence (~no coupling)
  - V_L couples to Higgs (and explodes* at high masses if the Higgs does not exist)

- If the Higgs exists, $V_L V_L$ dominates under the peak, and dies out immediately, while $V_T V_T$ remains and dominates at high mass

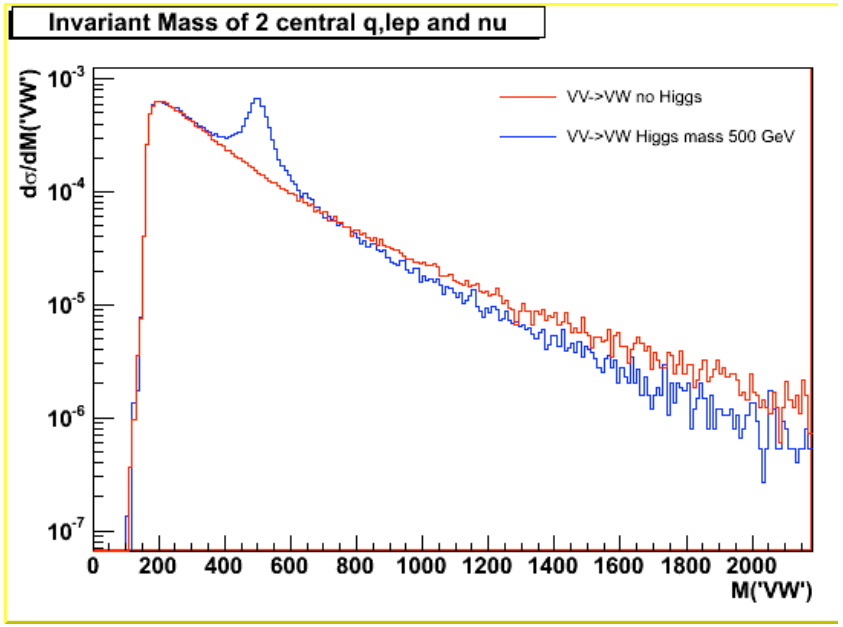
- If the Higgs does not exist V_T and V_L are of the same order at M_{VV}>1 TeV

•Violation of unitarity not strongly felt at LHC because Ecm is too low and PDF's rapidily decrease

Higgs/no-Higgs ratio

- Differences are expected to appear in the High M(VV) region
- The ratio is calculated in this region, as a function of the M(VV) minimum cut
- Additional selection wrt a “VBF H” analysis maybe necessary to enhance the difference between Higgs and no-Higgs
- The following discriminant is studied:

$$\frac{\int_{M_{cut}}^{\infty} dM_{VV} \frac{d\sigma_{noHiggs}}{dM_{VV}}}{\int_{M_{cut}}^{\infty} dM_{VV} \frac{d\sigma_{m_H=500\ GeV}}{dM_{VV}}}$$



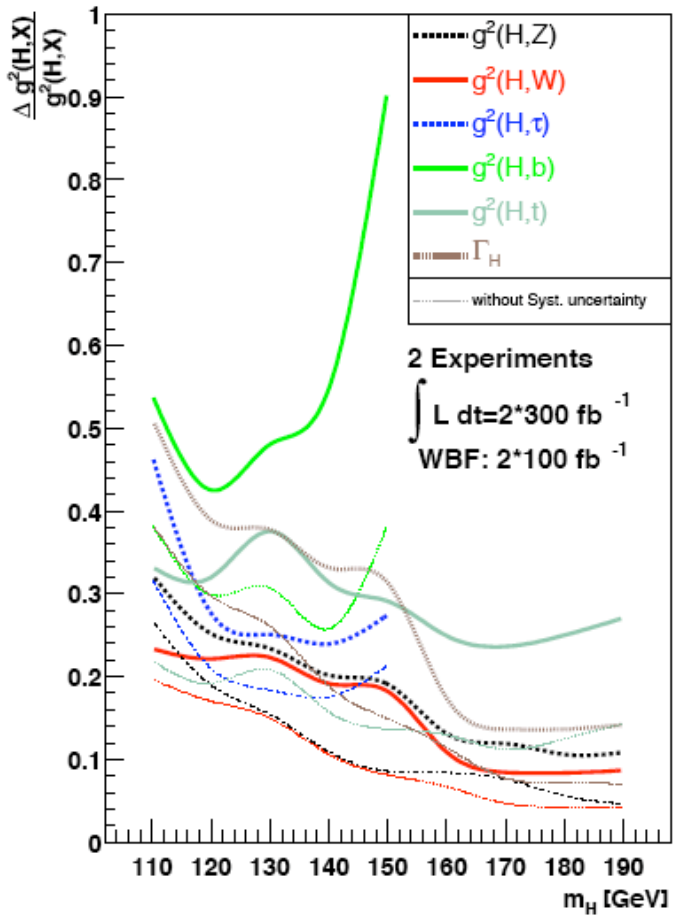
The High M_{VV} mass region

- The no-Higgs case is the “extreme”, but can be used as reference
- If the Higgs is not SM, but is for example composite (see Giudice et al.),i.e. there is also a strong component that breaks the symmetry, then the M(VV) cross section will lie in between the Higgs and no-Higgs case.

The Vector Boson scattering is the “ultimate” study to understand the EWSB.

Higgs SM or not?

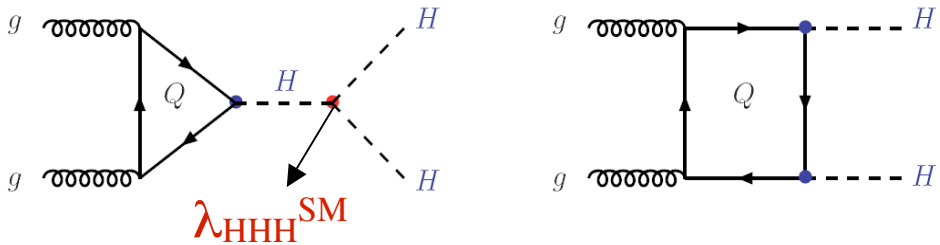
- SM or Susy or ….?
- This will depend if other particles have been discovered or not (SUSY sparticle, other Higgses or strong-resonances, or KK…)
- If only one Higgs has been discovered then a measurement of the couplings can discriminate between different models



We need H->bb otherwise measurements only for >150 GeV

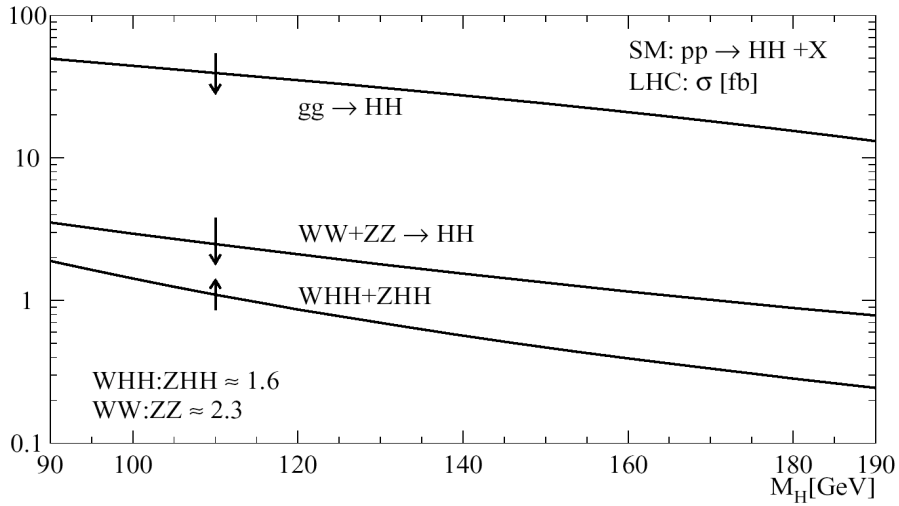
Self Coupling: double Higgs production

- Trilinear Higgs coupling contributes to double Higgs production HH



We finally have the 2 diagrams in Madgraph!

- Cross section x BR very small
- No sensitivity at LHC, need SLHC



Higgs boson pair production sensitivity to λ_{HHH} variations, arrows correspond to variations of λ_{HHH} from 1/2 to 3/2 of its SM value

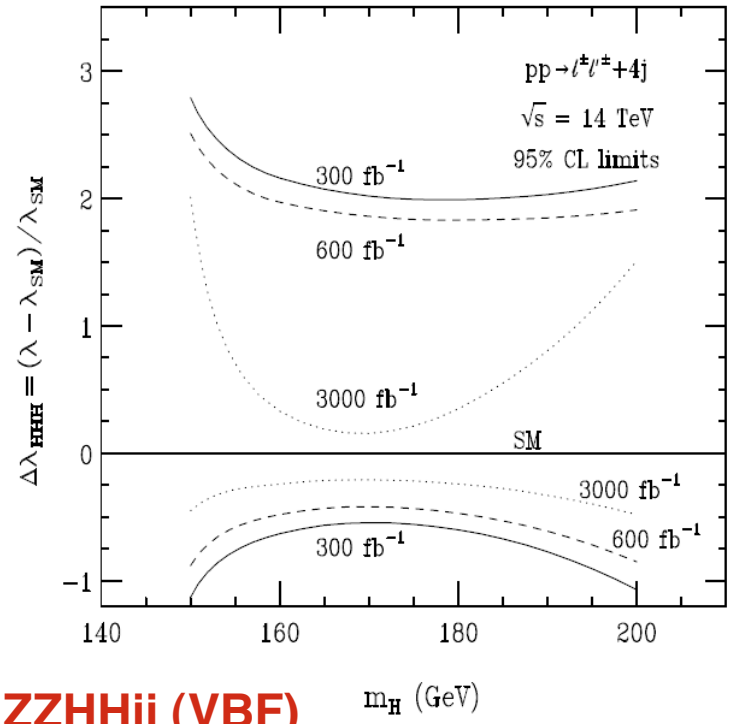
Double Higgs production

- gg ->HH -> W+W- W+W- -> l±vjj l±vjj – same sign dileptons
  - Main backgrounds:ttW, WWW
  - Investigated for 170 < MH < 200 GeV
  - total cross section and λ_{HHH} determined with ~ 25% statistical error for 6000 fb^{-1}
- Analysis done up to now is now known to be optimistic (it was carried out in 2001) no realistic pileup considered
- All 8-fermion final states should be considered
- We also want to study HH->ZZZZ -> 8l and ZZVV->4l4j
- In case of new physics (Extra Dimensions..) the cross section can be enhanced by up to 100 times and we can get hints/exclusions already after few fb^{-1} (preliminary - under study)

Constraints for λ_{HHH}

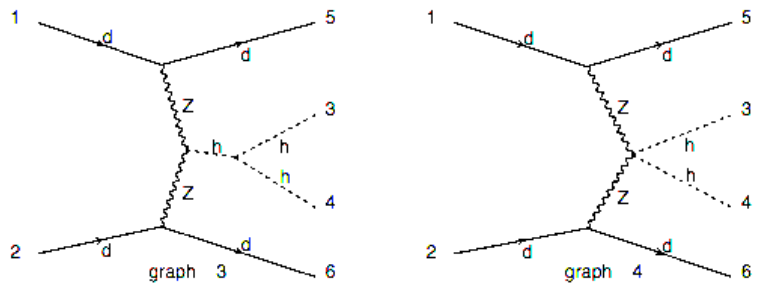
U. Baur, T. Plehn, D. Rainwater hep-ph/0211224
Parton level analysis
Considered gg->HH->WWWW
ll same sign +4j and lll+2j

LHC - SLHC



For lower M_H=120-140 GeV
Possibility to use gg->HH->bbγγ
Baur, Plehn, Rainwater hep-ph/0310056

New studies now of WWHHjj, ZZHHjj (VBF)

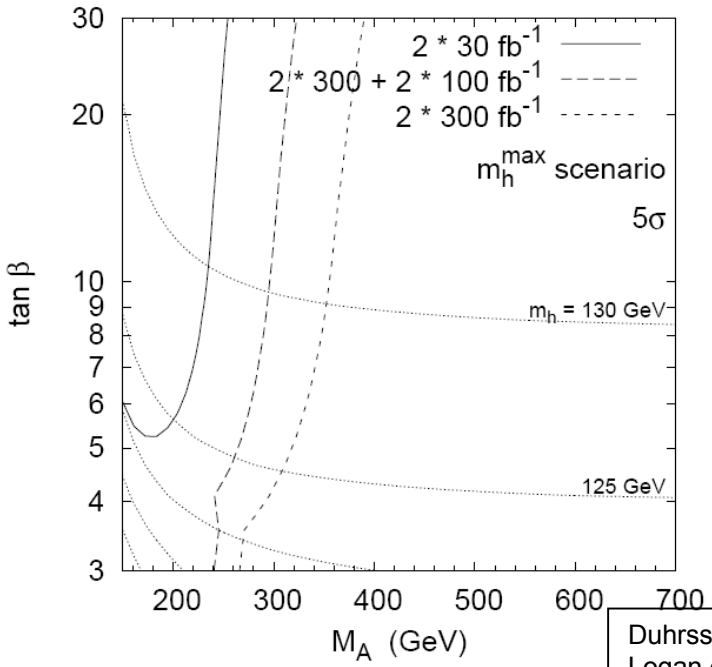


*

Interesting for determining if the Higgs is SM or composite (Giudice, Grosjean et al…)

SM vs MSSM: indirect & direct search

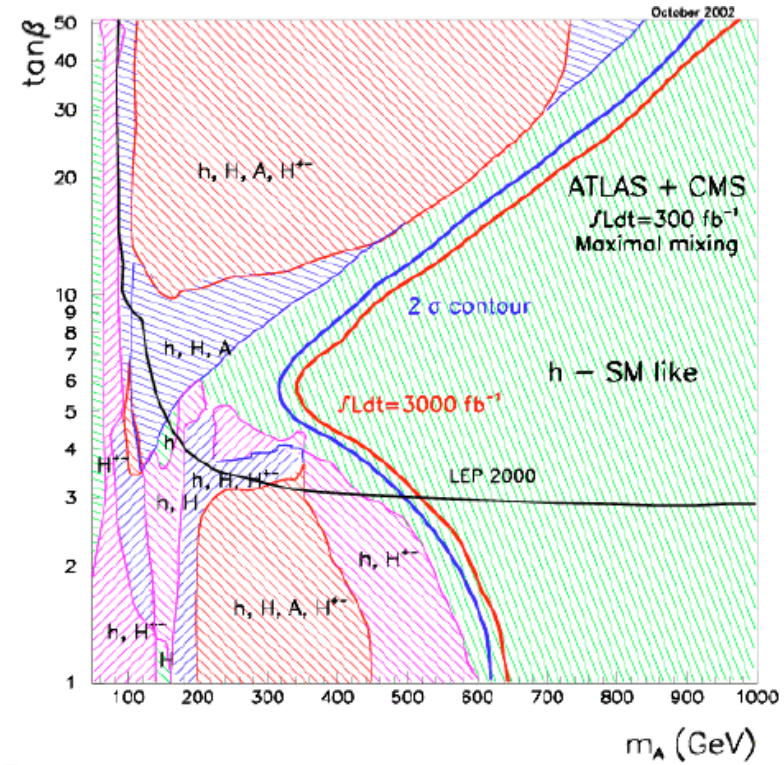
Combining all the coupling measurements, assuming to have seen only the H: Where,in the parameter plane, can we ruled out the SM?



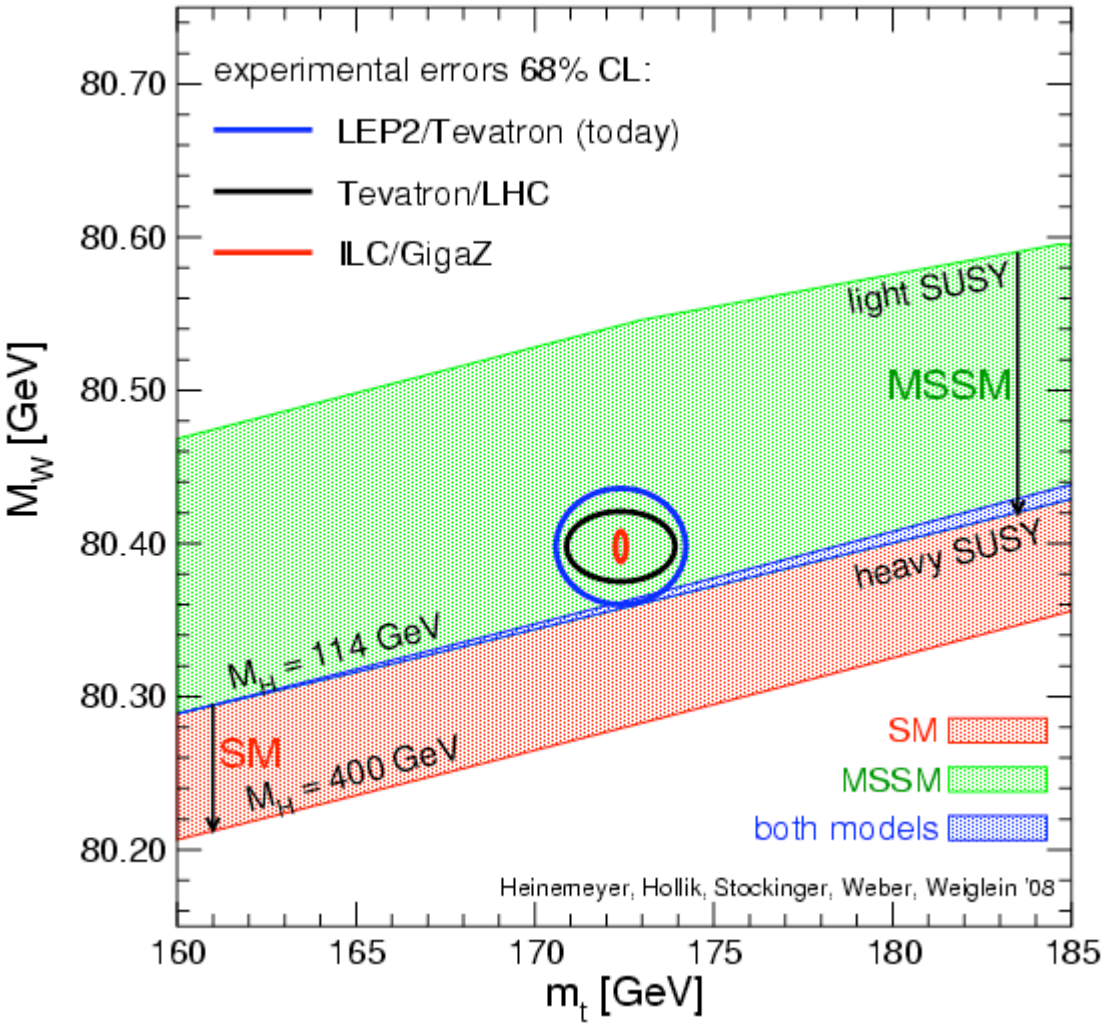
Duhrssen et al
Logan et al

LHC sensitivity dominated by VBF H to WW and ττ

LHC can cover a large part of the plane.

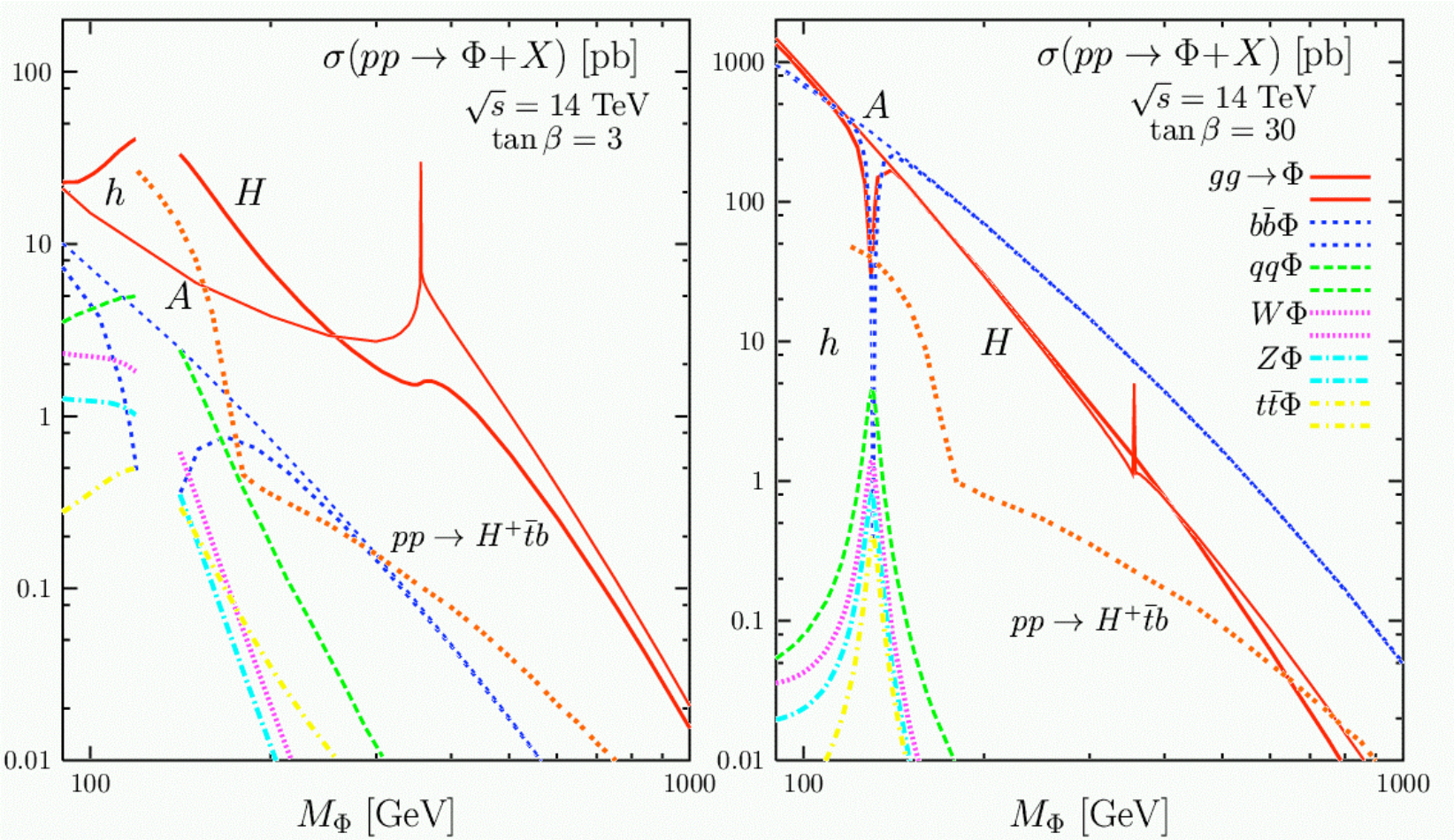


Searches for MSSM Higgs Bosons



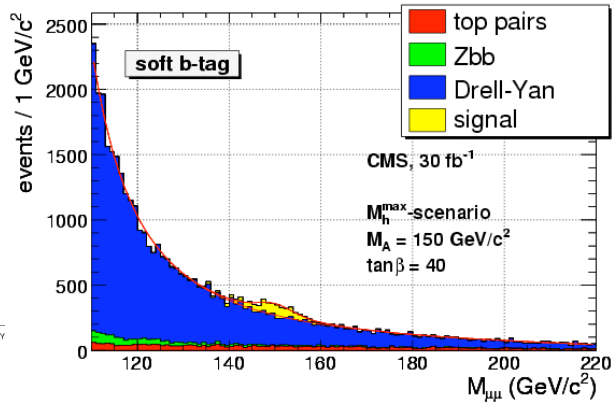
M_t=172.4±1.2 GeV
M_W=80.398±0.025 GeV

Cross sections for MSSM Higgs bosons production at LHC

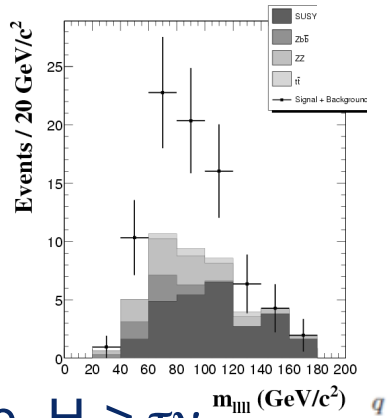


$X_t=6^{1/2}M_S$ (m_h^{max} scenario), M_S=2TeV, m_t=178 GeV, $m_b(m_b)$=4.9 GeV; NLO QCD corrections for all channels, but $tt\Phi$, $bb\Phi$; $\mu_R=\mu_F=1/2(M_\Phi+2m_t)$ for $tt\Phi$ and $\frac{1}{4}(M_\Phi+2m_b)$ for $bb\Phi$. NLO MRST set of PDF

SUSY Higgs

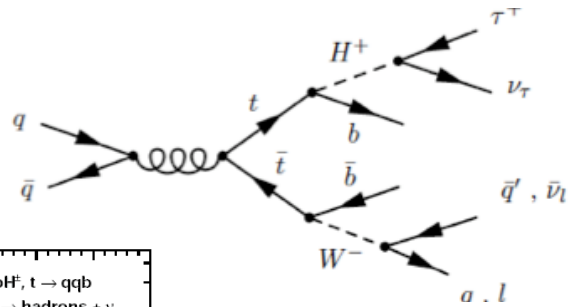


- Neutral ϕ=h,H,A:
  large tanb --> bbϕ, ϕ -> $\mu\mu$, $\tau\tau$
  low tanb --> A->Zh, Z->ll, h->bb

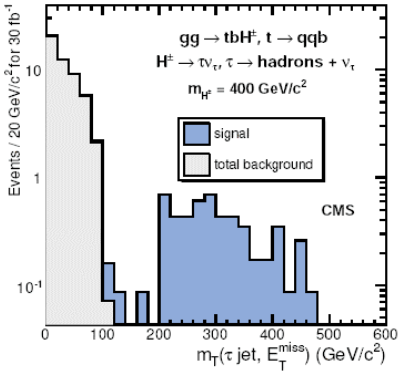


- A/H -> $\chi_2^0\chi_2^0$ ->4l +E_t^{miss}

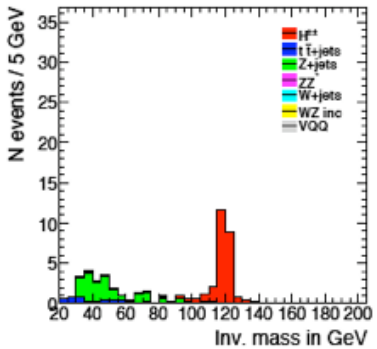
- Light Charged Higgs: pp->tt->WbH$^+$b, H-> $\tau\nu$



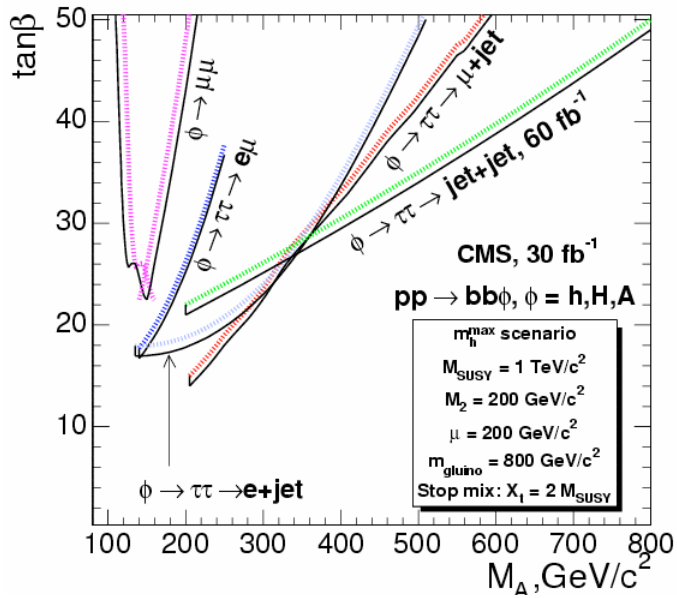
- Heavy Charged Higgs: pp->tH$^+$, H$^+$->$\tau\nu$

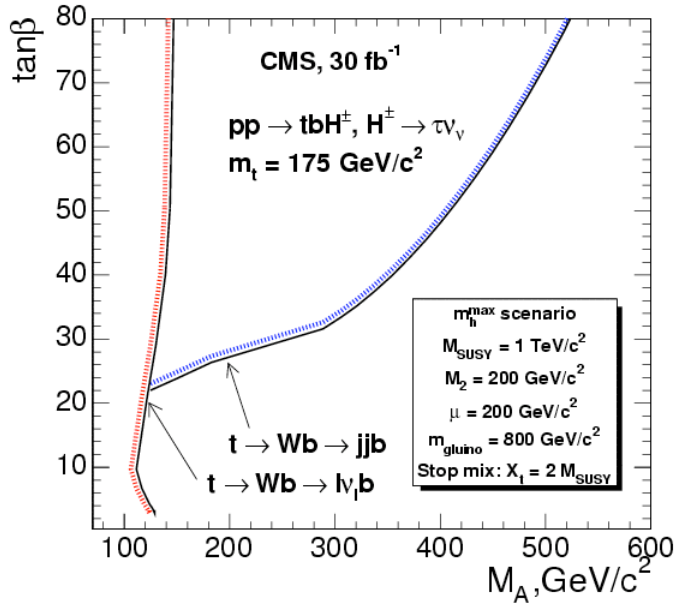


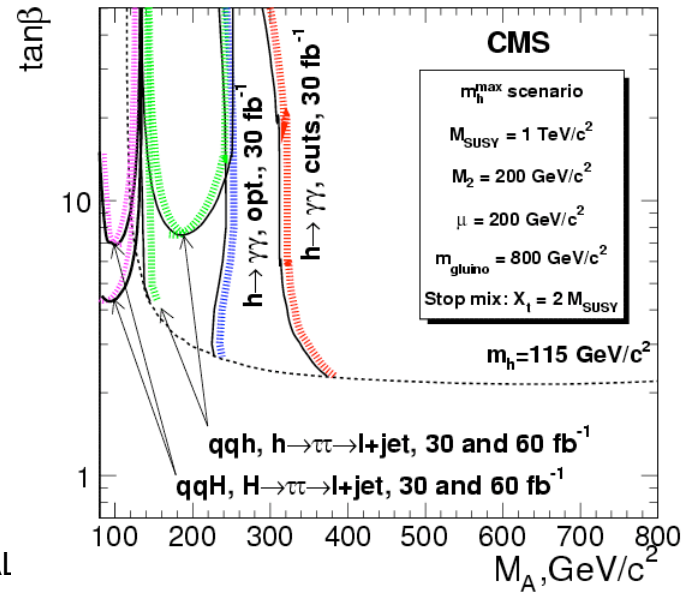
- Double charged: H^{++}H^{--} -> 4l ->e$^+\mu^+\tau^-$e$^-$

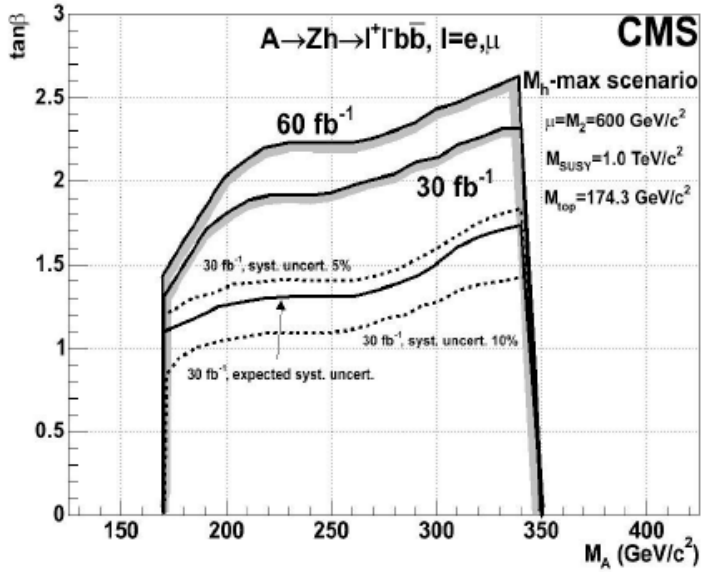


Summary of the CMS reach in M_A-tanβ

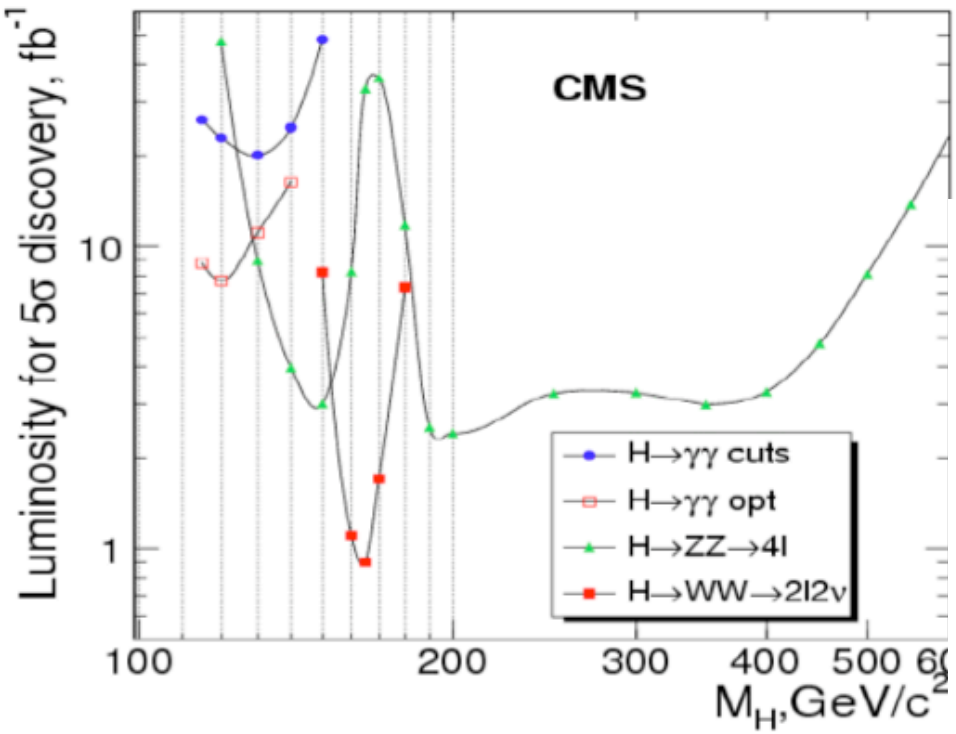




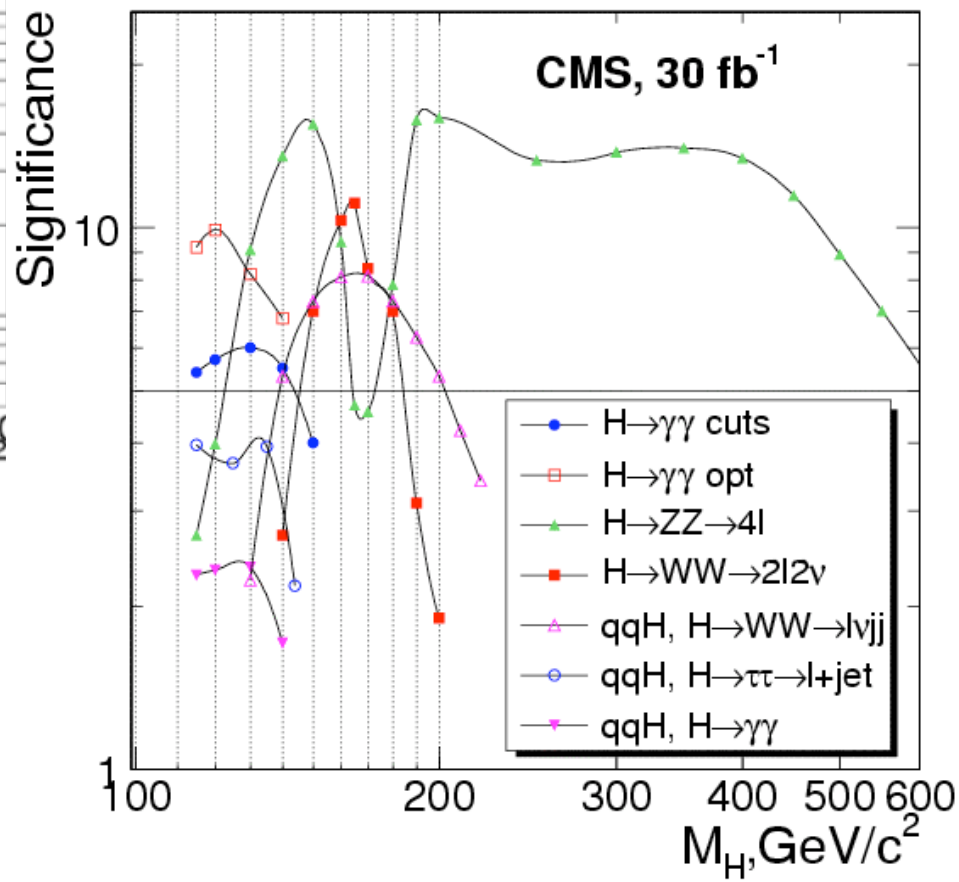




Conclusion: the CMS Higgs potential



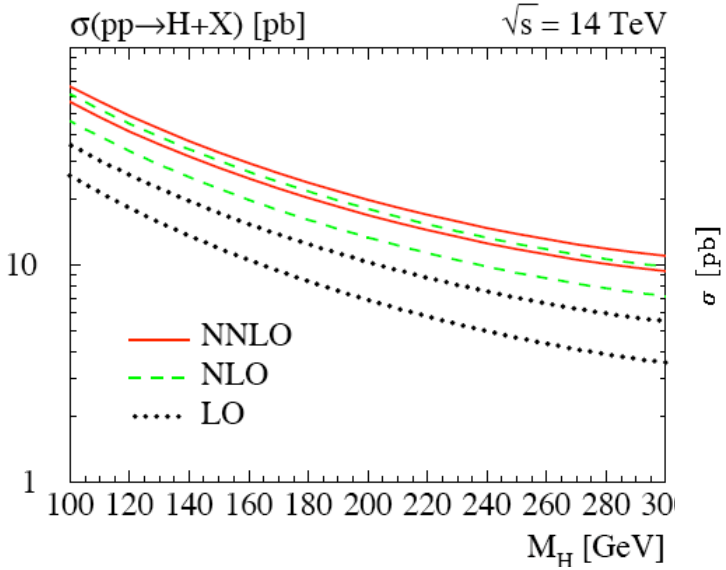
(at the PTDR)

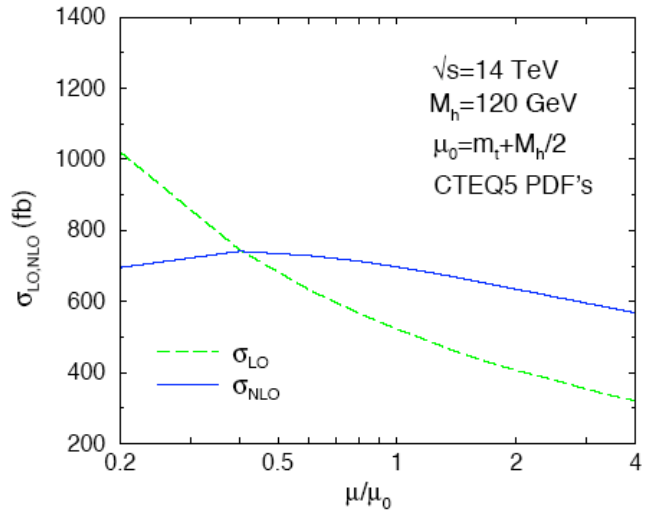


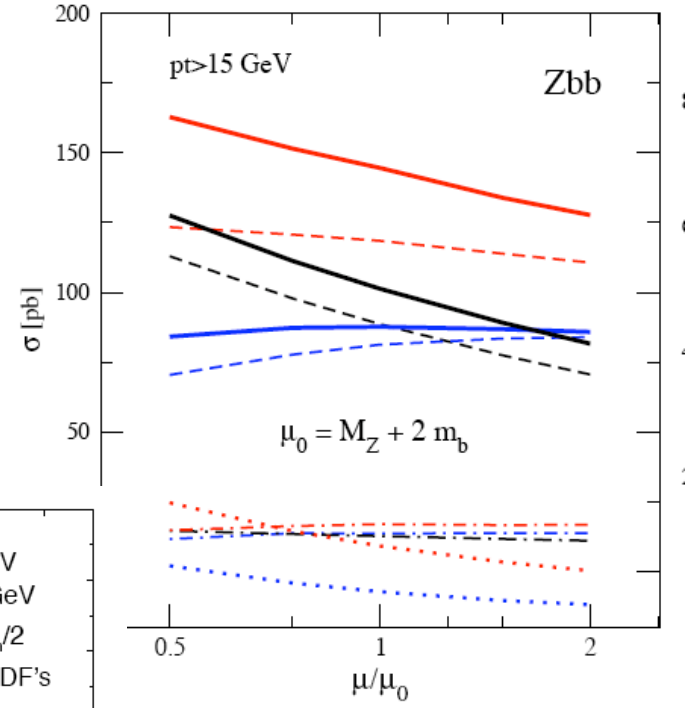
The theoretical effort

- For the LHC physics we need to go to NLO (QCD and EW) computation for signal and background:

  k factor and kinematics dependences







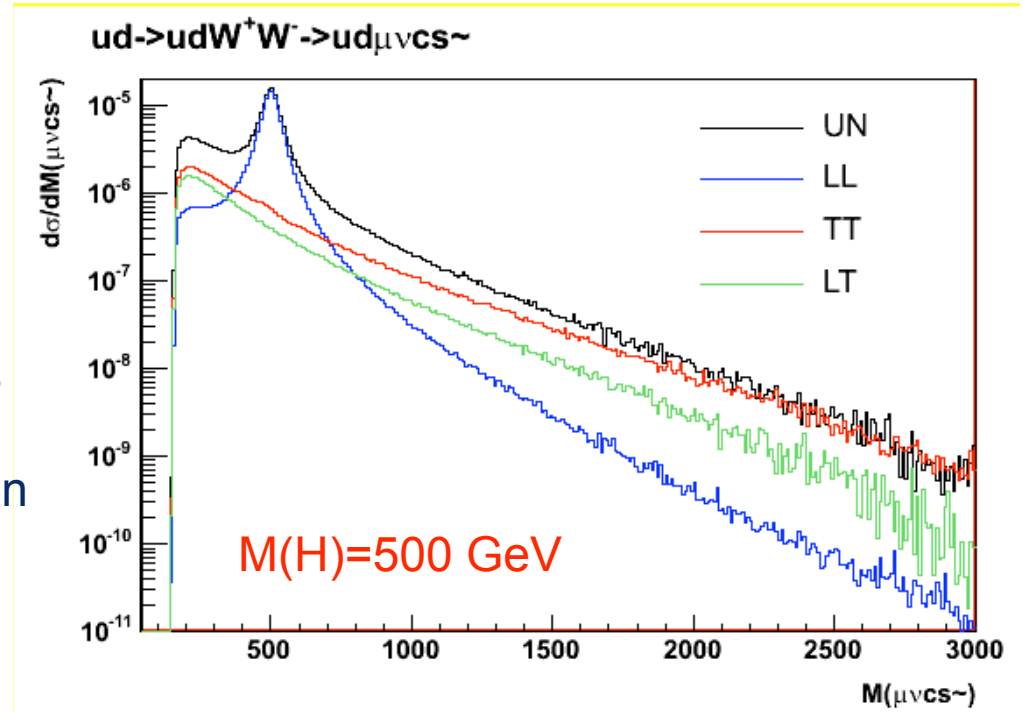
LHC time: a new era

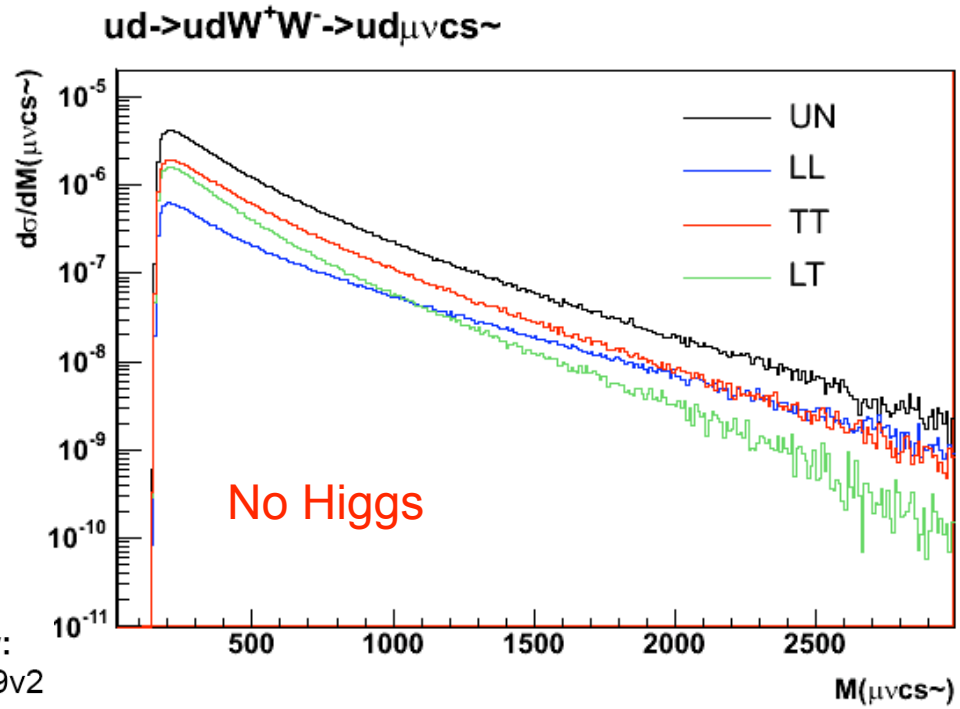
- When we finally will start, a new era will open: we will need time to be able to exploit all our power (look at CDF and D0, at all the physics they can do!
- For the moment LEP and Tevatron did precise (beautiful) measurement, but only set limits…
- Let's hope that finally LHC, going to an incredibly vast new energy domain, will stop setting limits …

Back-up

Polarization

- The V_L are coupled to the Higgs and their behavior gives informations on the EWSB.
- The behavior of the $V_L V_L$ cross section can give information on the scale at which the symmetry breaks.
- In the No-Higgs case, at large M(VV) the TT cross section is of the same order as the LL.
- If the Higgs exist, TT dominates at large M(VV)





PROCESS $ud \to udW^+W^- \to udc\bar{s}\mu\bar{\nu}_\mu$

$1 < \eta(d) < 5.5$ $\quad -1 > \eta(u) > -5.5$

$E(u,d,c,s,\mu) > 20$ GeV $\quad P_t(u,d,c,s,\mu) > 10$ GeV

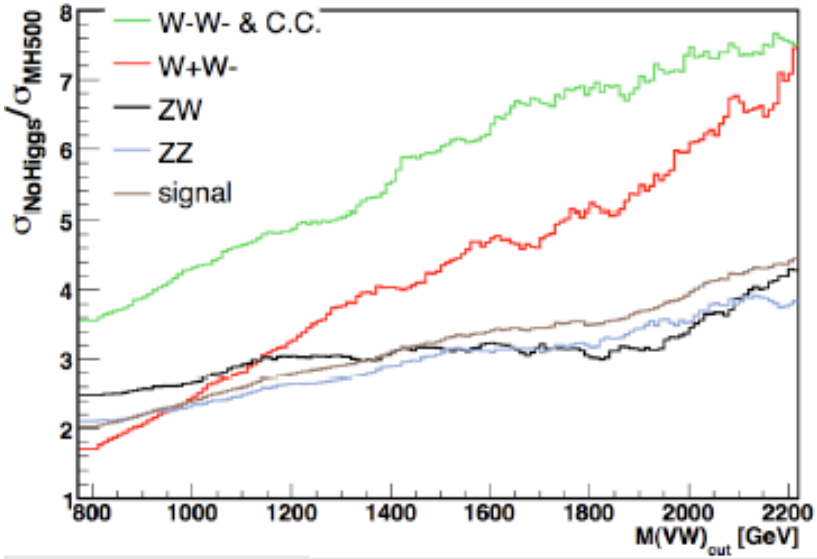
$70 < M(sc, \mu\nu) < 90$

E. Accomando *et al.* **Boson-boson scattering and Higgs production at the LHC from a six fermion point of view: four jets + lν processes at $O(\alpha^6_{em})$** arXiv:hep-ph/0512219v2

Higgs/no-Higgs at parton level

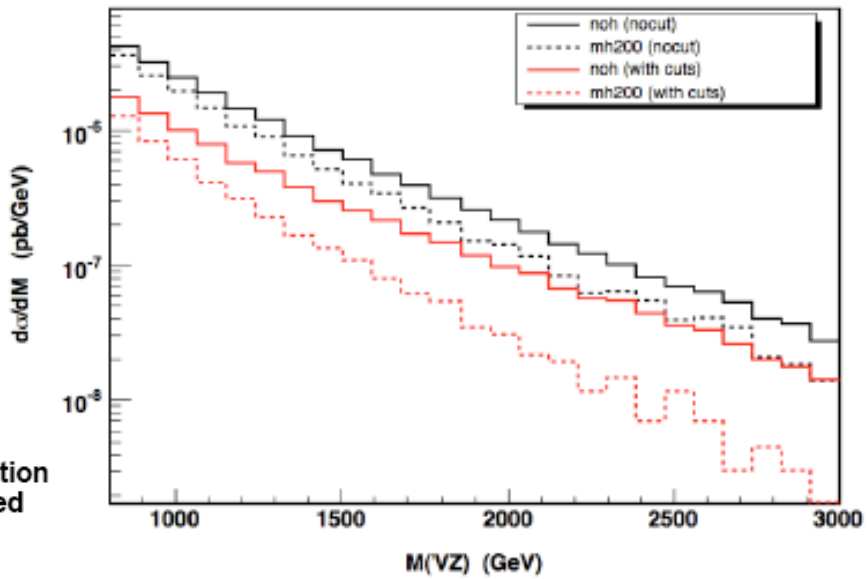
- Final state qqqqμν

a NN has been trained to discriminate Higgs from no Higgs at large MVV
- good discrimination
- certain channel more sensitive



- Final state qqμμμμ

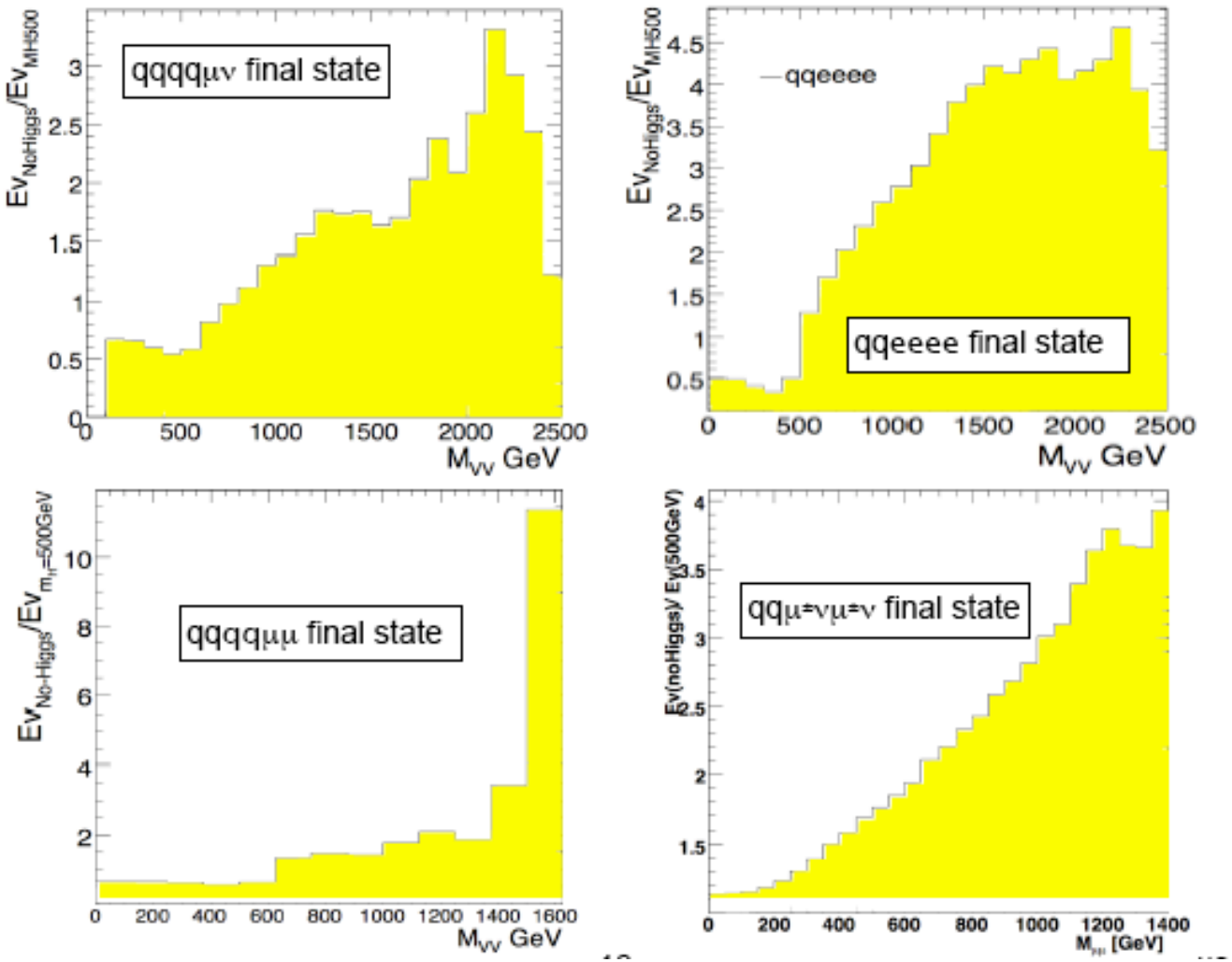
a cut on $|\eta_V|<2$ has been applied to enhance the difference between Higgs and no-Higgs at large M_{VV}



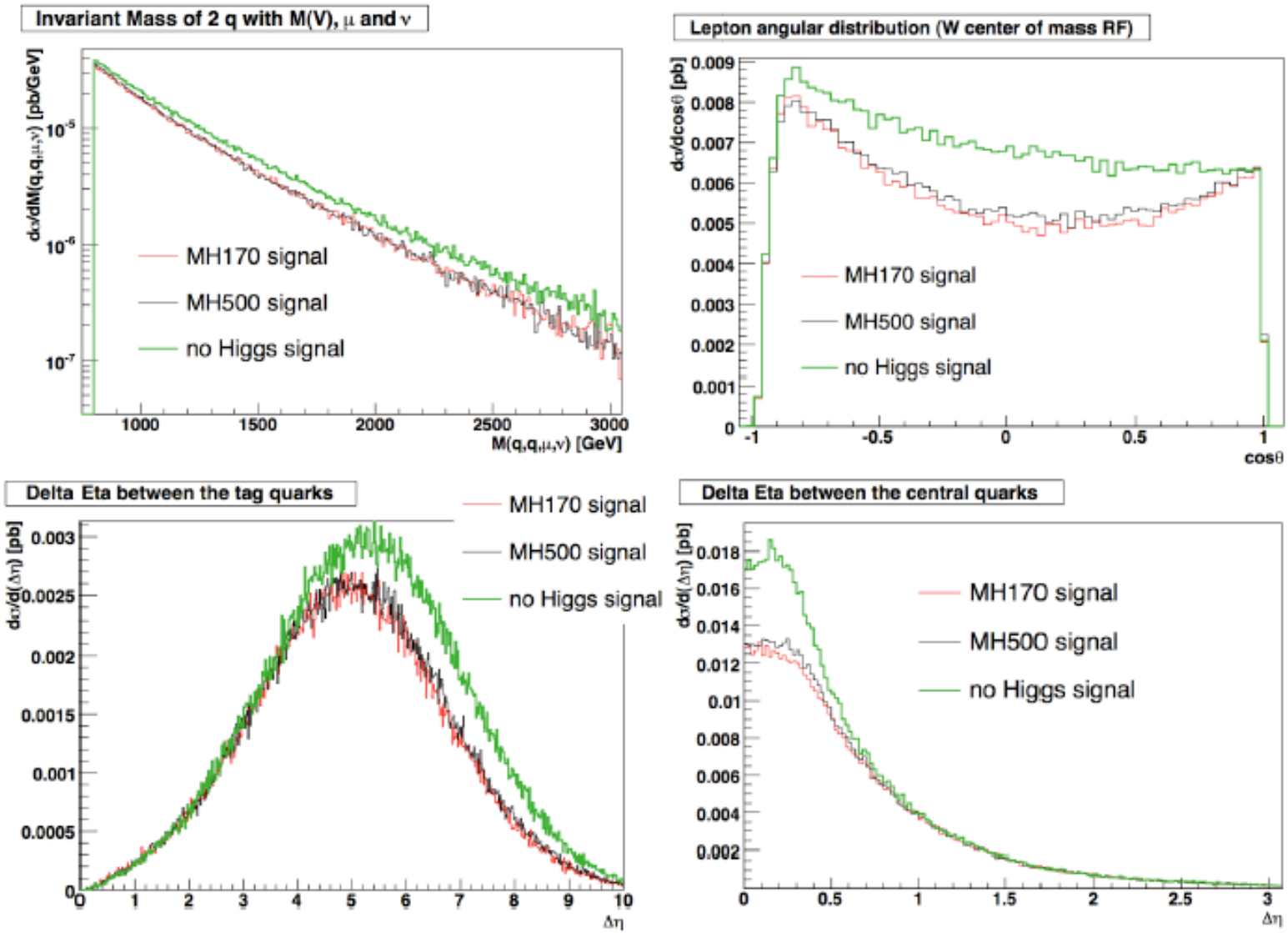
E. Accomando *et al.* **Boson fusion and Higgs production at the LHC in six fermion final state with one charged lepton pair** arXiv:hep-ph/0603167v4

Higgs/no-Higgs ratio in CMS

- $|\eta_V|<2$ and $|\eta_j-\eta_V|<2$ to enhance the difference (fast sim)



Different mass hypoteses



E. Accomando *et al.* **Boson-boson scattering and Higgs production at the LHC from a six fermion point of view: four jets + lν processes at $O(\alpha^6_{em})$** arXiv:hep-ph/0512219v2