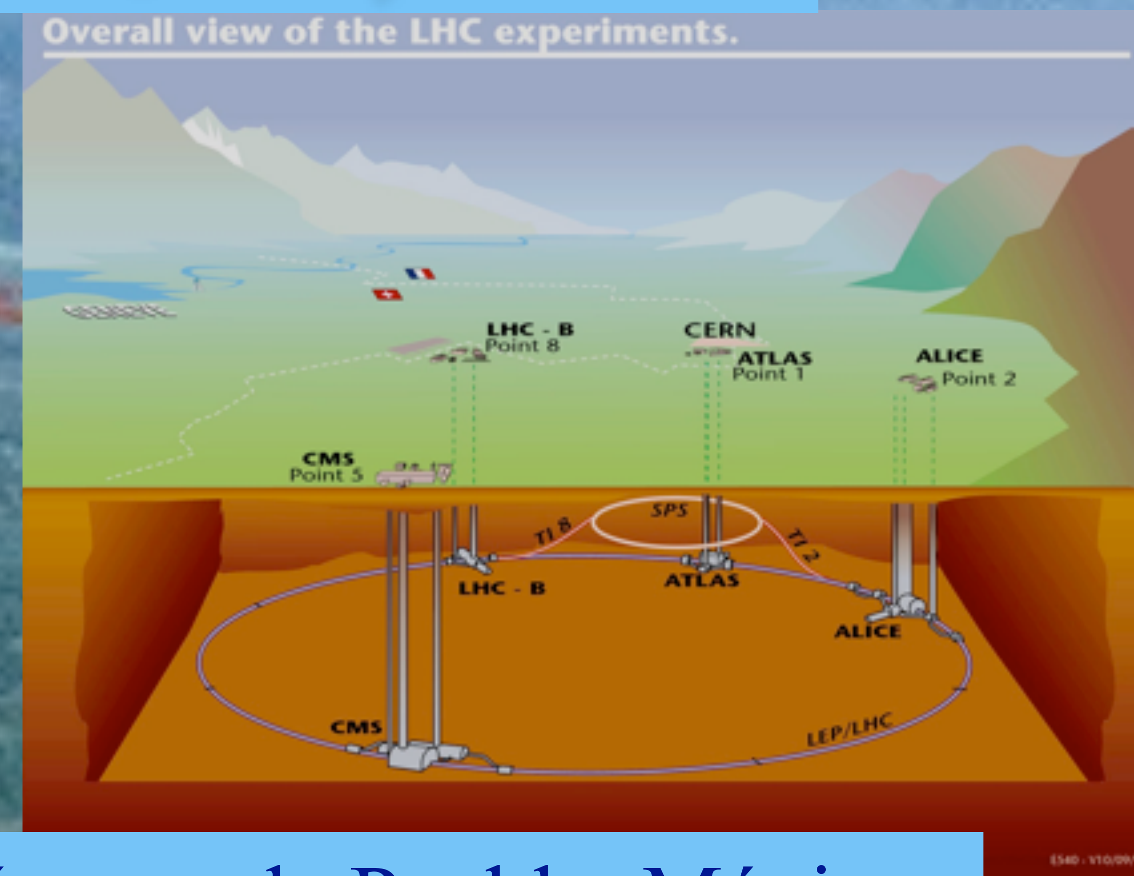
Highlights on CERN discovery of a 125 GeV boson

Luciano Maiani. Roma La Sapienza. Italy



Benemérita Universidad Autónoma de Puebla. México
August 15, 2012

Latin America at CERN

- From 2005, participation of LA countries in CERN experiments has been partially supported by exchange programs funded by the European Commission:
- HELEN, 2005-2009
- EPLANET, 2011-2015
- For Mexico, BUAP, CINVESTAV, Michoacan, UNAM
- BUAP participates in ALICE and CMS

1. LHC Milestones

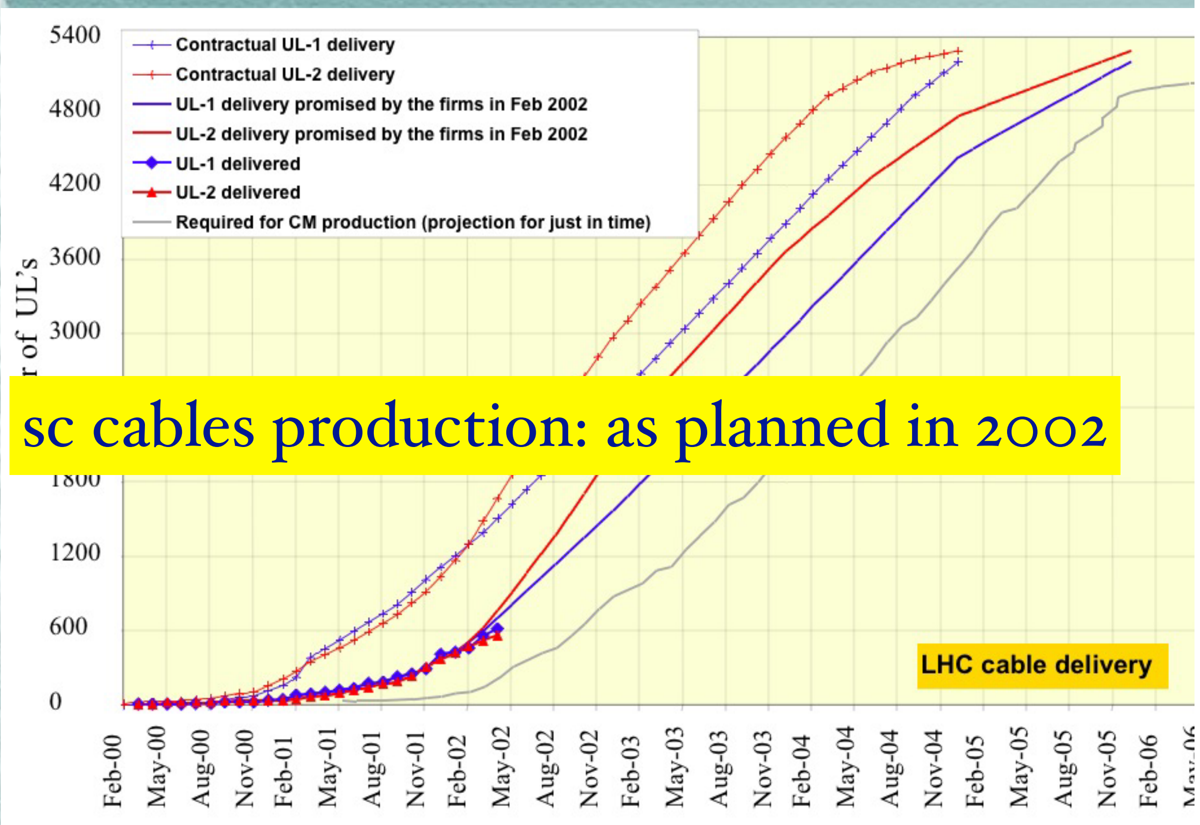
•first approval of LHC in1994, two stages

- 1996 approval of LHC in one two stage with the participation of USA, Russia, Japan and other non Member States
- Llwellyn Smith's great successes !

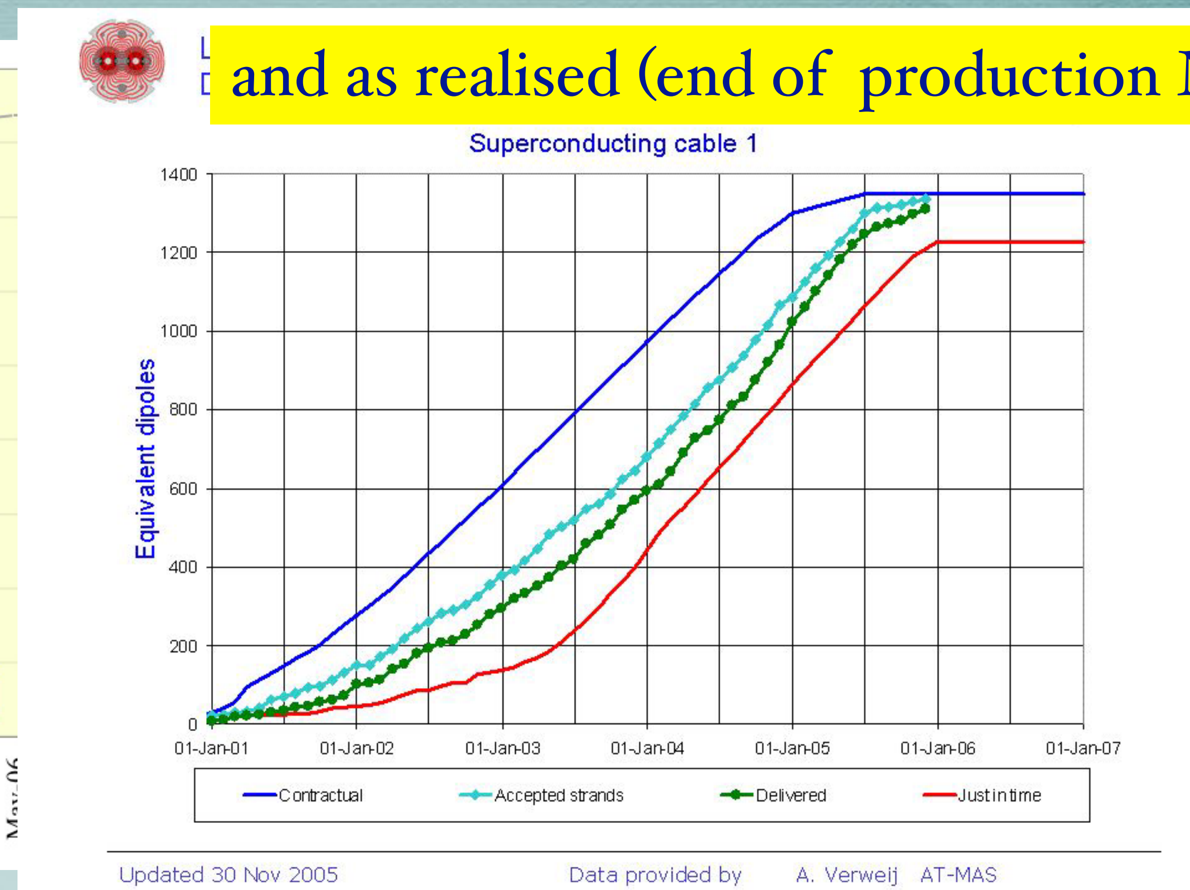
15 m prototype LHC dipole. 1998

Signature of the US-CERN agreement, Dec.1996.
From left:
for USA , N. Lane, NSF, Federico Peña, Secretary of Energy;
for CERN, Luciano Maiani, President of Council, Chris Llewellyn Smith, Director General.

The making of the LHC dipoles



sc cables production: as planned in 2002



and as realised (end of production Nov. 2005)

LHC dipoles waiting for installation, Dec. 2003 (see the LEP magnets!)

Lyn Evans and Lucio Rossi receive the last dipole, Nov. 2006

LHC Milestones (cont'd)

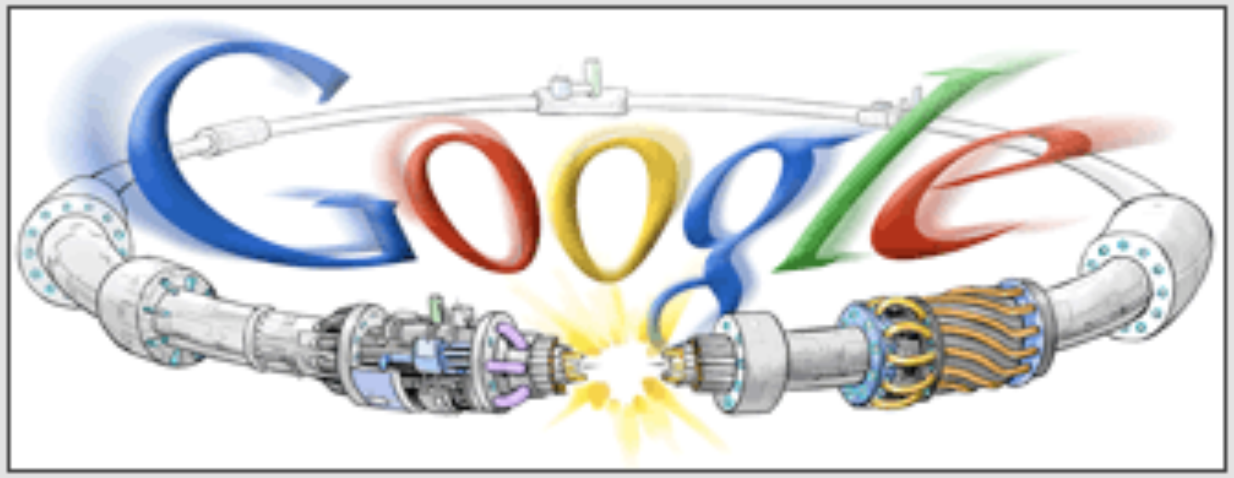
- last dipole lowered in tunnel, April 27, 2007

- beams circulated, 10 September 2008

GOOGLE and the LHC (10Sept.08)

Google LHC Logo

Today, Google place a different logo for their homepage having Large Hadron Collider (LHC) experiment theme.



We can easily see the excitement about this LHC experiment on any face who have interest in science and scientific things specially in physics as this would be the future of physics.

Scientists at the CERN research centre in Switzerland are aiming to use this wonder machine to gain a better understanding of the birth and structure of the universe, and to fill gaps in our knowledge of physics.

Well, it's a big topic to discuss…I am not that much intelligent…however a well known **Prof Stephen Hawking** said that "Whatever the LHC finds or fails to find, the results will tell us a lot about the structure of the universe."

Cheers!

September 10, 2008 - Posted by **imstrategist** | **Uncategorized** | **Google, LHC Experiment** | **1 Comment**

1 Comment »

1. Yaaay, im still alive, no black holes

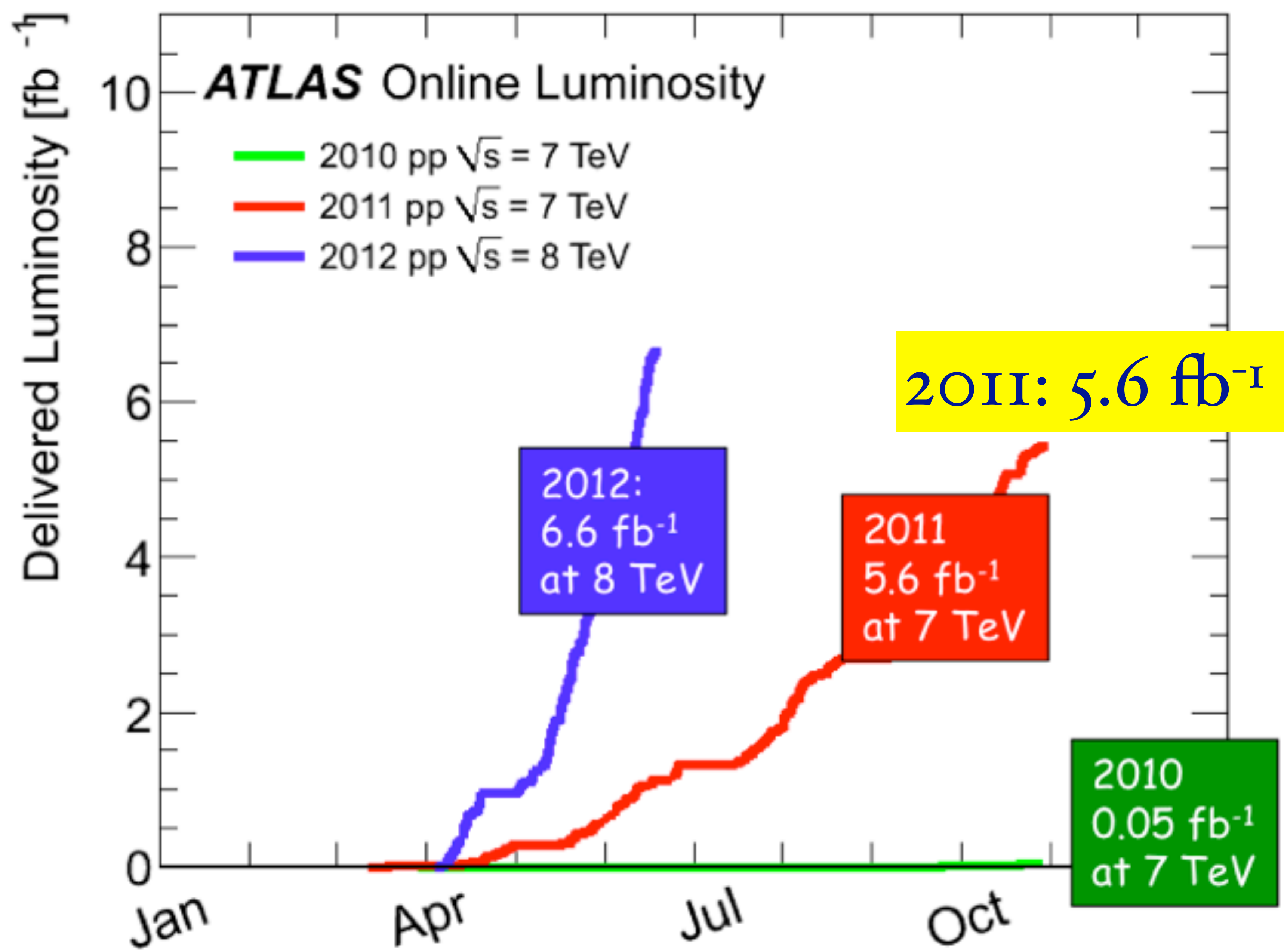
   Comment by ZeroZool | September 10, 2008

Last of 53 repaired magnets back in the tunnel (Apr. 30, 2009)

The Latest from the LHC

The 53rd and final magnet for the Sector 3-4 repairs was lowered into the tunnel on Thursday, 30 April, marking the end of repair work above ground.

The memorable raise of luminosity: 2011 and 2012



2011: 5.6 fb^{-1} per expt at E=7 TeV

2012: 6.6 fb^{-1} per expt at E=8 TeV in July

A long term work...

- Giorgio Brianti: first design, 1986
- Lyn Evans: final design, 1993, and LHC project Leader up to 2008

Giorgio Brianti in 2003

Lyn Evans in 2008

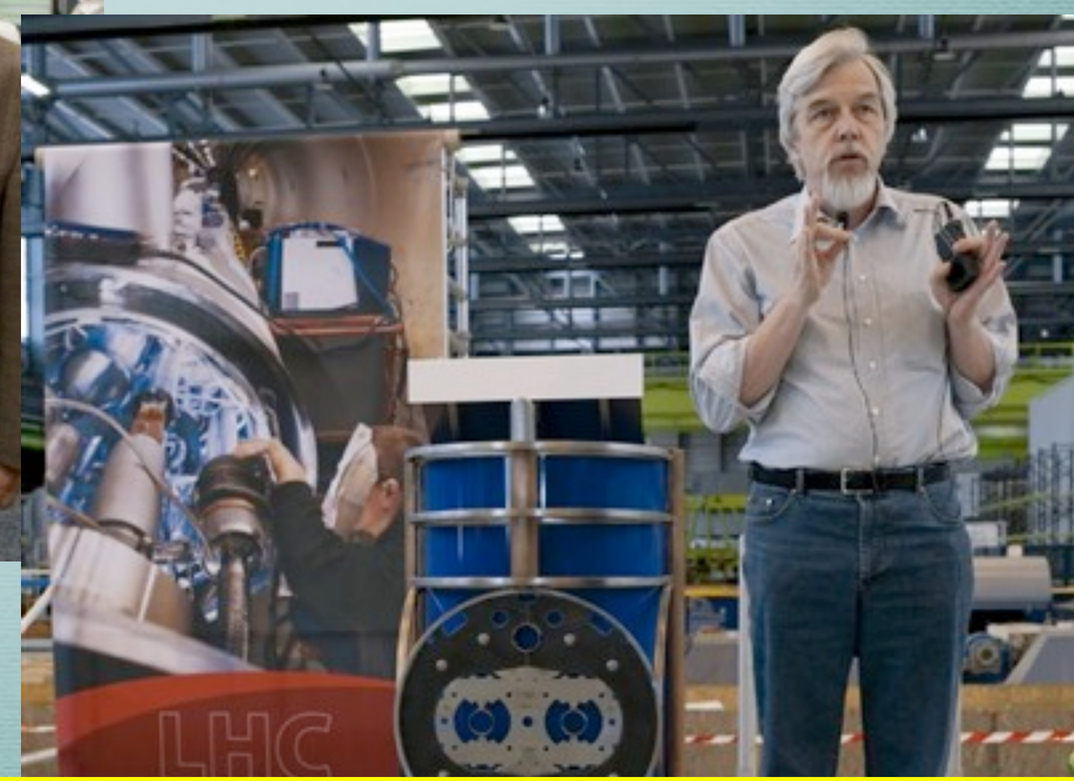
- Steve Myers: LHC director from 2009

Steve Myers in 2009

...five CERN Director Generals (1989 until today)...

- Carlo Rubbia
- Chris Llewellyn Smith
- Luciano Maiani
- Robert Aymar
- Rolf Heuer

E. Schopper (right) with 4 LHC Director Generals at LHC first beams, Sept. 2008.
From left: Aymar, Maiani, Llewellyn Smith, Rubbia



Rolf Heuer, celebrates the repair of LHC magnets, July 2009

2. Spontaneusly broken symmetry in particle physics

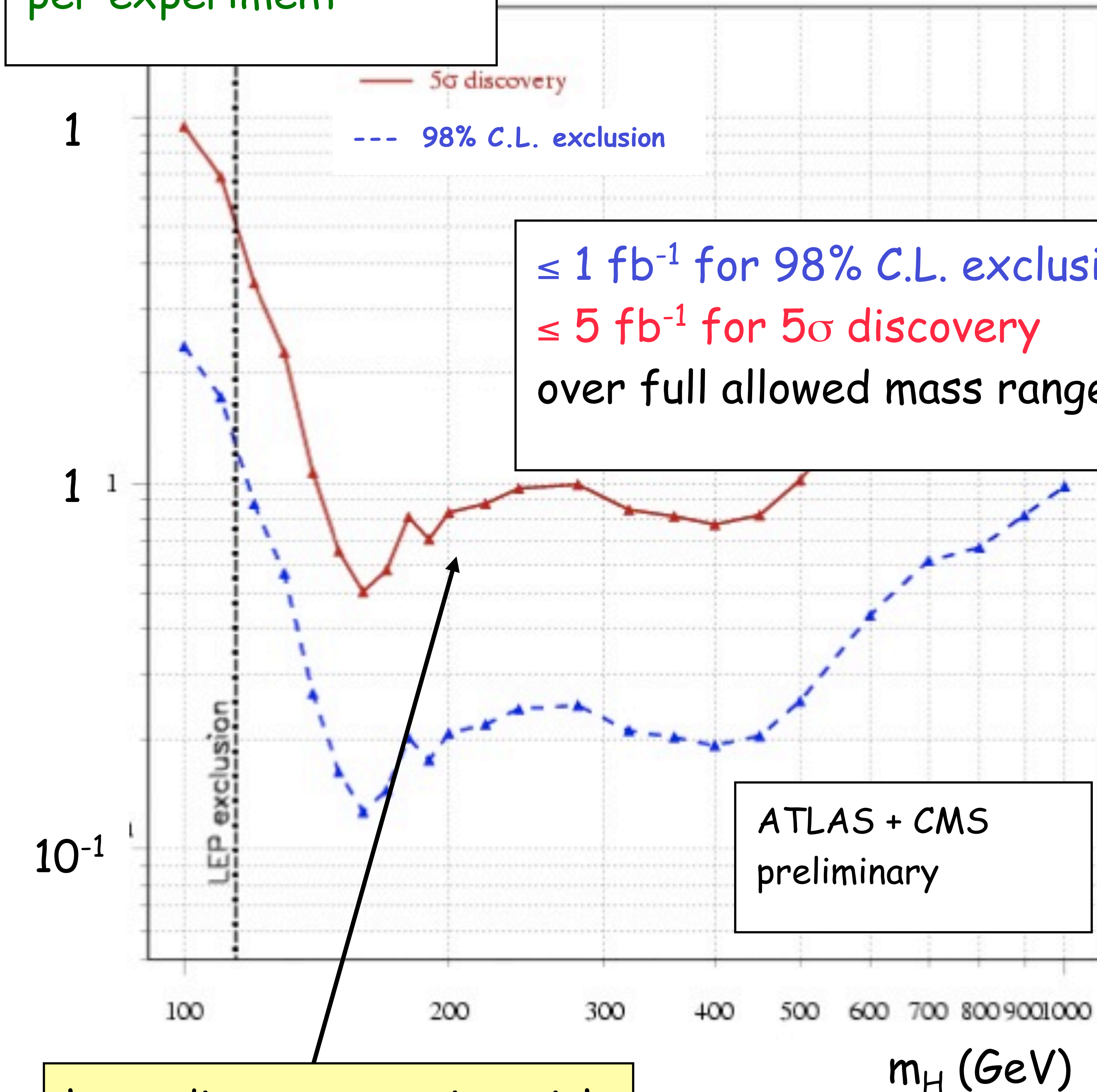
- The most important transfer from the "very many" to the "very small" physics.
- For relativistic theories, the concept was elucidated by:
  - -Nambu and Jona Lasinio (1961): chiral symmetry as Spontaneously Broken Symmetry, pion as quasi-Goldstone boson, nucleon mass because: $< \bar{\psi}\psi >_0 \neq 0$
  - -Gell-Mann and Levy (1960): sigma-model
  - -Goldstone (1961), Kibble,
  - -Higgs; Brout and Englert; Guralnik, Hagen, Kibble (1964): SBS of a gauge symmetry
- the Higgs field as a source of quark, lepton and intermediate boson masses is the basis for modern unified electroweak theory
- the signature is the existence of a scalar boson, the Higgs-Brout-Englert boson, with typical couplings to the other particles.

The search for the Higgs boson in the range allowed by the SM has been one of the benchmarks of LHC (luminosity) and LHC detectors.

What about the SM Higgs boson ?

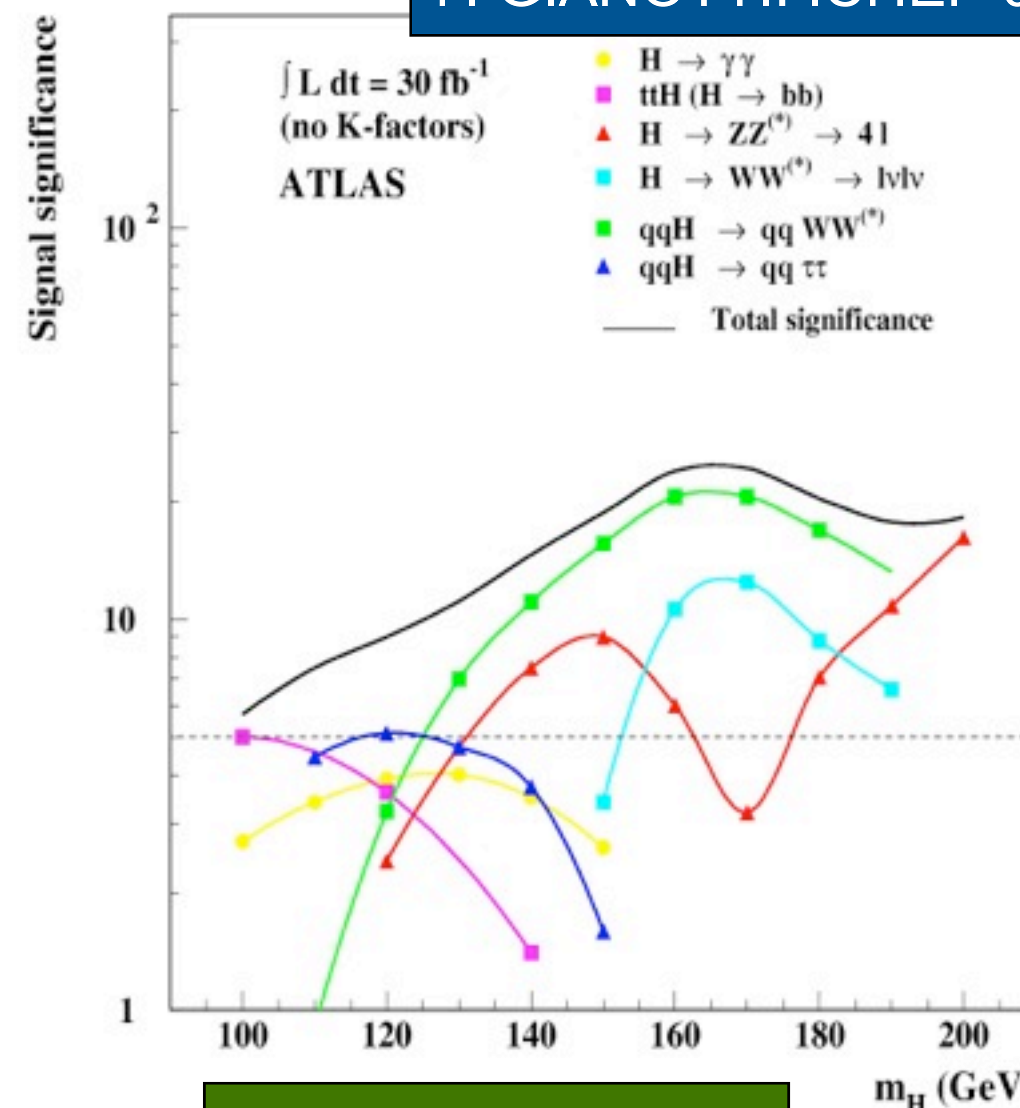
F. GIANOTTI. ICHEP 06

Needed ∫Ldt (fb^{-1})
per experiment

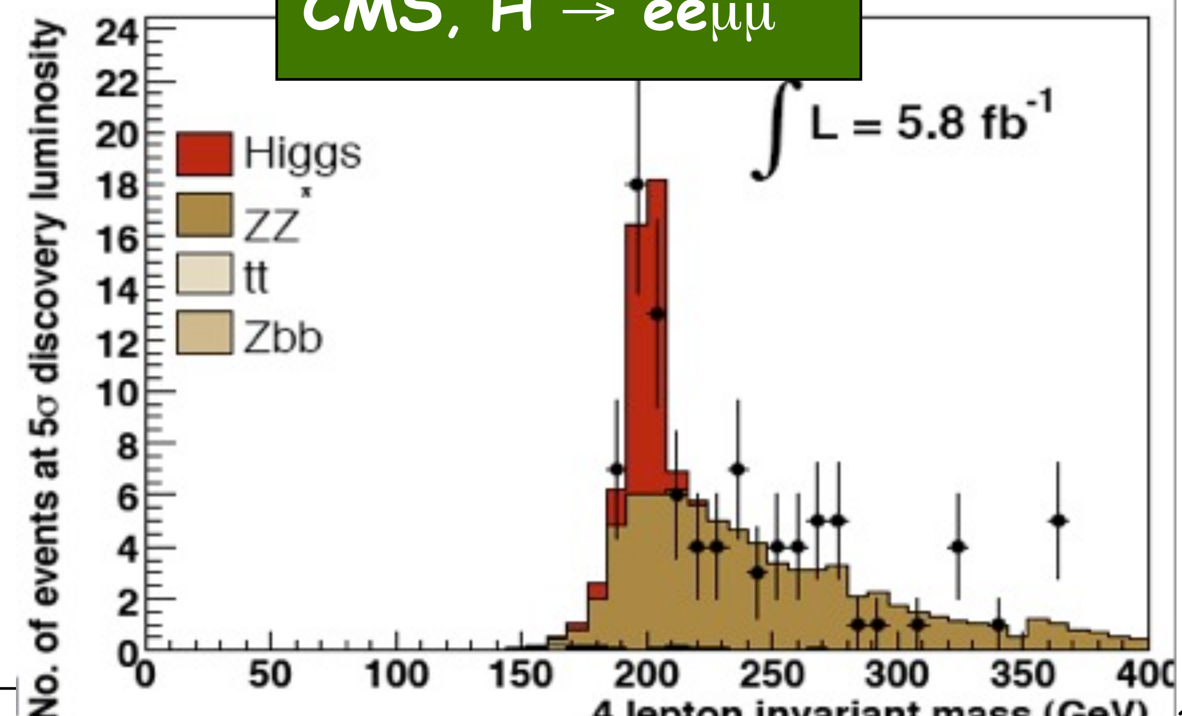


≤ 1 fb^{-1} for 98% C.L. exclusion
≤ 5 fb^{-1} for 5σ discovery
over full allowed mass range

here discovery easier with
gold-plated H → ZZ → 4l
→ by end 2008 ?



CMS, H → eeμμ



H → 4l : narrow mass peak, small background
H → WW → lνlν (dominant at the Tevatron):
counting channel (no mass peak)

3. Announcing the boson:
ATLAS and CMS, CERN Seminar

In the coming years, we will recognize a clear discontinuity in physics: BEFORE and AFTER the 4th of July talks by CMS and ATLAS.

•Englert and Higgs at CERN seminar, July 4th, 2012..
• and Fabiola Gianotti with John Ellis
•people arrived 4 o'clock in the morning to find a seat
•a completely full conference room
•talks by Joe Incandelas, CMS, and Fabiola Gianotti, ATLAS

ATLAS final statement (Fabiola Gianotti)

We observe an excess of events at $m_H \sim 126.5$ GeV with local significance 5.0 σ

CMS final statement (Joe Incandelas)

We have observed a new boson with a mass of **125.3 ± 0.6 GeV** at **4.9 σ** significance !

Papers available (July 31, 2012):
ATLAS: ArXiv 1207.7214
CMS: ArXiv 1207.7235

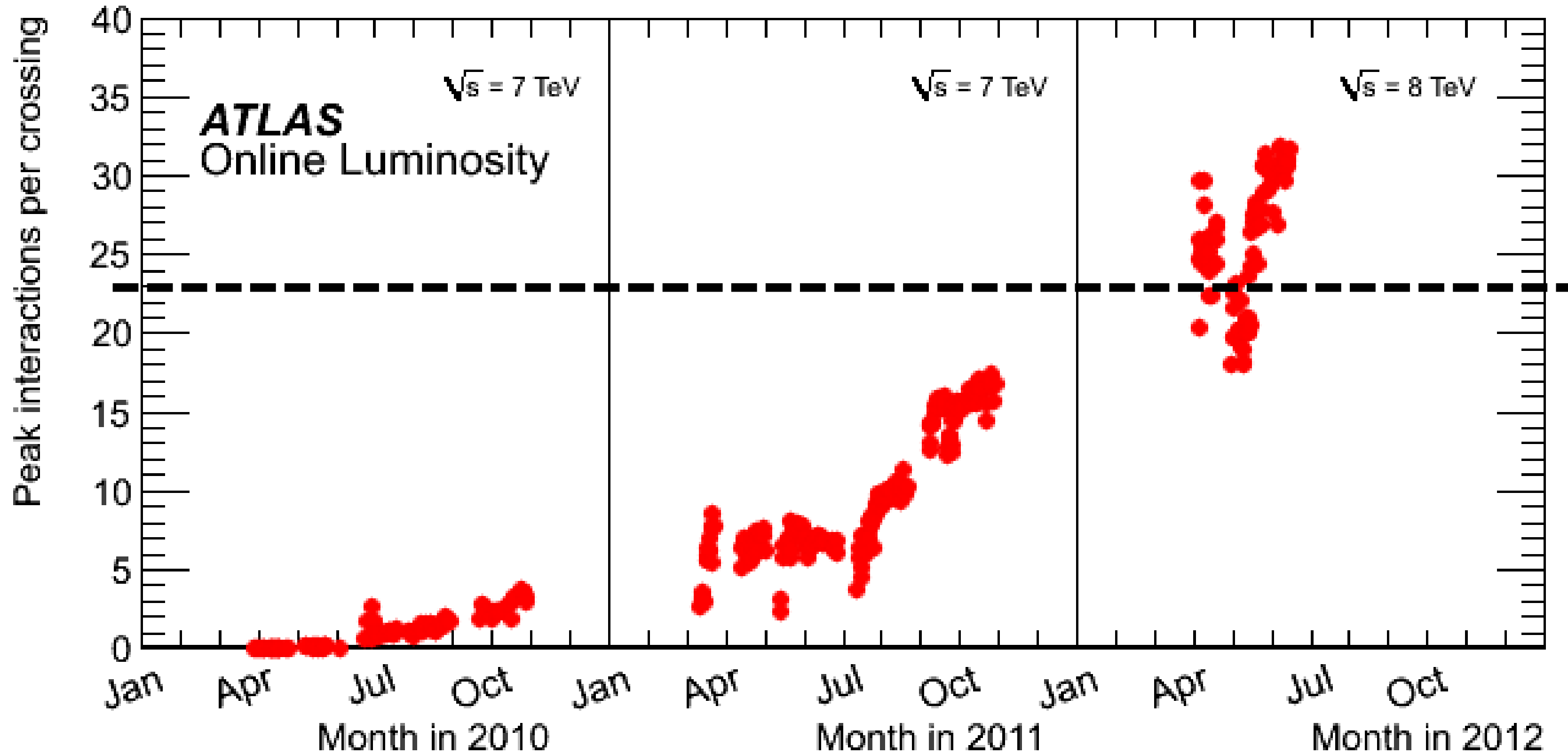
Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC

Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

3. High luminosity: price to pay is pile up!

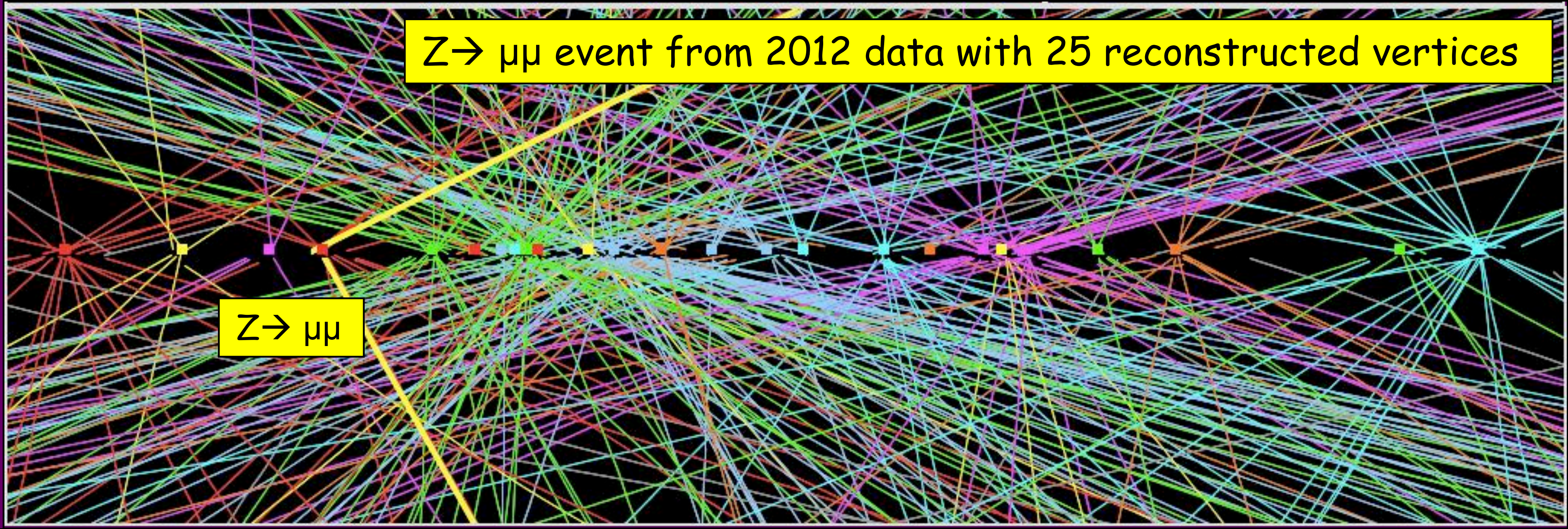
The BIG challenge in 2012: PILE-UP

F. Gianotti



Experiment's design value (expected to be reached at $L=10^{34}$!)

Z→ μμ event from 2012 data with 25 reconstructed vertices



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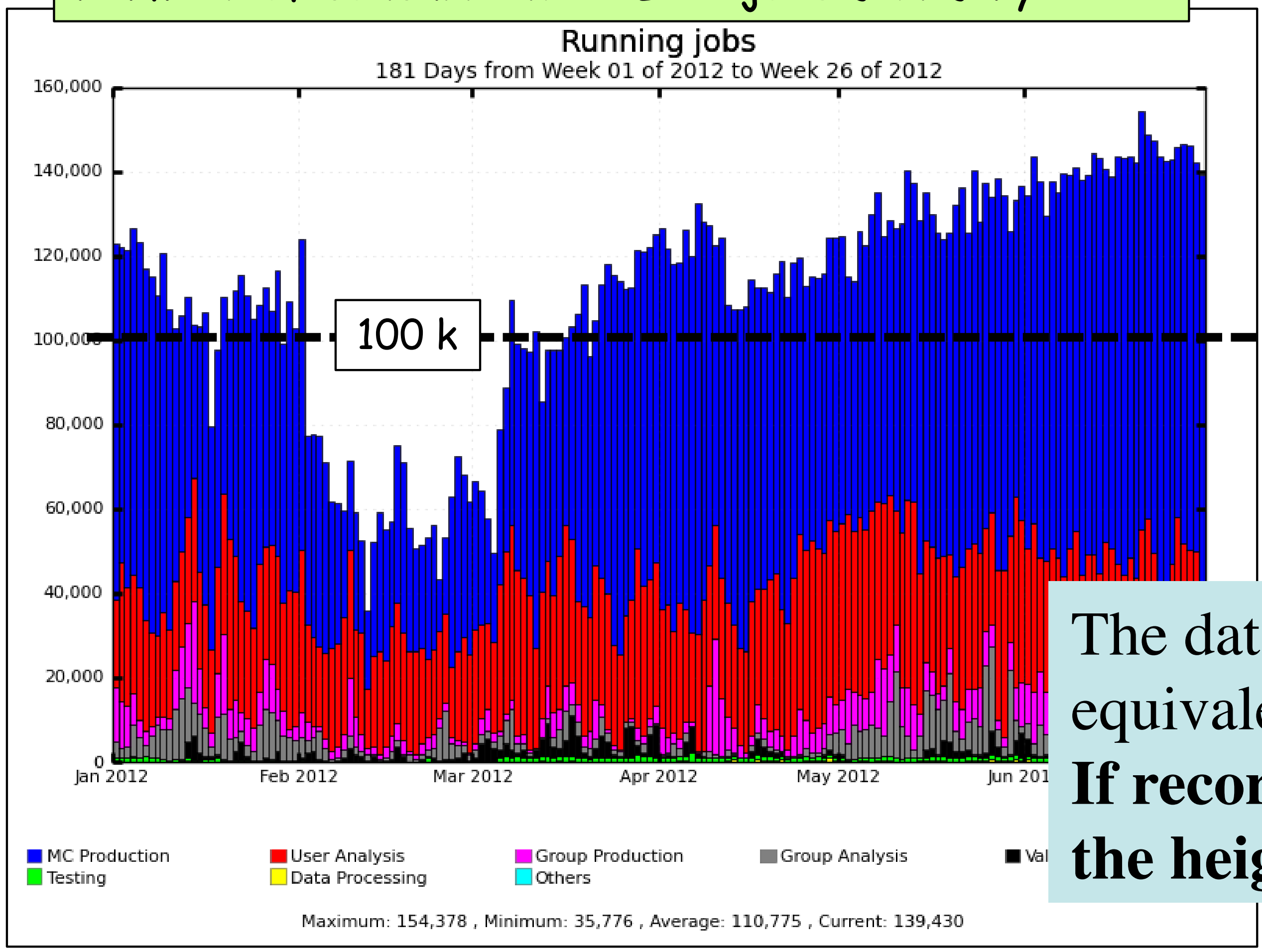
The LHC data GRID, launched in 2001… is working perfectly

It would have been impossible to release physics results so quickly without the outstanding performance of the Grid (including the CERN Tier-0)

Number of concurrent ATLAS jobs Jan-July 2012

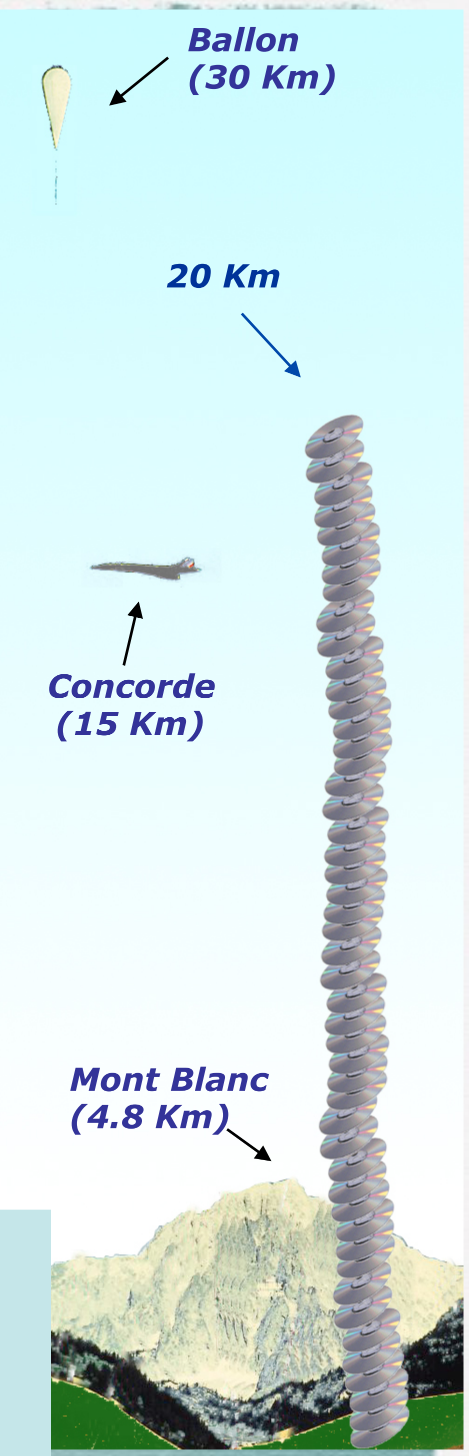
F. Gianotti



Includes MC production, user and group analysis at CERN, 10 Tier1-s, ~ 70 Tier-2 federations → > 80 sites

> 1500 distinct ATLAS users do analysis on the GRID

The data to be recorded in 1 year are equivalent to **15 millions DVD movies; If recorded on CDs, they would reach the height of 20 km !!**



- ❑ Available resources fully used/stressed (beyond pledges in some cases)
- ❑ Massive production of 8 TeV Monte Carlo samples
- ❑ Very effective and flexible Computing Model and Operation team → accommodate high trigger rates and pile-up, intense MC simulation, analysis demands from worldwide users (through e.g. dynamic data placement)

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1990 The LEP revolution

Processor farms : the 90's supercomputer

- PC+Linux: the new supercomputer for scientific applications

obswww.unige.ch/~pfennige/gravitor/gravitor_e.html

www.cs.sandia.gov/cplant/

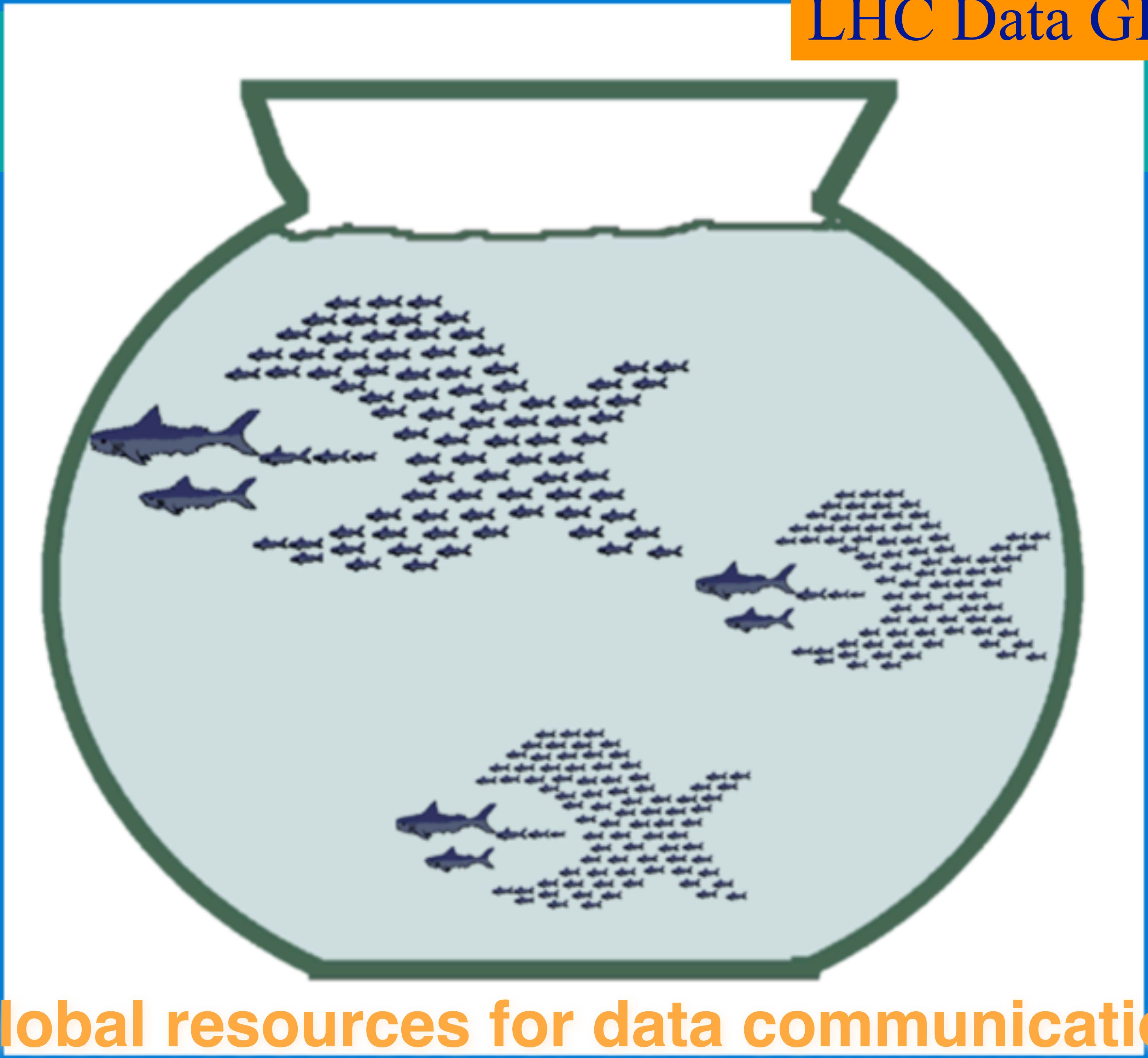
- Principle well established; farm examples abound

now.cs.berkeley.edu

www.ncsa.uiuc.edu/General/CC/ntcluster/

After commodity farms what next?

LHC Data GRID, 2001

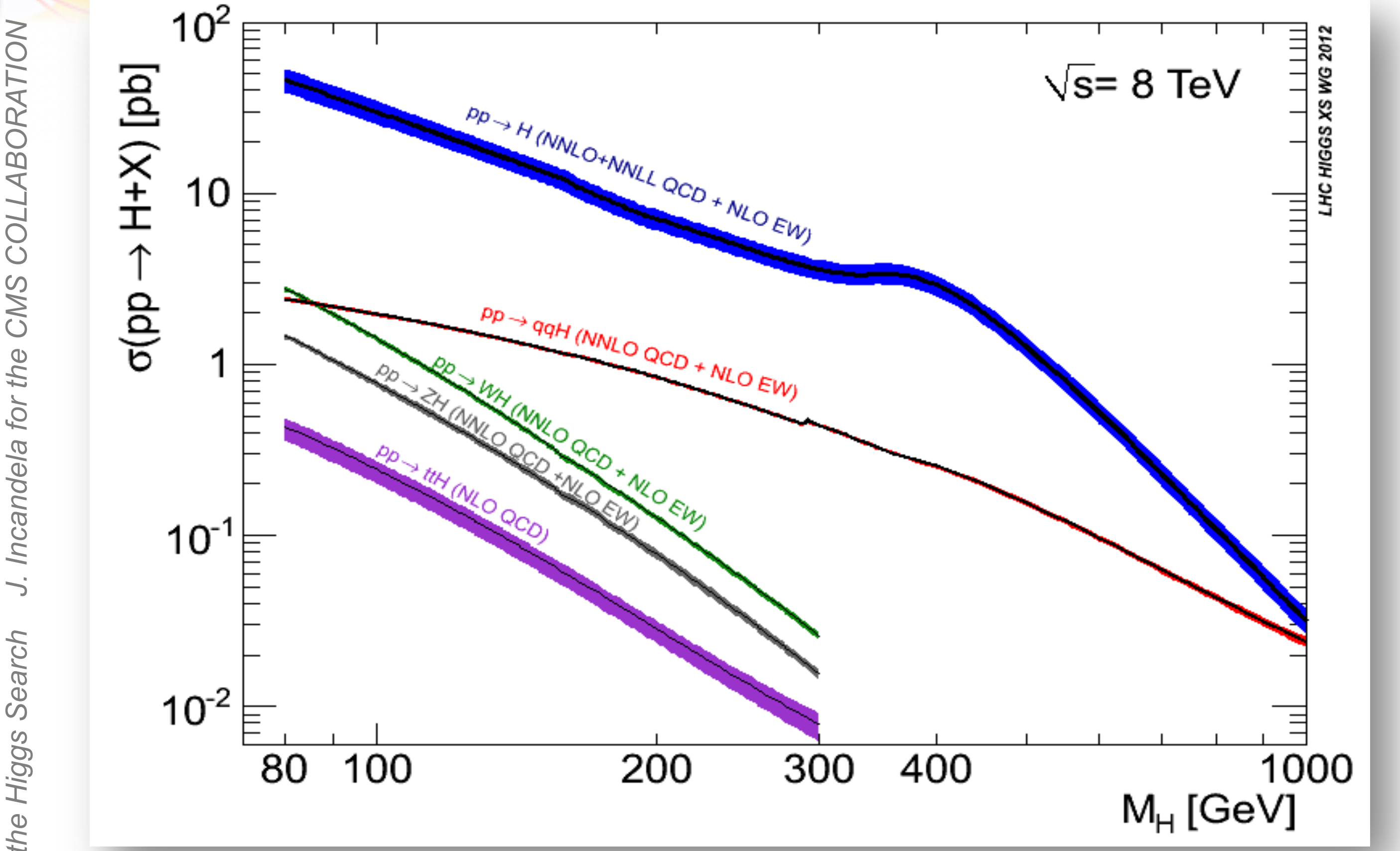


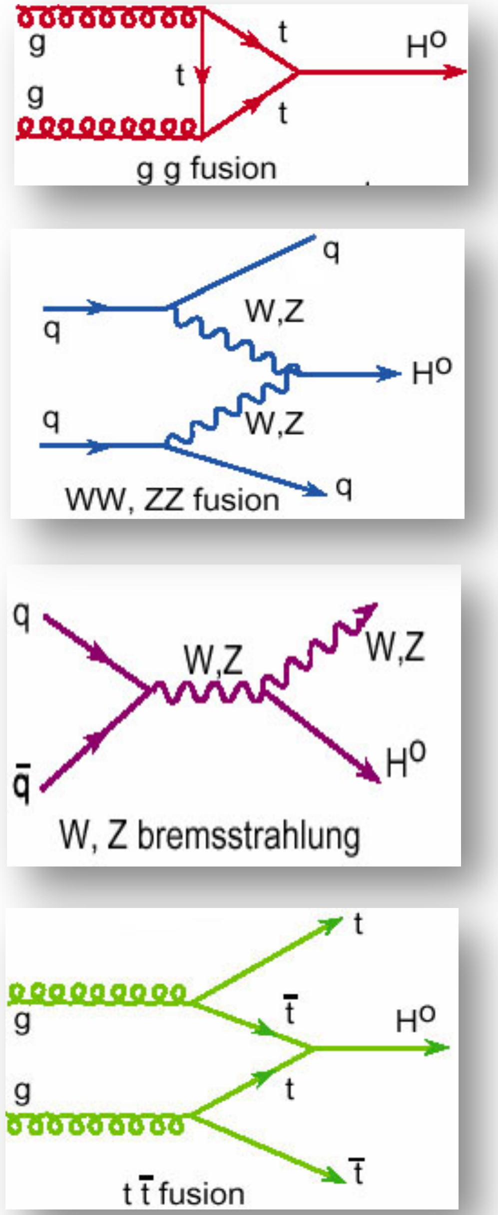
Fusion of global resources for data communication, data processing and data archive: Grid approach ?

4. Summary of Data

J. Incandelas

Higgs boson production





- $\sqrt{s}$=8 TeV: 25-30% higher σ than $\sqrt{s}$=7 TeV at low m_H
- All production modes to be exploited
  - gg VBF VH ttH
  - Latter 3 have smaller cross sections but better S/B in many cases

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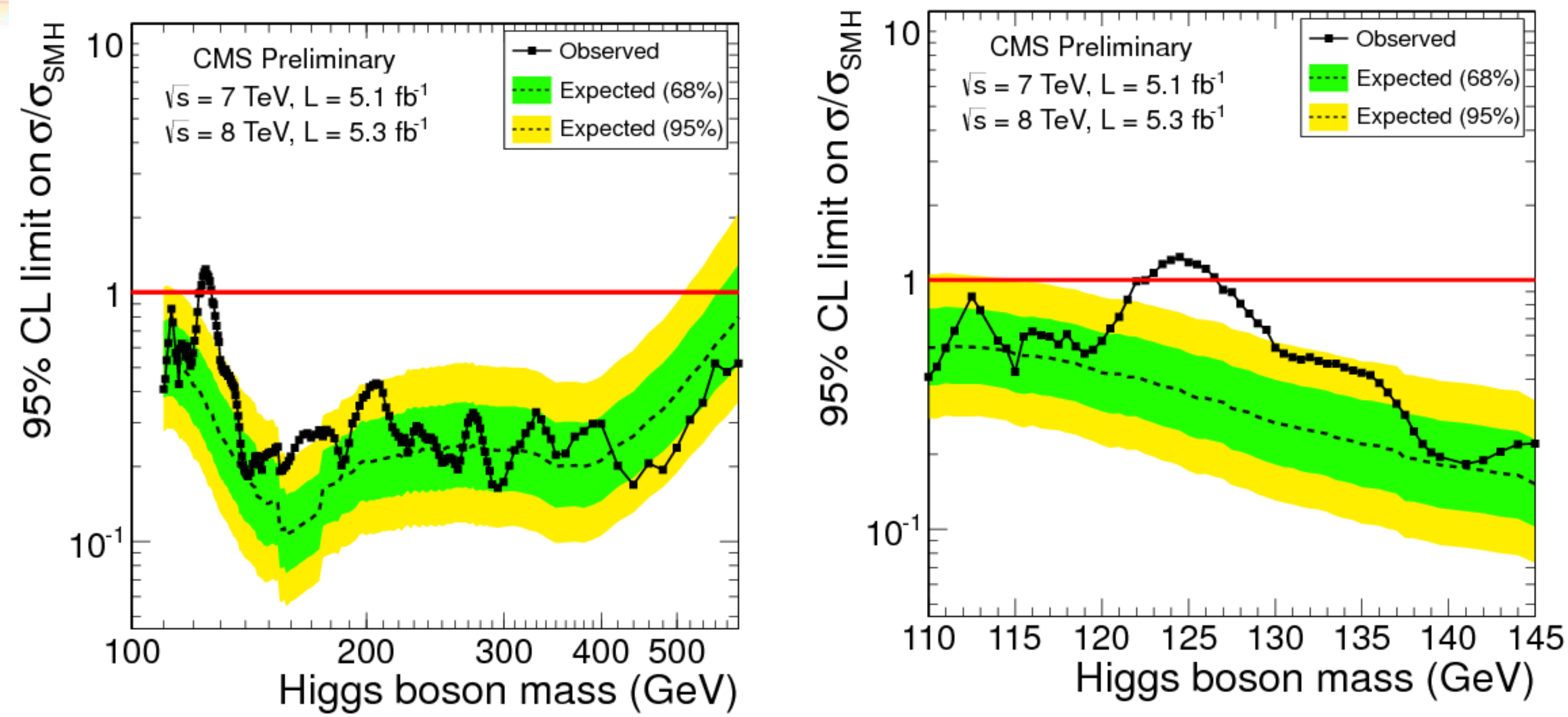
CMS summary

J. Incandelas

SM Higgs exclusion: signal strength



Observed: 110 – 122.5 .... 127 – 600 GeV at 95% CL

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

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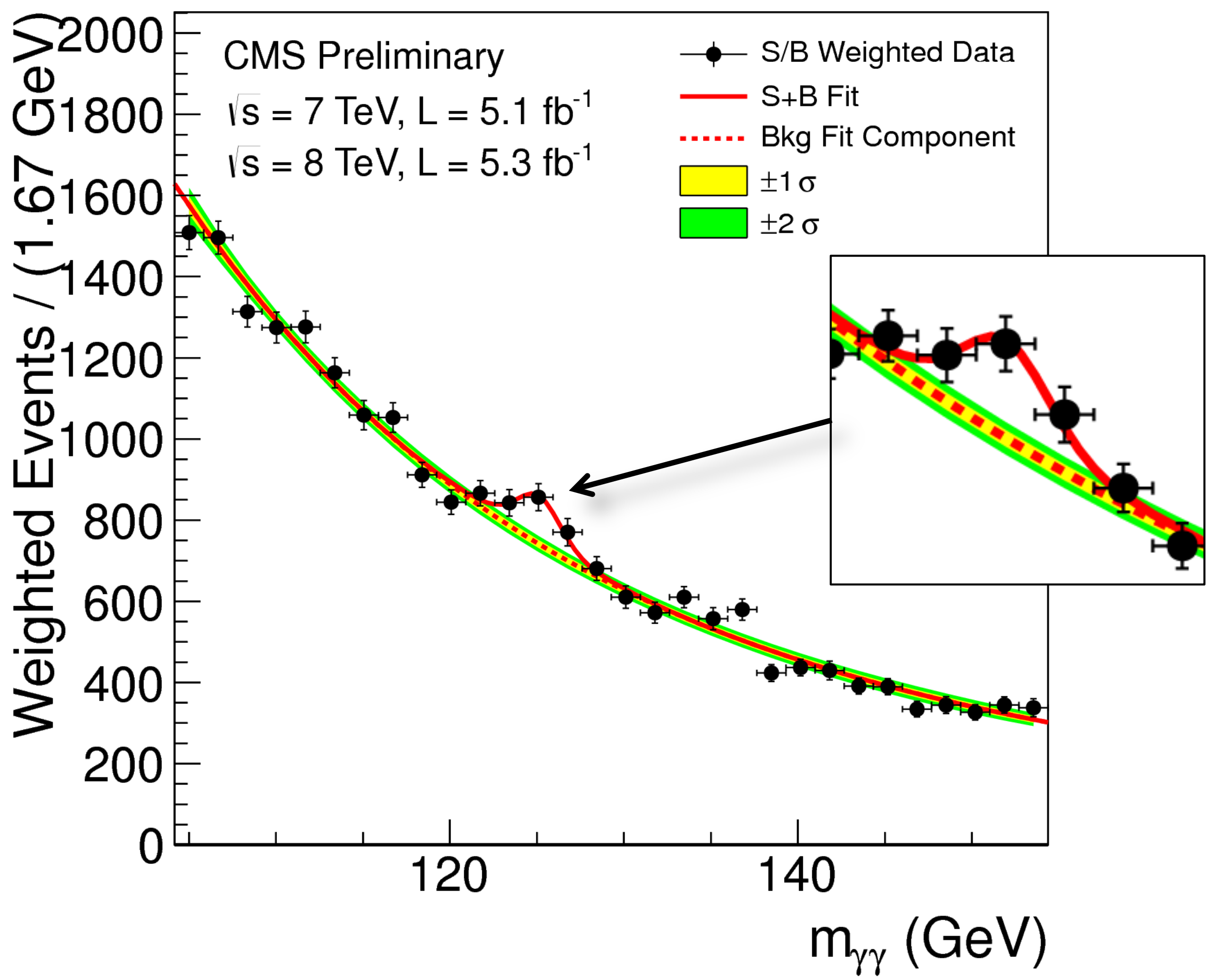
J. Incandelas

S/B Weighted Mass Distribution

- Sum of mass distributions for each event class, weighted by S/B
  - B is integral of background model over a constant signal fraction interval



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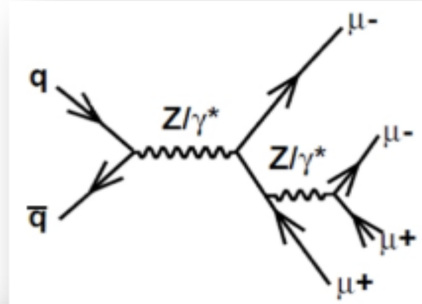
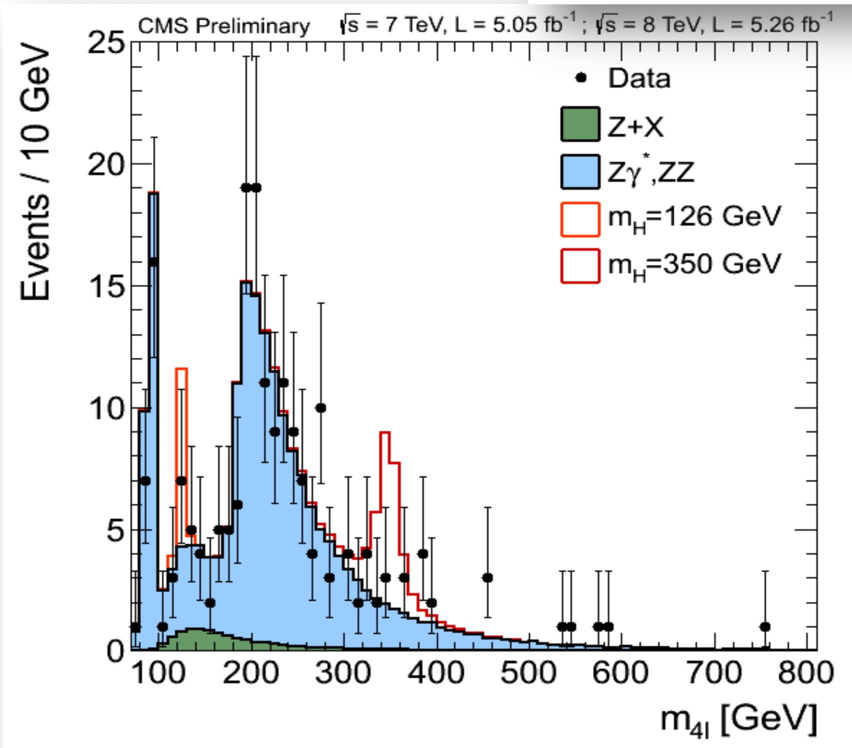
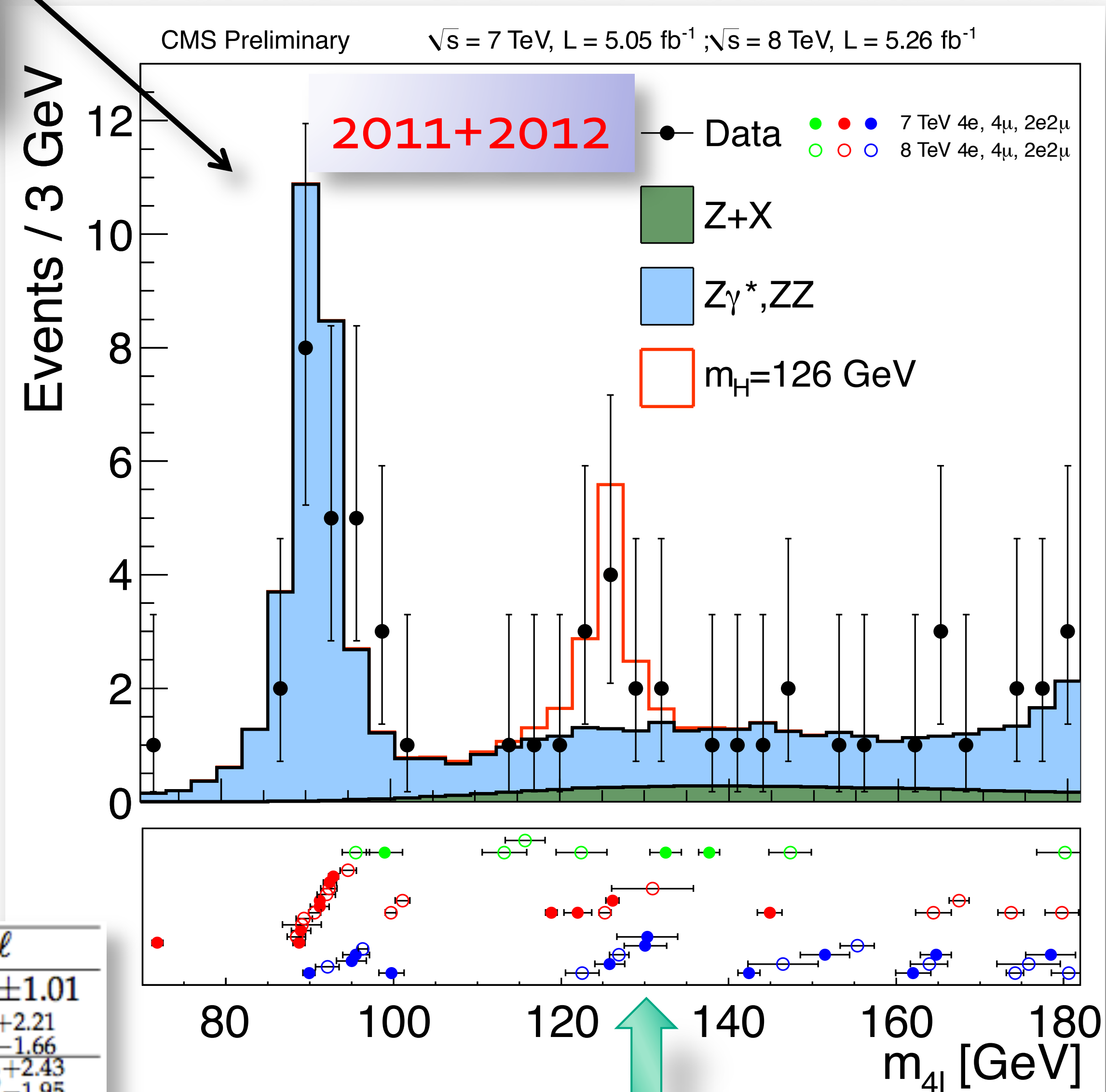
J. Incandelas

Results: m(4l) spectrum







Event-by-event errors

Yields for m(4l)=110..160 GeV

Channel	4e	4μ	2e2μ	4ℓ
ZZ background	2.65 ± 0.31	5.65 ± 0.59	7.17 ± 0.76	15.48 ± 1.01
Z+X	$1.20^{+1.08}_{-0.78}$	$0.92^{+0.65}_{-0.55}$	$2.29^{+1.81}_{-1.36}$	$4.41^{+2.21}_{-1.66}$
All backgrounds	$3.85^{+1.12}_{-0.84}$	$6.58^{+0.88}_{-0.81}$	$9.46^{+1.96}_{-1.56}$	$19.88^{+2.43}_{-1.95}$
m_H = 126 GeV	1.51 ± 0.48	2.99 ± 0.60	3.81 ± 0.89	8.31 ± 1.18

164 events expected in [100, 800 GeV]
172 events observed in [100, 800 GeV]

July 4 … s of the Higgs Search J. Incandela for the CMS COLLABORATION

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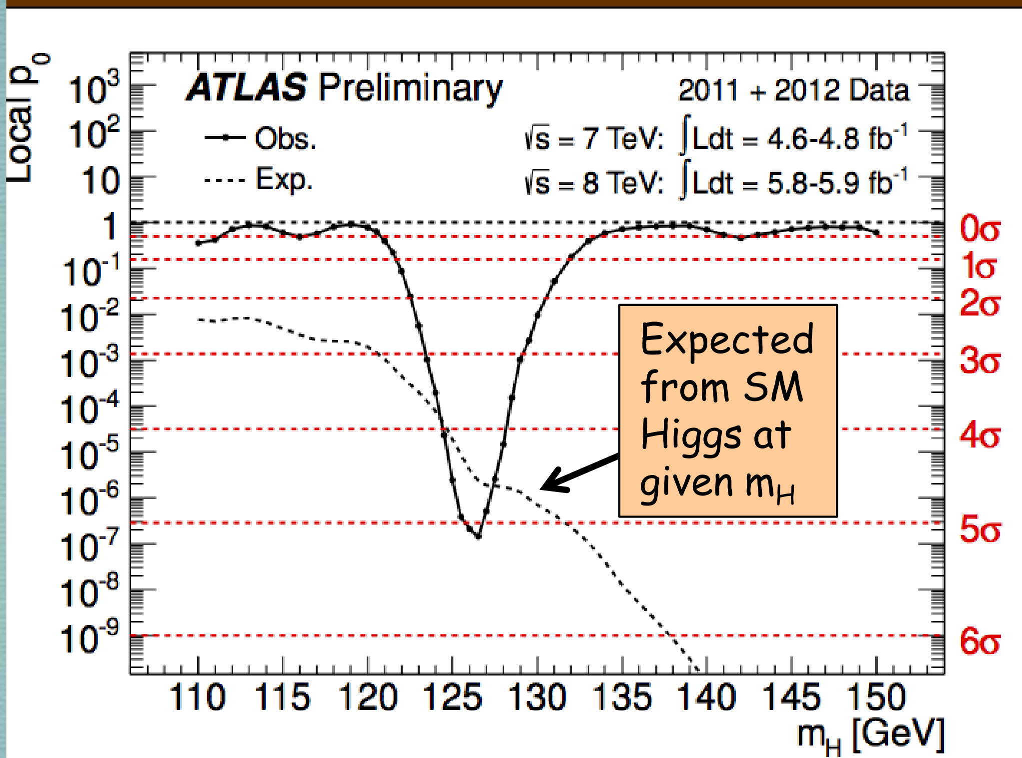
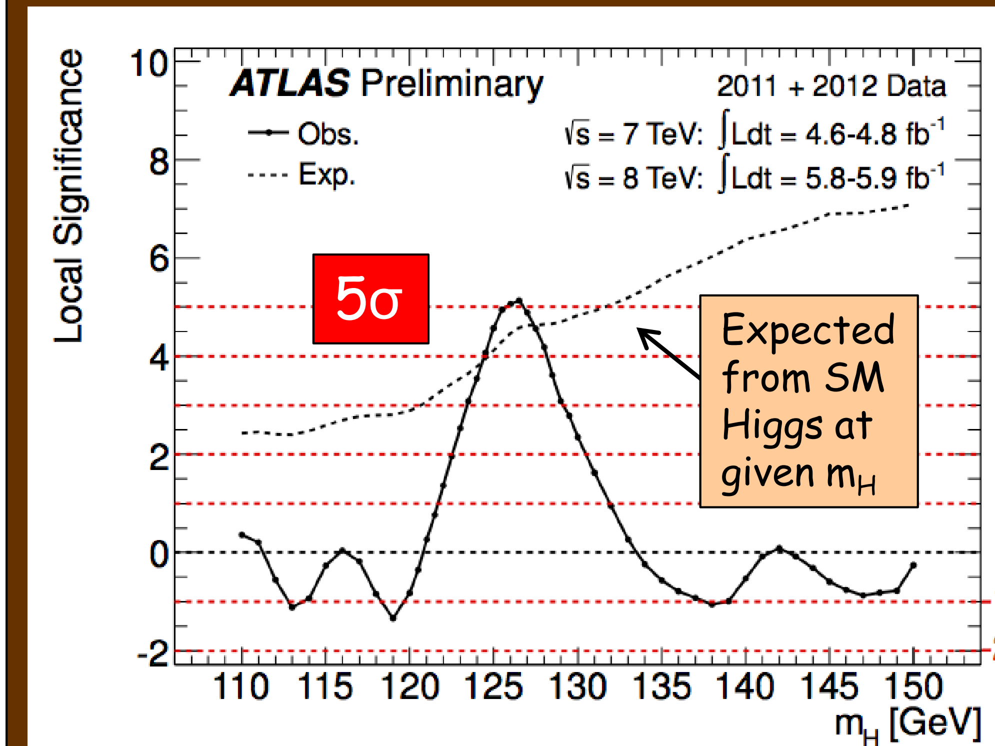
ATLAS summary

Combined results: the excess

F. Gianotti

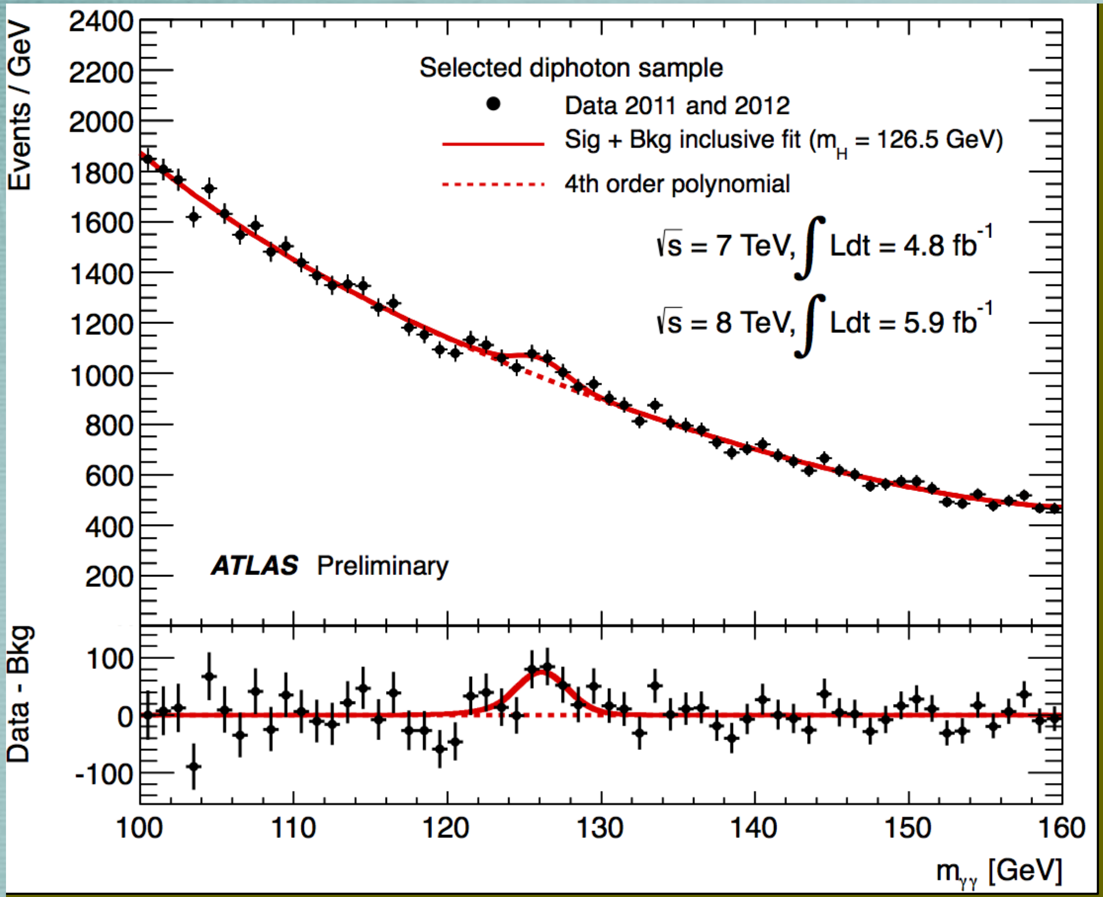




Maximum excess observed at	m_H = 126.5 GeV
Local significance (including energy-scale systematics)	5.0 σ
Probability of background up-fluctuation	3×10^{-7}
Expected from SM Higgs m_H=126.5	4.6 σ

Global significance: 4.1-4.3 σ (for LEE over 110-600 or 110-150 GeV)

ATLAS digamma



Total after selections: 59059 events

F. Gianotti

$m_{\gamma\gamma}$ spectrum fit, for each category, with Crystal Ball + Gaussian for signal plus background model optimised (with MC) to minimize biases

Max deviation of background model from expected background distribution taken as systematic uncertainty

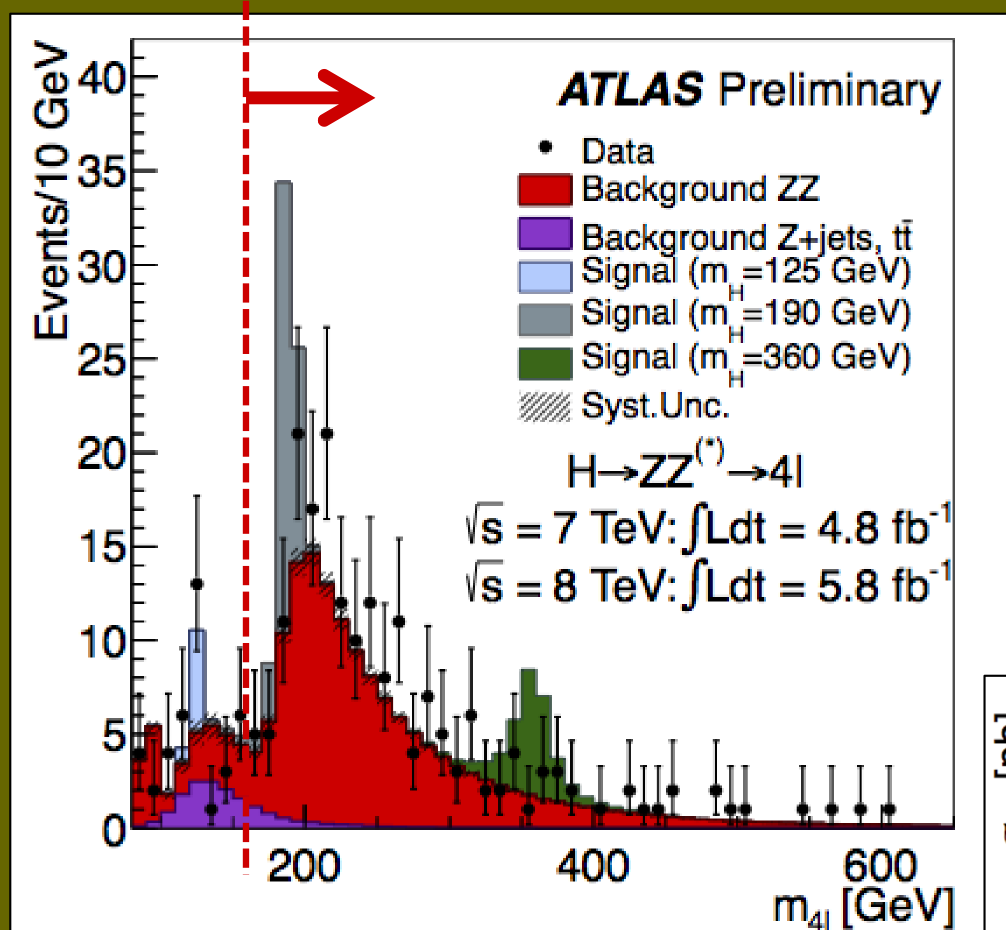
Main systematic uncertainties

Signal yield	
Theory	~ 20%
Photon efficiency	~ 10%
Background model	~ 10%
Categories migration	
Higgs p_T modeling	up to ~ 10%
Conv/unconv γ	up to ~ 6%
Jet E-scale	up to 20% (2j/VBF)
Underlying event	up to 30% (2j/VBF)
H→ $\gamma\gamma$ mass resolution	~ 14%
Photon E-scale	~ 0.6%

ATLAS 4 leptons

H→ 4l mass spectrum after all selections: 2011+2012 data

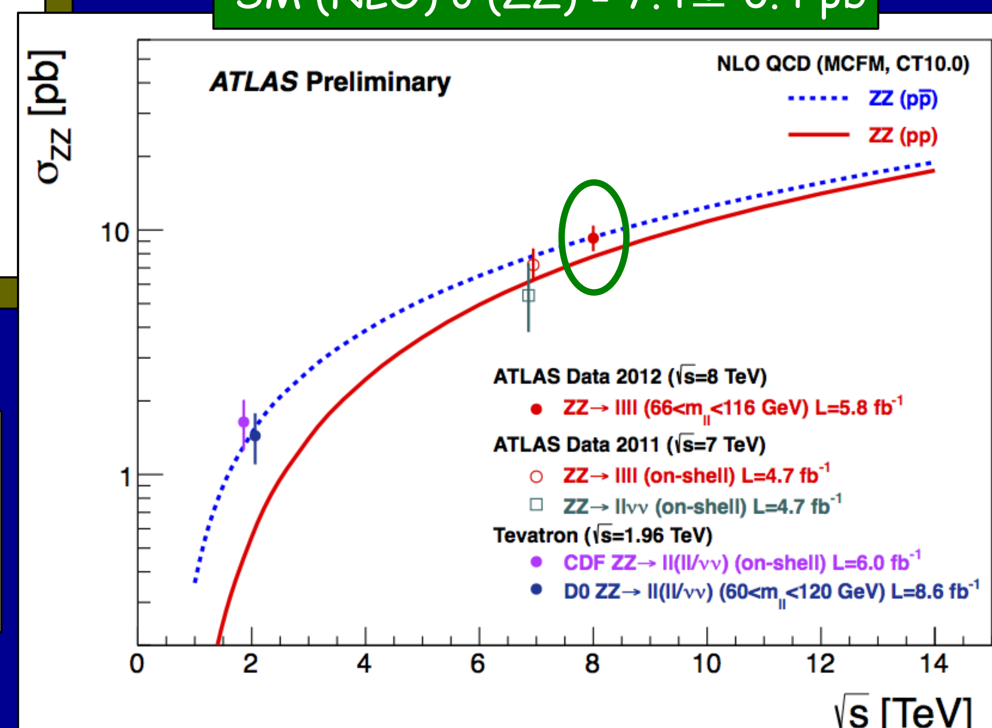
F. Gianotti



m(4l) > 160 GeV
(dominated by ZZ background):
147 ± 11 events expected
191 observed

~ 1.3 times more ZZ events in data than SM prediction →in agreement with measured ZZ cross-section in 4l final states at √s = 8 TeV

Measured σ (ZZ) = 9.3 ± 1.2 pb
SM (NLO) σ (ZZ) = 7.4± 0.4 pb



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Discrepancy has negligible impact on the low-mass region < 160 GeV
(no change in results if in the fit ZZ is constrained to its uncertainty or left free)

ATLAS exclusion and signal regions

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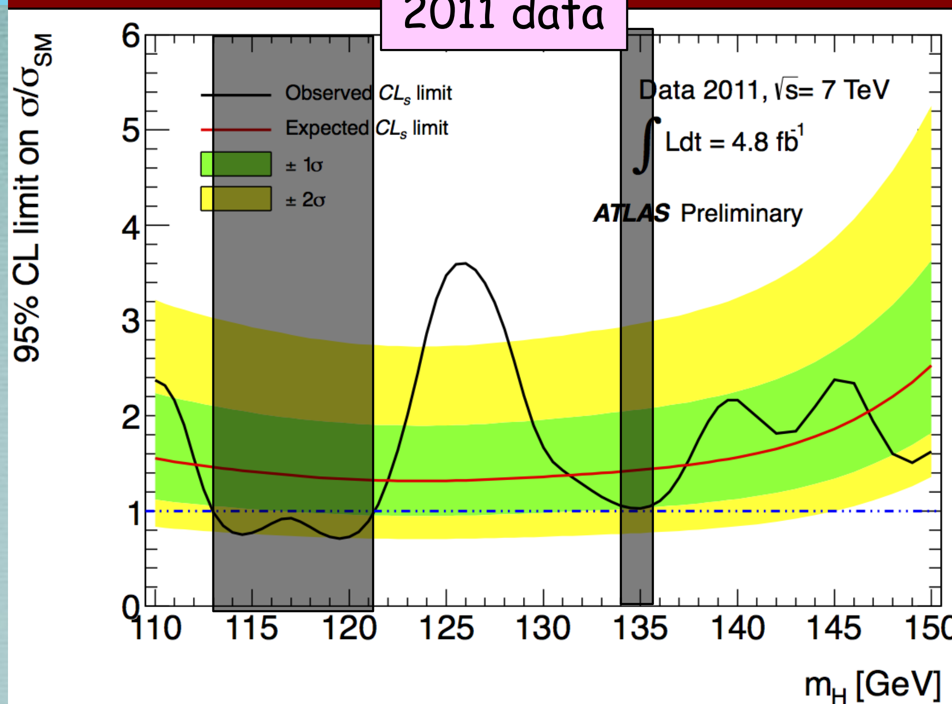
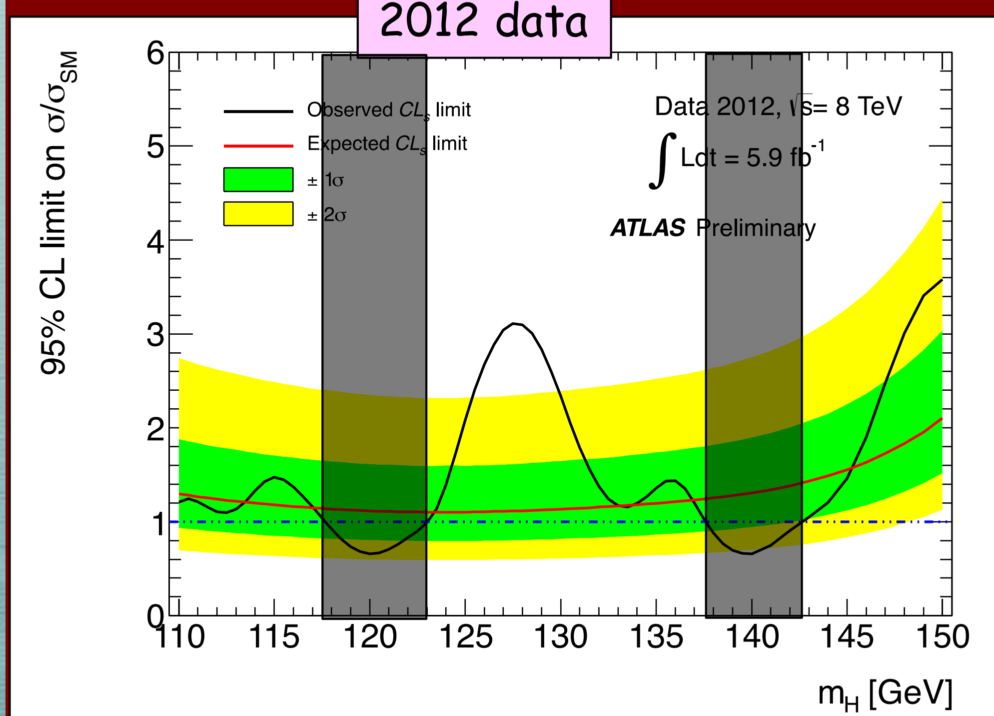
2011 data

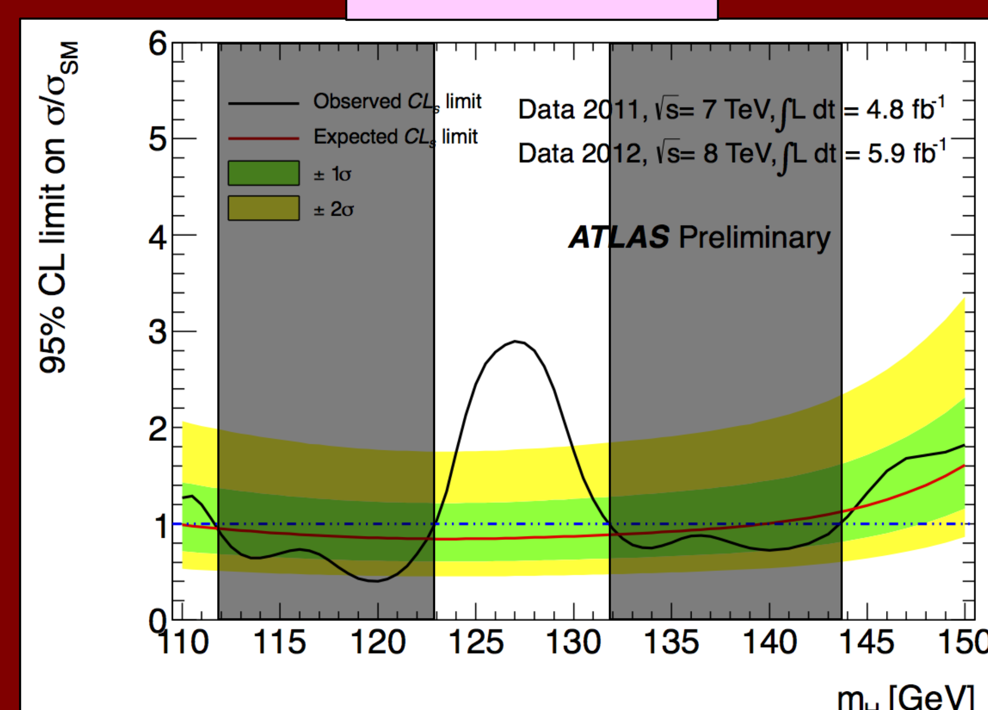


Excluded (95% CL):
112-122.5 GeV, 132-143 GeV
Expected: 110-139.5 GeV

2012 data



2011+2012 data

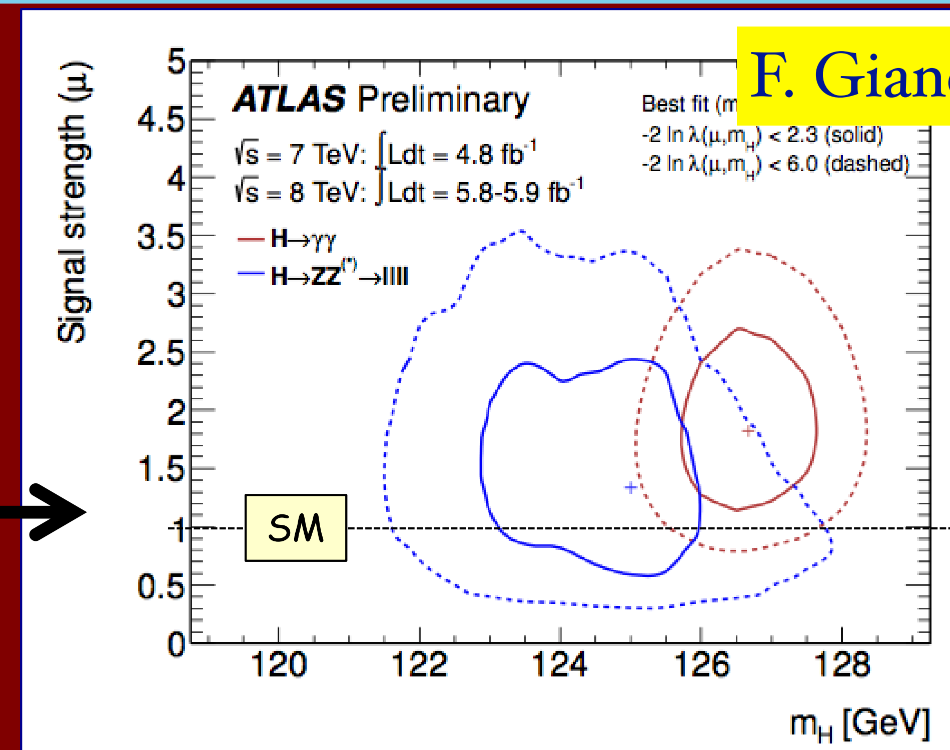


The mass of the new particle

Combined results: consistency of the global picture

Are the 4l and γγ observations consistent ?

From 2-dim likelihood fit to signal mass and strength → curves show approximate 68% (full) and 95% (dashed) CL contours



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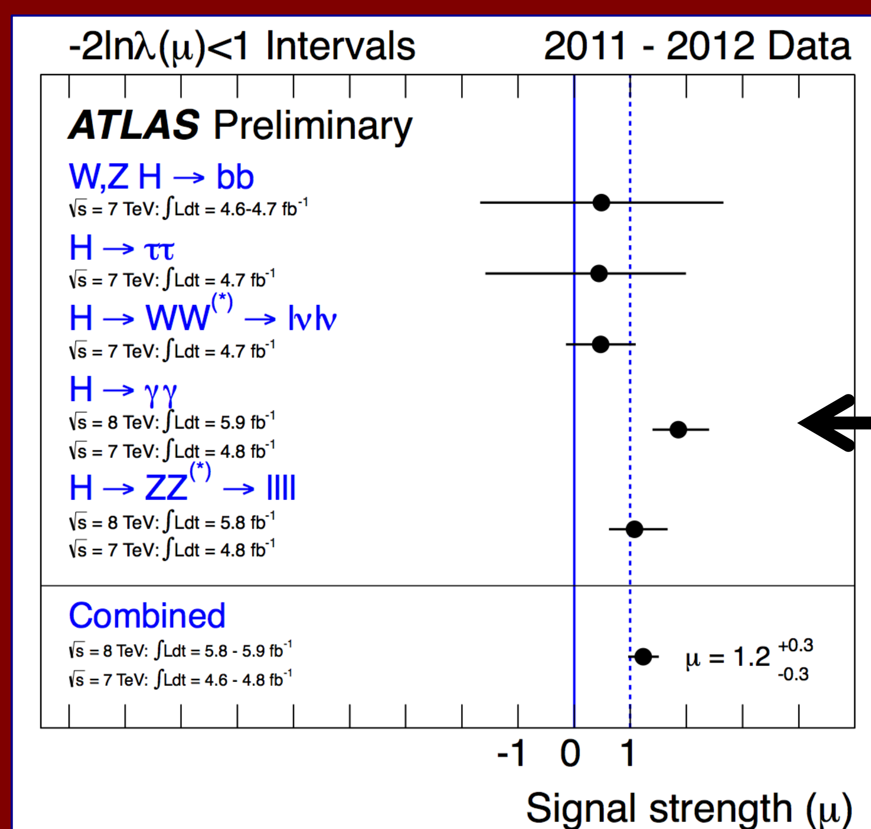

Best-fit signal strengths, normalized to the SM expectations, for all studied channels, at m_H = 126.5 GeV,

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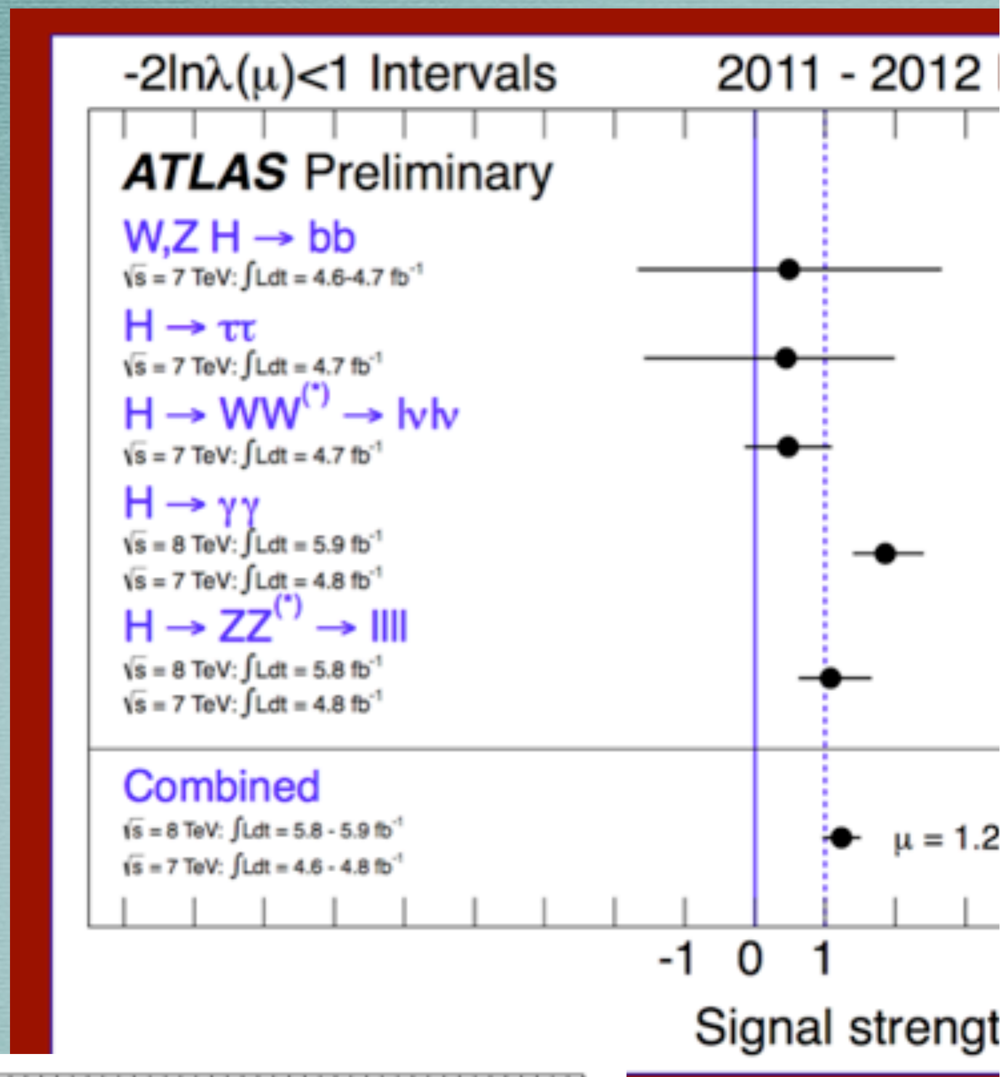
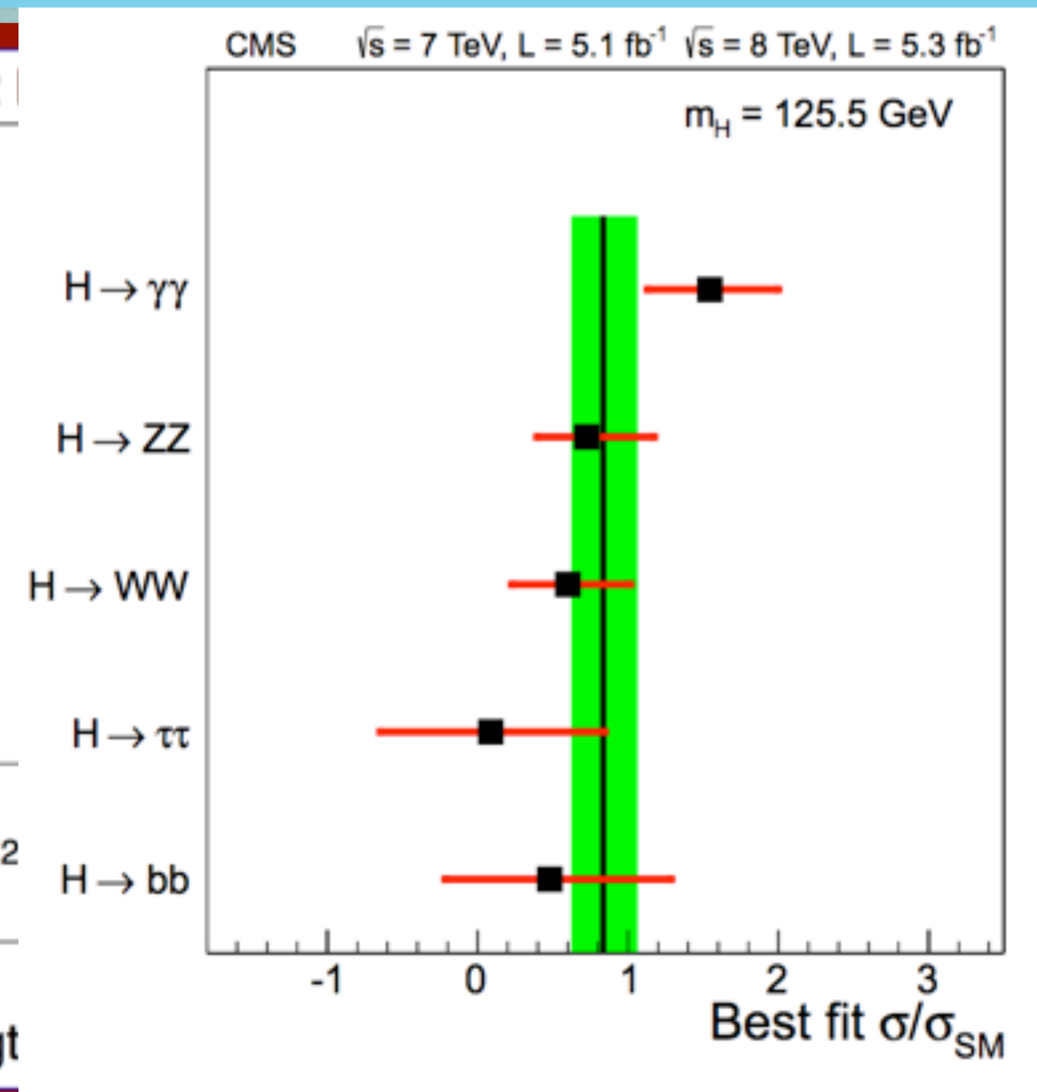
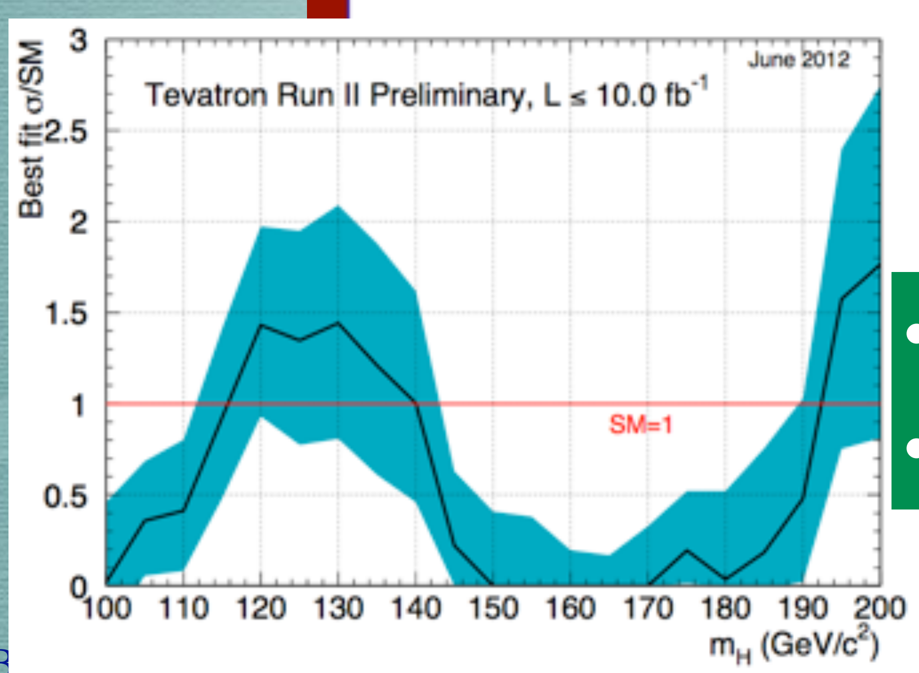
5. h(125): is it the SM Higgs?

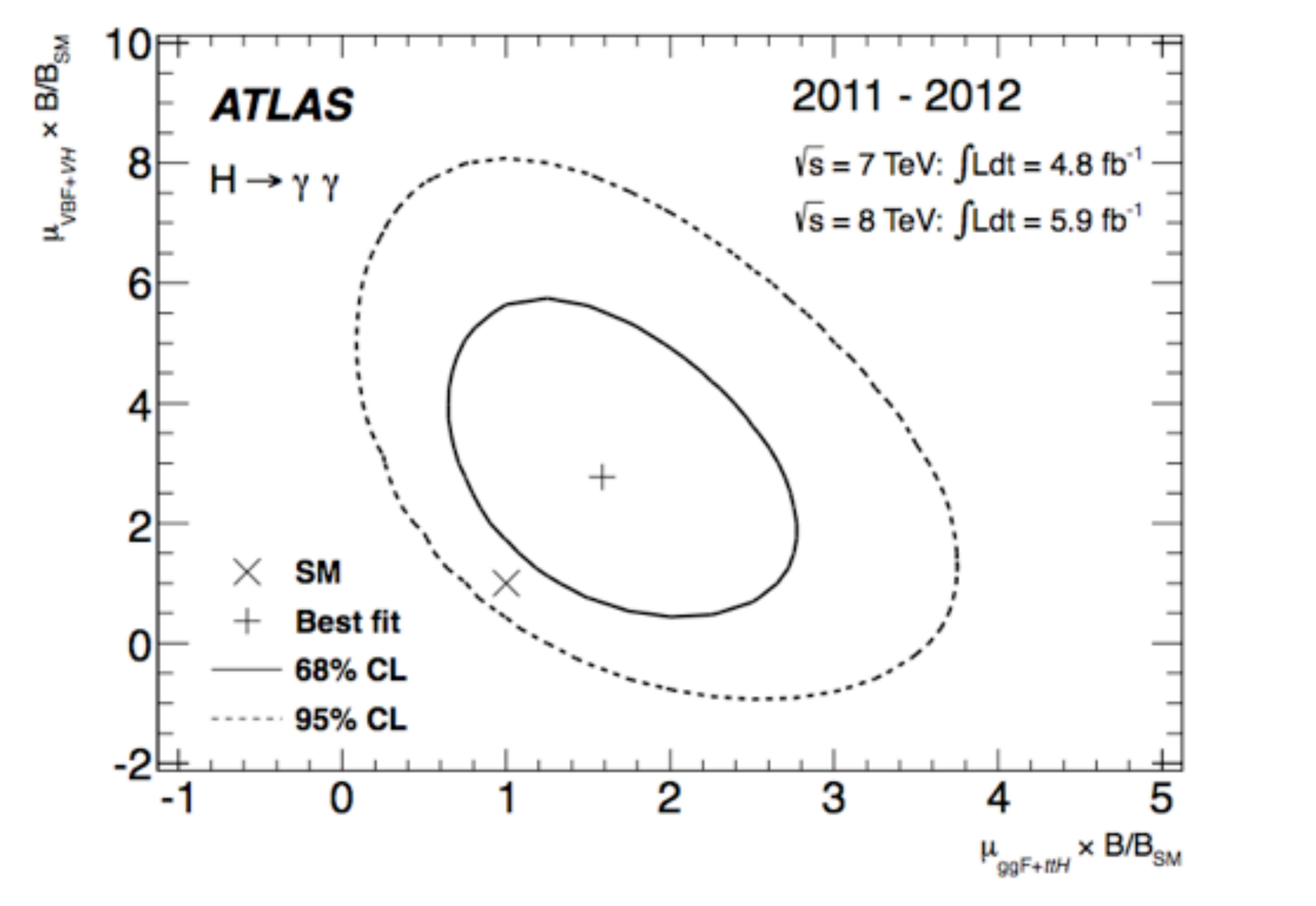




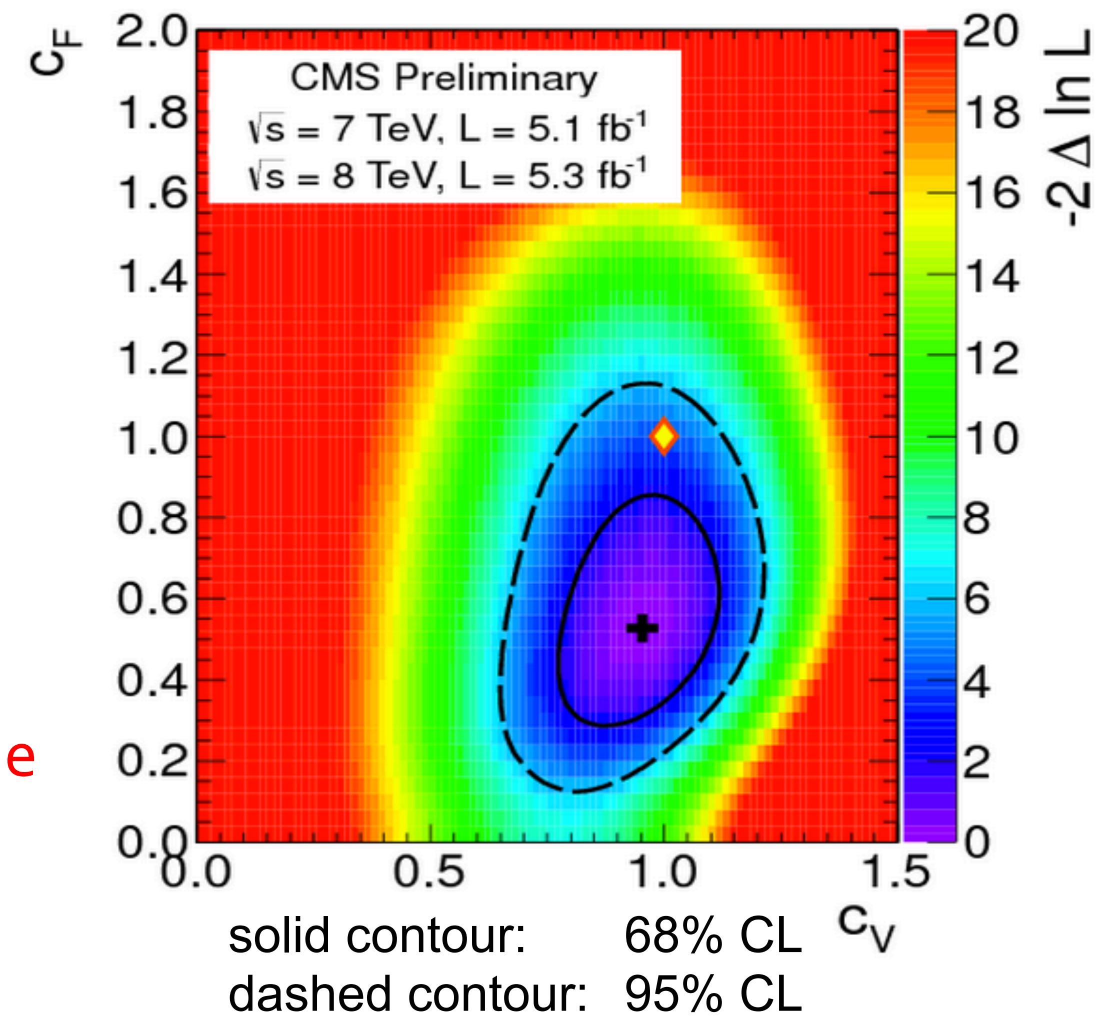


- b-b bar and tau-tau still in the background;
- b-b bar barely visible in Tevatron data

More γ γ than f f bar?



Fit to C_V and C_F



July 4th 2012 The Status of the F

In agreement with the SM within the 95% confidence range

→ Need more data!

Too much of gamma gamma?

•Pure Fermiophobic Higgs, i.e. Higgs boson coupled to vector bosons only

B. Mele, E. Gabrielli

-h branching ratios into WW, ZZ, γγ are larger of factor 3

-gluon fusion cross section ~ 0 (no h coupling to top)

-VV produced by: Vector Boson Fusion *and* q q bar →V → VH, which is ~ 1/3 of SM, so that VV rate ~ SM

-γγ produced by Vector Boson Fusion as before, so that γγ rate ~ 3xSM

• who takes care of fermion masses?

• Tevatron sees normal b-b bar ?

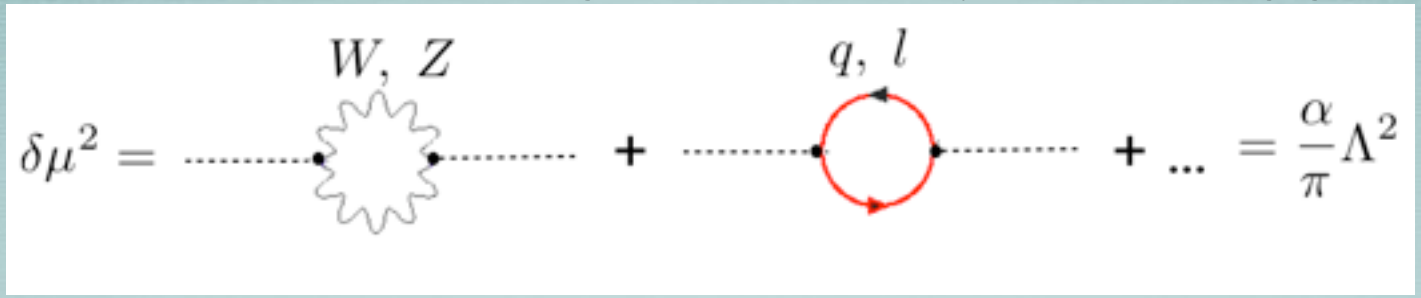
• Alternatively: more scalars in the loop increase Γ(h-> γγ) ? difficult to get a large effect !

M. Carena, I. Low, C. Wagner

the γγ channel may reveal very unconventional effects: watch out !

6. What's wrong with SM and nothing else..... until the Planck Mass, i.e. Quantum Gravity ?

• quantum fluctuations change violently the Higgs boson mass



•the total mass equals the "bare mass" plus corrections

$$\mu^2 = \mu_0^2 + \delta\mu^2$$

•if: $\Lambda = M_{Planck}$, bare mass and corrections must cancel to 25 digits, or so, to provide a physical mass of about 100 GeV

• this requires a symmetry, i.e. Supersimmetry

•or a composite Higgs boson

•either one or the other effects must show up at energies of O(TeV).

- It is the well known Hyerarchy problem of the '80s, but it is still with us;
- a 125 GeV particle looks more like "elementary" than "bound at TeV energies"

SUSY Higgs ? H_u, H_d

$$\langle 0|H_u^0|0\rangle = v\sin\beta; \quad \langle 0|H_d^0|0\rangle = v\cos\beta; \quad 0 < \tan\beta < +\infty$$

$$v^2 = (2\sqrt{2}G_F)^{-1} = (174\ \mathrm{GeV})^2$$

Physical H bosons

$$h\ :\ 125GeV$$

$$H,\ A,\ H^{\pm}\ ???$$

- if $\sin\beta=1$, $h=H^0_u$ and H_d is a “matter multiplet”: no VEV, no WW or ZZ couplings;
- the mass matrix of H^0_u and H^0_d contains M_Z, M_A, m_{stop}, $\tan\beta$
- m_{stop} appears in the radiative correction:

$$\delta = \frac{3\sqrt{2}}{\pi^2\sin^2\beta}G_F(M_t)^4 t; \quad t = \log\left(\frac{\sqrt{M_{\tilde{t}_R}M_{\tilde{t}_L}}}{M_t}\right)$$

Mass matrix and a famous inequality

$$M_h^2 \leq \cos^2(2\beta) M_Z^2 + \delta$$

delta saves us from disaster

- If we know M_h and make an hypothesis on M_H, we are left with one parameter only, i.e. $\tan\beta$
- we may also determine:

(i) how the level of observation of the 125 GeV signal compares to the SM;
(ii) what is the visibility level of H in $\gamma\gamma$ *and* ZZ
(iii) which are the best suited channels for the observation of H.

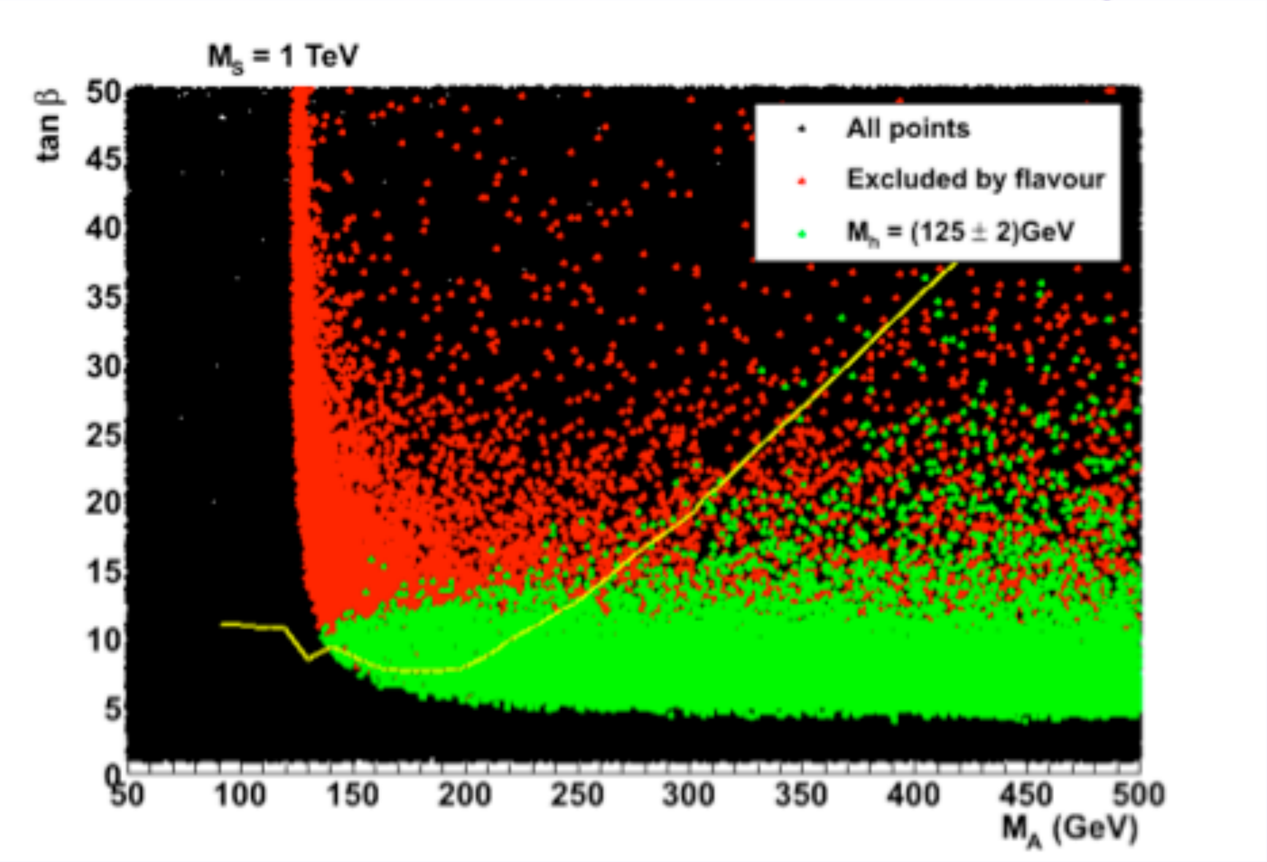
Limits on tan beta

• weak limits in $\tan\beta$ derive from the fact that Yukawa couplings of b and t become too large for $\tan\beta$ very small or very large;

•much stronger upper limits to $\tan\beta$ derive from the non observation of FCNC processes in B decay.

In the maximal mixing scenario ($X_t = \sqrt{6} M_S$):

Preliminary



yellow line: CMS limit with 4.6/fb

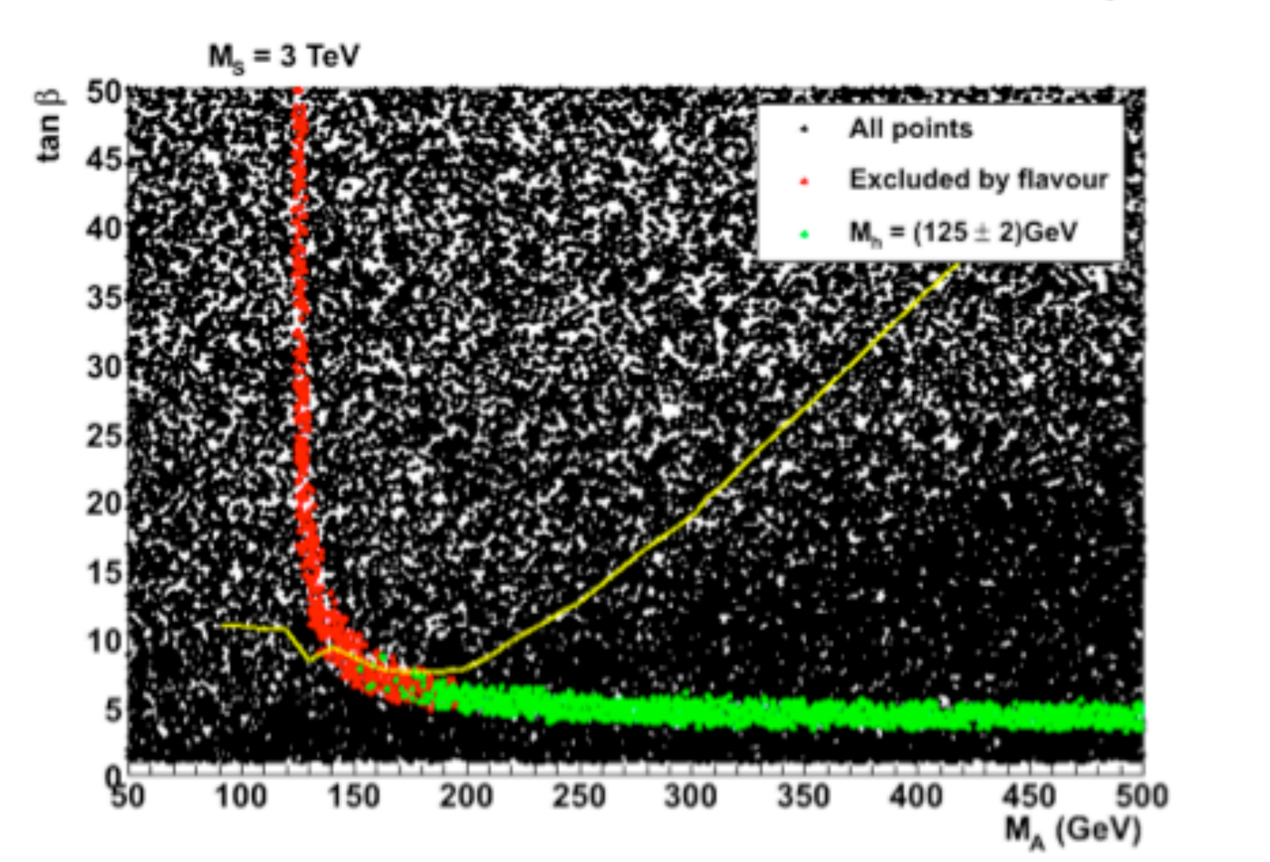
Flavour constraints: $b \to s\gamma$, $B \to \tau\nu$ and the **new** LHCb limit on $B_s \to \mu\mu$

Very strong constraint from the neutral Higgs searches!

Consequences of a 125 GeV scalar on pMSSM

In the maximal mixing scenario ($X_t = \sqrt{6} M_S$):

Preliminary



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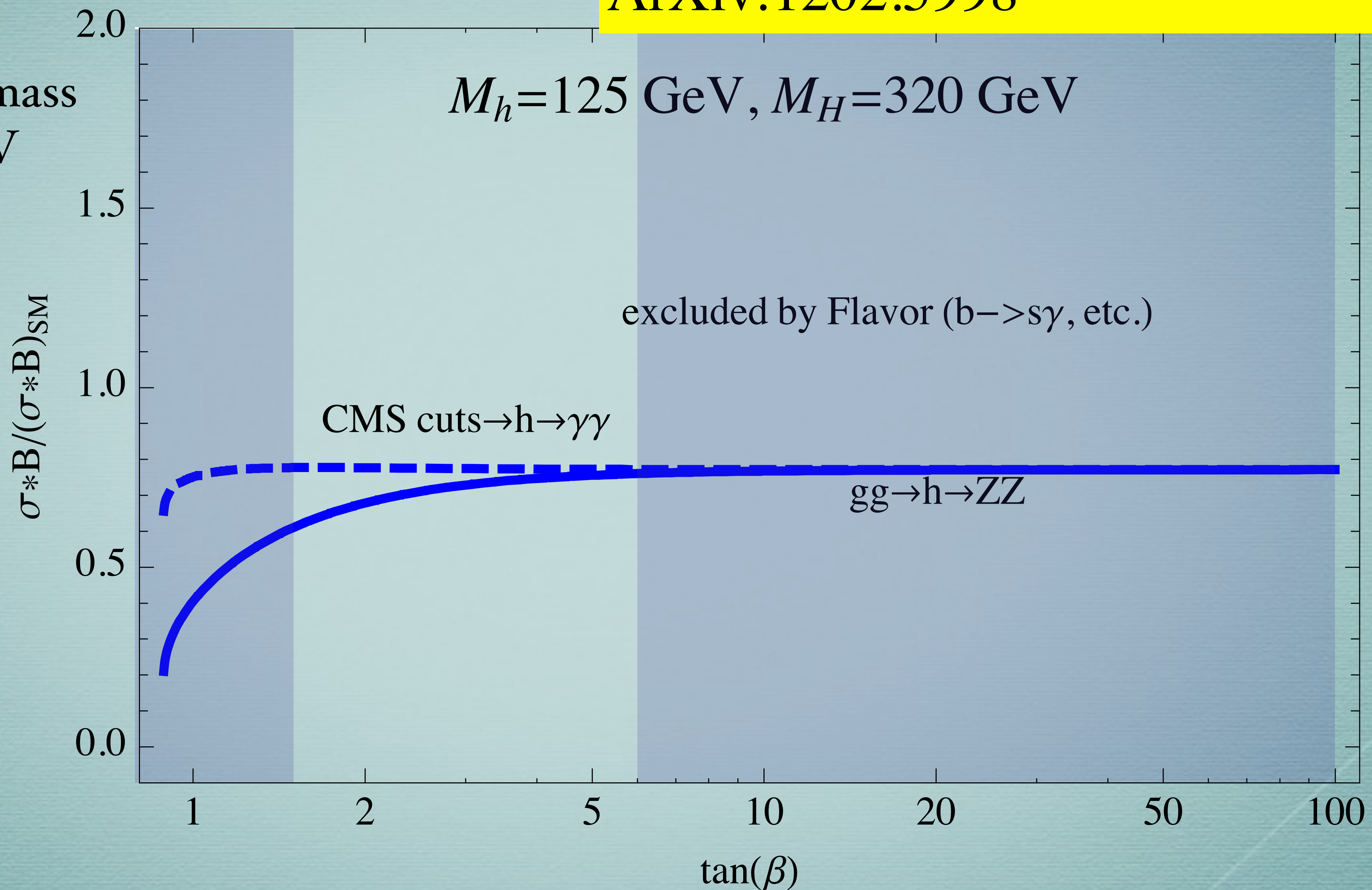
Very strong constraint from the neutral Higgs searches!

h-> ZZ and h->γγ (CMS /ATLAS cuts)

L. M., A. Polosa, V. Riquer, NJP 2012
ArXiv:1202.5998

- The scalar top mass is about 4 TeV



- h behaves like a SM Higgs to 70-80%
- in ZZ and γγ

H-> ZZ and H->γγ (CMS /ATLAS cuts)

L. M., A. Polosa, V. Riquer, NJP 2012
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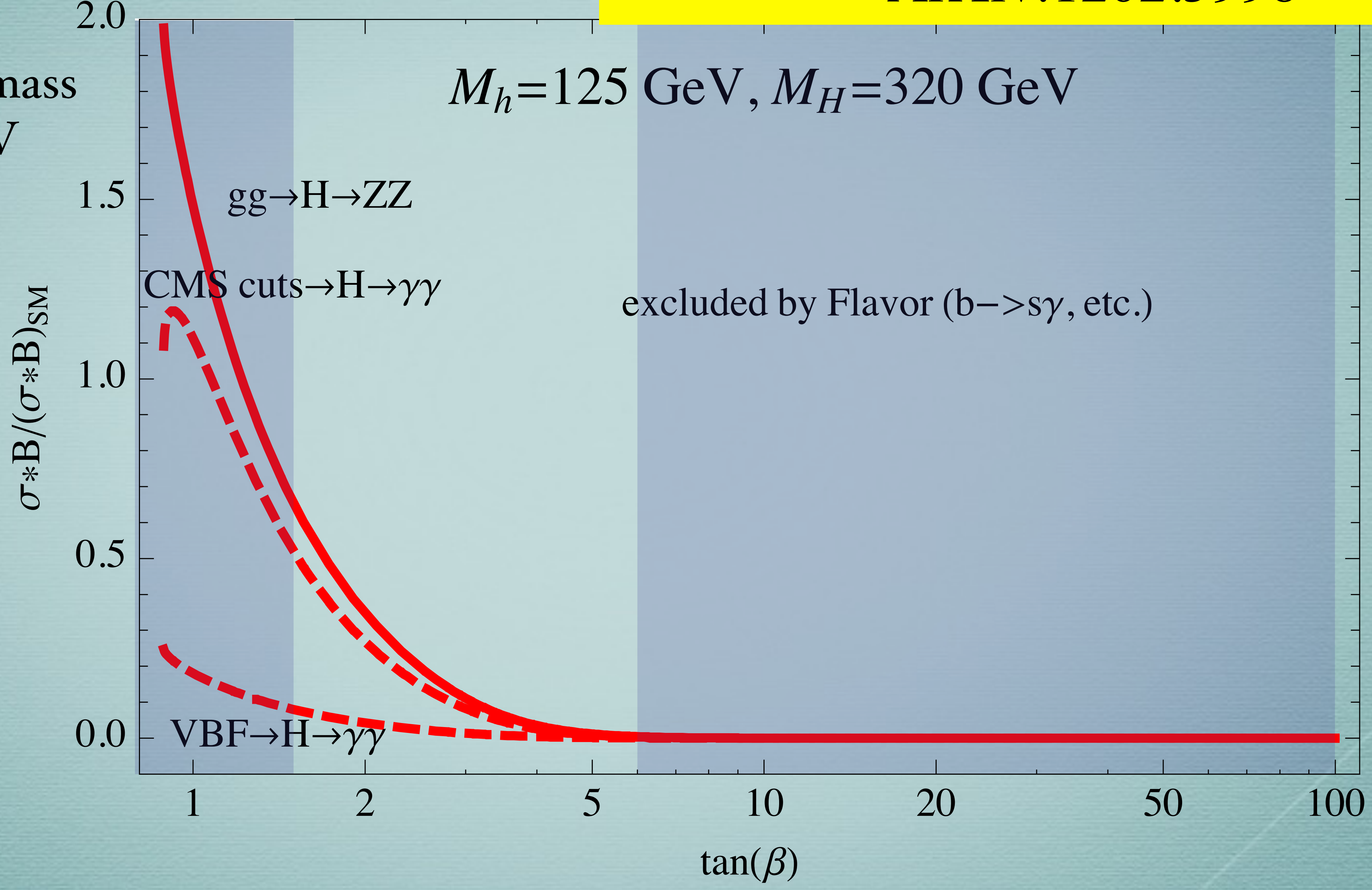
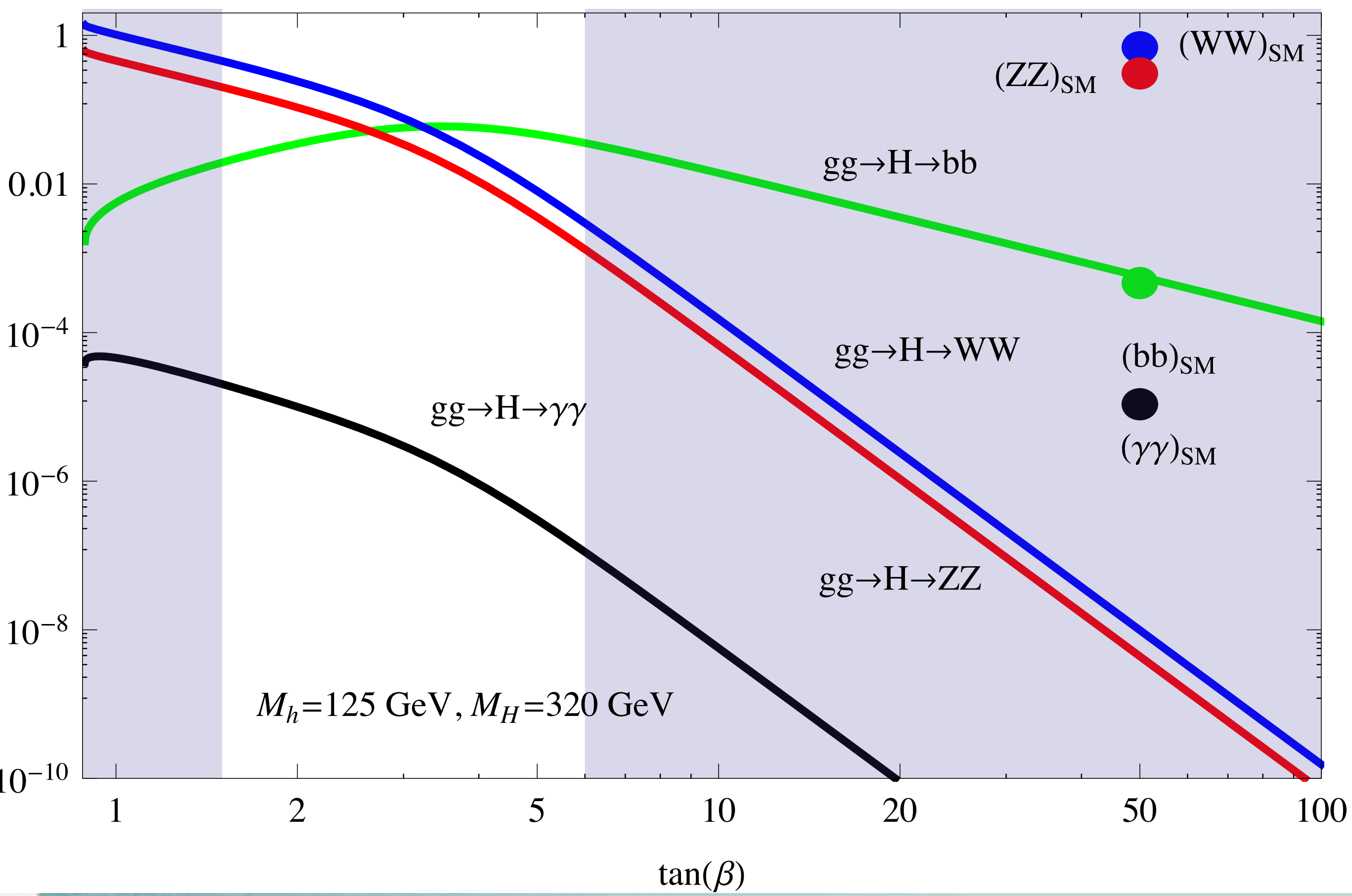


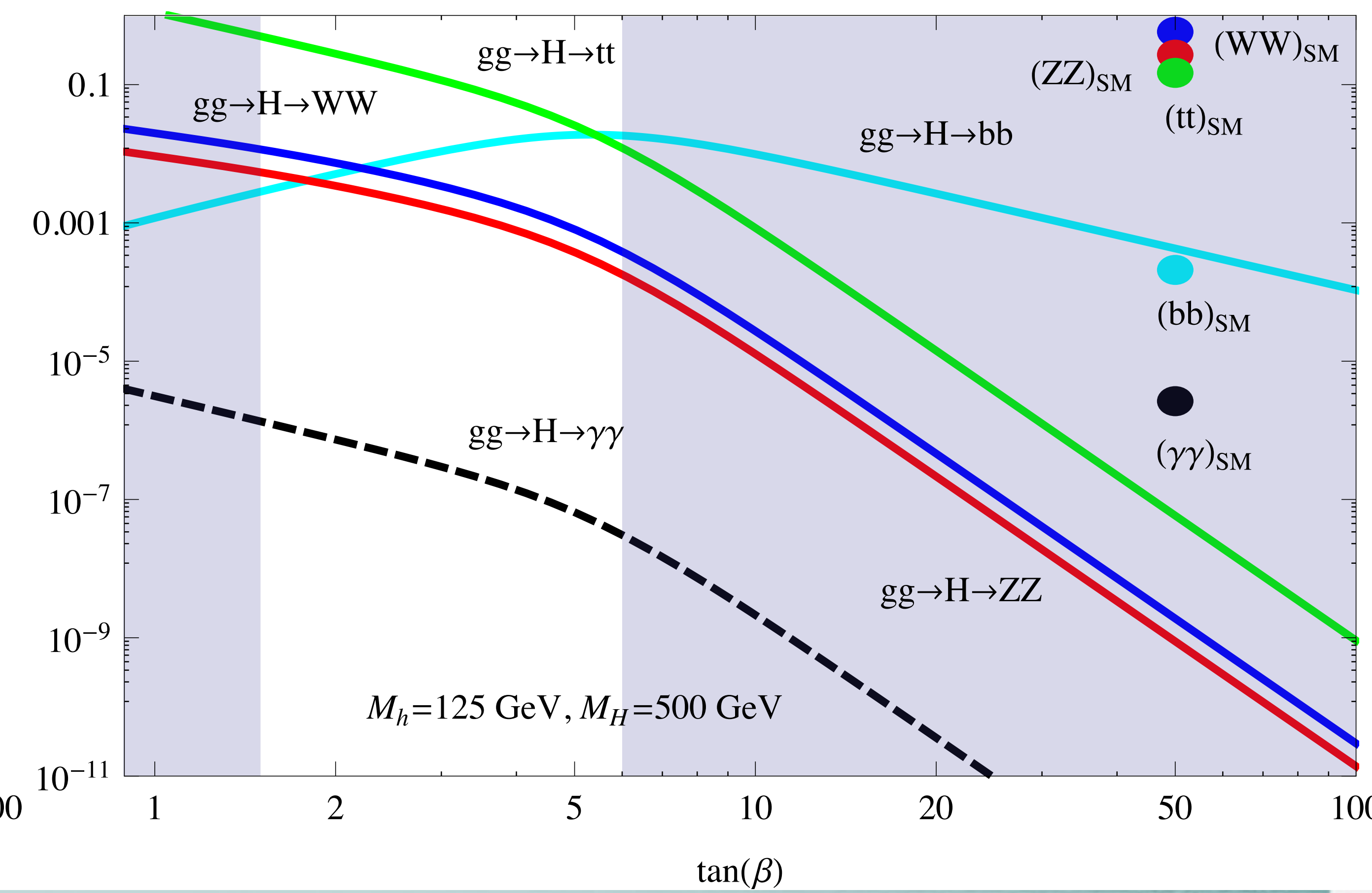
- H behaves like a satellite line
- intensity ~1/3 for tanβ=2

Visibility of H in different channels

M_H = 300 GeV



M_H = 500 GeV



- For the different channels and M_H= 300, 500 GeV, we plot the ratios (SM BRs on the right):

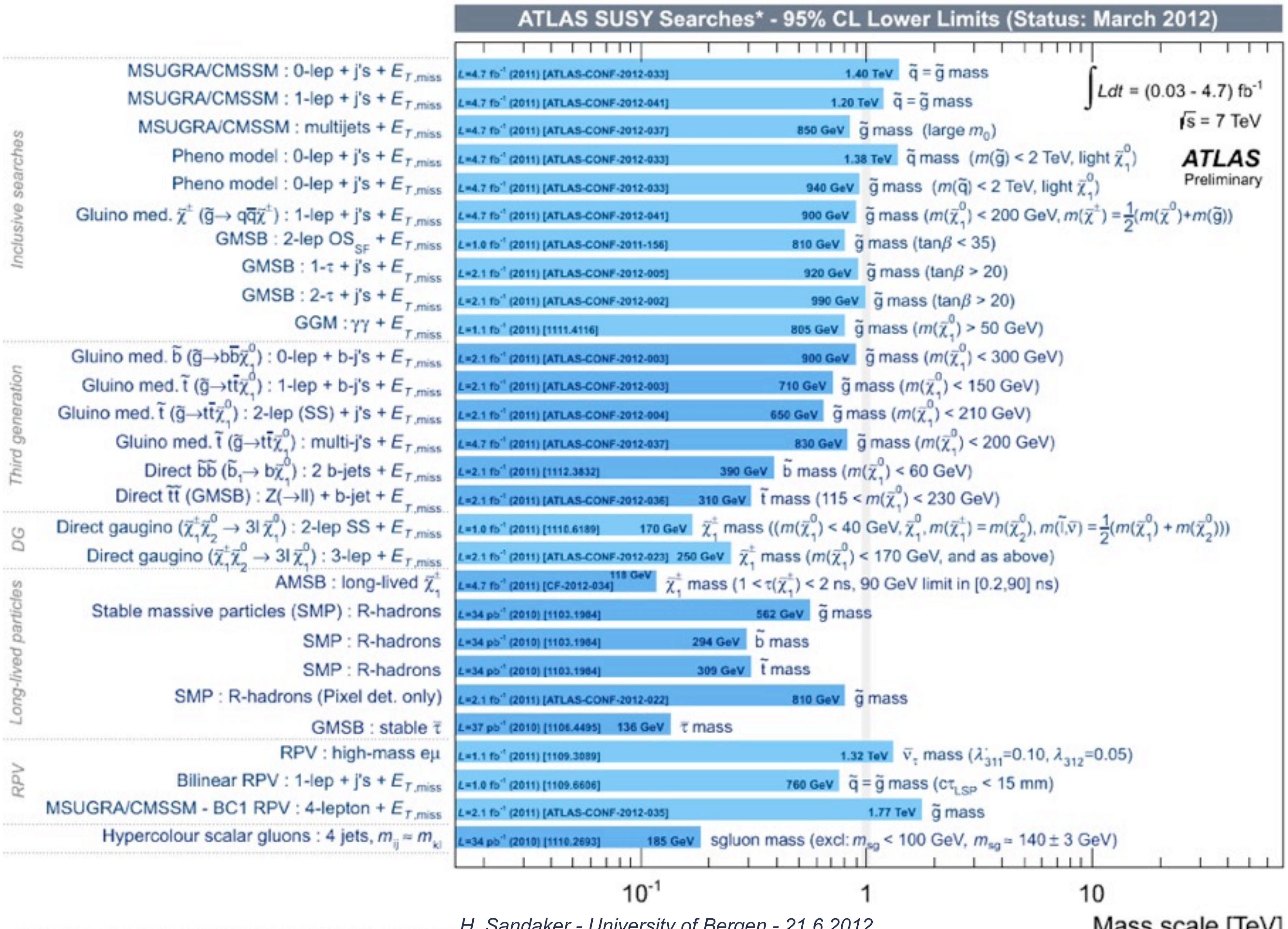
$$(BR)_{eff} = \frac{\sigma \times BR}{\sigma_{SM}}$$

- $$\text{rate} = \sigma_{SM} \times (BR)_{eff}$$

- for tanβ increasing, H tends to align with H_d and decouple from t and from VV.
- control of the t-t bar and b-b bar channes is crucial !

7.Remarkable absence of SUSY signal in LHC searches and in virtual effects

ATLAS SUSY results - Summary



*Only a selection of the available mass limits on new states or phenomena shown

H. Sandaker - University of Bergen - 21.6.2012

8. Conclusions

• The 4th of July announcement marked a crucial turn for particle physics;

• now, we want to know quantum numbers and branching fractions in the different channels of h(125);

- control of the fermion channels, b-b bar, tau-tau bar and t- t bar is crucial;
- search for “beyond SM”, SUSY etc., signals has to continue;
- “secondary lines” in Higgs boson spectrum may be at hand with increasing integrated luminosity (H, A, $H^{\pm}$) if masses below 5-600 GeV, identikit of decays available, as functions of M_H and tanβ (which begins to be severely restricted);

• We expect similarly important results from ALICE and LHCb

• Preparation for Higher luminosity LHC (SLHC) has to start, to increase the discovery potential, in case of not-so-light SUSY particles

With the Higgs-Brout-Englert boson found, next target is the Dark Matter: the real bridge between particle and astro-cosmo physics