PART 2

Precise measurements of: m_W , m_{top}

Motivation:

W mass and top mass are fundamental parameters of the Standard Model:

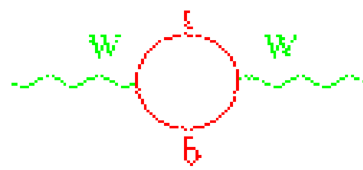
Electromagnetic constant
measured in atomic transitions,
e^+e^- machines, etc.

$$m_W = \left(\frac{\pi \, \alpha_{EM}}{\sqrt{2}\, G_F} \right)^{1/2} \frac{1}{\sin\theta_W \sqrt{1-\Delta r}}$$

Fermi constant
measured in muon decay

Weinberg angle
measured at LEP/SLC

radiative corrections
$\Delta r \sim f\,(m_{top}^2, \log m_H)$
$\Delta r \approx 3\%$

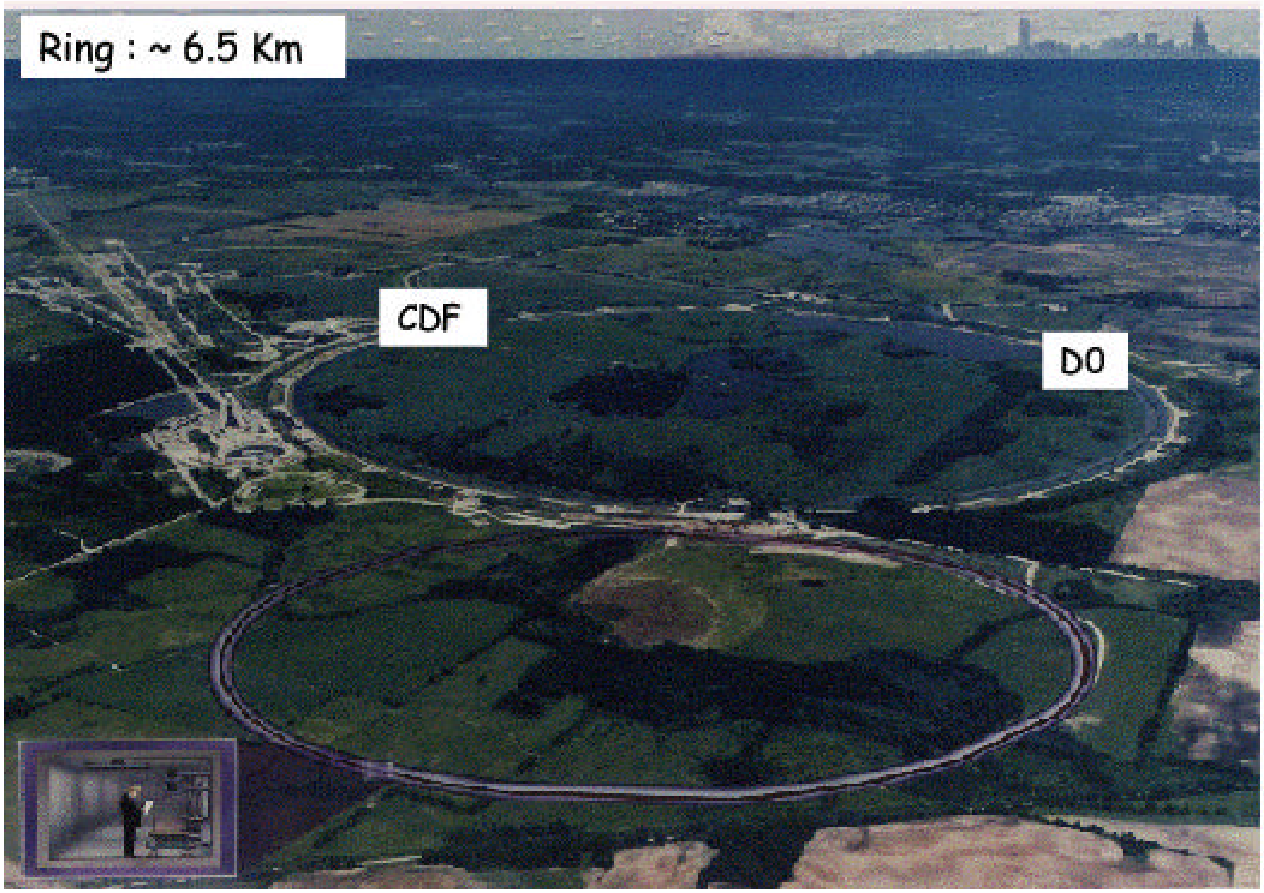


→ since G_F, α_{EM}, $\sin\theta_W$ are known with high precision, precise measurements of m_{top} and m_W constrain radiative corrections and Higgs mass (weakly because of logarithmic dependence)

So far : W mass measured at LEP2 and Tevatron
top mass measured at the Tevatron

The Tevatron $p\bar{p}$ Collider at Fermilab

$\sqrt{s} \approx 2$ TeV



Run 1 ('89-'96) : $\approx$ 200 top events, $\approx$ 80 000 W events → discovery of top; measurement of m_W and m_{top}

Run 2 (2001-2007 ?) : $\geq$ 100 times more data → better measurements of m_W and m_{top}, searches for Higgs and new particles

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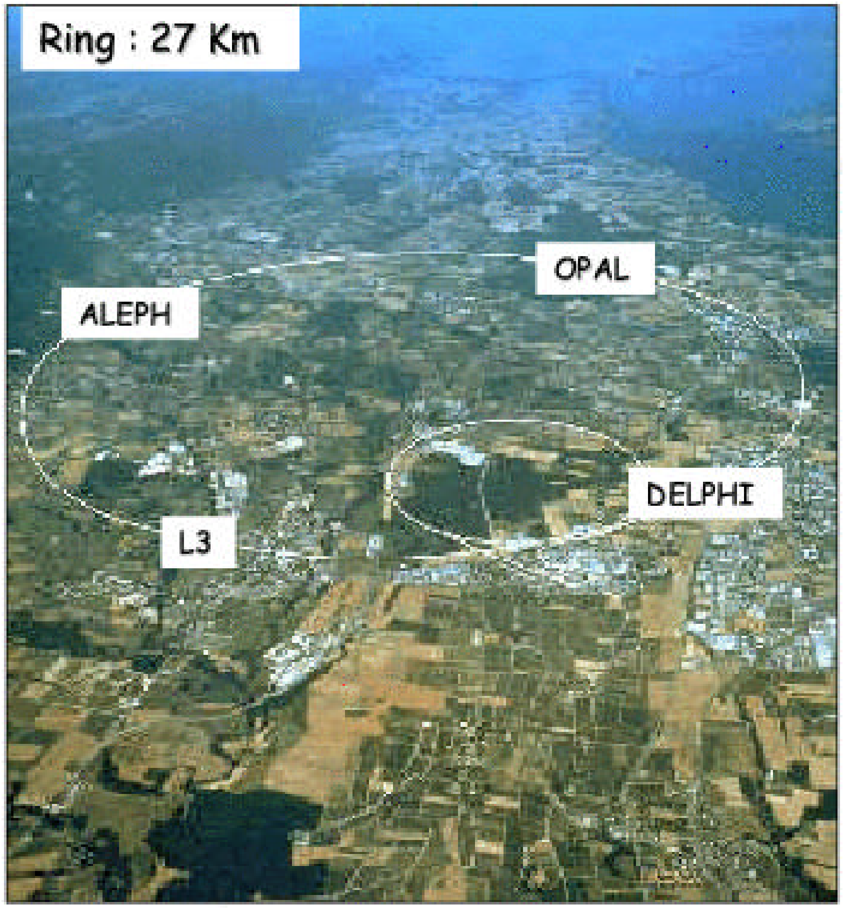
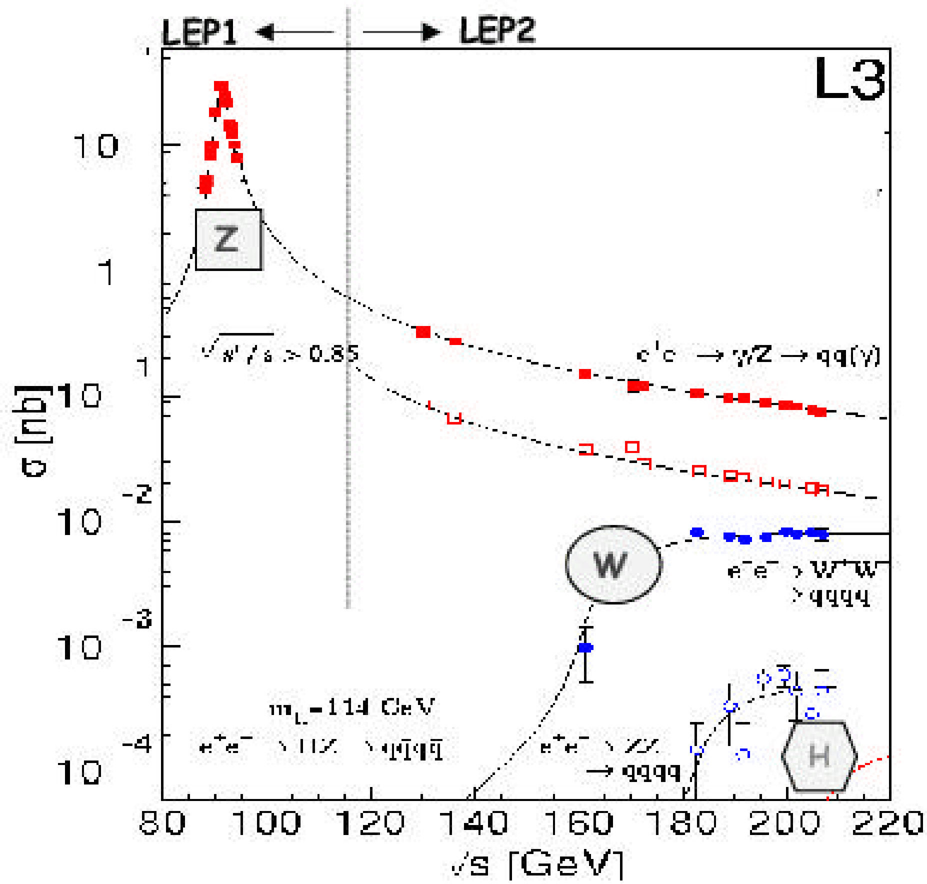
The LEP e+e- Collider at CERN

LEP1 ('89-'95) : $\sqrt{s} \approx m_Z \rightarrow$ 17 million Z recorded $\rightarrow$ precise Z measurements
LEP2 ('96-2000) : $\sqrt{s} \rightarrow$ 209 GeV $\rightarrow$ WW production, m_W, search for Higgs and new particles





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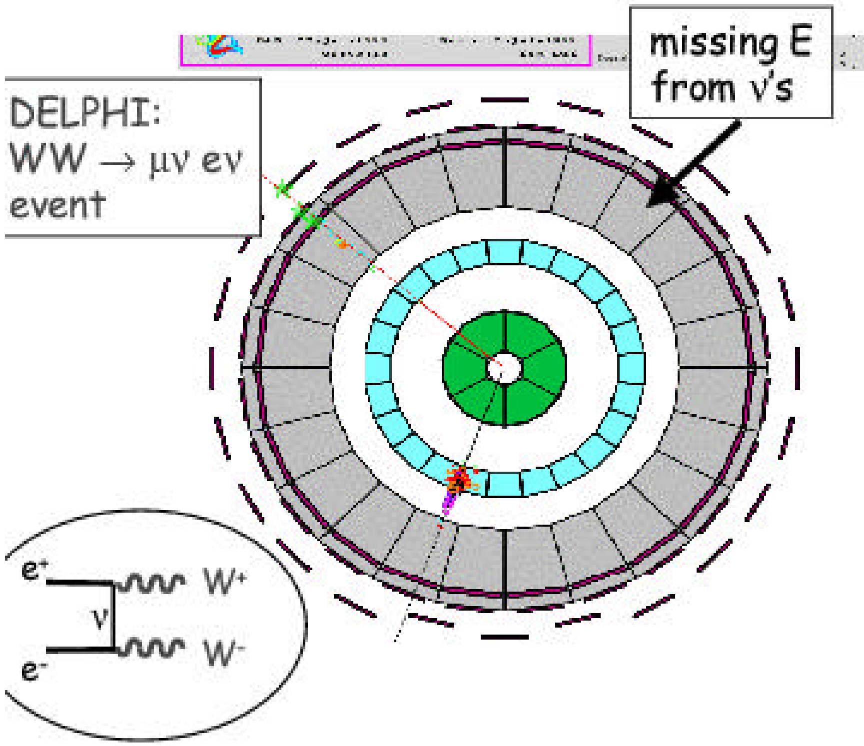
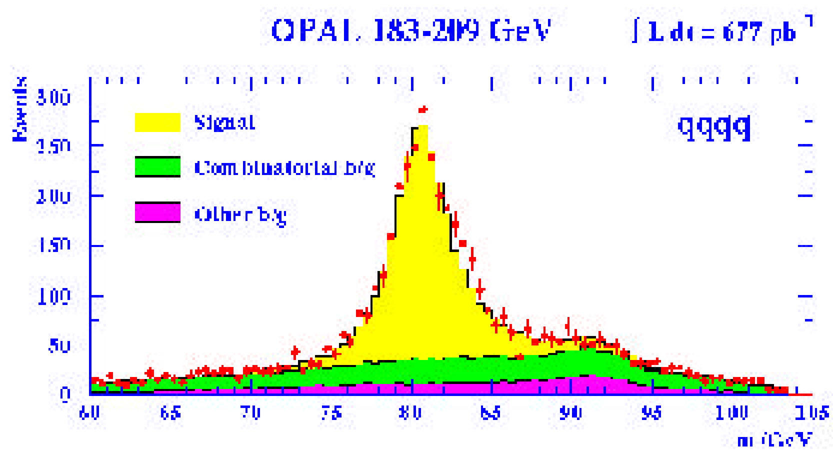
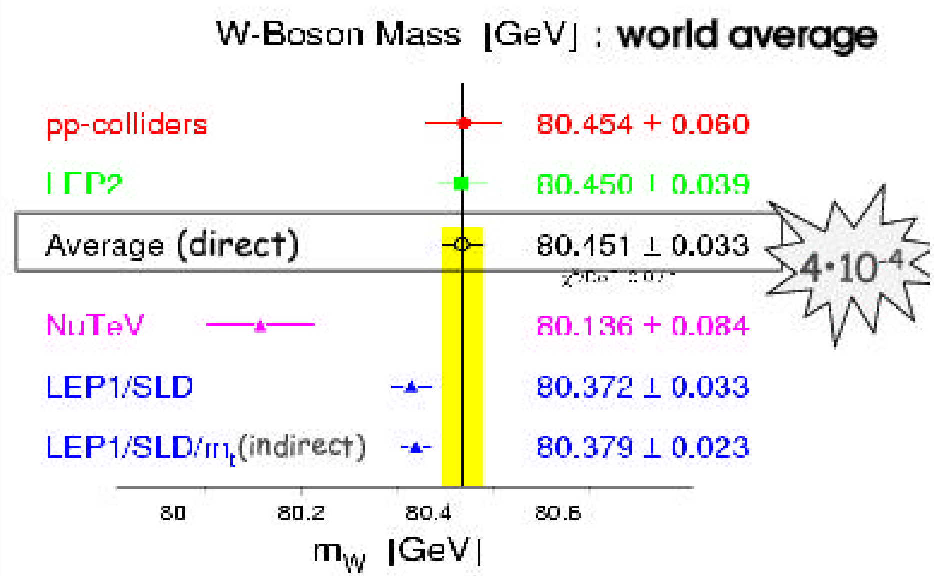






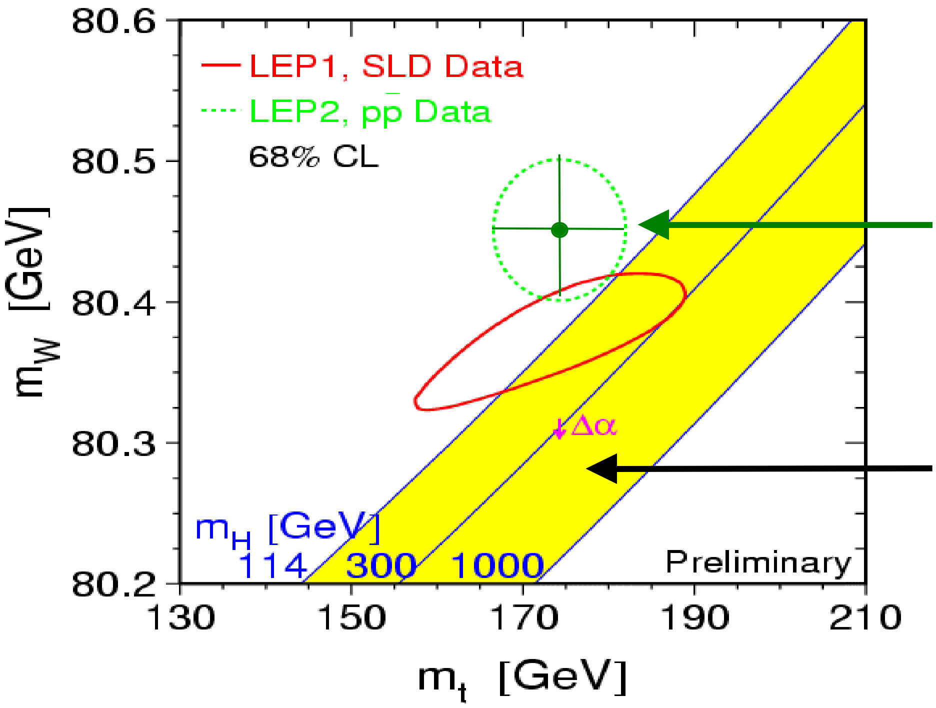
Δr (measured) =
0.0311 ± 0.0020
($\sim 15\sigma$ from 0)

→ radiative corrections exist

$$m_W = \left(\frac{\pi \, \alpha_{EM}}{\sqrt{2}\, G_F} \right)^{1/2} \frac{1}{\sin\theta_W \sqrt{1-\Delta r}}$$

m_W (from LEP2 + Tevatron) = 80.451 ± 0.033 GeV

m_{top} (from Tevatron) = 174.3 ± 5.1 GeV



Direct measurements

m_H dependence in SM through radiative corrections

→ light Higgs is favoured

Year 2007:

$\Delta m_W \approx 25$ MeV (0.3 ‰) from LEP/Tevatron

$\Delta m_{top} \approx 2.5$ GeV (1.5 %) from Tevatron

Can LHC do better ?

YES : thanks to large statistics

Measurement of W mass

Method used at hadron colliders different from e^+e^- colliders

- W $\rightarrow$ jet jet : cannot be extracted from QCD jet-jet production   cannot be used

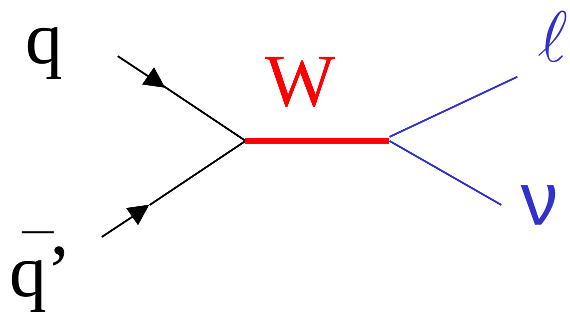
- W $\rightarrow$ $\tau\nu$: since $\tau \rightarrow \nu$ + X , too many undetected neutrinos   cannot be used

⬇

only W $\rightarrow$ eν and W $\rightarrow$ $\mu\nu$ decays are used to measure m_W at hadron colliders

W production at LHC :

Ex.

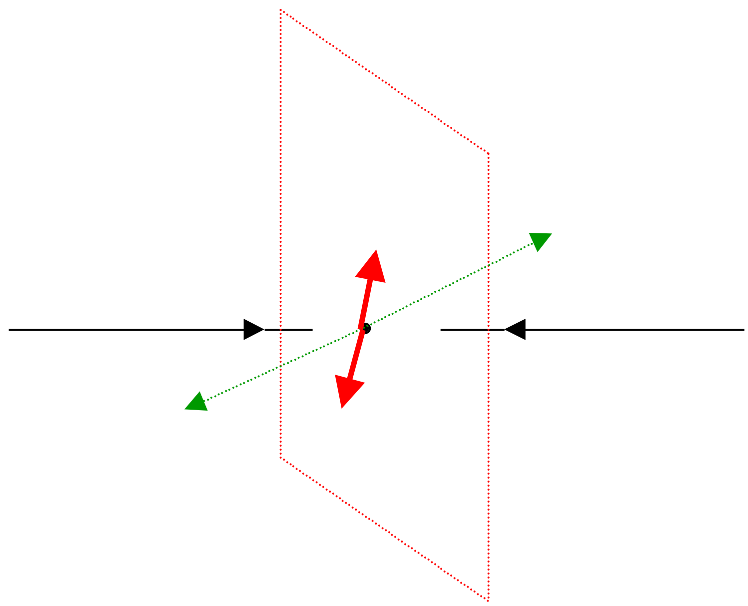


σ (pp $\to$ W + X) $\approx$ 30 nb
↳ eν, $\mu\nu$

~ 300×10^6 events produced
~ 60×10^6 events selected after analysis cuts
} one year at low L, per experiment

~ 50 times larger statistics than at Tevatron
~ 6000 times larger statistics than WW at LEP

Since $\vec{p}_L^{\,\nu}$ not known (only $\vec{p}_T^{\,\nu}$ can be measured through E_T^{miss}), measure transverse mass, i.e. invariant mass of $\ell\nu$ in plane perpendicular to the beam :



$$m_T^W = \sqrt{p_T^{\,l}\, p_T^{\,\nu}\,(1-\cos\Delta\varphi_{l\nu})}$$

$p_T^{\,\nu} \equiv E_T^{miss}$

$W \rightarrow e\nu$ events (data) from CDF experiment at the Tevatron

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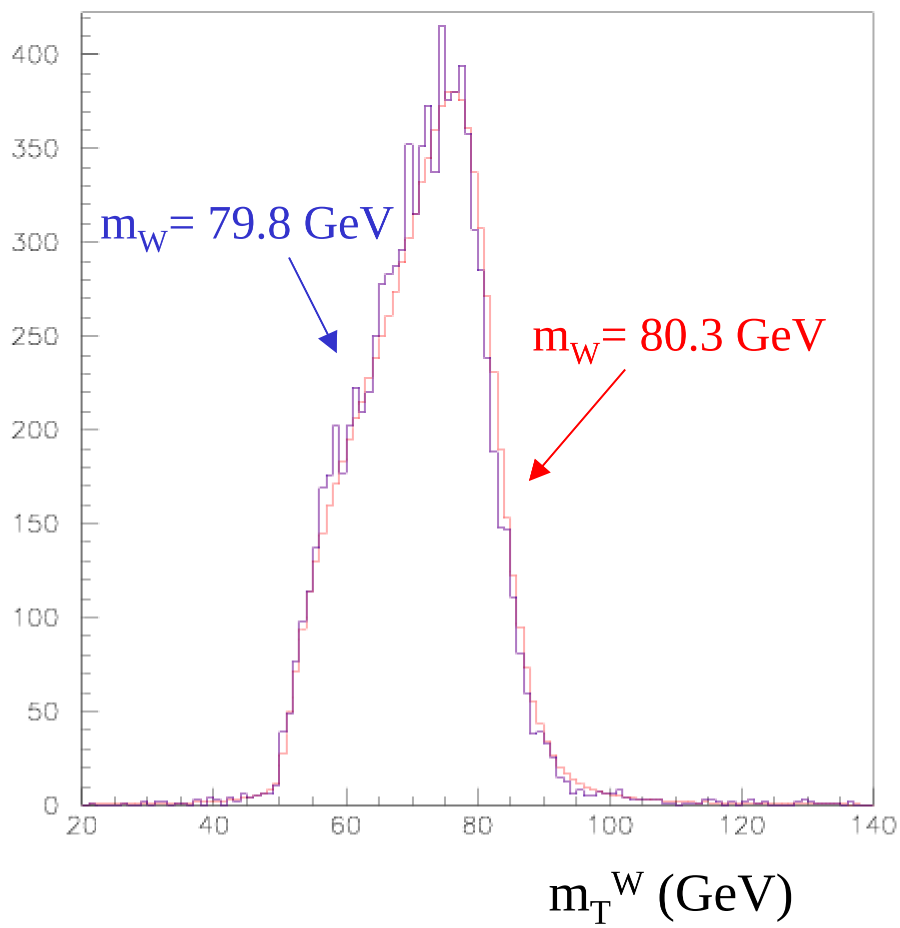
m_T^W distribution is sensitive to m_W

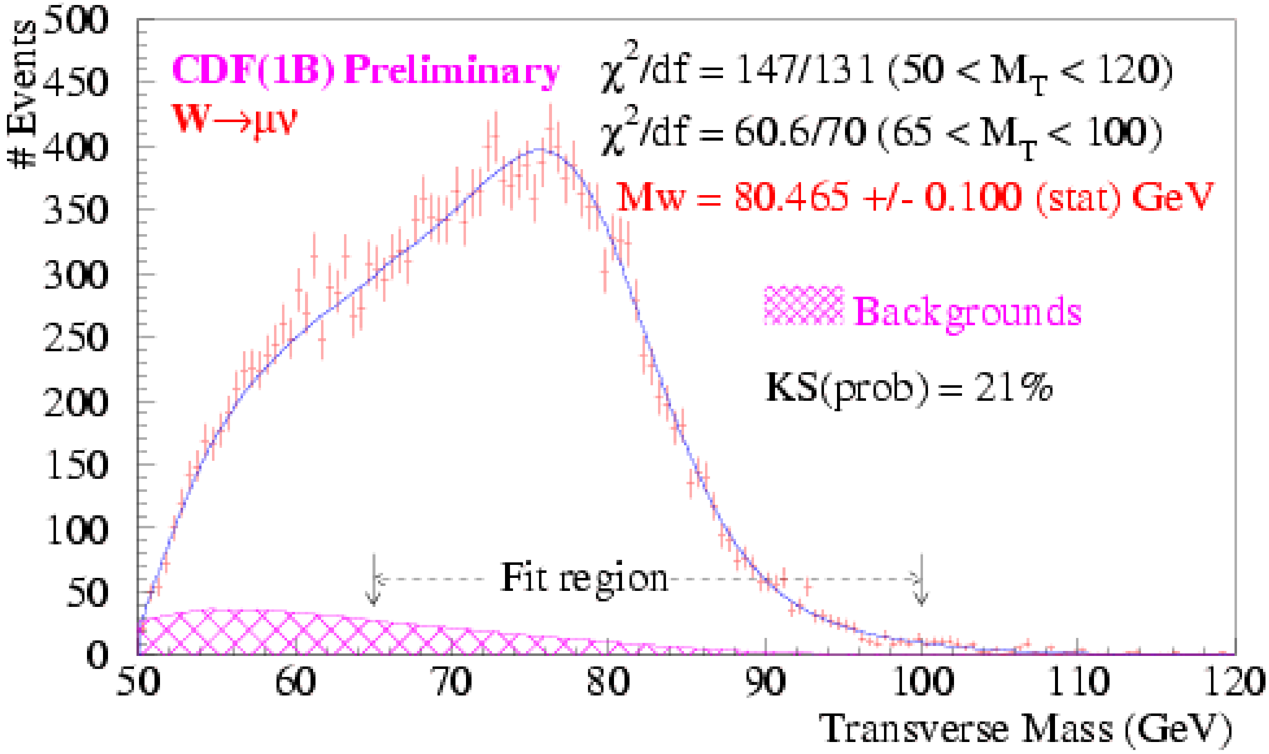


m_T^W distribution expected in ATLAS

fit experimental distributions with Monte Carlo samples with different values of m_W → find m_W which best fits data

CDF data :

$W \rightarrow \mu\nu$ transverse mass



From fit to transverse mass distribution:

$m_W = 80.465 \pm 0.100$ GeV

Uncertainties on m_W

Statistical error negligible → dominated by systematics (mainly Monte Carlo reliability to reproduce real life):

- detector performance: lepton energy resolution, lepton energy scale, recoil modeling, etc.
- physics: p_T^W, θ_W, Γ_W, structures functions, background, etc.

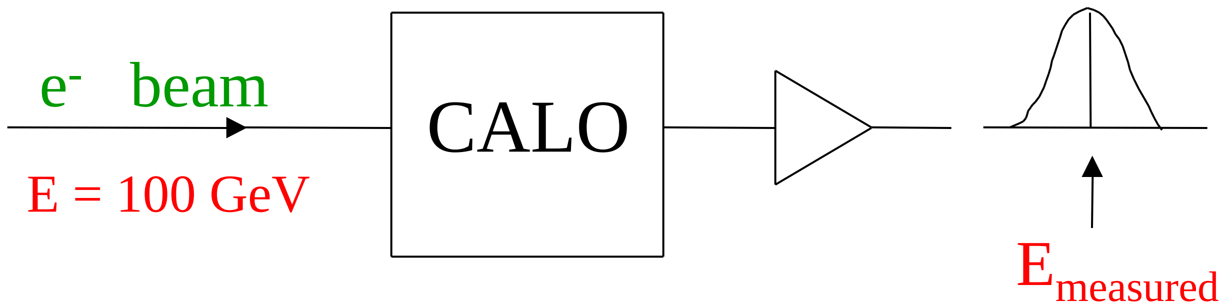
Constrained *in situ* by using mainly $Z \to \ell\ell$ decays (1 Hz at low L per ℓ) :

e.g. calibrate the electron energy scale in the EM calorimeter requiring $m_{ee} = m_Z$

Dominant error (today at Tevatron, also at LHC): knowledge of lepton energy scale of the detector: if lepton energy scale wrong by 1%, then measured m_W wrong by 1% → to achieve $\Delta m_W \approx 20$ MeV (~ 0.2‰) need to know lepton scale to ≈ 0.2 ‰ → most serious experimental challenge

Calibration of detector energy scale

Example : EM calorimeter



- if $E_{measured}$ = 100.000 GeV → calorimeter is perfectly calibrated
- if $E_{measured}$ = 99, 101 GeV → energy scale known to 1%

- to measure m_W to ~ 20 MeV need to know energy scale to 0.2 ‰ , i.e.

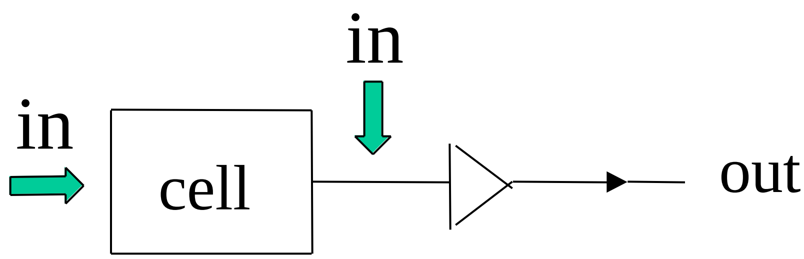
  if $E_{electron}$ = 100 GeV then

  99.98 GeV < $E_{measured}$ < 100.02 GeV

one of most serious experimental challenges

Calibration strategy:

- detectors equipped with calibration systems which inject known pulses:



→ check that all cells give same response: if not → correct

- calorimeter modules calibrated with test beams of known energy → set the energy scale

- inside LHC detectors: calorimeter sits behind inner detector → electrons lose energy in material of inner detector → need a final calibration " *in situ* " by using physics samples:

e.g. $Z \to e^+ e^-$ decays 1/sec at low L

constrain $m_{ee} = m_Z$

reconstructed (↑ m_{ee})

known to ≈ 10^{-5} from LEP (↖ m_Z)

Expected precision on m_W at LHC

Source of uncertainty	Δm_W
Statistical error	<< 2 MeV
Physics uncertainties (p_T^W, θ_W, Γ_W, …)	~ 15 MeV
Detector performance (energy resolution, lepton identification, etc,)	< 10 MeV
Energy scale	15 MeV
Total (per experiment, per channel)	~ 25 MeV

Combining both channels ($e\nu$, $\mu\nu$) and both experiments (ATLAS, CMS), $\Delta m_W \approx 15$ MeV should be achieved.
However: very difficult measurement

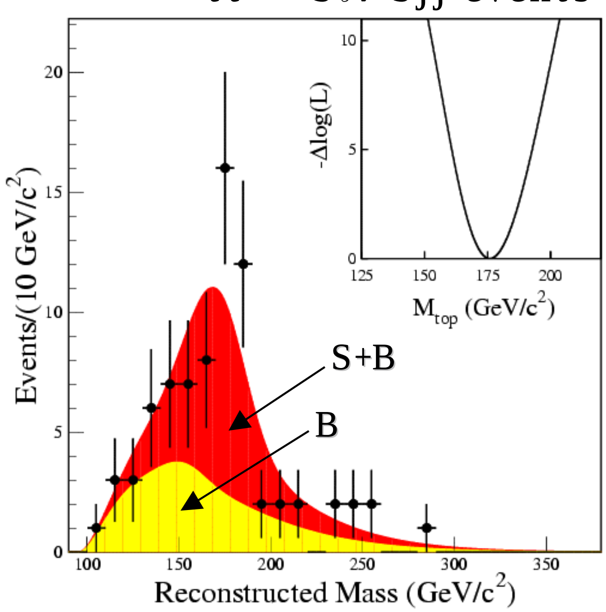
Measurement of m_{top}

- Top is most intriguing fermion:
  - -- $m_{top} \approx 174$ GeV → clues about origin of particle masses ?
  - -- $\Gamma_{top} \approx 1.8$ GeV → decays before hadronising
  - -- $\begin{pmatrix} u \\ d \end{pmatrix}$ $\begin{pmatrix} c \\ s \end{pmatrix}$ $\begin{pmatrix} t \\ b \end{pmatrix}$ ← Δm (t-b) ≈ 170 GeV → radiative corrections

- Discovered in '94 at Tevatron → precise measurements of mass, couplings, etc. just started

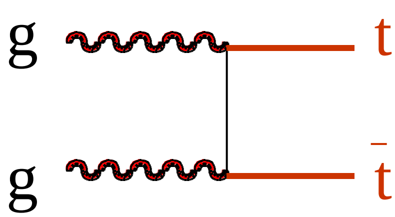
Top mass spectrum from CDF

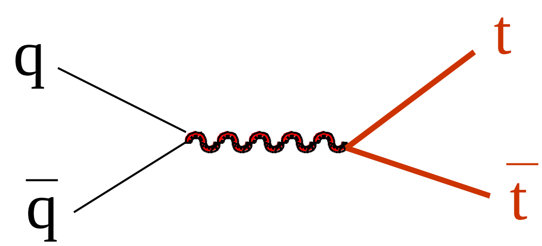
$t\bar{t} \to b\ell\nu\, bjj$ events



Top production at LHC:

e.g.





$\sigma\,(pp \rightarrow t\bar{t} + X) \approx$ 800 pb

⬇

10^7 $t\bar{t}$ pairs produced in one year at low L

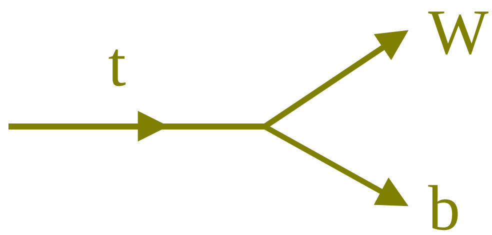
~ 10^2 times more than at Tevatron

⬇

measure m_{top}, σ_{tt}, BR, V_{tb}, single top, rare decays (e.g. $t \rightarrow Zc$), resonances, etc.

$t\bar{t}$ production is the main background to new physics (SUSY, Higgs)

Top decays:



BR ≈ 100% in SM

-- hadronic channel: both W → jj
6 jet final states. BR ≈ 50 % but large QCD multijet background.

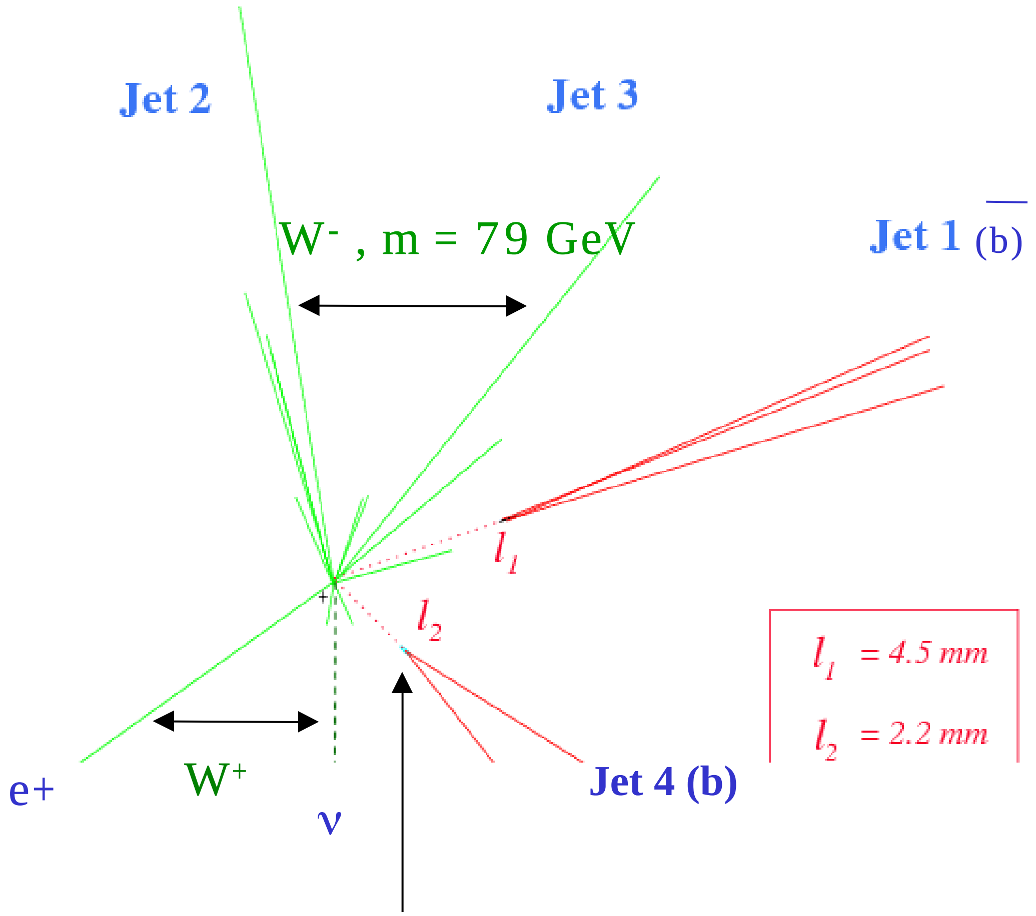
-- leptonic channel: both W → $\ell\nu$
2 jets + 2ℓ + E_T^{miss} final states. BR ≈ 10 %.
Little kinematic constraints to reconstruct mass.

-- semileptonic channel: one W → jj , one W → $\ell\nu$
4 jets + 1ℓ + E_T^{miss} final states. BR ≈ 40 %.
If ℓ = e, μ : gold-plated channel for mass measurement at hadron colliders.

In all cases two jets are b-jets → displaced vertices in the inner detector

Example from CDF data :

$t\bar{t} \rightarrow Wb\,Wb \rightarrow b\ell\nu\,bjj$ event

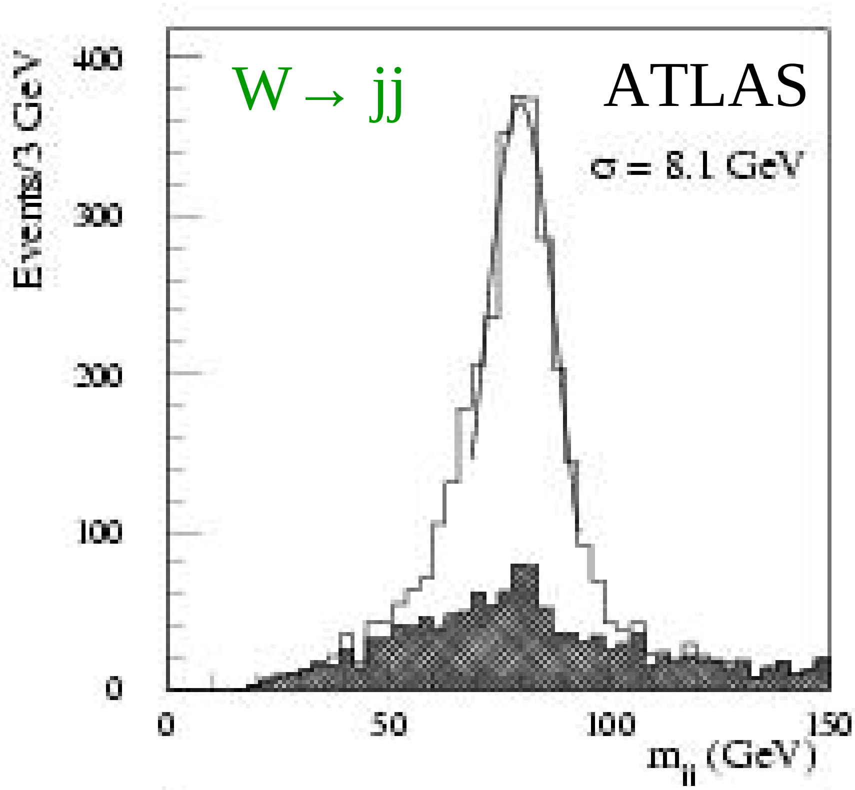


Secondary vertices

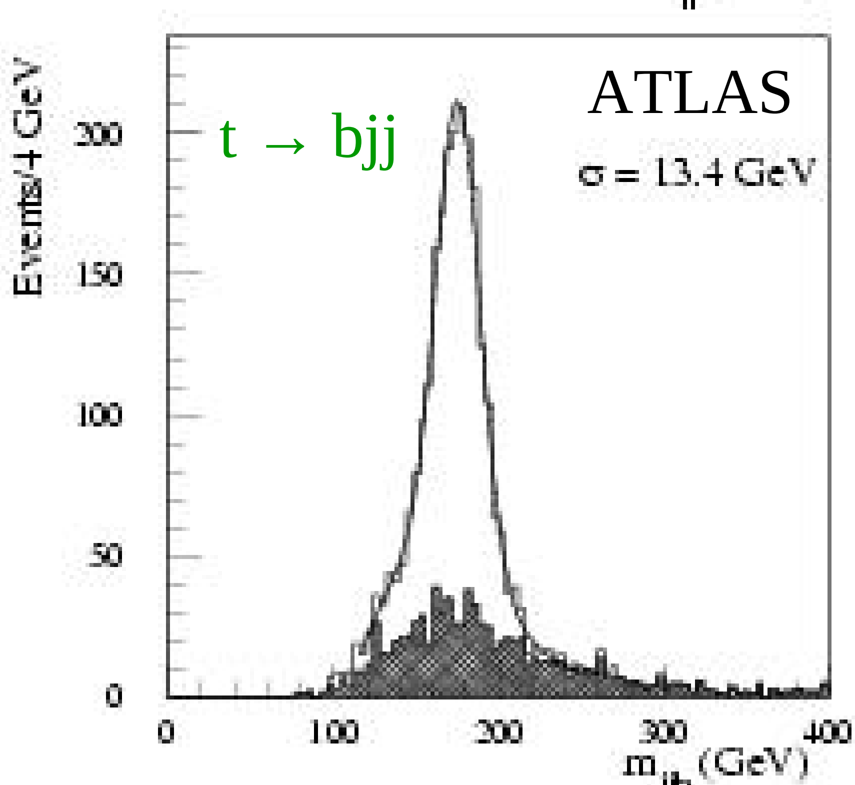
τ (b-hadrons) ~ 1.5 ps → decay
at few mm from primary vertex
Detected with high-granularity
Si detectors (b-tagging)

Selection of $t\bar{t} \rightarrow bW\,bW \rightarrow b\,\ell\nu\,bjj$

Require:
- -- two b-tagged jets
- -- one lepton $p_T > 20$ GeV
- -- $E_T^{miss} > 20$ GeV
- -- two more jets



Then require:
- -- $|m_{jj}-m_W| < 20$ GeV
- -- combine jj with b-jets. Choose combination which gives highest p_T top



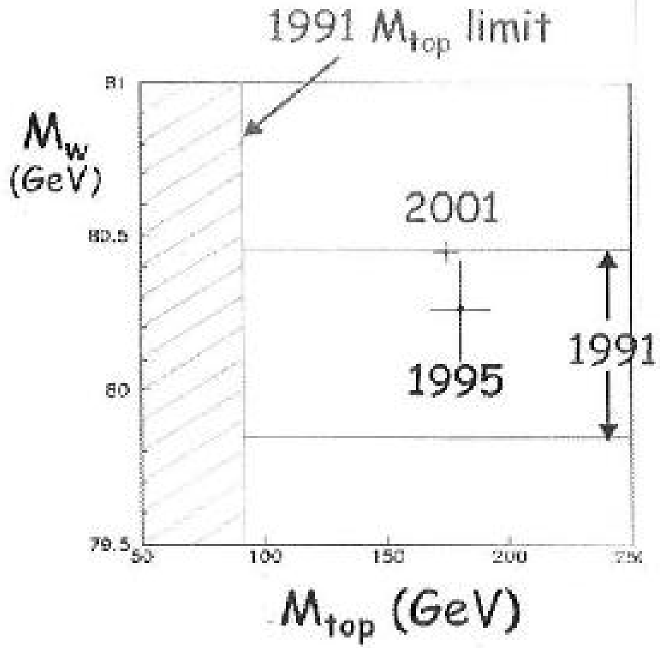
Note : W → jj can be used to calibrate jet energy scale

Expected precision on m_{top} at LHC

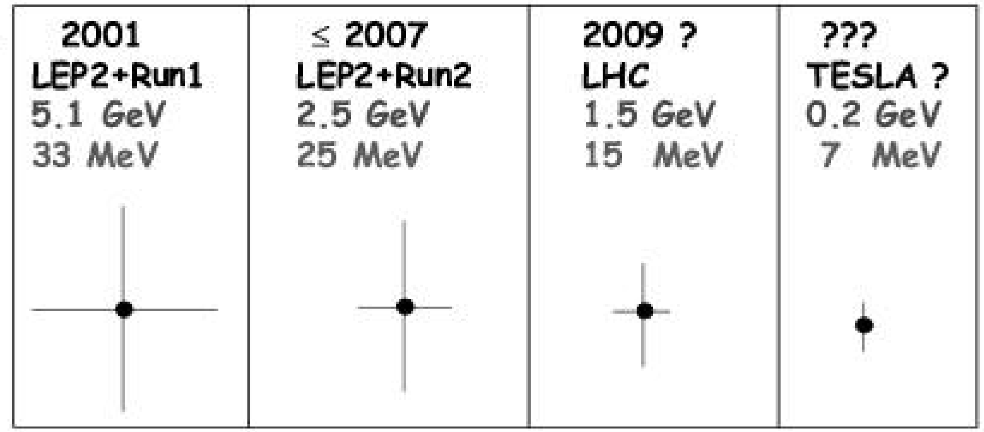
Source of uncertainty	Δm_{top}
Statistical error	<< 100 MeV
Physics uncertainties (background, FSR, ISR, fragmentation, etc.)	~ 1.3 GeV
Jet scale (b-jets, light-quark jets)	~ 0.8 GeV
Total (per experiment, per channel)	~ 1.5 GeV

Uncertainty dominated by the knowledge of physics and not of detector.

The last ~ 10 years ...



... and the future



⬇ $\frac{\Delta m_H}{m_H}$

~ 50%	~ 35%	~ 25%	~ 10%

If Higgs discovered → comparison of measured m_H with indirect measurement
→ important consistency checks of EWSB

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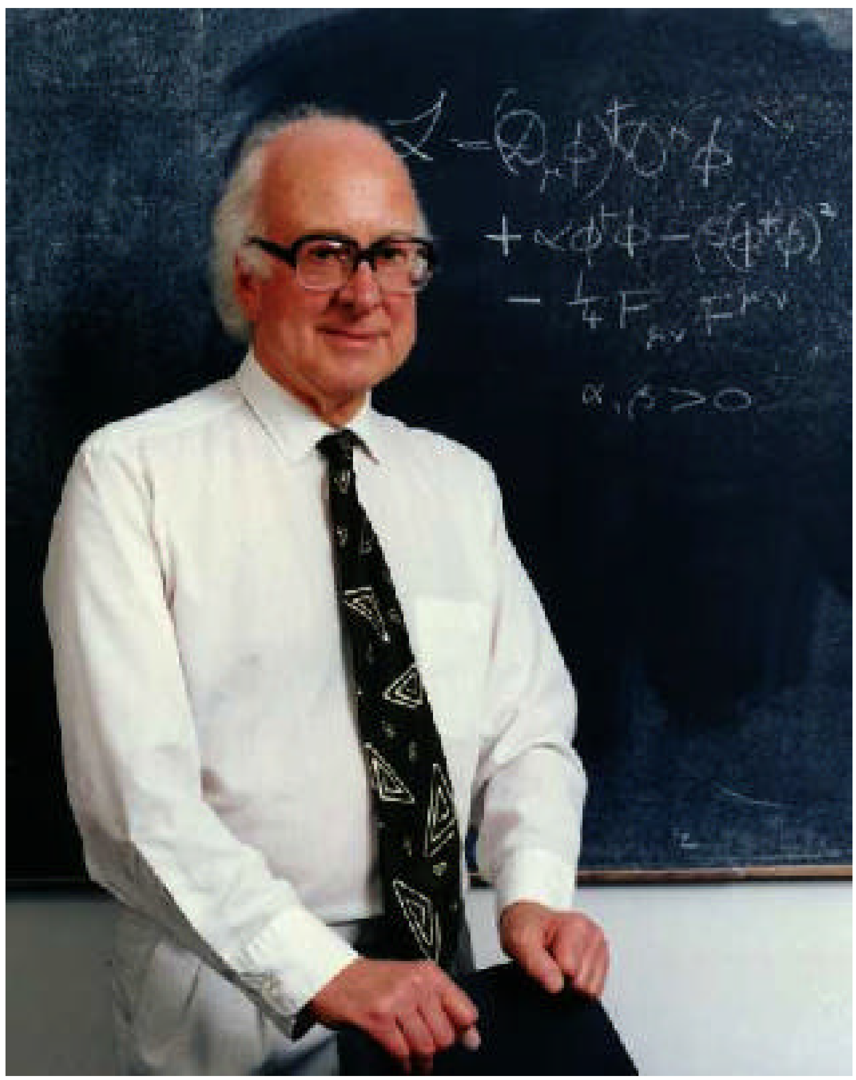
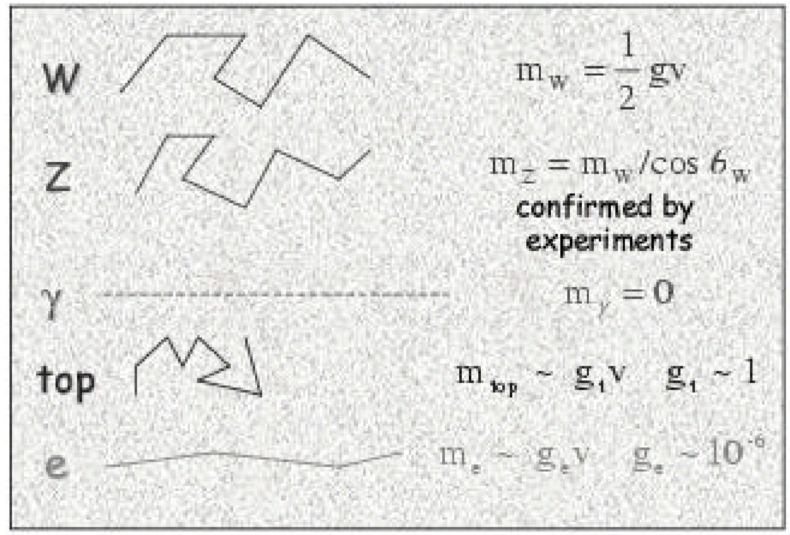
Searches for the Standard Model Higgs boson



What do we know today ?

- Needed in SM to generate particle masses
  (i.e. to explain EW symmetry breaking) :
  -- Higgs field fills vacuum
  -- vacuum ground state : $v \approx 250$ GeV $\neq 0$
  -- particles interact with non-empty vacuum
  $\rightarrow$ get mass
  -- the stronger the interaction the larger the mass



- Higgs couplings to fermions and bosons :

$\Rightarrow$ $H \rightarrow bb$ dominates for $m_H < 120$ GeV

- Higgs mass not predicted. Today we know:
  -- 114.1 GeV (from LEP) < m_H < 1000 GeV (from theory)
  -- EW data prefer light Higgs ($\leq$ 200 GeV)
  -- LEP " hint " for $m_H \sim 115$ GeV ?

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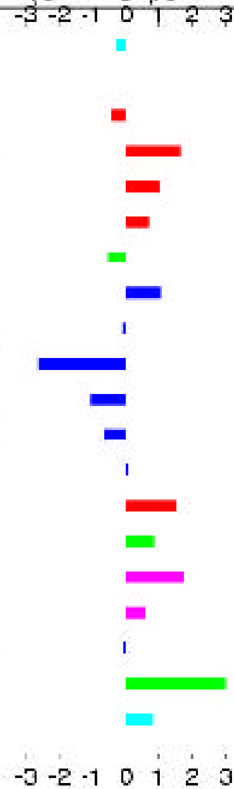
Global fit of the SM to data

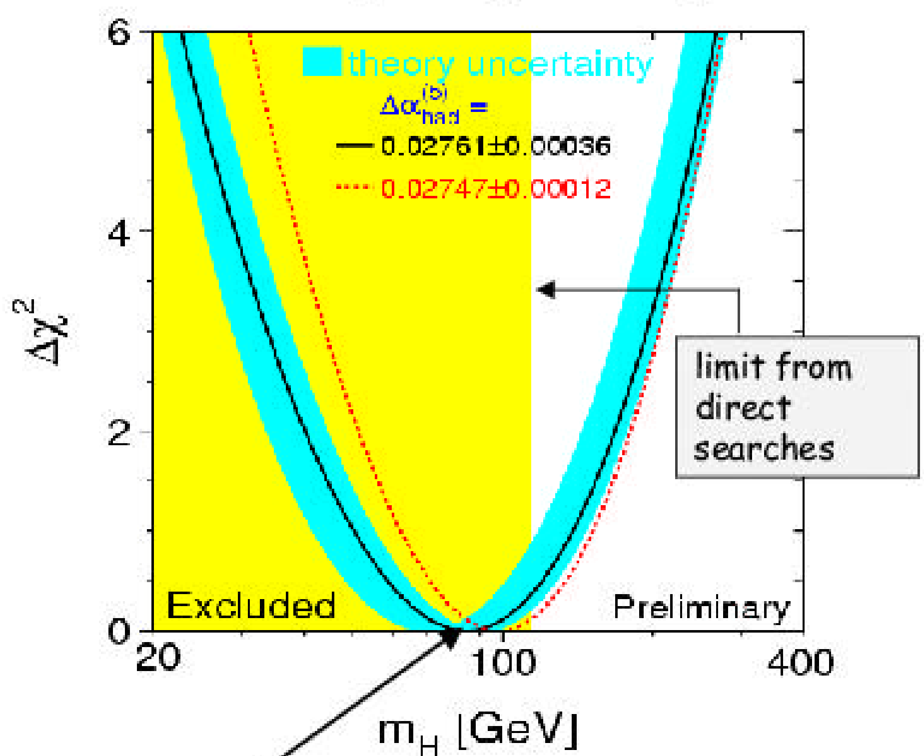
Winter 2002 preliminary

	Measurement	Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.27
m_Z [GeV]	91.1875 ± 0.0021	.01
Γ_Z [GeV]	2.4952 ± 0.0023	-.42
σ^0_{had} [nb]	41.540 ± 0.037	1.63
R_l	20.767 ± 0.025	1.05
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.70
$A_l(P_\tau)$	0.1465 ± 0.0033	.53
R_b	0.21646 ± 0.00065	1.06
R_c	0.1719 ± 0.0031	-.11
$A^{0,b}_{fb}$	0.0994 ± 0.0017	-2.64
$A^{0,c}_{fb}$	0.0707 ± 0.0034	-1.05
A_b	0.922 ± 0.020	-.64
A_c	0.670 ± 0.026	.06
A_l(SLD)	0.1513 ± 0.0021	1.50
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	.86
m_W [GeV]	80.451 ± 0.033	1.73
Γ_W [GeV]	2.134 ± 0.069	.59
m_t [GeV]	174.3 ± 5.1	-.08
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	3.00
$Q_W(Cs)$	-72.39 ± 0.59	.84



from NuTeV (νN scattering)

→ deduce m_H which gives best χ^2



$m_H^{EW} = 85^{+54}_{-34}$ GeV

$m_H^{EW} < 196$ GeV 95% C.L.

} radiative corrections ~ log m_H

Largest discrepancies (two observables): $\leq 3\sigma$

$P(\chi^2) \sim 2\%$ all

$P(\chi^2) \sim 14\%$ without NuTeV

(affected by some theoretical uncertainties)

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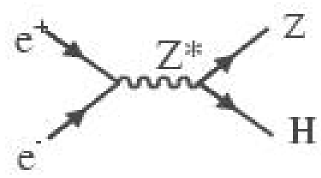
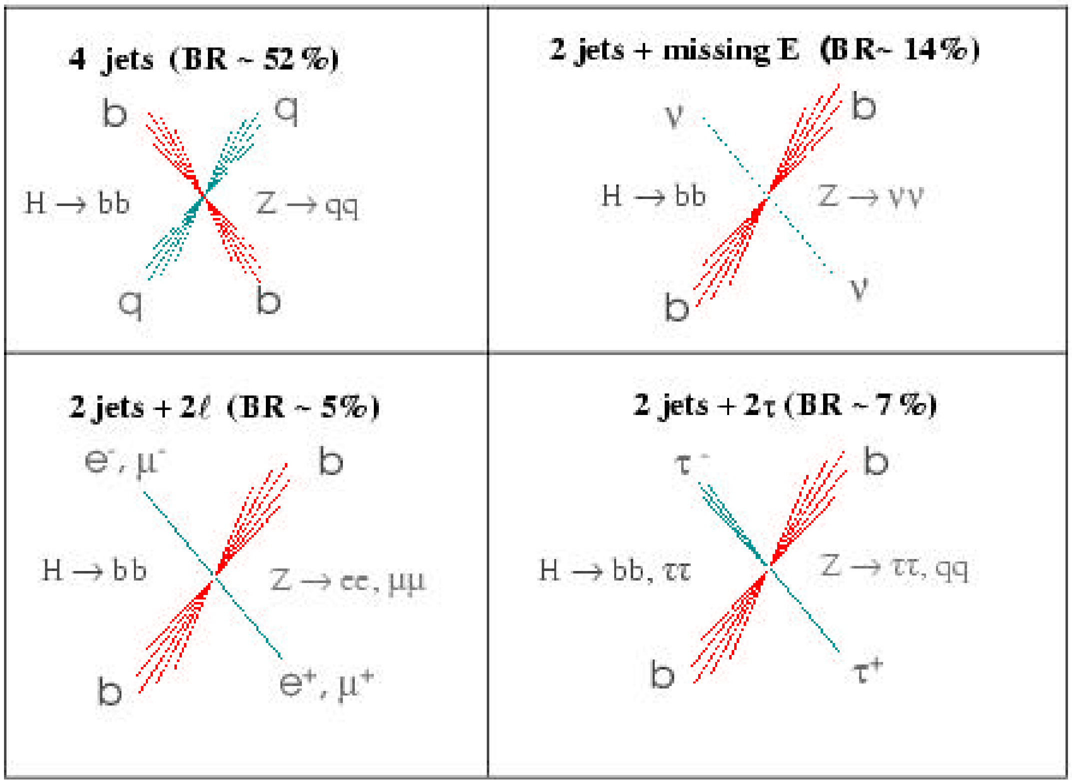
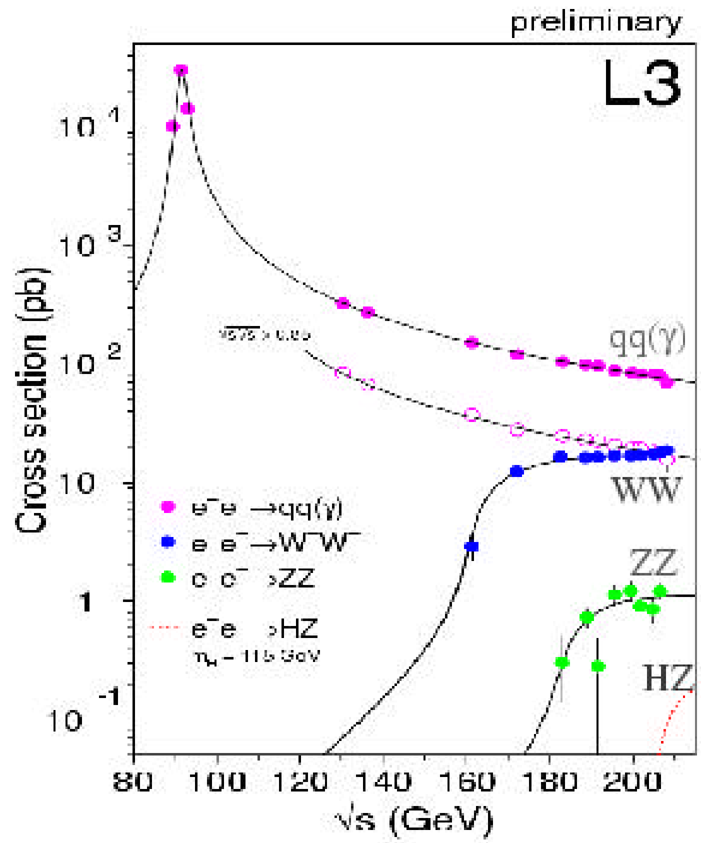
Direct Higgs searches at LEP2

$\sqrt{s} \to 209$ GeV



$m_H + m_Z < \sqrt{s} \to$ LEP sensitive up to $m_H \approx 116$ GeV





Main handles to reject background : b-tagging , presence of Z, m_H is large, etc...

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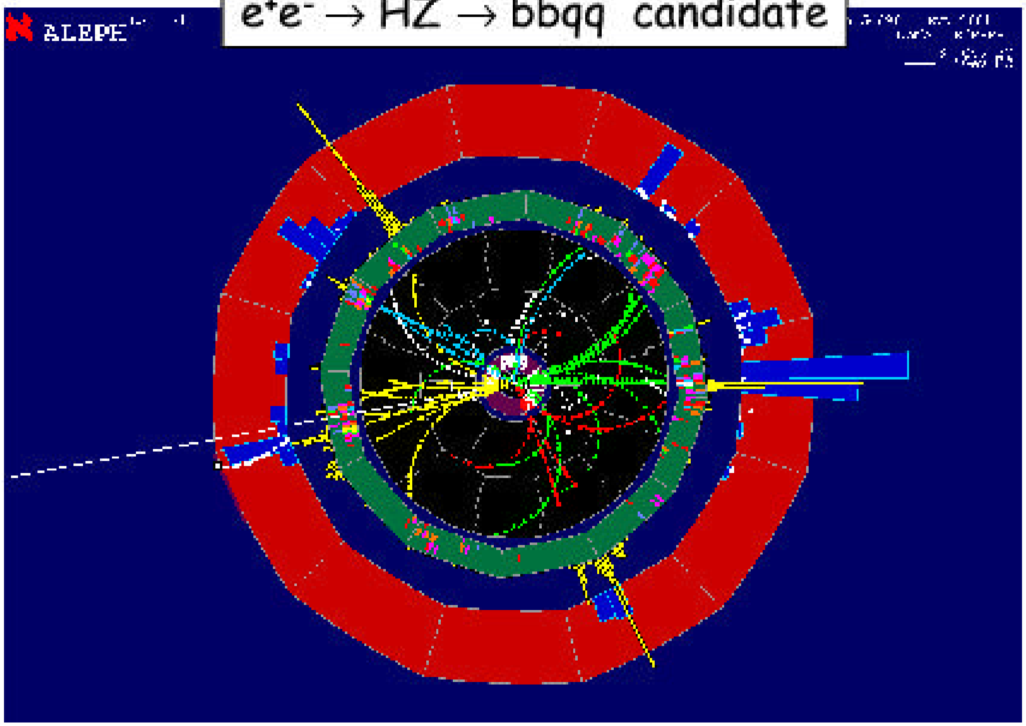
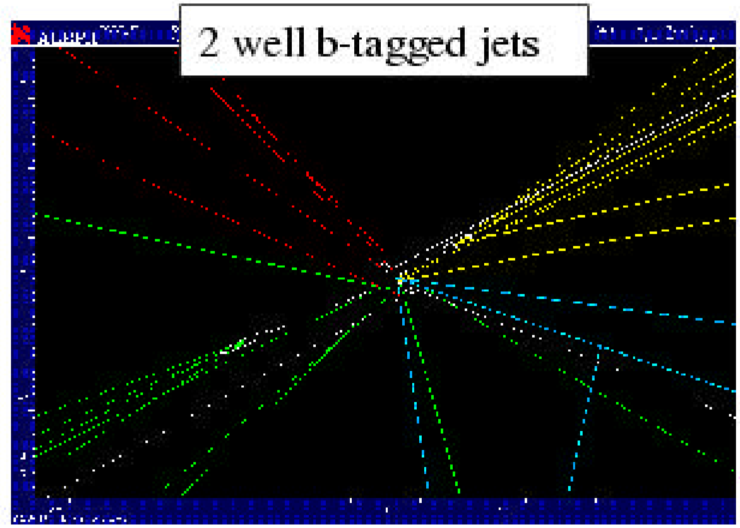
In year 2000 (last year of LEP)

A few Higgs-like events, compatible with m_H ~115 GeV, observed

Best candidate : collected by ALEPH on 14/6/2000 at $\sqrt{s}$ = 206.7 GeV

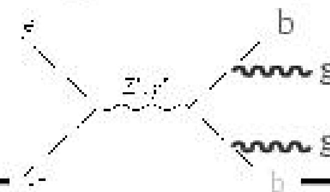




$m(j_1, j_2) = 92.1$ GeV

$m_H(j_3, j_4) = 114.3 \pm 3$ GeV

Background interpretation: bbgg



P ~ 1%

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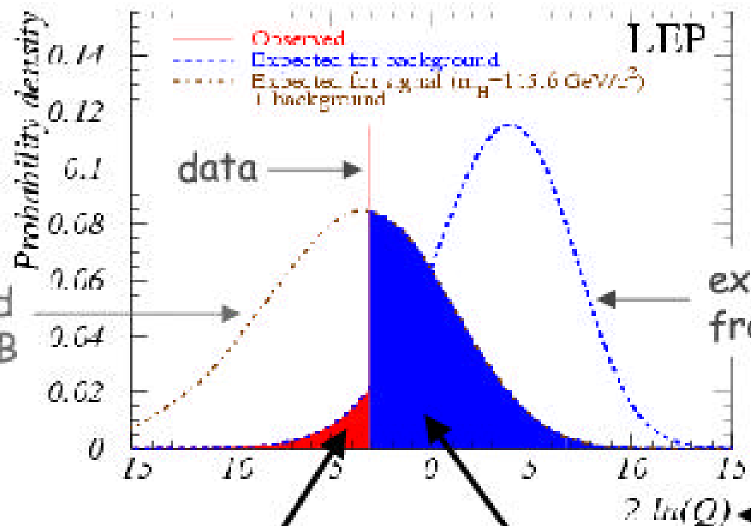
A ≈ 2σ excess ....



variable related to event features (e.g. b-tagging)

probability of B fluctuation : 3.5%
→ ~ 2σ excess

probability of S+B : 43%
Note : consistent with expectation for signal with $m_H \sim 115$ GeV

not enough to claim discovery
need 5σ, i.e. P (B fluctuation) ~ 10^{-7}

Mass lower limit :
$m_H > 114.1$ GeV 95% C.L.

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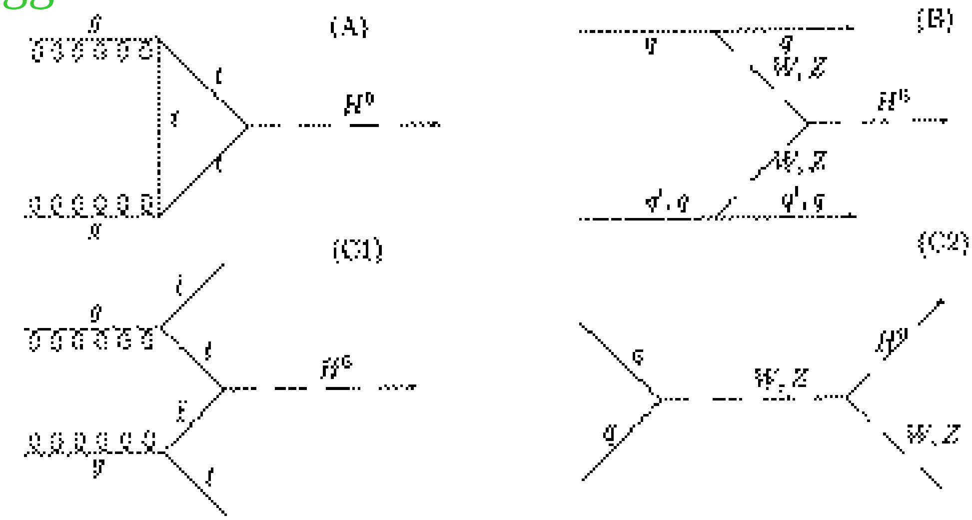
Higgs production at LHC

gg fusion

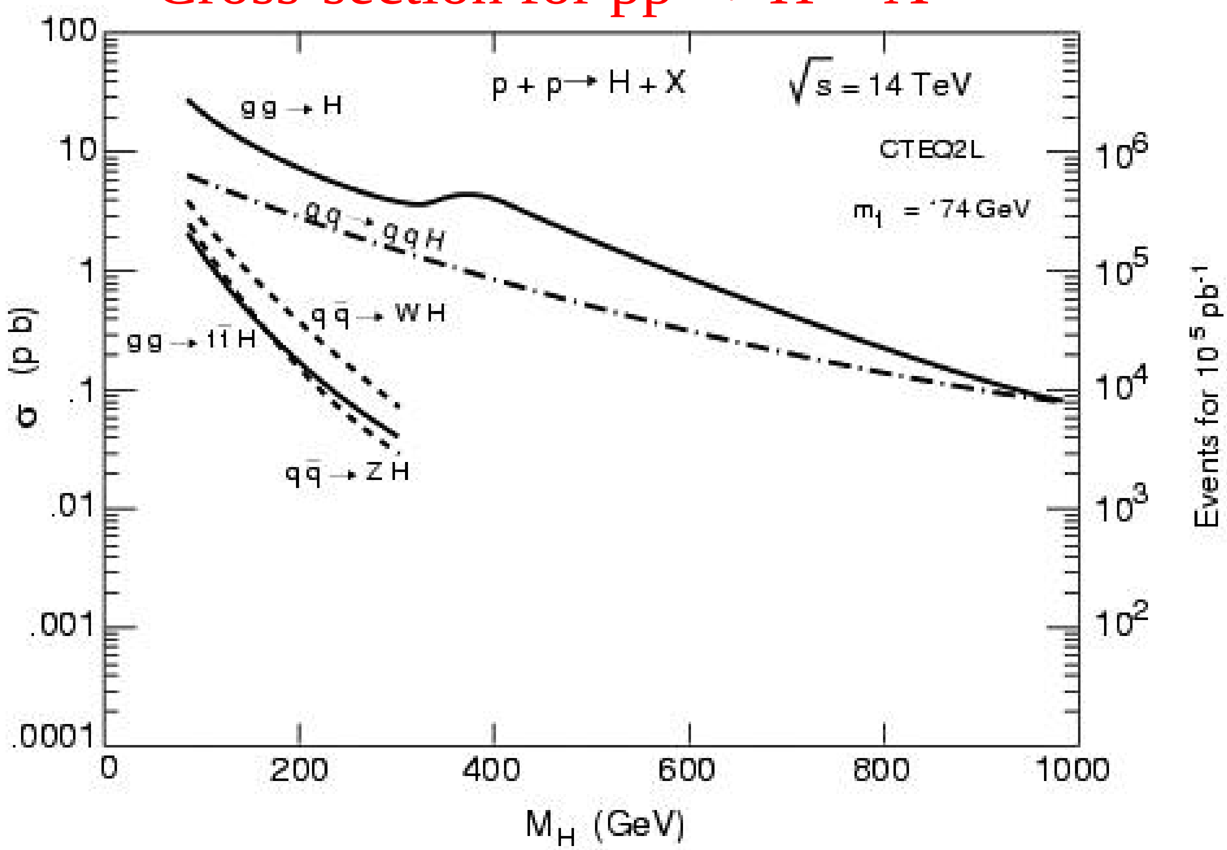
WW/ZZ fusion



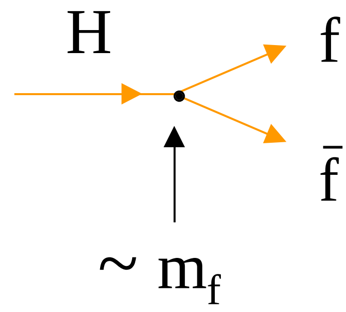
associated $t\bar{t}H$

associated WH, ZH

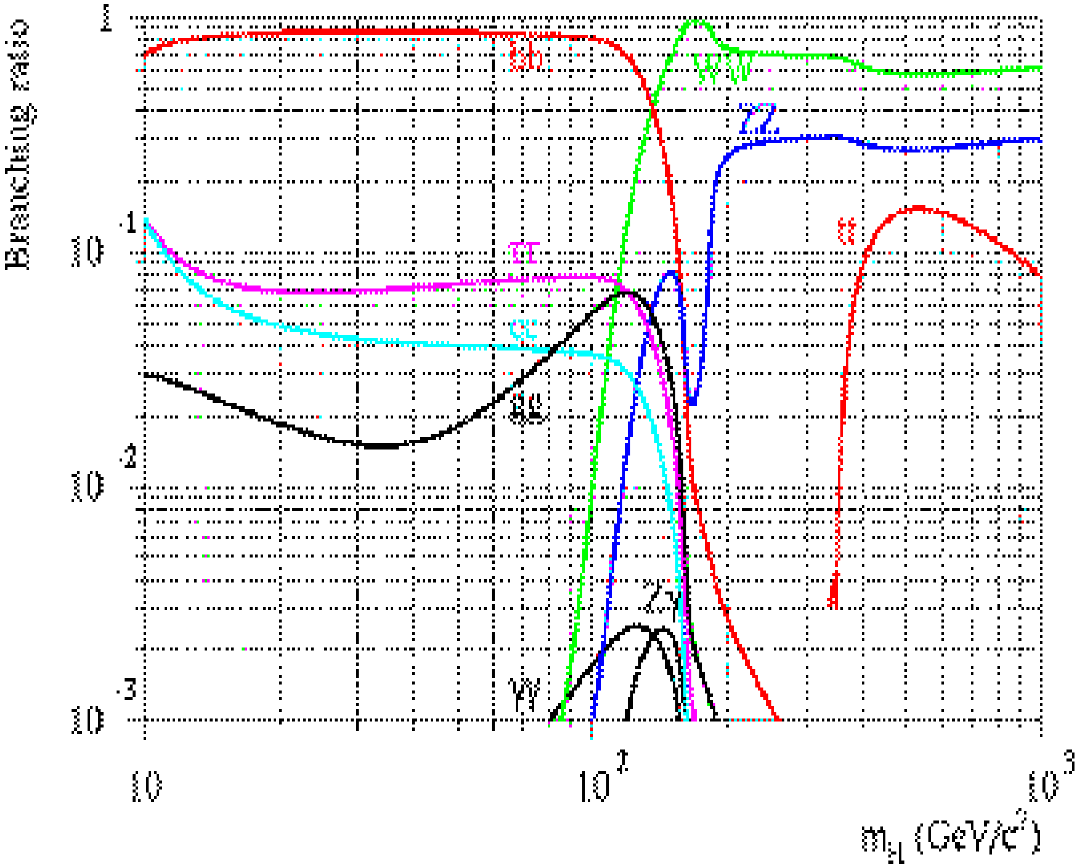
Cross-section for pp $\rightarrow$ H + X



Higgs decays



Decay branching ratios (BR)



- m_H < 120 GeV: H → $b\bar{b}$ dominates
- 130 GeV < m_H < 2 m_Z : H → $WW^{(*)}$, $ZZ^{(*)}$ dominate
- m_H > 2 m_Z : 1/3 H → ZZ
  2/3 H → WW
- important rare decays : H → γγ

N. B.: $\Gamma_H \sim m_H^3$ Γ_H ~ MeV (100 GeV) m_H ~100 (600) GeV

Search strategy

Fully hadronic final states dominate but cannot be extracted from large QCD background → look for final states with leptons and photons (despite smaller BR).

Main channels:

- Low mass region (m_H < 150 GeV):

-- H → $b\bar{b}$: BR ~ 100% → σ ≈ 20 pb

however: huge QCD background ($N_S/N_B < 10^{-5}$)

→ can only be used with additional leptons:
W H → $\ell\nu\, b\bar{b}$, $t\bar{t}$ H → $\ell\nu X\, b\bar{b}$ associated production
(σ ≈ 1 pb)

-- H → γγ: BR ~ 10^{-3} → σ ≈ 50 fb
however: clean channel ($N_S/N_B \approx 10^{-2}$)

- Intermediate mass region (120 GeV $\leq m_H \leq 2\, m_Z$):

-- $H \rightarrow WW^* \rightarrow \ell\nu\ \ell\nu$
-- $H \rightarrow ZZ^* \rightarrow \ell\ell\ \ell\ell$

~ only two channels which can be extracted from background

- High mass region ($m_H > 2\, m_Z$):

-- $H \rightarrow ZZ \rightarrow \ell\ell\ \ell\ell$

gold-plated channel (~ no background) !

-- $H \rightarrow ZZ \rightarrow \ell\ell\ \nu\nu$, $\ell\nu$ jet jet
-- $H \rightarrow WW \rightarrow \ell\nu$ jet jet

} larger BR $\rightarrow$ increase rate for $m_H > 500$ GeV

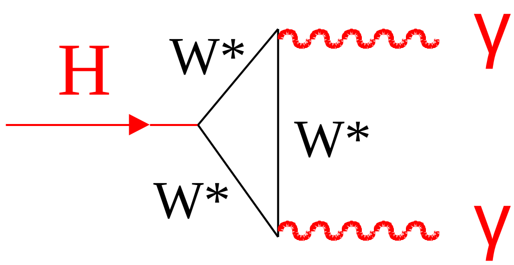
This mass region is disfavoured by EW data (SM internal consistency if Higgs is so heavy ?)

Only two examples discussed here :

$H \rightarrow \gamma\gamma$
$H \rightarrow 4\ell$

$H \to \gamma\gamma$

$m_H \lesssim 150$ GeV



$\sigma \times BR \approx 50$ fb
$m_H \approx 100$ GeV

- Select events with two photons in the detector with $p_T \sim 50$ GeV
- Measure energy and direction of each photon
- Measure invariant mass of photon pair

$$m_{\gamma\gamma} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

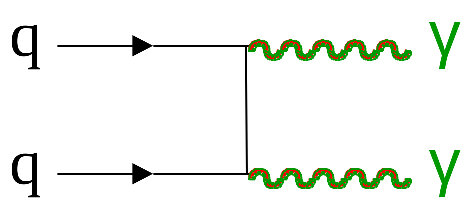
- Plot distribution of $m_{\gamma\gamma} \to$ Higgs should appear as a peak at m_H

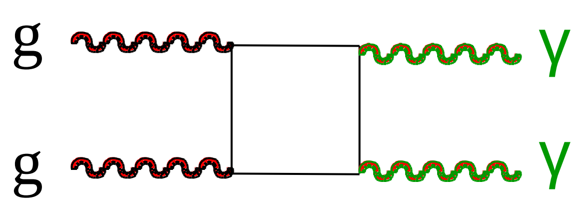
Most challenging channel for LHC electromagnetic calorimeters

Main backgrounds:

- γγ production: irreducible (i.e. same final state as signal)

  e.g. :

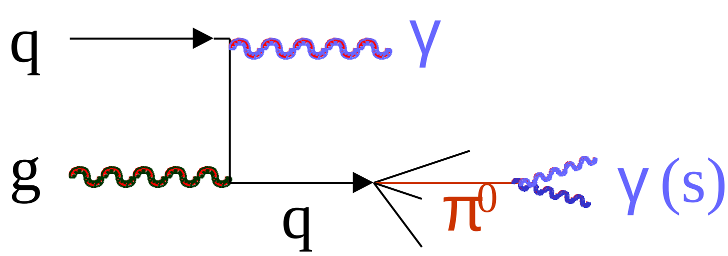




$$\frac{\sigma(\gamma\gamma)}{\sigma(H \to \gamma\gamma)} \approx 60 \qquad m_{\gamma\gamma} \sim 100 \text{ GeV}$$

- γ jet + jet jet production where one/two jets fake photons: reducible

  e.g. :



$$\frac{\sigma_{jj}}{\sigma(H \to \gamma\gamma)} \sim 10^8$$

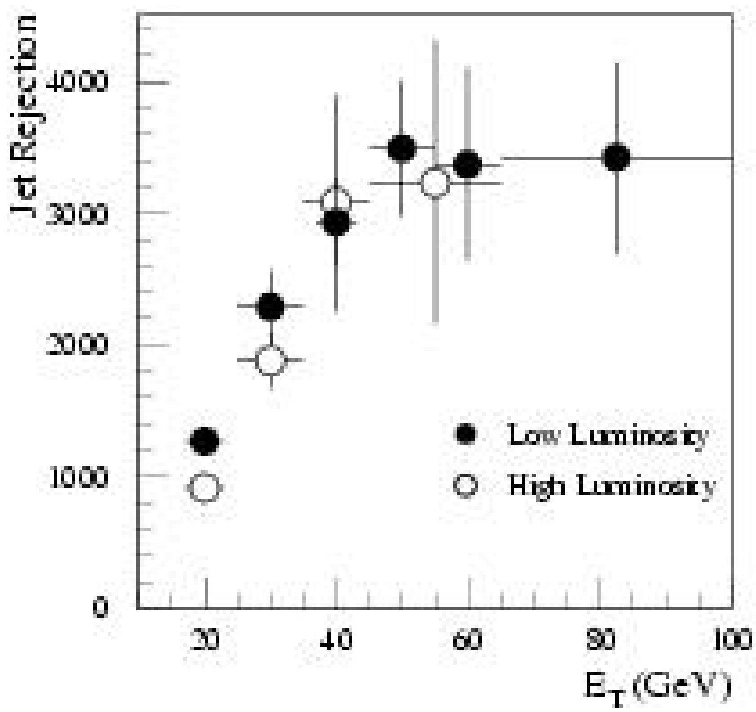
How can one fight these backgrounds ?

• Reducible γjet, jet-jet: need excellent γ/jet separation (in particular γ/π^0 separation) to reject jets faking photons

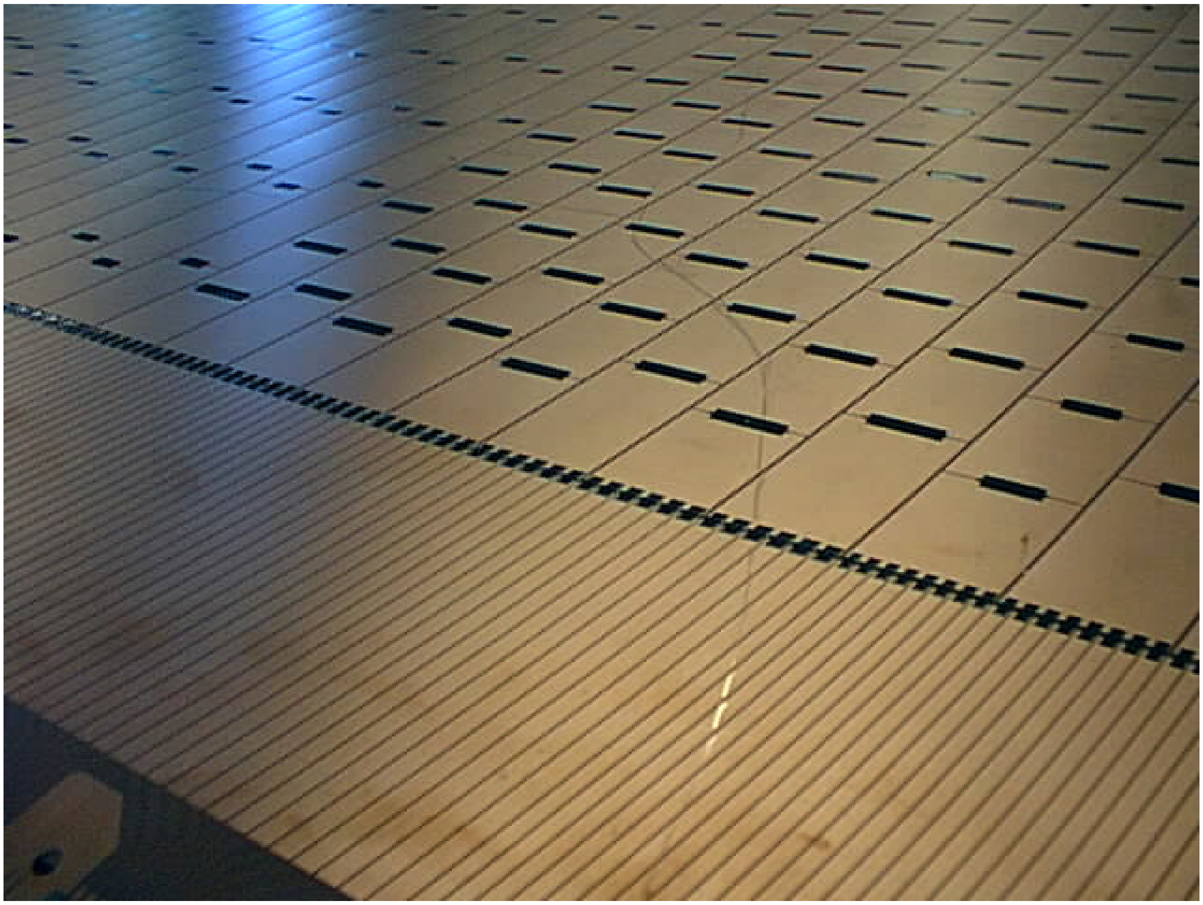
$R_{jet} \approx 10^3$ needed for $\varepsilon_\gamma \approx 80\%$

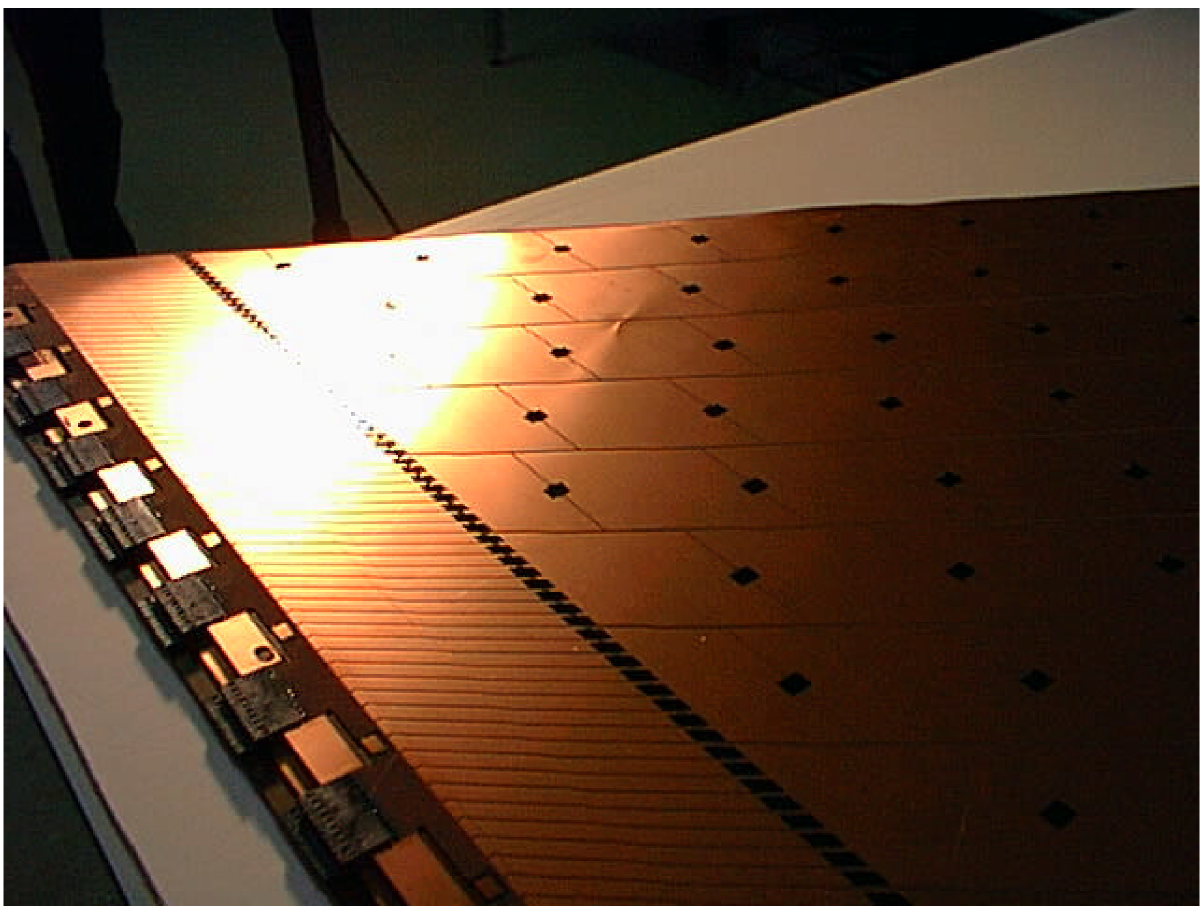
ATLAS and CMS have calorimeters with good granularity to separate single γ from jets or from $\pi^0 \rightarrow \gamma\gamma$.

Simulation of ATLAS calorimeter



With this performance : (γjet + jet-jet) ≤ 30% γγ → small





- Irreducible γγ: cannot be reduced. But signal can be extracted from background if mass resolution good enough

$$S \quad \frac{1}{\sqrt{\sigma_m}}$$

$\Gamma_H < 10$ MeV for $m_H \sim 100$ GeV

$$m_{\gamma\gamma}^{\;2} = (E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2 = 2E_1E_2(1 - \cos\theta_{12})$$

$$\frac{\sigma(m)}{m} = \frac{1}{\sqrt{2}} ¾ \frac{\sigma(E_1)}{E_1} \quad \frac{\sigma(E_2)}{E_2} \quad \frac{\sigma(\vartheta)}{tg\vartheta/2} √$$

energy resolution of EM calorimeter

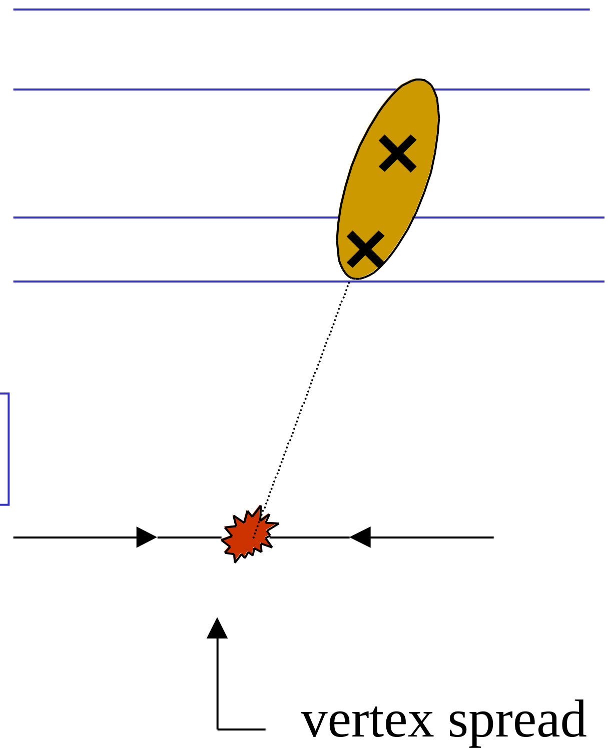
resolution of the measurement of the γ angle θ

ATLAS EM calorimeter:

- liquid-argon/lead sampling calorimeter $\frac{\sigma(E)}{E} \quad \frac{10\%}{\sqrt{E}}$

- longitudinal segmentation
  → can measure γ direction

$$\sigma(\theta) \quad \frac{50\ \text{mrad}}{\sqrt{E}}$$



$\sigma_m \approx 1.3$ GeV $m_H \sim 100$ GeV

$\varepsilon \approx 30\%$

CMS EM calorimeter:

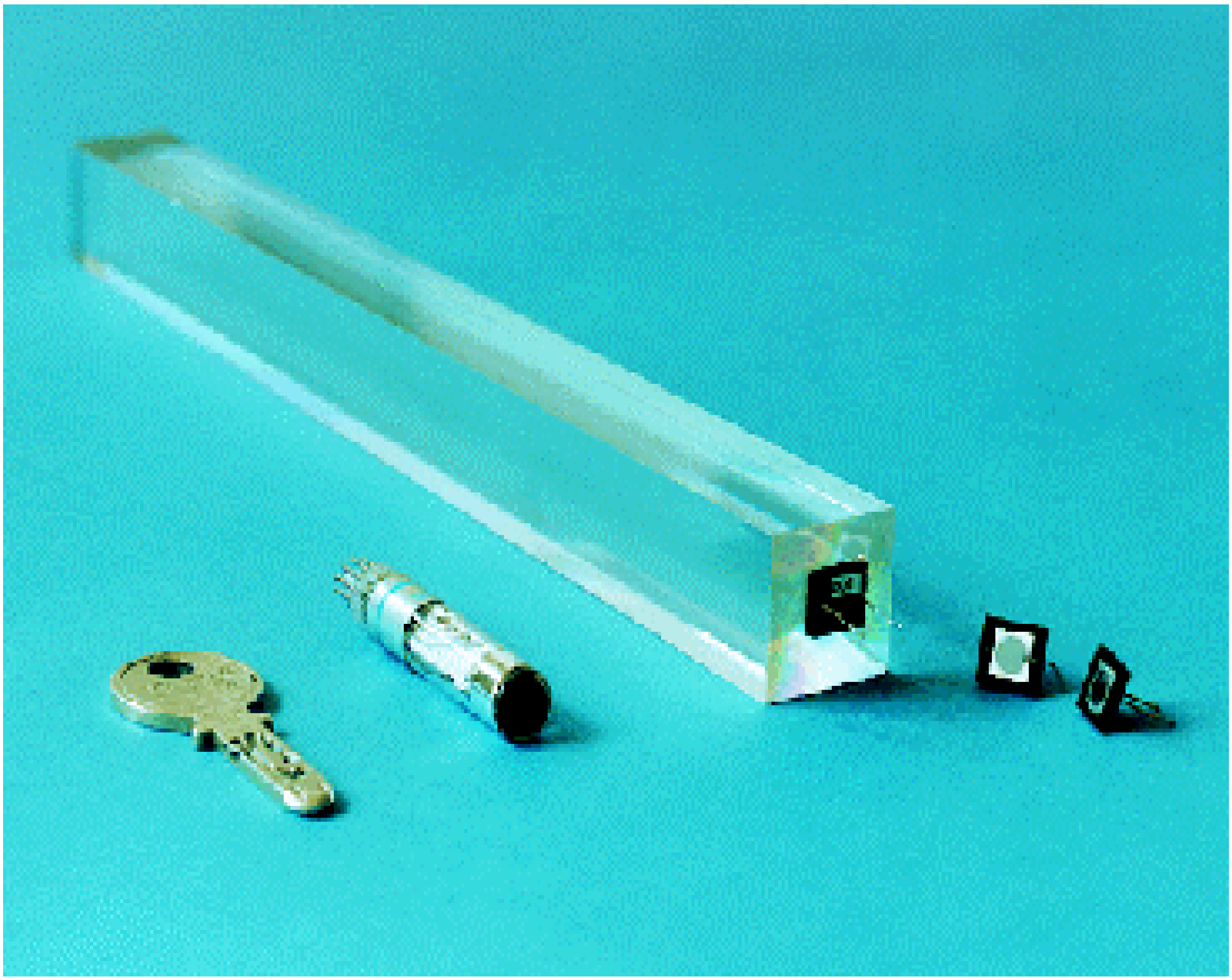
- homogeneous crystal calorimeter $\frac{\sigma(E)}{E} \quad \frac{2-5\%}{\sqrt{E}}$

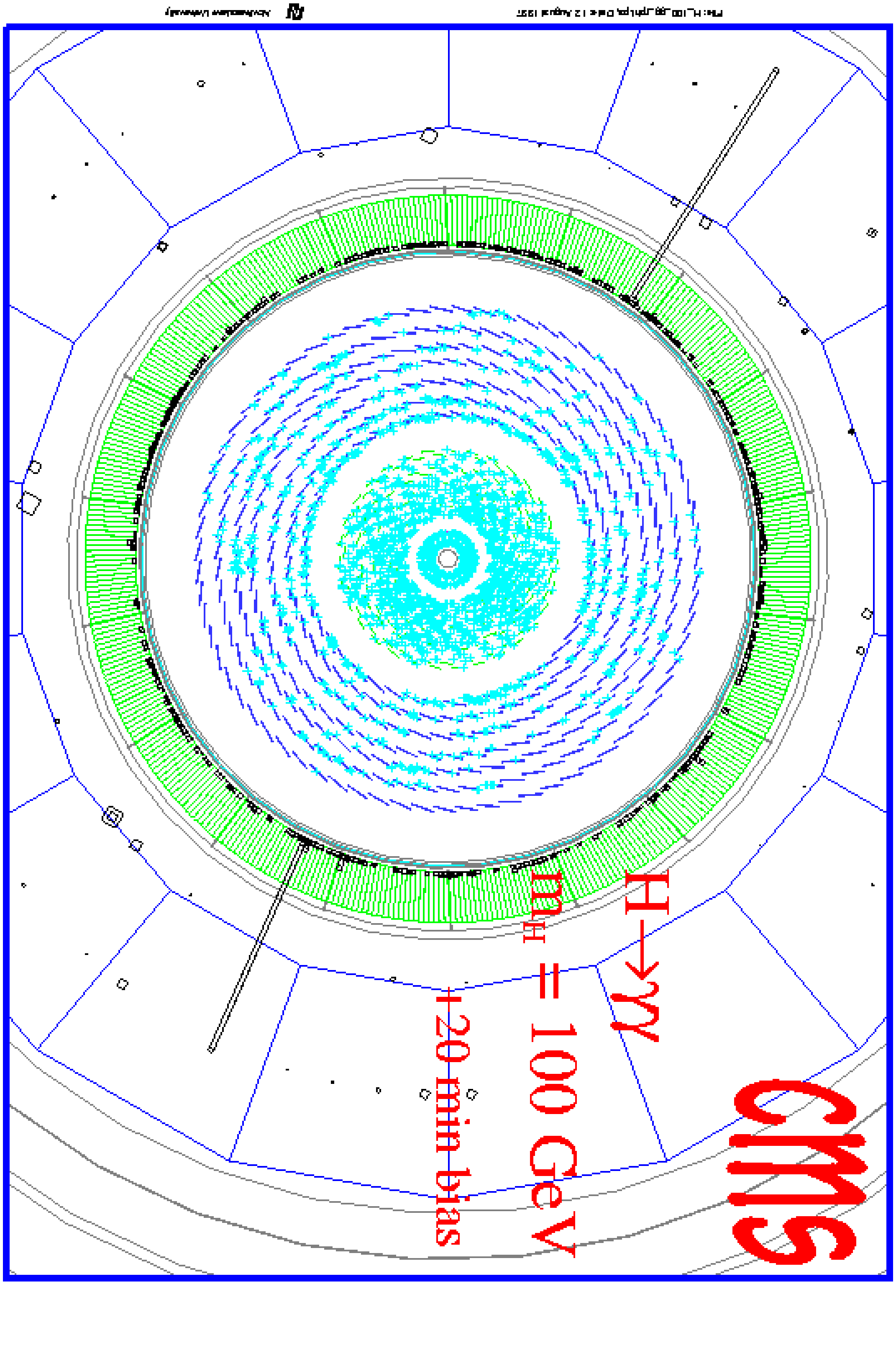
- no longitudinal segmentation → vertex measured using secondary tracks from spectator partons → difficult at high L → often pick up the wrong vertex

$\sigma_m \approx 0.7$ GeV $m_H \sim 100$ GeV

$\varepsilon \approx 20\%$

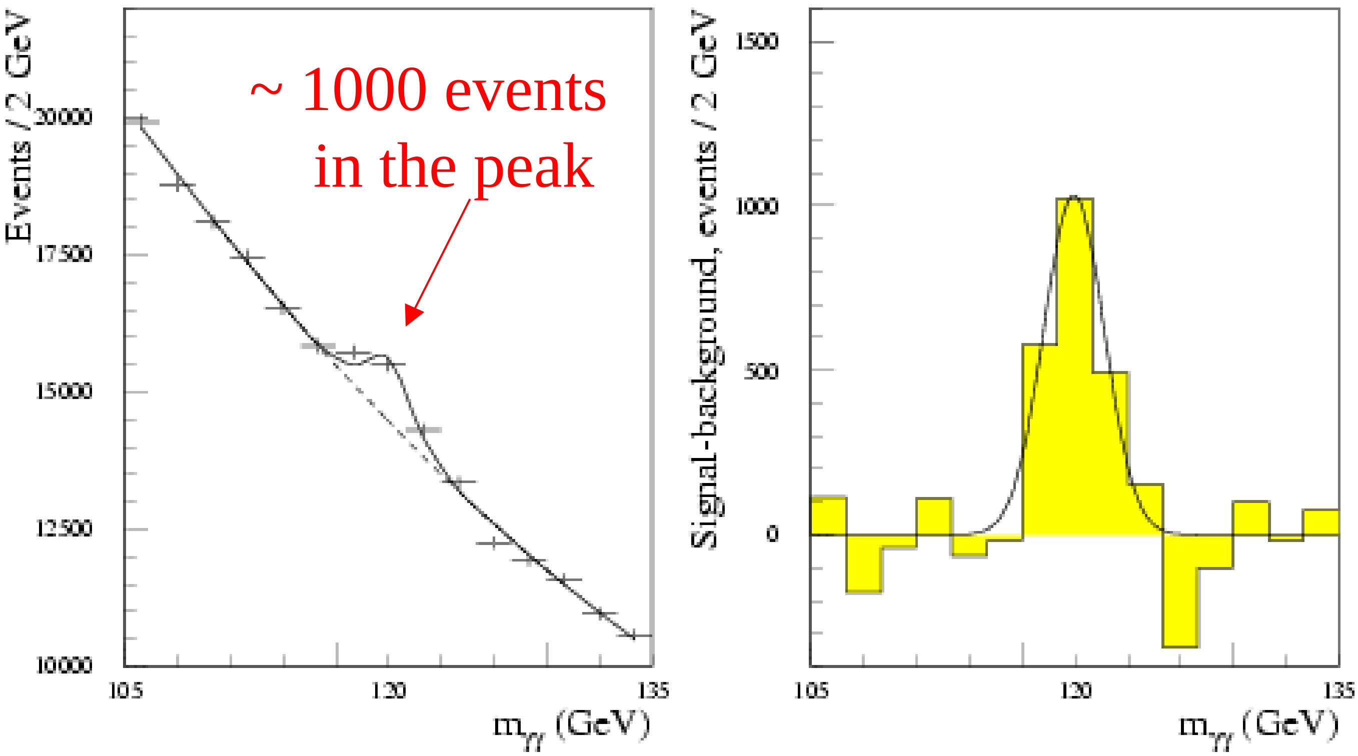
CMS crystal calorimeter




CMS
H→γγ
m_H = 100 GeV
+20 min bias

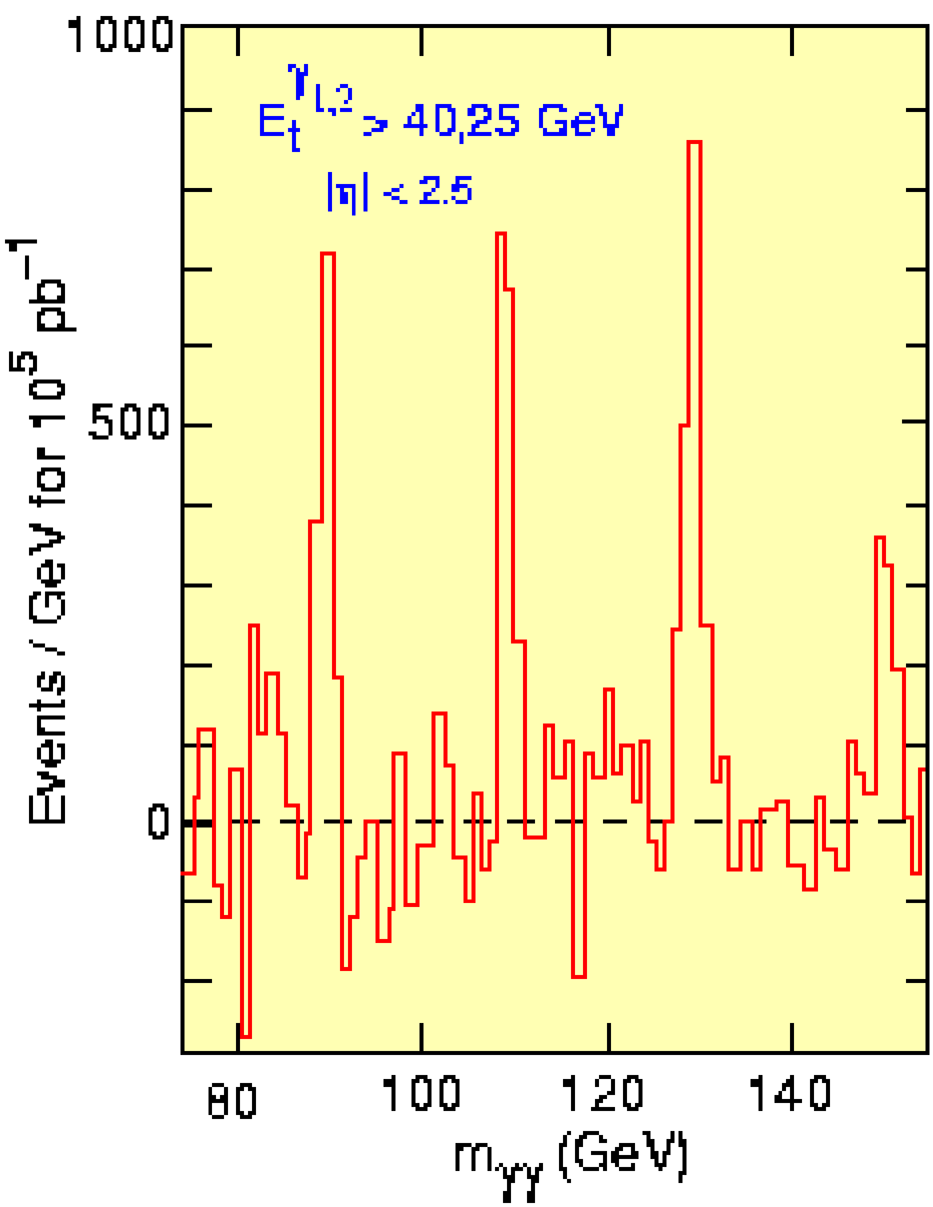
Expected performance

ATLAS : 100 fb^{-1}



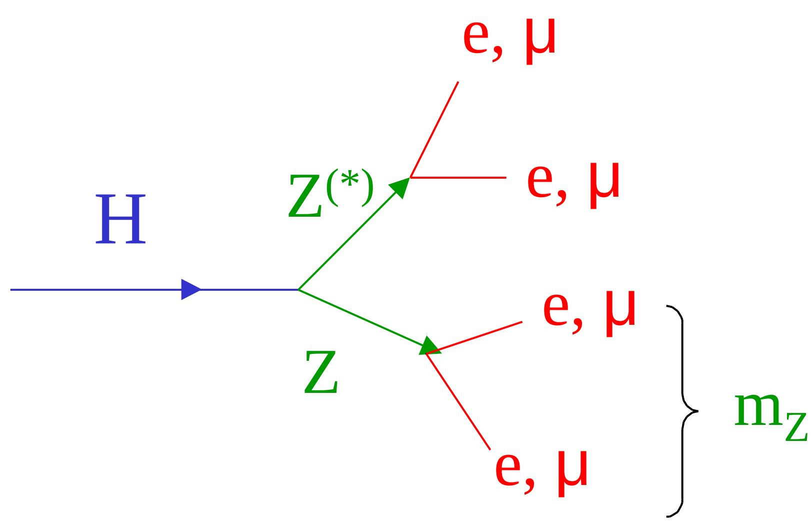
m_H (GeV)	100	120	150
Significance ATLAS, 100 fb^{-1}	4.4	6.5	4.3

CMS : significance is ~ 10% better
thanks to better EM calorimeter
resolution



100 fb^{-1}

$H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ $\quad 120 \leq m_H < 700$ GeV



- "Gold-plated" channel for Higgs discovery at LHC
- Select events with 4 high-p_T leptons (τ excluded): $e^+e^-\, e^+e^-$, $\mu^+\mu^-\, \mu^+\mu^-$, $e^+e^-\, \mu^+\mu^-$
- Require at least one lepton pair consistent with Z mass
- Plot 4ℓ invariant mass distribution :

$$m^2 = \sum_i E_i^2 - (\sum_i \vec{p}_i)^2$$

Higgs signal should appear as peak in the mass distribution

Backgrounds:

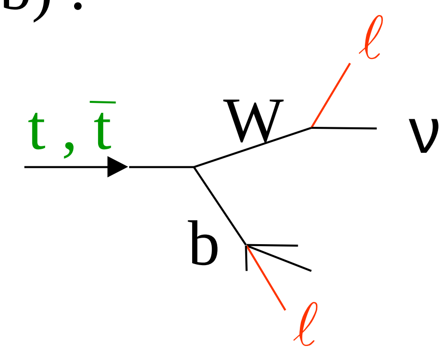
-- irreducible : $pp \rightarrow ZZ^{(*)} \rightarrow 4\ell$

$\sigma_m (H \rightarrow 4\ell) \approx$ 1-1.5 GeV   ATLAS, CMS

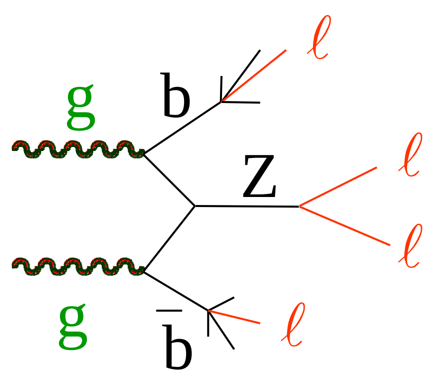
For $m_H >$ 300 GeV $\Gamma_H > \sigma_m$

-- reducible ($\sigma \sim$ 100 fb) :

$t\bar{t} \rightarrow 4l + X$



$Zb\bar{b} \rightarrow 4l + X$



Both rejected by asking:

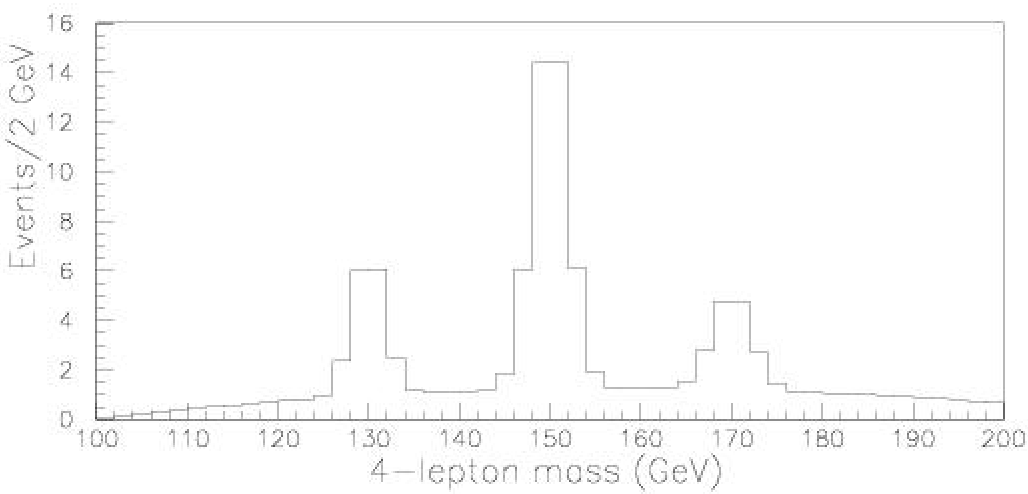
-- $m_{\ell\ell} \sim m_Z$

-- leptons are isolated

-- leptons come from interaction vertex
(leptons from B produced at ≈ 1 mm from vertex)

Expected performance

- Significance : 3-25 (depending on mass) for 30 fb^{-1}
- Observation possible up to $m_H \approx 700$ GeV
- For larger masses:
  - -- σ (pp $\rightarrow$ H) decreases
  - -- $\Gamma_H > 100$ GeV

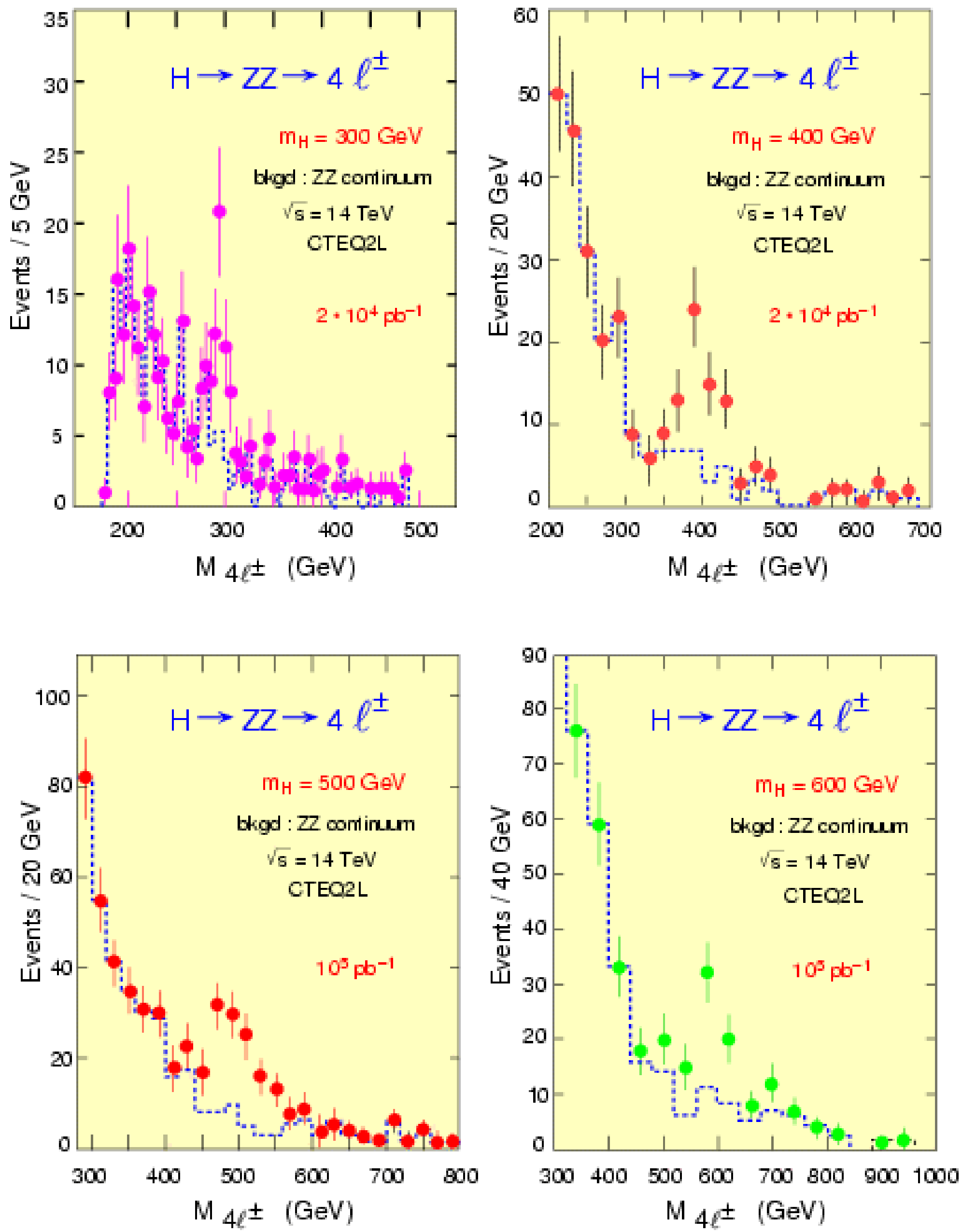


$H \rightarrow ZZ^* \rightarrow 4\ell$

ATLAS, 30 fb^{-1}

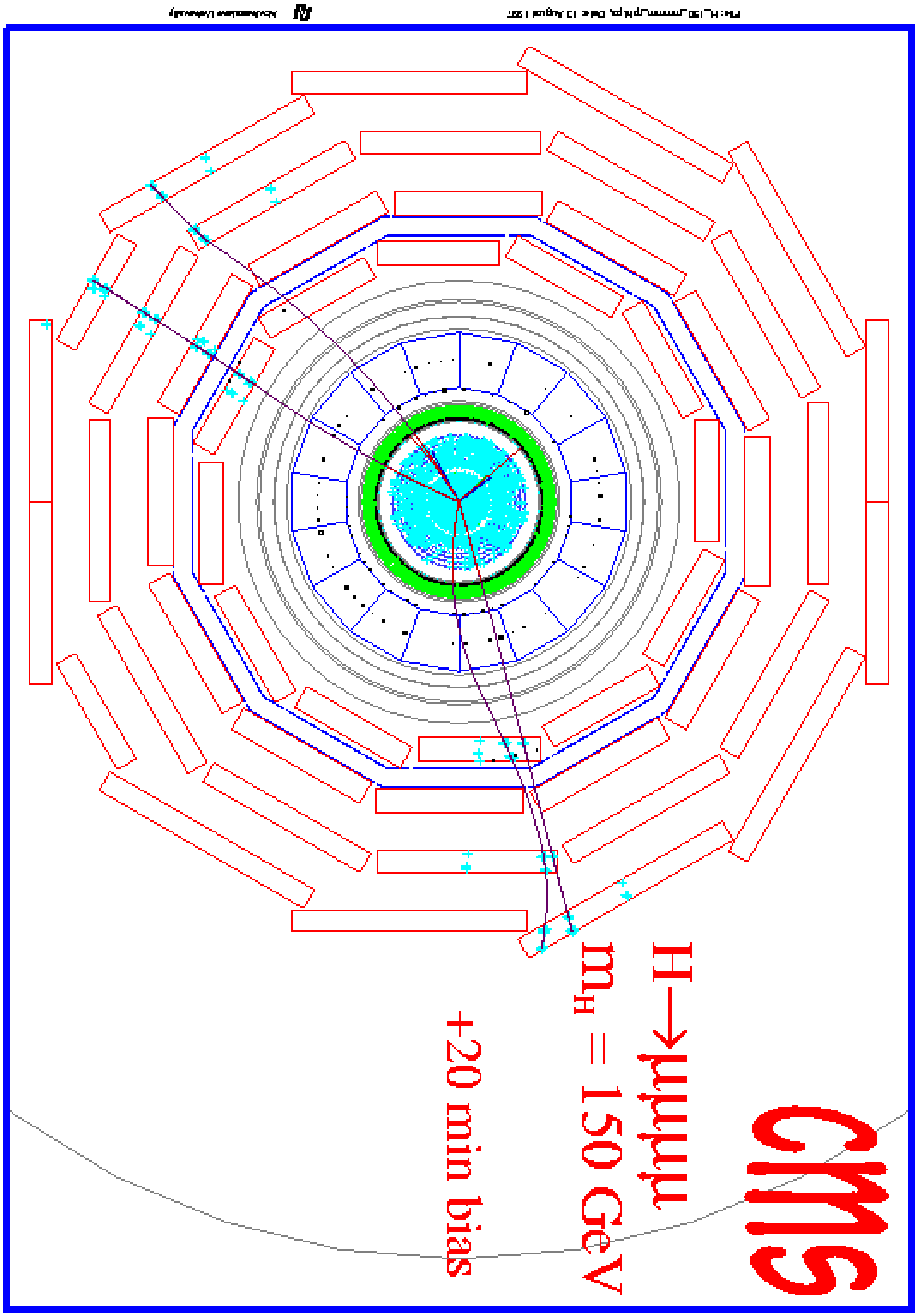
$H \rightarrow ZZ \rightarrow 4\ell^{\pm}$

in CMS



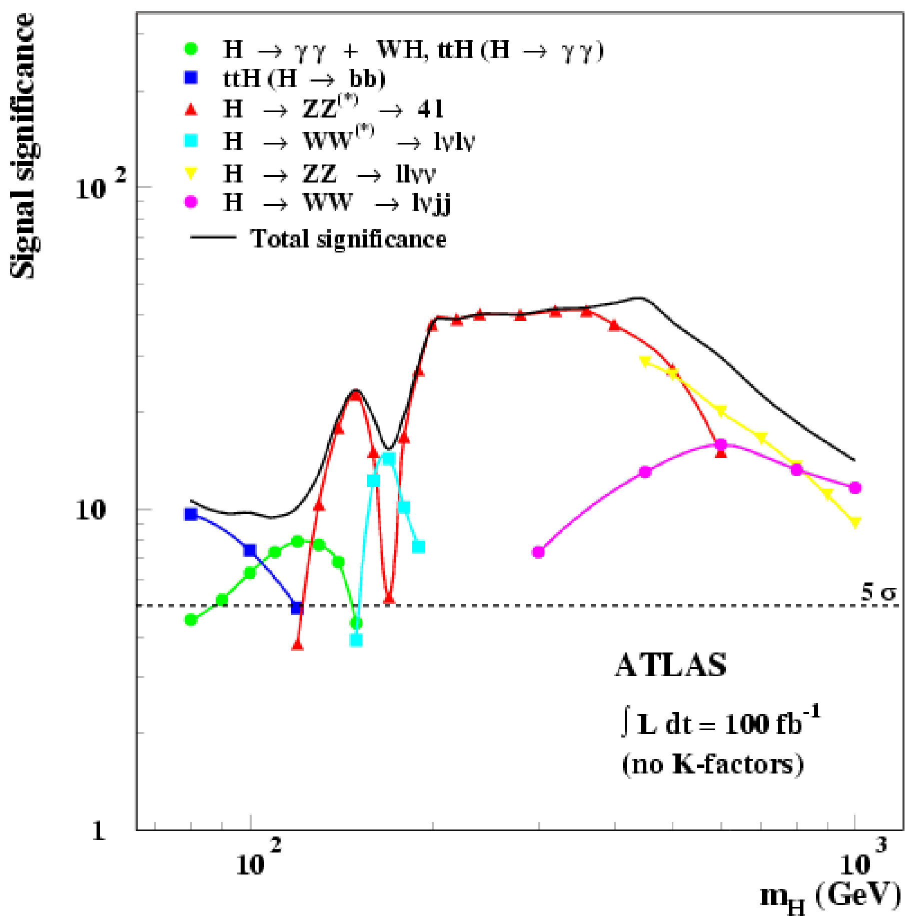
20 fb^{-1}

100 fb^{-1}

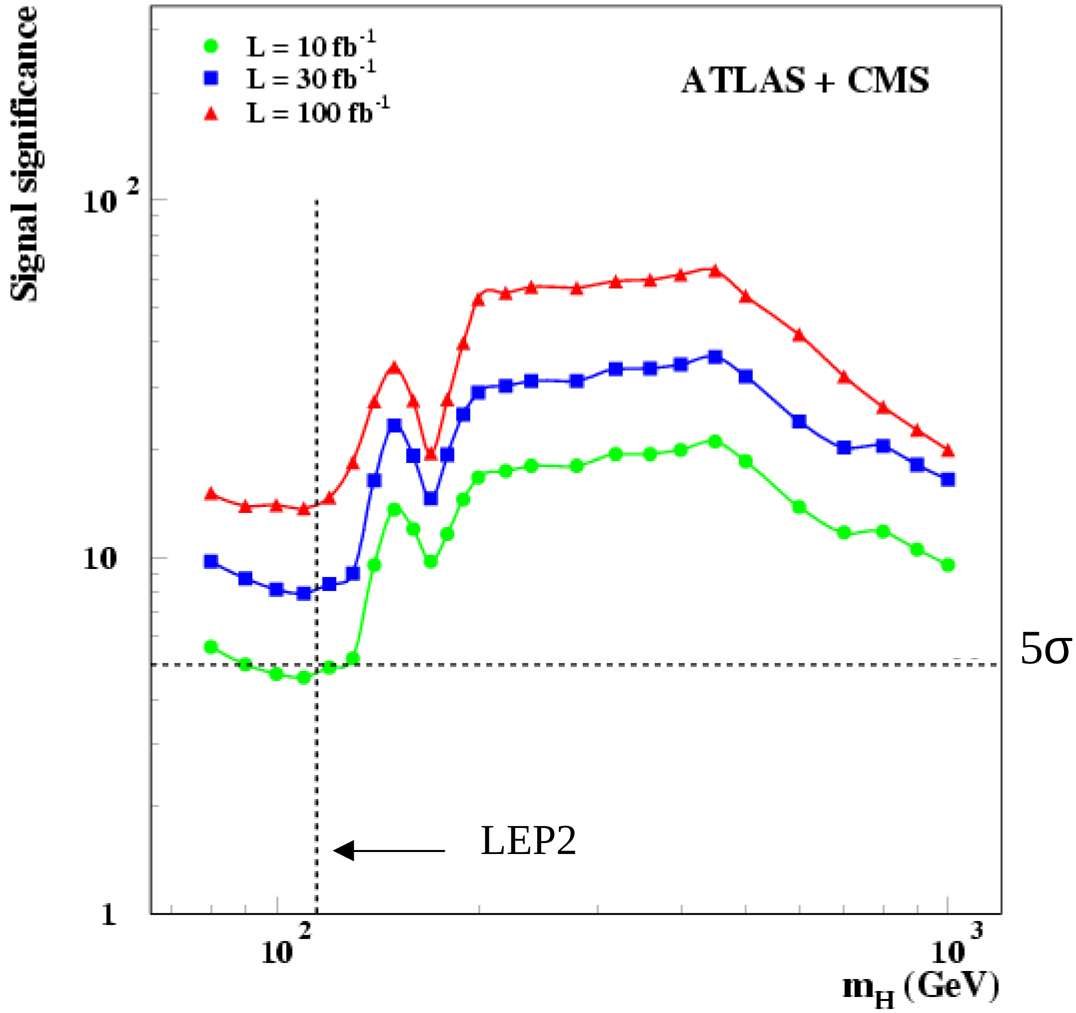

CMS
H→μμμμ
m_H = 150 GeV
+20 min bias

Summary of Standard Model Higgs

Expected significance for one experiment over mass range → 1 TeV



- LHC can discover SM Higgs over full mass region (S > 5) after ≤ 2 years of operation
- in most regions more than one channel is available
- detector performance (coverage, energy/momentum resolution, particle identification, etc.) crucial in most cases
- mass can be measured to ≈1‰ for m_H < 600 GeV



L is per experiment

-- SM Higgs boson can be discovered at ≈ 5 σ with 10 fb^{-1}/ experiment (nominally one year at 10^{33} cm^{-2} s^{-1}) for $m_H \leq 130$ GeV

-- Discovery faster for larger masses

-- Whole mass range can be excluded at 95% CL after ~1 month of running at 10^{33} cm^{-2} s^{-1}.

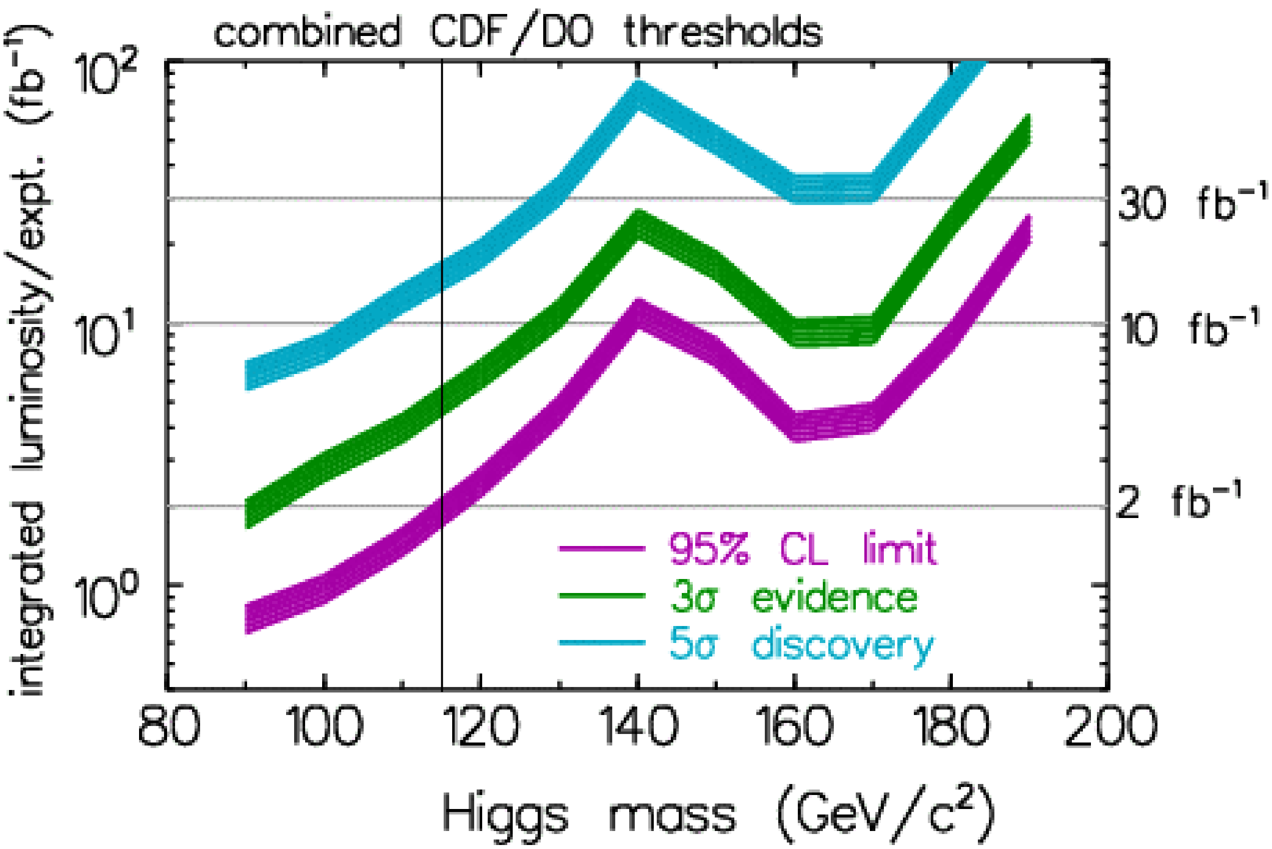
However, it will take time to operate, understand, calibrate ATLAS and CMS → Higgs physics will not be done before 2007-2008 given present machine schedule

What about Tevatron ?

Tevatron schedule :

-- Run 2A : March 2001-end 2003 : ~ 2 fb^{-1} /expt.

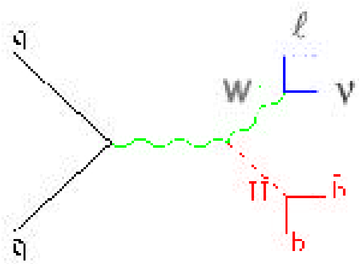
-- Run 2B : middle 2004 → ? : ~ 15 fb^{-1} /expt by end 2007

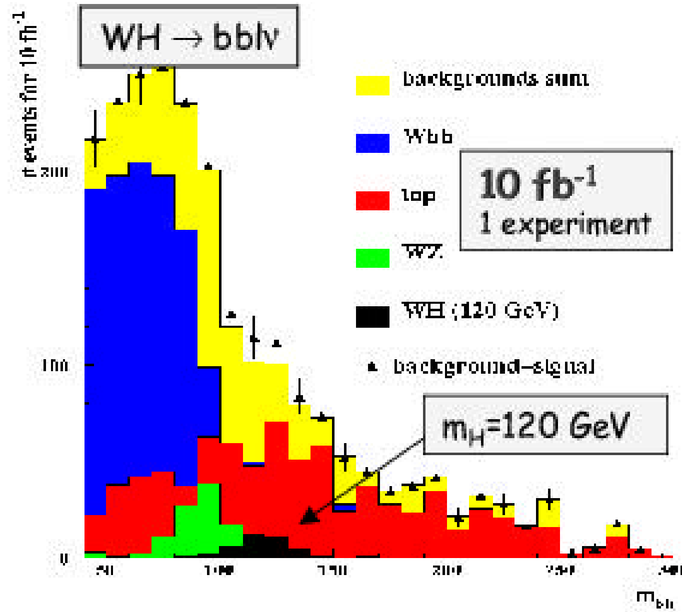


- For m_H ~ 115 GeV Tevatron needs (optimistic analysis):
  - ~ 2 fb^{-1} for 95% C.L. exclusion → end 2003 ?
  - ~ 5 fb^{-1} for 3σ obervation → end 2004 ?
  - ~ 15 fb^{-1} for 5σ discovery → end 2007 ?
- Discovery possible up to m_H ~120 GeV
- 95% C.L. exclusion possible up to m_H ~185 GeV

Best channel at the Tevatron for $m_H \leq 120$ GeV :

$WH \rightarrow \ell\nu\ bb$





Note :

-- this is a very difficult channel (small S/B, background shape not known, etc.)

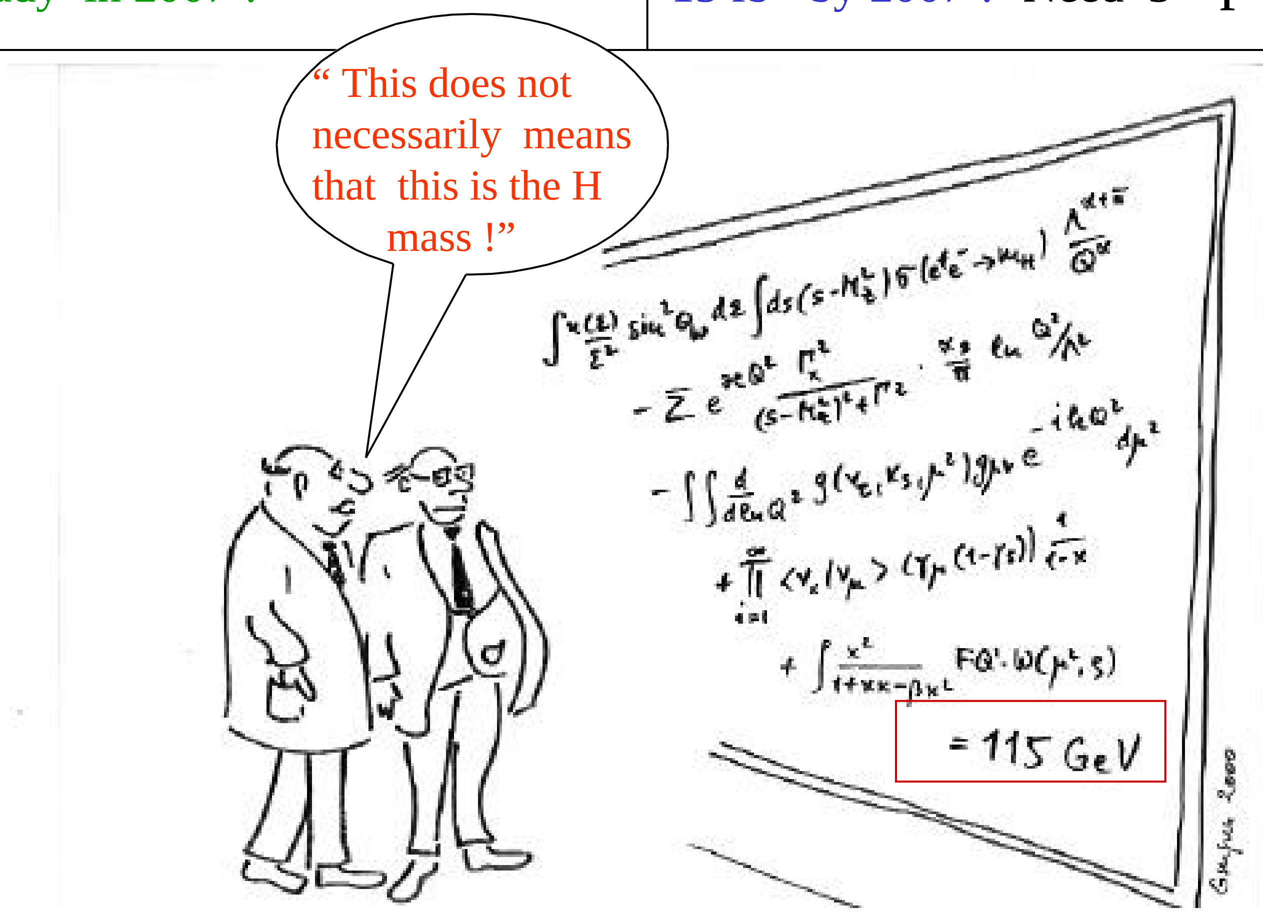
-- **H** $\rightarrow \gamma\gamma$ (best channel at **LHC**) has too small rate at $\sqrt{s} = 2$ TeV

Fabiola Gianotti, Physics at LHC, Pisa, April 2002

2008

Both machines (Tevatron, LHC) could achieve 5σ discovery if $m_H \approx 115$ GeV.
Who will find it first ?

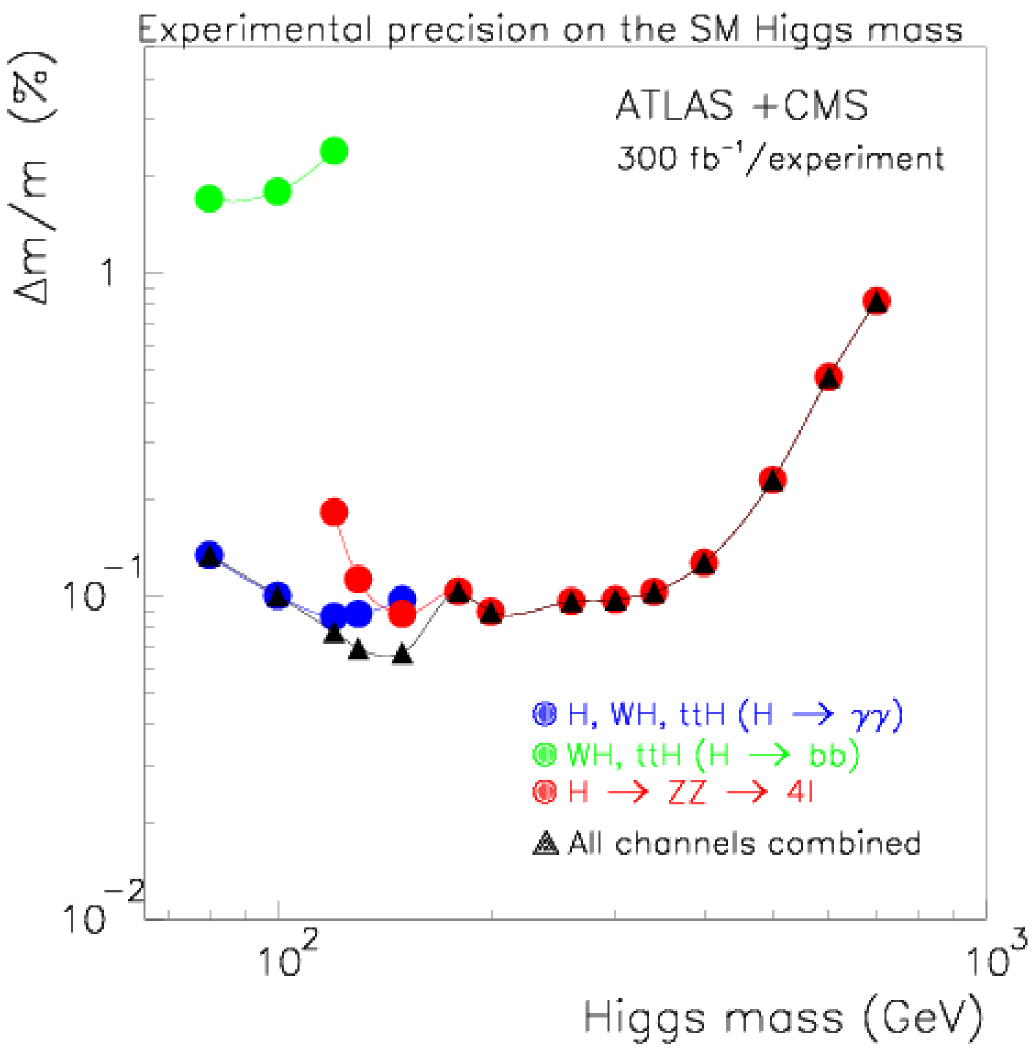
LHC versus	TEVATRON
Higgs cross-section ~10-100 higher	S/B ~ 5 higher
Conservative estimates (cross-sections, cut analyis, etc.) m_H=115 GeV 10 fb^{-1} $S/\sqrt{B} \approx 4.7$ 4.7 → 7 using Tevatron approach	Less conservative predictions (e.g. Neural Network analysis) m_H=115 GeV 10 fb^{-1} $S/\sqrt{B} \approx 5.3$
Will take lot of time to understand Detectors and physics	Has lot of time to understand detectors and physics
Ready in 2007 ?	15 fb^{-1} by 2007 ? Need 3 * $\bar{p}$



Let's assume the Higgs is found; what do we do now ?

Want to measure the Higgs properties, e.g.

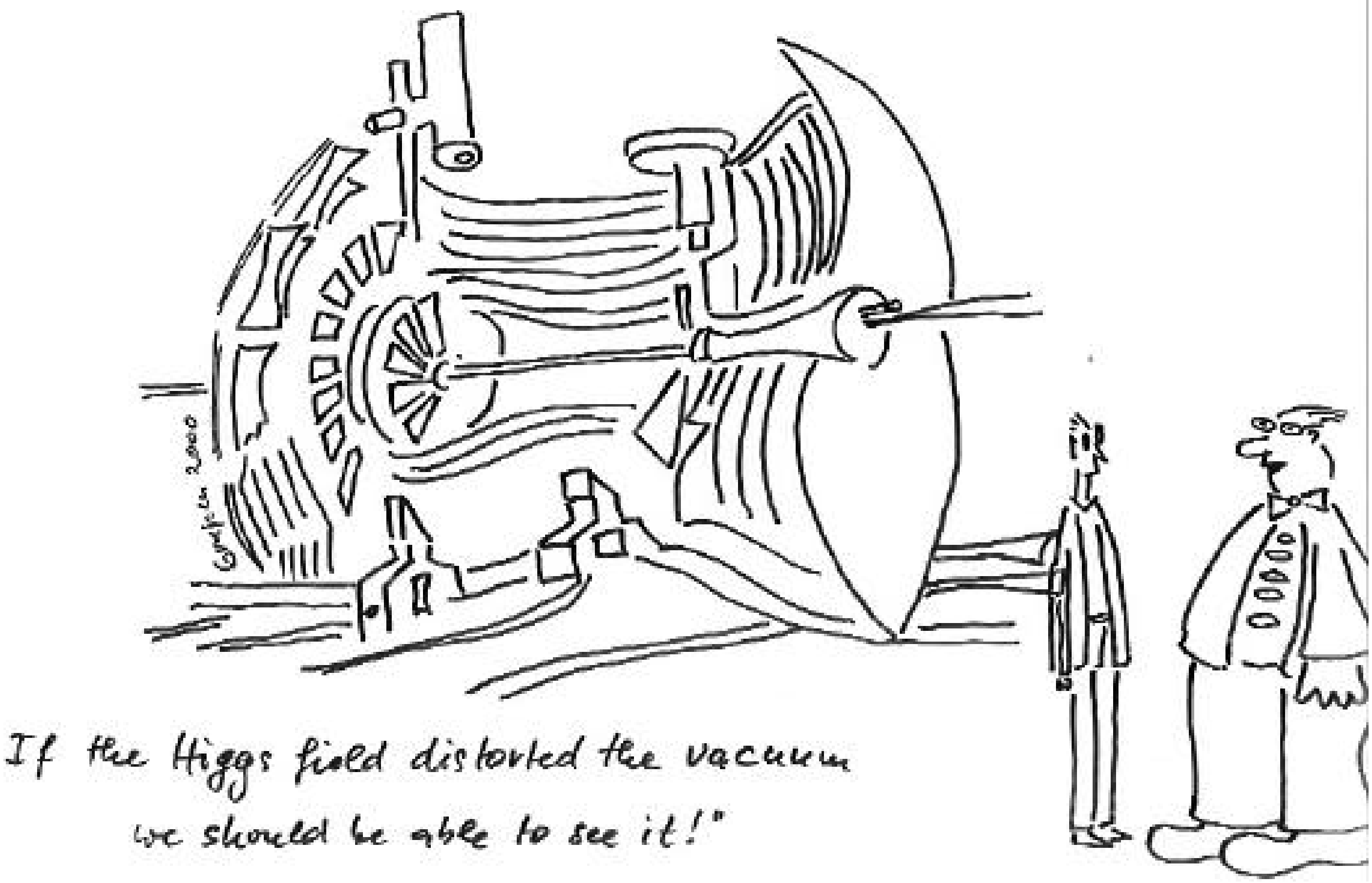
m_H



→ m_H can be measured to 0.1% using precise calorimeter and muon systems of ATLAS and CMS

Summary of Part 2

- Examples of precision physics at LHC: W mass can be measured to ~15 MeV, top mass to ~ 1.5 GeV
- Standard Model Higgs boson can be discovered over the full mass region up to 1 TeV in ~ 1 year of operation.
- Excellent detector performance required:
  → Higgs searches have driven the LHC detector design.
- Main channels : H → γγ, H → 4ℓ
- If SM Higgs not found before / at LHC, then alternative methods for electroweak symmetry breaking will have to be found



End of Part 2