ヒッグスボソンみたいな粒子の発見

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Motivation of Higgs Physics

素粒子の質量の起源

- もしクォークや電子の質量がなかったら...
  - 急速な p → n e^{+} ν ：陽子が不安定
  - ボーア半径無限大 $$a_{Bohr} = \frac{4\pi\epsilon_0\hbar^2}{me^2}$$

質量は，宇宙が現在の姿になるために不可欠

Lagrangian in the GWS Model

$$
\begin{aligned}
\mathcal{L} &= \bar{\nu}(i \not\partial - m_\nu)\nu + \bar{l}(i \not\partial - m_l)l + \frac{1}{2}(\partial_\mu \chi \partial^\mu \chi - \mu^2 \chi^2) \\
&- \frac{1}{4}F^i_{\mu\nu}F^{i\mu\nu} + m_W^2 W^*_{+\mu} W^\mu_+ - \frac{1}{4}G_{\mu\nu}G^{\mu\nu} + \frac{m_Z^2}{2} Z_\mu Z^\mu \\
&+ eA_\mu(\bar{l}\gamma^\mu l) - \frac{g}{\sqrt{2}}[W^\mu_+(\bar{\nu}\gamma^\mu P_L l) + c.c.] \\
&- \bar{g}Z_\mu[\bar{\nu}\gamma^\mu(s_{\nu L}P_L + s_{\nu R}P_R)\nu + \bar{l}\gamma^\mu(s_{l_L}P_L + s_{l_R}P_R)l] \\
&+ \frac{2v\chi + \chi^2}{4}(g^2 W^*_{+\mu}W^\mu_+ + \frac{\bar{g}^2}{2}Z_\mu Z^\mu) \\
&- \frac{m_l}{v}\chi(\bar{l}l) - \frac{m_\nu}{v}\chi(\bar{\nu}\nu) \\
&+ \dots
\end{aligned}
$$

Lagrangian in the GWS Model

$$
\begin{aligned}
\mathcal{L} &= \bar{\nu}(i \not{\partial} - m_\nu)\nu + \bar{l}(i \not{\partial} - m_l)l + \frac{1}{2}(\partial_\mu \chi \partial^\mu \chi - \mu^2 \chi^2) \\
&- \frac{1}{4}F^i_{\mu\nu}F^{i\mu\nu} + m_W^2 W^*_{+\mu}W^\mu_+ - \frac{1}{4}G_{\mu\nu}G^{\mu\nu} + \frac{m_Z^2}{2}Z_\mu Z^\mu
\end{aligned}
$$

わかった気になるのは早い

$$
\begin{aligned}
&- \bar{g}Z_\mu[\bar{\nu}\gamma^\mu(s_{\nu L}P_L + s_{\nu R}P_R)\nu + \bar{l}\gamma^\mu(s_{l_L}P_L + s_{l_R}P_R)l] \\
&+ \frac{2v\chi + \chi^2}{4}(g^2 W^*_{+\mu}W^\mu_+ + \frac{\bar{g}^2}{2}Z_\mu Z^\mu) \\
&- \frac{m_l}{v}\chi(\bar{l}l) - \frac{m_\nu}{v}\chi(\bar{\nu}\nu) \\
&+ \dots
\end{aligned}
$$

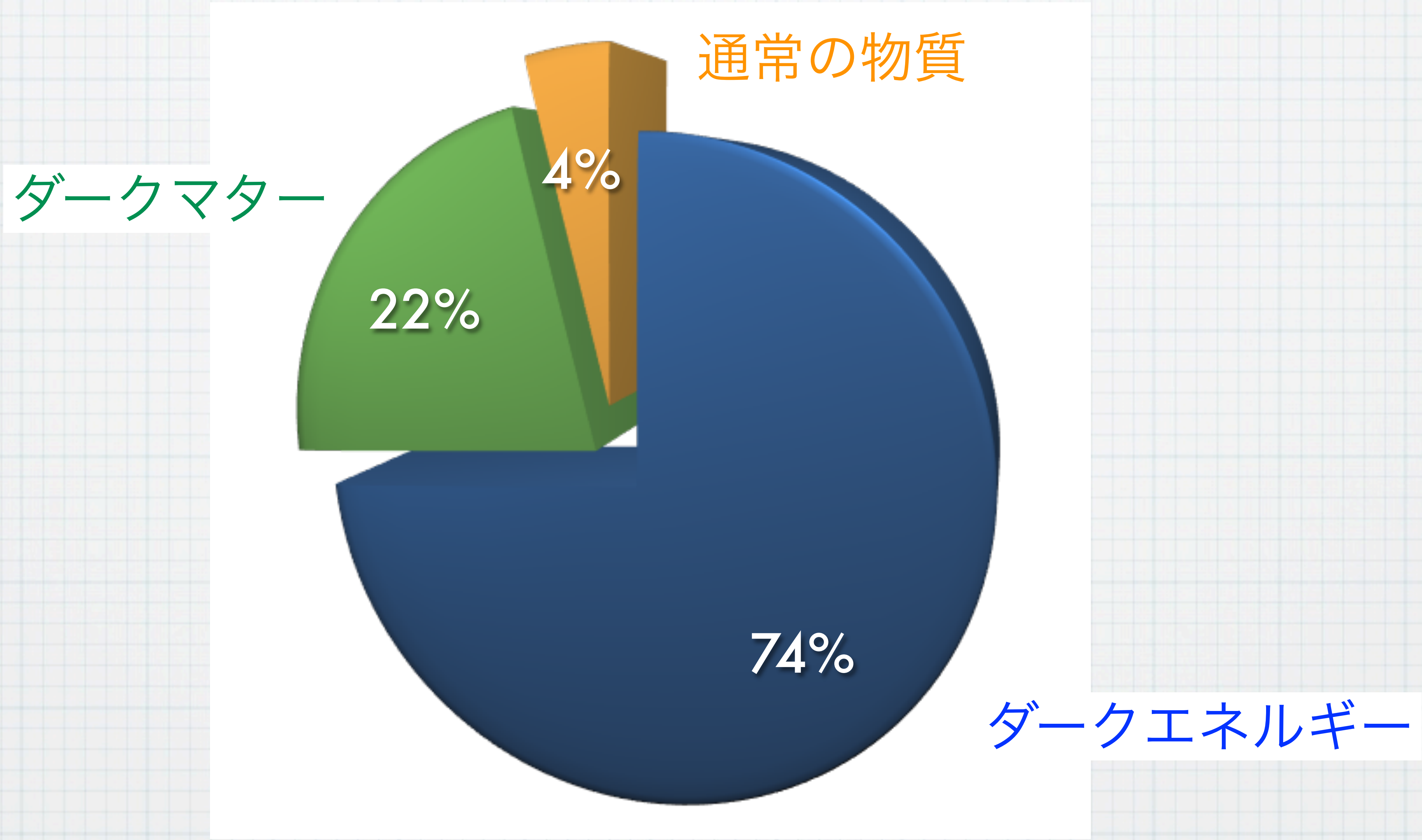
ヒッグスの不思議さ

- ゲージ対称性より
  - ゲージボソンは質量ゼロ
  - フェルミオンは質量ゼロでなくてもよい

    ⇒ なぜ同じメカニズム？
- 湯川結合の導入
  - 全てのフェルミオンに固有の値

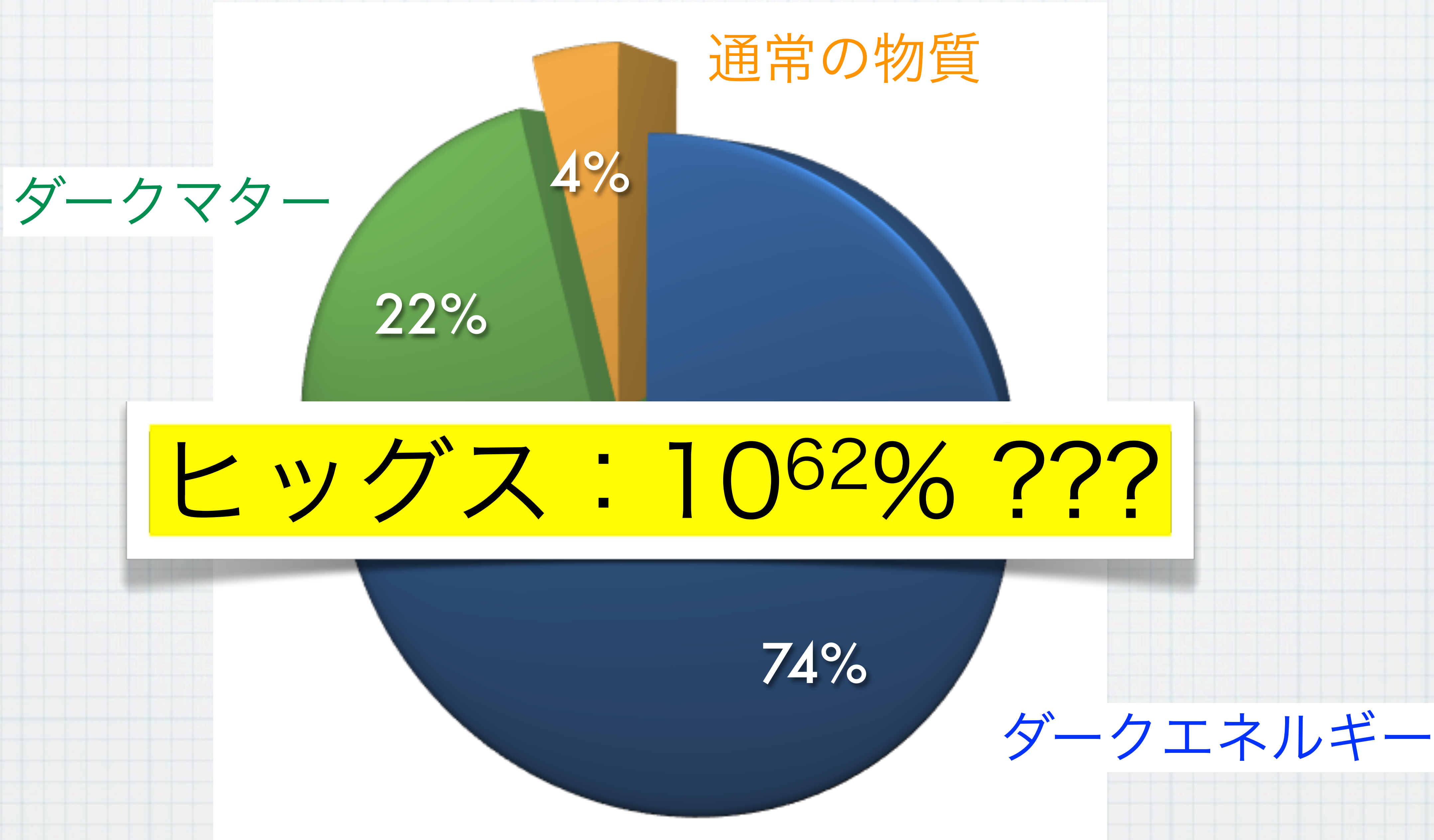
    ⇒ ヒッグスはなぜ相手がわかるのか？
- スカラー粒子？
- ボソン？？？

宇宙のエネルギー密度



ヒッグスは？？？

宇宙のエネルギー密度



ヒッグス：10^{62}% ???

ヒッグスは？？？

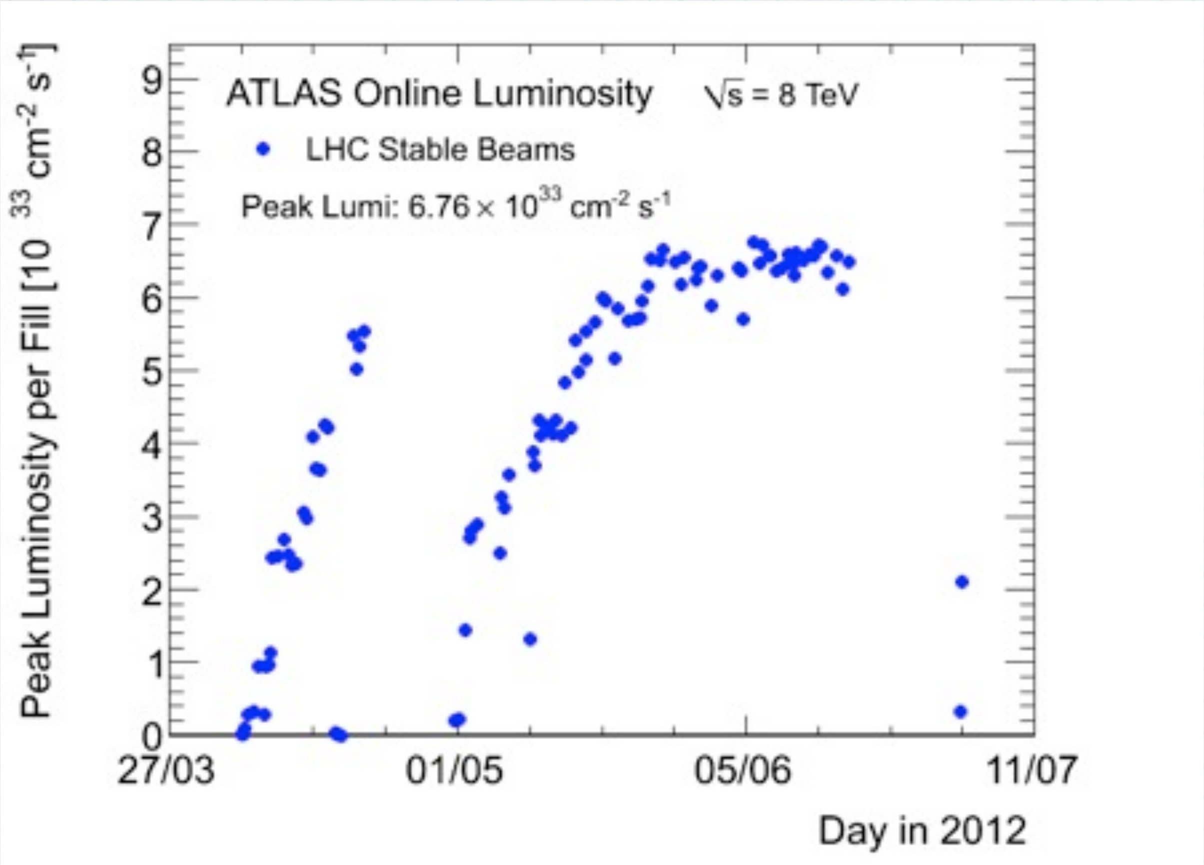
$$
\begin{aligned}
\mathcal{L} \;=\;& \bar{\nu}(i\,\partial\!\!\!/ - m_\nu)\nu + \bar{l}(i\,\partial\!\!\!/ - m_l)l + \frac{1}{2}(\partial_\mu\chi\partial^\mu\chi - \mu^2\chi^2) \\
-\;& \frac{1}{4}F^i_{\mu\nu}F^{i\mu\nu} + m_W^2 W^*_{+\mu}W^\mu_+ - \frac{1}{4}G_{\mu\nu}G^{\mu\nu} + \frac{m_Z^2}{2}Z_\mu Z^\mu \\
+\;& eA_\mu(\bar{l}\gamma^\mu l) - \frac{g}{\sqrt{2}}[W^\mu_+(\bar{\nu}\gamma^\mu P_L l) + c.c.] \\
-\;& \bar{g}Z_\mu[\bar{\nu}\gamma^\mu(s_{\nu L}P_L + s_{\nu R}P_R)\nu + \bar{l}\gamma^\mu(s_{l_L}P_L + s_{l_R}P_R)l] \\
+\;& \frac{2v\chi + \chi^2}{4}(g^2 W^*_{+\mu}W^\mu_+ + \frac{\bar{g}^2}{2}Z_\mu Z^\mu) \\
-\;& \frac{m_l}{v}\chi(\bar{l}l) - \frac{m_\nu}{v}\chi(\bar{\nu}\nu) \\
+\;& \ldots
\end{aligned}
$$

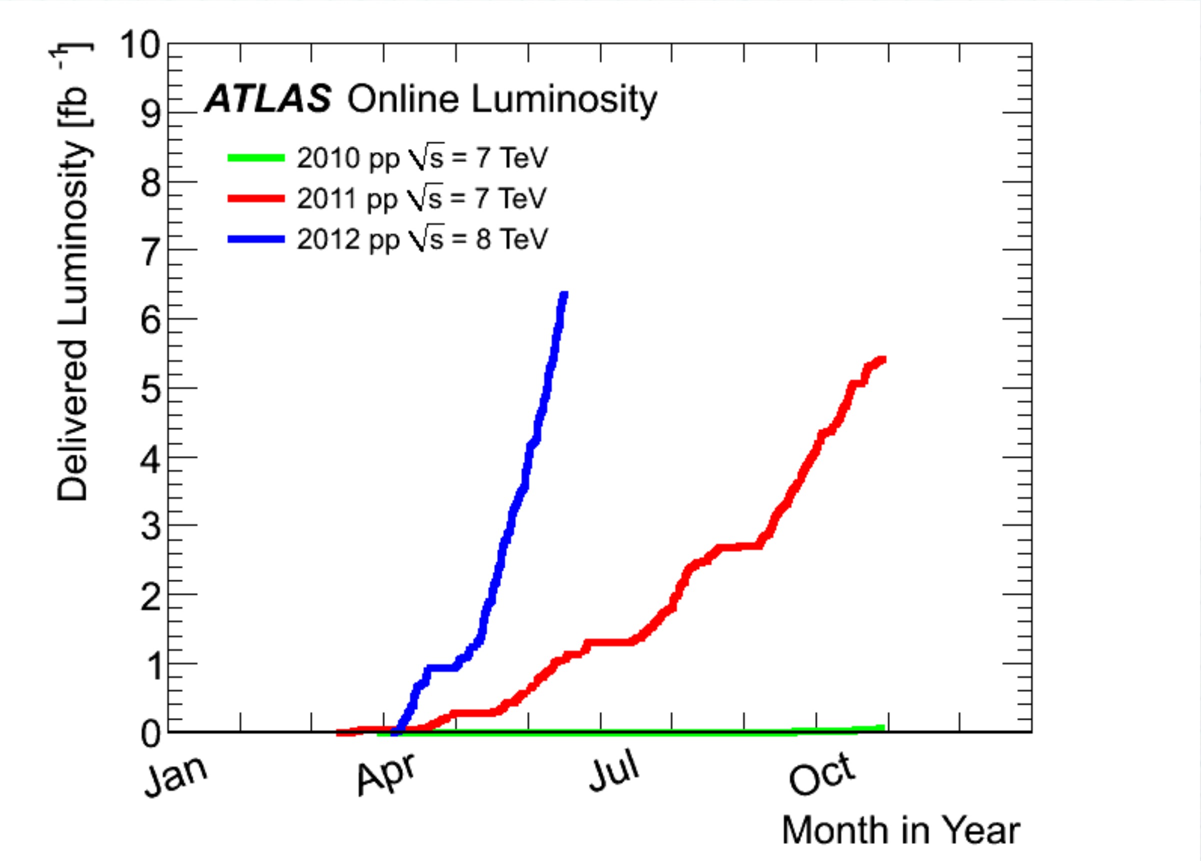
名前をつけるとわかった気になってしまう？

LHC / ATLAS 実験

加速器

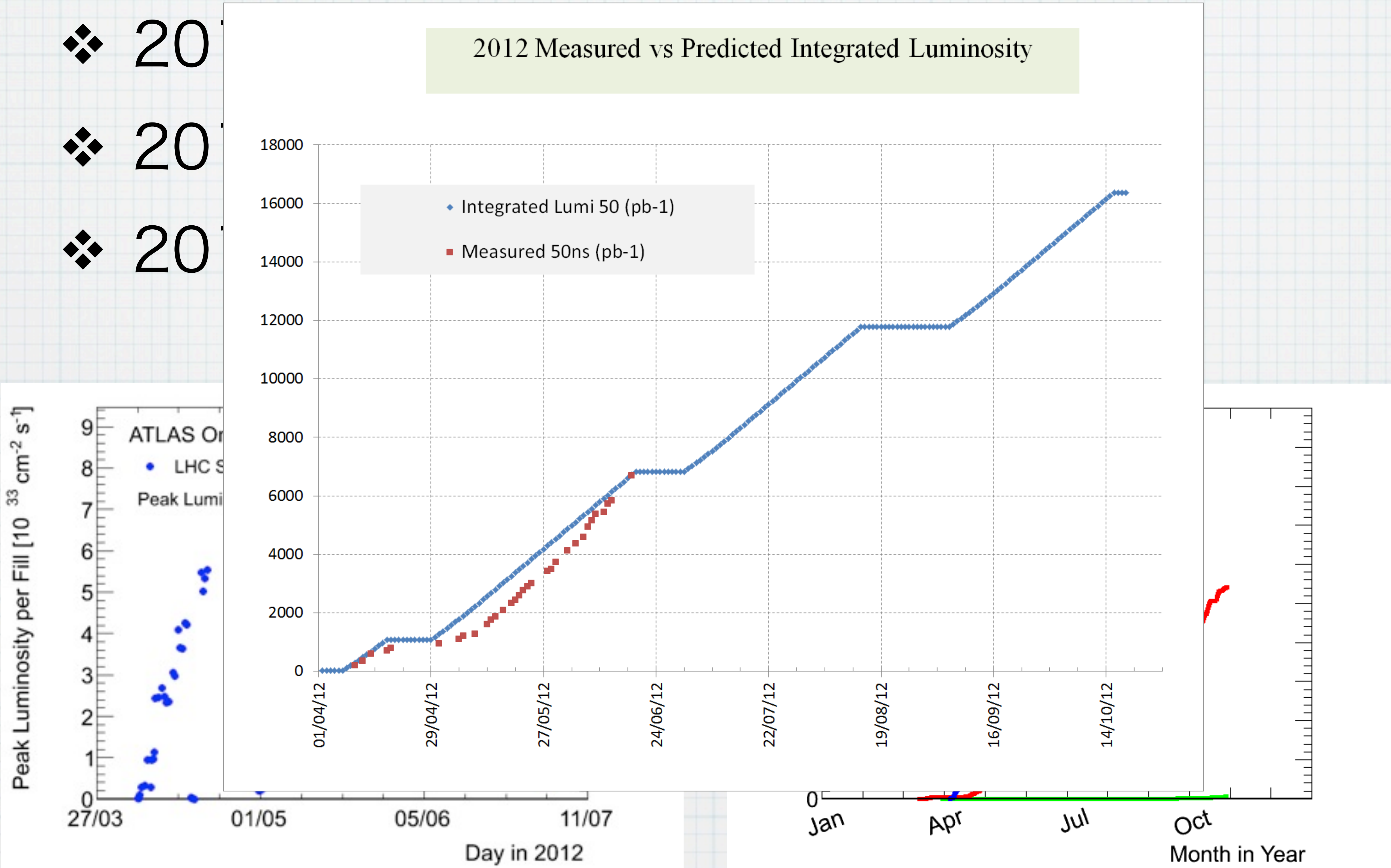
- 2010 : $\sqrt{s}$ = 7 TeV, 35 pb^{-1}
- 2011 : $\sqrt{s}$ = 7 TeV, 5 fb^{-1}
- 2012 : $\sqrt{s}$ = 8 TeV, 6 fb^{-1}





加速器

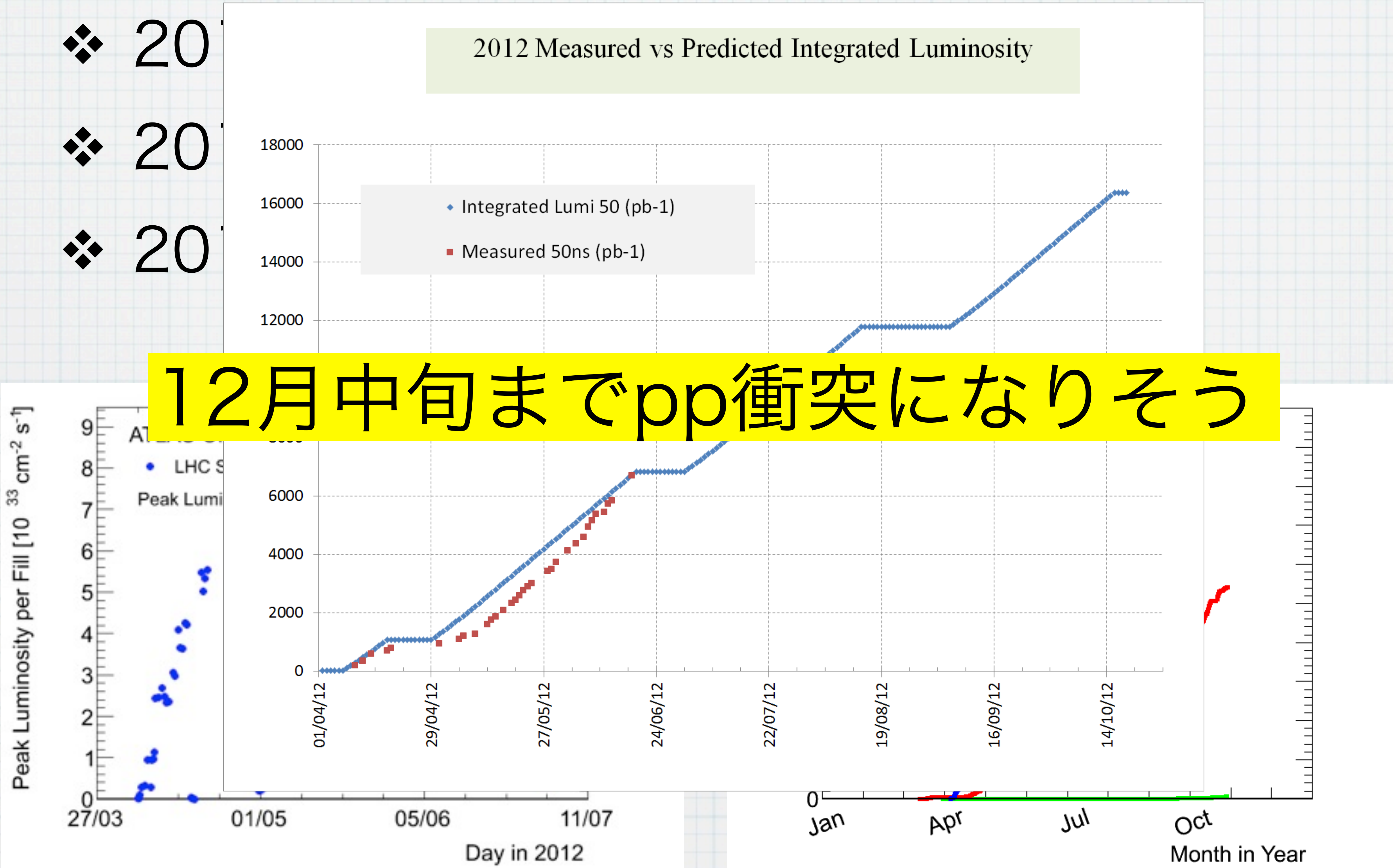
- 20
- 20
- 20



2012 Measured vs Predicted Integrated Luminosity
Integrated Lumi 50 (pb-1)
Measured 50ns (pb-1)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
01/04/12
29/04/12
27/05/12
24/06/12
22/07/12
19/08/12
16/09/12
14/10/12
Peak Luminosity per Fill [10 33 cm-2 s-1]
ATLAS On
LHC S
Peak Lumi
9
8
7
6
5
4
3
2
1
0
27/03
01/05
05/06
11/07
Day in 2012
0
Jan
Apr
Jul
Oct
Month in Year

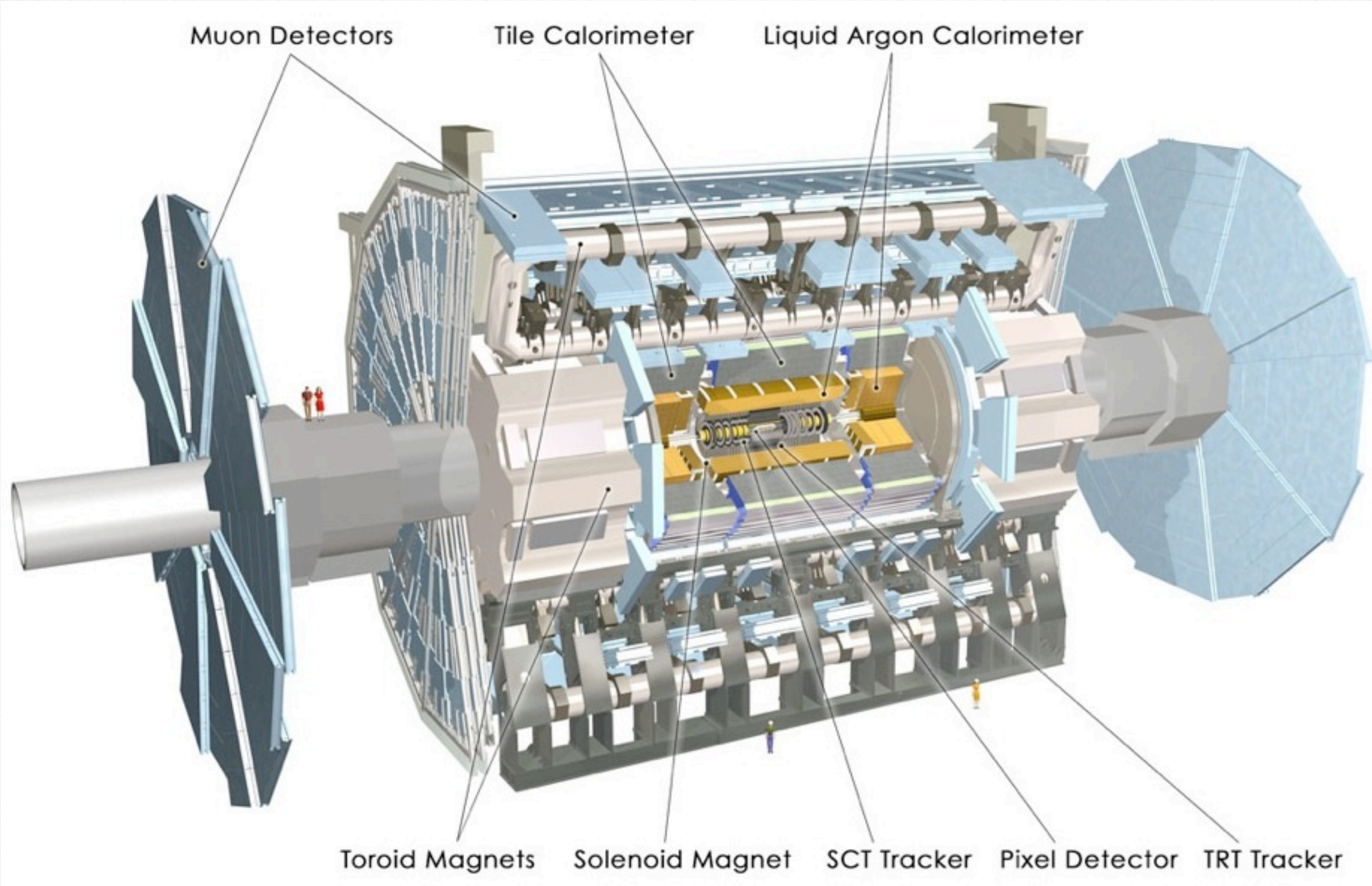
加速器

- 20
- 20
- 20



12月中旬までpp衝突になりそう

ATLAS 検出器


Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker

What Happens in Hadron Collisions

- Underlying Event
  - Initial/Final state radiation
  - Beam remnant
- Multiple Interactions
  - #events/unit time = $\sigma \times \mathcal{L}$
    #events/bunch = $\sigma \times \mathcal{L}$ x bunch space
    = ~30 @6E33 50ns bunch space

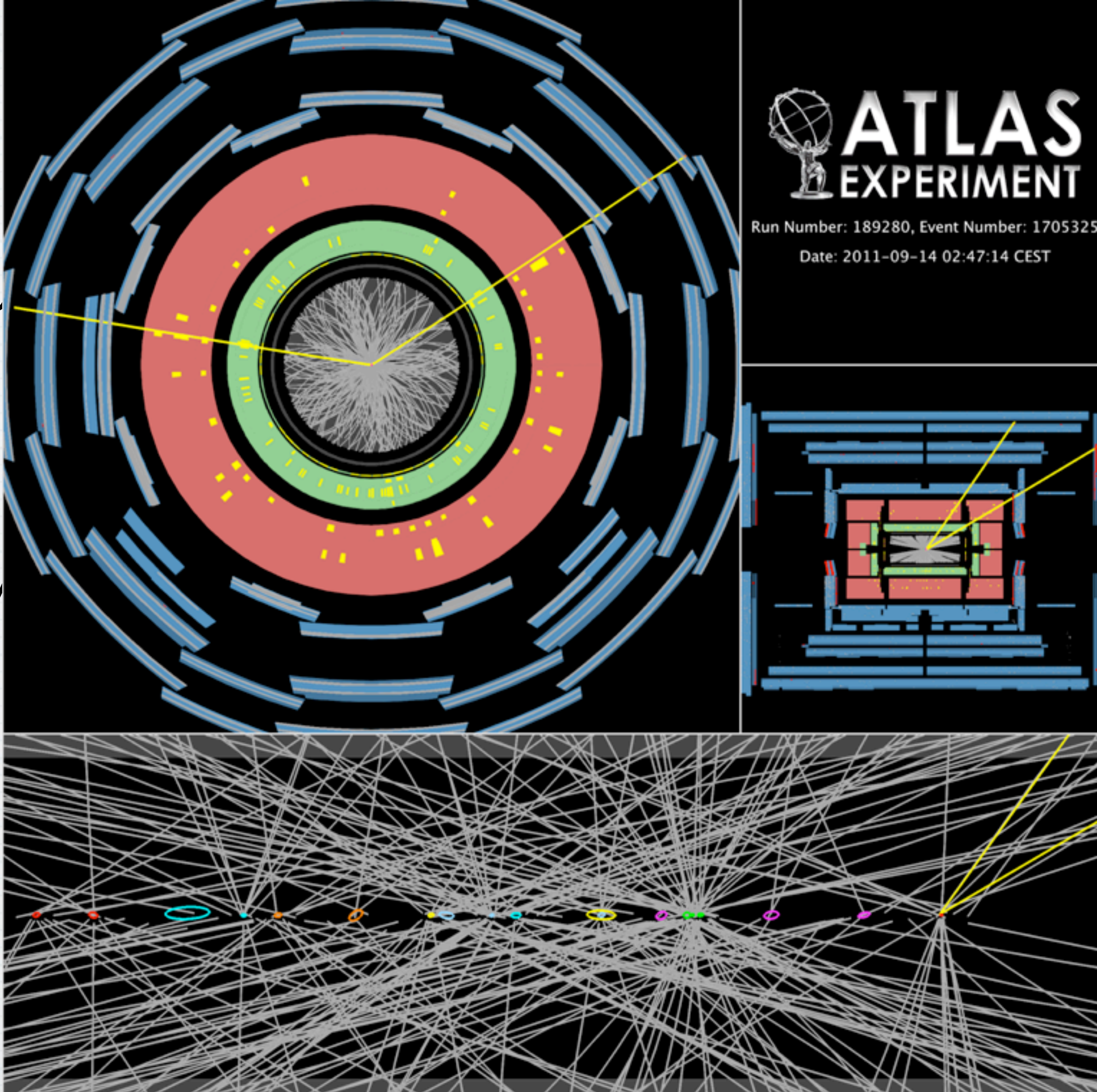
W … s

❖ U

❖ M

ce

ace


ATLAS
EXPERIMENT
Run Number: 189280, Event Number: 1705325
Date: 2011-09-14 02:47:14 CEST

W … s

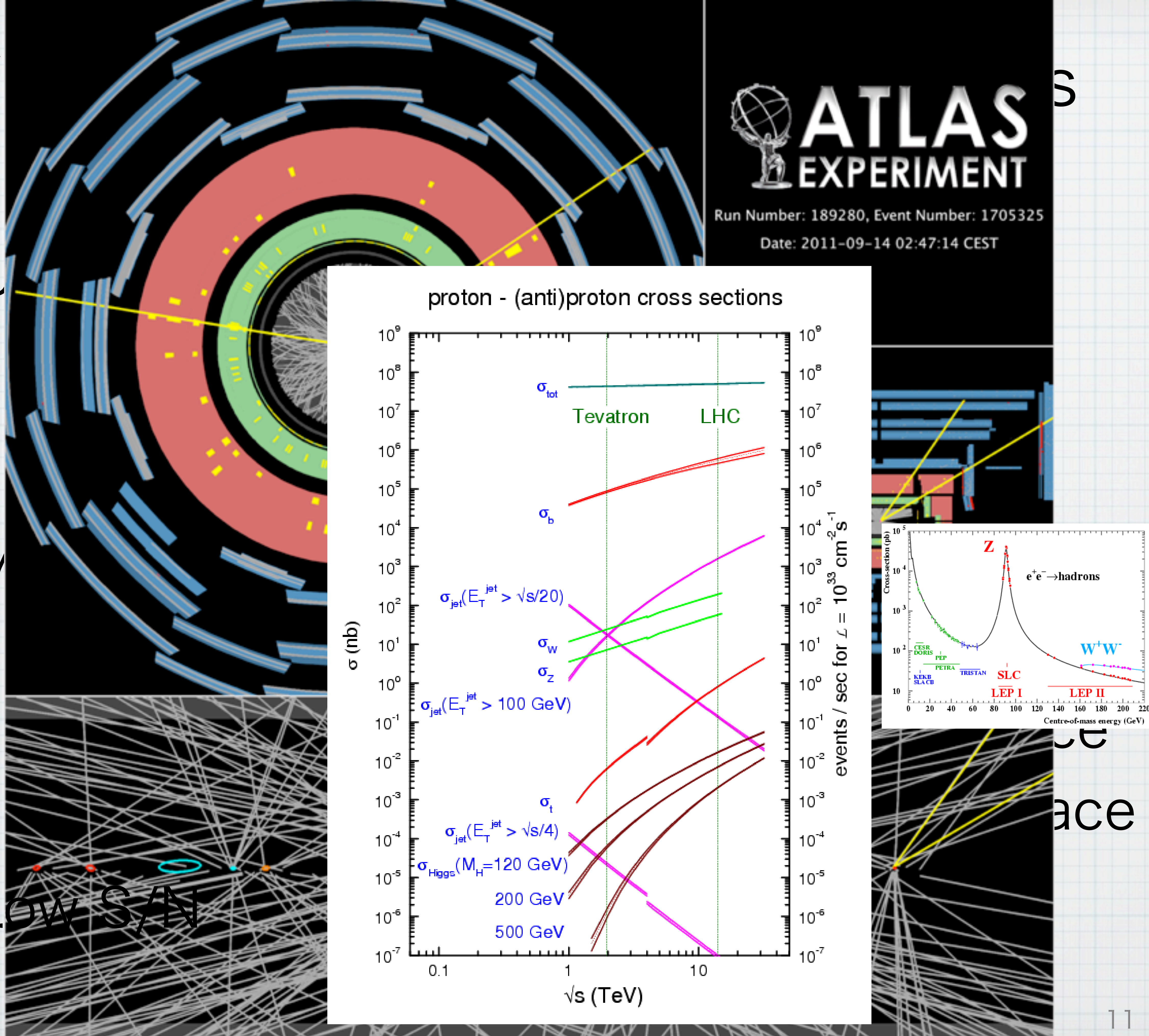
❖ U…

❖ M…

…ce

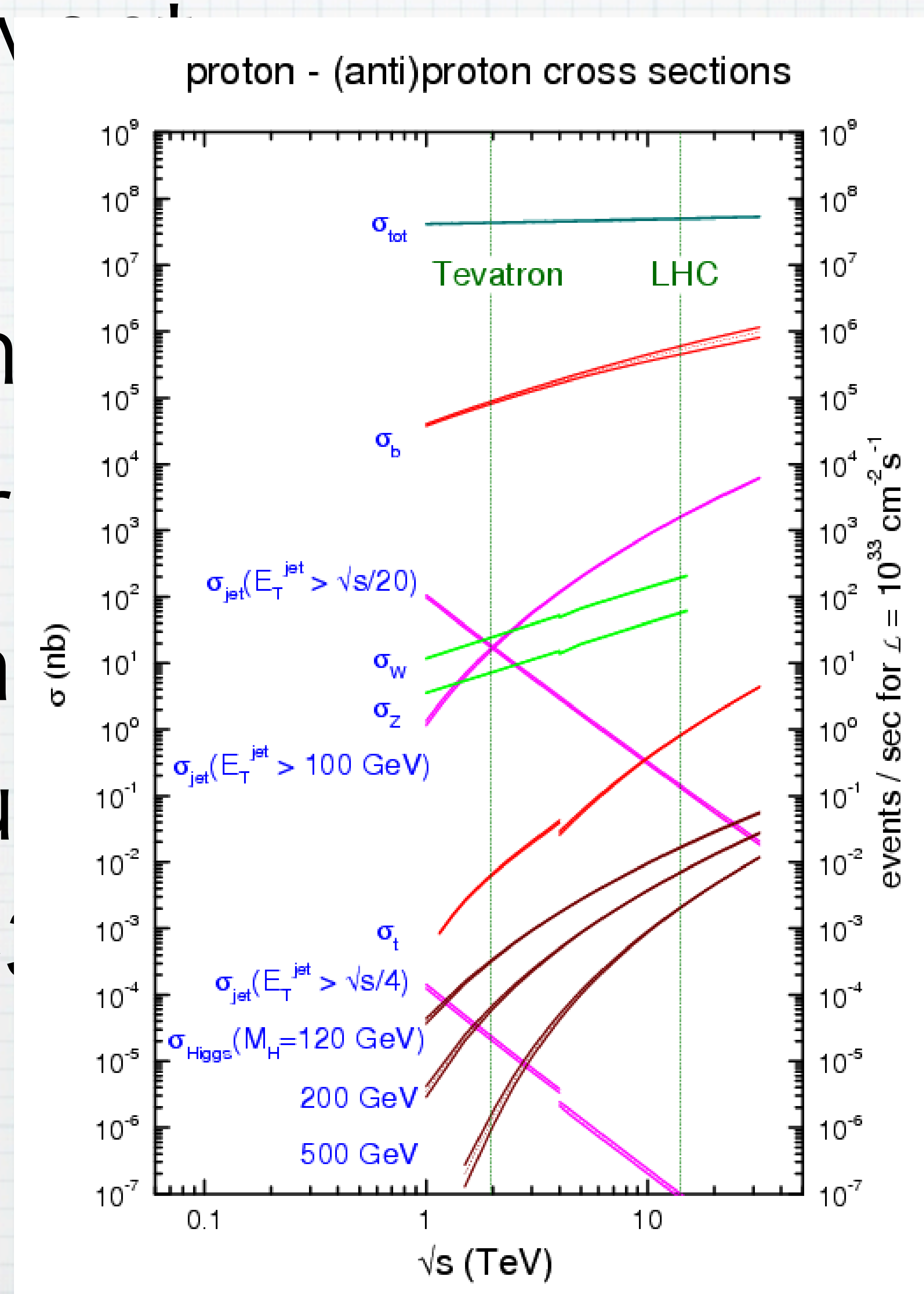
…ace

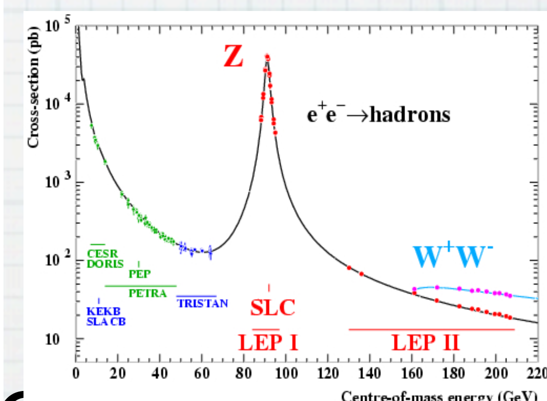
❖ Low S/N



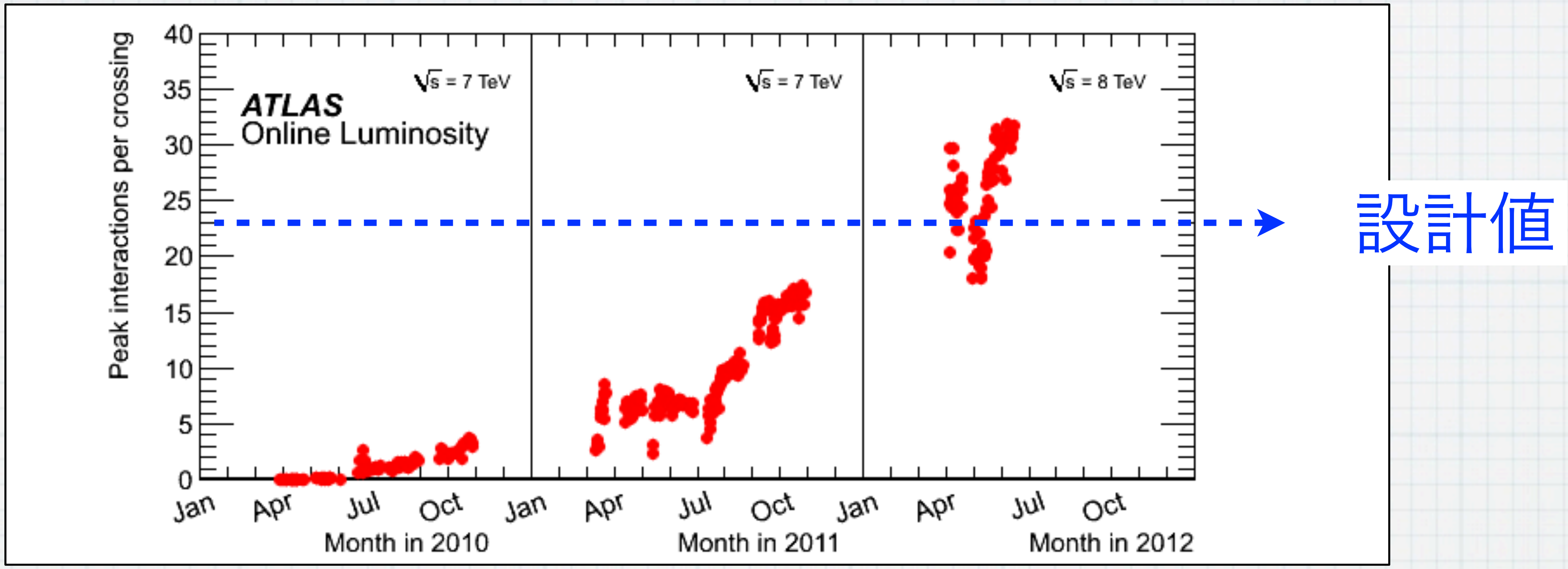
What Happens in Hadron Collisions

- Underlying Ev
  - Initial/Final
  - Beam remn
- Multiple Inter
  - #events/un
    #events/bu   ch space
    = ~3   nch space
- Low S/N

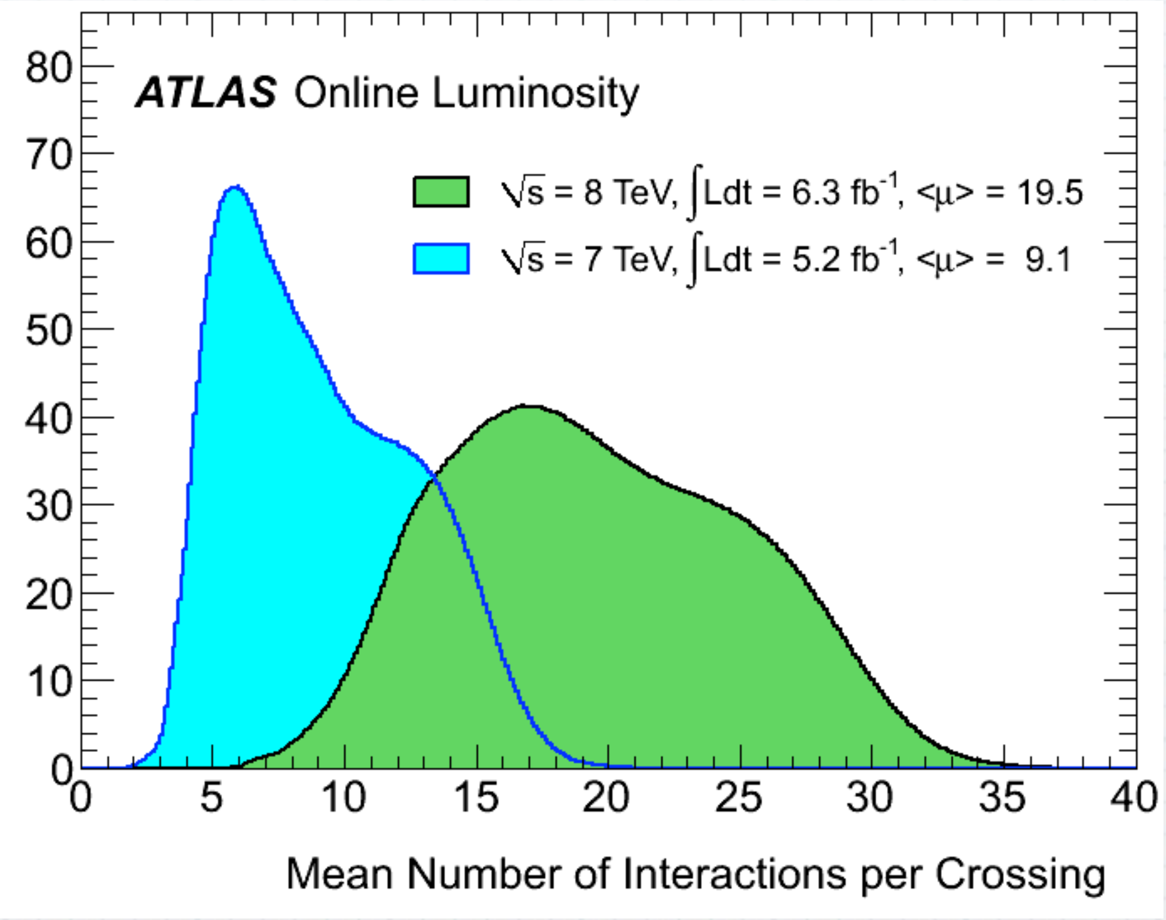




多重衝突



ATLAS
Online Luminosity
√s = 7 TeV
√s = 7 TeV
√s = 8 TeV
Peak interactions per crossing
0
5
10
15
20
25
30
35
40
Jan
Apr
Jul
Oct
Month in 2010
Month in 2011
Month in 2012
設計値

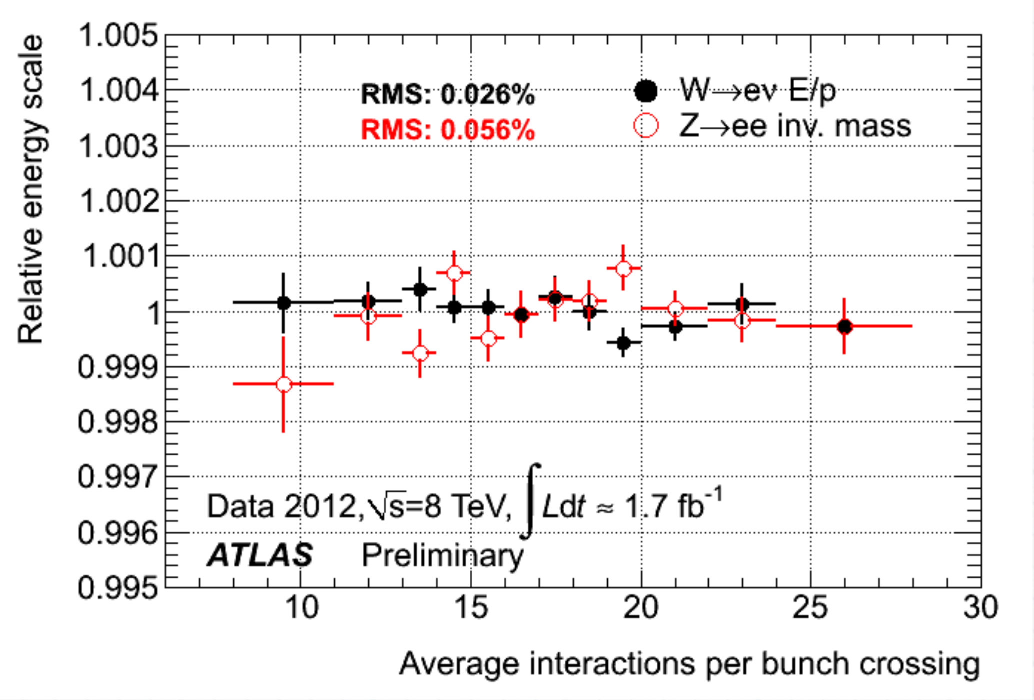


ATLAS Online Luminosity
√s = 8 TeV, ∫Ldt = 6.3 fb^-1, <μ> = 19.5
√s = 7 TeV, ∫Ldt = 5.2 fb^-1, <μ> = 9.1
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30
35
40
Mean Number of Interactions per Crossing

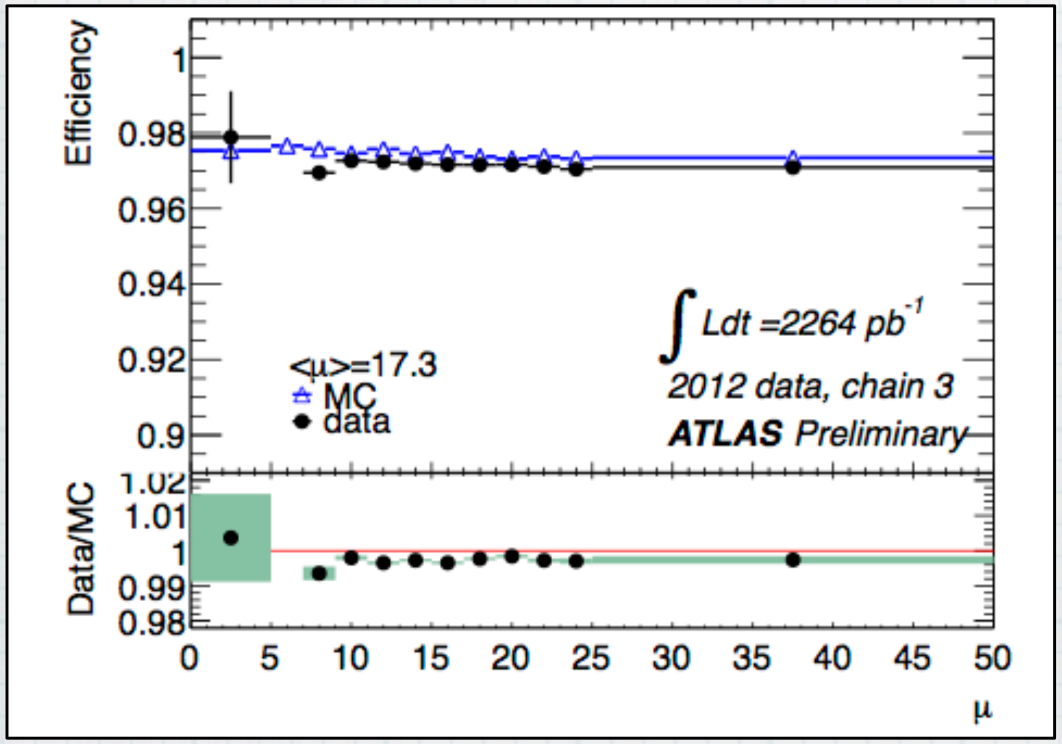
多重衝突に負けず

ATLAS

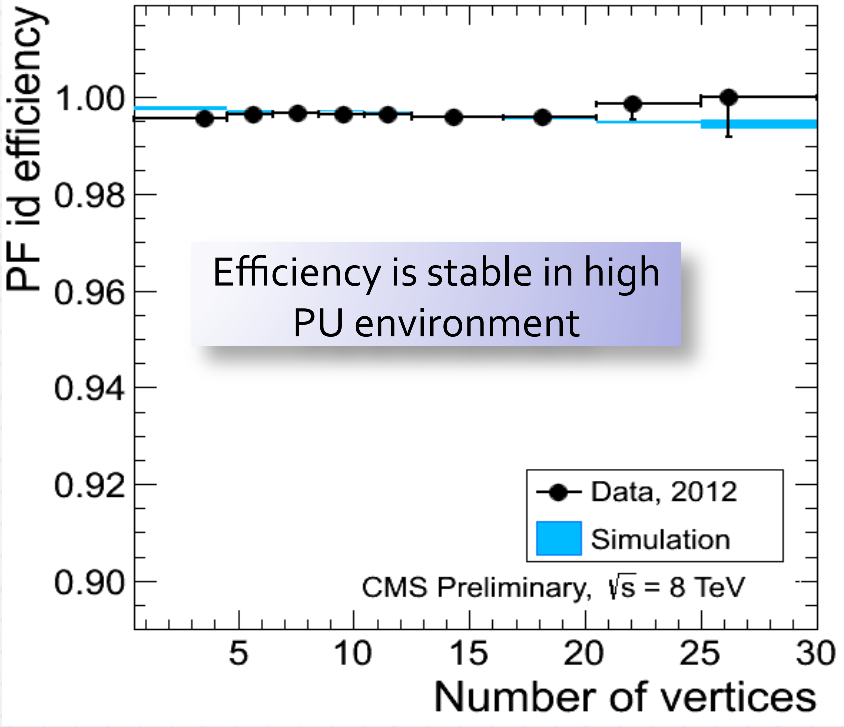
CMS



EMスケールの安定性



μ efficiencyの安定性



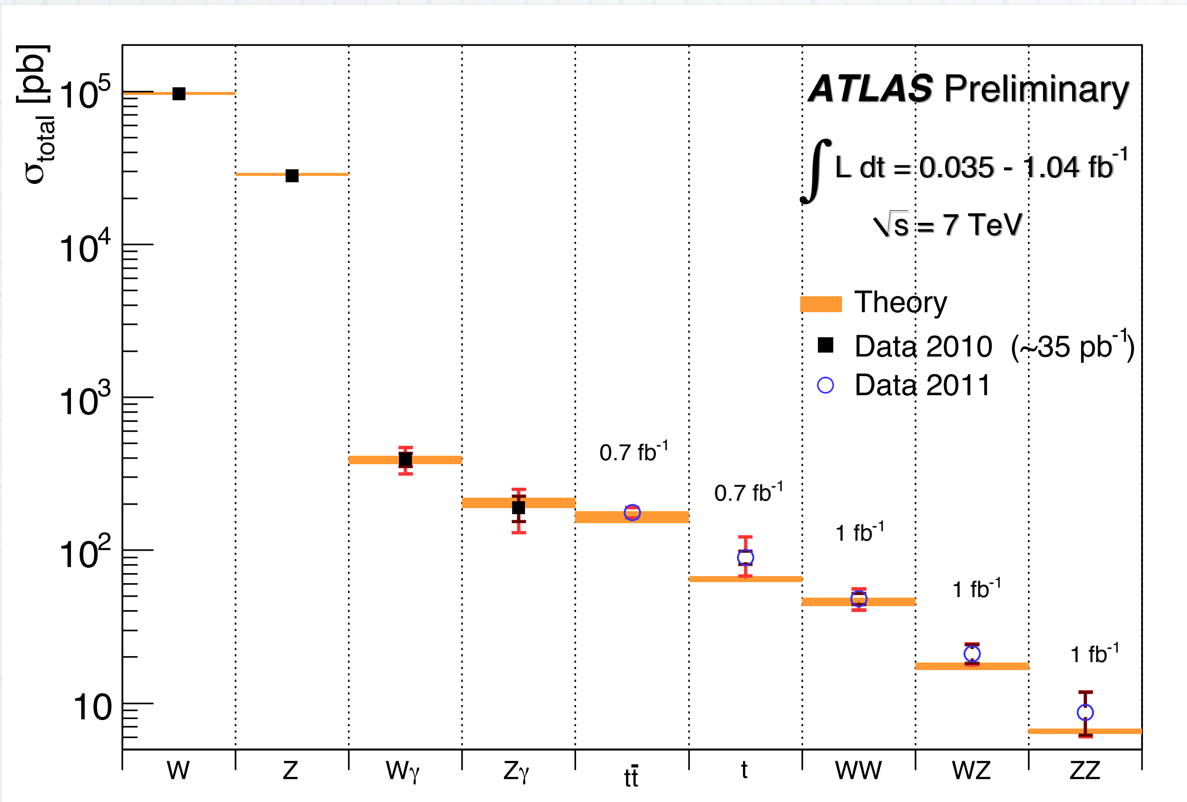
μ efficiencyの安定性

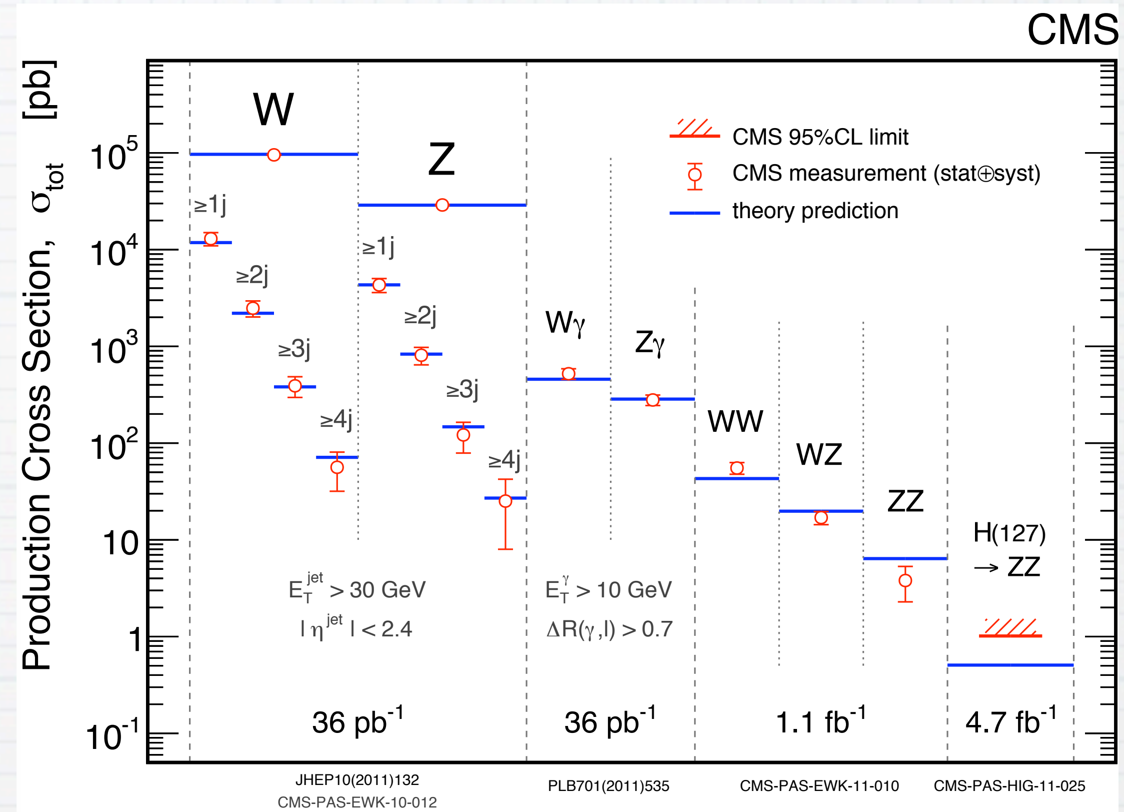
探索の戦略

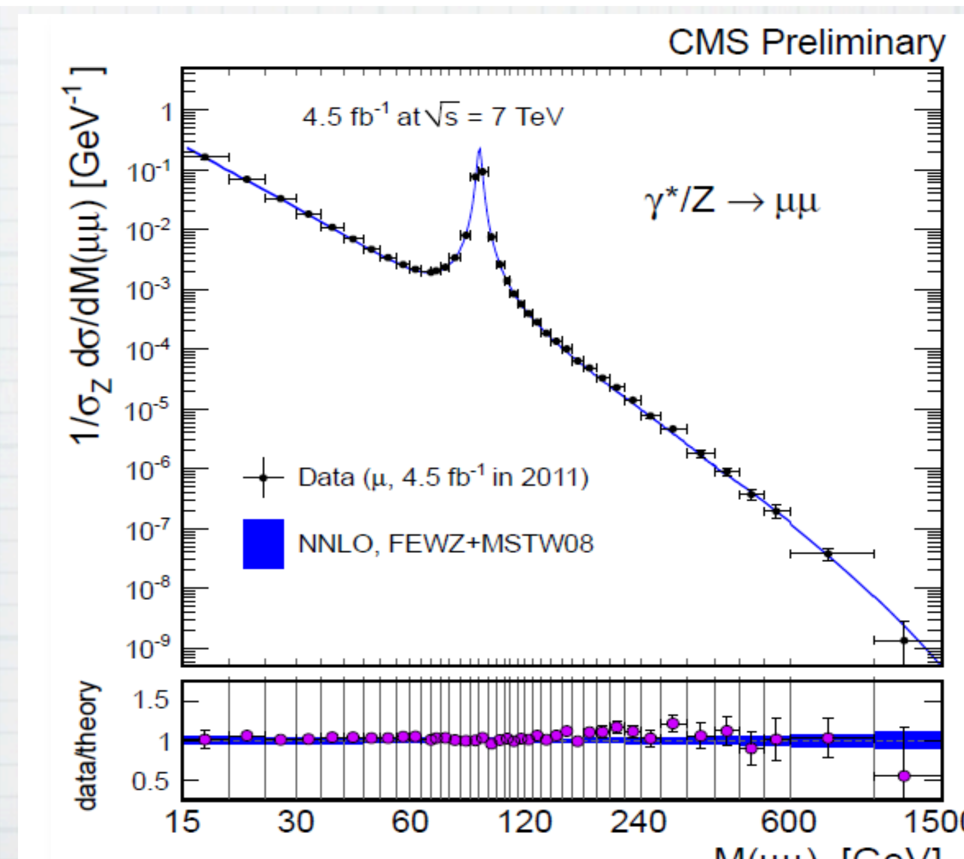
標準模型粒子

ATLAS

CMS



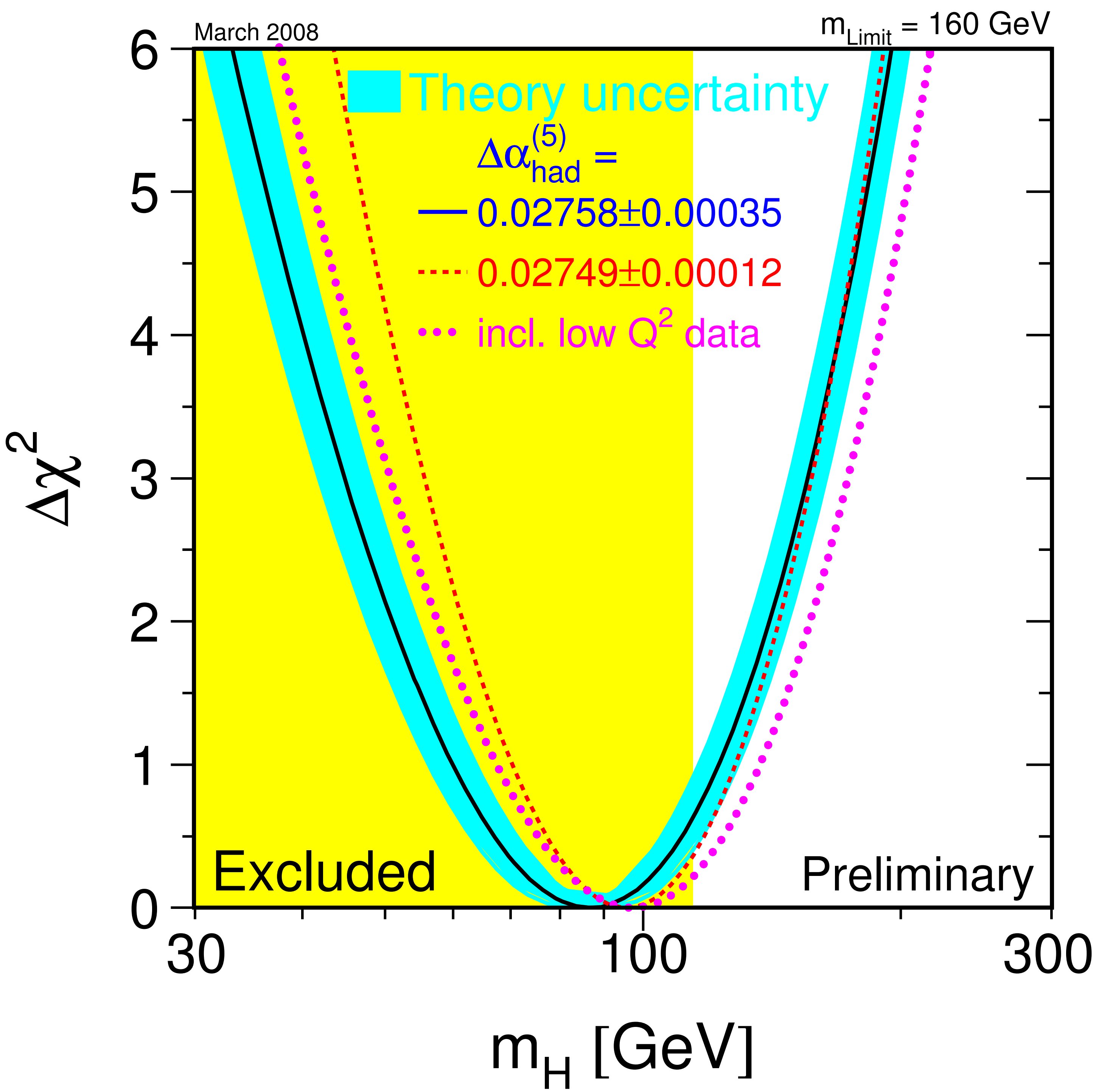




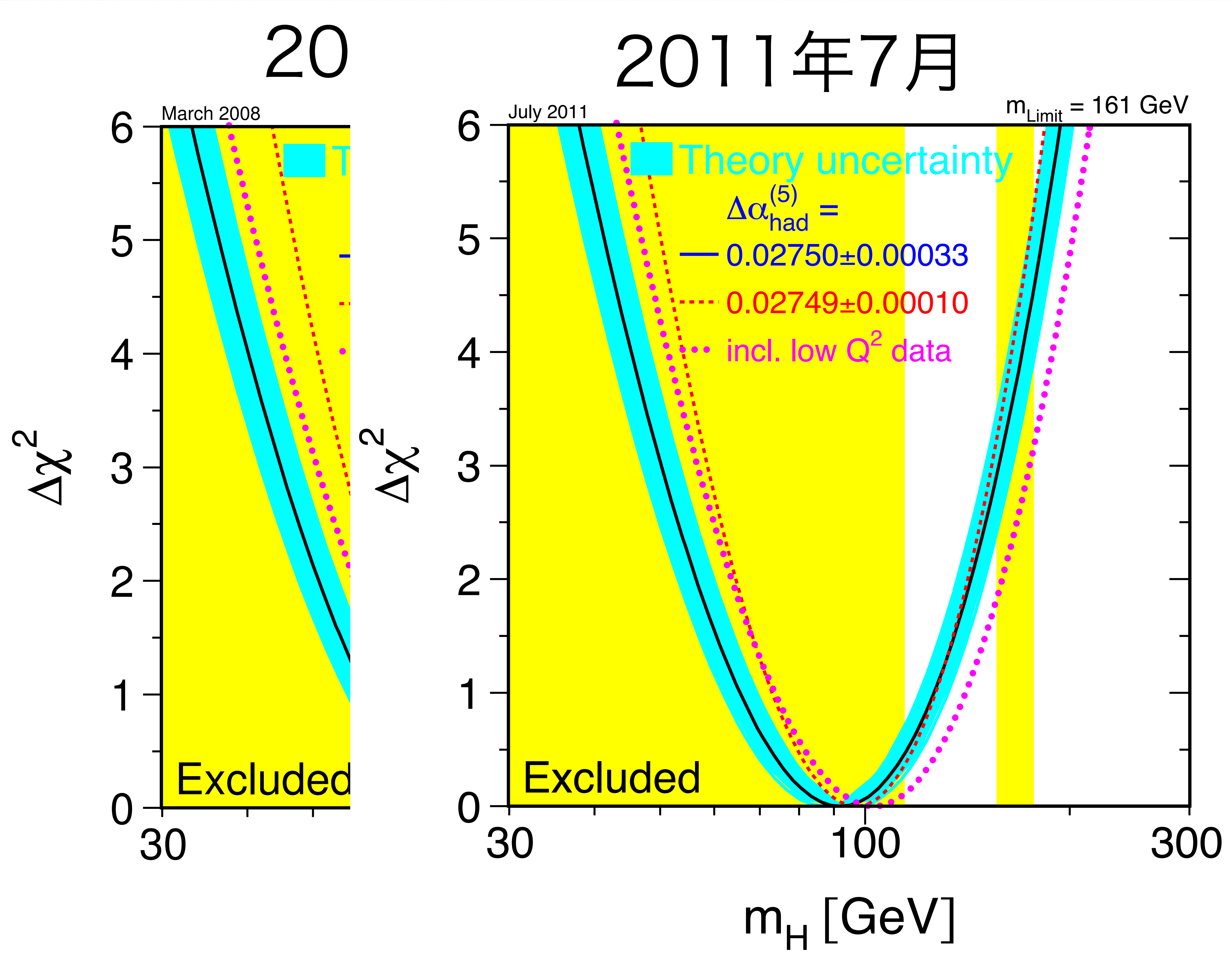
- 新粒子探索＝標準模型からのズレの探索
- Excellent agreement

探索の歴史

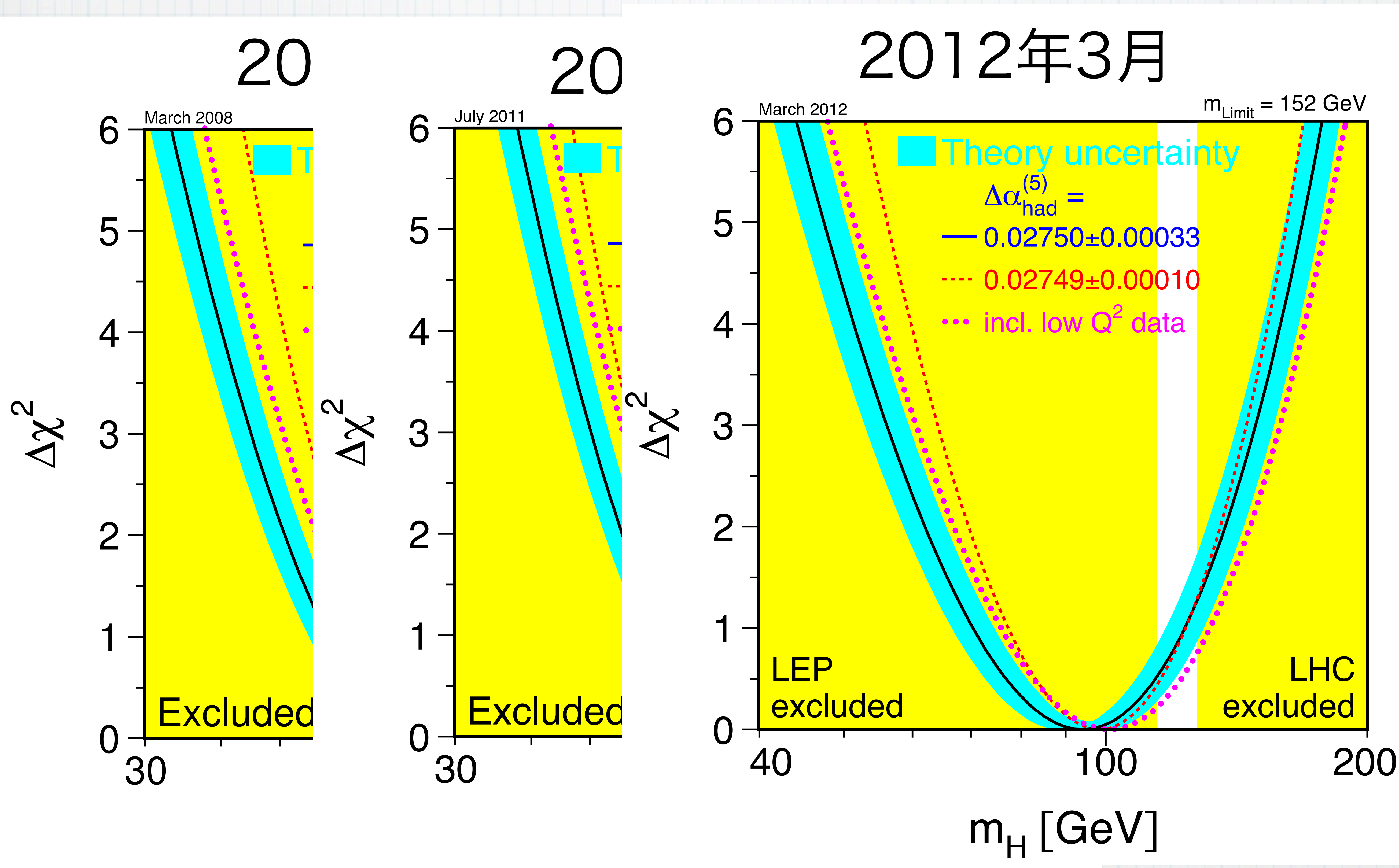
2008年3月



探索の歴史

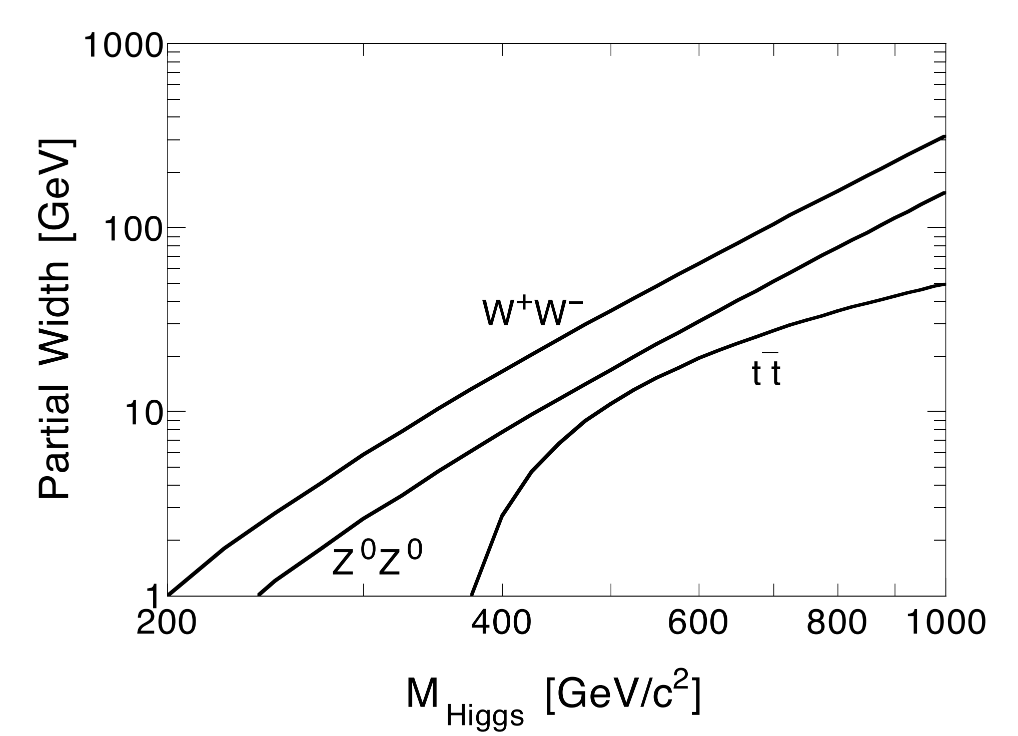

20
2011年7月
March 2008
July 2011
m_{Limit} = 161 GeV
Theory uncertainty
$\Delta\alpha_{had}^{(5)}$ =
0.02750±0.00033
0.02749±0.00010
incl. low Q^2 data
Excluded
Excluded
$\Delta\chi^2$
$\Delta\chi^2$
m_H [GeV]
0
1
2
3
4
5
6
30
100
300

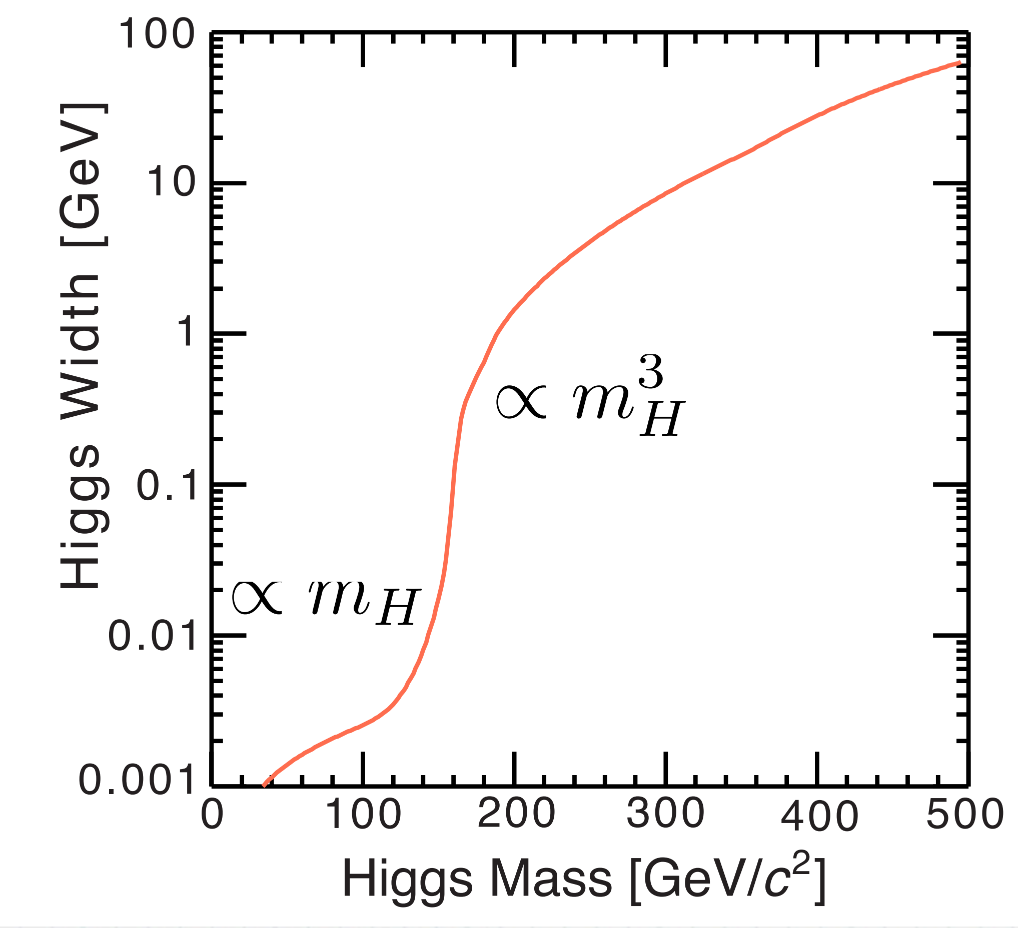
探索の歴史

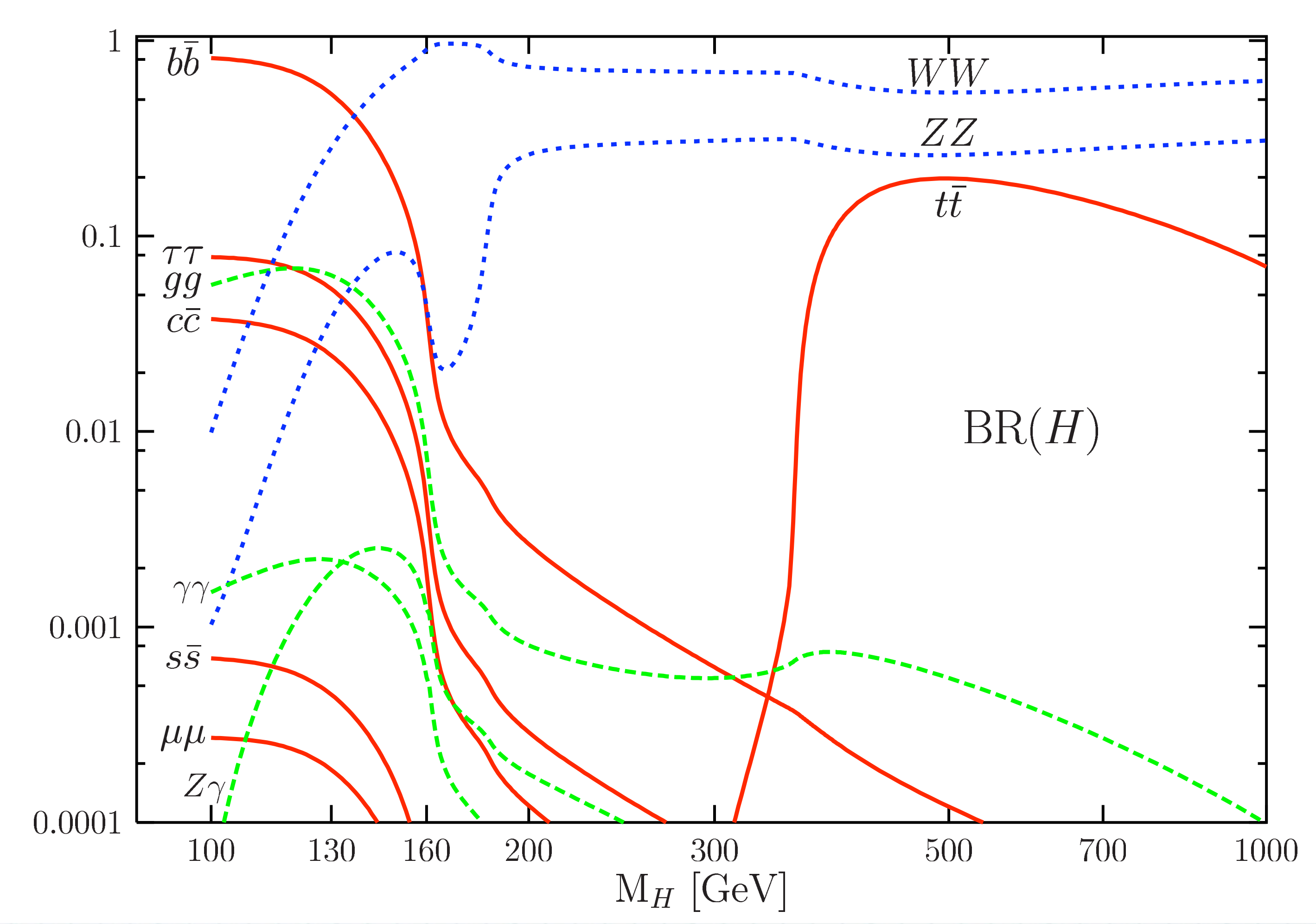


20
March 2008
Excluded
20
July 2011
Excluded
2012年3月
March 2012
m_Limit = 152 GeV
Theory uncertainty
Δα(5)had =
0.02750±0.00033
0.02749±0.00010
incl. low Q2 data
LEP
excluded
LHC
excluded
Δχ2
m_H [GeV]
0
1
2
3
4
5
6
30
40
100
200

ヒッグスの崩壊



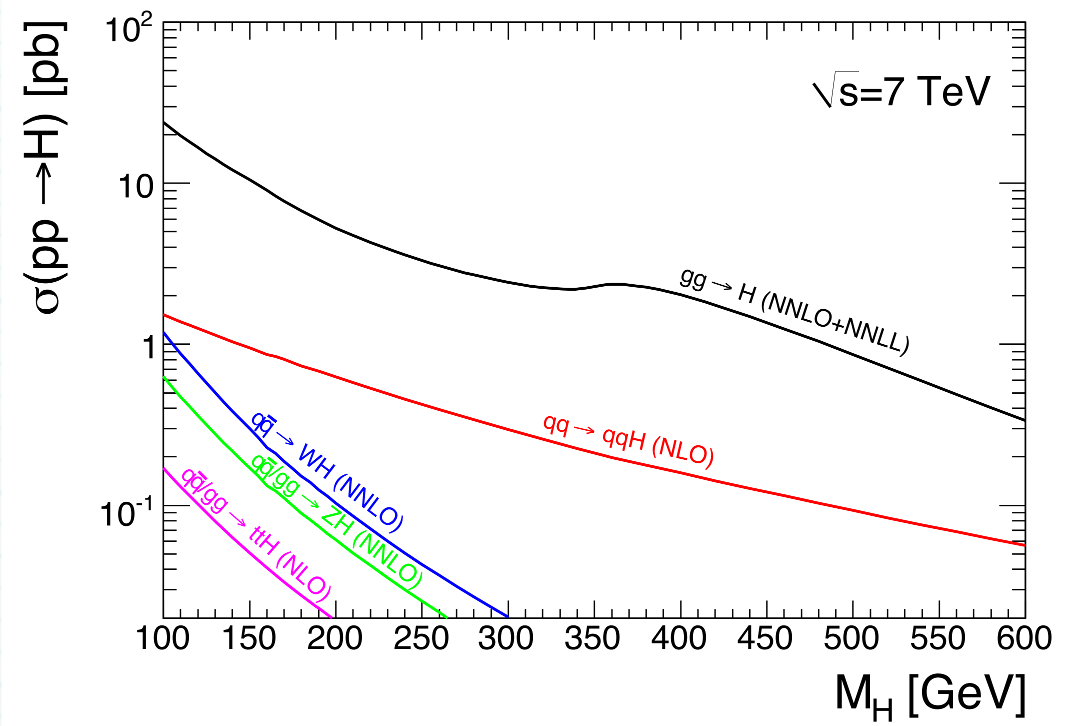




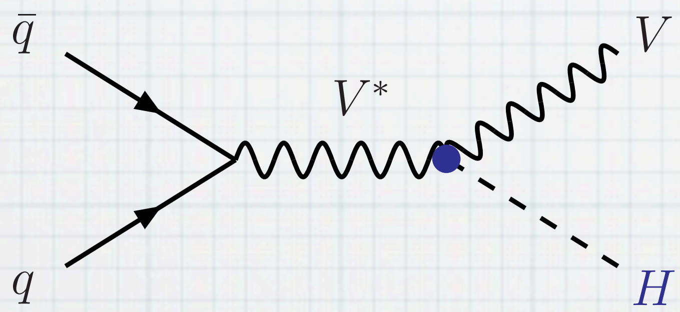
- Γ (vector boson) ∝ m_H^3
- Γ (fermion) ∝ m_H

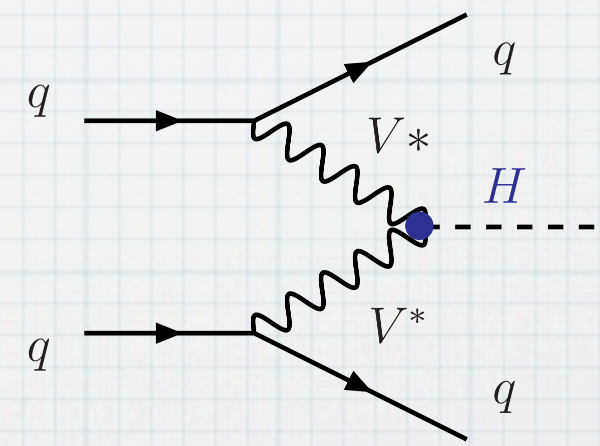
LHCでのヒッグスの生成

- Coupling ∝ mass
  - top the largest among fermions
- Gauge boson relatively larger



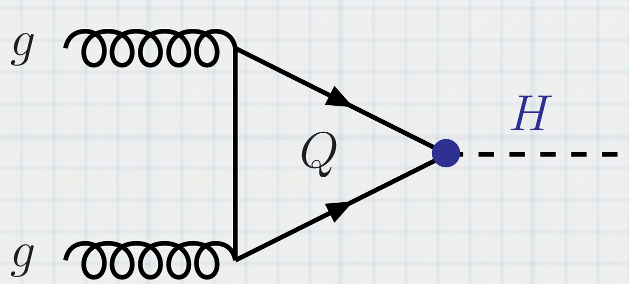
associated production of vector boson

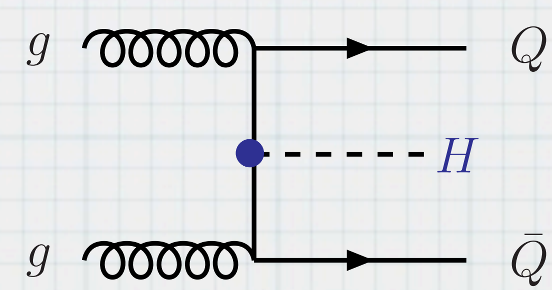




vector boson fusion (VBF)

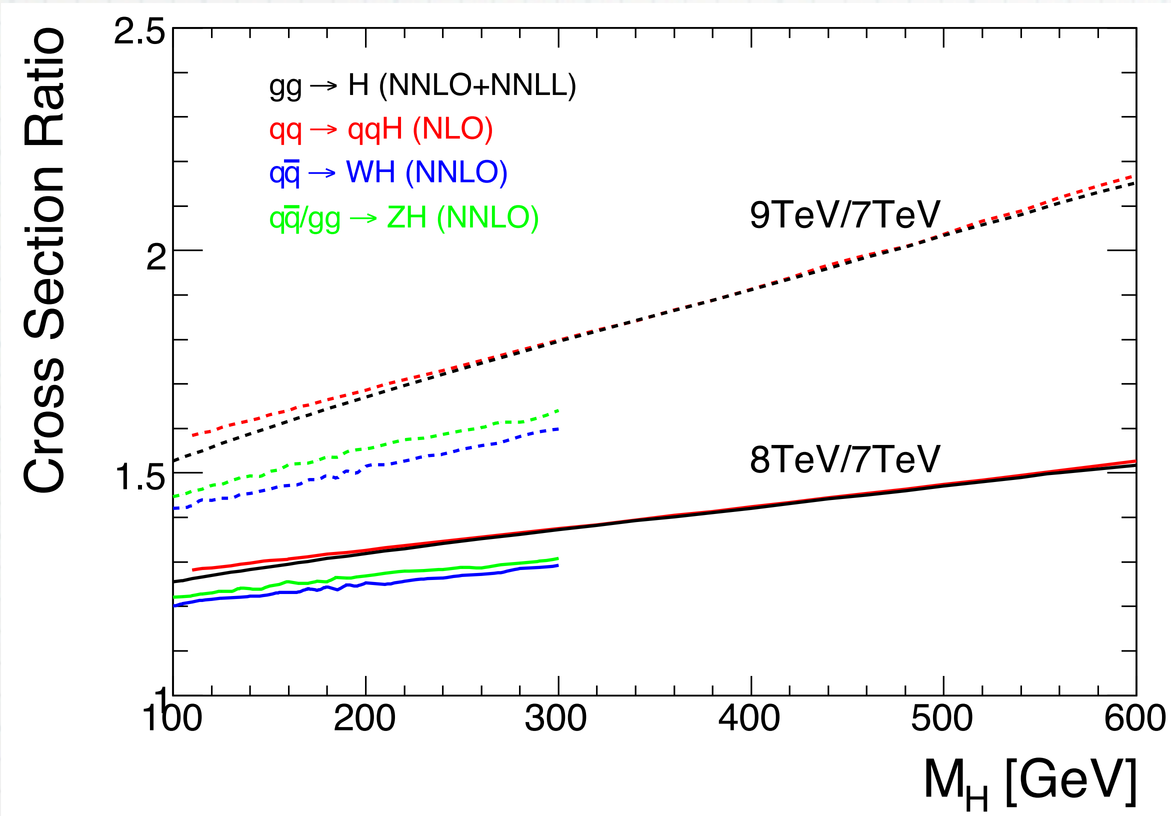
gluon fusion (GF)

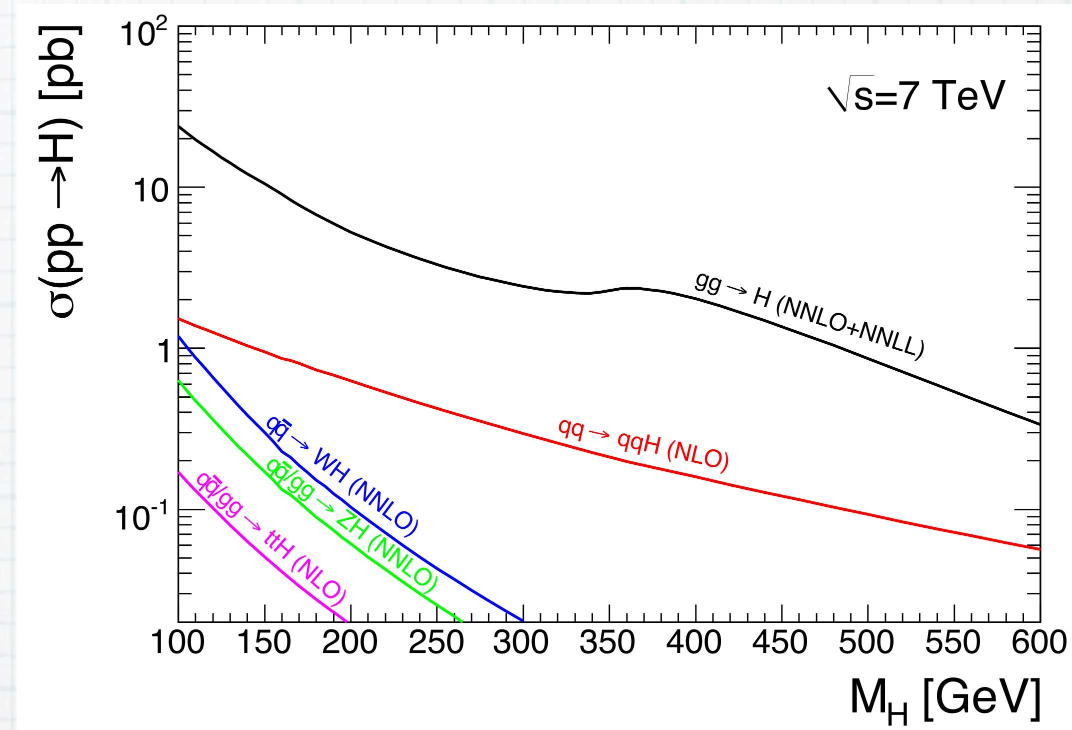




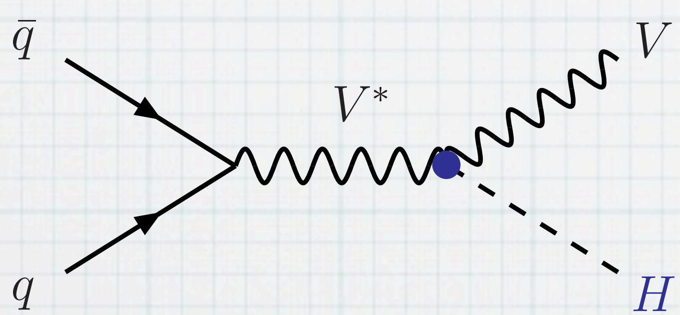
associated production of heavy quark（t, b)

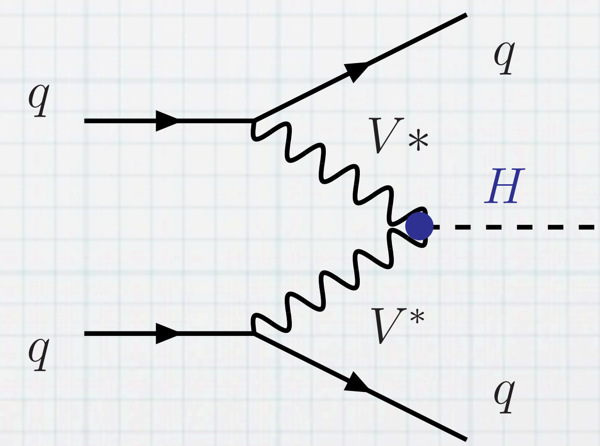
LHCでのヒッグスの生成





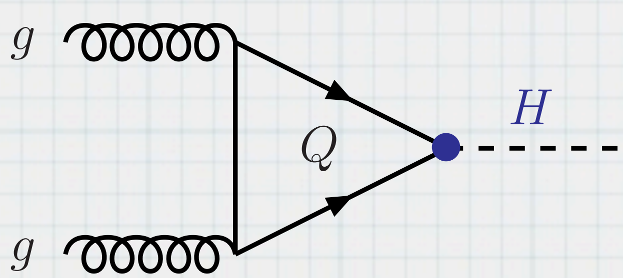
associated production of vector boson

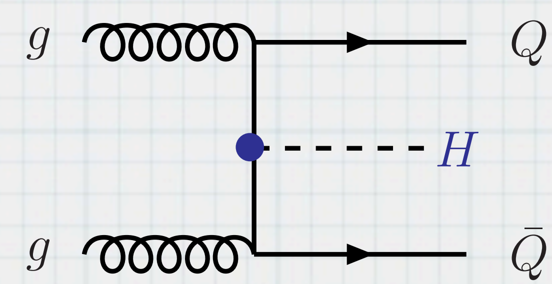




vector boson fusion (VBF)

gluon fusion (GF)





associated production of heavy quark (t, b)

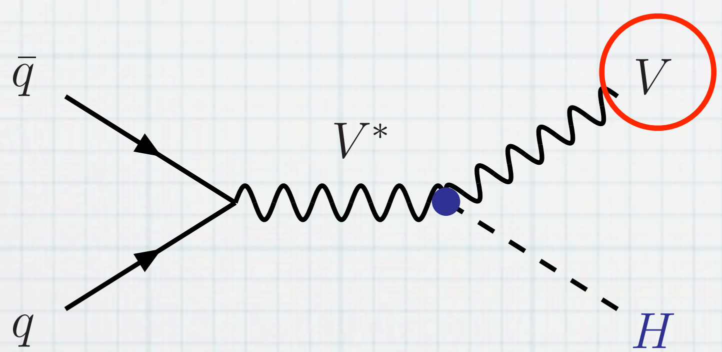
信号の手がかり

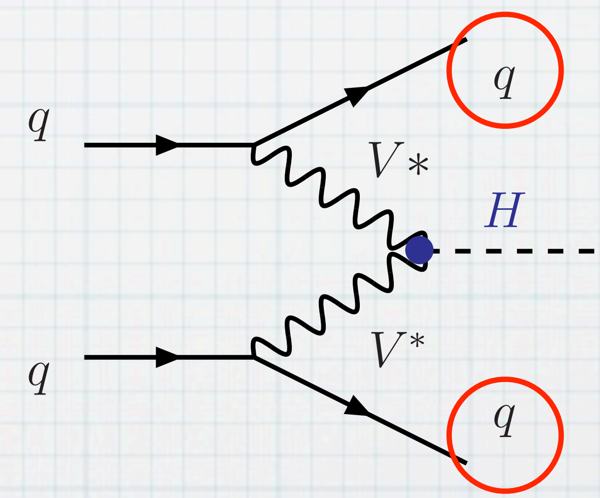
- 背景事象の多くはクォーク/グルーオン(=ジェット)生成

  ⇒ ジェット以外の何かが必要

  ◉ 孤立レプトン or 運動学的な特徴

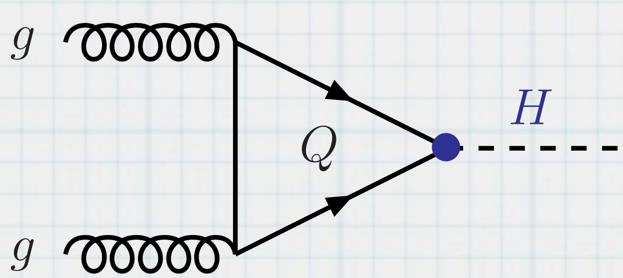
associated production of vector boson

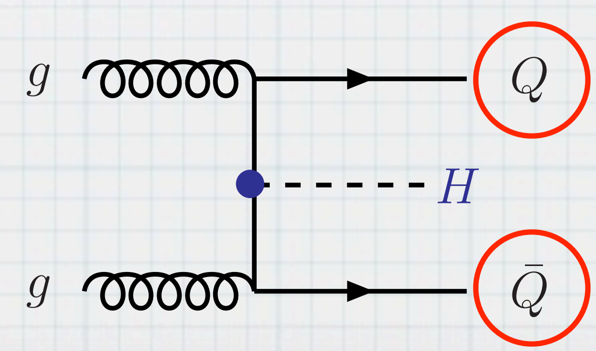




vector boson fusion (VBF)

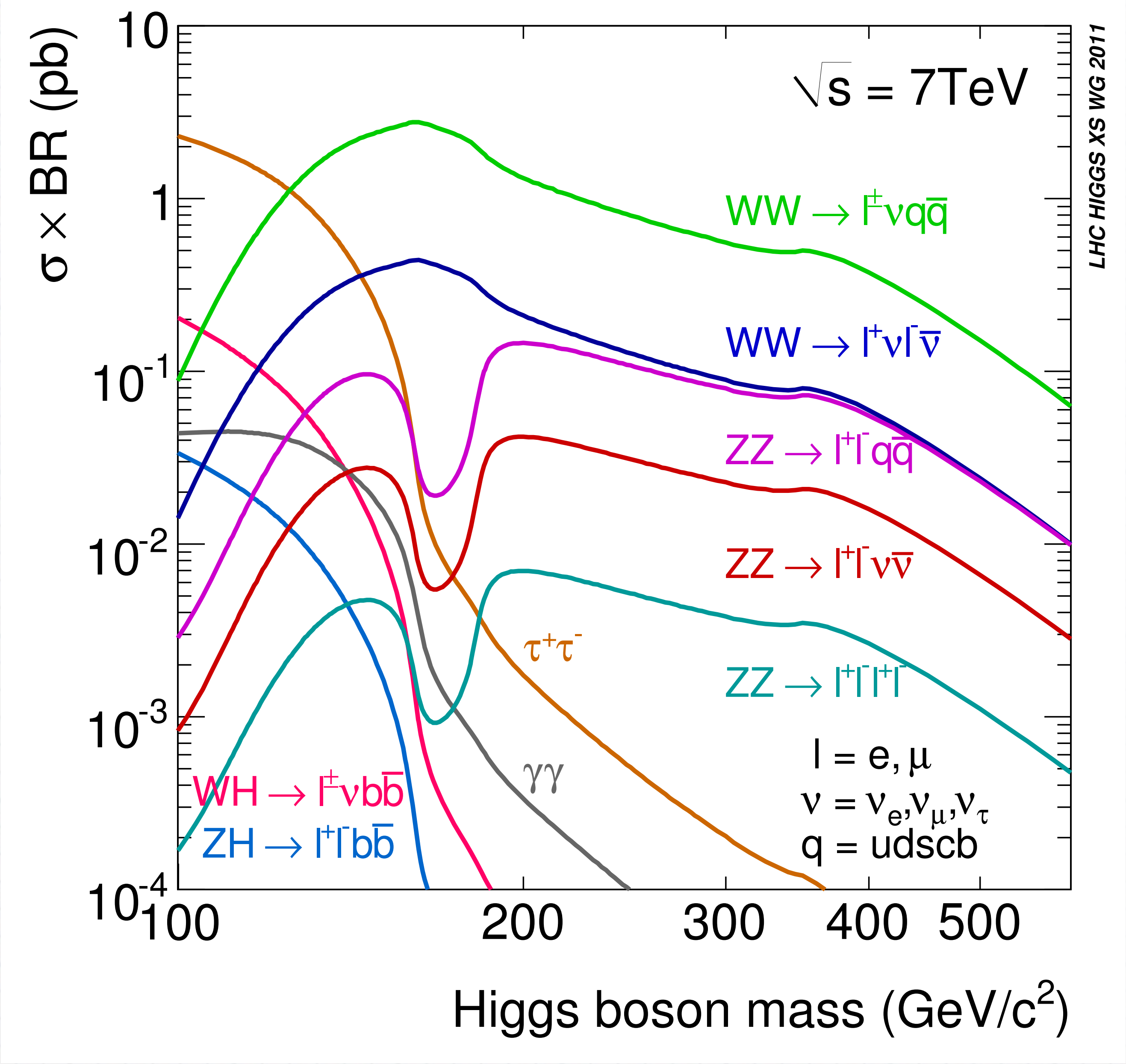
gluon fusion (GF)





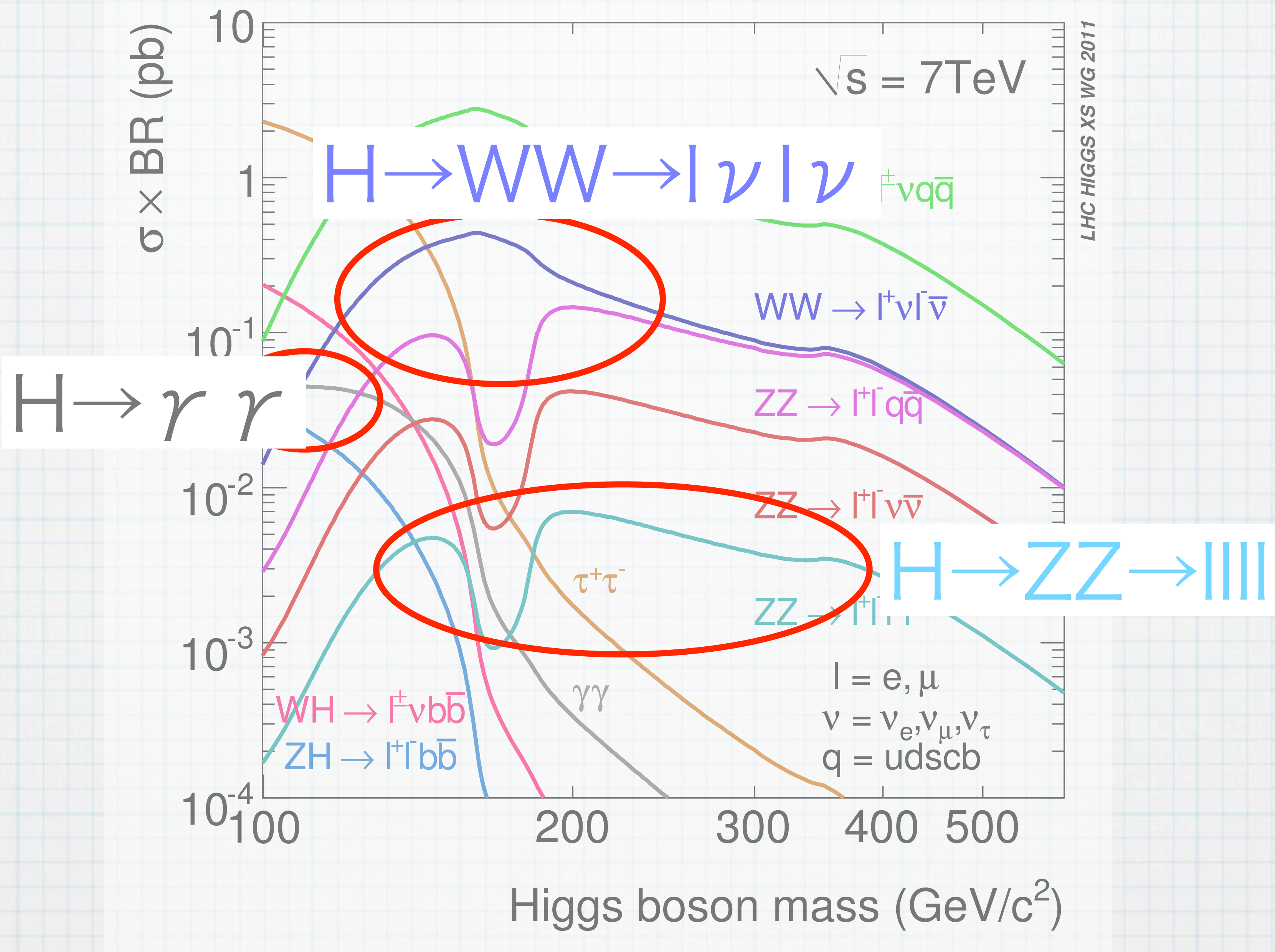
associated production of heavy quark (t, b)

生成される信号数



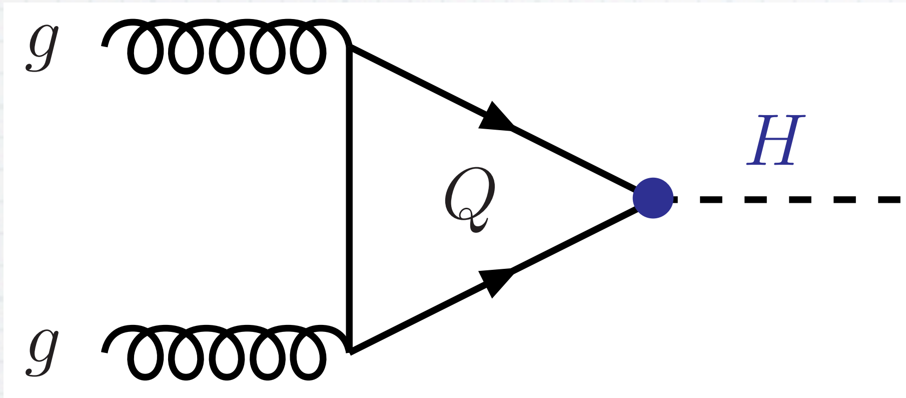
Multiplied by a factor “whether it’s easy to reject BG” (=acceptance)

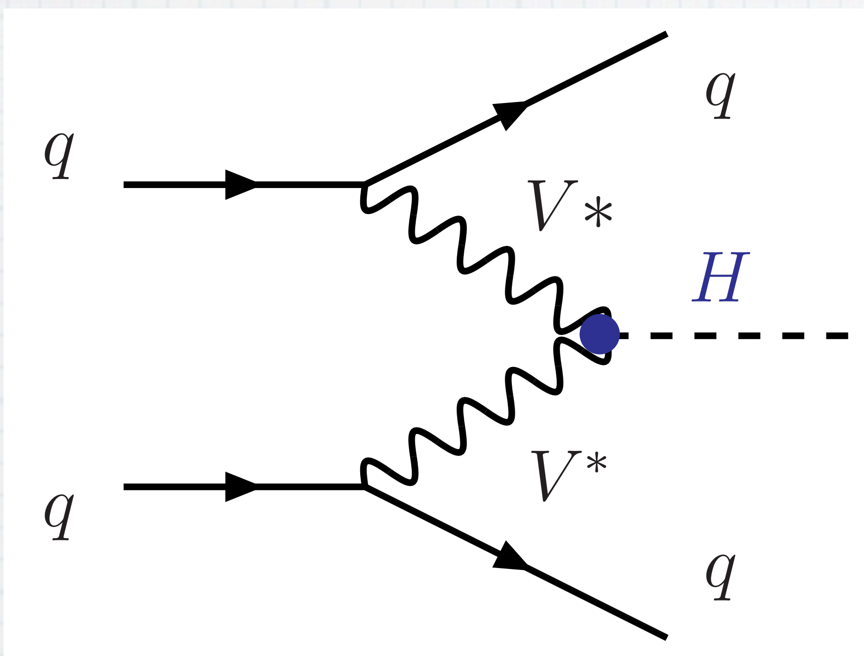
探索に使えるモード

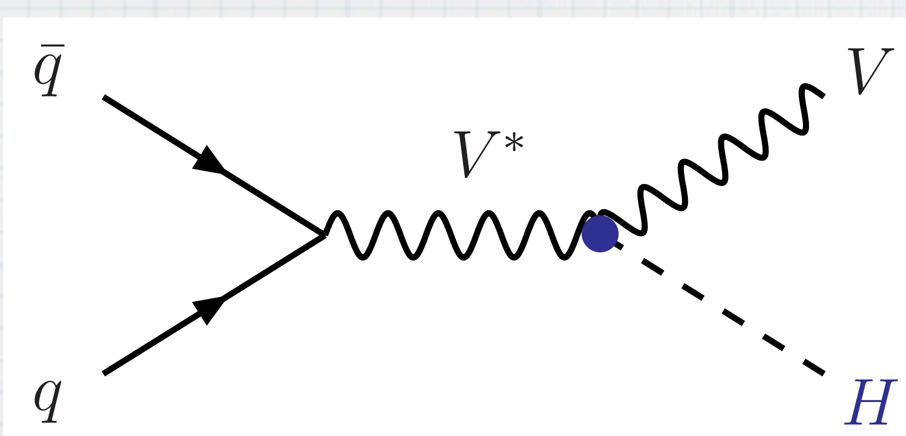


非常に軽いとき（<125GeV）は H → $\tau\tau$ と W/Z + H(→ bb)も寄与する

結合定数







- H → $\gamma\gamma$
  - 崩壊はゲージ
- H → WW or ZZ
  - 崩壊はゲージ
- H → $\tau\tau$
  - 崩壊は湯川
- V (H→bb, $\tau\tau$)
  - ゲージ生成 x 湯川崩壊

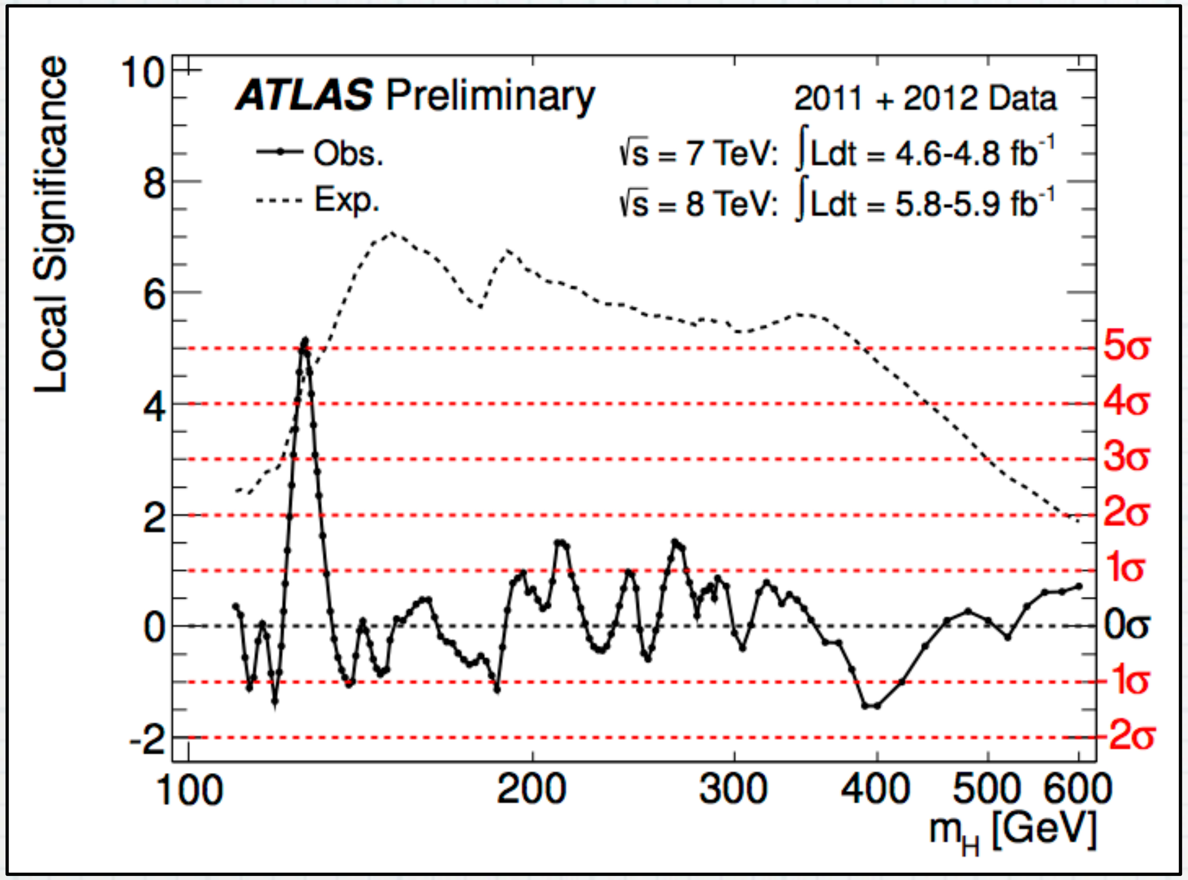
Full Result

Dataset and Channels

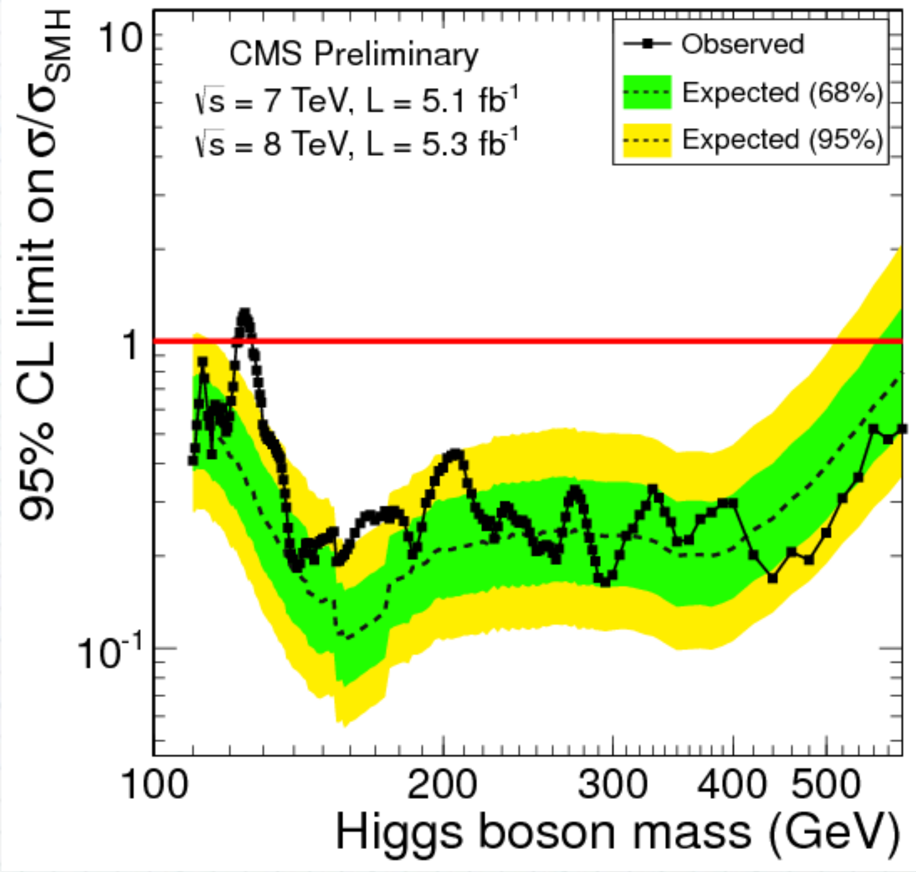
- ATLAS
  - $\gamma\gamma$とZZは2011年+2012年 (~10.7fb^{-1})
  - それ以外は2011だけ（4.9fb^{-1})
- CMS
  - すべてのチャンネルで2011（5fb^{-1}強）
    + 2012年（5fb^{-1}強）

広い質量領域

ATLAS



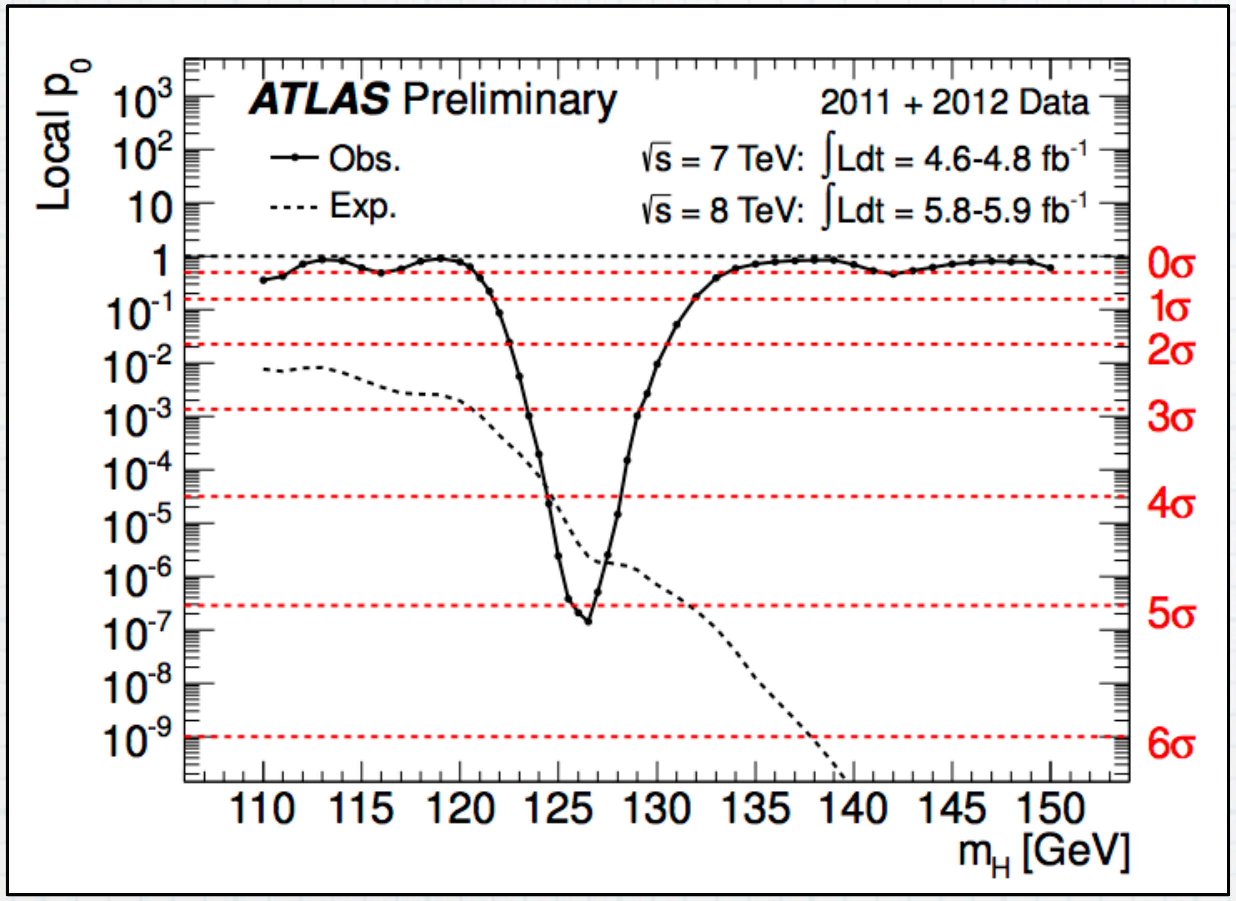
CMS



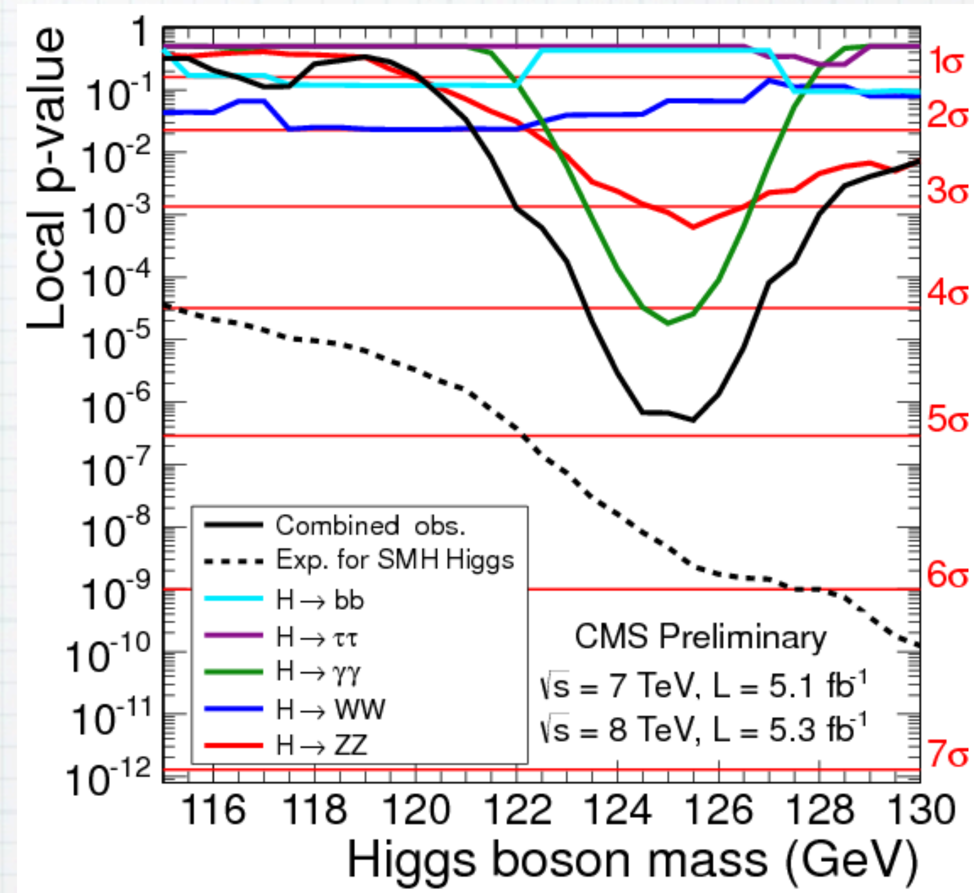
❖ とある質量領域以外は背景事象だけを仮定した場合とよく一致

Local p-value

ATLAS



CMS

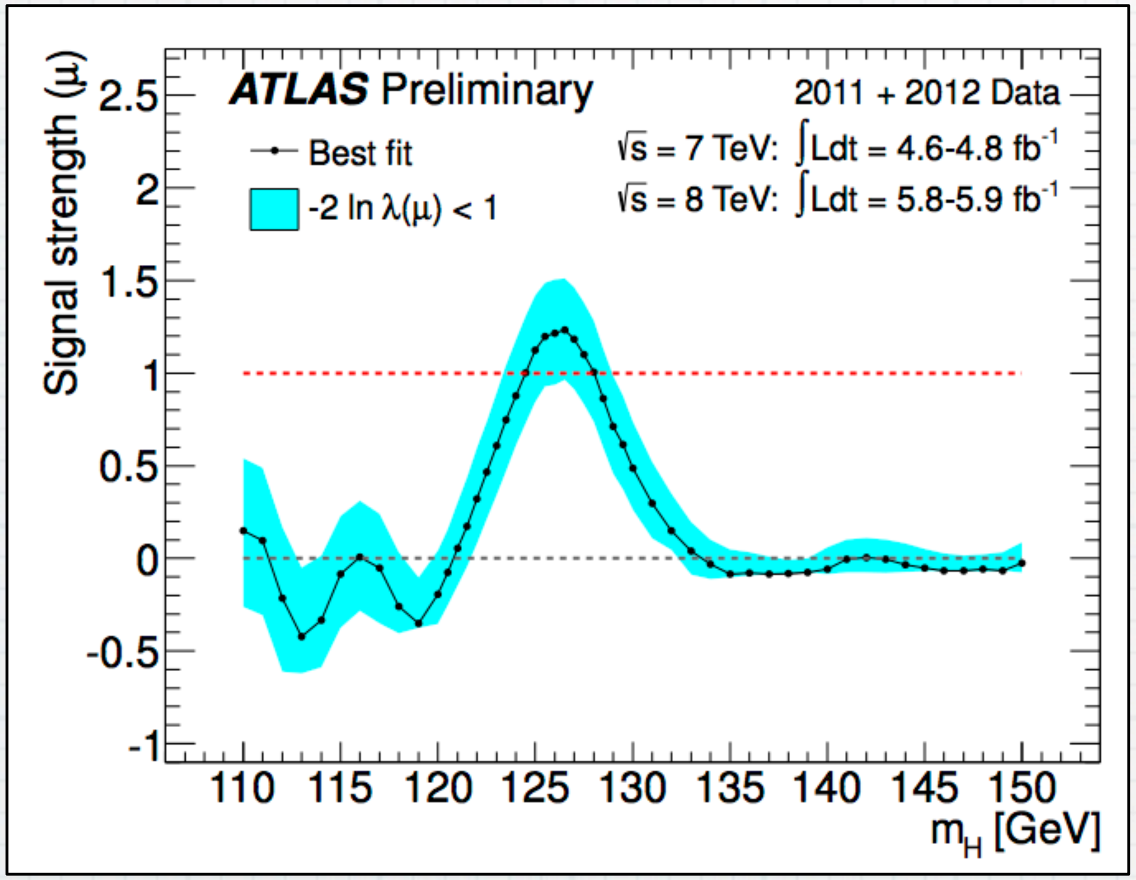


for 126.5 or 125 GeV	ATLAS	CMS
expected from SM	4.6 σ	5.9 σ
observed local p-value	5.0 σ	4.9 σ
global p-value	4.1-4.3 σ	

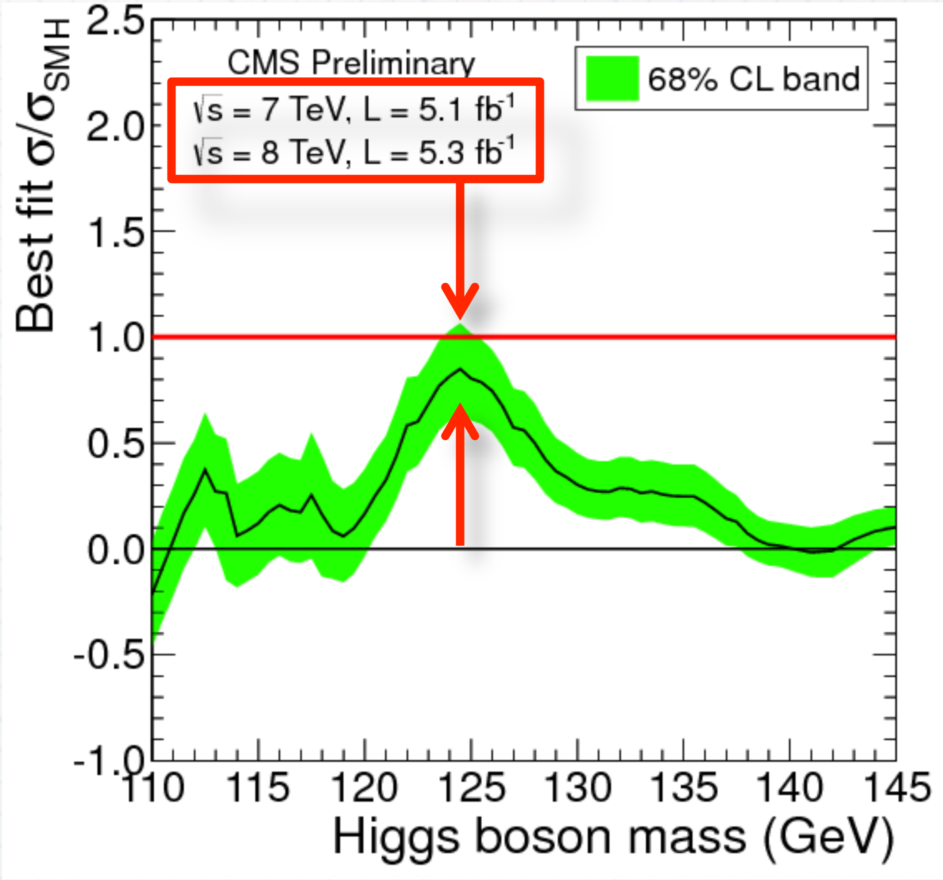
ATLAS global significance for 110-600 or 110-150 GeV

Signal Strength

ATLAS



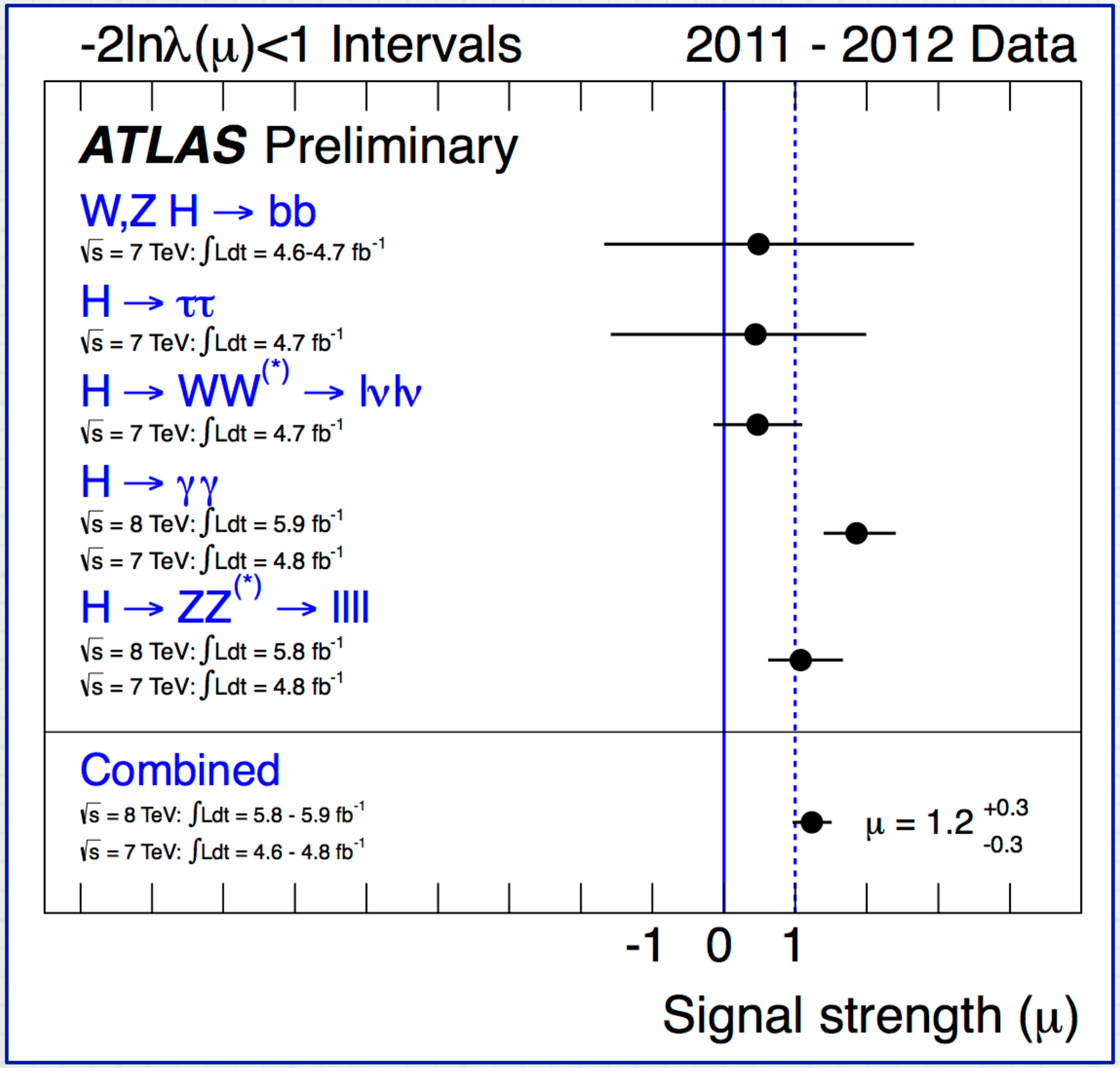
CMS



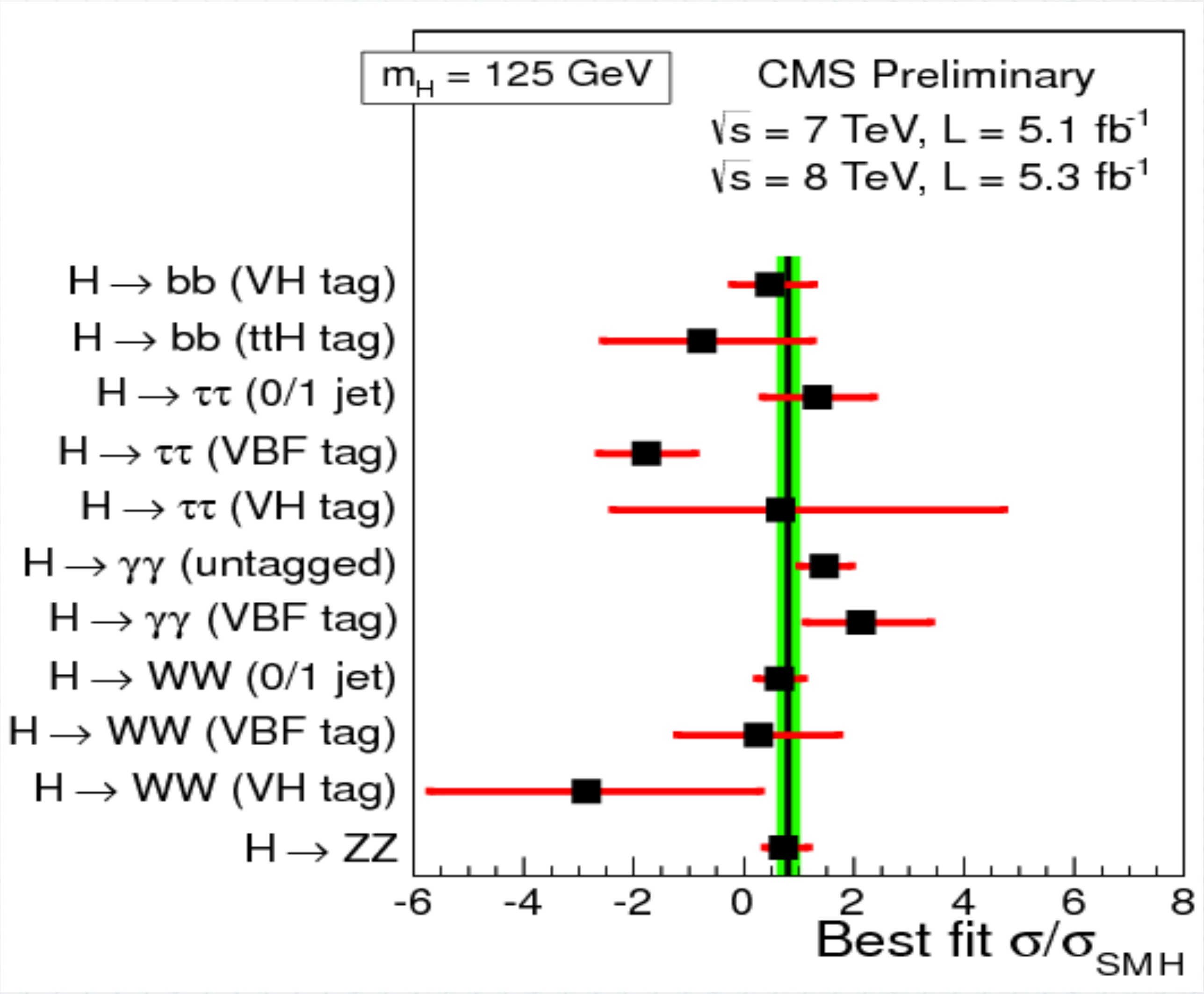
- ATLAS μ = 1.2 ± 0.3 for 126.5 GeV
- CMS μ = 0.8 ± 0.2 for 125 GeV

Channel by Channel

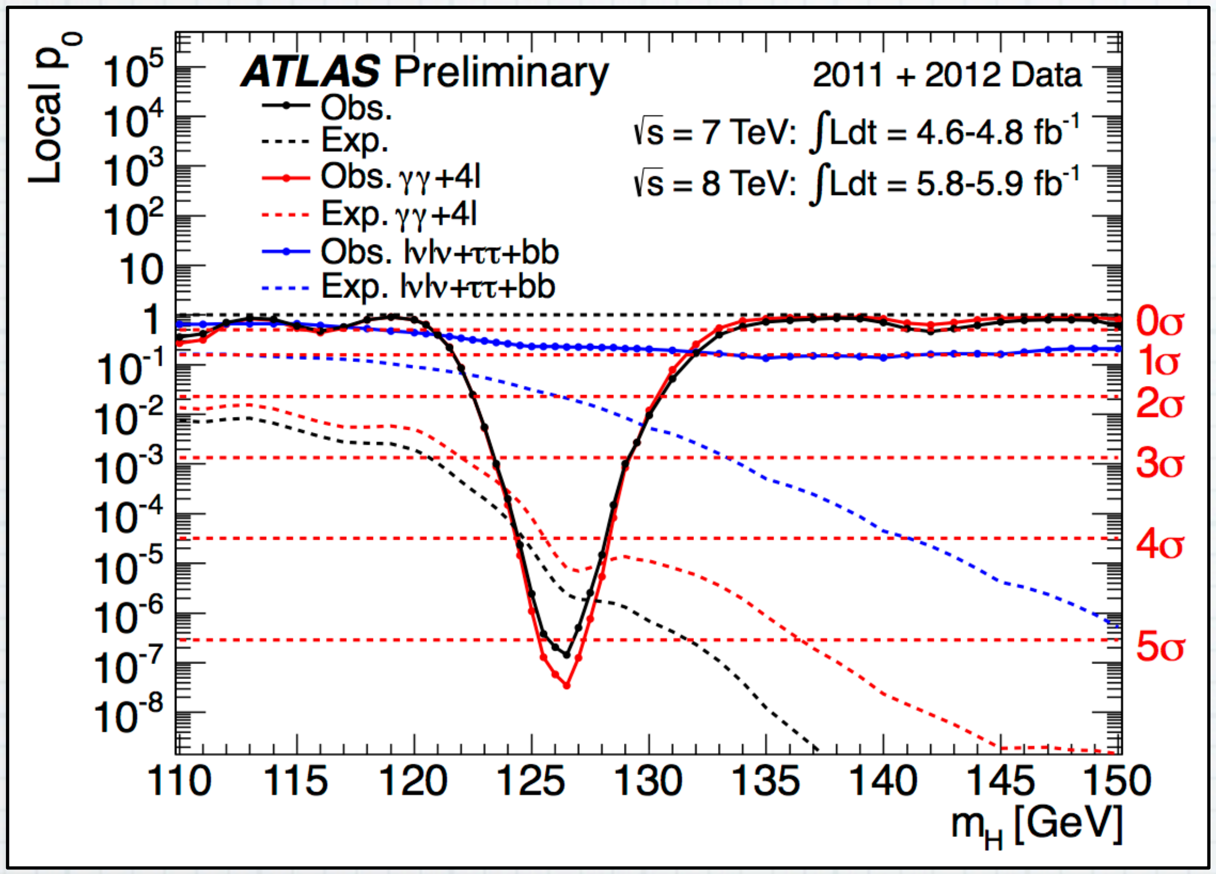
ATLAS

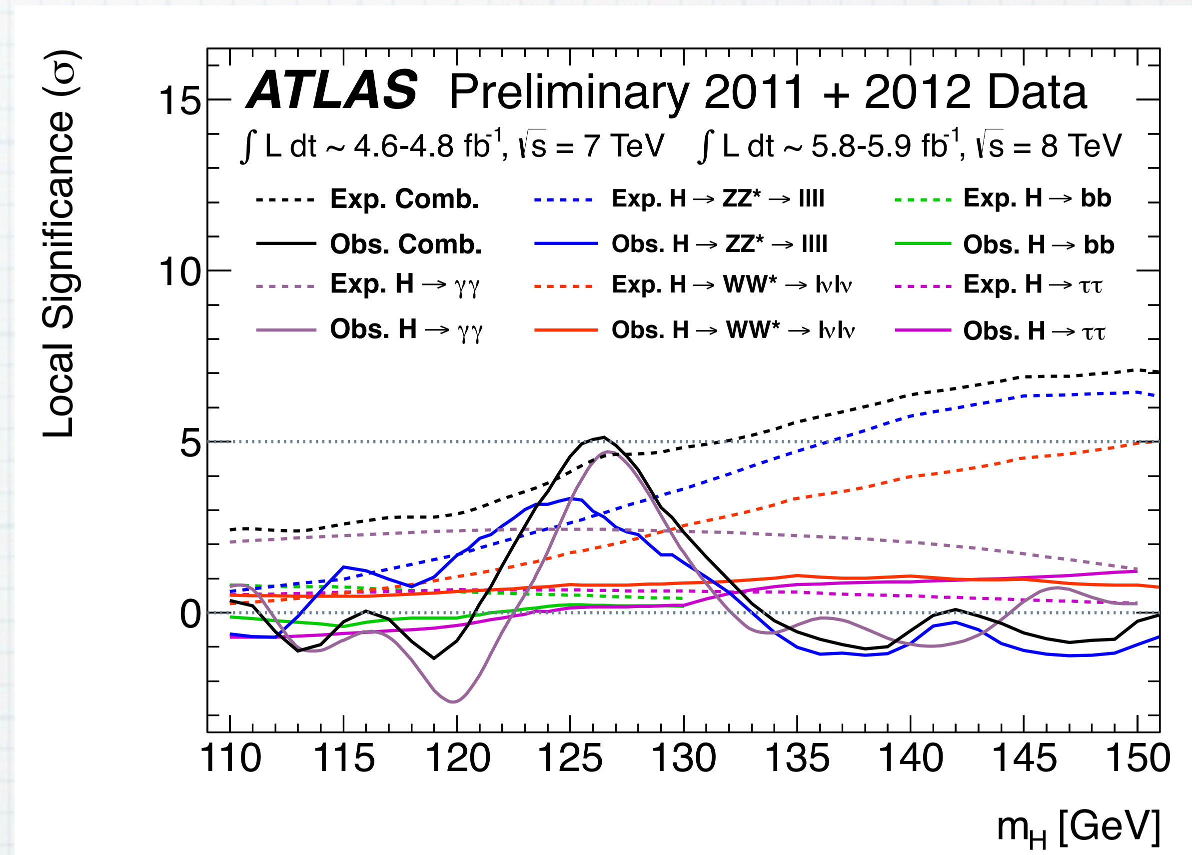


CMS



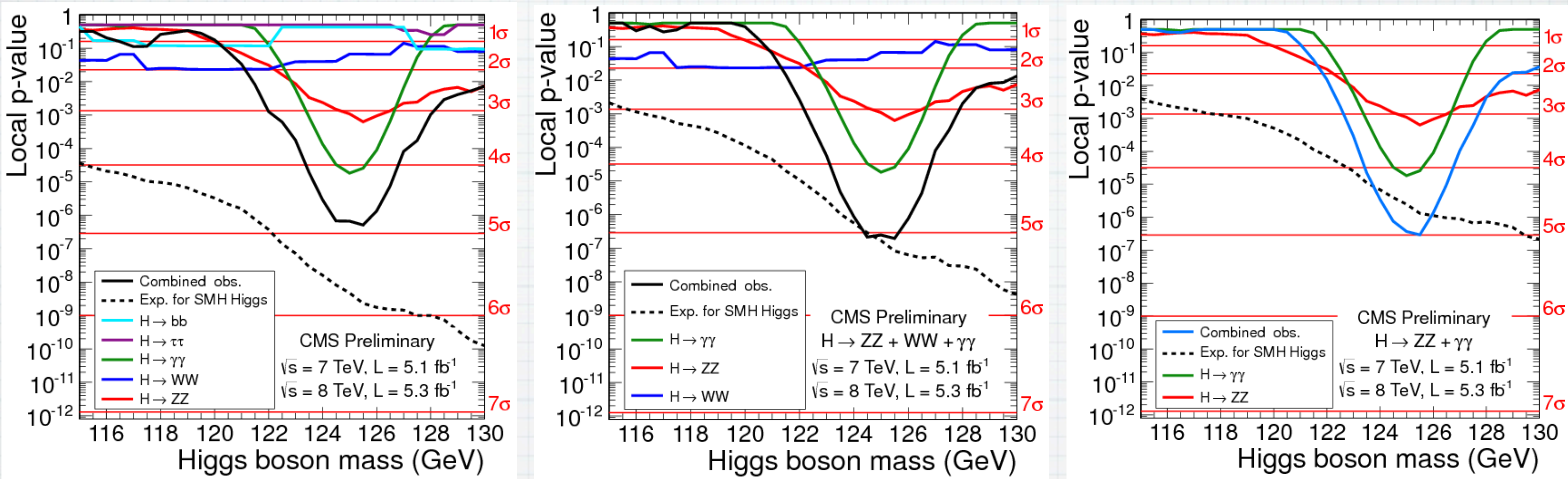
ATLAS Combination





- ❖ $\gamma\gamma$とZZでイベント数多め（ラッキー？）

CMS Combination

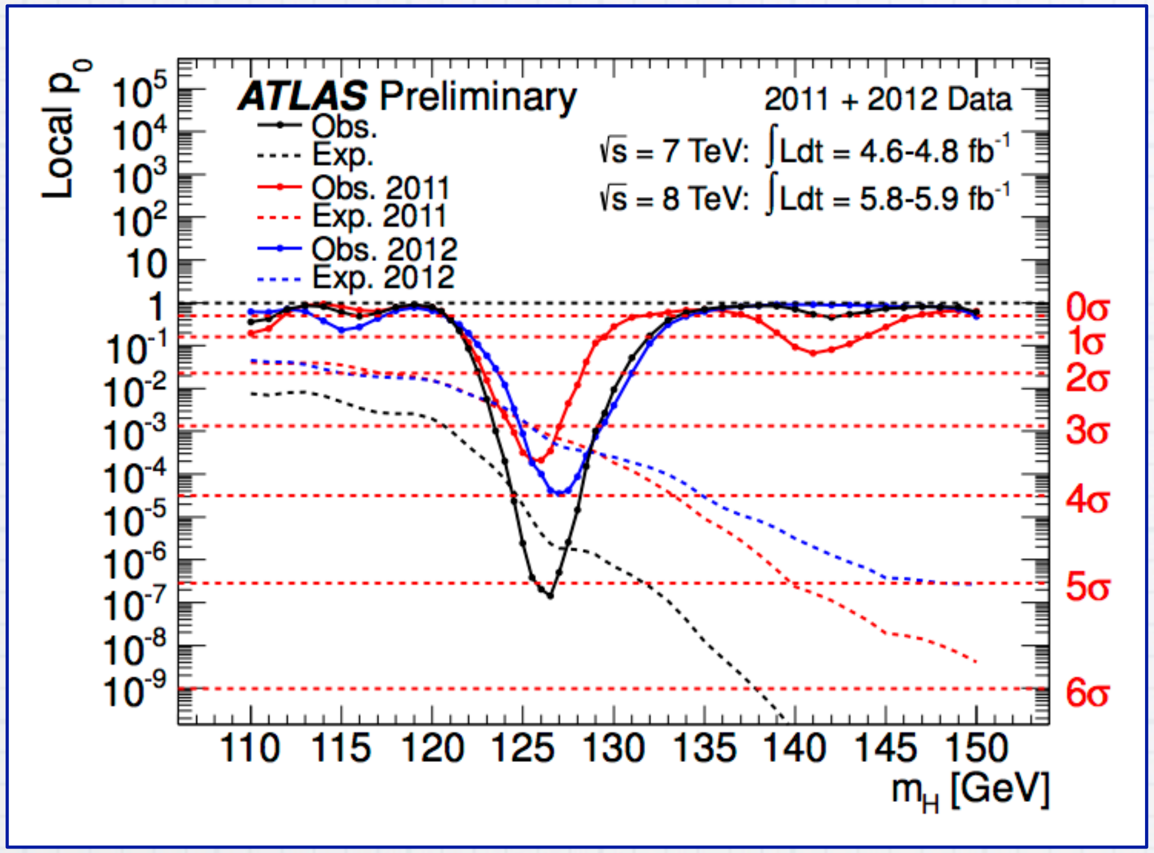


SM expected	5.9 σ	5.2 σ	4.7 σ
observed	4.9 σ	5.1 σ	5.0 σ

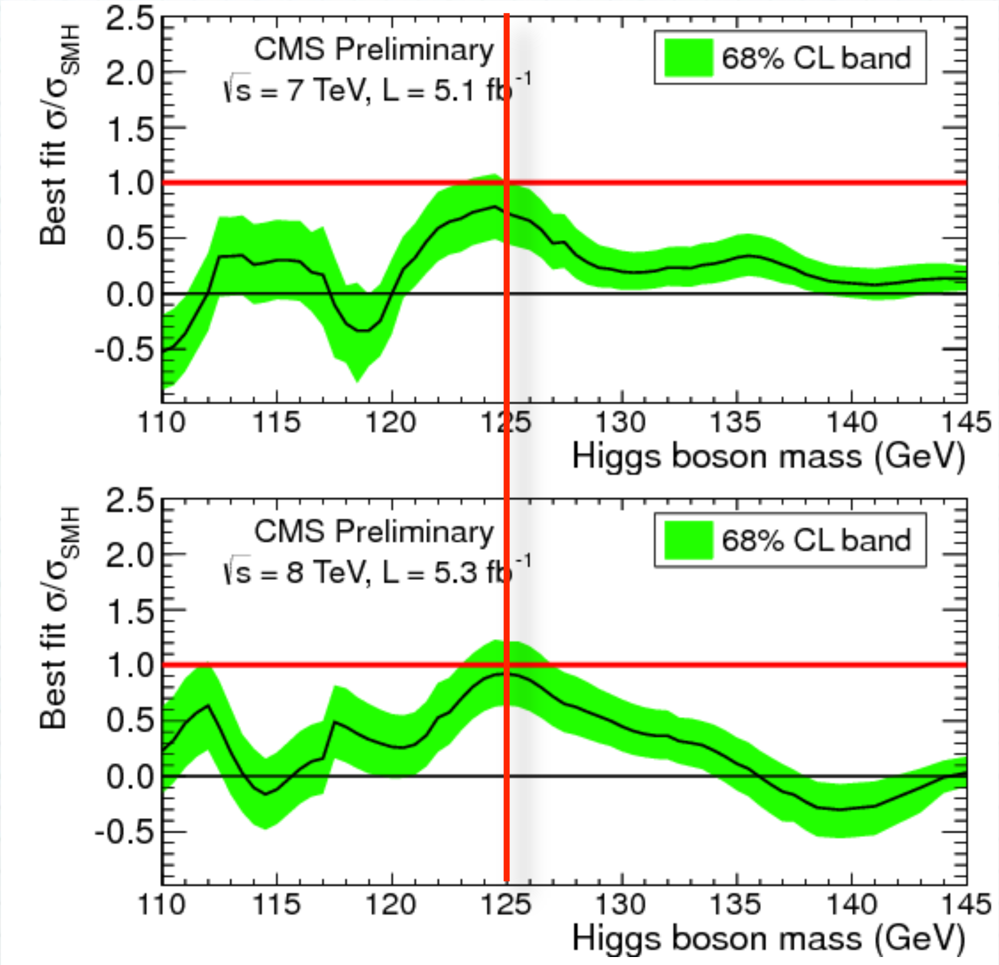
- ATLASに比べるとアンラッキーか

2011 vs 2012

ATLAS



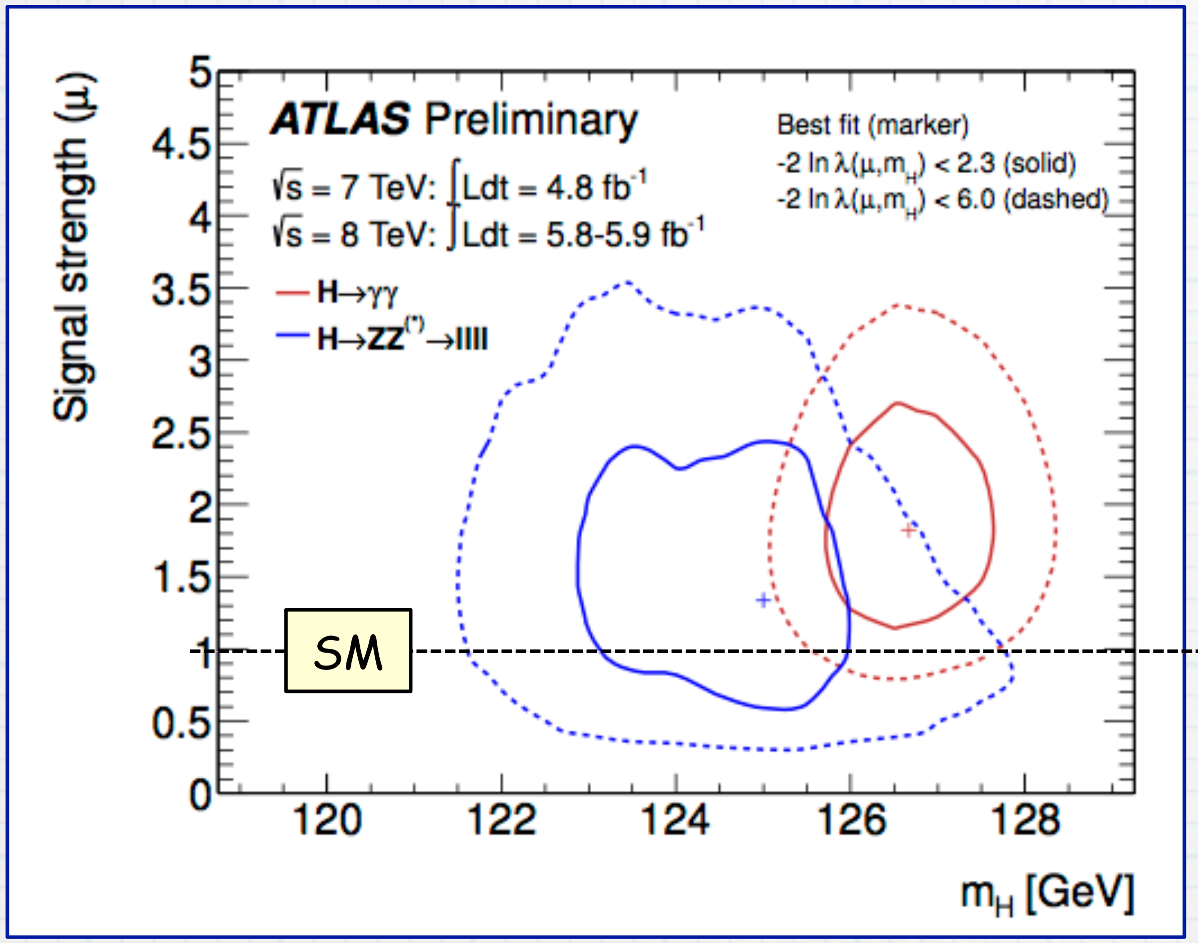
CMS



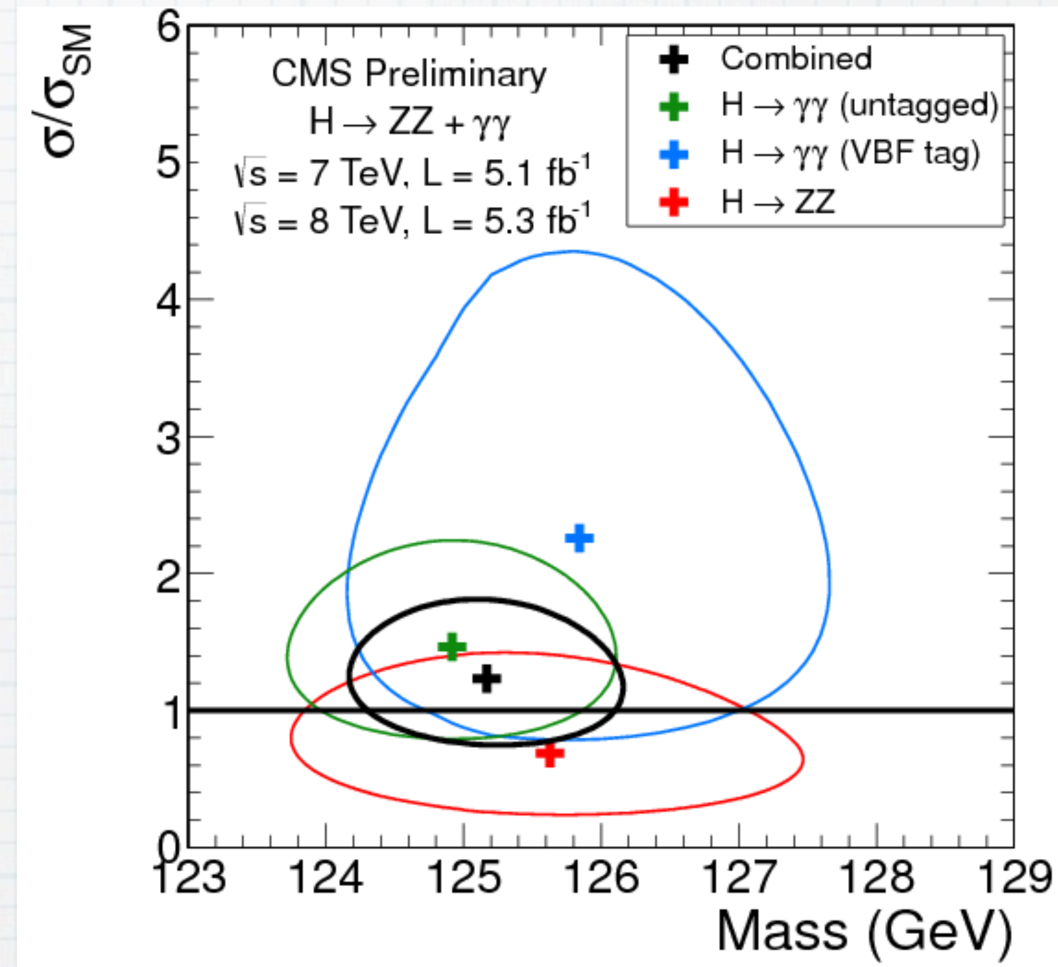
	Max deviation at m_H	Observed (exp.) significance
2011 data	126 GeV	3.5 (3.1) σ
2012 data	127 GeV	4.0 (3.3) σ

質量

ATLAS



CMS

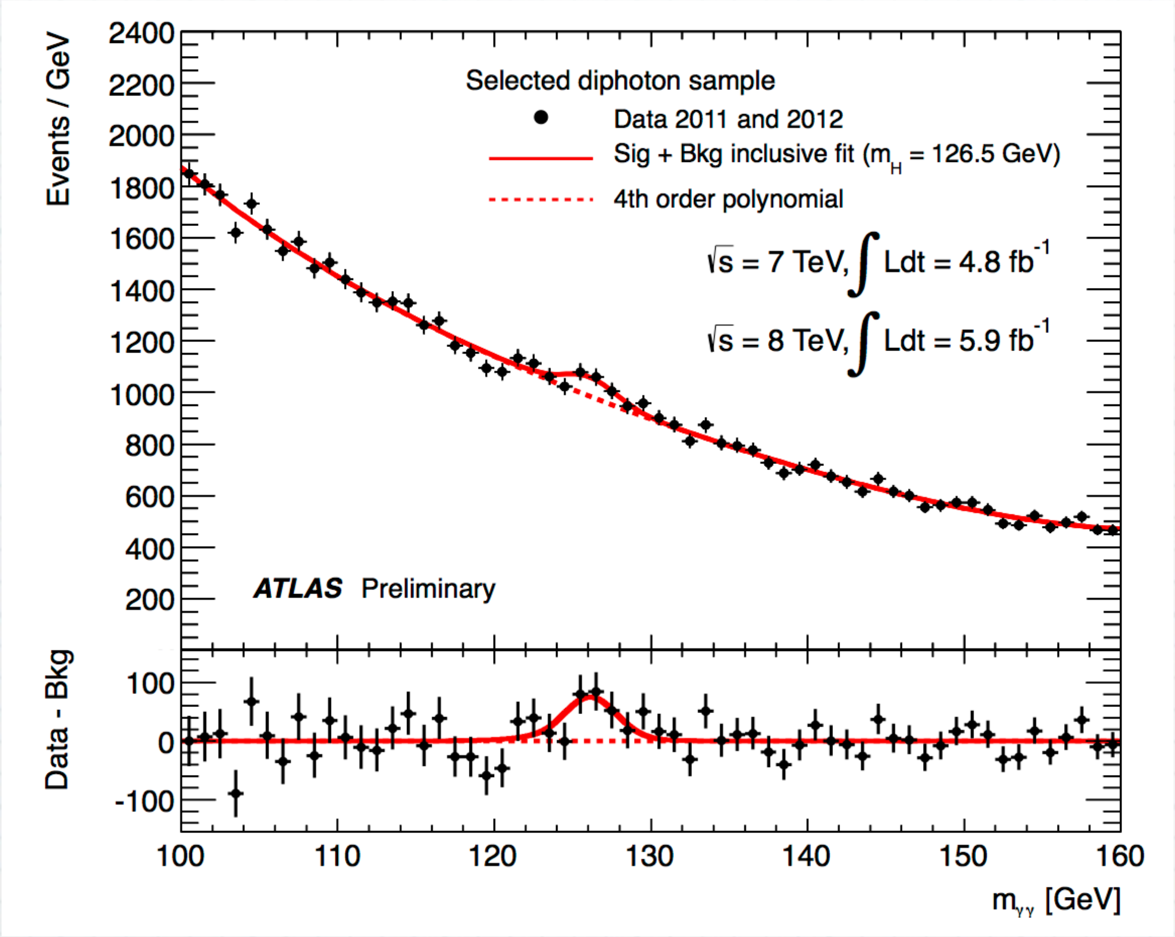


- CMS : M_X = 125.3 ± 0.6 GeV

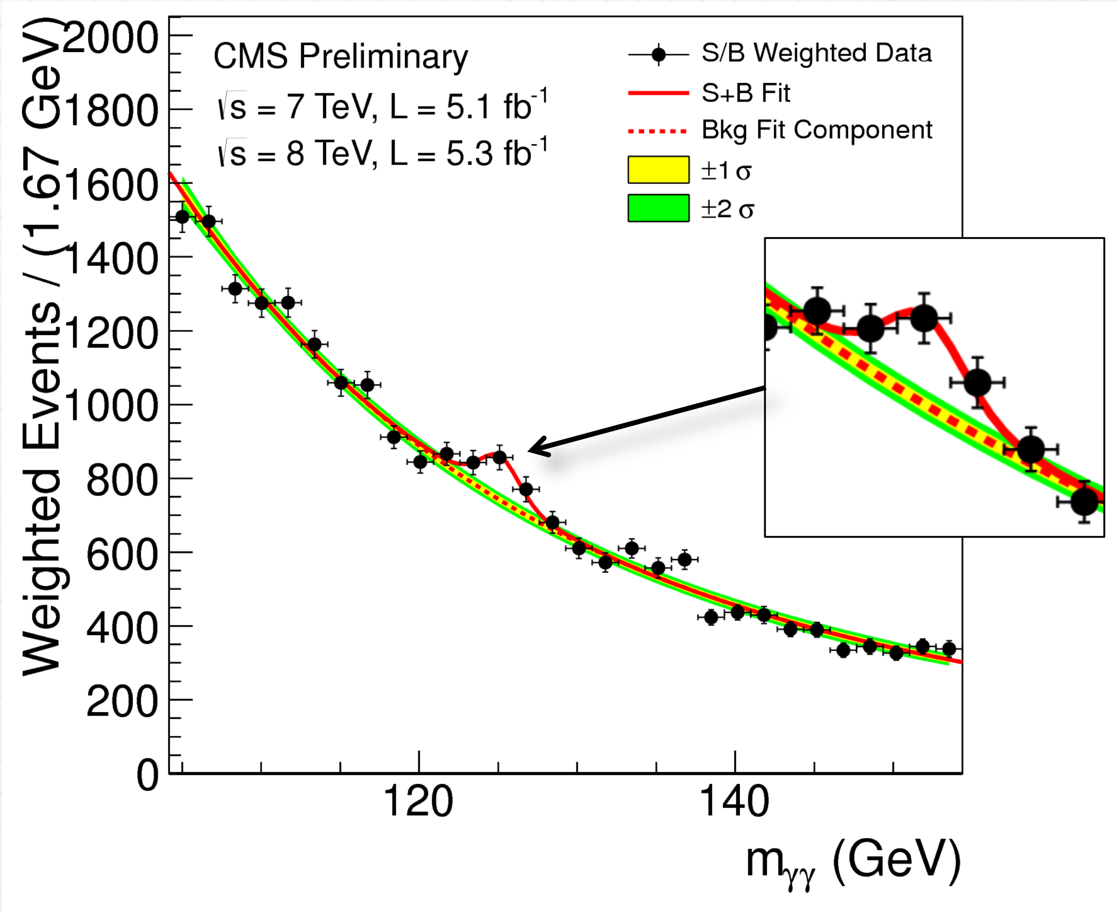
$$H \to \gamma\, \gamma$$

Mγγ

ATLAS

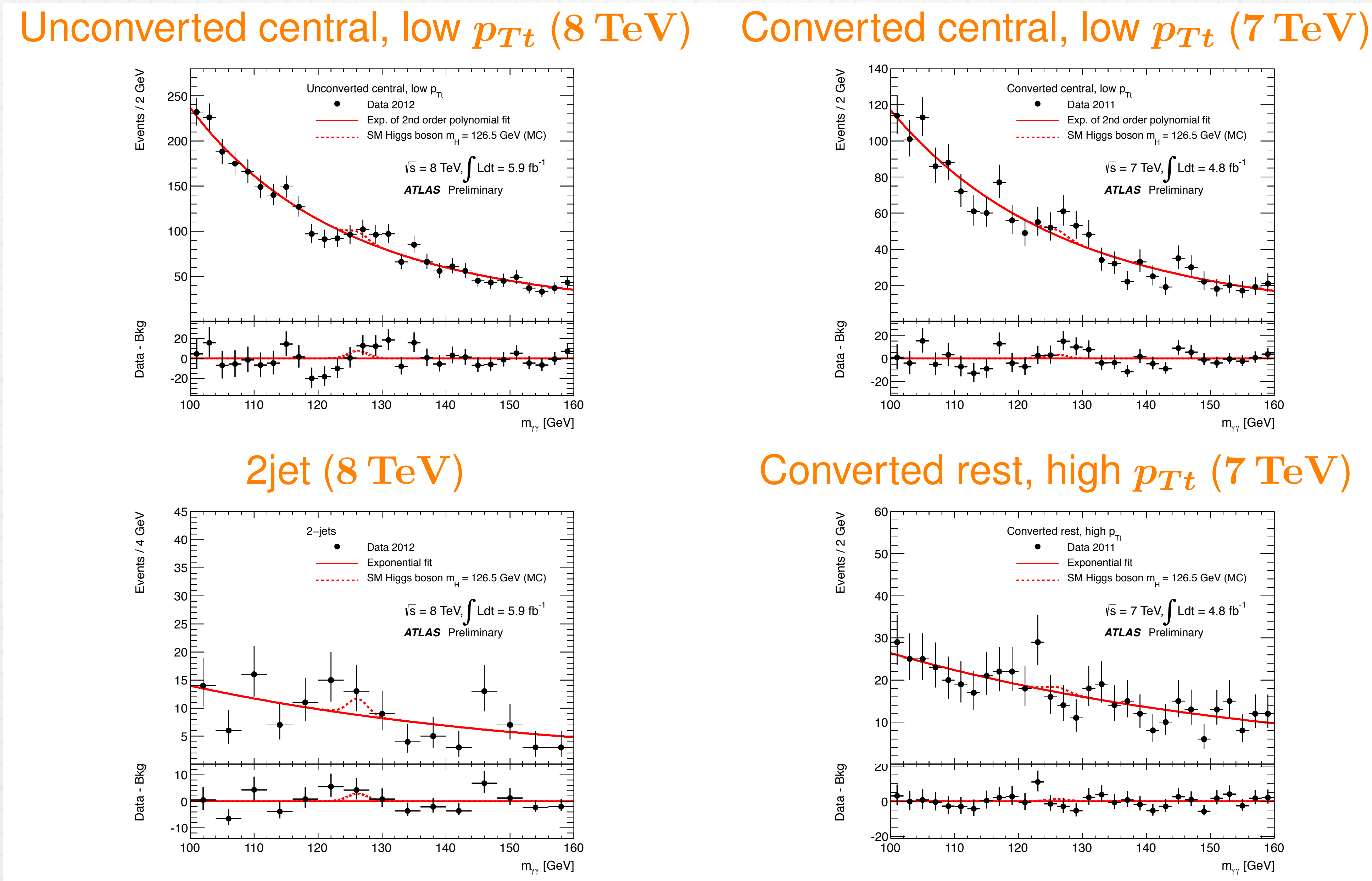


CMS

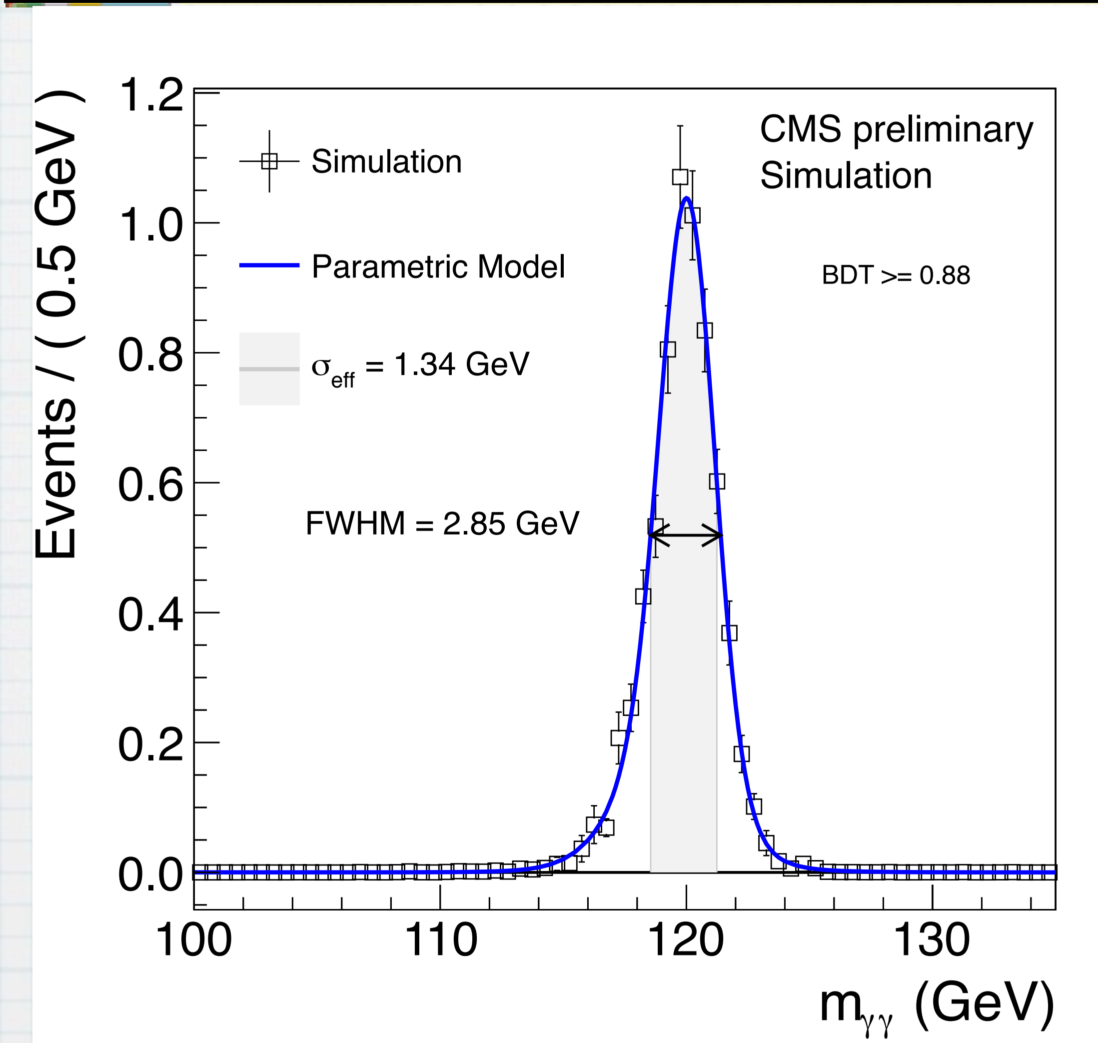


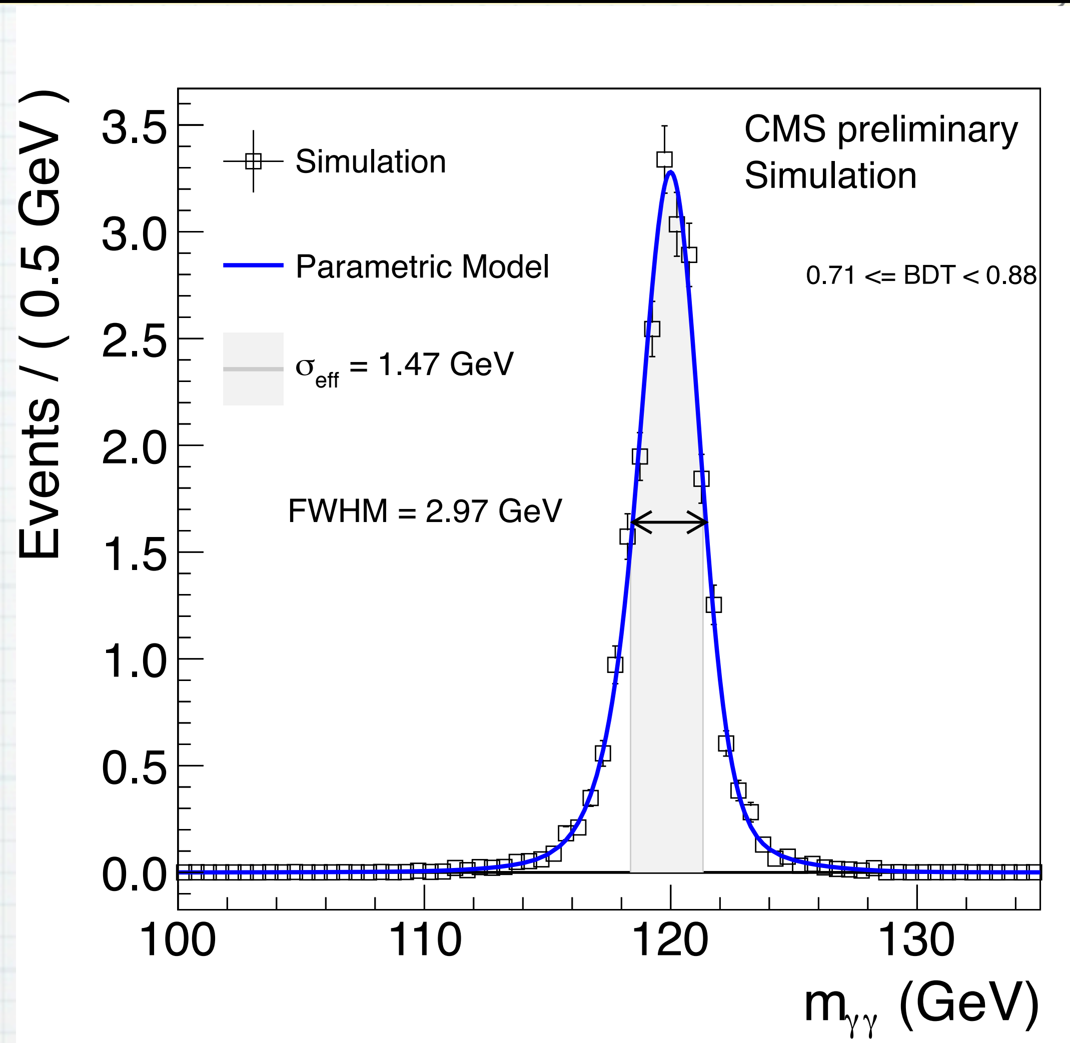
- ATLAS : E_T > 40, 30 GeV
  - Isolation : NN (2011), cut based (2012)
- CMS : E_T > 1/3 Mγγ, 1/4 Mγγ
  - Isolation : Multi-Variate-Analysis

カテゴリー分け



- ATLAS : cut based で10分割
- CMS : MVA based で6分割

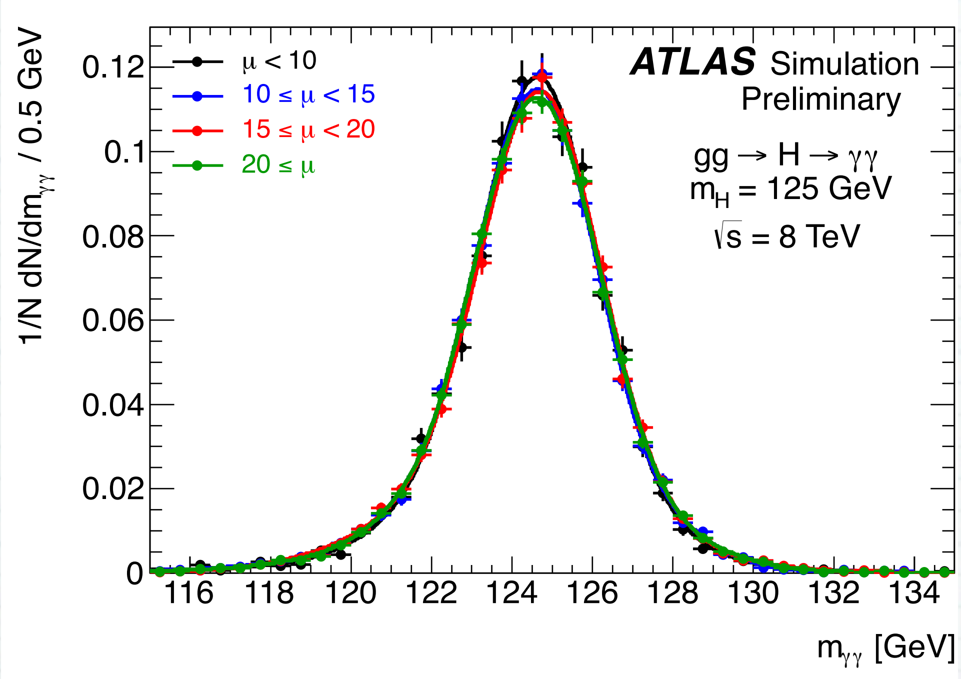




8 TeV dataset	0	1	2	3	Dijet $m_{jj} > 500$	Dijet $m_{jj} > 250$
SM signal expected $\mathrm{m_H} = \mathbf{120}$ GeV	2.9	13.9	20.7	28.7	1.6	2.0
Data (events/GeV)	4.3	44.6	112.2	303.0	1.2	3.4
σ_{eff} (GeV)	1.34	1.44	1.82	2.96	1.87	2.13
FWHM/2.35 (GeV)	1.28	1.28	1.45	2.43	1.57	1.77

Using prompt reconstruction, with quasi-online calibration constants for 8 TeV data

ATLAS Mass Resolution

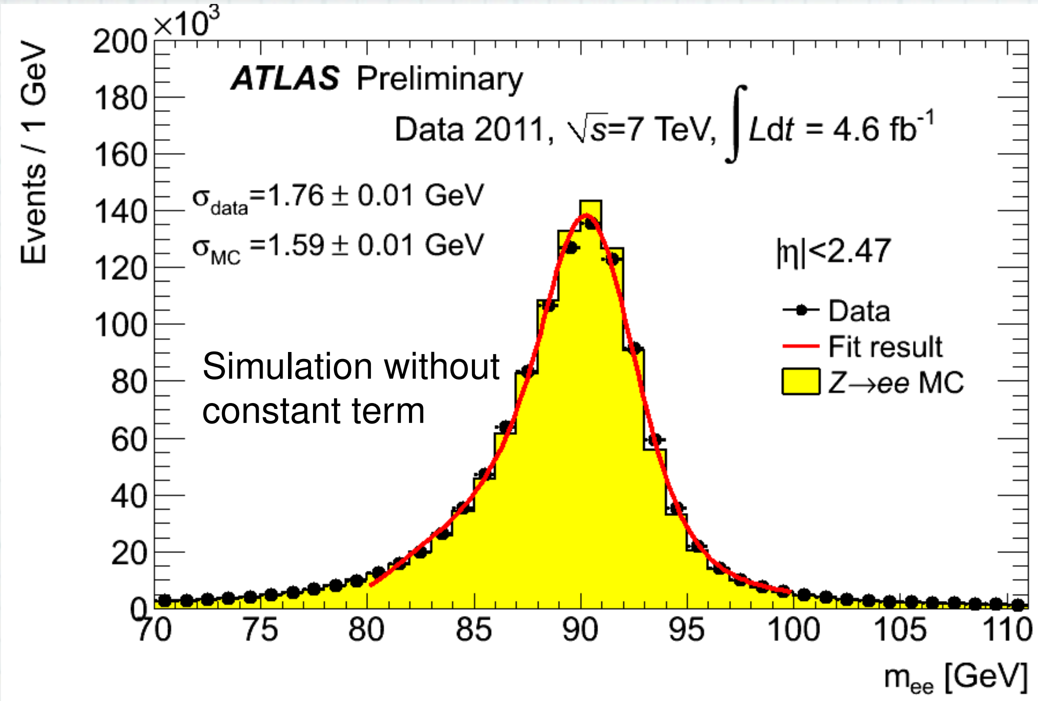


- σ ~ 1.6 GeV for inclusive sample

Category	σ_{CB} [GeV]	FWHM [GeV]	Observed [N_{evt}]	S [N_{evt}]	B [N_{evt}]
Inclusive	1.63	3.87	3693	100.4	3635
Unconverted central, low p_{Tt}	1.45	3.42	235	13.0	215
Unconverted central, high p_{Tt}	1.37	3.23	15	2.3	14
Unconverted rest, low p_{Tt}	1.57	3.72	1131	28.3	1133
Unconverted rest, high p_{Tt}	1.51	3.55	75	4.8	68
Converted central, low p_{Tt}	1.67	3.94	208	8.2	193
Converted central, high p_{Tt}	1.50	3.54	13	1.5	10
Converted rest, low p_{Tt}	1.93	4.54	1350	24.6	1346
Converted rest, high p_{Tt}	1.68	3.96	69	4.1	72
Converted transition	2.65	6.24	880	11.7	845
2-jets	1.57	3.70	18	2.6	12

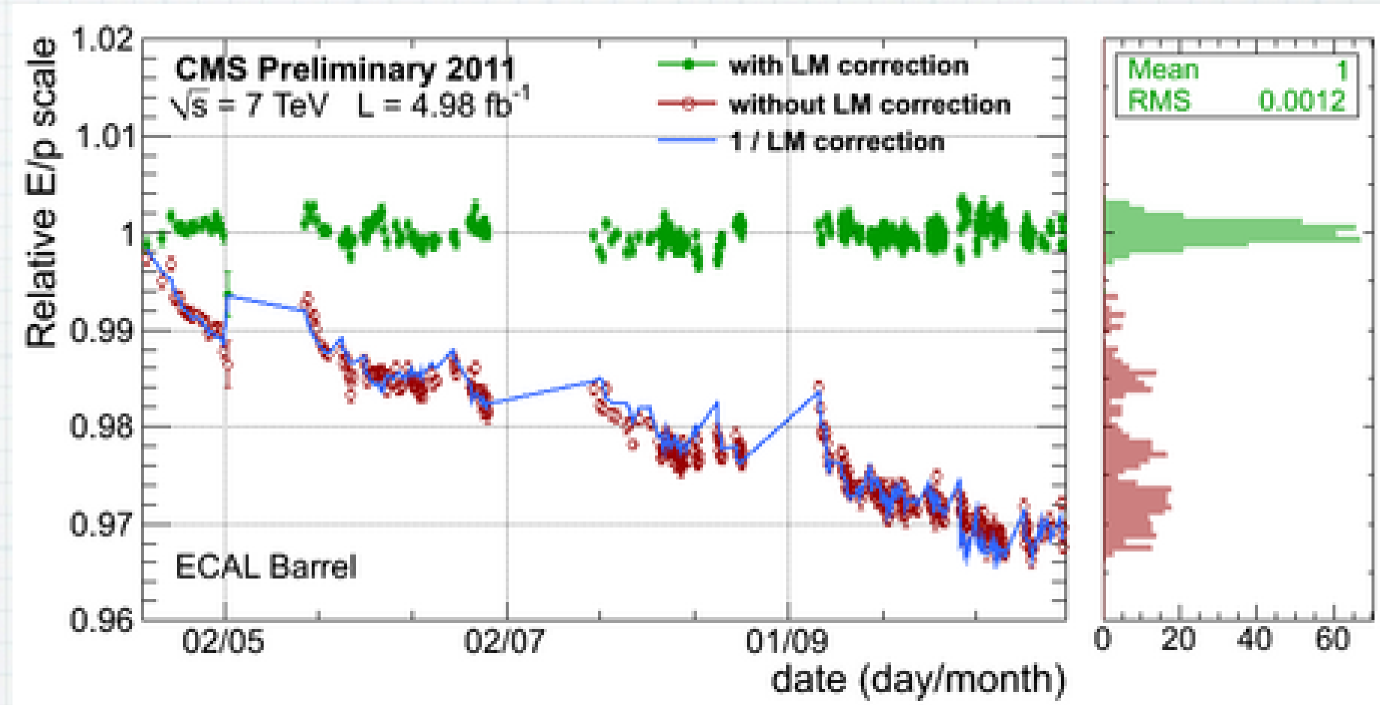
Energy Calibration

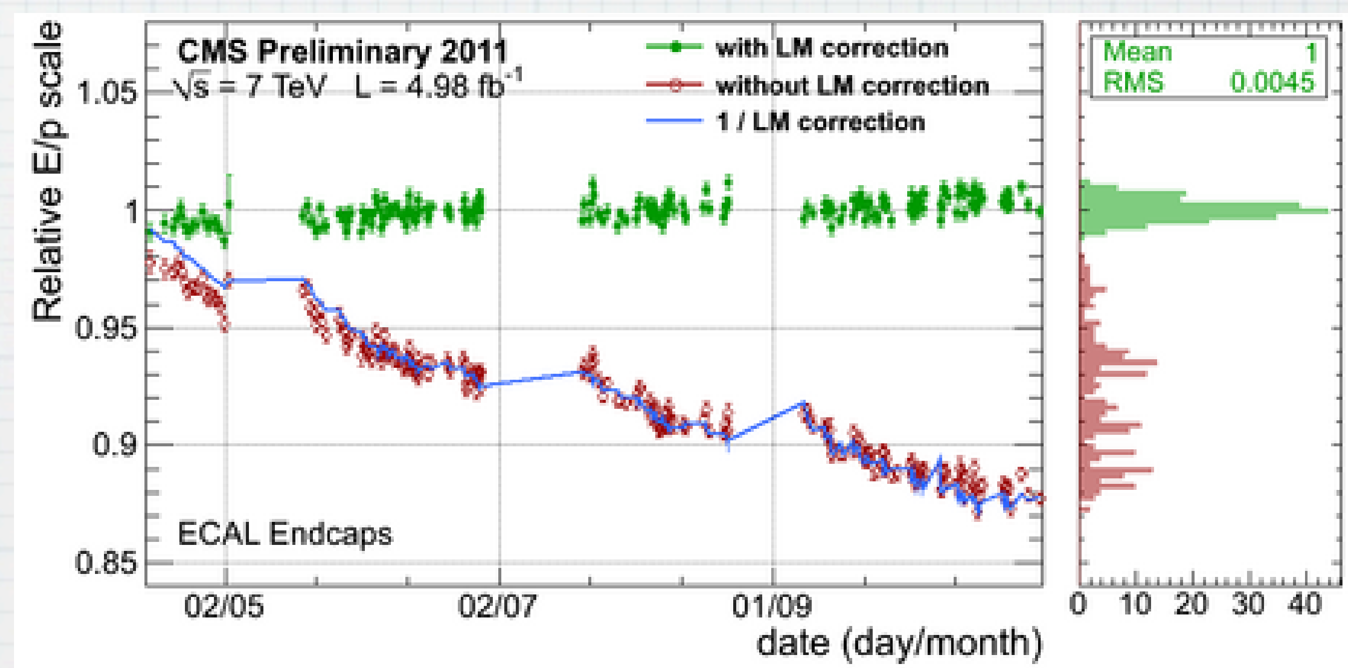
ATLAS



scale known to 0.3%

CMS

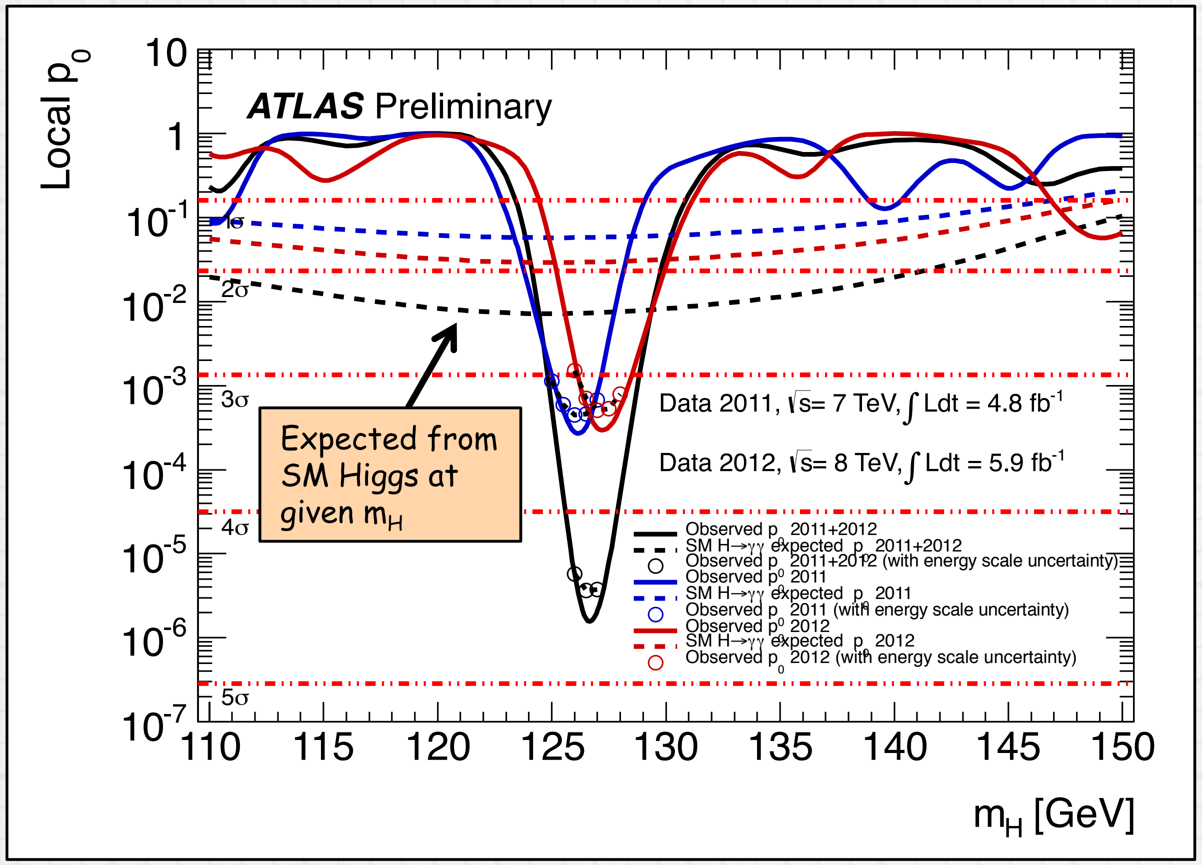




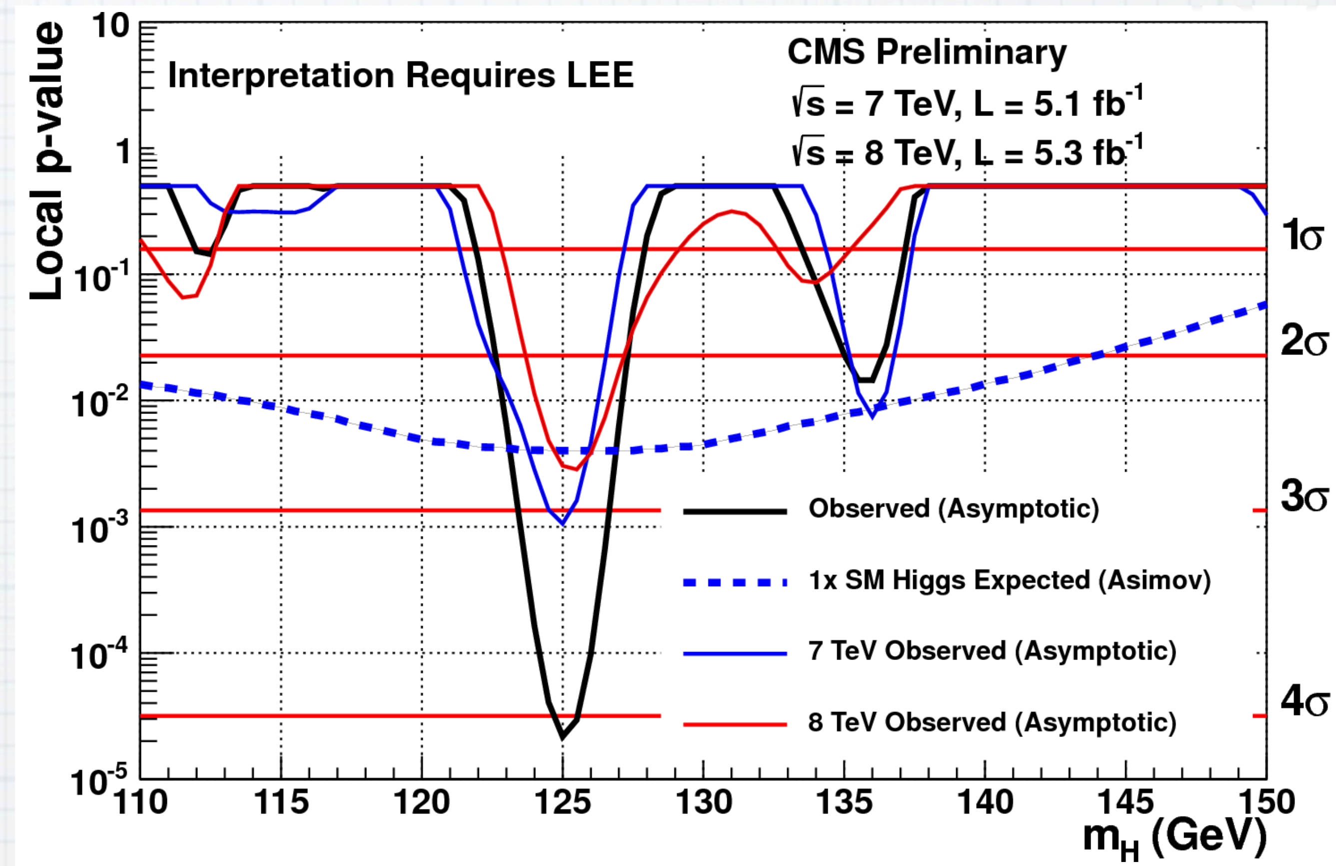
- ❖ W→eν, Z→ee, (J/ψ→ee) for calibration source

H→$\gamma\gamma$ p-value

ATLAS



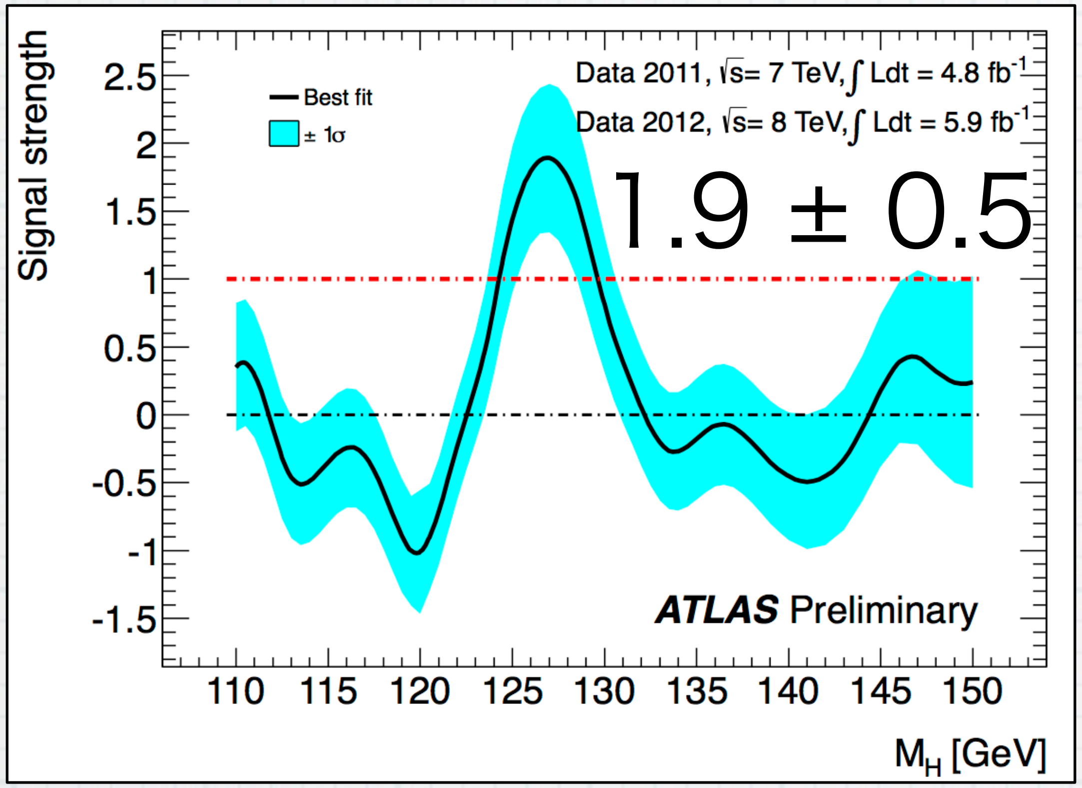
CMS



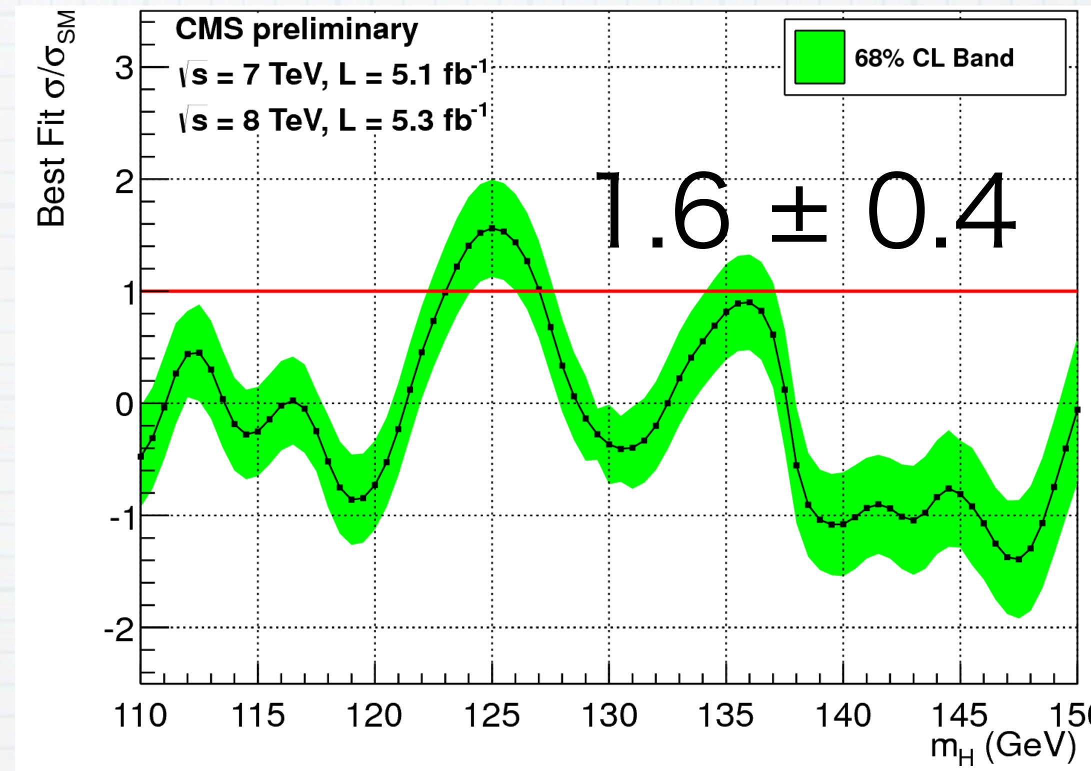
for 126.5 or 125 GeV	ATLAS	CMS
expected from SM	2.4σ	
observed local p-value	4.5σ	4.1σ
global p-value (110-150GeV)	3.6σ	3.2σ

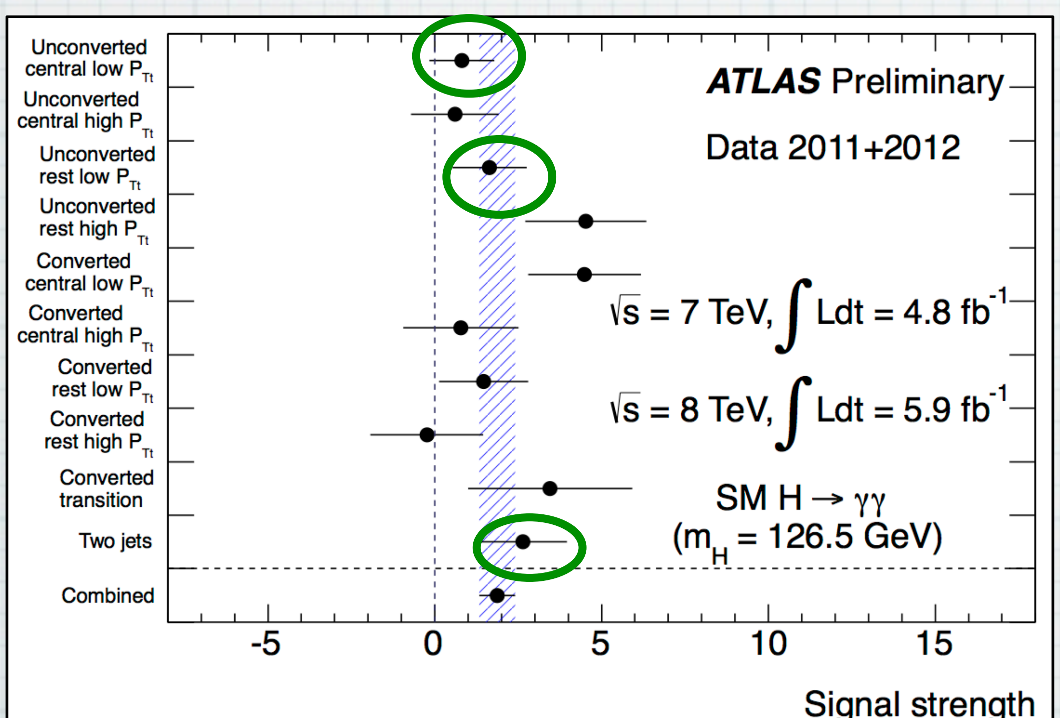
H→γγ Signal Strength

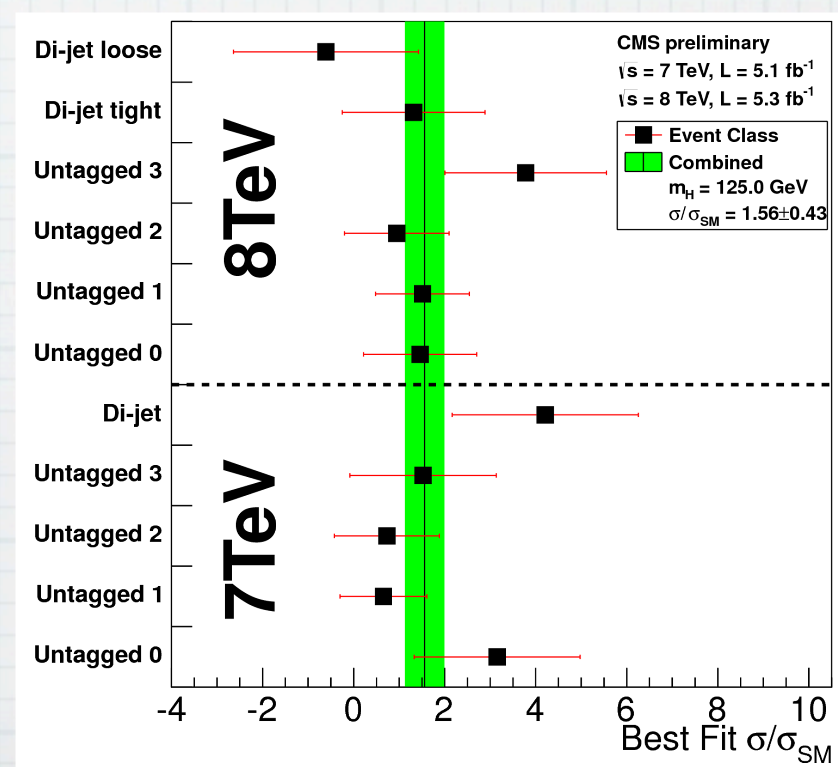
ATLAS



CMS







$H \to ZZ$

Event Selection for H→ZZ

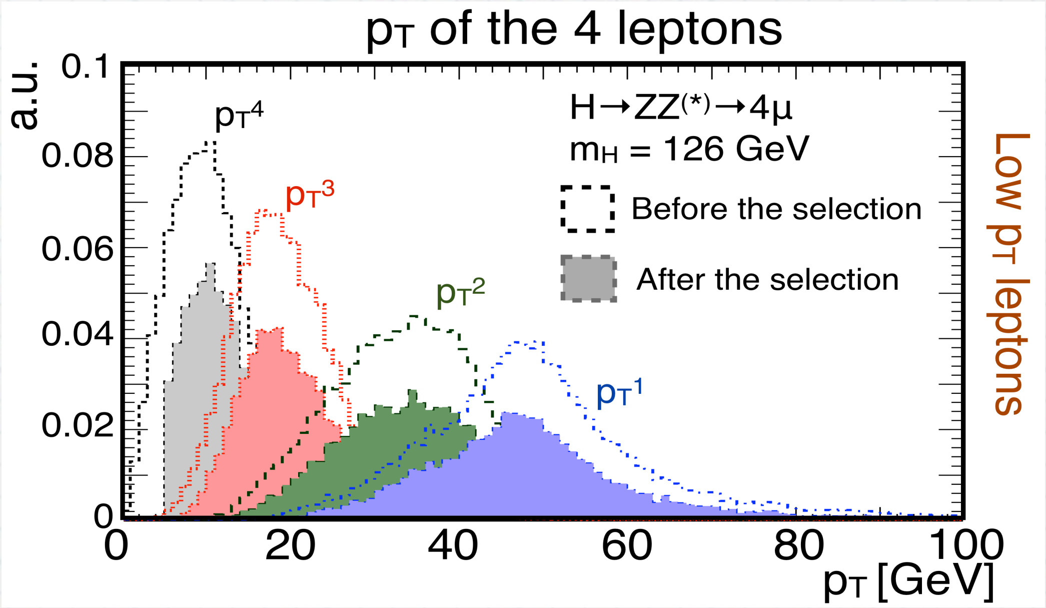
❖ ATLAS

- ❑ Tiny rate, BUT:
  - -- mass can be fully reconstructed → events should cluster in a (narrow) peak
  - -- pure: S/B ~ 1
- ❑ 4 leptons: $p_T^{1,2,3,4}$ > 20,15,10,7-6 (e-μ) GeV; 50 < m_{12} < 106 GeV; m_{34} > 17.5-50 GeV (vs m_H)
- ❑ Main backgrounds:
  - -- $ZZ^{(*)}$: irreducible
  - -- low-mass region $m_H < 2m_Z$: Zbb, Z+jets, tt with two leptons from b-jets or q-jets → l

→ Suppressed with isolation and impact parameter cuts on two softest leptons

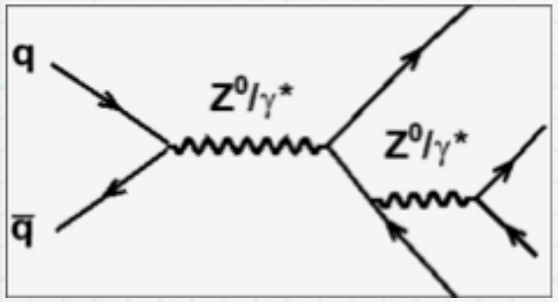
❖ CMS

- p_T > 20, 10, 5-7 (GeV)
- 40<M_{12}<120 GeV
- 4<M_{34}<120 GeV

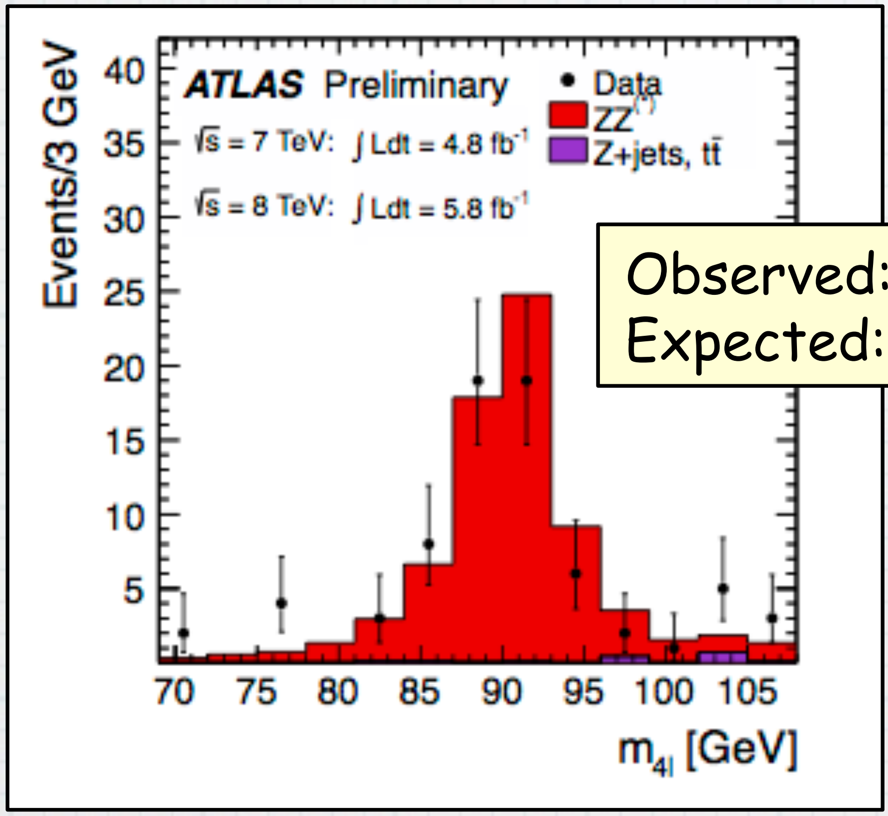


BG Studies by ATLAS

Peak at m(4l) ~ 90 GeV from single-resonant Z→ 4l production

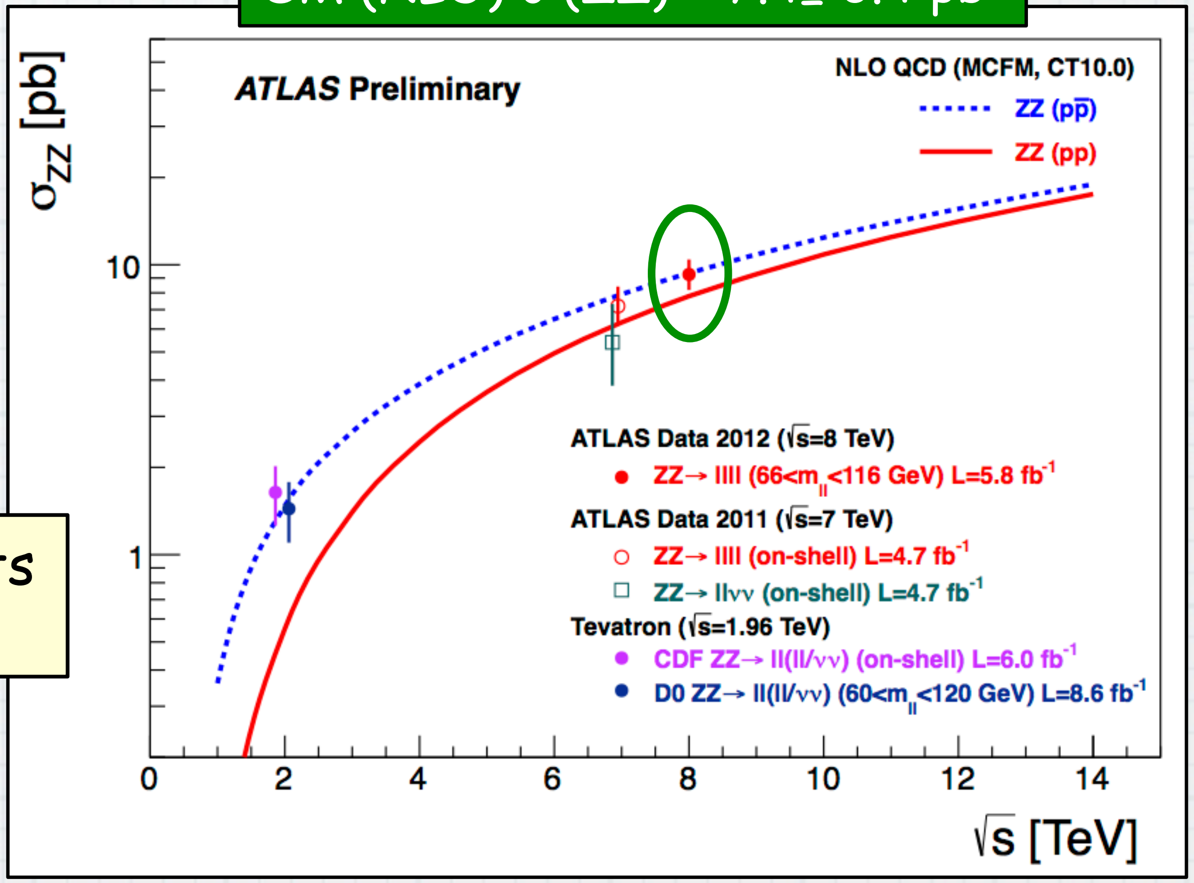


Enhanced by relaxing cuts on m_{12}, m_{34} and $p_T(\mu_4)$



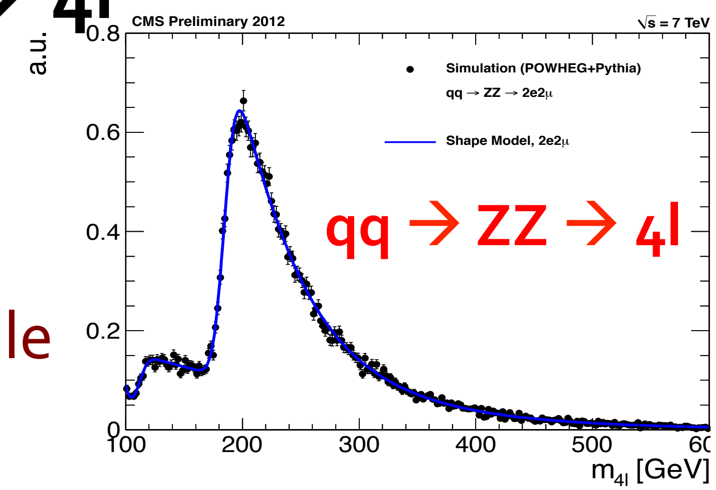
Observed: 57 events
Expected: 65 ± 5

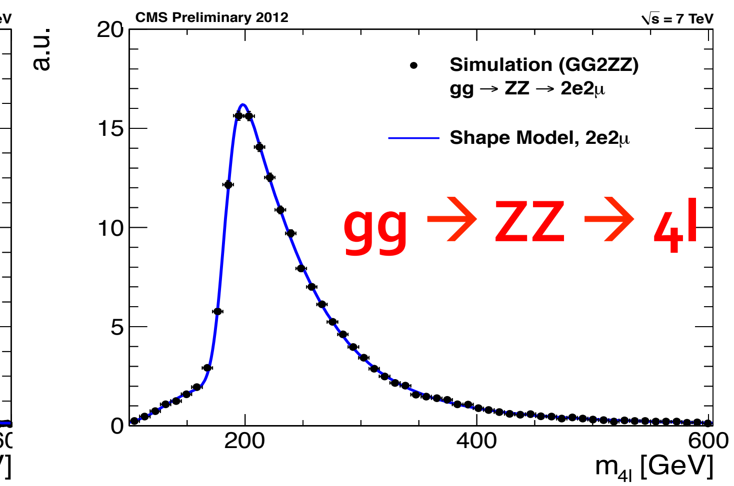
Measured σ (ZZ) = 9.3 ± 1.2 pb
SM (NLO) σ (ZZ) = 7.4± 0.4 pb



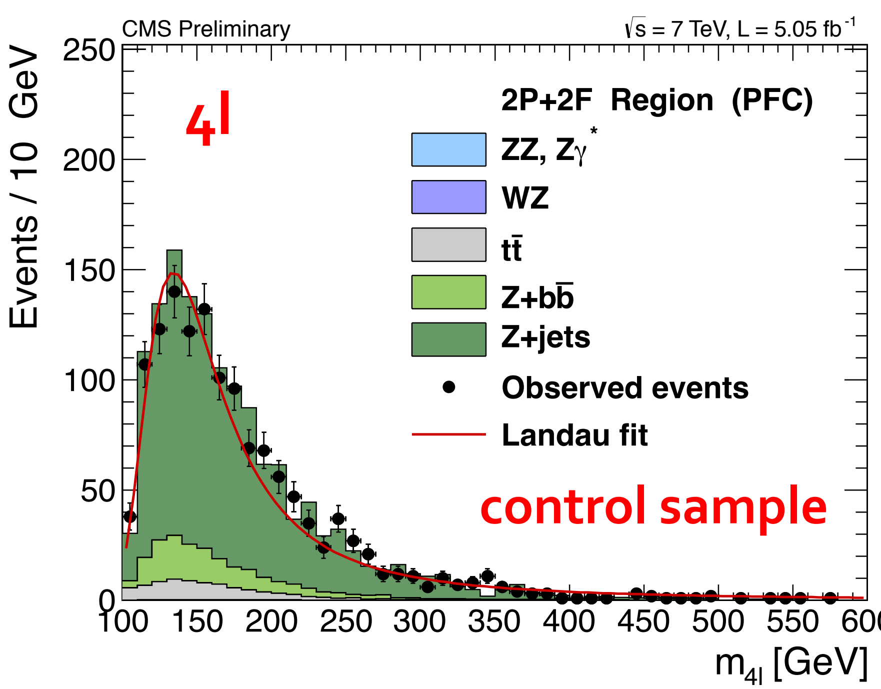
Background models

- **Irreducible background ZZ → 4l**
  - Estimated **using simulation**
  - Phenomenological shape models
  - Corrected for data/simulation scale

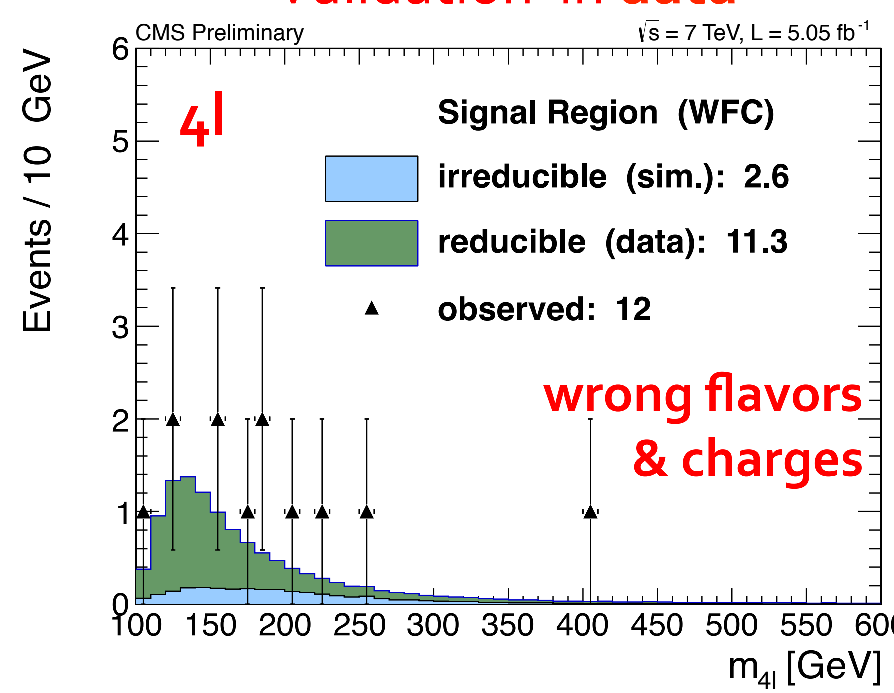




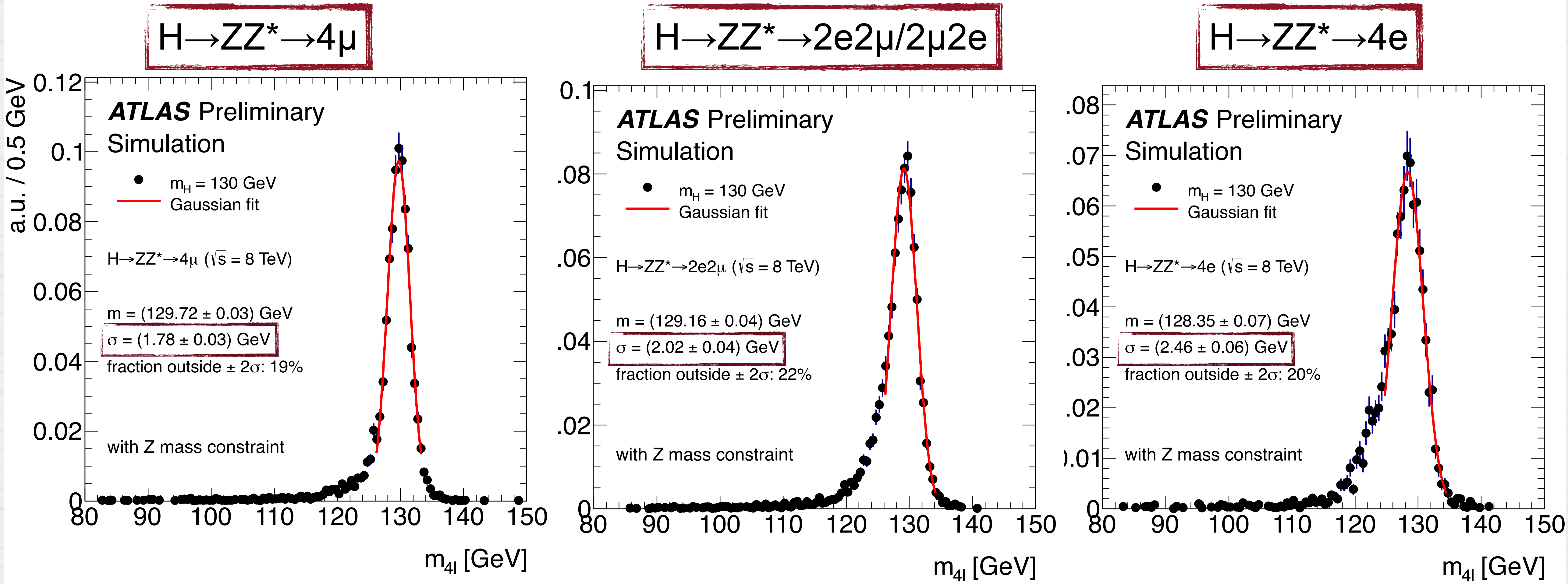
- **Reducible backgrounds estimated from data**
  - Extrapolation from control samples enriched with misidentified leptons
  - Total uncertainty ~50%



Validation in **data**



Mass resolution



Typical search for narrow peak on top of smooth background

→ Resolution crucial for sensitivity!

→ Final states separated in 4μ, 2μ2e, 2e2μ, 4e

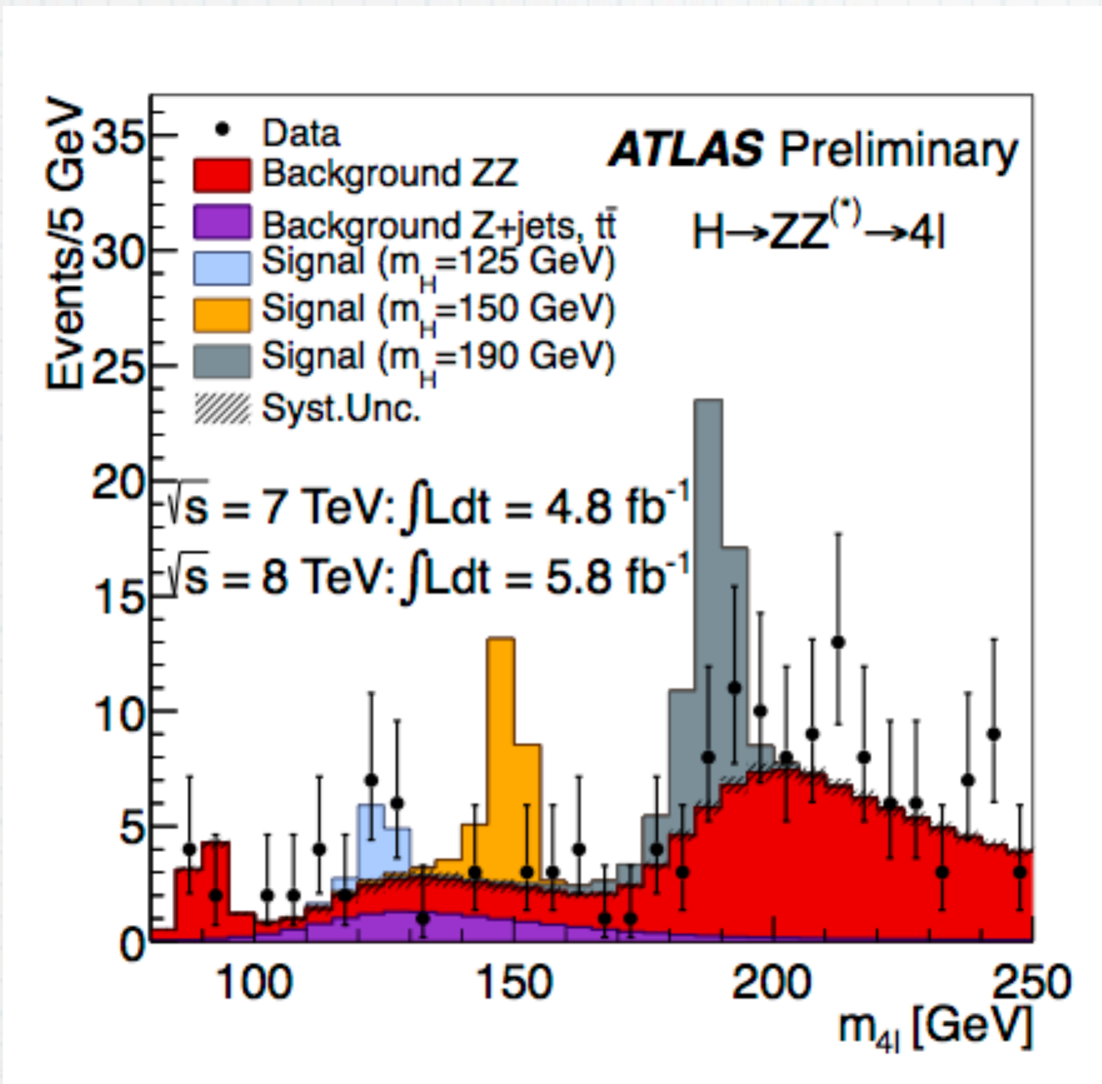
ATLAS detector provides excellent resolution!

→ Relative resolution of 1.6 - 2.1% for m_H=130 GeV

Further improved by using m_Z constrained fit

→ Relative resolution of 1.3 - 1.9% for m_H=130 GeV

ATLAS H→ZZ

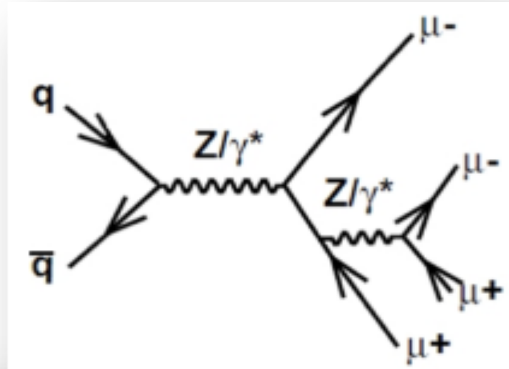


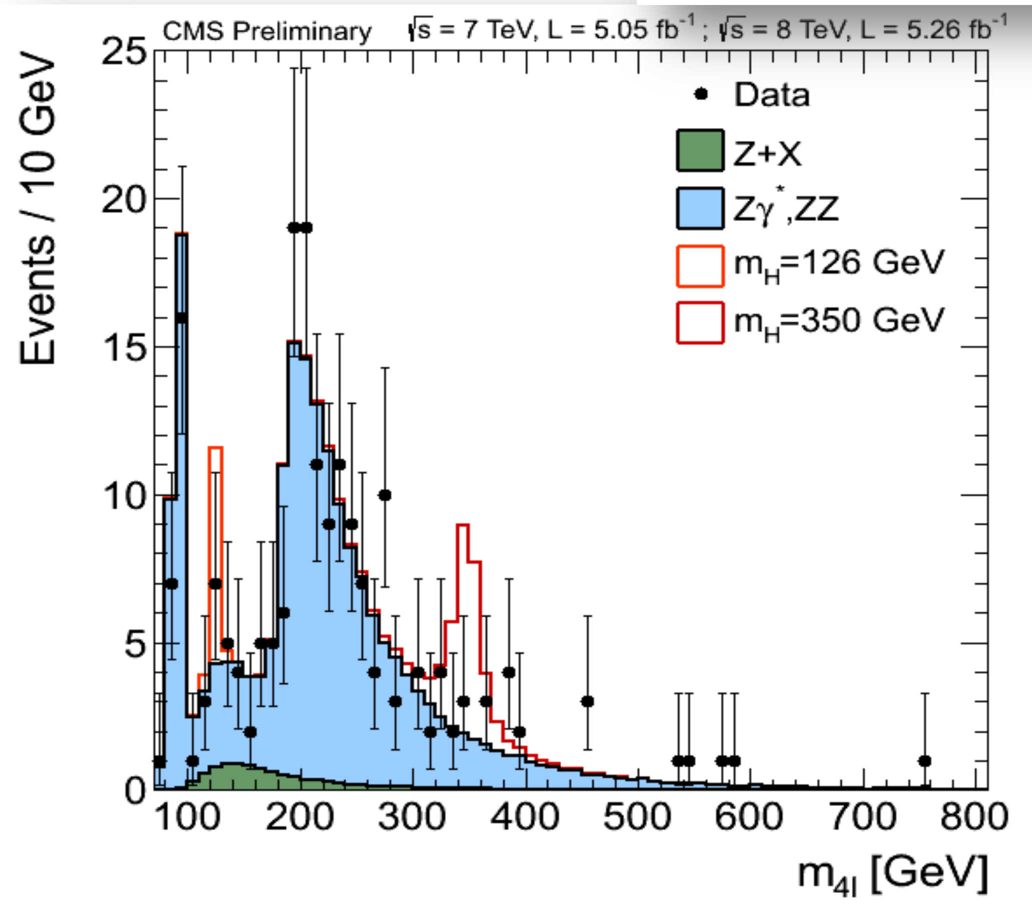
In the region 125 ± 5 GeV

Dataset	2011	2012	2011+2012
Expected B only	2±0.3	3±0.4	5.1±0.8
Expected S m_H=125 GeV	2±0.3	3±0.5	5.3±0.8
Observed in the data	4	9	13

2011+ 2012	4μ	2e2μ	4e
Data	6	5	2
Expected S/B	1.6	1	0.5
Reducible/total background	5%	45%	55%

Results: m(4l) spectrum

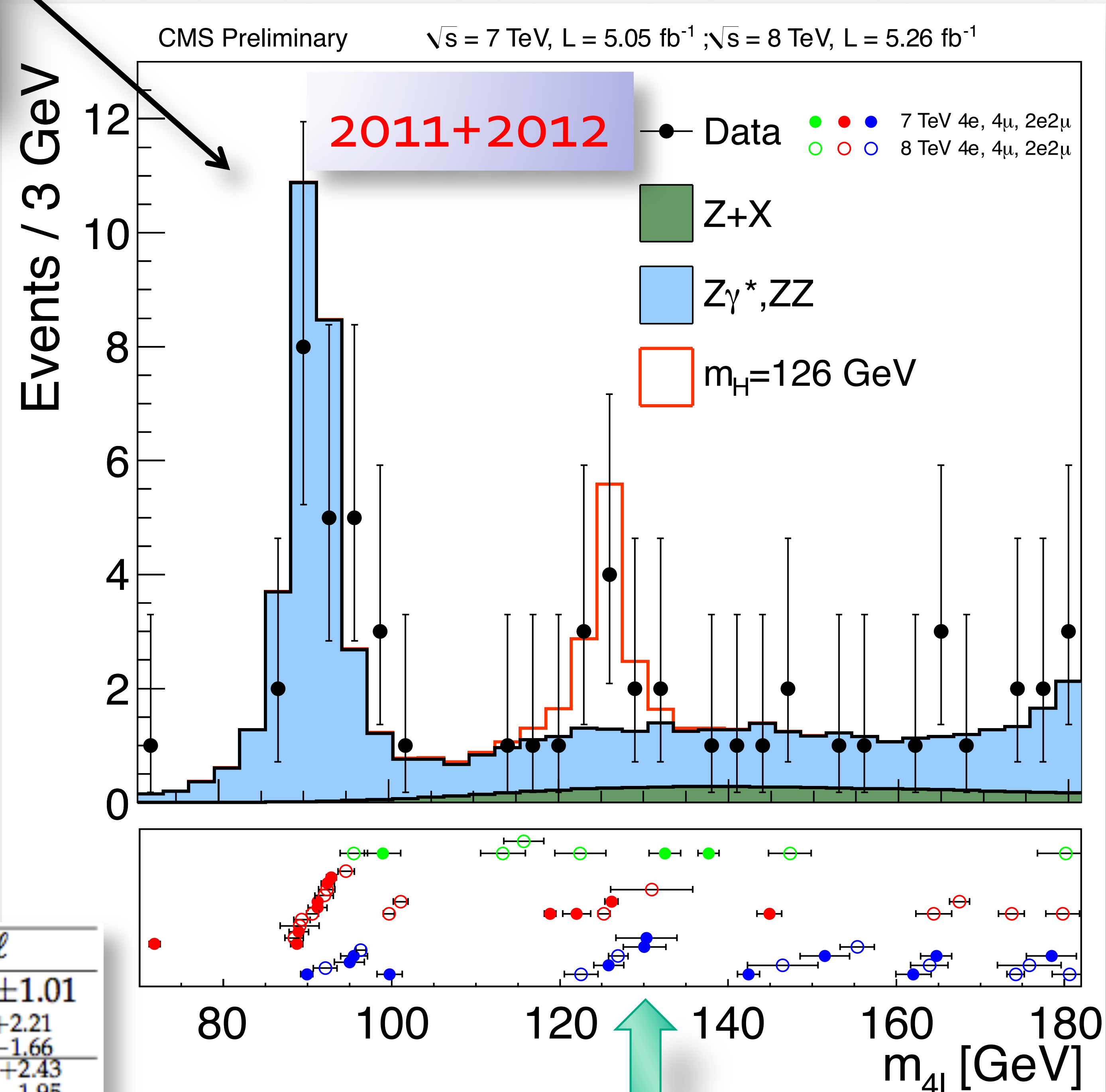




Yields for m(4l)=110..160 GeV

Channel	4e	4μ	$2e2\mu$	4ℓ
ZZ background	2.65 ± 0.31	5.65 ± 0.59	7.17 ± 0.76	15.48 ± 1.01
Z+X	$1.20^{+1.08}_{-0.78}$	$0.92^{+0.65}_{-0.55}$	$2.29^{+1.81}_{-1.36}$	$4.41^{+2.21}_{-1.66}$
All backgrounds	$3.85^{+1.12}_{-0.84}$	$6.58^{+0.88}_{-0.81}$	$9.46^{+1.96}_{-1.56}$	$19.88^{+2.43}_{-1.95}$
$m_H = 126$ GeV	1.51 ± 0.48	2.99 ± 0.60	3.81 ± 0.89	8.31 ± 1.18

164 events expected in [100, 800 GeV]
172 events observed in [100, 800 GeV]

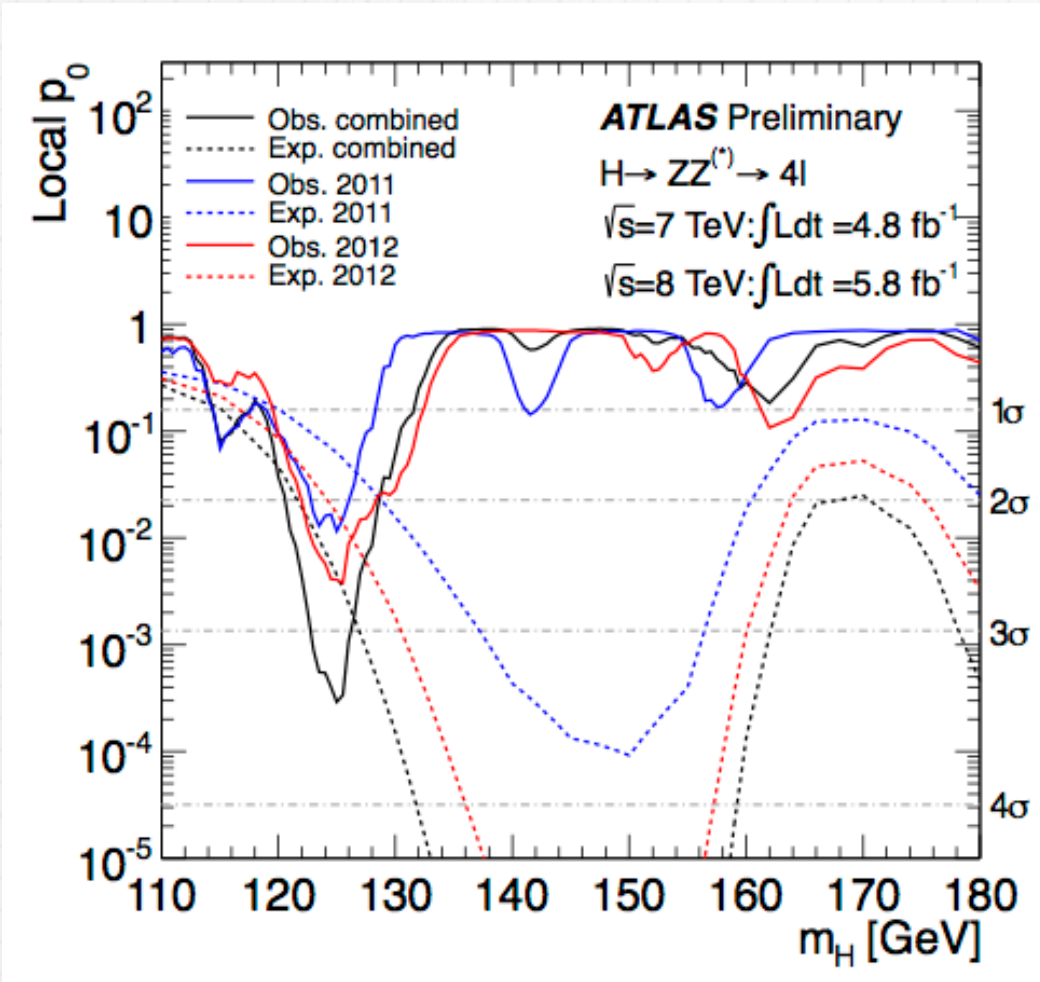


Event-by-event errors

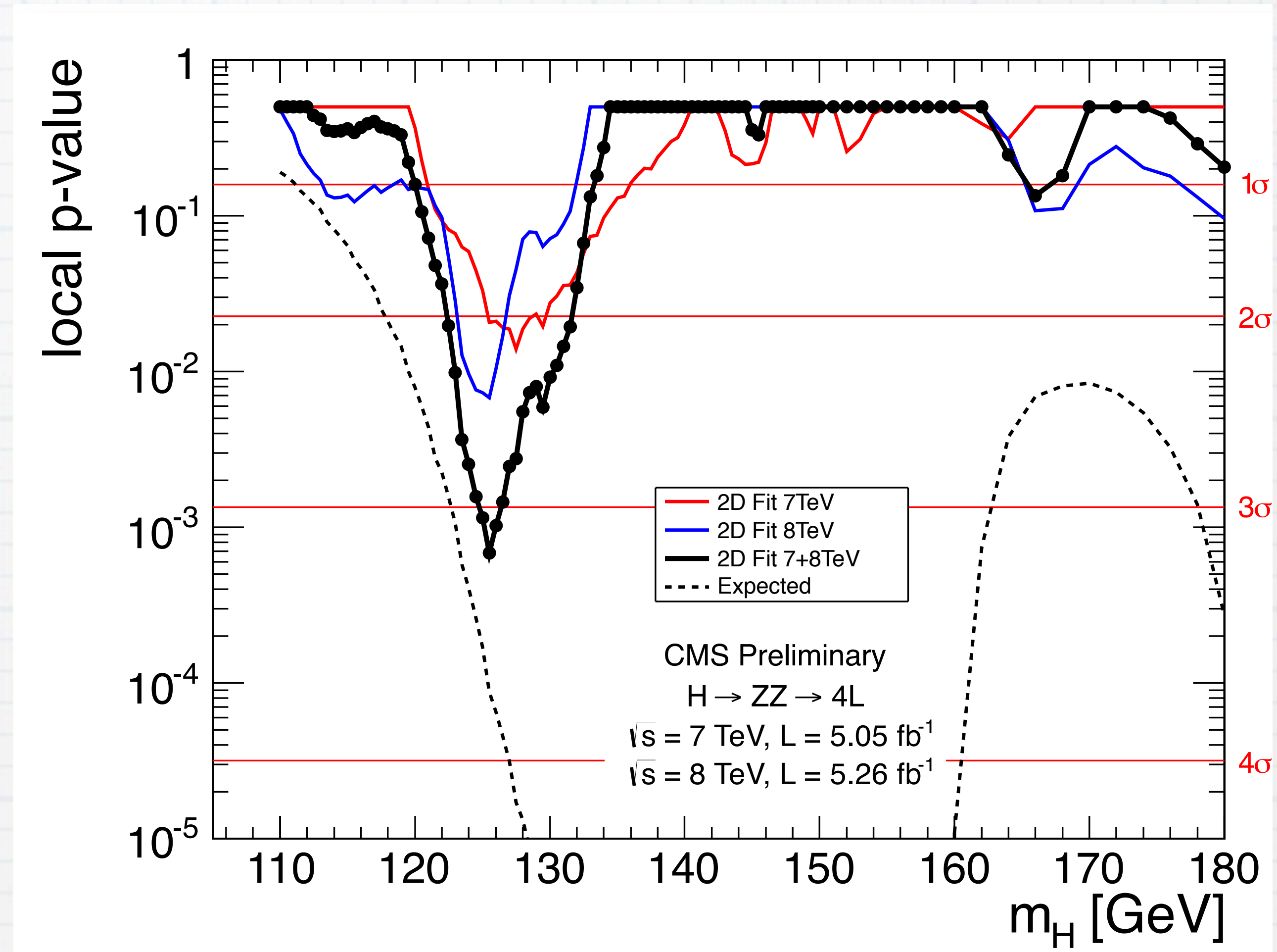
J. Incandela for the CMS COLLABORATION
...s of the Higgs Search
July 4

H→ZZ　p-value

ATLAS



CMS



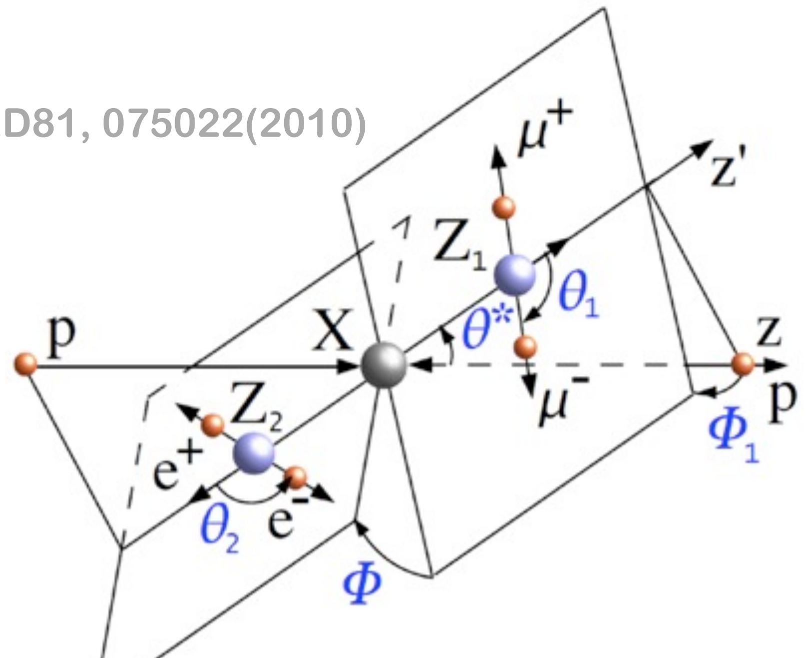
for 125 or 125.5 GeV	ATLAS	CMS
expected from SM	2.6 σ	3.8 σ
observed local p-value	3.4 σ	3.2 σ
global p-value (110-141GeV)	2.5 σ	

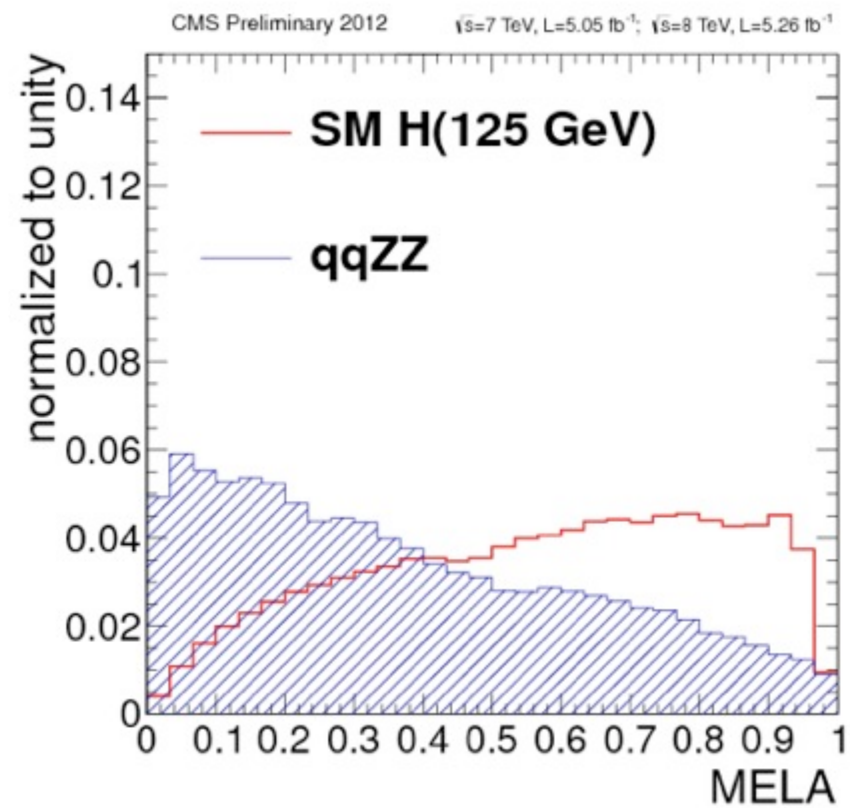
CMS Angular Analysis

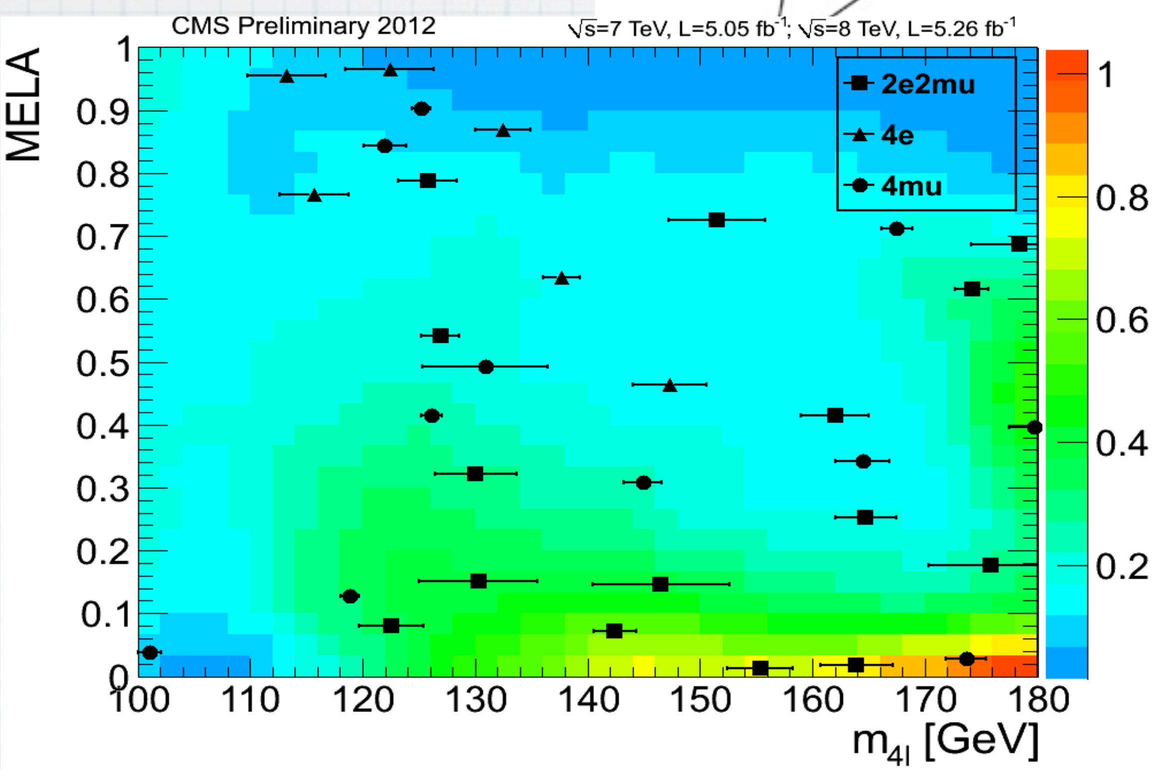
- Decay kinematic fully described by 5 angles and 2 masses
  - discriminates spin 0 particle from background
  - analogous of Δϕ in H ➜ WW analysis
  - MELA: matrix element likelihood analysis

$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

PRD81, 075022(2010)



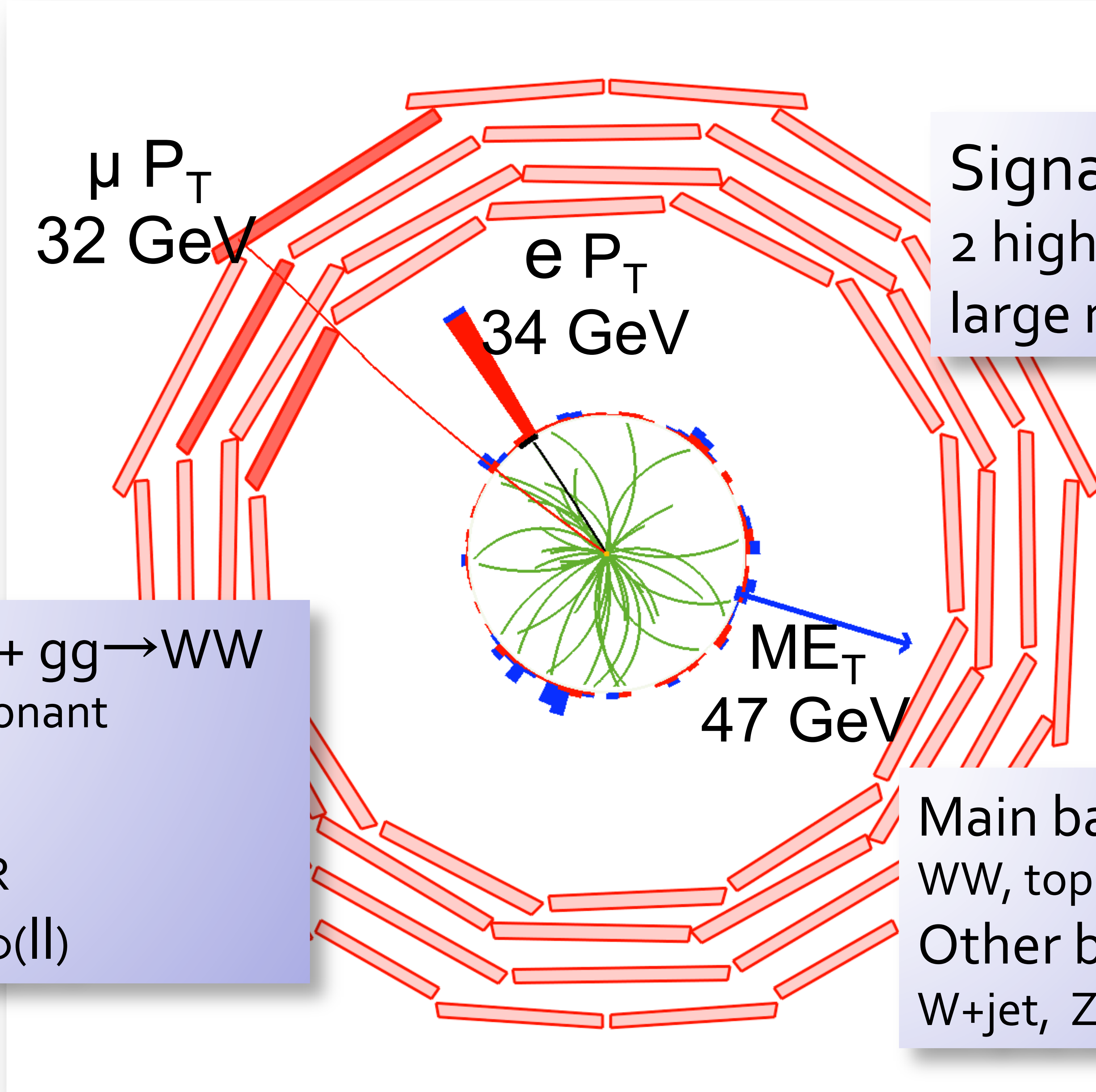




❖ これがCMSのほうが感度の良い原因か？

$H \rightarrow WW \rightarrow l\nu l\nu$

$H \to WW \to l\nu l\nu$ Signature



Signature:

2 high p_T leptons

large missing E_T

$qq \to WW + gg \to WW$

- Non-resonant

$H \to WW$

- Large BR
- Small $\Delta\phi(ll)$

Main backgrounds:

WW, top

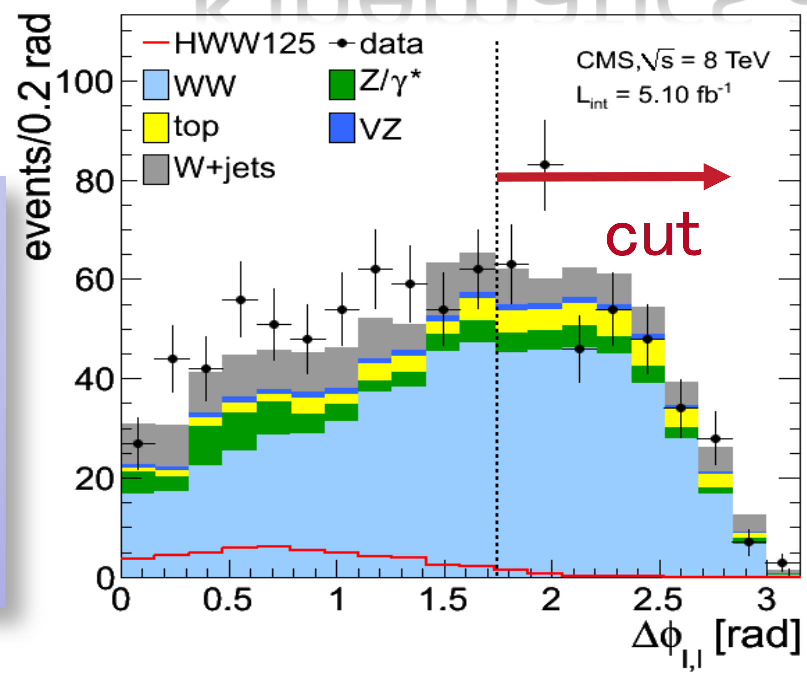
Other backgrounds:

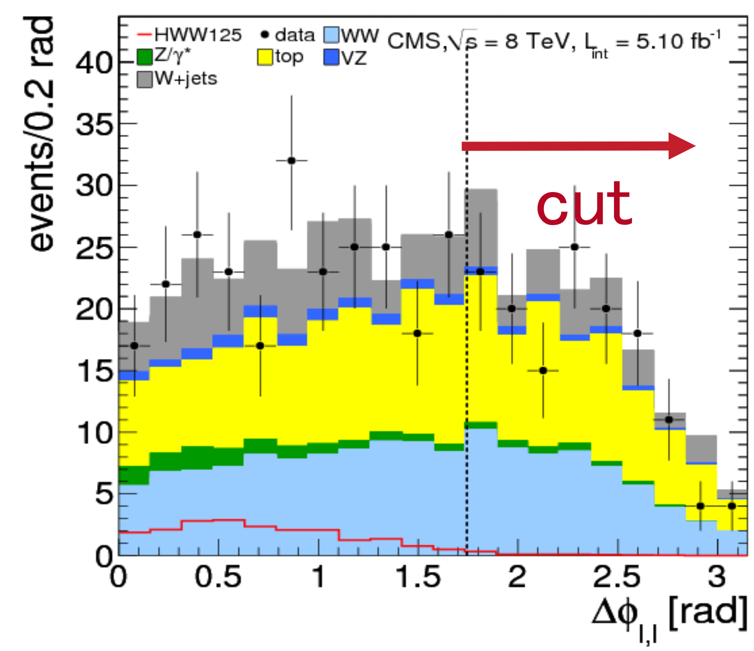
W+jet, Z/γ^*, WZ, ZZ, $W\gamma$

CMS H→WW

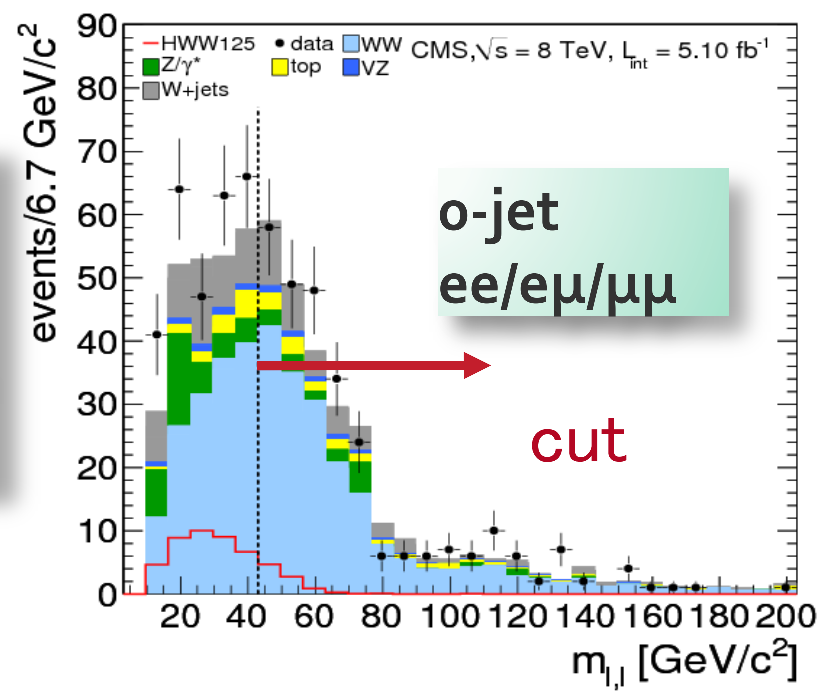
Kinematics at Final Selection

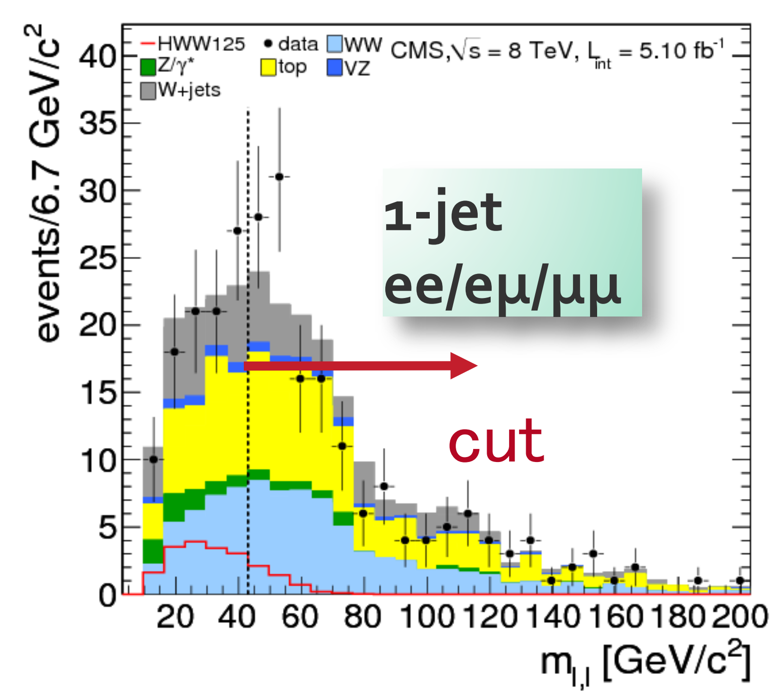
One step before the final selection
(no cuts on Δϕ(ll) and m(ll))



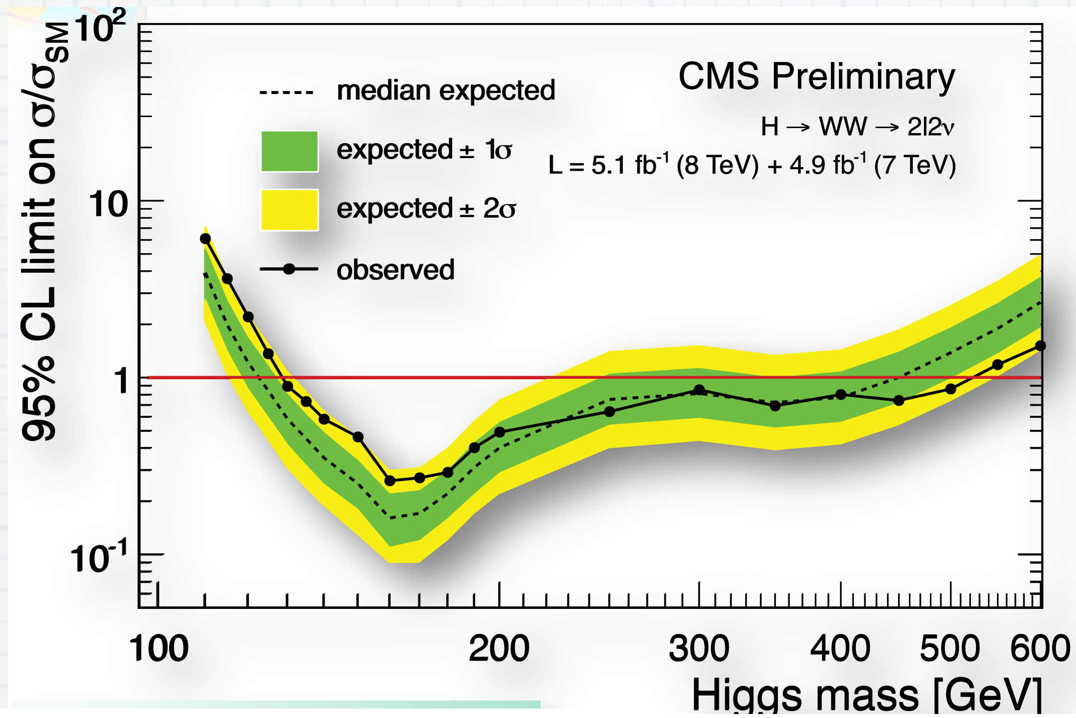


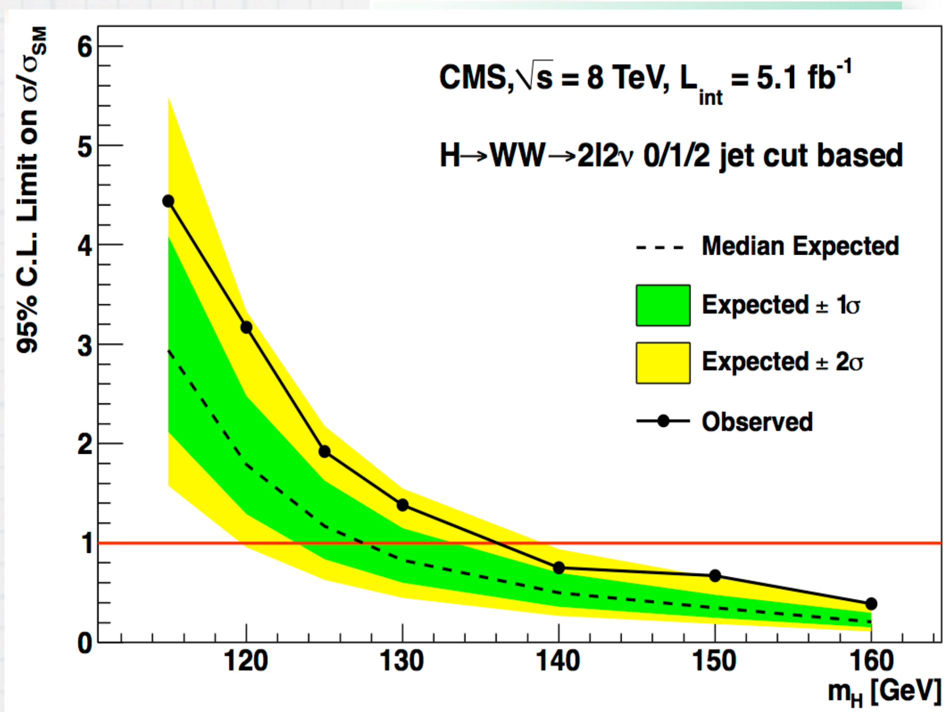
Final selection on m(ll)
(all other selection applied)

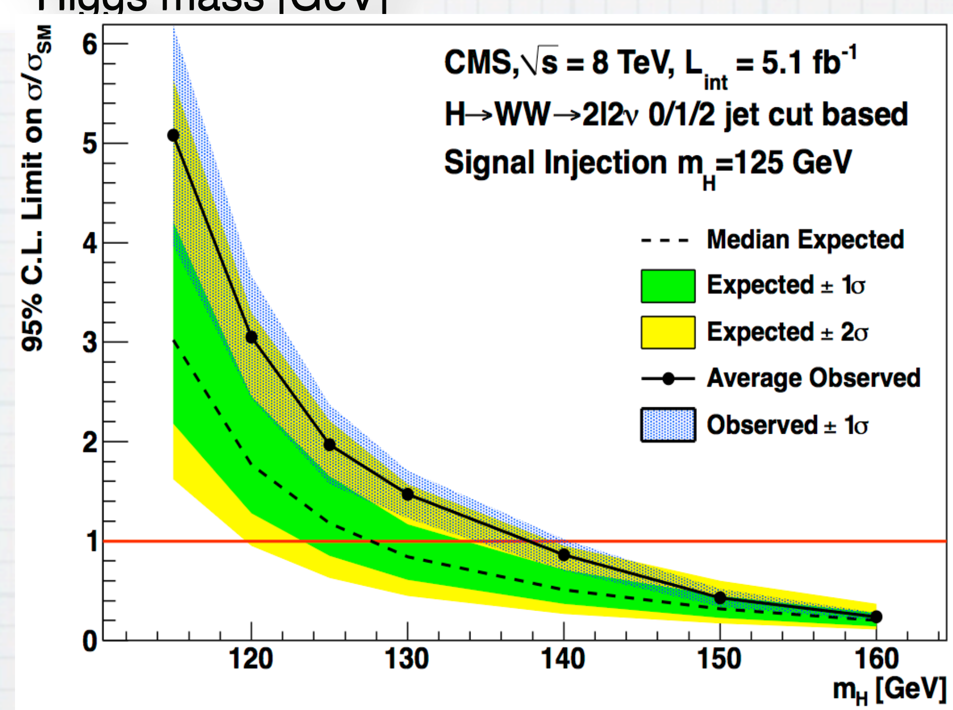




CMS H→WW



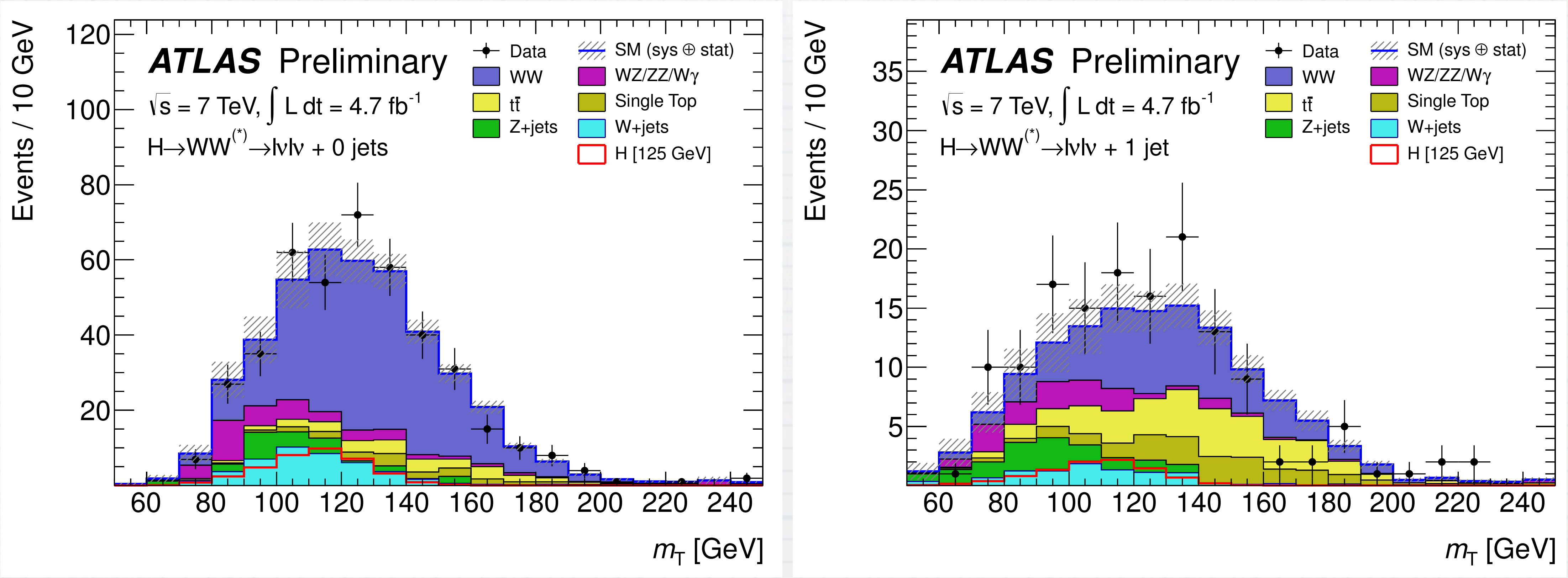




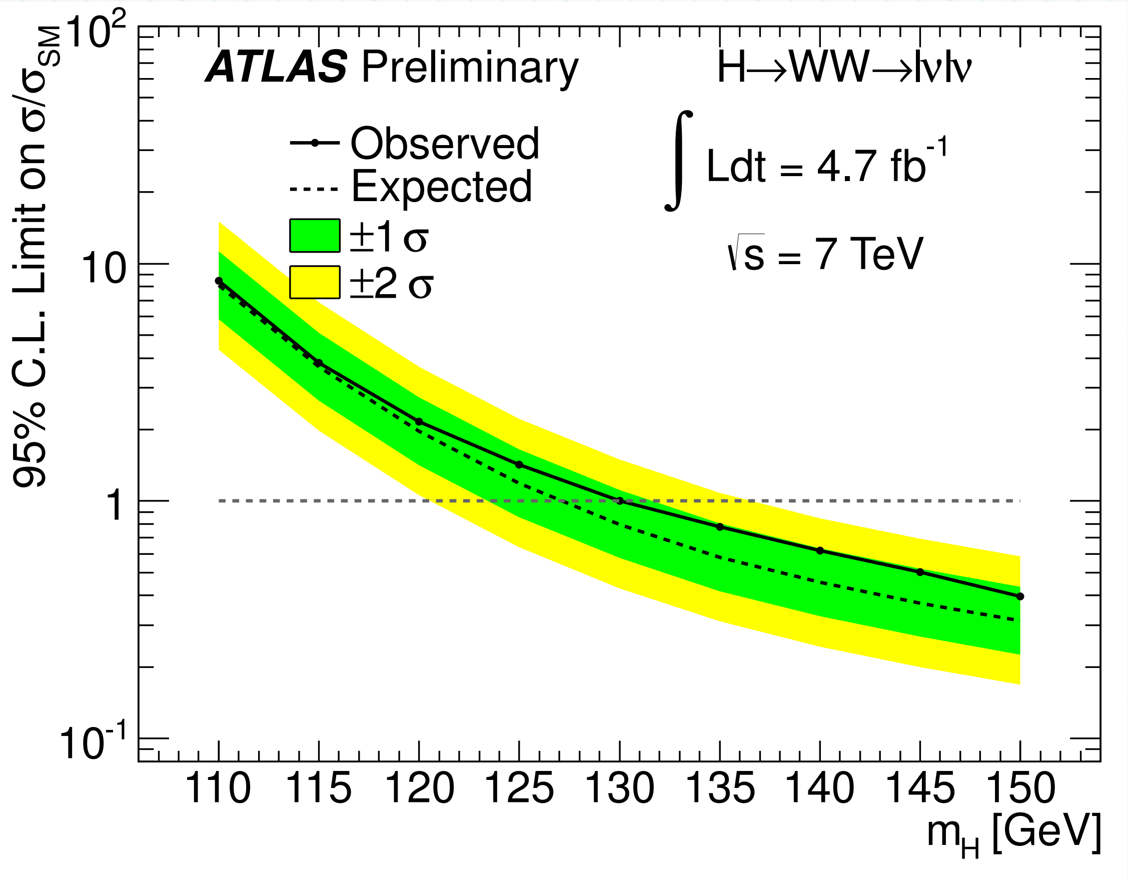
- ❖ Observation very similar to signal injection

ATLAS H→WW

- Two isolated leptons with $p_T > 25$, 15 GeV
- Jet $p_T > 25$ GeV
- No 2 jet bin



ATLAS H→WW



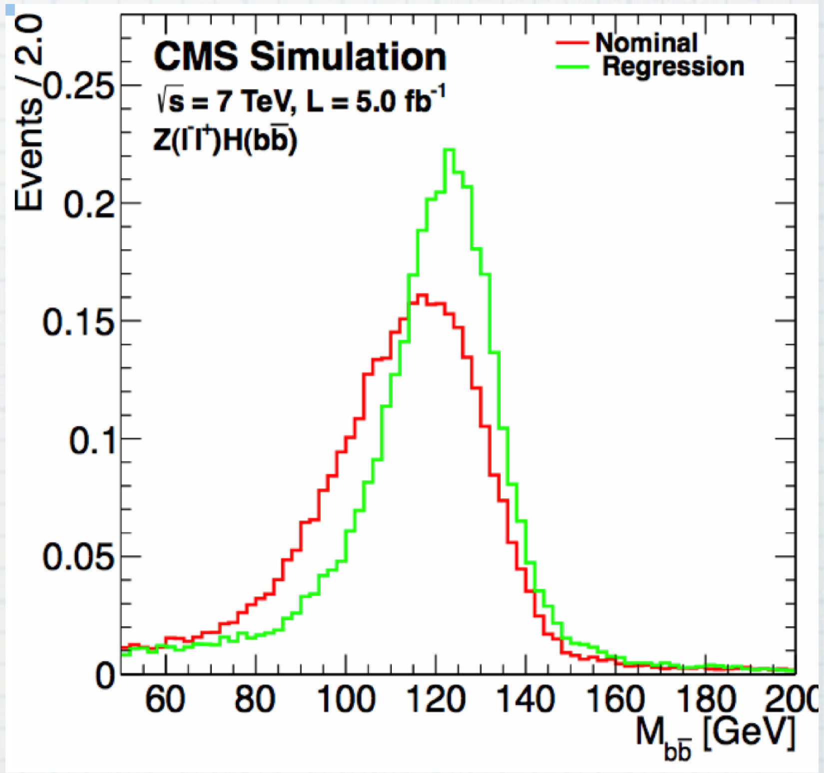
		Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	Z/γ^* + jets	W + jets	Total Bkg.	Obs.
0-jet	m_H = 125 GeV	25 ± 7	110 ± 12	12 ± 3	7 ± 2	5 ± 2	13 ± 8	27 ± 16	173 ± 22	174
	m_H = 240 GeV	60 ± 17	432 ± 49	24 ± 3	68 ± 15	39 ± 9	8 ± 2	36 ± 24	607 ± 63	629
1-jet	m_H = 125 GeV	6 ± 2	18 ± 3	6 ± 3	7 ± 2	4 ± 2	6 ± 1	5 ± 3	45 ± 7	56
	m_H = 240 GeV	23 ± 9	99 ± 22	8 ± 1	73 ± 27	35 ± 19	6 ± 2	7 ± 7	229 ± 55	232
2-jet	m_H = 125 GeV	0.4 ± 0.2	0.3 ± 0.2	negl.	0.2 ± 0.1	negl.	0.0 ± 0.1	negl.	0.5 ± 0.2	0
	m_H = 240 GeV	2.5 ± 0.6	1.1 ± 0.7	0.1 ± 0.1	2.6 ± 1.3	0.3 ± 0.3	negl.	0.1 ± 0.1	4.2 ± 1.7	2

- 2012年のデータ解析結果は未公表

$H \to bb$

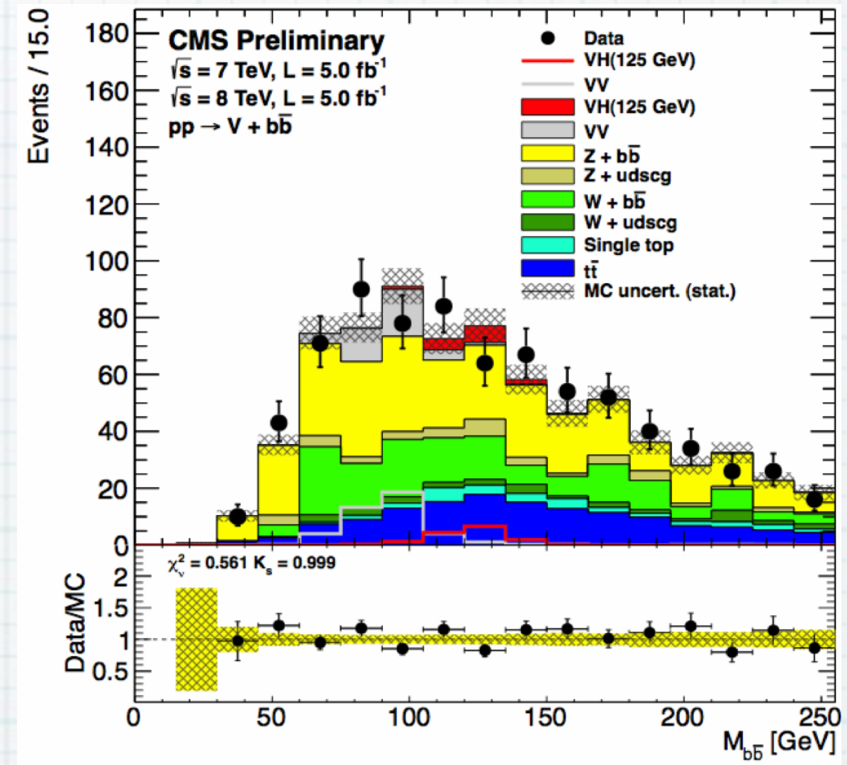
Overview H→bb

- V（W→lν/Z→$\nu\nu$/Z→ll）H と ttH
  - VHはVのp_Tによるカテゴリー分け
    - ◉ “boosted” topologyが感度高い
  - ttH : many combinatoric BG
    - ◉ 今回の結果公表はCMSだけ
- b-tag
  - ε_b ~ 70%, ε_c ~ 20%, ε_l ~ 0.6% (ATLAS)
- Di-b-jet mass resolution
  - CMSはMVAで改善

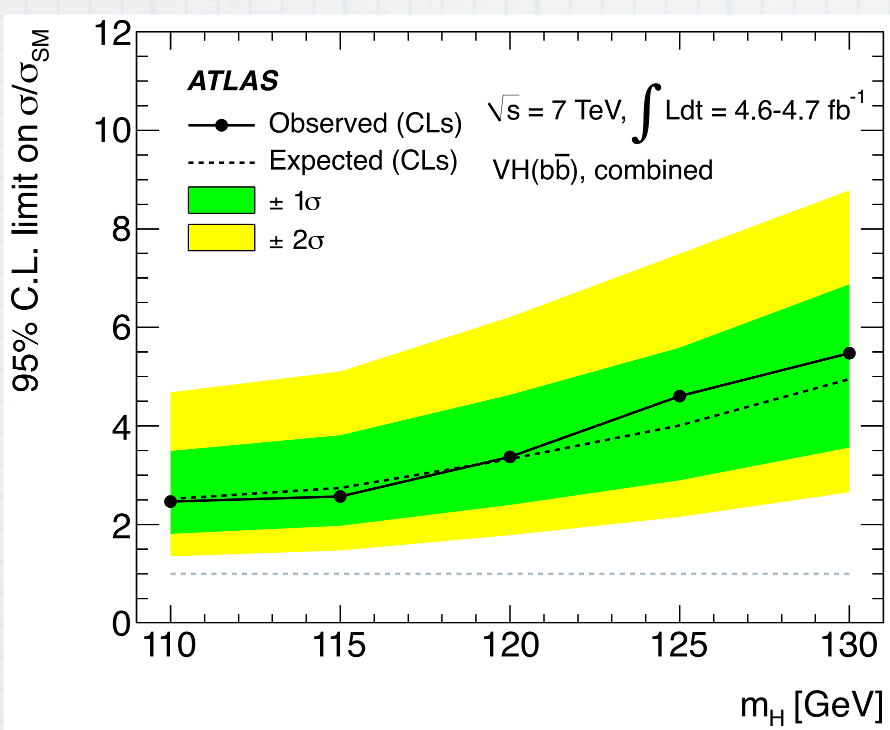


V+H(→bb)

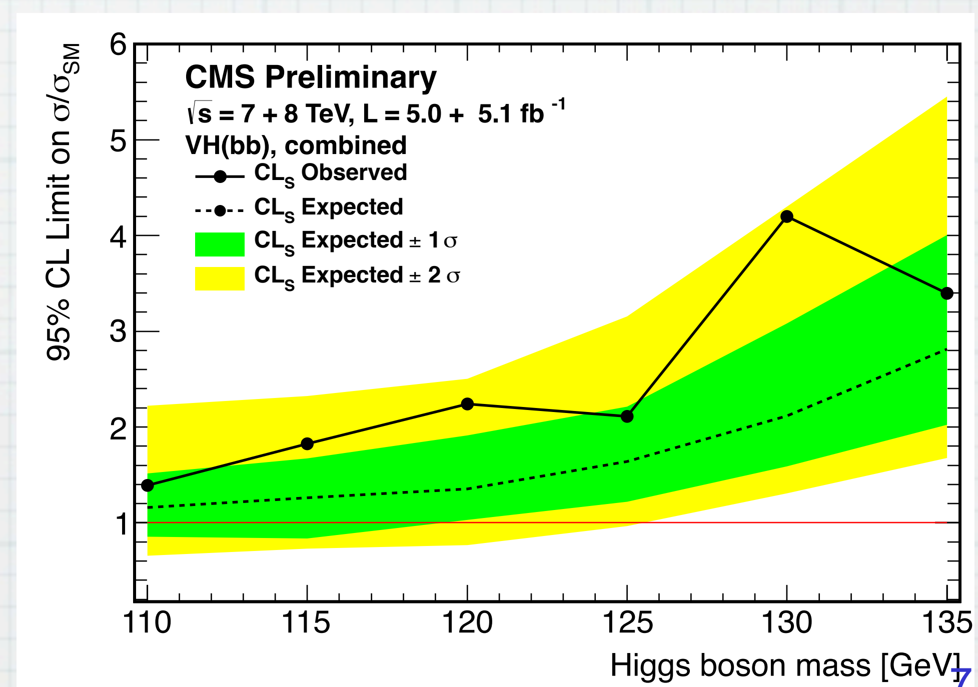
- W/Z/E_T^{miss}+2bjets
- ATLASとCMSの違い
  - データ量
  - Cut based (ATLAS) vs MVA (CMS)



ATLAS

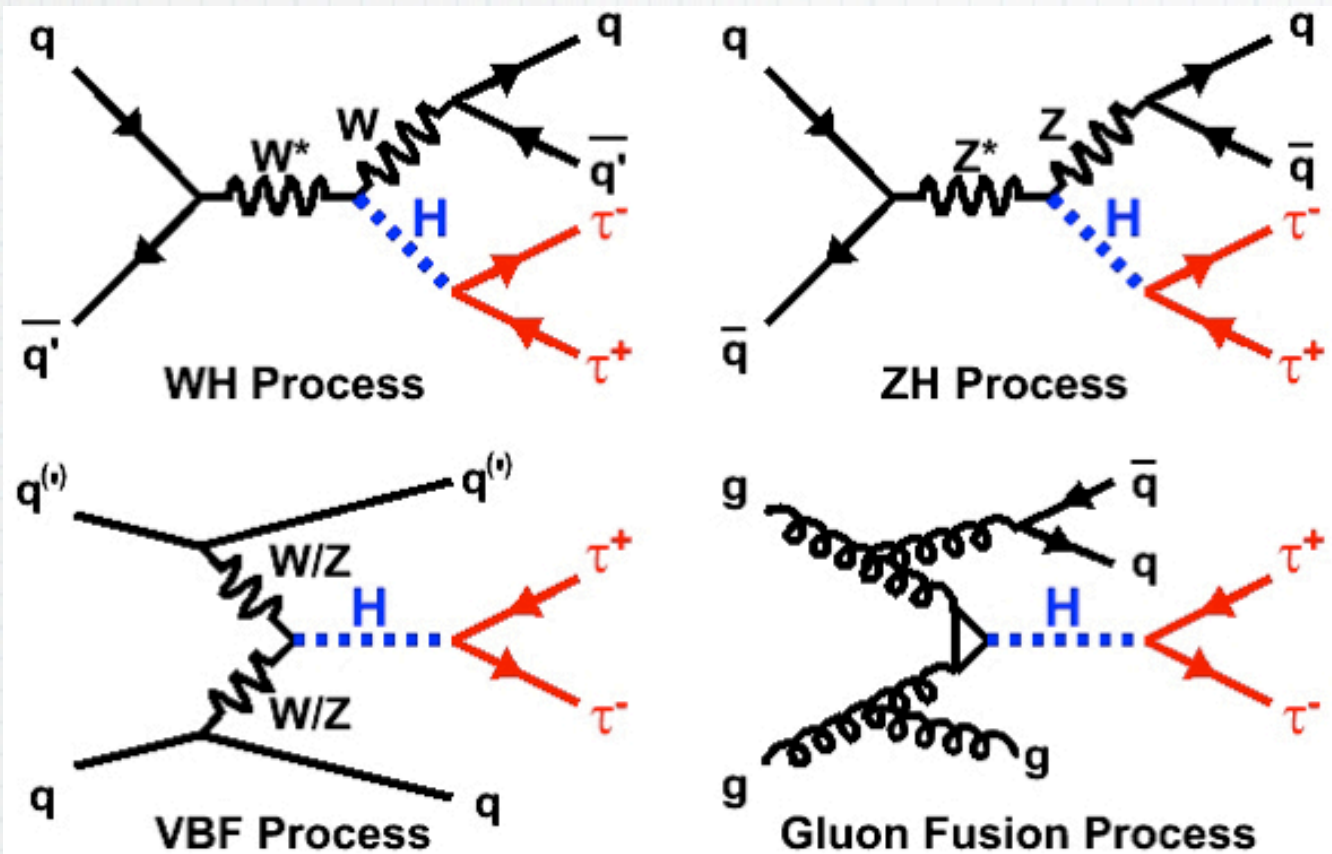


CMS



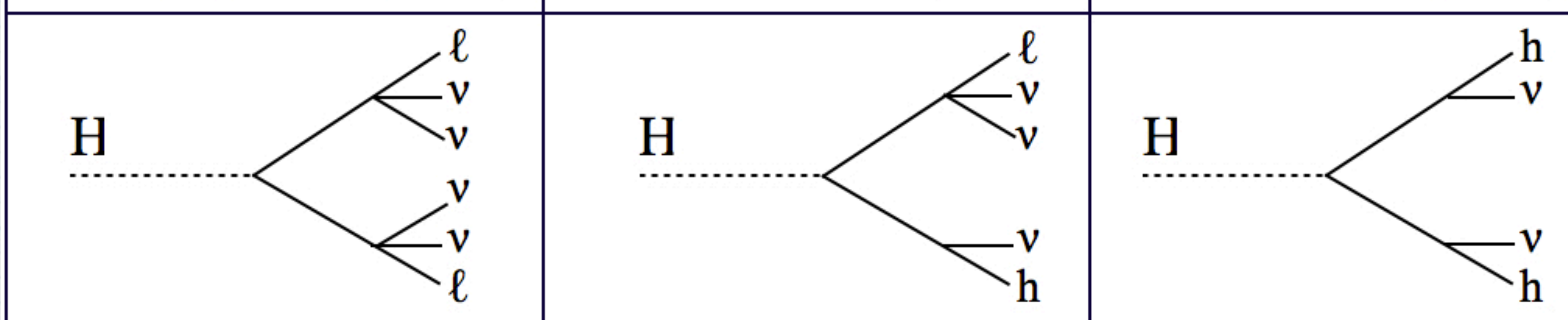
$$H \rightarrow \tau\ \tau$$

Overview H→τ τ



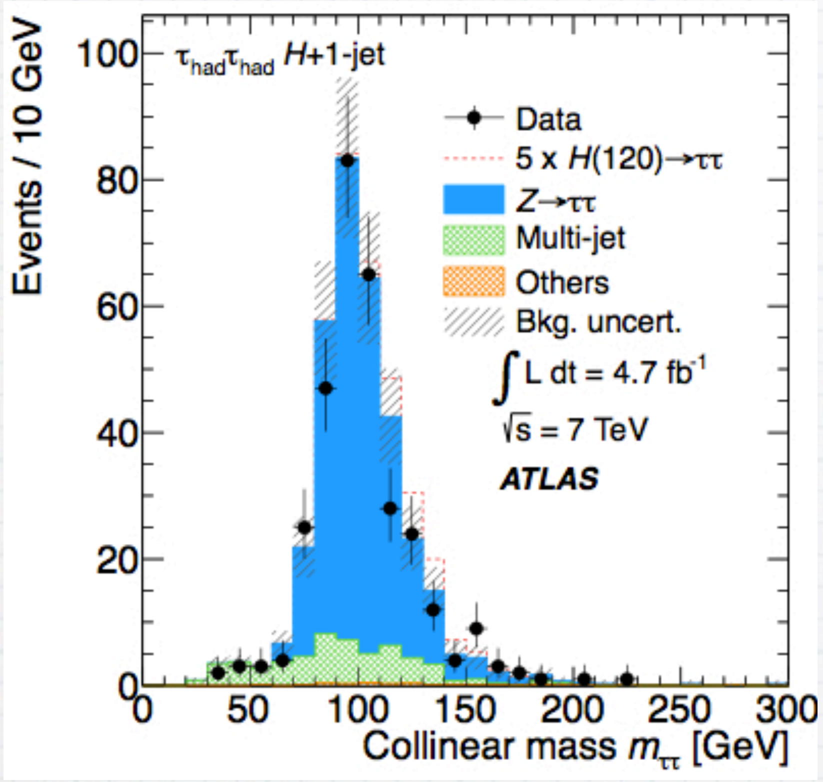
- 生成過程に応じた event selection
- Collinear mass approximation

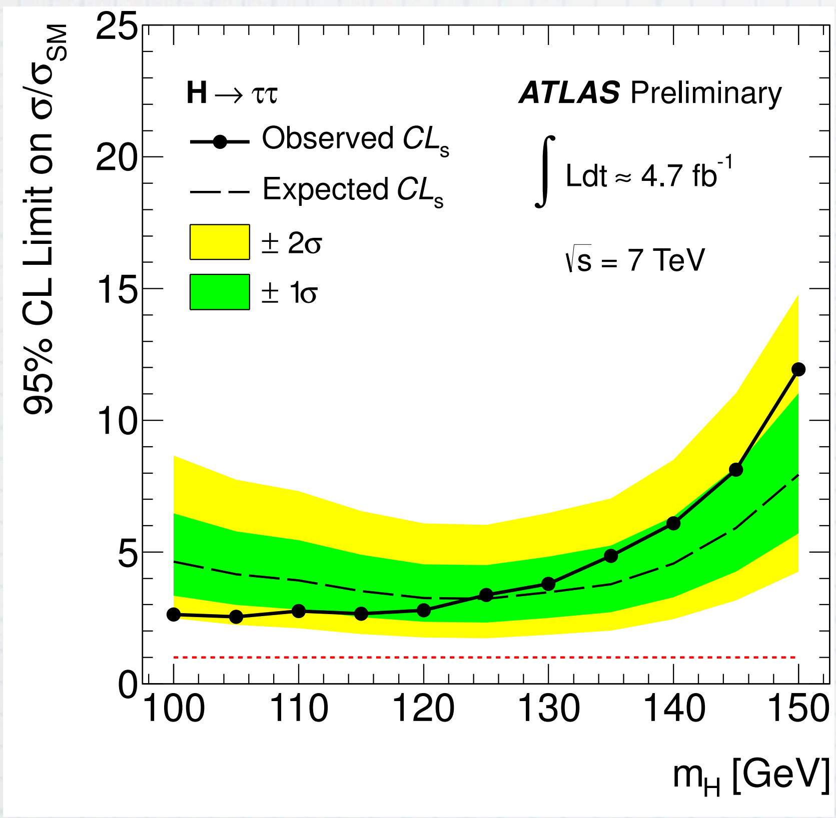
$H \to \tau_{lep}\,\tau_{lep} \to \ell\ell 4\nu$ (12.4%)	$H \to \tau_{lep}\,\tau_{had} \to \ell h 3\nu$ (45.6%)	$H \to \tau_{had}\tau_{had} \to hh 2\nu$ (42.0%)



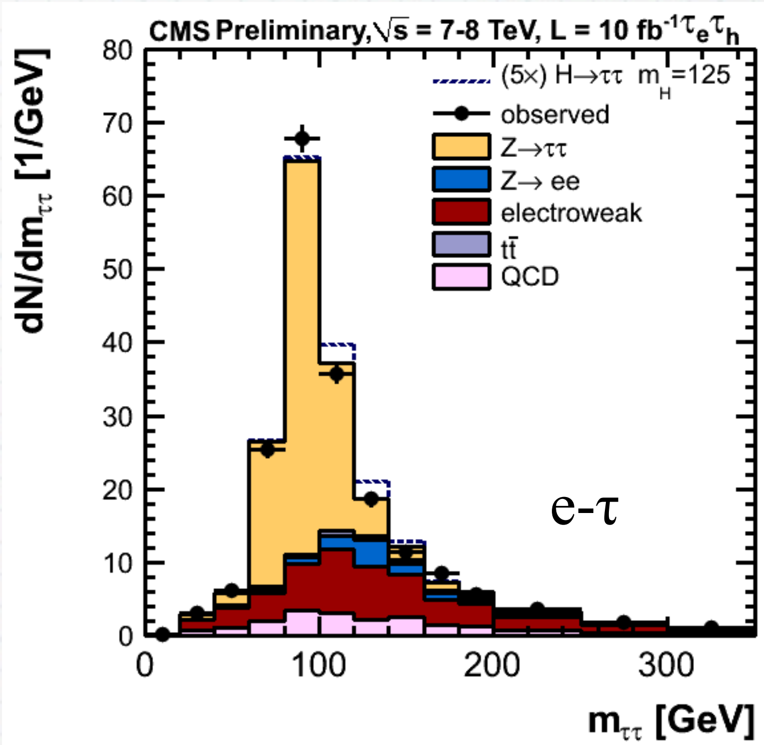
H→τ τ

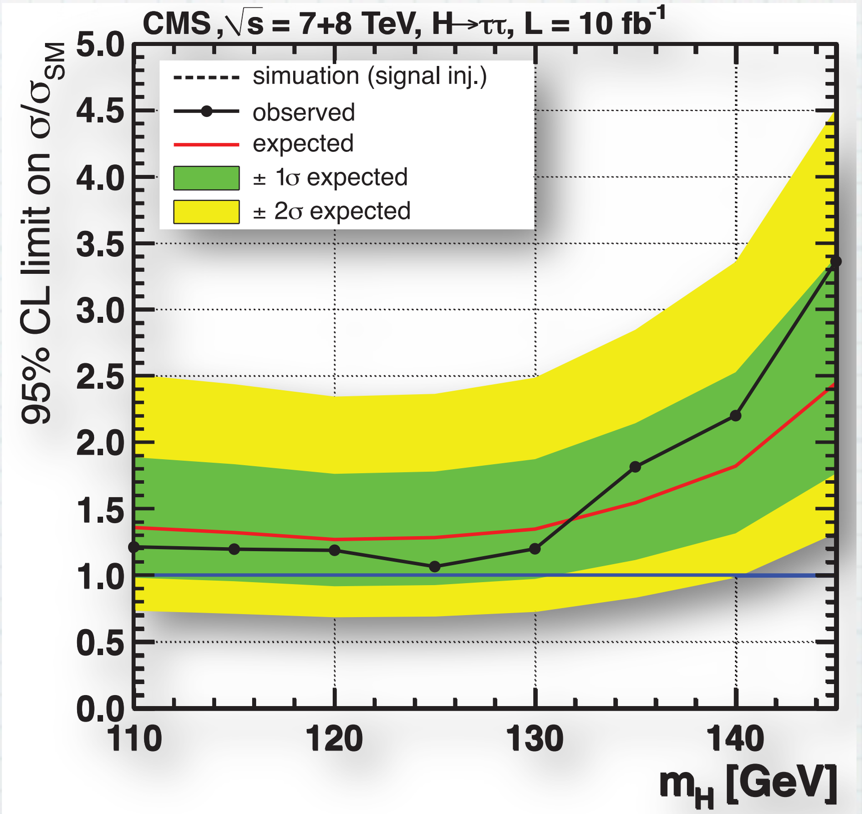
ATLAS





CMS





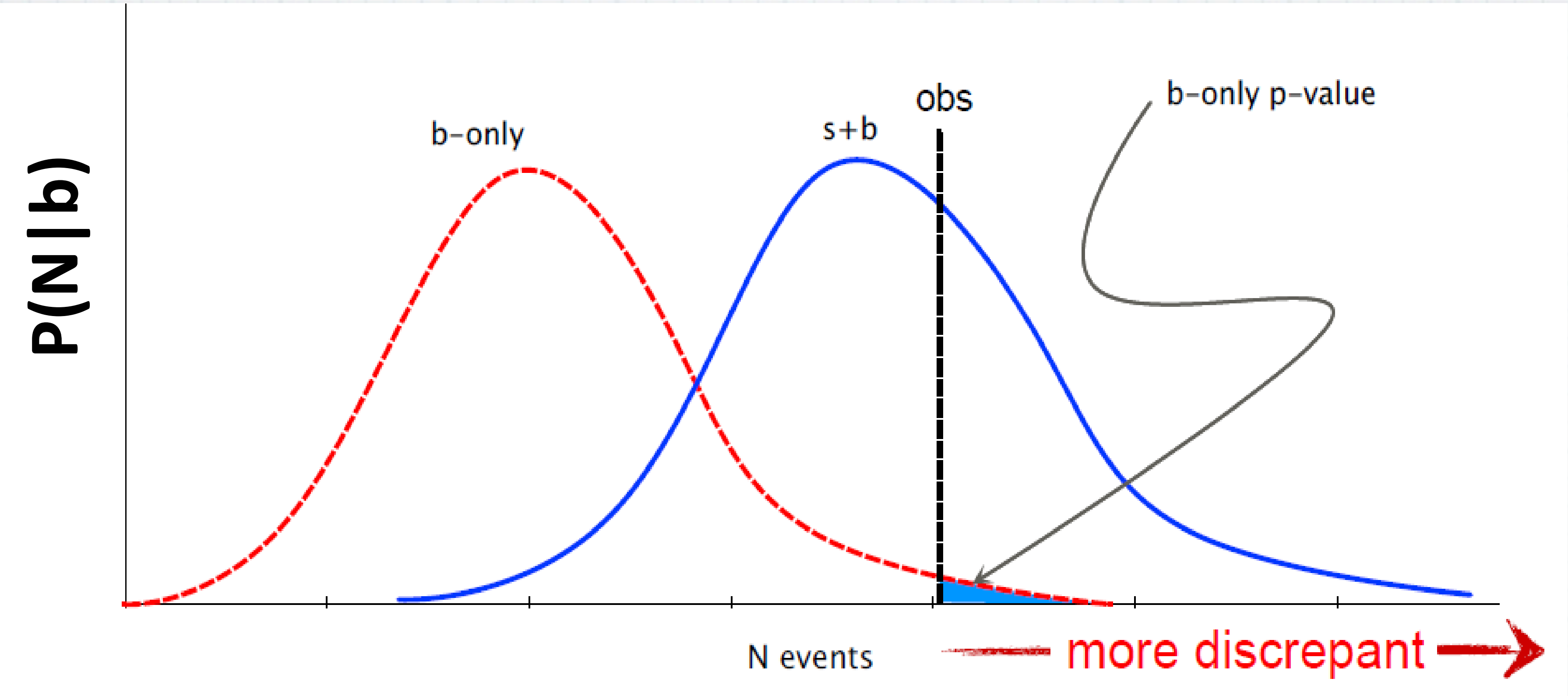
まとめ

結論

- ATLAS
  - 5.0σ excess at M_X ~ 126.5 GeV
    - Expected significance from SM : 4.6σ
- CMS
  - 4.9σ excess
    - Expected significance from SM : 5.9σ
  - M_X = 125.3 ± 0.6 GeV

プロットの見方

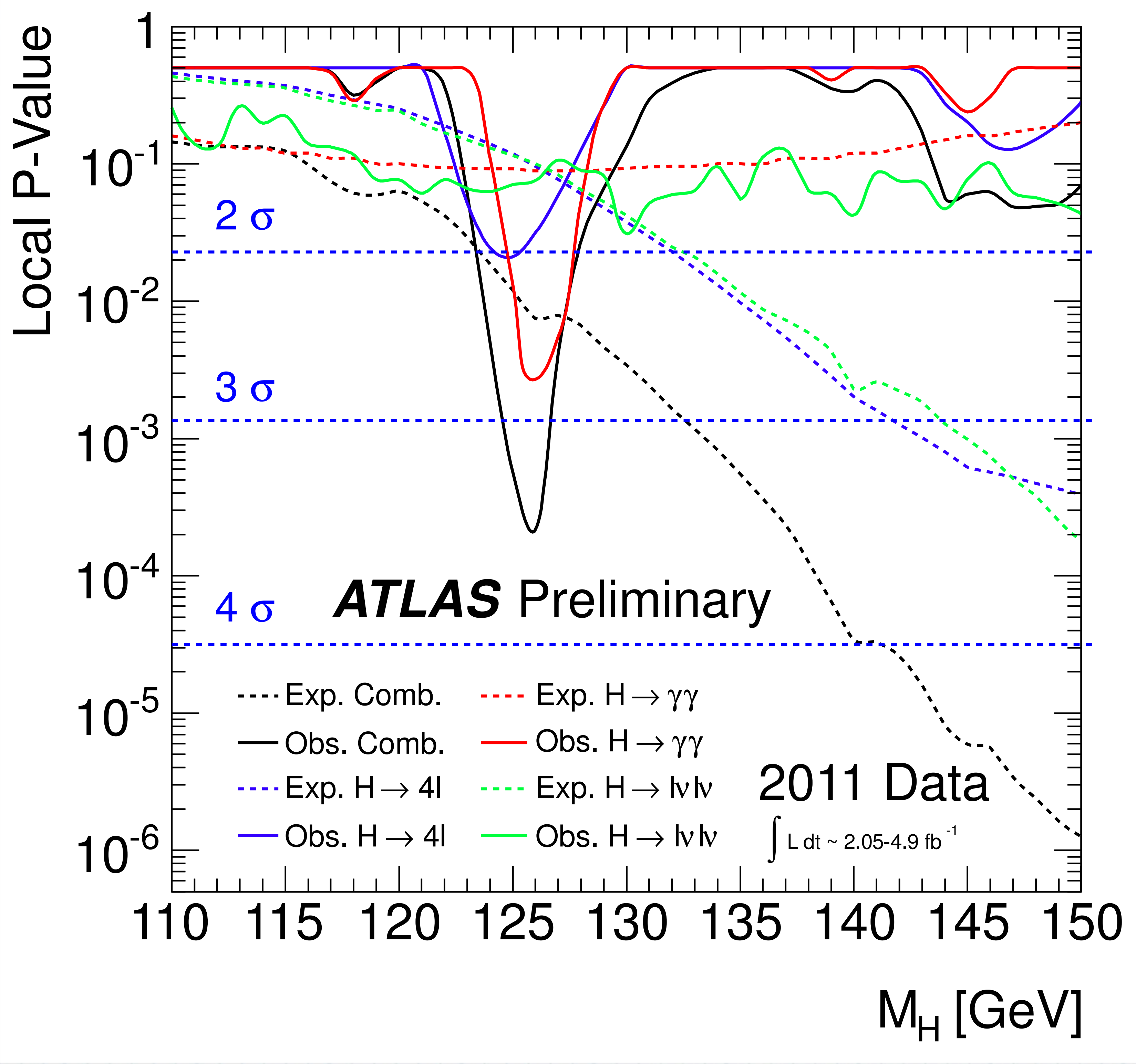
p-value



$$\text{p-value} = P(\, N > N_{obs} \mid b)$$

- 検定量は色々ある
  - 観測事象数，likelihood ratio, etc..
- （今回の）Significanceはp-valueから算出

2011年 ATLAS Local p-value



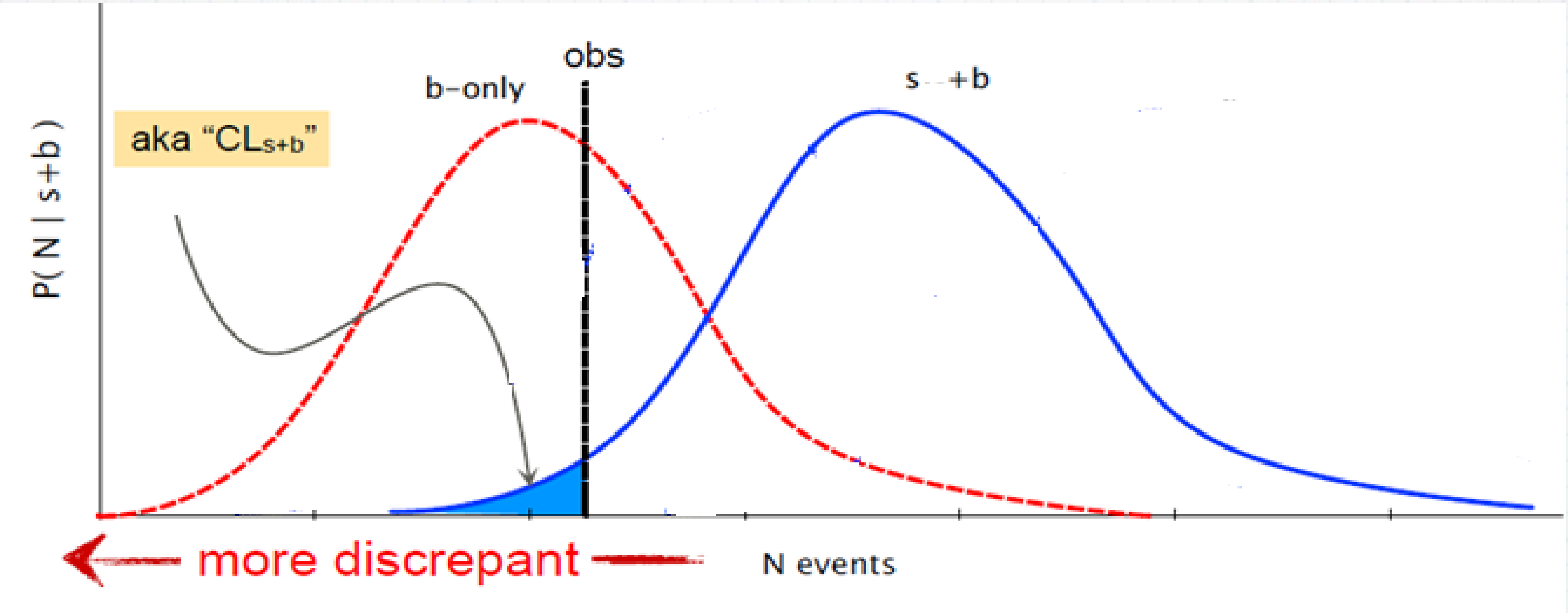
Local significance of excess : 3.6 σ

H→$\gamma\gamma$: 2.8 σ

H→llll : 2.1 σ

H→lνlν : 1.4 σ

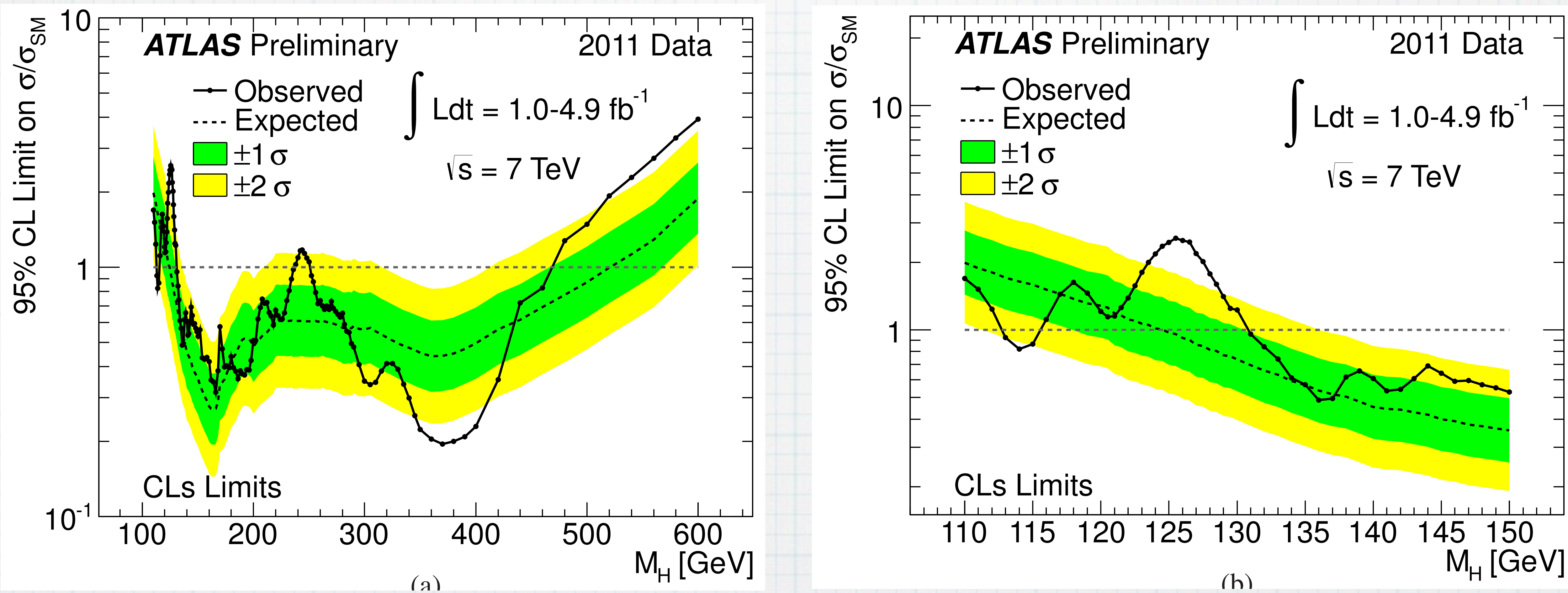
Confidence Level



$$CL_{s+b} = P(\ N < N_{obs}\ |\ s+b\ )$$

- $CL_{s+b} < 5\%$ なら95%CLで棄却
- $CL_{s+b}(\mu) = P(\ N < N_{obs}\ |\ \mu s+b\ ) = 5\%$ となるμを95%CLで棄却した，と言う

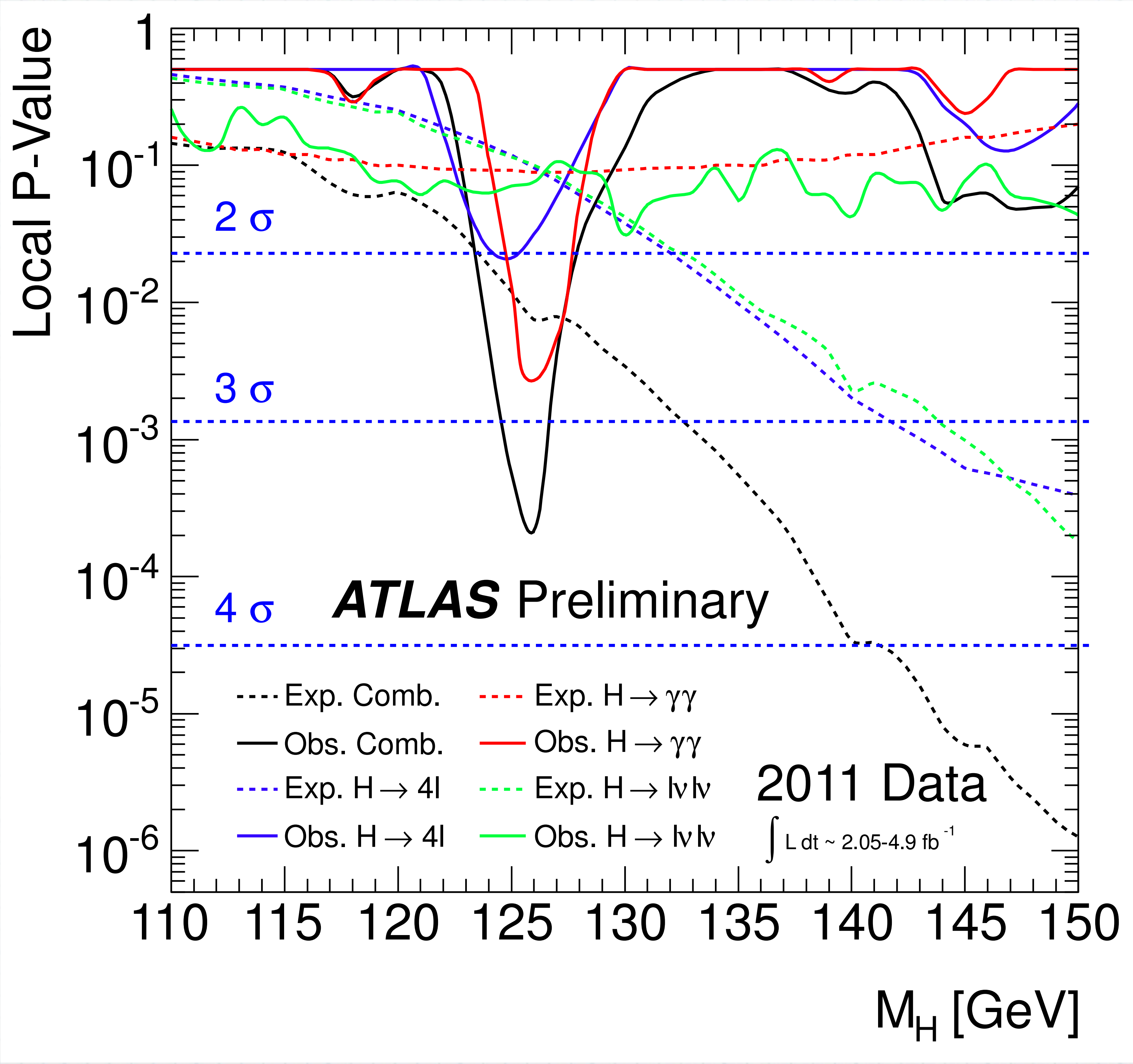
2011年ATLASによる除外領域



Look Elsewhere Effect

- サイコロを振り1が出る確率：1/6
  - でもn回振ると
    - 少なくとも1回1が出る確率：$1-(5/6)^n$
- 背景事象数の期待値が10^{-6}
  - 実験をn回やれば... nが非常に大きければ背景事象を観測することもある
- 何回独立な実験をやったかが大切
  - 質量がどれくらい離れると独立なのか？？
  - global p-value ⇐ 実験回数を考慮に入れる

2011年 ATLAS Global Significance



Local significance of excess : 3.6σ

H→γγ : 2.8σ

H→llll : 2.1σ

H→lνlν : 1.4σ

Global significance of excess

2.5σ (110-146GeV)

2.3σ (110-600GeV)