# Search for HIGGS Bosons in ATLAS

**Simonetta Gentile**
**Università di Roma**
**La Sapienza, INFN**

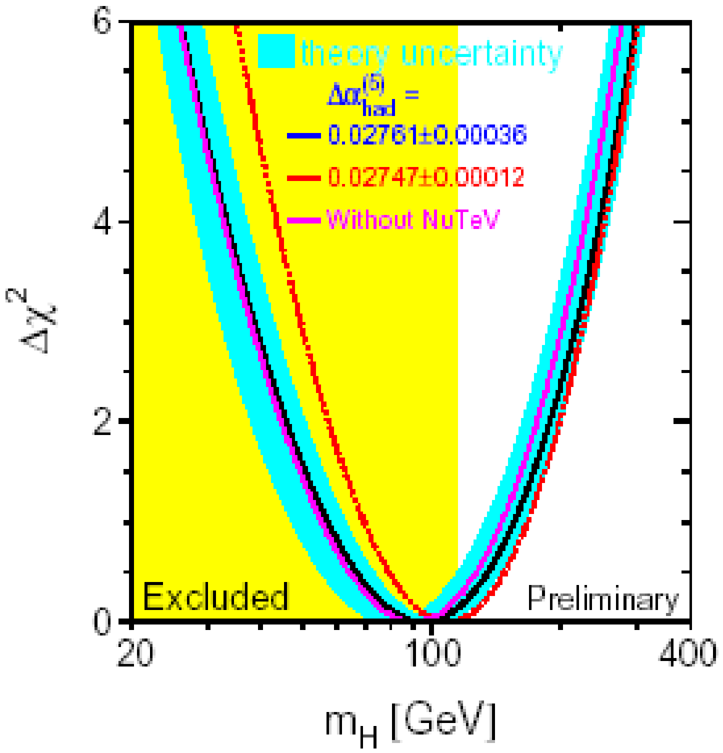
**11th Lomanosov, Moscow, 21-27 Aug. 2003**

# OUTLINE

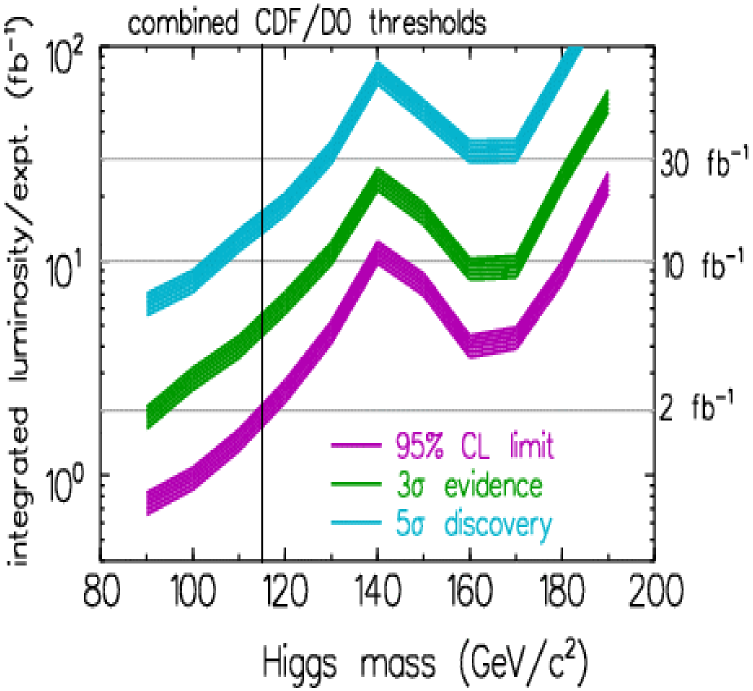
- Experimental Status: LEP and Tevatron
- Large Hadron Collider & Detector performances
- Standard Model Higgs
- MSSM Higgs
- Conclusions

# SM Higgs search at LEP

**Direct limit $M_H$ >114.4 GeV**
**Indirect constraints <219 GeV**



# SM Higgs search at Tevatron




**For $m_H \sim 115$ GeV :**

**$\sim$ 2 fb$^{-1}$ for 95% CL exclusion**

**$\sim$ 5 fb$^{-1}$ for 3σ obervation**

**$\sim$ 15 fb$^{-1}$ for 5σ discovery**

**Higher masses : discovery more difficult**

# SM Higgs search at Tevatron

Long term: **reaching 4-8 fb$^{-1}$** by FY09

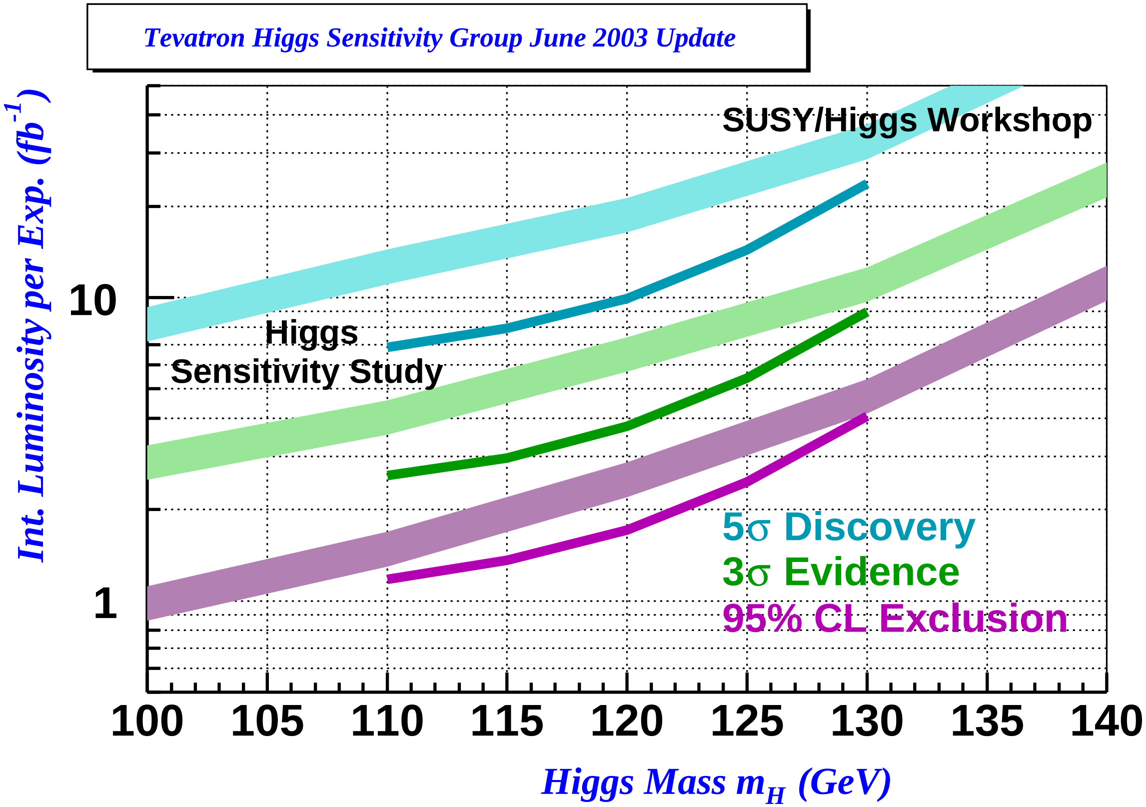
**Nikos Varelas**
**EPS03 Aachen**

**Detector upgrades** for FY06 (Si, trigger)

**11th Lomanosov, Moscow, 2003**

Tevatron Higgs Sensitivity Group: June 24, 2003

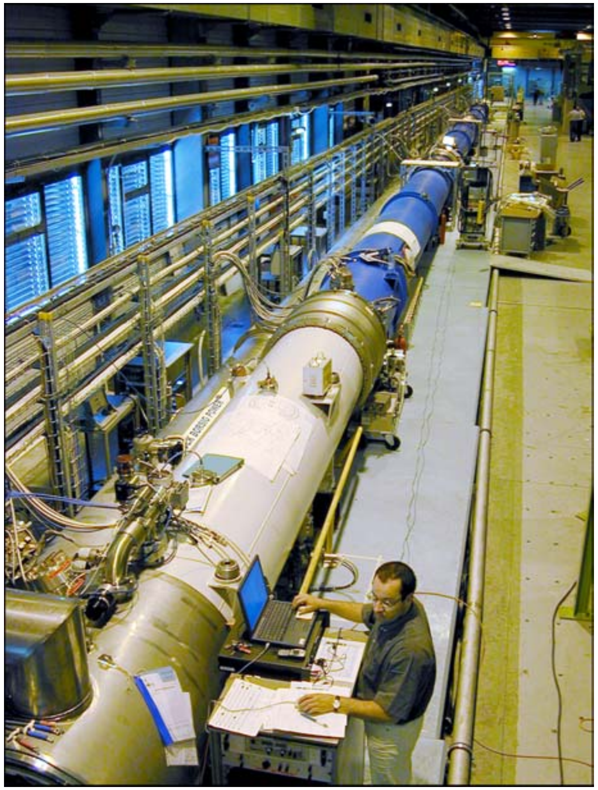
- WH→lνbb
- ZH →ννbb
- Improvement due mainly to sophisticated analysis techniques




There is already a tunnel long enough to produce multi-TeV energies if equipped with super-conducting magnets and filled with protons
… the LEP at CERN

# Large Hadron Collider

- Official Starting Date April 2007
- Initial Luminosity: ~ $10^{33}$ $cm^{-2}$ $s^{-1}$ , $E_b$=7 TeV
- Design Luminosity: $10^{34}$ $cm^{-2}$ $s^{-1}$
  after 2-3 years



- 10 $fb^{-1}$ per year at low lum.
- 100 $fb^{-1}$ per year at high lum.
  per experiment
- 300 $fb^{-1}$ ultimate
- fully performant detectors

## Events Statistics at low luminosity ($L=10^{33}$ cm$^{-2}$ s$^{-1}$)

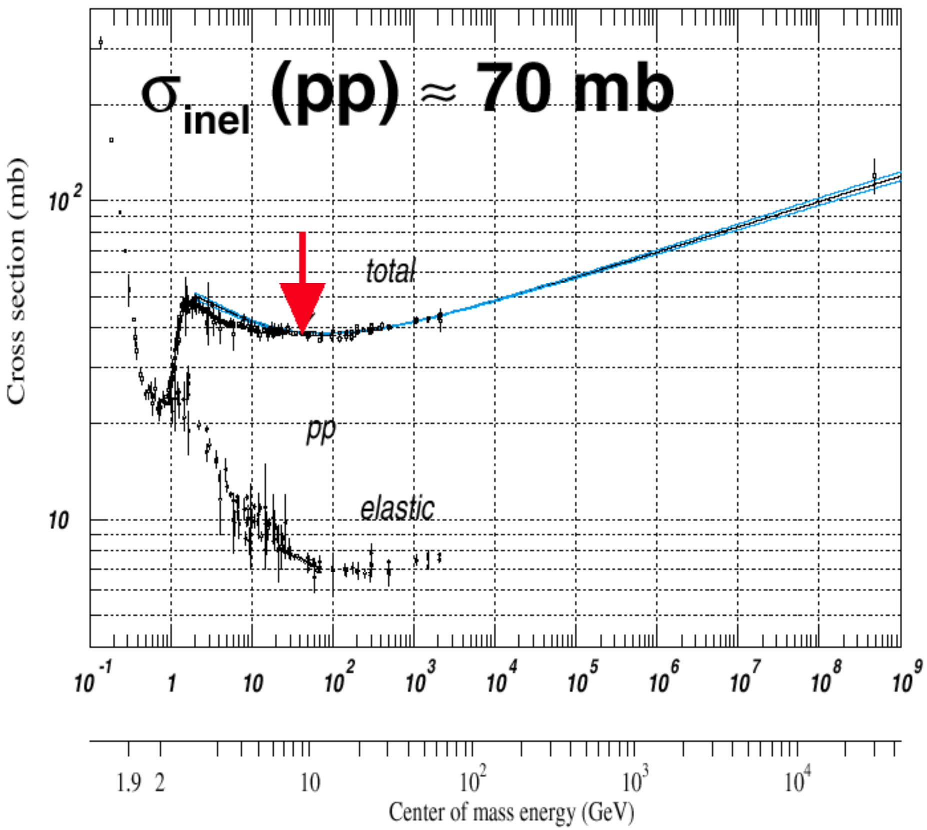
| Process | Events/s | Events/year | Other machines |
|---|---|---|---|
| $W \to e\nu$ | 15 | $10^8$ | $10^4$ LEP / $10^7$ Tev. |
| $Z \to ee$ | 1.5 | $10^7$ | $10^7$ LEP |
| $t\bar{t}$ | 0.8 | $10^7$ | $10^4$ Tevatron |
| $b\bar{b}$ | $10^5$ | $10^{12}$ | $10^8$ Belle/BaBar |
| $\tilde{g}\tilde{g}$ (m=1 TeV) | 0.001 | $10^4$ | — |
| H (m=0.8 TeV) | 0.001 | $10^4$ | — |
| QCD jets $p_T > 200$ GeV | $10^2$ | $10^9$ | $10^7$ |

→ LHC is a B-factory, top factory, W/Z factory, Higgs factory, SUSY factory

# EVENT RATE

11th Lomanosov, Moscow, 2003

- N = no. events / sec
- L = luminosity = $10^{34}$ cm$^{-2}$ s$^{-1}$
  $\sigma_{inel}$ = inel. cross-section = 70 mb
- E = no. events / bunch xing
  $\Delta t$ = bunch spacing = 25 ns



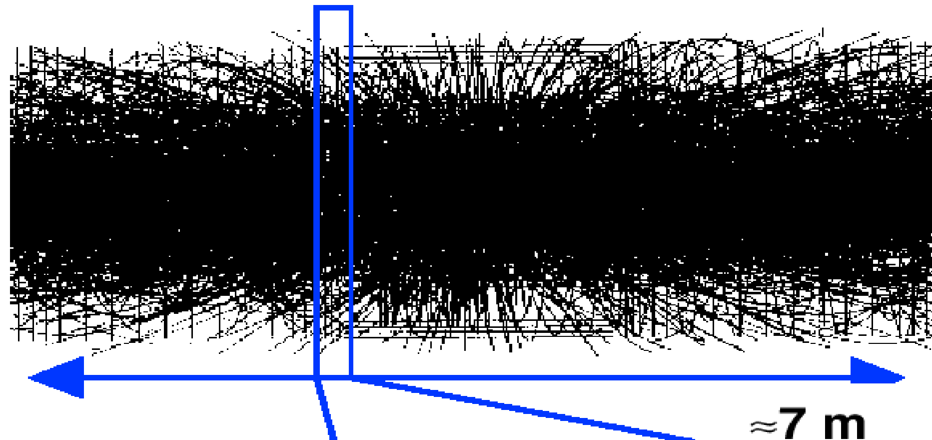

- $N = L \times \sigma_{inel}$
  $= 10^{34}\ \text{cm}^{-2}\ \text{s}^{-1} \times 7\ 10^{-26}\ \text{cm}^2$
  $= 7\ 10^{8}$ Hz

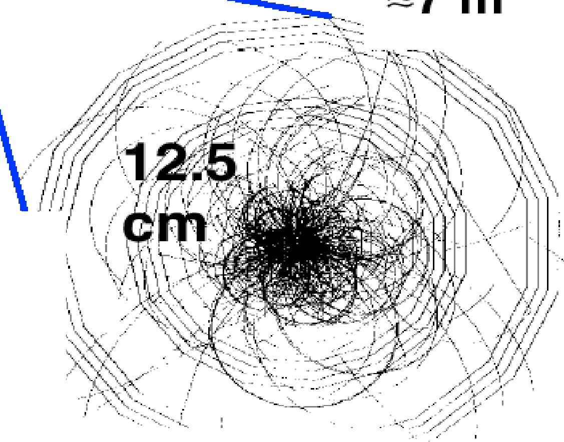
- $E = N / \Delta t$
  $= 7\ 10^{8}\ \text{s}^{-1} \times 25\ 10^{-9}\ \text{s} = 17.5$
  (not all bunches are filled)
  = 17.5 x 3564 / 2835
  = 22 events / bunch xing

**LHC produces 22 overlapping p-p interactions every 25 ns**

# Particle multiplicity

- η = rapidity  log(tgθ/2)(longitudinal dimension)
  - $u_{ch}$ = no. charged particles / unit-η = 7
  - $n_{ch}$ = no. charged particles / interaction
  - $N_{ch}$ = no. chrgd particles / xing
  - $N_{tot}$ = no. particles / bunch
- $\mathbf{n_{ch}} = u_{ch}$ x ḥ= 6 x 7 = **42**
- $\mathbf{N_{ch}} = n_{ch}$ x 22 = ~ **900**
- $\mathbf{N_{tot}} = N_{ch}$ x 1.5 = ~ **1400**



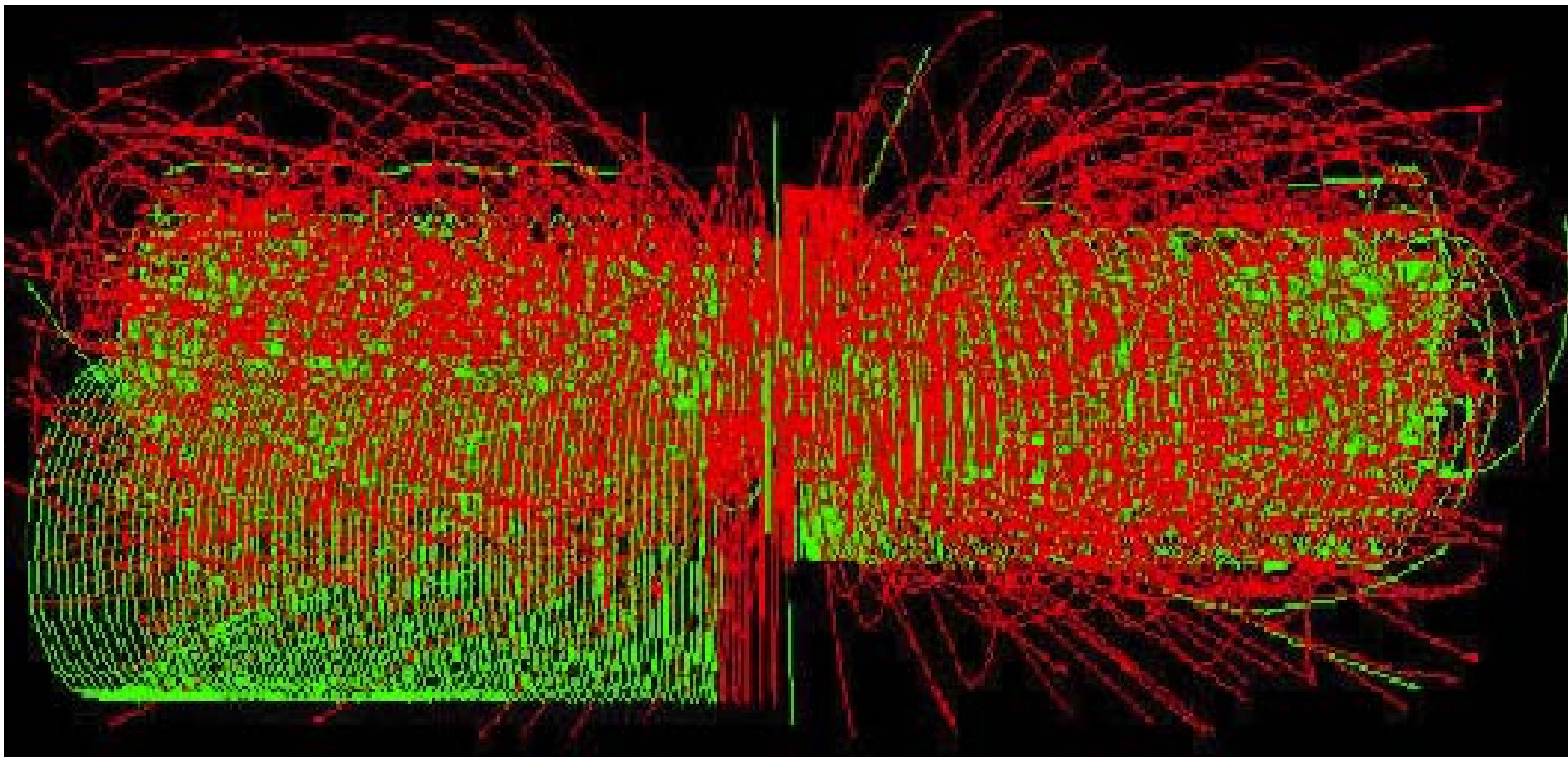

*… still much more complex than a LEP event*

**The LHC flushes each detector with ~1400 particles every 25 ns**

(p-p operation)

# The Challenge

**How to extract this...** **... from this ...**



**Higgs -> 4μ** **+30 MinBias**

11th Lomanosov, Moscow, 2003

- Detectors must be capable of

Resolving individual tracks, in-and-outside the calorimeters

Measuring energy depositions of isolated particles and jets

Measuring the vertex position.

- Detector size and granularity is dictated by

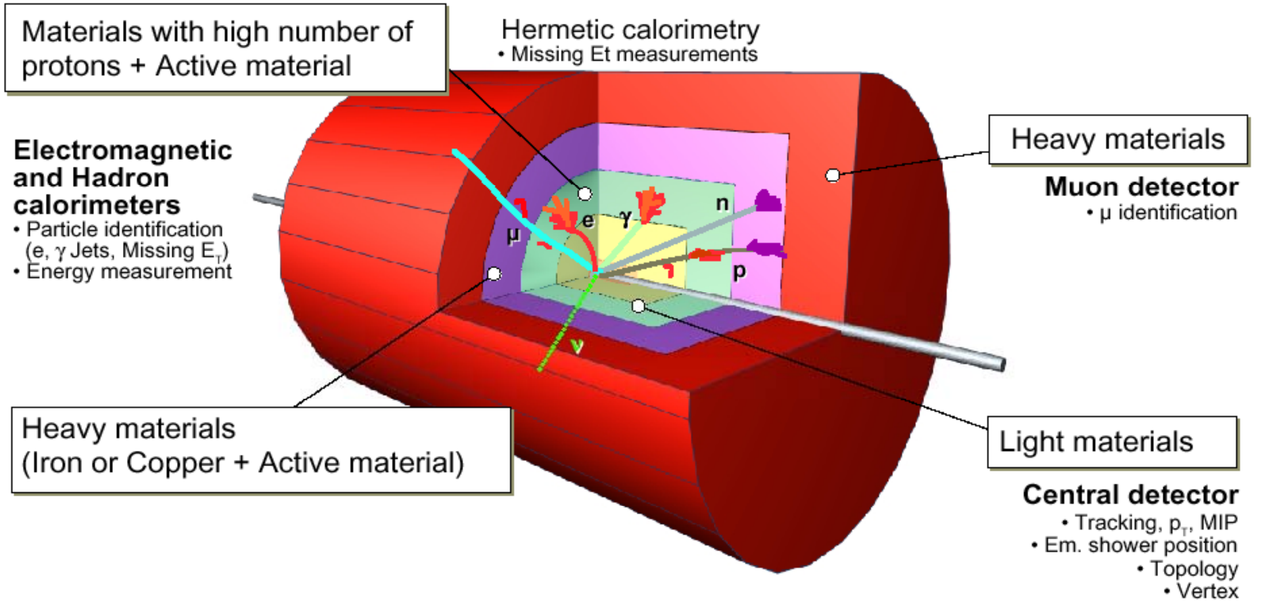
… the required (physics) accuracy
… the particle multiplicity.

- Size + granularity determine

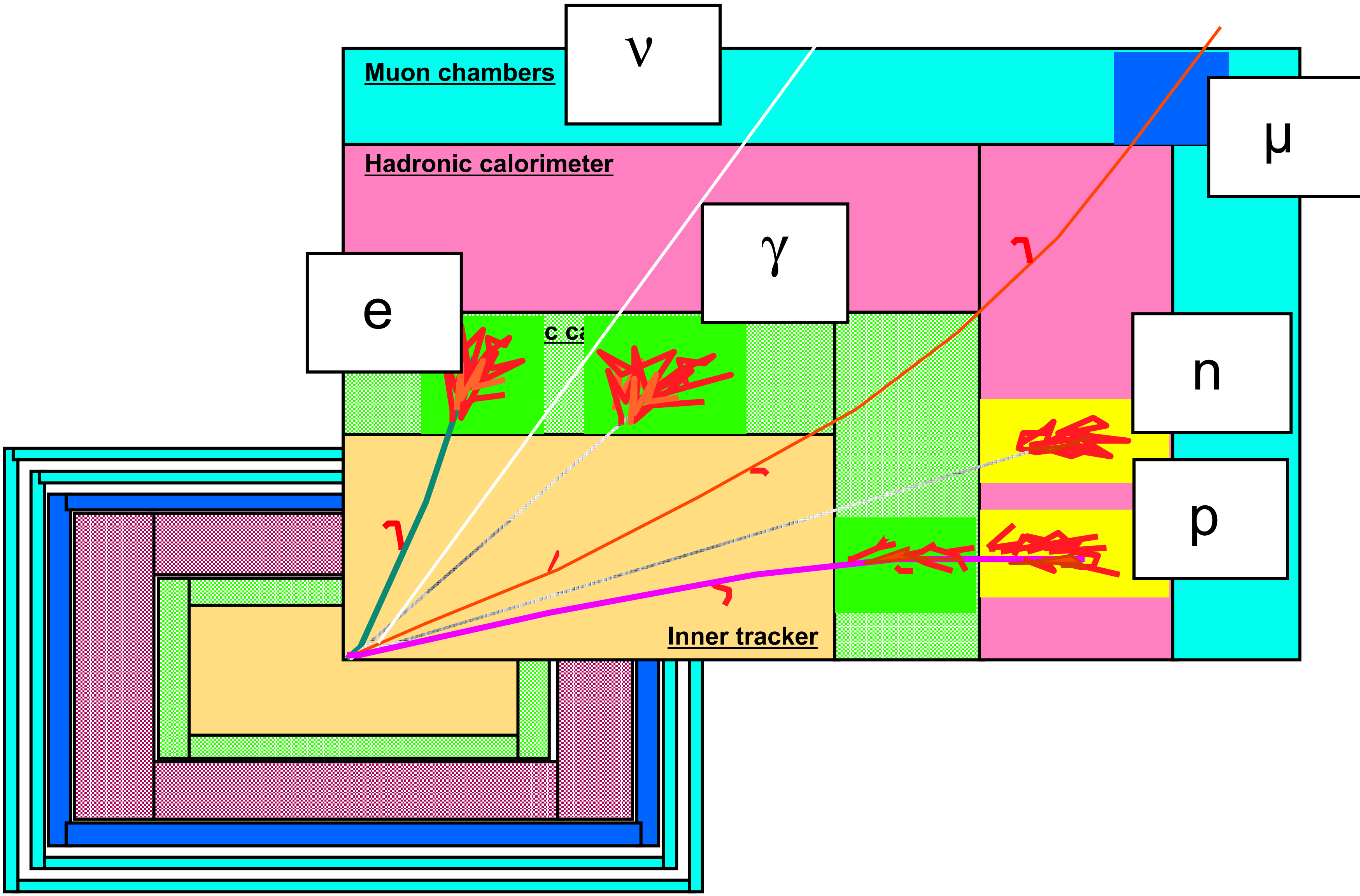
… the no. of measuring elements
… i.e. the no. of electronics channels.

# General purpose detector

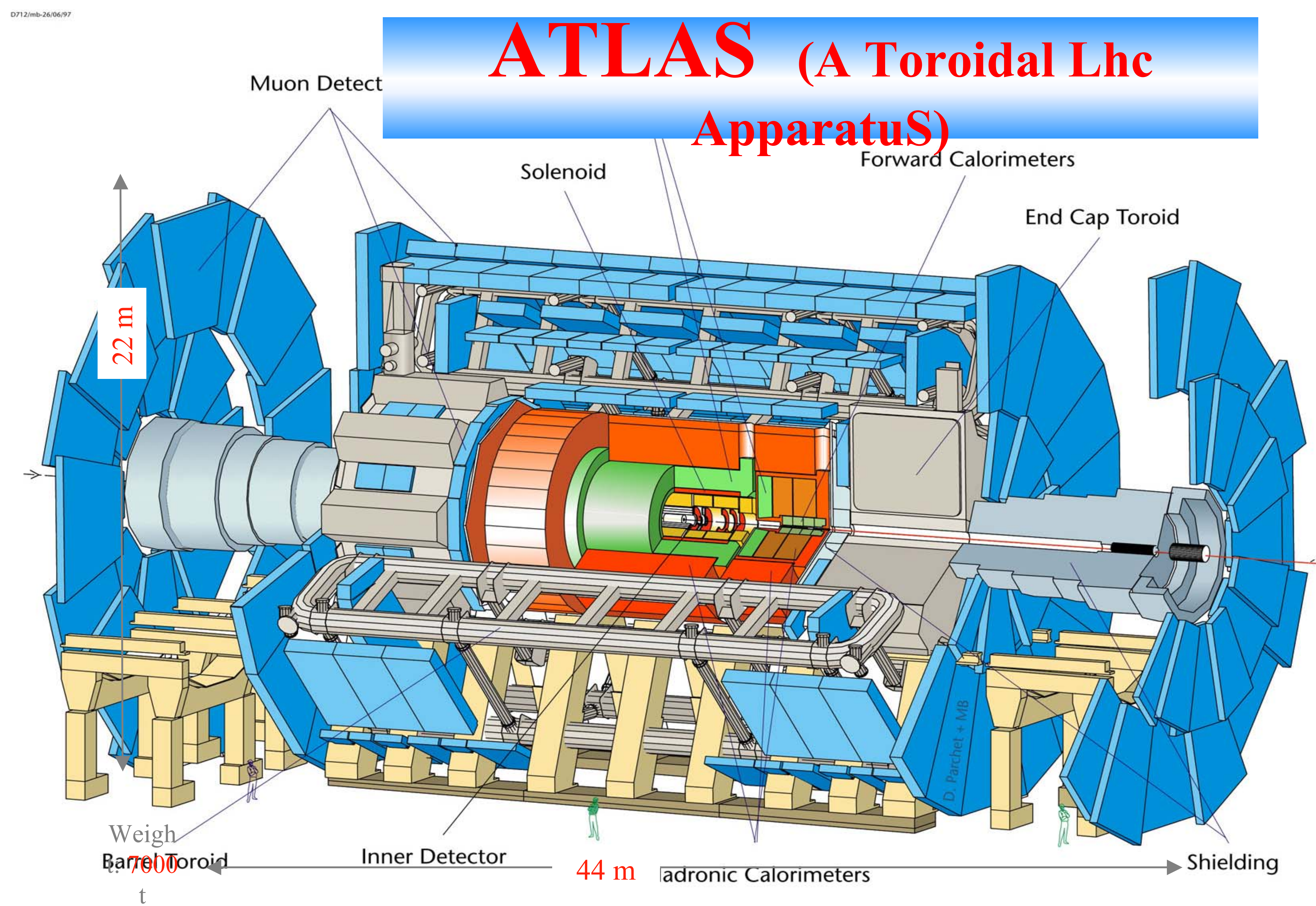
- Identification …
  - for event selection
- … and measurement
  - for event reconstruction.
- For both, need different stages:
  - Inner tracker
  - Calorimeters
  - Muon system (trigger and precision chambers)



# Particle identification

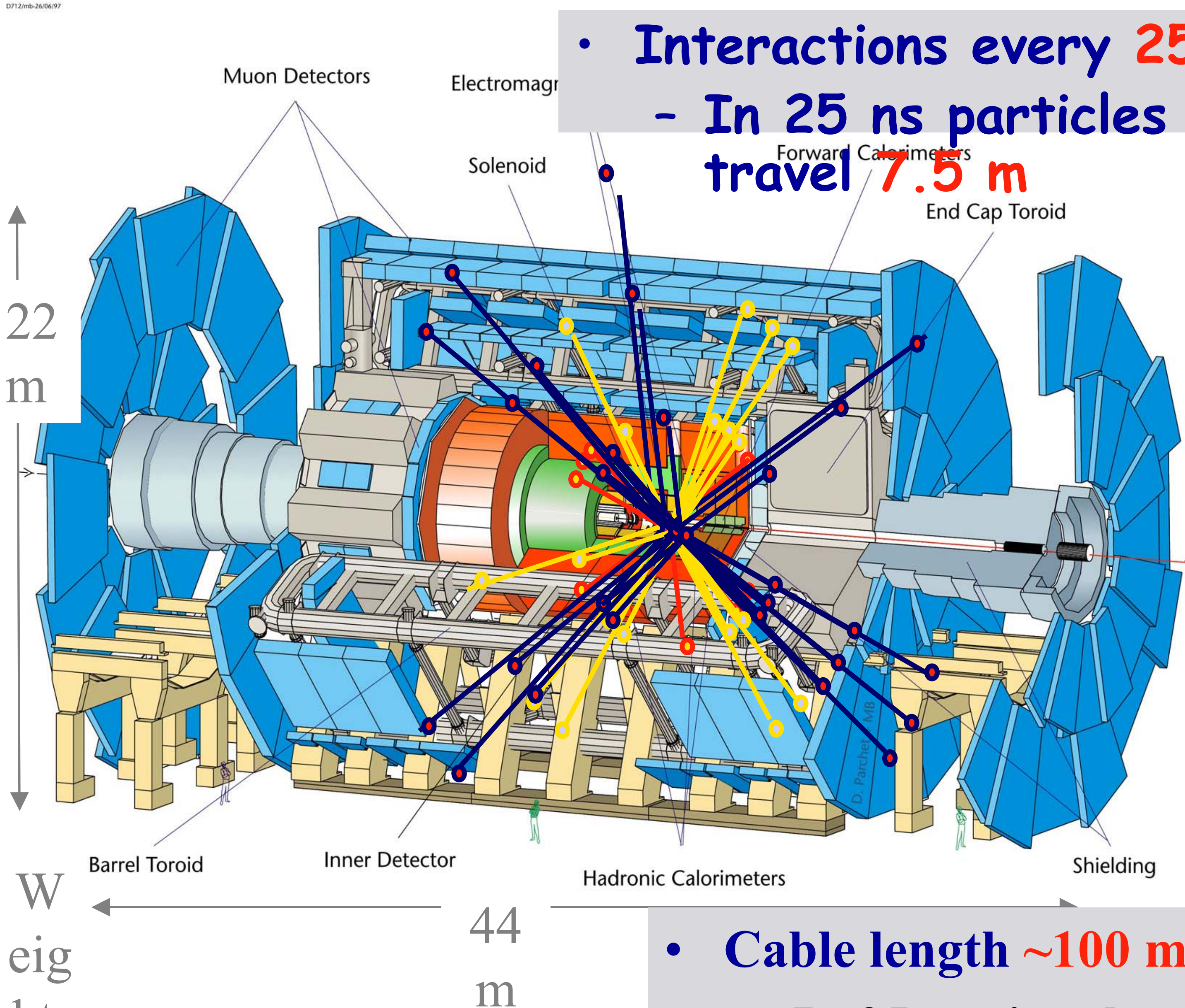


# ATLAS (A Toroidal Lhc ApparatuS)



# Time-of-flight

- Interactions every 25 ns
  - In 25 ns particles travel 7.5 m




- Cable length ~100 meters …
  - In 25 ns signals travel 5 m

# The ATLAS Detector

Length: ~44 m

Radius: ~12 m

Weight: ~ 7000 t

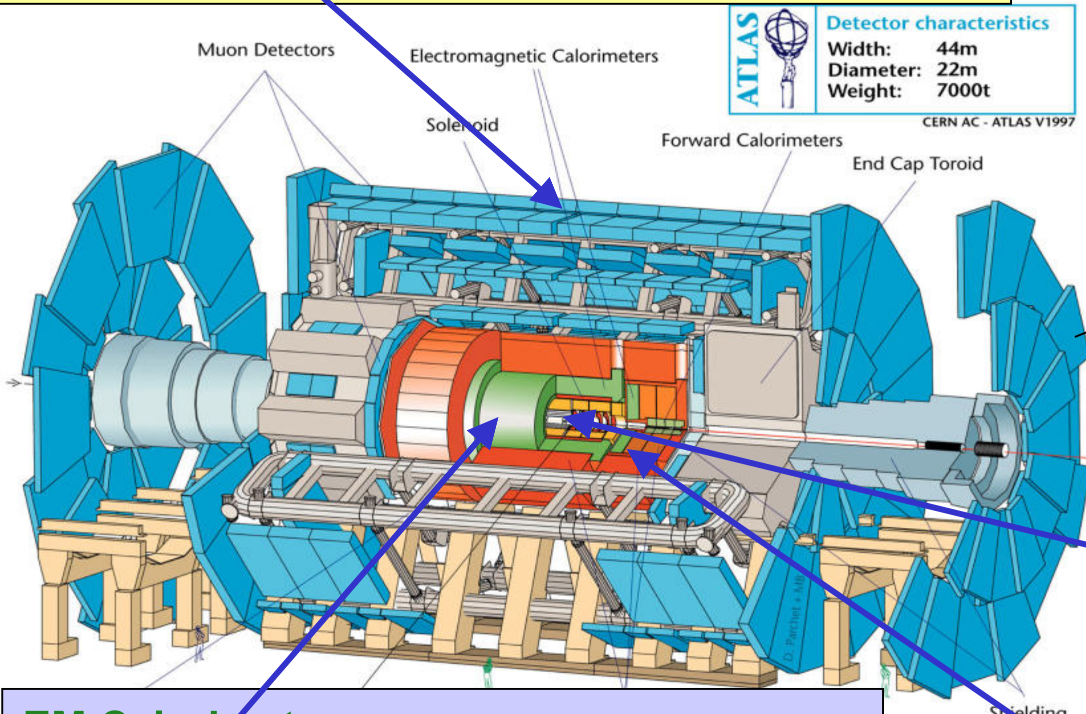
E l. Channels: ~$10^8$

Cables: ~3000 km

**Precision Muon Spectrometer** $\sigma / pT \sim 10\%$ at 1 TeV/c

**Fast response for trigger**

**Good *p* resolution (e.g., A/Z' $\rightarrow \mu\mu$)**




**Inner Detector**

$\sigma / p_T \sim 5 \cdot 10^{-4}\, p_T \oplus 0.001$

**Good impact parameter res.**

**(e.g., H $\rightarrow$ bb)**

**EM Calorimeters**

**excellent electron/ph** $\sigma / E \sim 10\% / \sqrt{E(\text{GeV})}$

**Good *E* resolution (e.g., H$\rightarrow\gamma\gamma$)**

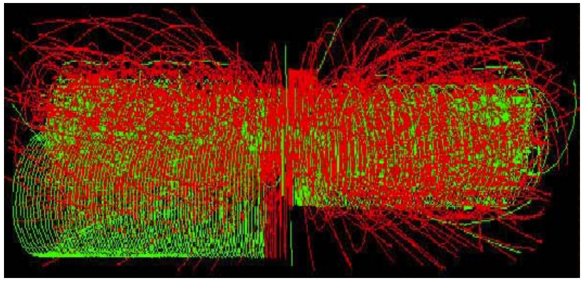
**Hadron Calorimeters**

**Good jet and $E_T$ miss performance**

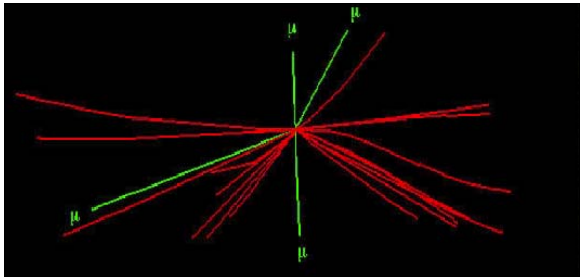
**(e.g., H $\rightarrow\tau\tau$)** $\sigma / E \sim 50\% / \sqrt{E(\text{GeV})} \oplus 0.03$

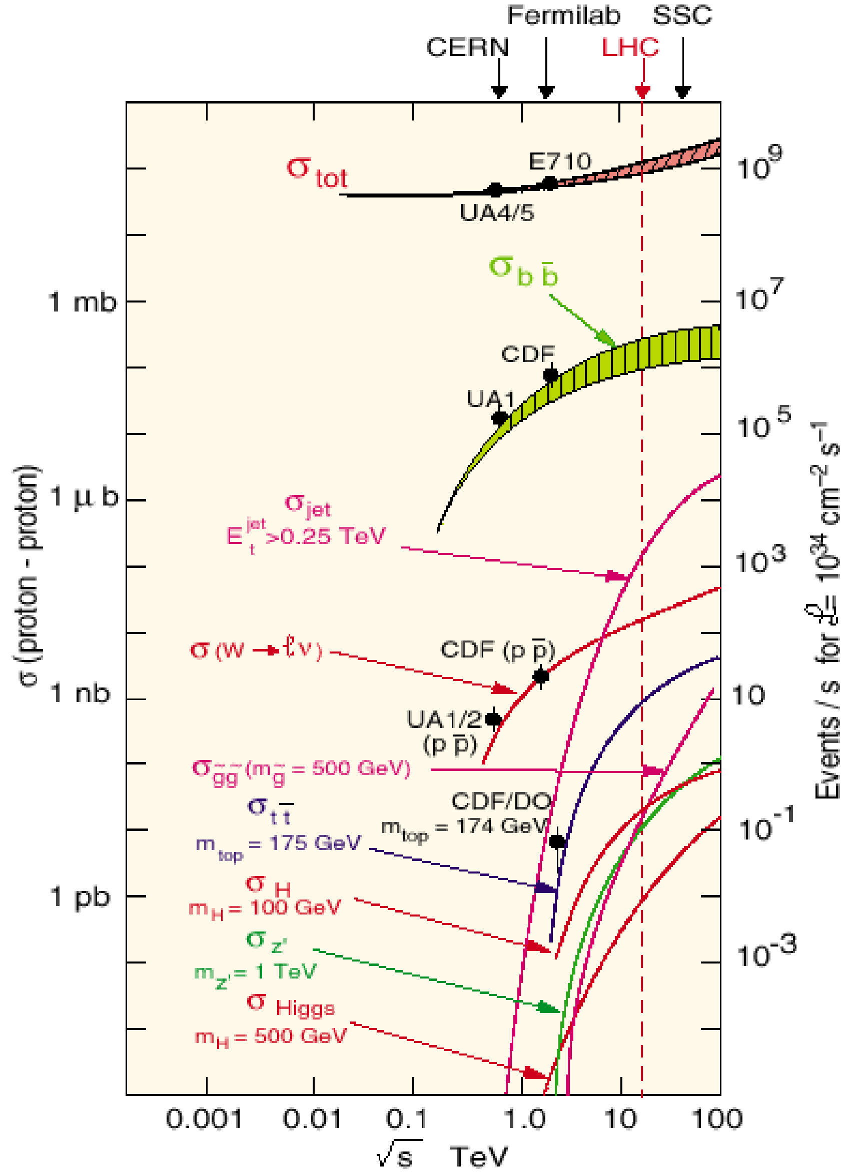
# The Challenge

**Knowing that there are 10 thousands billions of:**



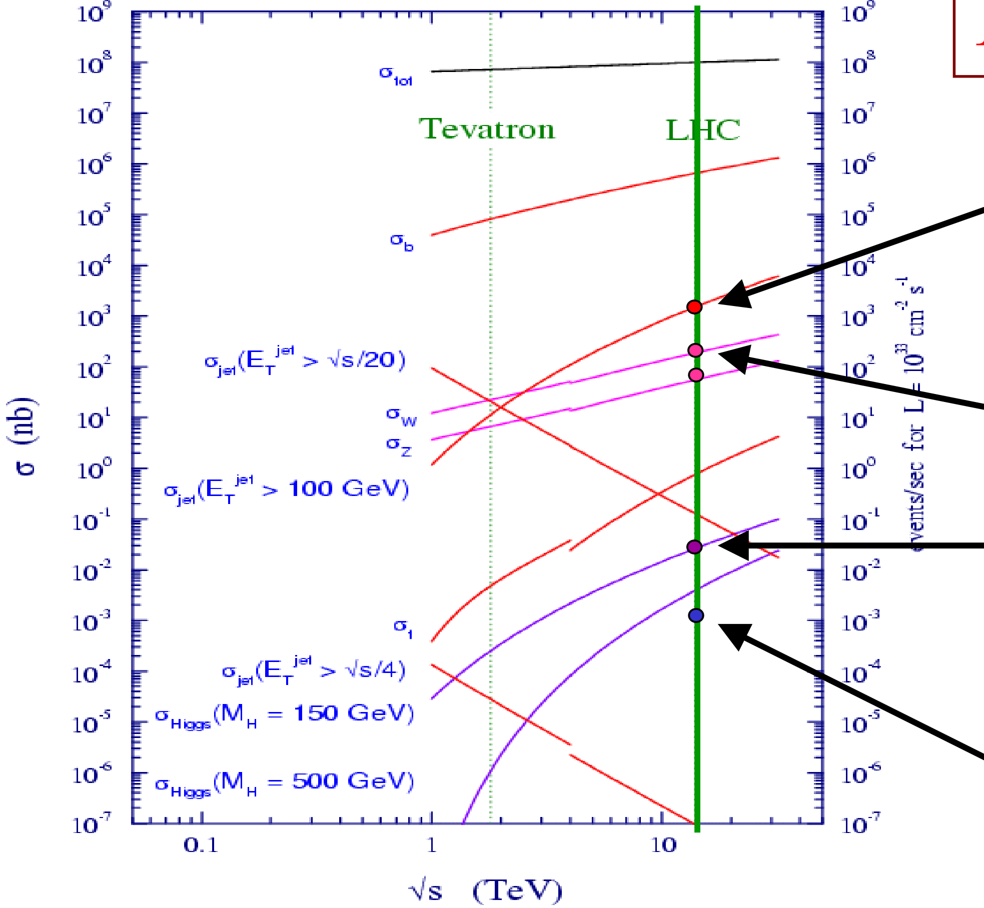
**for ONE of:**

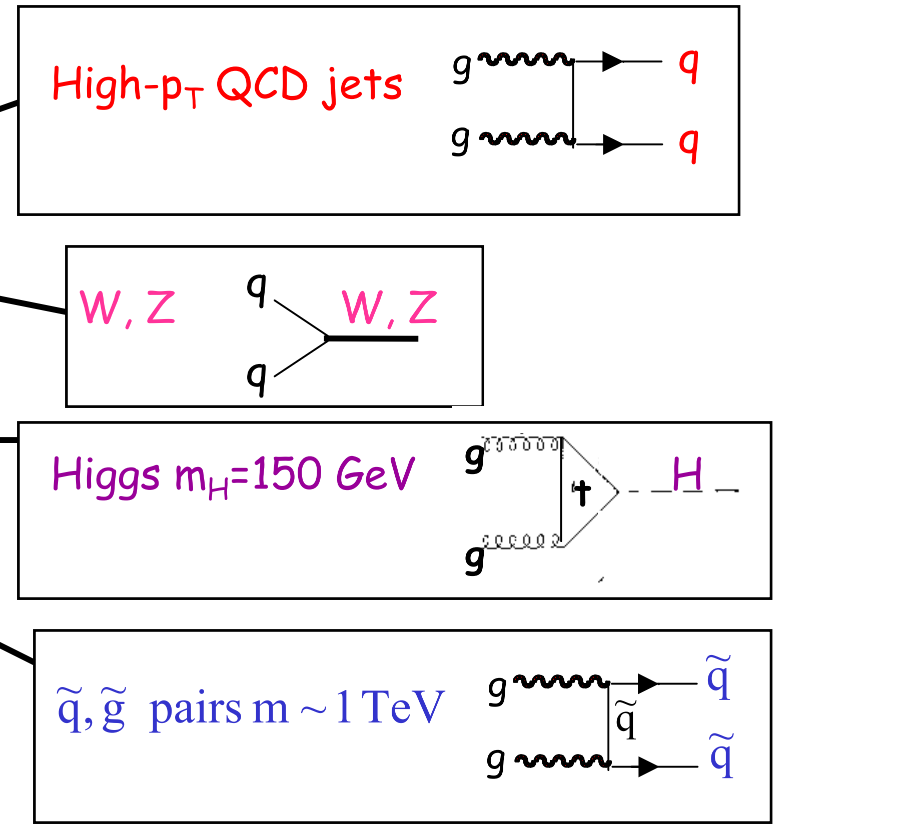





11th Lomanosov, Moscow, 2003

# Huge (QCD) backgrounds

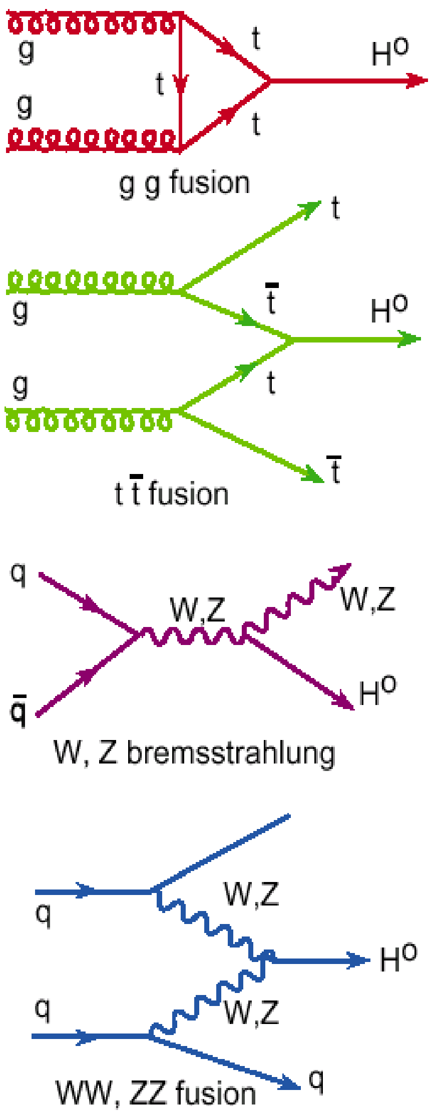


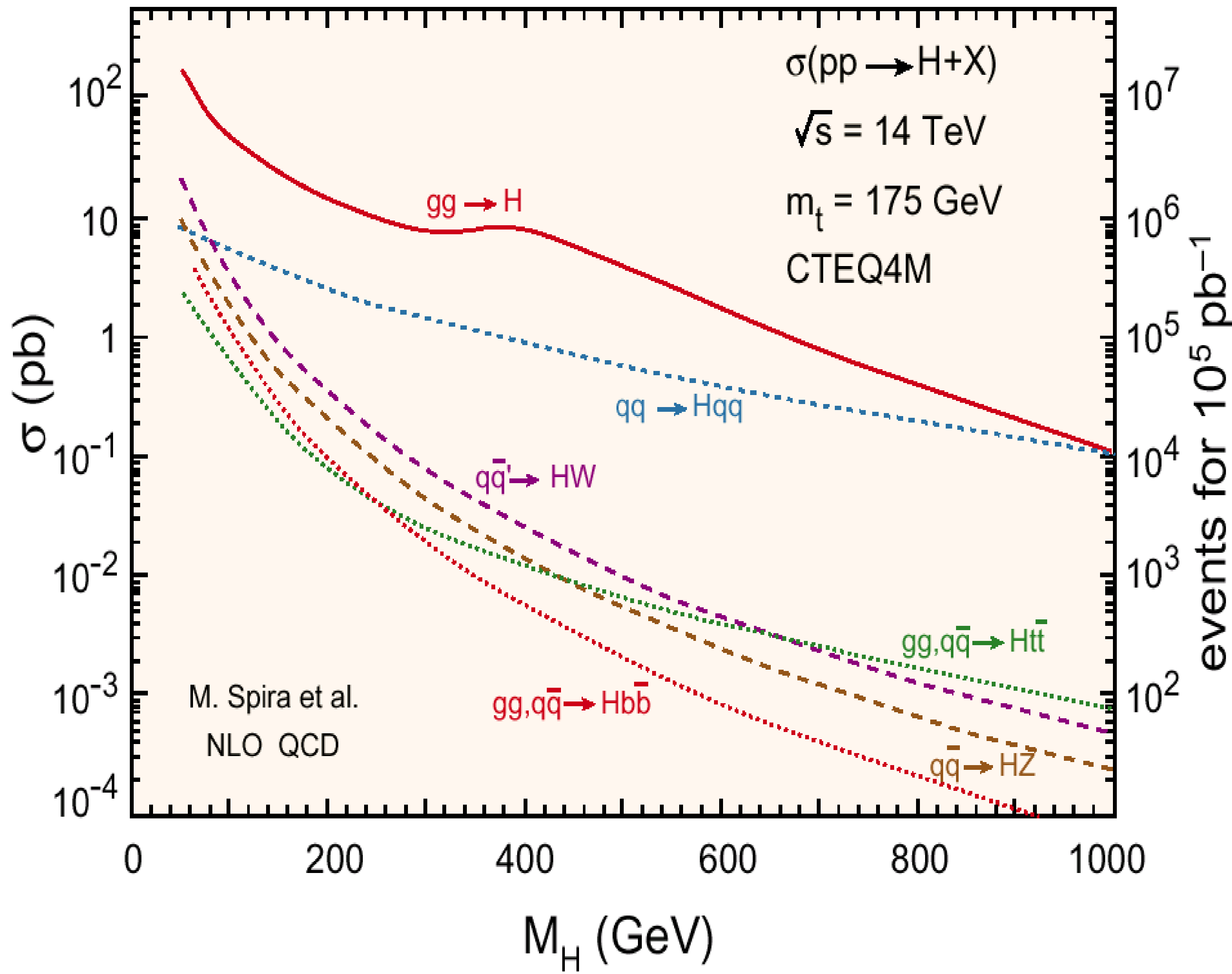




- No hope to observe the fully-hadronic final states → **rely on ℓ, γ**
- **Fully-hadronic** final states only with **hard 𝒪(100 GeV) $p_T$ cuts**
- **Mass resolutions of ~1% (10%) needed for ℓ, γ (jets)**
- Excellent particle identification: e.g. **e/jet ratio $p_T$ > 20 GeV is $10^{-5}$**

11th Lomano

# Higgs Production Mechanism@ LHC




**4 production mechanisms → key to measure H-boson parameters**

# Standard Model Higgs production



## Direct production

**gg fusion**

**gg fusion dominant**

## Associated production

**WW/ZZ fusion**

**VectorBosonFusion 20% of gg at 120 GeV**

- 2 jets @ large $\eta$

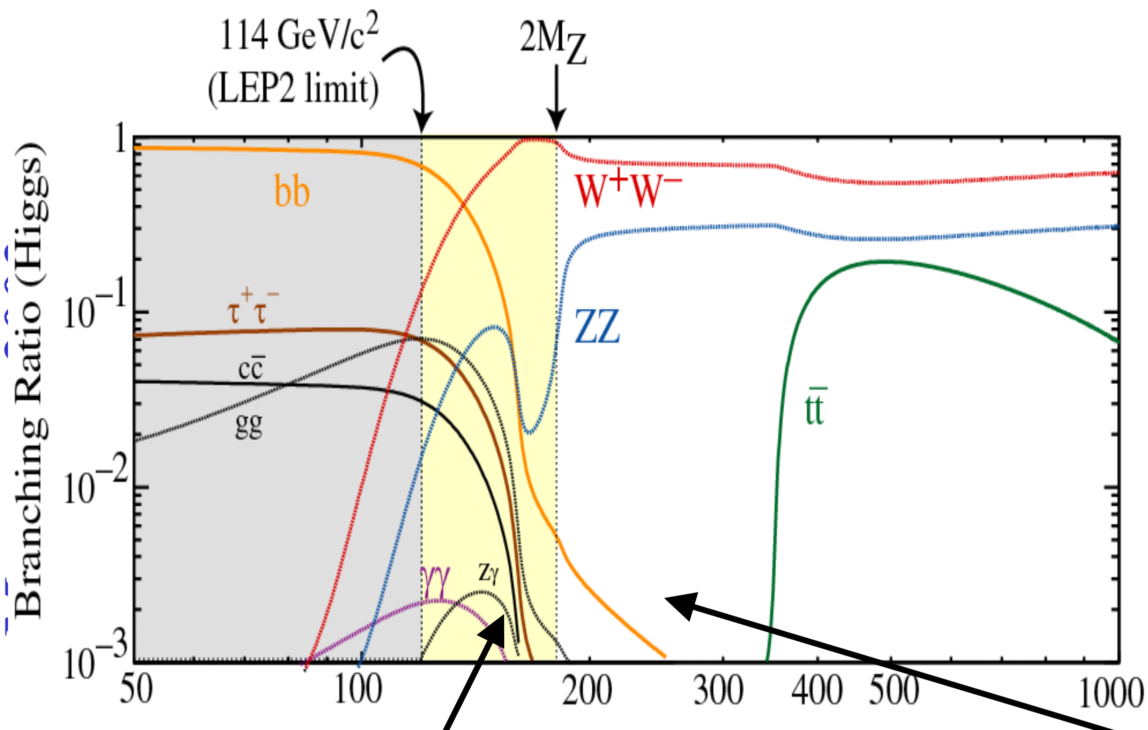
## Associated production

**tt H, WH, ZH :**

**1-10% of gg**

- isolated lepton from W decay
- reconstruct top-quarks

# Higgs Discovery Channels at LHC




Dominant BR for $m_H < 2m_Z$:
$\sigma$ (H → bb) ≈ 20 pb;
$\sigma$ (bb) ≈ 500 μb
for m(H) = 120 GeV
→ no hope to trigger or extract fully hadronic final states
→ look for final states with ℓ, γ (ℓ = e,μ )

**Low mass region: m(H) < 2 $m_Z$ :**

**H → γγ : small BR, but best resolution**

H → bb : good BR, extract backg➔ ttH, WH

**H → ZZ* → 4ℓ**

**H → WW* → ℓνℓν or ℓνjj : via VBFand direct production**

H → ττ : via VBF

**m(H) > 2 $m_Z$ :**

**H → ZZ → 4ℓ**

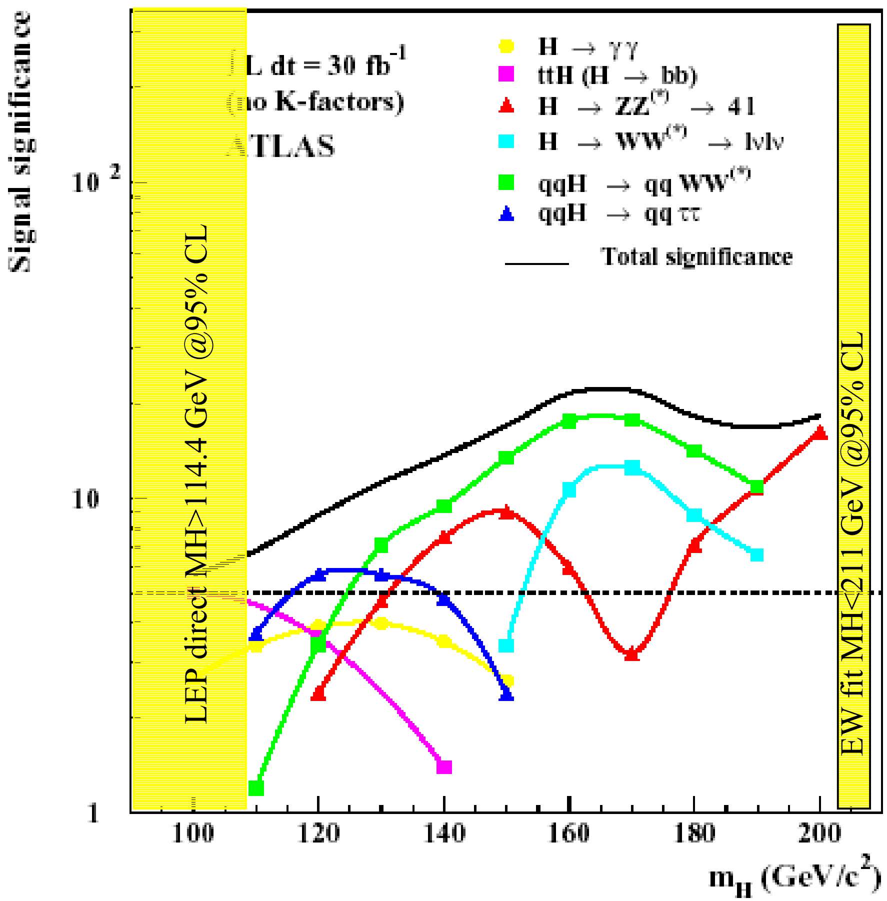
qqH → ZZ → ℓℓ νν *

qqH → ZZ → ℓℓ jj *

qqH → WW→ ℓνjj *

* for $m_H$ > 300 GeV forward jet tag

# Prospects for Standard Model Higgs searches



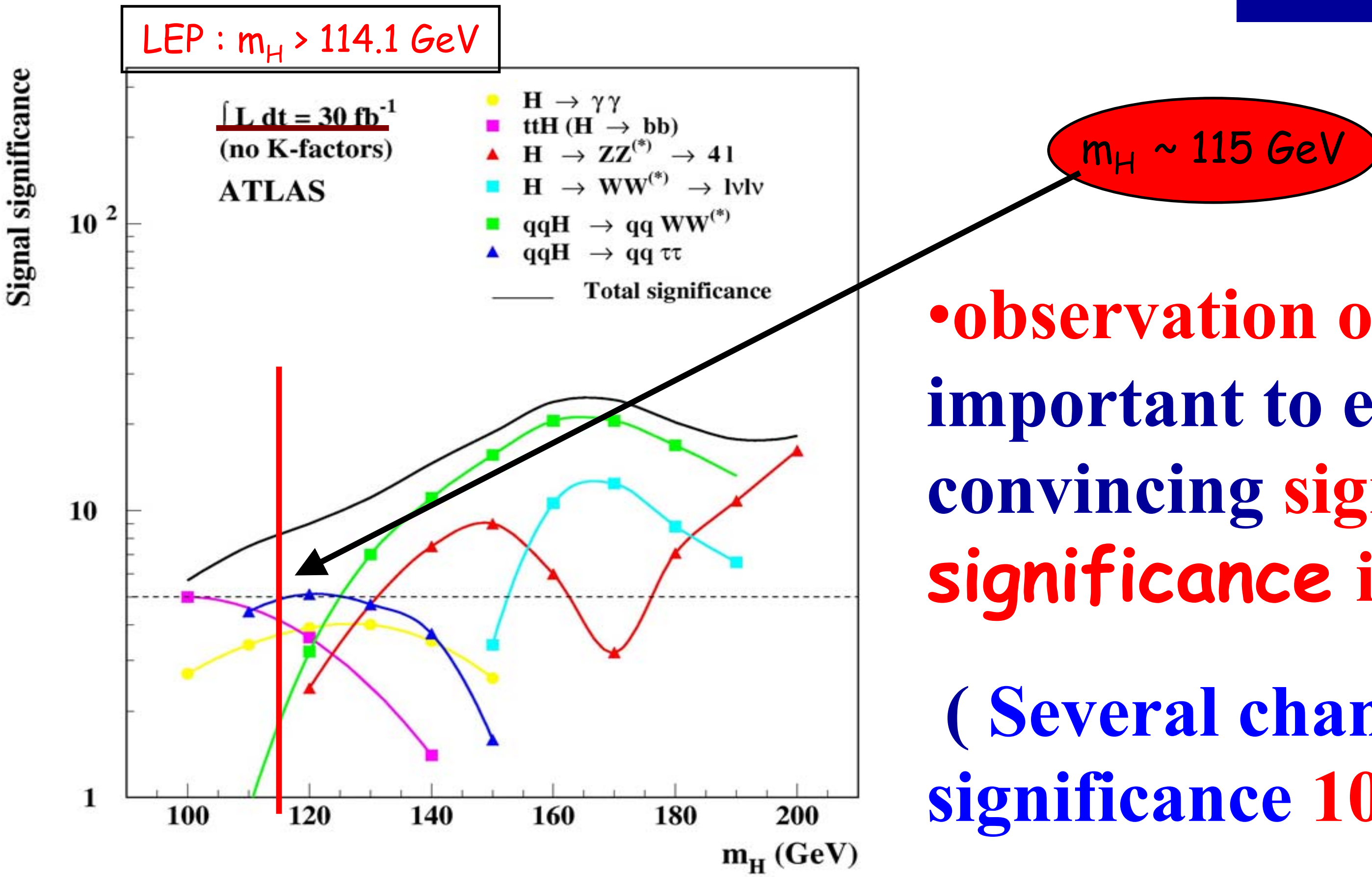

- **Discovery: several complementary channels.**
- some channels with very **exclusive topologies** (large bgd. suppression).
- **Coupling** measurements @ $30fb^{-1}$.
- Mass, width (direct and indirect).

- **Detector performance is crucial:** **b-tag, $\ell/\gamma$, E-resolution, $\gamma$/j separation, $E_T^{miss}$ resolution, forward jet tags, central jet-veto, t-reconstruction.**

**Expected results discussed at Integrated Luminosity of $10fb^{-1}$ $30fb^{-1}$ $100fb^{-1}$.**

# SM-like Higgs searches early reach

## Low mass




•observation of all channels important to extract convincing signal 4-5 σ significance in first year

( Several channels give ~ 2 σ significance 10 $fb^{-1}$ )

→H → γγ relies only on electromagnetic calorimeter, (constant term < 0.7 %)

# $M_H$= 115 GeV

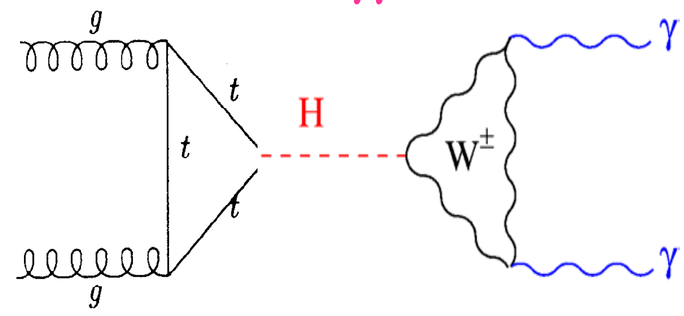
| | $H \to \gamma\gamma$ | $ttH \to ttbb$ | $qqH \to qq\tau\tau$ ($\ell\ell$ + $\ell$-had) |
|---|---|---|---|
| S<br>B<br>S/B | 150<br>3900<br>0.04 | 15<br>45<br>0.33 | ~ 10<br>~ 10 |
| Signif. | 2.4 | 2.1 | 3.5 |
| CLb | 9 $10^{-3}$ | 2 $10^{-2}$ | 4 $10^{-3}$ |

$K-\text{factor} \equiv \frac{\sigma_{NLO}}{\sigma_{LO}} \approx 2$ not included

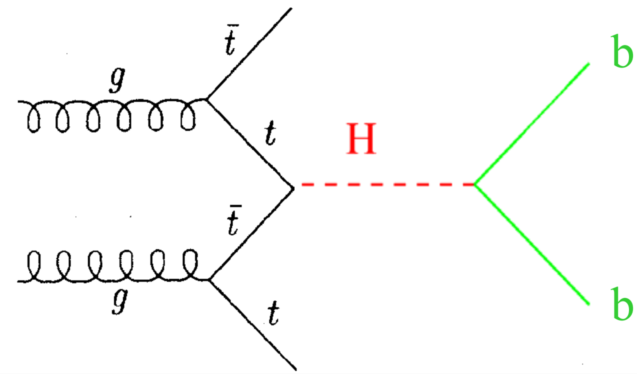
**Total $S/\sqrt{B}$ for 10 $fb^{-1}$ and complete detector: ~ 4.2 σ**

11th Lomanosov, Moscow, 2003

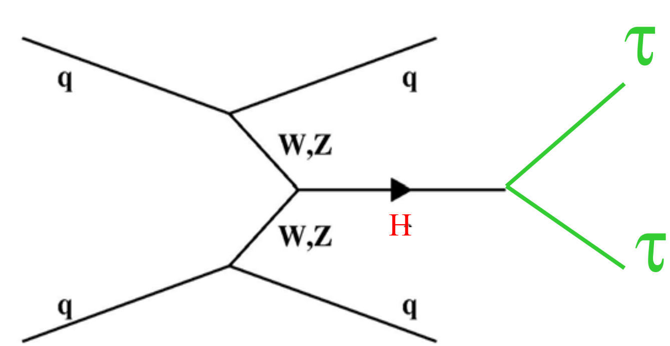
**$H \to \gamma\gamma$**




**$ttH \to tt\ bb \to b\ell\nu\ bjj\ bb$**

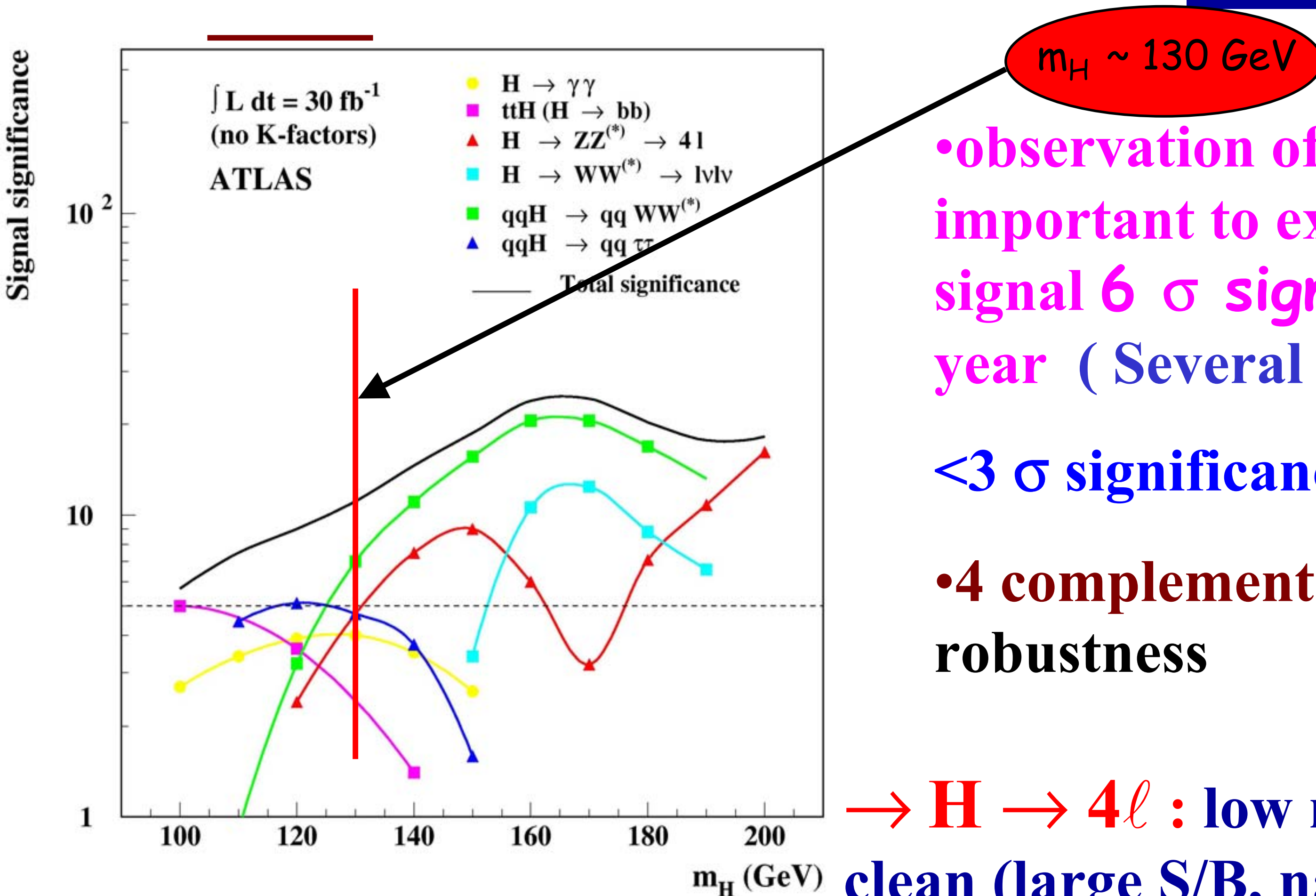



**$qqH \to qq\tau\tau$**



# SM-like Higgs searches early reach

# Inter mass




•observation of all channels important to extract convincing signal 6 σ significance in first year ( Several channels give

<3 σ significance 10 $fb^{-1}$ )

•4 complementary channels → robustness

→ $H \to 4\ell$ : low rate but very clean (large S/B, narrow mass peak)
< 3σ significance per channel
(except qqWW counting channel)

$M_H$= 130 GeV

# Intemediate mass

10 $fb^{-1}$ complete detector

| | $H \to \gamma\gamma$ | $qqH \to qq\tau\tau$ ($\ell\ell + \ell$-had) | $H \to 4\ell$ | $qqH \to qqWW$ |
|---|---|---|---|---|
| S | 120 | ~ 8 | ~ 5 | 18 |
| B | 2500 | ~ 6 | < 1 | 15 |
| S/B | 0.05 | | ~ 5 | ~ 1 |
| Signif. | 2.4 | ~ 2.7 | 3.2 | 3.9 |
| CLb | $9\ 10^{-3}$ | $4\ 10^{-3}$ | $6\ 10^{-4}$ | $4\ 10^{-5}$ |

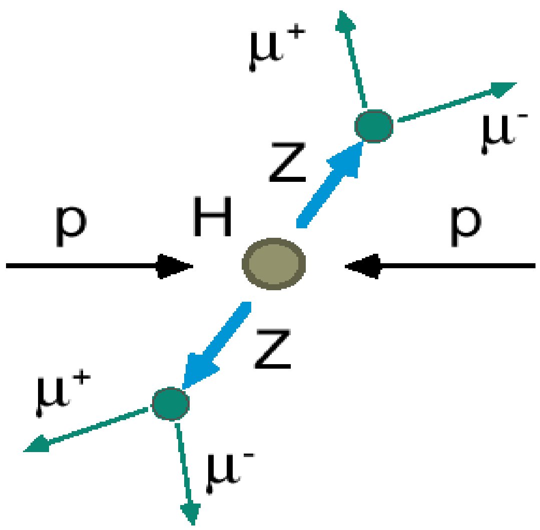
**Total $S/\sqrt{B}$ for 10 $fb^{-1}$ and complete detector:**
**~ 6.5 $\sigma$**

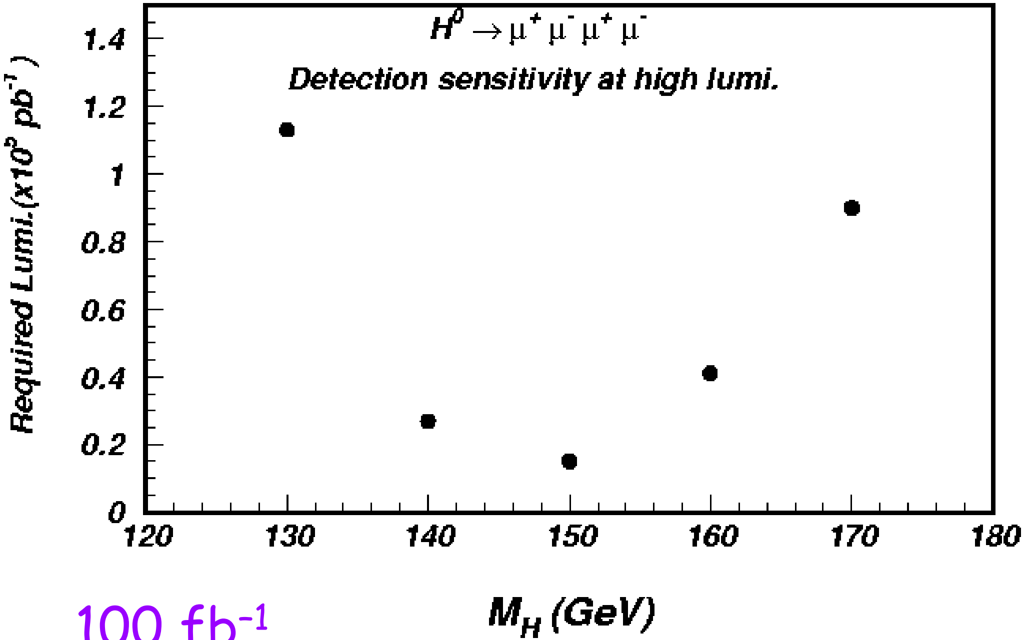
# Light Higgs Search: H -> ZZ* -> 4μ

100fb$^{-1}$

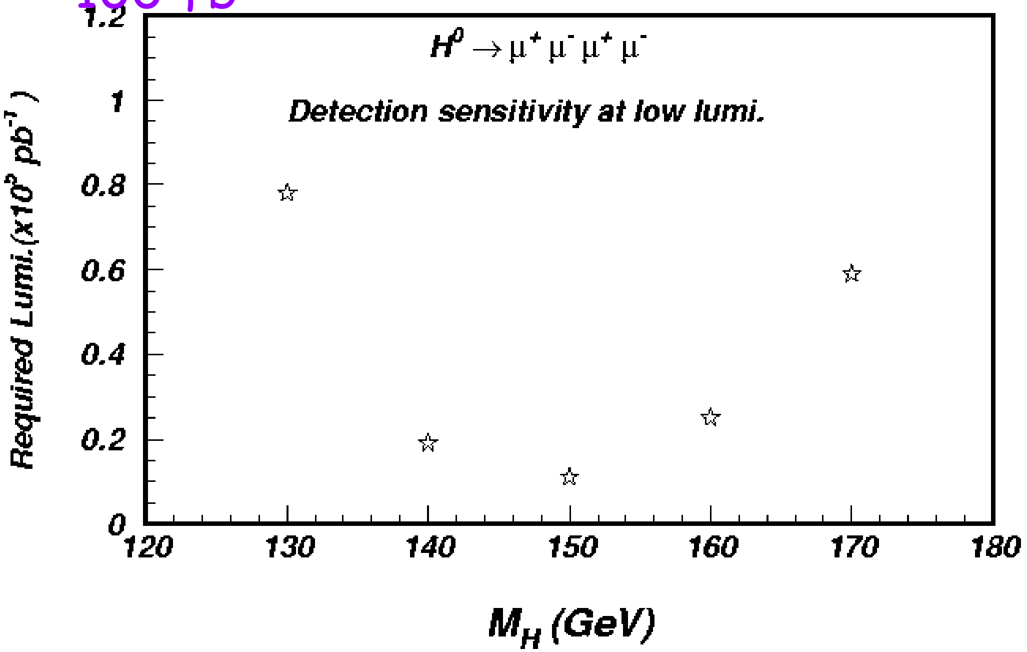
required lumi for discovery

11th Lomanosov, Moscow, 2003

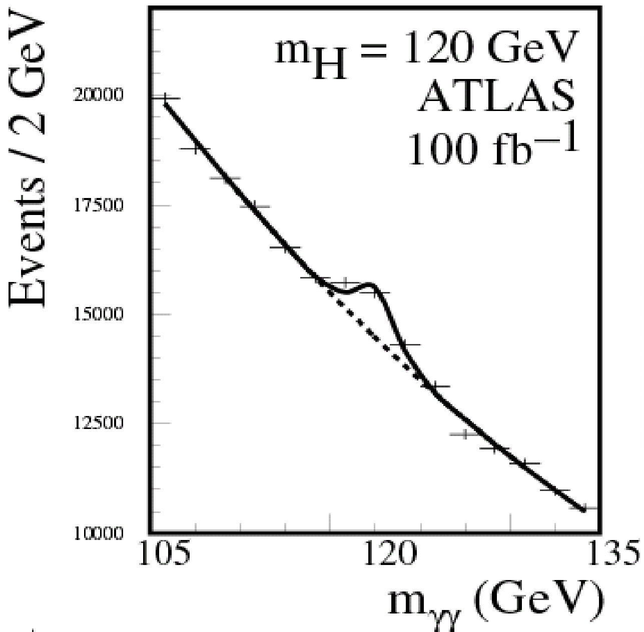


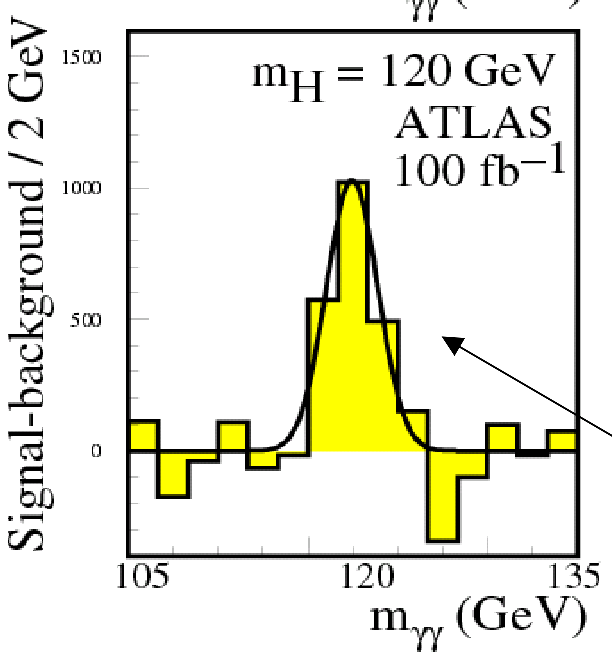




100 fb$^{-1}$



# Light Higgs Search: γγ, ttH channels




Significance:
2.8 to 4.3σ for
100 fb$^{-1}$

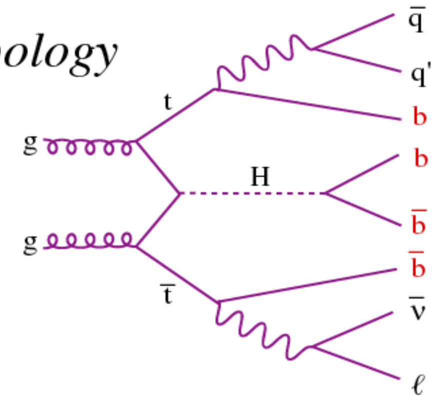
*Challenging and complex topology*

4 b-jets, 2 jets, 1 lepton

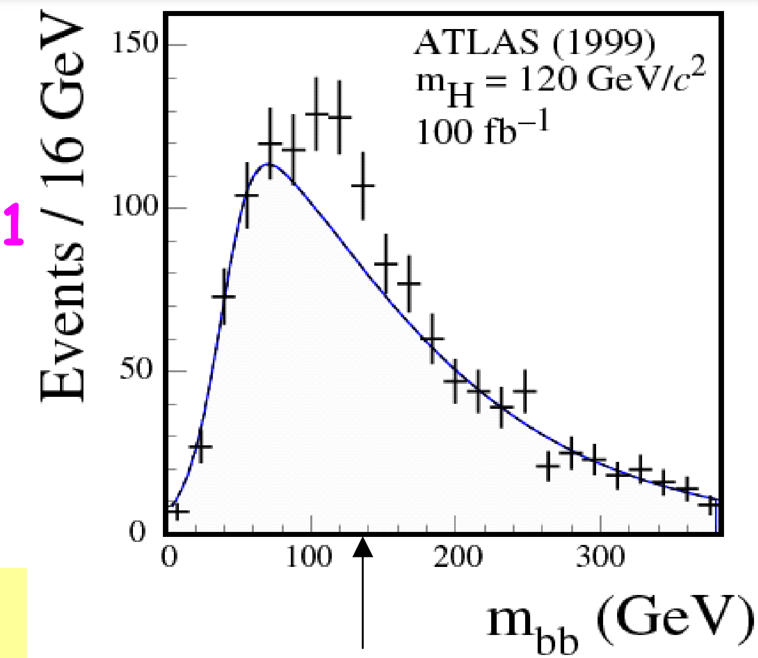
$H \to bb$

$t \to bqq'$

$t \to b\ell\nu$




**100fb$^{-1}$**




**Signal significance (5σ) :**

**mH < 120 GeV needs 100 fb$^{-1}$**

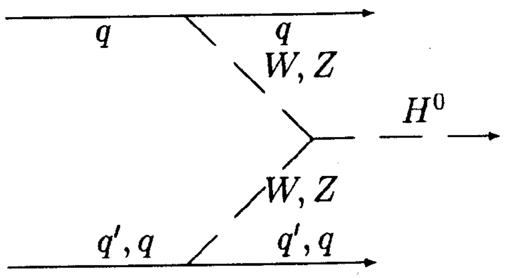
# VBF Higgs boson production at low mass



**Distinctive Signature of:**

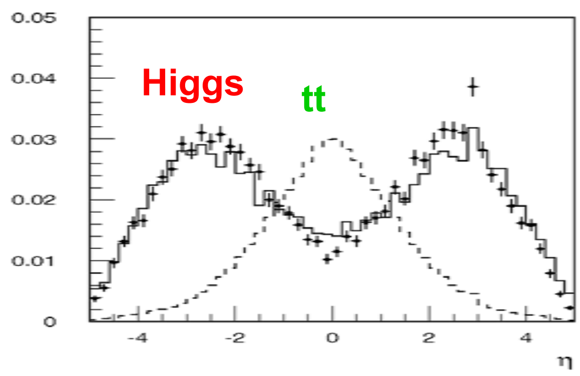
- two high $P_T$ forward jets
- little jet activity in the central region

$\Rightarrow$ Jet Veto




Rapidity distribution of tag jets

VBF Higgs events vs. tt-background




η jet

**Channels studied:**

qqH $\rightarrow$ qqWW* $\rightarrow$ qq $\ell\,\nu\ \ \ell\,\nu$

qqH $\rightarrow$ qq $\tau\ \ \tau$ $\rightarrow$ qq $\ell\,\nu\,\nu\ \ \ell\,\nu\,\nu$

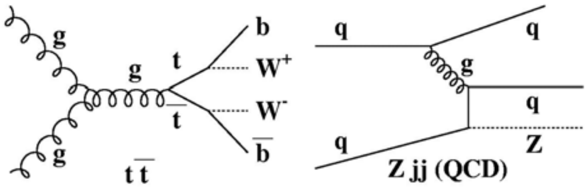
$\rightarrow$ qq $\ell\,\nu\,\nu$ had $\nu$

**Hard leptons with distinctive kinematics;**
**Full H->tt reconstruction possible**

# Background:

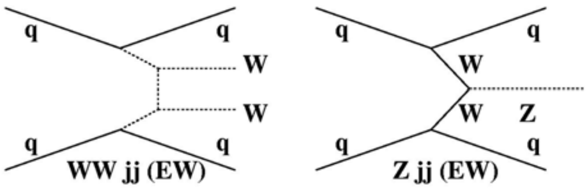
**QCD backgrounds:**

tt production Z + 2 jets




**el.weak background:**

WW jj production Z + 2 jets



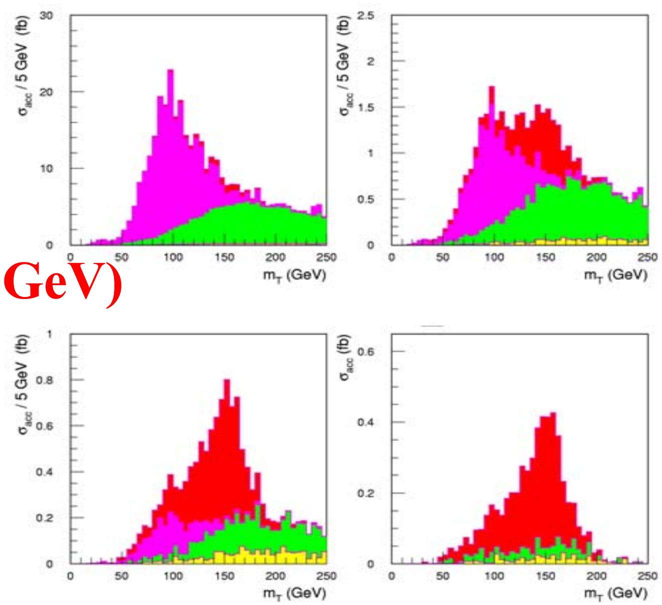



## Background rejection:

**qqH → qqWW* → qq l ν l ν**

- Lepton $P_T$ cuts and tag jet requirements ($\Delta\eta$, $P_T$)
- Require large mass of tag jet system
- Jet veto
- Lepton angular and mass cuts

$$M_T = \sqrt{(E_T^{ll} + E_T^{\nu\nu})^2 - (\vec{p}_T^{\,e\mu} + \vec{p}_T^{\,miss})^2}$$




**Higgs boson ($m_H$ = 160 GeV)**

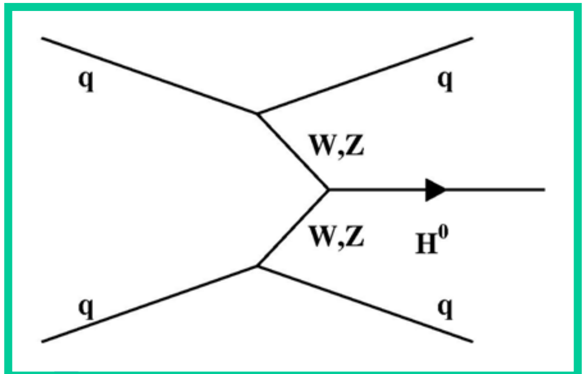
**tt background**

**γ* / Z + jets**

**el.weak WW jj**

# Signal and background rates

SIGNAL:qq->qqH

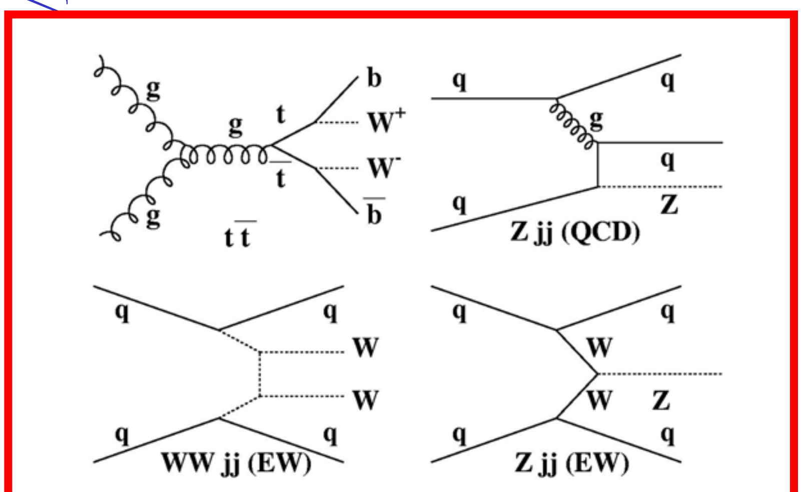



$m_H$ = 120 – 180 GeV

σ(qqH) = 4.4 - 2.8 pb

σ x BR (qqH -> WW*) = 530 - 2600 fb
σ x BR (qqH -> ττ ) = 300 - 2 fb

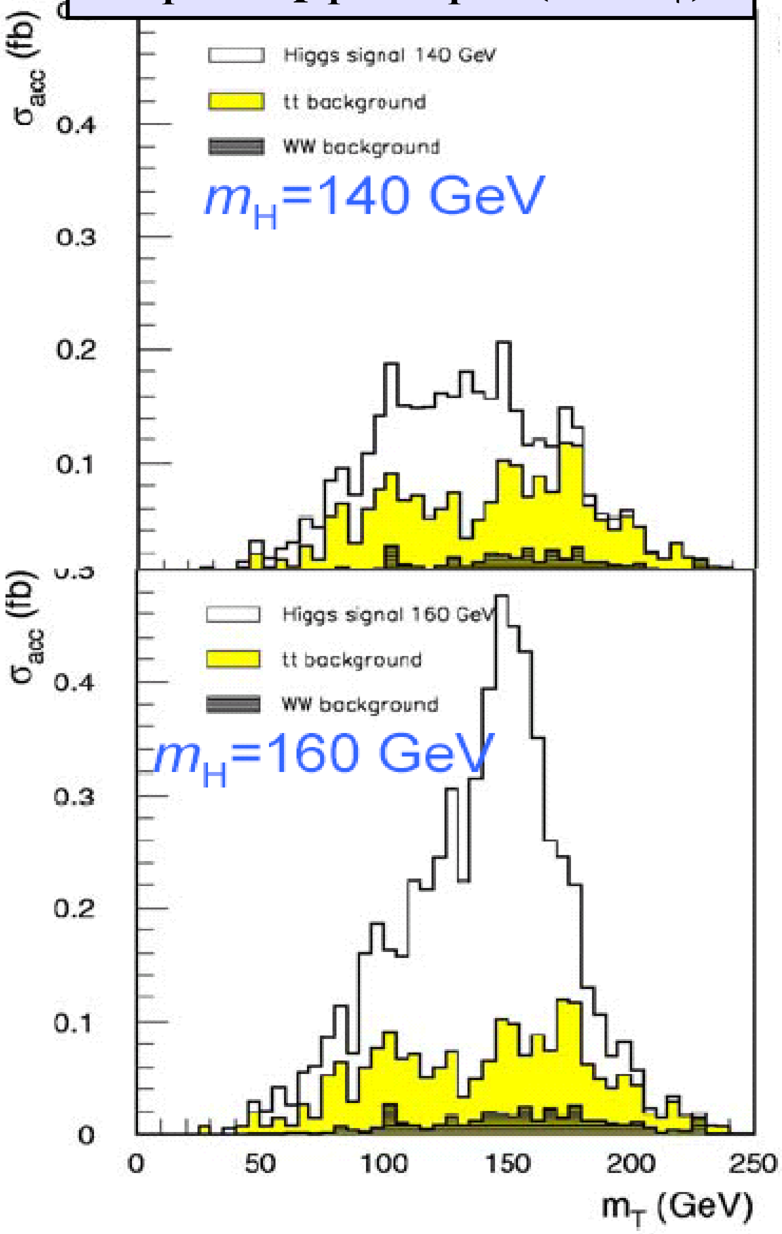
BKG




| | |
|---|---|
| $t\bar{t}$ | 55 pb |
| QCD $WW + jets$ | 17 pb |
| $Z/\gamma^* + jets$, $Z/\gamma^* \to \tau\tau$ | 2600 pb |
| EW $WW + jets$ | 82 fb |
| EW $\tau\tau + jets$ | 170 fb |
| $Z/\gamma^* + jets$, $Z/\gamma^* \to ee/\mu\mu$ | 5300 pb |
| $ZZ$ | 38 pb |

# $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$

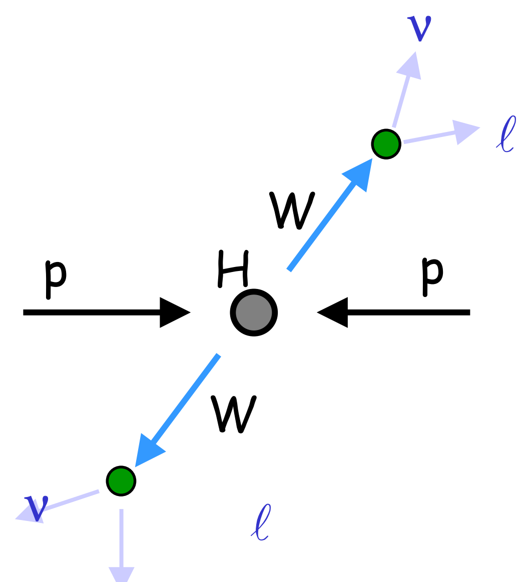
$m_T = \sqrt{2 p_T^{\ell\ell} E_T^{miss}(1-\cos\phi)}$




**Observe excess in transverse mass distribution**

S ~ 10-40 events for $10fb^{-1}$

B ~ 10-15 events




- **Two isolated leptons**
- **Two forward tag jets**
- **Central jet veto: $p_T$<20 GeV**
- **lepton angular correlation**

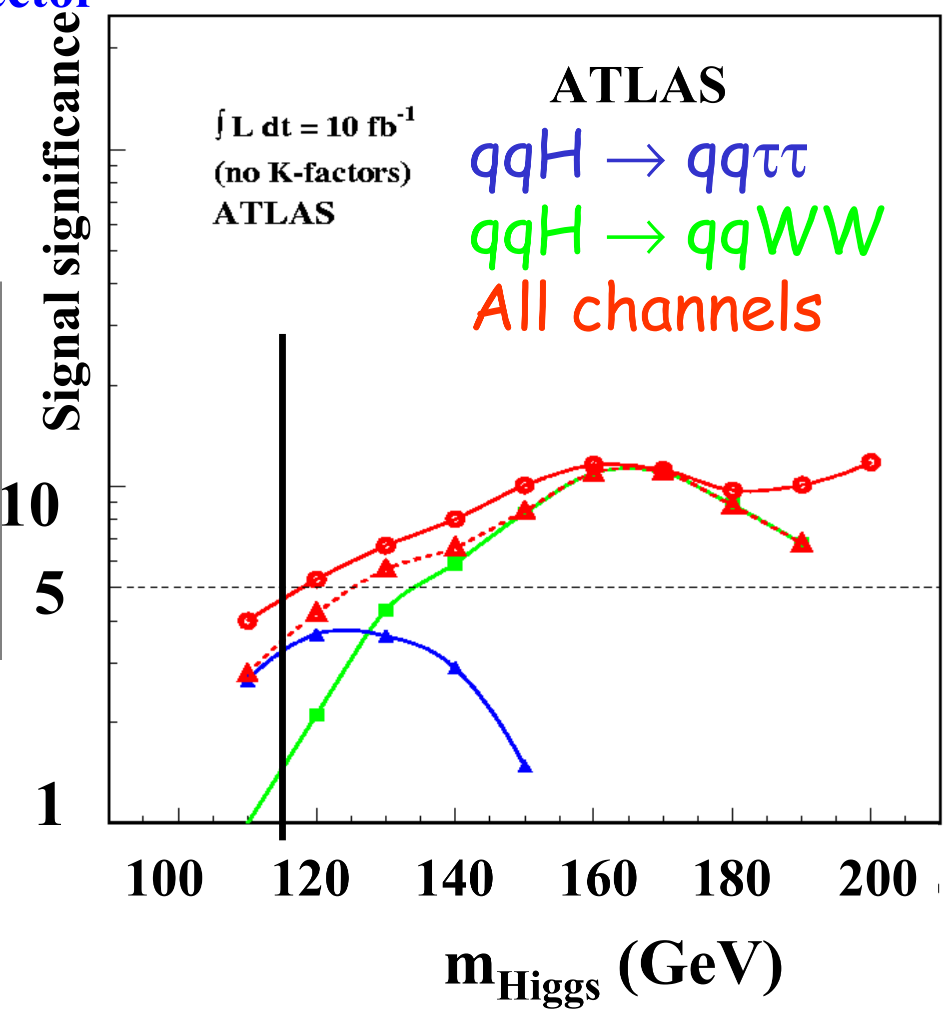
# Vector Boson Fusion

These studies demonstrate that vector boson fusion channels may be accessible in the low mass region already in the first year.

For **10 fb$^{-1}$** in ATLAS:

**5 σ significance for**

**$120 \leq m_H \leq 190$ GeV**




**Results are conservative:**

- K-factor not included
- very simple analyses used

# Low mass remarks

The 3 channels are complementary $\rightarrow$ robustness:

- different production and decay modes
- different backgrounds
- different detector/performance

requirements:

-- ECAL crucial for $H \rightarrow \gamma\gamma$ (in particular response uniformity) : $\sigma/m \sim 1\%$ needed

-- b-tagging crucial for ttH : 4 b-tagged jets needed to reduce combinatorics

-- efficient jet reconstruction over $|\eta| < 5$ crucial for $qqH \rightarrow qq\tau\tau$ : forward jet tag and central jet veto needed against background

Note :
all require "low" trigger thresholds.

e.g. ttH analysis cuts :

$p_T(\ell) > 20$ GeV,

$p_T(\text{jets}) > 15\text{-}30$ GeV

# 200 GeV<$M_H$<600 GeV

# Large mass

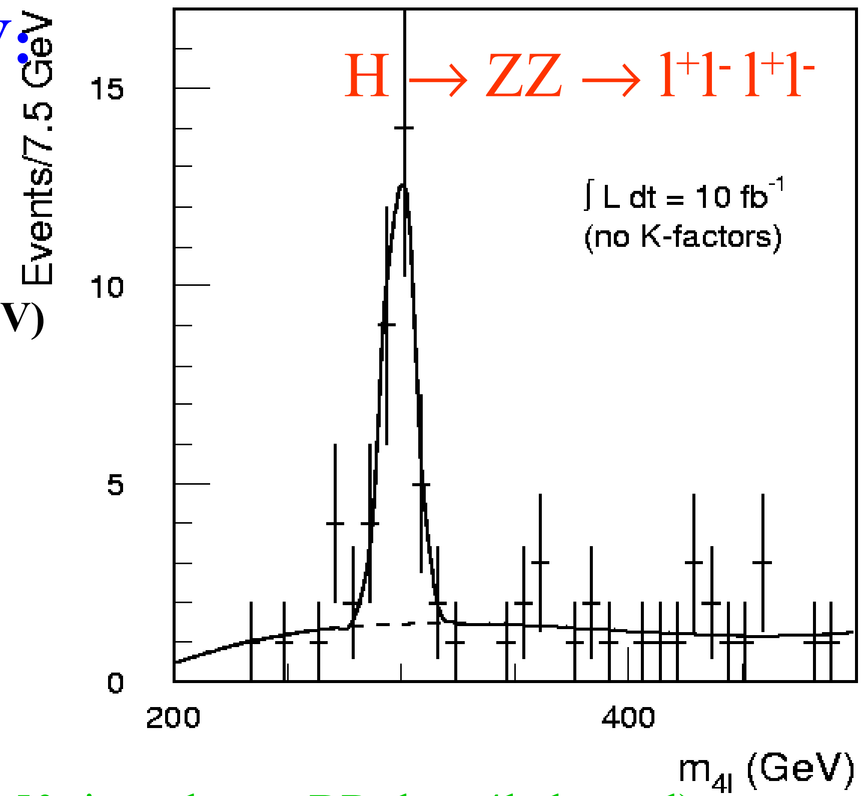
**complete detector** **10 $fb^{-1}$**

**200 GeV < m(Higgs) < 600 GeV :**

**- discovery in $H \rightarrow ZZ \rightarrow l^+l^- l^+l^-$**

**background smaller than signal,**
**Higgs natural width larger than**
**experimental resolution** ($m_{Higgs}$ > 300 GeV)

**- confirmation in $H \rightarrow ZZ \rightarrow l^+l^-$ jj channel**




**m(Higgs) > 600 GeV:**

**4 lepton channel statistically limited**

**$H \rightarrow ZZ \rightarrow l^+l^- \nu\nu$**

**$H \rightarrow ZZ \rightarrow l^+l^-$ jj , $H \rightarrow WW \rightarrow l\nu$ jj** (150 times larger BR than 4l channel)

**Event signature: high $p_T$ lepton, two high $p_T$ jets**

11th Lomanosov, Moscow, 2003

**Combination of analyses allows Higgs discovery in full mass range**

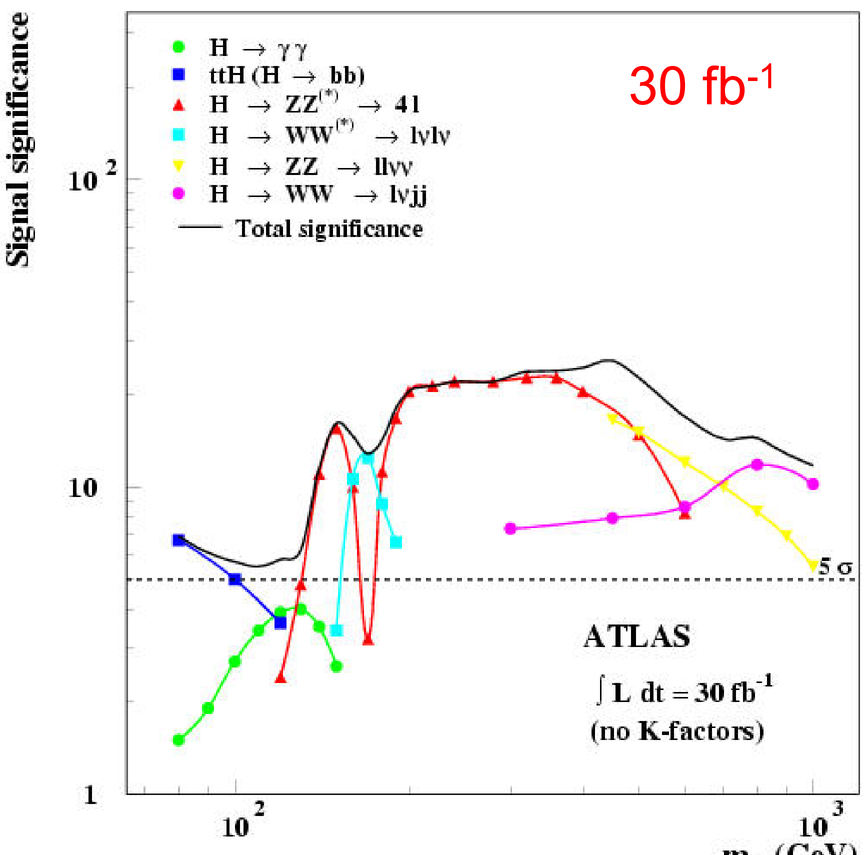
# SM Higgs Discovery Potential

## ATLAS
## All channels together
**(No K-factors)**

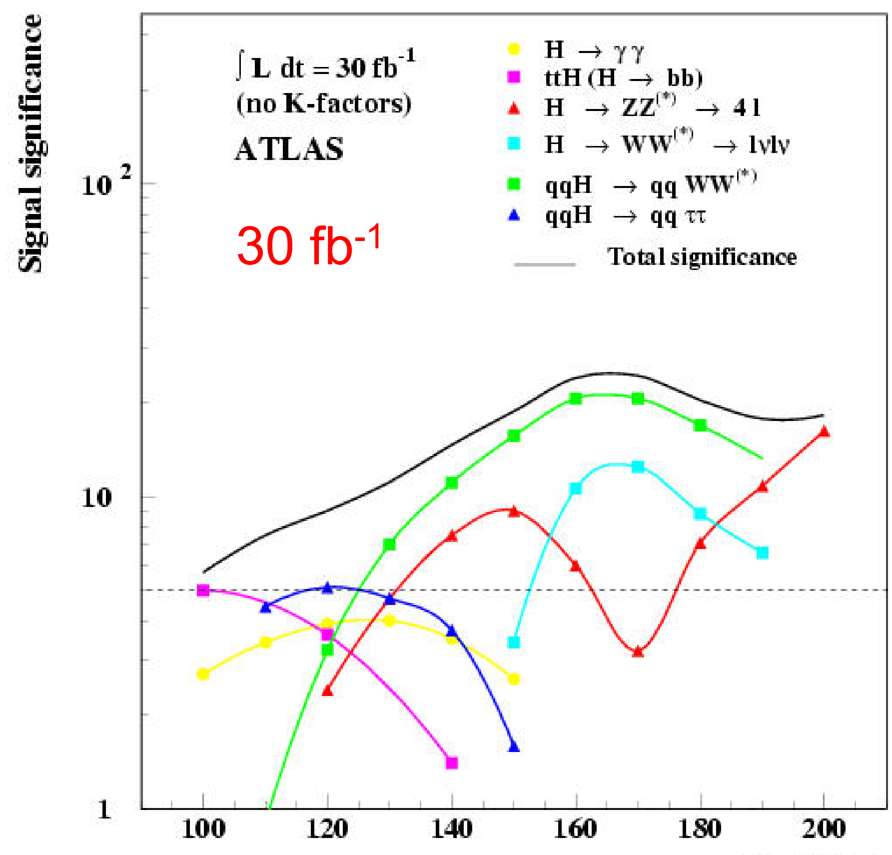
LHC can probe entire set of "allowed" Higgs mass values (100 GeV – 1 TeV)

✓at least 2 channels for most of range

**Without VBF at low mass**




**Significant boost from VBF at low mass**



# Discovery potential

All channels together

-> For most of the mass range at least two channels available

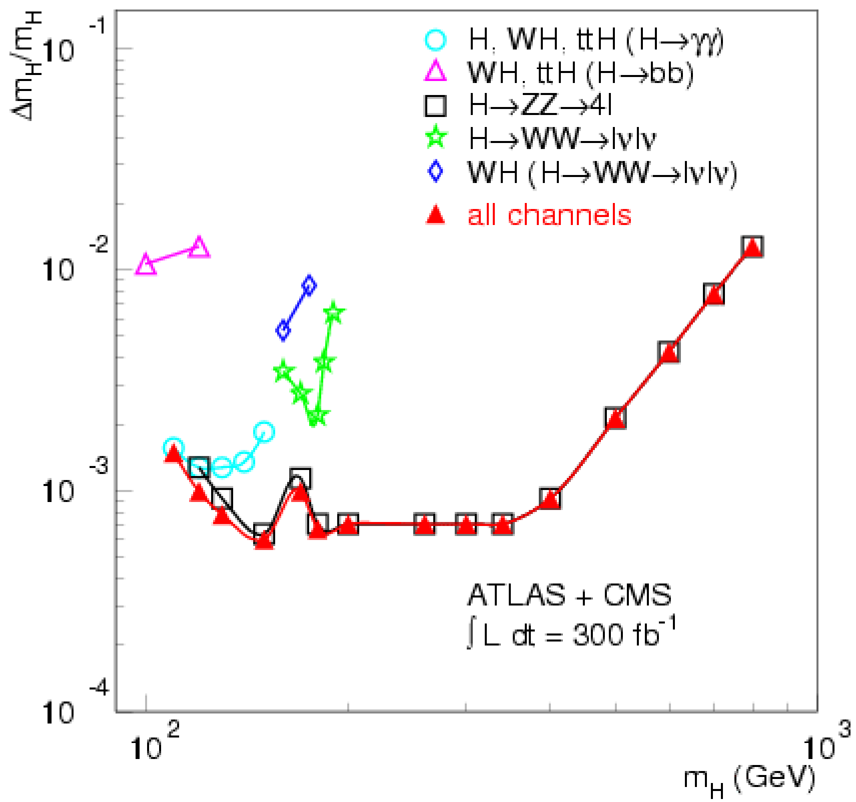
-> Good sensitivity over the full mass range from ~ 100 GeV to ~ 1TeV

-> $m_H$<180 GeV: several complementary channels (gg, ttbb, $2\ell E_T^{miss}$ , $3\ell E_T^{miss}$, 4 $\ell$, tt)

-> $m_H$>180 GeV: easy with gold-plated $H \rightarrow ZZ^* \rightarrow 4\ell$

Challenging channels (multijets…, WH) not included

# Measurement of the Higgs boson mass




- **No theoretical error**
- **Dominant systematic uncertainty: γ/ℓ, E scale.**

**Assumed 1‰**

Goal 0.2‰

Scale from $Z \rightarrow \ell\ell$

(close to light Higgs)

**Assumed 1% jets**

**Resolution for**

**γγ & ℓℓ 1.5 GeV/c²**

**bb 15 GeV/c²**

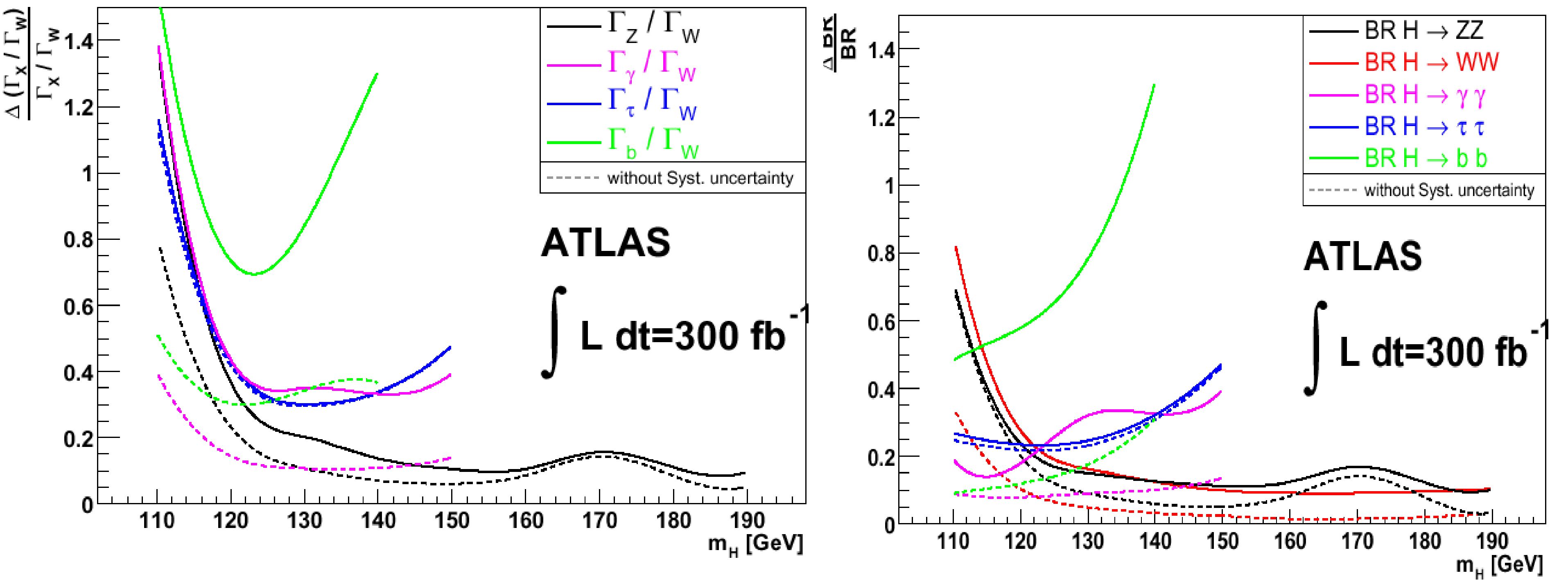
**At large masses decreasing precision dueto large $\Gamma_H$**

**Higgs boson mass can be measured with a precision of 0.1% over a large mass range (130 - ~450 GeV / c²)**

# Measurement of Branching Ratios

- **Measurement of relative branching ratios**
- **Fitting Br(H->XX)  (assume Higgs production works as in SM)**

- Fit of $BR(H \to ZZ)$, $BR(H \to WW)$, $BR(H \to \gamma\gamma)$, $BR(H \to \tau\tau)$ and $BR(H \to b\bar{b})$
- $(\sigma \cdot BR)_j\,(\vec{x}) = \sigma_j \cdot BR_j$



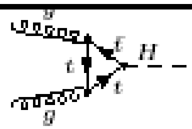
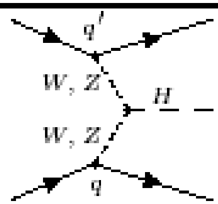
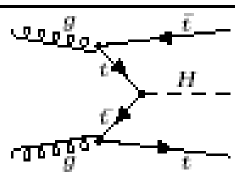
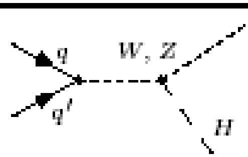
11th Lomanosov, Moscow, 2003

# Higgs Searches at the LHC

## - Measurement of coupling-parameters (110 GeV $\leq m_H \leq$ 190 GeV) -

### Global Fit to all ATLAS studies

- Maximum Likelihood Fit
- Systematic uncertainties are taken into account

| Production | | Decay | mass ranges |
|---|---|---|---|
|  | Gluon-Fusion ($gg \to H$) | $H \to ZZ \to 4l$ | 110 GeV - 200 GeV |
| | | $H \to WW \to l\nu\, l\nu$ | 110 GeV - 200 GeV |
| | | $H \to \gamma\gamma$ | 110 GeV - 150 GeV |
|  | WBF ($qq\, H$) | $H \to ZZ \to 4l$ | 110 GeV - 200 GeV |
| | | $H \to WW \to l\nu\, l\nu$ | 110 GeV - 190 GeV |
| | | $H \to \tau\tau \to l\nu\nu\, l\nu\nu$ | 110 GeV - 150 GeV |
| | | $H \to \tau\tau \to l\nu\nu$ had$\nu$ | 110 GeV - 150 GeV |
| | | $H \to \gamma\gamma$ | 110 GeV - 150 GeV |
|  | $t\bar{t}H$ | $H \to WW \to l\nu\, l\nu\, (l\nu)$ | 120 GeV - 200 GeV |
| | | $H \to b\bar{b}$ | 110 GeV - 140 GeV |
| | | $H \to \tau\tau$ (not included) | 110 GeV - 150 GeV |
| | | $H \to \gamma\gamma$ | 110 GeV - 120 GeV |
|  | $WH$ | $H \to WW \to l\nu\, l\nu\, (l\nu)$ | 150 GeV - 190 GeV |
| | | $H \to \gamma\gamma$ | 110 GeV - 120 GeV |
| | $ZH$ | $H \to \gamma\gamma$ | 110 GeV - 120 GeV |

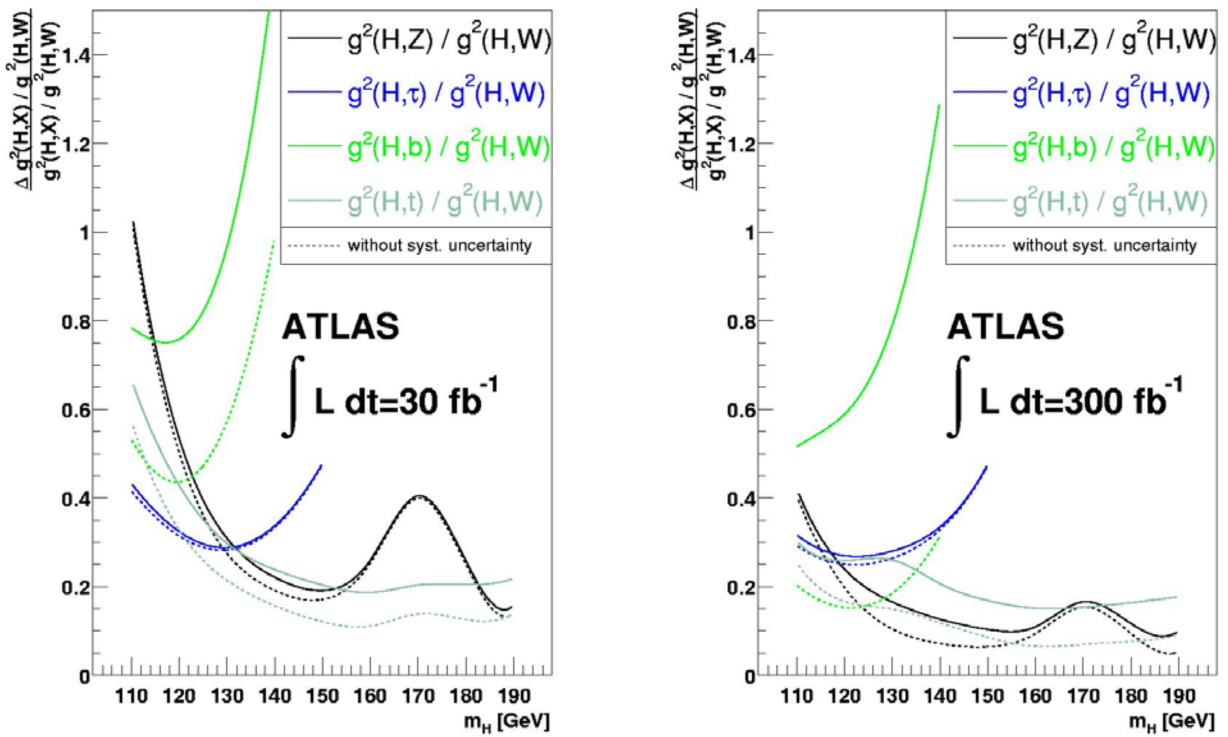
# Measurement of Higgs Boson Couplings

**Global likelihood-fit (at each possible Higgs boson mass)**

**Input: measured rates, separated for the various production modes**

**Output: Higgs boson couplings, normalized to the WW-coupling**

11th Lomanosov, Moscow, 2003




**Relative couplings** can be measured with a precision of **10-20% (for 300 $fb^{-1}$)**

# Conclusions to the SM part

Inclusion of VectorBosonFusion channels improves SM Higgs discovery potential:

- ~10 $fb^{-1}$ needed for 5σ discovery over the full (interesting) mass range

- At least 3 channels with 3σ sign for 30 $fb^{-1}$ for each mass: more robust result

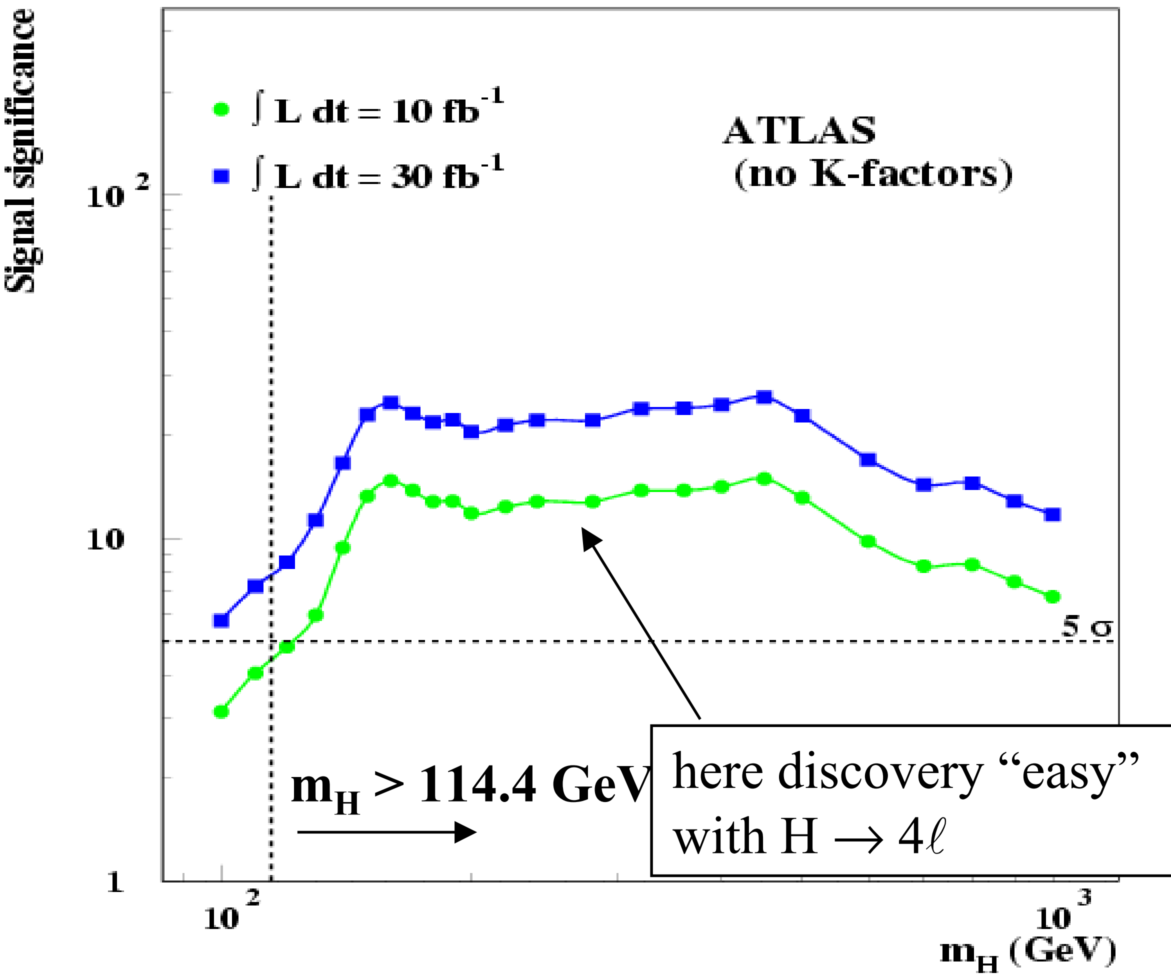
# Conclusions on the SM Higgs



Inclusion of Vector Boson Fusion channels improves SM Higgs discovery potential:

**~10 fb$^{-1}$** needed for **5σ discovery** over the full (interesting) mass range

**30 fb$^{-1}$** more robust result



# MSSM Higgs



**Minimal Supersymmetric Standard Model extention:**

**Two Higgs doublets: 5 Higgs particles**

**H, h, A**

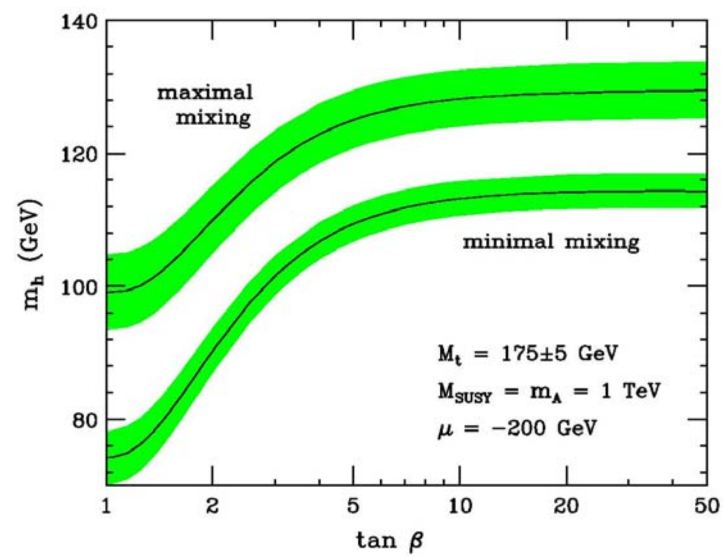
**$H^+$, $H^-$**

**Theory prediction m(h) < 135 GeV**

two parameters: **$m_A$, tan β**

- **Fixed mass relations at tree level,**
- **Important radiative corrections**
 (tree level relations are significantly modified)
- **For large mA  the h boson is SM like**

upper limit for the light Higgs mas

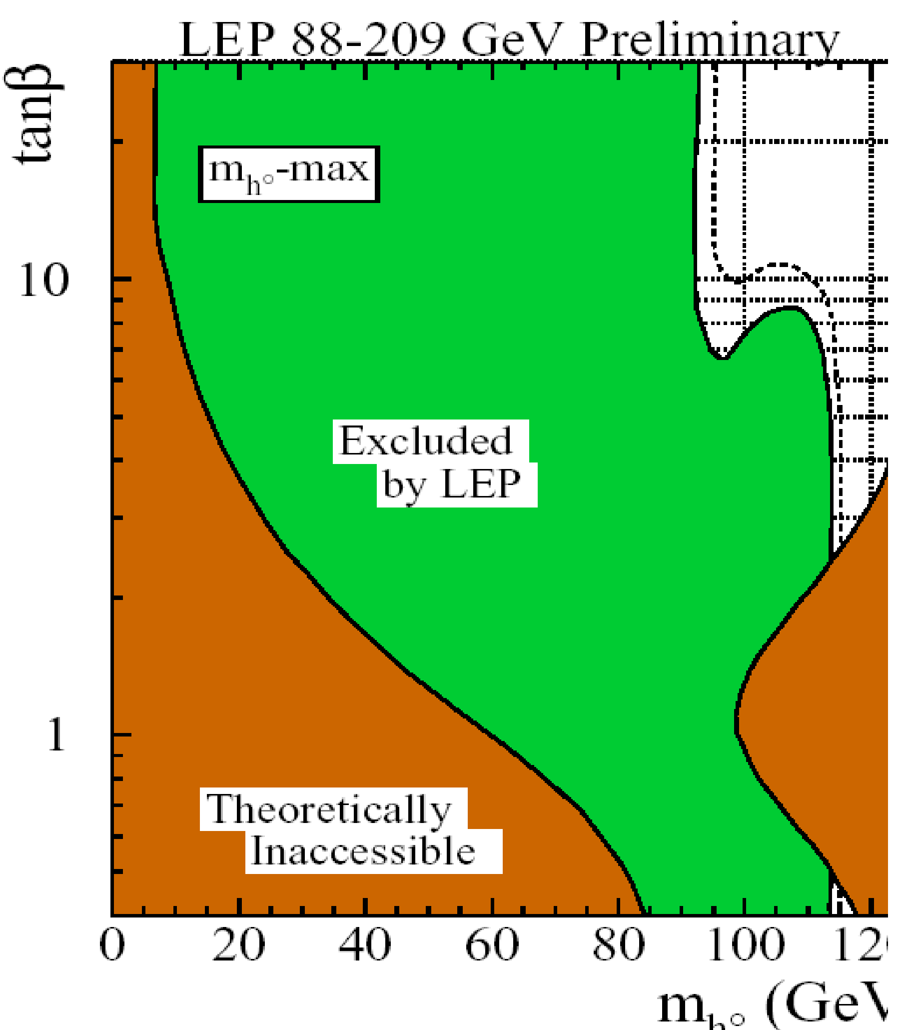


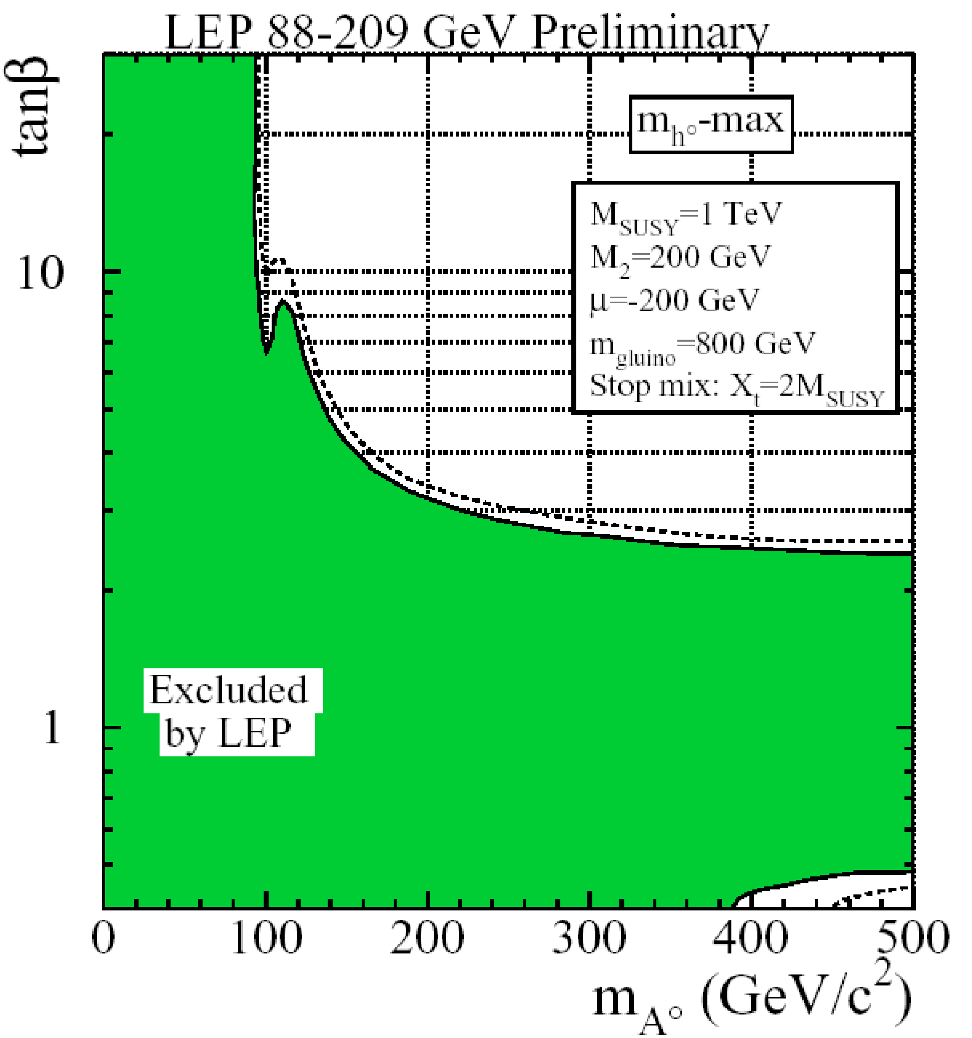
# Large variety of observation modes

- **if SUSY particles heavy**
  - **SM-like:** $h \to \gamma\gamma$, bb
    $H \to$ 4lept
  - **MSSM-specific:** $A/H \to \mu\mu$, $\tau\tau$, tt
    $H \to hh$
    $A \to Zh$
    $H^{\pm} \to \tau\nu$

- **if SUSY particles accessible: (not discussed)**
  - $H/A \to \chi^2{}_0\,\chi^2{}_0 \to \chi^1{}_0\,\chi^1{}_0 \to 4l$ + missing Energy
  - **h produced in cascade decays (e.g. $\chi^2{}_0 \to h\,\chi^1{}_0$)**

# MSSM neutral Higgs search at LEP




**$M_h$ >91.0 GeV** **$M_A$> 91.9 GeV**

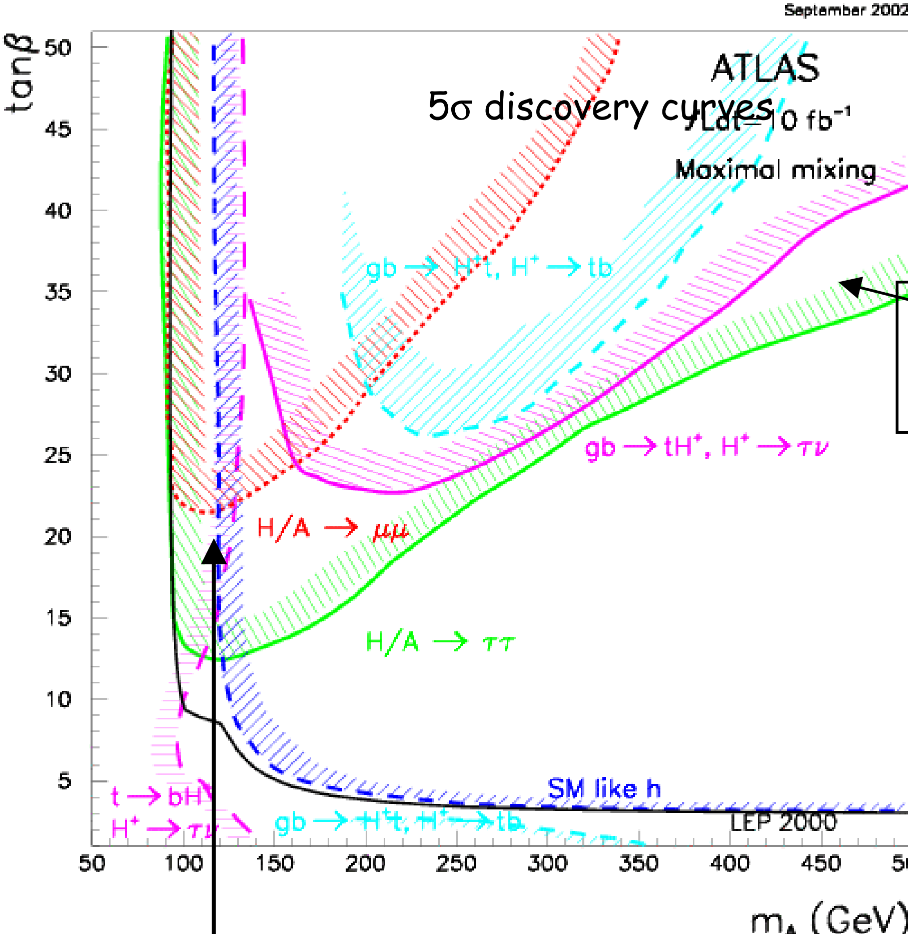
# MSSM Higgs Accesible channels at LHC

- **h →gg, tth →bb, H →ZZ$^{(*)}$→4l** as in Standard Model
- **HWW, HZZ** strongly suppressed with tanβ,
- **A/Hbb, A/Hττ, A/Hμμ** enhanced with tanβ
- typical of MSSM: **A/H →ττ, μμ; H$^{+}$ →τν, τb**

if SUSY accessible Higgs → SUSY particles or SUSY cascade → Higgs (not discussed)

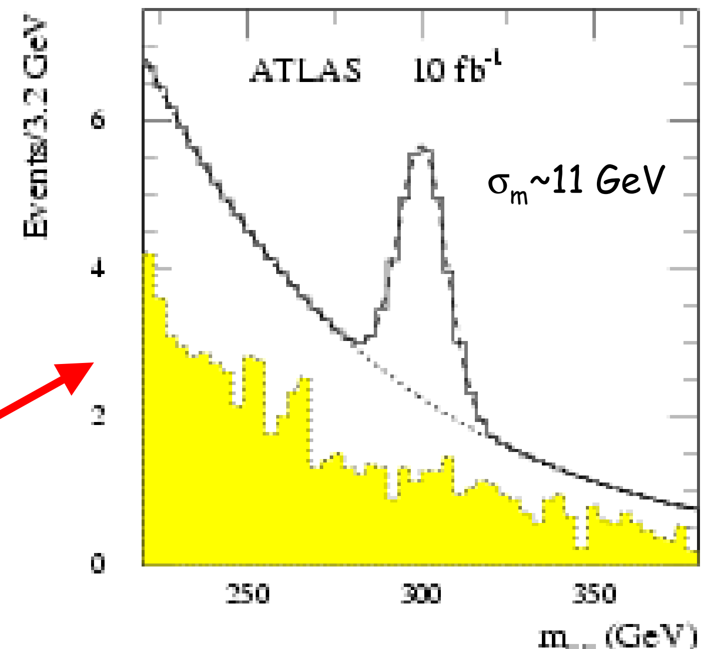
# MSSM Higgs bosons
# h, H, A, $H^{\pm}$

$m_h$ < 135 GeV
$m_A \approx m_H \approx m_{H\pm}$ at large $m_A$




A, H, $H^{\pm}$ cross-section ~ $tg^2\beta$
Best sensitivity from A/H → ττ, $H^{\pm}$ → τν

A/H → μμ, tg β = 38




**A/H → μμ :**

-- covers good part of region not excl. LEP
-- experimentally easier than A/H → ττ
-- crucial detector : Muon Spectrometer
(high-$p_T$ muons from narrow resonance)

# Overall discovery potential for MSSM Higgs bosons

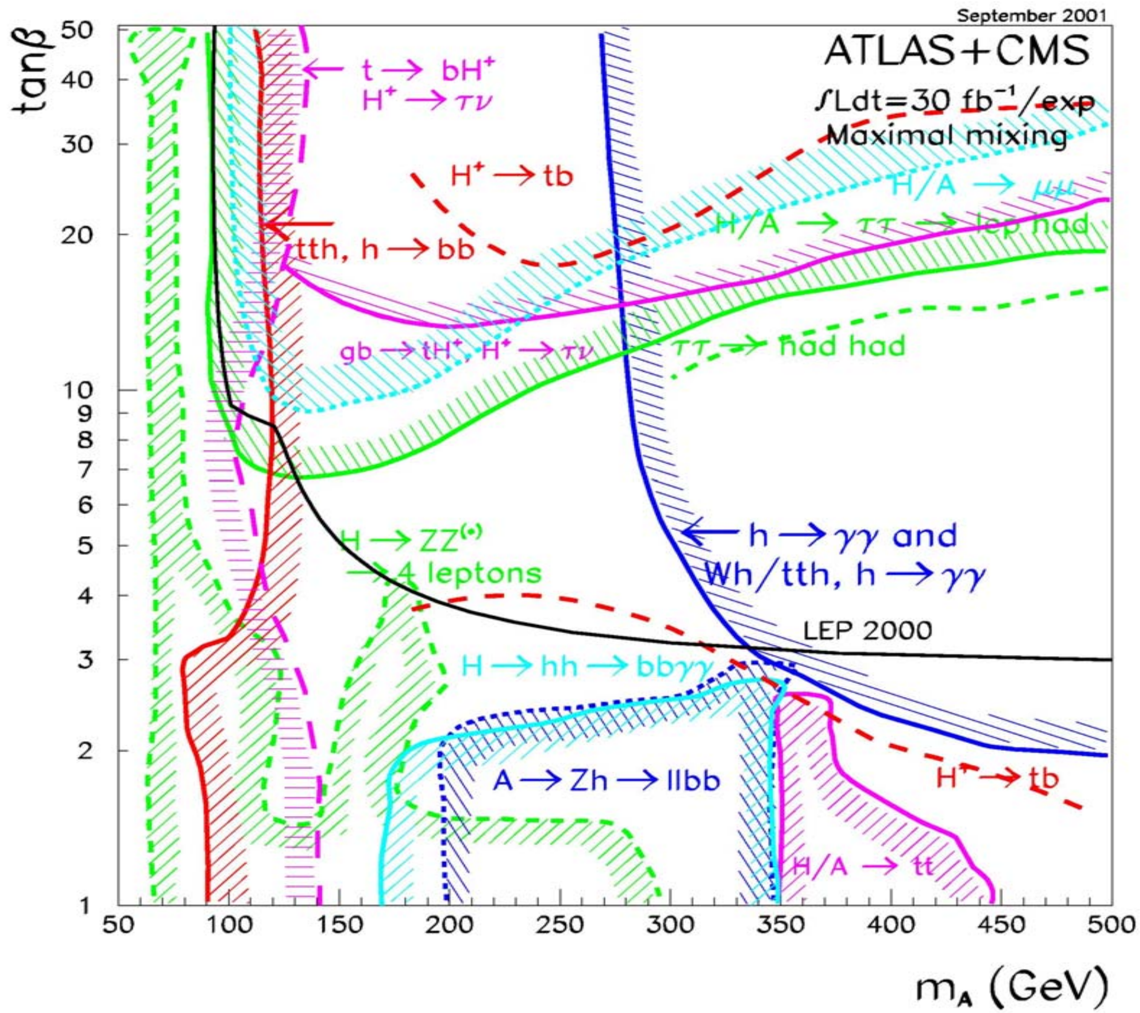
**SUSY particles heavy**

**5 σ contours**

11th Lomanosov, Moscow, 2003

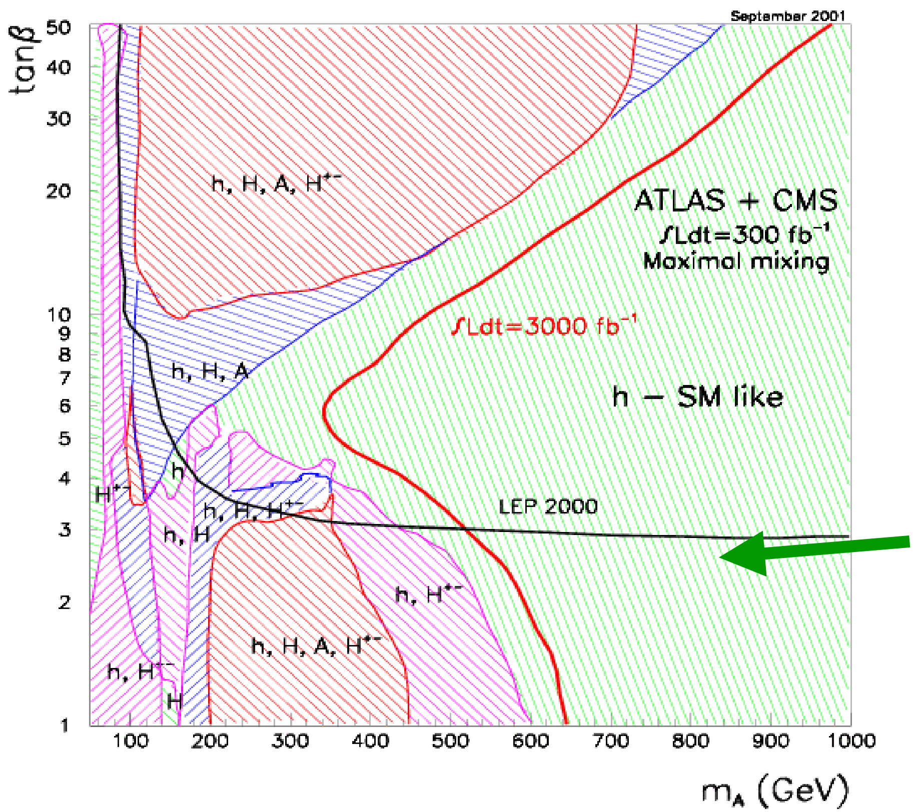
- **Plane fully covered (no holes) at low L (30 fb$^{-1}$)**

- **Two or more Higgs can be observed over most of the parameter space → disentangle SM / MSSM**



# Overall discovery potential for MSSM Higgs bosons

5 σ contours




- 4 Higgs
- 3 Higgs
- 2 Higgs
- 1 Higgs

only SM like h

**Two or more Higgs bosons can be observed over most of the parameter space → disentangle SM / MSSM**

# Tau's as final state signature in MSSM scenario

-> bbH, bbA with H/A-> $\tau\tau$ (lep-had and had-had)
-> tt->$H^+$bWb with H-> $\tau\nu$ (lep, had)
-> gb->$H^+$t with H-> $\tau\nu$ (had)



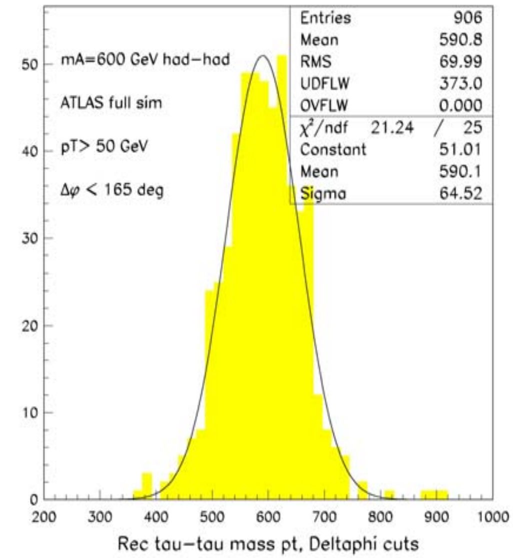
**In MSSM at large tan$\beta$ couplings**
**$H\tau\tau$, $A\tau\tau$, Hbb, Abb, $H^+\tau b$**
**strongly enhanced.**

- Extential a good $\tau$ identification

# Sensitivity for all A/H->ττ channels

**30 fb$^{-1}$**

A/H -> ττ in MSSM :
excellent benchmark channel;
several different observables
and performances issues
-> lepton reconstruction
-> tau-jet id, QCD jet rejection
-> $E_T^{miss}$ reconstruction
-> τ+$E_T^{miss}$, jet+$E_T^{miss}$ triggers




**mass resolution**

**below 15% (had-had)**

**σ= 65 GeV for**

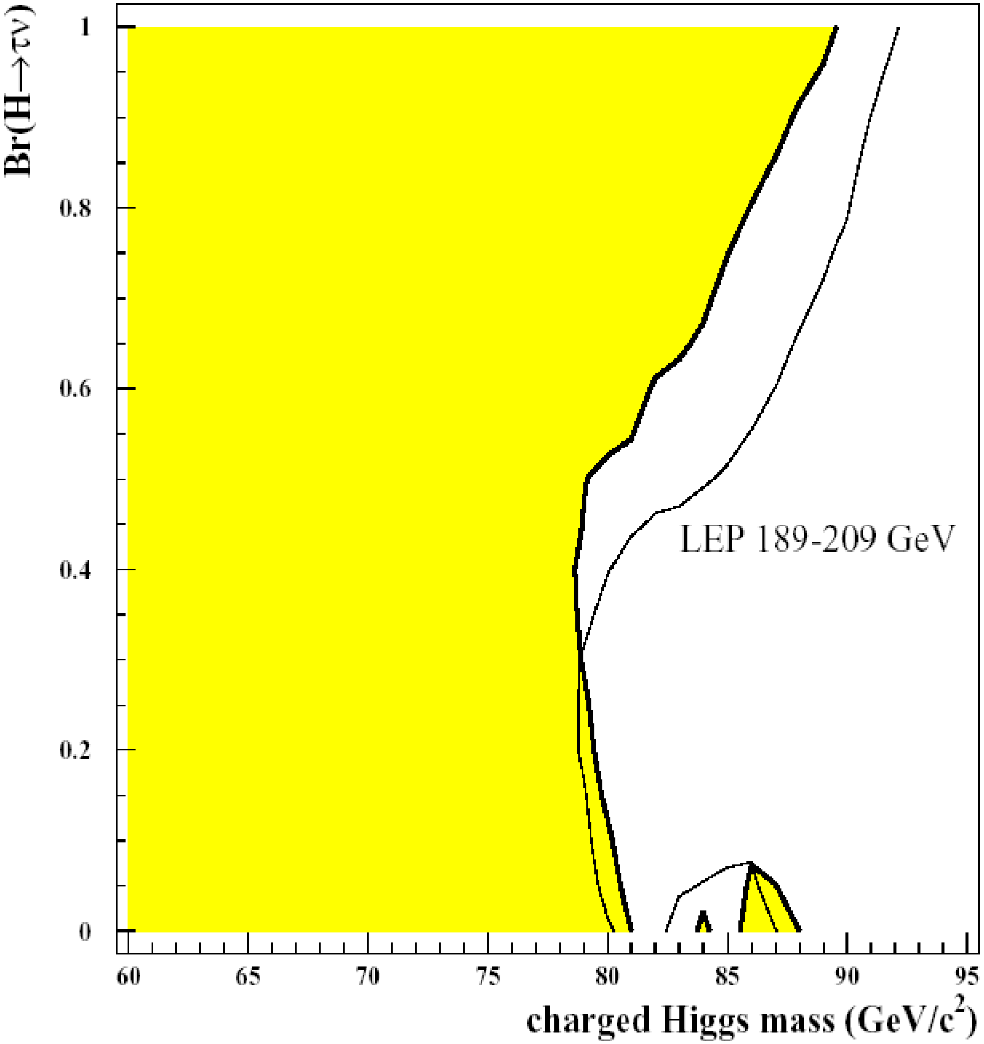
**mA = 600 GeV**

**Br (A/H -> ττ) ~ 10%**

# Charged Higgs at LEP

**MH+ > 78.6 GeV**

**@95% C.L.**



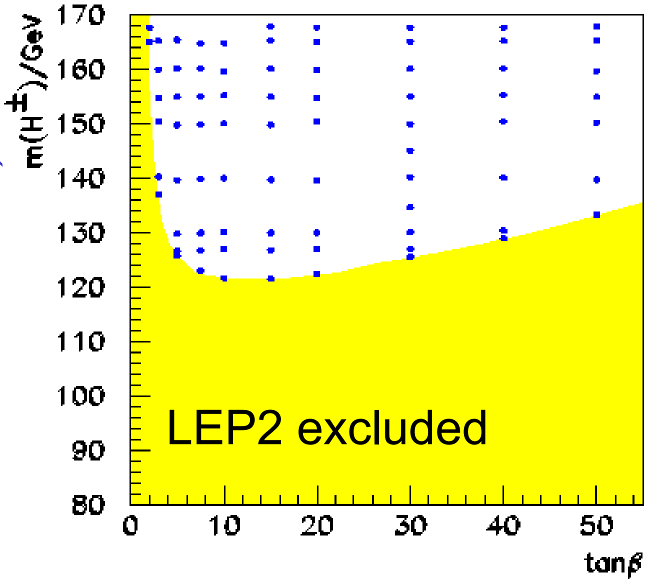
# Charged Higgs

## Production mechanisms:

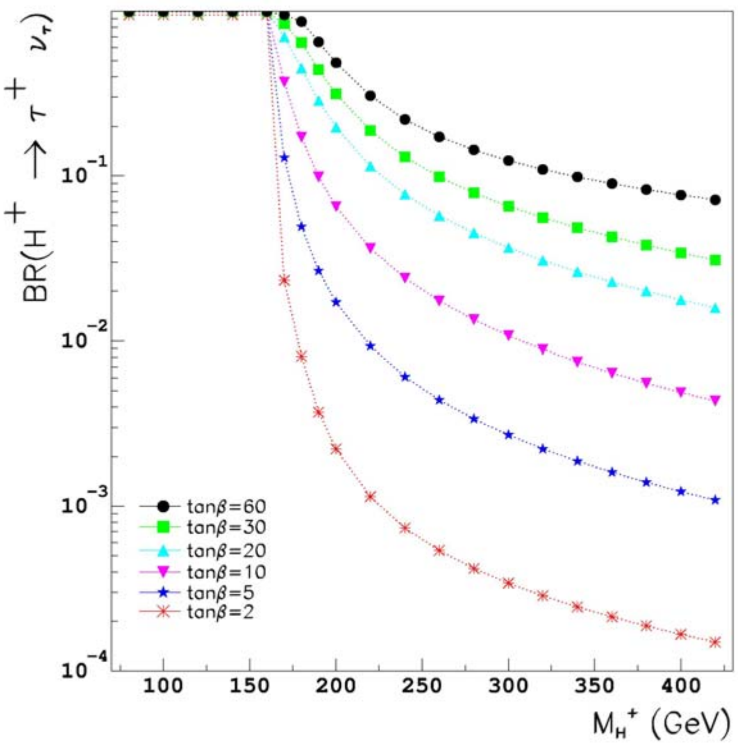
below top-quark mass: gg,qq -> tt->WbH$^+$b

above top-quark mass: gb->tH$^{+-}$

11th Lomanosov, Moscow, 2003




BR (H -> τν)



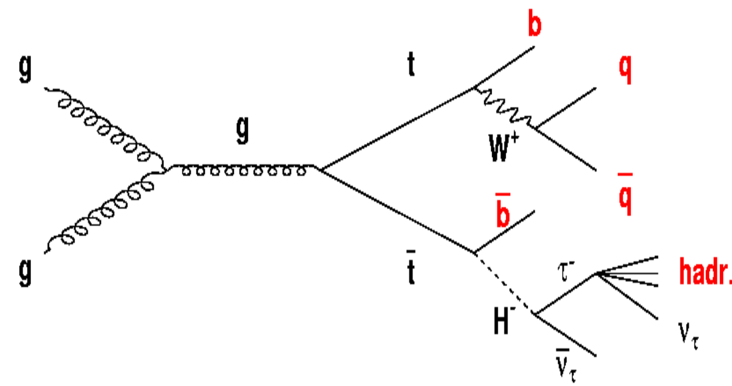
# Charged Higgs below top-quark mass



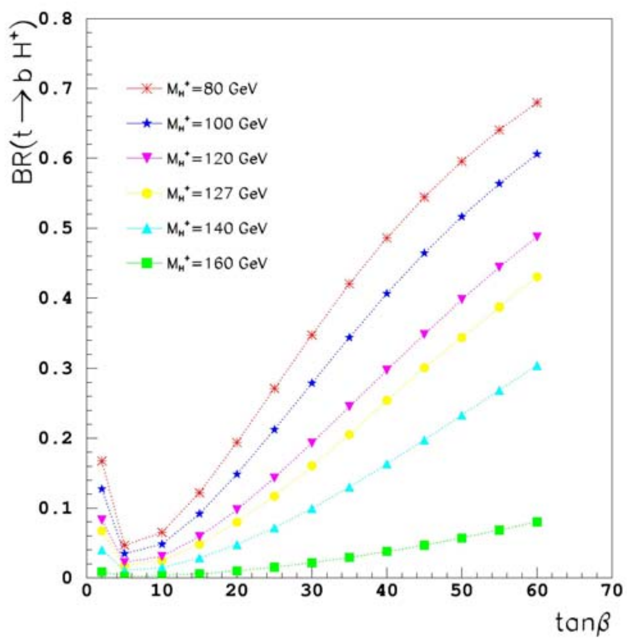
## Production mechanism:

below top-quark mass: gg,qq -> tt->WbH$^{+}$b

large $N_{exp}$(tt pairs)




**BR(t->H$^{+}$b)**



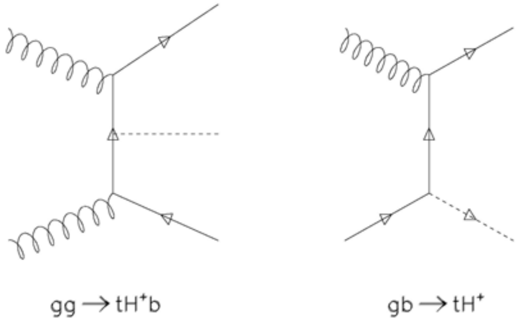

signal:

large BR (H-> τν) -> 100%

bgd. : BR(W-> τν) -> 10%

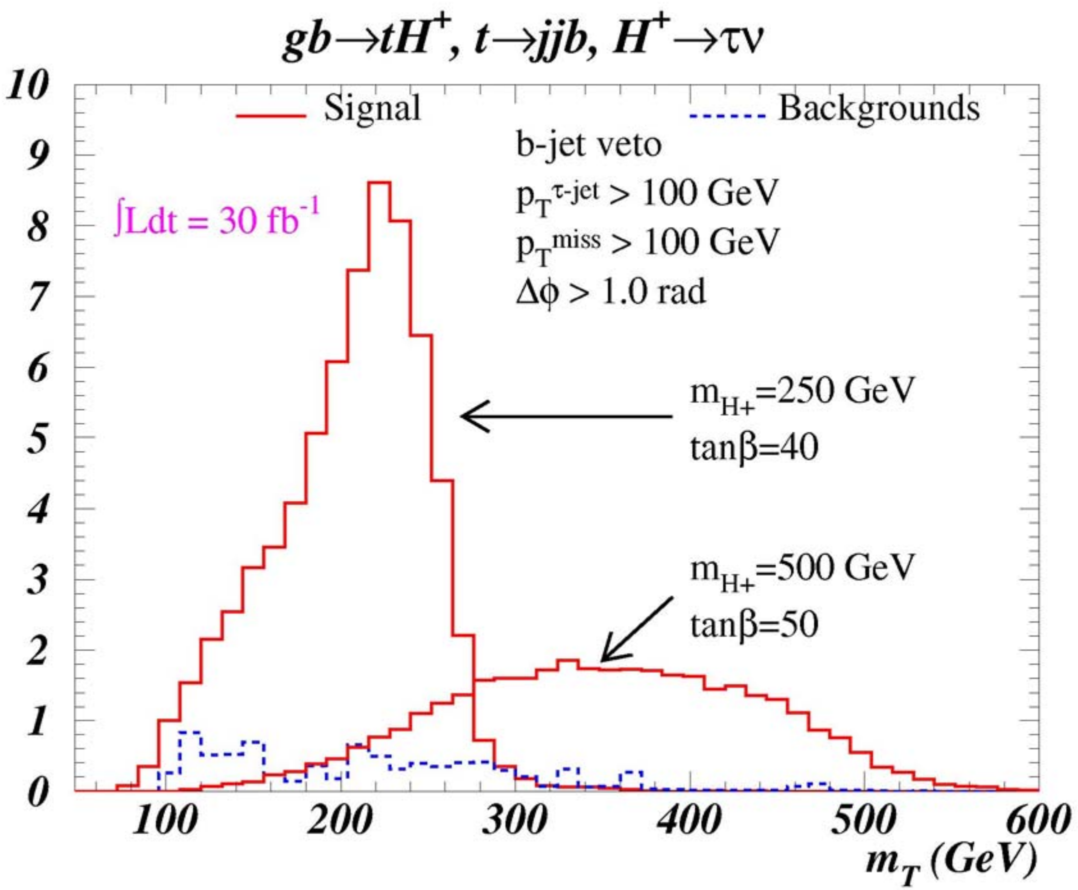
BR( τ-> had ν) -> 65%

# Charged Higgs at large masses




σ= 5 - 0.1 pb

Bgds: almost bgd free
W+jets, tt, Wbt




-> t->jjb reconstructed
-> trigger on tau+$E_T^{miss}$
-> tau-id crucial
-> profit from 100% tau polarisation to enhance rejection against W->τν
-> transverse mass can be reconstructed
-> good sensitivity to mass and tanβ measurement: at 300fb$^{-1}$:

$\Delta m/m \sim$ 1-2 %

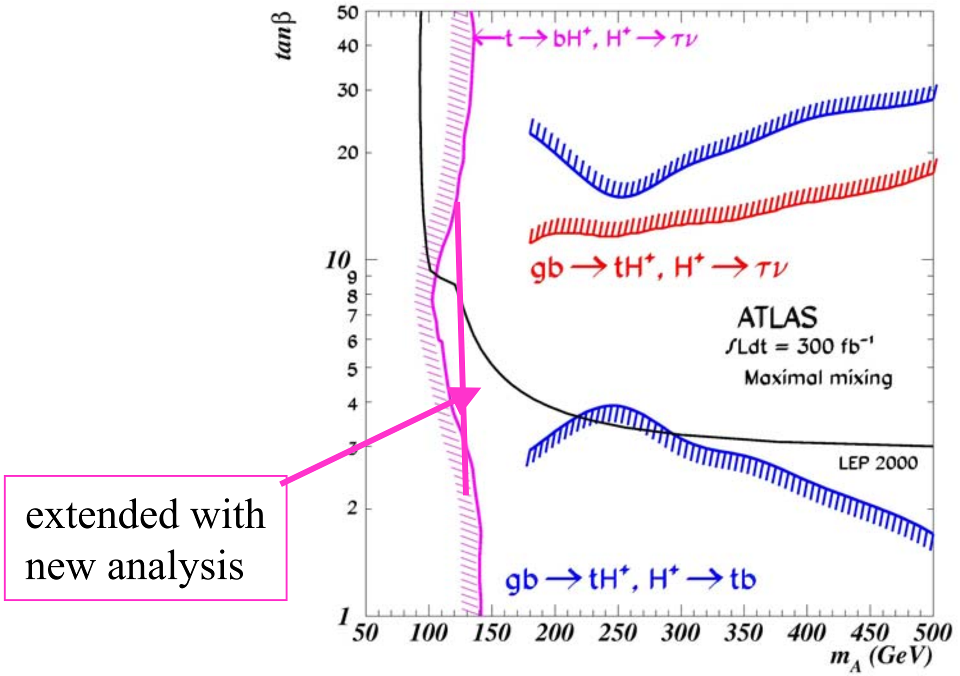
$\Delta\tan\beta/\tan\beta \sim$ 5-7 %

# Charged $H^{+-}$ -> $\tau\nu$

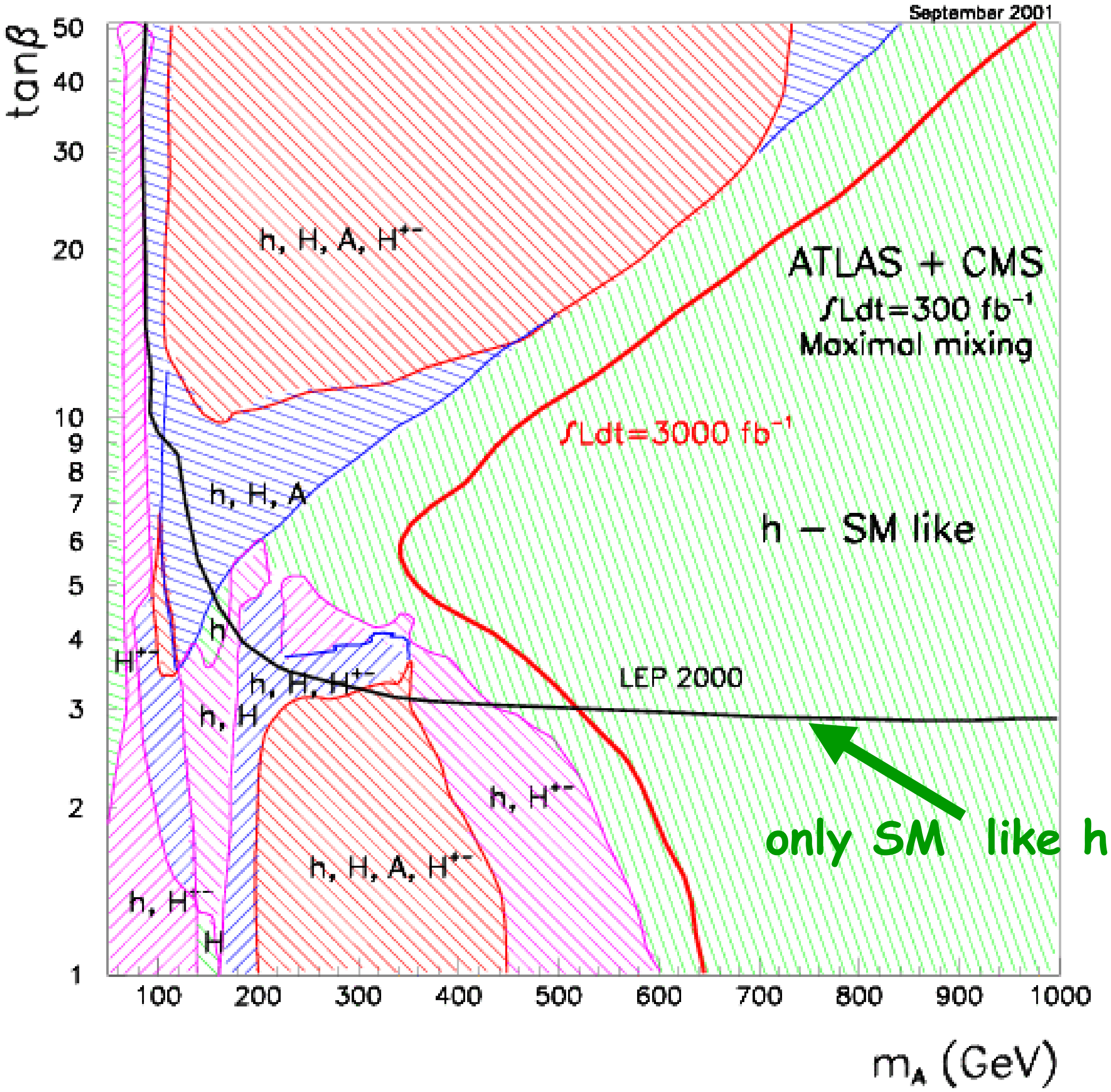
**at large masses**

5σ discovery contours





# Conclusions on MSSM Higgs sector




· **Discovery potential well understood** **with assumption of heavy SUSY particles**.

•**Several overlapping channels, studies extended to $m_A$=1 TeV range.**

- 4 Higgs
- 3 Higgs
- 2 Higgs
- 1 Higgs

# Conclusions

- SM / MSSM Higgs could be discovered with ~ **10 – 30 $fb^{-1}$**
  - Discovery of SM possible with 10 $fb^{-1}$
  - MSSM parameter space covered with 30 $fb^{-1}$

- Precise measurements of Higgs parameters with **300 $fb^{-1}$** :

**masses to 0.1 – 1%, width to ~ 5-30%, couplings to 10-30%**