LHC Results on the Search for the Standard Model Higgs Boson

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Outline of the talk

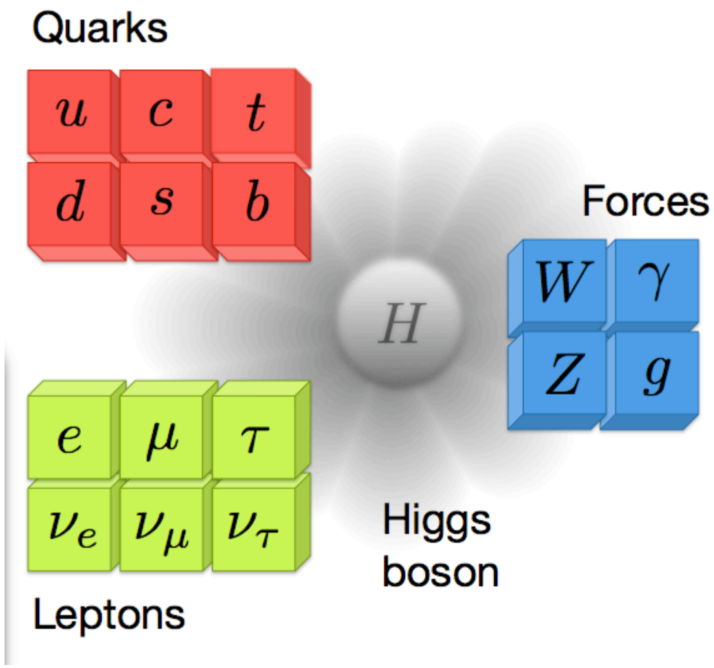
- Short introduction to the SM Higgs boson.
- Short overview of the LHC detectors
  - the LHC accelerator
  - ATLAS
  - CMS
  - Highlight of the performance
- Higgs Hunting basics.
  - Production mechanisms at LHC.
  - Decay modes and major experimental signatures
- Searches for the SM Higgs boson.
  - High mass region
  - Low mass region
- Combination of the searches and discussion of the results.
- Perspectives and Conclusion.

Short introduction to the SM Higgs boson.

The Standard Model: a “not yet complete” triumph.

The Standard Model is one of the most successful theory ever. It is simple and elegant: it explains a huge amount of data using only 19 parameters. It is sort of a monument of the physics of the 20° century by bringing together quantum mechanics and special relativity. It yielded an incredibly precise set of predictions (accuracy $<10^{-4}$ in tens of measurements up to an impressive 10^{-12} in electron g-2).

All of them have been so far verified…. but one.



Quantity	Value	Standard Model	Pull
m_t [GeV]	$172.7 \pm 2.9 \pm 0.6$	172.7 ± 2.8	0.0
M_W [GeV]	80.450 ± 0.058	80.376 ± 0.017	1.3
	80.392 ± 0.039		0.4
M_Z [GeV]	91.1876 ± 0.0021	91.1874 ± 0.0021	0.1
Γ_Z [GeV]	2.4952 ± 0.0023	2.4968 ± 0.0011	−0.7
$\Gamma(\text{had})$ [GeV]	1.7444 ± 0.0020	1.7434 ± 0.0010	—
$\Gamma(\text{inv})$ [MeV]	499.0 ± 1.5	501.65 ± 0.11	—
$\Gamma(\ell^+\ell^-)$ [MeV]	83.984 ± 0.086	83.996 ± 0.021	—
σ_{had} [nb]	41.541 ± 0.037	41.467 ± 0.009	2.0
R_e	20.804 ± 0.050	20.756 ± 0.011	1.0
R_μ	20.785 ± 0.033	20.756 ± 0.011	0.9
R_τ	20.764 ± 0.045	20.801 ± 0.011	−0.8
R_b	0.21629 ± 0.00066	0.21578 ± 0.00010	0.8
R_c	0.1721 ± 0.0030	0.17230 ± 0.00004	−0.1
$A_{FB}^{(0,e)}$	0.0145 ± 0.0025	0.01622 ± 0.00025	−0.7
$A_{FB}^{(0,\mu)}$	0.0169 ± 0.0013		0.5
$A_{FB}^{(0,\tau)}$	0.0188 ± 0.0017		1.5
$A_{FB}^{(0,b)}$	0.0992 ± 0.0016	0.1031 ± 0.0008	−2.4
$A_{FB}^{(0,c)}$	0.0707 ± 0.0035	0.0737 ± 0.0006	−0.8
$A_{FB}^{(0,s)}$	0.0976 ± 0.0114	0.1032 ± 0.0008	−0.5
$\bar{s}_\ell^2(A_{FB}^{(0,q)})$	0.2324 ± 0.0012	0.23152 ± 0.00014	0.7
	0.2238 ± 0.0050		−1.5
A_e	0.15138 ± 0.00216	0.1471 ± 0.0011	2.0
	0.1544 ± 0.0060		1.2
	0.1498 ± 0.0049		0.6
A_μ	0.142 ± 0.015		−0.3
A_τ	0.136 ± 0.015		−0.7
	0.1439 ± 0.0043		−0.7
A_b	0.923 ± 0.020	0.9347 ± 0.0001	−0.6
A_c	0.670 ± 0.027	0.6678 ± 0.0005	0.1
A_s	0.895 ± 0.091	0.9356 ± 0.0001	−0.4
g_L^2	0.30005 ± 0.00137	0.30378 ± 0.00021	−2.7
g_R^2	0.03076 ± 0.00110	0.03006 ± 0.00003	0.6
$g_V^{\nu e}$	-0.040 ± 0.015	-0.0396 ± 0.0003	0.0
$g_A^{\nu e}$	-0.507 ± 0.014	-0.5064 ± 0.0001	0.0
A_{PV}	-1.31 ± 0.17	-1.53 ± 0.02	1.3
$Q_W(\text{Cs})$	-72.62 ± 0.46	-73.17 ± 0.03	1.2
$Q_W(\text{Tl})$	-116.6 ± 3.7	-116.78 ± 0.05	0.1
$\frac{\Gamma(b\to s\gamma)}{\Gamma(b\to Xe\nu)}$	$3.35^{+0.50}_{-0.44} \times 10^{-3}$	$(3.22 \pm 0.09) \times 10^{-3}$	0.3
$\frac{1}{2}(g_\mu - 2 - \frac{\alpha}{\pi})$	4511.07 ± 0.82	4509.82 ± 0.10	1.5
τ_τ [fs]	290.89 ± 0.58	291.87 ± 1.76	−0.4

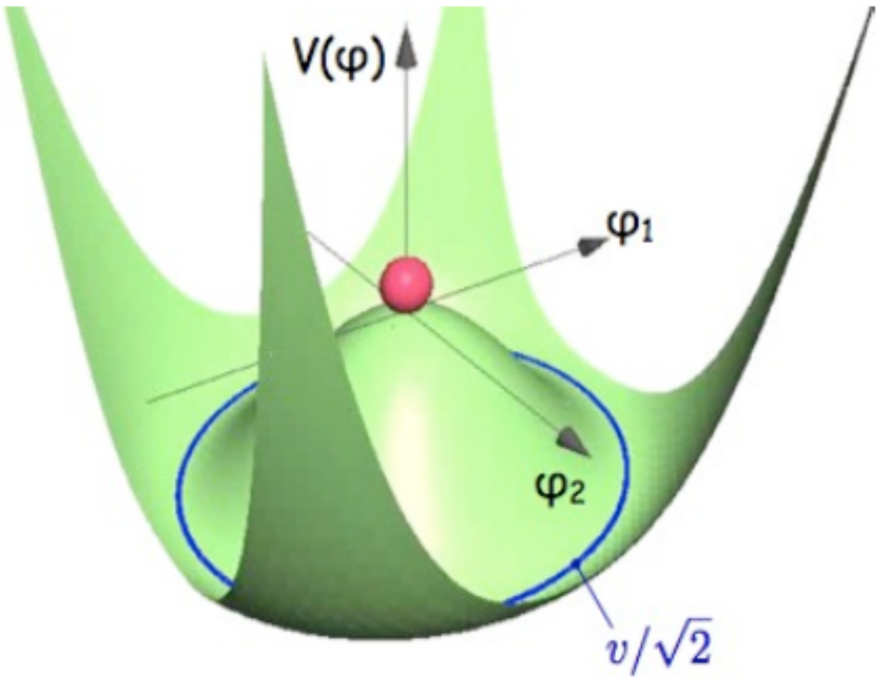
The elusive SM Higgs boson that plays such an important role in the theory has escaped so far all attempts of direct detection. It is the last (and crucial) missing piece.

Short Introduction to the SM Higgs Boson

The SM Higgs has been proposed to provide an elegant solution for the ElectroWeak Simmetry Breaking mechanism.

It introduces a scalar field with a non-vanishing value at zero. The scalar boson appears as an excitation of the field above its ground state.

Horizontal excitation→ massless mode.
Vertical excitation →massive mode.
W and Z become massive while the photon remains massless.



$$\boxed{M_Z \cos\theta_W = M_W = \frac{1}{2} v g}$$

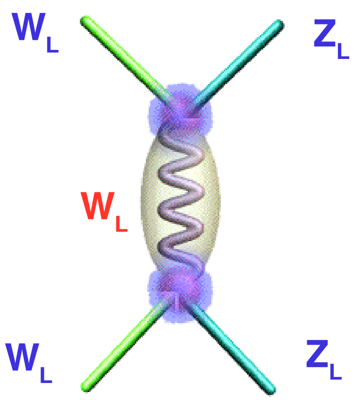
$$g^2 = 4\sqrt{2} M_W^2 G_F$$

Unfortunately, the theory does not predict precisely the mass of the boson

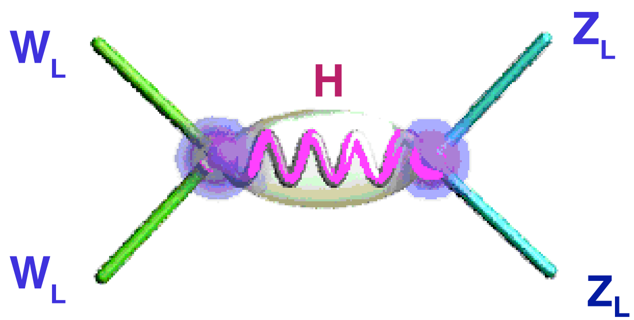
M_H is a free parameter $M_H^2 = 2\,\lambda\, v^2$
g=0.6574; v=246GeV

Constraints on the mass of the SM Higgs

Unitarity constraints: the exchange of a Higgs boson would allow to regulate the scattering amplitudes at high energies



To avoid unitarity violation (σ=~s) un-physical (>1) scattering probability of longitudinally polarized W bosons



$$A\left(W_L^+W_L^- \to Z_L Z_L\right) = \frac{G_F E^2}{8\sqrt{2}\pi}\left(1 - \frac{E^2}{E^2 - m_H^2}\right)$$

Without Higgs ⇨ SM limited to E < 1.2-1.4 TeV

With Higgs the SM is OK but ⇨ $M_H < 7\text{-}800\ \mathrm{GeV/c^2}$

Additional constrains on the Higgs mass

"Unitarity".

$$M_H < 700 - 800 \ GeV/c^2$$

"Triviality": Higgs self-coupling remains finite.

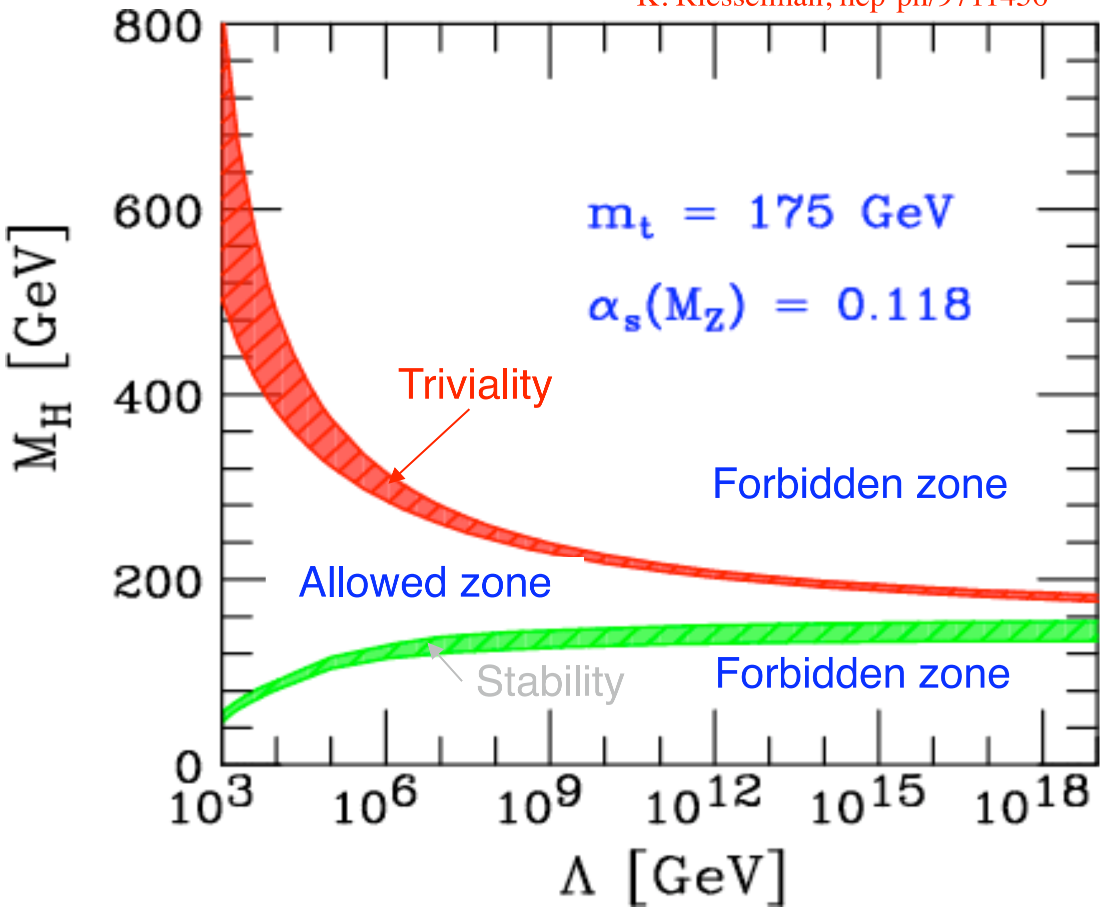
$$M_H^2 < \frac{4\pi^2 v^2}{3\ln(\Lambda/v)}$$

"Stability" of the vacuum.

$$M_H^2 > \frac{4m_t^4}{\pi^2 v^2}\ln(\Lambda/v)$$

Λ = cut-off scale

K. Riesselman, hep-ph/9711456



Constraints from EWK and direct searches

Constraints from EWK precision measurements favour a light Higgs with Standard Model like couplings (WW, ZZ, etc).

From the ElectroWeak fit

$M_H = 96(^{+31}_{-24})\,GeV/c^2$

$M_H < 158\,GeV/c^2$ at 95% CL.

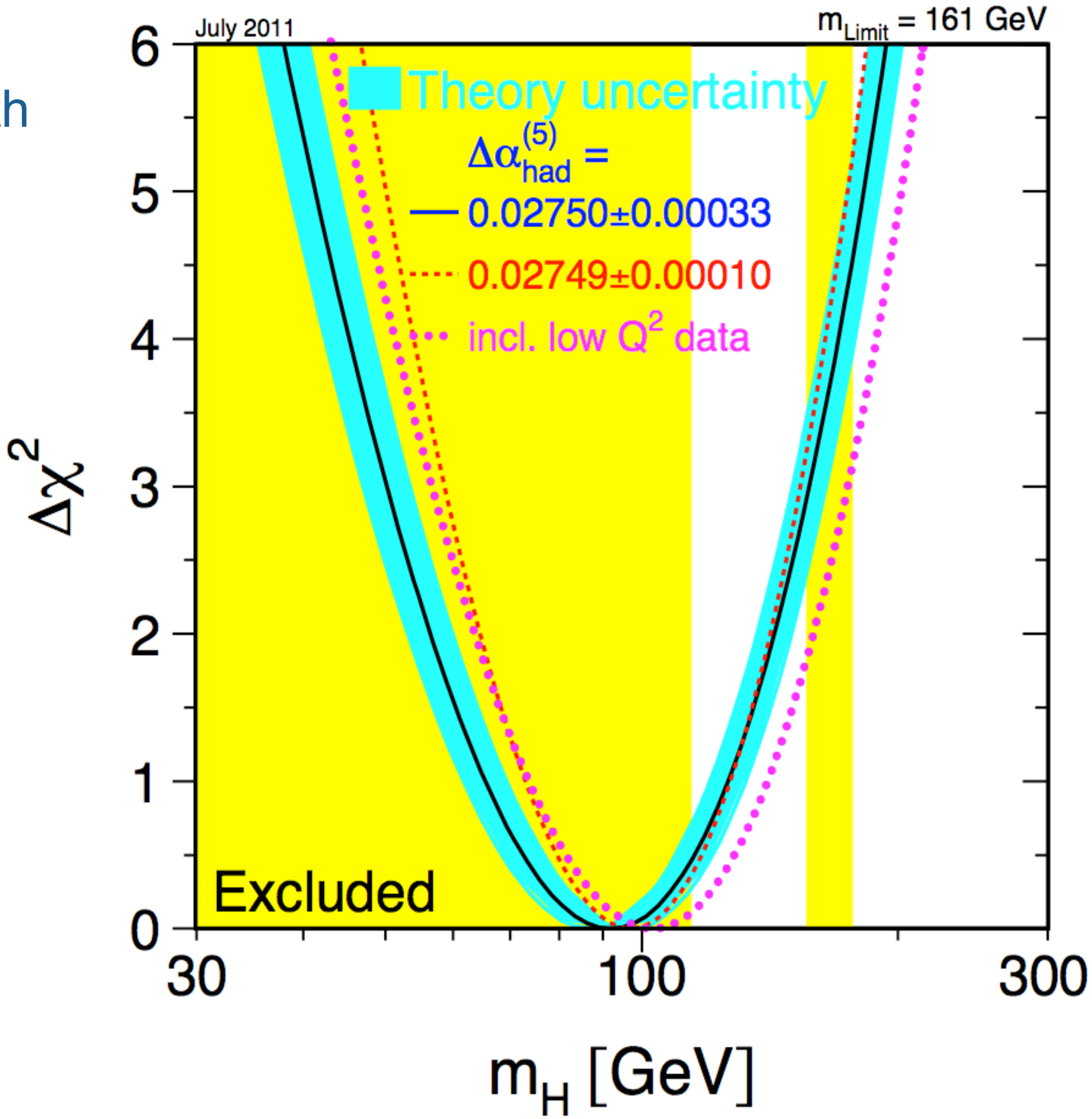
From direct search at LEP

$M_H > 114\,GeV/c^2$ at 95% CL.

From direct search at the Tevatron Collider

$175\,GeV/c^2 < M_H$

or $M_H < 158\,GeV/c^2$ at 95% CL.

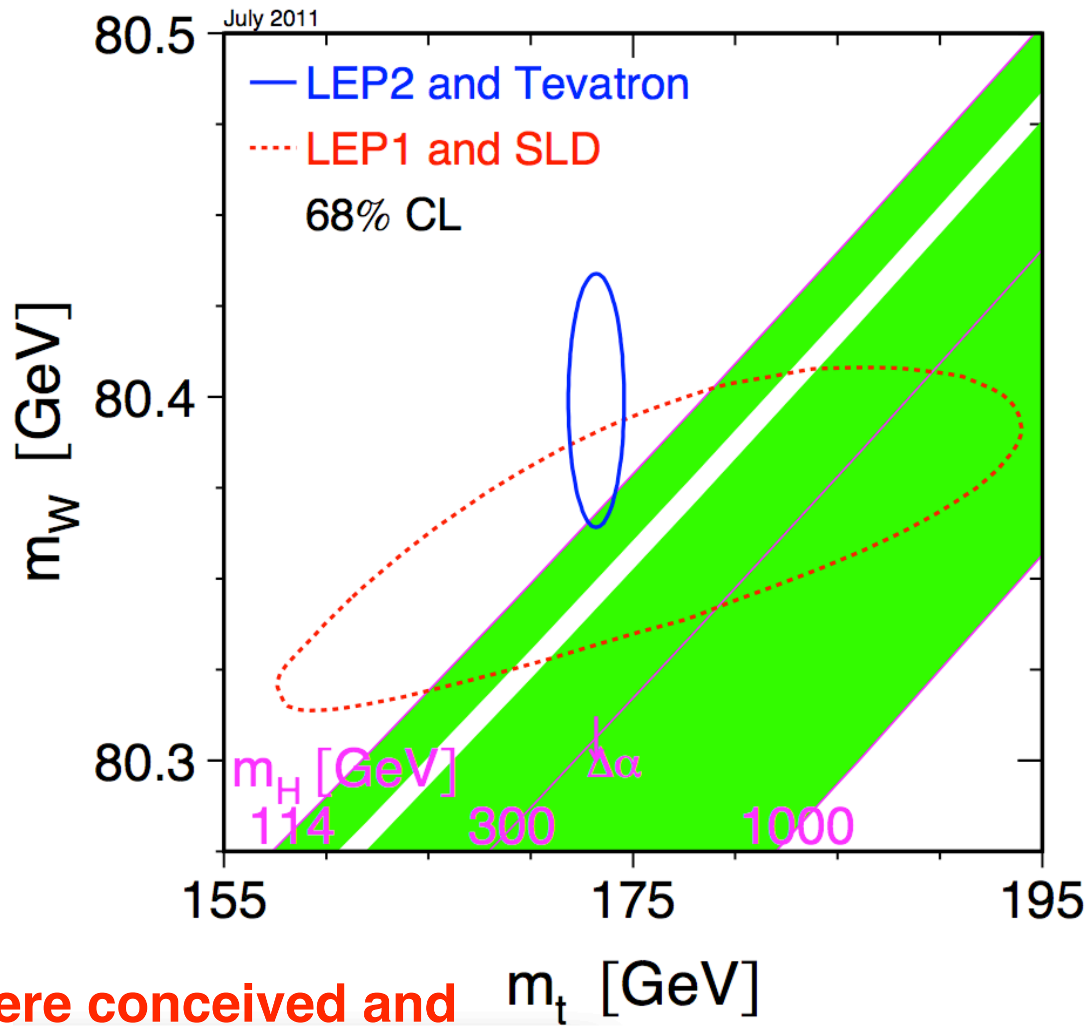


The state of the art before LHC

The global fit of the Electroweak parameters can be used to correlate, through radiative corrections, the mass of the Higgs to the mass of the W and of the Top.

Though electroweak data seem to favour a light mass Higgs there are logarithmic dependances so the constrains are not so strong.

Before the LHC results the Higgs boson was allowed to sit anywhere between 114GeV/c^2 and ~1TeV/c^2 apart a narrow band between 158 and 175 GeV/c^2 directly escluded by the Tevatron Collider.



The LHC and its major experiments were conceived and built to explore in depth the multi-TeV region and solve in a way or in another this major puzzle of particle physics.

Short overview of LHC and of its detectors.

The Large Hadron Collider: design parameters

Nominal settings	
Beam energy (TeV)	7.0
Number of particles per bunch	1.15 10^{11}
Number of bunches per beam	2808
Crossing angle (μrad)	285
Norm transverse emittance (μm rad)	3.75
Bunch length (cm)	7.55
Beta function at IP 1, 2, 5, 8 (m)	0.55,10,0.55,10

$$L = \frac{N_b^2 n_b f_{\text{rev}} \gamma_r}{4\pi \varepsilon_n \beta *} F$$

Cost 3 G€

3.2 x 10^{14} p/ beam

25 ns between crossing

Derived parameters	
Luminosity in IP 1 & 5 ($cm^{-2}\ s^{-1}$)	10^{34}
Luminosity in IP 2 & 8 ($cm^{-2}\ s^{-1}$)*	~5 10^{32}
Transverse beam size at IP 1 & 5 (μm)	16.7
Transverse beam size at IP 2 & 8 (μm)	70.9
Stored energy per beam (MJ)	362

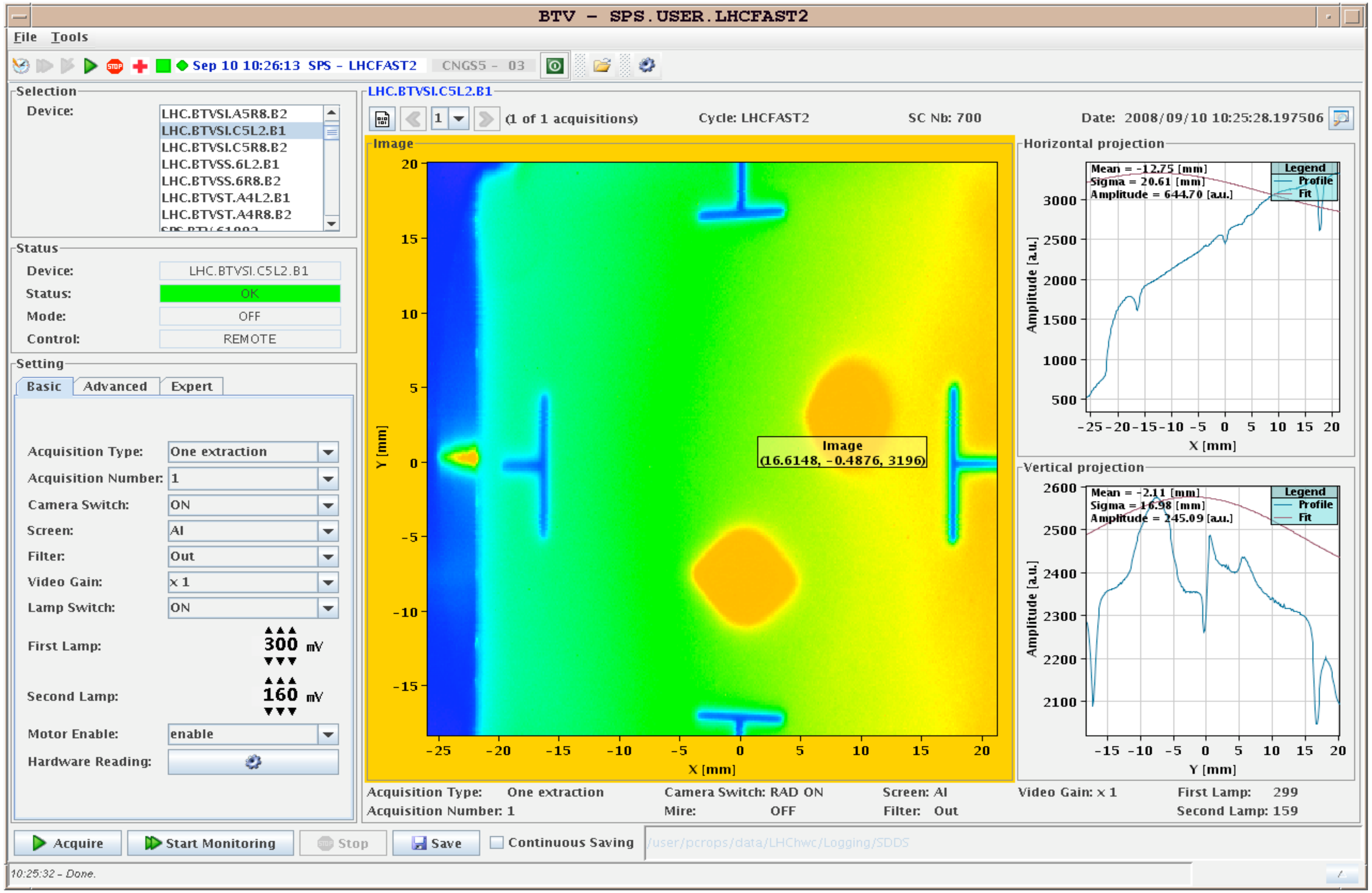
N_b = number of proton per bunch
n_b = number of bunches

f_{rev} = rotation frequency (~ 11Hz)
F = crossing angle factor

Rms transverse beam size =$\sqrt{\varepsilon\beta/\gamma}$
ε_n = renorm. transverse emittance
β^* = optics at beam crossing (m)
γ_r = relativistic factor

10/09/2008: first beam in LHC

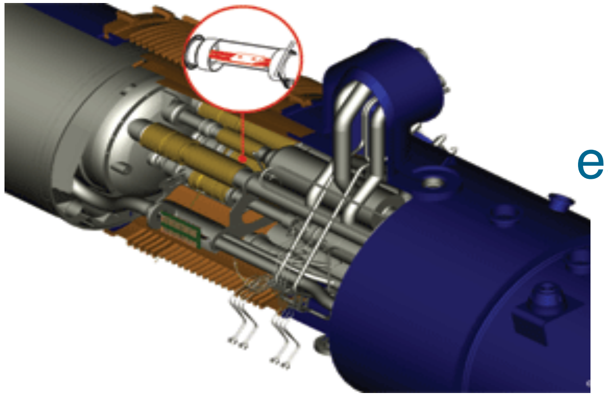
- 2 shots of clockwise beam: $2x10^9$ protons per beam



A lot of excitement in all control rooms

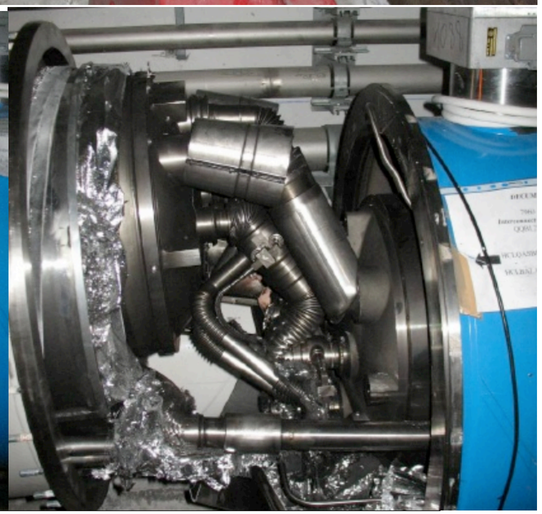
19/09/2008: our black friday

- An incident occurred during a powering test of one LHC sector for commissioning beam operation to 5 TeV. Massive helium loss in one arc of the tunnel; cryogenics and vacuum lost and important mechanical damage to tens of dipoles and quadrupoles
- The cause of the incident was determined to be a faulty electrical connection ("bus bar") between a dipole and a quadrupole.



Superfluid helium in quick expansion can easily displace a string of many 20t magnets…

… and these are the consequences: ~1 year of work to replace/repair/re-check 53 magnets and to put in place any sort of test and all possible preventive actions to avoid the same incident could happen again.



New plan for the LHC

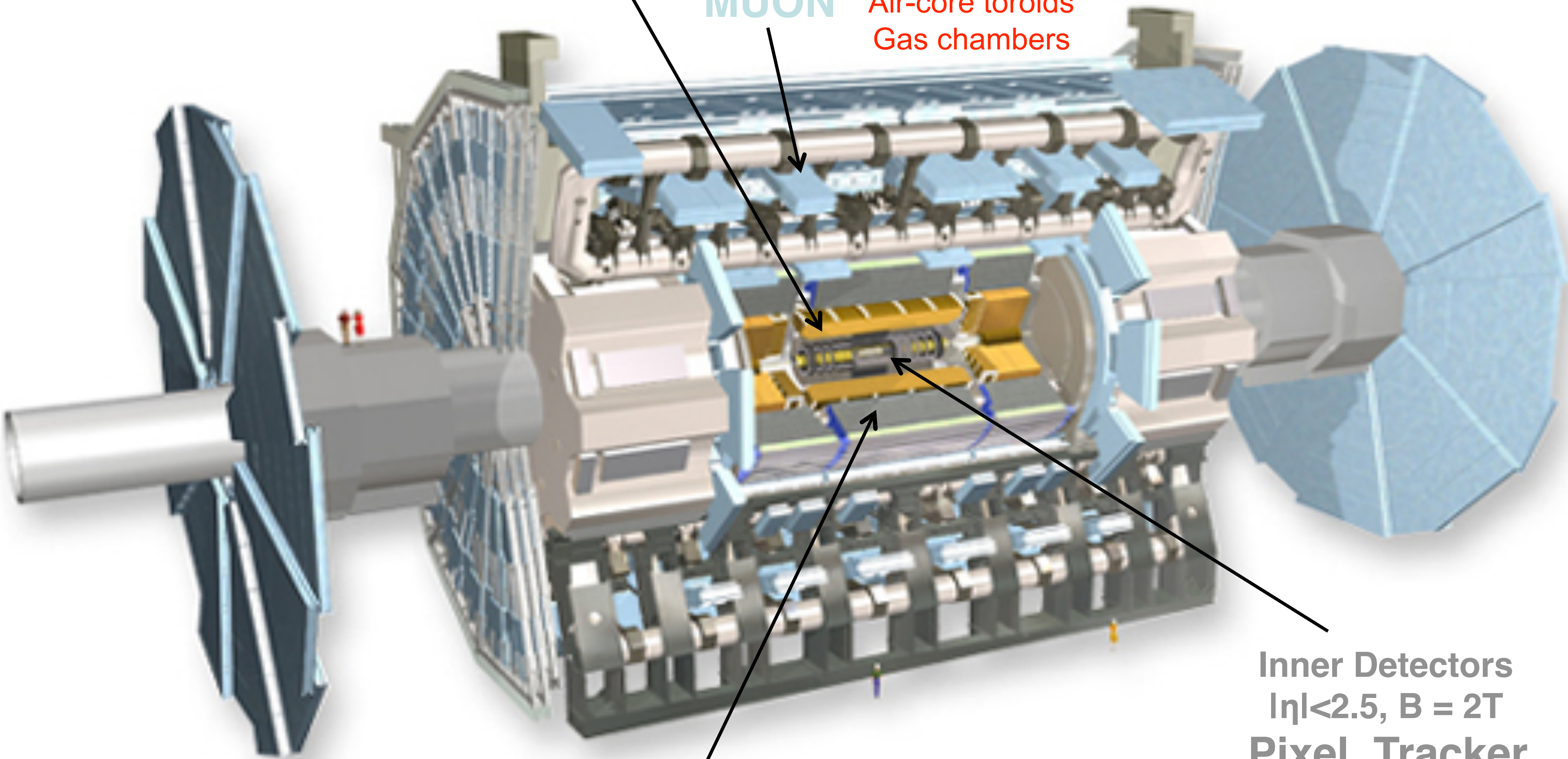
- **2010: first physics run, 7TeV, L>2x10^{32}cm^{-2}s^{-1}, (40pb^{-1} delivered)**
- **2011: 7TeV, L>3.5x10^{33}cm^{-2}s^{-1} (>5.5fb^{-1} delivered)**
- **2012: 8TeV , L≈ 7x10^{33}cm^{-2}s^{-1}(>15fb^{-1} promised to be delivered)**

- **Since 2010 LHC is running smoothly and with excellent performance often exceeding the most optimistic expectations.**

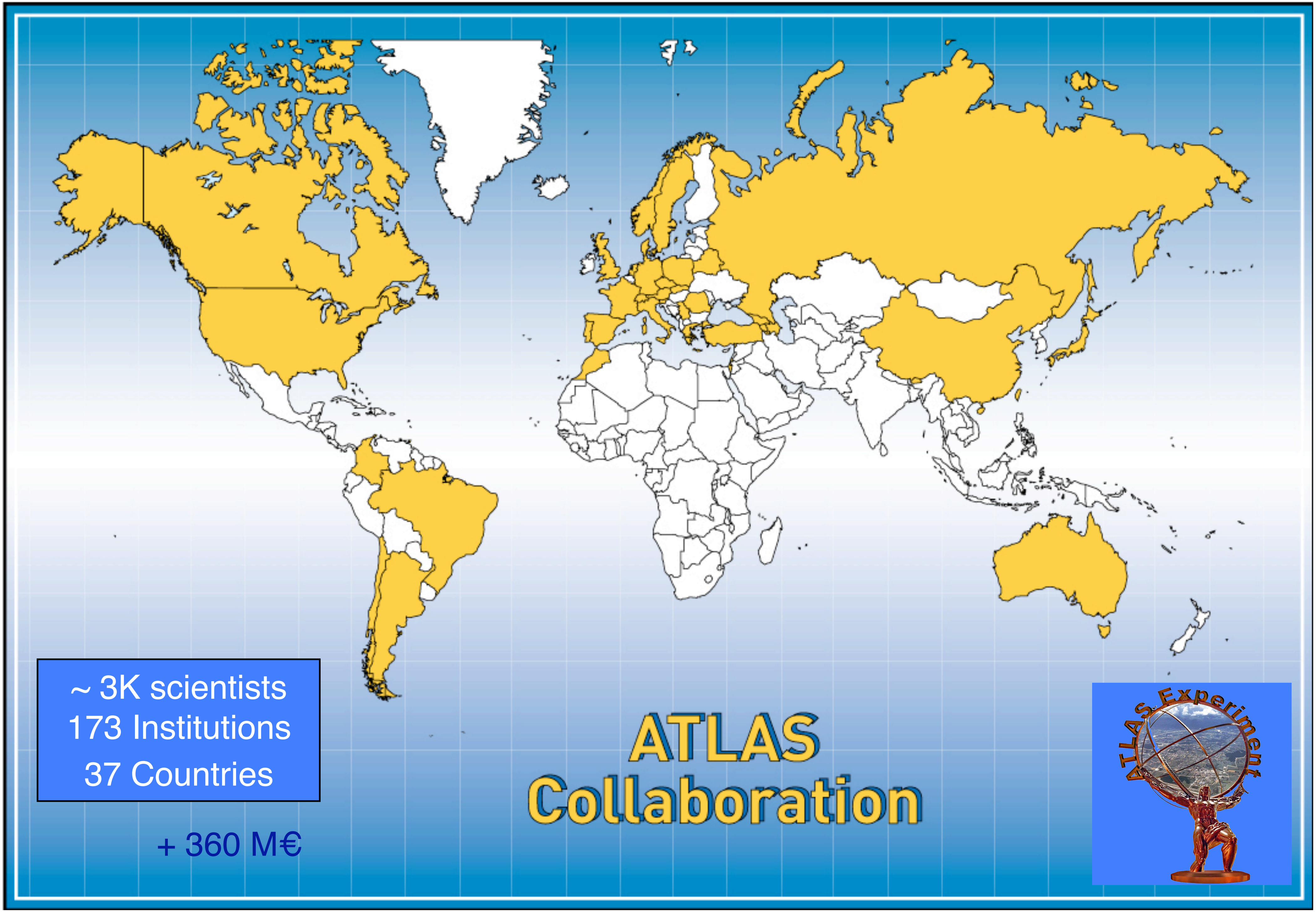
- 2013-14: long shutdown to completely repair all the splices interconnecting the magnets and prepare the machine for 14 TeV.
- 2014-2015-2016: LHC at **13.5-14TeV** and **L> 10^{34}cm^{-2}s^{-1}**

ATLAS

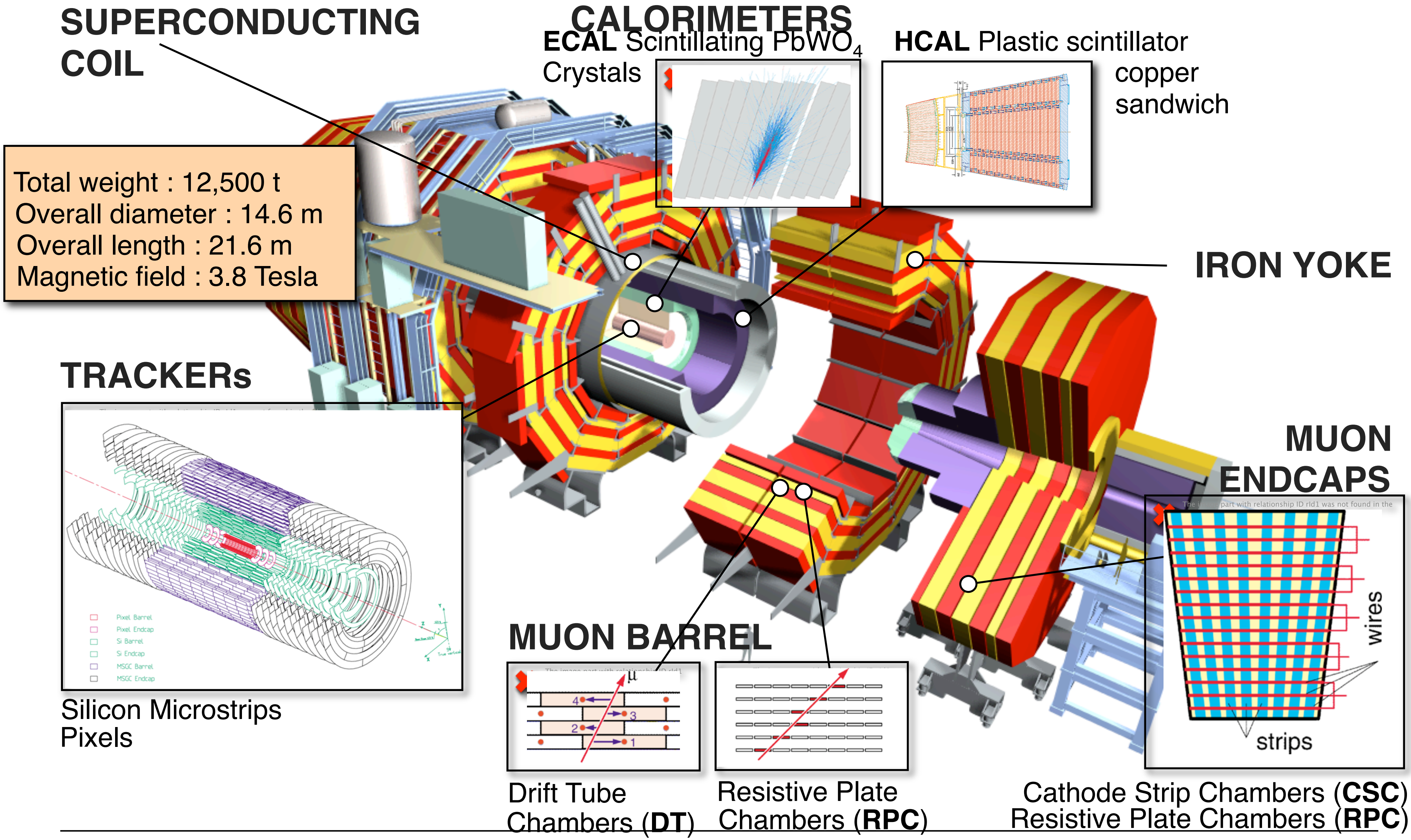
Total weight 7000 t
Overall diameter 25 m
Overall length 44 m

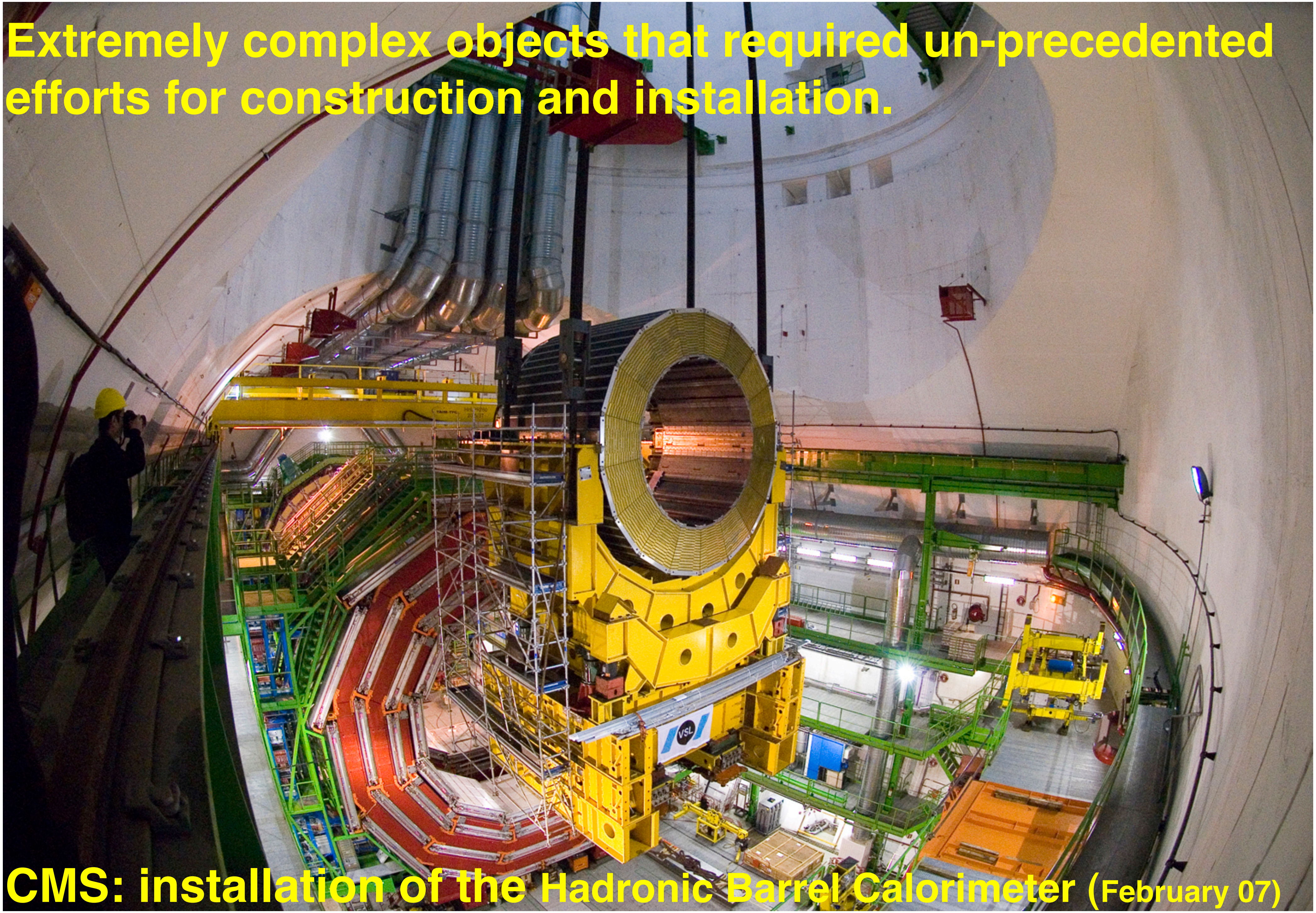


ATLAS: 7.7 × CMS in volume / 0.56 × CMS in weight

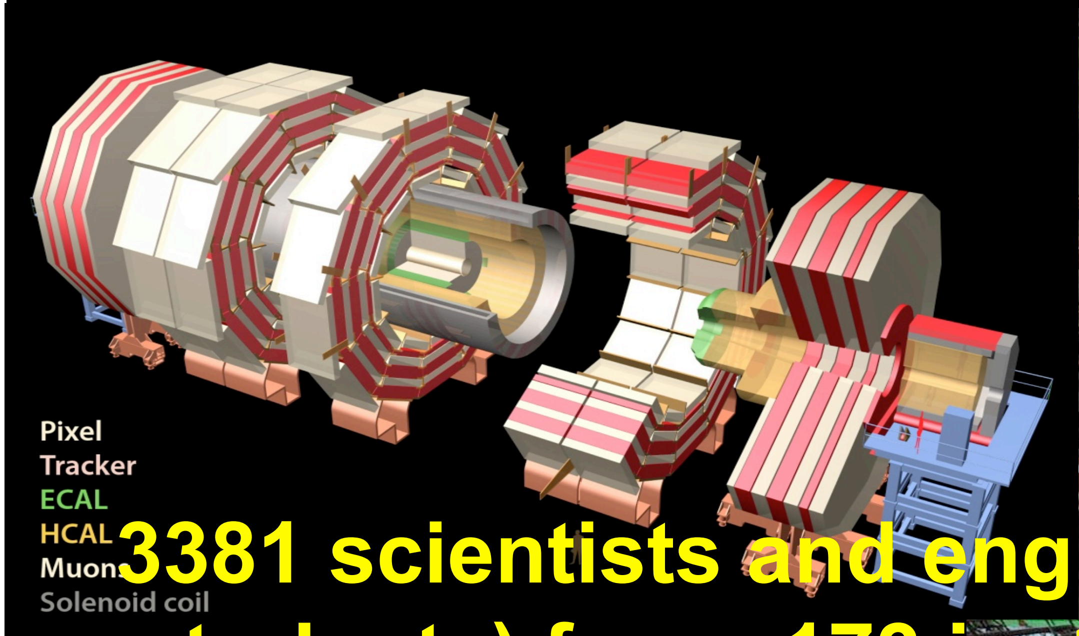

~ 3K scientists
173 Institutions
37 Countries
+ 360 M€
ATLAS
Collaboration
ATLAS Experiment

The Compact Muon Solenoid (CMS)

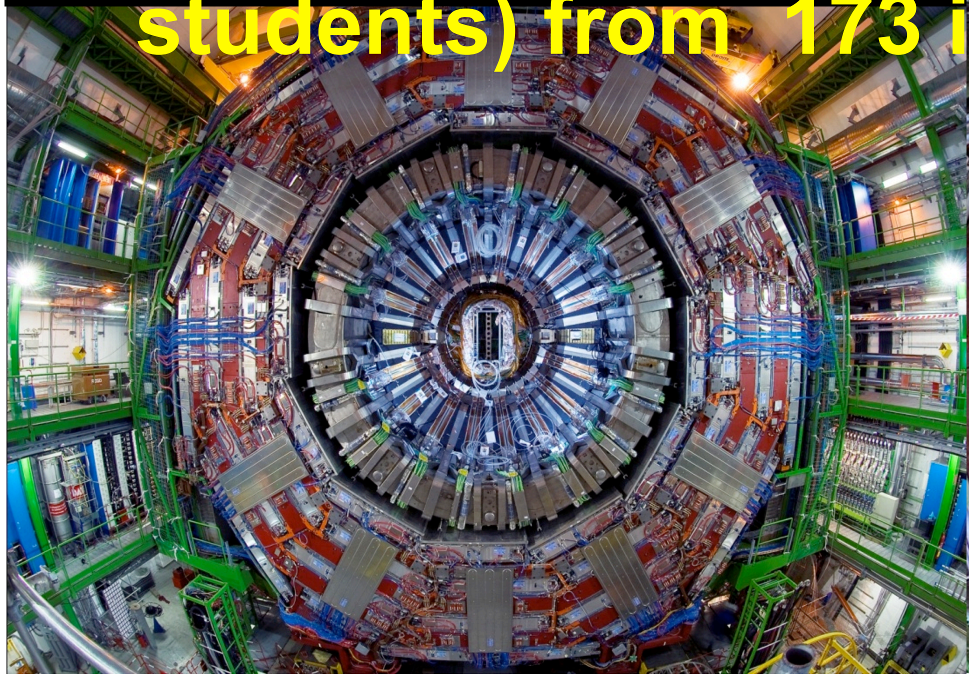


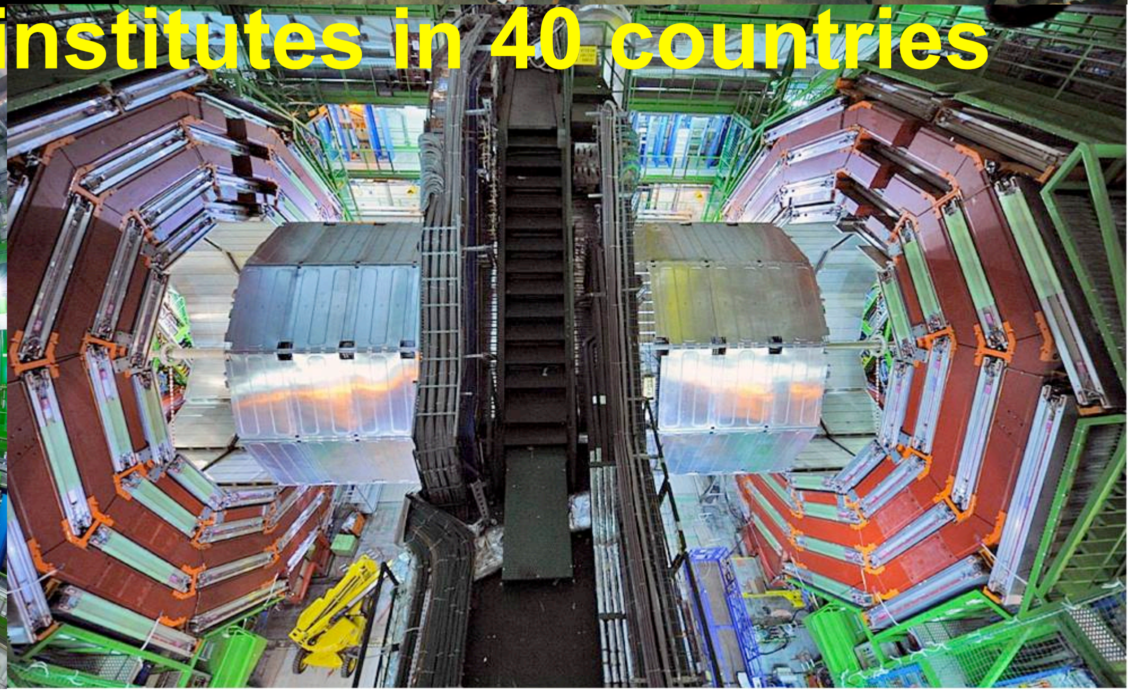

Extremely complex objects that required un-precedented efforts for construction and installation.
CMS: installation of the Hadronic Barrel Calorimeter (February 07)

The CMS Collaboration

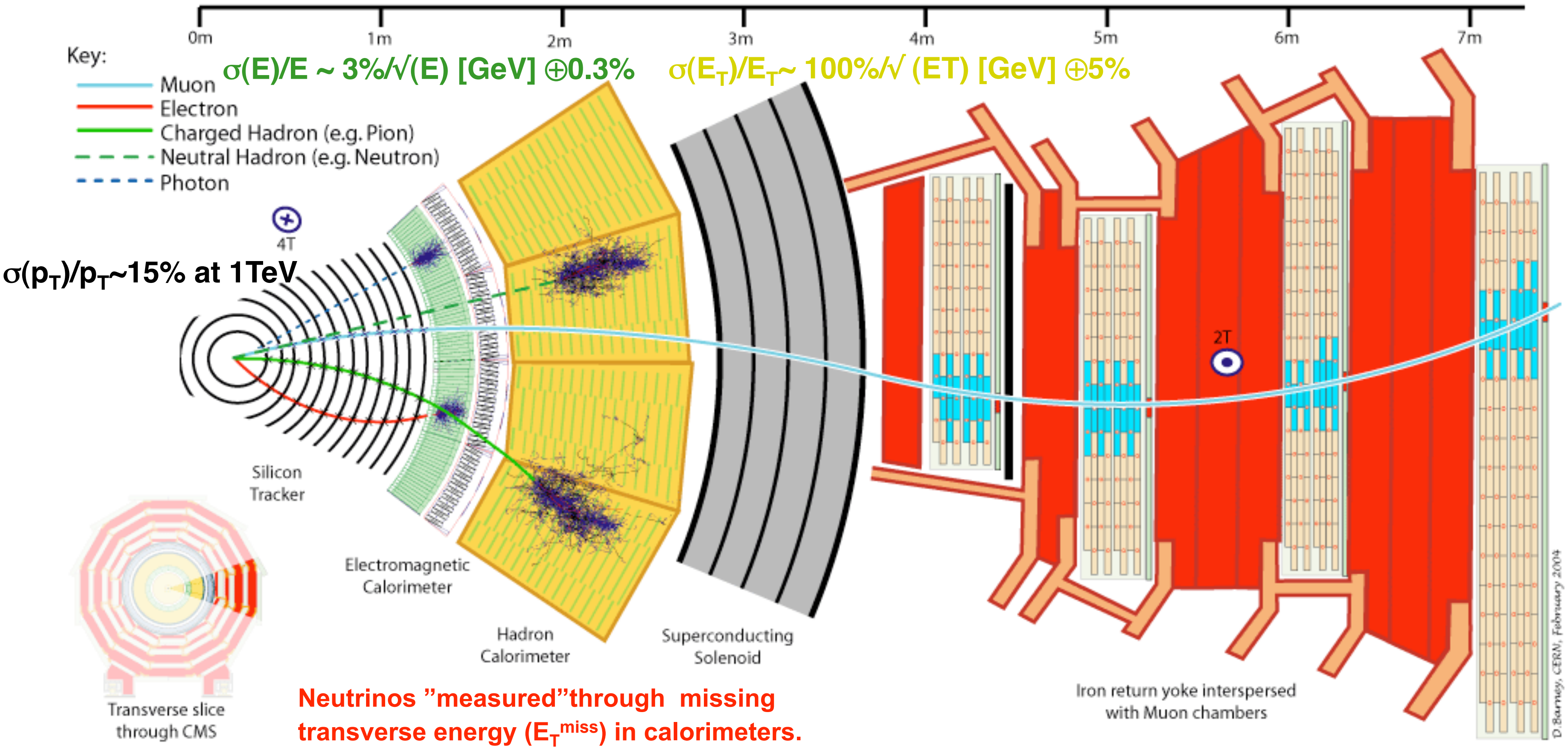


3381 scientists and engineers (including ~840 students) from 173 institutes in 40 countries





Particles through a CMS slice



Fast detectors: 25-50ns bunch crossing

High granularity: 20-40 overlapping complex events

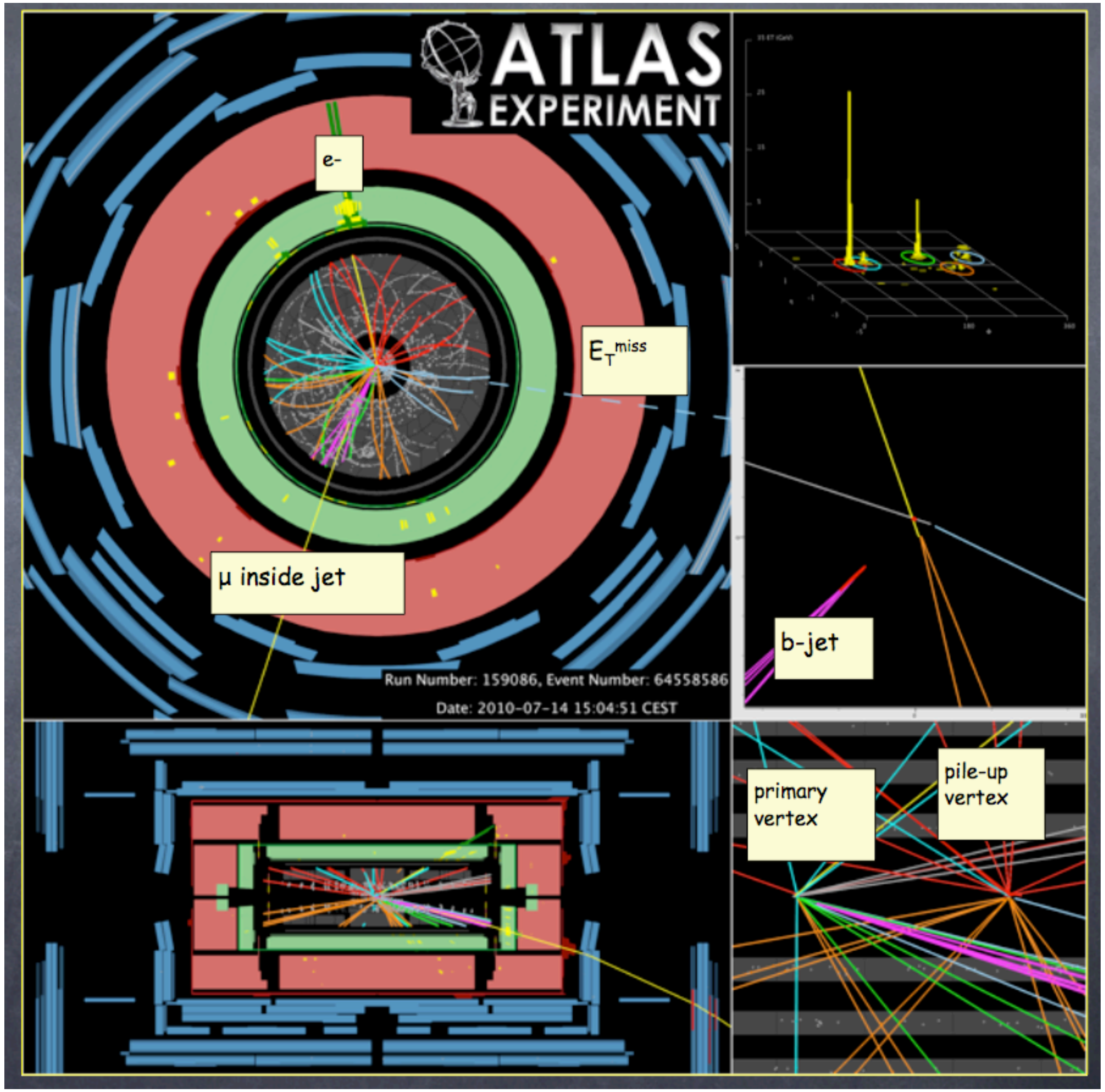
High radiation resistance: >10 years of operation

$\sigma(p_T)/p_T < 1\%$ @ 100GeV
$\sigma(p_T)/p_T < 10\%$@1 TeV

Physics objects in ATLAS

Higgs searches require detailed understanding of all of the physics objects:

- electrons,
- muons,
- light-quarks (jets),
- heavy flavours (charm, bottom- jets),
- missing energy ($E_T$miss)



Signal and background@10^{33}

Cross sections for various physics processes vary over many orders of magnitude

Higgs (500 GeV/c^2) σ ~1pb @10^{33} → 10^{-3} Hz

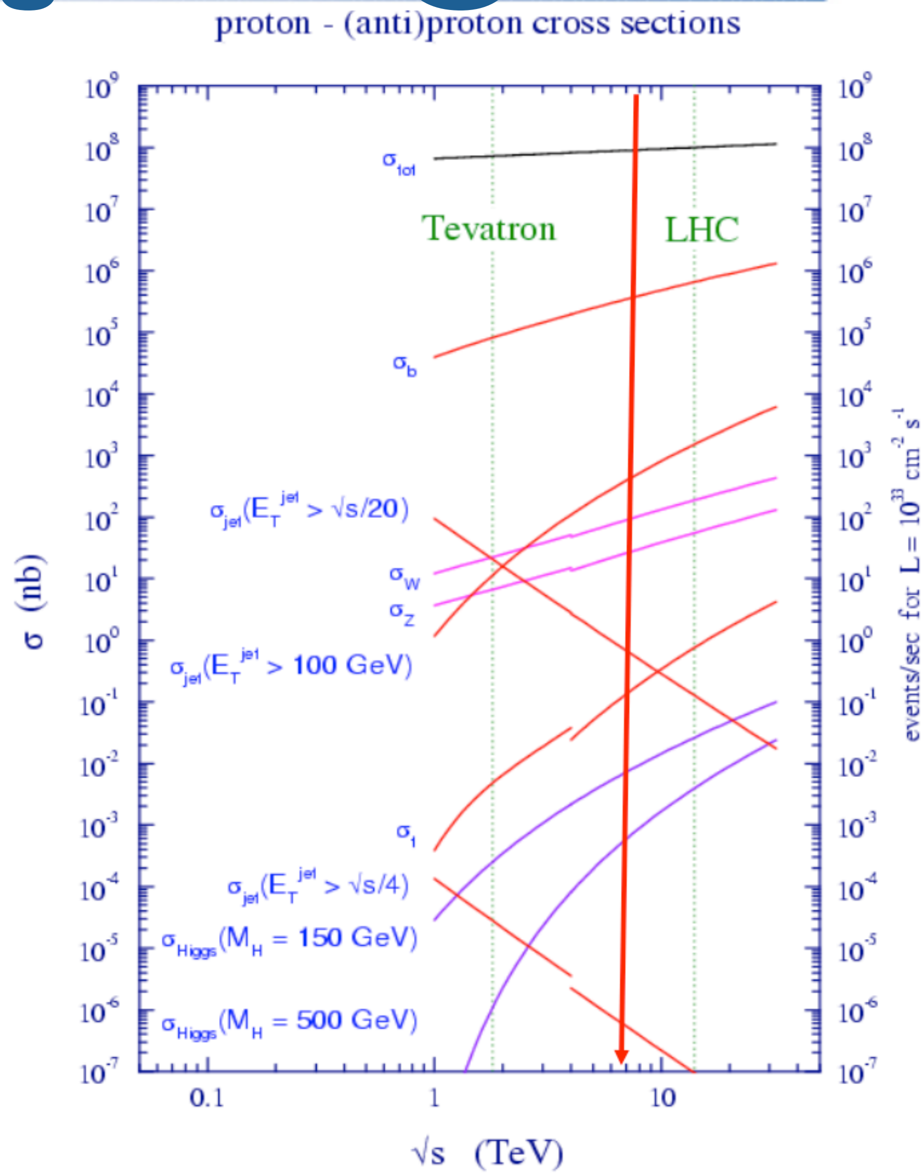
Higgs (150 GeV/c^2) σ ~10pb@10^{33} → 10^{-2} Hz

tt production: → 1 Hz

W→ $\ell\,\nu$: → 100 Hz

bb inclusive: → 10^{5-6} Hz

Inelastic: → 10^{8} Hz

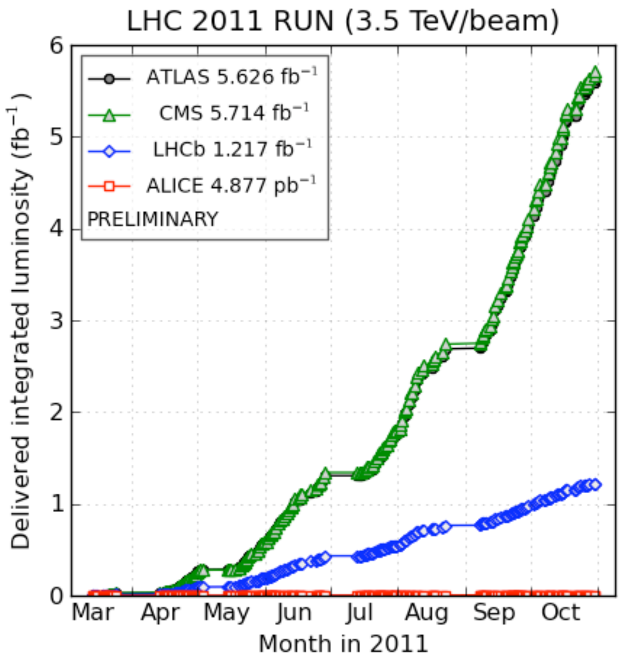


The needed selection (10^{-11}) is feasible but a fast and efficient Trigger system is a key ingredient for success.

Protons collide at 20MHz but we can record on tape only 300Hz. Trigger selection, based on electron, muon, tau, jet and missing energy signatures is crucial for all analyses.

… and then we need to collect a lot of good quality data.

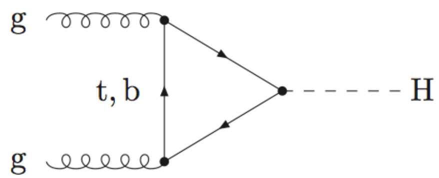
- **>5.5 fb^{-1} delivered in pp mode at 7 TeV in 2011 (1fb^{-1} was the official goal for the machine).**
- ATLAS and CMS detectors recorded typically **90-95%** of the delivered luminosity and about **85-90%** was good quality data for physics.
- **Average fraction of operational channels per subsystem typically >98%**. Luminosity known at a 2-4% level.



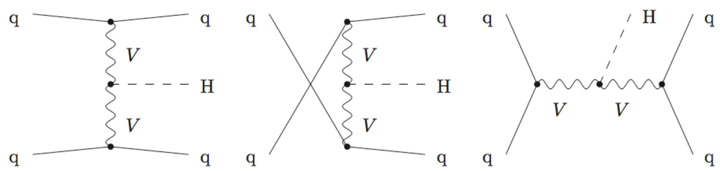
Higgs hunting basics.

SM Higgs production at LHC

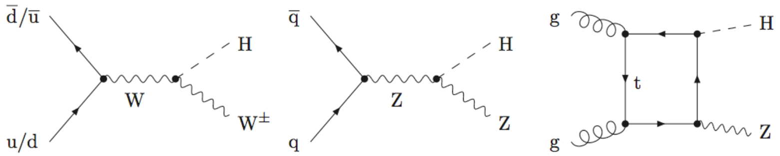
Gluon-gluon fusion



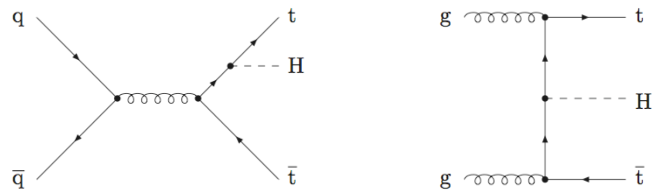
Vector bosons fusion

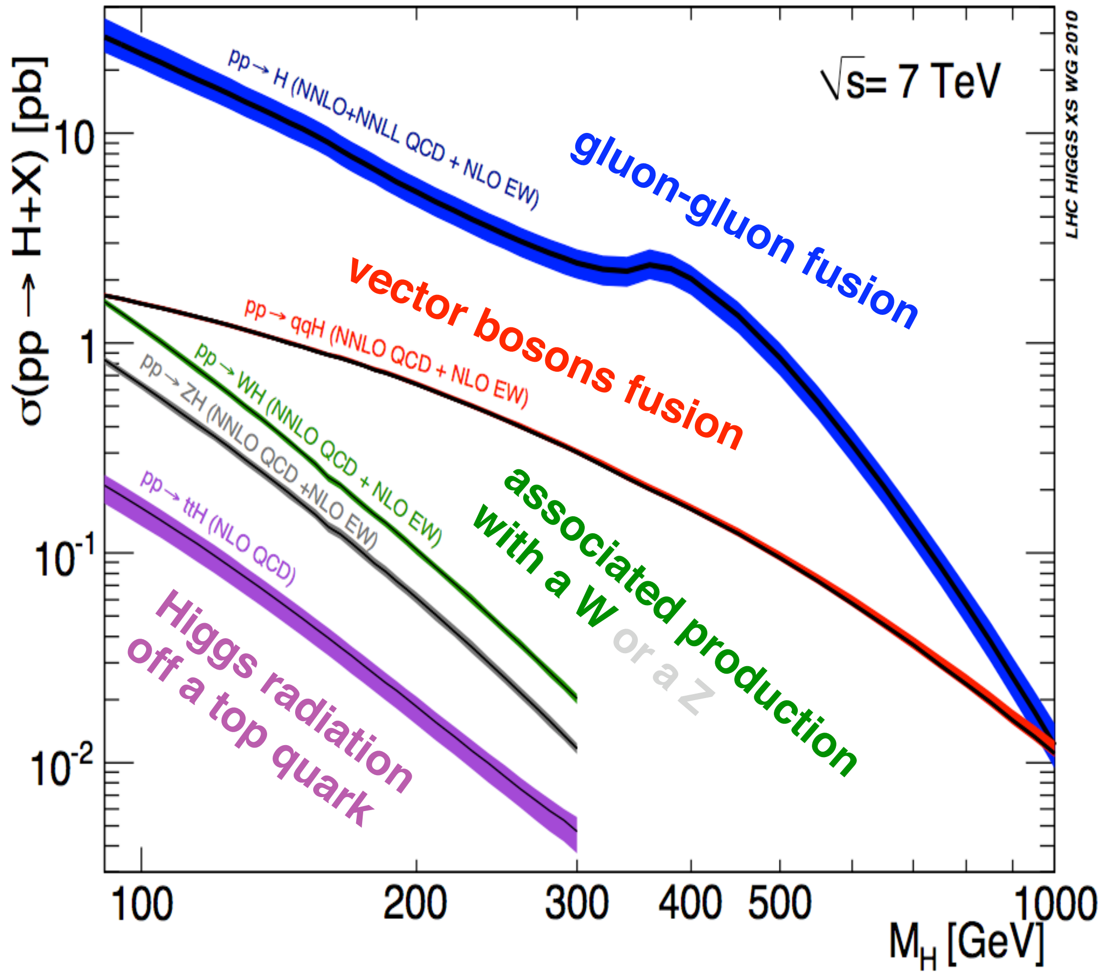


Associated production with W or Z



Higgs radiation off a top quark





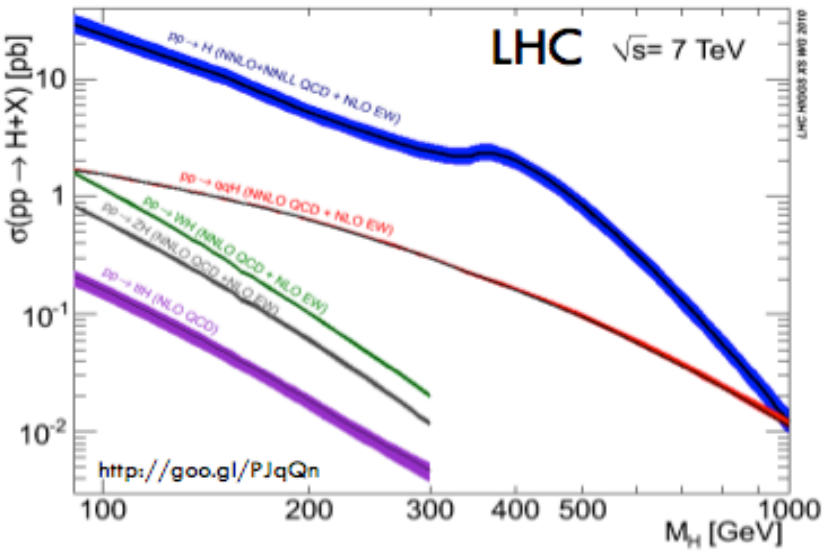
Typical size of the uncertainty (there is also a dependance on the mass)

	ggF	VBF	WH/ZH	$t\bar{t}H$
QCD scale:	$^{+12\%}_{-8\%}$	$\pm1\%$	$\pm1\%$	$^{+3\%}_{-9\%}$
PDF + α_s:	$\pm8\%$	$\pm4\%$	$\pm4\%$	$\pm8\%$
Mass line shape:	$(150\%) \times \left(\frac{M_H}{TeV}\right)^3$			

Comparison with the Tevatron Collider

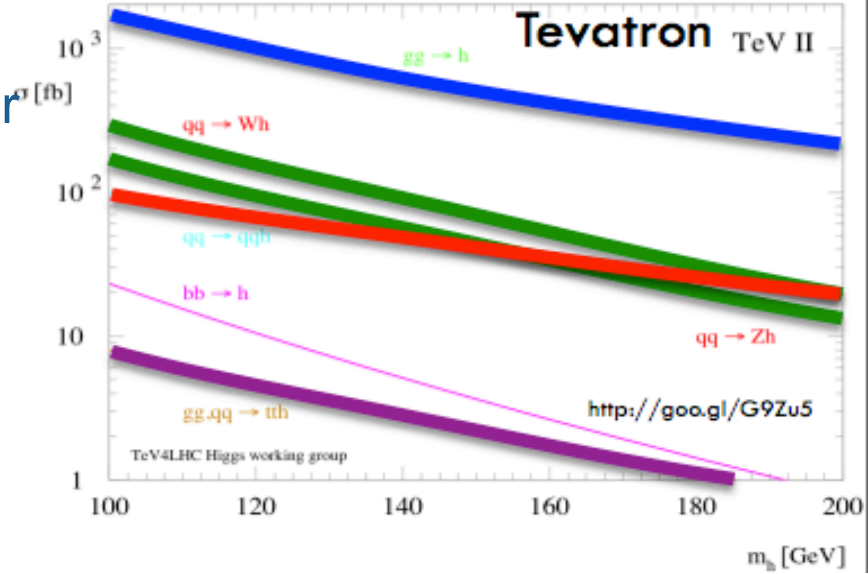
Large gain in cros section due to the higher collision energy (7TeV vs 2TeV).

Compare the 1-2pb cross section at the Tevatron for a Higgs of 120GeV of mass with the 15-20pb equivalent cross section at LHC.



Gluon fusion (gg→ H) is the dominant production mechanism at LHC.
Irreducible backgrounds in H → WW, ZZ, γγ are from qq annihilation. Signal to Noise better than at Tevatron except in VH.

VBF and VH also very useful at LHC since they can be identified through un-ambiguous signatures: typically two jets well separated in the forward regions or high p_T leptons.

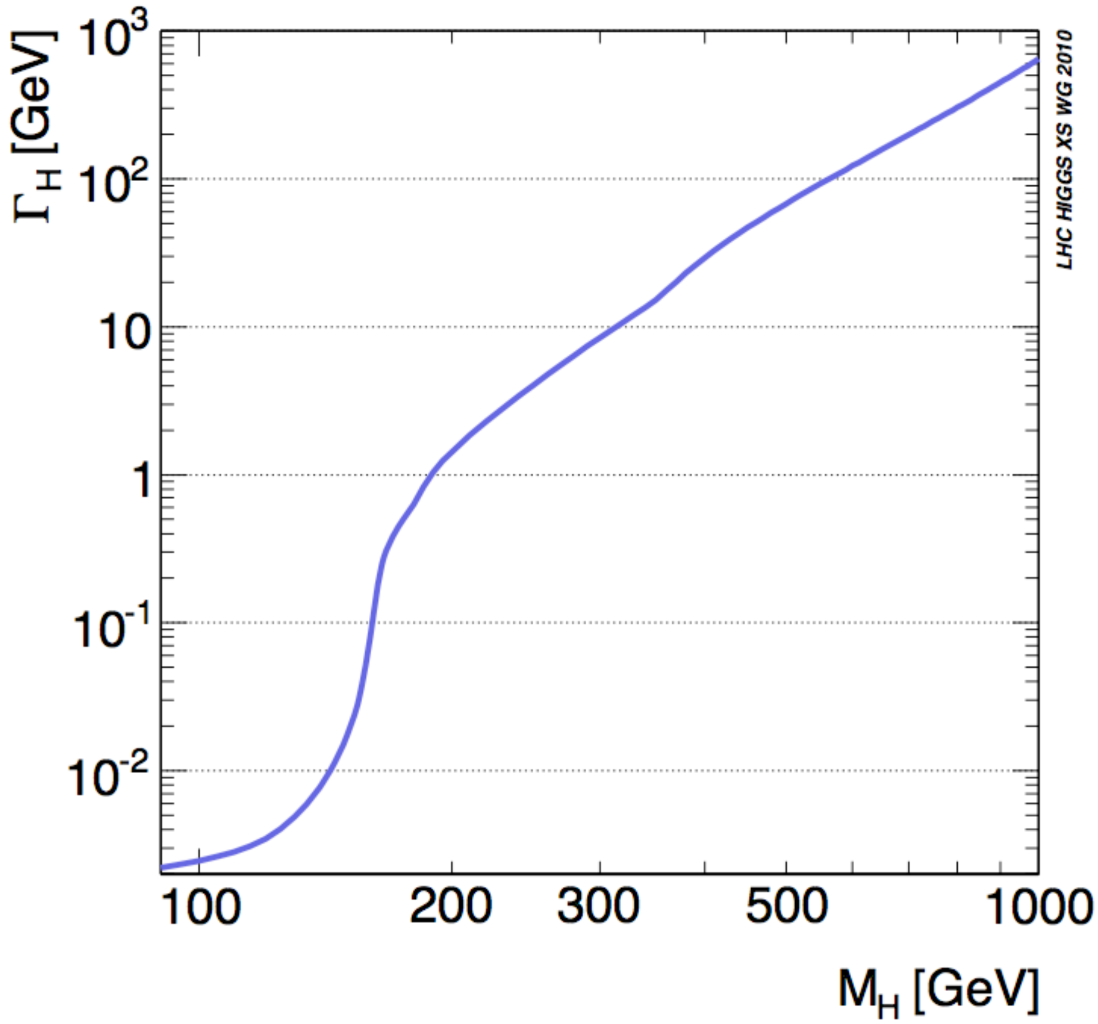


SM Higgs boson width

Very narrow resonance at low mass: ~4MeV at 125GeV/c^2

The width grows rapidly with the mass.

Around 1TeV the width of the boson becomes comparable to its mass i.e the concept of particle fades away.



SM Higgs boson width vs mass under the relativistic Breit-Wigner assumption

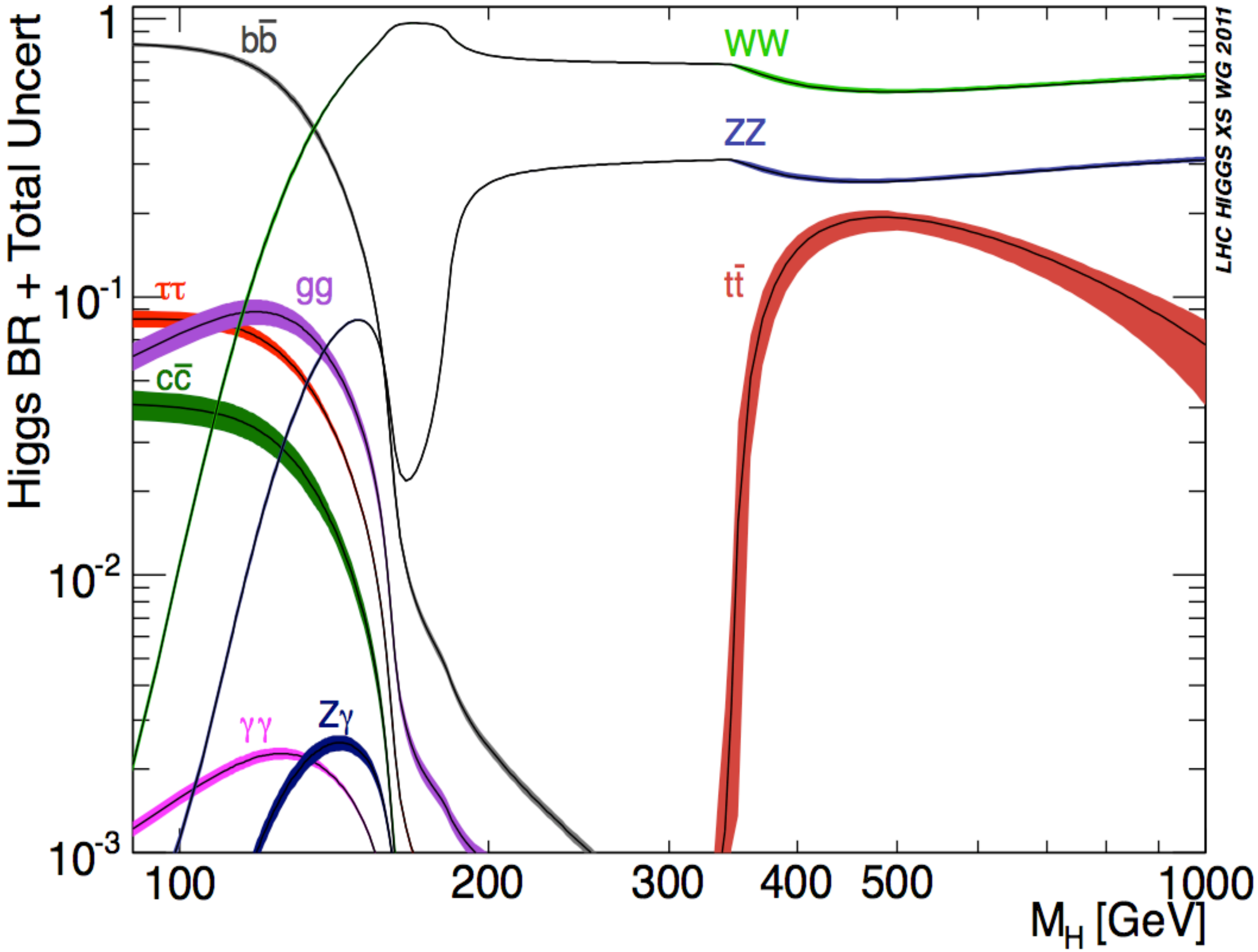
SM Higgs decay modes vs mass

Higgs couples to mass

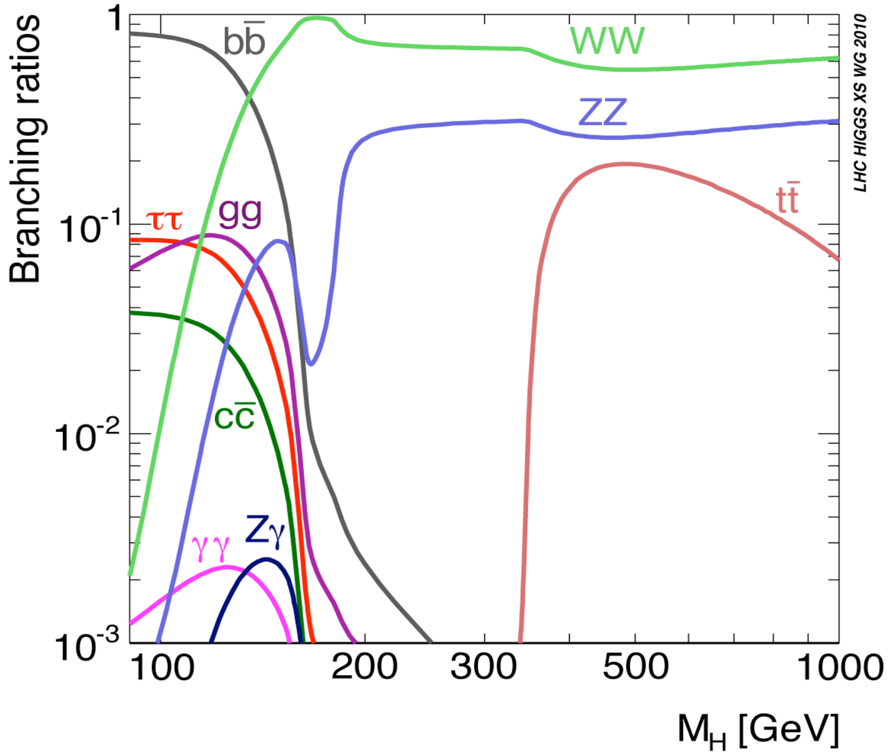
$\Gamma_{Hff} \sim m_f^2$
$\Gamma_{HVV} \sim m_V^4$

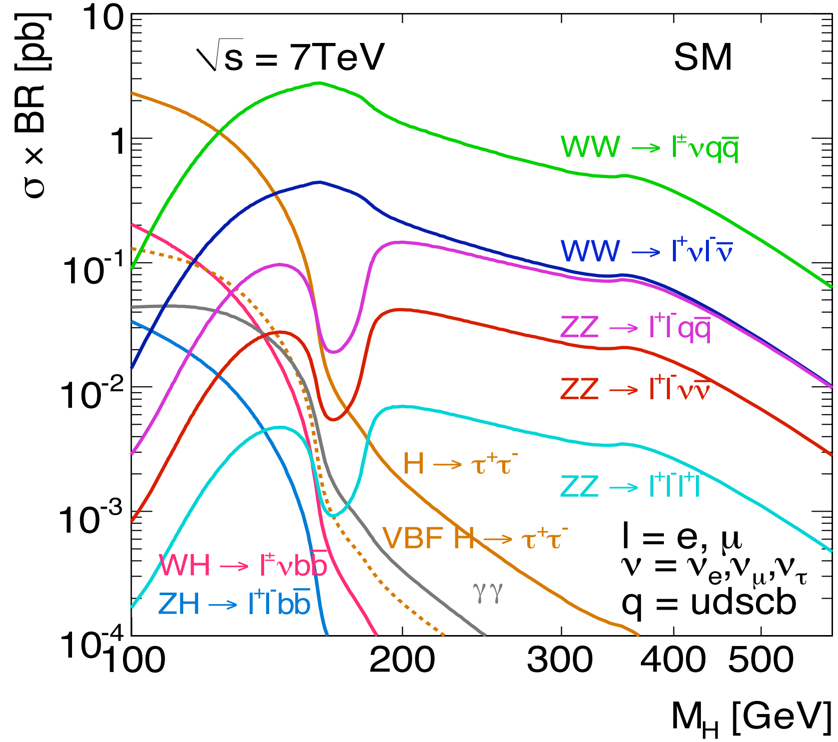
Different decay channels are used to explore the low and the high mass region.

All available channels are combined to increase the sensitivity.



SM Higgs Decay Modes Vs Mass





High mass searches: based on H→WW and H→ZZ decay modes reconstructed in several channels; i.e H→WW→lνjj + H→WW→lνlν

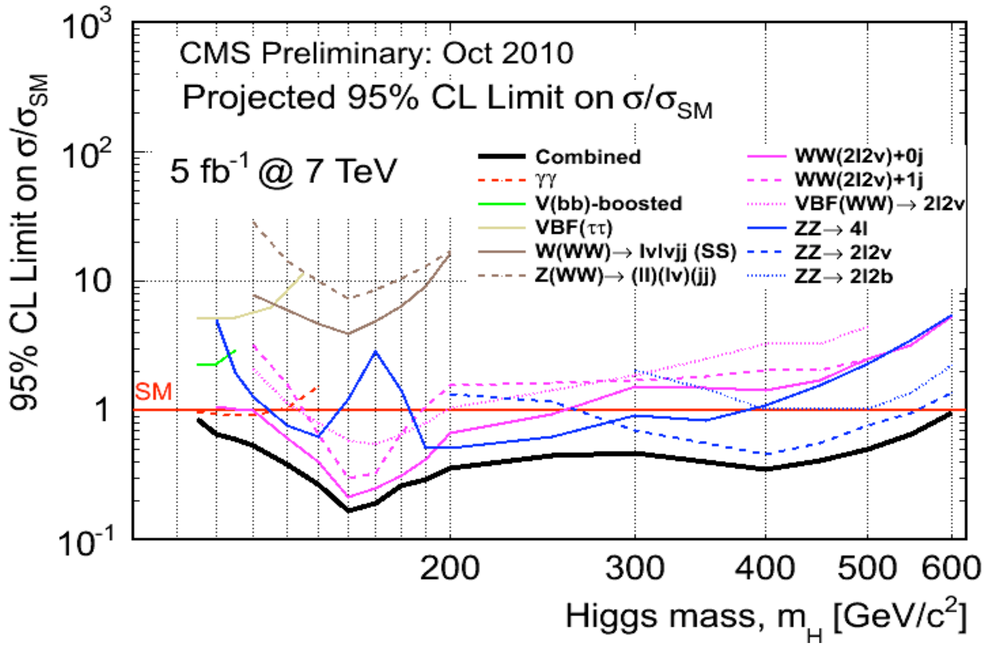
Events expected to be produced with L=1 fb^{-1}

m_H, GeV	WW→lνlν	ZZ→4l	γγ
120	127	1.5	43
150	390	4.6	16
300	89	3.8	0.04

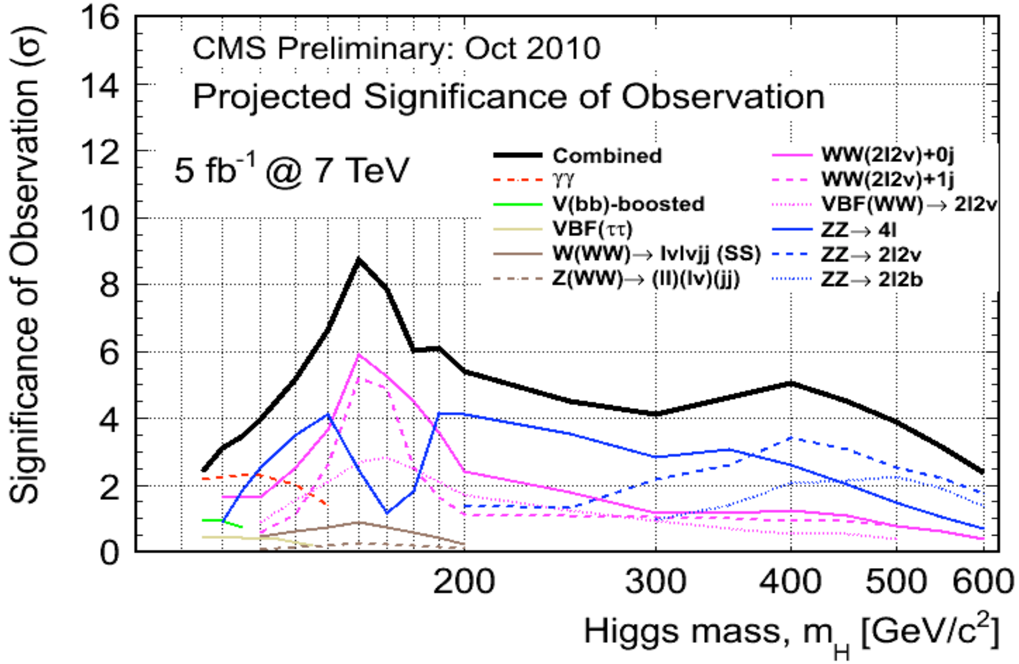
Low mass searches: H→γγ ; H→bb; H→ ττ, H→ZZ→4leptons, H→WW→lνlν.

The challenge

CMS Projected Sensitivity @5fb^{-1}



CMS Projected Significance @5fb^{-1}



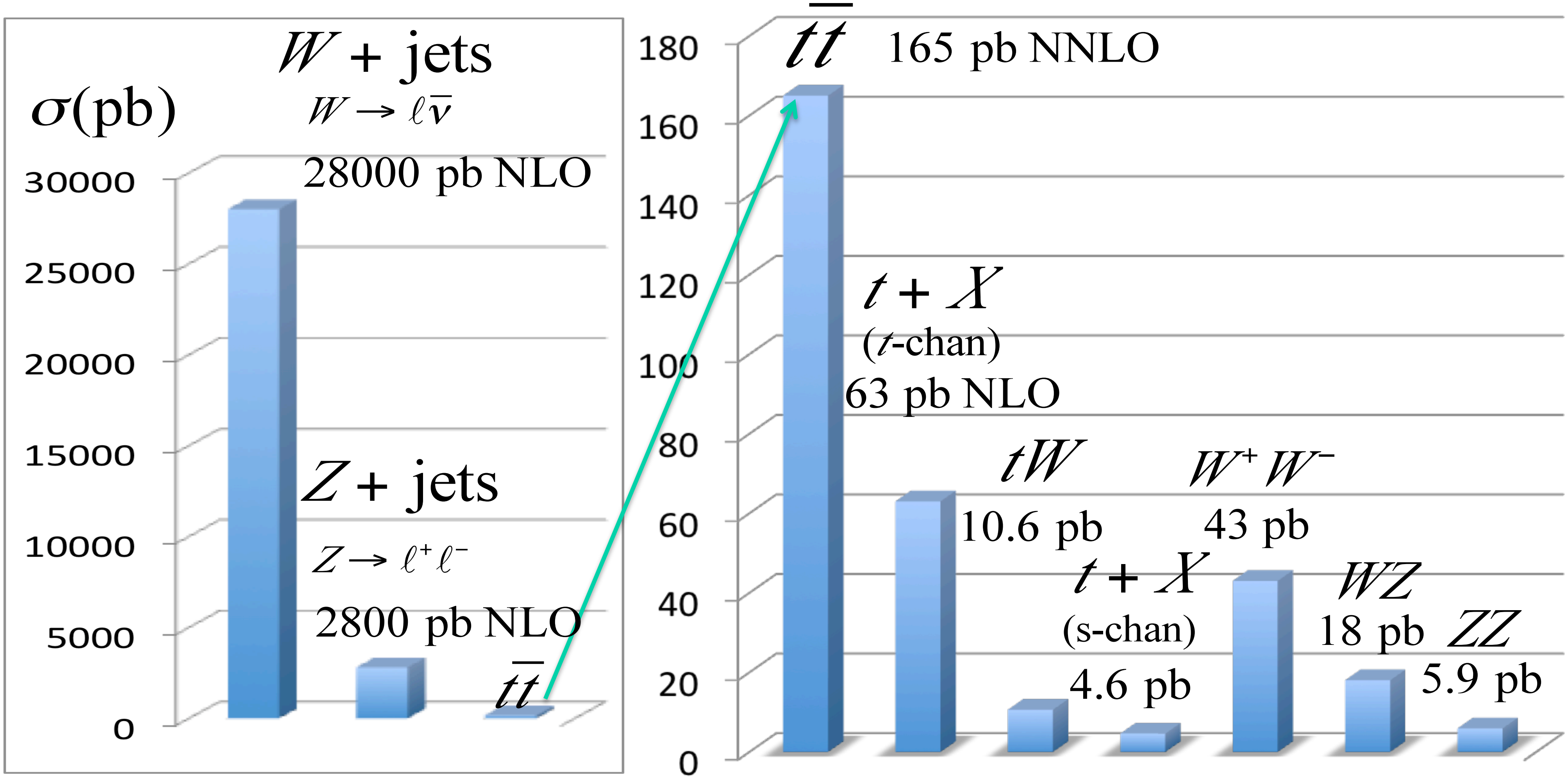
October 2010: with 5fb^{-1} delivered by LHC we could reach a sensitivity below 1xSM in the full mass range.

If the SM Higgs boson would be hidden in the low mass region we could start seeing excesses with a significance of 2-3 sigma.

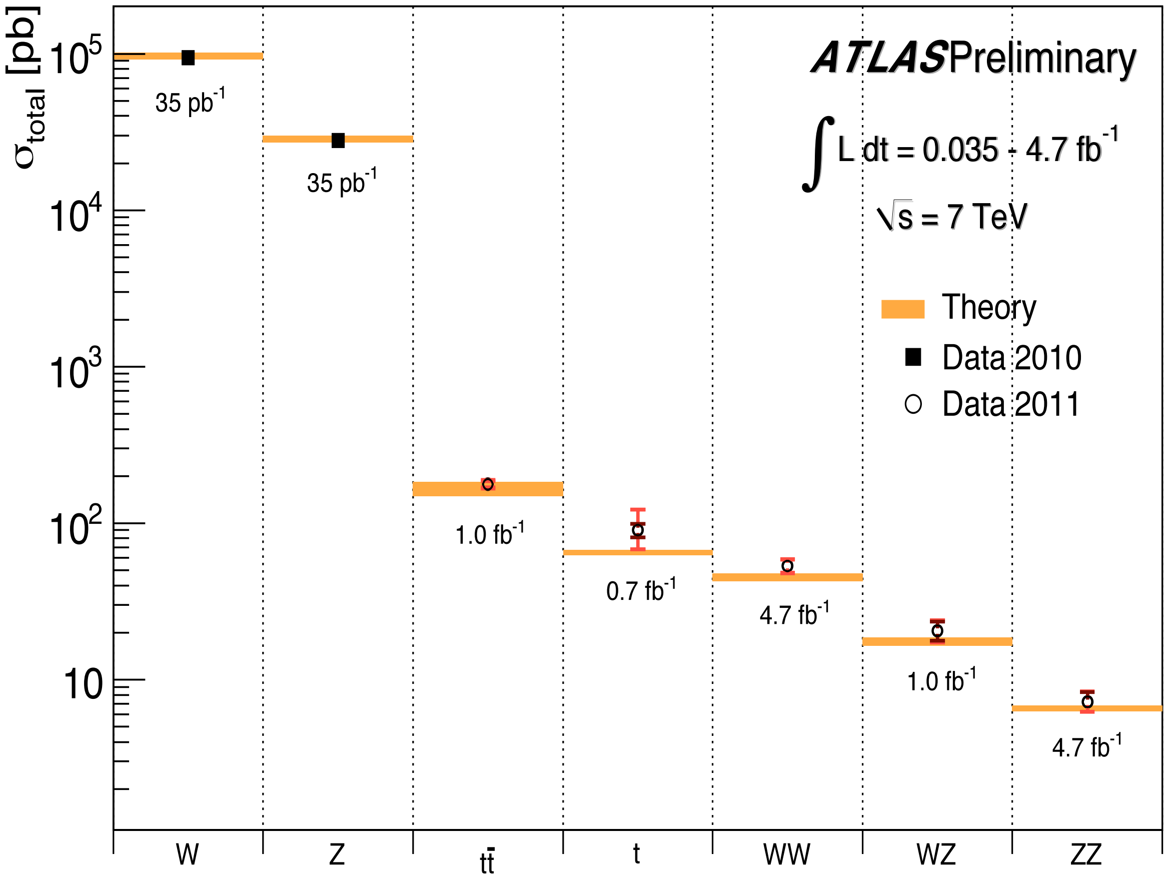
Every single channel, particularly in the low mass region, brings very important information.

Key SM Background Processes

$\sqrt{s} = 7$ TeV



EWK measurements are SM Higgs background

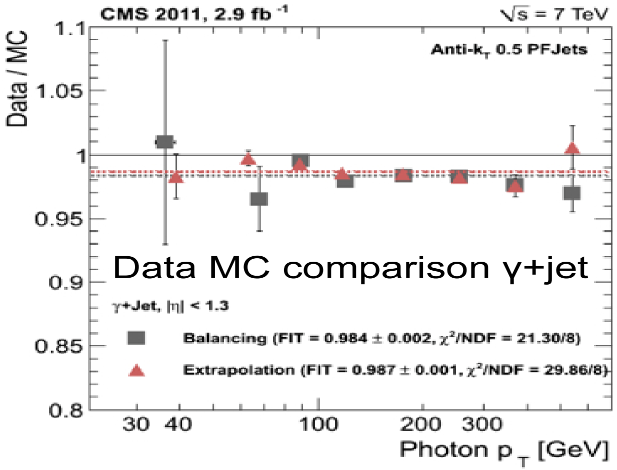


$\sigma(pp) \rightarrow H$ (with m_H=125GeV) =17.5pb

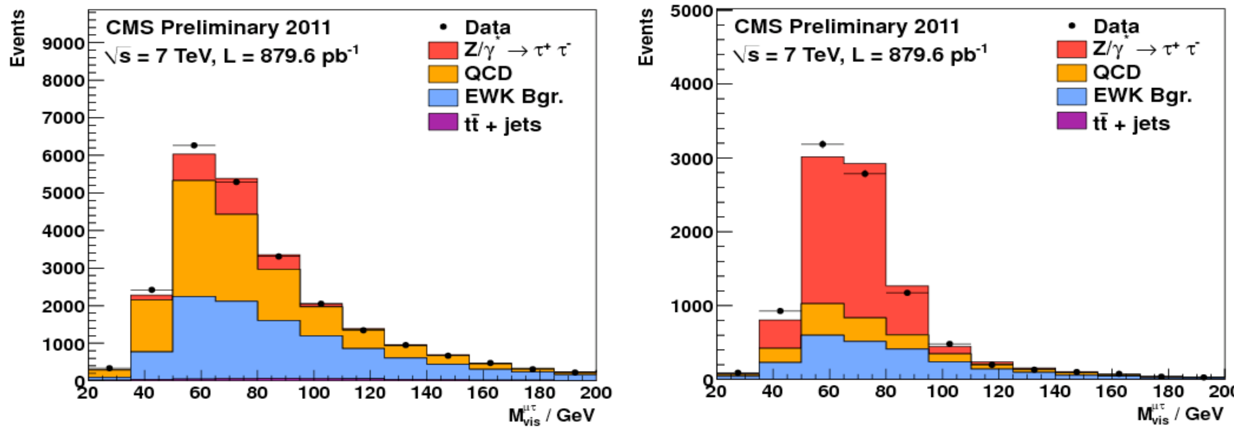
Same order of manitude of the diboson (WW,WZ,ZZ production).

These measurements are also very important to validate detector/physics simulation, object reconstructions, event selections and in general the analysis techniques.

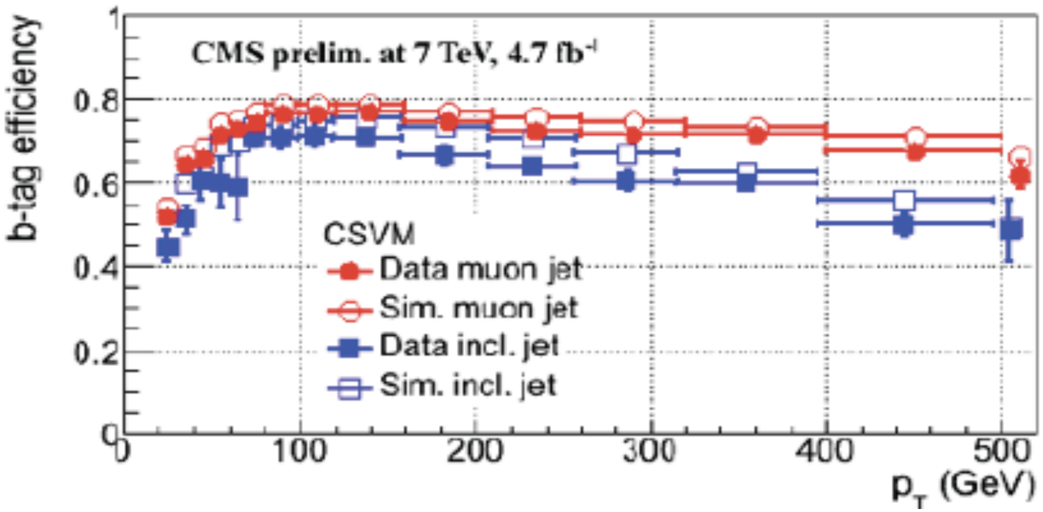
Excellent understanding of the physics “objects”



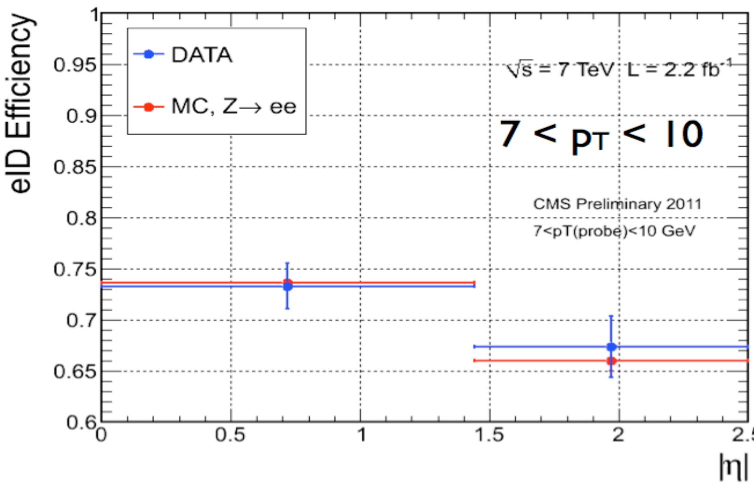
Jet Calibration with pileup



Tau efficiency with T&P on the Z measured to 6%



B- tagging efficiency measured to 10% up to 500 GeV

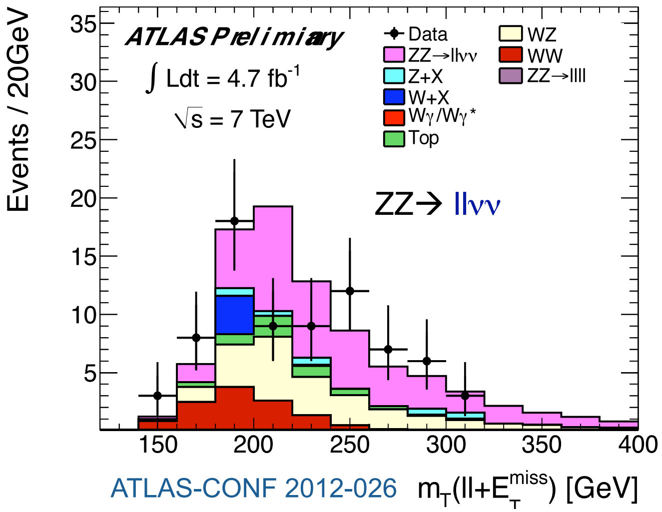


Electron efficiency with T&P on the Z measured down to 7 GeV

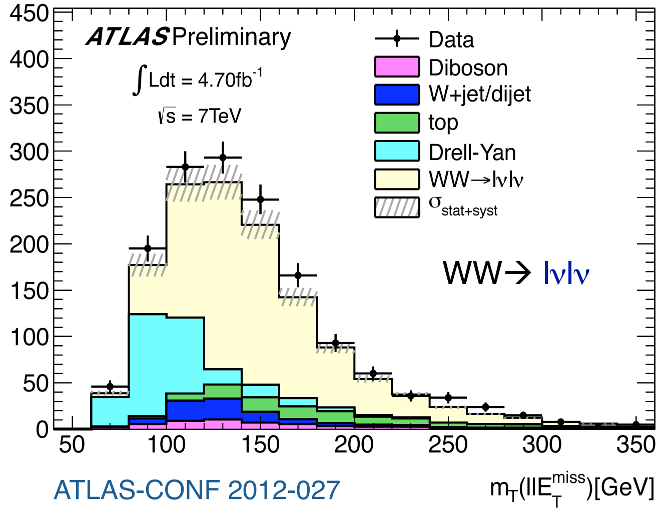
… and of the key SM background

ZZ, WW cross-sections very important test of the SM and irreducible background for SM Higgs searches; ZZ→ 4l and WW→ lνlν + ZZ→ llνν with full 2011 statistics.

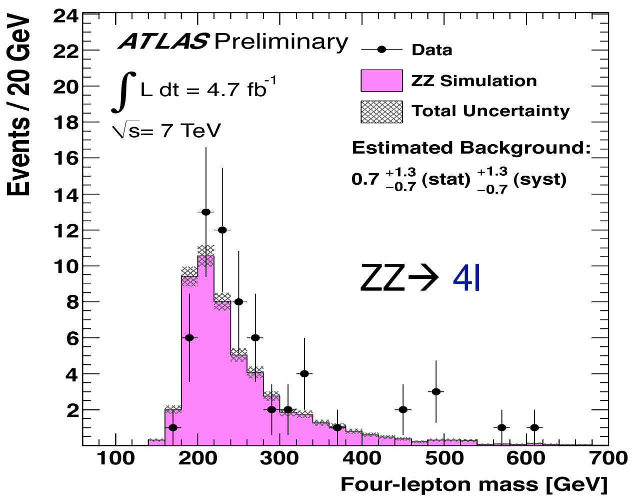
ATLAS-CONF 2012-027



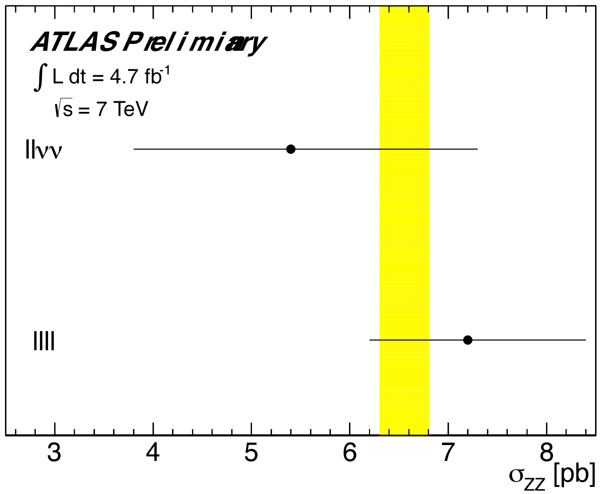
ATLAS-CONF 2012-025



ATLAS-CONF 2012-026



ATLAS-CONF 2012-027



$\sigma^{TOT}(W^+W^-)=53.4\pm2.1_{stat}\pm4.5_{sys}\pm2.1_{lumi}$ pb

$\sigma^{SM}(W^+W^-)NLO=45.1\pm2.8$

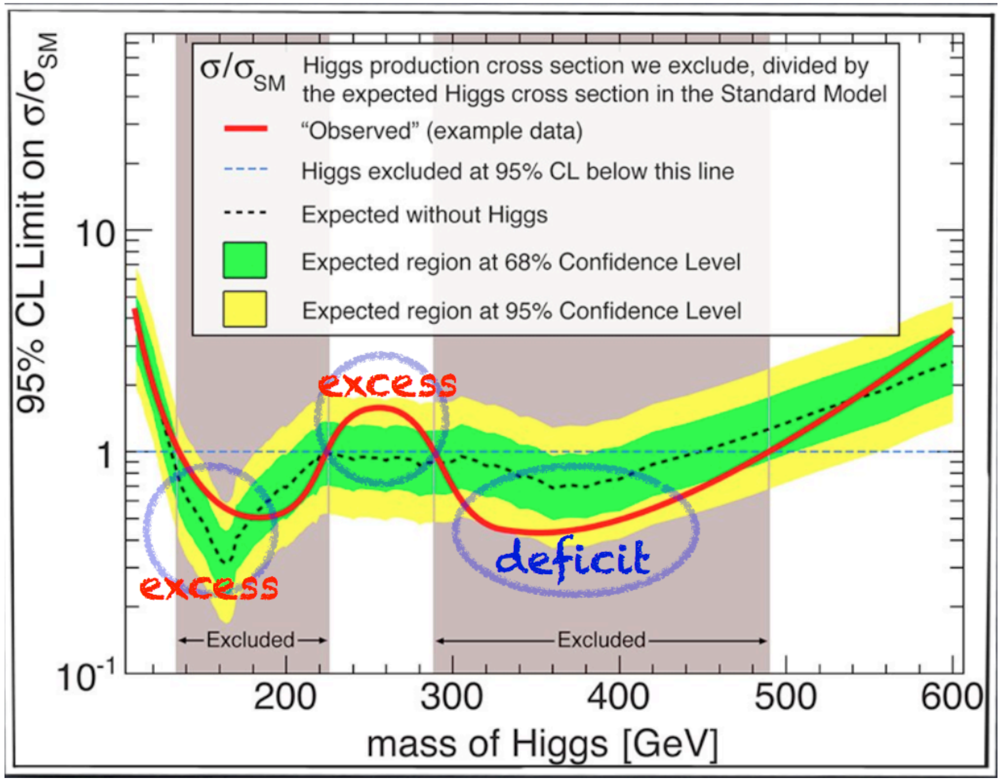
All results compatible with SM predictions.

Higgs hunting basics: μ and CL_S

Understanding the yellow and green bands.

μ is the ratio between the measured cross section at a given mass assuming the presence of a SM Higgs signal and the expected cross section at that mass.

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



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

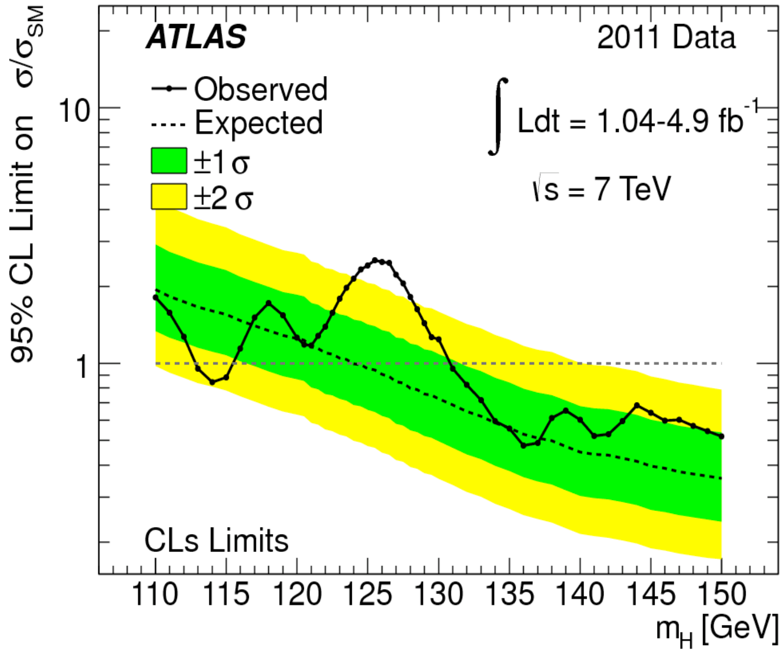
If CLs<5% the signal hypothesis is excluded at the 95% CL.

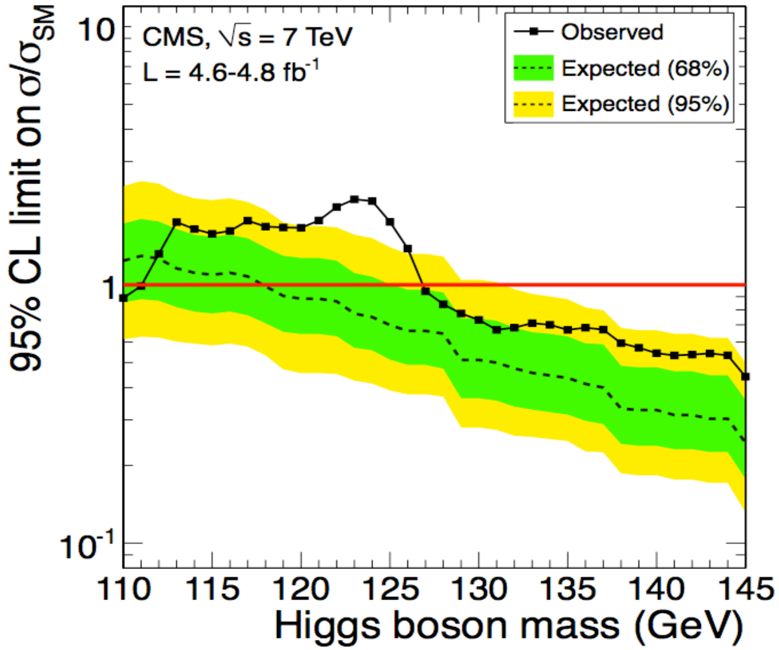
μ_{up} is the signal strength for which CLs=5%. If, for a given mass hypothesis, m_H, μ_{up} <1 then $\sigma_{meas}<\sigma_{SM}$ and m_H is excluded at 95% CL.

Search for the SM Higgs boson

Preliminary results shown on Dec13th

Both experiments, ATLAS and CMS presented preliminary results on 2011 data.





ATLAS : "We observe an excess of events around **m_H~ 126 GeV**: local significance 3.6 σ SM Higgs expectation: 2.4 σ local → observed excess compatible with signal strength within +1σ; the global significance (taking into account Look-Elsewhere-Effect) is 2.3 sigma"

CMS : "We observe an excess of events which is most compatible with a SM Higgs hypothesis in the vicinity of **m_H~ 124 GeV**, but the statistical significance (2.6σ local and 1.9σ global after correcting for the LEE in the low mass region) is not large enough to say anything conclusive"

Since then submission of all papers and new results with refined analyses presented in Moriond.

Update since December 13-th Seminar

Channel	Mass range m_H (GeV)	Luminosity (fb^{-1})	Reference
$H\to\gamma\gamma$	110-150	4.9	arXiv:1202.1414
$H\to ZZ^{(*)}\to 4l$	110-600	4.8	arXiv:1202.1415
$H\to WW^{(*)}\to l\nu l\nu$	110-600	4.7	CONF-2012-012
$H\to\tau\tau\to ll4\nu$ $H\to\tau\tau\to l\tau_{had}3\nu$ $H\to\tau\tau\to\tau_{had}\tau_{had}2\nu$	100-150	4.7	CONF-2012-014
$WH\to l\nu bb$ $ZH\to llbb$ $ZH\to\nu\nu bb$	110-130	4.7	CONF-2012-015
$H\to ZZ\to ll\nu\nu$	200-600	4.7	CONF-2012-016
$H\to ZZ\to lljj$	200-600	4.7	CONF-2012-017
$H\to WW\to l\nu jj$	300-600	4.7	CONF-2012-018

New results produced on the full data set. Complete set of papers submitted and refined analyses presented at the Winter Conferences.

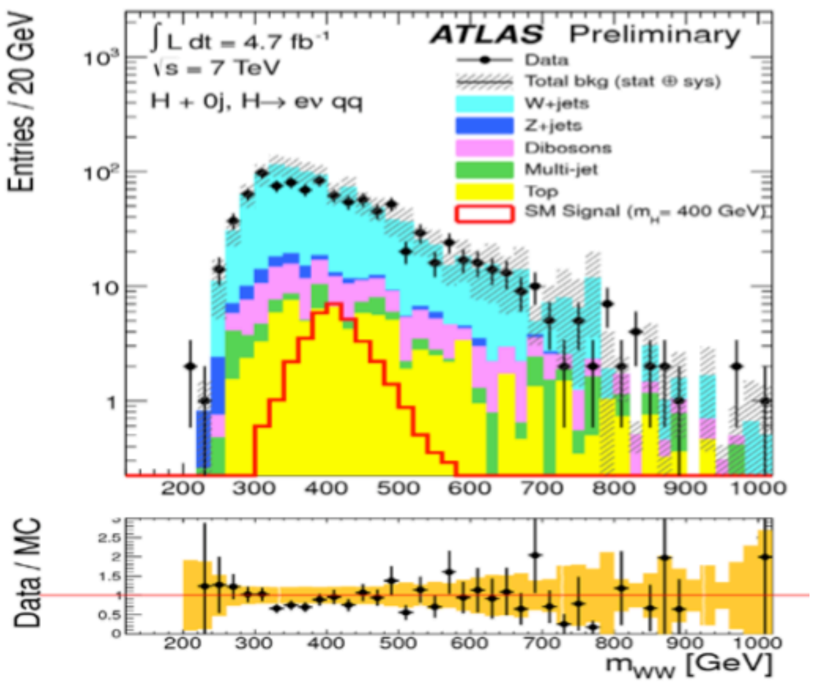
ATLAS public results

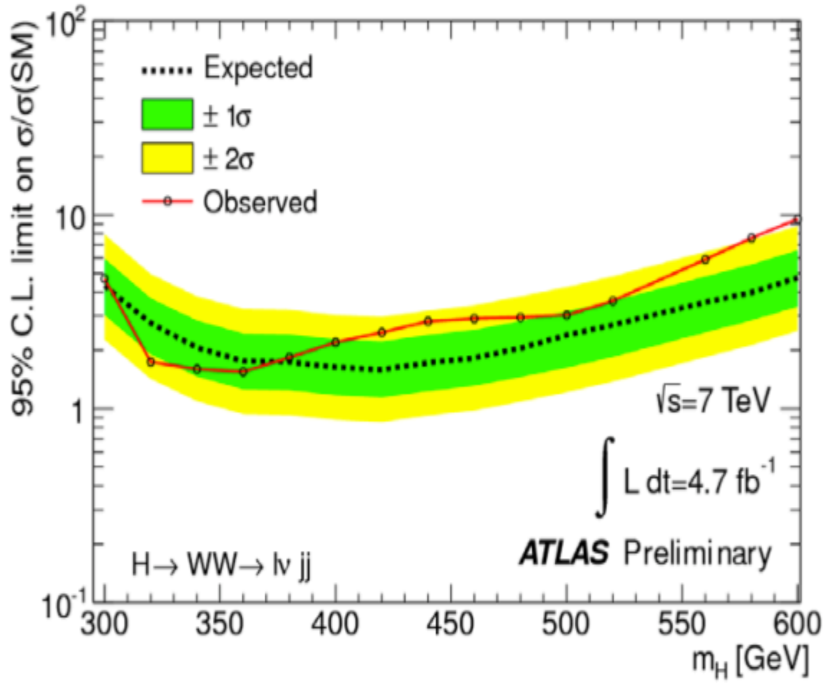
CMS public results

Mode	Mass Range	Data Used (fb^{-1})	Mass resolution	Document
$H\to\gamma\gamma$	110-150	4.8	1-3 %	arXiv:1202.1487
$H\to bb$	110-135	4.7	10 %	arXiv:1202.4195
$H\to\tau\tau$	110-145	4.6	20 %	arXiv:1202.4083
$H\to WW\to 2l\,2\nu$	110-600	4.6	20%	arXiv:1202.1489
$H\to ZZ\to 4l$	110-600	4.7	1-2%	arXiv:1202.1997
$H\to ZZ\to 2l2\tau$	190-600	4.7	10-15%	arXiV:1202.3617
$H\to ZZ\to 2l2j$	130-165/200-600	4.6	3%	arXiv: 1202.1416
$H\to ZZ\to 2l2\nu$	250-600	4.6	7%	arXiv: 1202.3478

ATLAS High Mass: H →WW → lνqq

Search for a “bump” over a smooth background dominated by W+jets. Good sensitivity for masses in the range 300-600GeV when both W’s are on shell. Mass resolution is about 9% at 400 GeV.





ATLAS-CONF-2012-018

Different categories based on different lepton flavours and production mechanisms: gluon gluon fusion with 0 and 1 jet and Vector Boson Fusion (2jets).

Major backgrounds: W+jets, Z+jets, di-bosons, top and multijets.

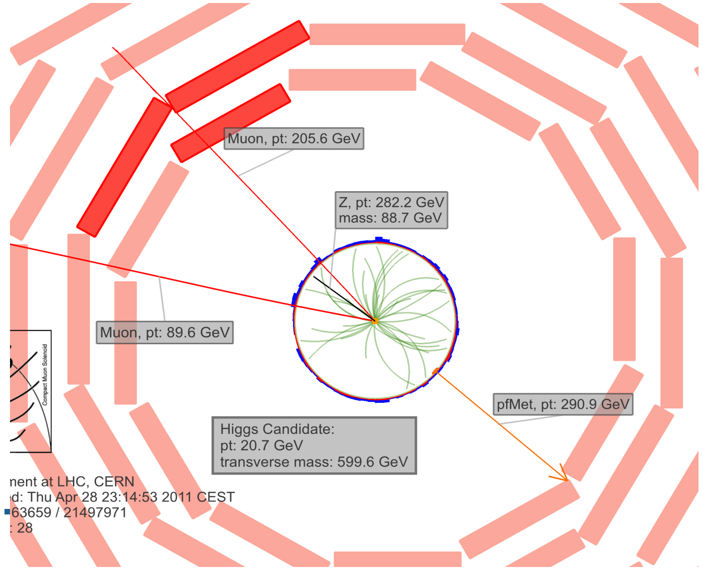
CMS High Mass Higgs: H →ZZ → 2l2ν

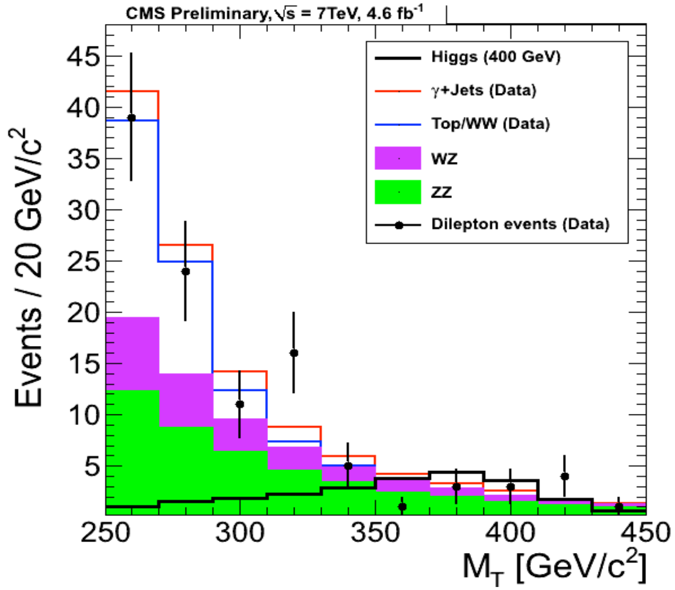
The most sensitive channel in the high mass region.

The presence of neutrinos implies a mass resolution of about 7%.

Main backgrounds:

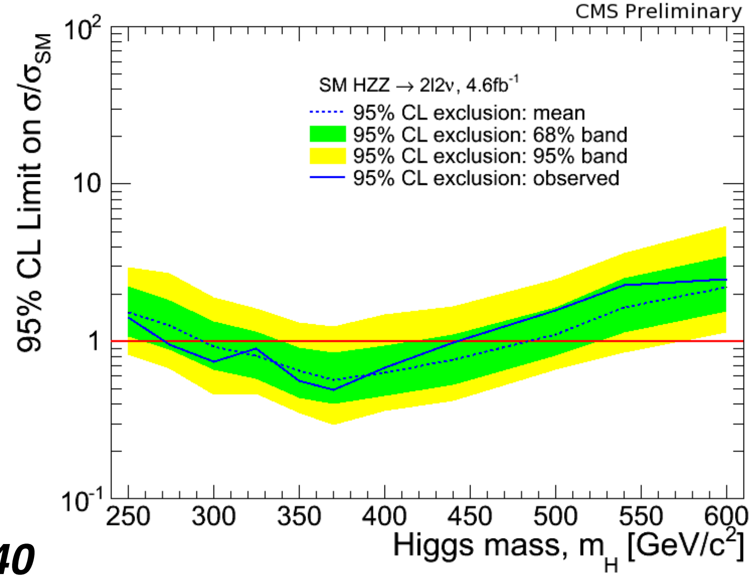
ZZ irreducible, Z+jets, tt, WZ.





The channel is accessible only for high mass (>250GeV) with the two Z bosons selected to be highly boosted and large ME_T present in the event. Discriminating variable for shape analysis, the transverse mass

$$M_T{}^2 = \left(\sqrt{P_{TZ}{}^2 + M_Z{}^2} + \sqrt{MET^2 + M_Z{}^2}\right)^2 - \left(\vec{P_{TZ}} + \vec{MET}\right)^2$$



95%CL exclusion limits for a SM Higgs boson in range 270-440 GeV

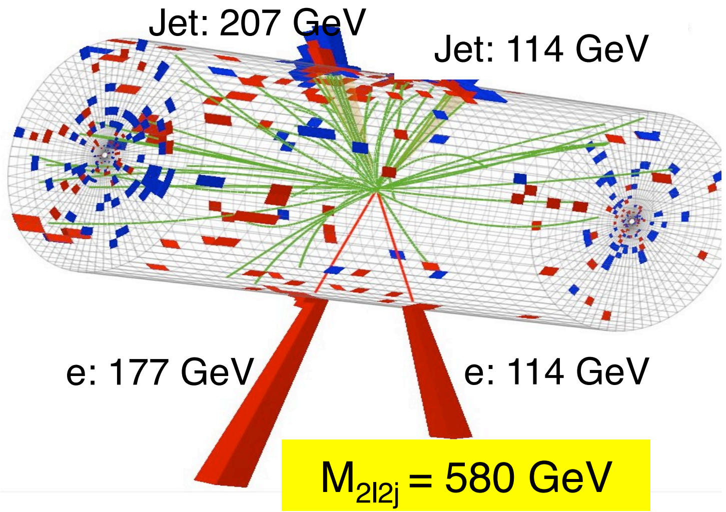
arXiv: 1202.3478

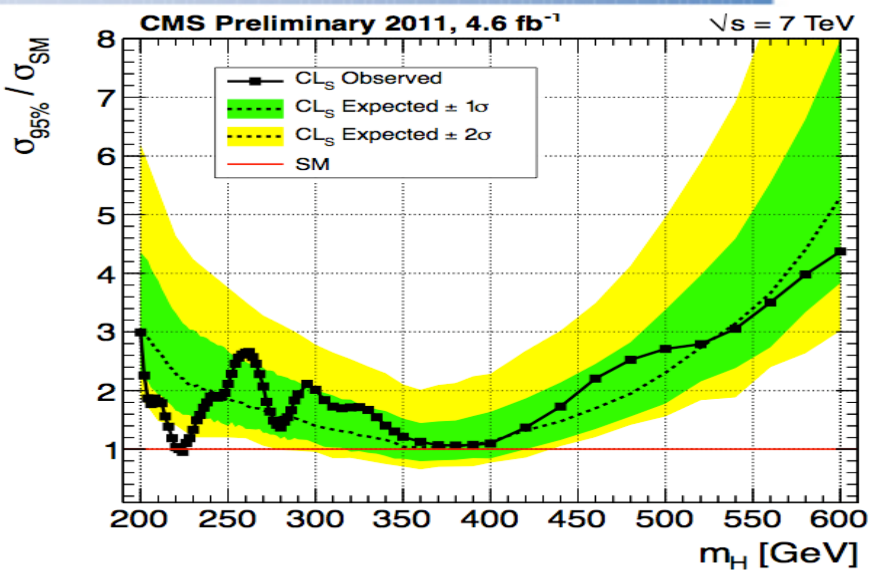
J. High Energy Phys. 03 (2012) 040

CMS other High Mass channels: H →ZZ →2l2q and 2l2τ

H→ ZZ→ 2l2q

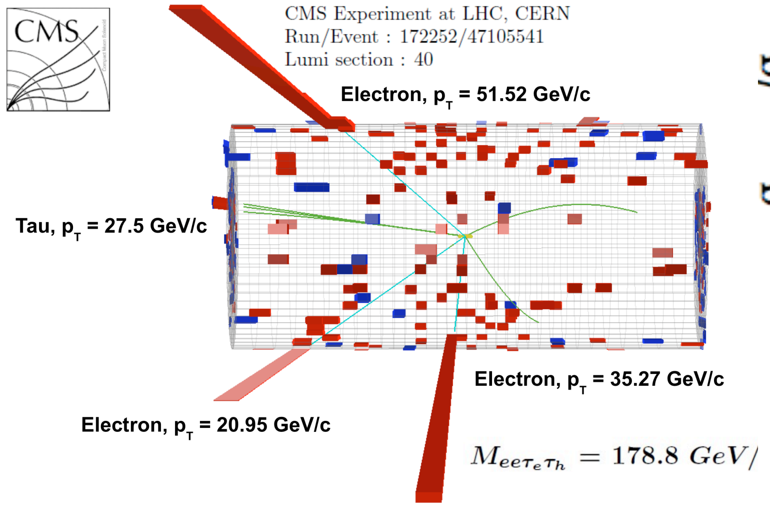
arXiv: 1202.1416
J. High Energy Phys. 04 (2012) 036



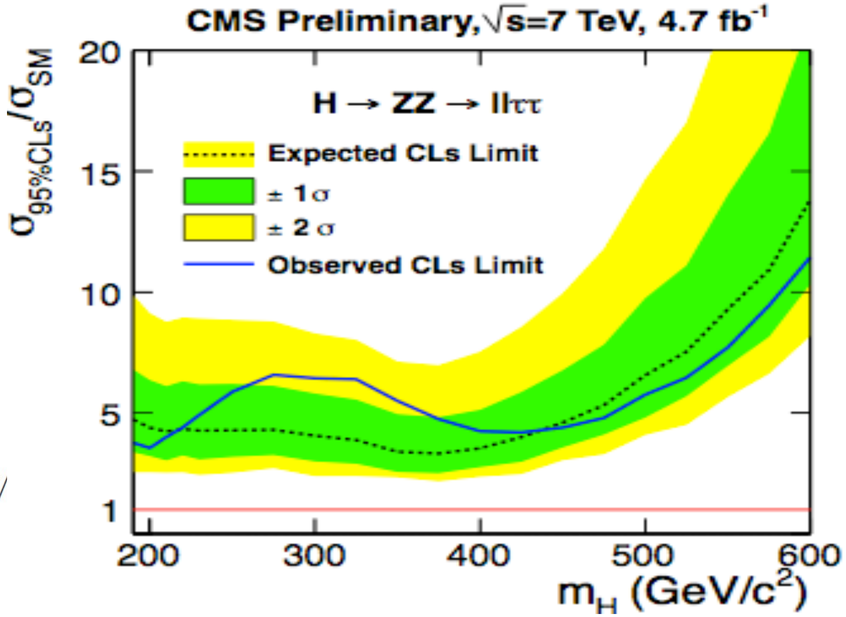


H→ZZ→2l2τ

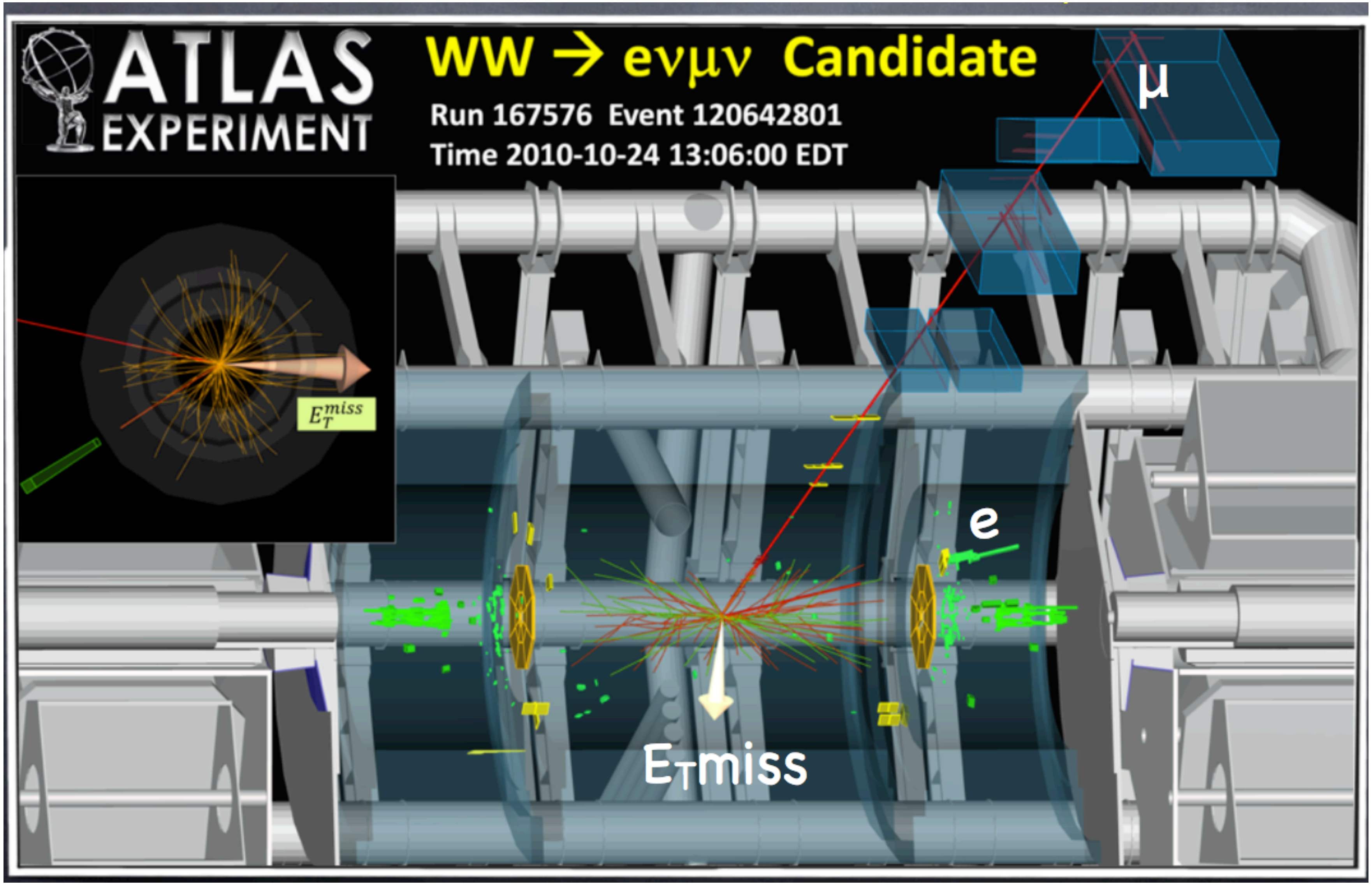
arXiV:1202.3617
J. High Energy Phys. 03 (2012) 081



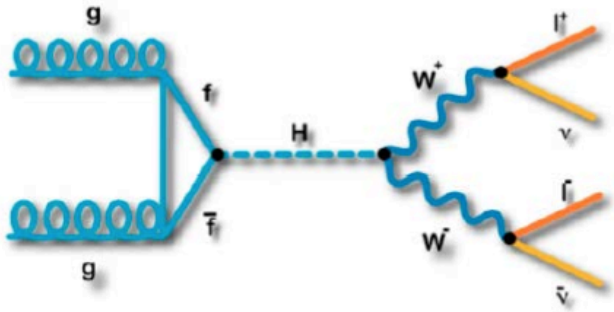
eeeτ candidate



H→ WW→2l2ν: the "work horse"



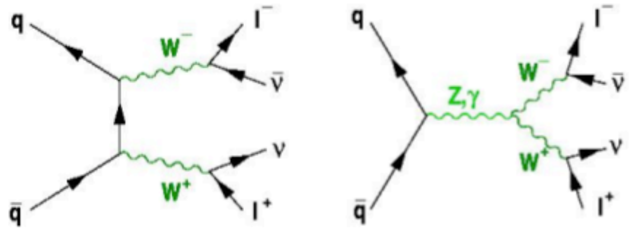
H→ WW→2l2ν: the "work horse"



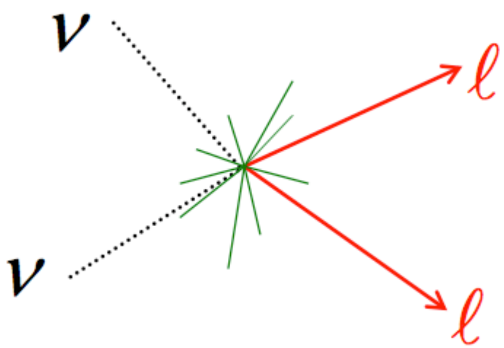
$$\sigma\left(H \to WW^* \to \ell\nu\ell\nu\right) \approx 0.18 \text{ pb}$$

(m_H=125 GeV)

The SM WW is said to be "irreducible"

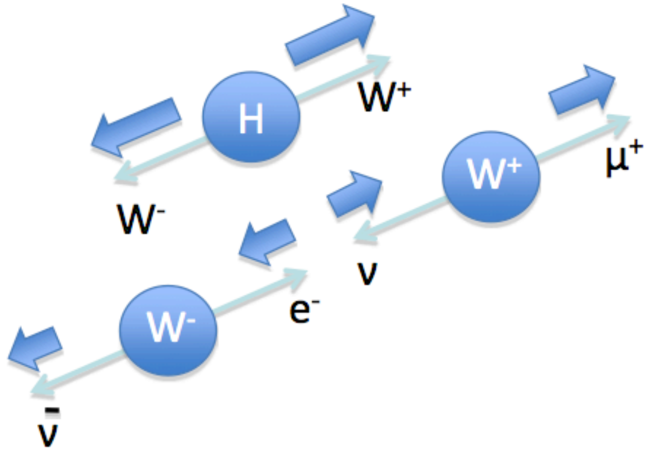


However, WW from the scalar Higgs is expected to have different kinematics



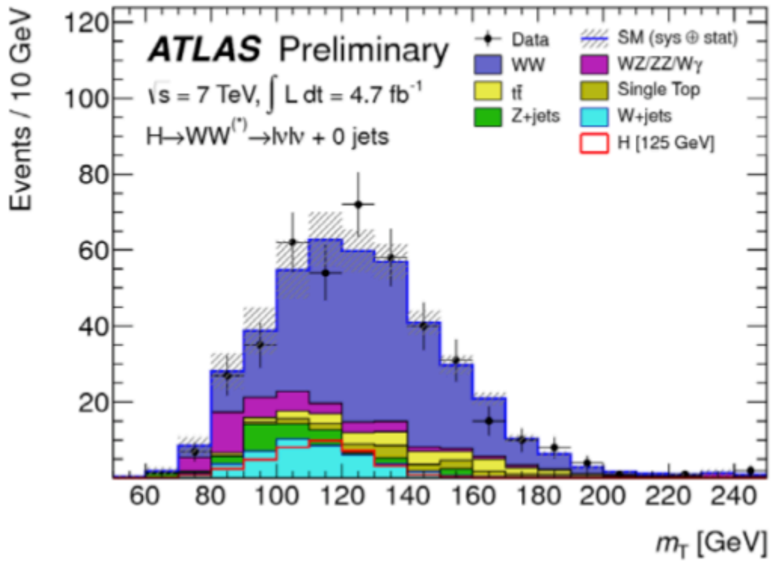
Main background:

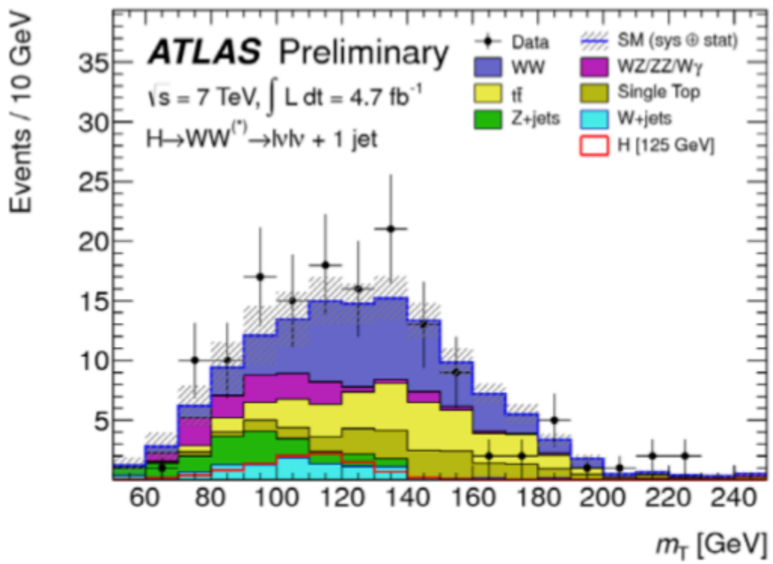
WW, W/Z+jets, $t\bar{t}$, ,...



The spin correlation leads to a smaller average opening angle between the two leptons

ATLAS: H→ WW→2l2ν

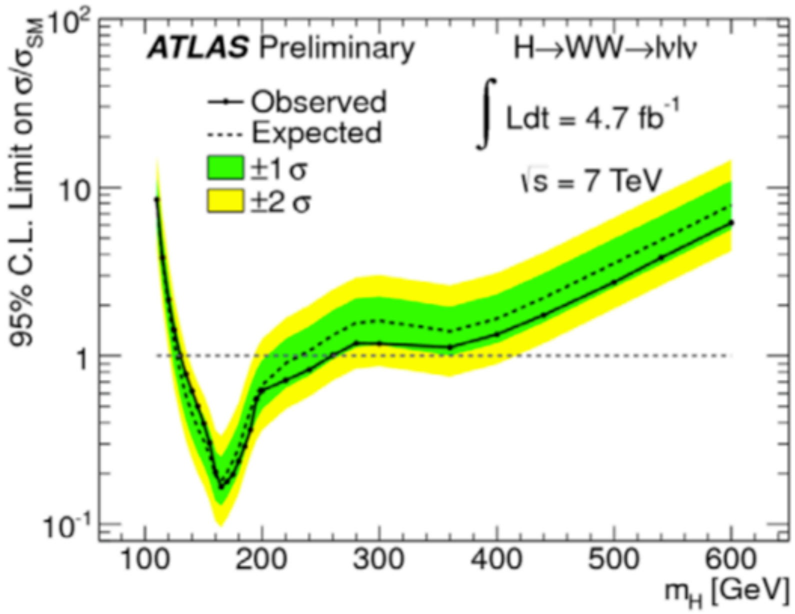




Small opening angle between leptons.
Use of M_T as main discriminating variable.

$$m_T = \sqrt{\left(E_T^{\ell\ell} + E_T^{\text{miss}}\right)^2 - \left(\vec{p}_T^{\,\ell\ell} + \vec{E}_T^{\text{miss}}\right)^2}$$

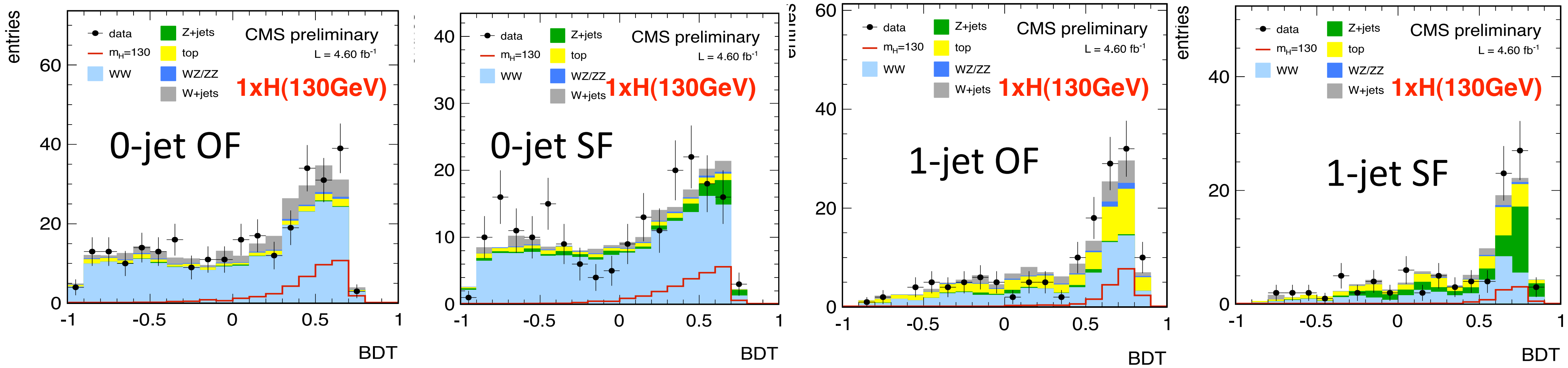
For m_H =125GeV $0.75m_H < m_T < 1.0m_H$

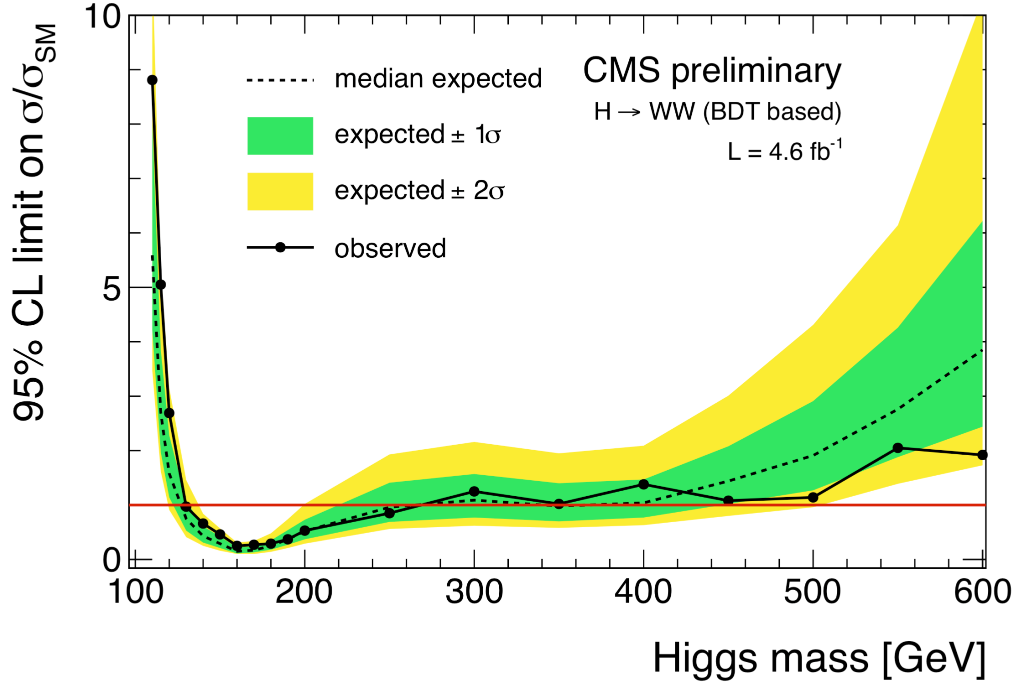


ATLAS-CONF-2012-012

Observed Exclusion: 130-260 GeV (expected: 127-234 GeV)

CMS: H→ WW → 2l2ν





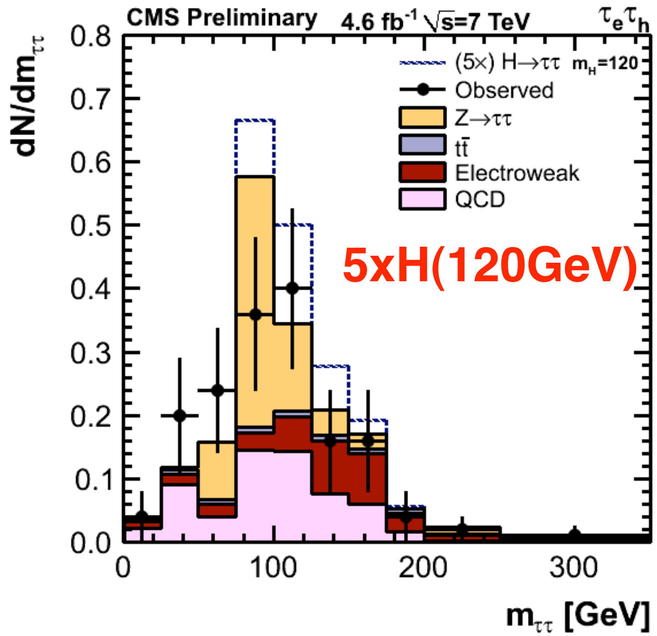
Expected range: 127 < M_H < 270 GeV
Observed range: 129< M_H < 270 GeV

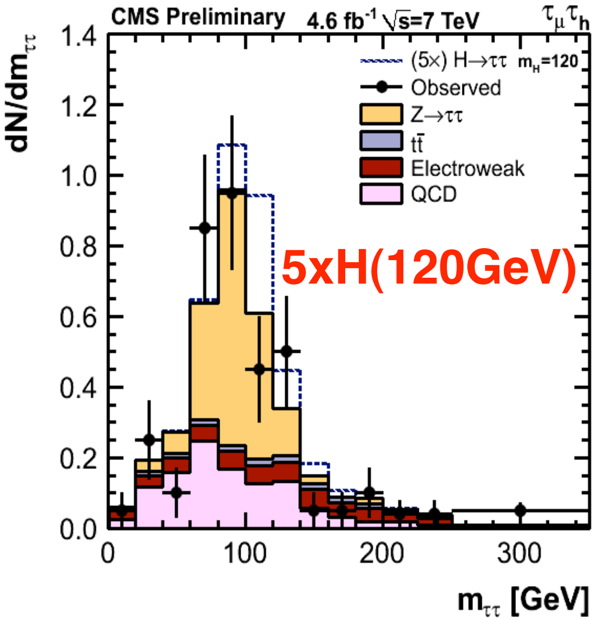
This channel contributes in the whole mass region but the presence of the two neutrinos yields a poor mass resolution (~20%): expect a broad excess and no mass peak in presence of signal.
Very challenging to achieve high sensitivity in the low mass region.

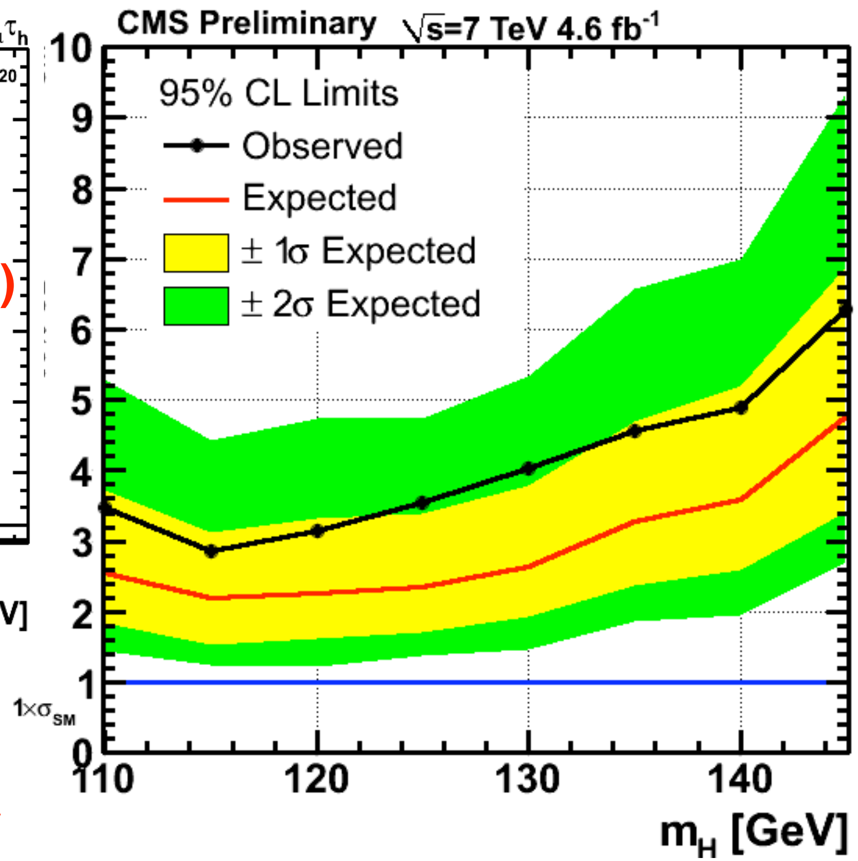
arXiv:1202.1489 *Phys. Lett. B 710 (2012) 91-113*

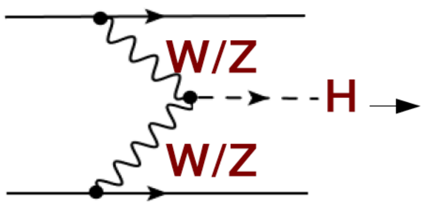
CMS low mass: H→ ττ

The VBF mode is the cleanest and most sensitive channel.







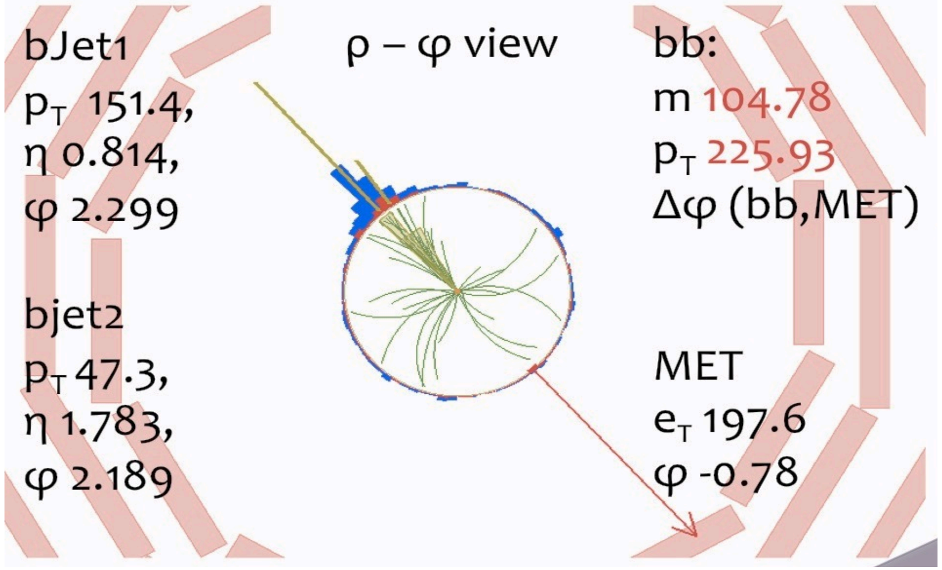


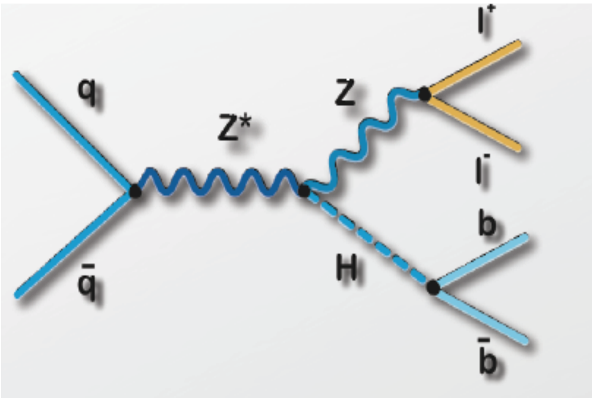
>= 2jets >30GeV
$\Delta\eta>4$, $M_{jj}>400$GeV
No additional jets with $P_T>30$GeV
in the rapidity gap

arXiv:1202.4083

CMS low mass: H→bb

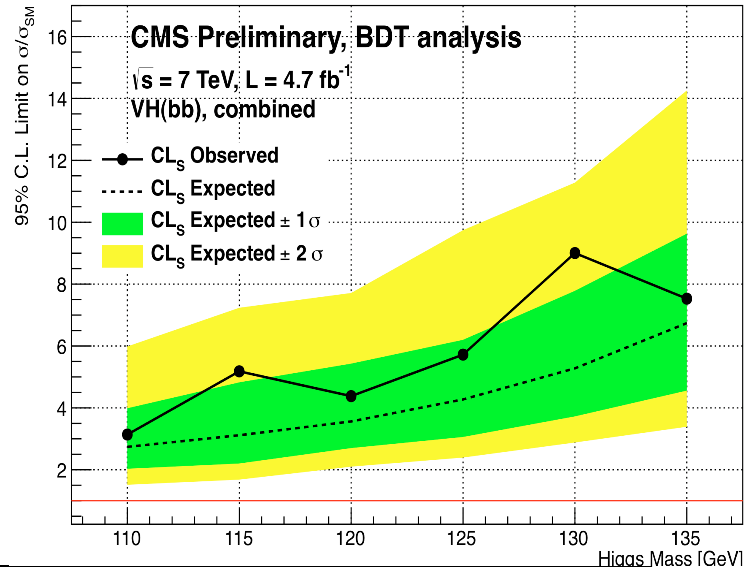
- gg→ H→ bb and VBF are dominant production modes but overwhelmed by enormous QCD di-jet background
- **Best option: qq→ VH; H → bb**
  - Major backgrounds are V+jets, VV, ttbar
- Use
  - **VH topology : ΔΦ(V,H) > 3**
  - **P_T(V)> 100-160 GeV (boosted W/Z)**
  - Tight b-tagging & MET quality
  - **Backgrounds estimated from control data**





5 sub channels

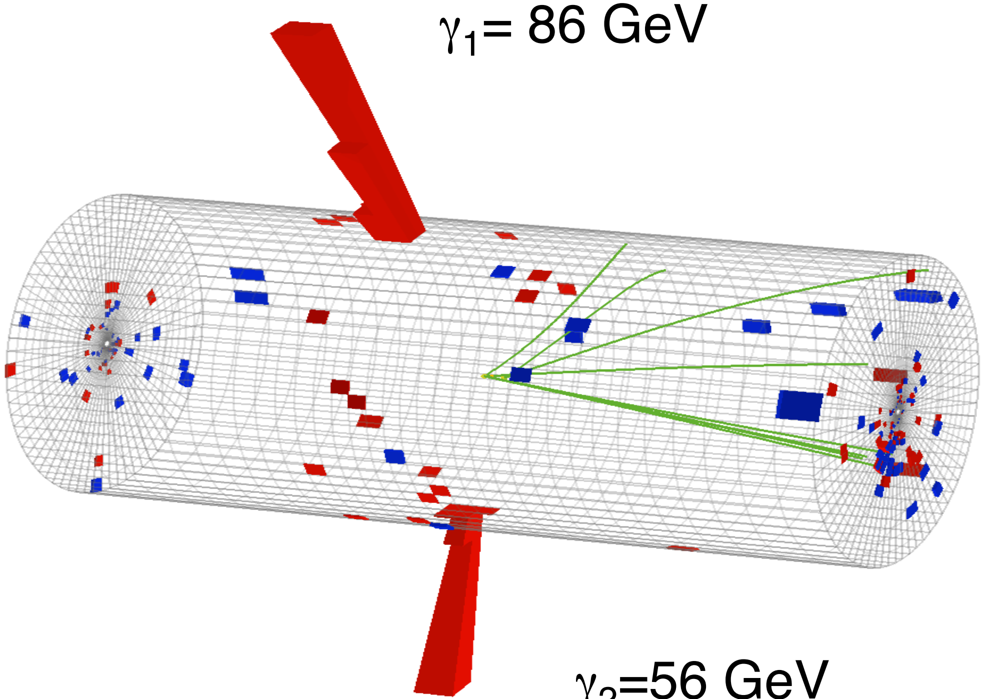
Z(→*ll*); H→bb, *l*=μ,e
W(→lν); H→bb, *l*=μ,e
Z(→νν); H→bb



***Phys. Lett. B 710 (2012) 284-306,* arXiv:1202.4195**

The specialist of the Low Mass: H→ γγ

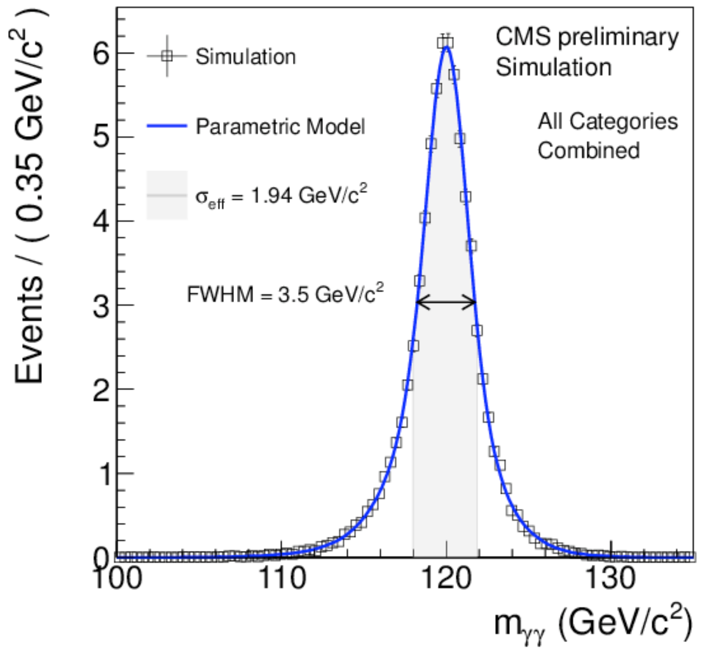
Signal: 2 energetic, isolated γ.
Search for a narrow mass excess over a smoothly falling background.



Excellent resolution: 1-2%

Challenges: vertexing with PU, calibration of the electromagnetic calorimeters.

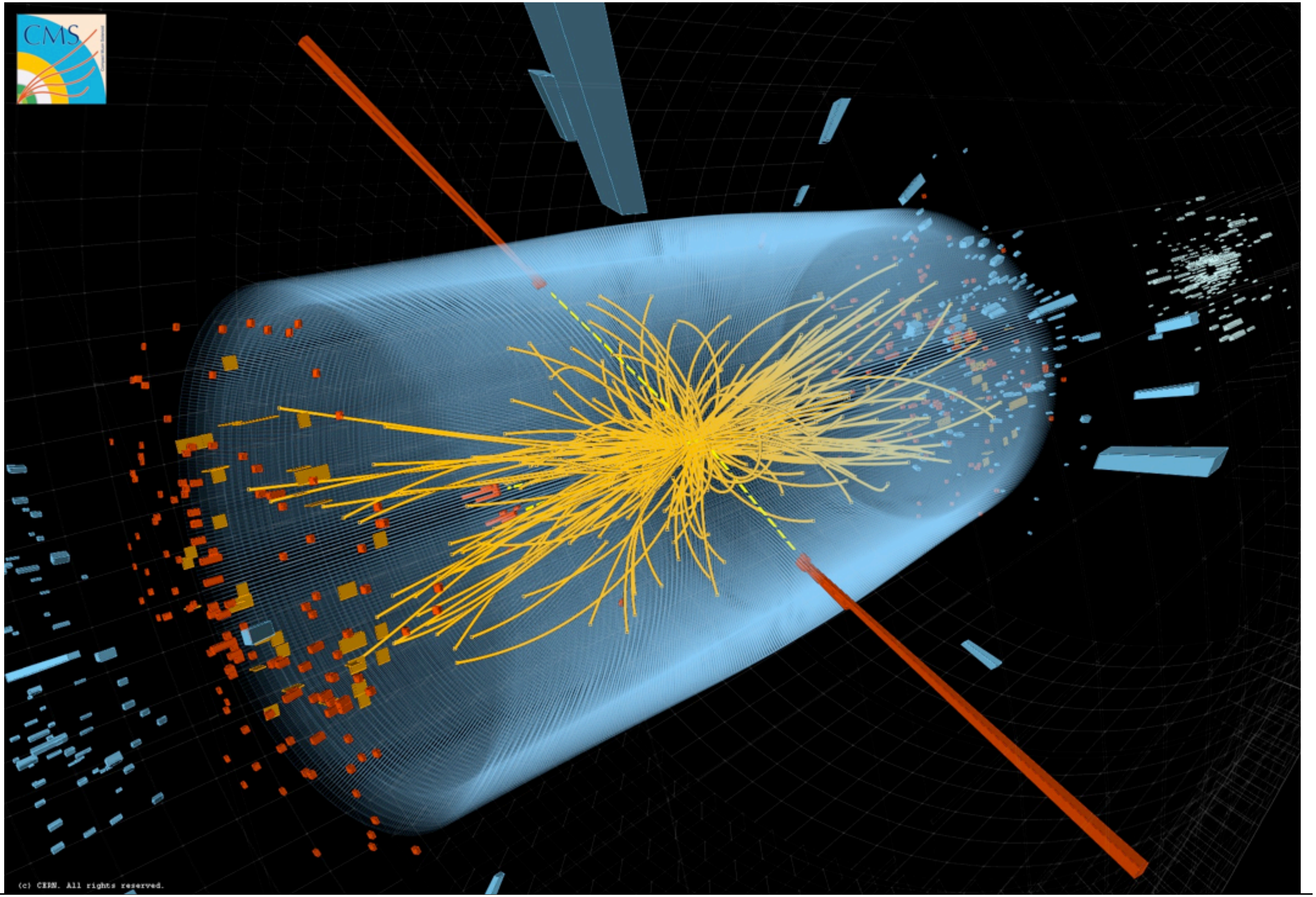
Calibration constants derived from Z→ee data.



Background: Large and mostly irreducible QCD di-photons.
Measured from $M_{\gamma\gamma}$ sidebands in data

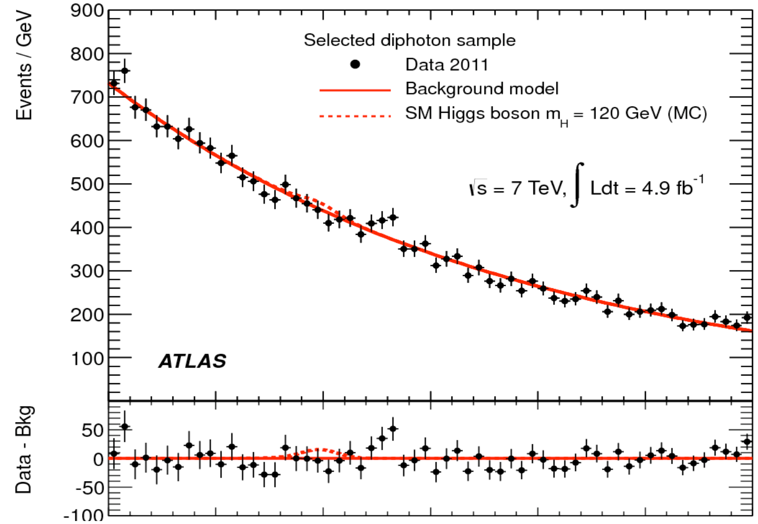
Phys. Lett. B 710 (2012) 403-425

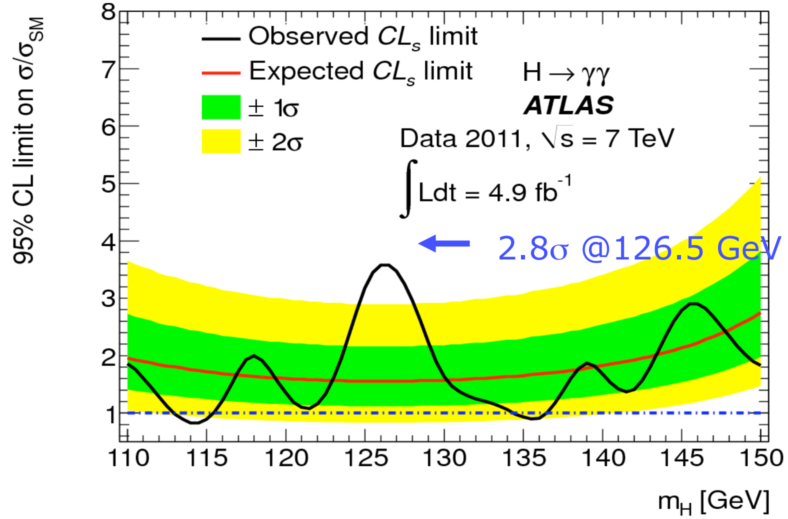
Clean, spectacular events.

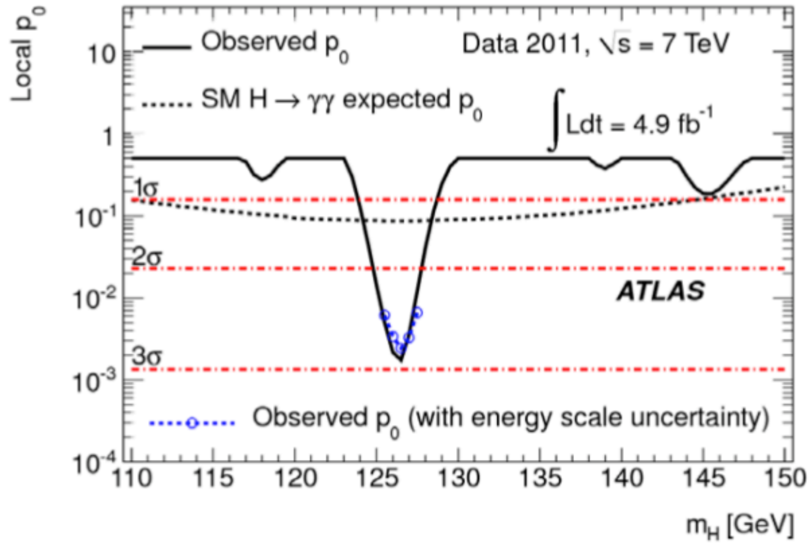


ATLAS: H→γγ

Fit the observed γγ mass distribution with a signal+background model.
Exponential spectrum for the background. Crystal-ball function to describe the signal.







Observed exclusion:

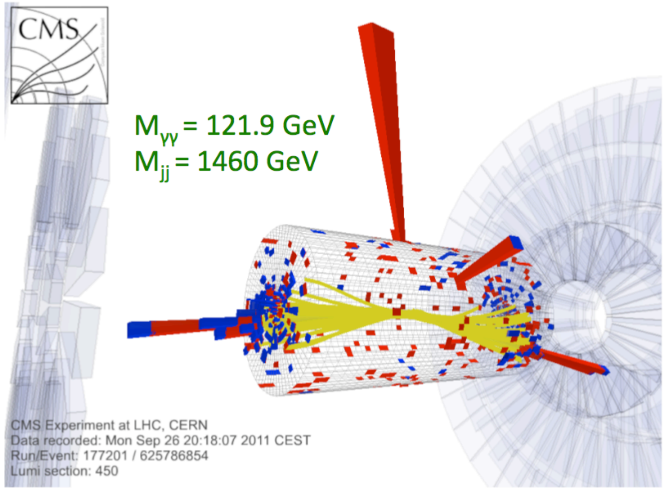
113-115 GeV

134.5-136 GeV

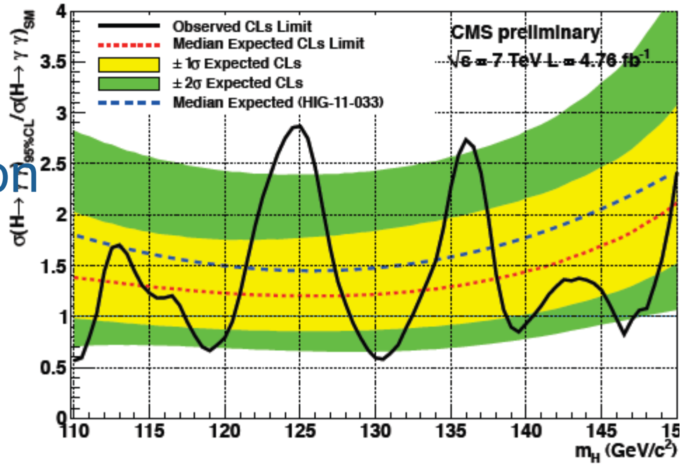
Phys. Rev. Lett. 108, 111803 (2012)

Excess at 126.5 GeV with a significance of
2.8σ – local
1.5σ – global (110-150 GeV)

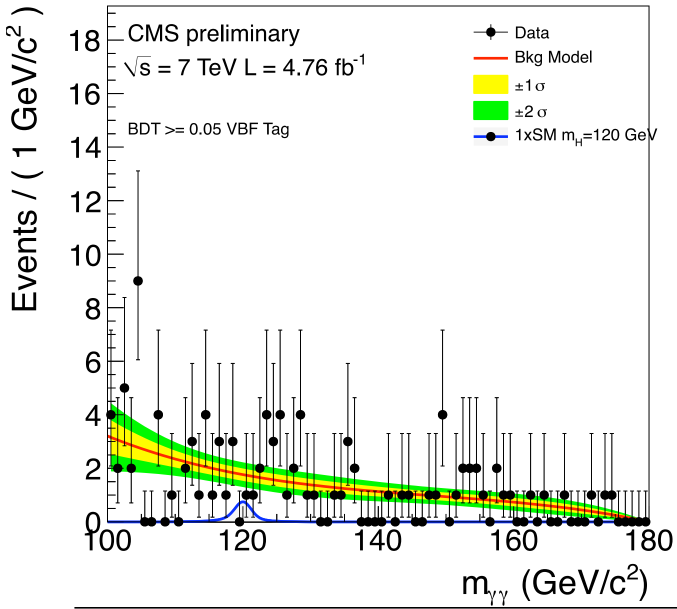
H→γγ in CMS: added VBF and MVA.



Gain in sensitivity adding MVA and VBF.
Exclusive di-jet tag selection has better S/N~1/3.

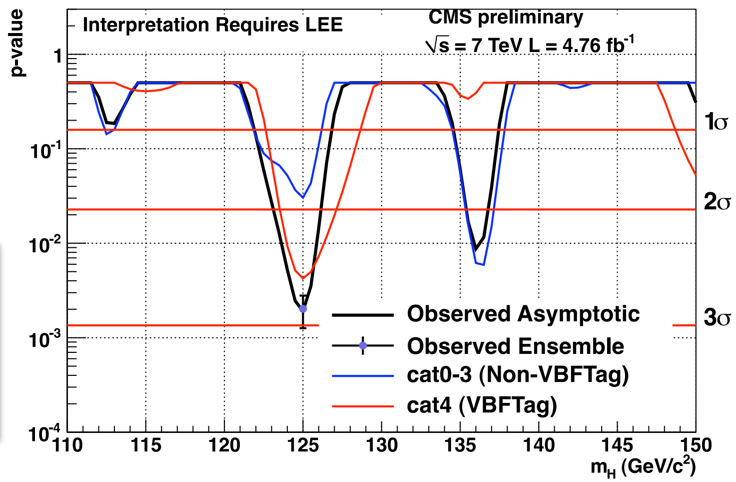


110-111, 117.5-120.5,128.5-132,139-140,146-147GeV SM Higgs excluded at 95% CL.

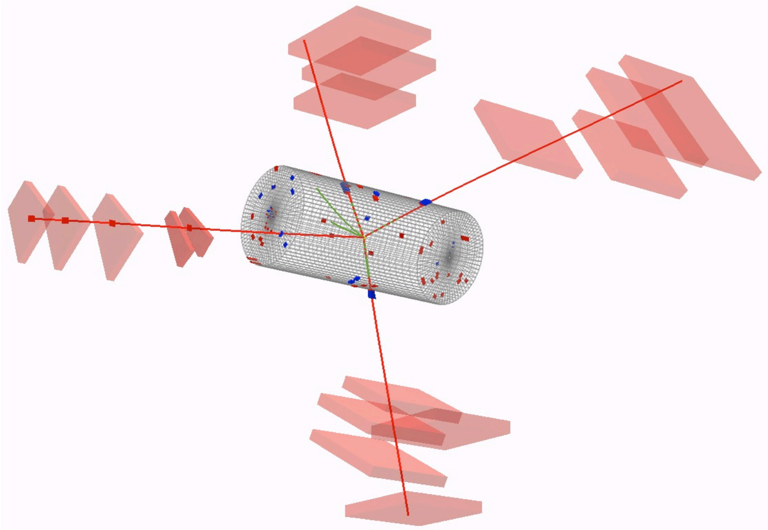


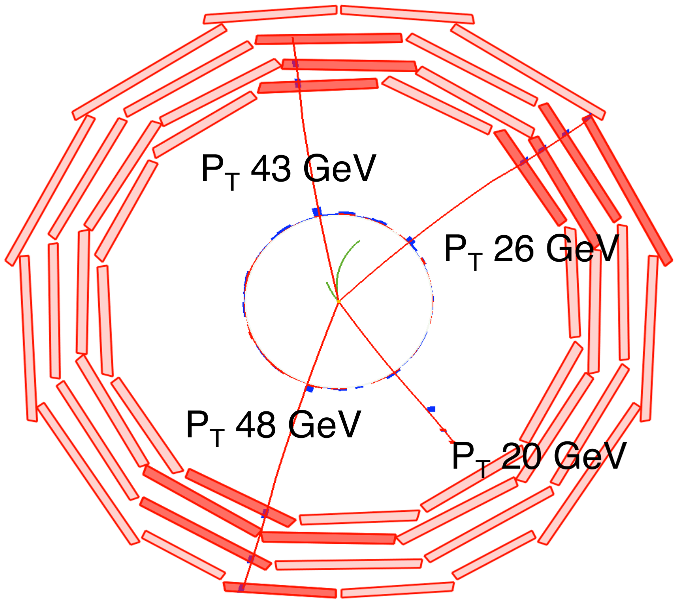
CMS-PAS- HIG-12-001

Excess at 125GeV with a local significance of 2.9σ; 1.6σ global 110-150 GeV.



H → ZZ →4e, 4μ, 2e2μ: The Golden Channel





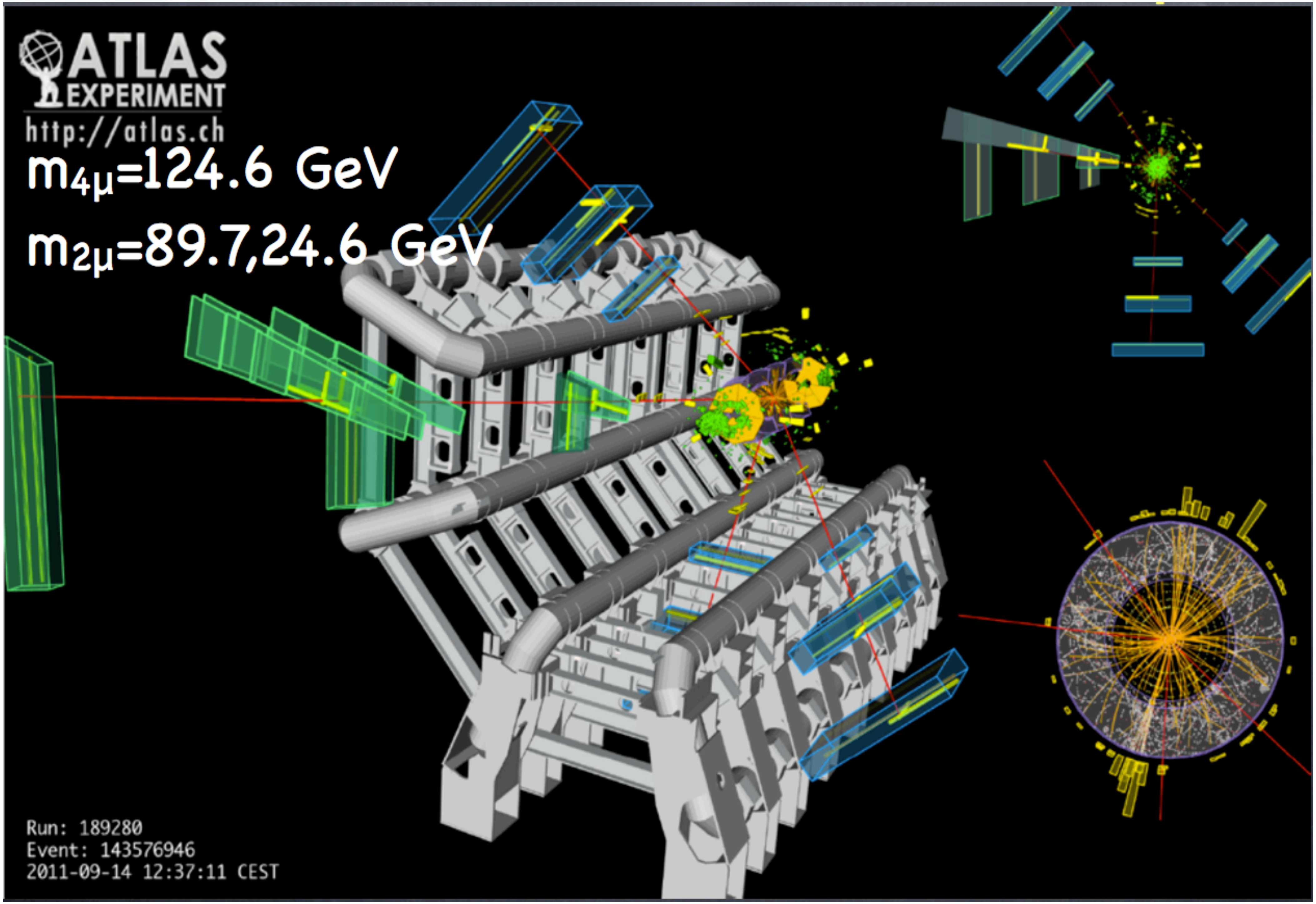
Signature: Two pairs of same flavor high pT oppositely charged isolated leptons. One or both pairs with invariant mass compatible with the Z.

Extremely clean, high resolution channel (1-2%) but very low rate (σ~2-5fb).

Kinematics fully available: reconstruction of the invariant mass of the system.

Main backgrounds: ZZ* (irreducible) for $m_H<2m_Z$, Zbb, Z+jets, tt

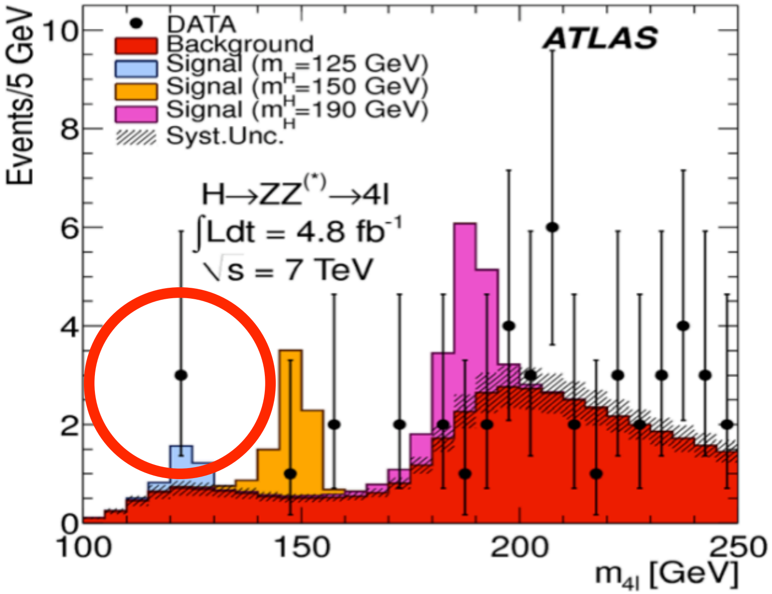
Suppress backgrounds with isolation and impact parameters cuts on two softest leptons.


ATLAS
EXPERIMENT
http://atlas.ch
$m_{4\mu}$=124.6 GeV
$m_{2\mu}$=89.7,24.6 GeV
Run: 189280
Event: 143576946
2011-09-14 12:37:11 CEST

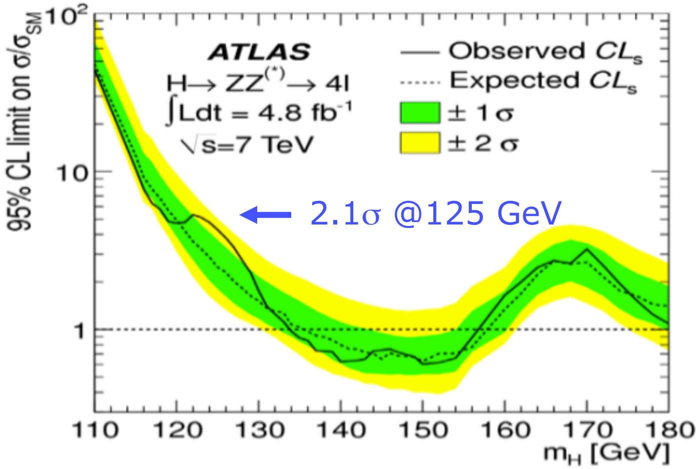
ATLAS: H → ZZ →4e, 4μ, 2e2μ

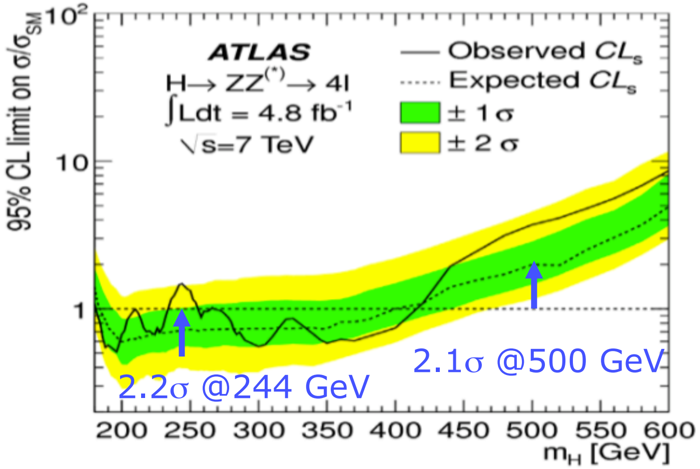
Event yield (full search range)

	4e	2e2μ	4μ
Background	13.4±2.0	29.7±4.5	18.6±2.8
Signal (130 GeV)	0.43±0.08	1.22±0.21	1.00±0.17
Data	17	30	24



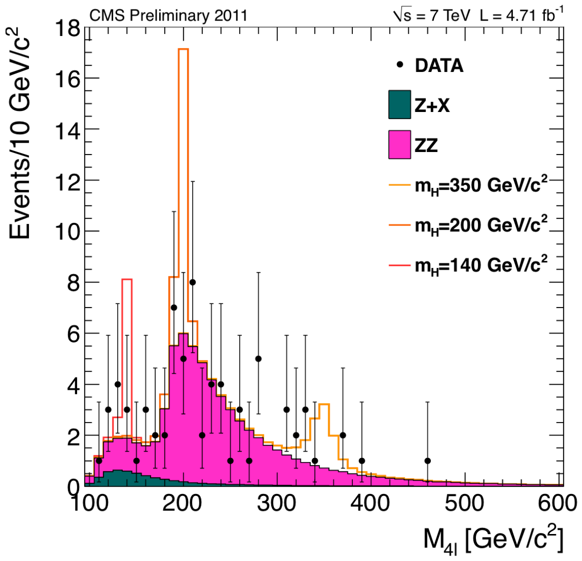
Phys. Lett. B710 (2012) 383

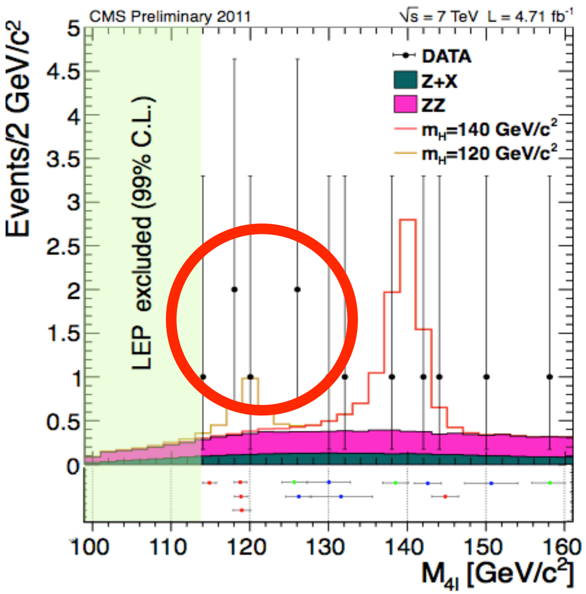




Excess at 125GeV (3 events vs 1.5 expected from BKG only hypothesis) with a local significance of 2.1σ (global 1.5σ)

CMS: H → ZZ →4e, 4μ, 2e2μ





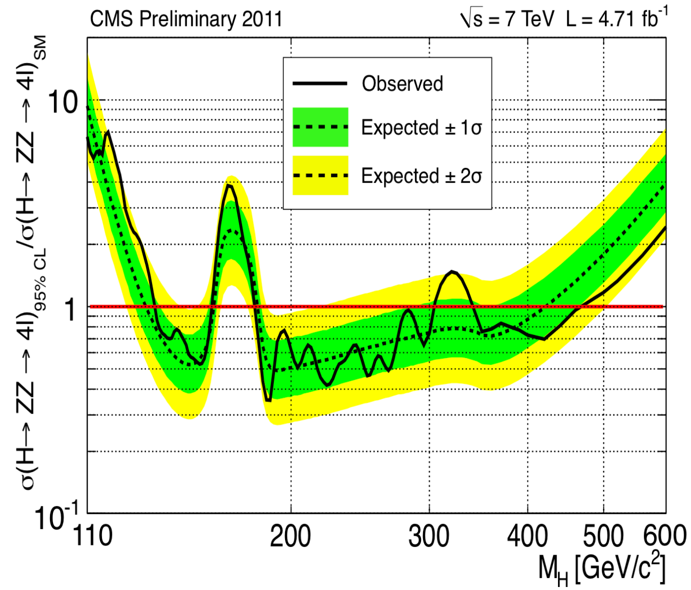
In the low mass region
$100 < m_{4l} < 160$ GeV/c²

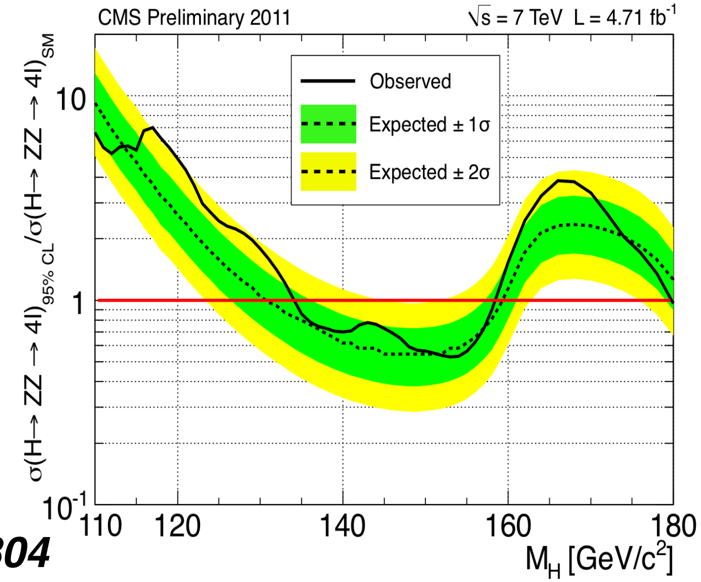
Observed events: 13
Expected events: 9.5 ± 1.3

Largest excess observed at 119.5GeV (3 events vs ~1 expected from BKG only hypothesis) with a local significance of 2.5σ (global 1.6σ)

95% Exclusion limits:
$134 < M_H < 158$ GeV;
$180 < M_H < 305$ GeV;
$340 < M_H < 460$ GeV

arXiv:1202.1997
Phys. Rev. Lett. 108 (2012) 111804

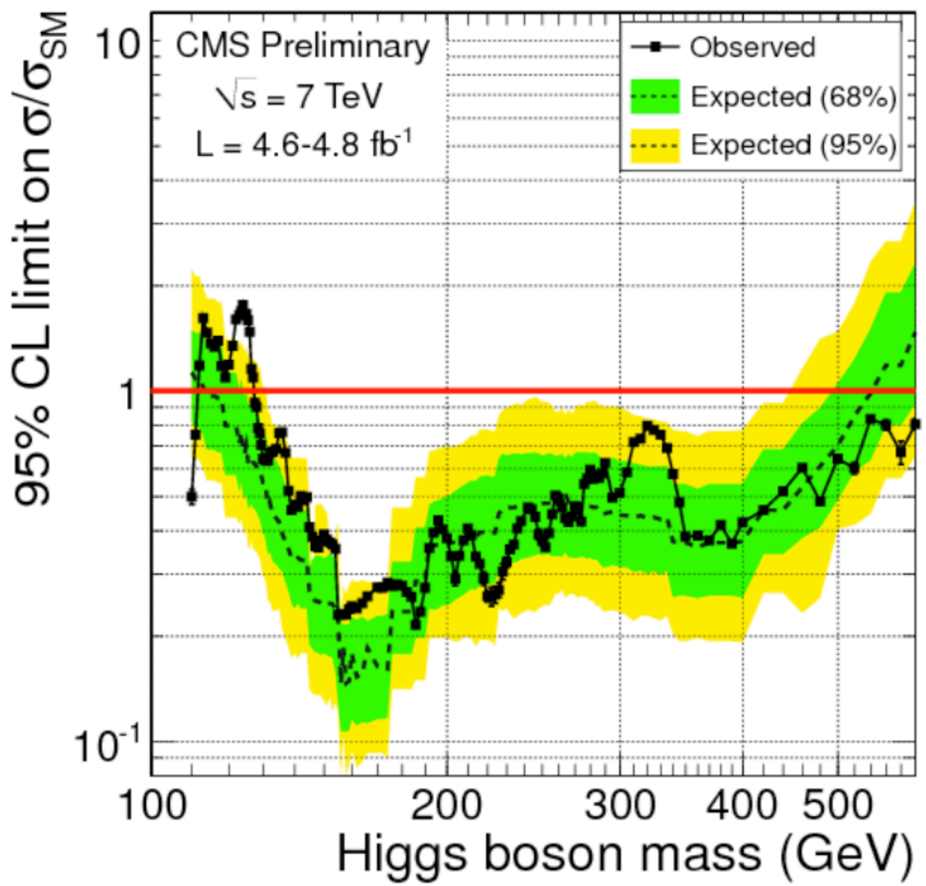




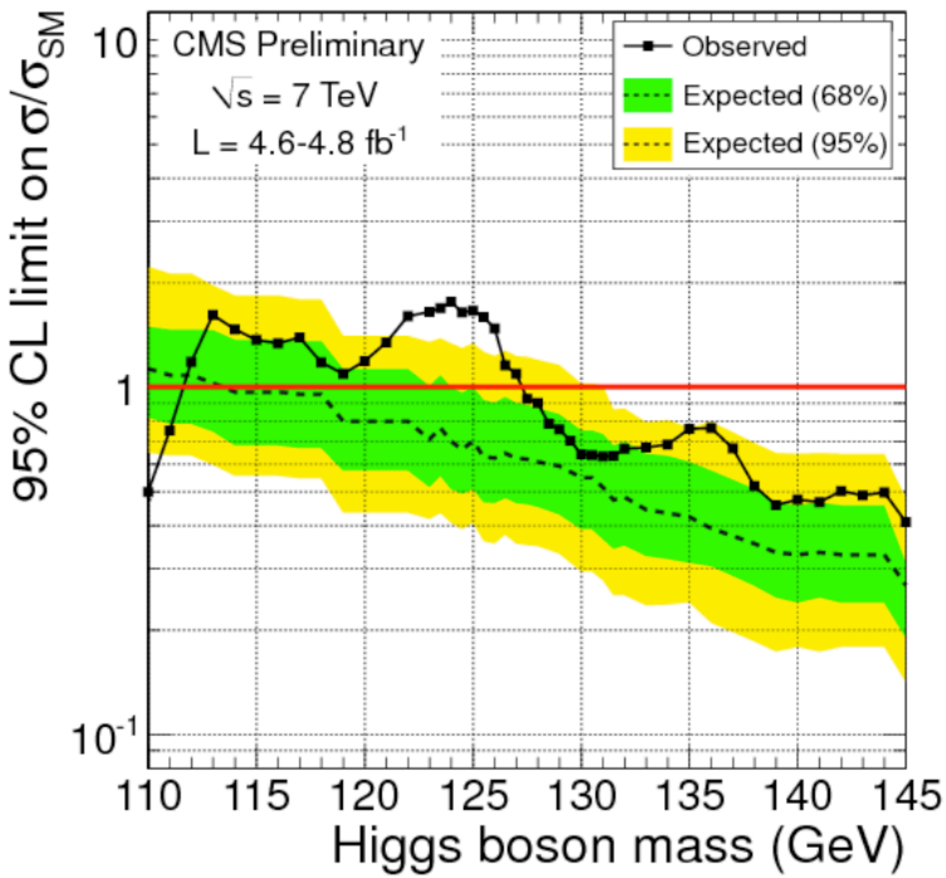
Combination of the results

CMS New Combination

Full mass range



Low mass region

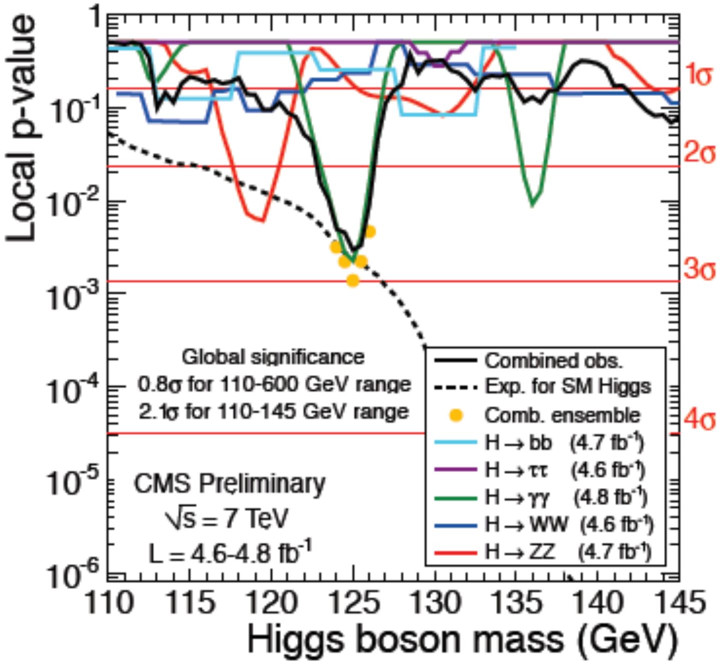


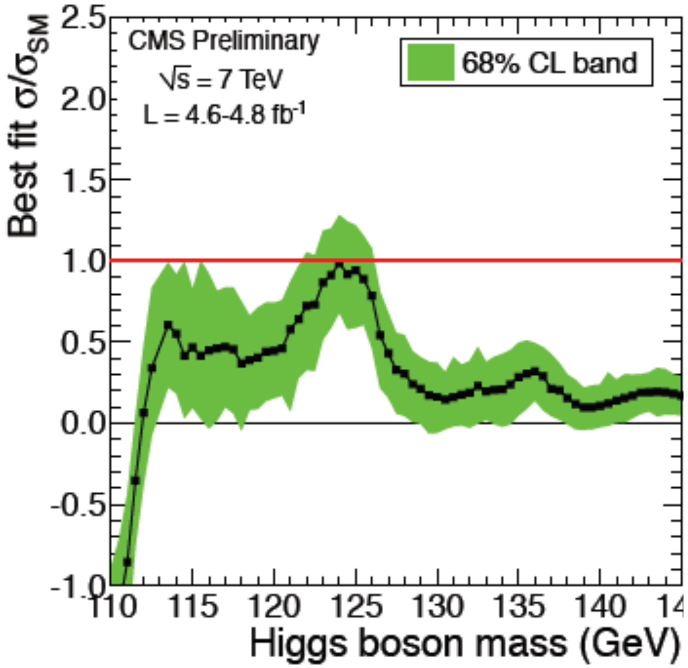
Expected exclusion 114.5 - 543 GeV

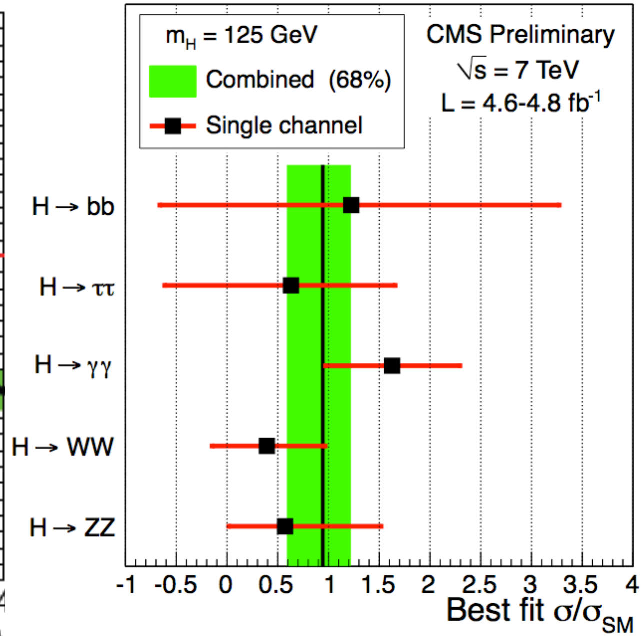
Observed exclusion 127.5 - 600 GeV

CMS-PAS-HIG-12-008

p-value and SM consistency





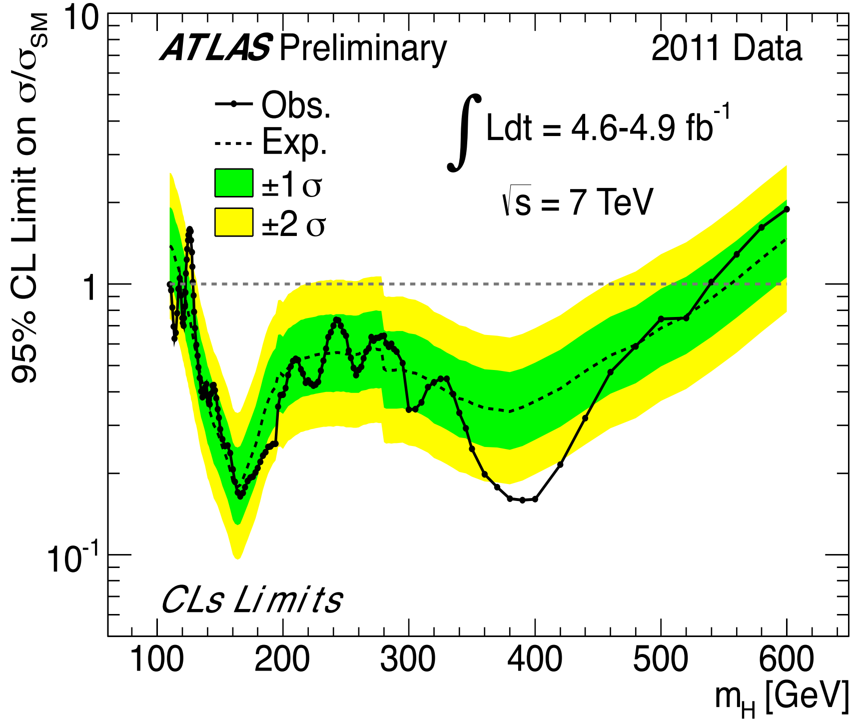


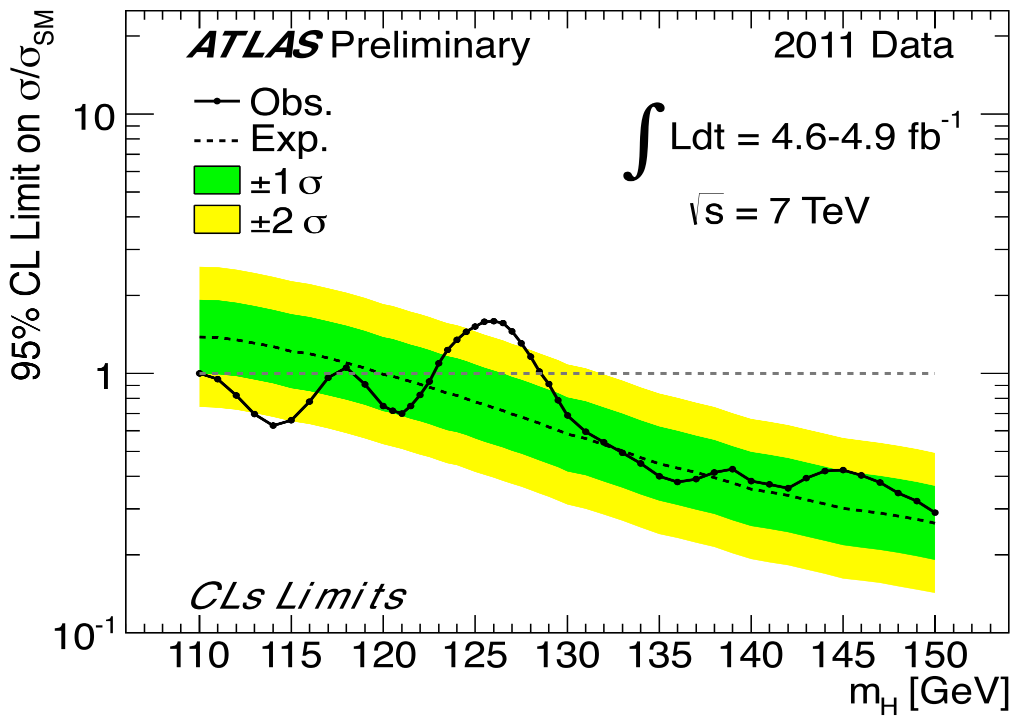
"excess" around 125 GeV

Local p-value 2.8σ
Global p value 0.8σ (110-600 GeV)
Global p-value 2.1σ (110-145 GeV)

New ATLAS combination

All 12 channels updated with full 2011 luminosity in a new combination.





Expected exclusion @ 95%CL **[120-555] GeV. Observed exclusion @ 95%CL [110-117.5], [118.5-122.5], [129-539]GeV.** Tiny NOT-excluded region [117.5-118.5] GeV.

The "excess" around 126 GeV does not allow exclusion between 122.5 and 129GeV.

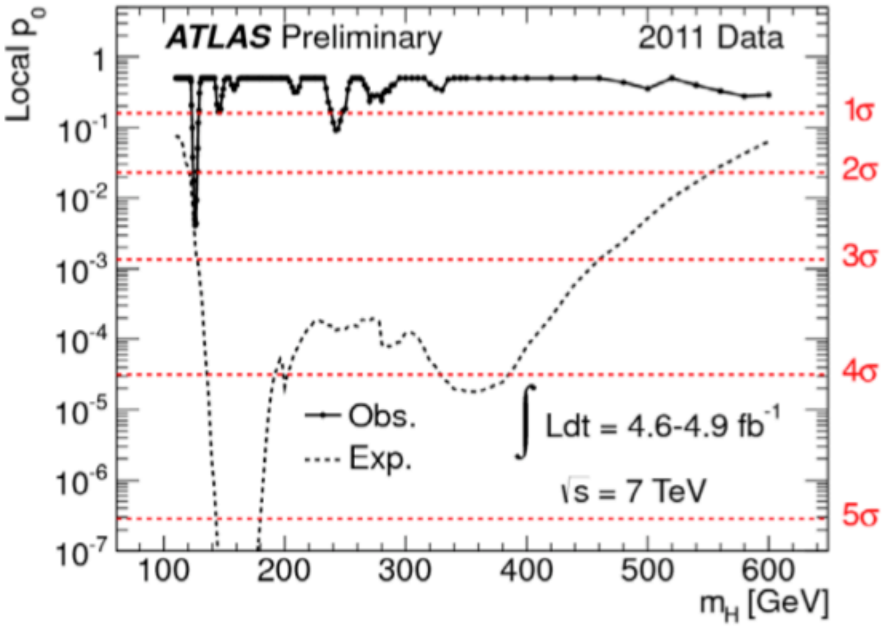
ATLAS-CONF 2012-019

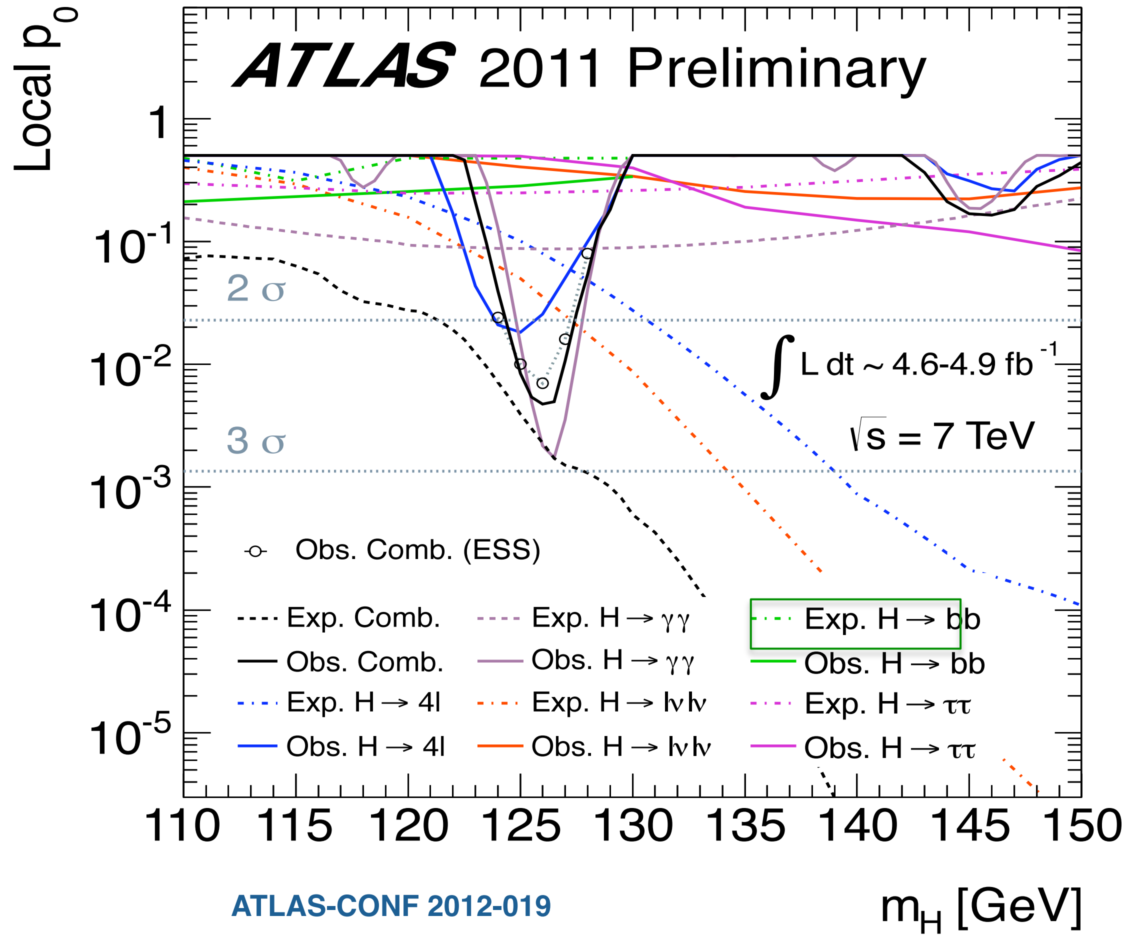
Closer look to the "excess"

The most significant excess is at local P_0= 126 GeV (P_o= compatibility with bkg-only hypothesis).

$\gamma\gamma$	2.8 (1.4) σ
$ZZ^* \rightarrow 4l$	2.1 (1.4) σ
$WW^* \rightarrow 2l\ 2\nu$	**0.2 (1.6) σ**

… + $\tau\tau$ and **bb** final states



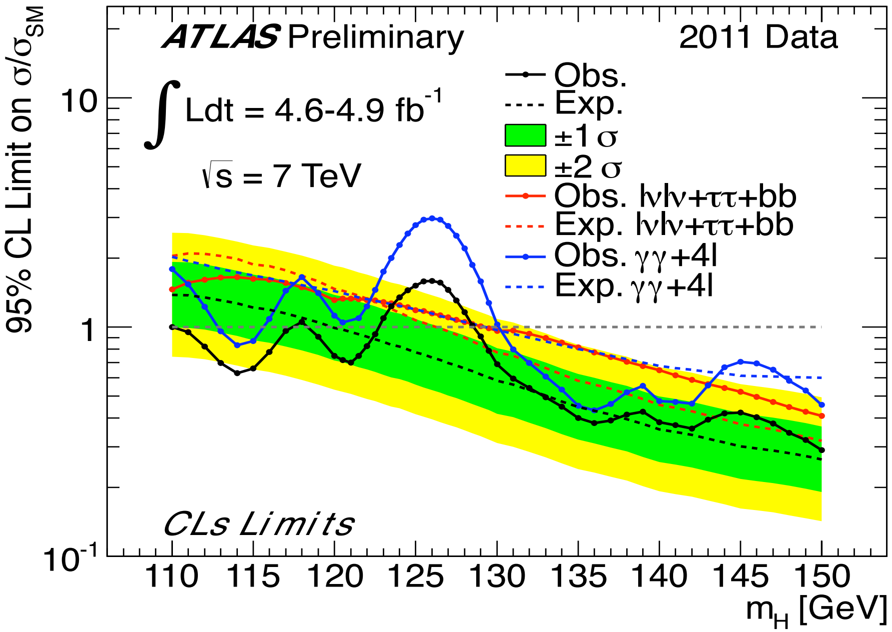


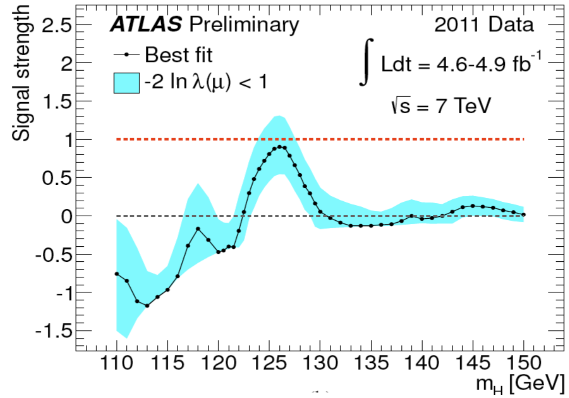
ATLAS-CONF 2012-019

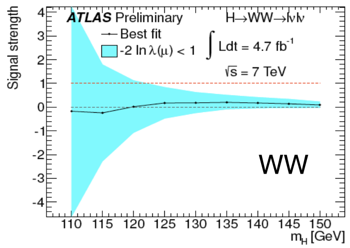
Combined observed 2.6σ.

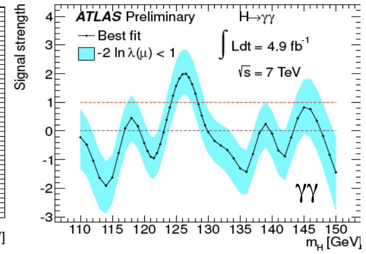
2.9σ expected as median value in presence of a SM Higgs signal.

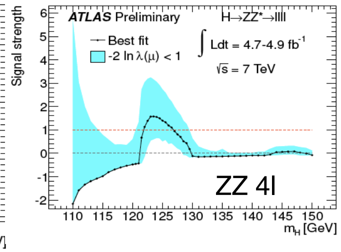
Compatibility between channels











Excess from "high-resolution" γγ and ZZ→ 4l
WW+ττ+bb ("low resolution" channels)
do NOT exclude 126 GeV Higgs

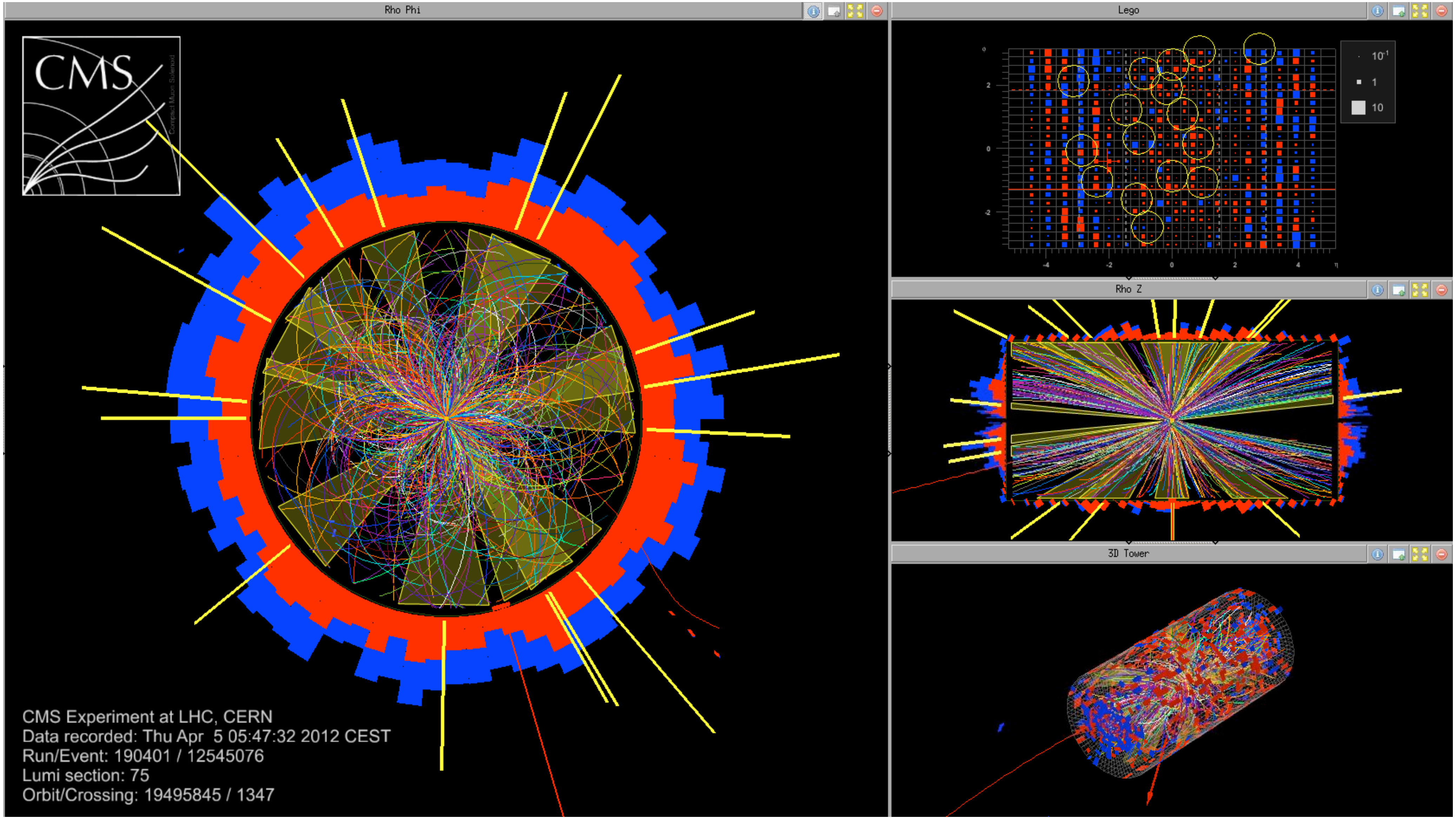
Best Fit value at 126 GeV $\hat{\mu} = 0.9^{+0.4}_{-0.3}$

Combination and each individual channel compatible "signal strength"=1 at 126 GeV

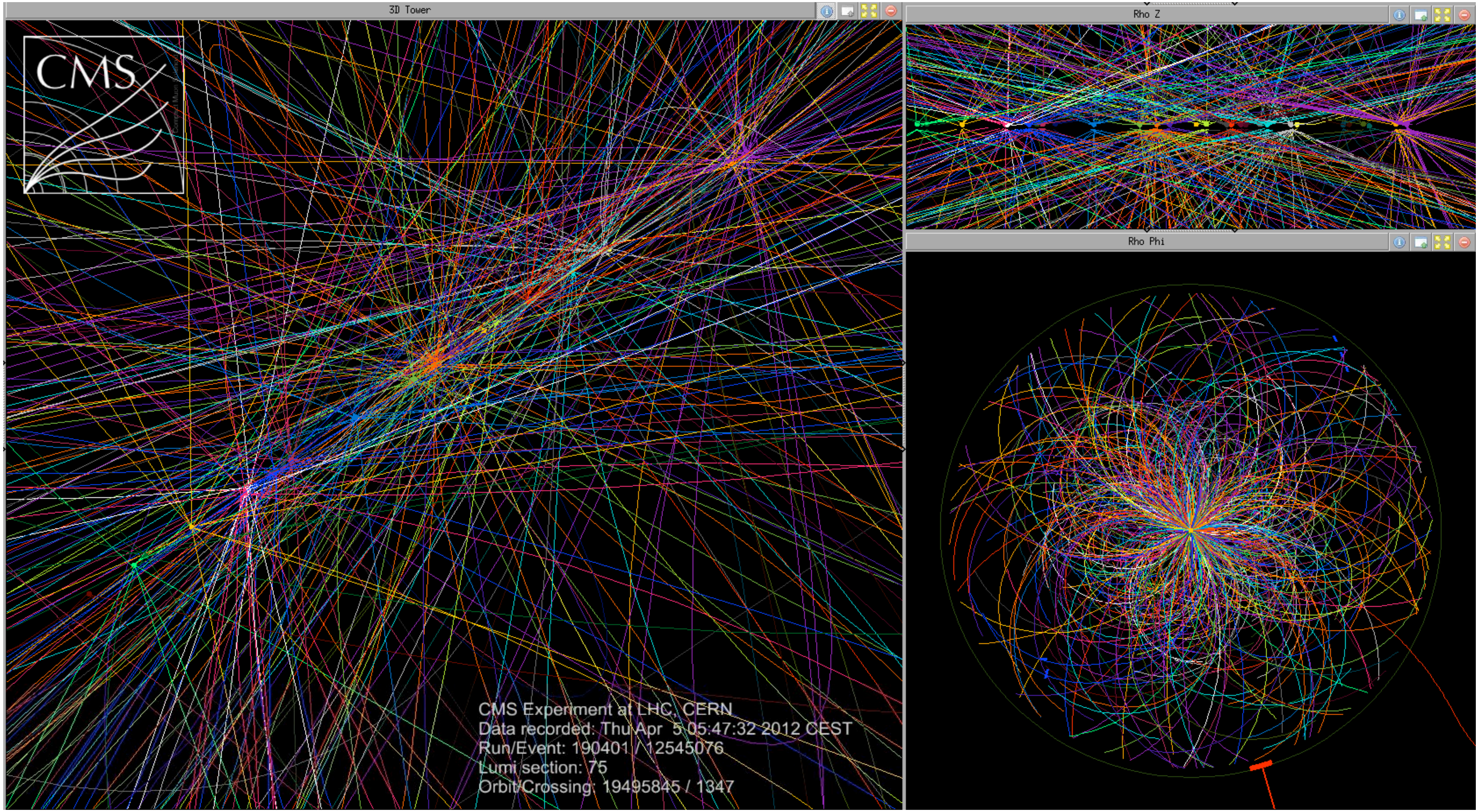
Both hypotheses "S+B" and "B-Only" still alive.
Need 2012 data for definitive answer.

Perspectives and conclusions

The challenge of the 2012 run

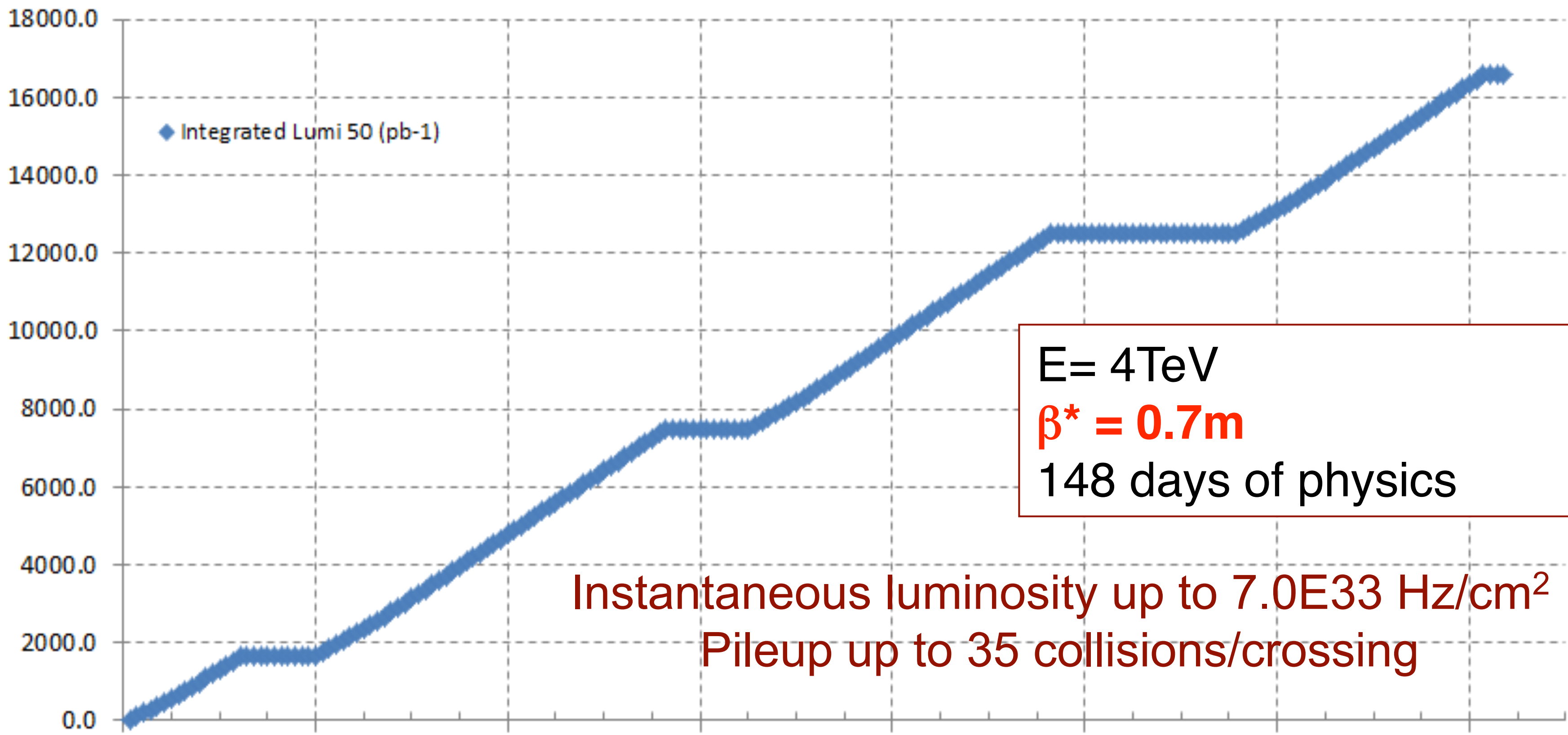


8 TeV and high pile-up conditions



Expected Integrated Luminosity in 2012

Steve Myers February 2012

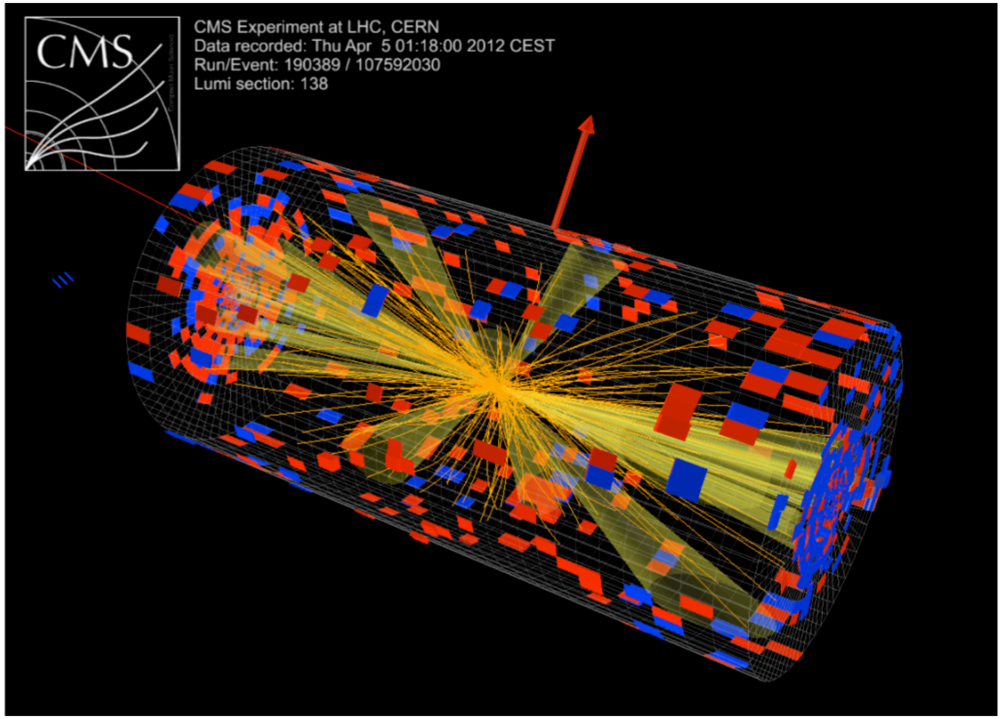


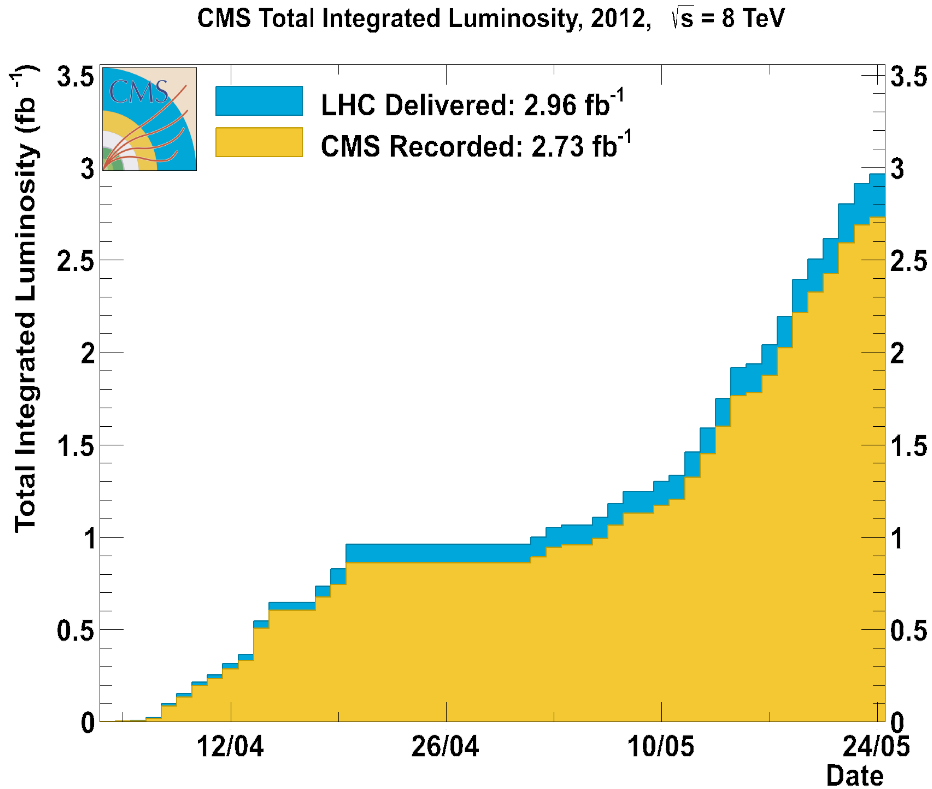
E= 4TeV
β^* = 0.7m
148 days of physics

Instantaneous luminosity up to 7.0E33 Hz/cm^2
Pileup up to 35 collisions/crossing

Reasonable to expect that the integrated luminosity estimate is conservative
(**β^*=0.6 m may be possible, other improvements**)

The LHC 2012 run at 8 TeV is ongoing





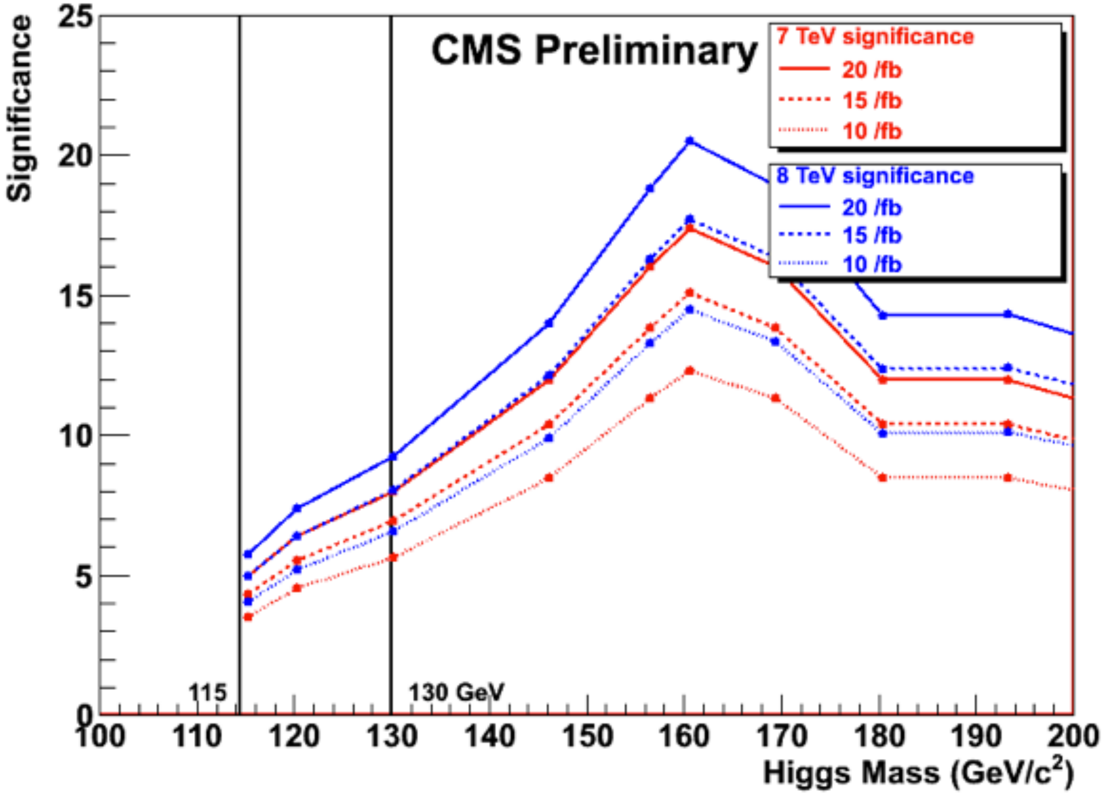
Current running conditions 1380 bunches, **β^*=0.6m**, bunch charges up to **1.5×10^{11}protons/bunch**, pile-up up to **30 events/crossing** at the beginning of the fill, emittance in collision at **2.0-2.5μm**, record instantaneous luminosity: **$6.5\times10^{33}cm^{-2}s^{-1}$**

In track for >15fb^{-1} by the end of the year

but please continue keeping your fingers crossed.

Priority: search for the Higgs

- Integrated luminosity is the key
- Energy of 8 TeV allows higher lumi and higher cross-sections
  - ~30% higher σ for low-mass Higgs.
- High pileup
  - up to 35 events/crossing



Discovery potential for the SM Higgs Boson (non-optimized analysis)

Conclusion.

- Thanks to the fantastic performance of the LHC and its detectors in 2011, an incredible amount of progress has been achieved in the search for the Standard Model Higgs boson.

- The presence of the SM Higgs has been substantially excluded at 95% CL in the full mass region below 600GeV with the exception of a very narrow region between 122.5 and 127.5GeV.

- Intriguing hints of the possible presence of the SM Higgs boson in LHC data around a mass of 125GeV/c^2 have been reported independently by ATLAS and CMS. We expect conclusive statements (confirmation at the observation level or exclusion at least at 95% CL) using the current 2012 data.

- LHC 2012 run at 8TeV has successfully started with expectations for an integrated luminosity >15fb^{-1}.

Stay tuned !