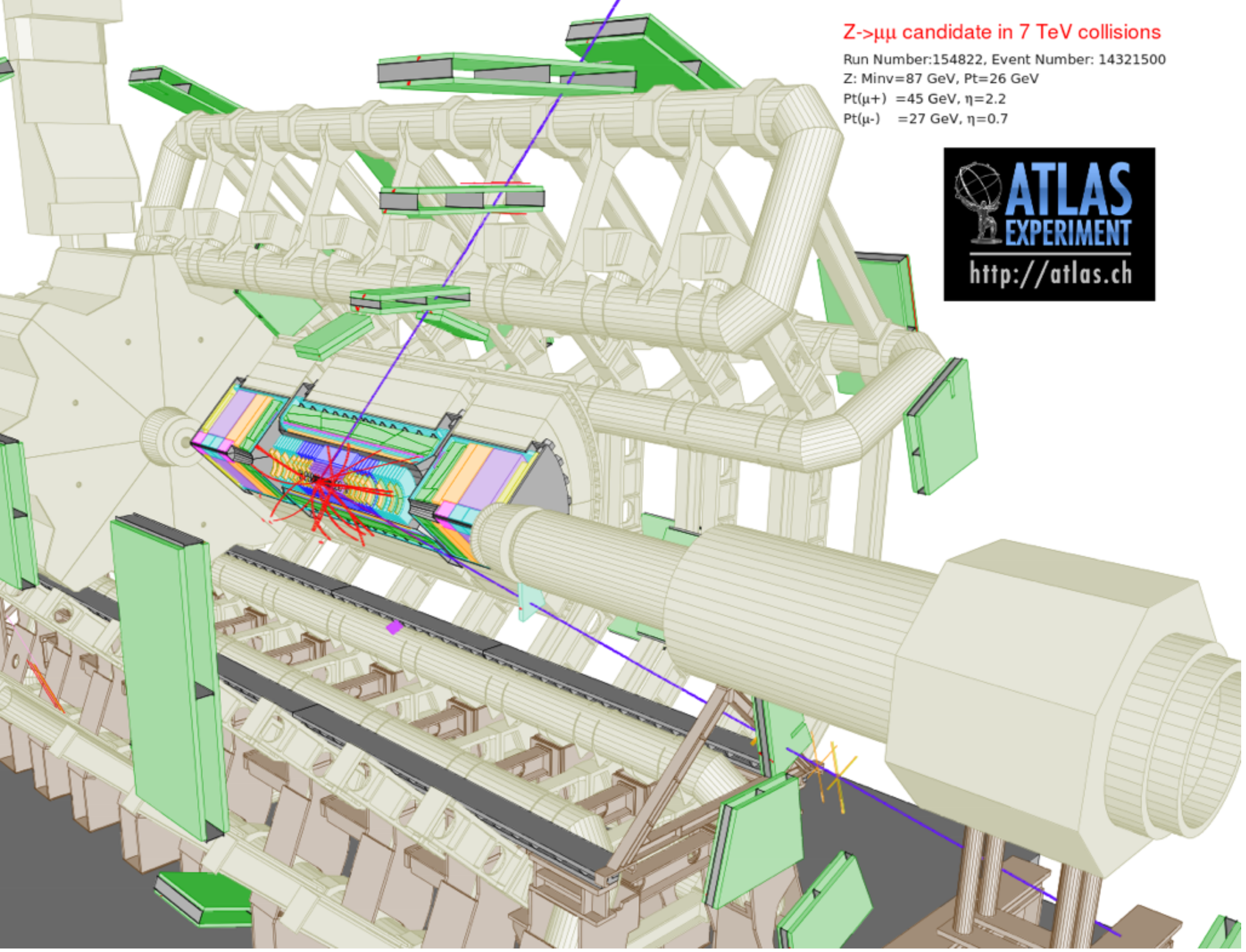
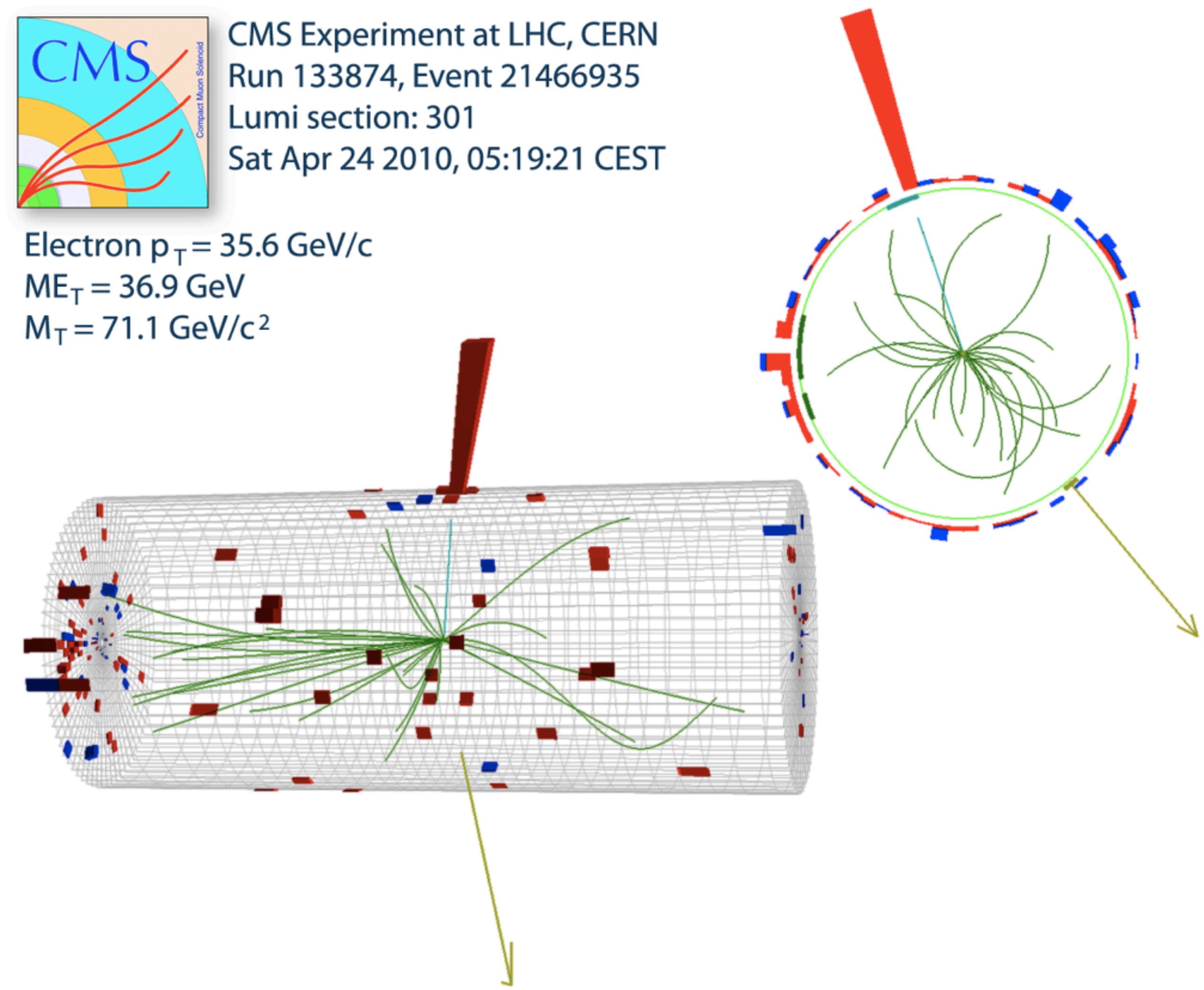



# Higgs Searches with ATLAS and CMS

Konstantinos Nikolopoulos
Brookhaven National Laboratory

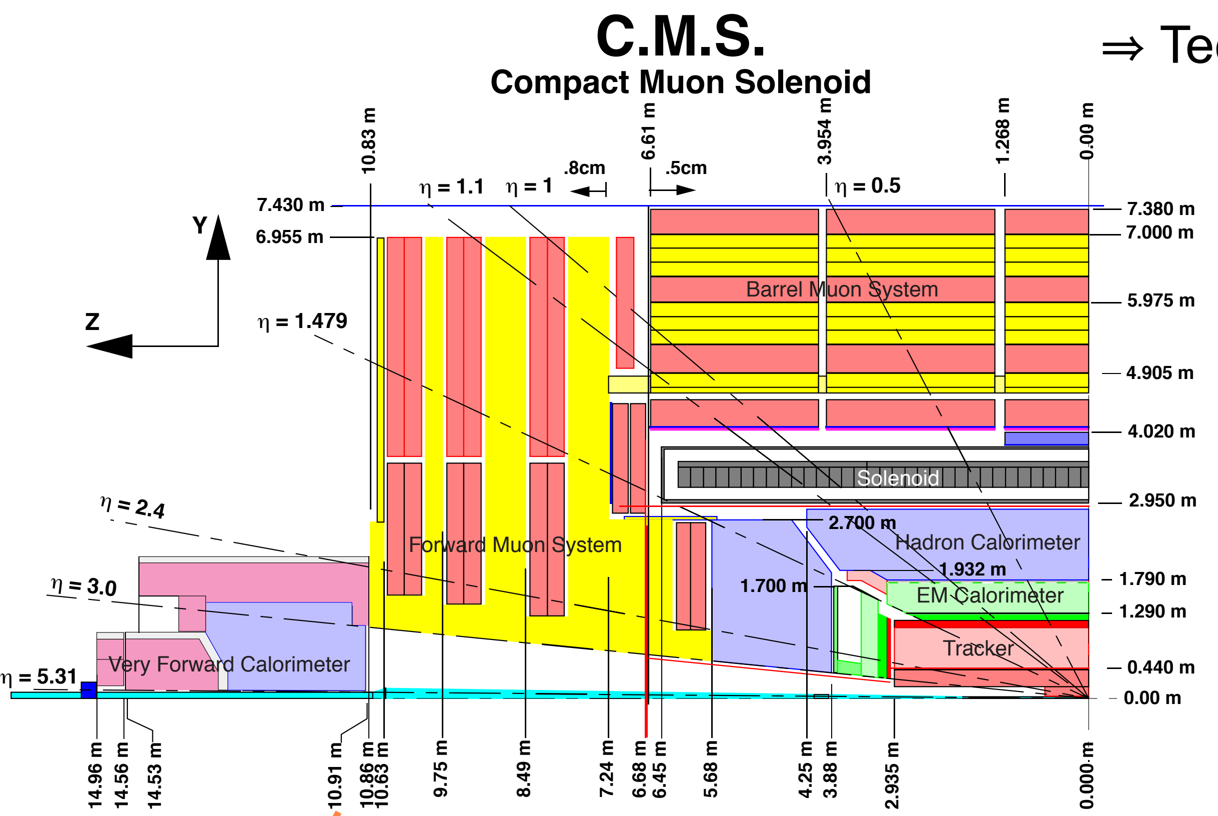
Higgs Cross Sections for the LHC Workshop,
May 4th 2011, BNL

BROOKHAVEN NATIONAL LABORATORY

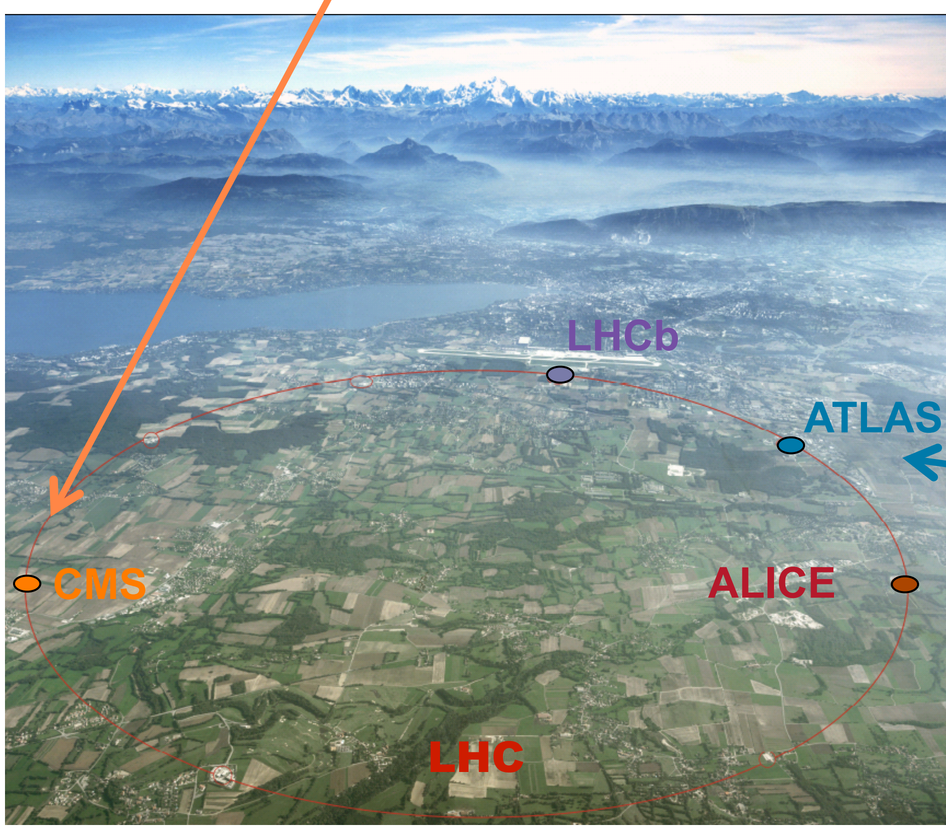
# ATLAS and CMS @ LHC

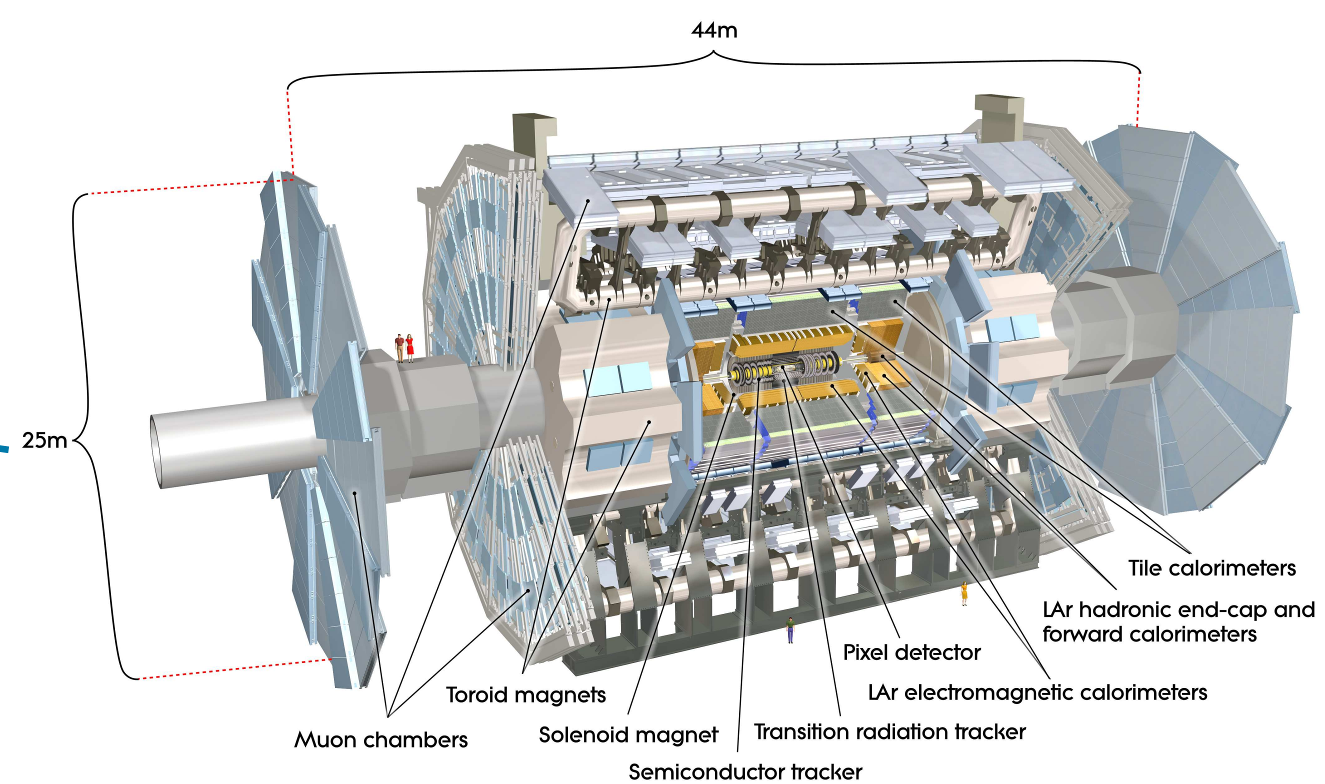
⇒ General purpose detectors at the LHC → different design choices

⇒ Technological/design diversity for the harsh LHC environment

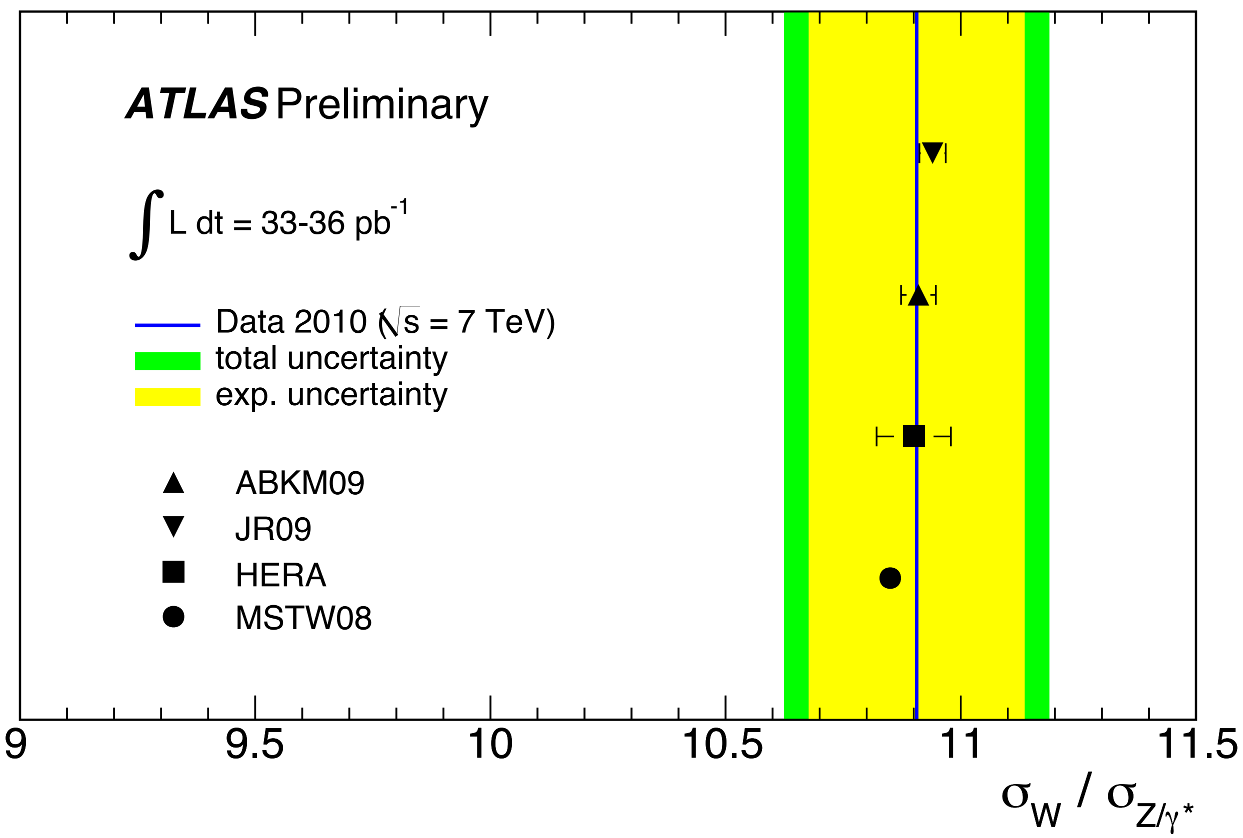


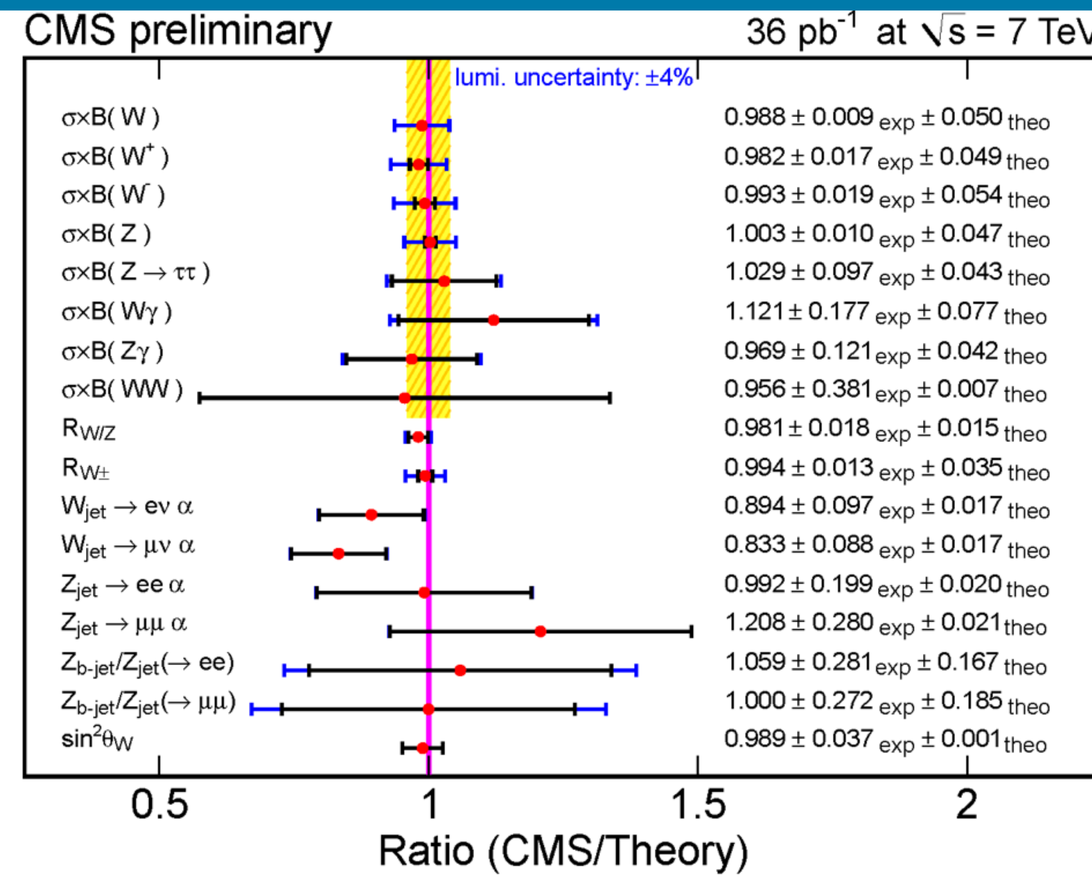

| | ATLAS | CMS |
|---|---|---|
| Magnets | 2T solenoid<br>3 air-core toroids | 3.8T solenoid<br>iron return |
| Tracking | silicon + transition radiation tracker | all silicon |
| EM Calorimetry | sampling<br>LAr technology | homogeneous scintillating crystals |
| Hadron Calorimetry | plastic scintillator (barrel)<br>LAr technology (endcap) | plastic scintillator |
| Muon | independent system with trigger capabilities | muon id and trigger |



# LHC in 2010



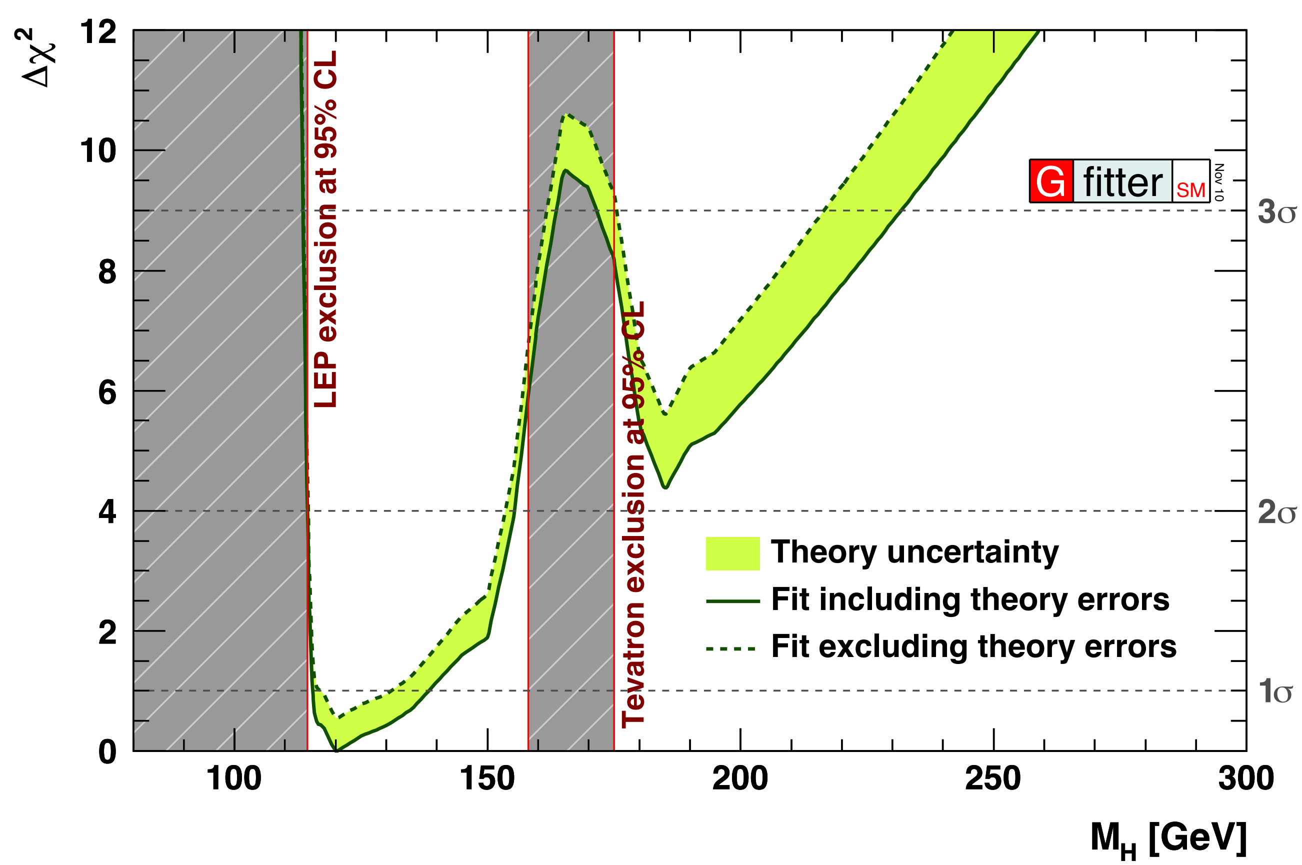




⇒ 48 pb$^{-1}$@ 7TeV delivered by LHC during 2010

⇒ 35 - 43 pb$^{-1}$ for **physics**

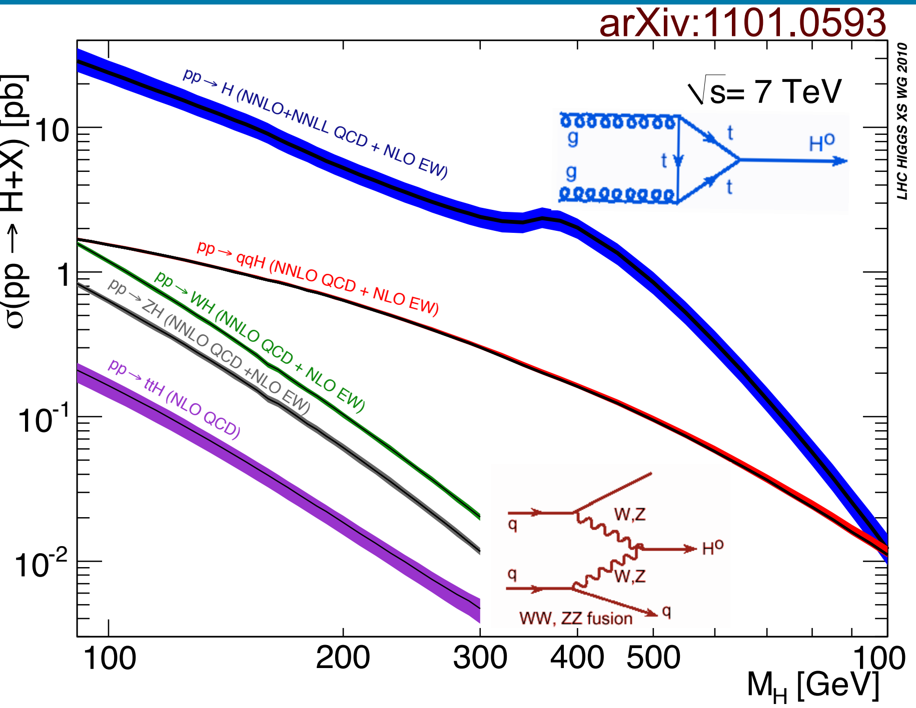
⇒ Peak stable luminosity 2.1×10$^{32}$cm$^{-2}$s$^{-1}$

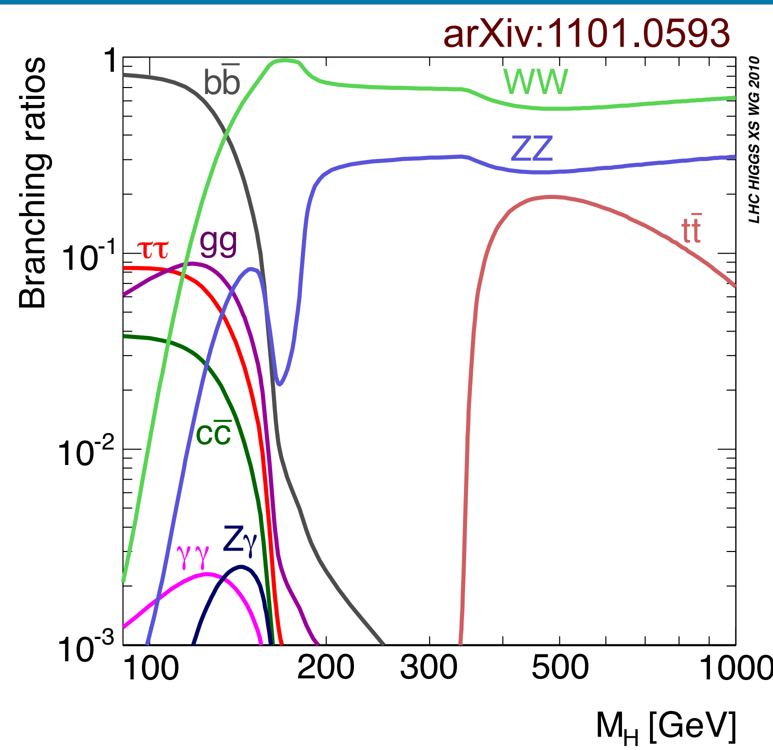
⇒ Max <interactions/bunch-crossing>=3.8




The (SM) Higgs boson is the holy-grail of high energy physics for the last decades: Both experiments already looking!

# Higgs Boson Production @ LHC




## SM Higgs Boson Production

⇒ gluon fusion dominates

⇒ VBF relative contribution rises with $M_H$

## SM Higgs Boson Decays

⇒ H→WW dominates

⇒ H→ZZ follows

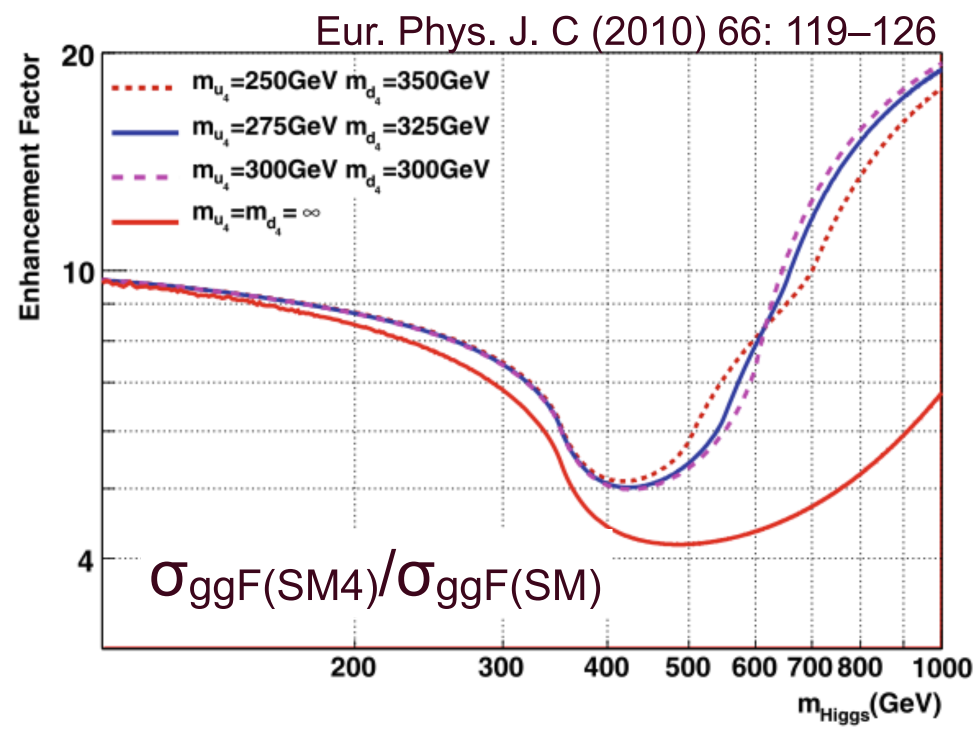
⇒ H→γγ low BR/distinct final state

⇒ BSM 4th generation models

→ enhancement of gluon fusion Higgs production

⇒ Light neutral and charged Higgs bosons in MSSM

→ enhanced coupling to 3rd generation fermions




Short note on 95% CL exclusion limits

**ATLAS**: Frequentist $CL_{S+B}$ (test statistic: profile likelihood ratio) and power constraint ($CL_{S+B}$ >16%)

→ results with $CL_S$ also available

**CMS**: Both Bayesian method (flat prior and nuisance parameter marginalization) and $CL_s$ used

→ found to give similar results

# $H \rightarrow \gamma\gamma$

⇒Sensitive at challenging low $M_H$ region

⇒Main Backgrounds:

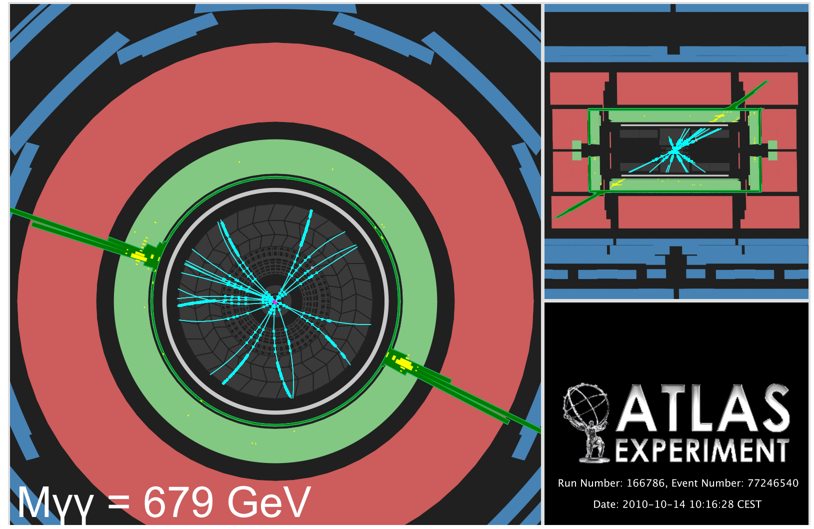
  di-photon → $M_{\gamma\gamma}$ resolution

  jj and γj → photon-ID

<u>Selection</u>:

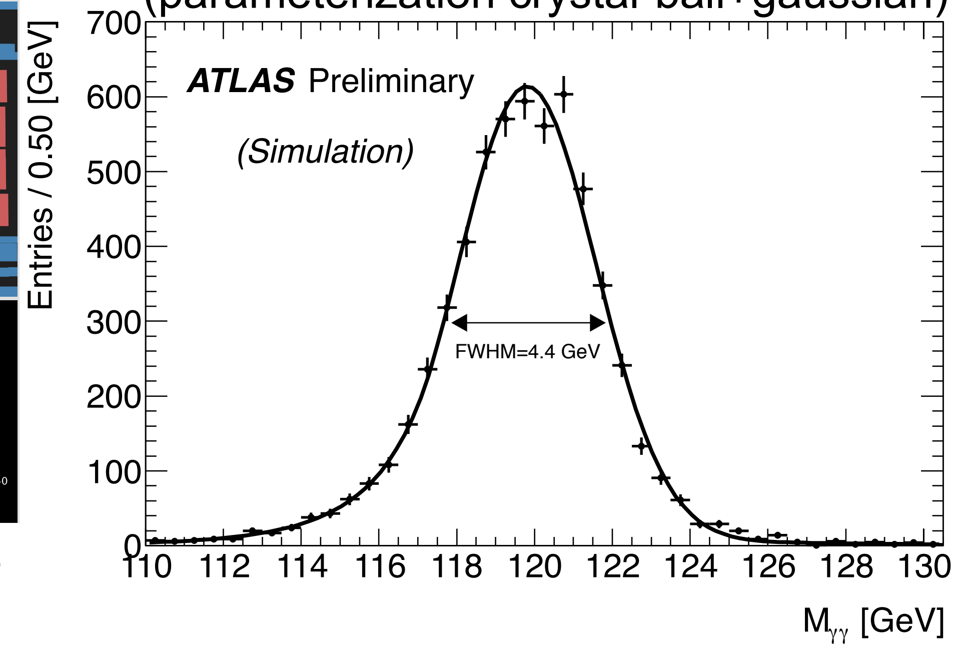
2 high-pT isolated γ (40/25GeV)

<u>Data-driven background estimation</u>:

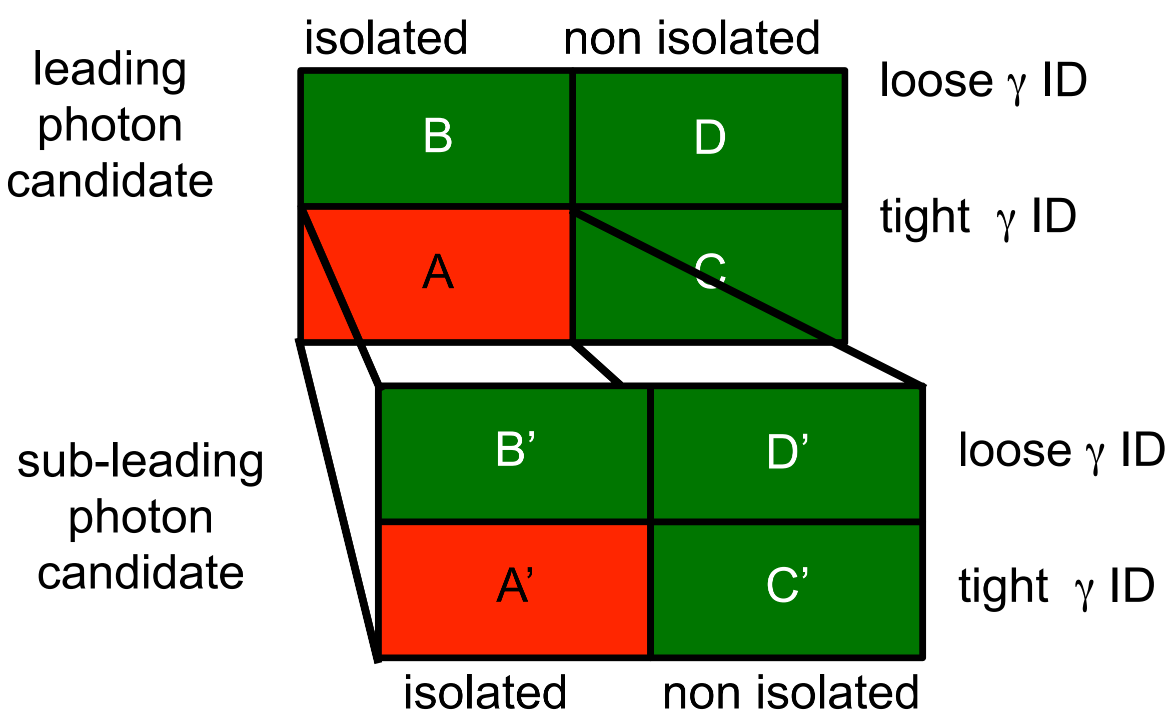


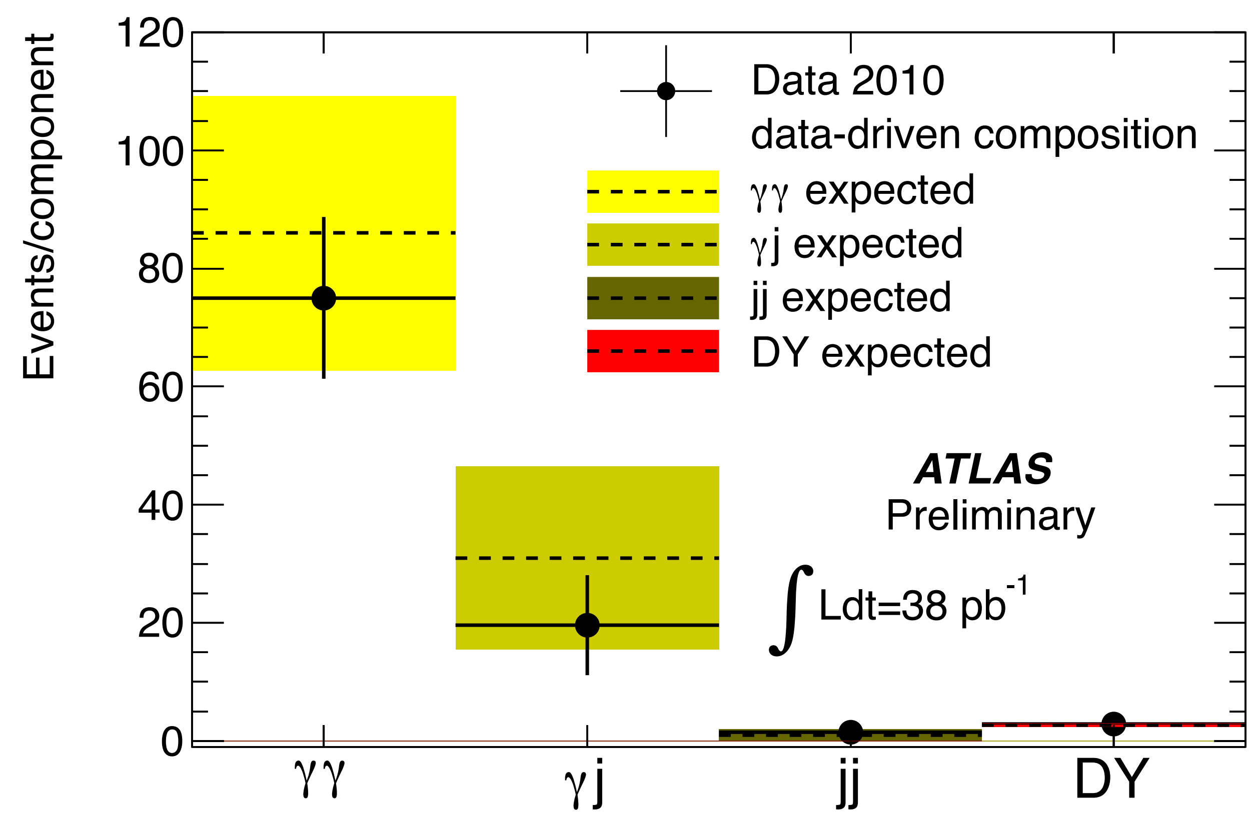

2010 highest mass γγ candidate

(parameterization crystal-ball+gaussian)

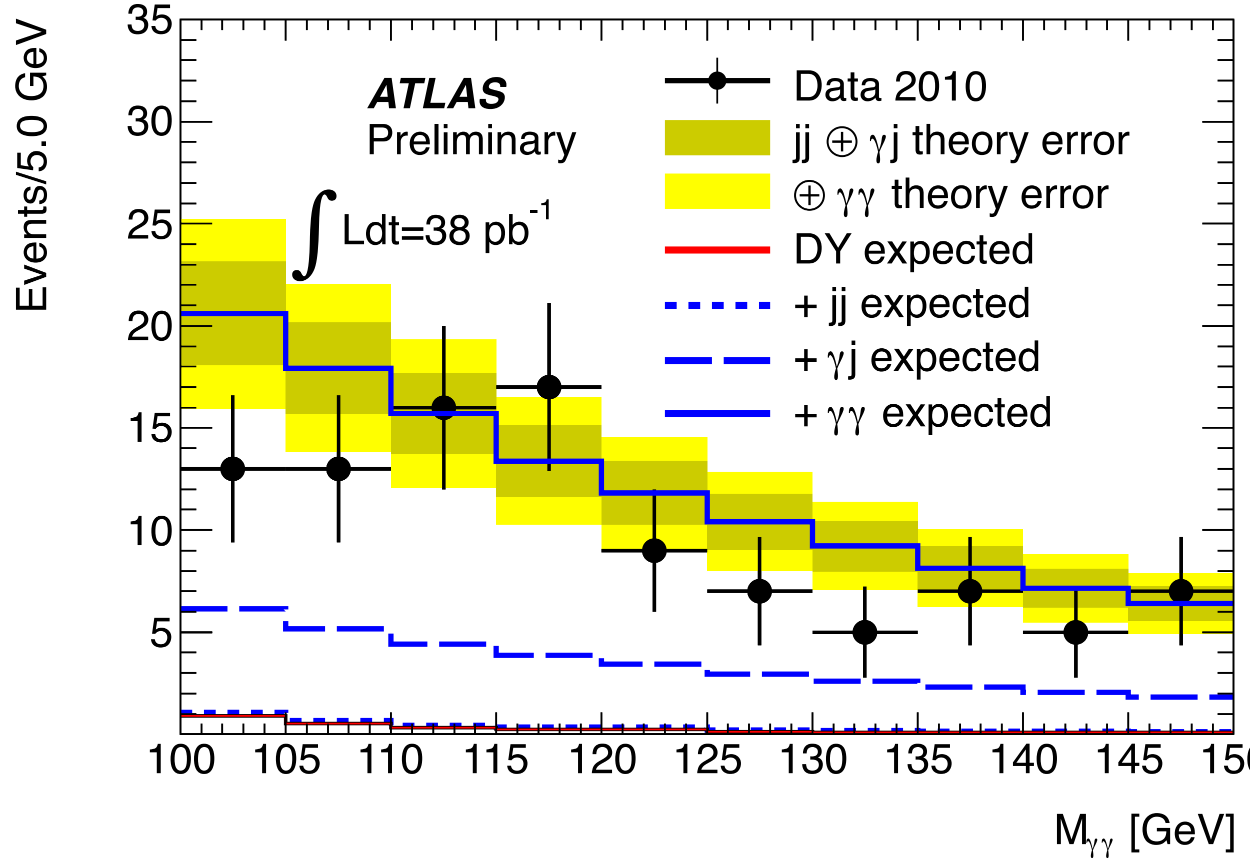


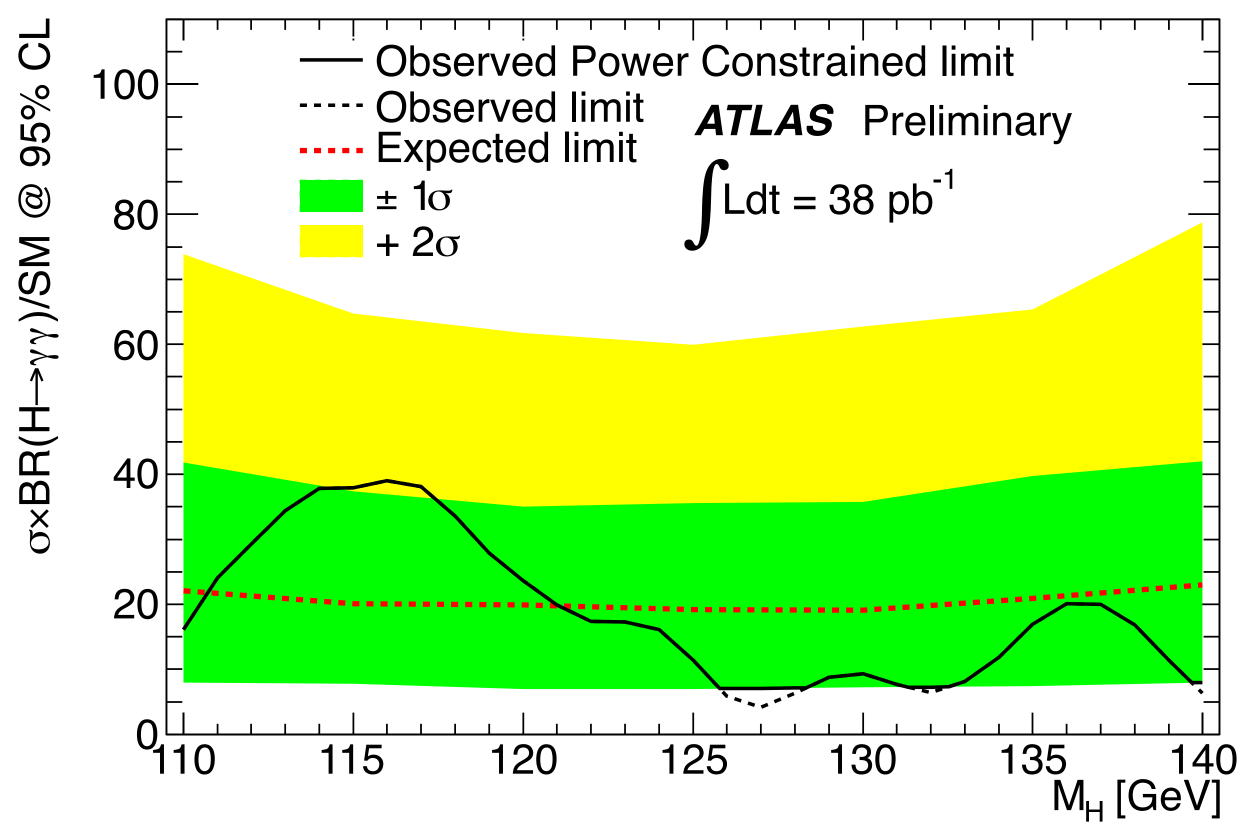

- Jet fragmentation/cross sections uncertainties → MC expectation unreliable
- Estimate separate contributions (γγ,jγ,γj,jj) using double-ABCD method
- Z→ee tag-and-probe for "e→γ" fake rate



# $H\rightarrow\gamma\gamma$




| Higgs boson mass [GeV] | 110 | 115 | 120 | 130 | 140 |
|---|---|---|---|---|---|
| Number of signal events | $0.43^{+0.11}_{-0.09}$ | $0.45^{+0.11}_{-0.10}$ | $0.45^{+0.11}_{-0.10}$ | $0.41^{+0.10}_{-0.08}$ | $0.31 \pm 0.08$ |

⇒ 99 events passing the full selection with 100GeV<$M_{\gamma\gamma}$<150GeV

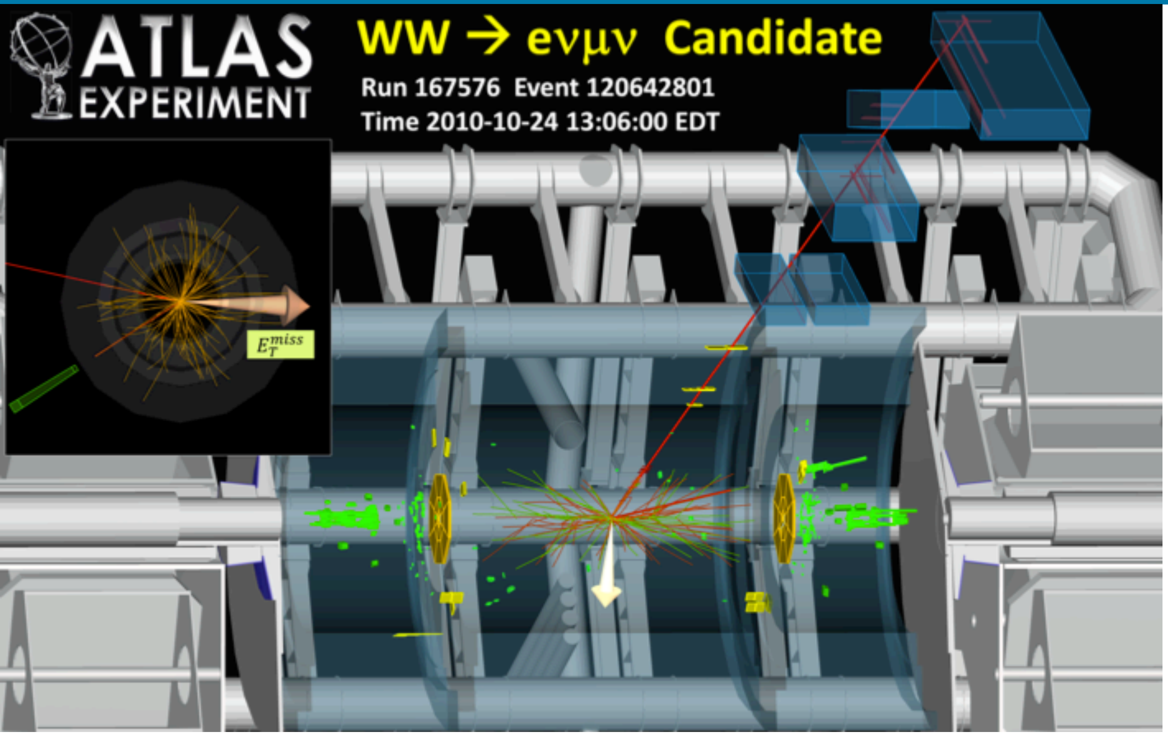
⇒ Maximum likelihood fit to exponential background and signal templates

⇒ Expected exclusion limit ~20x$\sigma_{SM}$ for 110GeV<$M_H$<140GeV

⇒ Observed limit between 8x$\sigma_{SM}$ ($M_H$=127 GeV) to 38x$\sigma_{SM}$ ($M_H$=116 GeV)

⇒ Sensitivity is in the same ballpark with Tevatron results (up to 8.2 $fb^{-1}$)

# H→WW→lνlν




⇒ Most sensitive channel for $M_H$ between 130 and 190 GeV

⇒ Main background: WW production, ttbar, Z+jets, W+jets,

**ATLAS**

⇒ Bin analysis in lepton flavor and jet multiplicity

→(ee,eμ,μμ) × (0j,1j,2j) = 9 channels

⇒ 0/1jet optimized for gluon fusion

⇒ 2jet optimized for VBF

(tag jets opposite hemispheres, rapidity gap)

**CMS**

⇒ Bin analysis in lepton flavor

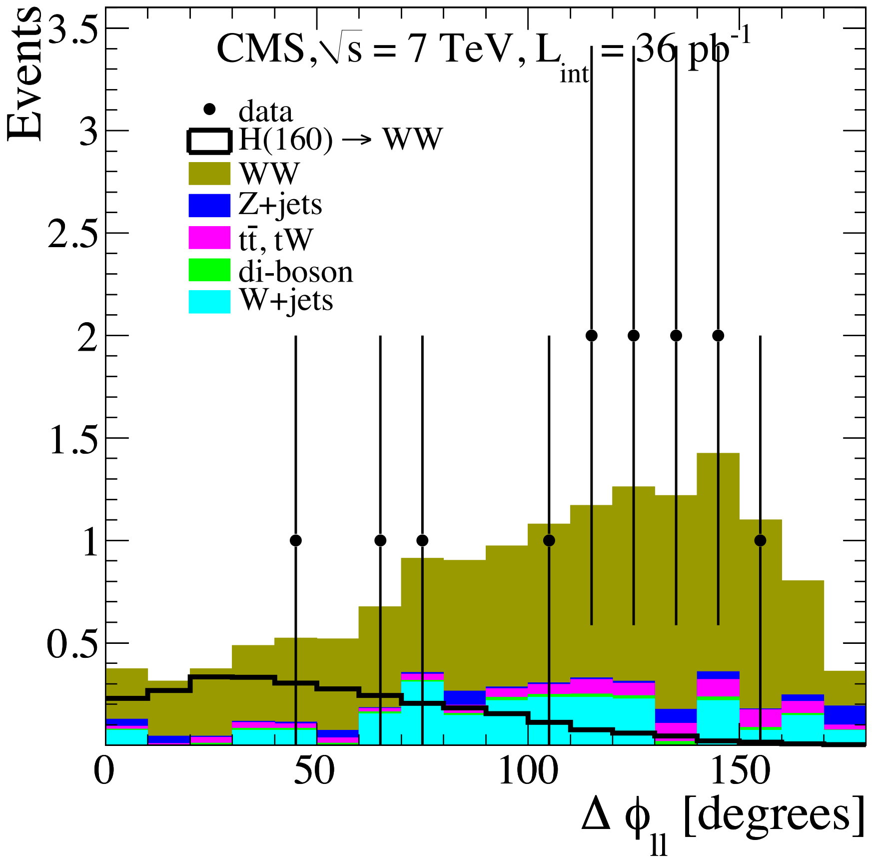
⇒ 0 jet channel only

<u>Event Preselection</u>

- 2 isolated high $p_T$ leptons (e,μ) [QCD, W+jets]
- Lower bound for $M_{ll}$ to suppress low mass resonances
- Z-veto in same flavor events [Drell-Yan]
- MET or projected MET requirement [Drell-Yan]

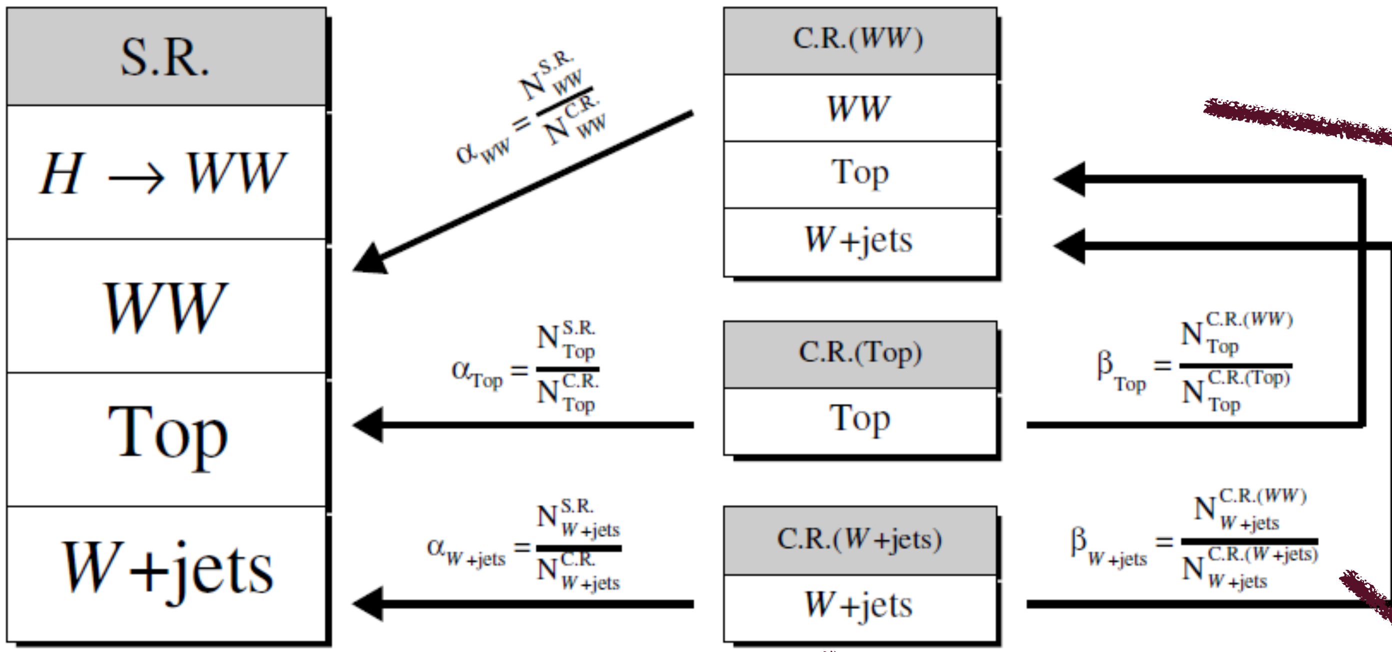
⇒Major Discriminating power against irreducible WW

- $P_T$
- $\Delta\phi_{ll}$
- $M_{ll}$
- $M_T$

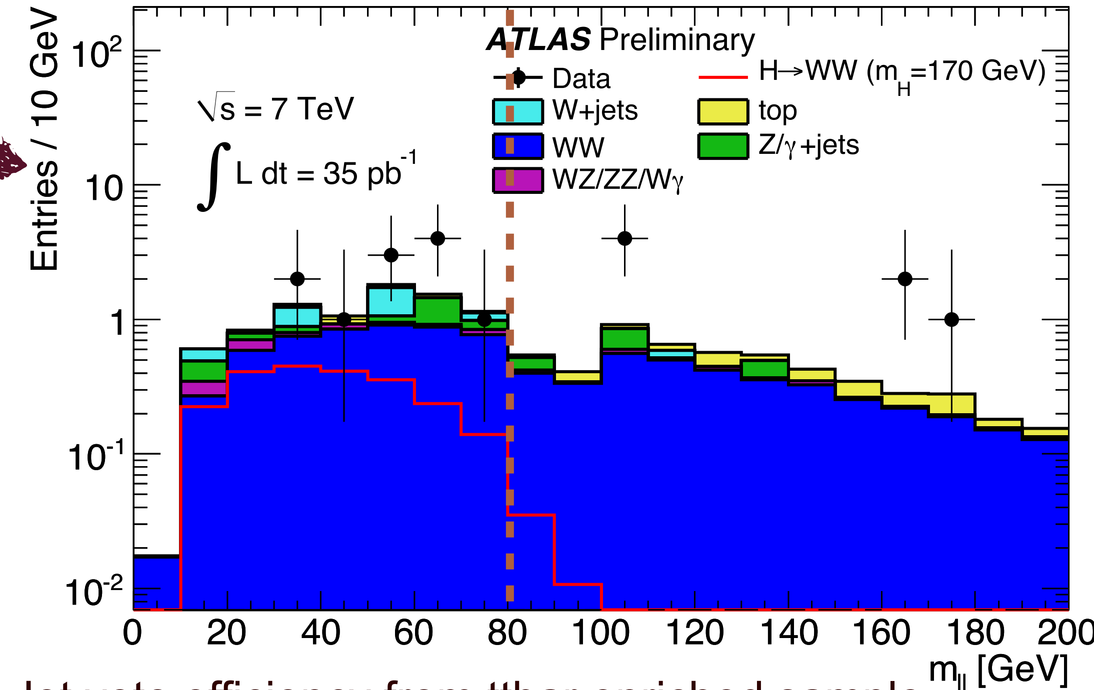


# H→WW→lνlν : Data driven Backgrounds

**Background Estimate**: Data-driven extensive use of control regions and fit of the signal and background model.



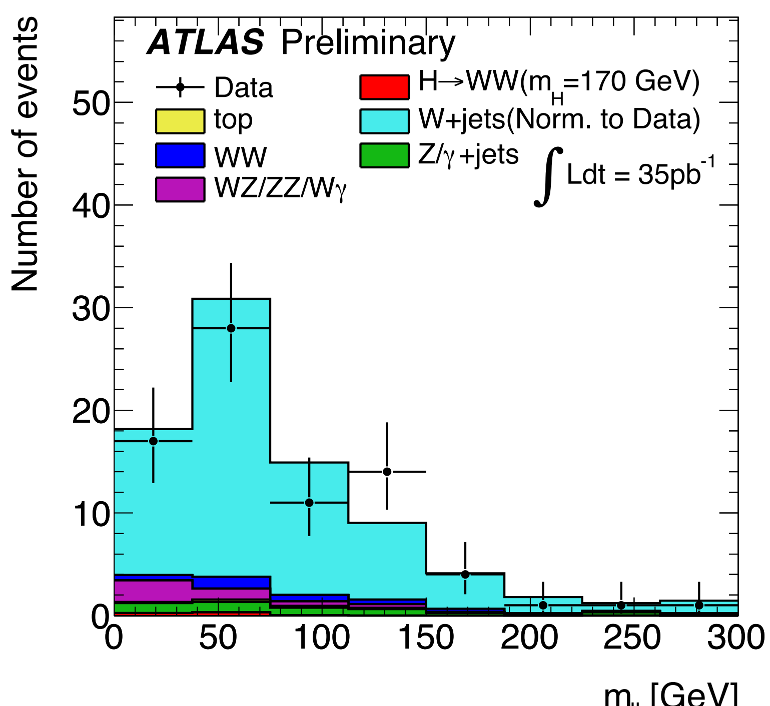

Relax angular requirement
Low Mass Higgs → High $M_{ll}$ WW dominated
High Mass Higgs → Low $M_{ll}$ WW dominated

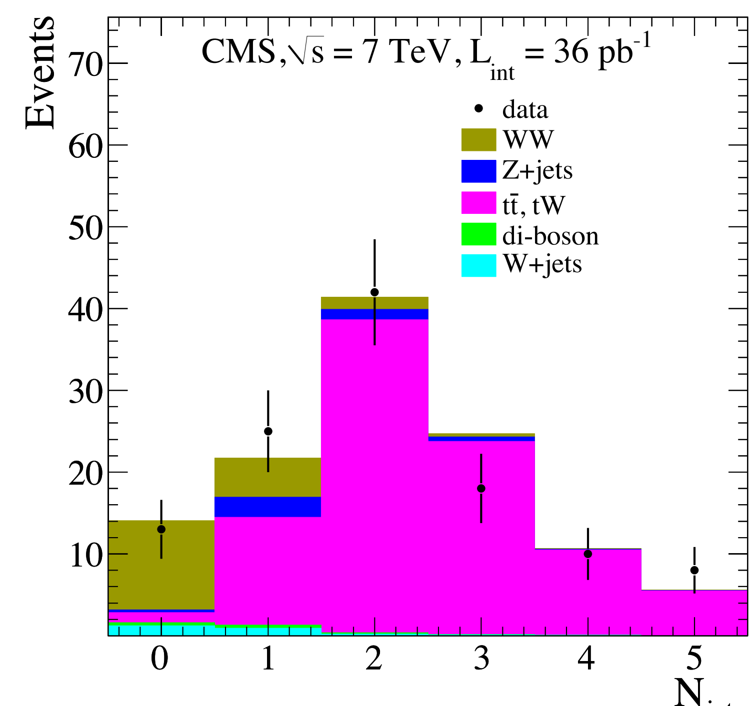



Z+jets background estimated using ABCD method

Relax lepton ID requirements in one of the leptons
Measure fake rate from independent sample

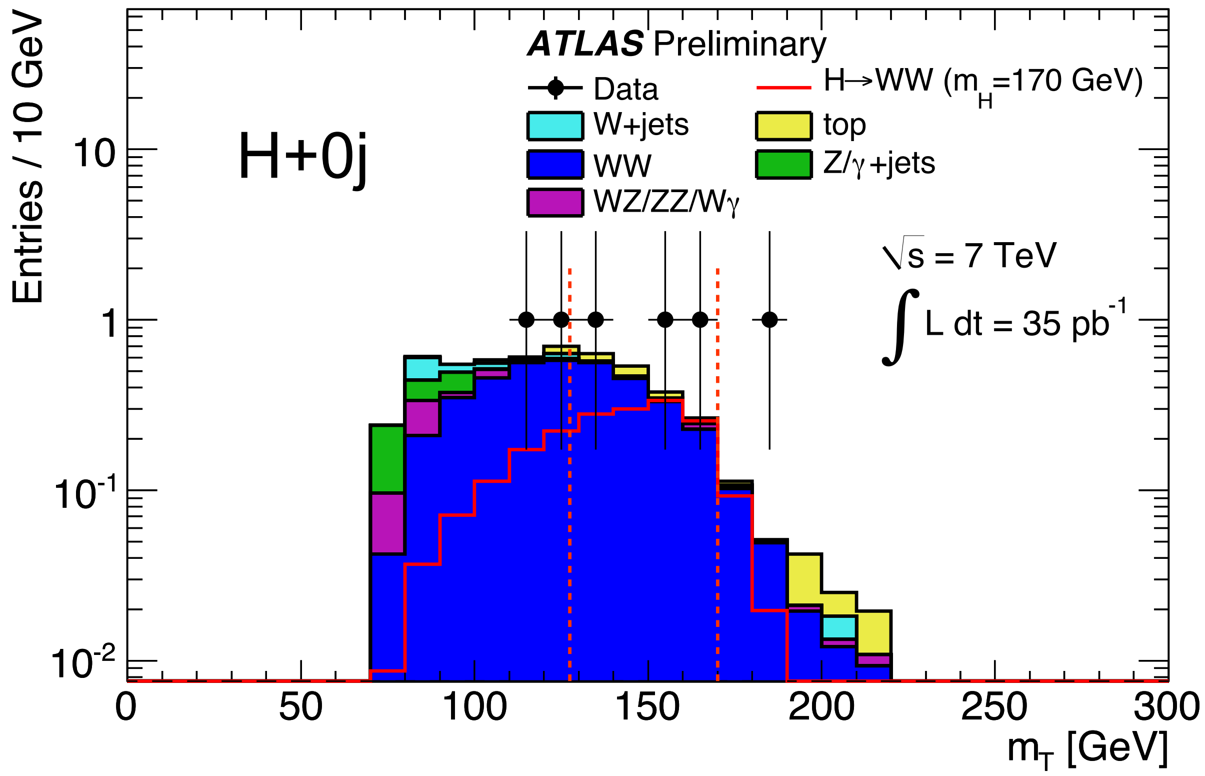
Jet veto efficiency from ttbar enriched sample using b-tagging, then apply it to ll+MET sample for 1/2 jet analysis reverse b-veto

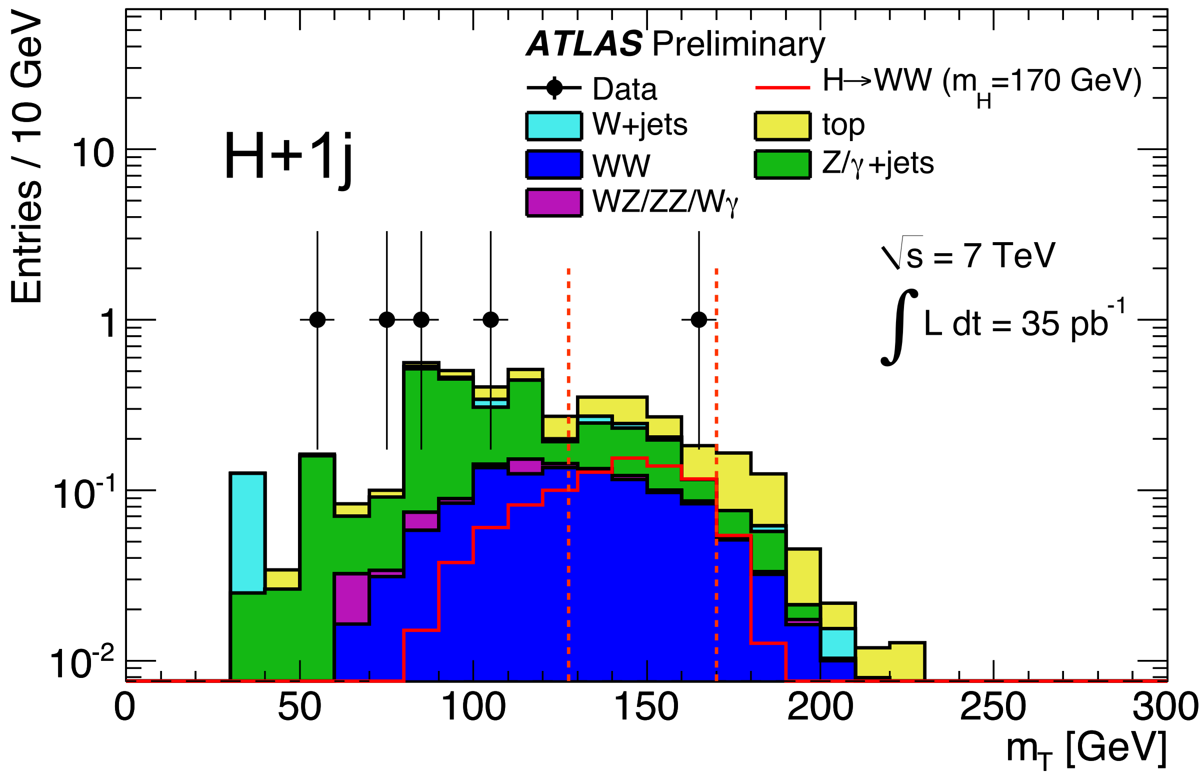



CMS checks after jet veto effect of b-tagging on remaining events
→ in agreement with MC

# H→WW→lνlν



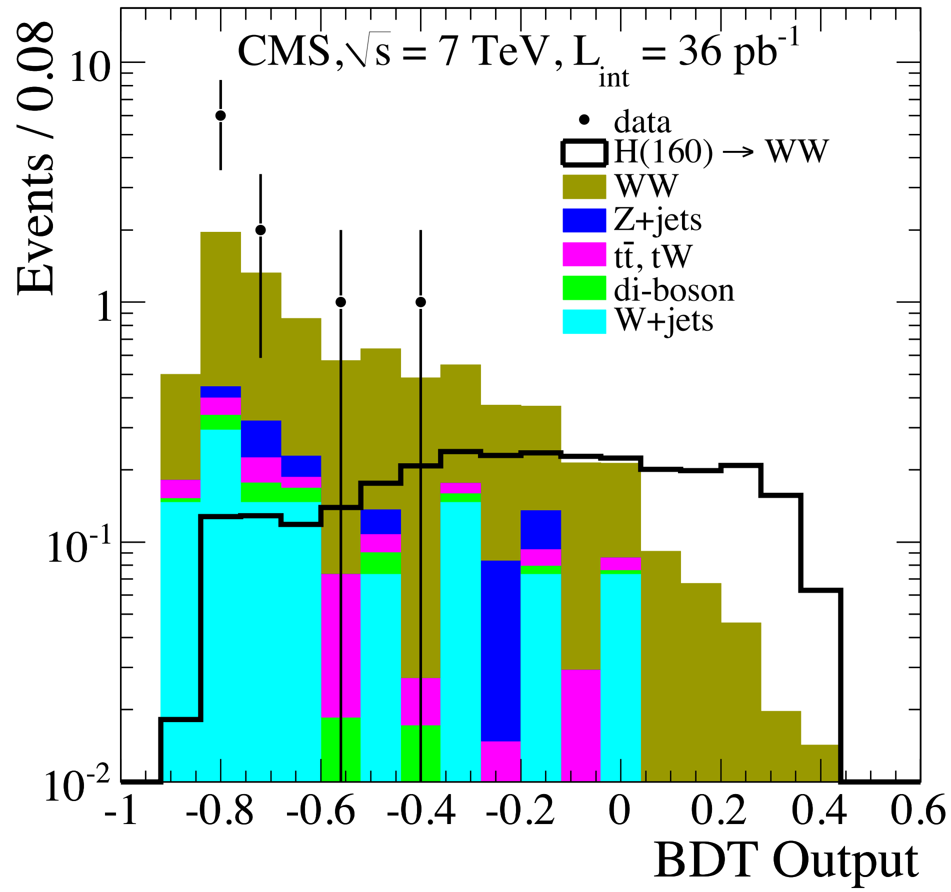




⇒ In ATLAS the final discriminant is the transverse mass

$$0.75M_H < M_T = \sqrt{\left(E_T^{\ell\ell} + E_T^{miss}\right)^2 - \left(\vec{P}_T^{\ell\ell} + \vec{P}_T^{miss}\right)^2} < M_H$$

⇒ In CMS output of Boosted Decision Tree

→ cut-based also available



# H→WW→lνlν : Jet Veto Uncertainty

**CMS**

Physics Letters B 699 (2011) 25–47

*5.3. Systematic uncertainties*

Systematic uncertainties related to acceptance and efficiencies for $H \to W^+W^-$ are estimated in a similar way as described in Section 3.3.

Simulated events are used to predict the $H \to W^+W^-$ signal efficiency, and $Z \to \ell^+\ell^-$ events are used to study the data-to-simulation efficiency scale factors of the lepton selection and jet veto requirement. Due to details in the implementation of the POWHEG calculation [47], the resulting Higgs boson $p_T$ spectrum is harder than the most precise spectrum calculated [48] to NNLO with resummation to next-to-next-leading-log (NNLL) order. Therefore, the Higgs boson $p_T$ distribution is reweighted in POWHEG to match the NNLO+NNLL prediction. The signal efficiency, estimated after this reweighting, is 14% larger than that from uncorrected POWHEG calculations, and it is independent of the Higgs boson mass. This effect is expected since harder $p_T$ spectrum of Higgs is associated with more initial state radiation, which makes the jet veto efficiency lower.

The overall uncertainty on the $H \to W^+W^-$ signal yield is estimated to be of about 14%, where the uncertainty on the jet veto efficiency and the luminosity determination are the main contributions. The uncertainties on the background estimations in the $H \to W^+W^-$ signal regions are about 40%, dominated by statistical uncertainties in the data control regions.

**ATLAS**

⇒ substantial uncertainty on fraction of gluon fusion events in 0/1/2 jets : 10/6/35%

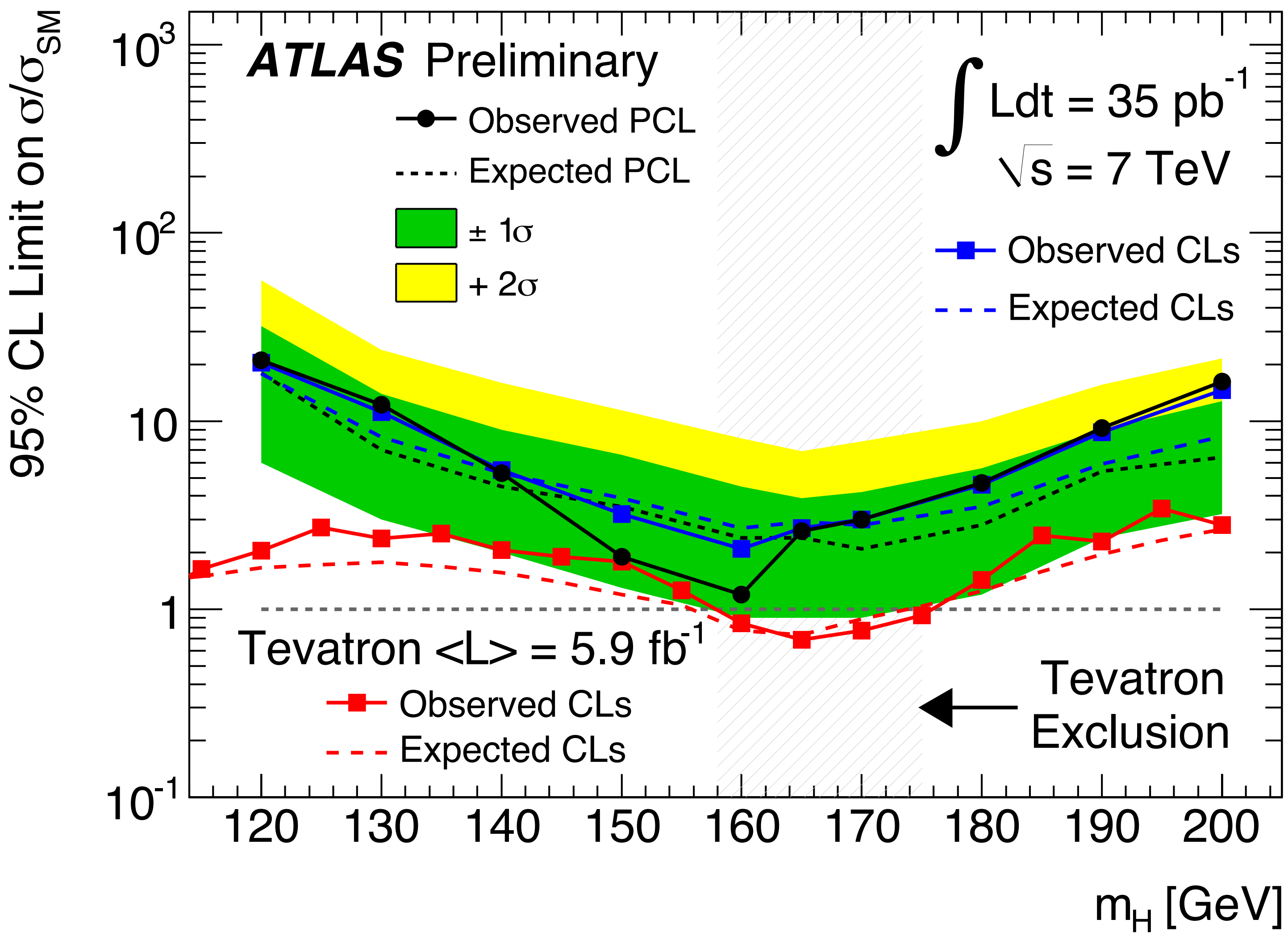
⇒ dominated by scale uncertainties.

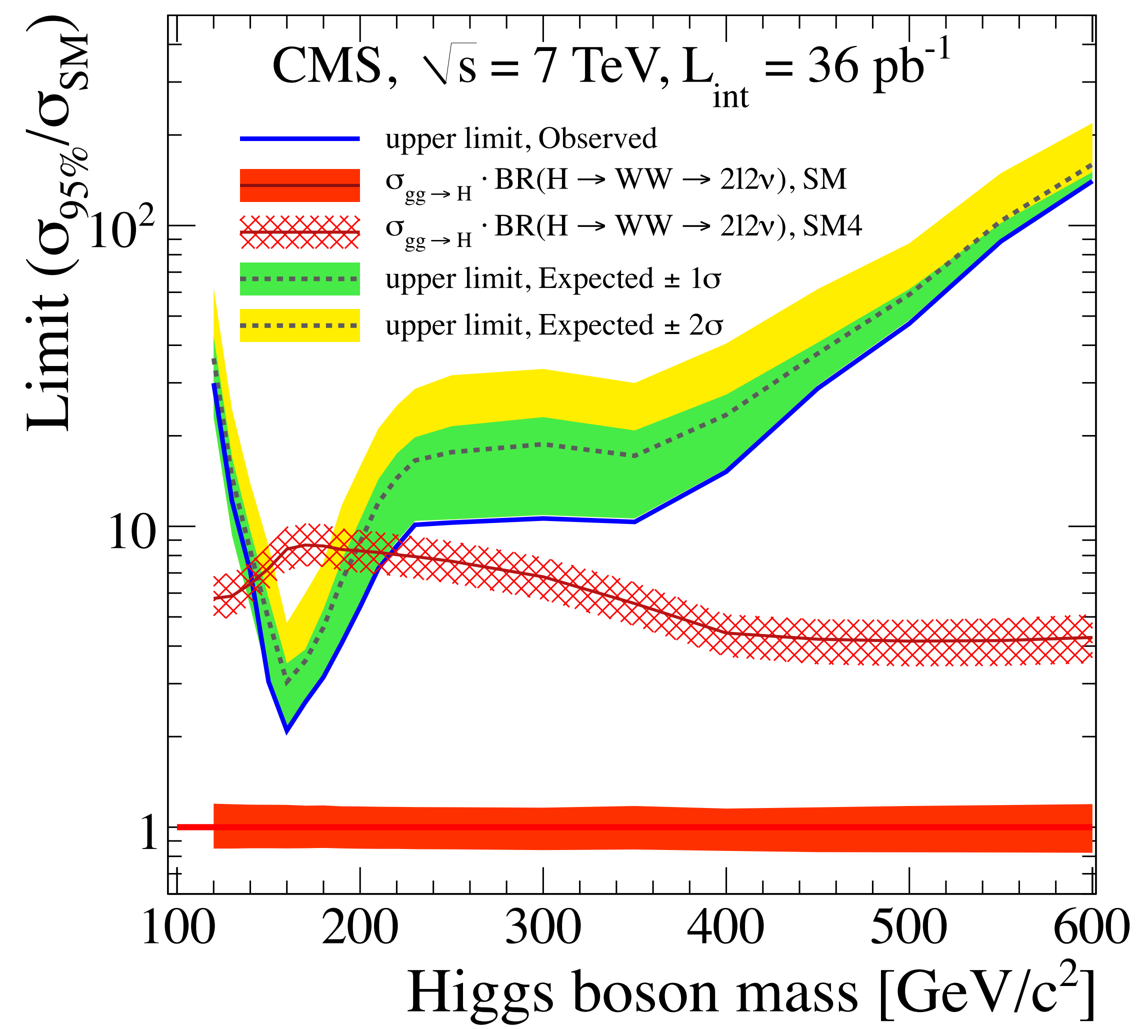
Analyses binned in jet multiplicity or using Central Jet Veto in VBF production are more sensitive to theoretical uncertainties.

→ Large logarithms depending on the jet thresholds involved in cross section calculation

⇒ Characteristic example where input from LHC Higgs cross section WG is needed

# H→WW→lνlν : Exclusion Limits




⇒ At $M_H$=160 GeV

→ ATLAS excludes 2.1×$\sigma_{SM}$ (obs) and 2.7×$\sigma_{SM}$(exp) $CL_S$

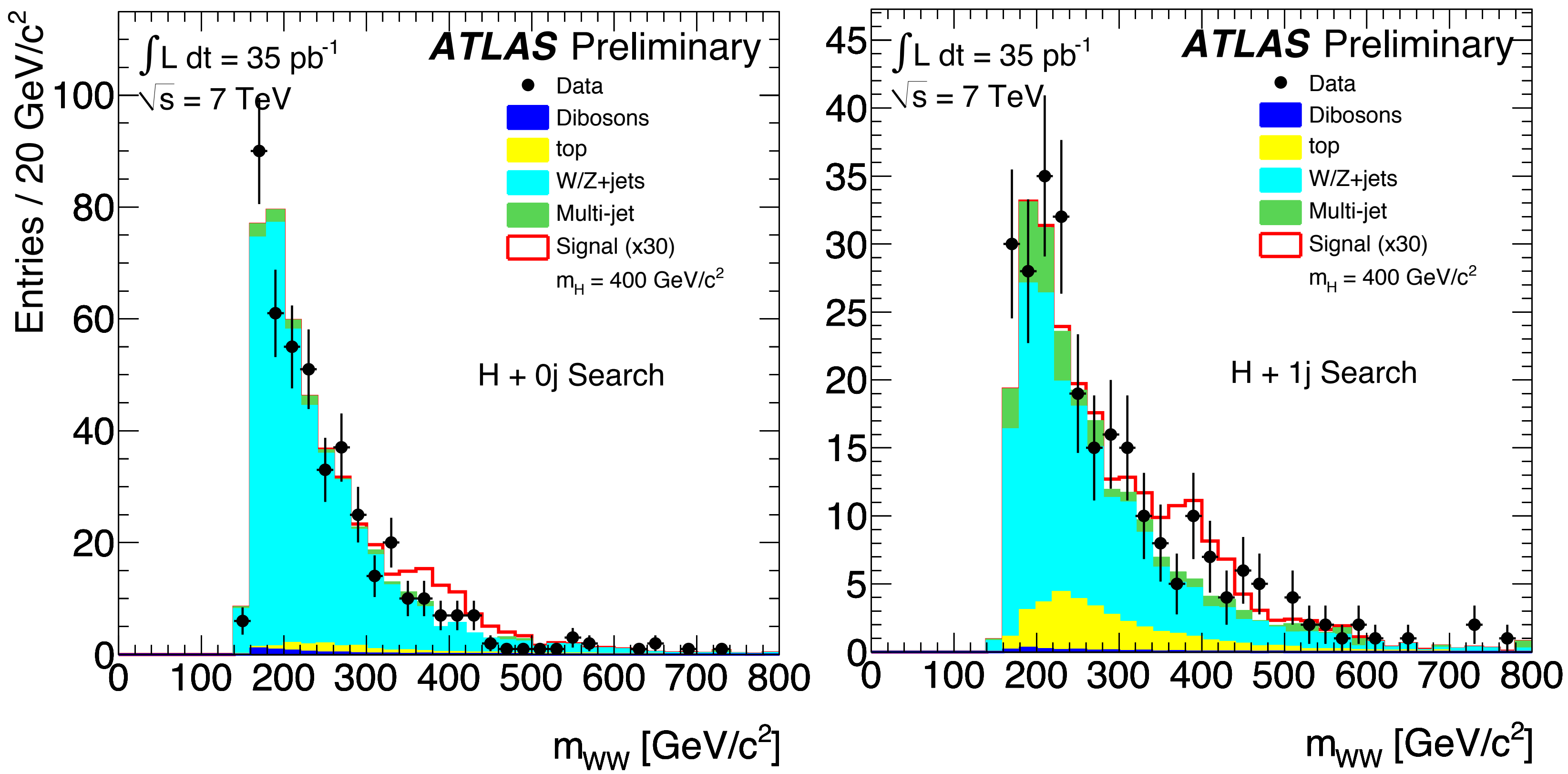
→ CMS excludes 2.1×$\sigma_{SM}$ (obs) and 3.0×$\sigma_{SM}$(exp) bayesian

⇒ Neither experiment excludes any $M_H$ in the Standard Model

⇒ Assuming a heavy 4th generation CMS excludes a Higgs with 144 GeV<$M_H$<207 GeV

# H→WW→lνqq

Full Higgs boson Mass reconstruction using $M_{l\nu}=M_W$




⇒ Enhancing H→WW sensitivity in high $M_H$

⇒ Binning in jet multiplicity H+0j and H+1j

⇒ Main Background: W/Z+jets

<u>Selection</u>:

Lepton (e/μ) with pT>30GeV,

no other lepton with pT>20GeV,

MET>30GeV,

2/3 jets (H+0/1j) with pT>30GeV,

$|M_{jj} - M_W|<10$GeV, B-tag veto

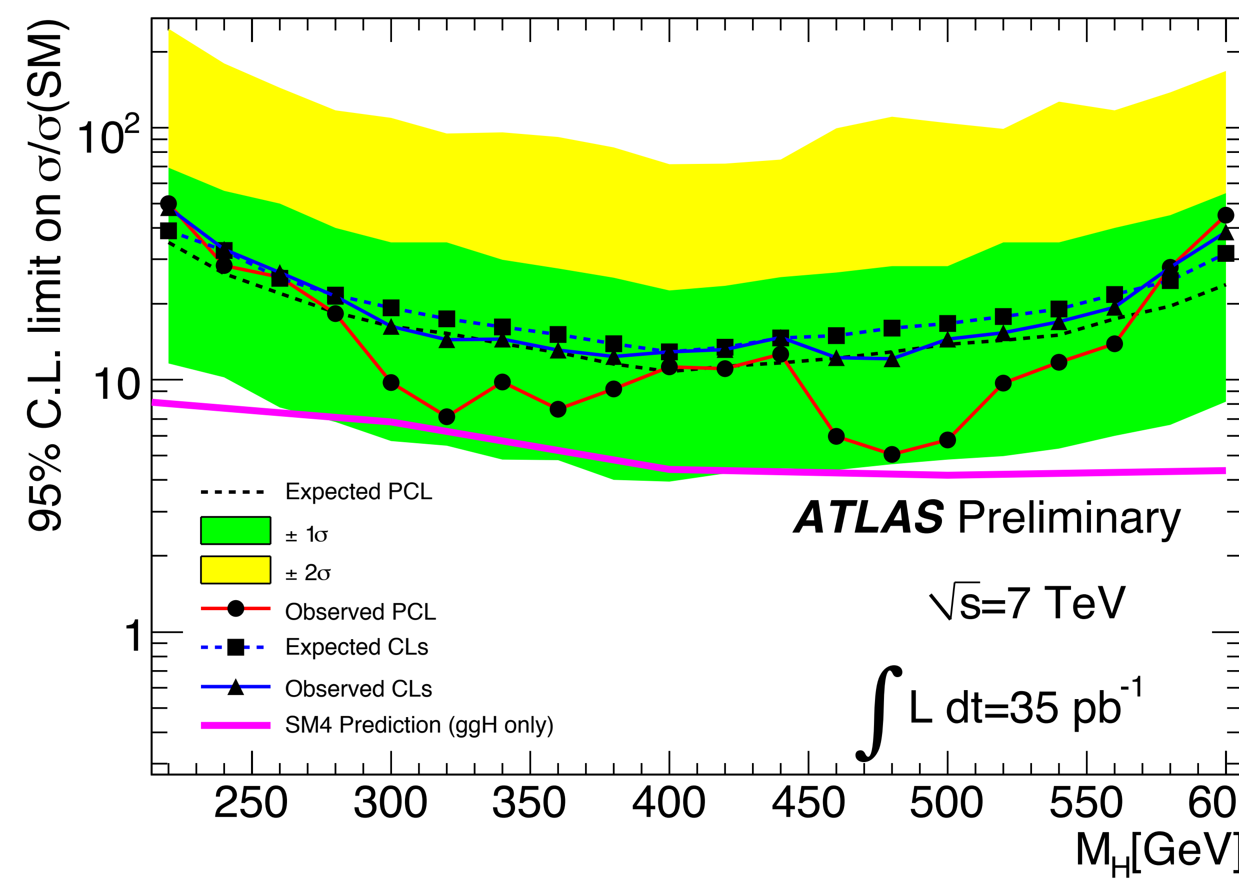
⇒ <u>Limit</u>: Maximum likelihood fit to exponential background and signal templates.

⇒ Using $CL_{S+B}$ at $M_H$=400GeV exclude:

→ $10.8\times\sigma_{SM}$ (exp)

→ $11.2\times\sigma_{SM}$ (obs)

⇒ The most sensitive channel for $M_H$>400GeV



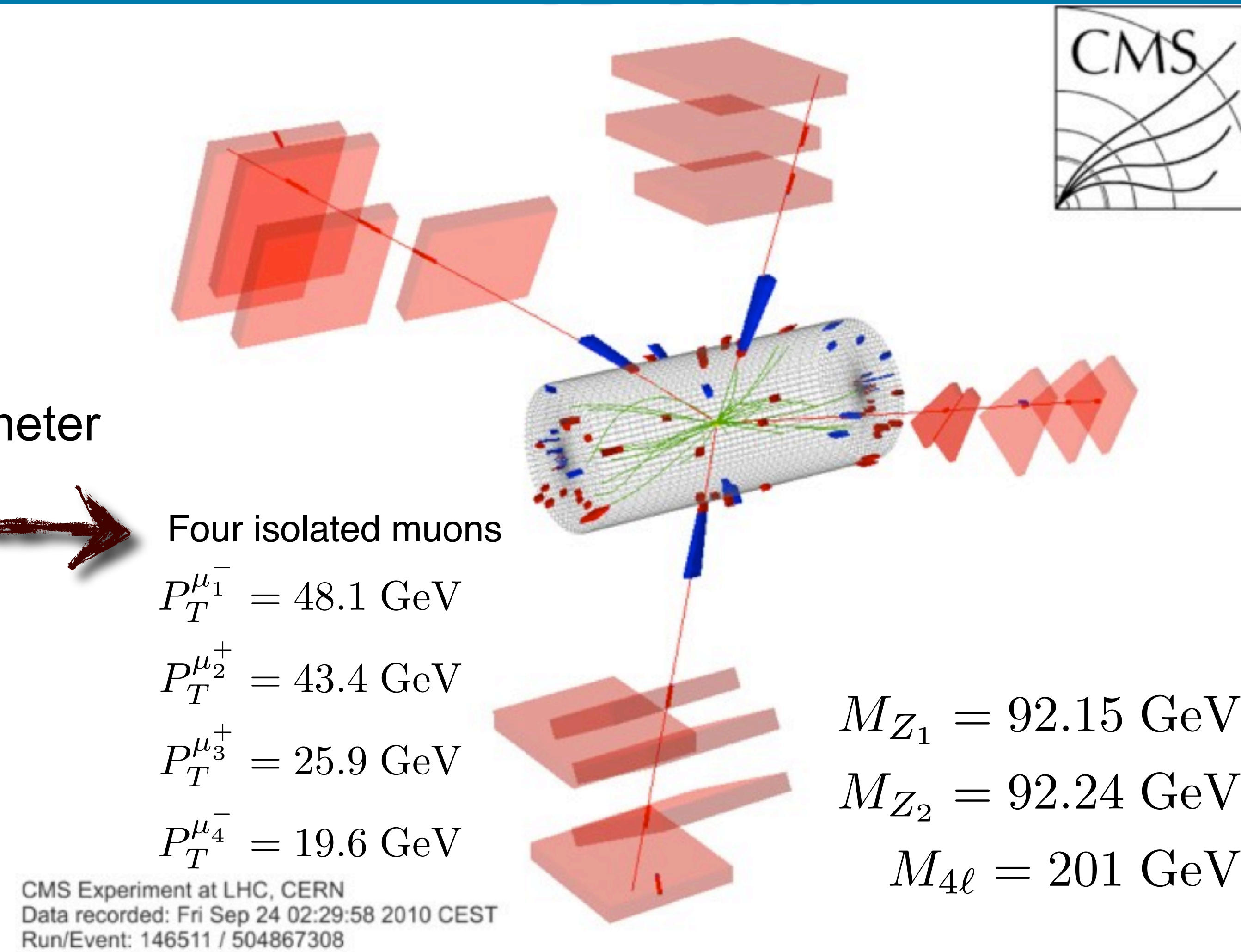
# H→ZZ(*)→4l

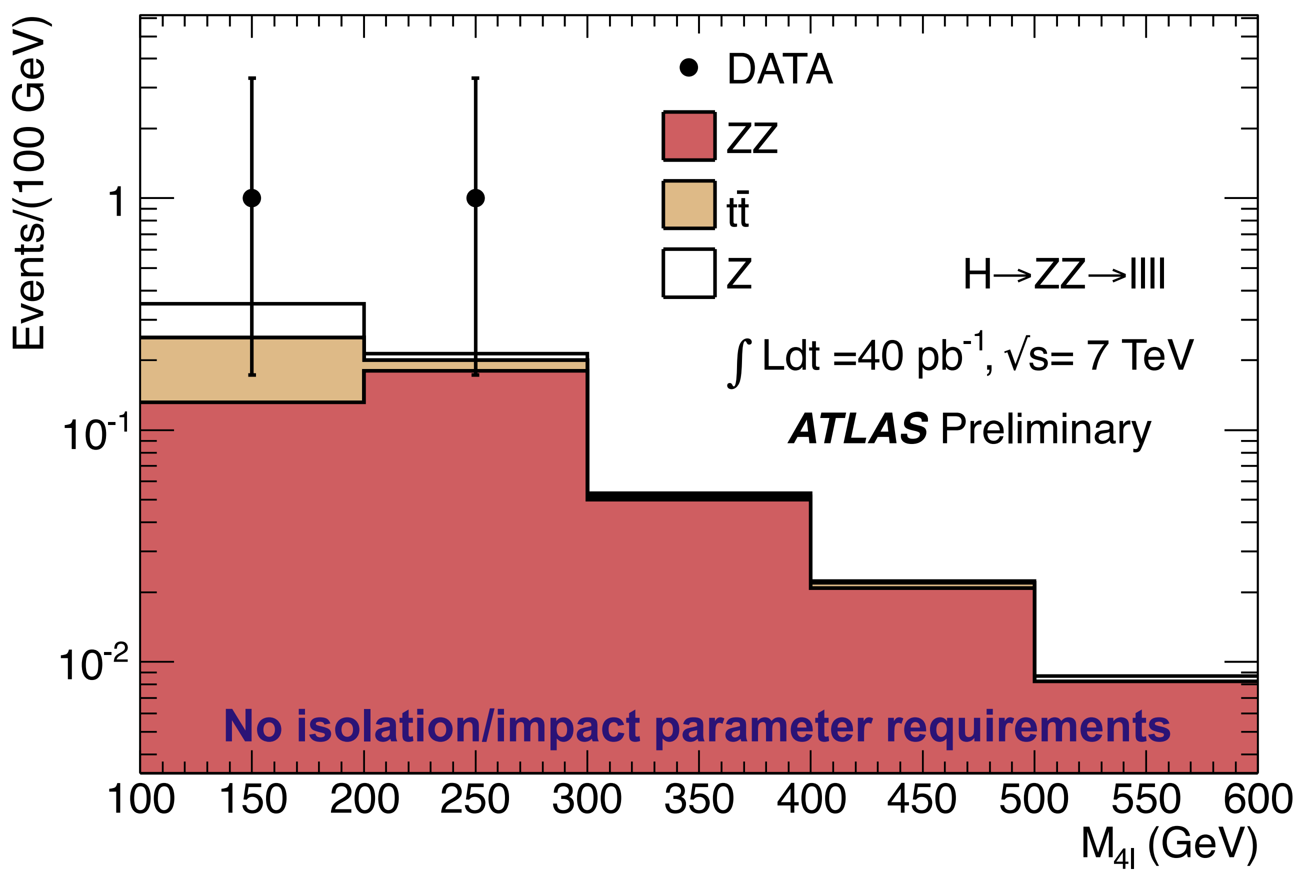
⇒ The “gold-plated” channel : clean with small rates

⇒ Main Background: ZZ→4l

  → Z+jets/ttbar suppressed with isolation/impact parameter

⇒ CMS found the first candidate in the 2010 data




Selection:

Two same-flavor/opposite-sign isolated lepton (e/μ) pairs,

Di-lepton mass cuts,

Low $M_H$ : also impact parameter requirements

⇒ ATLAS :No candidates observed after full event selection

# $H \rightarrow ZZ^{(*)} \rightarrow 4l$

Background Estimates:

⇒ $ZZ \rightarrow 4l$ yield normalized to observed $Z \rightarrow ll$ yield

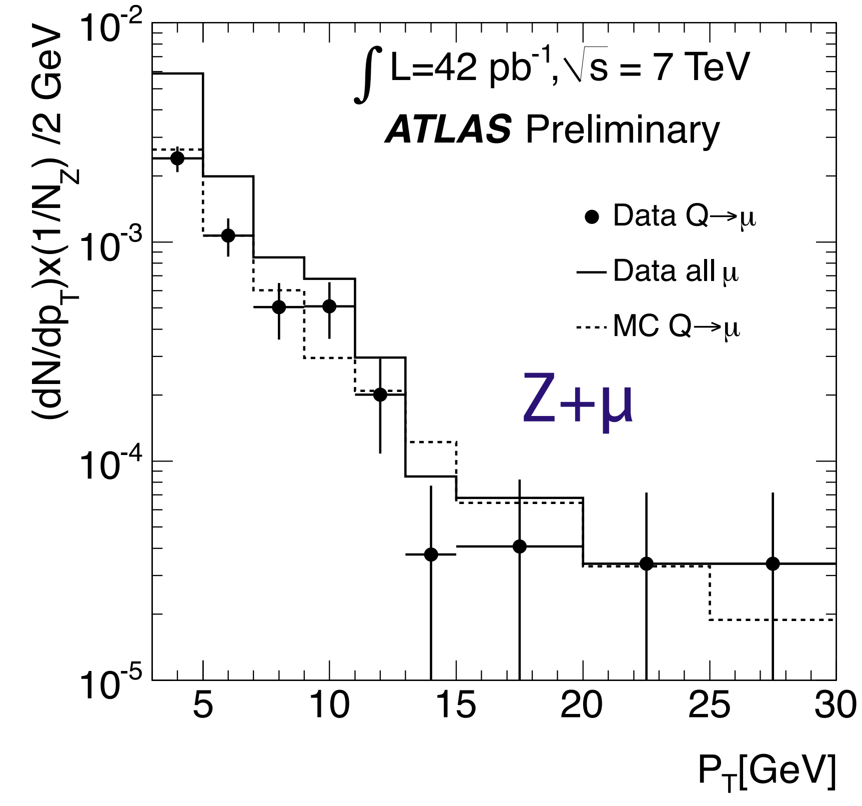
(luminosity uncertainty cancels, scale/PDF uncertainties partly cancel)

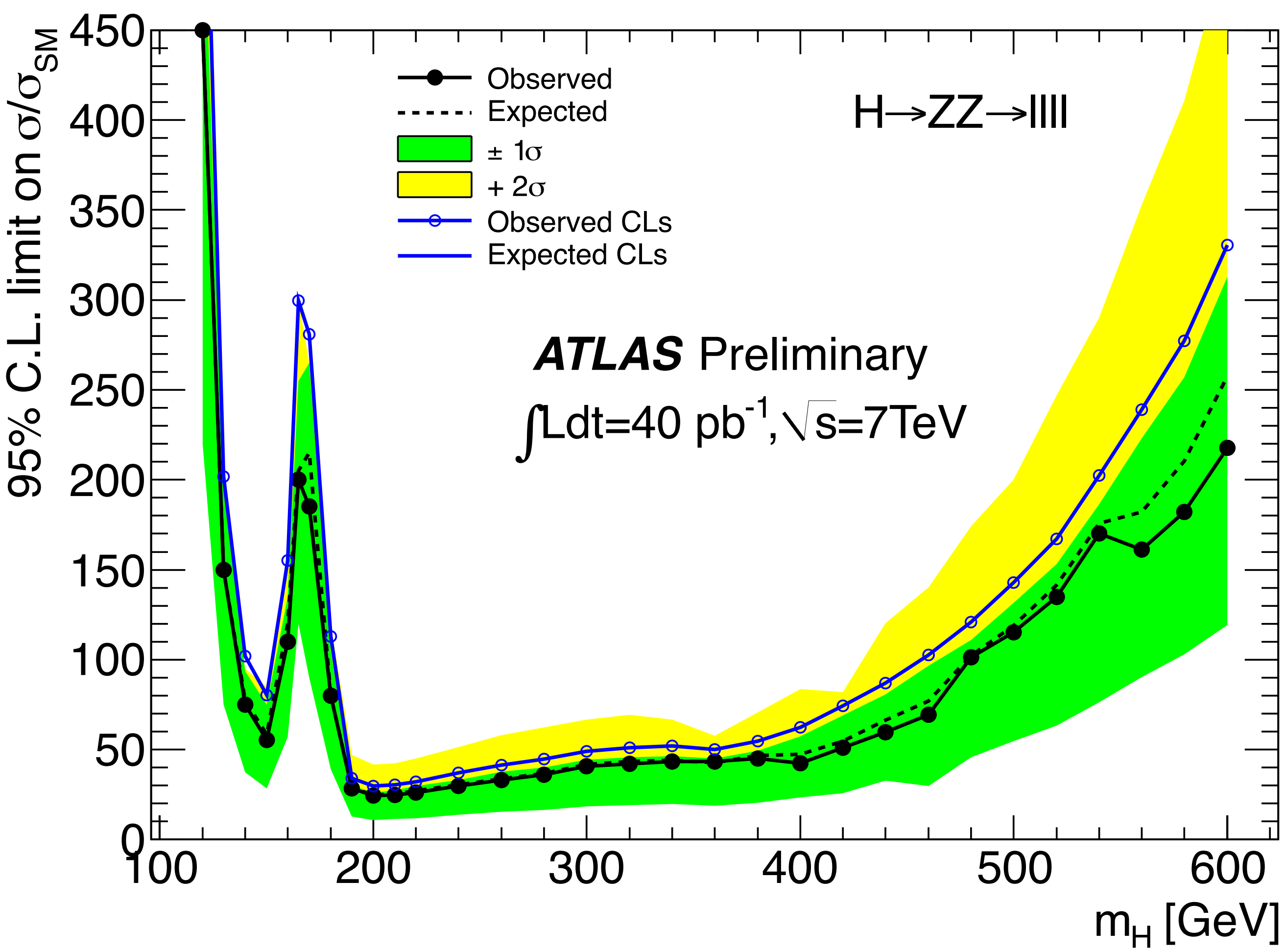
$$N_{ZZ} = \sigma_{ZZ}\varepsilon_{ZZ}^{exp} L \times \left[ \frac{N_Z^{Data}}{\sigma_Z \varepsilon_Z^{exp} L} \right]$$

⇒ Check $Z(\rightarrow ll)+\mu\mu/ee$ yields without isolation/impact parameter requirements for additional leptons

→ separate heavy flavor and fake components

→ eventually extrapolate to signal region




**⇒ With 2010 integrated luminosity not the most sensitive channel for any $M_H$**

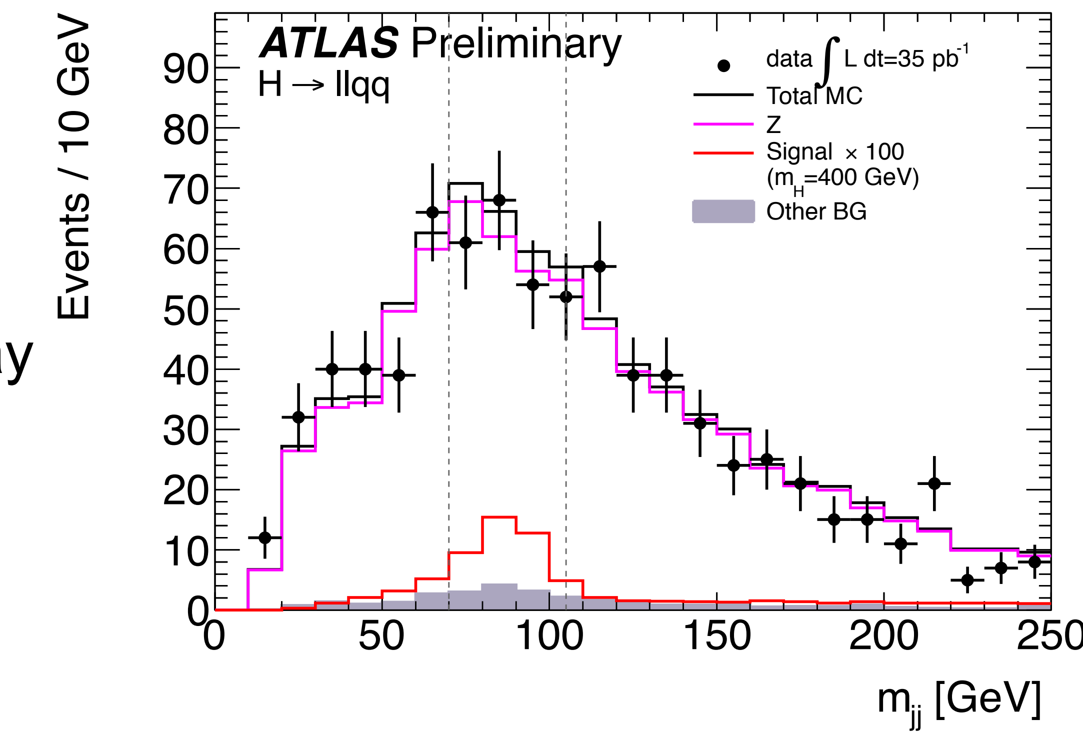
**⇒ For $M_H \approx 200$GeV sensitivity comparable with other channels**

**⇒ Very clean channel**

**→ expected limit to improve ~$1/\mathcal{L}_{int}$**

# H→ZZ→llqq/llνν

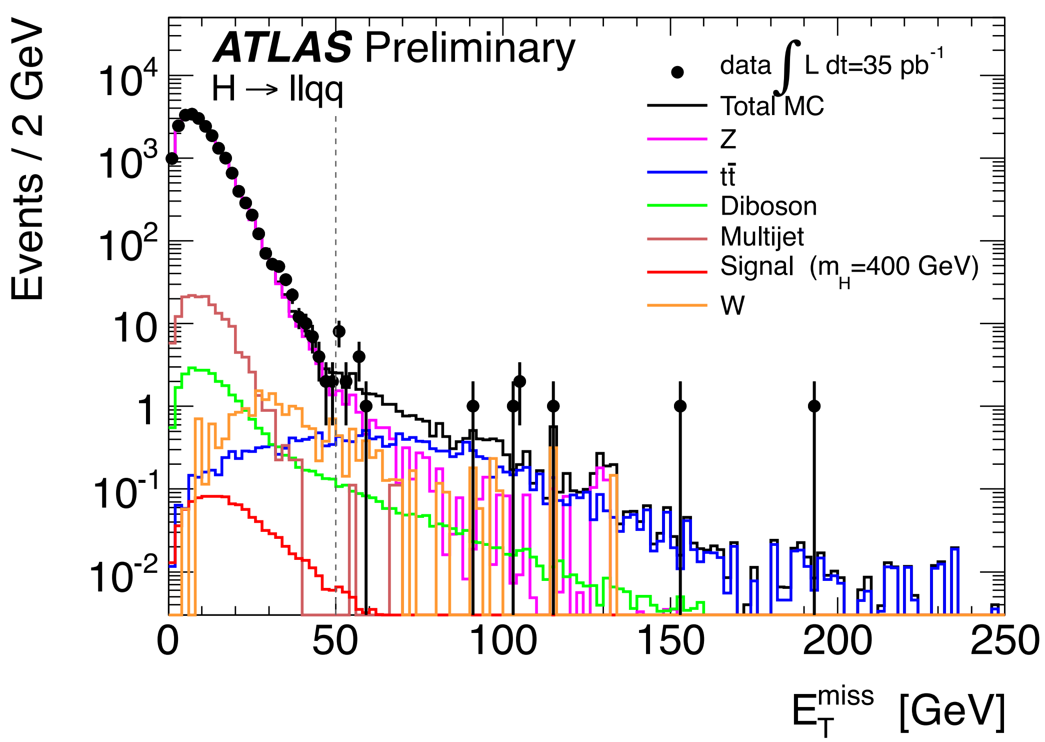
⇒ Higher rates than H→ZZ→4l!
×21 (llqq) and ×6.1 (llνν)
⇒ Not nearly as clean: llνν better s/b but llqq mass peak
⇒ Main Background:
Z+jets, but ttbar and di-boson significant for llνν
⇒ Search in 200 GeV<$M_H$<600 GeV region
→ Analyses optimized in low/high mass sub-regions

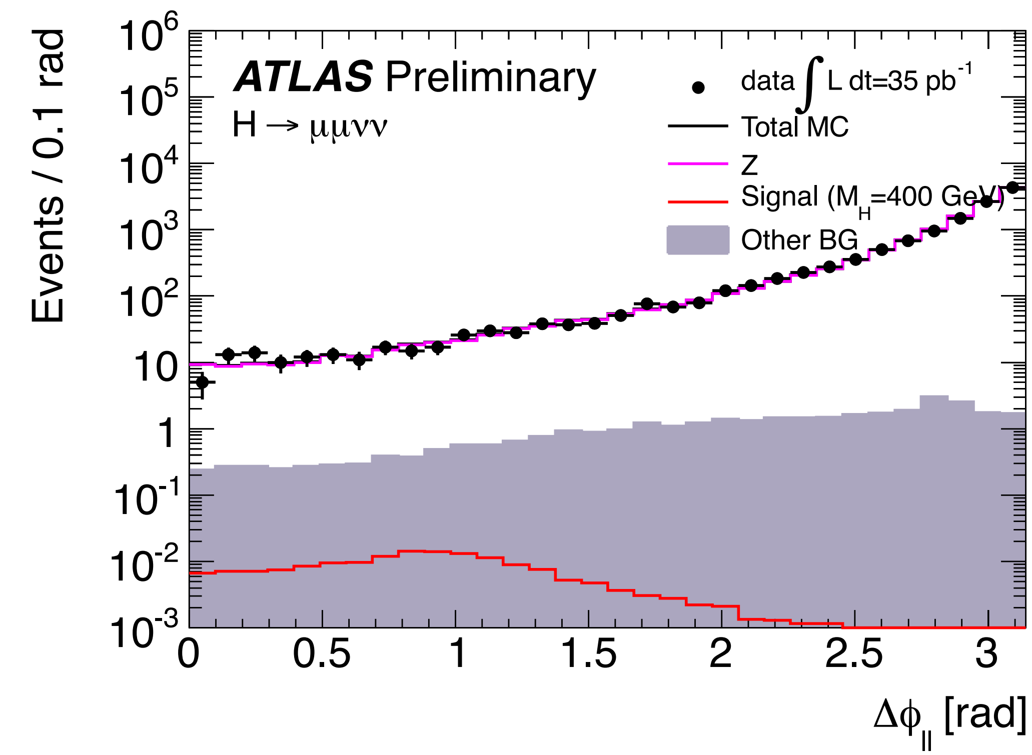



<u>Selection</u>: Same-flavor di-lepton consistent with Z boson decay

⇒<u>llqq</u>: MET<50 GeV, 70< $M_{jj}$<105 GeV,
$M_H$≥360 GeV: pT(jets)>50GeV, $\Delta\varphi_{ll}<\pi/2$, $\Delta\varphi_{jj}<\pi/2$

⇒<u>llνν</u>: b-jet veto, MET>66GeV, $1<\Delta\varphi_{ll}<2.64$
$M_H$≥280GeV MET>82GeV, $\Delta\varphi_{ll}<2.25$



# H→ZZ→llqq/llνν : Backgrounds

⇒ Z+jets, ttbar and W+jets control regions from sidebands in $M_{jj}$ and $M_{ll}$ and reversed cuts

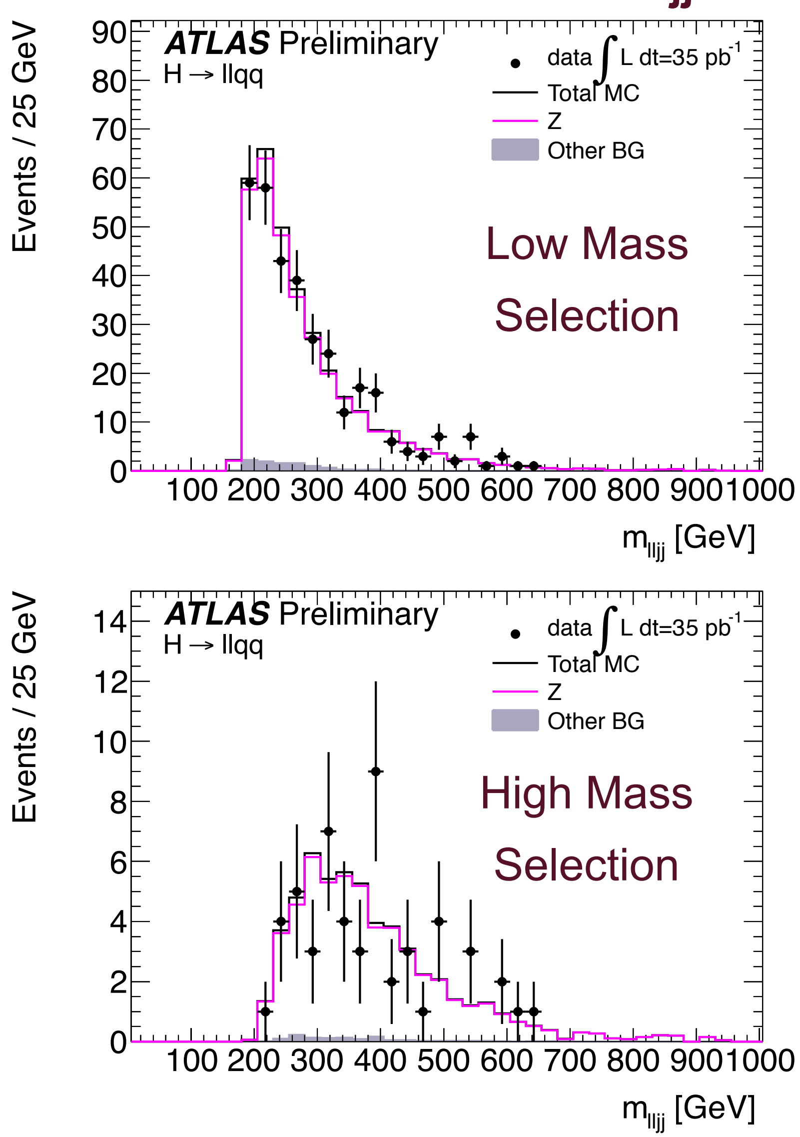
→ used as confirmation to the MC expectation

→ uncertainties 5%, 25% and 50% respectively

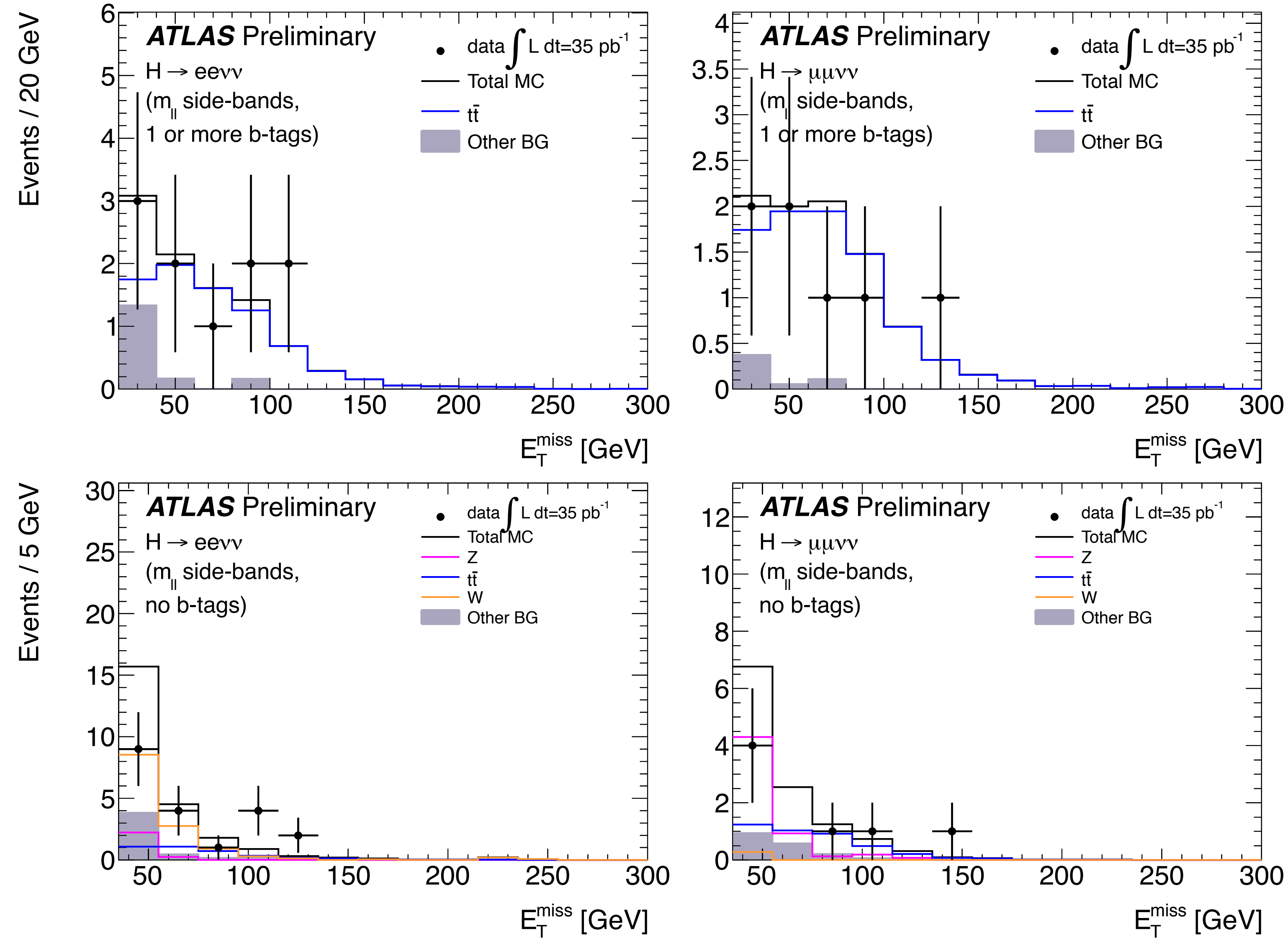
⇒ QCD multijets found negligible using data-driven method (relaxed lepton id)

⇒ di-boson backgrounds (ZZ/WW/WZ) taken from MC - uncertainty 15%

## Side-bands of $M_{jj}$

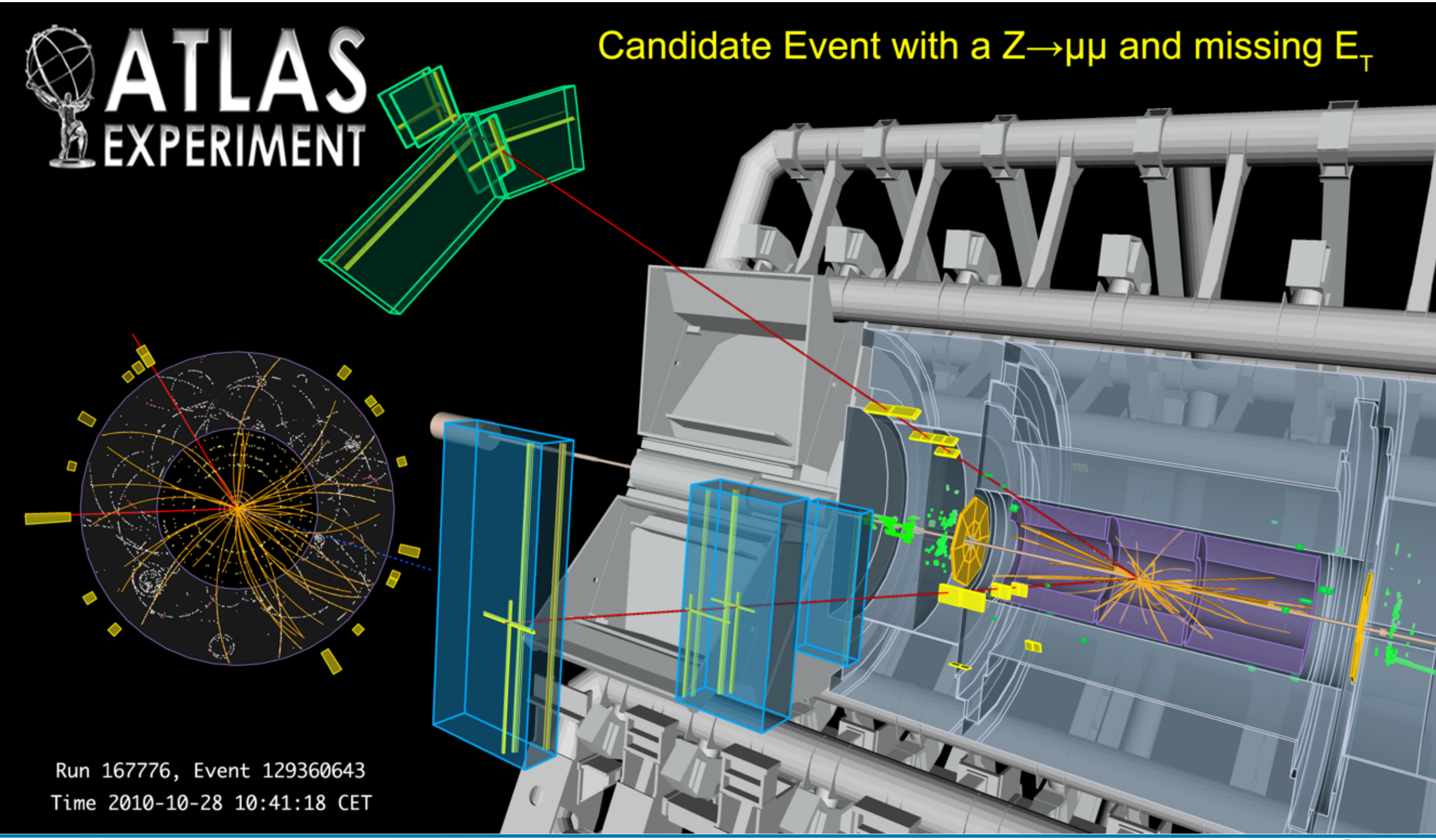



## Side-bands of $M_{ll}$



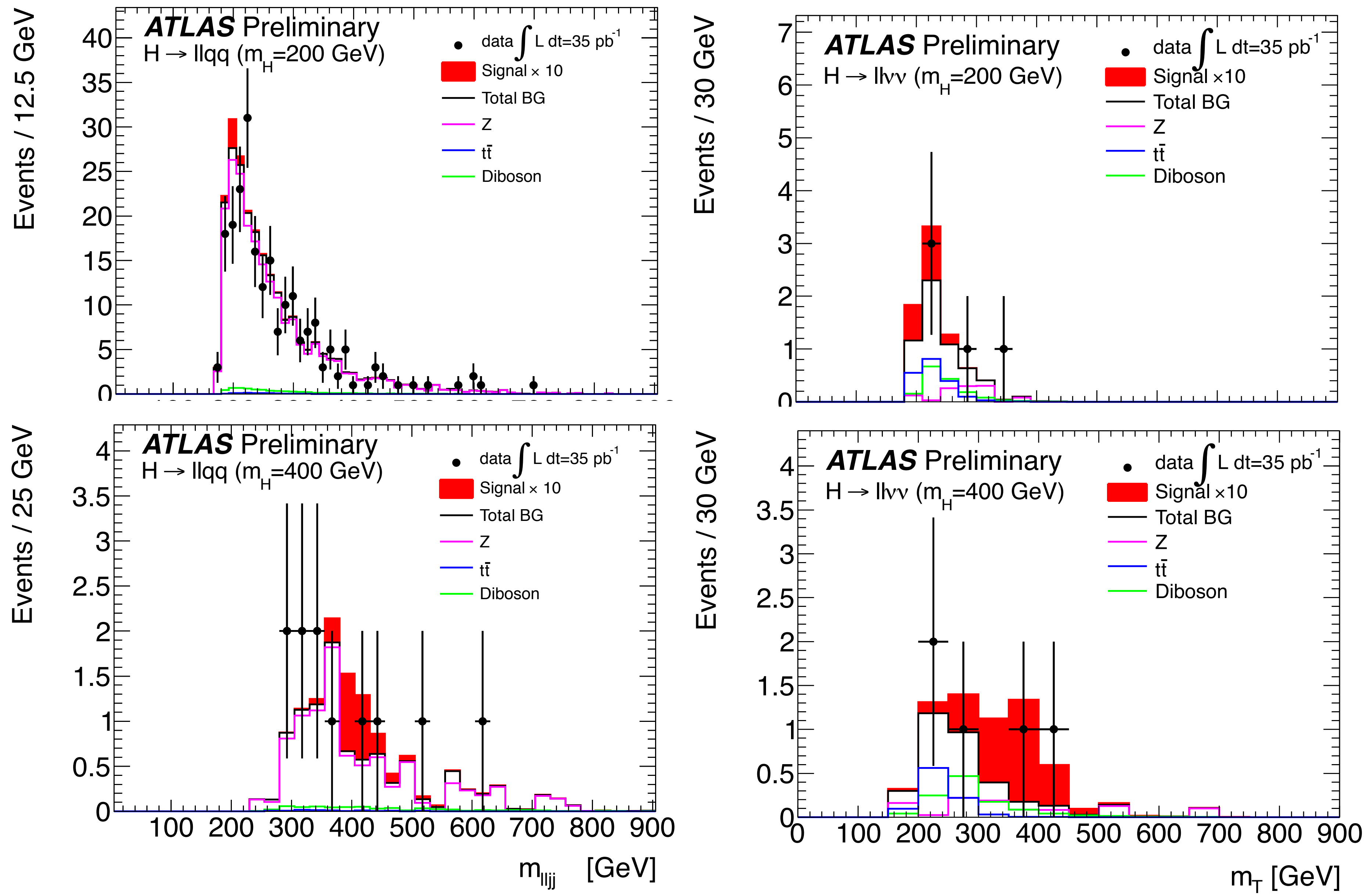
# H→ZZ→llqq/llνν

Candidate event with a Z decay to muon pairs, recoiling against missing-$E_T$. The muon candidates have transverse momenta of 50 and 126 GeV and a dimuon invariant mass of 94 GeV; the missing $E_T$ is measured to be 161 GeV.



# H→ZZ→llqq/llνν

⇒ Final discriminant: $M_{lljj}$ and $M_T$ $m_T^2 \equiv \left[\sqrt{m_Z^2+|\vec{p}_T^{\,\ell\ell}|^2}+\sqrt{m_Z^2+|\vec{p}_T^{\,\mathrm{miss}}|^2}\right]^2-\left[\vec{p}_T^{\,\ell\ell}+\vec{p}_T^{\,\mathrm{miss}}\right]^2$

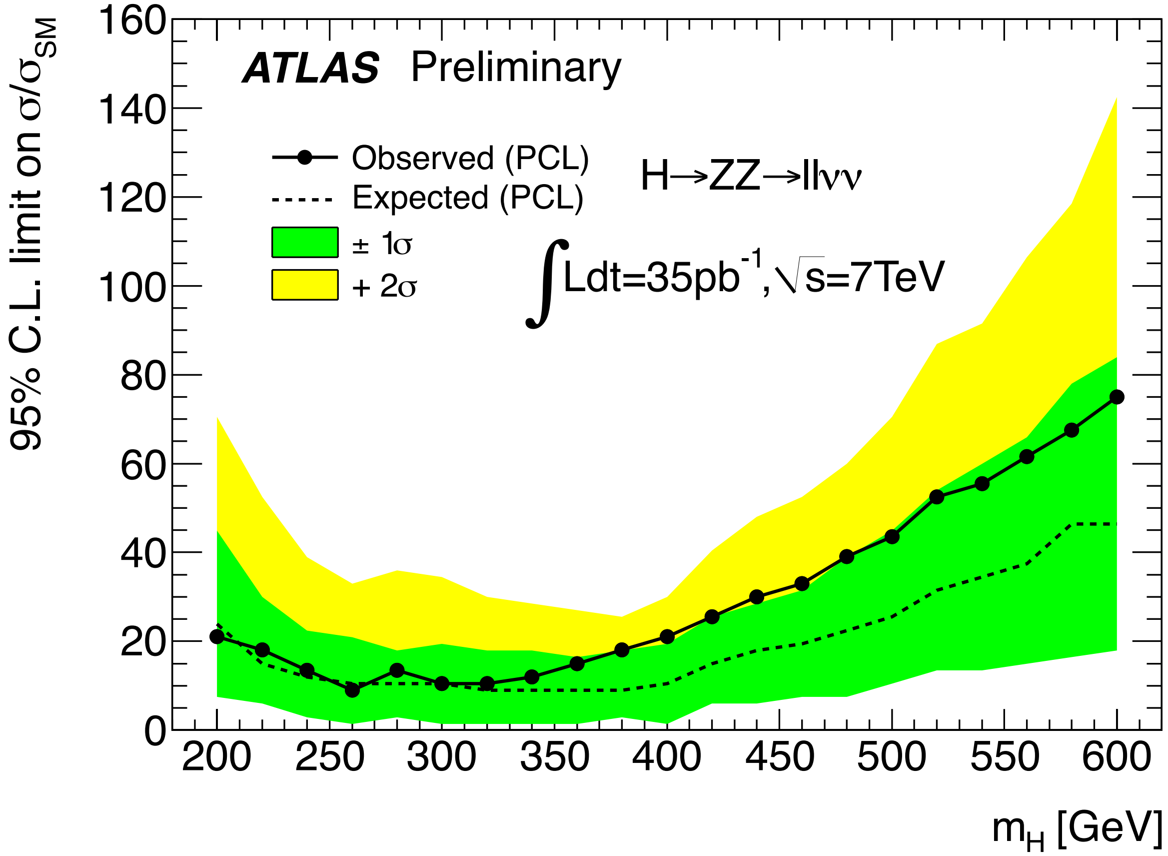


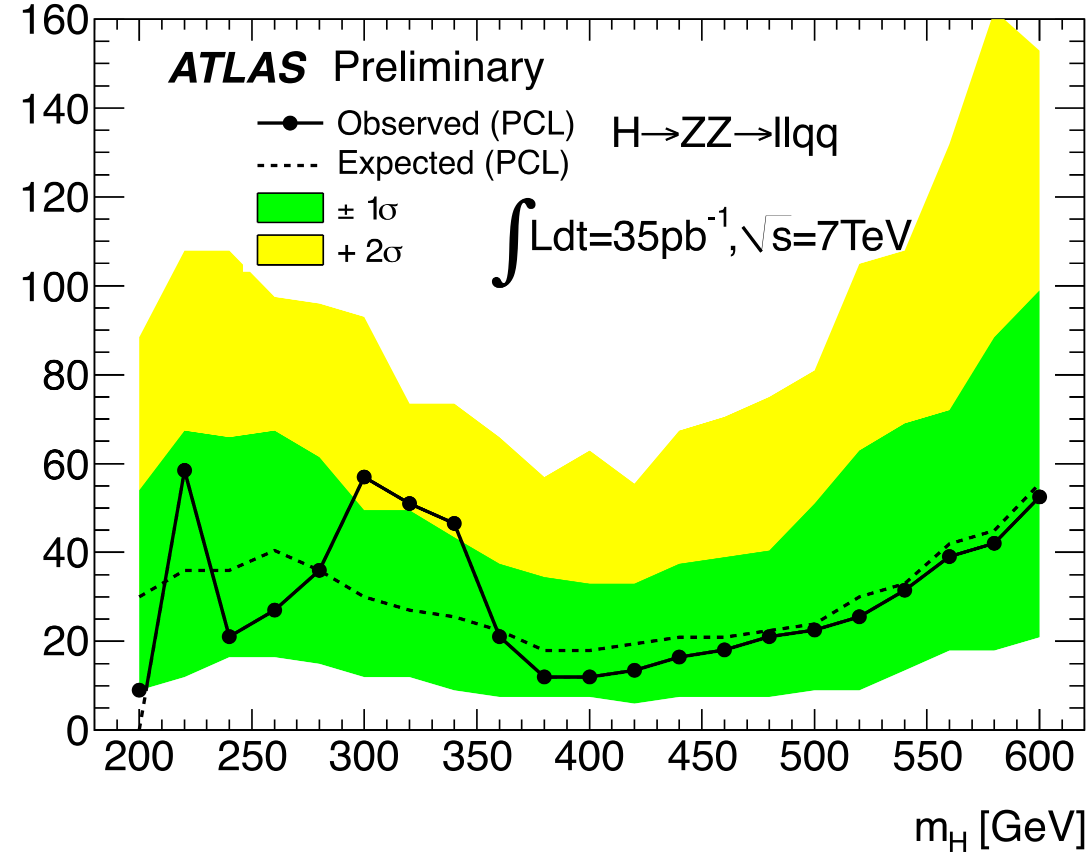

**$M_H$=200 GeV**

**$M_H$=400 GeV**

| ATLAS | llqq $M_H$<360GeV | llqq $M_H$≥360GeV | llνν $M_H$<280GeV | llνν $M_H$≥280GeV |
|---|---|---|---|---|
| Data | 216 | 11 | 5 | 5 |
| Background | 226 ± 28 | 9.88 ± 1.75 | 5.76 ± 1.38 | 3.45 ± 0.86 |
| Higgs | 0.60 ± 0.12 ($M_H$=200GeV) | 0.24 ± 0.05 ($M_H$=400GeV) | 0.19 ± 0.04 ($M_H$=200GeV) | 0.30 ± 0.06 ($M_H$=400GeV) |

# H→ZZ→llqq/llvv



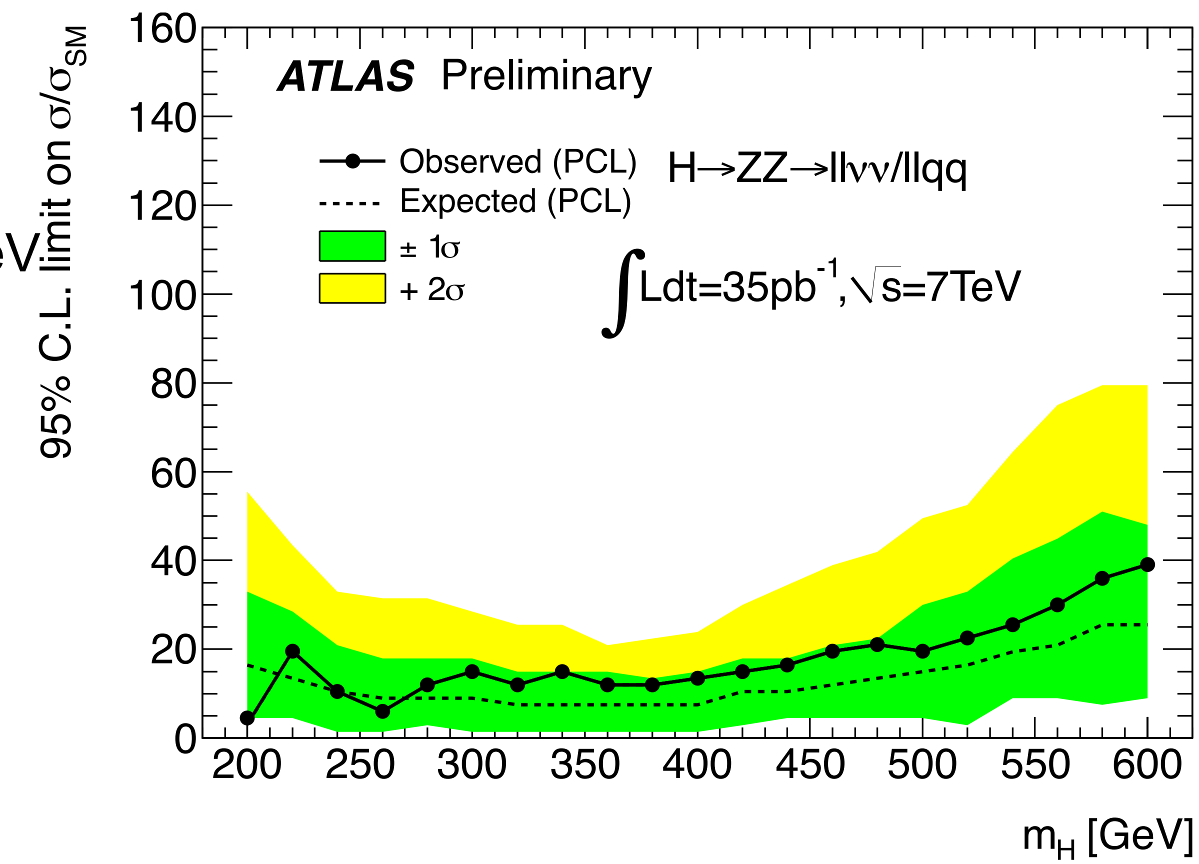




⇒H→ZZ→llvv the most sensitive channel in 200 to 400 GeV

→Excluding 9.5x$\sigma_{SM}$ (exp) and 10.5x$\sigma_{SM}$ (obs) at $M_H$=300GeV

⇒H→ZZ→llqq good sensitivity in the whole mass range from 200 to 600 GeV

⇒H→ZZ→llqq/llvv combined sensitive to <10×$\sigma_{SM}$ (exp) between 240 GeV and 440 GeV



# MSSM A/H/h→ττ

⇒ MSSM Higgs sector: 5 bosons (h,H,A,H±)
described by 2 parameters $M_A$, tanβ at Born level

⇒ Main Backgrounds : Z/γ*→ττ (irreducible), W+jets, QCD multijets

⇒ Look at the lepton-hadron channel

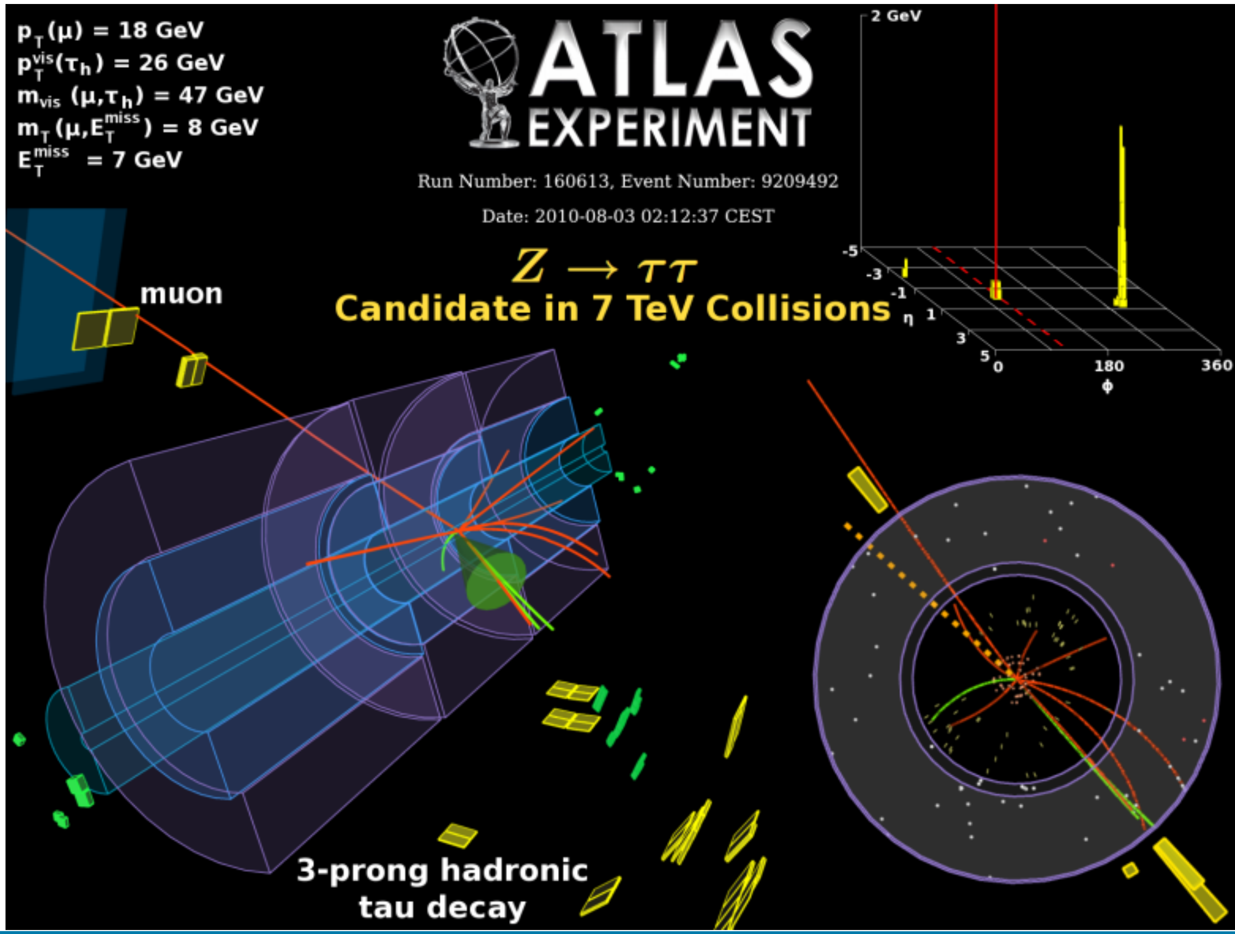
→ CMS includes also A/H/h→ττ→eμ final state which is important near the Z peak

⇒ Very Similar Event Selection:

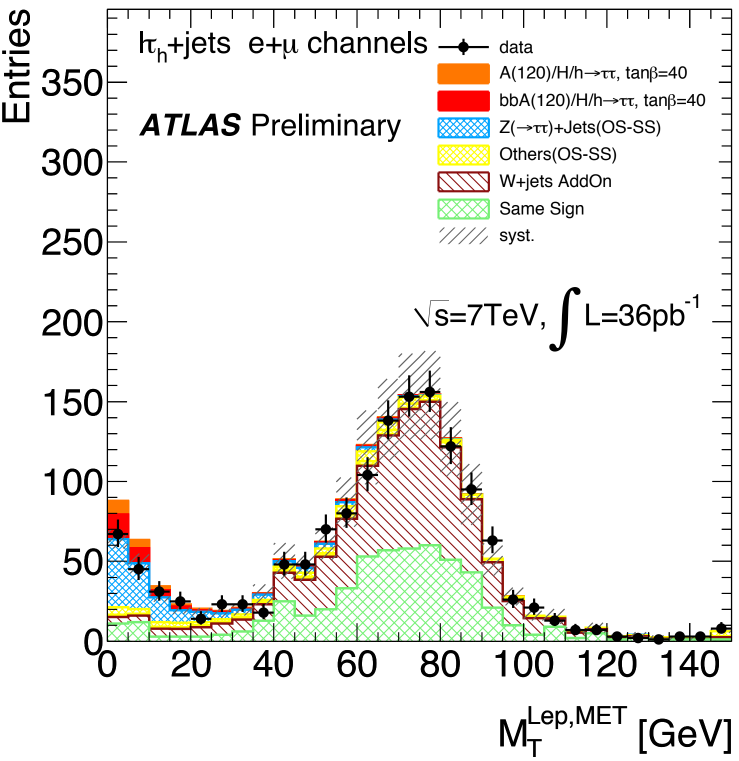
- (1e XOR 1μ) isolated + $1\tau_{had}$
- $Q_l \cdot Q_\tau < 0$
- $M_T = \sqrt{2p_T^{e/\mu} E_T^{miss}(1 - \cos\Delta\phi)} < 30\,\mathrm{GeV}$
- MET cut (ATLAS)

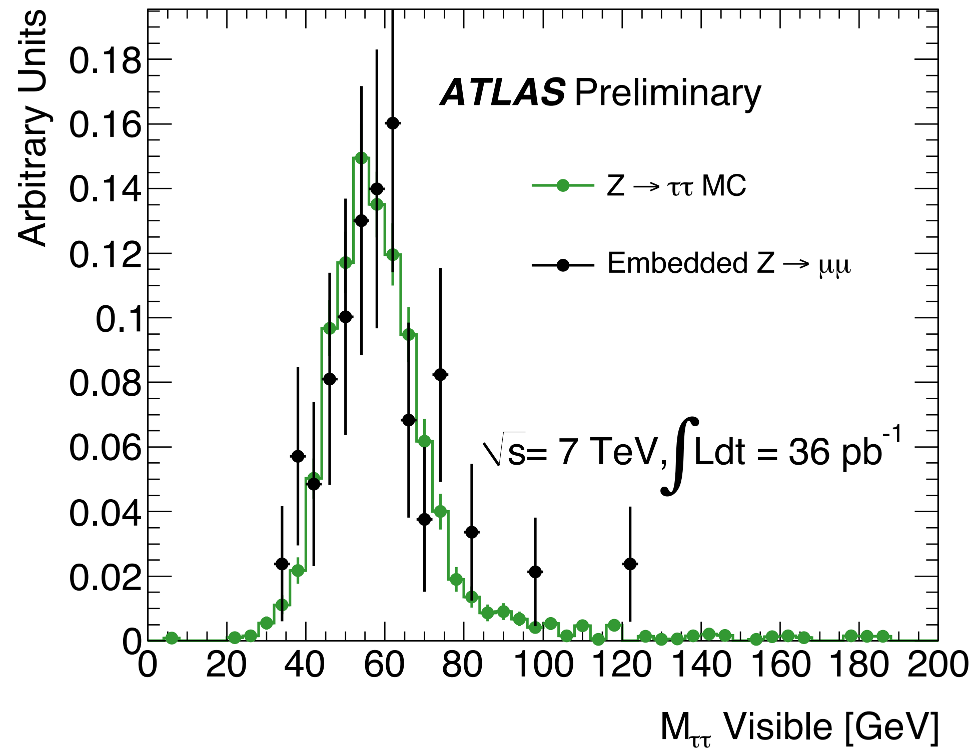
⇒ CMS Energy Flow reconstruction of hadronic-τ candidates

→ explicit reconstruction of visible τ-decay products



# MSSM A/H/h→ττ




Background Extraction

⇒ Same Sign/Opposite Sign yield

for QCD and W+jets

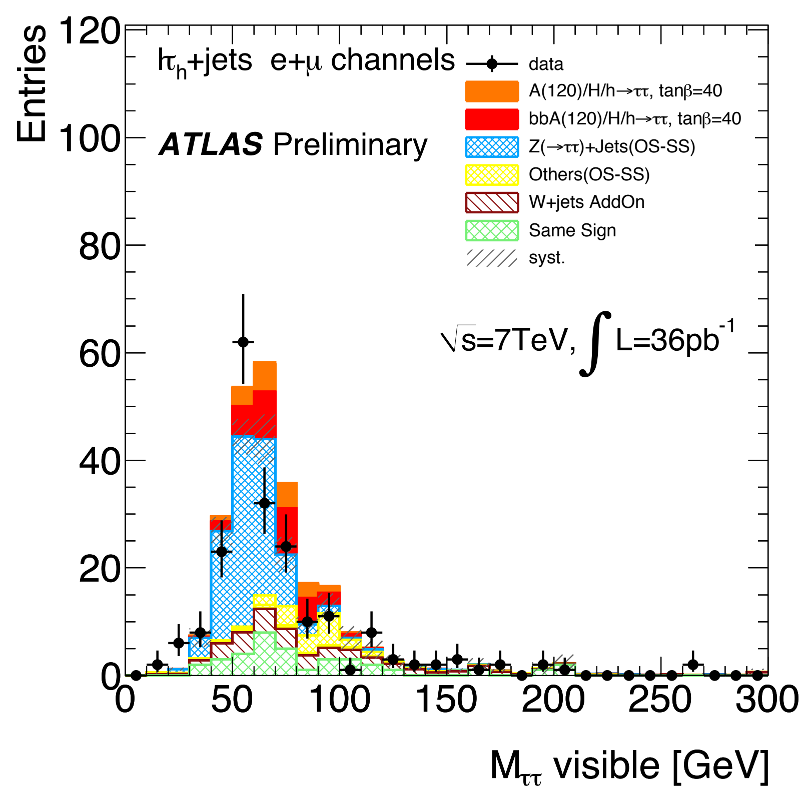
⇒ ATLAS check $M_{vis}$ shape for $Z/\gamma^* \to \tau\tau$

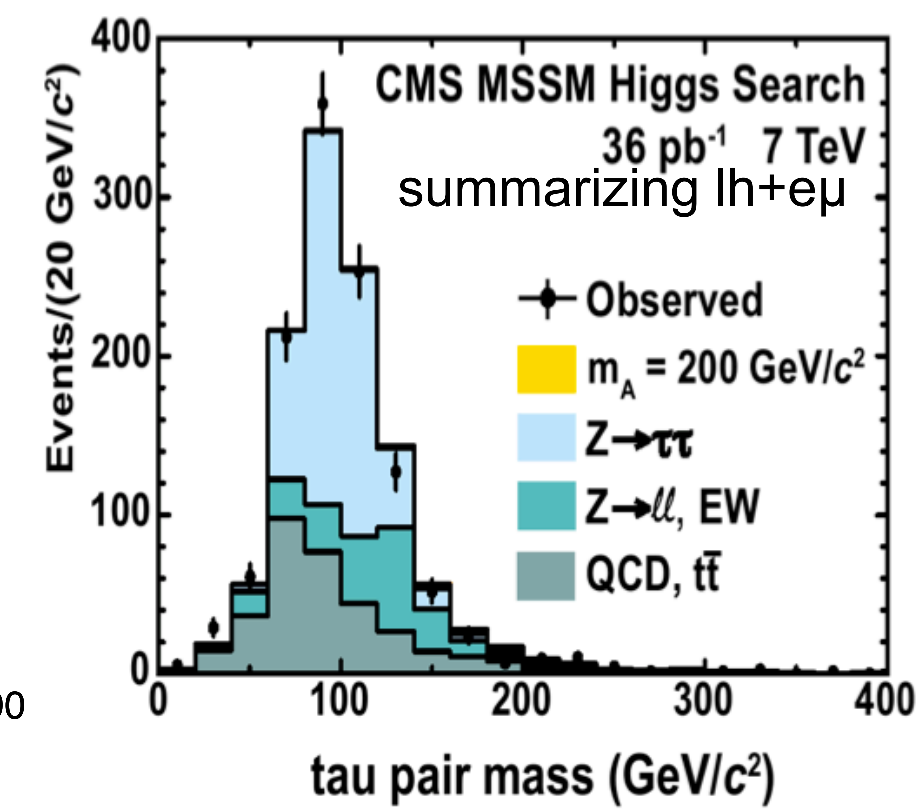
with embedding techniques

⇒ Final discriminant

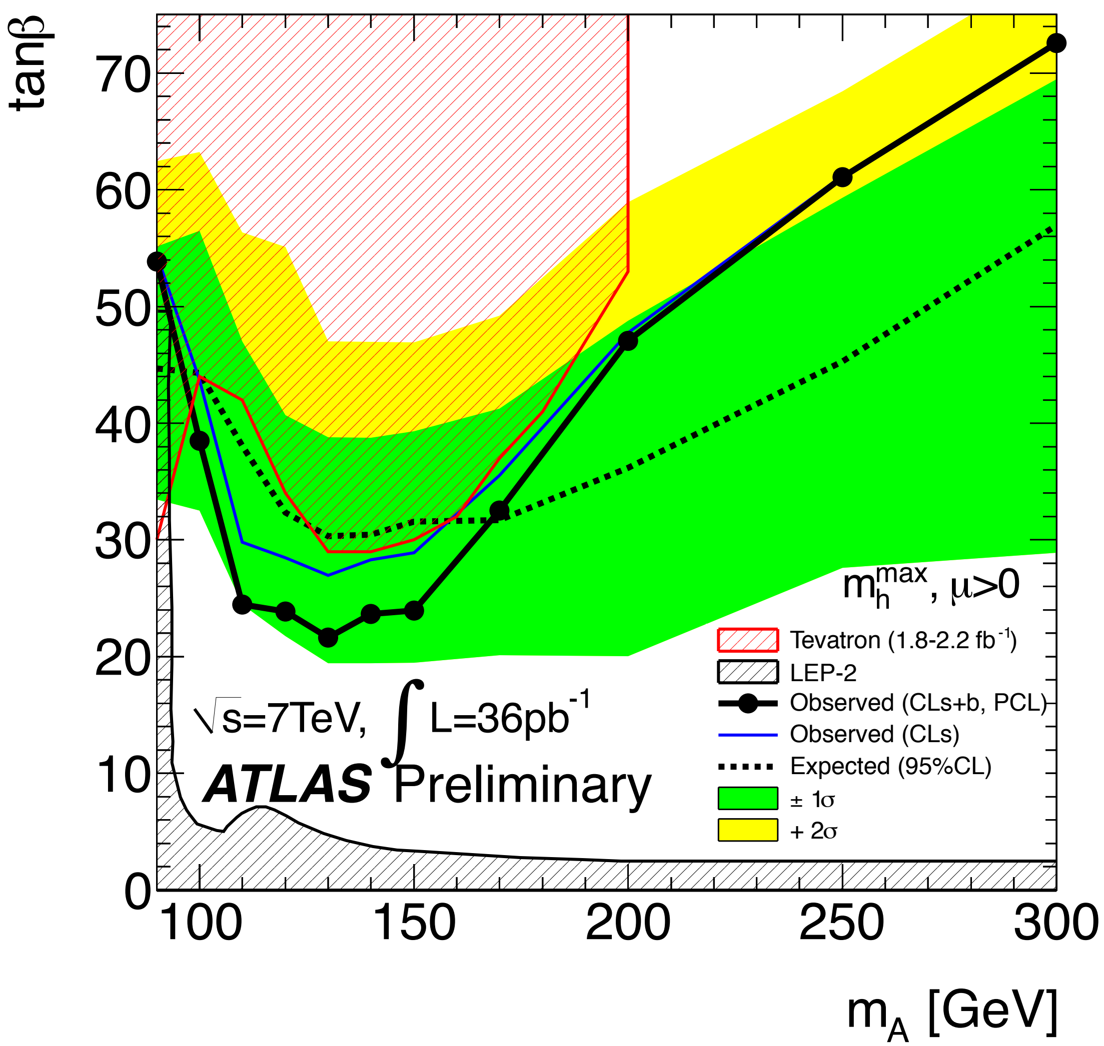
→ ATLAS uses $M_{vis}$

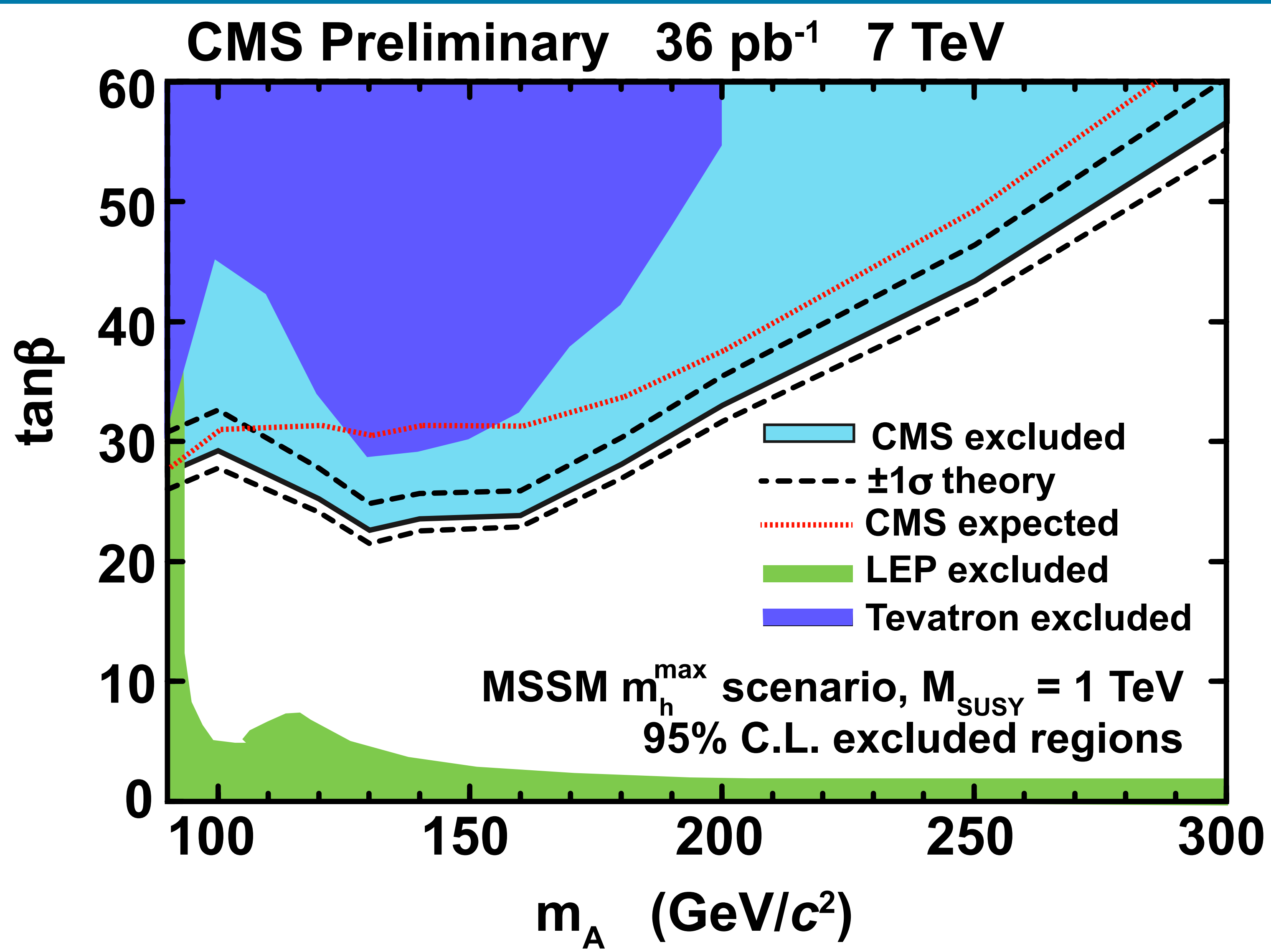
→ CMS uses $M_{\tau\tau}$ calculated using maximum likelihood constraint fit for the missing tau neutrino momenta



# MSSM A/H/h→ττ




Both ATLAS and CMS:

⇒ No excess observed

⇒ 95% CL exclusion limits in $M_A$-tanβ plane similar for both experiments:

→ tanβ~23-25 for $M_A$=110-150 GeV is excluded

→ tanβ>60 (theoretically not favored) for $M_A$=250-300 GeV

⇒Increase excluded parameter space with respect to Tevatron and LEP results

# Charged Higgs

⇒ $H^+$ predicted in the context of MSSM

⇒ If $M_{H+}<(M_t-M_b)$ then $t \to H^+b$ promising production mechanism

⇒ $H^+$ decays preferentially as $H^+ \to \tau\nu$ for $\tan\beta>10$

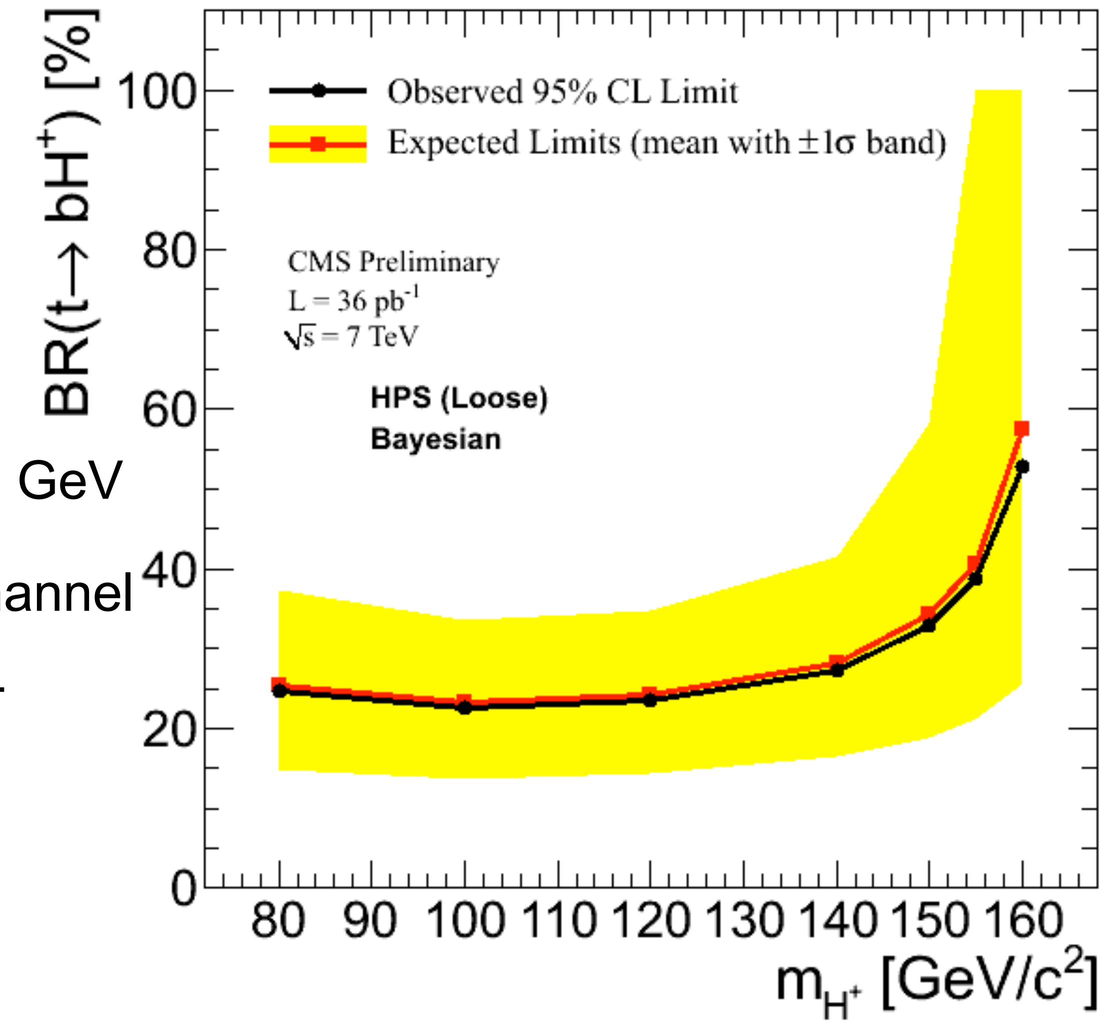
⇒ LEP excluded the existence of $H^+$ for $M_{H+}<80$ GeV

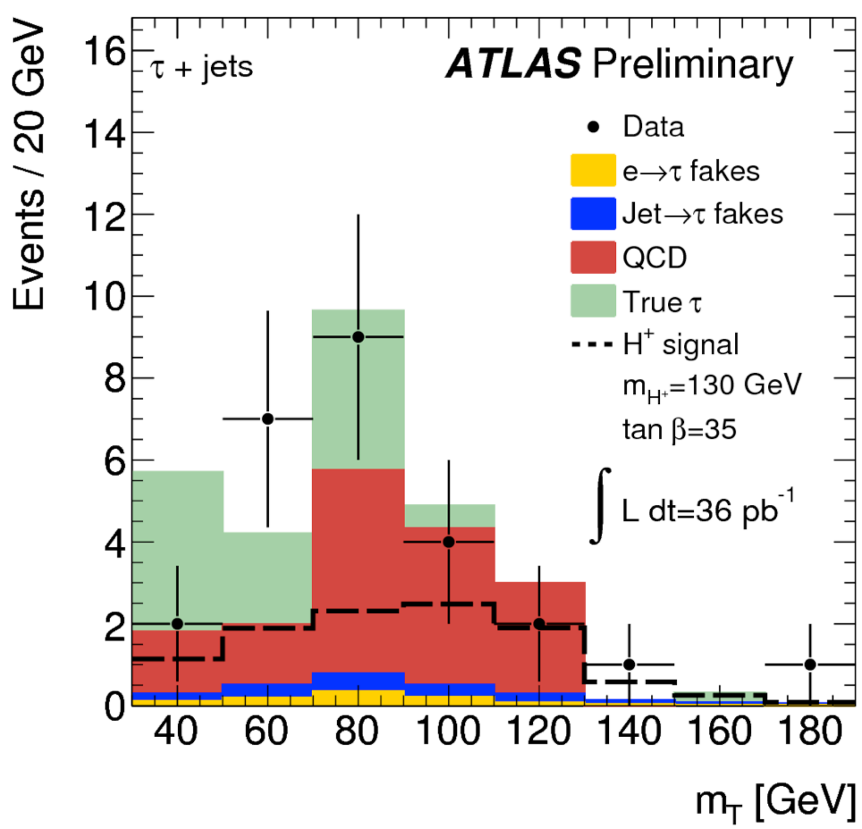
⇒ Current Tevatron limit $BR(t \to H^+b)\sim0.15-0.20$ for 80 GeV$<M_{H+}<$155 GeV

⇒ CMS analysis follows ttbar cross section measurement in l+jets channel

→ similarities with $H\to\tau\tau\to lh$ but require at least two jets and MET

→ fake τ background extraction using the $j\to\tau$ fake rate




Assuming $BR(t \to bH^+) \approx 6\%$

⇒ ATLAS performed checks/studies on

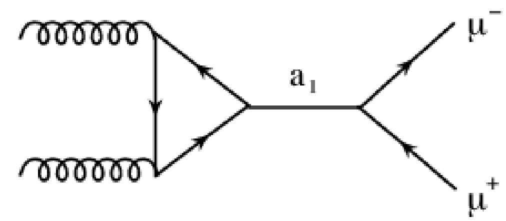
→ data-driven background extraction methods
(τ-fakes, embedding techniques, QCD-shape from looser selection)

→ more powerful discriminants

# NMSSM a1→μμ

⇒ Low mass scalar A search in range [6,9] and [11,12] GeV

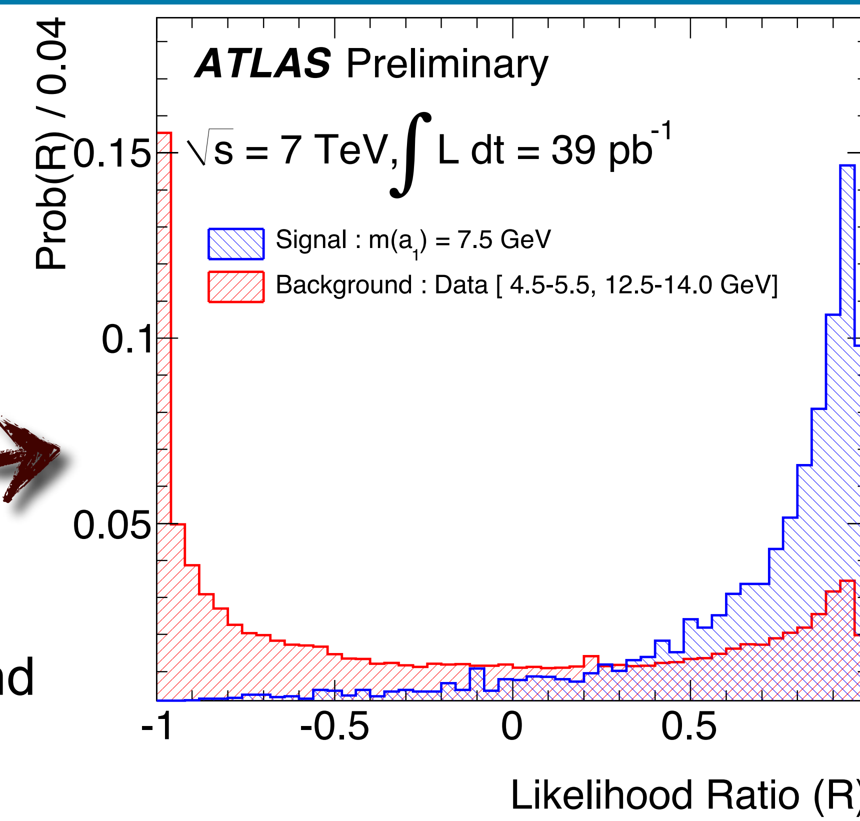
⇒ "Ideal Higgs" NMSSM scenario ($m_{a1}<2m_B$) escapes LEP limit on h→bb




Selection:
Opposite charged muon ($p_T$>4 GeV) pair

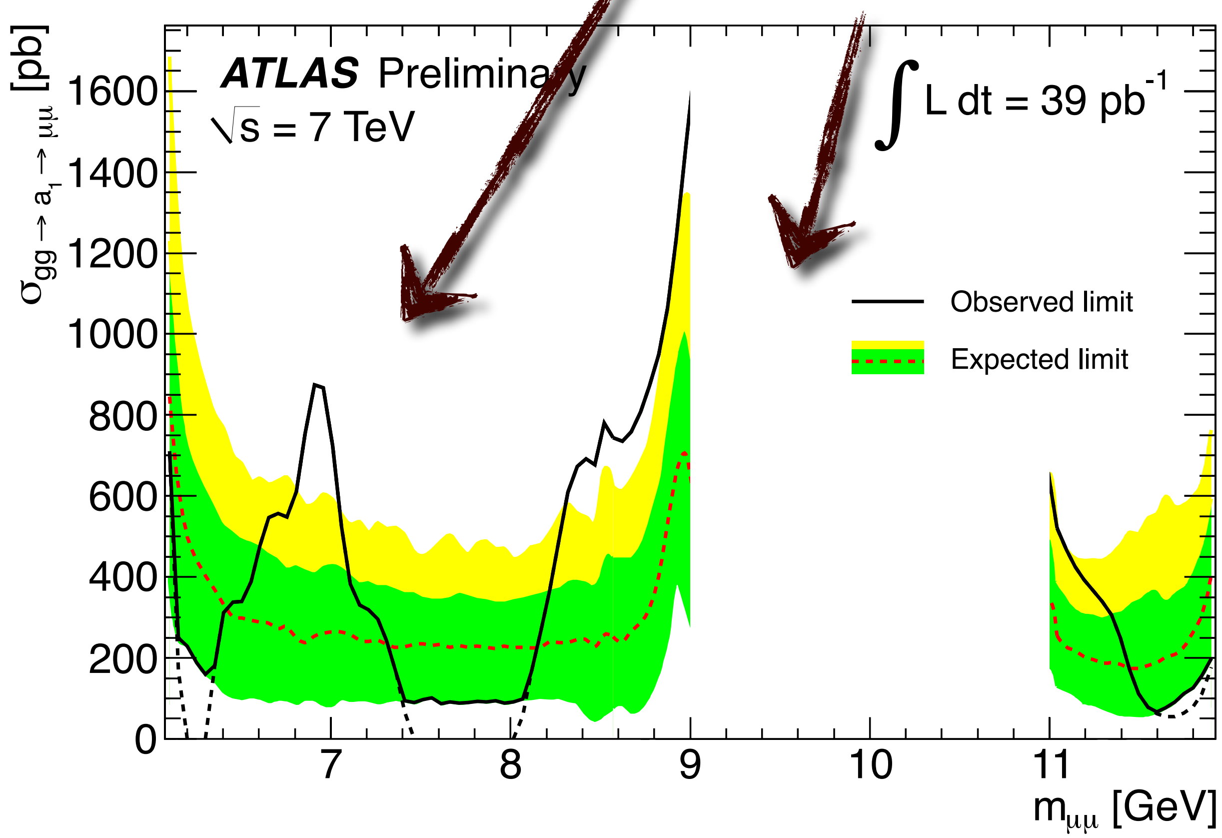
Likelihood ratio: $\chi^2$ of $\mu^+\mu^-$ vertex fit and muon isolation

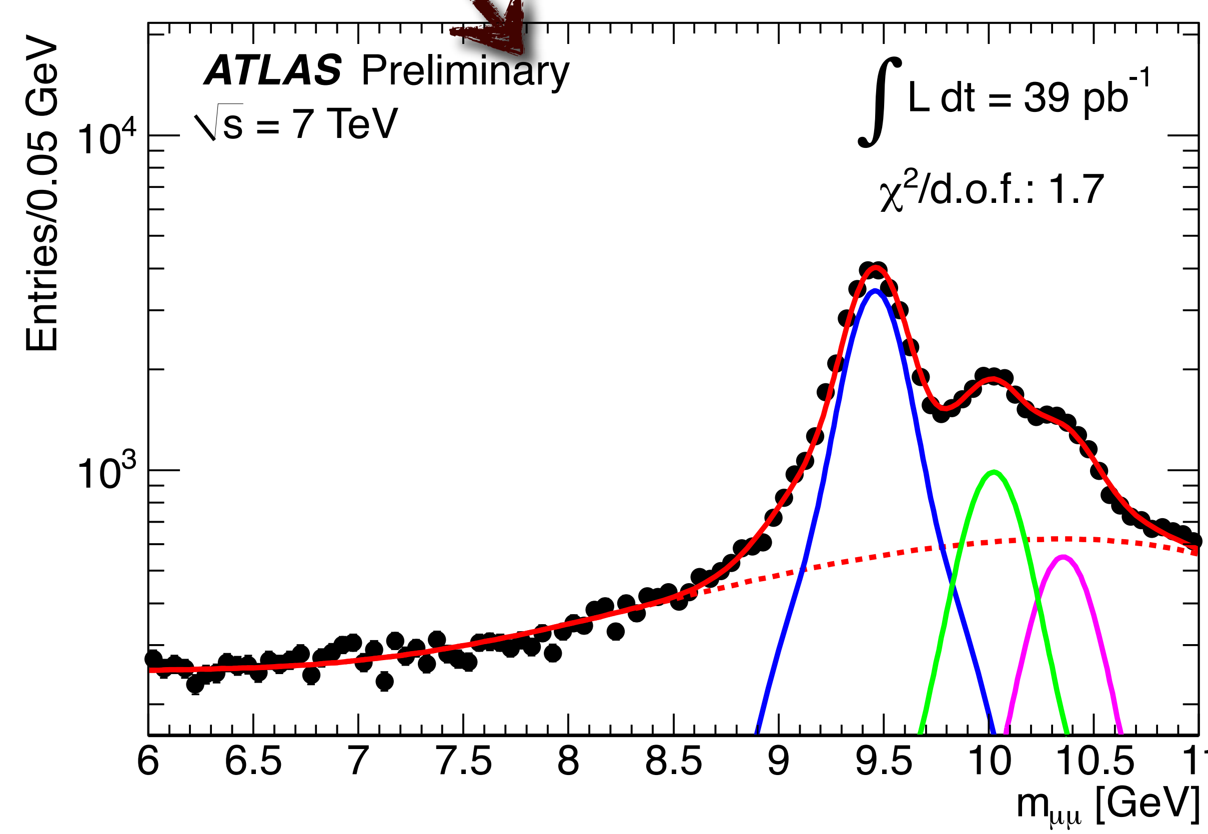
→ PDFs derived from data (signal Υ, background sidebands)




Limit :
Double gaussian for signal and 4th order Chebyshev polynomial for background
Observed limit fluctuations ➞ look-else-where effect.

accurate Υ production rates needed



# Summary of 2010 results and LHC in 2011 and beyond

⇒ LHC delivered 48 $pb^{-1}$ in 2010 → 35-43 $pb^{-1}$ used depending on final state

⇒ Mostly inclusive searches

⇒ Cut based analyses but also some multivariate results

⇒ Data-driven background as much as possible (limited by $\mathcal{L}_{int}$)

⇒ $H\to\gamma\gamma$ sensitivity comparable to Tevatron 2010 findings

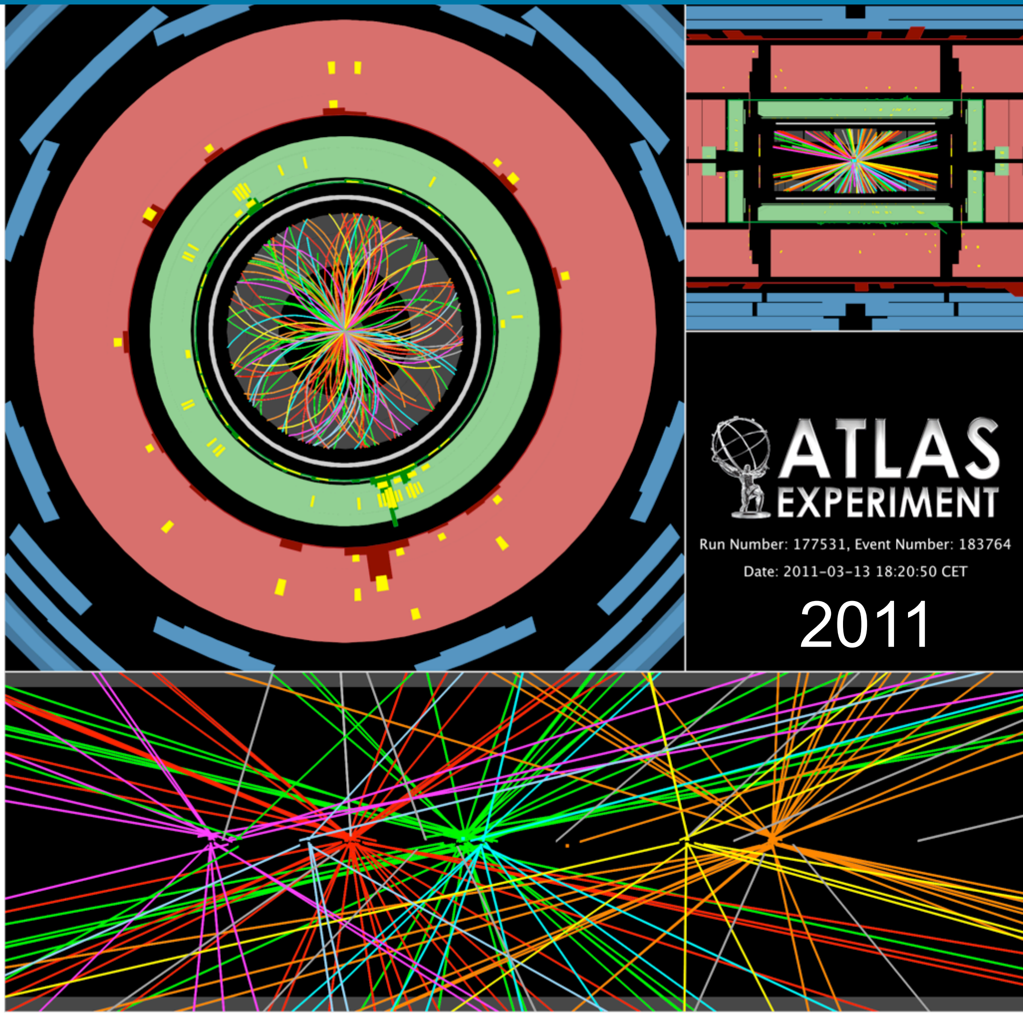
⇒ $H\to WW\to l\nu l\nu$ limit near Standard Model (2.4x$\sigma_{SM}$ expected@$M_H$=170GeV)

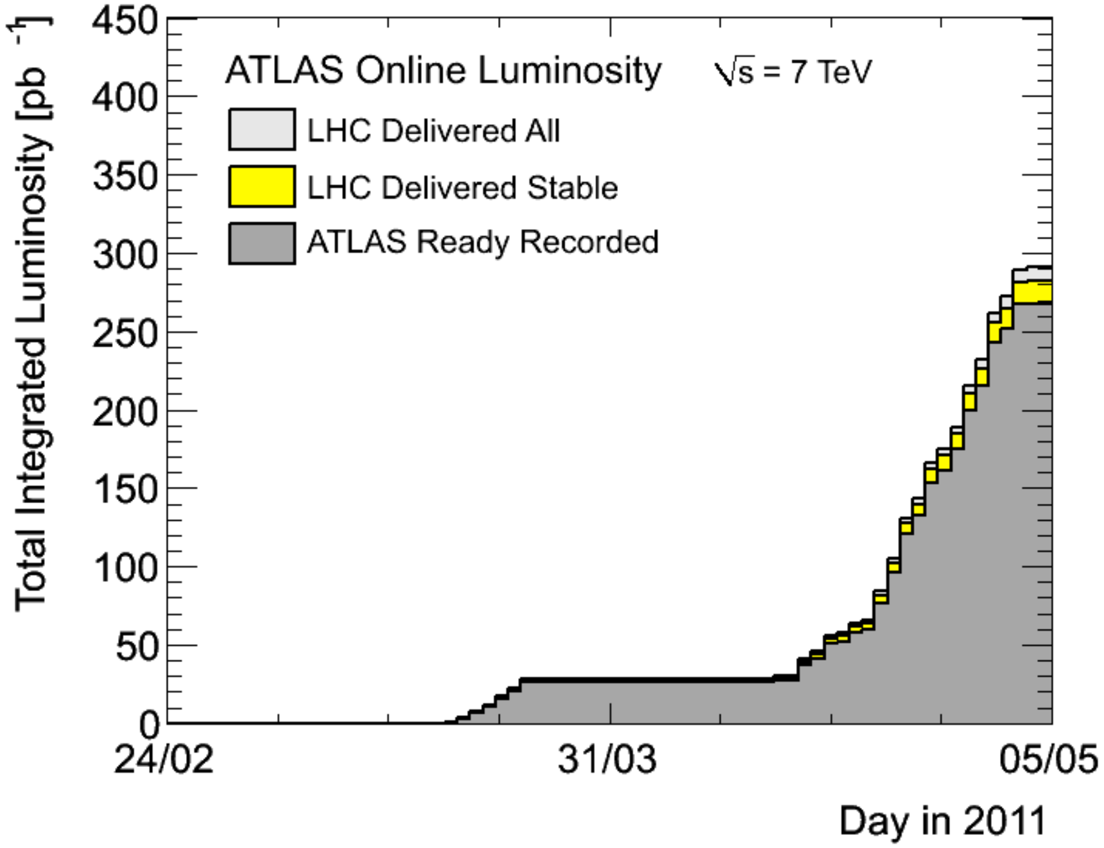
⇒ $H\to ZZ\to 4l$ no candidates → limit to improve as $1/\mathcal{L}_{int}$

⇒ $H\to ZZ\to ll\nu\nu/llqq$ world's best limits between 200 - 400 GeV

⇒ $H\to WW\to l\nu qq$ most sensitive single channel for $M_H$>400GeV

⇒ $h/H/A\to\tau\tau$ in MSSM supersedes published Tevatron 2010 results




**LHC operation for 2011 well under way with excellent performance!**

→ 280/pb already delivered!

→ Peak stable luminosity $8.84\times10^{32}cm^{-2}s^{-1}$

→ Max <interactions/bunch-crossing>=8.9

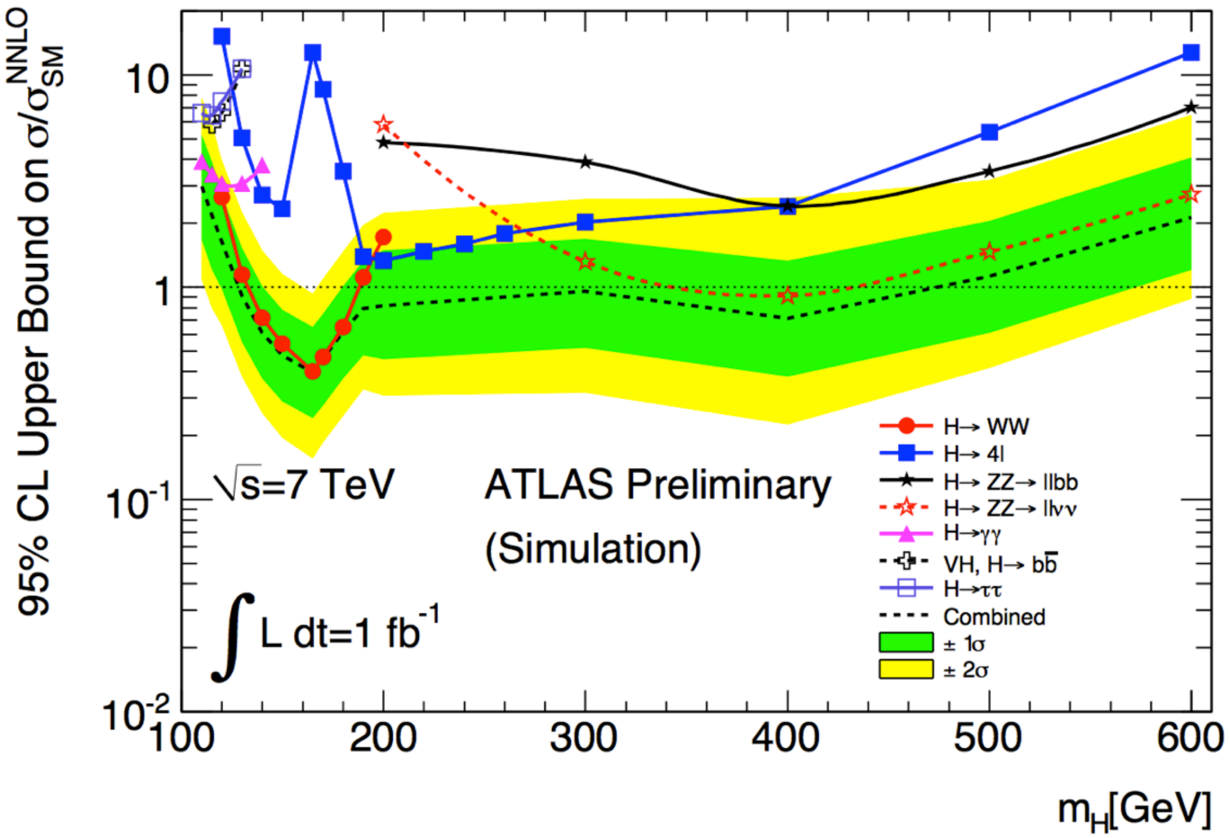
→ to run until the end of 2012 @ 7TeV

→ then shutdown (~1.5yr) to increase √s

**Several $fb^{-1}$/experiment expected by end of 2012**

→ ~1 $fb^{-1}$ for EPS meeting and ~2 $fb^{-1}$ by the end of summer!

# Higgs boson prospects for the (near) future

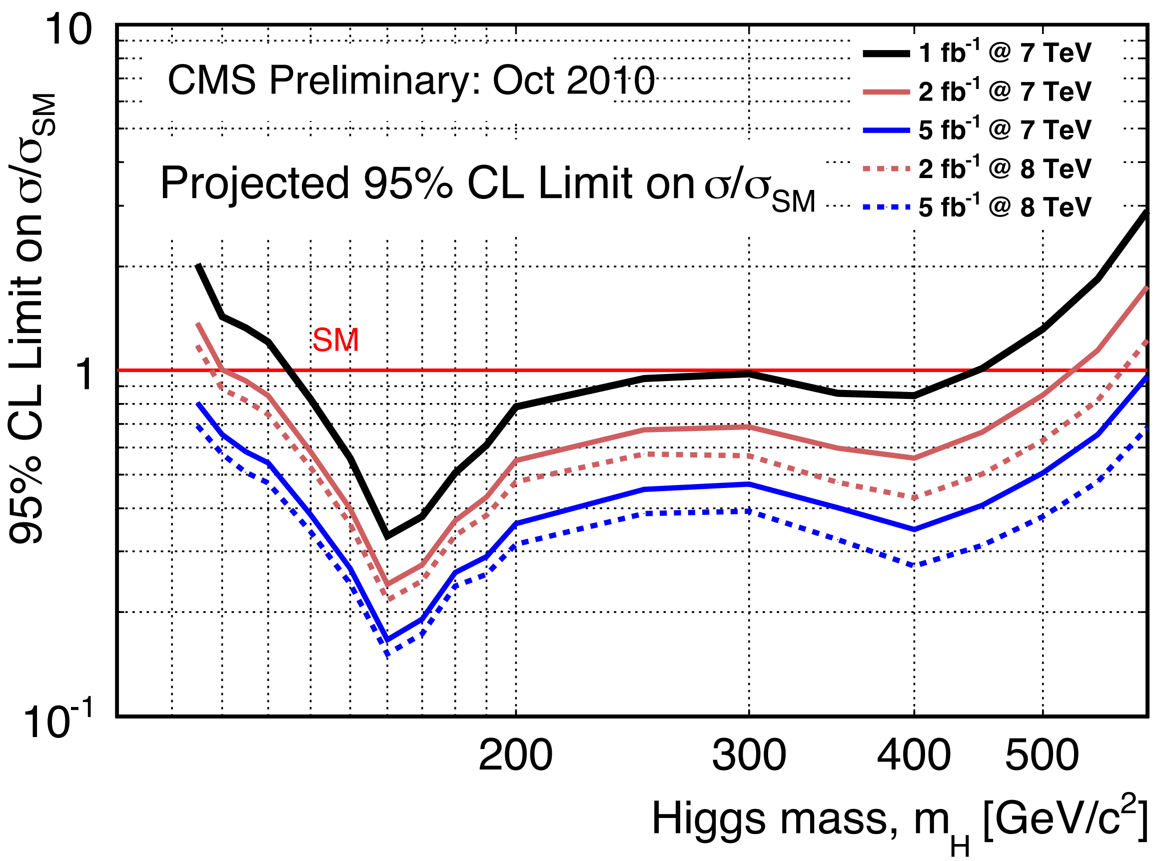


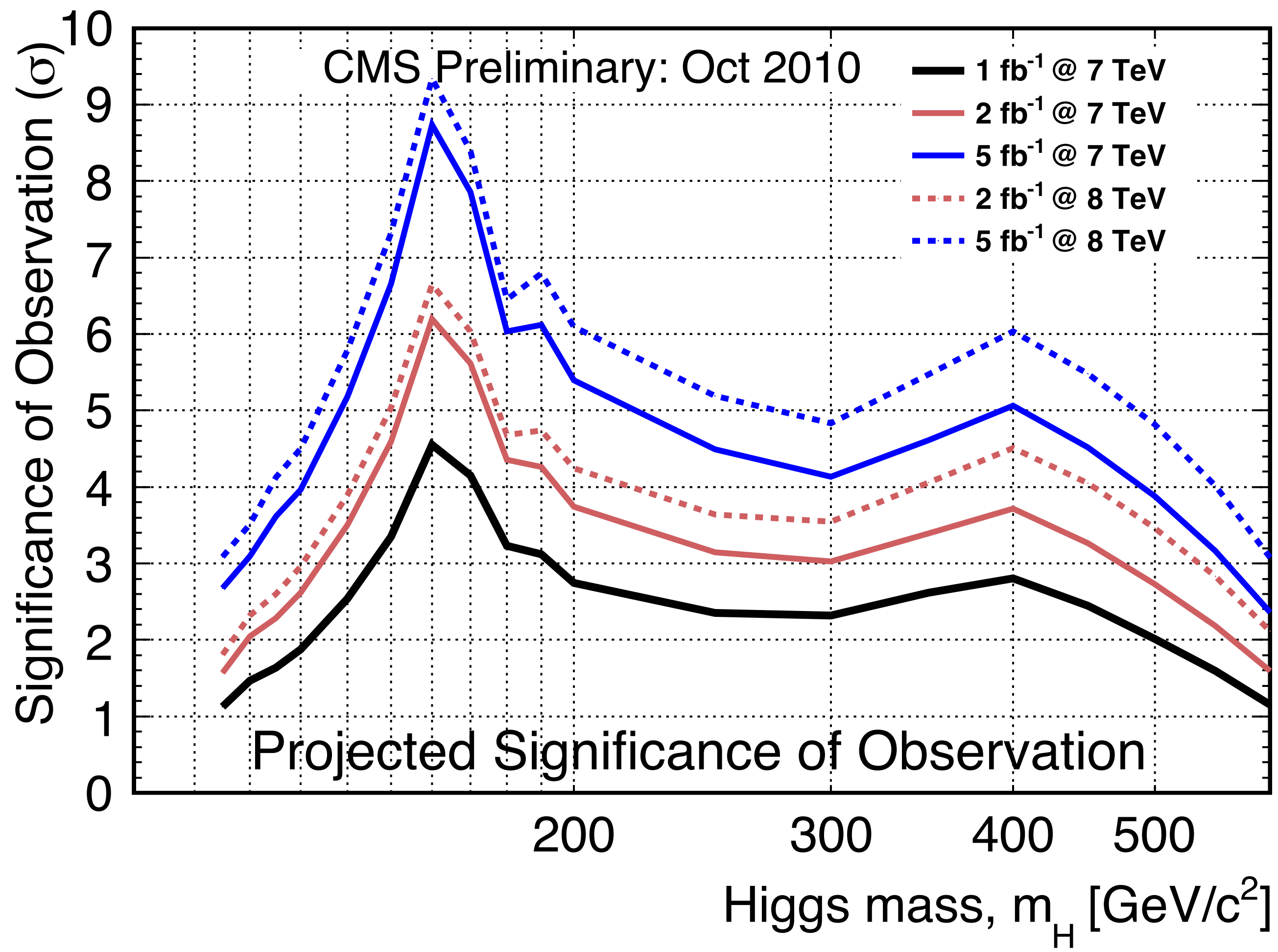

With ~1 $fb^{-1}$ for EPS and 2 $fb^{-1}$ by end of summer for each experiment

⇒<u>Sensitive to SM Higgs boson cross sections this summer!</u>

If SM Higgs is not Nature's choice we'll know by the end of this summer

Discovery more difficult ➙ BUT upward fluctuations may be observed!



# LHC Higgs and Cross Section WG

⇒ To maximize physics output, ATLAS and CMS will combine their results

⇒ Already LHC Higgs combination under preparation

→ Aiming for EPS 2011 (July 21st).

→ Only SM Higgs for now

→ Expand to MSSM in the future

⇒ **LHC-H**iggs**C**ombination**G**roup great progress in working together using common tools

⇒ Agreement on theoretical input is central in such an effort:

→ Role of LHC Higgs Cross Section Working important

→ Representatives appointed in the LHC-HCG

⇒ During this workshop all analysis aspects needed theory input are to be discussed.

Few highlights where guidance needed:

→ Exclusive final state ➙ sensitive to higher order effects

→ Line-shape and definition of mass for heavy SM Higgs boson

→ Interference between SM Higgs boson signal and SM backgrounds

→ Uncertainty on cross section×acceptance calculated by varying QCD scales and PDFs. Correlations between experiments? Particularly important for analysis using jet counting.

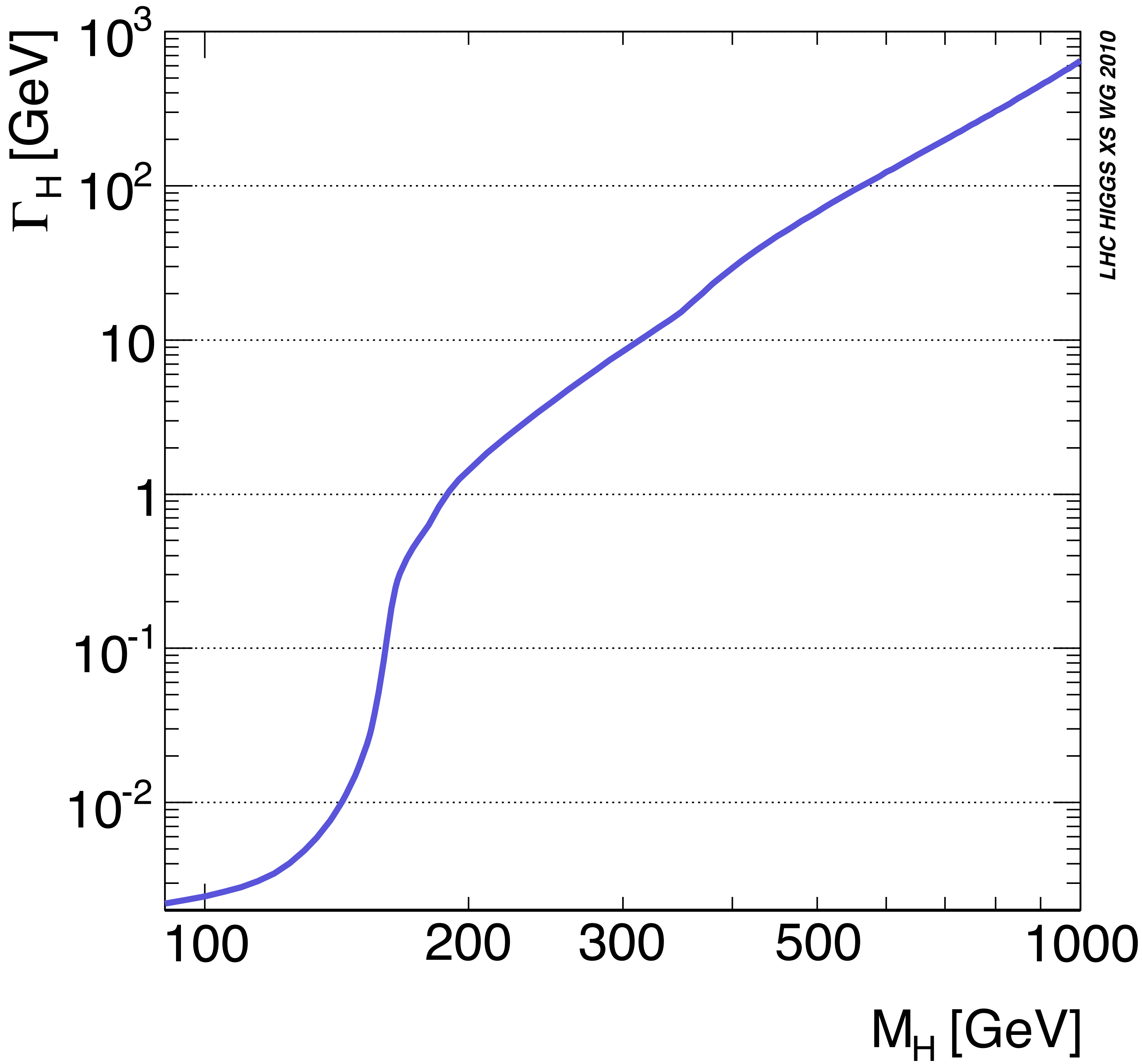
→ Backgrounds estimated using control regions ➙ Uncertainty on transfer factors

→ Diboson production taken directly from MC in several cases ➙ Normalization/shape uncertainty

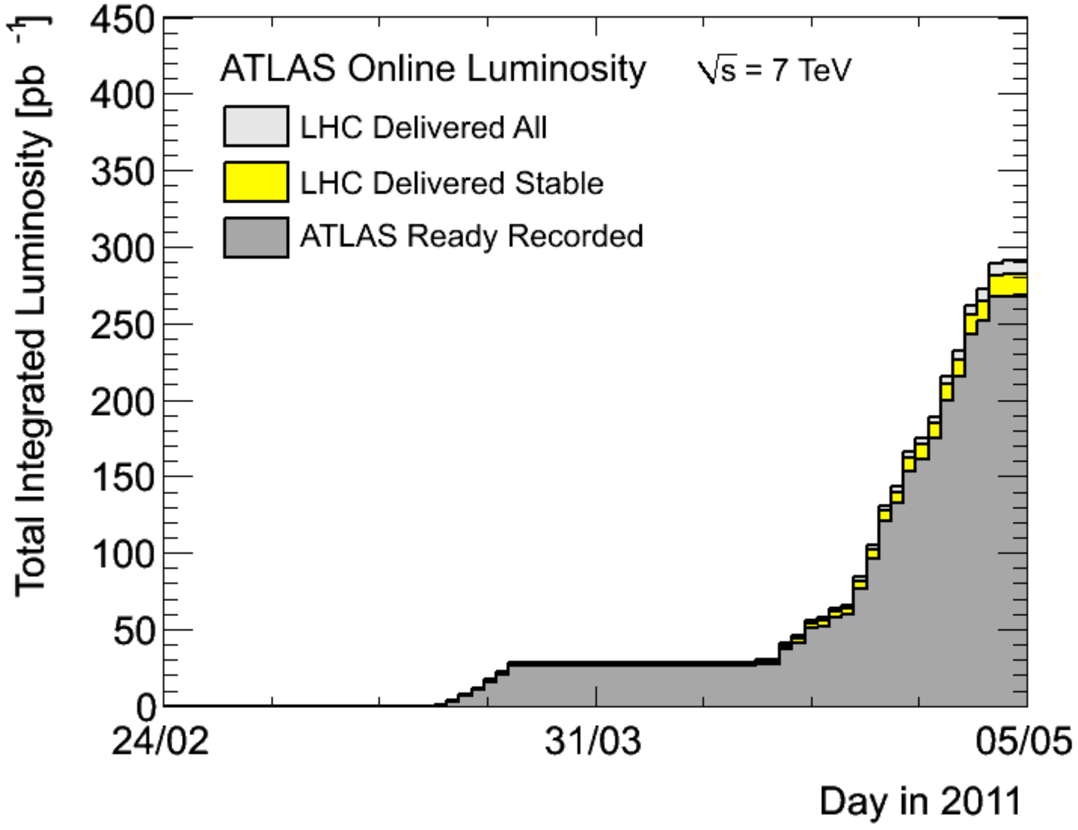
→ 4 vs 5 Flavor Schemes and Santander matching for associated Higgs-bottom quark production

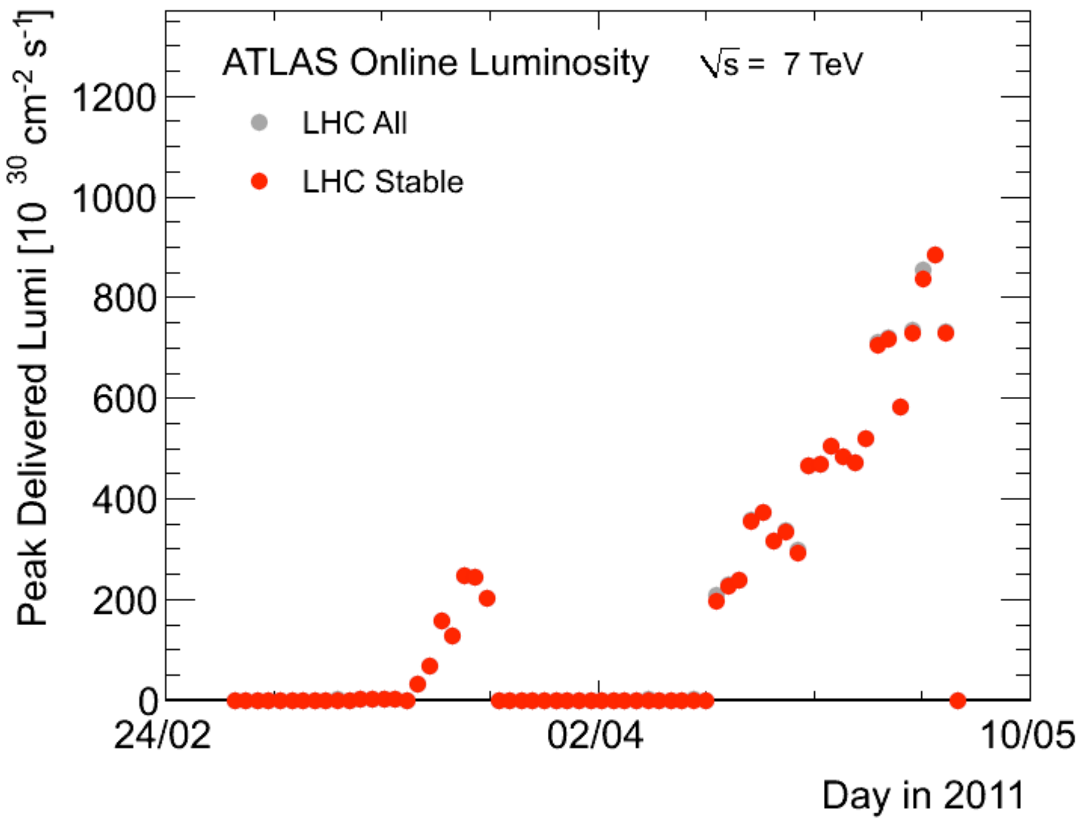
**Additional Slides**

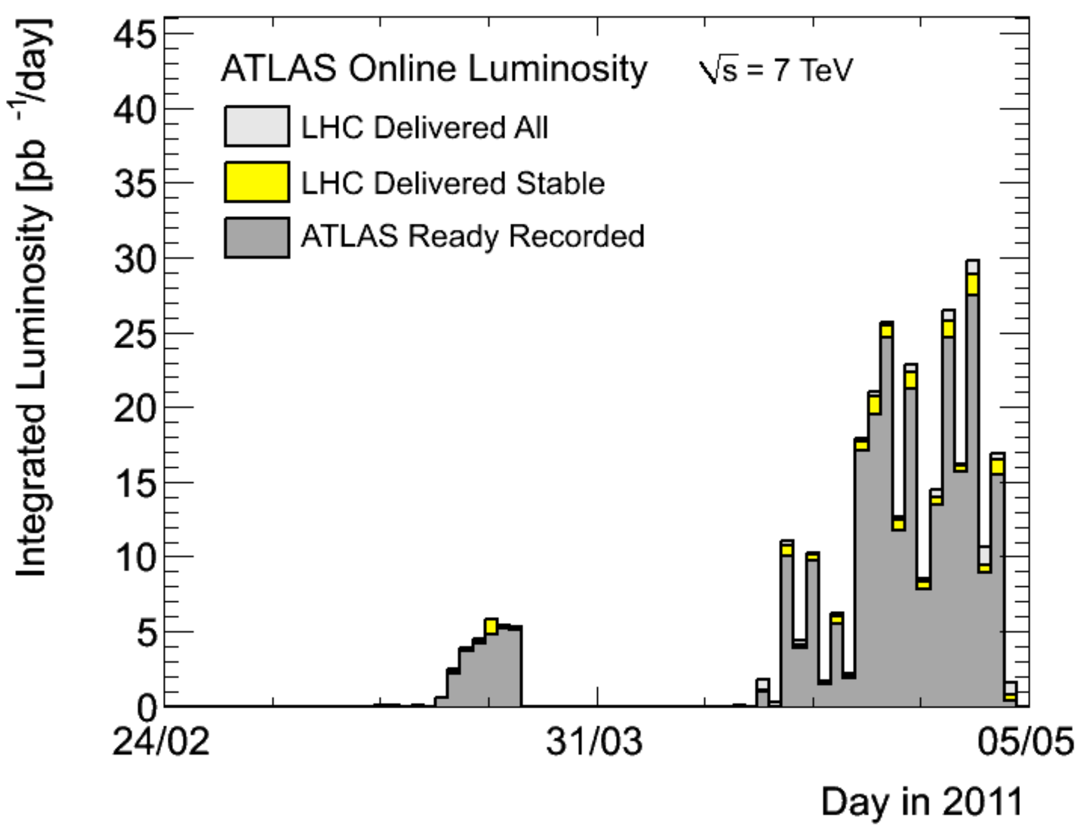
# SM Higgs Natural Width



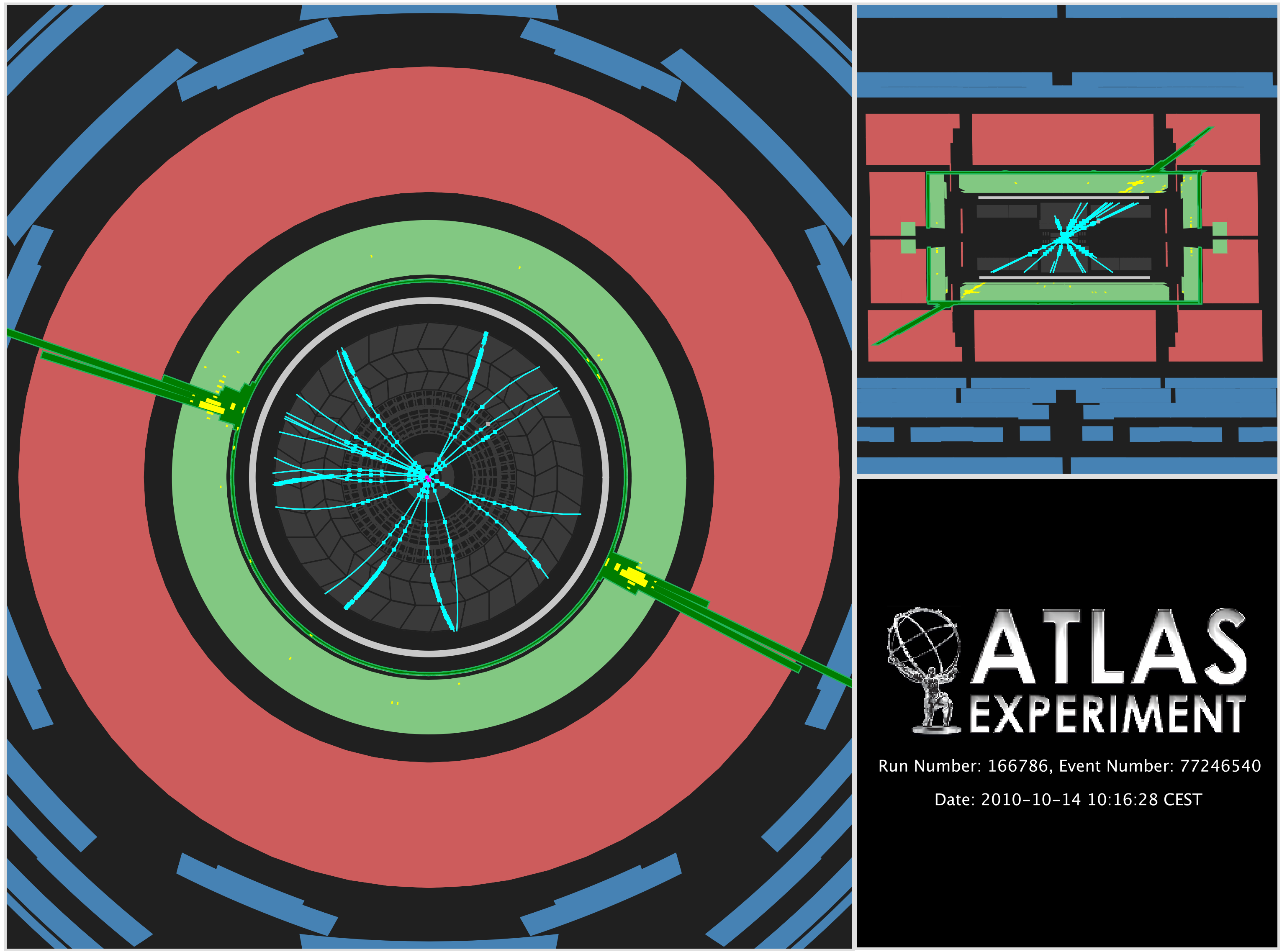
# LHC Performance



# 2010 highest mass γγ candidate



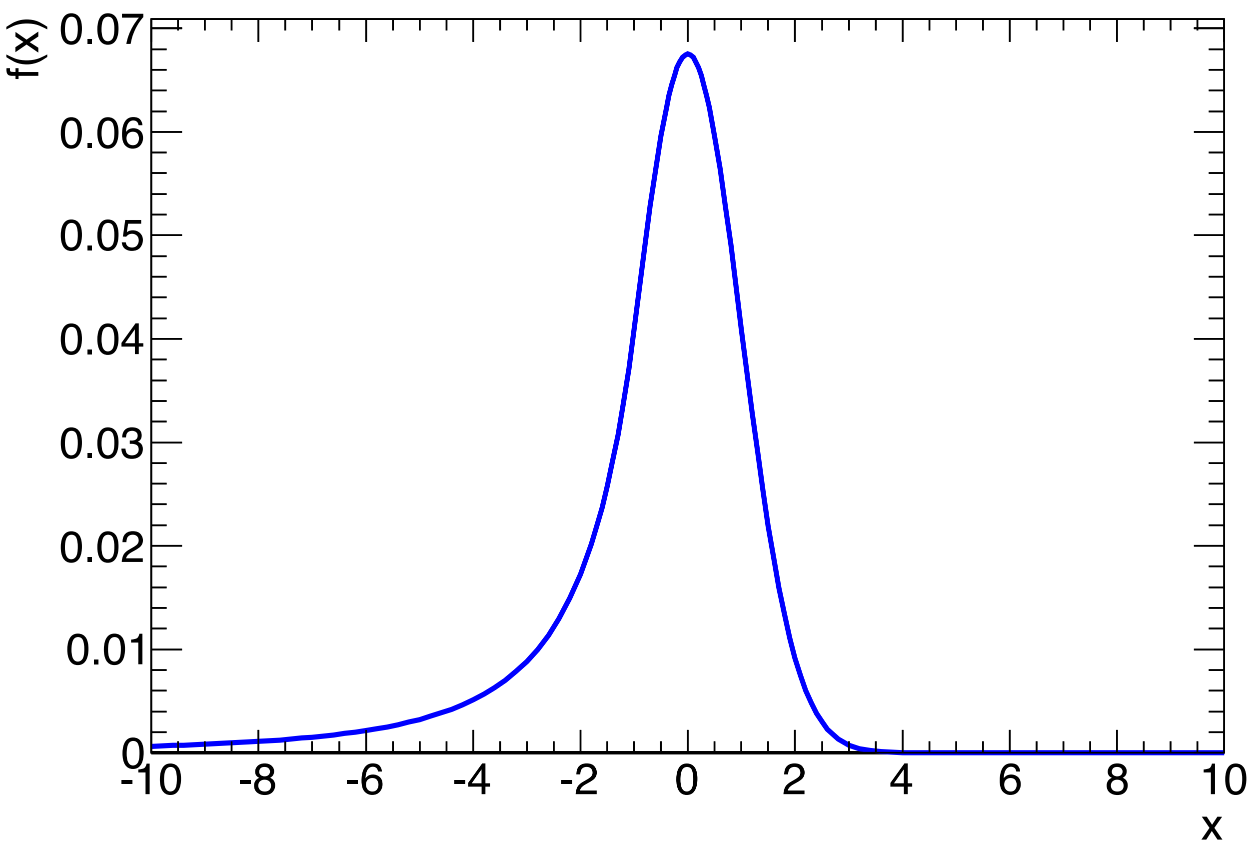

An event display of the highest invariant mass diphoton event in which both candidate photons satisfy the more stringent photon identification cuts. The highest transverse momentum photon has pT = 194 GeV and (eta, phi) = (-1.32,-0.44). The trailing photon has pT = 173 GeV and (eta, phi)= (1.10,2.82). The diphoton invariant mass is equal to 679 GeV.

# Crystal Ball function

It's a smooth function describing the line shape composed of a central Gaussian, with a power lat tail. Was used to parametrise the detector response function of the Crystall Ball detector - an almost hermetic spherical calorimeter - 98% of the solid angle - with scintillating crystals (NaI(TI)) which started it's carrier initially at SPEAR (SLAC) in 1978 and then moved to DESY (1982) and is now at Mainz.

$$f(x;\alpha,n,\bar{x},\sigma) = N \cdot \begin{cases} \exp(-\frac{(x-\bar{x})^2}{2\sigma^2}), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot (B - \frac{x-\bar{x}}{\sigma})^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha \end{cases}$$

$$A = \left(\frac{n}{|\alpha|}\right)^n \cdot \exp\left(-\frac{|\alpha|^2}{2}\right) \qquad B = \frac{n}{|\alpha|} - |\alpha|$$




$\bar{x}$=0 ⇒Gauss mean

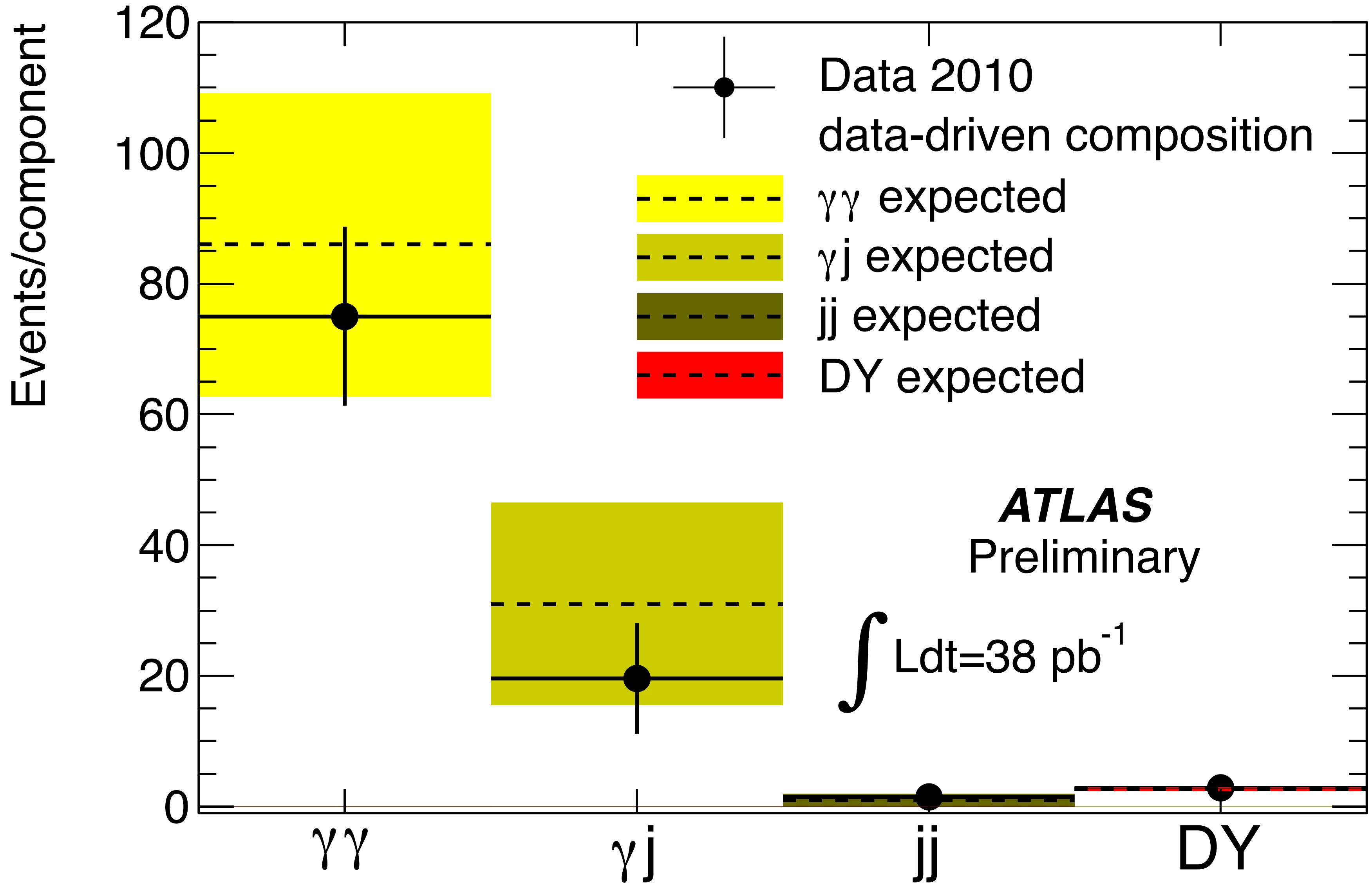
σ=1 ⇒Gauss sigma

α=1 ⇒ Gauss-Power low change over

n=3 ⇒ Power low exponent

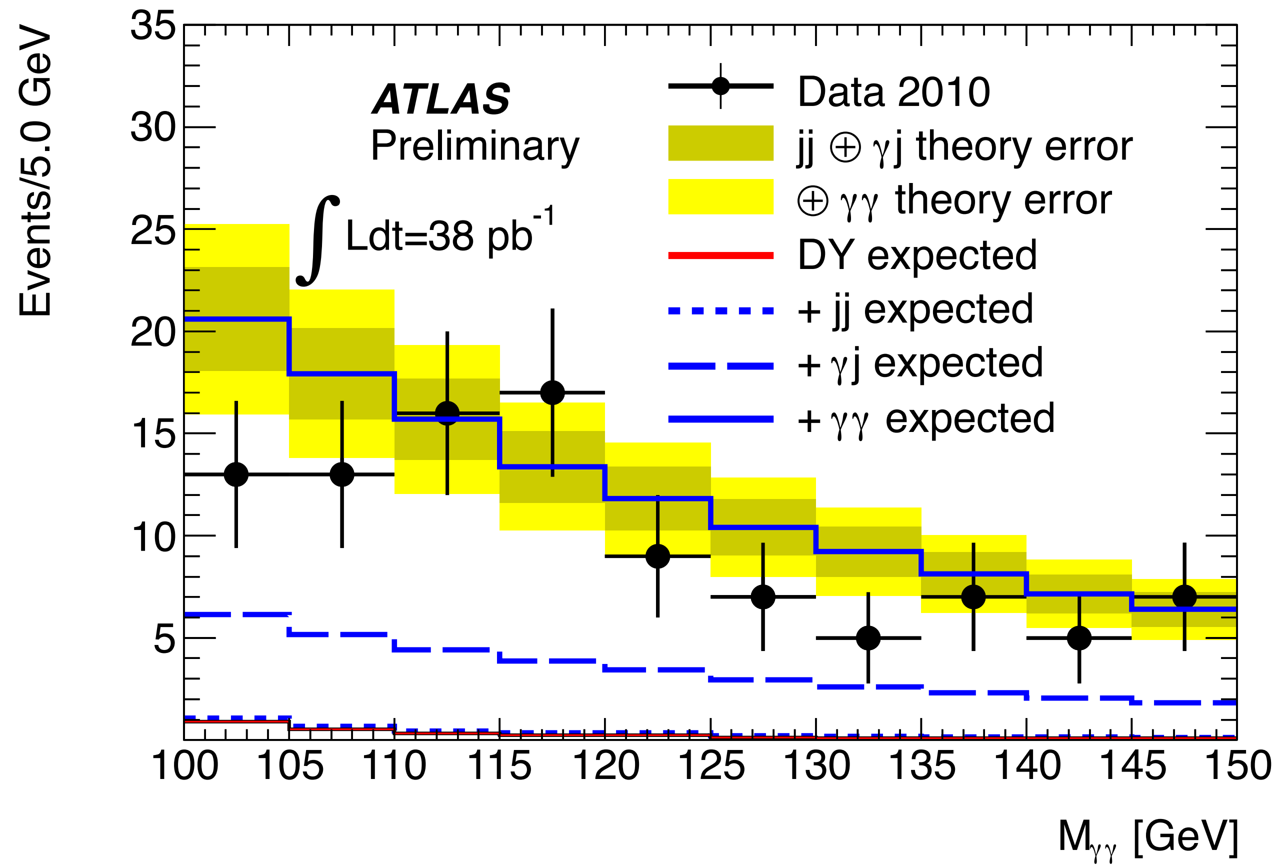
# H→γγ

| | $N_{\gamma\gamma}$ | $N_{\gamma j}+N_{j\gamma}$ | $N_{jj}$ | $N_{DY}$ |
|---|---|---|---|---|
| Data | $75.0\pm13.3^{+2.7}_{-3.6}$ | $19.6\pm7.5\pm3.9$ | $1.5\pm0.7^{+1.8}_{-0.5}$ | $2.9\pm0.1\pm0.6$ |
| Expected | $86\pm23$ | $31\pm15$ | $1\pm1$ | $2.7\pm0.2$ |



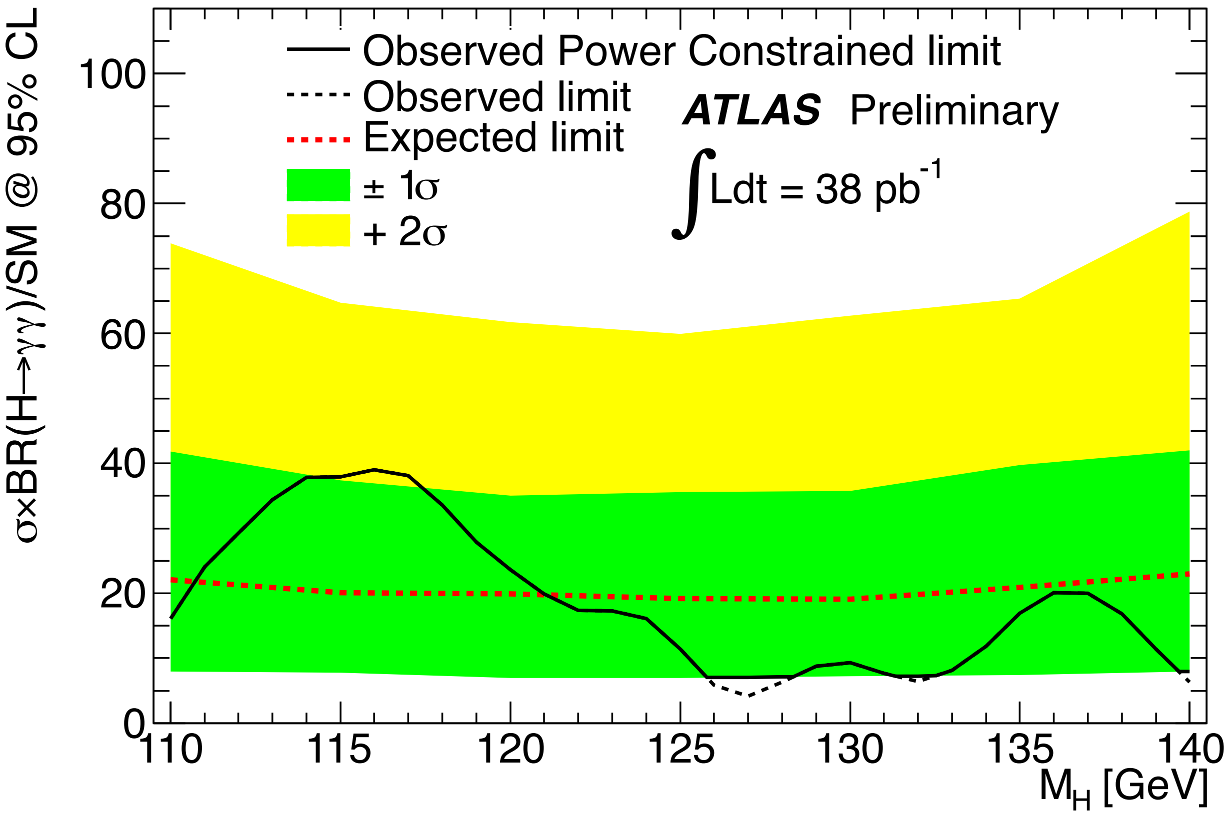
# H→γγ

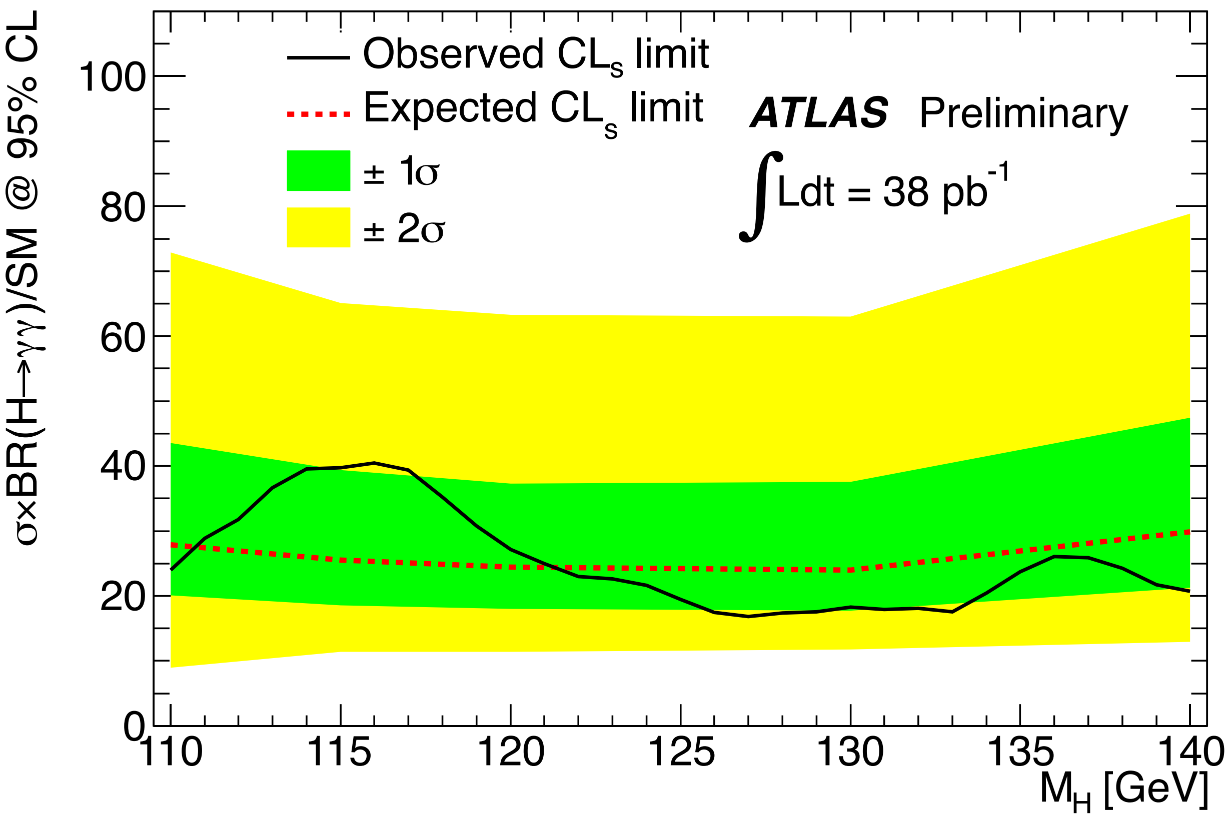
| Source | Uncertainty |
|---|---|
| Luminosity | ±3.4% |
| Cross section | +20%/-15% |
| γ-ID | ±11% |
| γ-Isolation | ±10% |
| Trigger | +1.1%/-3.7% |
| Energy resolution | ±13% on $\sigma_M$ |




| Higgs boson mass [GeV] | 110 | 115 | 120 | 130 | 140 |
|---|---|---|---|---|---|
| Number of signal events | $0.43^{+0.11}_{-0.09}$ | $0.45^{+0.11}_{-0.10}$ | $0.45^{+0.11}_{-0.10}$ | $0.41^{+0.10}_{-0.08}$ | $0.31 \pm 0.08$ |

# H→γγ

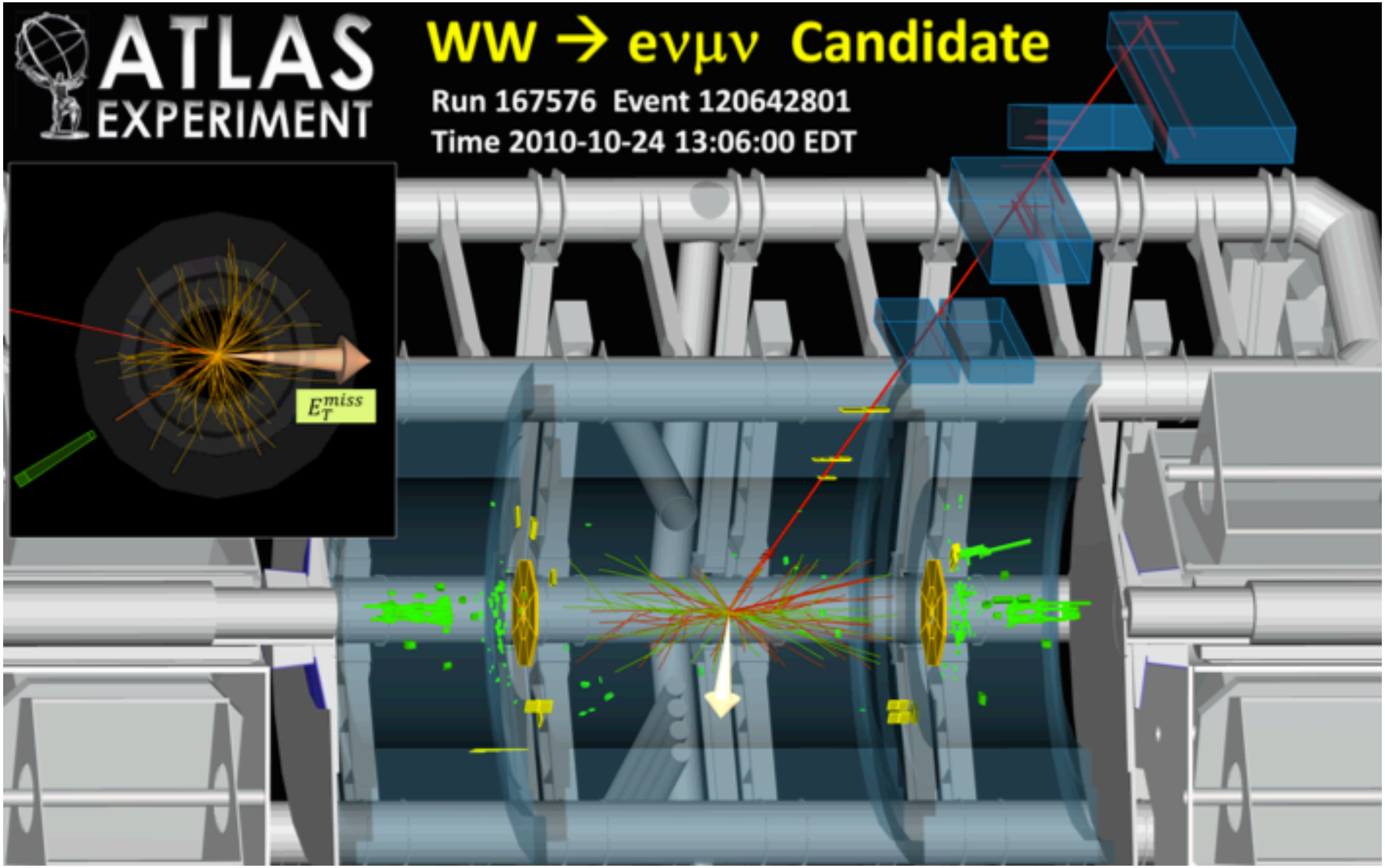


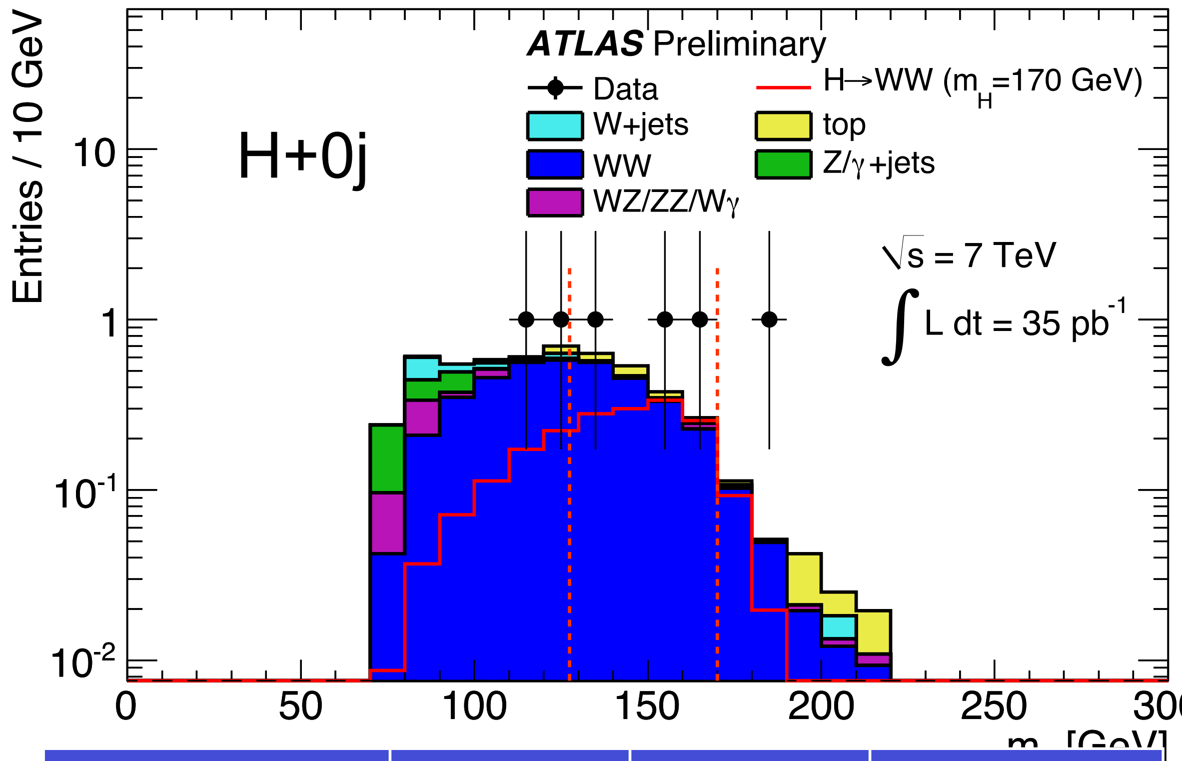

| $m_H$ [GeV] | Expected limit | | Observed limit | |
|---|---|---|---|---|
| | $CL_{s+b}$ | $CL_s$ | $PCL_{s+b}$ | $CL_s$ |
| 110 | 22.1 | 27.9 | 16.1 | 24.0 |
| 115 | 20.1 | 25.5 | 37.9 | 39.7 |
| 120 | 19.9 | 24.4 | 23.6 | 27.2 |
| 130 | 19.1 | 24.0 | 9.3 | 18.3 |
| 140 | 23.0 | 29.9 | 8.0 | 20.7 |

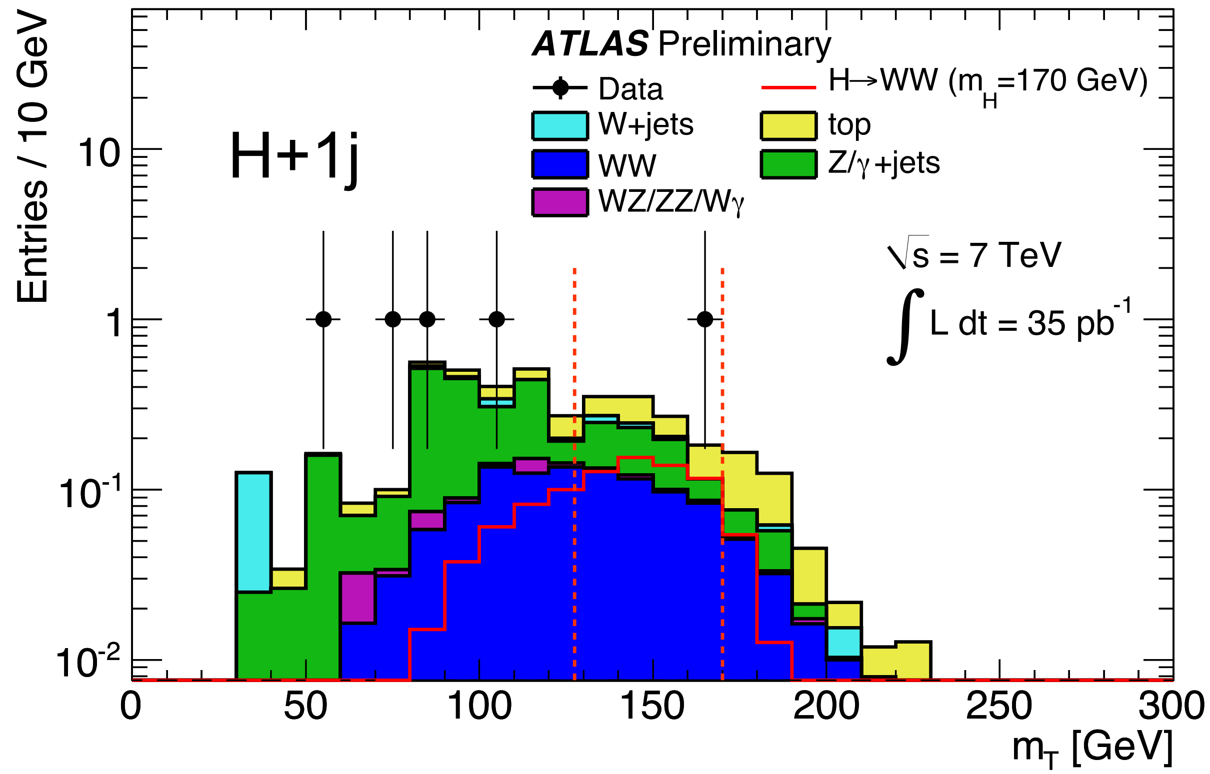
# H→WW→lνlν

| Run number | Event number | $p_T^{\mu^-}$ [GeV] | $\eta^{\mu^-}$ | $\phi^{\mu^-}$ | $p_T^{e^+}$ [GeV] | $\eta^{e^+}$ | $\phi^{e^+}$ | $E_T^{miss}$ [GeV] | $\phi_{E_T^{miss}}$ |
|---|---|---|---|---|---|---|---|---|---|
| 167576 | 120642801 | 67.8 | -0.63 | 0.20 | 21.2 | -1.56 | -0.56 | 68.8 | -3.08 |



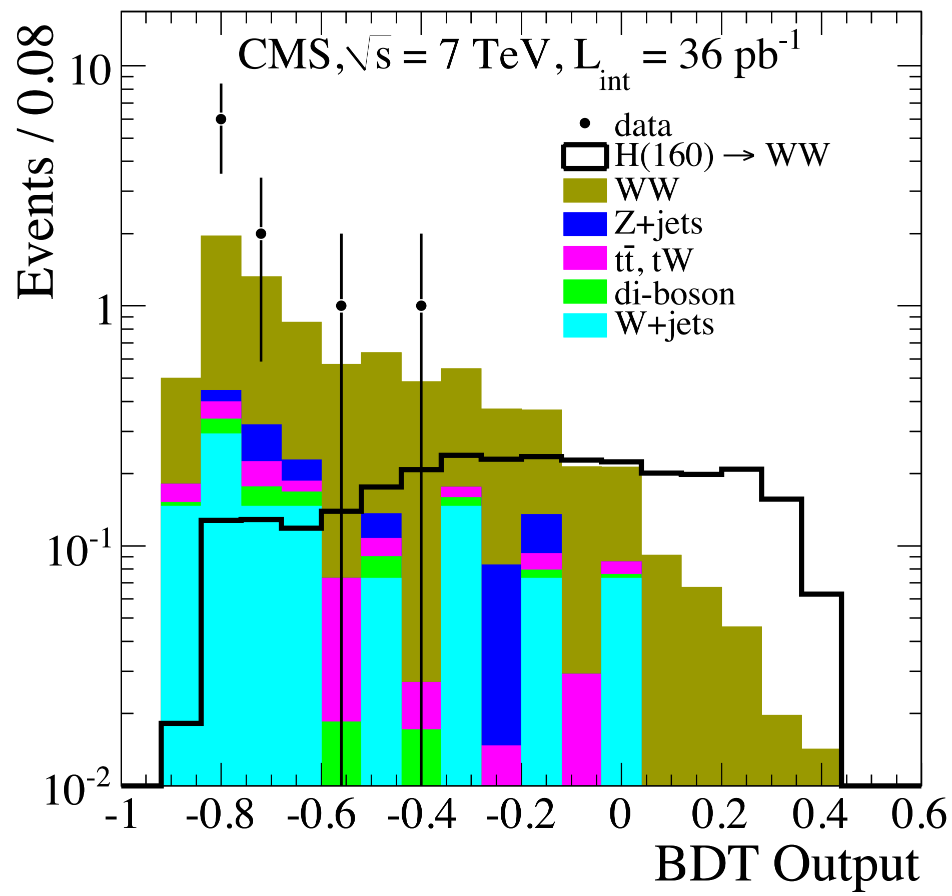
# H→WW→lνlν



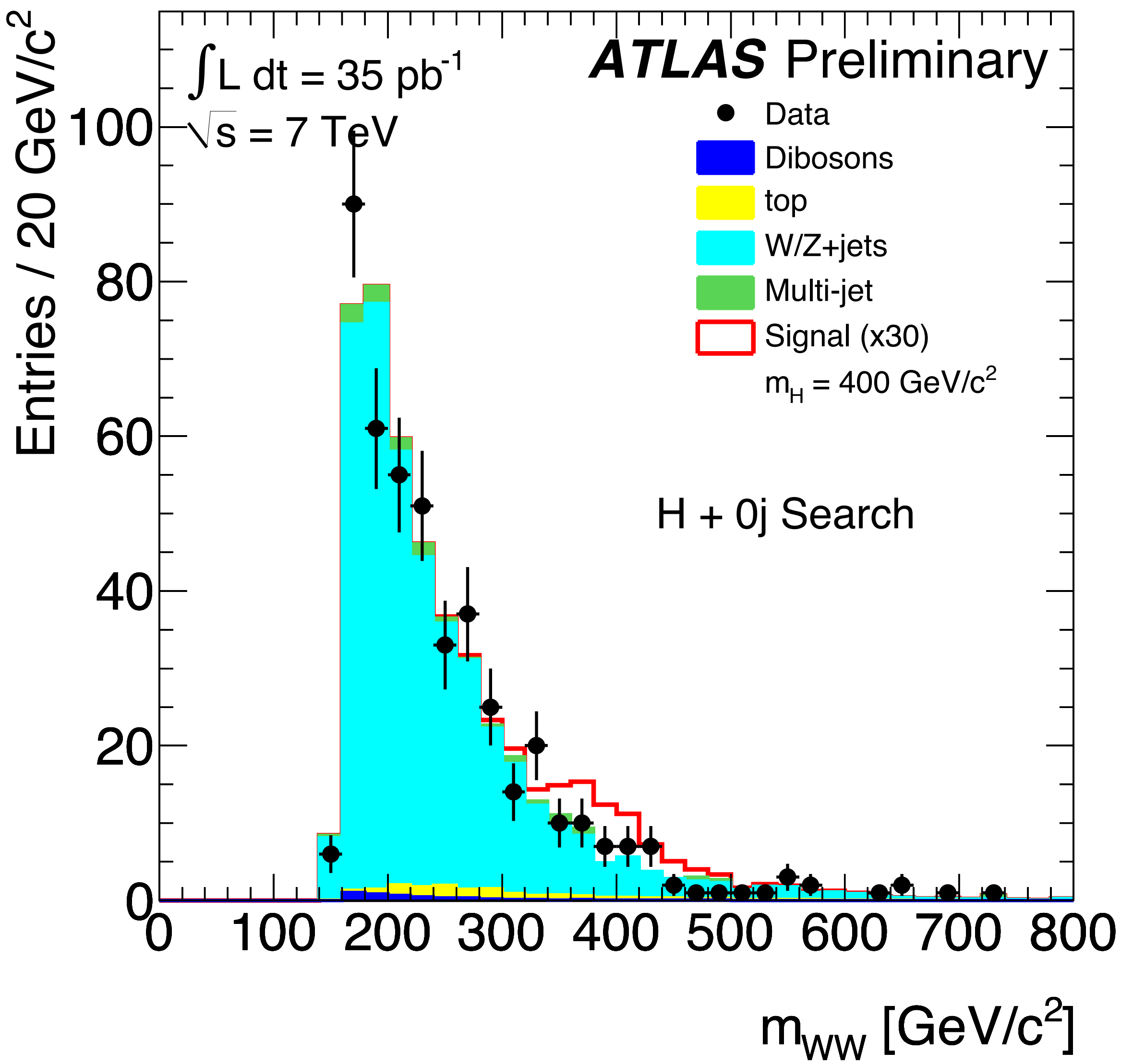



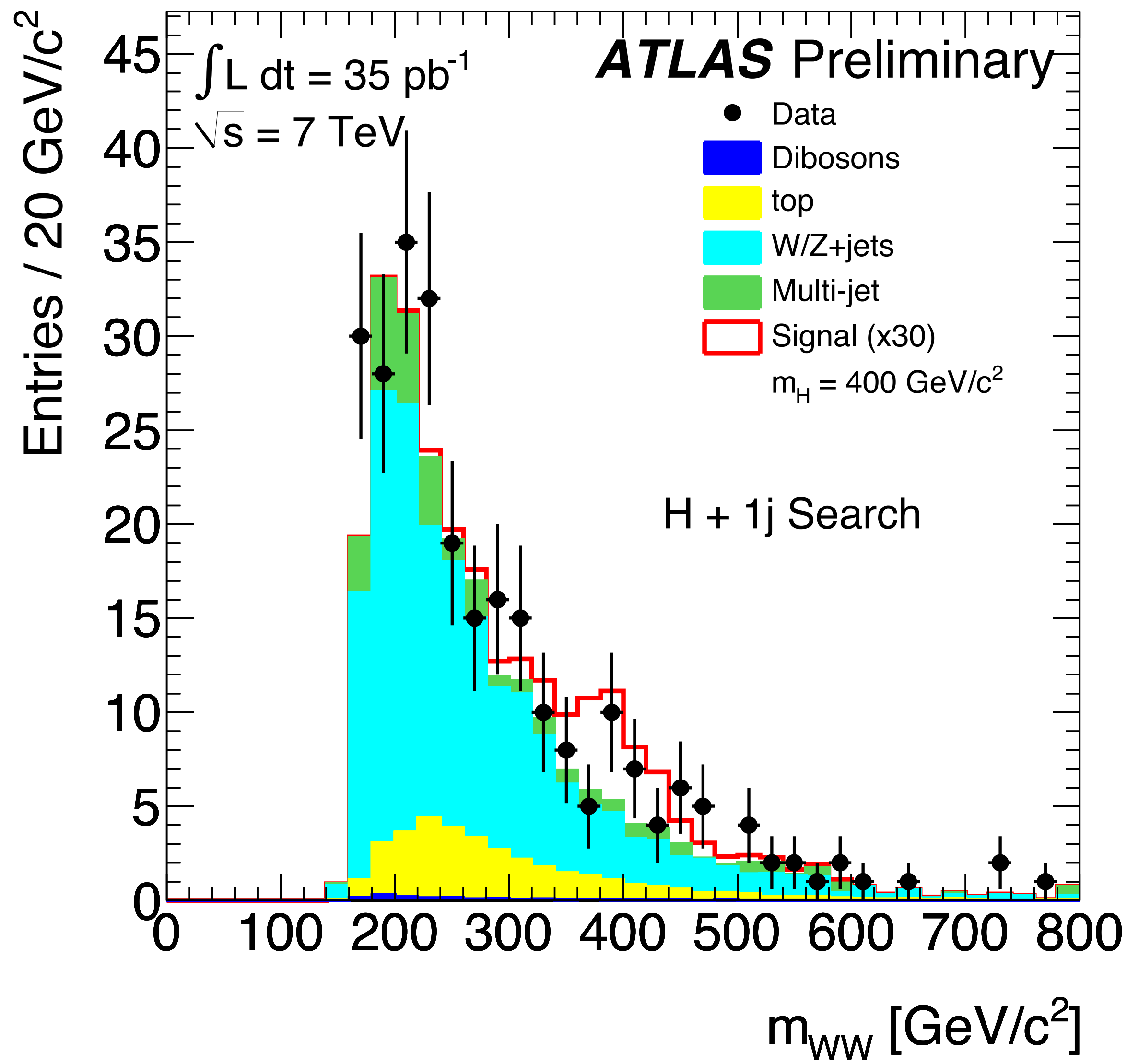

| ATLAS $M_H$=170 GeV | 0jet | 1jet | 2jet |
|---|---|---|---|
| Data | 3 | 1 | 0 |
| BG | 1.7±0.3 | 1.3±0.5 | 0.02±0.03 |
| Signal | 1.3±0.4 | 0.6±0.2 | 0.06±0.03 |

| CMS $M_H$=160 GeV | BDT | Cut |
|---|---|---|
| Data | 0 | 0 |
| BG | 0.92±0.103 | 0.91±0.05 |
| Signal | 1.47±0.02 | 1.23±0.02 |



# H→WW→lvqq




| ATLAS | H(eνqq)+0j | H(μνqq)+0j | H(eνqq)+1j | H(μνqq)+1j |
|---|---|---|---|---|
| Data | 177 | 273 | 87 | 176 |
| Background | 175 ± 22 | 275 ± 34 | 72.9 ± 8.4 | 151 ± 13 |
| Signal ($M_H$=400GeV) | 0.5 ± 0.2 | 0.6 ± 0.2 | 0.5 ± 0.2 | 0.5 ± 0.2 |

# H→WW→lvqq

| Source | Uncertainty on Signal Efficiency |
|---|---|
| Electron Efficiency | ±5% |
| Muon Efficiency | ±2% |
| Jet Energy Scale | ±26% |
| Luminosity Measurement | ±11% |
| Theory Error on $\sigma(gg \to H)$ | ±19% |

# $H \rightarrow ZZ \rightarrow llqq$

| Source | low $m_H$ selection | high $m_H$ selection |
|---|---|---|
| $Z$+jets | $214 \pm 4 \pm 27$ | $9.11 \pm 0.90 \pm 1.39$ |
| $W$+jets | $0.33 \pm 0.16 \pm 0.17$ | – |
| $t\bar{t}$ | $0.94 \pm 0.09 \pm 0.25$ | $0.08 \pm 0.02 \pm 0.03$ |
| Multijet | $3.81 \pm 0.65 \pm 1.91$ | $0.11 \pm 0.11 \pm 0.06$ |
| $ZZ$ | $3.80 \pm 0.10 \pm 0.73$ | $0.30 \pm 0.03 \pm 0.06$ |
| $WZ$ | $2.83 \pm 0.05 \pm 0.88$ | $0.29 \pm 0.02 \pm 0.10$ |
| Total background | $226 \pm 4 \pm 28$ | $9.88 \pm 0.91 \pm 1.49$ |
| Data | 216 | 11 |
| | | |
| $m_H$ (GeV) | Expected number of Higgs bosons selected | |
| 200 | $0.60 \pm 0.01 \pm 0.12$ | |
| 300 | $0.46 \pm 0.01 \pm 0.10$ | |
| 400 | | $0.24 \pm 0.00 \pm 0.05$ |
| 500 | | $0.14 \pm 0.00 \pm 0.03$ |
| 600 | | $0.07 \pm 0.00 \pm 0.01$ |

# $H \to ZZ \to ll\nu\nu$

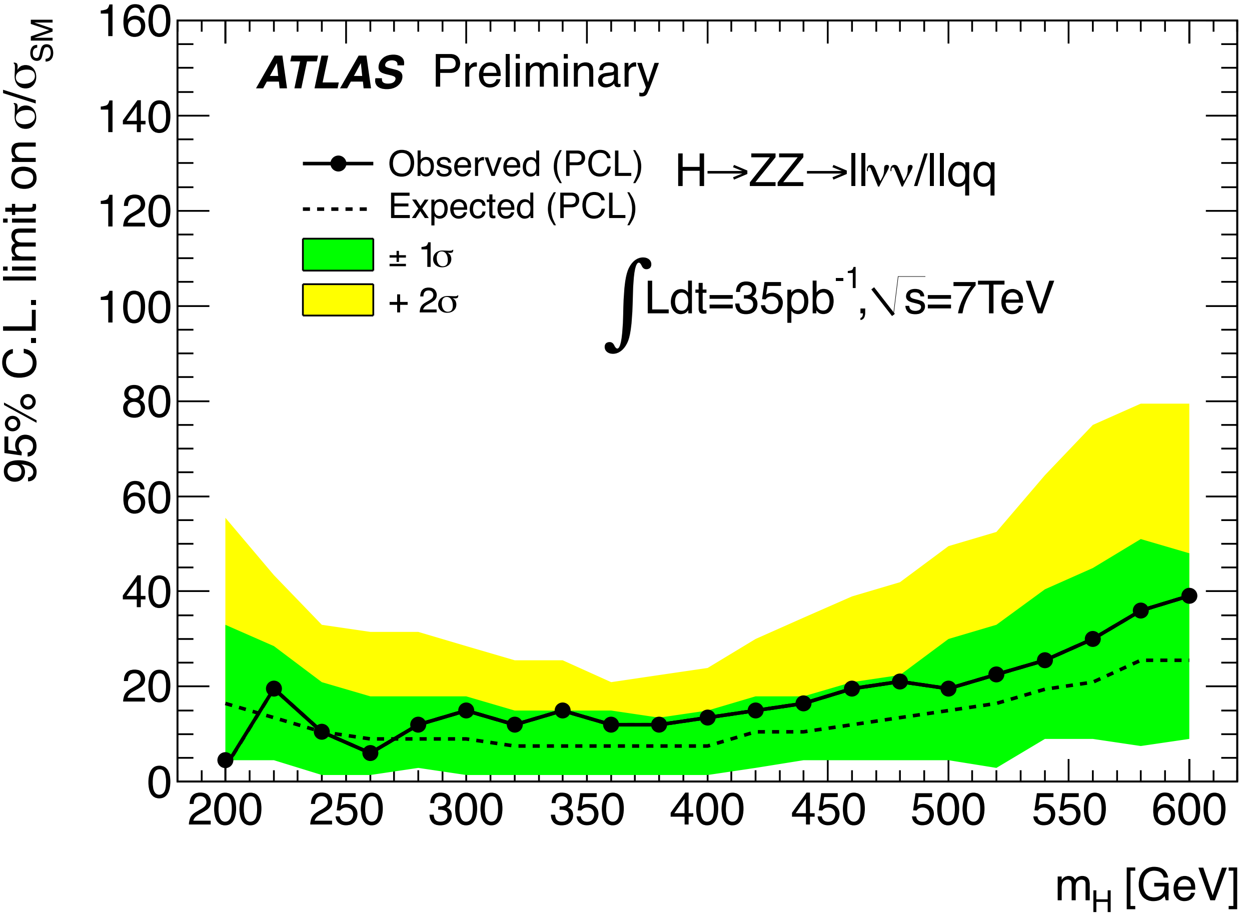
| Source | low $m_H$ selection | high $m_H$ selection |
|---|---|---|
| $Z$+jets | $1.09 \pm 0.29 \pm 0.59$ | $1.01 \pm 0.29 \pm 0.58$ |
| $W$+jets | $1.07 \pm 0.31 \pm 0.64$ | $0.41 \pm 0.19 \pm 0.22$ |
| $t\bar{t}$ | $1.90 \pm 0.10 \pm 0.63$ | $0.91 \pm 0.07 \pm 0.31$ |
| Multijet | $0.11 \pm 0.11 \pm 0.06$ | – |
| $ZZ$ | $0.58 \pm 0.01 \pm 0.11$ | $0.51 \pm 0.01 \pm 0.10$ |
| $WZ$ | $0.57 \pm 0.01 \pm 0.10$ | $0.45 \pm 0.01 \pm 0.09$ |
| $WW$ | $0.43 \pm 0.02 \pm 0.09$ | $0.16 \pm 0.01 \pm 0.04$ |
| Total background | $5.76 \pm 0.45 \pm 1.30$ | $3.45 \pm 0.36 \pm 0.78$ |
| Data | 5 | 5 |

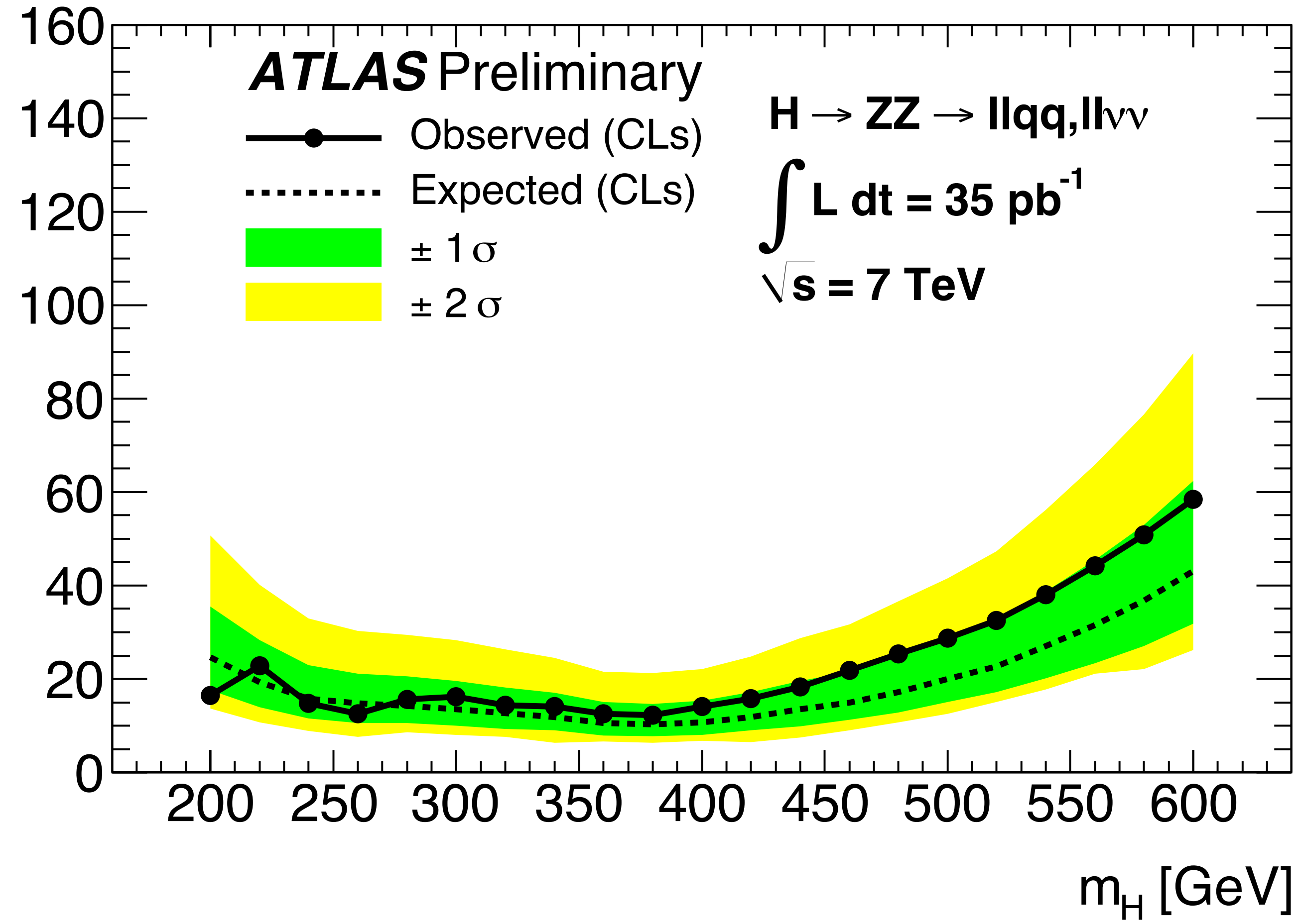
| $m_H$ (GeV) | Expected number of Higgs bosons selected | |
|---|---|---|
| 200 | $0.19 \pm 0.00 \pm 0.04$ | |
| 300 | | $0.33 \pm 0.00 \pm 0.07$ |
| 400 | | $0.30 \pm 0.00 \pm 0.06$ |
| 500 | | $0.14 \pm 0.00 \pm 0.03$ |
| 600 | | $0.06 \pm 0.00 \pm 0.01$ |

# Exclusion Limits at high Higgs boson mass

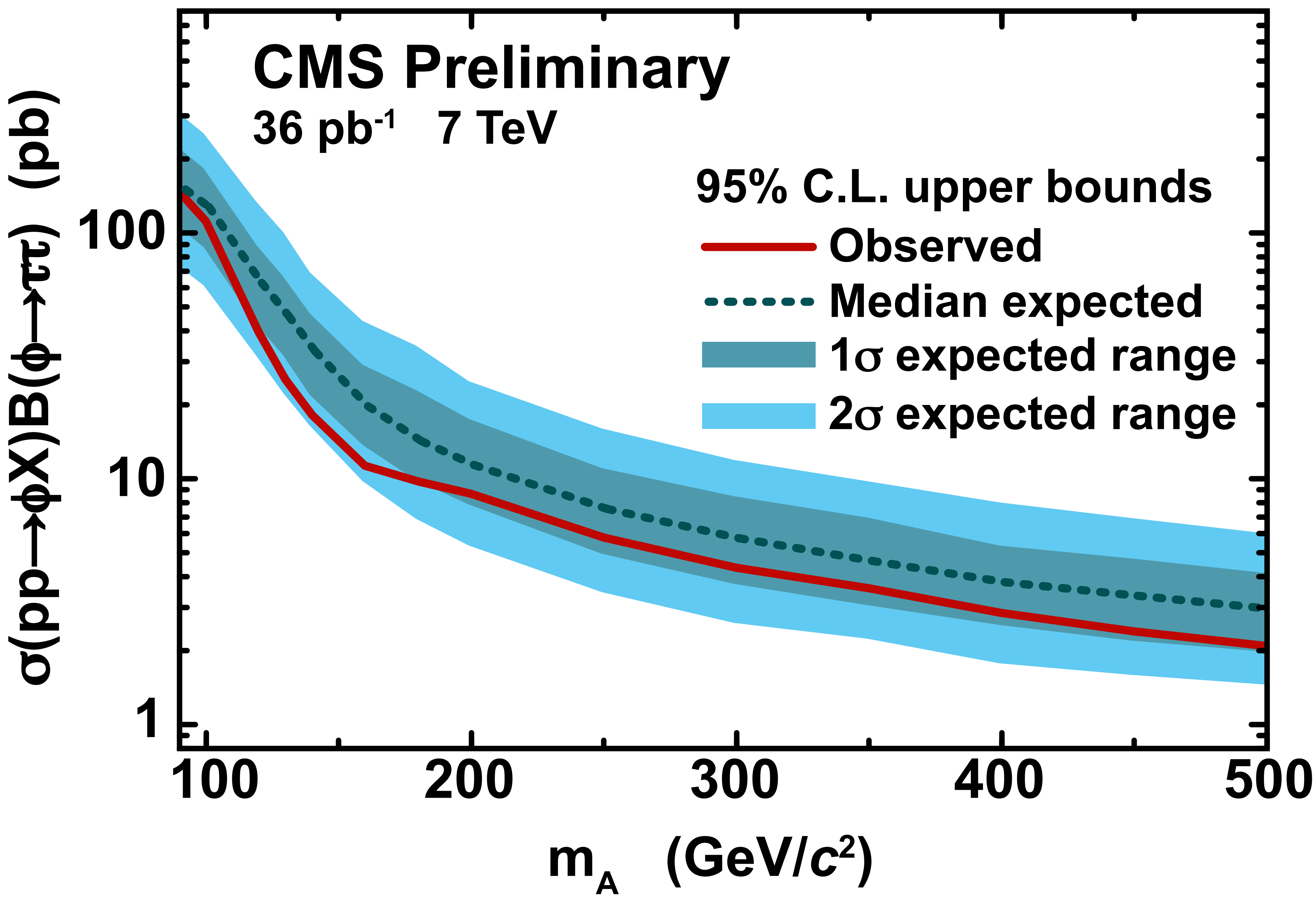
| $m_H$ | $H \to ZZ \to \ell^+\ell^- q\bar{q}$ | | $H \to ZZ \to \ell^+\ell^- \nu\bar{\nu}$ | | Observed | E | H→WW→lvqq | |
|---|---|---|---|---|---|---|---|---|
| (GeV) | Observed | Expected | Observed | Expected | $\mu/\mu_{SM}$ | Median | PCL (Expected) | PCL (Observed) |
| 200 | 8.5 | 29.5 | 21.0 | 23.5 | 3.5 | 15.5 | 35.0 | 50.0 |
| 220 | 58.5 | 35.5 | 18.0 | 14.5 | 19.5 | 12.5 | 26.3 | 28.4 |
| 240 | 21.0 | 35.5 | 13.5 | 11.5 | 10.5 | 9.5 | 22.0 | 25.5 |
| 260 | 27.0 | 39.5 | 9.0 | 9.5 | 6.0 | 8.5 | 18.4 | 18.3 |
| 280 | 36.0 | 35.5 | 13.5 | 9.5 | 12.0 | 8.5 | 16.3 | 9.77 |
| 300 | 57.0 | 29.5 | 10.5 | 9.5 | 15.0 | 8.5 | 15.3 | 7.13 |
| 320 | 51.0 | 26.5 | 10.5 | 8.5 | 12.0 | 6.5 | 13.9 | 9.81 |
| 340 | 46.5 | 24.5 | 12.0 | 8.5 | 15.0 | 6.5 | 12.9 | 7.65 |
| 360 | 21.0 | 21.5 | 15.0 | 8.5 | 12.0 | 6.5 | 11.5 | 9.18 |
| 380 | 12.0 | 17.5 | 18.0 | 8.5 | 12.0 | 6.5 | 10.8 | 11.2 |
| 400 | 12.0 | 17.5 | 21.0 | 9.5 | 13.5 | 6.5 | 11.3 | 11.1 |
| 420 | 13.5 | 18.5 | 25.5 | 14.5 | 15.0 | 9.5 | 11.7 | 12.6 |
| 440 | 16.5 | 20.5 | 30.0 | 17.5 | 16.5 | 9.5 | 12.2 | 5.98 |
| 460 | 18.0 | 20.5 | 33.0 | 18.5 | 19.5 | 11.5 | 12.9 | 5.06 |
| 480 | 21.0 | 21.5 | 39.0 | 21.5 | 21.0 | 12.5 | 13.8 | 5.79 |
| 500 | 22.5 | 23.5 | 43.5 | 24.5 | 19.5 | 14.5 | 14.3 | 9.70 |
| 520 | 25.5 | 29.5 | 52.5 | 30.5 | 22.5 | 15.5 | 15.1 | 11.7 |
| 540 | 31.5 | 32.5 | 55.5 | 33.5 | 25.5 | 18.5 | 17.4 | 13.9 |
| 560 | 39.0 | 41.5 | 61.5 | 36.5 | 30.0 | 20.5 | 19.6 | 27.9 |
| 580 | 42.0 | 44.5 | 67.5 | 45.5 | 36.0 | 24.5 | 23.8 | 45.0 |
| 600 | 52.5 | 54.5 | 75.0 | 45.5 | 39.0 | 24.5 | | |

# H→ZZ→llqq/llνν : Comparison of $PCL_{S+B}$ and $CL_S$



# A/H/h→ττ


CMS Preliminary
36 pb-1 7 TeV
95% C.L. upper bounds
Observed
Median expected
1σ expected range
2σ expected range
σ(pp→φX)B(φ→ττ) (pb)
100
10
1
100
200
300
400
500
mA (GeV/c2)

# Exotic Higgses

Standard model extension by a scalar triplet

adding three new particles : $\Phi^{++}$,$\Phi^{+}$,$\Phi^{0}$

Triplet responsible for small neutrino mass, but unknown neutrino mass matrix means unknown branching ratios, broad search, but below ~2$M_W$ only leptonic decays

Considering both pair ($\Phi^{++}\Phi^{--}$) and associated ($\Phi^{++}\Phi^{-}$) production
→ 4 lepton and 3 lepton final states