Discussion on Higgs Physics

- Which results can be expected until LHC LS1:
  - For ICHEP with 5/fb at 7 TeV + 5/fb of data at 8 TeV, so 10/fb/ experiment at LHC, basically doubling 2011 integrated luminosity
  - Main challenges
  - At the end of the year where 5/fb at 7 TeV + 15/fb of data at 8 TeV doubling the "ICHEP" luminosity
- The two options,
  - **"X(125)" is confirmed**, then
    - Is the SM Higgs? Confirm and study its properties at LHC, or interpret it properly.
    - Implications for the future of HEP and next generation of colliders
  - "it" is **ruled-out**
    - Continue to study all possible alternatives for EWSB at LHC
    - Implications for the future of HEP and next generation of colliders

Summary of LHC results

- A robust exclusion interval for the SM Higgs. Essentially only a narrow window below 600 GeV: 122-128 GeV, with an independent exclusion in the region 130-486 GeV at 99% CL.

- Some indication for m_H ~ 125 GeV, both experiments observe an excess of 2.5-2.9 σ (local p-value) and measure a production cross section times BR **as** in the SM

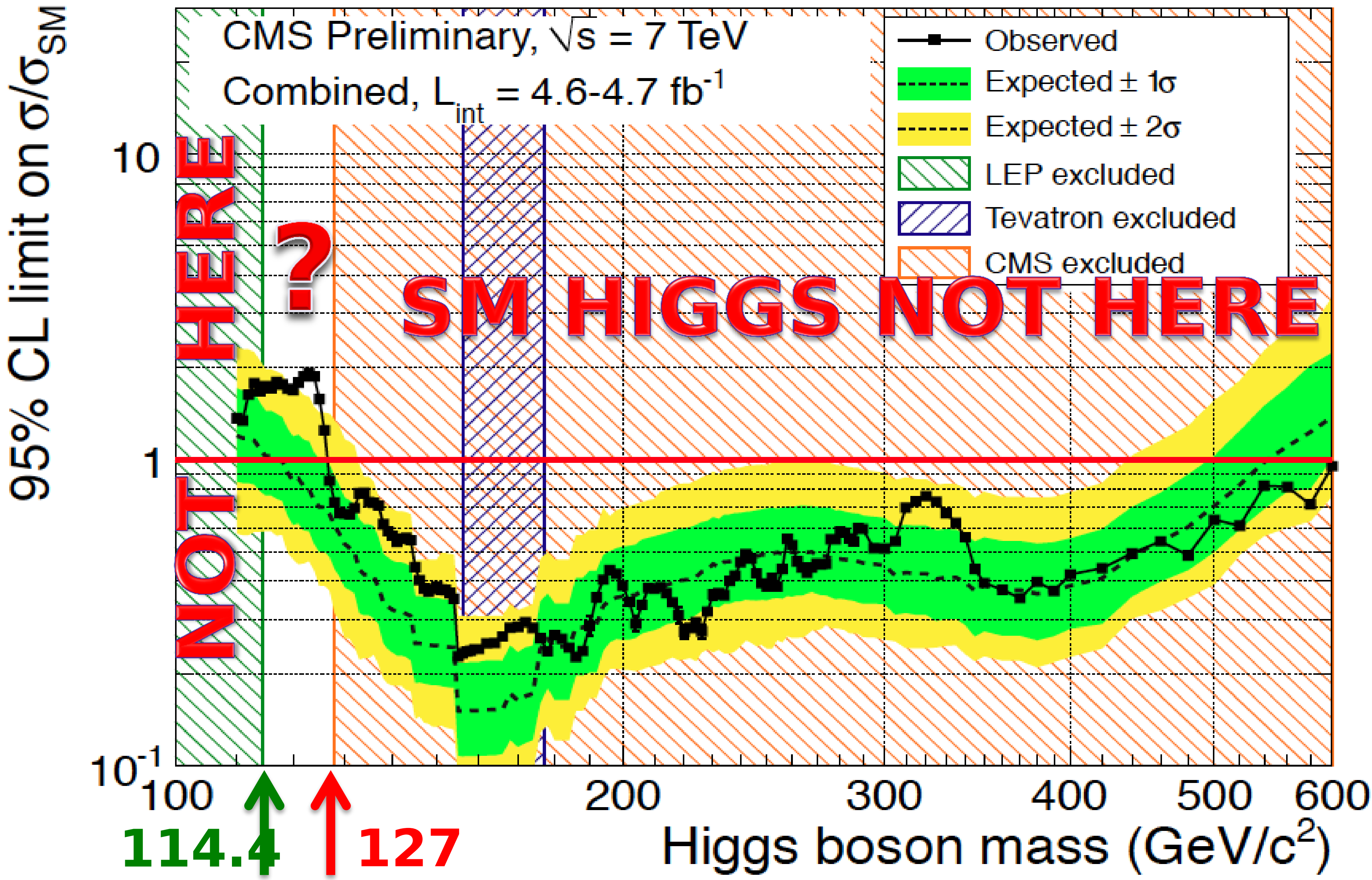
- The global p-value (LEE effect) if we consider the full search range is not significant from either experiment.

- Both experiments taking data since 2 months at 8 TeV, already more than **3.5/fb** delivered to each.
  - 25-30% higher cross-sections
  - **In 2012 2-3 times higher PU than in 2011**

- Expect to discover the SM Higgs in each experiment by the end of 2012 if it is around 125 GeV, and ready to measure its properties if/when it will be discovered.

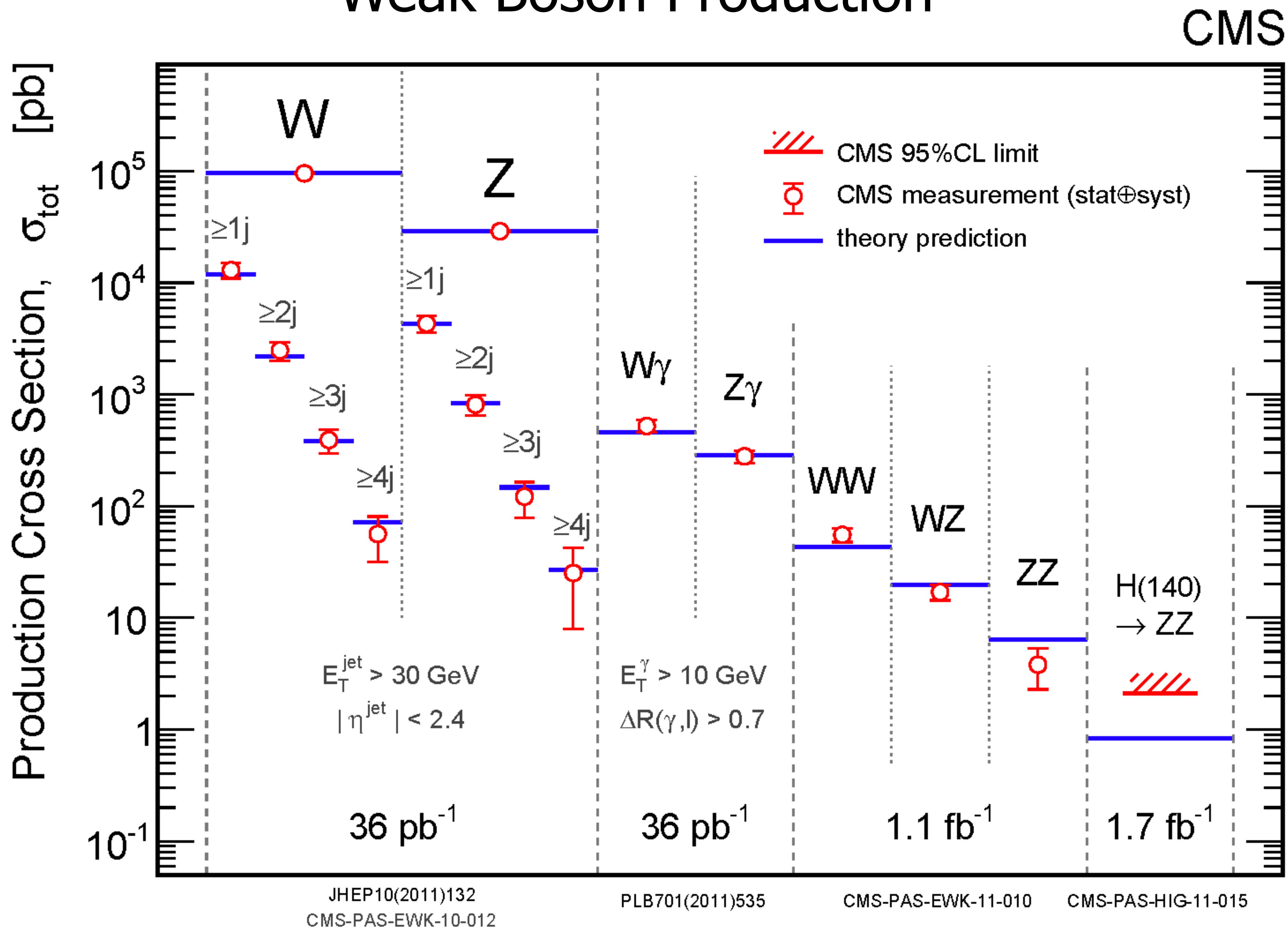
Summary of 2011 Higgs Searches (CMS)

Phys.Lett. B710 (2012) 26-48 Feb 2012, CMS physics paper most cited, already 176 times
Phys.Lett. B710 (2012) 49-66 Feb 2012, ATLAS physics paper most cited, already 176 time



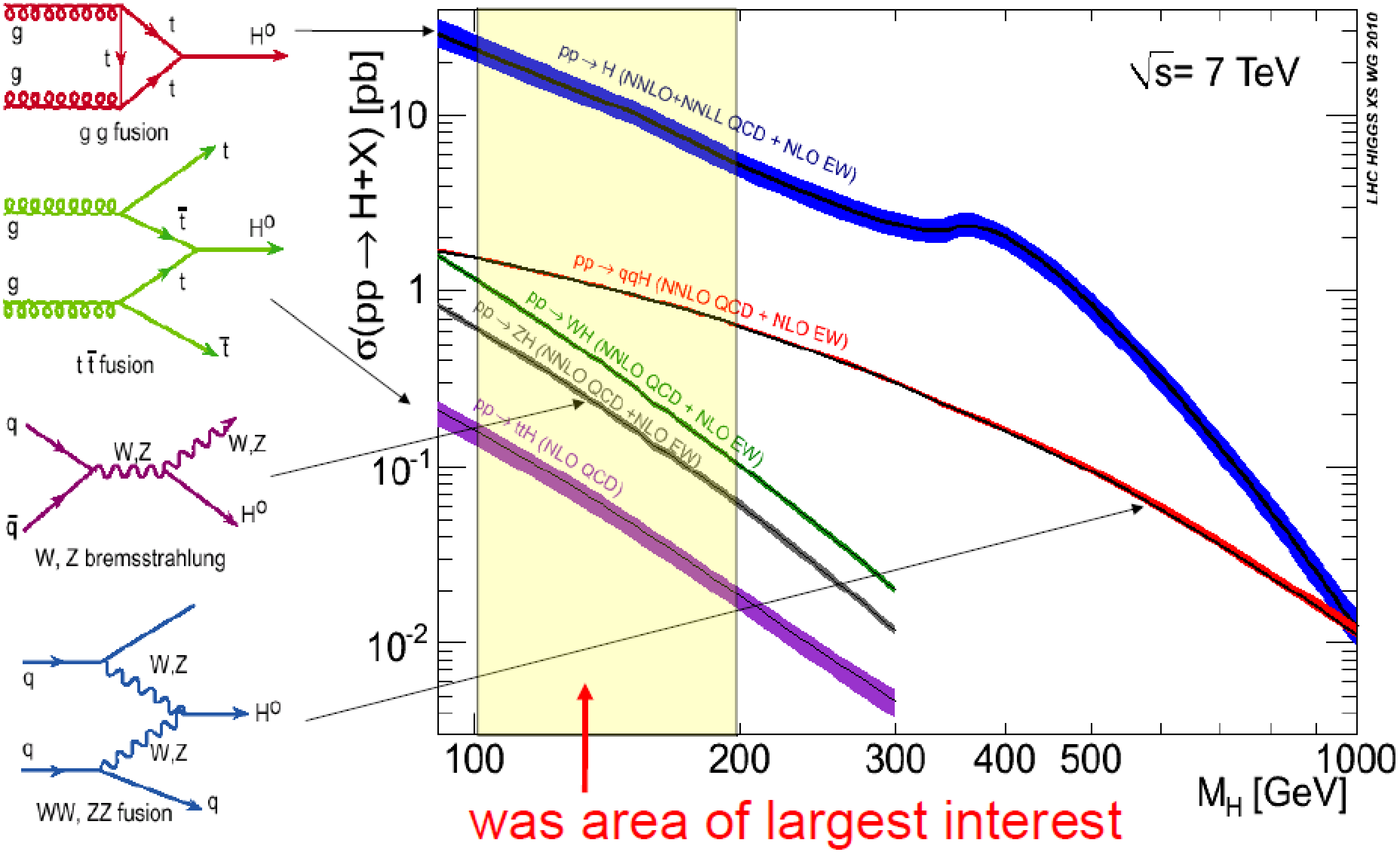
 Remaining corridor of uncertainty

Weak Boson Production

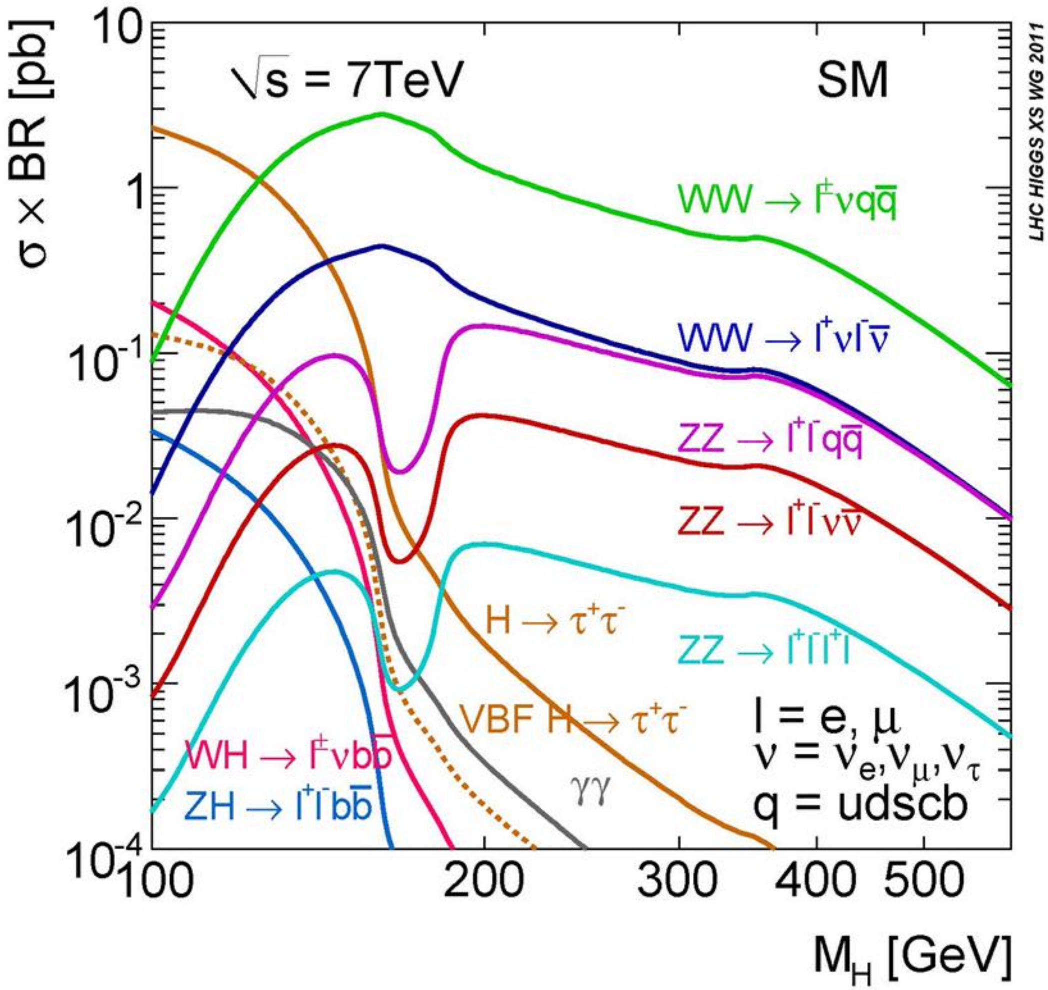


Higgs Production at the LHC

Higgs production in proton-proton collisions



Summary of LHC SM Higgs final states at low mass



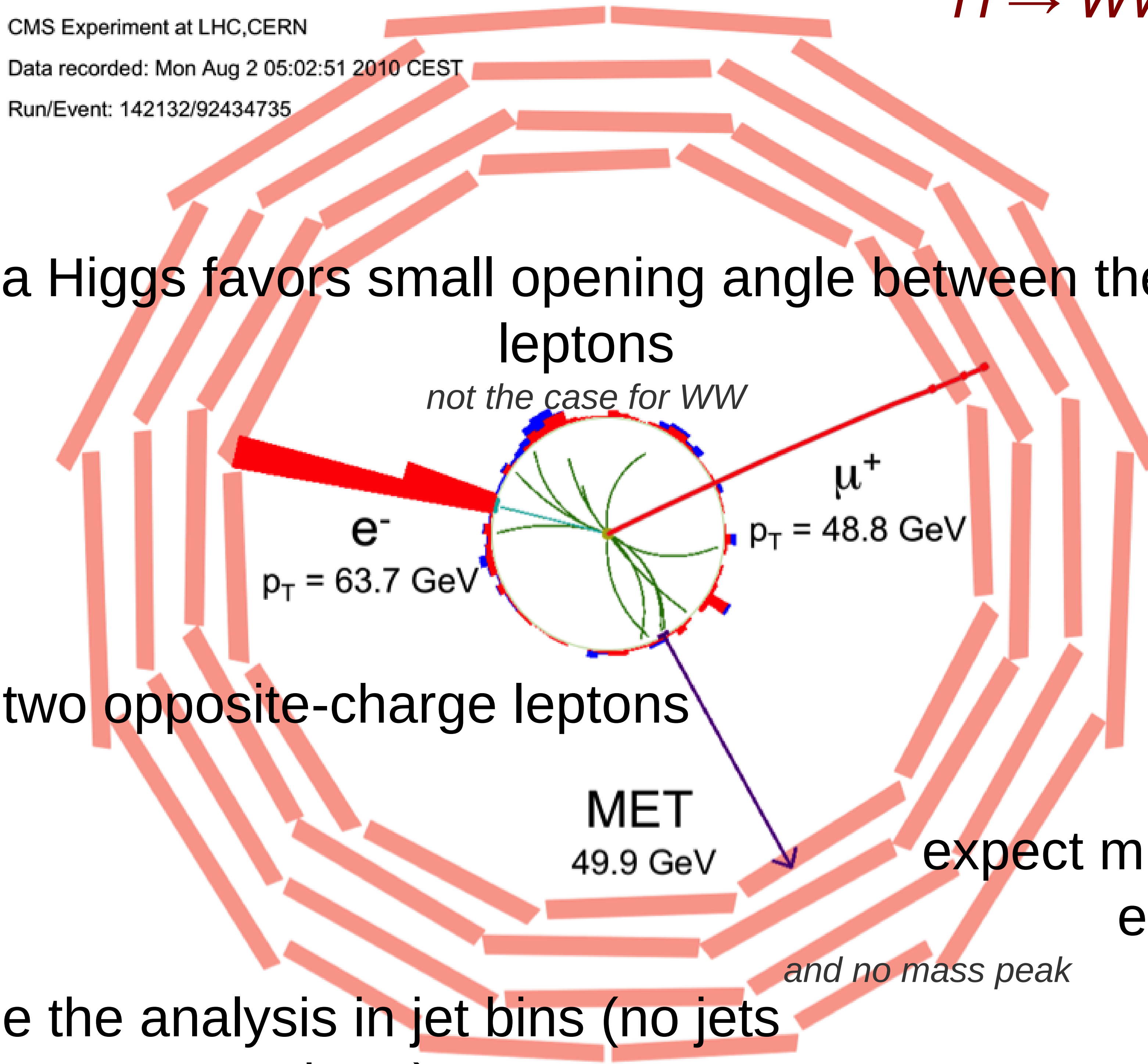
- WW/ZZ modes:
- Advantages: large fraction of all effective production at almost all masses
- **ZZ**->llll,llqq fully reconstructible, can (eventually) provide angular information ; llll has very good mass resolution
- Powerful (and only) modes at high mass
- Disadvantages: **WW** has poor mass resolution and large backgrounds at low mass. ZZ has low branching fraction.
- Without something like the Higgs, W_LW_L scattering amplitude violates unitarity at large s
- V_LV_L couplings to the Higgs are vital
- Diphoton mode:
- A: very good mass resolution, small-ish backgrounds
- D: small signal
- Ditau mode:
- A: large signal at lowest masses
- D: poor mass resolution, large backgrounds
- VH modes: A: Practical test of bb coupling
- D: Small signal, large V+jets backgrounds, poor mass resolution

the channels

channel	m_H range [GeV]	m_H resolution	sub channels
$H \rightarrow \gamma\gamma$	110 - 150	1-3%	4
$H \rightarrow \tau\tau$	110 - 145	15%	9
$H \rightarrow bb$	110 - 135	10%	5
$H \rightarrow WW \rightarrow l\nu l\nu$	110 - 600	20%	5
$H \rightarrow ZZ \rightarrow 4l$	110 - 600	1-2%	3
$H \rightarrow ZZ \rightarrow 2l2\tau$	190 - 600	10-15%	8
$H \rightarrow ZZ \rightarrow 2l2\nu$	250 - 600	7%	2
$H \rightarrow ZZ \rightarrow 2l2q$	130 - 165, 200 - 600	3%	6

all of them use 4.6 - 4.8 fb^{-1}

$H \rightarrow WW \rightarrow l\nu l\nu$



a Higgs favors small opening angle between the leptons

not the case for WW

look for two opposite-charge leptons

expect missing energy

and no mass peak

divide the analysis in jet bins (no jets here) *to increase sensitivity*

main backgrounds

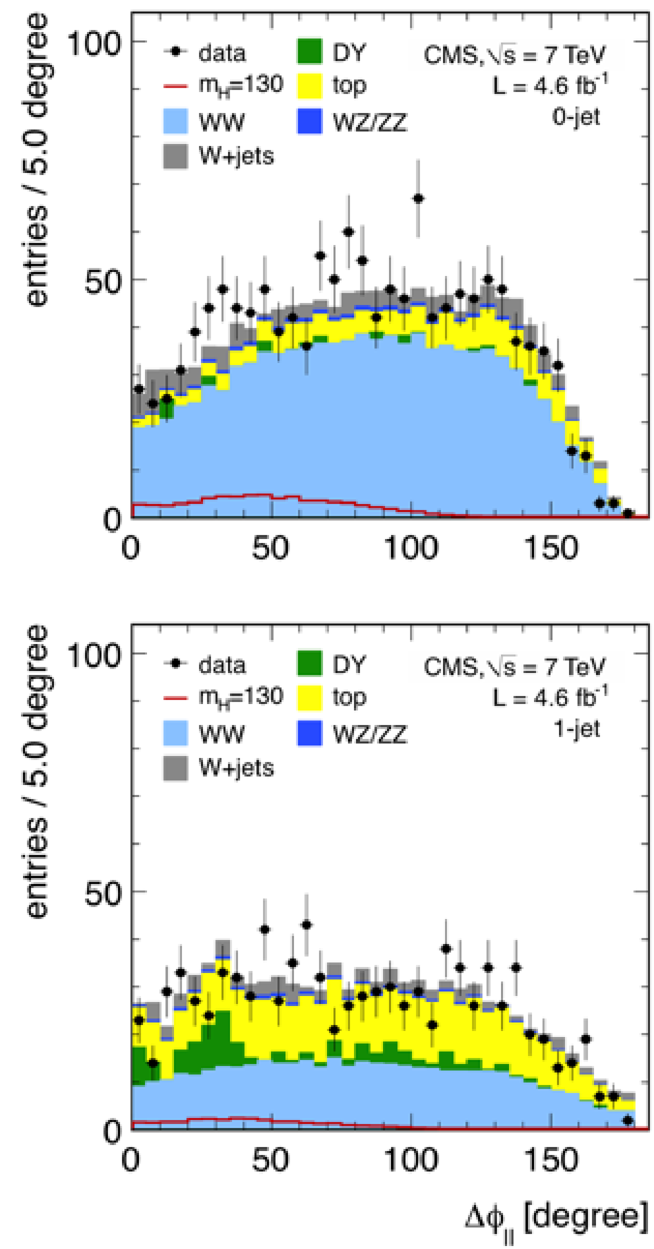
- irreducible *WW*
  - rejected with $\Delta\phi_{ll}$ and m_{ll}

    estimated from high m_{ll} control region
- *W+jets*
  - rejected with tight lepton ID

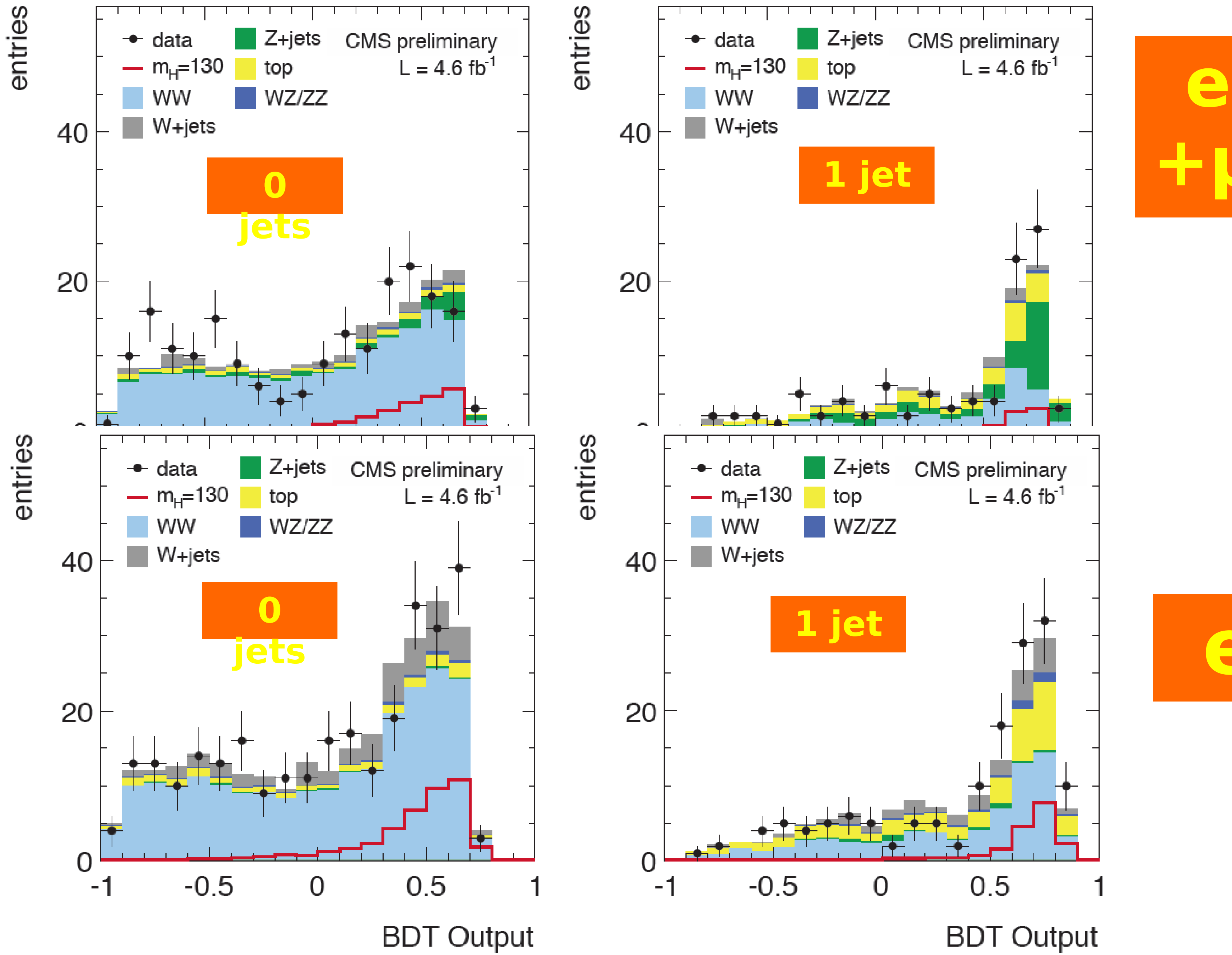
    fake rate estimated from *dijet* sample
- *top*
  - rejected with anti *b*-tagging

    estimated from *b*-tagged events
- $Z \rightarrow ll$
  - rejected with MET cut and *Z* veto

    estimated from *Z* peak



Multivariate (BDT) Classifier



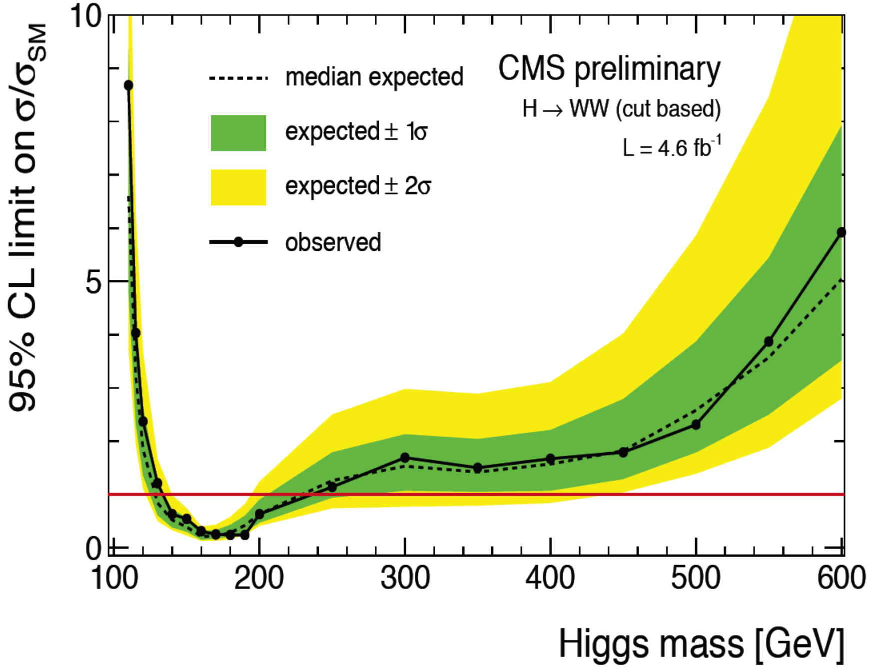
ee +μμ

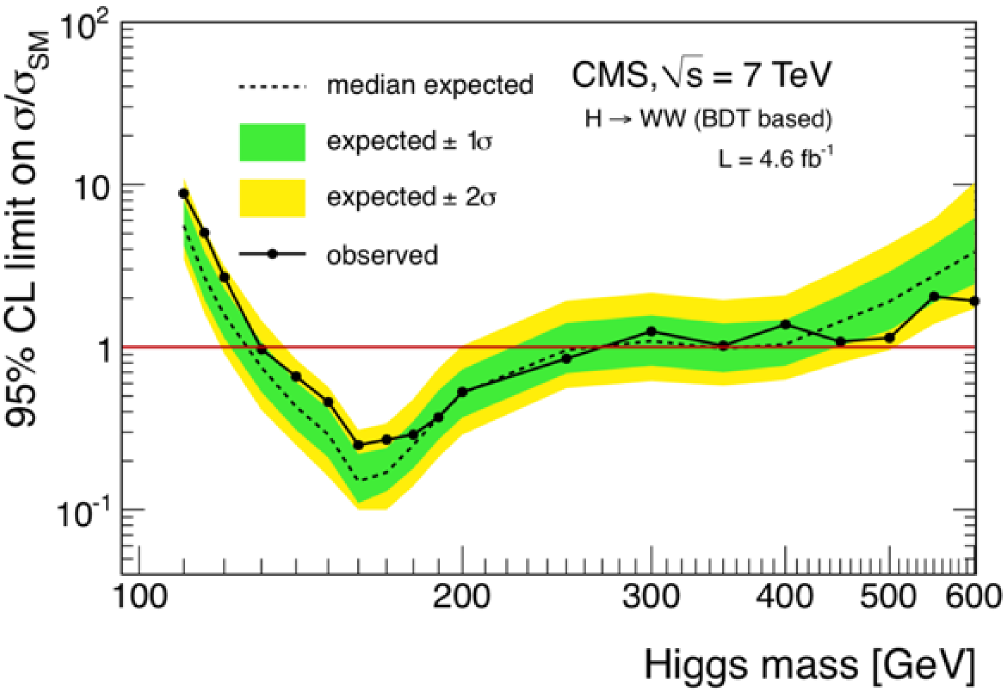
eμ

HWW results

129 < m_H < 270 GeV excluded

mH	DY→ll	ttbar+tW	W+jets	WZ+ZZ+Wγ	WW	all BG	H→WW	data
120	8.8±9.2	6.7±1.0	14.7±4.7	6.1±1.5	100.3±7.2	136.7±12.7	15.7±0.8	136
130	13.7±7.8	10.6±1.6	17.6±5.5	7.4±1.6	142.2±10.0	191.5±14.0	45.2±2.1	193
160	3.4±3.4	10.5±1.4	3.0±1.5	2.2±0.4	82.6±5.4	101.7±6.8	122.9±5.6	111





Expected 95% CL limit: 129 < M_H < 236 GeV

Observed 95% CL limit: 132< M_H < 238 GeV

- ***WH → WWW*** **recently added (~5x SM)**

Multivariate analysis (BDT) trained at different masses to distinguish from *WW*

Expected limit: 127 < M_H < 270 GeV

Observed limit: 129< M_H < 270 GeV

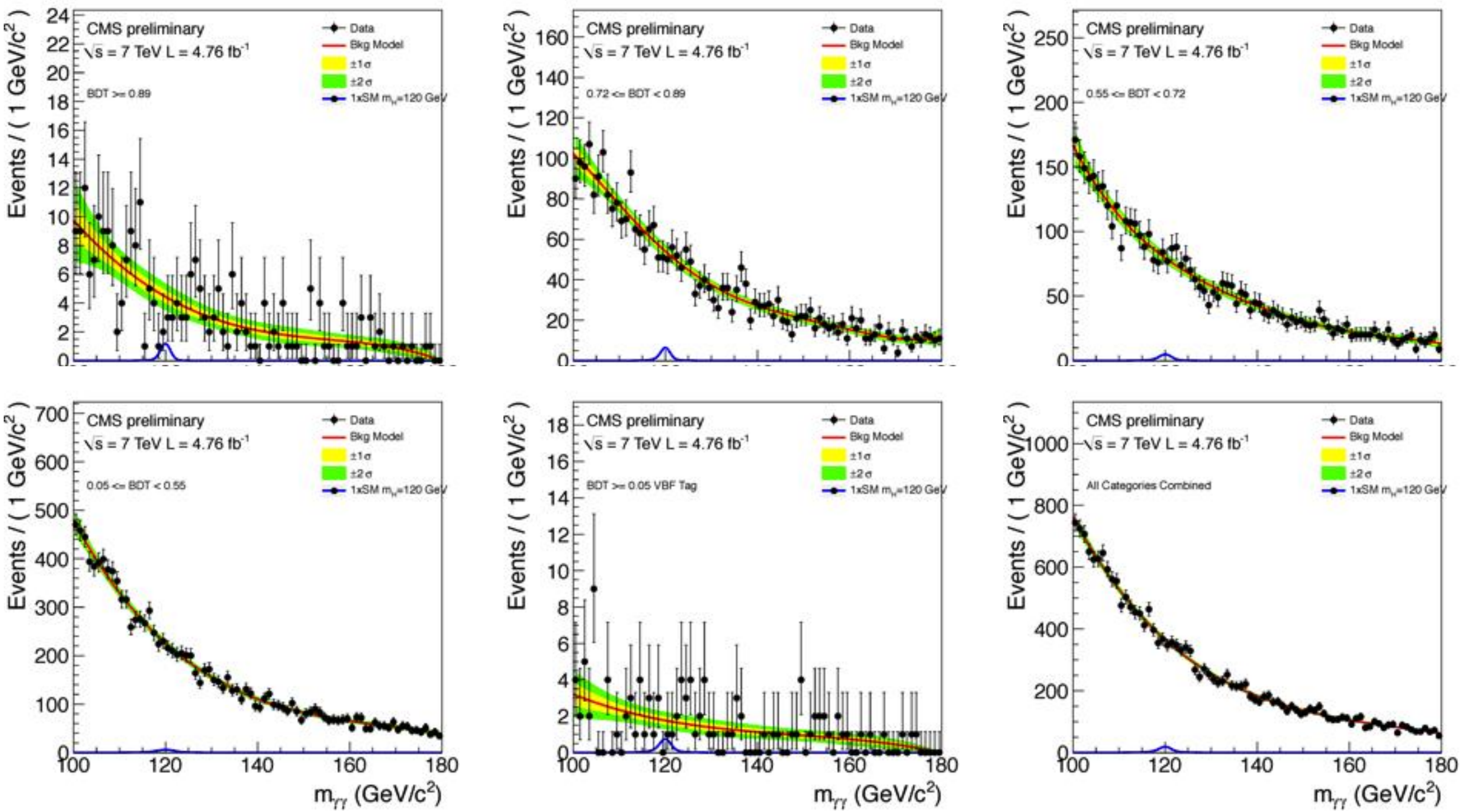
Phys.Lett. B 710 (2012) 91-113

$H \rightarrow \gamma\gamma$

- search for a narrow peak in the di-photon mass distribution
  - good mass resolution (1-2%) over a large smoothly decreasing background
- backgrounds
  - di-photon QCD production
  - photon+jet + fake photon
  - DY with electrons faking photons
  - **modeled directly from data using polynomial forms**
- multivariate analysis (improves published arXiv:1202.1487)
  - **event-by-event mass resolution, photon id discriminant, di-photon kinematic variables and vertex probability combined in a BDT**
  - the sensitivity improvement is equivalent to a ~50% luminosity increase

strategy

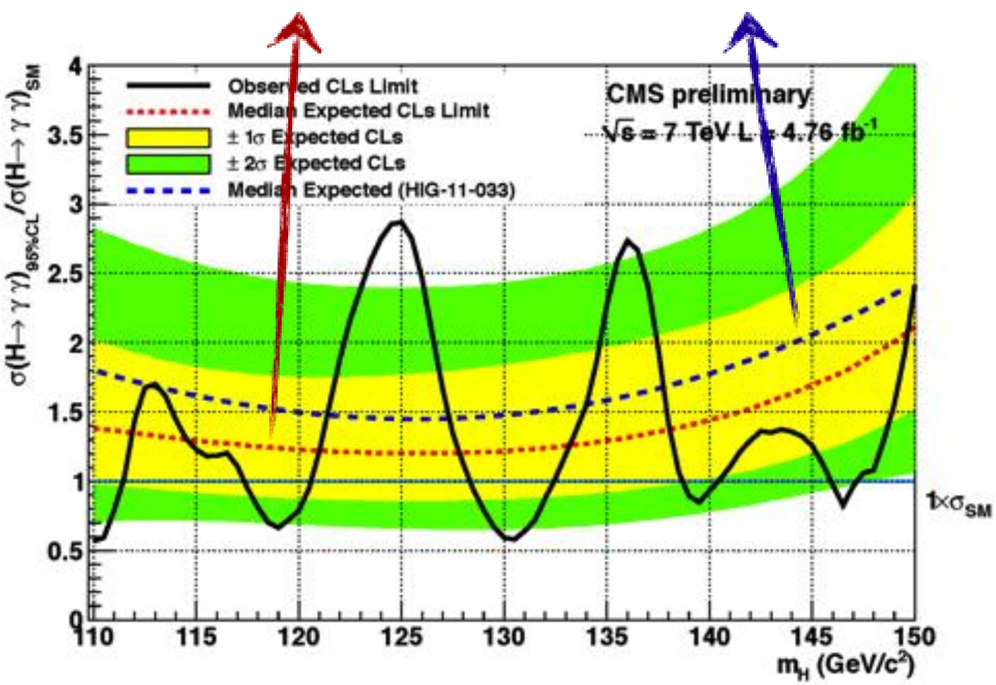
- start with a separate event class for VBF-tagged events
- remaining events subdivided into 4 event classes according to BDT

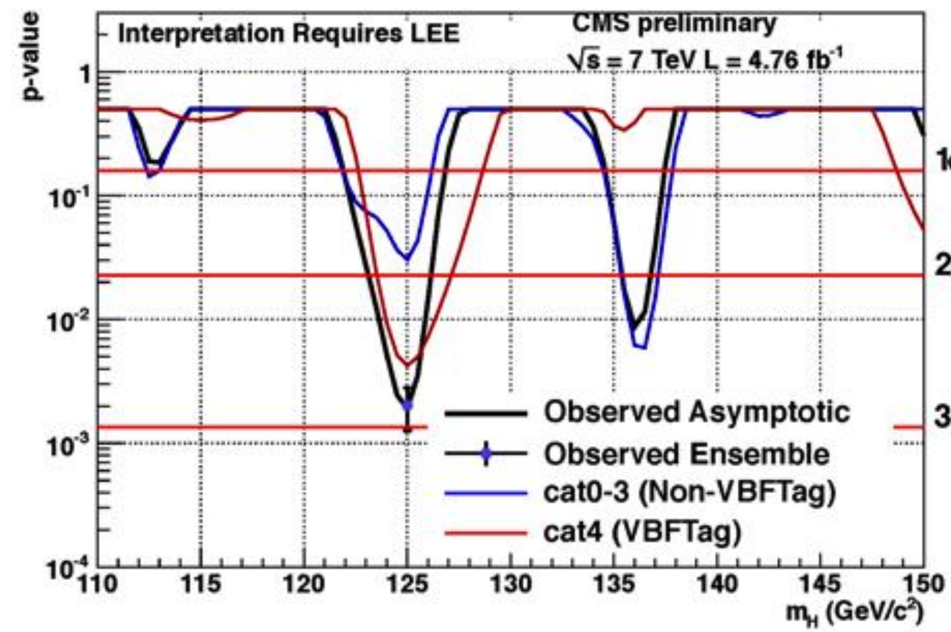


results

expected limit from MVA analysis

expected limit from cut-based analysis



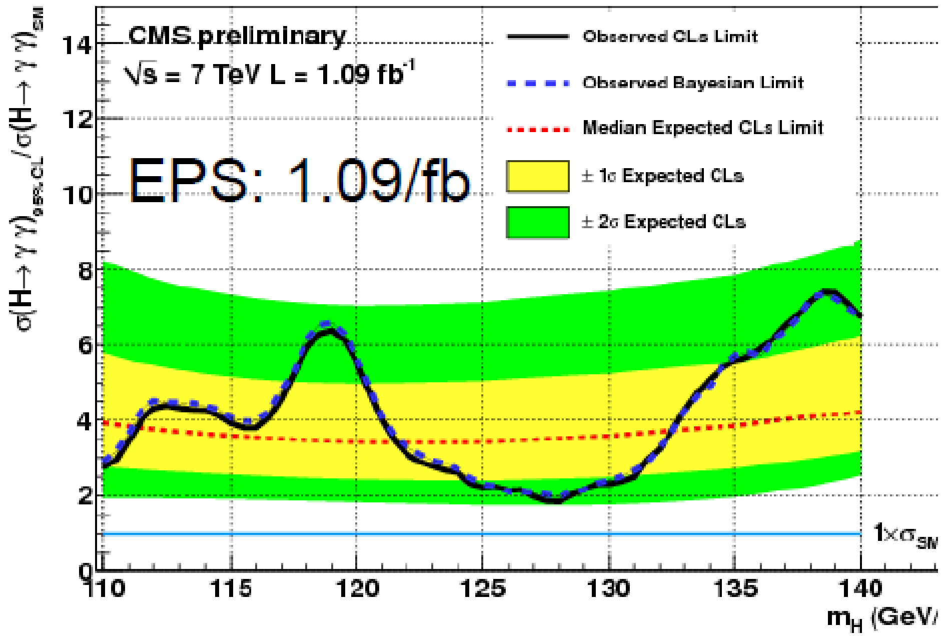


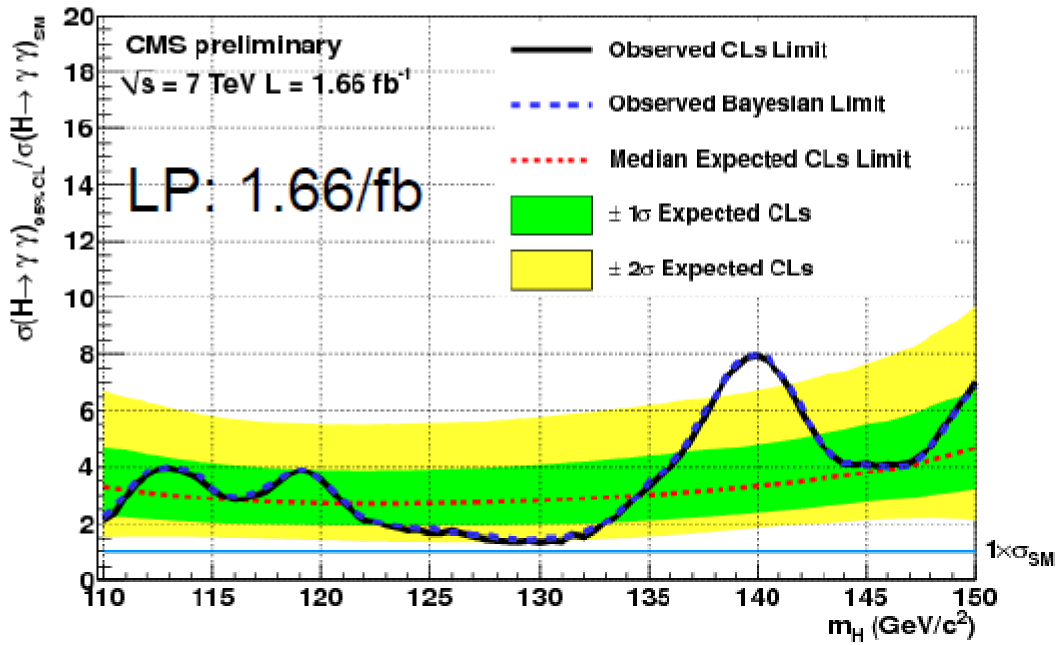
excess at 125 GeV

local *p*-value 2.9σ

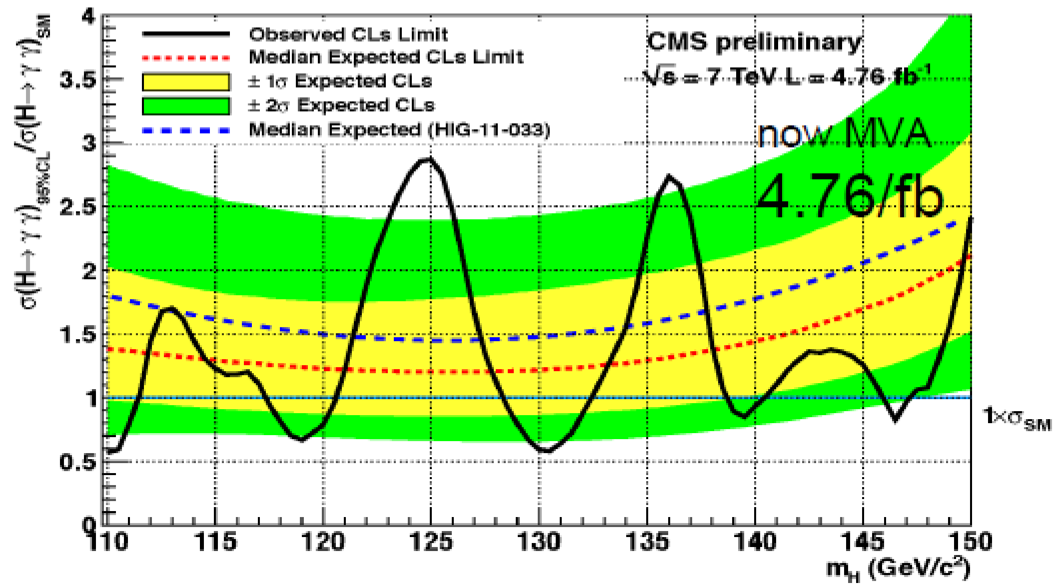
global *p*-value (110-150 GeV window) 1.6σ

CMS History: $H \to \gamma\gamma$

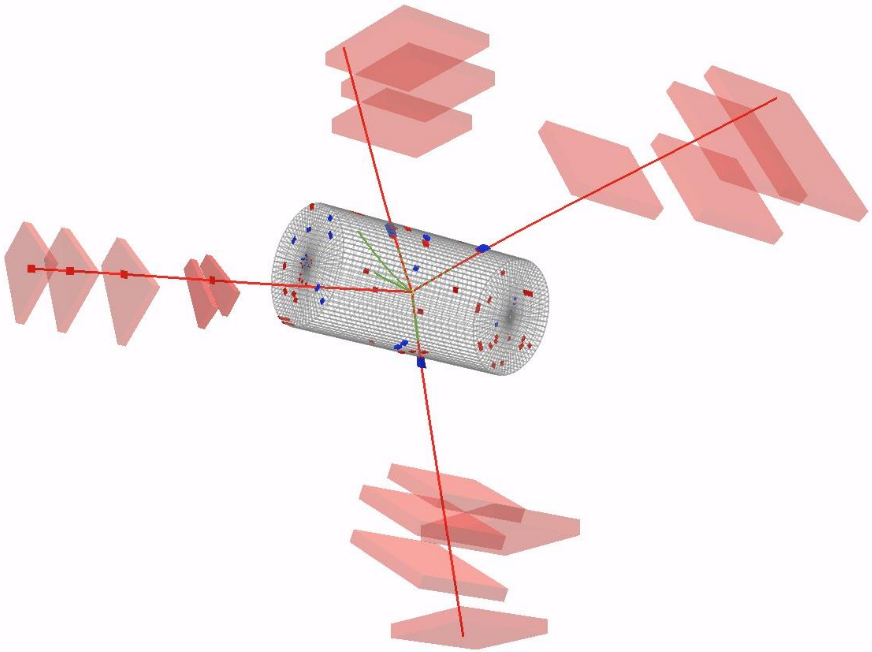


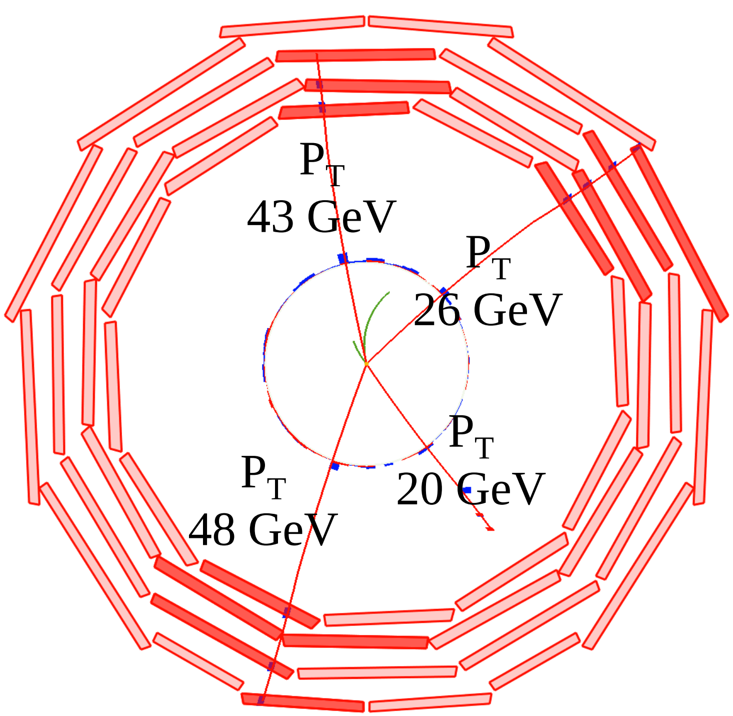


- EPS (1.09/fb) LP (1.66/fb) Dec 19 (4.76/fb)
- ‘peaks’ come and go
- we are getting into interesting territory, and peaks can also stay



H → ZZ → 4e, 4μ, 2e 2μ : The Golden Channels



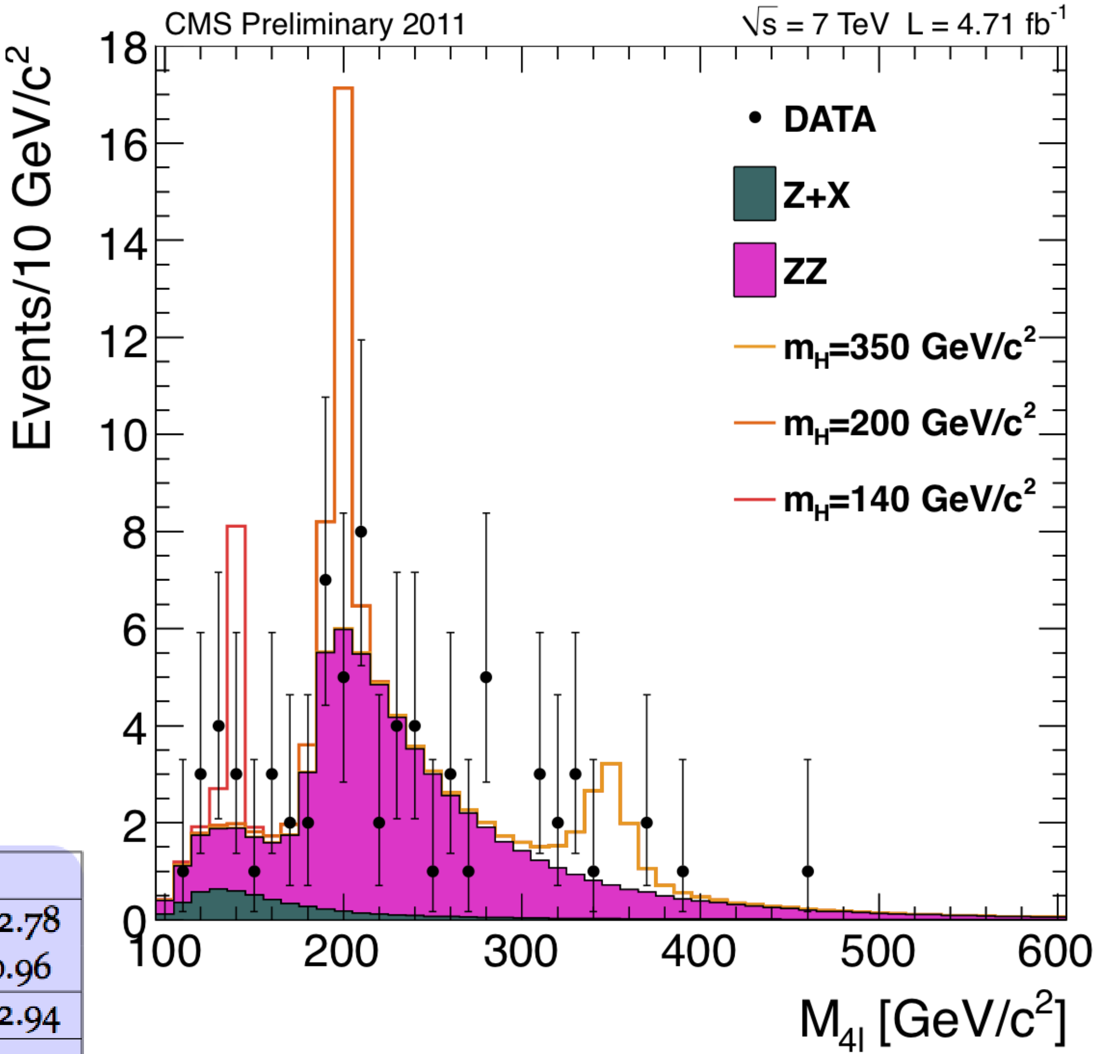


- Signal: 4 isolated lepton from common vertex
- Fully reconstructed, Mass resolution ~ 1%
- Reducible backgrounds:
  - ttbar → 2l2υ2b ; Z+bb
  - Removed by Isolation & Impact parameter requirements
- Irreducible background: pp → ZZ Continuum
- Event Selection: Same Flavor, opposite charge
  - Z_1 : P_T(min) > 10, P_T(max)>20 GeV, 50<M_{ll}<120
  - Z_2: 12 < M_{ll}< 120 GeV
  - M_{4l} > 120 GeV
  - Impact parameter significance > 4
- Reducible background contribution from data
- **ZZ Continuum:**
  - Shape known at NLO, corrected for gg → ZZ →4l evaluated with MCFM
  - Rate obtained from Z yield in data & theoretical prediction for ratio of ZZ to Z cross sections

H → ZZ → 4l : Expected & Observed Yields

M_{4l} > 100 GeV/c²
Observed events: 72
Expected events: 67.1 ± 6.0

Baseline	4e	4μ	2e2μ
ZZ	12.27 ± 1.16	19.11 ± 1.75	30.25 ± 2.78
Z+X	1.67 ± 0.55	1.13 ± 0.55	2.71 ± 0.96
All background	13.94 ± 1.28	20.24 ± 1.83	32.96 ± 2.94
$m_H = 120$ GeV/c^2	0.25	0.62	0.68
$m_H = 140$ GeV/c^2	1.32	2.48	3.37
$m_H = 350$ GeV/c^2	1.95	2.61	4.64
Observed	12	23	37



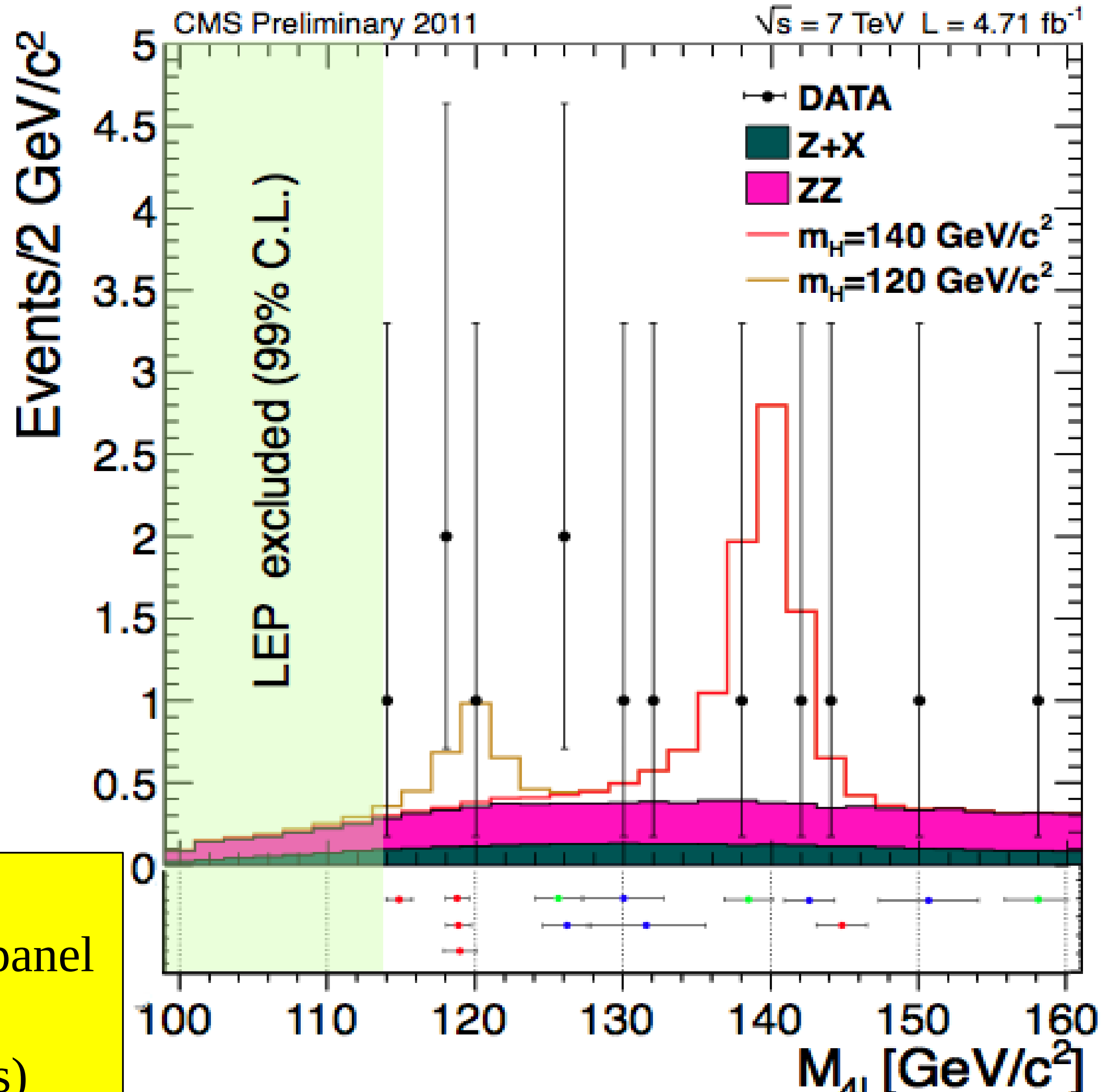
H → ZZ → 4l : Zoom Of Low Mass Range

100 < M_{4l} < 160 GeV/c^2

Obs. events: 13

Exp. events: 9.5 ± 1.3

Final state:	4e	4μ	2e2μ
Obs. events:	3	5	5
Exp. events:	1.7	3.3	4.5

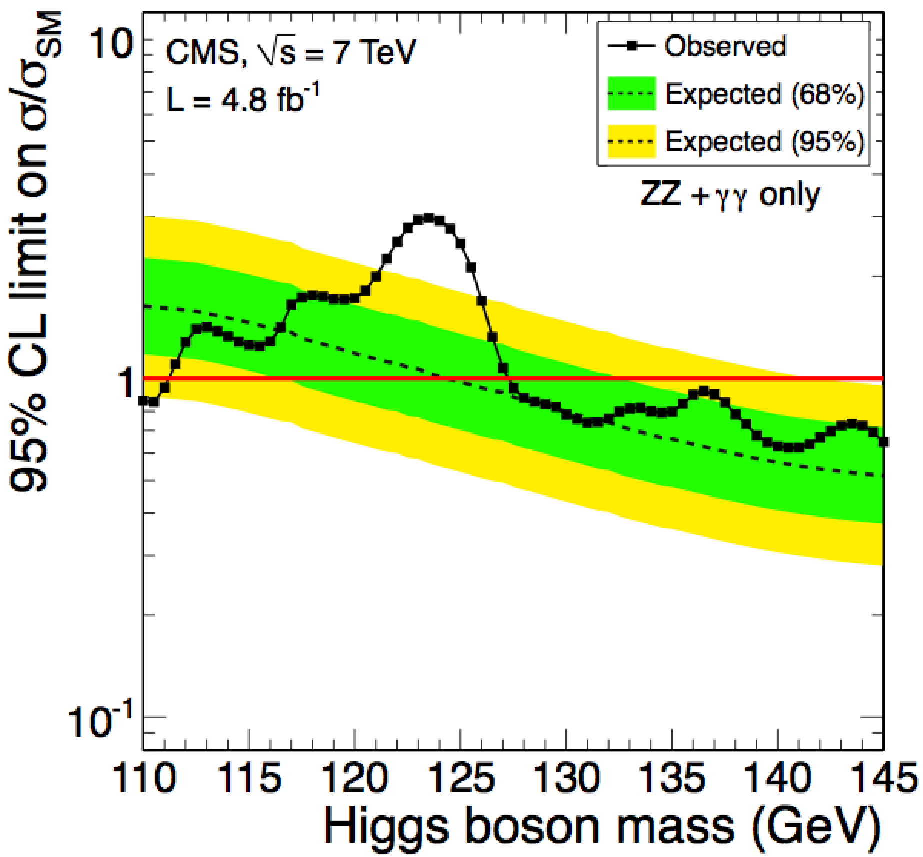


Note:

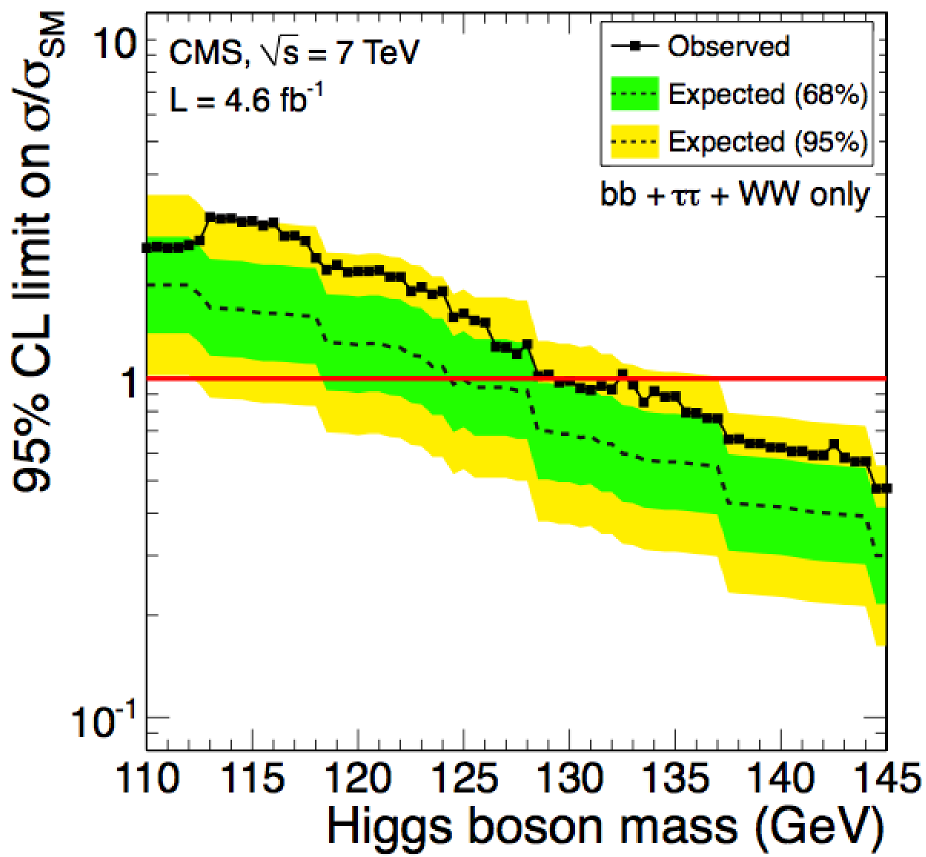
- unbinned events in the bottom panel
- 4e, 4μ, 2e2μ
- Event-by-event mass error (bars)

By High & Low Mass Resolution Channels

High mass resolution channels: γγ + 4l

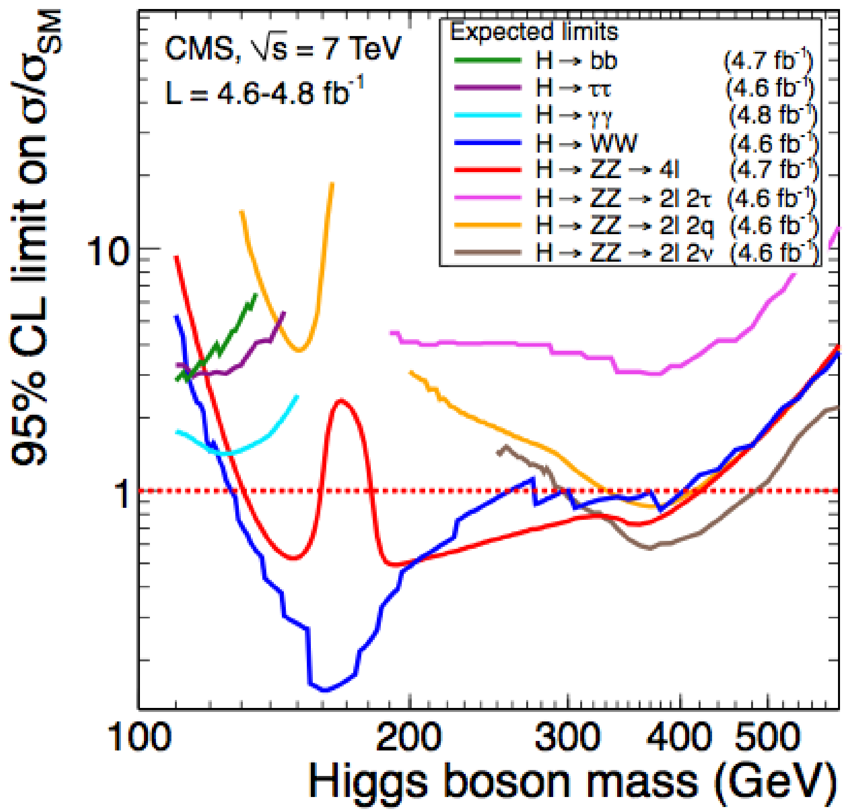


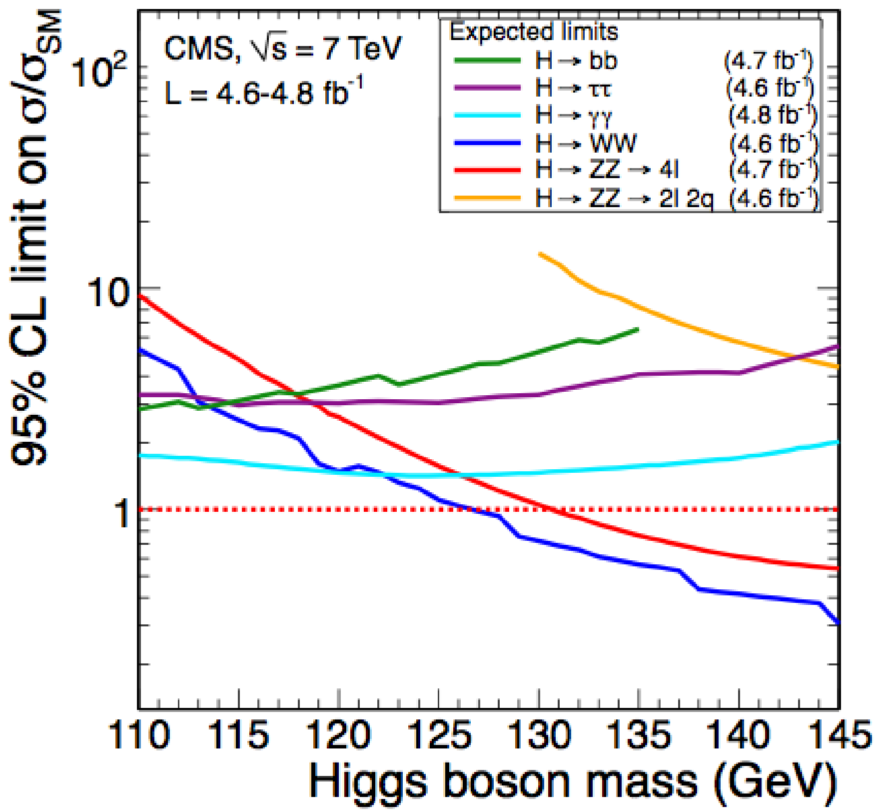
Poor mass resolution channels: WW + ττ + bb



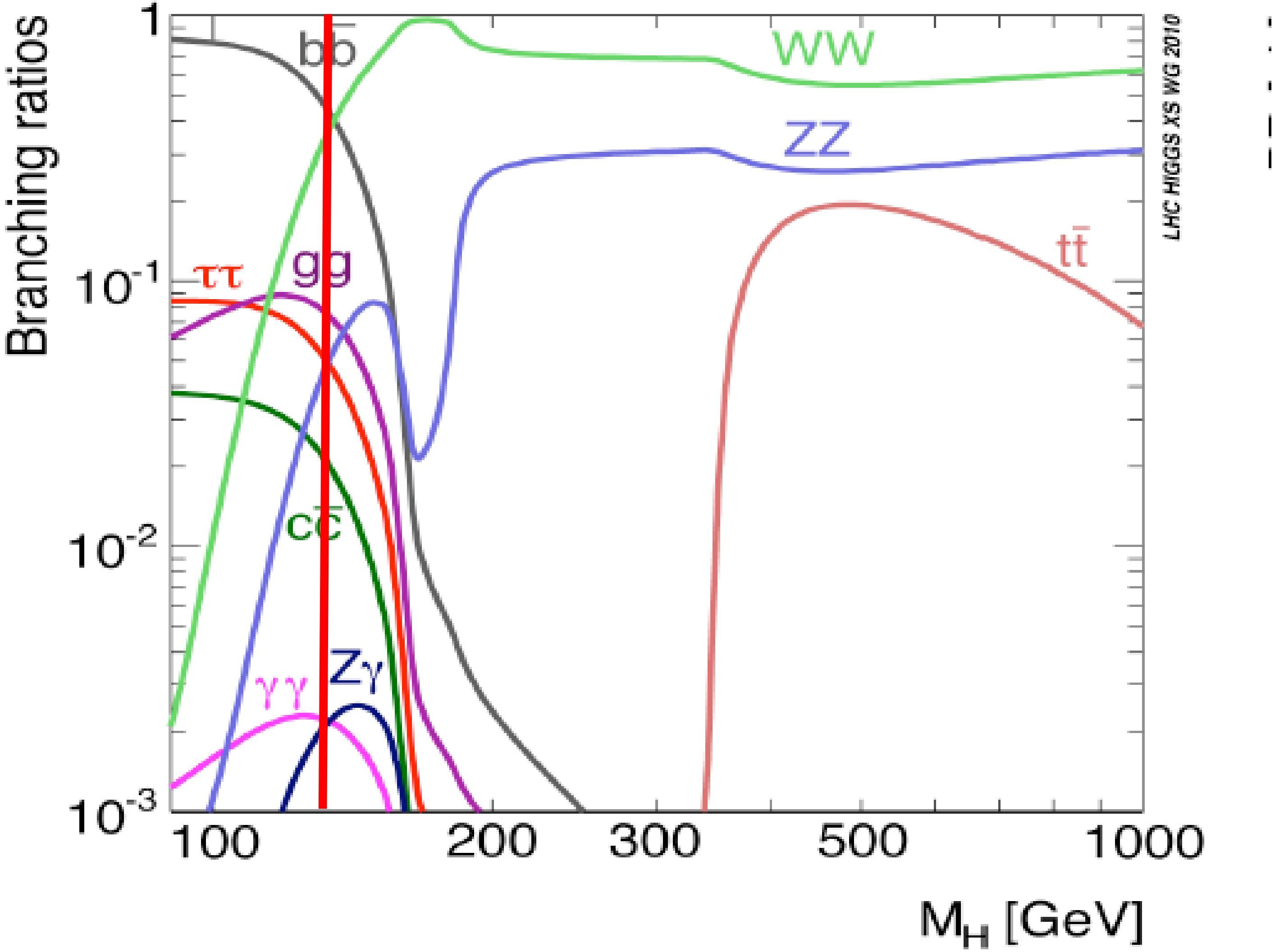
- The two sets have nearly identical sensitivity
- The γγ+4l group shows a localized excess >2σ around m_H=121-125 GeV
- The WW+ττ+bb group shows a broad excess, reaching 2σ around 115-125 GeV

Expected Sensitivity with 4.7 fb^{-1}





95% CL expected sensitivity: 117—543 GeV

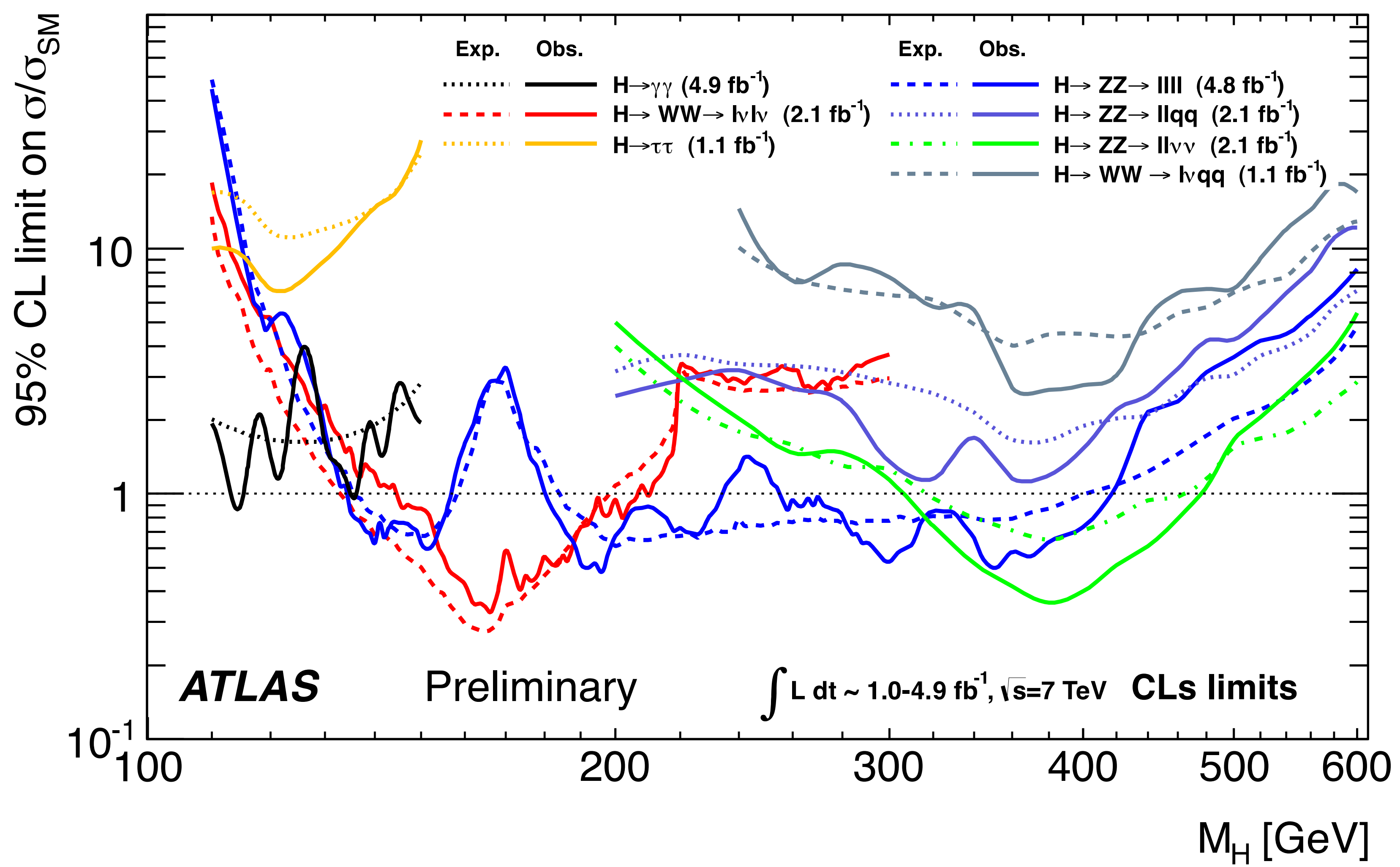


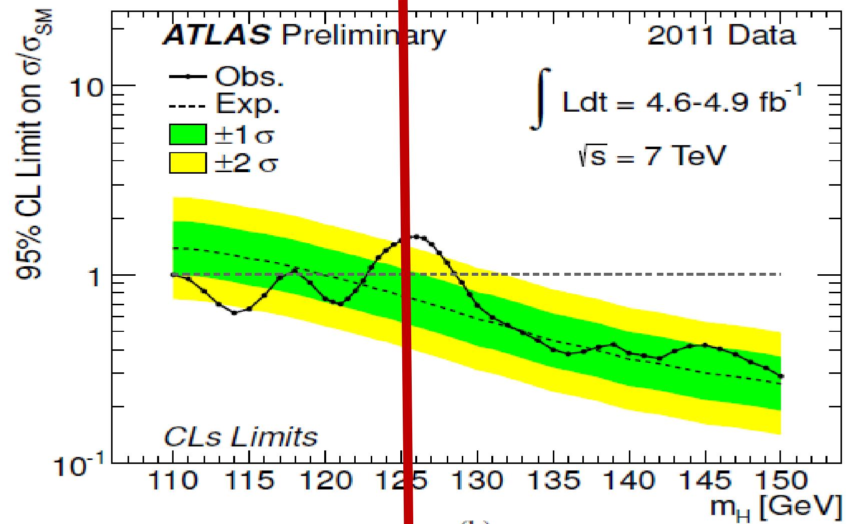
125 GeV is really a good place to be:

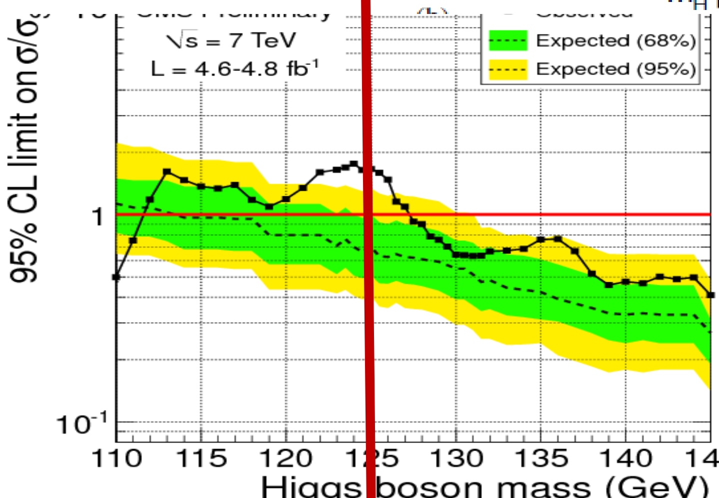
$\bar{b}b$, WW, gg, $\tau\tau$, ZZ, $\bar{c}c$ are all above a few % and $\gamma\gamma$ is ~maximal

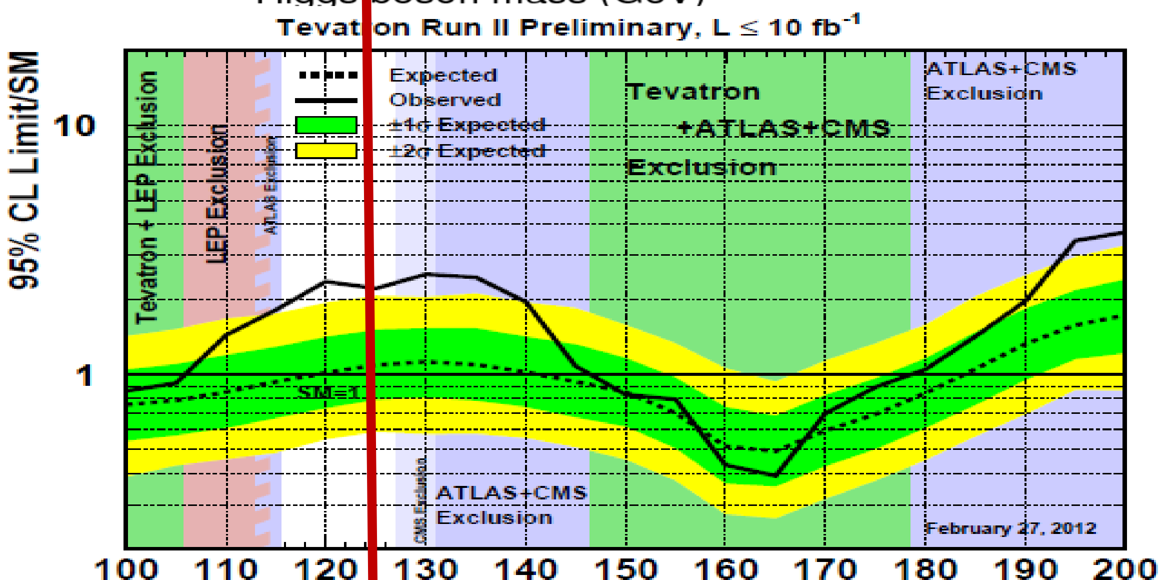
Summary of the current status of the Higgs boson search in ATLAS

- excluded cross sections by individual channels -









Both ATLAS and CMS exclude a SM scalar boson up to ~550 GeV except in range (117-128 GeV): excess 2.5-2.9 σ at 125-126 GeV/c^2 (consistent)

ATLAS : $\gamma\gamma$ and ZZ
CMS : $\gamma\gamma$
CDF+ D0 mostly $b\bar{b}$&WW

Too soon to claim even evidence, but…
‘Who would bet against Higgs boson @125 GeV?’

My guess: Look Elsewhere + Look There
→ CL probably >~ local significance of 2d experiment

More data in 2012→ 5σ and more channels!

Overview of the 125 GeV region

- Tevatron
  - bb: CDF yes, DØ no
  - WW: CDF no, DØ yes
- LHC
  - $gg \rightarrow H \rightarrow \gamma\gamma$: CMS not much, ATLAS YES
  - $VV \rightarrow H \rightarrow \gamma\gamma$ + 2 jets: CMS yes, ATLAS not much?
  - $ZZ^{(*)}$: ATLAS YES, CMS yes
  - $WW^{(*)}$: ATLAS no, CMS a bit

Significance of the result

- This could go away
  - What looks like a signal for a 125 GeV Higgs boson could be a result of misestimated backgrounds and/or random fluctuations. It is for the moment not as convincing as the evidence for instance with the top quark at 1995.
  - Maybe the SM Higgs boson will be ruled out. If so, we will need to find a non-Standard-Model version. Then it will be significant that Atlas and CMS already can rule out a SM-like Higgs up to 540 to 600 GeV.
- or the Higgs boson could be discovered this year.
  - It looks like the Standard Model Higgs boson, but is it?
  - Is there more than one?
  - Are the couplings to W, Z, t, b, tau right?
  - Is the spin right?
  - Does W-W scattering work as claimed?
  - This involves the Higgs self coupling.
- It is experimentally very difficult.

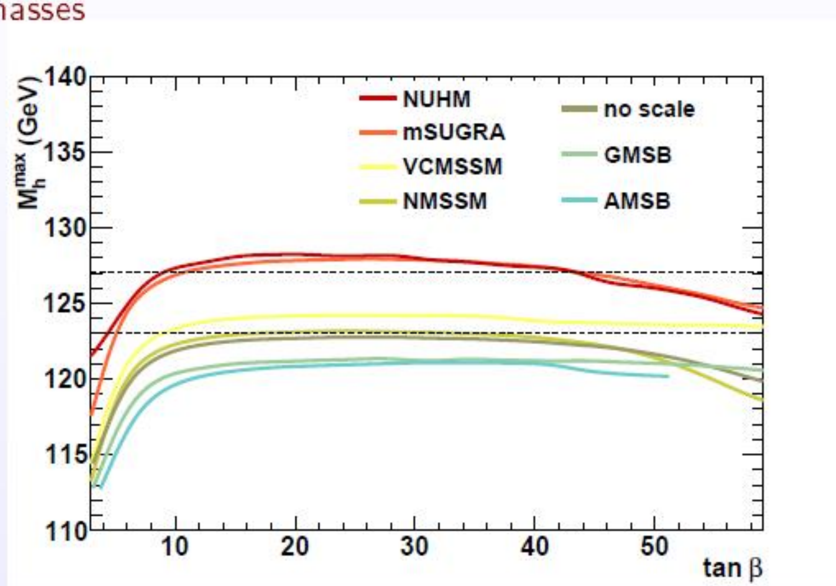
We should wait until the « 125 GeV effect » is either killed or establsished.
A particle decaying in two photons is not spin 1 and more probably spin 0

Is it elementary? Does it have all properties of the SM scalar of EBH et al?
It will be exciting to investigate this NEW object!

Just as for EWRCs, its discovery would eliminate a great number of hypotheses.

Consequences of a 125 GeV Higgs on constrained MSSM scenarios

Maximal Higgs masses



A. Arbey, M. Battaglia, A. Djouadi, F.M., J. Quevillon, Phys.Lett. B708 (2012) 162

model	AMSB	GMSB	mSUGRA	no-scale	cNMSSM	VCMSSM	NUHM
M_h^{max}	121.0	121.5	128.0	123.0	123.5	124.5	128.5

End of AMSB and GMSB in their minimal versions!

How shall we study X(125)?

At LHC?

It is there, and will do it.

The question: with which precision? O(10%) or worse (assume 600fb^{-1})

Effect of pile-up?. Etc. etc.

do we need another machine to study more properties or more precisely?

Performance on couplings self couplings and invisible width?

At a linear collider ?

For 125 GeV Higgs, peak cross-section at ~250 GeV = m_H+m_Z+30 GeV

But.. 250 GV of accelerastion and luminosity at that energy still requires a large amount of power and superb alignment. *Cost?*

At a small e+ e- machine? LEP3 in LHC tunnel (see next slides)

Much easier and cheaper than LC but not expandable.

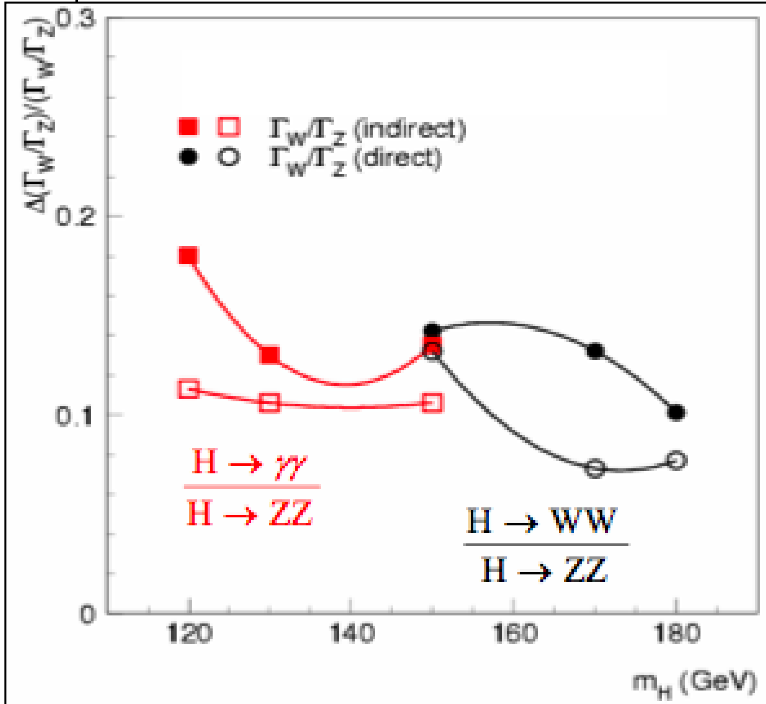
At a muon collider ?

Feasibility study ongoing. Not an easy machine!

Ionization coolinng (MICE experiment)

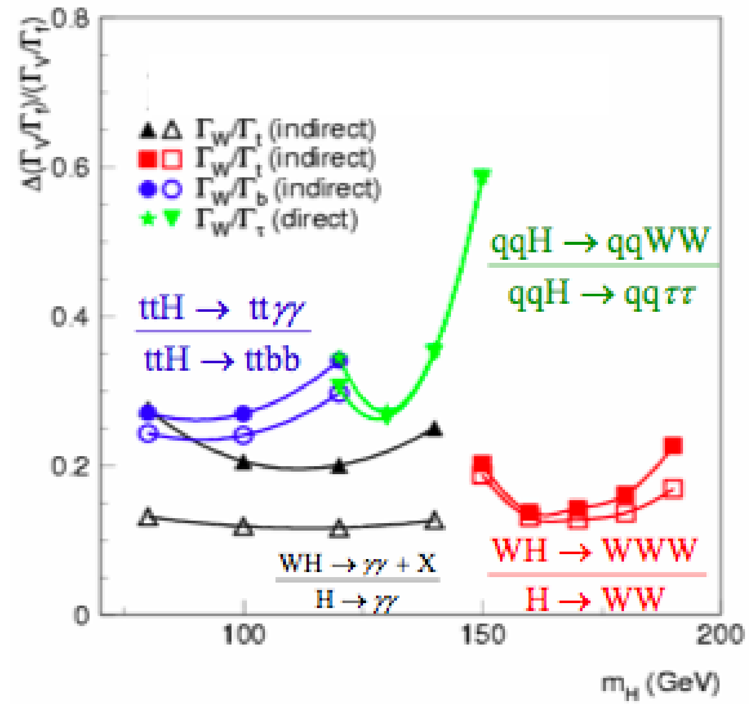
Virtue: s-channel production $\mu^+ \mu^- \rightarrow H$, exquisite energy calibration and very small energy spread if needed.

Measurements of Higgs Couplings



Closed symbols:
LHC 600 fb^{-1}

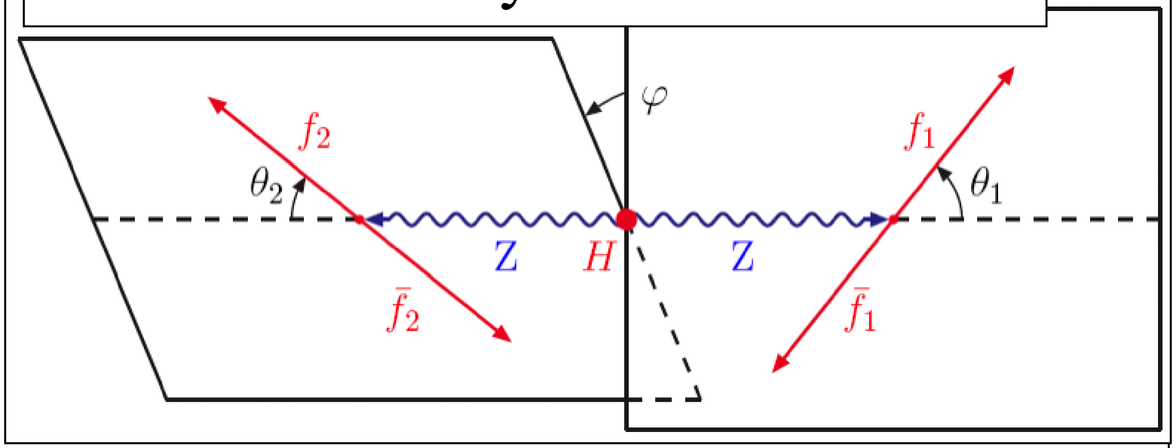
Open symbols:
SLHC 6000 fb^{-1}

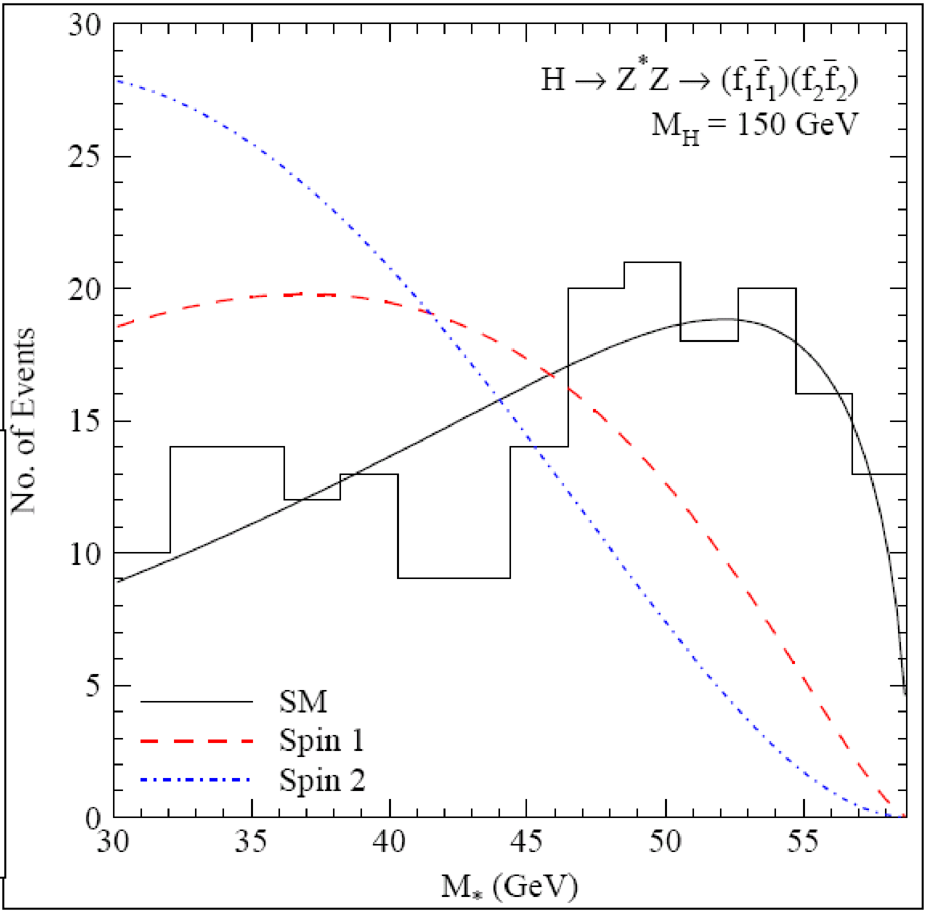


The Spin of the Higgs Boson @ LHC

Low mass: if $H \rightarrow \gamma\gamma$,
It cannot have spin 1

Higher mass: angular correlations in $H \rightarrow ZZ$ decays





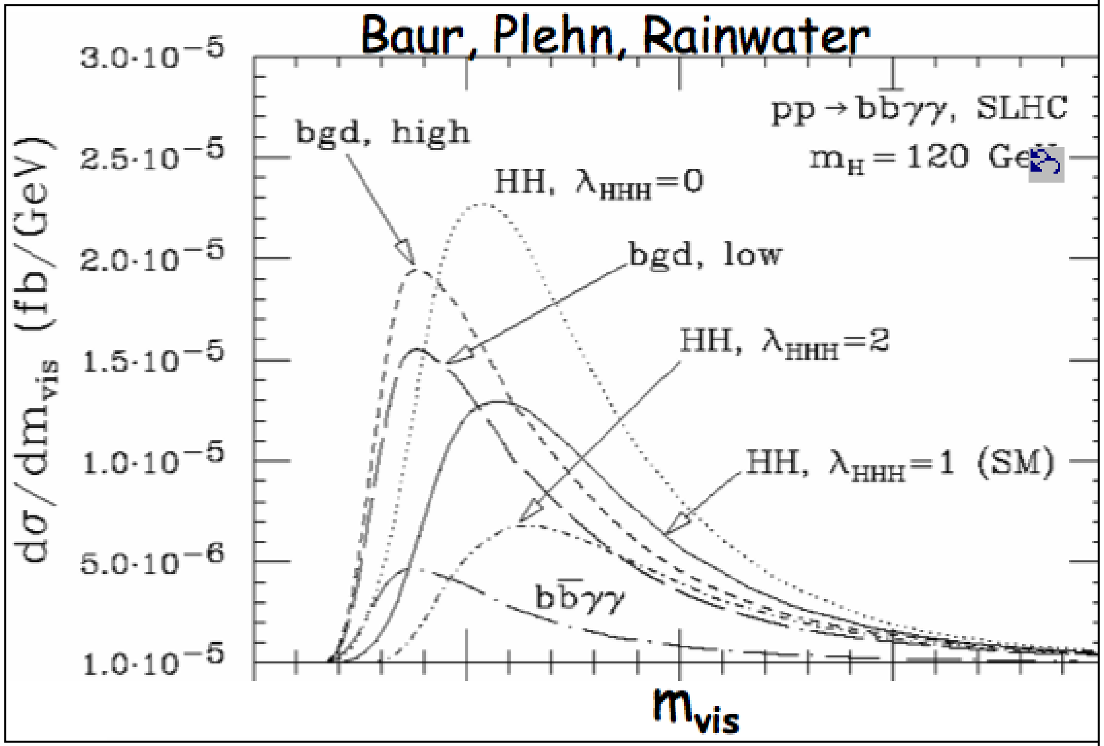
Significance for exclusion of other J^{CP} states than 0^+

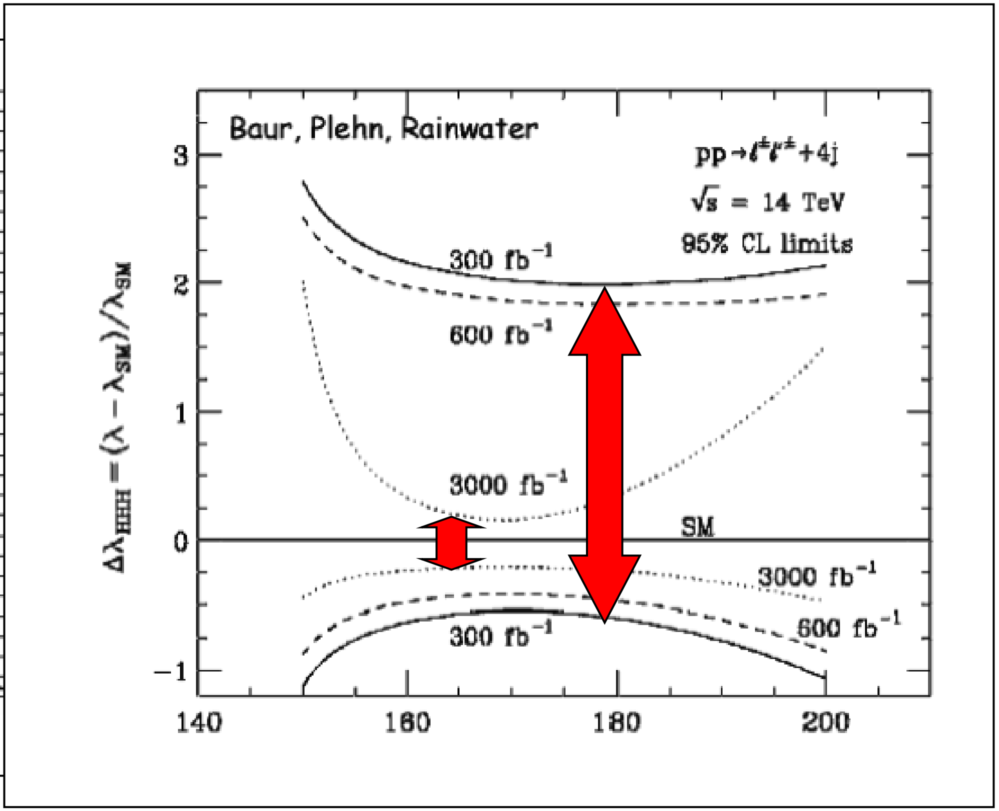
ATLAS + CMS, 2 x 300 fb^{-1}

m_H (GeV)	$J^{CP} = 1^+$	$J^{CP} = 1^-$	$J^{CP}=0^-$
200	6.5 σ	4.8 σ	40 σ
250	20 σ	19 σ	80 σ
300	23 σ	22 σ	70 σ

Higgs Self-coupling @ Hi-Lumi LHC?

Measure triple-Higgs-boson coupling with accuracy comparable to 0.5 TeV ILC?





Awaits confirmation by detailed experimental simulation

Thanks to the sophisticated and thorough use of data-driven techniques, the (un)suitability of theoretical MC generation tools is not standing on the way of the Higgs discovery

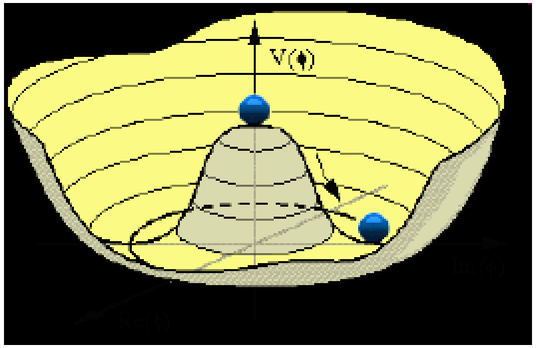
- Independently of this, explicit comparisons, checks and validations show that tools appear to be in rather good shape and up to the task of discovery
- Nevertheless, some aspects of the simulation of Higgs production are still poorly tested (e.g. VBF)
- Higgs-search studies are bringing in valuable information for the validation and further improvement of the tools, and further efforts should be made, alongside the discovery race, to fully exploit the potential of these data, to benefit improved tools, and further applications to studies of the Higgs once found, or other BSM searches

Is it *the* Higgs?

- Measure couplings to fermions & gauge bosons

$$\frac{\Gamma(H \to b\bar{b})}{\Gamma(H \to \tau^+\tau^-)} \approx 3\frac{m_b{}^2}{m_\tau{}^2}$$

- Measure spin/parity



$$J^{PC} = 0^{++}$$

- Measure self interactions

$$V = \frac{M_H{}^2}{2}H^2 + \frac{M_H{}^2}{2v}H^3 + \frac{M_H{}^2}{8v^2}H^4$$

- Make sure there's only one Higgs-like particle

Direct Measurements Crucial

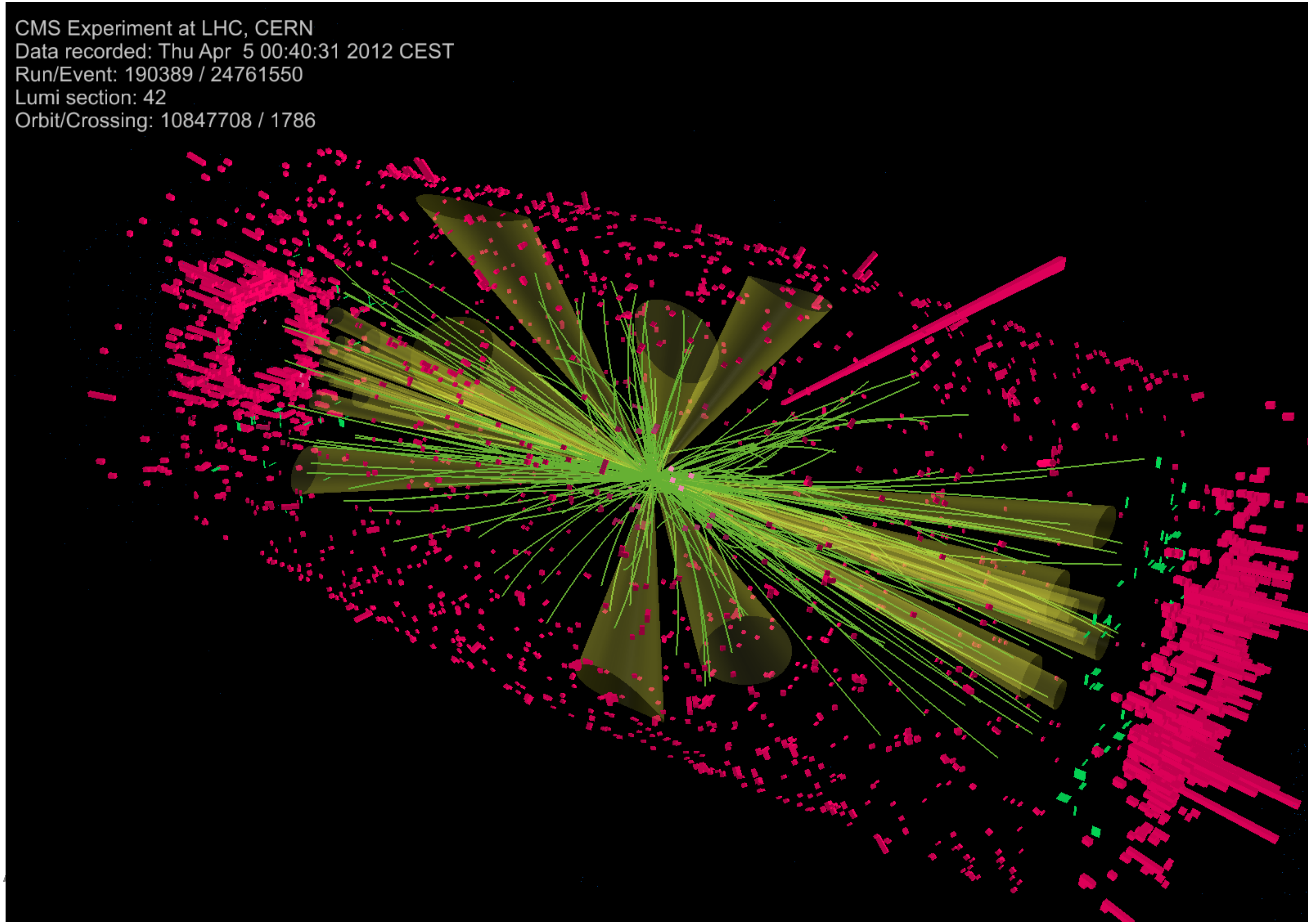
- VH, VBF, ttH measure couplings directly
  - WH known at NNLO, ttH & VBF at NLO
  - Reliable theory predictions
  - VH can give Hbb coupling, ttH gives Htt coupling
- Modern studies rely on high p_T region
  - Now have distributions at NLO
  - Theory uncertainties larger at tails of distributions
  - Direct processes implemented in POWHEG, mC@NLO (see Frixione talk)

Time to rethink ttH!

Collisions at 8 TeV with stable beams

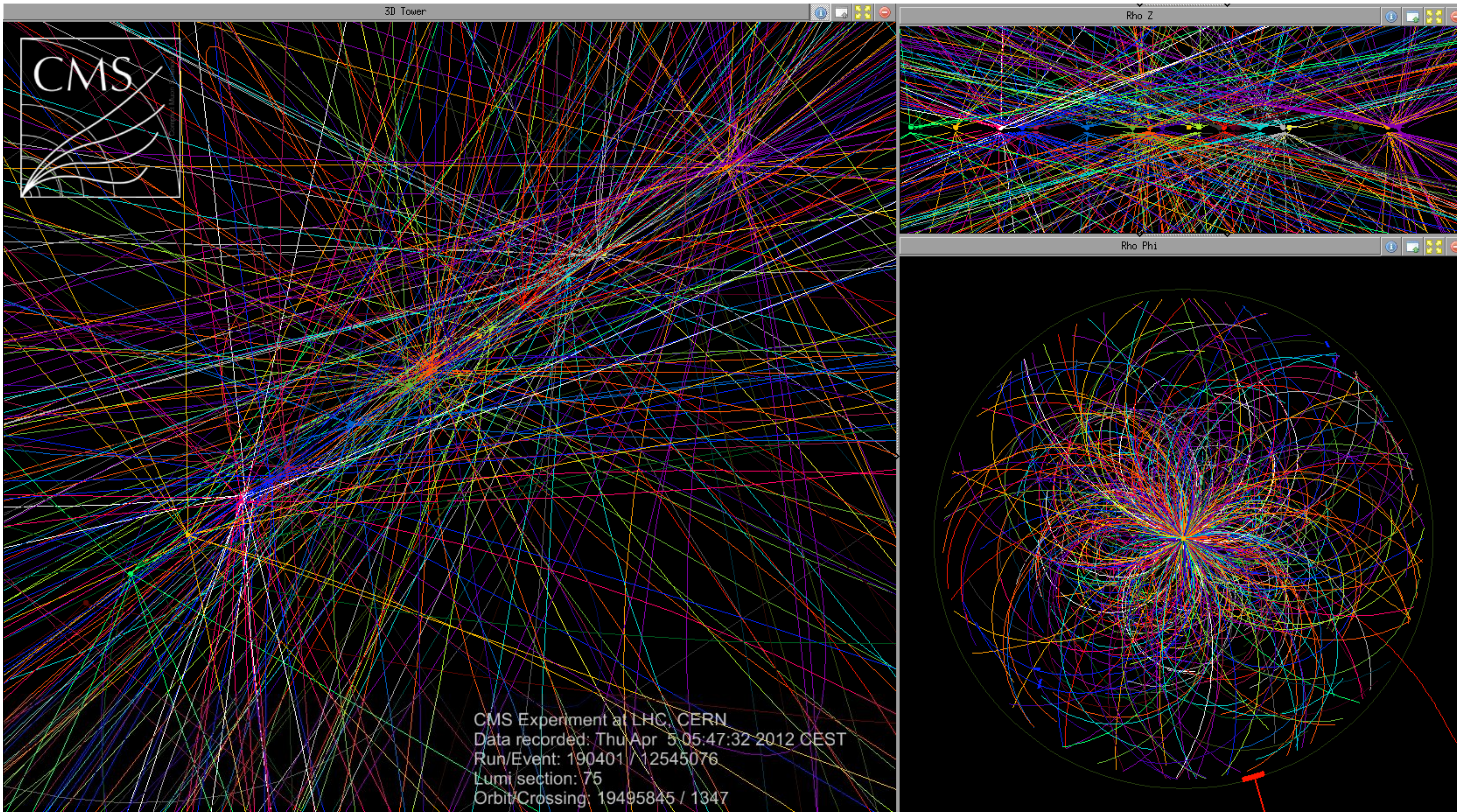
- Very successful restart of LHC at 8 TeV
  - First collisions with stable beams on April 5th
  - Beta* is 0.6m; bunch charges 1.3 10^{11} protons (pileup ~ 27)
    - One fill with 264 bunches of 1.5 10^{11} p (pileup ~30)
  - Increasing number of bunches: 48, 84, 264, 624, … 1380

p-p collision at 8 TeV in CMS

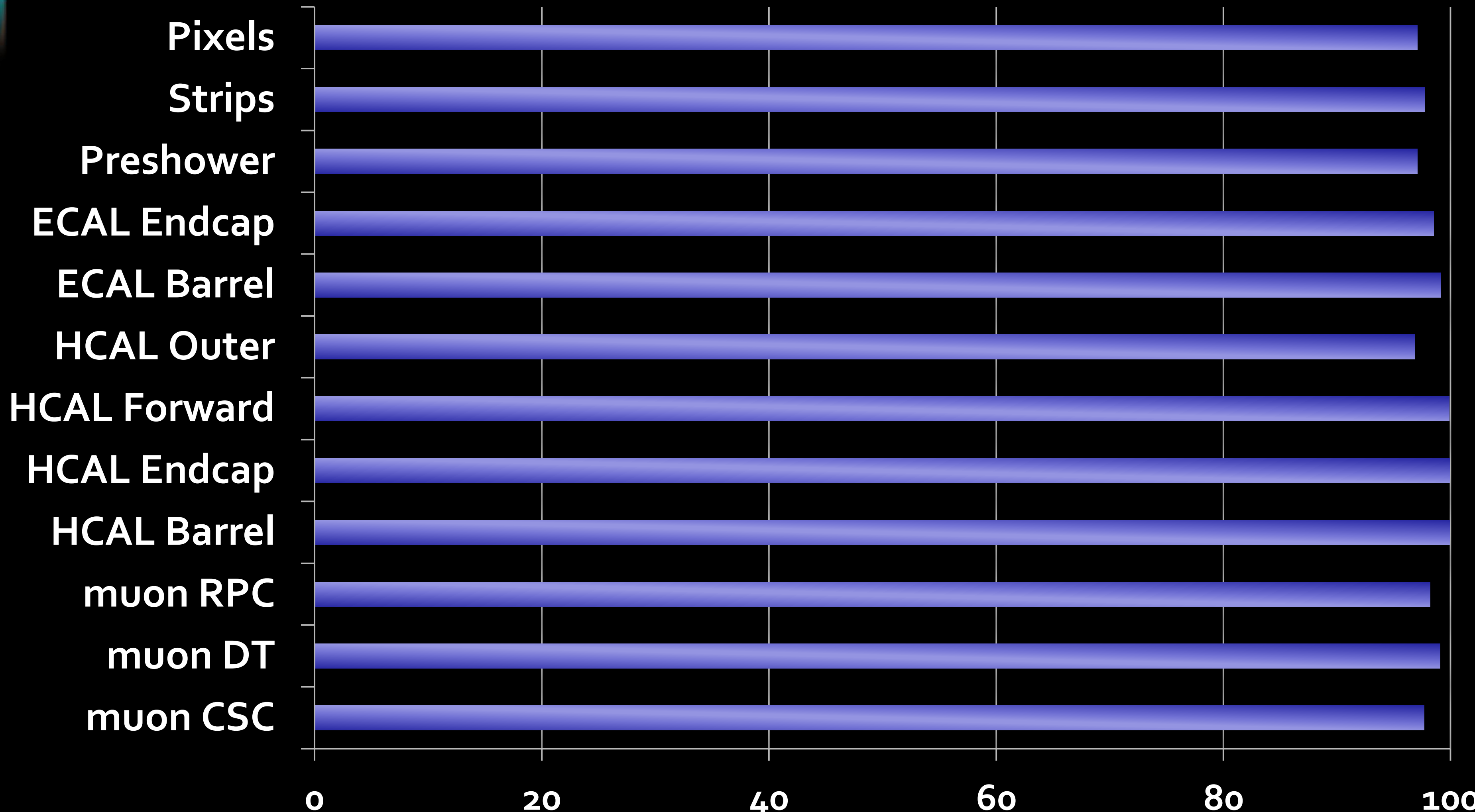


p-p collision at 8 TeV in CMS

- fill 2670 stable beams, with bunch intensity 1.5e11, RECORD peak lumi 6.6e33Hz/cm^2



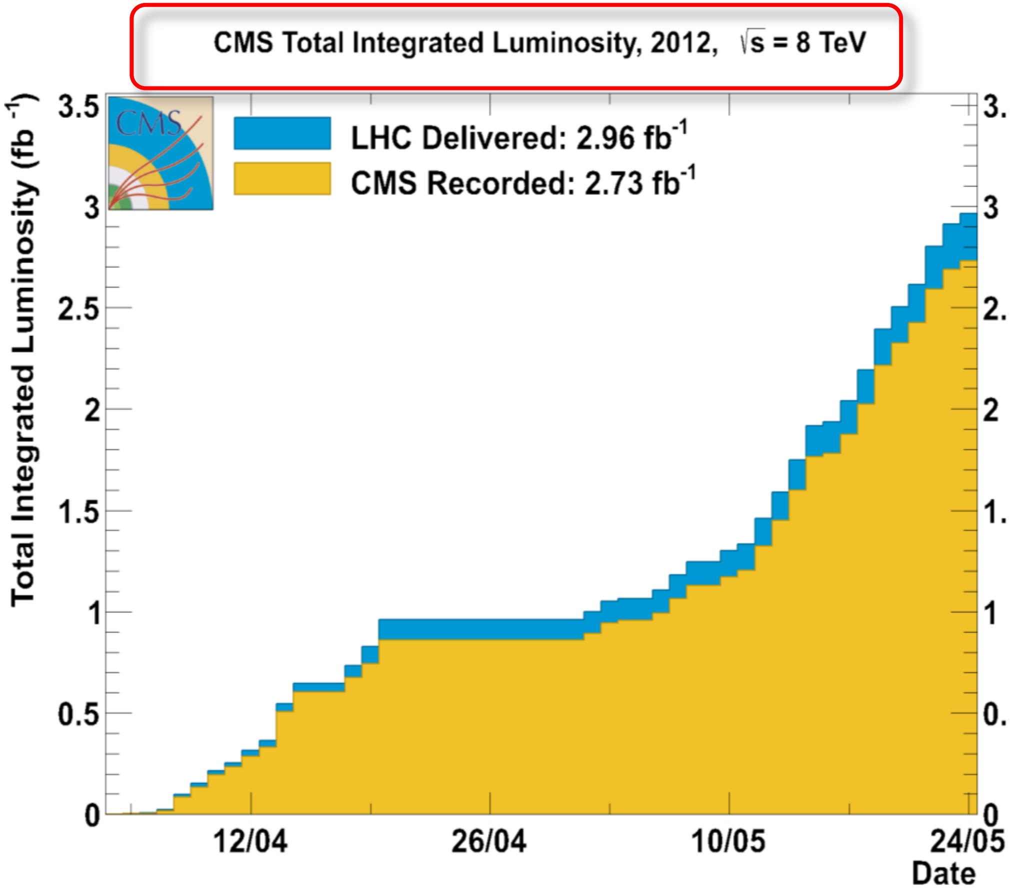
Current Operational Status*

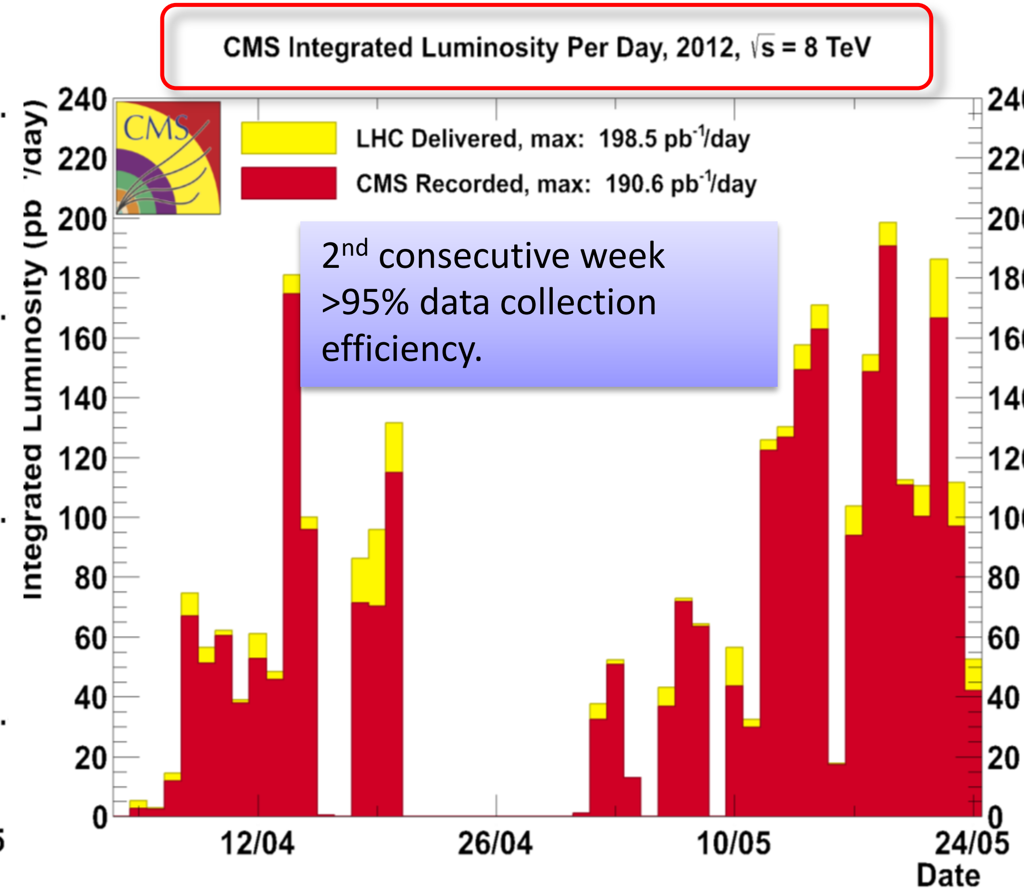


Pixel Tracker	Strip Tracker	Preshower	ECAL Barrel	ECAL Endcaps	HCAL Barrel	HCAL Endcaps	HCAL Forward	HCAL Outer	Muon DT	Muon CSC	Muon RPC
97.1%	97.75 %	97.1%	99.16 %	98.54%	99.92 %	99.96%	99.88%	96.88 %	99.1 %	97.67 %	98.2 %

*As of May 15 2012

LHC Status



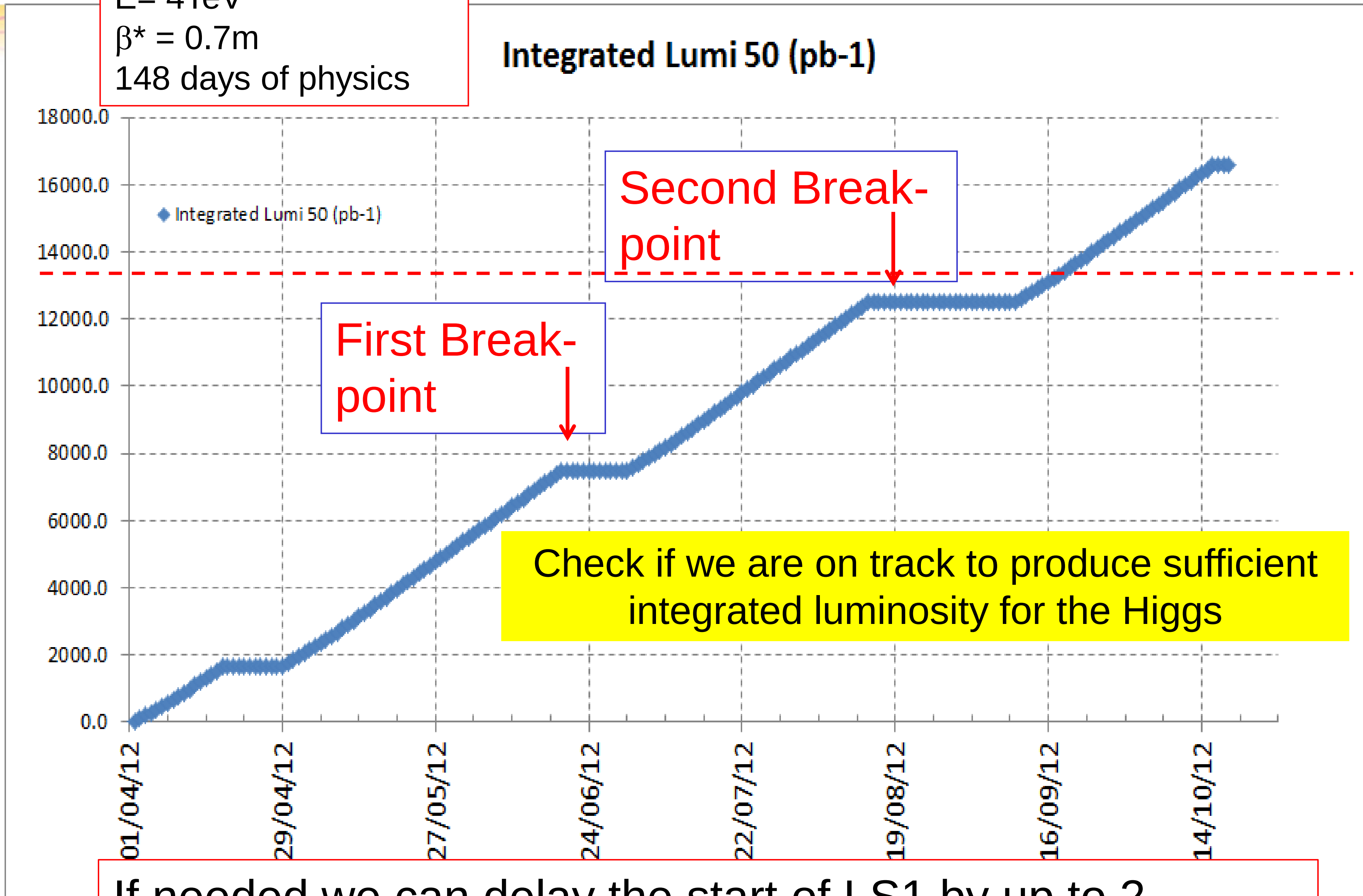


- LHC is mostly back on track
  - Record peak luminosity
  - L ~ 6.5×10^{33} $cm^{-2}s^{-1}$ in one of the most recent fills
- 43% in stable beams last week
  - Despite injector chain, RF problems and tune shifts

- 0.9 delivered last week
- 220 pb^{-1} in one fill
- 2+ weeks left for data that could be used for ICHEP analyses
  - >5 fb^{-1} delivered is possible

LHC projection

E= 4TeV
$\beta^* = 0.7m$
148 days of physics

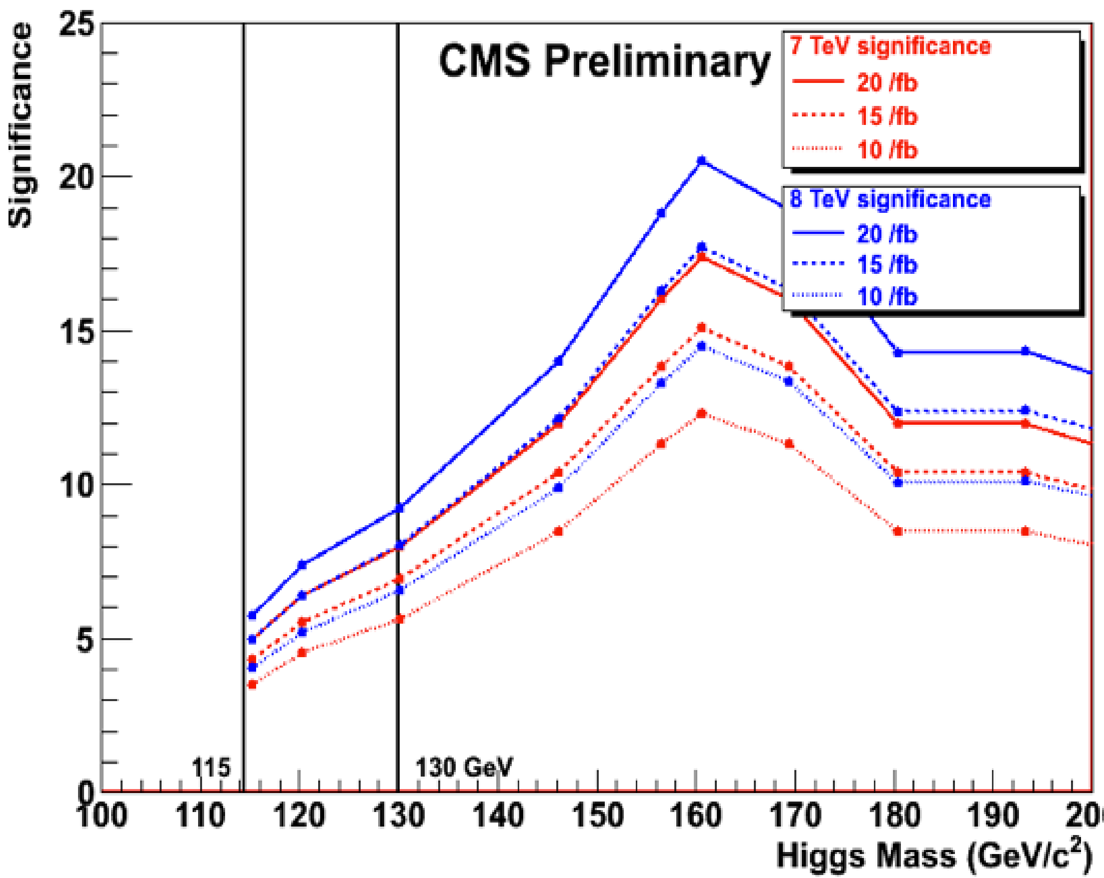


Check if we are on track to produce sufficient integrated luminosity for the Higgs

If needed we can delay the start of LS1 by up to 2 months *Steve Myers*

Some of our input: search for the Higgs

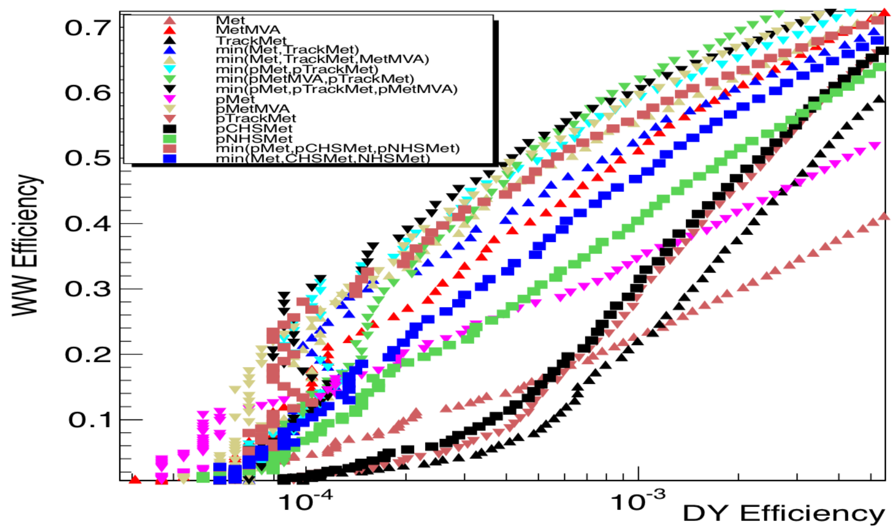
- Integrated luminosity the key
  - Need >20 fb^{-1}/expt going into LS1
  - Could use 2 experiments as they are ideally intended, to corroborate conclusively rather than combine.
- Can reach same ∫Ldt with lower pile-up at 8 TeV
  - Important for low-masses, particularly γγ channel
- Luminosity leveling
  - May be an attractive option provided sufficiently long fills
- Enhanced discovery reach in the full mass range



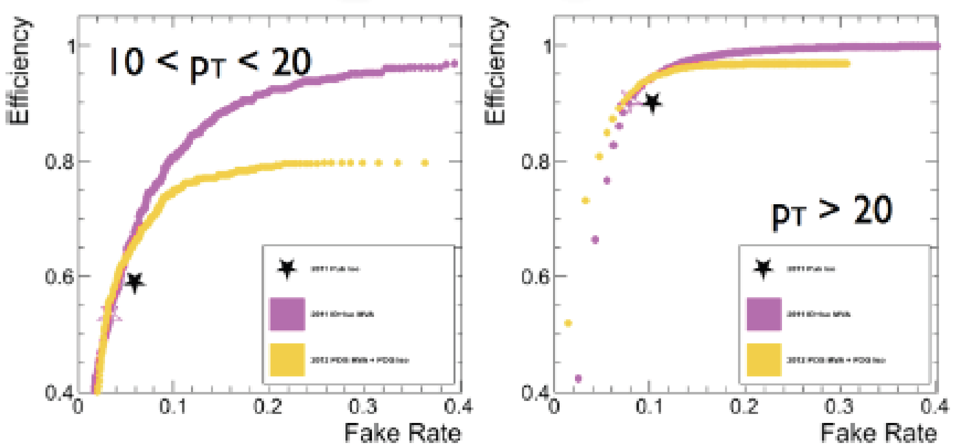
Discovery potential
(non-optimized analysis)
L. Malgeri

Higgs to WW Progress

Many Options Are Considered



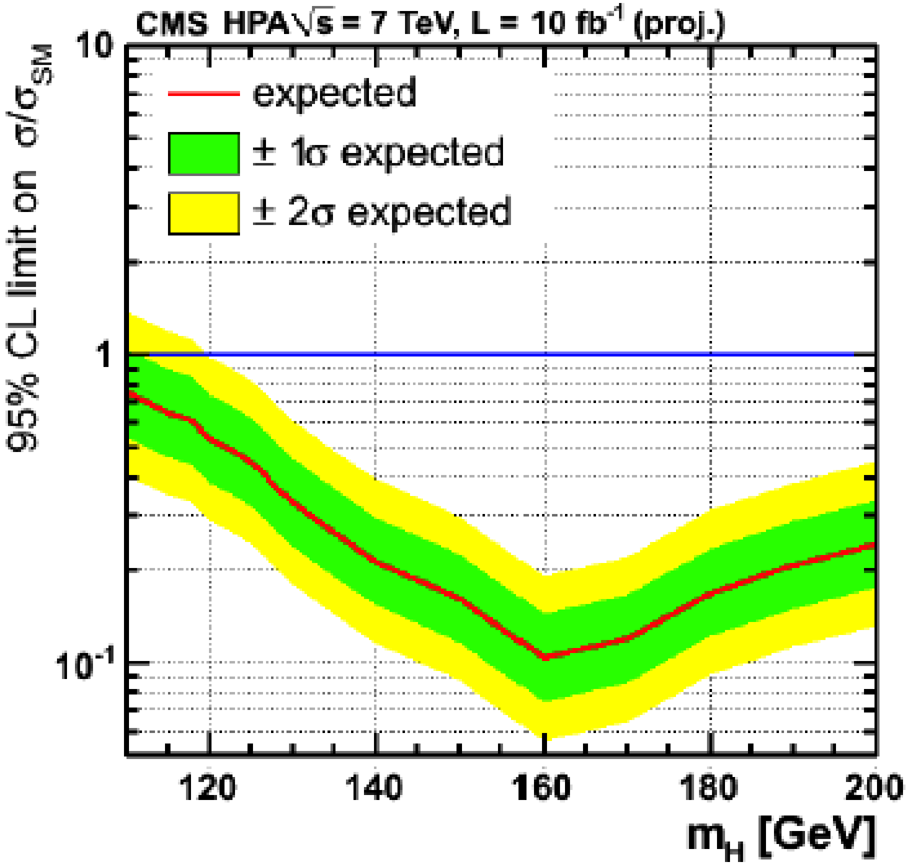
Use POG recommendations where we don't see a significant improvement

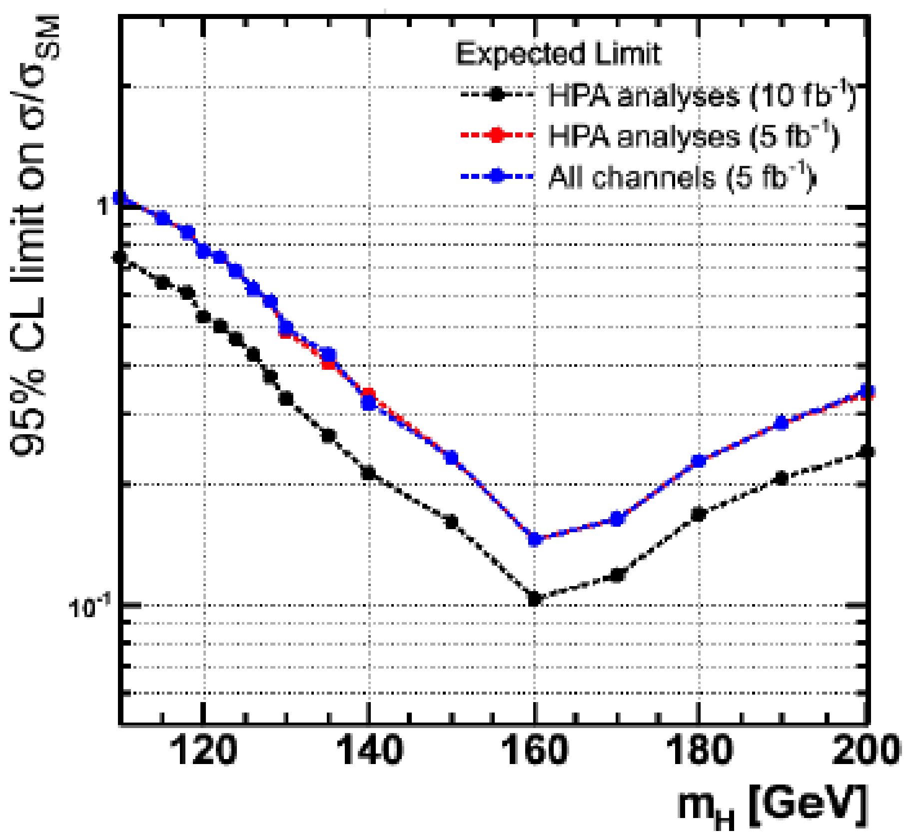


- This report covers WW→2 ℓ 2ν analysis for Higgs and SMP PAGs
- Physics objection selection:
  - By April 30 we had final list of physics object implementations to be considered for ICHEP. The list of candidates can be seen here: https://twiki.cern.ch/twiki/bin/viewauth/CMS/HiggsWWSummer2012
  - This week we reviewed their performance for HWW analysis and finalized: electrons, muons, jets and b-jets.
    - There is a delay on MET, because results by different groups disagree a lot
  - By May 8th we will finalize all the working points and start synchronization on event by event level
    - Good synchronization between groups is critical for background estimations and comparisons across the groups (currently we are synchronized for 2011 selection)

Exclusion sensitivity @ 10/fb

Expected exclusion sensitivity at 10/fb (7 TeV) with combination of HPA Higgs analysis

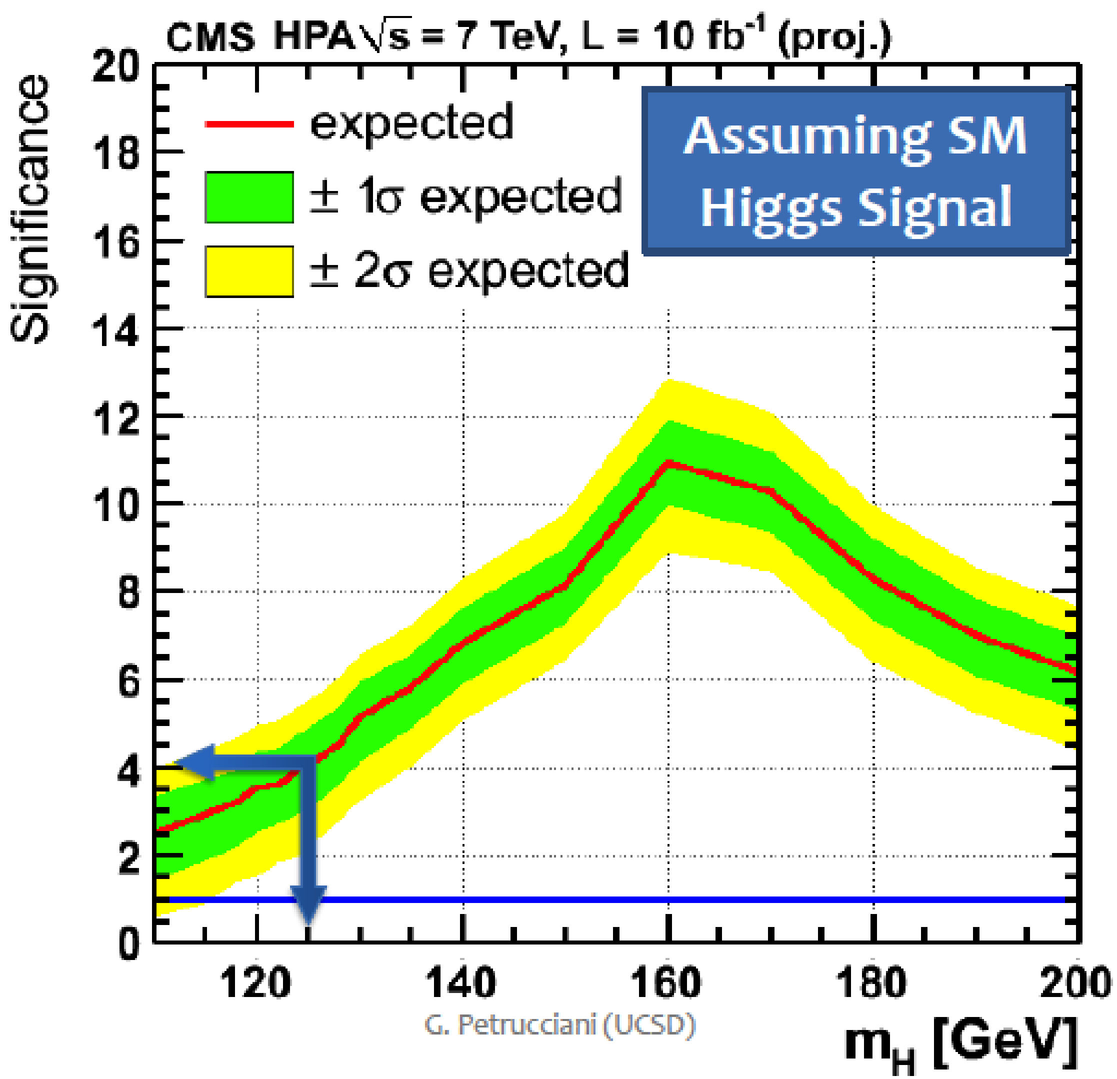




Only based on the published 2011 analyses, does not include any of the 2012 improvements

Discovery sensitivity @ 10/fb

Expected discovery sensitivity at 10/fb (7 TeV) with combination of HPA Higgs analysis



Only based on the published 2011 analyses, does not include any of the 2012 improvements

summary

- impressive progress in the SM Higgs search during 2011
  - **with 5 fb^{-1} the small window left is 114.4 GeV < m_H < 127.5 GeV @ 95% CL**
  - **in the low mass region**
    - excluded (m_H > 127.5 GeV) less than expected (m_H > 114.5 GeV)
    - small and inconclusive excess around 125 GeV
- LHC and the detectors are performing in 2012 even better than in 2011, so we are working to produce a **major** result, by the end of this year, with a good check point at ICHEP