Early Higgs searches with the ATLAS data

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On behalf of the ATLAS collaboration

2nd International Conference

on Particle Physics

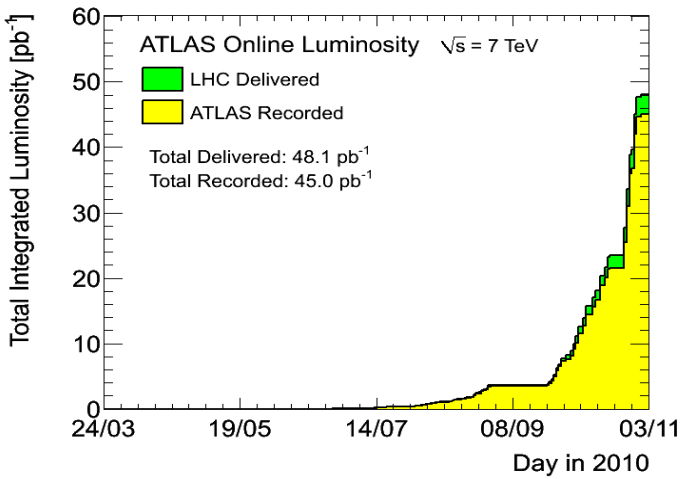
20/06/2011

LHC status

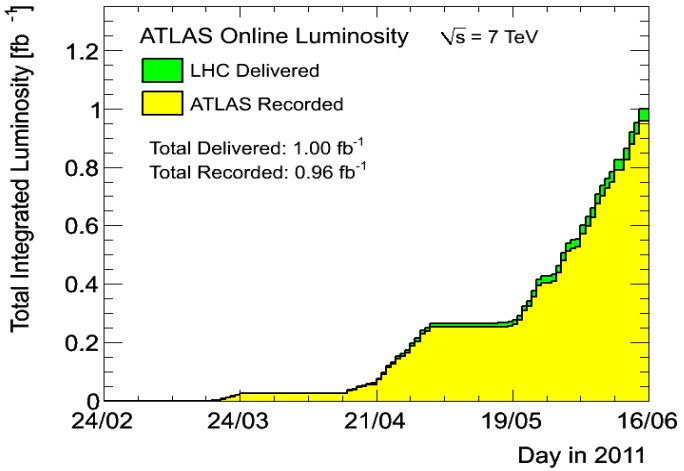
<LHC accelerator>

- The Atlas Detector started to take 7TeV collision data since Mar 30 in 2010.
- Data taking in 2010 :
  - Recorded : 45pb^{-1}
    (Good data : ~35-40pb^{-1})
- Data taking in 2011 (up to 16/06) :
  - 1fb^{-1} delivered! (Peak lumi : 1.2e+32 /cm^2/s^2 was already achieved.)
  - We will take ~3fb^1 by the end of this year?

<Data in 2010>



<Data in 2011>



Outline

- **Introduction**
- **The result for the Higgs boson search at the ATLAS experiment**

(i) SM Higgs boson

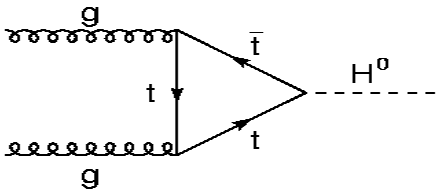
- **H→2 photons with 209pb-1 (2011 data)**
- **H→WW (2010 data)**
  - ✓ **WW→lνlν with 35pb-1**
  - ✓ **WW→lνqq with 35pb-1**
- **H→ZZ (2010 data)**
  - ✓ **ZZ→llνν, llqq with 35pb-1**
  - ✓ **ZZ→llll with 40pb-1**

(ii) BSM case

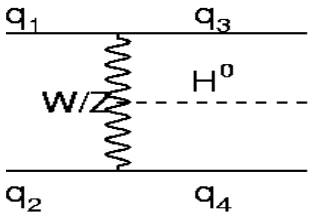
- **MSSM H→ττ with 35pb-1 (2010 data)**
- **A→μμ at low mass with 35pb-1 (2010 data)**

The Higgs search

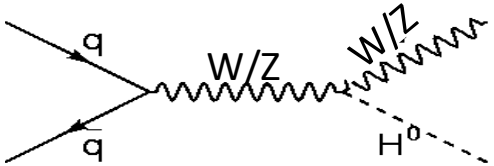
◆ Signal production



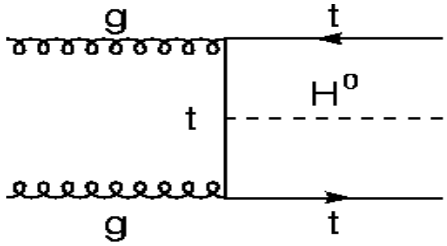
gluon-gluon fusion



vector-boson fusion

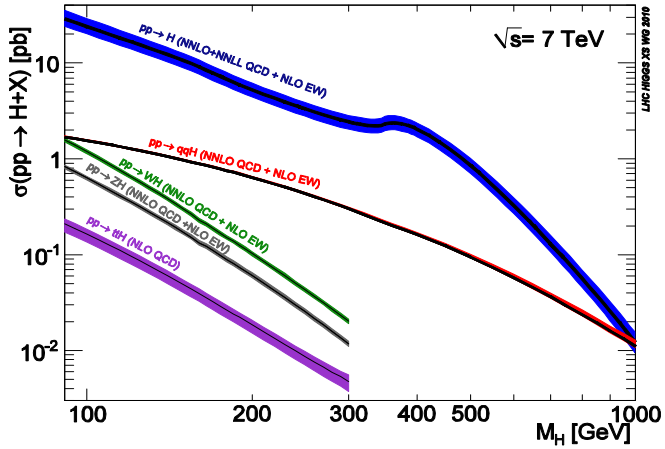


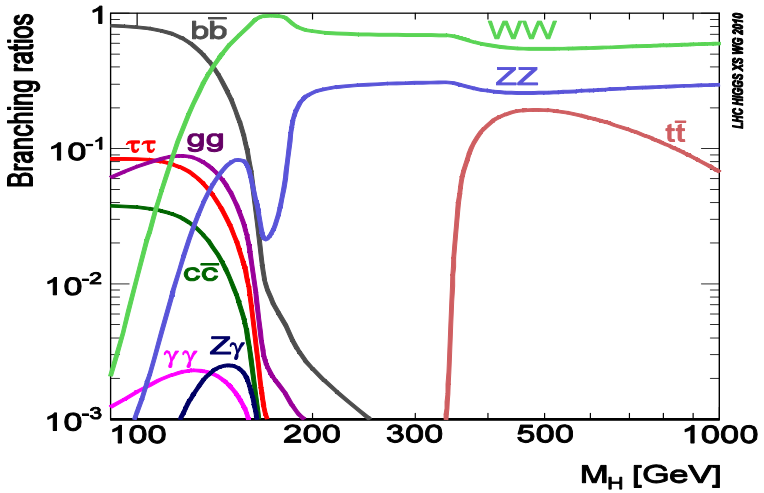
WH/ZH



ttH

◆ x-sec and branching fraction





Signal's x-sec and its uncertainty has been given by :

"Handbook of LHC Higgs Cross sections : 1. Inclusive Observables"

(arXiv : 1101.0593 (hep-ph))

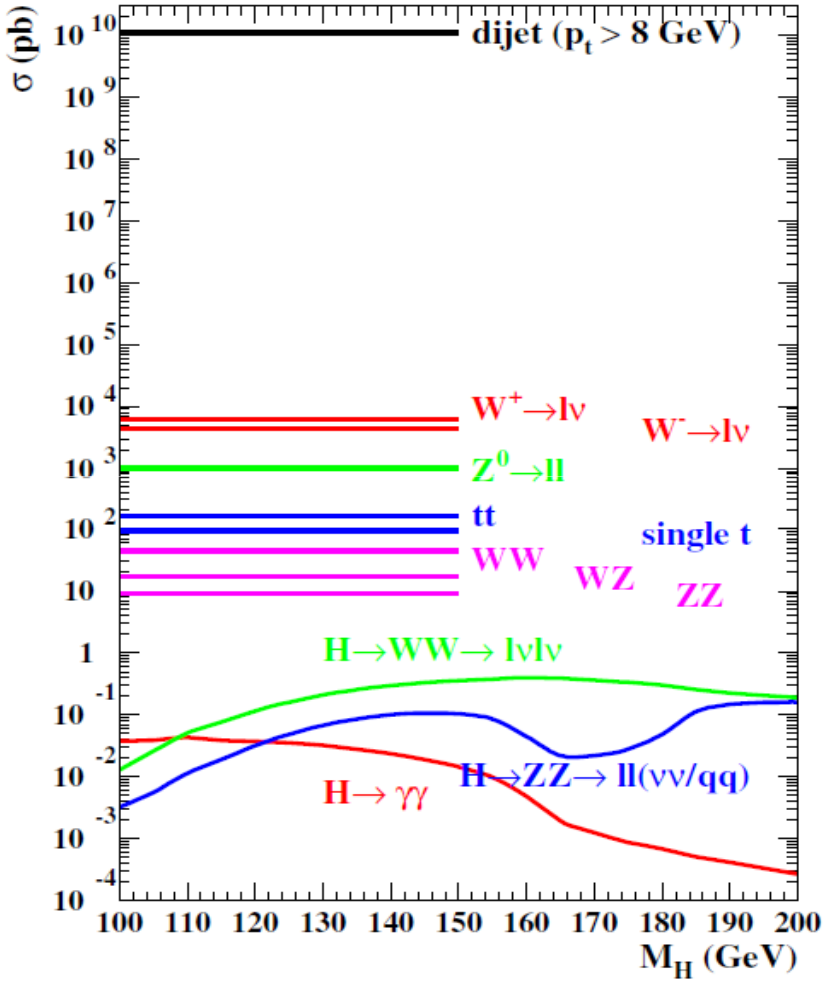
The Higgs search at the ATLAS

◆ Signal vs. background

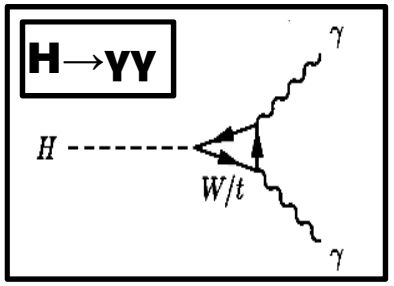
- SM process has been already measured and analyzed reliably. (W, Z, ttbar etc.)
- S/B ratio is very small.

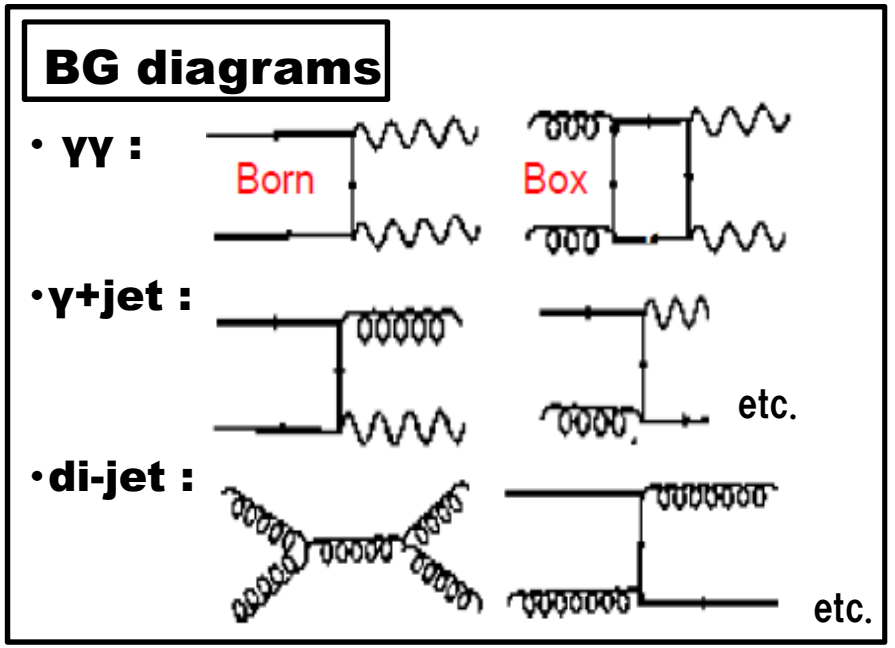
  < 1 detectable Higgs boson per 10^{12} collisions

- But by using the LHC machine operating stably with great luminosity, the discovery of the Higgs boson is now realistic.



H→2 photons(γγ)





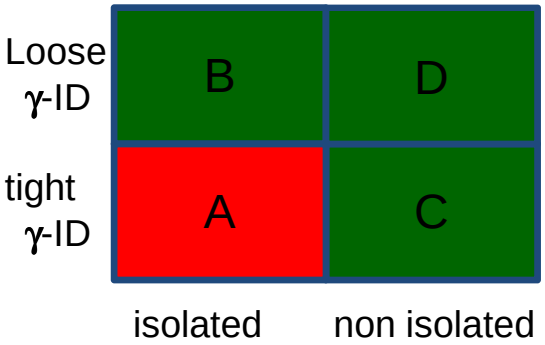
◆ **Selection :**

2 isolated photons with p_T> 40/25 GeV

◆ **BG processes**

- **Irreducible (γγ)**
- **Reducible (γ+jets, QCD jets)**
- **Drell-Yan : very small contributions**

◆ **Data-driven BG decomposition (for γγ, γj and jj)**



- **Using *"ABCD" method"*(i.e. A=B*C/D), # of fake photons in "tight-isolated" region can be checked.**
- **This method is applied to leading and subleading photons iteratively.**

◆ **Drell-Yan : Z(ee)-enriched sample is defined by selecting "eγ" events.**

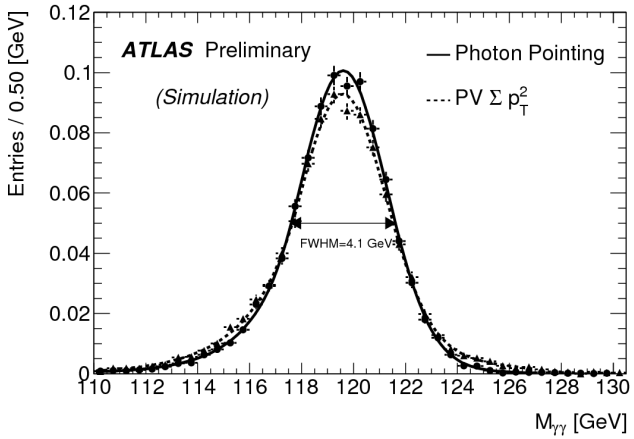
(Z(ee) with one electron faking as a photon is obtained.)

By applying fake rate for e→γ, DY contribution to the signal region is extracted.

H→γγ : Limit extraction with 209pb^{-1} (2011 data)

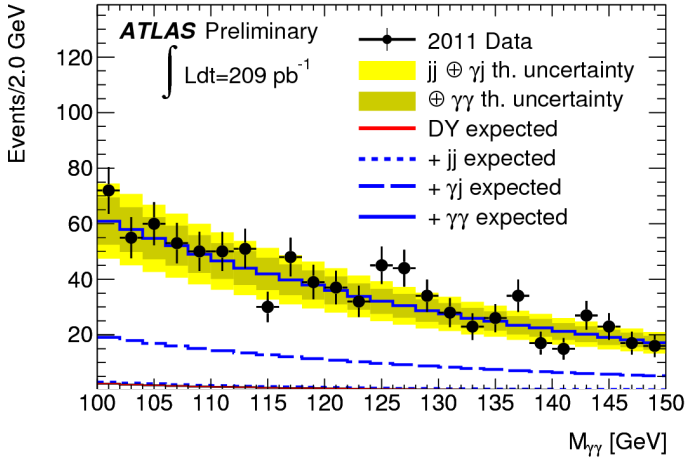
◆ Signal peak shape

"Crystal Ball + Gaussian" is used.

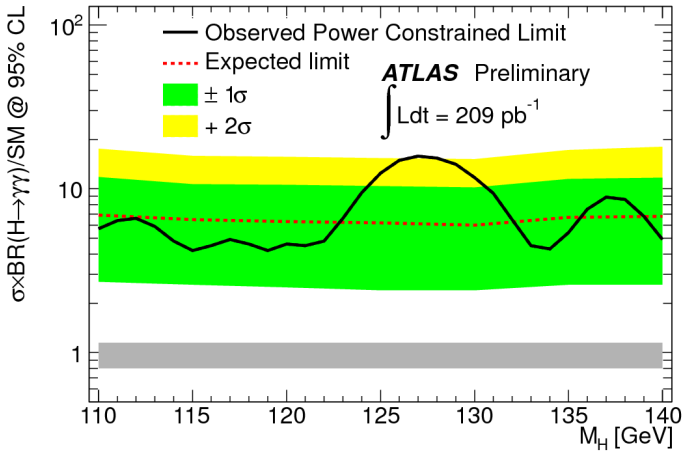


◆ BG shape

Modeled by "exponential".



◆ Limit extraction



Limit derivation

Power-constraint CL$_{s+b}$ (PCL) is used.

(Impose CL$_B$>16%.)

Result for limit setting

6.4×SM (expected) @120GeV

(worlds best)

H→WW→lνlν with 35pb^{-1}

◆ **Event topology :** "di-lepton" + "high missing ET" + "N jets"

(1st >20GeV, 2nd >15GeV) (MET>30GeV) (>25GeV, b-veto)

- di-lepton : ee/eμ/μμ
- N jets : 0/1/2 jets

Totally, 3×3=9 channels are analyzed.

◆ **Main BGs : WW / W+jets / ttbar**

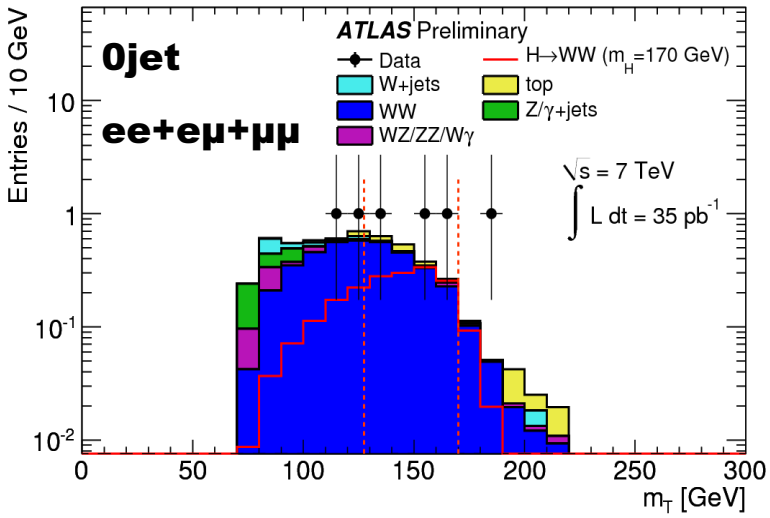
◆ **In each analysis channel, kinematics cut is optimized.**

- Cut variables : ⊿φ(ll), m(ll), MT etc. (depending on signal mass)
- Z veto (for ee, μμ)

◆ **Data-driven BG estimation**

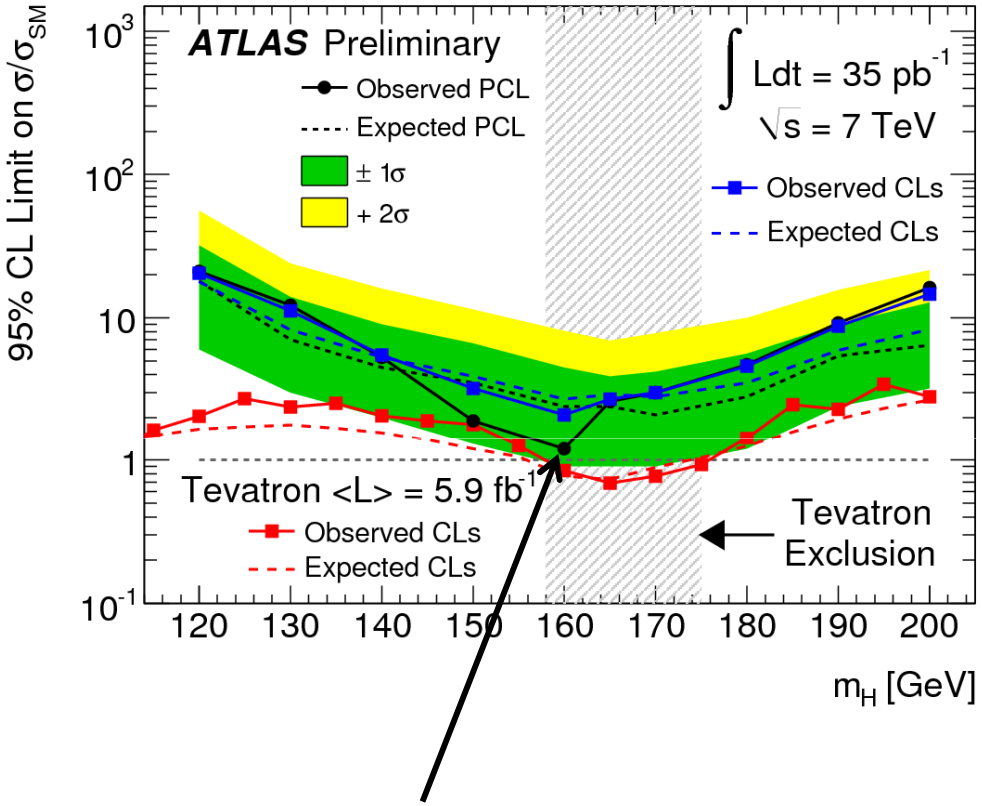
For each process of main BGs (WW, W+jets, top), its contribution to the sig region is extracted from the control region.

MT distribution (35pb^{-1})



H→WW→lνlν : Limit extraction with 35pb^{-1} (2010 data)

◆ Limit w.r.t. SM prediction



2.4×SM (expected) @ 160GeV

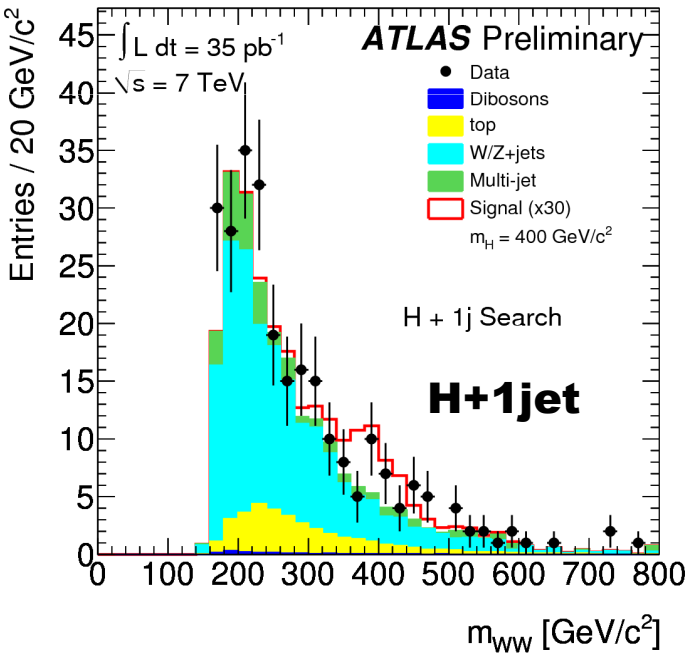
"Close to SM prediction."

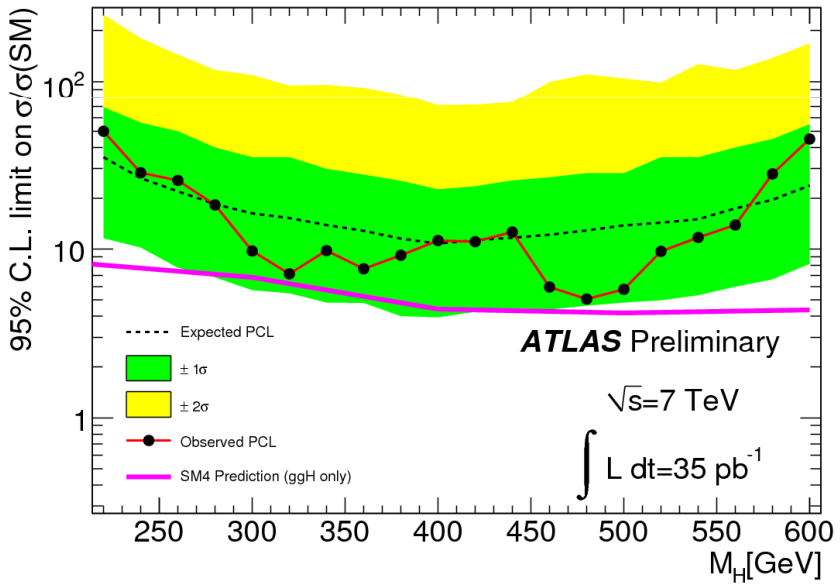
H→WW→lvqq channel is also analyzed. (35pb-1)

- **Evt topology : one lepton (e or μ) + high MET + 2/3 jets**

(H+0/1jet analysis)

- **Mass reconstruction using W mass constraint.**
- **BG level is determined by side-band fitting.**
- **Limit setting is performed for high mass region. (m_H=200-600GeV)**





~11.2×SM @ 400GeV

H→ZZ→llνν and llqq with 35pb^{-1}

◆ **Require a lepton pair with M(ll)∼M(Z)**

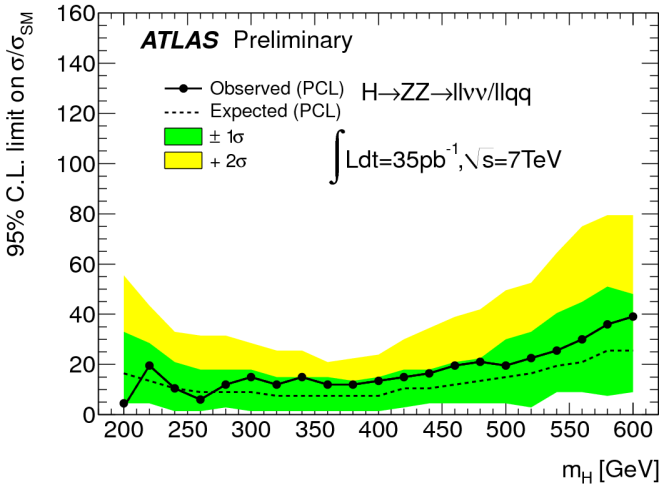
◆ **Kinematics cuts**

- **llνν**
  - ✓ **MET>66(82)GeV for low(high) mass**
  - ✓ **Require boost Z boson for high mass search.**
- **llqq**
  - ✓ **MET<50GeV, 70<M(jj)<105GeV**
  - ✓ **Require boost Z boson for high mass search**

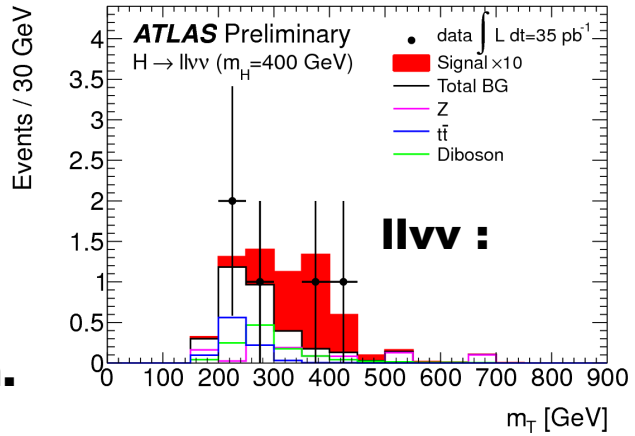
◆ **BG estimation**

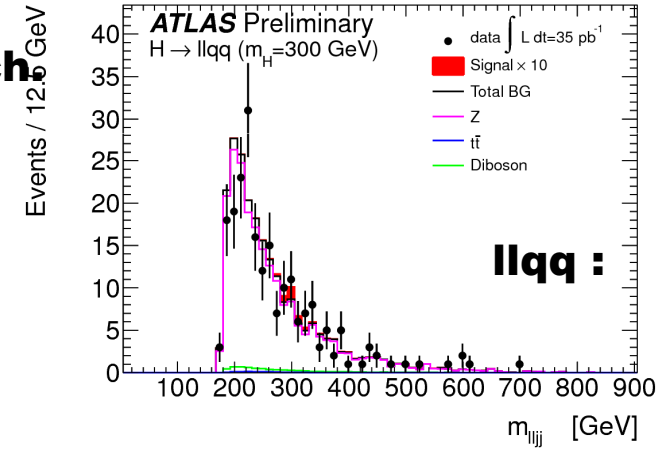
- **ZZ/WW/WZ : from MC**
- **Z, tt, W, QCD : from sideband**

◆ **Exclusion limit**



<bg estimation>





∼6.5×SM (expected)

@ 320-400GeV

H→ZZ→llll with 40pb^{-1}

◆ Selection

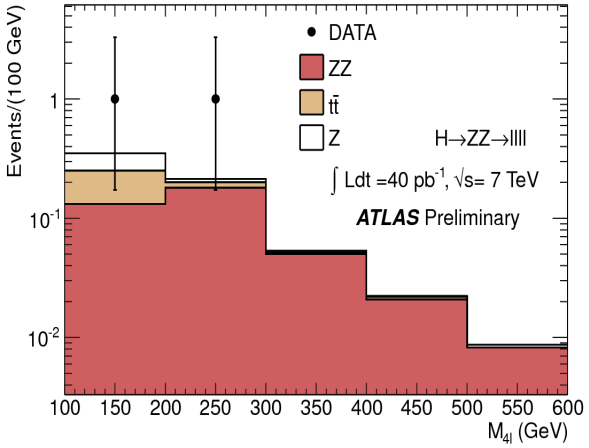
- Final state with 4 leptons
  (eeee/eeμμ/μμμμ)
- 1st and 2nd leptons : p_T>20GeV
- 3rd and 4th leptons : p_T>15(7)GeV
  (for e(μ))
- Require one lepton pair
  with M(ll)～M(Z)
- The other lepton pair :
  M(ll) cut is optimized
  by higgs mass.
- ⊿R(ll)>0.1
- Isolation and IP significance selection

➡ **No events observed**
after all the selections.

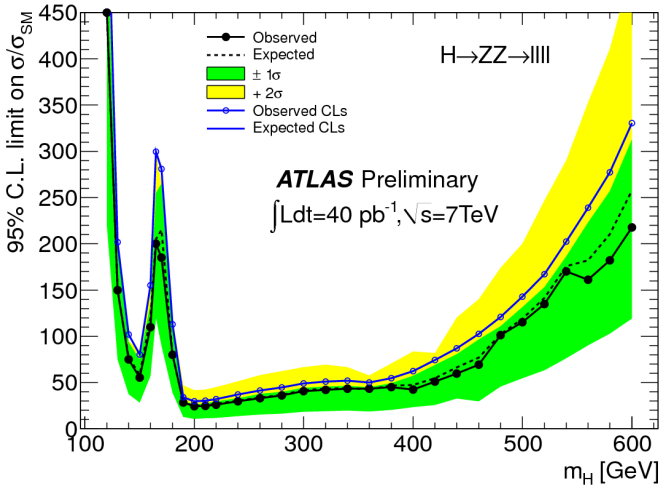
◆ Main BGs :

ZZ and Z+jets

<M_{4l} distribution>
(after the di-lepton kinematics cut)



◆ Exclusion limit

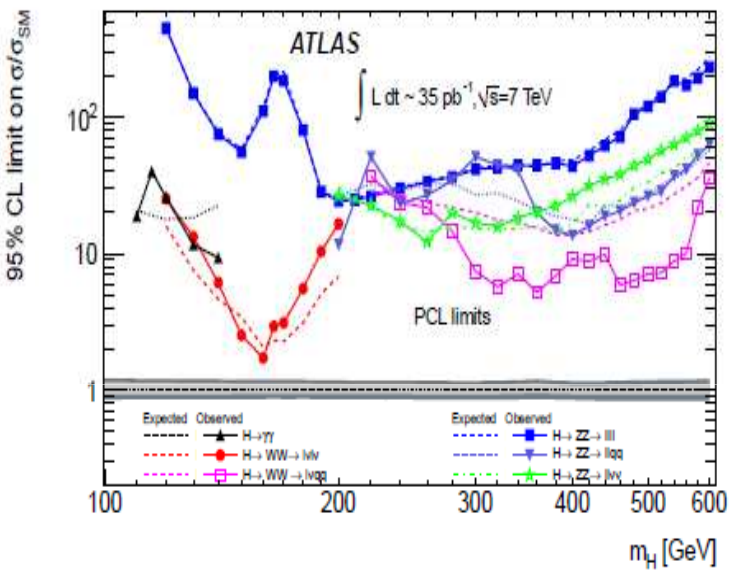


～24×SM (expected)
@ 200GeV

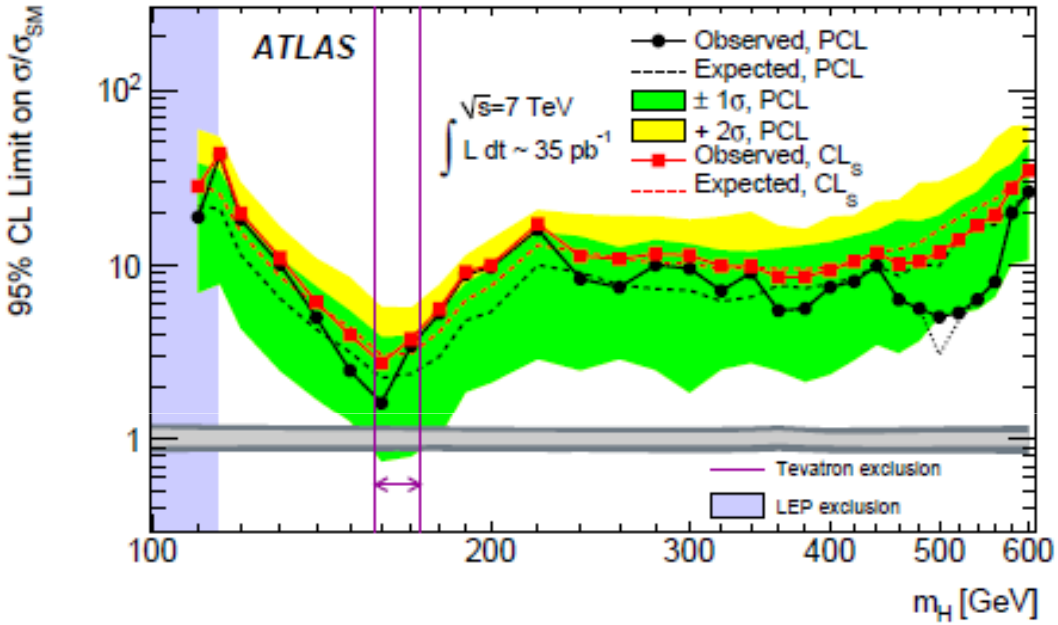
(arXiv:1106.2748 [hep-ex])

Combined result for SM Higgs Boson search (For 35pb-1)

PCL limit for each analysis channel



Combined result



- H→γγ
- H→WW→lνlν
- H→WW→lνqq
- H→ZZ→llll
- H→ZZ→llqq
- H→ZZ→llνν

MSSM H→ττ search

◆ **MSSM models extend Higgs sector**

- 5 bosons : ϕ = (h, H, A) and $H^{\pm}$

  governed by m_A and tanβ

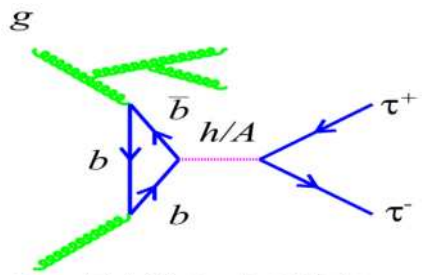
◆ **Signal production :**

- gg→ϕ, bb→bbϕ : dominant
- Branching fraction : 90% bb, 10% ττ

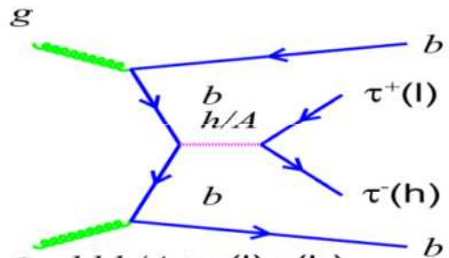
◆ **2 analysis channels are considered.**

- lh channel : ττ → e/μ + τhad
- ll channel : ττ → eμ4ν

<Sig process>



g ggF h/A->τ⁺τ⁻+jets



g bbh/A->τ(l) τ(h)

Selection

<lh channel>

- 1 Lepton(e/μ) + 1 τ_{had} with opposite charge
- MET>20GeV
- Transverse mass : MT<30GeV

<ll channel>

- 1e + 1μ with opposite charge
- $p_T(e)+p_T(\mu)+MET<120GeV$
- $\Delta\varphi(e\mu)>2.0rad$

MSSM H→ττ with 36pb^{-1}

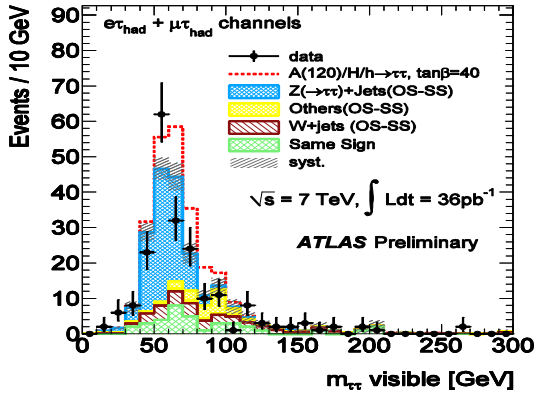
Main BGs

- Irreducible : Z→ττ
- Reducible : QCD/ W+jets etc.

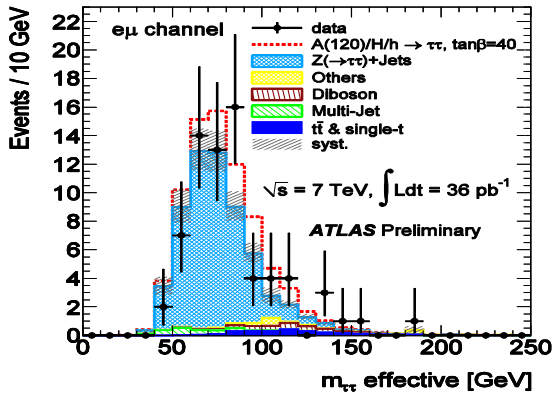
Checked by data.

◆ BG estimation

<lh channel>

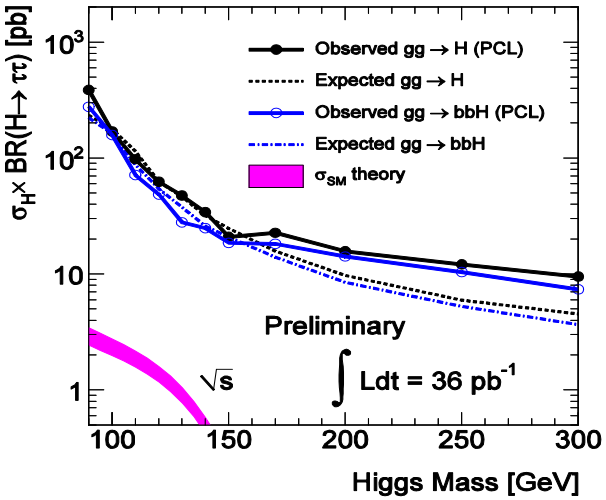


<ll channel>

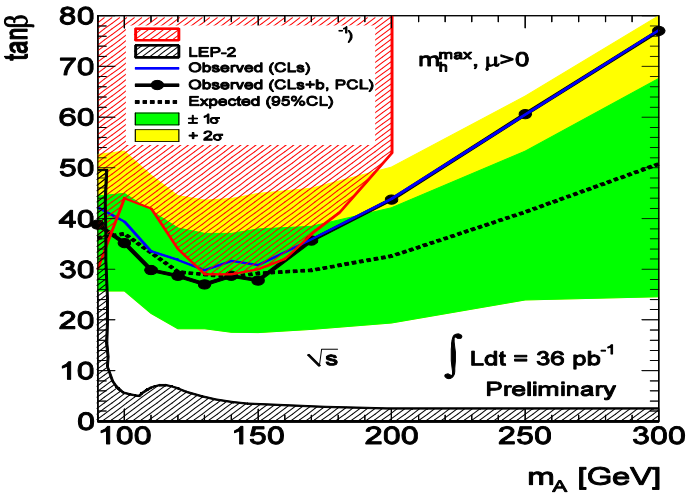


Combined result for exclusion limit (lh + ll channels)

◆ Limit on x-sec*Br



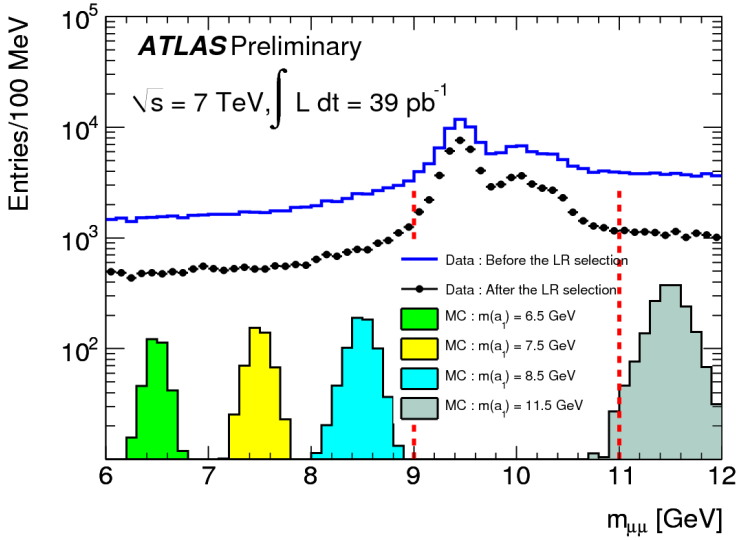
◆ Exclusion on (m$_A$, tanβ)



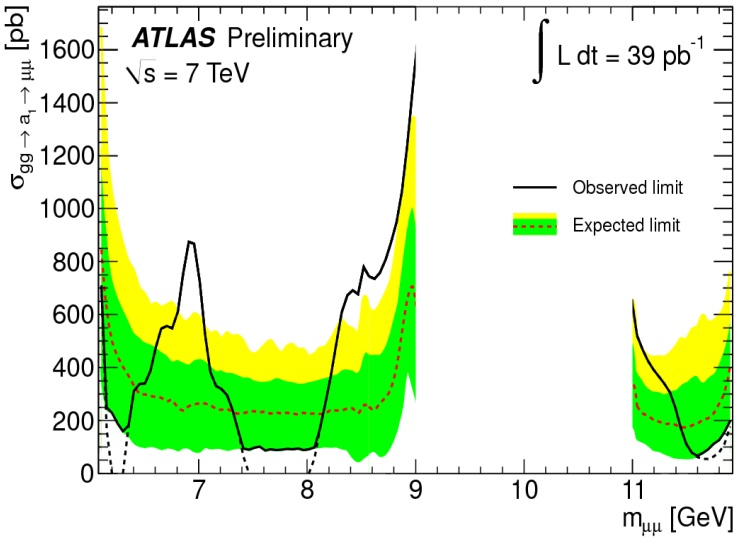
A→μμ at low mass with 39pb^{-1}

- **NMSSM inspires very low mass scalar A.**
- **Search the regions [6,9] and [11,12]GeV**
- **Event selection**
  - **2 muons with p_T>4GeV**
  - **Likelihood ratio selection**
- **Modeling for $M_{\mu\mu}$ shape**
  - **Signal A : double-gaussian**
  - **Y(1/2/3s) : double-gaussian**
  - **Continuum BGs :**

    4th Chebyshev polynomial



- **Exclusion limit**



Conclusions

◆ Search for the the Higgs boson at the ATLAS experiment have been made by using various analysis channels.

(H→ 2photons, WW, ZZ, ττ, μμ etc.)

◆ There is no report for Higgs observation up to now.

◆ The background contributions are well understood by mainly using data-driven method.

◆ Upper limit on x-sec (for SM Higgs boson)

(i) Low mass Higgs (m_H<200GeV)

- H→γγ (209pb^{-1}) : 6.4×SM @m_H=120GeV (worlds best)
- H→WW→lνlν (35pb^{-1}) : 2.4×SM @m_H=160GeV (close to SM prediction)

(ii) High mass Higgs (m_H>200GeV)

H→ZZ : The worlds best limit achieved in high mass region.

◆ Search for BSM case is also performed. (MSSM H→ττ, A→μμ)

<Prospect for the higgs search>

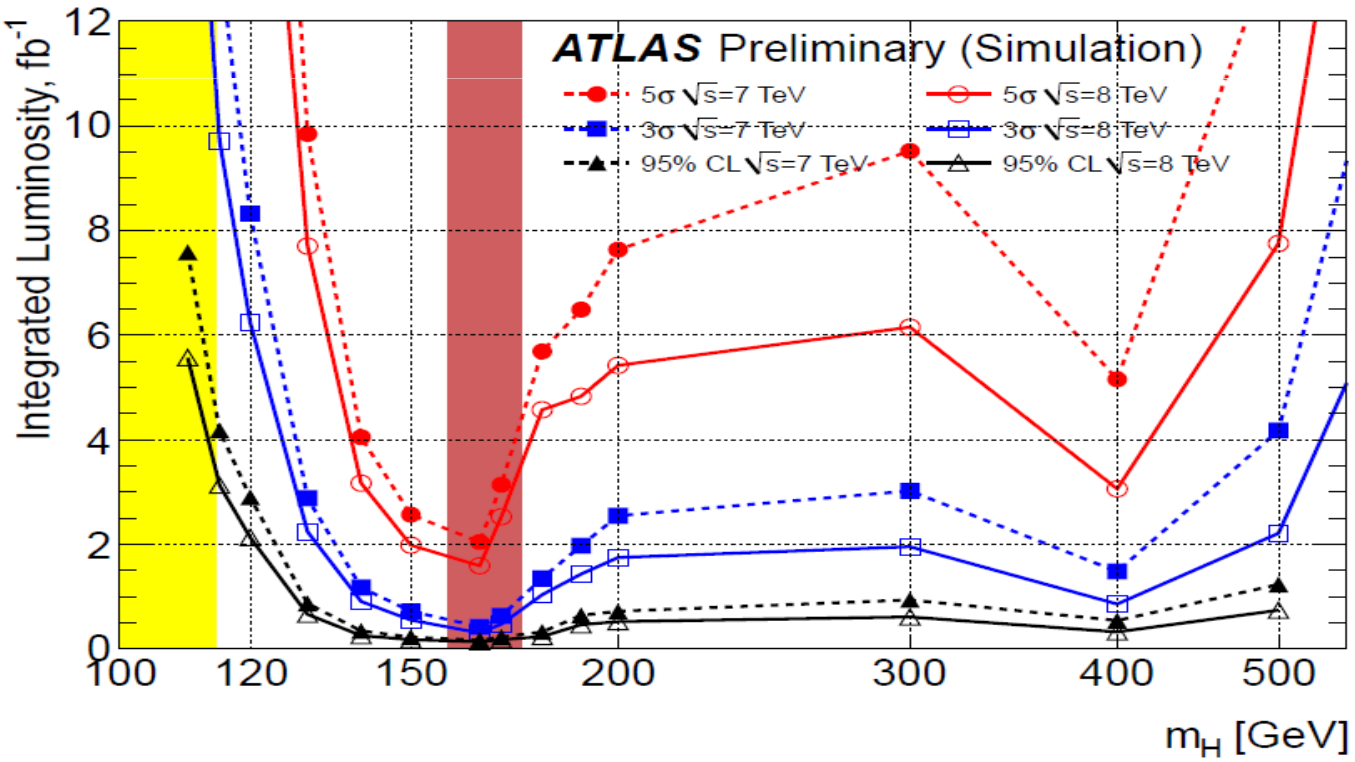
◆ $4fb^{-1}$

We could exclude
down to LEP limit.

◆ $10fb^{-1}$

- 3σ observation for $m_H \gtrsim 120GeV$
- 5σ discovery for $m_H \gtrsim 135GeV$

Projected sensitivity of the SM Higgs boson



Backup

The Higgs search at the ATLAS

◆ Limit derivation

- profile likelihood method (nuisance parameters for systematic uncertainties)
- power constraint CL_{S+B} (impose CL_B >16%) i.e. if observed cross section limit smaller than median expected – 1σ, then quote median expected – 1σ
- for comparison also CL_S used at LEP and TEVATRON shown

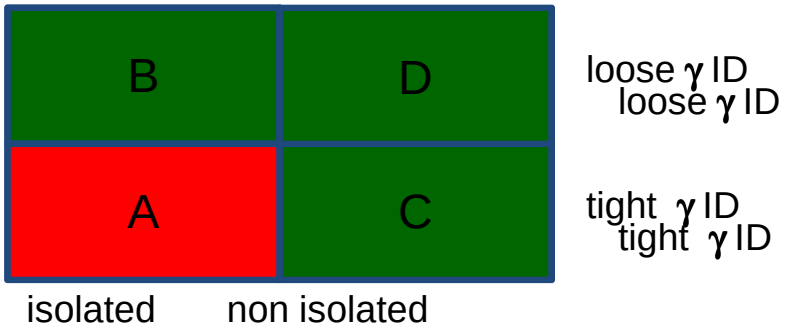
(i) H→ two photons with 209pb^{-1}

(2011 data)

H→γγ : Background estimation

◆ Data-driven BG decomposition (for γγ, γj and jj)

- Using *"ABCD"* (i.e. A=B*C/D) method,
  # of fake photons in "tight-isolated" region can be checked.
- By applying the ABCD method to the leading and the sub-leading photons iteratively, each #evts for γγ, γj and jj in the signal region is extracted.



◆ Drell-Yan

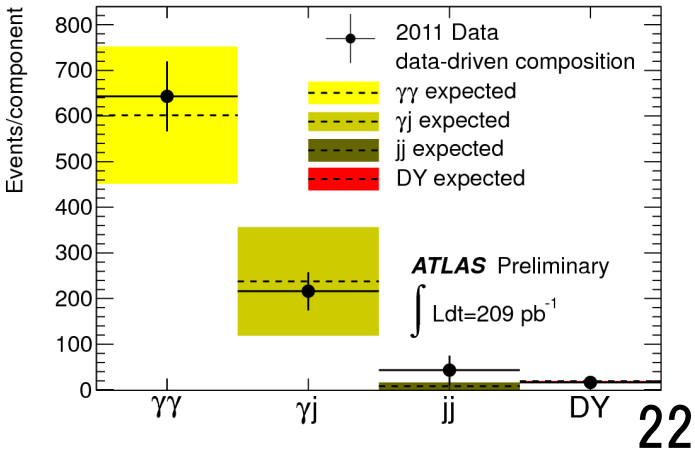
- Z(ee)-enriched sample is defined by selecting "eγ" events.

(Z(ee) with one electron faking as a photon is obtained.)

↓ Apply fake rate for e→γ

DY contribution to the signal region is extracted.

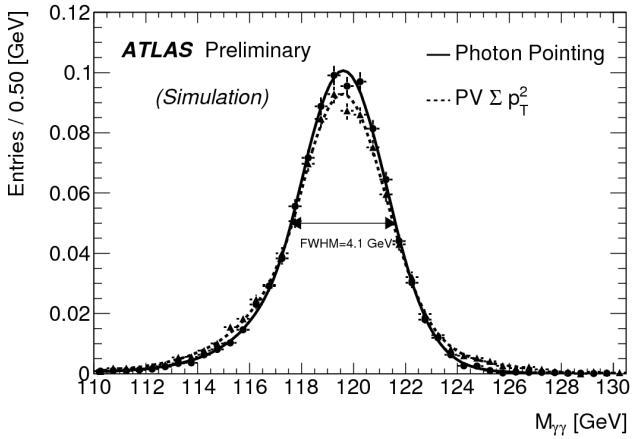
◆ BG decomposition result (Data/MC comparison)



H→γγ : Limit extraction

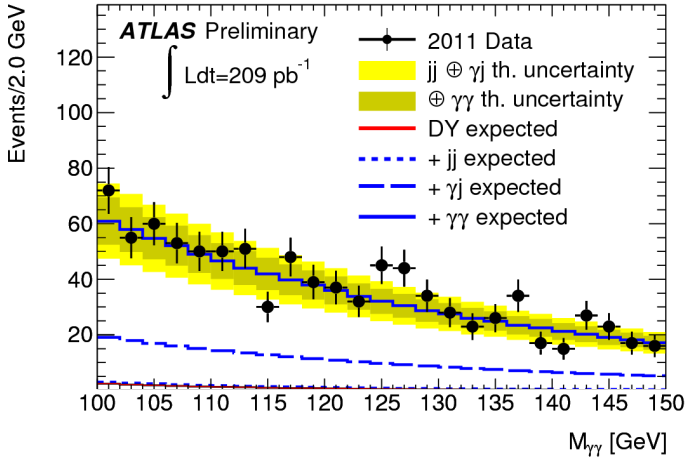
◆ Signal peak shape

"Crystal Ball + Gaussian" is used.



◆ BG shape

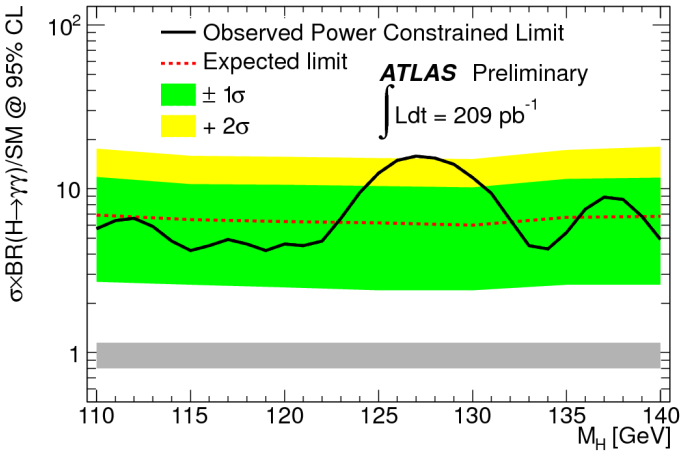
Modeled by "exponential".



<Systematics on signal yield>

- **Luminosity : ±4.5%**
- **x-sec : +20/-15%**
- **Trigger : ±1%**
- **photon-ID : ±5% /photon**
- **photon-isolation : ±3% /evt**
- **Energy resolution :**
  ±13% on σ(Mγγ)

◆ Limit extraction



(ii) H→WW→lvlv with 35pb^{-1}

(2010 data)

H→WW→lνlν

◆ Event topology :

"di-lepton" + "high missing ET" + "N jets"

- di-lepton : ee/eμ/μμ
- N jets : 0/1/2 jets

} Totally, 3×3=9 channels are analyzed.

◆ Backgrounds

WW / W+jets / Z+jets / top (ttbar, single-top)

◆ Event selection

Pre-selection

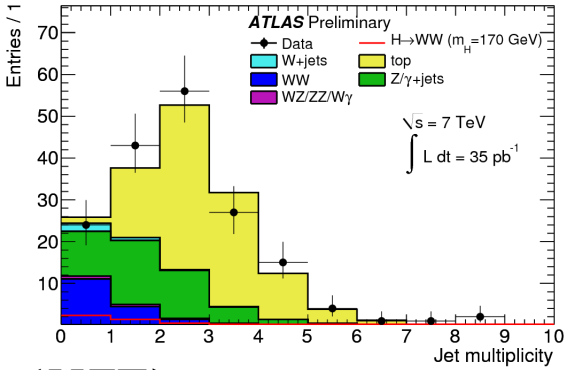
- 2 leptons with opposite charge
- lepton pT >20/15GeV
- MET>30GeV
- M(ll)>15GeV, |M(ll)-M(Z)|>10GeV(for ee, μμ)

Topological selection (← Cut is optimized by jet category and signal mass.)

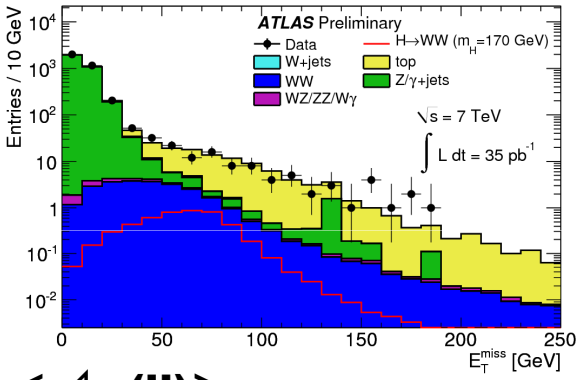
- ⊿φ(ll)<1.3 or 1.8
- M(ll)<50, 65 or 80GeV
- Transverse mass cut : 0.75*MH < MT < MH

$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - (\mathbf{P}_T^{\ell\ell} + \mathbf{P}_T^{miss})^2}$$

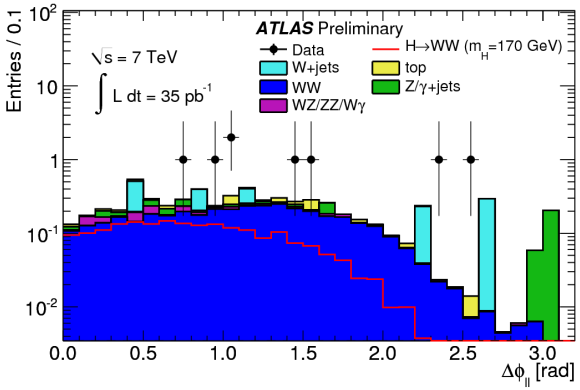
<Njets>



<MET>

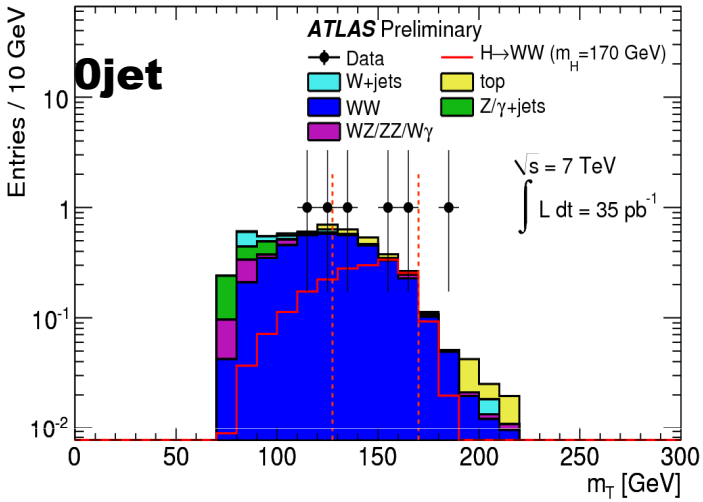


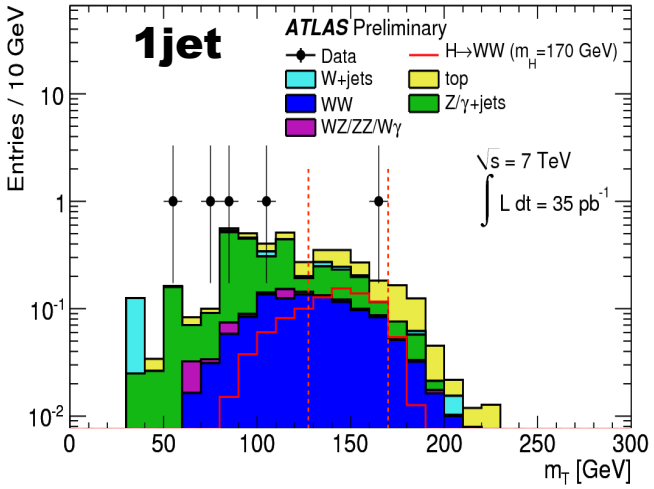
<⊿φ(ll)>



H→WW→lνlν : Background estimation

◆ Mᴛ distribution (after all the other cuts than Mᴛ selection)





Result for BG estimation

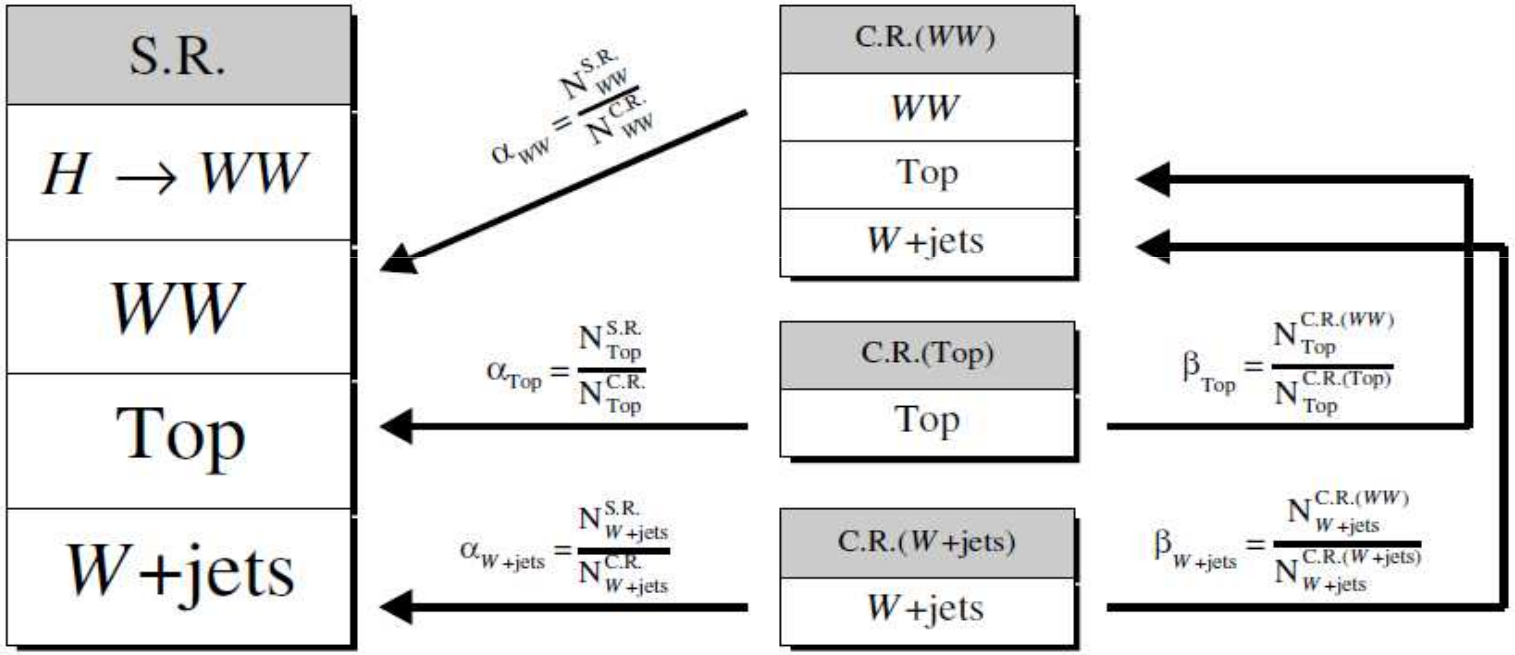
(in the analysis for Mʜ=170GeV)

	0 jet	1 jet	2jet
Data	3	1	0
BG	1.7±0.3	1.3±0.5	0.02±0.03
Higgs	1.3±0.4	0.6±0.2	0.06±0.03

H→WW→lvlv : Background estimation

◆ Data-driven background estimation

- Control region(C.R.) for each of main BG processes is defined.
- By using C.R., the contribution from each process to signal region (S.R.) is estimated in a data-driven manner.



Systematics on α, β

- Experimental
  - -- E scale, resolution, tag efficiency
- Theoretical

(iii) $H \rightarrow ZZ$ (with 2010 data)

- $H \rightarrow ZZ \rightarrow llvv$, $llqq$ with $35pb^{-1}$
- $H \rightarrow ZZ \rightarrow llll$ with $40pb^{-1}$

H→ZZ→llνν and llqq with 35pb^{-1}

Event topology

- One lepton pair with M(ll)∼M(Z)
- llqq : One jet pair with M(jj)∼M(Z)

◆ Pre-selection

- 2 leptons(ee or μμ) with p_T>20GeV
- |M(ll)-M(Z)|<15GeV

◆ Additional selection

llνν :

- b-jet veto
- MET>66 or 82GeV
- ⊿φ(ll)<2.64 or 2.25

llqq :

- MET<50GeV
- 70<M(jj)<105GeV
- $p_{T,jet}$>50GeV (for M_H>360GeV)
- ⊿φ(ll), ⊿φ(jj)<π/2 (for M_H>360GeV)

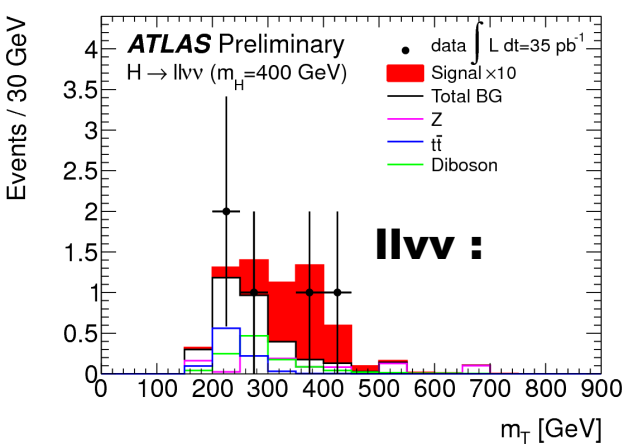
◆ Background estimation

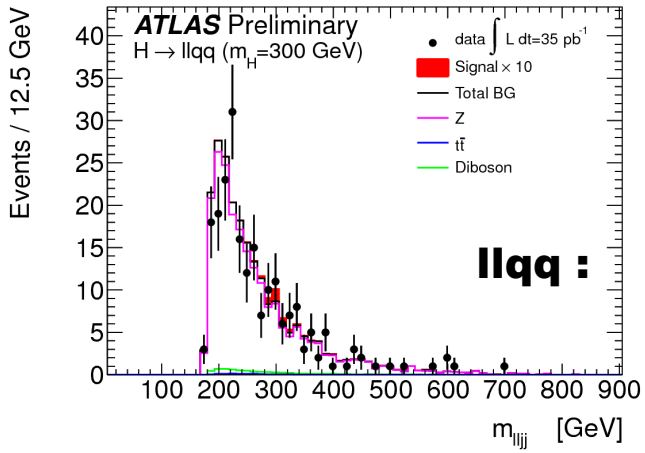
- ZZ/WW/WZ : from MC
- Others : from sideband

<BG uncertainties>

	Uncertainty
Diboson	15%
Z	5%
tt	25%
W	50%
QCD	50%

<Result for bkg estimation>

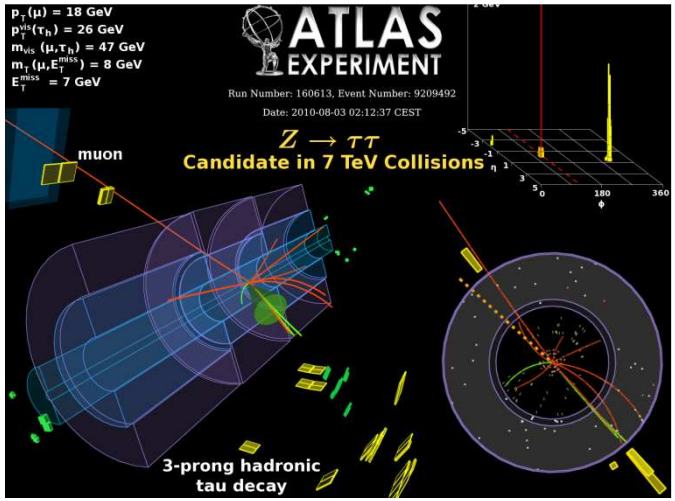




(iv) $H \rightarrow \tau\tau$ in MSSM with $36 pb^{-1}$

(2010 data)

MSSM H→ττ→e/μ + τ_{had}

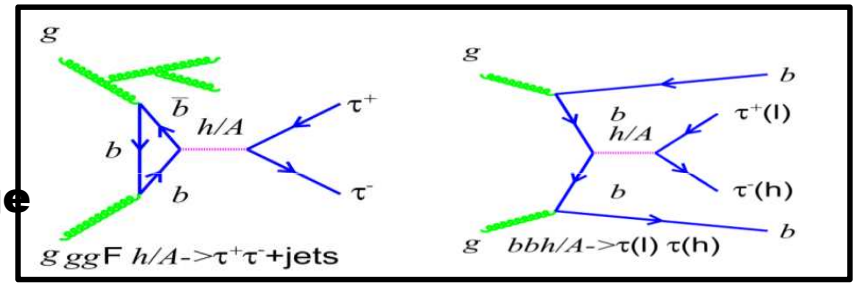


◆ MSSM models extend Higgs sector

5 bosons : ϕ = (h, H, A) and $H^{\pm}$

◆ Signal production

- gg→ ϕ , bb→bb ϕ : dominant
- 10-100 times larger cross section than SM
- Branching fraction :
  - ✓ 90% bb, 10% ττ --- enhanced



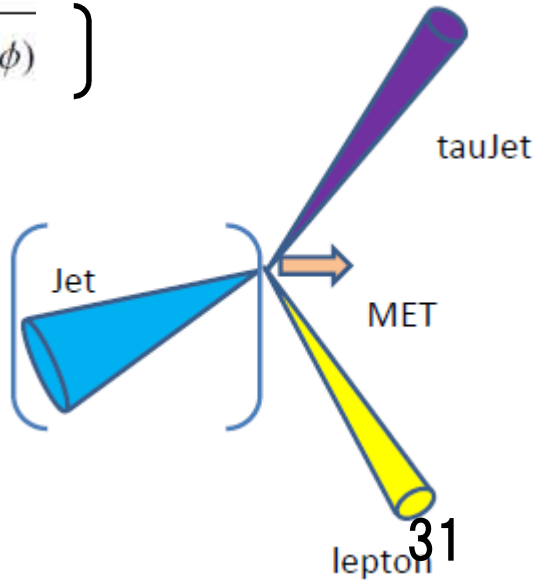
◆ Selection

- 1 Lepton(e/μ) + 1 τ_{had} with opposite charge
- MET>20GeV
- Transverse mass : MT<30GeV $\left(m_T = \sqrt{2 p_T^{e/\mu} E_T^{miss} (1 - \cos \Delta\phi)} \right)$

◆ Main BGs

- Z→ττ (irreducible)
- W+jets : jet→τ fake
- QCD : 1 jet→τ_{lep} and 1 jet→τ_{had} fakes

} Needs to be checked with data.



◆ Final discriminant : ττ visible mass

MSSM H→ττ→e/μ + τ_{had} with 36pb^{-1}

◆ Selection

- 1 Lepton(e/μ) + 1 τ_{had} with opposite charge
- MET>20GeV
- Transverse mass : MT<30GeV

◆ Main BGs

- Z→ττ (irreducible)
- W+jets : jet→τ fake
- QCD : 1 jet→τ_{lep} and 1 jet→τ_{had} fakes

} Needs to be checked by data.

◆ BG estimation by the same-sign driven method

※ SS/OS : Same/Opposite-sign

- Signal : Charge of lepton and τ-jet should be opposite sign.
- Fake tau events : #events with OS and SS are expected to be similar.

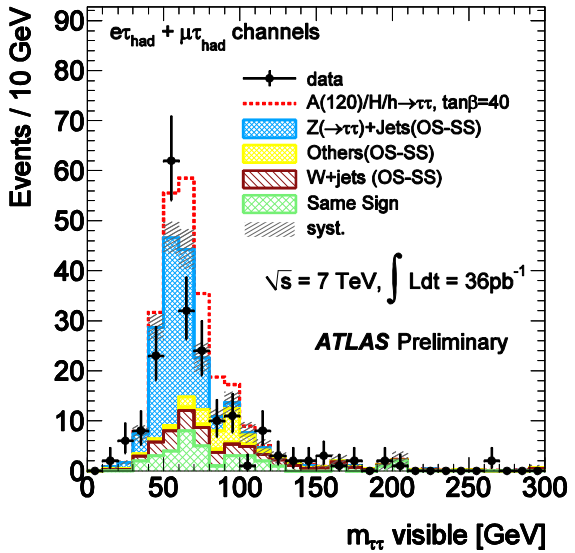
➡ # of BGs in signal region is extracted from SS region. (OS→SS)

<OS/SS ratio in theory>

- QCD jets : OS=SS
- W+ jets : OS>SS ➡ Needs correction. (Add-on)

Result for BG estimation

$N_{totalbkg} = N_{ss} + N_{addon} + N_{mc(os-ss)}$



H→ττ→eμ4ν with 36pb^{-1}

	Both- iso	Both Non-Iso	One iso + One no-iso	e iso + μ no-iso
OS	A	C	E	G
SS	B	D	F	H

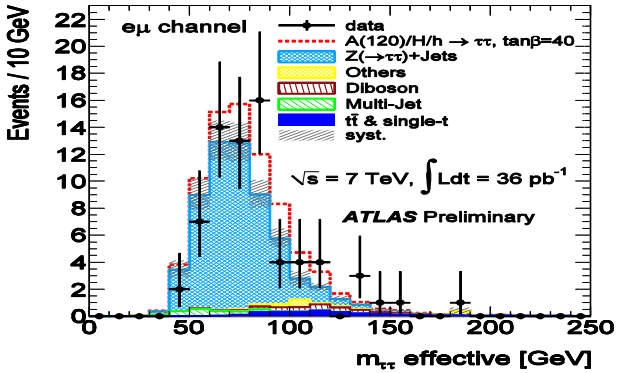
◆ Selection

- 1e + 1μ with opposite charge
- $p_T(e)+p_T(\mu)+MET<120GeV$
- $\Delta\varphi(e\mu)>2.0rad$

◆ BG estimation

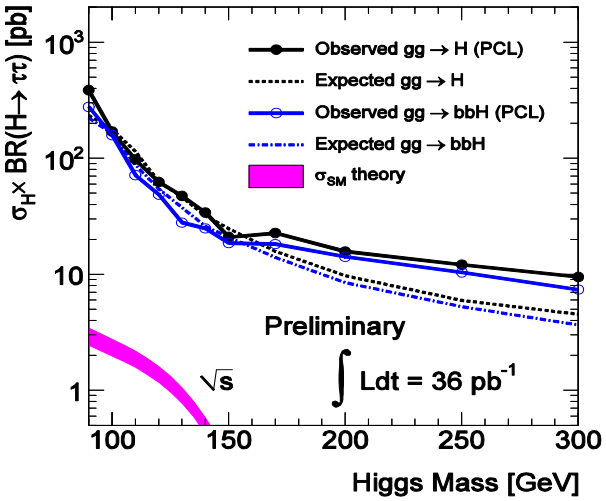
- $Z\rightarrow\tau\tau$: from MC
- QCD : "ABCDEFGH method"

Control region defined by lepton-isolation & charge correlation.

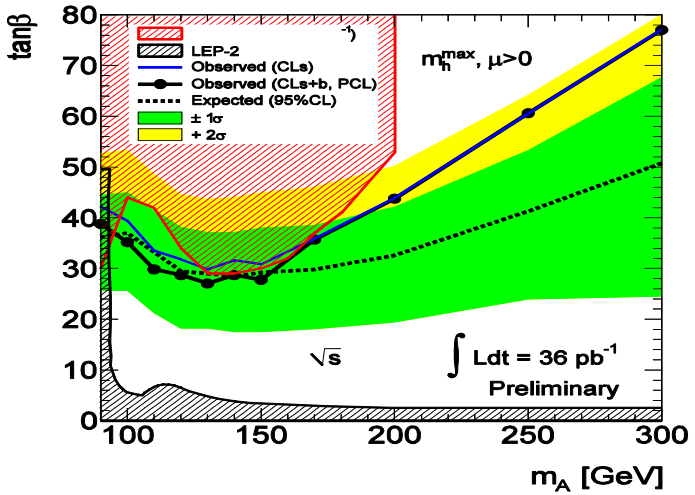


Combined result for exclusion limit (lh + ll channels)

◆ Limit on x-sec*Br



◆ Exclusion on (m_A, tanβ)



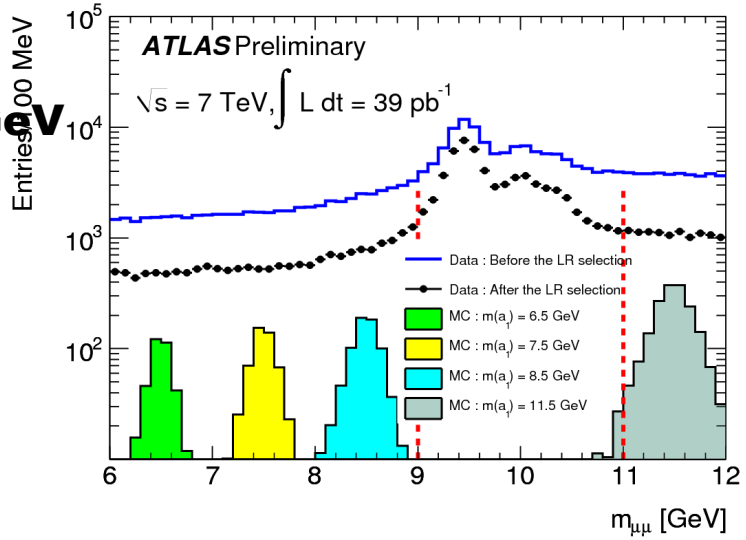
(v) A→μμ at low mass with 35pb^{-1}

(2010 data)

A→μμ at low mass

◆ **NMSSM inspires very low mass scalar A.**

➡ **Search in the regions [6,9] and [11,12]GeV**



◆ **Event selection**

- **2 muons with p_T>4GeV**
- **Likelihood ratio selection**

PDF --- determined with data.

✓ **Sig : 9-11GeV (Ys & A agree.)**

✓ **BG : 4.5-5.5, 12.5-14.5GeV**

◆ **Inputs for likelihood ratio : primary vtx χ2/ndf, calo-isolation**

◆ **Signal & BG modeling for limit derivation**

- **Y(1/2/3s) : double-gauss**

✓ **Mass – fixed to PDG value**

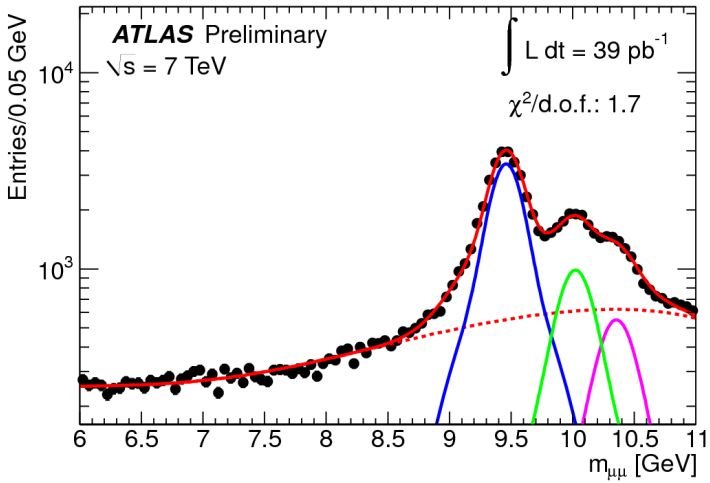
✓ **Width**

✓ **Fraction of 2 gauss**

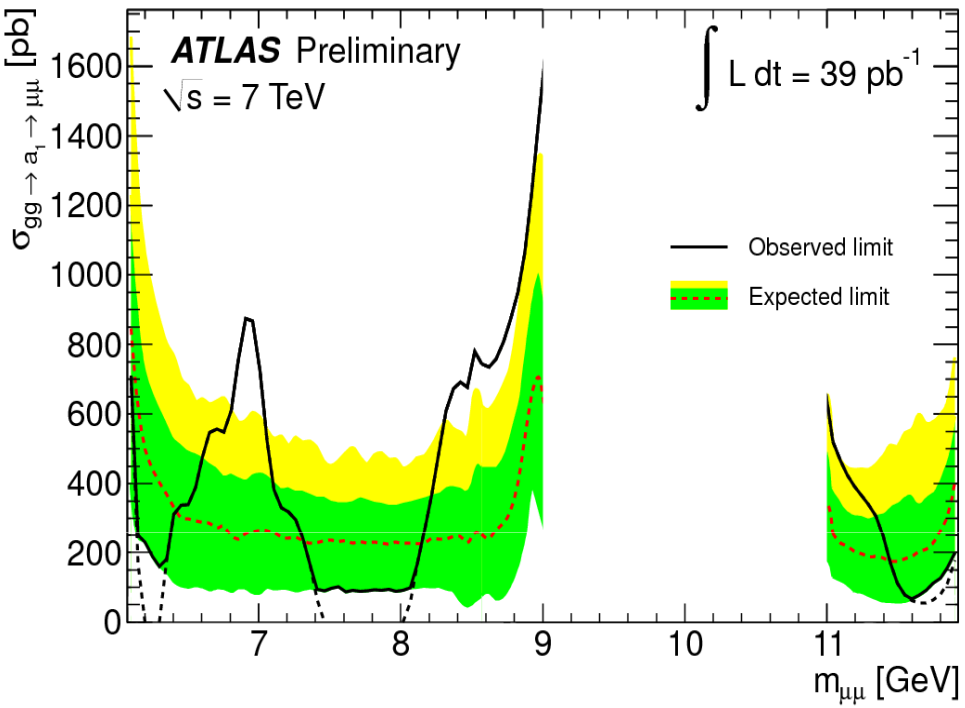
} **free parameters**

- **Continnum BGs : 4th Chebyshev polynomial**
- **Signal A : double-gaussian**

✓ **Width and fraction are related to those of Y(1/2/3s).**



A→μμ : Limit derivation



Systematics on signal eff.

Source	M_A=6(11.5)GeV
Luminosity	3.4 (3.4)%
PYTHIA vs MC@NLO	67 (20)%
Muon Efficiency	14 (15)%
Dimuon Trigger	13 (12)%
Likelihood Method	3 (3) %
Total	70(28)%