That Olde Boson

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RAL
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- **Quick reminder of theory**
- **A historical perspective**
- **The Tevatron search**
- **The LHC and beyond**

Disclaimer

The following presentation assumes the world consists of the Standard Model, no more no less
This is not the view of the author.

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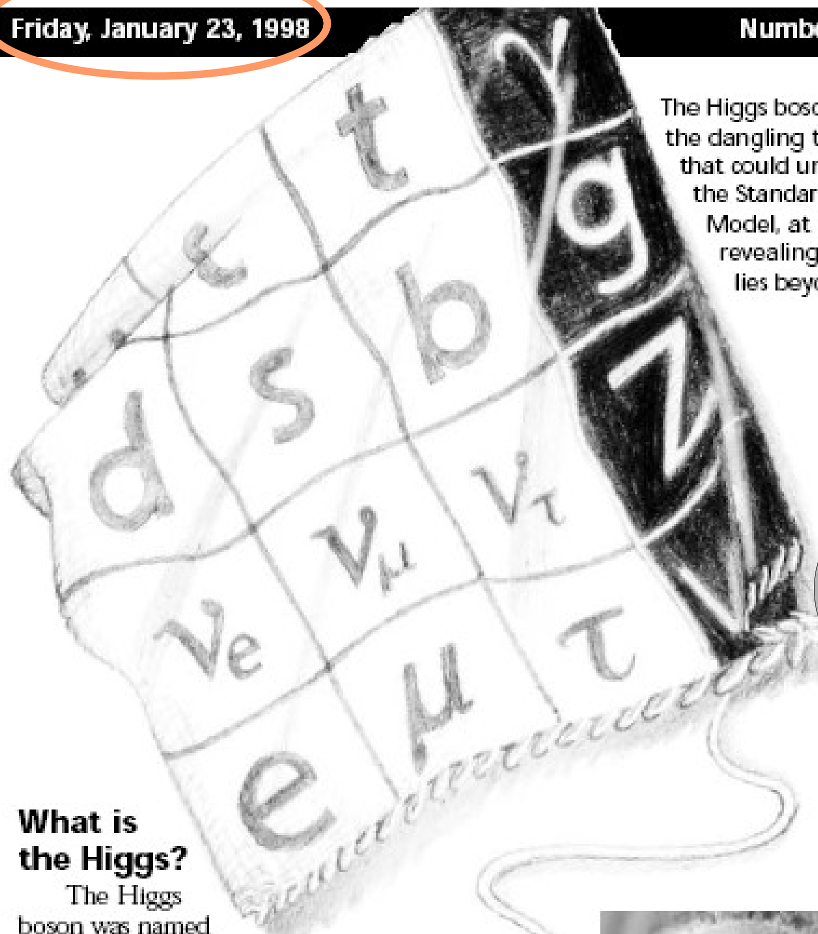
What Is Electroweak Symmetry Breaking, Anyway?

At high-energy physics labs, including Fermilab, the search is on for the Higgs boson.

By David Kestenbaum

"I drive the sea!"
-Captain Ahab, peg-legged whale hunter, Moby Dick

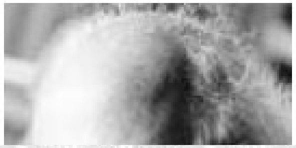
"We will find the Higgs.... I promise!"
-Gordy Kane, theoretical physicist, University of Michigan



The Higgs boson is the dangling thread that could unravel the Standard Model, at last revealing what lies beyond it.

What is the Higgs?

The Higgs boson was named after Peter Higgs, a Scottish theorist who, in the early 1960s, was among the first to find it hiding in the equations that would become the Standard Model.



10 years ago..

"The LHC would certainly ferret out the Higgs by 2007"

E-W symmetry breaking

$$SU(3) \times SU(2) \times U(1)$$

- This gauge symmetry predicts γ,W,Z,gluons
  - Requires them to be massless
- Symmetry breaking is needed for W/Z masses

Why do we need the Higgs?

Fermions

families,
with leptons

$$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}, \nu_R, e_R$$

and quarks

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix}, u_R, d_R$$

Gauge Symmetries ⇒ Bosons, Interactions

$U(1)_Y$: $\psi(x) \rightarrow \exp\left[i\frac{g'}{2}Y_\psi \omega(x)\right]\psi(x)$

$SU(2)_L$: $\psi_L(x) \rightarrow \exp\left[i\frac{g}{2}\vec{\sigma}.\vec{\theta}(x)\right]\psi_L(x)$

$SU(3)_c$: $\psi_q(x) \rightarrow \exp\left[i\frac{g_s}{2}\lambda_a \theta^a(x)\right]\psi_q(x)$

γ : QED

Z, W$^\pm$: Weak

$$\tan\vartheta_W = \frac{g'}{g}$$

gluons : QCD

A mass term couples L & R
and would violate $SU(2)_L$

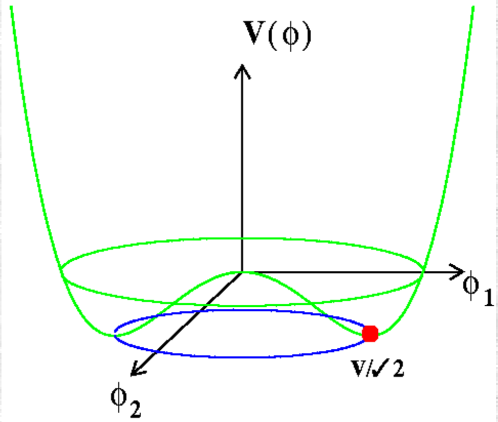
solution: The Higgs Mechanism

What is the Higgs mechanism?

- **Doublet of SU(2)$_L$, $\Phi=(\Phi_1,\Phi_2)$**
- **Potential respects SU(2)$_L$**

  But Vacuum does not!

$$V(\Phi) = \frac{\lambda}{3!}\{\overline{\Phi}\Phi - v^2/2\}^2$$



Fermions:

Interact with Higgs field slows them down → generates mass

Bosons:

SU(2)$_L$ interact, gain mass

U(1)$_\gamma$ and SU(3)$_c$ do not, massless

3 degrees of freedom in Boson masses
4th becomes fundamental scalar

What does it predict?

$m_\gamma = 0$

$m_Z = m_W/\cos\theta_W$

$(\rho=1)$

Tree level Z couplings:

axial: $a=\pm 1/2$

vector: $v=a(1-4|Q|\sin^2\theta_W)$

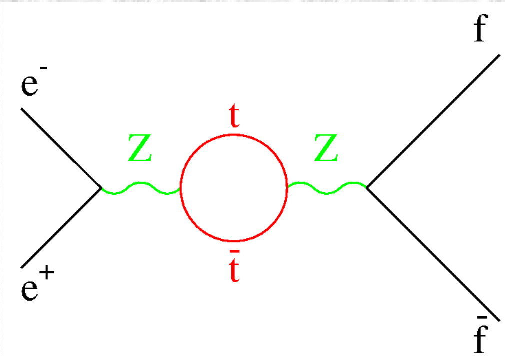
Direct consequences of the Higgs mechanism

We can test them

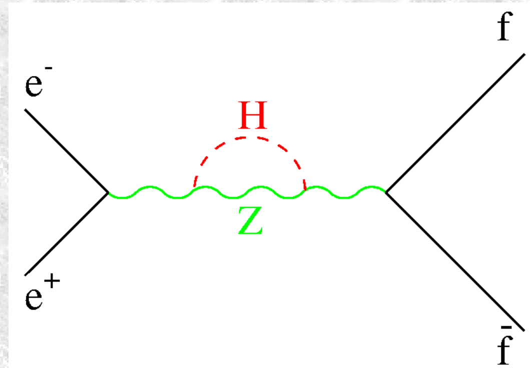
But the Higgs mass is not predicted

Loop corrections to Z^0s

Propagator corrections



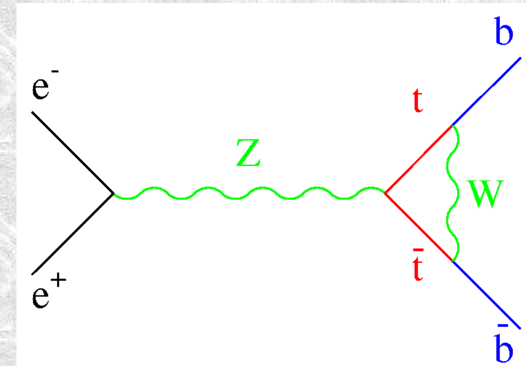
$$\frac{\alpha\, m_t^2}{\pi\, m_Z^2} = 0.01$$



$$\frac{-\alpha}{4\pi} \log \frac{m_H^2}{m_Z^2}$$

0.1% Precision needed!

Vertex corrections



Only sensitive to m_{top}

Tree level	Corrected
$a_0 = \pm 1/2$	$a = a_0(1+\Delta\rho r)$
$v_0 = a_0(1-4\|Q\|\sin^2\theta_w)$	$v = a(1-4\|Q\|\sin^2\theta_w^{eff})$
$\sin^2\theta_w = 1 - m_W^2/m_Z^2$	$\sin^2\theta_w^{eff} = 1 - m_W^2/m_Z^2(1+\Delta k)$

with

$$\Delta\rho = \frac{\alpha\, m_t^2}{\pi\, m_Z^2} - \frac{\alpha}{4\pi} \log \frac{m_H^2}{m_Z^2} + \ldots$$

Two experimental themes

- Precision Electroweak data
  - Is $\rho=1$ true?
  - Are the loop effects correctly seen?
  - Can we predict the Higgs mass from them?
- Direct Higgs search
  - A brief history of LEP
  - What can the TeVatron say about SM Higgs
  - What does the future hold? And when?

Precision Electroweak

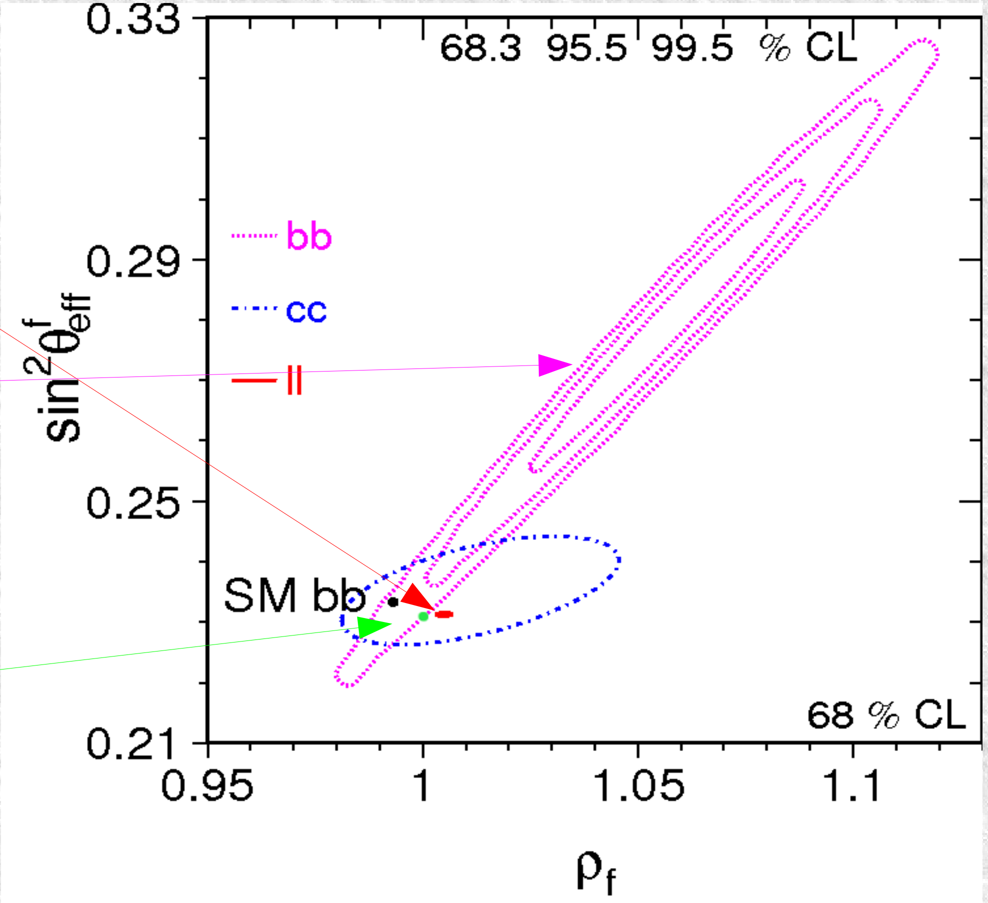
Does the S.M. give M_W, M_t and Z properties correctly?

- Z properties
  - Largely from **LEP/SLC**
  - Final: “Phys Rept. **427** (2006) 257”
- W mass
  - LEP II results
  - Tevatron run I+II
  - **New D0 result**
- Top mass
  - Tevatron: Runs I and **II**

Z Properties: LEP

$$M_z = 91.1876 \pm 0.0021 \mathrm{GeV}/c^2$$
$$\Gamma_z = 2.4952 \pm 0.0023 \mathrm{GeV}/c^2$$

- Coupling example: ρ and $\sin^2\theta_{eff}$
- Leptons precise
- b quarks incompatible
- Non-universal EW corrections observed!
- *Born* level not quite correct – ρ close to 1



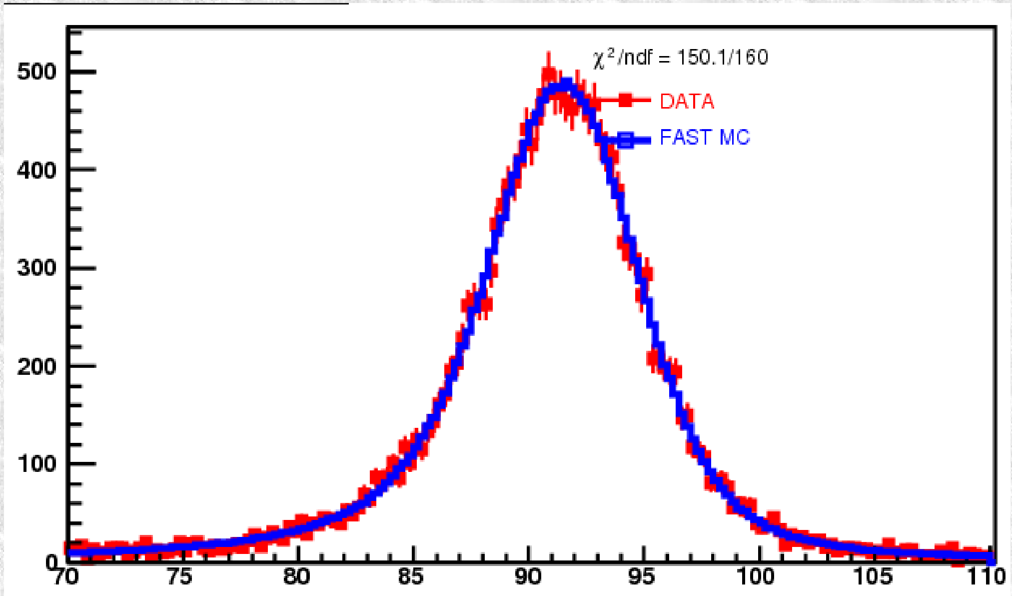
W mass

- LEP results, stable for years but not final:
  - $M_W = 80.376 \pm 0.033$
- Tevatron results:
  - $M_W = 80.432 \pm 0.039$
- Plus: D0 Run II result
  - Based on $1 fb^{-1}$ of electrons

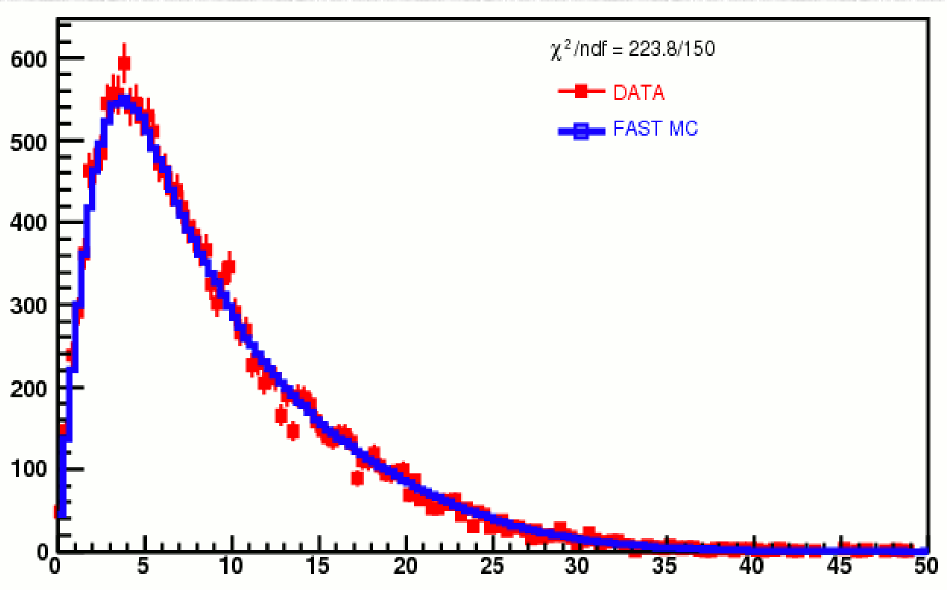
    See J. Stark, Moriond EWK
  - Summary follows....

D0 electron quality plots:

m(ee), electrons

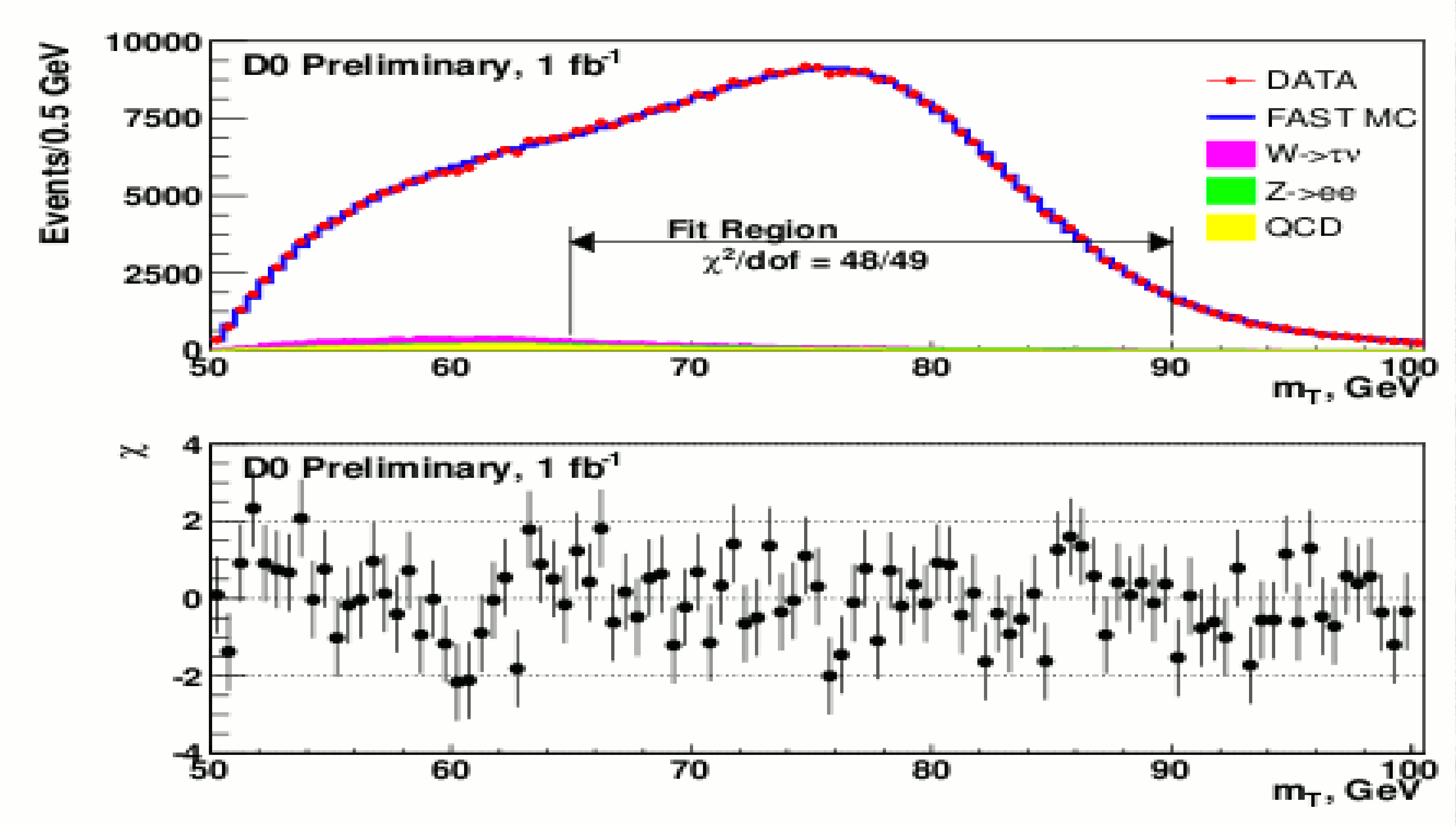


$Z \rightarrow ee\ p_T$



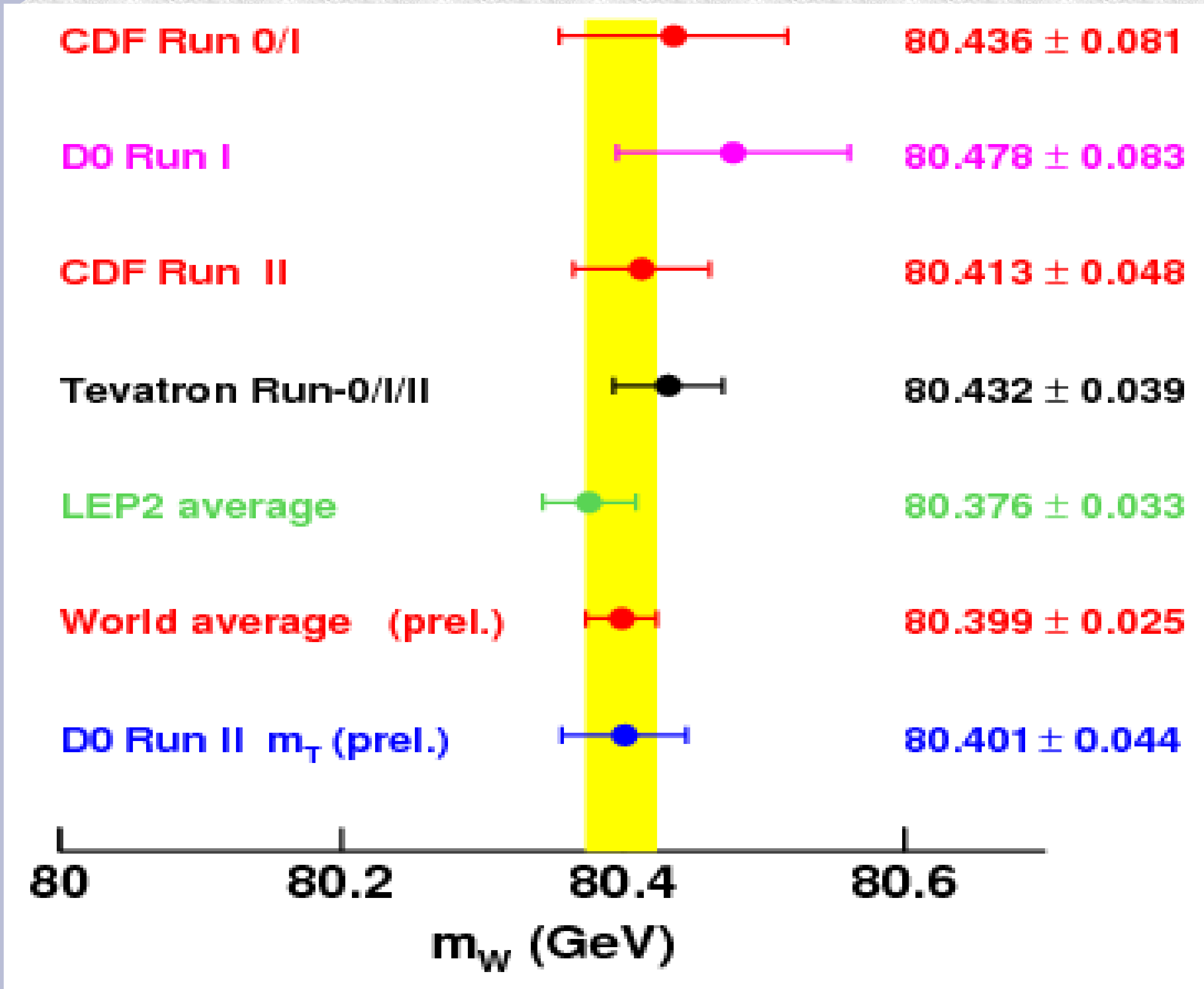
- Electron modeling excellent
- Control of the Z p_T means modeling of W reliable

Measured Transverse mass



- MW = 80.401±0.044
- c/f CDF electron result was 80.493±0.48
  - I always said the CDF result was too high.

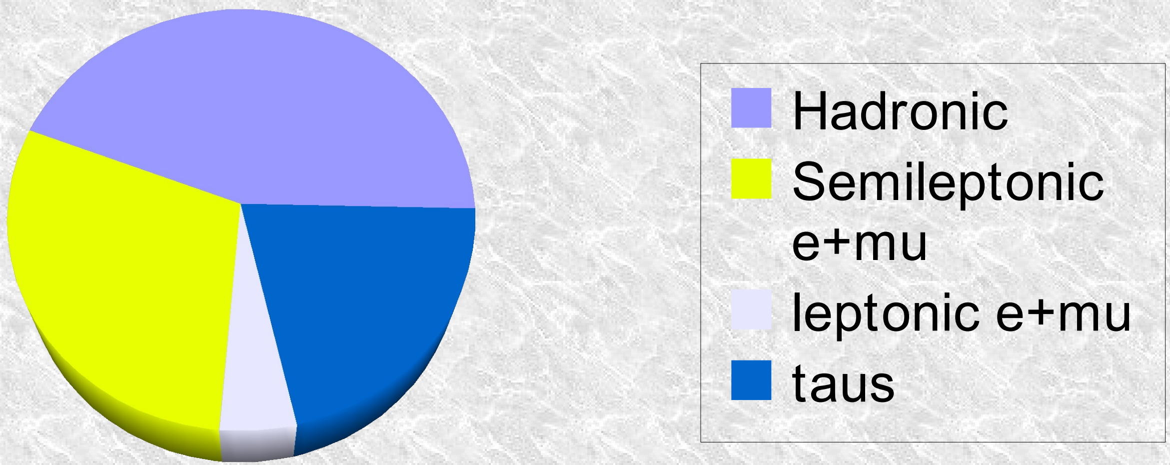
Combined W mass



- New result compatible with existing 80.4±0.022?
- Most precise result
  - Only 1fb^{-1}, only electrons
  - Much more to come

Top Mass measurement

- A unique particle to the Tevatron
- When pair produced, top decays:



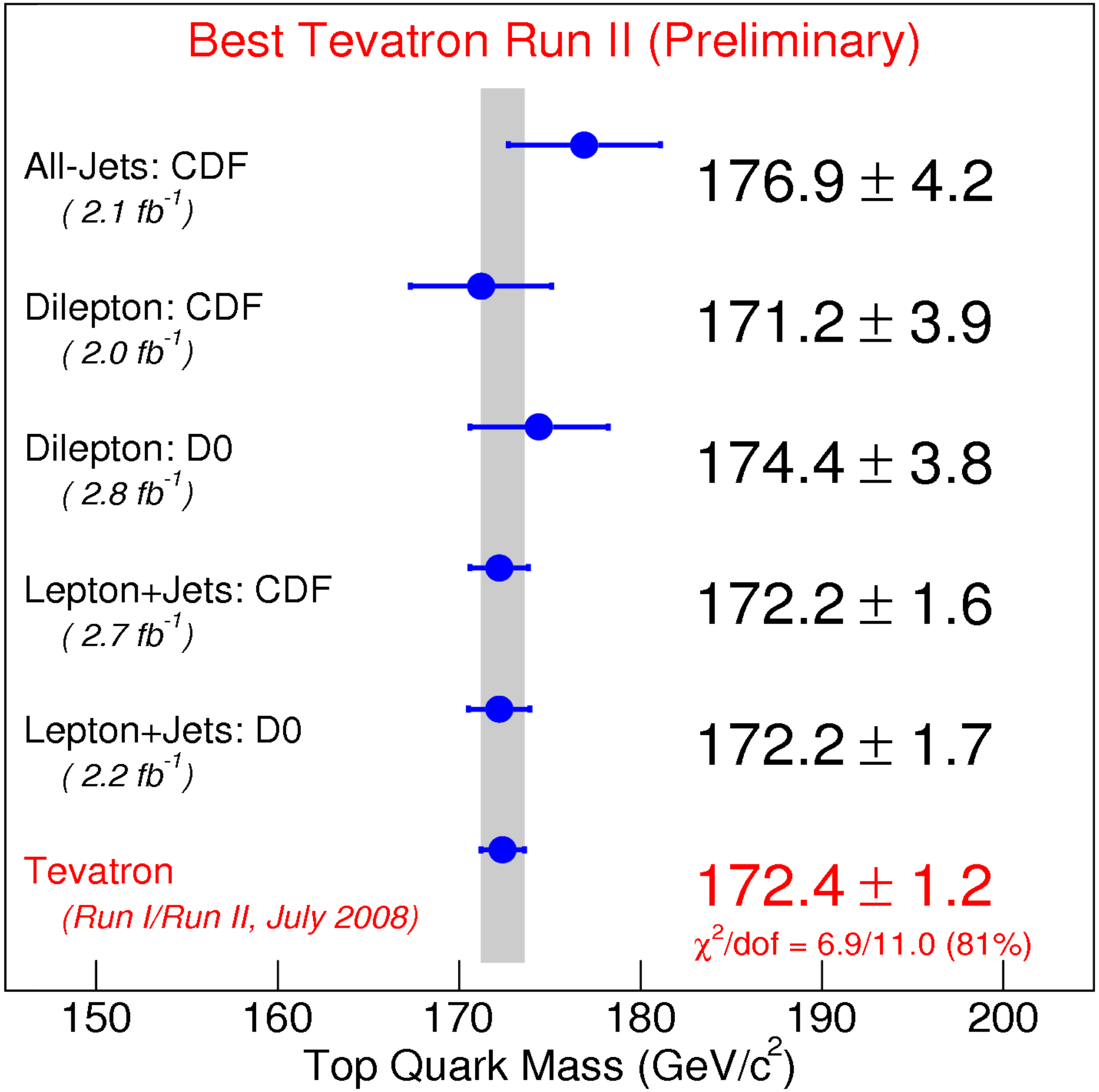
- The semi-leptonic are often 'golden'
- The other decay modes contribute too.

Top by channel/experiment:

- The lepton plus jets channels dominate the average

$m_t = 172.4 \pm 1.2$

- Best fermion mass
- Systematic errors important – future gains will be hard

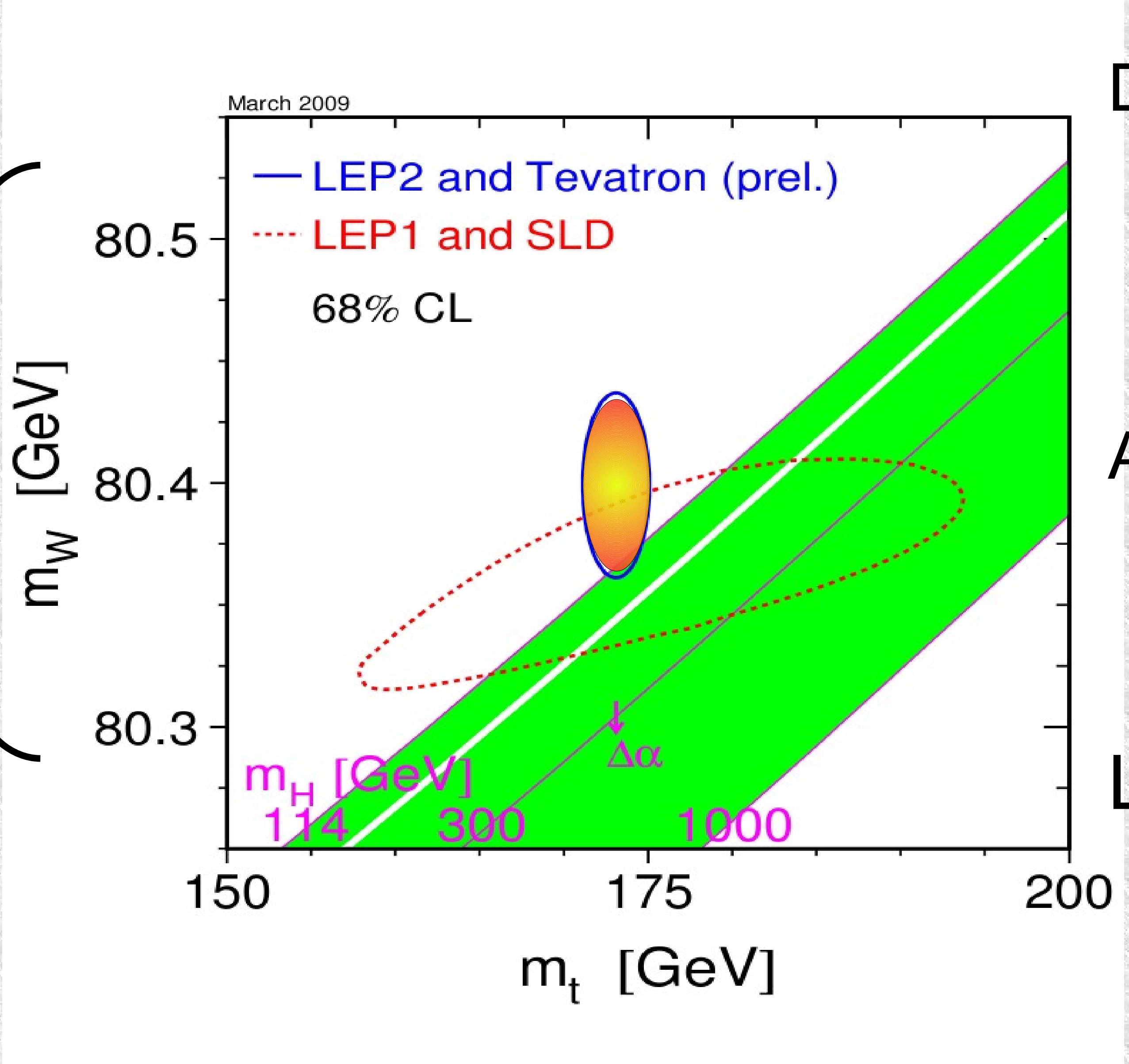


Combined Electroweak

- The consistency of the data can be used to test the use of EW correction
- It also constrains the Higgs mass

The Electroweak fit:

Note 0.2GeV range of scale



Direct and indirect agree – QFT works!

Also suggests m_H around 100GeV

LEP direct: M_H>114

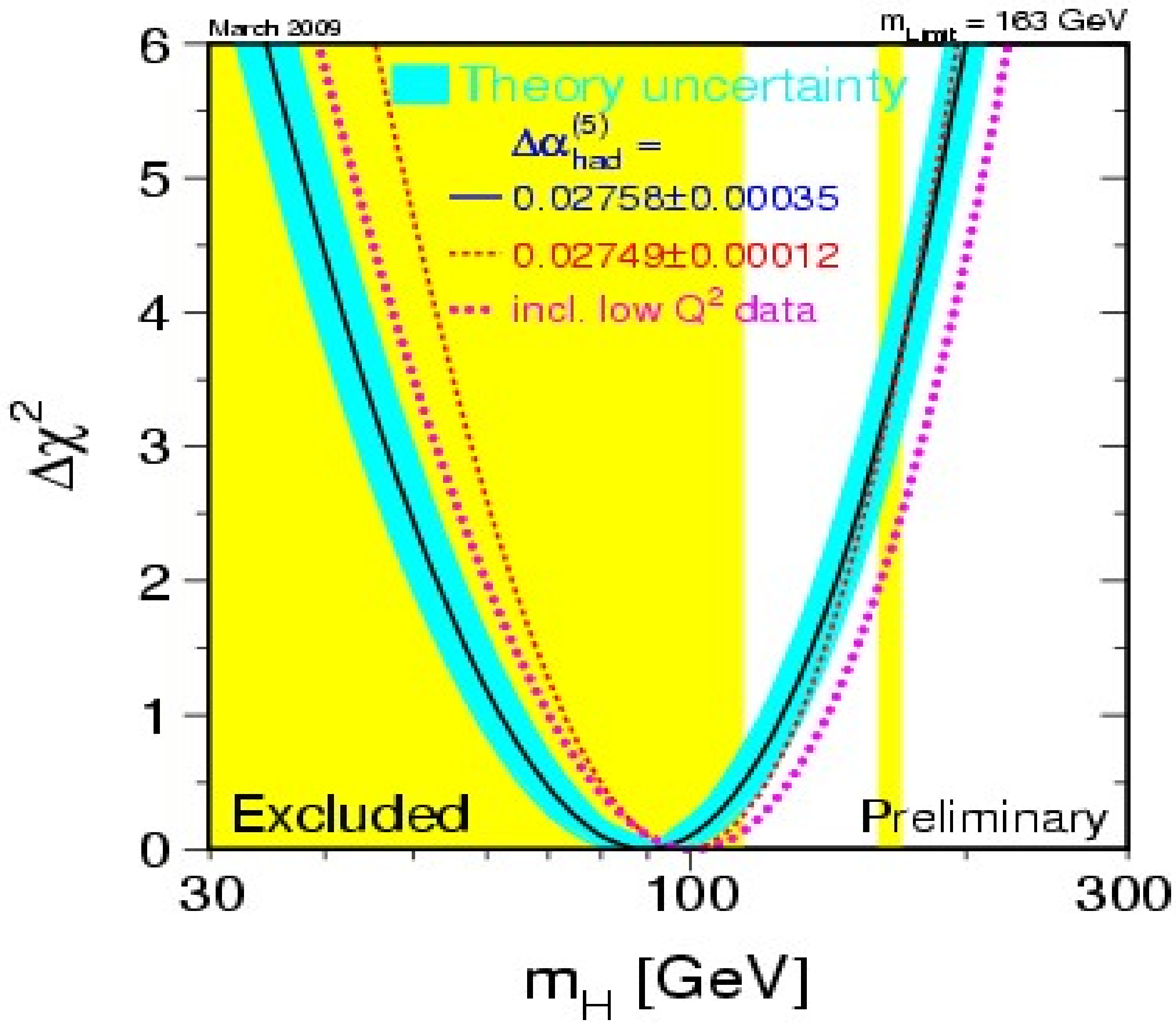
Why believe in a light Higgs?

- Electroweak fit (Z properties, W and top mass) give at 95%:

  $M_H<163GeV/c^2$

  $M_H<191GeV/c^2$ (with search bound)*

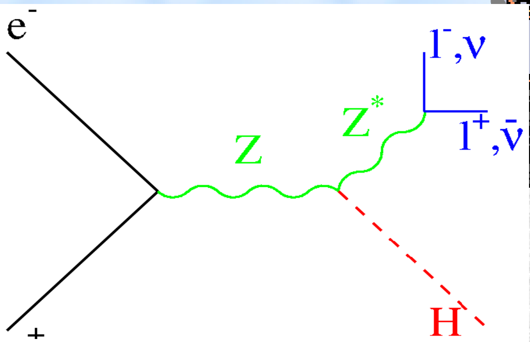
- Will drop with new m_W



Direct Searches

- SM Higgs:
  - Past: LEP
  - Present: Tevatron
  - Close at hand: LHC
  - Future: GLC
  - Somewhere-over-the-rainbow: Muon Collider

Direct Searches at LEP 1



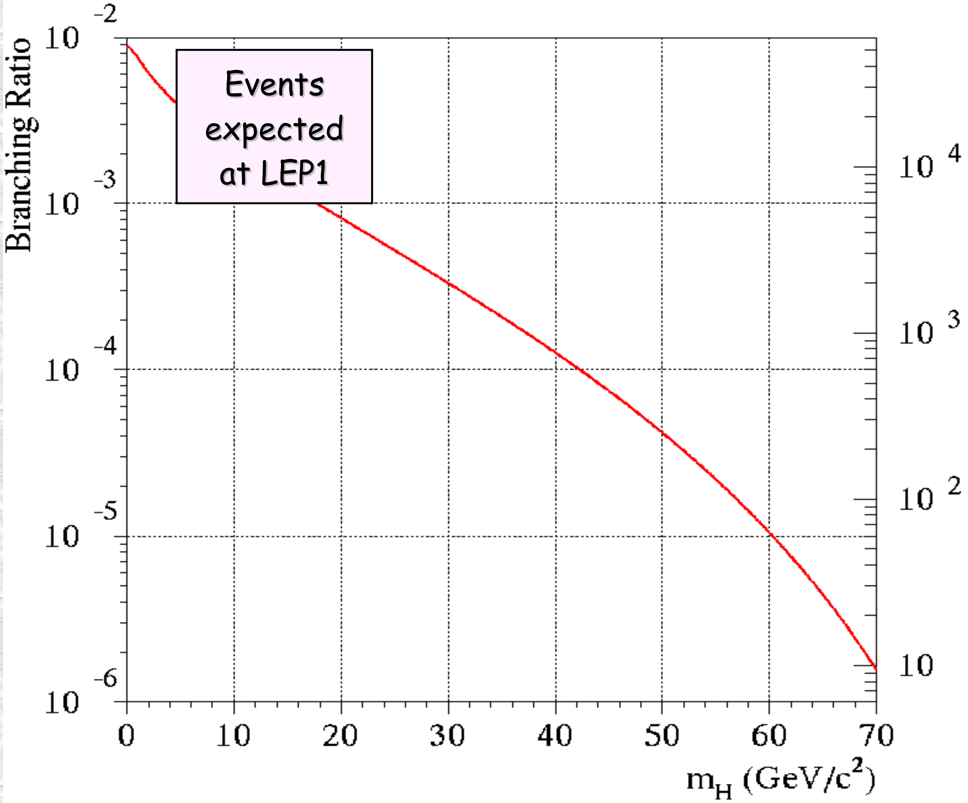
- Great effort - which I have no time to describe

Many modes:

Stable,γγ,ee,μμ,ττ,ππ,bb

- Clean Z decays (ll, ν ν) used
- Prior to LEP only some patchy constraints

The mass range to 0 now excluded, no holes.



$0.0 < m_H < 65$ GeV/c^2
Excluded at 95% C.L.

LEP 2

- Energy raised in steps from m_Z to 208 GeV
- Around $0.5 fb^{-1}$ of data taken.
- Sensitive to $Z^* \rightarrow ZH$
- Therefore approximate reach:

$$E_{CoM} - m_Z - 2$$

- Or $115 GeV/c^2$ at 208.

- In final year energy was raised to 206 then 208.

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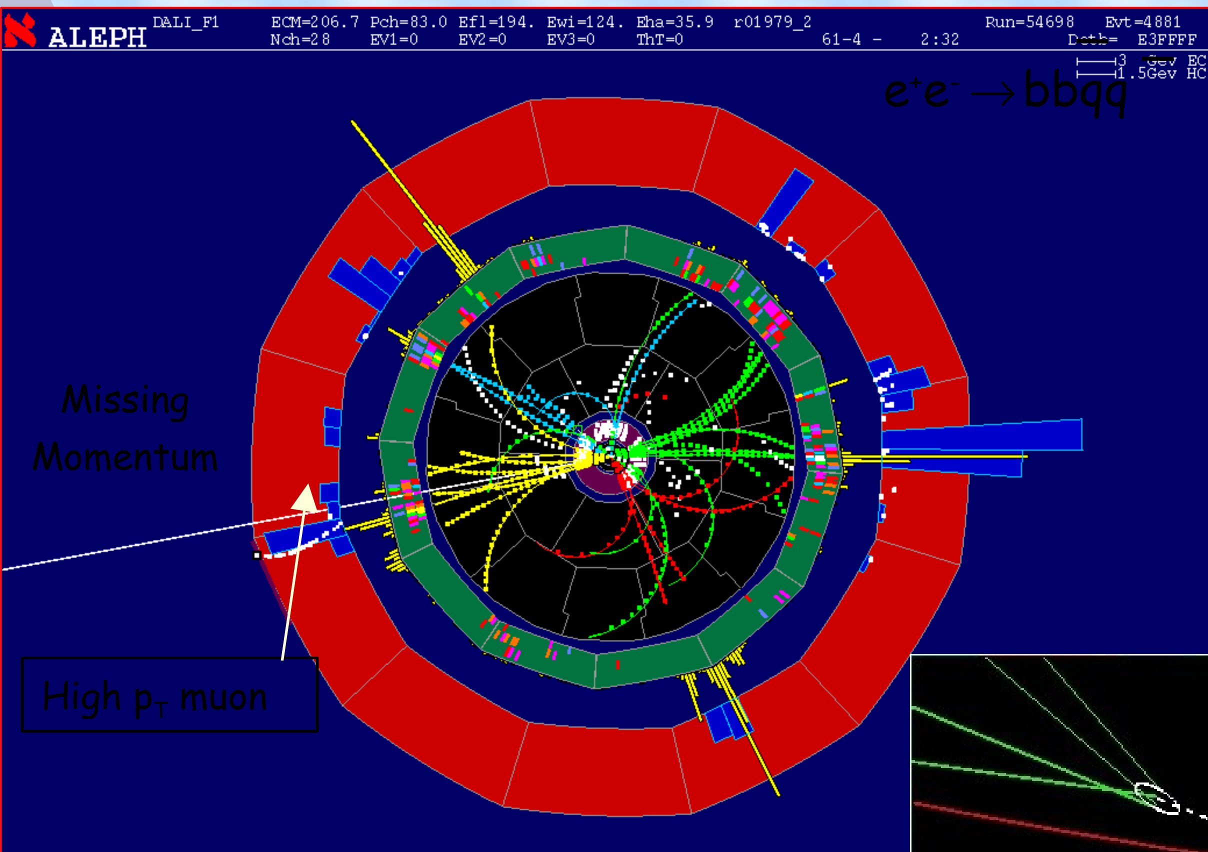
The best candidate, ALEPH

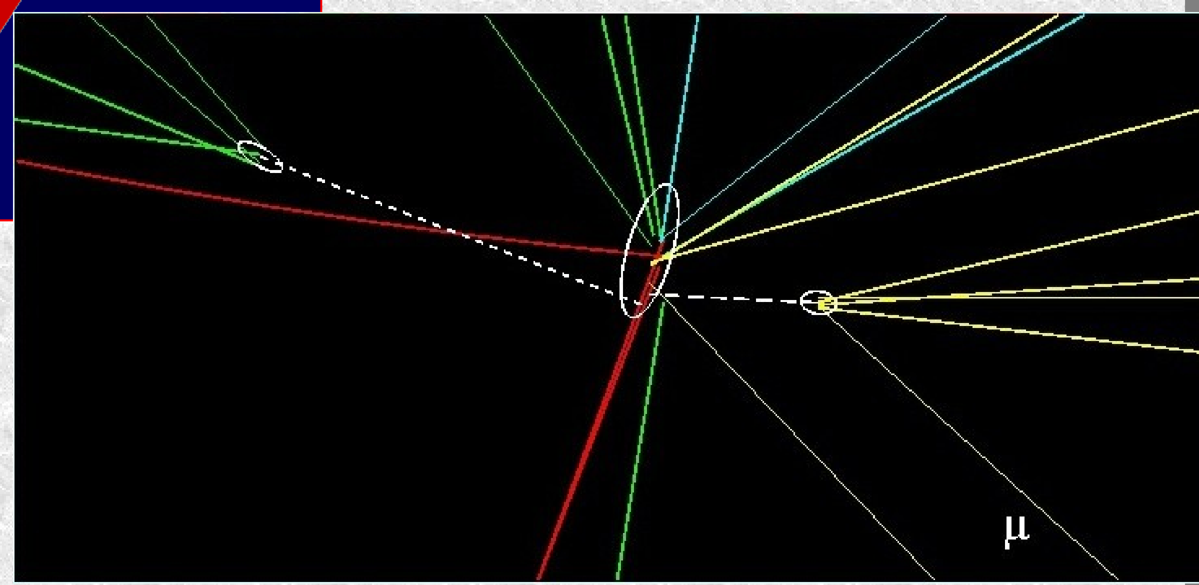


(14-Jun-2000, 206.7 GeV)

- Mass 114.3 GeV/c2;
- Good HZ fit;

  Poor WW and ZZ fits;
- P(Background) : 2%
- s/b(115) = 4.6

The purest candidate event ever!



b-tagging

(0 = light quarks, 1 = b quarks)

- Higgs jets: 0.99 and 0.99;
- Z jets: 0.14 and 0.01.

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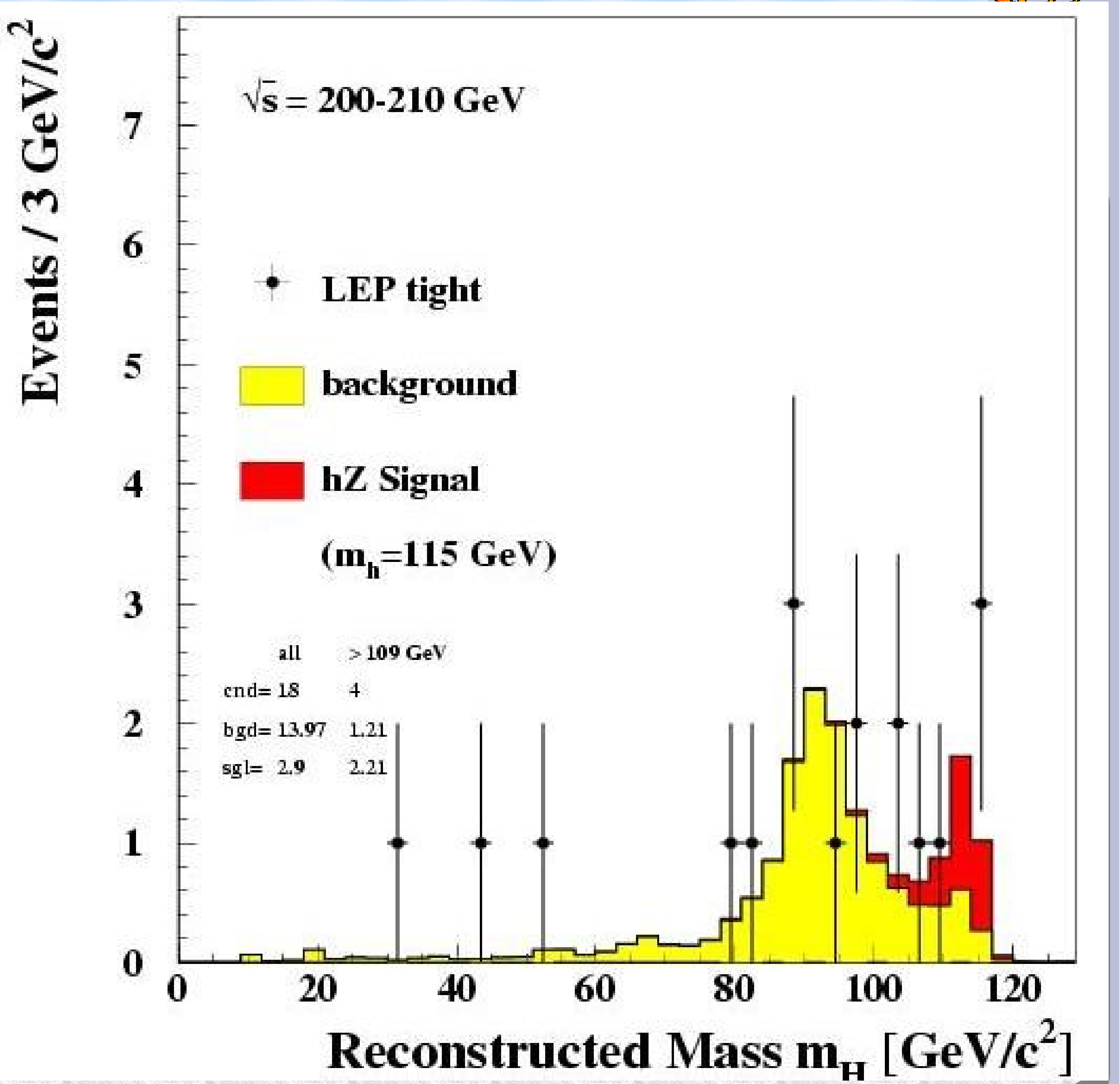
Mass Plot

Distribution of the reconstructed Higgs boson mass with a Higgs boson of mass 115 GeV/c^2

Yellow is background

Red is Higgs, if it weighs 115GeV

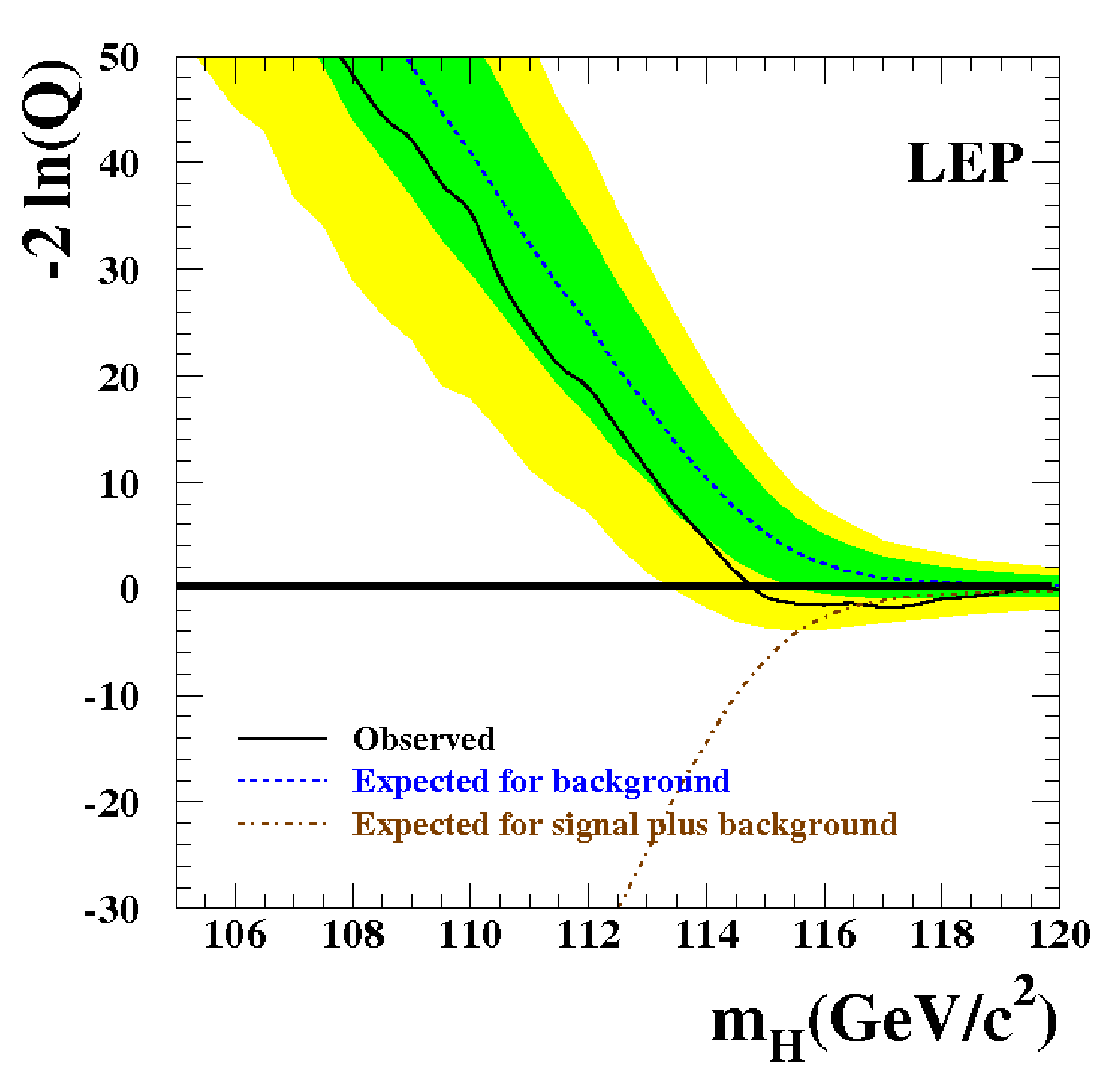


Higgs then: LEP SM Higgs

- Final LEP result:

M_H>114.4GeV
(95%CL)

Excess at 115GeV would happen in 9% cases without signal
But signal remains the best fit



Higgs now: The Tevatron

- Tevatron is running well, pp at 2TeV collision energy
  - 5fb^{-1} delivered
  - Records broken all the time
- CDF and D0 are in great shape
  - Run II results coming out – top quality
  - B tagging working well (e.g. B_s oscillations!)
- Now sensitive to SM Higgs

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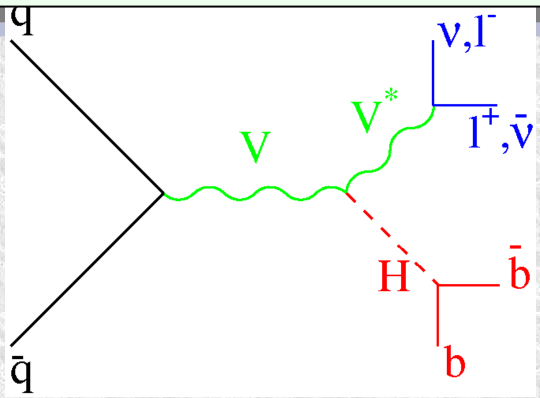
Slide from 2001

Same process as at LEP:

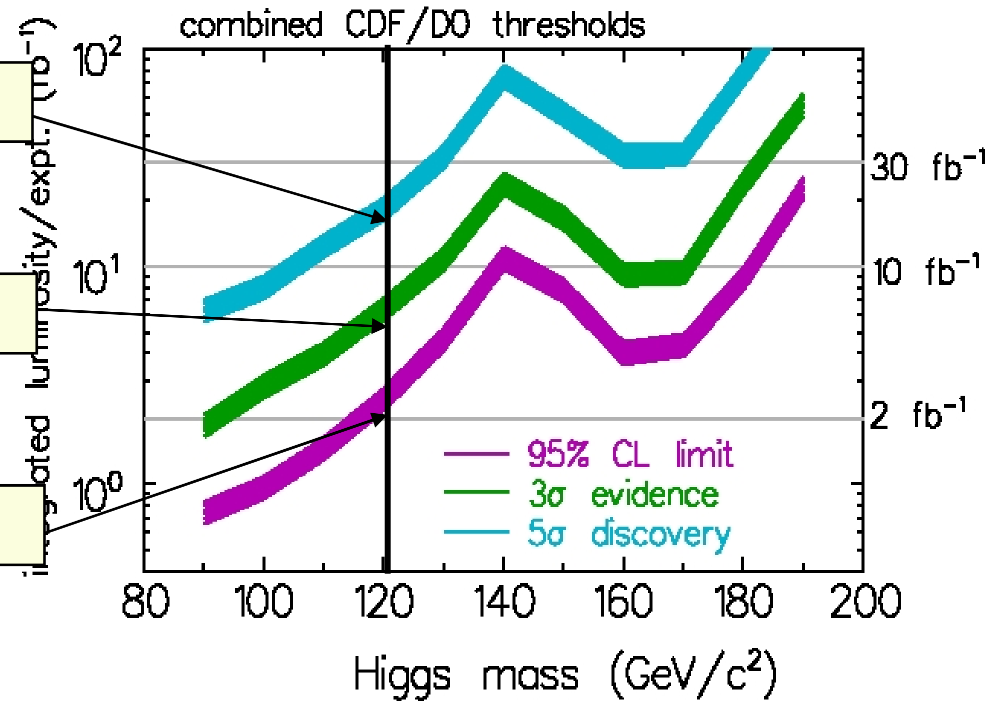


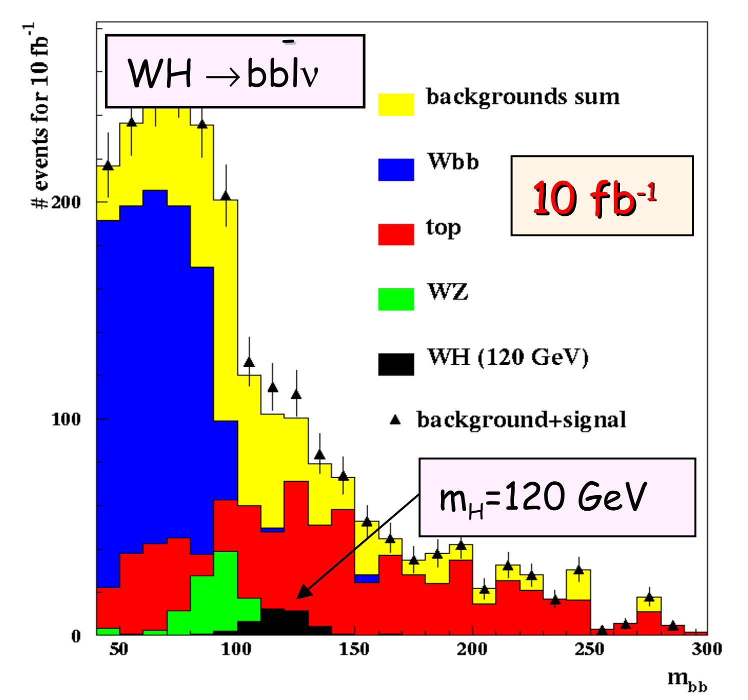
Produced: 50 events / fb^{-1}

5σ in 2007

3σ in 2004

2σ in 2002





- Should confirm LEP hints;
- Much more difficult environment;
- Somewhat later; (3σ from 2004 to 2007);
- No detailed studies of the Higgs mechanism…
- Difficult above 115 GeV/c^2.

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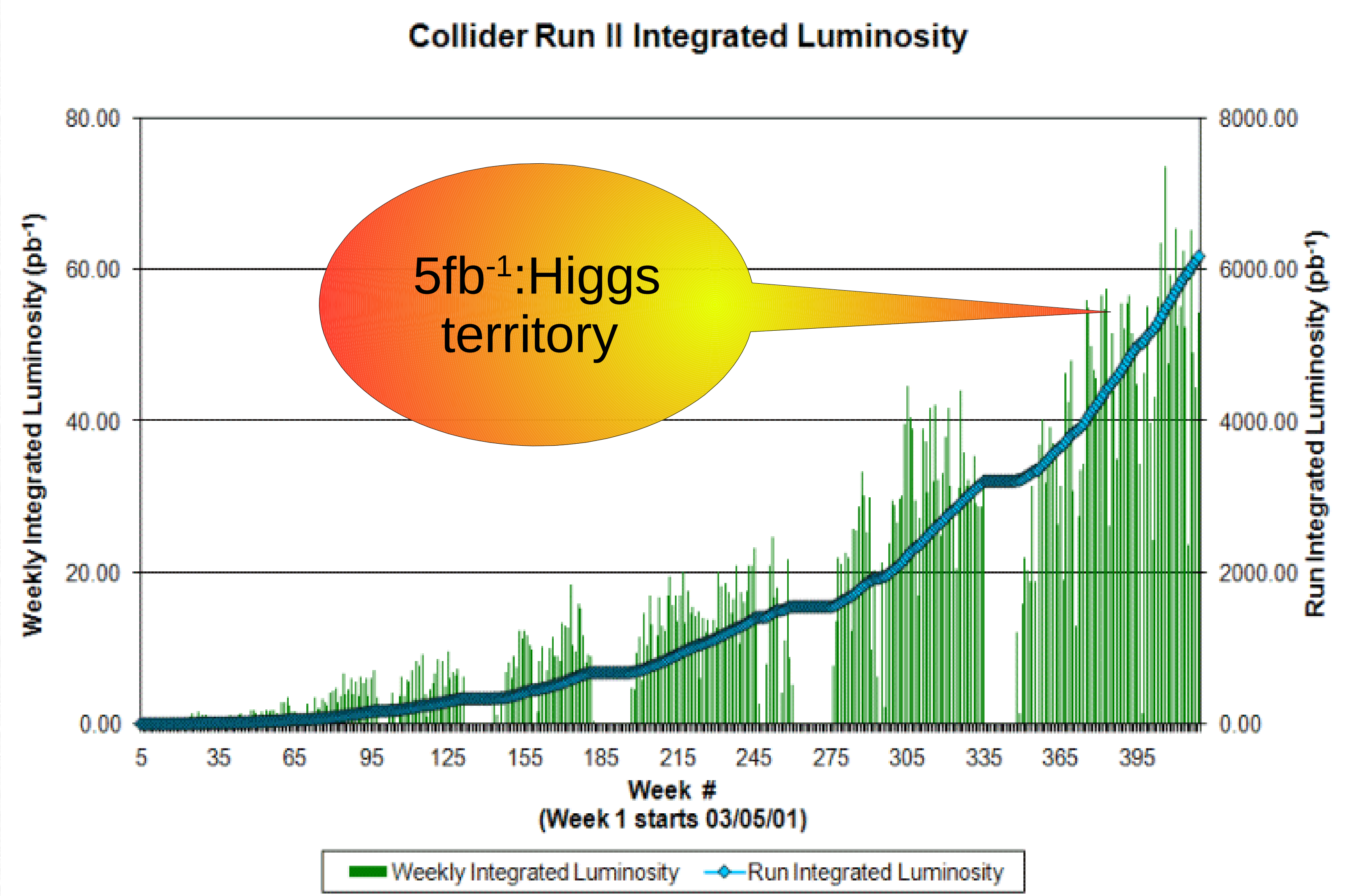
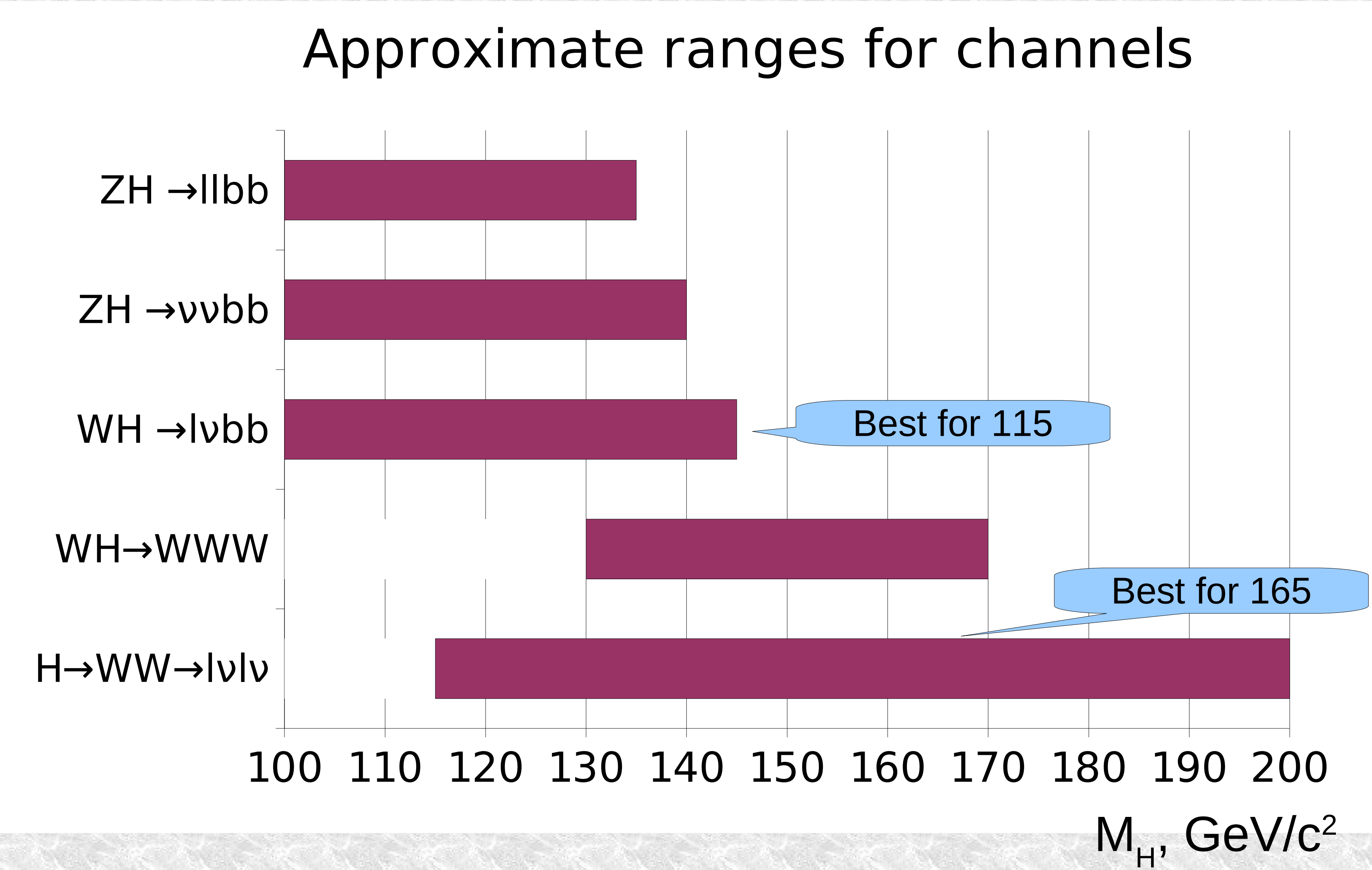
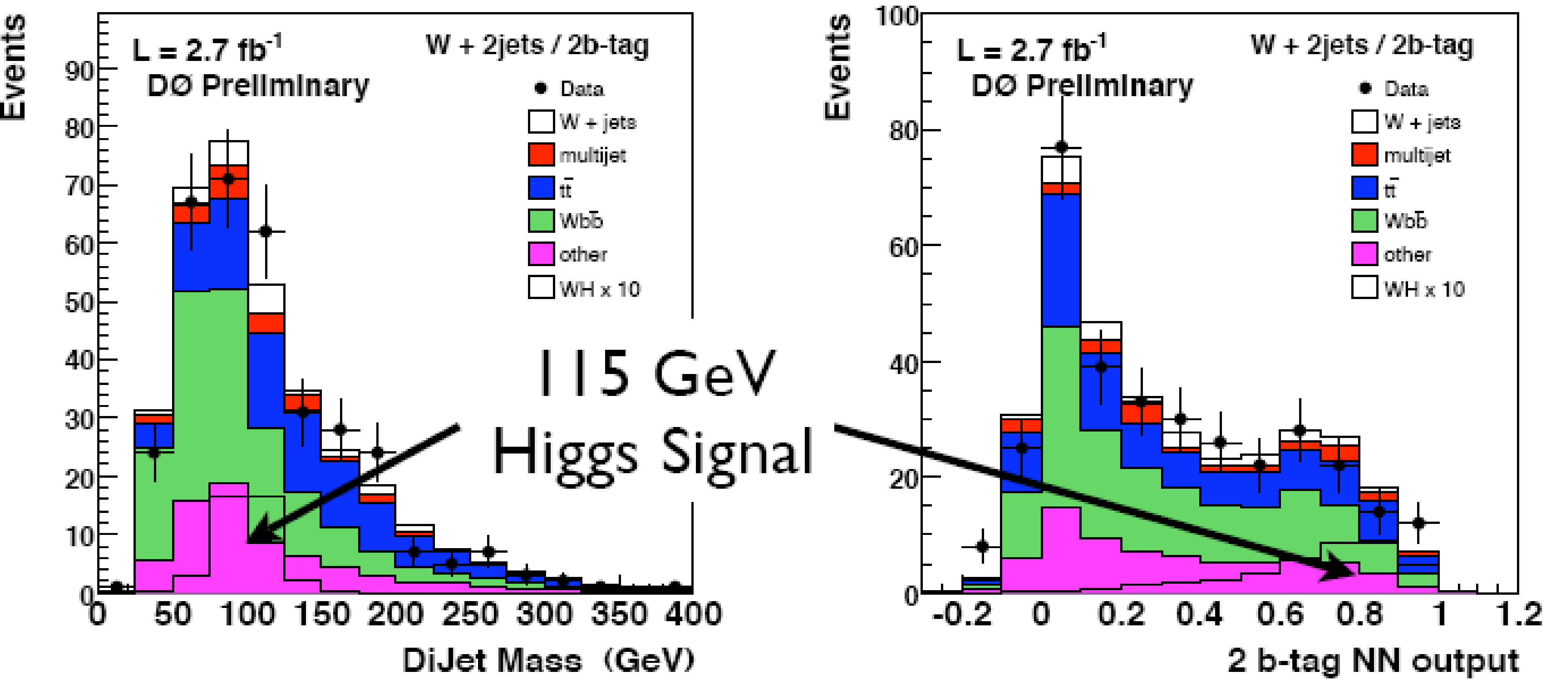
Higgs now: The Tevatron



Tevatron Search channels



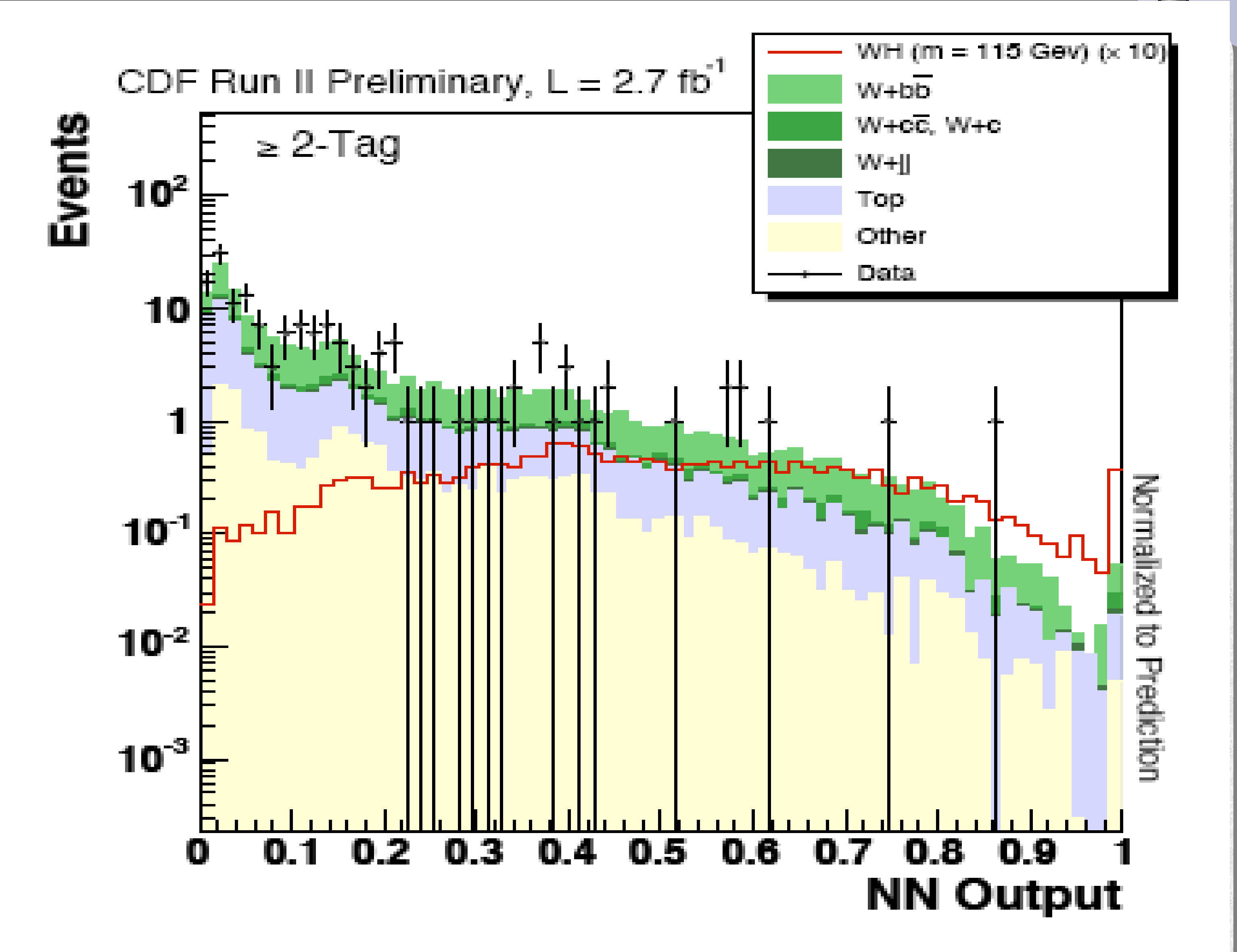
D0 WH → lνbb



- Expected 6.4, observed 6.7 $2.7fb^{-1}$ s/b=1/20

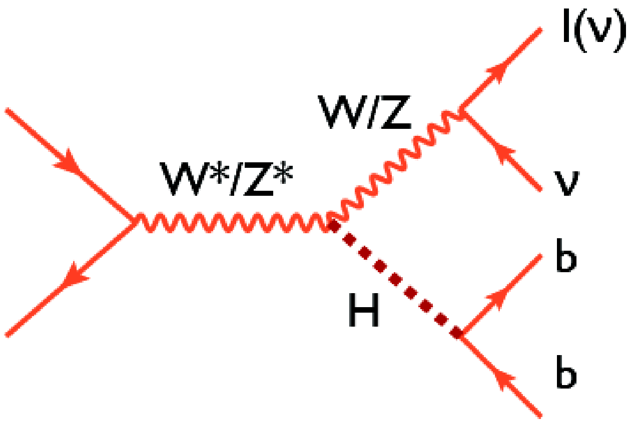
CDF WH → lνbb

- Expected 4.8
- Observed 5.6
- $2.7 fb^{-1}$
- s/b 1/10

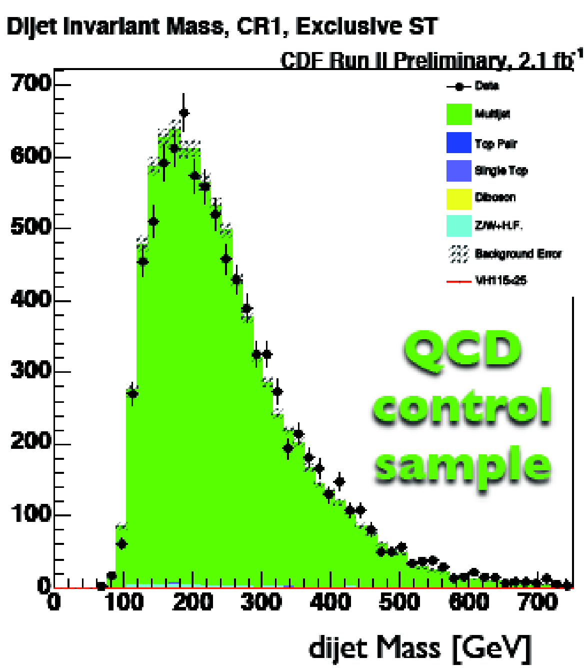


W/Z+H → ννbb Search

- Signature: 2 high p_T b-jets and large missing E_T from undetected Z→νν decay.
  - ➡ Accept WH→lνbb where lepton is not found (~50% of total signal)
- Both CDF and DØ analyzed 2.1 fb^{-1} for this search.

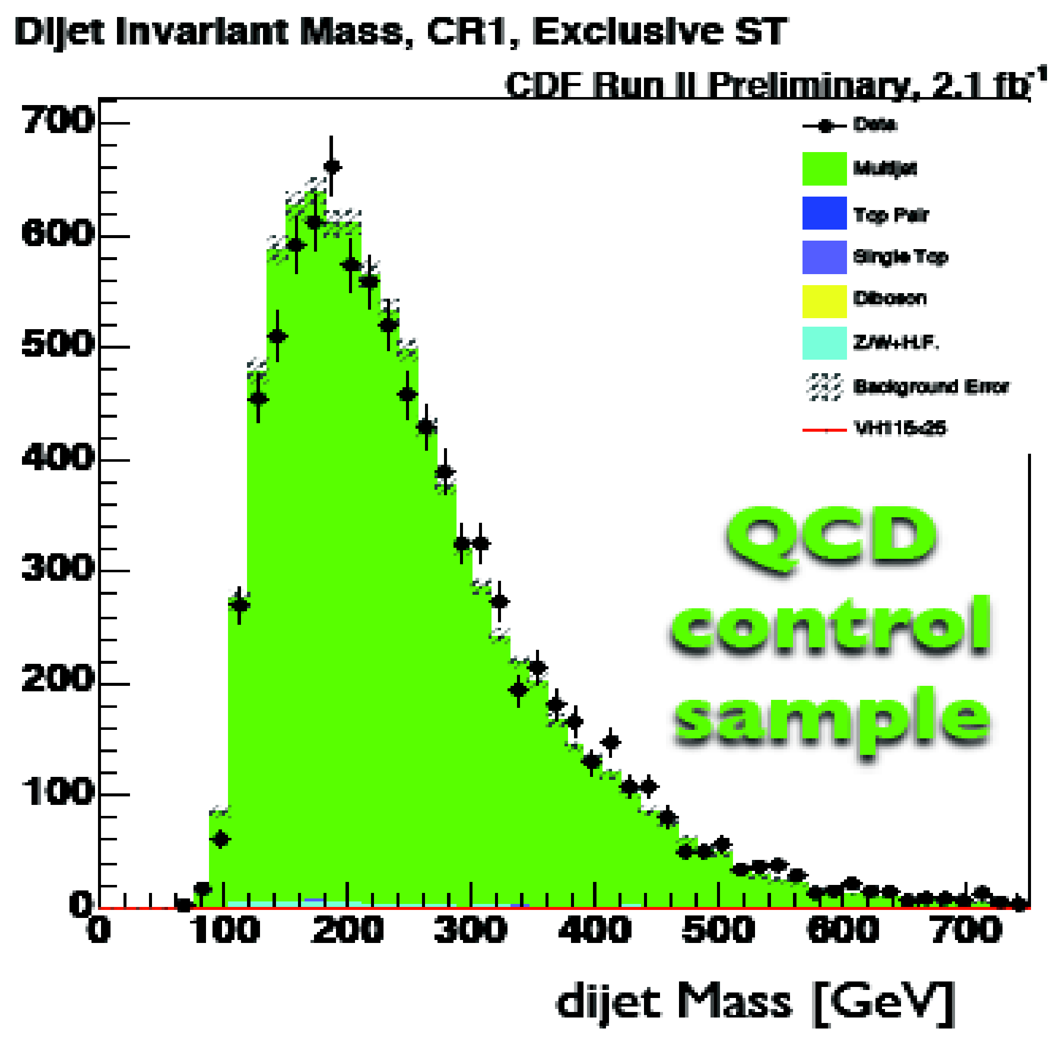


	Missing E_T	Jets
DØ	ME_T > 50 GeV	≥2 jets, (ΔΦ(jet1, jet2) < 165° jets P_T > 20 GeV, $\|\eta^{jet}\|$ < 2.5
CDF	ME_T > 50 GeV	≥2 jets, jet P_T > (35)20 GeV, $\|\eta^{jet}\|$ < 2.0



- Background dominated by QCD multijet production. Difficult to model in MC ⇒ Use Data!
- Define multijet and W+jets dominated control samples test backgrounds.
- Events sorted by number of tagged jets similar to WH and ZH→llbb search.

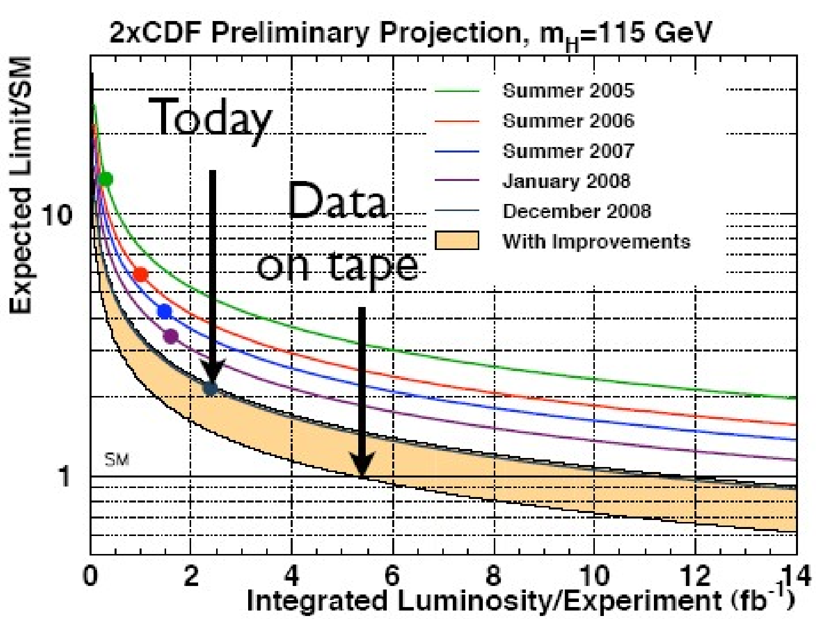
Look at control!

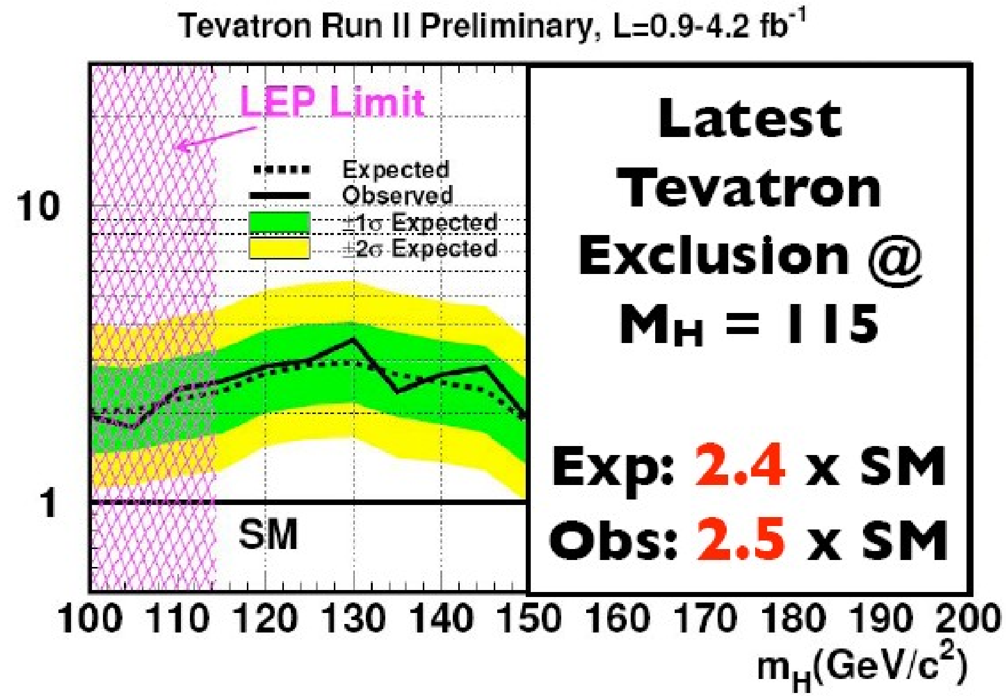


- 10% off around 120GeV.
- This is not good enough for s/b 1/10

Summary

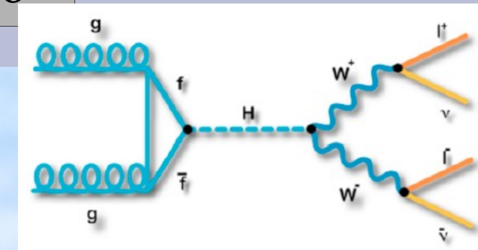
- Very exciting time to be at the Tevatron!
- CDF and DØ set Higgs limits only 2.6 times the Standard Model prediction using between 0.9 and 4.2 fb^{-1} of Run II data.
- Recent improvements in lepton ID, b-tagging, and multivariate techniques make analyses sensitive beyond $1/\sqrt{L}$ improvements from increased statistics.



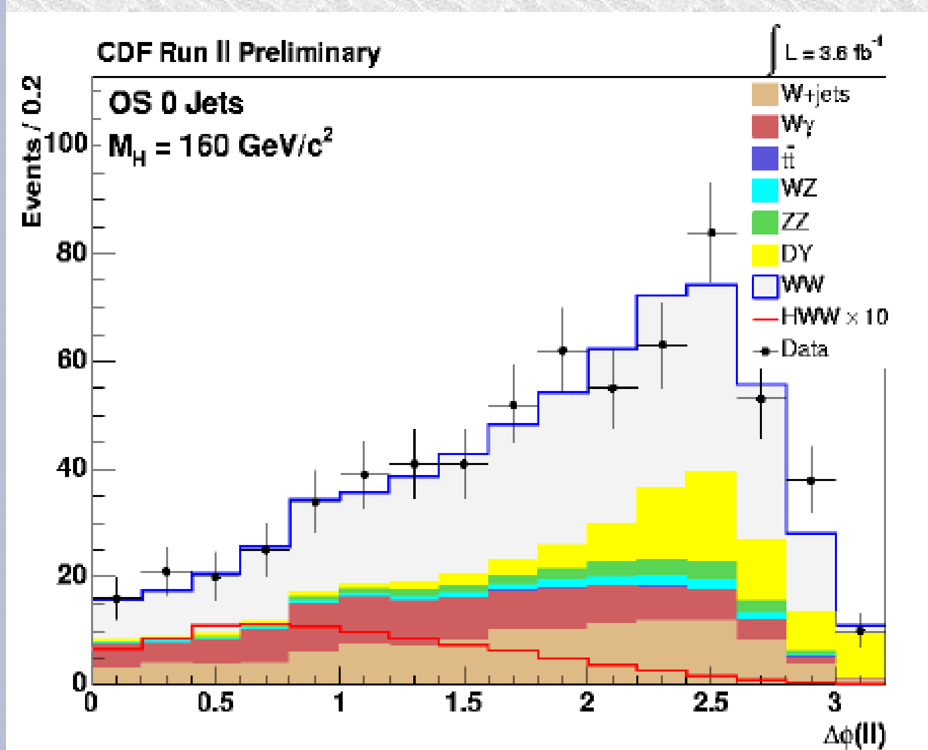


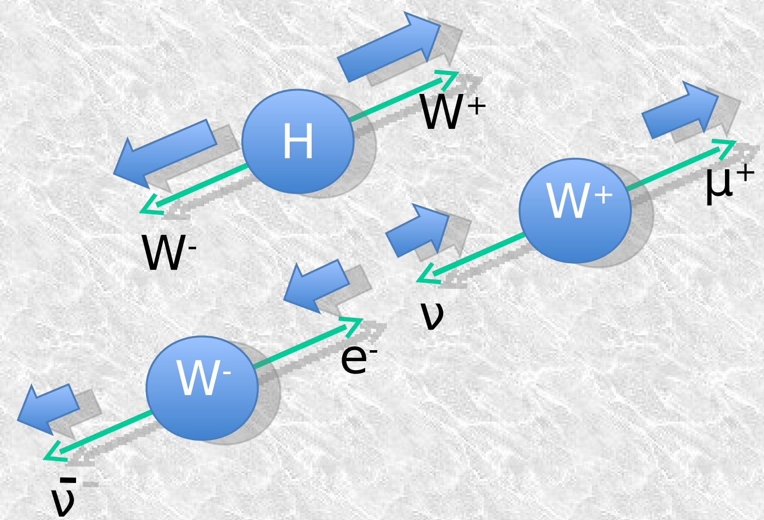
- CDF recently made projections for combined Tevatron sensitivity for M_H = 115 GeV.
- If we work hard and keep collecting high quality data we may soon talk about the Tevatron low mass limit!

SM Higgs: H→WW



- H→WW→lν lν - signature: Two high p_T leptons and MET
  - Primary backgrounds: WW and top in di-lepton decay

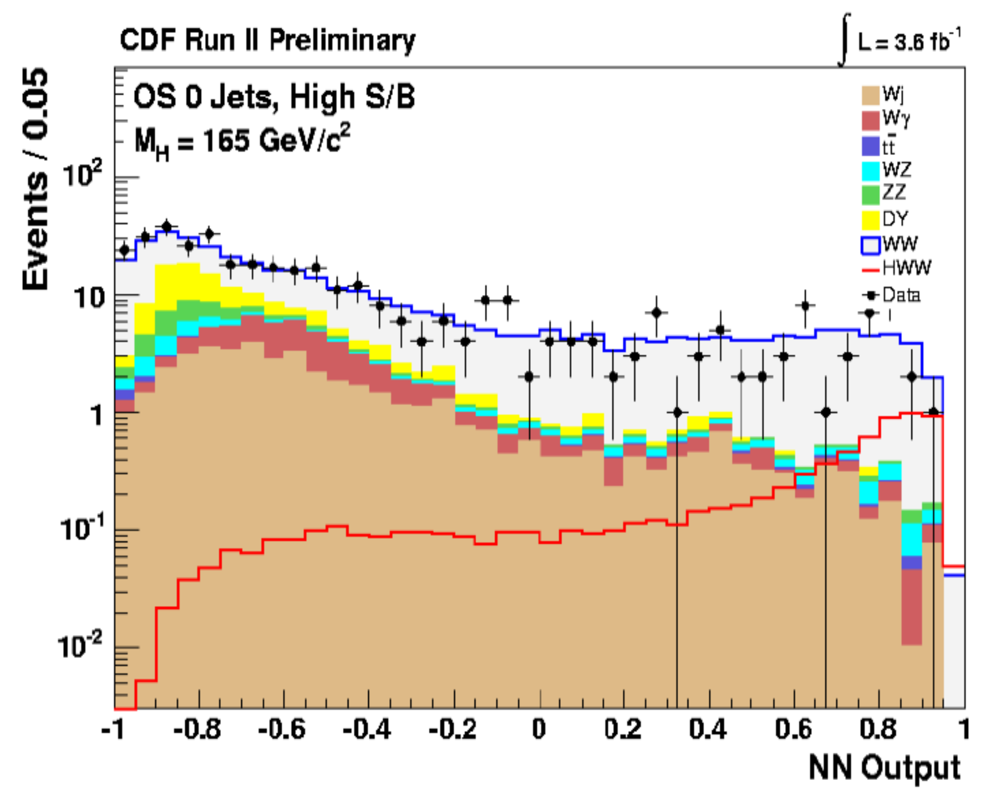


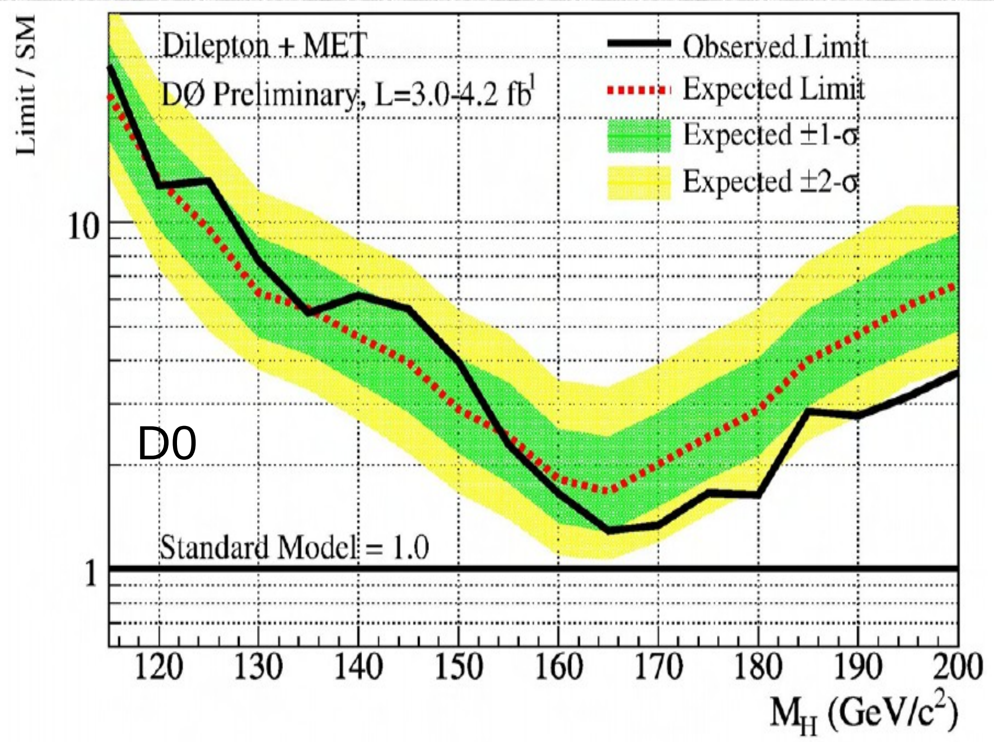


Spin correlation: Charged leptons go in the same direction

SM Higgs: H→WW

- Most sensitive Higgs search channel at Tevatron





Both experiments Approaching SM sensitivity!

Results at mH = 165GeV : 95%CL Limits/SM

Analysis	Lum (fb^{-1})		Exp. Limit	Obs. Limit
CDF	3.6		1.5	1.3
DØ	3.0-4.2		1.7	1.3

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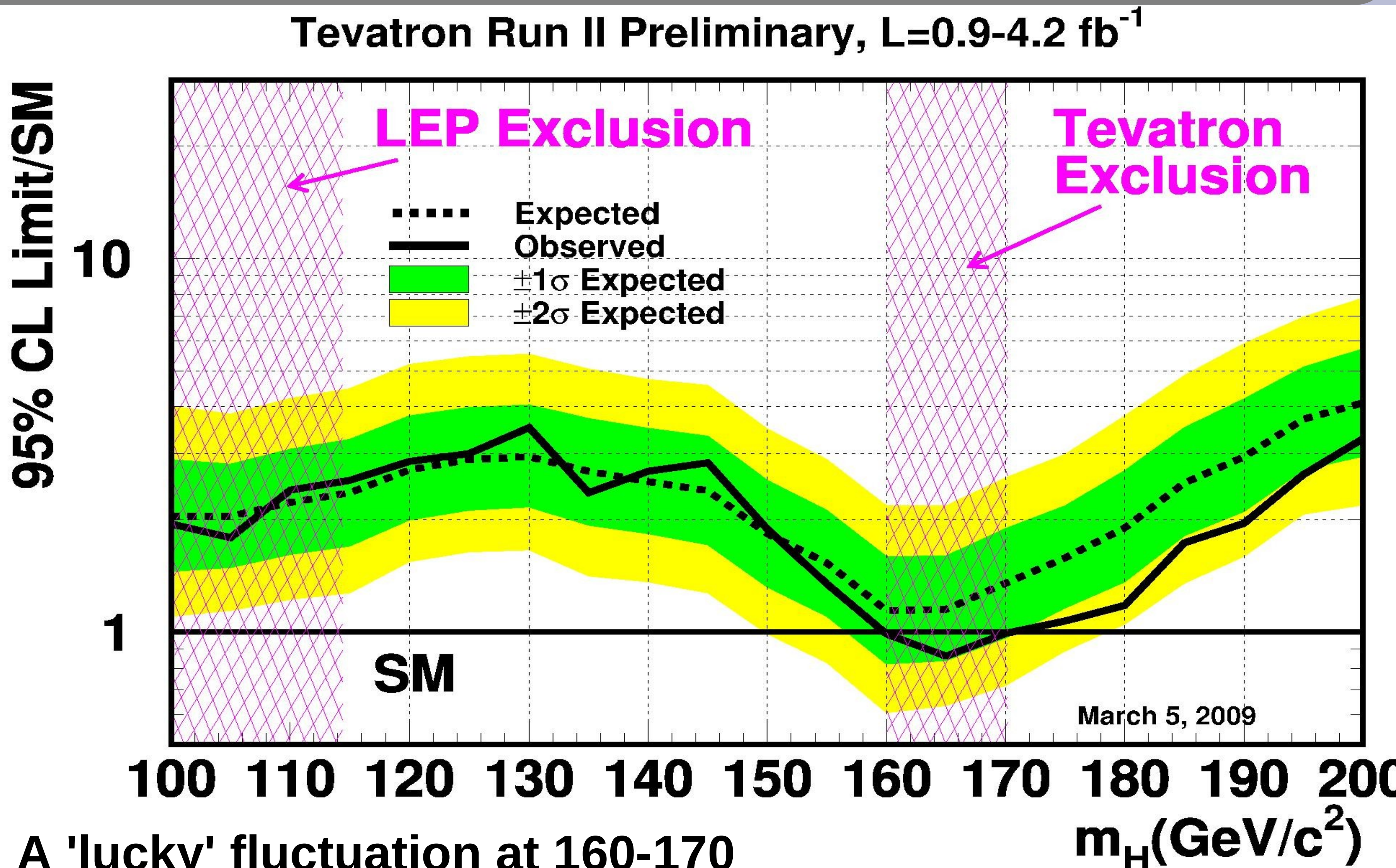
Tevatron Higgs Combination



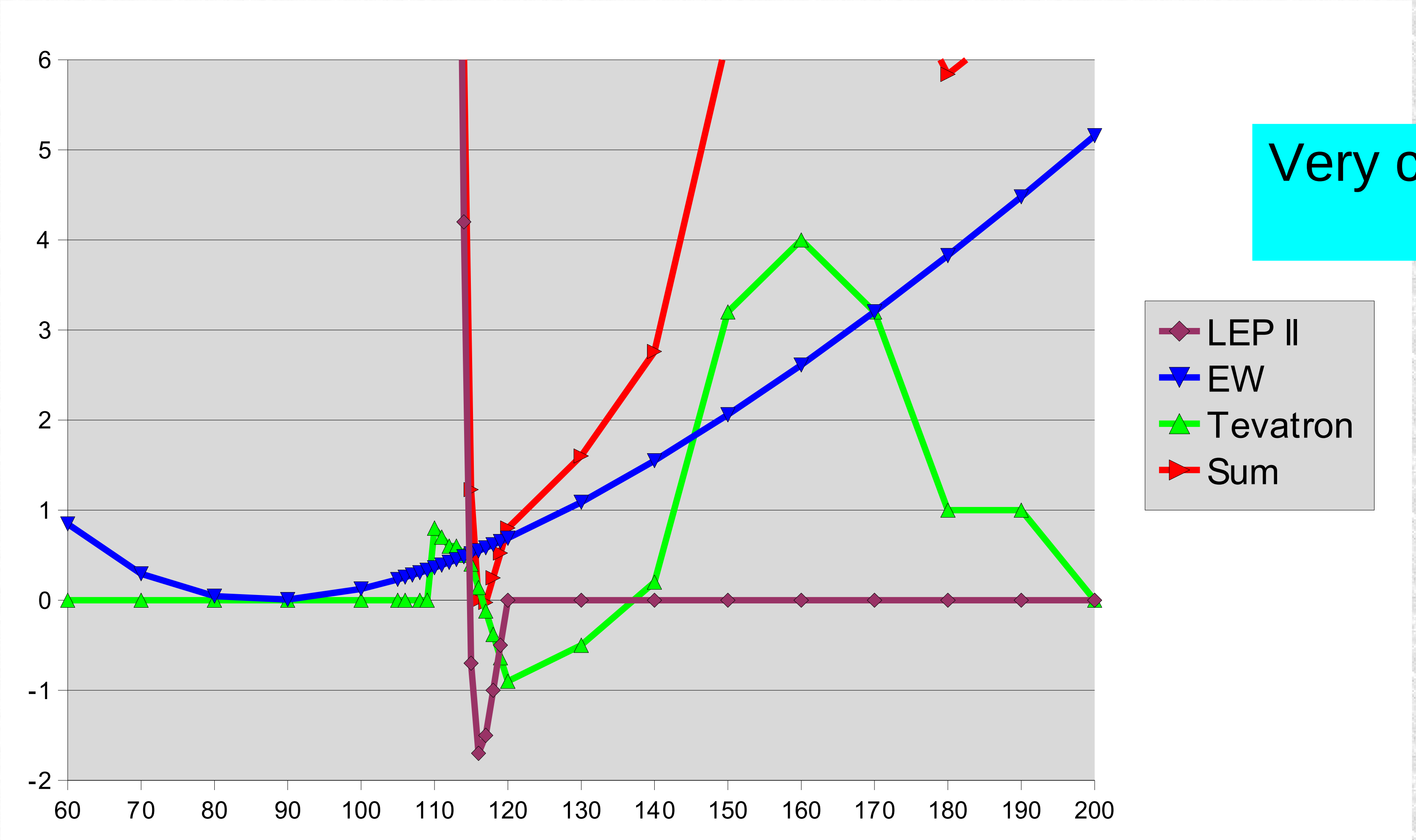
A 'lucky' fluctuation at 160-170

Would you believe the SM excluded at 2 sigma?

Tevatron Summary

- Results are not where they should be
- The data is years behind the estimates
  - 5fb^{-1} was supposed to be 2004, not 2008
- The analysis is way behind expected
  - 2fb^{-1} should have brought 2 sigma at 120
  - Instead 2.7 brings about 1 sigma
- There is a lucky exclusion, ruling out what was already known to be wrong
  - Adding 63 channels together is an art.
- But they are the only game in town.
  - Expect a factor 2 before LHC starts.
  - They can never discover anything
  - The may CLAIM large exclusions.

Add likelihoods from EW/LEP/TeV

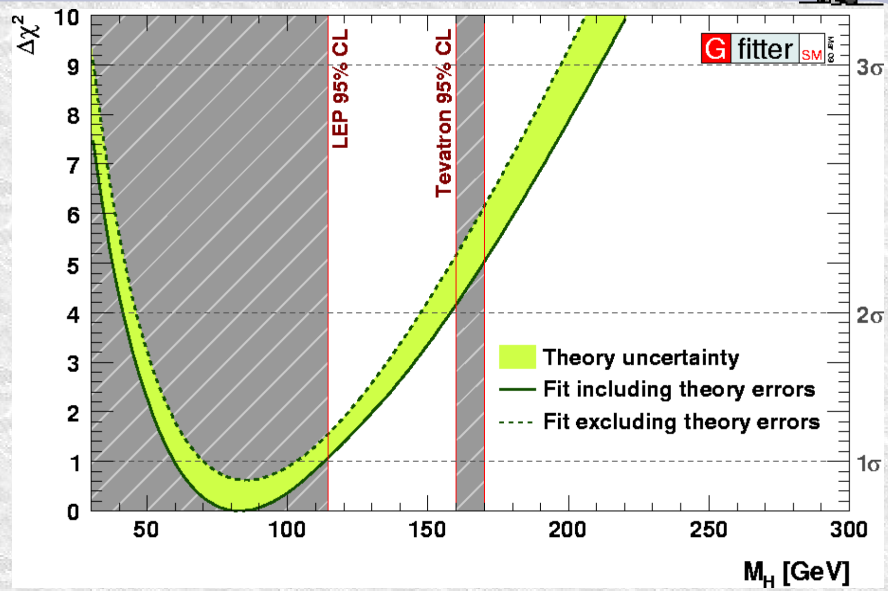


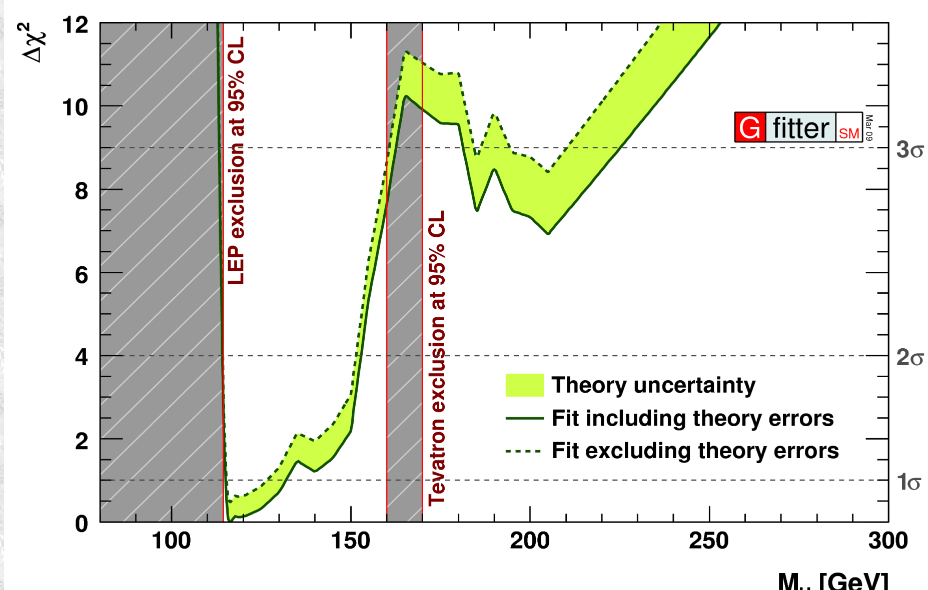
Very crude

- Higgs mass 115 to 135GeV

Electroweak fit: M_H

- Reproduce EW fit
- But also include search results
  - This is not done correctly
  - Discussion ongoing (this morning)
- Upper limit ~150 at 95% is conservative.





J Haller – ICHEP 08

Next: The LHC

- The 14TeV pp energy raises the Higgs cross section
  - Factor 1000 c/f 2TeV Tevatron
- Designed for 10^{34} luminosity
  - c/f 2 10^{32} currently at Tevatron
- Decades of preparation continue

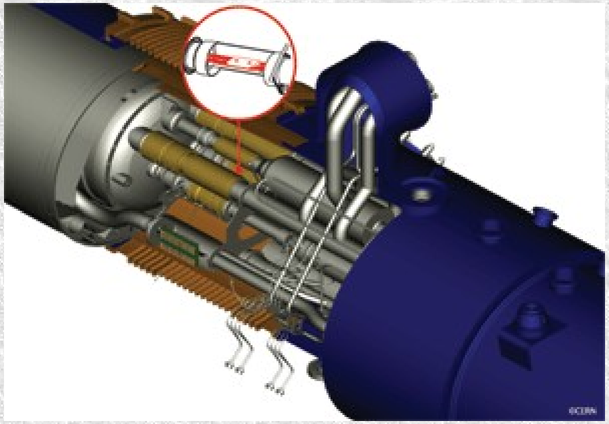
LHC status

September 10th: Ran wonderfully

September 18th: I got to CERN for LTA

September 19th: The incident...

The 'incident'



- Interconnect between two dipoles had resistive joint
  - Tens of nΩ?
- At 9KA this is watts..
  - Splice went normal conducting..and vaporized
- Punched hole from helium vessel to cryo vacuum, then to beam pipes
  - Helium poured down the vacuum tube
  - Vacuum seals every 200m tried to block it
  - 3 were forced open..pushed with their quadrupoles
- Now we have to clean up the soot.

Danger of Stored Power

- The be
- This B
  12 kno
- Steere
  hole

- The m
  fields i

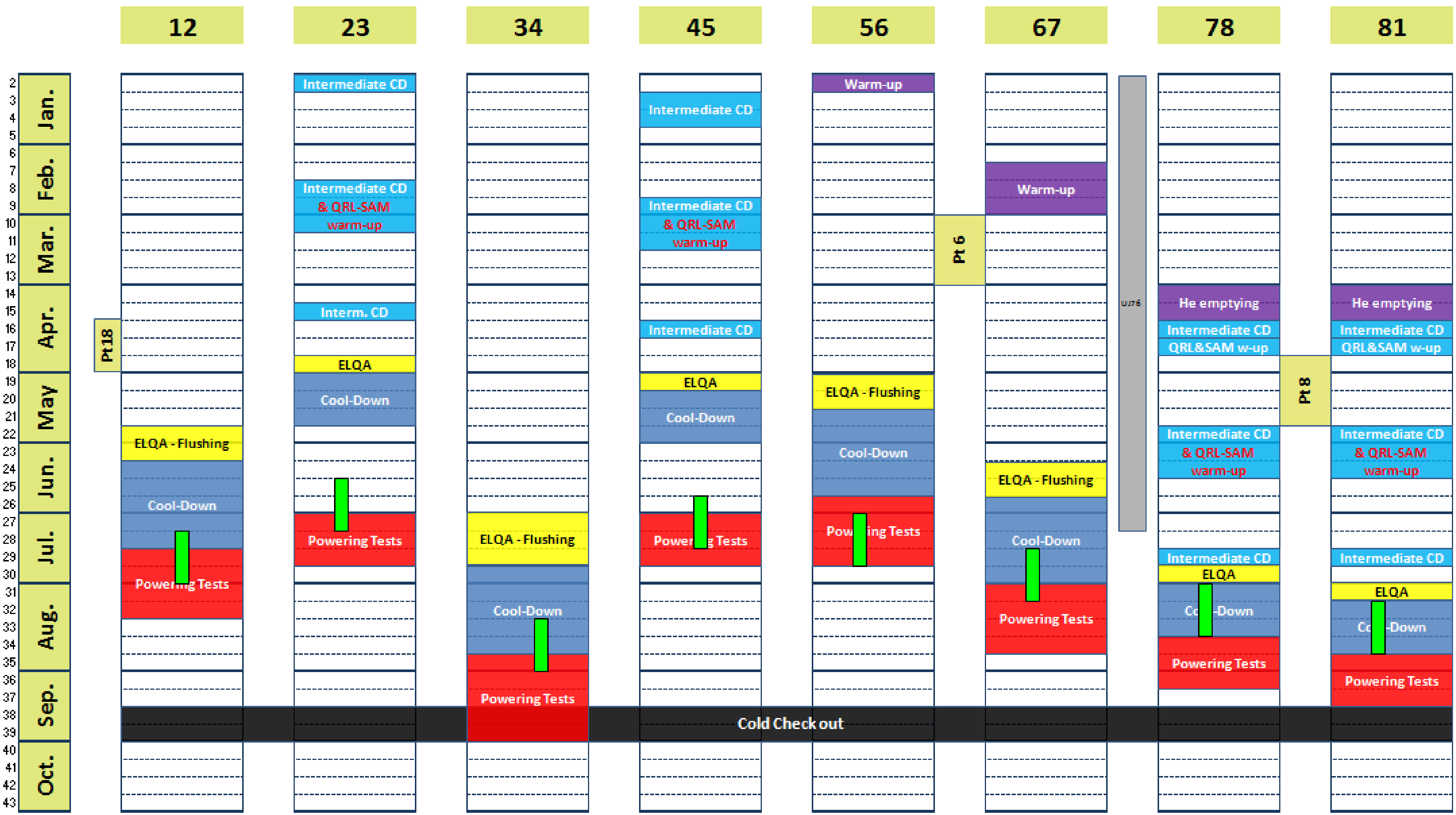
- This American aircraft carrier at 32 knots

SMA18

A22 (1085)/ B22 (3118) / C22 (1071): under preparation for cold testing

With powering tests

Katy Foraz



Fair to say that the schedule is very tight

Schedule with running in winter months

- Gains 20 weeks of LHC physics (independent of "slip")

Year	2009											2010														
Month	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Baseline	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH		SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	SH	SH	SH	SH
	24 weeks physics possible																									
Base '	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH	SH
	44 weeks physics possible																									
	Gain 20 weeks of physics in 2010 by running during winter months																									
	HIGH price Electricity																									
Delay (4W)	SH	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH
Delay (8W)	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH

Steve Myers

Beam – Chamonix baseline

- 4 TeV "on the way" to 5 TeV (no higher in 2010)
- Physics at 5 TeV
- Start with low number of bunches, low intensity
  - increase slowly 1,4,12,43, 156….
- Estimated integrated luminosity
  - during first 100 days of operation.. ≈100pb-1
  - during next 100 days of operation.. ≈ 200 – 300 pb-1
- End of 2010 run – one month ions

LHC Possible runs?

- Don't shoot me...just random guesses

Year	Energy TeV	Luminosity	Luminosity, fb^{-1}	
			Per year	Total
2009-10	10	Up to 10^{32}	0	0
2011	14	10^{33}	8	8.2
2012	14	10^{33}	8	16.2
2013-2015	14	10^{34}	80	258
2018+ SLHC	14	10^{35}	800	1058

- 30fb^{-1} often used: Nominal first 3 years

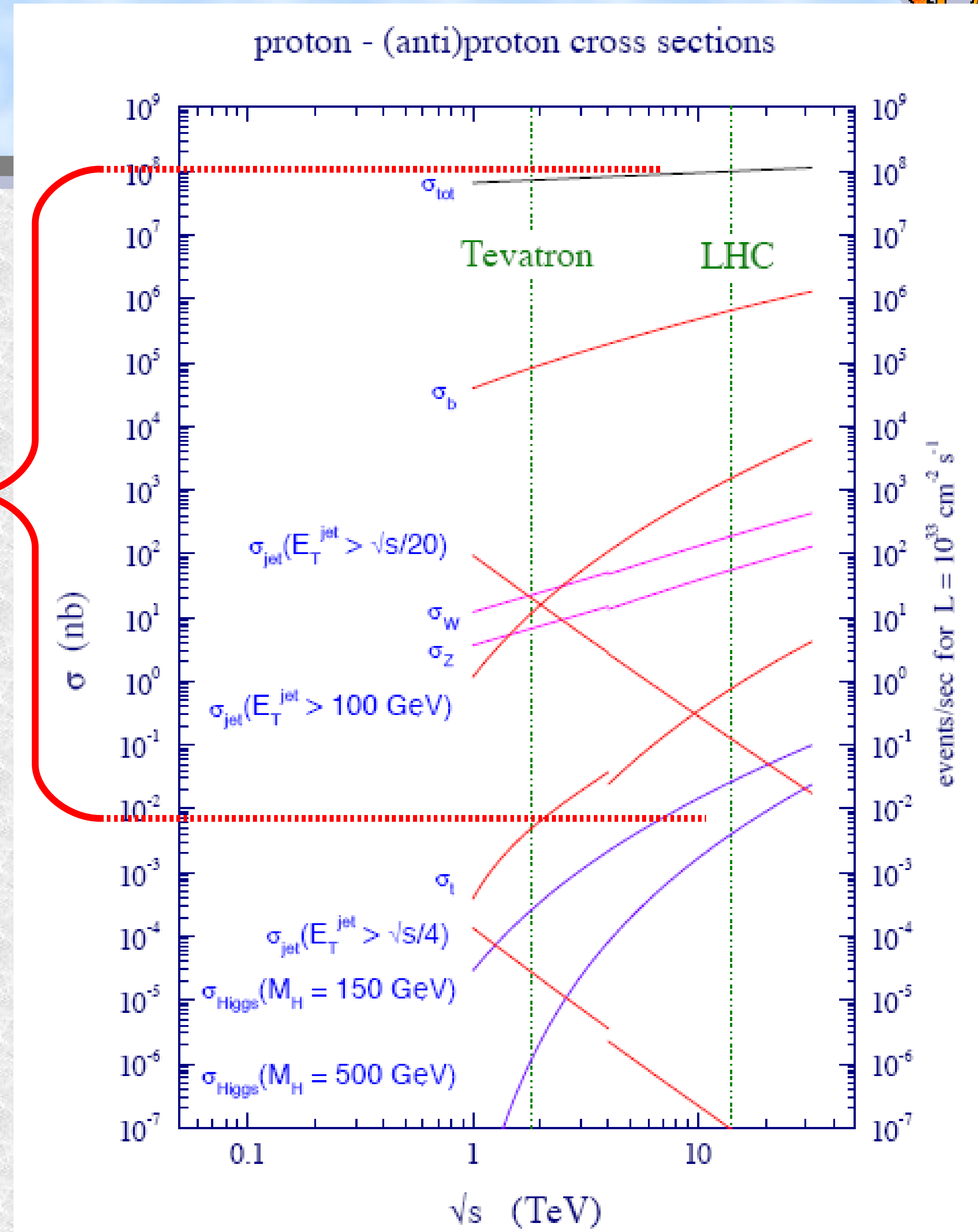
Rates?

- LHC backgrounds!

10^{10}

Every event at a lepton collider is physics; every event at a hadron collider is background

Sam Ting



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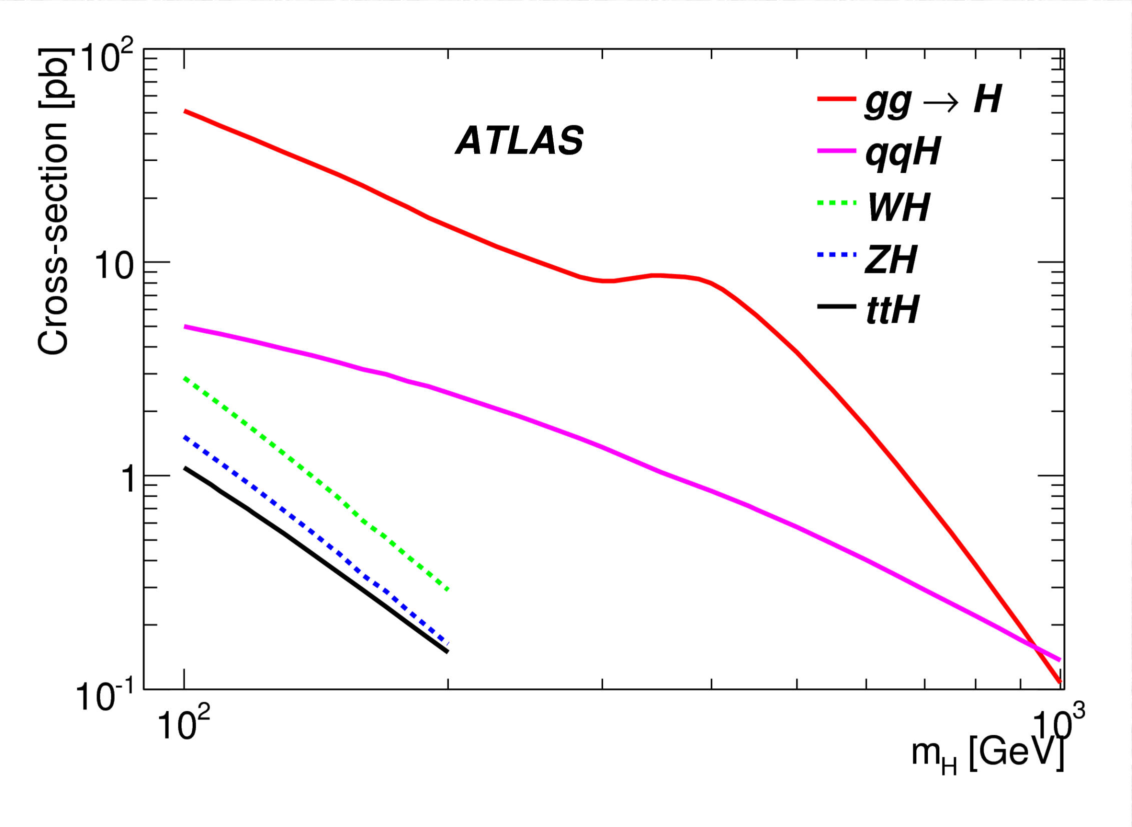
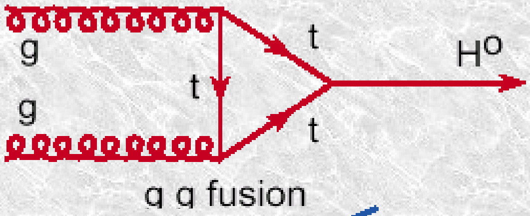
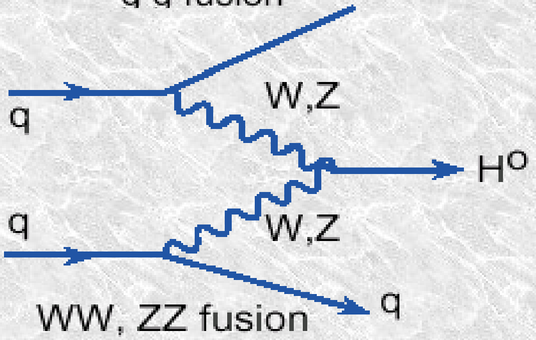
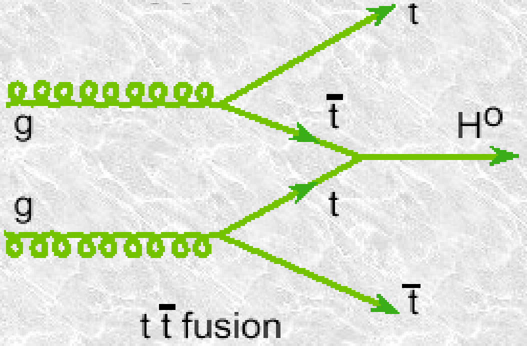
Higgs production

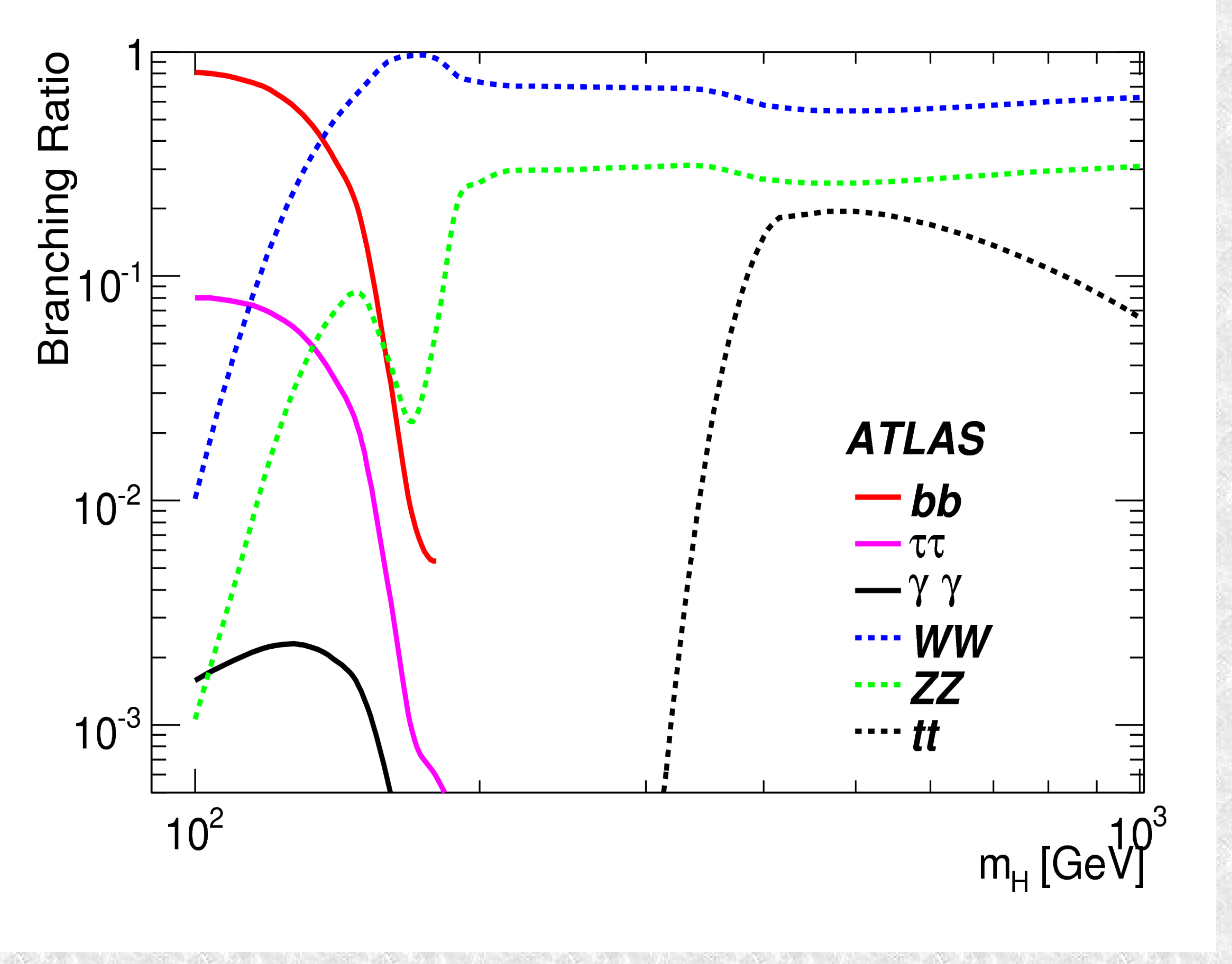




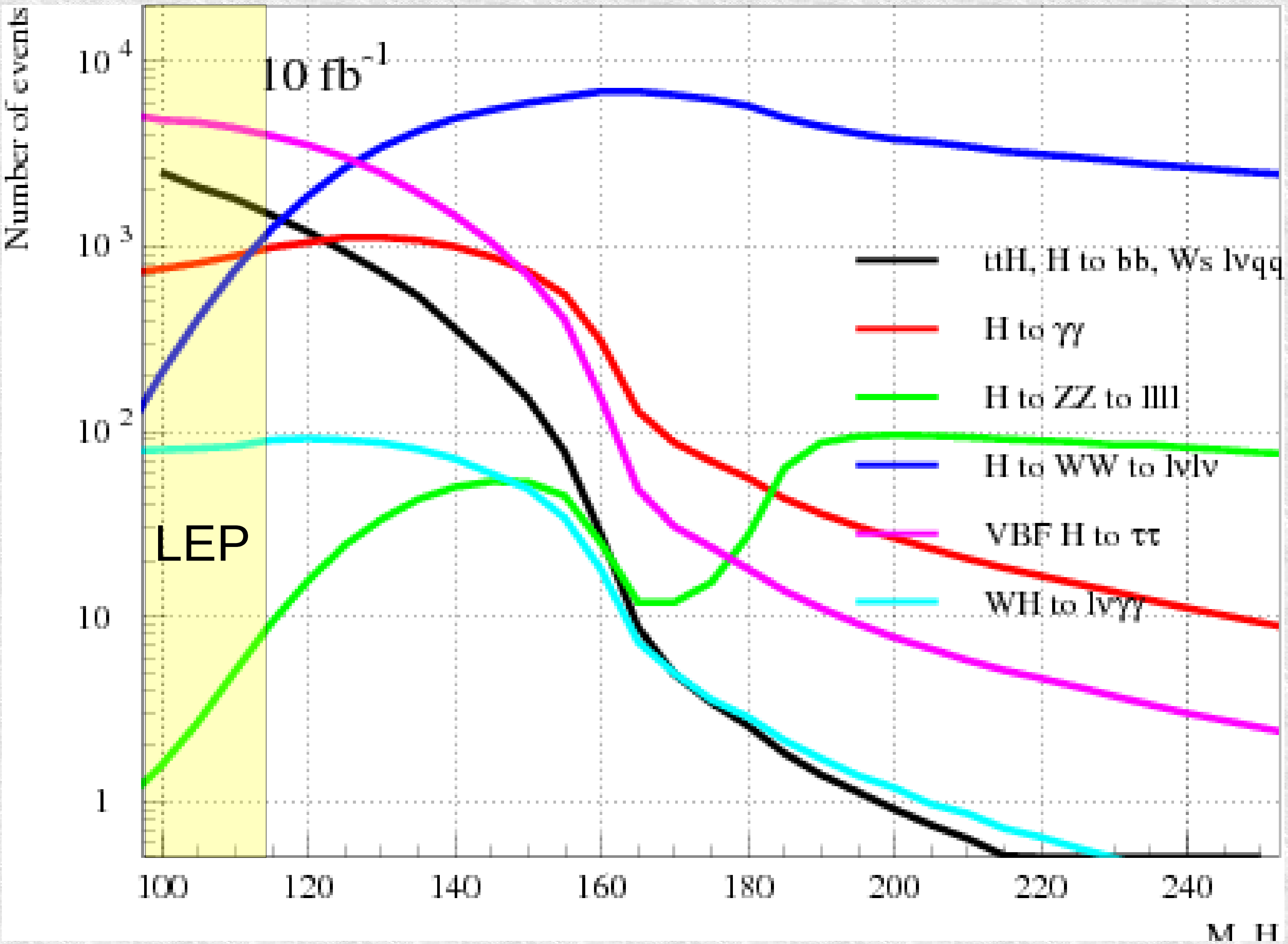




Higgs Decay


Branching Ratio
1
10^-1
10^-2
10^-3
10^2
10^3
m_H [GeV]
ATLAS
bb
ττ
γ γ
WW
ZZ
tt

Rates in channels used

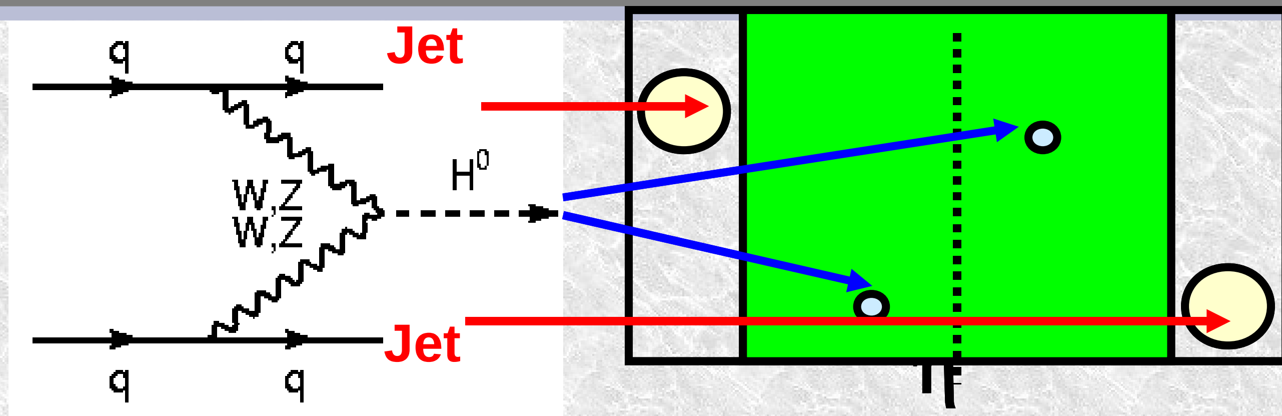


- Rates in major channels
- No cuts, just branching ratios
- l: e or μ
- Thousands of events to look for...
  - Far less will pass cuts

How to find the thing

- If Higgs boson is heavy (>140GeV/c^2)
  - Serious decays to WW, ZZ
  - These have clearly leptonic decay modes
  - ZZ→4l is frankly nicer, but WW→lνlν more common
  - The discovery is fairly straightforward.
- If Higgs boson is light (<140GeV/c^2)
  - (and it is)
  - Use rare H→γγ
  - Or VBF H→ττ – can trigger leptons
  - H→bb is dominant mode – can we find it?
    - Not without something to make it stand out
    - ttH, Z/W+H?

Boson fusion: qq→qqH→ττ



Low mass

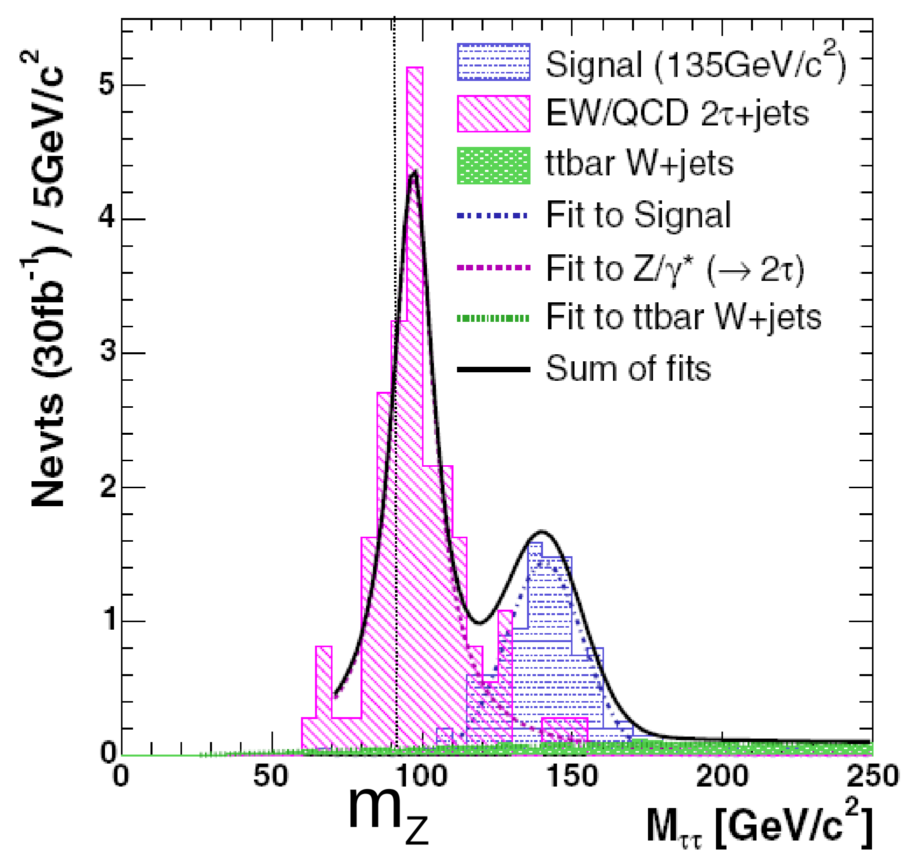
- Two forward jets, P_T like $M_W/2$
- Higgs products central
- No colourflow → suppressed central jets
- Z→ττ plus two jets main background

  - τ τ →lν l'ν ', lν+jet final states (τ hadronic ident.)
  - τ τ mass reconstruction: need P_T^{miss}

qqH(→τ τ) via VBF

Need to undestand tails in Z mass resolution

But signal to background could be good



- $S/\sqrt{B}$~2.5 in one LHC year

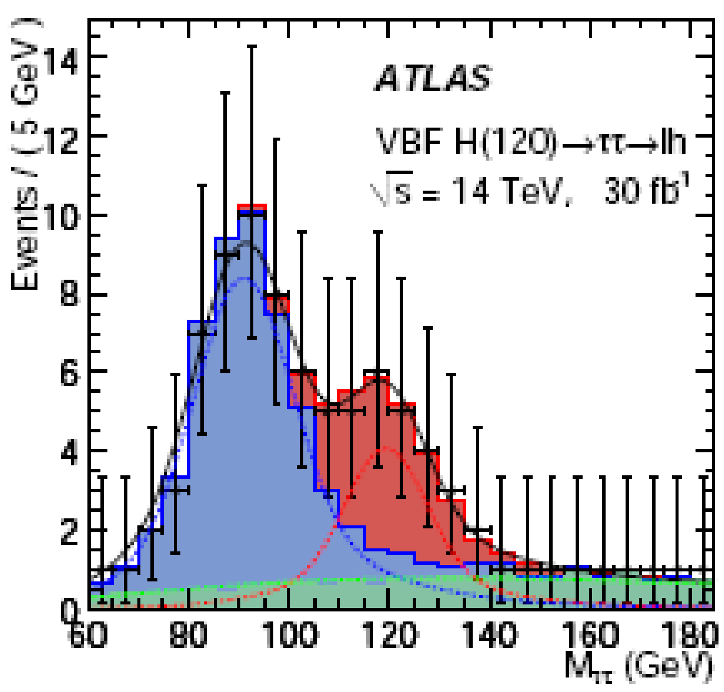
CMS: 40 fb^{-1} for discovery in m_H=120-140 GeV range

ATLAS: Maybe 20fb^{-1}

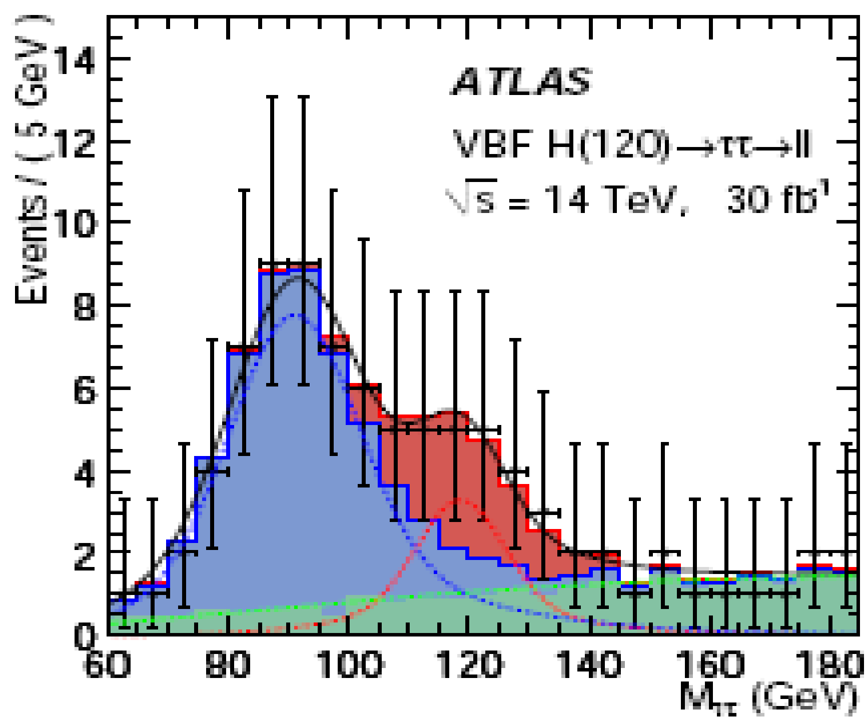
- Measures Yukawa coupling Hτ τ

H to ττ

- lh and ll plots for 120GeV signal



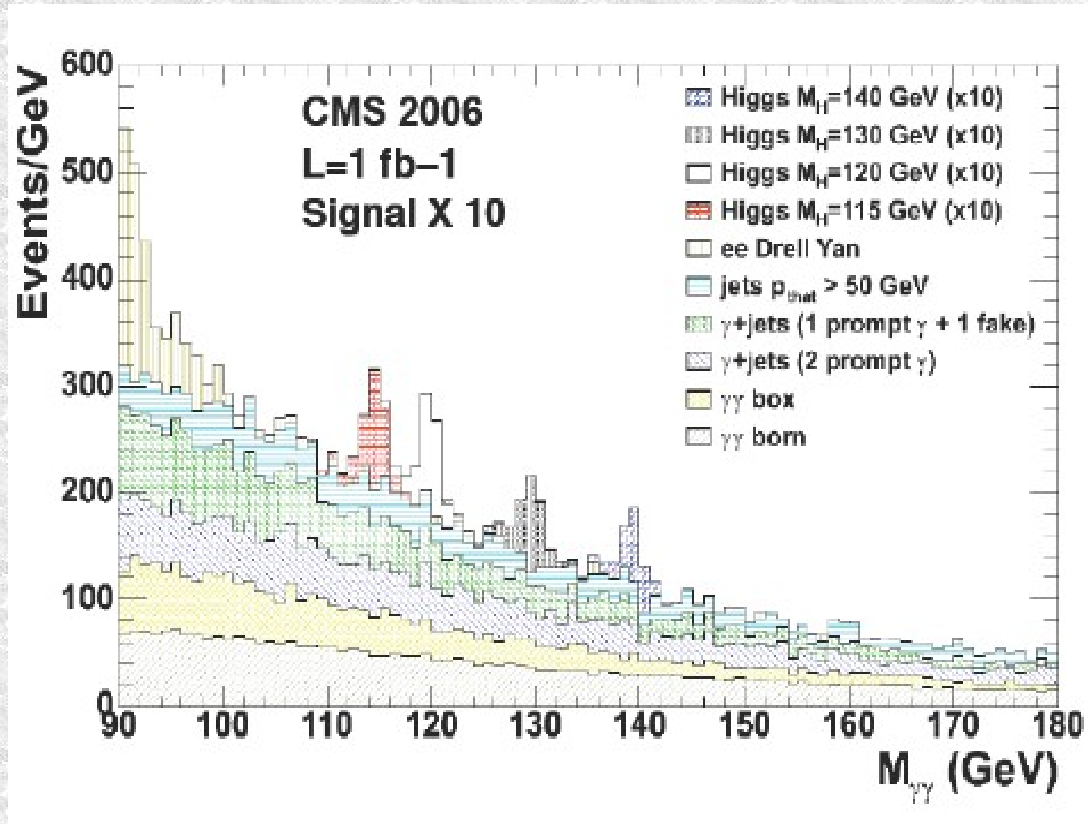
(a)



(c)

H→γγ

- Very rare (10^{-3}) decay mode – top loop
- But trigger, mass resolution are good
- Large backgrounds of γγ, γ-jet and jet jet
  - Jet rejection 10^3 required
  - CMS resolution 0.5GeV best
  - Production mechanism can be used to improve signal-to-background



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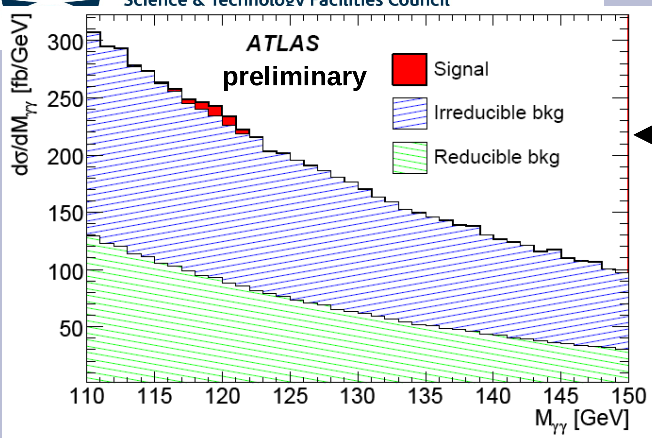
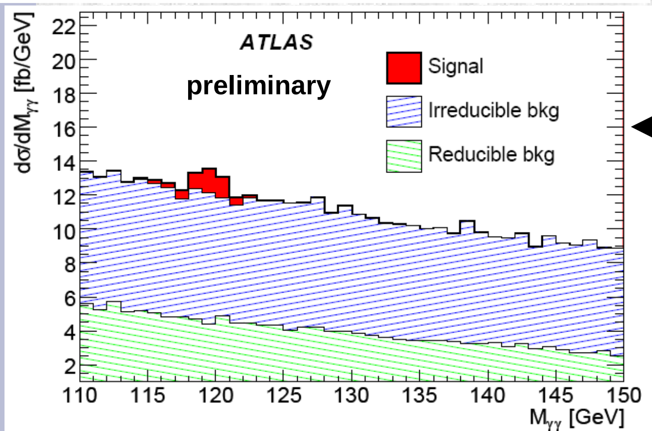
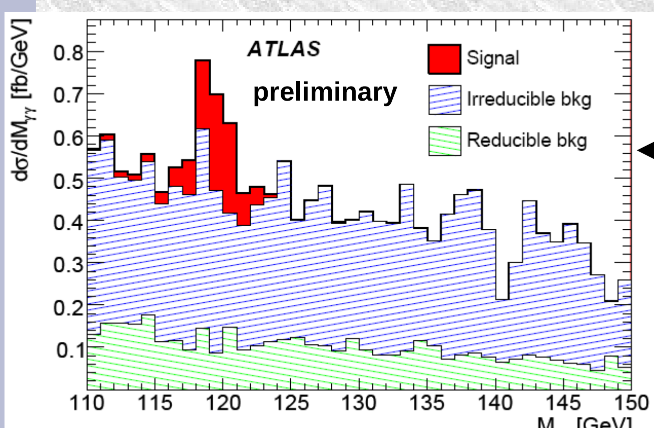
ATLAS



inclusive
S/B ~ .03

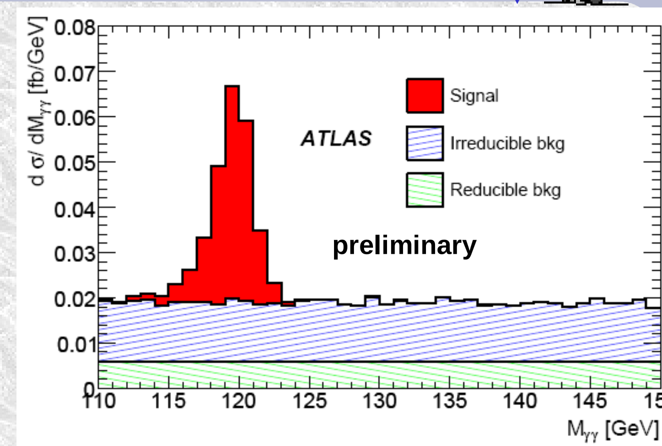


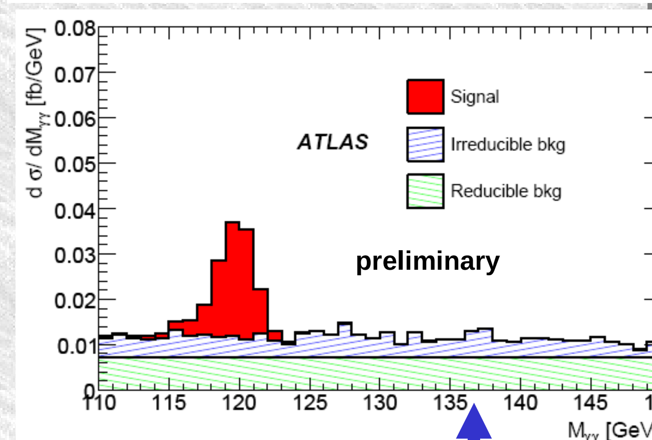
H+1j
S/B ~ .08
VBF + more jets with gg→H



H+2j
S/B ~ .4
VBF mainly

$H+E_T^{miss}$+ 1/
S/B ~ 2
ttH WH





$H+E_T^{miss}$
S/B ~ 2
ZH WH

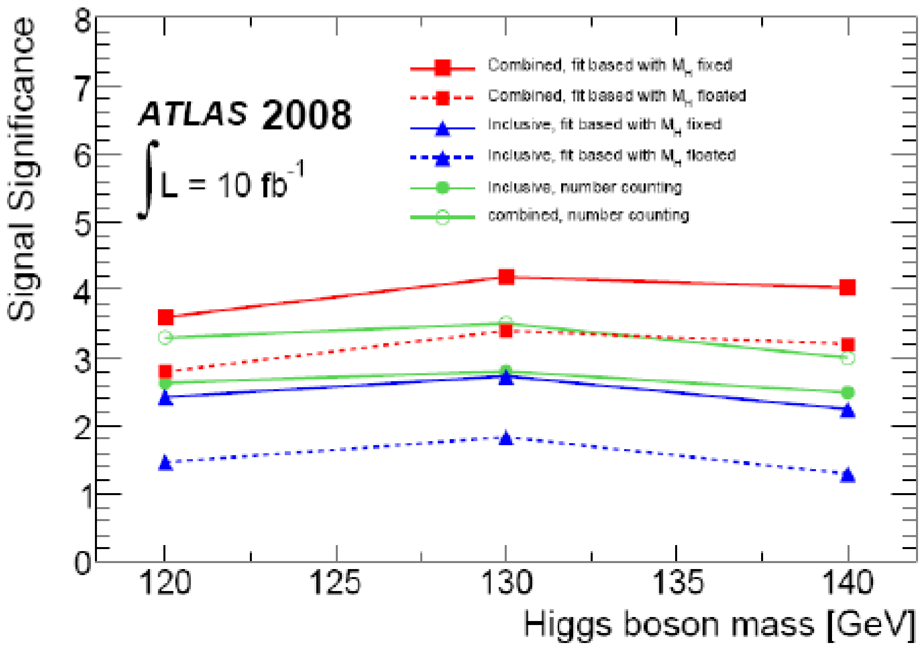
For different final states different S/B

Results for H→γγ

ATLAS

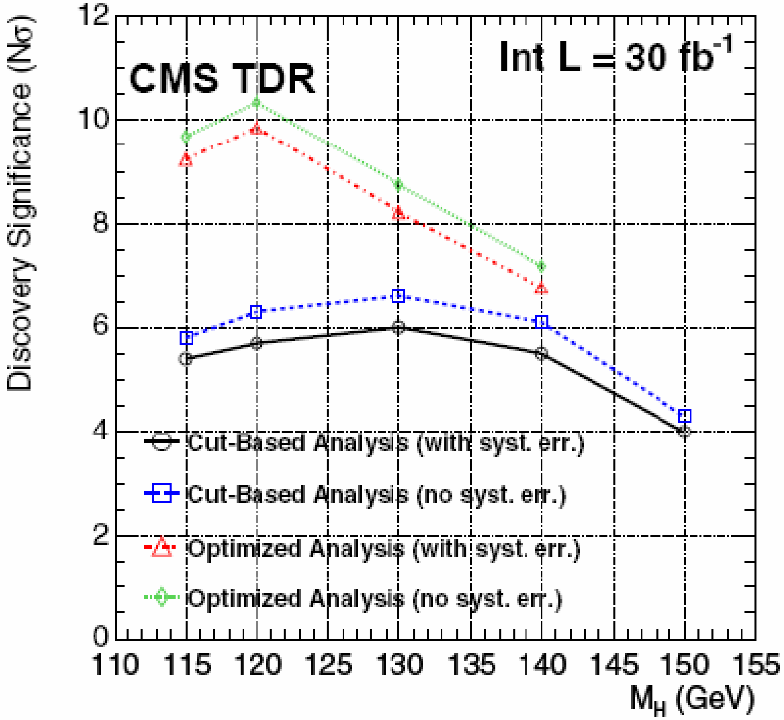
For m_H=120 GeV/c²:

- **Event Counting :** σ= 2.6 for 10fb⁻¹
- **Floating (fixed) mass fit, associated production with jets:** σ=2.8 (3.6) for 10fb⁻¹
- **Changes:**
  - more reducible background with one fake photon(x2)
  - combining the 0,1 and 2 jets analyses



CMS

- **5σ discovery between LEP lower limit and 140 GeV/c² with less than 30 fb⁻¹ of integrated luminosity.**
- **5σ discovery with event by event estimation of the S/B ratio possible at m_H=120GeV/c² with 7-8fb⁻¹**

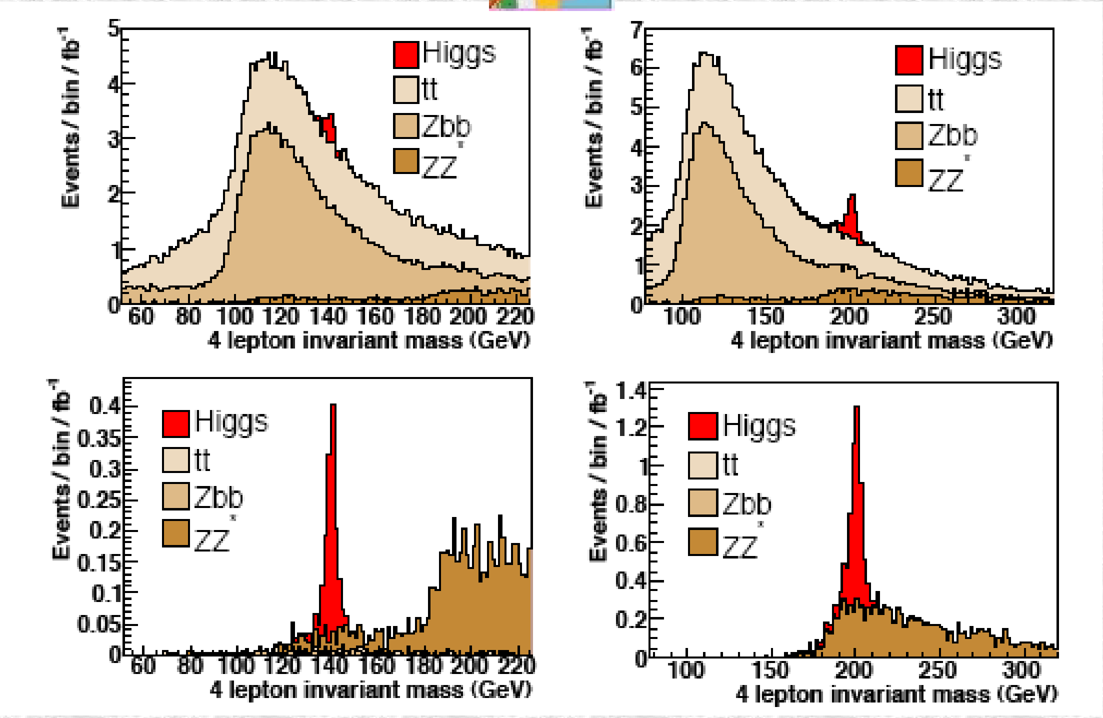


✓ **CMS slighlty higher sensitivity**

✓ **Improvements possible by using more exclusive γγ + jet topologies**

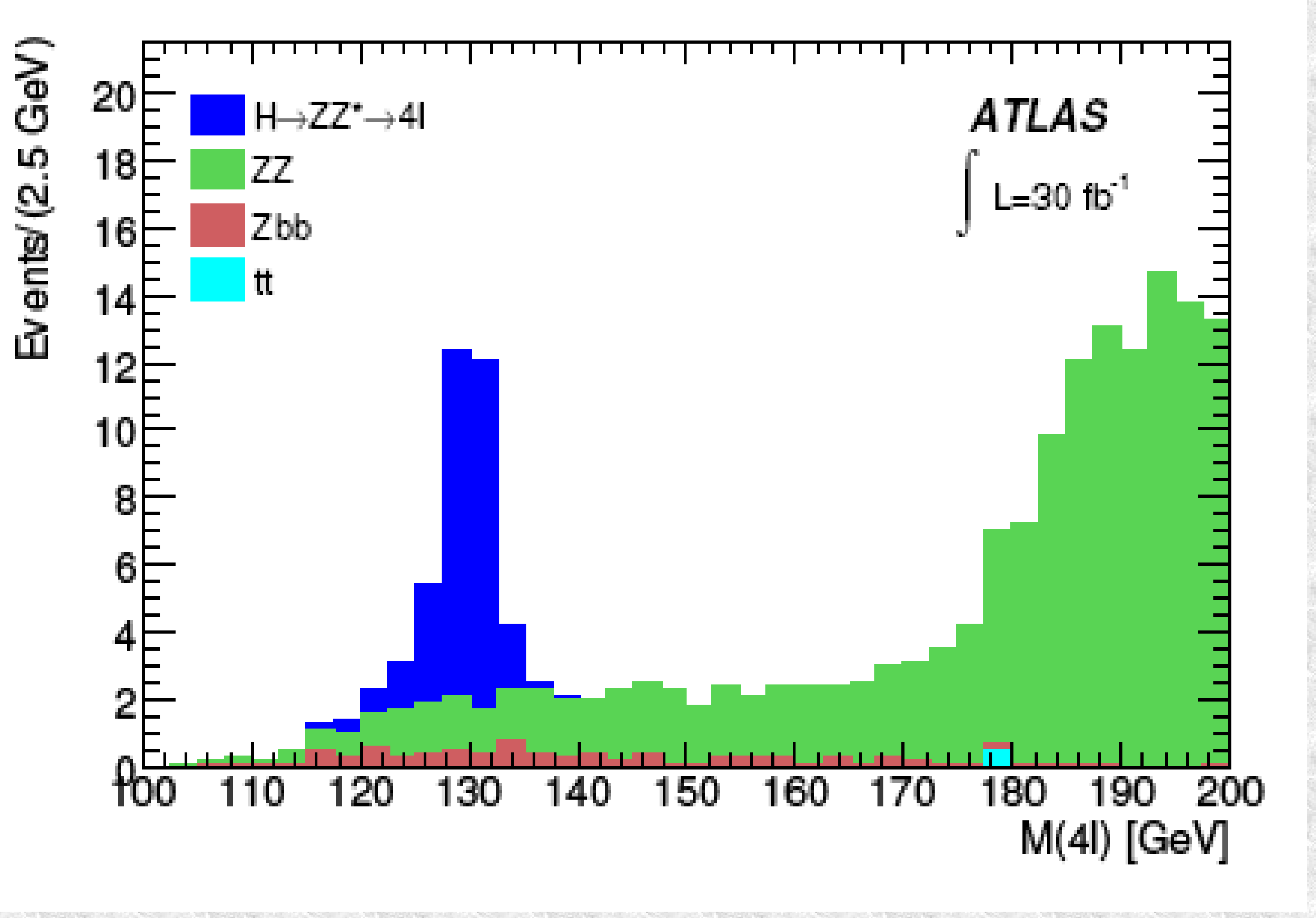
$H \rightarrow ZZ \rightarrow l^+l^-l^+l^-$

- Golden channel m_H>140GeV/c^2
  - Above ~200 two real Z's
- Good mass resolution, trigger
- Backgrounds:
  - Irreducible QCD ZZ to llll
  - Reducible Zbb, tt
- Multivariate (p_t, η) methods for low m_H
- ATLAS toroids help

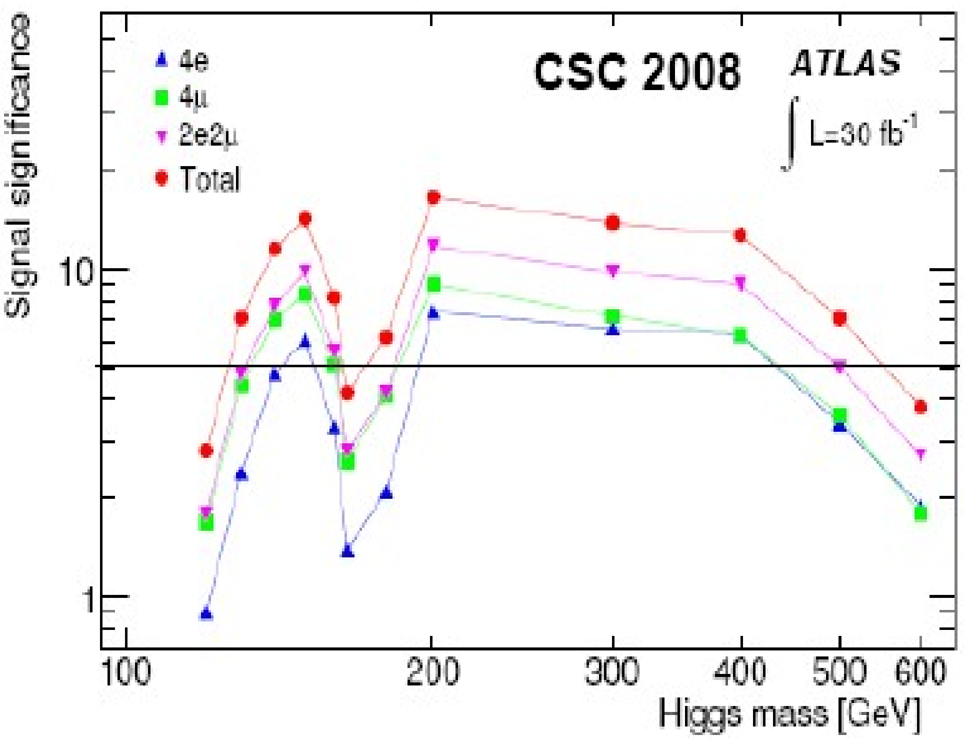


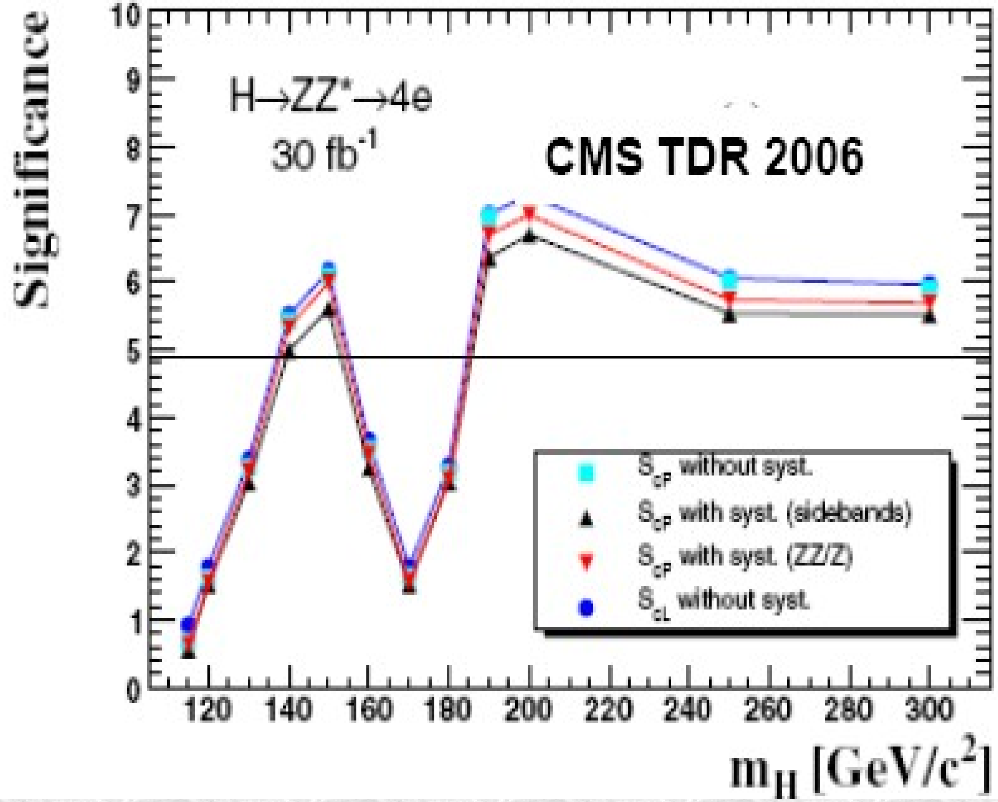
H to llll

- Signal for 130GeV



H to llll significance





- Atlas expect 5σ here 130 to 500 (nearly)
- CMS recently re-optimised for 1fb^{-1}

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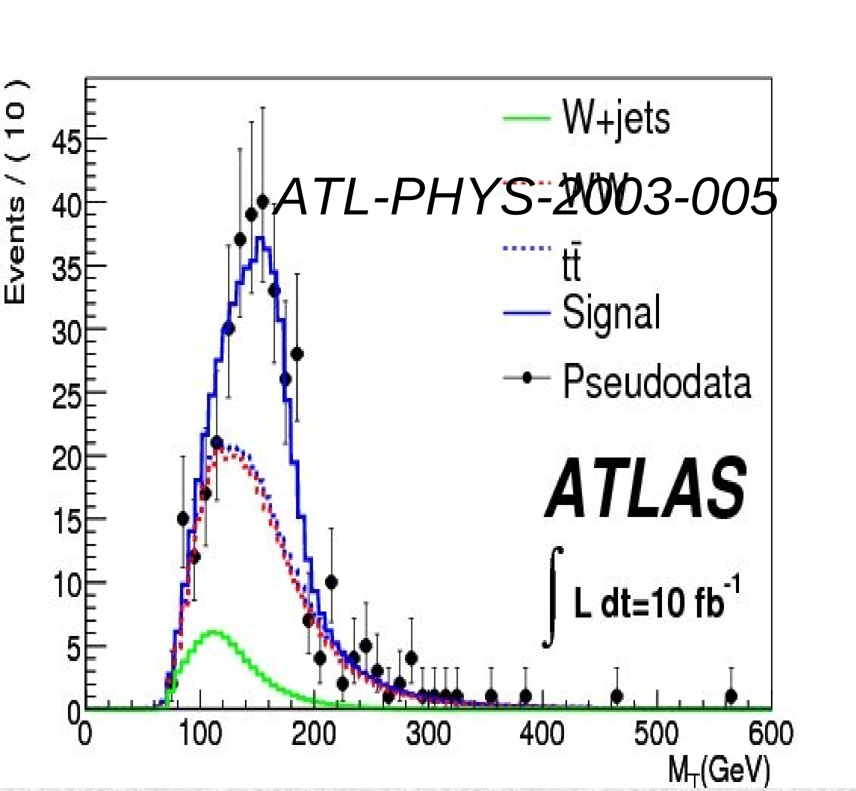
H ■ WW$^{(*)}$

Important for M_H~170 GeV, Higgs mass not fully reconstructed, sensitive to systematics bck

- Isolated leptons $WW^{(*)} \rightarrow l\nu \; l\nu$ (l=e,μ)
- Missing transverse energy E_T^{miss}

Background t(→Wb)t(→Wb)

-Request central jet veto



-WW spin correlations for the signal

-small l^+l^- opening angles

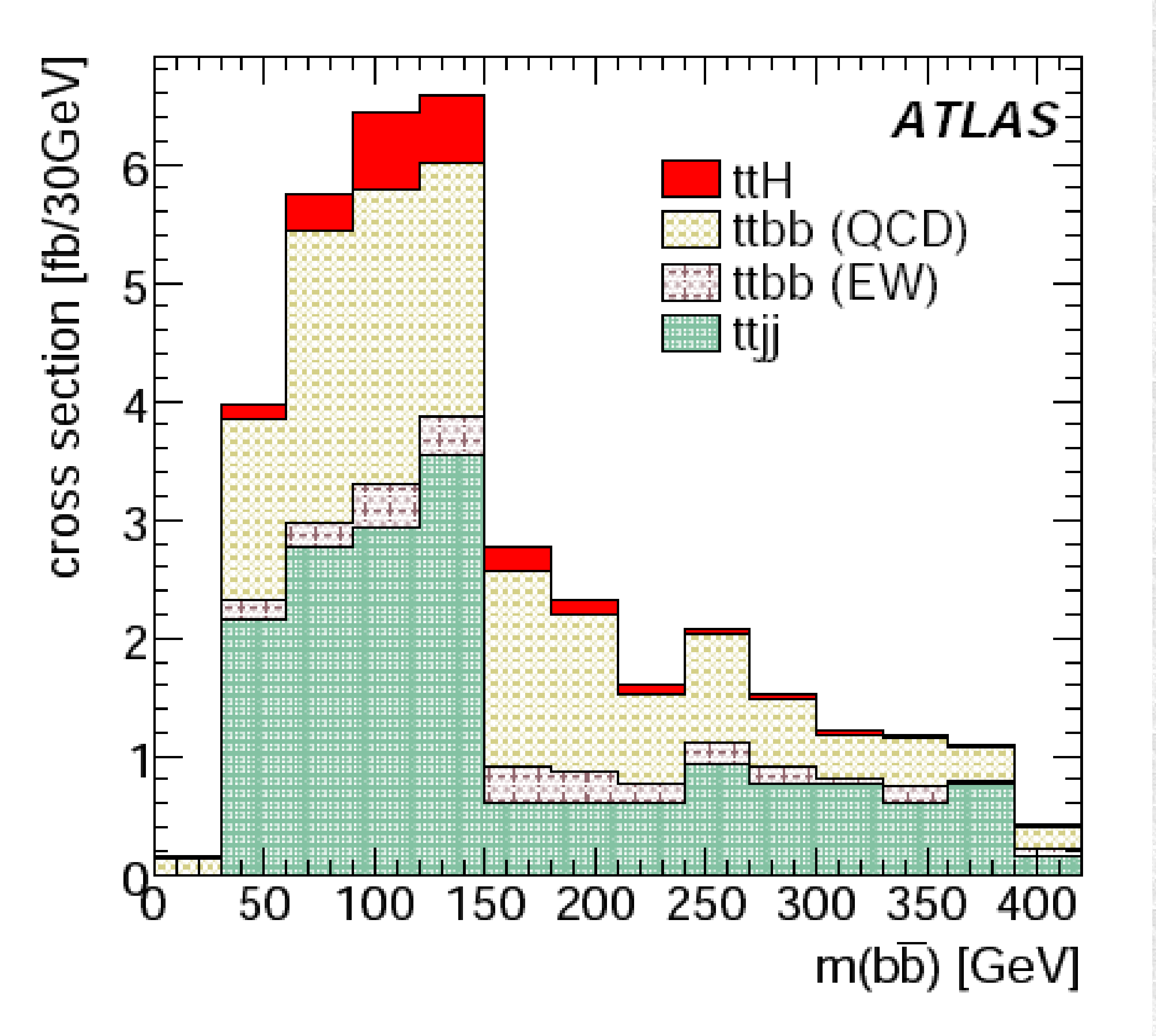
VBF $qqH \rightarrow qqWW$

Presence of forward jets allows purer signal

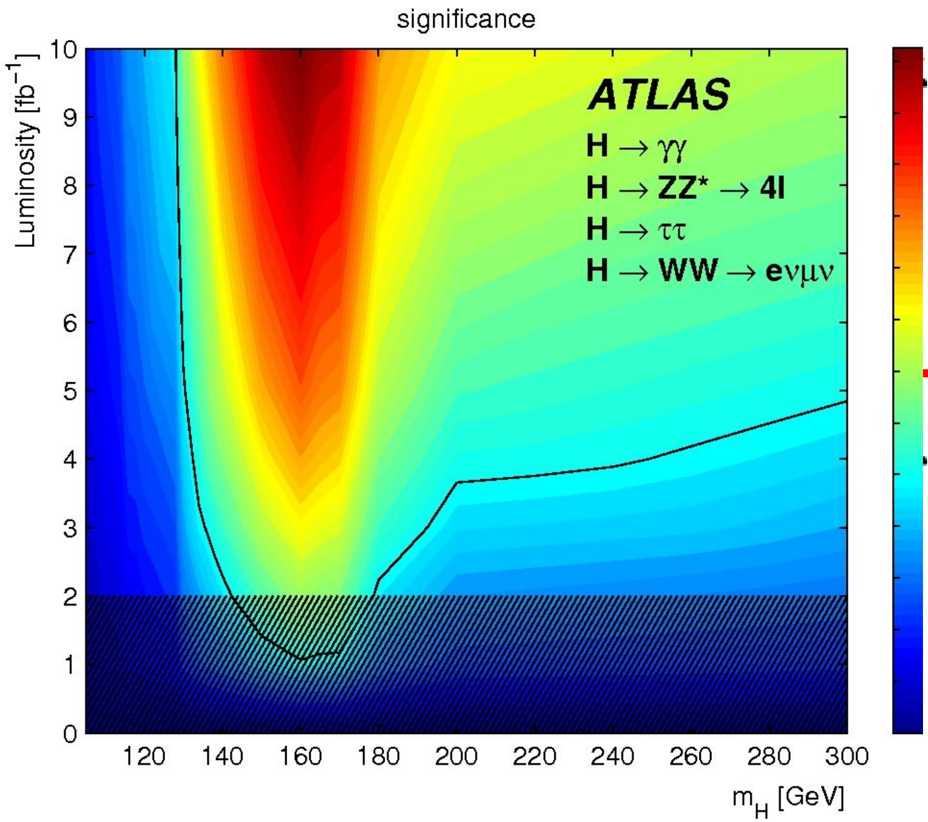
most low-mass range accessible

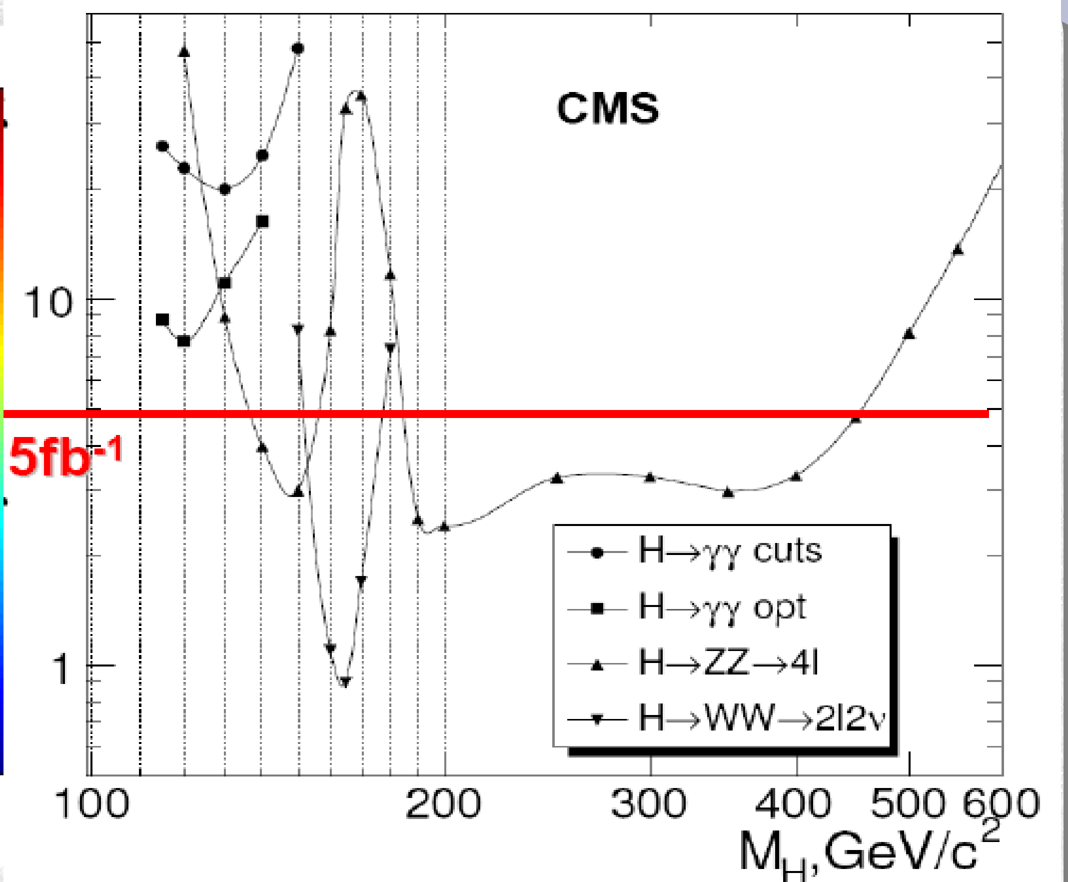
ttH, H to bb

- s/b poor
- Accurate Monte Carlos suggest more problems from extra jets



SM Discovery





5fb^{-1} allows a Higgs from 130 to 300/400 GeV to be found
As the Higgs weighs less than this, it will take longer

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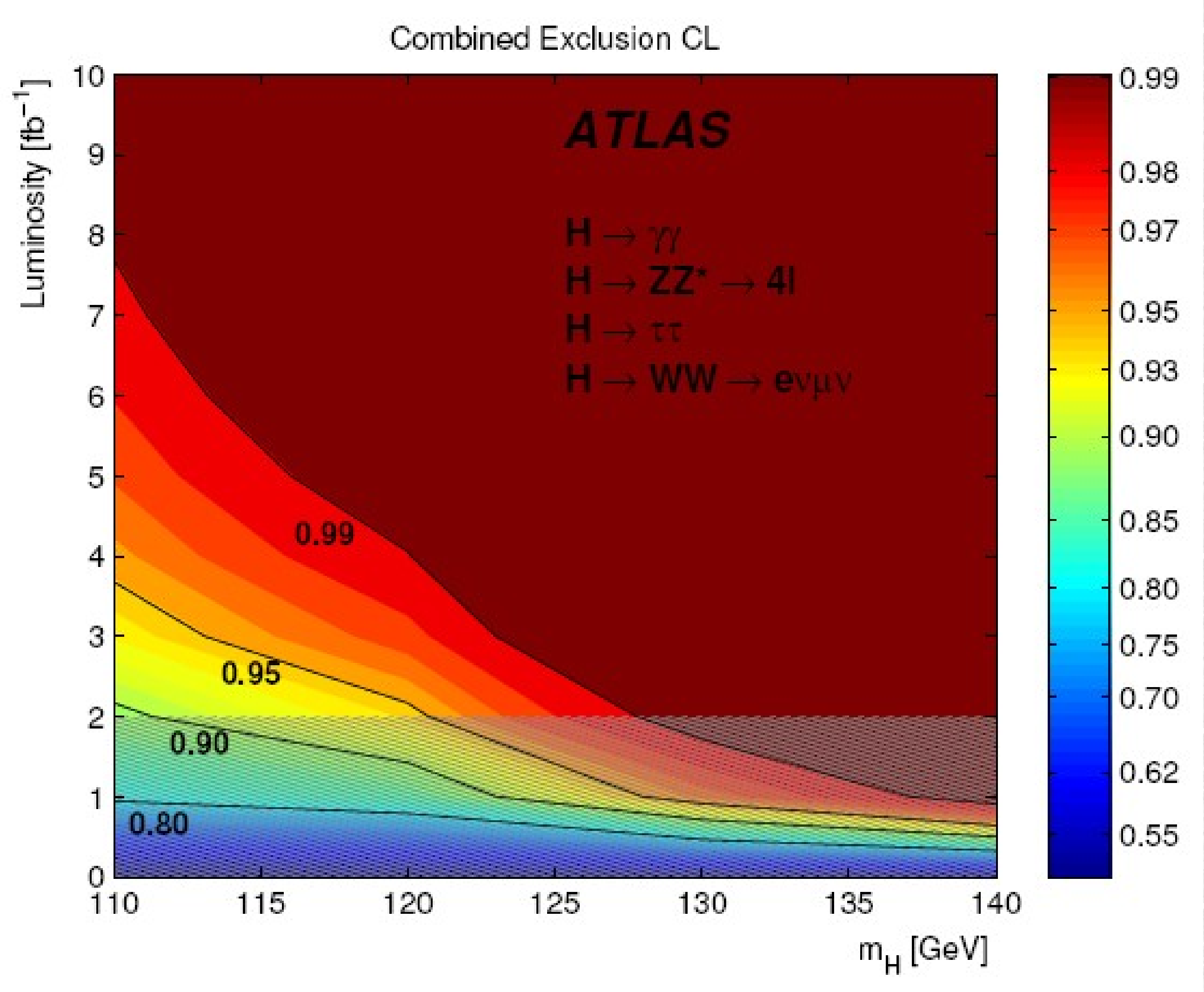
Higgs Exclusion

- We didn't build LHC to exclude the Higgs
- But $3fb^{-1}$ should allow 95% exclusion of all relevant masses.



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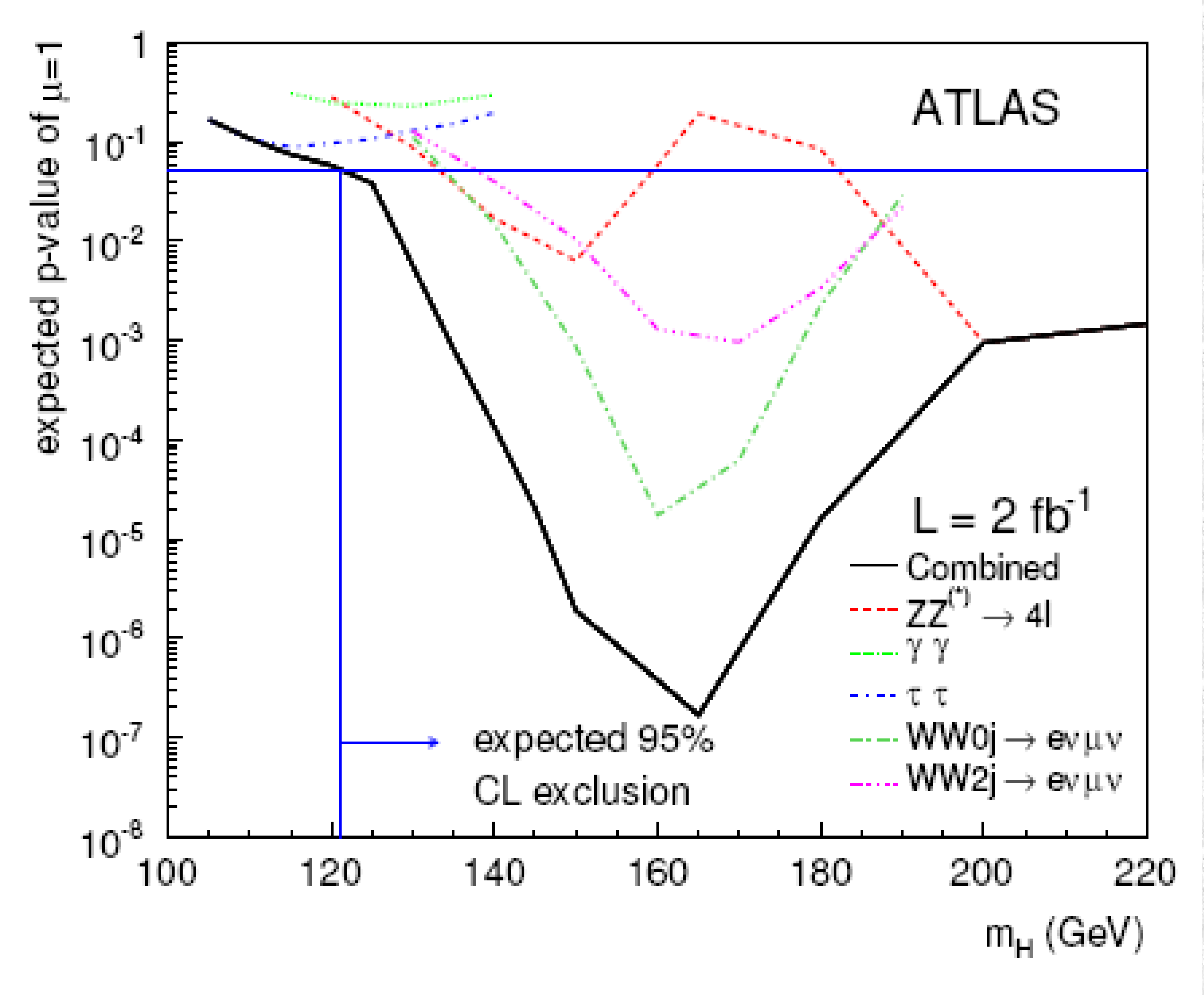
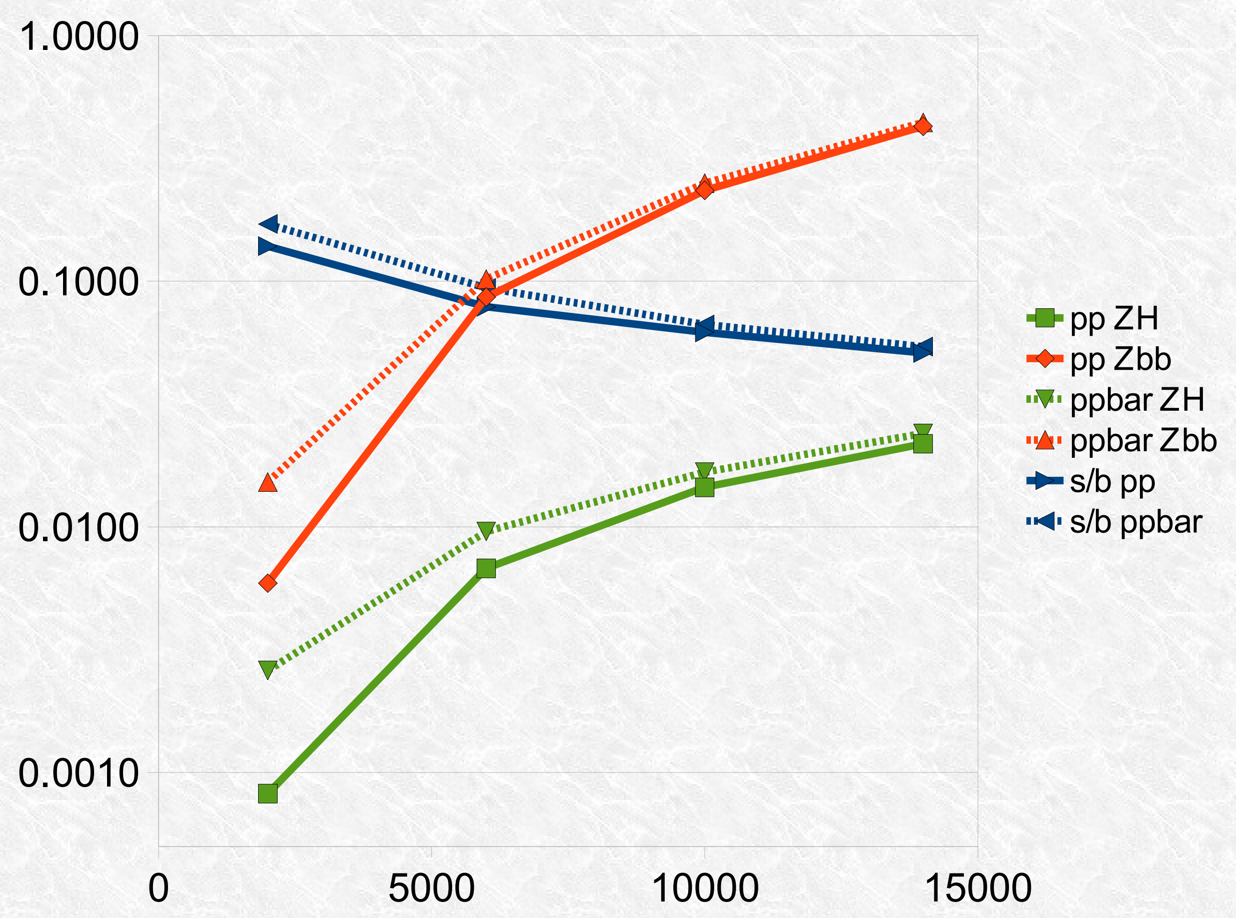
Contributions of channel

- Low mass region has contributions from:
  - ττ
  - γγ
  - llll
- We have ignored ttH
- Can ZH+WH help?



Why is VH missing?

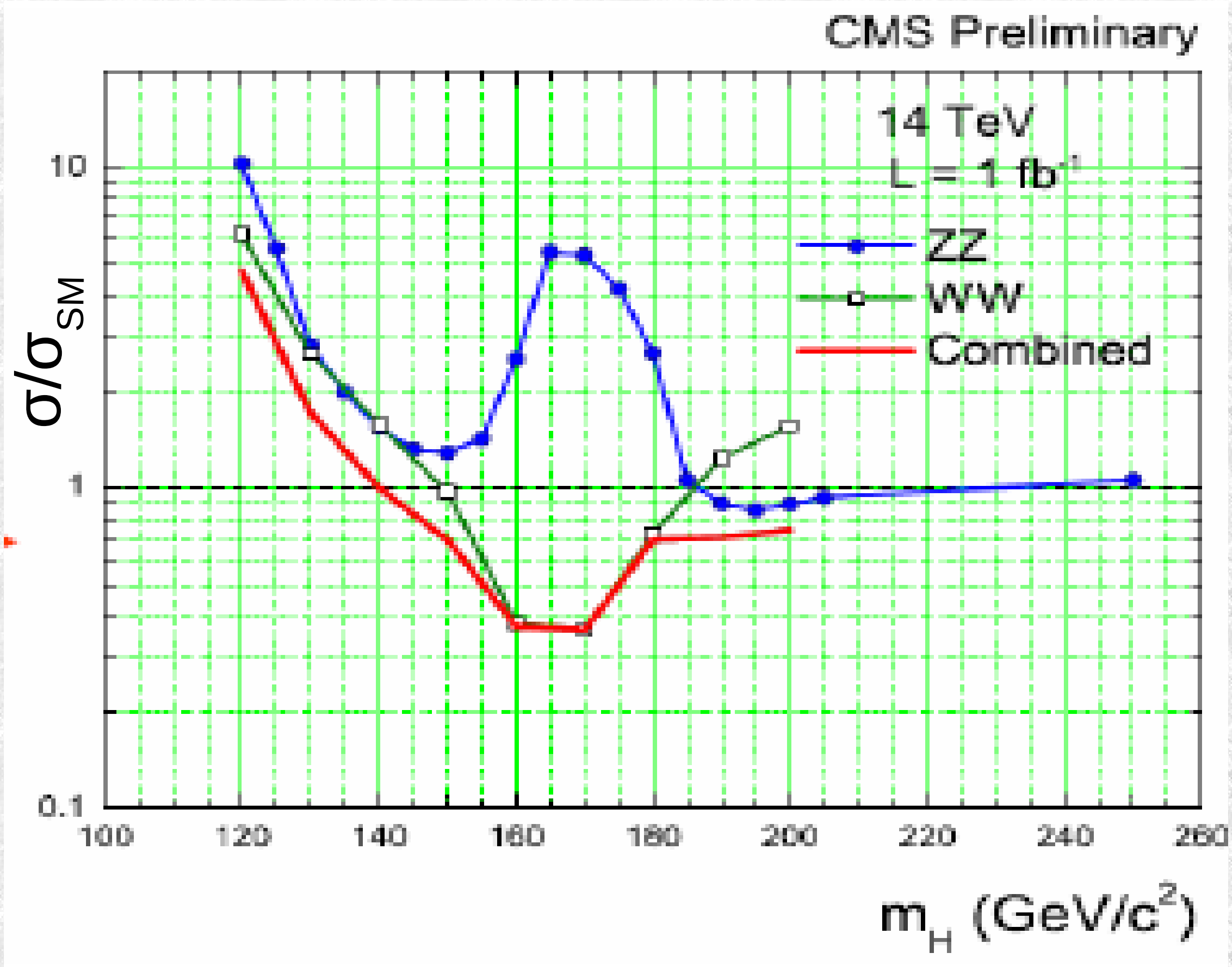
- Z/W+H provides low mass result at TeVatron
- Why not at LHC?
  - More phase space for gluons



- Signal to backgrounds falls by factor 4.
- ATLAS now claims 3.5σ for 120GeV and 30fb^{-1}

What about 10TeV

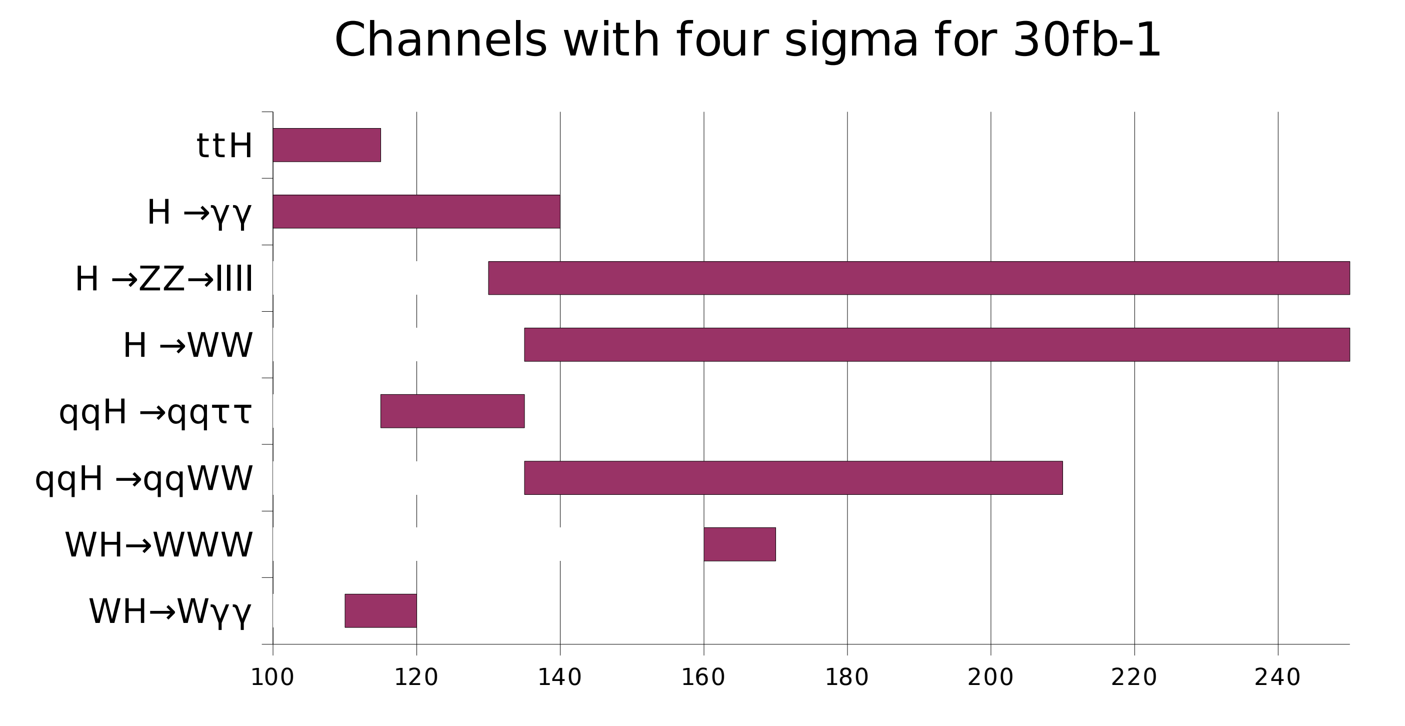
- CMS AN 2009/20
- 200pb^{-1} at 10TeV
- Sensitive to the region the TeVatron just excluded



What do theorists want?

- Is it there? Is there only one?
- What are its quantum numbers?
- Does the Higgs boson generate mass both for the electro-weak gauge bosons and for the quarks?
- How does the Higgs boson interact with itself?

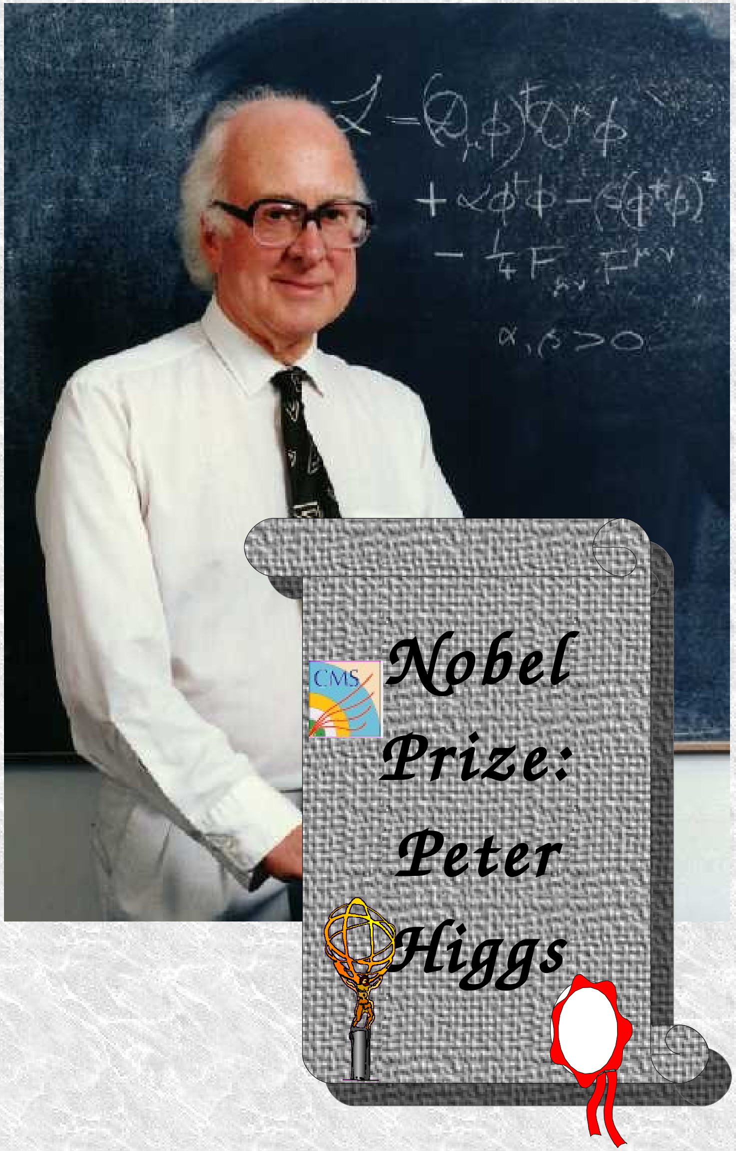
Branching ratio information



- 3 channels for almost all m_H<200GeV
- Comparison of rates gives coupling info.
- e.g. glue/W rate to 25%
- Hard to measure better than 10%
- Quark couplings rarely accessible (ttH, H to bb)

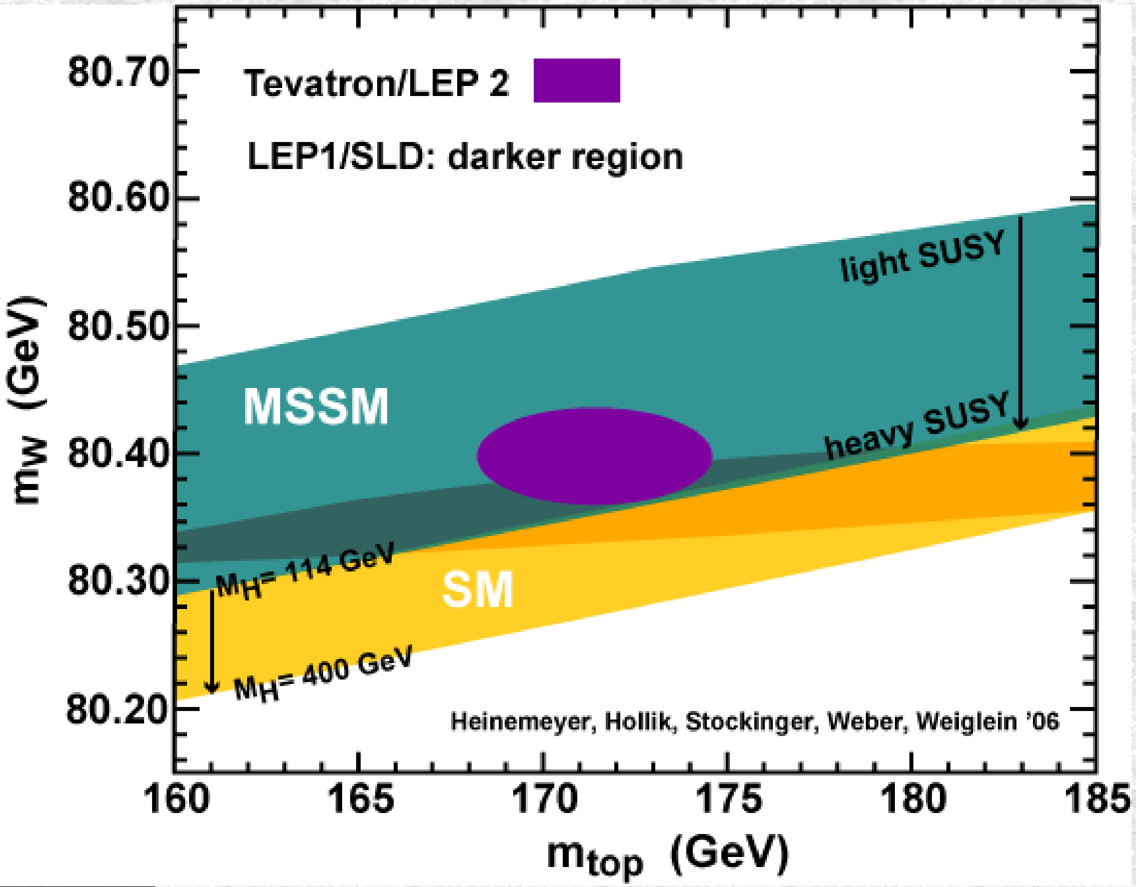
Conclusions

- We re knocking at the door
- But it is a few years before we will get an answer.



Supersymmetry

- EW fit result favours SUSY region:
  - Heavy SUSY
- SUSY has two Higgs doublets
  - 5 Higgses
- Two parameters:
  - M_A, $\tan\beta$



$$M^2_{H^0,h} = \frac{1}{2}\left[M_A^2 + M_Z^2 \pm \sqrt{M_A^2 + M_Z^2 \quad - 4M_A^2 M_Z^2 \cos^2 2.}\right]$$

$$\Rightarrow M_h^2 + M_{H^0}^2 = M_A^2 + M_Z^2$$

$$M_H^2 = M_A^2 + M_W^2$$

Including Run II CDF $M_{W,}$ not m_T

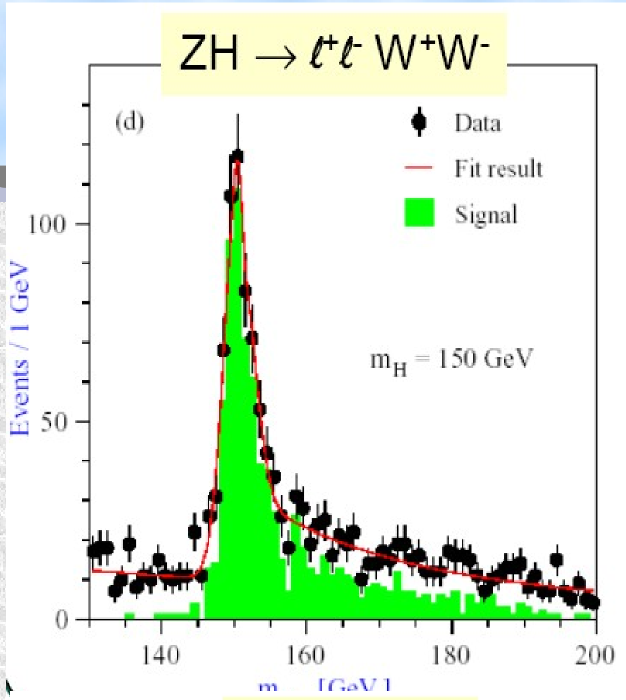
xLC

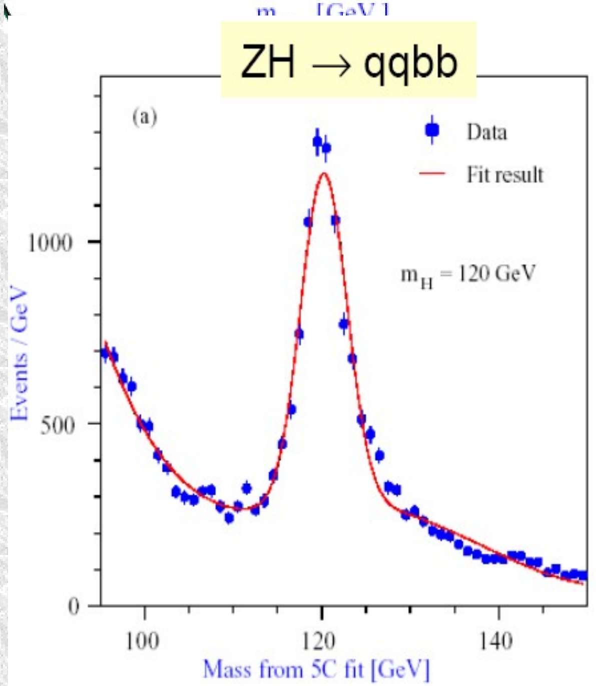
- The clean ZH production allows accurate studies
- Unbiased channel reconstruction
- Excellent detectors will enable accurate branching ratio measurements. e.g. cc
- Self coupling should be possible

- This machine allows precision Higgs property determination.

Mass Measurement

Garcia-Abia, et al., hep-ex/0505096





Decay mode	$\Delta(m_H)$ in MeV		
	120	150	180
$ZH \rightarrow \ell^+\ell^- q\bar{q}$	85	100	–
$ZH \rightarrow q\bar{q}q'\bar{q}'$	45	170	–
$ZH \rightarrow \ell^+\ell^- WW$	–	90	80
$ZH \rightarrow q\bar{q}WW$	–	100	150
Combined	40	65	70

$\sqrt{s}$= 350 GeV   500 fb^{-1}

Beam systematics included

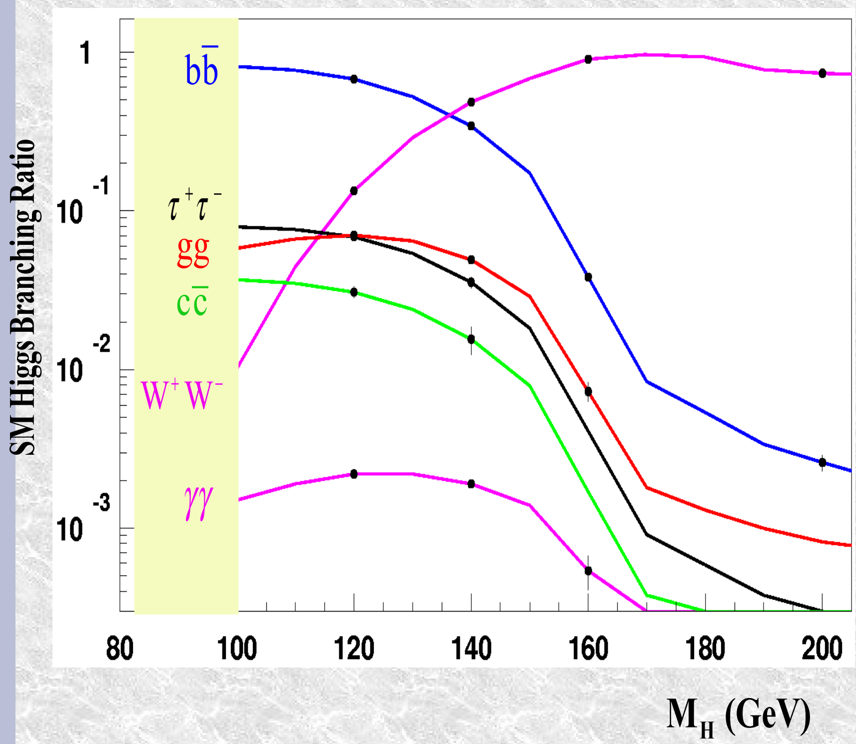
Determine the Higgs mass to about 40-70 MeV

How much can theory handle/does theory want?

ILC Higgs Branching Ratios

Tim Barklow, LCWS04

Combine 500 fb^{-1} @ $\sqrt{s}$ = 350 GeV & 1000 fb^{-1} @ $\sqrt{s}$ = 1000 GeV

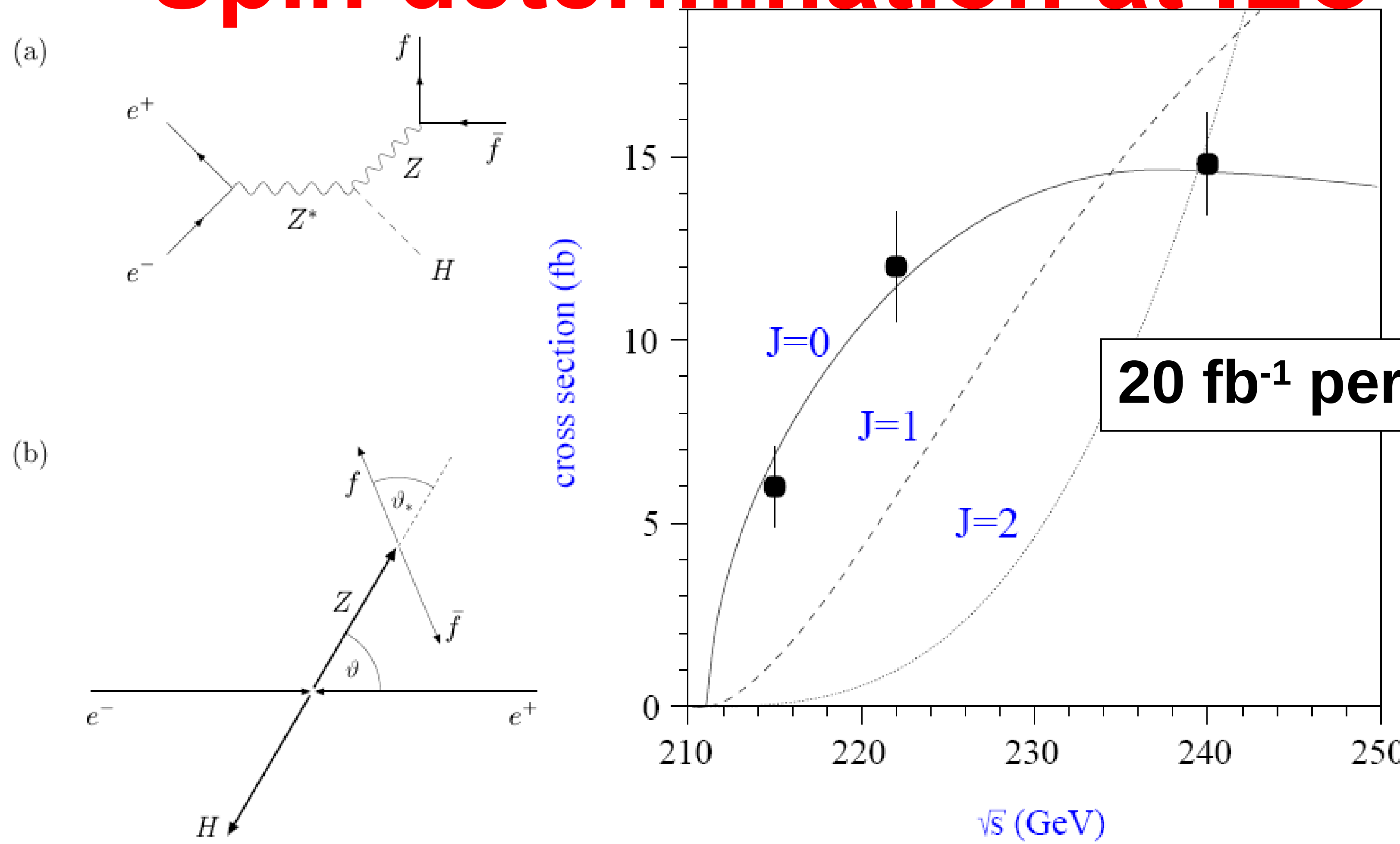


	Higgs Mass (GeV) 120	140	160	180
$\Delta B_{bb}/B_{bb}$	±0.016	±0.018	±0.020	±0.090
$\Delta B_{WW}/B_{WW}$	±0.020	±0.018	±0.010	±0.025
$\Delta B_{gg}/B_{gg}$	±0.023	±0.035	±0.146	
$\Delta B_{\gamma\gamma}/B_{\gamma\gamma}$	±0.054	±0.062	±0.237	
$\Delta B_{\tau\tau}/B_{\tau\tau}$	±0.050	±0.080		
$\Delta B_{cc}/B_{cc}$	±0.083	±0.190		
$\Delta\Gamma_{tot}/\Gamma_{tot}$	±0.034	±0.036	±0.020	±0.050

- Model independent
- Absolute branching ratios! Normalized to absolute HZ cross section
- Precise measurements: few % to 10%.
- Special options to improve further e.g. Δ BR(H→γ γ) ~ 2% at photon collider

Spin determination at ILC

ILC



20 fb^{-1} per point

FIG. 38: Left: Feynman diagram for $e^+e^- \to ZH$ and schematic [88] showing the analyzing angles. Right: curves showing the threshold rate dependence for $J = 0, 1, 2$ states in this channel [71].

J.A.Aguilar-Saavedra et al. arXiv:hep-ph/0106315
D.Miller,S.Choi,B.Eberle,M.Muhlleitner and P.Zerwas Phys.Lett.B505:149-154,2001
D.Rainwater hep-ph/0702124

Conclusions

- Incredible results from Tevatron
  - M_W, m_T precision improving
  - Higgs mass below 150GeV seems clear
  - Direct Higgs searches close to sensitive
- LHC will start next year
  - There is a real race happening
- Do **NOT** assume the unknown is true
  - But in 3 years electroweak symmetry breaking of the SM will be established – or clearly wrong
- A lepton collider will be required to explore properties