NAGOYA UNIVERSITY

KMI
Kobayashi-Maskawa Institute
for the Origin of Particles and the Universe

Results of LHC-ATLAS 8TeV Run

Makoto Tomoto

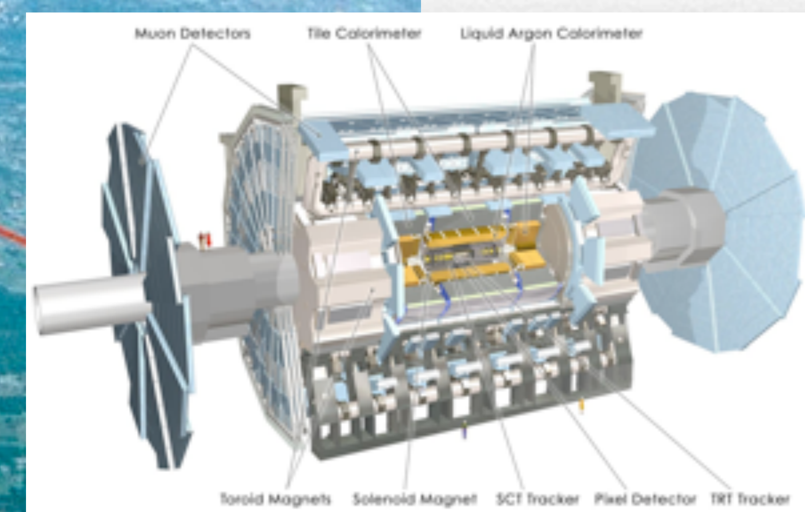
Tau-Lepton Physics Research Center
Graduate School of Science
Nagoya University

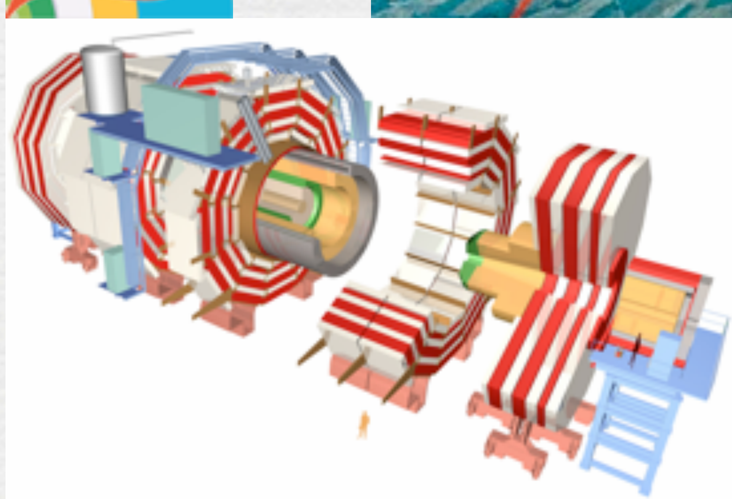
Nagaya University
Tau Lepton Physics Research Center

Contents

LHC experiments

2010 : started physics run
2011 : physics data (√s=7)
2012 : physics data (√s=8)
2012, July : Higgs discovery
2013- : upgrade





ATLAS

published >270 papers

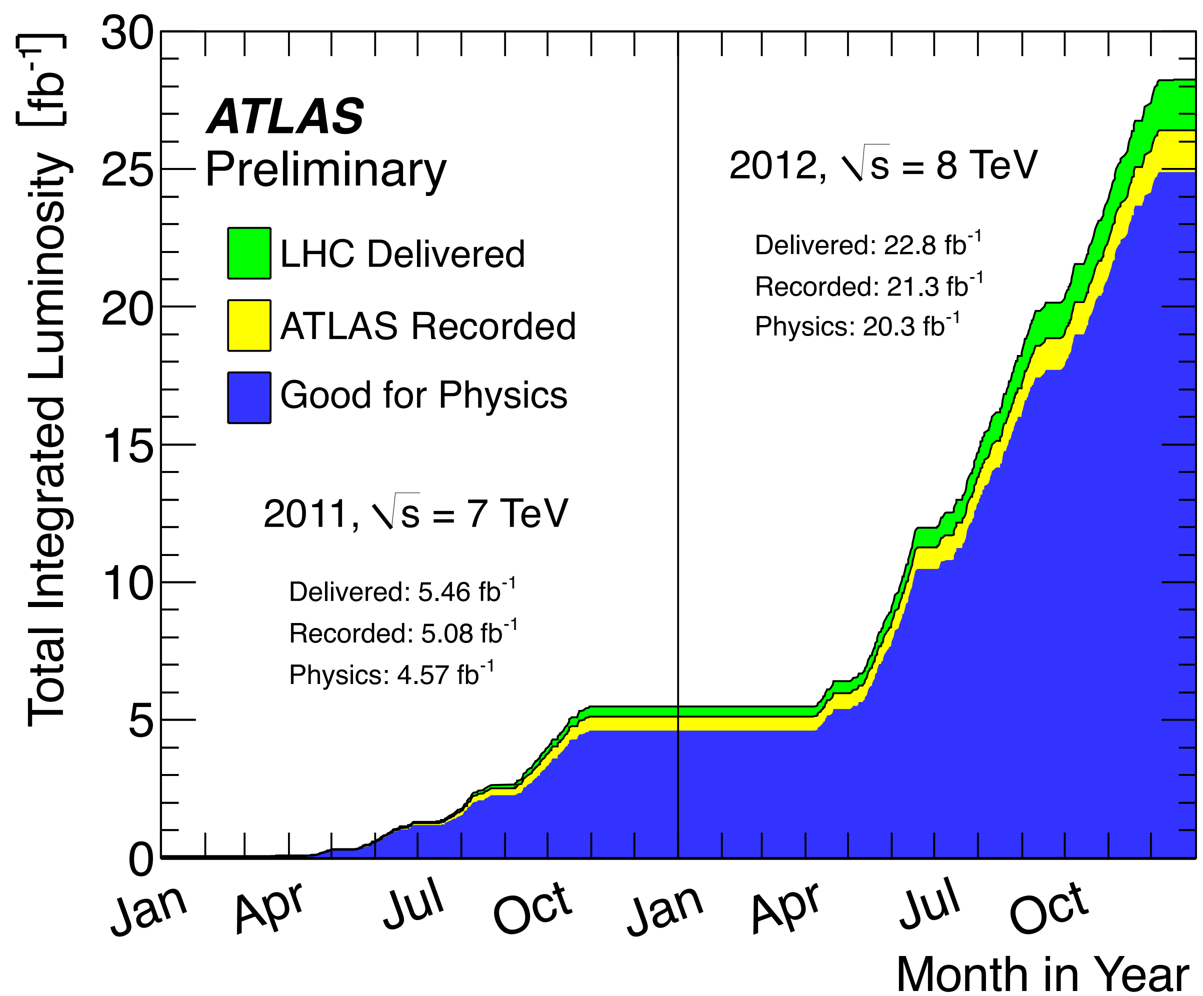
Today, show a part of them.

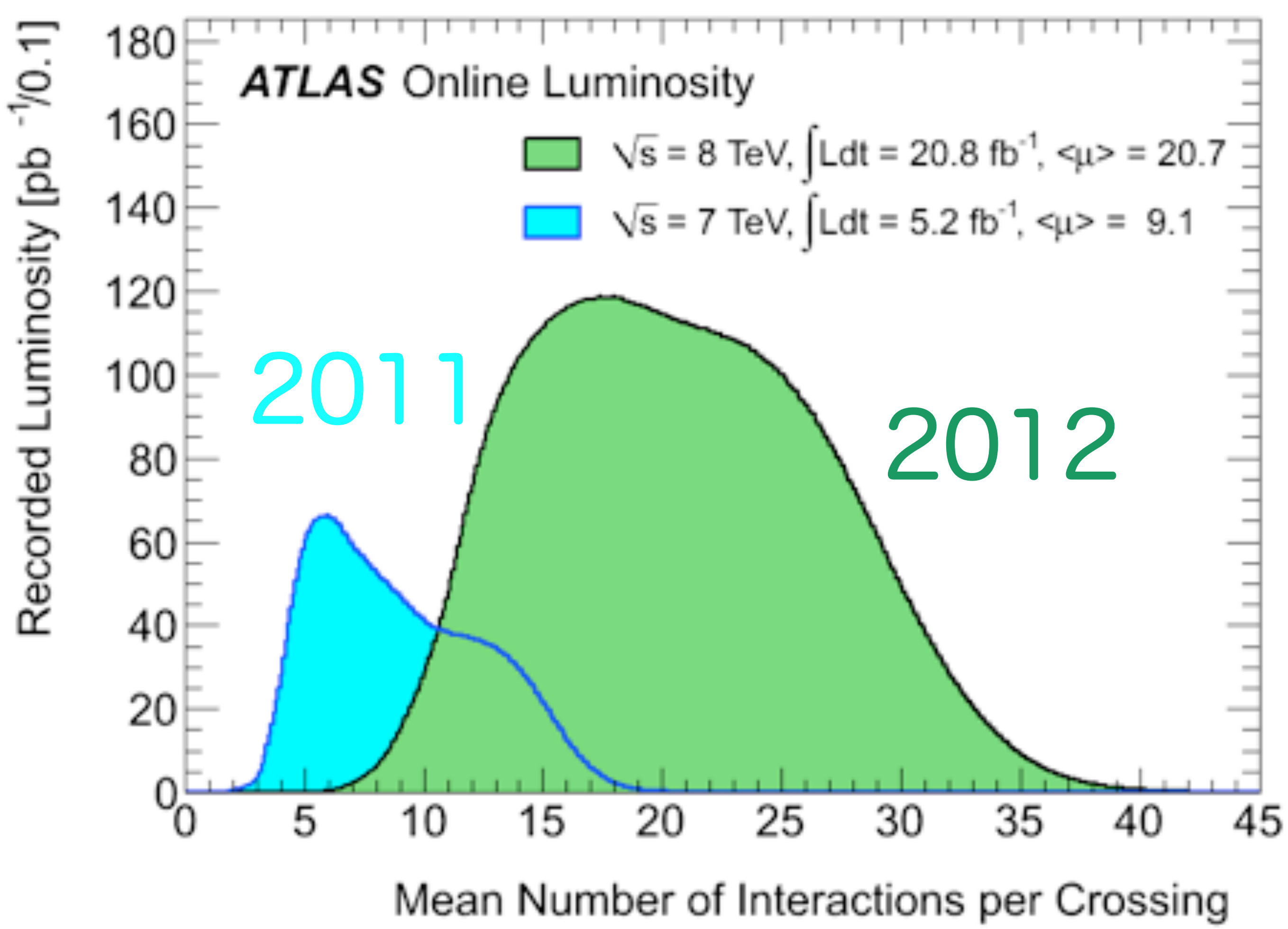
Mainly, Higgs Physics!!

LHC Run I performed very well

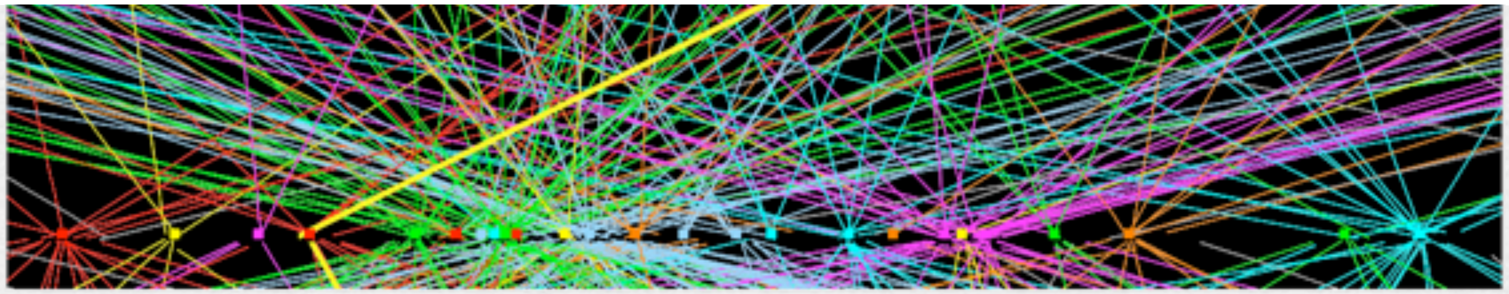
2011 : $\sqrt{s}$=7TeV, $\int Ldt$ = 5fb^{-1}, $<\mu>$=9

2012 : $\sqrt{s}$=8TeV, $\int Ldt$ = 21fb^{-1}, $<\mu>$=21



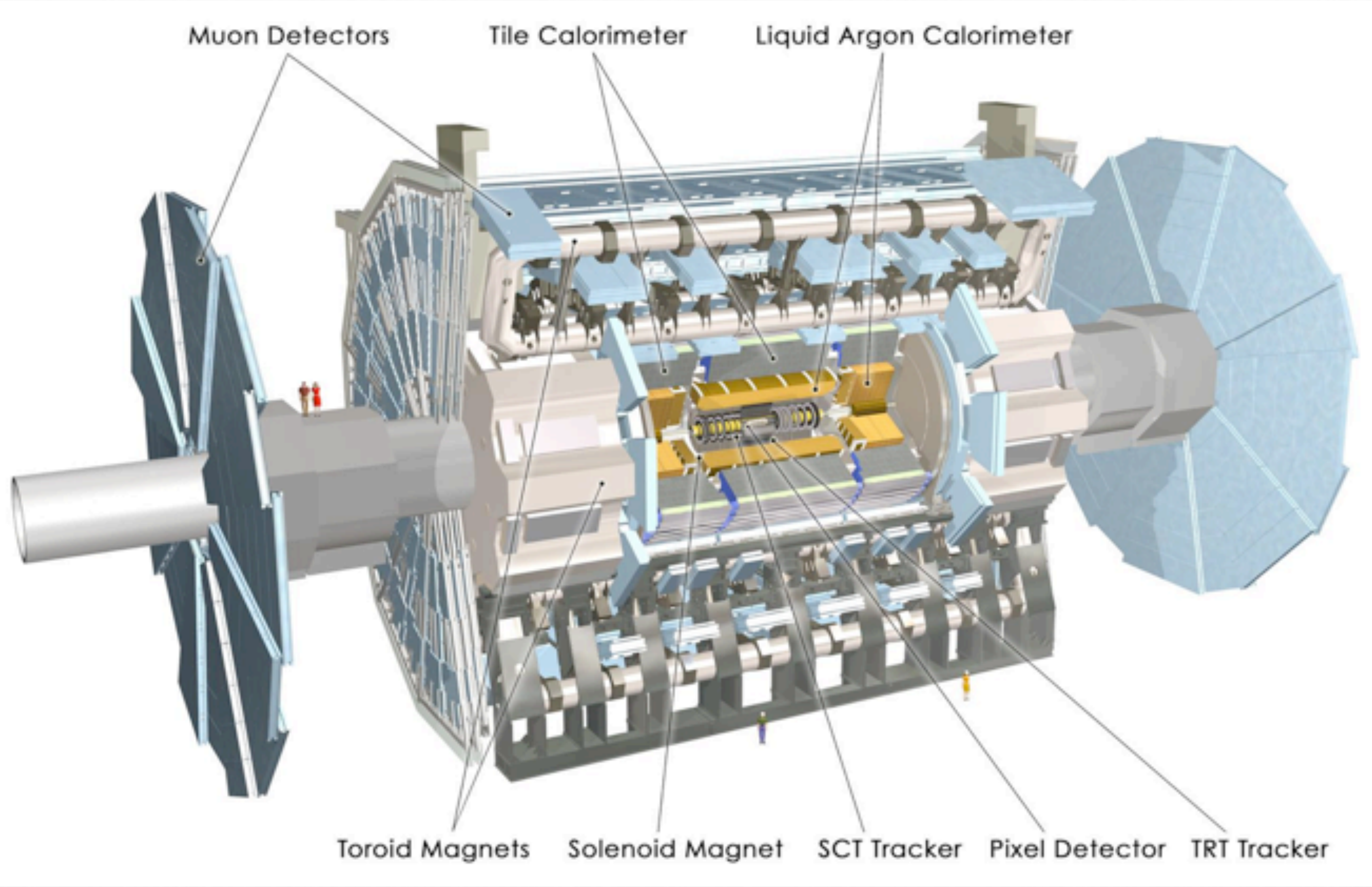


~20 pile-ups!!



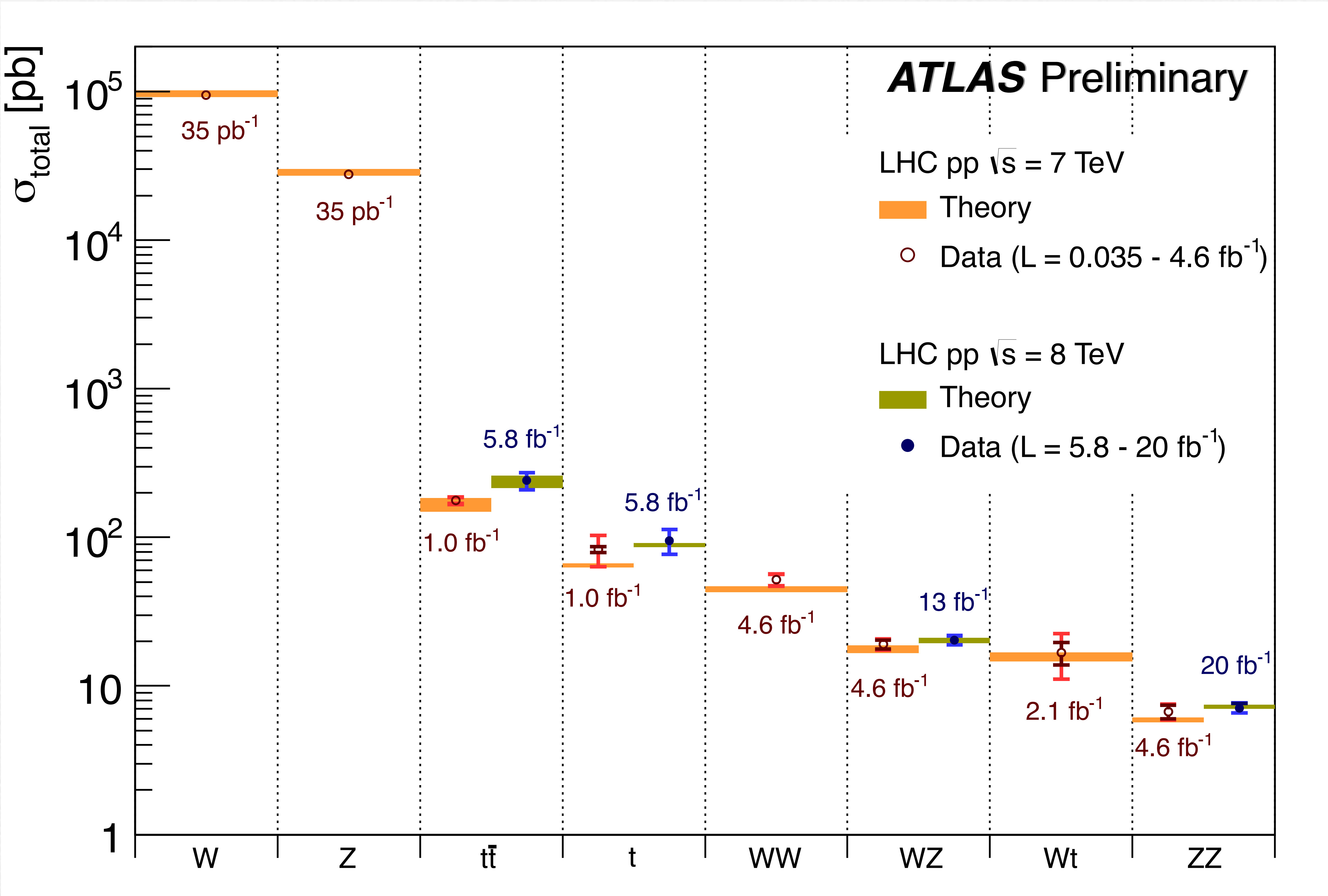
ATLAS detector

The ATLAS detector was designed with discovery of [the Higgs boson / new physics] in mind

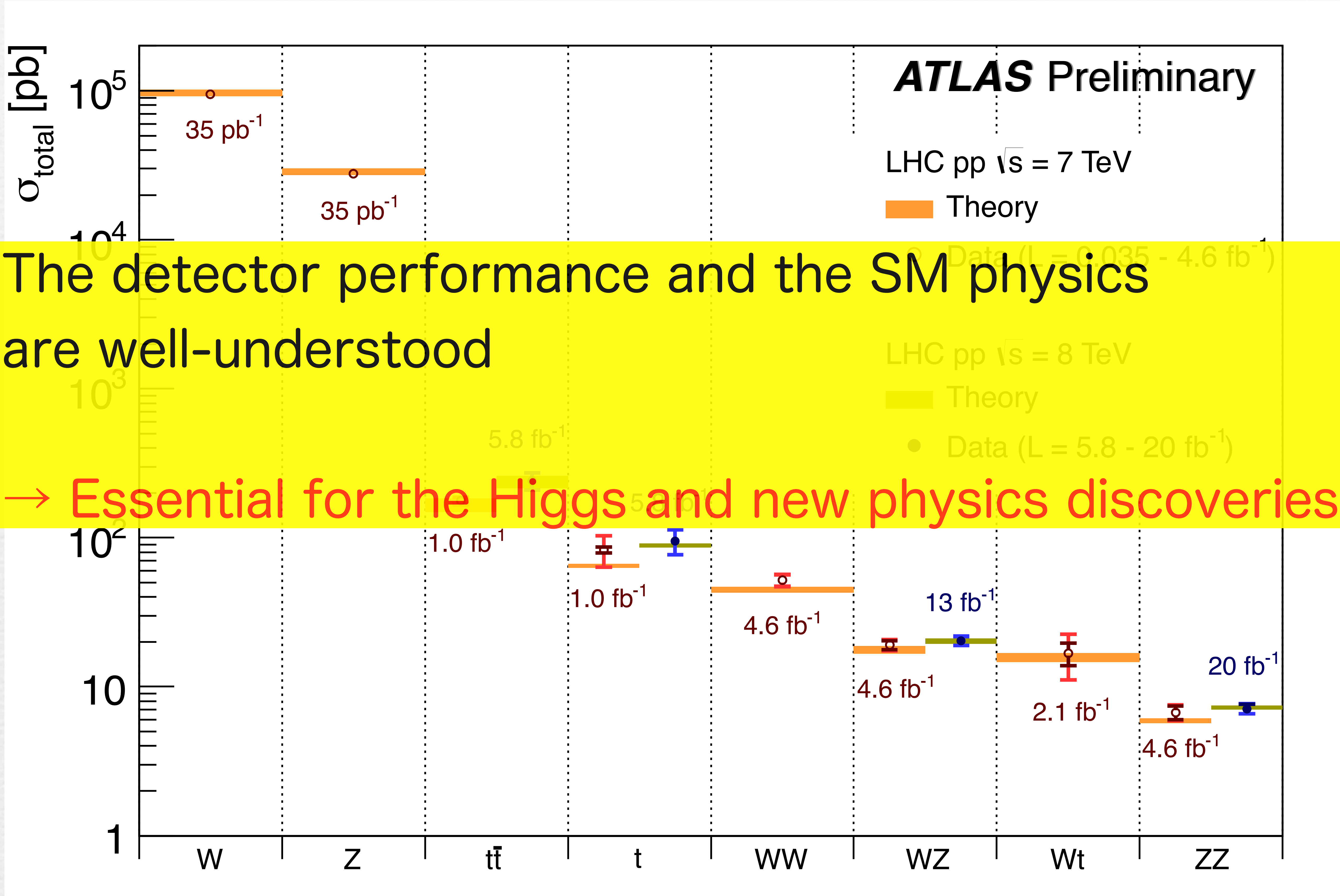


- Precise measurement of the charged tracks by inner detectors
- Identification of electrons and photons against QCD jets
- Excellent calorimeter hermeticity and energy resolution
- Precise muon reconstruction and triggering by muon detectors

Physics towards Higgs discovery



Physics towards Higgs discovery



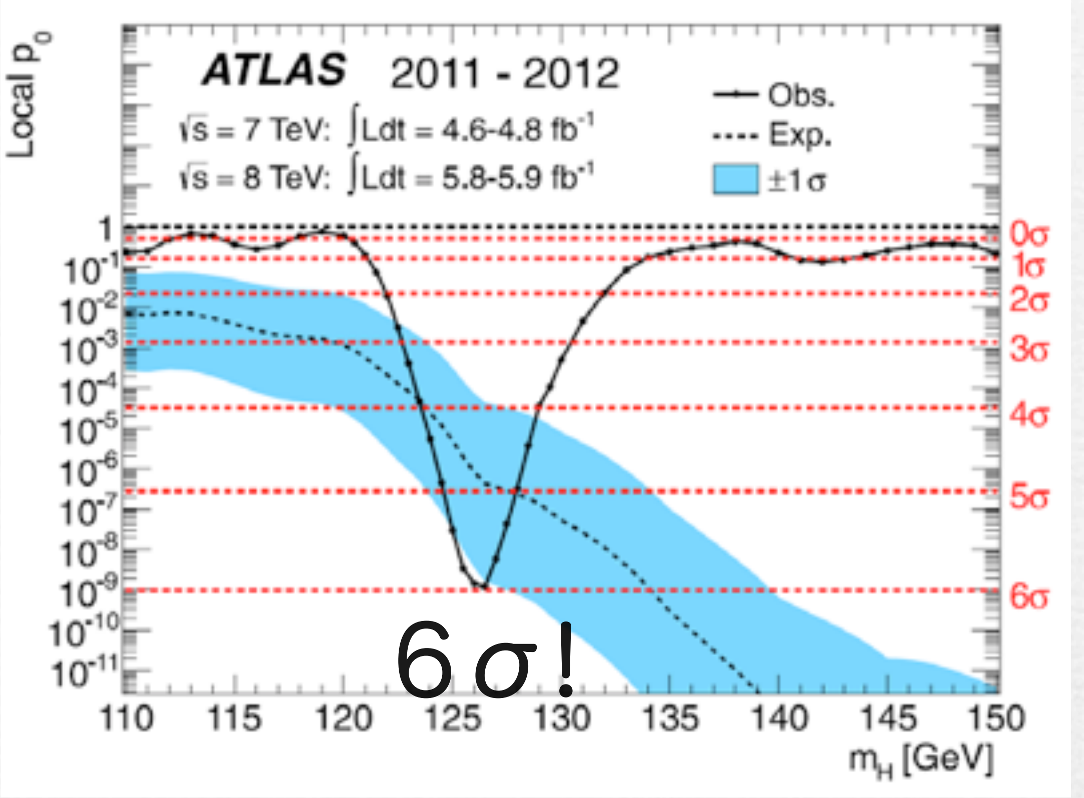
The detector performance and the SM physics are well-understood

→ Essential for the Higgs and new physics discoveries

Higgs discovery

July 2012,

We observed a Higgs-like resonance at m_H=125.5GeV



Since then, we focus our interests on whether :

this resonance is really the Higgs predicted by SM?

there are any signs of physics beyond the SM ?

They are addressed by

Precise measurements on Higgs property

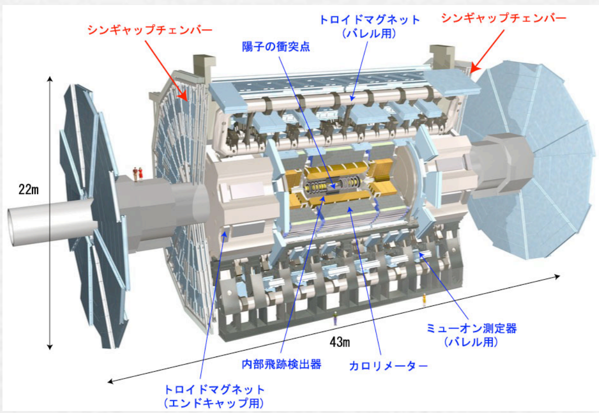
signal strength, couplings and spin-parity

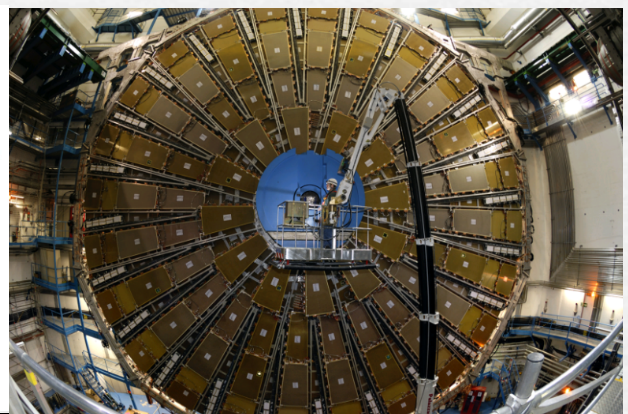
Direct searches for the physics beyond the SM

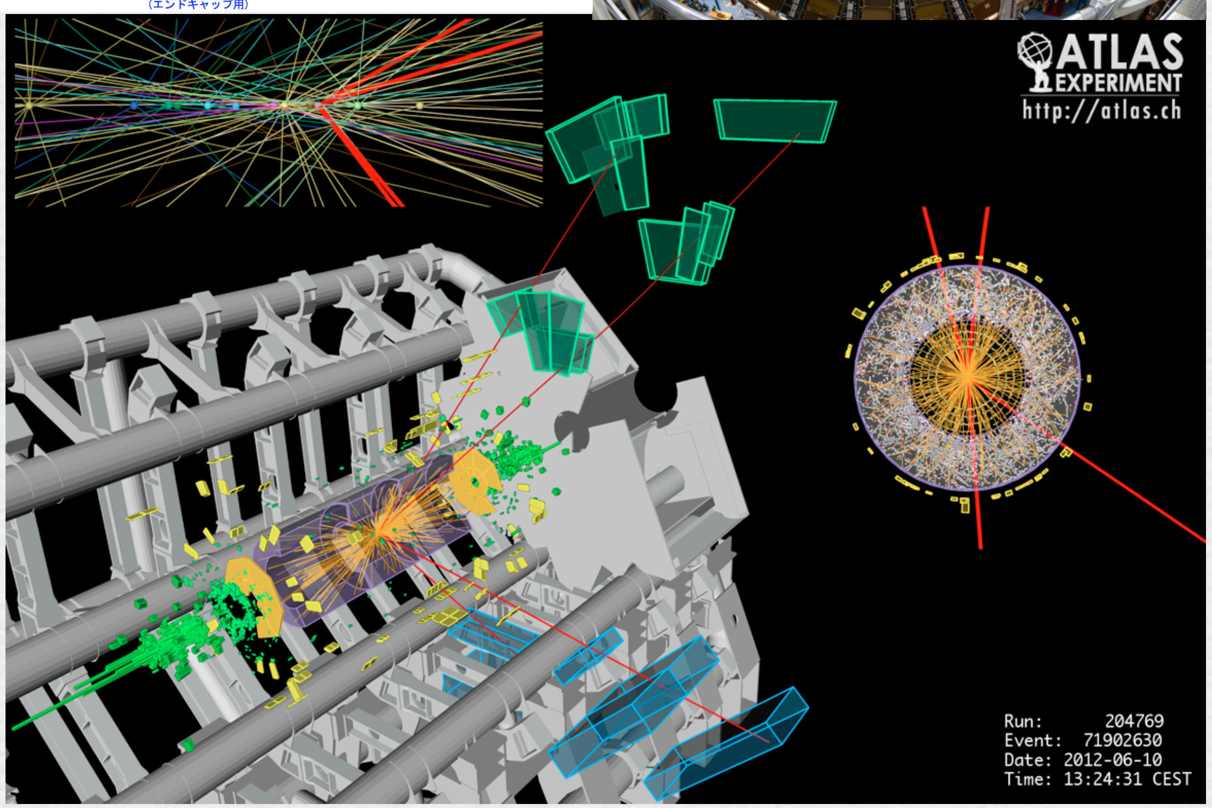
Nagoya contributions

1. L1 muon trigger system

Installation/commissioning/operation



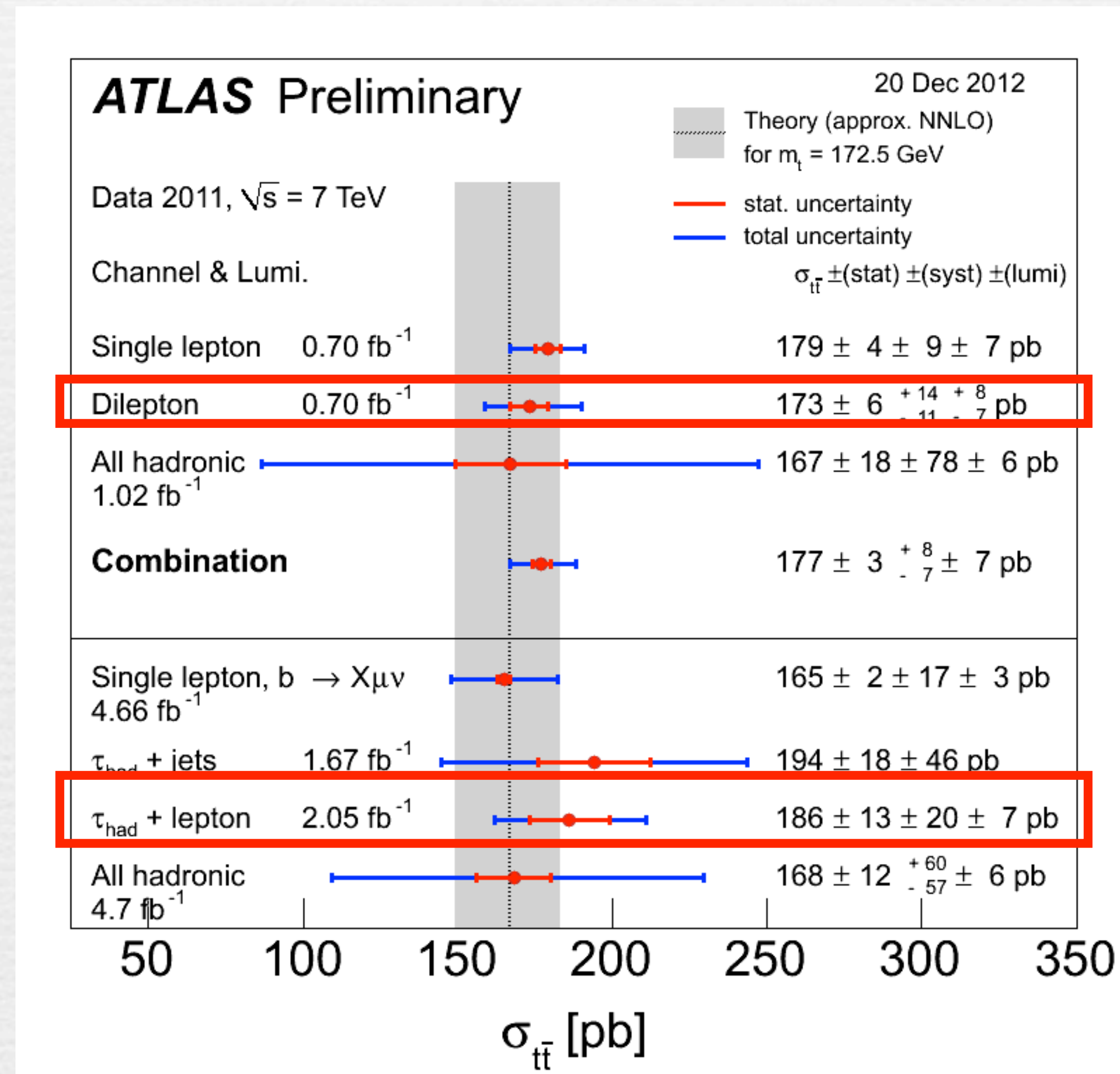




2. Physic analysis

Top quark physics

Higgs, new physics searches



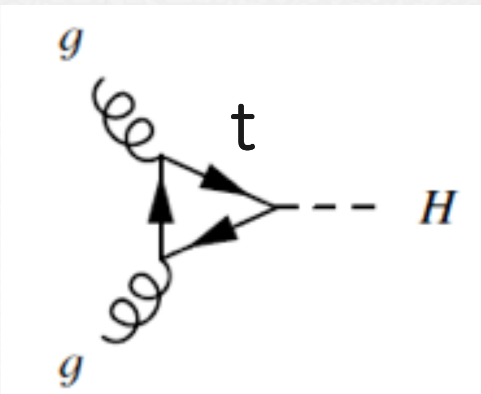
Trying to extend the research area to the Higgs and new physics through top quark productions and decays.

Higgs Physics

Higgs productions and decays

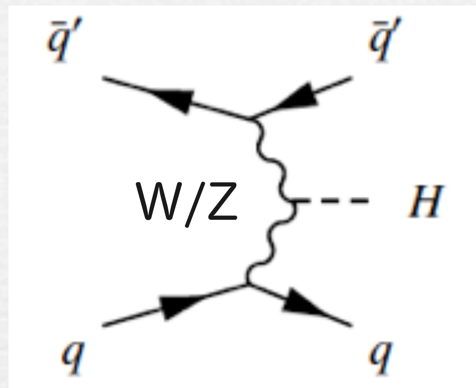
Productions

ggF



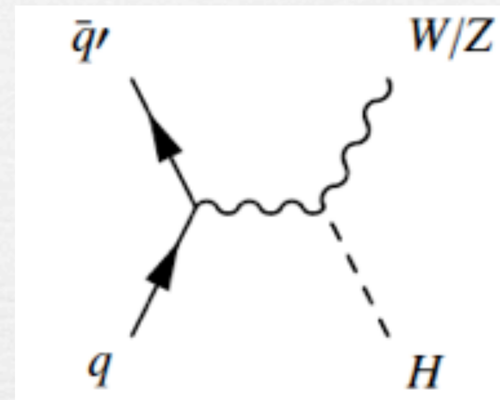
σ=19pb

VBF



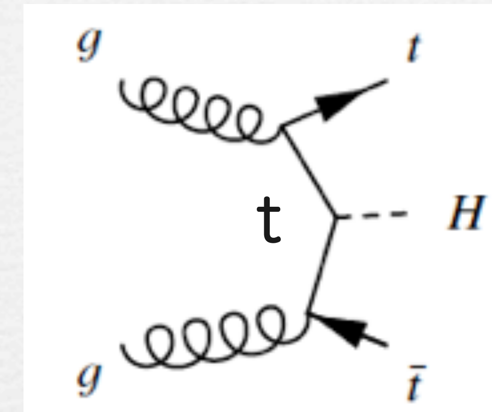
σ=1.6pb

VH(V=W or Z)



σ=0.7pb(W), 0.4pb(Z)

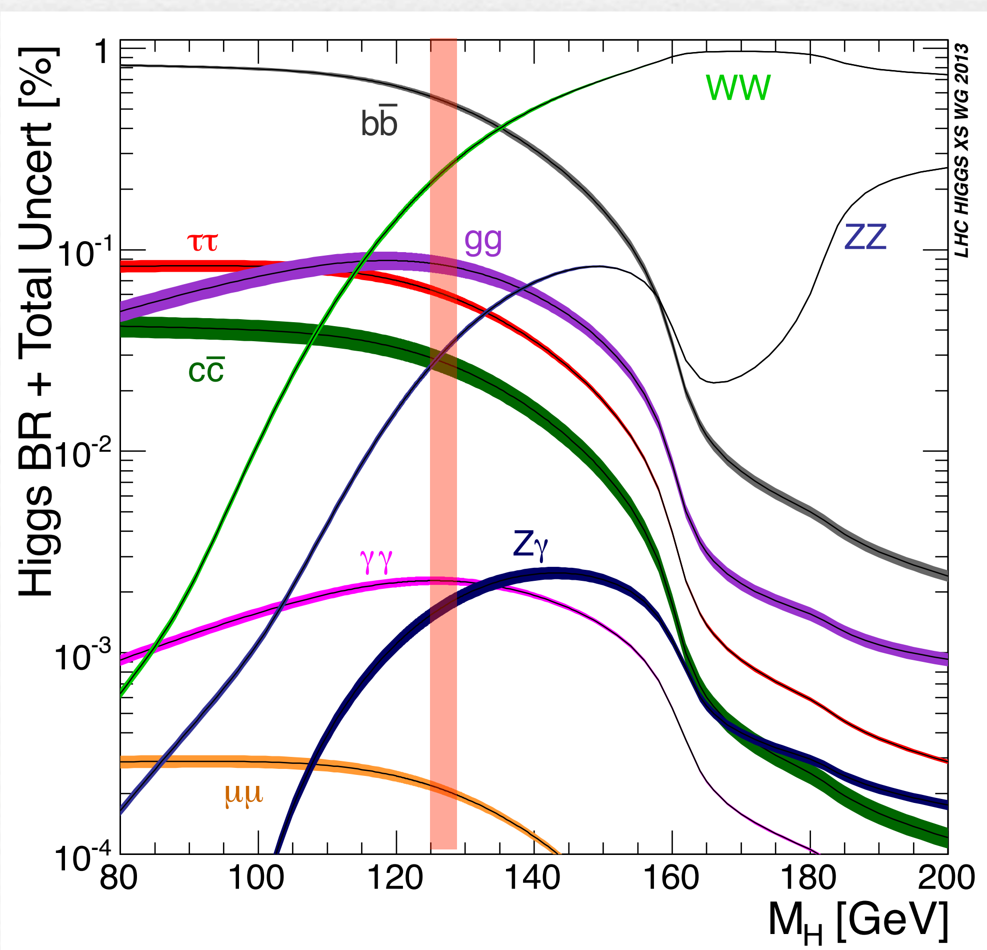
ttH



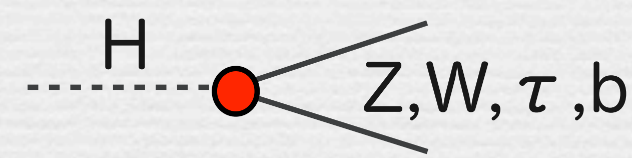
0.13pb

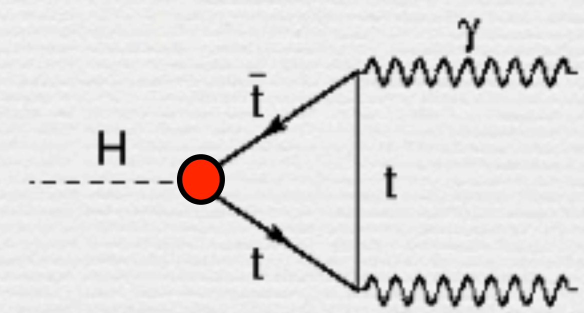
Decays

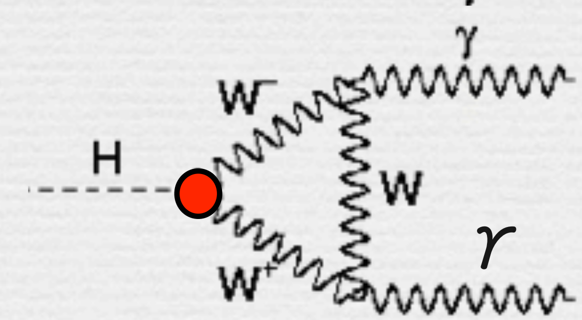
Mass of m_H~125.5GeV gives us maximally rich decay modes !!



m_H=125.5GeV	BR(%)
$H\to\gamma\gamma$	0.23
H→ZZ	2.8
H→WW	22
$H\to\tau\tau$	6.2
H→bb	57

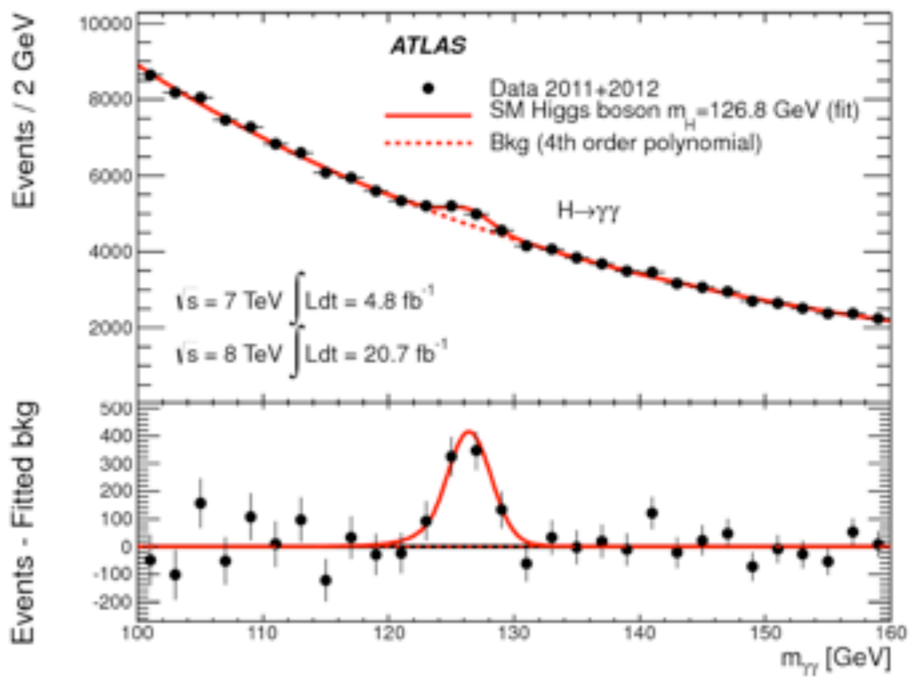


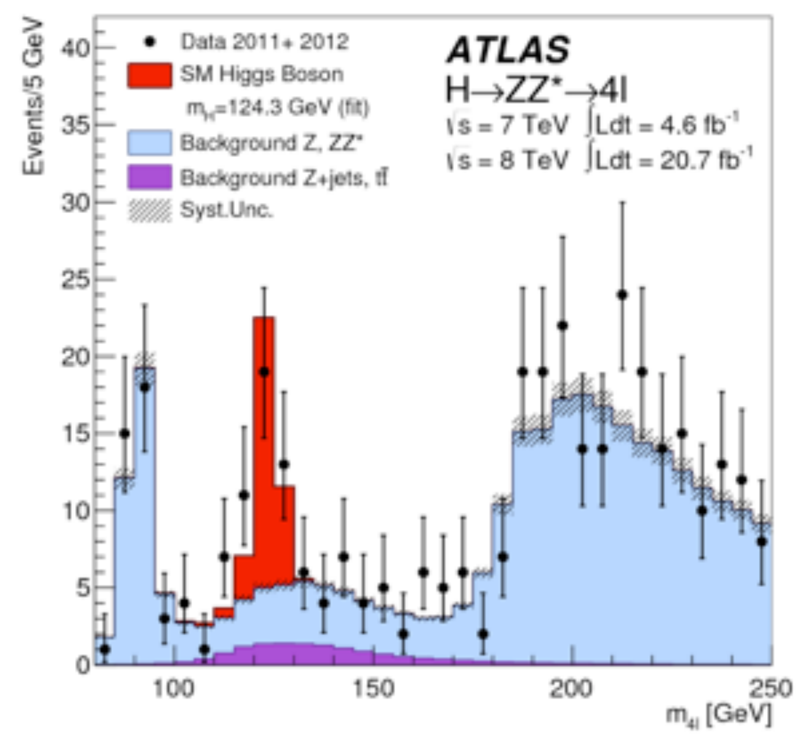


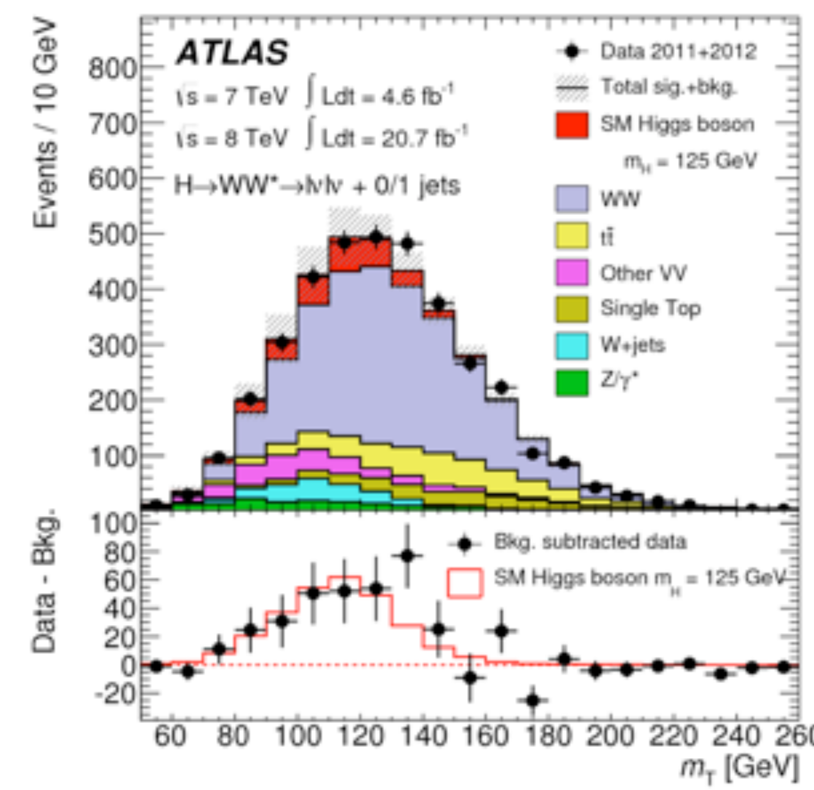


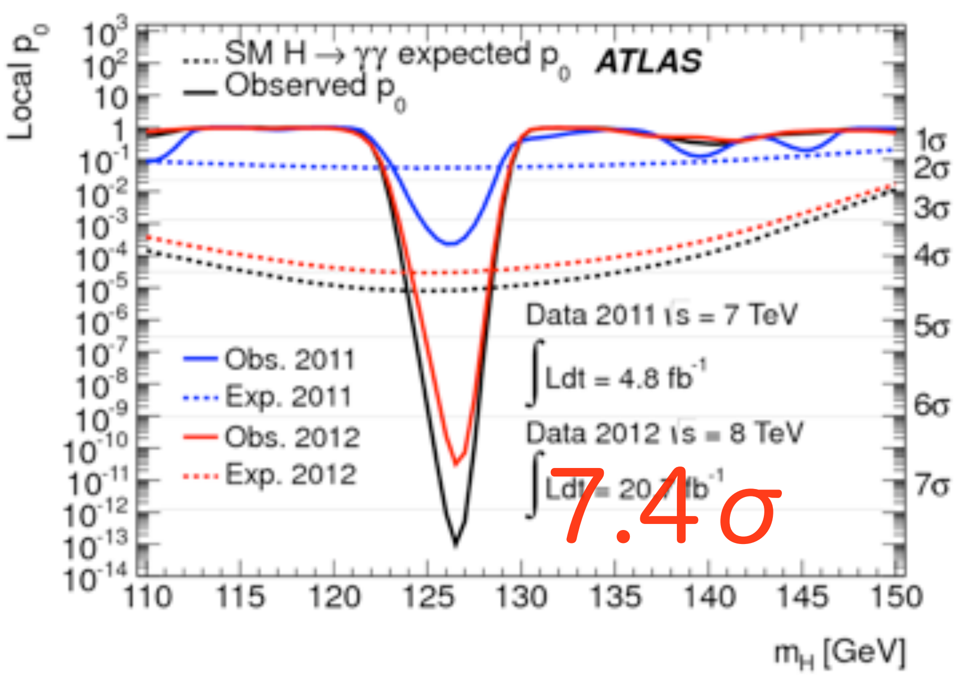
Yields in the discovery channels

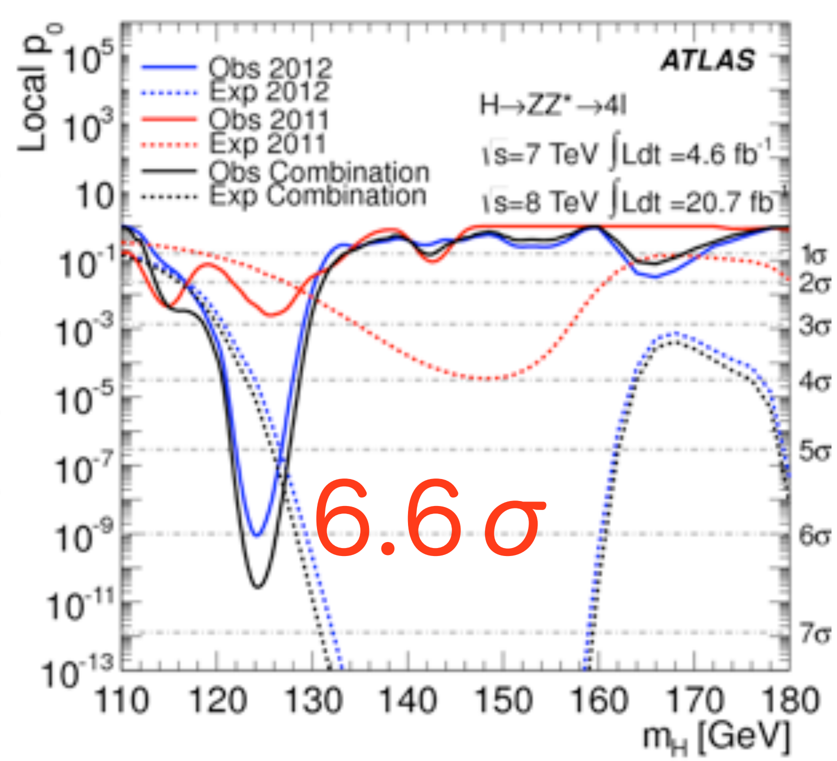
$H \to \gamma\gamma$ | $H \to ZZ$ | $H \to WW$

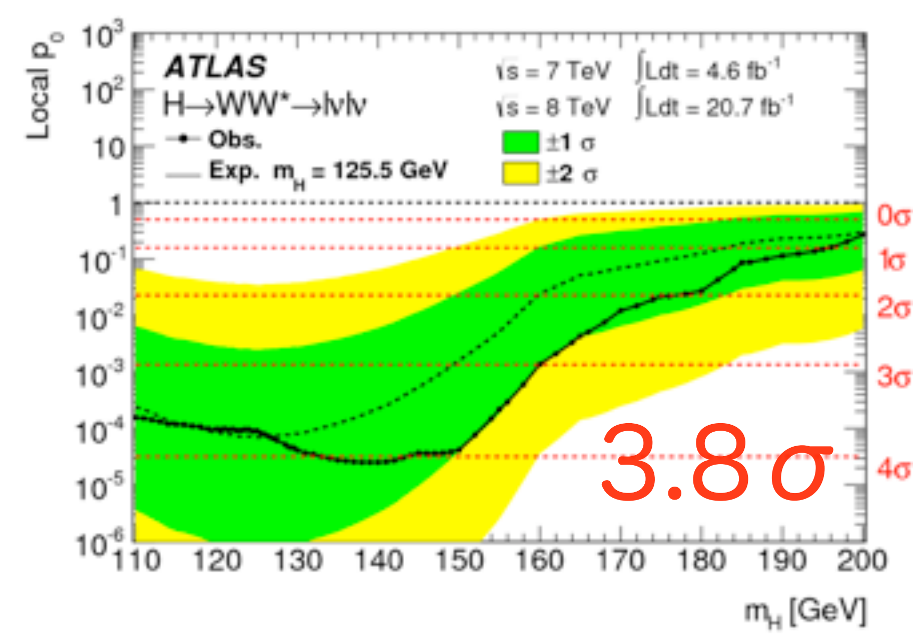












~450 signal events expected | ~15 signal events expected | ~180 signal events expected

Signal strength

arXiv:1307.1427

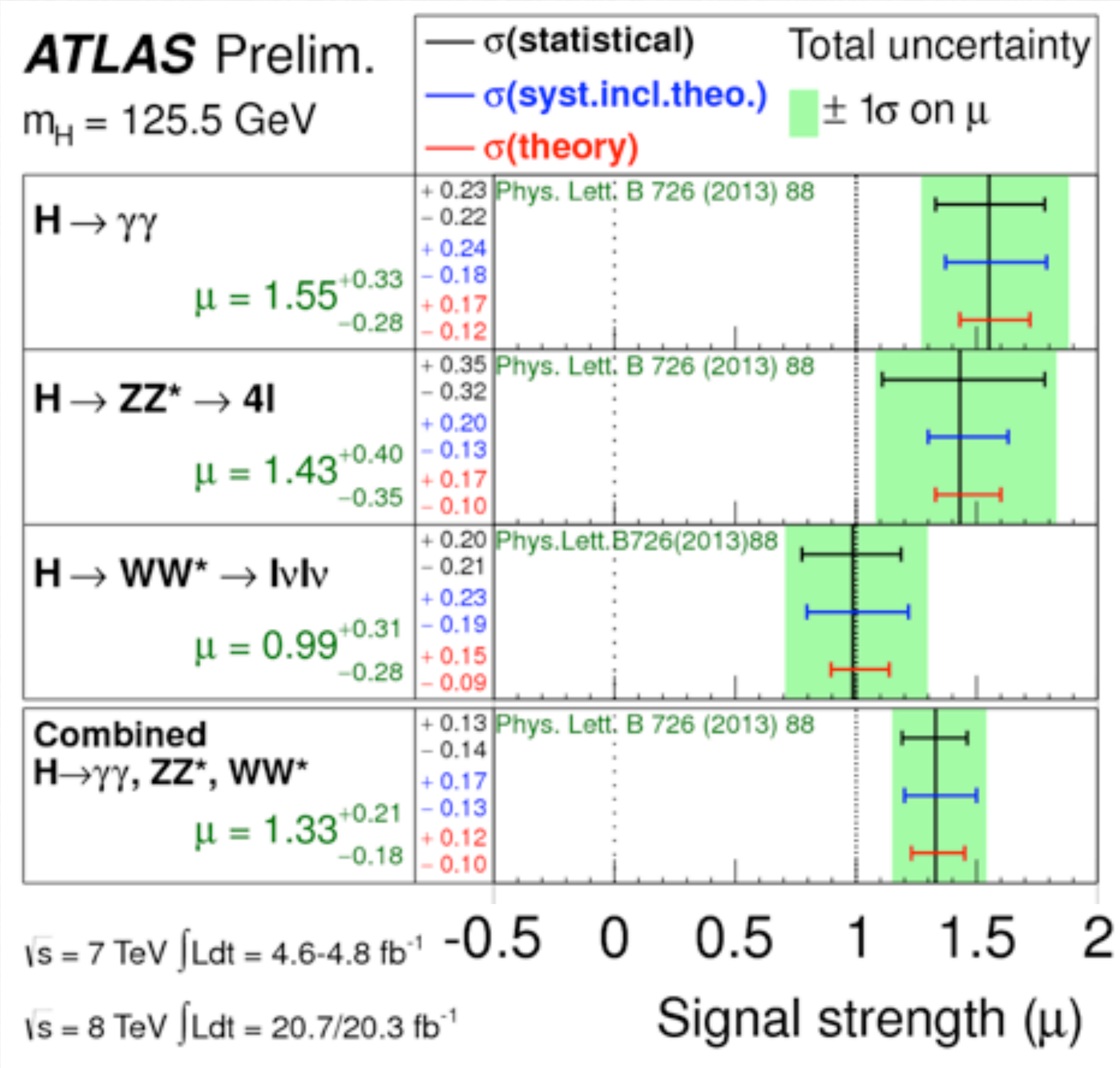
$$\mu = \frac{\sigma \times \mathrm{BR}}{(\sigma \times \mathrm{BR})_{\mathrm{SM}}}$$

μ=1 (if SM Higgs), μ=0 (if no SM Higgs)

combined ($H \to \gamma\gamma$, ZZ, WW)

$$\mu = 1.33 \pm 0.14(\mathrm{stat}) \pm 0.15(\mathrm{sys})$$

(m_H=125.5GeV)



Result is consistent with the SM prediction with 15% precision.

Statistical, systematic and theory (QCD scale, PDF) uncertainties are already comparable.

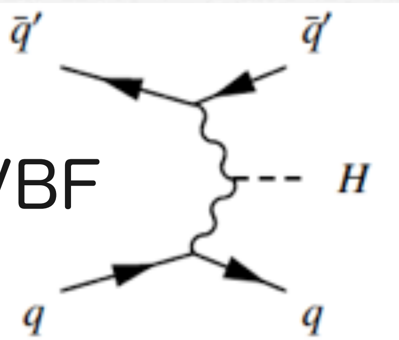
Evidence for production via VBF

arXiv:1307.1427

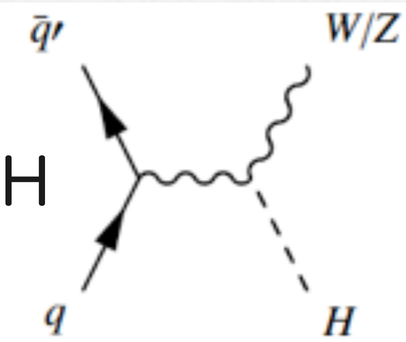
Signal strength is categorized by

vector-boson-mediated processes and gluon-mediated processes

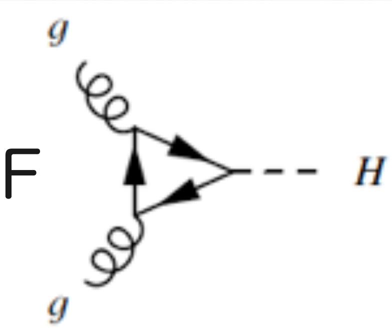
VBF



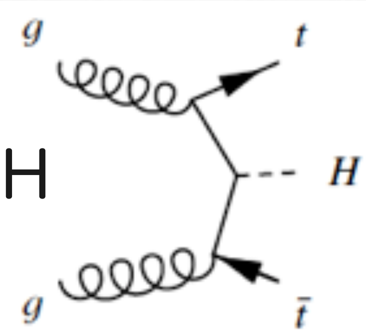
VH

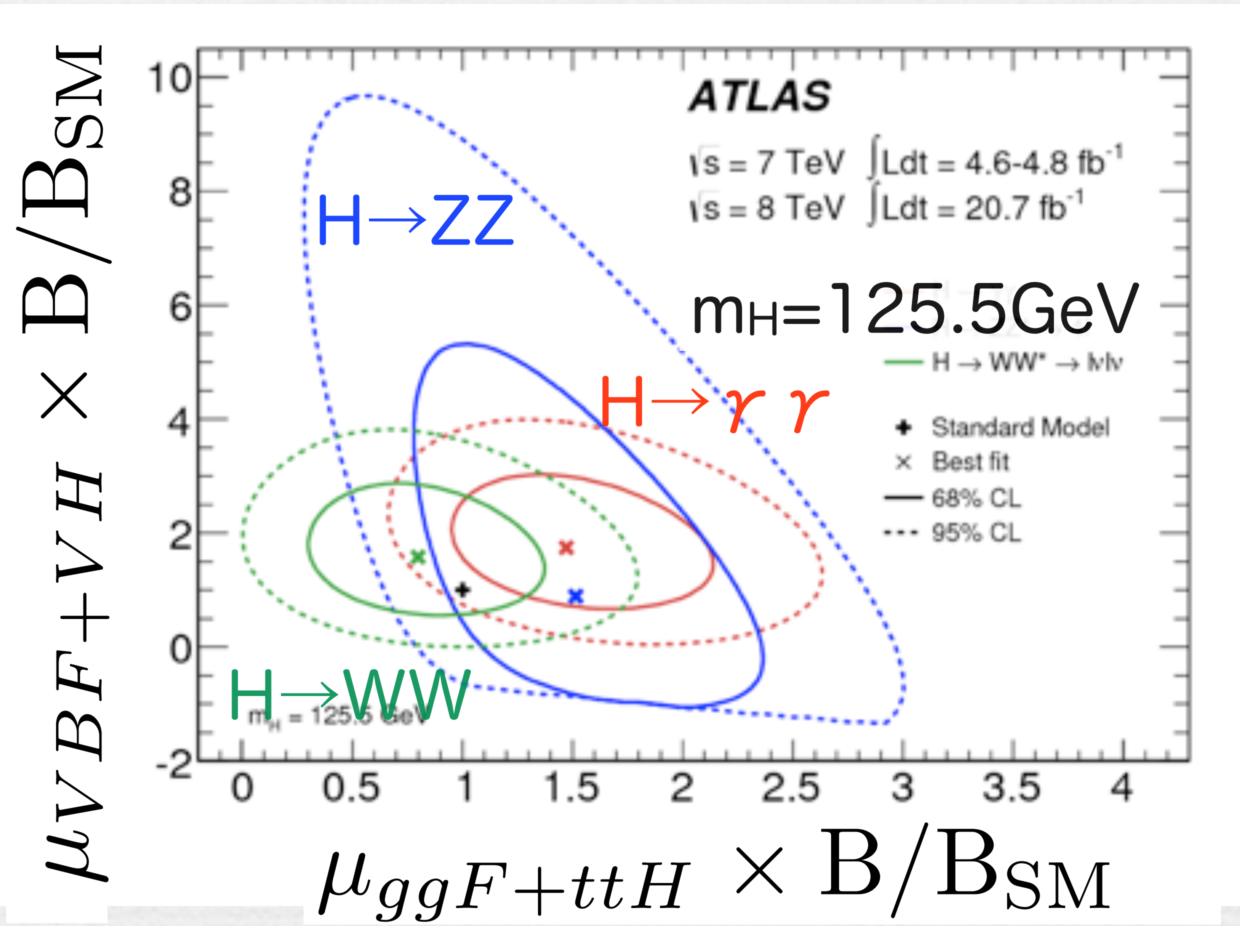


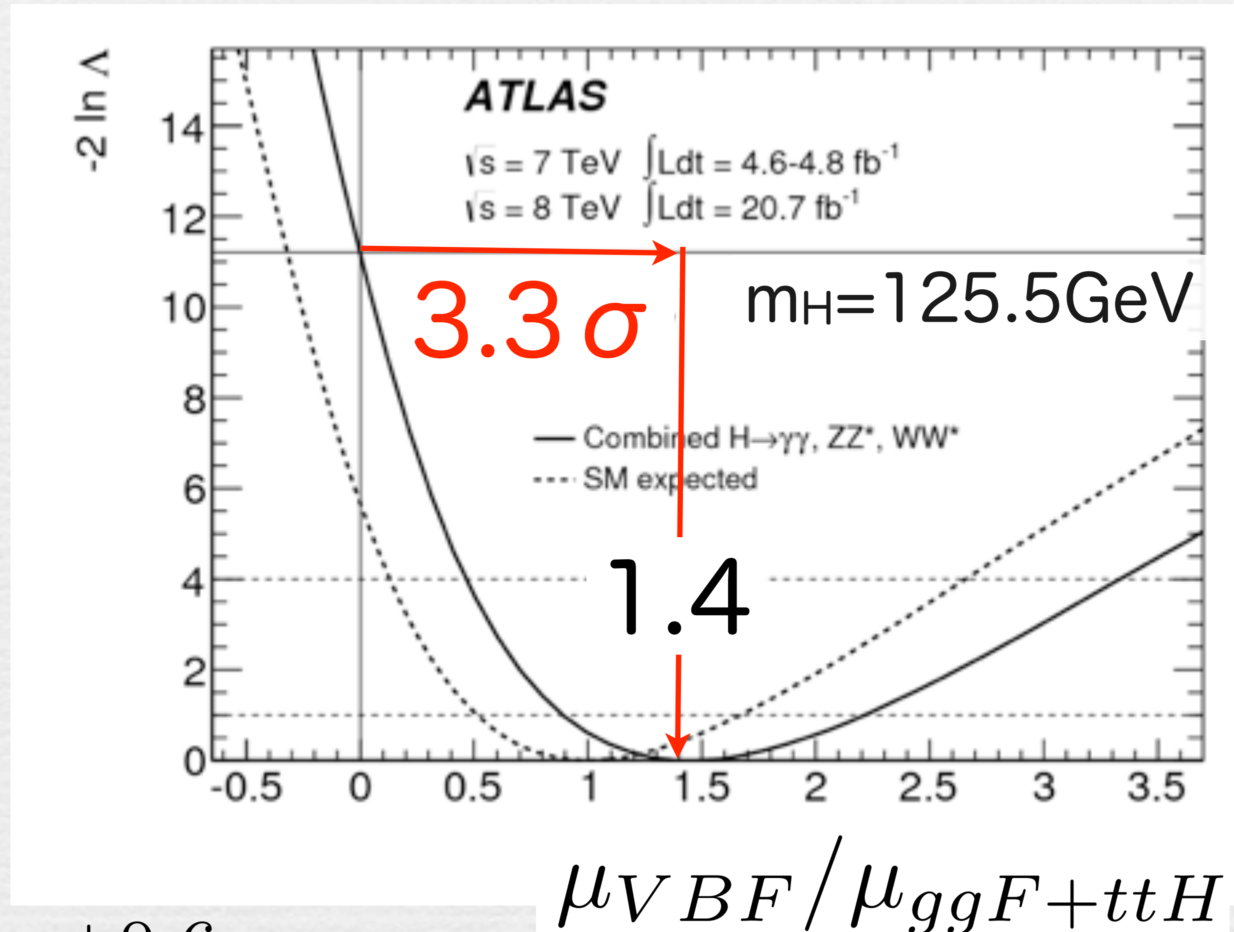
ggF



ttH







$$\mu_{VBF}/\mu_{ggF+ttH} = 1.4^{+0.4}_{-0.3}(\mathrm{stat})^{+0.6}_{-0.4}(\mathrm{sys})$$

3.3σ evidence that a fraction of Higgs boson production occurs through VBF

Coupling measurements

In the standard model,

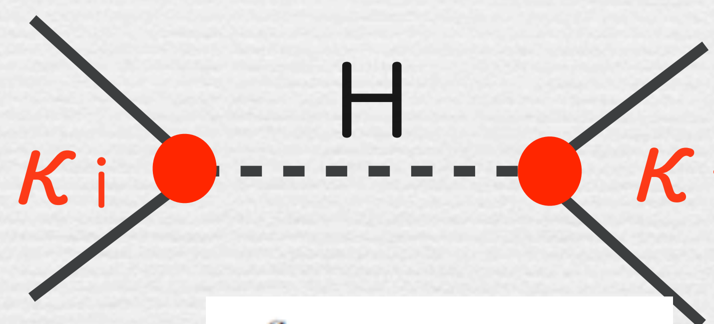
coupling to fermion $g_F^{\mathrm{SM}} = \sqrt{2}\dfrac{m_F}{v}$ coupling to gauge boson $g_V^{\mathrm{SM}} = 2\dfrac{m_V^2}{v}$

SM couplings are tested introducing coupling scale factors κ : $g_i = g_i^{\mathrm{SM}} \times \kappa_i$

The total Higgs boson width is also tested introducing κ_{H}^2 : $\Gamma_H = \Gamma_H^{\mathrm{SM}} \times \kappa_H^2$

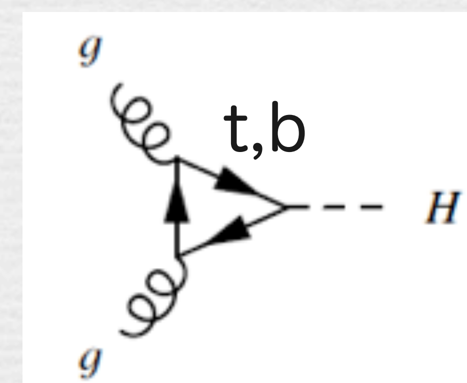
$$\sigma \cdot B(i \to H \to f) = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_H}$$

→ signal strength can be written by κs



For example, gg→H→$\gamma\gamma$ process can be written as

$$\frac{\sigma \cdot \mathrm{B}(\mathrm{gg} \to \mathrm{H} \to \gamma\gamma)}{\sigma_{\mathrm{SM}}(gg \to H) \cdot \mathrm{B}_{\mathrm{SM}}(\mathrm{H} \to \gamma\gamma)} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

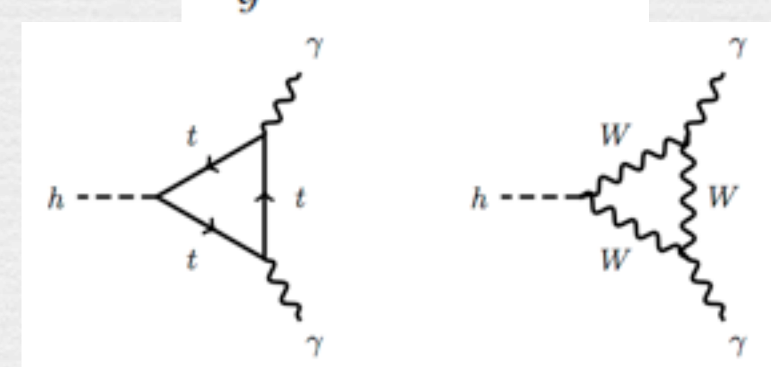


κ_{H} and effective scale factors κ_γ, κ_{g} (loop induced processes)

- Expressed as a function of the SM coupling scale factors

  $\kappa_\gamma(\kappa_W, \kappa_t)$ $\kappa_g(\kappa_b, \kappa_t)$ $\kappa_H(\kappa_b, \kappa_W, \kappa_Z, \ldots)$

- Treated as free parameters to test BSM contributions

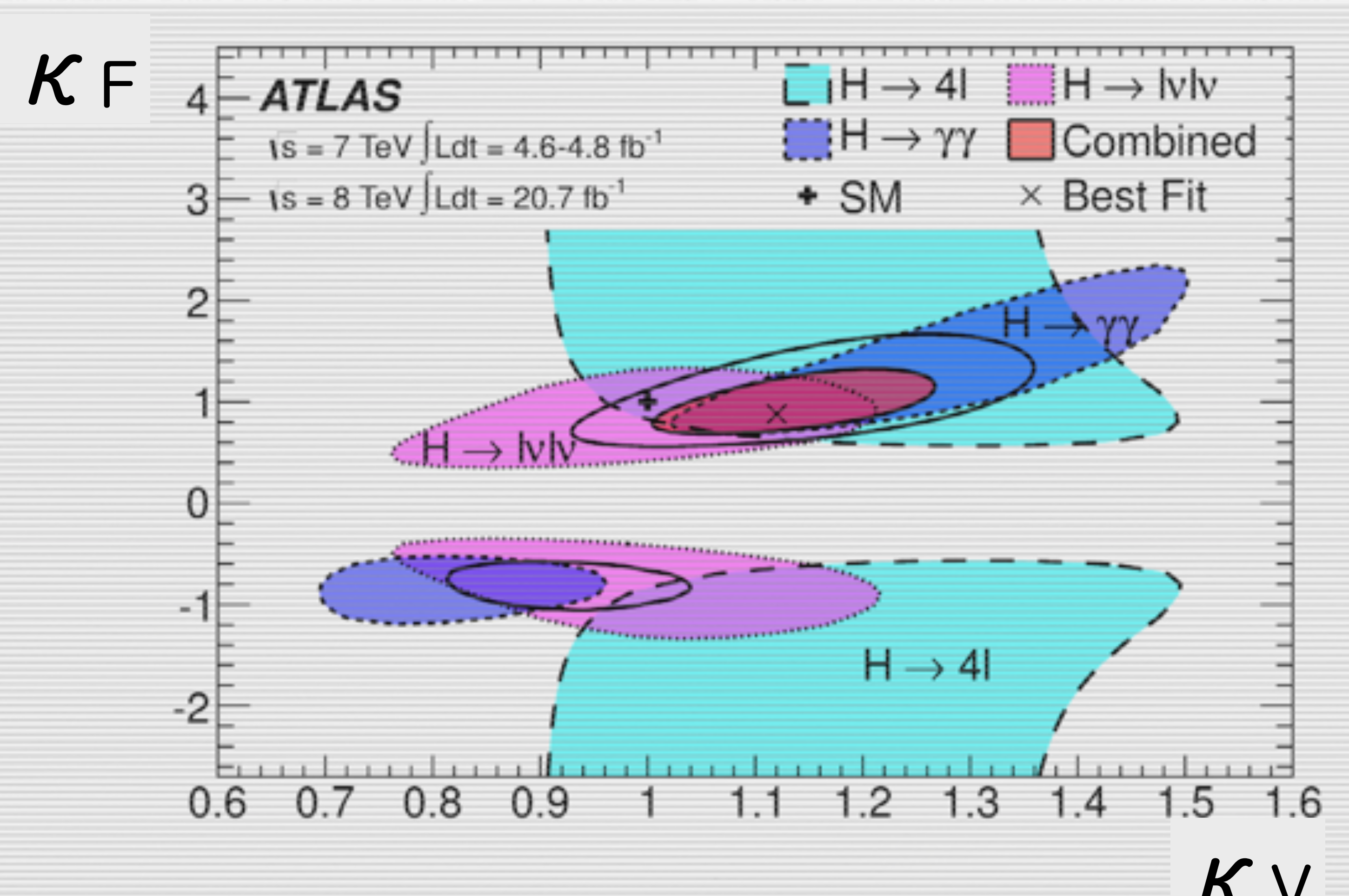


Couplings to fermions and bosons

arXiv:1307.1427

In this analysis, we assume

- One coupling scale factor for fermions .... $\kappa_F = \kappa_t = \kappa_b = \kappa_\tau = \ldots.$
- One coupling scale factor for bosons .... $\kappa_V = \kappa_W = \kappa_Z$
- κ_g, κ_γ, and κ_H depends only on κ_F and κ_V → No contributions from BSM



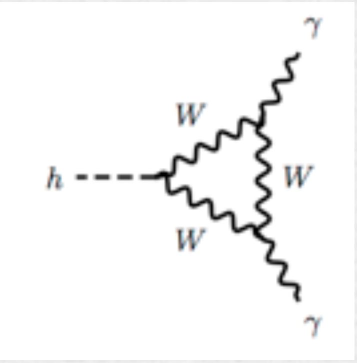
$$\kappa_F \in [0.76, 1.18]$$

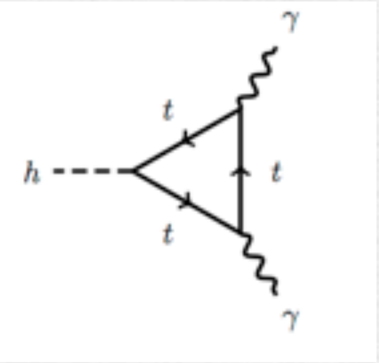
$$\kappa_V \in [1.05, 1.22]$$

at 68% C.L.

compatibility of the SM is 12%

$$\kappa_\gamma^2 \simeq |1.26\kappa_V - 0.26\kappa_F|^2$$





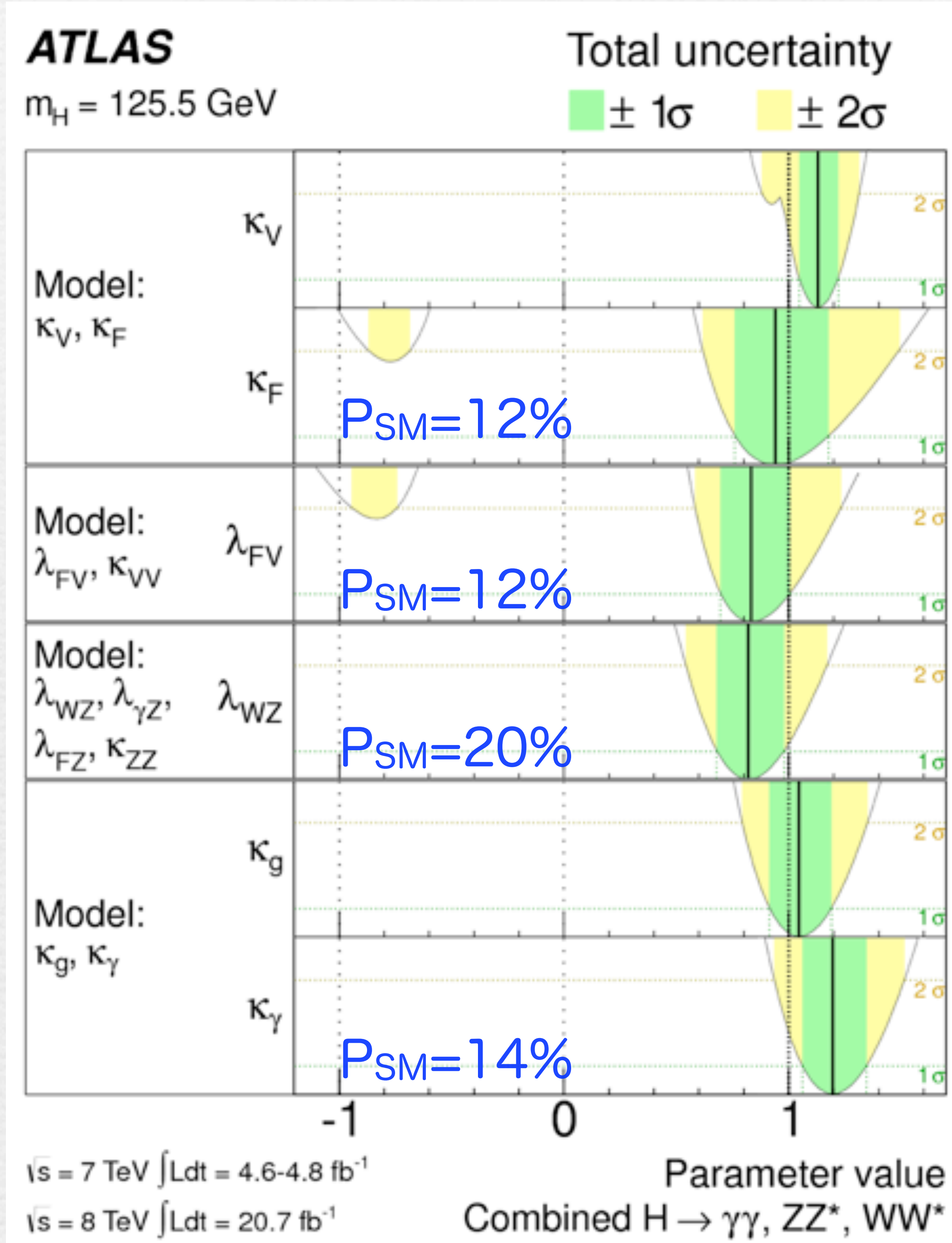
H→$\gamma\gamma$ prefers the minimum with positive relative sign

- Thanks to the negative interference between W-boson loop and t-quark loop

κ_F=0 is excluded at >5σ → Indirect evidence of the Higgs-fermion coupling!!

Summary of the Higgs couplings

arXiv:1307.1427



$=\kappa_V$

$=\kappa_F$

$=\kappa_F/\kappa_V$

$=\kappa_W/\kappa_Z$

$=\kappa_g$

$=\kappa_\gamma$

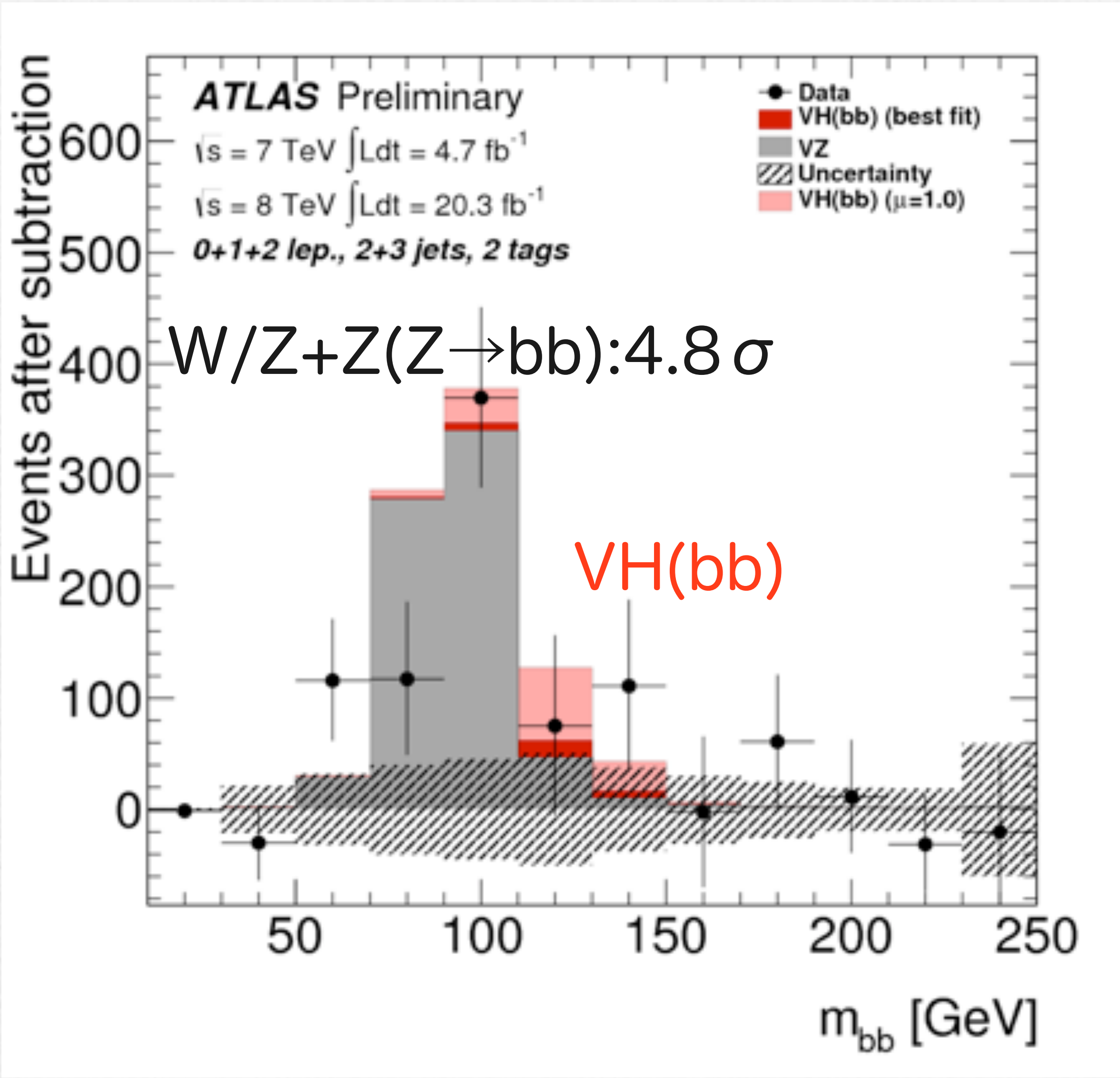
Measurements are compatible with SM Higgs expectations (=1)

Their compatibilities are 12%~20%

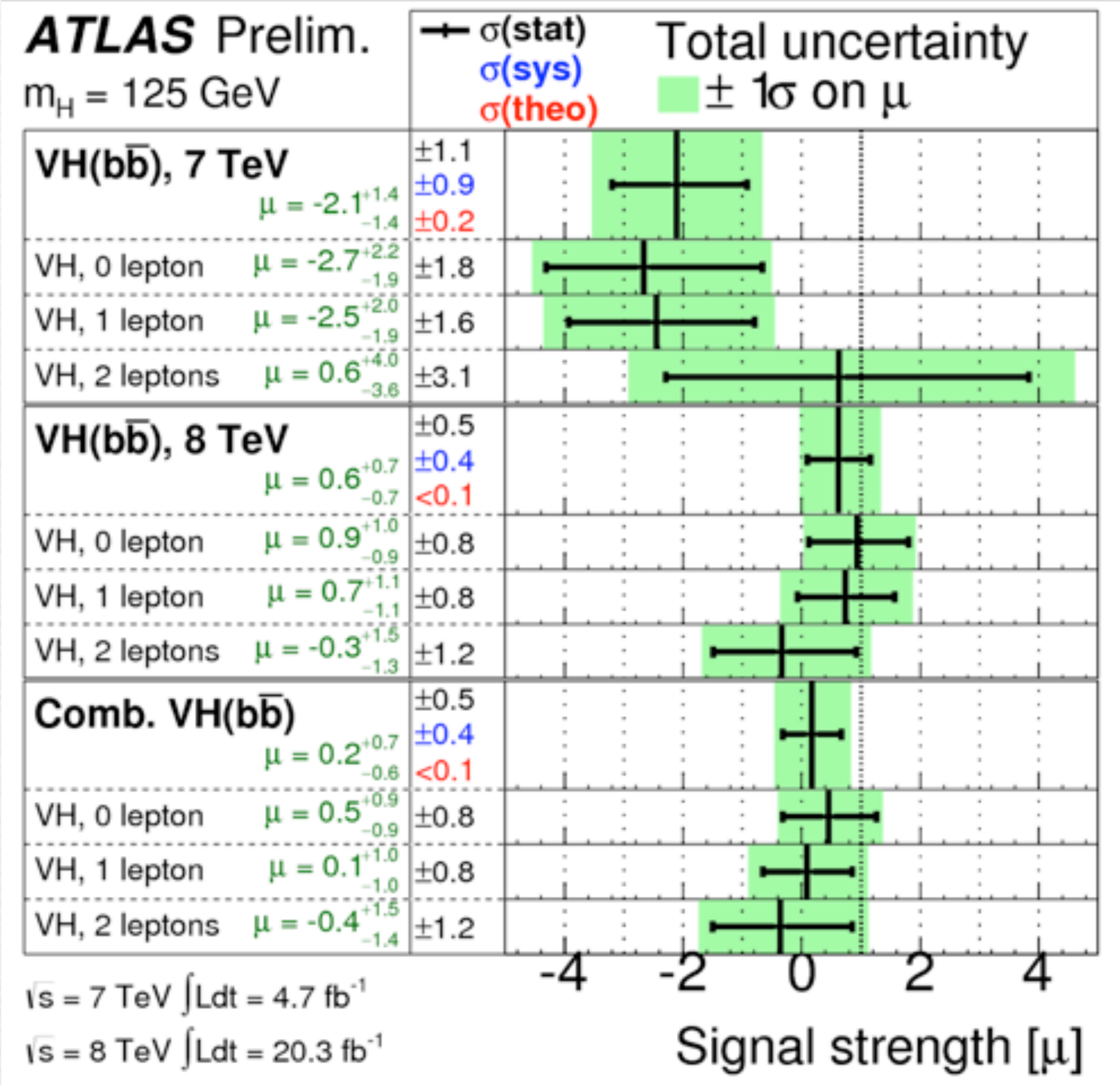
H→bb direct measurement

ATLAS-CONF-2013-079

W/Z+H (H→bb) : 2, 1, 0(large E_T^{miss})-lepton + 2 b-jets



Best fit $\mu = 0.2^{+0.7}_{-0.6}$



We need more data to obtain evidence of H→bb

H→$\tau\tau$ direct measurement

ATLAS-CONF-2013-108

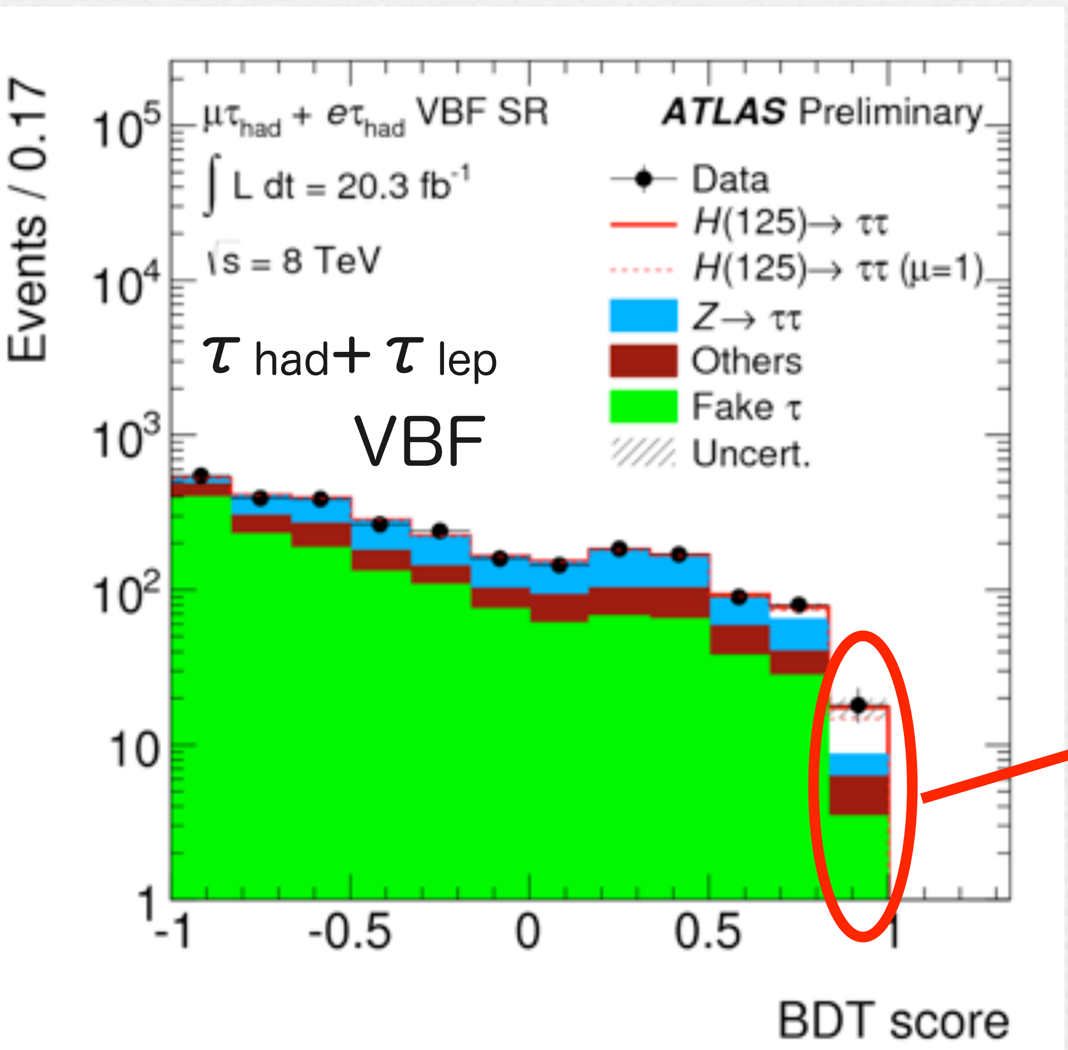
Both hadronic and leptonic τ decays(τ_{had}, τ_{lep}) are used

Events are categorized by "VBF" and "Boosted"

$\tau\tau$+di-jets with large η $\tau\tau$ with large $p_T^{\tau\tau}$

Signals are extracted from the fit of the BDT score dist.

BDT(boosted decision tree) : multivariate analysis based on E_T^{miss}, $m_{\tau\tau}$,,



bkg-like ⟷ signal-like

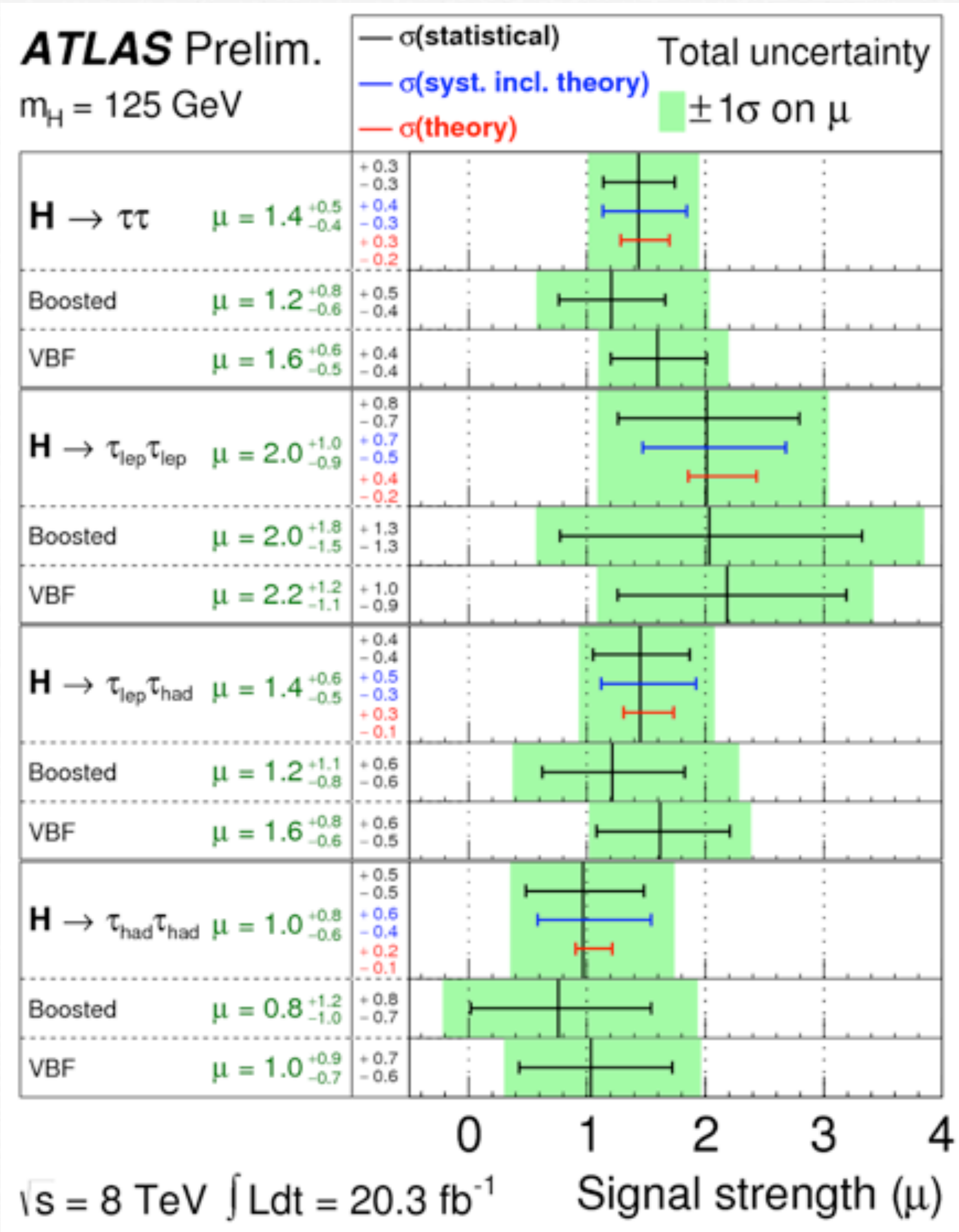
Number of events in highest BDT score bin

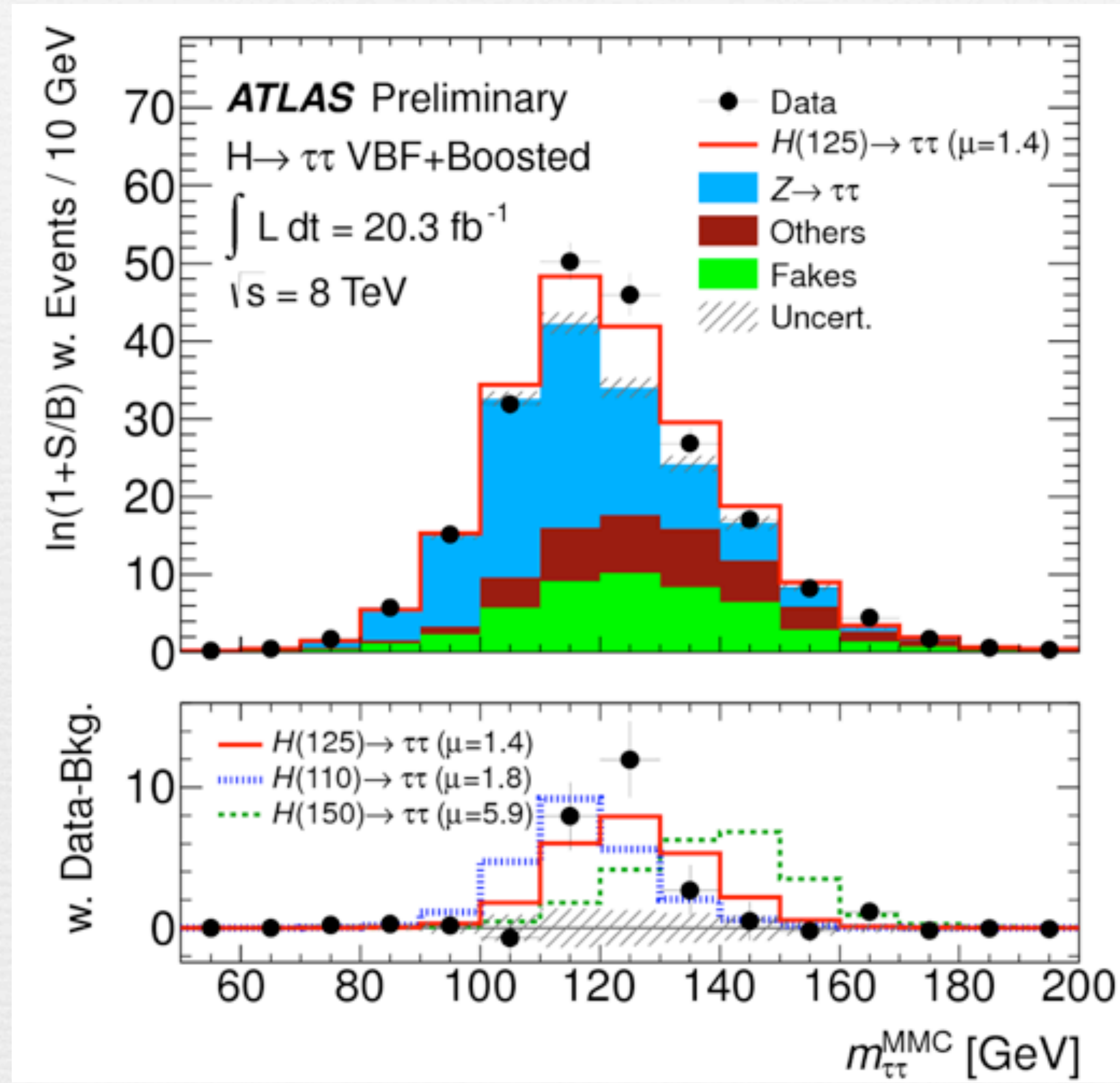
VBF	Lep-lep	Lep-had	Had-had
Signal	5.7±1.7	8.7±2.5	8.8±2.2
Bckg	13.5±2.4	8.7±2.4	11.8±2.6
Data	19	18	19

Boosted	Lep-lep	Lep-had	Had-had
Signal	2.6±1.7	8.0±2.5	3.6±1.1
Bckg	20.2±1.8	32±4	11.2±1.9
Data	20	34	15

H→τ τ direct measurement

ATLAS-CONF-2013-108





combined $\mu = 1.4^{+0.5}_{-0.4}$

Observed significance corresponds to 4.1 σ

Expected significance corresponds to 3.2 σ

Spin-parity measurements

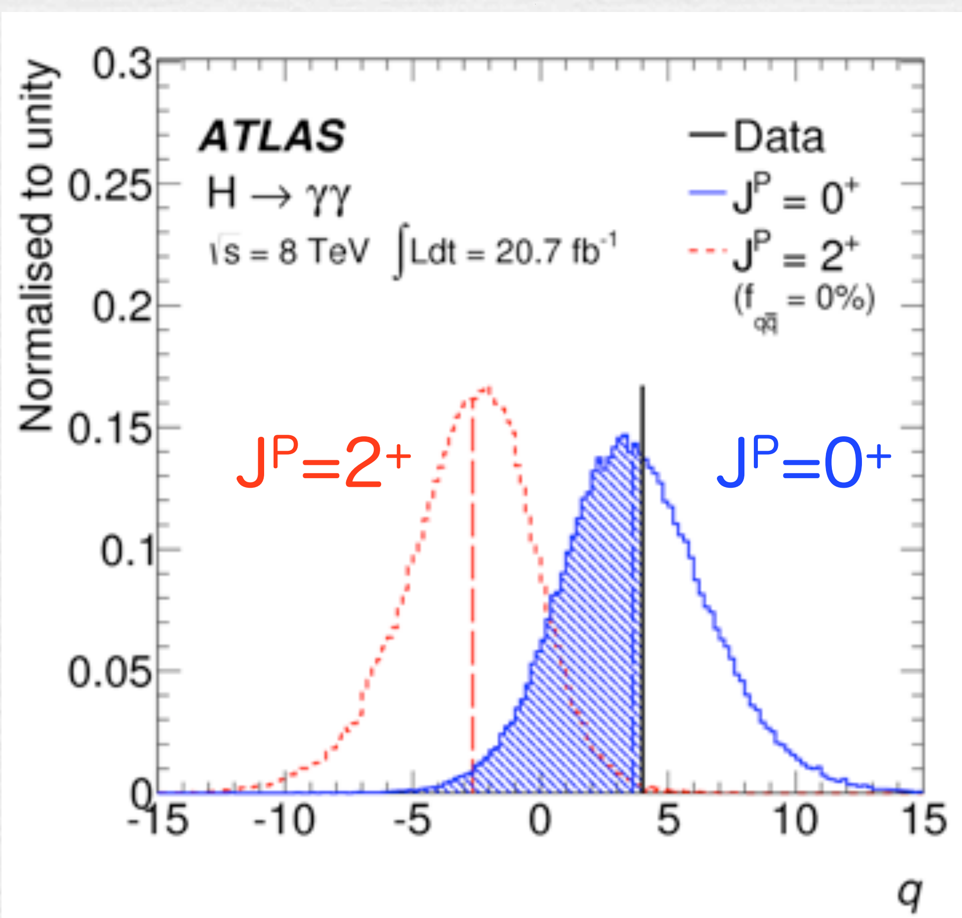
arXiv:1307.1432

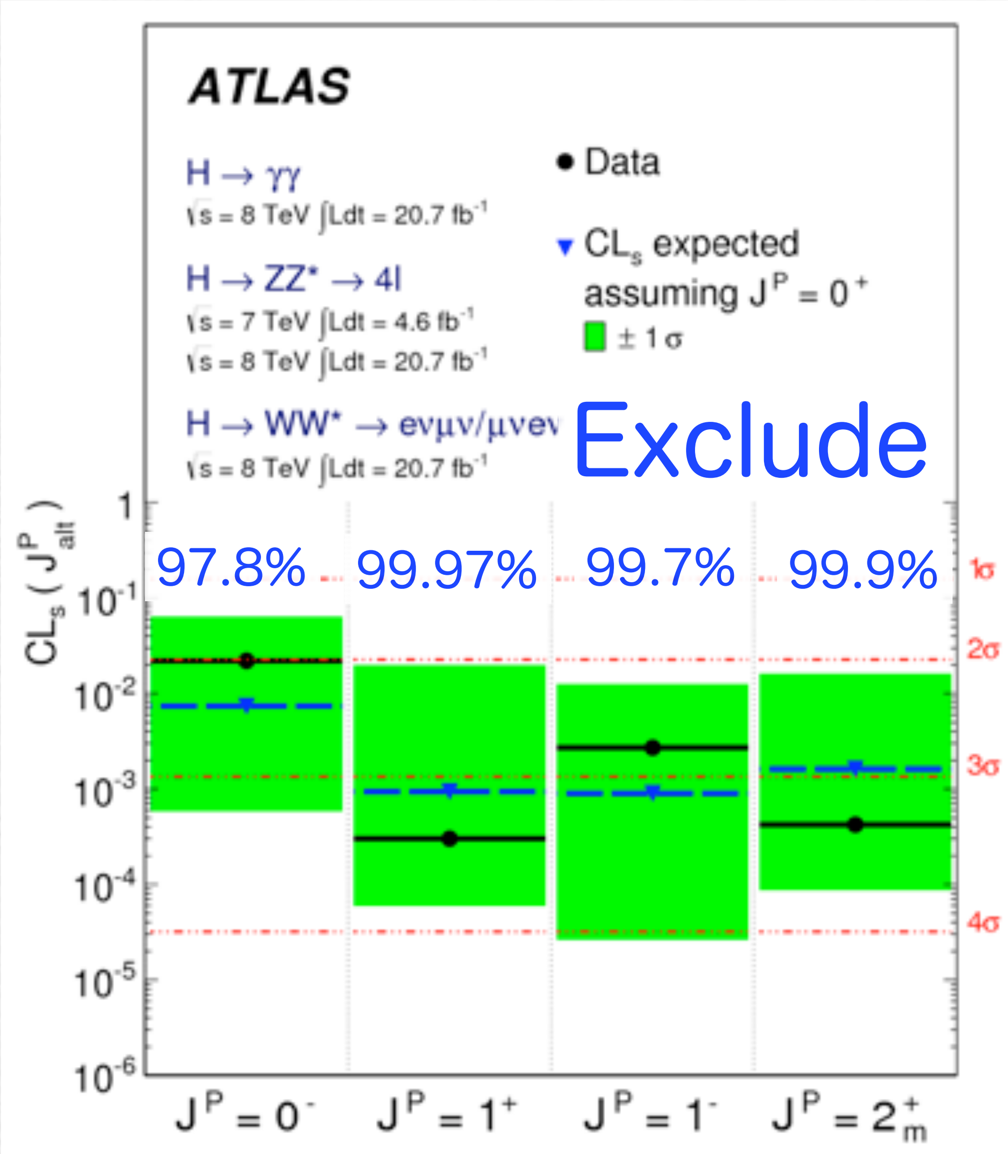
Spin-Parity $J^P=0^-,1^+,1^-, 2^+$ are tested against SM ($J^P=0^+$)

Existence of $H\rightarrow\gamma\gamma$ rules out J=1 (Landau-Yang theorem)

Kinematics and angular distributions of the decay products sensitive to spin-parity measurement

Log likelihood ratio $q = \log \frac{L(J^P=0^+)}{L(J^P=2^+)}$





2^+ are excluded at 99.9% CL

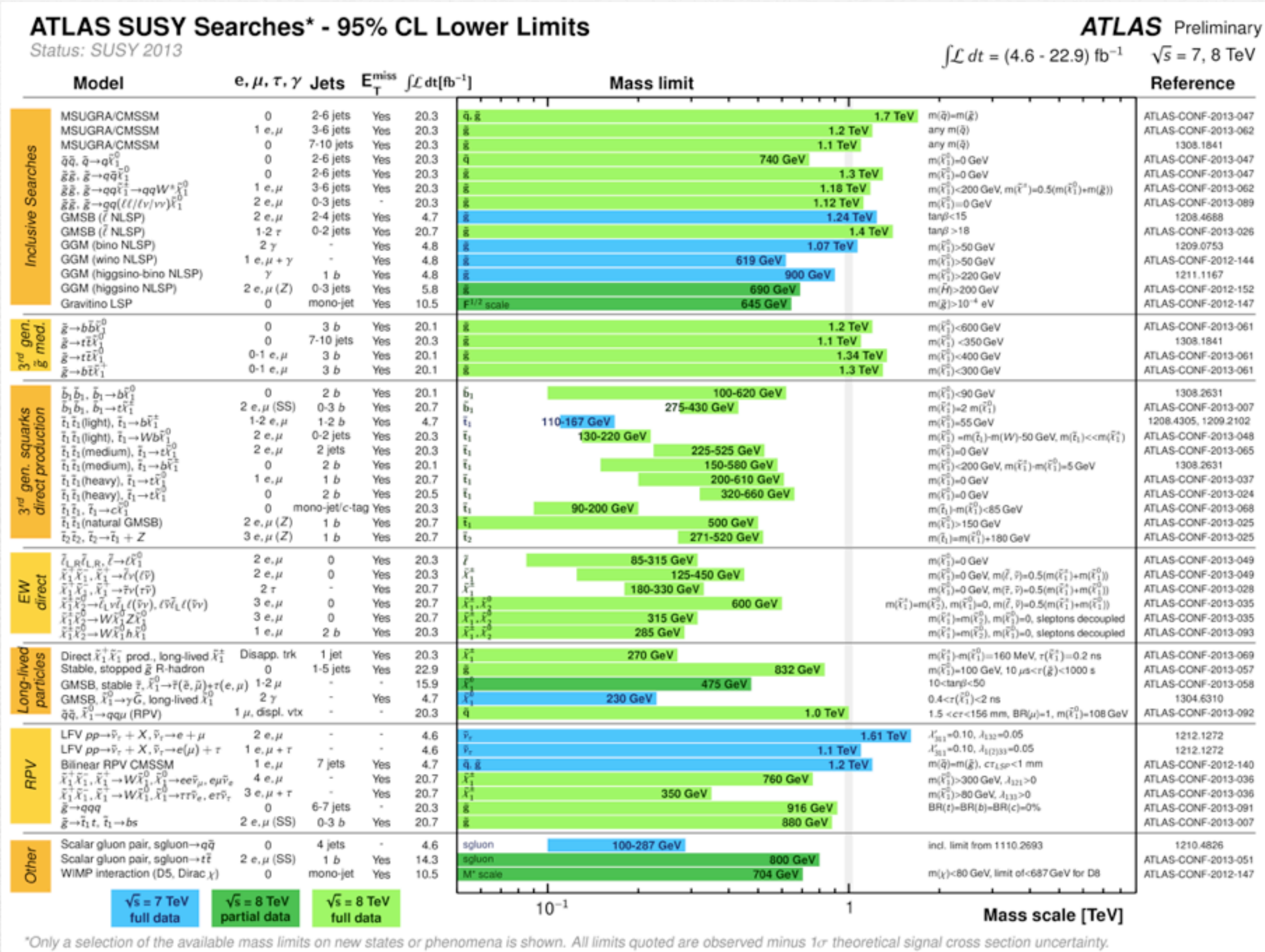
$J^P=0^-,1^+,1^-$ and 2^+ are excluded at > 97.8% CL

New physics searches

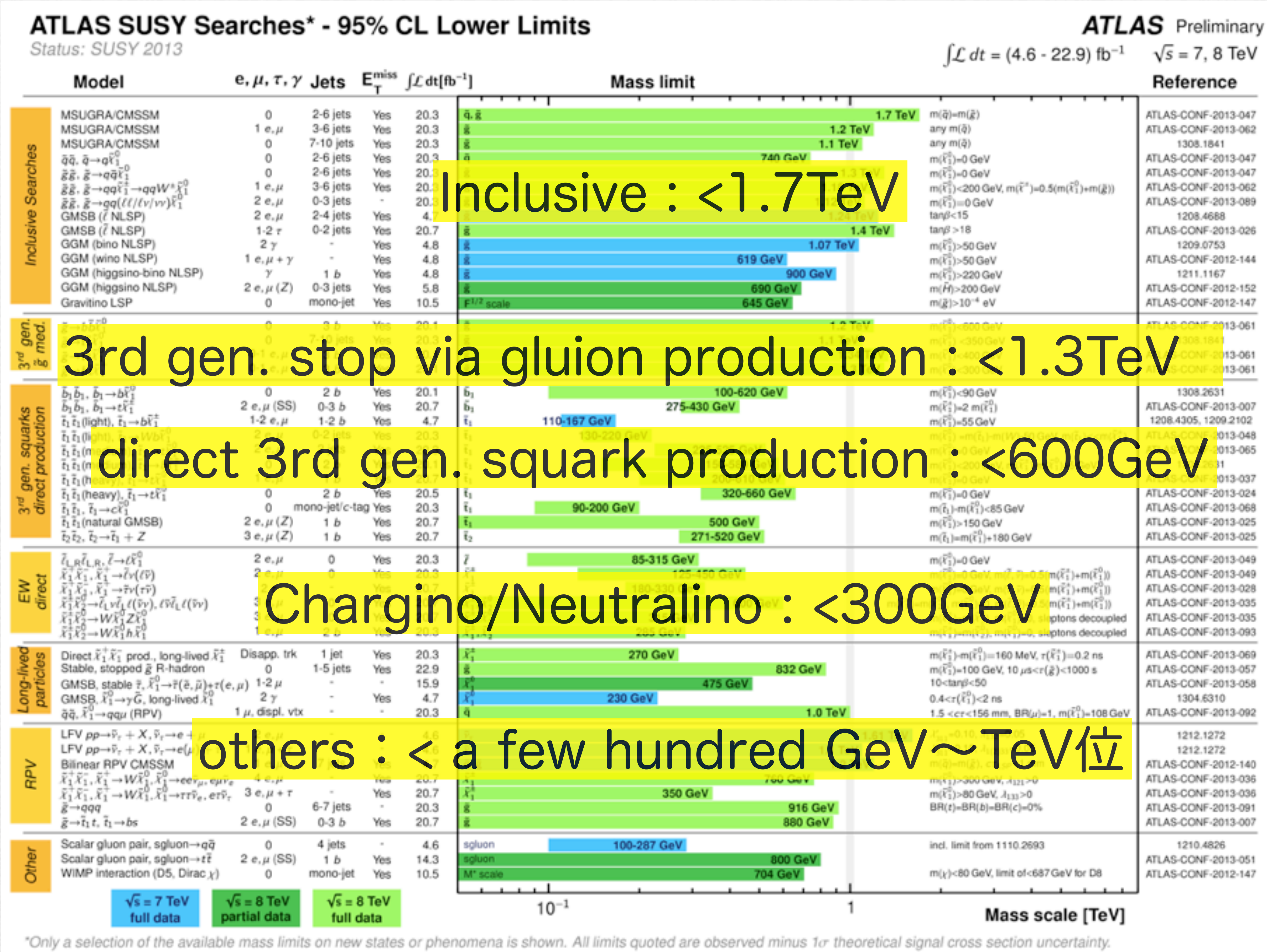
New physics has not been observed yet

We start excluding the large area of the parameter space of the new physics (ex. SUSY)

SUSY exclusion



SUSY exclusion



Inclusive : <1.7TeV

3rd gen. stop via gluion production : <1.3TeV

direct 3rd gen. squark production : <600GeV

Chargino/Neutralino : <300GeV

others : < a few hundred GeV～TeV位

Prospects of LHC upgrades

2013	2015	2018	2020	2022	
Run-1	shutdown1	Run-2	shutdown2	Run-3	shutdown3	Hi-L LHC

$$\sqrt{s} = 13 - 14\mathrm{TeV}$$
$$\mathcal{L} = 1 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$$
$$\int \mathcal{L}dt = 100\mathrm{fb}^{-1}$$

$$\sqrt{s} = 14\mathrm{TeV}$$
$$\mathcal{L} = 2 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$$
$$\int \mathcal{L}dt = 300\mathrm{fb}^{-1}$$

$$\sqrt{s} = 14\mathrm{TeV}$$
$$\mathcal{L} = 5 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$$
$$\int \mathcal{L}dt = 3000\mathrm{fb}^{-1}$$

The 14TeV run (Run 2) will start 2015.
Two other shutdowns after Run-2 are scheduled

Luminosity improvements will be achieved

To discover new physics beyond the SM

To measure the Higgs property precisely

Conclusion

LHC-Run I ends with great success.

- SM physics has been precisely measured and understood.
- A Higgs-like resonance at 125.5GeV has been discovered.
  - → All measured properties are compatible with SM Higgs boson, so far
- The large area of the new physics parameter space has been excluded.

Nagoya-ATLAS group contributes greatly to :

- detector installation/commissioning/operation
- physics analysis (in particular top quark physics)

Enlarge <u>our group activity</u>, towards 14 TeV LHC-Run !!

End

LHC-ATLAS Run I performance

LHC has performed very well

- Peak luminosity : 7.7 x 10^{33} cm^{-2} s^{-1}
- Delivered luminosity to ATLAS ~29 fb^{-1}

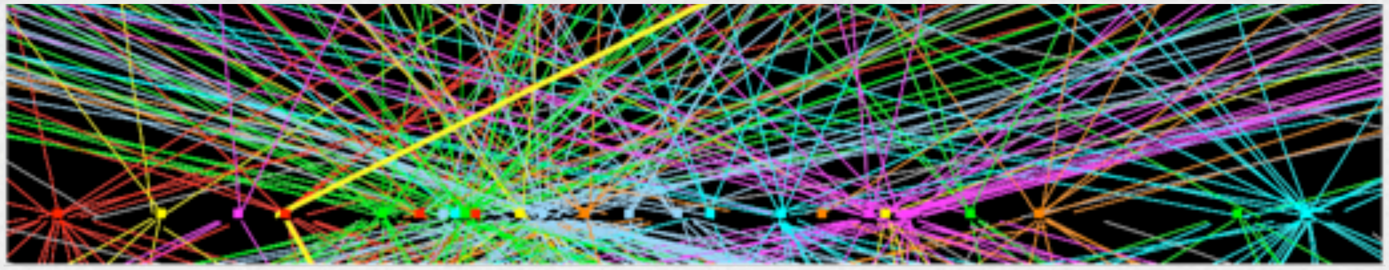
ATLAS collects good quality of data 95% of the time

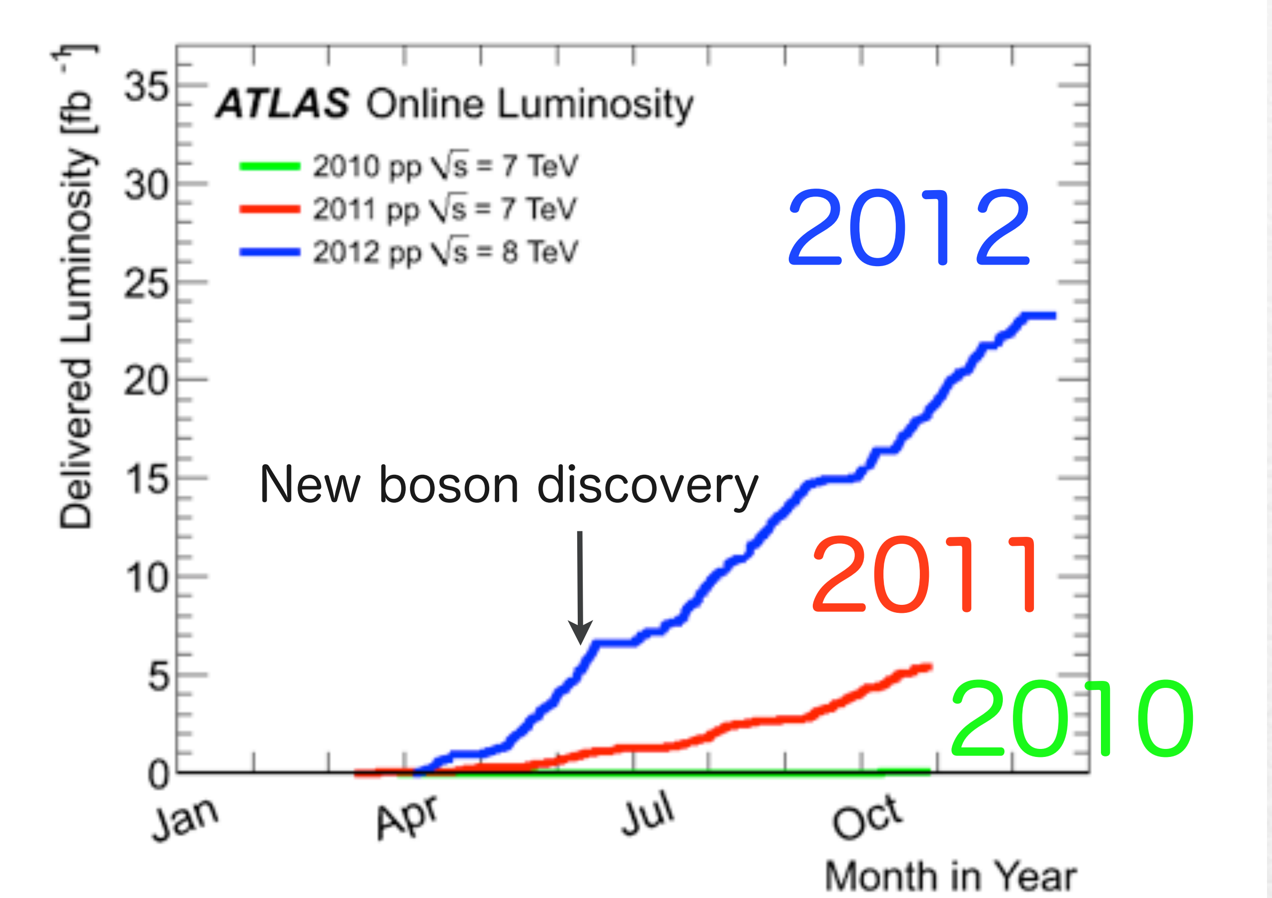
For physics analysis presented here, we use

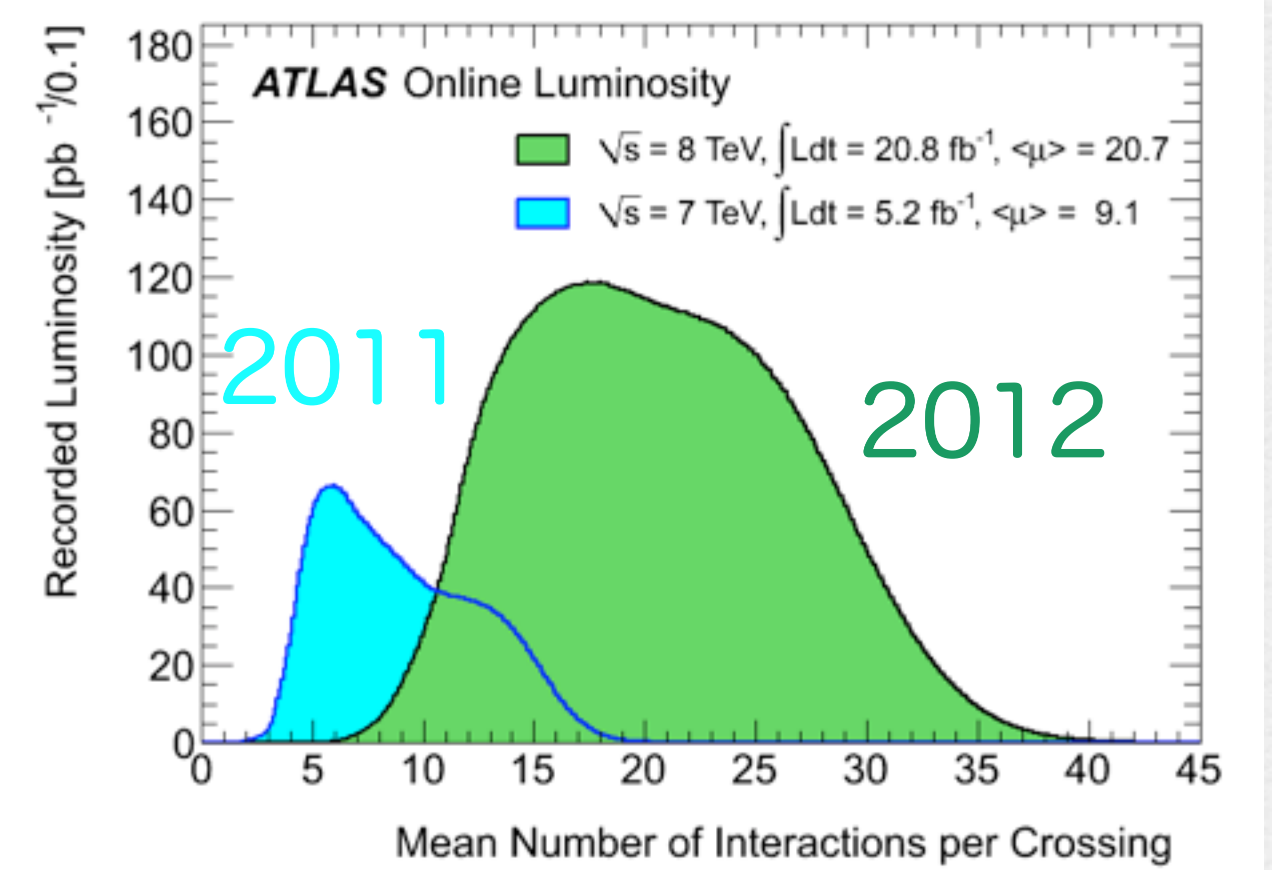
- ~5fb^{-1} collected in 2011 $\sqrt{s} = 7$ TeV
- ~21fb^{-1} collected in 2012 $\sqrt{s} = 8$ TeV

With increase of the luminosity, pile-up becomes higher.

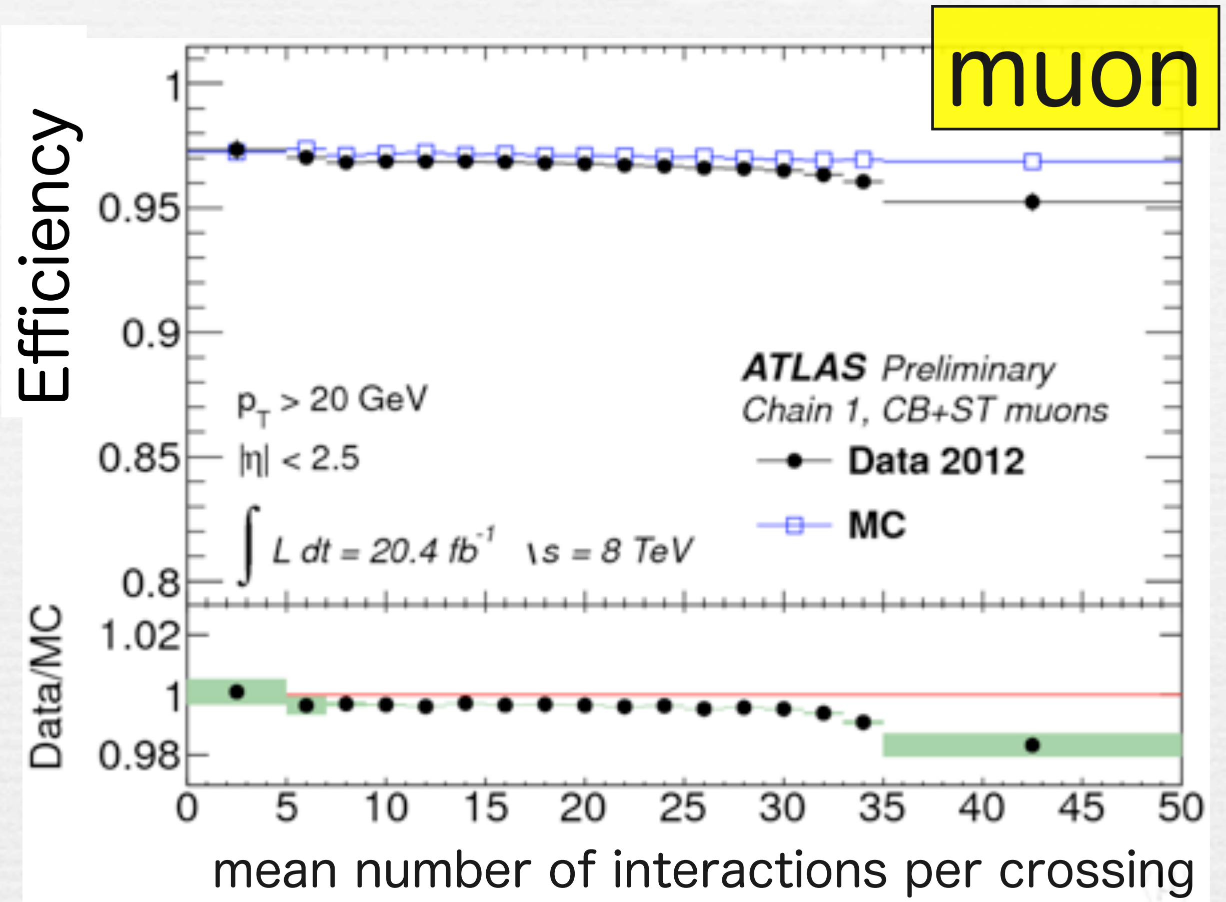
Typically, we must reconstruct ~20 vertices within the space of ~5 cm (=p-beam length)

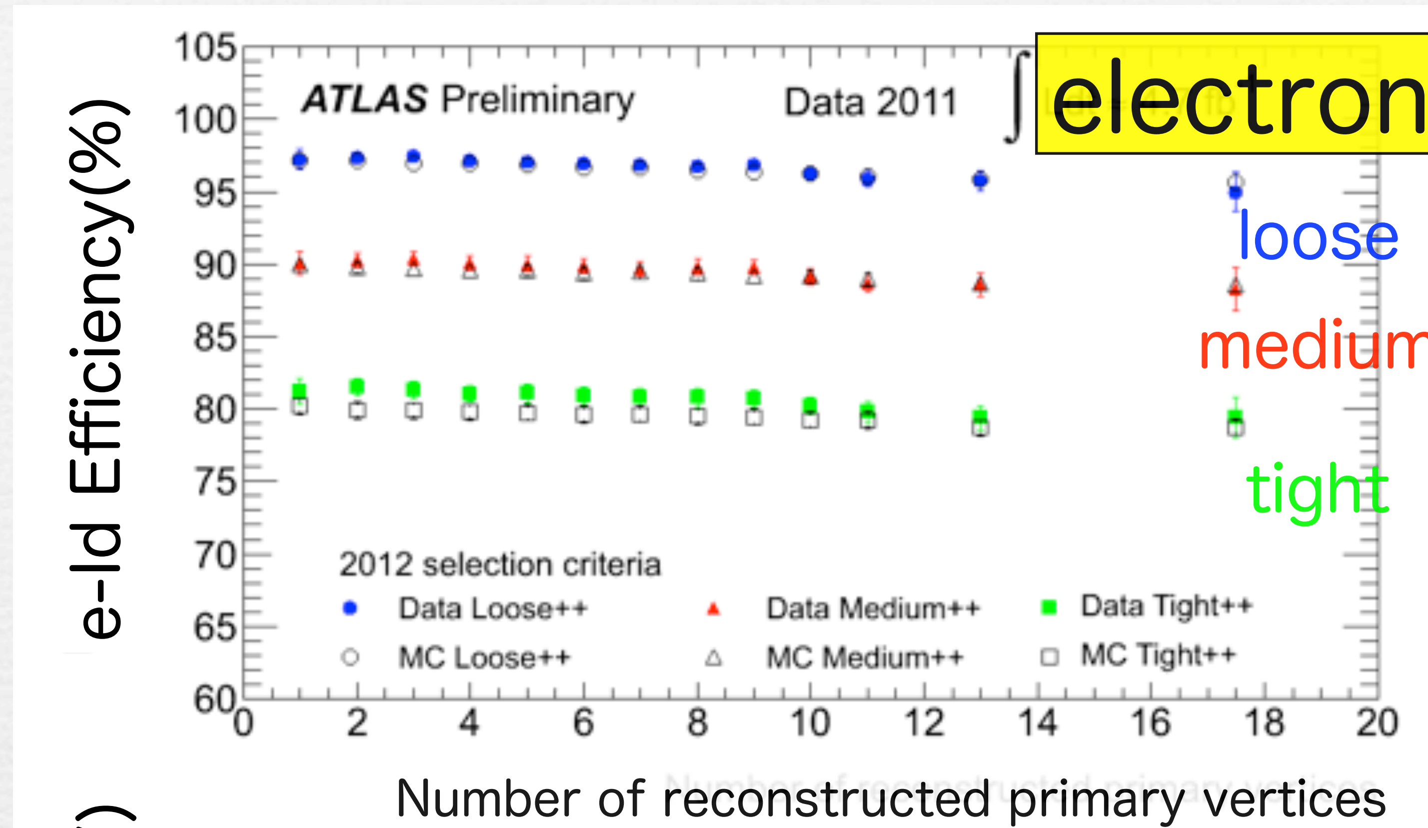


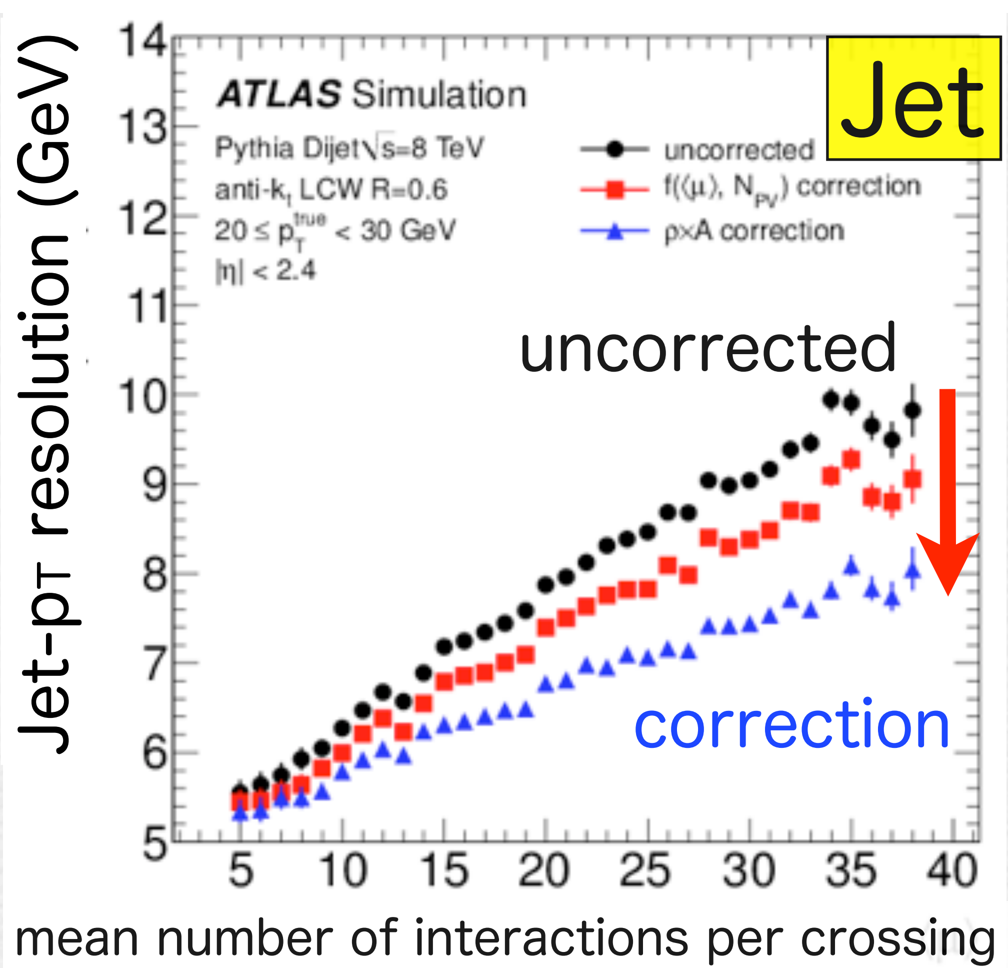


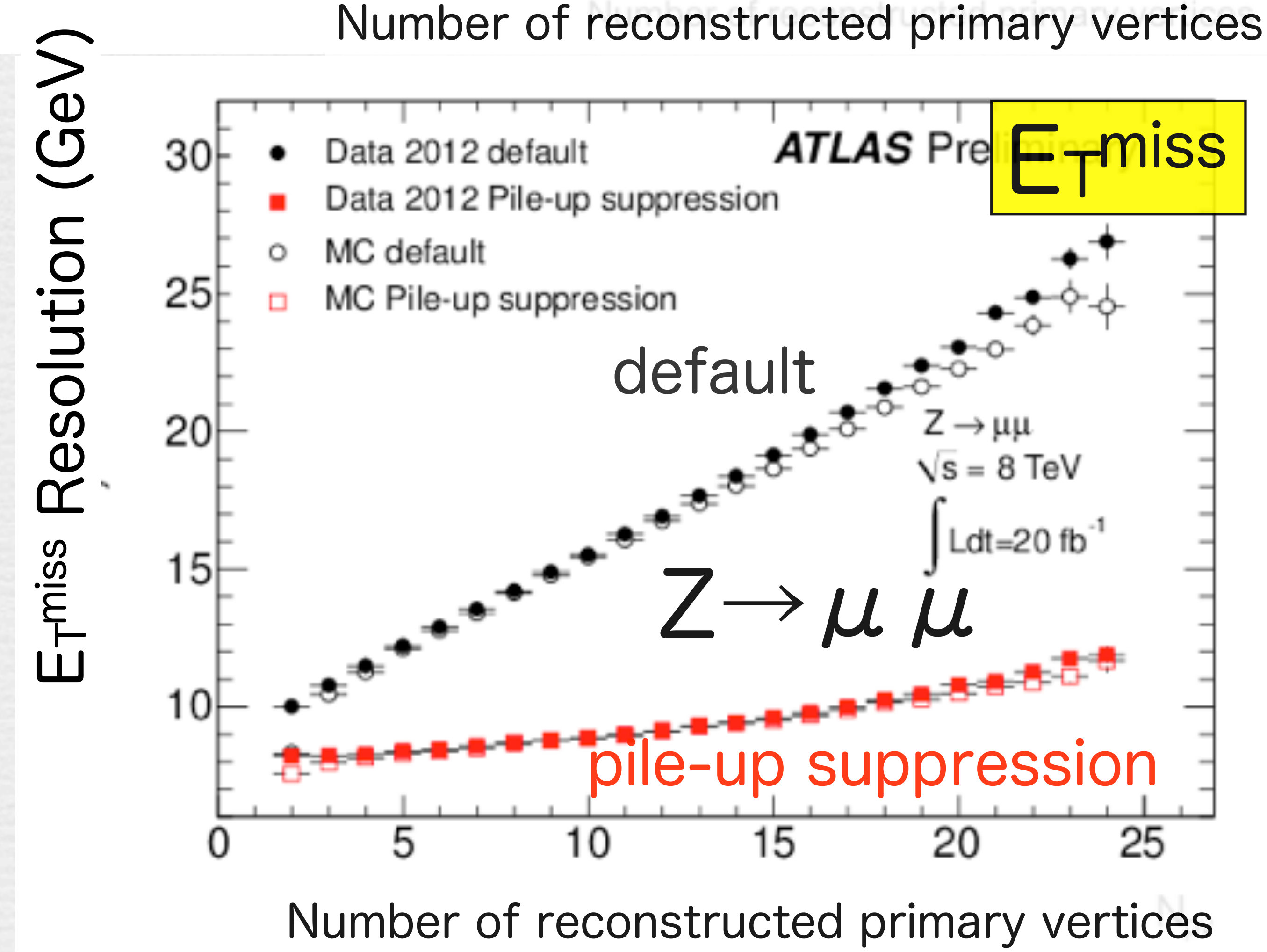


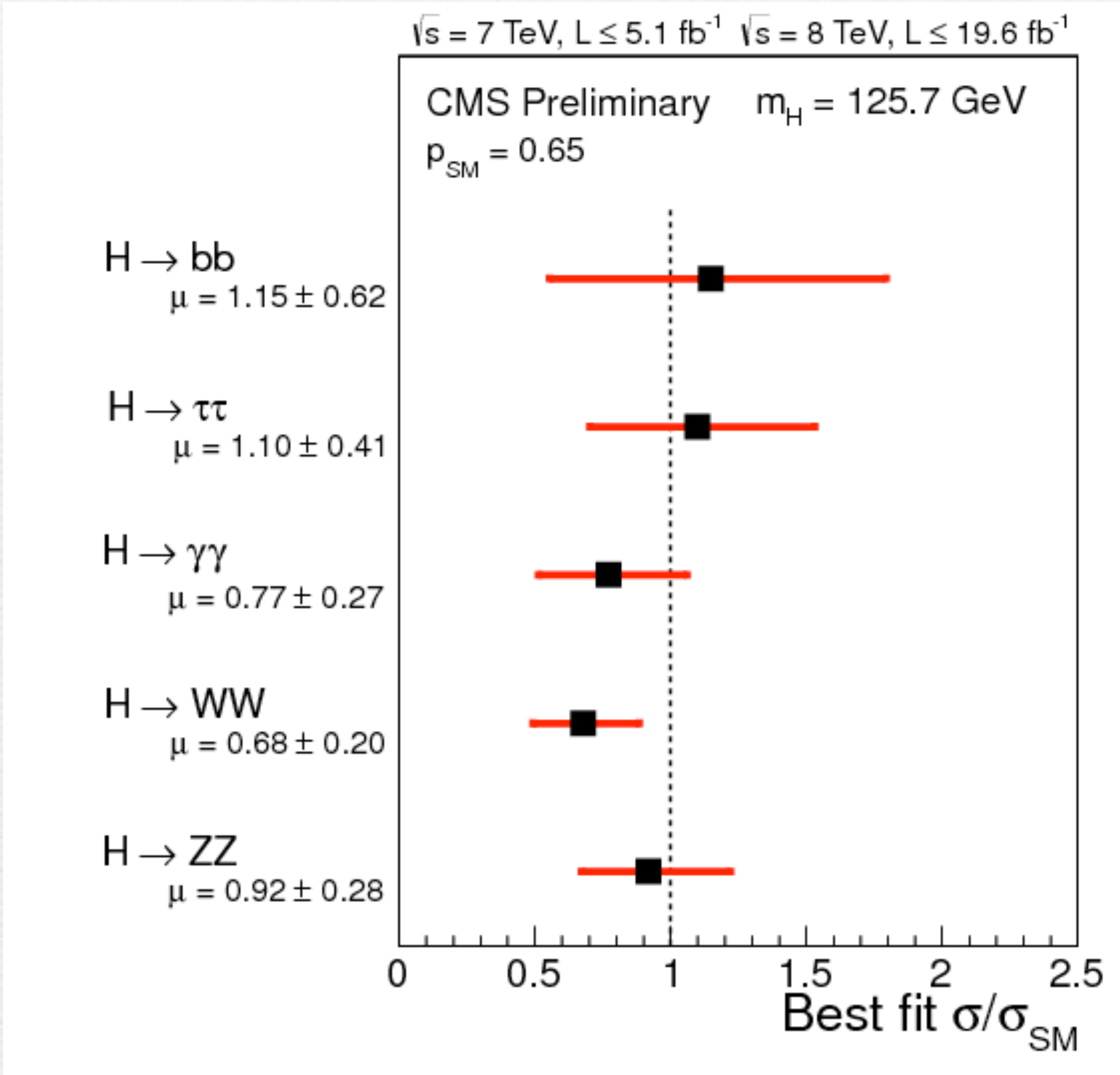
Detector Performance



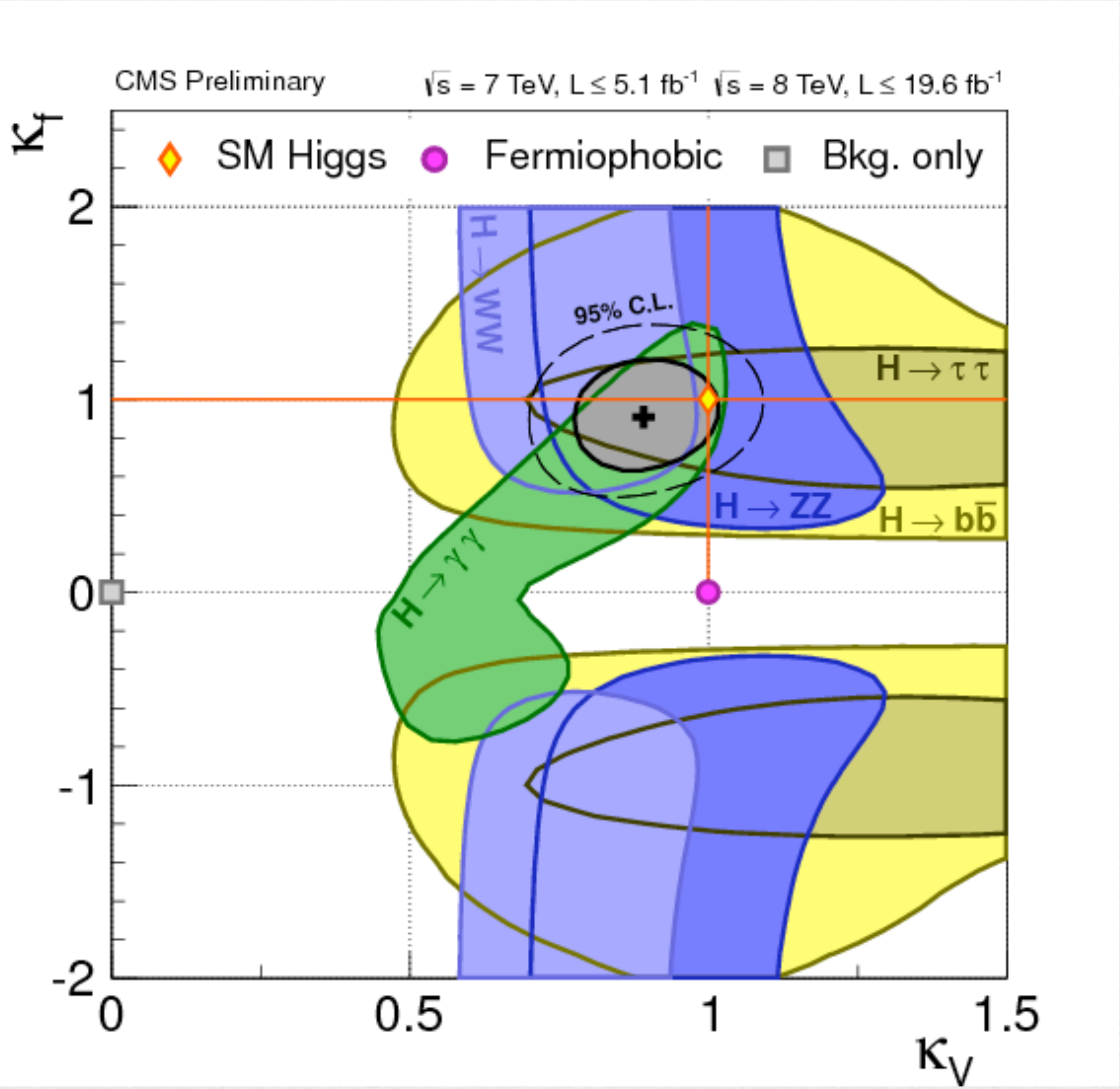


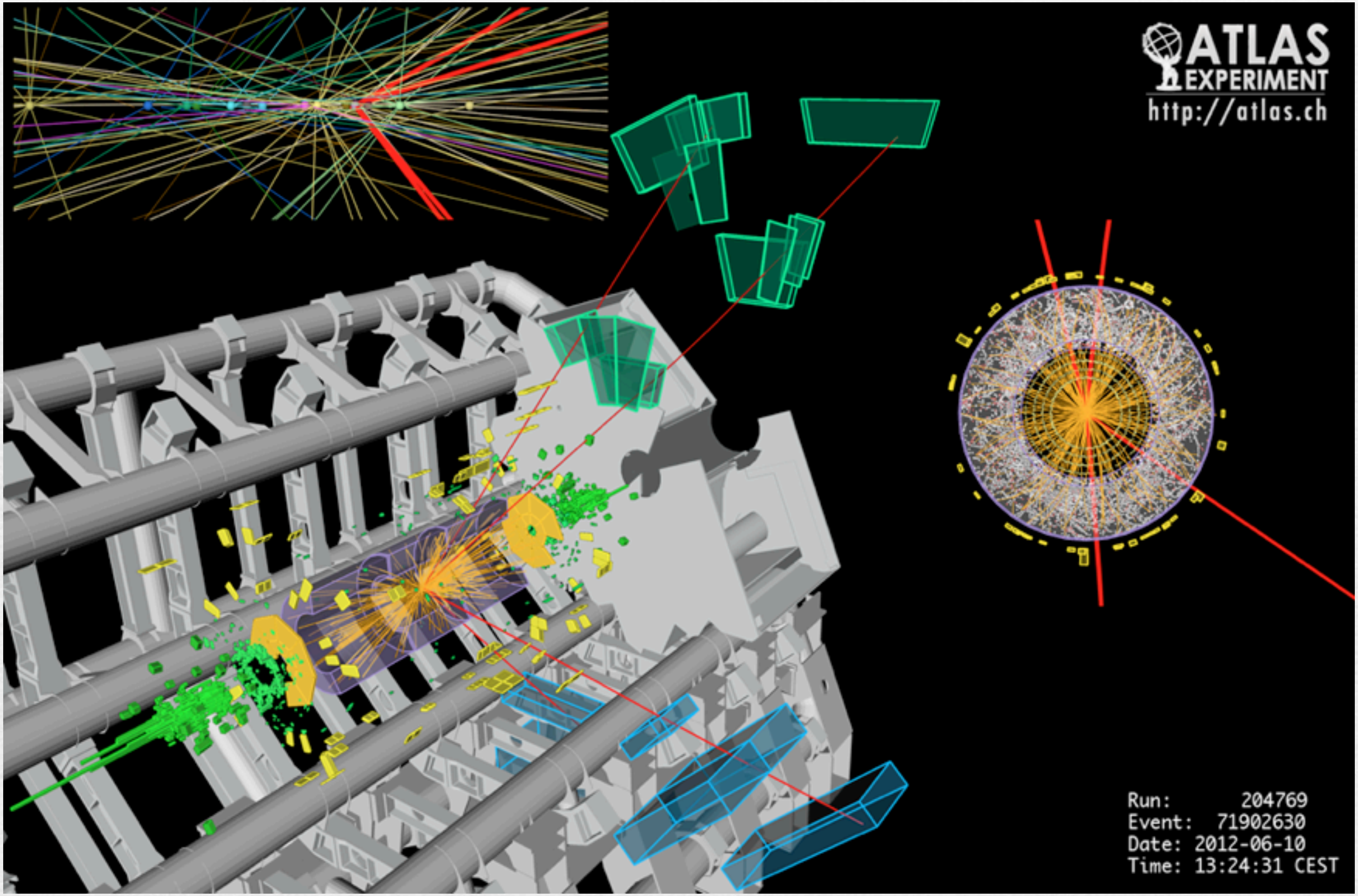


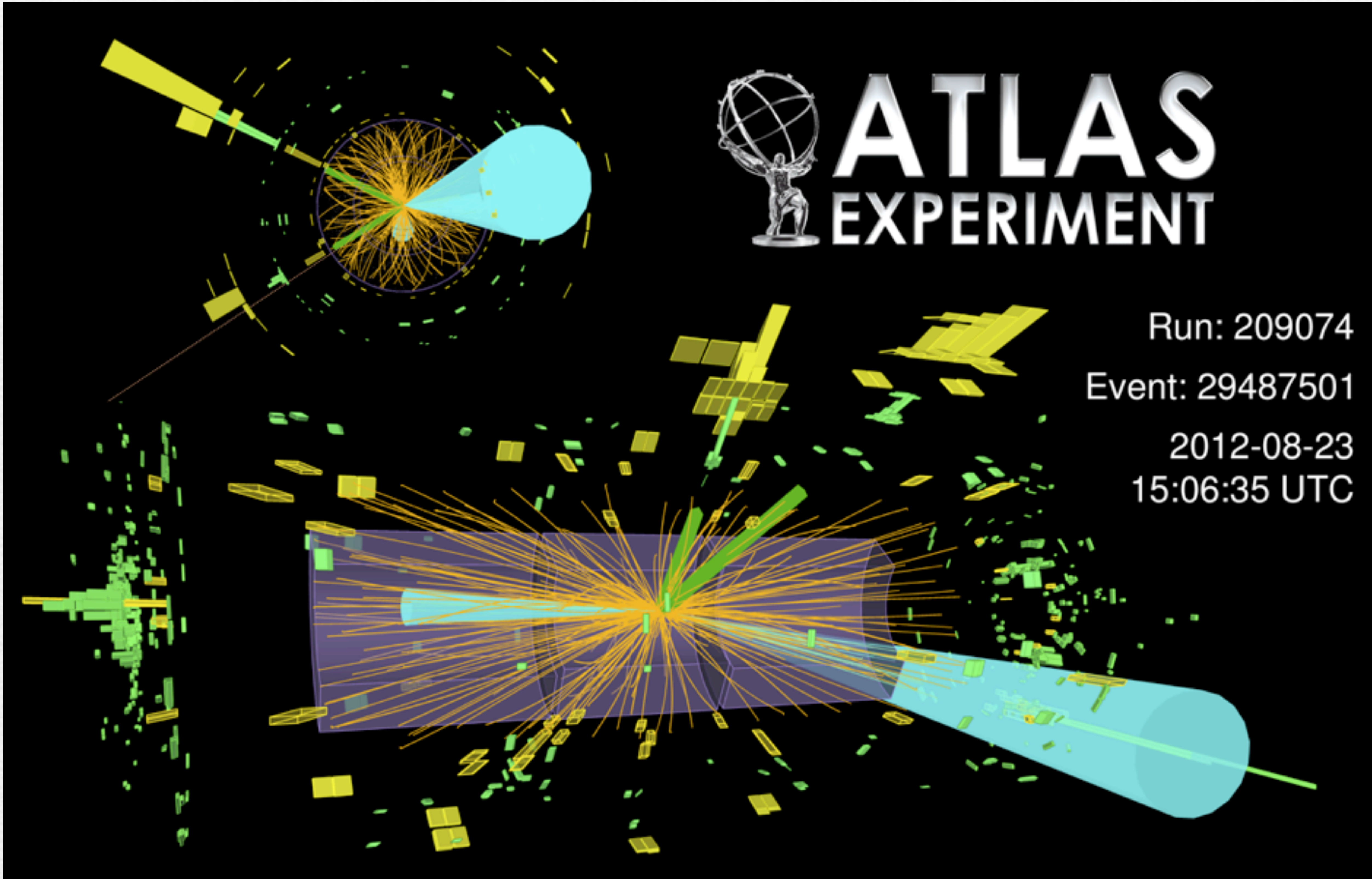




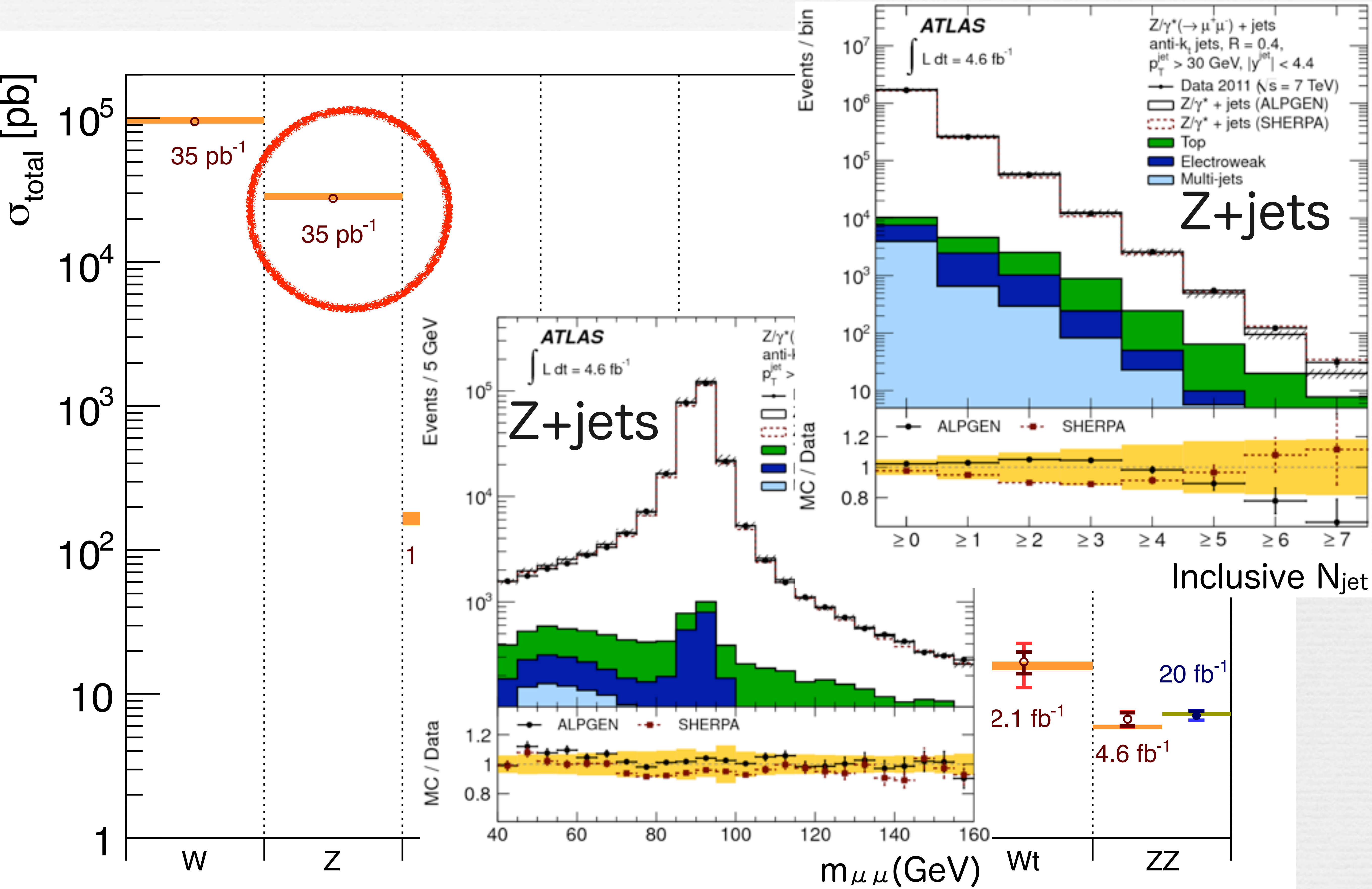
√s = 7 TeV, L ≤ 5.1 fb^{-1} √s = 8 TeV, L ≤ 19.6 fb^{-1}
CMS Preliminary
m_H = 125.7 GeV
p_{SM} = 0.65
H → bb
μ = 1.15 ± 0.62
H → ττ
μ = 1.10 ± 0.41
H → γγ
μ = 0.77 ± 0.27
H → WW
μ = 0.68 ± 0.20
H → ZZ
μ = 0.92 ± 0.28
0
0.5
1
1.5
2
2.5
Best fit σ/$σ_{SM}$


CMS Preliminary
√s = 7 TeV, L ≤ 5.1 fb⁻¹ √s = 8 TeV, L ≤ 19.6 fb⁻¹
SM Higgs
Fermiophobic
Bkg. only
95% C.L.
H → WW
H → ττ
H → ZZ
H → bb̄
H → γγ
κf
κV
2
1
0
-1
-2
0
0.5
1
1.5

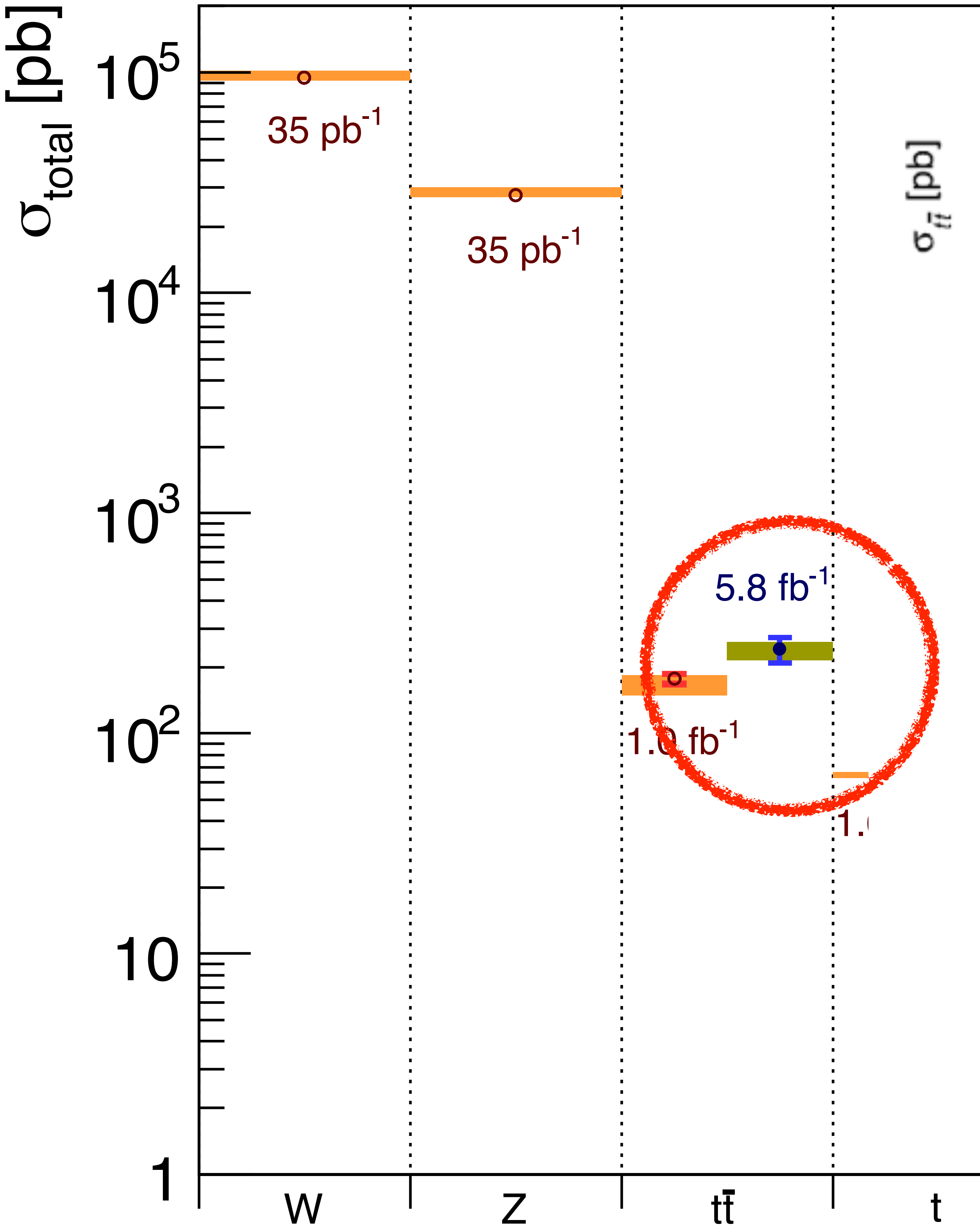

ATLAS
EXPERIMENT
http://atlas.ch
Run: 204769
Event: 71902630
Date: 2012-06-10
Time: 13:24:31 CEST


ATLAS
EXPERIMENT
Run: 209074
Event: 29487501
2012-08-23
15:06:35 UTC

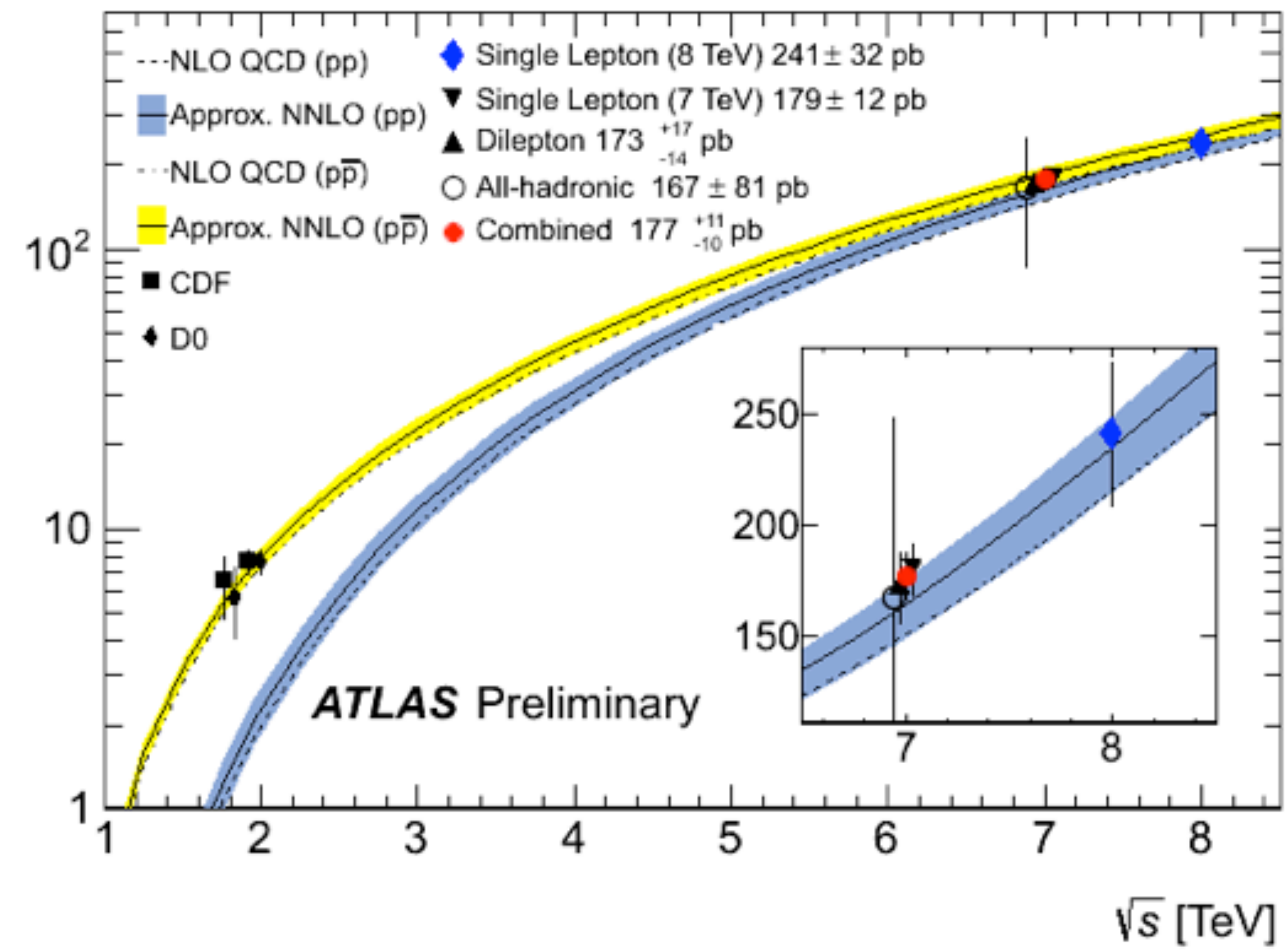
Physics towards Higgs discovery



Physics towards Higgs discovery

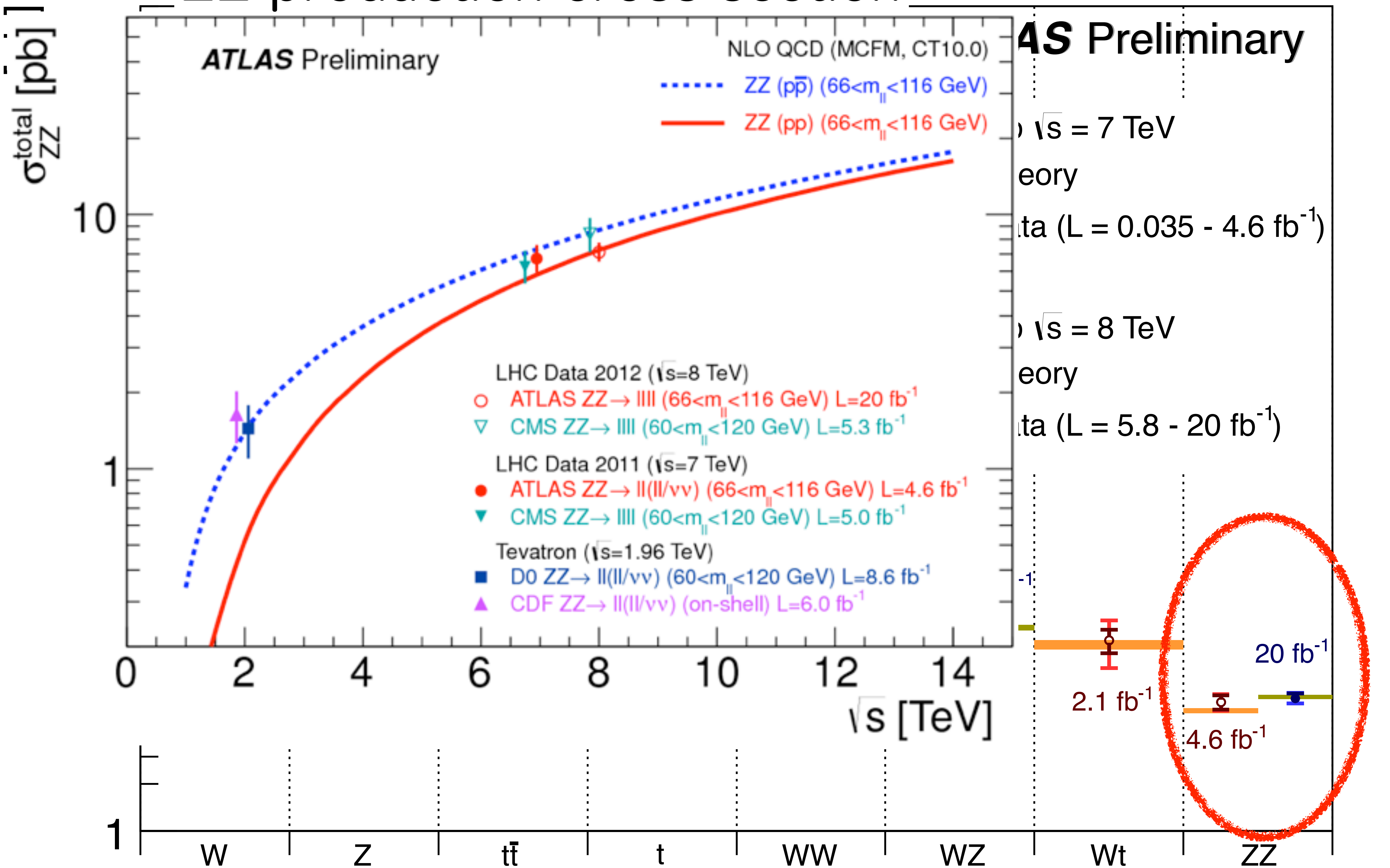


top quark pair production
cross-sction



Physics towards Higgs discovery

ZZ production cross section



Loop induced couplings (κ_g v.s. κ_γ)

arXiv:1307.1427

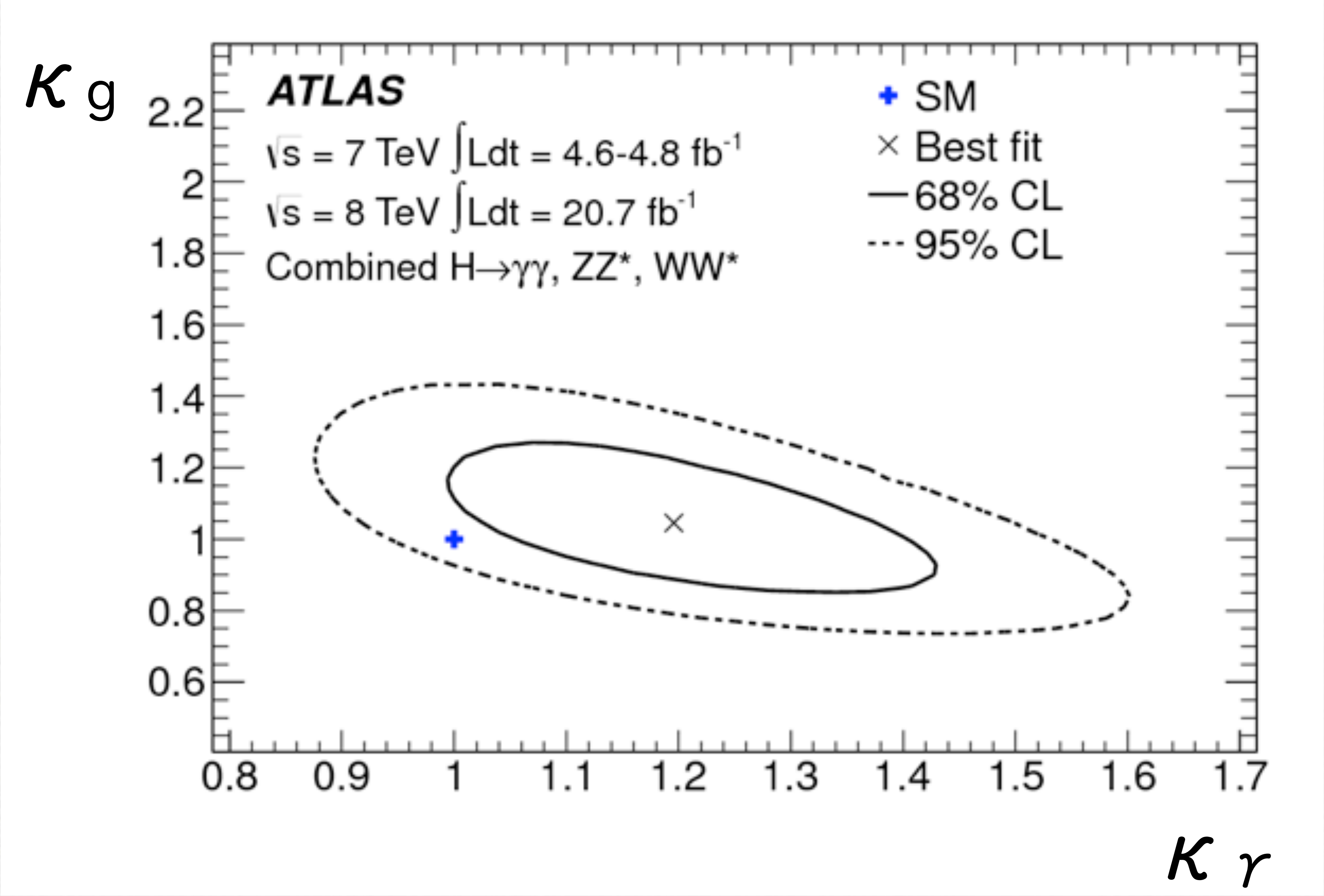
Prove the BSM contributions in the loop of gg→H and H→$\gamma\gamma$

We assume

Couplings of the known particles to the Higgs boson have SM strength

$$\kappa_W = \kappa_Z = \kappa_t = \kappa_b = \kappa_\tau = \ldots = 1$$

New particles do not contribute to the Higgs boson width Γ_H

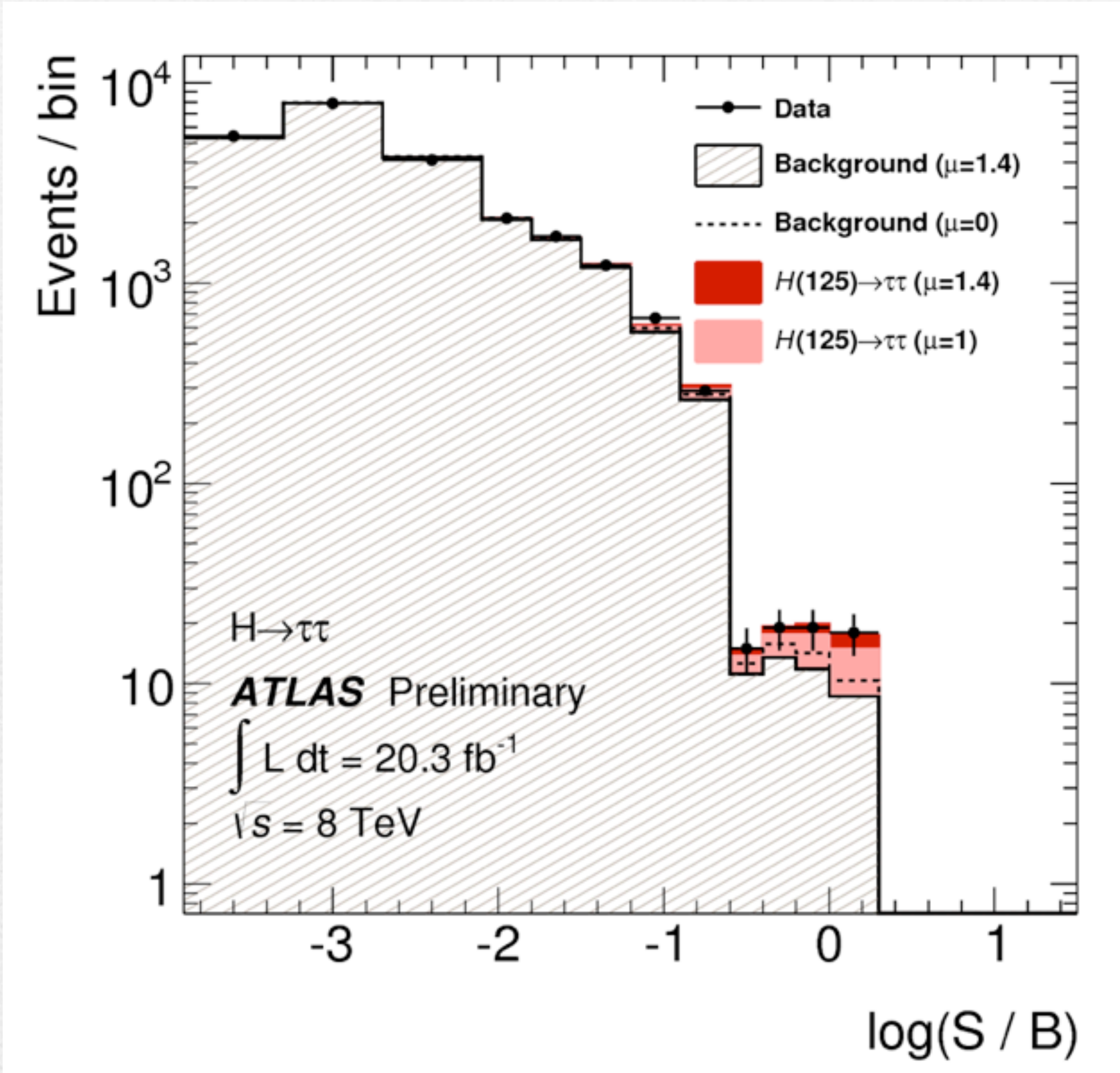


$$\kappa_g = 1.04 \pm 0.14$$

$$\kappa_\gamma = 1.20 \pm 0.15$$

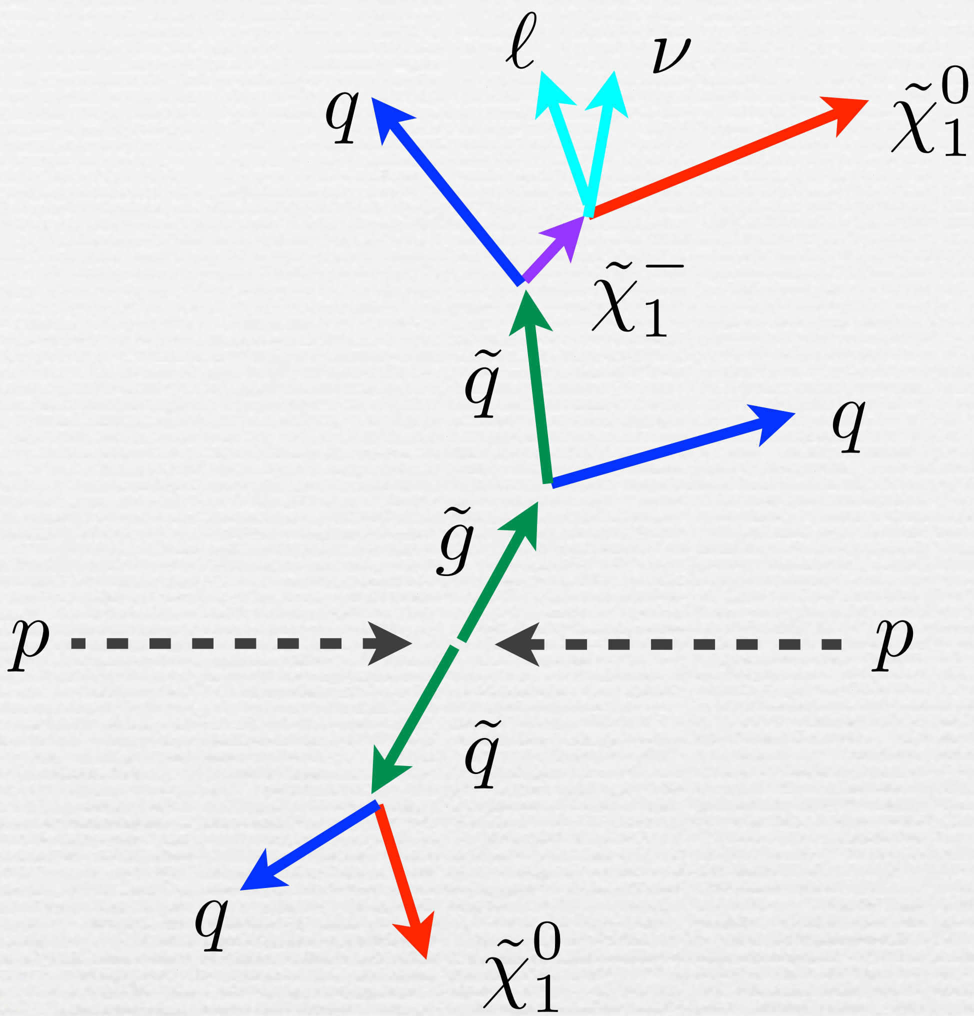
at 68% C.L.

Compatibility of the SM is 14%



Events / bin
10^4
10^3
10^2
10
1
-3
-2
-1
0
1
log(S / B)
Data
Background (μ=1.4)
Background (μ=0)
H(125)→ττ (μ=1.4)
H(125)→ττ (μ=1)
H→ττ
ATLAS Preliminary
$\int L\,dt = 20.3\ fb^{-1}$
$\sqrt{s} = 8$ TeV

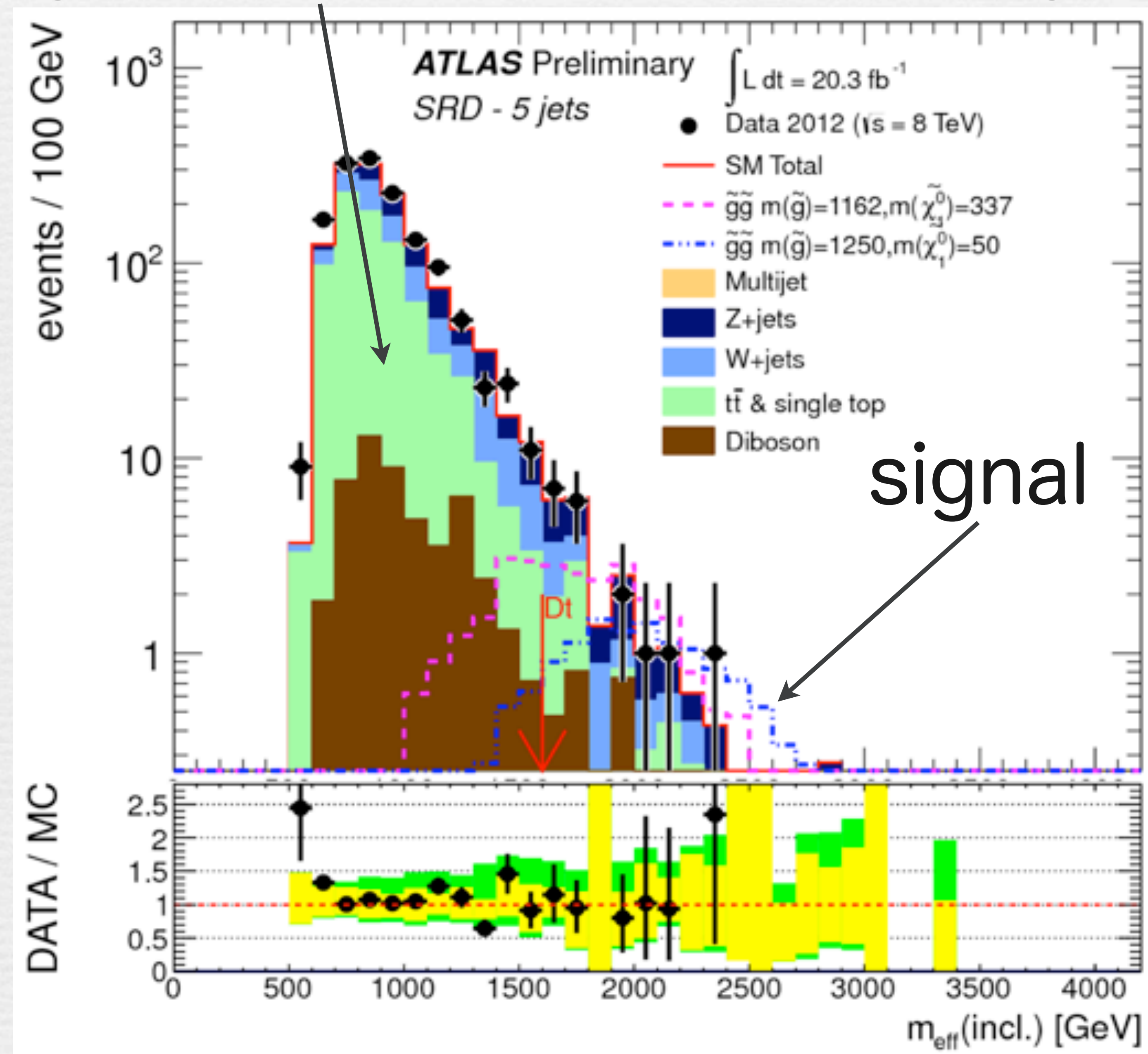
LHCでのSUSY探索

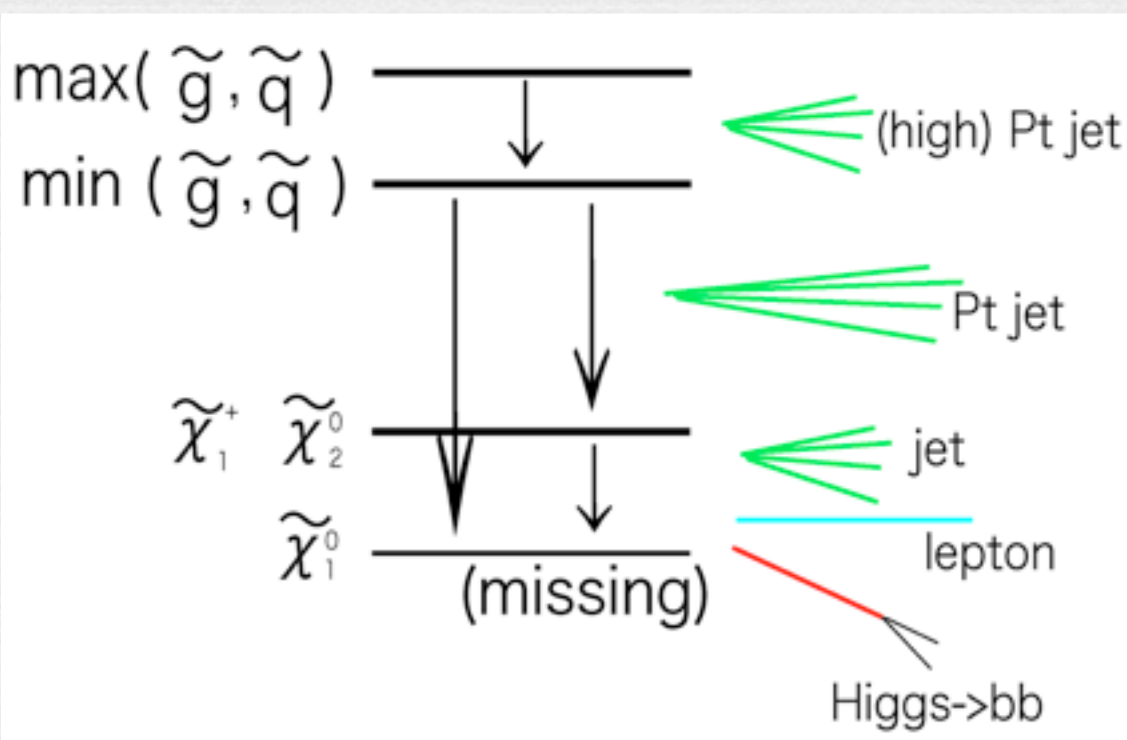


high p_T Jets + leptons + E_T^{miss} + X

$$m_{eff} = \sum_{\text{jets}} p_T + \sum_{\text{leptons}} p_T + E_T^{miss}$$

Backgrounds are estimated from control region

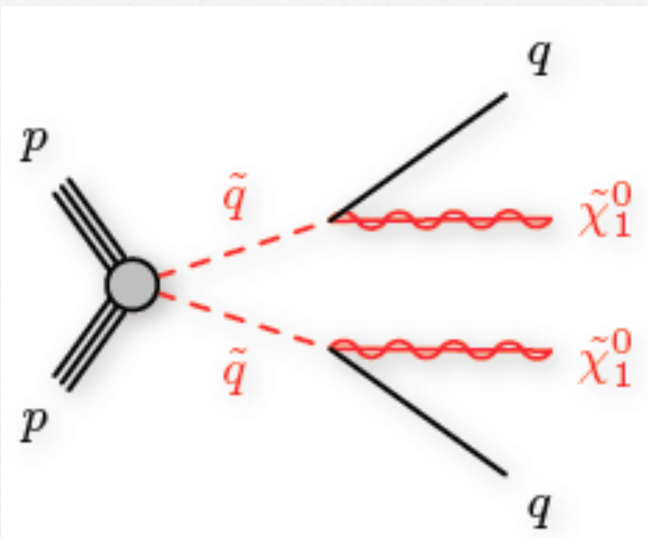


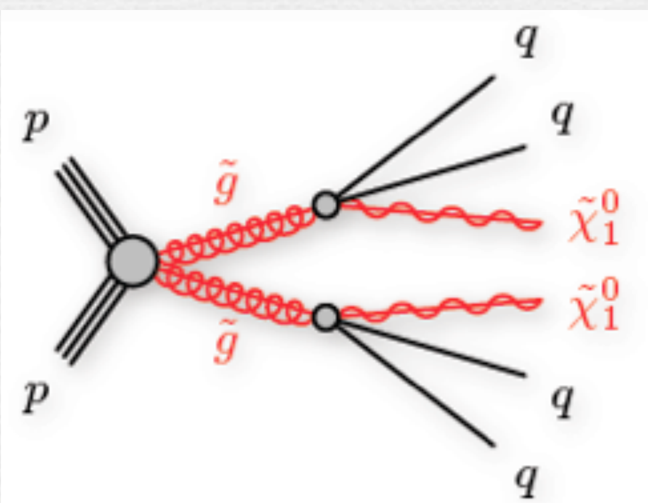


Inclusive search

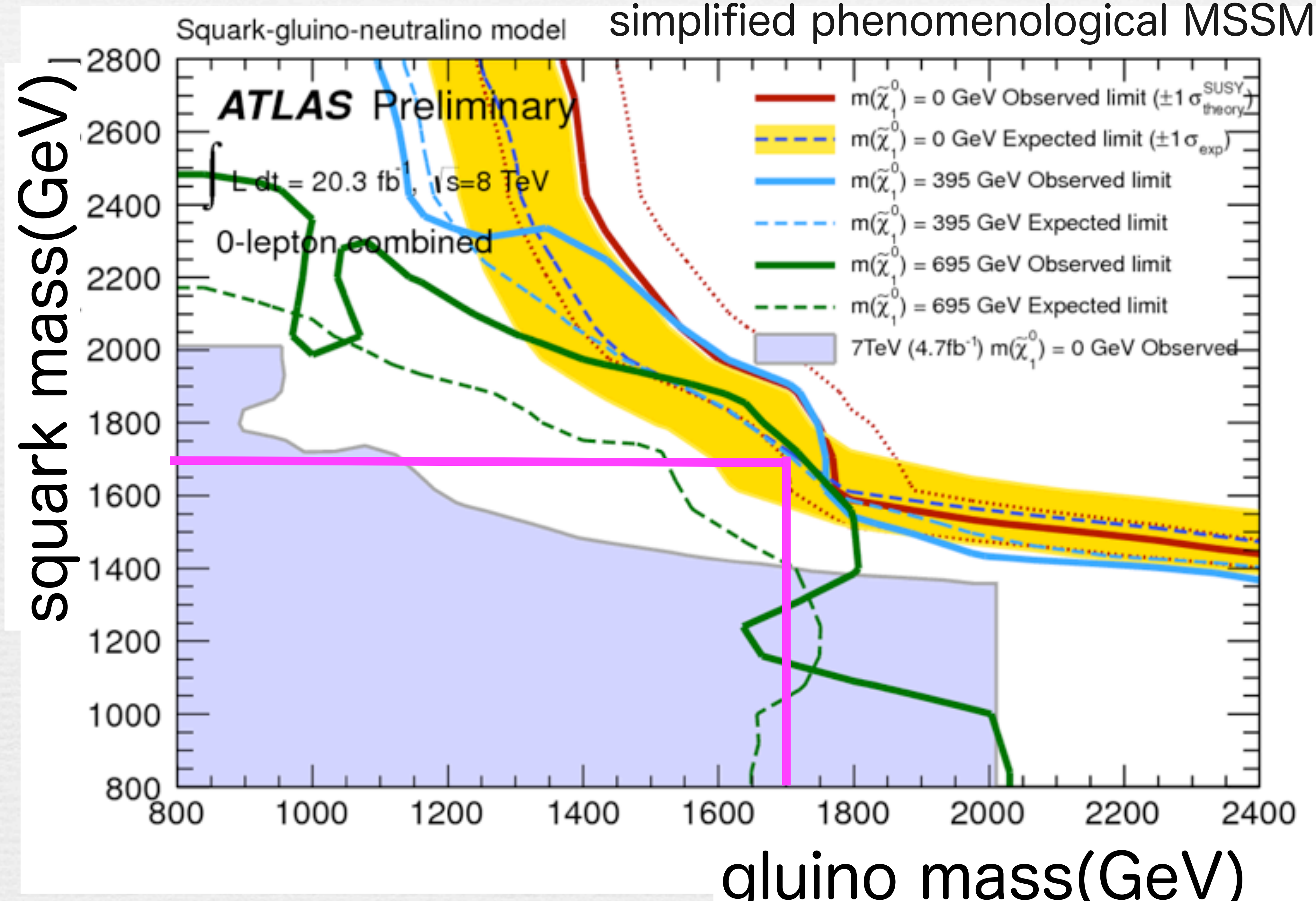
ATLAS-CONF-2013-047

High pT jets (up to 6 jets) + 0 lepton + E_T^{miss}>160GeV





simplified phenomenological MSSM

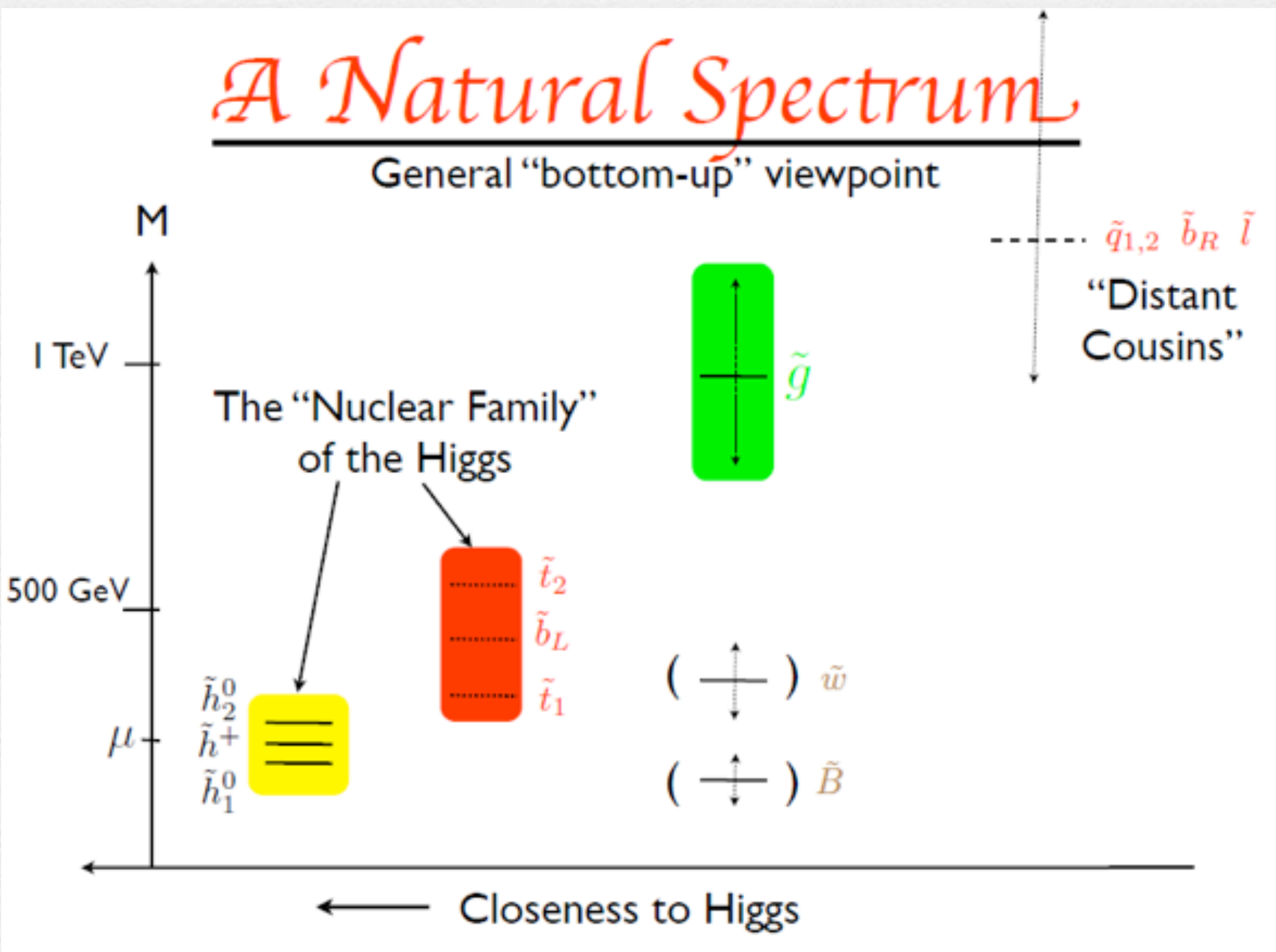


<1.7TeV excluded ($m_{\tilde{g}} = m_{\tilde{q}}$)

“Natural” SUSY

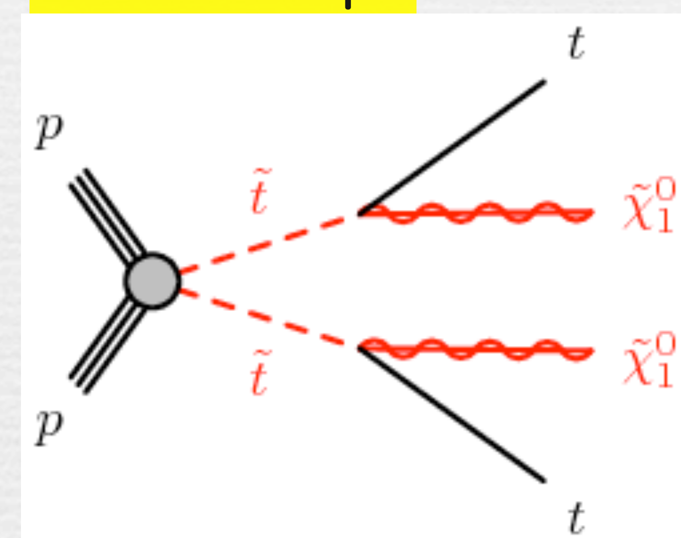
To stabilize the Higgs mass
- 3rd generation squark
- Higgsino(chargino/neutralino)

should be light

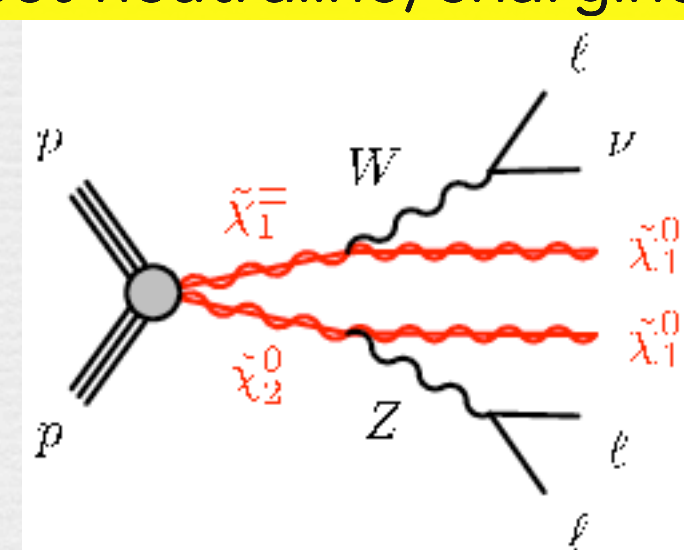


From slide by Lawrence Hall

direct stop



direct neutralino/chargino

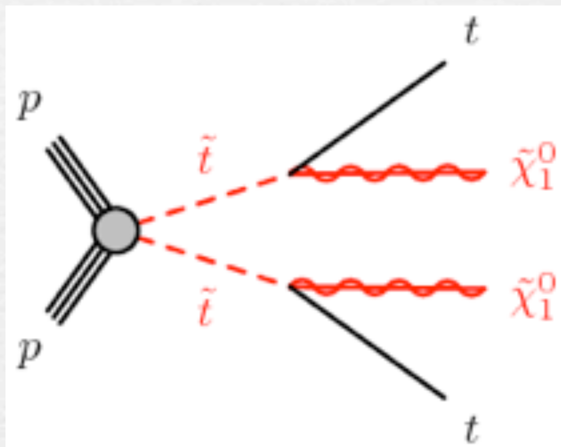


Direct stop pair production

In case of stop is light

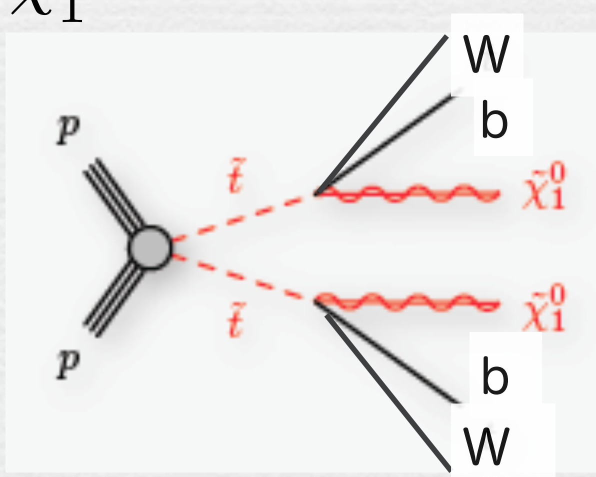
(1) $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} > m_t$

$$\tilde{t}_1 \to t\tilde{\chi}_1^0$$



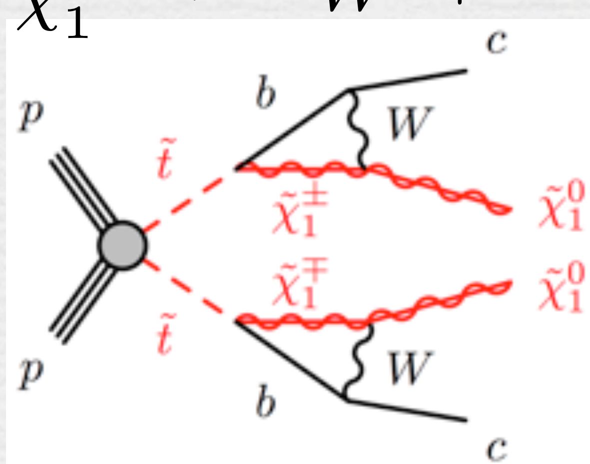
(2) $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} > m_W + m_b$

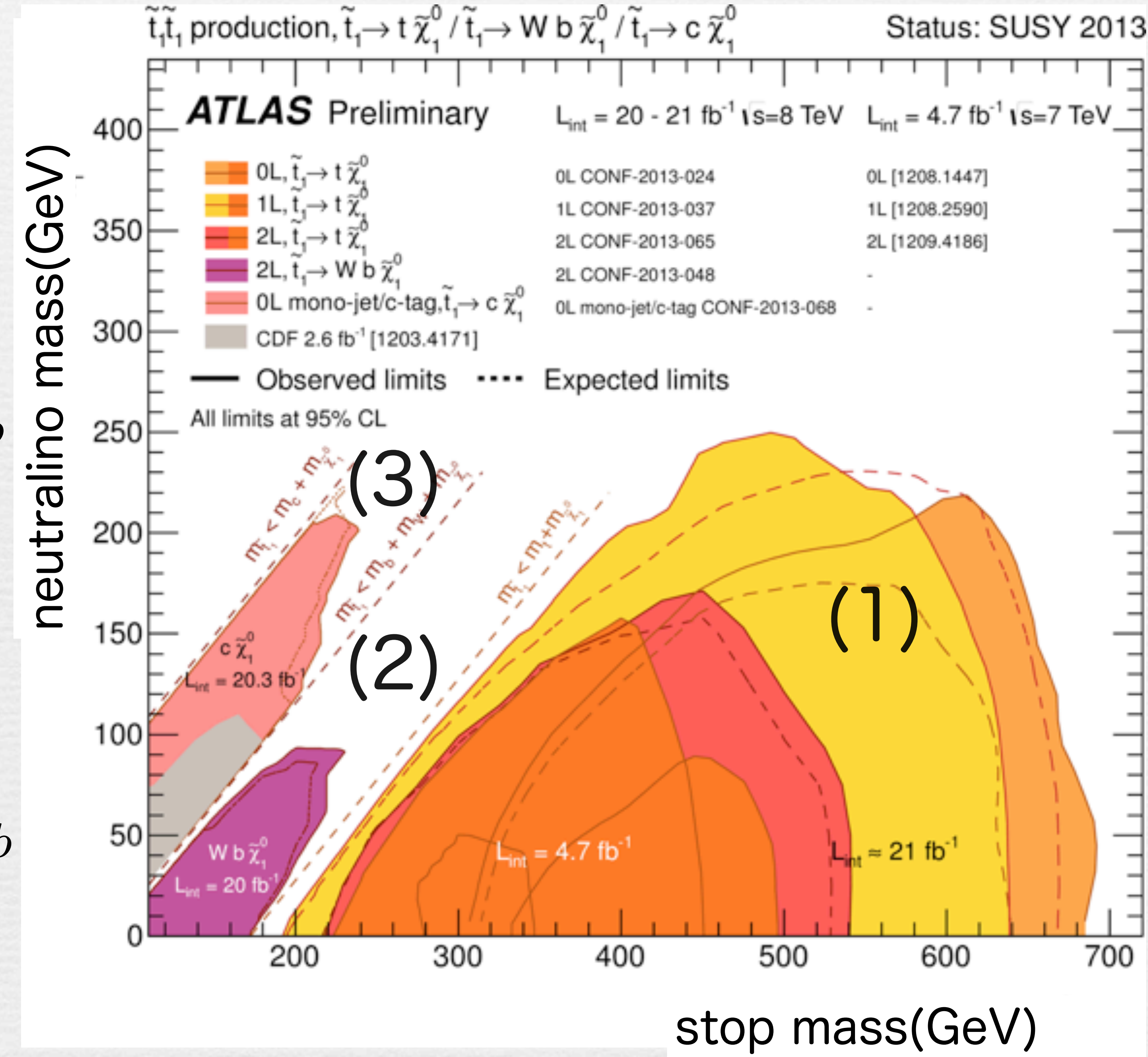
$$\tilde{t}_1 \to Wb\tilde{\chi}_1^0$$



(3) $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} < m_W + m_b$

$$\tilde{t}_1 \to c\tilde{\chi}_1^0$$



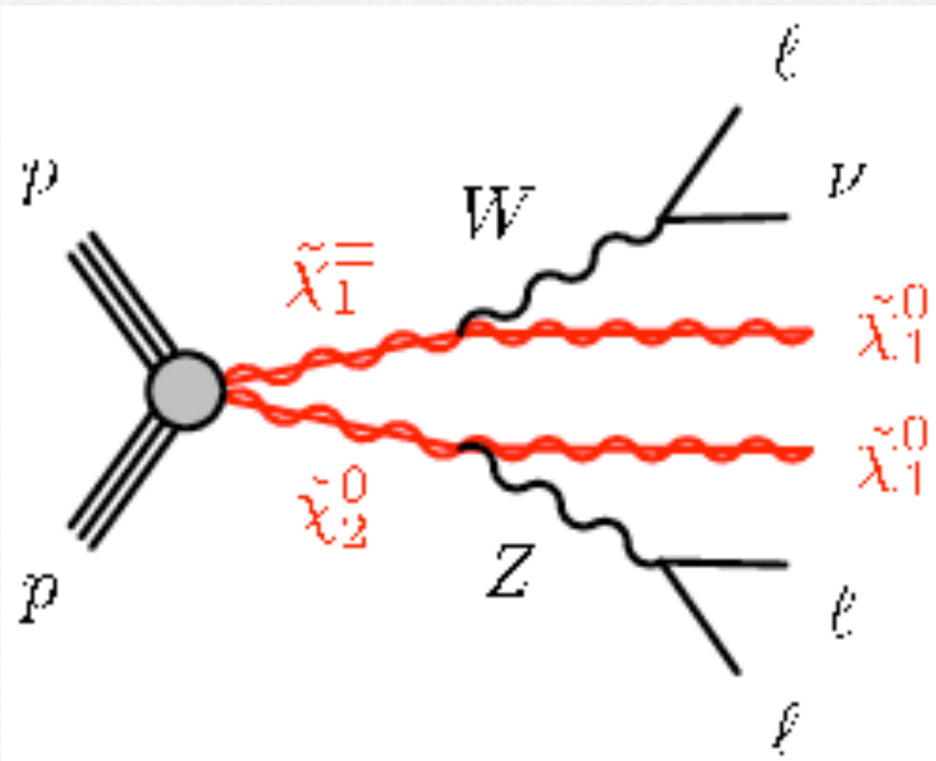


$m_{\tilde{t}} < 660$ GeV excluded (m_{LSP}=0)

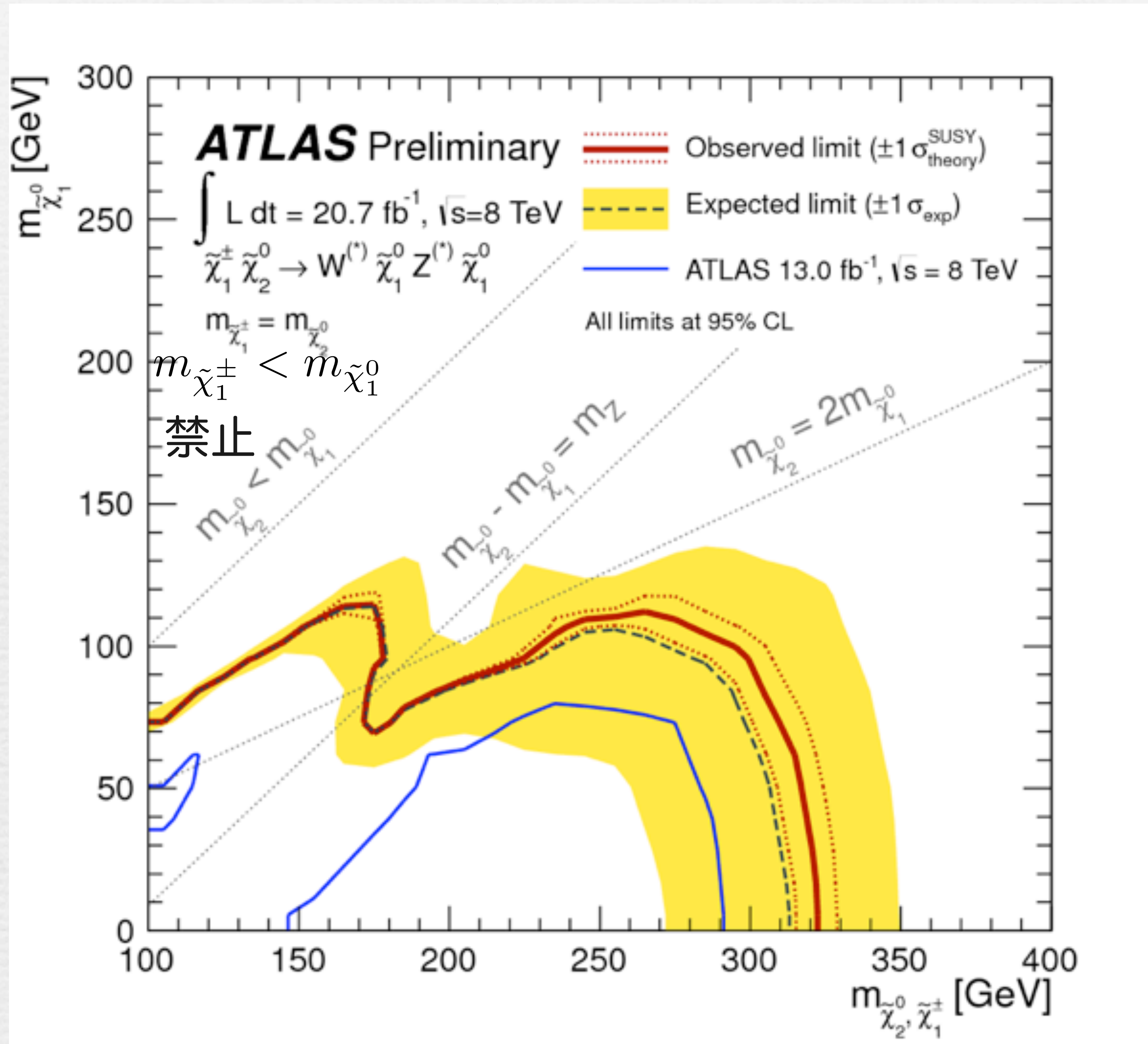
Direct chargino/neutralino production

Light chargino and neutralino

$$m_{\tilde{\chi}_1^\pm} > m_{\tilde{\chi}_1^0}$$

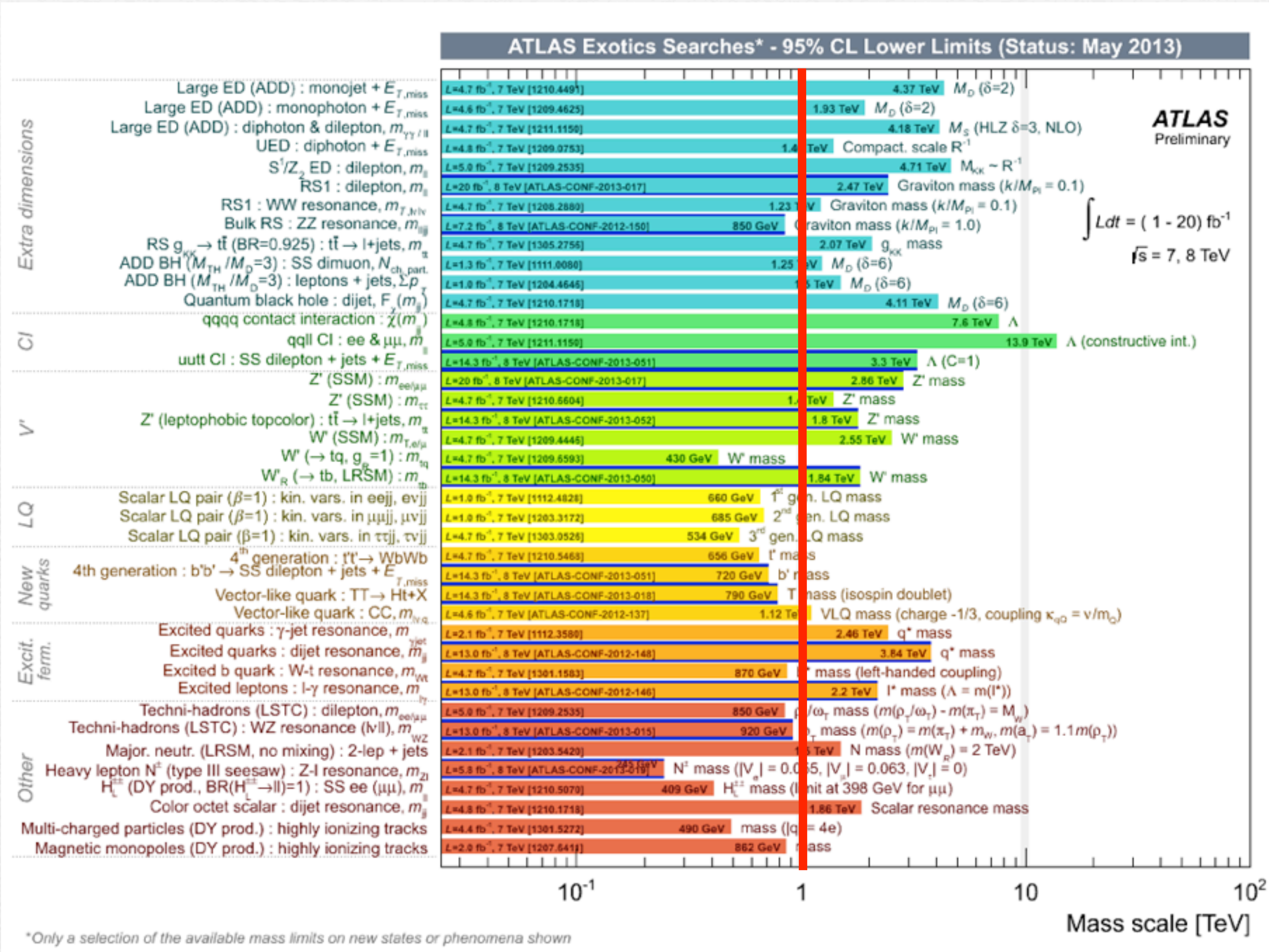


3 lepton + E_T^{miss}

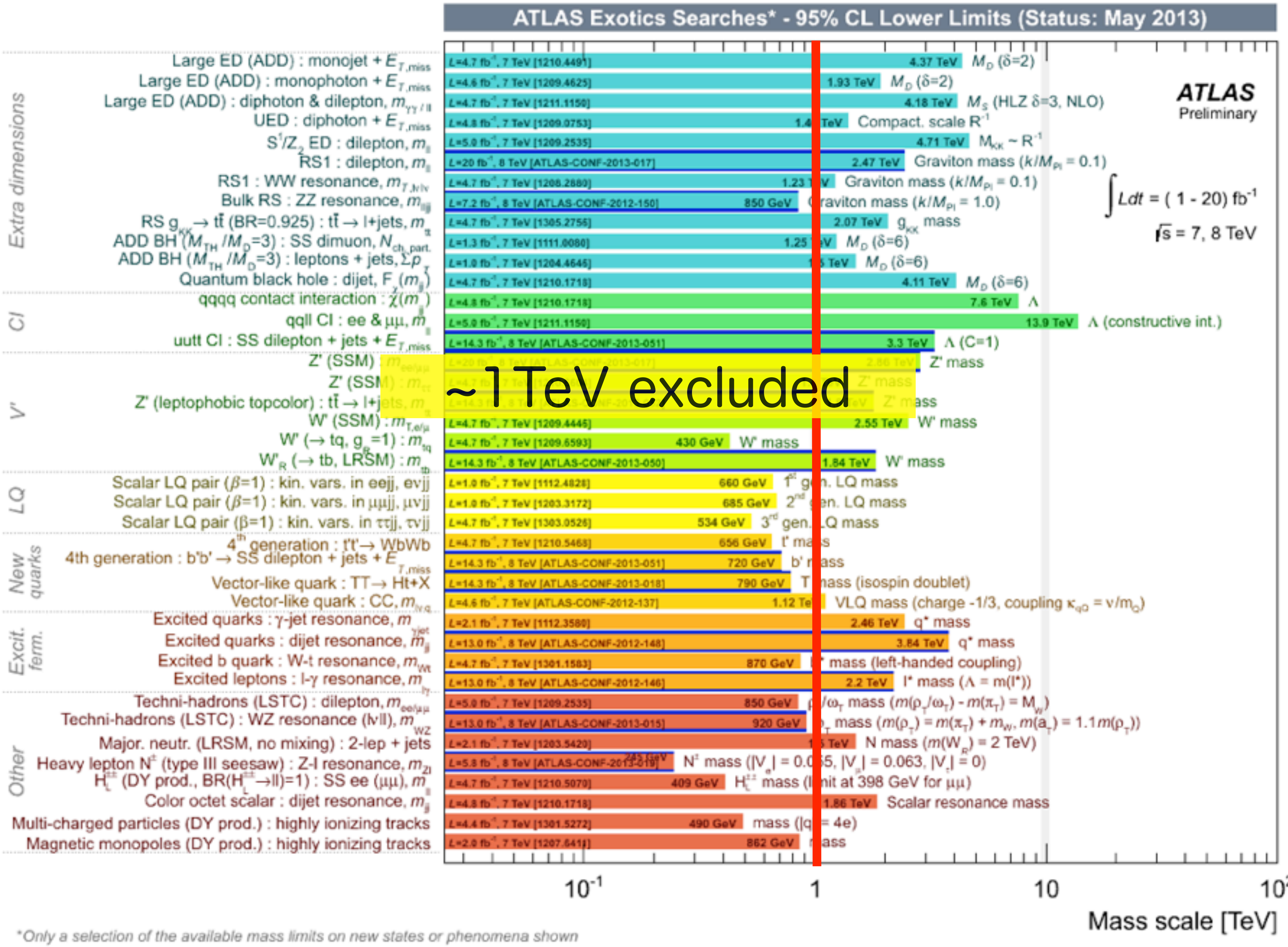


$m_{\tilde{\chi}_2^0}, m_{\tilde{\chi}_1^\pm} < 315\ \mathrm{GeV}$ excluded

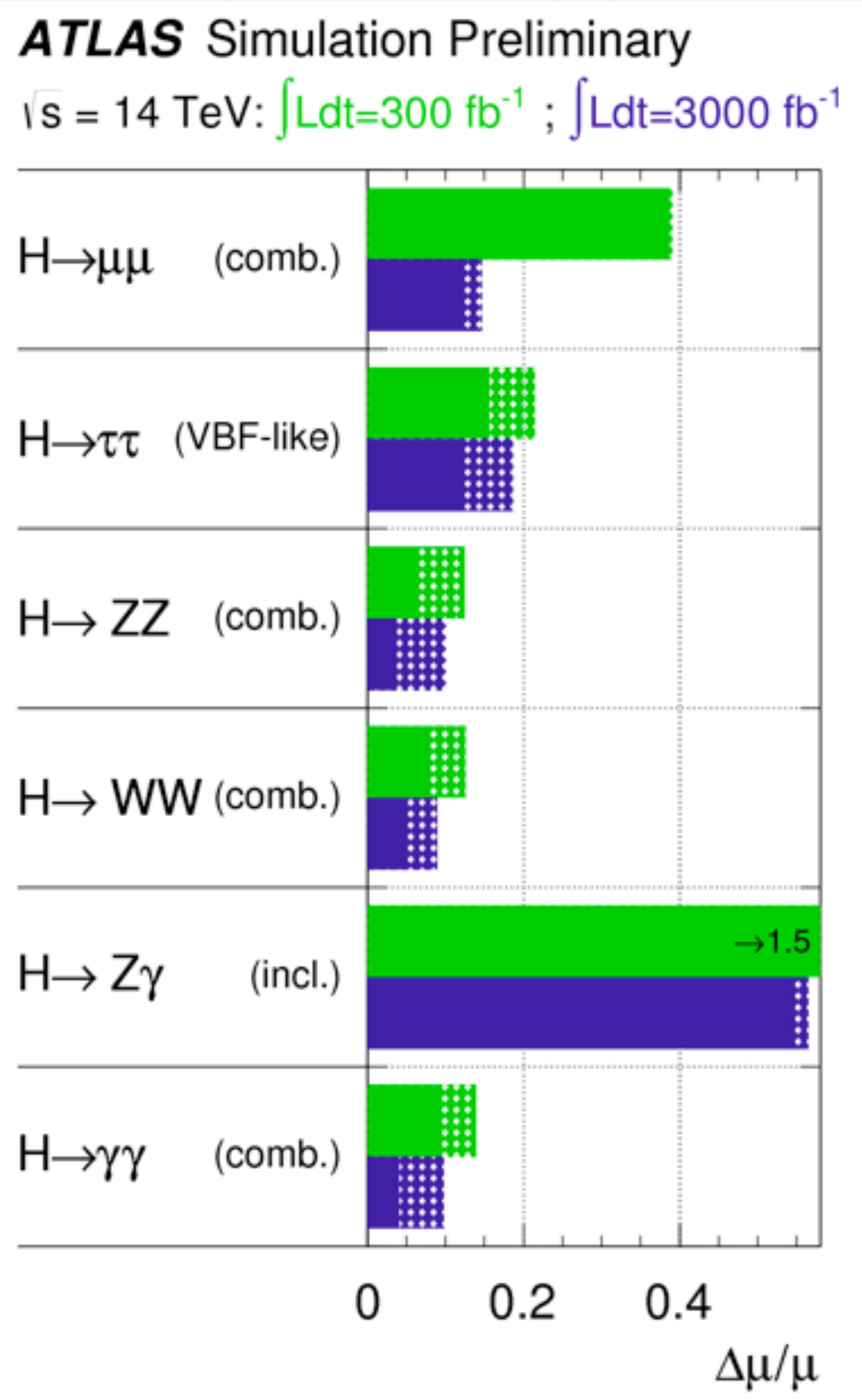
New physics search summary

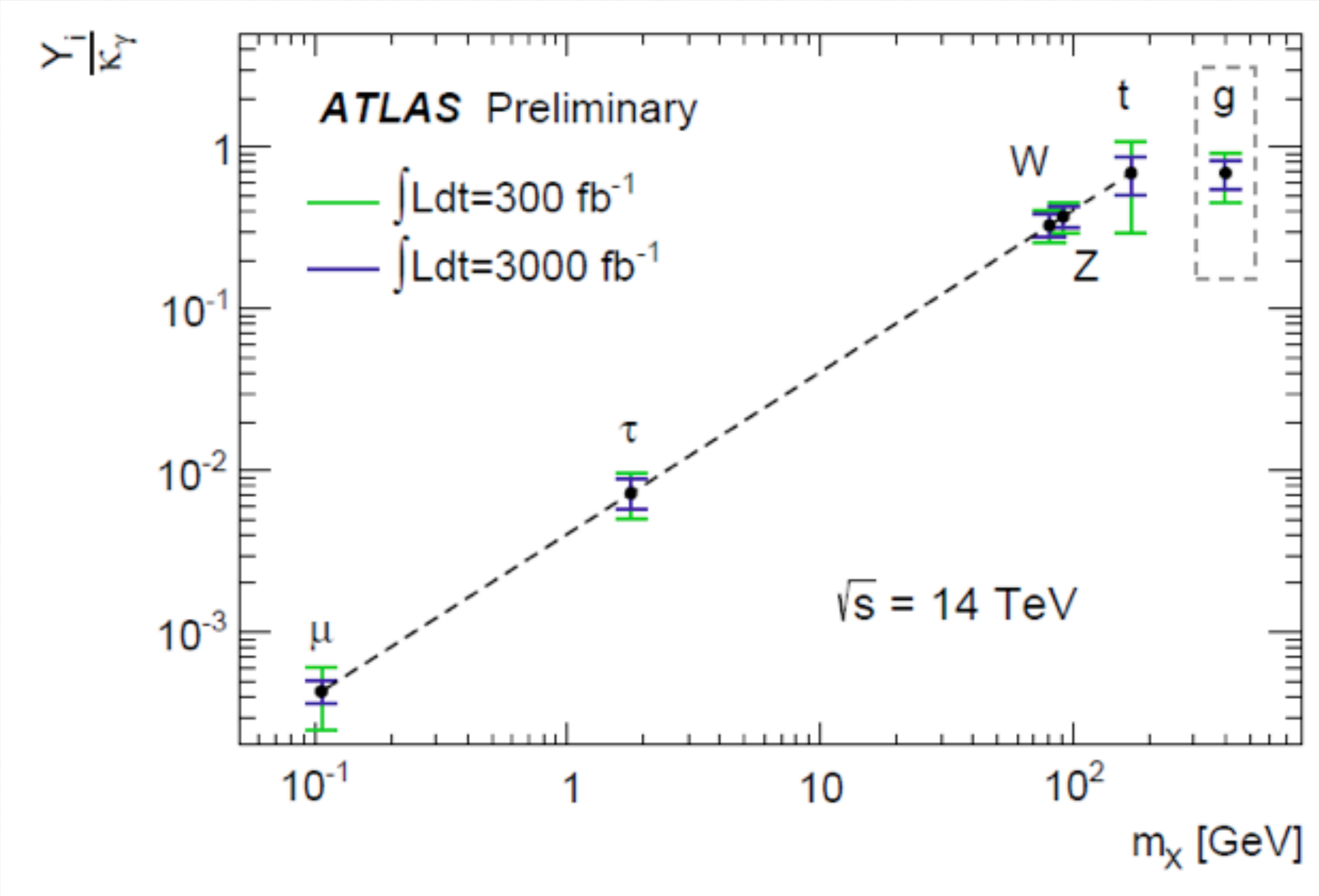


New physics search summary

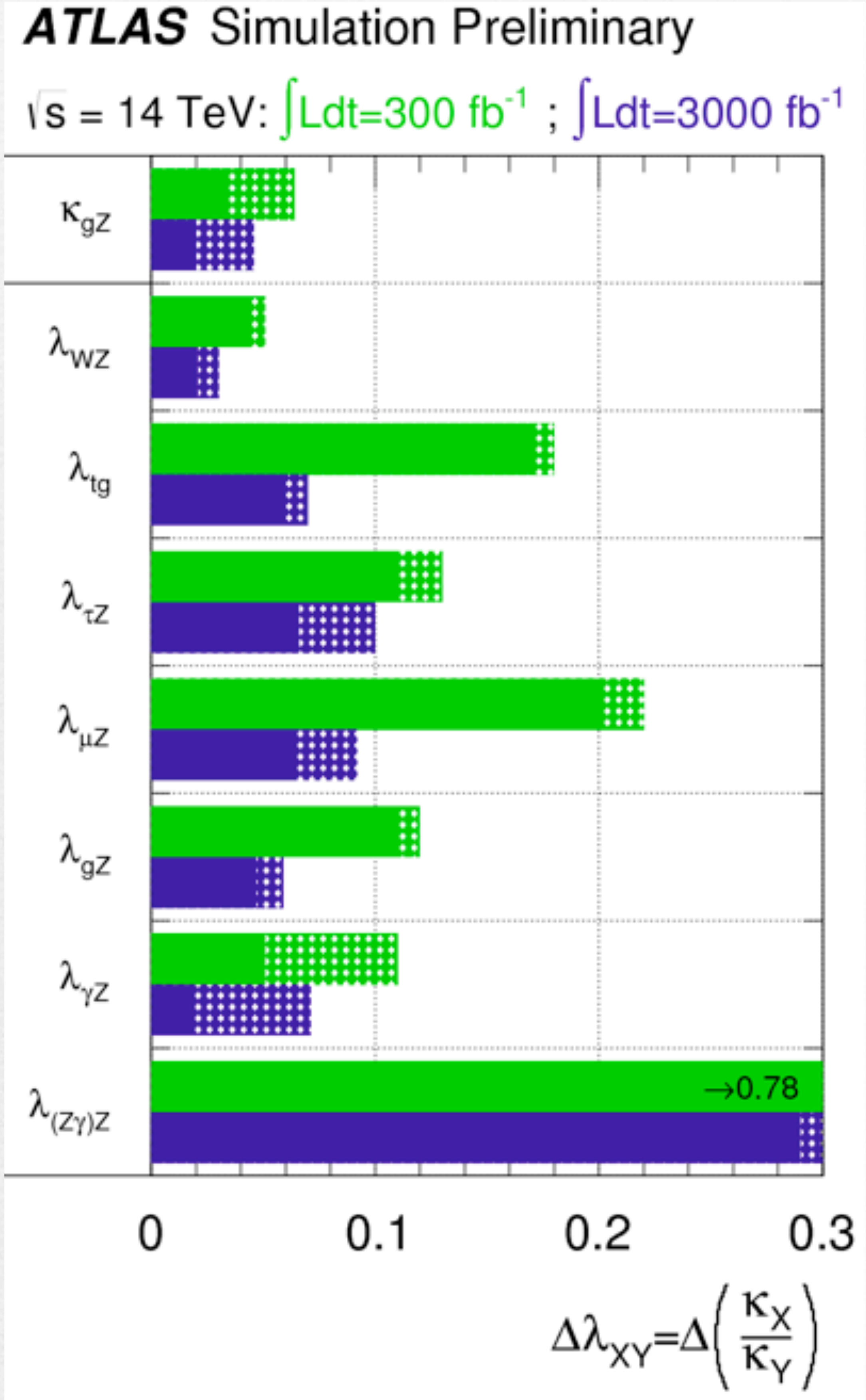


Higgs prospects





Higgs prospects



SUSY prospects