"וְעֵילָם נָשָׂא אַשְׁפָּה..."

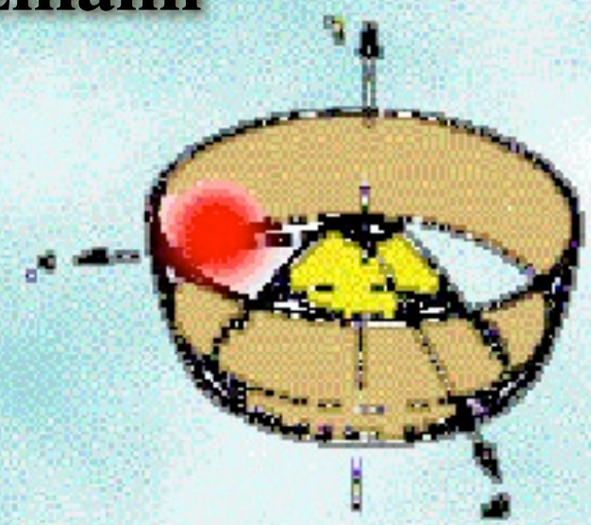
ישעיה כב

Eilam Gross

On behalf of the ATLAS collaboration

Hunting the Higgs

Weizmann



ATLAS EXPERIMENT

"And Eilam bare the quiver..."

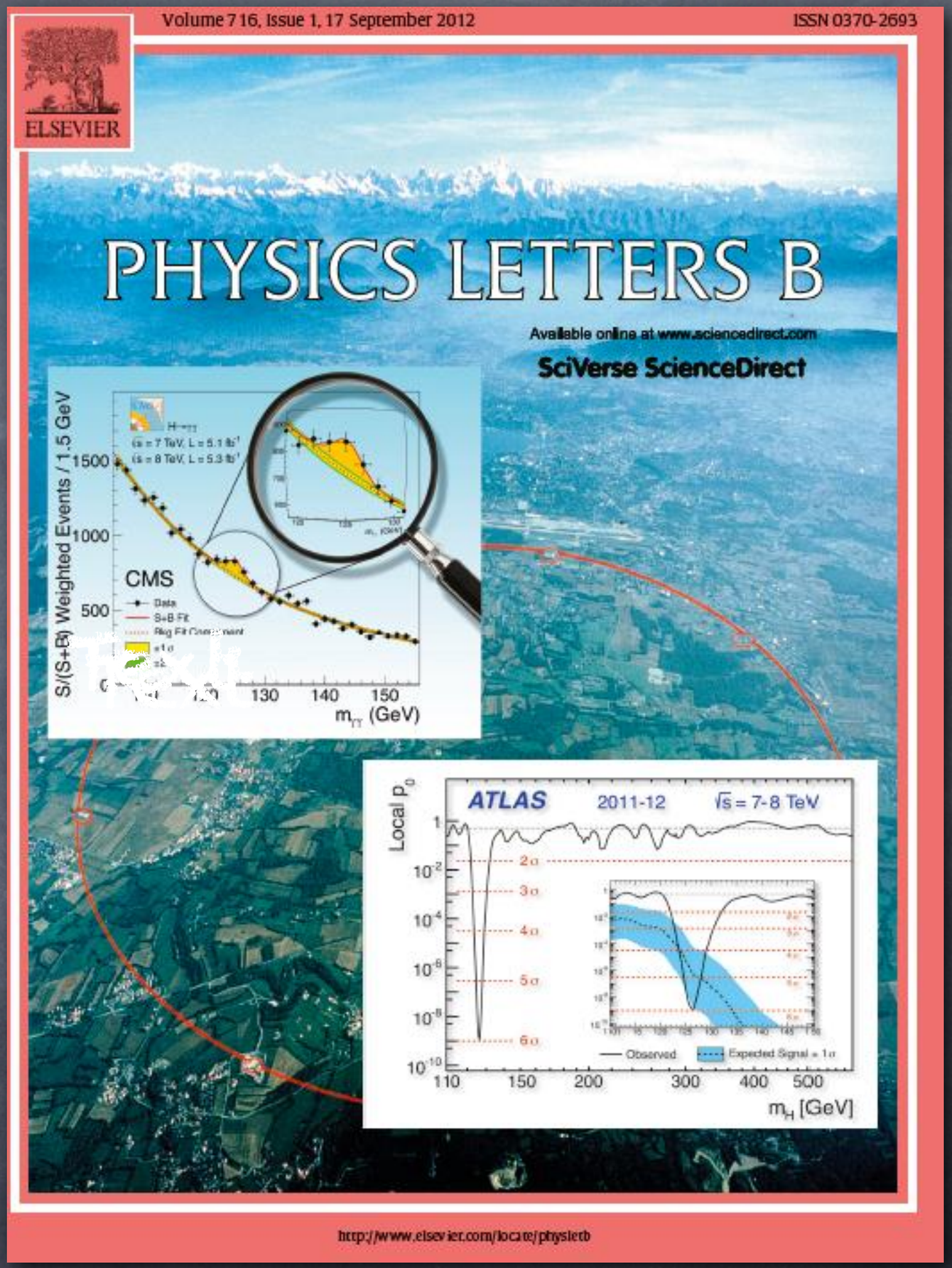
Jesaia 22

On behalf of the ATLAS collaboration

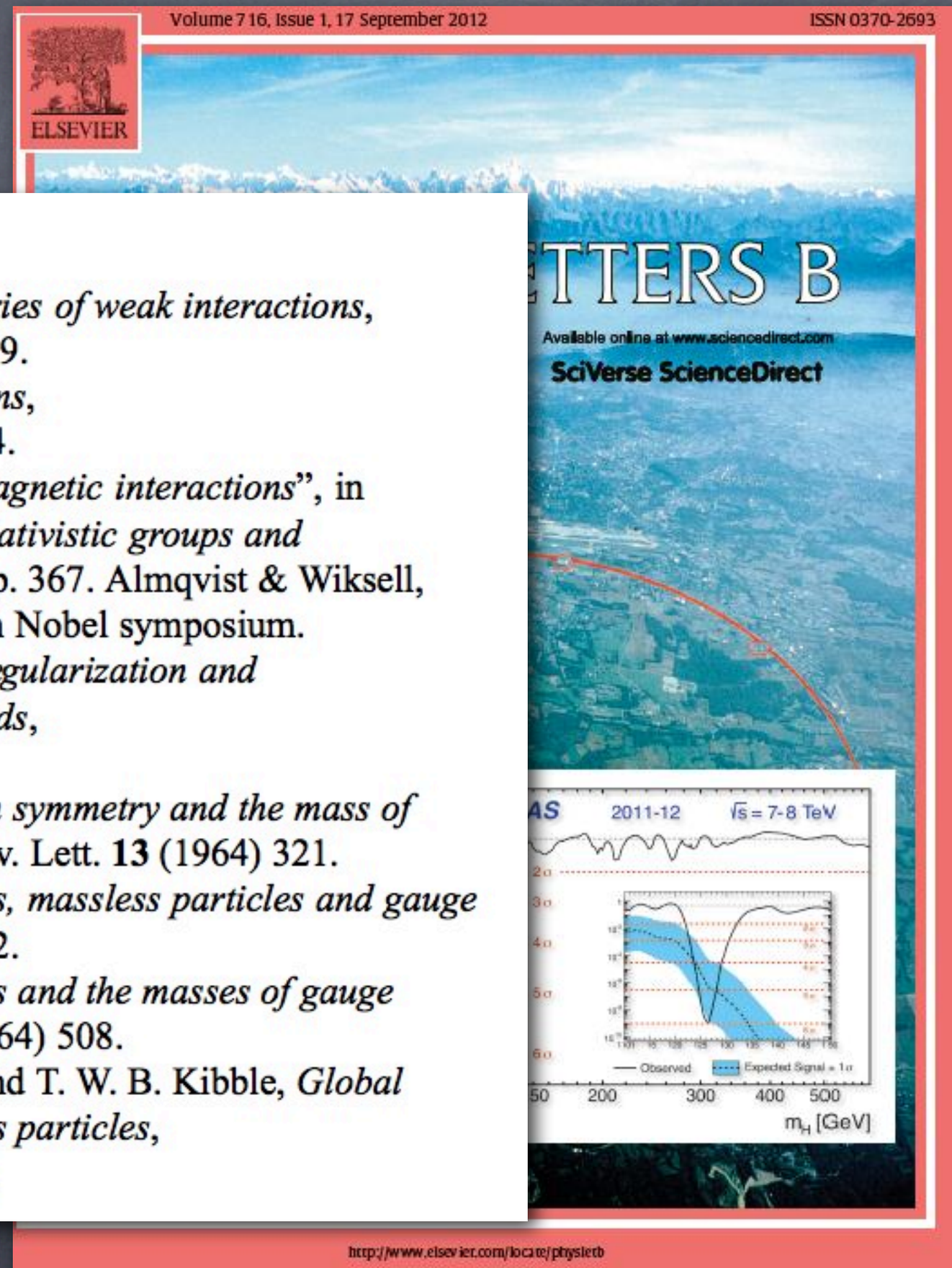
4th JULY 2012

Higgs Hunters' Independence Day

17 september 2012



17 september 2012



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[1] S. L. Glashow, *Partial-symmetries of weak interactions*, Nucl. Phys. **22** no. 4, (1961) 579.

[2] S. Weinberg, *A Model of Leptons*, Phys. Rev. Lett. **19** (1967) 1264.

[3] A. Salam, *"Weak and electromagnetic interactions"*, in *Elementary particle theory: relativistic groups and analyticity*, N. Svartholm, ed., p. 367. Almqvist & Wiksell, 1968. Proceedings of the eighth Nobel symposium.

[4] G. 't Hooft and M. Veltman, *Regularization and Renormalization of Gauge Fields*, Nucl. Phys. **B44** (1972) 189.

[5] F. Englert and R. Brout, *Broken symmetry and the mass of gauge vector mesons*, Phys. Rev. Lett. **13** (1964) 321.

[6] P. W. Higgs, *Broken symmetries, massless particles and gauge □elds*, Phys. Lett. **12** (1964) 132.

[7] P. W. Higgs, *Broken symmetries and the masses of gauge bosons*, Phys. Rev. Lett. **13** (1964) 508.

[8] G. S. Guralnik, C. R. Hagen, and T. W. B. Kibble, *Global conservation laws and massless particles*, Phys. Rev. Lett. **13** (1964) 585.


Air Mail
27 FEB 2010
90p
Easter
Dr Eilam Gross
Particle Physics Department
Weizmann Institute of Science
76100 Rehovoth
ISRAEL
FROM
Peter Higgs
2 Darnaway Street
Edinburgh EH3 6BG

Higgs (in a snail mail to me):

History of SSB

(1) Order of contributions:-

1. Nambu (1960), Nambu & Jona-Lasinio (1961)
2. Goldstone (1961)
3. Goldstone, Salam & Weinberg (1962)
4. Anderson (1963)
5. Englert & Brout (Aug. 1964)
6. Higgs (Sep & Oct 1964)
7. Guralnik, Hagen & Kibble (Nov. 1964)

See the enclosed reprint for my account of papers 1 to 6.

Guralnik, Hagen & Kibble (7) showed how the Goldstone theorem is evaded in a simple linear model. Note that all six of us were awarded the 2010 Sakurai Prize by the APS.

Higgs (in a snail mail to me):

History of SSB

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6. Higgs (1964)
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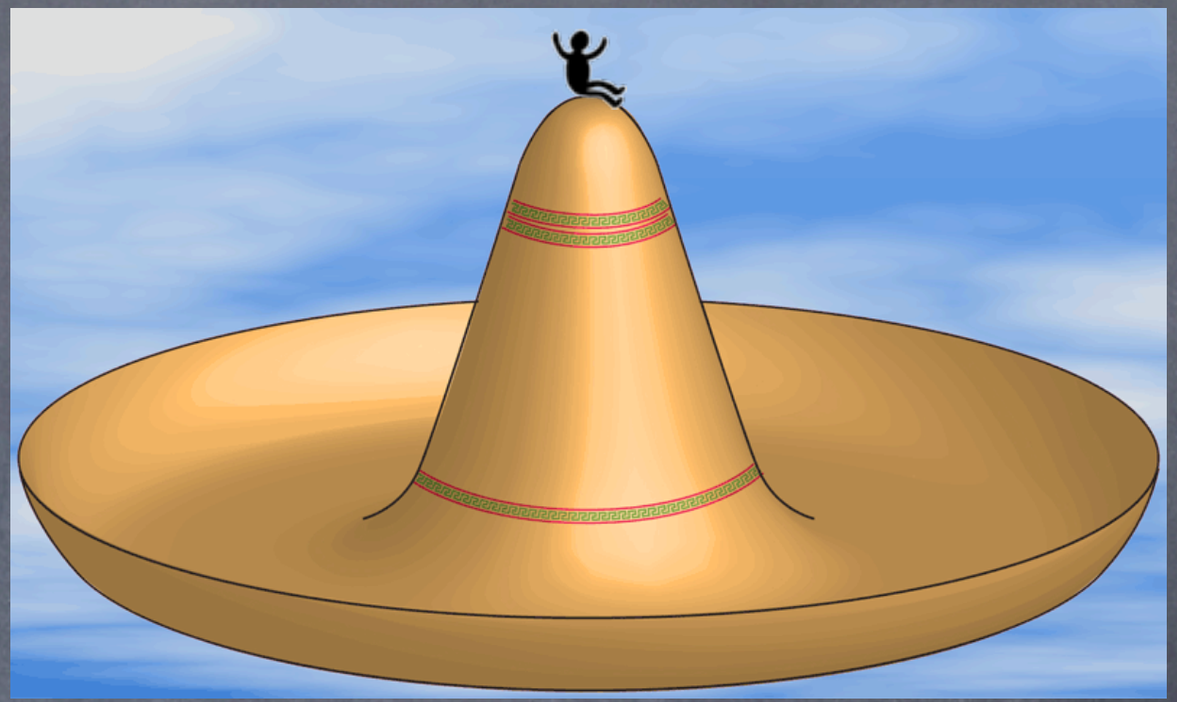
A Prelude to the Nobel Prize

- 2010 Sakurai Prize awarded for 1964 Higgs Boson theory work to Hagen, Guralnik, Kibble, Brout, Englert & Higgs

Spontaneous Symmetry Breaking

- Spontaneously Symmetry Breaking was first introduced by Ginzburg & Landau (1950,1957)
(in an attempt to explain superconductivity)



- The physics of the system (Lagrangian) posses some exact symmetry, but the vacuum (ground state) breaks this symmetry

- Nambu (1960) proposed for the first time that SSB is the source of fermion masses in elementary particle physics:
"the existence of such a condensate (scalar field) would break the symmetry of the model.... . In particle physics, that would be a non-Abelian group containing the U(1) group associated with electric charge conservation as a subgroup"

Spontaneous Symmetry Breaking

- Inspired by Nambu, Goldstone (1961) studies models featuring scalar fields and finds that all these models contains (under SSB) massless (Nambu-Goldstone) Bosons

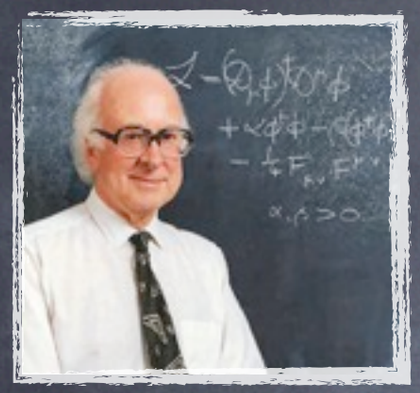
- Goldstone, Salam and Weinberg (1962) prove formally that Goldstone Bosons must occur whenever a symmetry (*"like isospin or strangeness"*) is broken (Goldstone Theorem). But no such Bosons were observed experimentally.

- Weinberg recalls in his Nobel lecture (1979) that he was so disappointed that he added a quote to the paper from King Lear: *"Nothing will come out of nothing, speak again"*

- Is Quantum Field Theory a one trick pony?
  Can it explain only long range interactions?

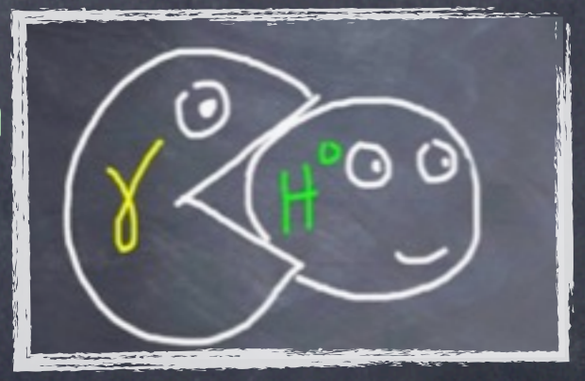
Spontaneous Symmetry Breaking

Philip Anderson (1963) points out that in a superconductor the Goldstone mode becomes a massive plasmon-mode, due to its electromagnetic interaction.



Peter Higgs (Phys. Lett. July 1964) shows that one can evade Goldstone theorem. He shows that if the broken symmetry is local gauge symmetry (like electromagnetic U(1) gauge invariance), then, although the Goldstone Bosons exist formally, and in some sense real, they can be eliminated by gauge transformation, so that they do not appear as physical particles. That explains why experiment fails to detect the massless Bosons.

- The missing Gloldstone boson appears instead as helicity zero state of the massless boson which thereby acquire a mass.
- The massless boson eats the Goldstone Boson and acquires mass.



The Higgs Mechanism

- Based on field theory (using a lagrangian formalism) Higgs develops the formalism of the mechanism by which the Goldstone Boson is "eaten" by the photon and the pohoton becomes massive -> short range interaction

- He sends the 3 pages paper to Physics Letter, the paper is rejected. Higgs: *"I was rather shocked. I did not see why they would accept a paper that said this is a possible way to evade the Goldstone theorem, and then reject a paper that showed how you actually do it."*

- Higgs adds an epilogue to the paper: *"it is worth noting that an essential feature of this type of theory is the prediction of incomplete multiplets of scalar and vector bosons"* and sends the revised version to PRL.

The Higgs Mechanism

- Higgs: "The referee who, I discovered later, was Nambu, drew my attention to a paper by Englert and Brout that they had just published in Physical Review Letters". Higgs is asked to cite Englert & Brout and the paper is accepted (August 1964)

- Guralnik, Hagen and Kibble (1964).
  Guralnik (2009): "As we were literally placing the manuscript in the envelope to be sent to PRL, Kibble came into the office bearing two papers by Higgs and the one by Englert and Brout. These had just arrived in the then very slow and unreliable... Imperial College mail. We were very surprised and even amazed."

The Higgs Mechanism

- Higgs (in a snail mail to me):

My first paper outlined how to evade the Goldstone theorem.
Englert & Brout showed how a gauge field interaction turns Goldstone massless spin-0 bosons (elementary or composite) into helicity-0 states of massive spin-1 particles.
They started from Feynman diagrams and didn't discuss the remaining massive spin-0 particles.
In my second paper I used Lagrangian field theory explicitly with elementary scalar fields (à la Goldstone) coupled to a gauge field, so the massive spin-0 boson was an obvious feature, to which I drew attention.
All three of us tried without success

The Higgs Mechanism

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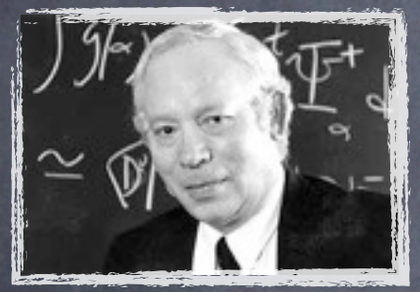
The Birth of the Standard Model

- Glashow (1961) suggests that the symmetry of the Electro-Weak interaction is SU(2)xU(1) and is broken to U(1) em. But Glashow puts the masses of the force carriers by hand and his theory is therefore non-renormalizable



- Weinberg (1967) implements Higgs mechanism to Glashow's SU(2)xU(1) and writes the most quoted paper in the history of particle phsyics

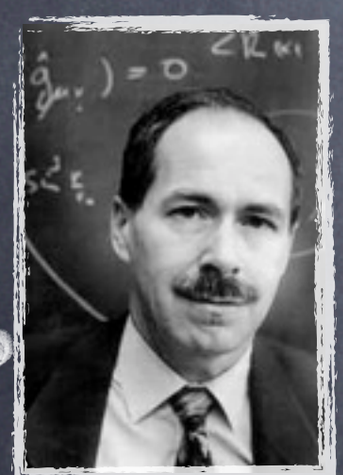
  (one of the most quoted . .... >8000 citations).

- Weinberg predicts that the mass of the weak interaction force carriers is mW=80 GeV and mZ=90 GeV, but it took another 14 years to confirm it experimentally.

The Birth of the Standard Model

wrong.

Is this model renormalizable? We usually do not expect non-Abelian gauge theories to be renormalizable if the vector-meson mass is not zero, but our Z_μ and W_μ mesons get their mass from the spontaneous breaking of the symmetry, not from a mass term put in at the beginning. Indeed, the model Lagrangian we start from is probably renormalizable, so the question is whether this renormalizability is lost in the reordering of the perturbation theory implied by our redefinition of the fields.



- The (theoretical) story was completed when 'tHooft (& Veltman) proved the renormalizability of Yang-Mills theories with masses generated by spontaneous symmetry breaking in a scalar field system in 1971.

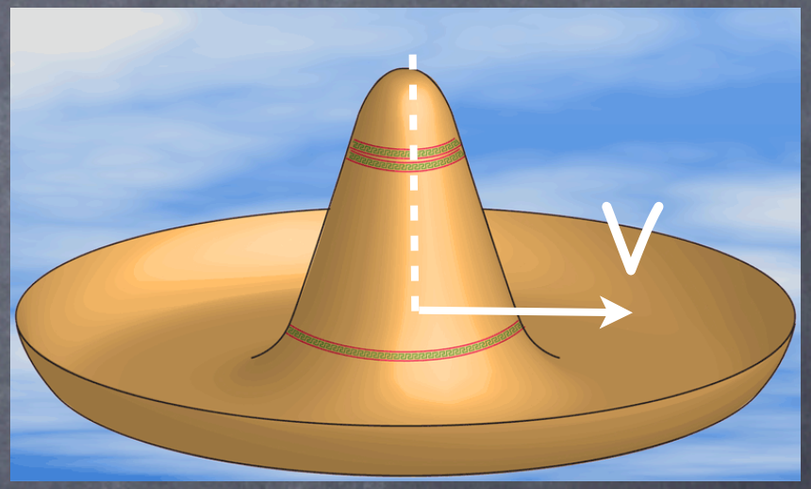
- All that is left is to find the mass generator, the Higgs Boson

How Elementary Particles Acquire Mass

- A mass term is given by $m\bar{\psi}_L\psi_R$
- Only left handed fields carry weak charge.
- Via SSB the Higgs field "charges" the vacuum with a weak charge and the symmetry is preserved ("hidden")

$$g_{H\psi}H_L\bar{\psi}_L\psi_R -> g_{H\psi}\langle H_L\rangle\bar{\psi}_L\psi_R = g_{H\psi}\mathrm{v}\bar{\psi}_L\psi_R$$

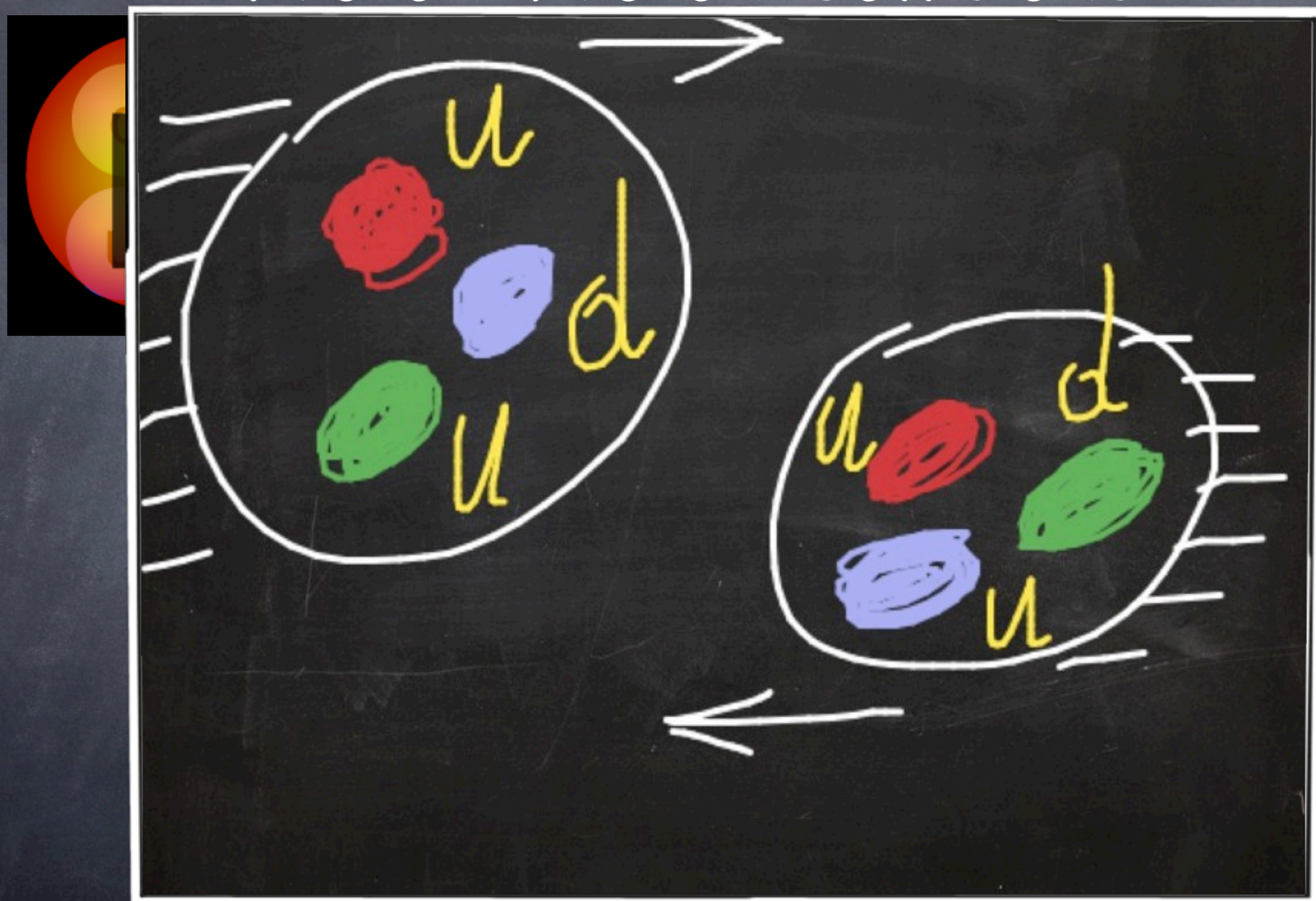
$$m_\psi = g_{H\psi}\mathrm{v}, \qquad g_{H\psi} = \frac{m_\psi}{\mathrm{v}}$$

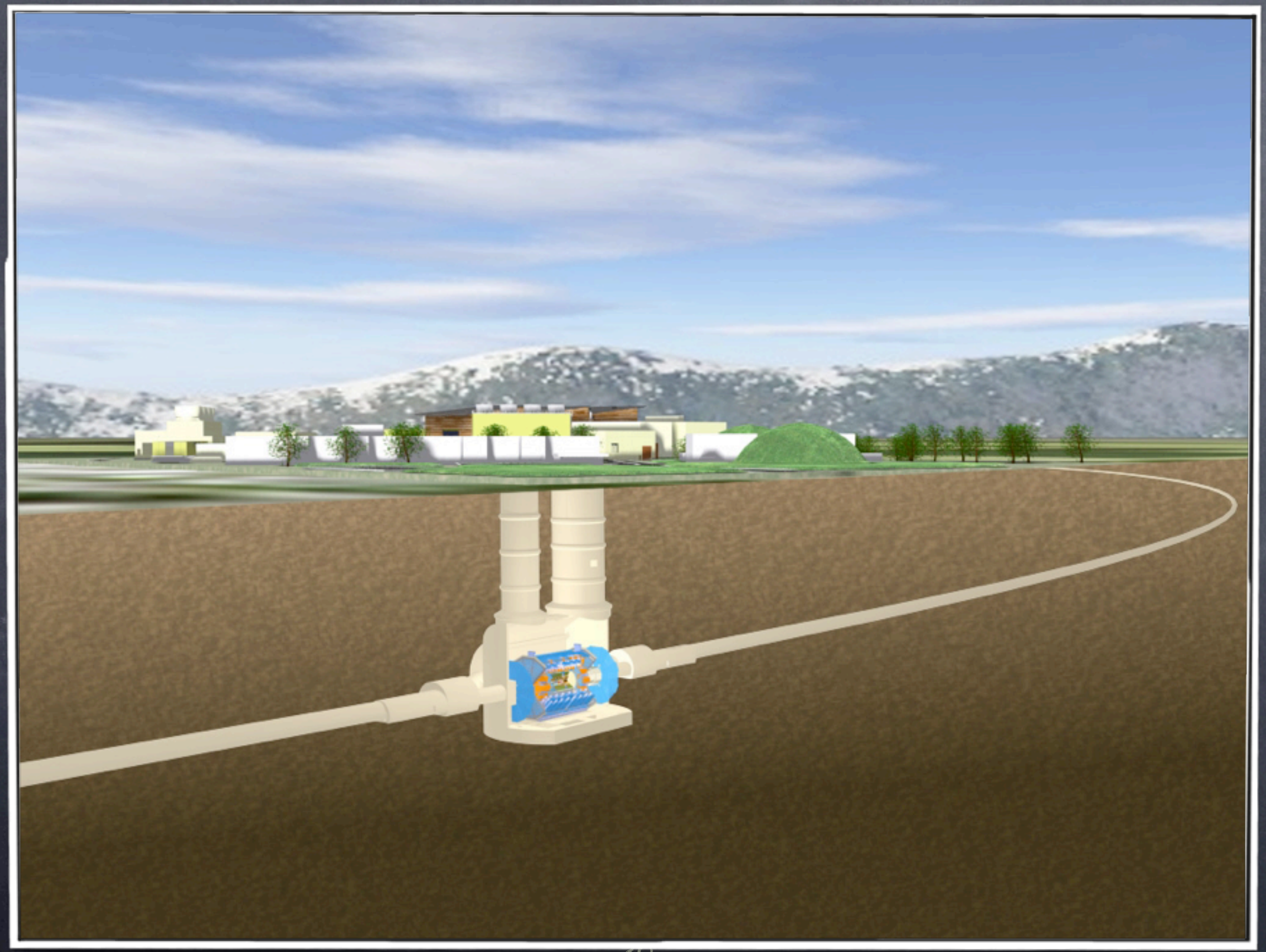


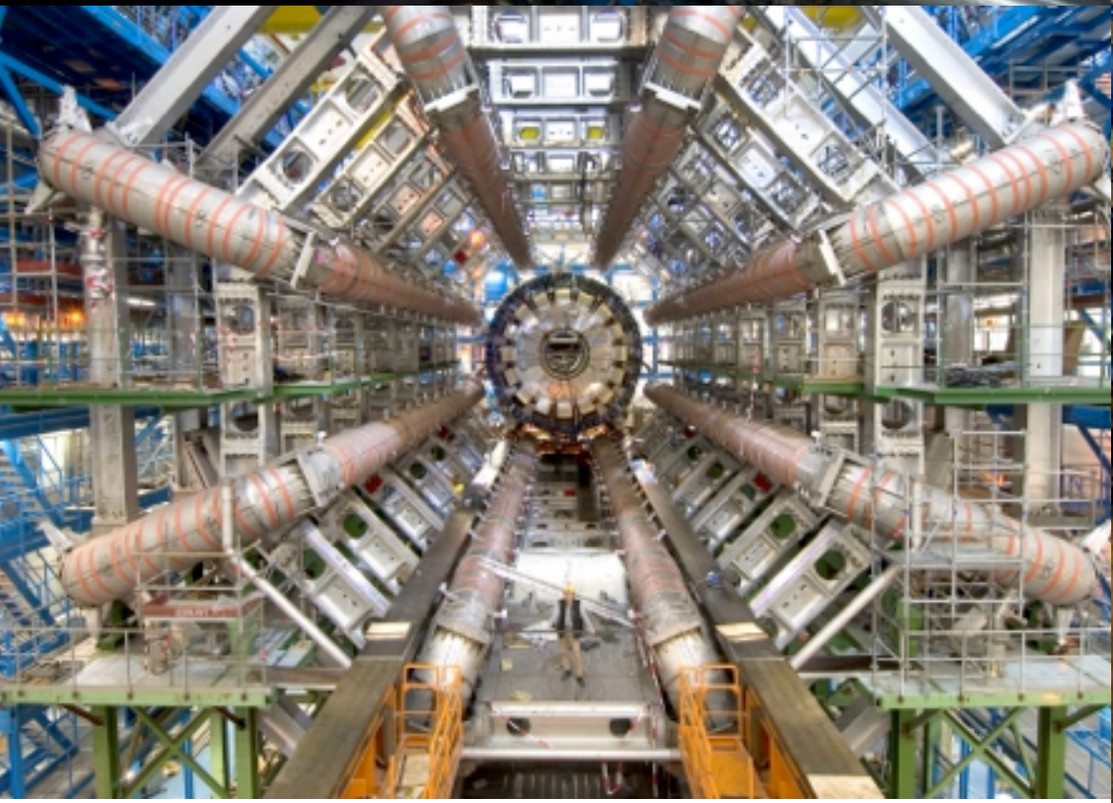
- The coupling of the Higgs to particles is proportional to the particles' mass
- The Higgs Boson will therefore decay with a higher probability to the heaviest particle kinematically available

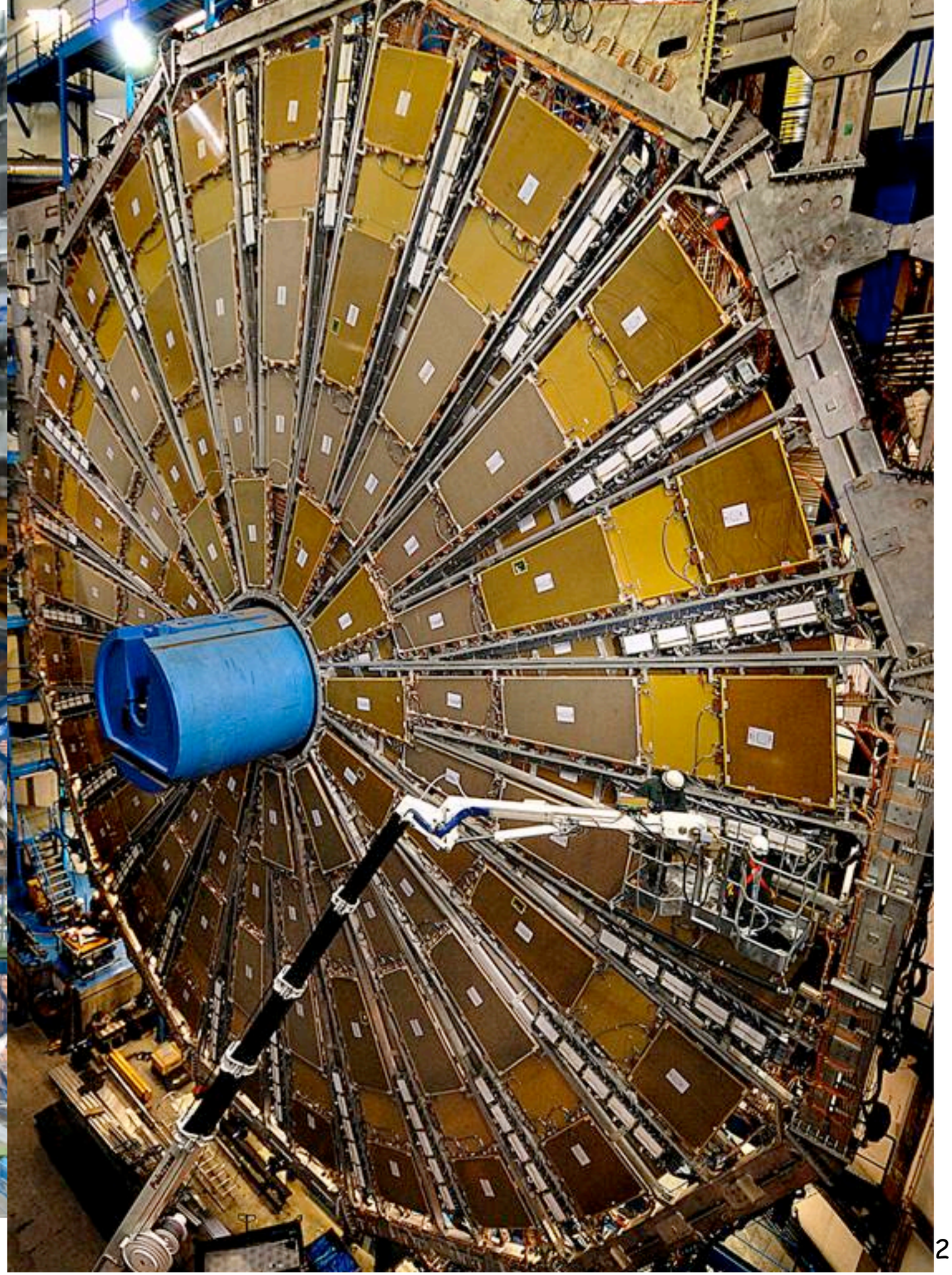
Seeing The Higgs Boson - How To?

Proton-Proton Collisions



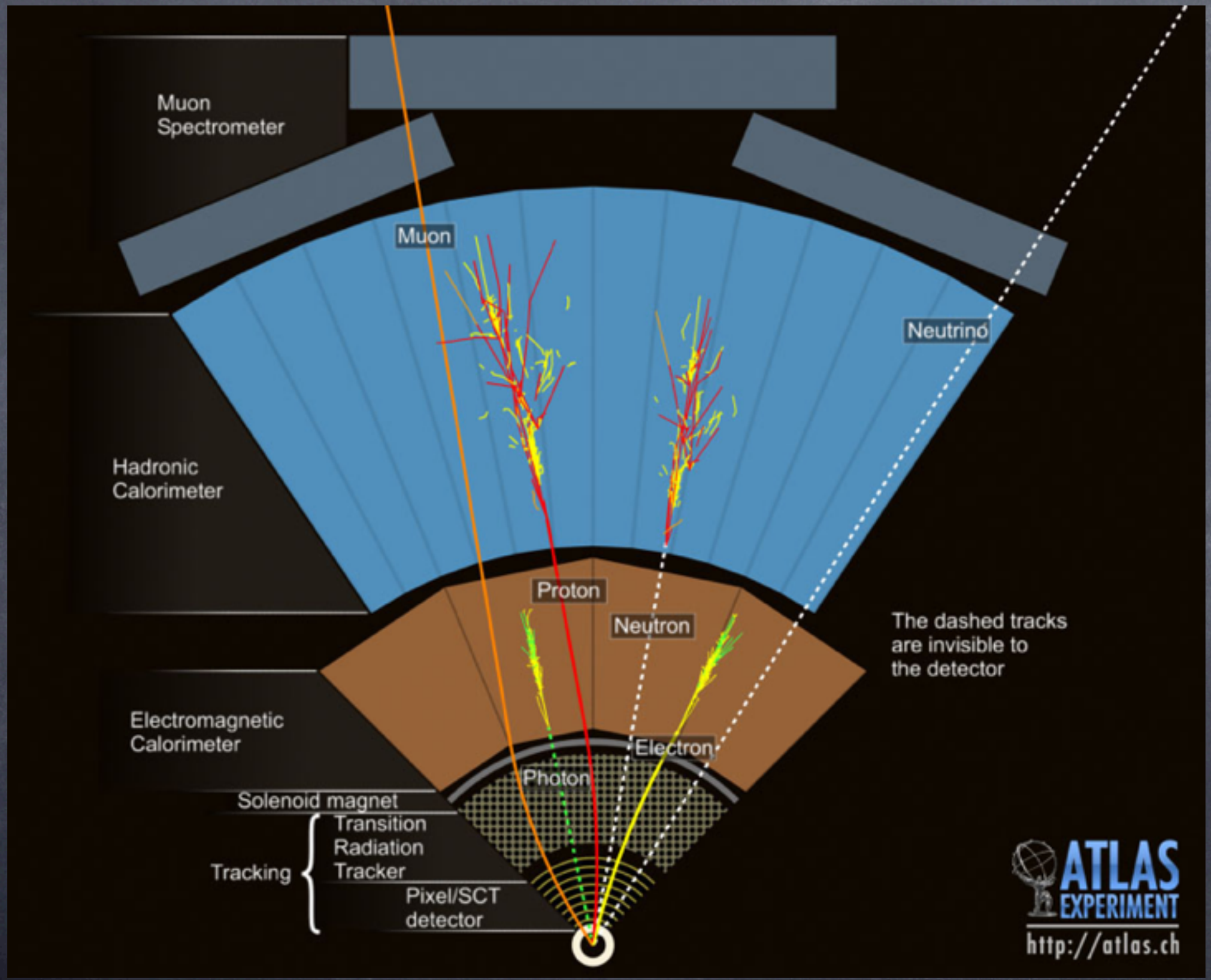




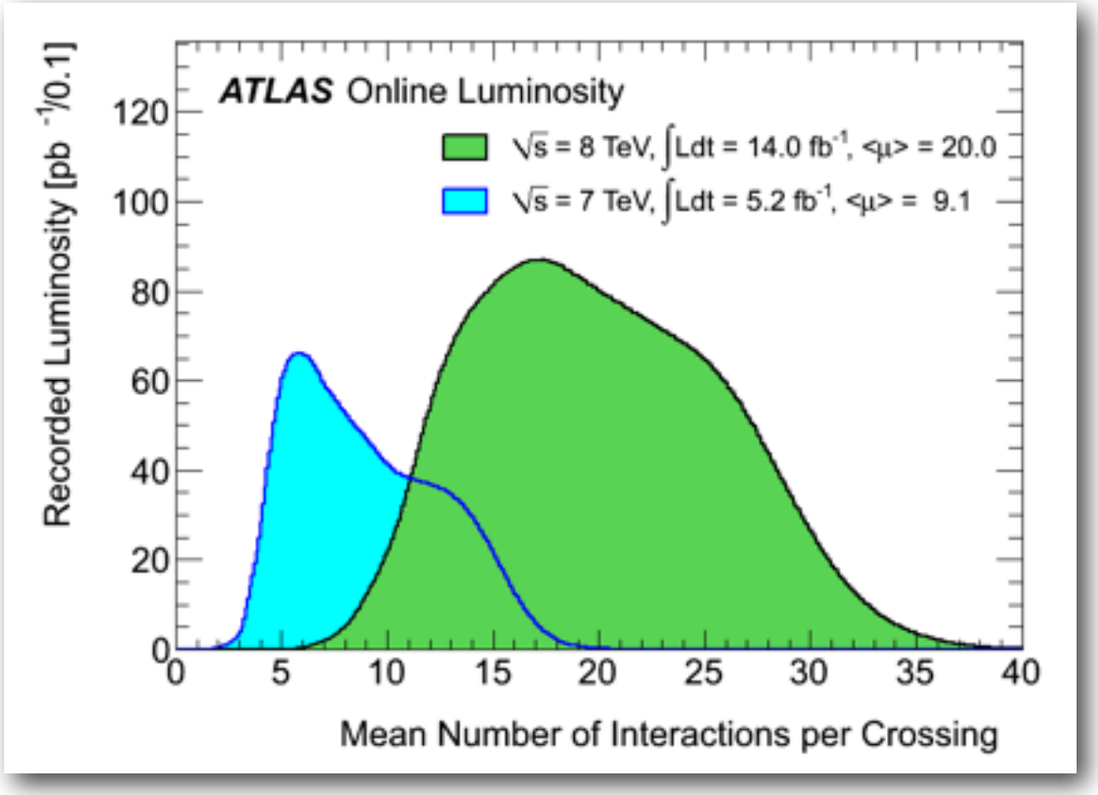


Eilam Gross, Bar Ilan University, October 2012

Seeing Particles



The BIG challenge in 2012: PILE-UP



Proton Runs 2010-12

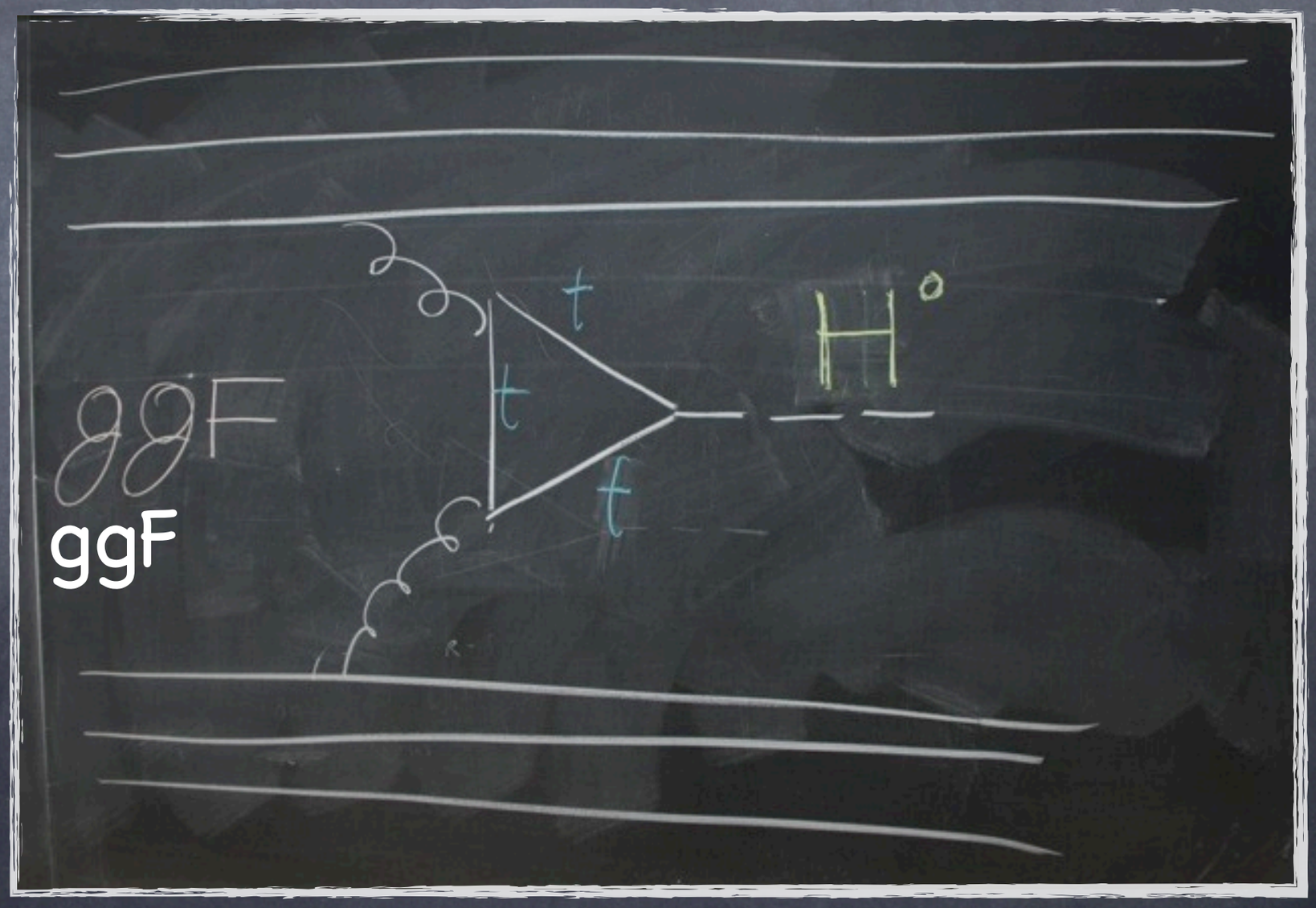
Highest luminosity = $7.73 \cdot 10^{33}$ $cm^{-2}s^{-1}$

Total Collisions = $1.71 \cdot 10^{15}$ = 1 710 000 000 000 000

Recorded luminosity = 25.62 fb^{-1}

Higgs Production @ the LHC

- Higgs hardly couples to u & d quarks (which make protons)
- To produce a Higgs Boson in P-P collisions 4 processes are used: ggF, VBF, Associate Production and ttH



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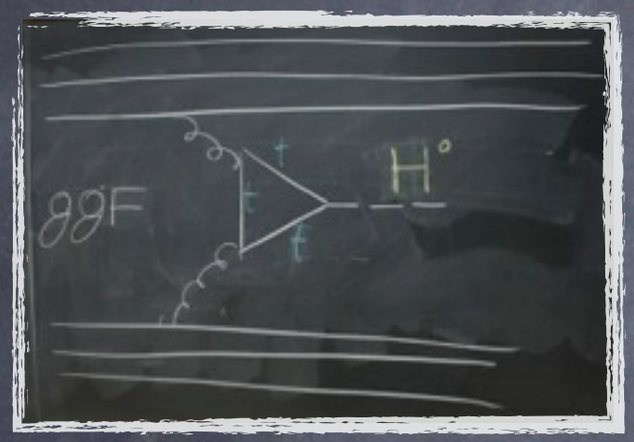

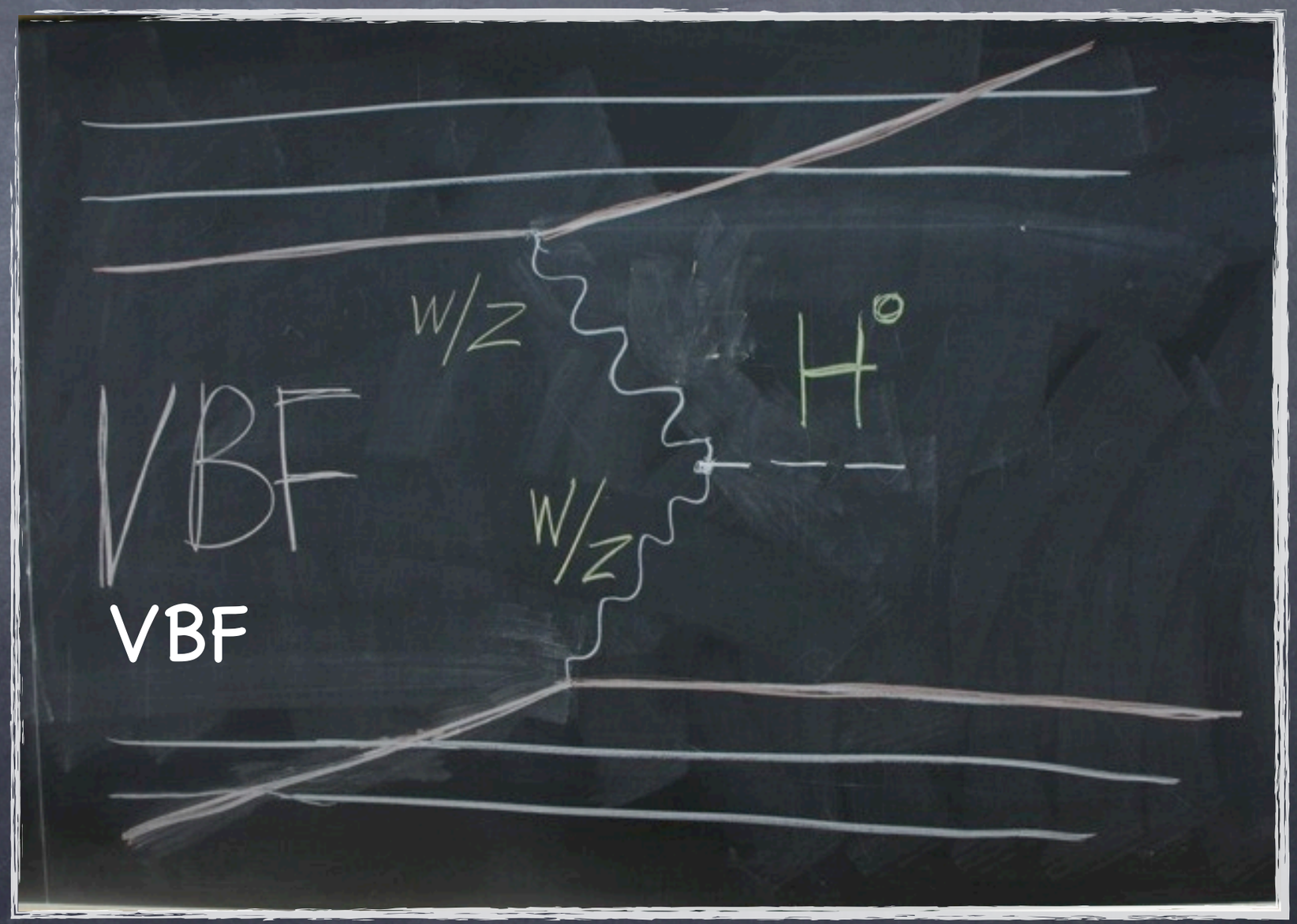

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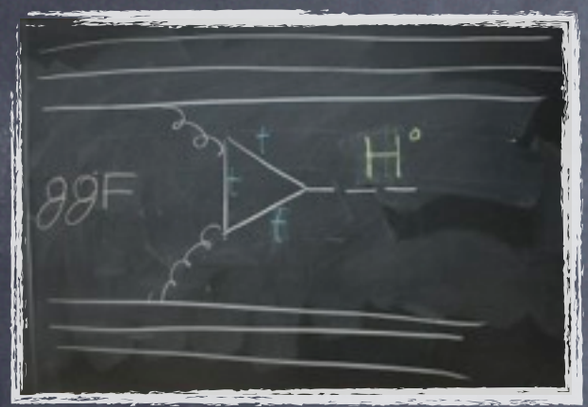

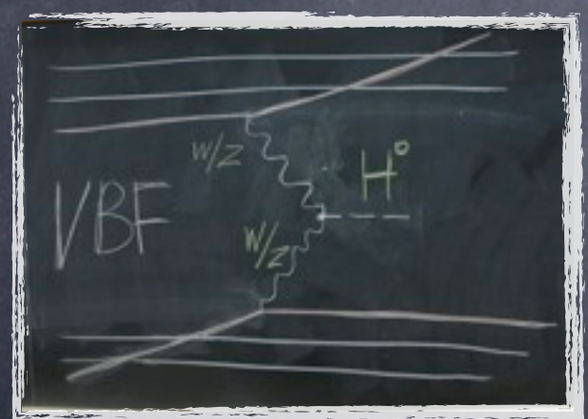

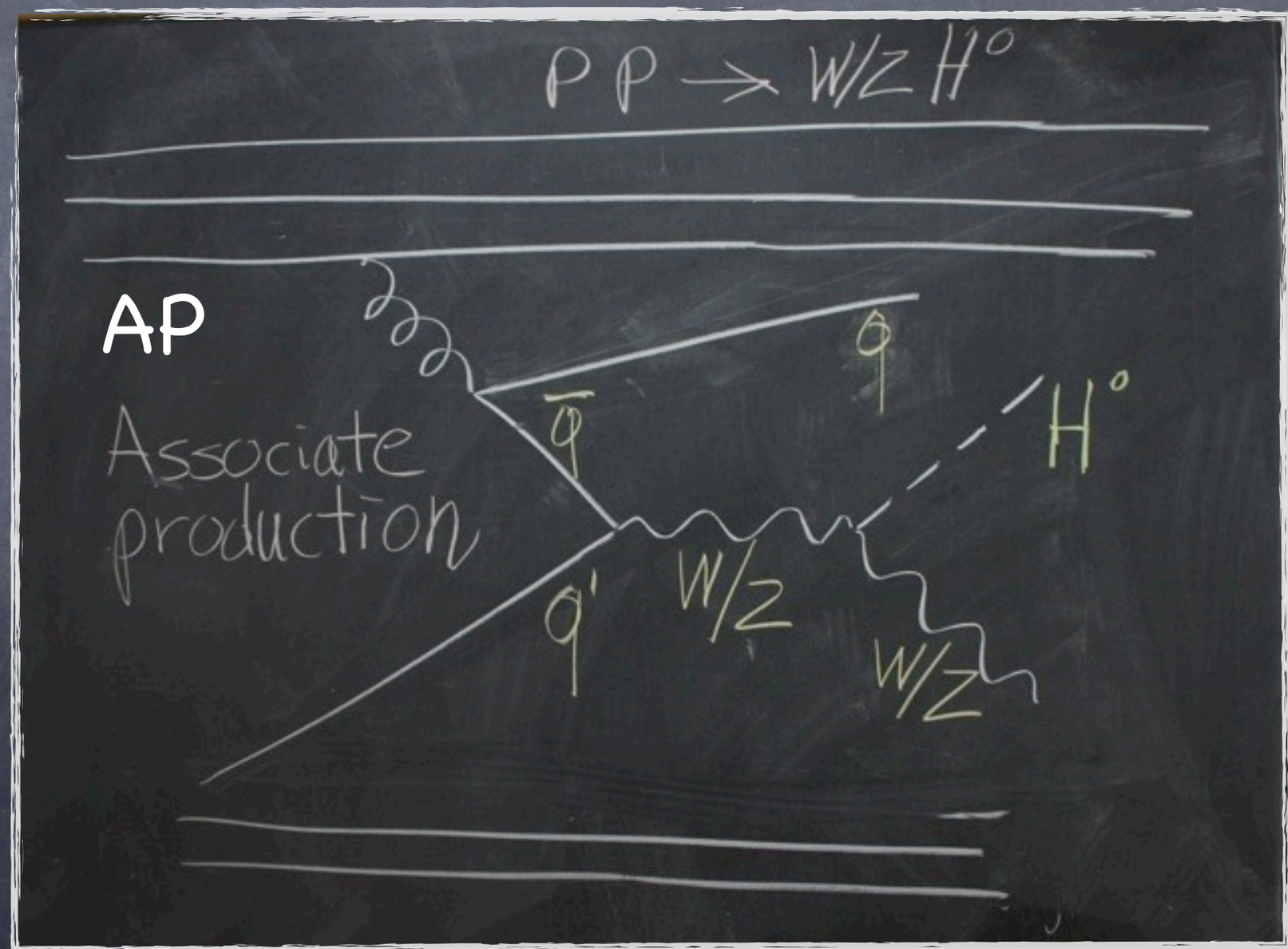

Higgs Production @ the LHC

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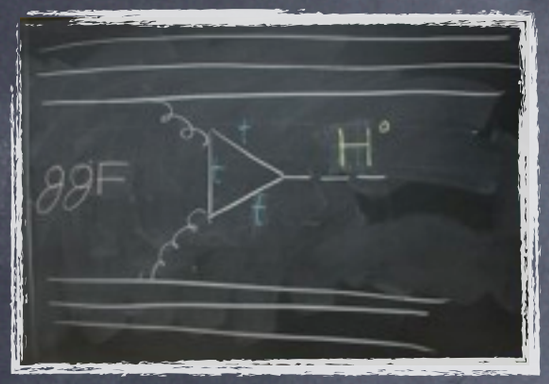
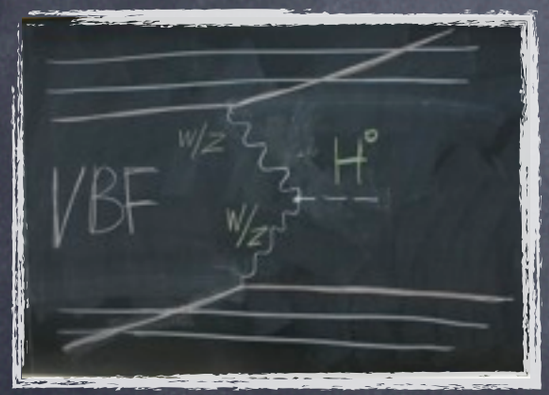
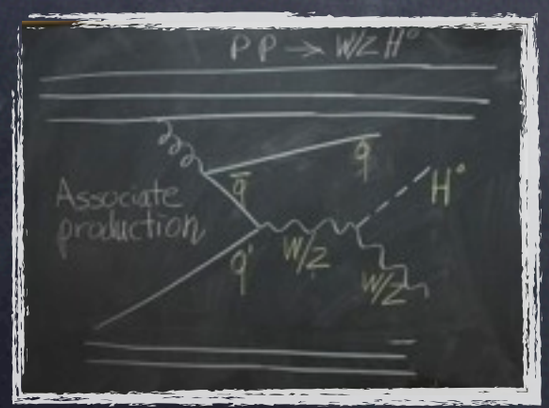
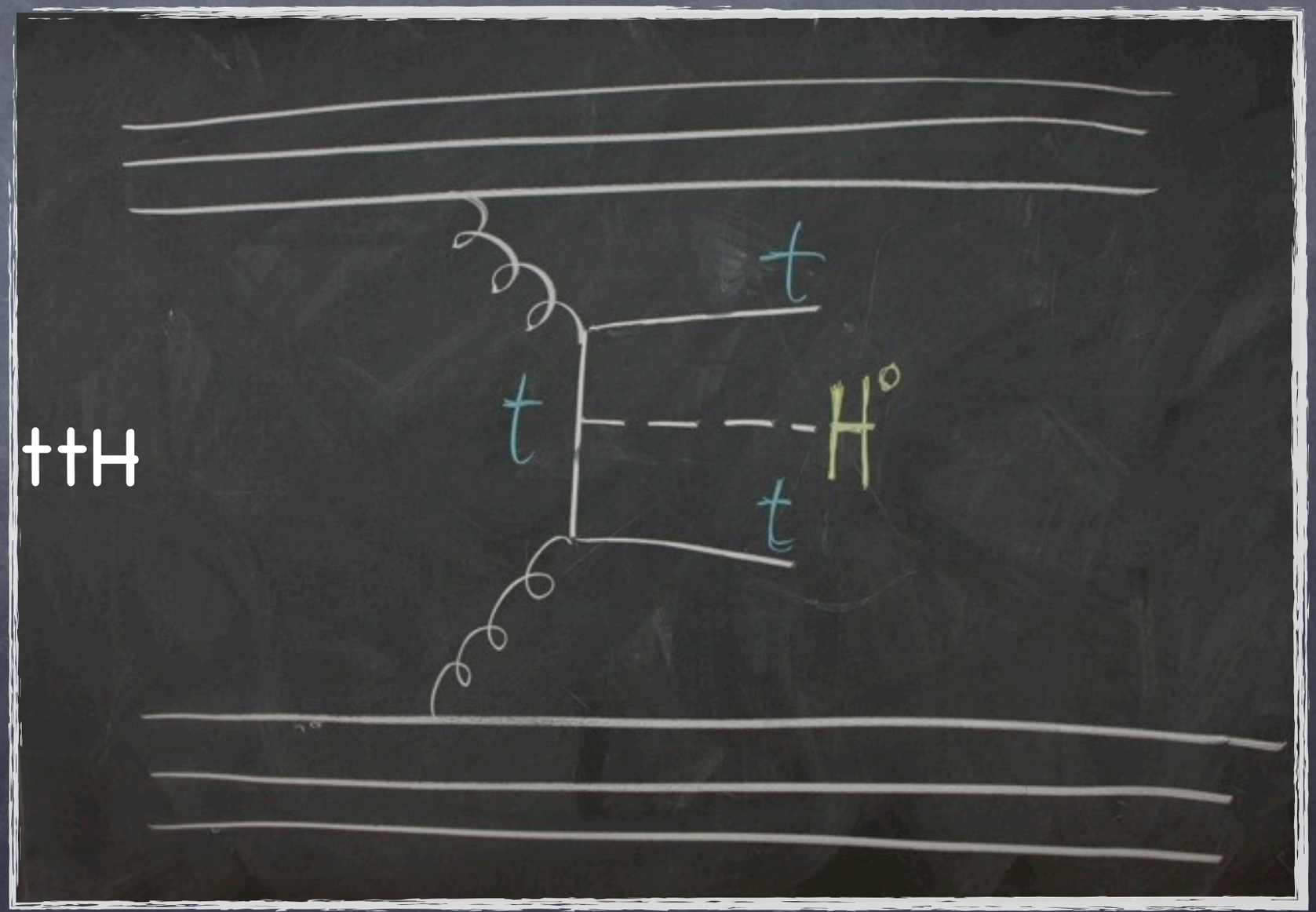


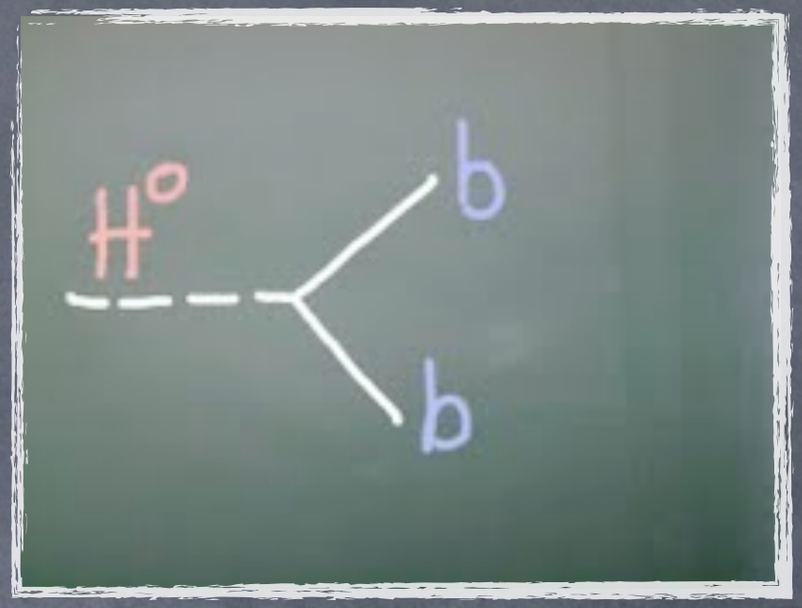


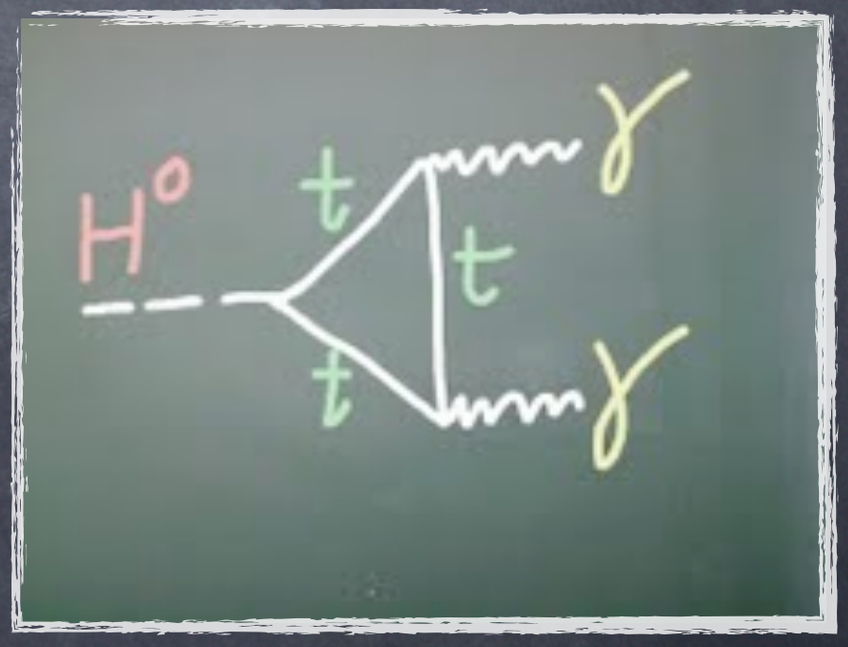




Higgs Decay Modes

- The Higgs Boson decays to the heaviest kinematically available particles pair
- A light Higgs (mH~125 GeV) decays to $\tau\ \tau$ and mainly to a pair of bottom Quarks (bb)
- But H->bb is hard to detect or trigger on (unless produced in association with a W or a Z)
- Leptons (electrons or muons) and photons are easy to trigger on and detect.
- Though BR(H->gamma gamma)~10^{-3}, H->gamma gamma is the favorite channel for a Higgs with mH~110-130

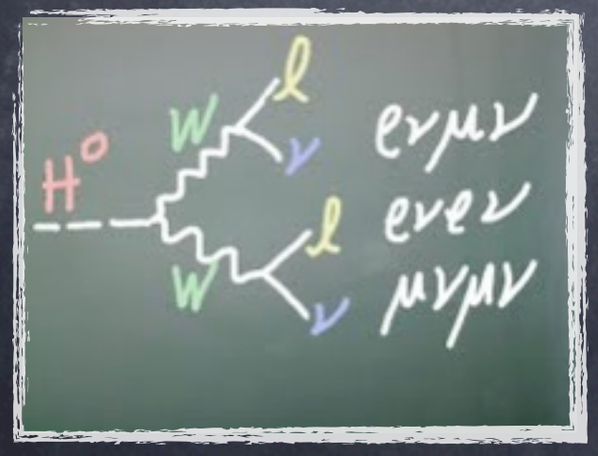


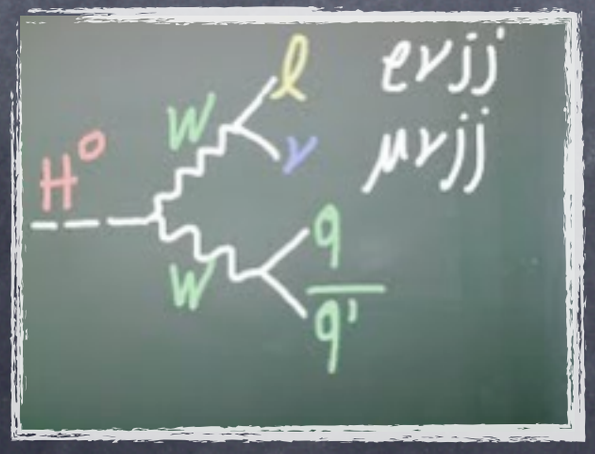


Higgs Decay Modes

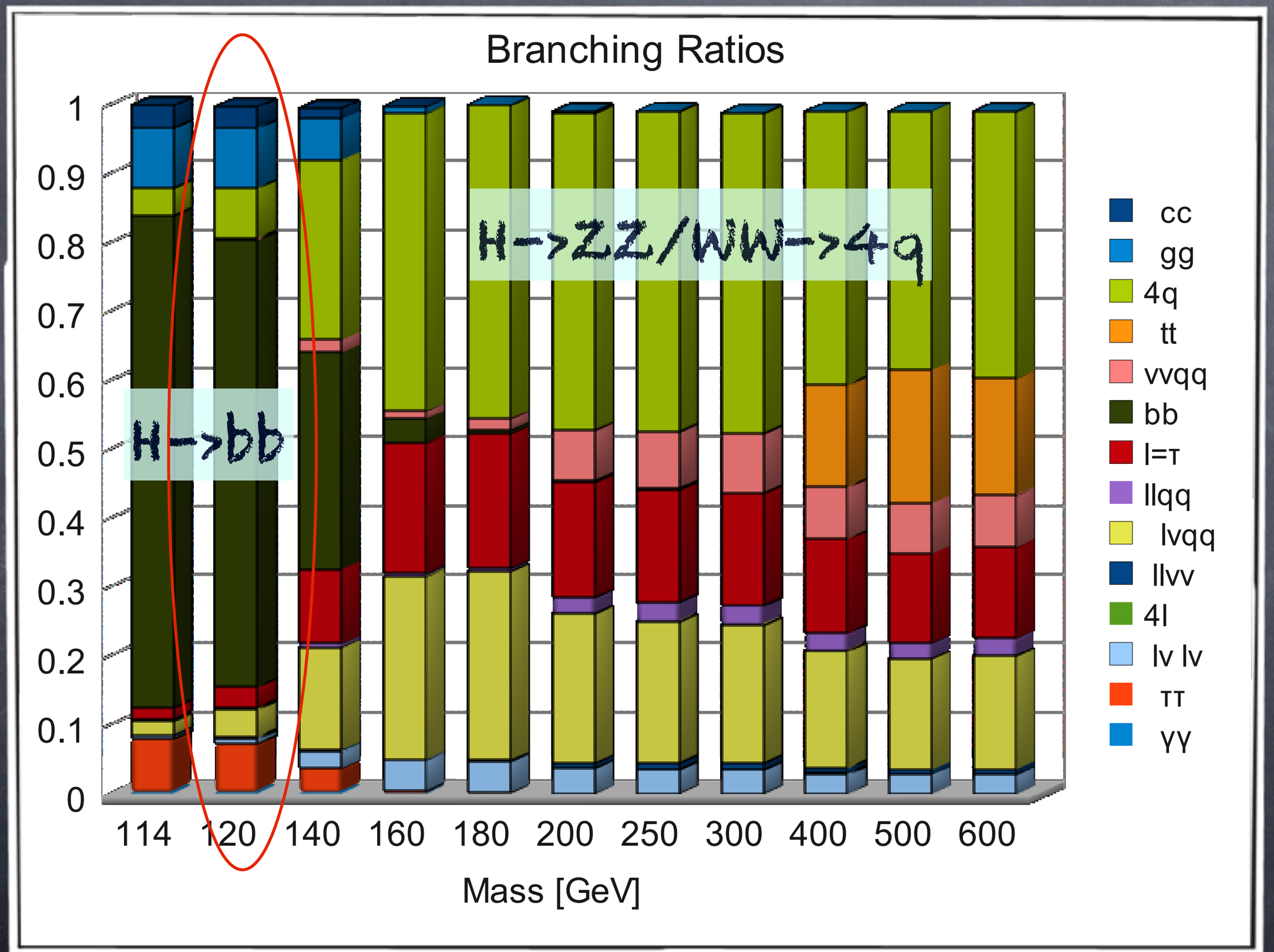
- Once the Z and W channels are open (mH>120) it decays to ZZ* and WW*
- The Higgs decay modes are classified according to the decays of the daughter bosons, thus the main decay modes are
- the golden channel 4l=4 leptons

- and other WW or ZZ channels

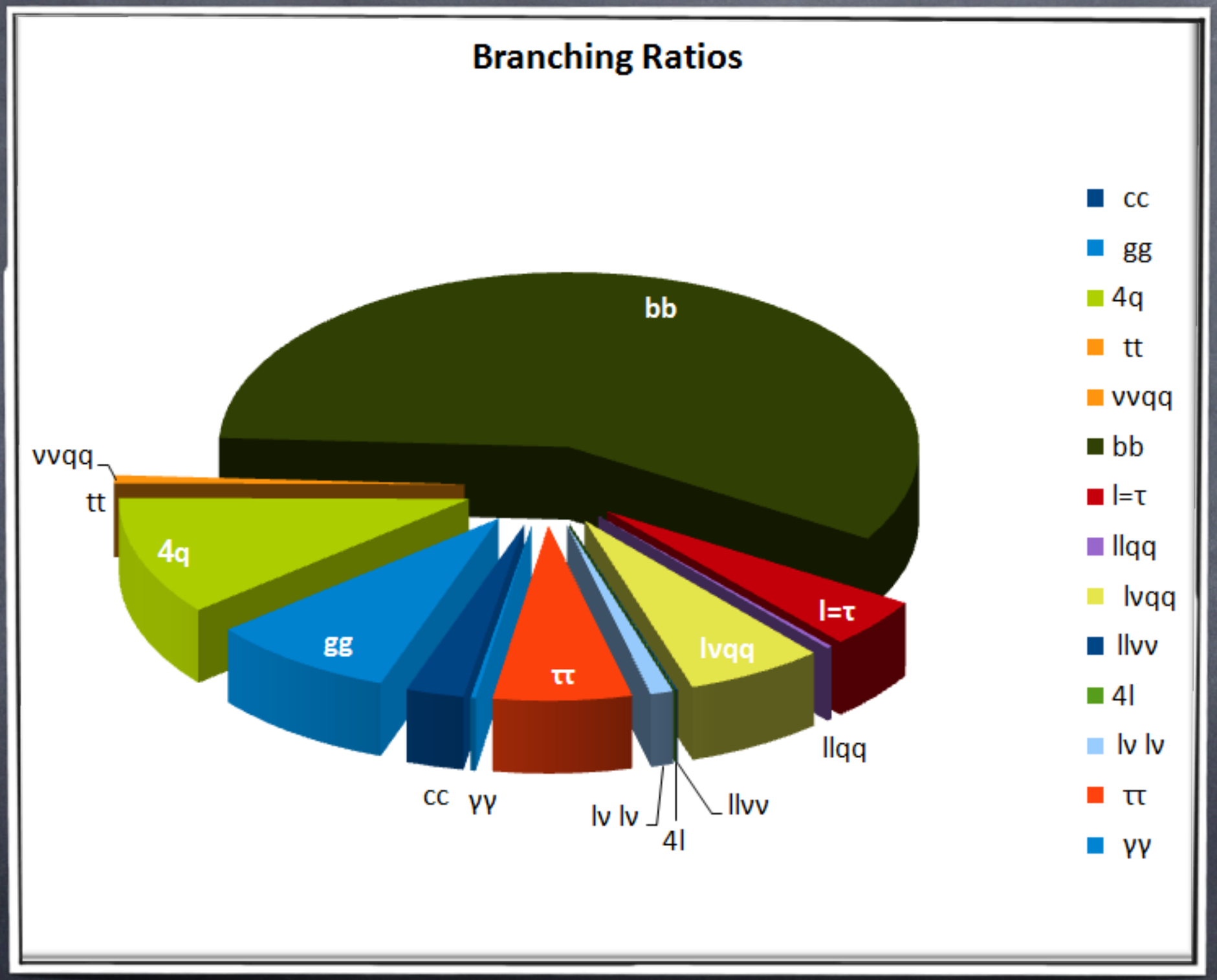




Higgs Decay Rates

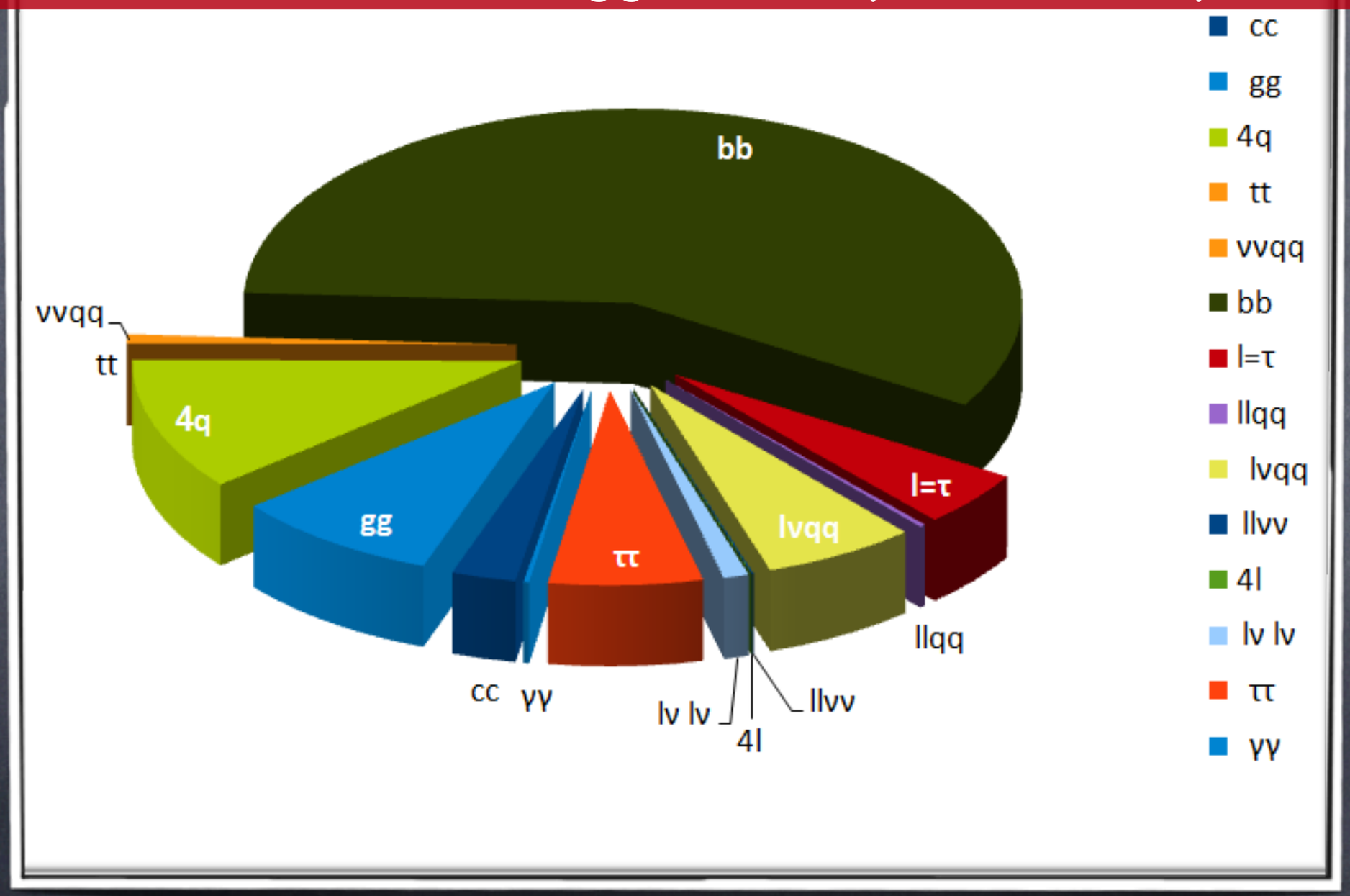


m_H=125 GeV


Branching Ratios
bb
vvqq
tt
4q
gg
cc
γγ
ττ
lv lv
4l
llvv
lvqq
llqq
l=τ
cc
gg
4q
tt
vvqq
bb
l=τ
llqq
lvqq
llvv
4l
lv lv
ττ
γγ

m_H=125 GeV

- For a channel to be usable, we must be able to trigger it
- Most efficient and clean triggers are photon or lepton based



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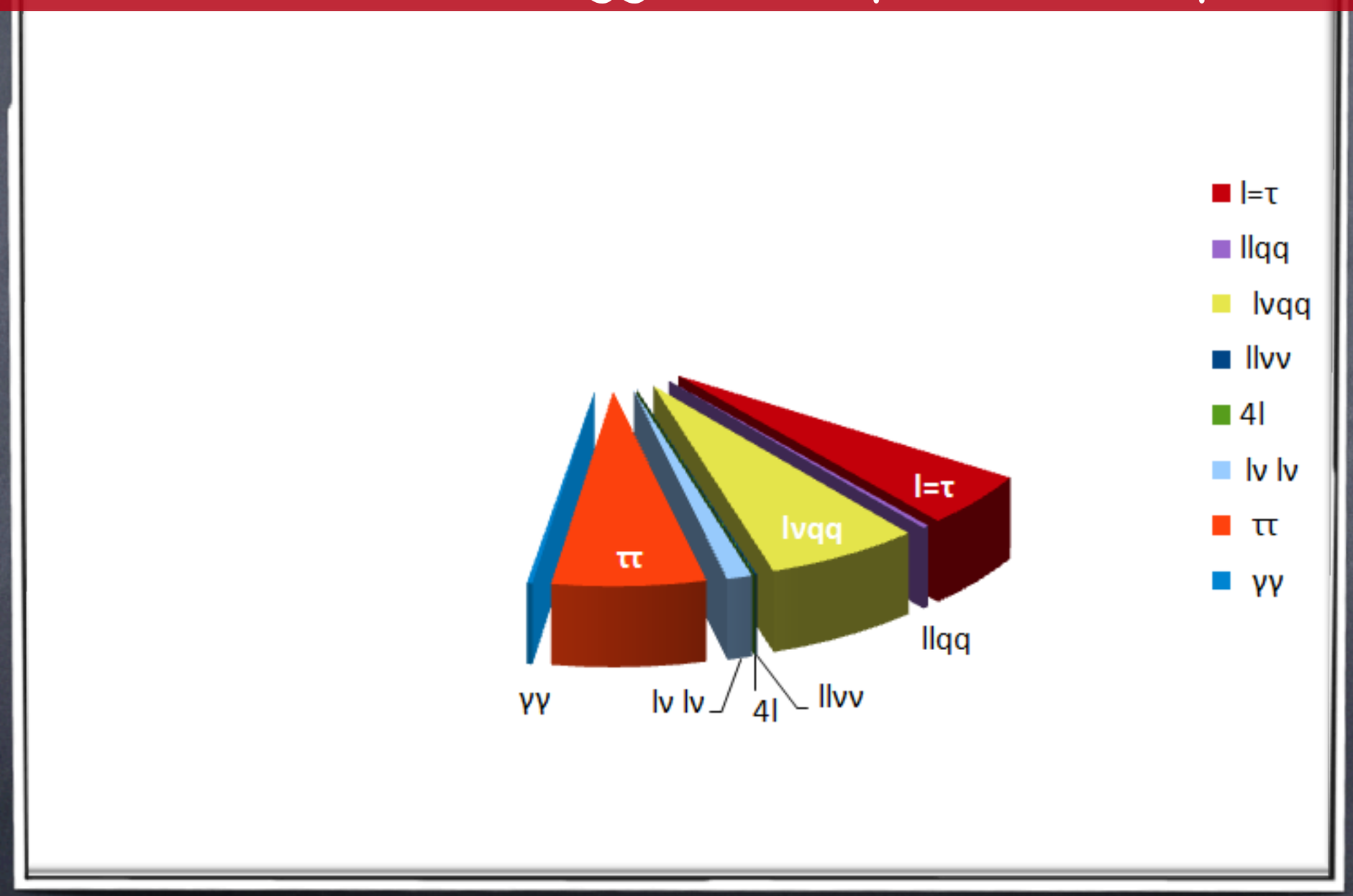
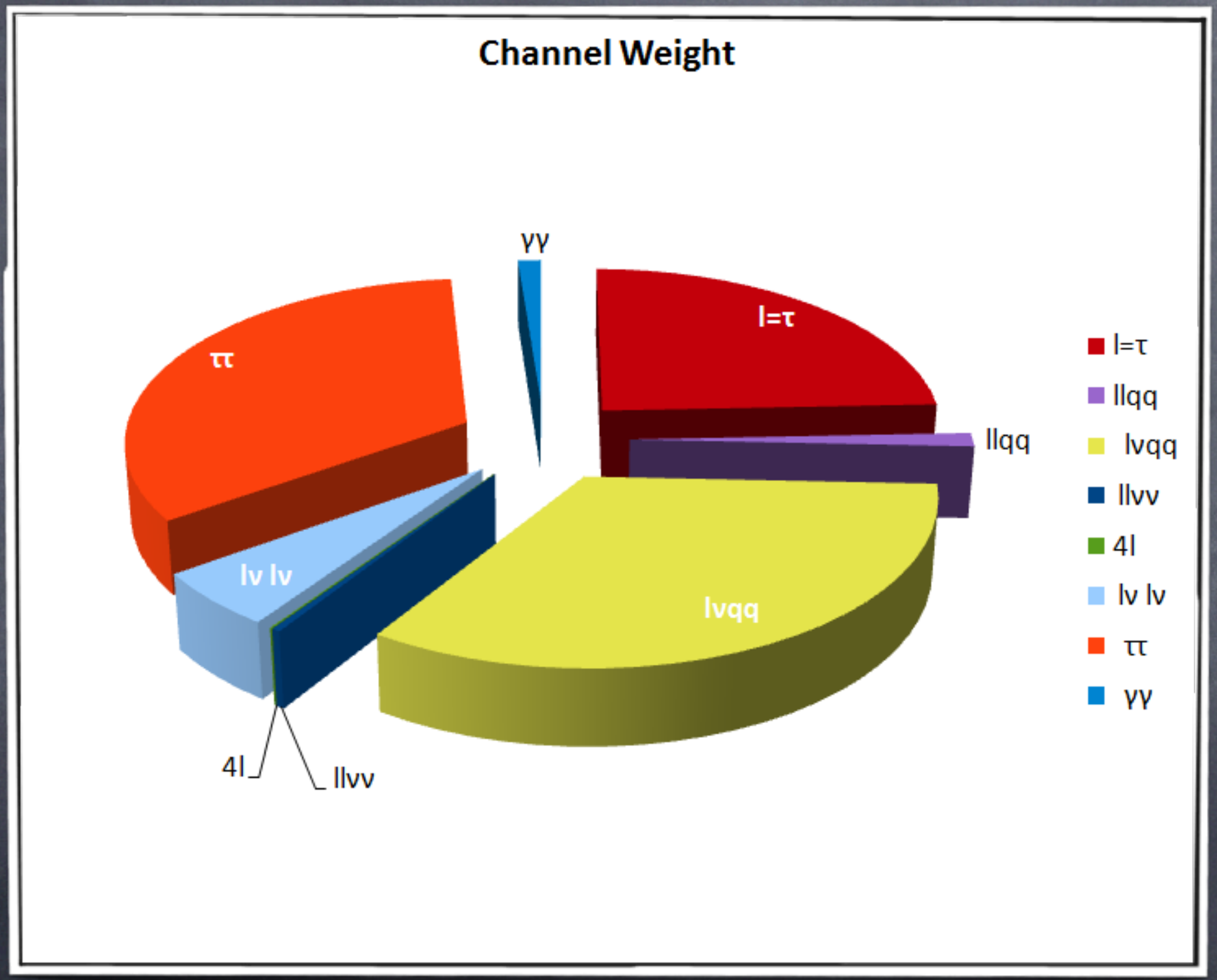
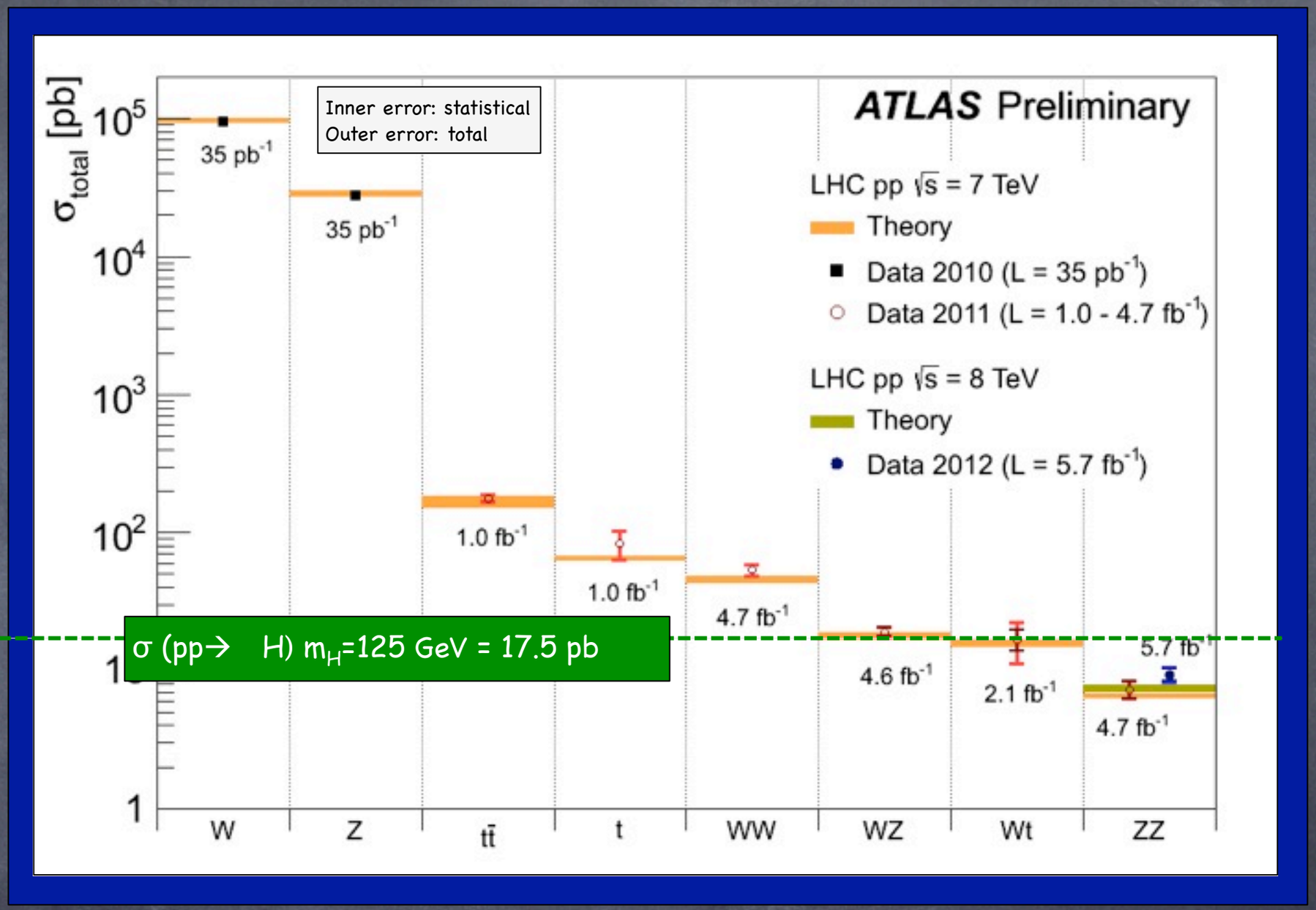


m_H=125 GeV Normalized Usable BRs



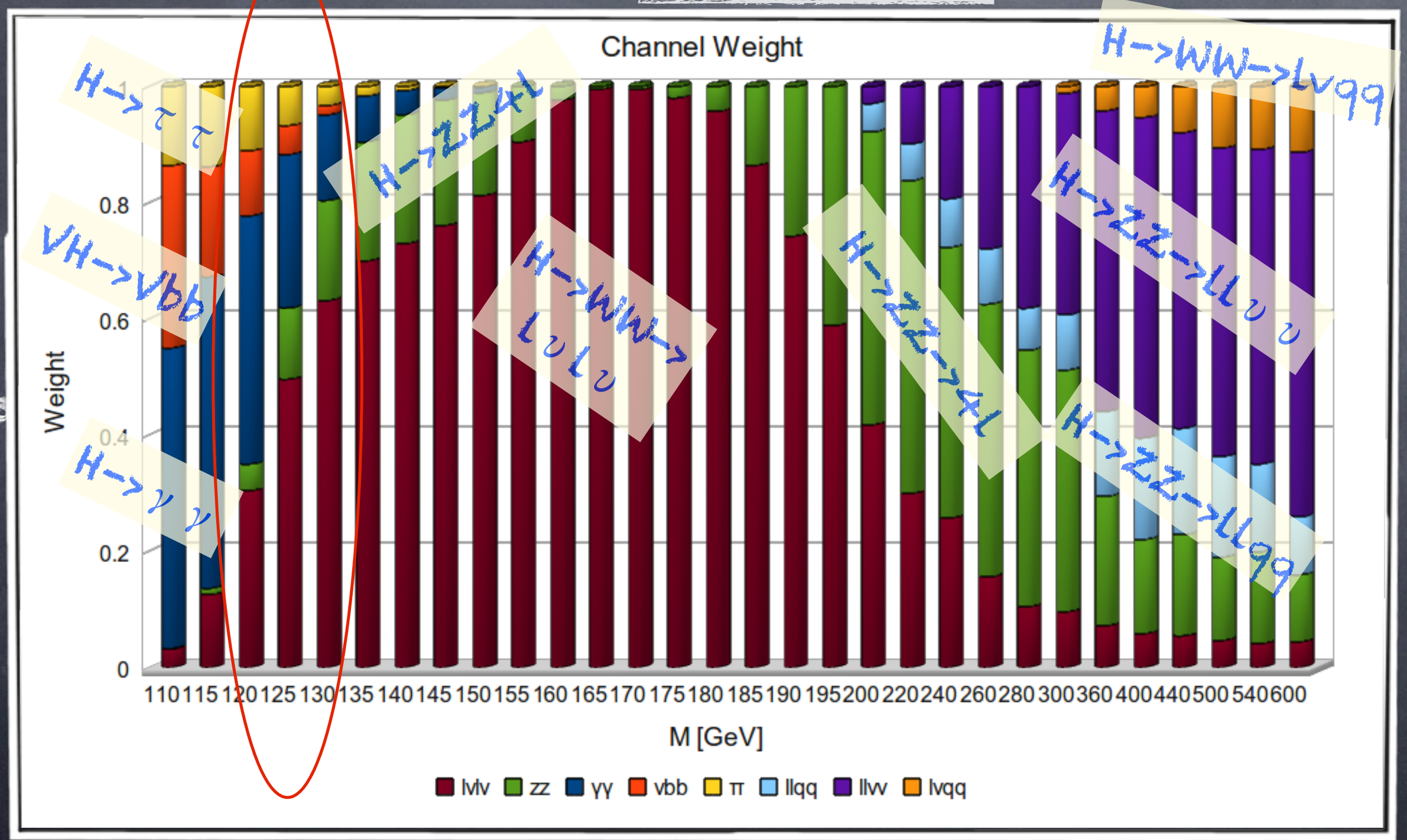
Electroweak measurements are **Higgs backgrounds**



- Good agreement with theory , W, Z, tt become a challenge for theory
- Systematics dominate
- Higgs cross section same order of magnitude as Di-Boson production (WW,WZ,ZZ)

m_H=125 GeV

$$w_i \simeq \frac{\left(s_i / \sqrt{s_i + b_i}\right)^2}{\sum_i \left(s_i / \sqrt{s_i + b_i}\right)^2}$$



m_H=125 GeV Channels Weight

$$w_i \simeq \frac{\left(s_i / \sqrt{s_i + b_i}\right)^2}{\sum_i \left(s_i / \sqrt{s_i + b_i}\right)^2}$$

- Probing mH=125 GeV
- Probing channels:

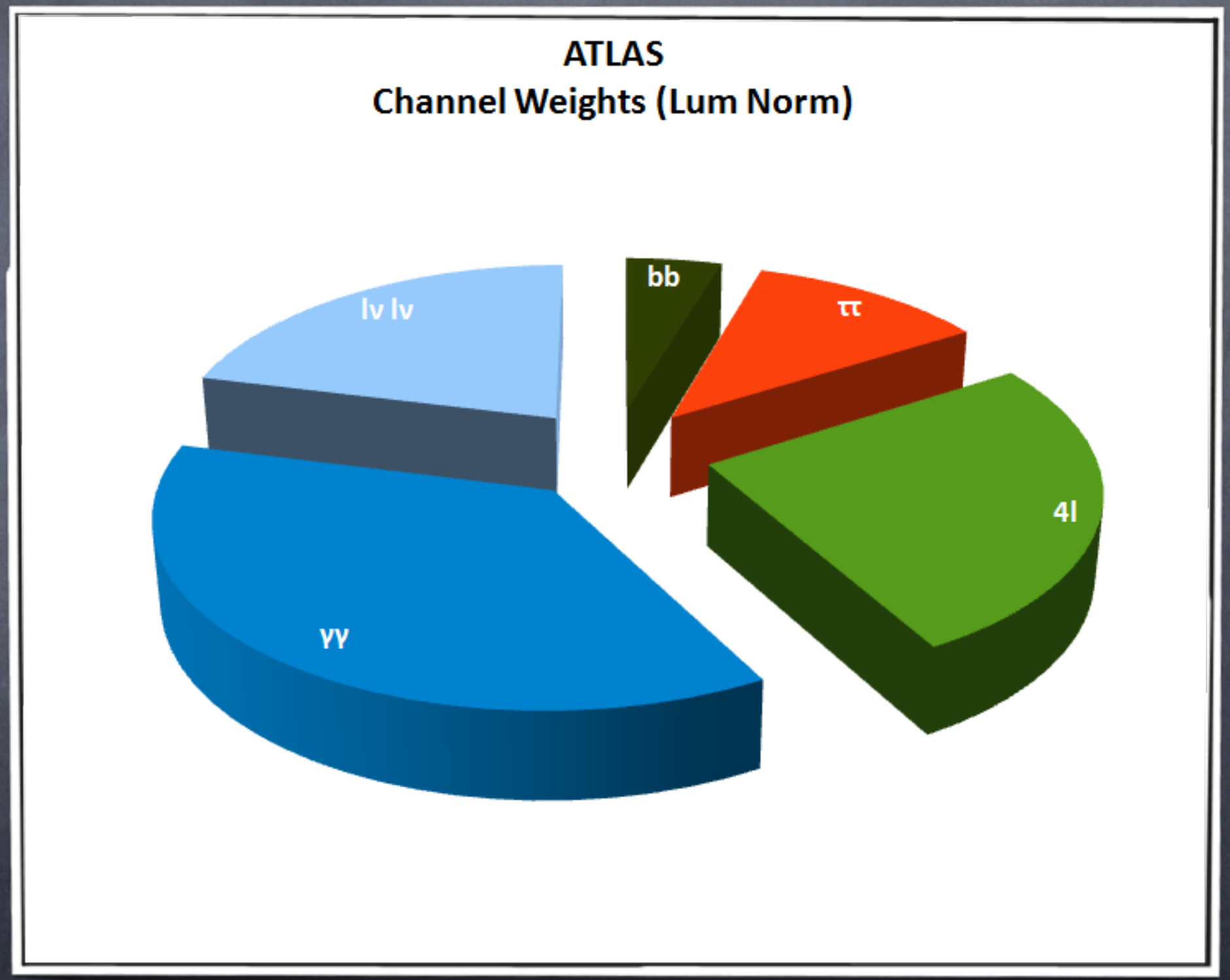
H-> γ γ

H->4l

H->WW->lvlv

VH-> Vbb,

H-> τ τ



H->γγ Probing LEP 114 GeV

$$w_i \simeq \frac{\left(s_i / \sqrt{s_i + b_i}\right)^2}{\sum_i \left(s_i / \sqrt{s_i + b_i}\right)^2}$$

- Probing mH=125 GeV
- Probing channels:

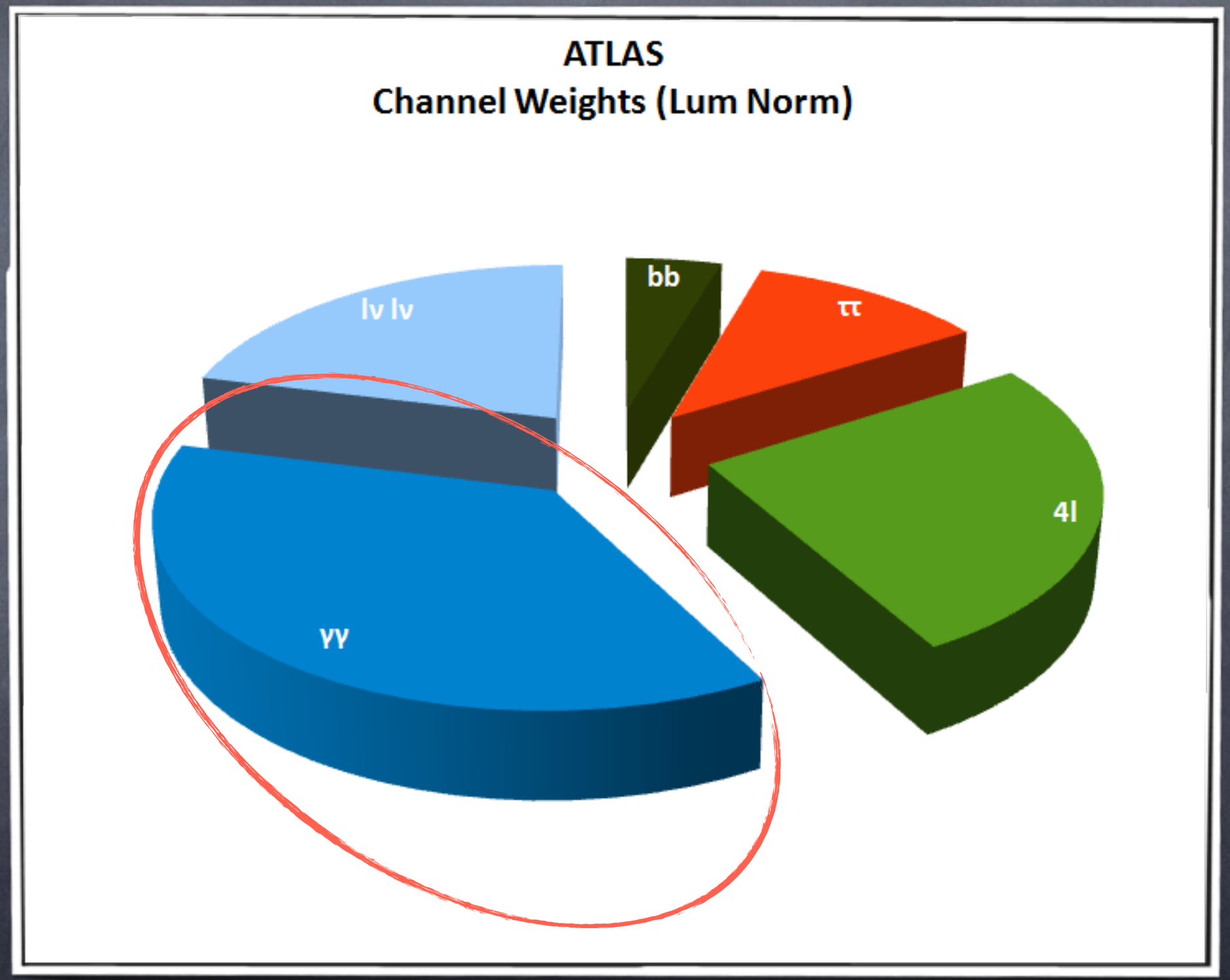
H-> γ γ

H->4l

H->WW->lvlv

VH-> Vbb,

H-> τ τ



H->γγ Probing LEP 114 GeV

Clean signature: 2 energetic isolated photons->narrow mass peak

E^T (γ 1, γ 2) > 40, 30 GeV

A narrow peak is searched for over a large, smooth background.

Data are split into 9+1(VBF) categories based on direction of photons (detector region) , conversion mode (which affect γ γ mass resolution, which is excellent)
and $p^T_{\gamma\gamma}$ perpendicular to γ γ thrust axis

A fit is performed to the background side band under the BG only hypothesis (an exponential or polynomial carefully chosen to avoid bias in EACH category) (only data is considered)

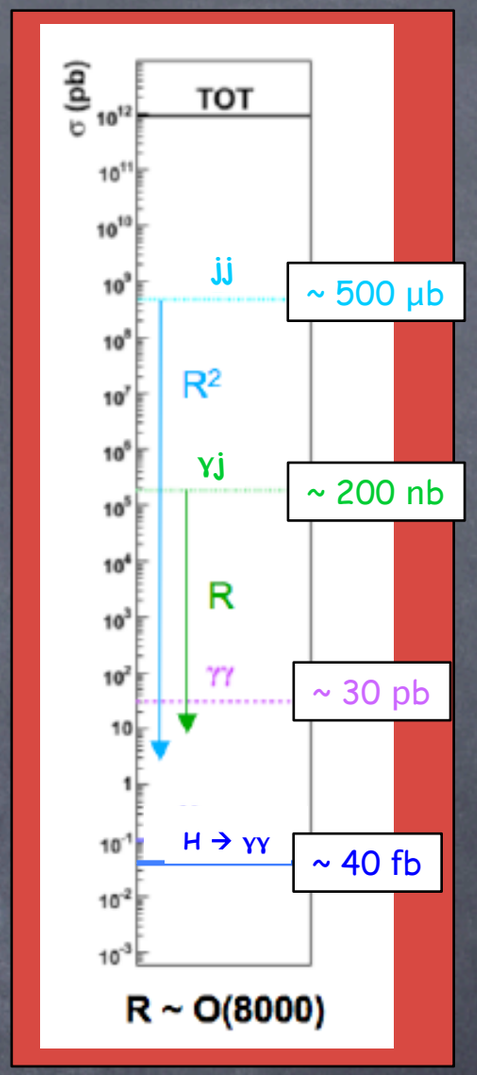
H->γγ Experimental Aspects

.Needs a powerful γ /jet separation to

suppress γ j and jj background

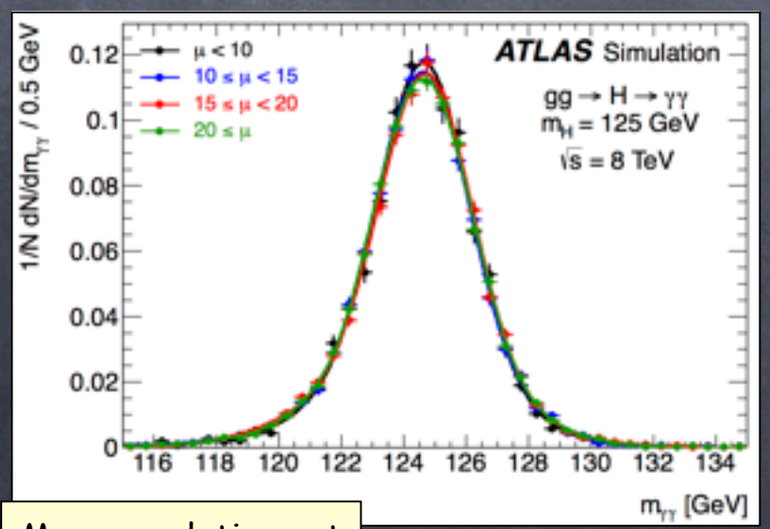
with jet -> π^0 faking single γ

$$m^2_{\gamma_1\gamma_2} = 2E_{\gamma_1}E_{\gamma_2}\left(1 - cos\measuredangle(\gamma_1,\gamma_2)\right)$$

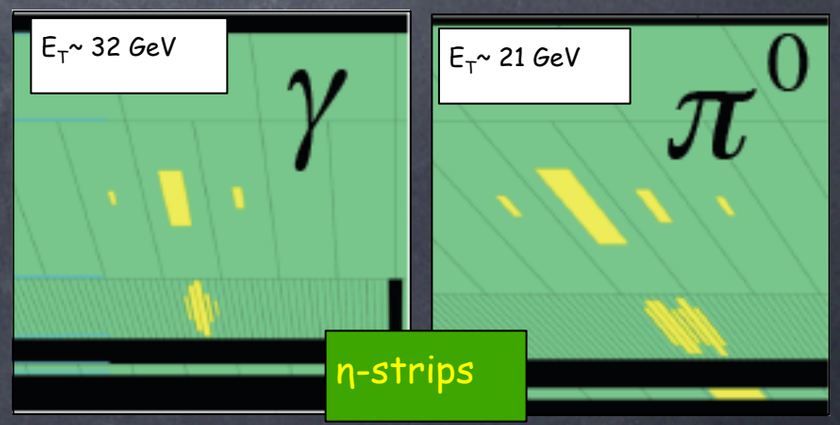


The fine longitudinal and lateral segmentation and pointing geometry of the ATLAS EM calorimeter enable good γγ angular separation and better Z-vertex determination. This is crucial in high pile up environment and in identifying fake photons from pions

Present understanding of calorimeter
E response (from tag&probe Z->ee, J/ψ ->ee, W->eν data and MC)->
Excellent mass resolution

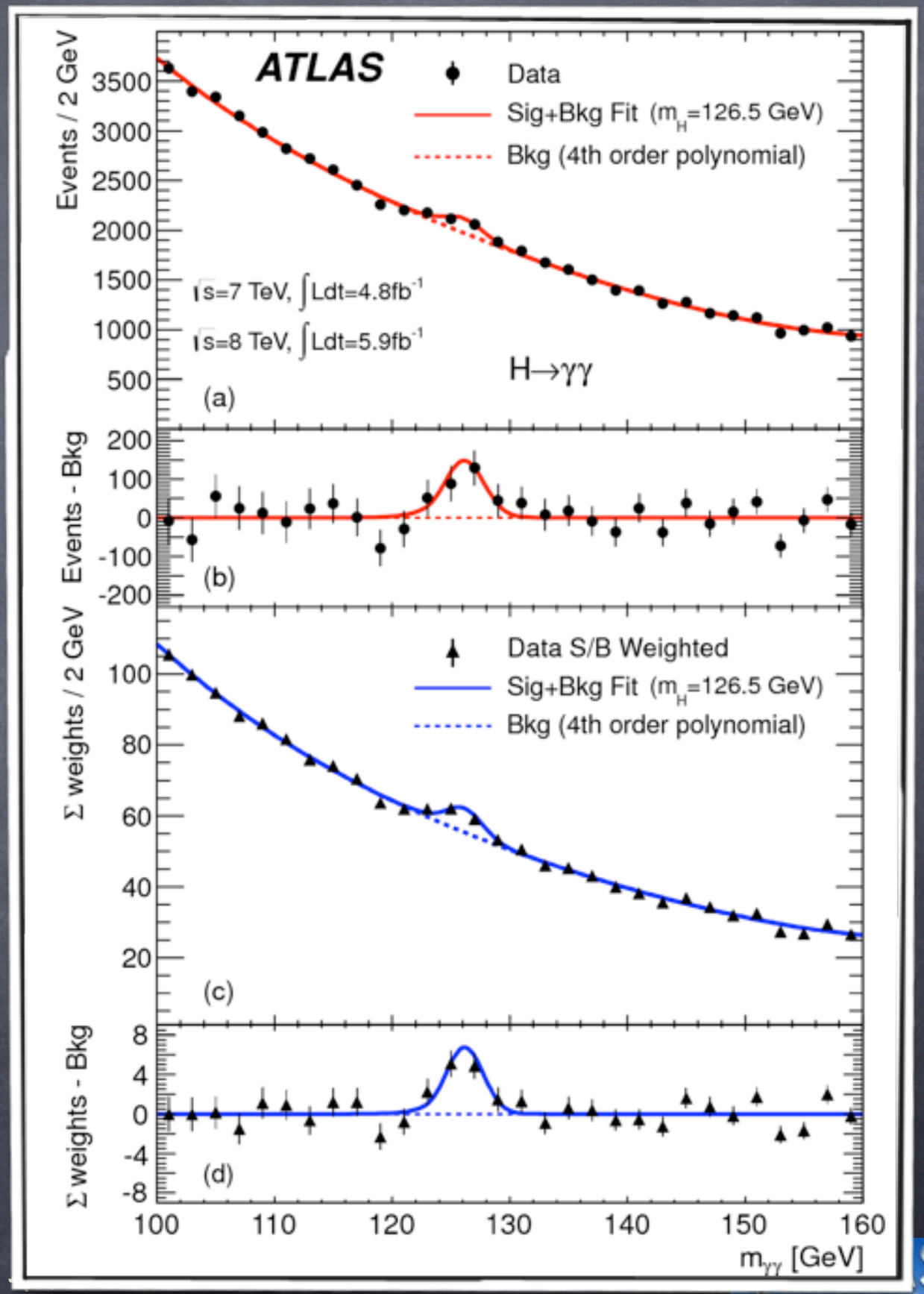


Mass resolution not affected by pile-up



H->γγ Results

- $m_{\gamma\gamma}$ was fit (per category) with exponential or polynomials functions for background plus a sum of Crystal Ball and Gaussian (for tails) for signal.
- Background was fitted from data
- ~170 signal events are expected in 10 fb^{-1} for m_H=126 GeV
- ~6340 expected in m_H=125 GeV mass window -> S/B~3% in signal mass window (20% in VBF)



Exclusion: CLs

$$\mu = \frac{\sigma}{\sigma_{SM}(m_H)}$$

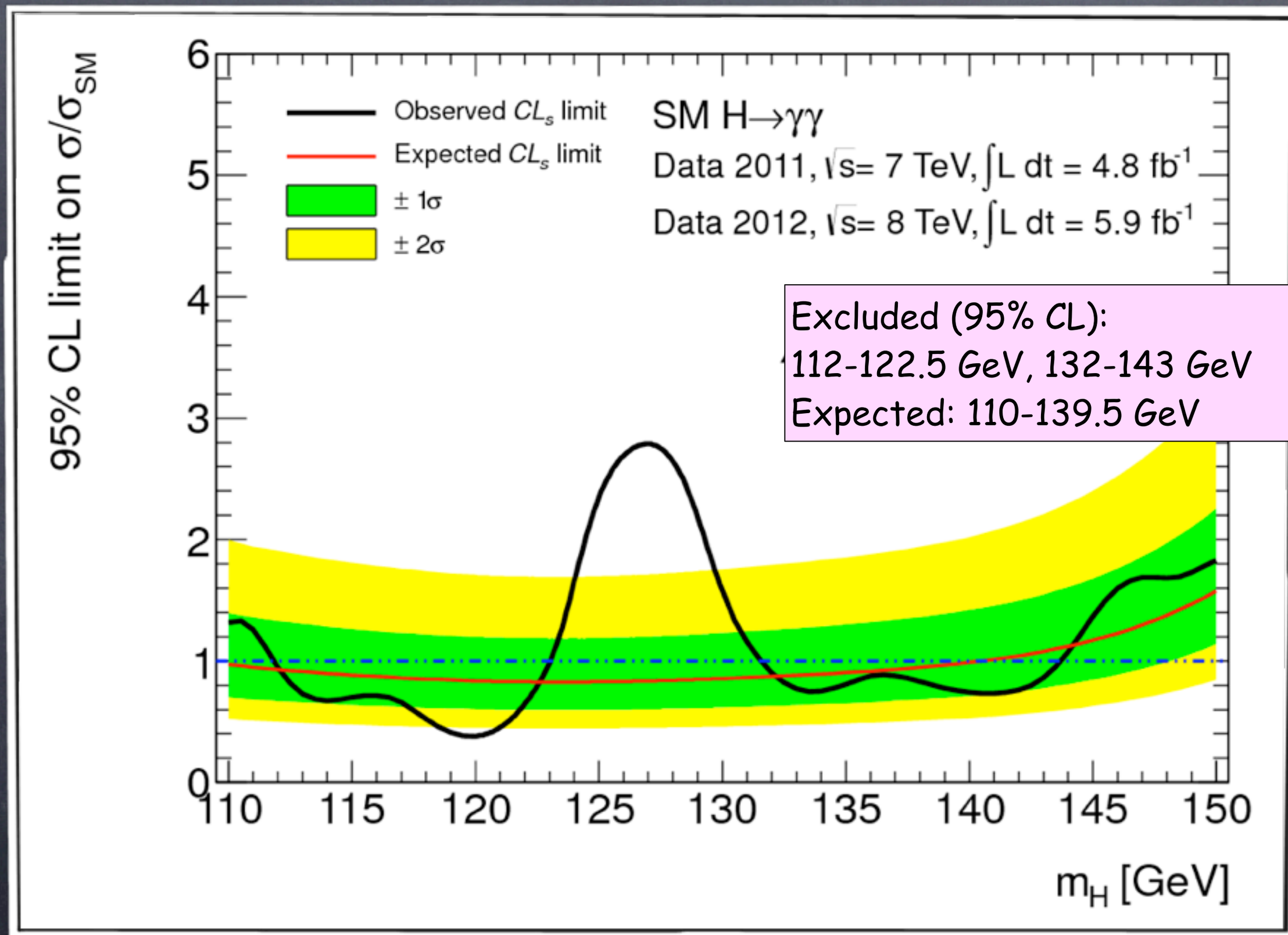
->CLs measures the compatibility of the data with the signal hypothesis.

->If CLs<5% the signal hypothesis is excluded at the 95% CL

-> μ_{up} is the signal strength for which CLs=5%

-> If $\mu_{up}<1$ => $\sigma(m_H)<\sigma_{SM}$

=>m_H is excluded at the 95% Confidence Level



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

Discovery: p_0

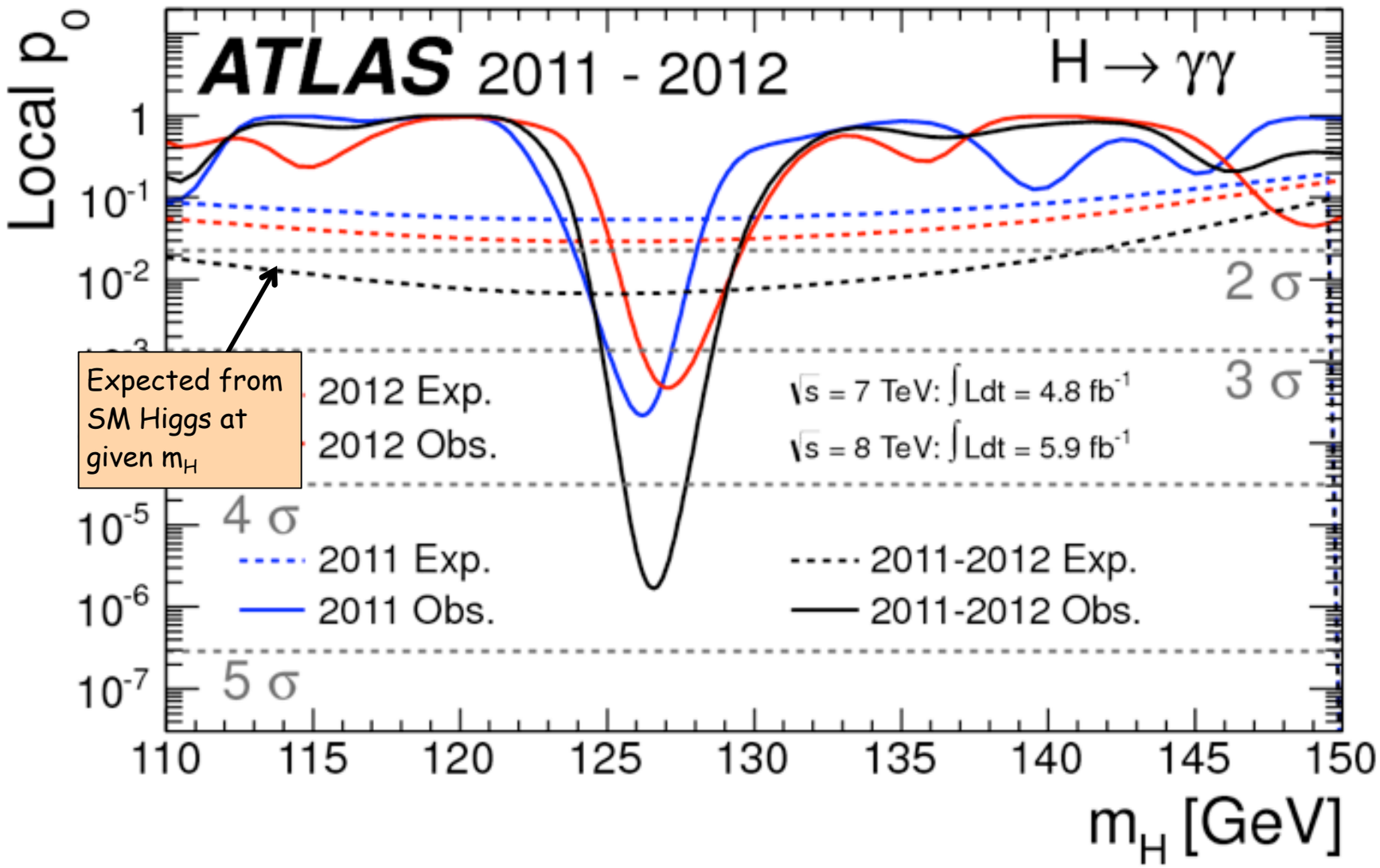
$$q_0 = -2\log\frac{max_{\{b\}}L(b)}{max_{\{\mu,b\}}L(\mu s(m_H)+b)}$$

->p_0 measures the compatibility of the data with the NO-HIGGS hypothesis.

->If p_0=0.025 the NO-HIGGS hypothesis is rejected at the 2σ level

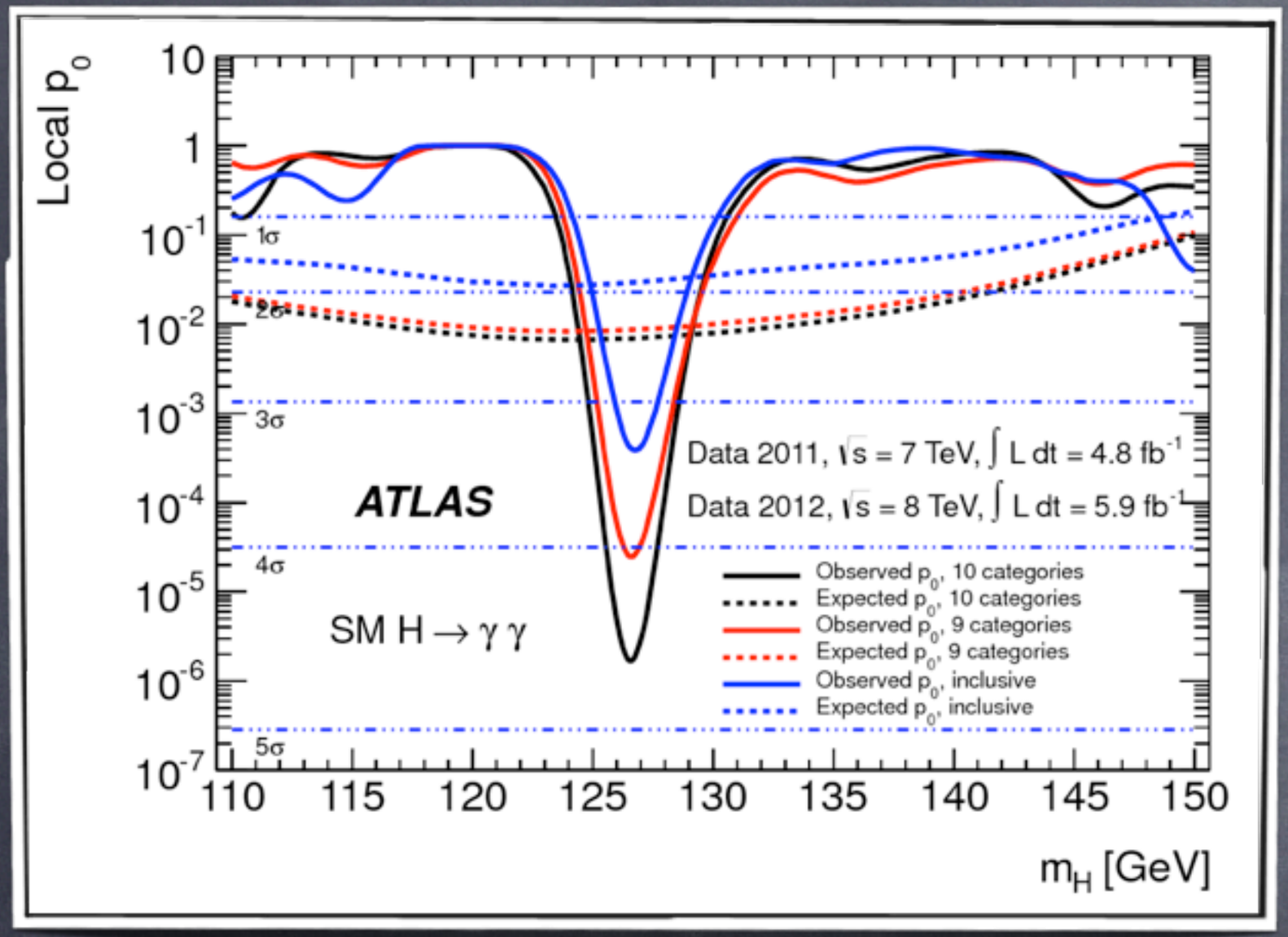
$$p_0 = Prob(q_0 > q_0^{obs} \mid H_0)$$

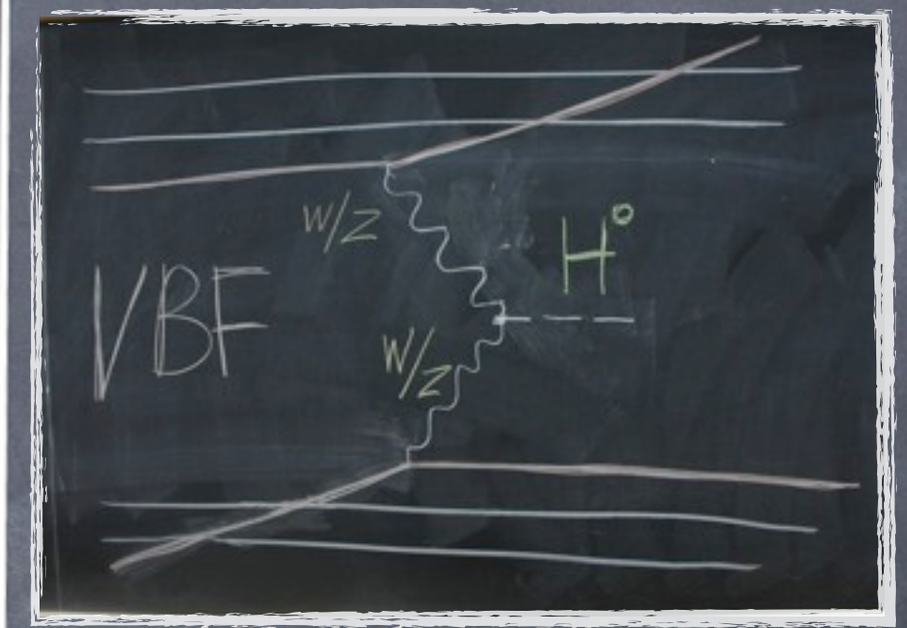
Consistency of data with background-only expectation



Data sample	m_H of max deviation	local p-value	local significance	expected from SM Higgs
2011	126 GeV	3×10^{-4}	3.5 σ	1.6 σ
2012	127 GeV	3×10^{-4}	3.4 σ	1.9 σ
2011+2012	126.5 GeV	2×10^{-6}	4.5 σ	2.4 σ

Global 2011+2012 (including LEE over 110-150 GeV range): 3.6 σ





2jet/VBF category brings ~ 3% gain in expected sensitivity; observed gains in data are 10-15% (both years):

→ is this a fluctuation or something more fundamental ?

→ further studies needed (next step !)

Caveat: 2jet category affected by largest systematics (~ 40% on signal yield)

VBF

$m_{\gamma\gamma}$=126.9 GeV

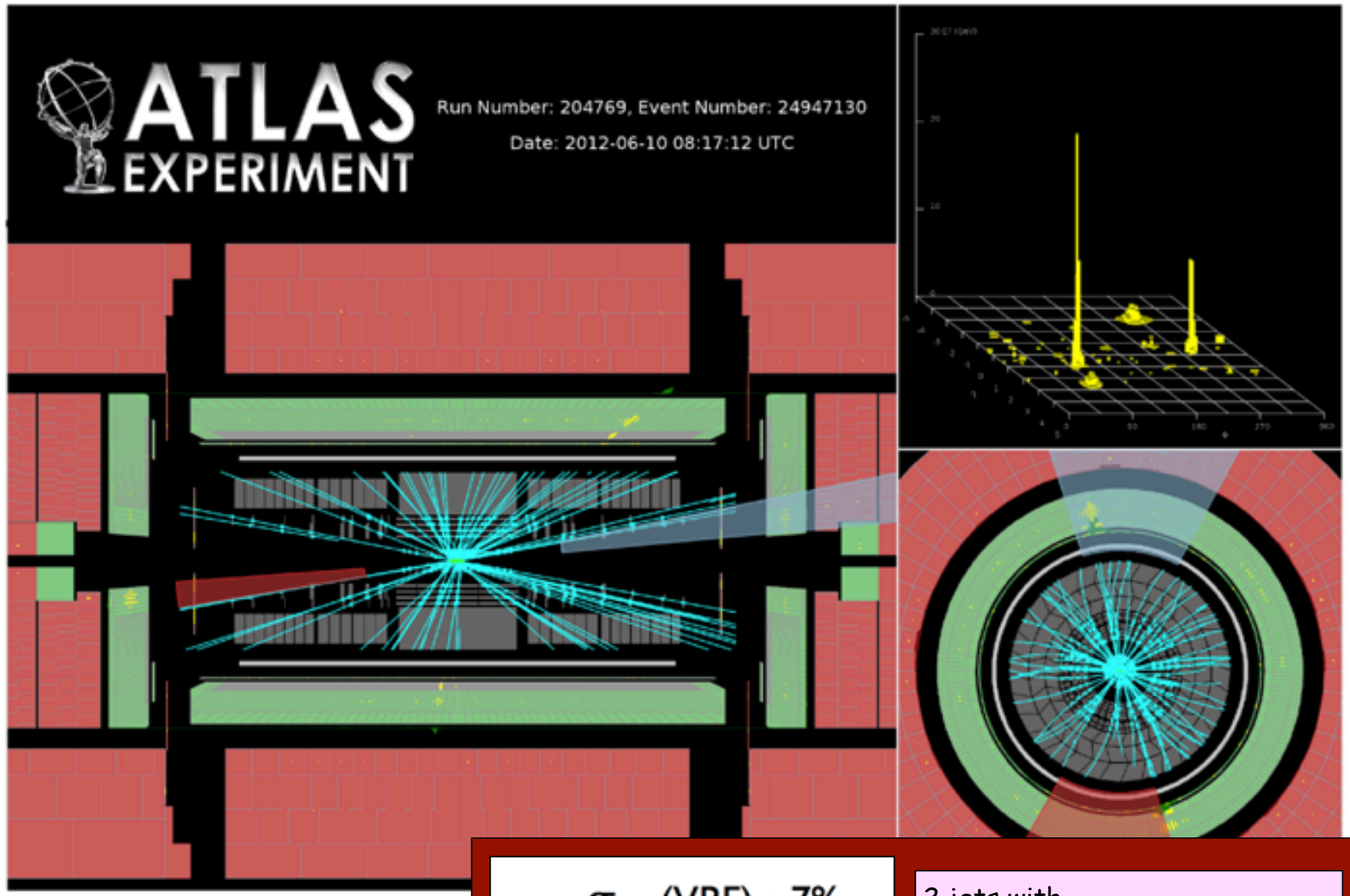
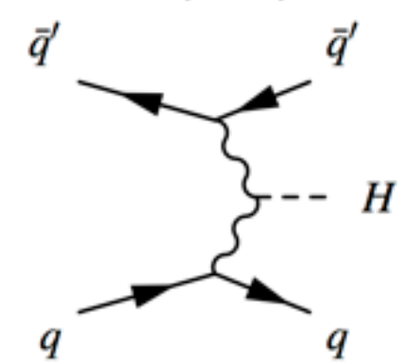


Figure 33: Event display of a diphot
converted. The event number is 249
leading photon has E_T=80.1 GeV an
The measured diphoton mass is 126.
respectively. The leading jet has E_T
η =2.7. The measured two-jets mass
the two-jets is 2.9. Only reconstructe
hits with a high threshold are shown.

σ_{SM} (VBF) ~7%



2 jets with
p_T > 25-30 GeV
$|\eta|$<4.5
$|\Delta\eta|_{jj}$ > 2.8
M_{jj} > 400 GeV
$|\Delta\varphi|$ ($\gamma\gamma$-jj) > 2.6

Expected gain in sensitivity: 3%

$m_{\gamma\gamma}$=126.9 GeV

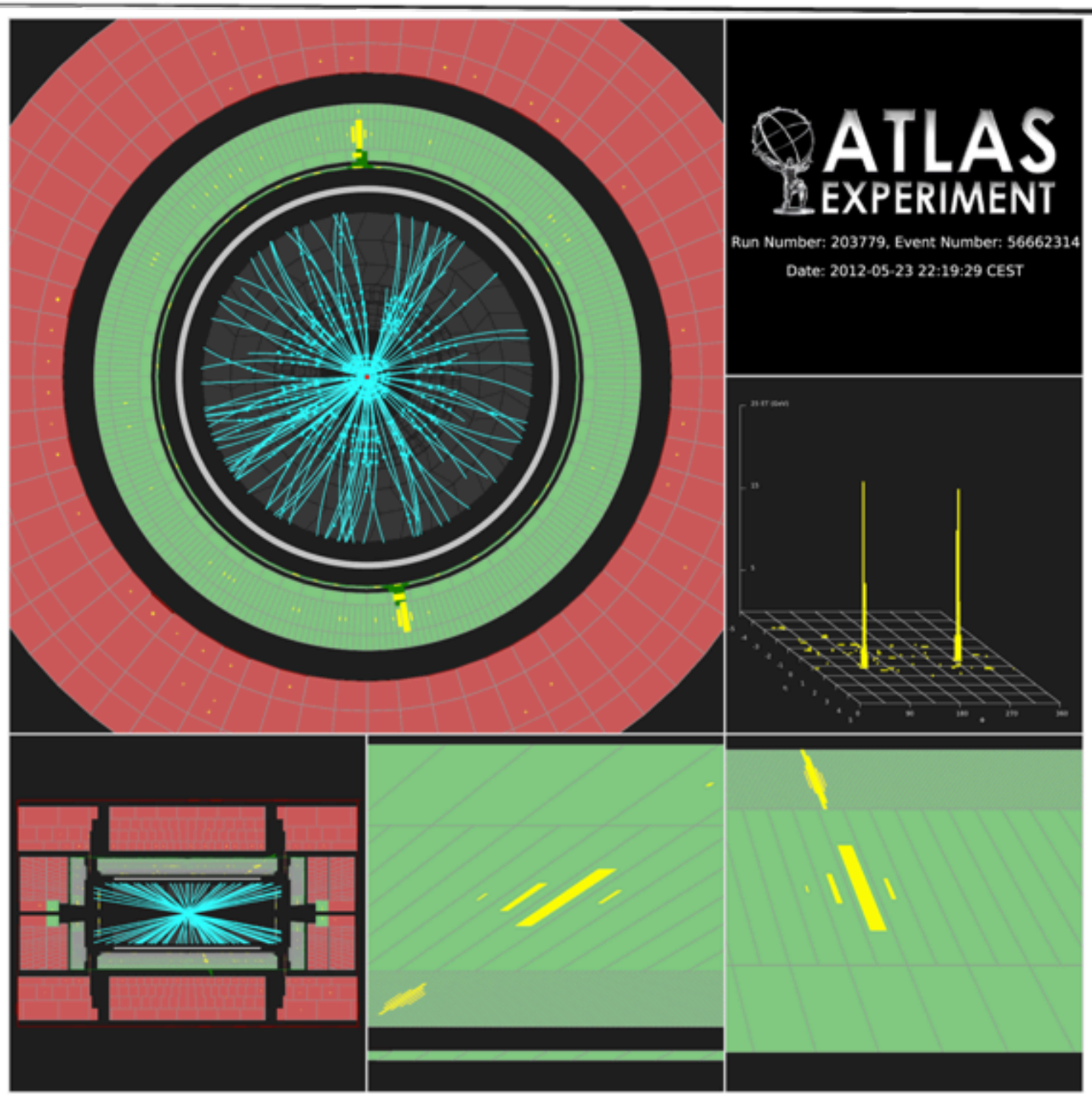


Figure 31: Event display of a diphoton event candidate where both photon candidates are unconverted. The event number is 56662314 and it was recorded during run 203779 at $\sqrt{s}$ = 8 TeV. The leading photon has E_T=62.2 GeV and η =0.39. The subleading photon has E_T=55.5 GeV and η =1.18. The measured diphoton mass is 126.9 GeV. The p_T and p_{Tt} of the diphoton are 9.3 GeV and 6.5 GeV, respectively. Only reconstructed tracks with p_T>1 GeV, hits in the pixel and SCT layers and TRT hits with a high threshold are shown.

$m_{\gamma\gamma}$=127.0 GeV

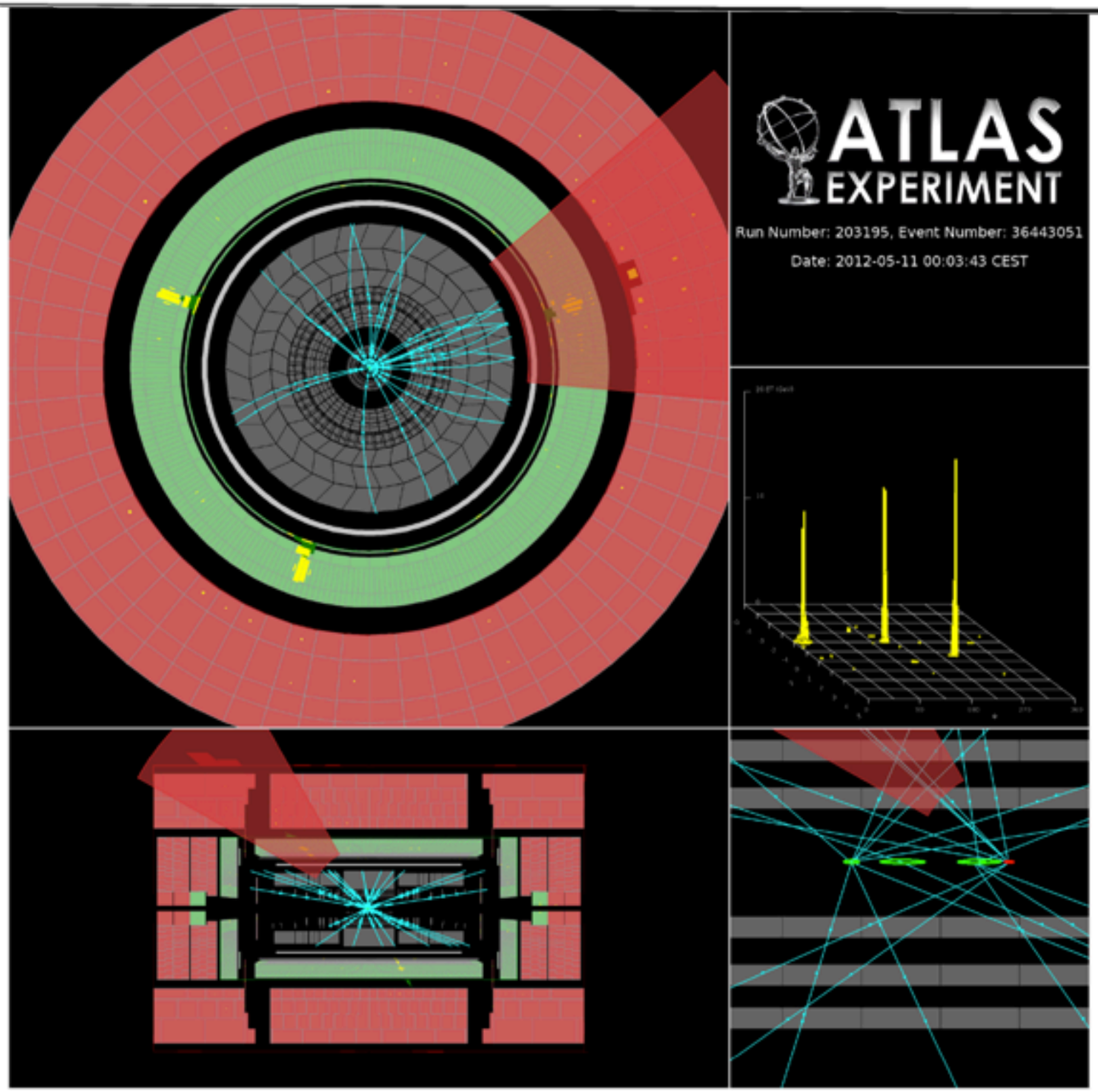


Figure 32: Event display of a diphoton with a jet event candidate where both photon candidates are unconverted. The event number is 36443051 and it was recorded during run 203195 at $\sqrt{s}$ = 8 TeV. The leading photon has E_T=63.0 GeV and η =0.50. The subleading photon has E_T=56.1 GeV and η = −0.96. The measured diphoton mass is 127.0 GeV. The p_T and p_{Tt} of the diphoton are 83.9 GeV and 83.3 GeV, respectively. The jet has E_T=113 GeV and η = −0.9. Only reconstructed tracks with p_T>1 GeV, hits in the pixel and SCT layers and TRT hits with a high threshold are shown.

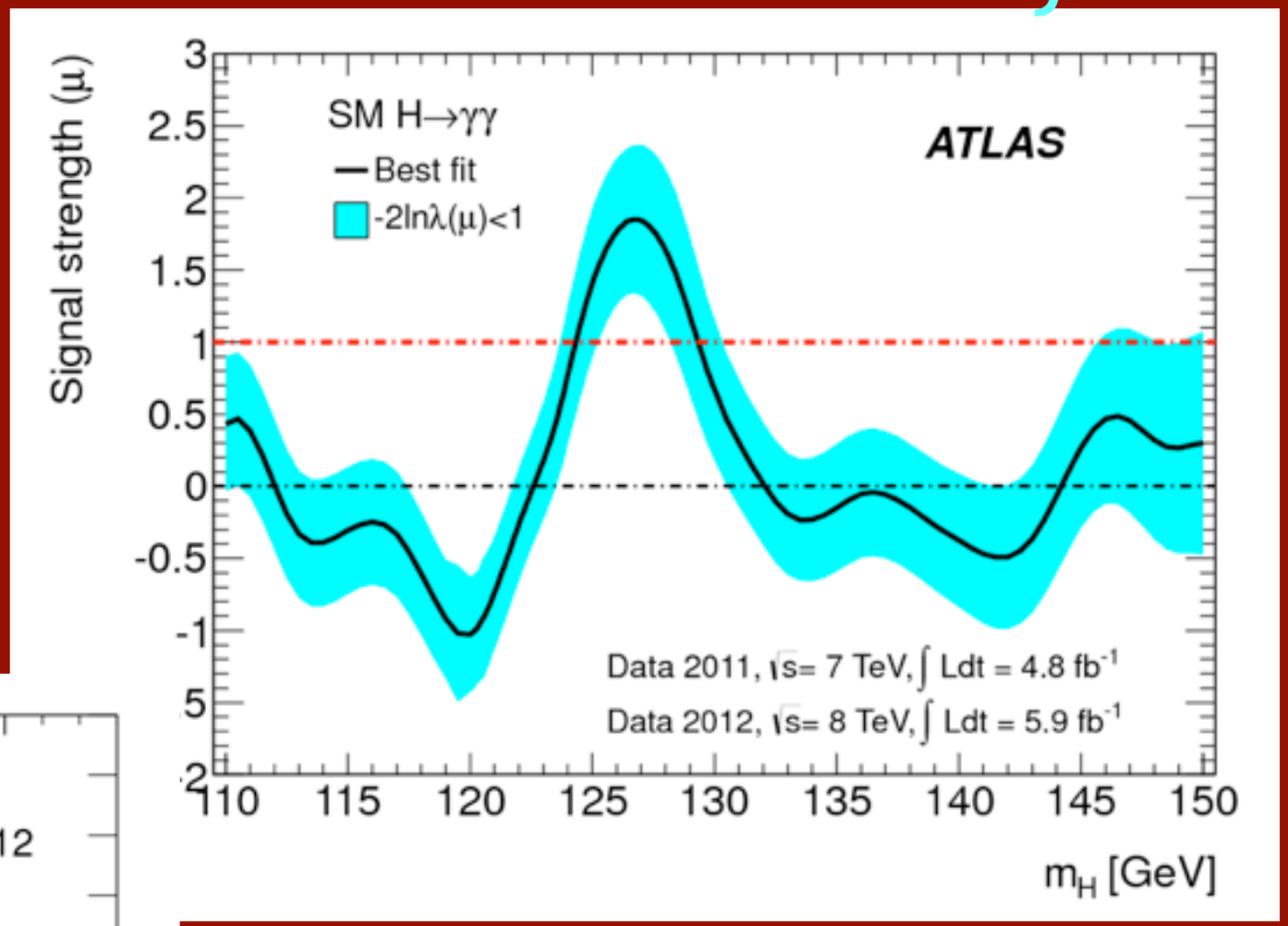
$$\hat{\mu} = \left\{ \mu \middle| L\left(\mu s(m_H) + b\right) = \max L(\mu, b) \right\}$$

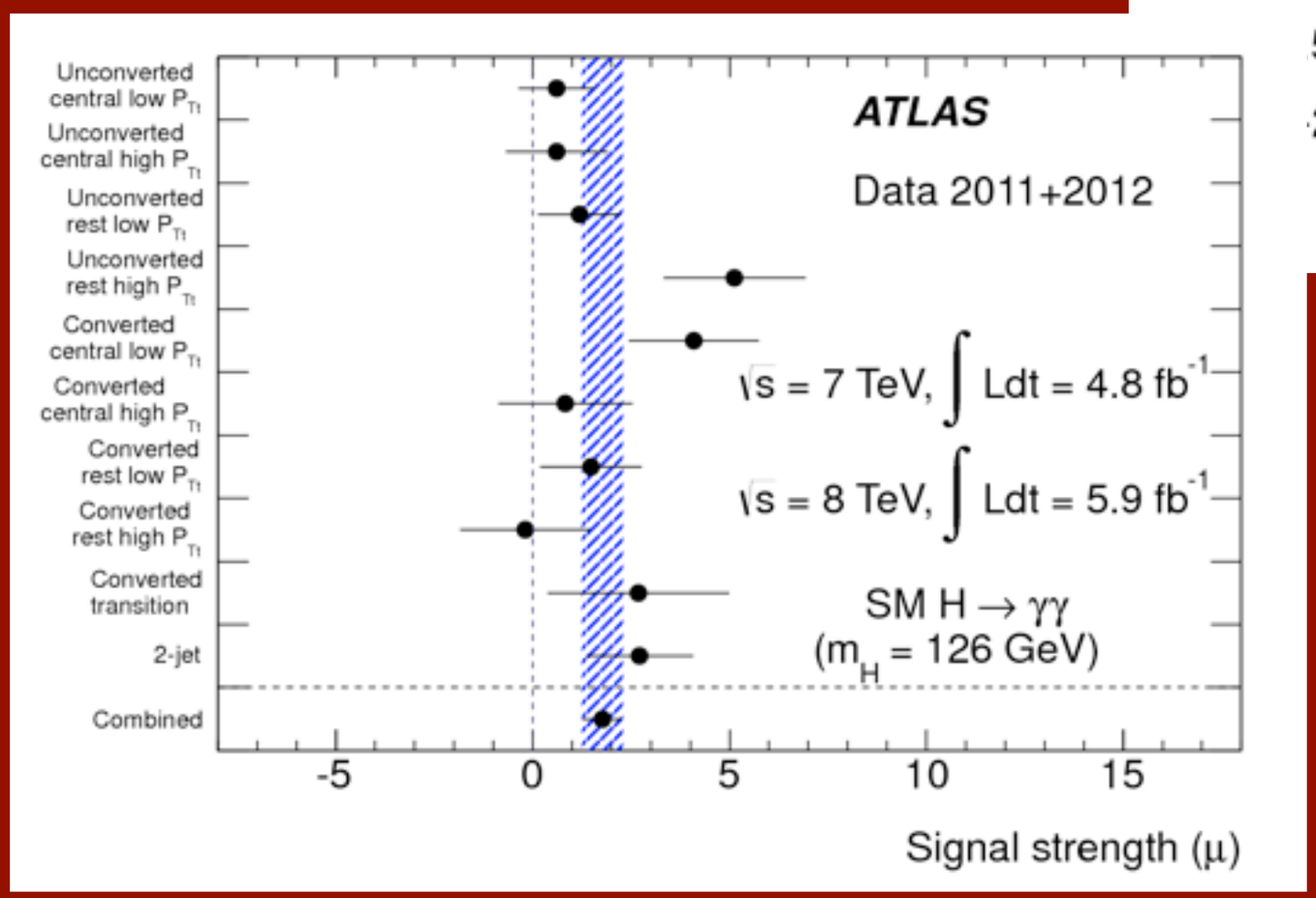
$$\mu = \sigma / \sigma SM$$

Fitted signal strength

Normalized to SM Higgs expectation at given m_H (μ)

Best-fit value at 126.5 GeV: μ=1.9 ± 0.5





Consistent results from various categories within uncertainties (most sensitive ones indicated)

The Golden Channel H->ZZ->4l

$$w_i \simeq \frac{\left(s_i / \sqrt{s_i + b_i}\right)^2}{\sum_i \left(s_i / \sqrt{s_i + b_i}\right)^2}$$

- Probing mH=125 GeV
- Probing channels:

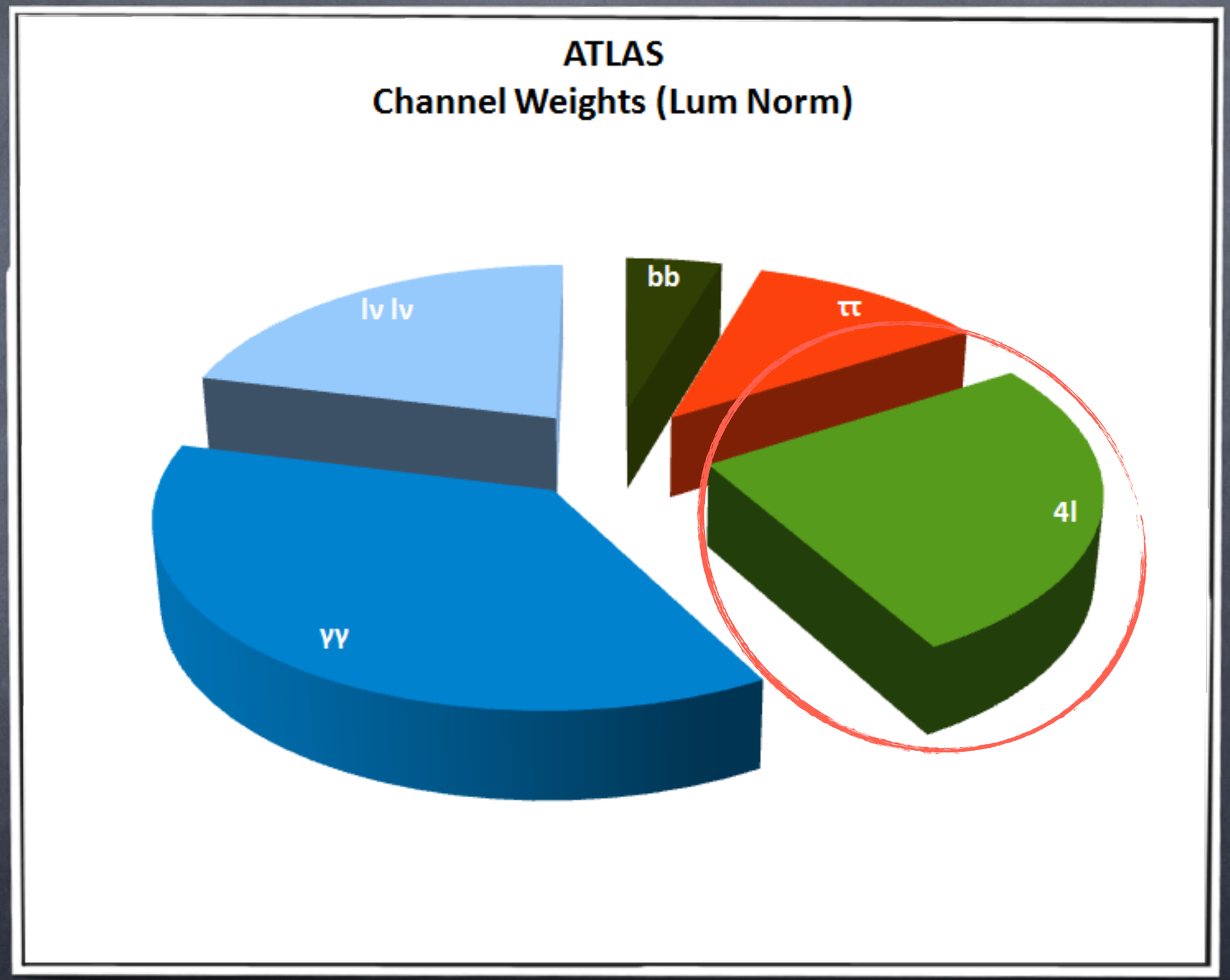
H-> γ γ

H->4l

H->WW->lvlv

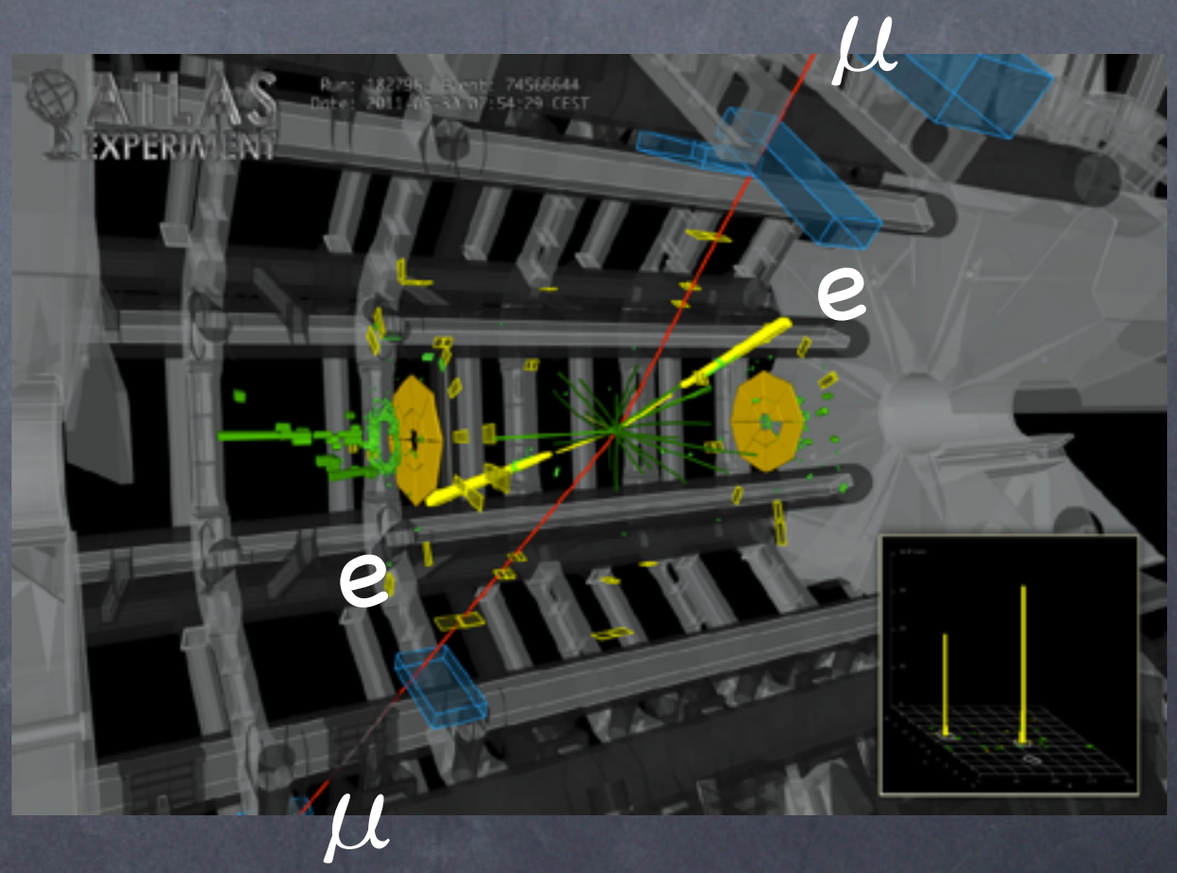
VH-> Vbb,

H-> τ τ

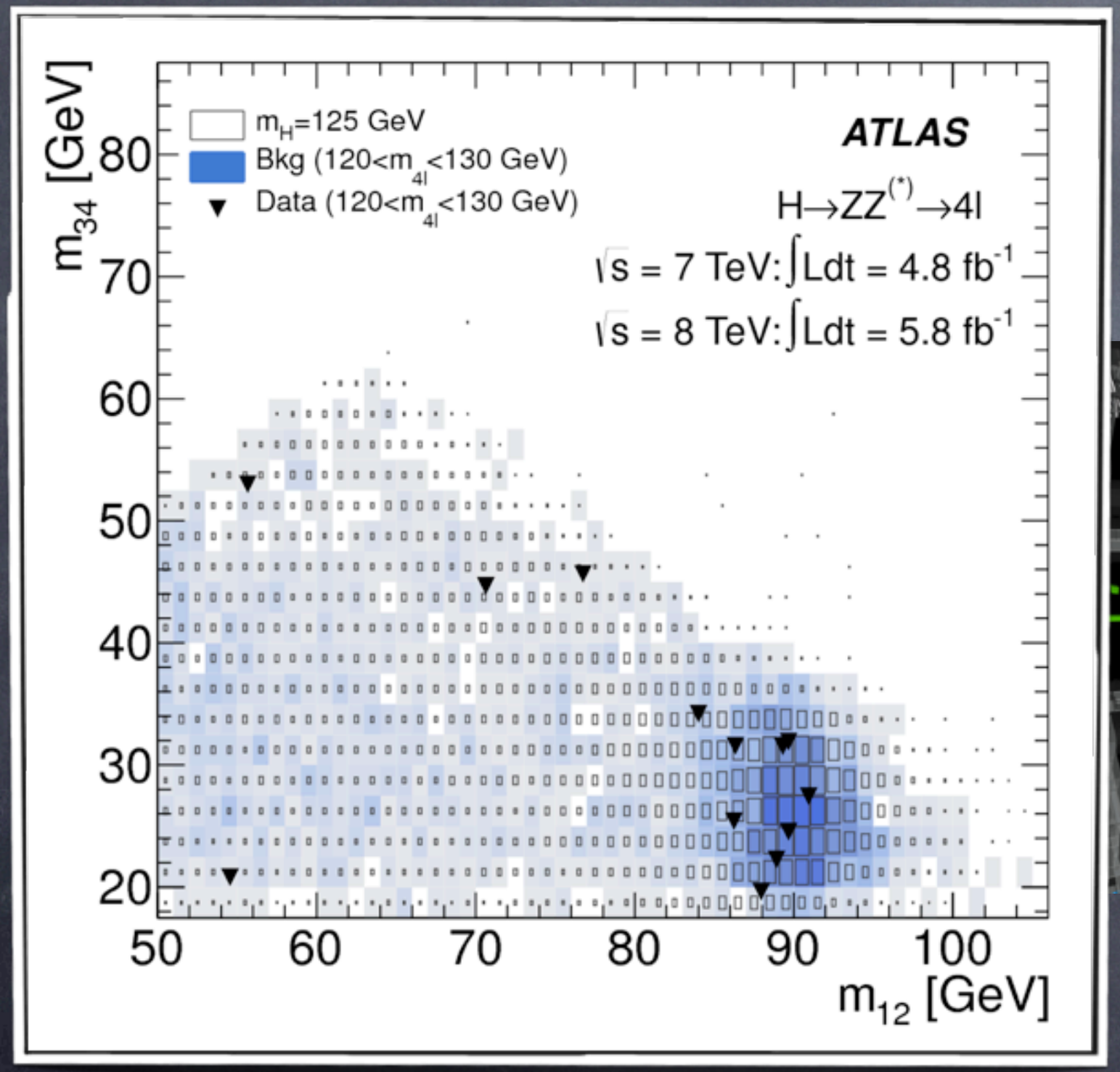


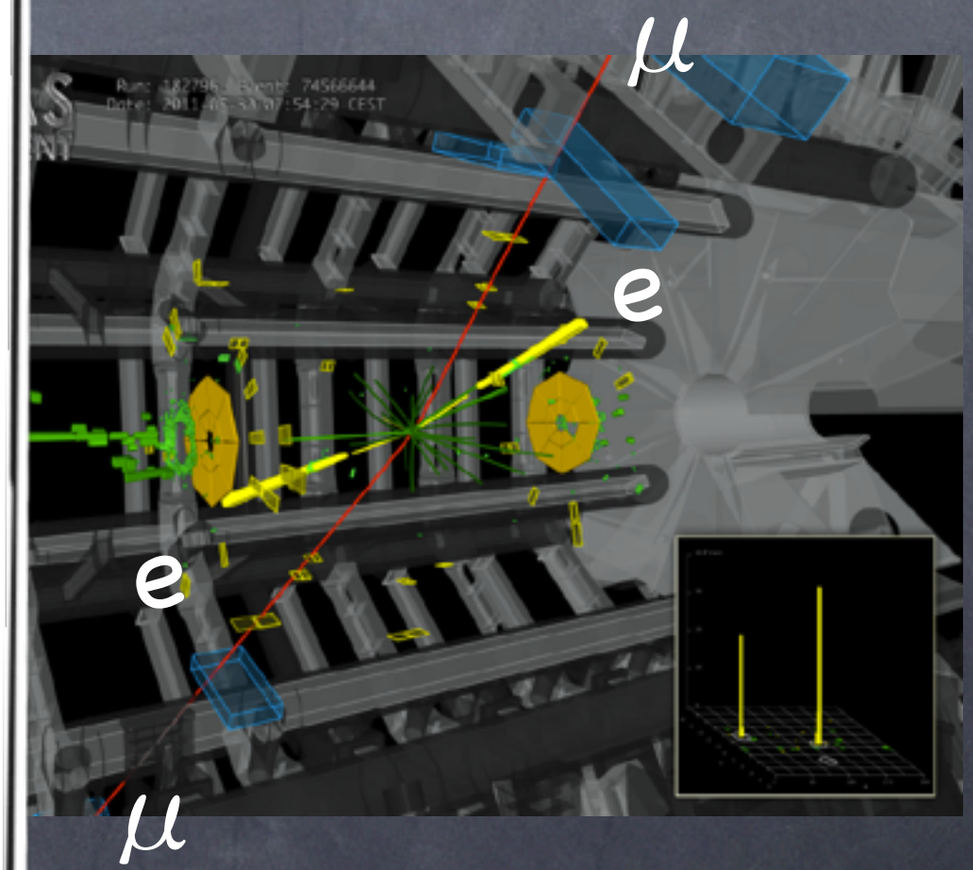
The Golden Channel: H->ZZ->4l

- CLEAN but very low rate (σ ~2-5fb), yet probably most trustable
- All information is available, one can fully reconstruct the kinematics and the masses (m_{2l}, m_{4l})
- Signature: Two pairs of same flavor opposite charged isolated leptons, one or both compatible with Z ->narrow peak
- Main backgrounds:
  - ZZ* (irreducible)
  - for $m_H<2m_Z$, Zbb, Z+jets, tt
- Suppress backgrounds with isolation and impact parameters cuts on two softest leptons

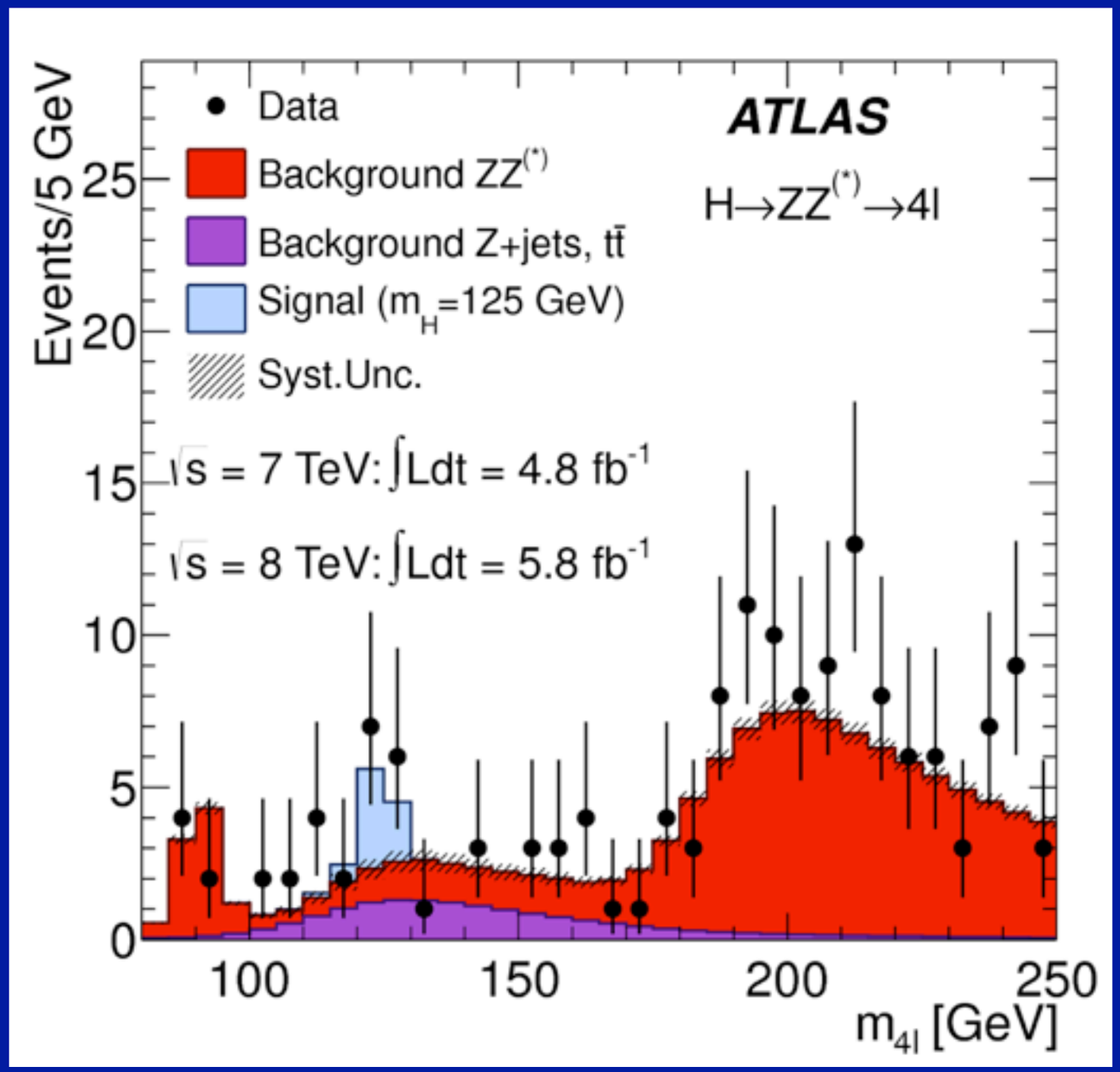


The Golden Channel: H->ZZ->4l





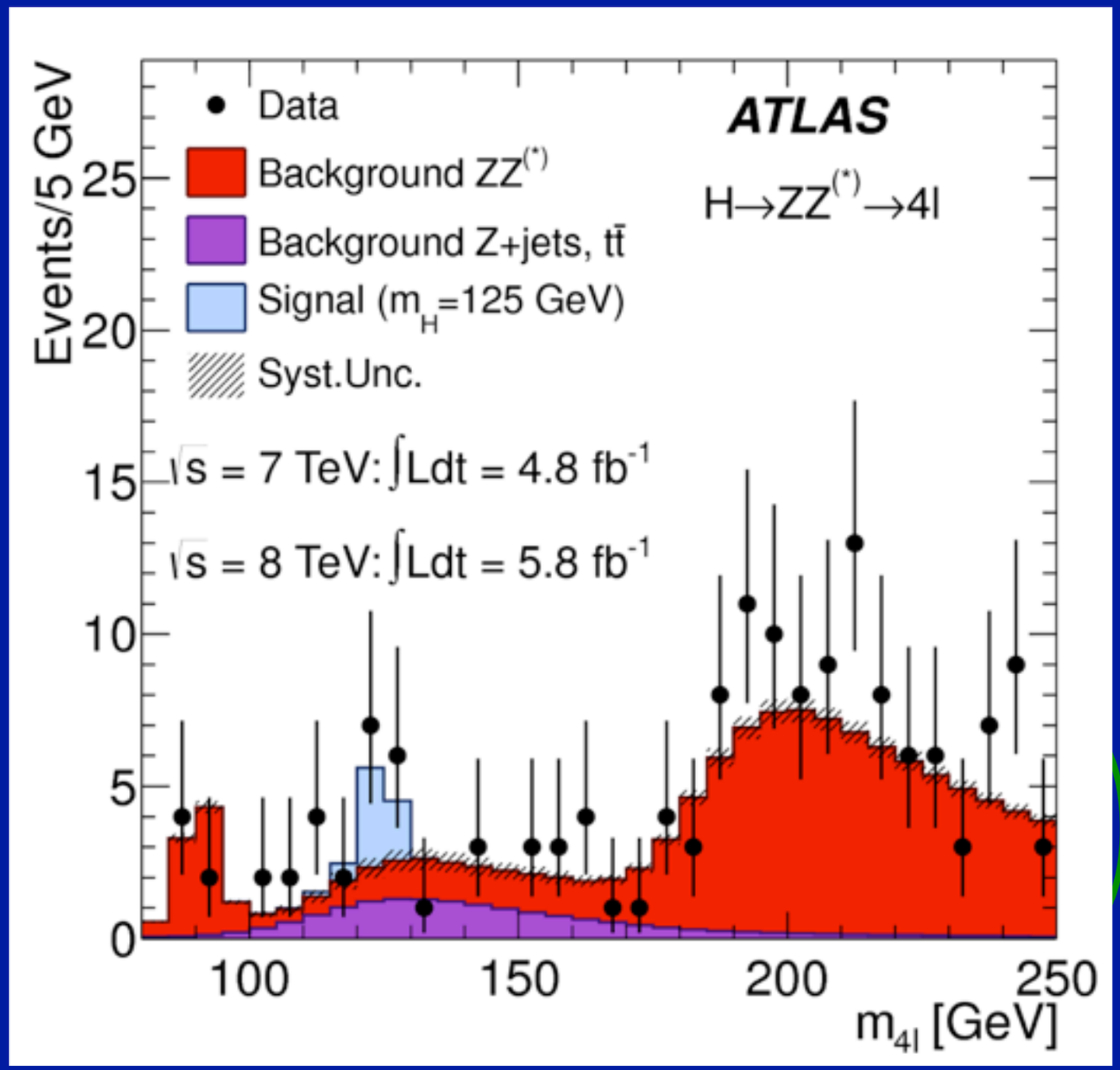
H→ 4l mass spectrum after all selections: 2011+2012 data



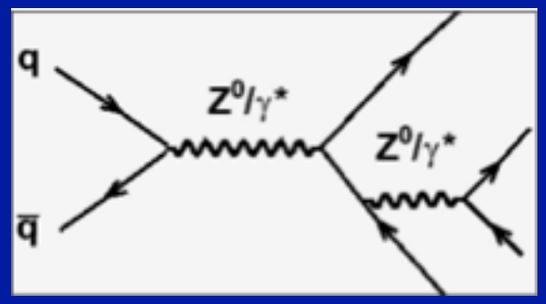
m(4l) > 160 GeV
(dominated by ZZ background):
147 ± 11 events expected
191 observed

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

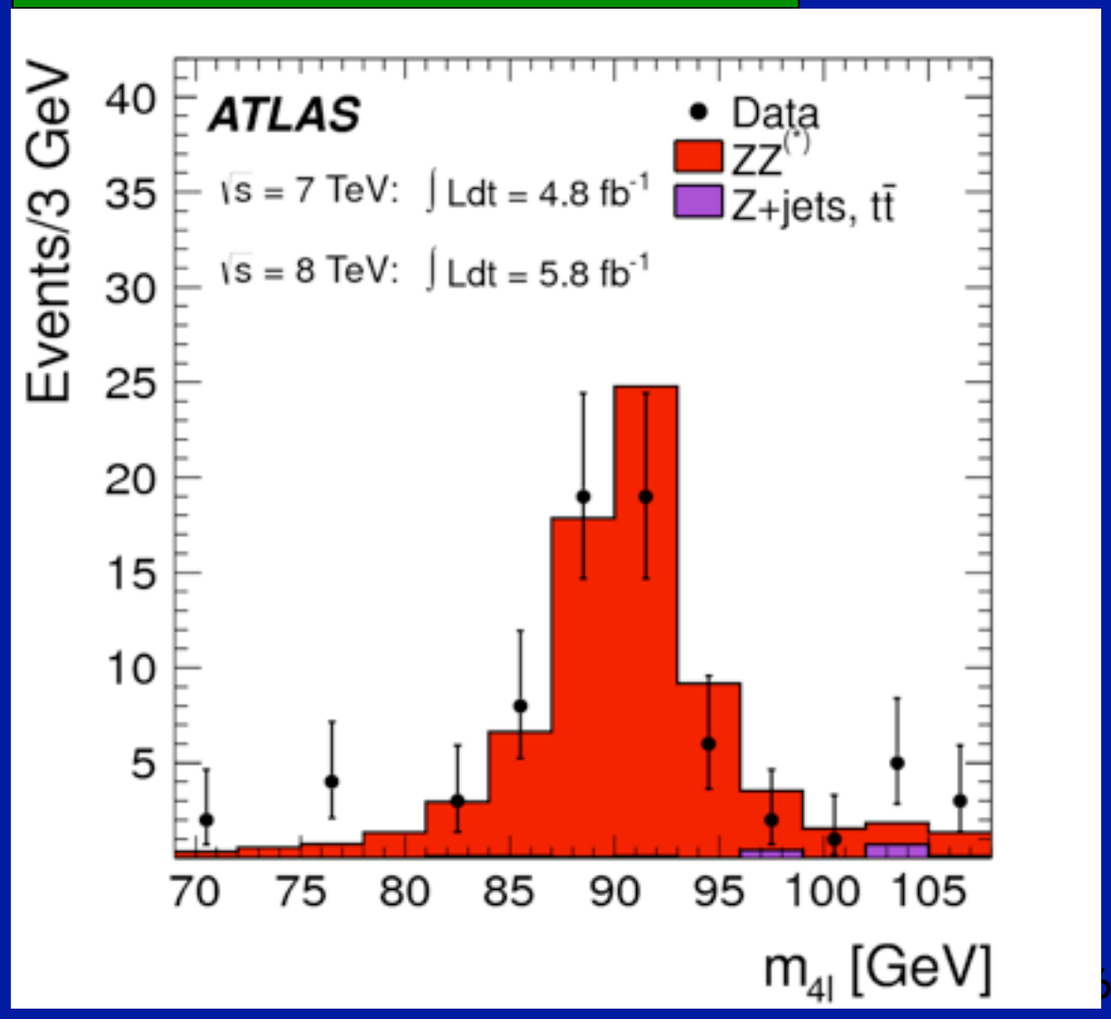
H→ 4l mass spectrum after all selections: 2011+2012 data



Peak at m(4l) ~ 90 GeV from single-resonant Z→ 4l production



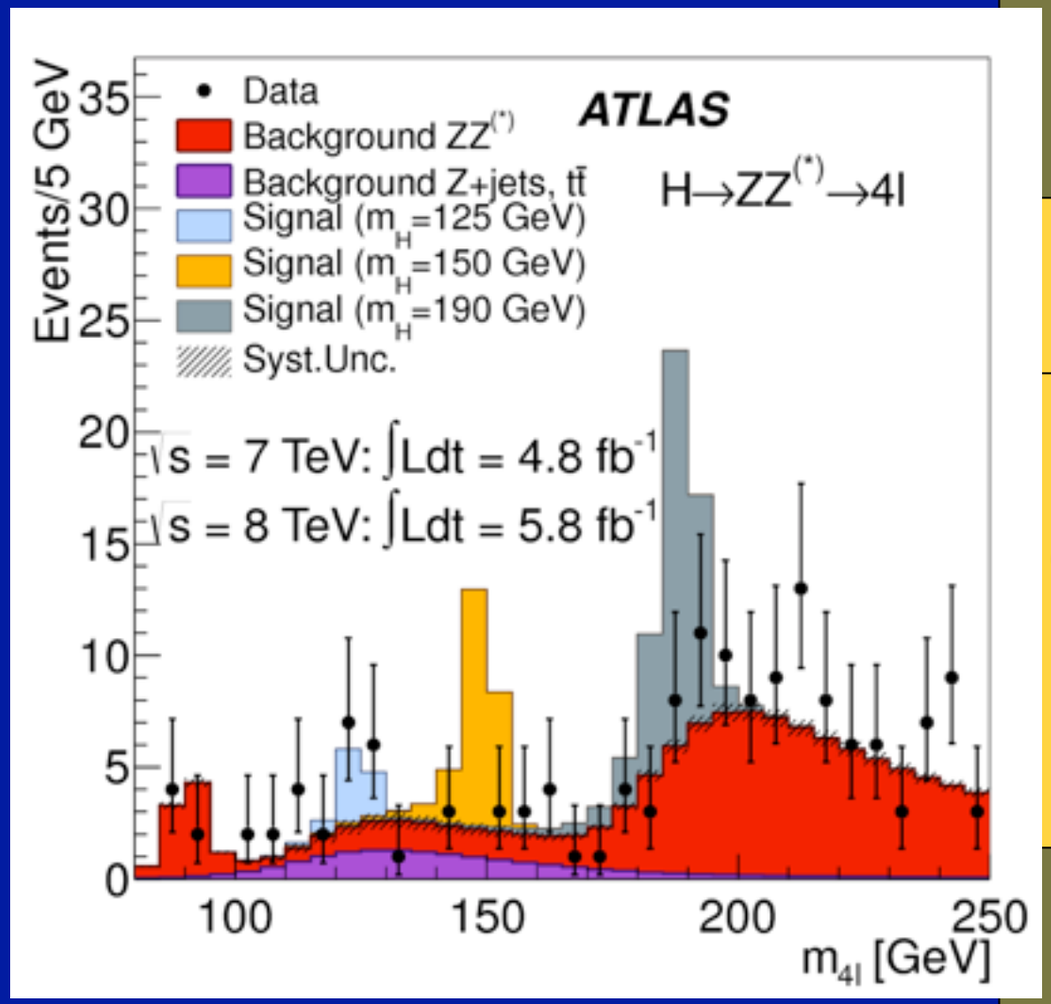
Enhanced by relaxing cuts on m_{12}, m_{34} and $p_T(\mu_4)$



2011+2012 data

The low-mass region

m4l <160 GeV:
Observed: 39
Expected: 34± 3



In the region 125 ± 5 GeV

Dataset	2011	2012	2011+2012
Expected B only	2±0.3	3±0.4	5.1±0.8
Expected S m_H=125 GeV	2±0.3	3±0.5	5.3±0.8
Observed in the data	4	9	13

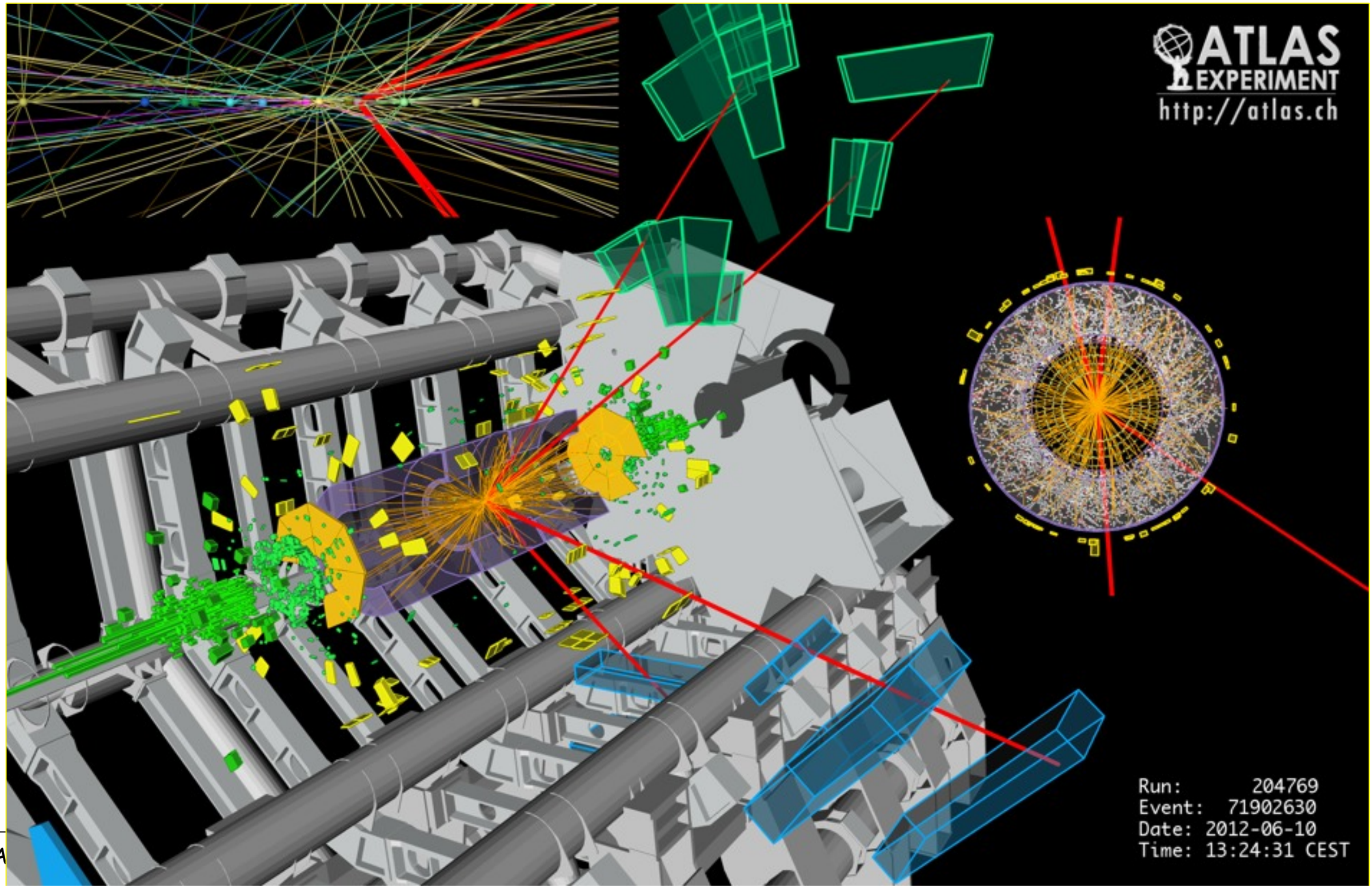
2011+ 2012	4μ	2e2μ	4e
Data	6	5	2
Expected S/B	1.6	1	0.5
Reducible/total B	5%	45%	55%

4μ candidate with $m_{4\mu}$= 125.1 GeV

TRIGGERED BY TGC

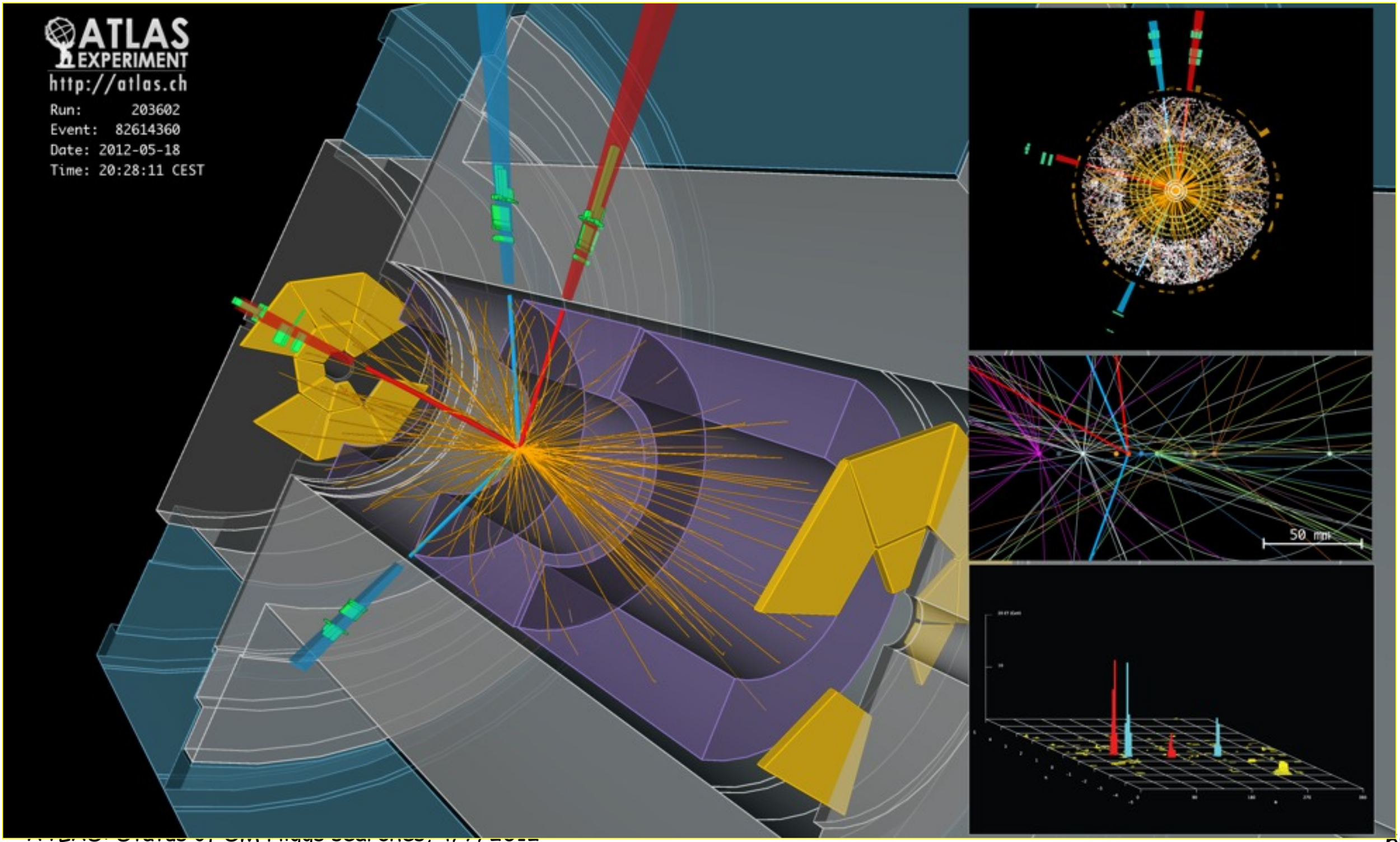
p_T (muons)= 36.1, 47.5, 26.4, 71 .7GeV m_{12}= 86.3 GeV, m_{34}= 31.6 GeV

15 reconstructed vertices



4e candidate with m_{4e}= 124.6 GeV

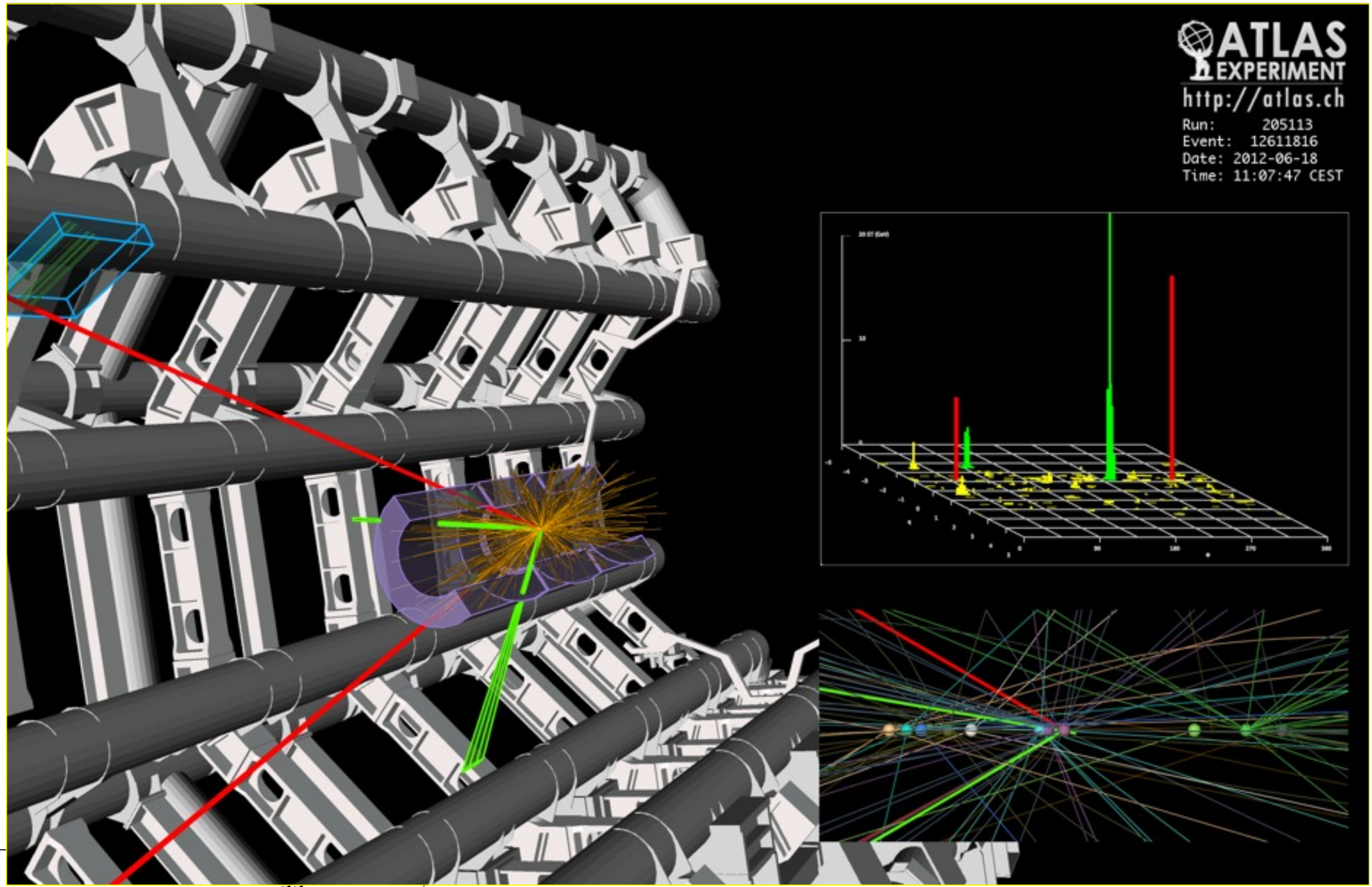
p_T (electrons)= 24.9, 53.9, 61.9, 17.8 GeV. m_{12}= 70.6 GeV, m_{34}= 44.7 GeV
12 reconstructed vertices

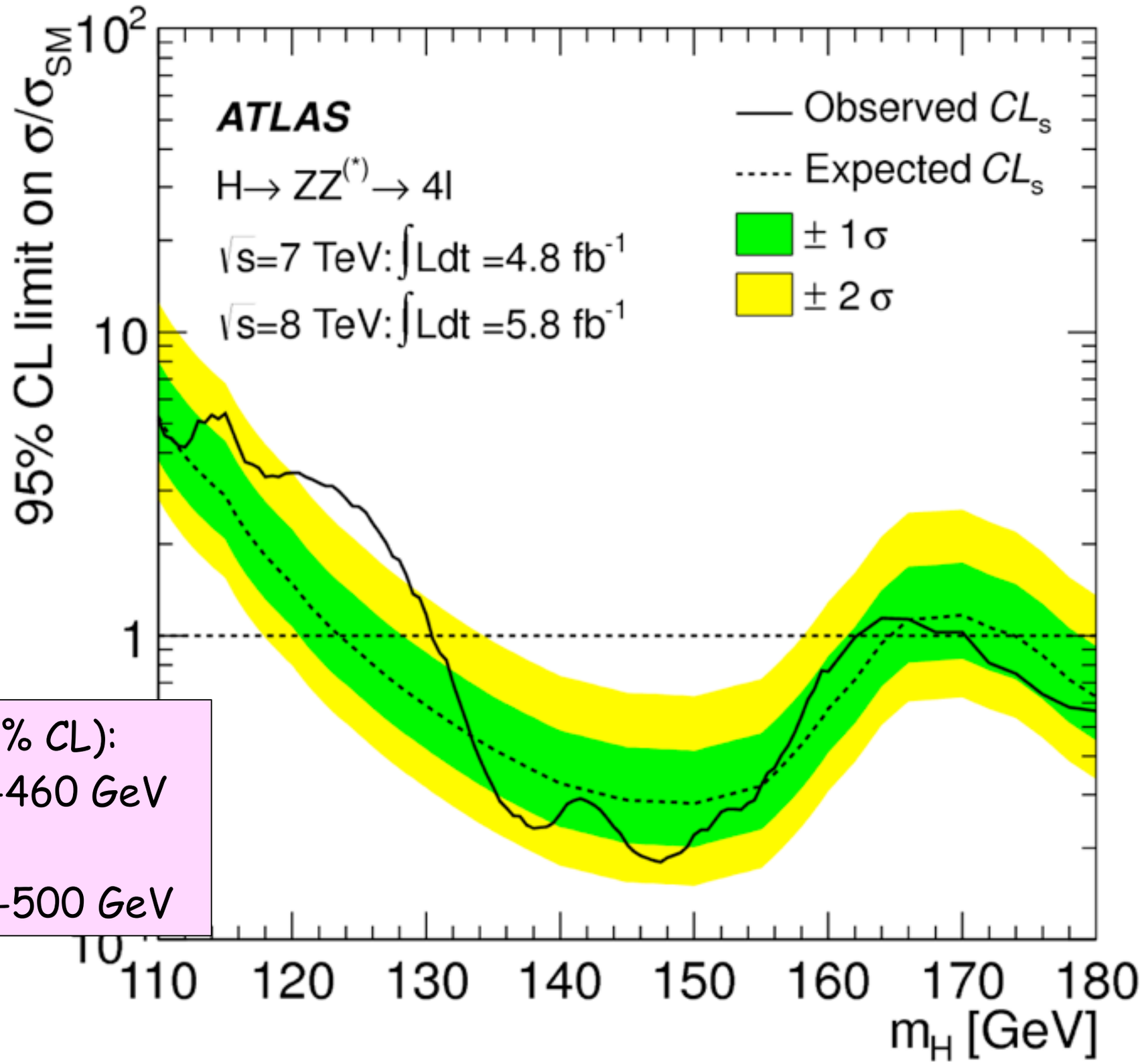


2e2μ candidate with $m_{2e2\mu}$= 123.9 GeV

p_T (e,e,μ,μ)= 18.7, 76, 19.6, 7.9 GeV, m (e^+e^-)= 87.9 GeV, m($\mu^+\mu^-$) =19.6 GeV

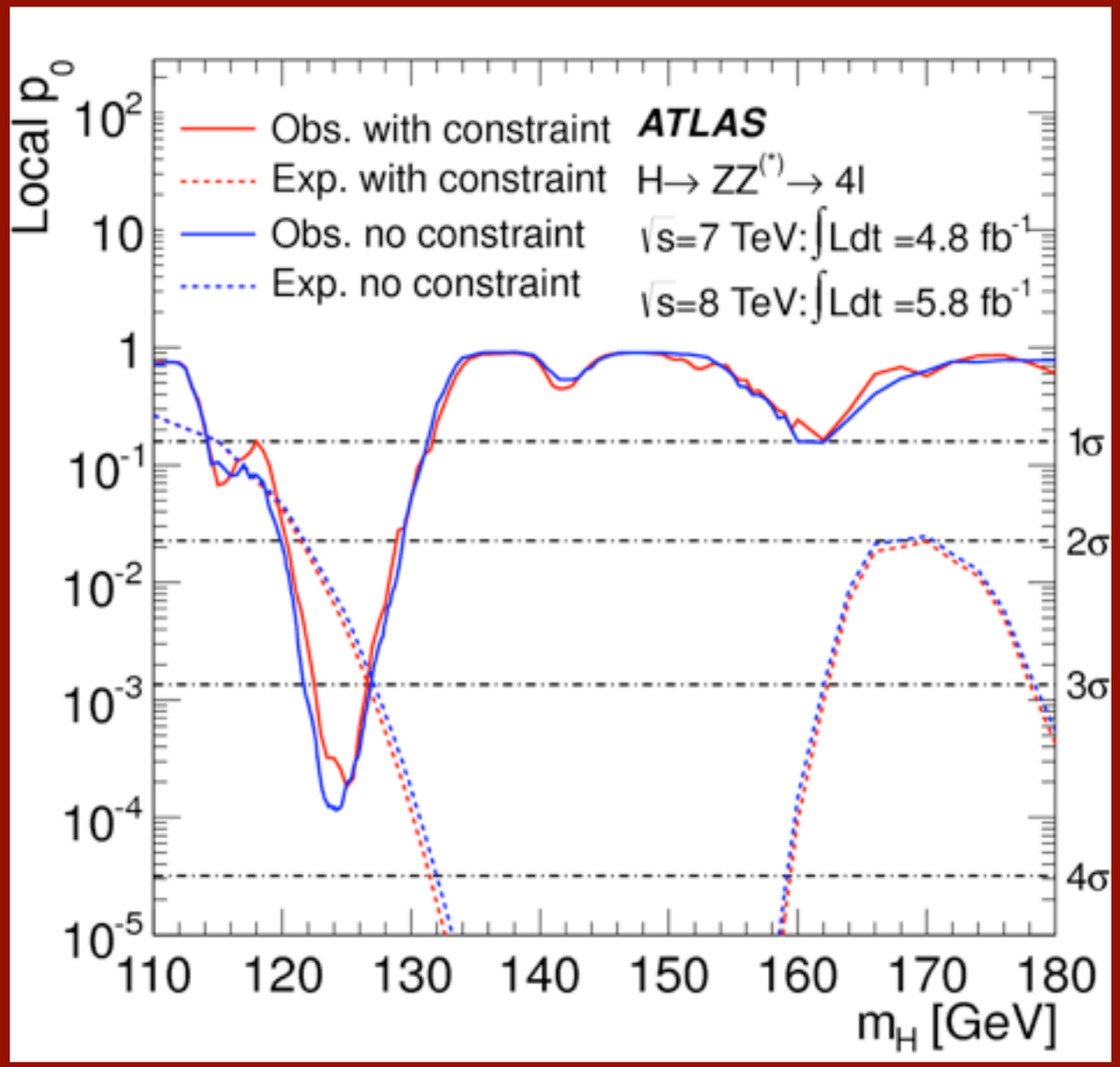
12 reconstructed vertices





Excluded (95% CL):
131-162, 170-460 GeV
Expected:
124-164, 176-500 GeV

Consistency of the data with the background-only expectation

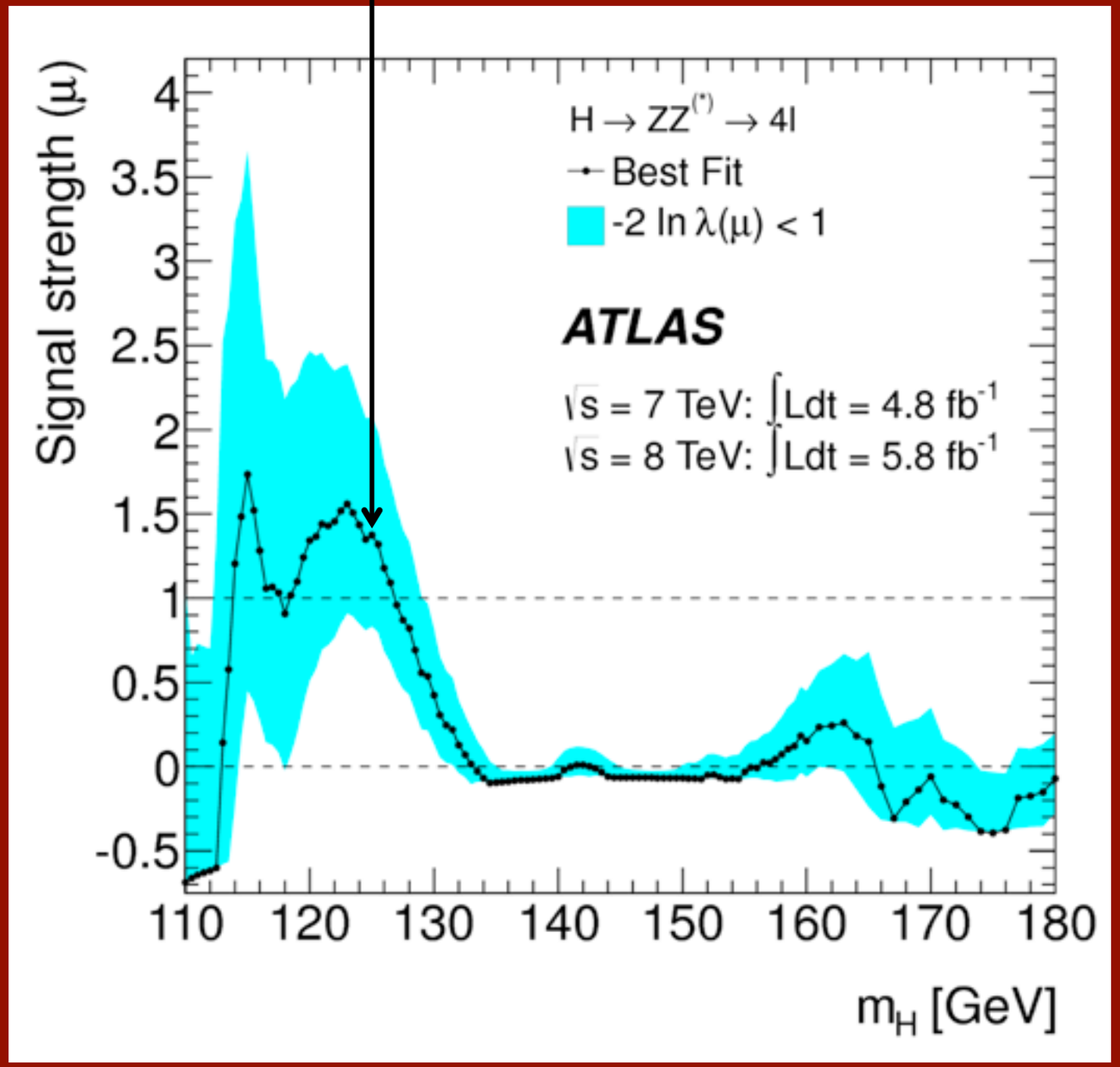


Data sample	m_H of max deviation	local p-value	local significance	expected from SM Higgs
2011	125 GeV	1.1%	2.3 σ	1.5 σ
2012	125.5 GeV	0.4%	2.7 σ	2.1 σ
2011+2012	125 GeV	0.03%	3.4 σ	2.6 σ

Global 2011+2012 (including LEE over full 110-600 GeV range): 2.1σ

Fitted signal strength

Best-fit value at 125 GeV: μ=1.3 ± 0.6



"TEVATRON" Channel H->WW

$$w_i \simeq \frac{\left(s_i / \sqrt{s_i + b_i}\right)^2}{\sum_i \left(s_i / \sqrt{s_i + b_i}\right)^2}$$

- Probing mH=125 GeV
- Probing channels:

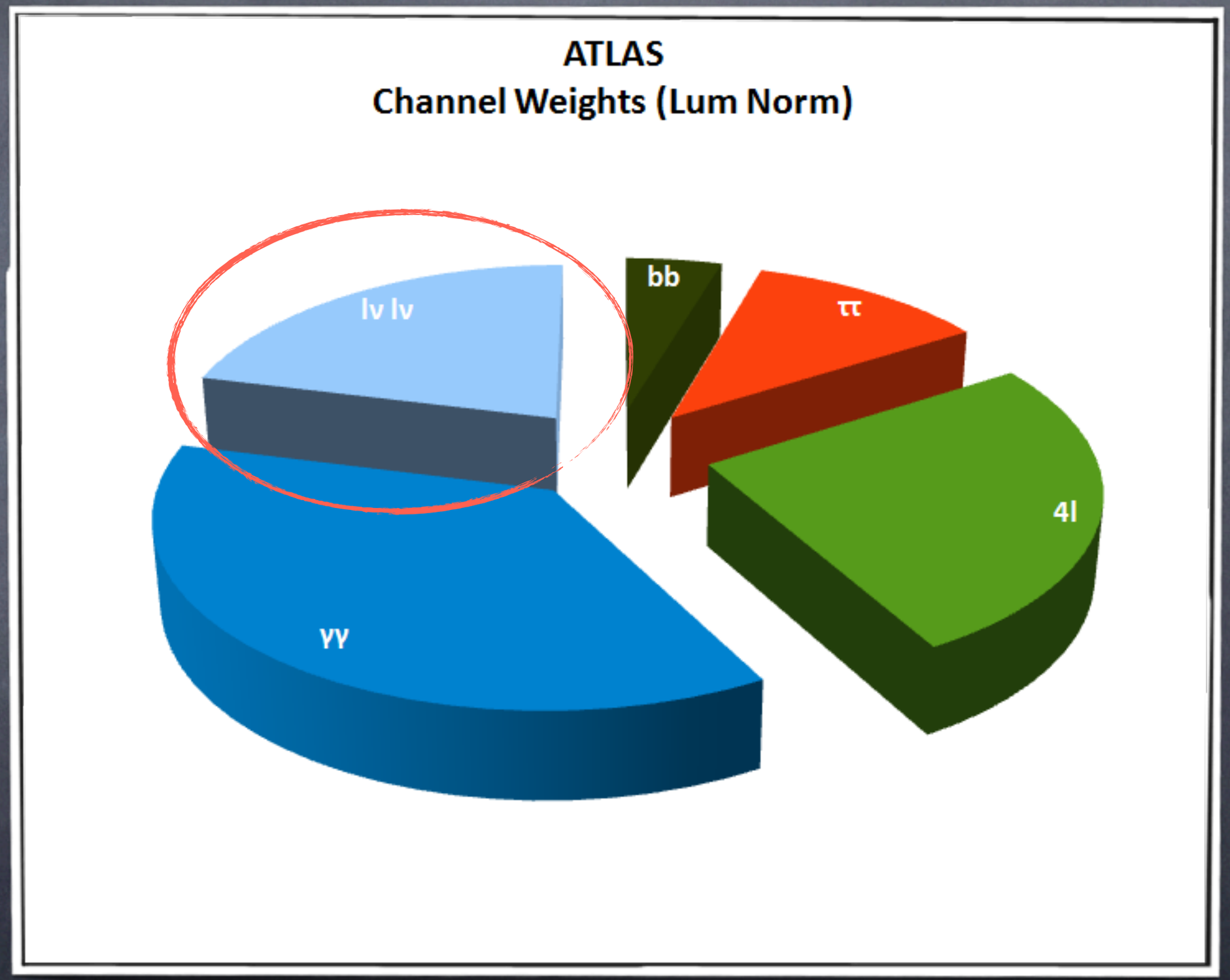
H-> γ γ

H->4l

H->WW->lvlv

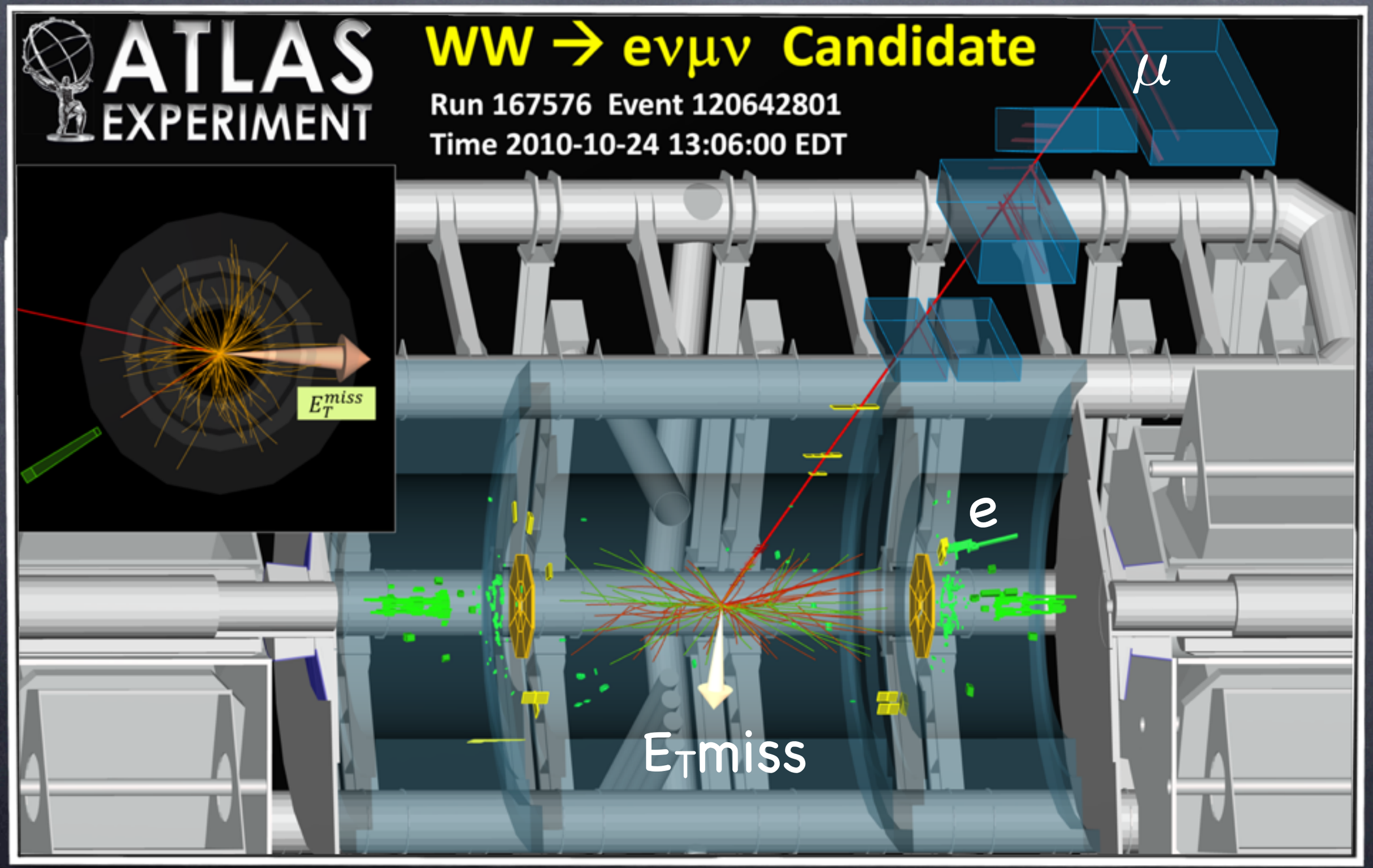
VH-> Vbb,

H-> τ τ



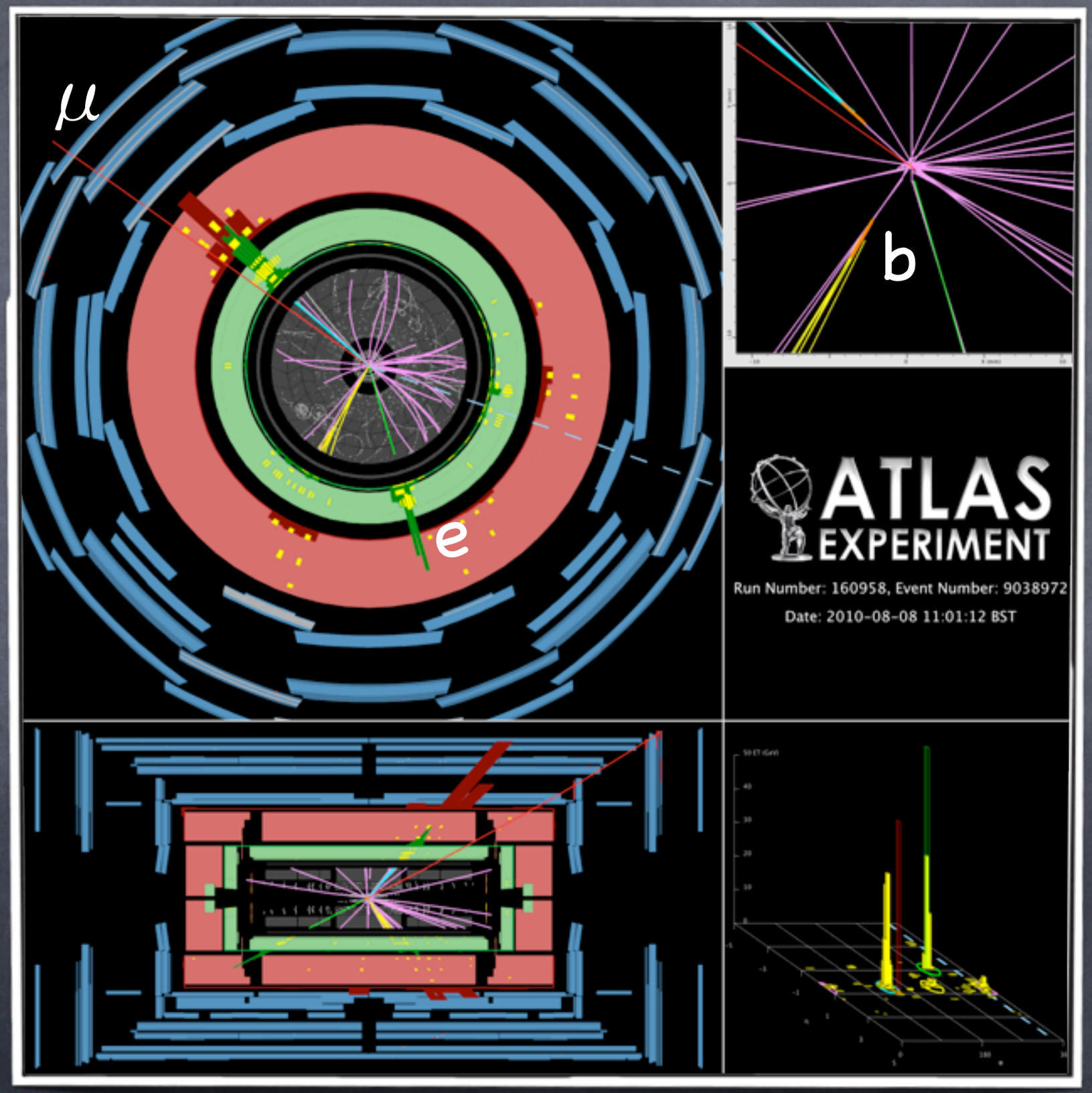
H->WW->l ν l ν : WW->e μ "Irreducible" BG

- WW can be reduced by exploiting the Higgs spin, require small $\Delta\Phi_{ll}$



H->WW->l ν l ν : tt->e μ background

Event display of a top pair e-mu dilepton candidate with two b-tagged jets.
The electron is shown by the green track pointing to a calorimeter cluster, the muon by the long red track intersecting the muon chambers, and the missing ET direction by the dotted line on the XY view. The secondary vertices of the two b-tagged jets are indicated by the orange ellipses on the zoomed vertex region view.



Reject by b-tag veto

H->WW->l ν l ν

- The cannel is challenging
  2 neutrinos- no mass reconstruction ->mT

- Signature: 2 high p_T opposite sign isolated leptons with large E_T^{miss}->Understanding of E_T^{miss} is crucial

- Main background from WW, top, Z+jets, W+jets ->Use of control regions to estimate fakes

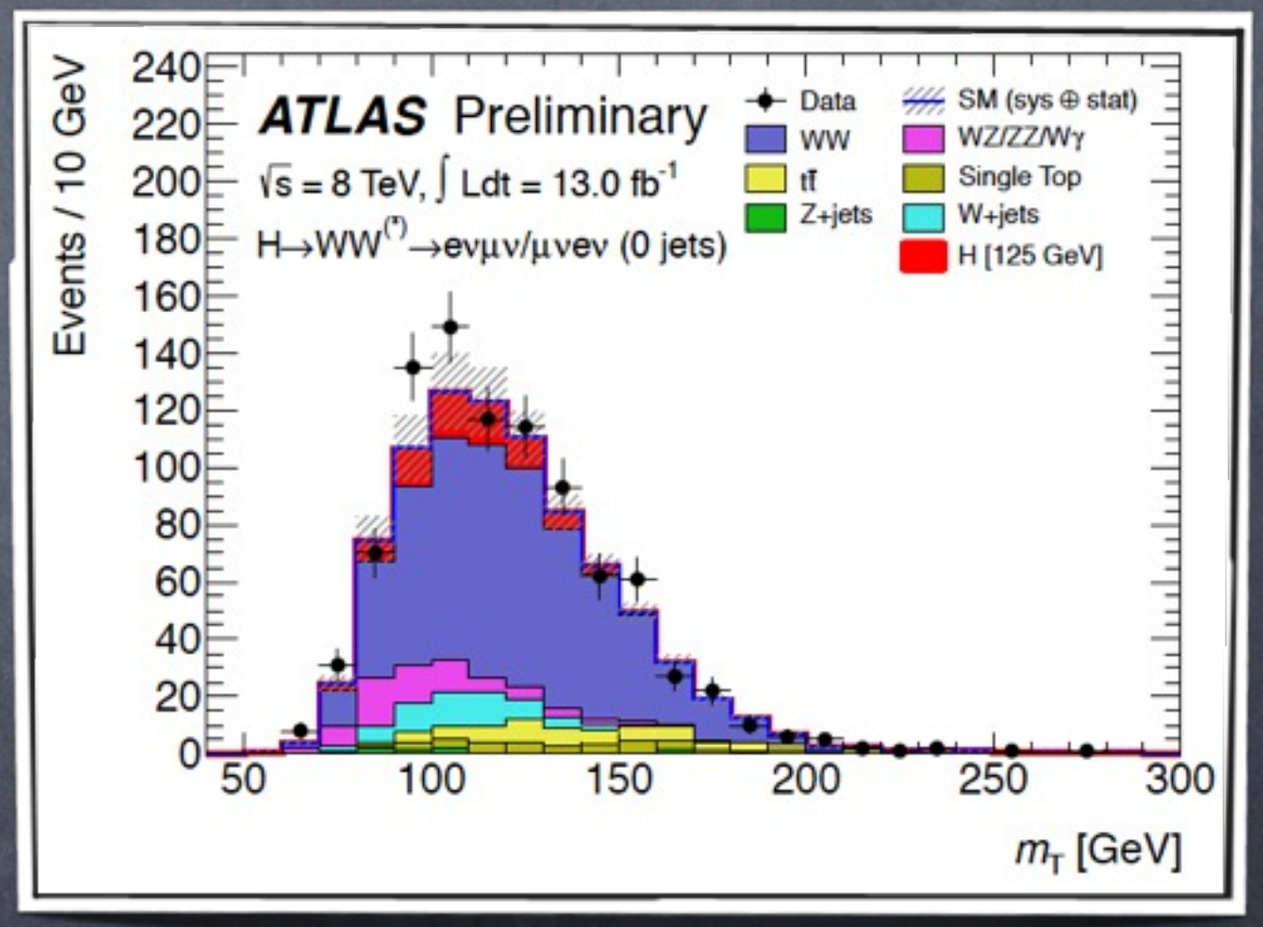
- A control region is defined rich in the measured BG (e.g. WW or top), contaminations are being subtracted and then the BG is extrapolated to the signal region (mostly using MC)
  Example: b-tag is inverted to estimate Top BG

- -> large E_T^{miss}, m_{ll} incompatible with m_Z (DY),
  -> b jet veto (tt),
  ->Topological cuts against irreducible WW ($\Delta\Phi_{ll}$)

- Jet bins: +0j, +1, +2jet (VBF)

- Discriminating variable $m_T = \sqrt{(E_T^{ll} + E_T^{miss})^2 + (p_T^{ll} + p_T^{miss})^2}$

$$m_T = \sqrt{(E_T^{ll} + E_T^{miss})^2 + (p_T^{ll} + p_T^{miss})^2}$$



N_{jets} with p_T>25 GeV

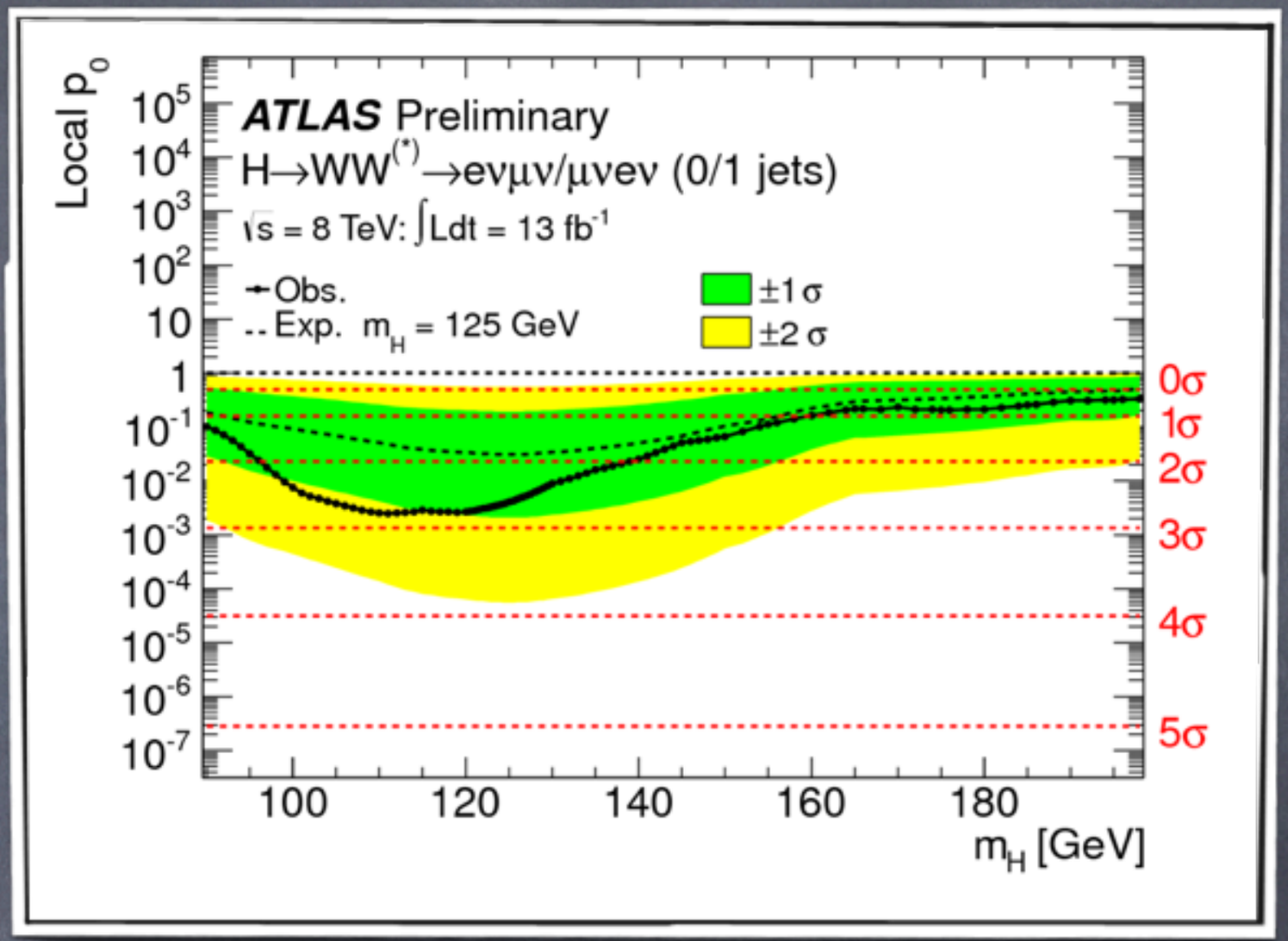
H->WW->l ν l ν

ATLAS Significance
(13 fb^{-1}, 8 TeV 0+1-jet only)

Largest Observed :
2.8 σ at 110 GeV

Observed at 125 GeV: 2.7 σ

Expected at 125 GeV: 1.9 σ



The Fermionic Channels

$$w_i \simeq \frac{\left(s_i / \sqrt{s_i + b_i}\right)^2}{\sum_i \left(s_i / \sqrt{s_i + b_i}\right)^2}$$

- Probing mH=125 GeV
- Probing channels:

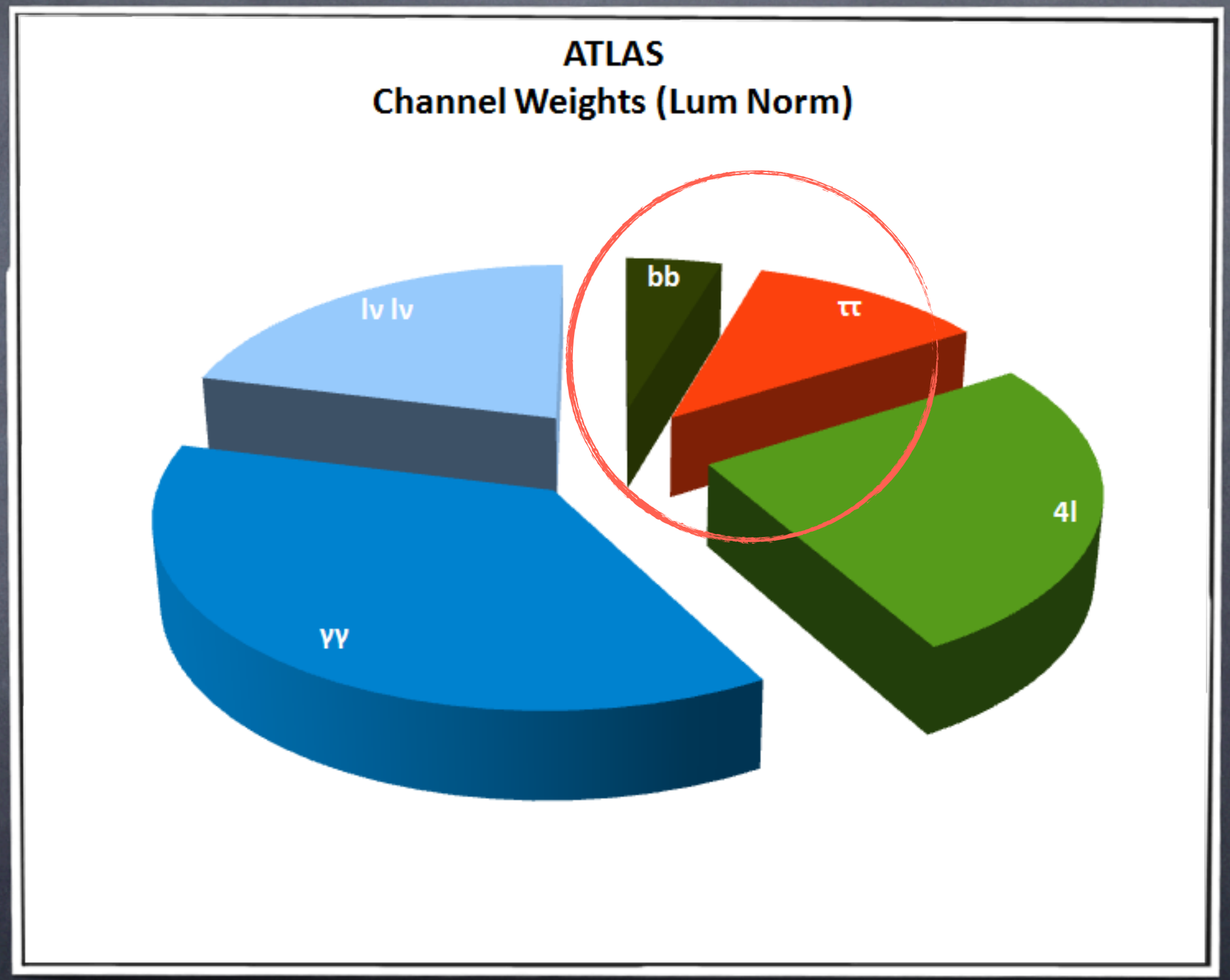
H-> γ γ

H->4l

H->WW->lvlv

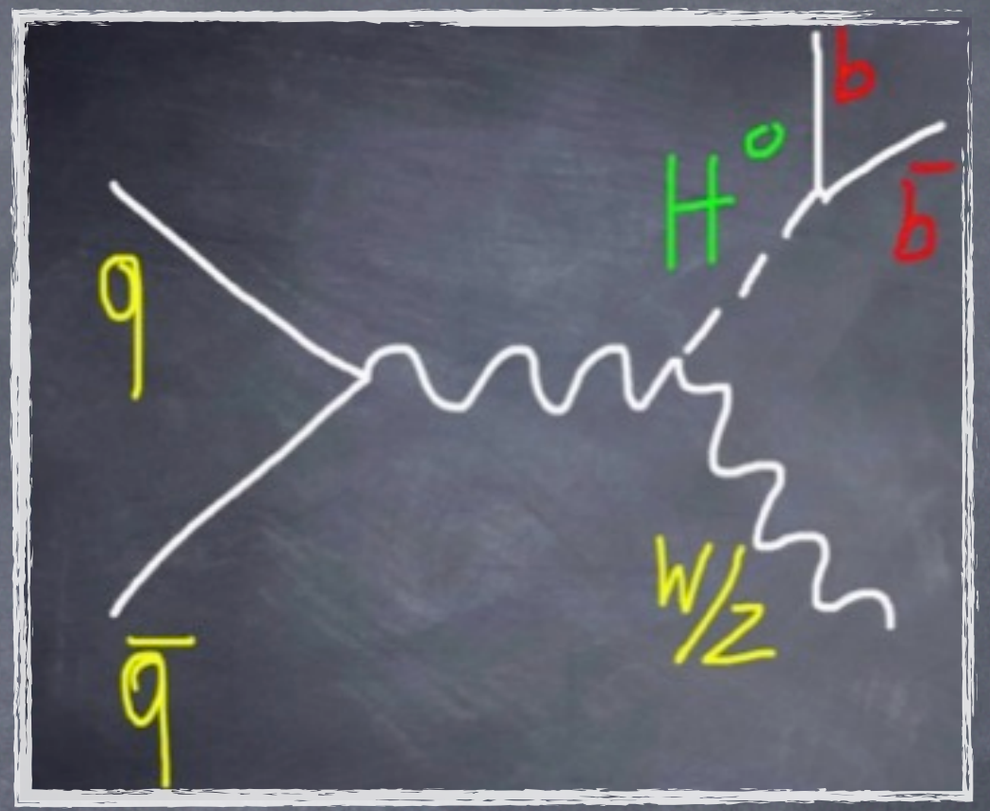
VH-> Vbb,

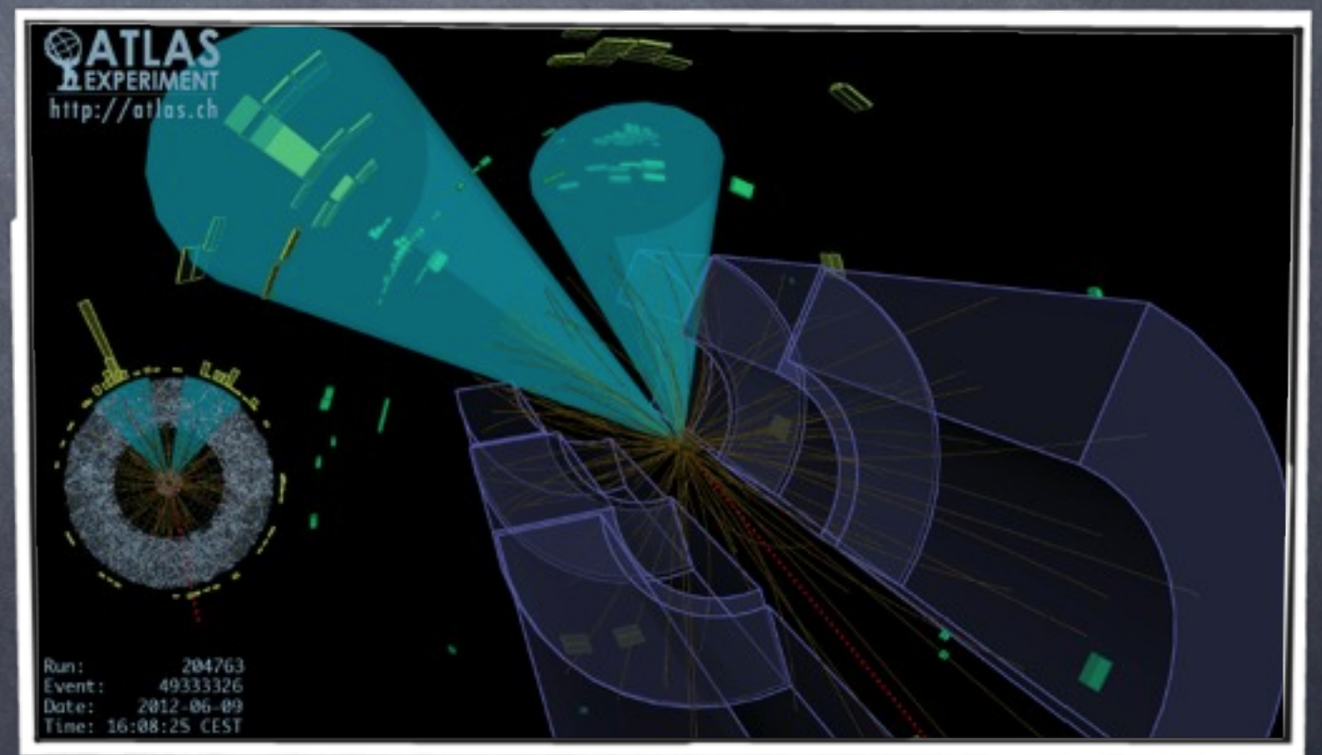
H-> τ τ

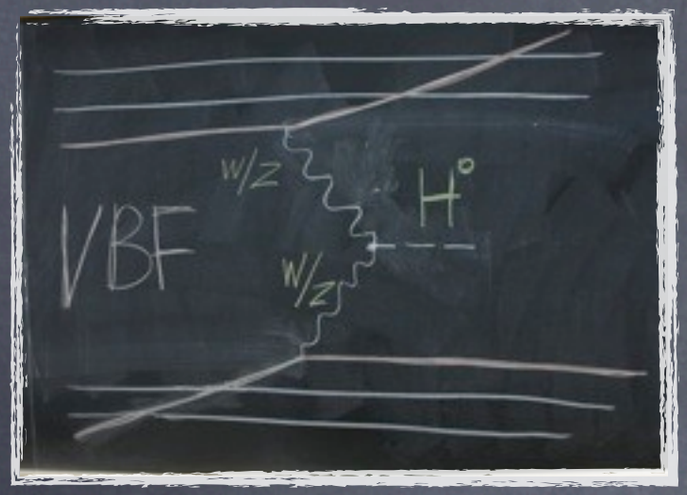


H->bb: W/ZH->W/Zbb

- H->bb is the dominant decay of a low mass Higgs.
  It also extremely important to measure Higgs couplings.
- Multi-jet background kills its inclusive production
- W/ZH is feasible for low Higgs mass channels: l υ bb,llbb and υ υ bb
- Signature
  lepton,MET and b-tag
- Z/W+jets and tt BG can be reduced by requiring boosted Higgses with tight b-tag
- Sensitivity is still very low
  p0 expxted=0.15 obs= 0.64 (a deficit)

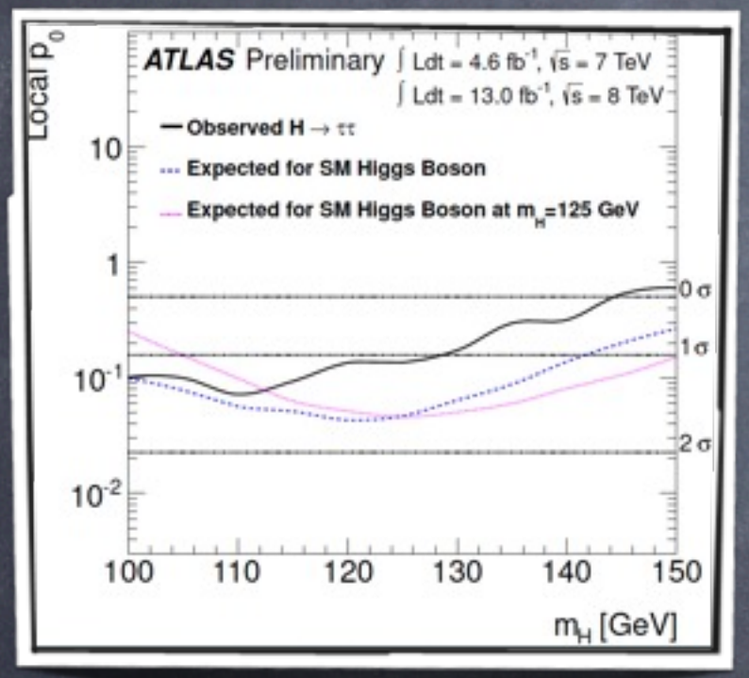


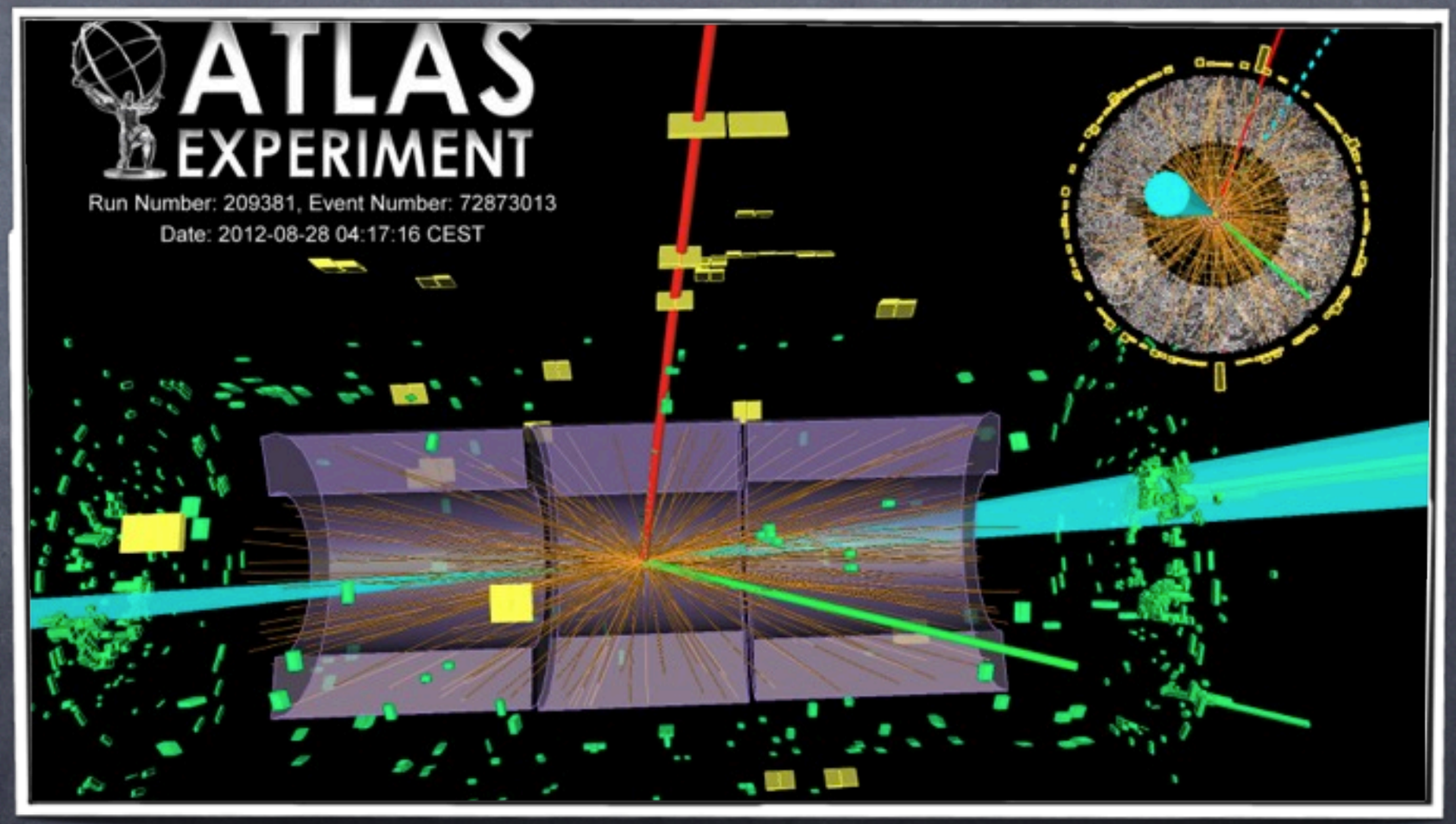




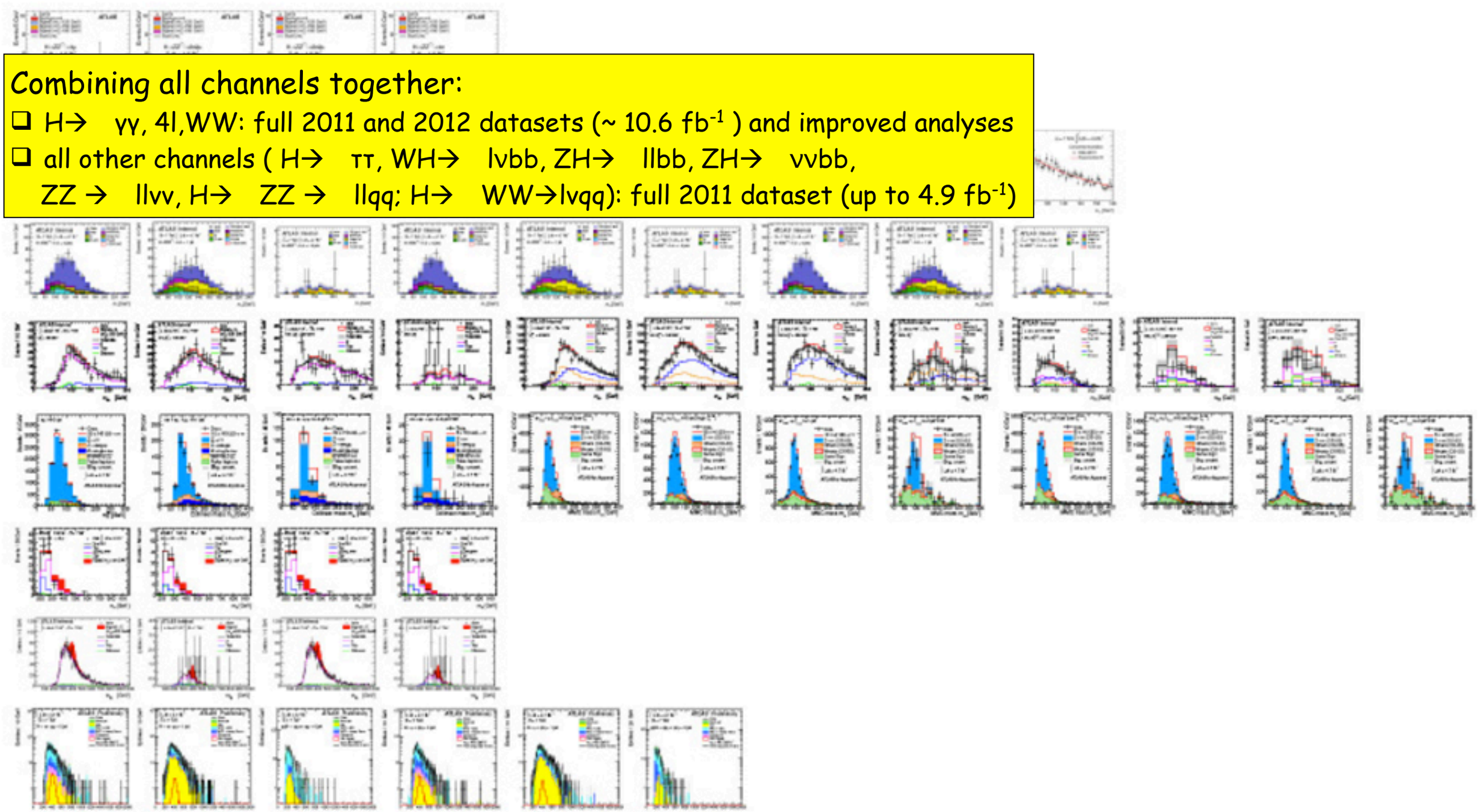
H->τ τ

- VBF clean and sensitive
- 2 tagged back to back forward jets and two tagged taus





All for one - Combine forces

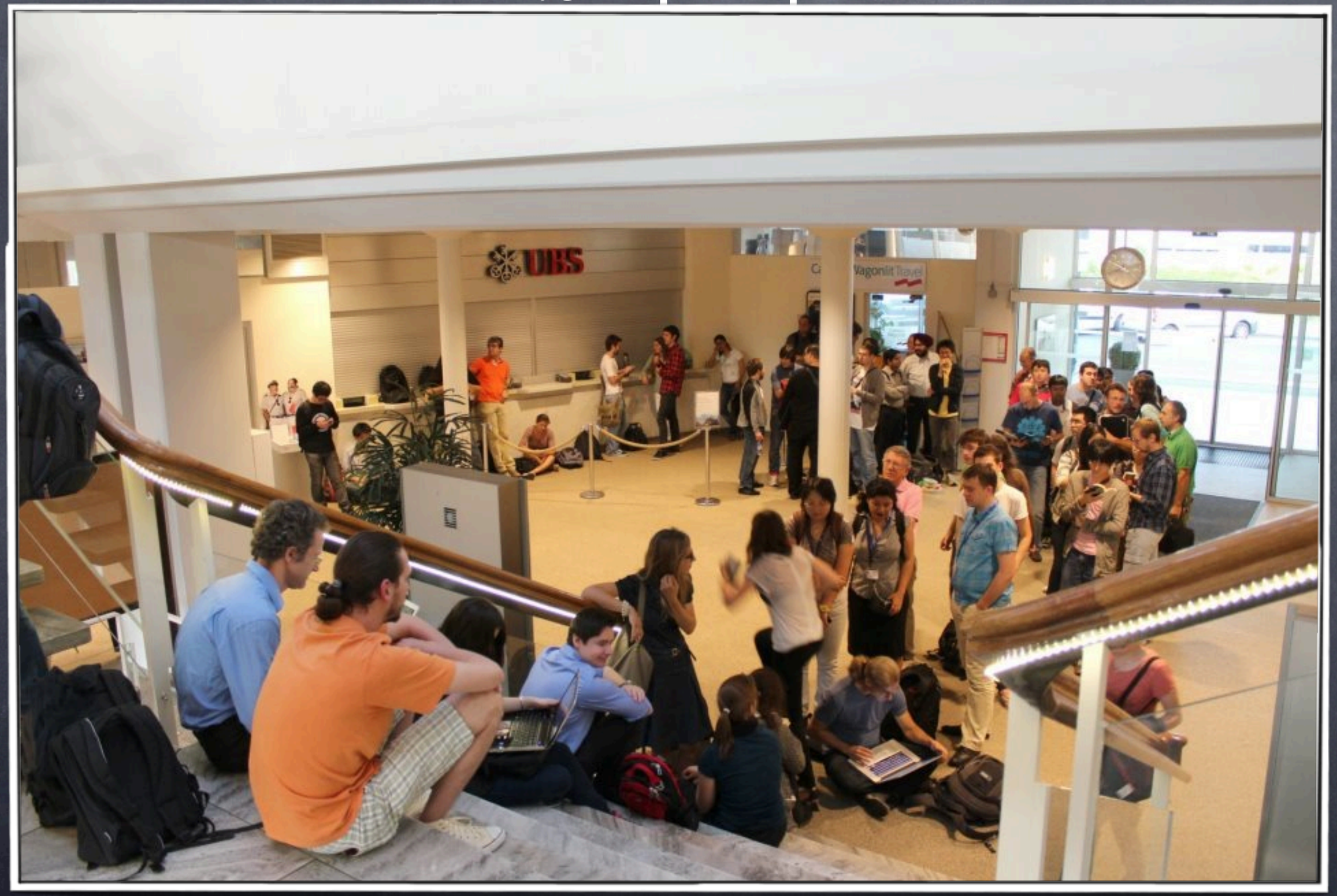


Combining all channels together:

- H→ γγ, 4l,WW: full 2011 and 2012 datasets (~ 10.6 fb^{-1}) and improved analyses
- all other channels (H→ ττ, WH→ lνbb, ZH→ llbb, ZH→ ννbb, ZZ → llνν, H→ ZZ → llqq; H→ WW→lνqq): full 2011 dataset (up to 4.9 fb^{-1})

4th July 2012: A long night

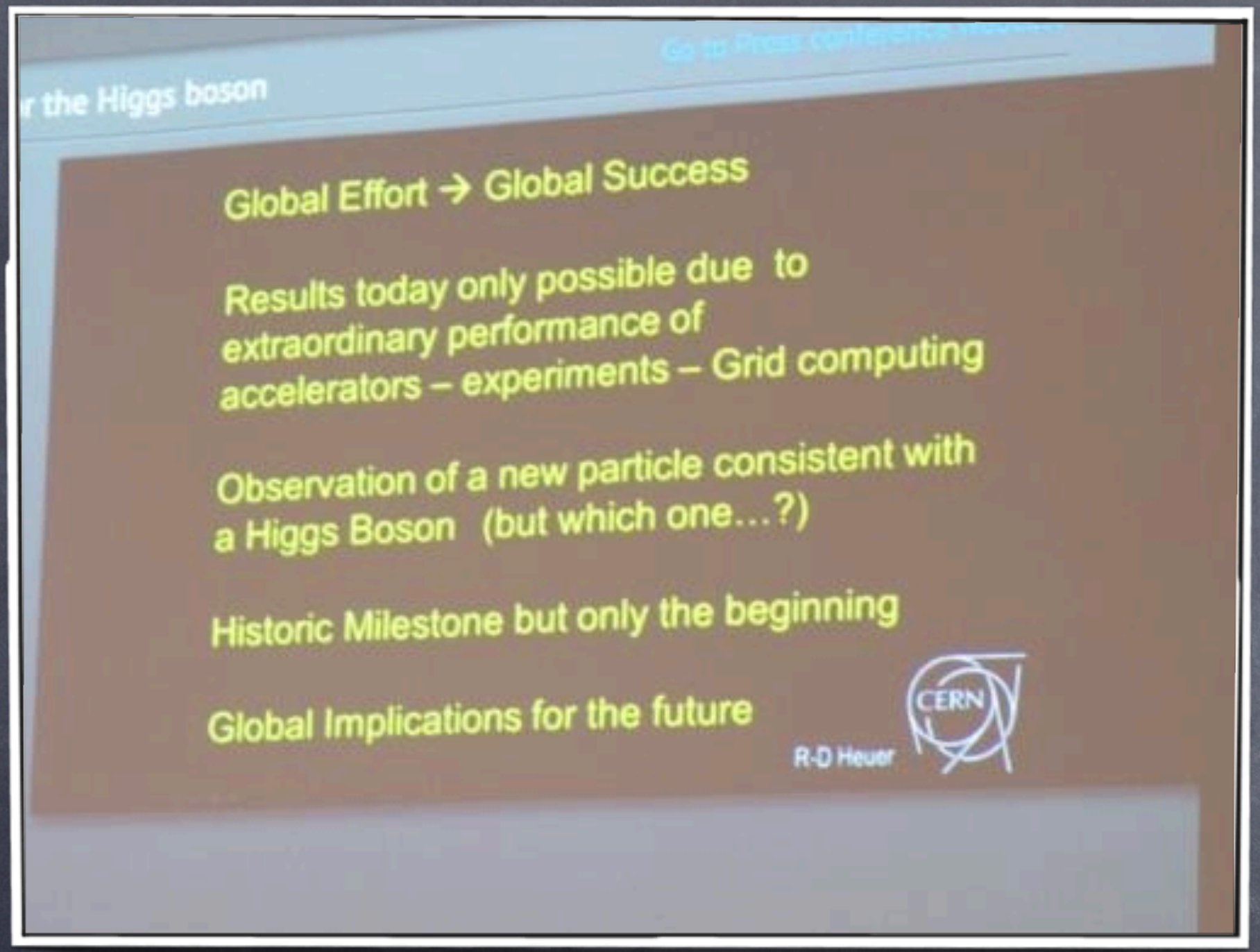
A long night



Peter Higgs

Englert

Where were you when....



Rolf:
I think we have it, you agree?
We have a discovery. We should state it. We observed a new particle, consistent with the Higgs Boson.
It is a milestone.

Higgs: Really , I did not expect to see it in my lifetime


I was looking for you for over 20 years
Now you have found me

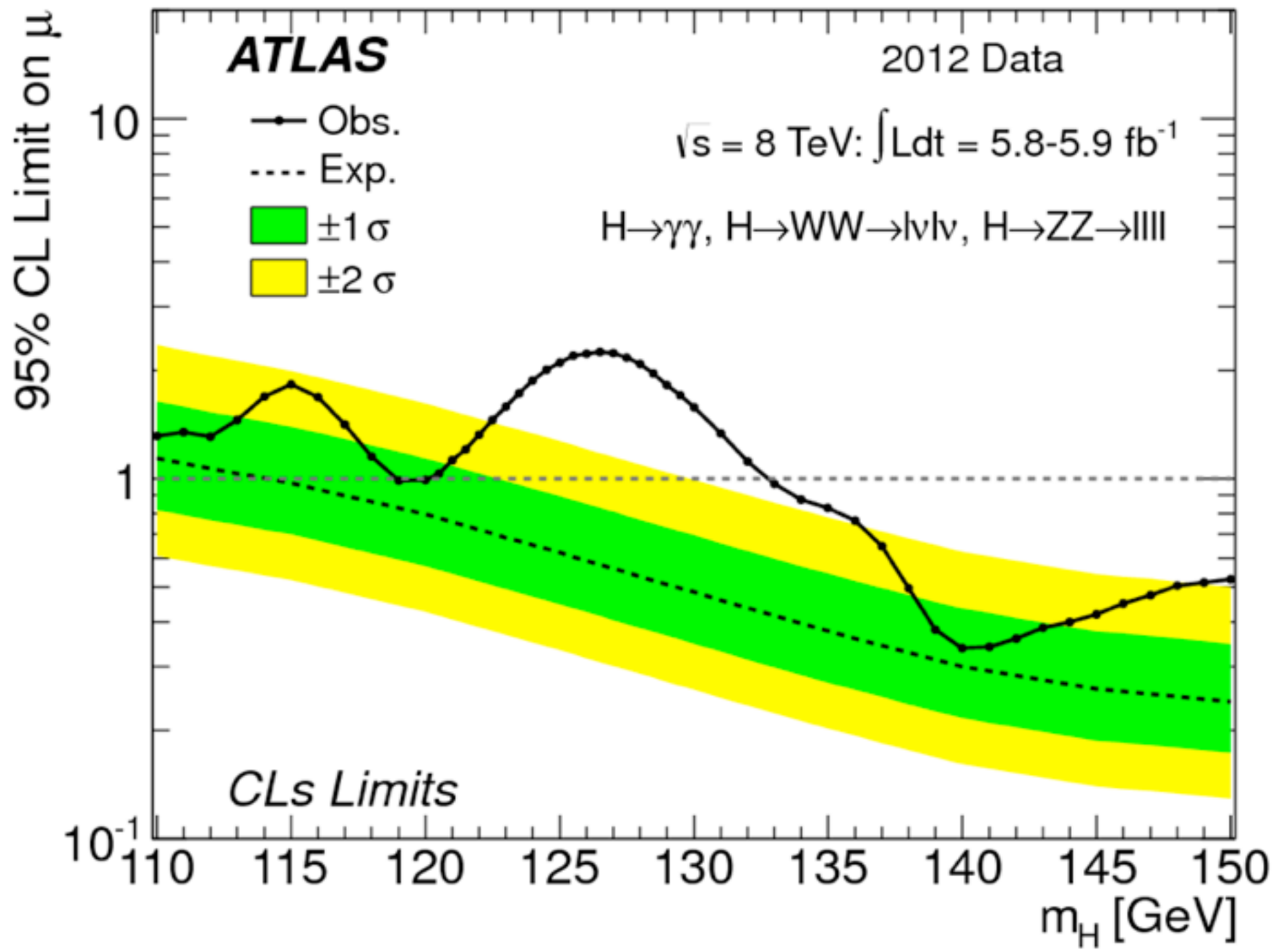
ATLAS Higgs Group

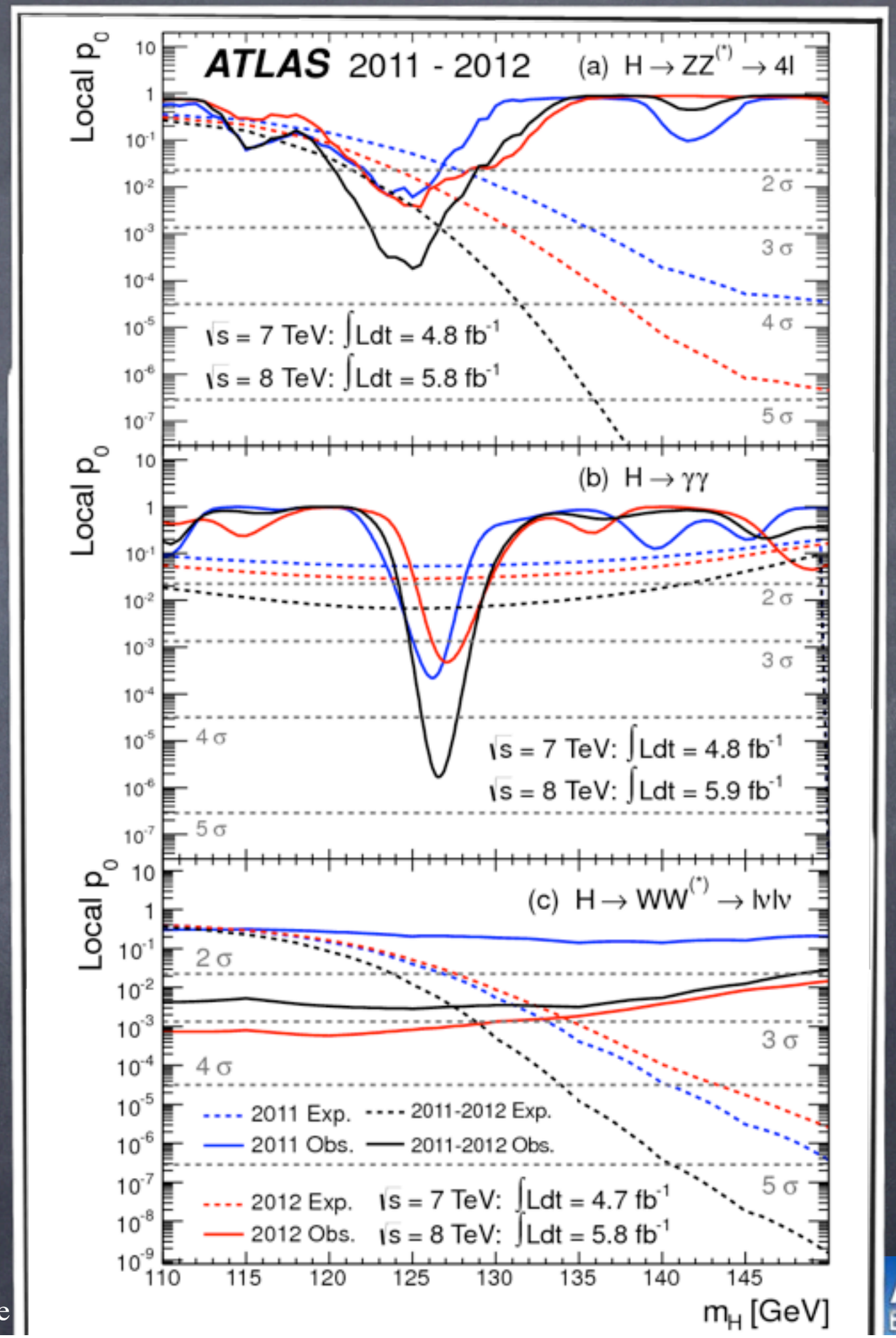
ATLAS Higgs Group

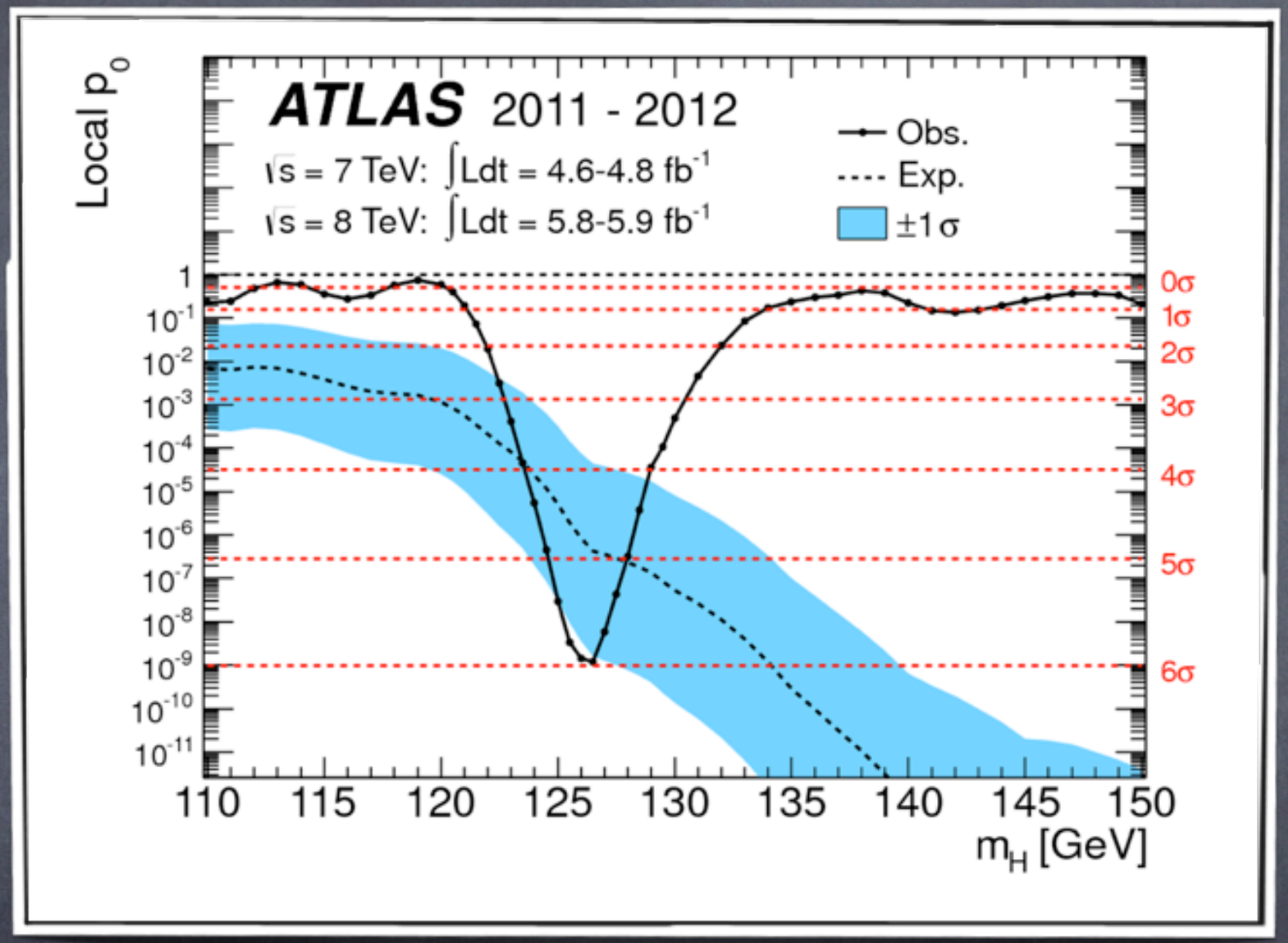

40

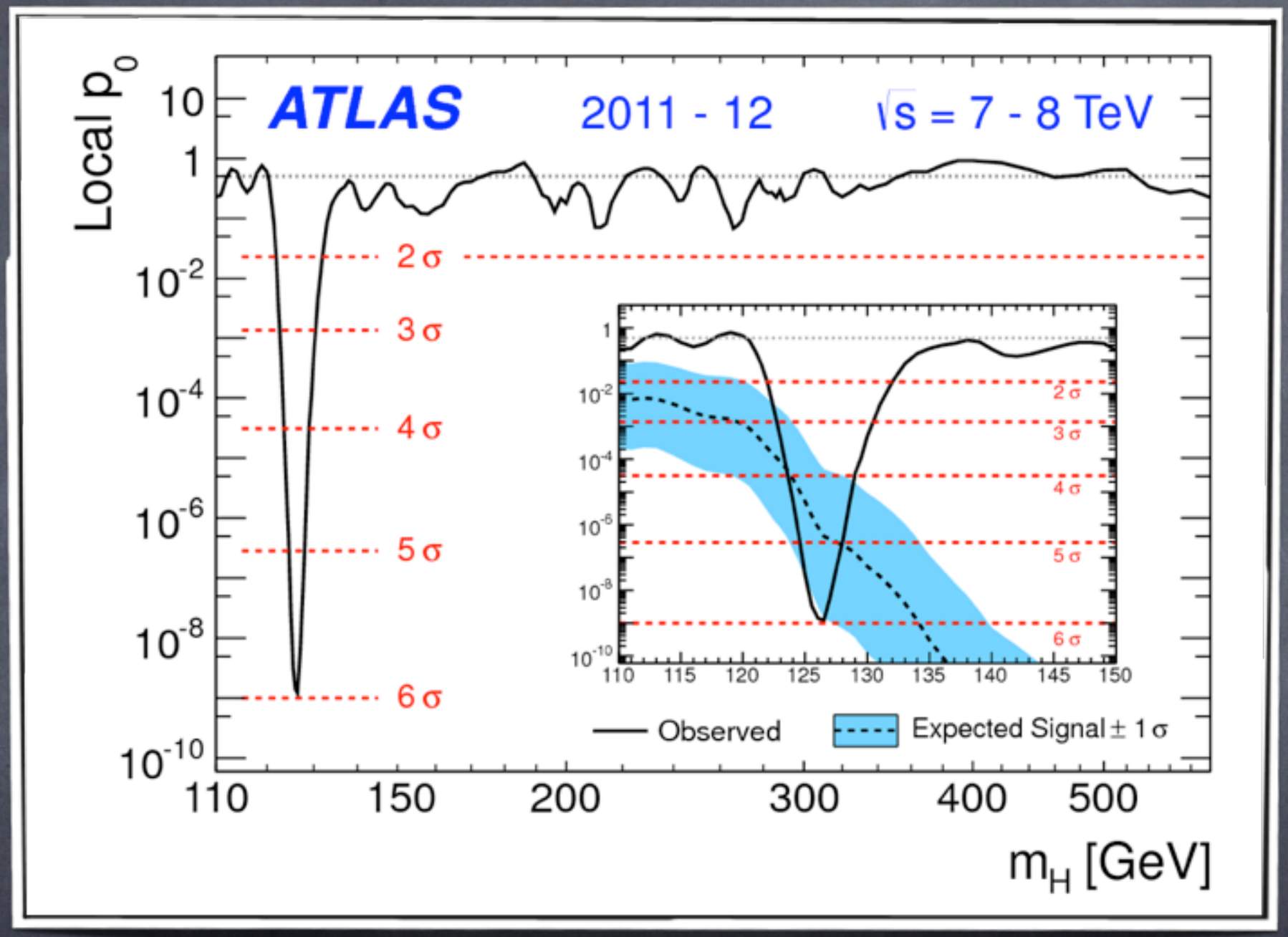
Disclaimer

- Correlated uncertainties (Jet energy scales, Luminosity etc... taken into account)
- When data driven methods are used, systematics are not correlated
- Theory uncertaintes are carefully taken into account across channels using the recommendation of the LHC Higgs cross section group


ATLAS
2012 Data
Obs.
Exp.
±1 σ
±2 σ
√s = 8 TeV: ∫Ldt = 5.8-5.9 fb⁻¹
H→γγ, H→WW→lνlν, H→ZZ→llll
95% CL Limit on μ
10
1
10⁻¹
CLs Limits
110
115
120
125
130
135
140
145
150
m_H [GeV]


ATLAS 2011 - 2012
(a) H → ZZ(*) → 4l
√s = 7 TeV: ∫Ldt = 4.8 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
(b) H → γγ
√s = 7 TeV: ∫Ldt = 4.8 fb-1
√s = 8 TeV: ∫Ldt = 5.9 fb-1
(c) H → WW(*) → lνlν
2011 Exp.
2011-2012 Exp.
2011 Obs.
2011-2012 Obs.
2012 Exp.
2012 Obs.
√s = 7 TeV: ∫Ldt = 4.7 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
Local p0
mH [GeV]
2σ
3σ
4σ
5σ

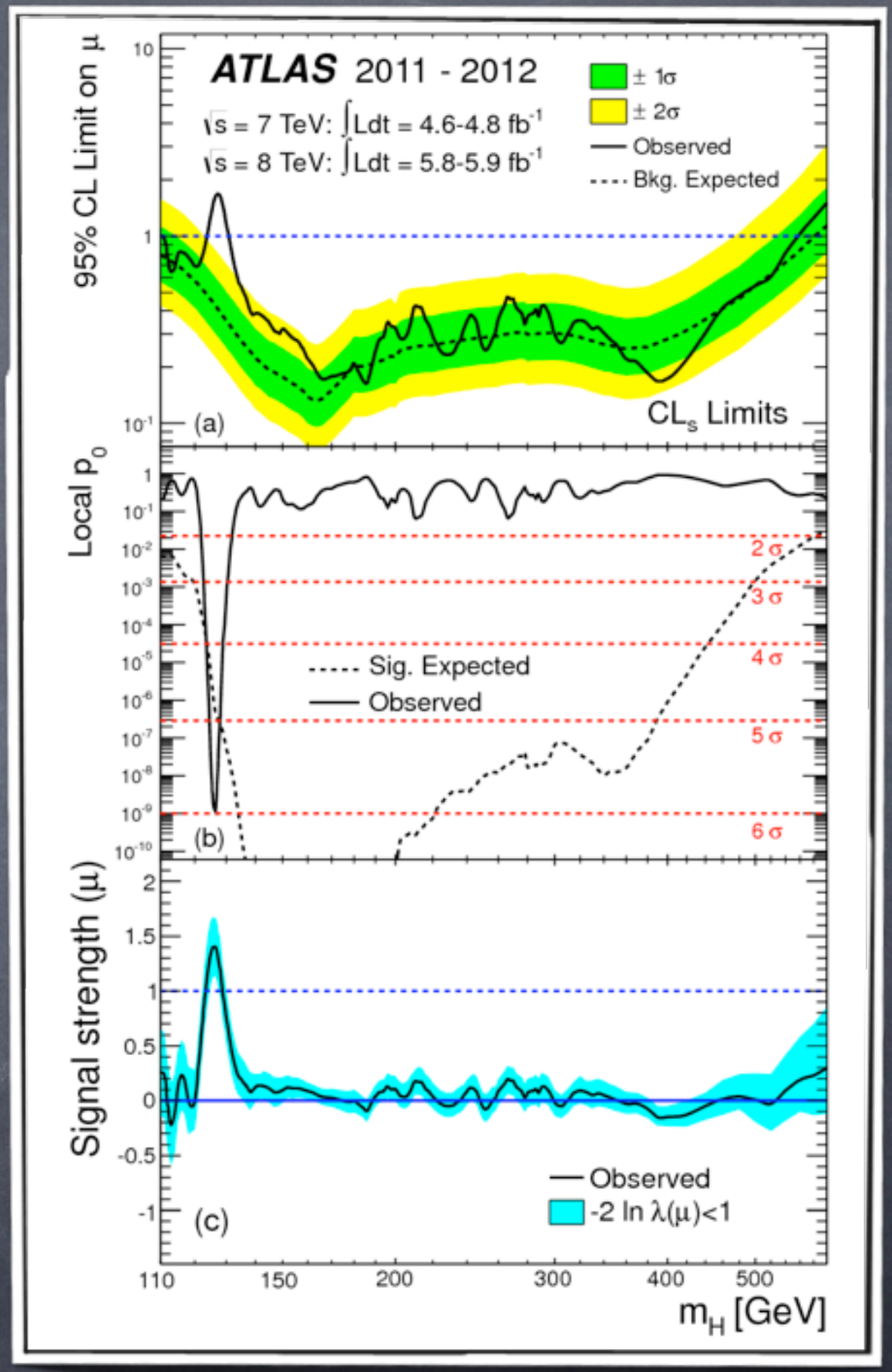

ATLAS 2011 - 2012
√s = 7 TeV: ∫Ldt = 4.6-4.8 fb⁻¹
√s = 8 TeV: ∫Ldt = 5.8-5.9 fb⁻¹
Obs.
Exp.
±1σ
Local p0
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
0σ
1σ
2σ
3σ
4σ
5σ
6σ
110
115
120
125
130
135
140
145
150
mH [GeV]



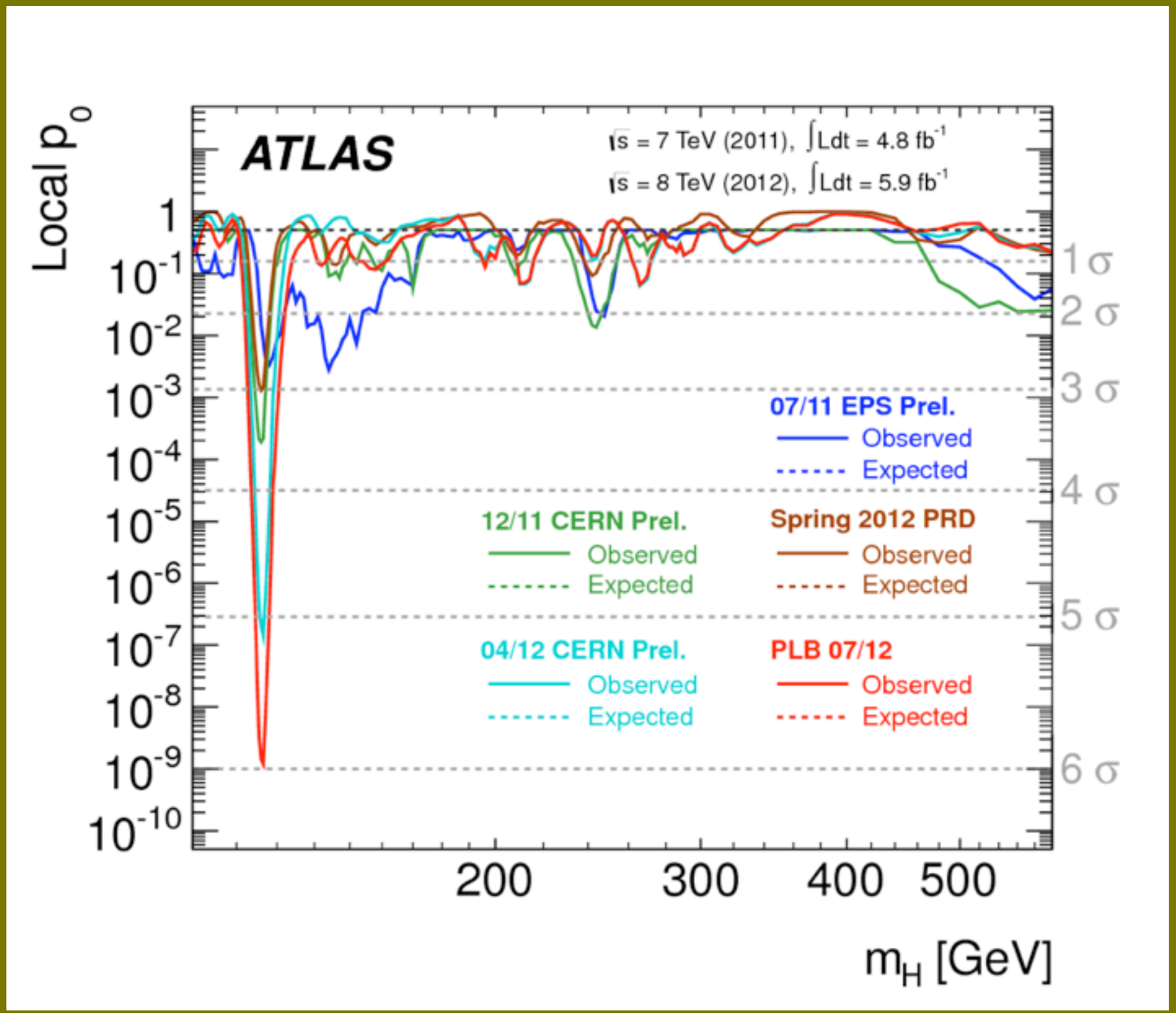
Excellent consistency (better than 2σ !) of the data with the background-only hypothesis over full mass spectrum

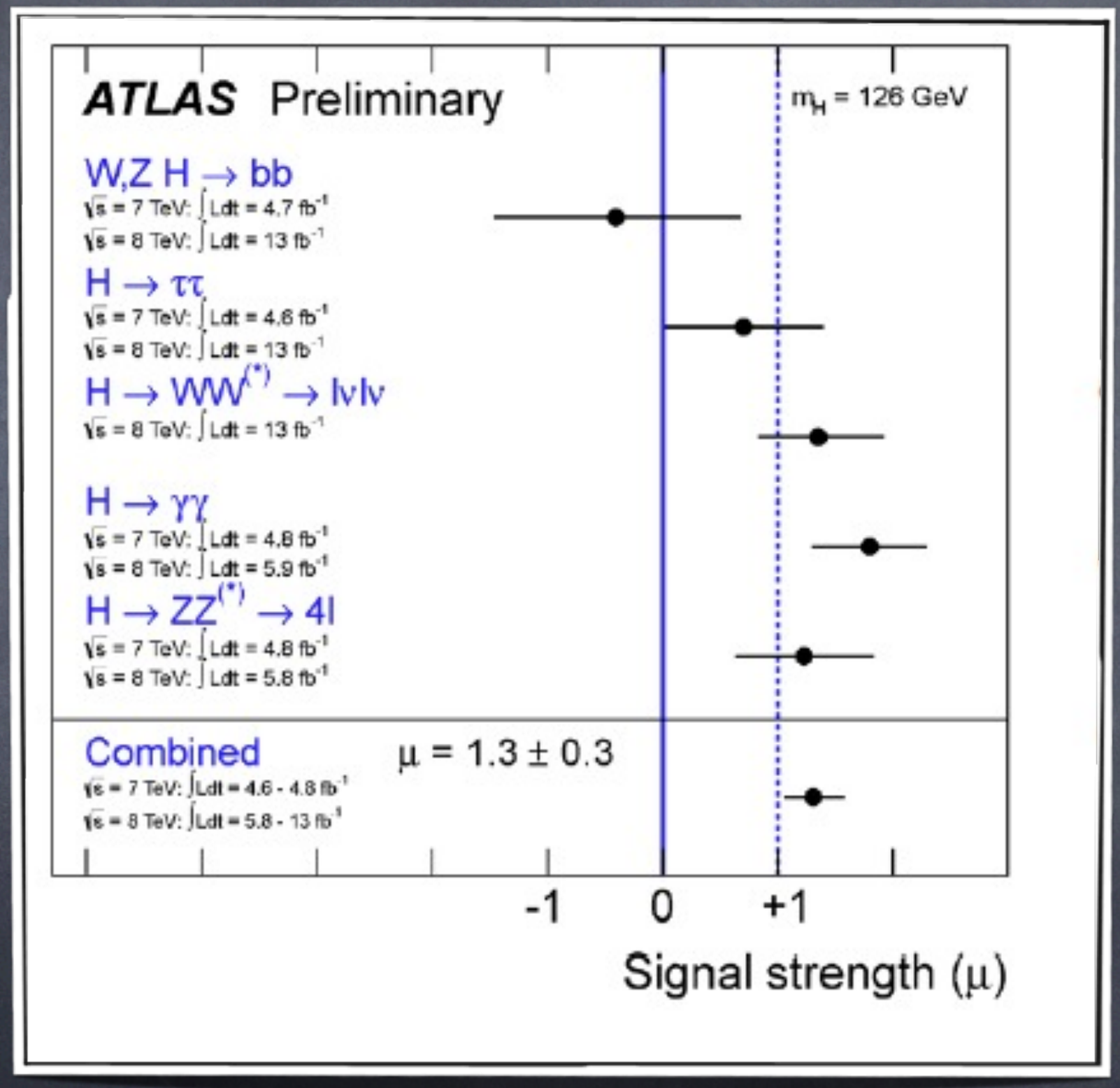
except in one region

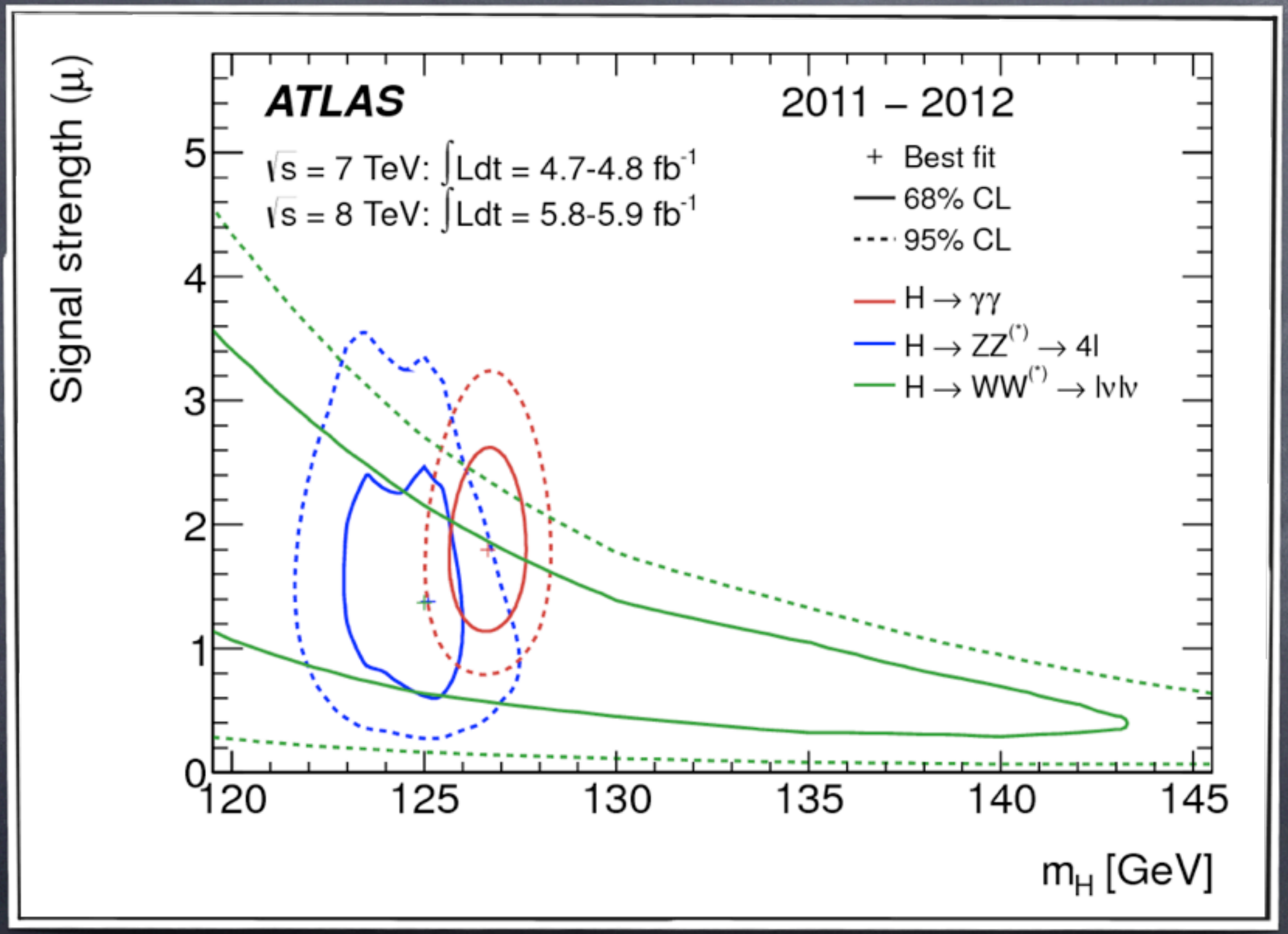
Maximum excess observed at	m_H = 126.0+-0.4 GeV
Local significance	5.9σ
Probability of B up-fluctuation	10^{-9}
Expected from SM Higgs m_H=126.5	4.9 σ



Evolution of the excess with time

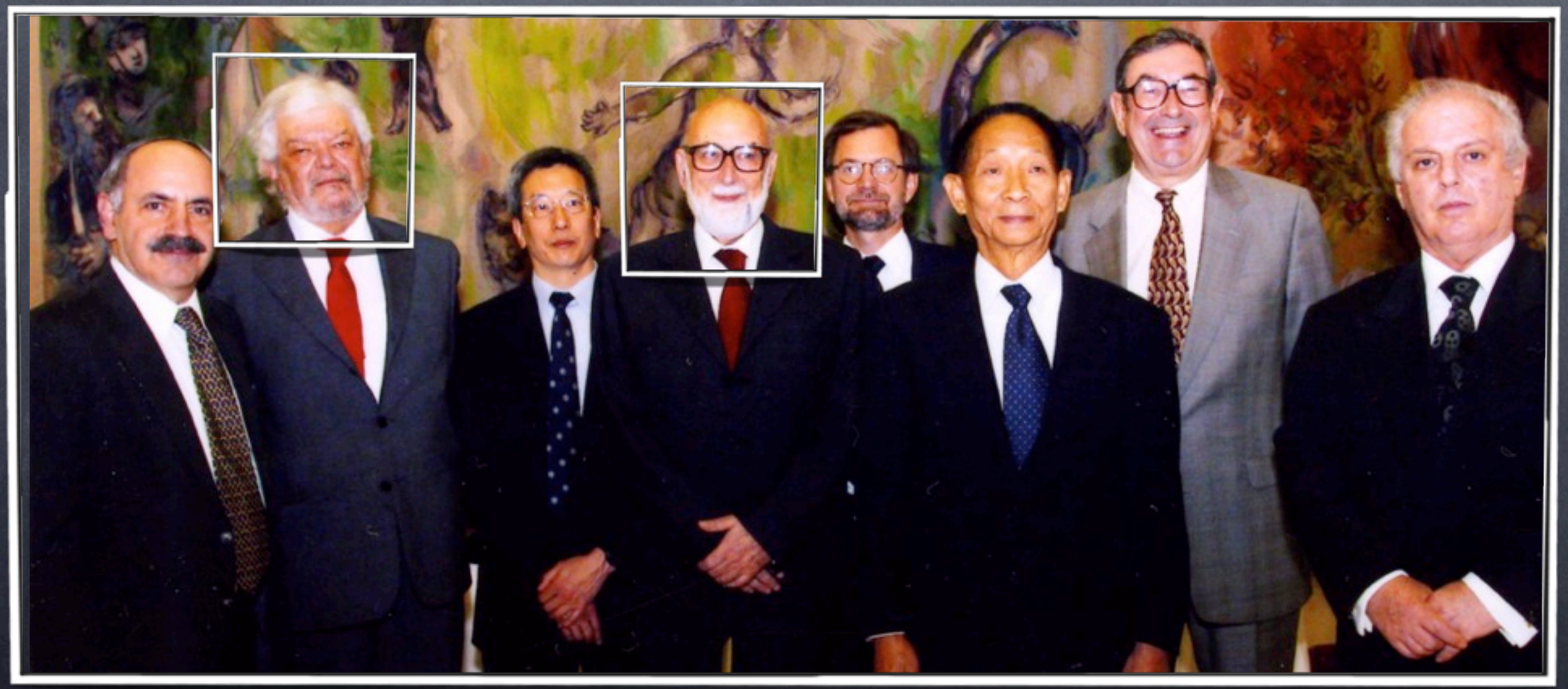



ATLAS Preliminary
m_H = 126 GeV
W,Z H → bb
√s = 7 TeV: ∫Ldt = 4.7 fb⁻¹
√s = 8 TeV: ∫Ldt = 13 fb⁻¹
H → ττ
√s = 7 TeV: ∫Ldt = 4.6 fb⁻¹
√s = 8 TeV: ∫Ldt = 13 fb⁻¹
H → WW(*) → lνlν
√s = 8 TeV: ∫Ldt = 13 fb⁻¹
H → γγ
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
√s = 8 TeV: ∫Ldt = 5.9 fb⁻¹
H → ZZ(*) → 4l
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
√s = 8 TeV: ∫Ldt = 5.8 fb⁻¹
Combined
√s = 7 TeV: ∫Ldt = 4.6 - 4.8 fb⁻¹
√s = 8 TeV: ∫Ldt = 5.8 - 13 fb⁻¹
μ = 1.3 ± 0.3
-1
0
+1
Signal strength (μ)


ATLAS
2011 – 2012
√s = 7 TeV: ∫Ldt = 4.7-4.8 fb⁻¹
√s = 8 TeV: ∫Ldt = 5.8-5.9 fb⁻¹
Best fit
68% CL
95% CL
H → γγ
H → ZZ(*) → 4l
H → WW(*) → lνlν
Signal strength (μ)
m_H [GeV]
0
1
2
3
4
5
120
125
130
135
140
145

A Prelude to the Nobel Prize

- The 2004 Wolf prize, awarded by the Wolf Foundation, is often thought to be the most prestigious prize in physics after the Nobel prize
  (in the pic. Brout & Englert).



A Prelude to the Nobel Prize

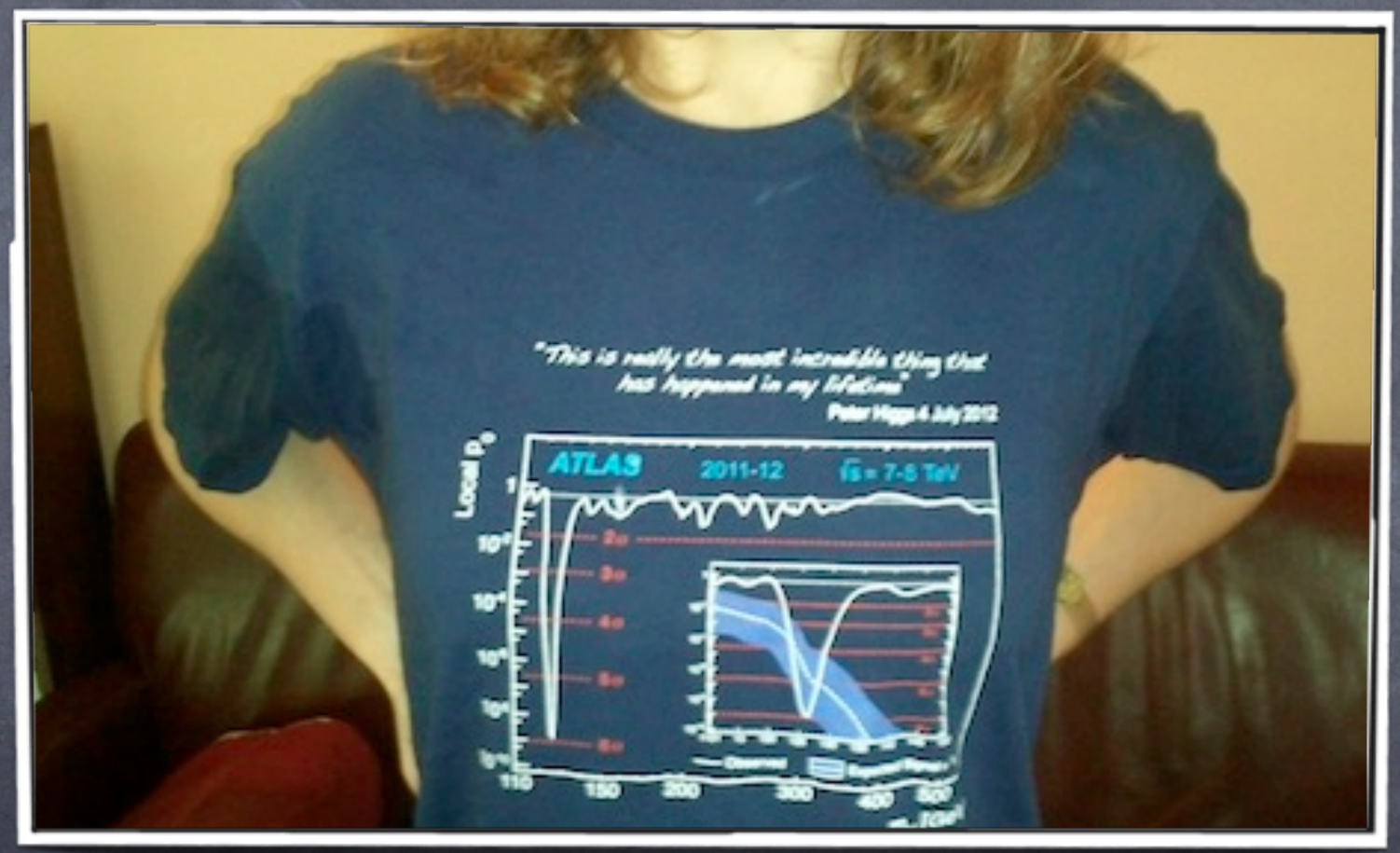
- 2010 Sakurai Prize awarded for 1964 Higgs Boson theory work to Hagen, Guralnik, Kibble, Brout, Englert & Higgs


4th July 2012
Higgs Hunters
Independence
Day

ATLAS T-shirt

- This is the most incredible thing that have happned to me in my lifetime

  P. Higgs 4th July 2012



A Phenomenological Profile of the Higgs Boson

1976

Nuclear Physics B106 (1976) 292–340

A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
CERN, Geneva

Received 7 November 1975

The situation with regard to Higgs bosons is unsatisfactory. First it should be stressed that they may well not exist. Higgs bosons are introduced to give intermediate vector bosons masses through spontaneous symmetry breaking. However, this symmetry breaking could be achieved dynamically [10] without elementary Higgs bosons. Thus the confirmation or exclusion of their existence would be an important constraint on gauge theory model building. Unfortunately, no way is known to calculate the mass of a Higgs boson, at least in the context of the popular Weinberg-Salam [11]

A Phenomenological Profile of the Higgs Boson

1976

Nuclear Physics B106 (1976) 292–340

A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

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CERN, Geneva

Received 7 November 1975

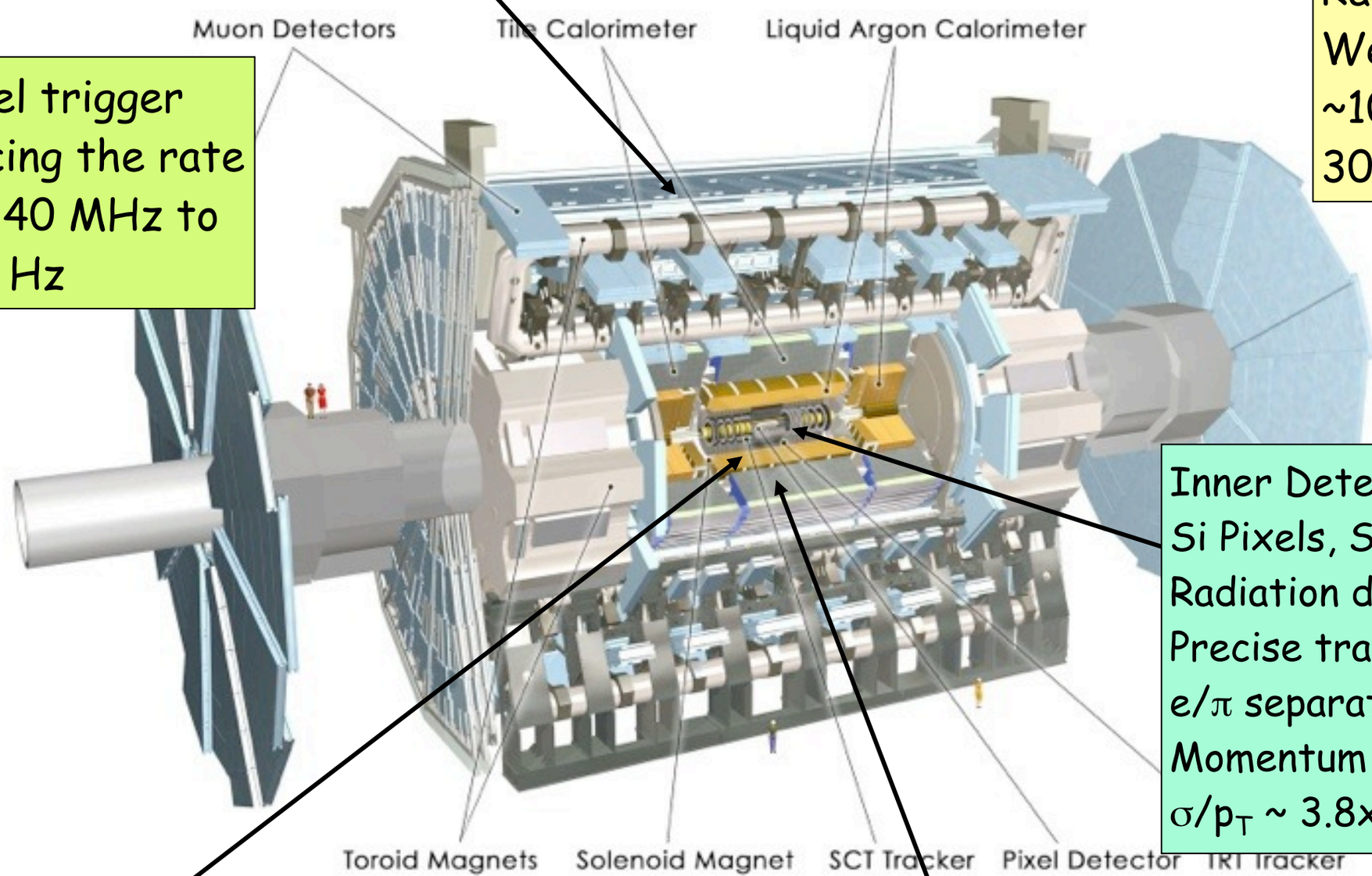
We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

Thank You

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 1 TeV

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

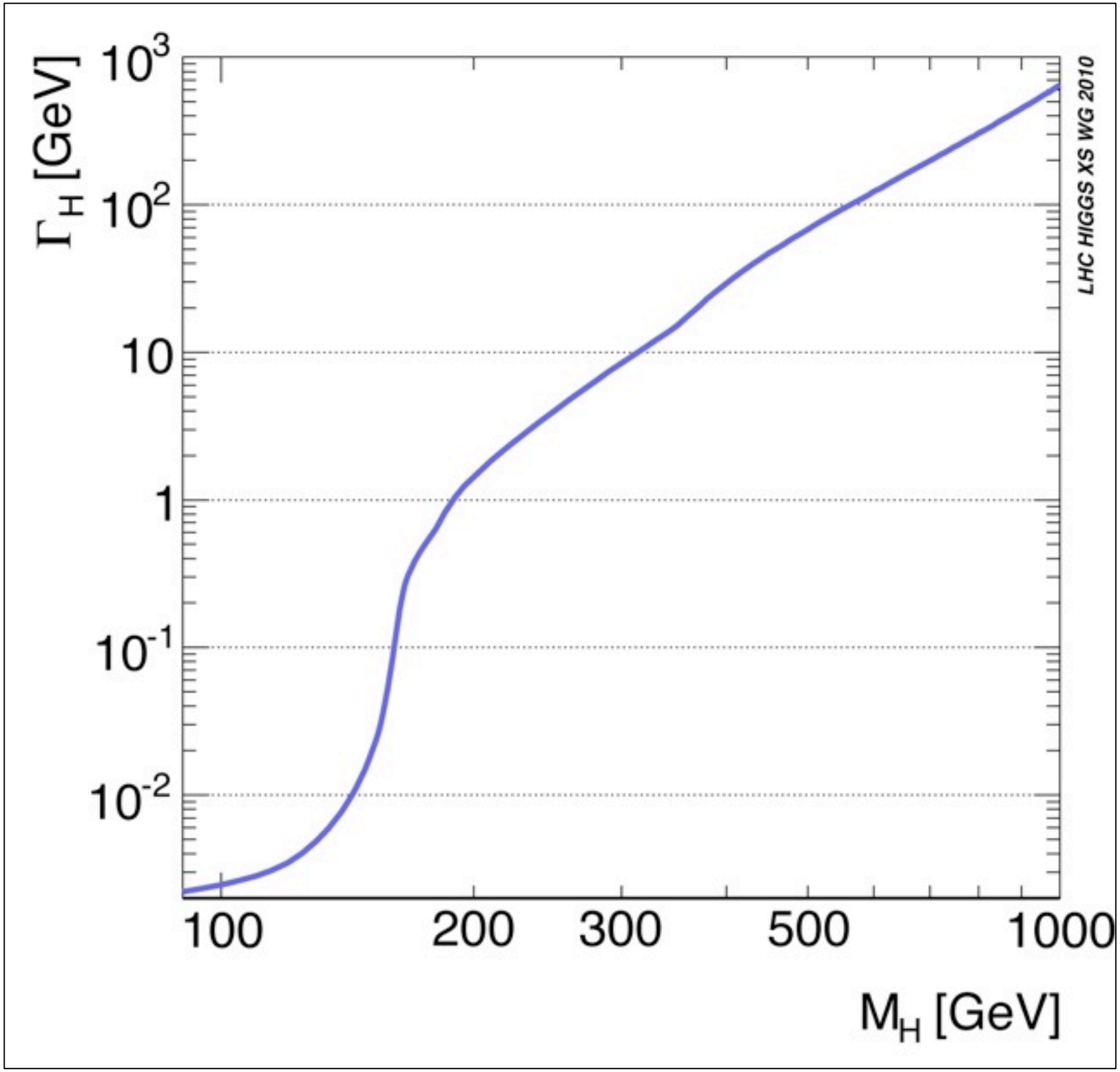
3-level trigger reducing the rate from 40 MHz to ~200 Hz



Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing, e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\mathrm{GeV}) \oplus 0.015$

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$


Γ_H [GeV]
10^3
10^2
10
1
10^{-1}
10^{-2}
100
200
300
500
1000
M_H [GeV]
LHC HIGGS XS WG 2010