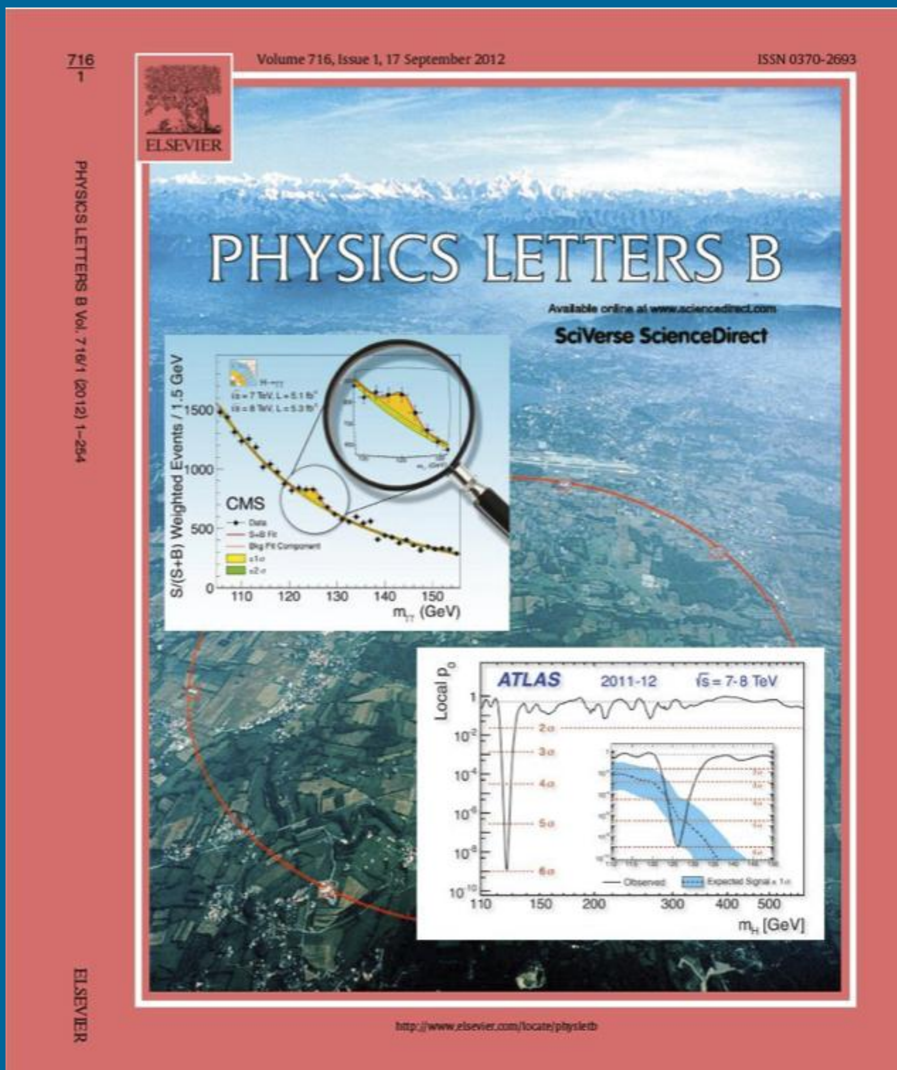
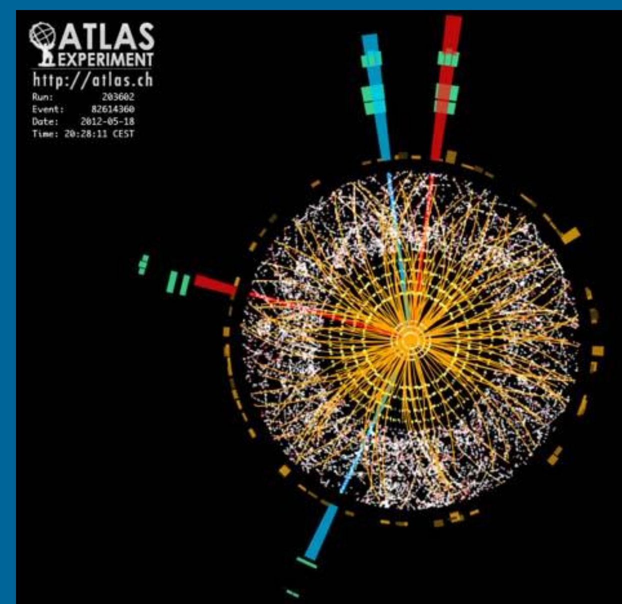
LHCの成果と展望：
新粒子発見、ヒッグス粒子か？



2. Nov. 2012
日大理工・益川塾連携シンポジウム



東京大学
素粒子物理国際研究センター
小林富雄

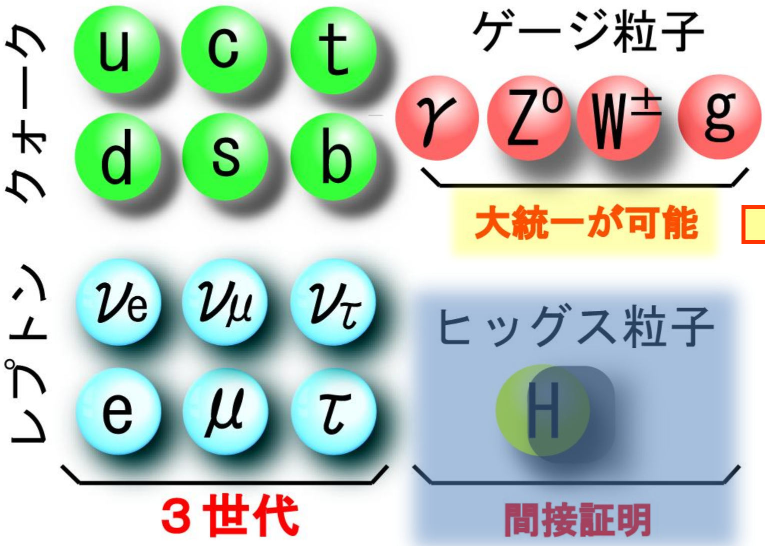
Higgs セミナー（7月4日、CERN）

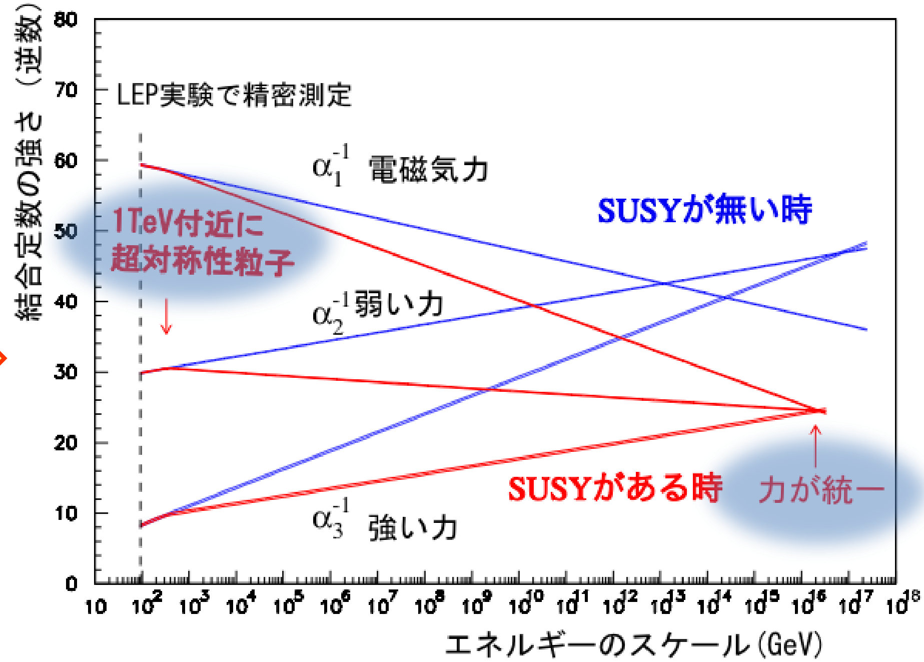
プレスリリース「ヒッグスボゾンとみられる粒子をCERNの実験で観測」

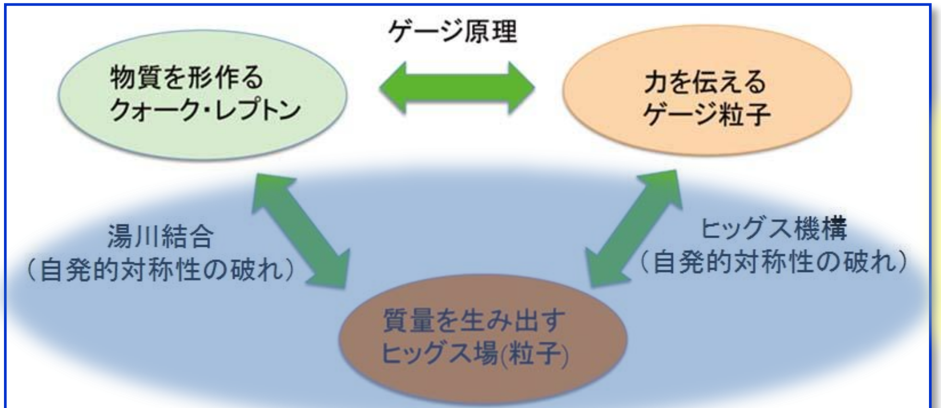
シャンパンを開けているのは
東大素粒子センターの
田中純一さん

LHC開始以前の素粒子物理

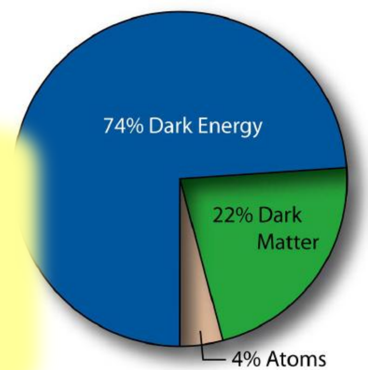
素粒子の標準モデル



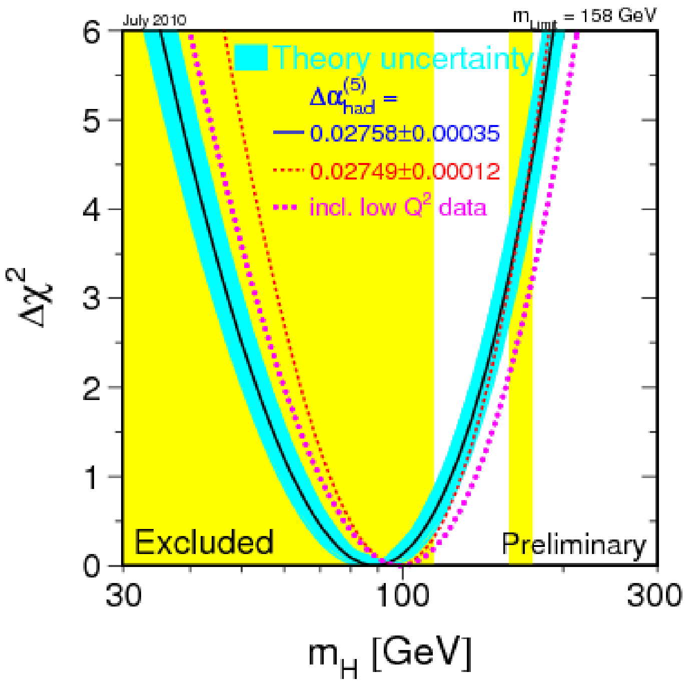


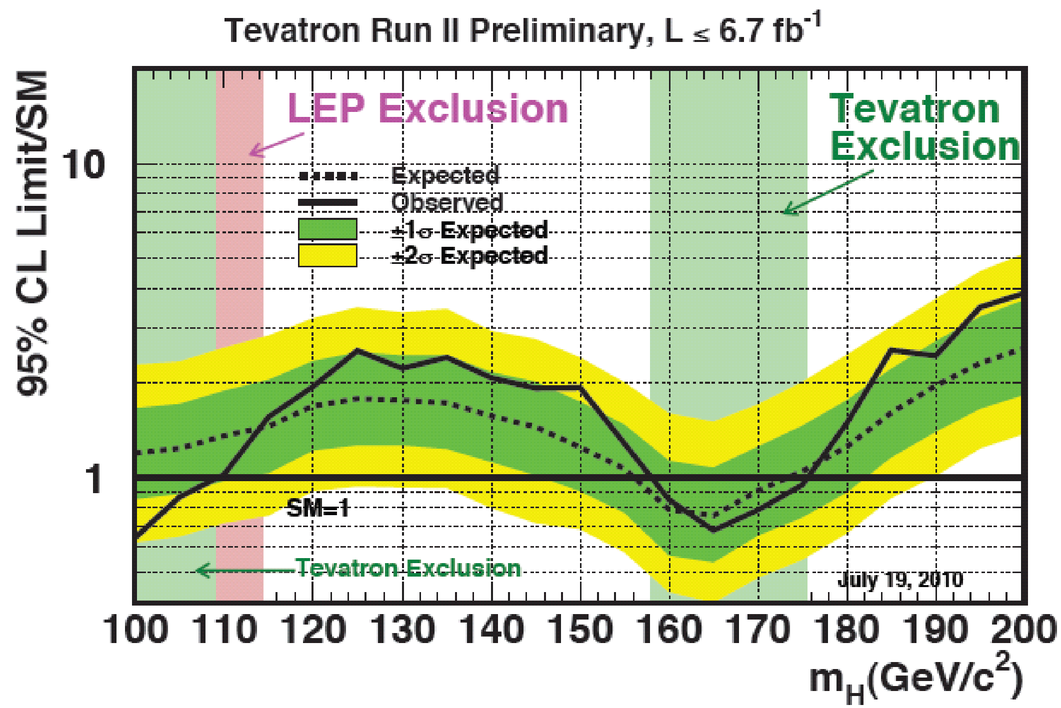


TeV領域に
新物理の期待



ヒッグス粒子（SM）：LHC開始前の状況





直接探索(LEP）

M_H > 114.4GeV（95% C.L.)

EW精密測定

M_H=89 GeV+35−26GeV

M_H < 158GeV（95% C.L.)

直接探索(Tevatron）

158 GeV < M_H < 175GeV（95% C.L.)

→ Excluded

⇨ **114 GeV < M_H < 158GeV**

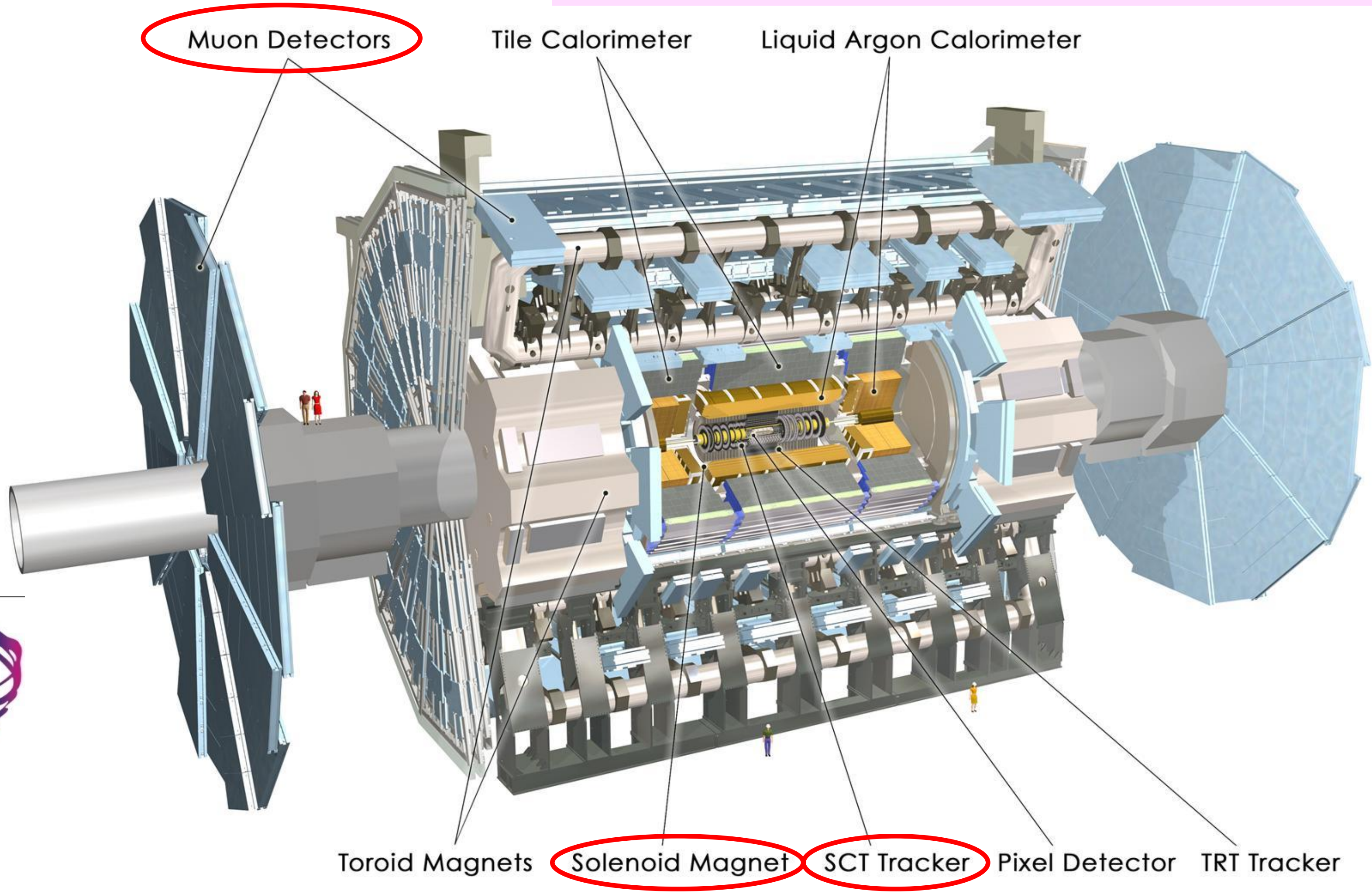
LHC Large Hadron Collider at CERN

- LEPトンネル内に建設（1994年に建設決定）
- 8.3テスラの超伝導磁石
- 7+7TeV 陽子陽子コライダー
- Luminosity（設計値）= 10^{34} $cm^{-2}s^{-1}$
- 2008年9月に完成、…
- 3.5+3.5TeV（世界最高エネルギー）での
  運転を2010年3月に開始
- 2012年4月からは 4+4TeV に

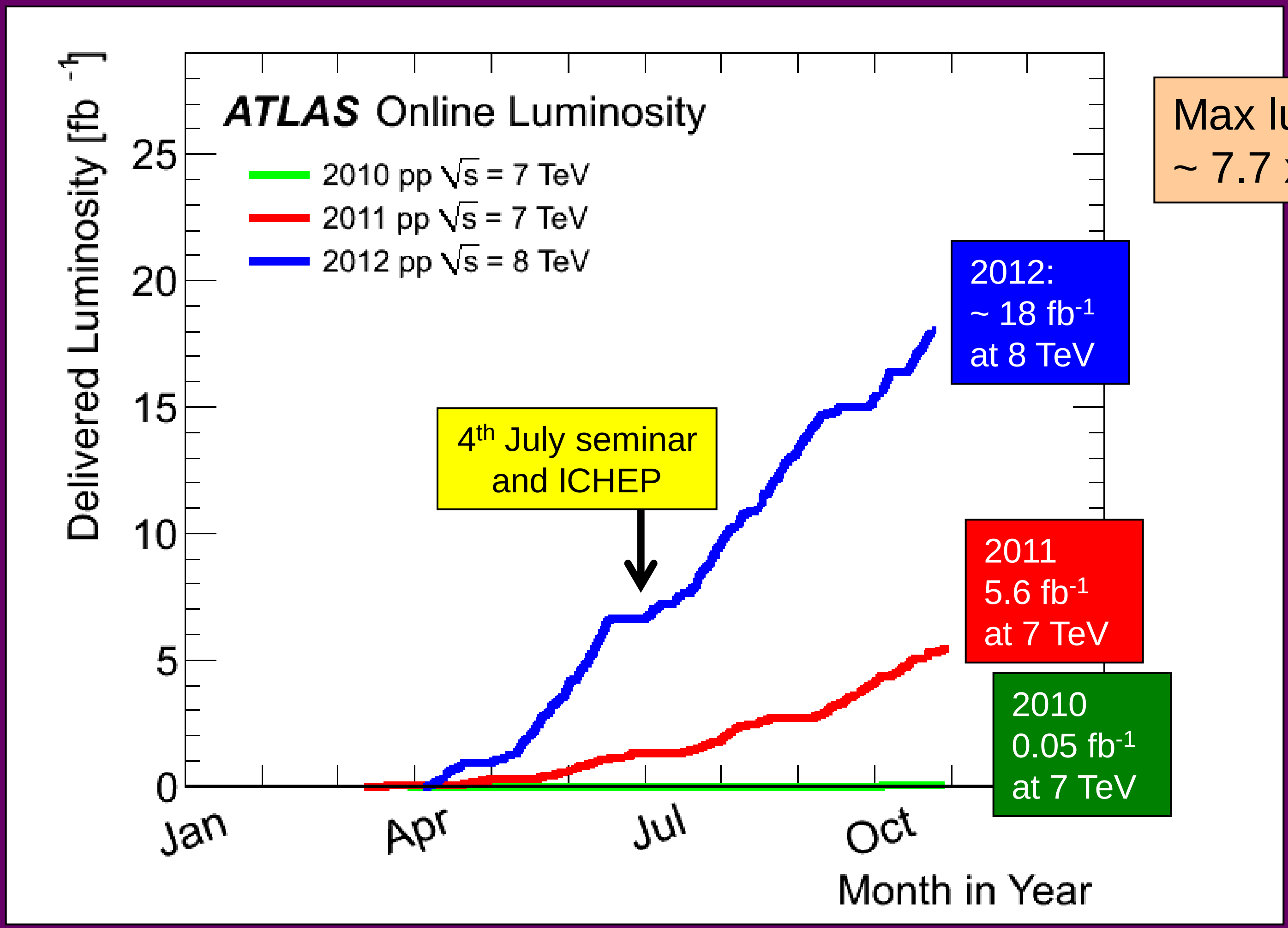
ATLAS実験

(A Toroidal LHC Apparatus)

- 直径 22m、長さ 44m、重さ 7000t
- 世界最大の超伝導トロイド磁石
- 粒子検出器のセンサー数は全部で約1億チャンネル
- 38ヵ国からの約3000名の研究者による国際共同実験
- 日本グループ(15の大学・研究所、110名)はミューオントリガー検出器、内部飛跡検出器、ソレノイド超伝導磁石などに貢献

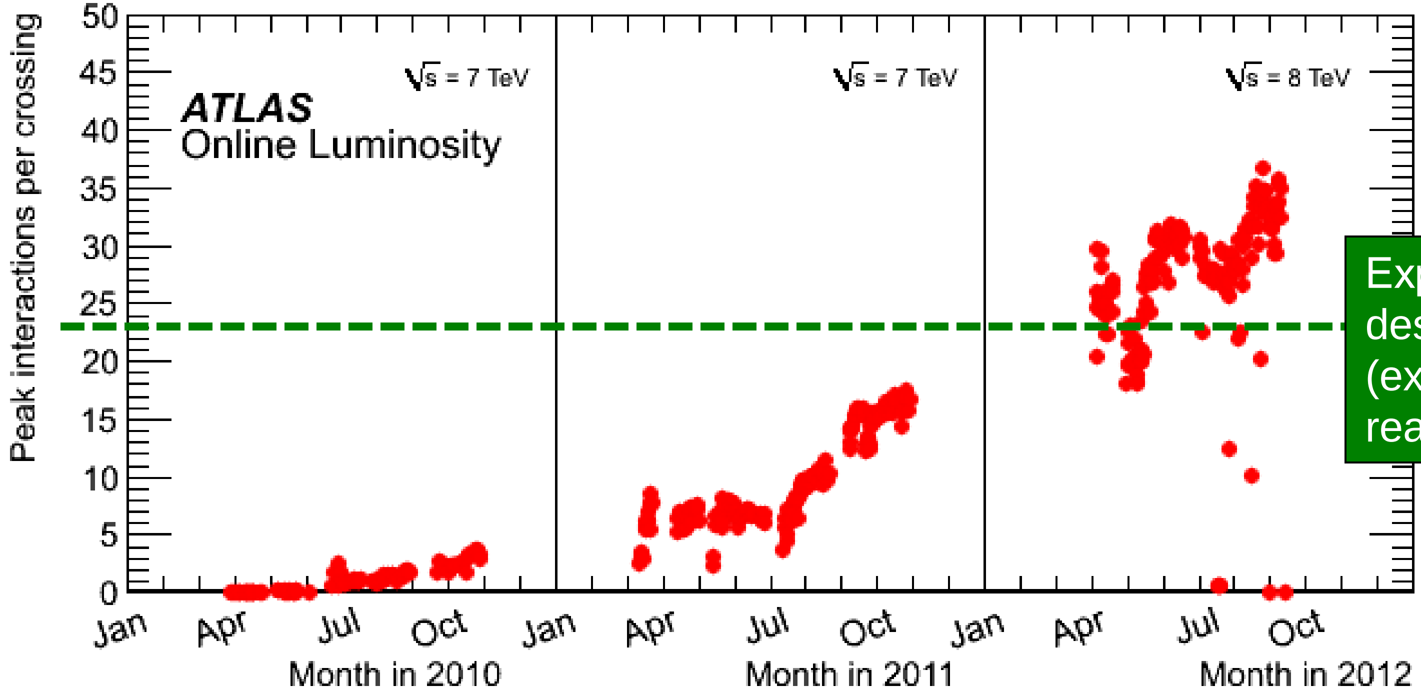


Luminosity delivered to ATLAS since the beginning



Max luminosity: ~ 7.7 x10^{33} cm^{-2} s^{-1}

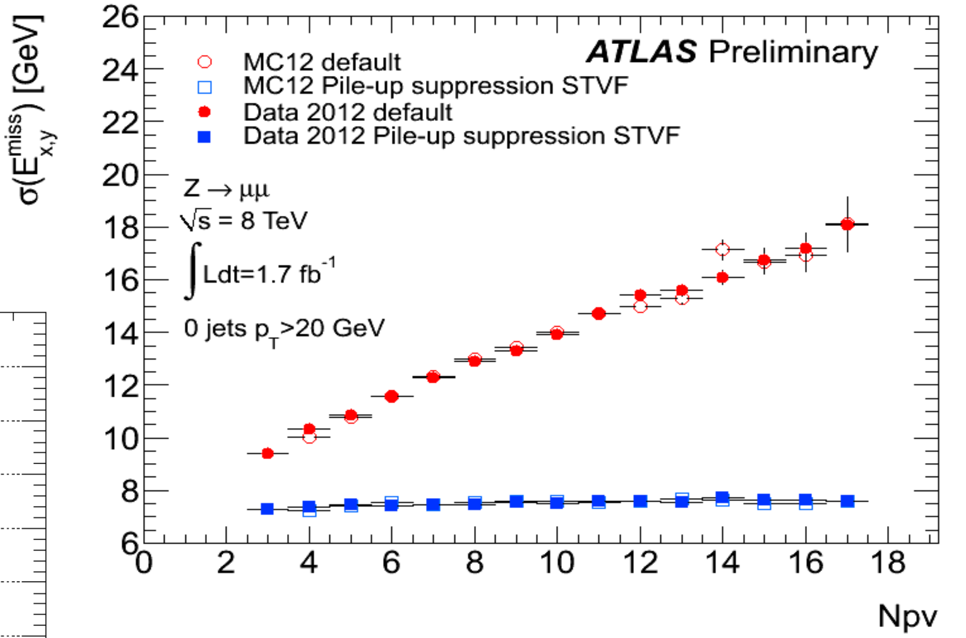
The BIG challenge in 2012: PILE-UP



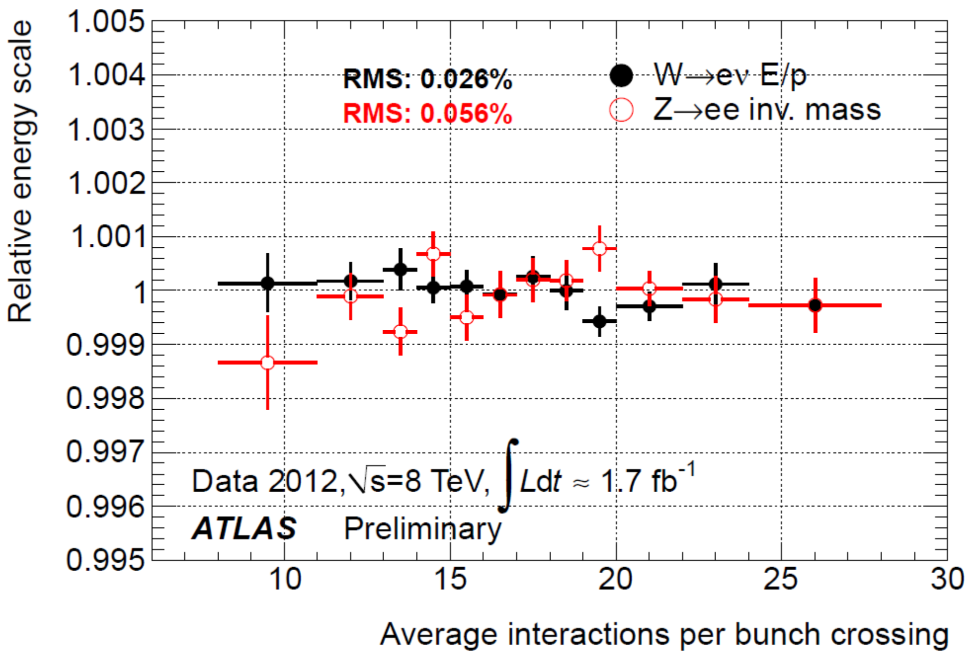
Experiment's design value (expected to be reached at $L=10^{34}$!)

Pile-upの中でも測定器はよく動いている

E_T^{miss} resolution vs pile-up **before** and **after** pile-up suppression using tracks

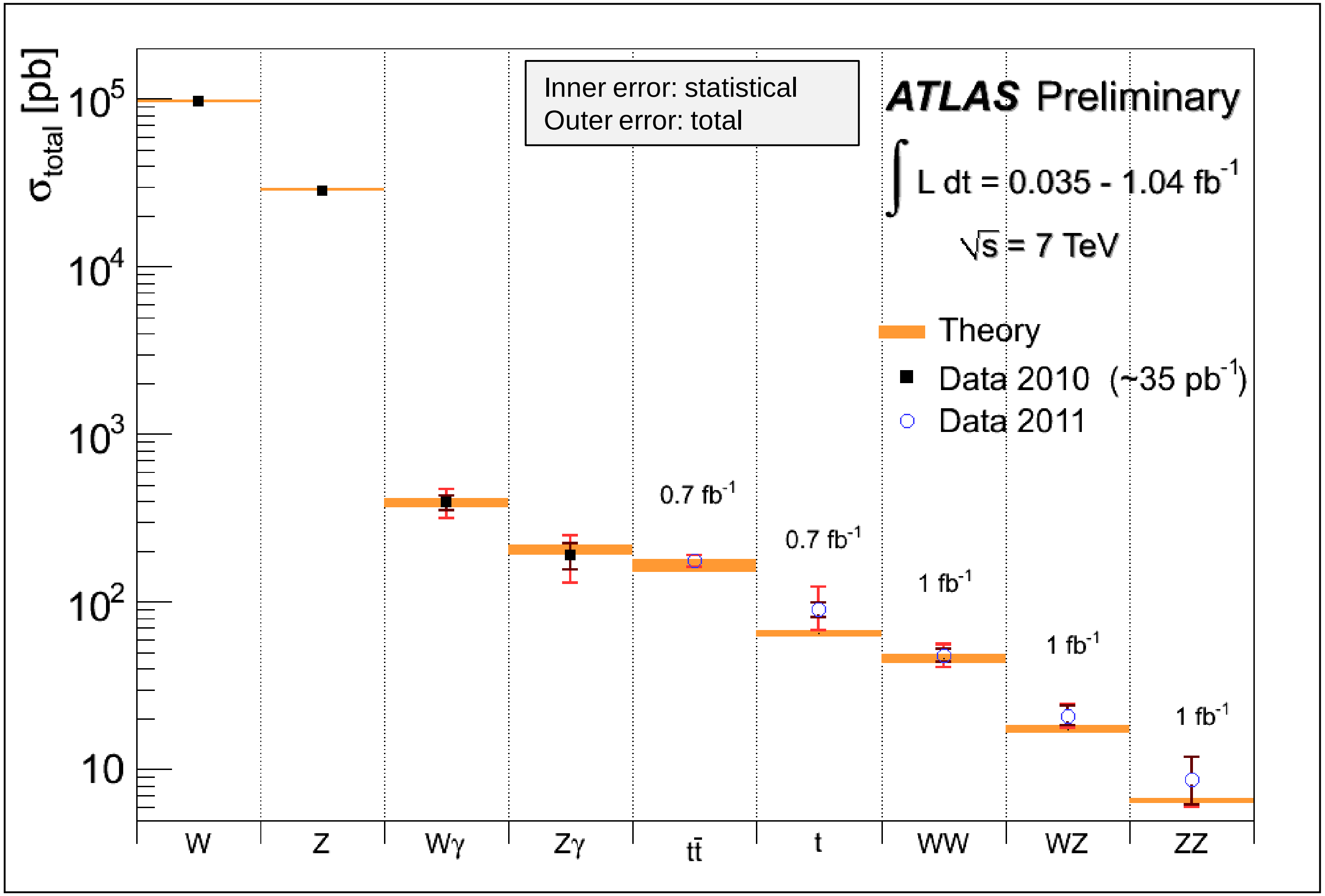


Electron energy response stability with pile-up in 2012 data



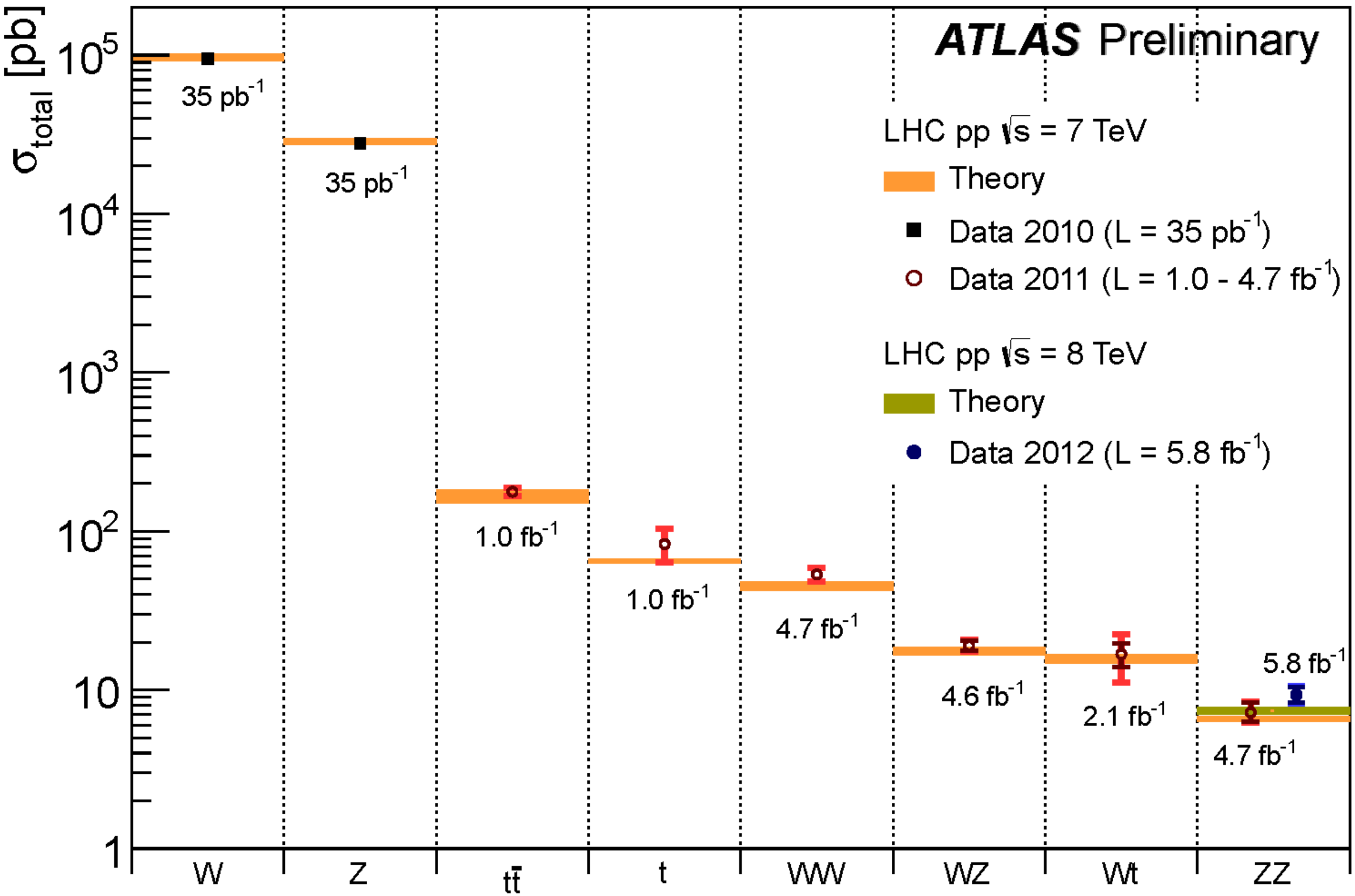
Summary of main electroweak and top cross-section measurements

2011年10月31日
日大理工・益川塾連携
素粒子物理学シンポジュウム



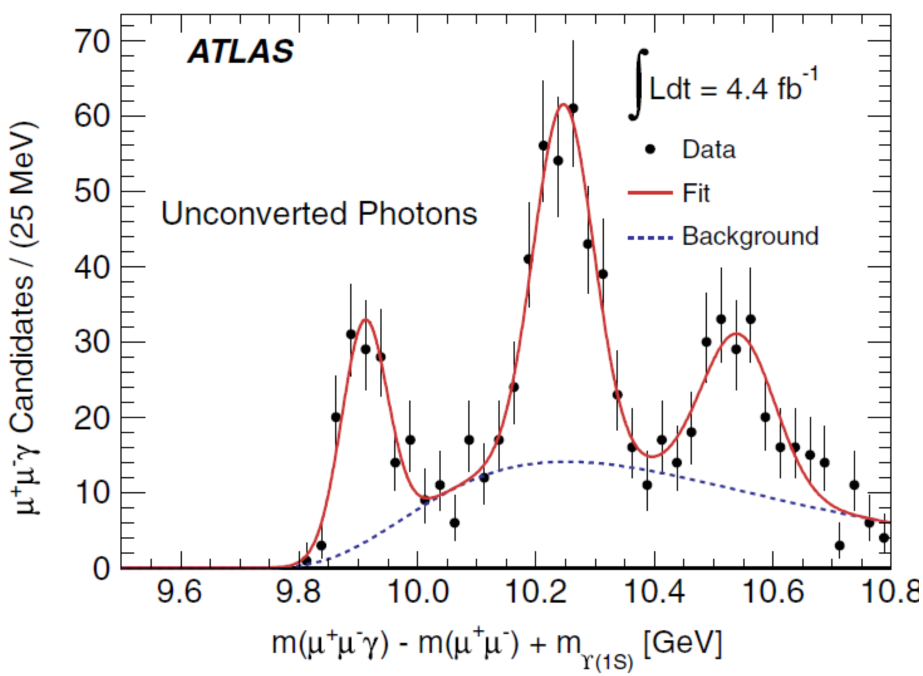
→ SM予想値とよい一致

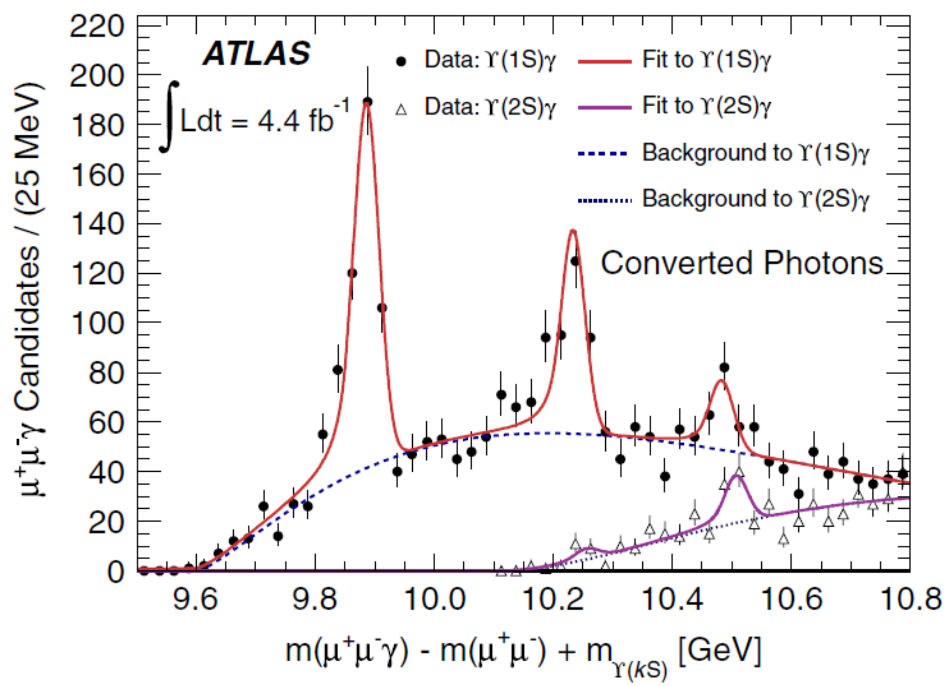
さらに統計を上げても、よい一致



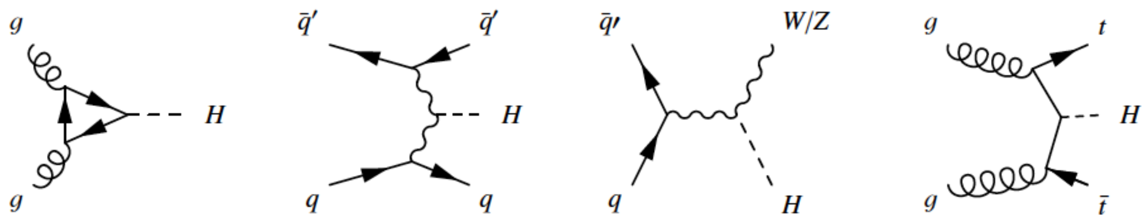
Observation of a New χ_b State in Radiative Transitions to $\Upsilon(1S)$ and $\Upsilon(2S)$ at ATLAS

The $\chi_b(nP)$ quarkonium states are produced in proton-proton collisions at the Large Hadron Collider at $\sqrt{s} = 7$ TeV and recorded by the ATLAS detector. Using a data sample corresponding to an integrated luminosity of 4.4 fb^{-1}, these states are reconstructed through their radiative decays to $\Upsilon(1S, 2S)$ with $\Upsilon \to \mu^+\mu^-$. In addition to the mass peaks corresponding to the decay modes $\chi_b(1P, 2P) \to \Upsilon(1S)\gamma$, a new structure centered at a mass of $10.530 \pm 0.005(\text{stat}) \pm 0.009(\text{syst})$ GeV is also observed, in both the $\Upsilon(1S)\gamma$ and $\Upsilon(2S)\gamma$ decay modes. This structure is interpreted as the $\chi_b(3P)$ system.

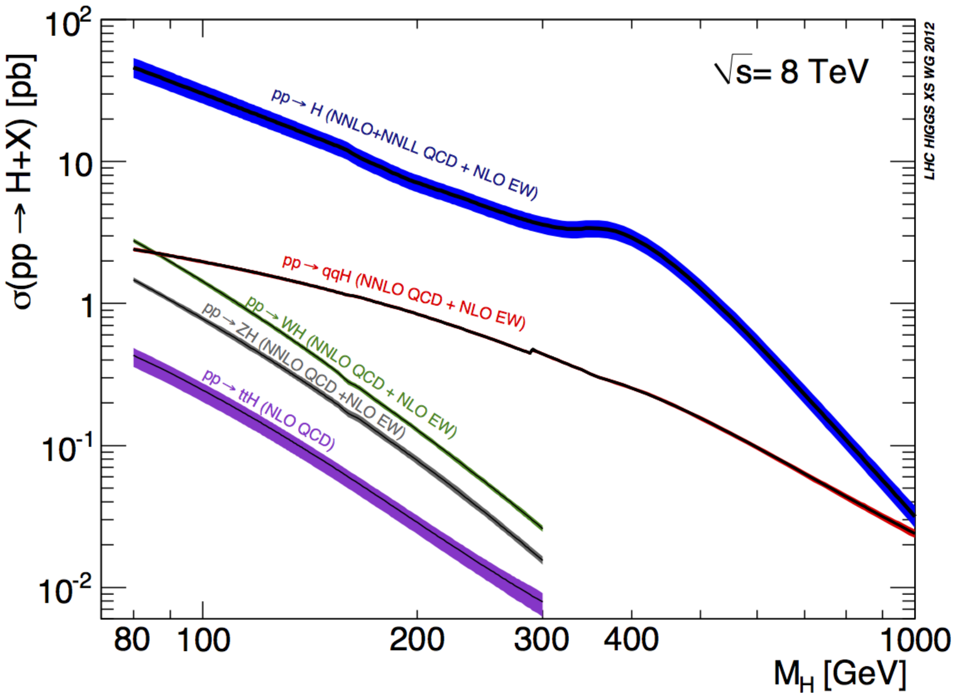




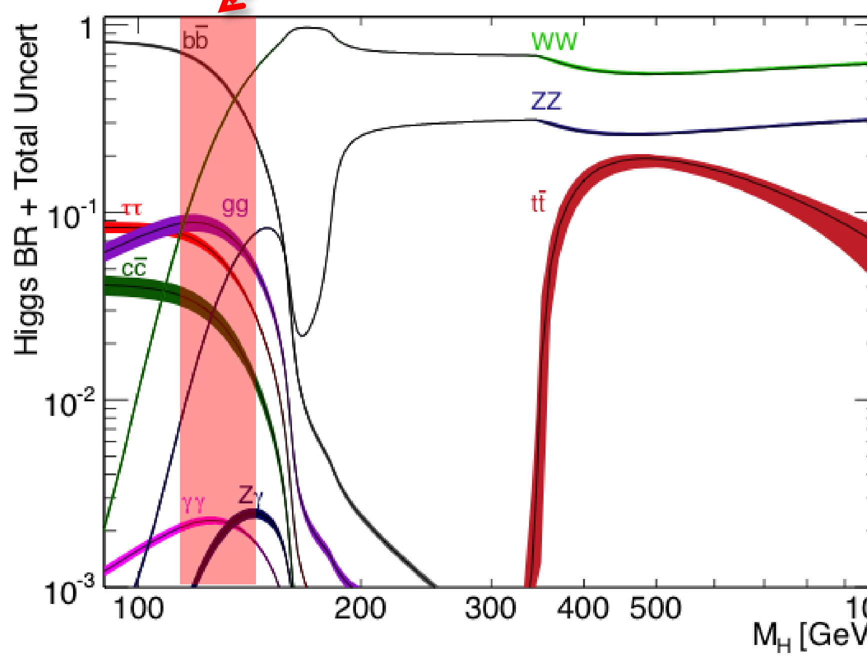
標準モデルヒッグス粒子探索

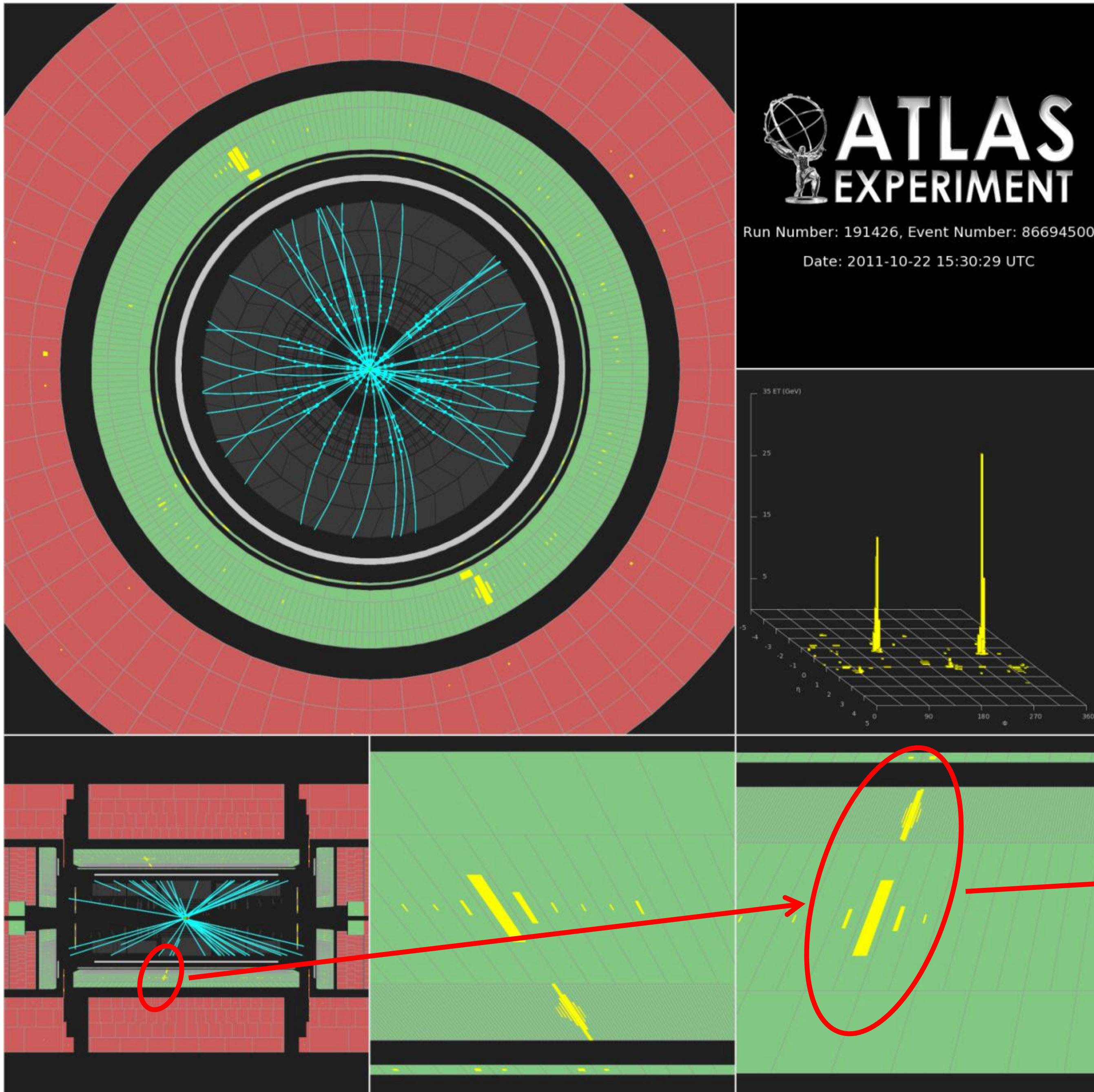


(a) $gg \to H$ (b) VBF (c) VH (d) $t\bar{t}H$



"The nature is very kind…"





$pp \to \mathrm{H} + \cdots$

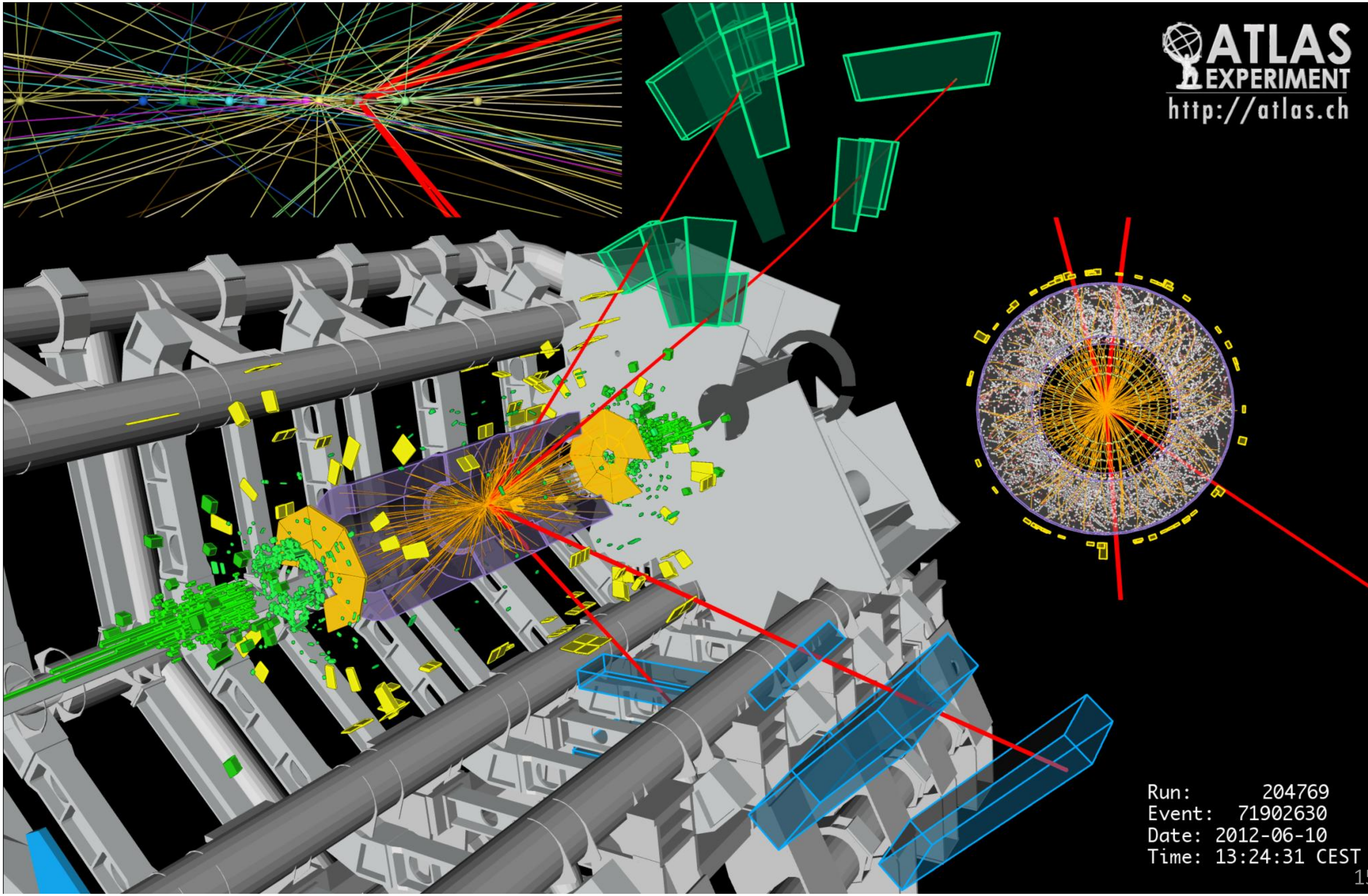
$\quad \to \gamma\gamma + \cdots$

LHCの陽子陽子衝突でヒッグス粒子が生成され２光子に崩壊する事象の候補。

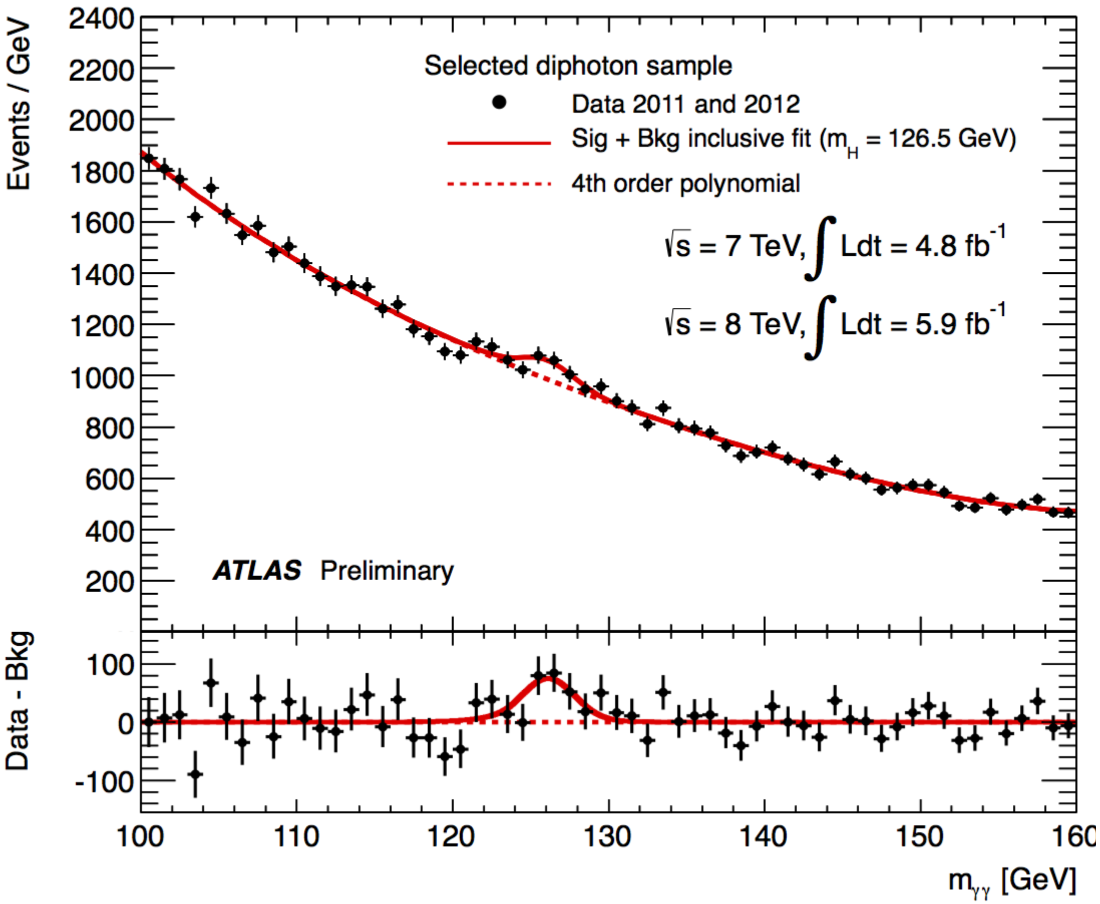
バックグランド事象も多い。

γ の方向も測定可能

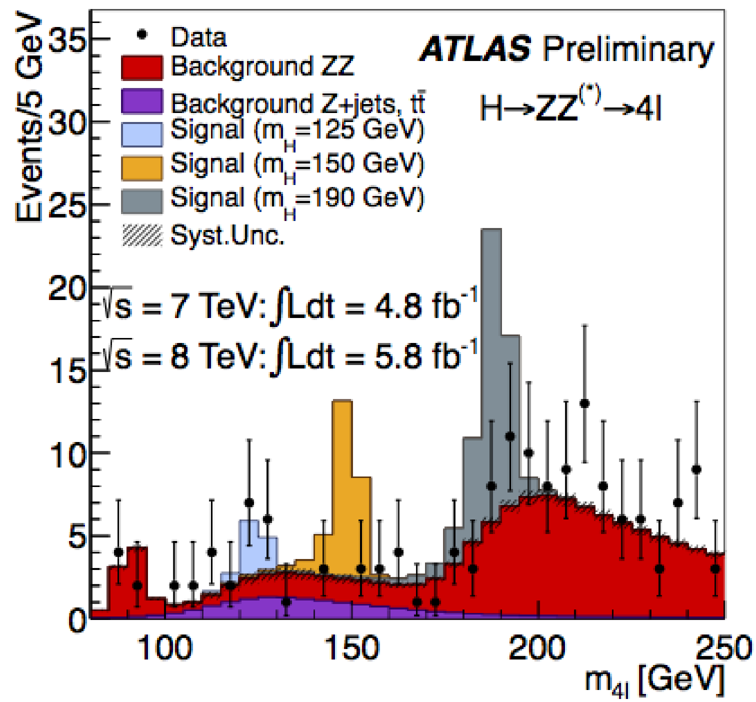
H → ZZ(*) → 4μ 候補事象（$m_{4\mu}$= 125.1 GeV）



ATLAS実験結果(7月4日発表)



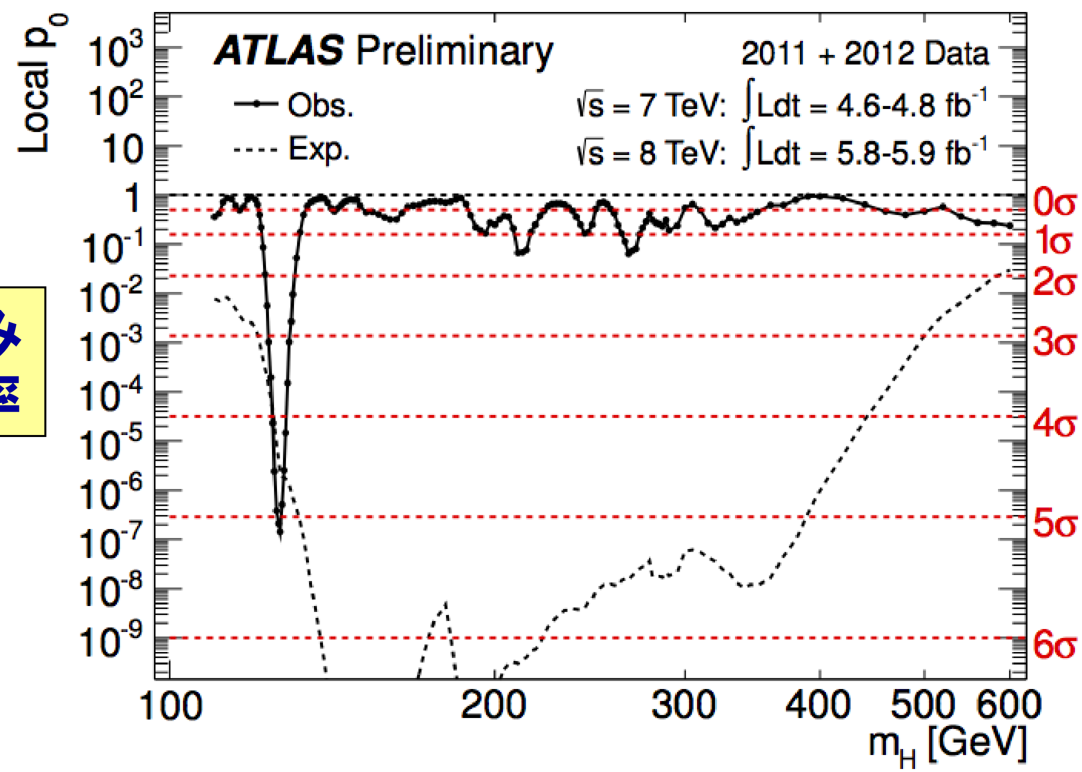
γγ 不変質量分布



4レプトン不変質量分布

Combined results: 新粒子発見！

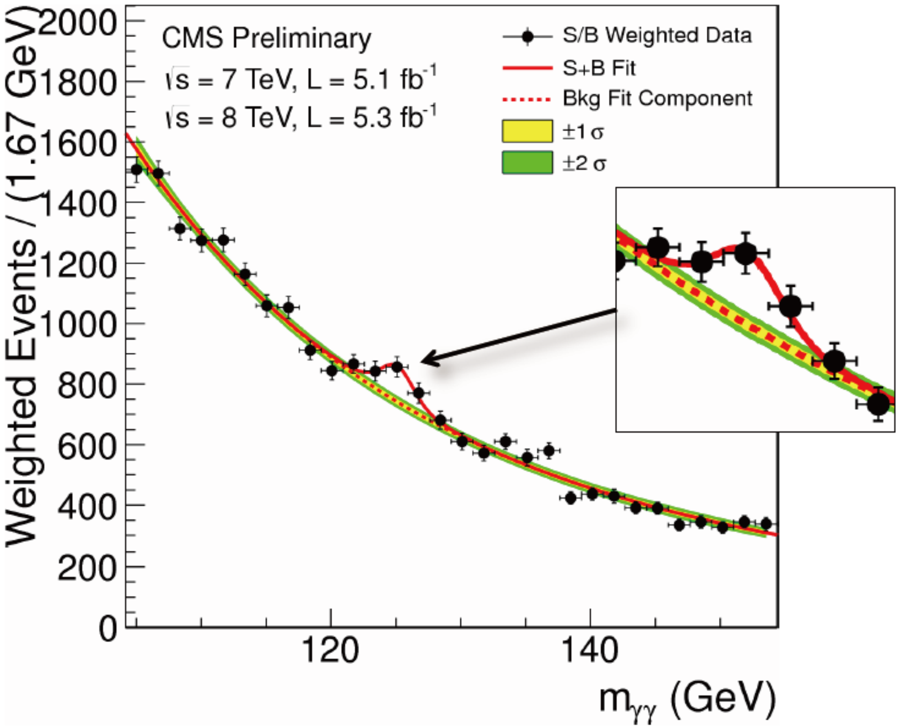
p_0: バックグラウンドのみから期待される確率



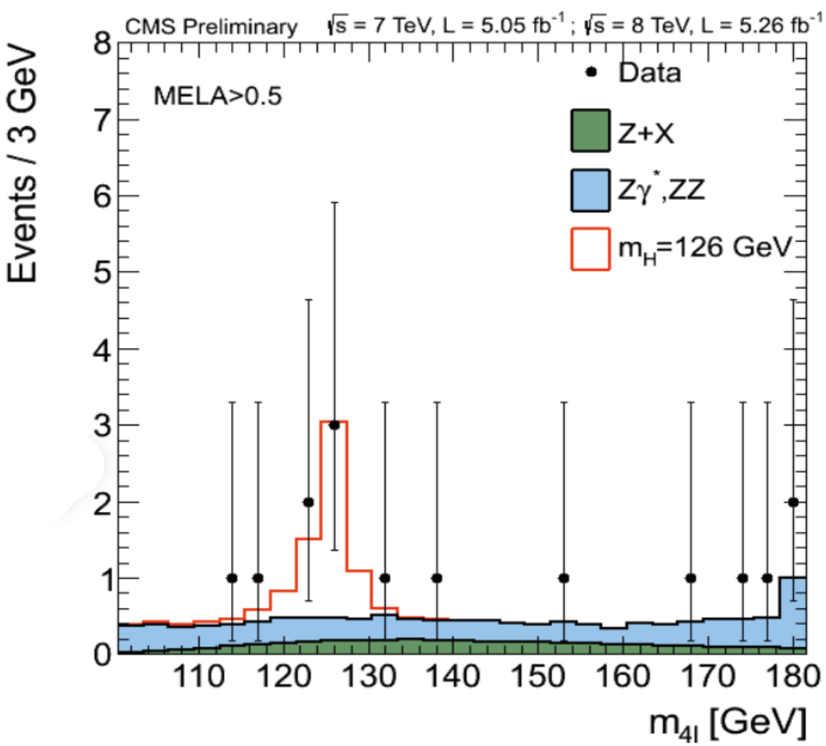
Maximum excess observed at	m_H = 126.5 GeV
Local significance (including energy-scale systematics)	5.0 σ
Probability of background up-fluctuation	3 x 10^{-7}
Expected from SM Higgs m_H=126.5	4.6 σ

CMS実験結果（7月4日発表）

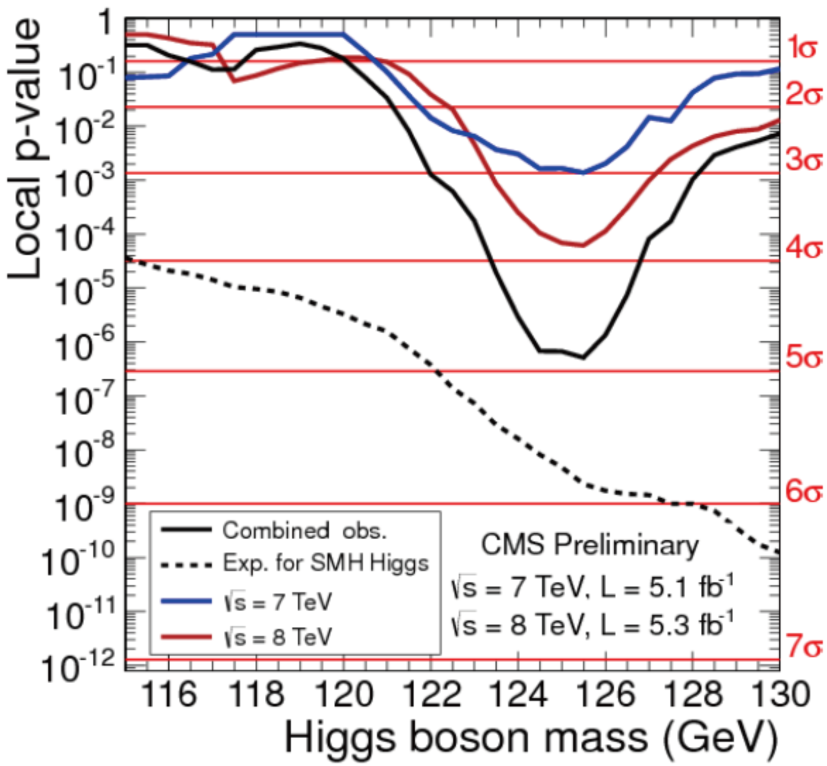
$H \to \gamma\gamma$



$H \to ZZ \to 4\ell$



Characterization of excess near 125 GeV

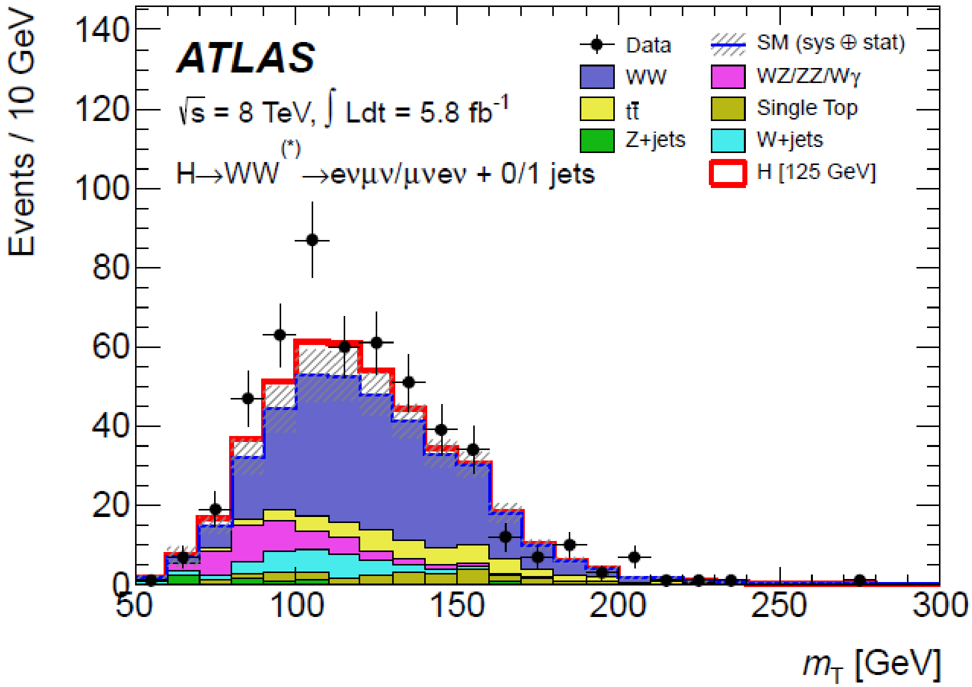


- **Observed significance: 4.9 σ**
- **Excess seen in both**
  - **7 TeV data (3.0 σ)**
  - **8 TeV data (3.8 σ)**
  - **near the <u>same mass</u> 125 GeV**

$m_X = 125.3 \pm 0.6$ GeV

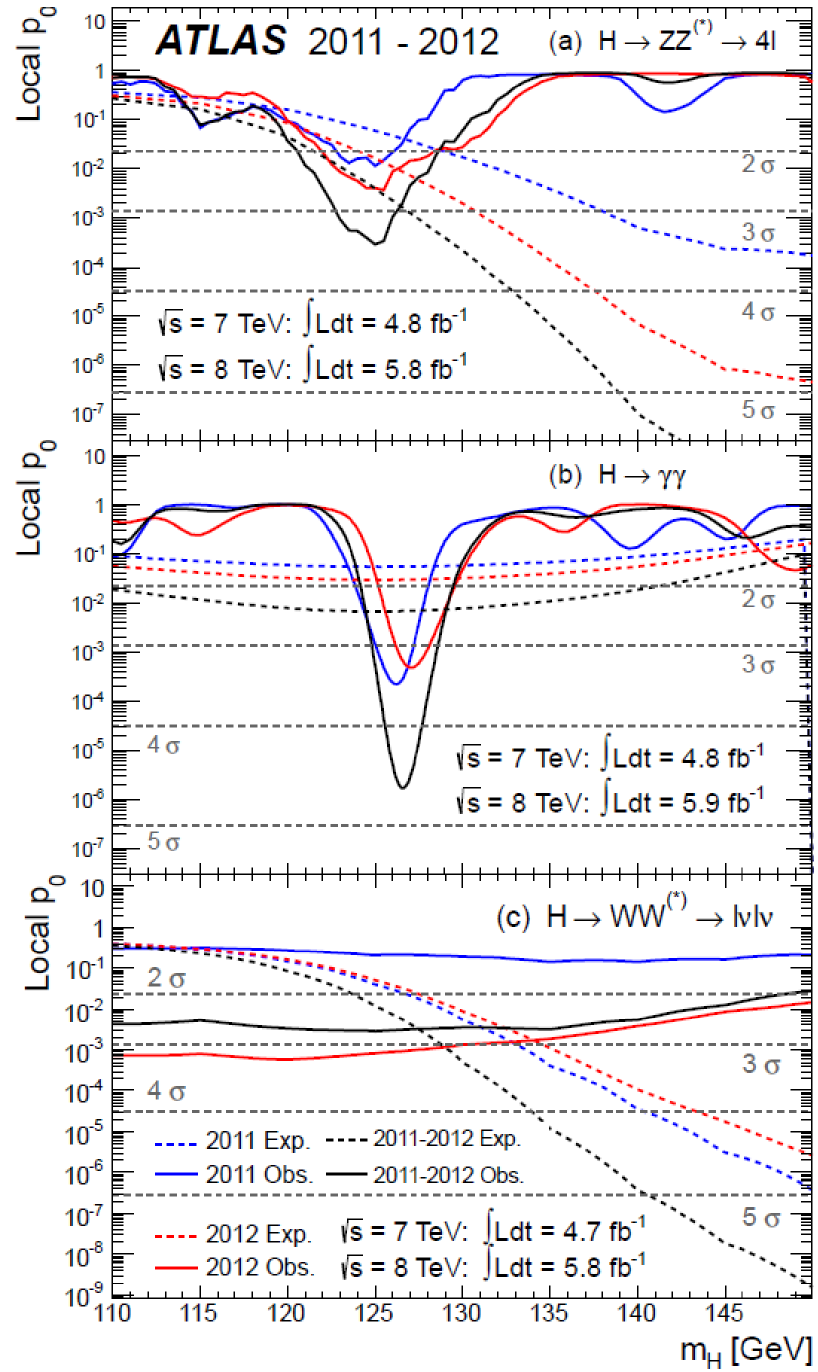
ATLASはH→WWの解析を更新

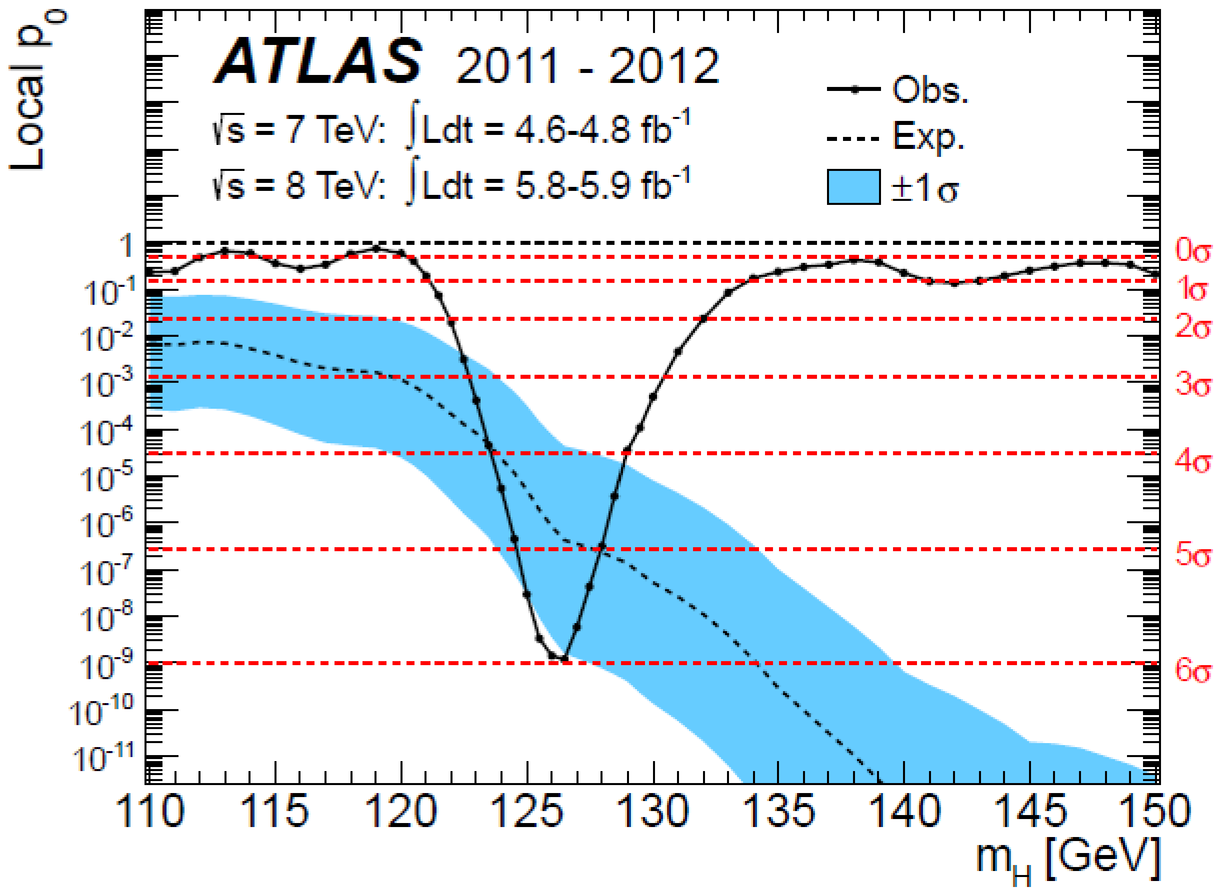
arXiv:1207.7214v1 [hep-ex] 31 Jul 2012



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

$$E_T^{\ell\ell} = \sqrt{|\mathbf{p}_T^{\ell\ell}|^2 + m_{\ell\ell}^2}$$





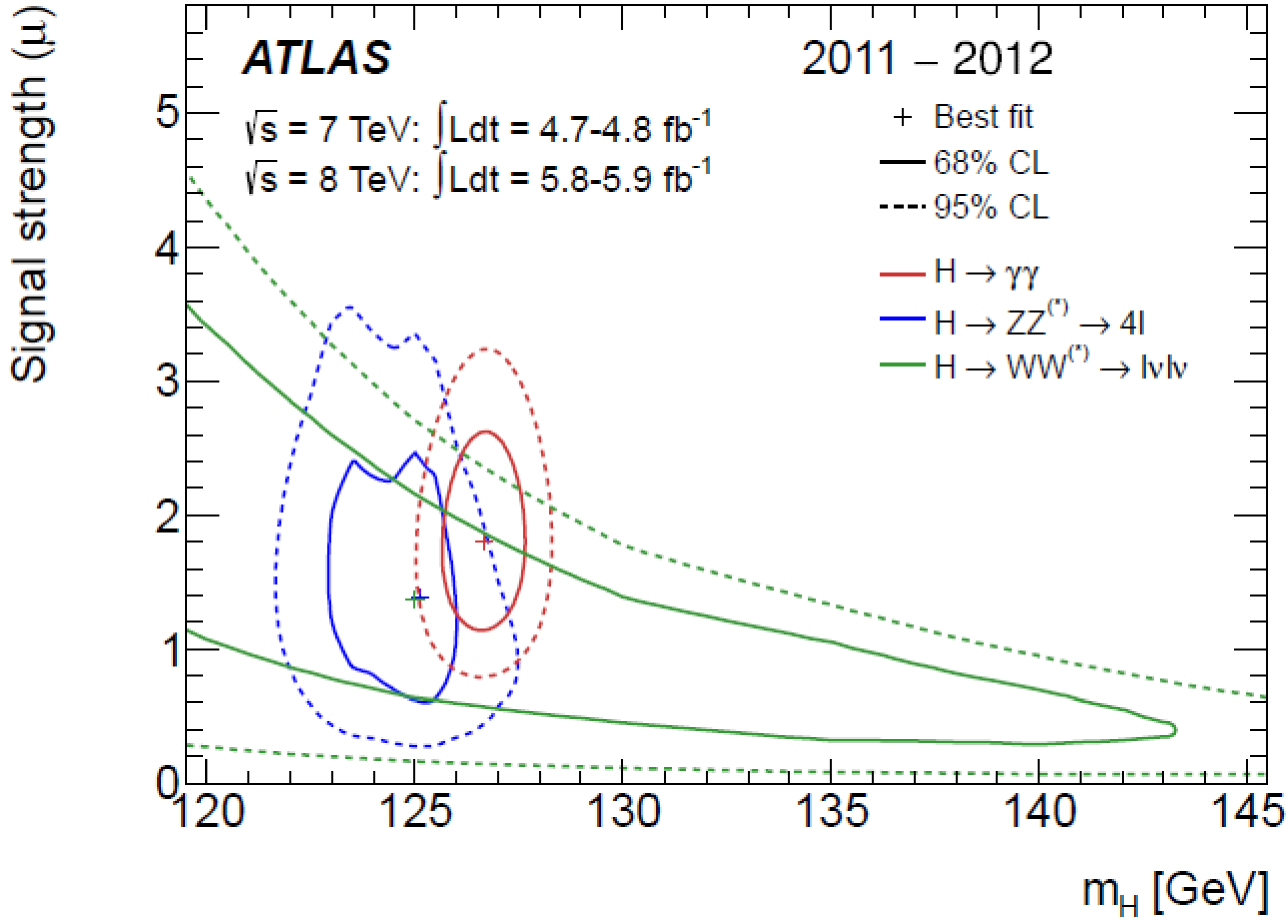
Local significance (including energy-scale systematics) 5.9 σ

Probability of background up-fluctuation 1.7×10^{-9}

Signal strength parameter μ

$\mu = 0$ --- BG only

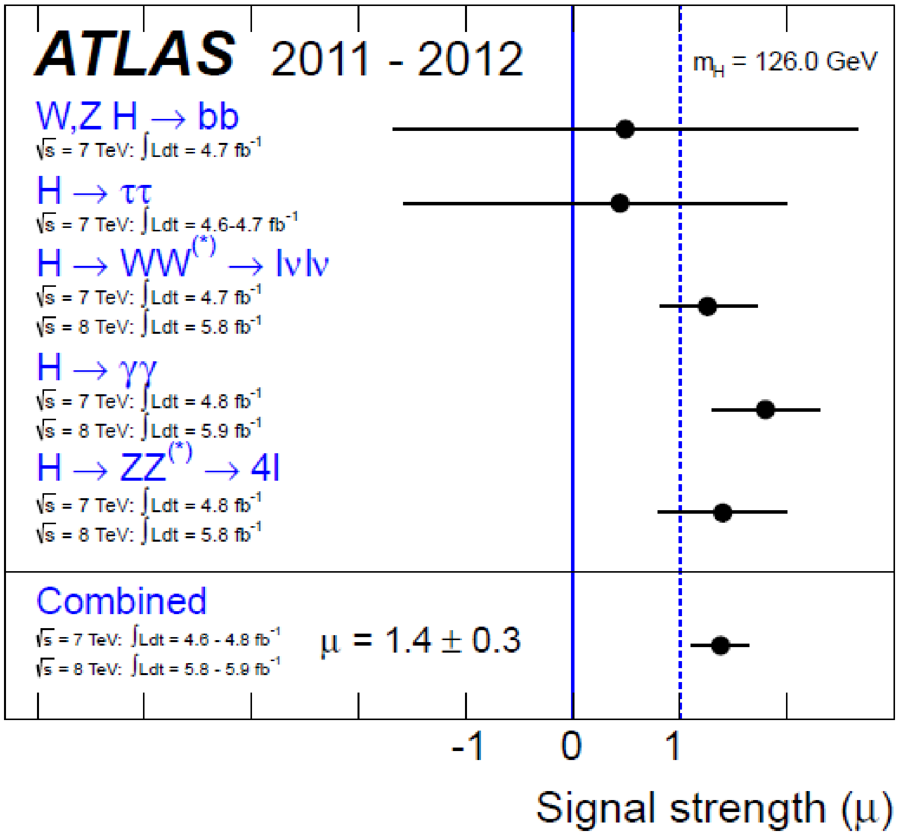
$\mu = 1$ --- SM-Higgs signal + BG

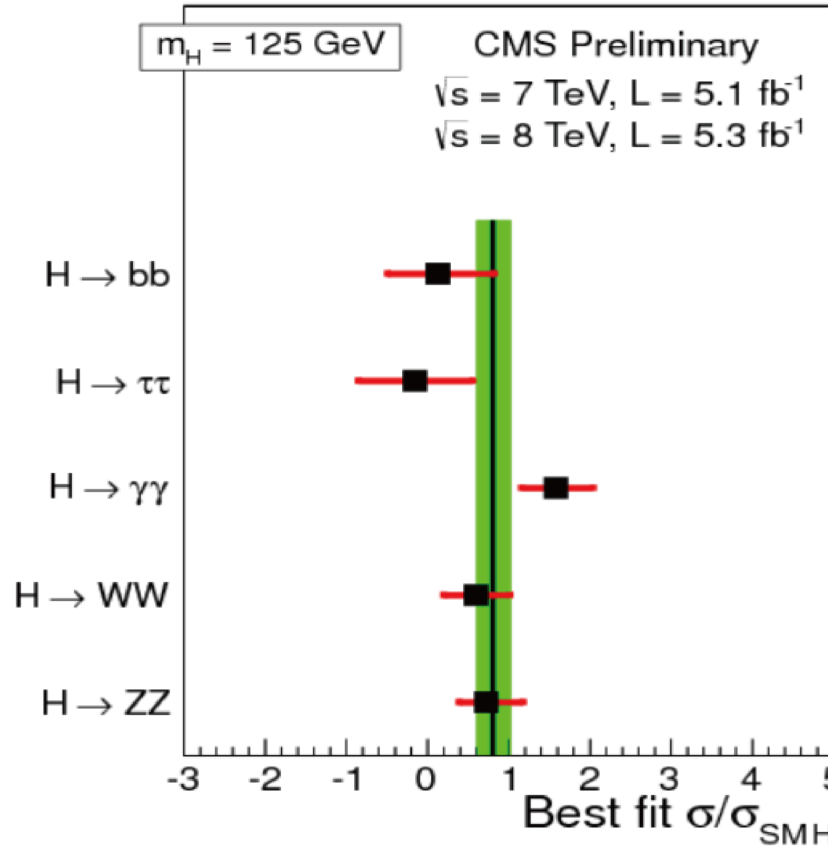


Measured mass = 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV

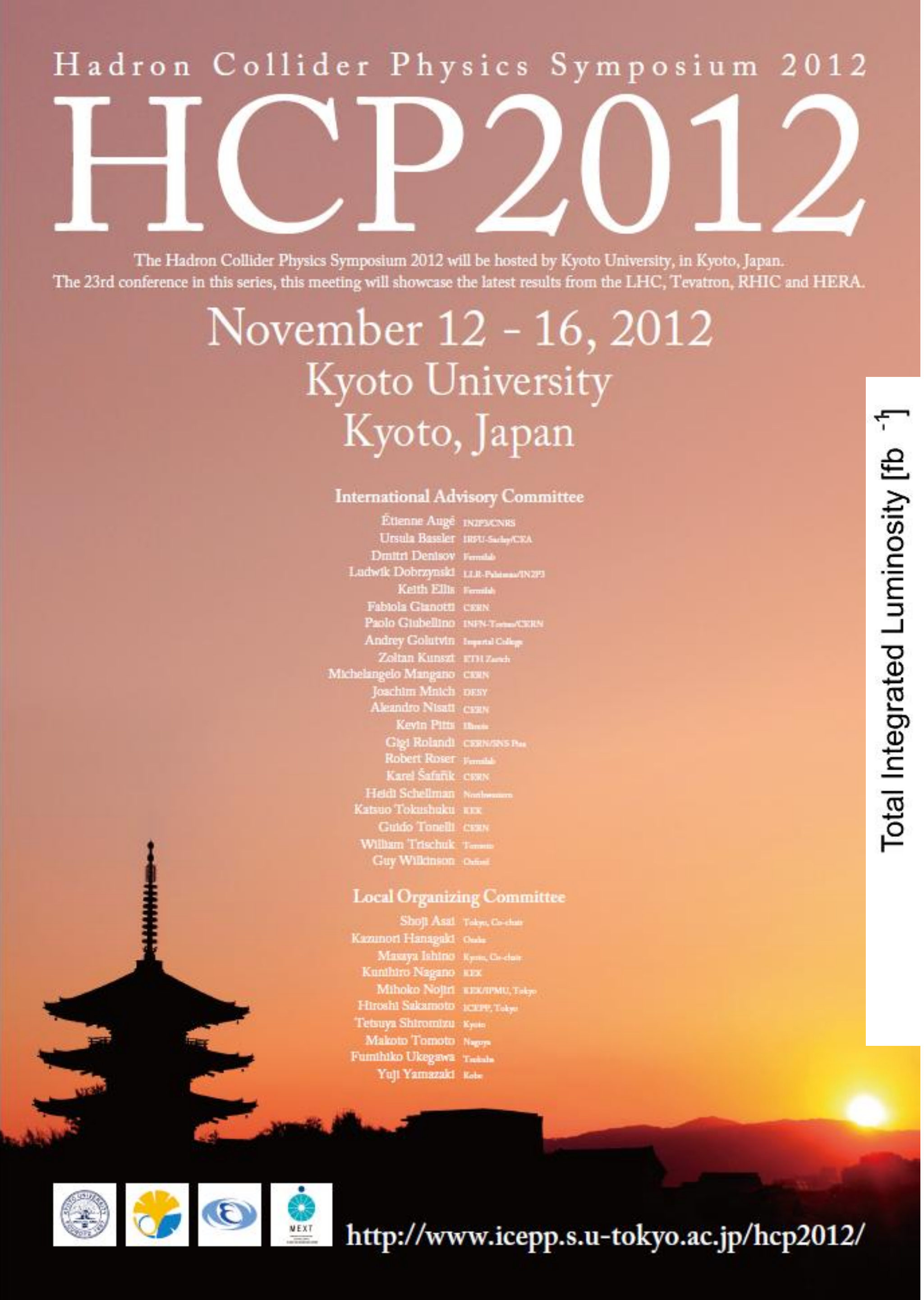
Best fit signal strength: $\hat{\mu} = 1.4 \pm 0.3$

発見された新粒子は標準理論のヒッグス粒子か？





- Spin, CP, coupling strength to f/V, self coupling
- SUSY-Higgs? Composite? Pseudo-NG boson? …


Hadron Collider Physics Symposium 2012
HCP2012
The Hadron Collider Physics Symposium 2012 will be hosted by Kyoto University, in Kyoto, Japan.
The 23rd conference in this series, this meeting will showcase the latest results from the LHC, Tevatron, RHIC and HERA.
November 12 - 16, 2012
Kyoto University
Kyoto, Japan
International Advisory Committee
Étienne Augé IN2P3/CNRS
Ursula Bassler IRFU-Saclay/CEA
Dmitri Denisov Fermilab
Ludwik Dobrzynski LLR-Palaiseau/IN2P3
Keith Ellis Fermilab
Fabiola Gianotti CERN
Paolo Giubellino INFN-Torino/CERN
Andrey Golutvin Imperial College
Zoltan Kunszt ETH Zurich
Michelangelo Mangano CERN
Joachim Mnich DESY
Aleandro Nisati CERN
Kevin Pitts Illinois
Gigi Rolandi CERN/SNS Pisa
Robert Roser Fermilab
Karel Šafařík CERN
Heidi Schellman Northwestern
Katsuo Tokushuku KEK
Guido Tonelli CERN
William Trischuk Toronto
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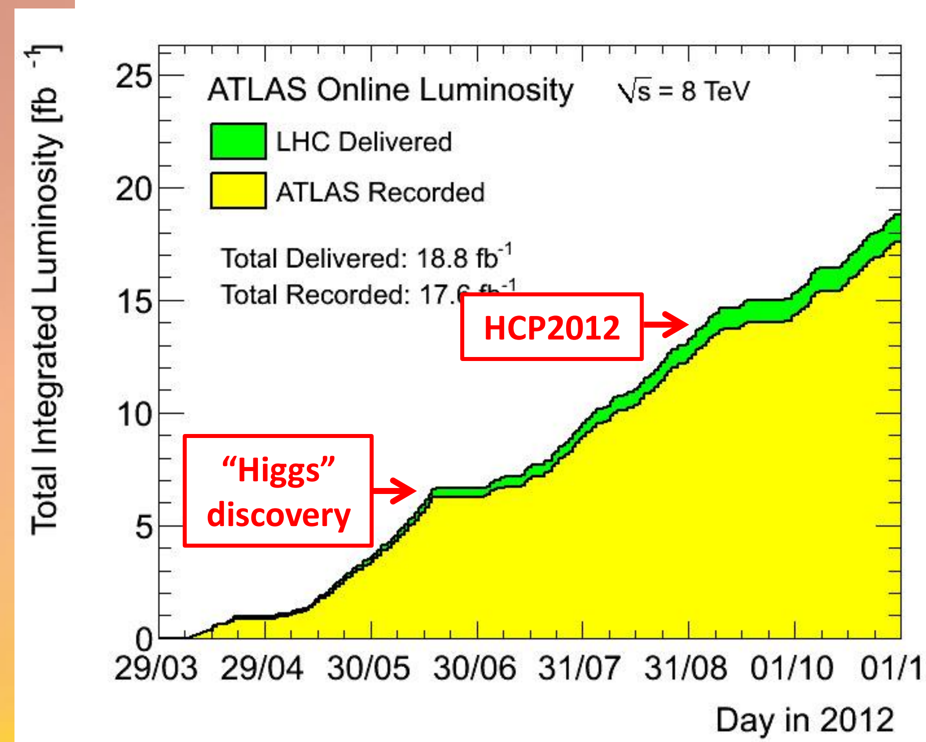
Hiroshi Sakamoto ICEPP, Tokyo
Tetsuya Shiromizu Kyoto
Makoto Tomoto Nagoya
Fumihiko Ukegawa Tsukuba
Yuji Yamazaki Kobe
http://www.icepp.s.u-tokyo.ac.jp/hcp2012/


ATLAS Online Luminosity
√s = 8 TeV
LHC Delivered
ATLAS Recorded
Total Delivered: 18.8 fb⁻¹
Total Recorded: 17.6 fb⁻¹
HCP2012
"Higgs" discovery
Total Integrated Luminosity [fb⁻¹]
0
5
10
15
20
25
29/03
29/04
30/05
30/06
31/07
31/08
01/10
01/11
Day in 2012

News

HUNDRED AND SIXTY-FOURTH SESSION OF COUNCIL

20 September 2012

RESTRICTED SESSION

TERMINOLOGY TO BE USED WITH RESPECT TO THE ELECTROWEAK SYMMETRY-BREAKING MECHANISM

The Council agreed that the electroweak symmetry-breaking mechanism should continue to be referred to as the **Brout-Englert-Higgs (or BEH) mechanism** in all official CERN communications, while the boson associated with that mechanism could continue to be called "**the Higgs boson**", as that term had long since passed into common parlance.

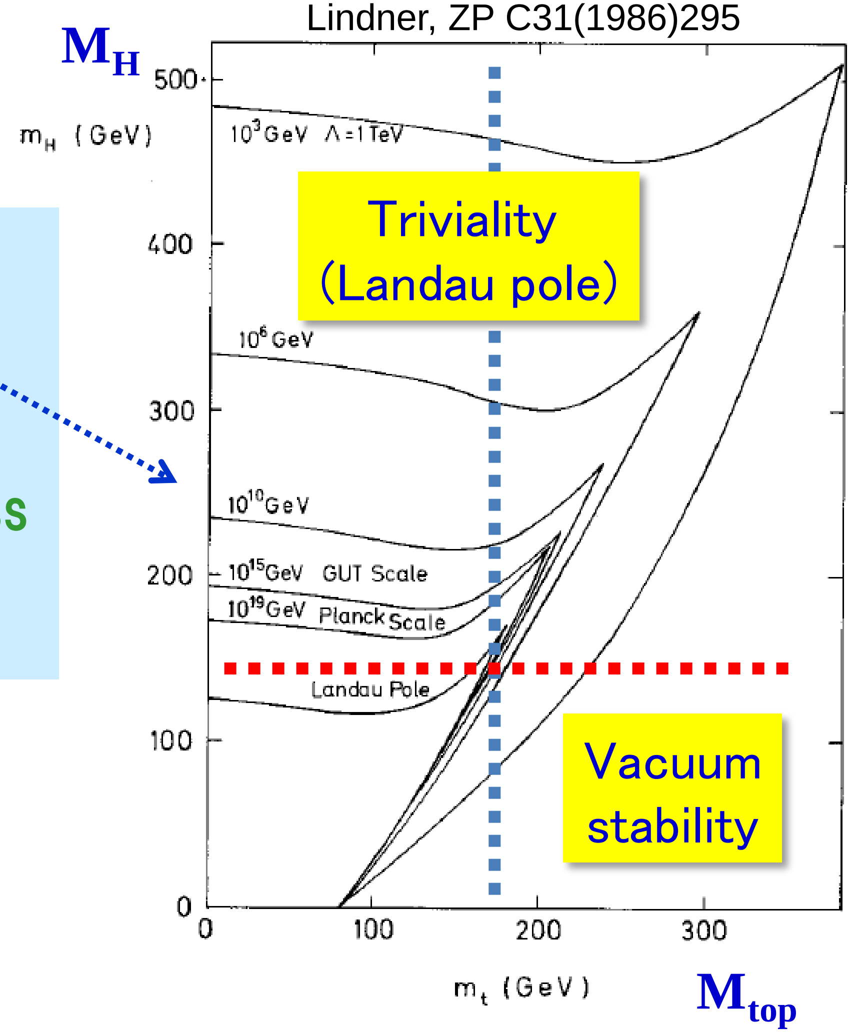
"ヒッグス粒子"質量は実に微妙な値…

Measured mass = 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV ←ATLAS

125.3 ± 0.4 (stat.) ± 0.5 (syst.) GeV ←CMS

- SM(がM$_{Pl}$まで正しいとすると)のHiggsとしては、やや軽過ぎ
- SUSY Higgsとしては、やや重過ぎ
  - Hierarchy problem / naturalness
  - GUT
  - Dark matter

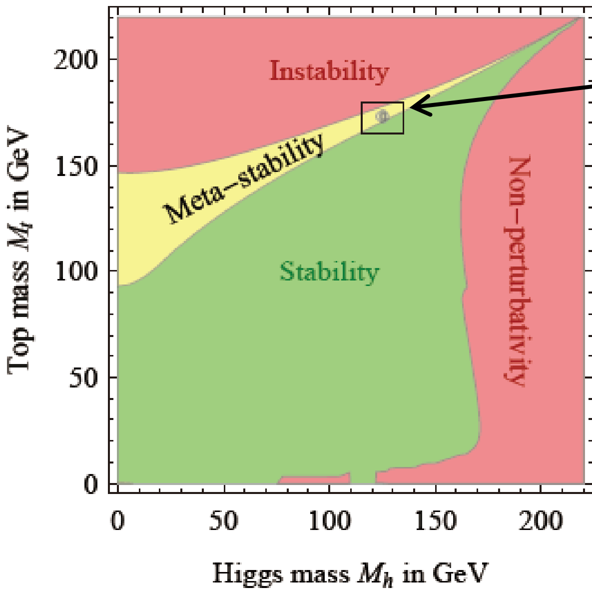
Lindner, ZP C31(1986)295

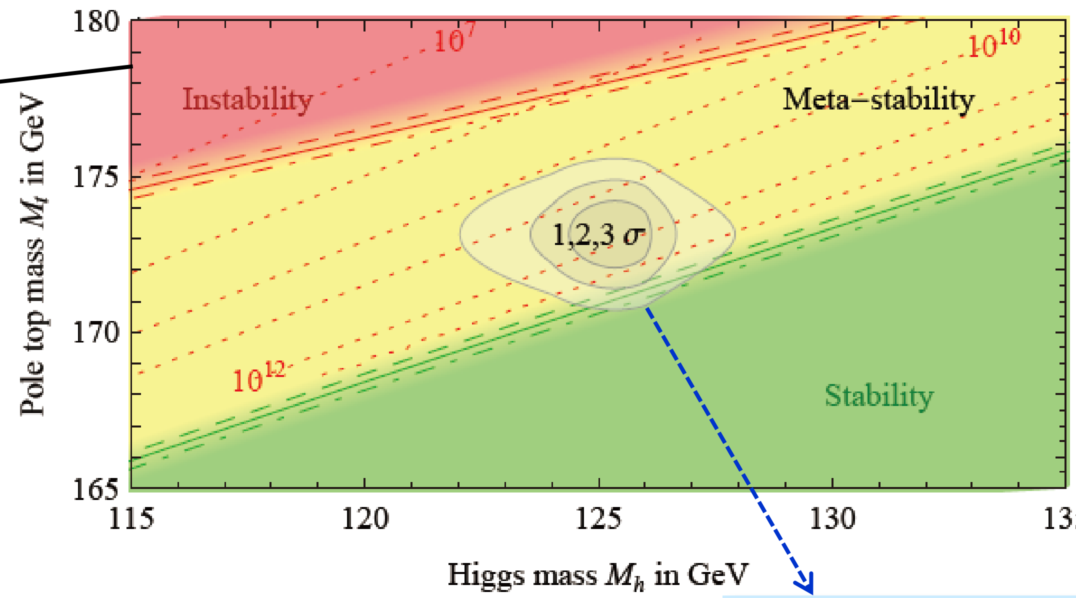


標準理論はどこまで正しいか？

Assume SM correct up to M_{Pl}

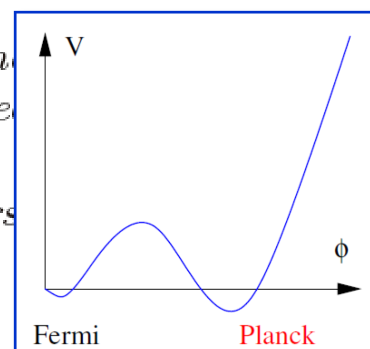
G.Degrassi et al., JHEP 08(2012)098





Higgs inflation?

Figure 5: *Regions of absolute stability, meta-stability an*… *M vacuum in the* M_t–M_h *plane.* **Right**: *Zoom in the region of the preferre*… *e of* M_h *and* M_t *(the gray areas denote the allowed region at 1, 2, and 3σ).* … *es lines correspond to* $\alpha_s(M_Z) = 0.1184 \pm 0.0007$*, and the grading of the colors* … *f the theoretical error. The dotted contour-lines show the instability scale Λ in* … $_Z) = 0.1184$.



F.Bezrukov et al., arXiv:1205.2893

Higgs searches

SUSY Higgs?

- In the SM, the Higgs mass is essentially a free parameter
- In the MSSM, the lightest CP-even Higgs particle is bounded from above:
  $M_h^{max} \approx M_Z |\cos 2\beta| +$ radiative corrections $\lesssim 110 - 135$ GeV
- Imposing M_h places very strong constraints on the MSSM parameters through their contributions to the radiative corrections

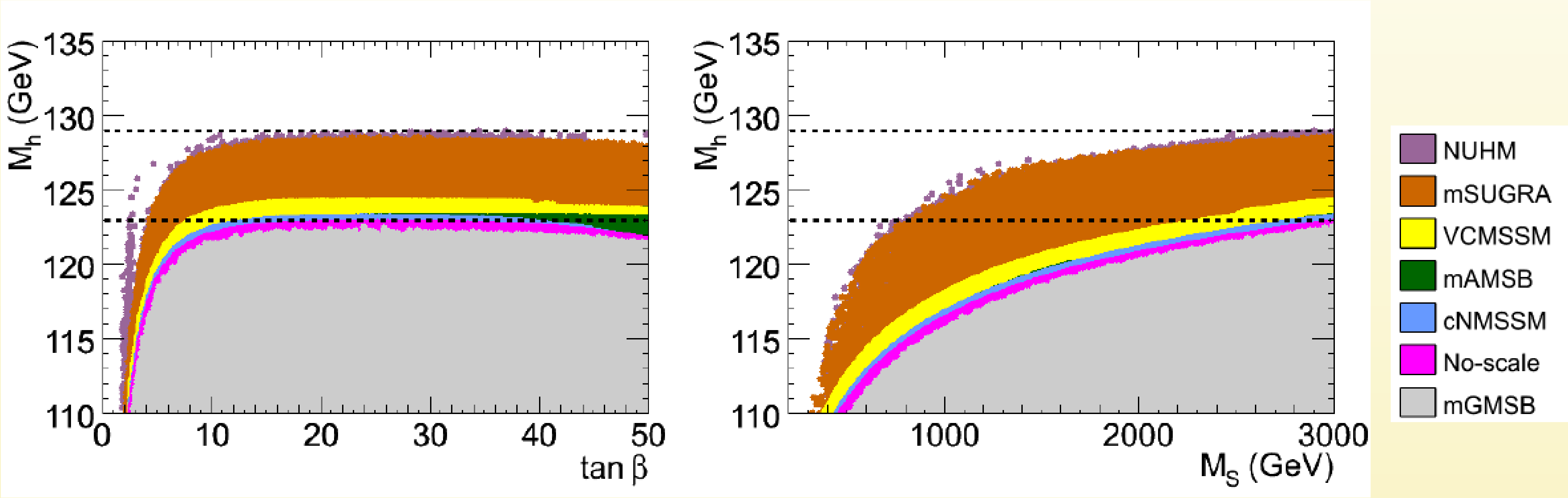
$$M_h^2 \overset{M_A \gg M_Z}{\approx} M_Z^2 \cos^2 2\beta + \frac{3m_t^4}{2\pi^2 v^2}\left[\log\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right]$$

- Important parameters for MSSM Higgs mass:
  - $\tan\beta$ and M_A
  - the SUSY breaking scale $M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$
  - the mixing parameter in the stop sector $X_t = A_t - \mu \cot\beta$
- M_h^{max} is obtained for:
  - a decoupling regime with a heavy pseudoscalar Higgs boson, $M_A \sim \mathcal{O}(\text{TeV})$
  - large $\tan\beta$, *i.e.* $\tan\beta \gtrsim 10$
  - heavy stops, *i.e.* large M_S
  - maximal mixing scenario, *i.e.* $X_t = \sqrt{6} M_S$

Consequences of a 126 GeV Higgs on constrained MSSM scenarios

Maximal Higgs mass

$m_t = 173$ GeV

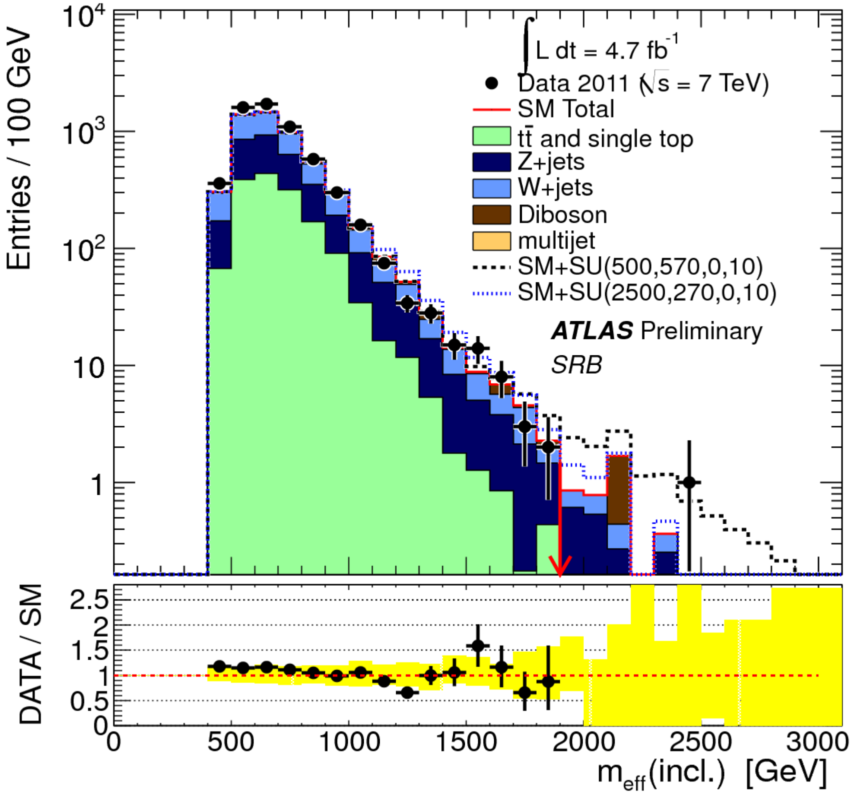


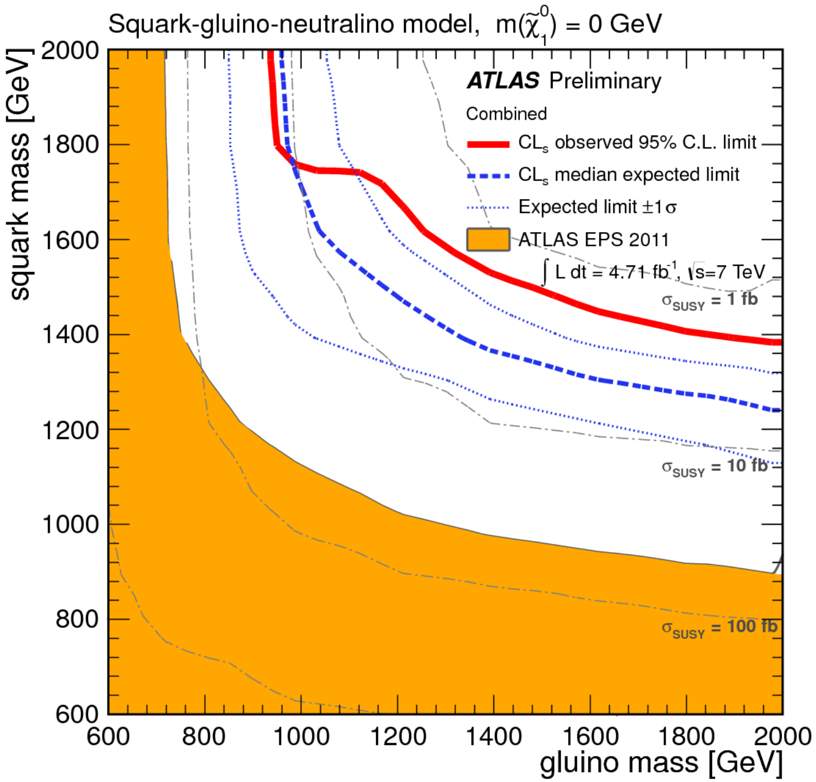
A. Arbey, M. Battaglia, A. Djouadi, F.M., to appear

Several constrained models are excluded or about to be!

SUSY Search

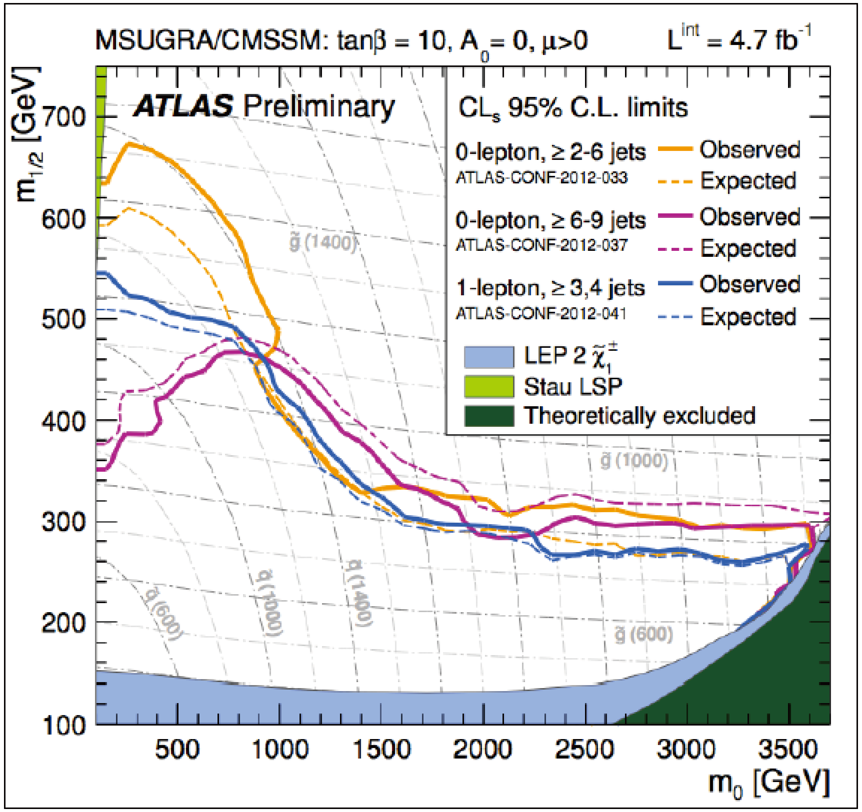
0-lepton + 2-6 jets + $E_{T,miss}$ Analysis

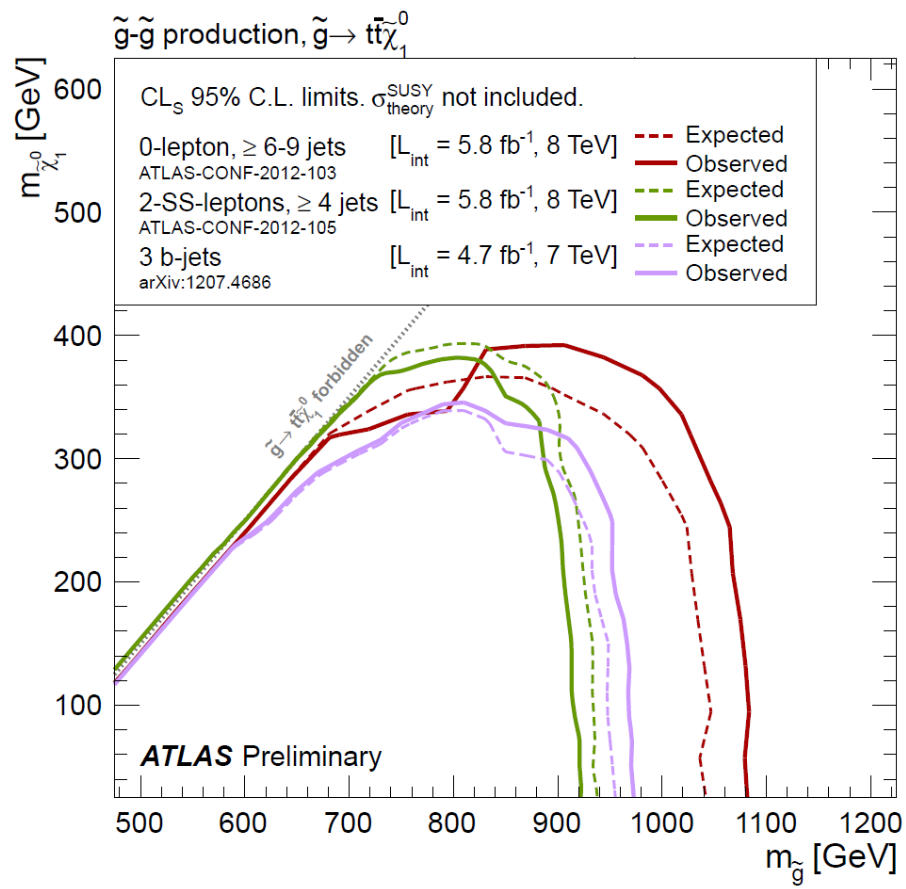




Simplified squark-gluino-neutralino model (m_{LSP} = 0)

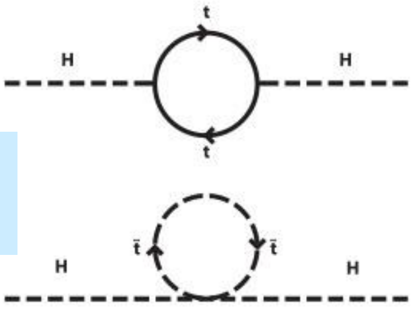
MSUGRA/CMSSM models with tanβ = 10, A_0 = 0 and μ > 0

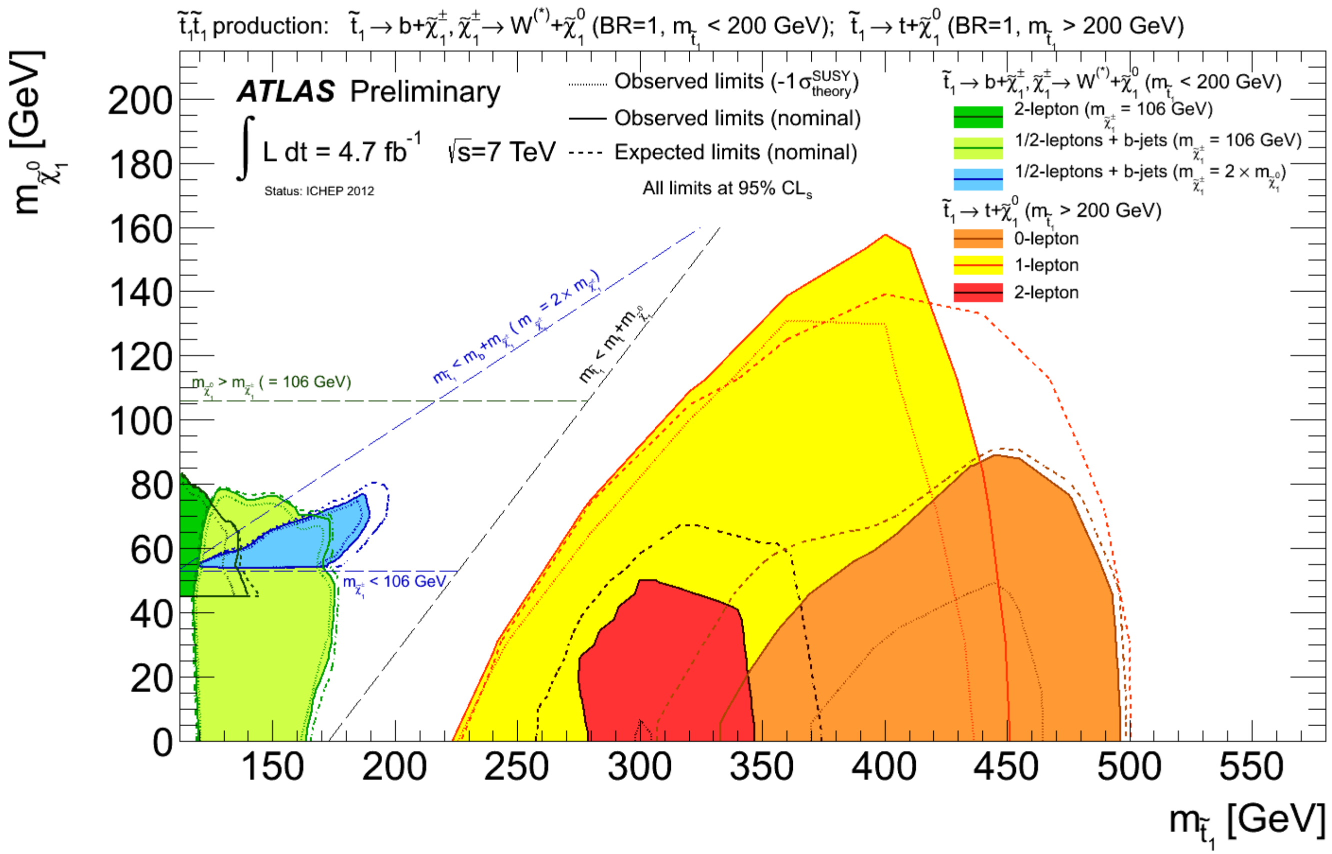


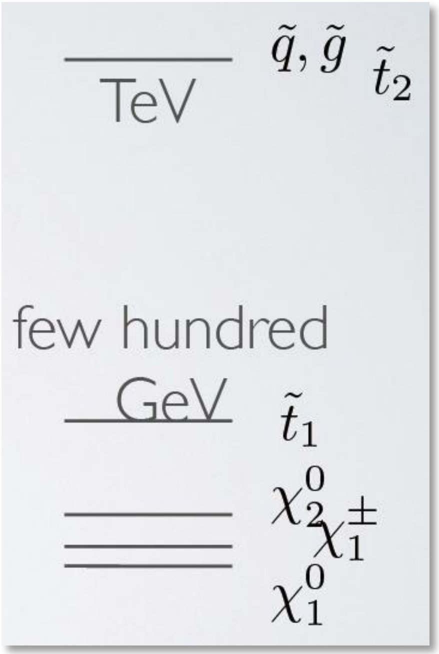


Combined Stop Exclusion

Natural SUSY?

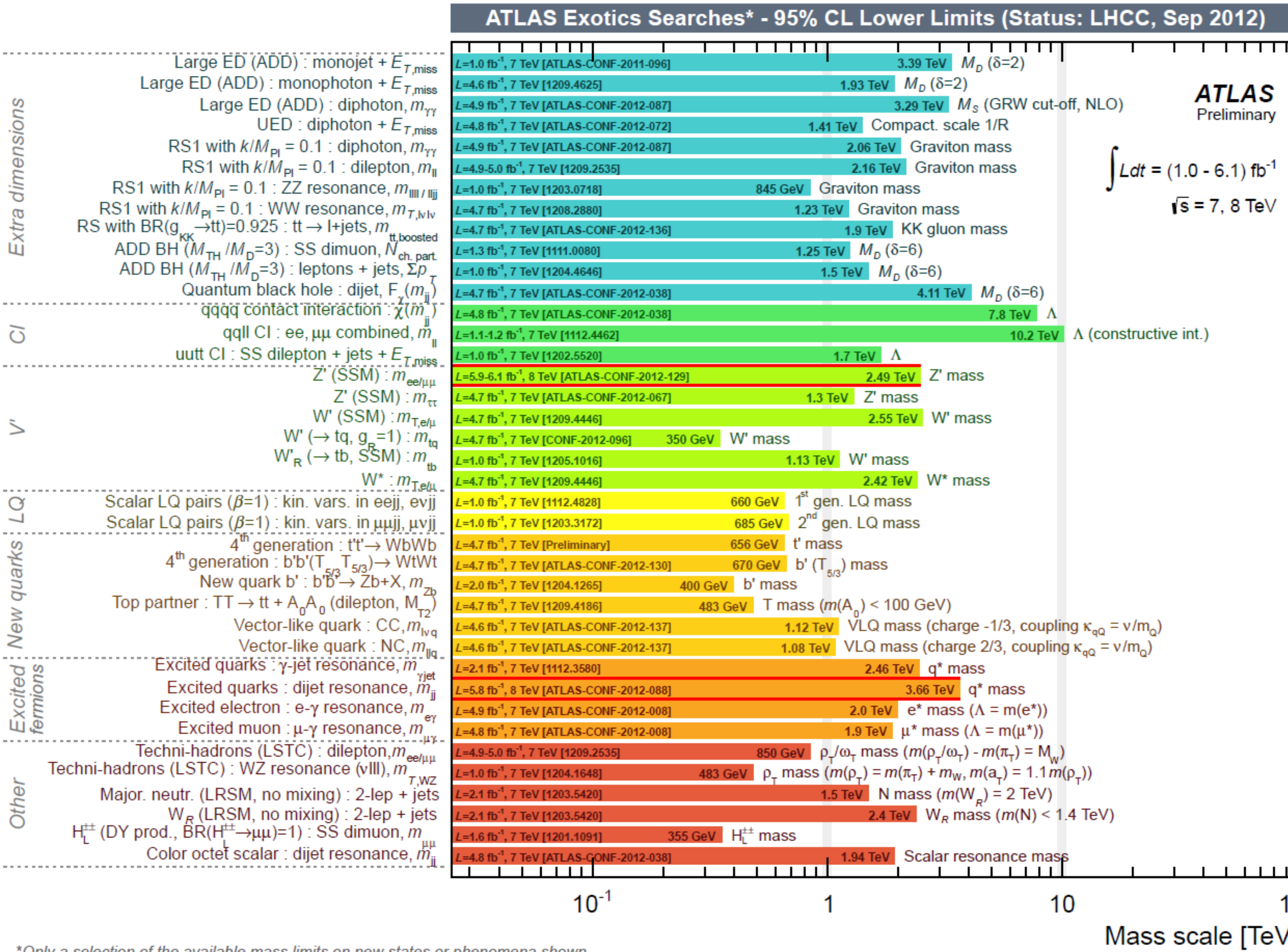




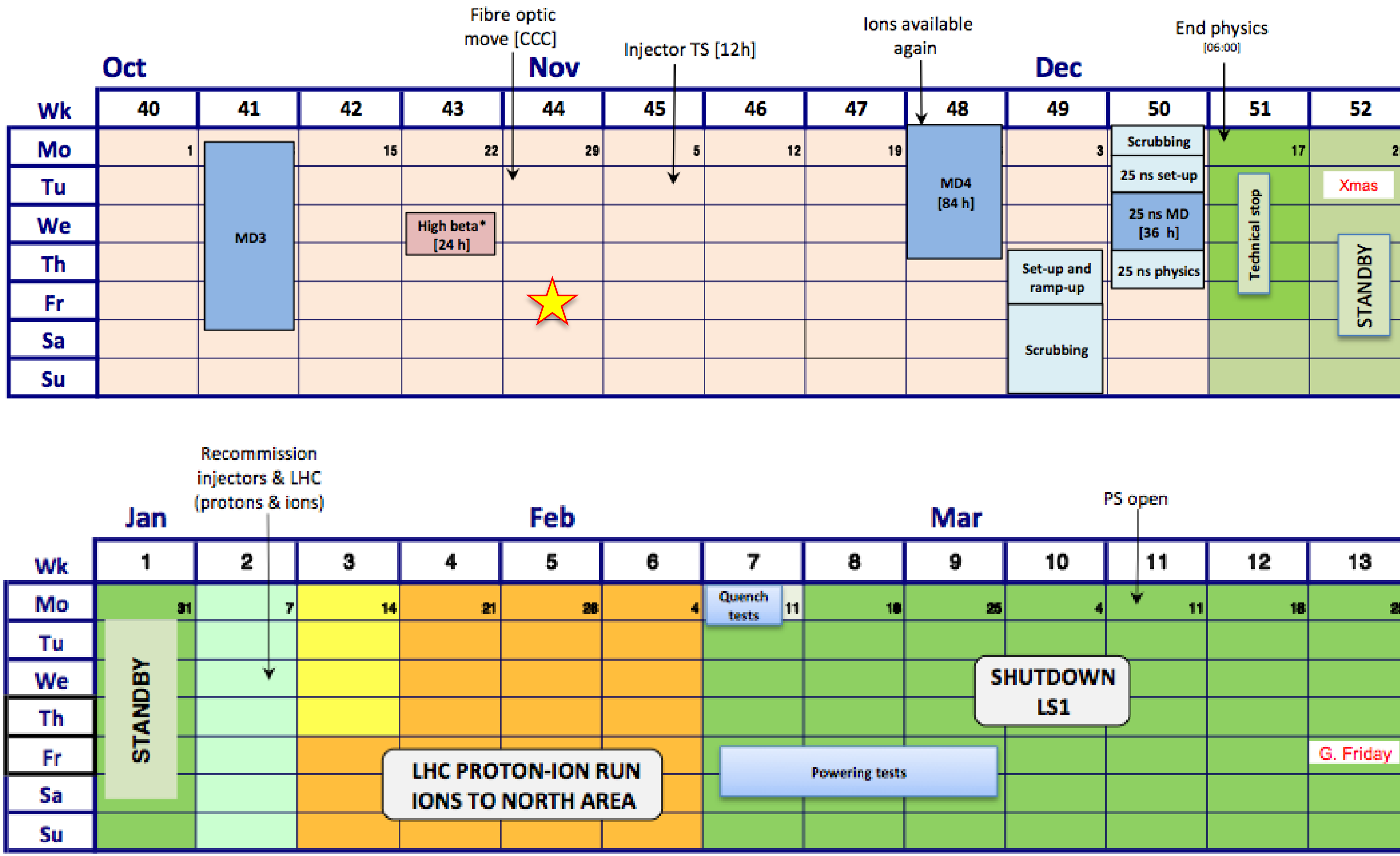


→ Is the nature unnatural?

No other hints for new physics, so far …

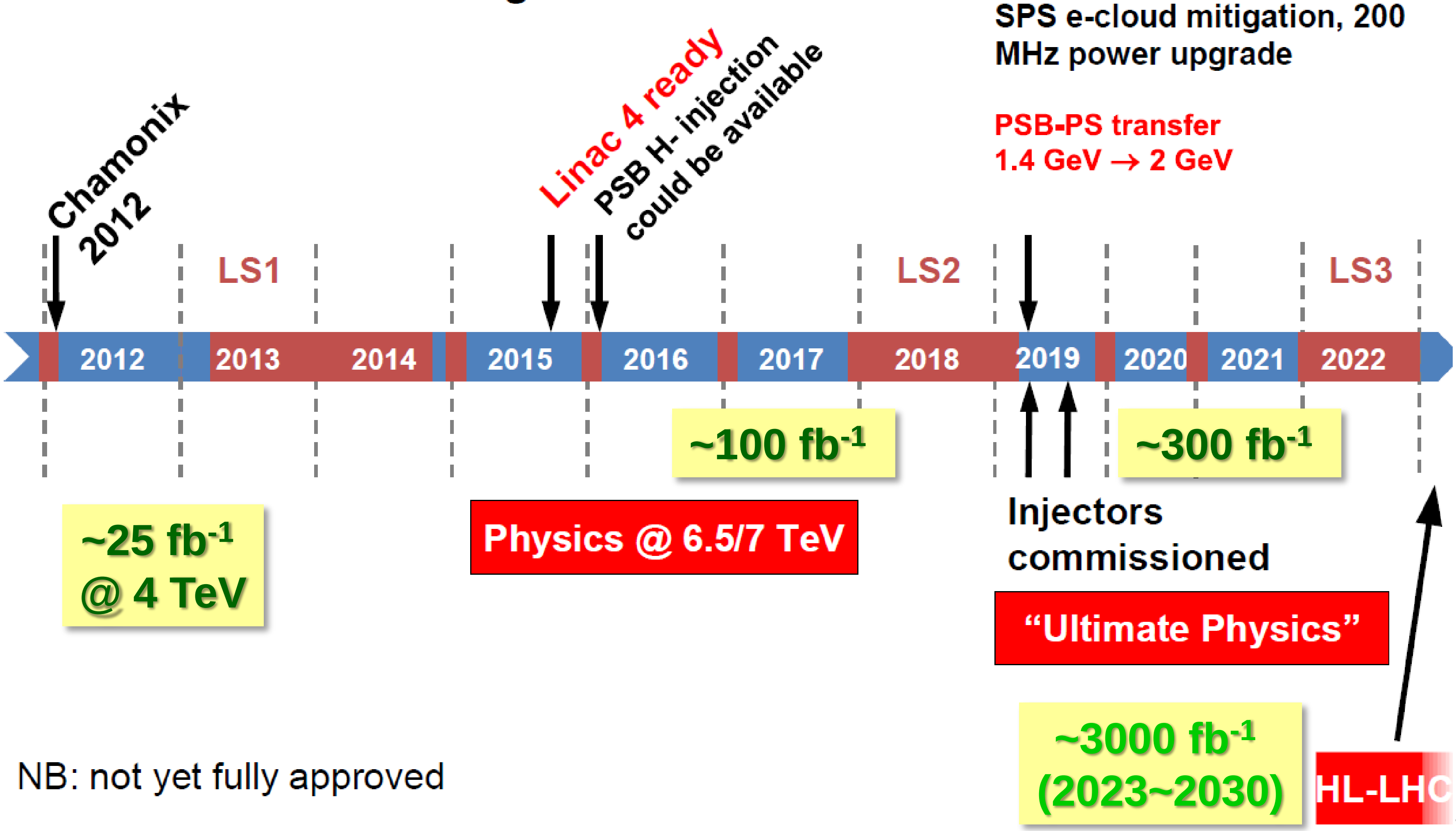


LHC今後の運転予定


Fibre optic move [CCC]
Injector TS [12h]
Ions available again
End physics [06:00]
Oct
Nov
Dec
Wk
40
41
42
43
44
45
46
47
48
49
50
51
52
Mo
Tu
We
Th
Fr
Sa
Su
1
15
22
29
5
12
19
3
17
24
MD3
High beta* [24 h]
MD4 [84 h]
Set-up and ramp-up
Scrubbing
Scrubbing
25 ns set-up
25 ns MD [36 h]
25 ns physics
Technical stop
Xmas
STANDBY
Recommission injectors & LHC (protons & ions)
PS open
Jan
Feb
Mar
1
2
3
4
5
6
7
8
9
10
11
12
13
31
7
14
21
28
4
11
18
25
4
11
18
25
STANDBY
Quench tests
SHUTDOWN LS1
LHC PROTON-ION RUN IONS TO NORTH AREA
Powering tests
G. Friday

LHC and LHC Injector Upgrade Reflected in 10 Year Plan

- Length of LS2: minimum 12months
- 2019 commissioning: several months



NB: not yet fully approved

Purpose of this Open Symposium

- Review the current scientific situation in particle physics:
  high energy frontier, flavour and symmetries,
  strong interactions, astroparticle (scientific enlargement),
  neutrino, theory
  and related area:
  accelerator, detector, computing, general infrastructure
  by plenary speakers. Talks reflect the community inputs but contain speaker's private view as well.
- Understand the situation in other regions: plenary speakers from Americas and Asia. (global perspective needed)
- Discussion session to collect opinions on the scientific priority in Europe by various communities.
- Starting point to build up a common understanding among the different communities in particle physics.

Physics potential of the LHC upgrade: few examples from Higgs sector

(part of the ATLAS input to the European Strategy Workshop, Cracow, Sept. 2012)

Without constraints, ratios of couplings can be measured with typical precisions:

- ❑ 20-50% with ~ 300 fb^{-1}
- ❑ 5-25% with 3000 fb^{-1}

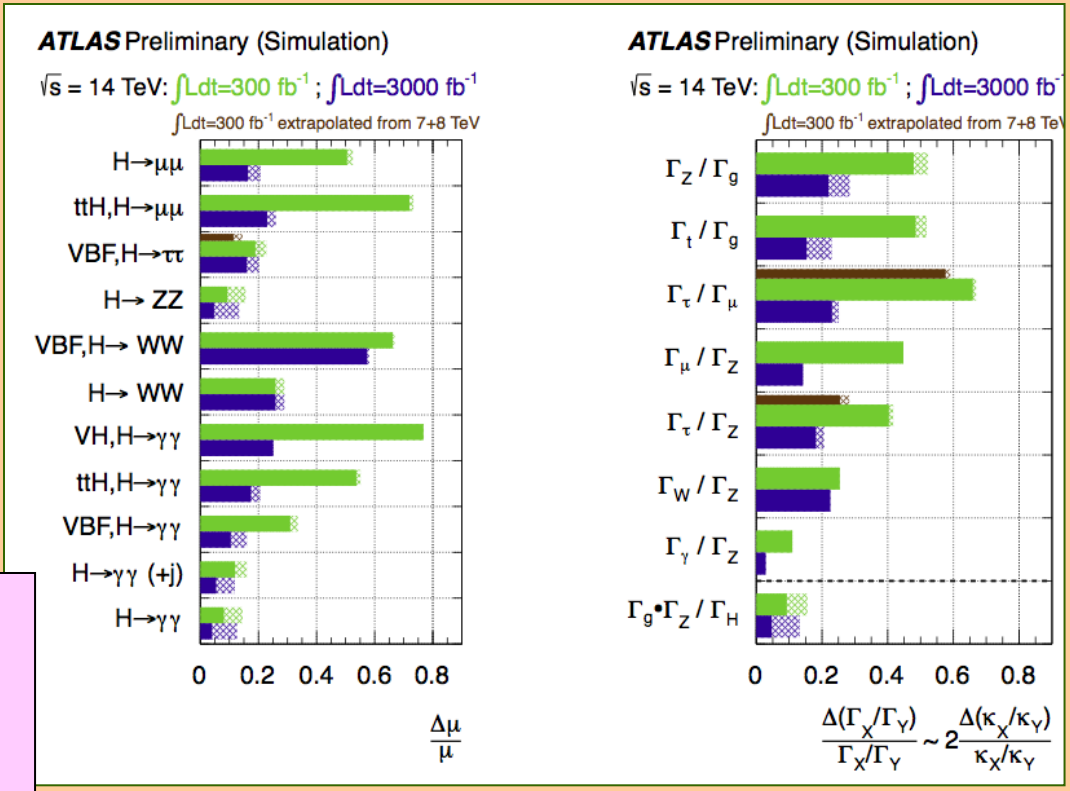
per experiment

Measurements of rare decays with 3000 fb^{-1} :

ttH → ttγγ: 200 events

H → μμ : 6σ

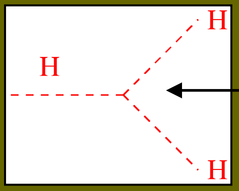
per experiment



Assuming Γ_H (SM) and one scale factor for the fermion/vector sector → measure k_F, k_V to 6% (3%) with 300 (3000) fb^{-1} per experiment

Higgs self-couplings: ~ 3σ per experiment expected from HH → bbγγ channel with 3000 fb^{-1}; HH→ bbττ also promising

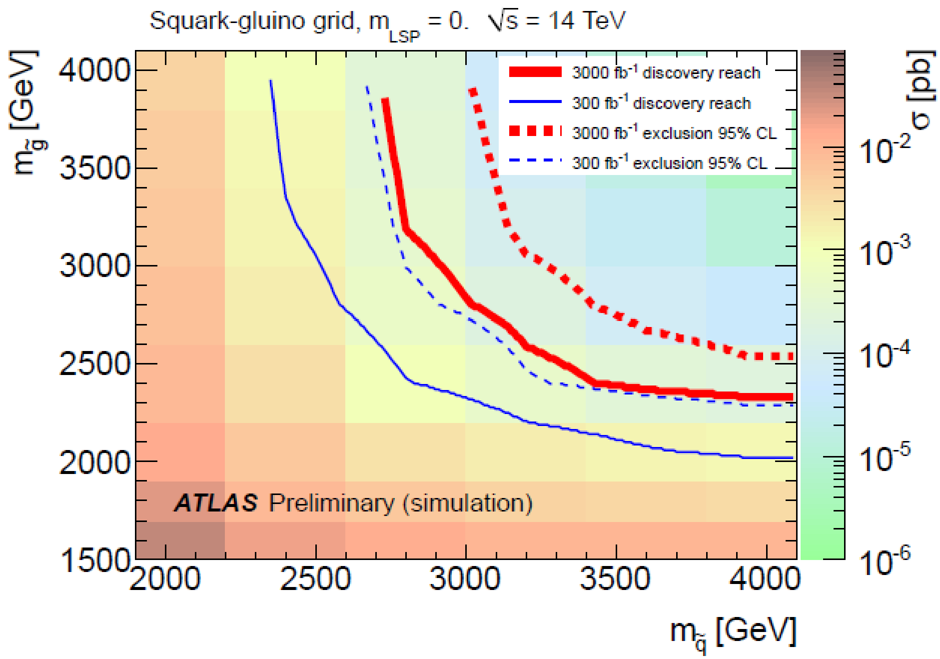
~ 30% measurement of λ/λ_{SM} may be achieved



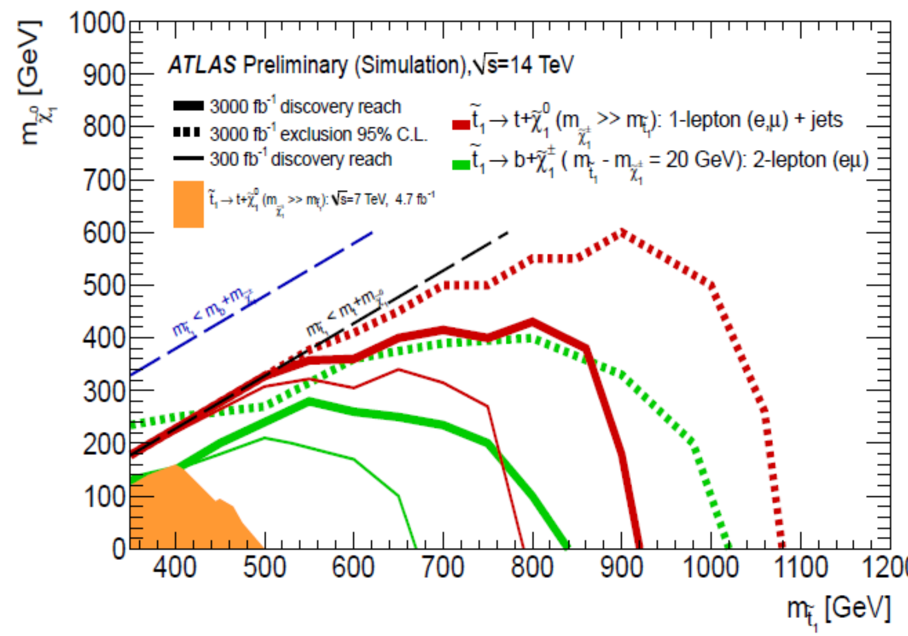
~ λv

$m_H^2 = 2\lambda v^2$

SUSY searches at 300 fb^{-1} and 3000 fb^{-1}



Third generation searches



まとめにかえて

T. Nakada
EPFL-LPHE
Lausanne, Switzerland

CERN | European Strategy for Particle Physics

Closing Session

High Energy Frontier

- Discovery of Higgs-like state is a landmark for the field (and a triumph for the LHC)
- Plethora of SM measurements with increasing precision (QCD,t,W,Z,VV,...)
- Searches for NP leading to o(TeV) limits on new particles

- Excellent prospects (much increased NP reach!) for 14 TeV LHC (300 fb^{-1})
- Higgs measurements & WW unitarity require HL-LHC 3000 fb^{-1} upgrade (detectors + machine)

- Excellent physics case for the study of „Higgs" state (+top, EW) in depth with high precision and complementary to LHC in e^+e^- (γγ?, ep??)
- Announcement from Japanese community to aim hosting ILC (250-500 GeV) as global project
- Assess which machine best suited for this program (linear vs. circular)
- Time matters – technical readiness also

- In absence of direct evidence for NP and strong theoretical guidance too early to decide on post-LHC facility for HEF (CLIC, HE-LHC(33), UHE-LHC(50+), μC, Plasma??, ...)
- Maintain critical R&D and feasibility studies