Physics at LHC Seminar

Higgs boson search in decays H->VV (V=W,Z) with early LHC data

09.06.2009

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Overview

1. LHC & Detectors (ATLAS & CMS)
2. SM Higgs
    2.1. Mass Limits
    2.2. Production
3. Decay channels
    3.1. H->ZZ$^{(*)}$ decay
    3.2. H->WW$^{(*)}$ decay
4. Conclusion

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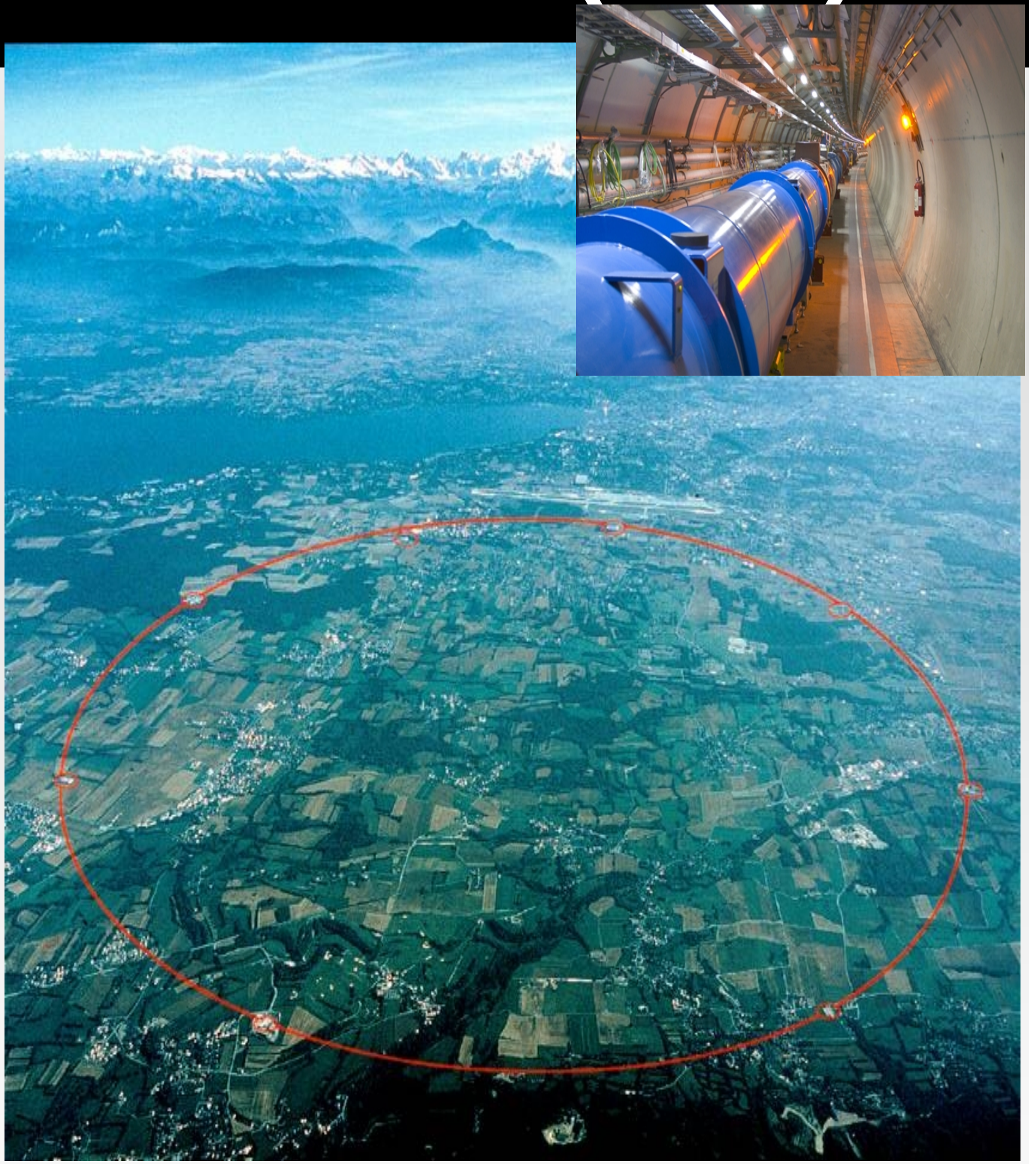
1. The Large Hadron Collider (LHC)

Parameters	Value
Operating beam energy	7 TeV
Relativistic γ	7461
Bunch spacing	24.95 ns / 7.48 m
Stored energy per beam	334 MJ
Number of all/full bunches	3564/2835
Protons per bunch	1.05×10^{11}
Average beam current	536 mA
Luminosity	2×10^{33} to $1 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Dipole magnetic field	8.4 T
Cryostat temperature	1.9 K
Beam lifetime	22 h
Luminosity lifetime	10 h
Number of interactions per beam crossing	23[a]
RMS bunch length σ_z	7.5 cm
RMS bunch radius $\sigma_x = \sigma_y$	16 µm
RMS length of luminous region	56 mm
Total crossing angle	300 µrad
Power consumption	125.75 MW
Cost	~3 billion CHF

Assuming 70 mb for the inelastic proton-proton cross-section and $\mathcal{L} = 1 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$.



http://www.uslhc.us/Images

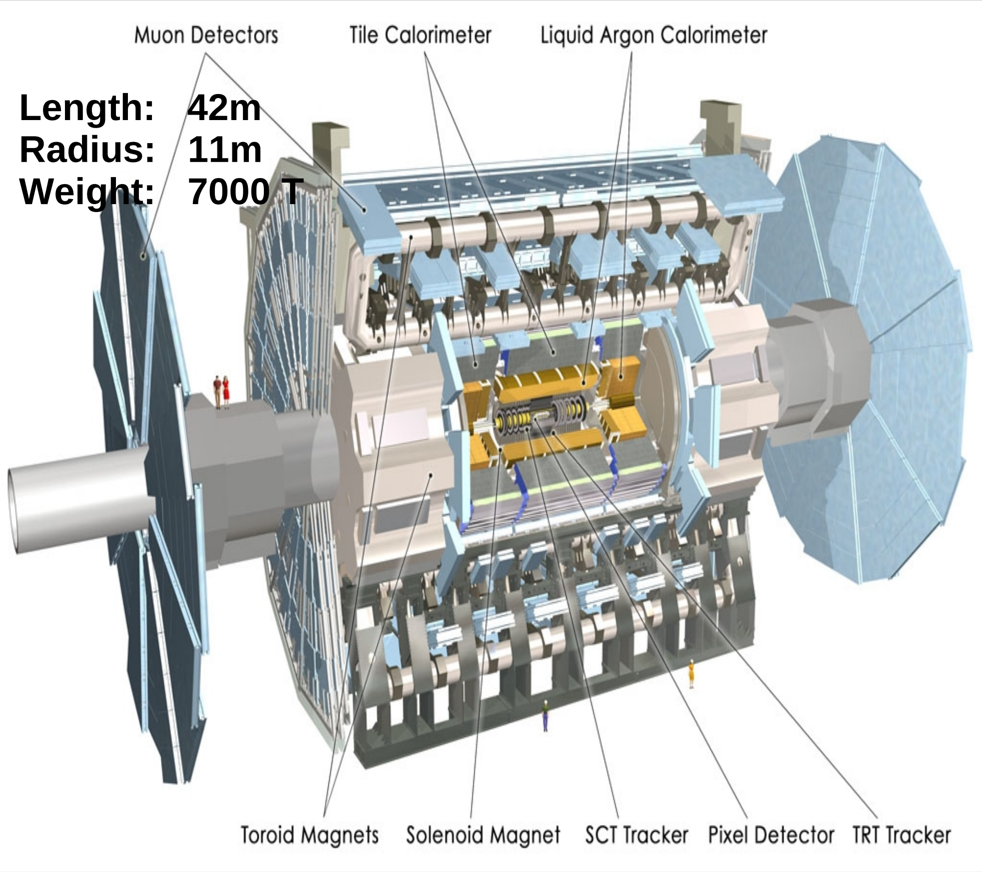
- pp collider at CERN, $\sqrt{s}$=14 TeV
- Start operation in autumn 2009

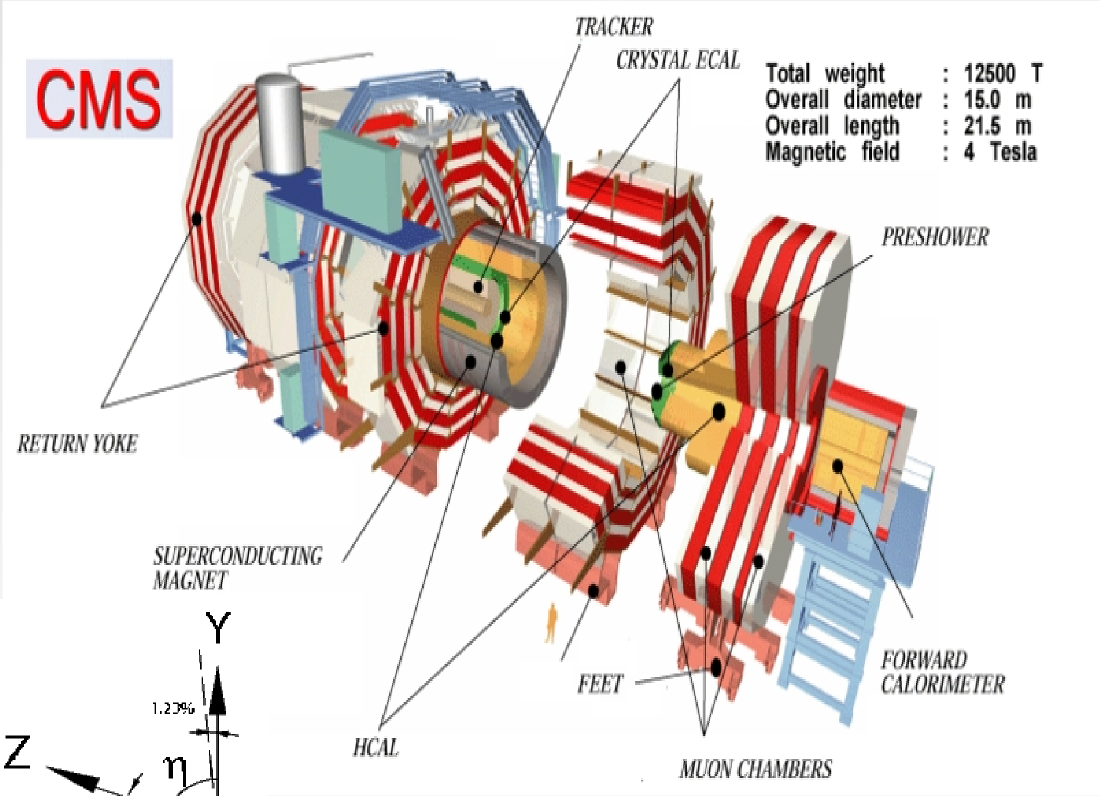
→ 10 TeV for this run

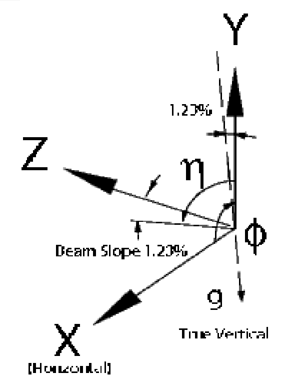
→ ~200pb^{-1} expected by autumn 2010

1. ATLAS & CMS

- Two general multi-purpose experiments with main goals:
  - search for supersymmetry particles
  - look for clues to the nature of dark matter
  - hunt for the Higgs boson







Important variables:

$\eta = -\log[\tan(\theta/2)]$

$p_T = \frac{p}{\cosh \eta}$

$\Delta R = \sqrt{(\eta^2 + \phi^2)}$

1.ATLAS & CMS: Differences

Dimension
- – ATLAS is larger than CMS in size

• Tracker
- – ATLAS has the additional Transition Radiation Tracker
- – Slightly better momentum resolution

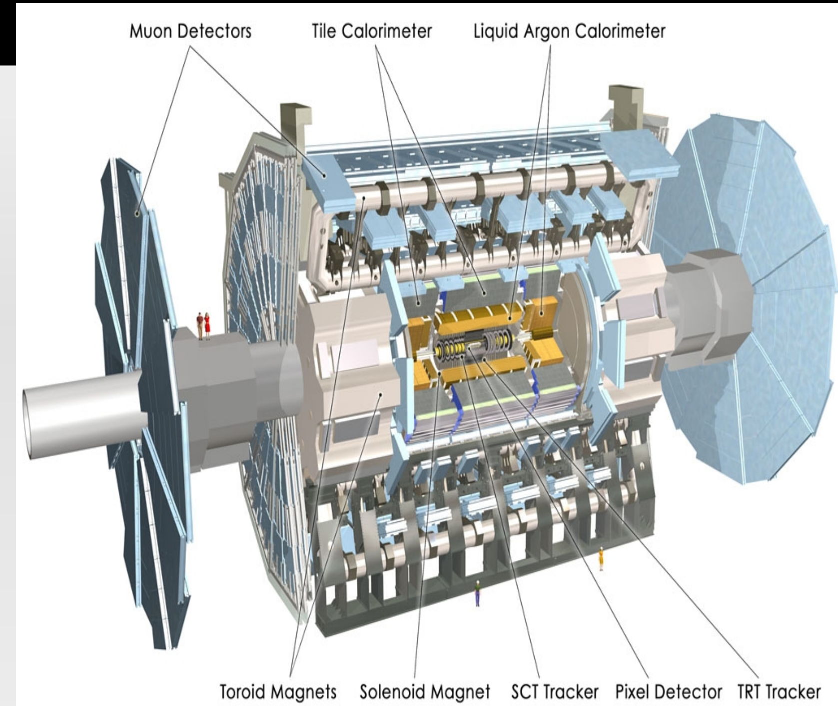
for CMS

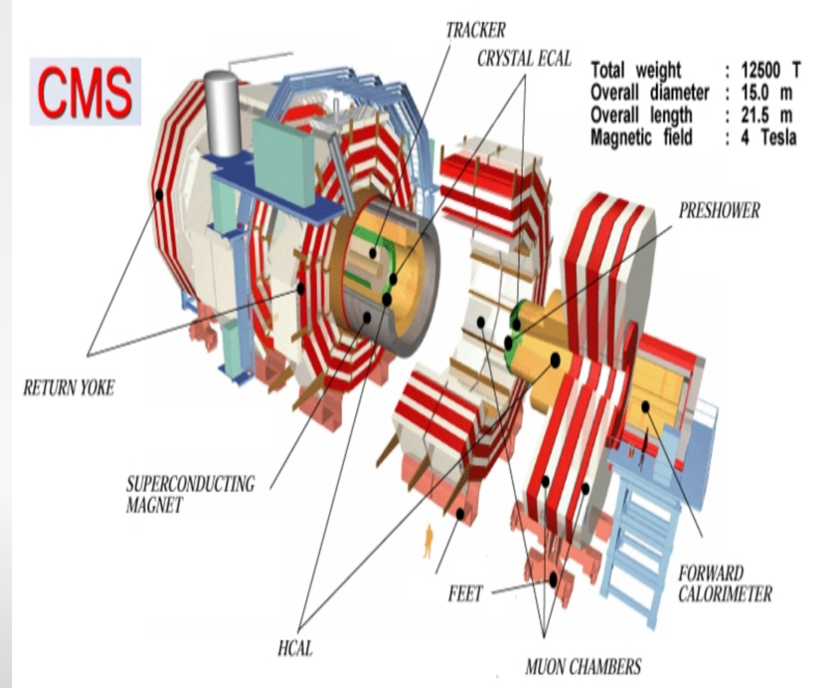
• Calorimeters
- – Different layout and material used

• Magnetic field
- – CMS: Solenoidal field of 4T
- – ATLAS: Solenoidal and Toroidal field of 2T

• Muon System
- – Different layout of chambers
- – CMS has a better muon momentum resolution

• Trigger
- – CMS: 2-level trigger system
- – ATLAS: 3-level trigger system





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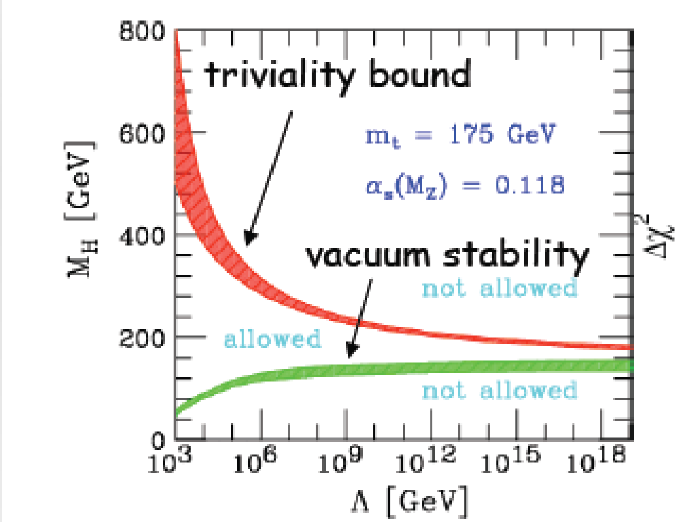
2.1. SM Higgs Mass Limits

Theoretical: from finite and positive Higgs Coupling

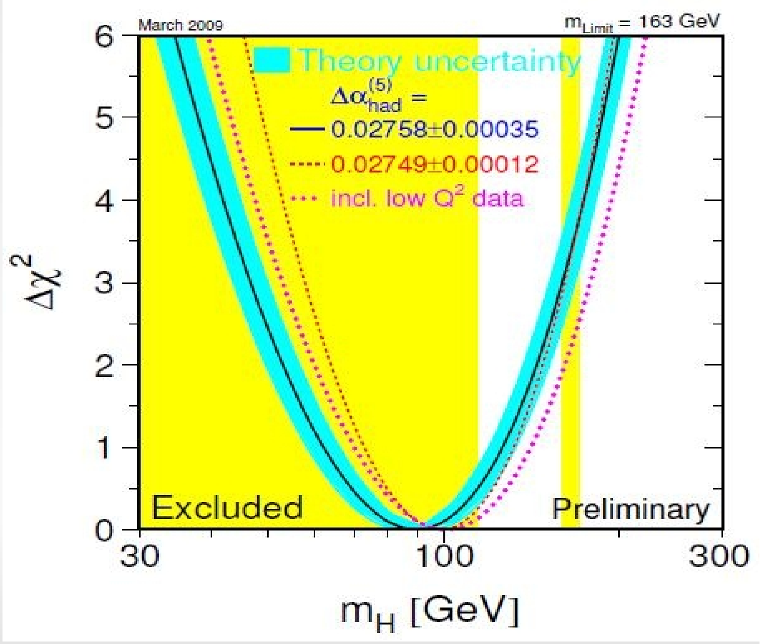
If Standard Model is valid

- up to the Planck scale ($\Lambda \approx 10^{19}$ GeV)
  → Higgs mass: $130\ \text{GeV/c}^2 < m_H < 180\ \text{GeV/c}^2$
- or up to $\Lambda = 1$ TeV
  → Higgs boson: $50\ \text{GeV/c}^2 < m_H < 700\ \text{GeV/c}^2$



Experimental Bounds:

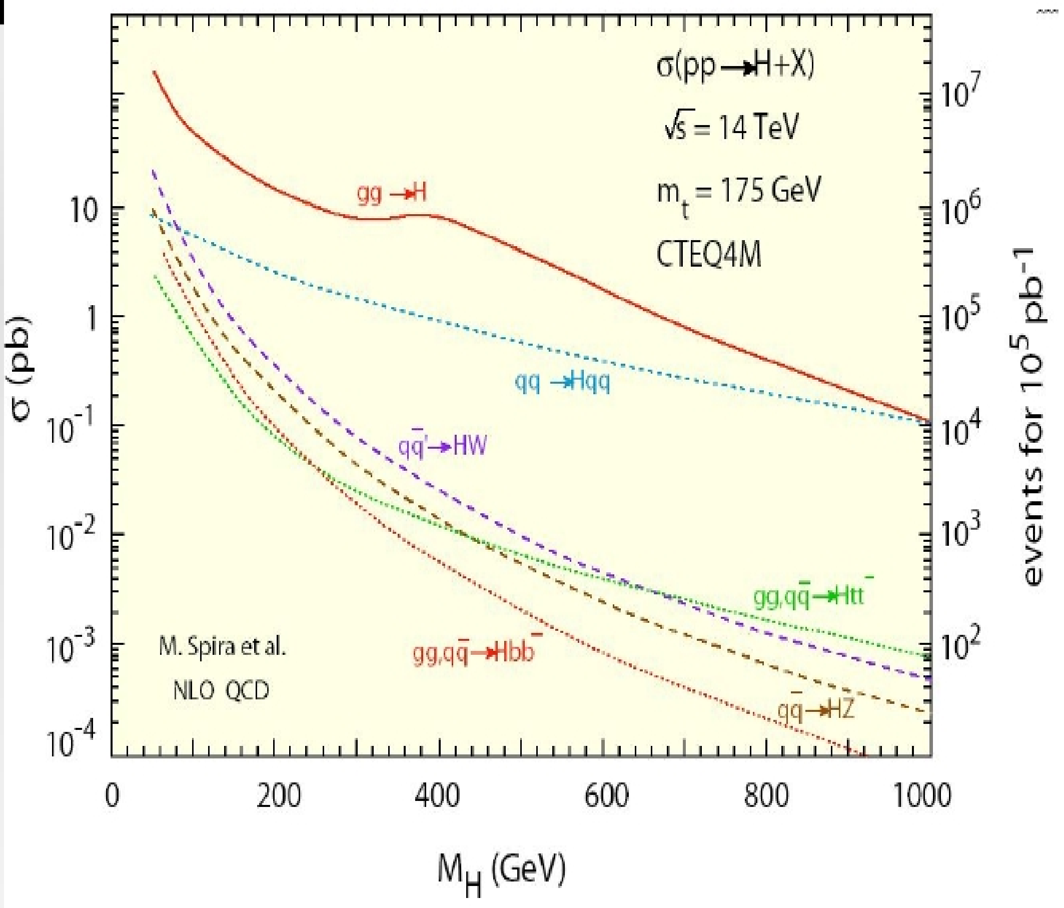
- Lower bound $m_H > 114\ \text{GeV/c}^2$ excluded by LEP
- Upper bound $m_H < 251\ \text{GeV/c}^2$ by fit of the SM to all measured observables (e.g. Z&W boson lineshape, t-quark mass)
- Tevatron excluded $160 < m_H < 170\ \text{Gev/c}^2$

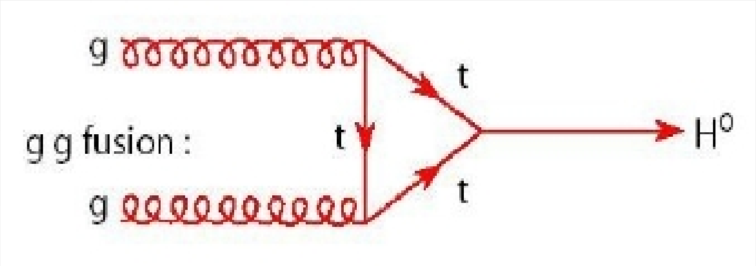


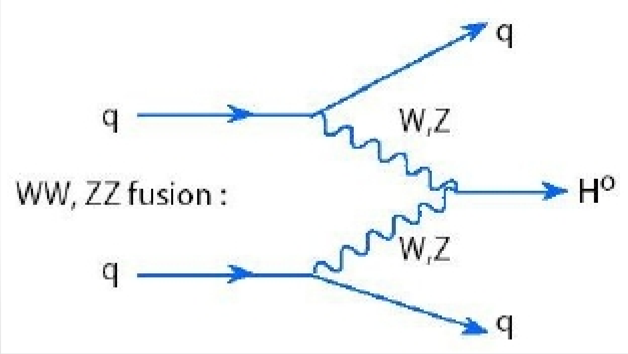
http://dorigo.wordpress.com/tag/tevatron/

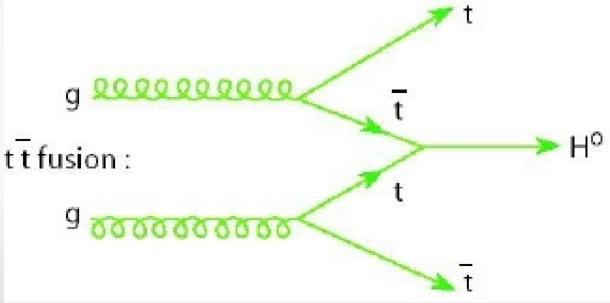
2.2. SM Higgs Production

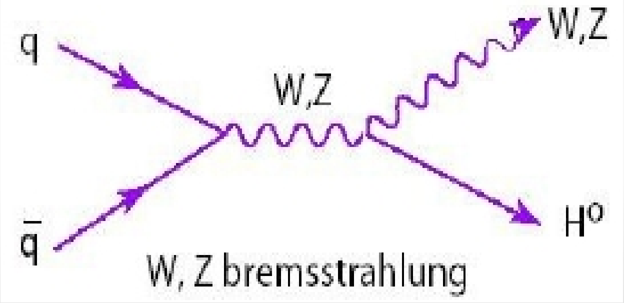
- cross-section (NLO): 0.1-50 pb
- gluon fusion dominates at LHC
  - Especially at low m_H
  - Factor ~10 at 100 GeV











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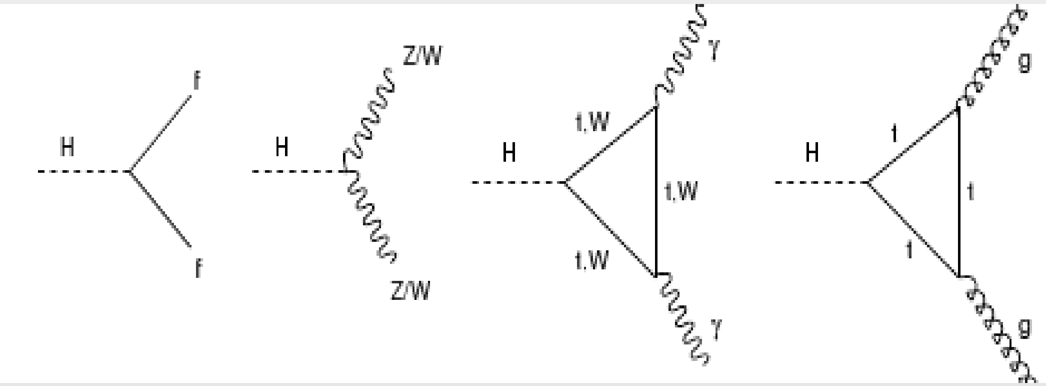
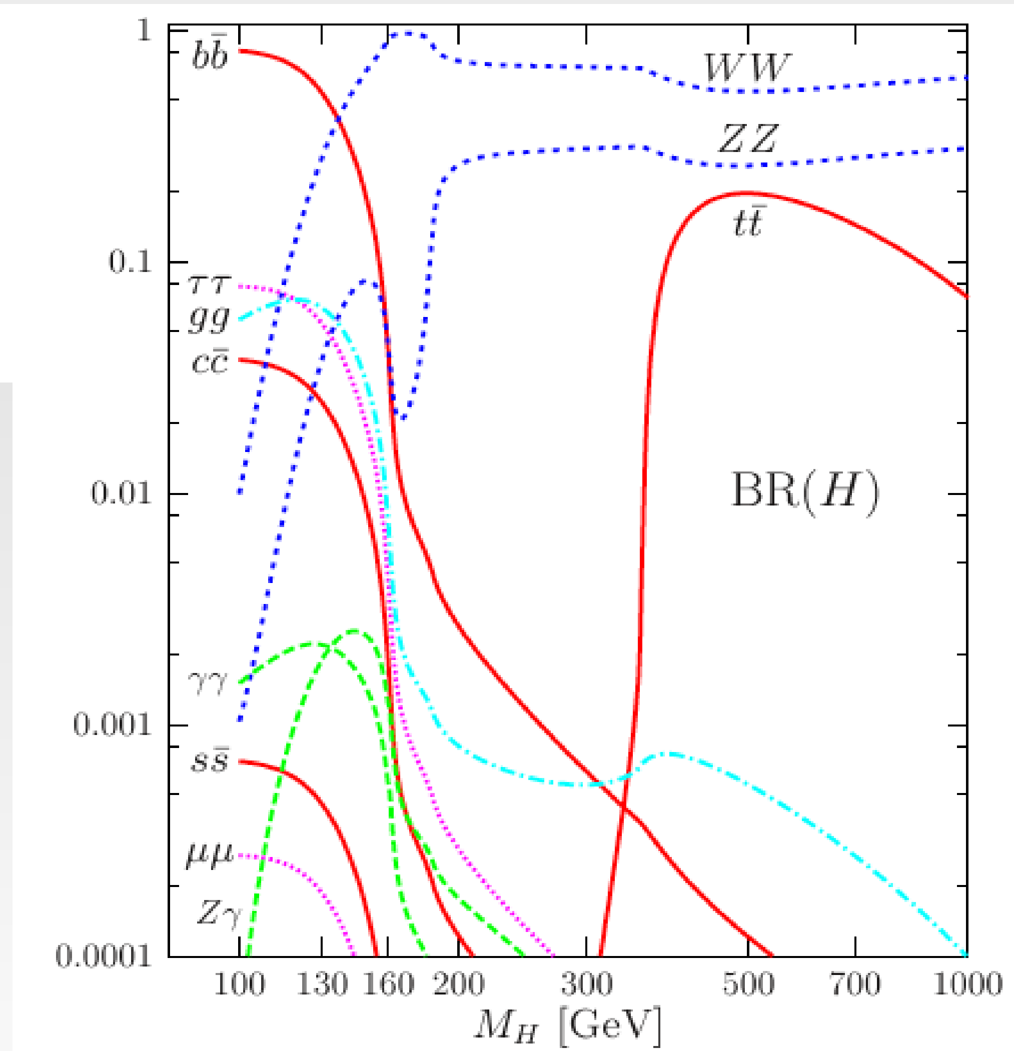
3. SM Higgs Decay Channels

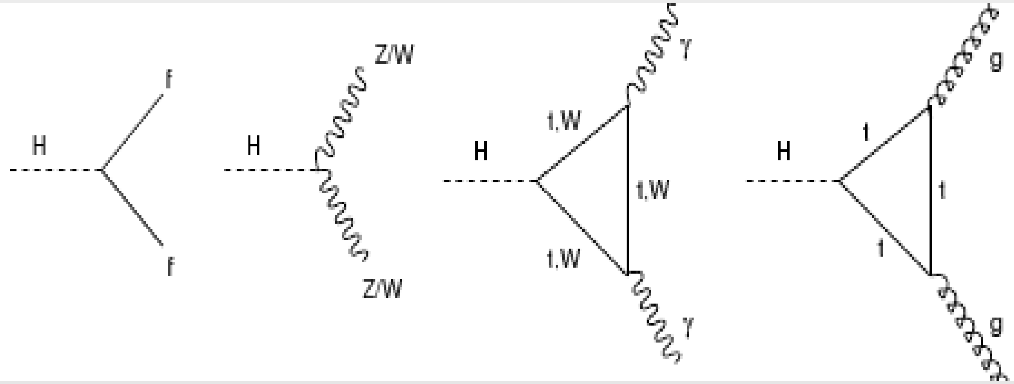




For m_H < 120 GeV/c^2

- bb dominant decay mode but is hard to see because of large QCD background
- γγ main discovery channel due to ECAL resolution
- ττ decay

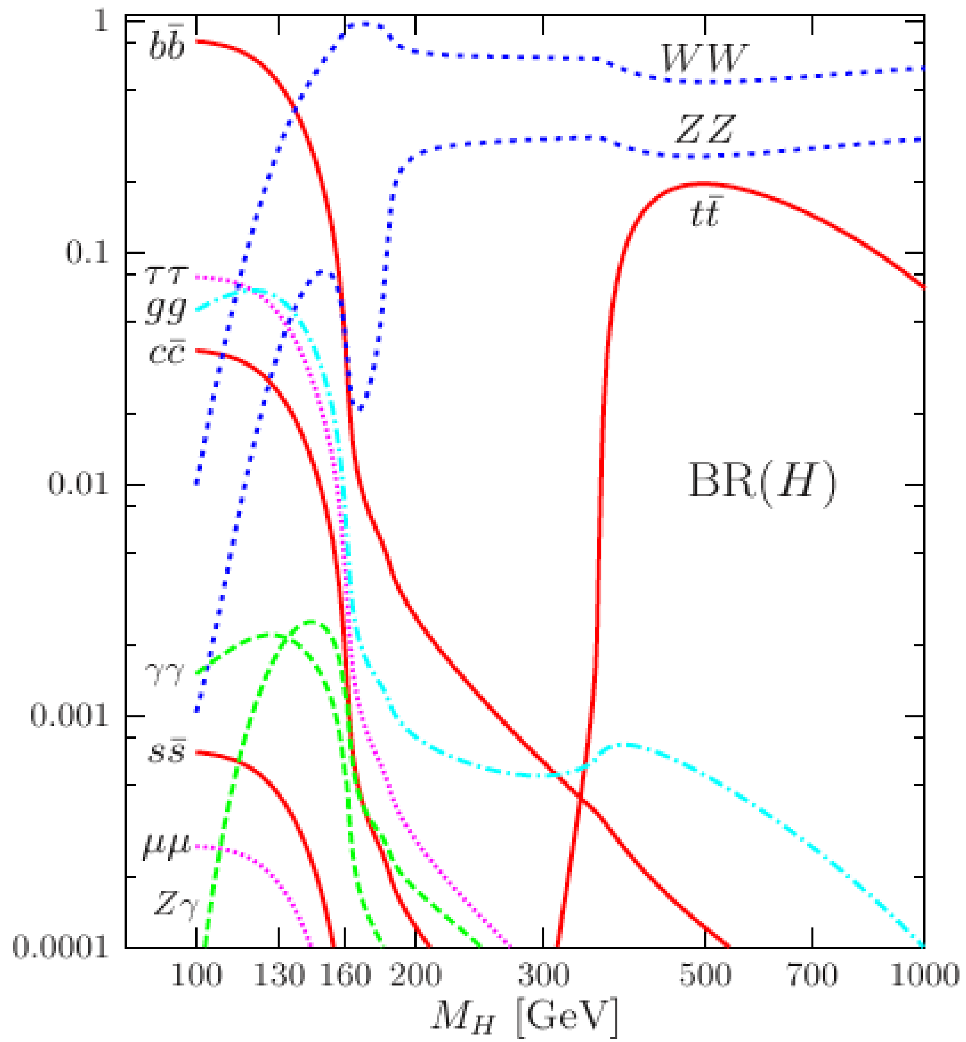
3. SM Higgs Decay Channels



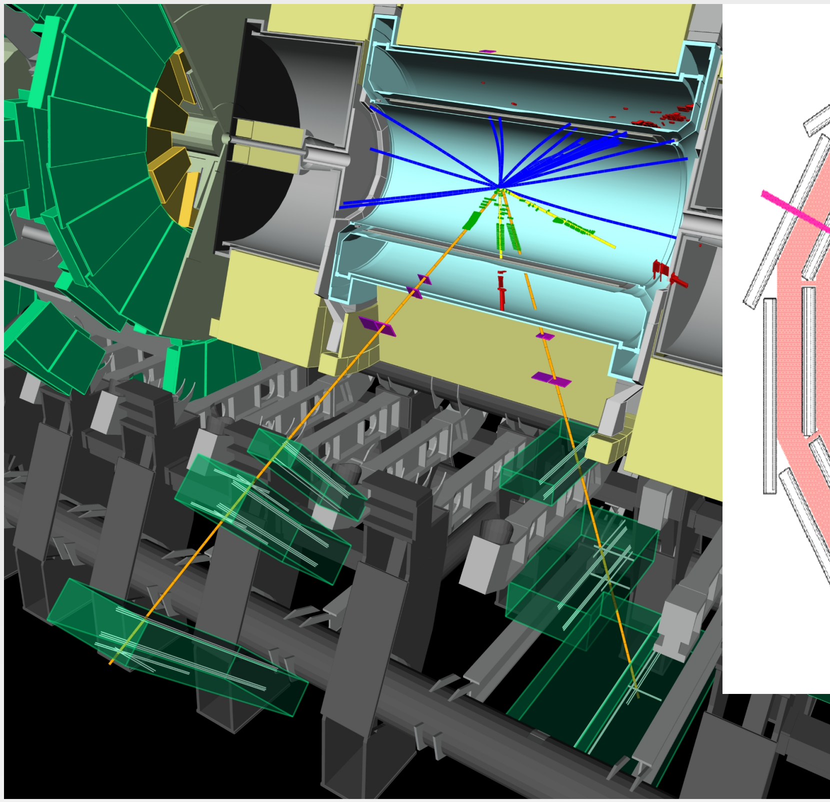
For m_H > 140 GeV/c²

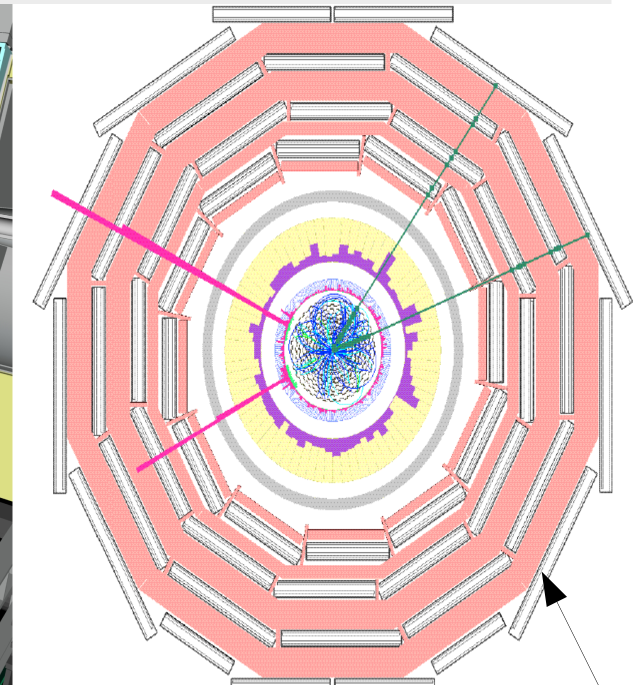
H → WW(*) and H → ZZ(*) are main discovery channels

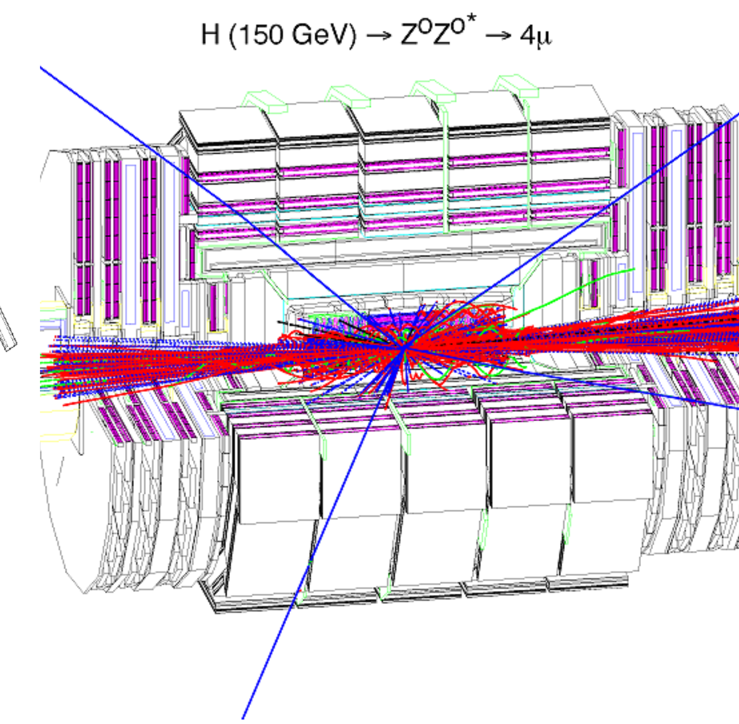
- Highest BRs for $m_H > 2m_W$
- Clean leptonic decay modes
  - BR(W → lν): 10.8%; BR(Z → l⁺l⁻): 3.4%
- Cover high m_H region and down to ~$2m_W$



3.1. Higgs → ZZ$^{(*)}$ → 4l
1. Signal







H->ZZ->2e2μ

www.atlas.ch/photos/events-simulated-higgs-boson.html

Possible topologies: 4e, 4μ, 2e2μ

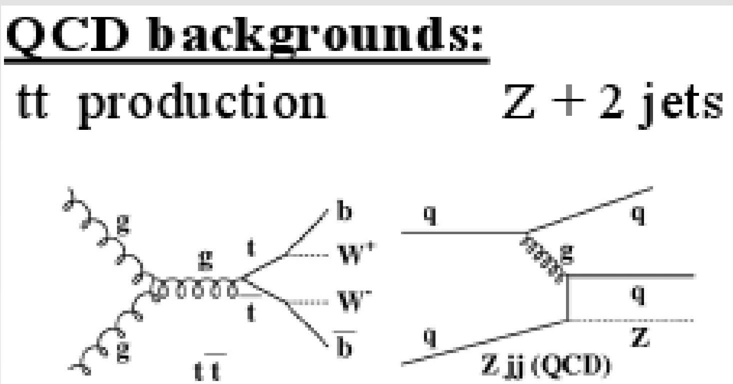
- 2e2μ has twice the rate as 4e an 4μ channels

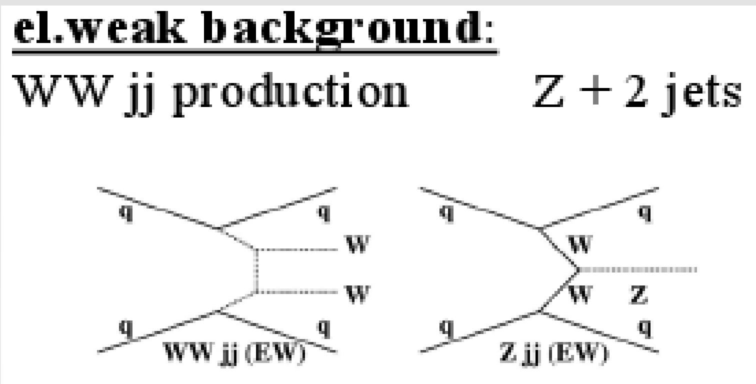
Cleanest discovery channel for m_H > 140 GeV/c^2

=> "The Golden Channel"

3.1. Higgs → $ZZ^{(*)}$ → 4l

2. Background

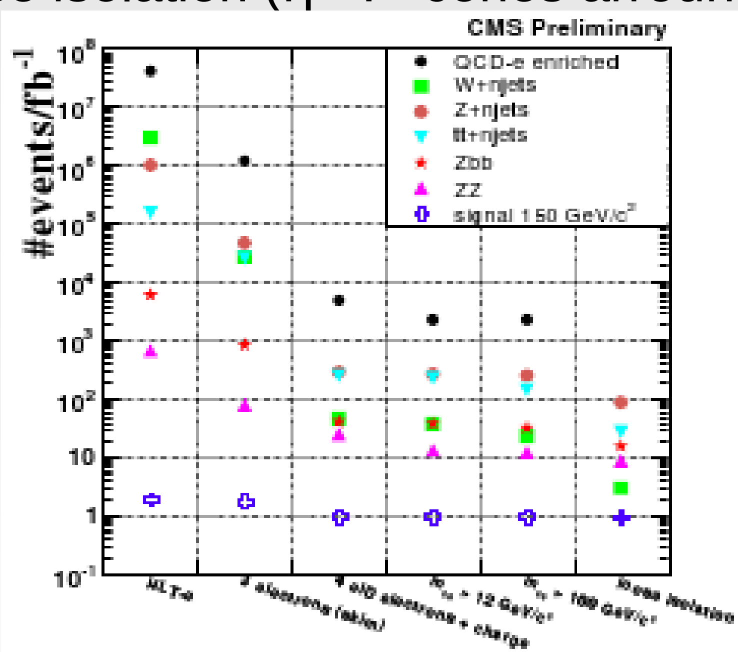




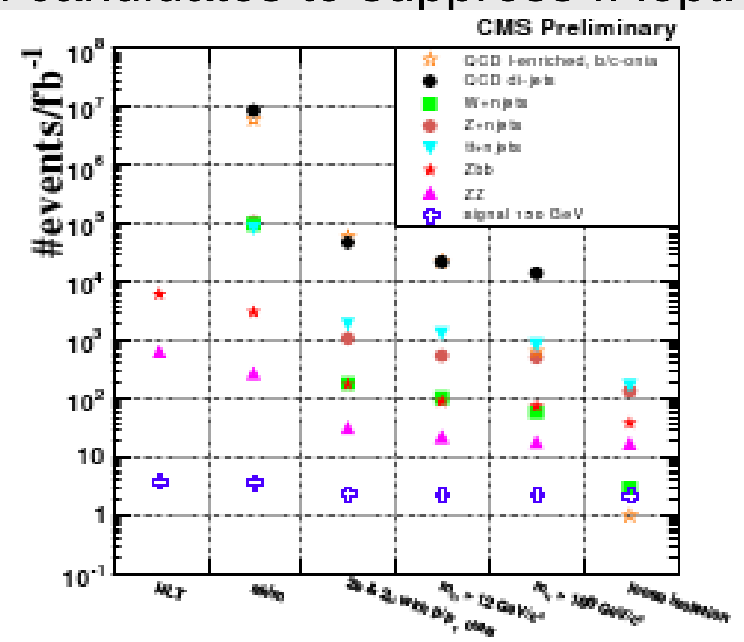
- qq → ZZ*/γ*
  - => Irreducible, dominant background
- gg → $t\bar{t}$ → $WWb\bar{b}$
- $Zb\bar{b}$ → $2l\, b\bar{b}$
  - => Reducible backgrounds
  - => non-isolated leptons from b decays

3.1. Higgs → ZZ(*) → 4l
3. Analysis (I)

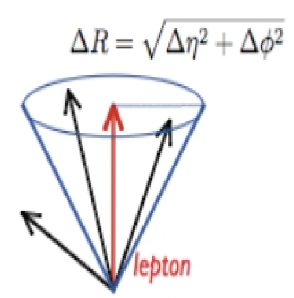
- Pre-selection to suppress backgrds involving fake leptons
  - Single and double lepton triggers
  - >= 2 pairs of opposite charged, matching flavoured leptons
    - P_t^{lepton} > 5 GeV/c
  - M_{ll} > 12 GeV/c² (all pairs) → fake leptons of low mass hadr. resonances
  - M_{4l} > 100GeV/c² (at least one) → search on non-excluded mass range
  - Loose isolation (η -Φ -cones arround candidates to suppress f. lept. from jets)



ZZ → 4e



ZZ → 2e2μ



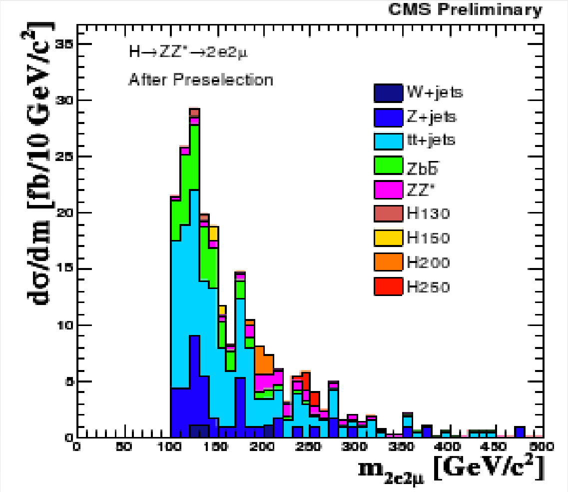
=> 98,5% of signal events pass pre-selections at m_H=150 GeV/c²

3.1. Higgs $\rightarrow ZZ^{(*)} \rightarrow 4l$

3. Analysis (II)

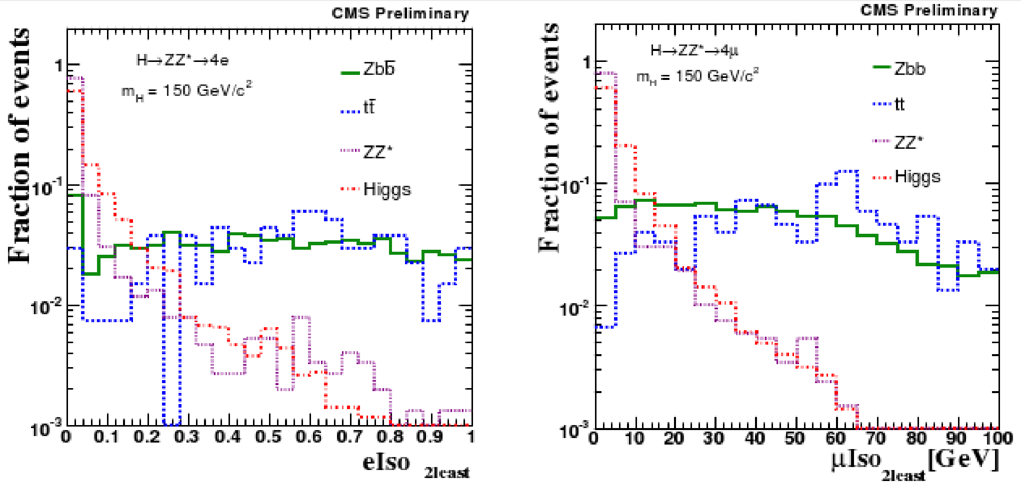
Main reducible backgrounds after pre-selection:

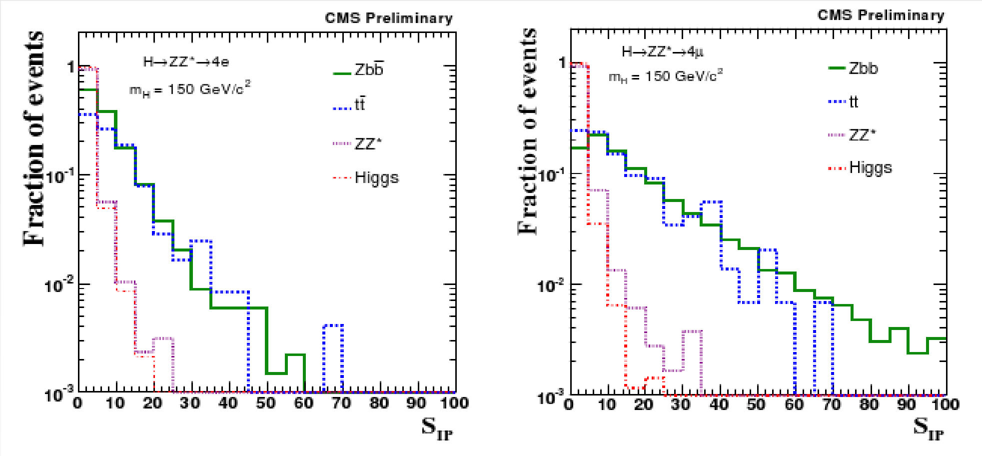
Z+jets, $t\bar{t}$ and $Zb\bar{b}$



Rejection (m_H independent):

- Isolation (Iso3+Iso4), Impact Parameter



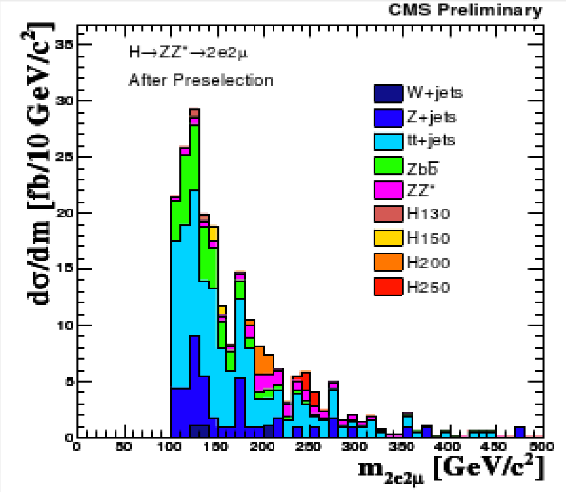


(a) (b)

3.1. Higgs → ZZ$^{(*)}$ → 4l
3. Analysis (III)

Main reducible backgrounds after pre-selection:

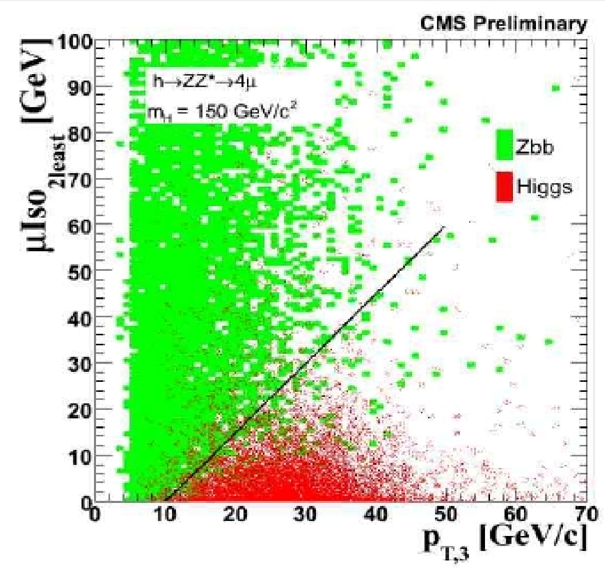
Z+jets, $t\bar{t}$ and $Zb\bar{b}$

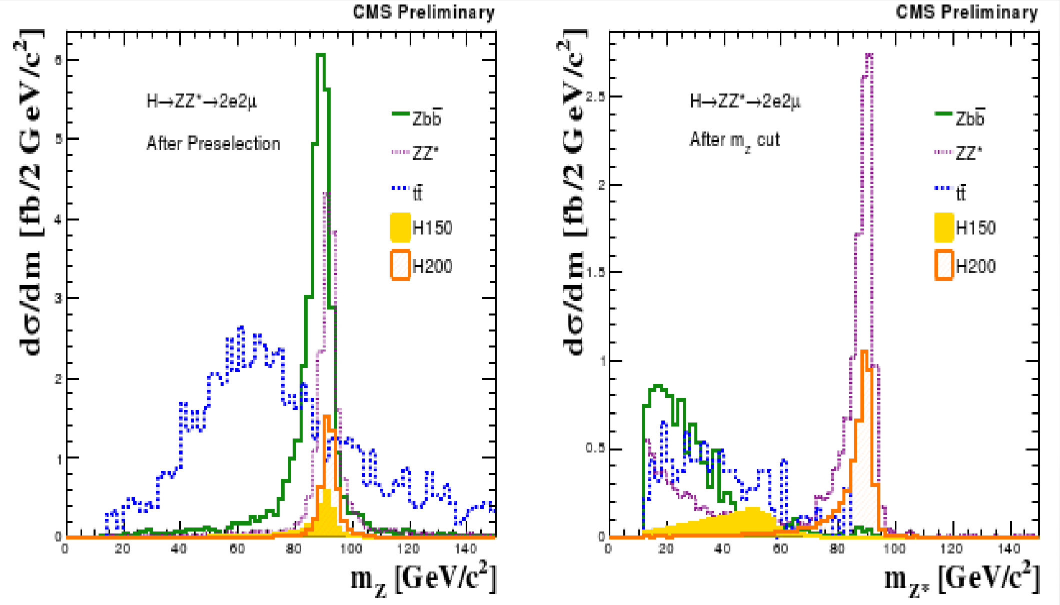


Rejection (m_H independent):

- Isolation (Iso3+Iso4), Impact Parameter
- p_T^e>7GeV/c, p_T^μ > 5GeV/c
- 50< m_Z< 100GeV/c
- 20< m_{Z^*}< 100GeV/c

$m_{4l} \approx m_Z + m_{Z^*}$

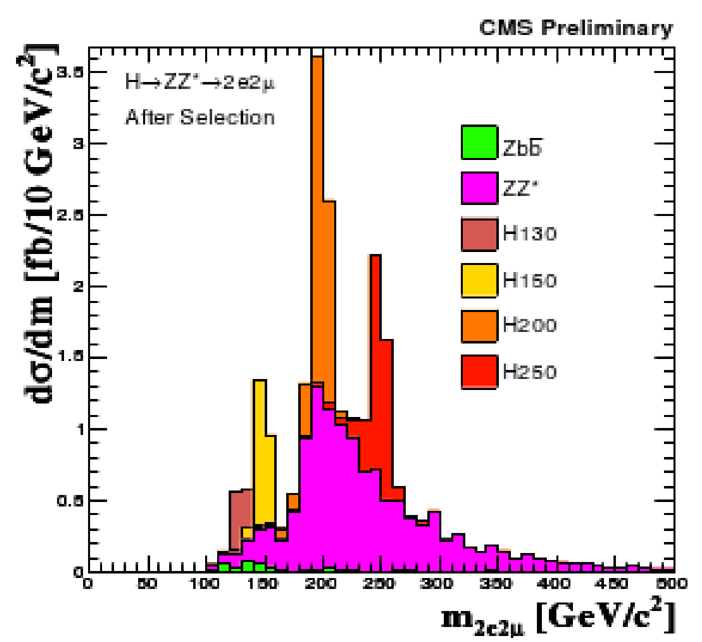


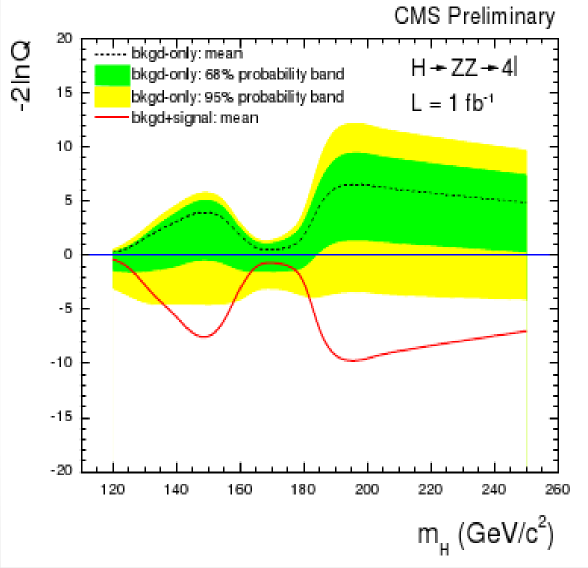


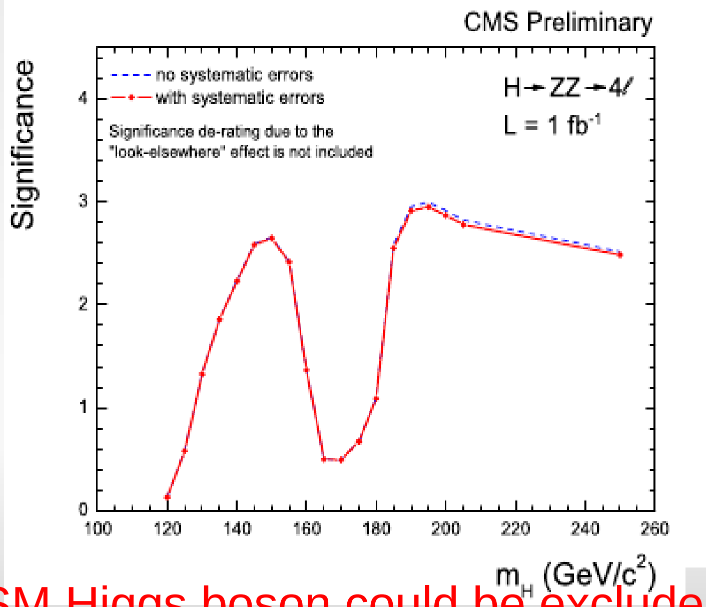
3.1. Higgs → ZZ(*) → 4l
4. Result (14 TeV, ∫Ldt=1fb⁻¹)

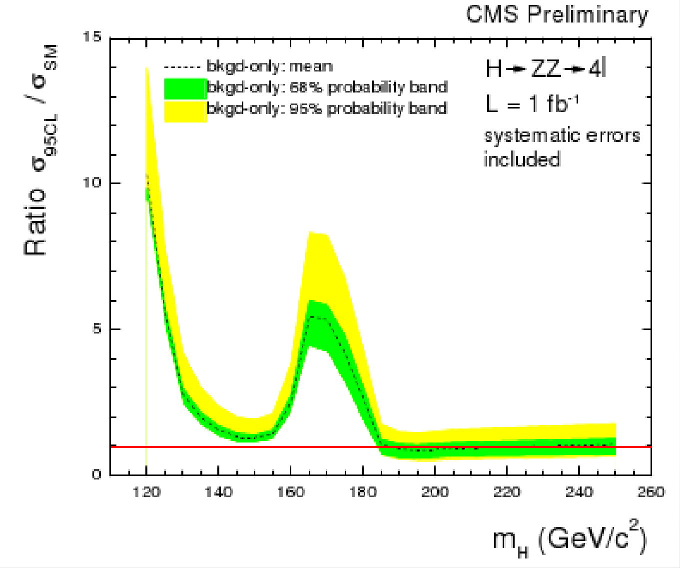
- Counting experiment
  → Quanititative Measures
  - Log-likelihood:
    $-\ln Q = -2\, N_{S+B} \ln(1+N_S/N_B)+2N_S$
  - Significance
  - Bayesian approach

- Systematic errors small



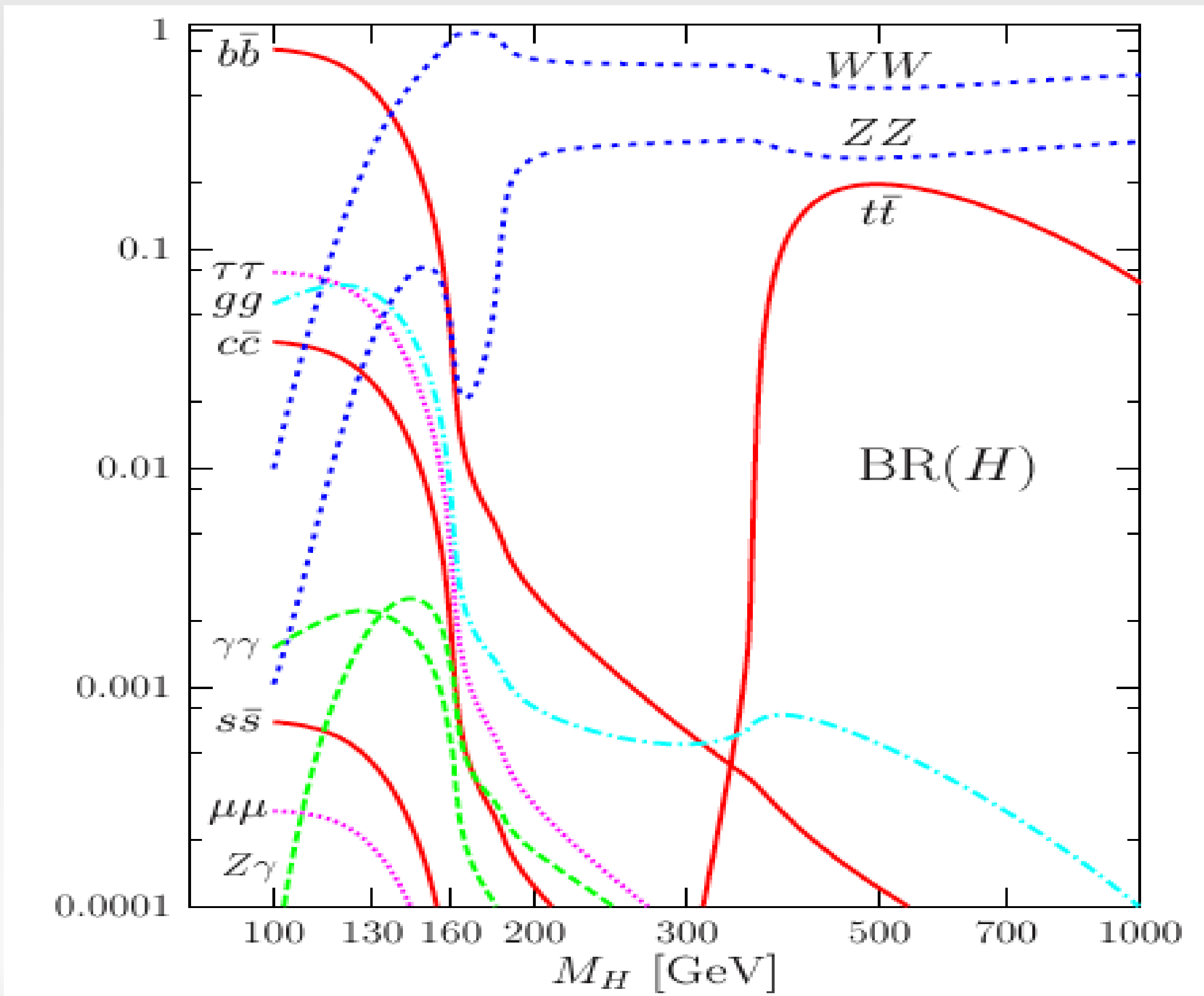






=> SM Higgs boson could be excluded for $185 < m_H < 250$ GeV/c²

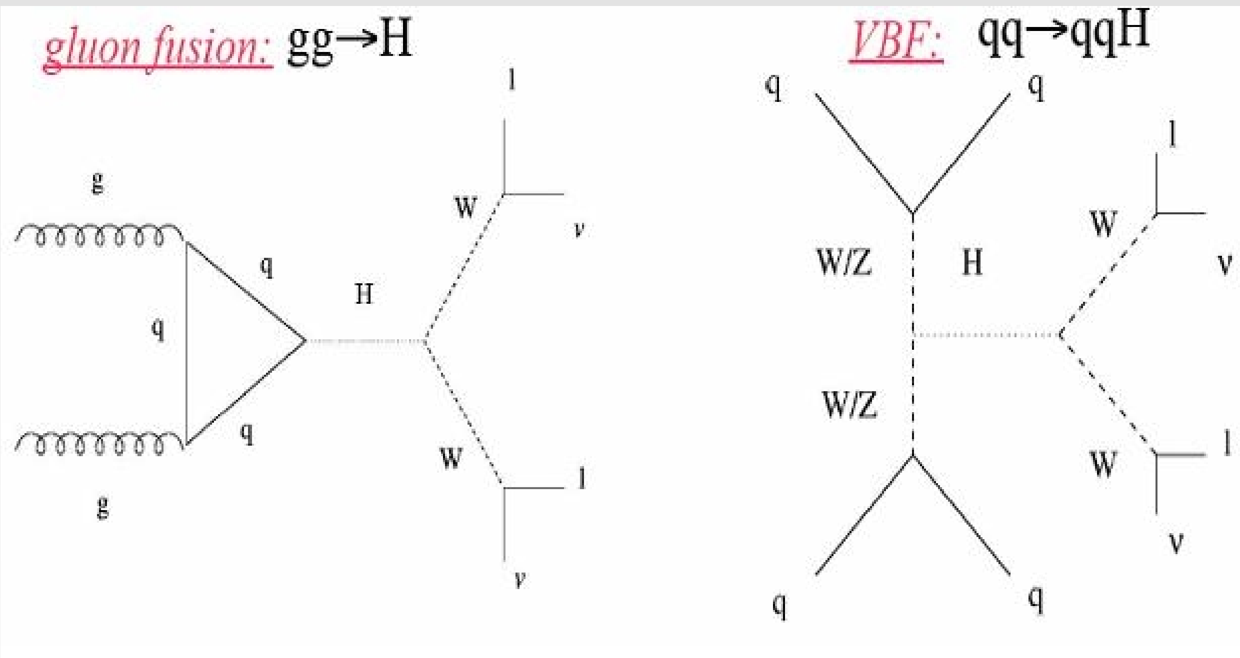
3.2. Higgs → WW(*) → lυlυ

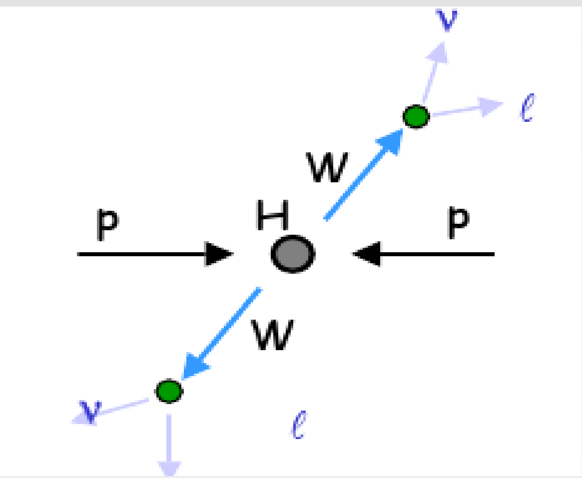


3.2. Higgs → WW(*) → lυlυ
1. Signal

Event topology: - 2 isolated high p_T leptons e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\pm$

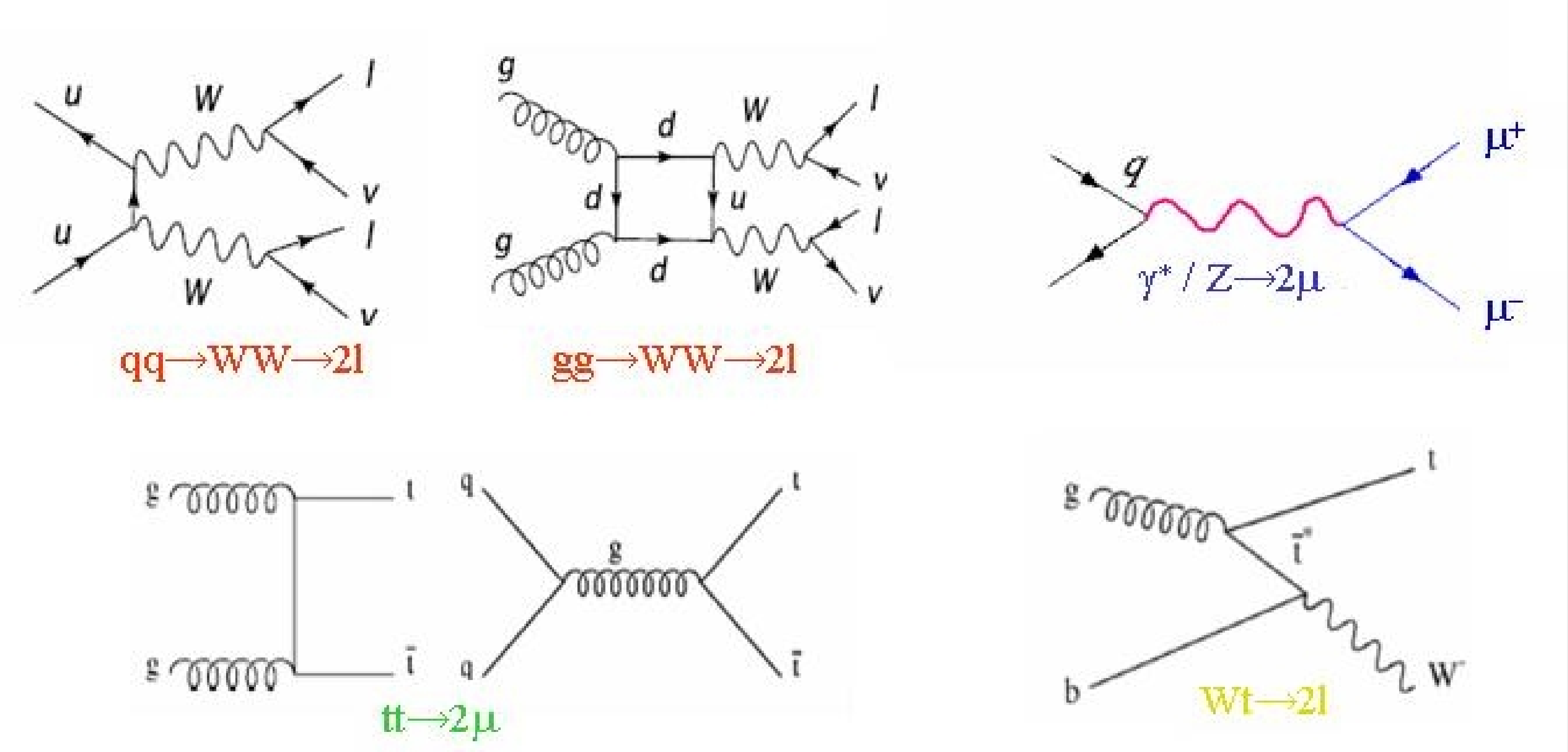
- E_T miss, no hadr. activity





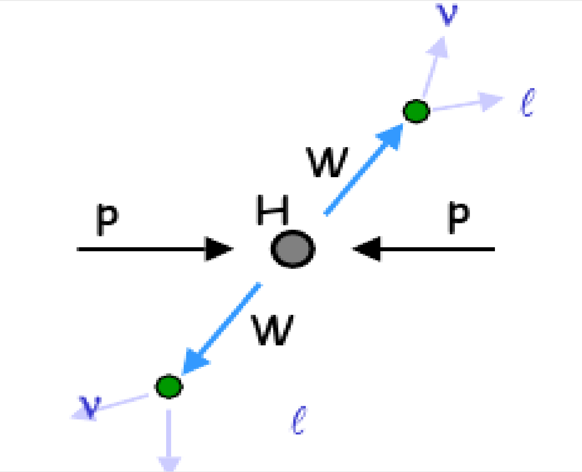
- Main discovery channel for the Higgs Boson in the mass range: $2M_W < m_H < 2M_Z$

3.2. Higgs → WW(*) → lυlυ
2. Background



- Primary backgrounds
  - Continuum WW
  - tt → 2μ
  - γ*/Z → 2l
- Other backgrounds: ZW → 3l, tWb → 2l, ZZ → 2l
- Most samples generated with Pythia

3.2. Higgs → WW(*) → lυlυ
3. Analysis



- Preselection to select leptonic WW events
  - Single lepton triggers
  - Exactly *2 isolated leptons* opp. charge
    - $P_T^{1,2}$ > 10 GeV or at least one p_T >20 GeV
  - E_T^{miss} > 30 GeV → required from the undetected neutrinos
  - m_{ll}>12 GeV → rejects bb-resonances backgrd

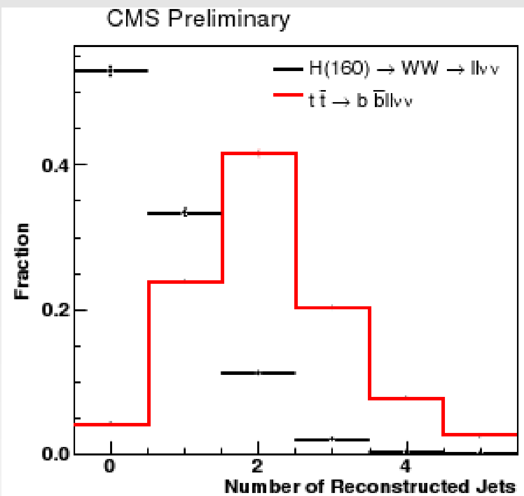
- Due to presence of 2 neutrinos, there is no mass peak.
→ Counting experiment needed for reconstruction of the Higgs mass
→ Accurate background (tt, WW) estimates from data are needed
→ Good reconstruction tools needed

- Well identified lepton reduces W+jet backgrd

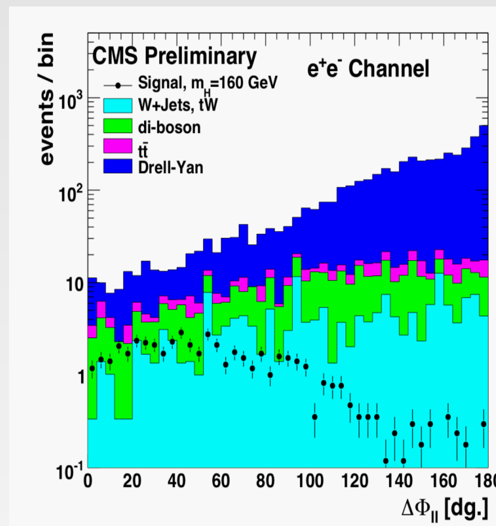
3.2. Higgs → WW(*) → lυlυ
3. Analysis

- Main selection observables for sequential cut based analysis

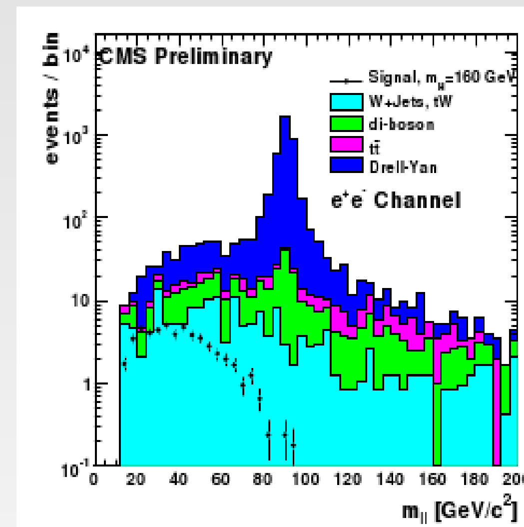
- Central jet (|η| < 2.5, P_T > 15 GeV) veto → reduce tt and tWb backgrd



- Angular correlation $\Delta\Phi_{ll}$ btw leptons

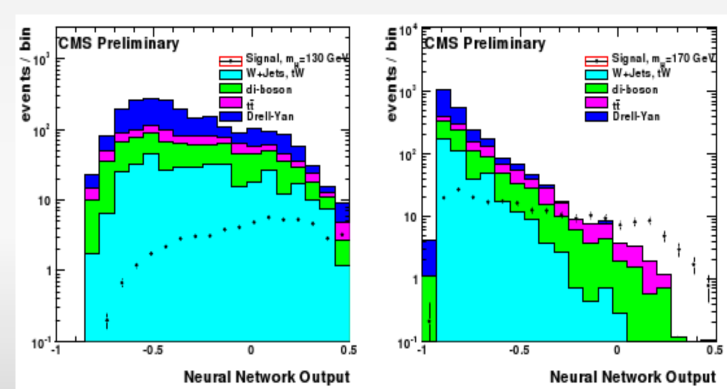


- Di-lepton mass → against leptons from Z boson decays



- E_T^{miss}, leptons p_T

- Additional variables used in NN analysis:
  e.g.: $\Delta\eta_{ll}$, transverse mass of each lepton, |η| of both leptons,...



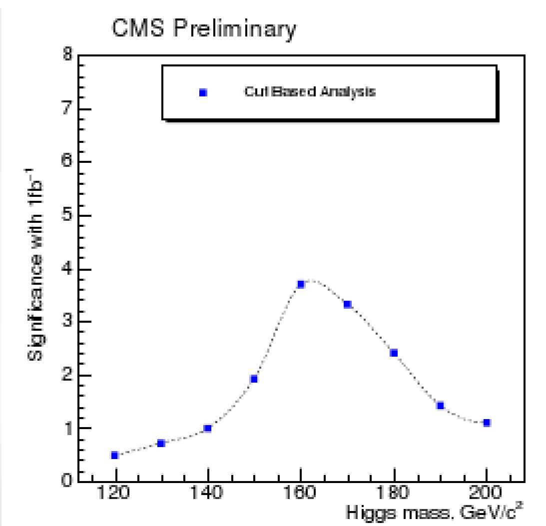
3.2. Higgs → WW(*) → lυlυ
3. Result (integr. Lumin. 1fb^{-1})

- Counting Experiment

- Two Analysis approaches:

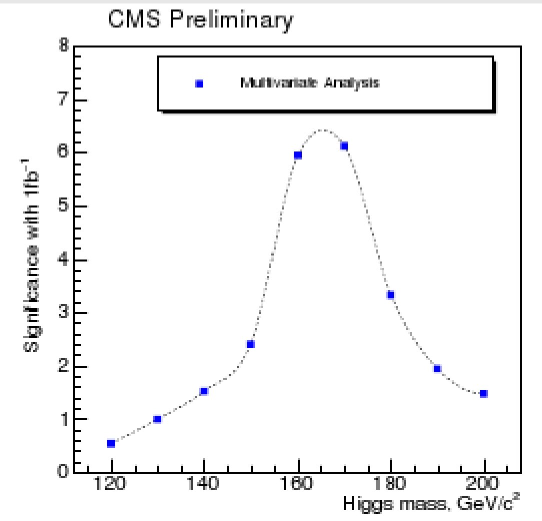
Cut based

$H \to 2\ell 2\nu$	m_H[GeV] 130	150	160	170	190
ee Preselection	24	58.7	81	82.7	58
Final selection	6.6	12.5	20.1	21.2	11.0
$\mu\mu$ Preselection	49	108	143	144	97
Final selection	8.7	9	21.0	17	5.6
$e\mu$ Preselection	61	150	195	202	139
Final selection	11.0	20.6	31.5	33.1	12.2



Neuronal network

m_H [GeV]	NN output Signal	Background
120	7.5±0.8	87.3±18.8
130	17.3±1.9	89.4±19.3
140	31.4±3.4	121.4±24.5
150	24.4±2.6	42.5±8.56
160	67.5±7.4	37.4± 7.8
170	66.8±7.3	40.0± 8.0
180	50.9±5.5	67.3±13.6
190	31.2±3.4	73.3±14.3
200	29.6±3.2	115.8±22.8



=> SM Higgs could be discovered for m_H~ 170 GeV/c^2

This is the Region, which Tevatron excluded on CL of 95%

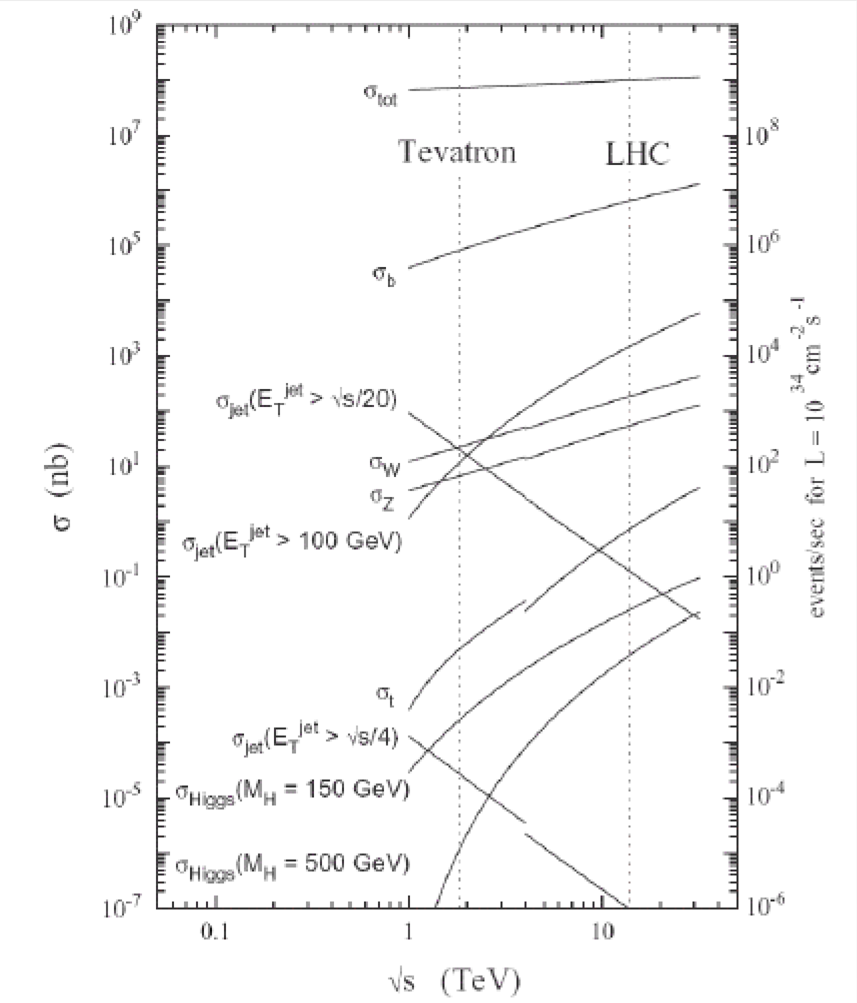
H→ZZ/WW: 10 TeV projection

- Most important effect is change in cross-section
  - gg→H: 10 TeV/14 TeV is ~0.54
  - WW/ZZ: 10 TeV/14 TeV is ~0.6

- Change of acceptance has been checked in ZZ → o(%)

- Very preliminary, full analyses for 10 TeV are in work

☛ 14→10 TeV is approximately equivalent to a loss of a factor 1.5 in sensitivity



4. Conclusion

- CMS analyses for $H \rightarrow WW$ and $H \rightarrow ZZ$ in leptonic modes in the context of an initial scenario

- Multivariate selection slightly better than simple cut based ($H \rightarrow WW$)

- Importance of methods for background estimation and control from data

- SM Higgs could be discovered at 5σ around m_H~170 GeV/c² in WW decay mode with 1fb-1

- SM Higgs could be excluded for 185 <m_H< 250 GeV/c² in ZZ decay mode with $1fb^{-1}$

- Using both channels, SM Higgs could be excluded for m_H>140 GeV/c² with $1fb^{-1}$

- 10 TeV bottom line: a loss of sensitivity by a factor ~1.5

References:

CMS Physics Analysis Summary, “Search strategy for the Higgs boson in the $ZZ^{(*)}$ decay channel with the CMS experiment”, 2009/02/07

CMS Physics Analysis Summary, “Search Strategy for a Standard Model Higgs Boson Decaying to Two W Bosons in the Fully Leptonic Final State”, 2009/01/29

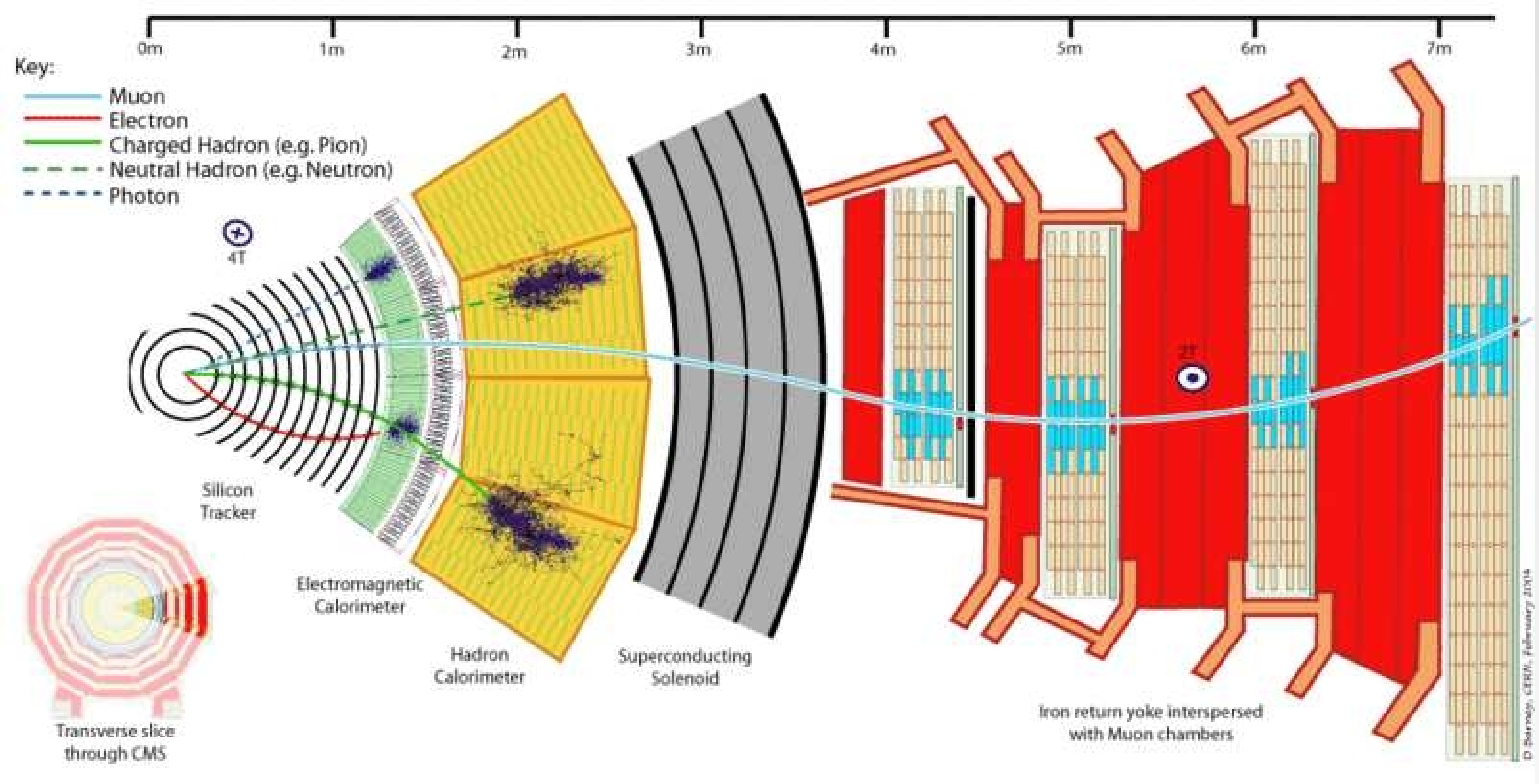
susy08.kias.re.kr/slide/17p/p1/1st/Sengupta.ppt

ATLAS, http://www.atlas.ch/photos/events-simulated-higgs-boson.html

physics.ucsd.edu/students/courses/fall2007/physics214/farsian.pdf

Thank you for listening!

Higgs → ZZ



0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS

Higgs → ZZ

<u>Main backgrounds</u> (after presel.): tt, Zbb , ZZ