6. Higgs searches

The only missing ingredient of the Standard Model: Higgs boson

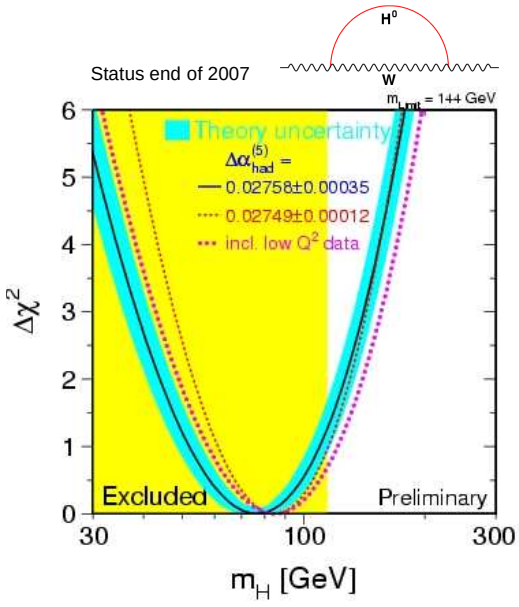
Higgs is needed in SM

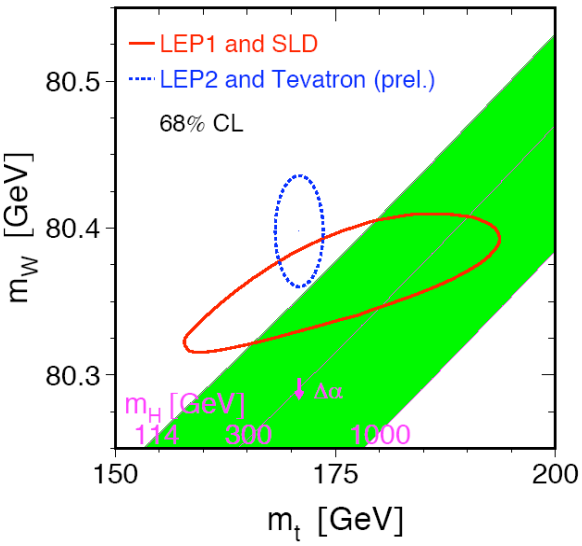
- to generate boson and fermion masses in a gauge invariant way
- to make SM renormalisable
- to keep WW cross section finite

➡ Huge efforts to find it

- Searches at LEP and Tevatron
- Major motivation to build the LHC

Higgs mass prediction

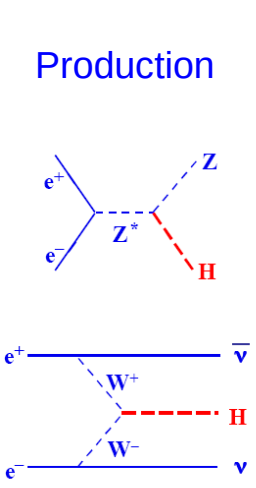




M_H > 114 GeV (from direct searches)

M_H < 144 GeV (from EW fits)

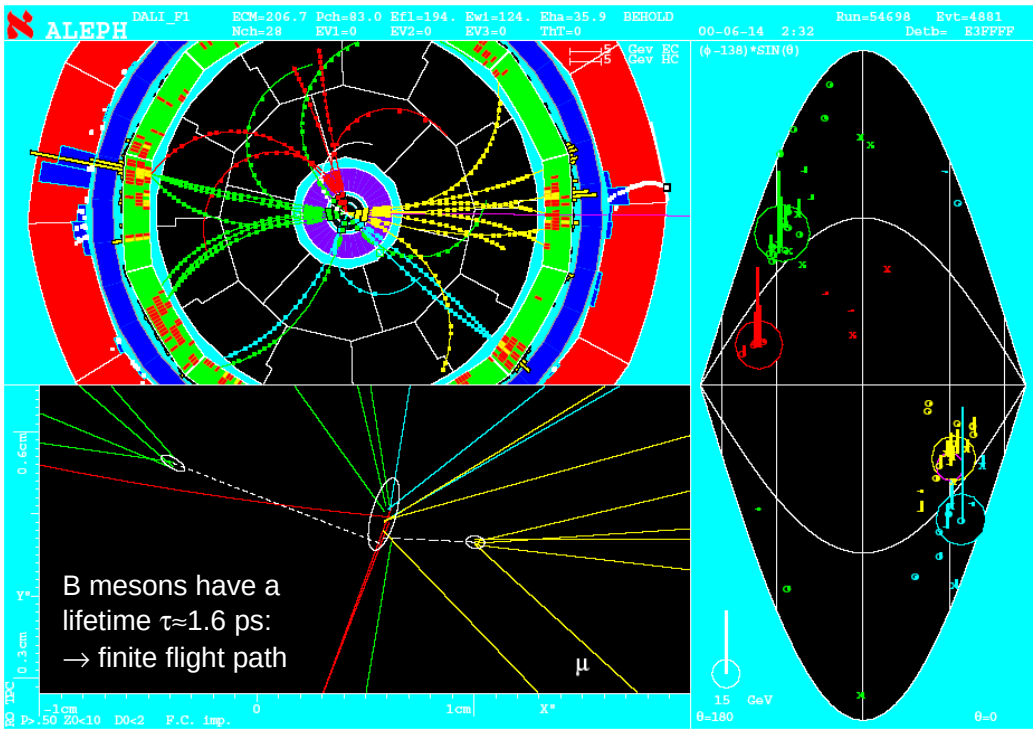
Direct Higgs Searches as LEP



Decay			Main background:
H→bb̄ Z→qq̄	4-Jet-Kanal	51%	WW→qqqq,ZZ→bbqq QCD 4jets
H→bb̄ Z→νν̄	Neutrino-Kanal	15%	WW→qqlν,ZZ→bbνν
H→bb̄ Z→τ⁺τ⁻	Tau-Kanal	2.4%	WW→qqτν,ZZ→qqττ QCD (low-mult. jets)
H→τ⁺τ⁻ Z→qq̄	Tau-Kanal	5.1%	WW→qqτν,ZZ→qqττ QCD (low-mult. jets)
H→bb Z→e⁺e⁻, μ⁺μ⁻	Lepton-Kanal	4.9%	ZZ→bbll

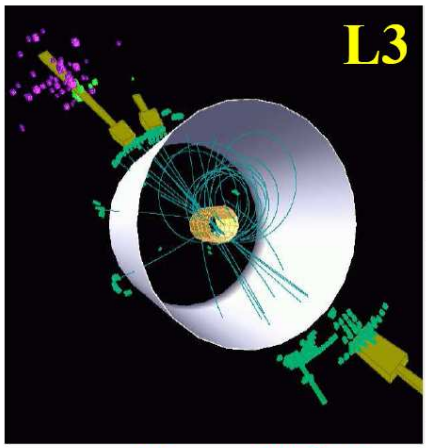
Higgs searches at LEP include 80% of the final states, selection efficiency ~40 - 50%

Higgs candidate with M_H=114 GeV



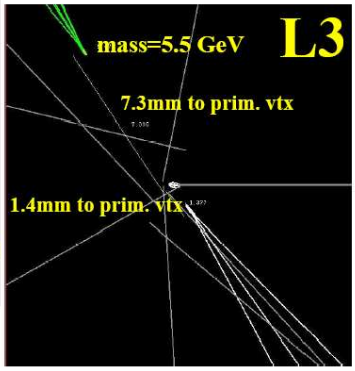
Another candidate with M_H=115 GeV

most significant Hνν candidate



measured H mass=115 GeV
H mass resolution ~3 GeV

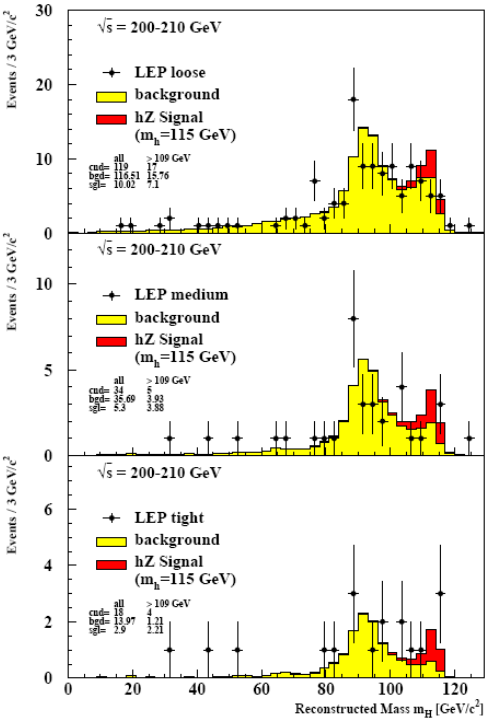
Secondary vtx's view



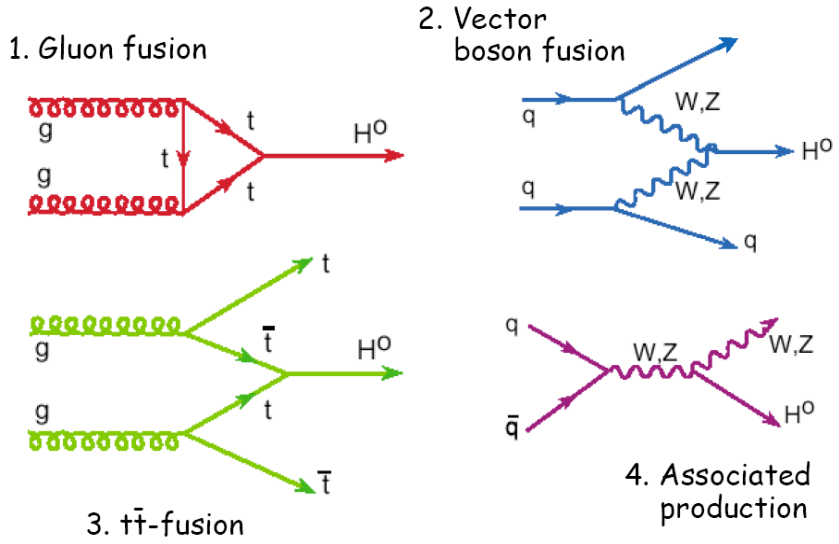
Invariant mass of Higgs candidates

LEP Summary: No signal above background seen

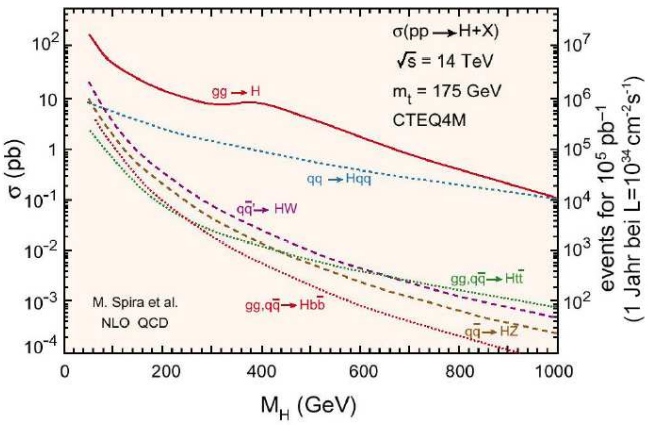
LEP excludes a 114.4 GeV Higgs boson @ 95% CL. (expected 115.3 GeV)

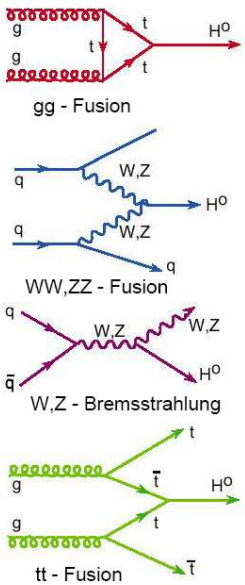


Higgs production at $p\bar{p}$ colliders

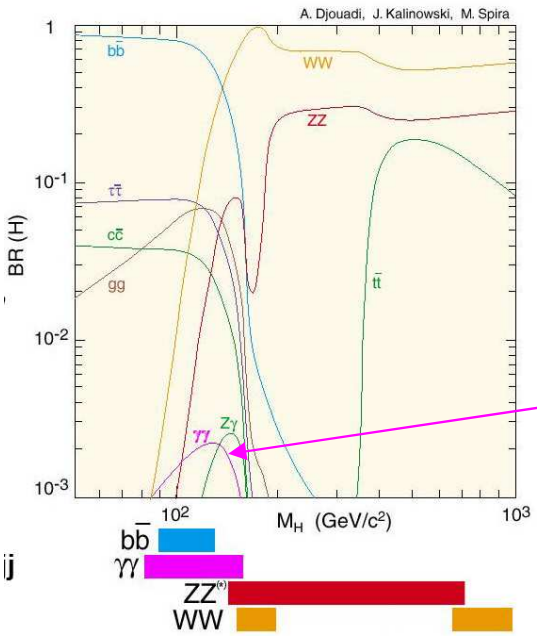


Higgs production at $p\bar{p}$ colliders





Higgs decay channels



@ **LEP**: Searches were done using

$H \to b\bar{b}$ $M_H > 114$ GeV

"golden" Higgs decay channel at LEP;
at $pp \to$ too much background,
BR is small above WW threshold

@ **Tevatron**:

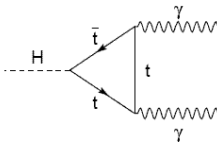
$ZH \to \ell^+\ell^- b\bar{b}$

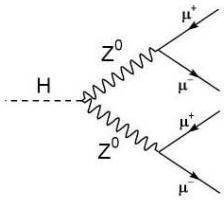
$H \to W^+W^-$

@ **LHC**:

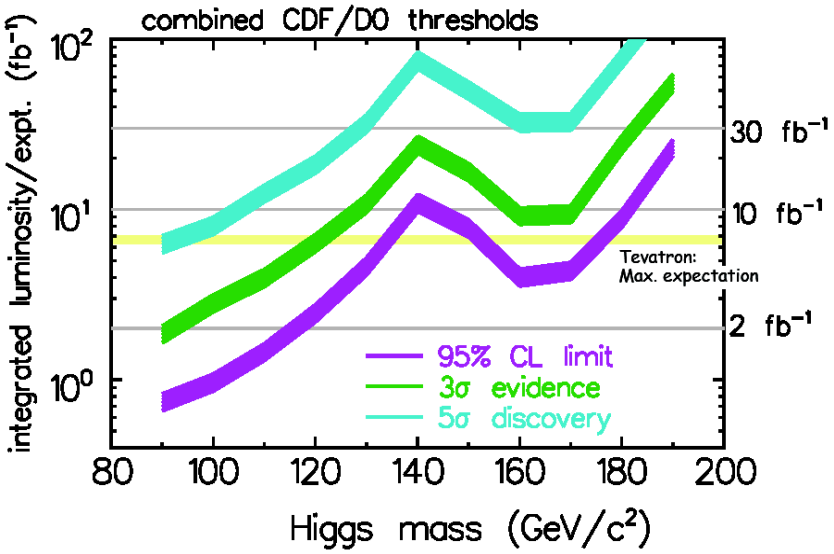
- $M_H < 150$ GeV: $H \to \gamma\gamma$
- 150 GeV < M_H < 1 TeV

$H \to ZZ^{(*)}$ und $H \to W^+W^-$



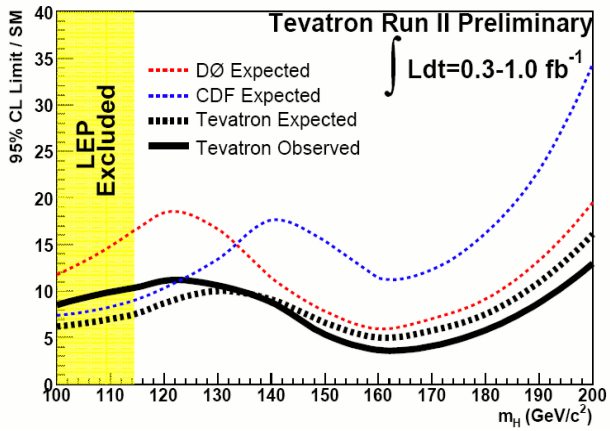


Tevatron Higgs discovery potential



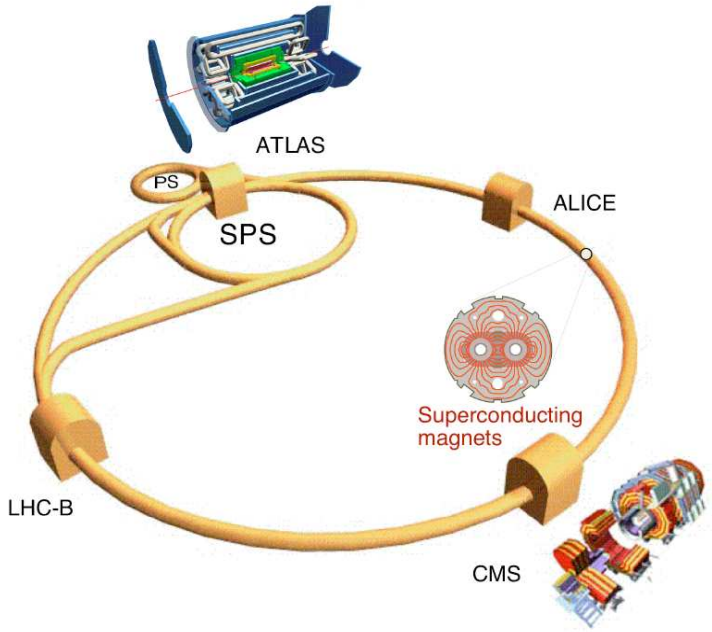
Tevatron has a chance to see the Higgs before LHC

Combined Tevatron Higgs limits



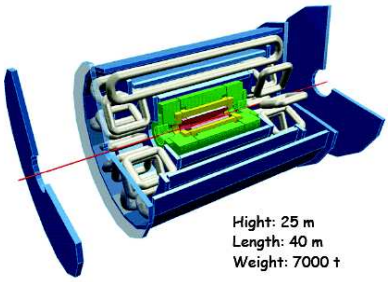
- Sixteen mutually exclusive final states for *WH, ZH, WW*
- Observed combined limits:
  - A factor of 10.4 above SM at M_H=115 GeV
  - A factor of 3.8 above SM at M_H=160 GeV

The Large Hadron Collider – *pp* @ 14 TeV

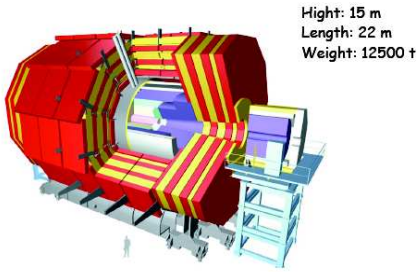


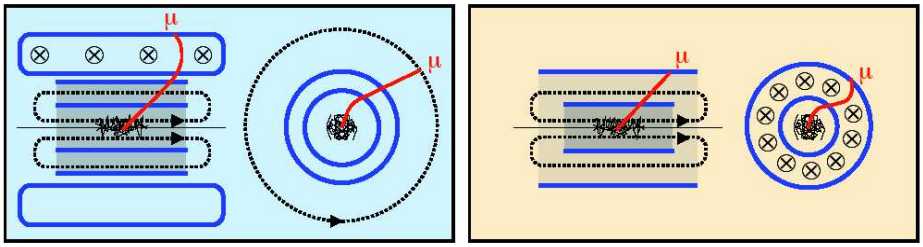
Two Experiments @ LHC

ATLAS: **A** Toroidal LHC **A**pparatu**S**

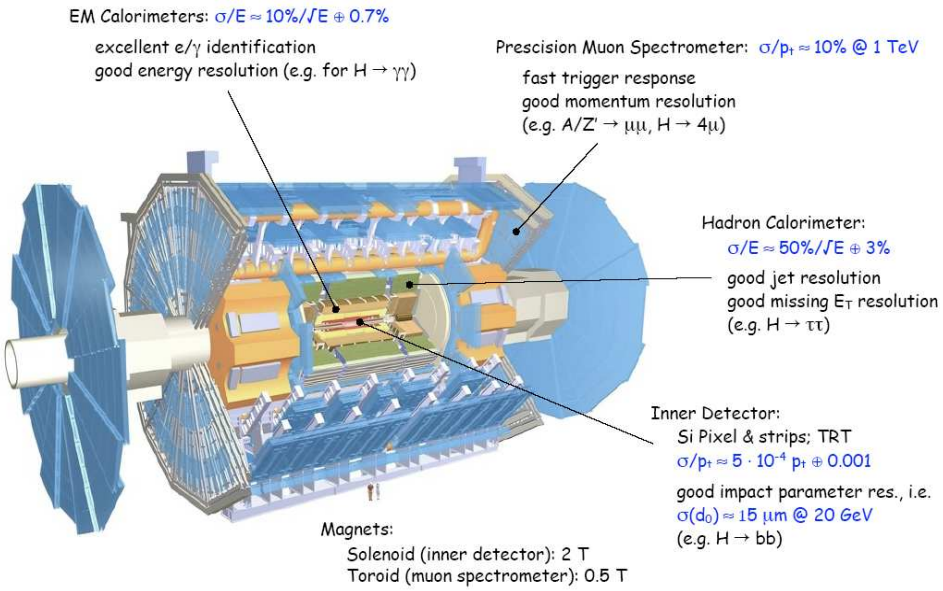


CMS: **C**ompact **M**uon **S**olenoid

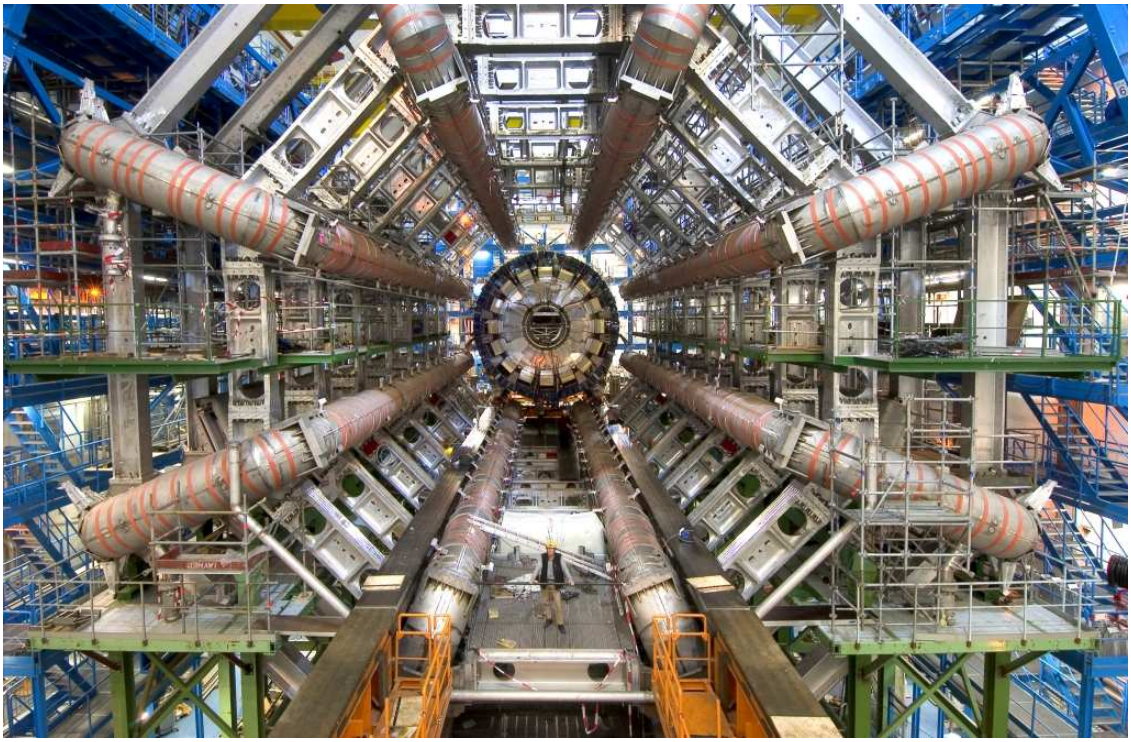




The ATLAS Detector



ATLAS October 2005



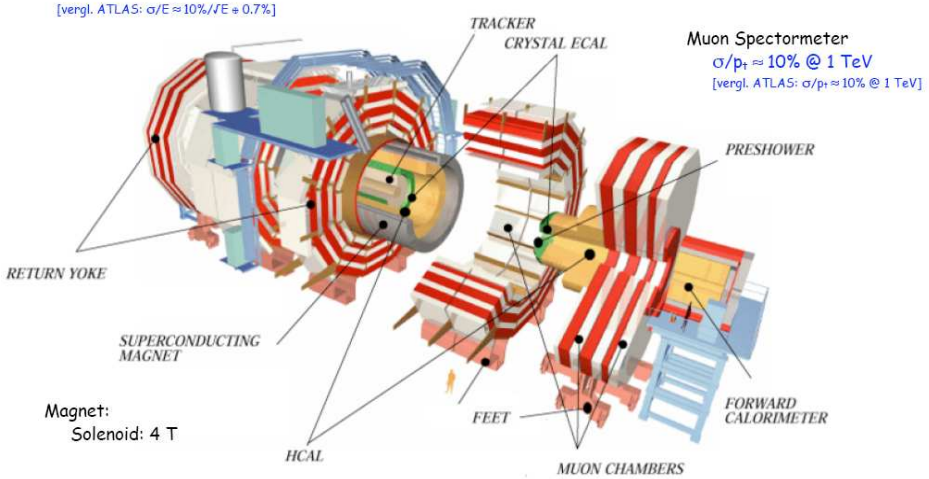
The CMS Detector

Inner Detector:
$\sigma/p_T \approx 5 \cdot 10^{-4}\ p_T \oplus 0.001$
[vergl. ATLAS $\sigma/p_T \approx 5 \cdot 10^{-4}\ p_T \oplus 0.001$]

Hadron Calorimeter:
$\sigma/E \approx 100\%/\sqrt{E} \oplus 5\%$
[vergl. ATLAS: $\sigma/E \approx 50\%/\sqrt{E} \oplus 3\%$]

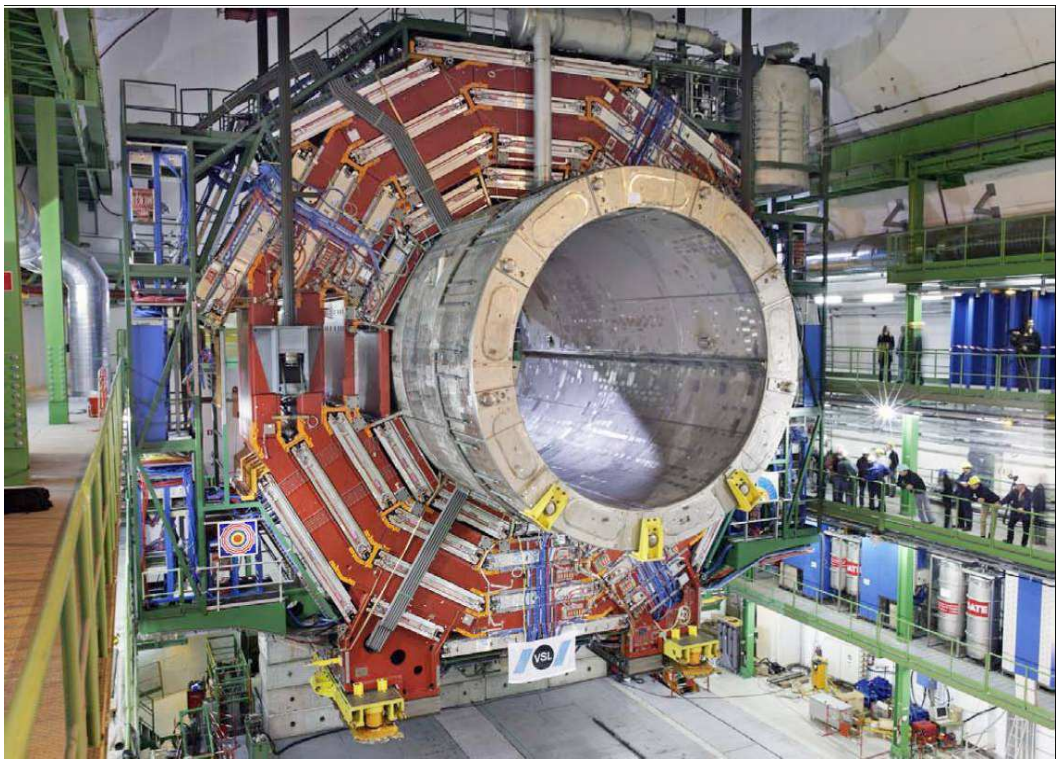
EM Calorimeters:
$\sigma/E \approx 3\%/\sqrt{E} \oplus 0.5\%$
[vergl. ATLAS: $\sigma/E \approx 10\%/\sqrt{E} \oplus 0.7\%$]

Muon Spectormeter
$\sigma/p_T \approx 10\%$ @ 1 TeV
[vergl. ATLAS: $\sigma/p_T \approx 10\%$ @ 1 TeV]

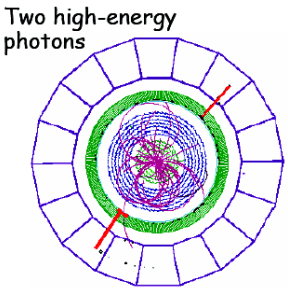


Magnet:
Solenoid: 4 T

CMS February 2007

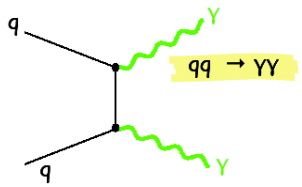


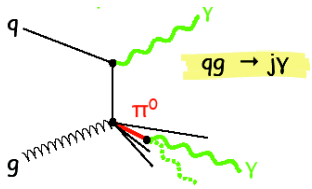
$H \rightarrow \gamma\gamma$



Main backgrounds:

- 2γ production: irreducible background
- γj and jj production: reducible background
  jet rejection of > 10^3 is required

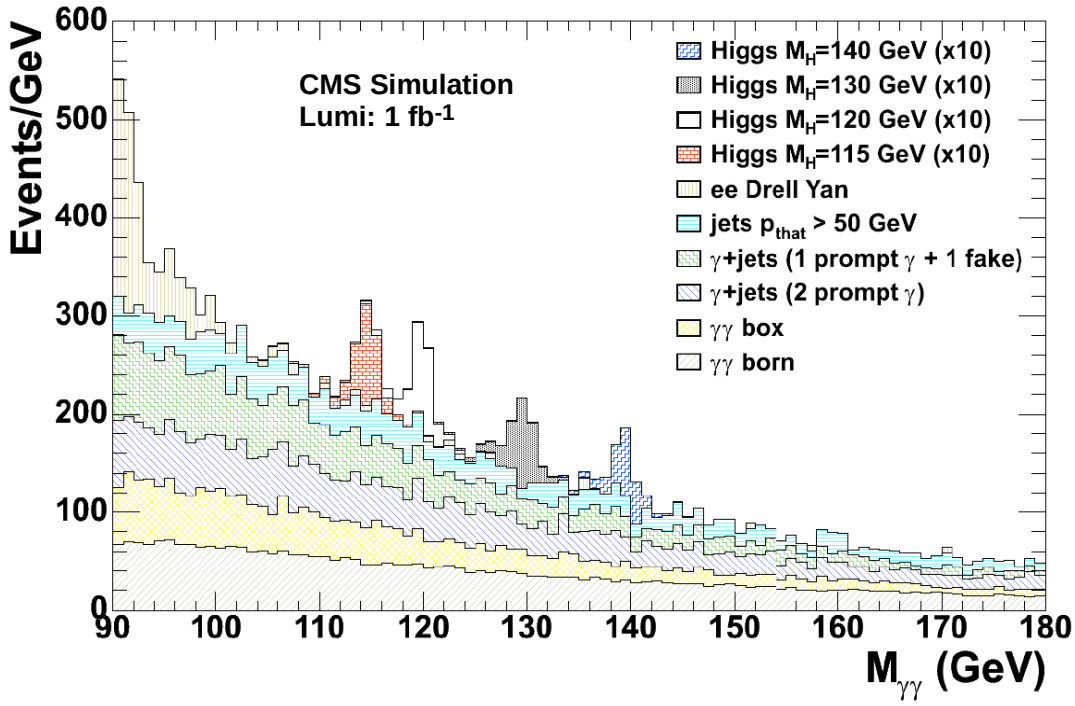




demands excellent calorimetry

$H \rightarrow \gamma\gamma$

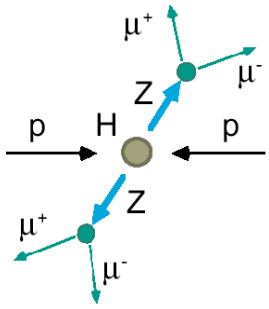
Signal significance: $S = \frac{N_{signal}}{\sqrt{N_{bg}}} = \frac{N_{tot} - N_{bg}}{\sqrt{N_{bg}}}$



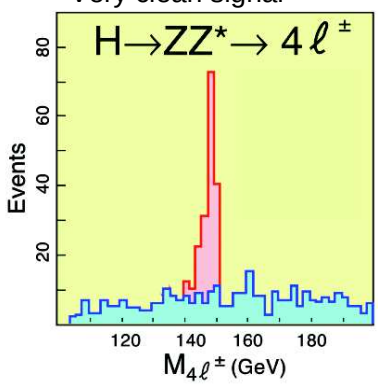
Golden" Higgs decay channel $H \rightarrow ZZ \rightarrow llll$

Discovery potential:
130 – 600 GeV

4 leptons p_T > 20 GeV



Very clean signal



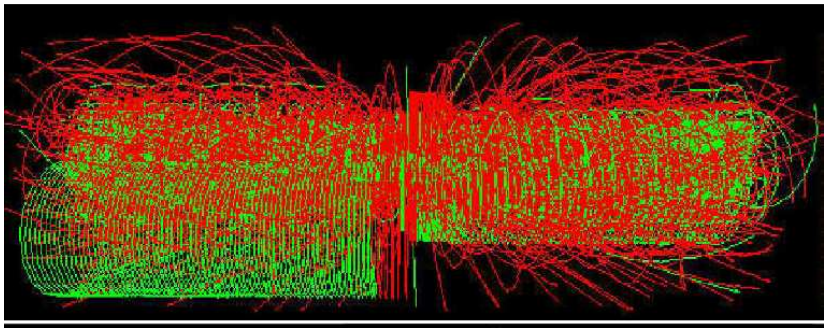
Backgrounds:

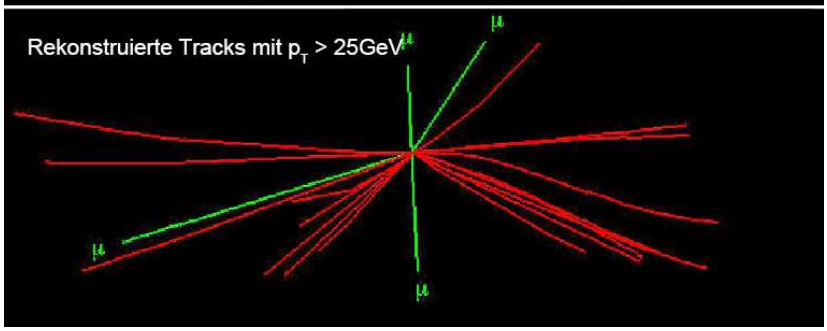
- *tt –> Wb Wb –> l*ν *c*l*ν *l*ν *c*l*ν
- *Z bb –> l l c*l*ν *c*l*ν
- *continuum ZZ*

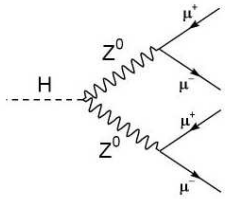
Simulated $H \rightarrow ZZ \rightarrow 4\mu$ event at the LHC

Large multiplicity

- 23 *pp* interactions / event
- Big multiplicity in hard interaction



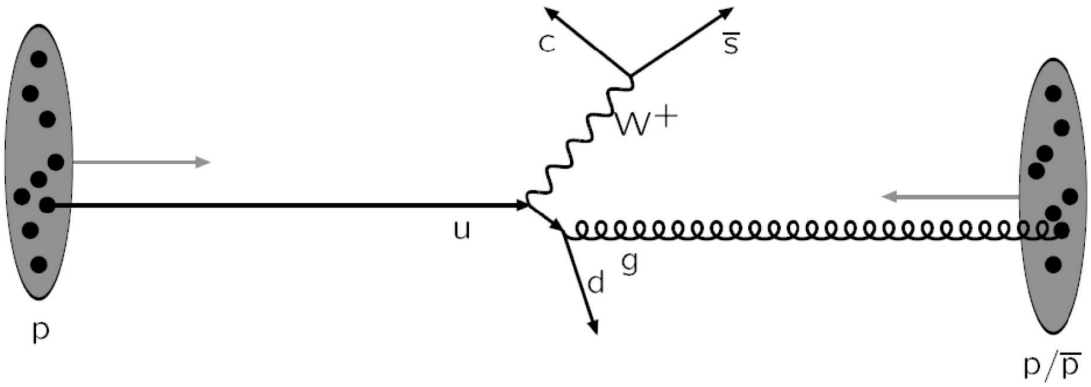




To trigger and to reconstruct these events is an experimental challenge

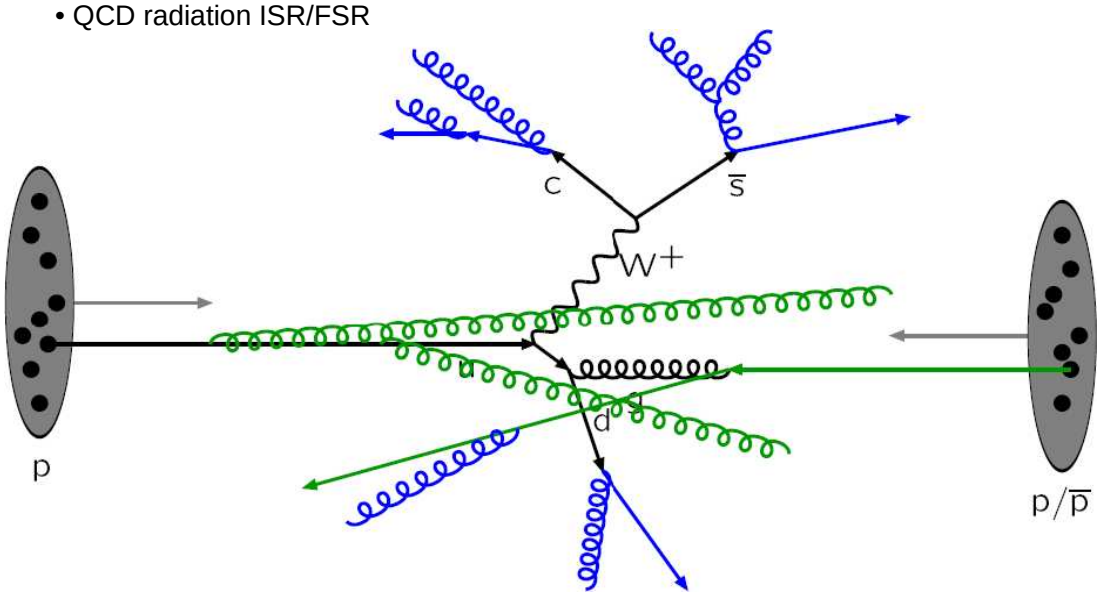
Proton-Proton Interaction at the LHC

- Hard interaction



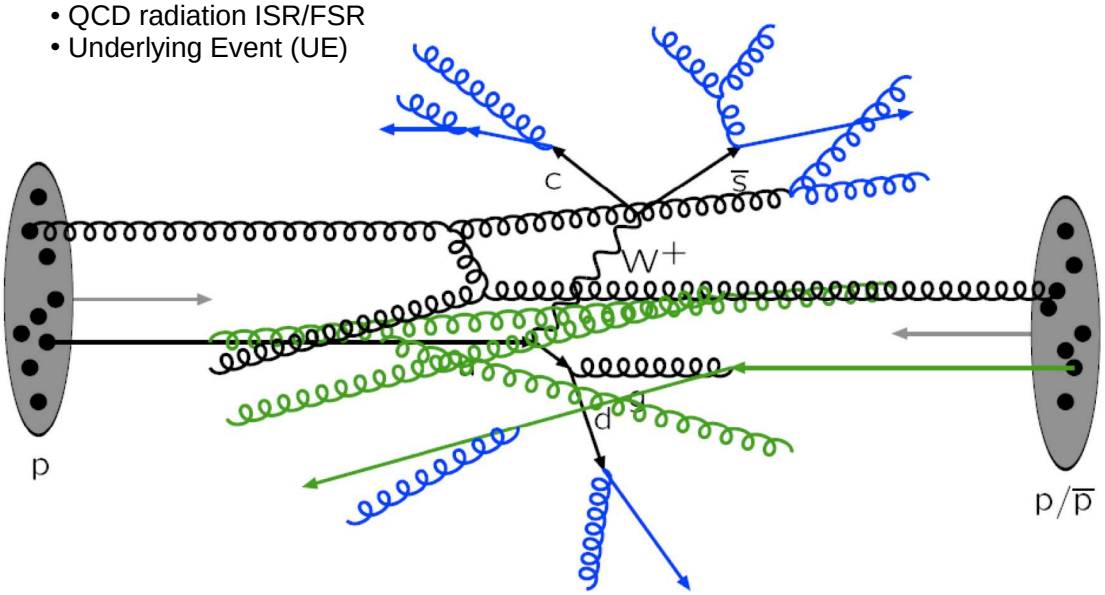
Proton-Proton Interaction at the LHC

- Hard interaction
- QCD radiation ISR/FSR

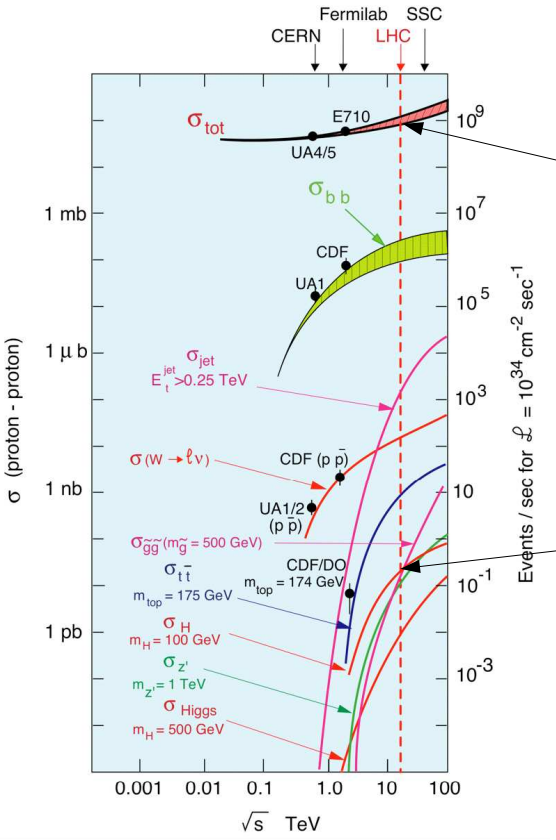


Proton-Proton Interaction at the LHC

- Hard interaction
- QCD radiation ISR/FSR
- Underlying Event (UE)



Trigger @ LHC



10^9 events/sec

10^{10} rate reduction

10 events/min
[M_H = 100 GeV]

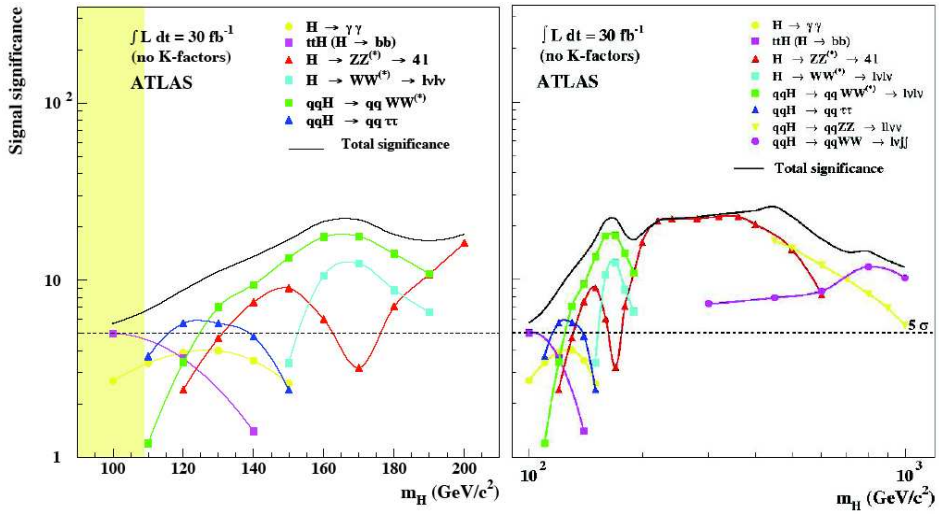
with 0.2% H → γγ
1.5% H → ZZ

Higgs discovery potential

Signal significance:

$$S = \frac{N_{\text{signal}}}{\sqrt{N_{\text{bg}}}} = \frac{N_{\text{tot}} - N_{\text{bg}}}{\sqrt{N_{\text{bg}}}}$$

Discovery: $S > 5$



Low mass region is not easy – demands combination of several channels

If the SM Higgs exists, it should be found in the first 3 years (30 fb^{-1}) of LHC