素粒子実験領域，素粒子論領域，ビーム物理領域合同シンポジウム

「ヒッグスからテラスケールへ」

LHC 8TeV実験の成果

戸本　誠

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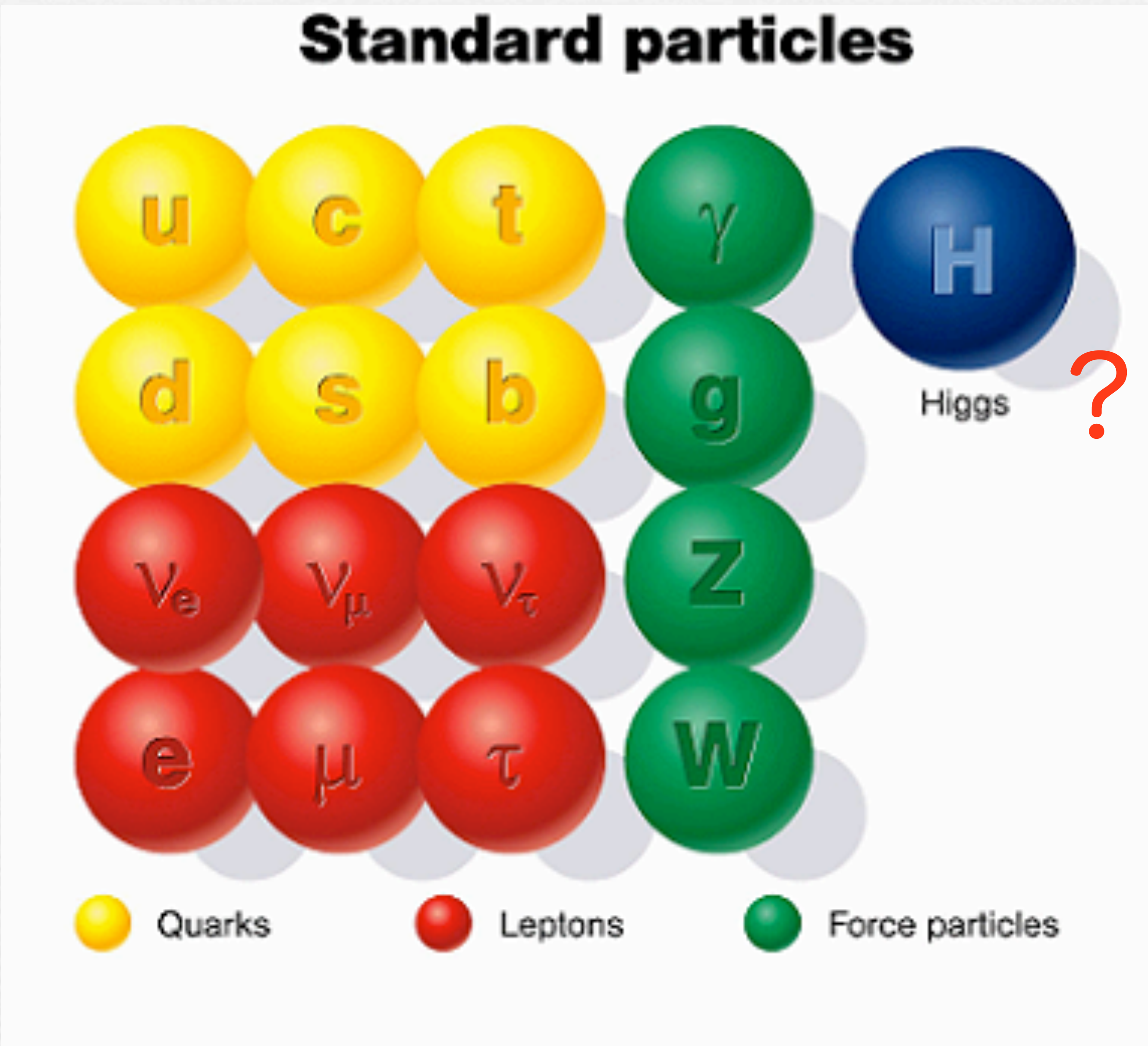
For the ATLAS collaboration

2013年9月21日 日本物理学会 2013年秋季大会 高知大学朝倉キャンパス

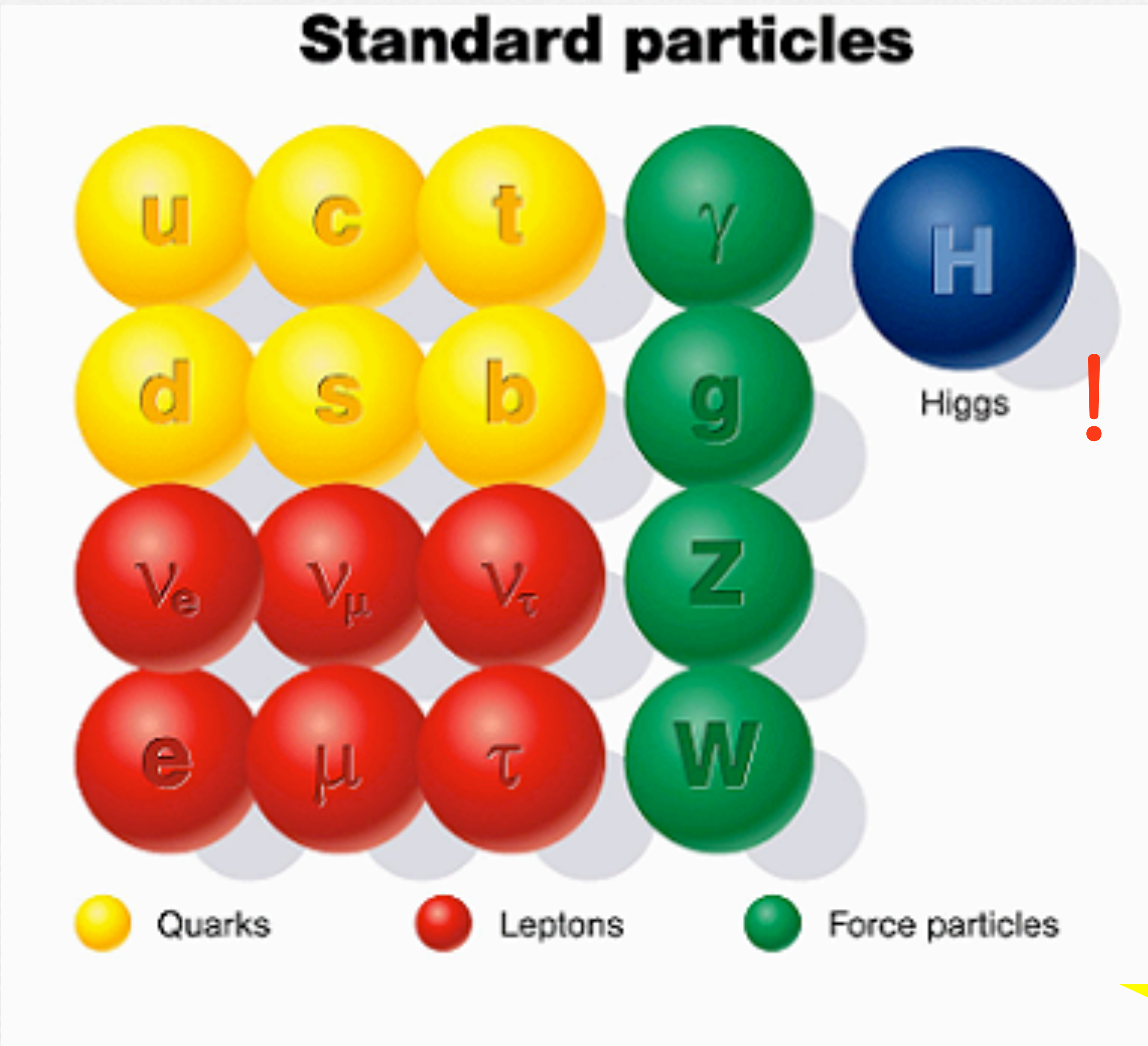
素粒子物理の状況 (LHC開始前)



1897年：electron
1900年：γ-ray
1932年：positron
1937年：μ
1956年：neutrino
1962年：ν_e and ν_μ are different
1969年：u,d,s quark
1974年：c quark
1975年：τ
1977年：b-quark
1979年：gluon
1983年：W/Z boson
1995年：t quark
2000年：ν_τ

標準模型

素粒子物理の状況 (LHC開始後)



!

LHC 2011年

: electron
: γ-ray
: positron
: μ
: neutrino
: ν_e and ν_μ are different
: u,d,s quark
: c quark
: τ
: b-quark
: gluon
: W/Z boson
: t quark
: ν_τ

標準模型

LHC 2012年：A Higgs boson

ヒッグスからテラスケールへ

ヒッグス粒子 ：人類初の種類の素粒子（スカラーボゾン）

質量 $m_H = 125.5 \pm 0.2\ (\mathrm{stat})\ {}^{+0.5}_{-0.6}\ (\mathrm{sys})\ \mathrm{GeV}$ (ATLAS)

ゲージ粒子やフェルミオンの質量と関連？

ヒッグス粒子の質量の安定性？

Fine tuning、階層性問題

ヒッグス粒子の「性質」の精密測定→「ヒッグス物理」開始

質量、スピンーパリティ、結合、、、、、

ヒッグス粒子の問題を解決する新しい物理探索

SUSY、余剰次元、.....、surprise？がテラスケールに

ヒッグスからテラスケールへ

ヒッグス粒子 ：人類初の種類の素粒子（スカラーボゾン）

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Fine tuning、階層性問題

1、ヒッグス粒子の「性質」の精密測定→「ヒッグス物理」

質量、スピンーパリティ、結合、、、、

2、ヒッグス粒子の問題を解決する新しい物理探索

SUSY、余剰次元、......、surprise？がテラスケールに

ヒッグス物理

と

新物理 (SUSY) 探索

ATLASでの現状

LHCとATLAS

LHC Run I

LHCは順調

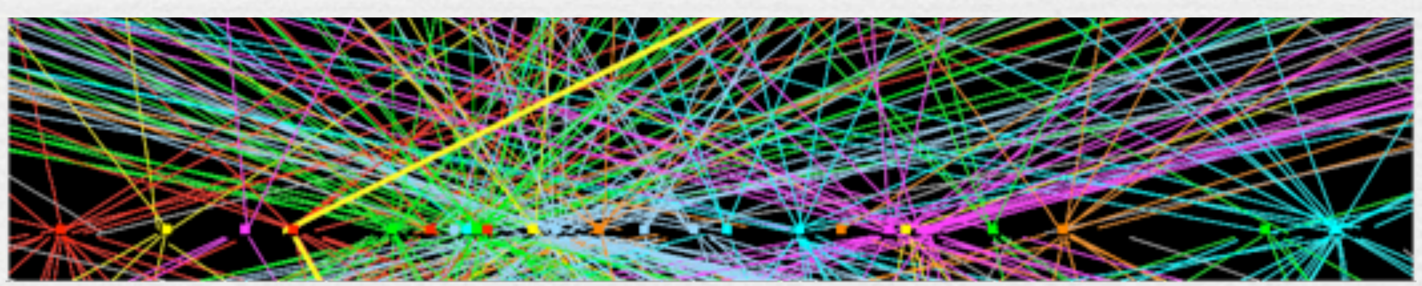
- Peak : 7.7 x 10^{33} cm^{-2} s^{-1}
- Delivered: 5.6 + 23.3 fb^{-1}

ATLAS検出器も順調

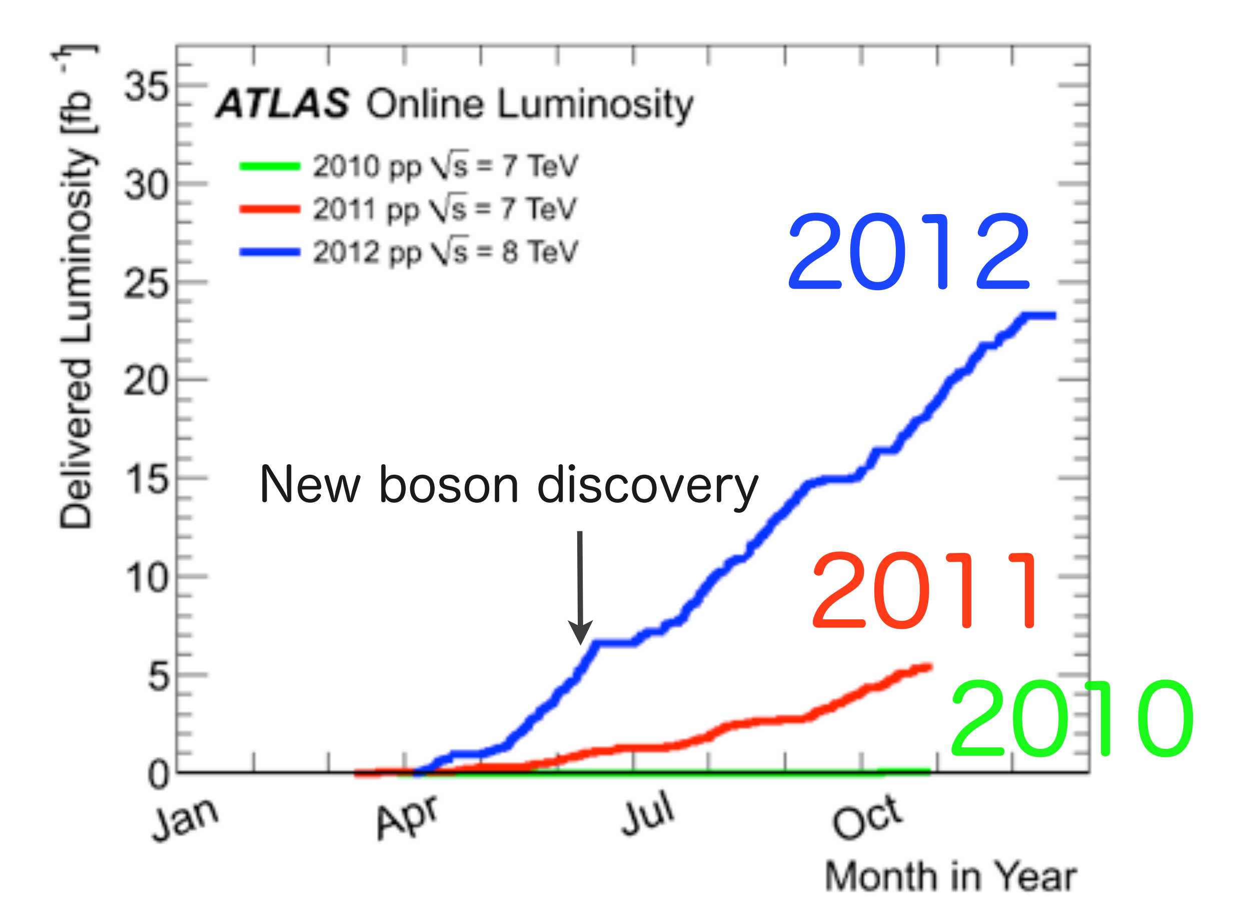
- ~5.2fb^{-1} (2011, $\sqrt{s} = 7$ TeV)
- ~21.3fb^{-1} (2012, $\sqrt{s} = 8$ TeV)

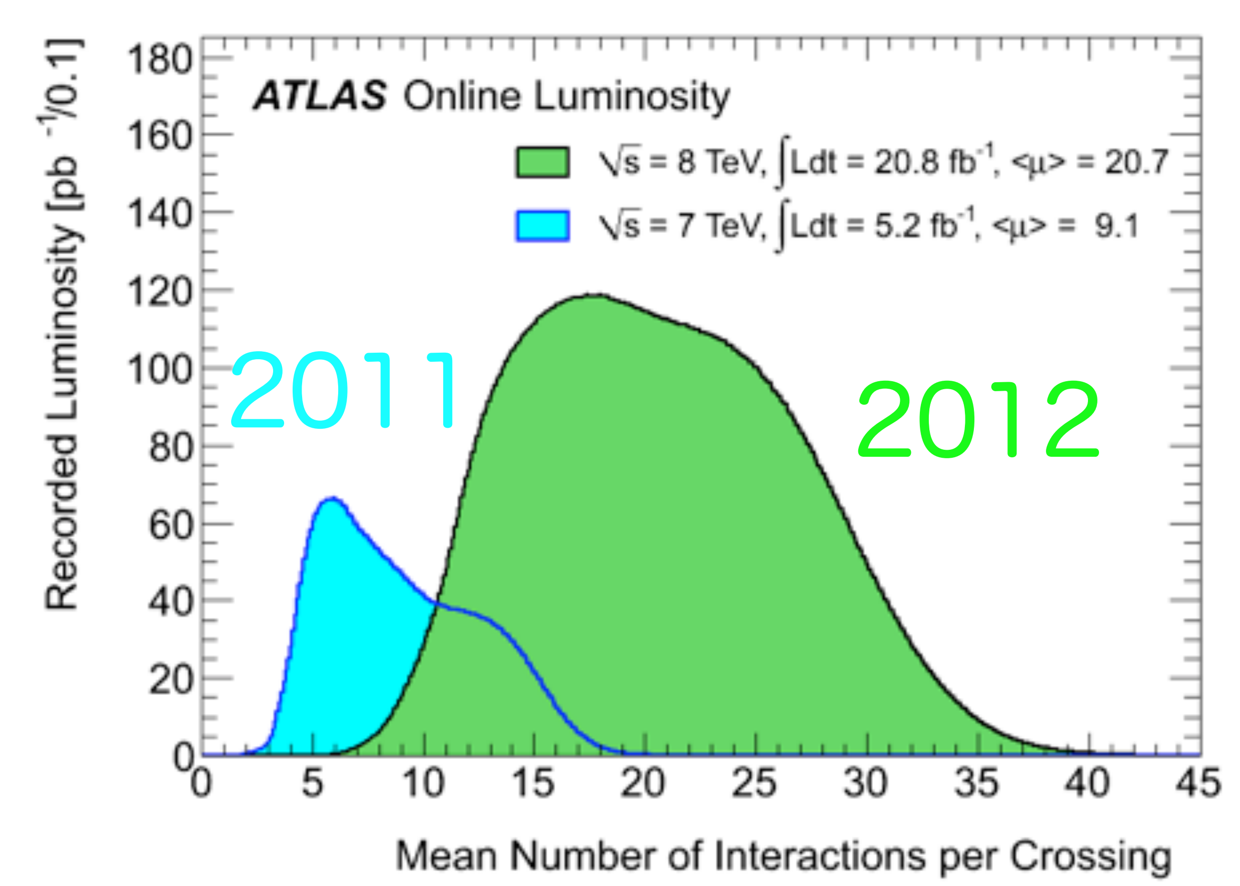
Pile-up事象の増加

- 平均20 interactions/crossing



Z→μμ事象 25 interactions

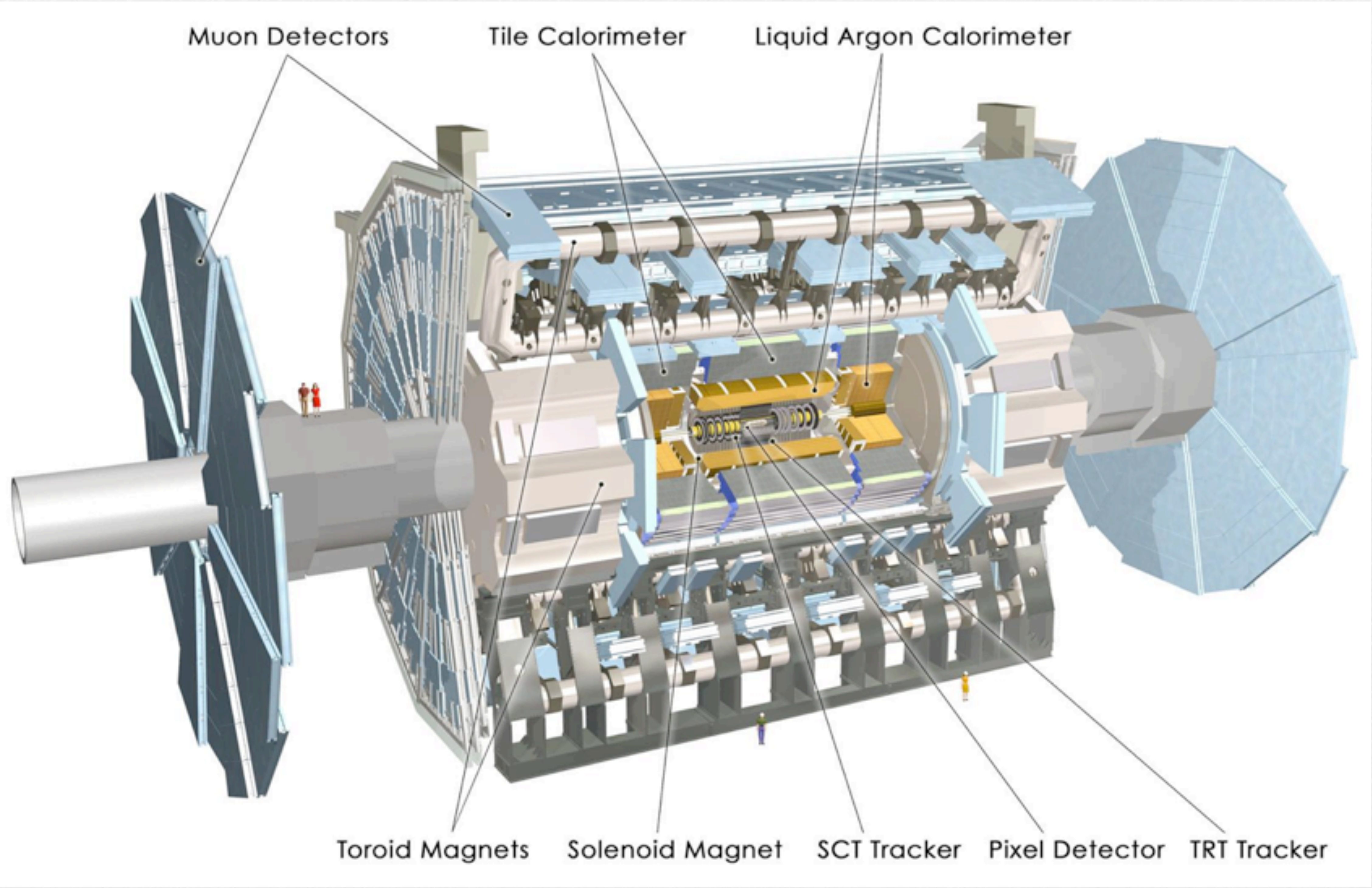




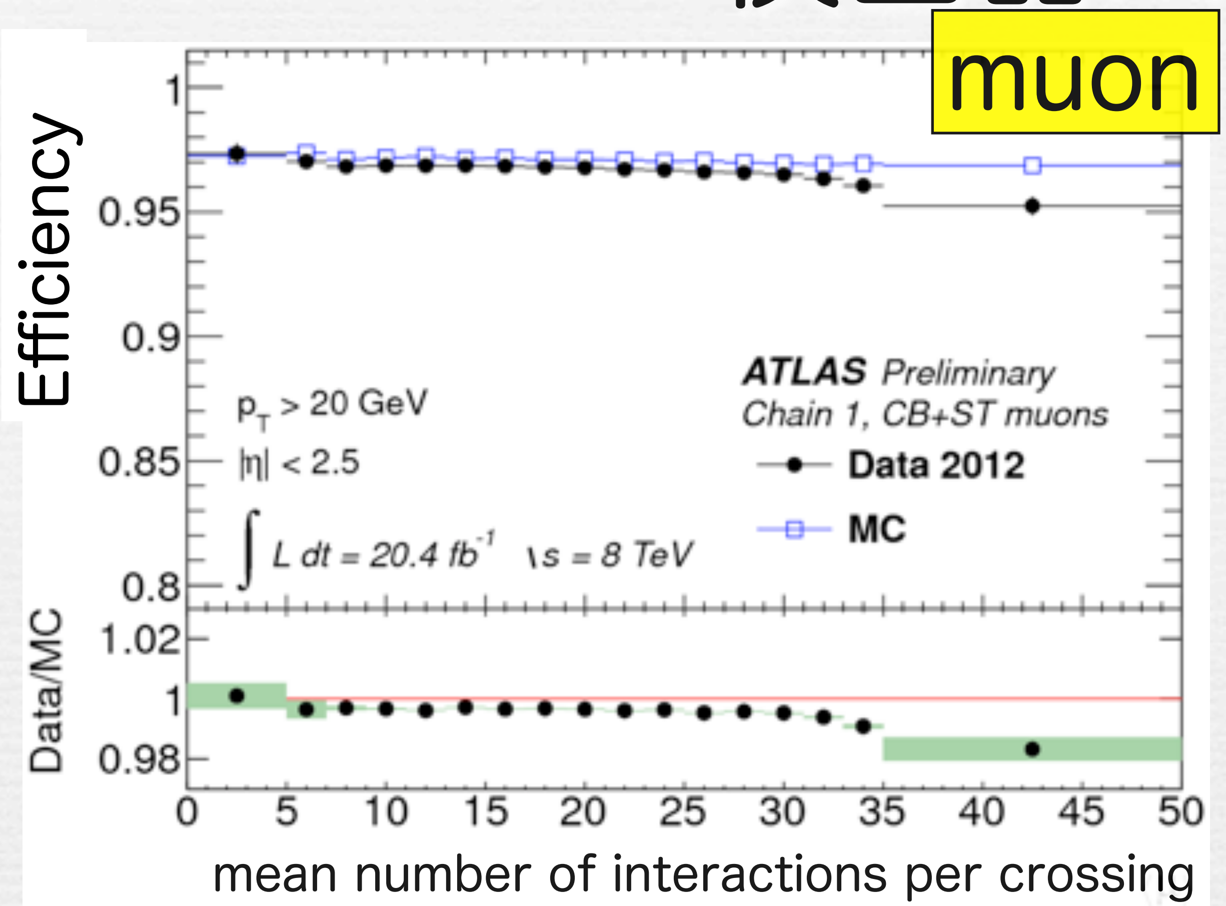
ATLAS 検出器

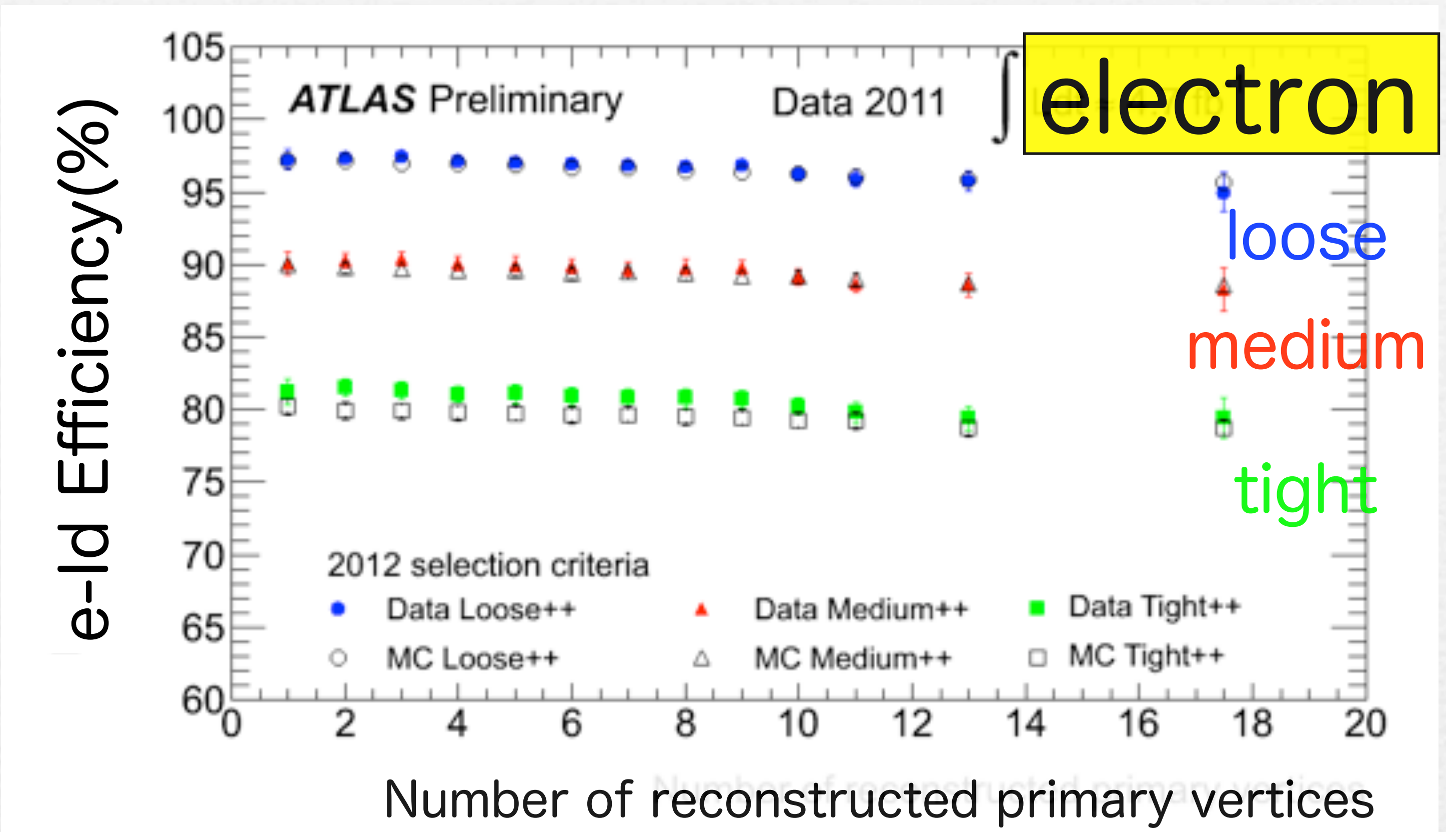
汎用検出器：標準模型、ヒッグス粒子、新物理に感度

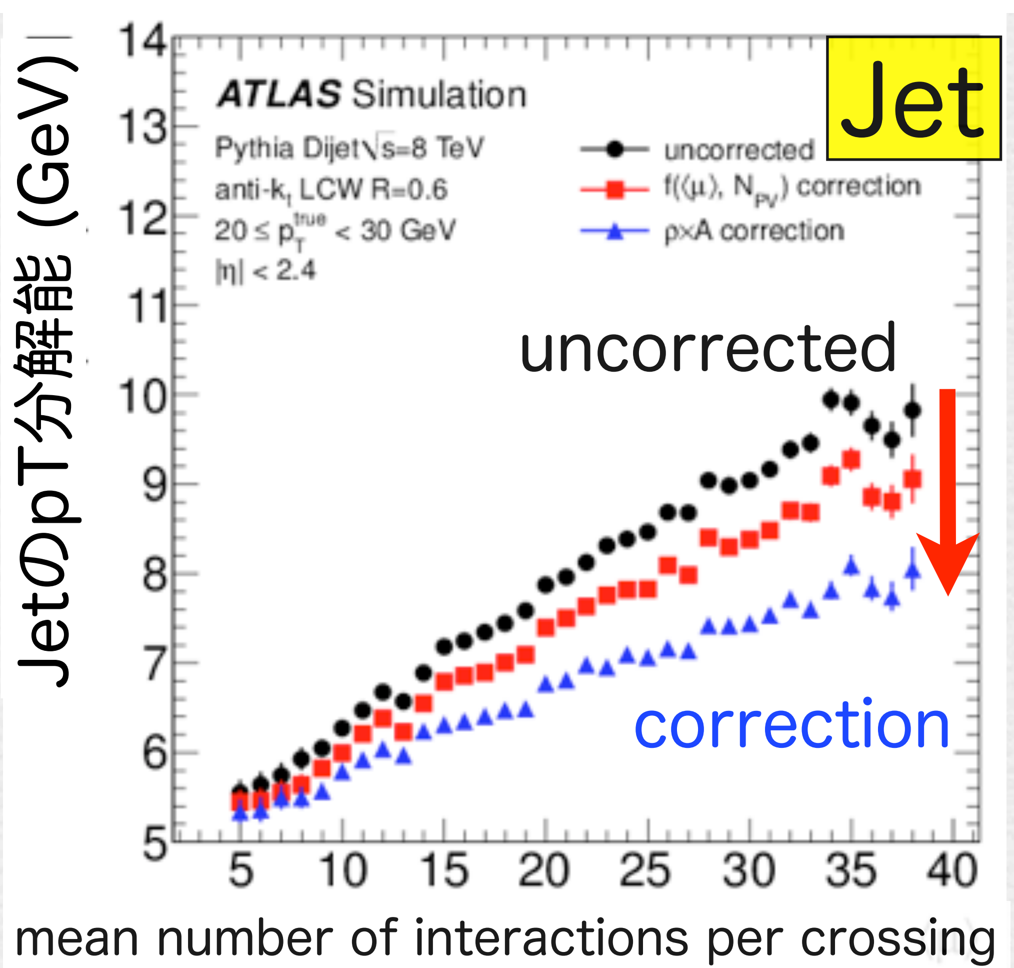
→e, γ, q/g-jets, μ, E_T^{miss} ... をバランスよく測定

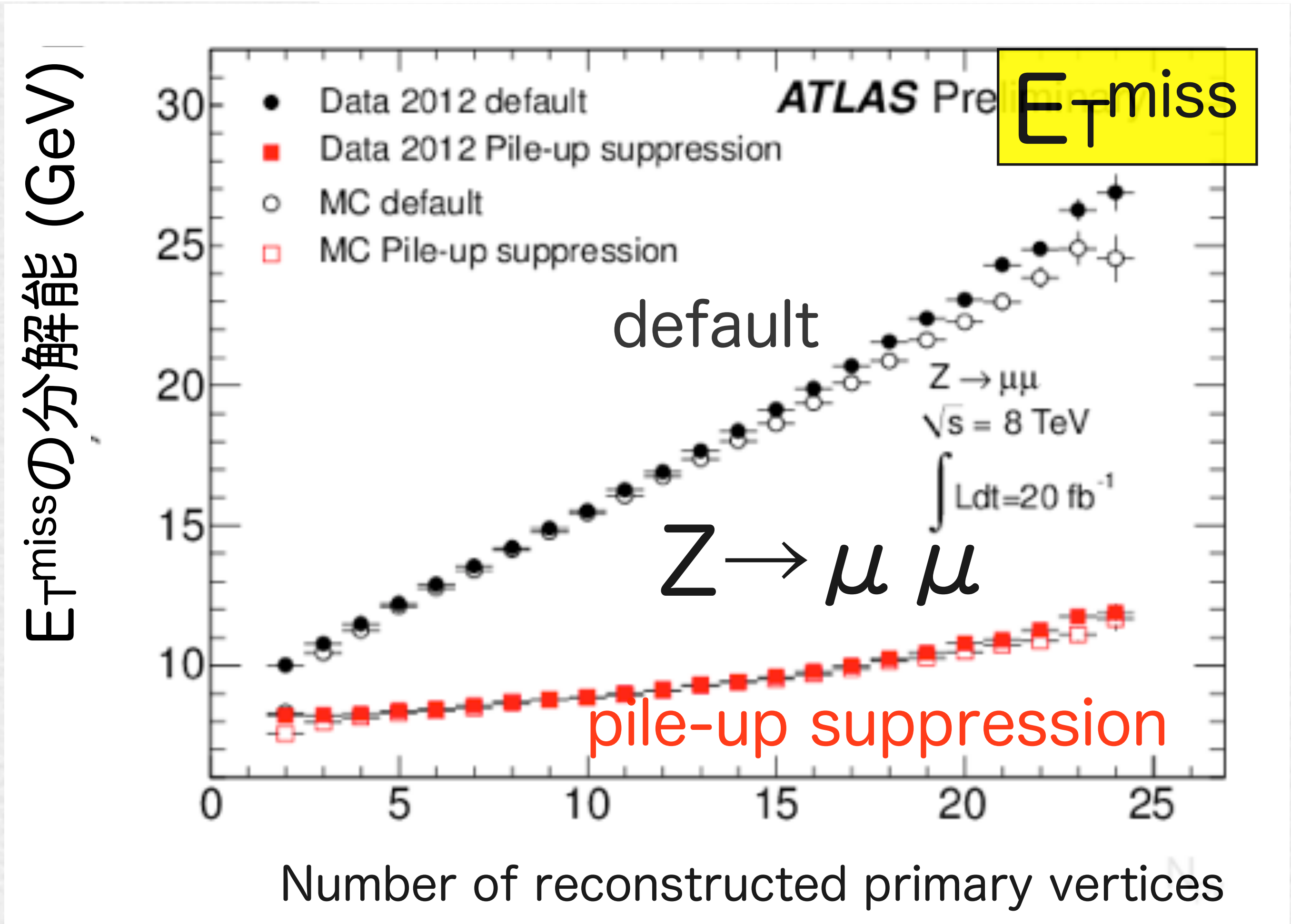


検出器パフォーマンス

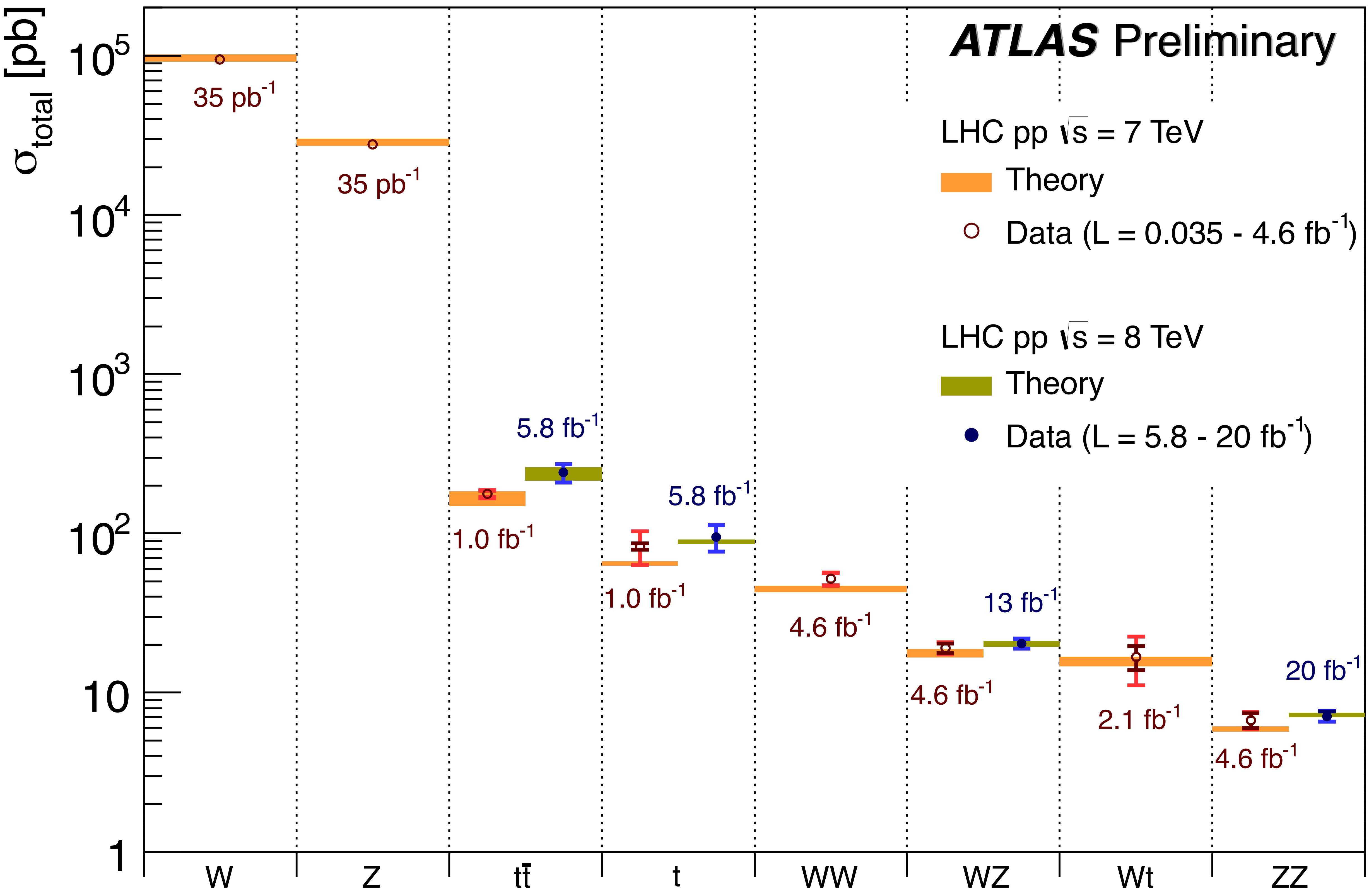

muon
Efficiency
Data/MC
ATLAS Preliminary
Chain 1, CB+ST muons
p_T > 20 GeV
|η| < 2.5
∫ L dt = 20.4 fb^-1 √s = 8 TeV
Data 2012
MC
mean number of interactions per crossing


electron
ATLAS Preliminary
Data 2011
e-Id Efficiency(%)
loose
medium
tight
2012 selection criteria
Data Loose++
MC Loose++
Data Medium++
MC Medium++
Data Tight++
MC Tight++
Number of reconstructed primary vertices


Jet
JetのpT分解能 (GeV)
ATLAS Simulation
Pythia Dijet √s=8 TeV
anti-k_t LCW R=0.6
20 ≤ p_T^true < 30 GeV
|η| < 2.4
uncorrected
f(⟨μ⟩, N_PV) correction
ρ×A correction
uncorrected
correction
mean number of interactions per crossing

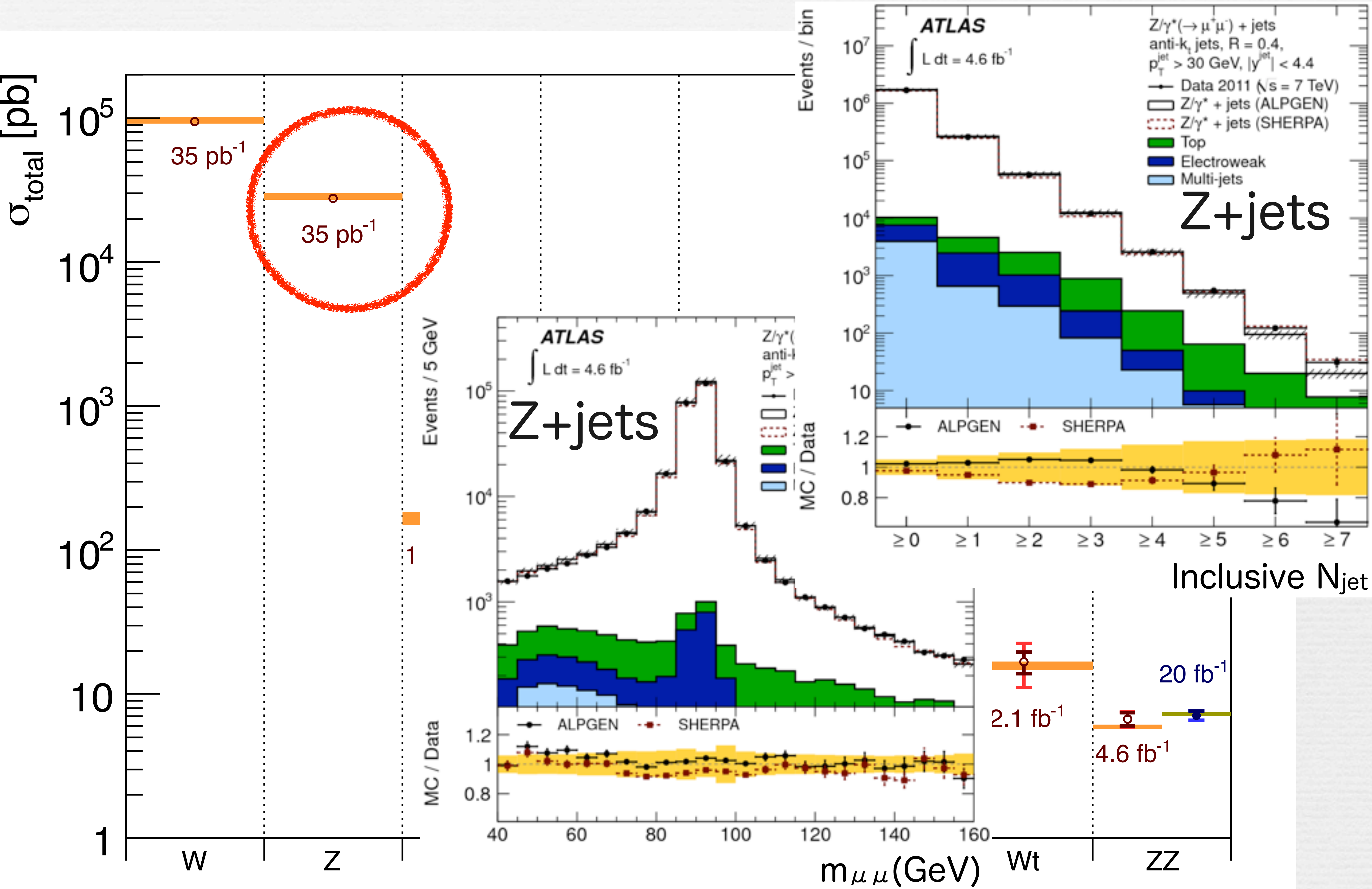

E_T^miss
ATLAS Pre
E_T^missの分解能 (GeV)
Data 2012 default
Data 2012 Pile-up suppression
MC default
MC Pile-up suppression
default
Z → μμ
√s = 8 TeV
∫Ldt=20 fb^-1
Z→μμ
pile-up suppression
Number of reconstructed primary vertices

標準模型の物理

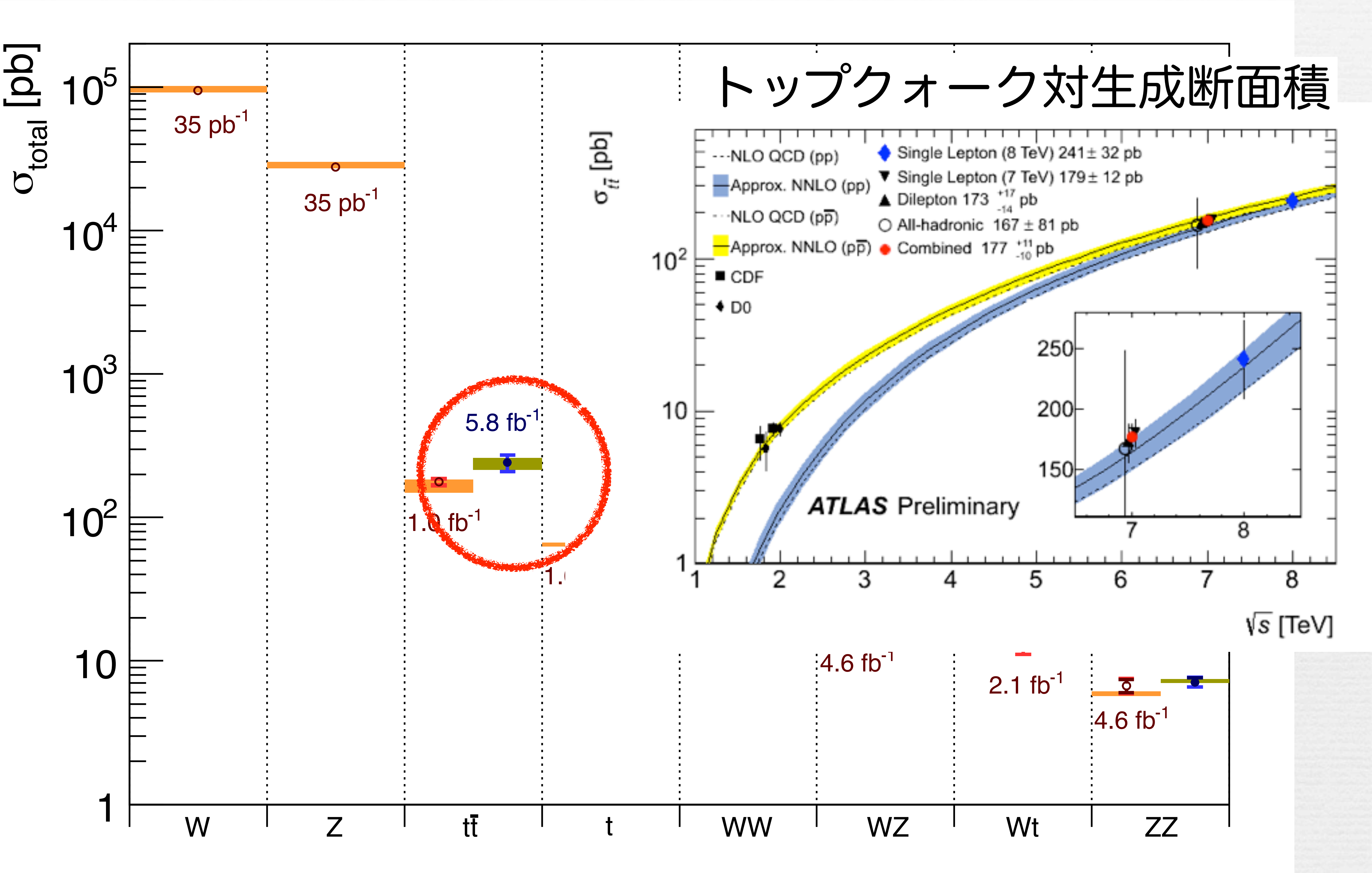


ATLAS Preliminary
LHC pp √s = 7 TeV
Theory
Data (L = 0.035 - 4.6 fb-1)
LHC pp √s = 8 TeV
Theory
Data (L = 5.8 - 20 fb-1)
σtotal [pb]
10^5
10^4
10^3
10^2
10
1
35 pb-1
35 pb-1
5.8 fb-1
1.0 fb-1
5.8 fb-1
1.0 fb-1
4.6 fb-1
13 fb-1
4.6 fb-1
2.1 fb-1
20 fb-1
4.6 fb-1
W
Z
tt̄
t
WW
WZ
Wt
ZZ

標準模型の物理


σtotal [pb]
35 pb-1
35 pb-1
1
2.1 fb-1
4.6 fb-1
20 fb-1
W
Z
Wt
ZZ
ATLAS
∫ L dt = 4.6 fb-1
Z/γ*(→ μ+μ-) + jets
anti-kt jets, R = 0.4,
pT jet > 30 GeV, |y jet| < 4.4
Data 2011 (√s = 7 TeV)
Z/γ* + jets (ALPGEN)
Z/γ* + jets (SHERPA)
Top
Electroweak
Multi-jets
Z+jets
Events / bin
MC / Data
ALPGEN
SHERPA
Inclusive Njet
Events / 5 GeV
Z+jets
mμμ(GeV)

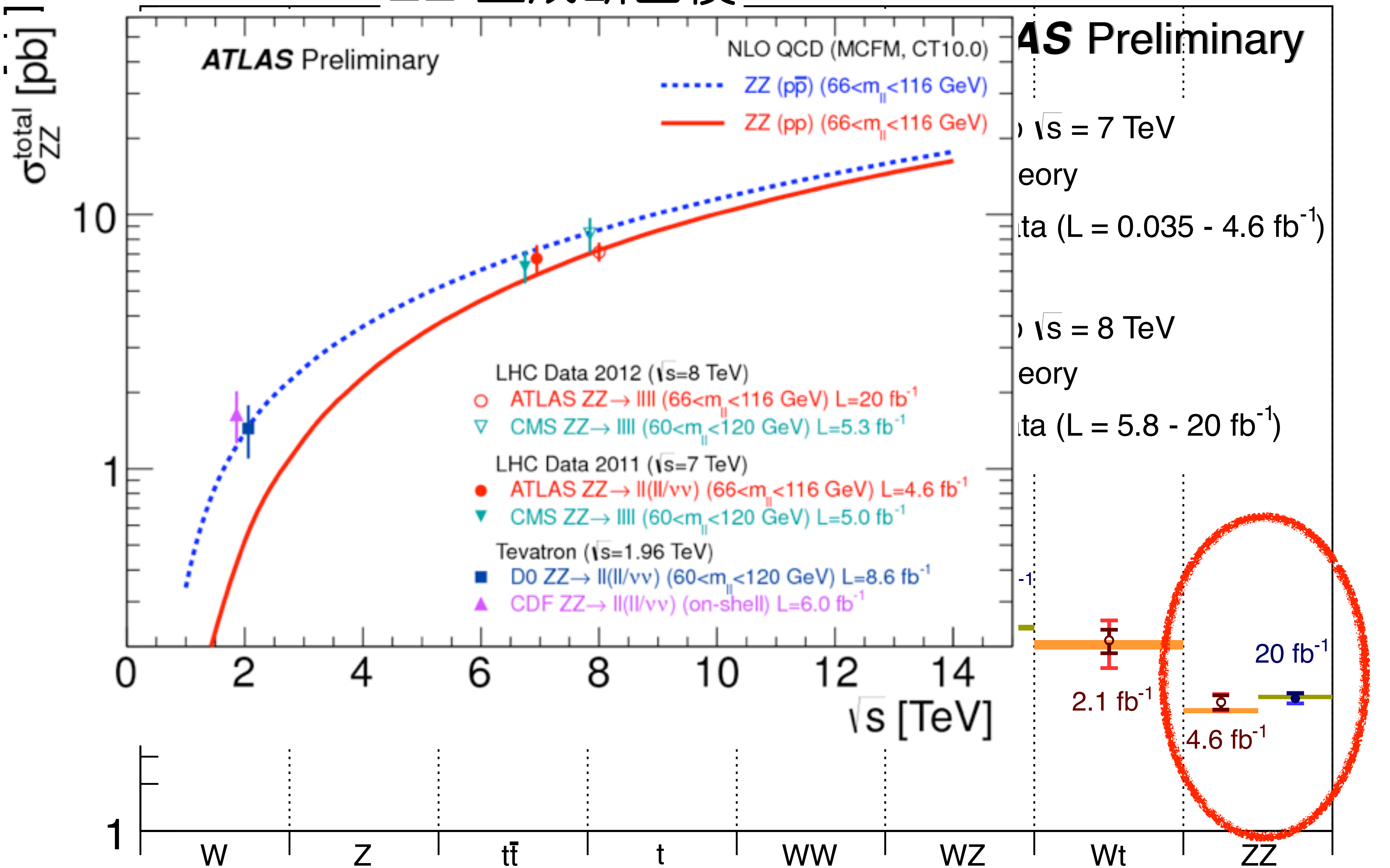
標準模型の物理



σtotal [pb]
10^5
10^4
10^3
10^2
10
1
35 pb-1
35 pb-1
5.8 fb-1
1.0 fb-1
4.6 fb-1
2.1 fb-1
4.6 fb-1
W
Z
tt̄
t
WW
WZ
Wt
ZZ
トップクォーク対生成断面積
σtt̄ [pb]
NLO QCD (pp)
Approx. NNLO (pp)
NLO QCD (pp̄)
Approx. NNLO (pp̄)
CDF
D0
Single Lepton (8 TeV) 241± 32 pb
Single Lepton (7 TeV) 179± 12 pb
Dilepton 173 +17 -14 pb
All-hadronic 167 ± 81 pb
Combined 177 +11 -10 pb
ATLAS Preliminary
√s [TeV]

標準模型の物理

ZZ 生成断面積



LHC 8TeV実験
ヒッグス物理の成果

生成過程

gluon-gluon融合 (ggF)

- 主にtop-quarkのループ
- フェルミオンとの結合の間接的証拠

Vector Boson融合 (VBF)

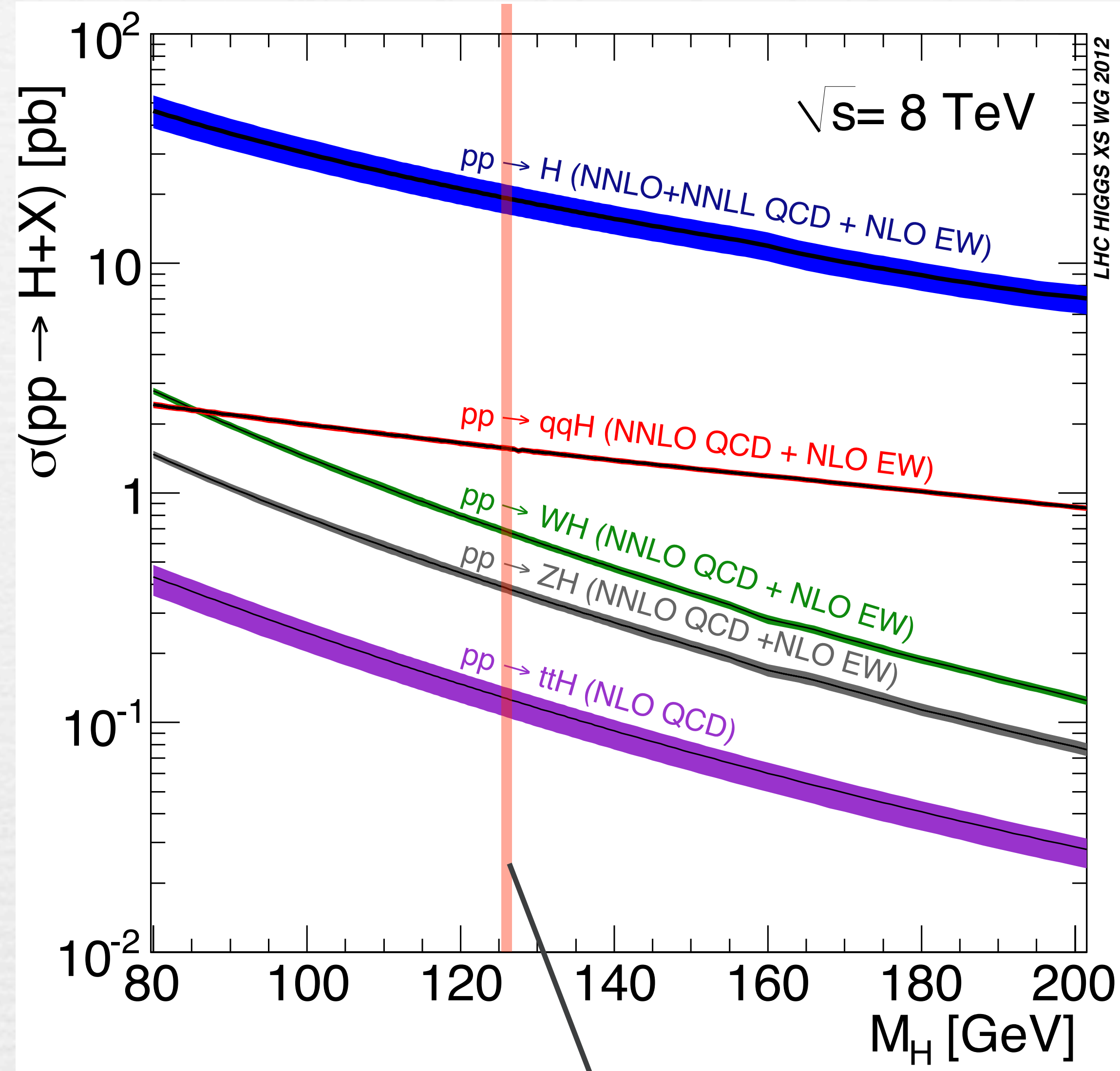
- ゲージボゾンとの結合の直接的証拠
- 前後方に出る2本のジェット

W/Zとの随伴生成 (VH)

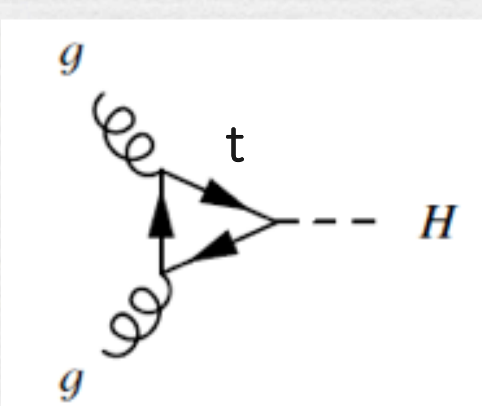
- ゲージボゾンとの結合の直接的証拠
- W/Zからの高運動量レプトン

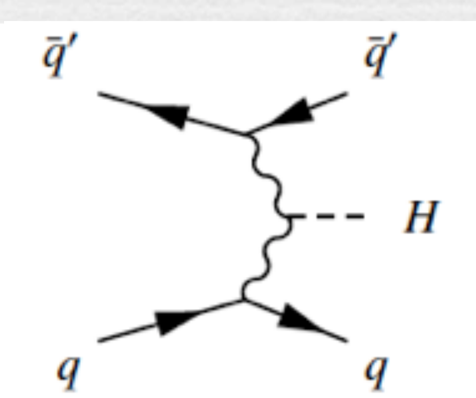
t-quark対との随伴生成 (ttH)

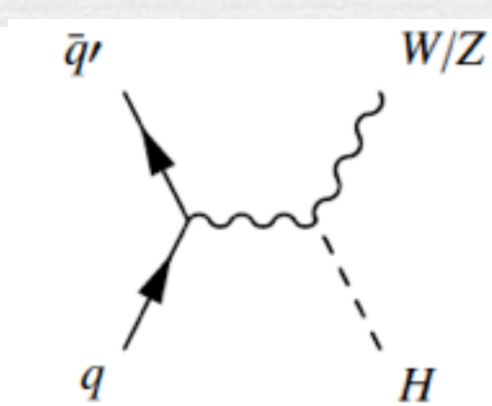
- Higgs-top quark結合の直接的証拠

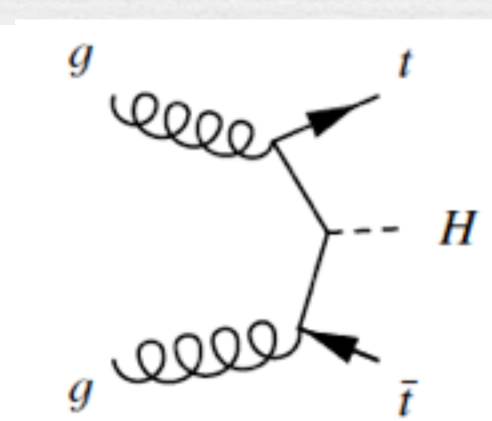


σ (pb)	7TeV	8TeV
ggF	15.1	19.2
VBF	1.2	1.6
WH	0.6	0.7
ZH	0.3	0.4
ttH	0.08	0.13



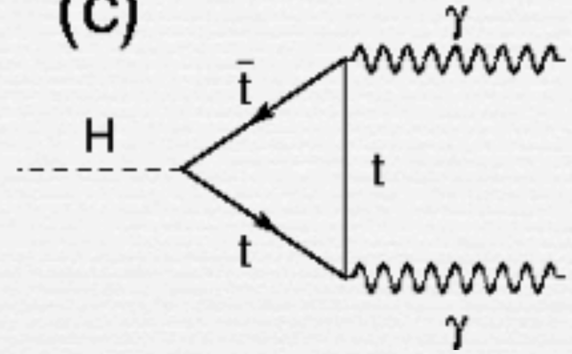






崩壊過程

(c)



H→γγ：Wとtop-quarkのLoopを経て崩壊

- Wとt-quarkは負符号で干渉する
- フェルミオンとの結合の間接的証拠

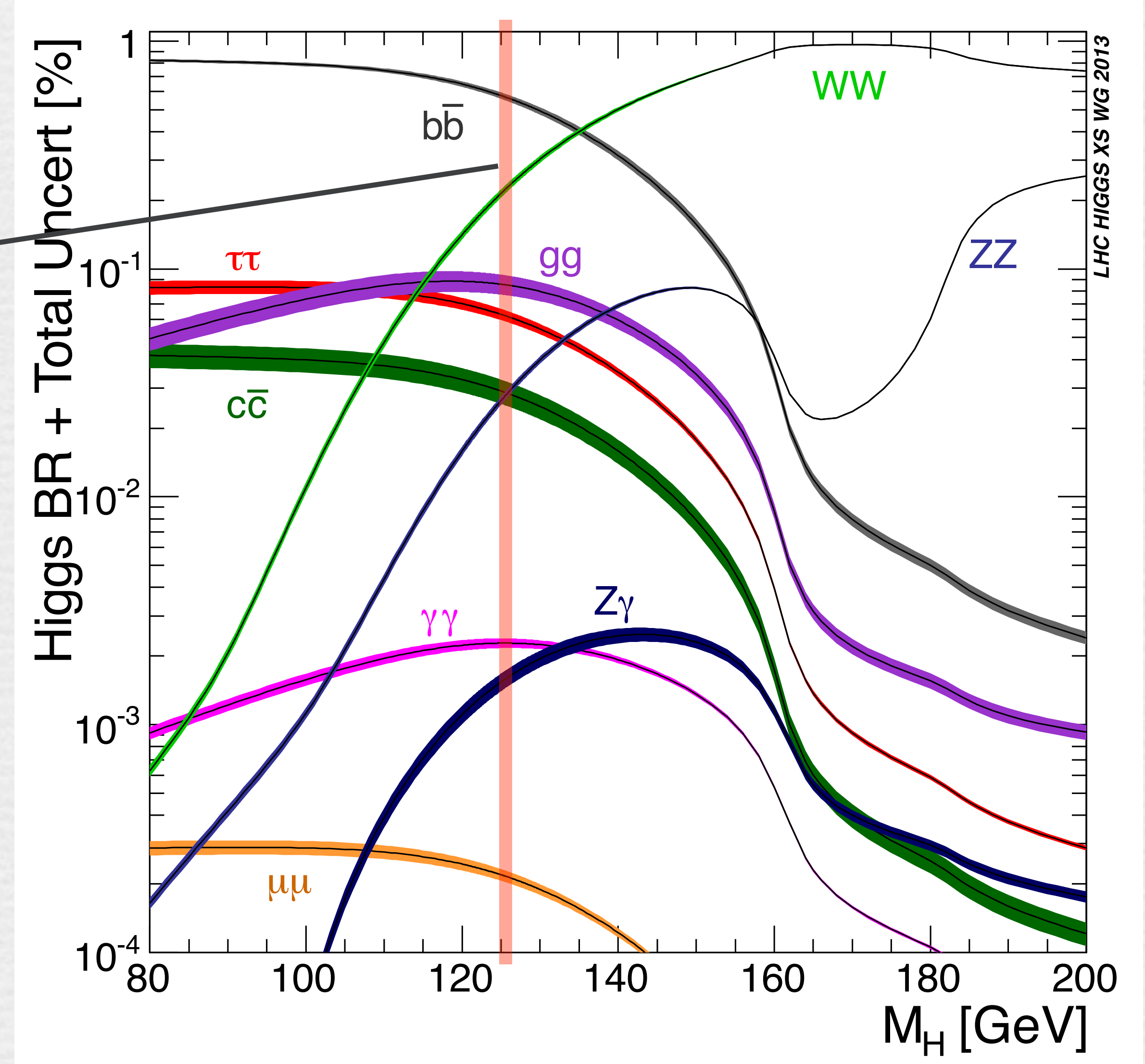
レプトンや光子が終状態のチャンネルが発見チャンネル

- H→γγ、ZZ(→4ℓ), WW(→ℓνℓν)

H→bb, H→ττ：膨大なQCD事象との分離が鍵

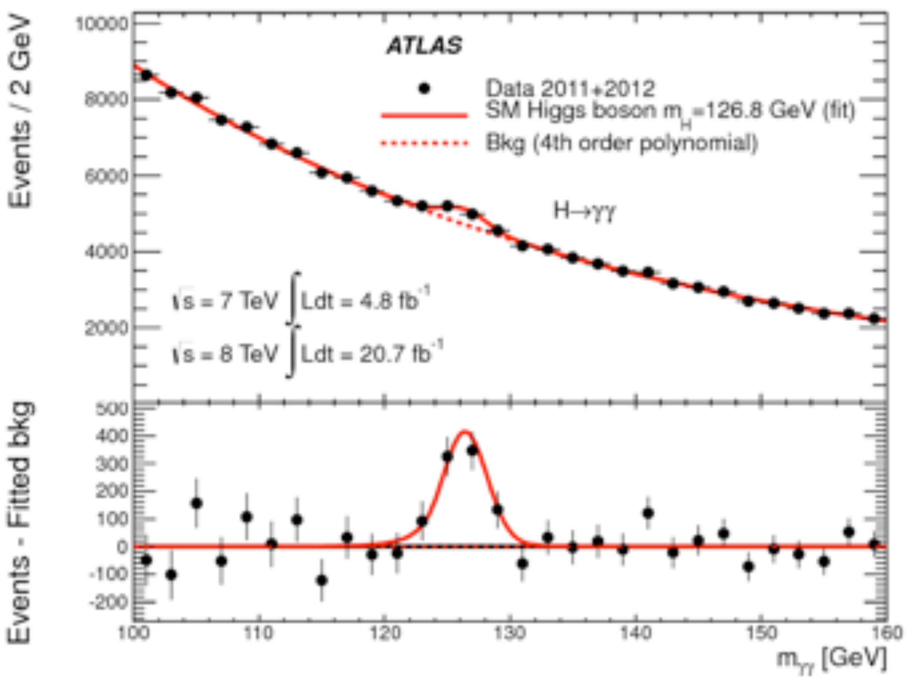
- フェルミオンとの結合の直接的証拠

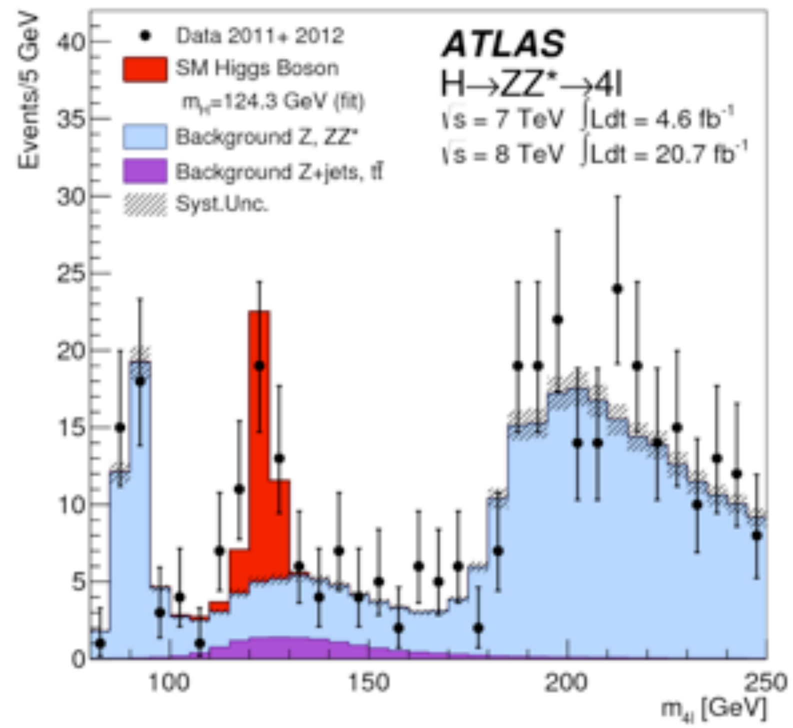
m_H=125.5GeV	BR(%)
H→γγ	0.23
H→ZZ	2.8
H→WW	22
H→ττ	6.2
H→bb	57

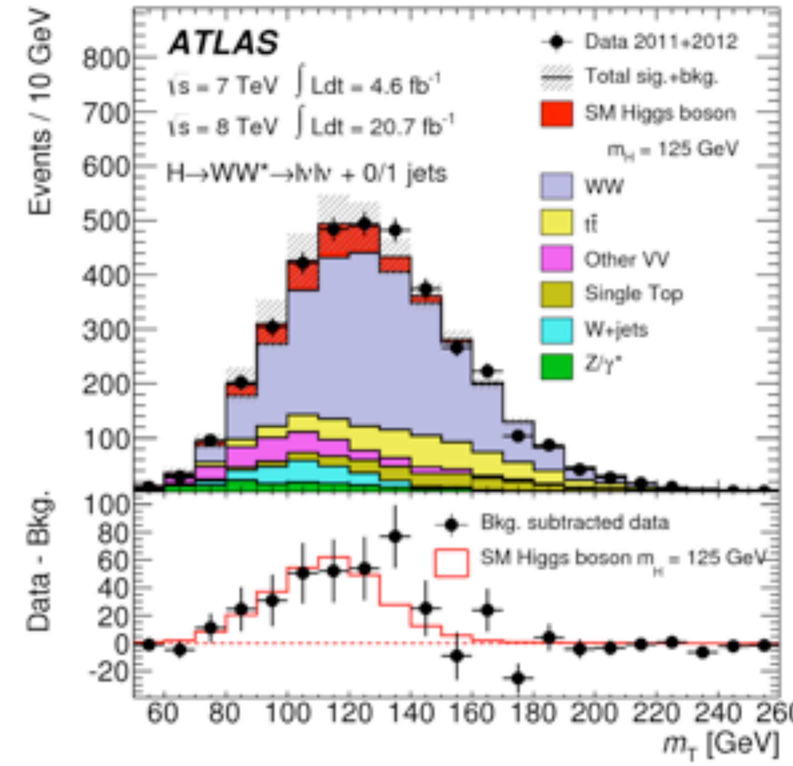


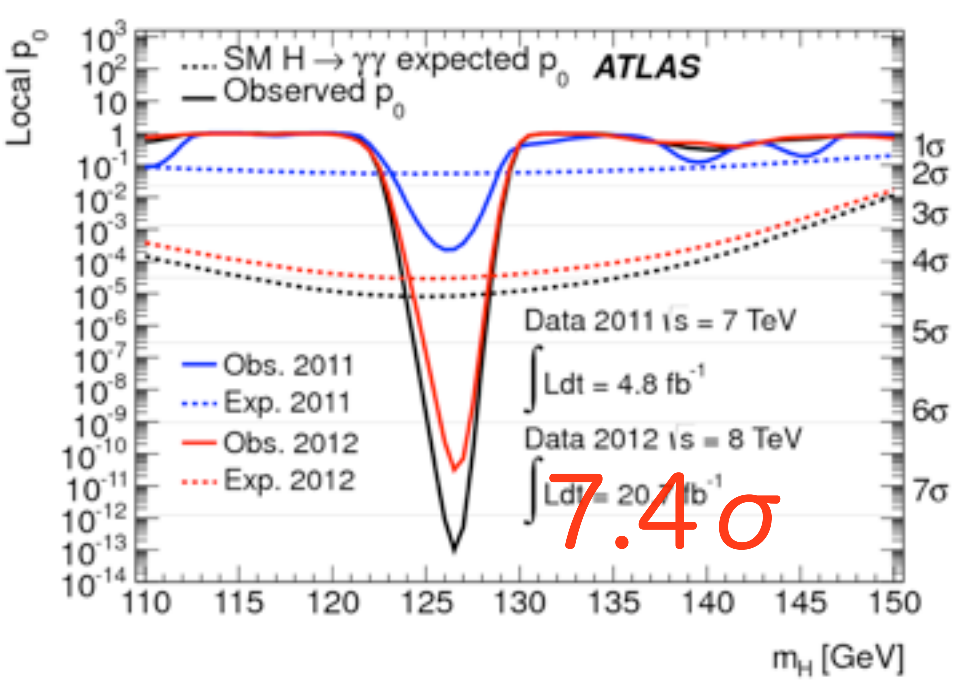
発見チャンネルの事象数

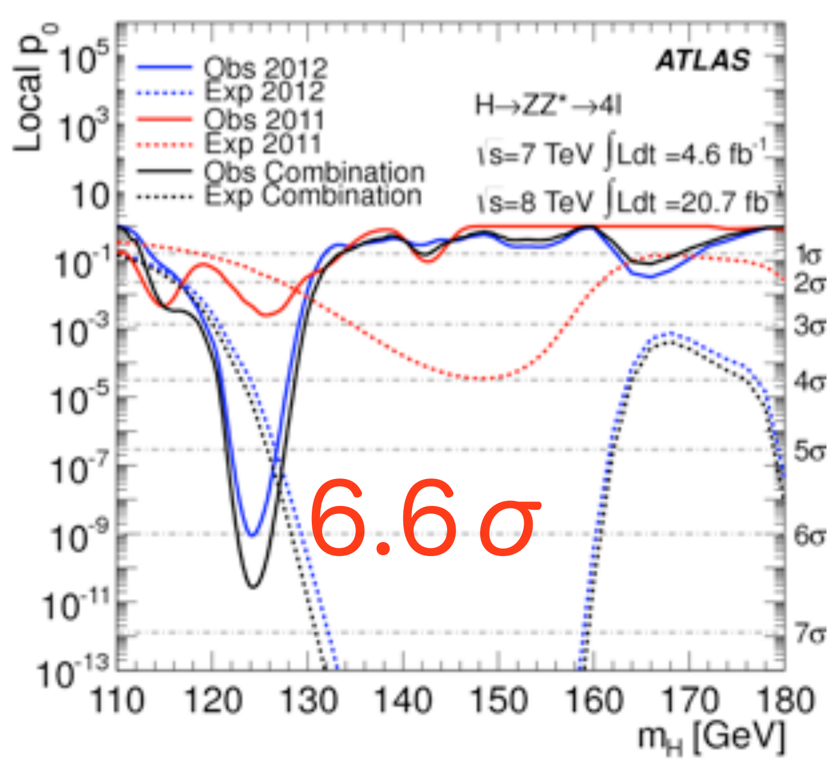
$H \to \gamma\gamma$	$H \to ZZ$	$H \to WW$

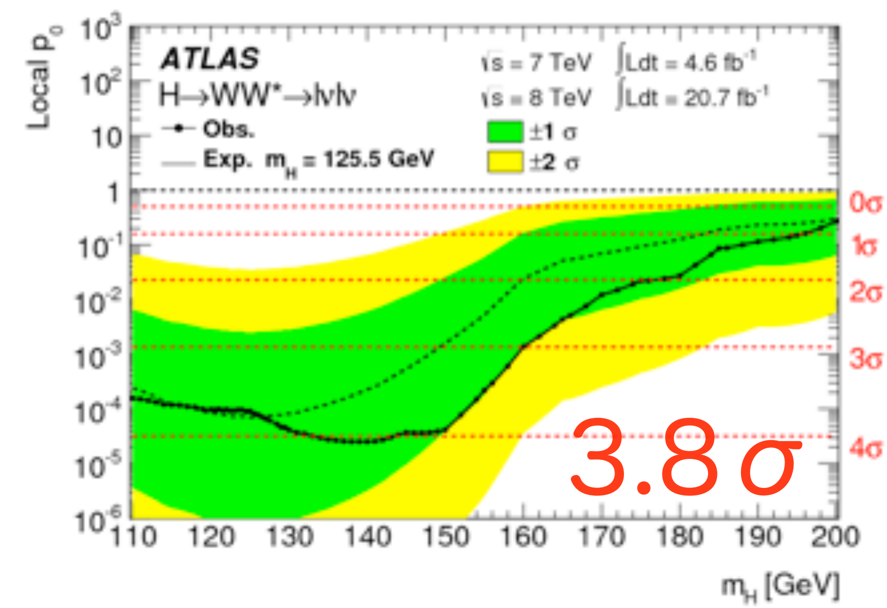








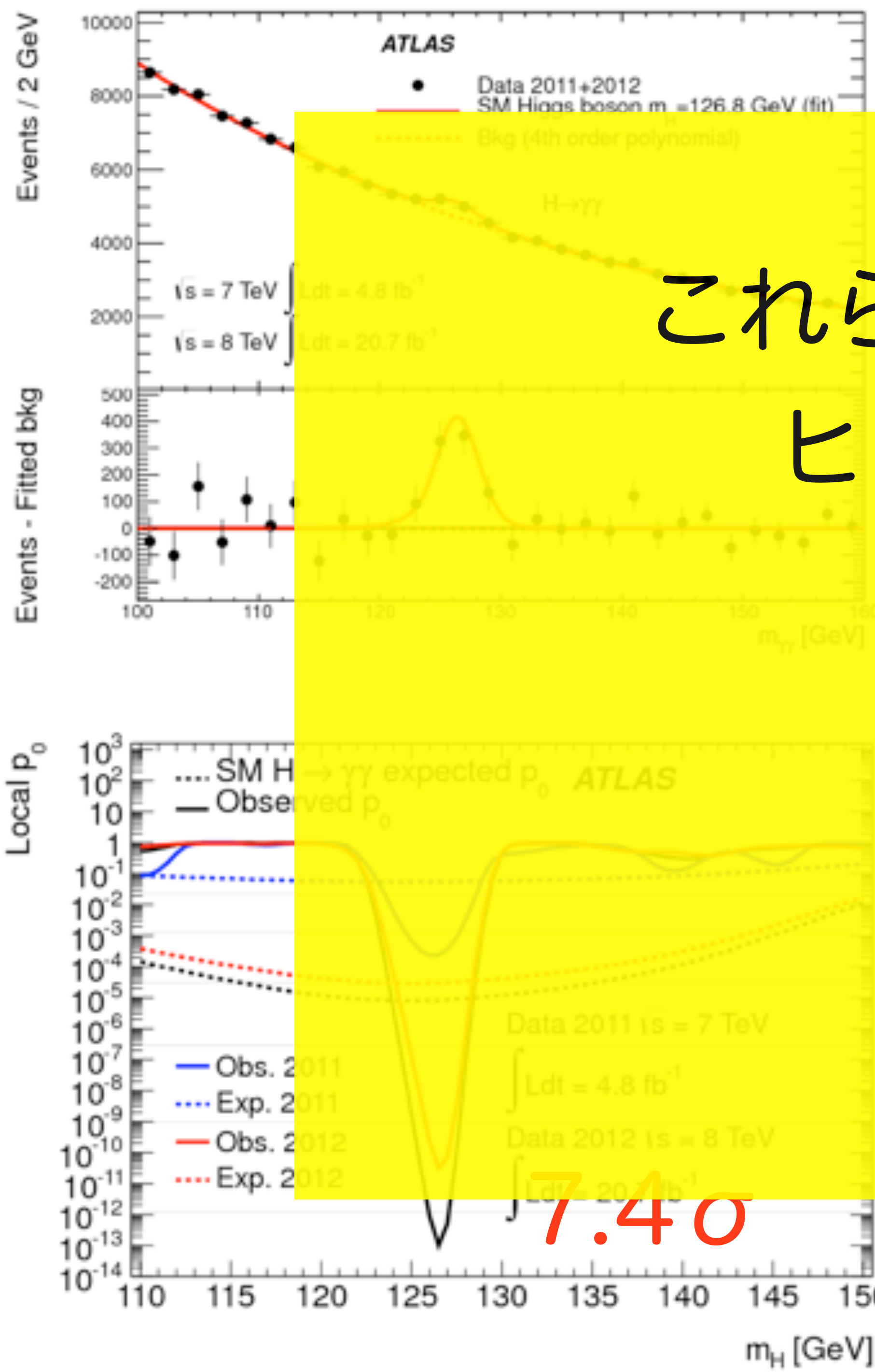




~370 信号事象	~15 信号事象	~150 信号事象

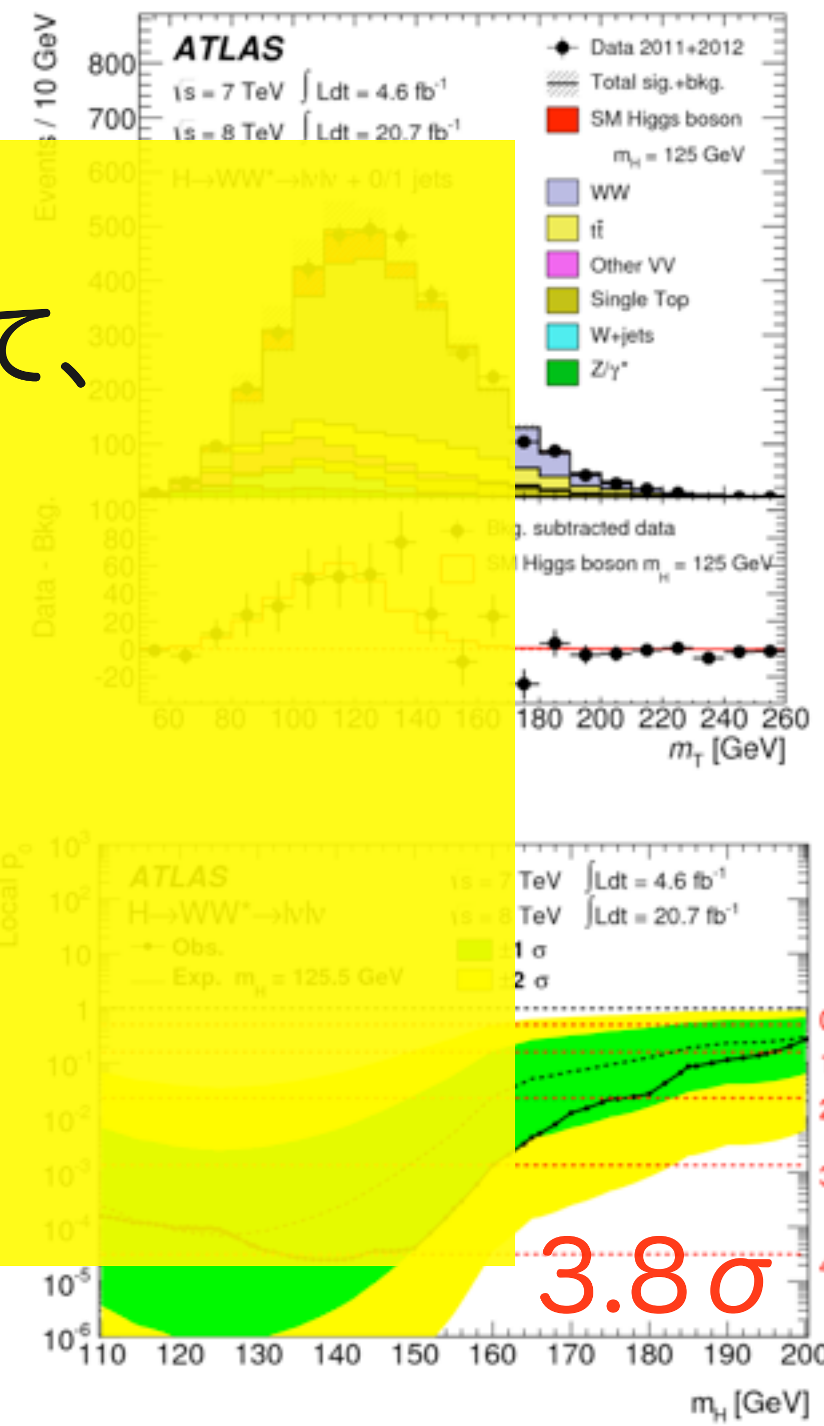
発見チャンネルの事象数

$H \to \gamma\gamma$



$H \to ZZ$

$H \to WW$



これらのチャンネルを使って、
ヒッグス粒子の「性質」
signal strengths,
結合,
スピン-パリティ
を測定

~370 信号事象

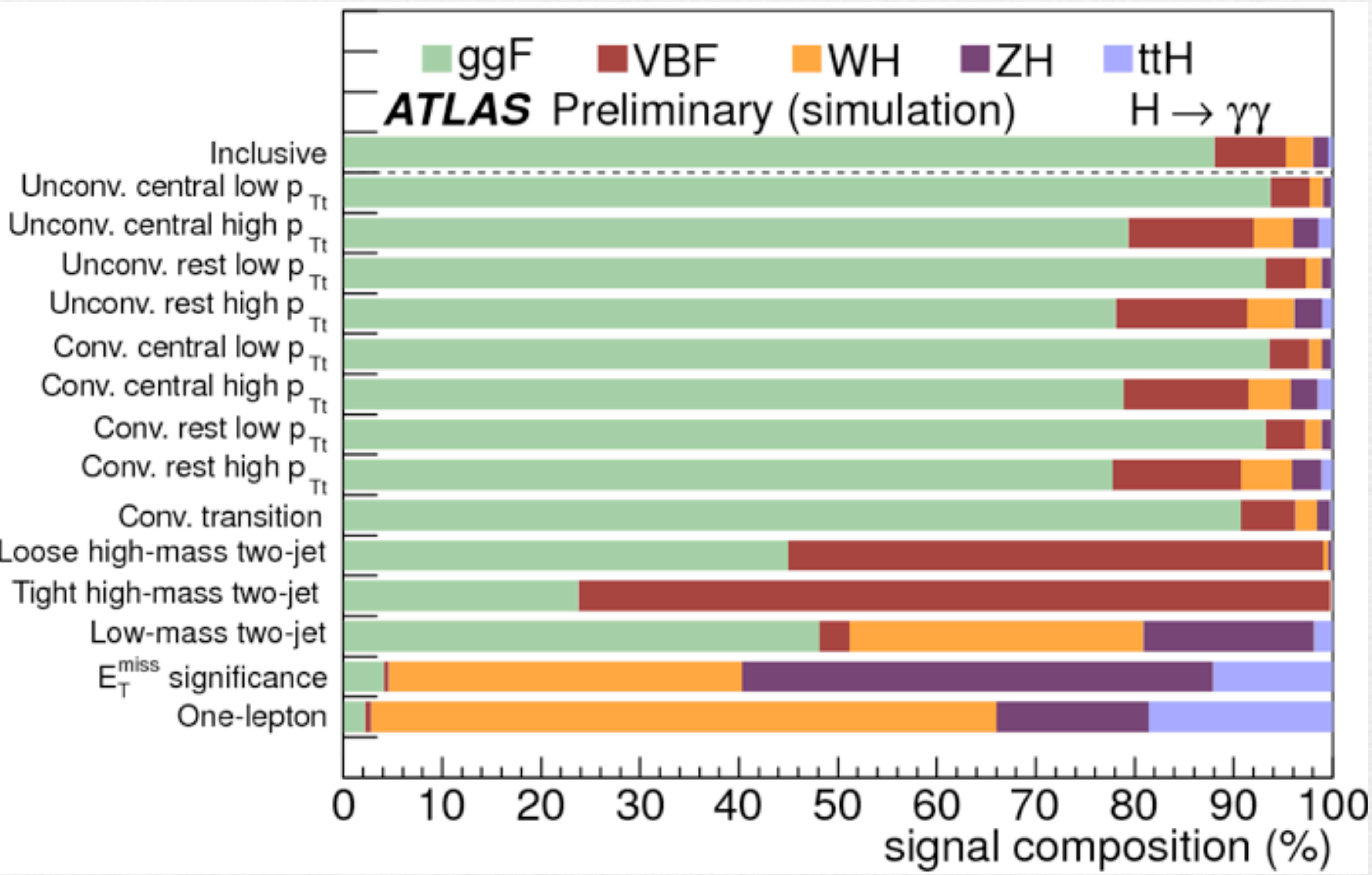
~15 信号事象

~150 信号事象

イベントの分類

測定感度をあげ 生成過程を特定 →couplingの測定で重要

H→γγ 9 categories for ggF, 2 for VBF, 3 for VH



γγ+

nothing →gluon融合

high mass di-jet →VBF

low mass di-jet
large E_T^{miss}
lepton
→W/Z+H

H→ZZ di-jet があるとVBF enriched、lepton があるとW/Z+H enriched カテゴリ

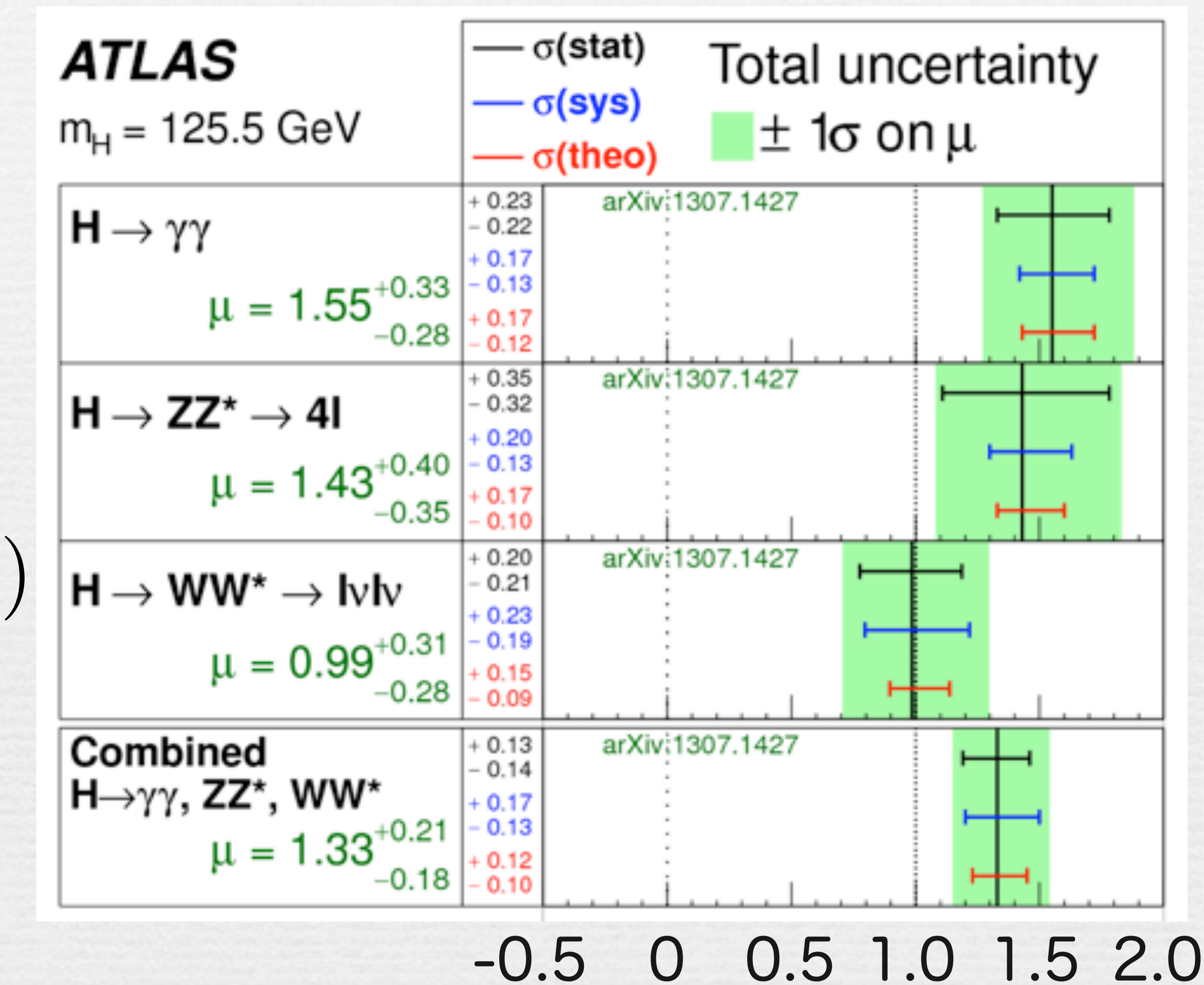
H→WW 2- jets があるとVBF enrichedカテゴリへ

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)



H→$\gamma\gamma$, ZZ, WW combined

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

(m_H=125.5GeV)

H→bb, $\tau\tau$ (L=13fb^{-1})

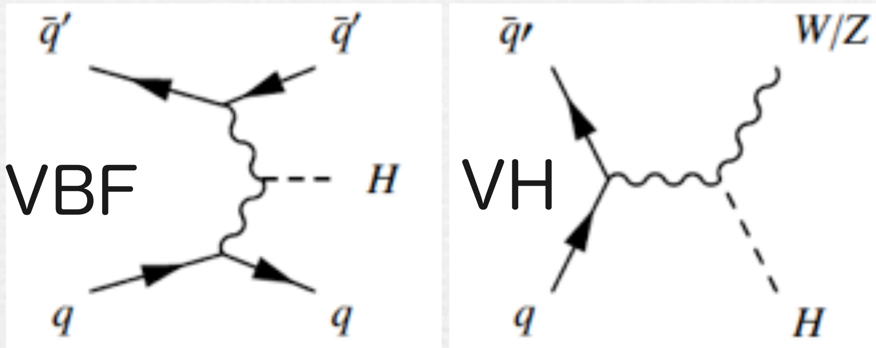
$$\mu = 1.23 \pm 0.18$$ (m_H=125.5GeV)

Evidence for production via VBF

arXiv:1307.1427

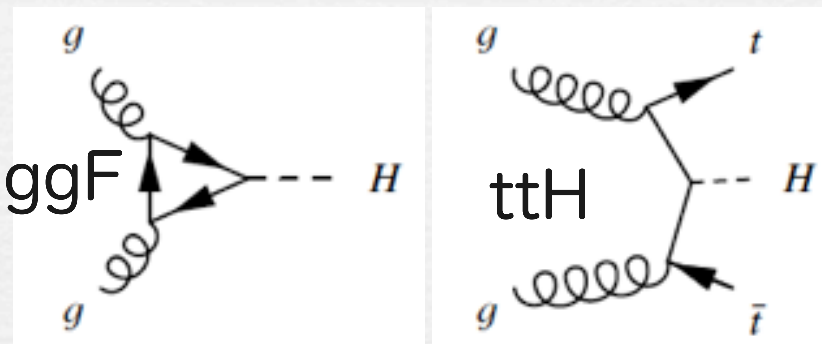
Signal strength μを

vector-boson-mediated processes

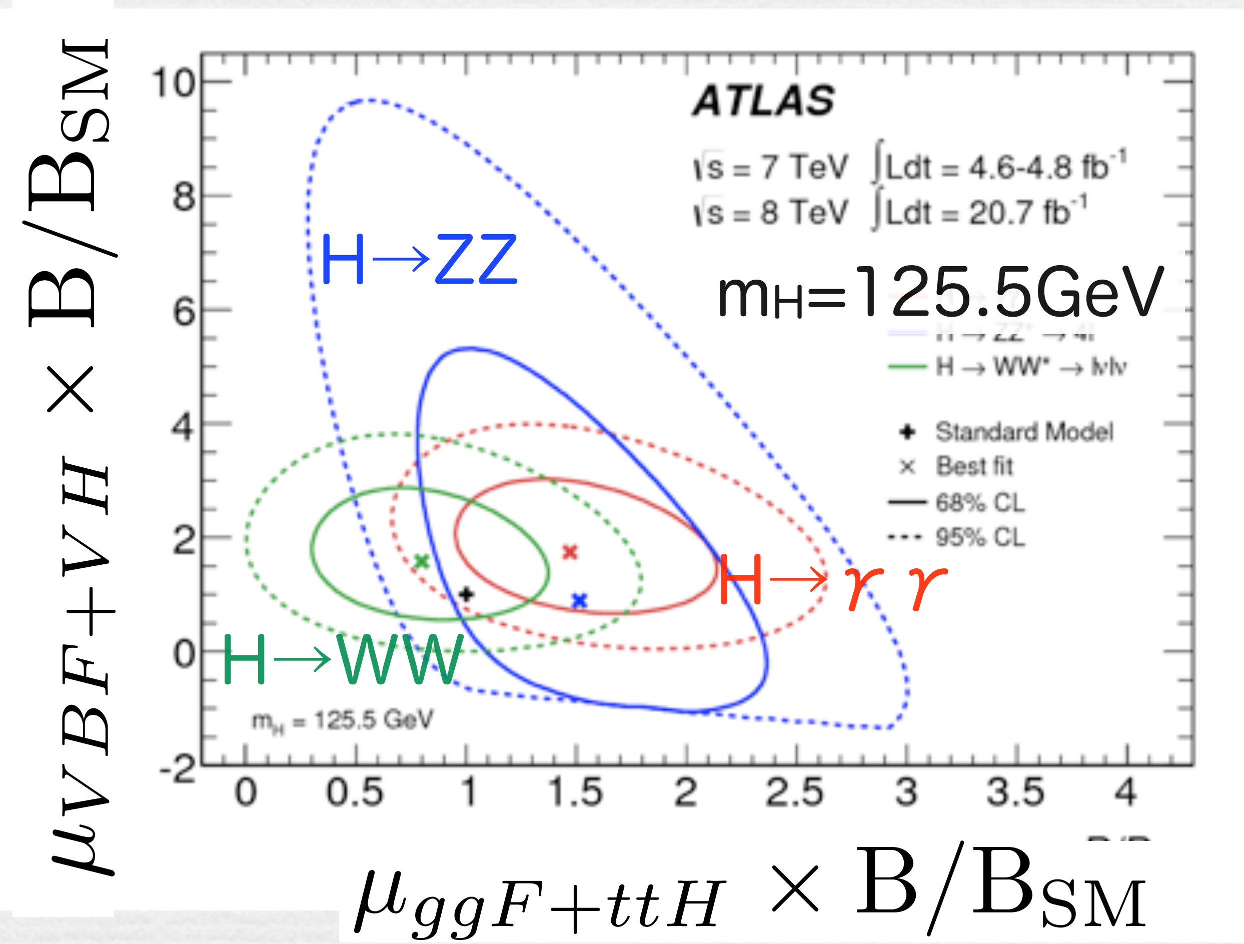


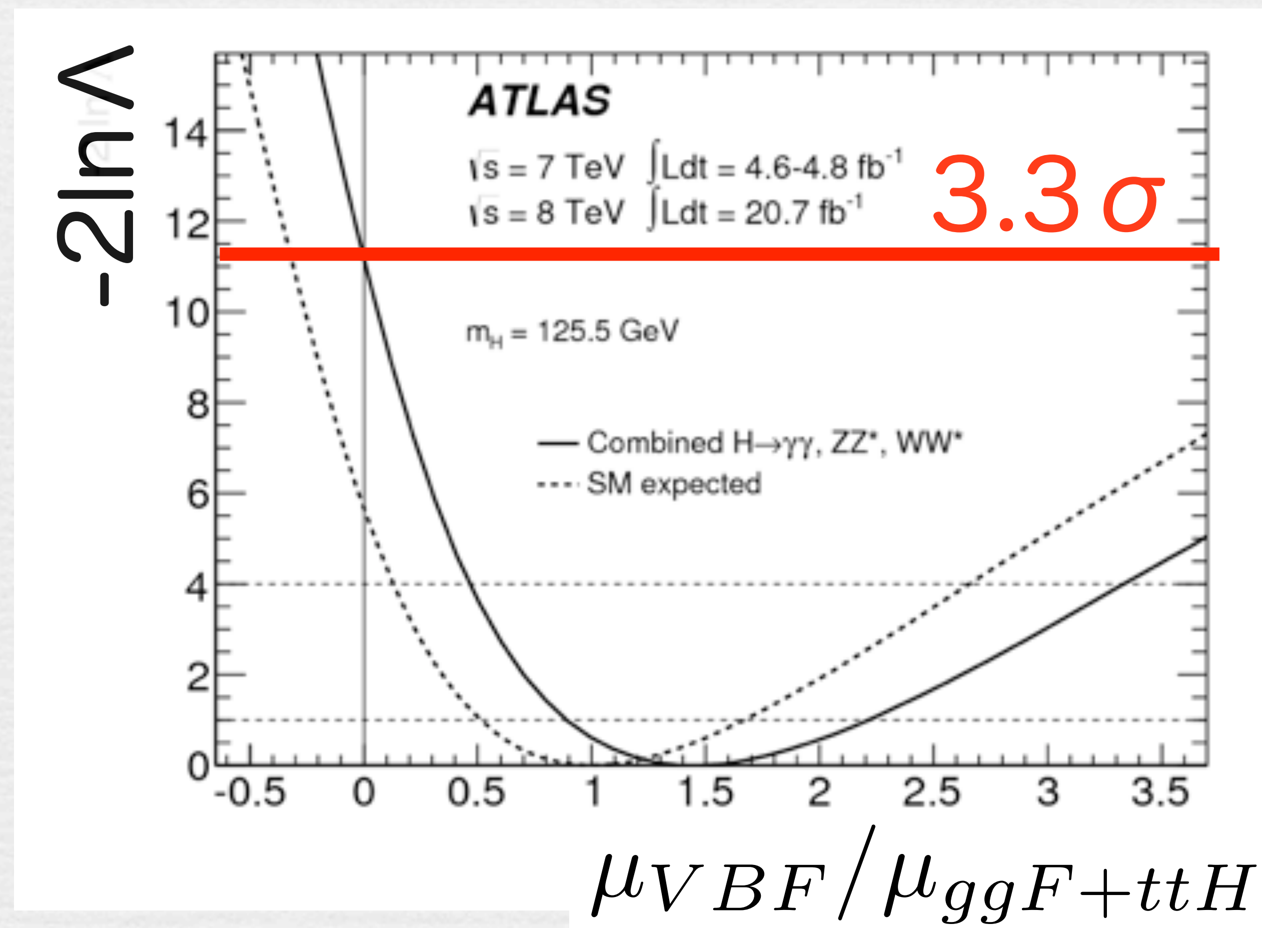
と

gluon-mediated processes



にわけて測定





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

3.3σでVBF生成の存在を示唆

結合測定

ヒッグス粒子との結合

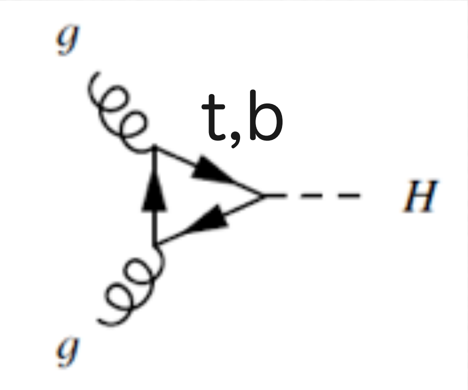
フェルミオン：$g_F^{\mathrm{SM}} = \sqrt{2}\frac{m_F}{v}$　ゲージボゾン： $g_V^{\mathrm{SM}} = 2\frac{m_V^2}{v}$

Coupling scale factors κ: $g_i = g_i^{\mathrm{SM}} \times \kappa_i$

Total width scale factor κH : $\Gamma_H = \Gamma_H^{\mathrm{SM}} \times \kappa_H^2$

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

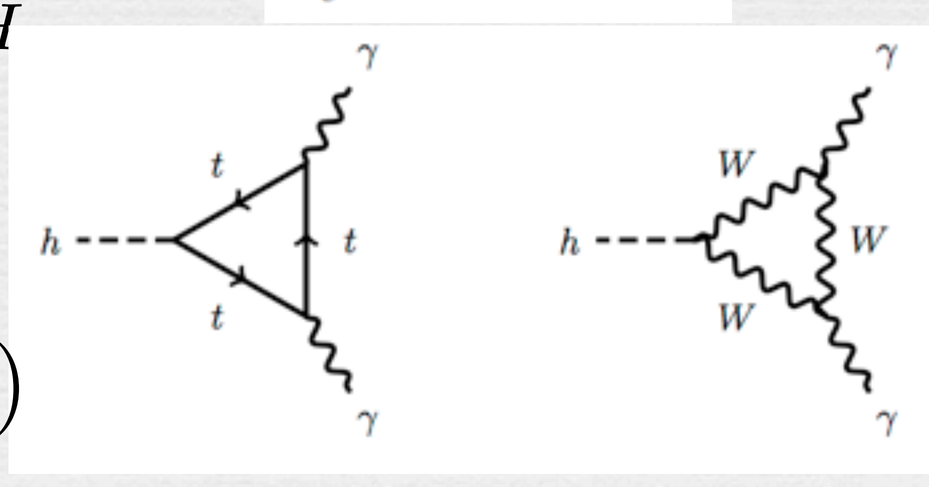
例)　gg→H→γγ process



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

標準模型を仮定した κg, κγ, κH

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



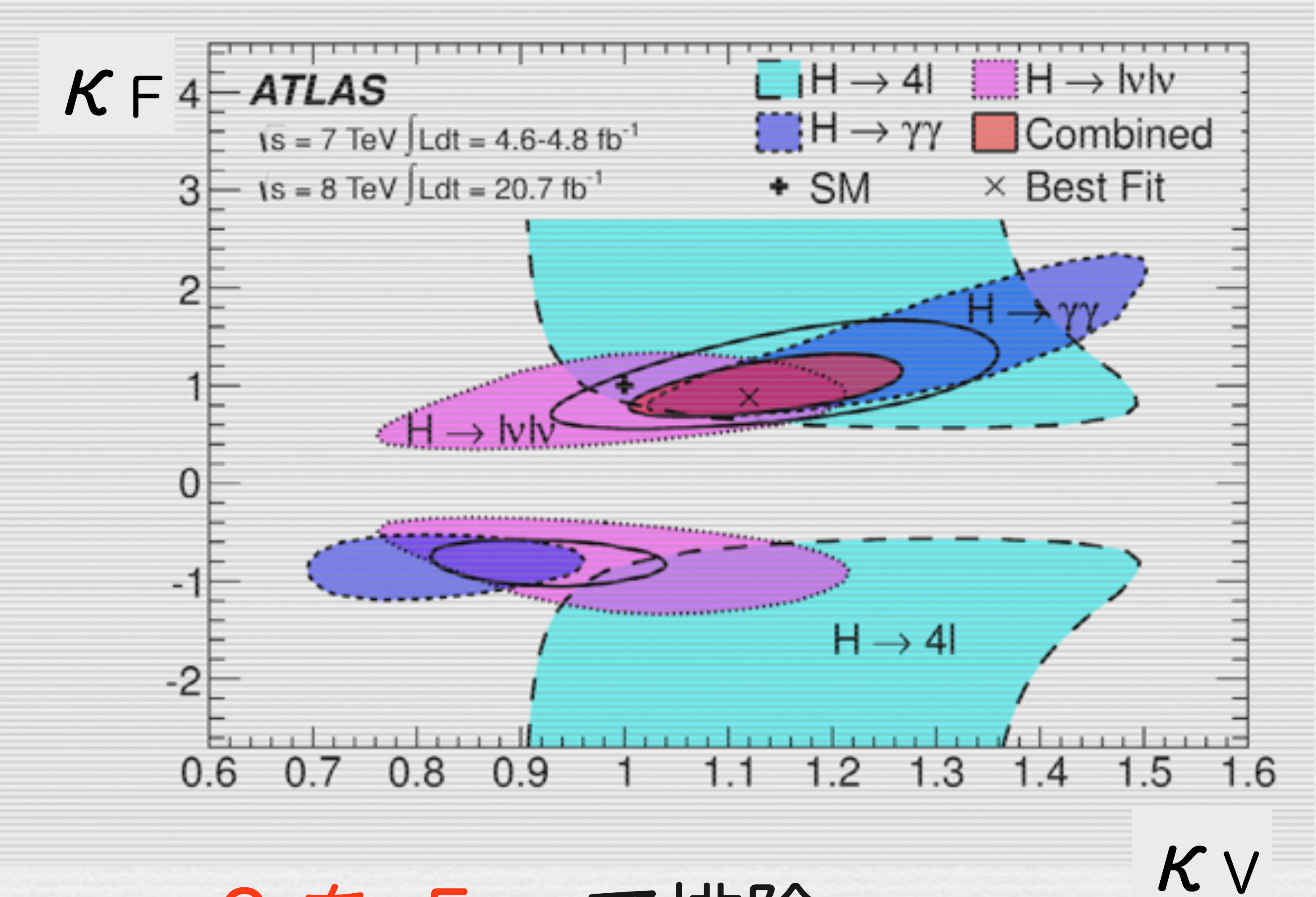
フェルミオンとボゾンの結合

arXiv:1307.1427

フェルミオンのscale factor １種類 $\kappa_F = \kappa_t = \kappa_b = \kappa_\tau = ...$

ボゾンのscale factor １種類 $\kappa_V = \kappa_W = \kappa_Z$

κ H, κ γ, κ gはκ F とκ Vのみに依存 → BSMからの寄与なし

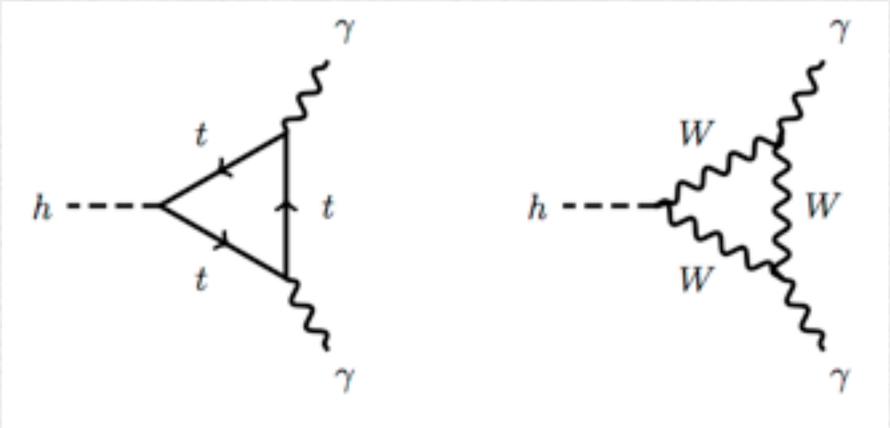


$\kappa_F \in [0.76, 1.18]$

$\kappa_V \in [1.05, 1.22]$

at 68% C.L.

κ F>0っぽい(H→γγ)



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

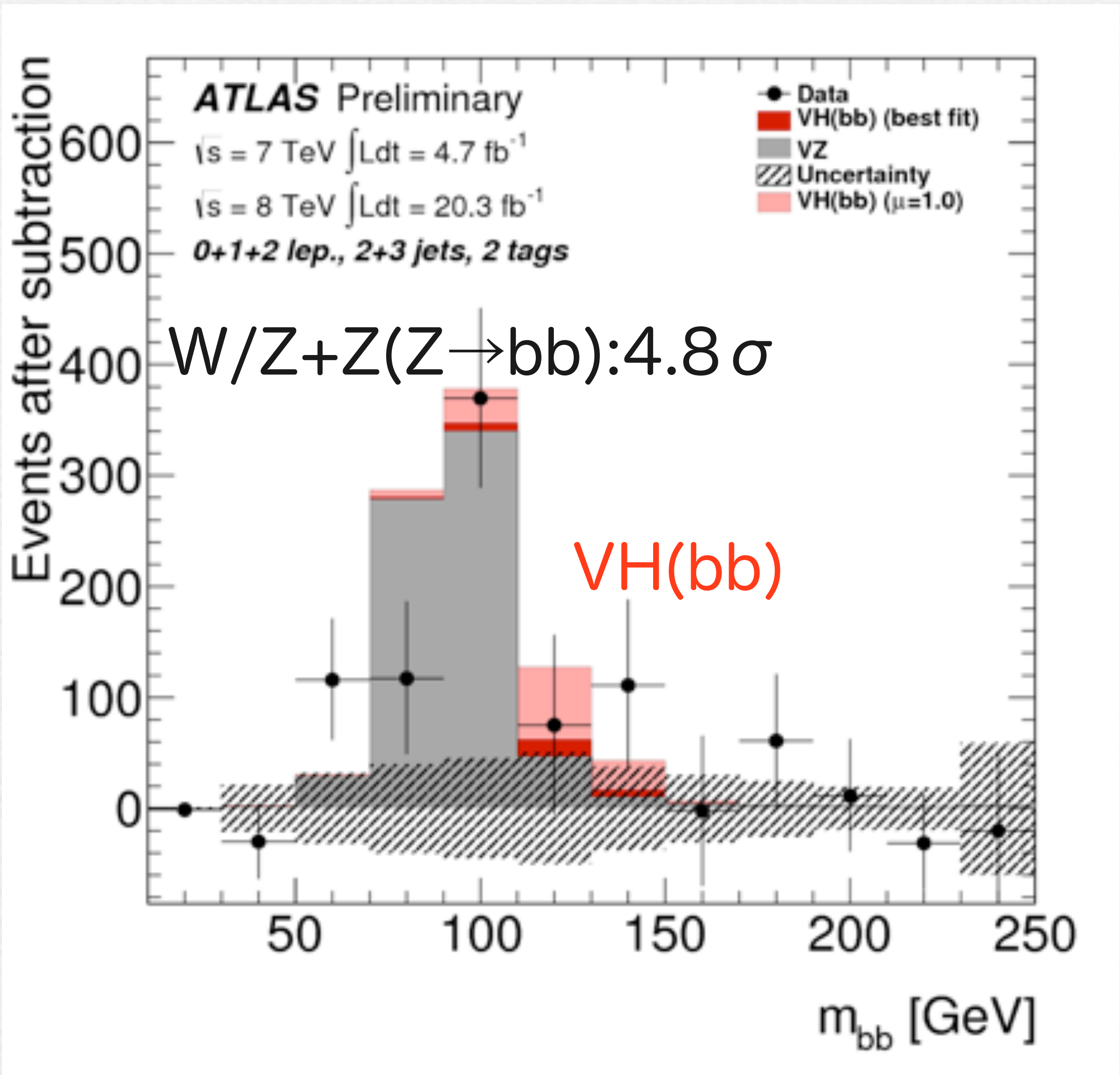
κ F=0 を>5σ で排除

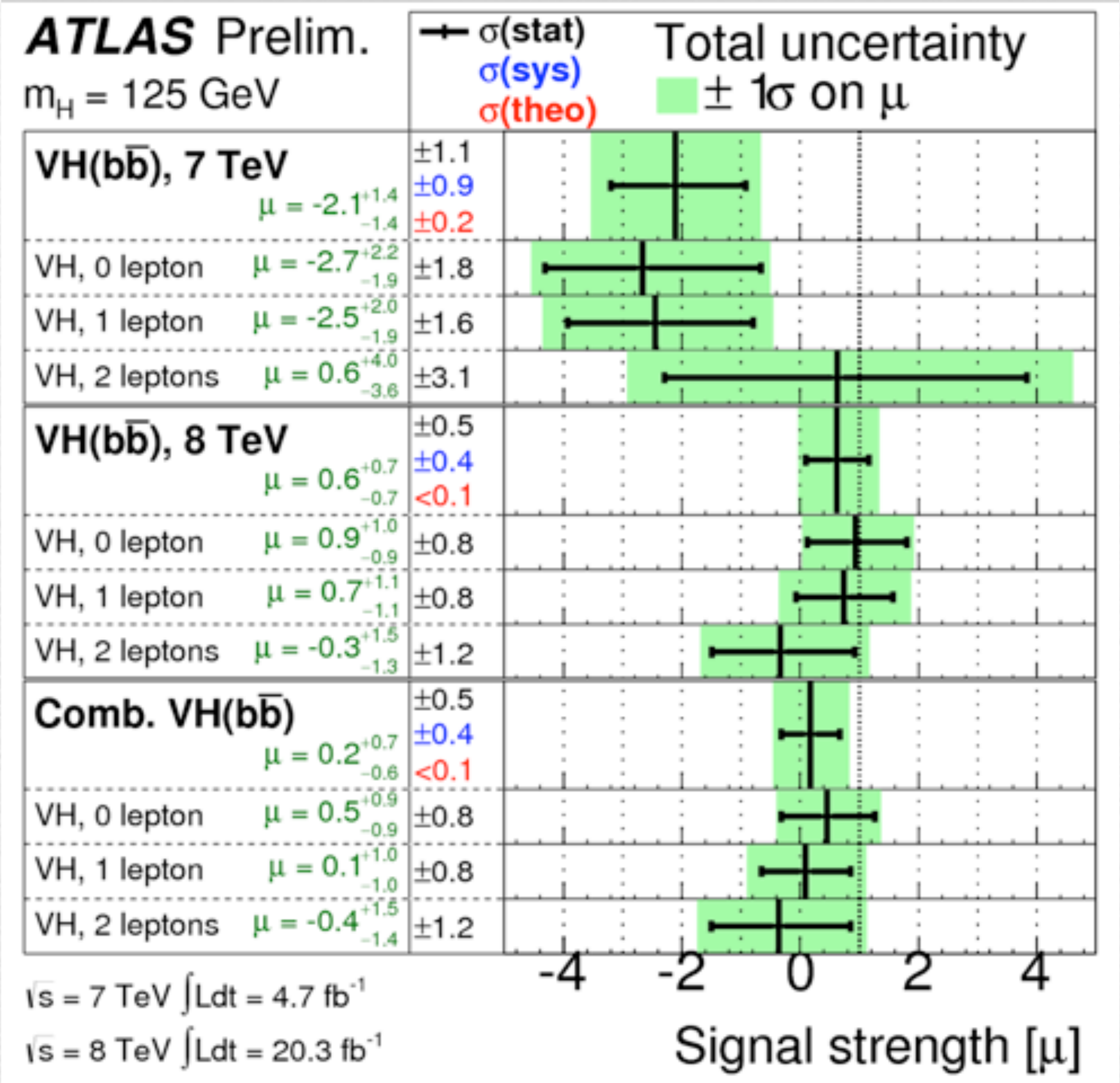
フェルミオン結合の間接的な証拠

フェルミオン結合　直接測定

ATLAS-CONF-2013-079

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





ベストフィット： $\mu = 0.2^{+0.7}_{-0.6}$

H→ττ（2012年の13fb^{-1}までのデータ）　$\mu = 0.7^{+0.7}_{-0.6}$

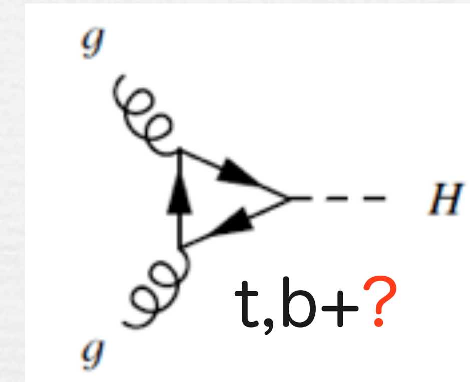
κ_gとκ_γ

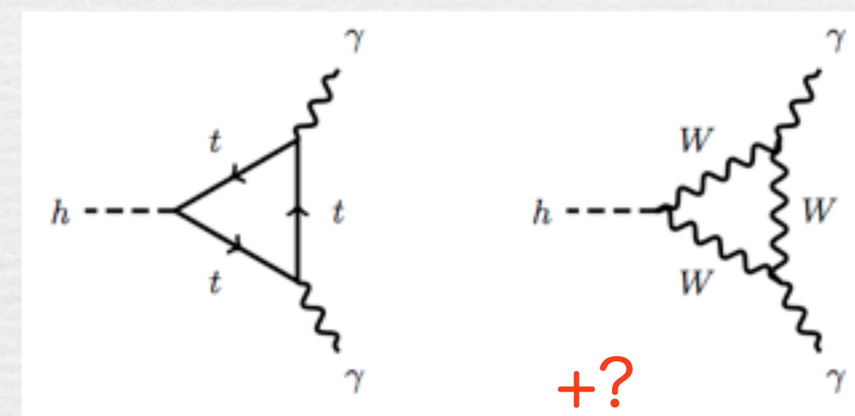
arXiv:1307.1427

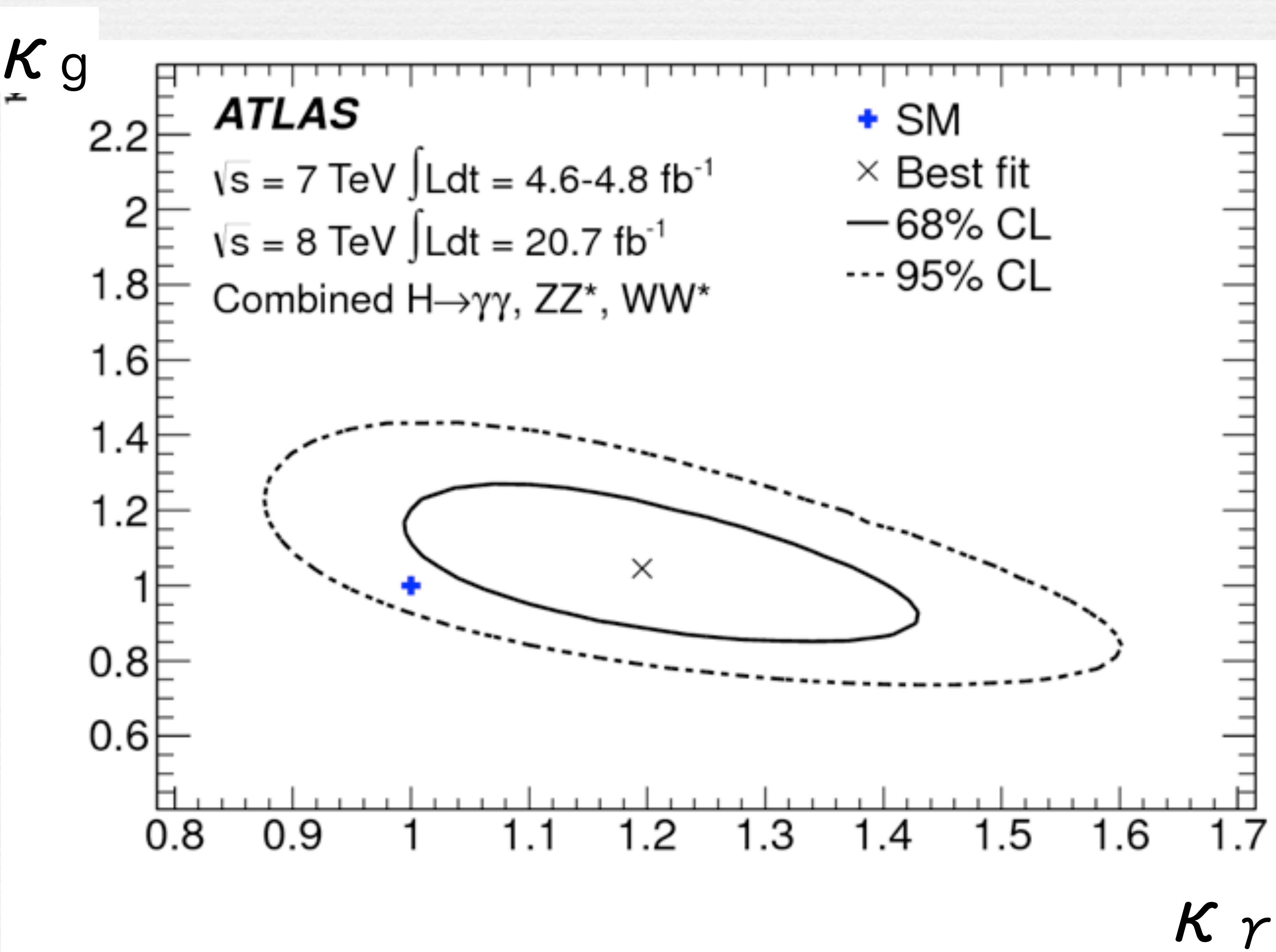
gg→HやH→$\gamma\gamma$のloop中の新物理探索

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

Higgs boson width Γ_Hは標準模型を仮定 (κ_H=1)





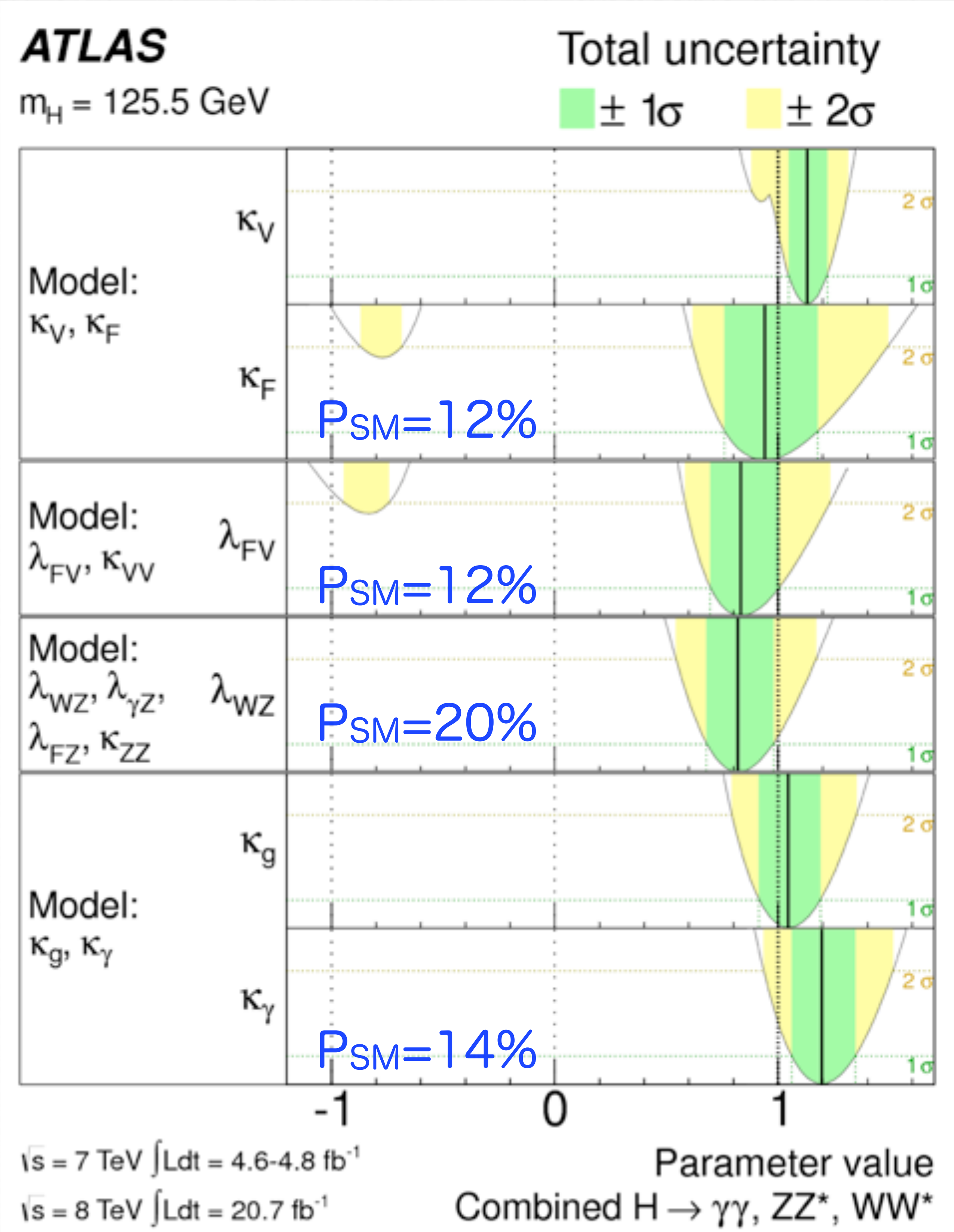


$$\kappa_g = 1.04 \pm 0.14$$
$$\kappa_\gamma = 1.20 \pm 0.15$$

at 68% C.L.

Couplingまとめ

arXiv:1307.1427



標準模型と無矛盾

スピンーパリティ

arXiv:1307.1432

H→$\gamma\gamma$

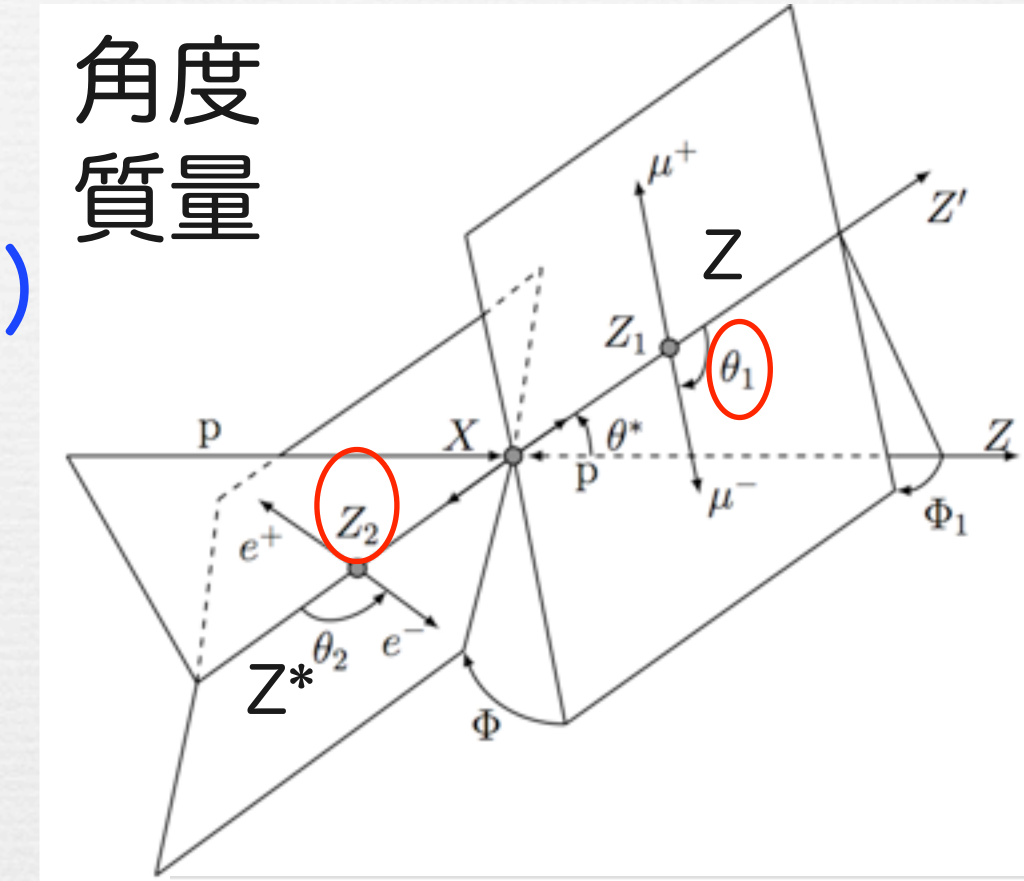
- $J^P=0^+$ v.s. $J^P=2^+$
- J=1は棄却 (Landau-Yang theorem)

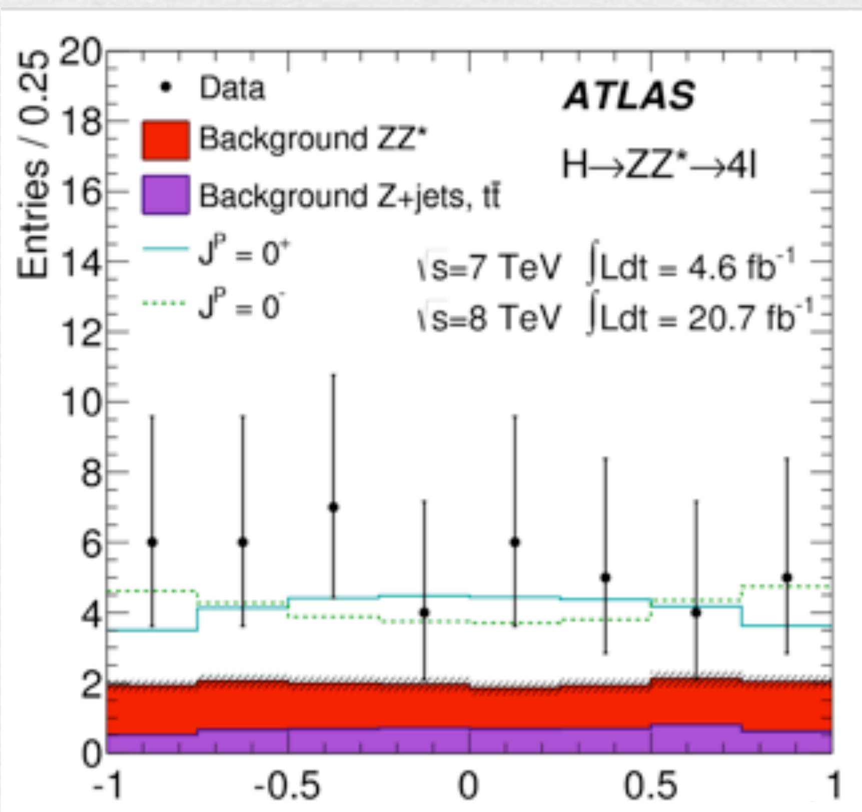
H→WW

- $J^P=0^+$ v.s. $J^P=1^-$, 1^+, and 2^+

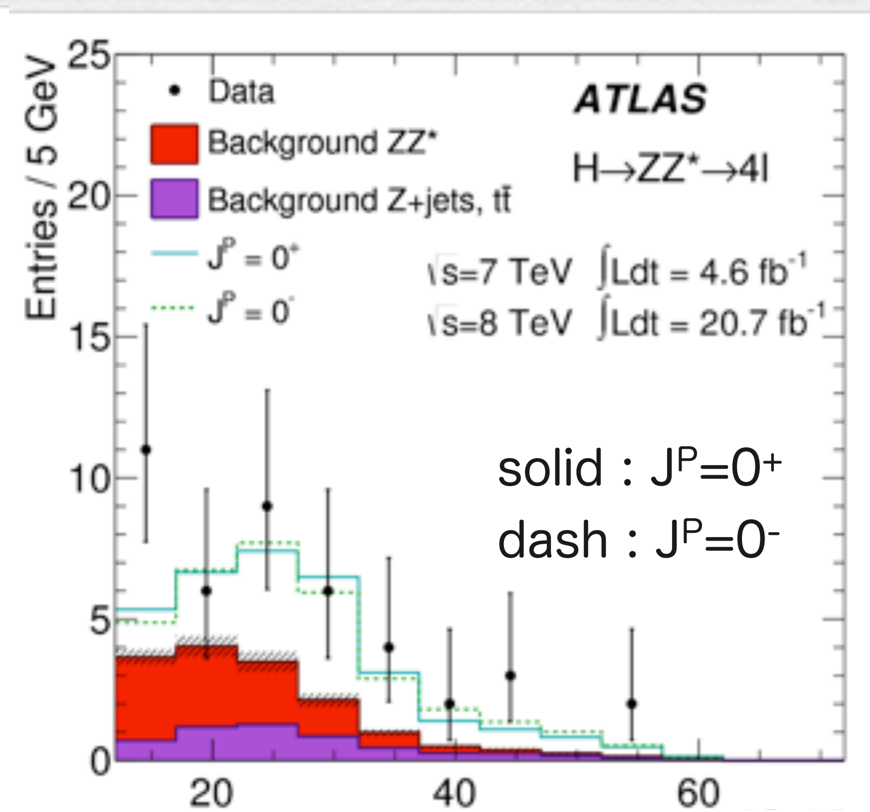
H→ZZ→4 lepton

- $J^P=0^+$ v.s. $J^P=0^-$, 1^-, 1^+, and 2^+

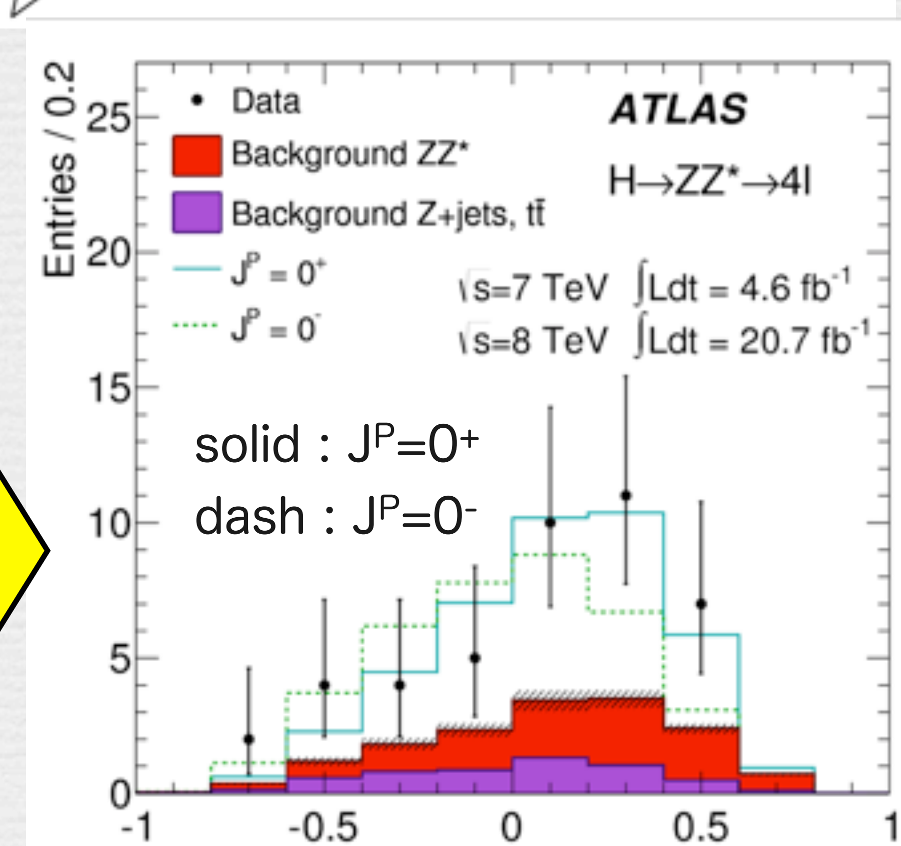




cos θ_1



m_{34}(GeV)



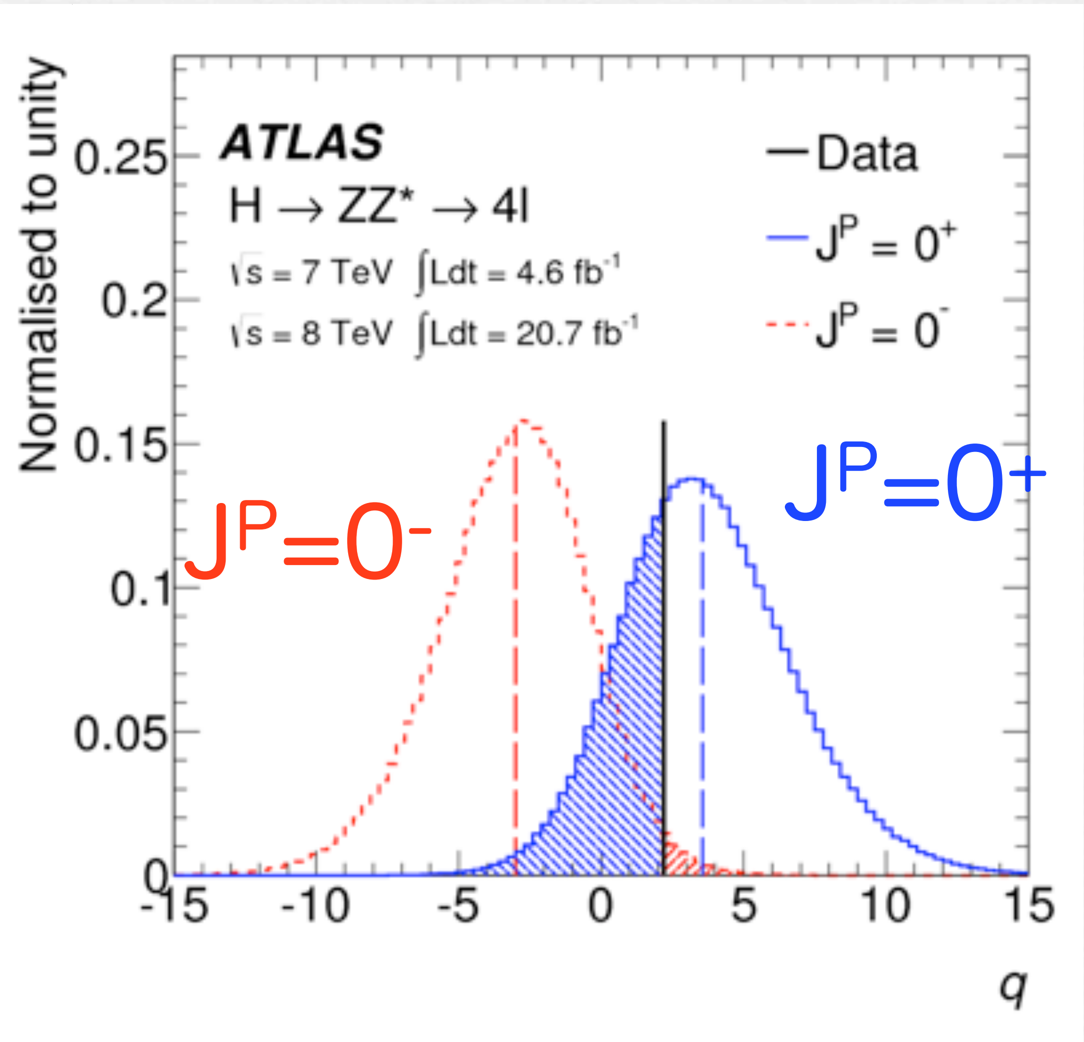
BDT output

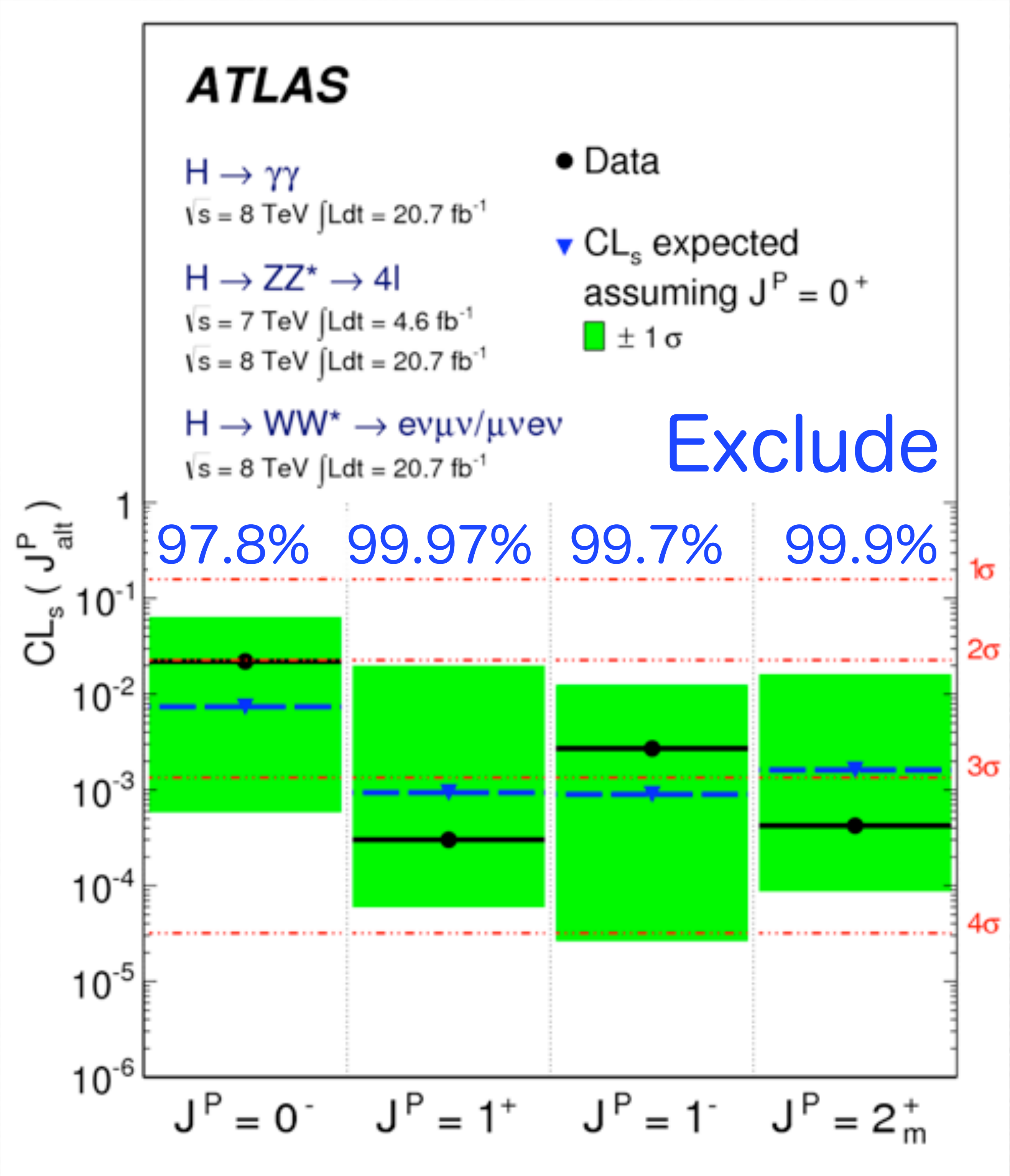
スピン－パリティ

arXiv:1307.1432

Log likelihood ratio q

$$q = \log \frac{L(J^P = 0^+)}{L(J^P = 0^-)}$$





0+ を支持

0- を 97.8% C.L.で排除

2^+_m : Graviton inspired model with minimum couplings to SM particles

arXiv:1001.3396

ヒッグス物理まとめ

発見の後、「ヒッグス物理」を開始

短い時間のうちに様々な「性質」を測定

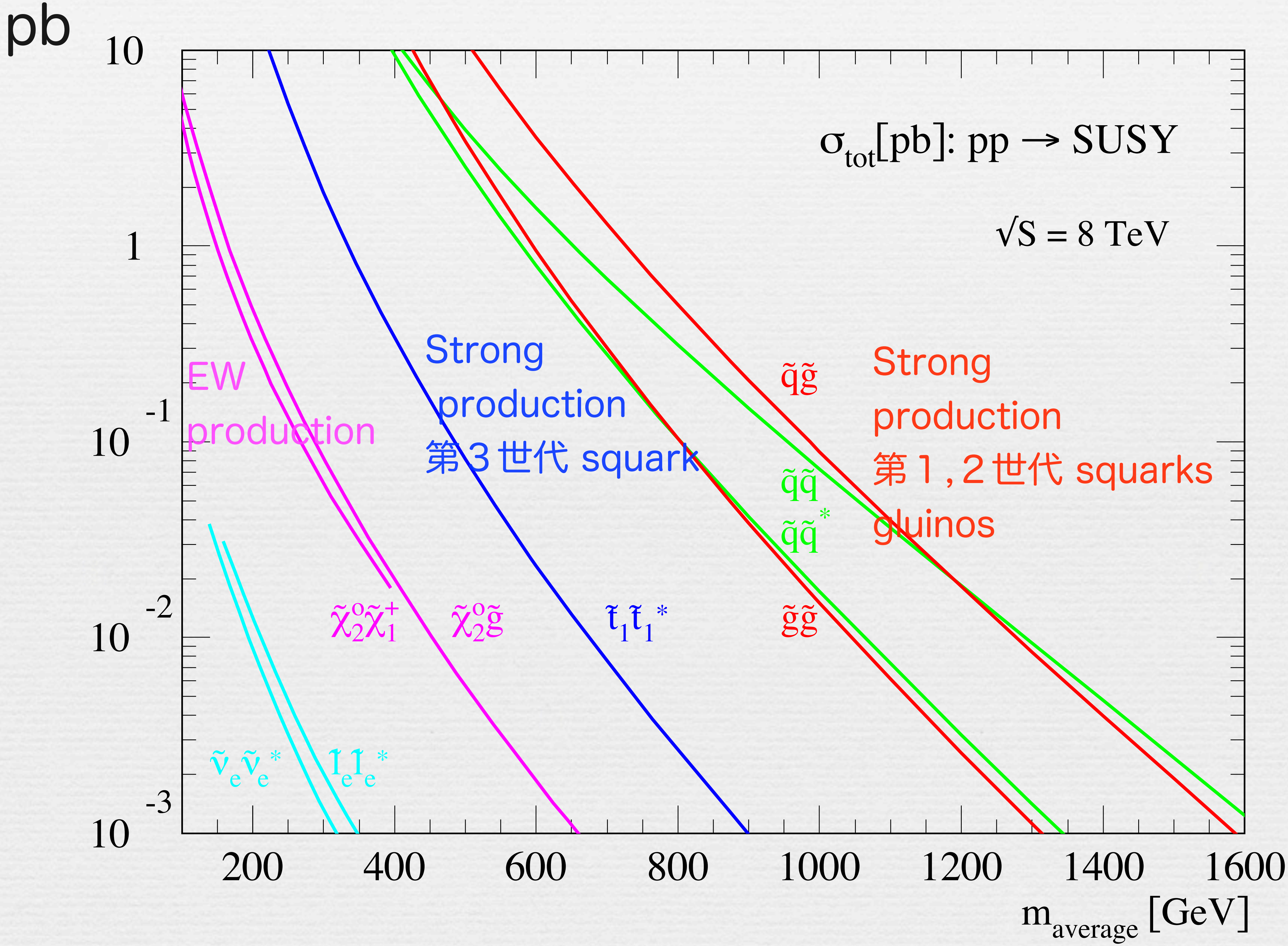
今の所、標準模型のヒッグス粒子の性質と無矛盾

より高統計な精密測定が不可欠

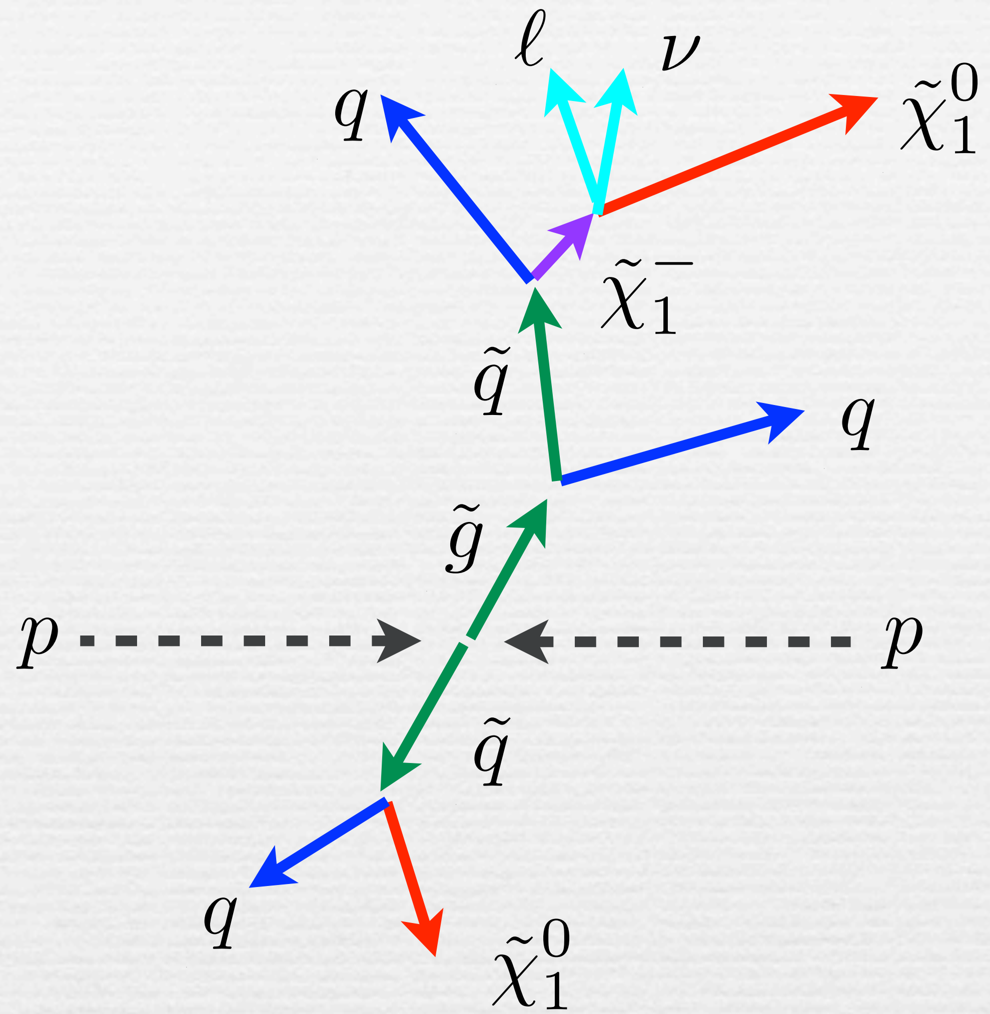
→ 14TeV LHCやHL-LHC、ILCに期待

LHC 8TeV実験
SUSY 探索の成果

8TeV LHCのSUSYの生成断面積



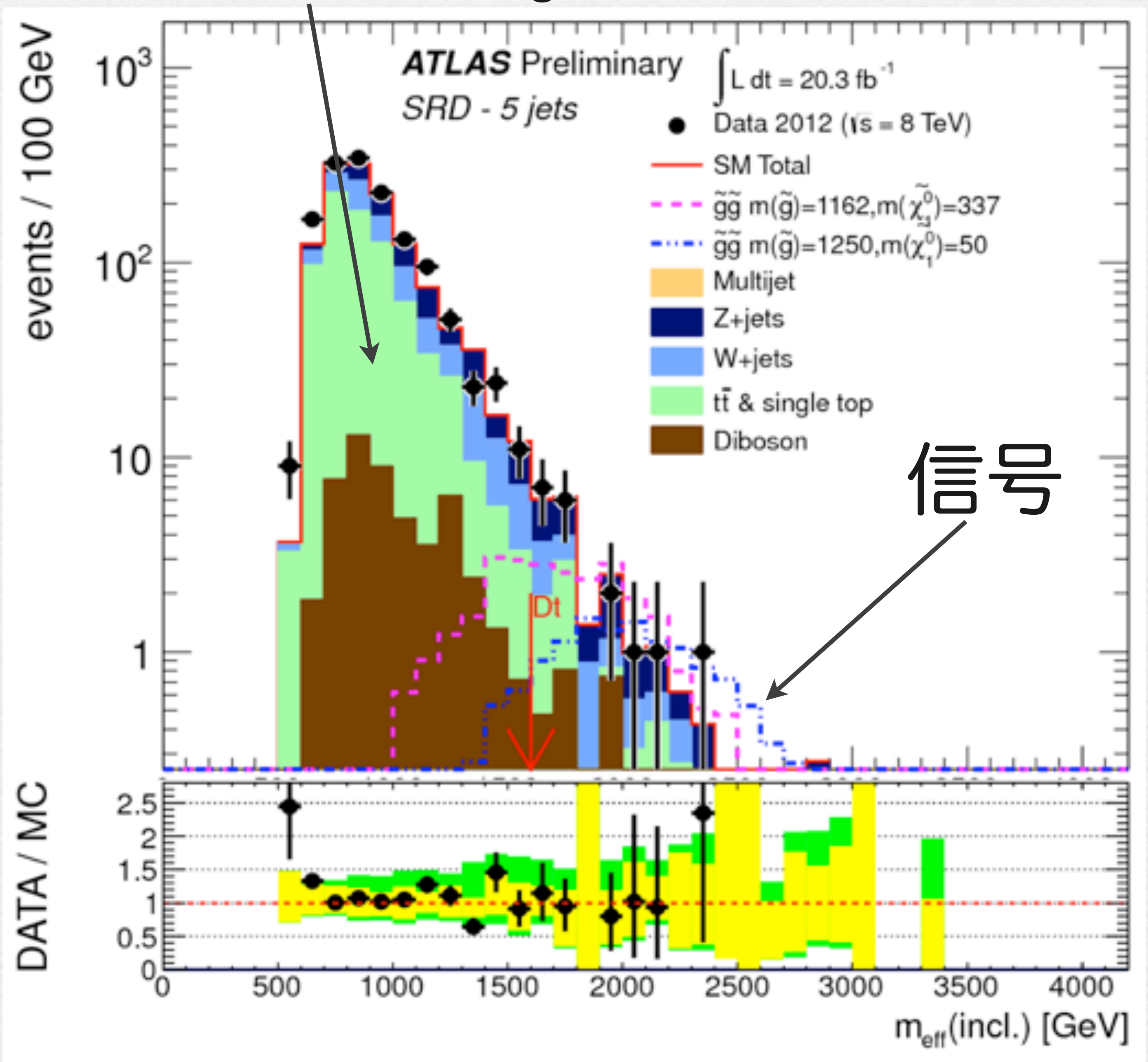
LHCでのSUSY探索

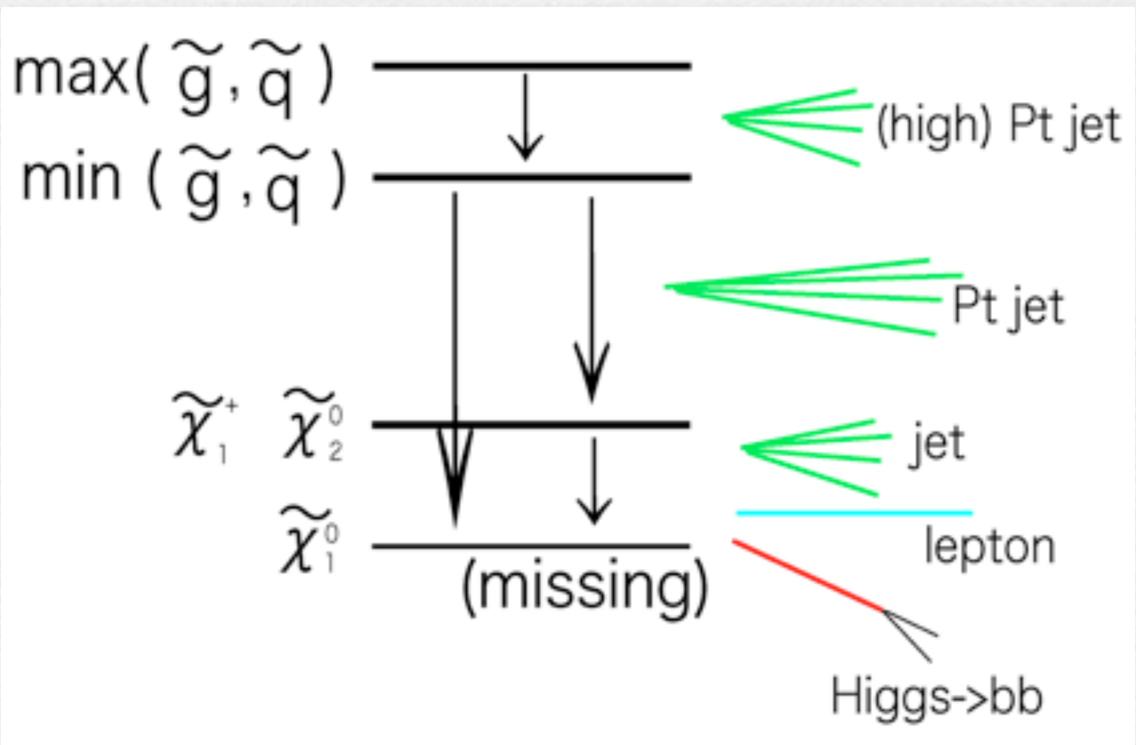


多数の高運動量Jets + E_T^{miss} + X

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

背景事象はcontrol regionから外挿

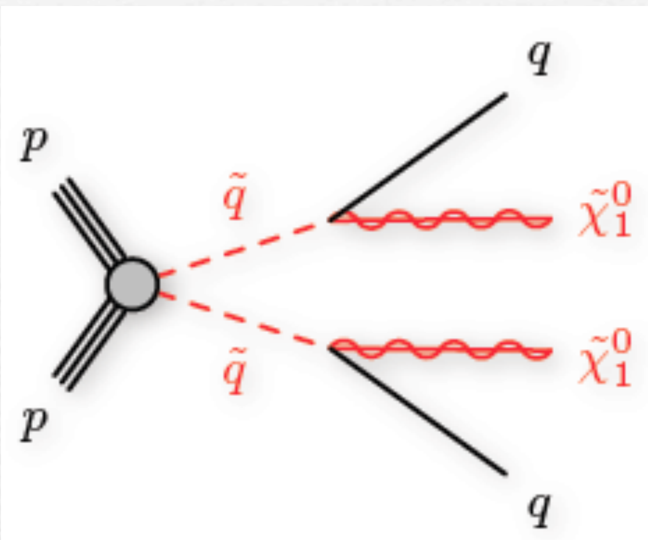


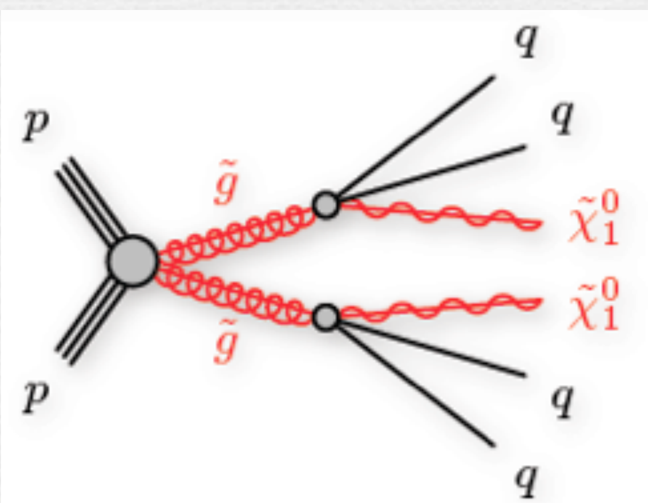


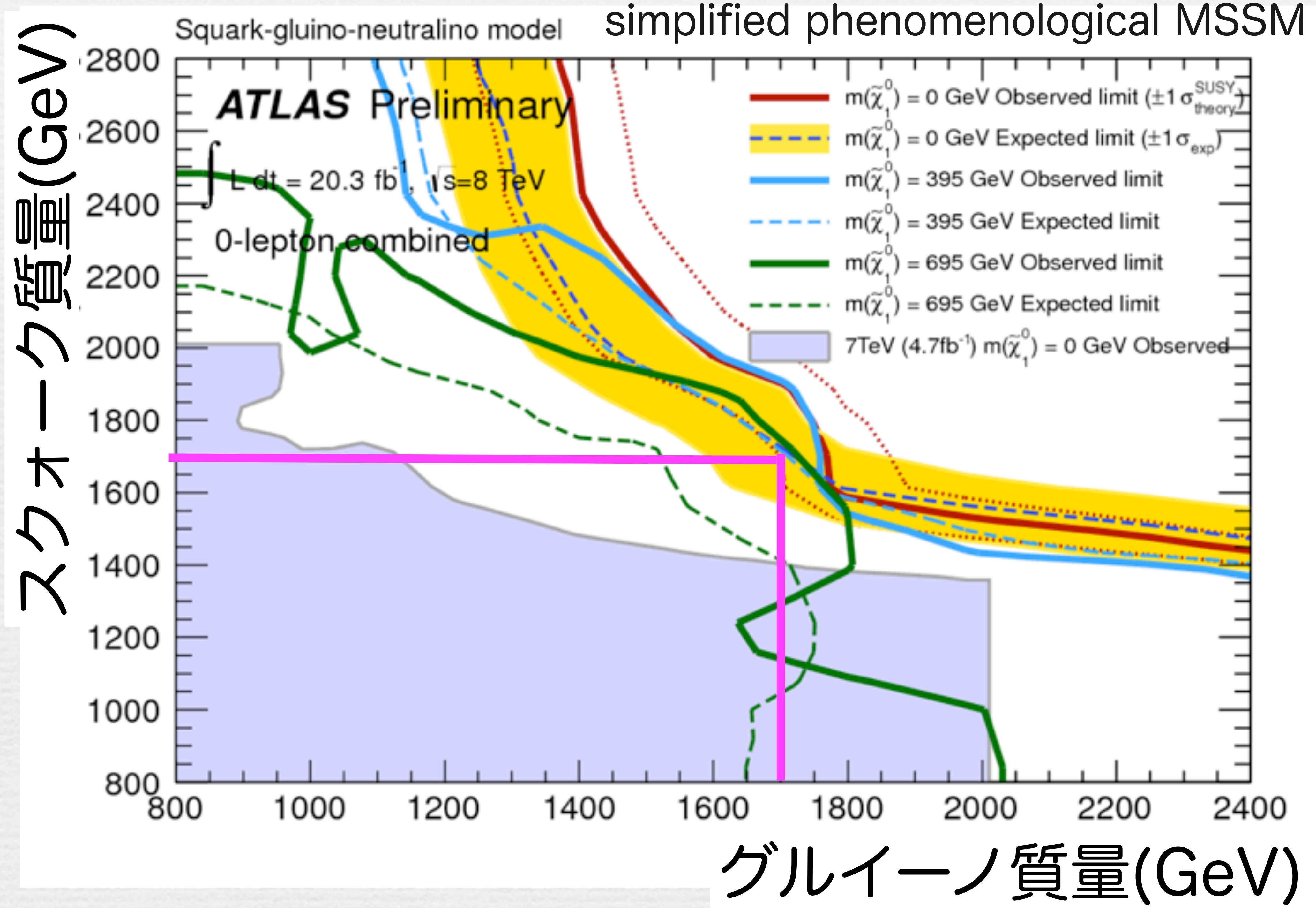
Inclusive search

ATLAS-CONF-2013-047

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







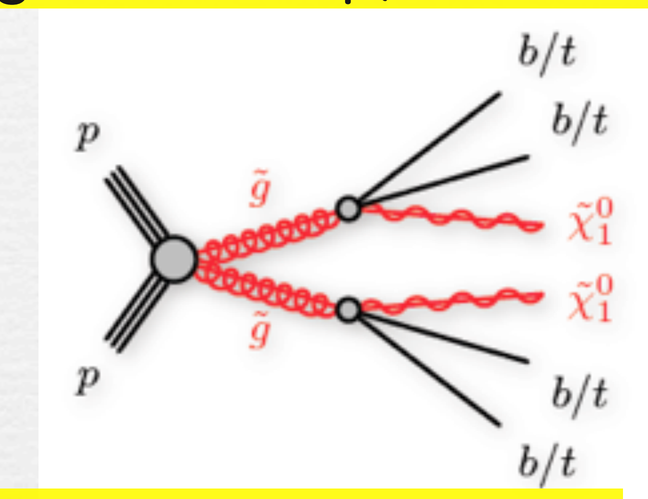
1.7TeVまで棄却 ($m_{\tilde{g}} = m_{\tilde{q}}$)

"Natural" SUSY

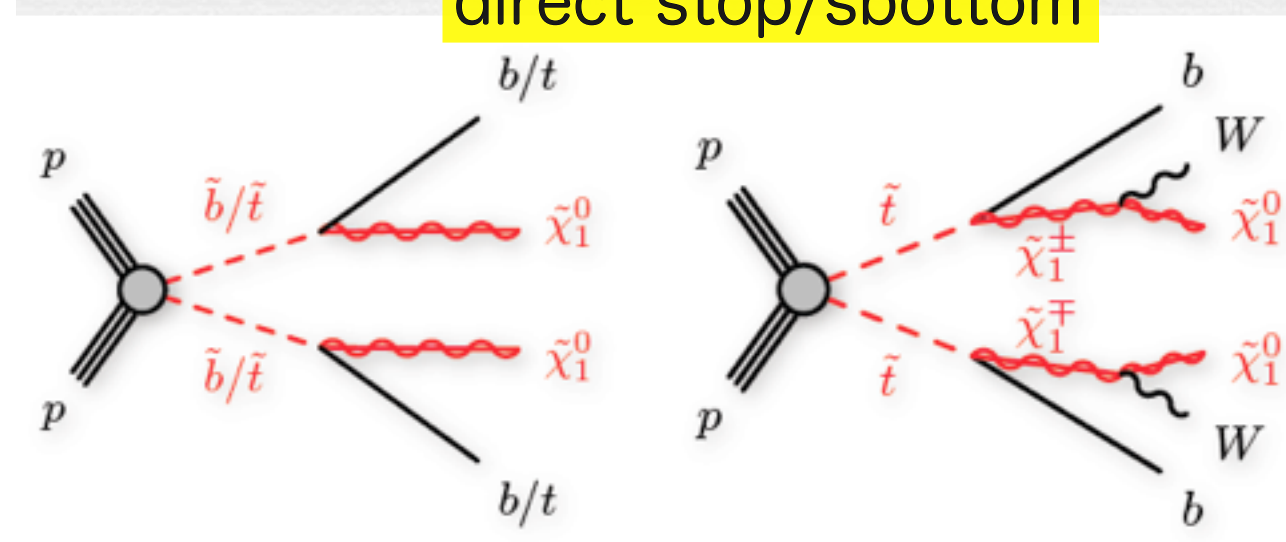
ヒッグス質量の安定性の観点から

- Higgsino(chargino/Neutralino)は軽い
- 第３世代のsquarkまたはgluinoは軽い

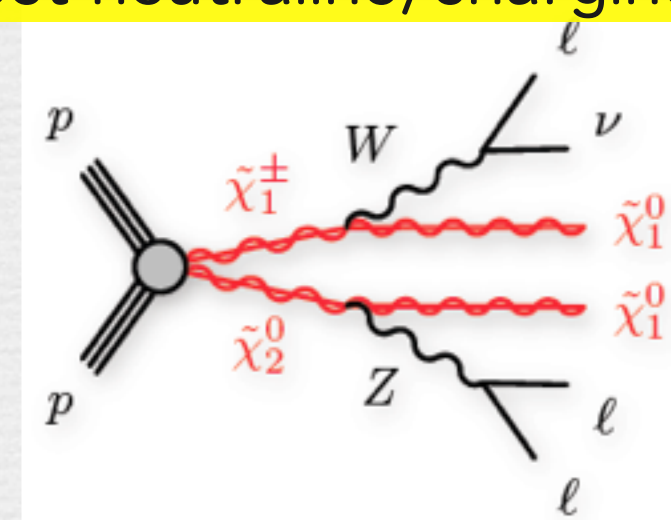
gluino→stop/sbottom

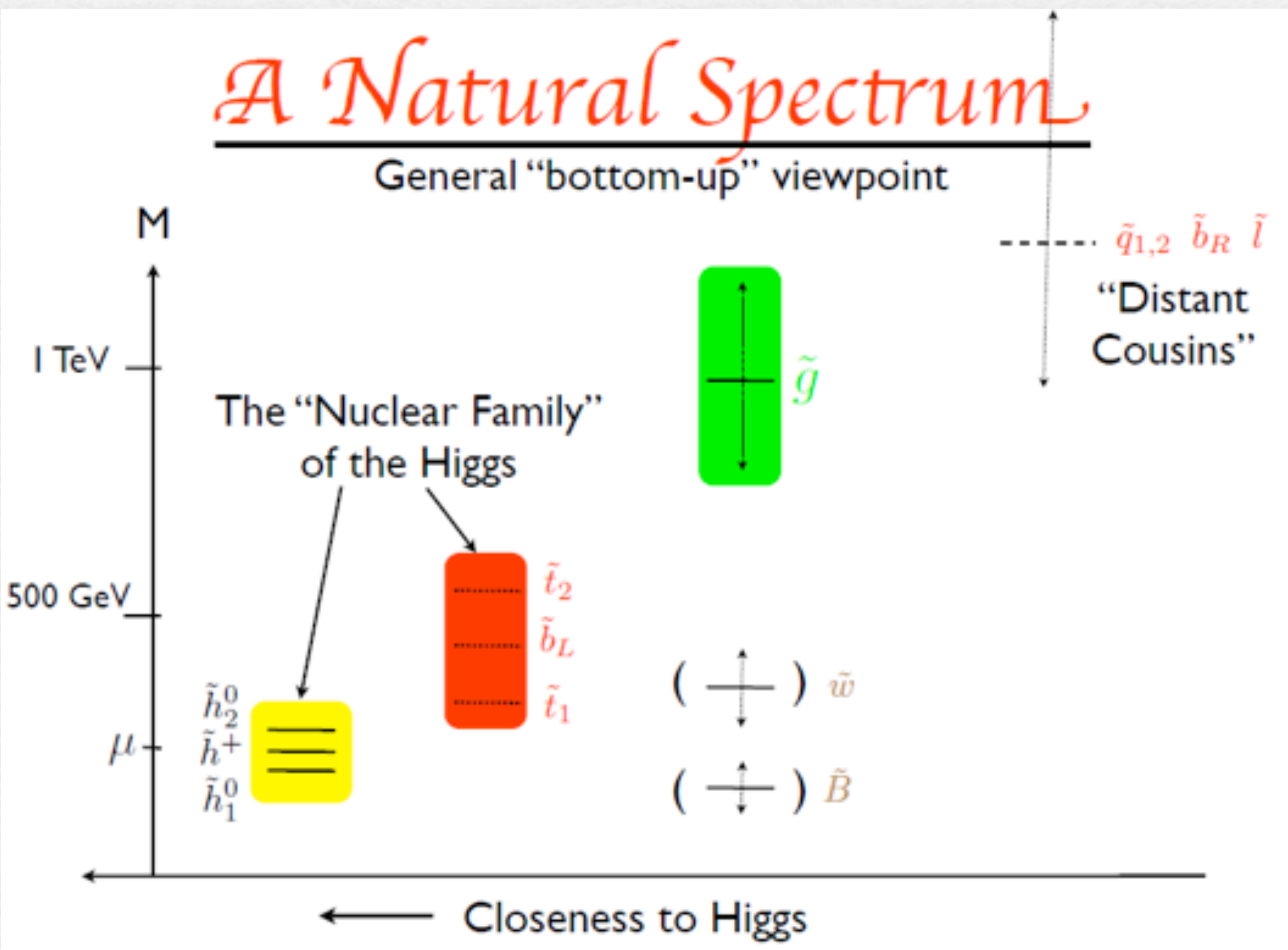


direct stop/sbottom



direct neutralino/chargino



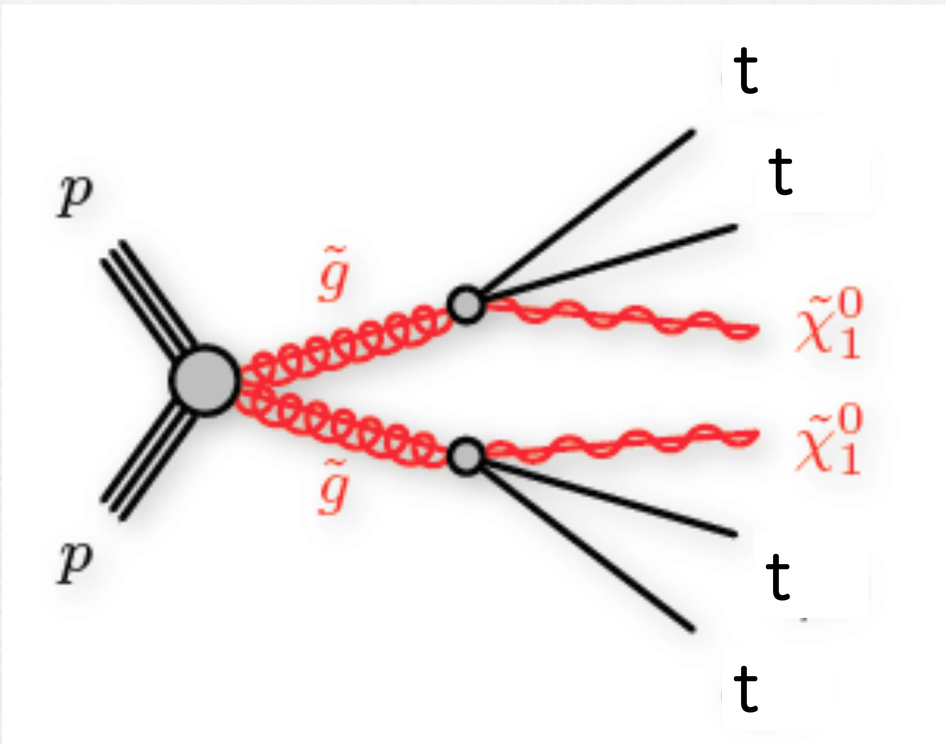


From slide by Lawrence Hall

stop production from gluino

ATLAS-CONF-2013-061など

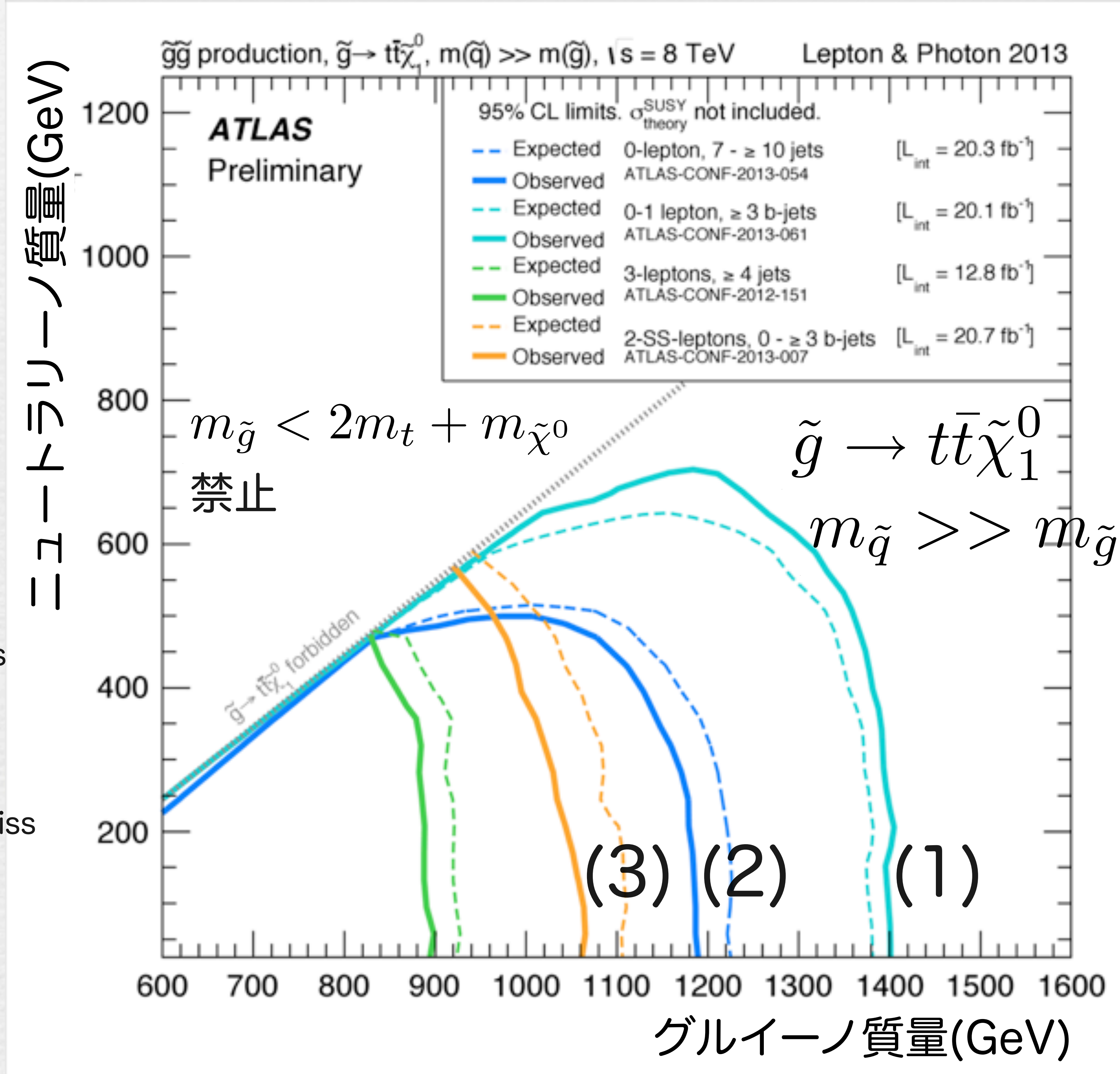
GluinoはLHCで生成できる、stopには崩壊できる。



(1) 0~1 Lepton + ≧ 3 bJets +E_T^{miss}

(2) 0-Lepton + 7~10 Jets +E_T^{miss}

(3) 同符号Lepton + ≧ 3 bJets +E_T^{miss}

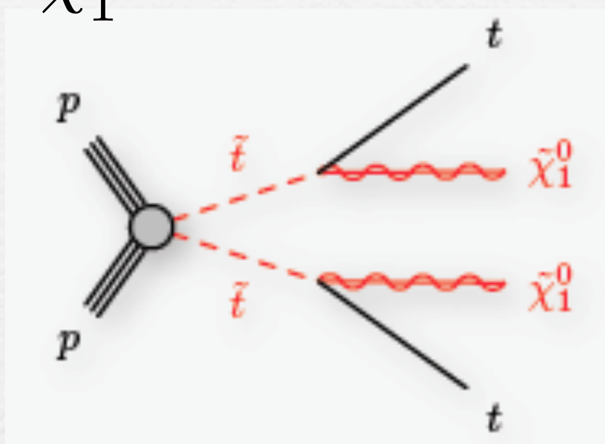


Direct stop pair production

カラーをもつSUSYの中でstopだけが軽い

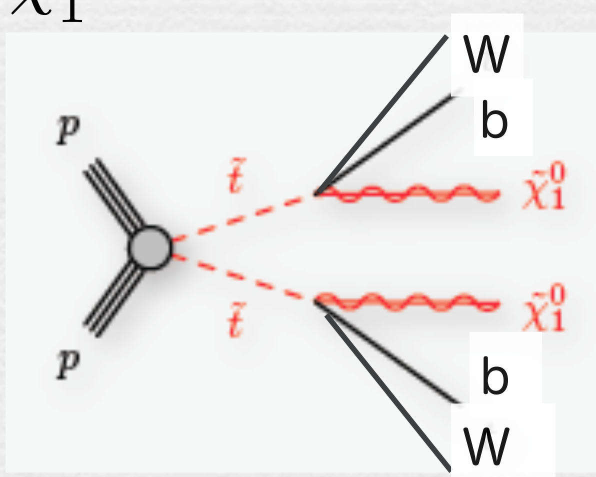
(1) $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} > m_t$

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



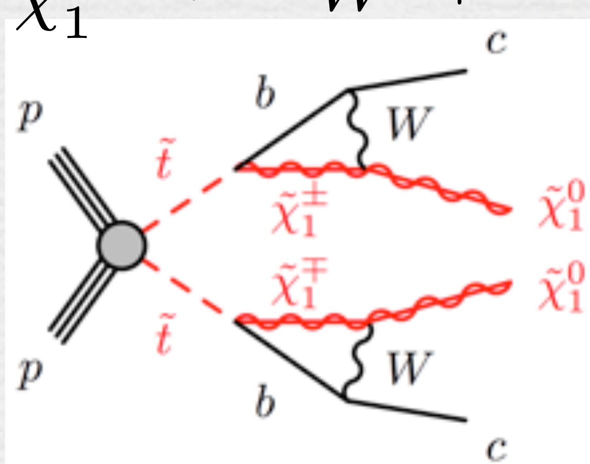
(2) $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} > m_W + m_b$

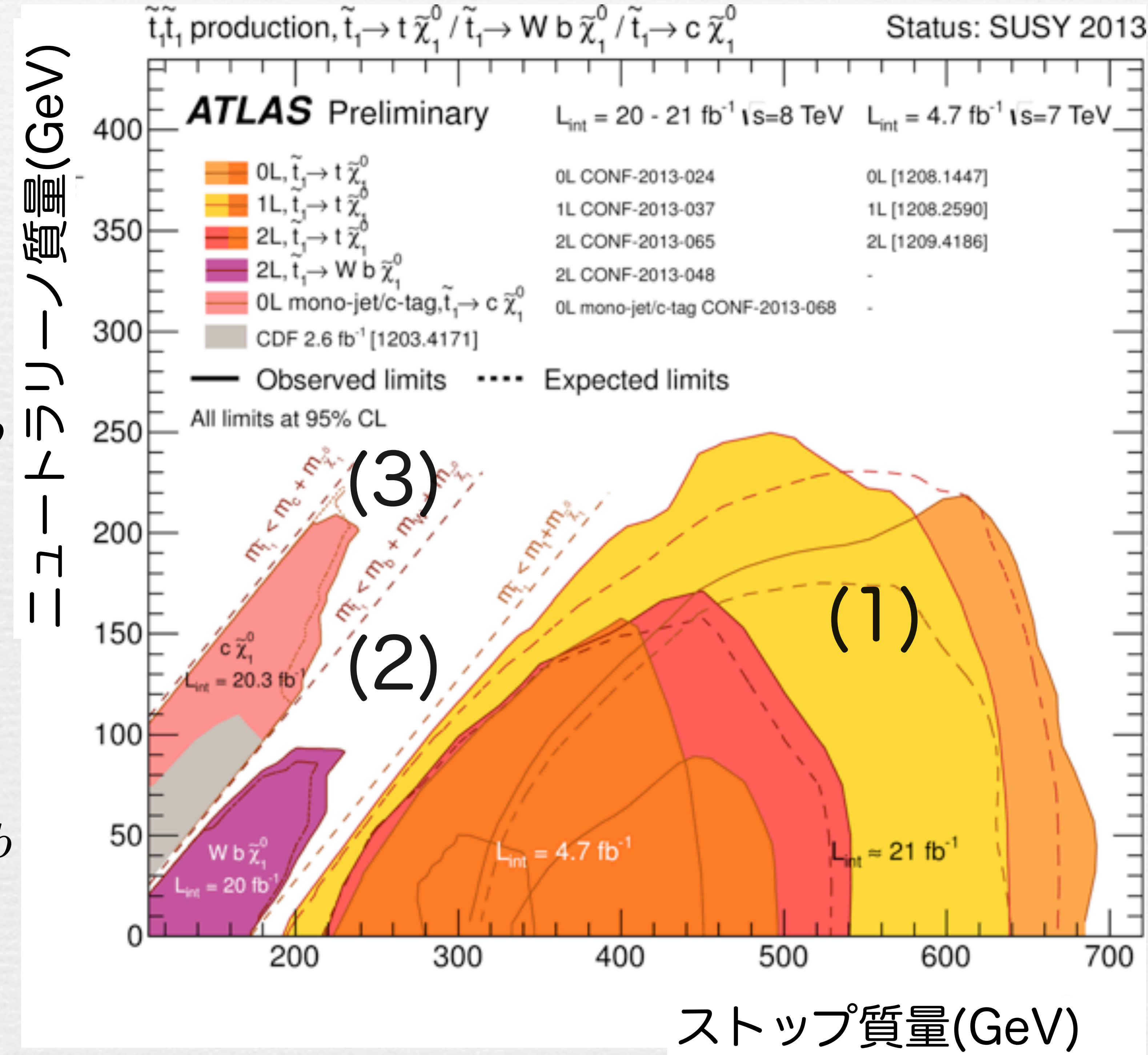
$\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$



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

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

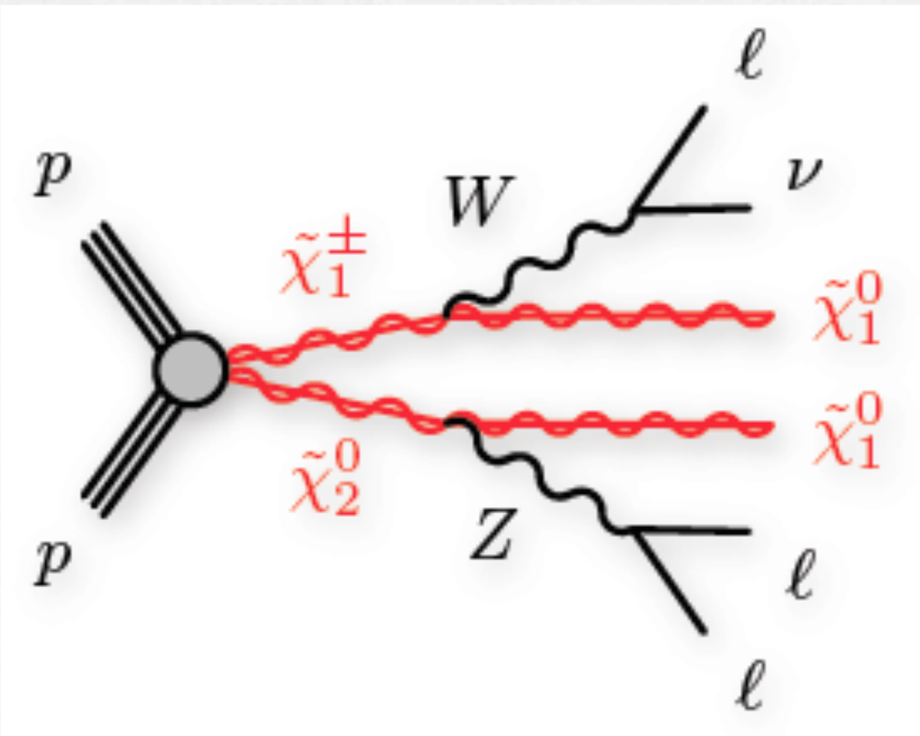




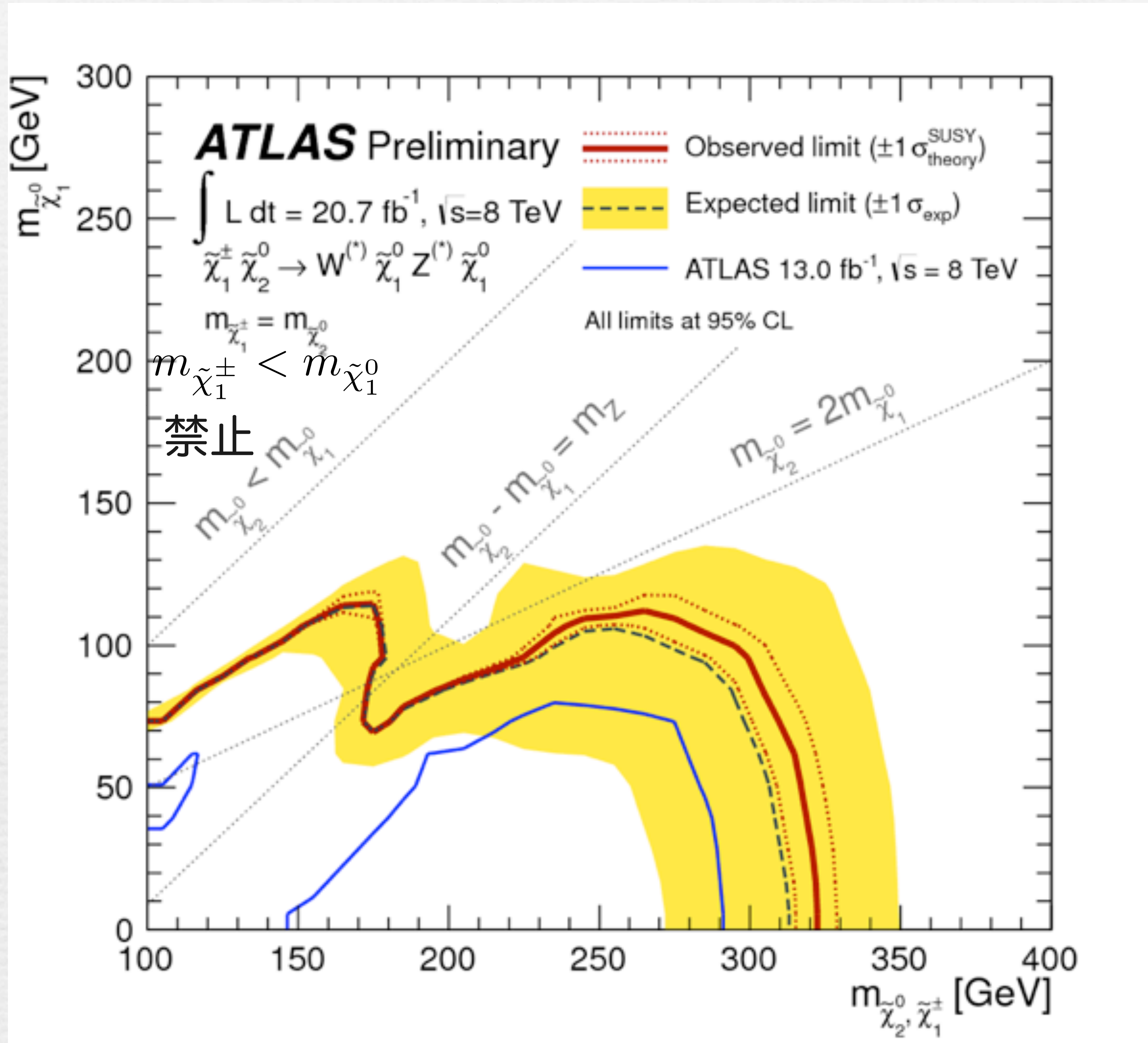
$m_{\tilde{t}} < 660$ GeV 棄却 (mLSP=0)

Direct chargino/neutralino production

chargino と neutralino だけが軽い場合 $m_{\tilde{\chi}_1^\pm} > m_{\tilde{\chi}_1^0}$

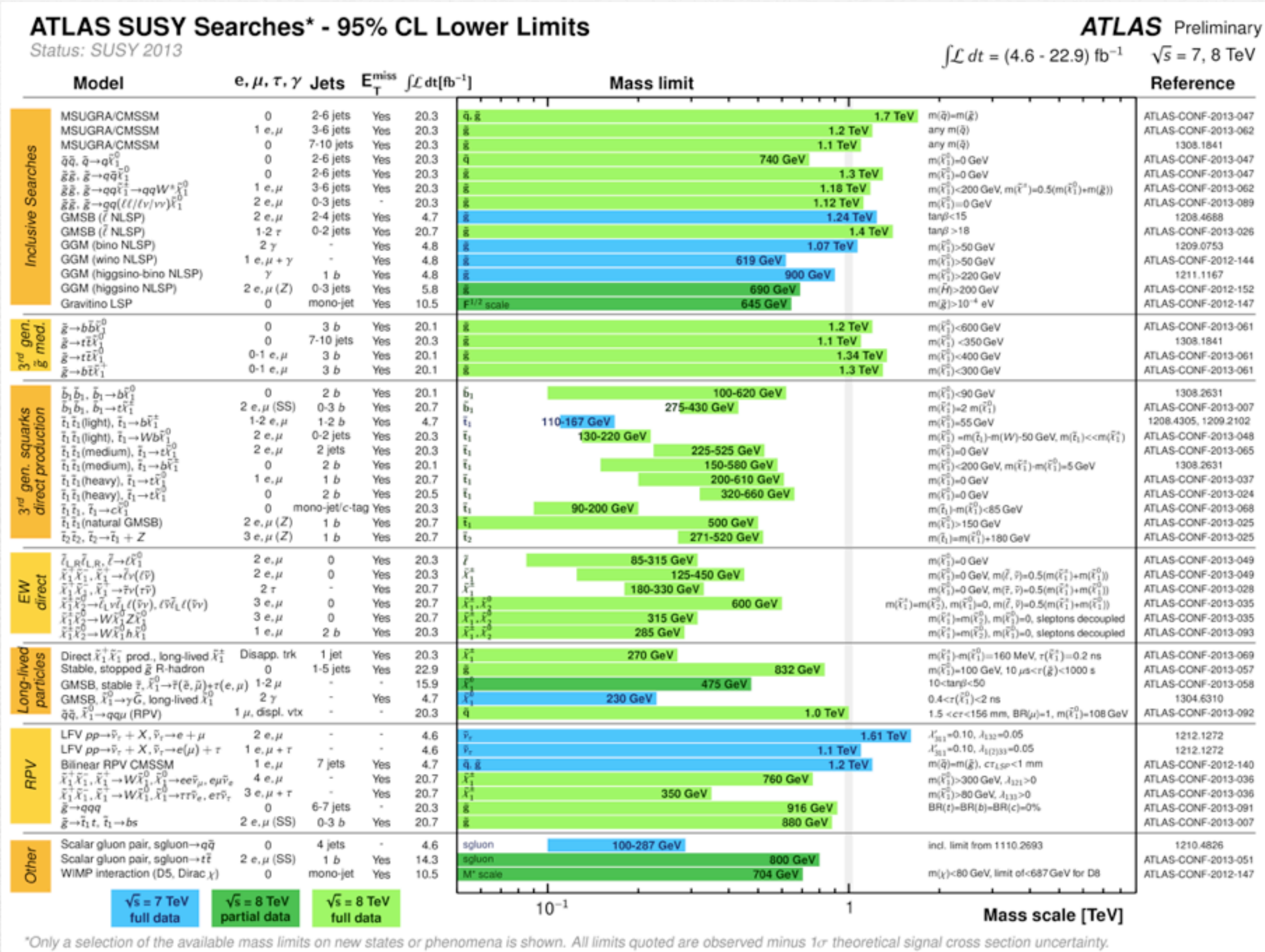


3 lepton + E_T^{miss}

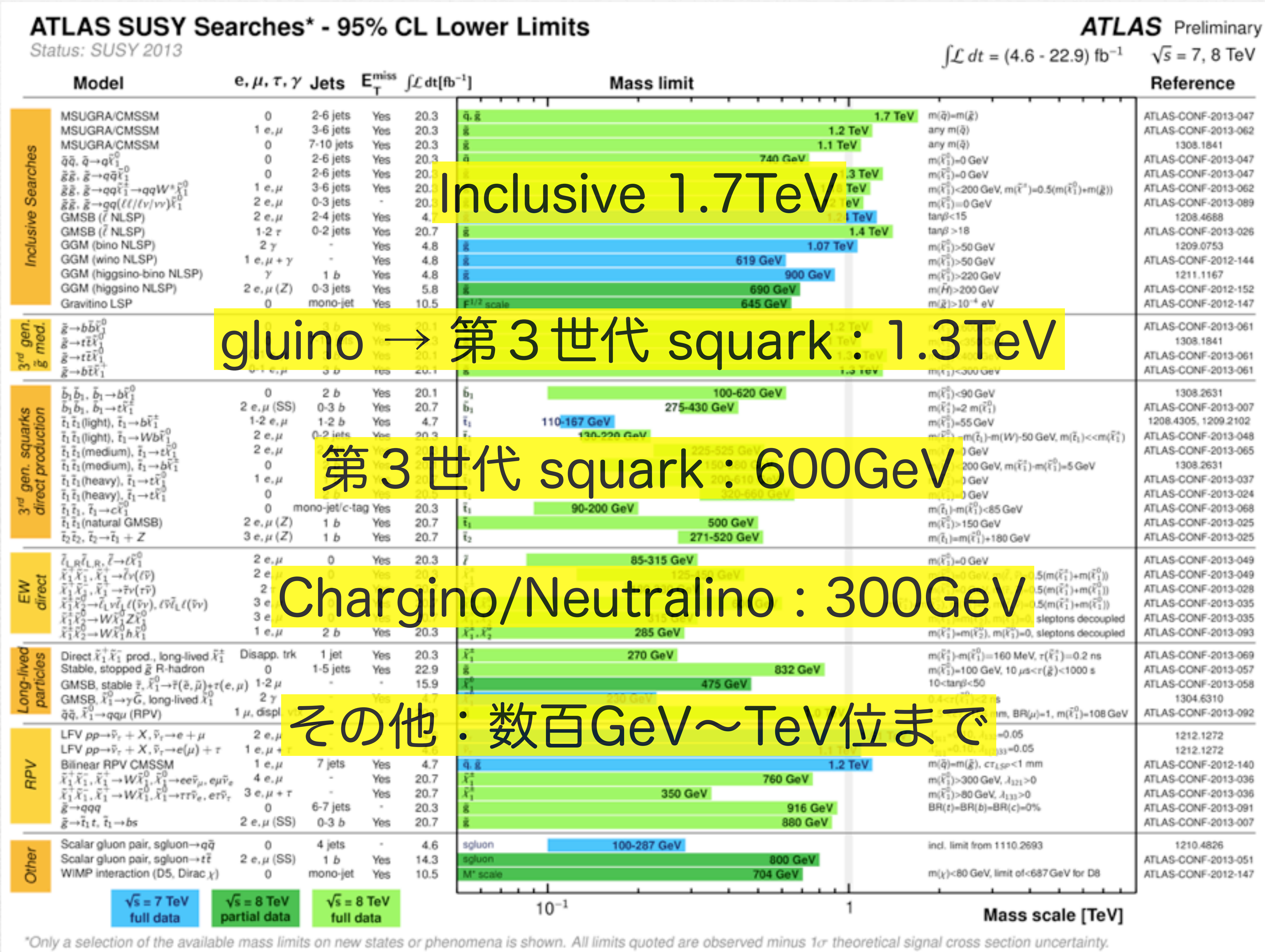


$m_{\tilde{\chi}_2^0}, m_{\tilde{\chi}_1^\pm} < 315$ GeV 棄却

SUSY探索のまとめ

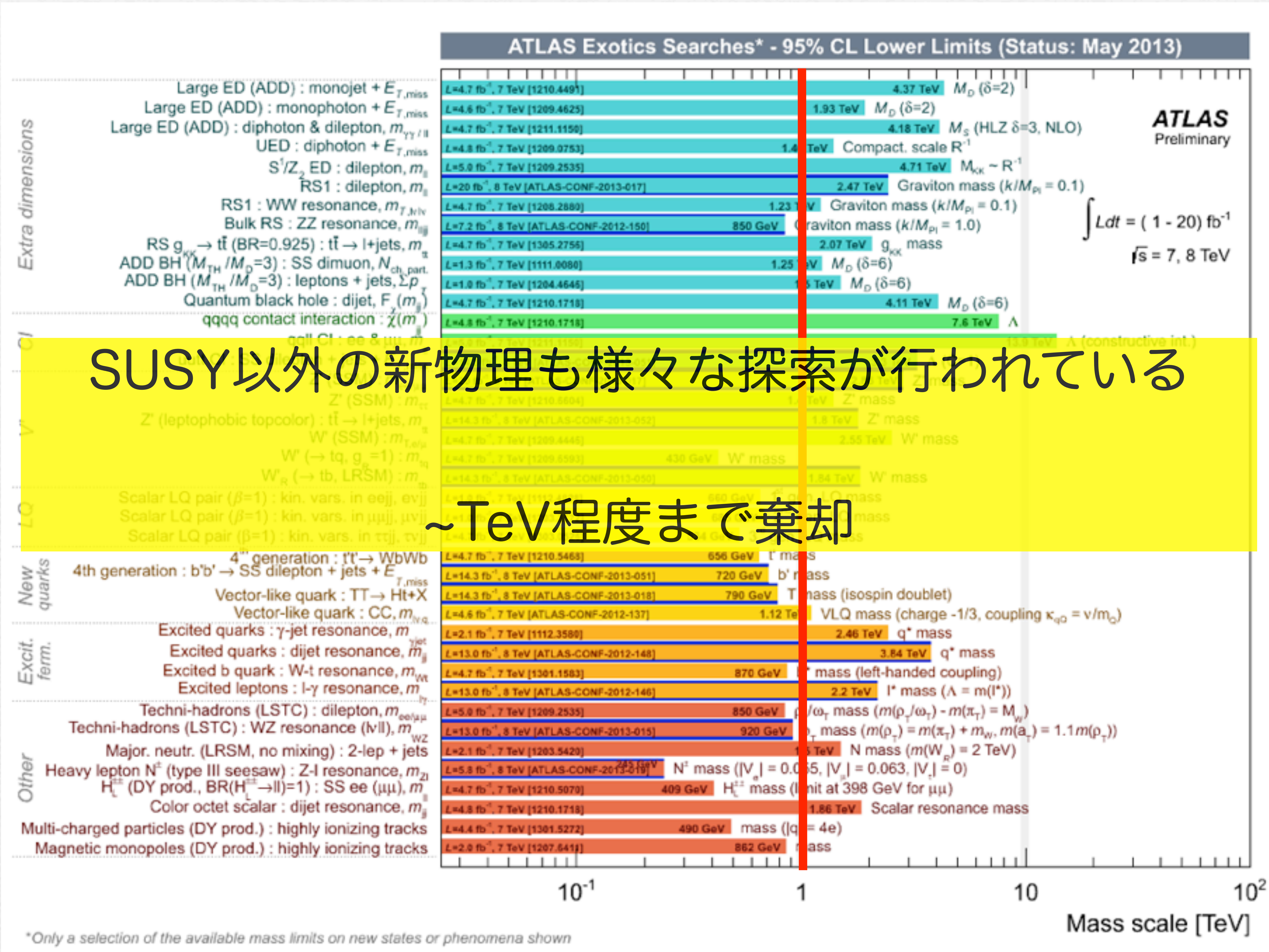

ATLAS SUSY Searches* - 95% CL Lower Limits
Status: SUSY 2013
ATLAS Preliminary
$\int \mathcal{L} dt = (4.6 - 22.9)$ fb^{-1} $\sqrt{s}$ = 7, 8 TeV
Model
e, μ, τ, γ
Jets
E_T^{miss}
$\int \mathcal{L} dt$[fb^{-1}]
Mass limit
Reference
Inclusive Searches
MSUGRA/CMSSM 1.7 TeV
MSUGRA/CMSSM 1.2 TeV
MSUGRA/CMSSM 1.1 TeV
740 GeV
1.3 TeV
1.18 TeV
1.12 TeV
GMSB ($\tilde{\ell}$ NLSP) 1.24 TeV
GMSB ($\tilde{\ell}$ NLSP) 1.4 TeV
GGM (bino NLSP) 1.07 TeV
GGM (wino NLSP) 619 GeV
GGM (higgsino-bino NLSP) 900 GeV
GGM (higgsino NLSP) 690 GeV
Gravitino LSP 645 GeV
3rd gen. $\tilde{g}$ med.
1.2 TeV
1.1 TeV
1.34 TeV
1.3 TeV
3rd gen. squarks direct production
100-620 GeV
275-430 GeV
110-167 GeV
130-220 GeV
225-525 GeV
150-580 GeV
200-610 GeV
320-660 GeV
90-200 GeV
500 GeV
271-520 GeV
EW direct
85-315 GeV
125-450 GeV
180-330 GeV
600 GeV
315 GeV
285 GeV
Long-lived particles
270 GeV
832 GeV
475 GeV
230 GeV
1.0 TeV
RPV
1.61 TeV
1.1 TeV
Bilinear RPV CMSSM 1.2 TeV
760 GeV
350 GeV
916 GeV
880 GeV
Other
Scalar gluon pair, sgluon→$q\bar{q}$ 100-287 GeV
Scalar gluon pair, sgluon→$t\bar{t}$ 800 GeV
WIMP interaction (D5, Dirac χ) 704 GeV
$\sqrt{s}$ = 7 TeV full data
$\sqrt{s}$ = 8 TeV partial data
$\sqrt{s}$ = 8 TeV full data
10^{-1}
1
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

SUSY探索のまとめ


ATLAS SUSY Searches* - 95% CL Lower Limits
Status: SUSY 2013
ATLAS Preliminary
∫L dt = (4.6 - 22.9) fb⁻¹
√s = 7, 8 TeV
Model
e, μ, τ, γ
Jets
E_T^miss
∫L dt[fb⁻¹]
Mass limit
Reference
Inclusive Searches
3rd gen. g̃ med.
3rd gen. squarks direct production
EW direct
Long-lived particles
RPV
Other
Inclusive 1.7TeV
gluino → 第３世代 squark：1.3TeV
第３世代 squark：600GeV
Chargino/Neutralino：300GeV
その他：数百GeV〜TeV位まで
√s = 7 TeV full data
√s = 8 TeV partial data
√s = 8 TeV full data
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

SUSY以外の新物理探索

SUSY以外の新物理探索



SUSY以外の新物理も様々な探索が行われている

~TeV程度まで棄却

まとめ

ヒッグス粒子の発見から１年+2.5ヶ月

”ヒッグス物理”が開始

今の所、標準模型ヒッグスと無矛盾

LHC Run X による精密測定 → ILC で面白くなる

ヒッグスの存在によって新物理発見にますます期待

今の所、まだ兆候はない

テラスケールの領域を広くExcludeし始めている

→ 発見目前のレベルにまで追いつめたか？？

14 TeV LHC → HL-LHC で新物理を捕らえ、ILCへ

まとめ

ヒッグス粒子の発見から１年+2.5ヶ月

”ヒッグス物理”が開始

「ヒッグスからテラスケール」
に向けた測定・探索が始まった

LHC Run X による精密測定 → ILC で面白くなる

ヒッグスの存在によって新物理発見にますます期待

今の所、まだ兆候は見つかっていない

14 TeV LHC, HL-LHC, ILCへ

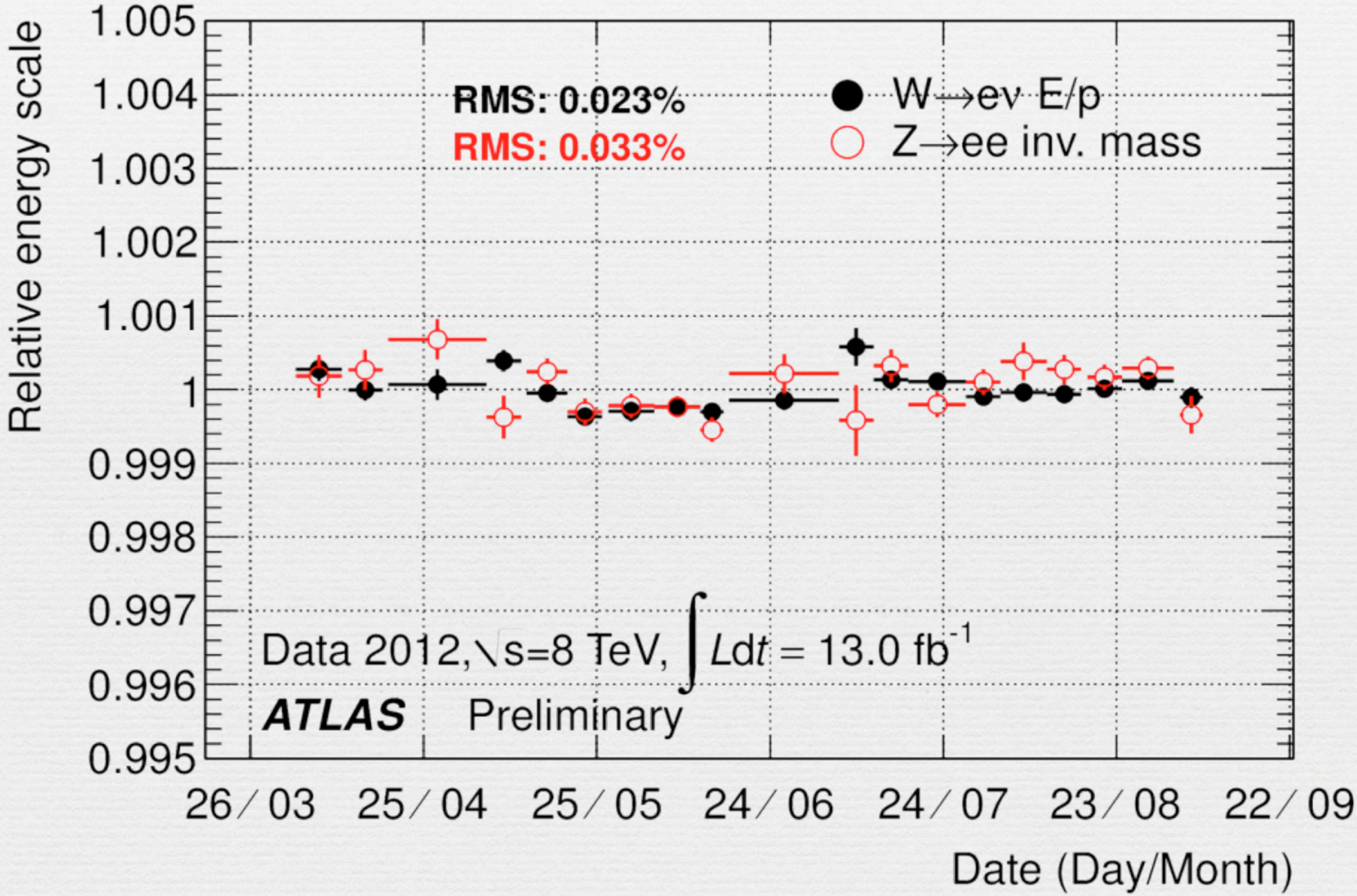
テラスケールの領域をExcludeし始めている

→ すぐ目の前まで追いつめたか？？

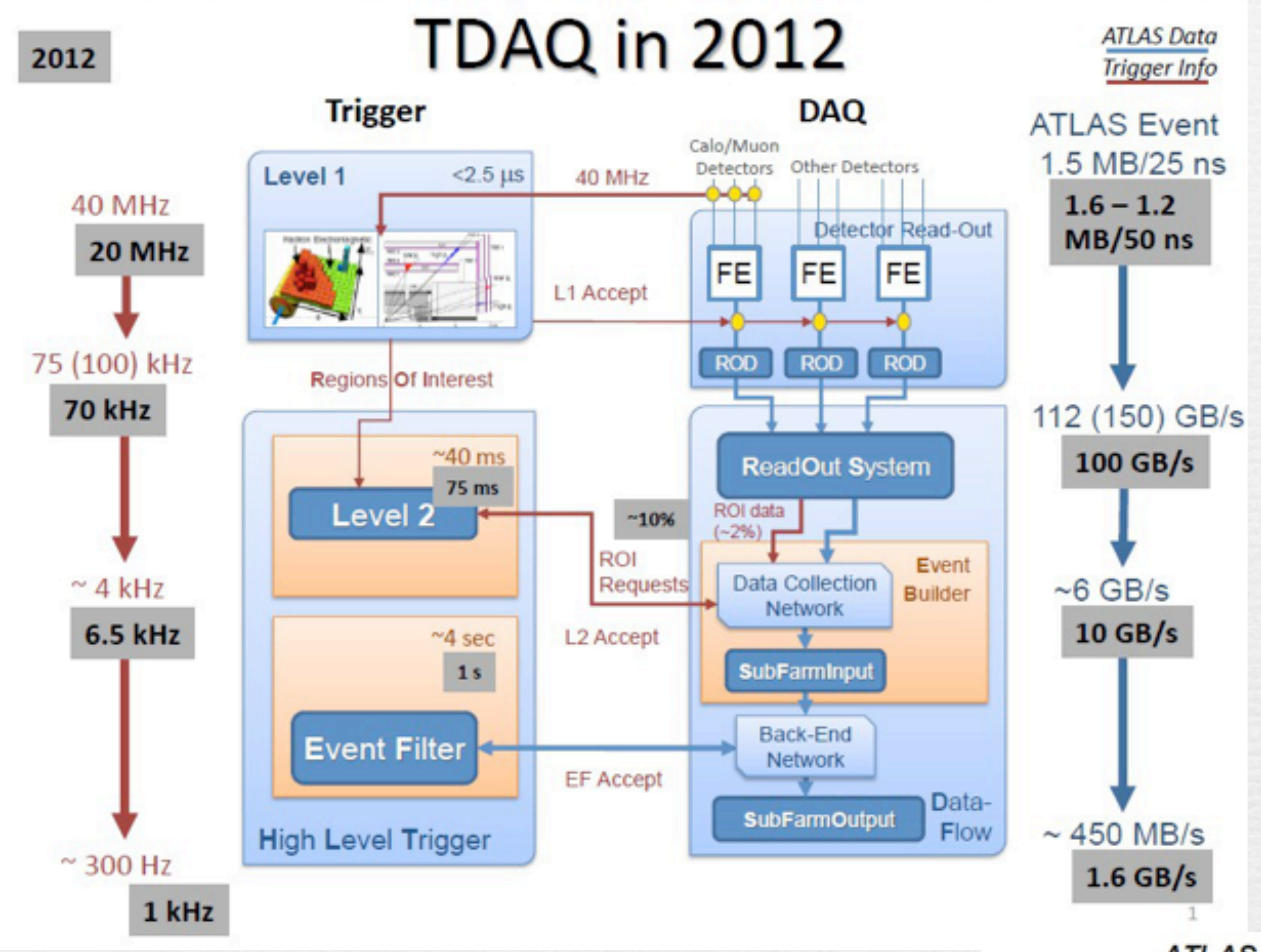
14 TeV LHC → HL-LHC で新物理を捕らえ、ILCへ

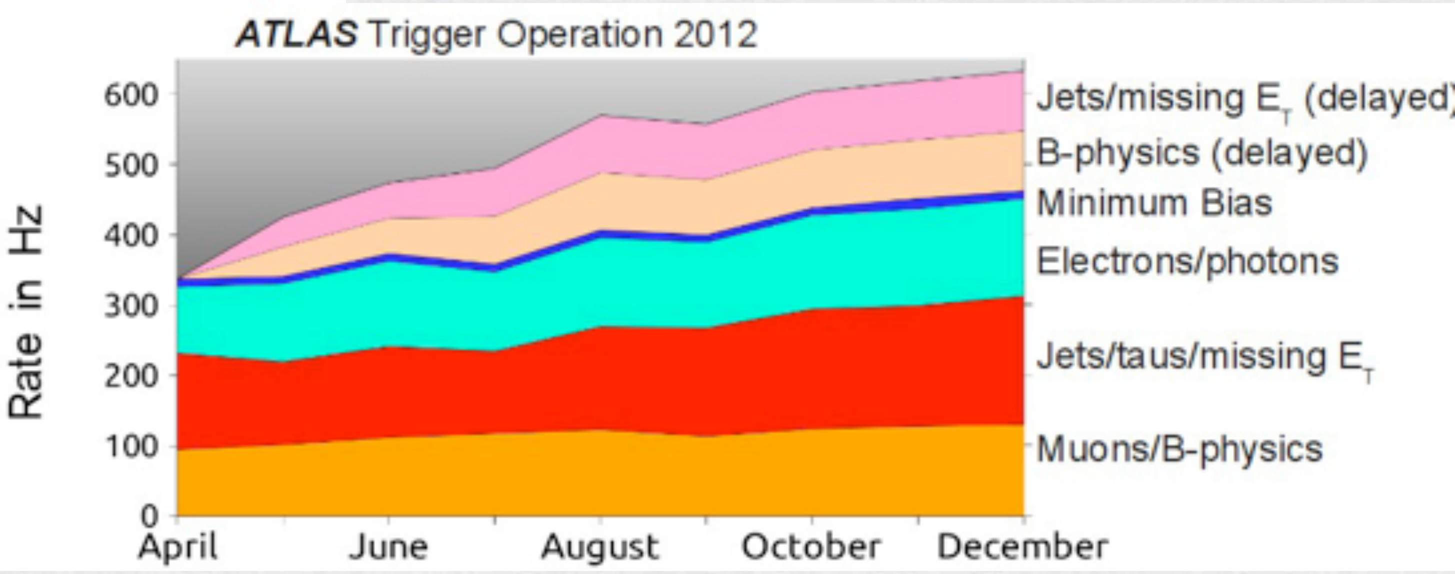
backup

Electron energy scale

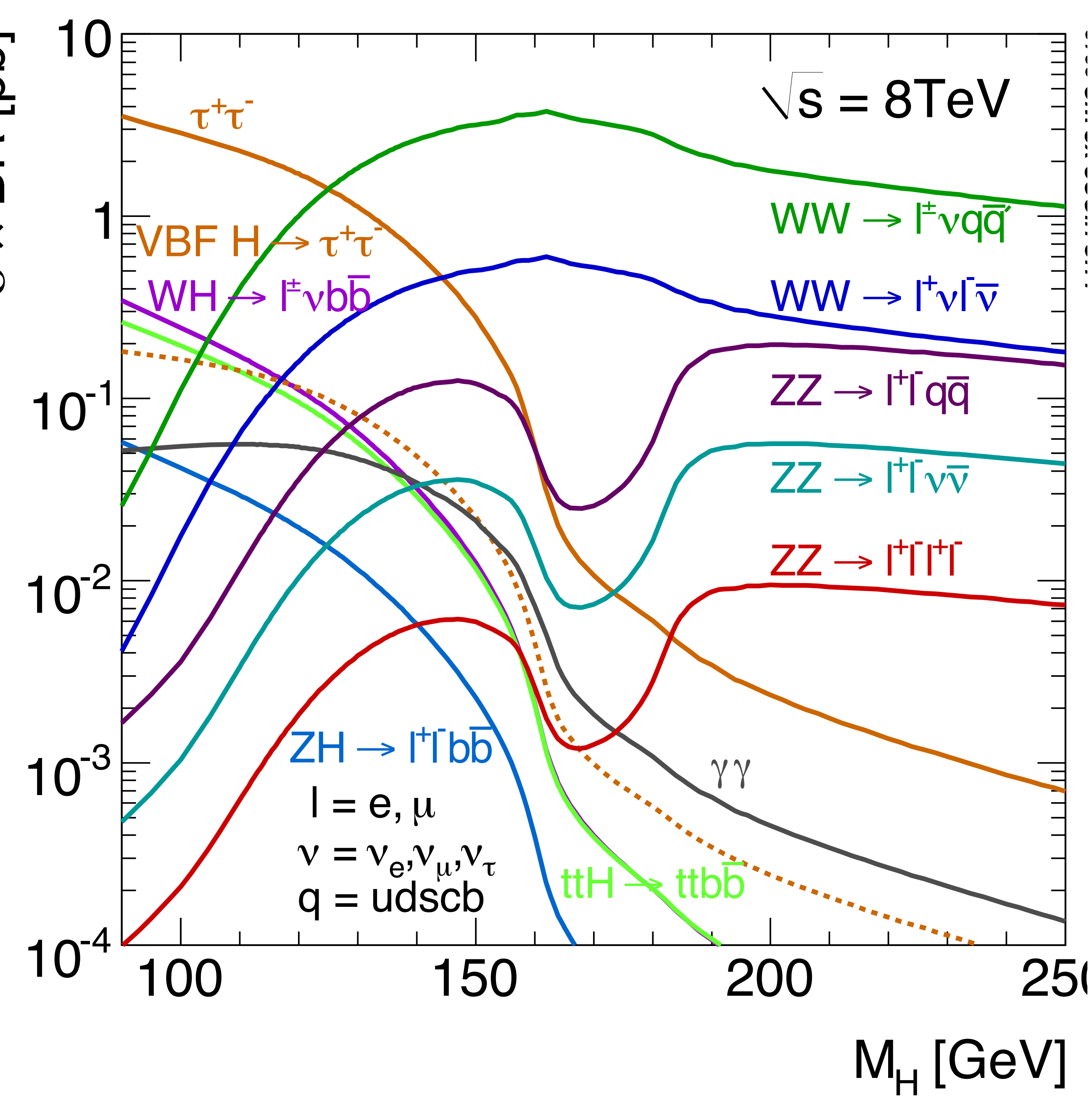


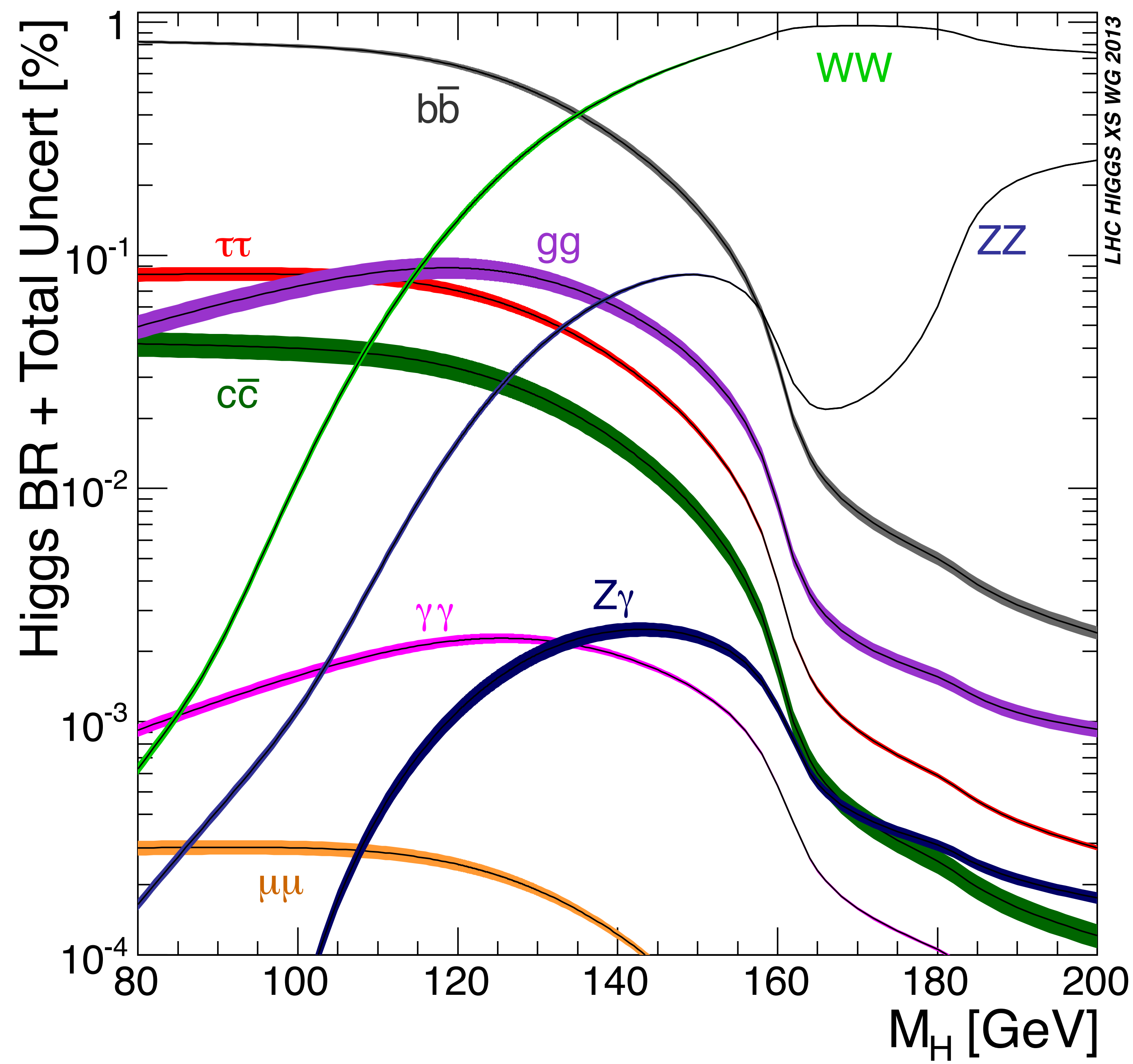
Trigger


2012
TDAQ in 2012
ATLAS Data
Trigger Info
Trigger
DAQ
ATLAS Event
1.5 MB/25 ns
1.6 – 1.2
MB/50 ns
40 MHz
20 MHz
Level 1
<2.5 μs
40 MHz
Calo/Muon
Detectors
Other Detectors
Detector Read-Out
FE
L1 Accept
ROD
75 (100) kHz
70 kHz
Regions Of Interest
112 (150) GB/s
100 GB/s
~40 ms
75 ms
Level 2
~10%
ReadOut System
ROI data
(~2%)
ROI
Requests
Data Collection
Network
Event
Builder
~ 4 kHz
6.5 kHz
~6 GB/s
10 GB/s
~4 sec
1 s
L2 Accept
SubFarmInput
Event Filter
Back-End
Network
EF Accept
SubFarmOutput
Data-
Flow
High Level Trigger
~ 300 Hz
1 kHz
~ 450 MB/s
1.6 GB/s

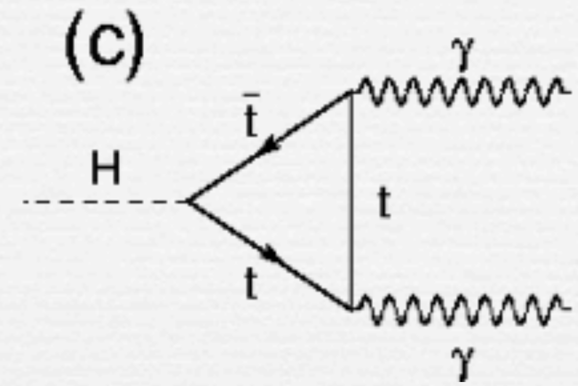

ATLAS Trigger Operation 2012
Rate in Hz
0
100
200
300
400
500
600
April
June
August
October
December
Jets/missing E_T (delayed)
B-physics (delayed)
Minimum Bias
Electrons/photons
Jets/taus/missing E_T
Muons/B-physics

Higgs production & decay





崩壊過程



H→γγ：Wとt-quarkのLoopを経て崩壊

・Wとt-quarkは負符号で干渉する

・フェルミオンとの結合の間接的証拠

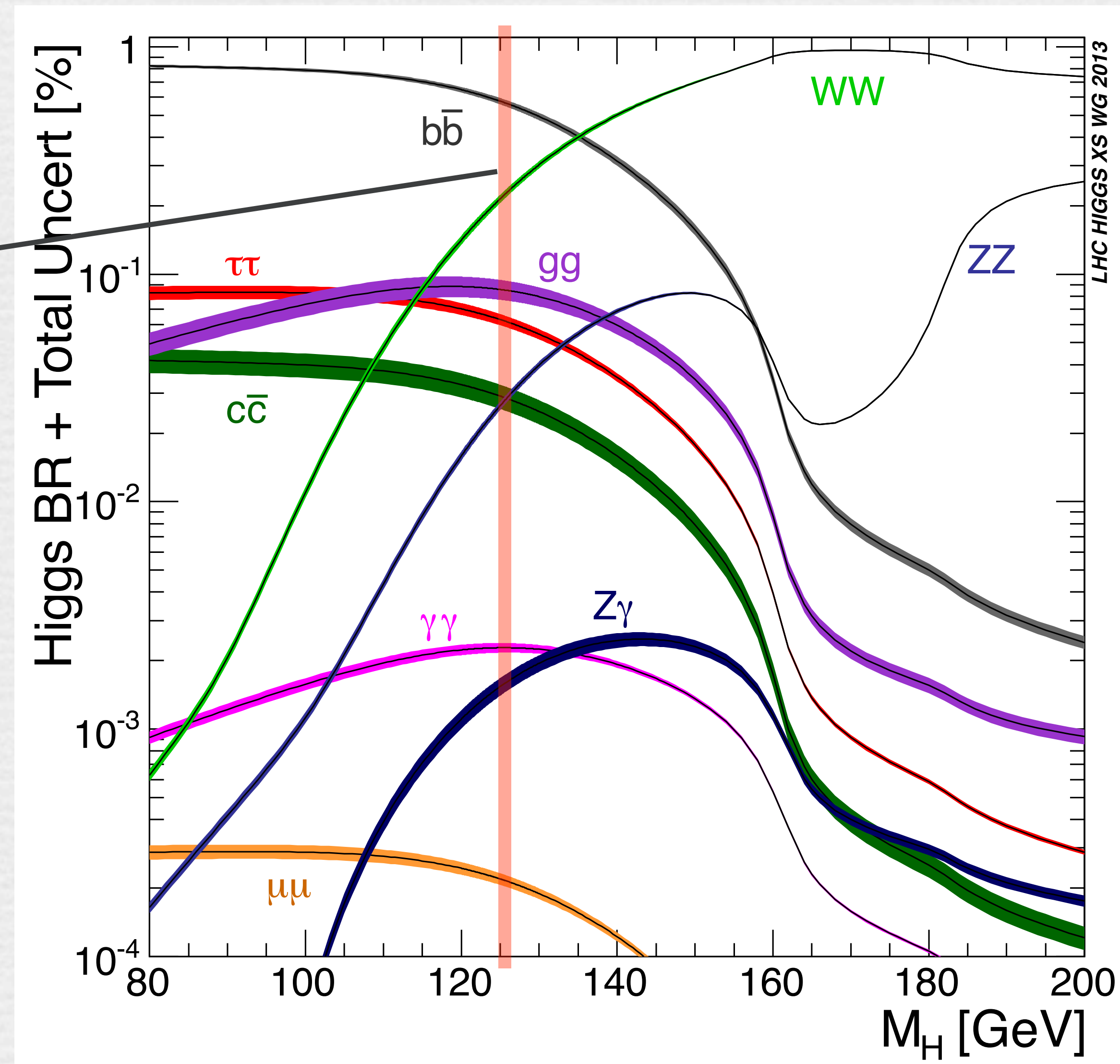
レプトンや光子が終状態のチャンネルが発見チャンネル

・ H→γγ、ZZ(→4ℓ), WW(→ℓνℓν)

H→bb, H→ττ：膨大なQCD事象との分離が鍵

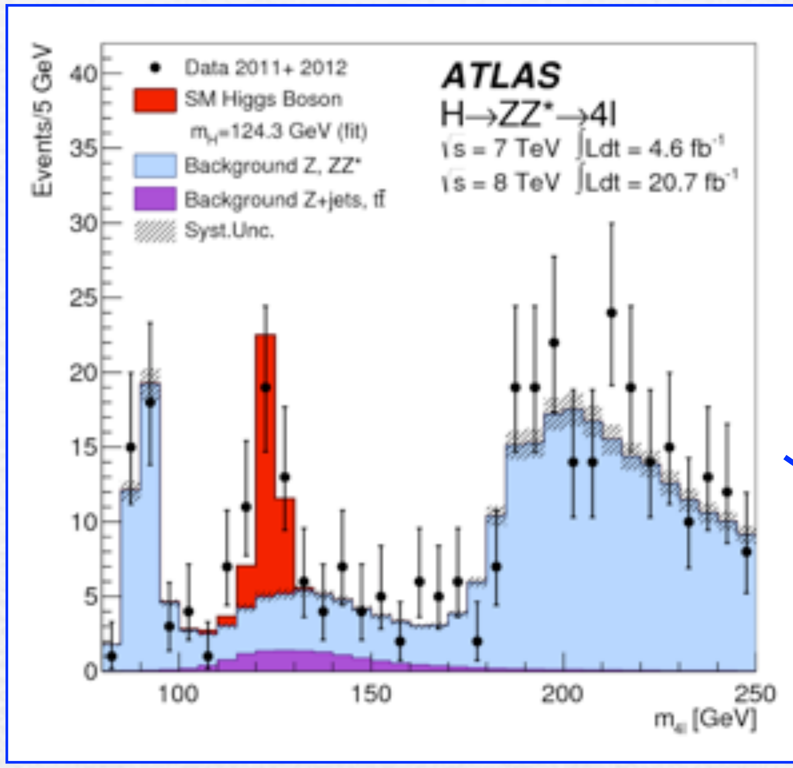
・フェルミオンとの結合の直接的証拠

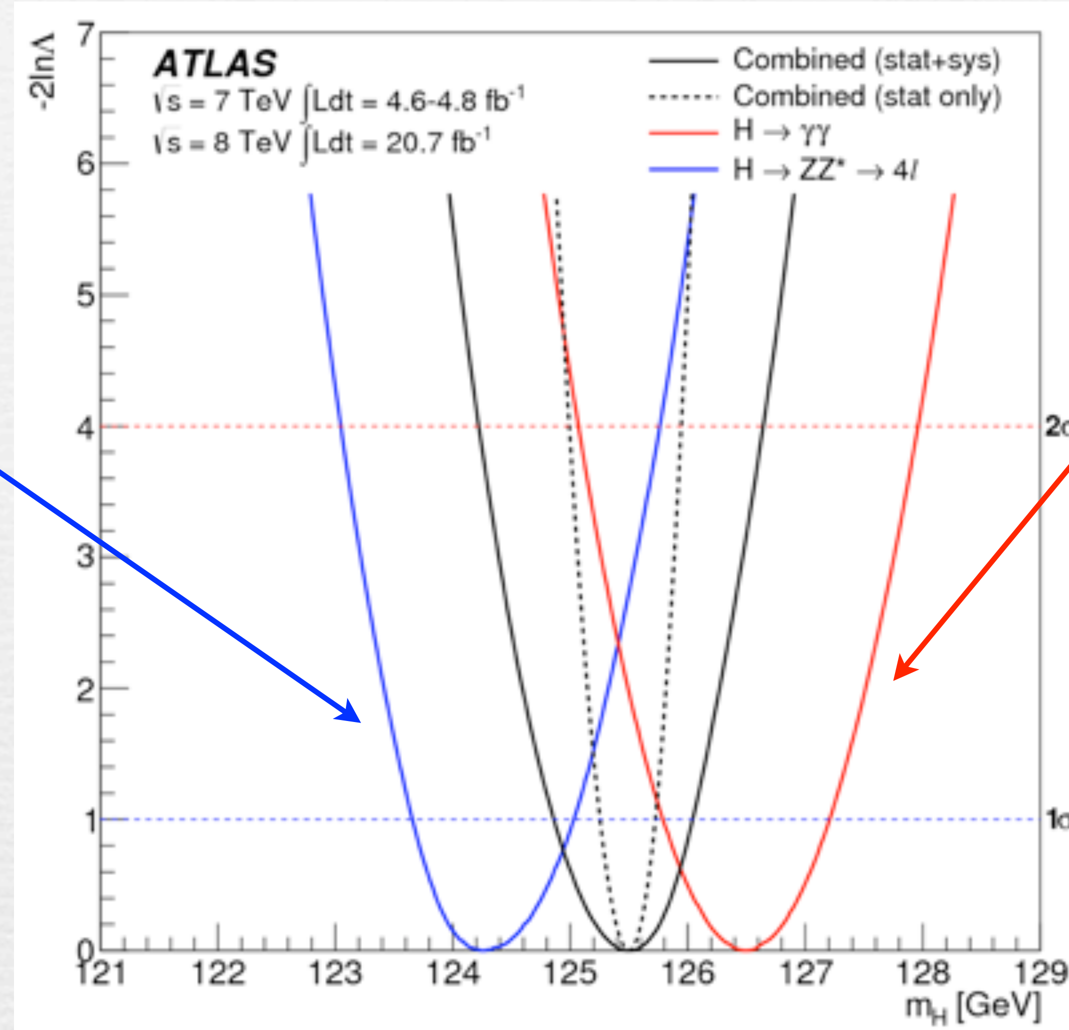
m_H=125.5GeV	BR(%)
H→γγ	0.23
H→ZZ	2.8
H→WW	22
H→ττ	6.2
H→bb	57
H→Zγ	0.16
H→μμ	0.02

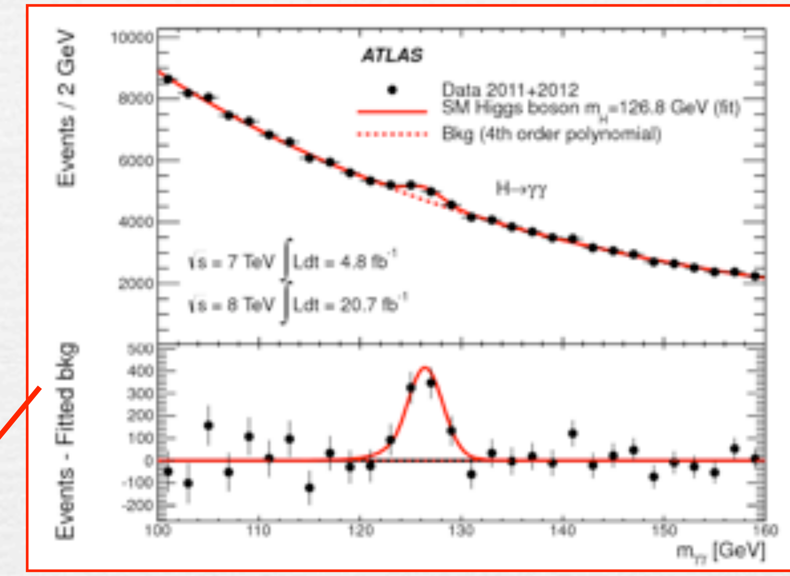


質量

arXiv:1307.1427





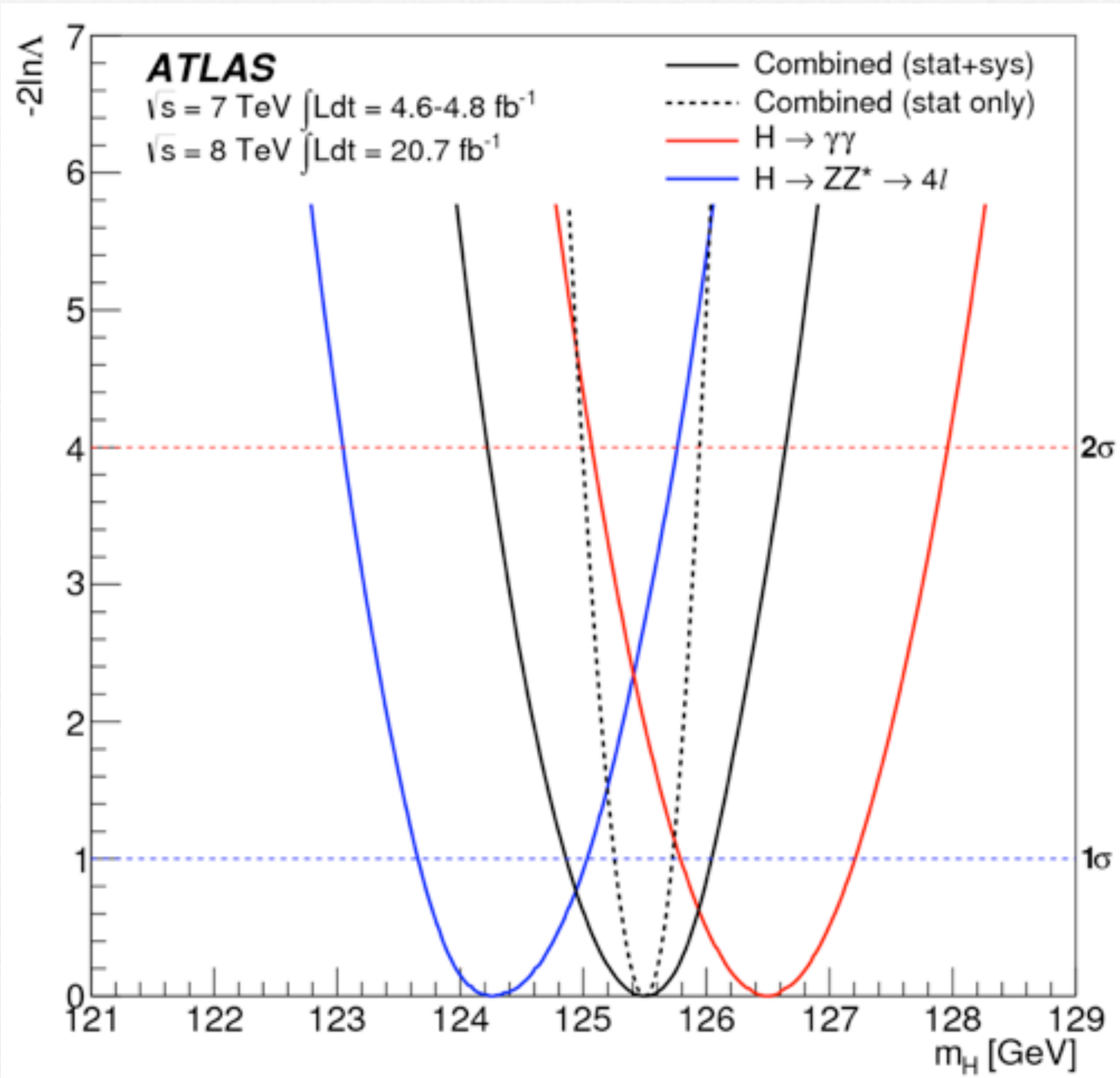


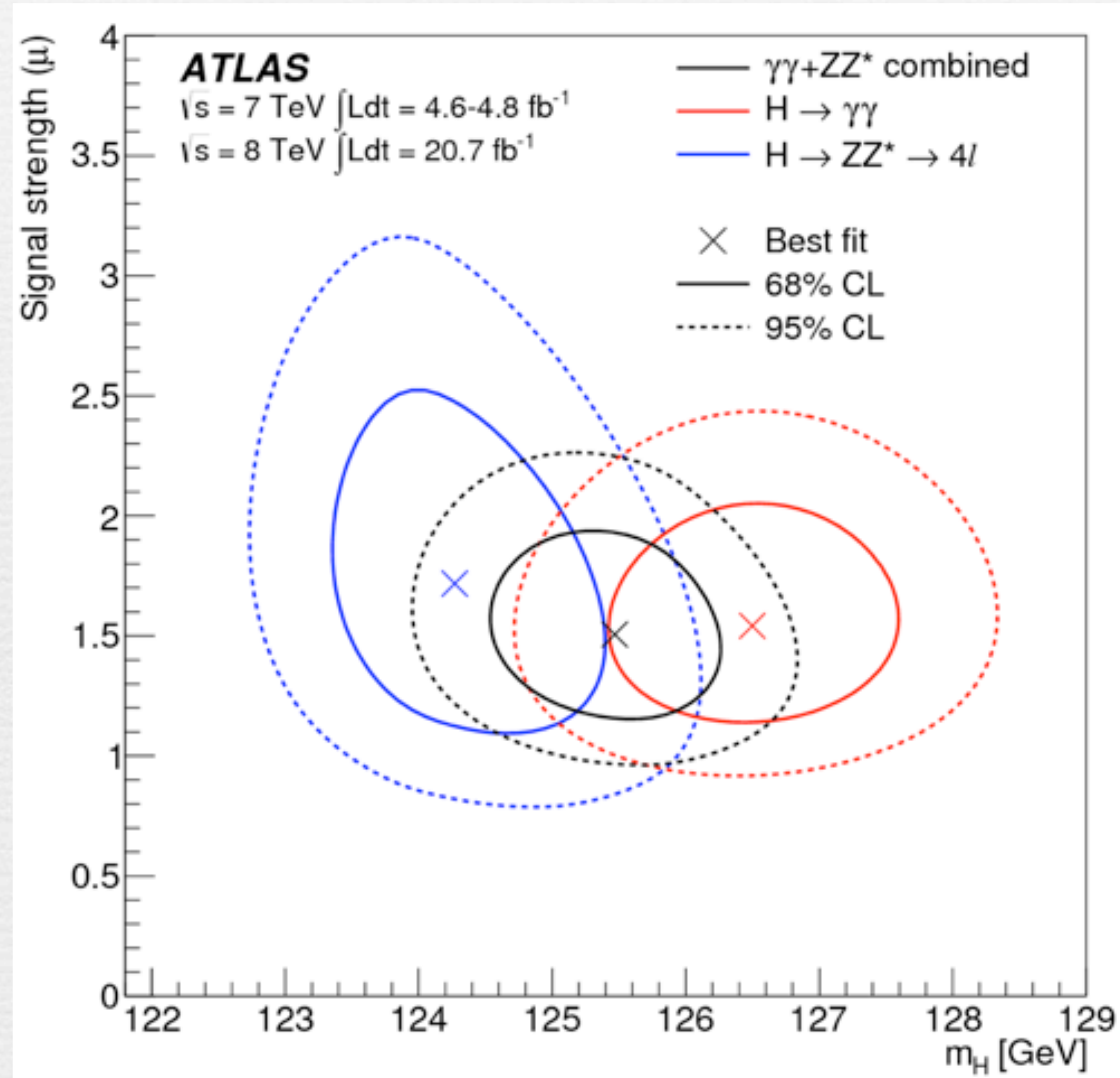
Combined $m_H = 125.5 \pm 0.2\ (\mathrm{stat})\ ^{+0.5}_{-0.6}\ (\mathrm{stat})\ \mathrm{GeV}$

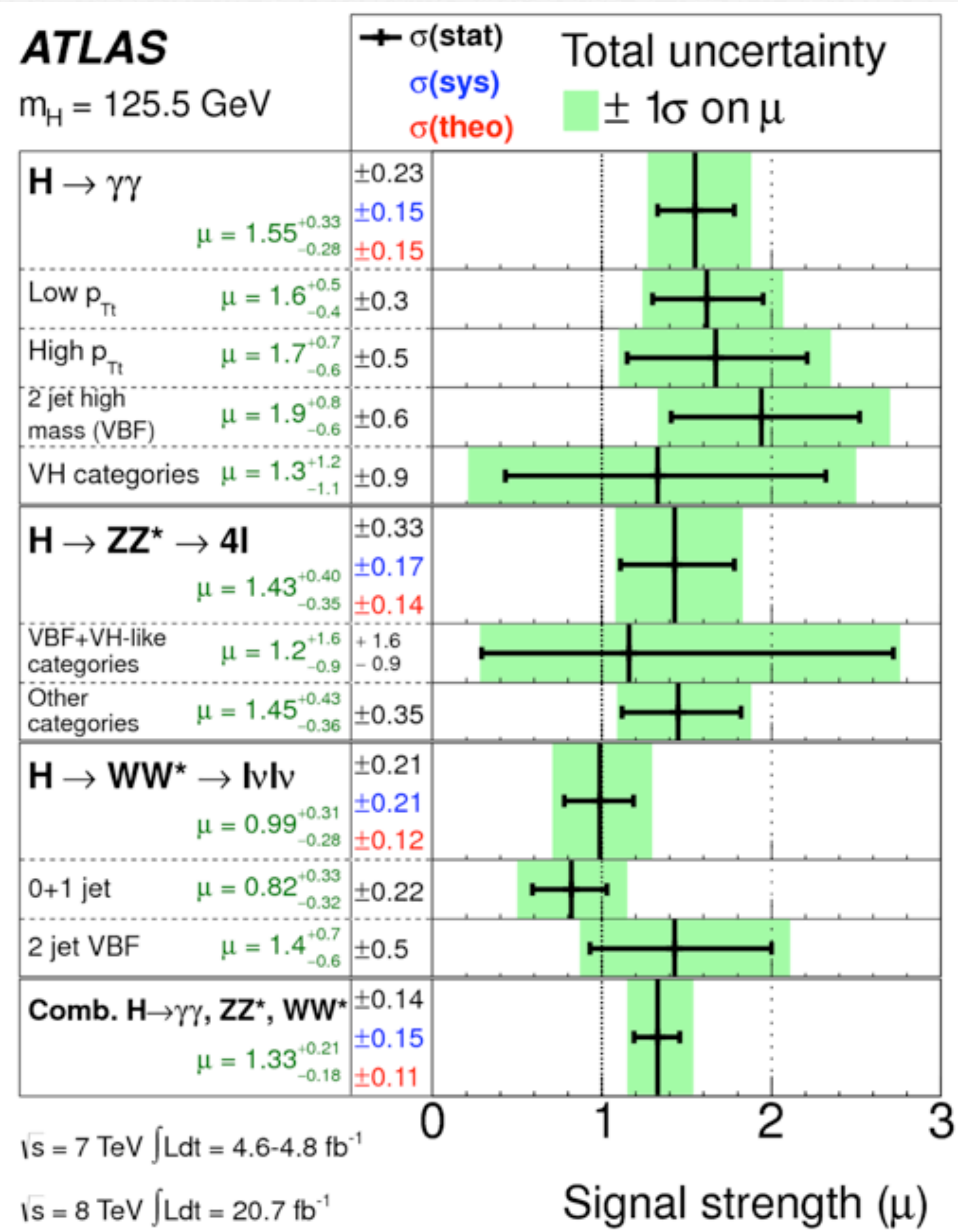
$$\Delta m_H = m_H^{\gamma\gamma} - m_H^{ZZ} = 2.3\ ^{+0.3}_{-0.7}\ (\mathrm{stat}) \pm 0.6\ (\mathrm{stat})\ \mathrm{GeV}$$

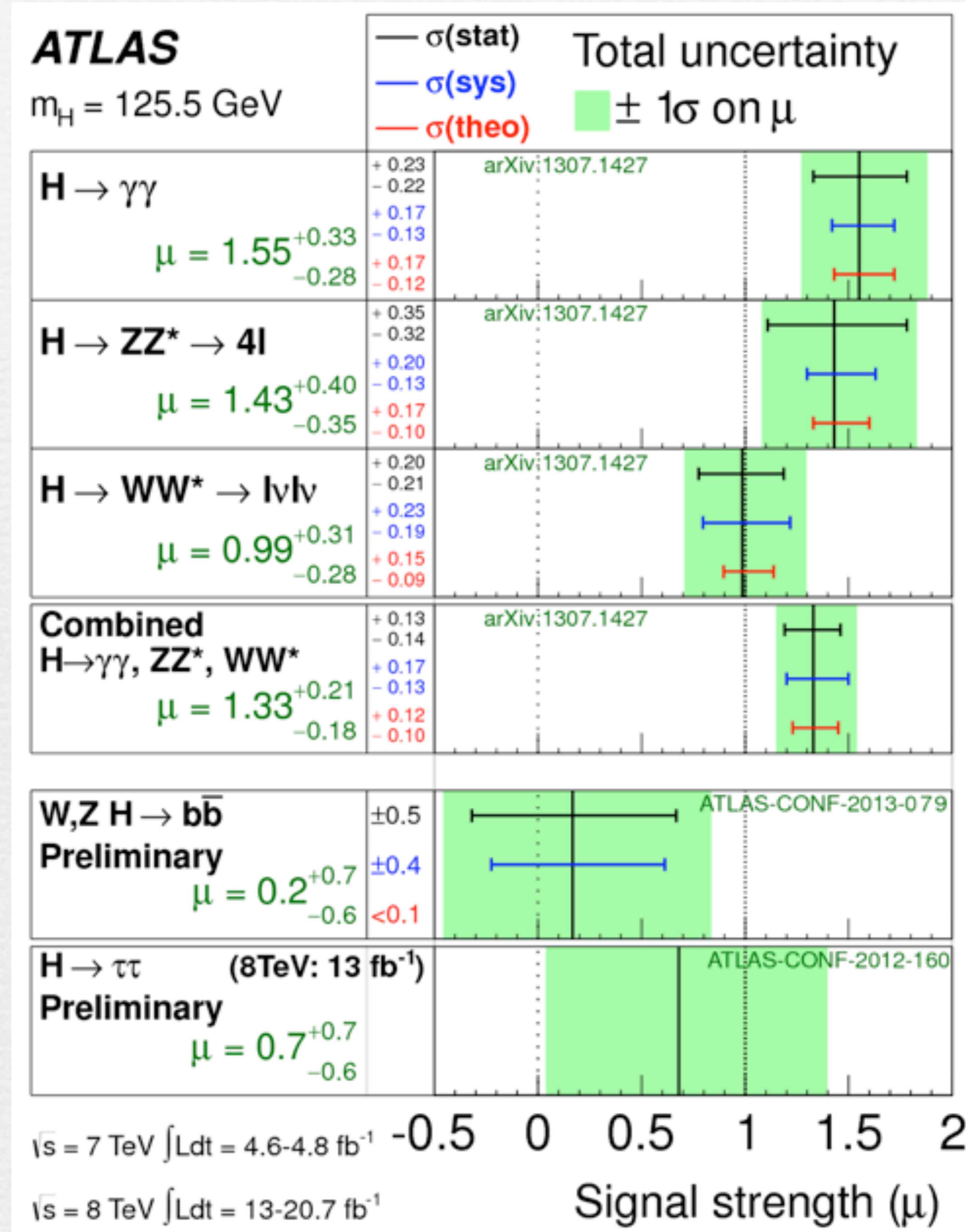
この質量差を生み出す確率 1.5% (2.4σ) ~ 8%

質量

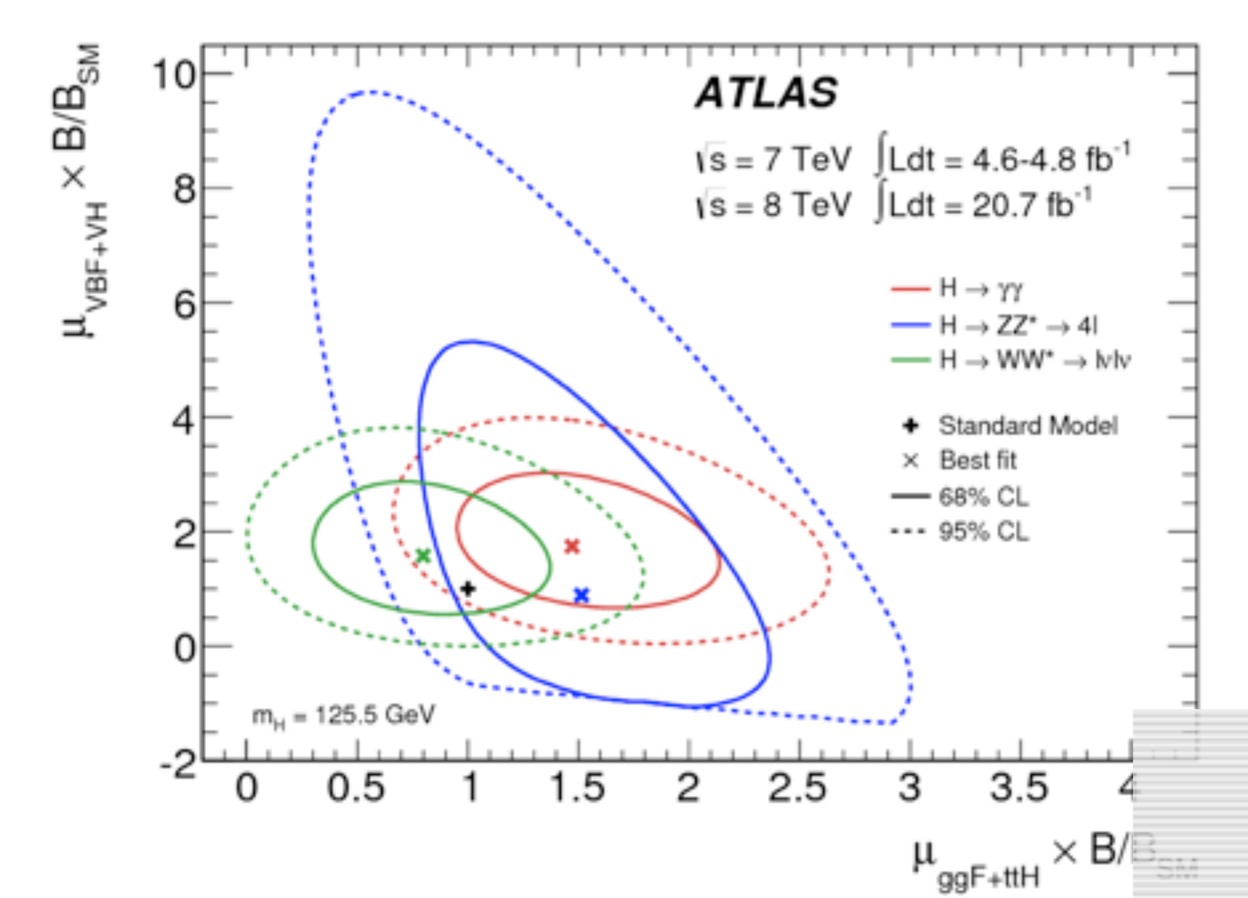

ATLAS
√s = 7 TeV ∫Ldt = 4.6-4.8 fb⁻¹
√s = 8 TeV ∫Ldt = 20.7 fb⁻¹
Combined (stat+sys)
Combined (stat only)
H → γγ
H → ZZ* → 4l
-2lnΛ
2σ
1σ
m_H [GeV]

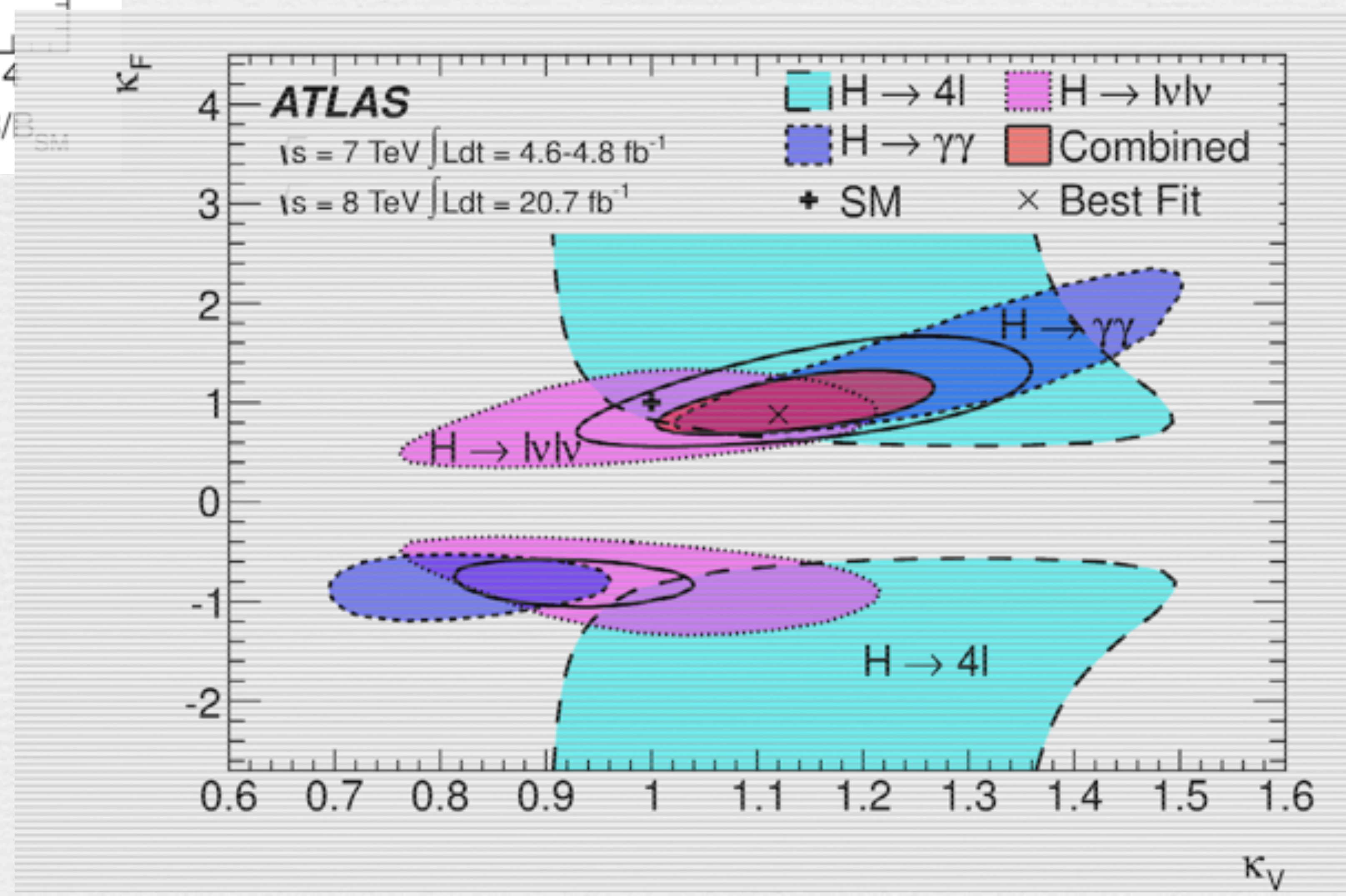

ATLAS
√s = 7 TeV ∫Ldt = 4.6-4.8 fb⁻¹
√s = 8 TeV ∫Ldt = 20.7 fb⁻¹
γγ+ZZ* combined
H → γγ
H → ZZ* → 4l
Best fit
68% CL
95% CL
Signal strength (μ)
m_H [GeV]


ATLAS
mH = 125.5 GeV
σ(stat)
σ(sys)
σ(theo)
Total uncertainty
± 1σ on μ
H → γγ
μ = 1.55 +0.33 −0.28
±0.23
±0.15
±0.15
Low pTt μ = 1.6 +0.5 −0.4 ±0.3
High pTt μ = 1.7 +0.7 −0.6 ±0.5
2 jet high mass (VBF) μ = 1.9 +0.8 −0.6 ±0.6
VH categories μ = 1.3 +1.2 −1.1 ±0.9
H → ZZ* → 4l
μ = 1.43 +0.40 −0.35
±0.33
±0.17
±0.14
VBF+VH-like categories μ = 1.2 +1.6 −0.9 + 1.6 − 0.9
Other categories μ = 1.45 +0.43 −0.36 ±0.35
H → WW* → lνlν
μ = 0.99 +0.31 −0.28
±0.21
±0.21
±0.12
0+1 jet μ = 0.82 +0.33 −0.32 ±0.22
2 jet VBF μ = 1.4 +0.7 −0.6 ±0.5
Comb. H→γγ, ZZ*, WW*
μ = 1.33 +0.21 −0.18
±0.14
±0.15
±0.11
0 1 2 3
√s = 7 TeV ∫Ldt = 4.6-4.8 fb⁻¹
√s = 8 TeV ∫Ldt = 20.7 fb⁻¹
Signal strength (μ)

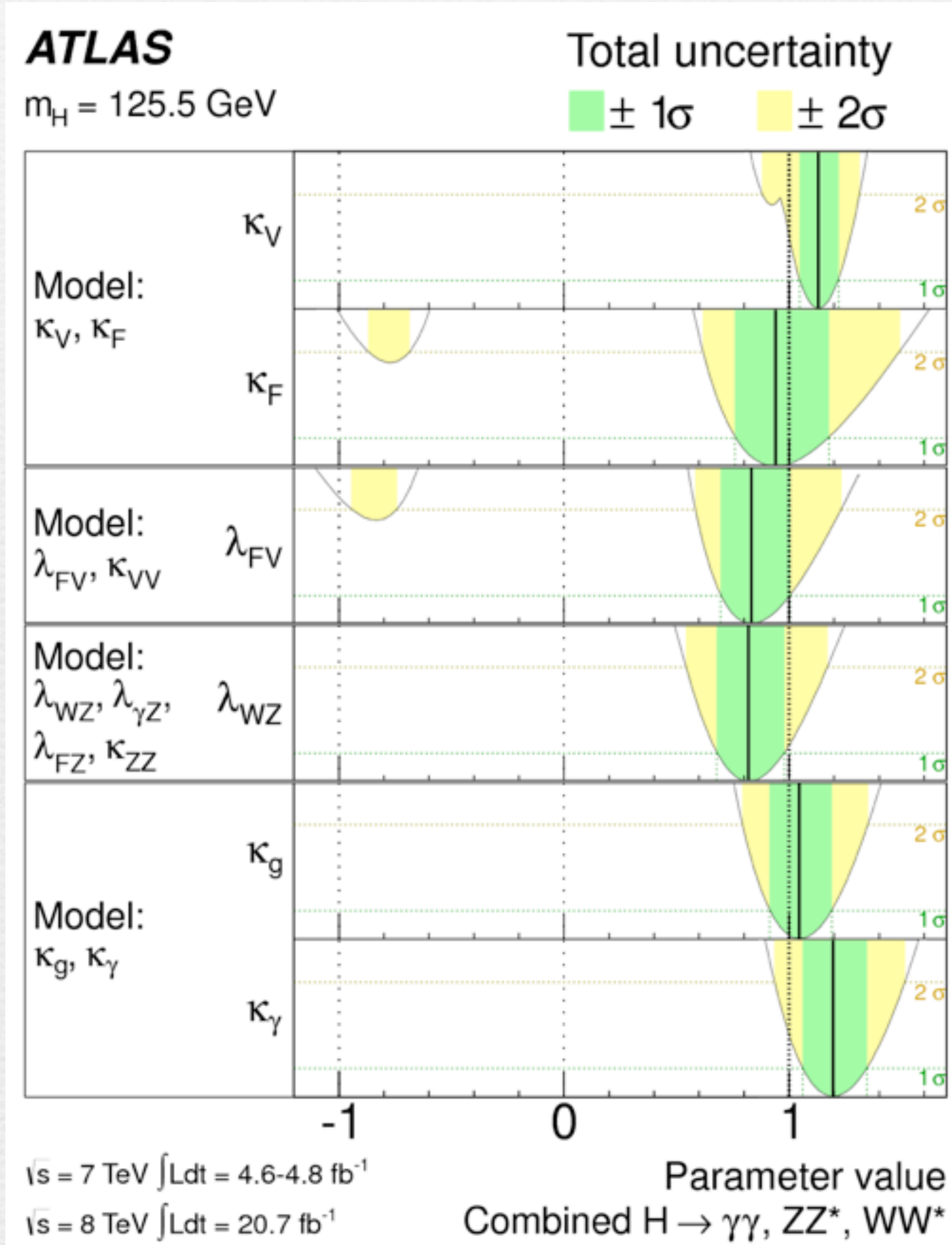

ATLAS
mH = 125.5 GeV
σ(stat)
σ(sys)
σ(theo)
Total uncertainty
± 1σ on μ
H → γγ
μ = 1.55 +0.33 −0.28
+ 0.23 − 0.22
+ 0.17 − 0.13
+ 0.17 − 0.12
arXiv:1307.1427
H → ZZ* → 4l
μ = 1.43 +0.40 −0.35
+ 0.35 − 0.32
+ 0.20 − 0.13
+ 0.17 − 0.10
arXiv:1307.1427
H → WW* → lνlν
μ = 0.99 +0.31 −0.28
+ 0.20 − 0.21
+ 0.23 − 0.19
+ 0.15 − 0.09
arXiv:1307.1427
Combined H→γγ, ZZ*, WW*
μ = 1.33 +0.21 −0.18
+ 0.13 − 0.14
+ 0.17 − 0.13
+ 0.12 − 0.10
arXiv:1307.1427
W,Z H → bb̄ Preliminary
μ = 0.2 +0.7 −0.6
±0.5
±0.4
<0.1
ATLAS-CONF-2013-079
H → ττ (8TeV: 13 fb⁻¹) Preliminary
μ = 0.7 +0.7 −0.6
ATLAS-CONF-2012-160
-0.5 0 0.5 1 1.5 2
√s = 7 TeV ∫Ldt = 4.6-4.8 fb⁻¹
√s = 8 TeV ∫Ldt = 13-20.7 fb⁻¹
Signal strength (μ)

VBF過程とfermion couplingの証拠

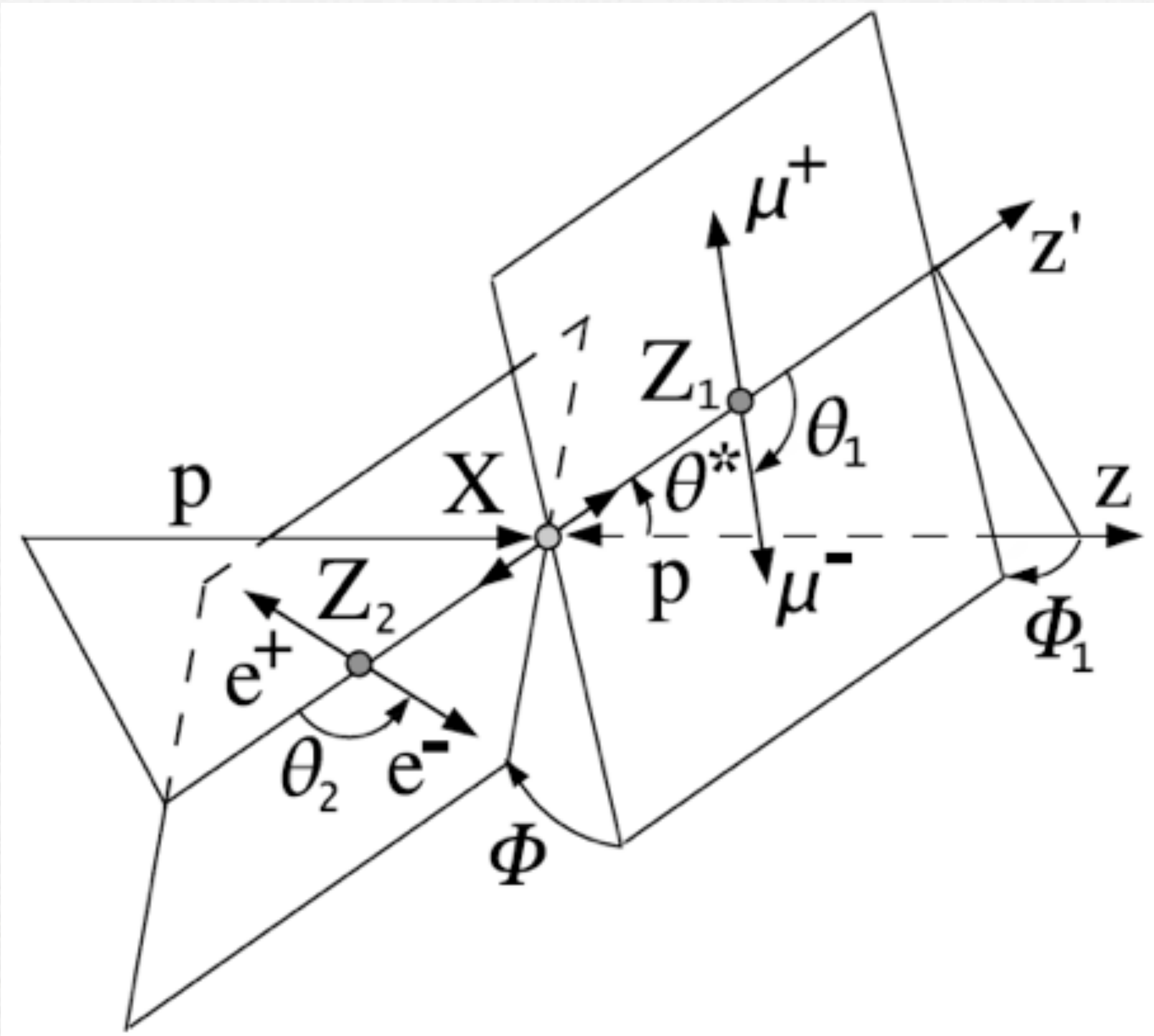


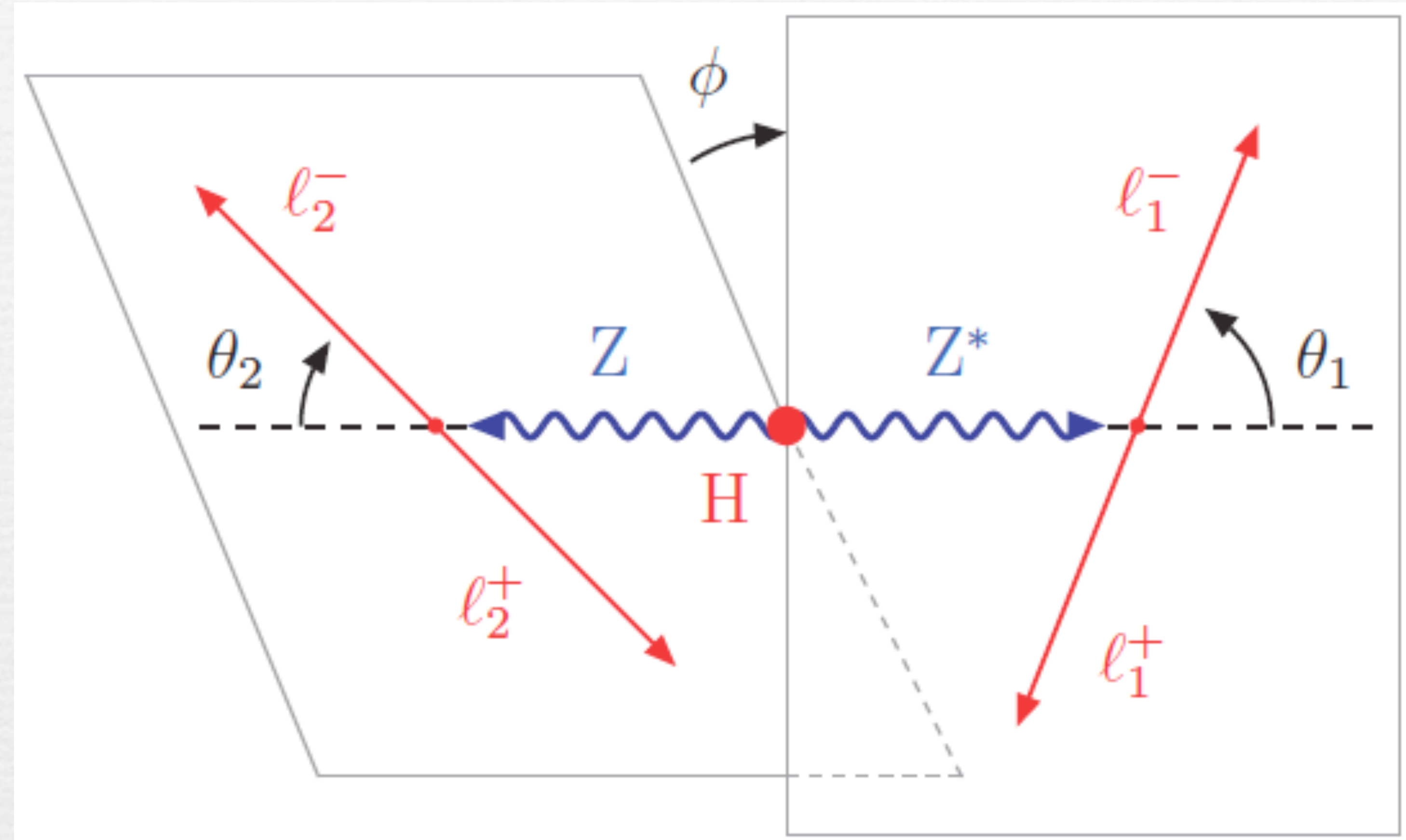


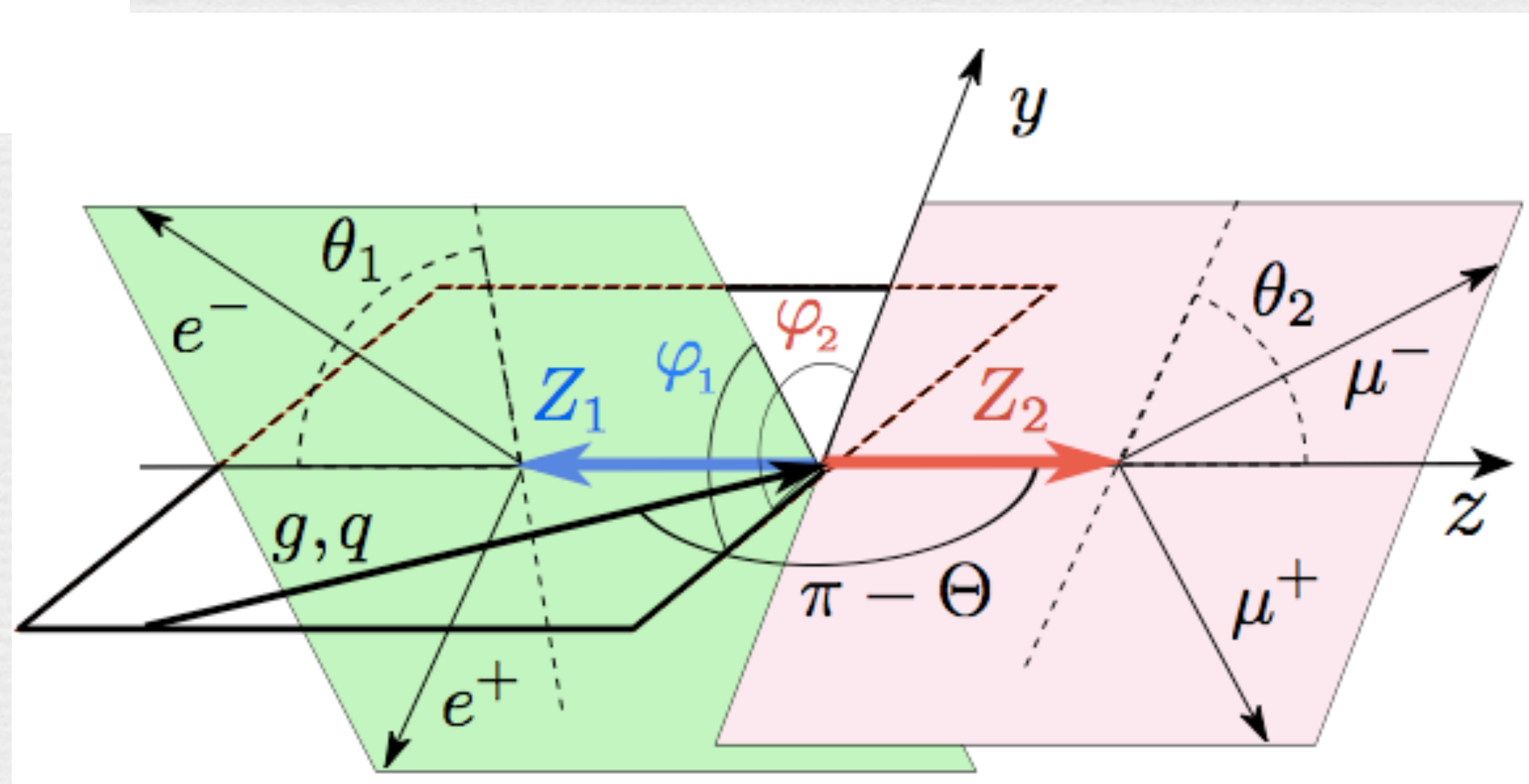
結合定数


ATLAS
m_H = 125.5 GeV
Total uncertainty
± 1σ
± 2σ
Model: κ_V, κ_F
κ_V
κ_F
Model: λ_{FV}, κ_{VV}
λ_{FV}
Model: λ_{WZ}, $\lambda_{\gamma Z}$, λ_{FZ}, κ_{ZZ}
λ_{WZ}
Model: κ_g, κ_γ
κ_g
κ_γ
2 σ
1 σ
-1
0
1
$\sqrt{s}$ = 7 TeV $\int Ldt$ = 4.6-4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV $\int Ldt$ = 20.7 fb^{-1}
Parameter value
Combined $H \rightarrow \gamma\gamma$, ZZ*, WW*

スピンーパリティ　測定


p
X
Z1
μ+
z'
θ*
θ1
z
p
μ-
Z2
e+
θ2
e-
Φ
Φ1


φ
ℓ2−
ℓ1−
θ2
Z
Z*
θ1
H
ℓ2+
ℓ1+

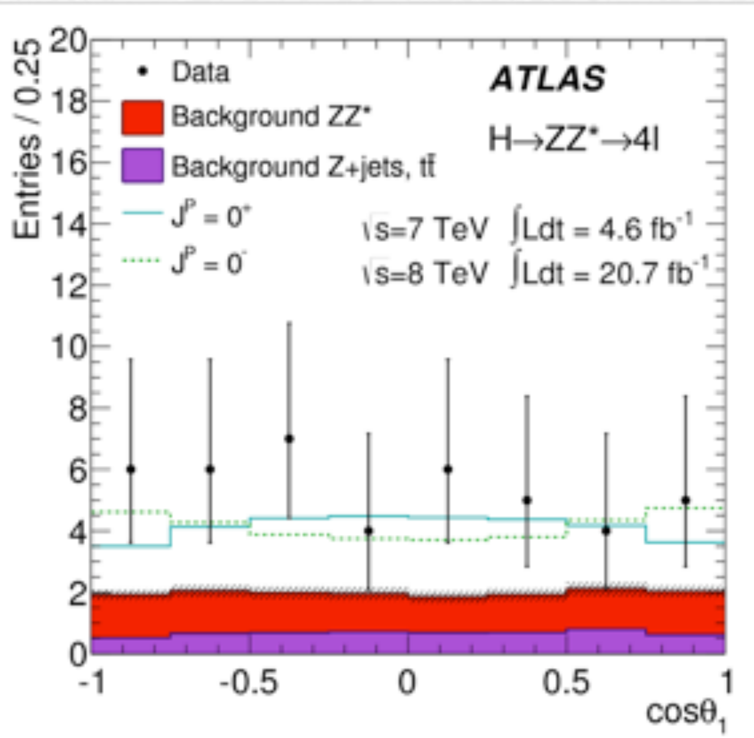

y
θ1
e−
φ2
φ1
Z1
Z2
θ2
μ−
z
g, q
π − Θ
μ+
e+

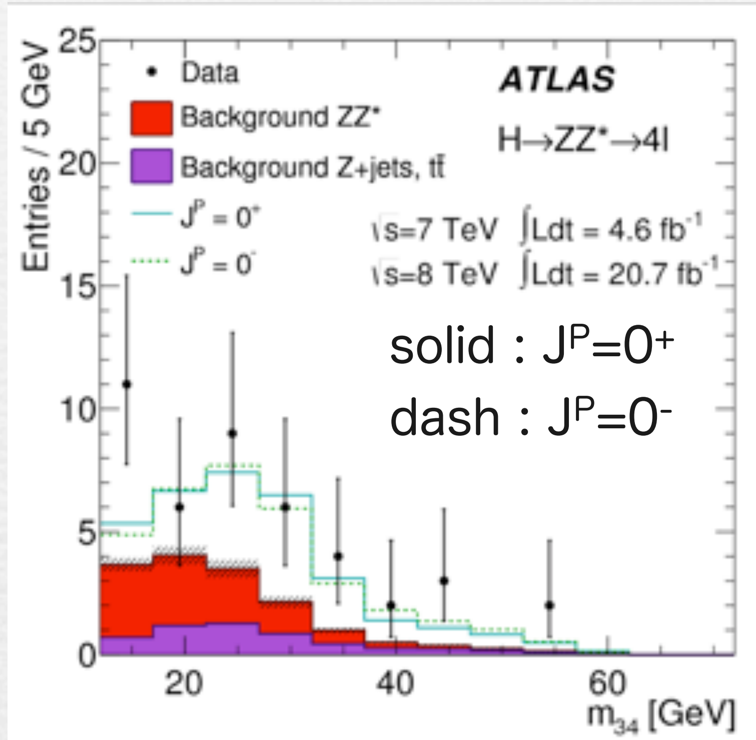
arXiv:1307.1432

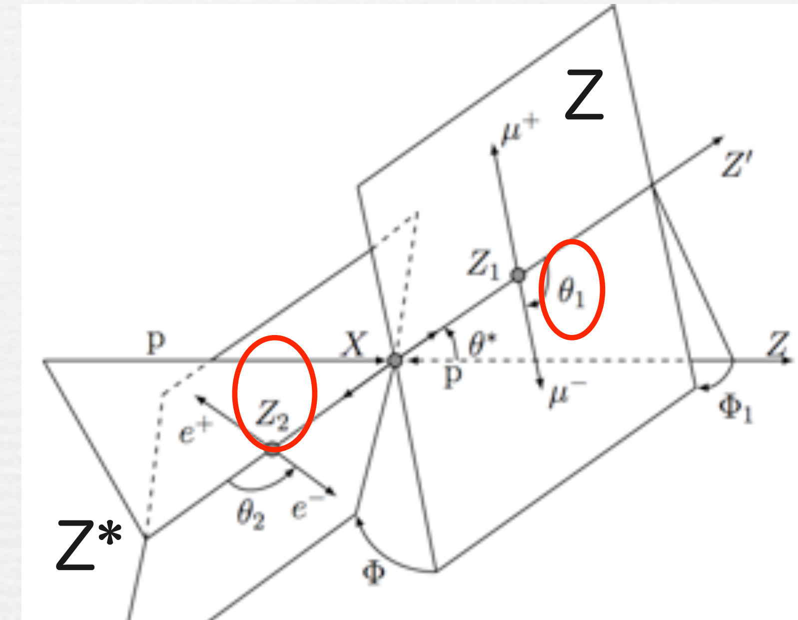
$J^P=0^+$ v.s. 0^-

Only H→ZZ*→4 lepton is used for this study

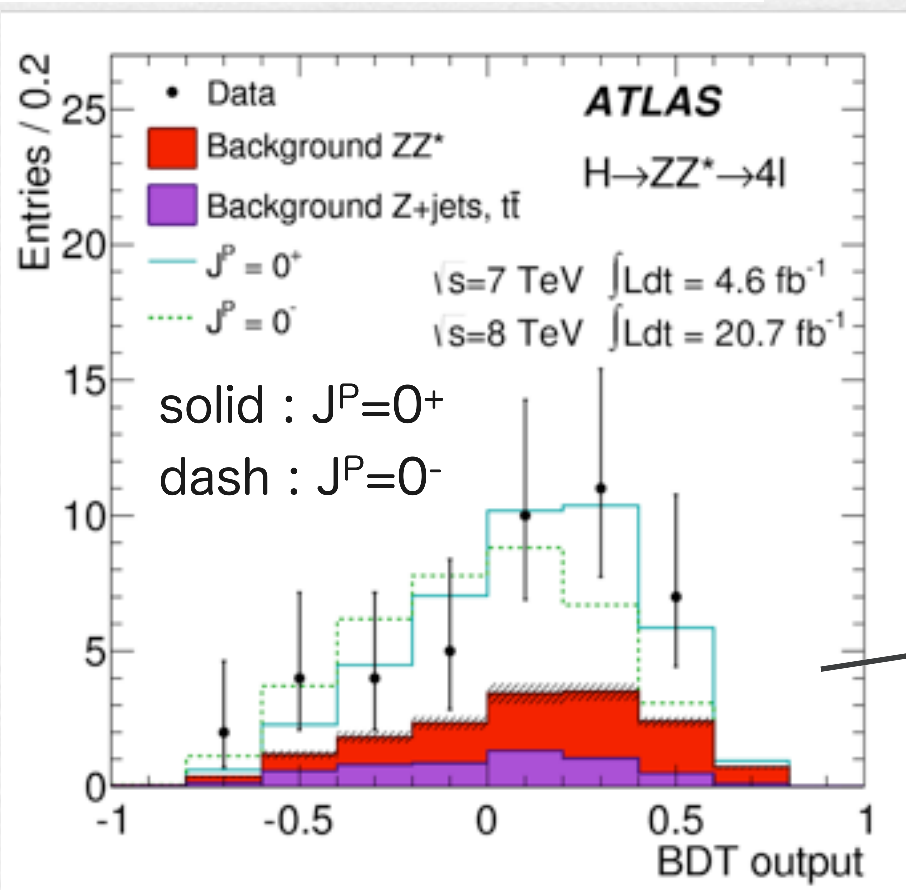
m_{12}, m_{34}, and 5 angles are the input of the BDT





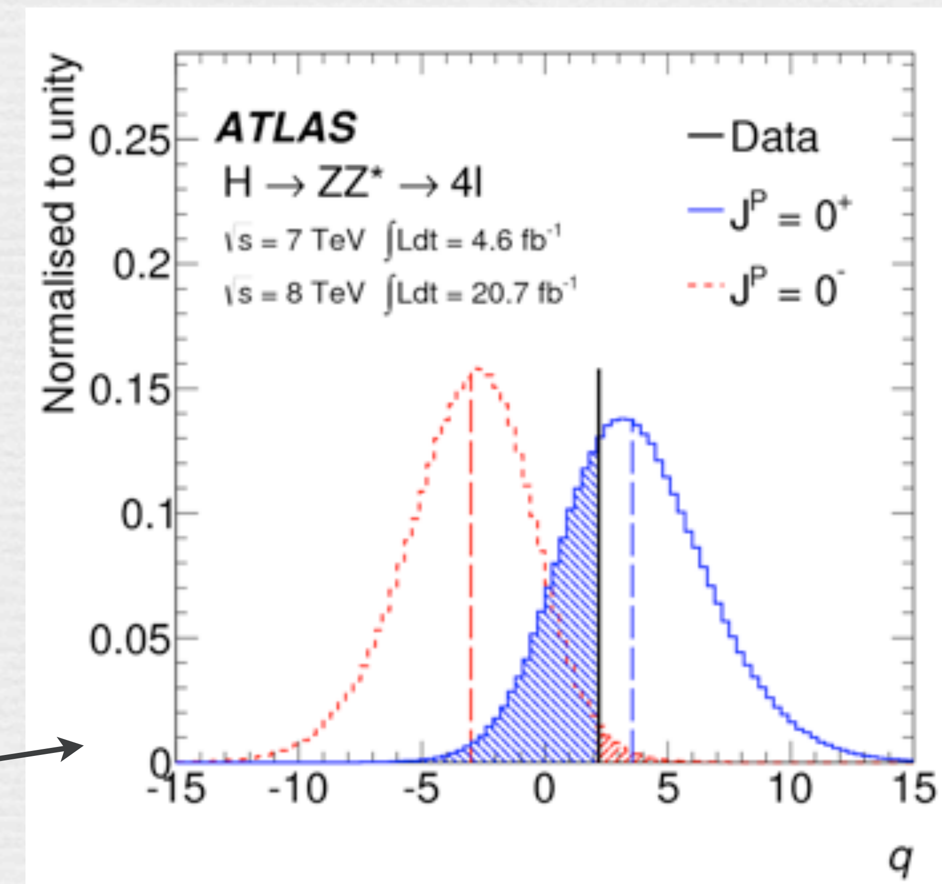


J=0 boson Produced mainly from gluon-gluon fusion



Log likelihood ratio q

$$q = \log \frac{L(J^P = 0^+)}{L(J^P = 0^-)}$$



Data agree with 0+ hypothesis,
0- hypothesis is excluded at 97.8% C.L.

$J^P=0^+$ v.s. 1^+ / 1^-

arXiv:1307.1432

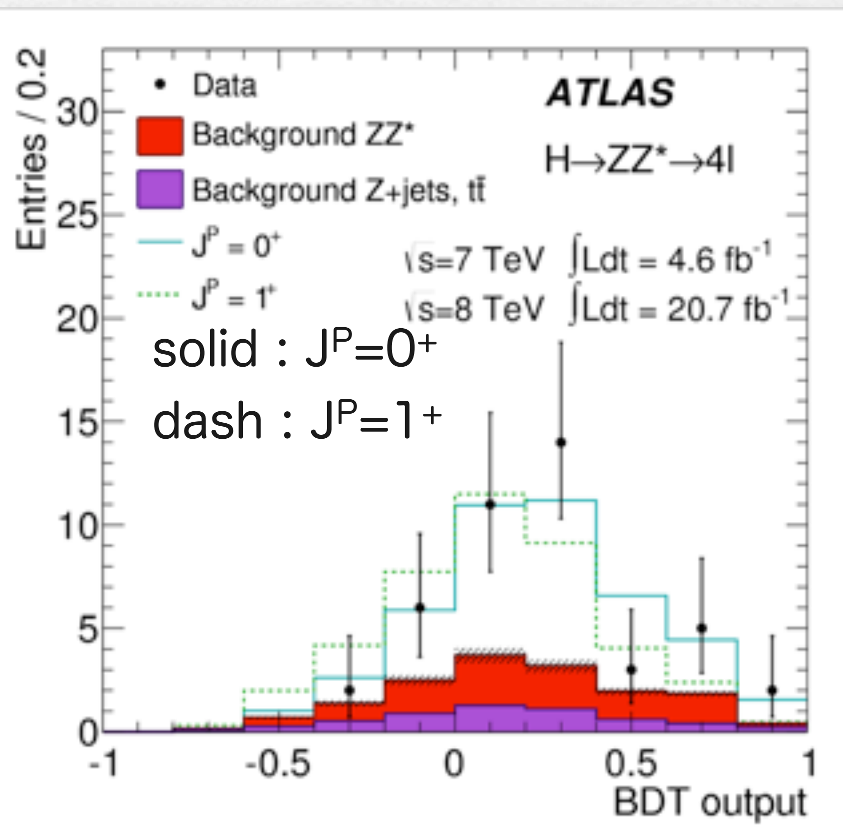
H→ZZ*→4 lepton and H→WW→$\ell\nu\ell\nu$ are sensitive for this study

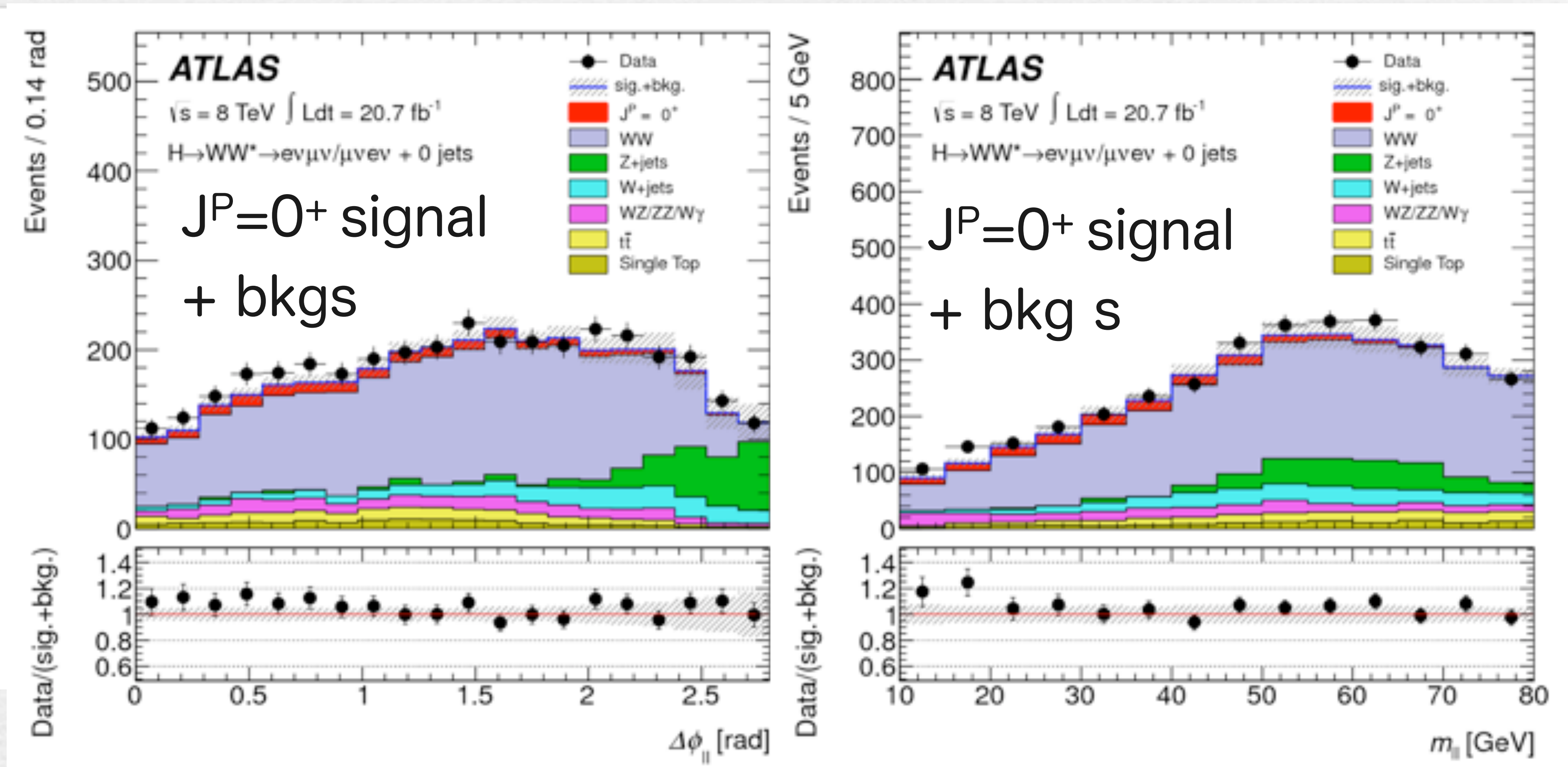
- H→$\gamma\gamma$ decay is forbidden (Landau-Yang theorem)
- For same reason, J=1 boson is produced only from quark-quark bar annihilation

H→ZZ*→4 lepton : uses BDT from the inputs of m_{12}, m_{34}, and 5 angles

H→WW→$e\nu\mu\nu$: uses 2 stage of BDT from inputs of m_T, $\Delta\phi_{\ell\ell}$, $m_{\ell\ell}$, and $p_T^{\ell\ell}$

- 1st classifier : Distinguish the signal from sum of the all backgrounds
- 2nd classifier : Distinguish the $J^P=0^+$ from $J^P=1^+$, 1^-





Combined ZZ/WW data agree with 0+ hypothesis,
$J^P=1^+$ ($=1^-$) hypothesis is excluded at 99.97% (99.7%) C.L.

$J^P=0^+$ v.s. 2^+

arXiv:1307.1432

$H\to\gamma\gamma$, $H\to ZZ^*\to 4$ lepton and $H\to WW\to \ell\nu\ell\nu$ are sensitive for this study

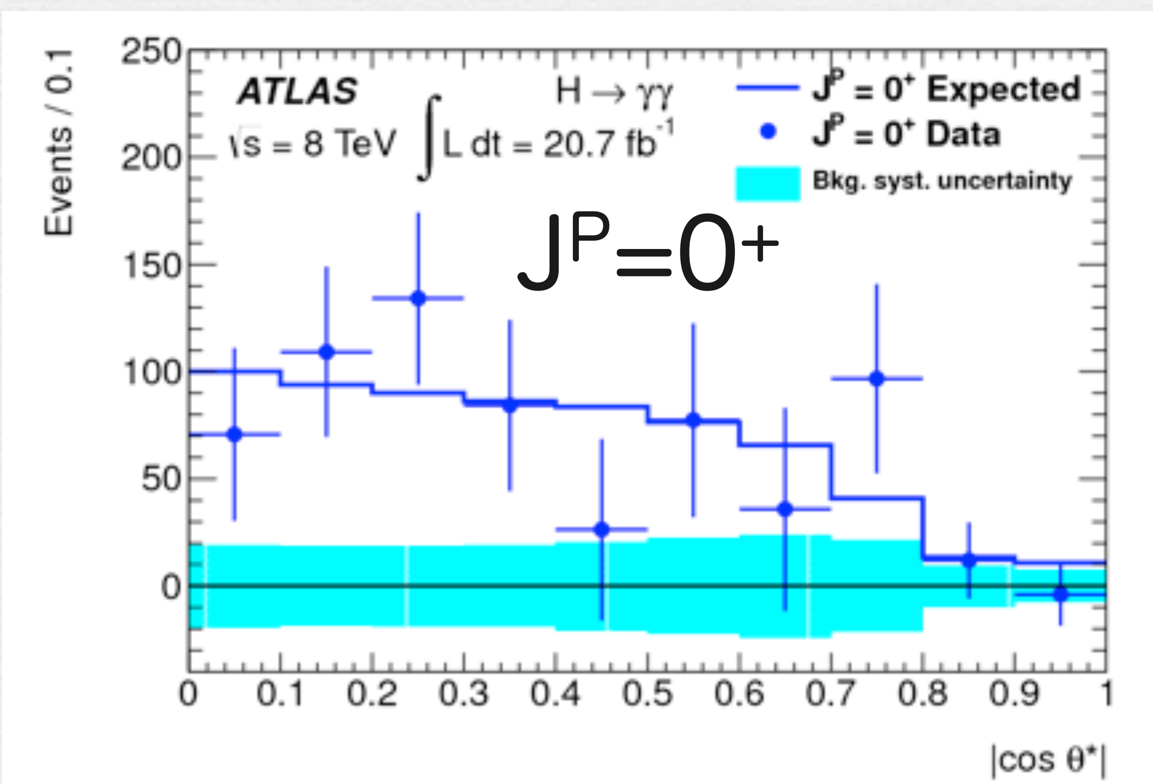
$H\to ZZ^*\to 4$ lepton : uses BDT from the inputs of m_{12}, m_{34}, and 5 angles

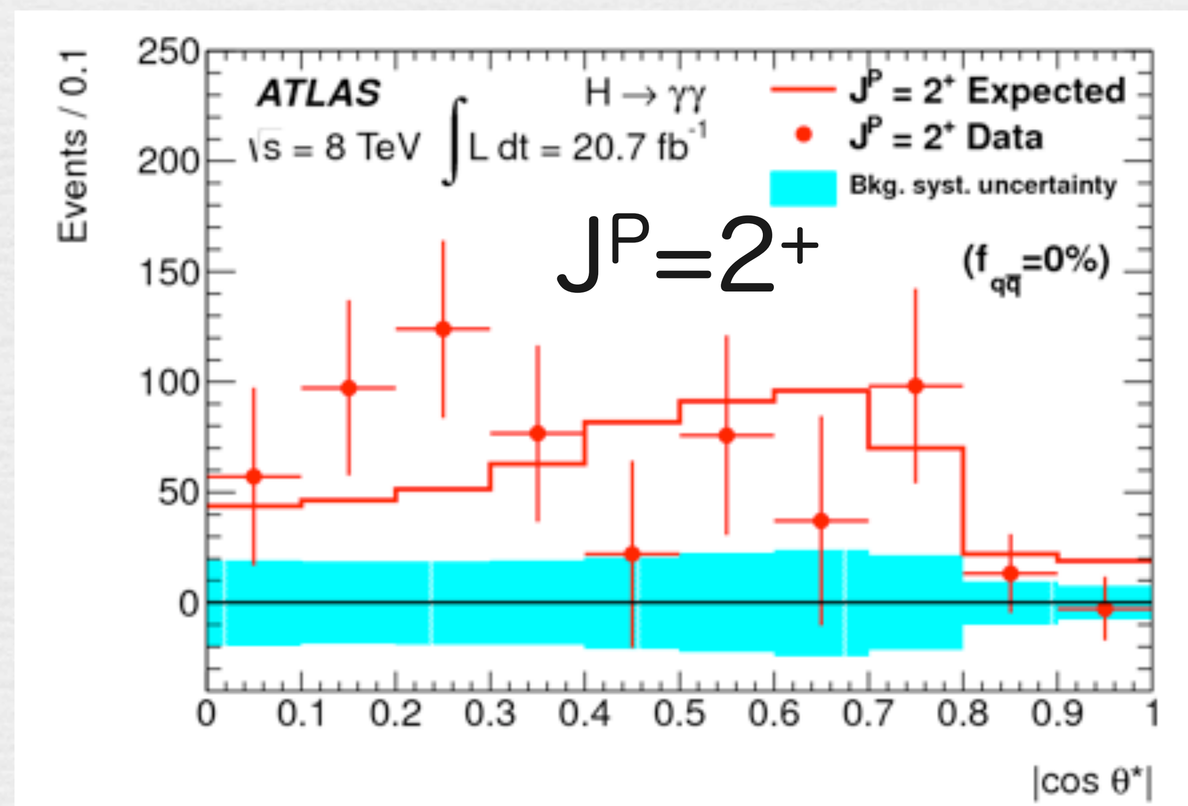
$H\to WW\to e\nu\mu\nu$: uses 2 stage of BDT from inputs of m_T, $\Delta\phi_{\ell\ell}$, $m_{\ell\ell}$, and $p_T^{\ell\ell}$

$H\to\gamma\gamma$: uses $m_{\gamma\gamma}$ and decay angle $|\cos\theta^*|$ in di-photon rest frame,

$$|\cos\theta^*| = \frac{|\sinh(\Delta\eta^{\gamma\gamma})|}{\sqrt{1+(p_T^{\gamma\gamma}/m_{\gamma\gamma}^2)}} \frac{2p_T^{\gamma_1}p_T^{\gamma_2}}{m_{\gamma\gamma}^2}$$

$|\cos\theta^*|$ distributions for the backgrounds is extracted from sideband of $m_{\gamma\gamma}$





Data agree with 0+ hypothesis,
$J^P=2^+$ hypothesis is excluded at 99.9% C.L.

Spin-Parity summary

arXiv:1307.1432

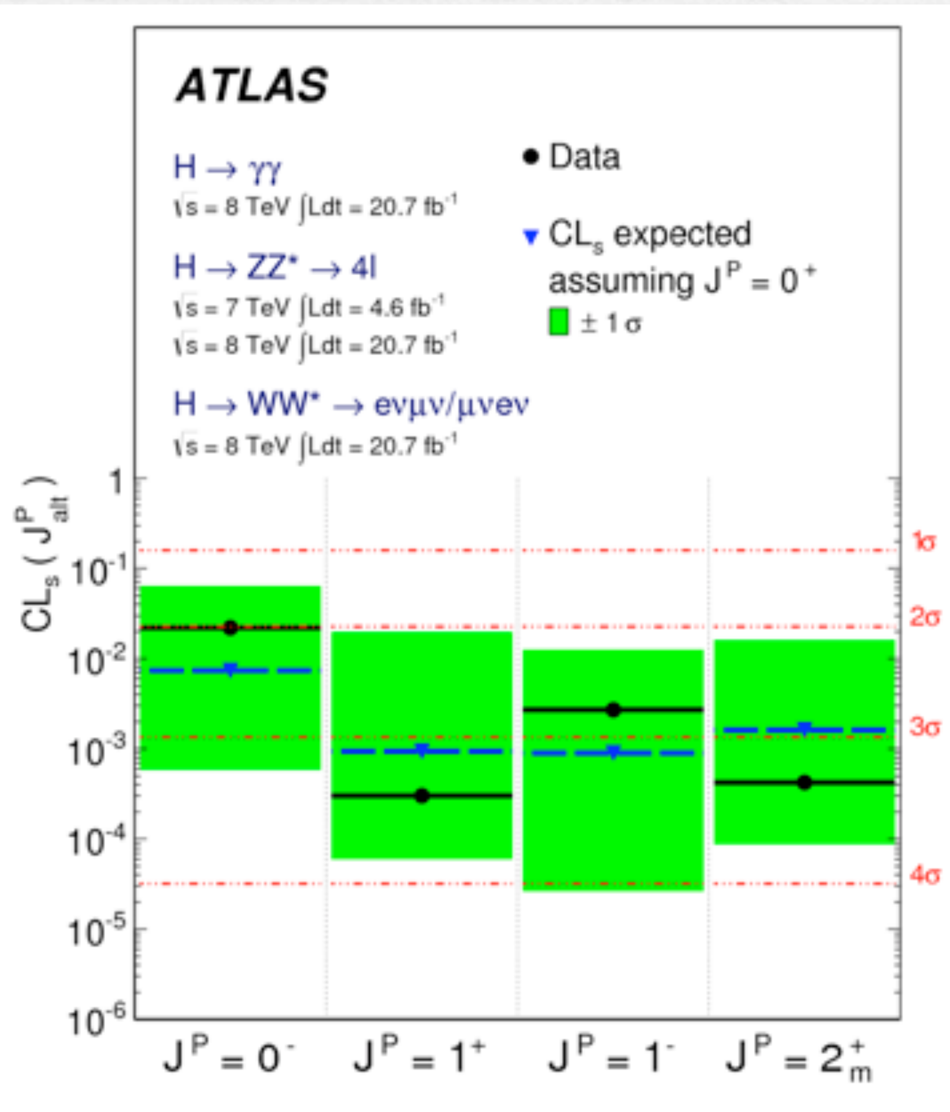
$J^P=0^-$ is excluded at 97.8% CL by ZZ→4 lepton channel

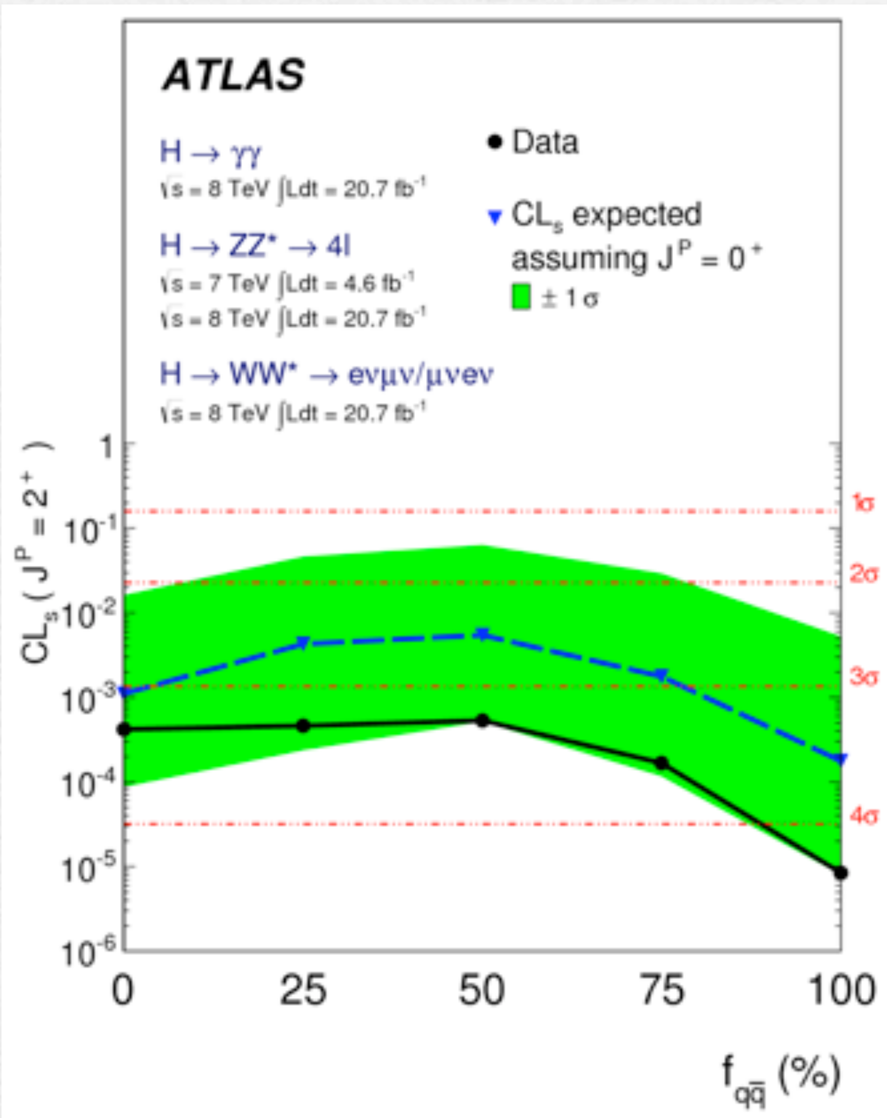
$J^P=1^-$ is excluded at 99.97% CL by ZZ→4 lepton and WW→$e\nu\mu\nu$ channels

$J^P=1^+$ is excluded at 99.7% CL by ZZ→4 lepton and WW→$e\nu\mu\nu$ channels

$J^P=2^+$ is excluded at 99.9% CL by ZZ→4 lepton, WW→$e\nu\mu\nu$, and $\gamma\gamma$ channels

- It can be produced via gluon-gluon or quark-quark bar annihilation
- 2+ is tested as a function of f_{qq} = fraction of qq/gg produced signals
  - f_{qq}=4% at LO for 2^+_m minimal model





● Data

▼ CLs expected assuming $J^P=0^+$

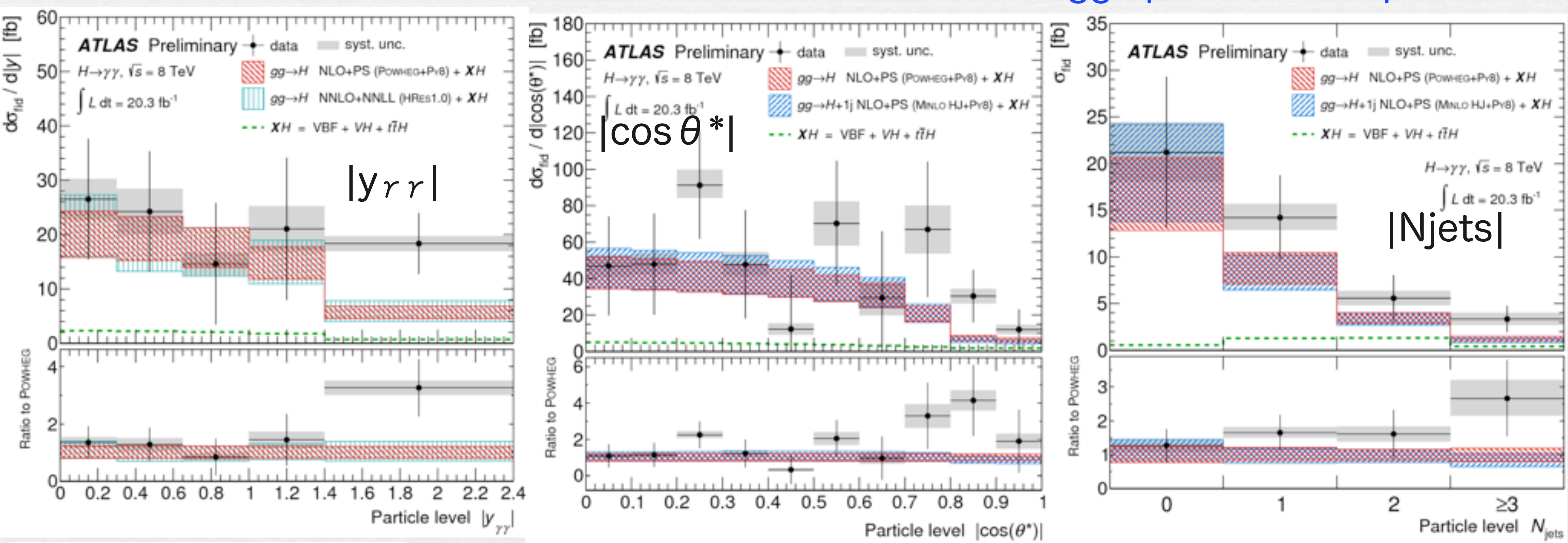
Compatible with SM 0^+

Differential cross-section in H→$\gamma\gamma$

ATLAS-CONF-2013-072

Fiducial differential cross-section as a function of

- 8 observables : $p_{T\gamma\gamma}$, $|y_{\gamma\gamma}|$, $|\cos\theta^*|$, N_{jets}, Φ_{jj}, ...,
- The distributions are unfolded to particle level
- Sensitive to PDF, radiative correction, relative rate of Higgs production, spin,...



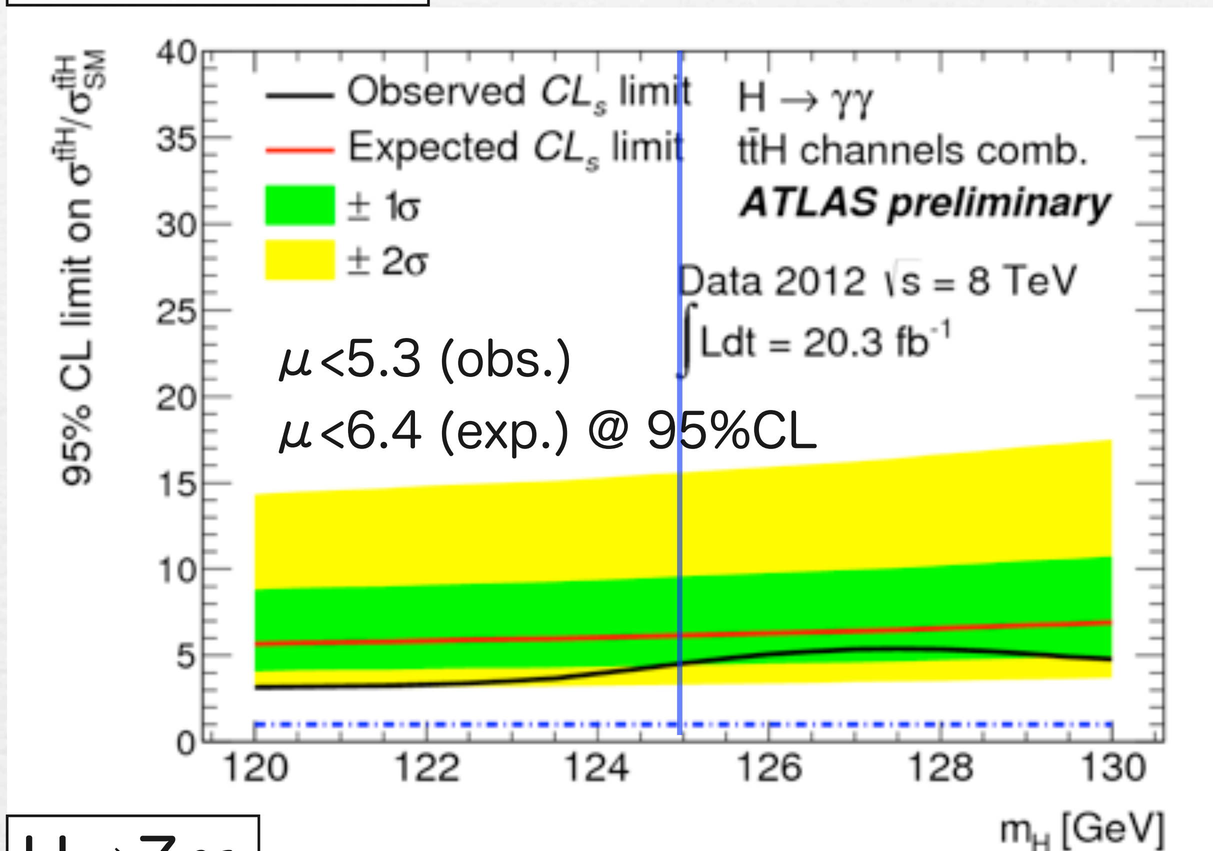
Probability of χ^2 test

	N_{jets}	$p_T^{\gamma\gamma}$	$\lvert y^{\gamma\gamma}\rvert$	$\lvert\cos\theta^*\rvert$	$p_T^{j_1}$	$\Delta\phi_{jj}$	$p_T^{\gamma\gamma jj}$
POWHEG	0.54	0.55	0.38	0.69	0.79	0.42	0.50
MINLO	0.44	–	–	0.67	0.73	0.45	0.49
HRES 1.0	–	0.39	0.44	–	–	–	–

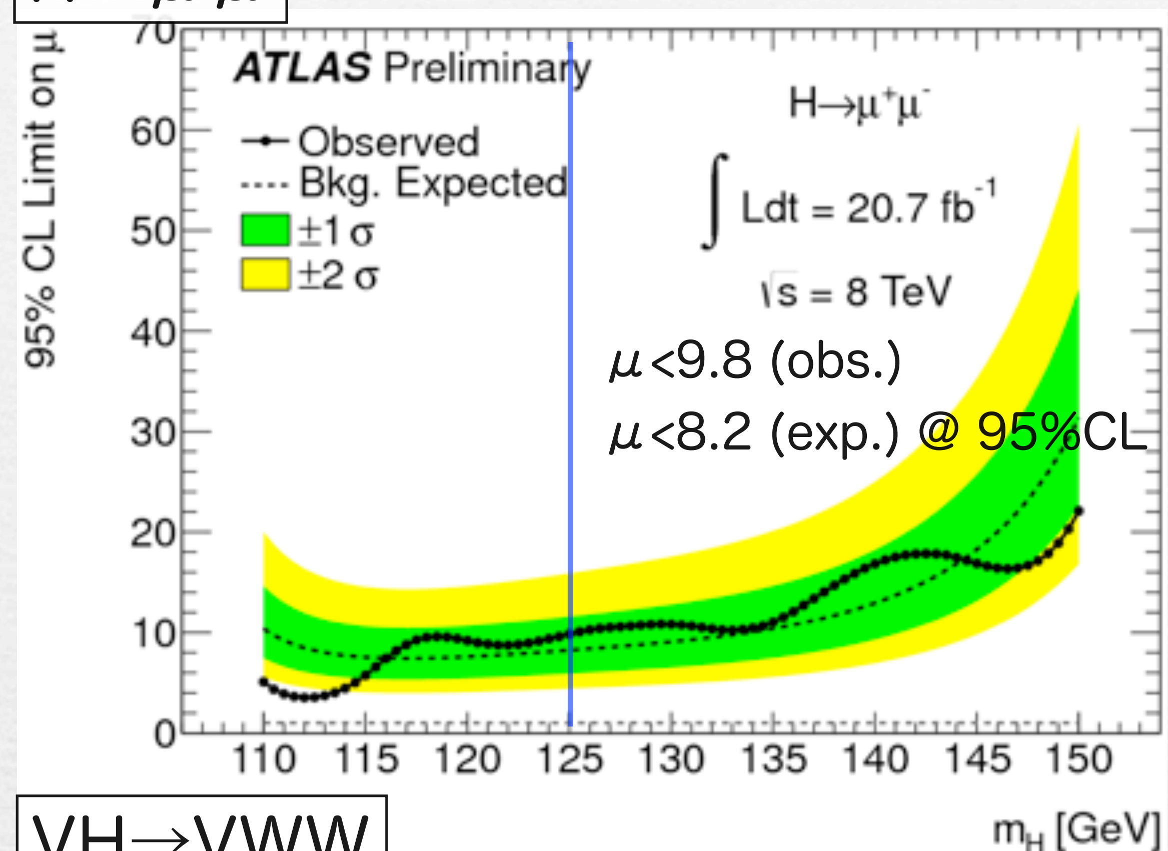
No significant deviation from SM (POWHEG, MINLO, HRES1.0) is observed.

稀生成・崩壊

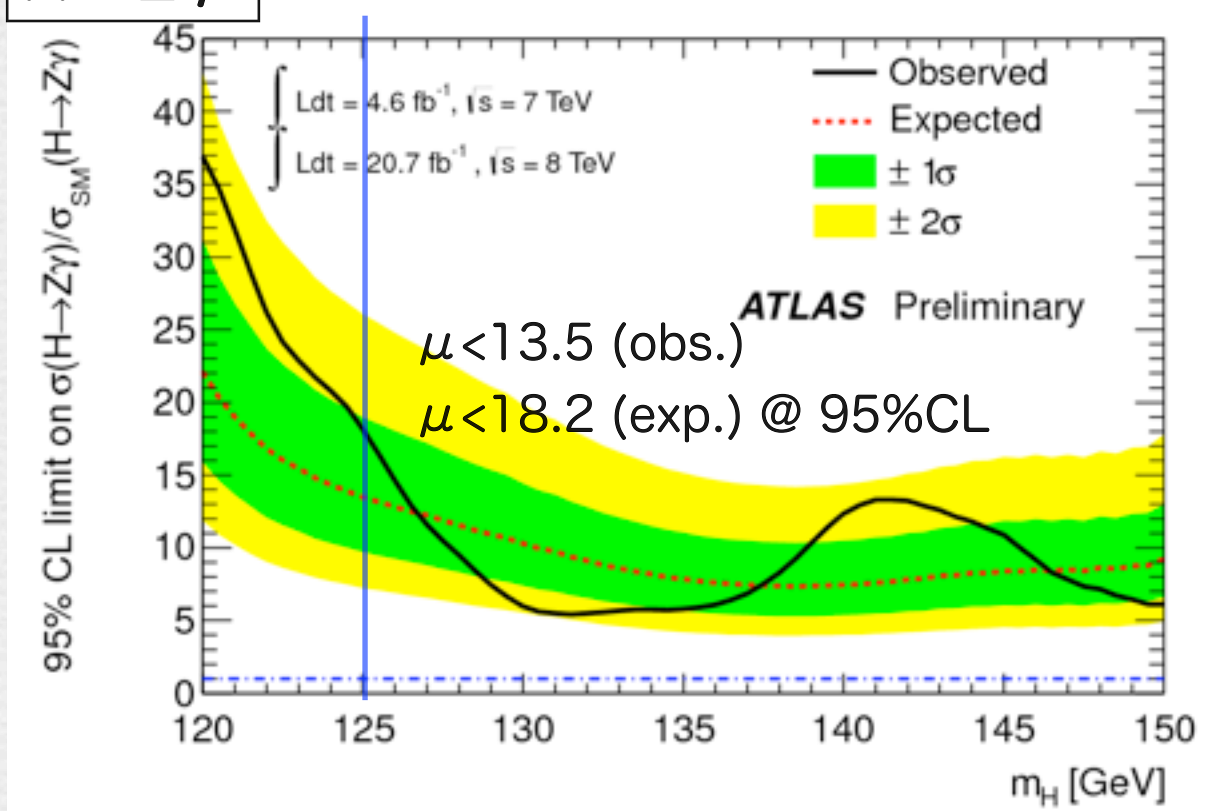
ttH(H→γγ)



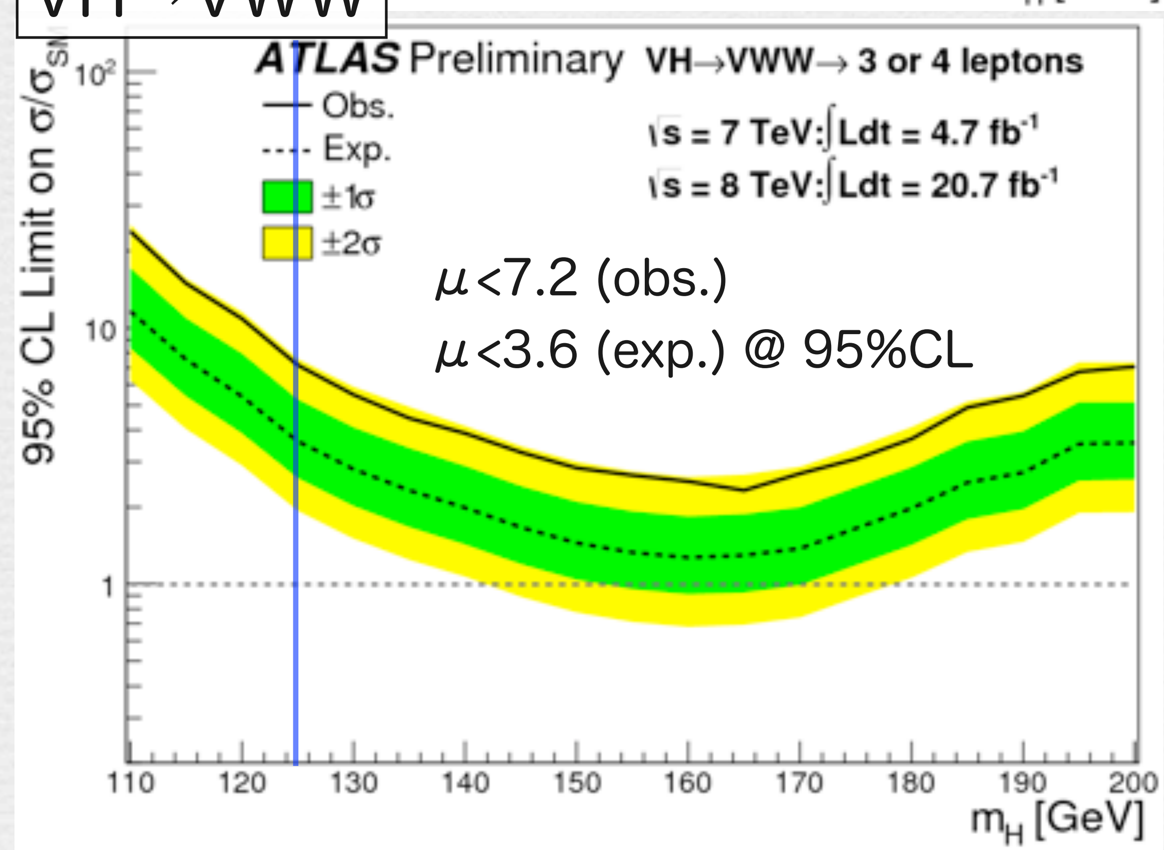
H→μμ



H→Zγ



VH→VWW

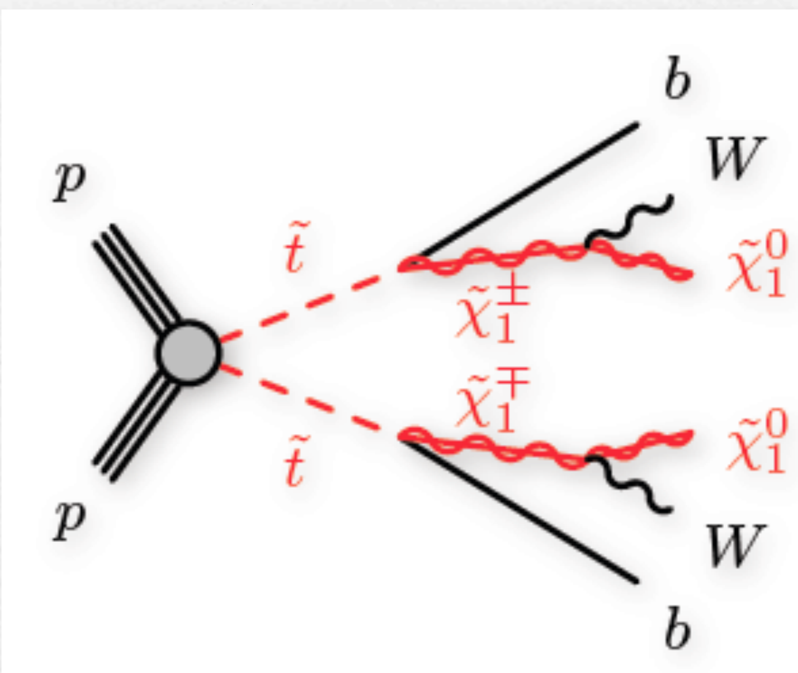


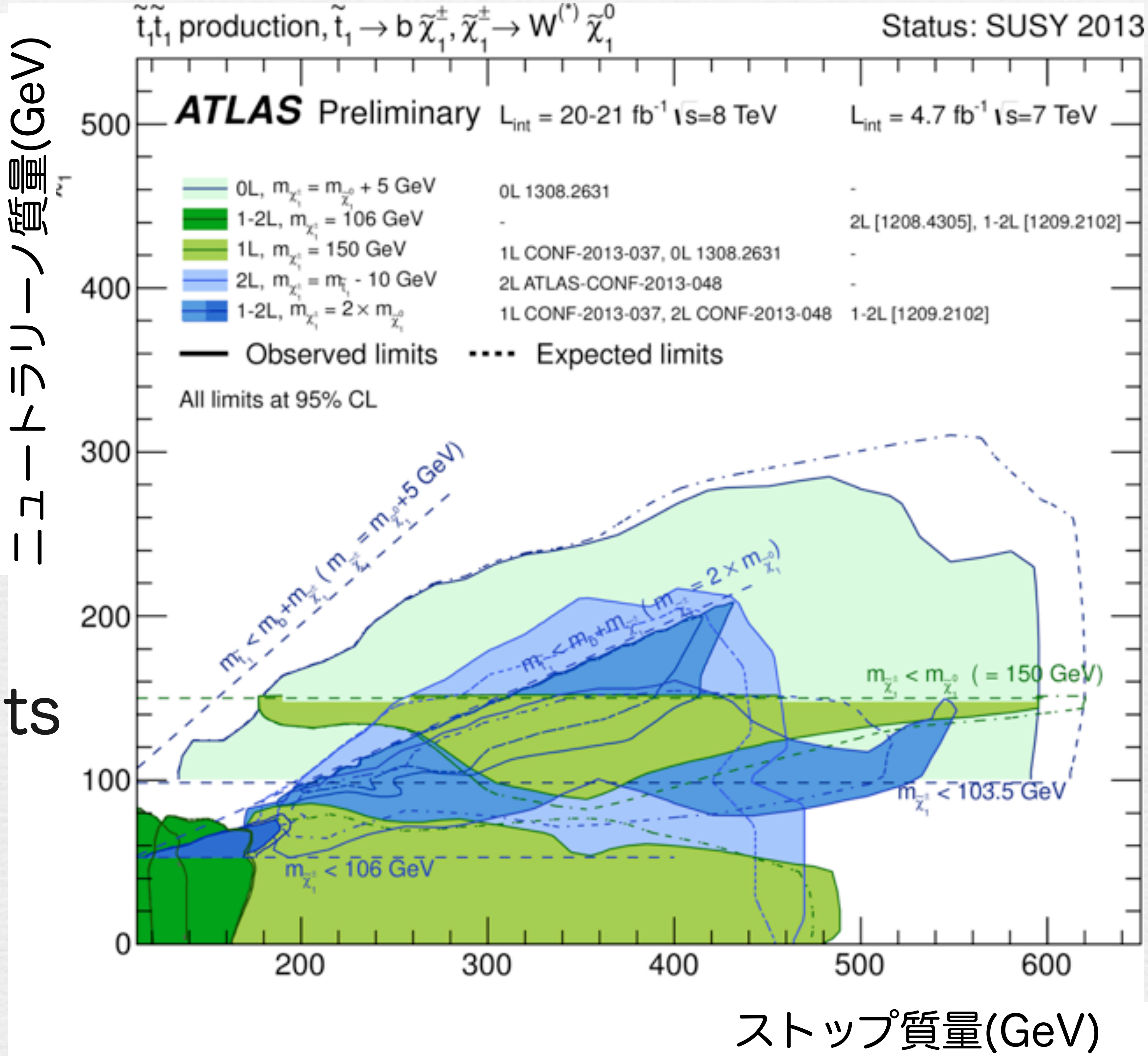
Direct stop pair production

カラーをもつSUSYの中でstopだけが軽い

$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$

$\tilde{\chi}_1^{\pm} \rightarrow W^{(*)}\tilde{\chi}_1^0$





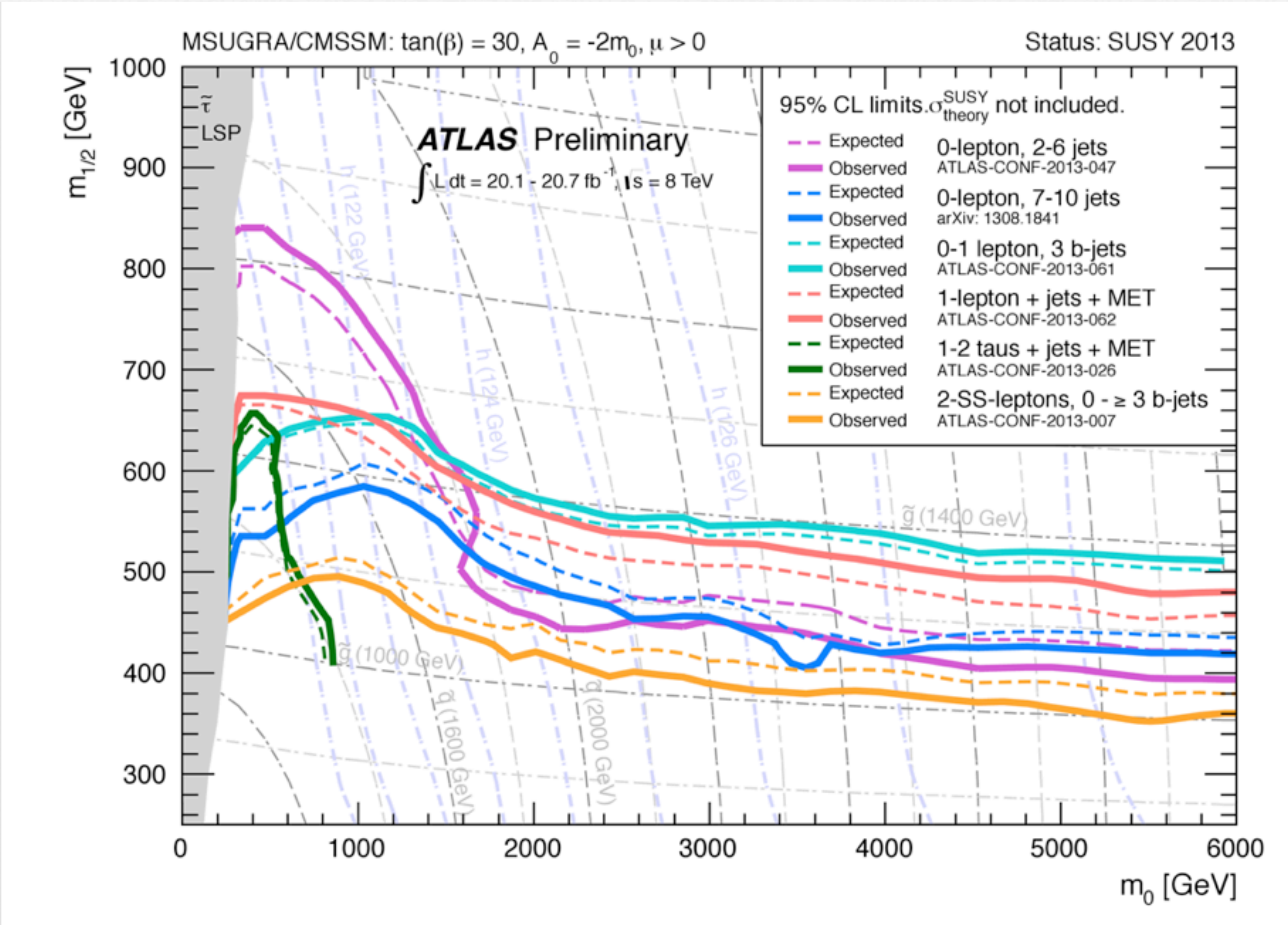
0~2 leptons +2 b-jets

+ E_T^{miss}

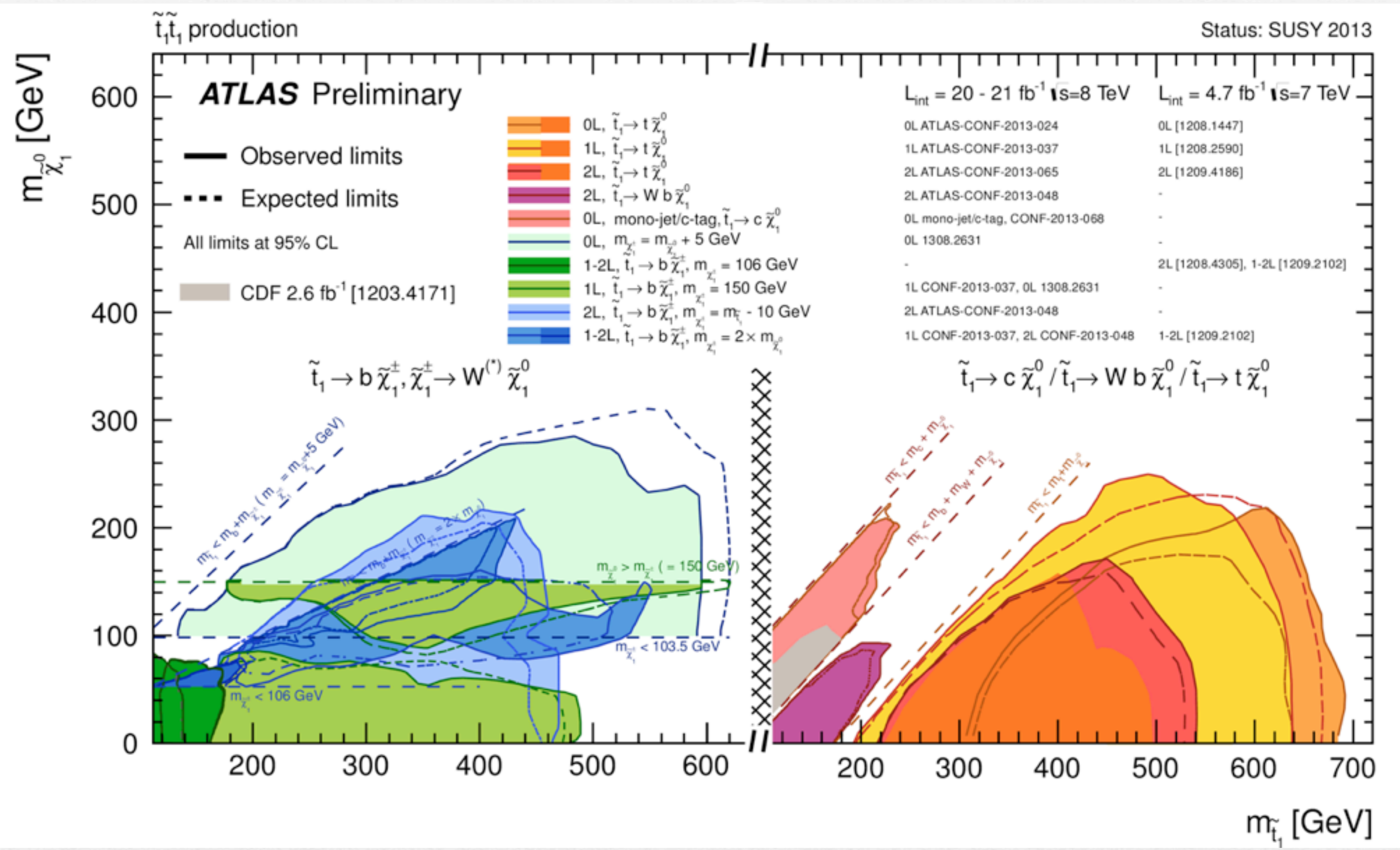
感度は、$m_{\tilde{t}}$, $m_{\tilde{\chi}_1^{\pm}}$, $m_{\tilde{\chi}_1^0}$

の関係に依存

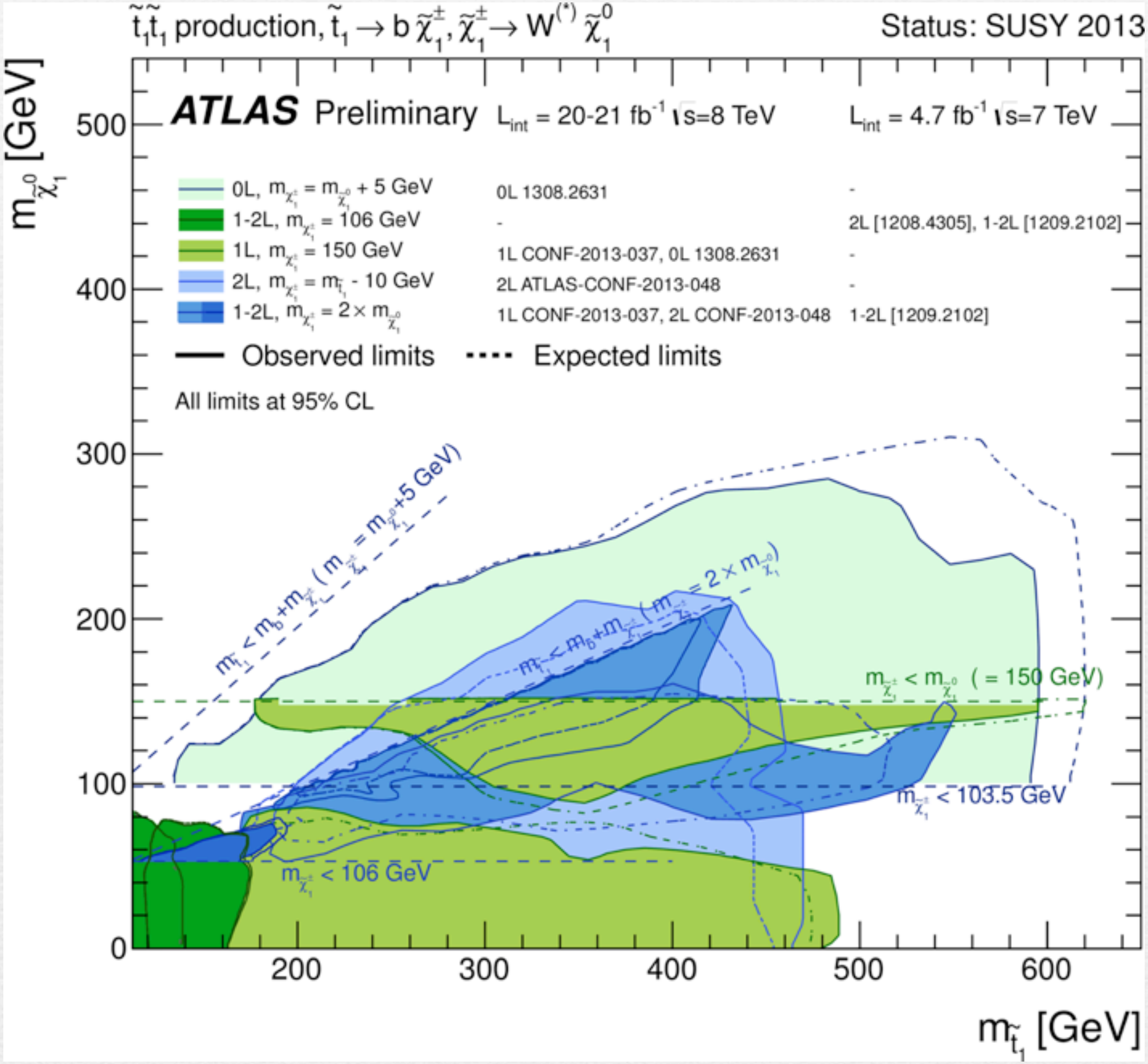
Inclusive search



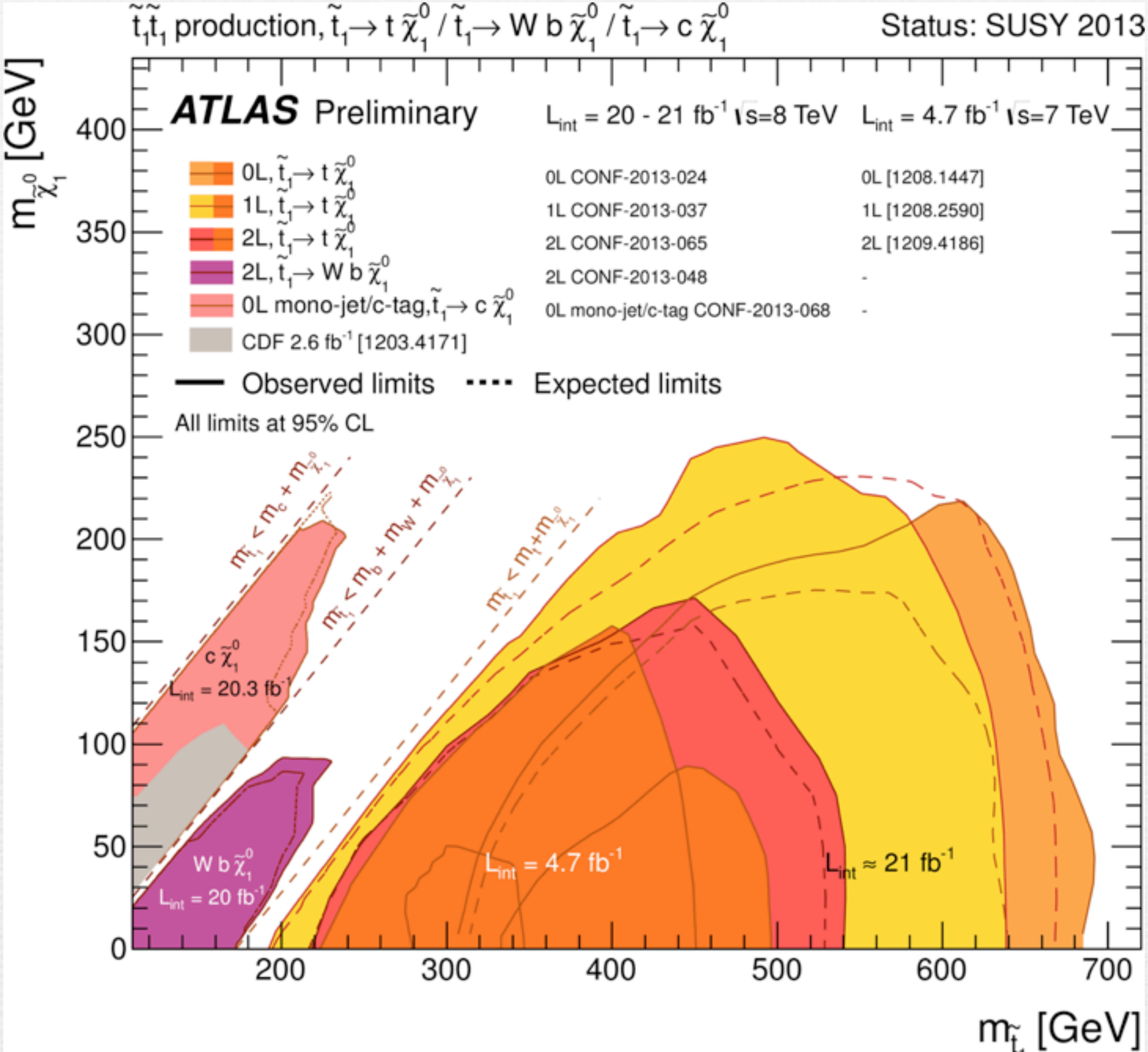
direct stop pair production



direct stop pair production



direct stop pair production

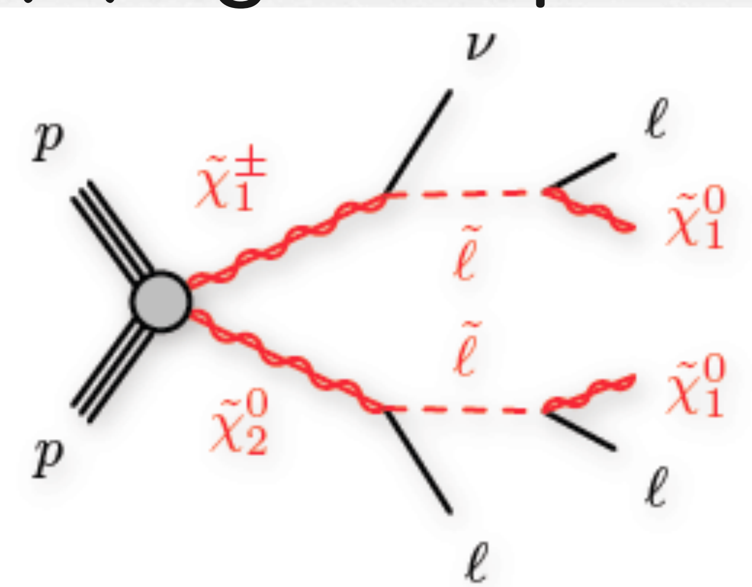


Direct chargino/neutralino production

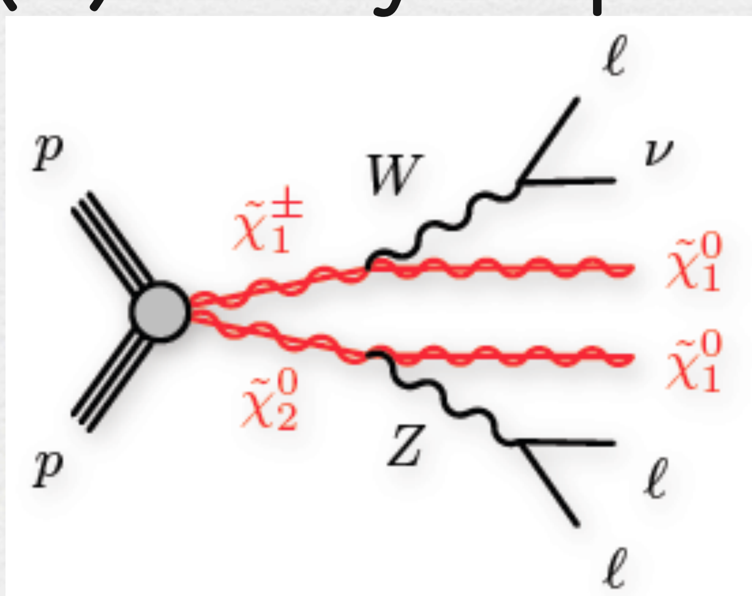
charginoとneutralinoだけが軽い場合 $m_{\tilde{\chi}_1^\pm} > m_{\tilde{\chi}_1^0}$

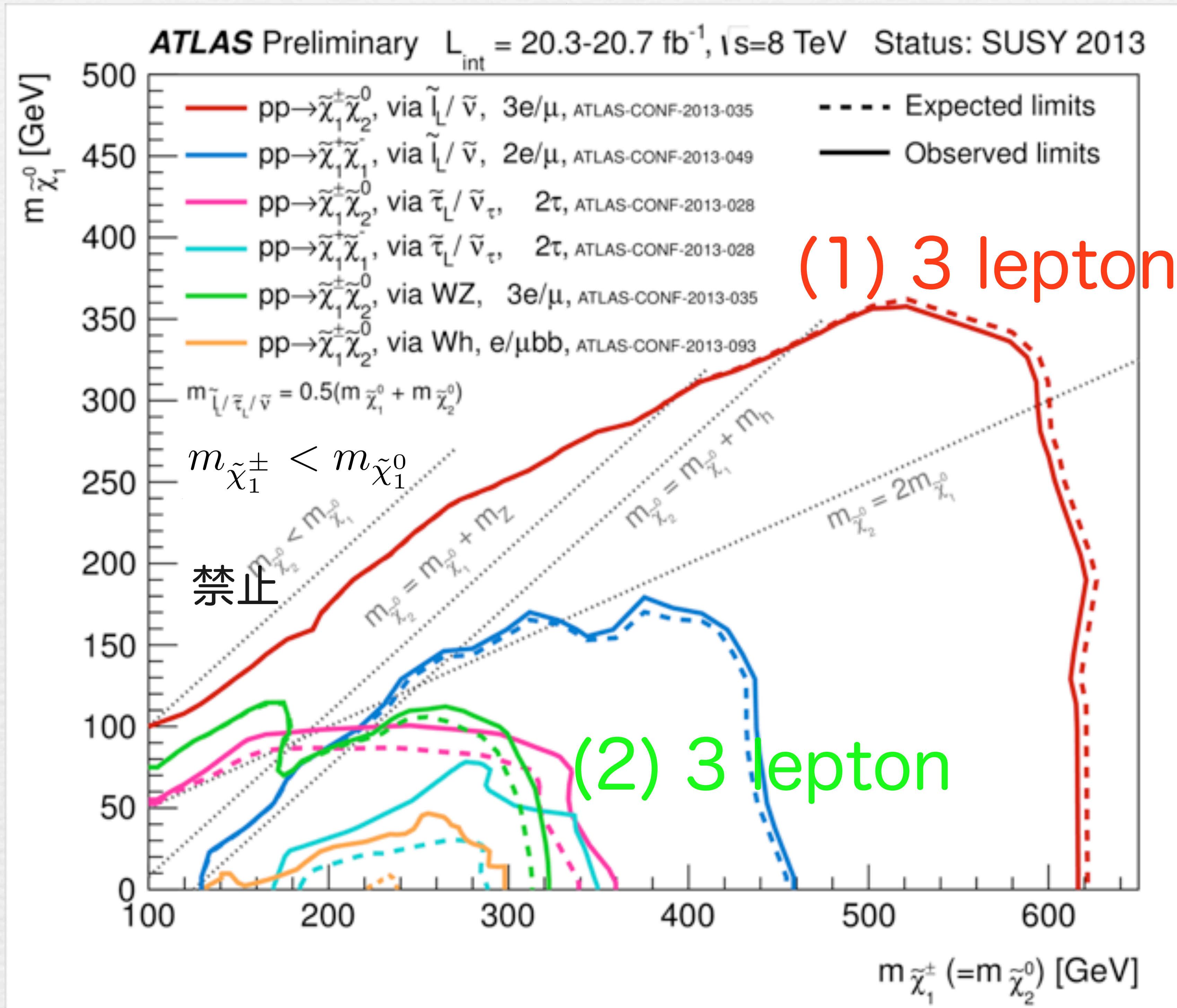
2-3 lepton + E_T^{miss}

(1) light slepton

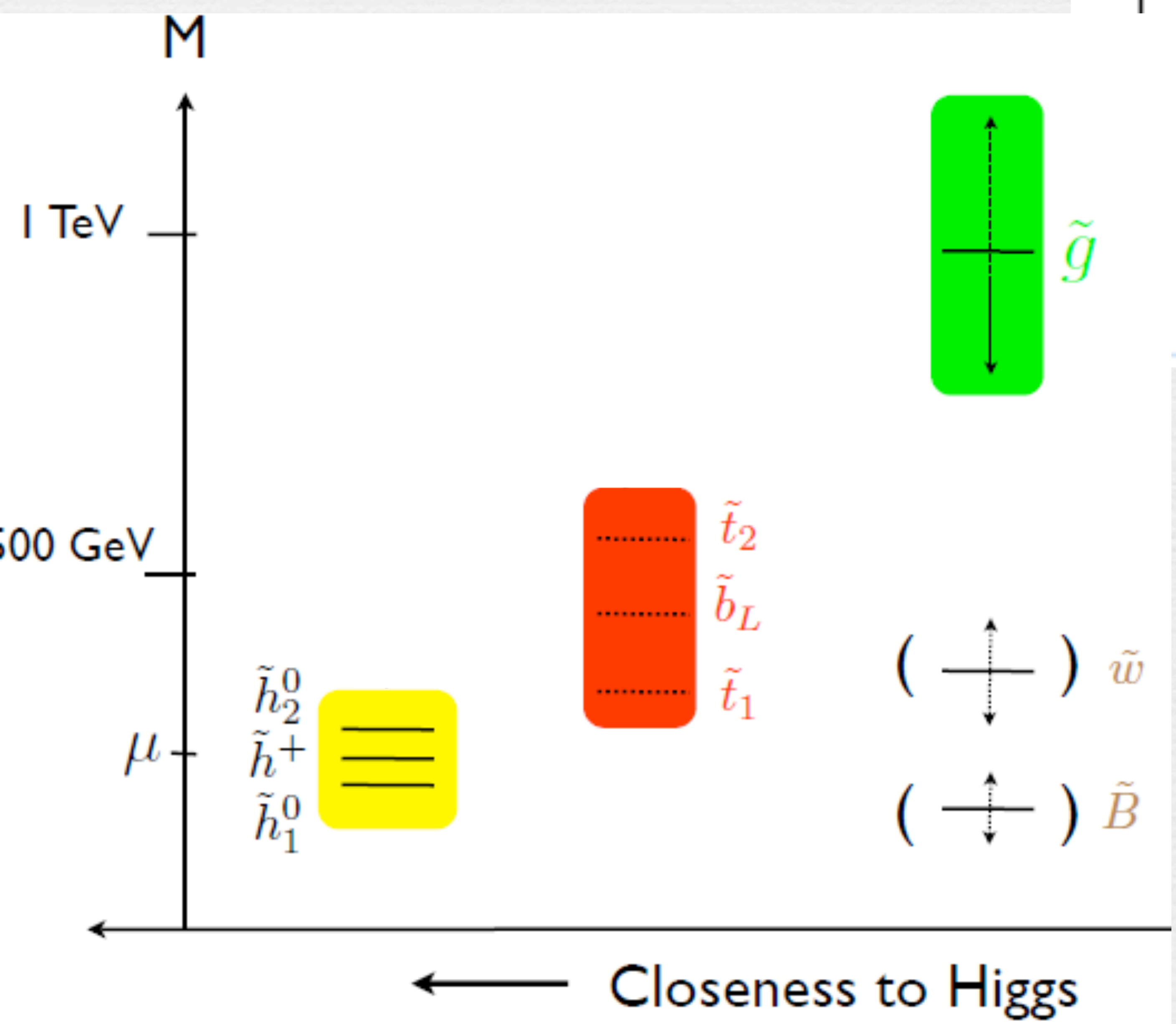


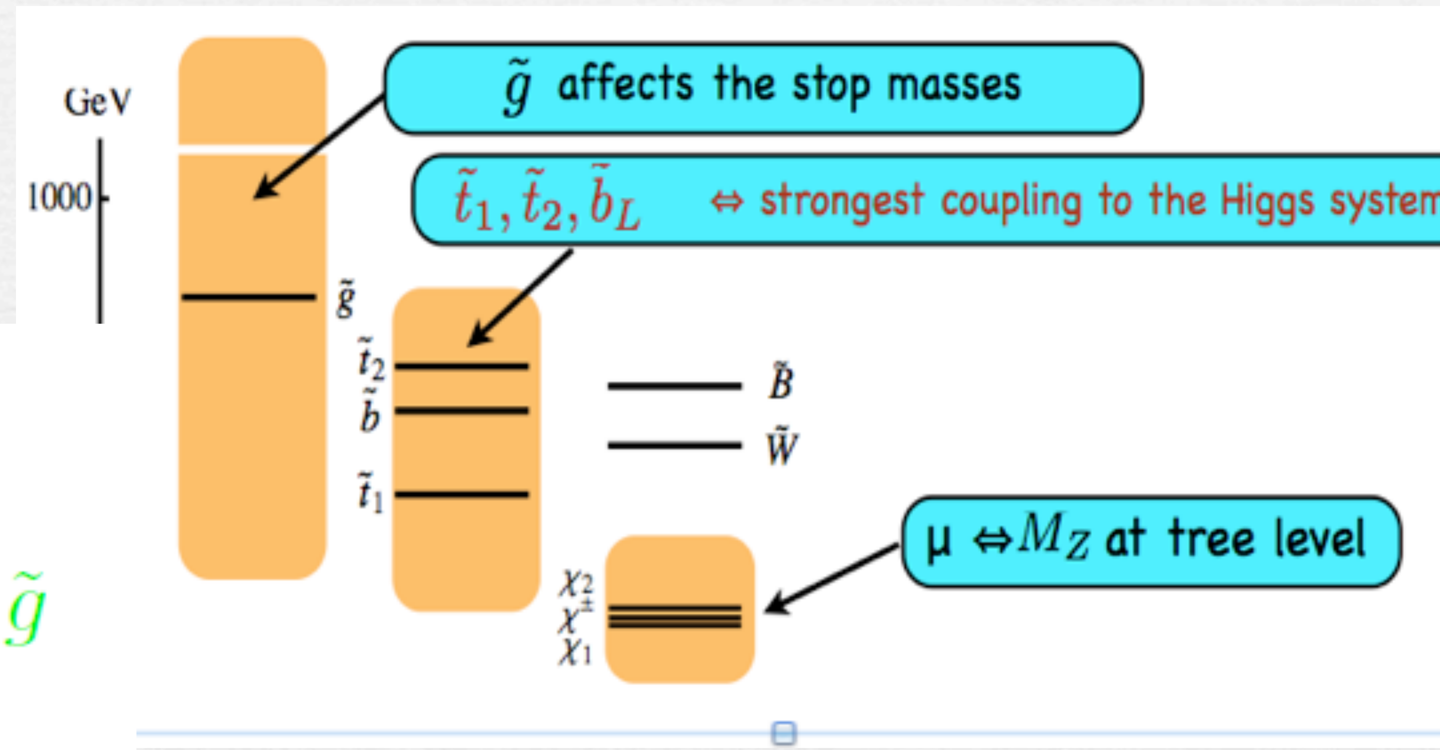
(2) heavy slepton





Natural SUSY



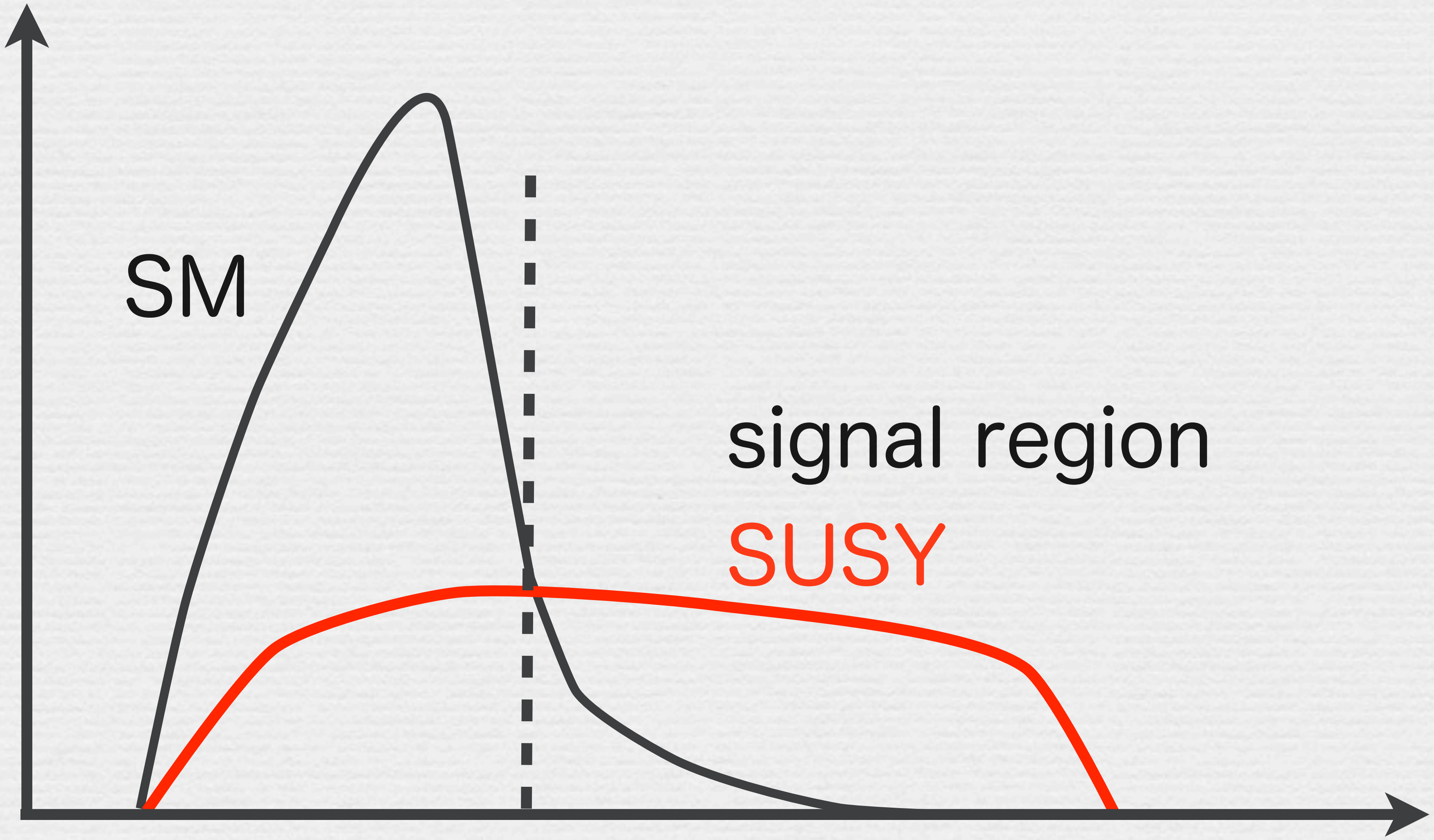


$$\mu <\sim 200 \text{ GeV}$$

$$m_{\tilde{t}},\ m_{\tilde{b}_L} <\sim 600 \text{ GeV}$$

$$m_{\tilde{g}} <\sim 1.5 \sim 2.0 \text{ TeV}$$

$$m_{\tilde{q},\tilde{\ell}} \sim 10 - 50 \text{ TeV}$$


SM
signal region
SUSY