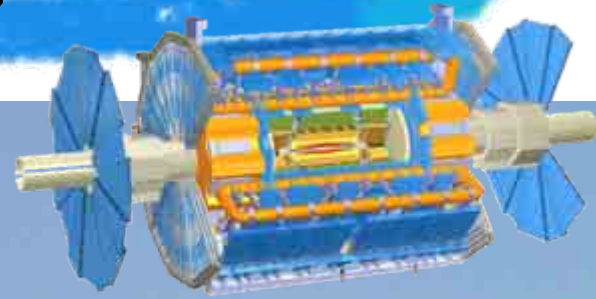


# Higgs discovery prospects and statistics at the LHC (ATLAS)



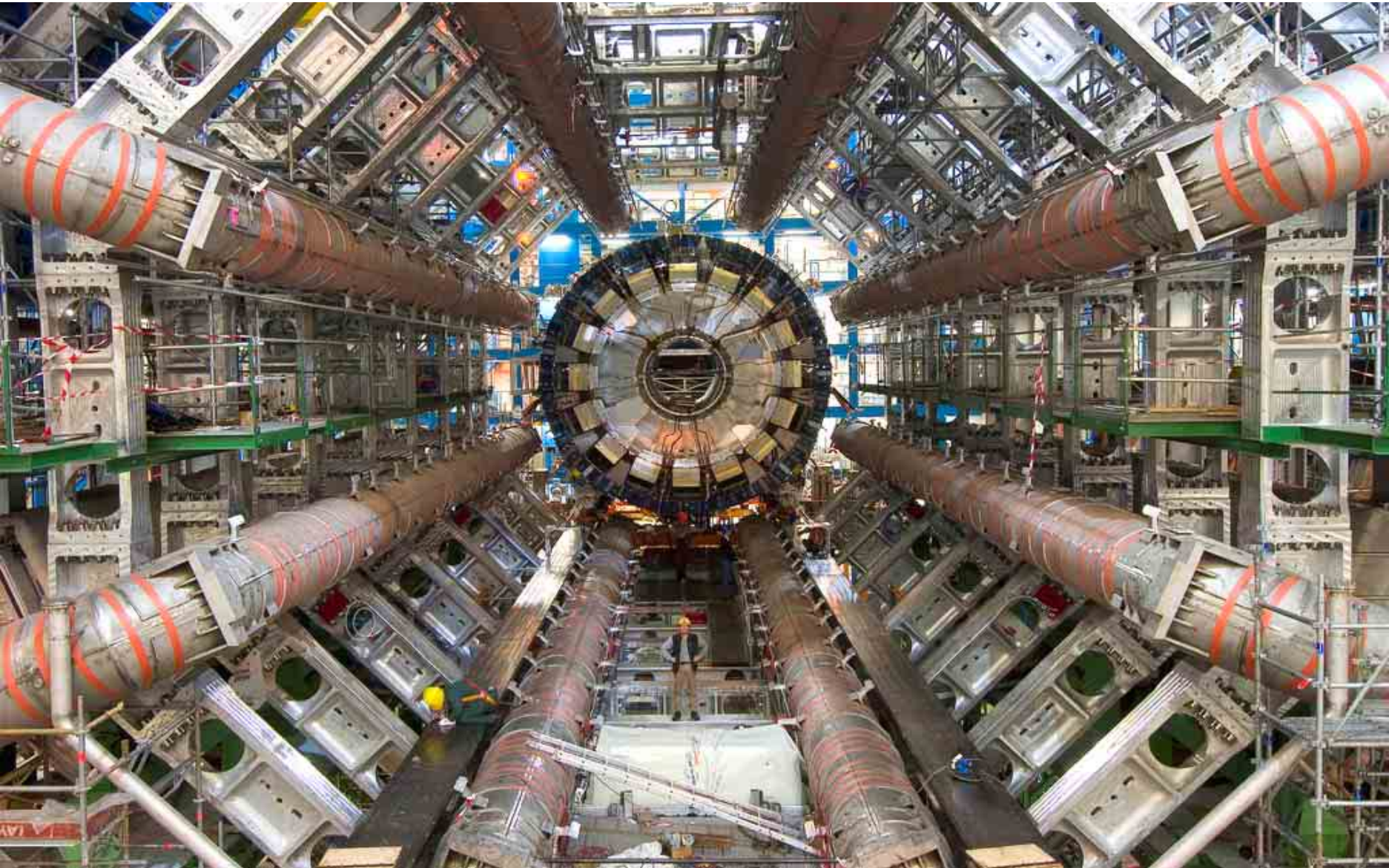
**Eilam Gross** Weizmann institute of Science/ATLAS

# ATLAS with a Perspective



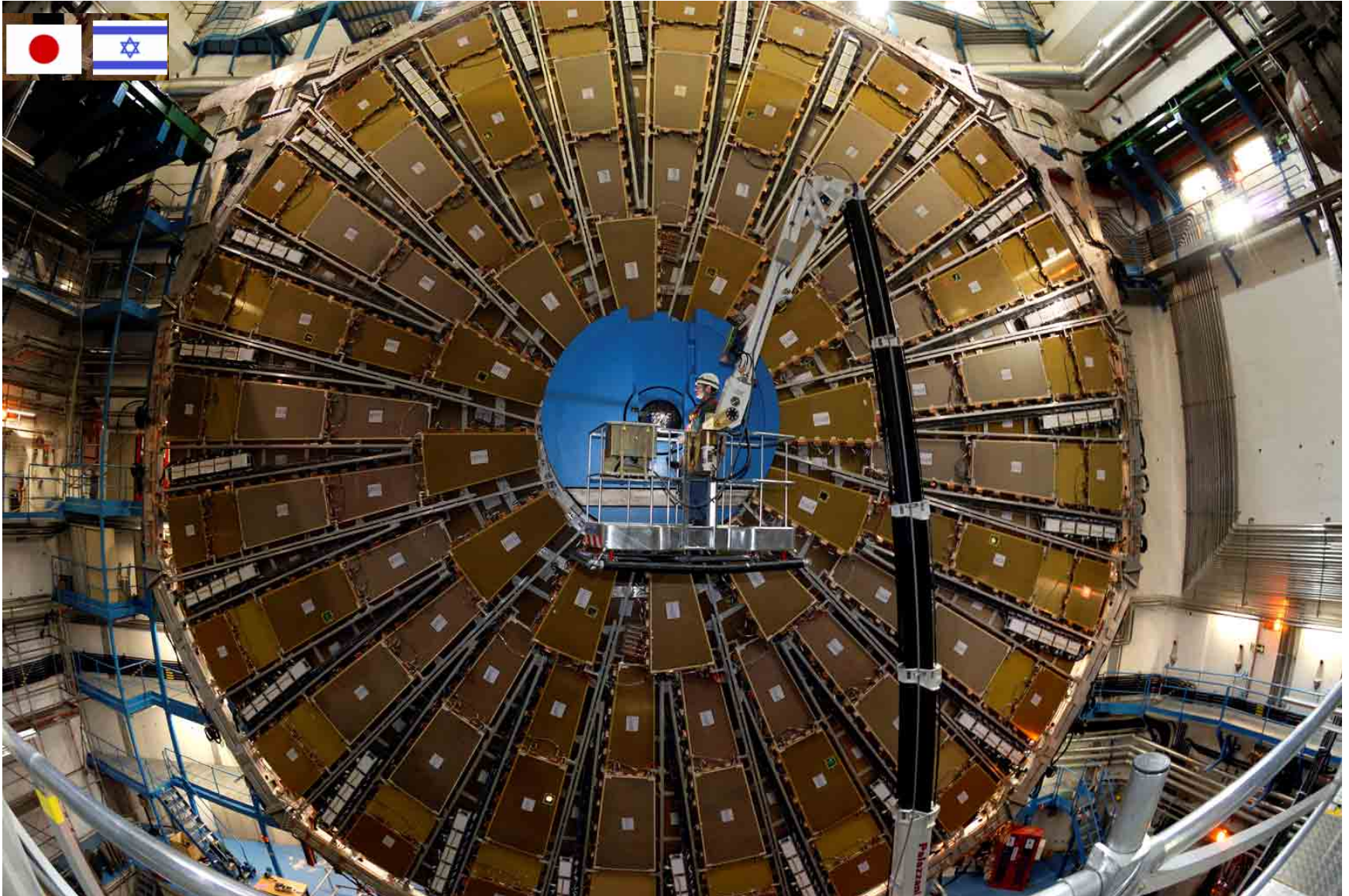


# A Legend Comes True



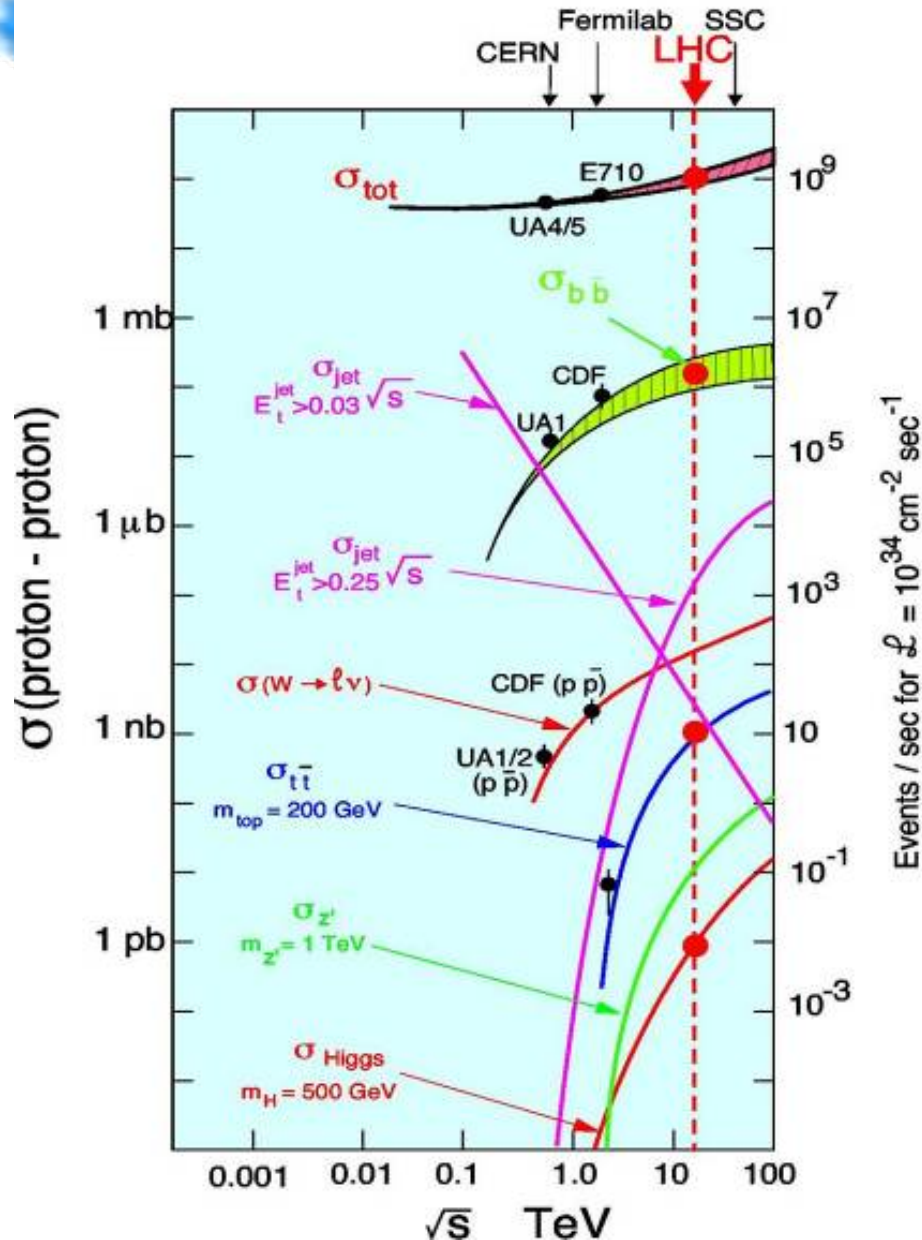


# A Legend Comes True





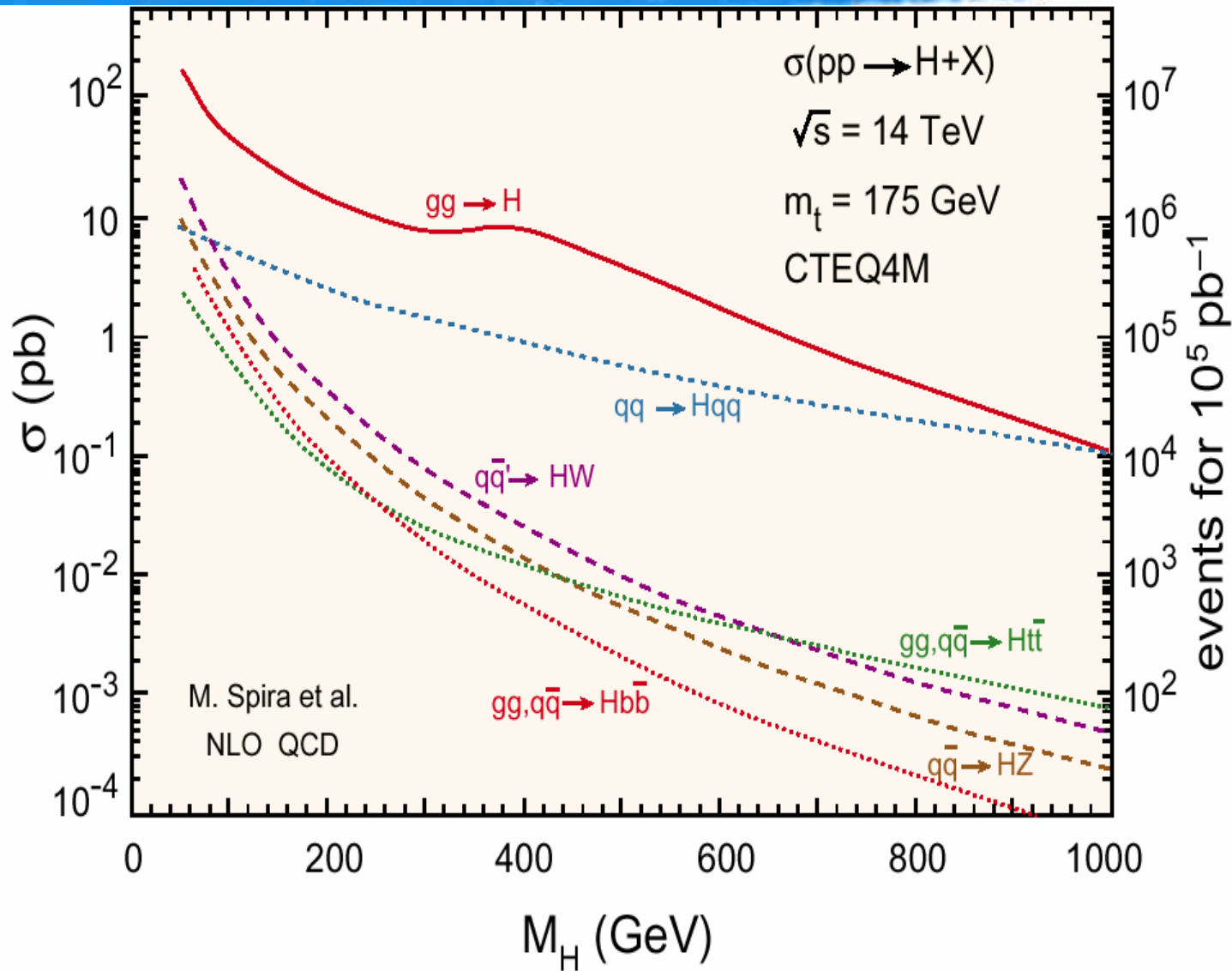
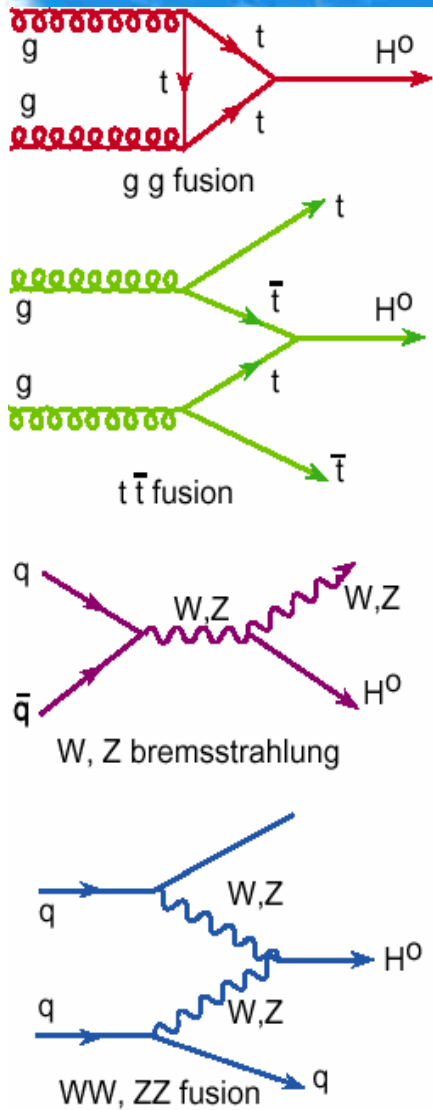
# The Technical Challenge



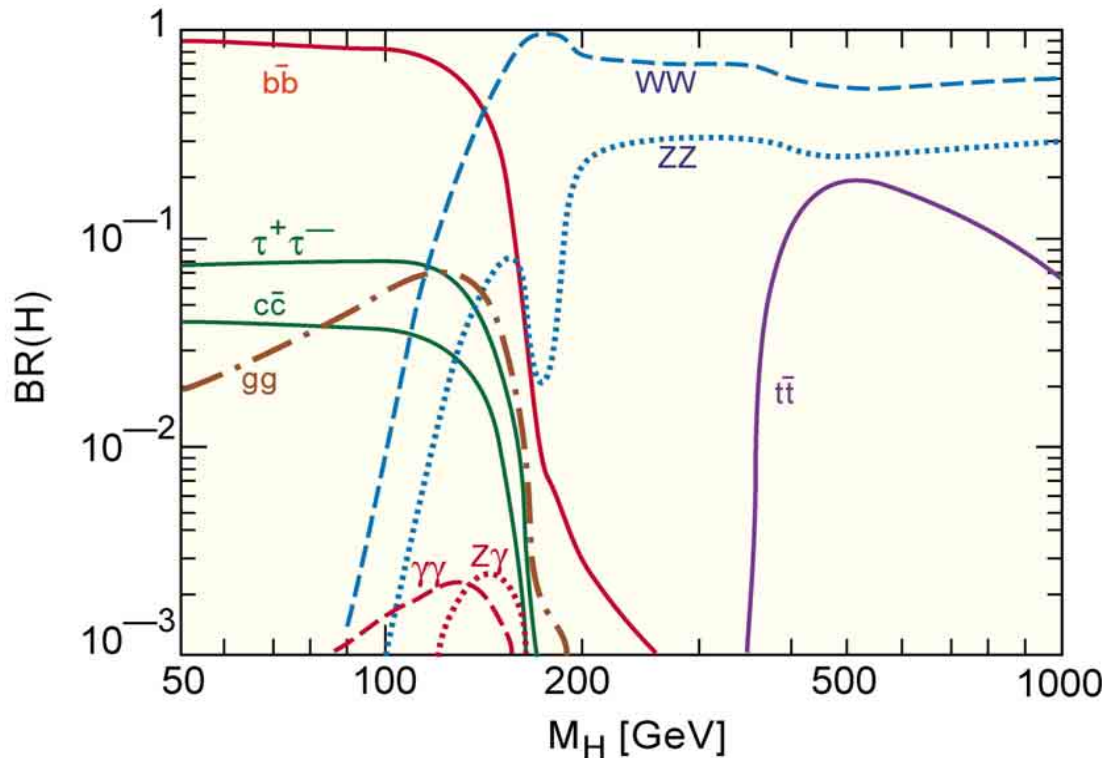
- $\sim 10^9$  proton-proton collisions/sec
- $\sim 1/10^{11}$  collisions produce a Higgs Boson
- One can only accommodate  $\sim 200$  collisions/sec
- Rejection rate  $> 99.9995\%$
- How do you make sure not to lose a Higgs Boson?
- Make sure we “push the button” (trigger) only when interesting things happen
- This is a tremendous technical challenge! Which require state of the art fast systems.
- $\sigma_{\text{tot}} \sim 100 \text{ mb}$ ,  $\sigma_b \sim 1 \text{ mb}$ ,  $\sigma_{\text{jet}} > 1 \text{ nb}$ ,  $\sigma_H > 1 \text{ pb}$   
The small S/B requires control samples to understand the background



# Higgs Production @ LHC



# $\sigma^* \text{BR}$ - The Analysis Challenge



- The Higgs decay to  $b\bar{b}$  is still dominant up to  $\sim 150$  GeV, the Weak Bosons then enter the game
- However,  $H \rightarrow 4$  leptons has a clear signature as well as  $H \rightarrow \gamma\gamma$  with BRs of  $O(10^{-3})$ . This is a challenge in analysis which makes the need for measuring background from data mandatory!
- The decay to  $\tau\tau$ , though only a few % is still very appealing for the medium – light SM Higgs
- For MSSM Higgs  $b\bar{b}$  and  $\tau\tau$  are dominant



# LHC - Brief Status

As reported by Sergio Bertolucci, LP07

- Engineering run originally foreseen at end 2007 now precluded by delays in installation and equipment commissioning.
- Beam commissioning starts May 2008
- First collisions at 14 TeV c.m. July 2008
- First month devoted to collecting millions of minimum bias events and di-jets events for first alignment, calibrations and performance studies of the detector (@  $10^{29}$ )

# LHC - Brief Status

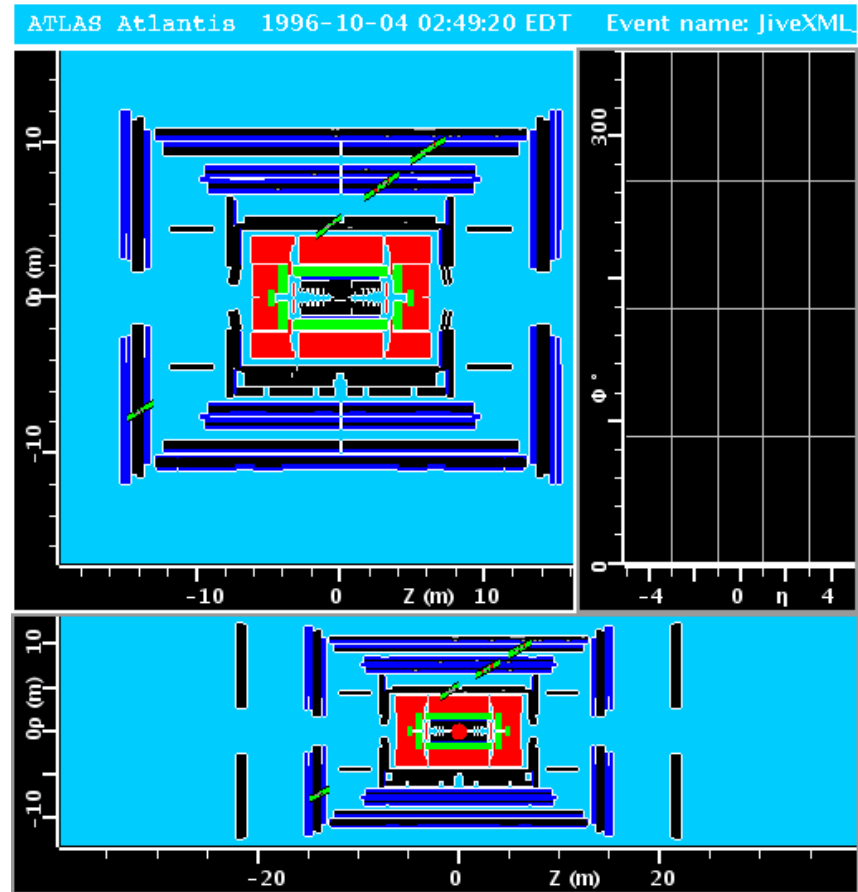
As reported by Sergio Bertolucci, LP07

- Pilot run pushed to reach  $10^{32} \text{ cm}^{-2} \text{ s}^{-1}$  by end 2008
- This is equivalent to  $O(100 \text{ pb}^{-1})/\text{experiment}$
- Use  $Z \rightarrow ee, \mu\mu$  to calibrate, align and understand the trackers, the EM CAL, and the Muon system.
- Use  $W \rightarrow jj$  to calibrate jets and study b-tag performance ( $tt \rightarrow b\bar{\nu} bjj$ )
- “Rediscover” SM Physics at  $\sqrt{s}=14 \text{ TeV}$ , this is your new background
- After all, the LHC is designed to go beyond the known SM Physics, first and foremost to discover the Higgs Boson.



# Cosmic Ray Tests

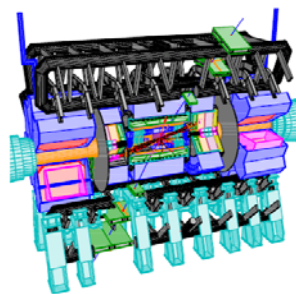
Tracks in the **Muon chambers**  
and in the  
Transition-Radiation Tracker  
**TRT**



# The References



## ATLAS DETECTOR AND PHYSICS PERFORMANCE



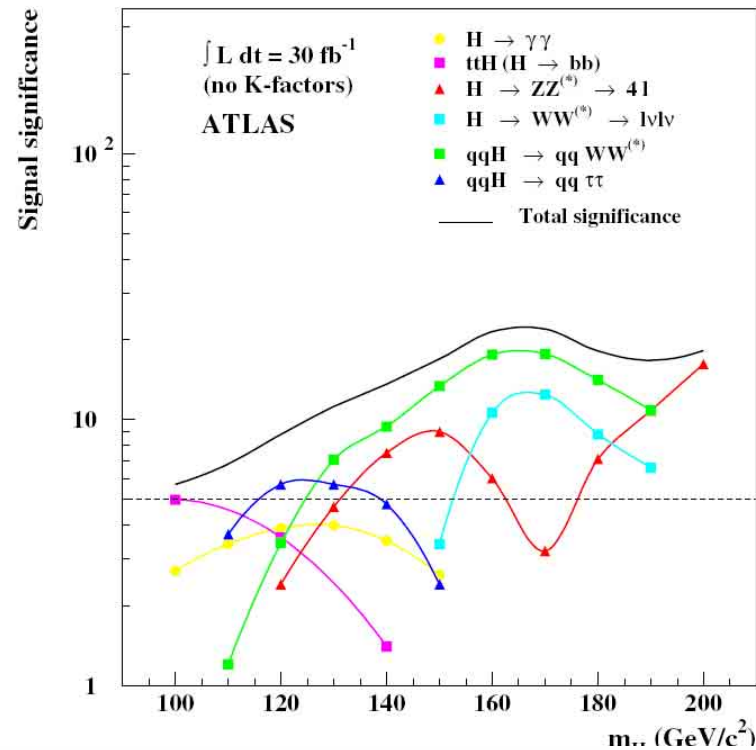
## Technical Design Report

Issue: 1  
Revision: 0  
Reference: ATLAS TDR 14, CERN/LHCC 90-14  
Created: 25 May 1999

Volume I

Eur Phys J C 32, s02, s19-s54 (2003)  
DOI: 10.1140/epjcd/s2003-01-010-8

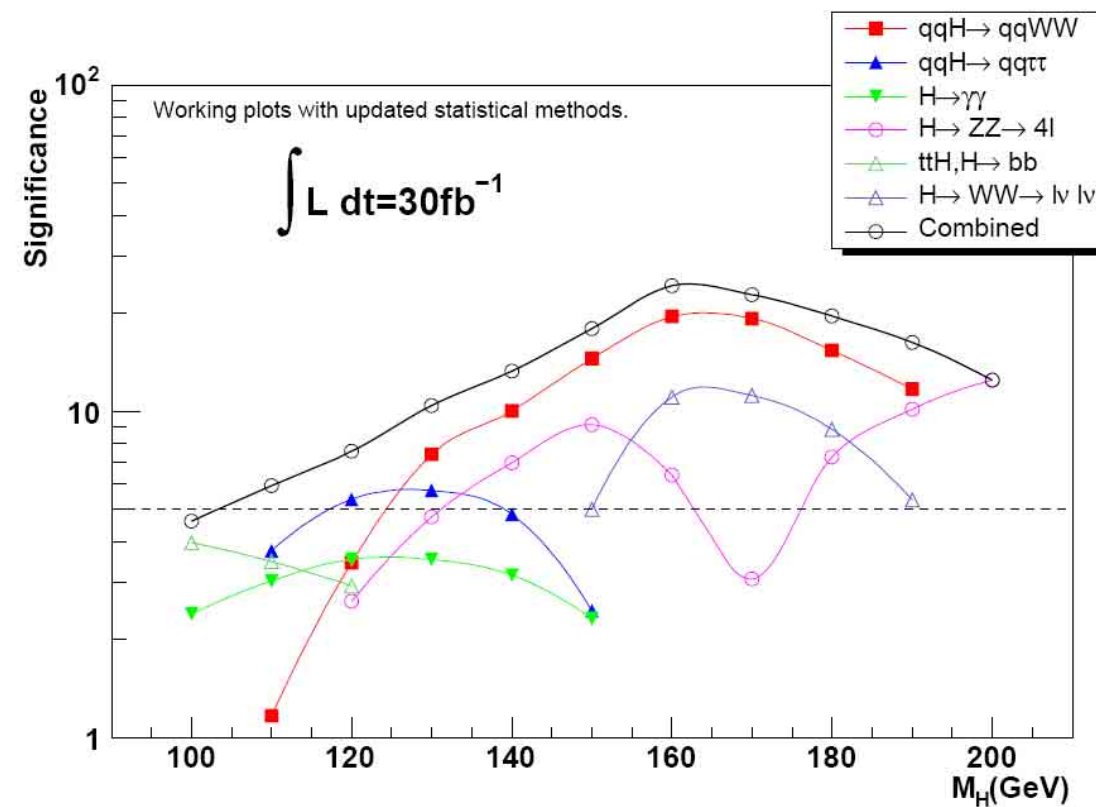
EPJ C direct  
electronic only  
© Springer-Verlag 2003  
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## Prospects for the search for a standard model Higgs boson in ATLAS using vector boson fusion

S. Asai<sup>8</sup>, G. Azuelos<sup>5</sup>, C. Buttar<sup>7</sup>, V. Cavasinni<sup>6</sup>, D. Costanzo<sup>6,\*</sup>, K. Cranmer<sup>9</sup>,  
R. Harper<sup>7</sup>, K. Jakobs<sup>4</sup>, J. Kanzaki<sup>3</sup>, M. Klute<sup>1</sup>, R. Mazini<sup>5</sup>, B. Mellado<sup>9</sup>,  
W. Quayle<sup>9</sup>, E. Richter-Was<sup>2</sup>, T. Takemoto<sup>3</sup>, I. Vivarelli<sup>6</sup>, Sau Lan Wu<sup>9</sup>

# The References



## Statistical Methods to Assess the Combined Sensitivity of the ATLAS Detector to the Higgs Boson in the Standard Model

Kyle Cranmer, Bruce Mellado, William Quayle, Sau Lan Wu

*University of Wisconsin - Madison  
Department of Physics*

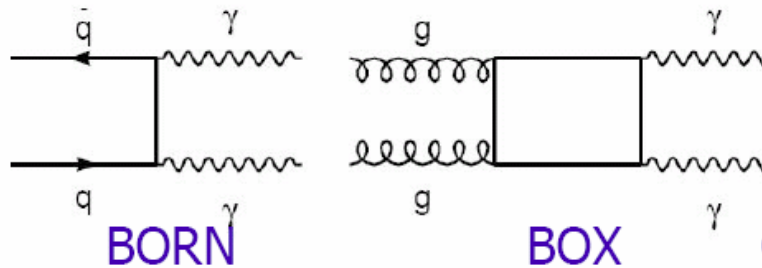
### Abstract

We discuss statistical methods used to assess the combined sensitivity to the Standard Model Higgs boson using the ATLAS detector. The combination is performed using the likelihood ratio as a test statistic. Combined results are calculated using the results of a recent scientific note. Difficulties in calculating the significance using likelihood ratio techniques in the high event rate and high significance environment of the LHC are discussed, and software packages which implement solutions to these problems are presented. We also provide a brief discussion about different ways to incorporate systematic error and introduce the statistical notion of power to the ATLAS Higgs search.

ATL-PHYS-2004-034  
01 December 2004



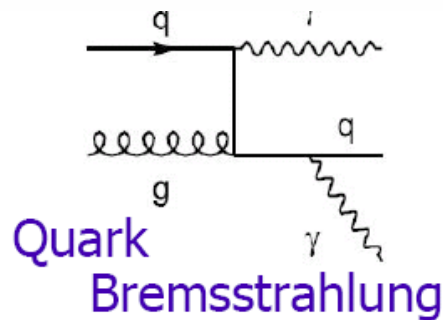
$$m_H \sim 120 \text{ GeV}$$



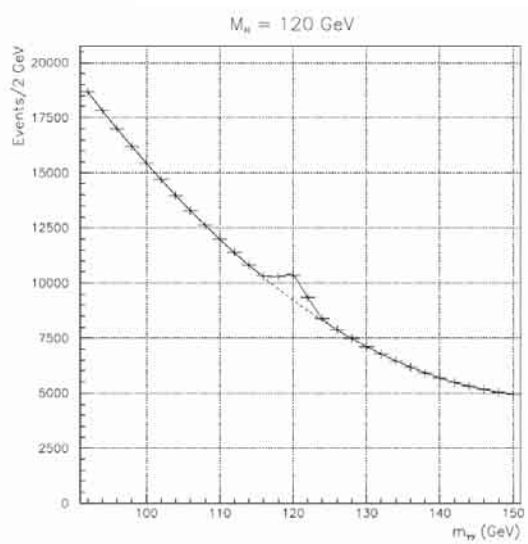
$H \rightarrow \gamma\gamma$ , classical bump hunting

BR  $\sim 2 \cdot 10^{-3}$

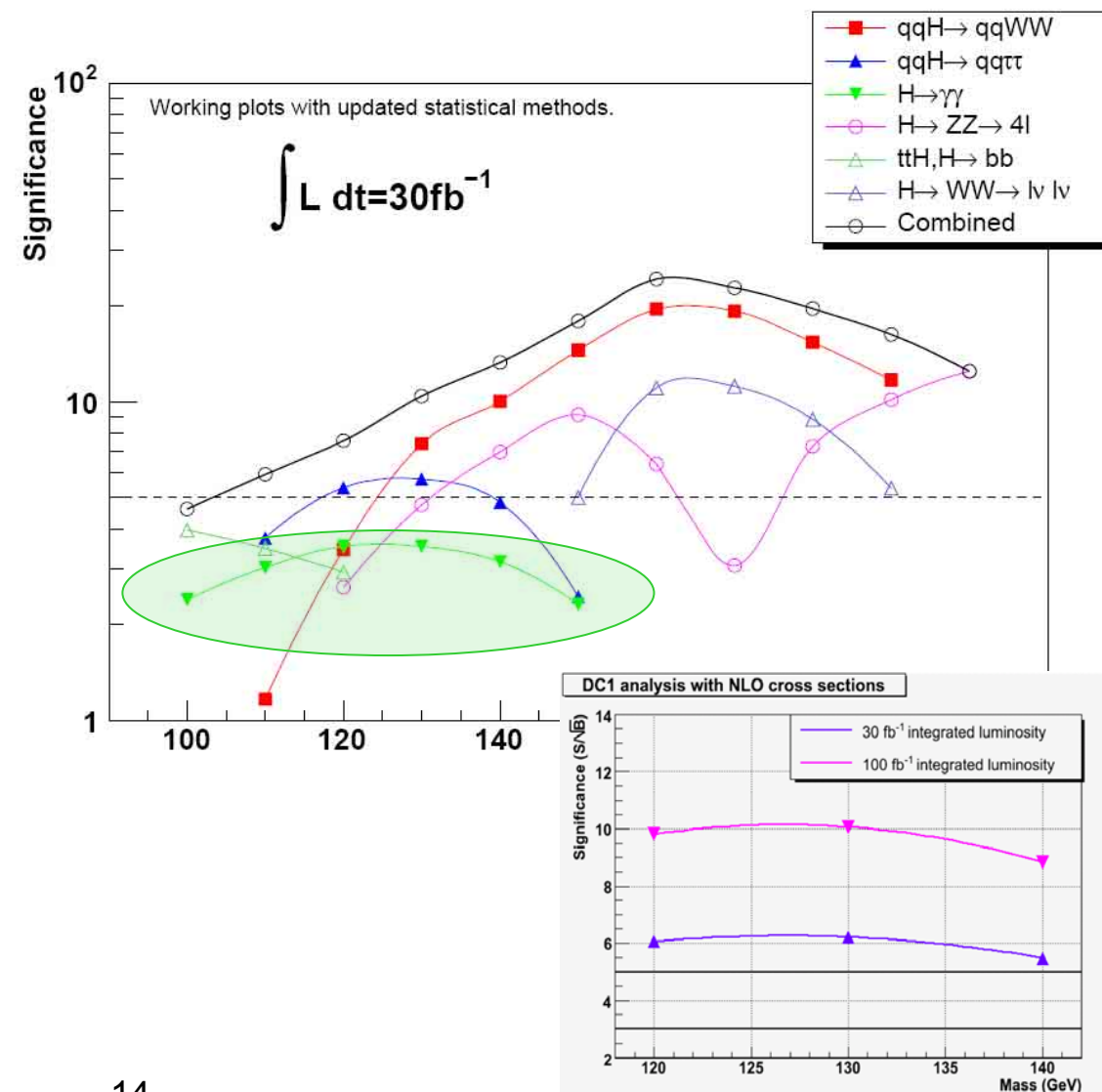
Irreducible background (now at NLO compared with TEVATRON)



- S/B  $\sim 1:20$ . requires control of the background
- Normalization via side bands
- For best mass need good measurements of photon angles & energy
- Need to reject fake photons and photons from pions.

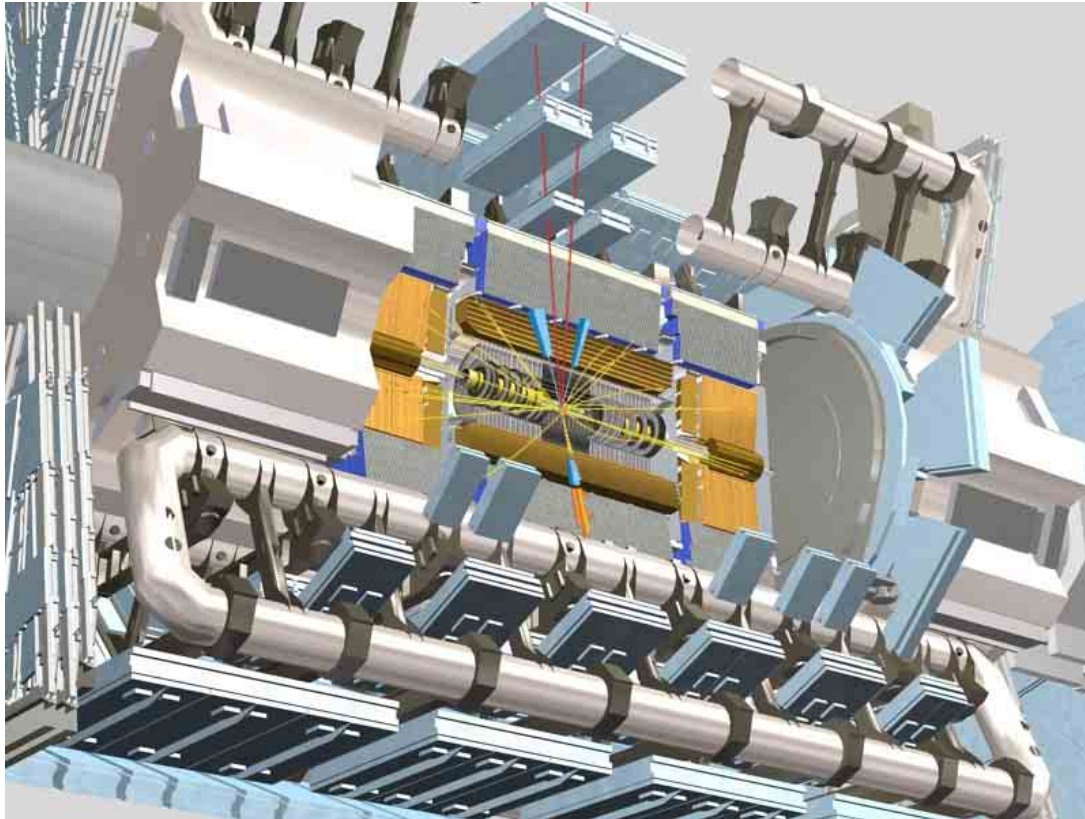


$$m_H \sim 120 \text{ GeV}$$

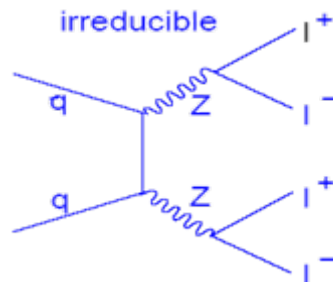
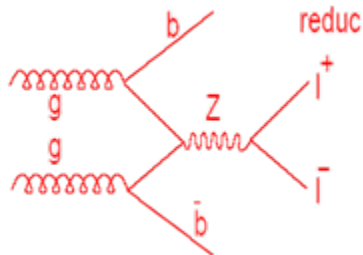


- Sensitivity can be increased by inclusive searches separating to
  - $H+0j$
  - $H+1j$
  - $H+2j$  (dominated by VBF,  $qq \rightarrow qqH$ )
- Resolution on mass  $\sim 1.6 \text{ GeV}$  ( $@ m_H = 120$ )
- Excellent prospects, especially for  $L > 10 \text{ fb}^{-1}$

# The Golden Channel $H \rightarrow ZZ^* \rightarrow 4 \text{ leptons}$

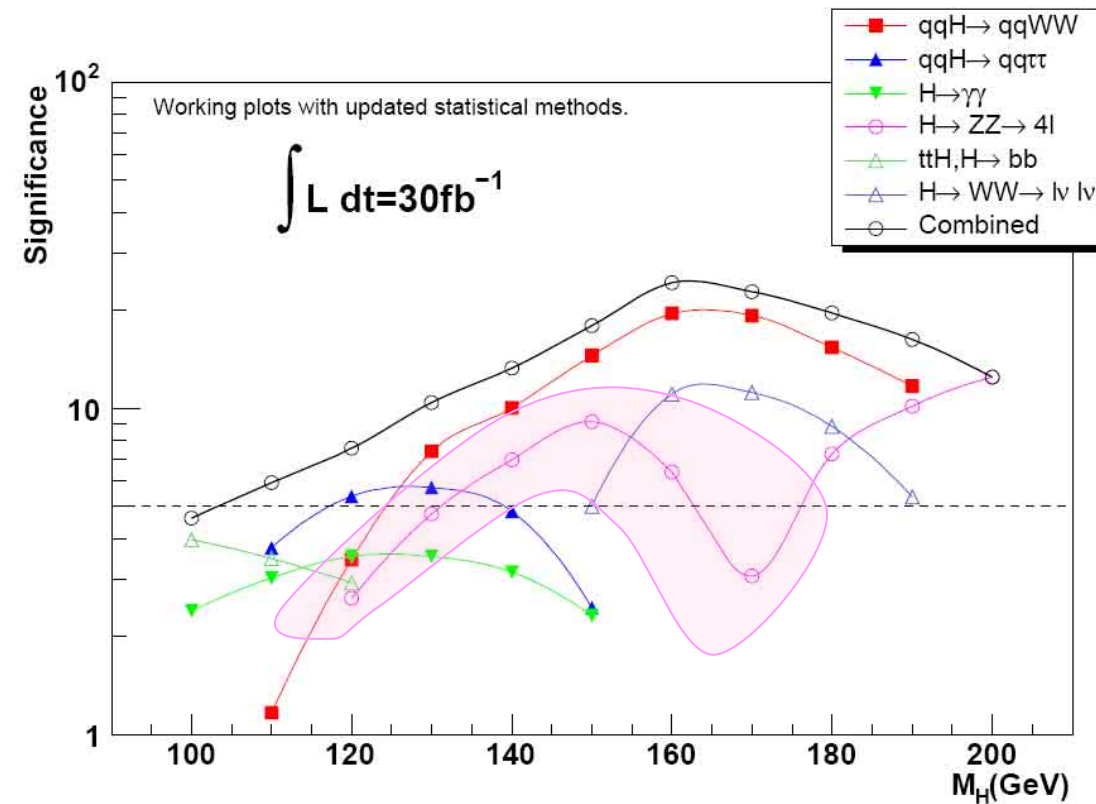


- Very low BR of  $H \rightarrow ZZ^*$  for low-medium  $m_H$
- Yet, very clean and therefore appealing especially  $H \rightarrow ZZ^* \rightarrow 4\mu$
- Resulting reconstructed mass resolution  $\sim 1\%$  (1.6-2.0 GeV)
- Reducible backgrounds (reject through lepton isolation, IP cuts):
  - $Zbb \rightarrow 4\text{leptons}$
  - $t\bar{t} \rightarrow 4\text{leptons}$
- $ZZ^*/\gamma^* \rightarrow 4 \text{ leptons}$  irreducible background dominant after selection





# The Golden Channel



$H \rightarrow 4$  leptons

Sensitivity best  
for  $\sim 160$  GeV  
and heavier  
Higgs Boson

# A Lesson in Systematic

- In absence of systematics significance can be approximated to be  $\frac{s}{\sqrt{b}}$

- For  $5\sigma$  one needs

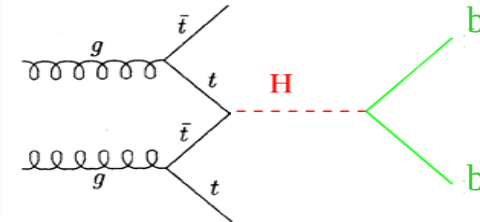
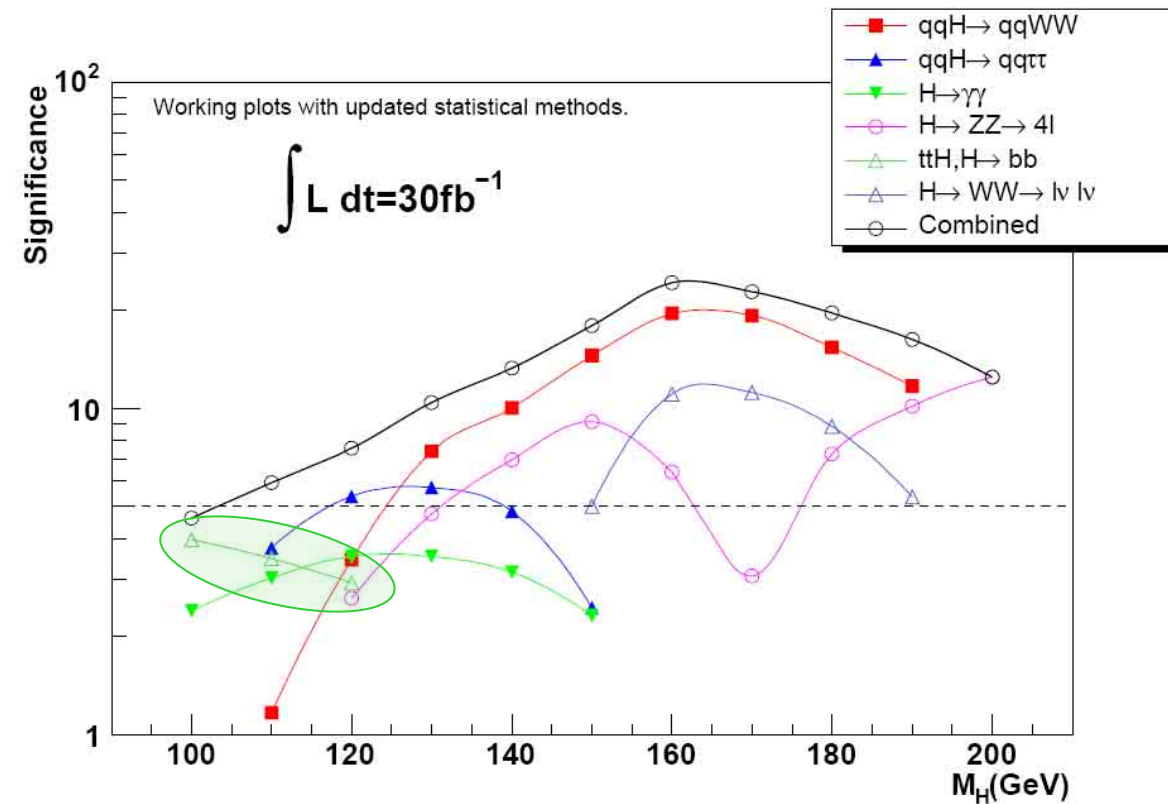
$$\frac{s}{b} > 5\Delta$$

- For 10% systematics this implies

$$\frac{s}{b} > 0.5$$

- However if there is systematics, say,  $\Delta b$  the significance is reduced to  $\frac{s}{\sqrt{b(1 + \Delta^2 \cdot b)}} \rightarrow \frac{s}{\Delta \cdot b}$

# A Lesson in Systematics, $t\bar{t}H$



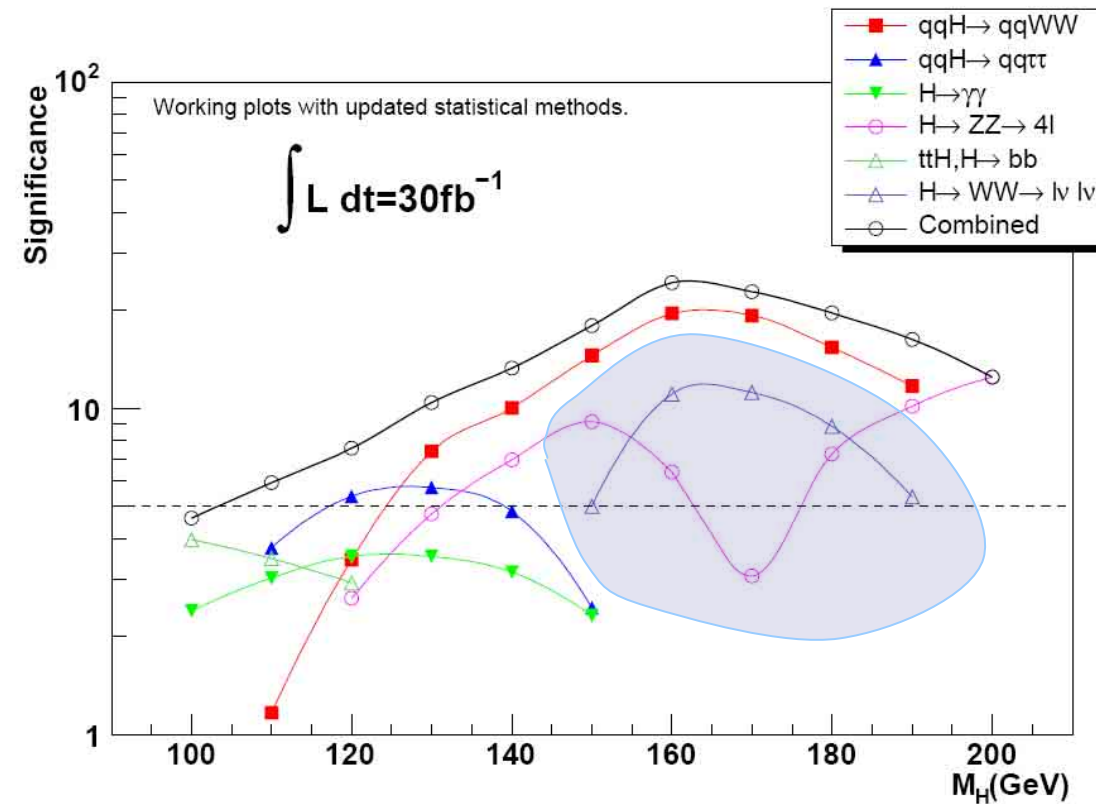
$t\bar{t}H, H \rightarrow bb$

A multi-jets final state

Looked promising until fast simulation was replaced by full simulation and systematics killed it



# $m_H \sim 160$ , Gauge Bosons Playground



$H \rightarrow WW \rightarrow \ell\nu \ell\nu$   
with  $l-l$  spin correlation

Dominant for  $m_H \sim 2m_W$

Signature of 2 isolated leptons + missing  $E_T$

No mass peak, use transverse mass need to understand missing  $E_T$

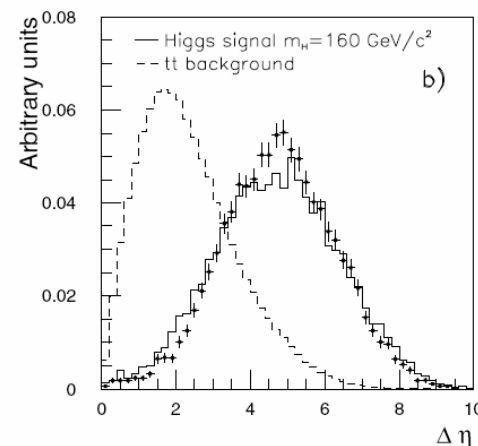
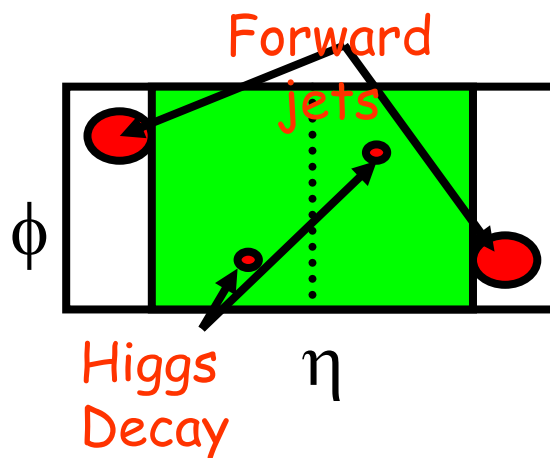
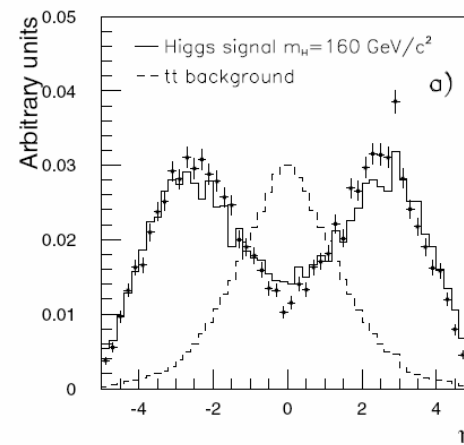
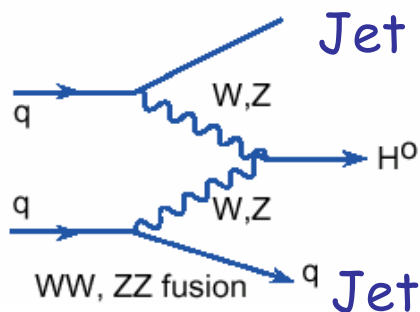
$$m_T = \sqrt{2 P_T^{\ell\ell} E_T (1 - \cos \Delta\varphi)}$$

Main background from  $Wt(b)$  and  $t\bar{t}$ , rejected via jet veto, yet systematics is still  $>10\%$

# The Breakthrough: VBF

Han, Valencia, Willenbrock (1992);  
Figy, Oleari, Zeppenfeld (2003,2004)

- $qqH, H \rightarrow WW, \tau\tau$
- Signature:
  - central jet veto  
(only signal decay products in the central region)
  - two high  $p_T$  jets with large  $\Delta\eta$  separation
- Success of channel relies on understanding of the Missing Energy



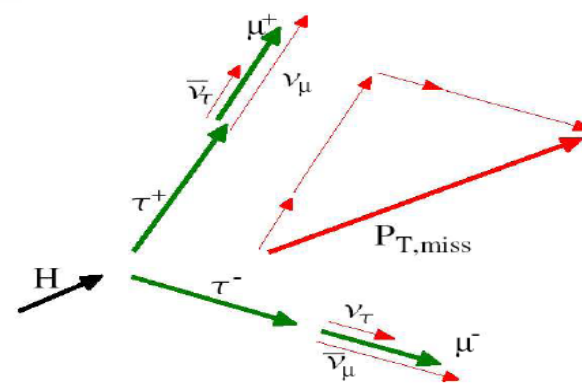
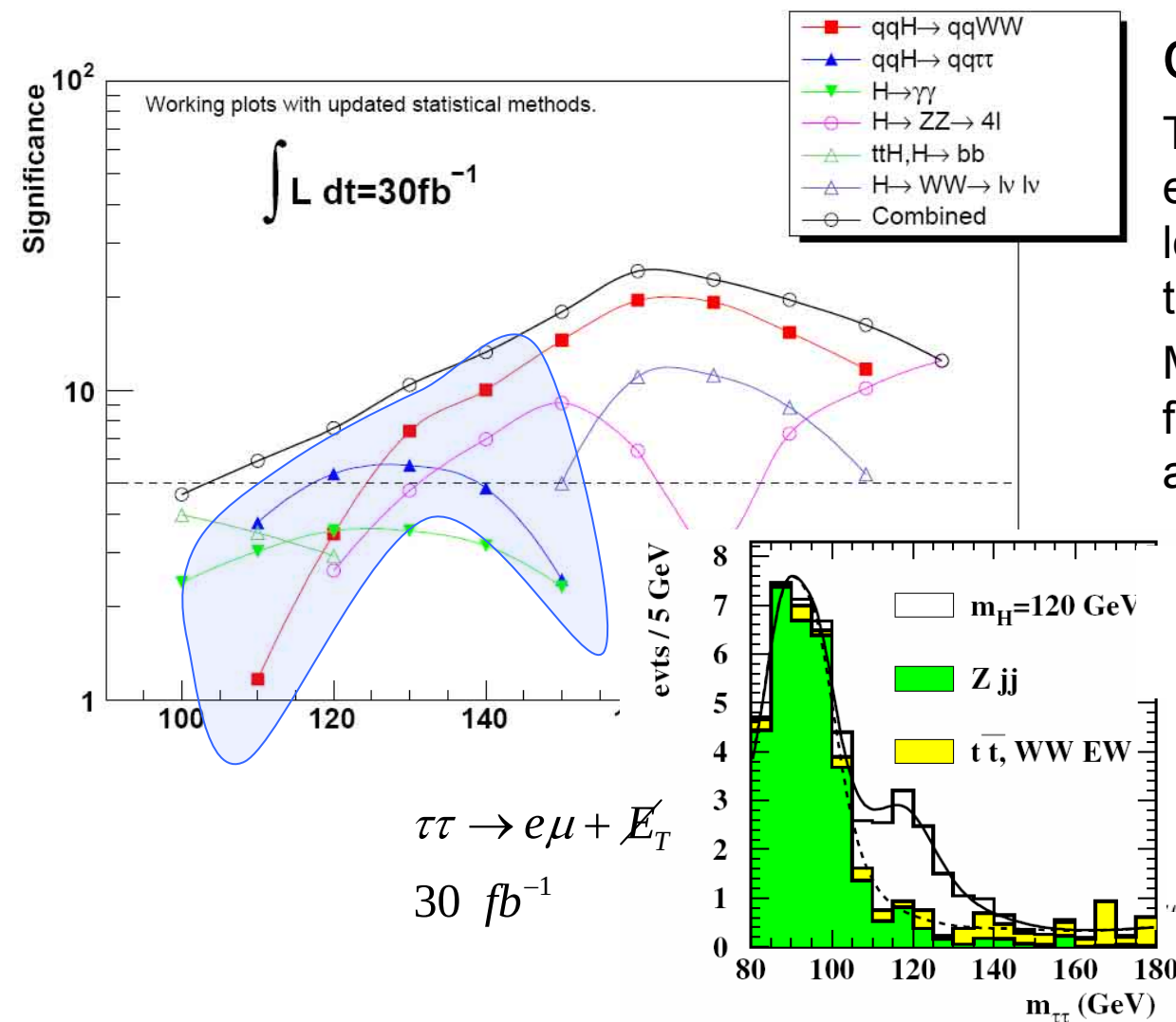
# The Breakthrough: VBF

Han, Valencia, Willenbrock (1992);  
Figy, Oleari, Zeppenfeld (2003,2004)

$qqH, H \rightarrow WW, \tau\tau$

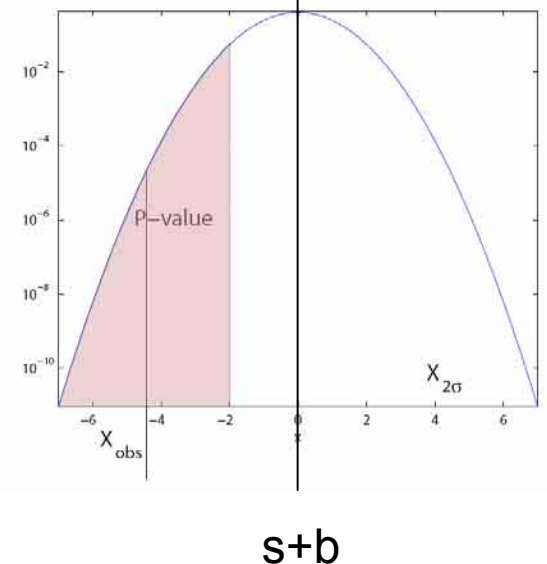
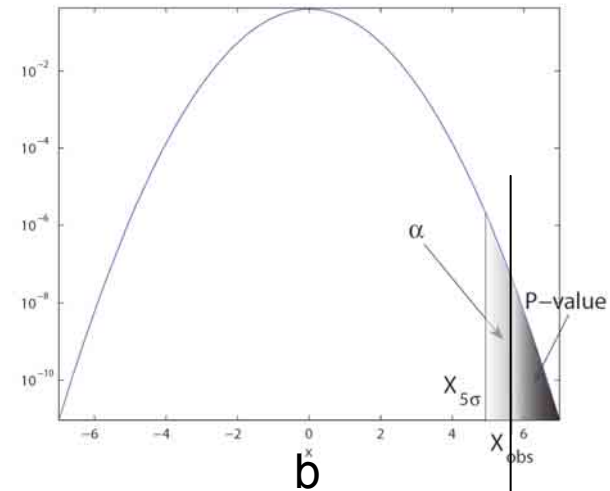
The  $\tau\tau$  decay mode  
extends the sensitivity to  
lower Higgs masses where  
there is a  $BR(H \rightarrow \tau\tau)$

Mass can be reconstructed  
for  $\tau\tau$  using the collinear  
approximation



# Towards Combination of Channels

- Discovery:  
If the probability of the background to give an observation as or more incompatible than the observed one ( $p\text{-value}=1-\text{CL}_b$ ) is less than  $\sim 2.8 \cdot 10^{-7}$  we claim a  $5\sigma$  discovery
- Exclusion:  
If the probability of the would be  $s+b$  to fluctuate down and give an observation as or less compatible with  $s+b$ , is less than  $\sim 5\%$  we claim an exclusion at the 95% C.L.





# The LEP $CL_b + C\&H$ Method

- The C&H is a hybrid (Bayesian nature)  
Integrate on all possible values of  
unknown true  $b$

$$n_{\text{expected}} = \mu s + b$$

$$\text{prob}(n_{\text{obs}}, b_{\text{obs}} \mid \mu) = \int P(n_{\text{obs}} \mid \mu s + b) \pi(b) db$$

- $\pi(b)$  is the prior of  $b$ , e.g.

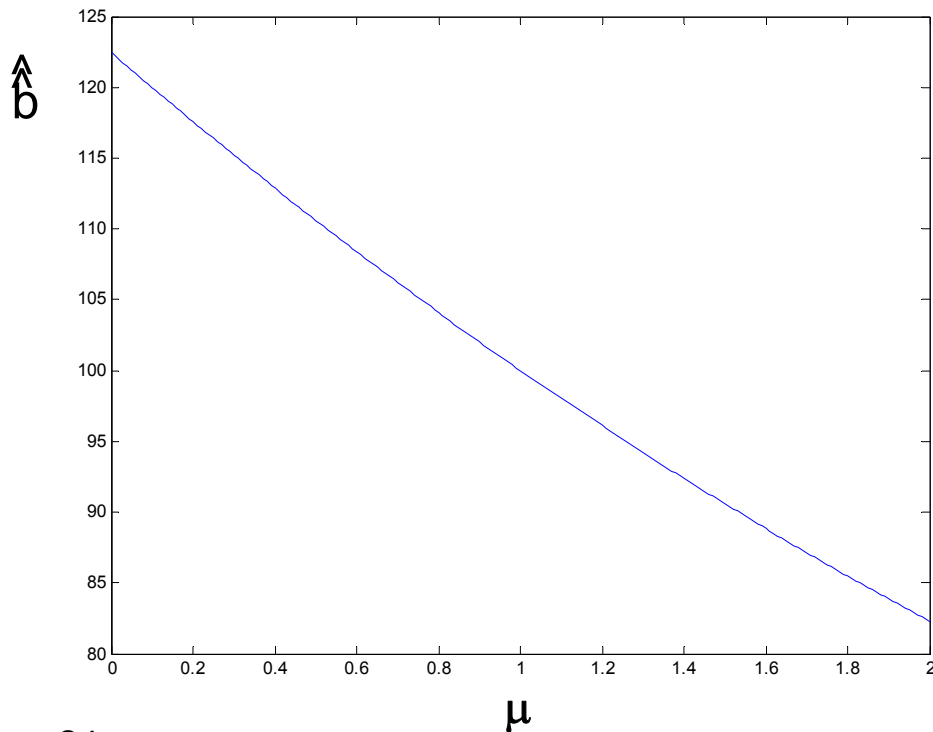
$$\pi(b) \sim G(b_{\text{obs}} \mid b, \sigma_b)$$

# Profiling the Likelihood

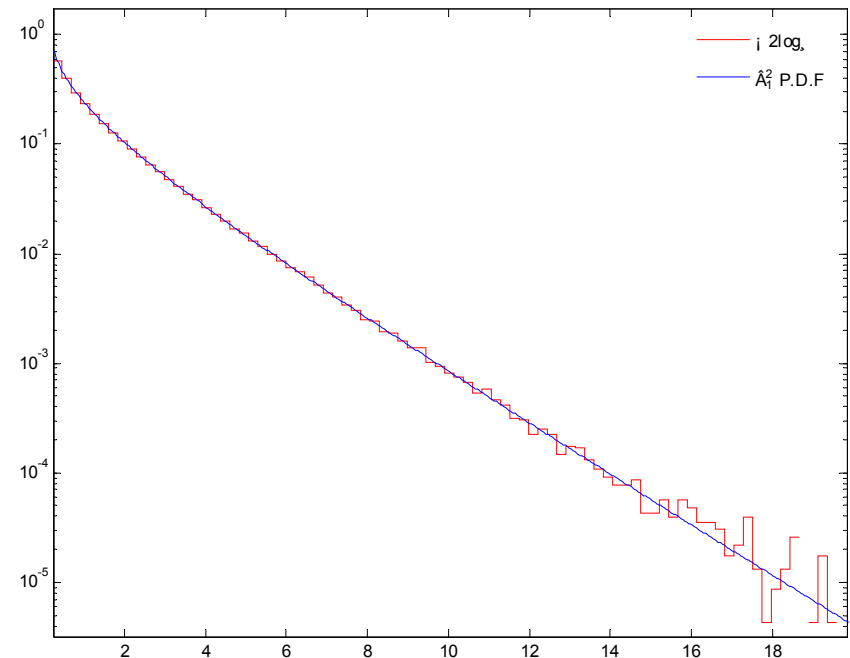
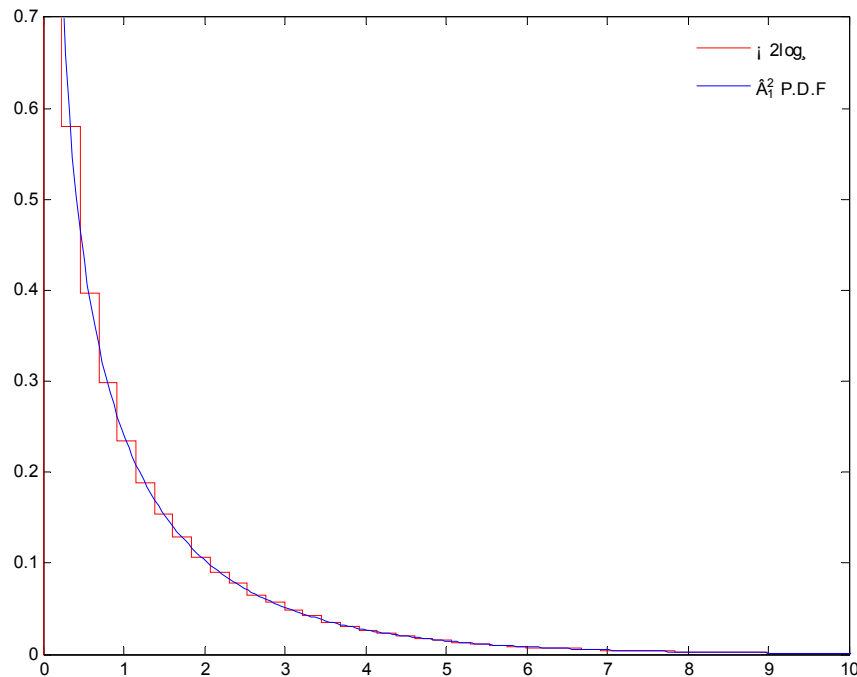
- Profile Likelihood:  $\lambda(\mu) = \frac{L(\mu s, \hat{b}(\mu s))}{L(\hat{\mu} s, \hat{b})}$

Where  $\hat{s}, \hat{b}$  are MLE

$\hat{b}(s)$  is the MLE of  $b$  given  $\mu$



- $\lambda(\mu) = \frac{L(\mu s, \hat{b}(\mu s))}{L(\hat{\mu} s, \hat{b})}$  distributes as a  $\chi^2$  with 1 d.o.f
- This ensures simplicity, coverage, speed



# The Profile Likelihood for Significance Calculation

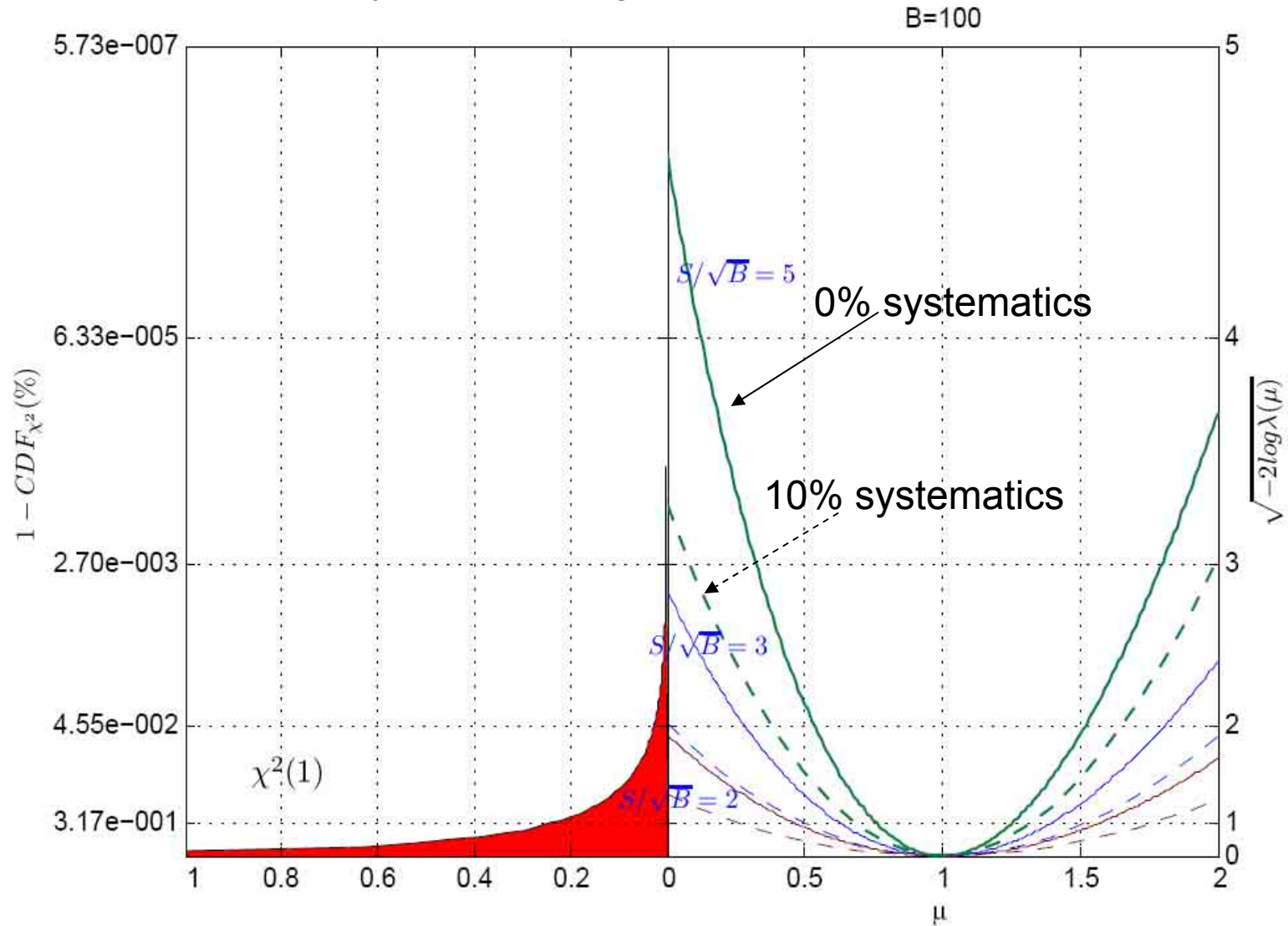
$$\lambda(\mu) = \frac{L(\mu s, \hat{\hat{b}}(\mu s))}{L(\hat{\mu} s, \hat{b})} \quad -2 \log \lambda(\hat{\mu} \pm N \sigma_{\hat{\mu}}) = N^2$$
$$N = \sqrt{-2 \log \lambda(\mu)}$$

- In particular if we generate **background only** experiments,  $\lambda(\mu=0)$  is distributed as  $\chi^2$  with 1 d.o.f
- Discovery has to do with a low probability of the background only experiment to fluctuate and give us a signal like result....
- To estimate a discovery sensitivity we simulate a data compatible with a signal (s+b) and evaluate for this data  $\lambda(\mu=0)$ . For this data, the MLE of  $\mu$  is 1

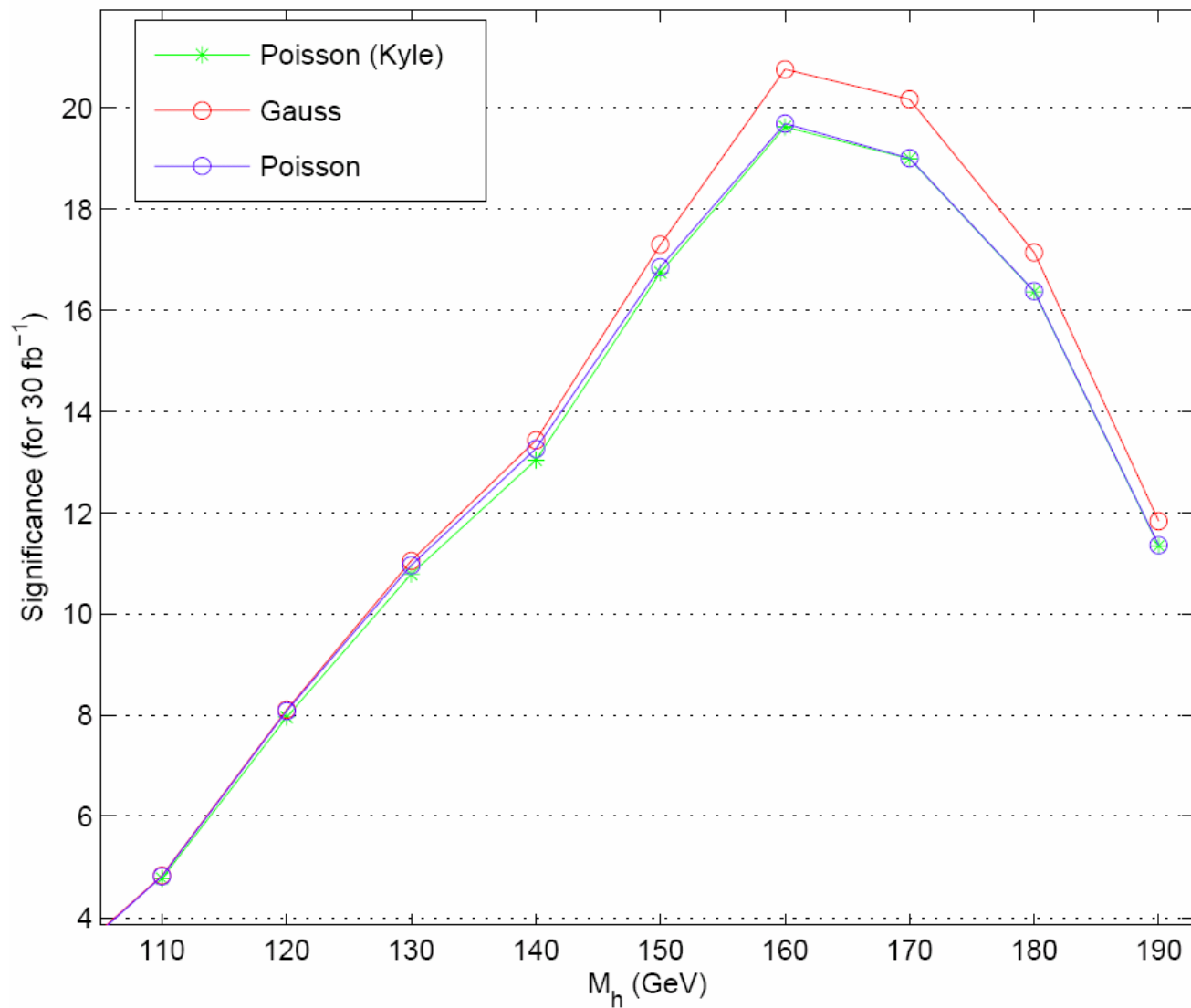


# With 10% Background Systematics

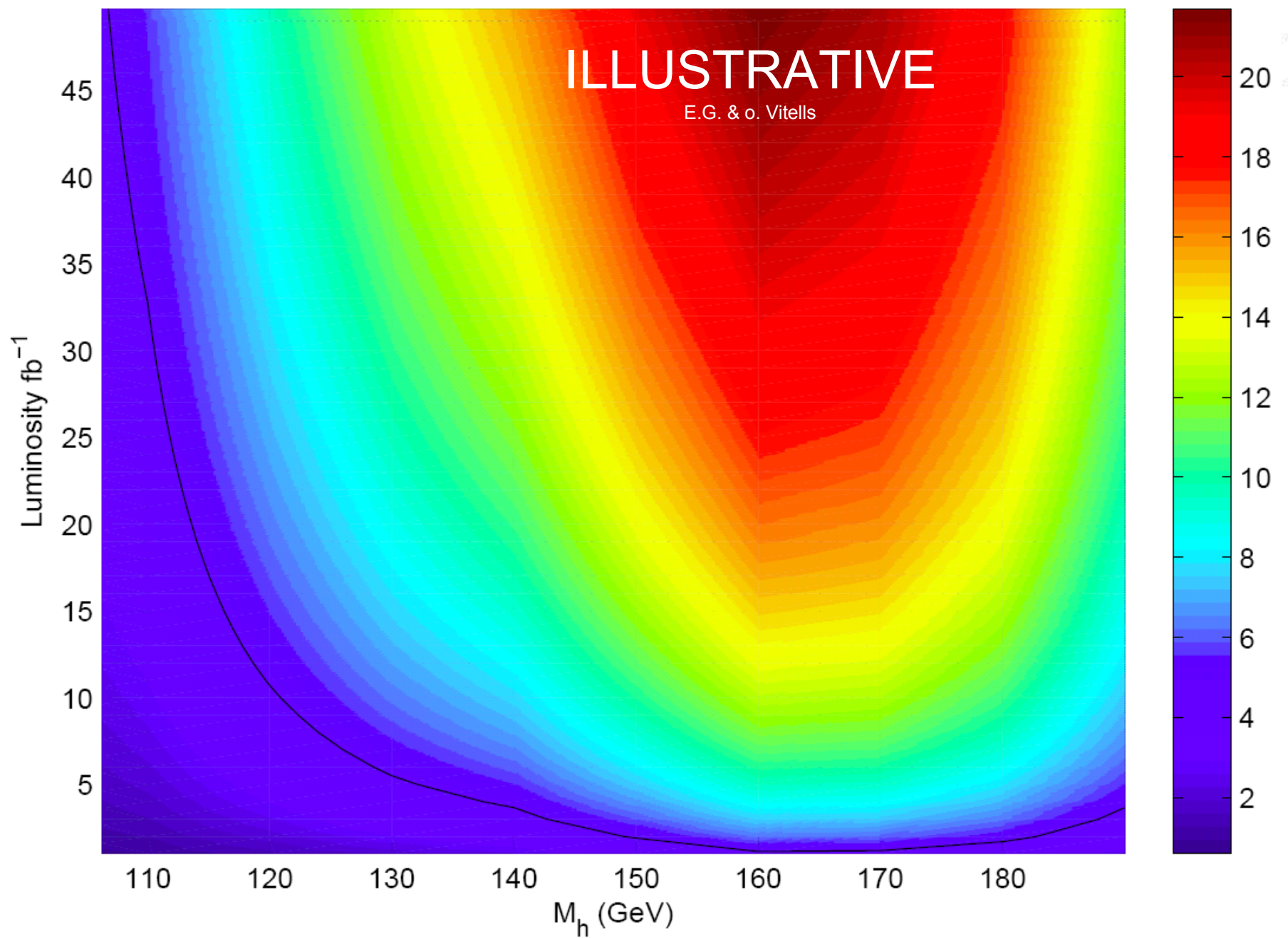
For  $b=100$  with 10% systematics, significance for  $S/\sqrt{B}=5$  drops to  $\sim 3.6$



# Results



Discovery significance ( $\sigma$ )



# Exclusion with Profile Likelihood

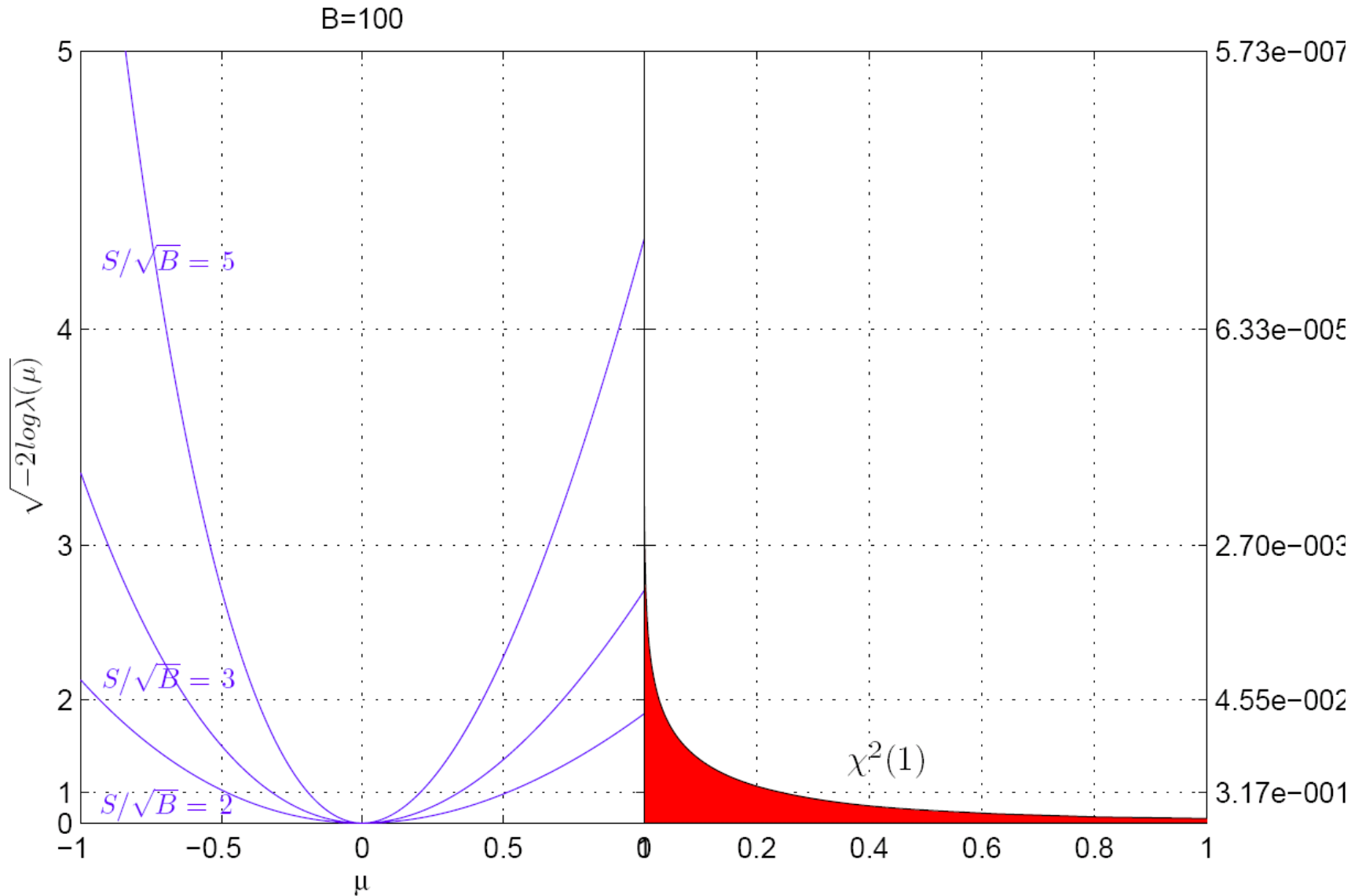
- Exclusion is related to the probability of the “would be” signal to fluctuate down to the background only region (i.e. the p-value of the s+b “observation” )

- Here we suppose the data is the background only and the exclusion sensitivity is given by

$$N = \sqrt{-2\lambda(\mu = 1)}$$

- Exclusion at the 95% C.L. means  $N=2$

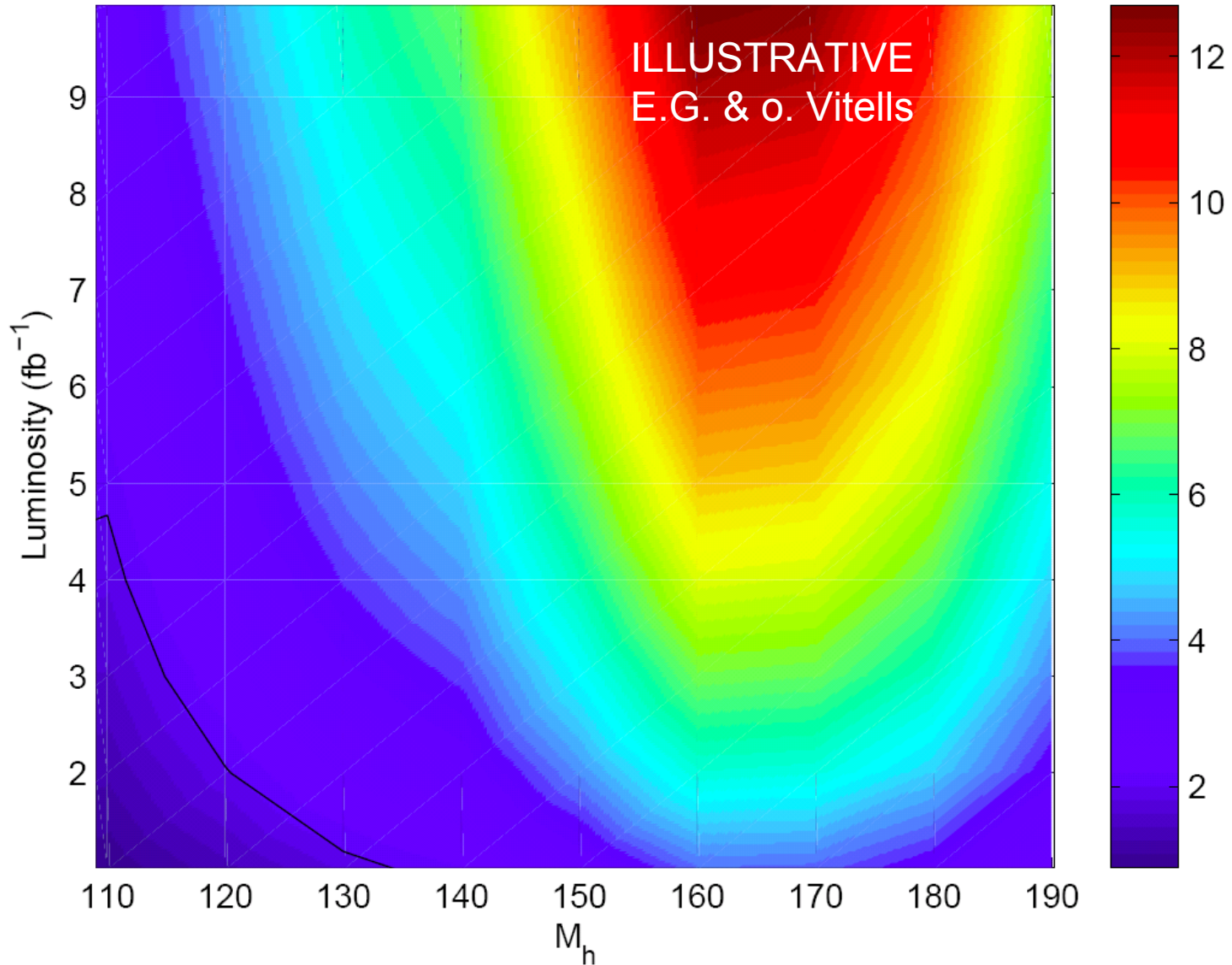
# Exclusion - Moderate $B$ ( $\Delta B=0$ )





# ATLAS Exclusion Sensitivity

Exclusion significance



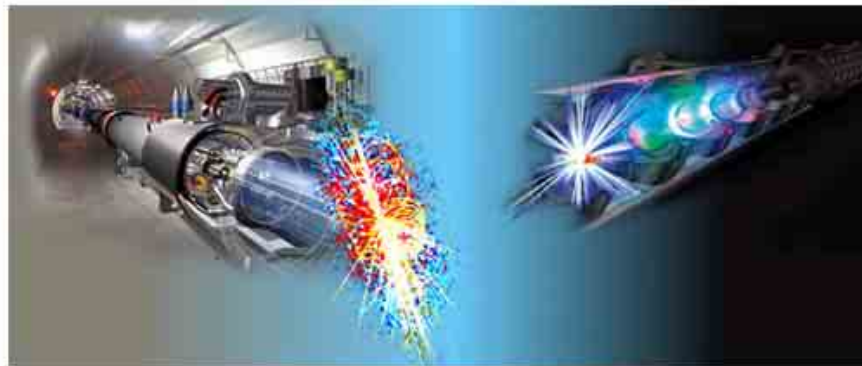
# Cases for ILC

- OK, so LHC discovered a Higgs Boson, now what?
- What happens if we observe one Higgs and nothing more?
  - Is it a SM Higgs Boson?
  - What is its width?
  - What is its spin?
  - What are its couplings?
- Even though some properties can be probed with the LHC, if the LHC is a Higgs hunter, the ILC would be a Higgs Probe.....

# From LHC to ILC

## The LHC Early Phase for the ILC

April 12 - 14, 2007



The LHC will produce its first physics data at 14 TeV in 2008 and has the promise of making groundbreaking discoveries with the first few femtobarns of data. This will certainly have profound implications for the complete high energy physics program. It is now time to examine the scenarios that may occur in the early phase of the LHC operation and investigate their impact for ILC physics.

A workshop on the LHC early phase and its impact on the ILC will be held at Fermilab, April 12-14, 2007. The purpose of this workshop is to bring together the LHC and ILC experimental and theoretical community with interest in collider physics to assess the prospects for LHC/ILC interplay based on early LHC data with an integrated luminosity of about 10 fb<sup>-1</sup>.

The workshop will combine plenary and working sessions, with the idea of initiating specific projects in these areas. We expect this activity will ramp up into a series of workshops throughout 2007 and 2008.

# From LHC to ILC

## LHC ILC Interplay

### Interplay and Synergy

K. Desch, LCWS 07

Also workshop for the LHC early phase for the ILC, Fermilab, 07

$$HC + LC > HC$$

$$HC \oplus LC > HC + LC$$

$$HC \otimes LC > HC \oplus LC$$



LCWS Korea 2002

LHC/ILC Study group  
Phys. Rept. 426 (2006) 47



Physics Reports 426 (2006) 47

www.elsevier.com/locate/physrep

Conclusion 2002-2006:

Terascale physics needs both  
LHC and ILC

Many examples for

- joint interpretation  
(added value from ILC)
- joint analyses  
(feedback from ILC to LHC)

Physics interplay of the LHC and the ILC<sup>☆</sup>

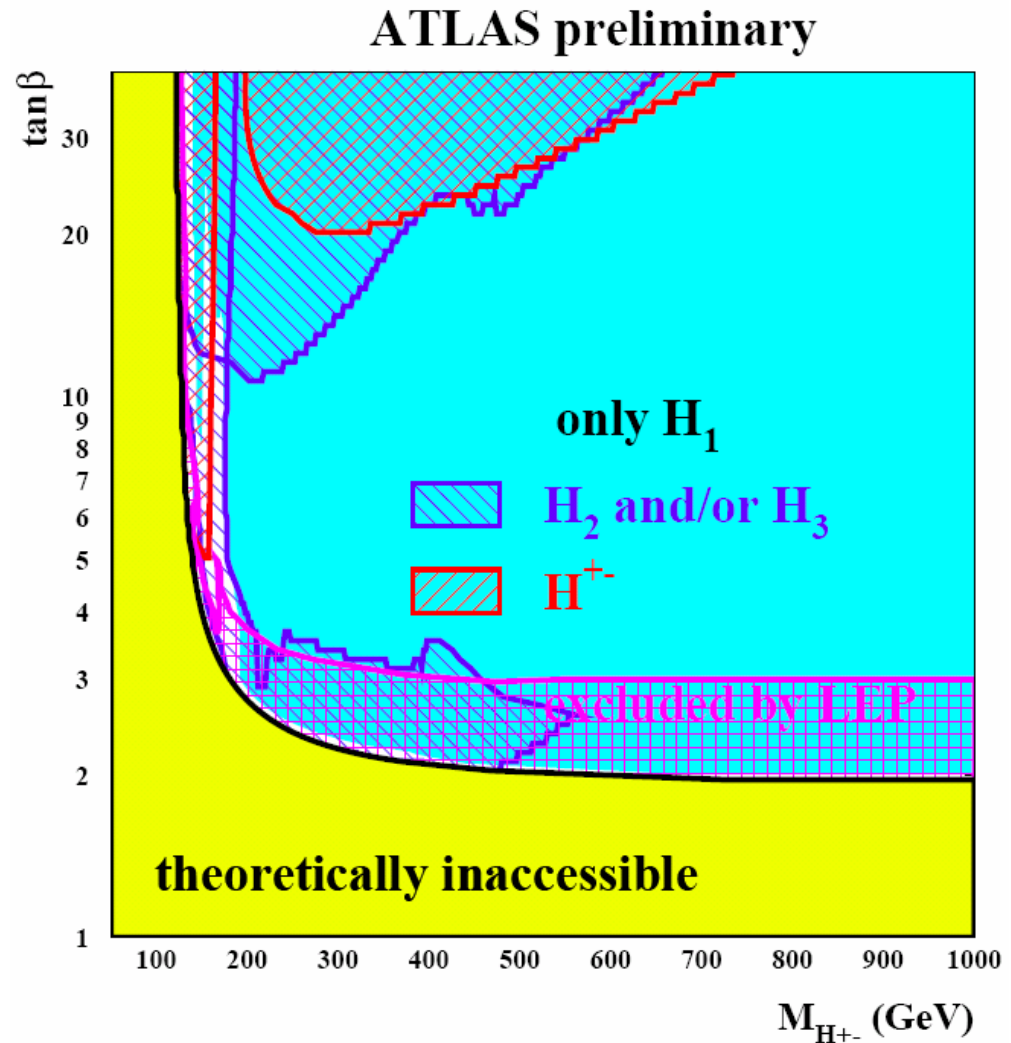
The LHC/ILC Study Group

G. Weiglein<sup>a,\*</sup>, T. Barklow<sup>b</sup>, E. Boos<sup>c</sup>, A. De Roeck<sup>d</sup>, K. Desch<sup>e</sup>, F. Gianotti<sup>d</sup>,  
R. Godbole<sup>f</sup>, J.F. Gunion<sup>g</sup>, H.E. Haber<sup>h</sup>, S. Heinemeyer<sup>d</sup>, J.L. Hewett<sup>b</sup>, K. Kawagoe<sup>i</sup>,  
K. Mönig<sup>j</sup>, M.M. Nojiri<sup>k</sup>, G. Polesello<sup>h,l</sup>, F. Richard<sup>m</sup>, S. Riemann<sup>n</sup>, W.J. Stirling<sup>a</sup>,  
A.G. Akeroyd<sup>o</sup>, B.C. Allanach<sup>o</sup>, D. Asner<sup>p</sup>, S. Asztalos<sup>q</sup>, H. Baer<sup>r</sup>, M. Battaglia<sup>s</sup>, U. Baur<sup>t</sup>,  
P. Bechtel<sup>c</sup>, G. Bélanger<sup>d</sup>, A. Belyaev<sup>r</sup>, E.L. Berger<sup>v</sup>, T. Binoth<sup>w</sup>, G.A. Blair<sup>x</sup>, S. Boegert<sup>y</sup>,  
F. Boudjema<sup>u</sup>, D. Bourilkov<sup>z</sup>, W. Buchmüller<sup>aa</sup>, V. Bunichev<sup>c</sup>, G. Cerminara<sup>ab</sup>,  
M. Chiorboli<sup>ac</sup>, H. Davoudiasl<sup>ad</sup>, S. Dawson<sup>ae</sup>, S. De Curtis<sup>af</sup>, F. Deppisch<sup>w</sup>, M.A. Díaz<sup>ag</sup>,  
M. Dittmar<sup>ah</sup>, A. Djouadi<sup>ai</sup>, D. Dominici<sup>aj</sup>, U. Ellwanger<sup>aj</sup>, J.L. Feng<sup>ak</sup>, I.F. Ginzburg<sup>al</sup>,  
A. Giolo-Nicollera<sup>ah</sup>, B.K. Gjelsten<sup>am</sup>, S. Godfrey<sup>an</sup>, D. Grellscheid<sup>ao</sup>, J. Gronberg<sup>d</sup>,  
E. Gross<sup>ap</sup>, J. Guasch<sup>aq</sup>, K. Hamaguchi<sup>ar</sup>, T. Han<sup>ar</sup>, J. Hisano<sup>as</sup>, W. Hollik<sup>at</sup>, C. Hugonie<sup>am</sup>,  
T. Hurth<sup>ah,d</sup>, J. Jiang<sup>v</sup>, A. Juste<sup>av</sup>, J. Kalinowski<sup>aw</sup>, W. Kilian<sup>ax</sup>, R. Kinnunen<sup>ax</sup>,  
S. Kraml<sup>ad,ay</sup>, M. Krawczyk<sup>aw</sup>, A. Krokhin<sup>az</sup>, T. Krupovnickas<sup>r</sup>, R. Lafaye<sup>aaa</sup>, S. Lehti<sup>ax</sup>,  
H.E. Logan<sup>at</sup>, E. Lykken<sup>ahb</sup>, V. Martin<sup>aac</sup>, H.-U. Martyn<sup>aad</sup>, D.J. Miller<sup>aac,aae</sup>, S. Moretti<sup>aae</sup>,  
F. Moortgat<sup>d</sup>, G. Moortgat-Pick<sup>ad</sup>, M. Mühlleitner<sup>aq</sup>, P. Niezurawski<sup>aaq</sup>,  
A. Nikitenko<sup>aa,ah</sup>, L.H. Orr<sup>aaai</sup>, P. Osland<sup>aaaj</sup>, A.F. Osorio<sup>aaak</sup>, H. Päs<sup>w</sup>, T. Plehn<sup>d</sup>,  
W. Porod<sup>aa,aaal</sup>, A. Pukhov<sup>c</sup>, F. Quevedo<sup>o</sup>, D. Rainwater<sup>aaai</sup>, M. Ratz<sup>aa</sup>, A. Redelbach<sup>w</sup>,  
L. Reina<sup>t</sup>, T. Rizzo<sup>b</sup>, R. Rückl<sup>w</sup>, H.J. Schreiber<sup>l</sup>, M. Schumacher<sup>ap</sup>, A. Sherstnev<sup>c</sup>,  
S. Slabopitsky<sup>aaam</sup>, J. Solà<sup>aaan,aaao</sup>, A. Sopczak<sup>aaap</sup>, M. Spira<sup>aaq</sup>, M. Spiropulu<sup>d</sup>, Z. Sullivan<sup>ay</sup>,  
M. Szleper<sup>aaq</sup>, T.M.P. Tait<sup>ay</sup>, X. Tata<sup>aaaz</sup>, D.R. Tovey<sup>aaas</sup>, author A. Tricomi<sup>aaq</sup>, M. Velasco<sup>aaag</sup>,  
D. Wackeroth<sup>t</sup>, C.E.M. Wagner<sup>aaat</sup>, S. Weinzierl<sup>aaai</sup>, P. Wienemann<sup>aa</sup>, T. Yanagida<sup>aaav,aaaw</sup>,  
A.F. Žarnecki<sup>aaag</sup>, D. Zerwas<sup>ai</sup>, P.M. Zerwas<sup>ai</sup>, L. Živković<sup>aaop</sup>



# The Case of Observing One Scalar

- Even if the Higgs is supersymmetric there is a large region in the parameters space where the LHC can observe only one of the Higgs Bosons
- An accurate measurements of the couplings & BRs of the observed Higgs can reveal its nature

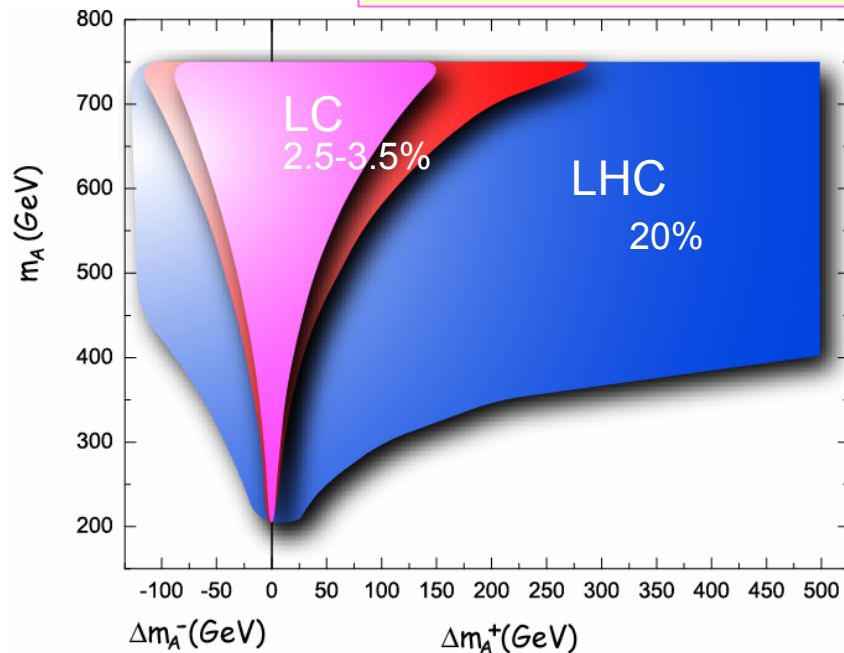




# Some Things ILC Does Better

- Here  $m_h = 120$

$$R = \frac{BR(H \rightarrow bb) / BR(H \rightarrow WW)}{[BR(H \rightarrow bb) / BR(H \rightarrow WW)]_{SM}}$$



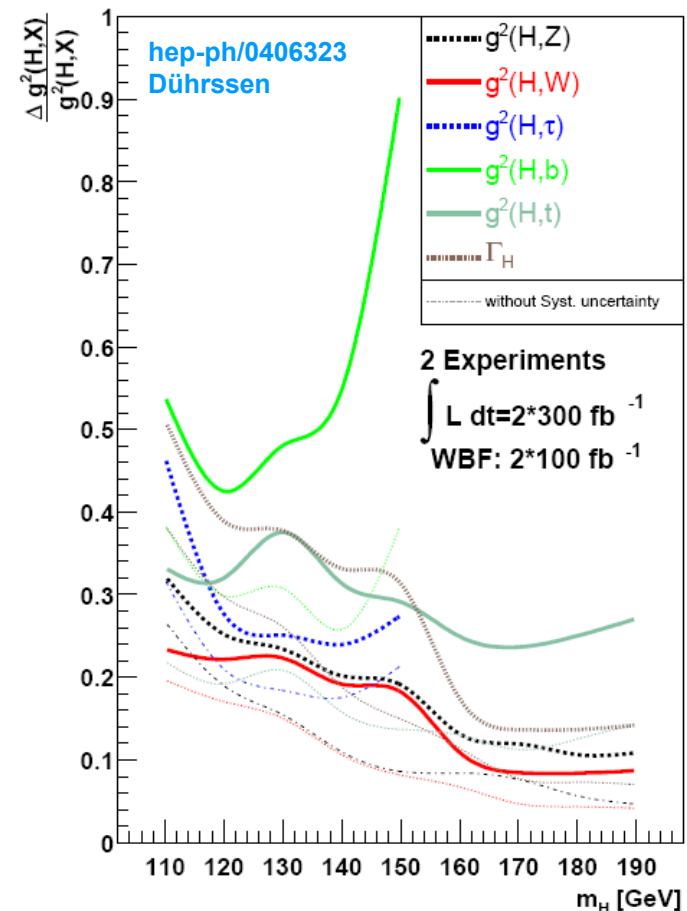
$\Delta m_A = 30\%$  for  $m_A = 800$  GeV  
also in parameter regions where  
LHC is blind

**LHC/LC interplay in the MSSM Higgs sector**

Georg Weiglein and Sven Heinemeyer, Lidia Zivkovic, E.G., Klaus Desch  
JHEP09(2004) (September 2004) 062 **2004** .J. High Energy Phys

- LHC: for  $300 \text{ fb}^{-1}$  and  $110 < m_H < 190$  GeV

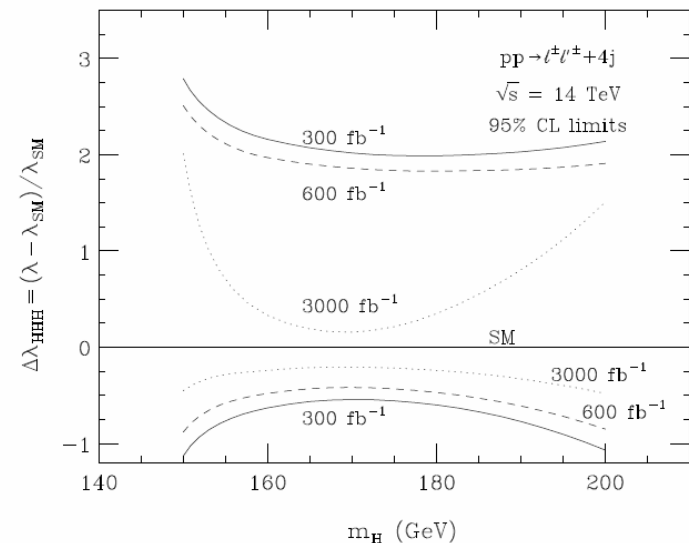
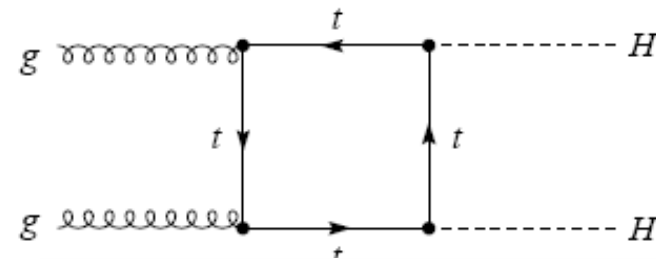
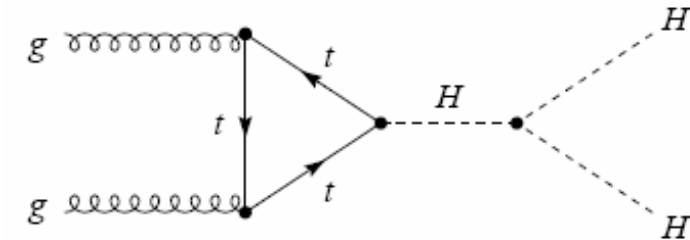
- $\Delta g^2/g^2 \sim 10\%-45\%$  (except for b)
- $\Delta \Gamma_H/\Gamma_H \sim 10\%-50\%$



# The Ultimate Goal: Probing the SSB Sector

Moriond QCD 2006 - Helenka Przysiezniak

- Derive 95%CL bounds from  $\chi^2$  fit to  $m_{\text{vis}}$  shape
- SM assumed to be valid except for self coupling.
- Assume  $m_H$  precisely known, and  $\text{BR}(H \rightarrow WW)$  known to 10% or better.
- **$gg \rightarrow HH \rightarrow (W^+W^-)(W^+W^-) \rightarrow (jj\ell^{\pm\nu})(jj\ell'^{\pm\nu})$  ( $\ell = e, \mu$ )**  
for  $m_H > 150 \text{ GeV}/c^2$ .
- The self coupling  $\lambda$  is determined to -60-300% within  $1\sigma$  for  **$150 < m_H < 200 \text{ GeV}$**
- This will have to wait for a future collider



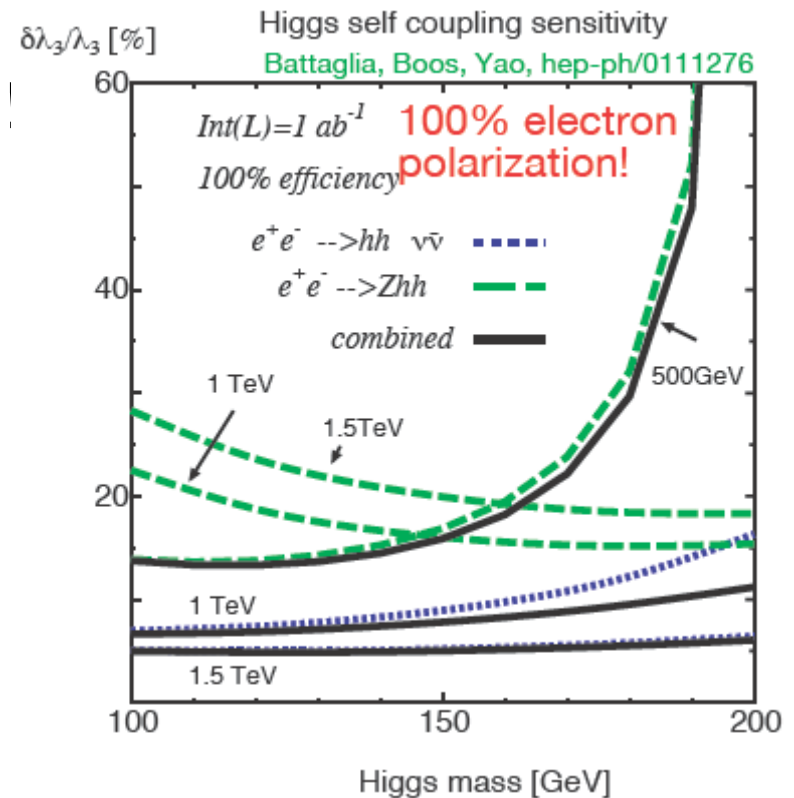
# The Ultimate Goal: Probing the SSB Sector

K. Desch, LCWS 07

Also workshop for the LHC early

phase for the ILC, Fermilab, 07

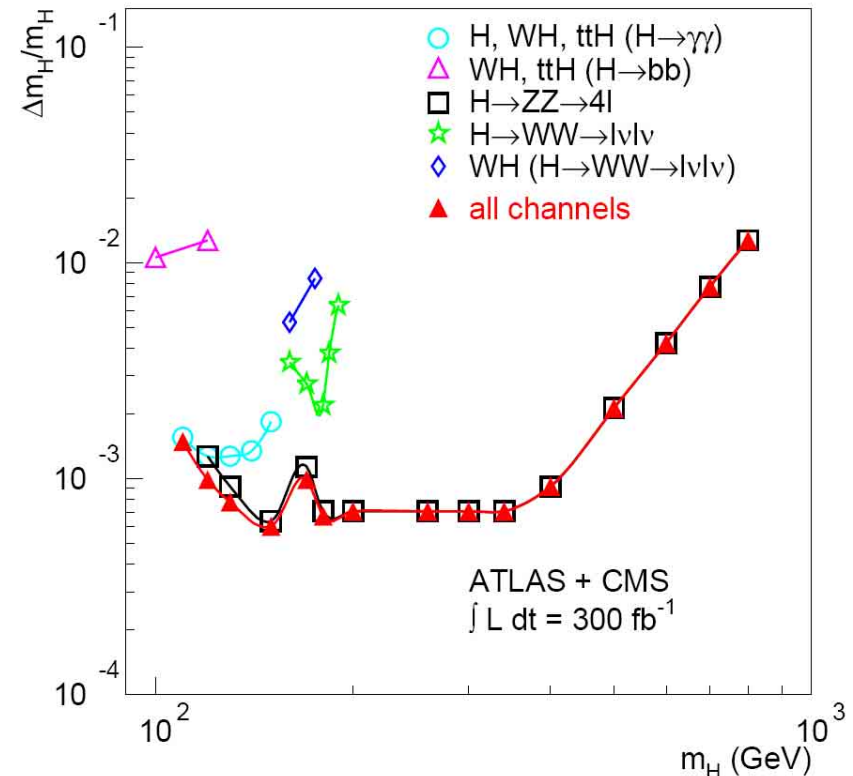
- Self Higgs coupling is not a piece of cake for a LC as well
- Needs  $>1$  TeV with a polarized electron beam and  $1 \text{ ab}^{-1}$  to probe it to the level of  $\sim 10\%$
- This by itself might justify a LC (If we observe a scalar)



# Some Things LHC Can Also Do

Moriond QCD 2006 - Helenka Przysiezniak

- Combining CMS and ATLAS with high luminosity (yet accessible within a few years) with channels like  $H \rightarrow \gamma\gamma$ ,  $H \rightarrow ZZ(*) \rightarrow 4\ell$ , WBF  $H \rightarrow \tau\tau \rightarrow \ell + \text{hadr}$  an accuracy of 0.1% might be achieved for the mass with  $m_H \sim 120\text{--}400$  GeV, that is not so different from LC
- This is under the condition that the systematics on the energy scale is below the 0.1% for photons/electrons and below 1% for jets....



# PDG 20xx?

E.G. Higgs&SUSY Orsay 2001

## Conclusion: PDG 2012?



### SUMMARY TABLES OF PARTICLE PROPERTIES

Extracted from the Particle listings of the

#### Review of Particle Physics

Published in Eur. Jour. Phys **C3**, 1 (2012)

Available at <http://www.eilamgross.com>

#### GAUGE AND HIGGS BOSONS

**H**

$J^{PC}=0^{++}$  [a]



Charge = 0

Mass  $m=120.0\pm0.040$  GeV [b]

Full Width  $\Gamma=3.6\pm0.2$  MeV [a]



**H DECAY MODES**<sup>[b]</sup>      **Fraction**

|                |                      |
|----------------|----------------------|
| bb             | $(67.8 \pm 1.6) \%$  |
| cc             | $(3.08 \pm 0.25) \%$ |
| $\tau\tau$     | $(6.8 \pm 0.35) \%$  |
| gg             | $(7.04 \pm 0.38) \%$ |
| $\gamma\gamma$ | $(0.21 \pm 0.05) \%$ |
| WW             | $(13.3 \pm 6.6) \%$  |

Or alternatively and much more interesting:

#### GAUGE AND HIGGS BOSONS

**h**

**h DECAY MODES**<sup>[c]</sup>      **Fraction**

|                              |                  |
|------------------------------|------------------|
| bb/WW                        | $11.06 \pm 0.25$ |
| $R=(bb/WW)_{\text{meas/SM}}$ | 1.32             |



**A**

Mass  $m=400.0 \pm 25$  GeV [d]



[a] LC,

[b] LC/LHC,

[c] LC-A Global Fit,

[d] LC indirectly



# Conclusions

- LHC is a discovery machine
- LHC is scheduled to deliver data starting end of 2008
- The optimist expects to see a hint of a Higgs Boson by the end of 2009
- The pessimist will wait another year
- SUSY might come earlier
- The ILC is a probing machine
- The ILC can measure some properties of the new particles discovered, yet hard to measure, by the LHC
- ILC can tell a SM scalar from a SUSY scalar
- ILC with high CM and high luminosity can probe SSB
- ILC seems to wait for the LHC....

# Backup



# Luminosity – Technology Pushed to the Limit

$$L \sim \frac{N_p^2 f_{rev} N_{bunches}}{\sigma_x \sigma_y}$$

- Beam parameters at LHC

- $N_p \cong 10^{11}$  ;  $\sigma \cong 15 \mu\text{m}$ ;  $f = 11 \text{ kHz}$ ;  
 $N_{bunches} = 2808$

- $L \sim 10^{34} \text{ cm}^{-2} \text{ s}^{-1} = 10 \text{ nb}^{-1} \text{ s}^{-1} = 10^7 \text{ mb}^{-1} \text{ s}^{-1}$ ,  
 $N = L \cdot \sigma \rightarrow$   
Access to rare (low cross section) processes

# How Does It Happen in ATLAS

## – Inner detector

- Pixel and strip silicon detectors at small radii
- Straw-tube “transition-radiation tracker” (TRT) at larger radii

## – EM calorimeter

- Lead – liquid-argon sampling calorimeter

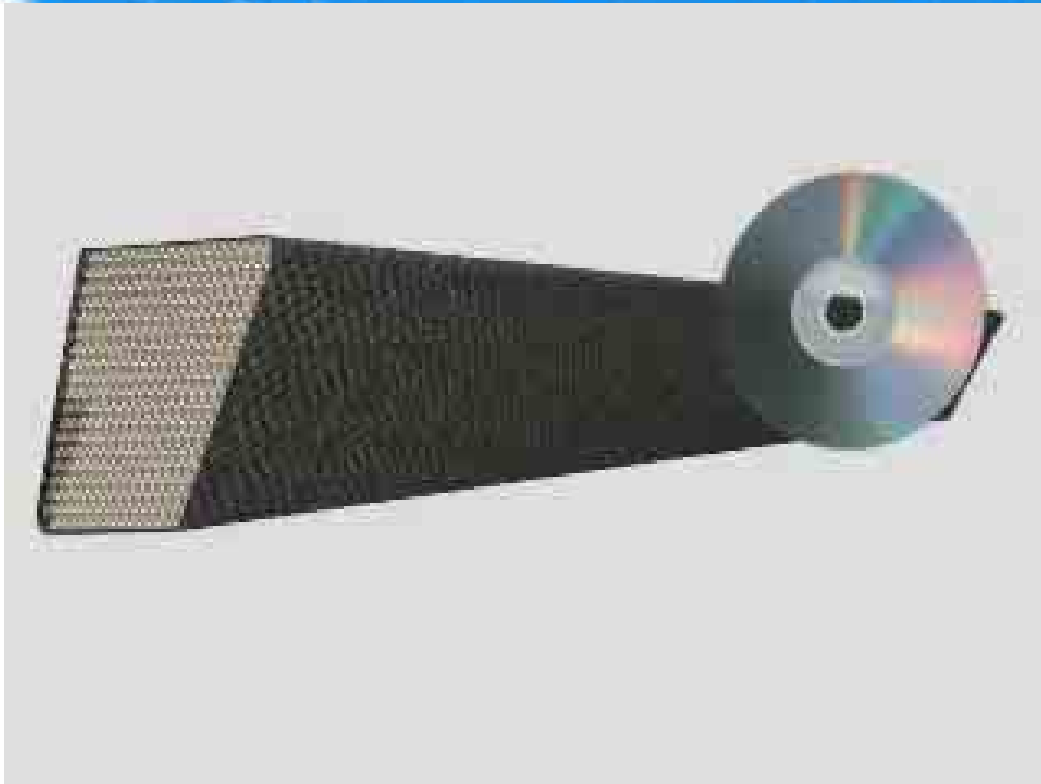
## – Hadronic calorimeter

- Iron – plastic scintillator calorimeter in barrel
- Copper – liquid-argon calorimeter in endcap

## – Muon spectrometer

- Drift tubes for precise tracking
- RPC and TGC detectors for triggering

# Telling an Electron from a Pion - TRT



- Electrons, in addition, interact with the plastic coating of the tubes emitting X-rays which help to distinguish electrons from Pions.

- Charged particles ionize the gas filled in tiny tubes (4 mm diameter) with straw like anodes which collect the electrons.
- There are over 300,000 1.5m straws in the end cap and over 50000 0.5 m straws in the barrel region

