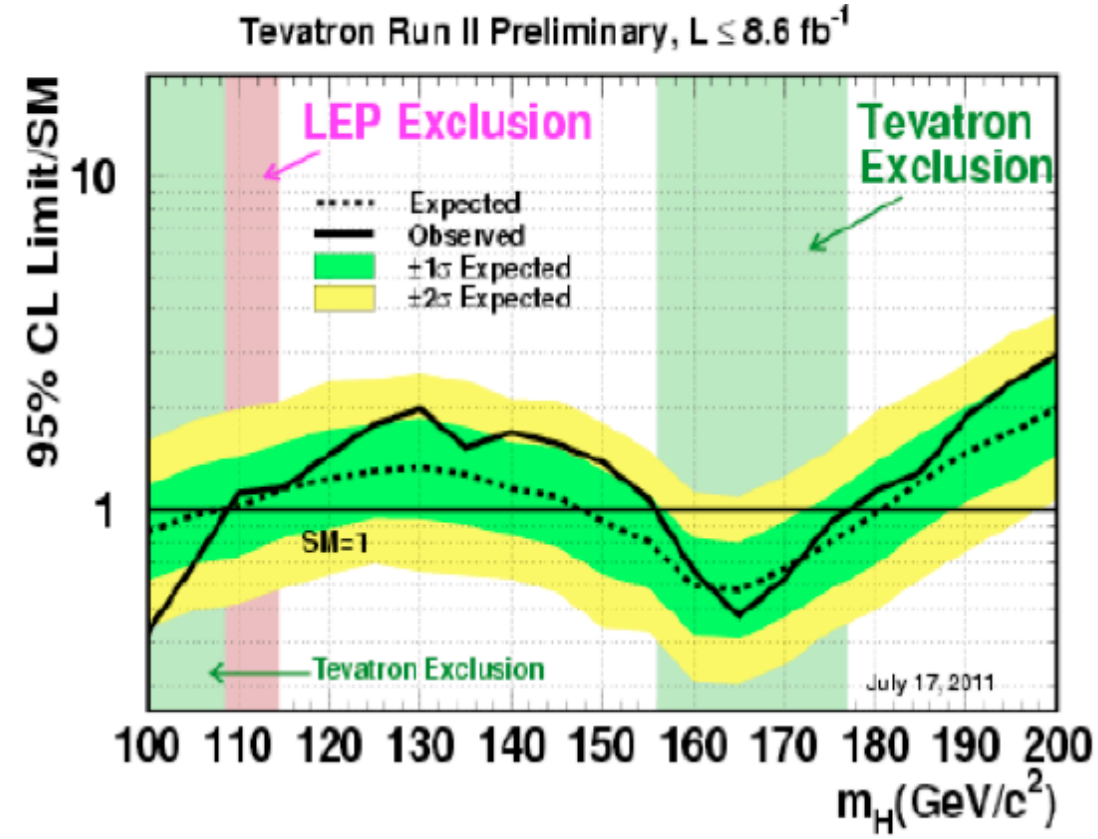
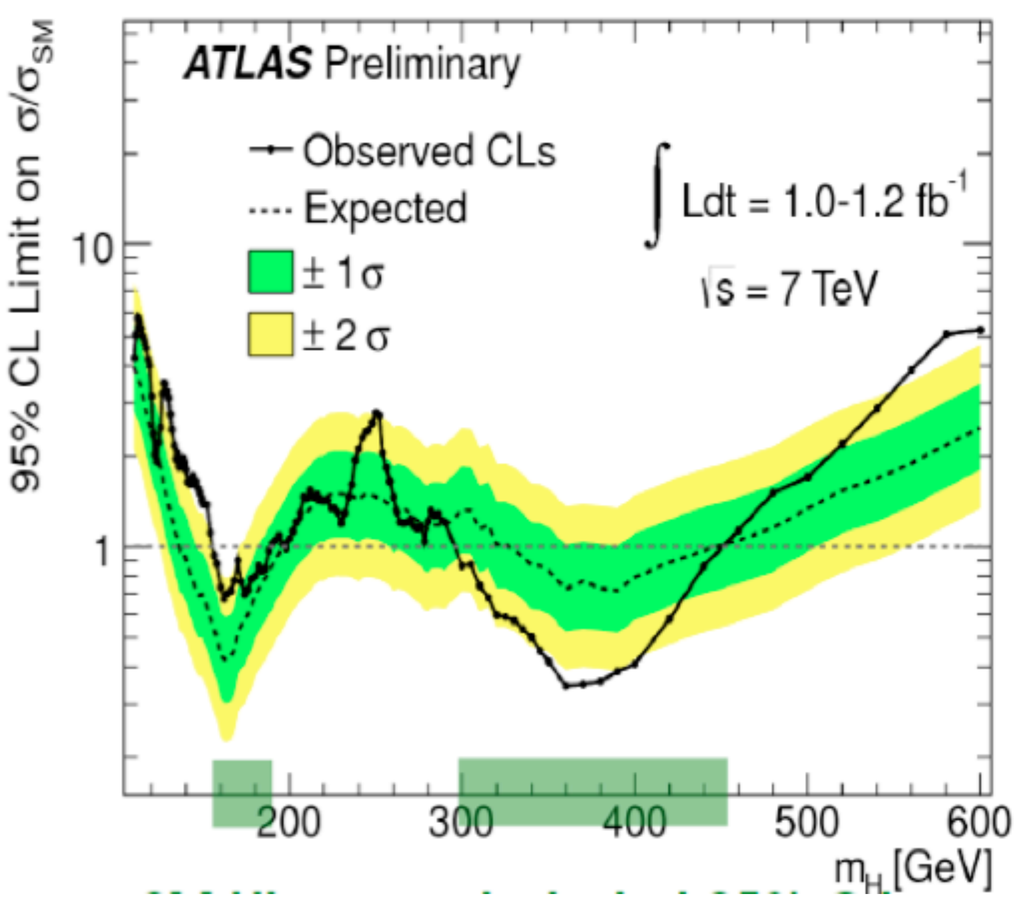
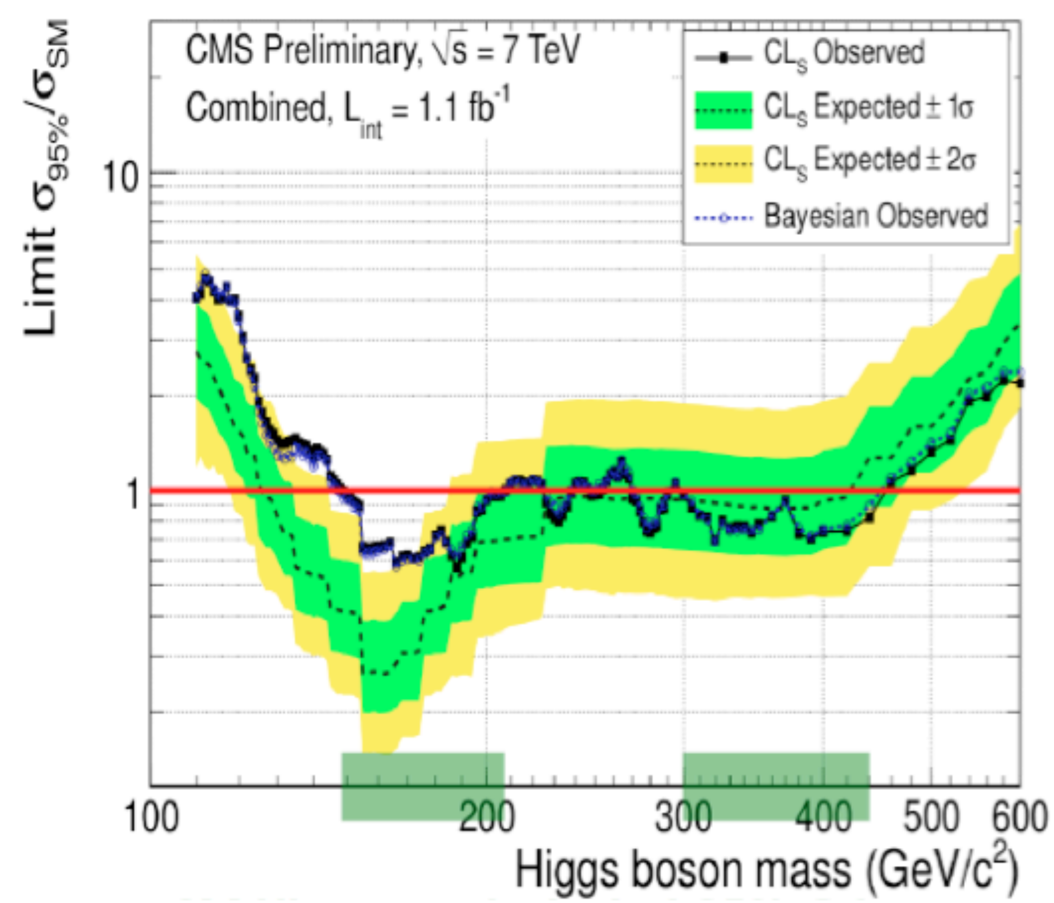
Experimental concluding talk

G.Unal (CERN)

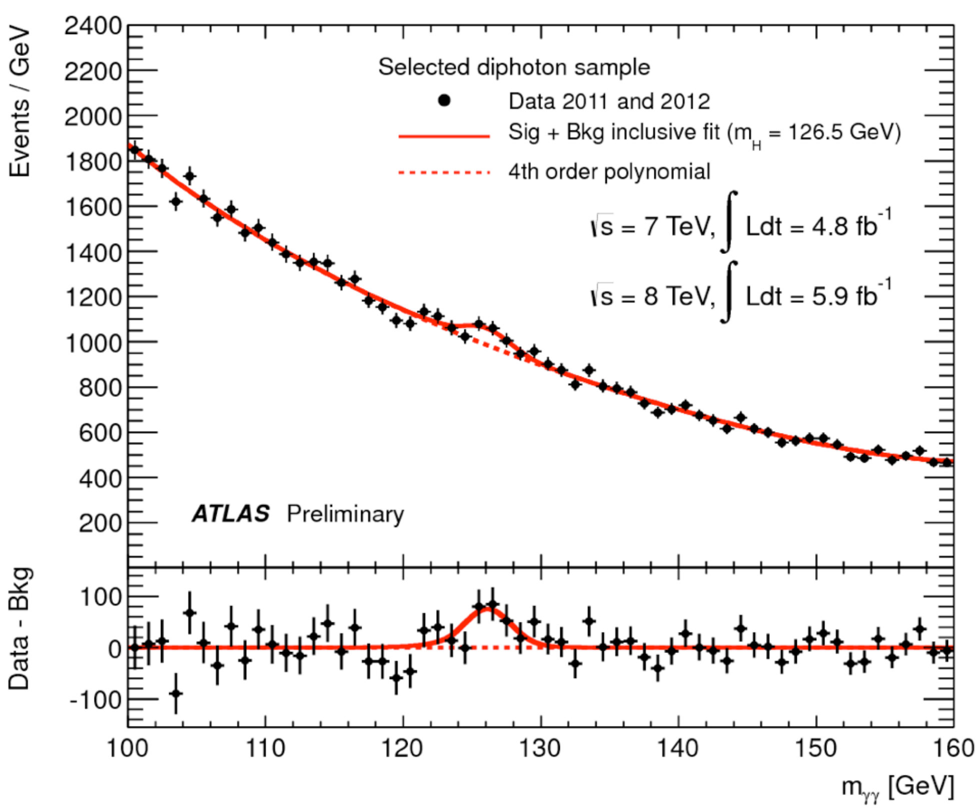
From last year...

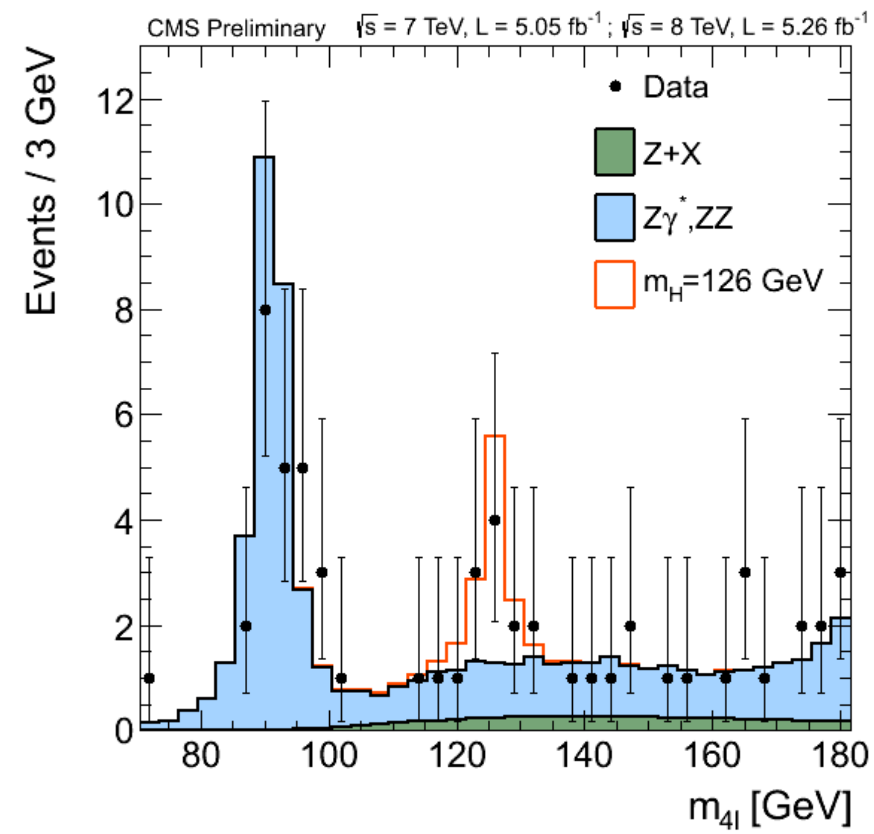


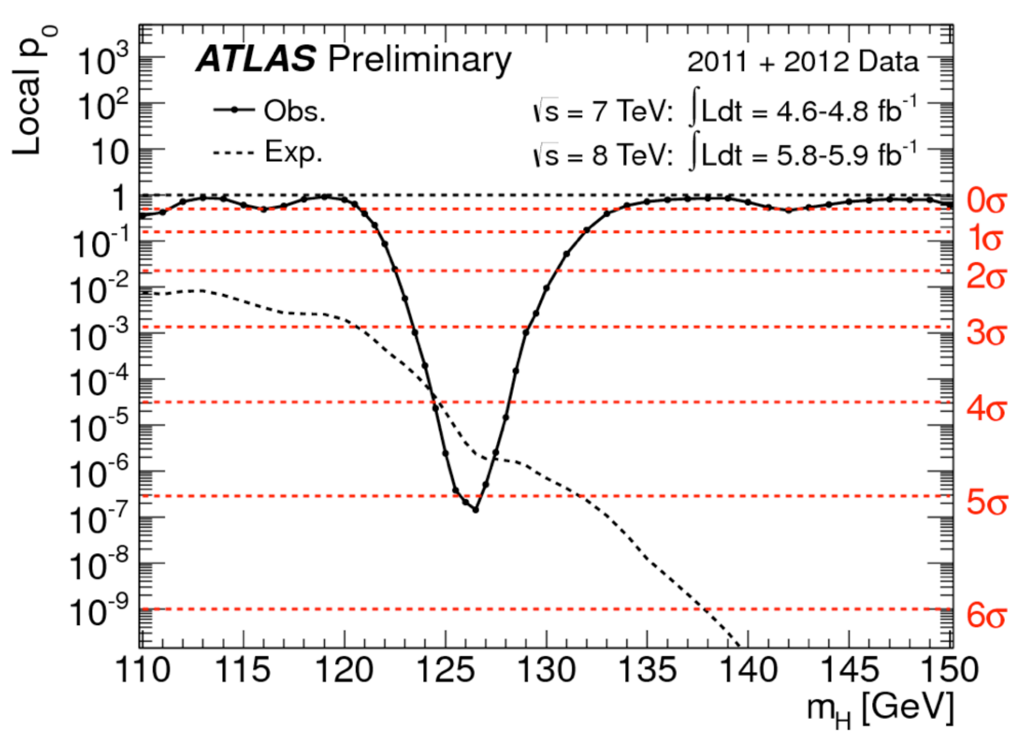


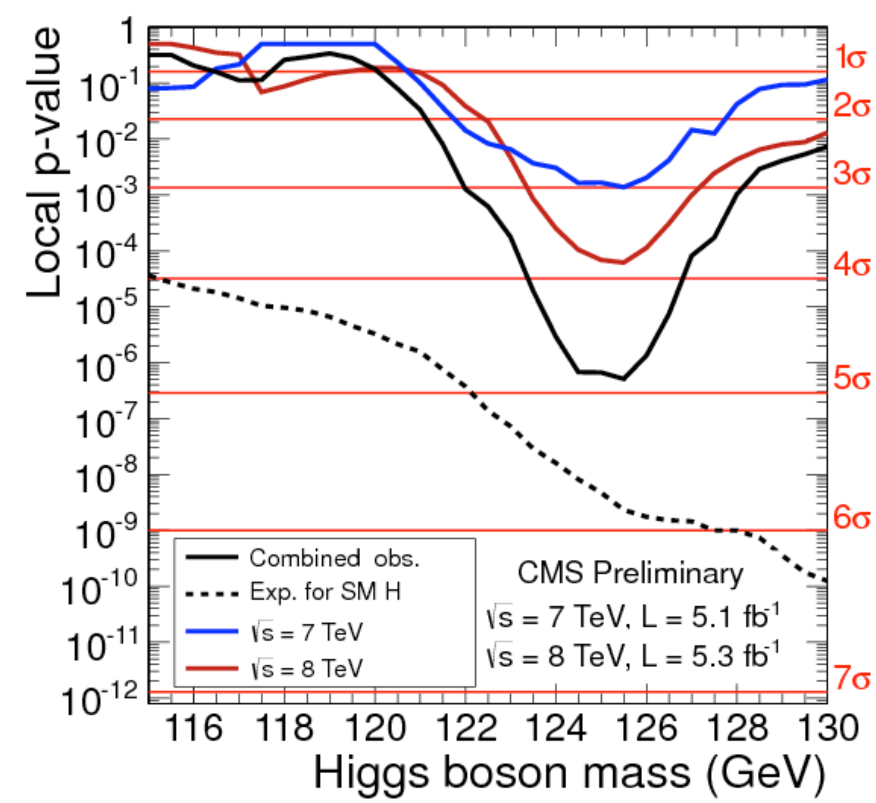


... to this year

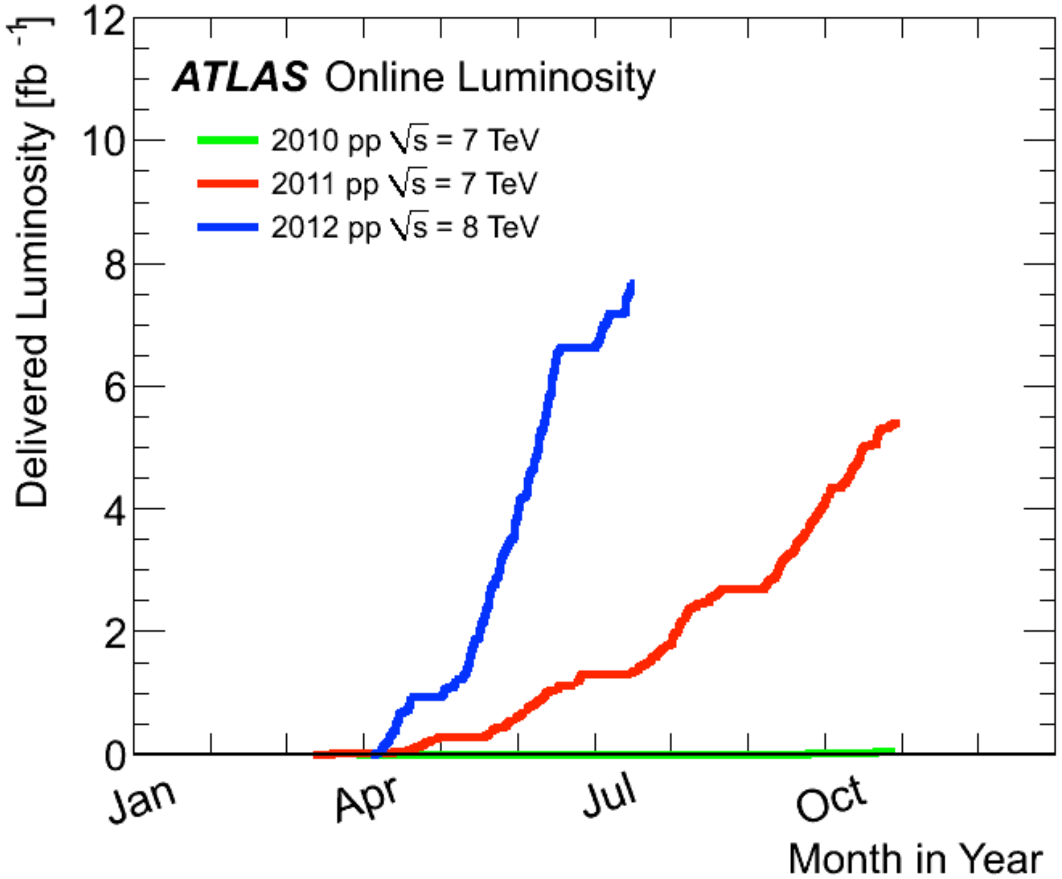

Selected diphoton sample
Data 2011 and 2012
Sig + Bkg inclusive fit (m_H = 126.5 GeV)
4th order polynomial
$\sqrt{s}$ = 7 TeV, $\int Ldt$ = 4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV, $\int Ldt$ = 5.9 fb^{-1}
ATLAS Preliminary
Events / GeV
Data - Bkg
$m_{\gamma\gamma}$ [GeV]

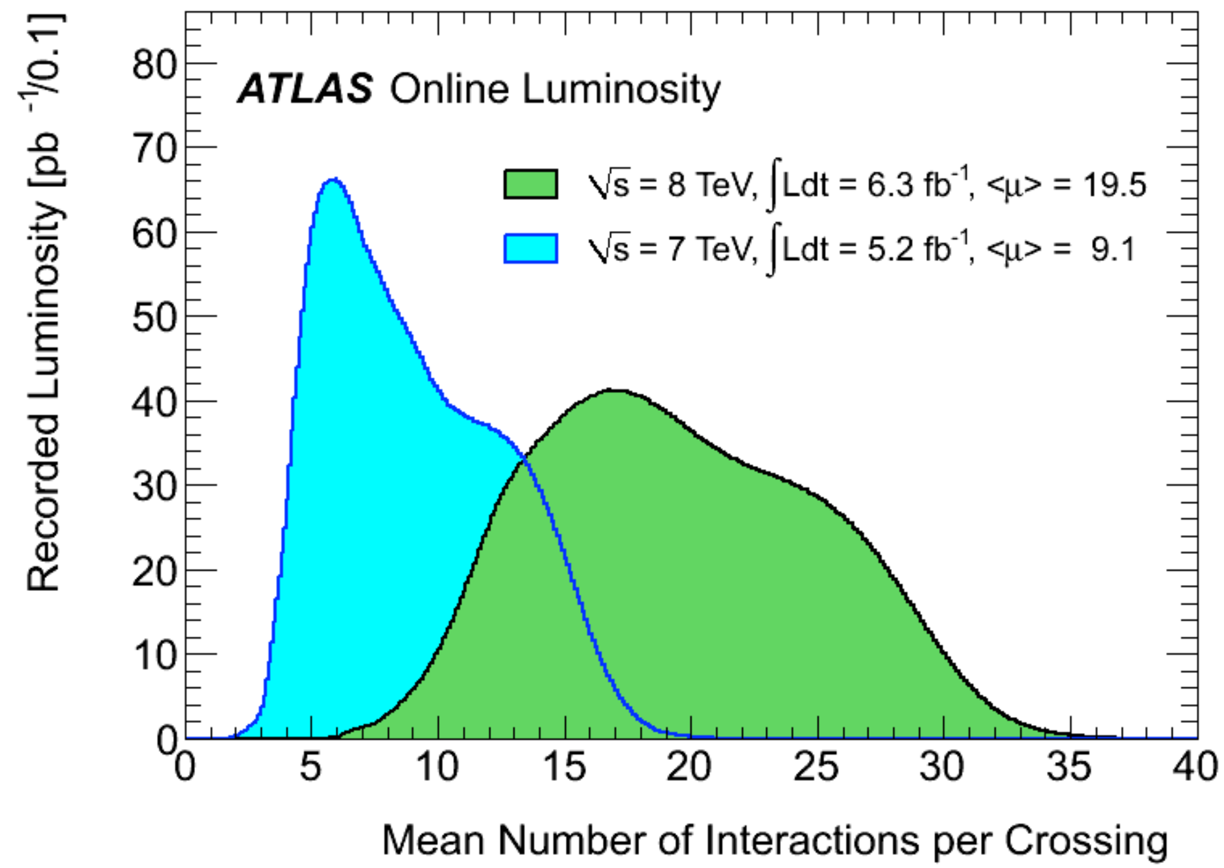

CMS Preliminary $\sqrt{s}$ = 7 TeV, L = 5.05 fb^{-1} ; $\sqrt{s}$ = 8 TeV, L = 5.26 fb^{-1}
Data
Z+X
Zγ^*,ZZ
m_H=126 GeV
Events / 3 GeV
m_{4l} [GeV]


ATLAS Preliminary
2011 + 2012 Data
Obs.
Exp.
$\sqrt{s}$ = 7 TeV: $\int Ldt$ = 4.6-4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV: $\int Ldt$ = 5.8-5.9 fb^{-1}
Local p_0
0σ 1σ 2σ 3σ 4σ 5σ 6σ
m_H [GeV]


Combined obs.
Exp. for SM H
$\sqrt{s}$ = 7 TeV
$\sqrt{s}$ = 8 TeV
CMS Preliminary
$\sqrt{s}$ = 7 TeV, L = 5.1 fb^{-1}
$\sqrt{s}$ = 8 TeV, L = 5.3 fb^{-1}
Local p-value
1σ 2σ 3σ 4σ 5σ 6σ 7σ
Higgs boson mass (GeV)

Thanks to large increase in LHC delivered luminosity

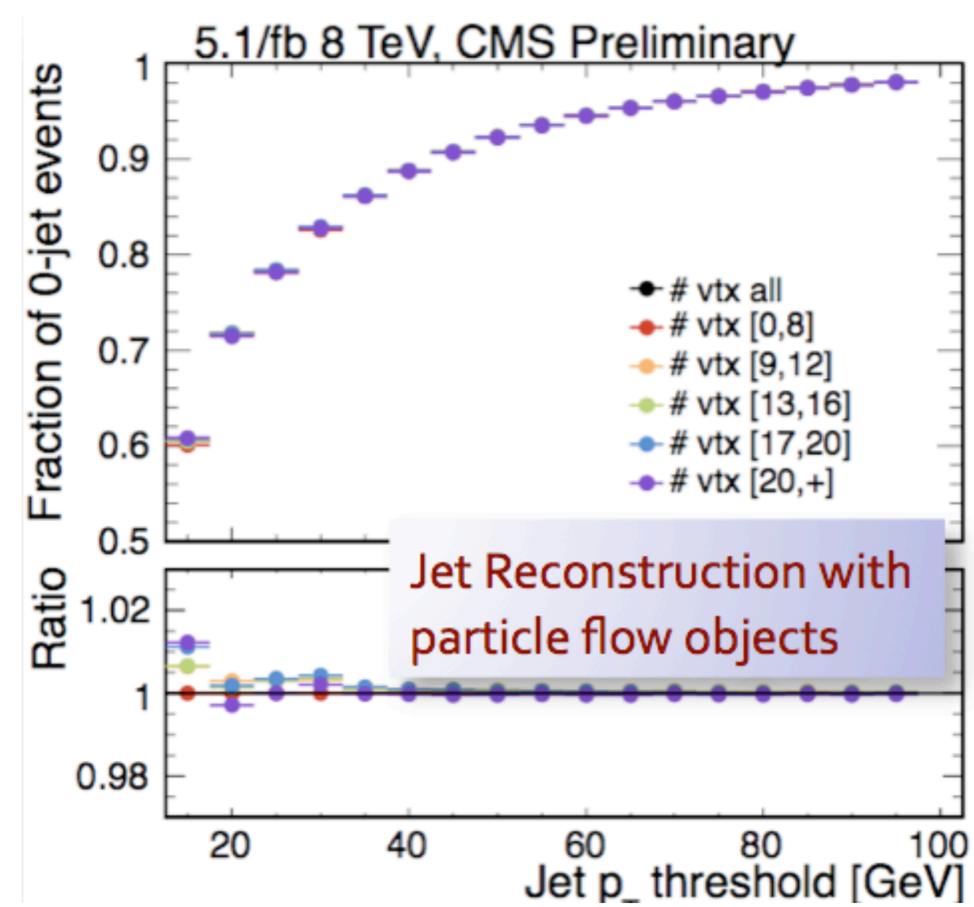




Price to pay is pileup: CMS and ATLAS already running at >= design values

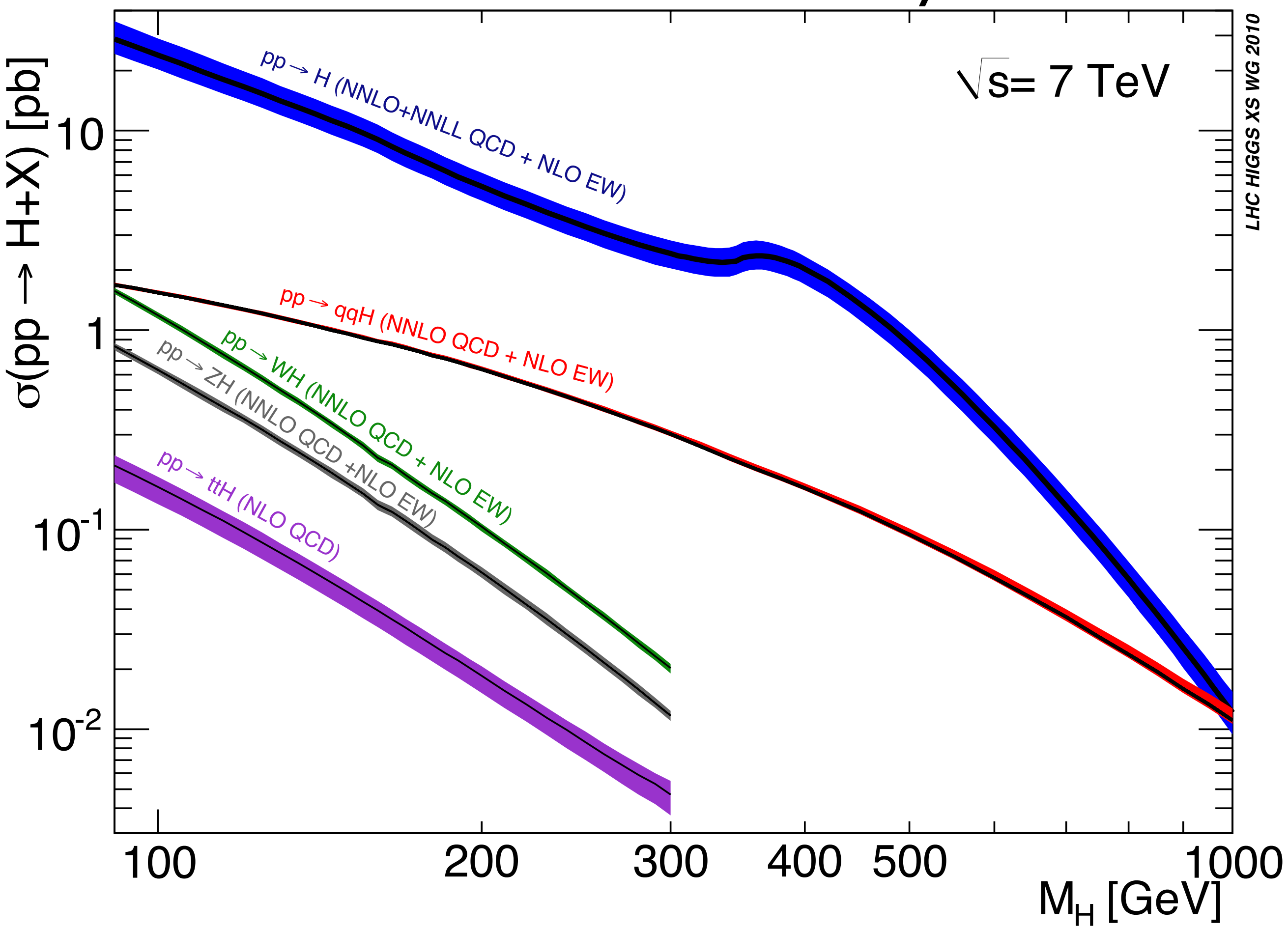
Several mitigation techniques developed:

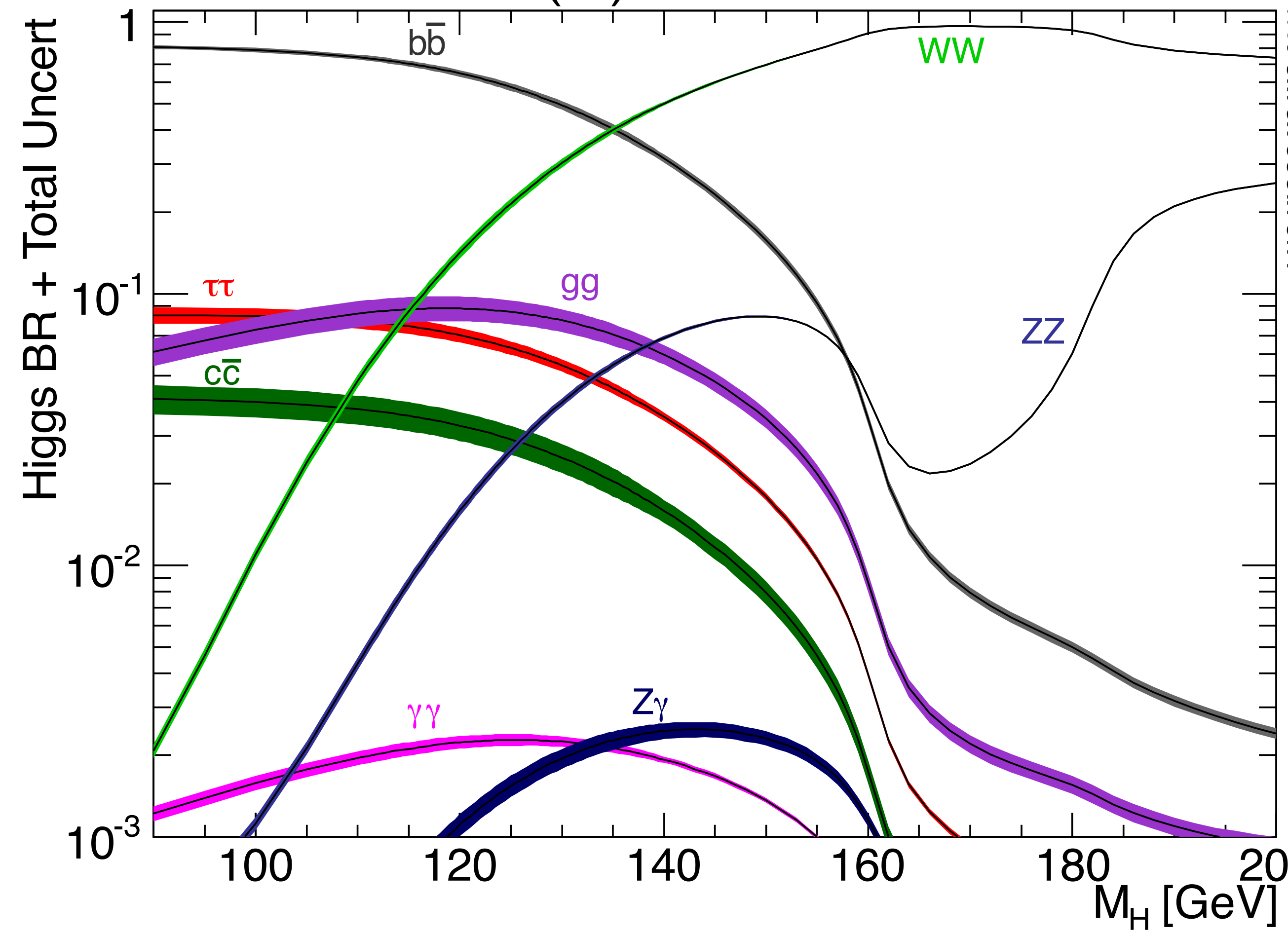
- Track-Vertex association for charged tracks
- Ambient energy correction for isolation and jets
- Track information and Jet shapes to reduce «pileup» jets



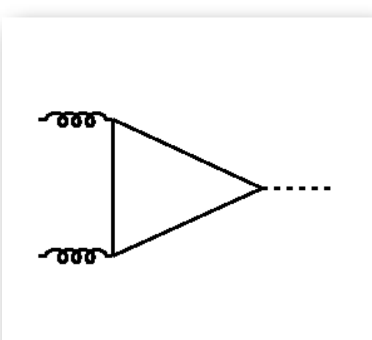
Brout-Englert-Higgs boson production (at the LHC) and decay

tremendous theory effort to compute cross-section at (N)NLO

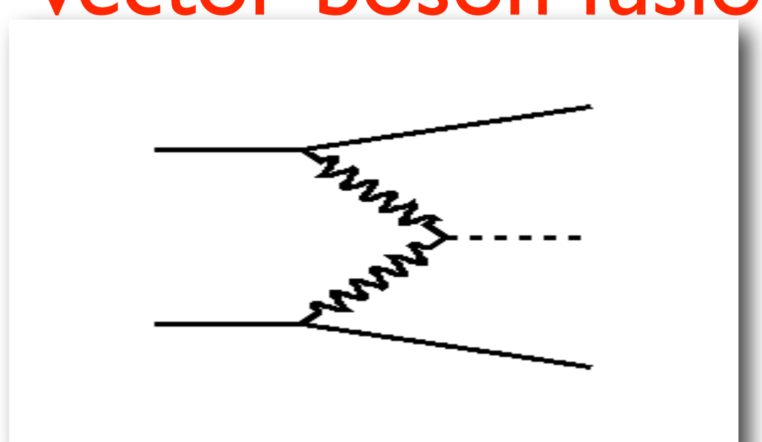




gluon fusion

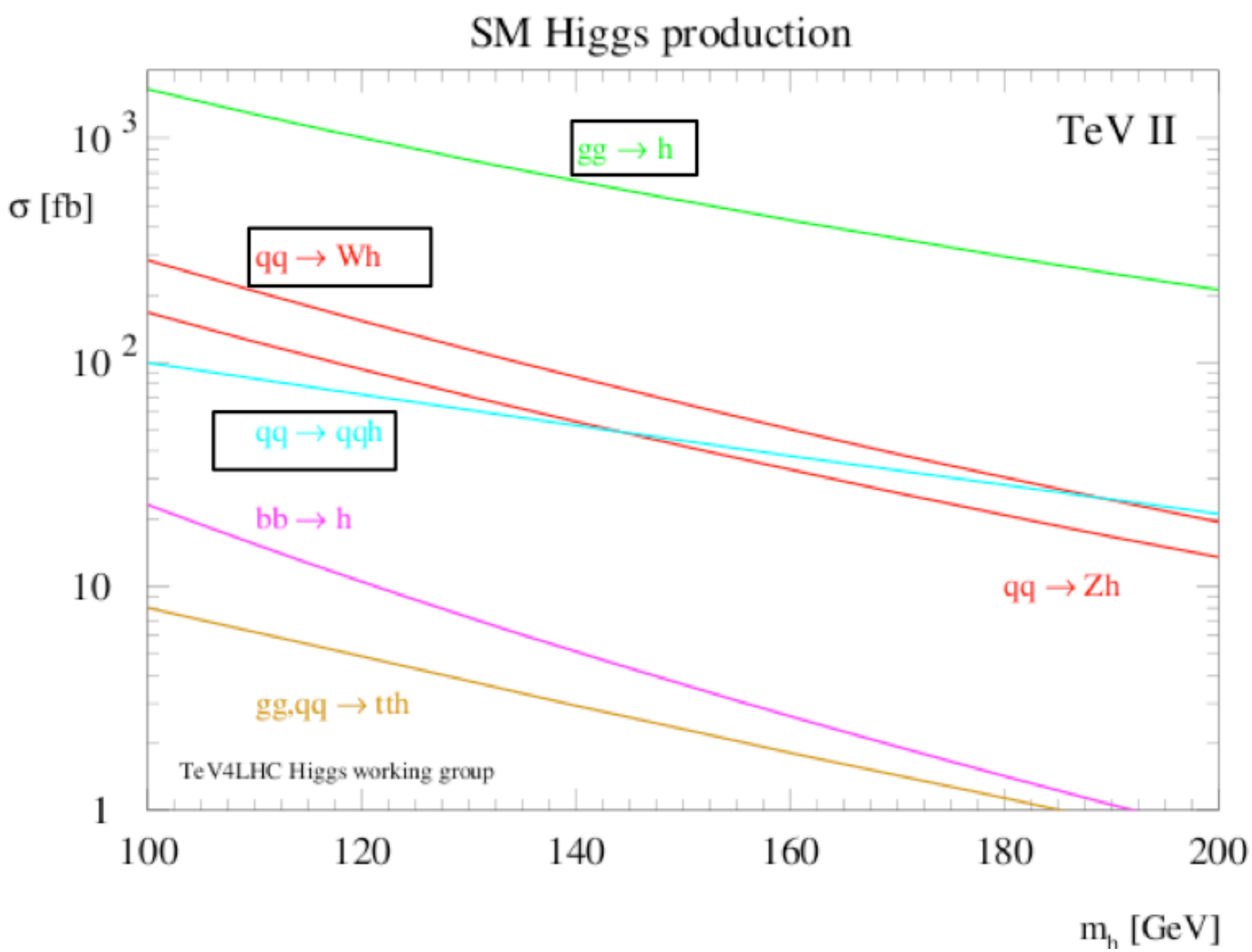


vector boson fusion



At high mass, WW and ZZ decays
At low mass, bb dominates but challenging
=> exploit also «rare» decays

Production at Tevatron



~factor 10 less gluon fusion than at LHC

VH production is second production process, better S/B than at LHC (ppbar vs pp)

$H \rightarrow \gamma\gamma$

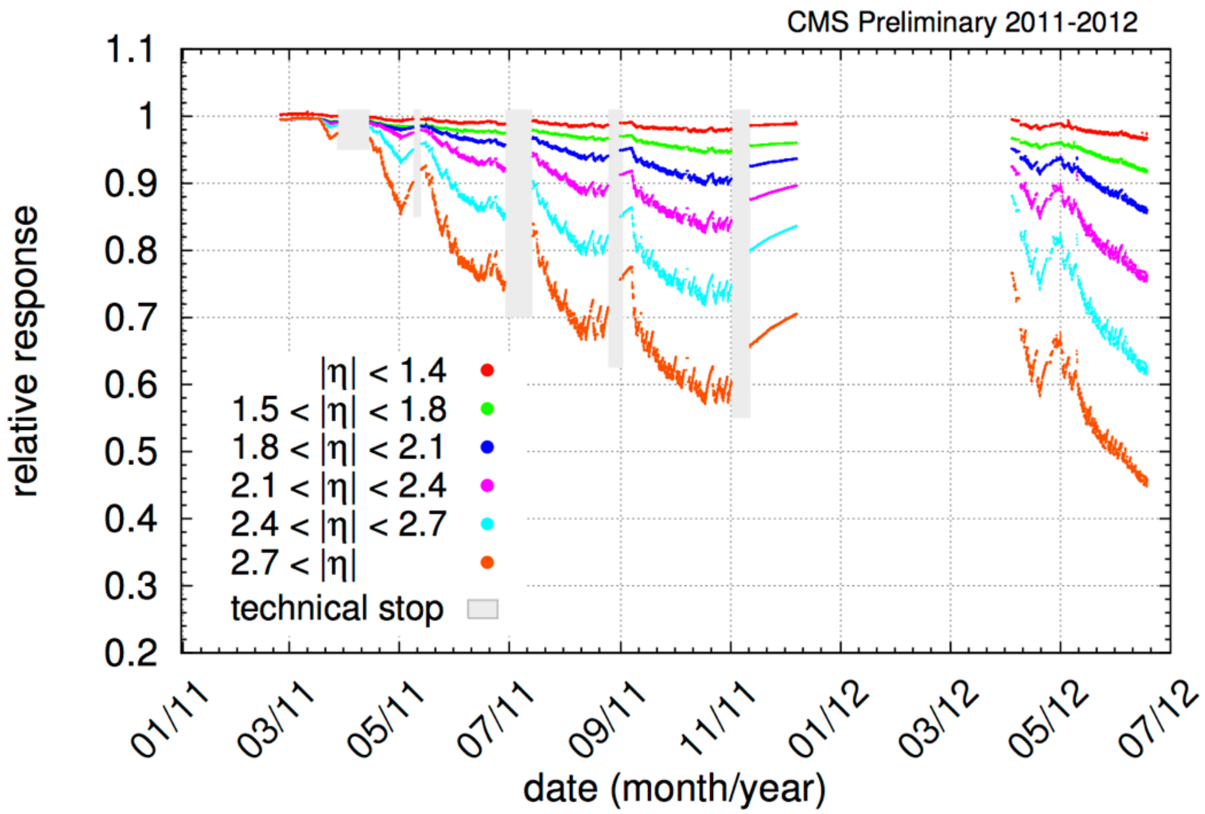
Analysis improved compared to last winter

K.Peters

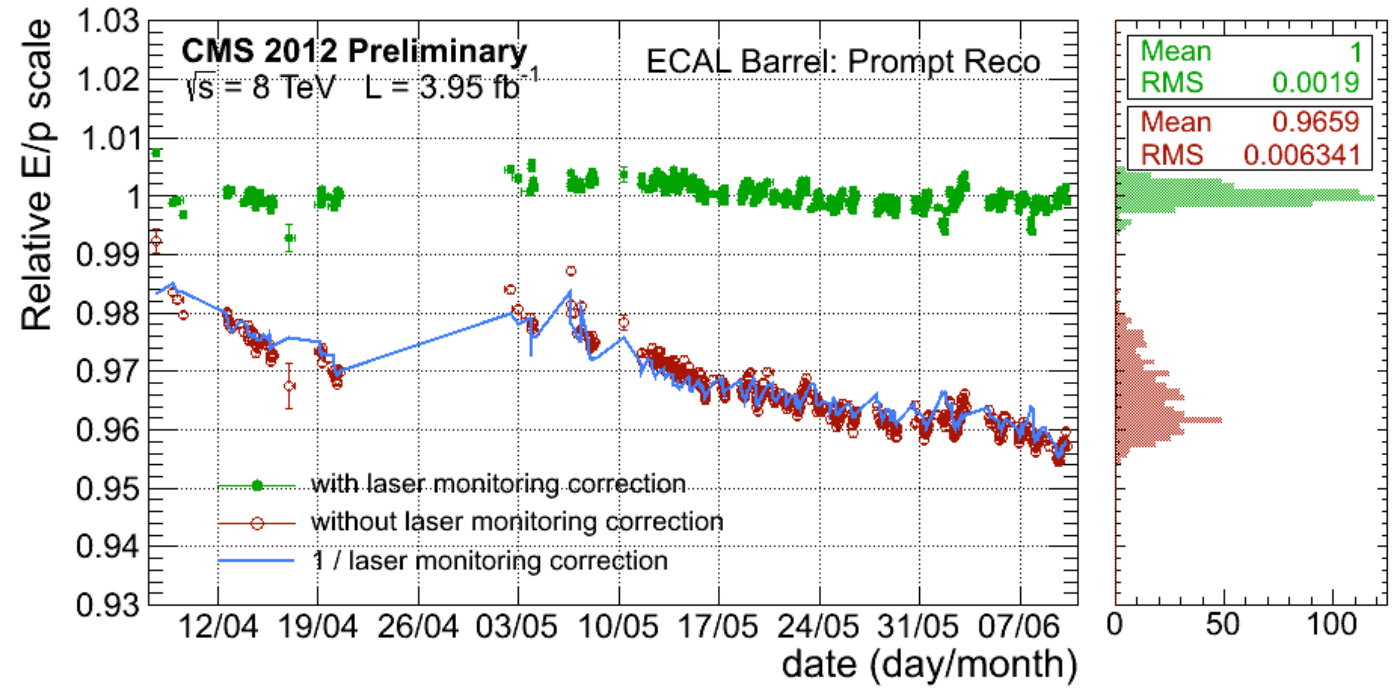
Y.Chang

- Benchmark channels for ATLAS and CMS calorimeter design
- Basic recipe:
  - Select two photons, minimise reducible background (mostly pi0 decays from jets), «easy» to trigger.
  - Reconstruct invariant mass as accurately as possible to separate from large «irreducible» background from diphoton production
    - Energy resolution
    - Opening angle => Vertex resolution
  - Optimise analysis by dividing events into categories with different S/B ratio or different mass resolution

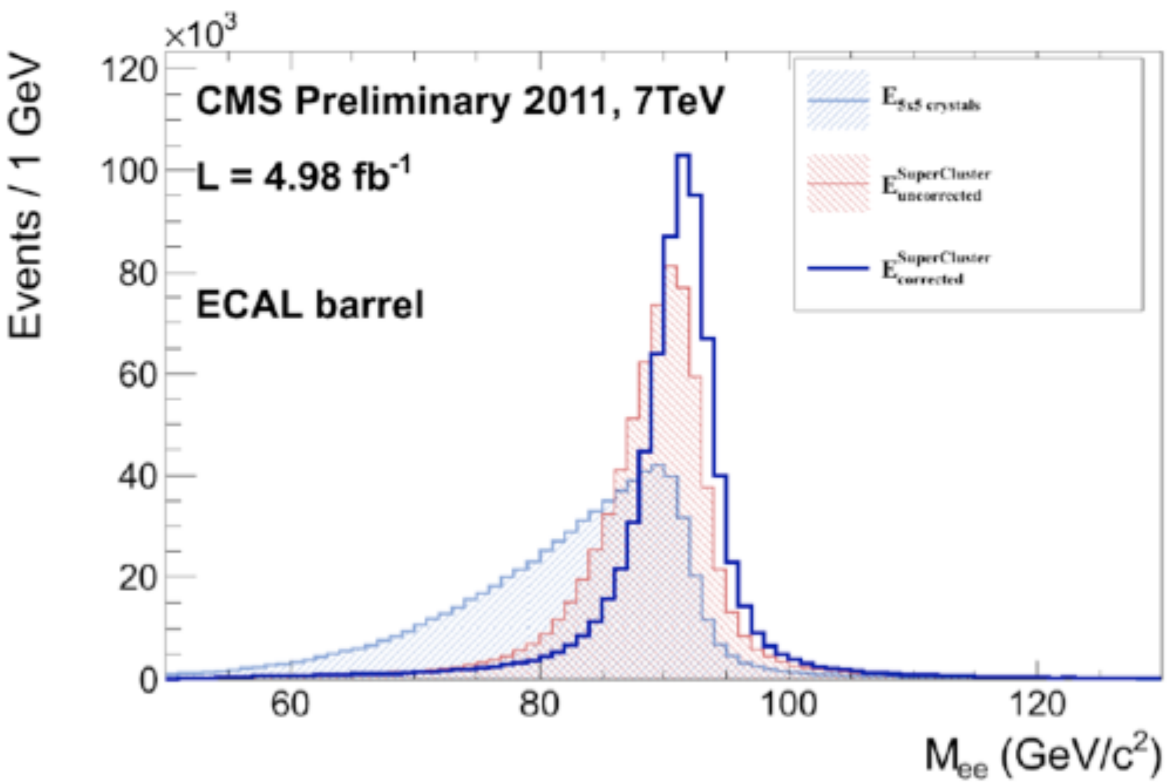
CMS Ecal



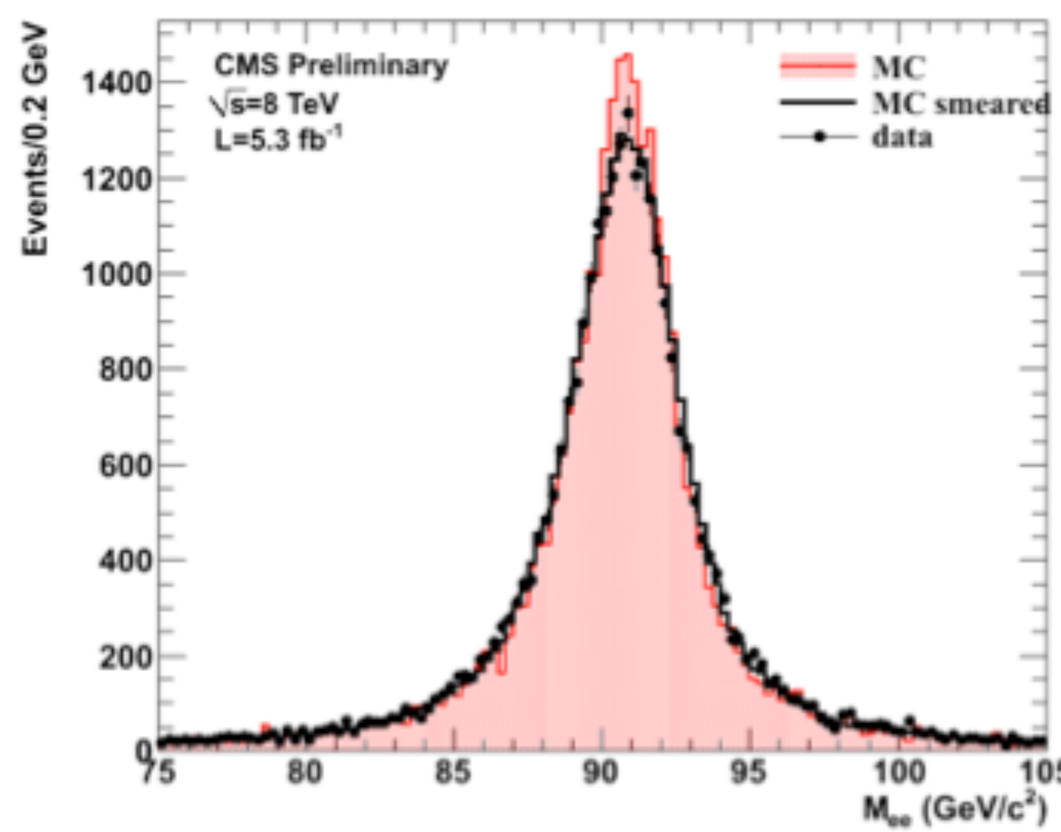
CMS Preliminary 2011-2012
relative response
|η| < 1.4
1.5 < |η| < 1.8
1.8 < |η| < 2.1
2.1 < |η| < 2.4
2.4 < |η| < 2.7
2.7 < |η|
technical stop
date (month/year)



CMS 2012 Preliminary
√s = 8 TeV L = 3.95 fb⁻¹
ECAL Barrel: Prompt Reco
Relative E/p scale
with laser monitoring correction
without laser monitoring correction
1 / laser monitoring correction
date (day/month)
Mean 1
RMS 0.0019
Mean 0.9659
RMS 0.006341

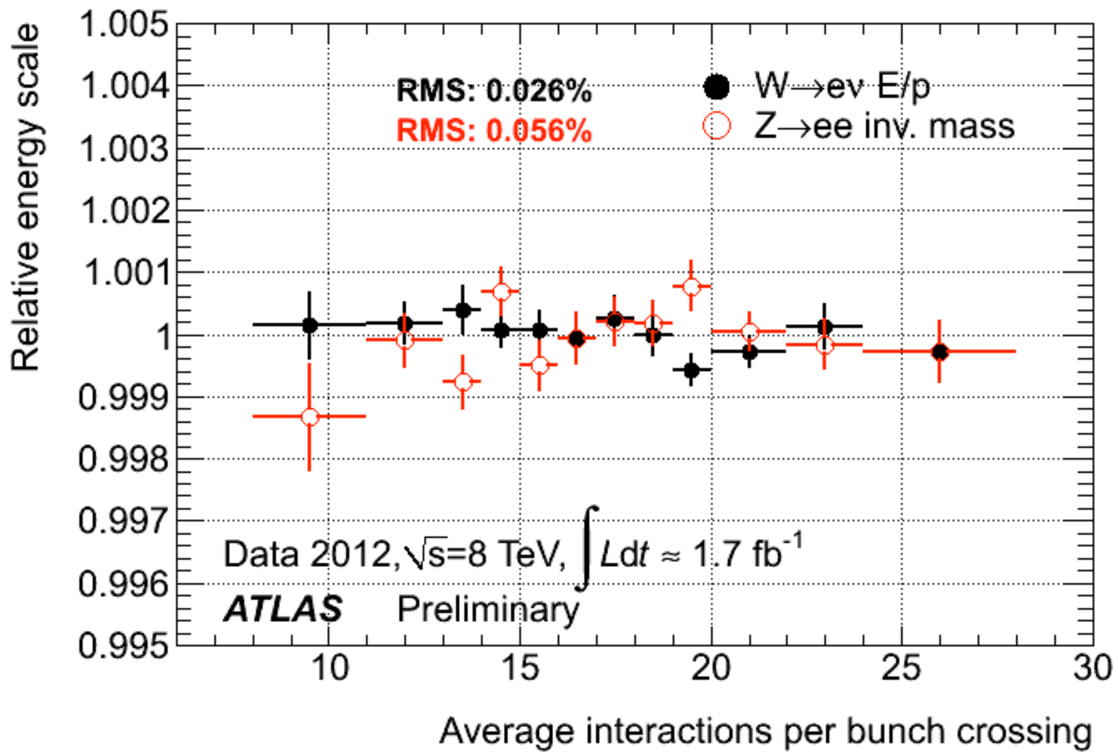


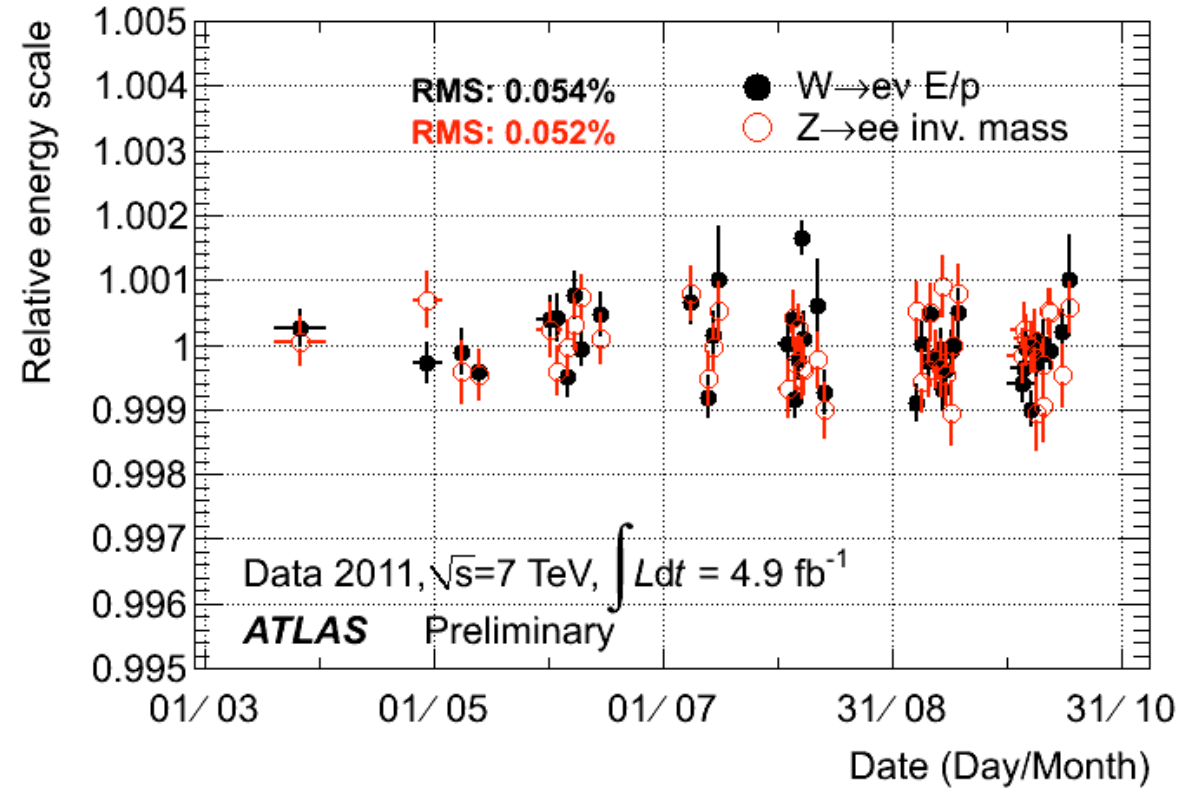
CMS Preliminary 2011, 7TeV
L = 4.98 fb⁻¹
ECAL barrel
Events / 1 GeV
M_ee (GeV/c²)

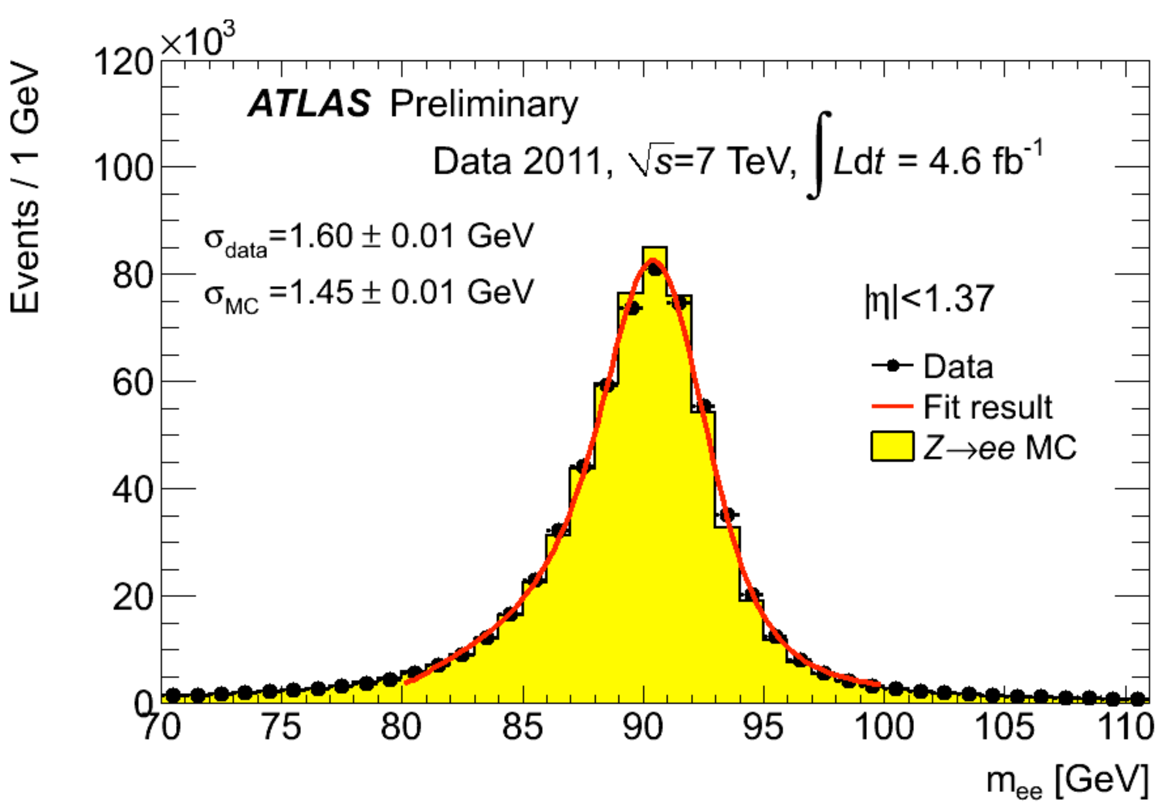


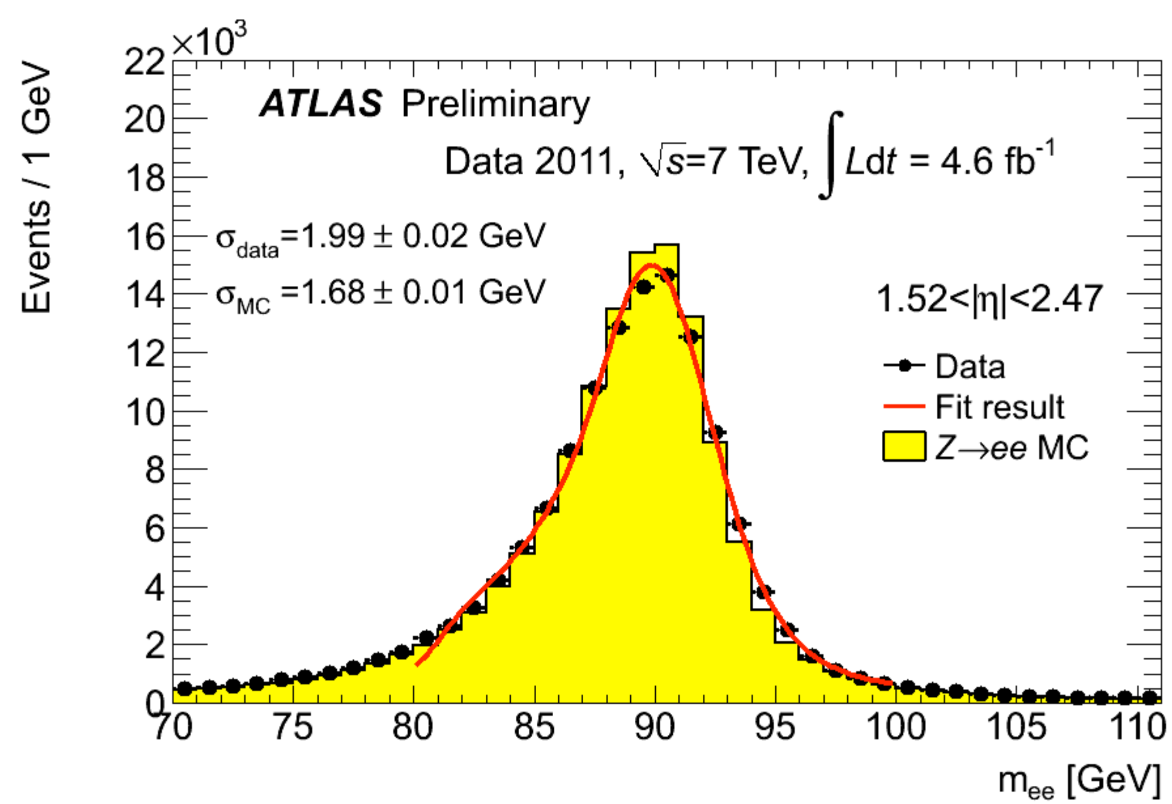
CMS Preliminary
√s=8 TeV
L=5.3 fb⁻¹
MC
MC smeared
data
Events/0.2 GeV
M_ee (GeV/c²)

ATLAS Ecal


Relative energy scale
RMS: 0.026%
RMS: 0.056%
W→eν E/p
Z→ee inv. mass
Data 2012, √s=8 TeV, ∫Ldt ≈ 1.7 fb-1
ATLAS Preliminary
Average interactions per bunch crossing


Relative energy scale
RMS: 0.054%
RMS: 0.052%
W→eν E/p
Z→ee inv. mass
Data 2011, √s=7 TeV, ∫Ldt = 4.9 fb-1
ATLAS Preliminary
Date (Day/Month)

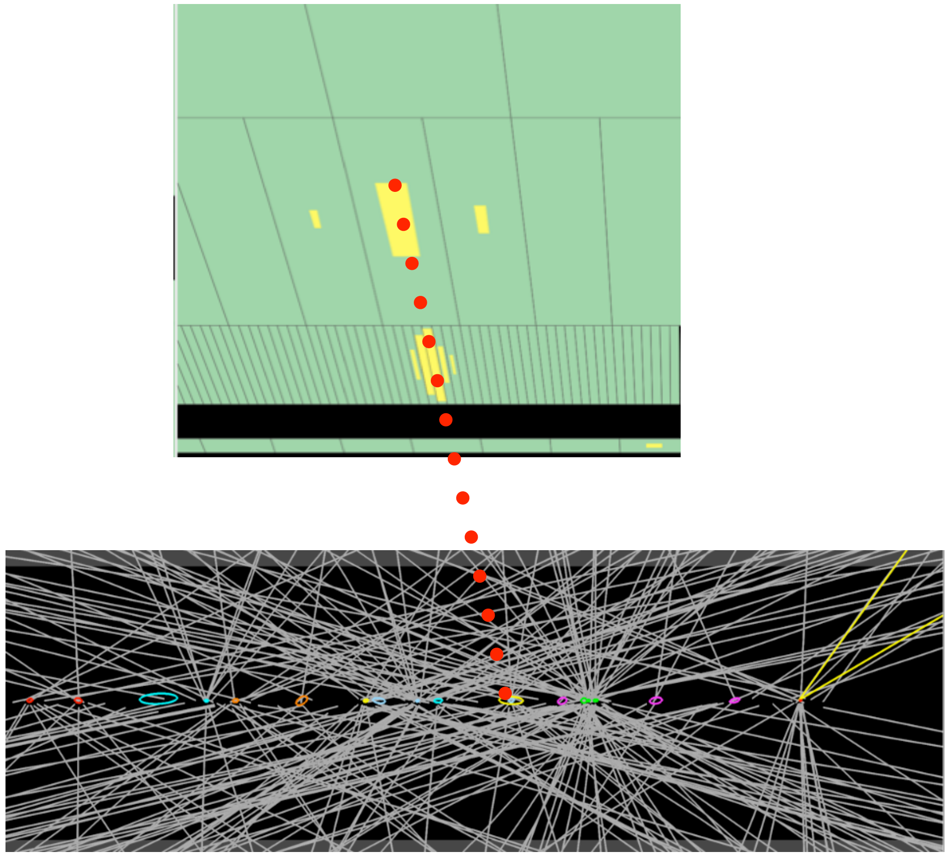

Events / 1 GeV
ATLAS Preliminary
Data 2011, √s=7 TeV, ∫Ldt = 4.6 fb-1
σdata=1.60 ± 0.01 GeV
σMC =1.45 ± 0.01 GeV
|η|<1.37
Data
Fit result
Z→ee MC
mee [GeV]

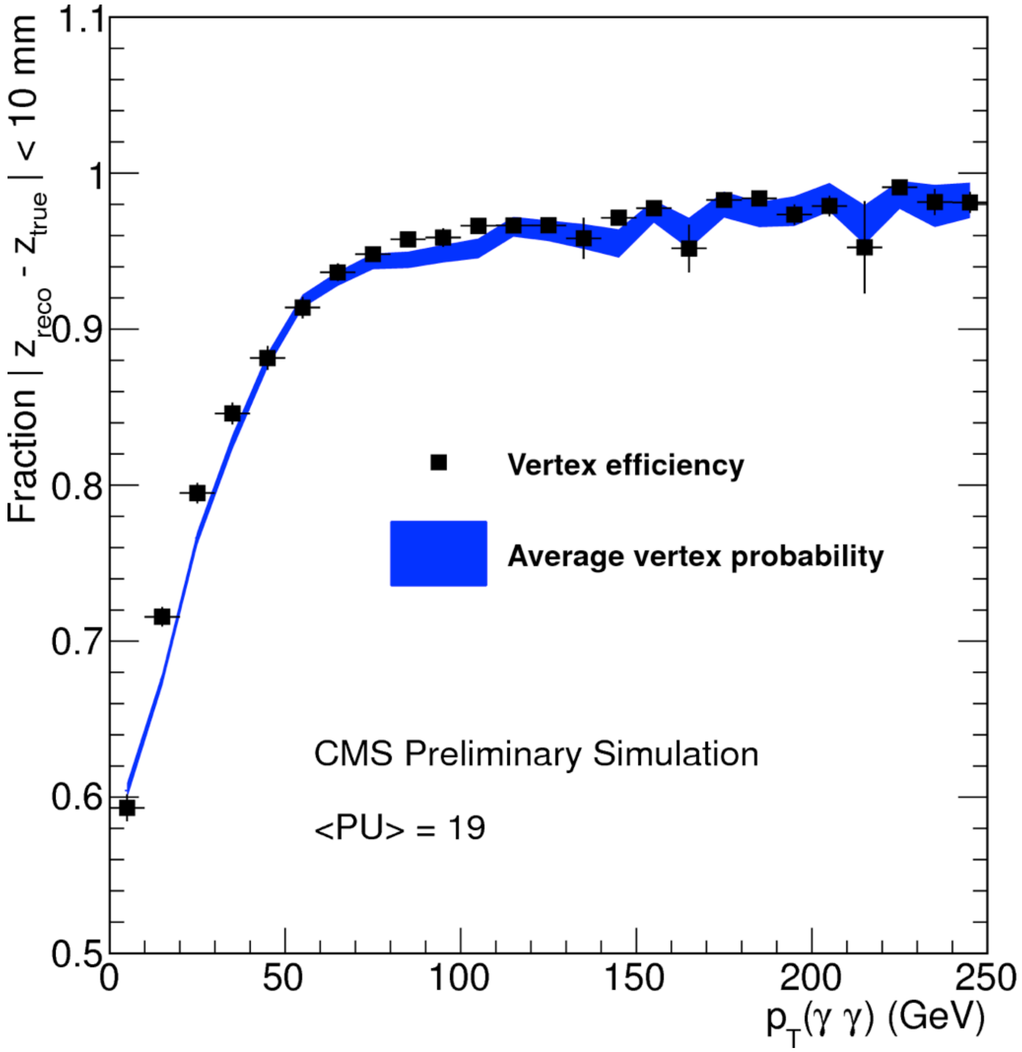

Events / 1 GeV
ATLAS Preliminary
Data 2011, √s=7 TeV, ∫Ldt = 4.6 fb-1
σdata=1.99 ± 0.02 GeV
σMC =1.68 ± 0.01 GeV
1.52<|η|<2.47
Data
Fit result
Z→ee MC
mee [GeV]

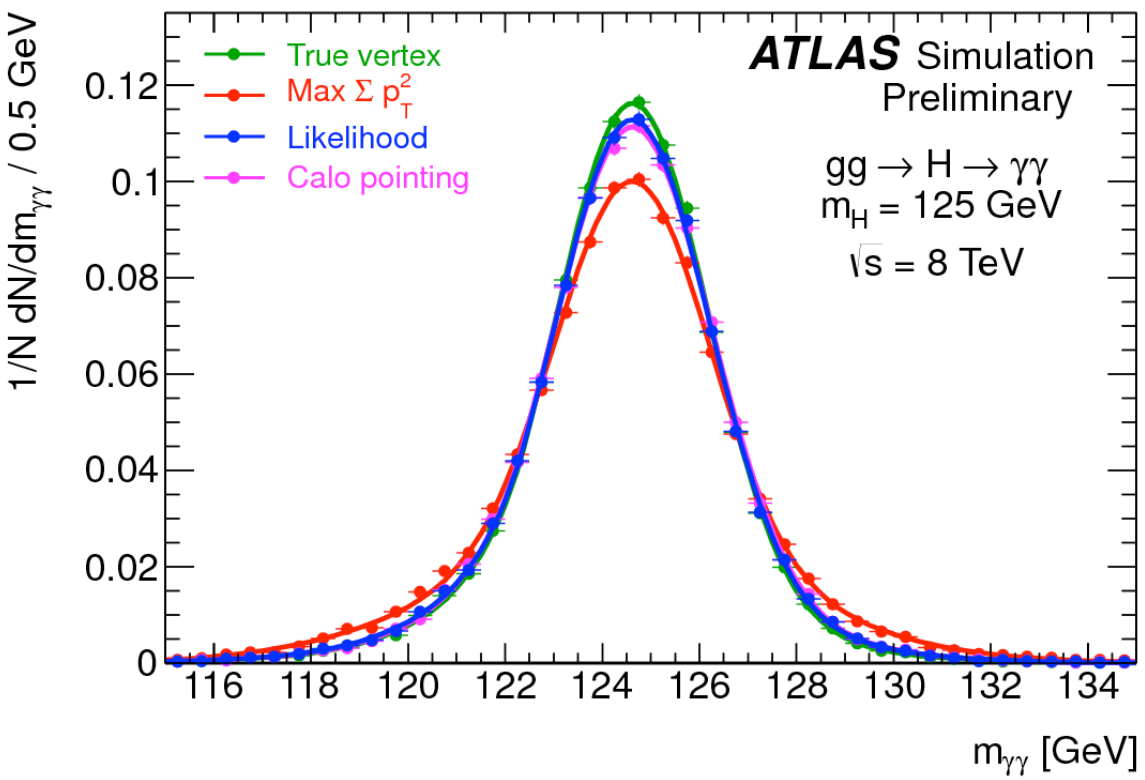
Vertex measurement:

ATLAS: Calorimeter «pointing» +tracking information

CMS : Tracking information (MVA)





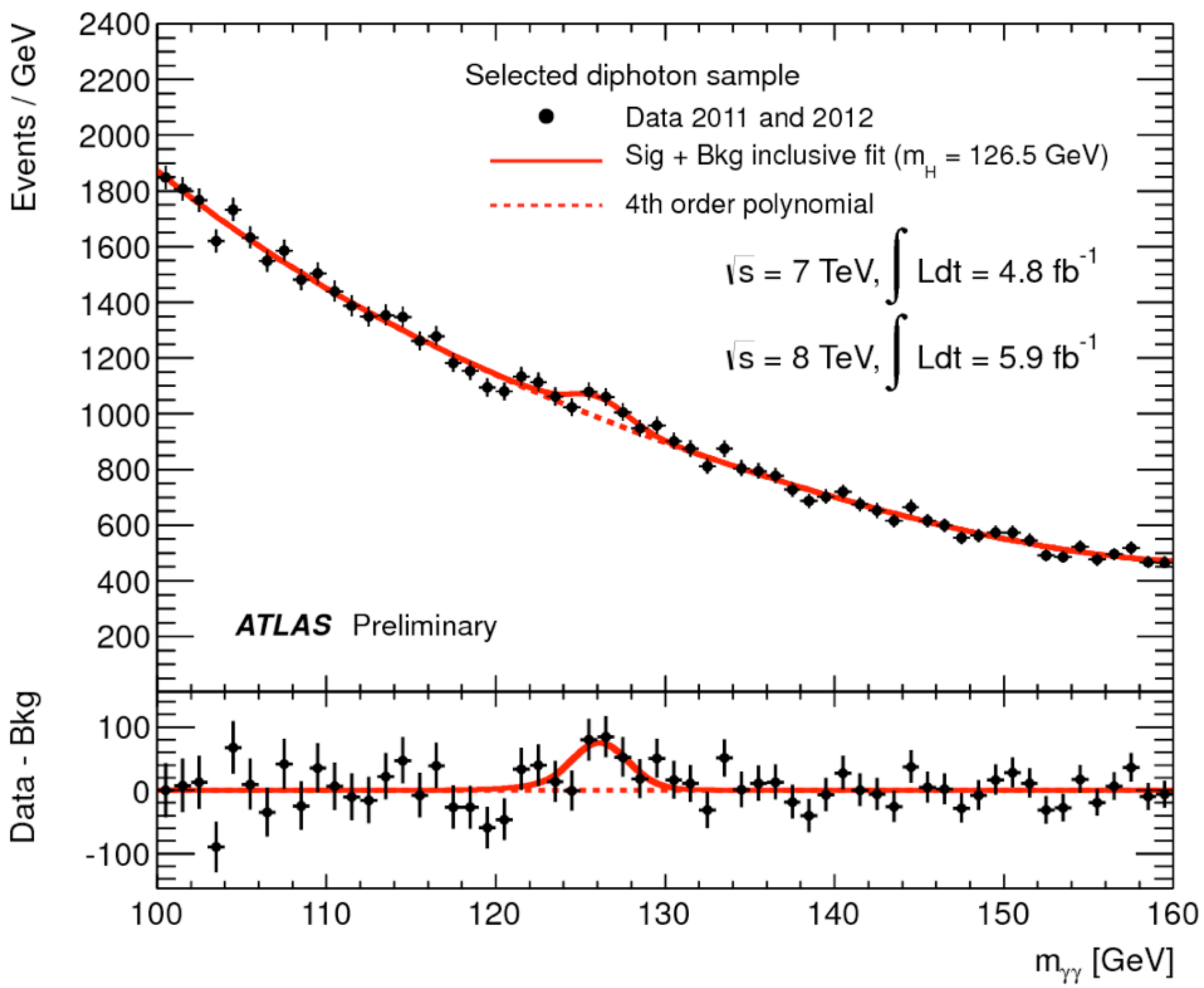


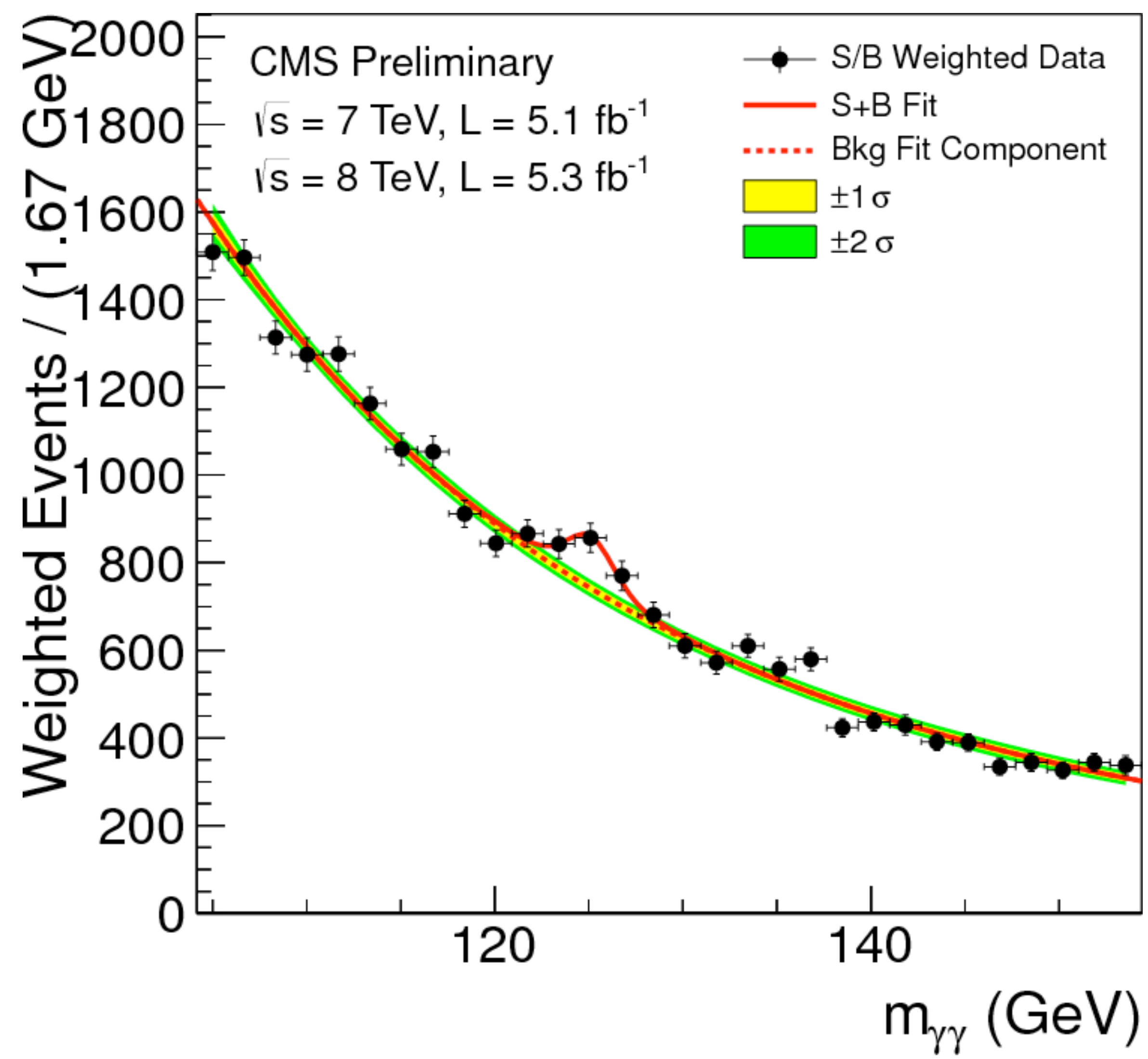
	ATLAS (8TeV, 5.9 fb-1)	CMS (8 TeV, 5.3 fb-1)
Photon identification	Cuts based (NN for 7 TeV sample)	MVA based
Event selection	Two «tight» photons + Pt>40,30 S= 19 events/fb-1, B=600/GeV/fb-1	Loose preselection + Diphoton MVA cut + Pt cuts S=19 events/fb-1, B=440/GeV/fb-1
Photon energy	MC based corrections, E-scale from Z	MVA based calibration, E-scale from Z
Primary vertex	Likelihood (calorimeter pointing + tracking)	MVA based on tracking information + pt balance
Mass resolution (FWMH/2.35)	~1.64 GeV (1.4 GeV for best category)	~1.6 GeV (~1.2 GeV for best category)
Categories	«2 jet» + 9 categories based on eta/conversion	Two «2 jets» +4 categories based on diphoton MVA (photon Id MVA, Mass resolution, kinematics)

~25-30 % improvement in sensitivity from categories

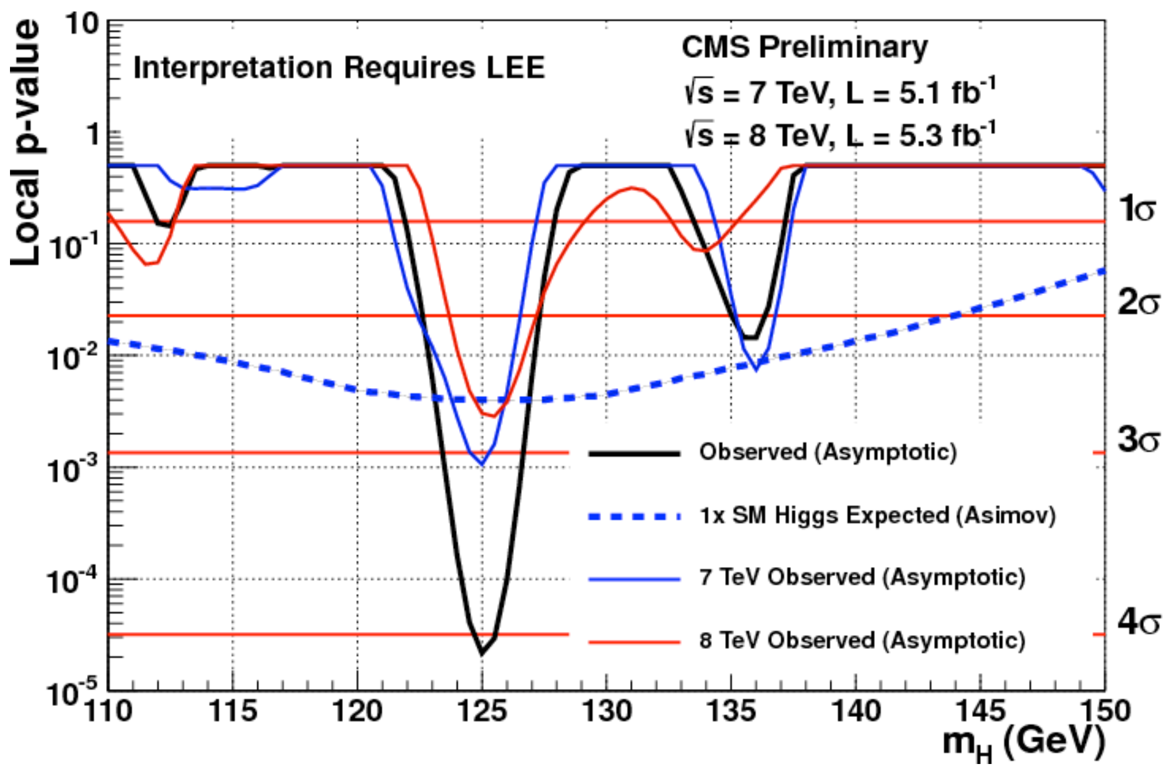
Diphoton mass distribution

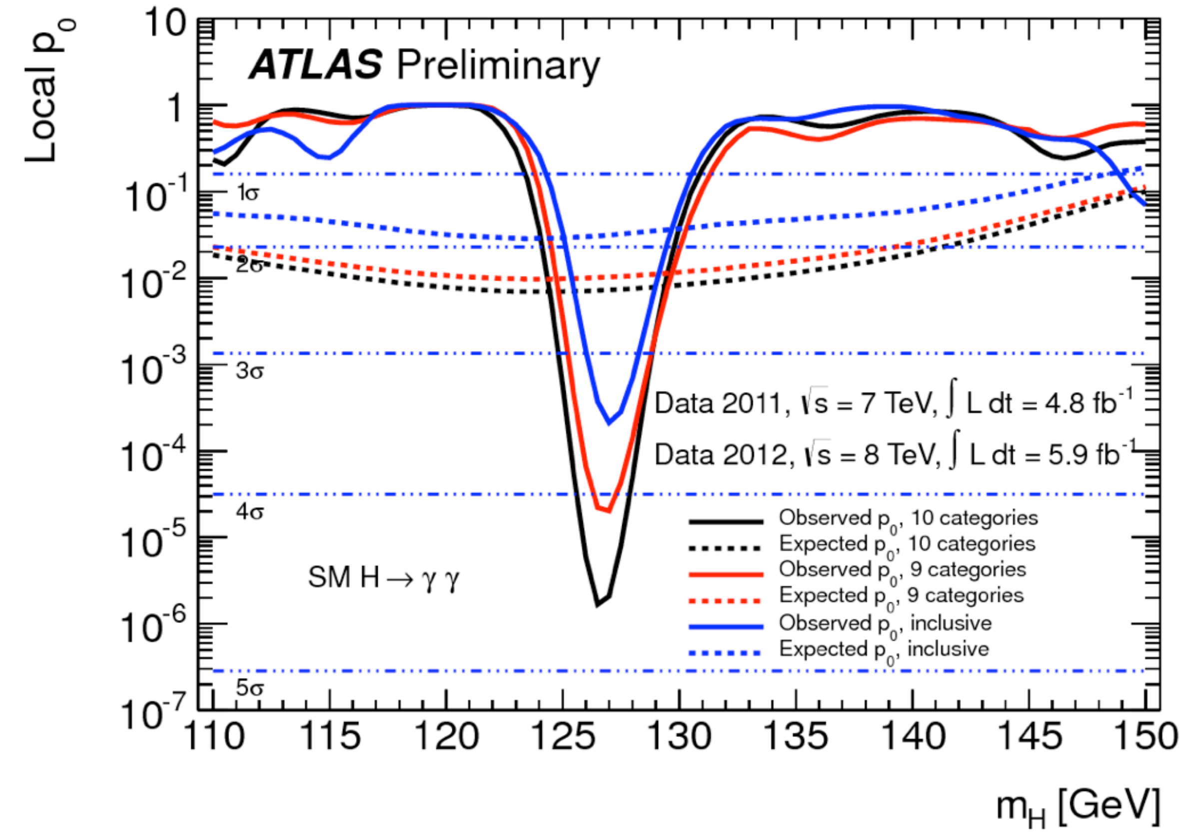
«inclusive»: All categories together
CMS: events are weighted by S/B, more typical of sensitivity after the exact analysis per category



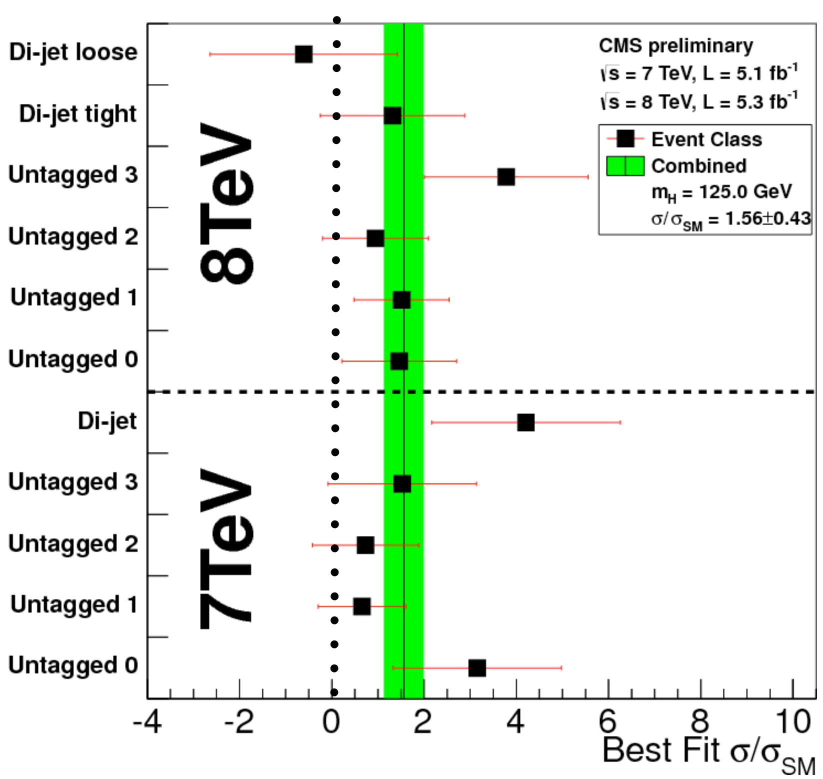


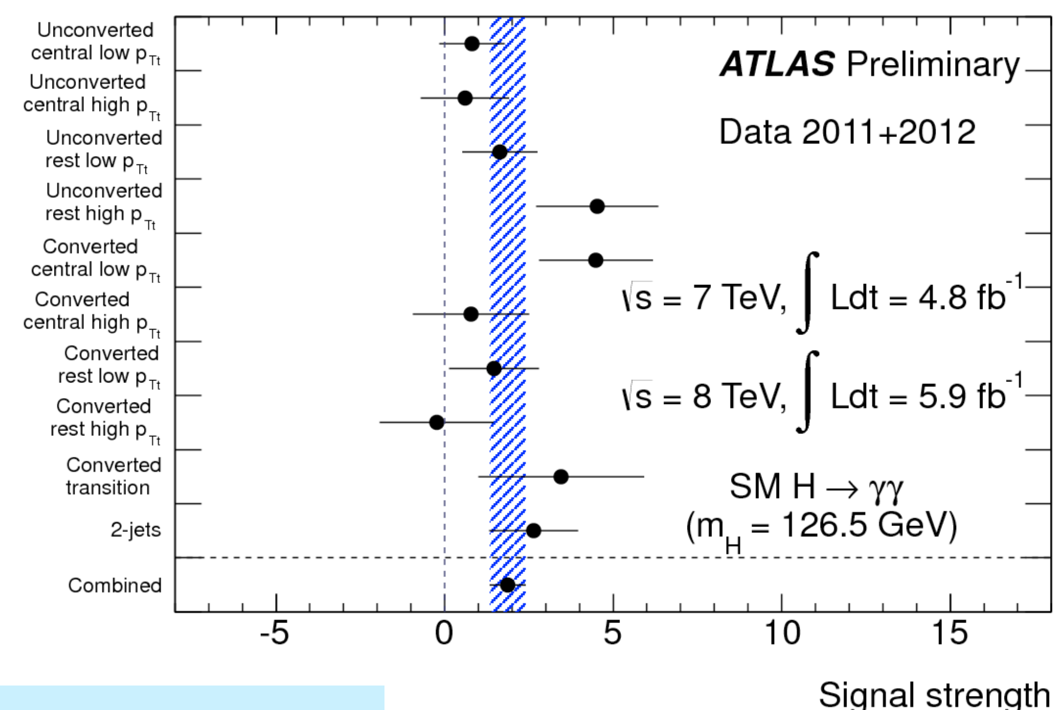
«p0» of background-only hypothesis





Signal rate normalised to expected SM rate





Caveat : No category is pure in only one production mode

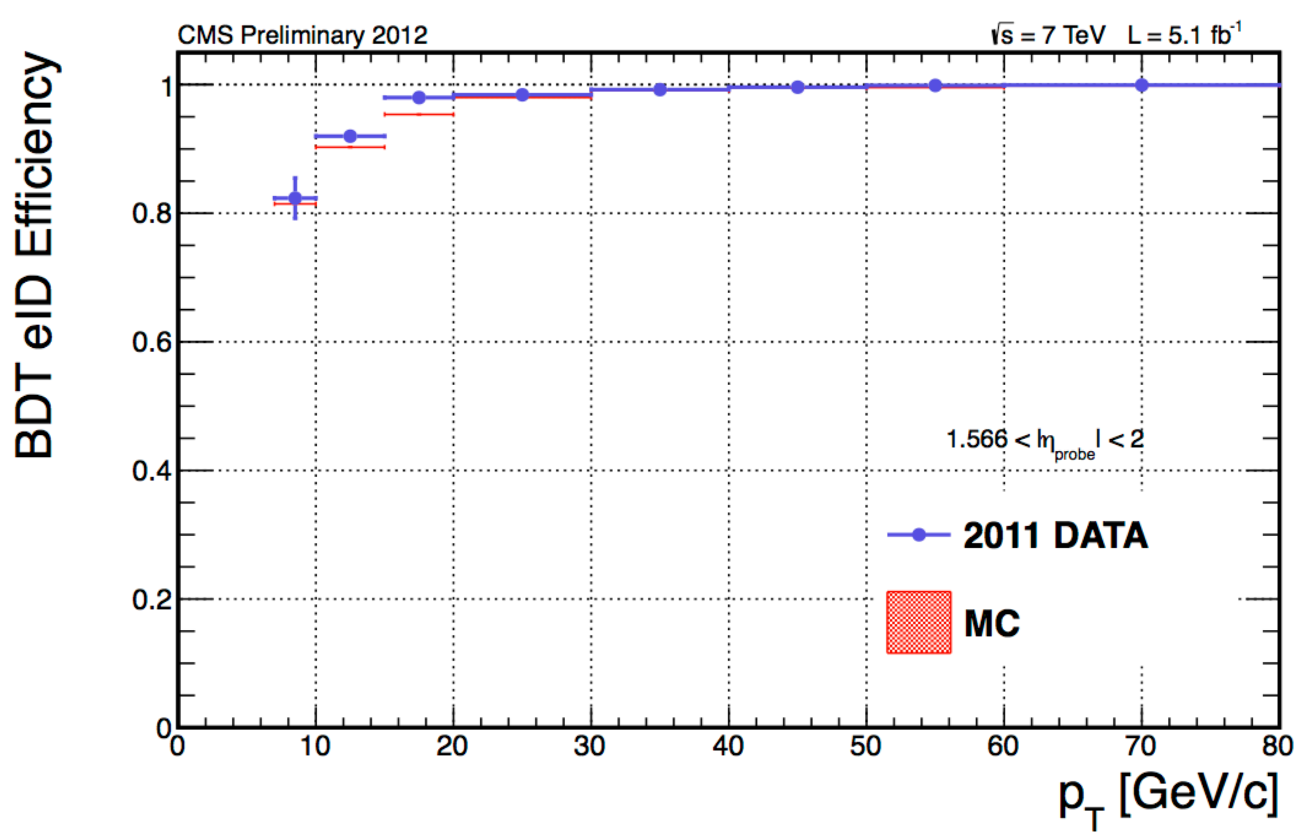
$H \rightarrow ZZ(*) \rightarrow 4l$

Analysis significantly improved compared to last winter

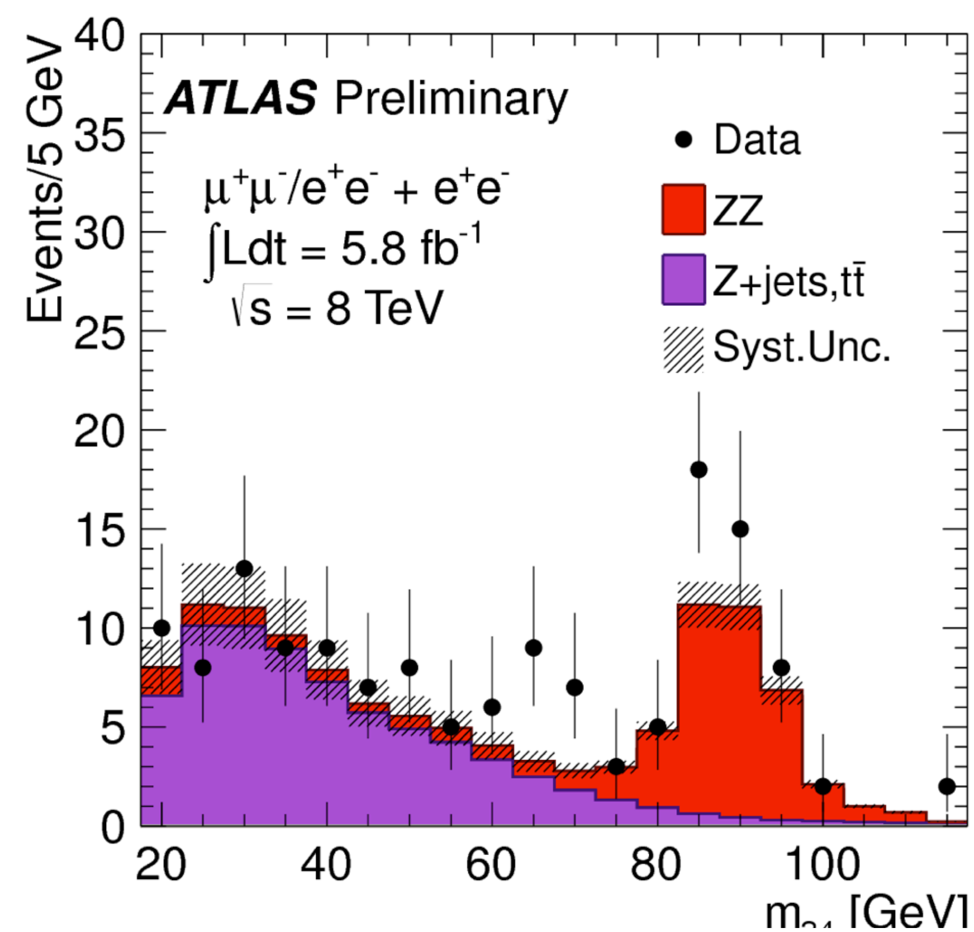
S.Baffioni
L.Flores
M.Xiao
S.Chhibra

«Clean» channel
Good mass resolution
Low rate at low mass => use low Pt leptons (e,mu down to 7,5 GeV)
Electron reconstruction optimised to account for material effects before calorimeter
Irreducible background from ZZ(*)
Reducible background from ttbar and Z+bbbar/jets => reduced by isolation and impact parameter cuts
CMS also includes 2l 2 taus, only for high mass

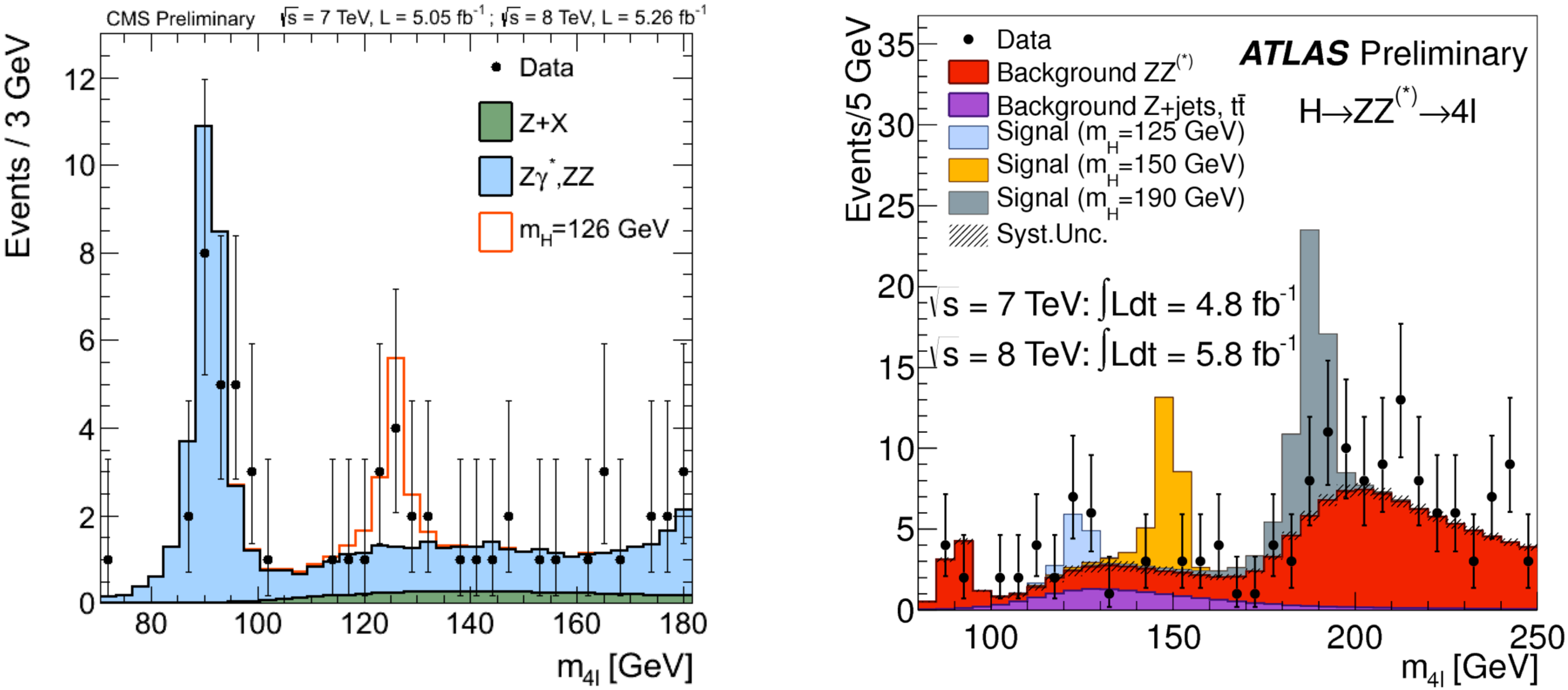
Control of electron identification efficiency (tag and probe)



Control of reducible background: relax isolation and impact parameter cuts



Invariant mass distributions (7+8 TeV samples)

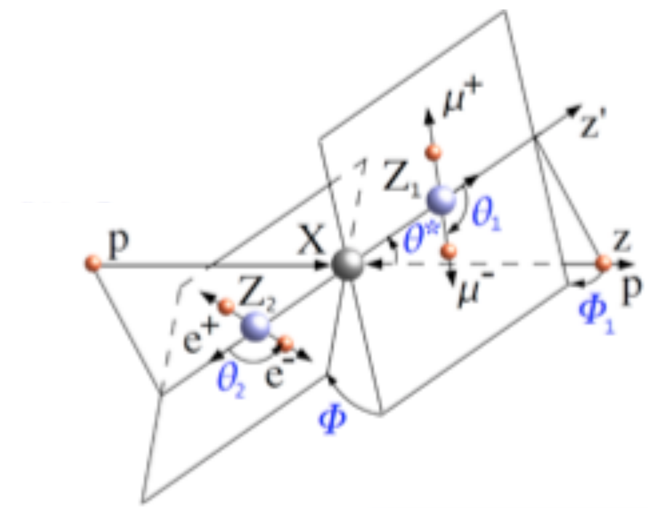


Somewhat better S/B in CMS
(for instance lower reducible background)
(also 7 TeV ATLAS analysis does not have latest improvements in electron reconstruction)

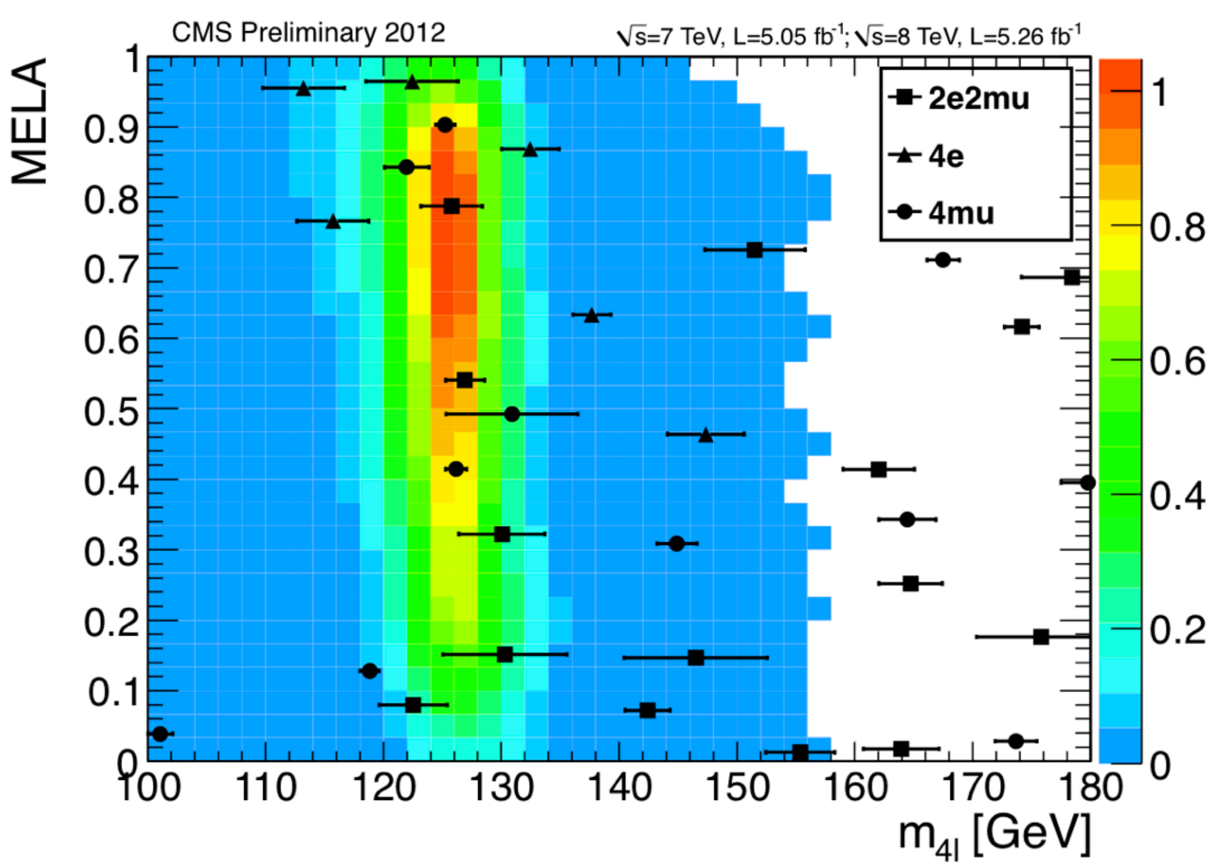
~25% more ZZ candidates in data than MC in ATLAS, not in CMS ?

Improving S/B using angular distributions

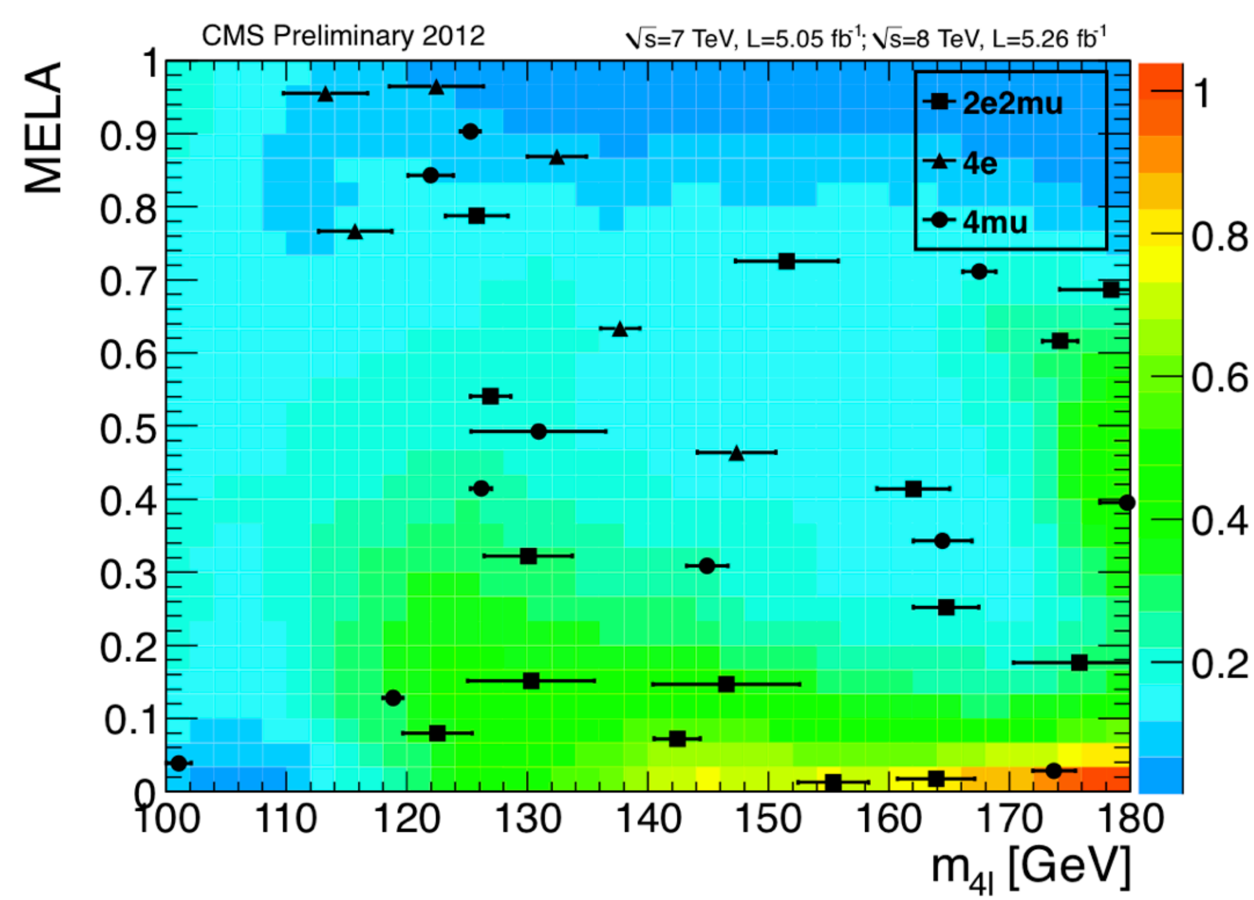
MELA = P(sig)/(P(sig)+P(bkg))
P = Matrix element(5 angles, M1,M2)



Data vs Signal

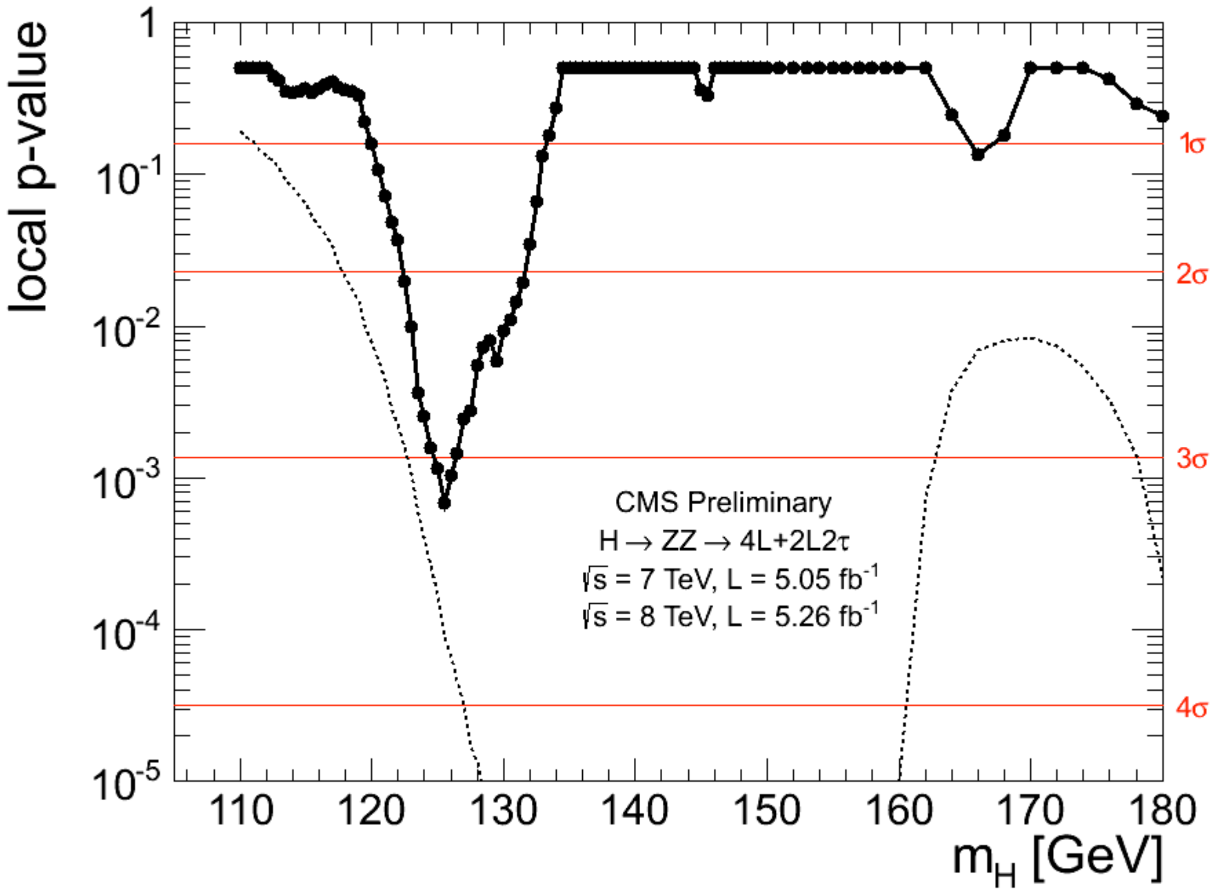


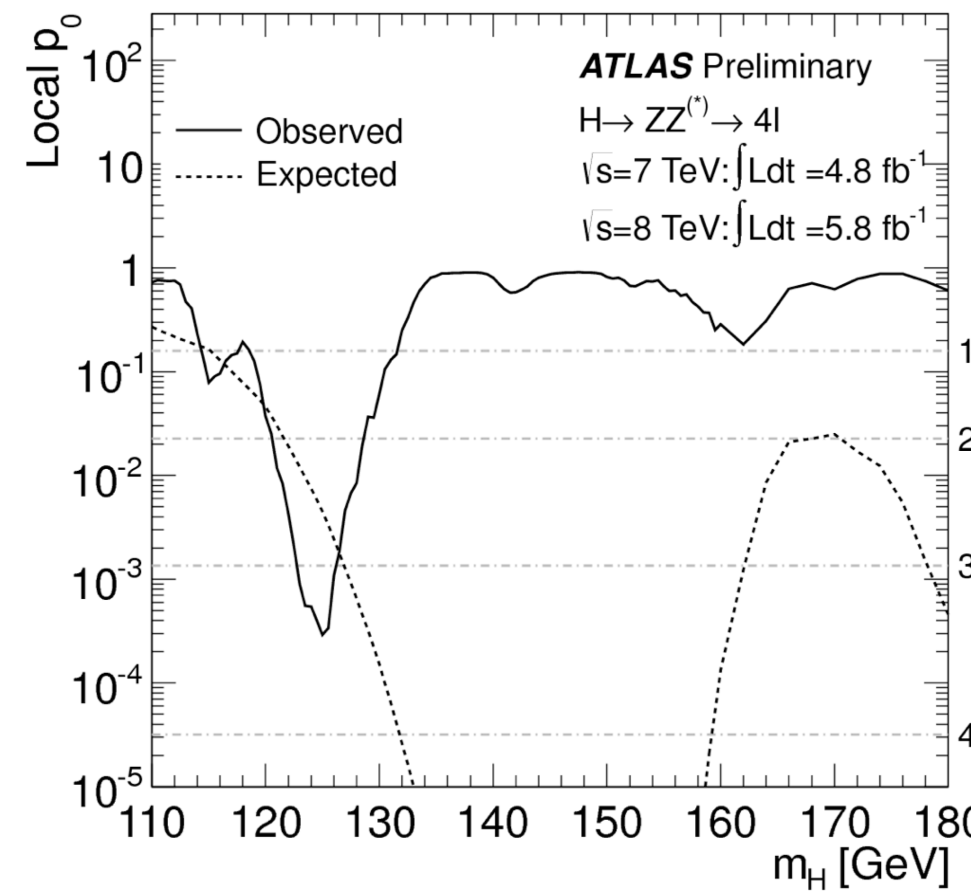
Data vs Bkg



«p0» of background-only hypothesis

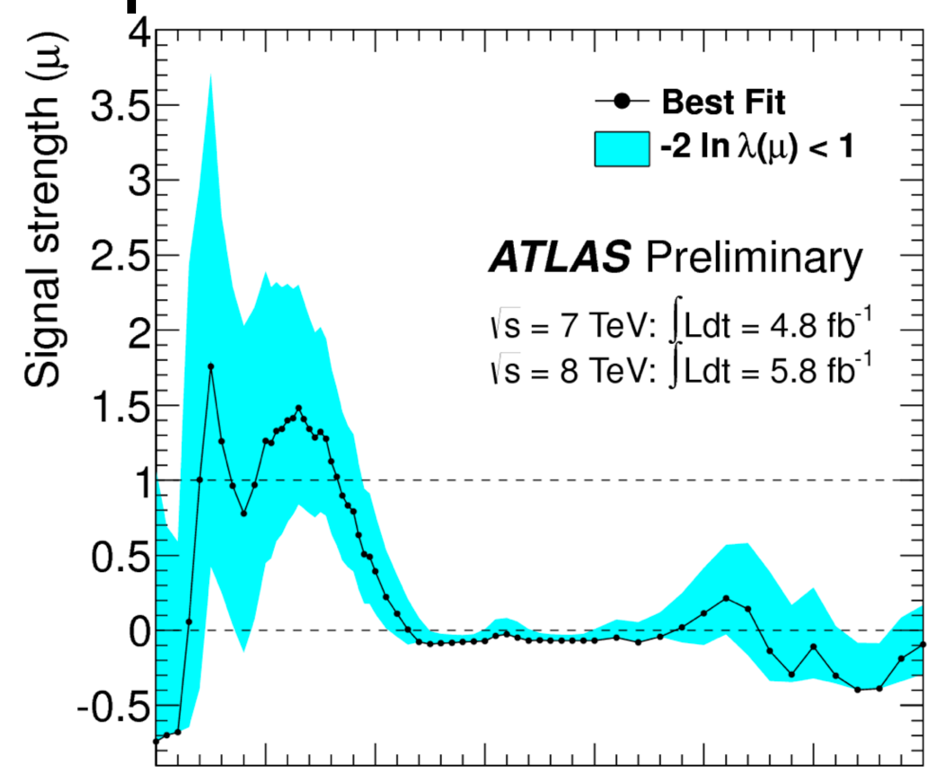
CMS better sensitivity from use of angular variables (20%) + better S/B at low mass (~20%)



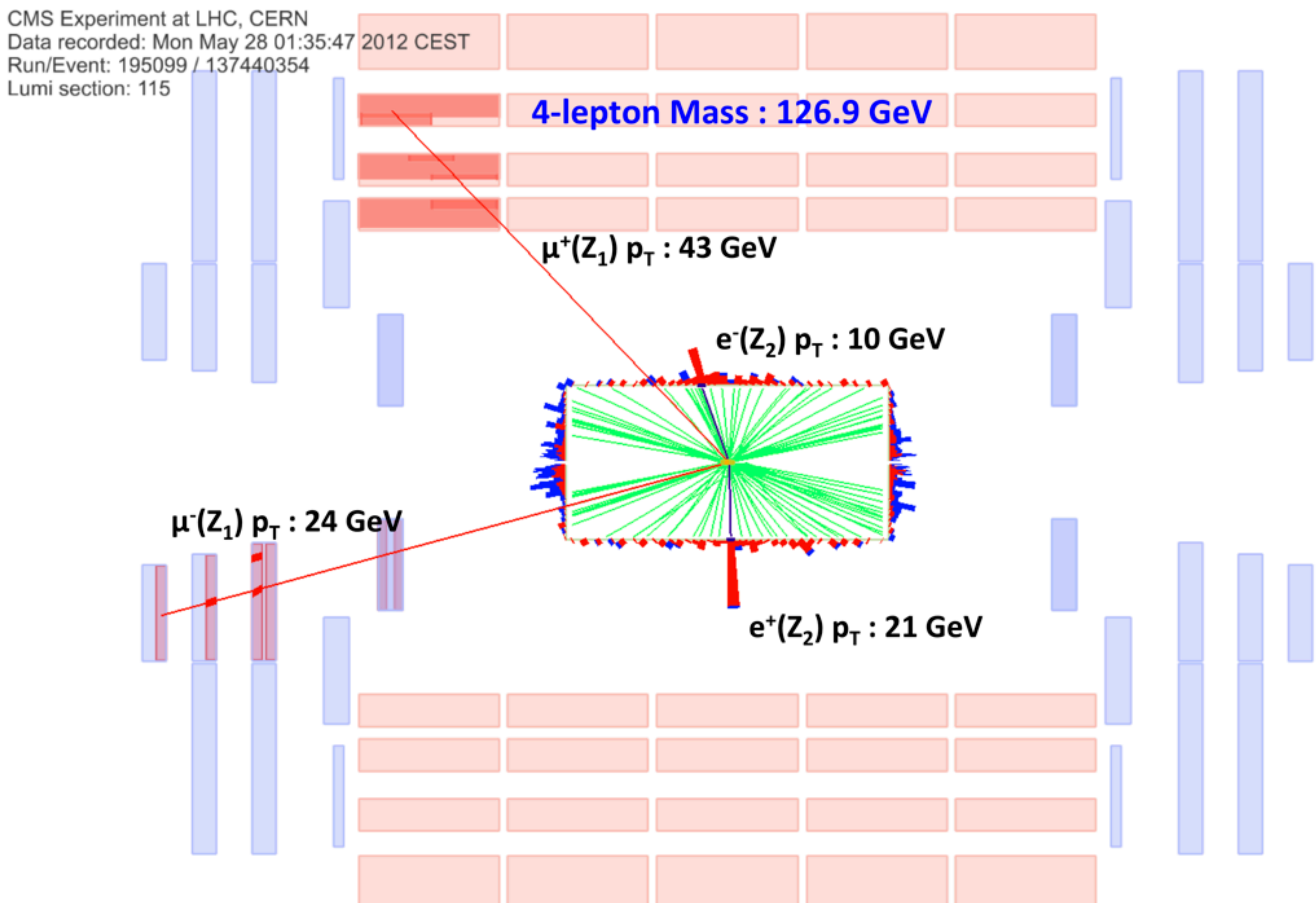


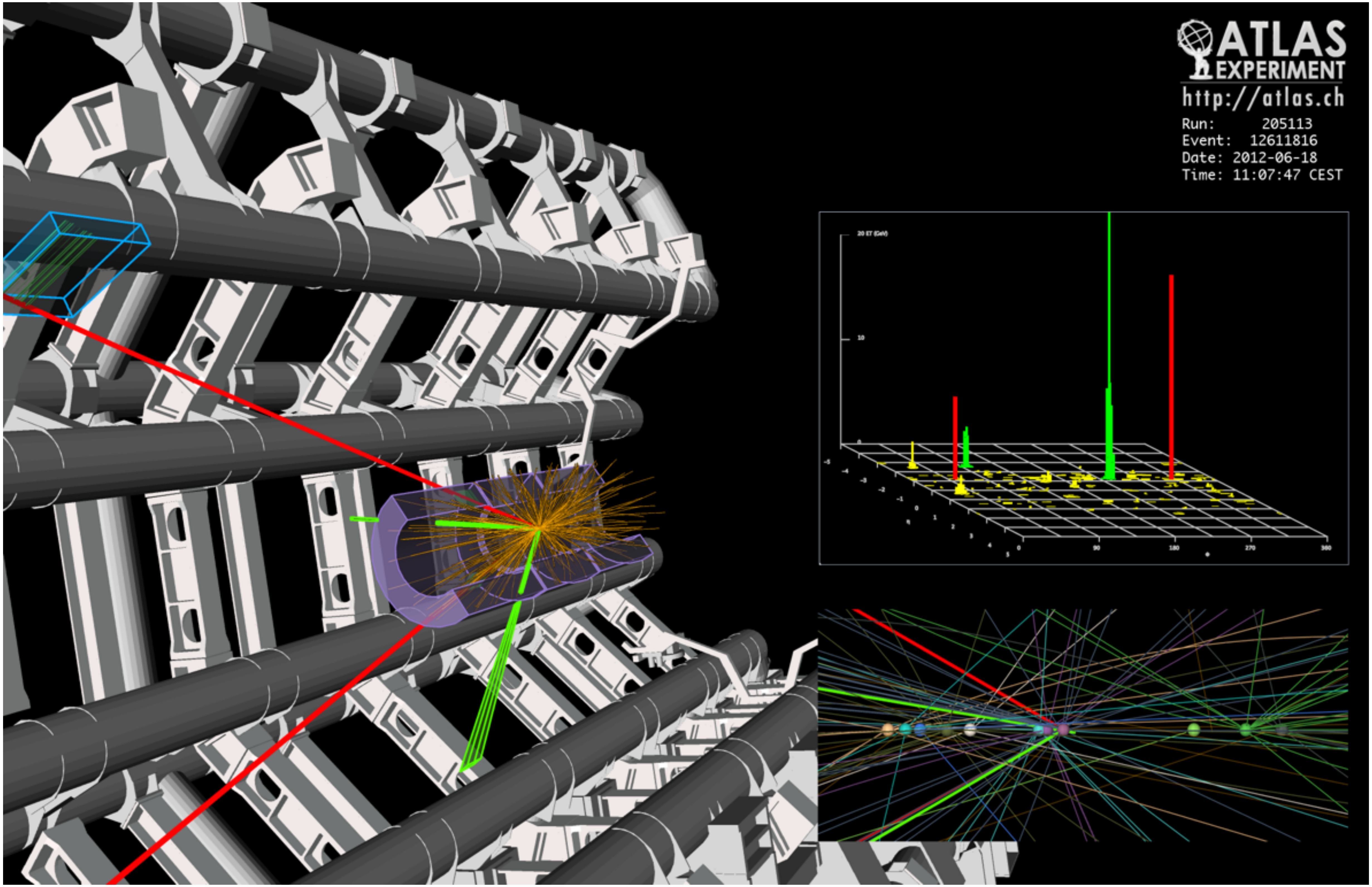
Signal rate normalised to expected SM rate

mu=0.7+0.4 (CMS)
Mass=125.6+-1.2 GeV



A likely 125 GeV boson event



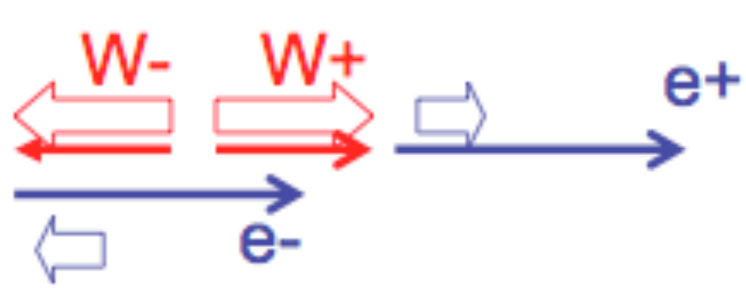

ATLAS EXPERIMENT
http://atlas.ch
Run: 205113
Event: 12611816
Date: 2012-06-18
Time: 11:07:47 CEST

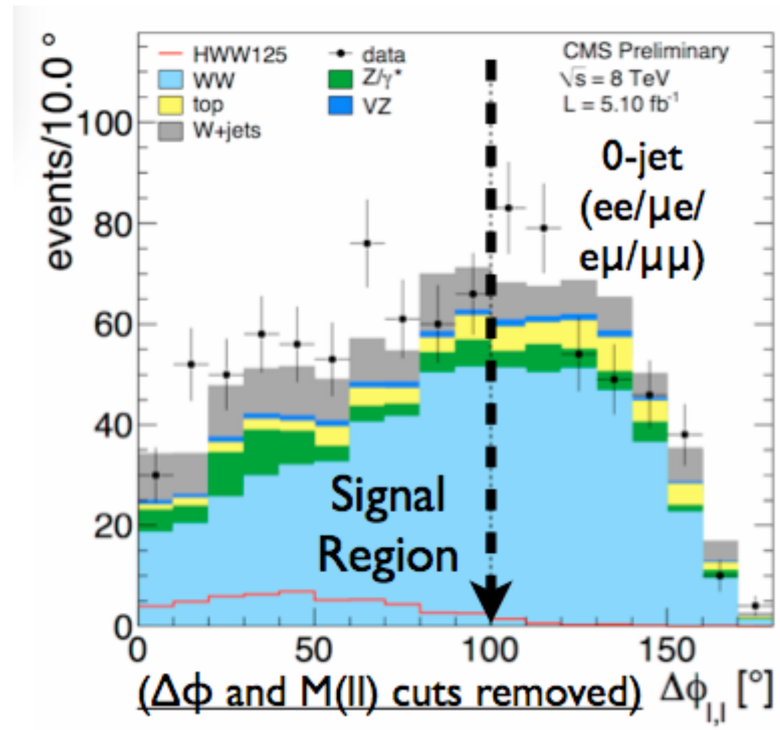
H→WW(*)→ leptons

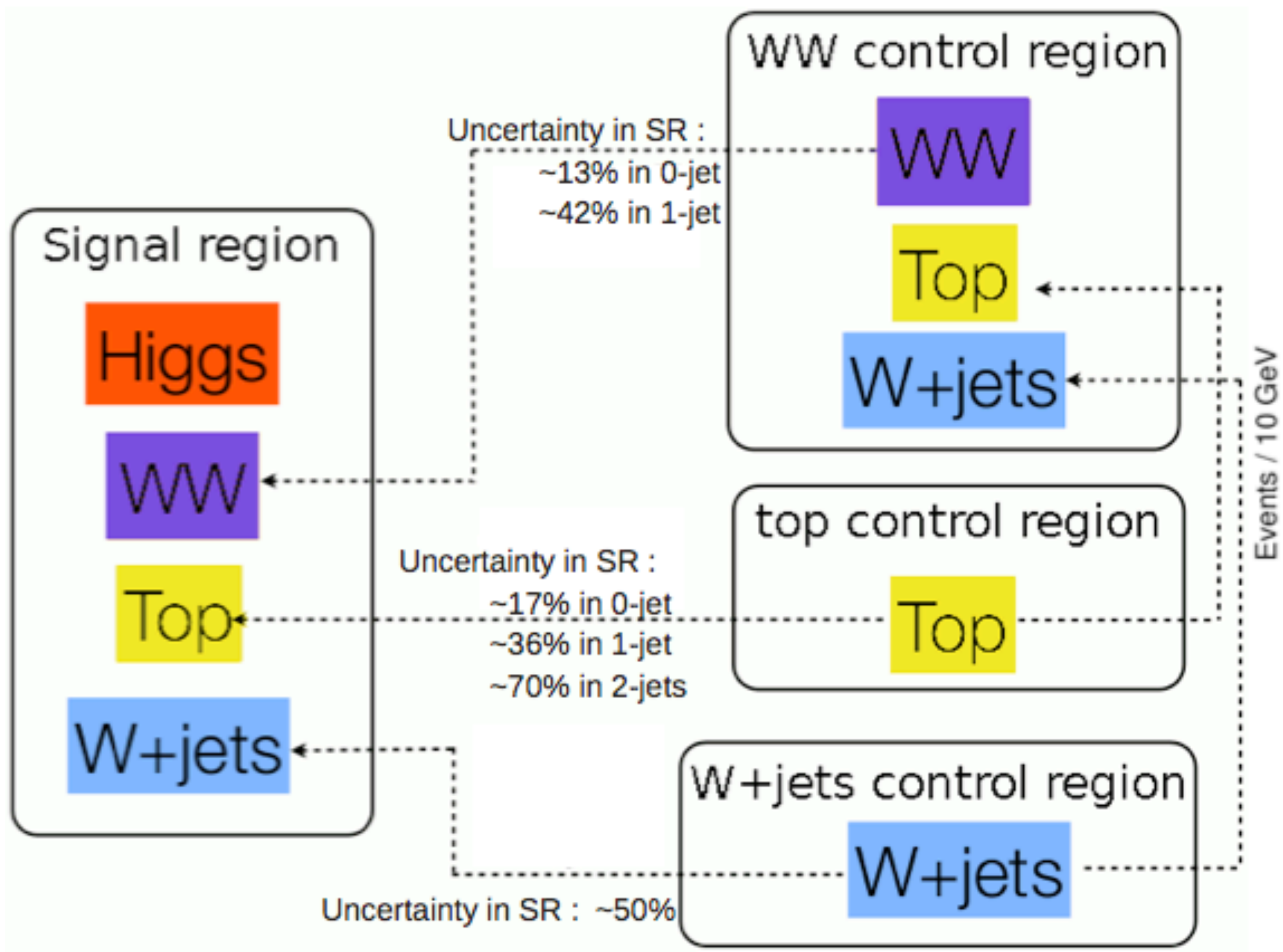
O.Arnaez

D.Evans

- Larger rate than ZZ(*)
- Look at leptonic decays (e,mu)
- 2 neutrinos => no accurate mass information
- Counting experiments: Background understanding is critical => Control regions
- Analysis optimised for spin 0: Cut on DeltaPhi(ll) + many kinematical variables
- Drell-Yan rejection in ee and mumu difficult at large pileup (=> ATLAS only use e-mu for the first analysis)
- Split analysis in jet bins
  - 0 jet and 1 jet mostly targeted for gluon fusion, continuum WW is main background in 0 jet, WW+top in 1 jet
  - 2 jets targeted for VBF signature, top is main background





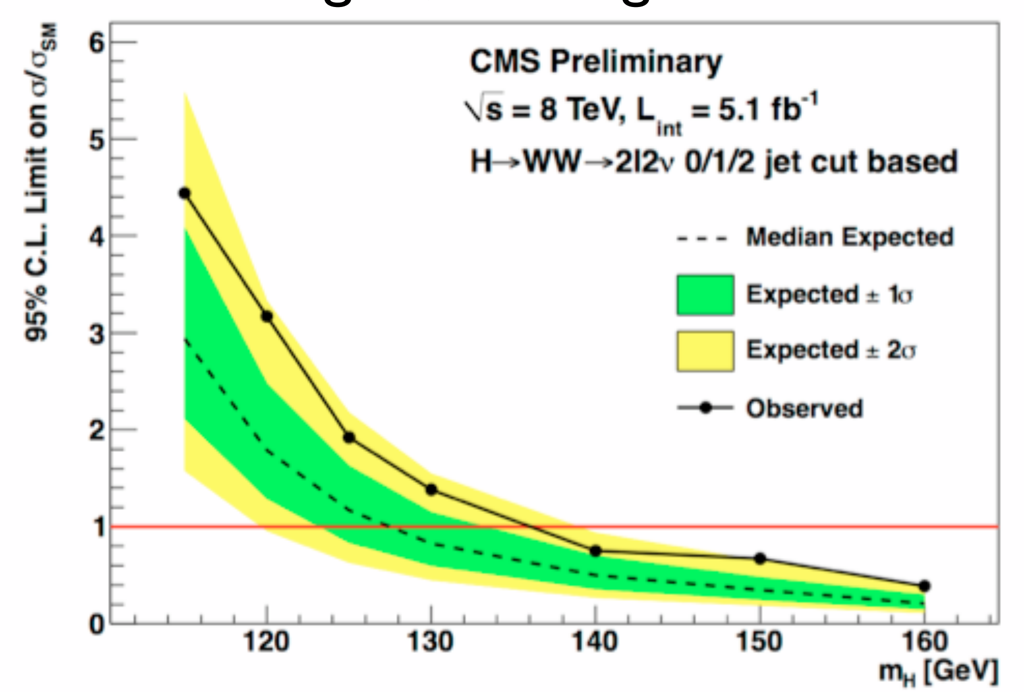


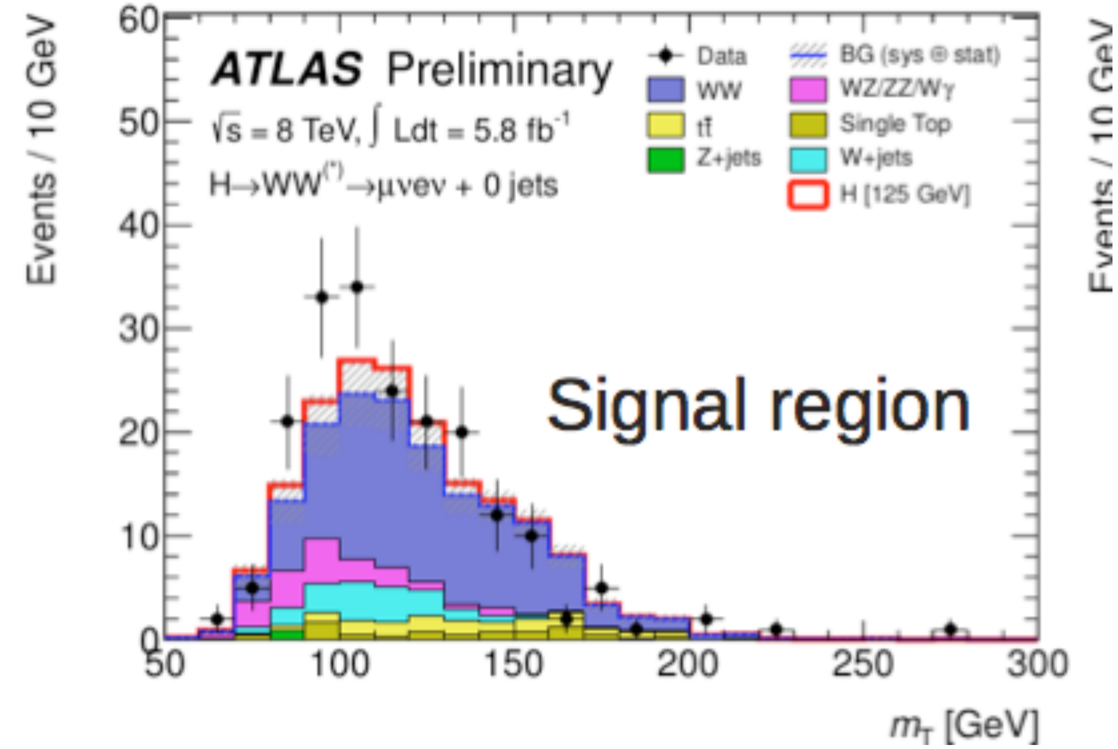
NEW

ATLAS 8 TeV analysis

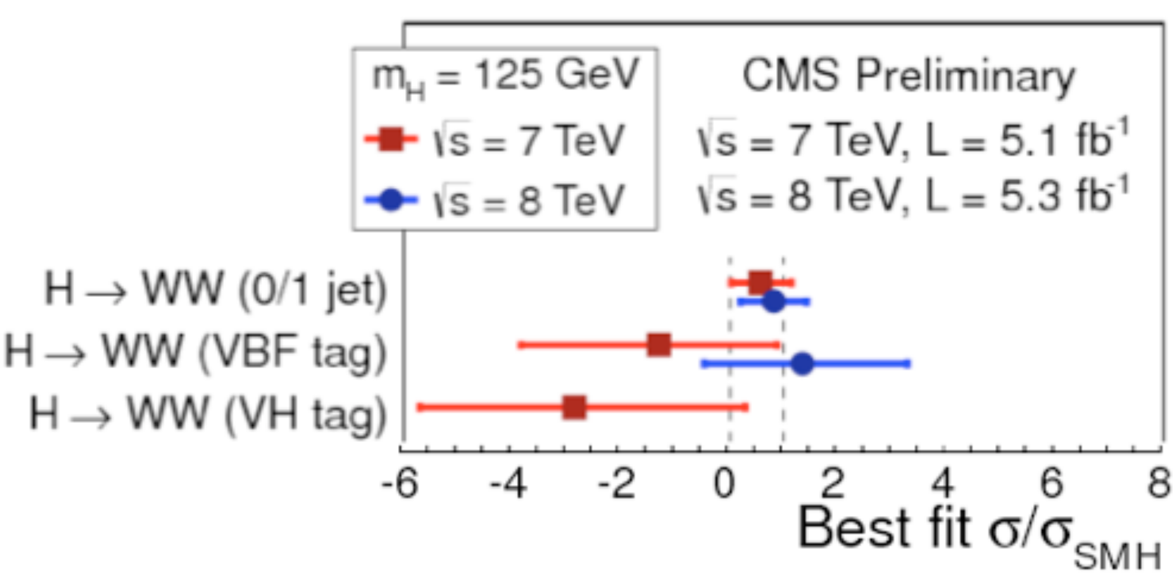
	Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	$Z/\gamma^* +$ jets	$W +$ jets	Total Bkg.	Obs.
$H+0$-jet	20 ± 4	101 ± 13	12 ± 3	8 ± 2	3.4 ± 1.5	1.9 ± 1.3	15 ± 7	142 ± 16	185
$H+1$-jet	5 ± 2	12 ± 5	1.9 ± 1.1	6 ± 2	3.7 ± 1.6	0.1 ± 0.1	2 ± 1	26 ± 6	38
$H+2$-jet	0.34 ± 0.07	0.10 ± 0.14	0.10 ± 0.10	0.15 ± 0.10	-	-	-	0.35 ± 0.18	0

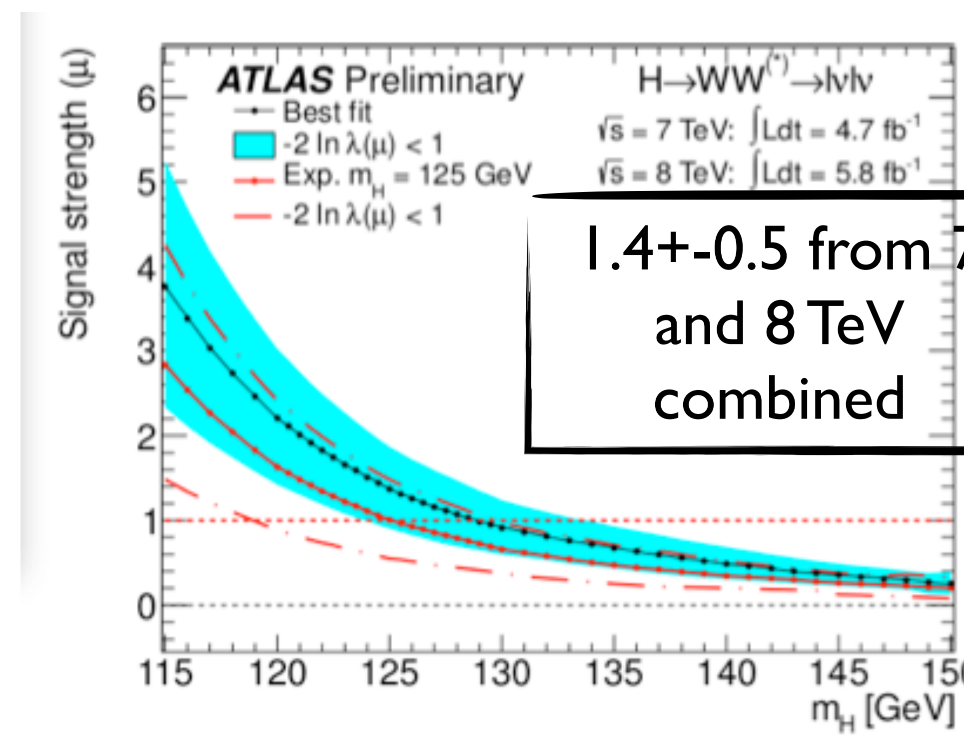
Limit worse than expected for bkg only, consistent with 125 GeV signal, ~1.5 sigma effect





~2.8 sigma excess for combined 7 and 8 TeV





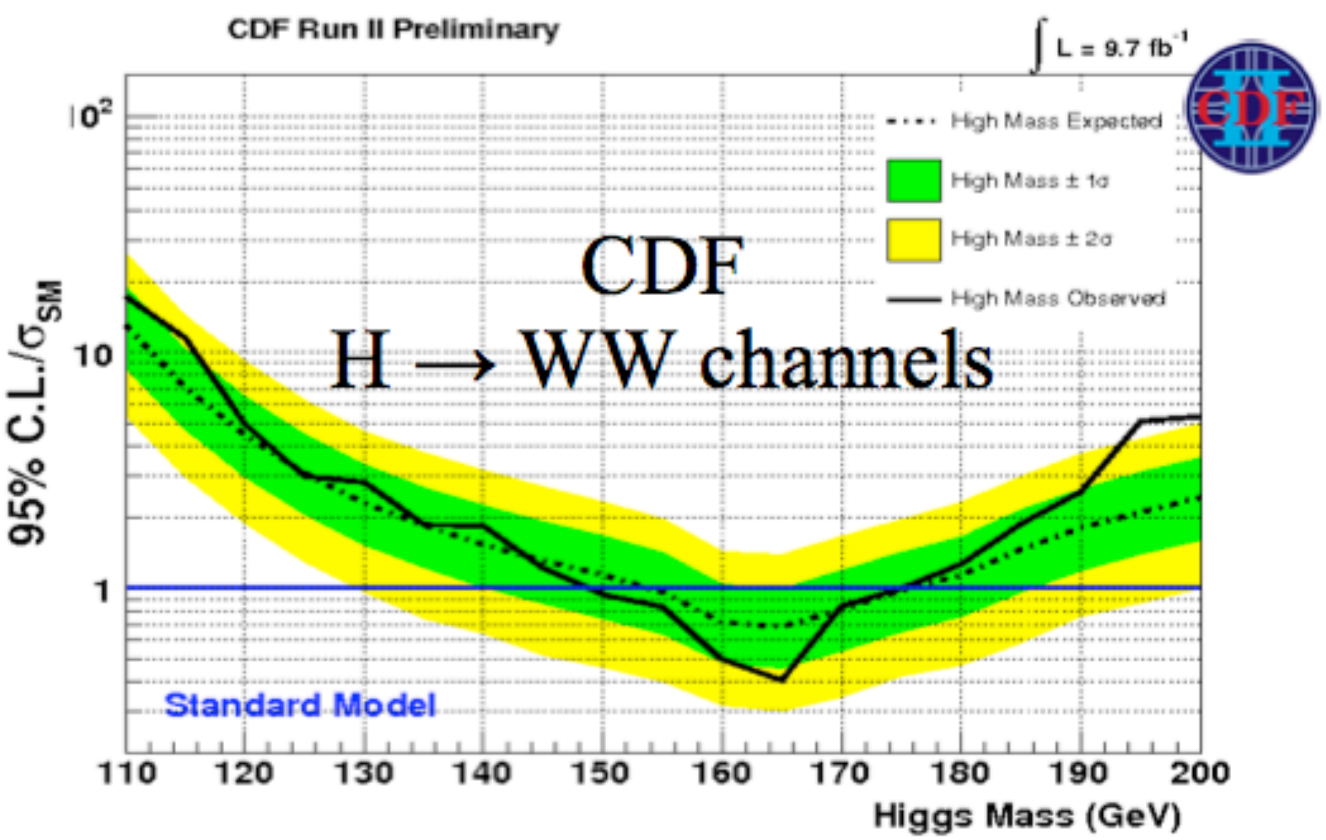
1.4+-0.5 from 7 and 8 TeV combined

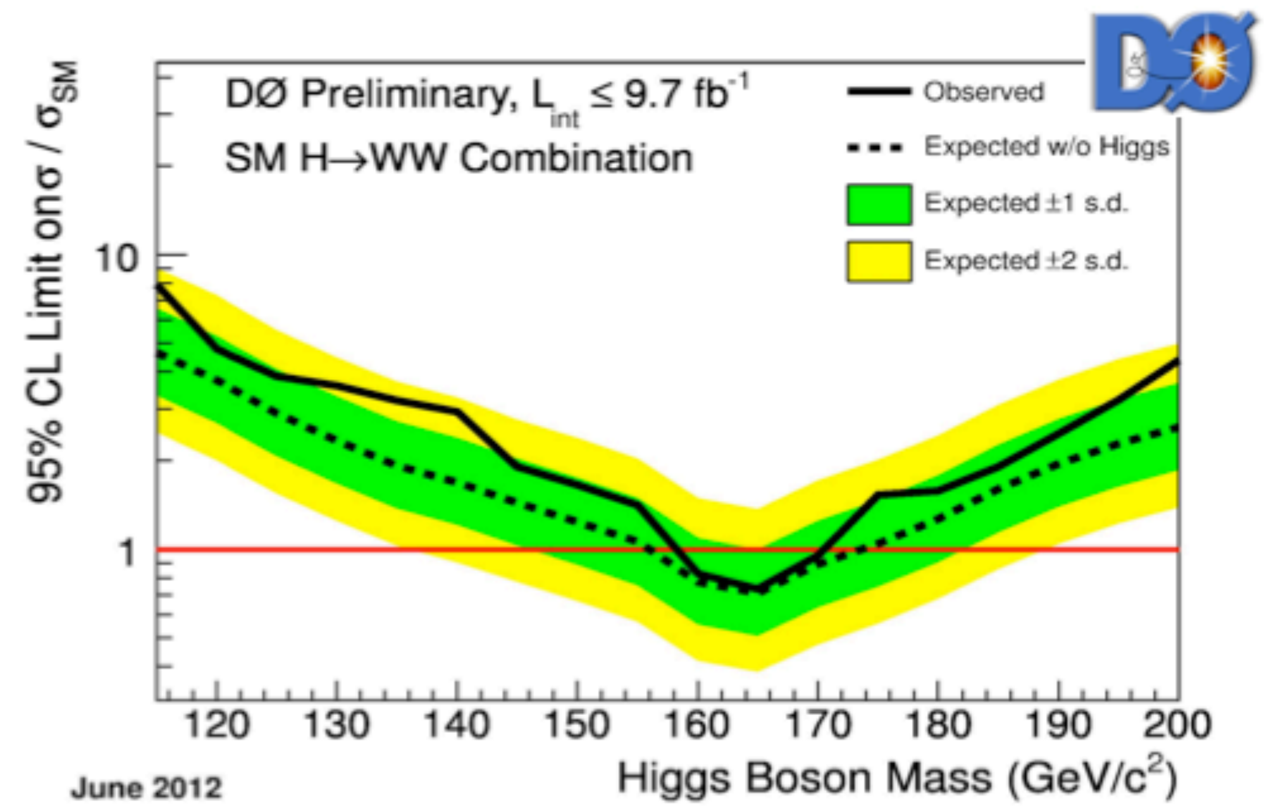
Background systematics likely to be critical for improvement of rate measurement
Not yet real sensitivity to SM in VBF production

At the Tevatron

Split analysis in many categories according to purity, ...
Use MVA to separate S and B (kinematics, event topology,..)
Validate measuring WW cross-section with same methods

B.Tuchming





Consistent with B only and S(125 GeV)+B, ~1 sigma excess in D0

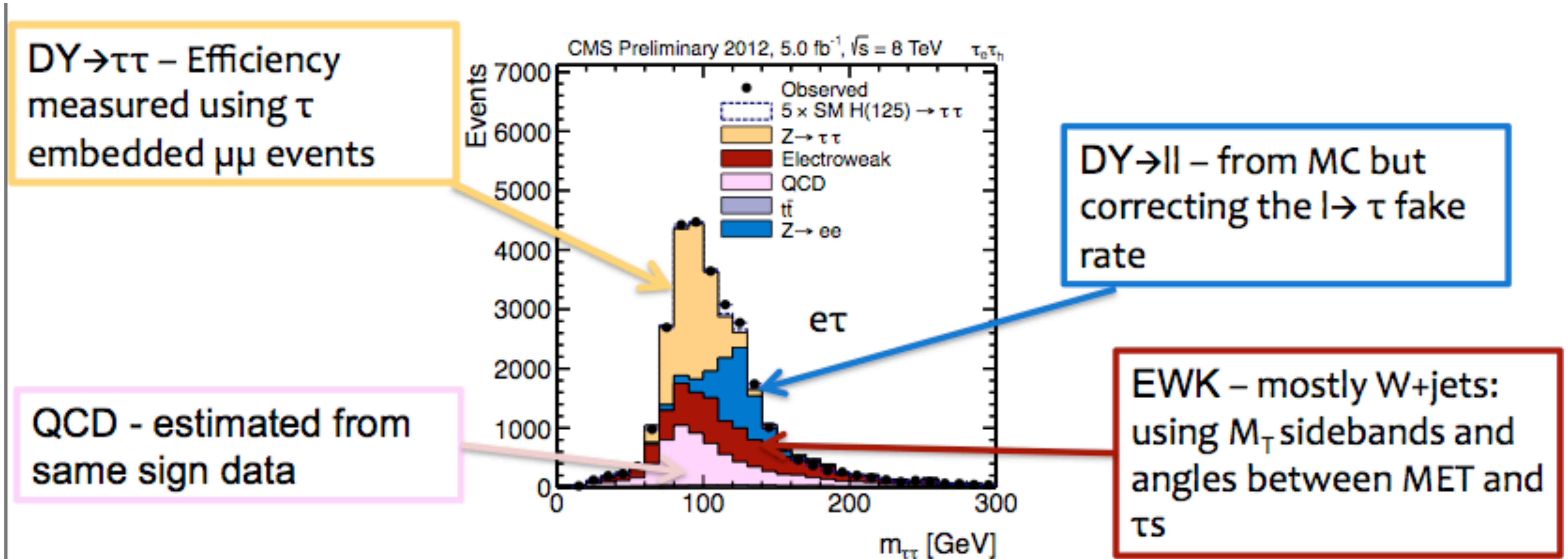
H→ττ

M.De Gruttola
J.Wang
K.Hanawa

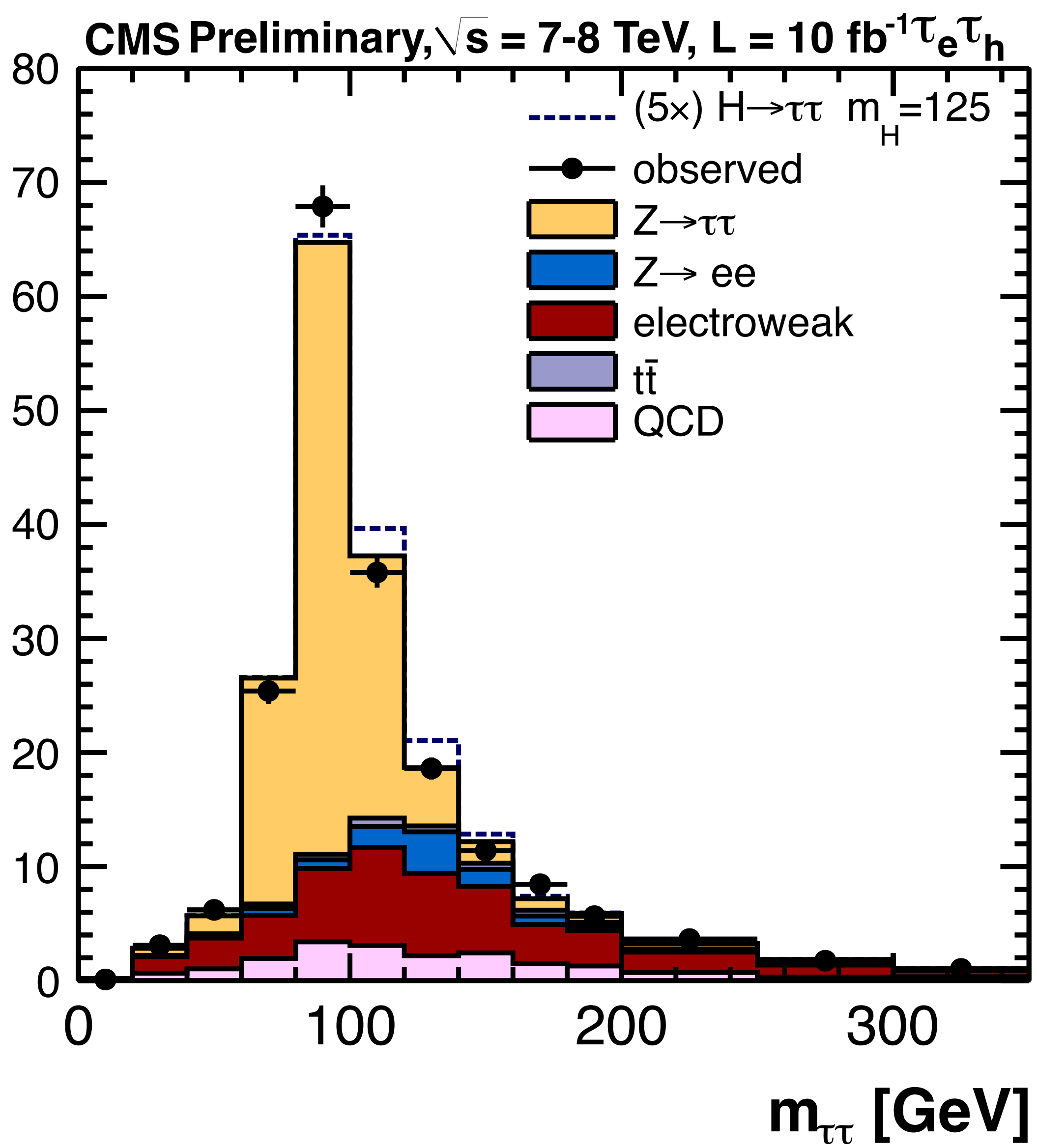
Split in:
- different tau decay modes: l-l, l-had, had-had (ATLAS)
- 0j, 1j («boosted») (targeted for gluon fusion), 2j («VBF» targeted selection)
  CMS uses MVA based «VBF» selection
- 0j, 1j further split in bins of lepton Pt (CMS)

Invariant mass reconstruction : Likelihood (CMS), MMC (ATLAS)

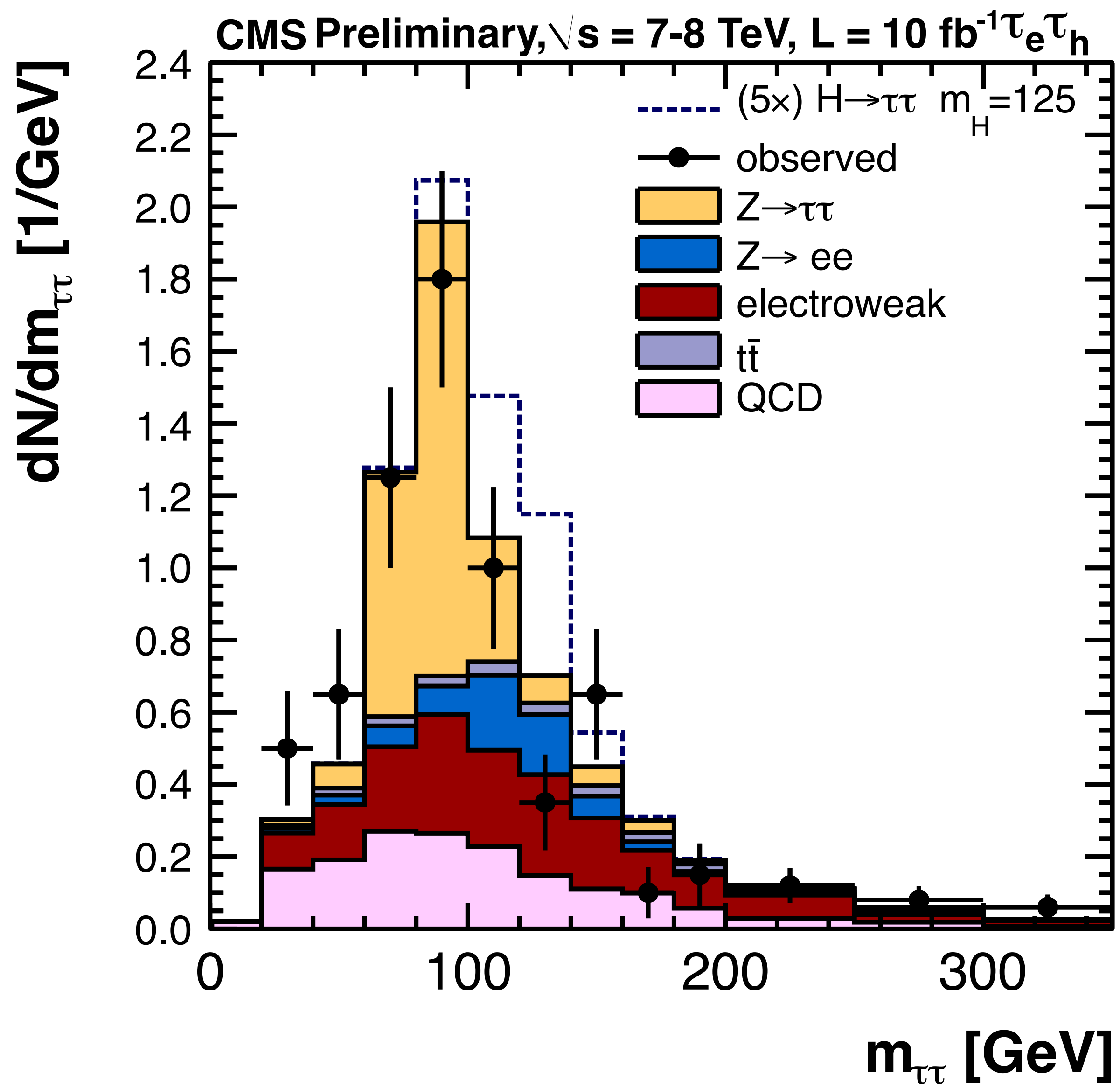
Main backgrounds: Z→ττ ,top, W+jets, Z→ ll, multijets



«boosted», S/B ~0.6% (without mass cut)



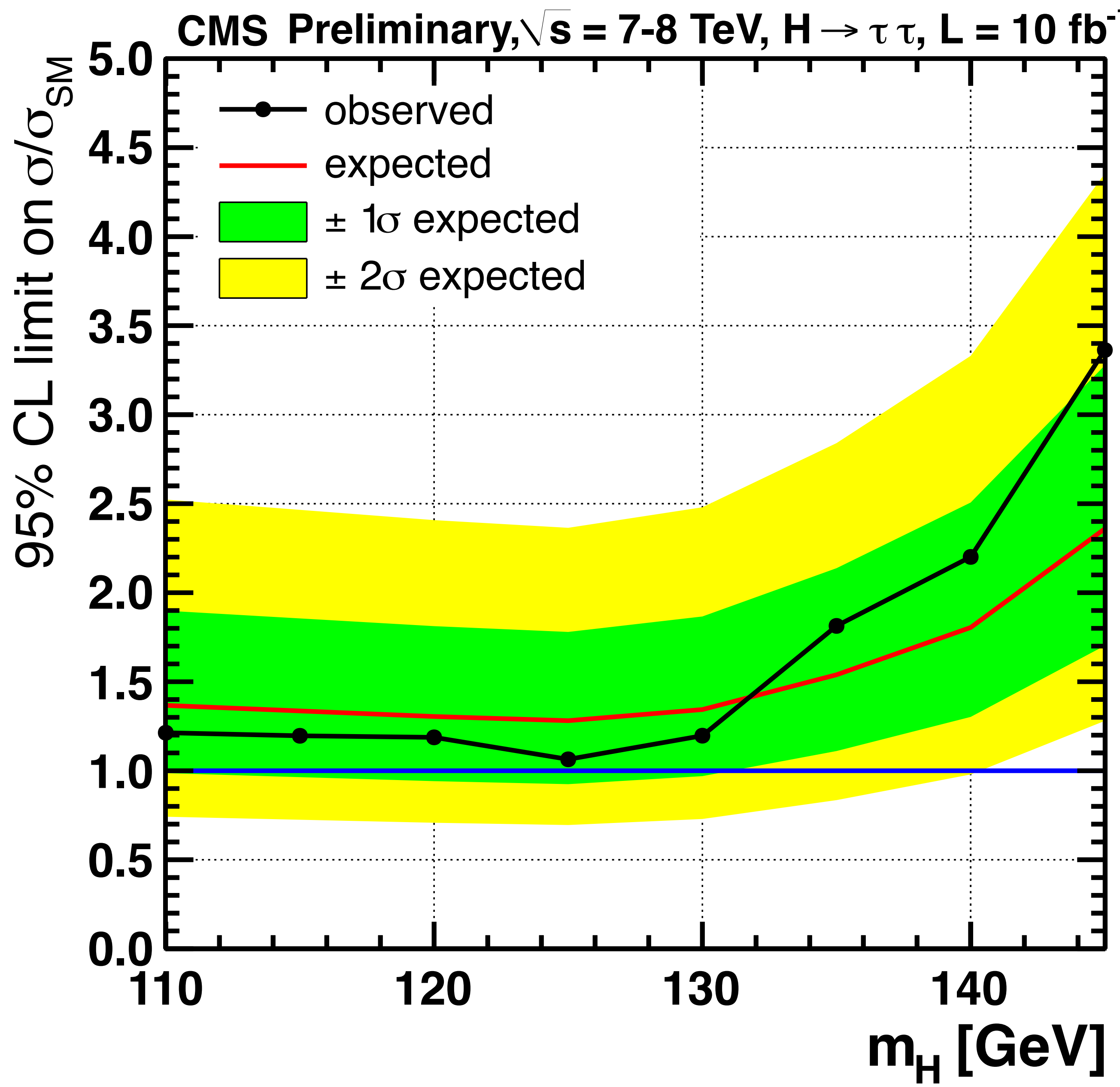
«VBF», S/B ~3% (without mass cut)



CMS 95%CL limit sensitivity from 7+8 TeV samples ~ 1.3*SM

Observed limit ~1.06

To be watched....



ATLAS 95%CL limit sensitivity with 7 TeV only analysis ~3.5*SM

H→bb

M.De Gruttola
J.Wang
P.Bortignon
A.Buzatu

Challenging at hadron collider
Only doable (so far) in associated production (VH or ttbarH)
VH has better S/B at Tevatron but LHC is starting to catch up

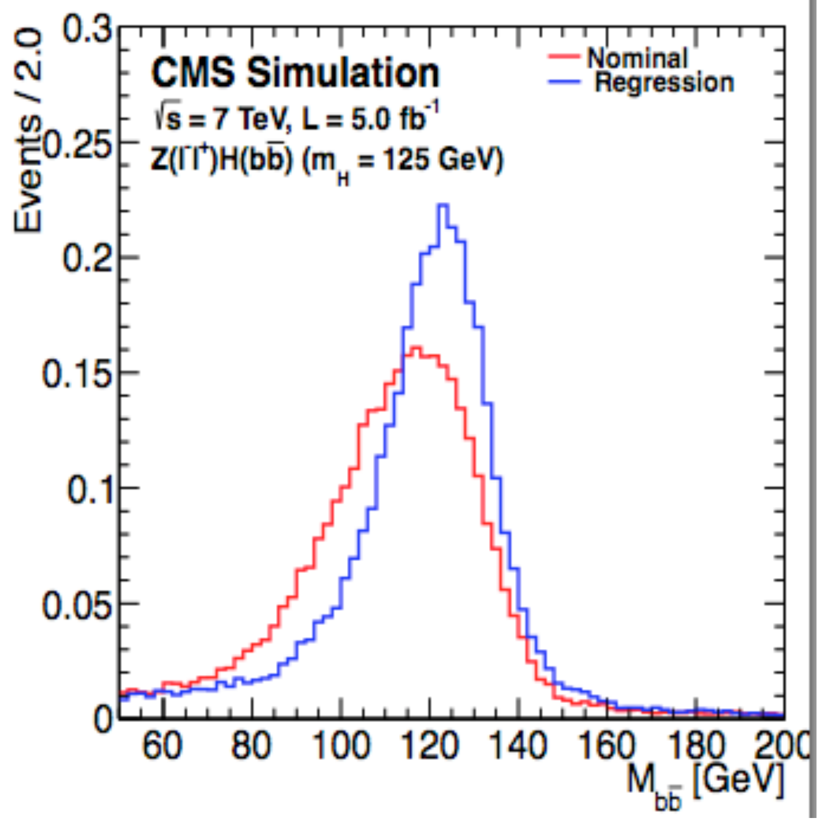
Use leptonic decays (W→lν, Z→ll, Z→νν)

Tevatron: Divide into categories, Use b-tag information, MVA tools (kinematics)
CMS: Divide in Pt(V) categories («low» and «high» boost),use b-tag information, MVA tools

Main kinematics discriminant from M(bb) => Improve calibration with MVA based regression techniques,

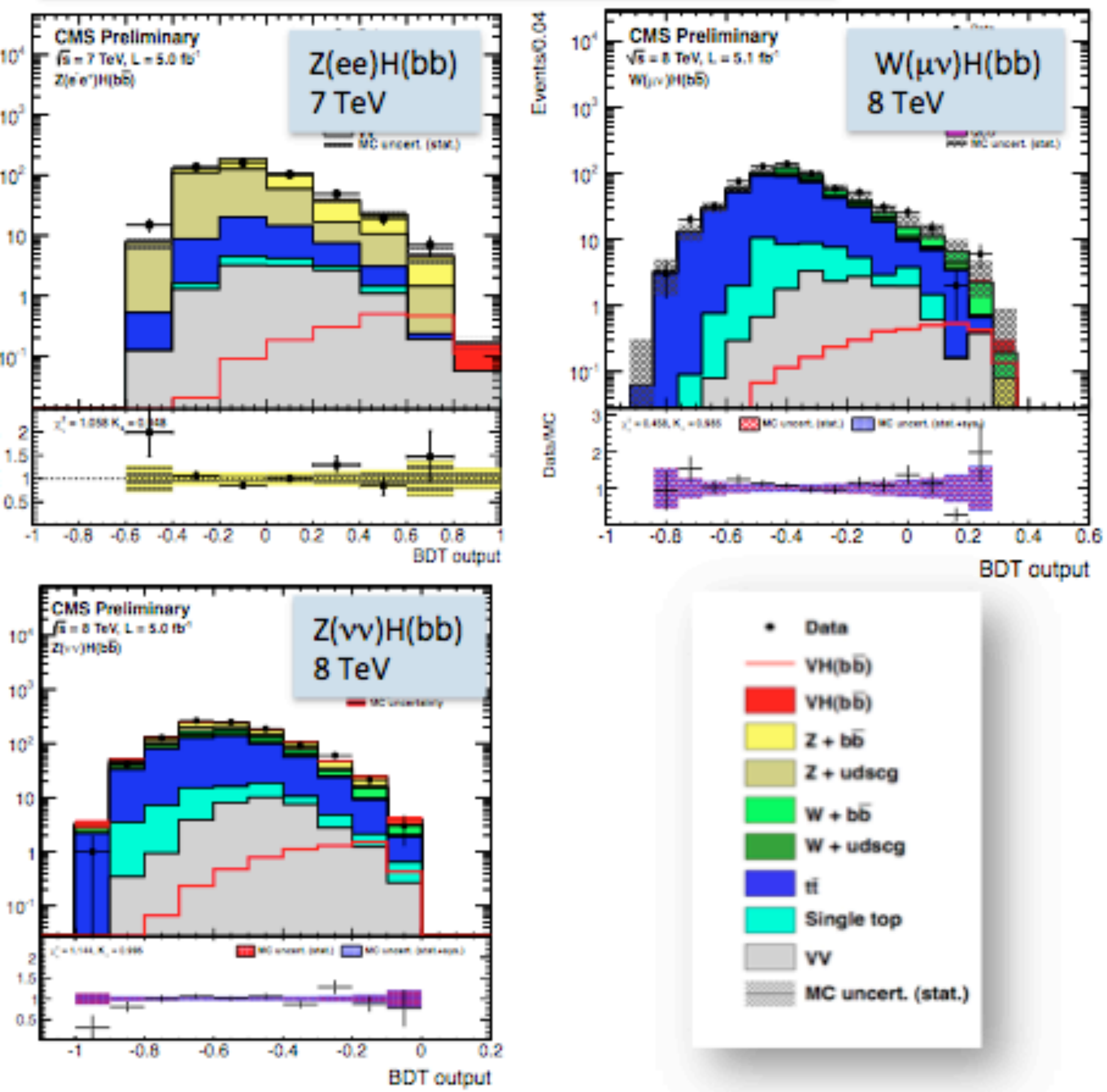
Backgrounds are V+jets, V+b's, top, Diboson. Various sets of control regions

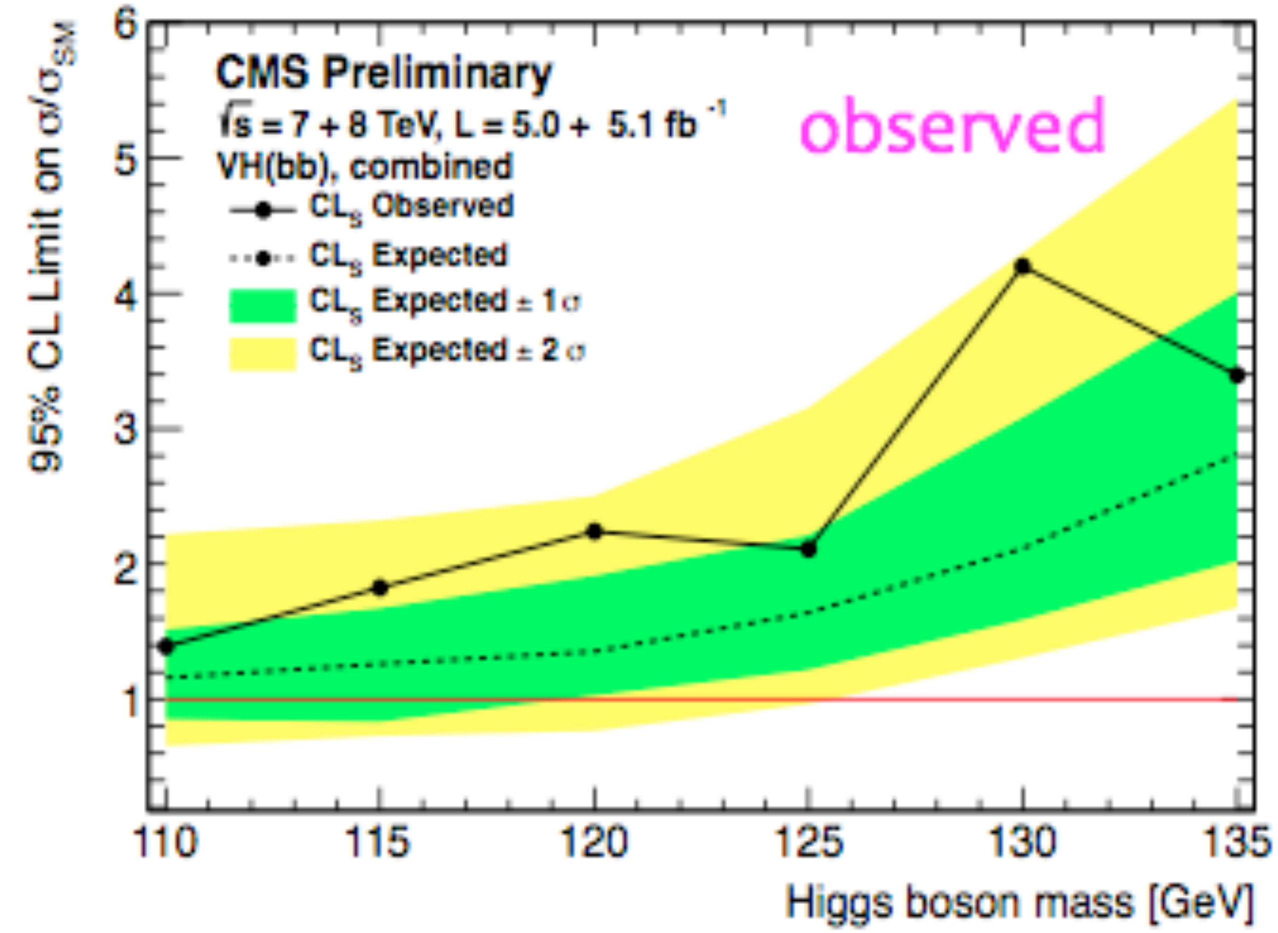
mass resolution



CMS results from 7+8 TeV samples

Examples of BDT distributions





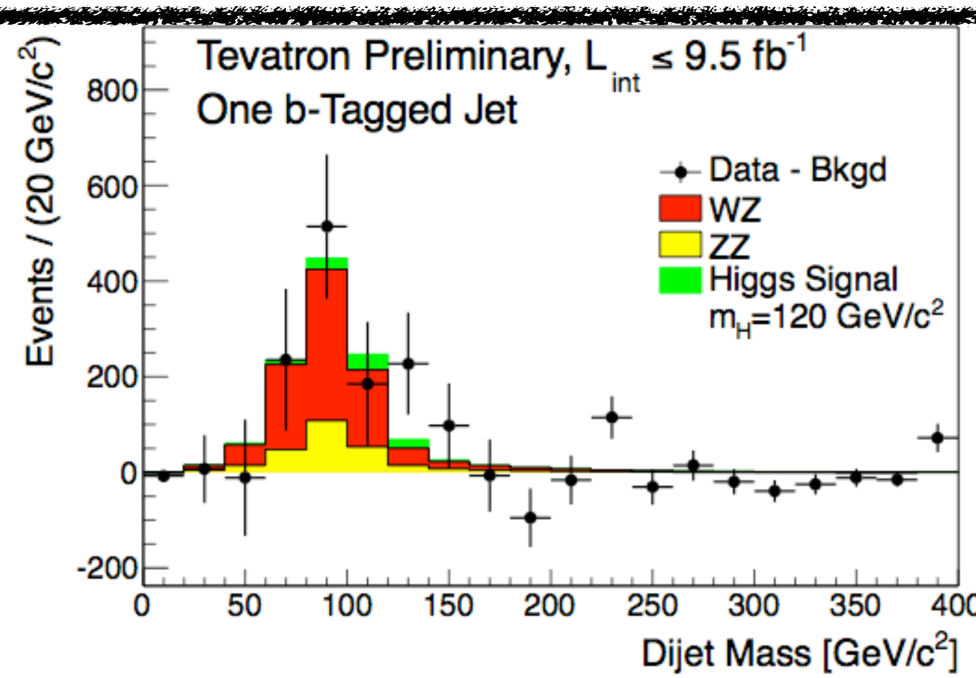
Consistent with S or S+B
slight excess looks like expected for S+B

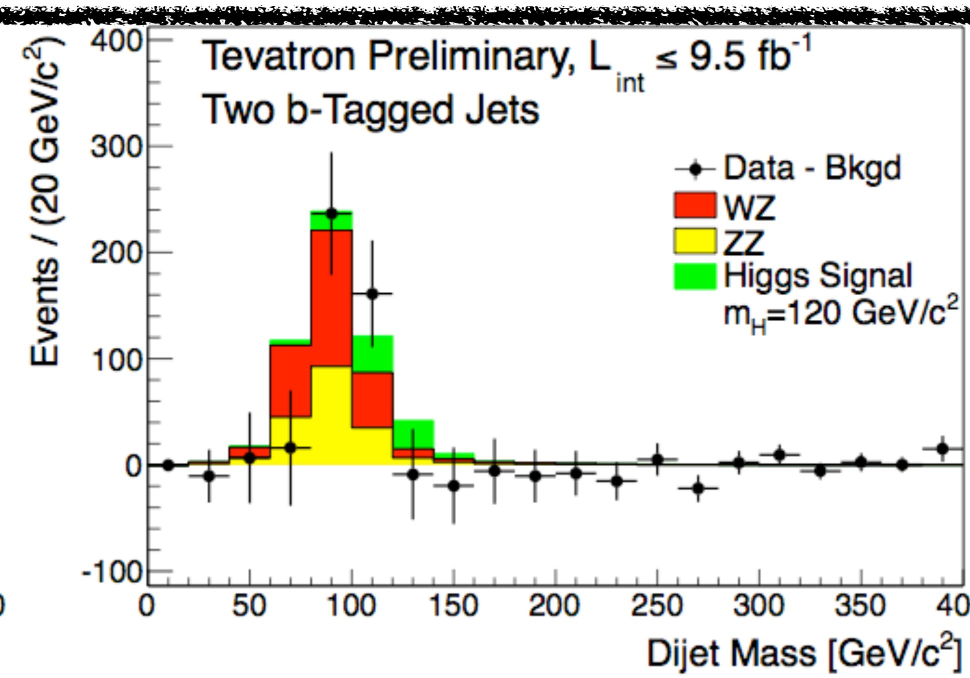
ATLAS sensitivity with 7 TeV sample ~ 4*SM

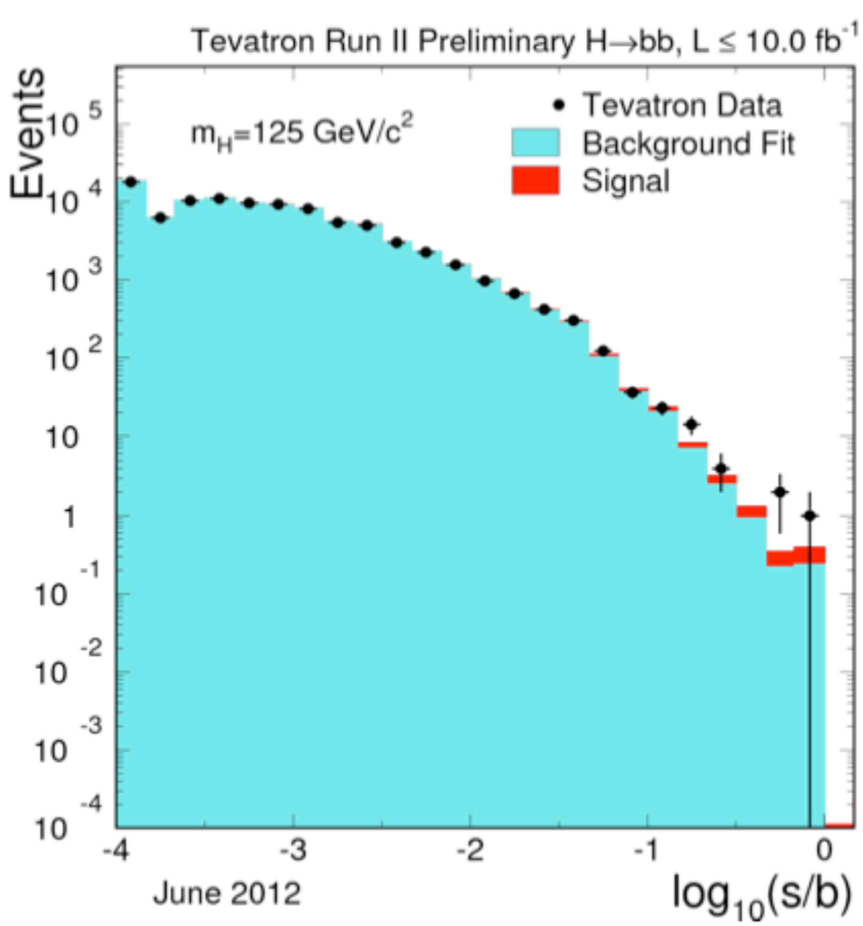
Highly boosted regime (jet sub structure) not yet used with current statistics

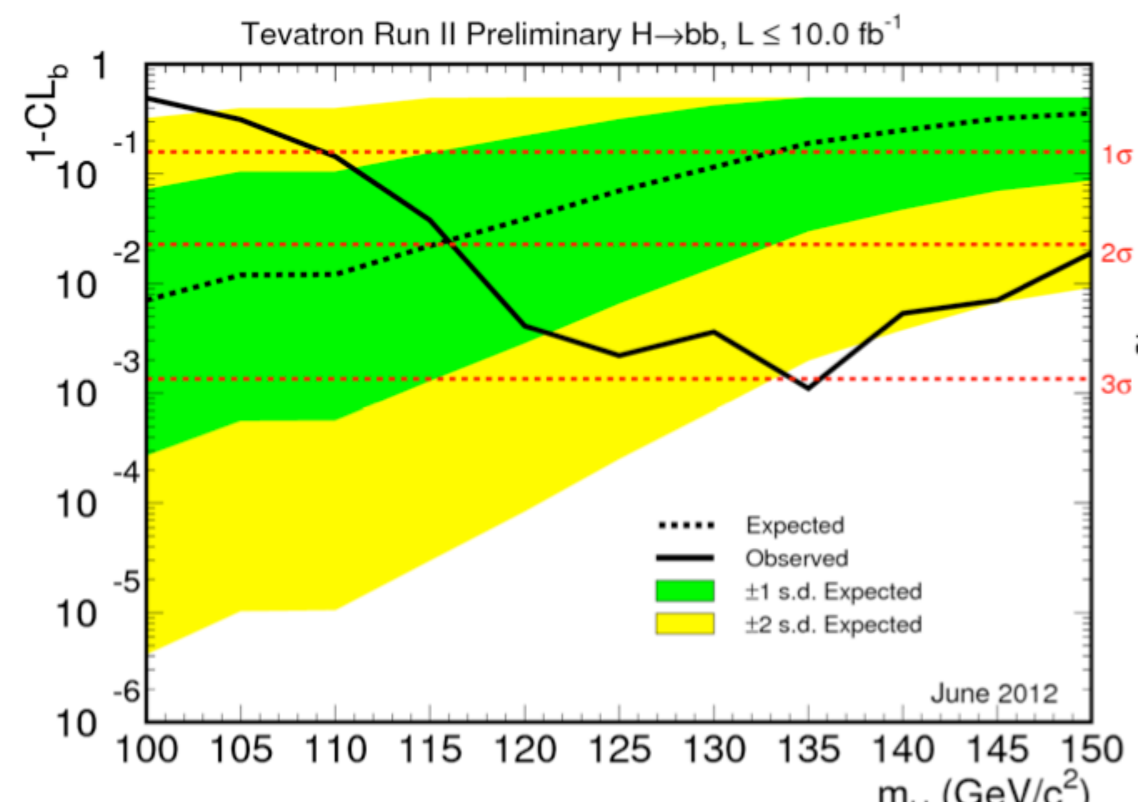
Tevatron results

Background (except WZ,ZZ) subtracted mass distribution (slightly less statistics)







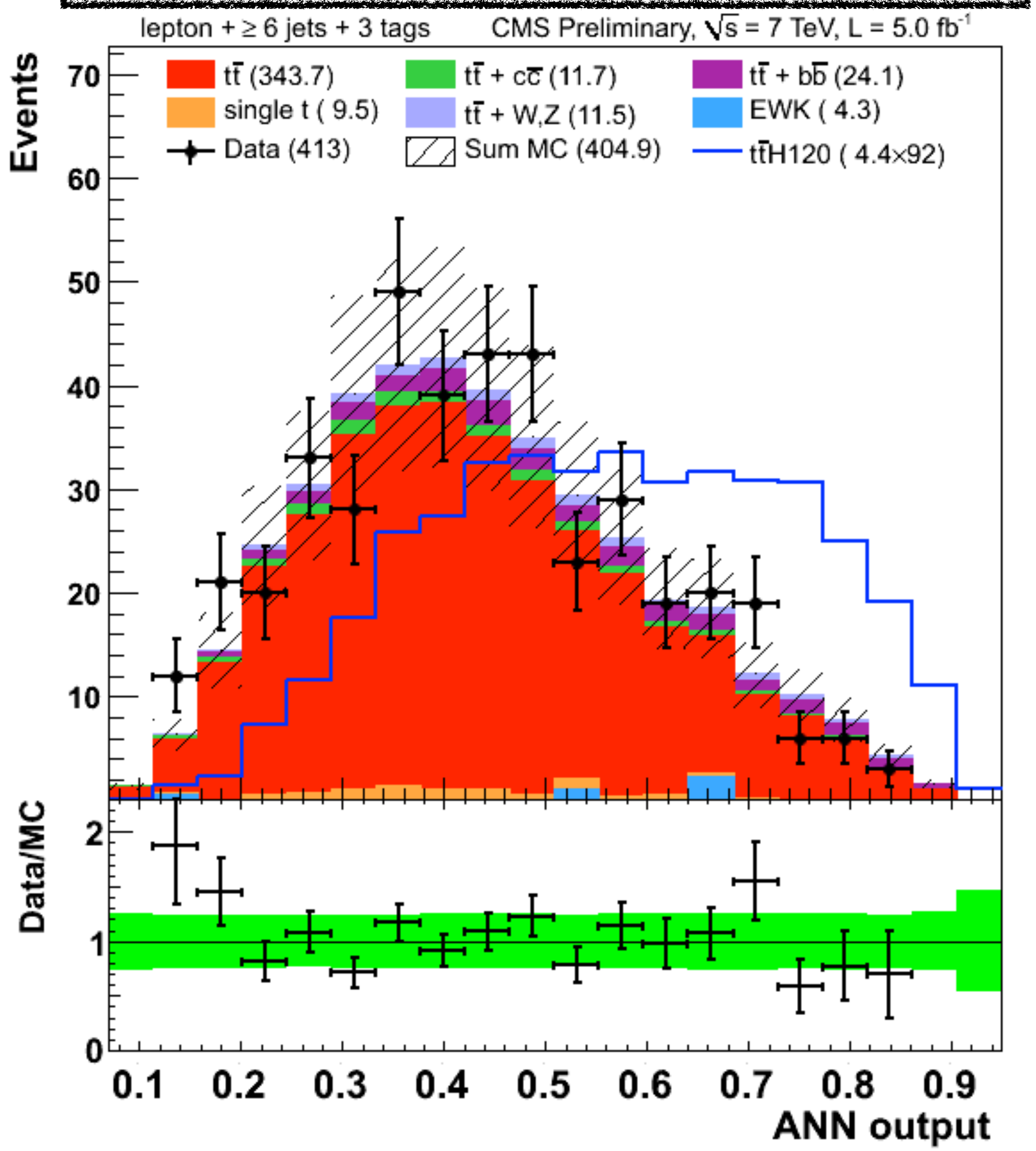


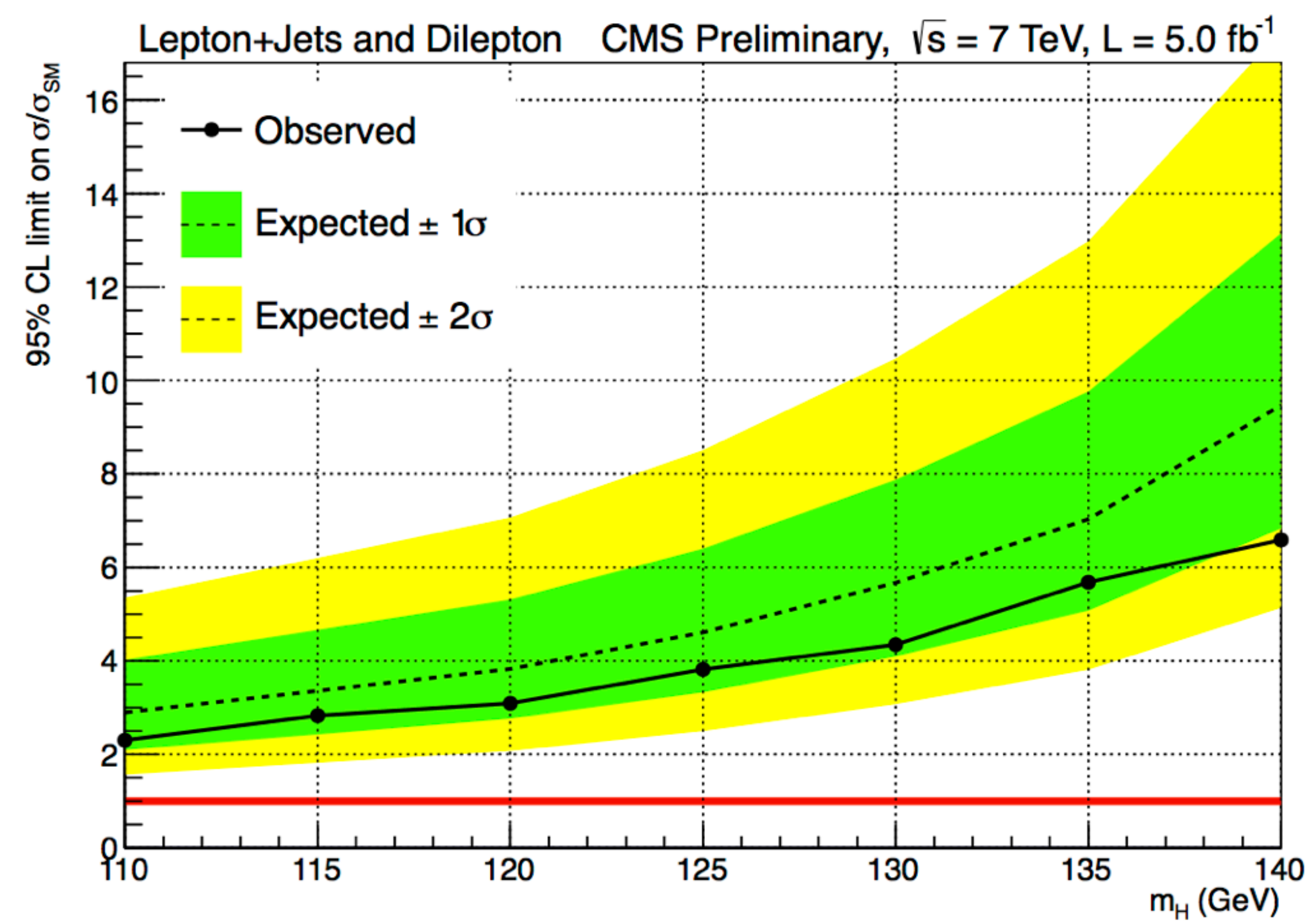
~ 3 sigma deviation from bkg only
Signal rate ~ 2*SM (~1.5 sigma from SM)

ttH associated production from CMS (7 TeV data)

Difficult final states: up to 6 jets, with 2 b-jets
Split analysis in (number of jets, number of b-jets) * (dilepton, lepton+jets)
Use NN (b-tag information, kinematics, angular information)

Example for >= 6 jets, 3b-tags in lepton+jets





Sensitivity ~ 4*SM
Still some way to go
but already quite impressive

High mass channels

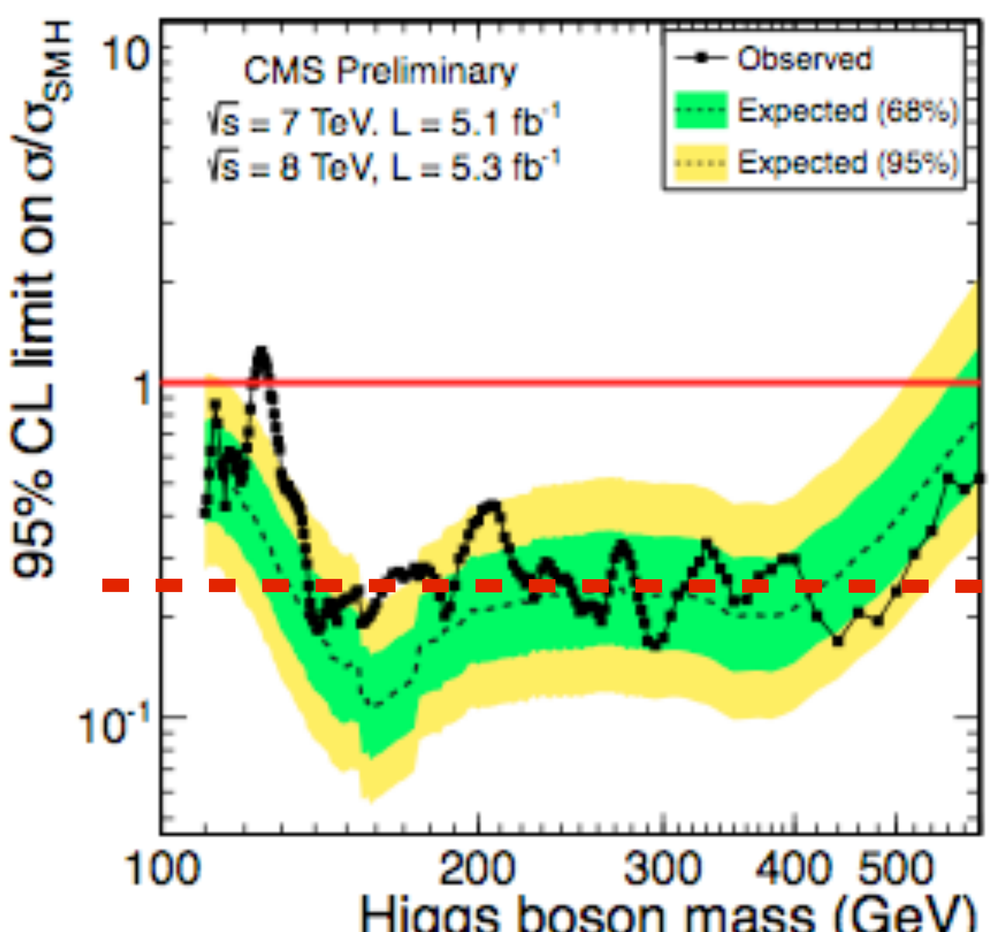
J.Kanzaki

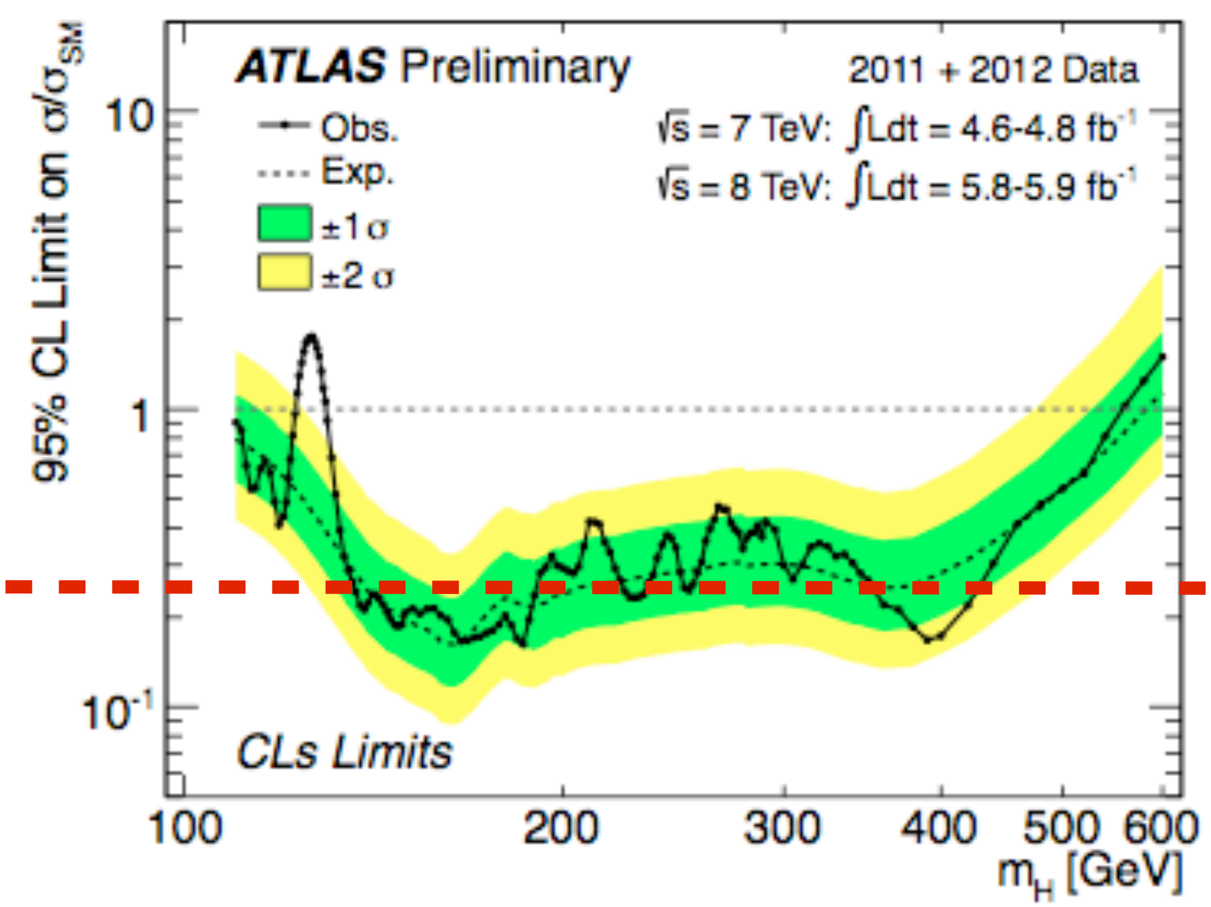
$H \rightarrow ZZ \rightarrow ll\nu\nu$

$H \rightarrow ZZ \rightarrow llqq$

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

No excess found, excluded SM scalar boson over large mass rage
Obviously sigma=sigma(SM) is not the target anymore





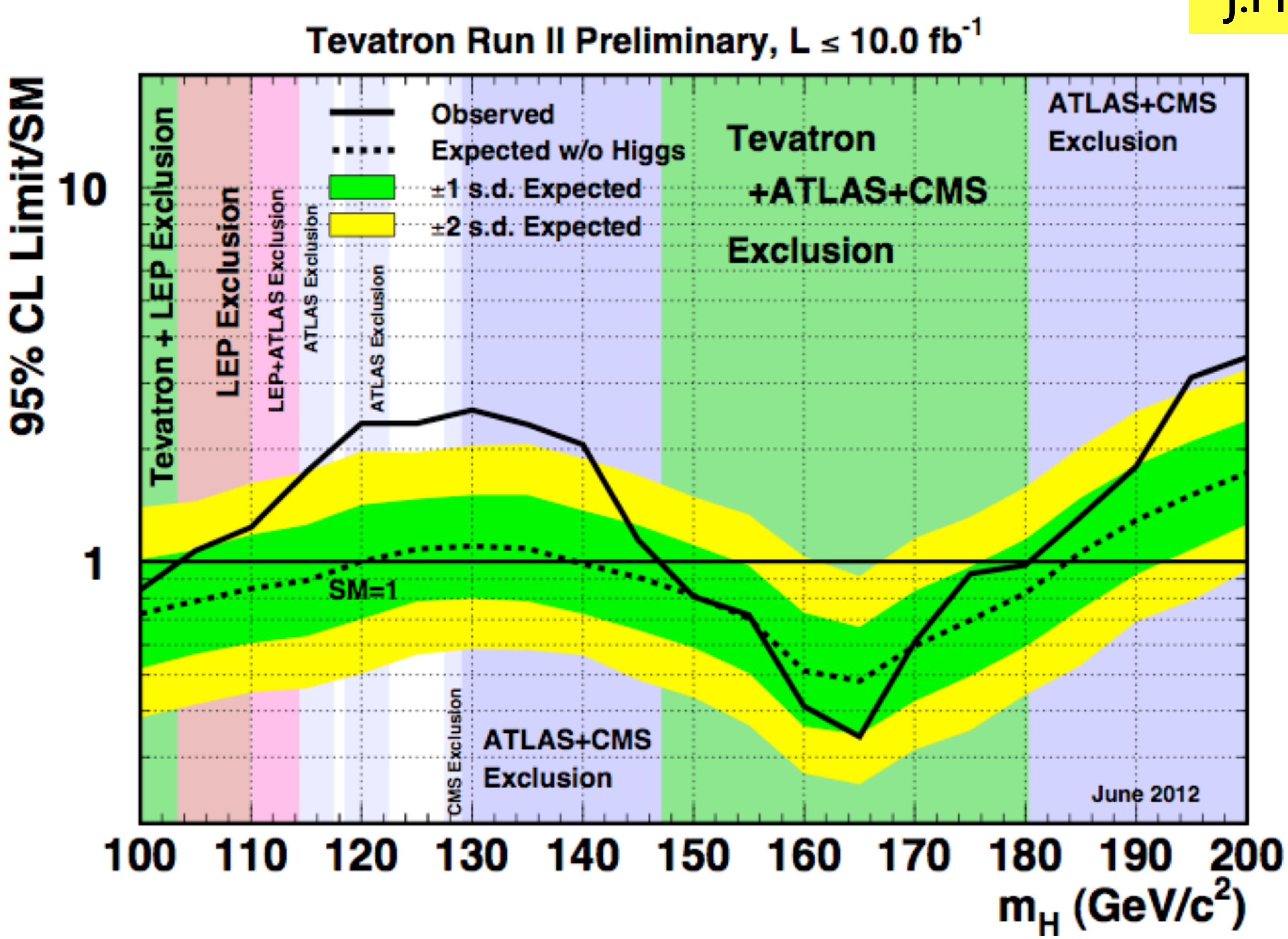
Tevatron Combination

Add also many other «small» channels

N.Osman

H.Nguyen

J.Haley

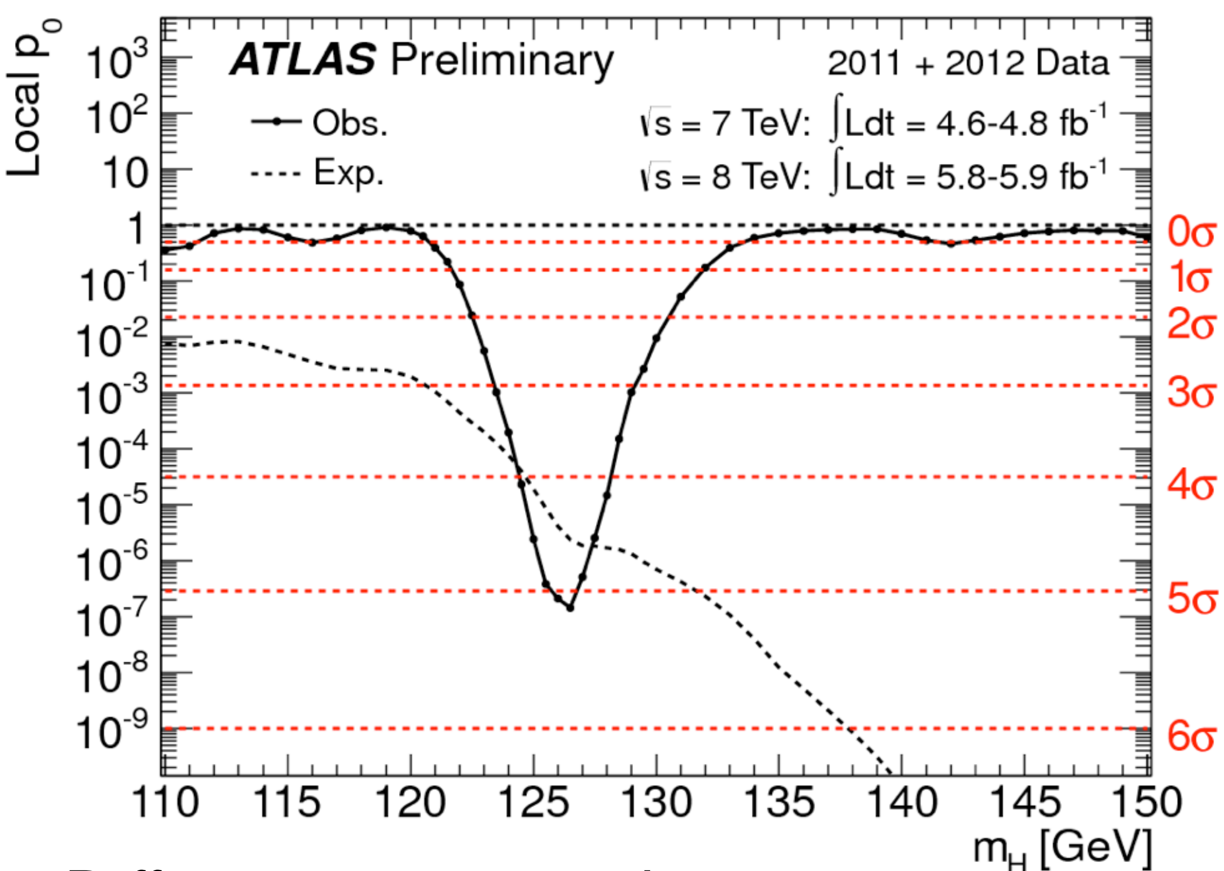


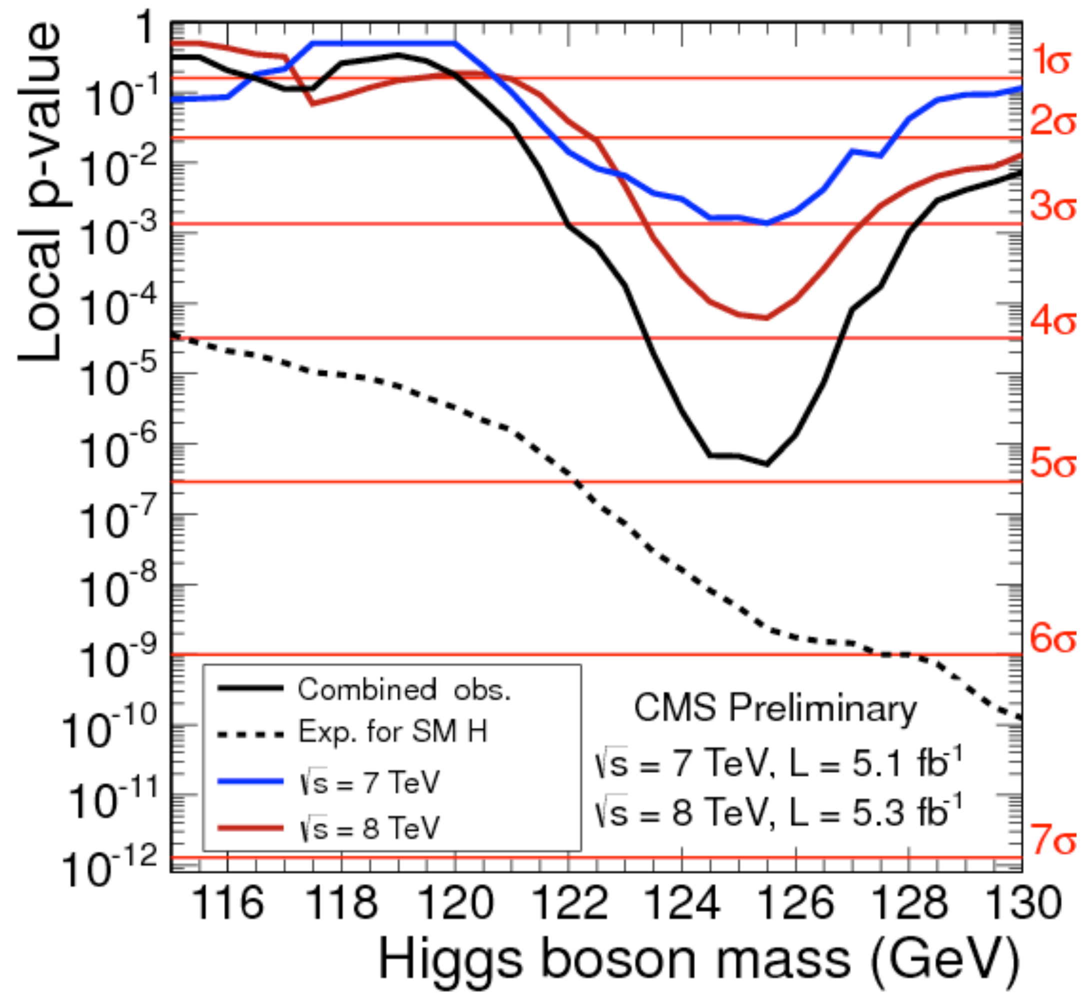
ATLAS and CMS Combinations

M.Chen

G.Steele

ATLAS : gamma-gamma and 4l from new 7+8 TeV analysis, other channels from 7 TeV only (WW 8TeV not included in combination shown here)
CMS : ~all channels from 7+8 TeV data



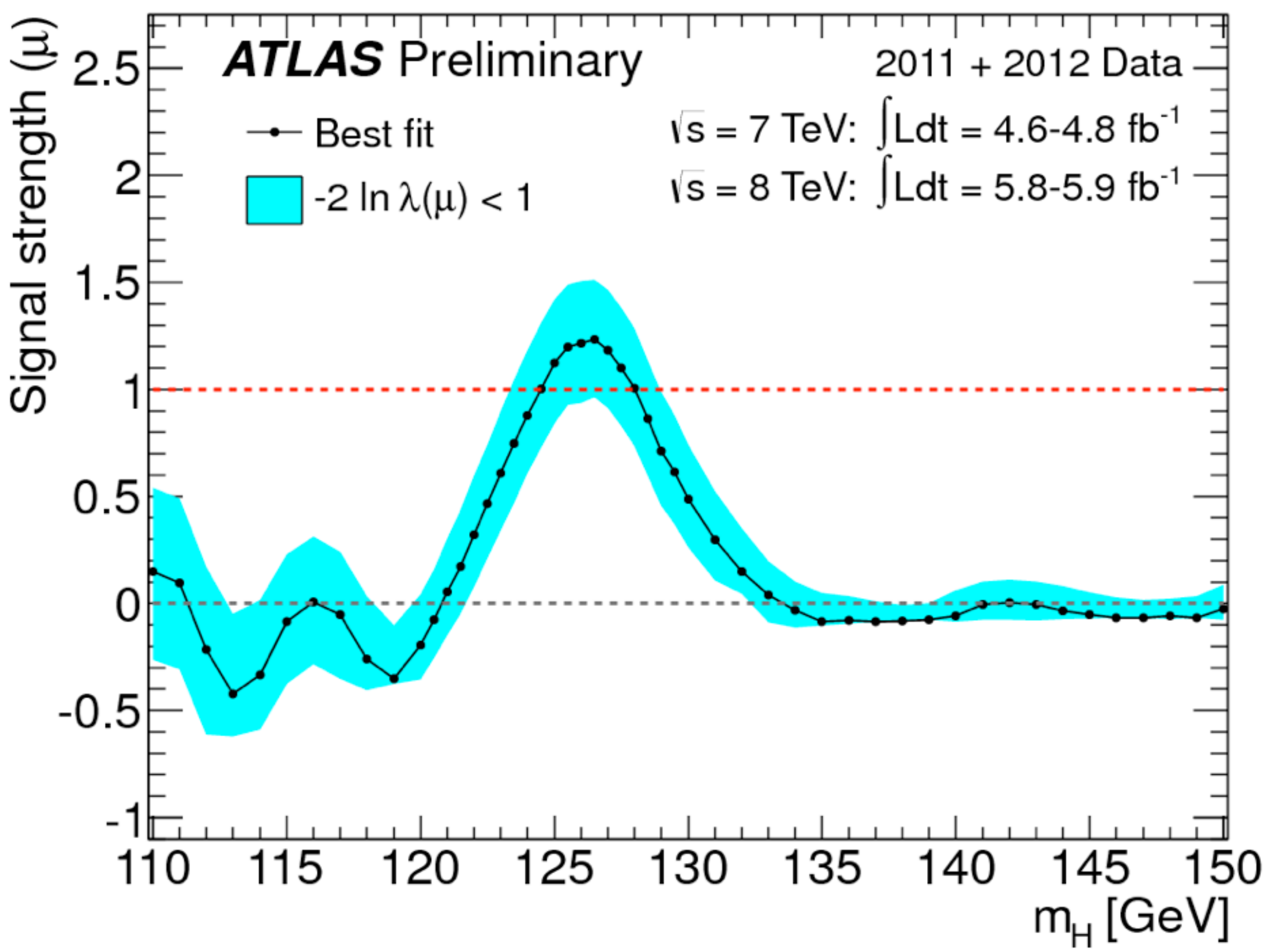


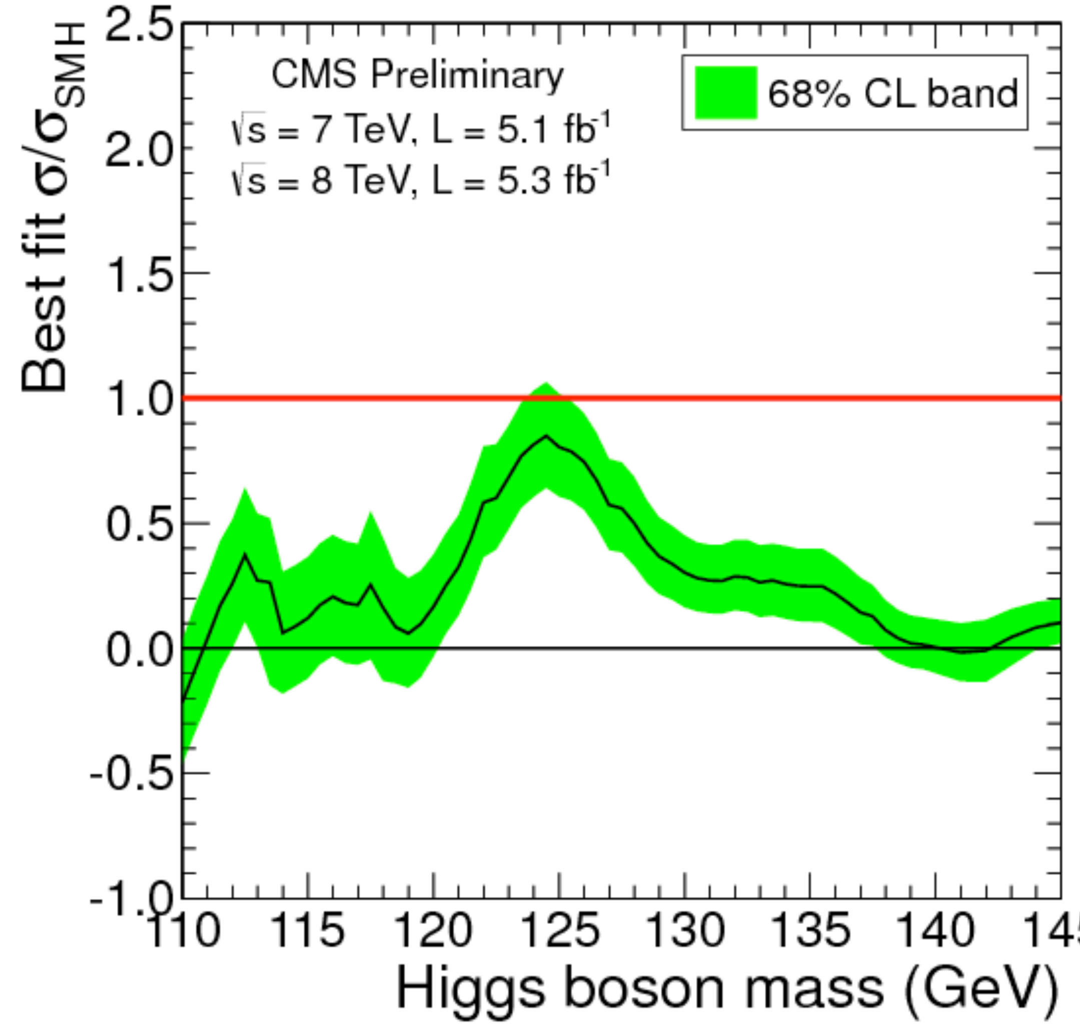
Difference in expected sensitivity:
- ZZ (CMS ~3.8 sigmas, ATLAS ~2.6)
- Full stat 7+8 TeV for WW and tau-tau

Global significance
~4.4 in 110-140 GeV range (CMS)
~4.3 in 110-150 GeV range (ATLAS)

There is a boson at M ~125 GeV looking not too different from the SM scalar boson

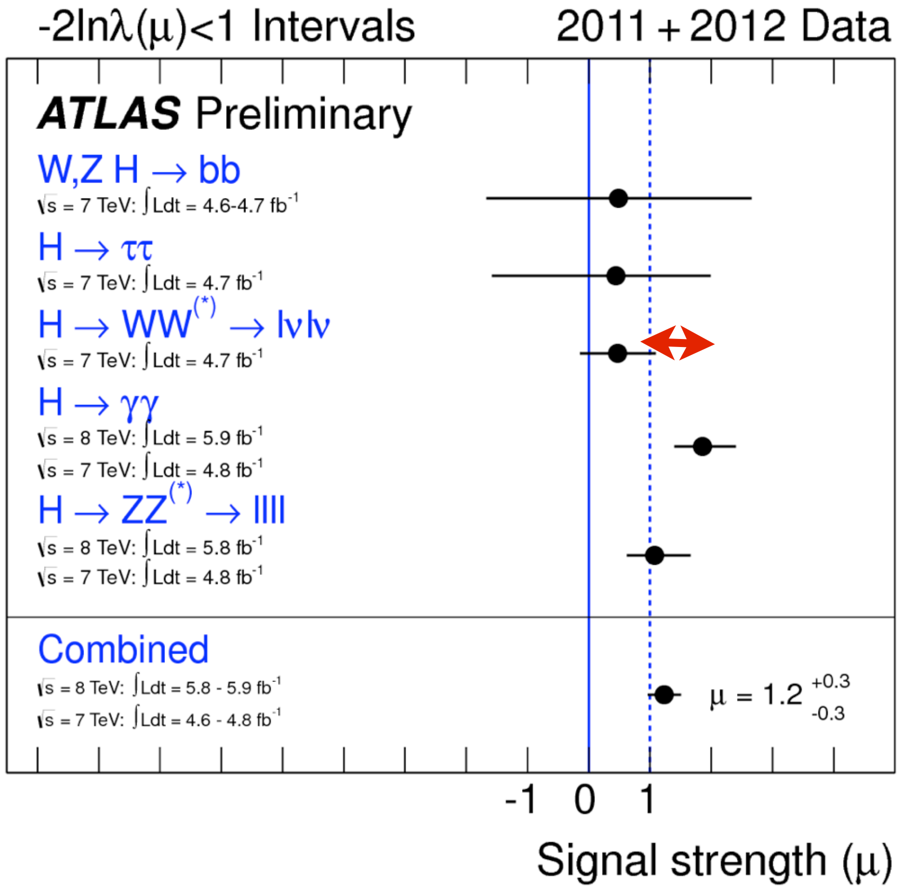
Signal rate normalised to expected SM rate





When averaging everything , pretty close to 1...
Caveat: Having a single «mu» for all channels mostly makes sense for the SM hypothesis
A non SM boson would give different mu in different channels

Splitting across decay modes or categories related to production mode

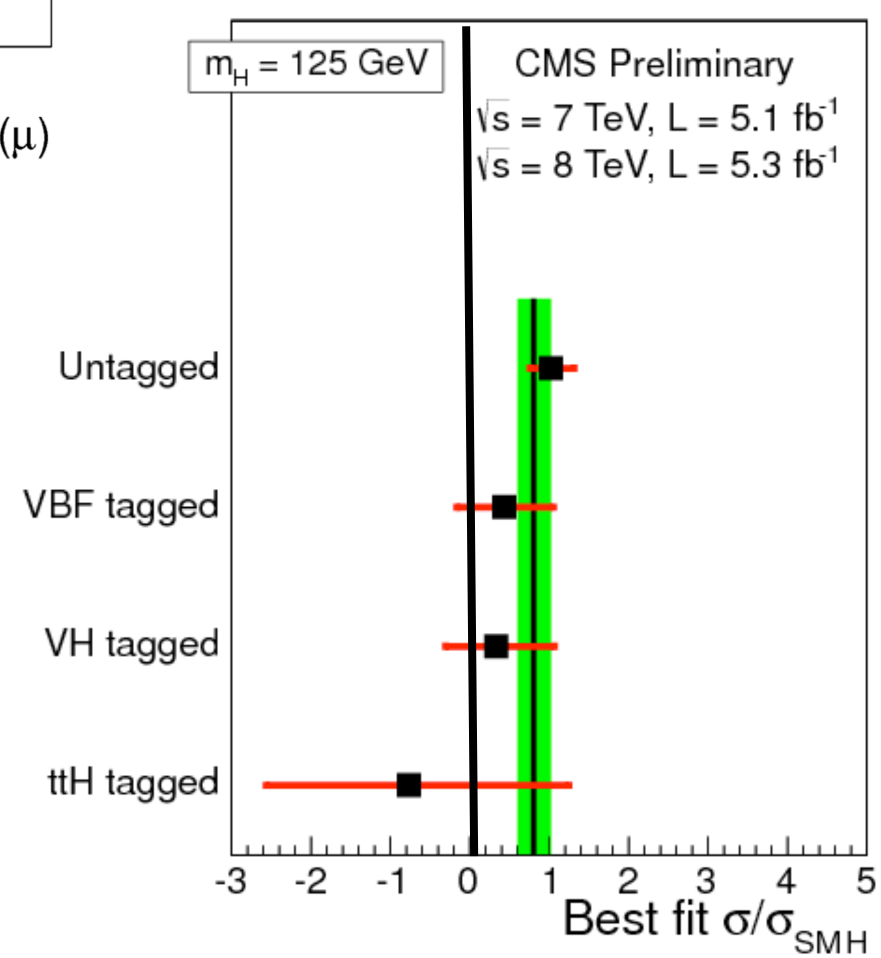


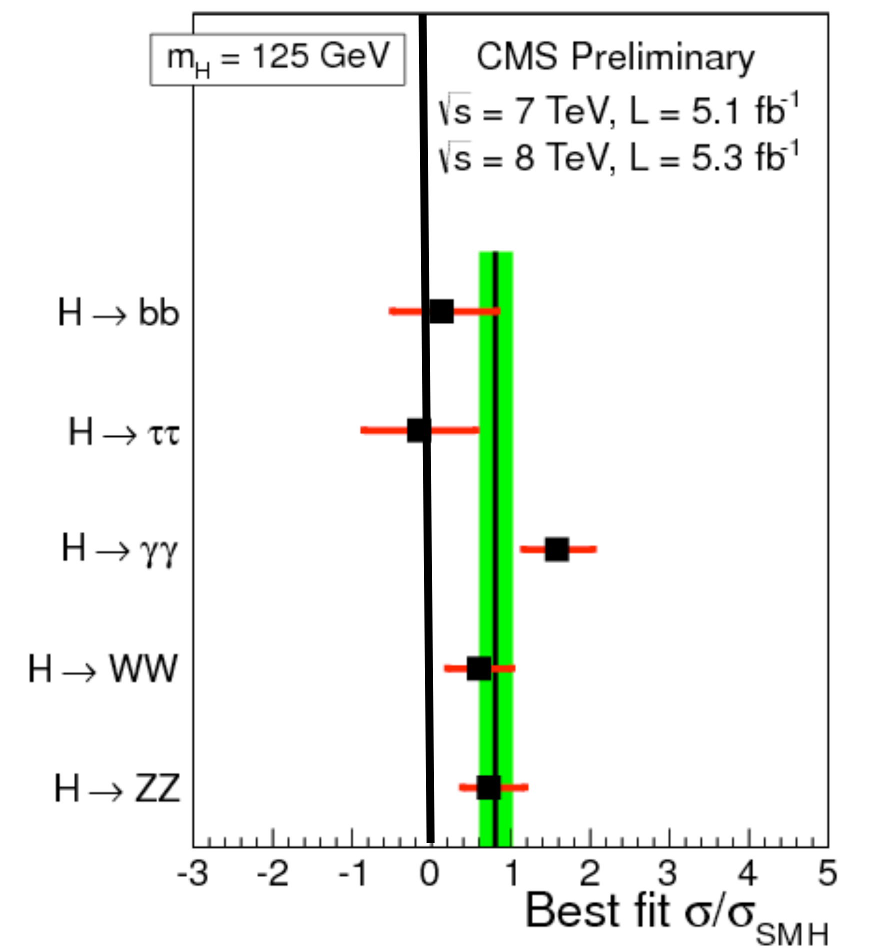
Some spread, but not inconsistent (yet?) within statistics

Main deviations:

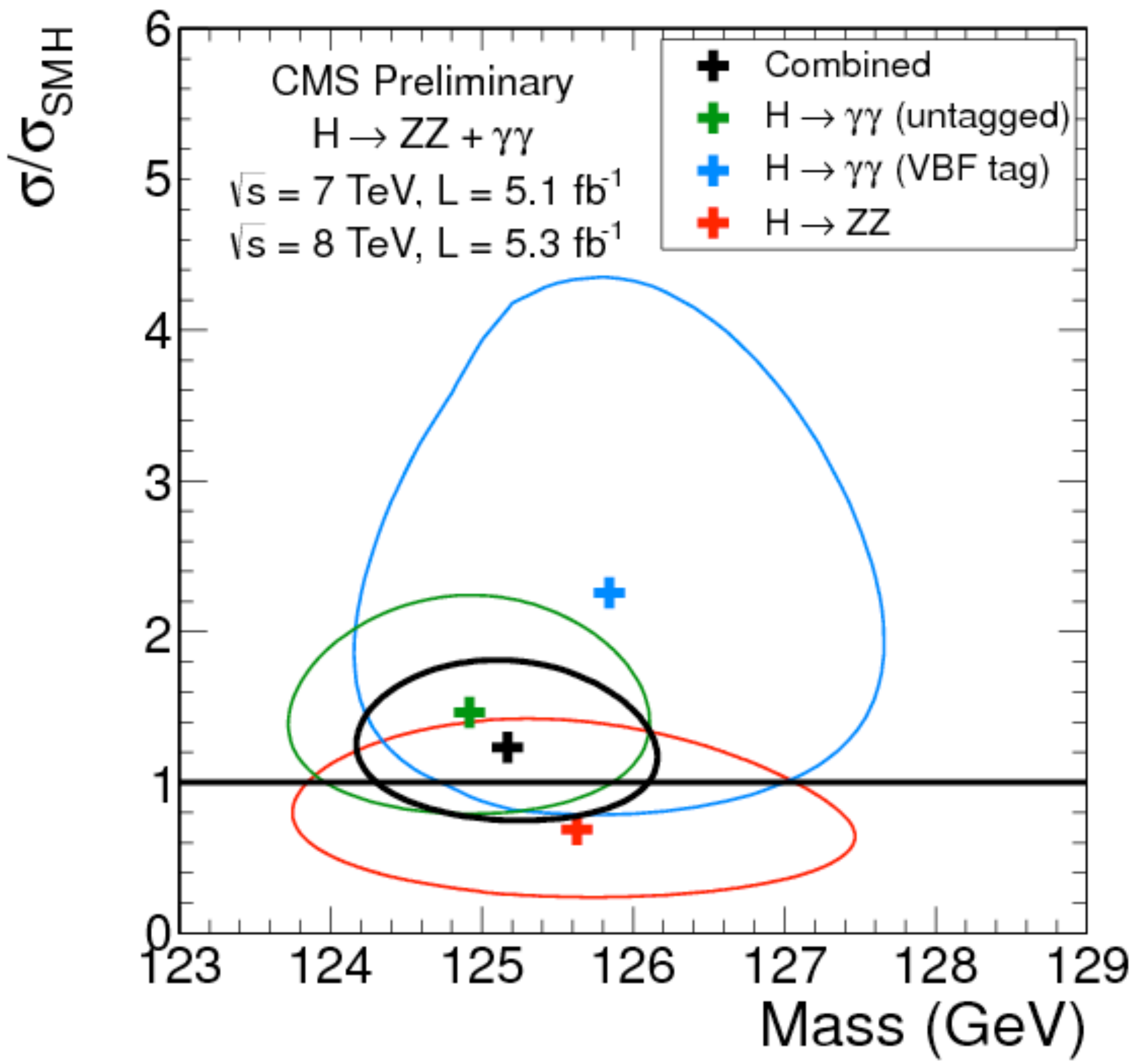
- gamma gamma high
- tau tau low

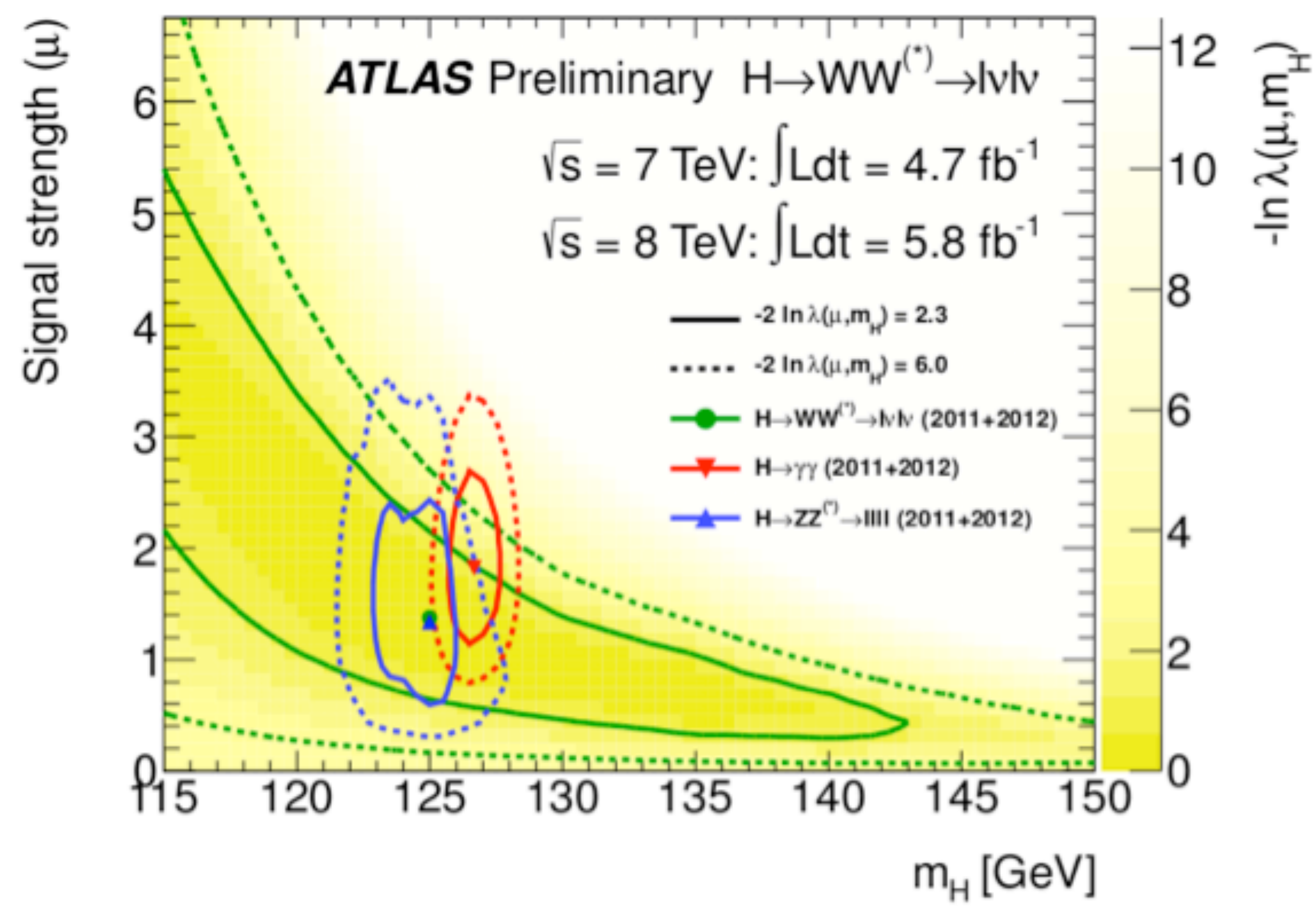
Caveat: categories are not pure in a given production mode





Mass measurement





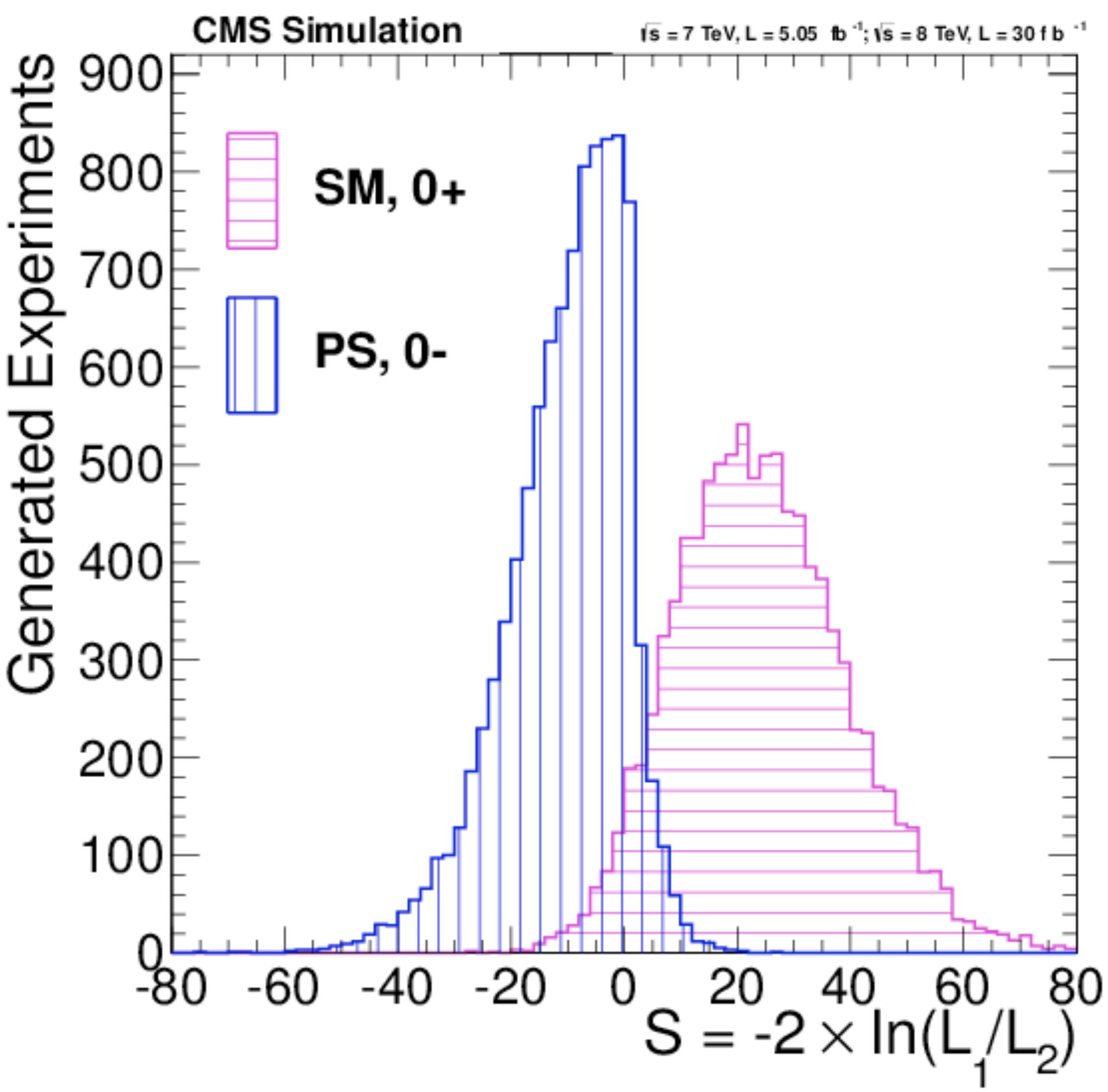
expect ~similar uncertainties as CMS

Mass=125.3+-0.4(stat)+-0.5(syst) GeV

Systematics dominated by energy
scale for photons, should decrease
with more work

Spin/SP

X(125) is a boson and cannot be spin 1
Spin 0, or 2
0+ or 0- or mixture?

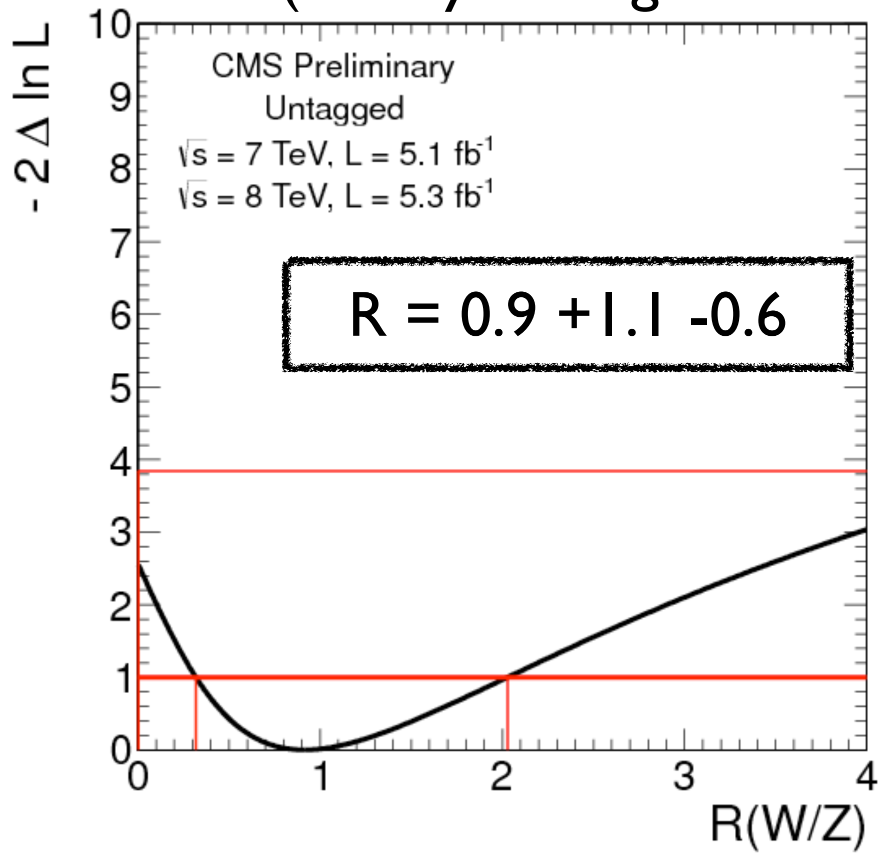


Can use 4l angular distributions to discriminate 0+ and 0- signal hypothesis ~3.1 sigma separation for 30 fb^{-1} at 8 TeV

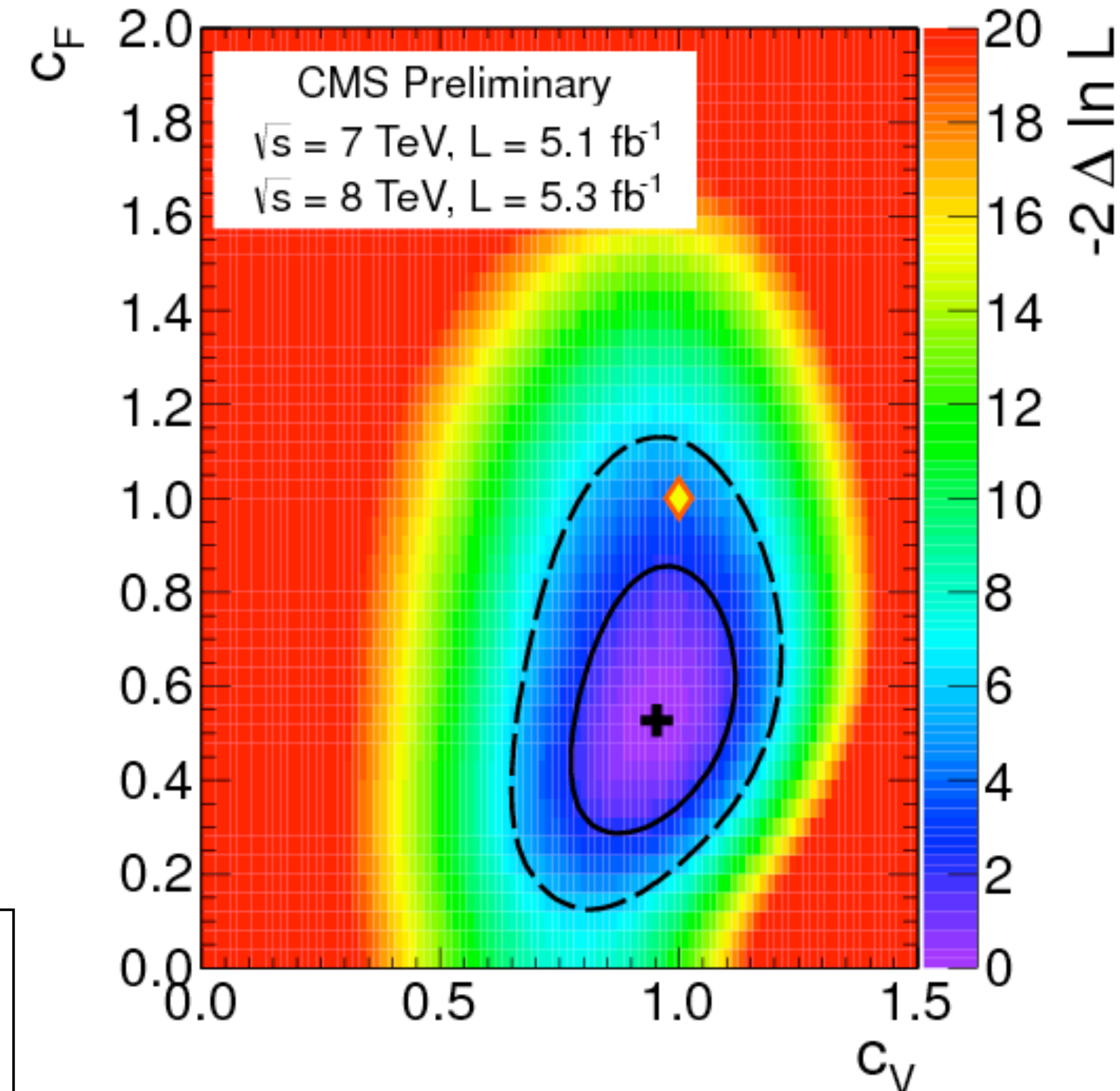
Could also use WW to distinguish spin 0 and 2 (changing some selection)

Couplings

W / Z coupling
from comparing ZZ* and WW*
rates (mostly from gluon fusion)



Scale fermion couplings by Cf
Vector bosons by Cv
=> New predictions for rates in each channel

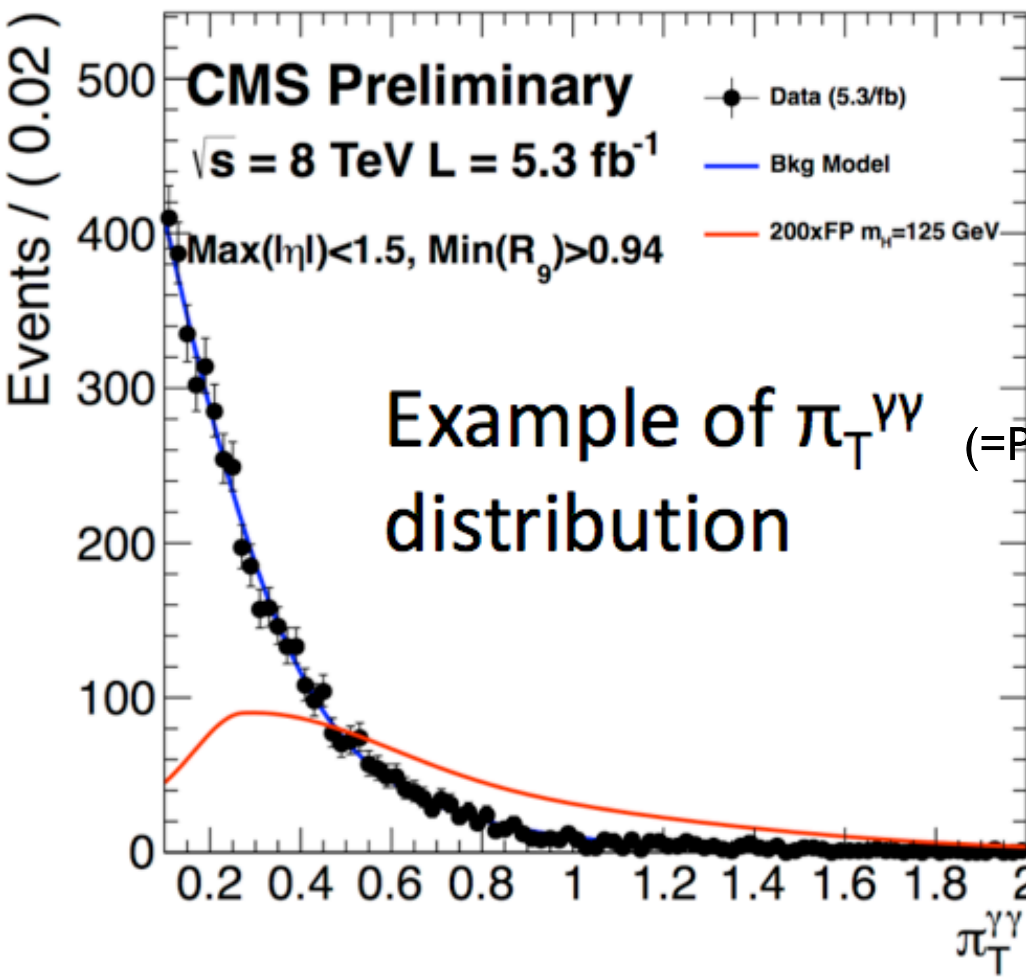


note: there are also negative solutions

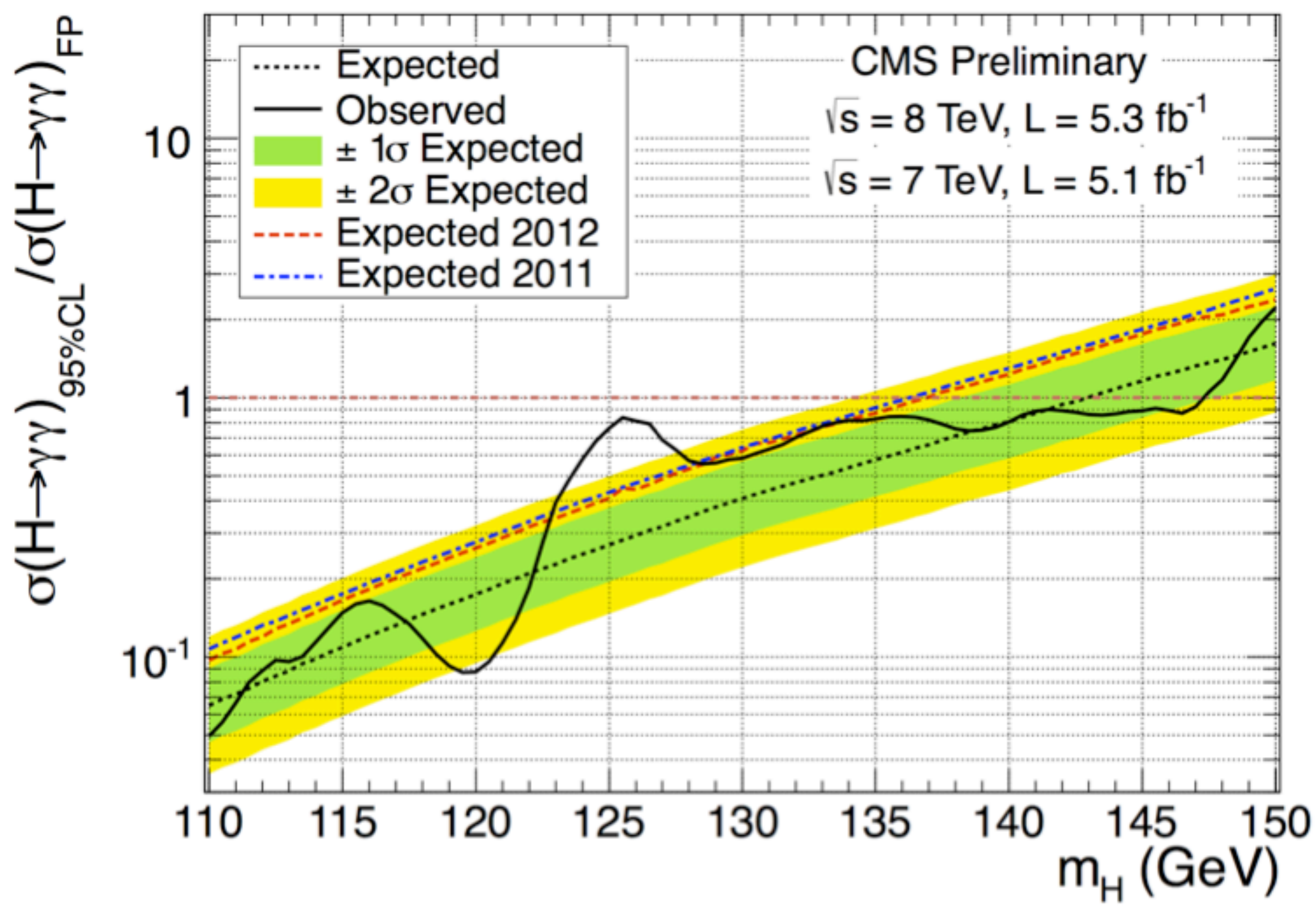
Obviously, only the beginning of this program
Should define optimal way to present this,
exploiting ratios.
May need to improve treatment of some
theoretical errors

Fermiophobic Higgs

The case Cf=0, Cv=1 corresponds to the Fermiophobic scenario
Could be investigated also with dedicated analysis in γ γ mode (no gluon fusion, only VBF and VH production => specific signatures: lepton or MET tag, Use of Pt(diphoton pairs))



(=Pt/M)



Excludes 125 GeV excess as «Fermiphobic» Higgs boson (at 99%CL)

BSM Higgs

R.Madar

J.Keller

A.Nayak

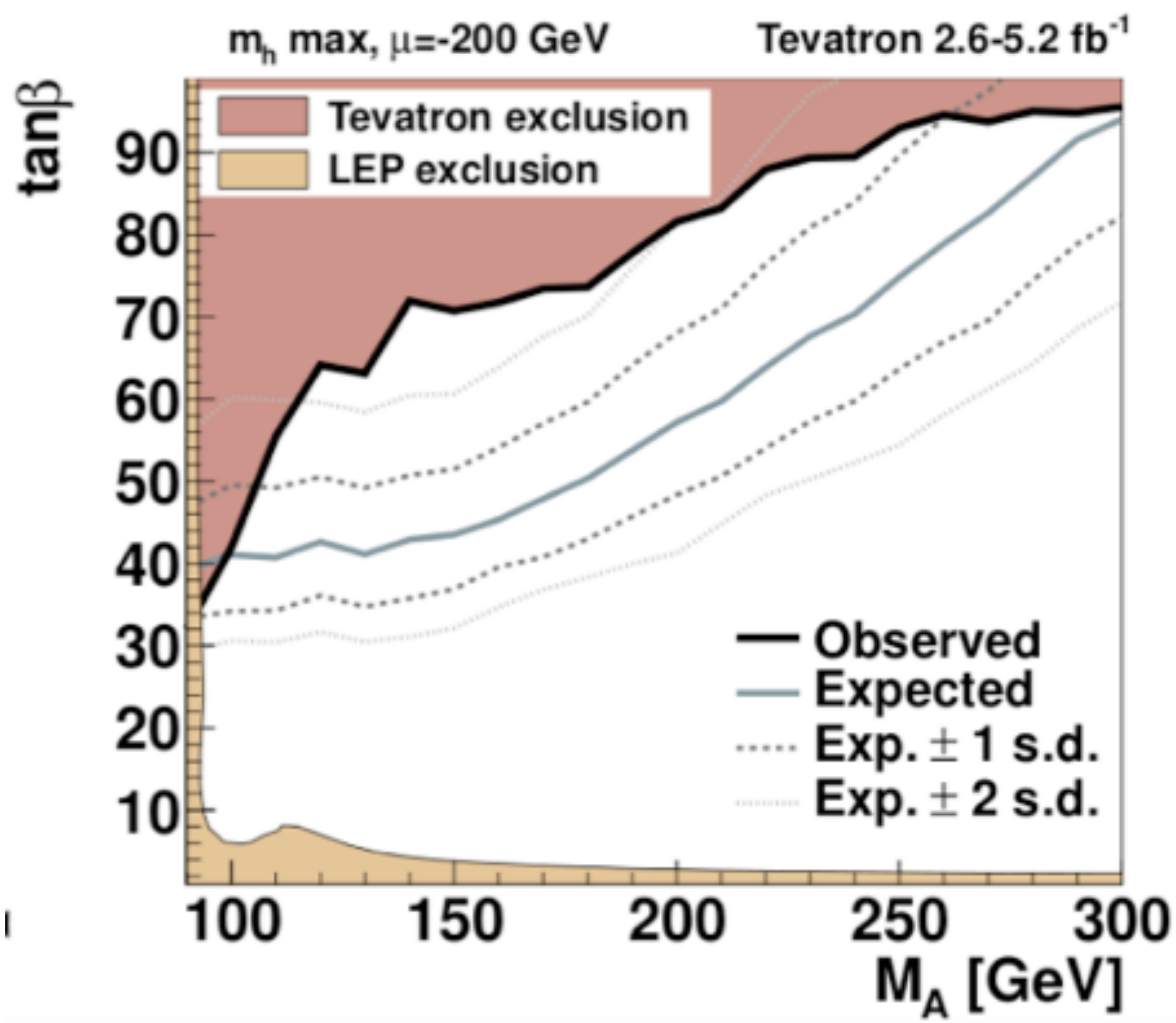
Measuring Higgs couplings is one way to check SM hypothesis

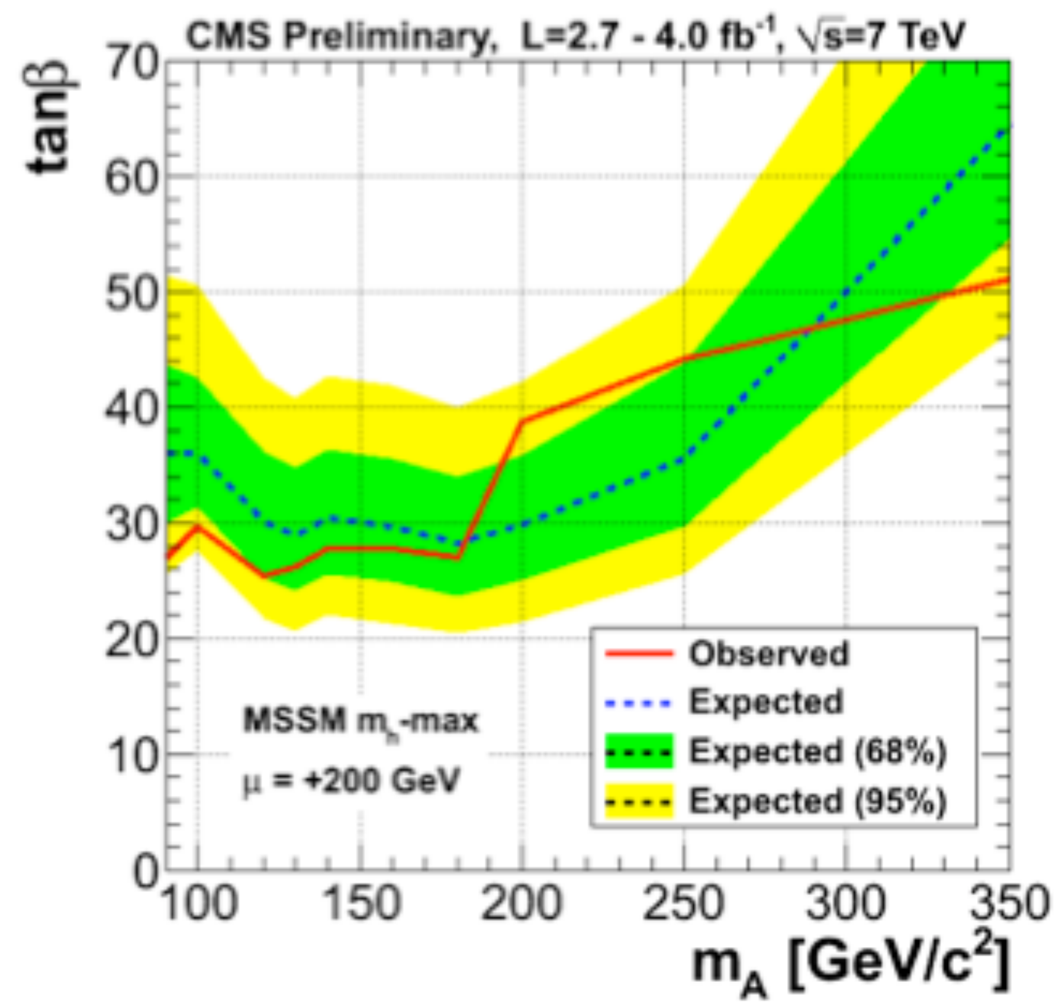
Another (complementary) way is to look for other scalar bosons
Typical benchmark examples: 2 HDM, especially in MSSM

Most relevant channels for direct searches $H/A \rightarrow \tau\tau$ (most sensitive), bb, $\mu\mu$
and Charged Higgs$\rightarrow \tau\nu$

A/H →bb

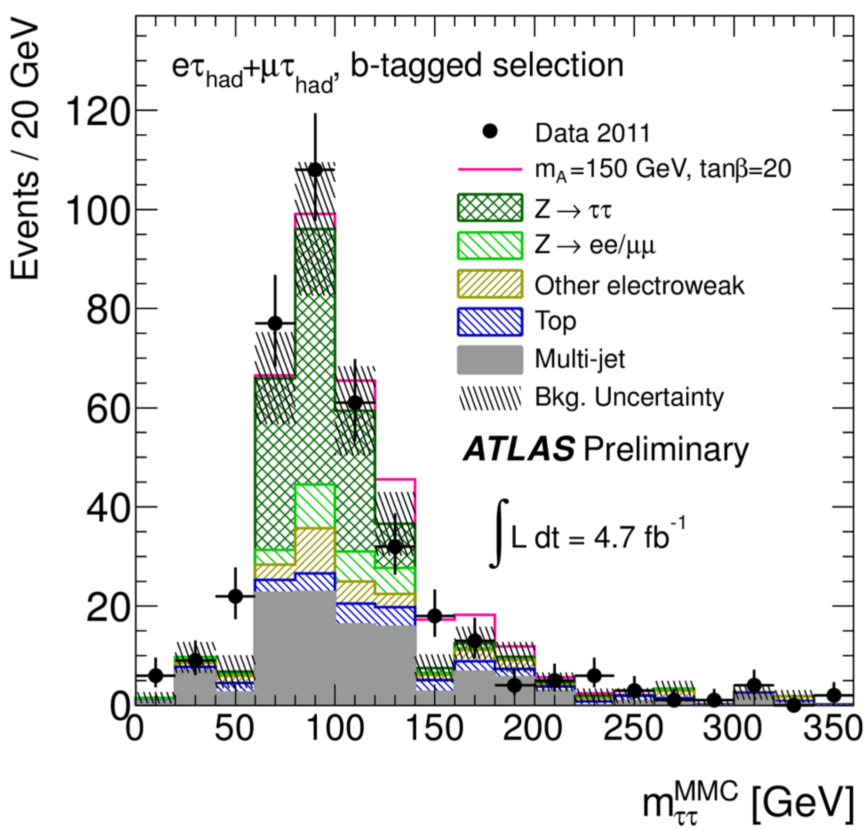
Doable in associated production with b => 3 b final state





Excess seen in Tevatron (2-3 sigmas) not observed at CMS (and probably excluded in simple models)

A/H →ττ

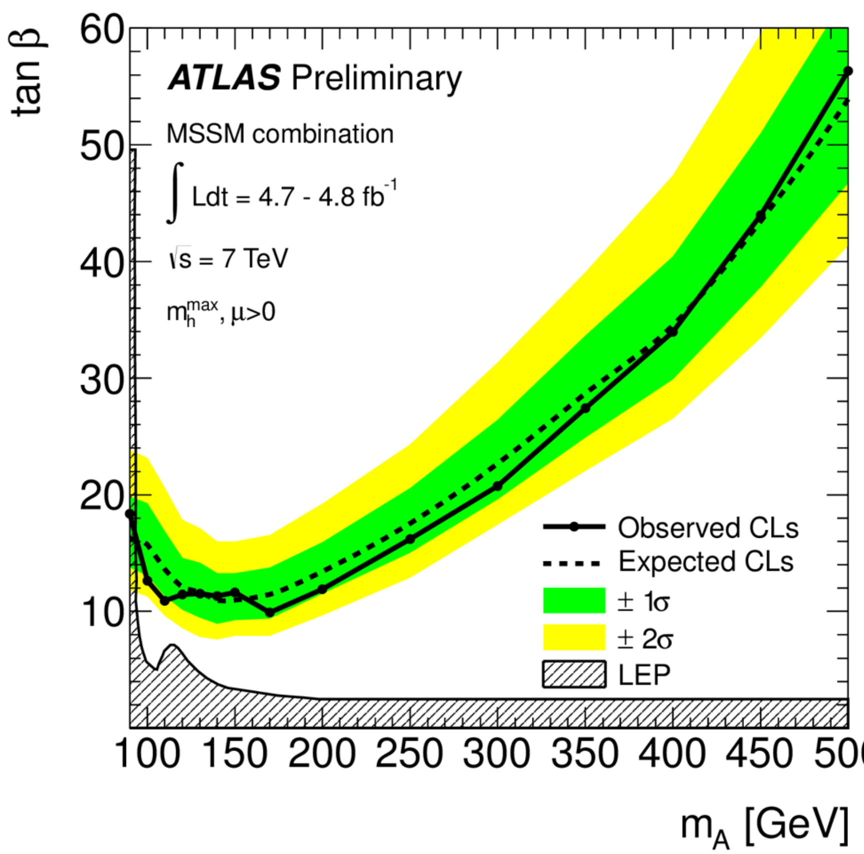


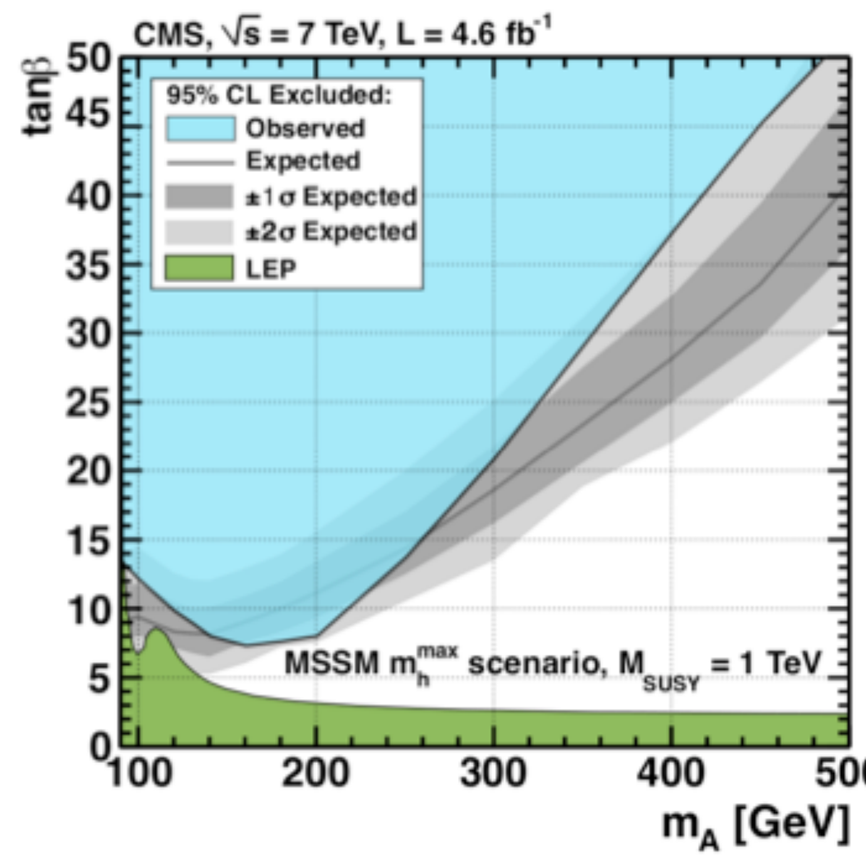
Separate in 0 b-tag and b-tag (associated production)

ATLAS use lepton-lepton, lepton-hadron and hadron-hadron tau final states
CMS uses lepton-lepton and lepton-hadron

di-muon final state also looked at H.Weber

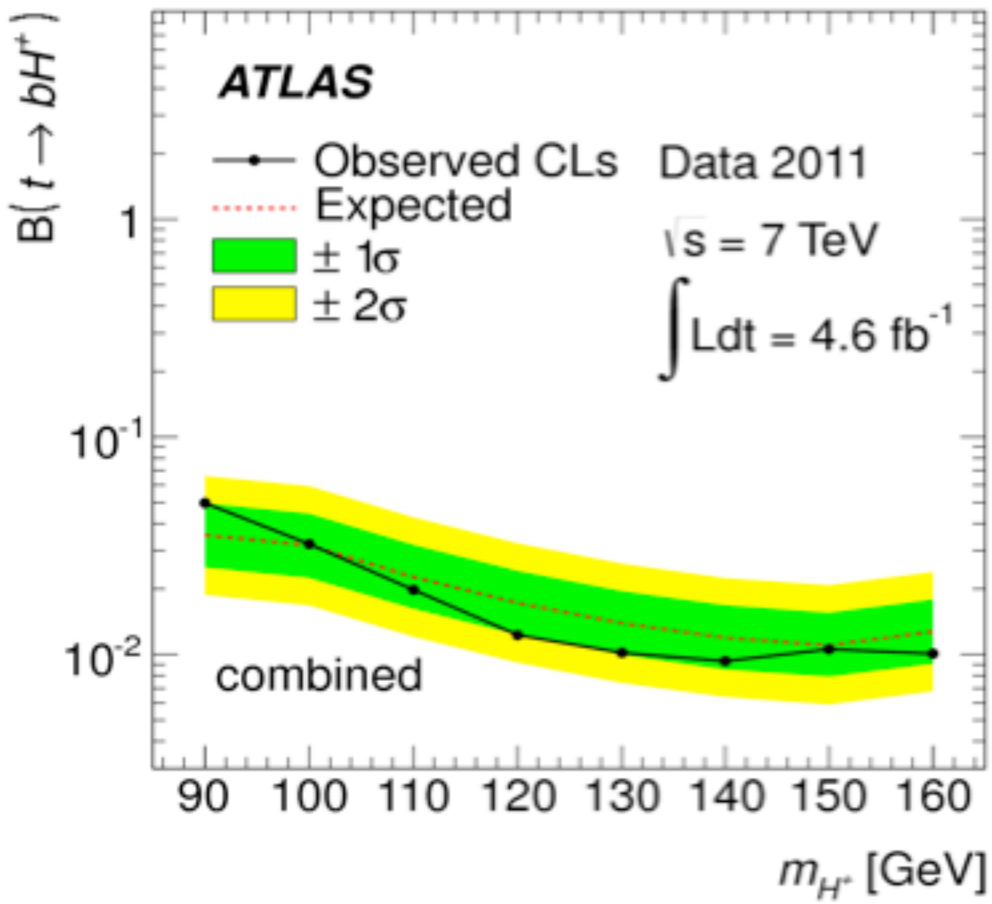
(Tevatron limits reach tan(beta)~20 at MA=150 GeV)

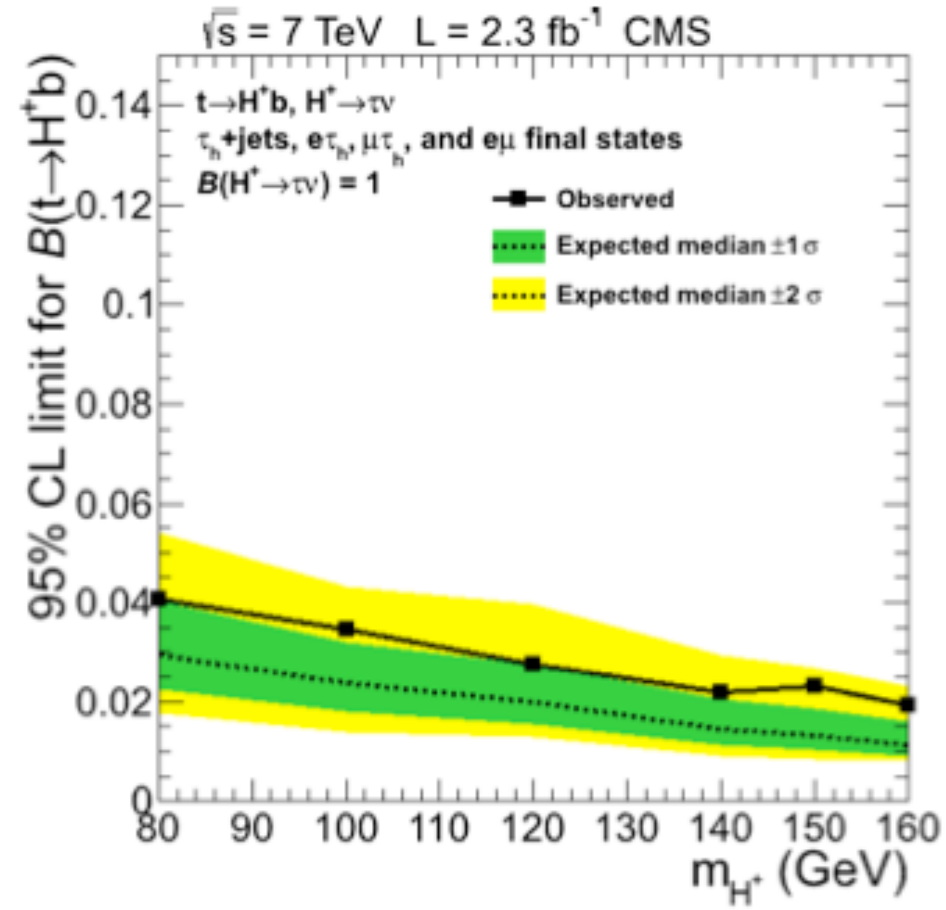




Charged Higgs

Charged higgs searched in top decays so far with $H^{+-} \rightarrow \tau\nu$
Different analysis depending on tau and top decays
(with or without leptons)





Not much room for a H^{+-} lighter than the top

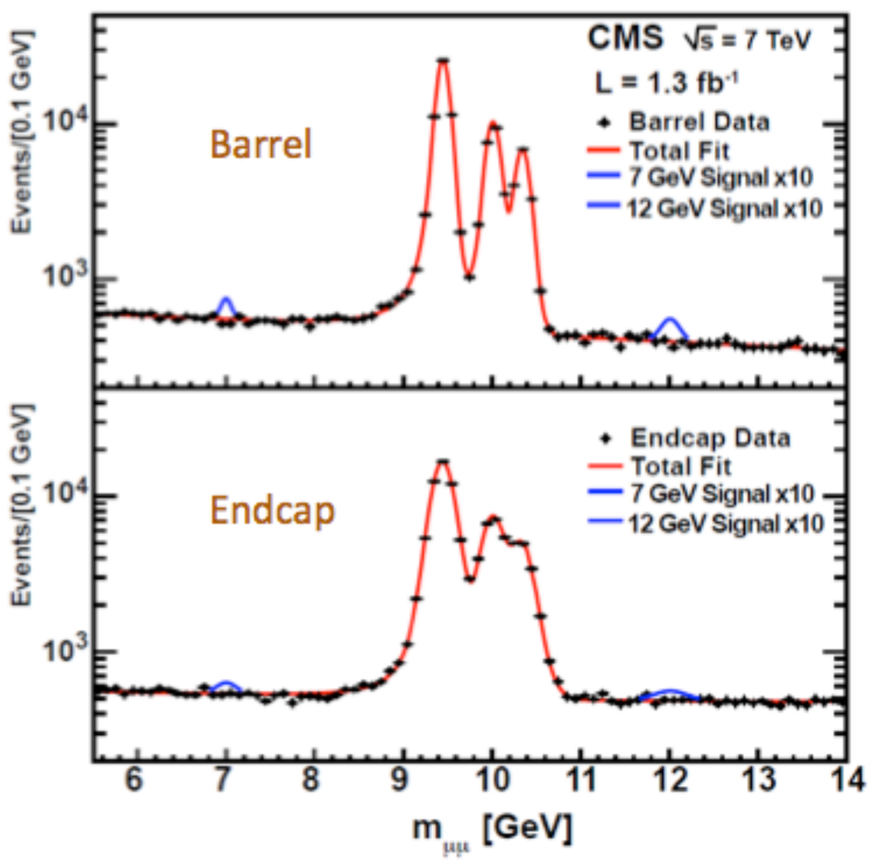
Looking for heavier H^{+-} has not been done yet: Much more complicated tbH^{+-} associated production (smaller cross-section) with H^{+-} decaying to tb (complicated final state) or tau

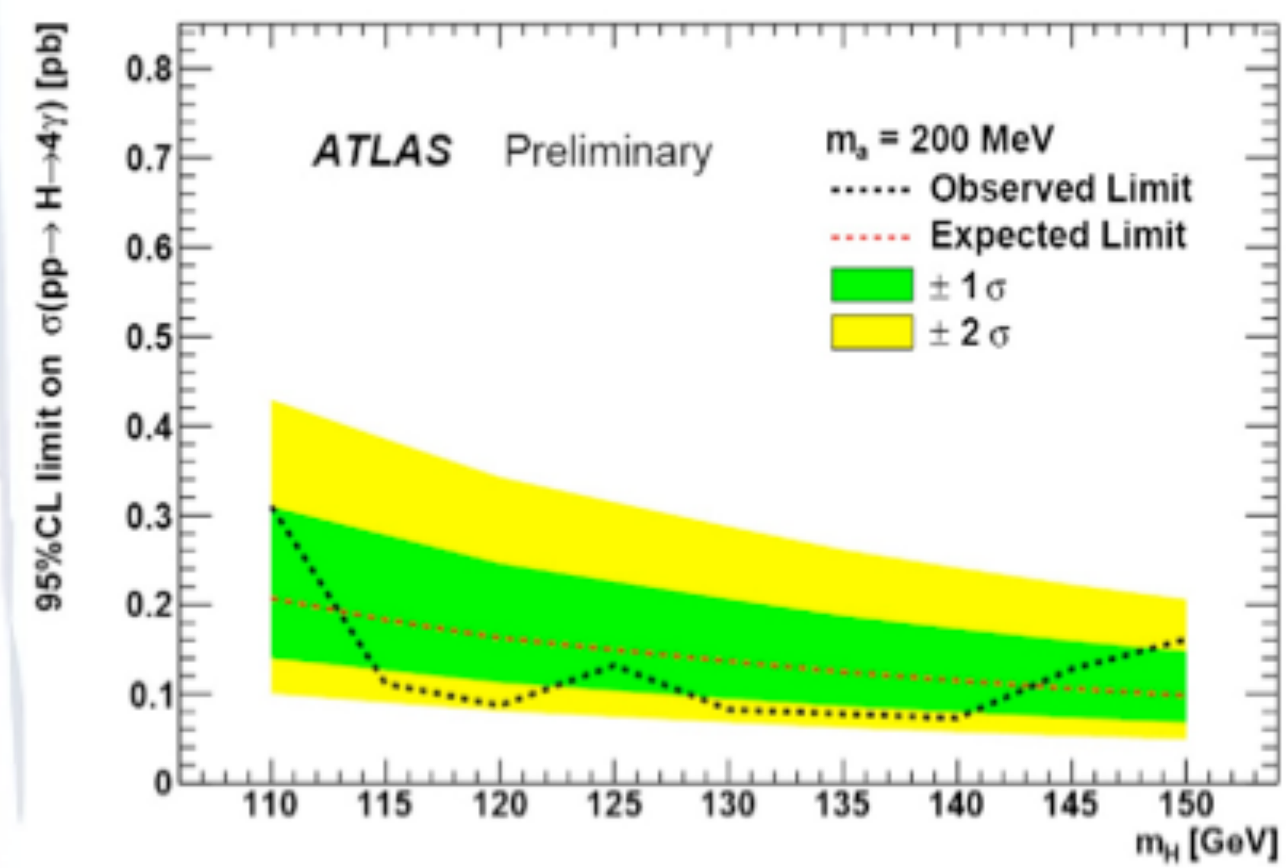
Other BSM Higgs searches

Searches for light A pseudoscalar (in NMSSM inspired models)
- A -> μμ with ~few to O(10) GeV
- H->a a -> 4 γ (very light a)
- H->a a -> 4 μ or 2μ 2τ

Searches for doubly charged Higgs

Higgs decays to hidden valley





Conclusions

A new boson with mass ~125 GeV is observed at LHC, looking «close» to the Standard Model scalar boson

This is the outcome of many years of preparation of the LHC, the experiments (design, R&D, construction, test-beam, preparatory work) and very successful LHC and detector operations since 2010 and also many theoretical progresses in understanding Higgs production and decay

Short term questions:
- Is the rate to gamma-gamma really higher than SM predictions ?
- Can we see tau-tau decays ?
- Can the b-bbar evidence (higher than SM) from the Tevatron be confirmed ?
- Can we have some first spin/CP indication before the end of the year ?

This is of course the beginning of detailed investigations on the properties of this new particle
And also an important input for future collider discussion

for next year workshop...

After a successful «hunt», a «banquet» ? We hope to have at least some food for thoughts from the ongoing run results..