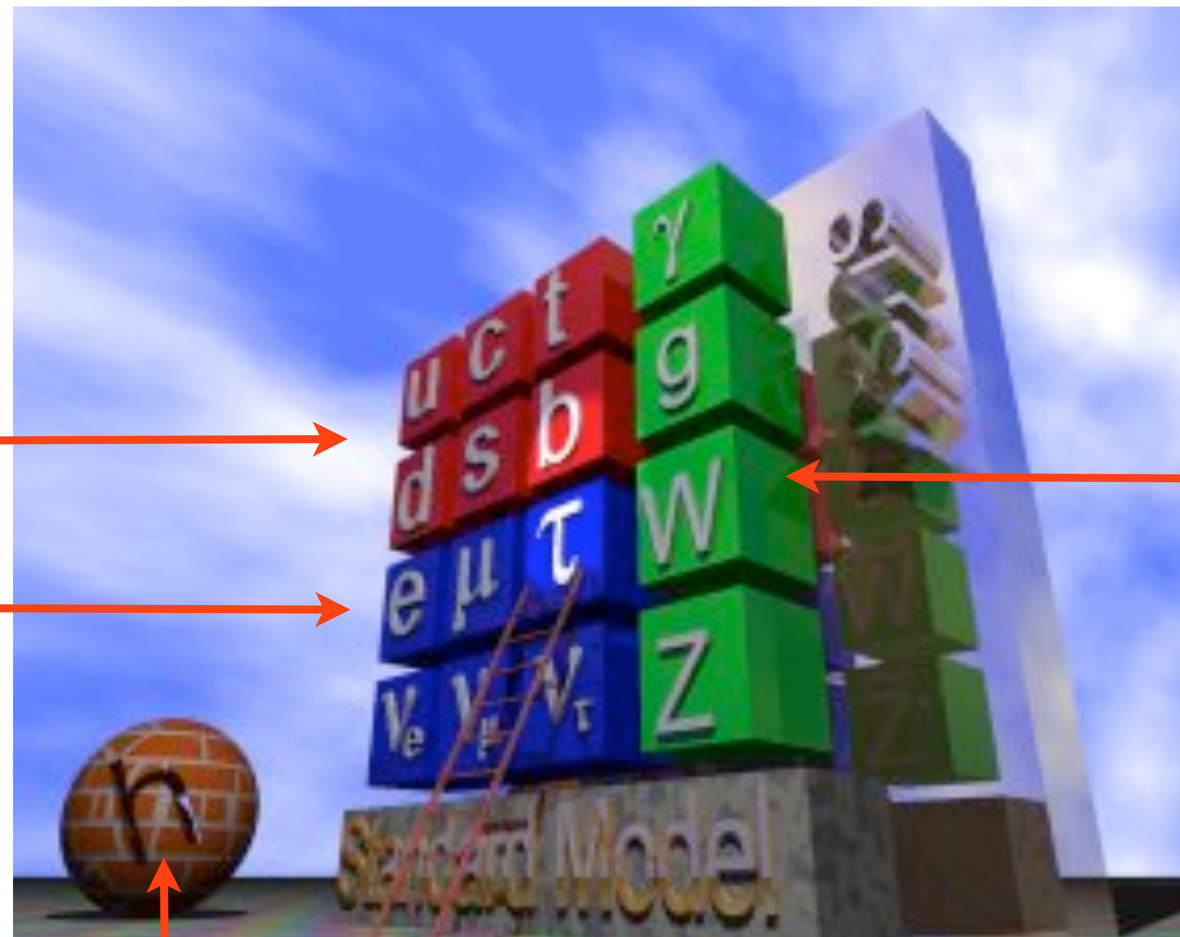
Light CP-Even Higgs -> $\gamma\gamma$ analysis
(using ATLAS SM simulation data)

Haichen Wang, 12/04/08

Final presentation of Physics 735 - Particle Physics

Standard Model

Elementary particles:
quarks
&
leptons



Fundamental interactions and the theories (electroweak and QCD) that describe the interactions

The only missing piece in the Standard Model is the Higgs boson, which is responsible for giving mass to the particles that should have mass.

What we know about Higgs?

Theory:

Higgs mass is unknown

Experiments:

LEP(1989-2000) @ CERN ->

the lower bound of Higgs mass 114.4 GeV

Tevatron @ Fermilab ->

One mass point Mh = 170 GeV excluded

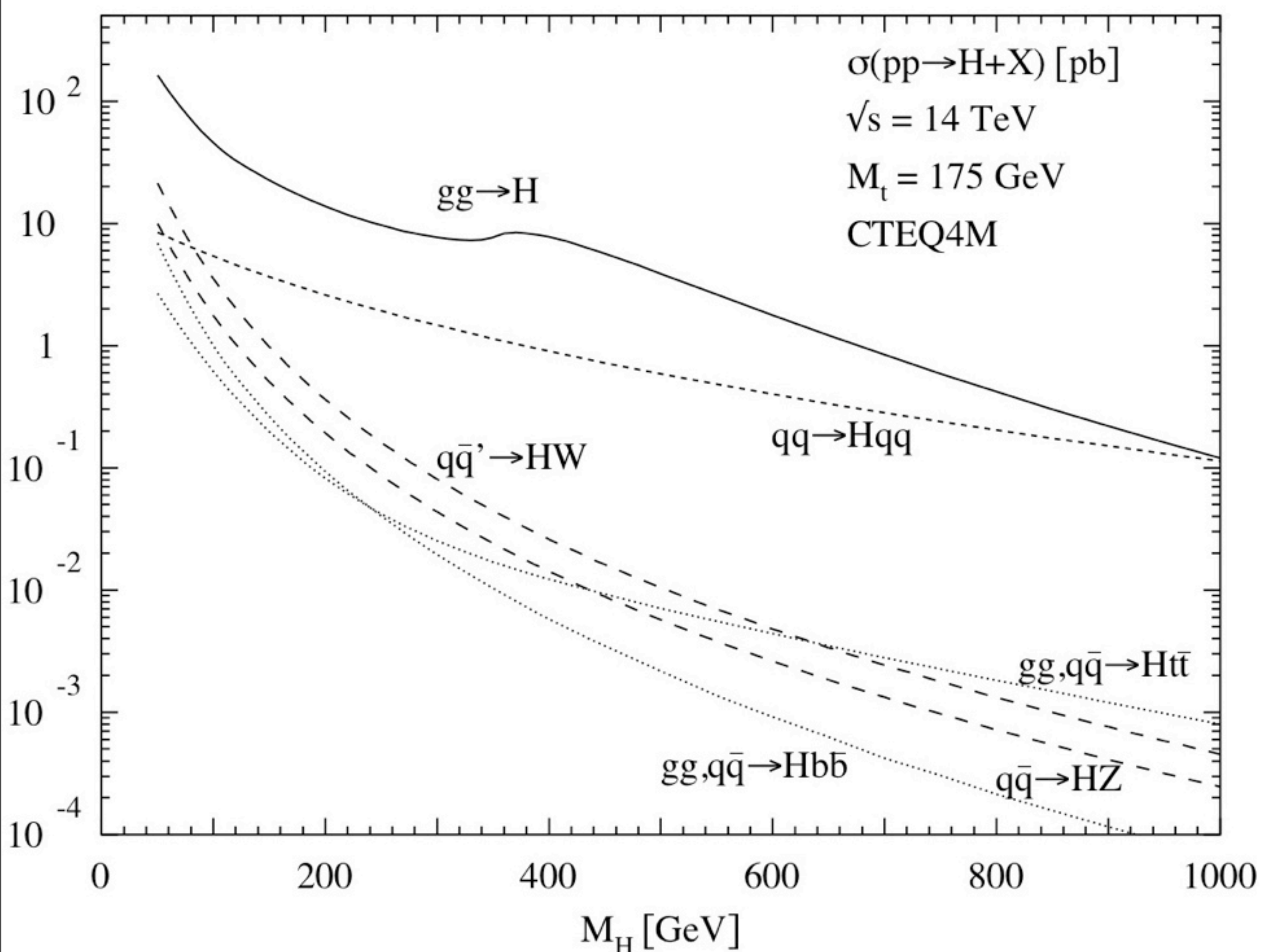
LHC @ CERN ->

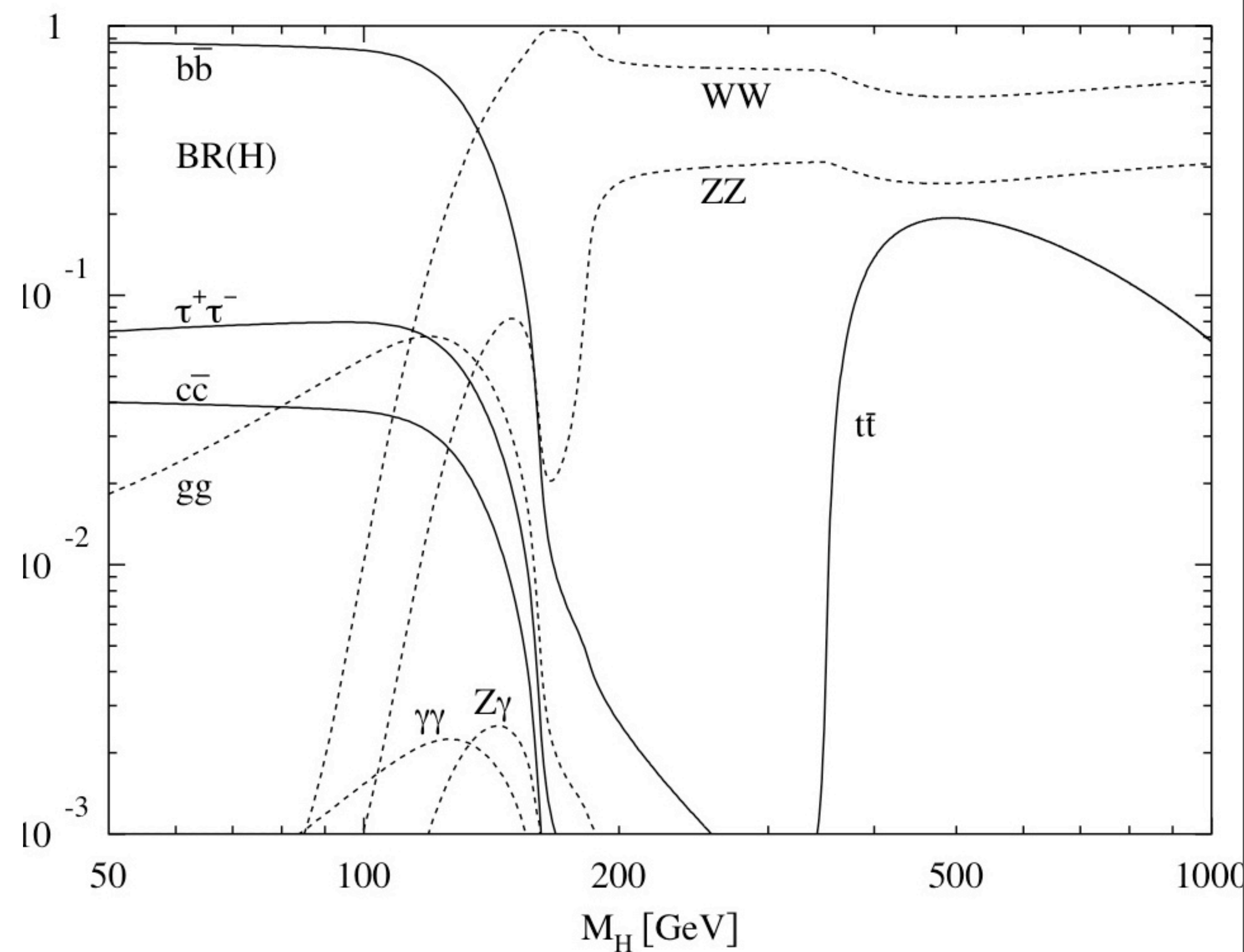
Both ATLAS and CMS have simulation data, and wait for the restart of LHC.

In this project, I used official simulation sample from ATLAS collaboration.

Experiment search for Higgs

Higgs production at LHC and decay modes



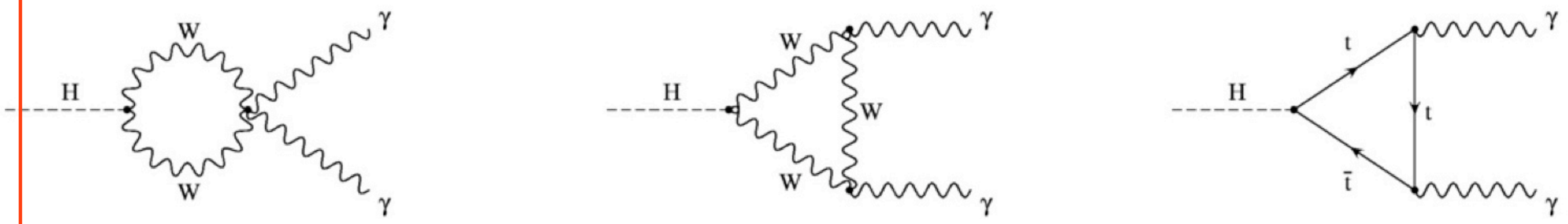


Higgs production cross section and its decay branching ratio are functions of Higgs mass.

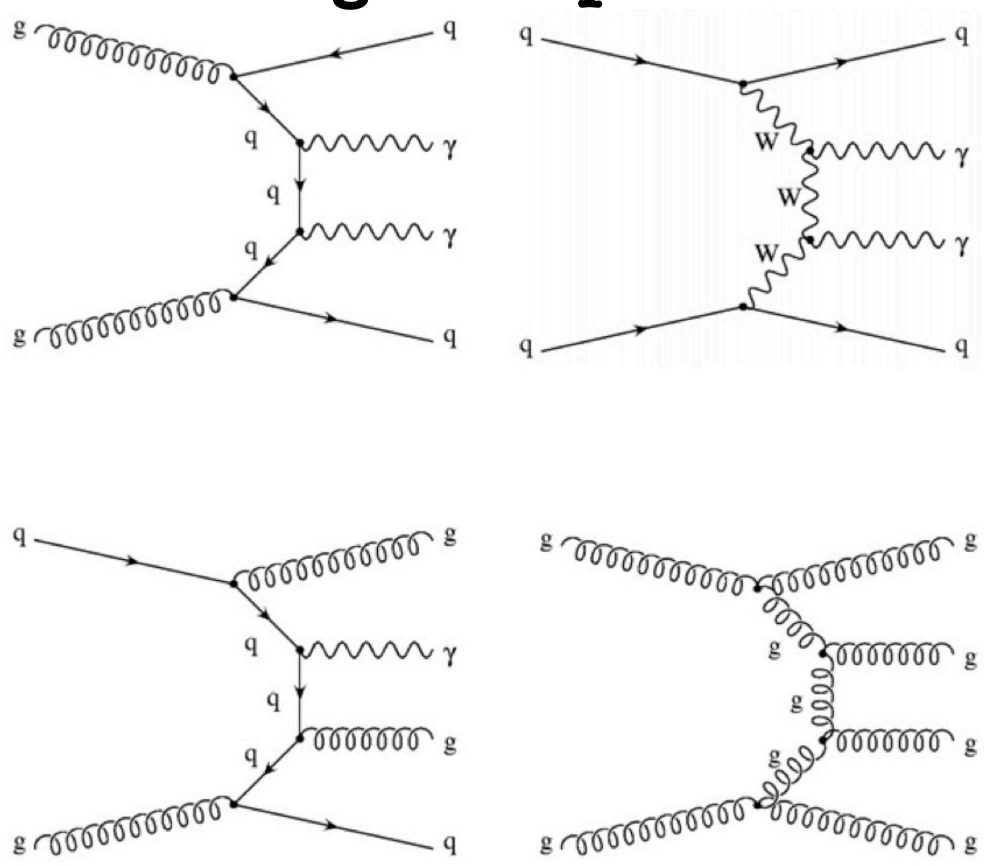
SM Higgs -> $\gamma\gamma$

Signal and Background

Signal processes

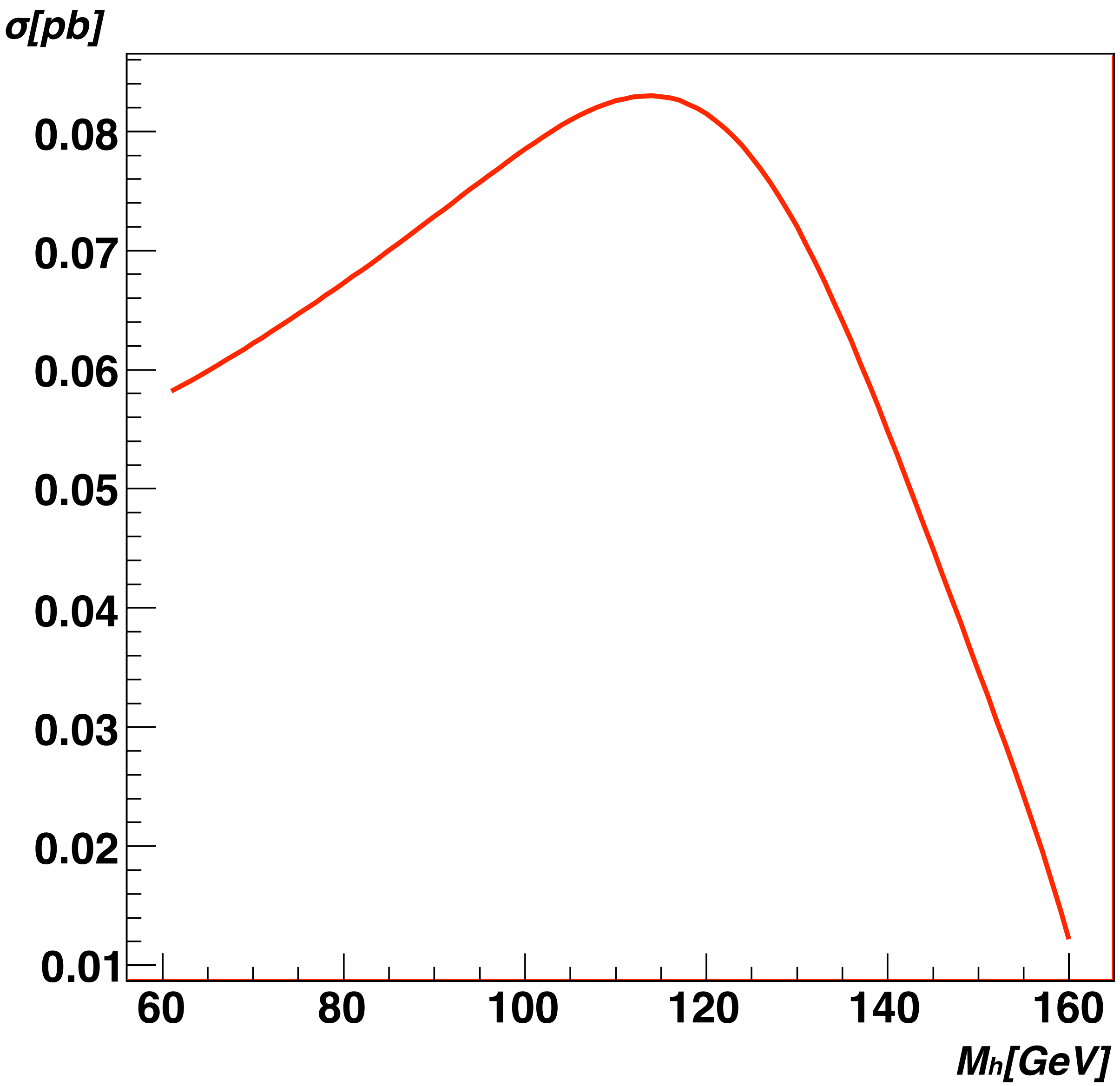


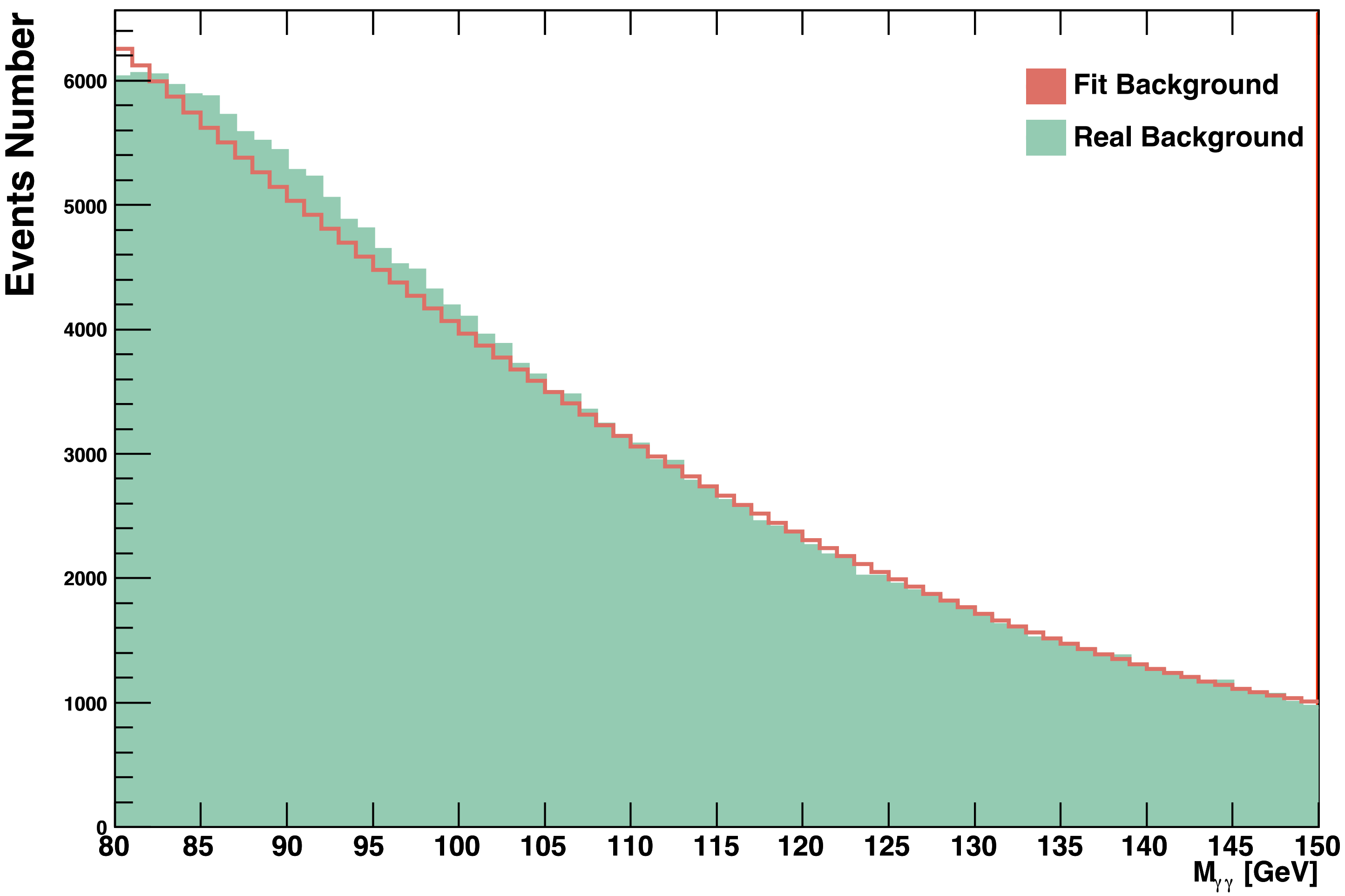
Background processes



SM Higgs -> γγ

Signal Cross section (14 TeV, p-p collider) and backgrounds

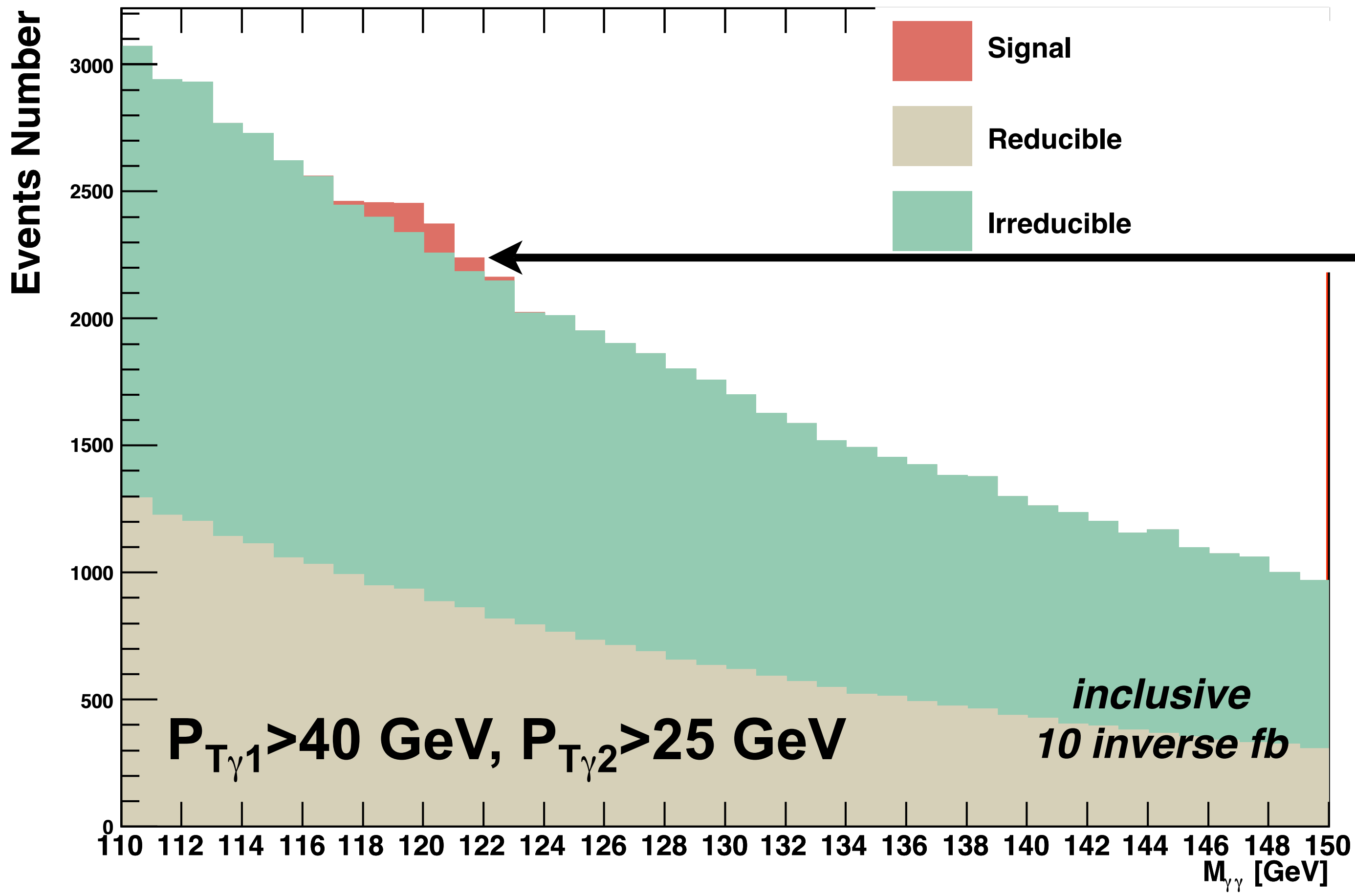


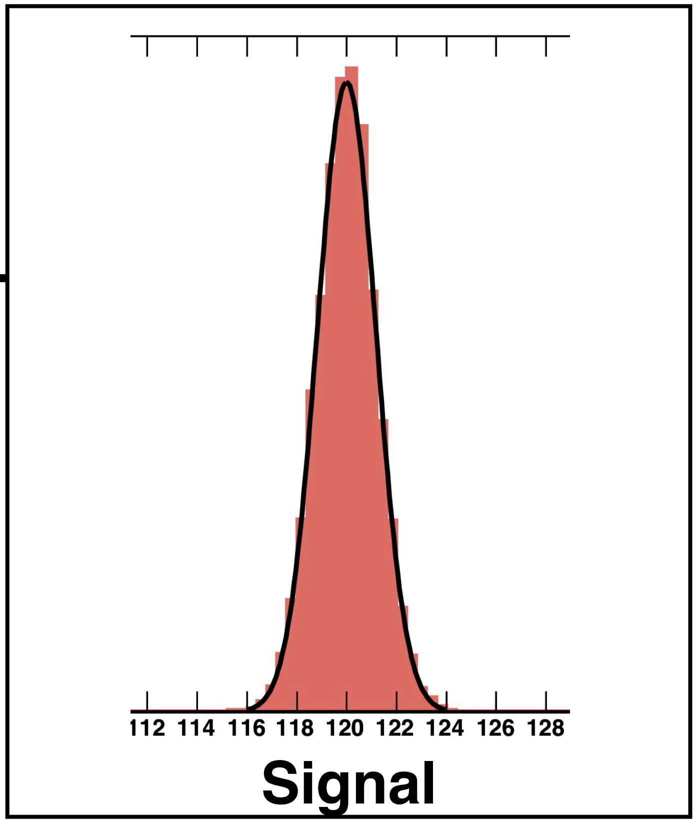


The cross section is evaluated by Higlu + pphtt, and the branching ratio is evaluated by HDecay

SM Higgs -> $\gamma\gamma$

Analysis of SM Higgs -> GammaGamma via ATLAS simulation data (14TeV)





A Gaussian distribution

(fast simulation)

Reconstruction the invariant mass of $\gamma\gamma$ <-> $M_{Higgs} = M_{\gamma\gamma}$

We have the signal and background in SM case, which we will use to study the MSSM Higgs discovery potential after some efforts .

MSSM Higgs sector

Minimal Supersymmetric Standard Model is the minimal extension to the Standard Model that realizes the Supersymmetry.

In MSSM, there are five Higgs bosons:
two CP-even Higgs bosons, one CP-odd Higgs boson and two charged Higgs bosons, and hence there are four Higgs masses:
M_h : mass of the light CP-even Higgs boson
M_H : mass of the heavy CP-even Higgs boson
M_A : mass of the CP-odd Higgs boson
M_c : mass of the two charged Higgs bosons

Another parameter $\tan\beta$, the ratio of two neutral Higgs field vacuum expectation values, is introduced.

At the tree-level, only M_A and $\tan\beta$ are free parameters.
=>
In Standard Model, we study the discovery potential along M_h axis.
In MSSM, we study the discovery potential on the M_A-$\tan\beta$ plane.

Light CP-even Higgs Mass

On the M_A-tanβ plane,
The mass of light CP-even Higgs has an upper bound:

$$m_h^2 \lesssim m_Z^2 + \frac{3g^2 m_t^4}{8\pi^2 m_W^2}\left[\ln\left(\frac{M_S^2}{m_t^2}\right) + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right].$$

$$X_t \equiv A_t - \mu \cot\beta\,,$$

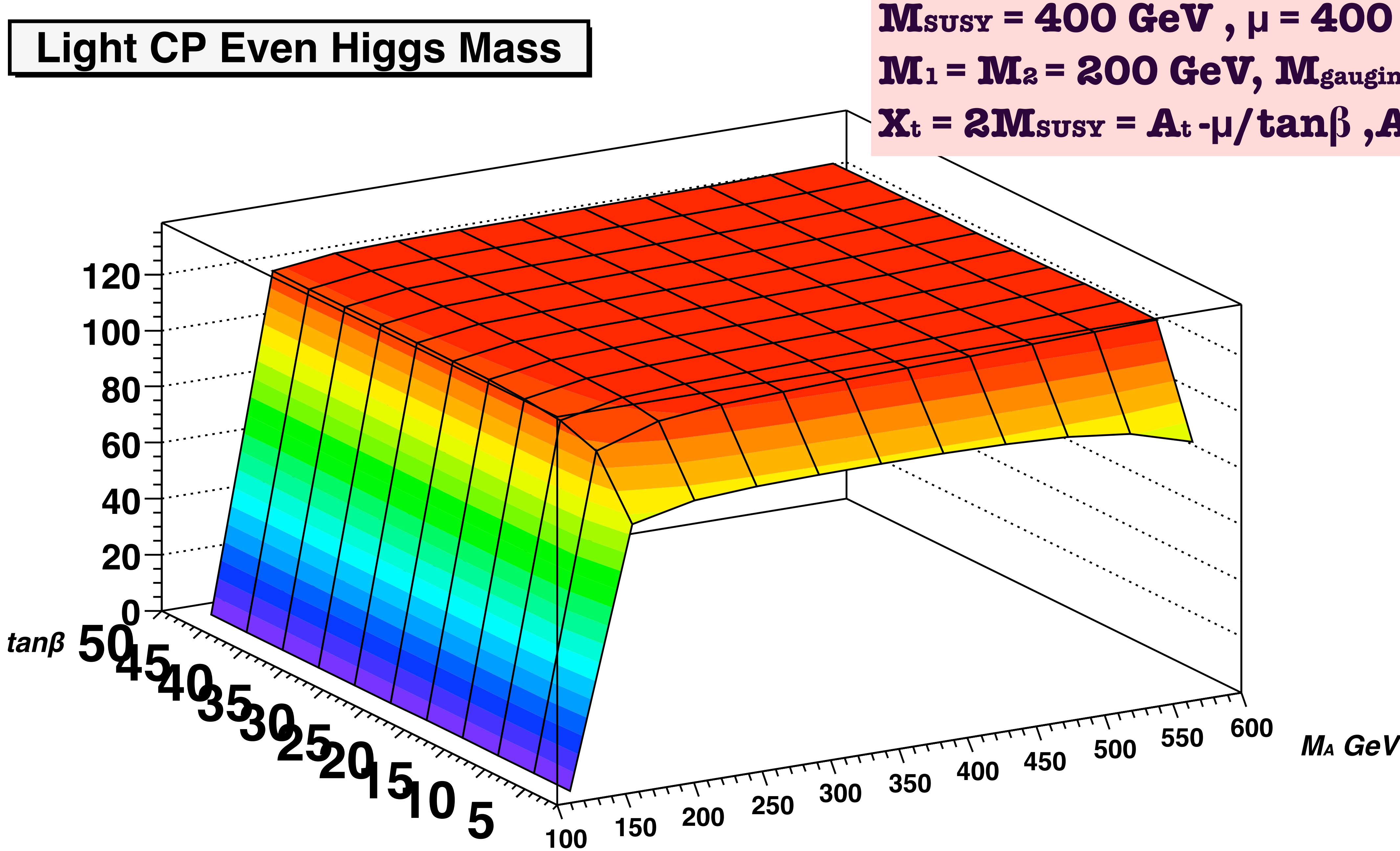
The exact value of the upper bound depends on several MSSM parameters. (so there is an upper bound of the upper bound!)

Roughly, the upper bound is around 135 GeV.

Therefore, the possible mass of light CP-even Higgs is in the best discovery range of the Higgs -> Gamma Gamma.

Light CP-even Higgs Mass

M_{SUSY} = 400 GeV , μ = 400 GeV
$M_1 = M_2$ = 200 GeV, $M_{gaugino}$ = 800 GeV
$X_t = 2M_{SUSY} = A_t - \mu/\tan\beta$, $A_t = A_b$, $A_f = 0$.



FeynHiggs is used to evaluate the mass of Higgs

A point at the M_A-tanβ corresponds to the mass of a light CP-even Higgs and its production cross section and branching ratios.

$$M_h = M_h(M_A, \tan\beta)$$

$$\sigma = \sigma(M_h) = \sigma(M_h(M_A, \tan\beta)),\ BR = BR(M_h) = BR(M_h(M_A, \tan\beta))$$

Higgs -> $\gamma\gamma$, from SM to MSSM

The cross section and BR of light CP-even Higgs are different from those of SM Higgs. But, its <u>shares the background with the SM Higgs</u>.

In order to obtain the MSSM signal , we rescale the SM signal by multiplying a factor:

$$N_{sig(MSSM)} = \delta \, N_{sig(SM)}$$

$$\delta = \sigma BR_{(MSSM)} / \sigma BR_{(SM)}$$

the ratio is evaluated under the condition
that SM Higgs and light cp-even higgs share the same mass

and use the rescaled signal as the MSSM signal

σ **and** BR **are evaluated on the M_A-tanβ plane, using some programs from phenomenologists.**

cross section: Higlu+pphtt, FeynHiggs
branching ratio: HDecay, FeynHiggs

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SM cross section modification

We only have the SM simulation data at 120 GeV, but on the M_A-tanβ plane, the light cp-even Higgs has different mass values, which means we need signals at other mass values. We have to add a modification factor to the SM signal (at 120 GeV) when its corresponding mass is not 120 GeV. The factor is , which I evaluated by Higlu and HDecay.

$$\alpha = \sigma BR(M_h) / \sigma BR(120GeV)$$

Cut efficiency modification

The $N_{sig(MSSM)}$ **is before any cuts. Now we assume that the cut efficiency of MSSM case is the same as that of SM.**

The cut efficiency is defined by:

$$\lambda = N_{event}(\text{after cuts}) / N_{event}(\text{before cuts})$$

Modification factor:

$$\chi = \lambda(m_h) / \lambda(120)$$

Standard Model

Cuts efficiency:

fit the 3 points by linear fucntion

cut efficiency	120GeV	130GeV	140GeV
inclusive	0.312	0.334	0.352
higgs+jet	0.388	0.411	0.428

MSSM signal

$$N_{sig(MSSM)} = \delta\alpha\chi\, N_{sig(SM)}$$

$$\delta_{(M_h)} = \sigma BR_{(MSSM)} / \sigma BR_{(SM)}$$

the ratio is evaluated under the condition
that SM Higgs and light cp-even higgs share the same mass
SM->MSSM modification

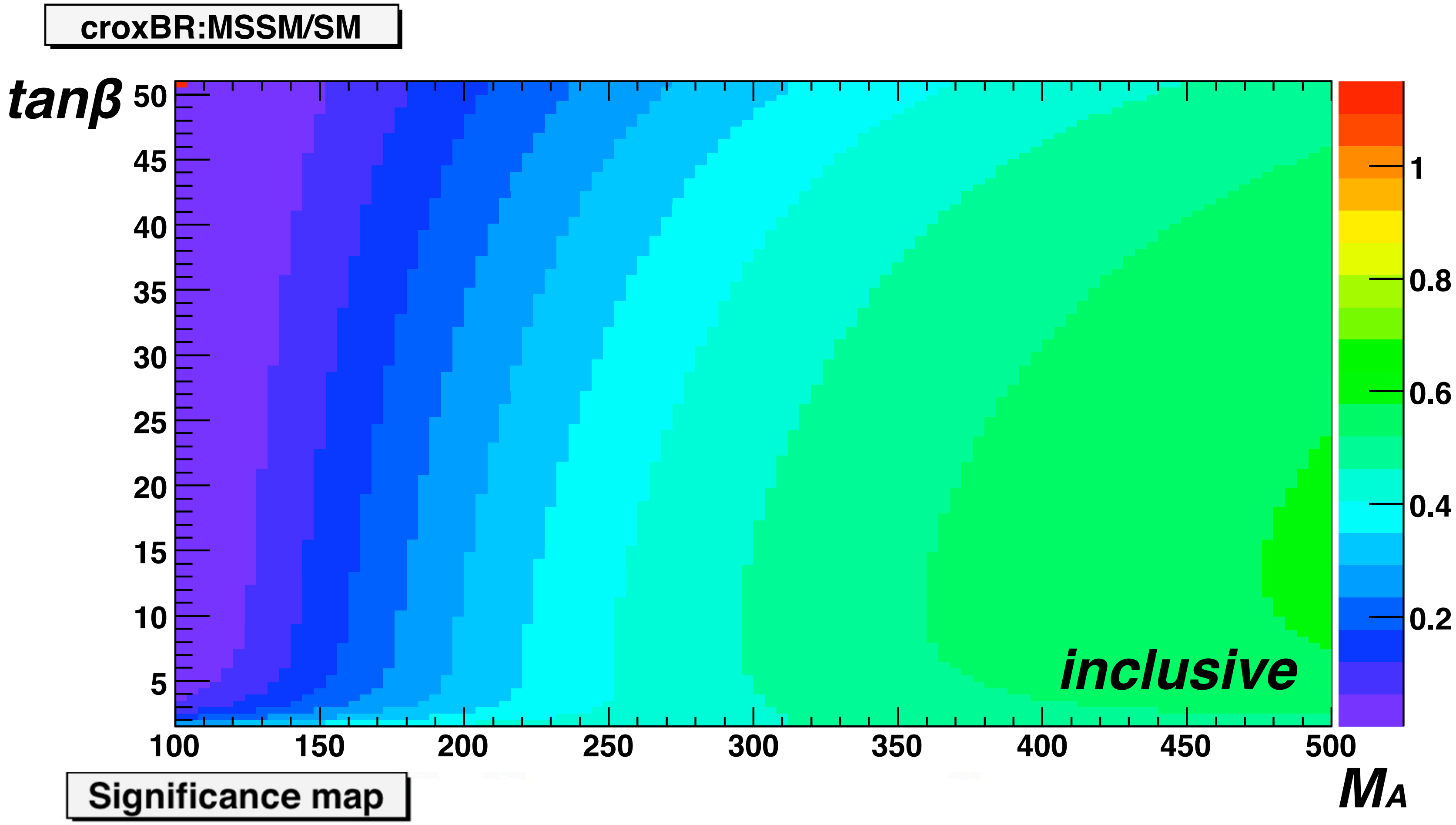
$$\alpha = \sigma BR_{(M_h)} / \sigma BR_{(120GeV)}$$

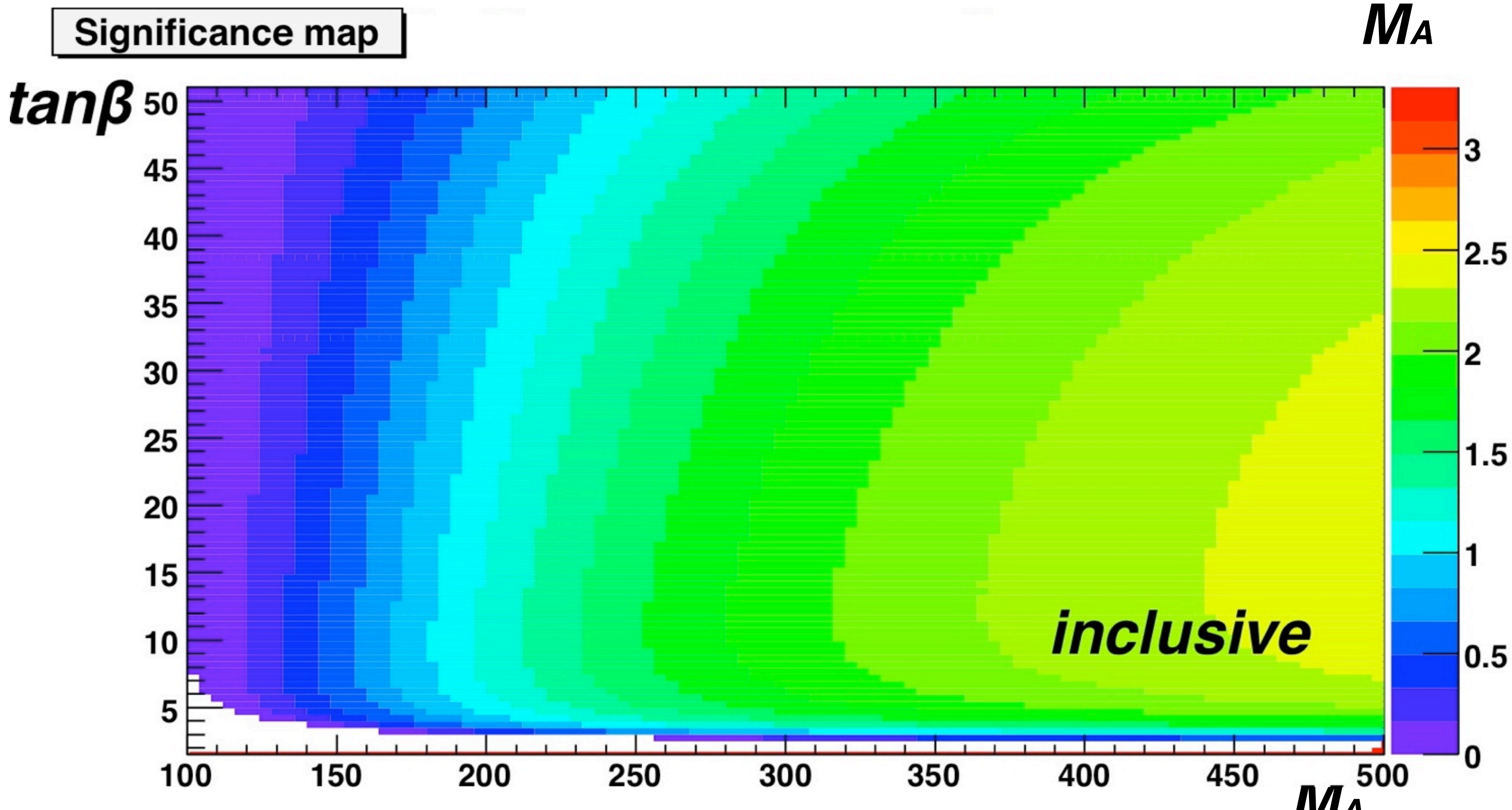
cross section modification

$$\lambda = N_{event}(\text{after cuts}) / N_{event}(\text{before cuts})$$

$$\chi = \lambda(m_h) / \lambda(120)$$

cut efficiency modification





10 inverse fb result

Conclusion

A method that use the SM Higgs -> $\gamma\gamma$ data to study the light cp-even Higgs -> $\gamma\gamma$ is developed and a significance map is presented.

Based on this method, we can study light cp-even Higgs -> $\gamma\gamma$ discovery potential in other benchmark scenarios.

References:

1. Prospects for the Discovery of the Standard Model Higgs Boson Using the H → γγ Decay with the ATLAS Detector, ALTAS CSC NOTE, 2008

2. Marcela Carena and Howard E. Haber, hep–ph/0208209

3. Michael Spira, hep-ph/ 9610350 (HDecay & Higlu)

4. S. Heinemeyer, W. Hollik, G. Weiglein, hep-ph/9812320 (FeynHiggs)

5. Tao Han, hep-ph/0508097

6. ATLAS Detector and Physics Performance Technical Design Report: http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/TDR/access.html

7. Prof. Herndon's ICHEP08 talk: http://www.hep.upenn.edu/ichep08/talks/misc/download_slides?Talk_id=465

Backup:
Cuts for the SM Higgs -> $\gamma\gamma$ analysis

Ia At least two photon candidates (see Section 3.2) in the central detector region defined as $|\eta| < 2.37$ excluding the transition region between barrel and endcap calorimeters, $1.37 < |\eta| < 1.52$ (*crack* in the following). At this level it is required that the event passes the trigger selection (see Section 4).

Ib Transverse momentum cuts of $40, 25$ GeV on the leading and sub-leading photon candidates, respectively.

Cross sections after cuts

Table 8: Expected cross-sections (in fb) for different signal ($m_H = 120$ GeV) and background processes within a mass window, $m_{\gamma\gamma}$ of ± 2 GeV (± 1.4 of the mass resolution in the no pileup case reported in Table 5) around 120 GeV. Cuts **Ia** and **Ib** were applied.

Signal Process	Cross-section (fb)	Background Process	Cross-section (fb)
$gg \to H$	21	$\gamma\gamma$	562
VBF H	2.7	Reducible γj	318
ttH	0.35	Reducible jj	49
VH	1.3	$Z \to e^+e^-$	18

Backup: Background

	Irreducible Backgrounds		Reducible Backgrounds	
Process	$q\bar{q}, qg \to \gamma\gamma x$	$gg \to \gamma\gamma$	γ-jets	jj
Cross-section calculator	RESBOS DIPHOX	RESBOS	JETPHOX	NLOJET++
Cross-section (pb)	20.9	8.0	$180{\cdot}10^3$	$477{\cdot}10^6$
Event generator (fullsim)	PYTHIA	PYTHIA	PYTHIA	PYTHIA
Event generator (fastsim)	ALPGEN	PYTHIA	ALPGEN	ALPGEN

Table 5.3: Summary of the cross-sections of the irreducible and reducible backgrounds used for the $H \to \gamma\gamma$ inclusive analysis. The last two rows indicate the MC packages used for event generation with a full and fast detector simulation, respectively.

Backup:

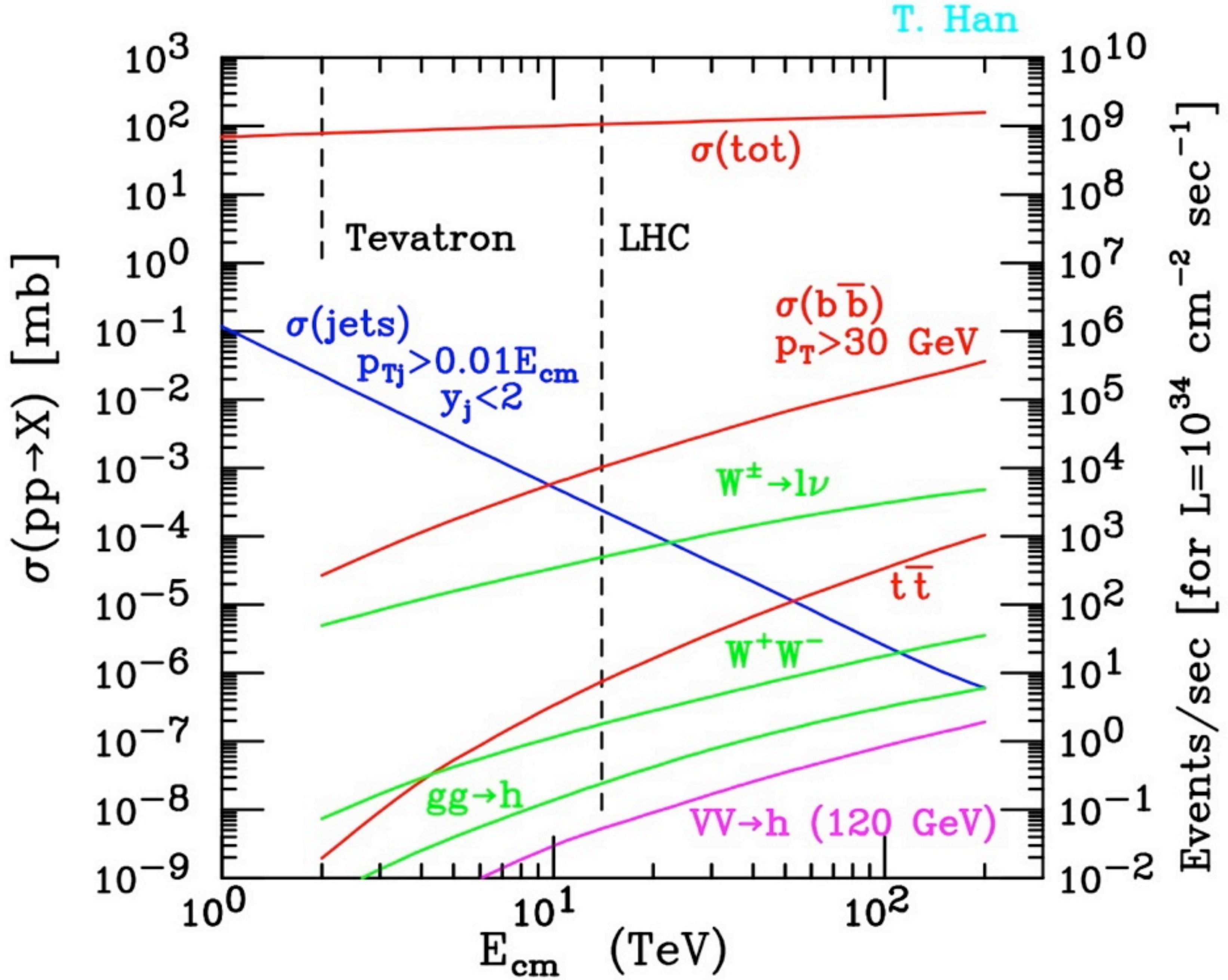
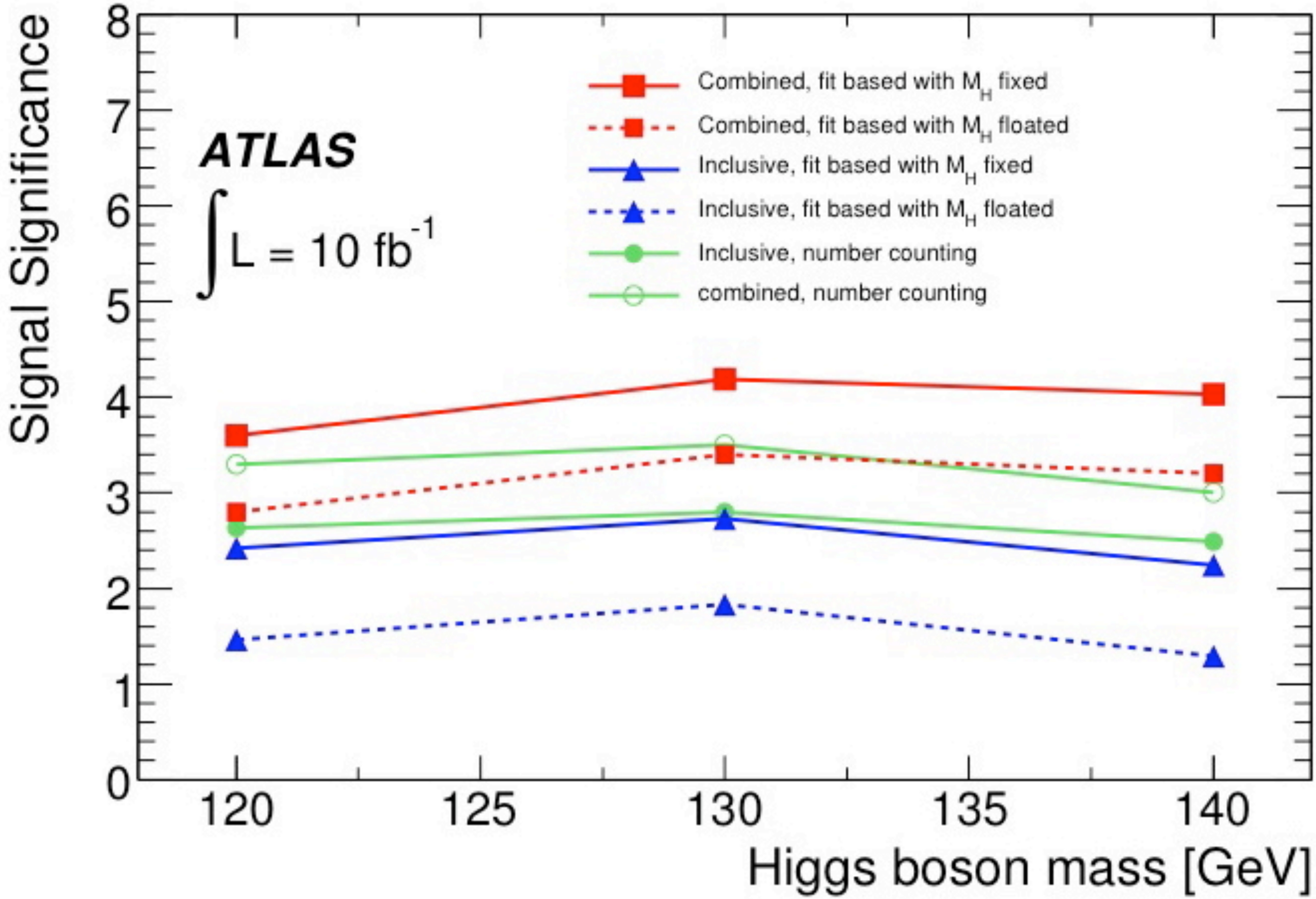


FIG. 6: Scattering cross sections versus c.m. energy for the SM processes in *pp* collisioins. The Higgs boson mass has been taken as 120 GeV.

Backup:


Signal Significance
ATLAS
$\int L = 10\ fb^{-1}$
Combined, fit based with M_H fixed
Combined, fit based with M_H floated
Inclusive, fit based with M_H fixed
Inclusive, fit based with M_H floated
Inclusive, number counting
combined, number counting
0
1
2
3
4
5
6
7
8
120
125
130
135
140
Higgs boson mass [GeV]