New Ways of Searching for New Physics at the LHC

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Fermilab LPC

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(i.e. some miscellaneous topics)

Questions we want to answer

- *How does electroweak symmetry breaking work?*
- *What is dark matter?*
- *Is the Standard Model a low-energy effective theory? What is the full theory?*

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Questions we want to answer

- *How does electroweak symmetry breaking work?*
- *What is dark matter?*
- *Is the Standard Model a low-energy effective theory? What is the full theory?*
- *What are we going to do for the next 30 years?*
  - *Only willing to predict what we're going to do for the next year....*

From last time— Higgs sensitivity with 5/fb @ 7 TeV projected from 2010 study

ATL-PHYS-PUB-2010-009

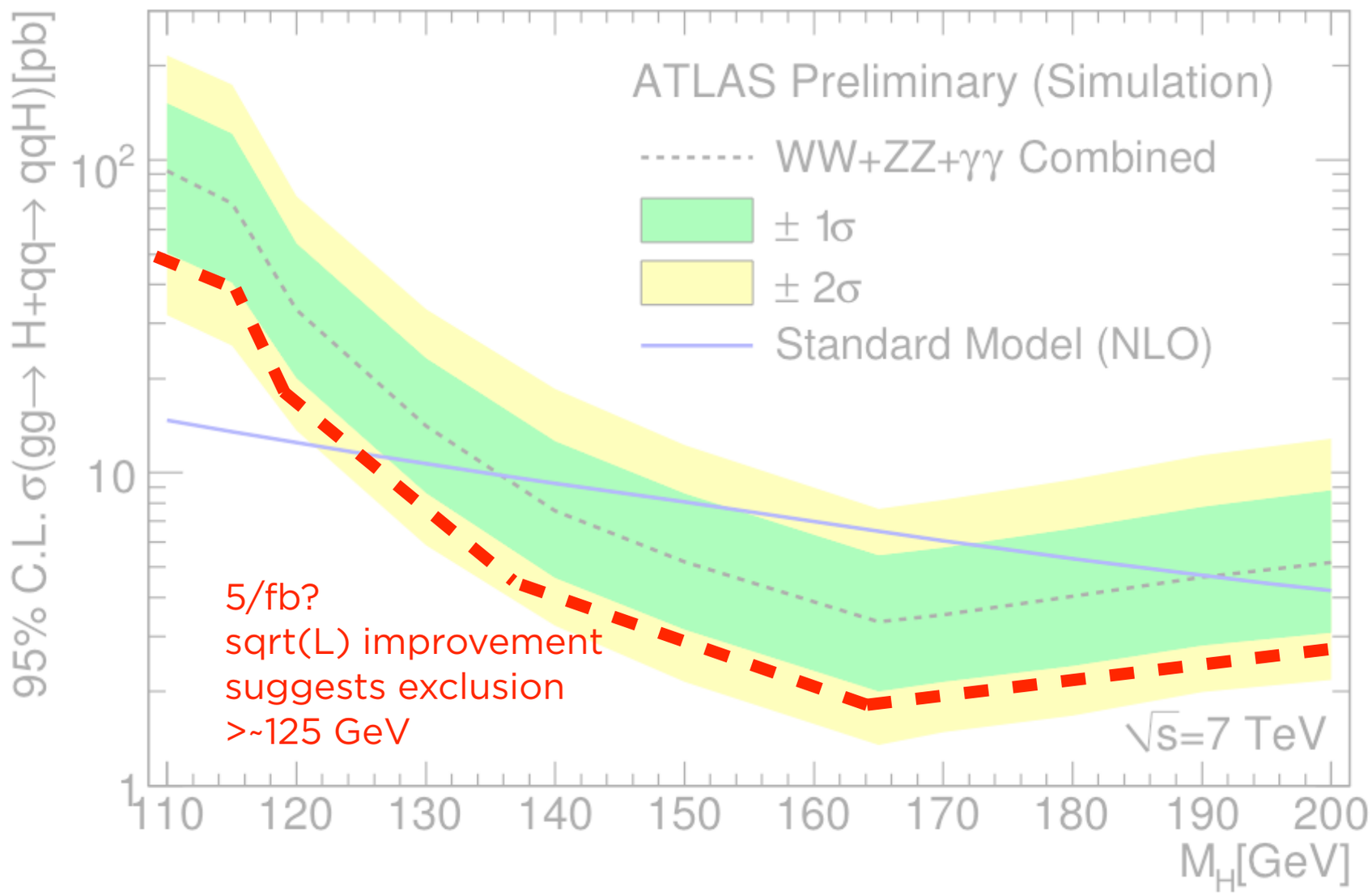
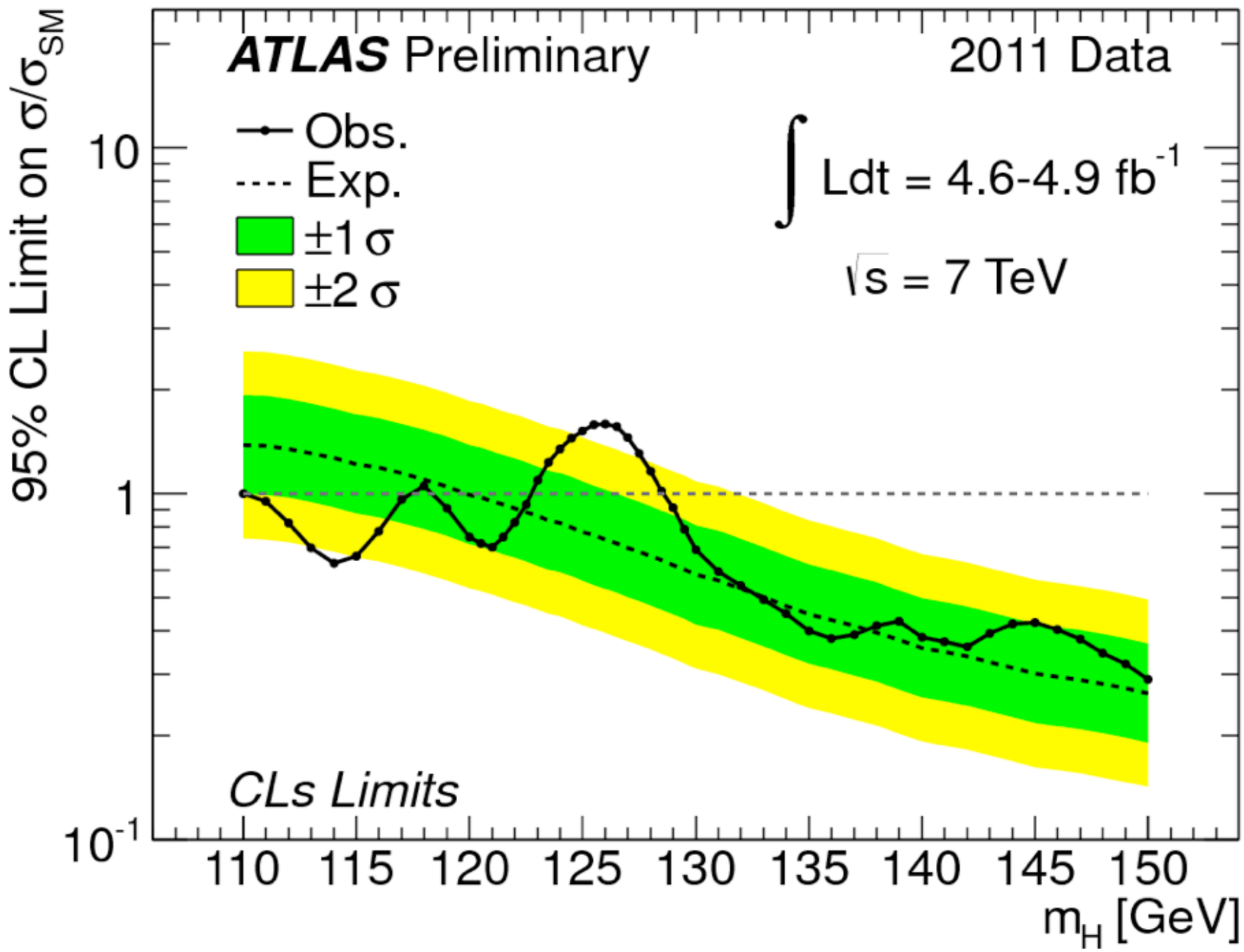


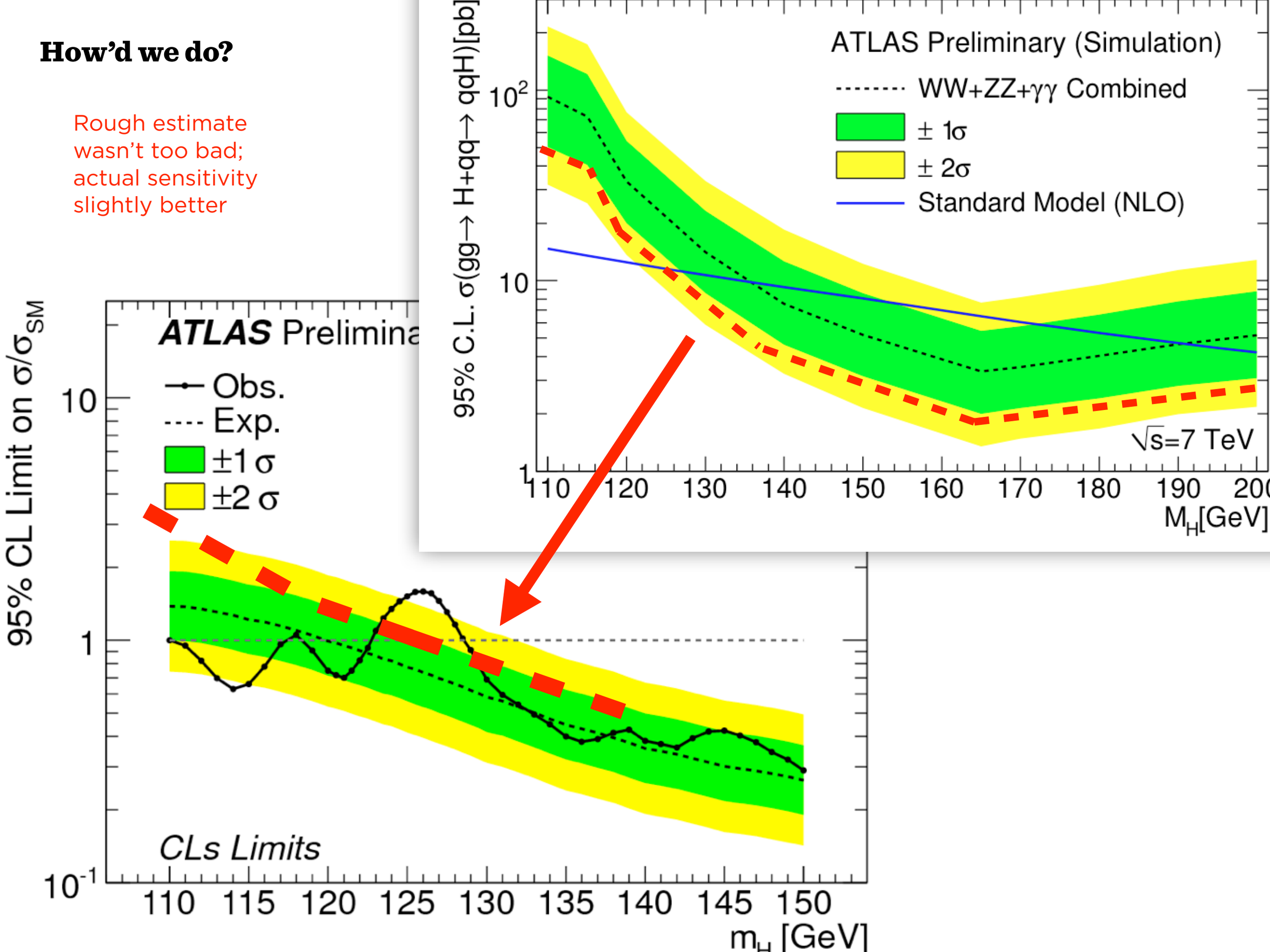
Figure 15: The expected upper bound on the Higgs boson production cross-section after collecting 1 fb^{-1} of integrated luminosity in 7 TeV collisions with the ATLAS detector: on the top plot, the limit is normalised to the NLO prediction of the SM cross-section and on the bottom plot, it is normalised to an absolute cross-section. The green and yellow bands represent the range in which we expect the limit will lie, depending upon the data. Only the $H \to WW \to ll\nu\nu$, $H \to ZZ \to 4l$ and $H \to \gamma\gamma$ channels are included in these plots. It is expected that in the low mass region, the addition of $H \to b\bar{b}$ and $H \to \tau\tau$ will improve this result. The expected limit in high mass region above $M_H \sim 200$ GeV is obtained from the $H \to ZZ \to 4l$ only as shown in Fig. 10; the limit in the high mass region will be improved with the addition of the $H \to ZZ \to llbb$ and $H \to ZZ \to ll\nu\nu$ channels.

How'd we do?


ATLAS Preliminary
2011 Data
Obs.
Exp.
±1 σ
±2 σ
∫ Ldt = 4.6-4.9 fb-1
√s = 7 TeV
95% CL Limit on σ/σSM
10
1
10-1
CLs Limits
110 115 120 125 130 135 140 145 150
mH [GeV]

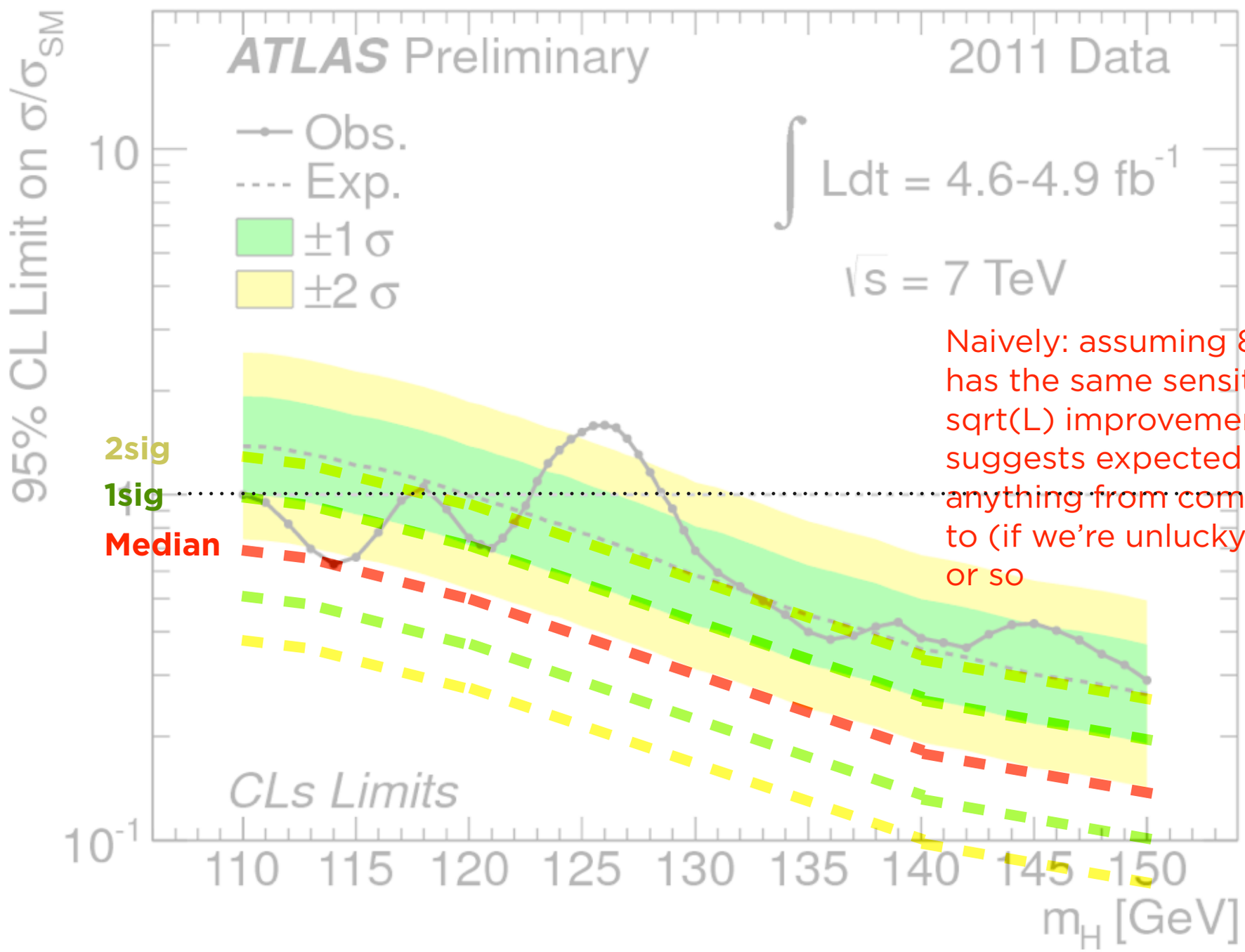
How'd we do?

Rough estimate wasn't too bad; actual sensitivity slightly better



Higgs in 2012

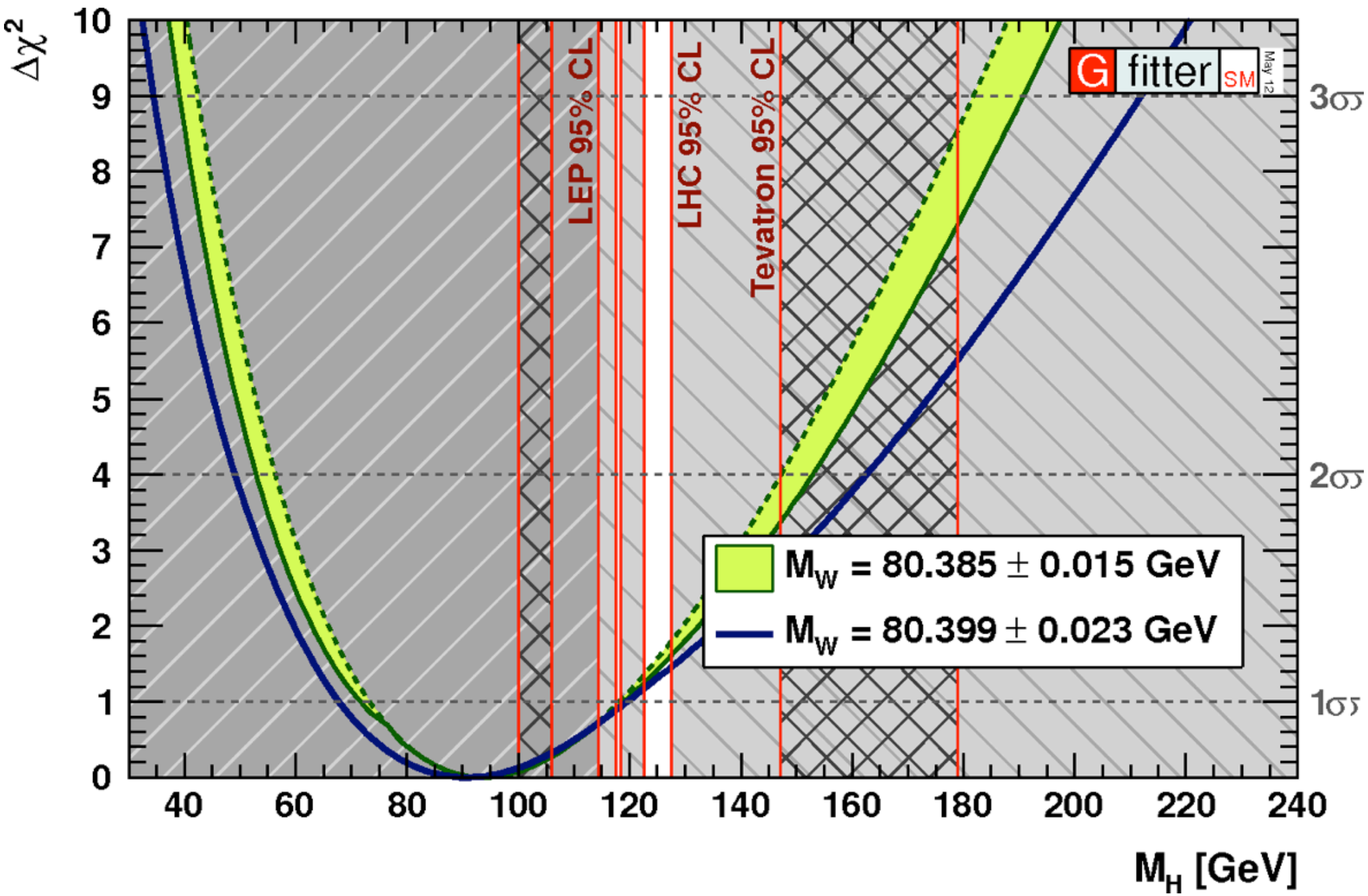
Many caveats to predictions: effect of pile-up on each channel, different signal to background, no new channels or other improvements, etc.



Naively: assuming 8 TeV analysis has the same sensitivity as at 7 TeV, sqrt(L) improvement with 4xL suggests expected limit with anything from complete exclusion to (if we're unlucky) m_H>~120 GeV or so

Updated EW Fit from Gfitter

http://gfitter.desy.de, 12 May 2012



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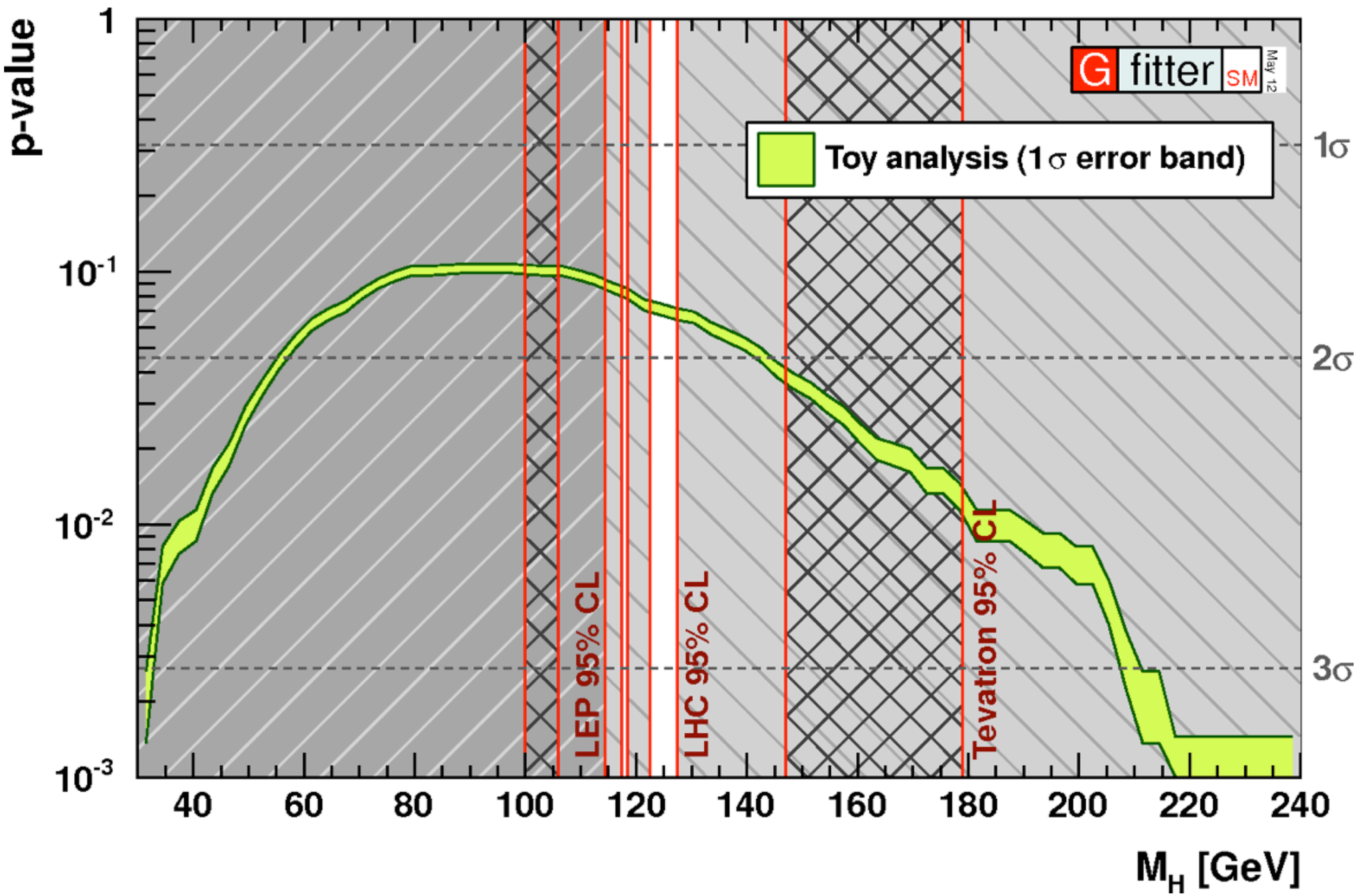
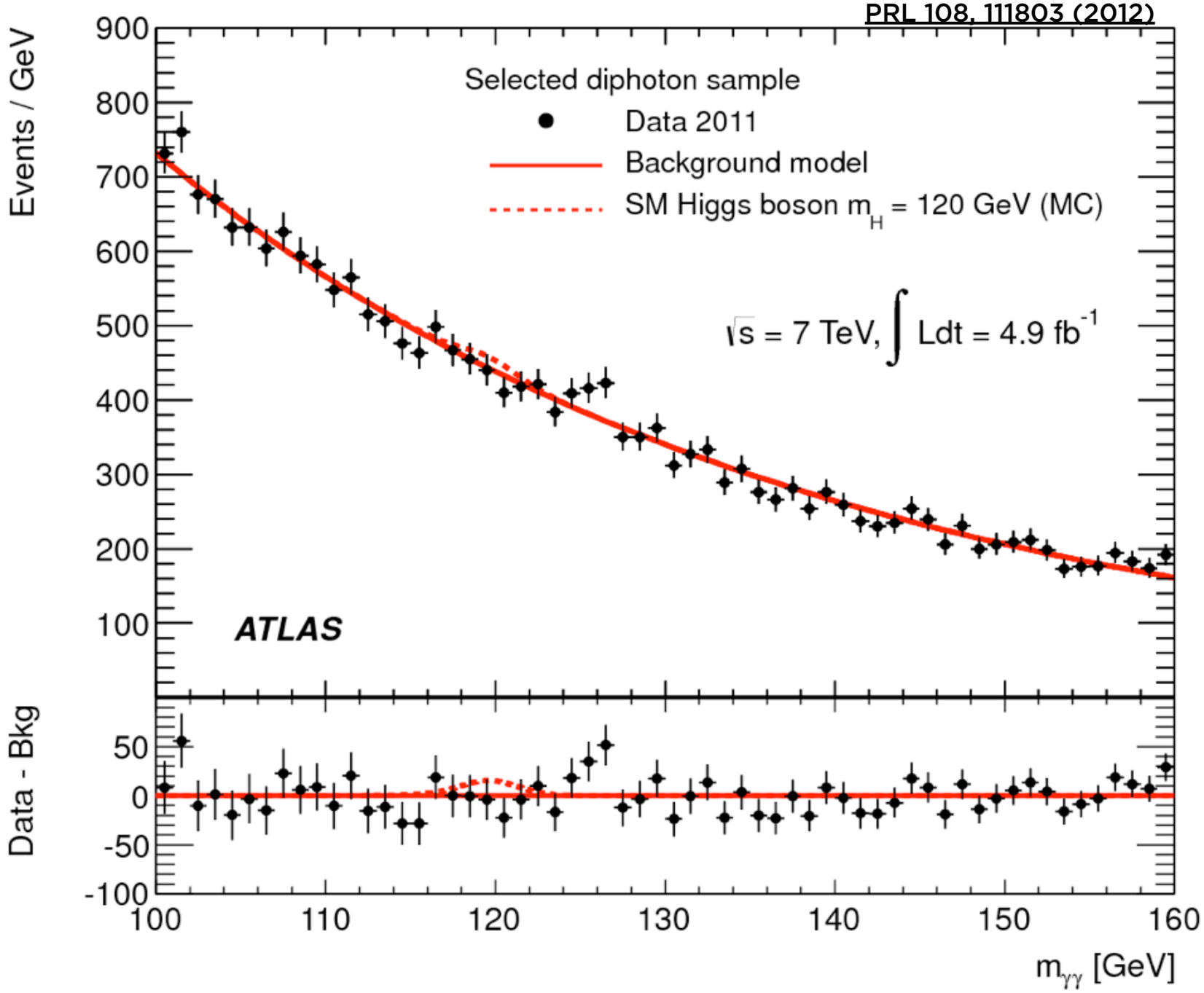


From last time: diphoton results

- *Expect O(10) signal events per 1/fb, roughly independent of signal mass*
- *Signal width: ~few bins + fitted background => ~50 events signal, ~1000 events background*
  - *=> local p-value of few x 10_{-2} (excluding systematics)*
  - *Double signal strength => local p-value of ~10_{-3}.*

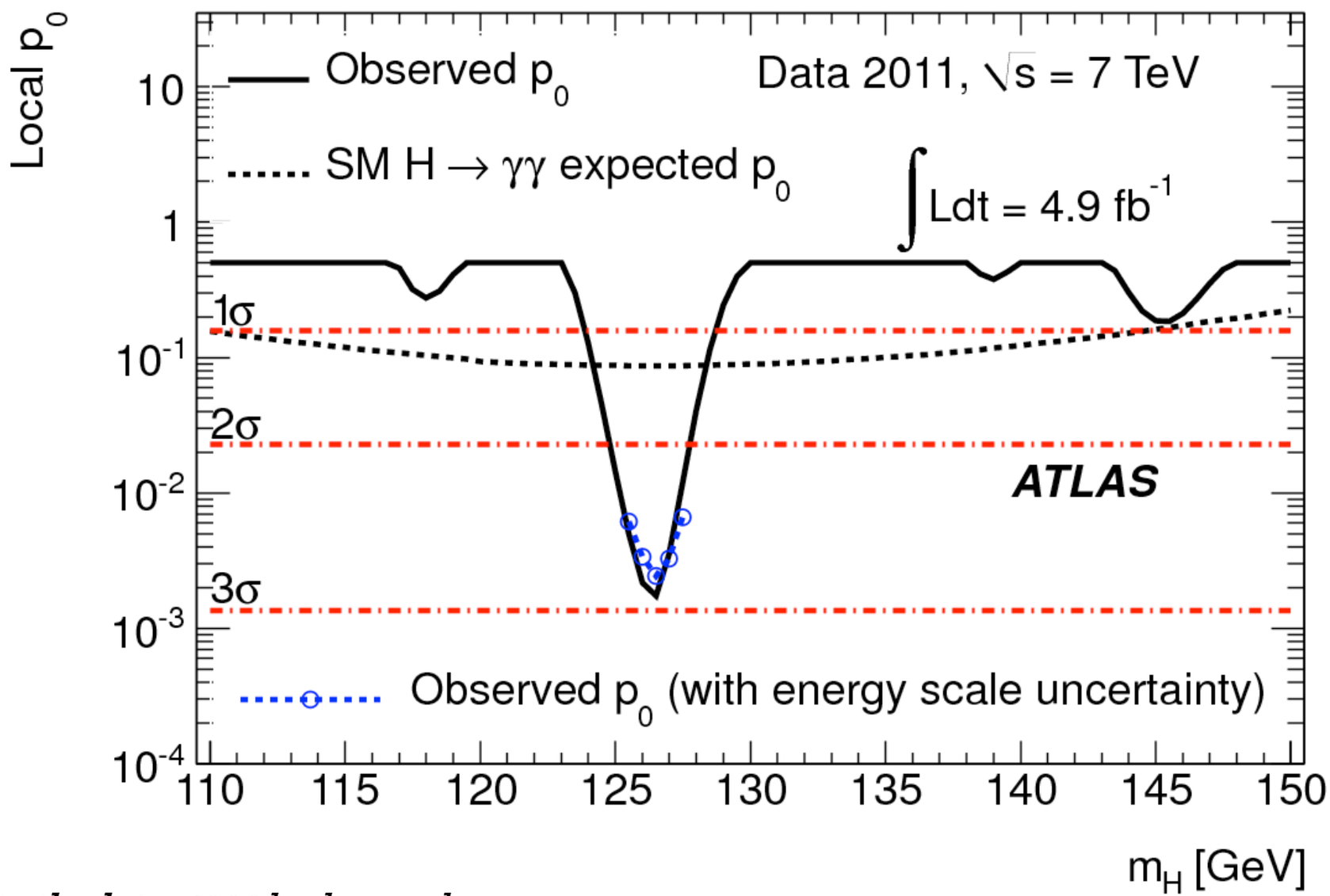
PRL 108, 111803 (2012)



From last time: diphoton results

- *Consistent with observed p-value*

PRL 108, 111803 (2012)



- ***Extrapolate to 4x the data:*** *4000 background events*
  - *Nominal SM production: 200 signal events => p-value: ~10^{-3}*
  - *2x SM production: 400 signal events => p-value: ~few 10^{-10}*
    (neglecting systematics)
- *Similar predictions for lower unexcluded masses...*

Predictions for 2012

Possible outcomes:

- *Rule out the SM Higgs at low mass*
- *or establish with a combination channels a statistically significant excess that may or may not be a Higgs.*

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Then what?

(n.b. until ~2015, when new data arrives.)

SM Higgs is ruled out:

- *Keep pushing down to lower and lower production cross section (gg vs VBF), possible suppressed decays*
  - *When to give up?*
- *What does this imply for BSM physics?*

Higgs-like object is found:

- *Nail down properties (mass, production rates and modes, all decays) to confirm Higgs hypothesis and constrain BSM physics*
- *Continue to do traditional BSM searches (BSM physics is hiding where seeing it is hard?)*
- *Is Higgs produced in association with anything unexpected?*

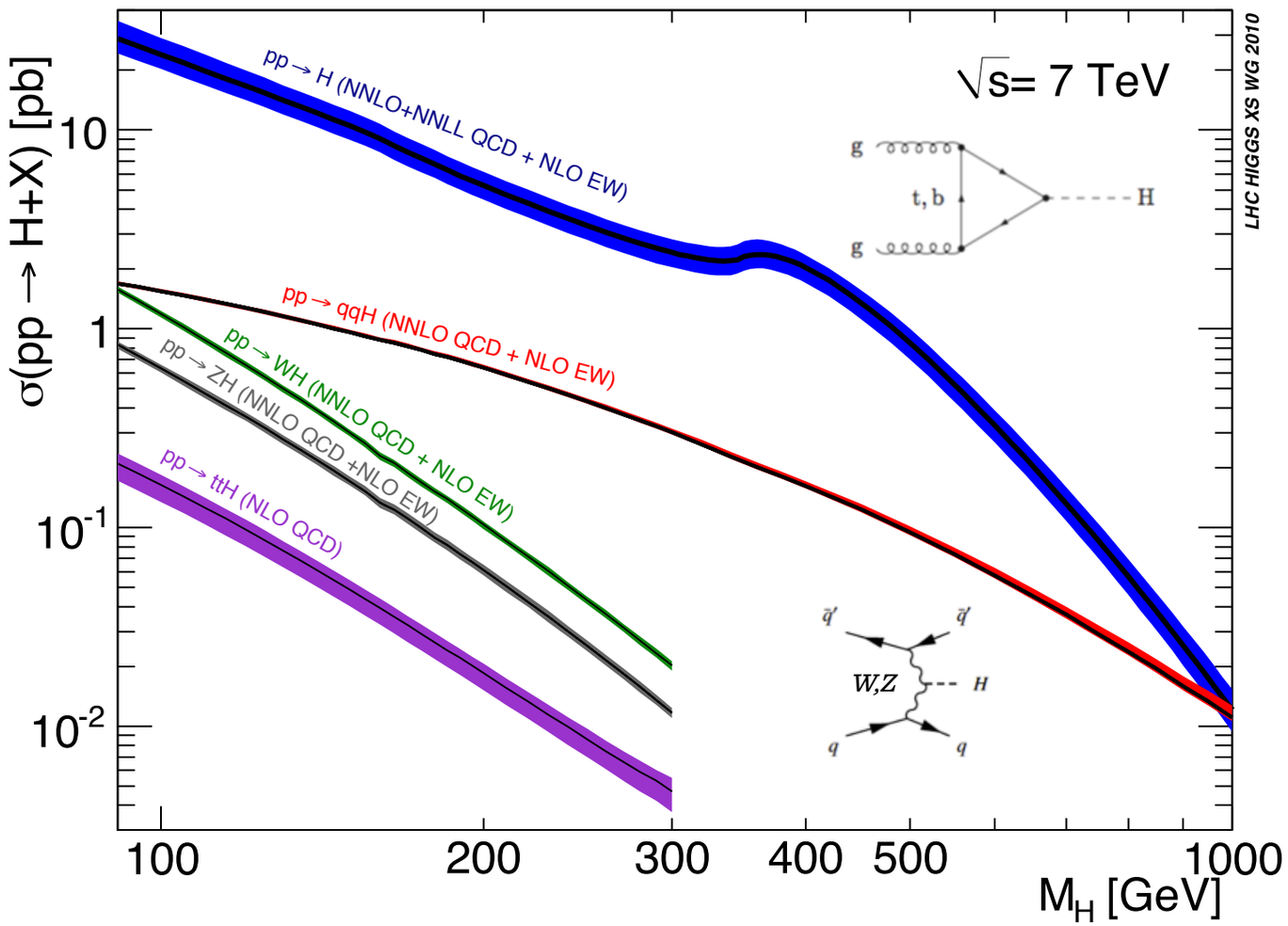
Look at these two possibilities from a BSM search perspective...

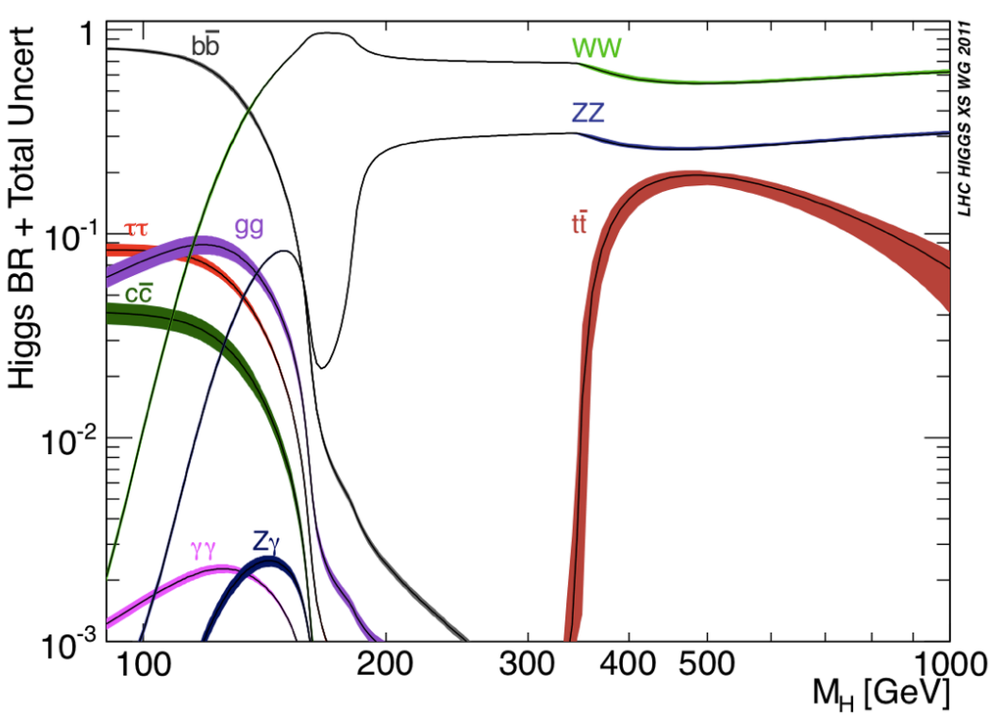
Two sides of the same issues:

How sensitive is Higgs to BSM physics (short answer: very)

Why haven't we seen BSM physics yet? (looking in the right ways?)

Predictions for Higgs Production and Decays





Production accurately known:

- *Total gg production uncertainty 15–20%*
  - *top loop, b-loop(O(5)%) calculated exactly at NLO*
  - *calculated to NNLO in heavy top limit*
  - *NNNLL resummation*
  - *Uncertainty is roughly half scale, half PDFs*

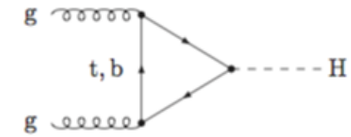
Widths also well-known

BSM physics could substantially modify both (new particles in loops, different total Higgs width), or add additional higgses (e.g. SUSY)

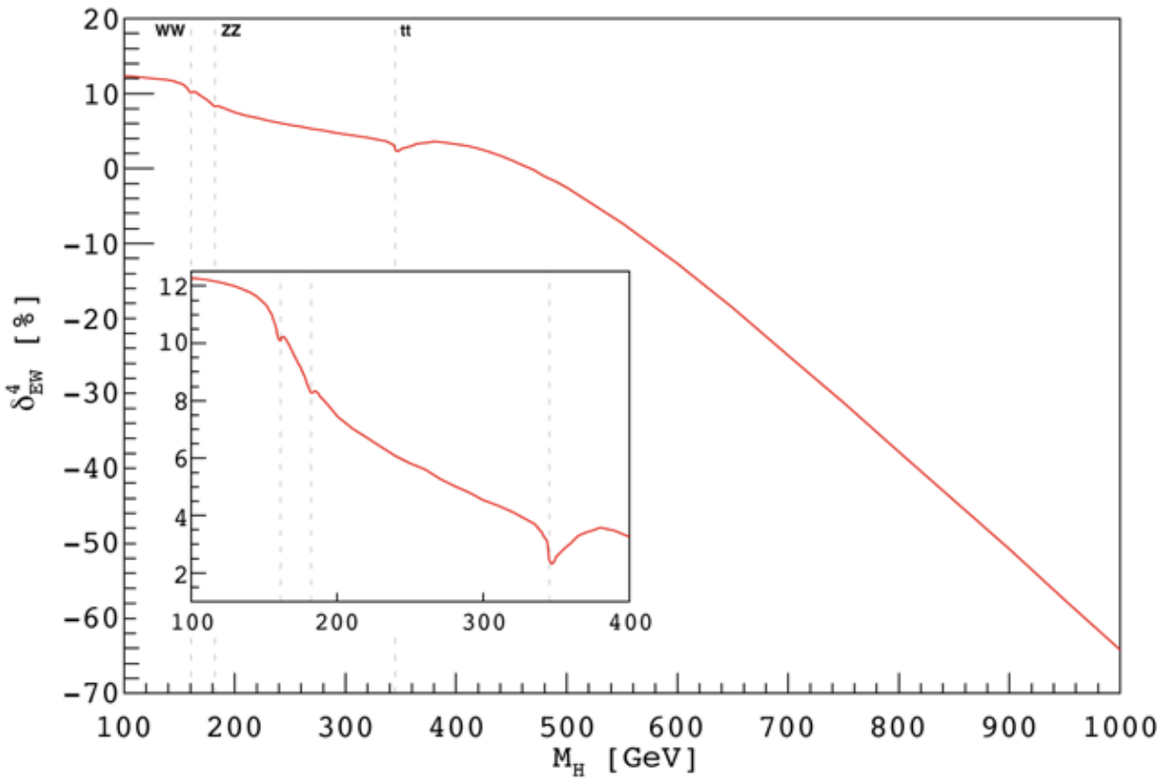
- *At low mass, total width is so small that new decay modes could overwhelm the expected width*

Goal should be to measure production and decay to at least theory precision.

Modified Higgs Rates: Fourth Generation Example



http://arxiv.org/abs/1108.2025v1



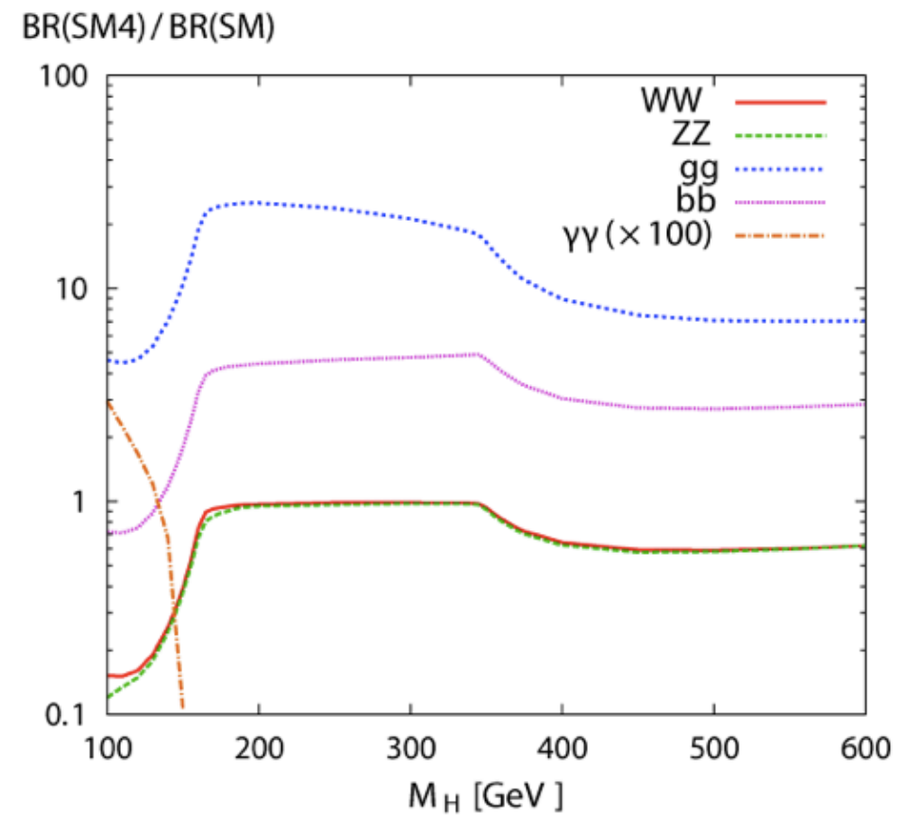
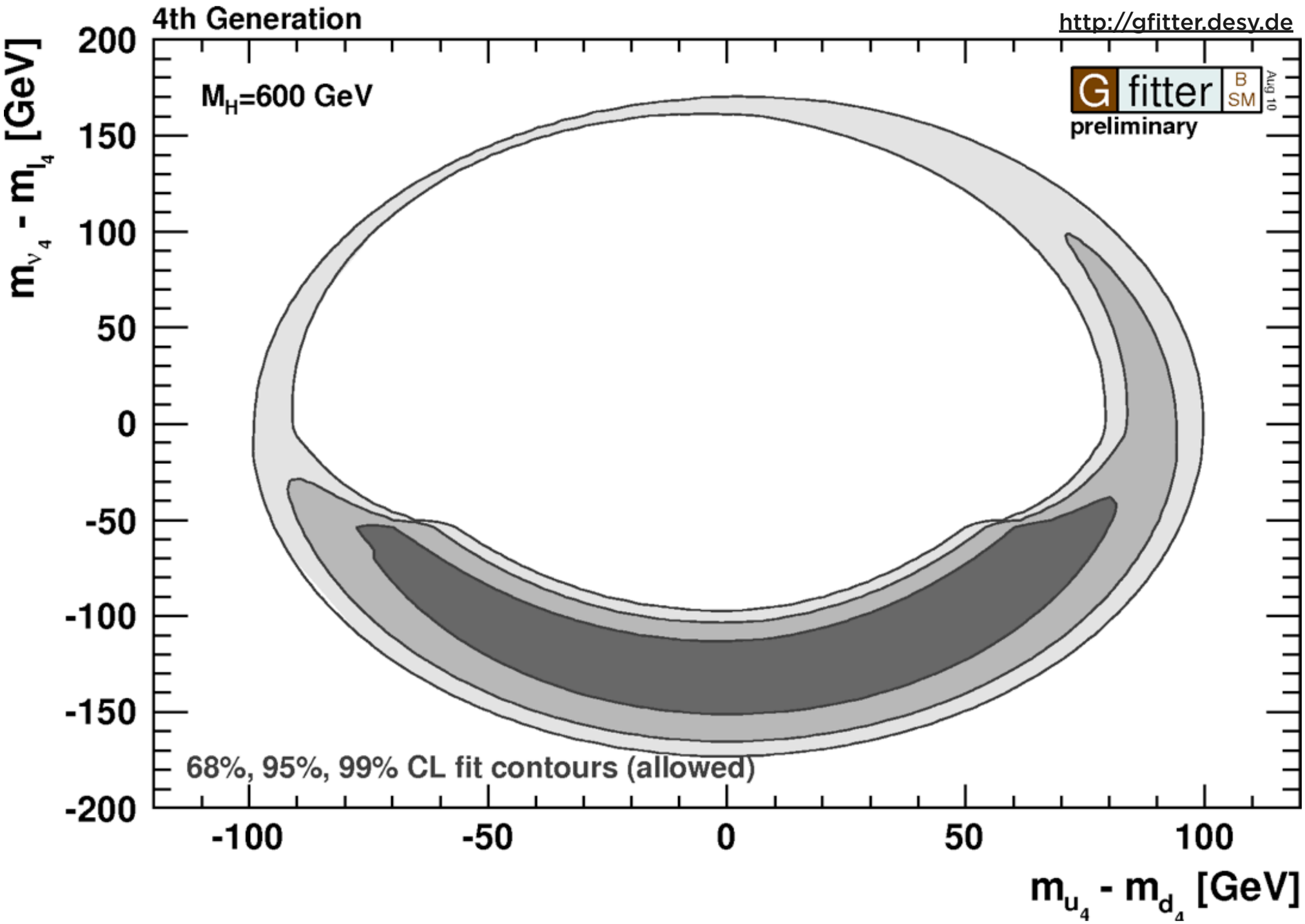


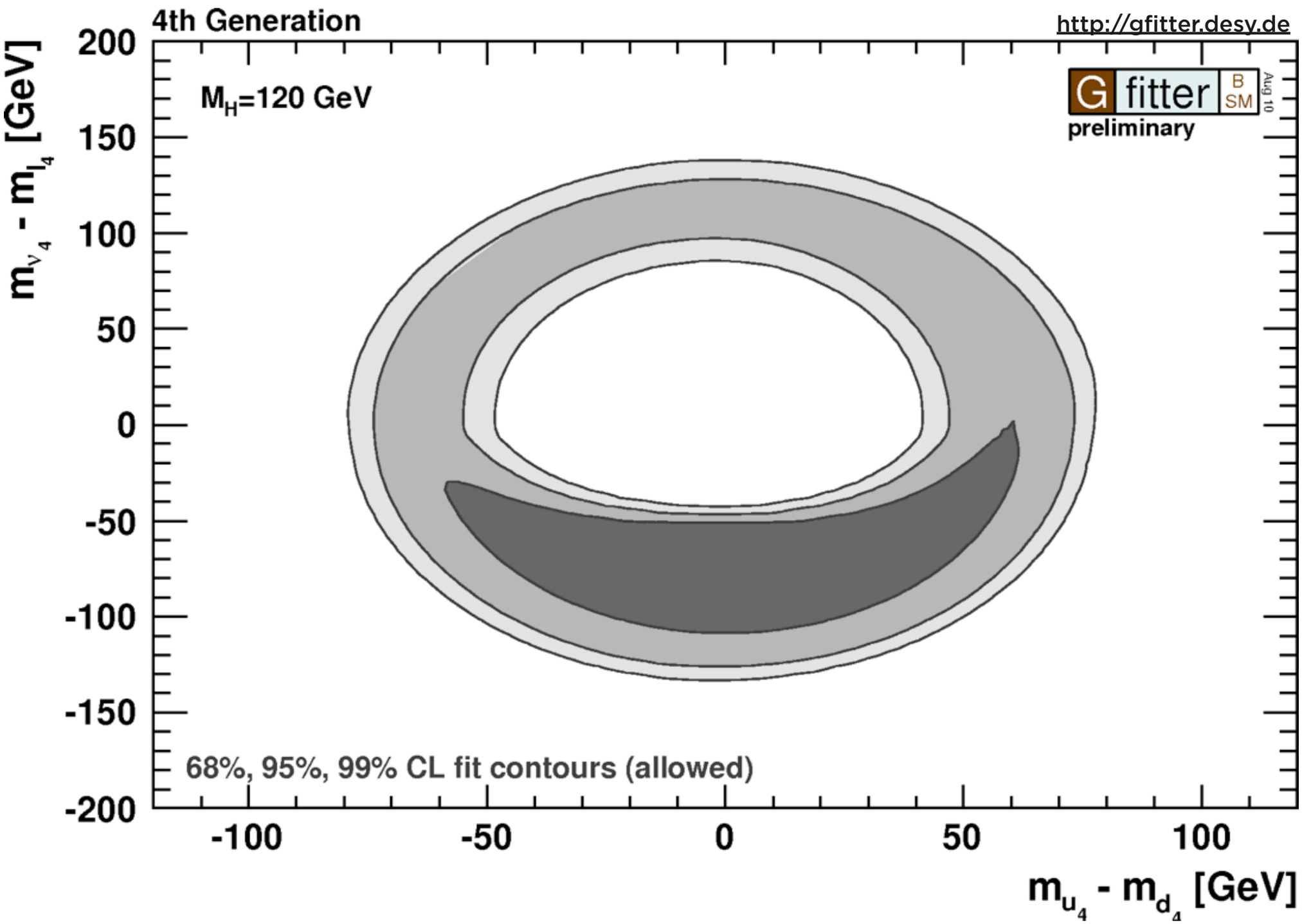
Figure 1: (left) NLO EW correction to the ggF Higgs production in SM4. (right) Ratio of BR in SM4/SM calculated with Prophecy4f and HDECAY .

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SM4At7TeVnew

- Higgs production and decay in the fourth generation model with SM-like couplings.
- $M_{D4}=M_{L4}=600$GeV and $M_{U4} - M_{D4} = [\ 1 + 1/5*\ln(M_H/115)\ ] * 50$ GeV).
- Assumes the same NNLO QCD corrections as SM for ggF.

Modest enhancement in gg->H production (X) order of magnitude suppression in diphoton branching fraction.
=> possible to constrain fourth generation models with accurate measurements of production and decay.


4th Generation
http://gfitter.desy.de
M_H=600 GeV
G fitter B SM
preliminary
Aug 10
68%, 95%, 99% CL fit contours (allowed)
$m_{\nu_4} - m_{l_4}$ [GeV]
$m_{u_4} - m_{d_4}$ [GeV]
200
150
100
50
0
-50
-100
-150
-200
-100
-50
0
50
100


4th Generation
http://gfitter.desy.de
M_H=120 GeV
G fitter B SM
preliminary
Aug 10
68%, 95%, 99% CL fit contours (allowed)
$m_{\nu_4} - m_{l_4}$ [GeV]
$m_{u_4} - m_{d_4}$ [GeV]
200
150
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-100
-50
0
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100

Modified Higgs Rates: Invisible Decays

If the higgs can decay to a new ~stable, neutral particle , total width is increased and all visible decays suppressed.

Not always hopeless:

detect via VBF->MET+2 jets, measure ZZ->4l lineshape

http://arxiv.org/pdf/1110.4405v2.pdf

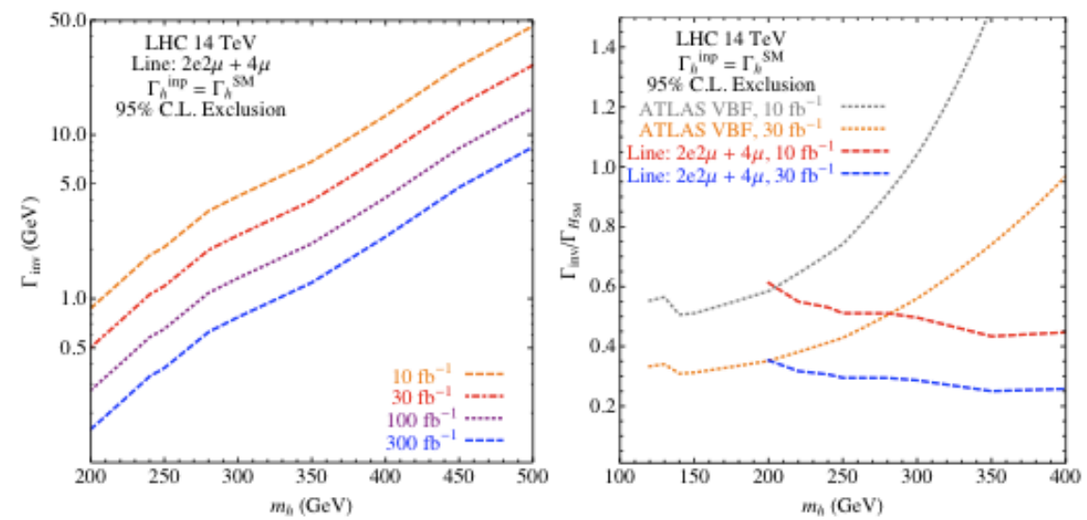


FIG. 3: *Assuming a SM input width, the uncertainty in width extraction can be converted to a 95% C.L. reach in the invisible width, as shown in the left panel. The right panel shows comparison in invisible width measurements between direct probe via VBF [33] and indirect probe via total width. The direct and indirect probes are complimentary to each other.*

ATL-PHYS-2003-006

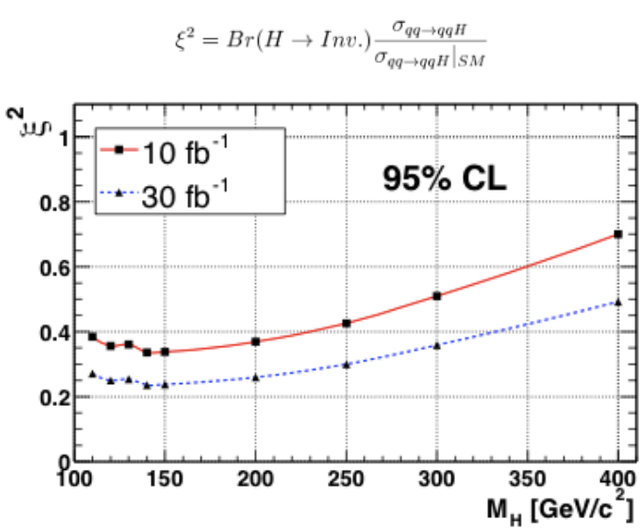


Figure 13: ξ^2 values as a function of the Higgs mass for 10 fb^{-1}(squares) and 30 fb^{-1}(triangles)

http://arxiv.org/abs/1010.2753v2

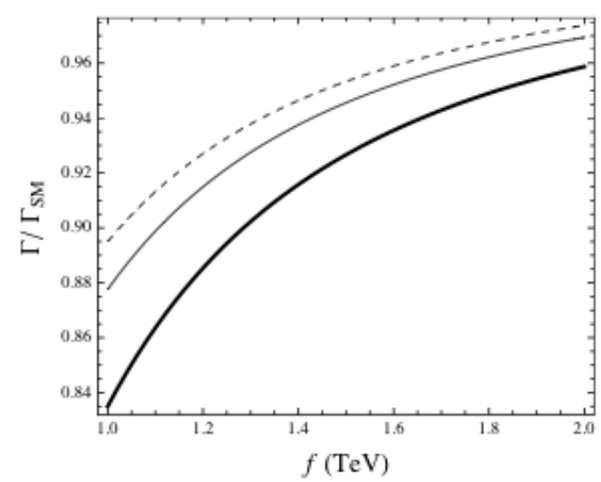
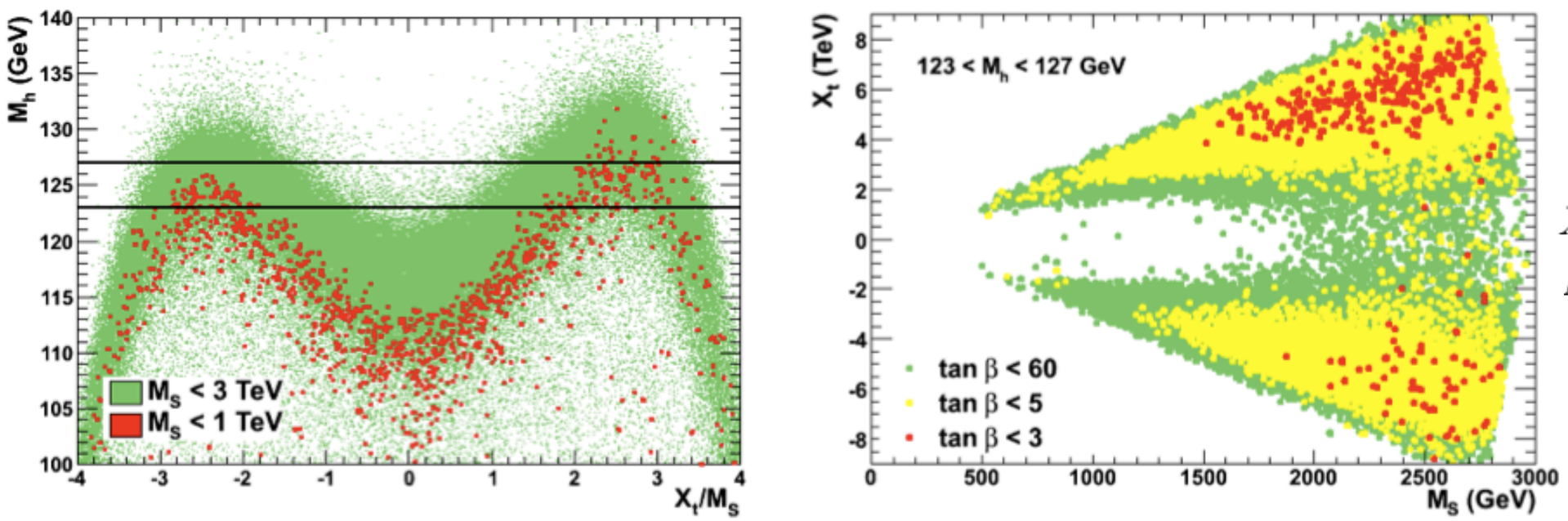


FIG. 3: *The ratio of the Higgs production rates in the gluon fusion channel in the littlest Higgs model over the SM expectation. The three curves, from top to bottom, are for $c_-/c_+ = 1$, 0.3, and 0, respectively. Precision electroweak constraints require $f \gtrsim 1.2$ TeV.*

Higgs as a way to constrain SUSY

Mass of lightest CP-even higgs depends on soft SUSY-breaking parameters through radiative corrections
Example: "phenomenological MSSM"

http://lanl.arxiv.org/pdf/1112.3028.pdf



$$X_t = A_t - \mu \cot \beta$$
$$M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

Figure 1: The maximal value of the h boson mass as a function of X_t/M_S in the pMSSM when all other soft SUSY–breaking parameters and $\tan\beta$ are scanned in the range Eq. (4) (left) and the contours for 123< M_h <127 GeV in the $[M_S, X_t]$ plane for some selected range of $\tan\beta$ values (right).

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Mass of lightest CP-even higgs depends on soft SUSY-breaking parameters through radiative corrections
Example: "constrained" MSSM

http://lanl.arxiv.org/pdf/1112.3028.pdf

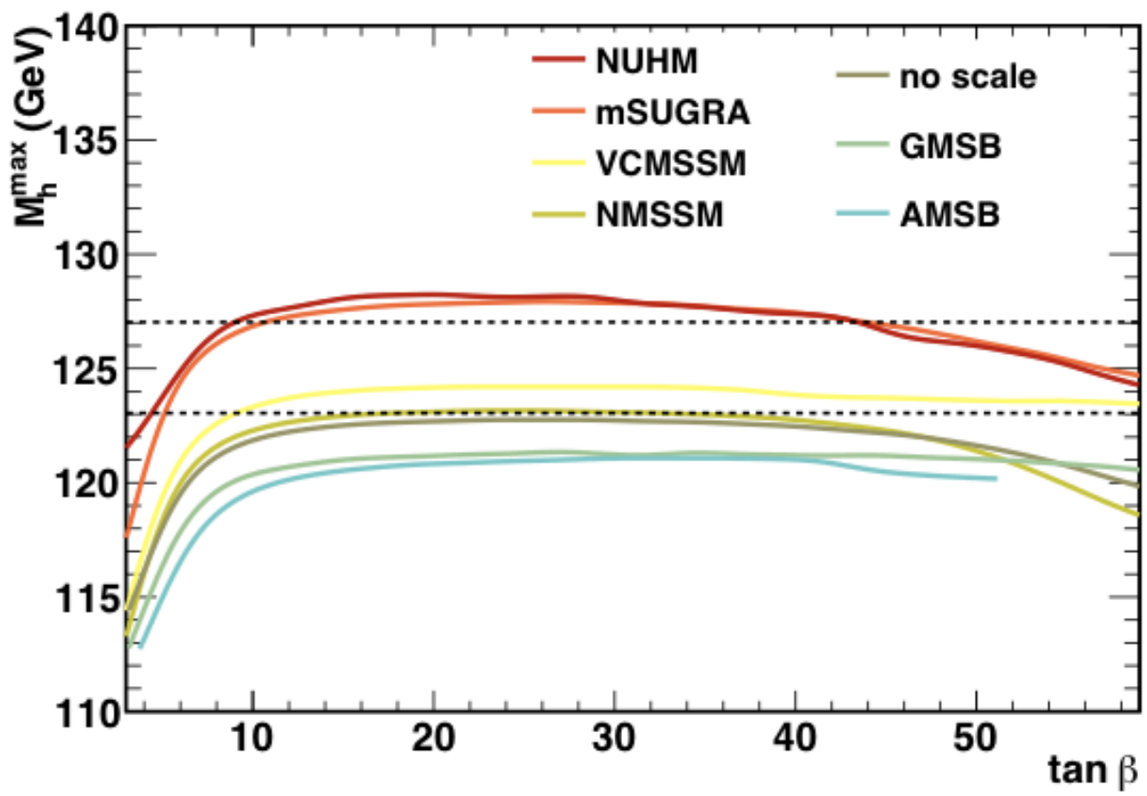

Figure 2: The maximal value of the h mass defined as the value for which 99% of the scan points have a mass smaller than it, shown as a function of $\tan\beta$ for the various constrained MSSM models.

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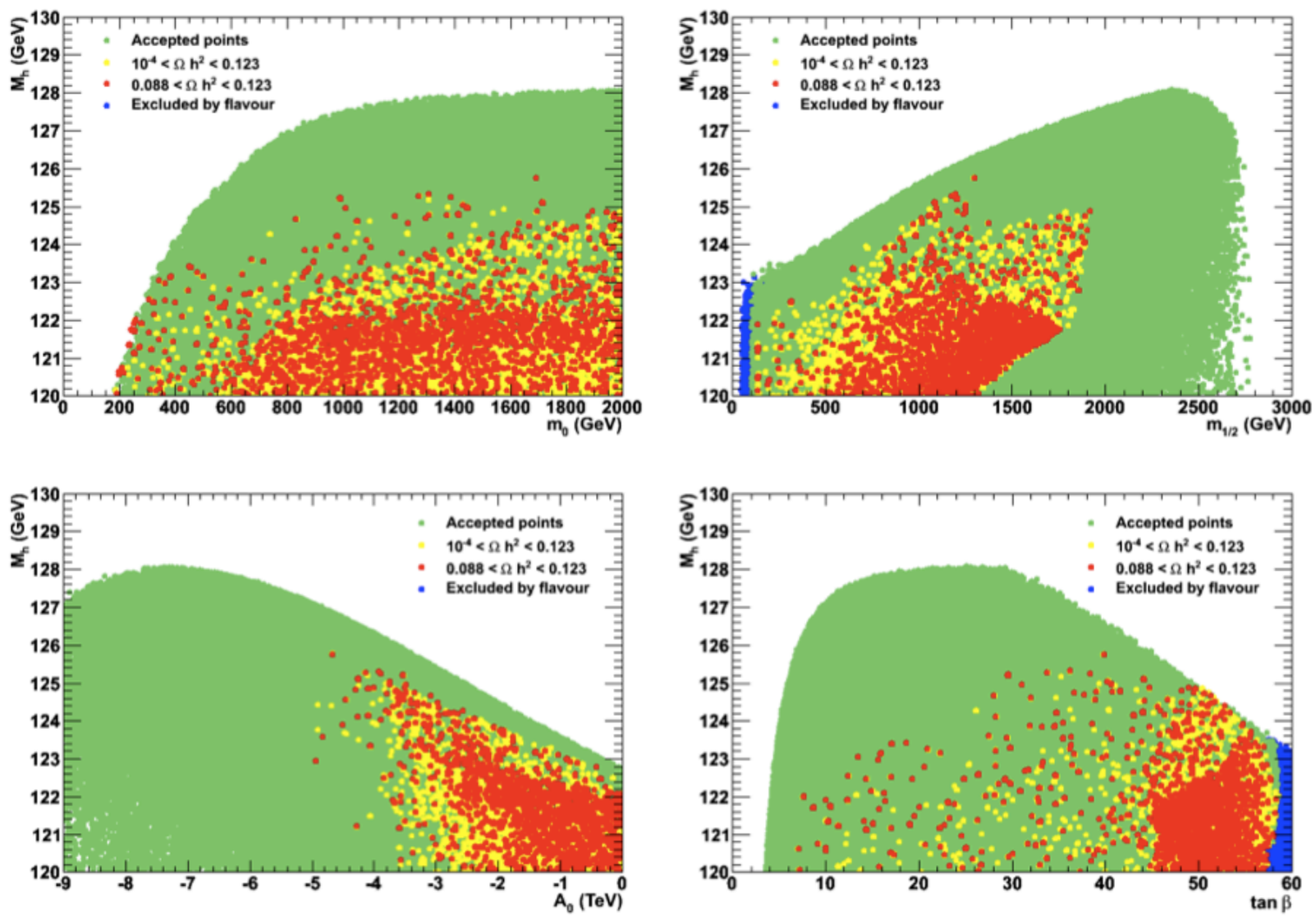

Figure 3: The value of M_h as a function of one mSUGRA continuous parameter when a scan is performed on the other parameters. The constraints from Higgs and SUSY searches at the LHC are included and the impact of flavour ($b \to s\gamma, B_s \to \mu^+\mu^-$, $B \to \tau\nu$) and DM constraints are shown.

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Mass of lightest CP-even higgs depends on soft SUSY-breaking parameters through radiative corrections
Example: mSUGRA

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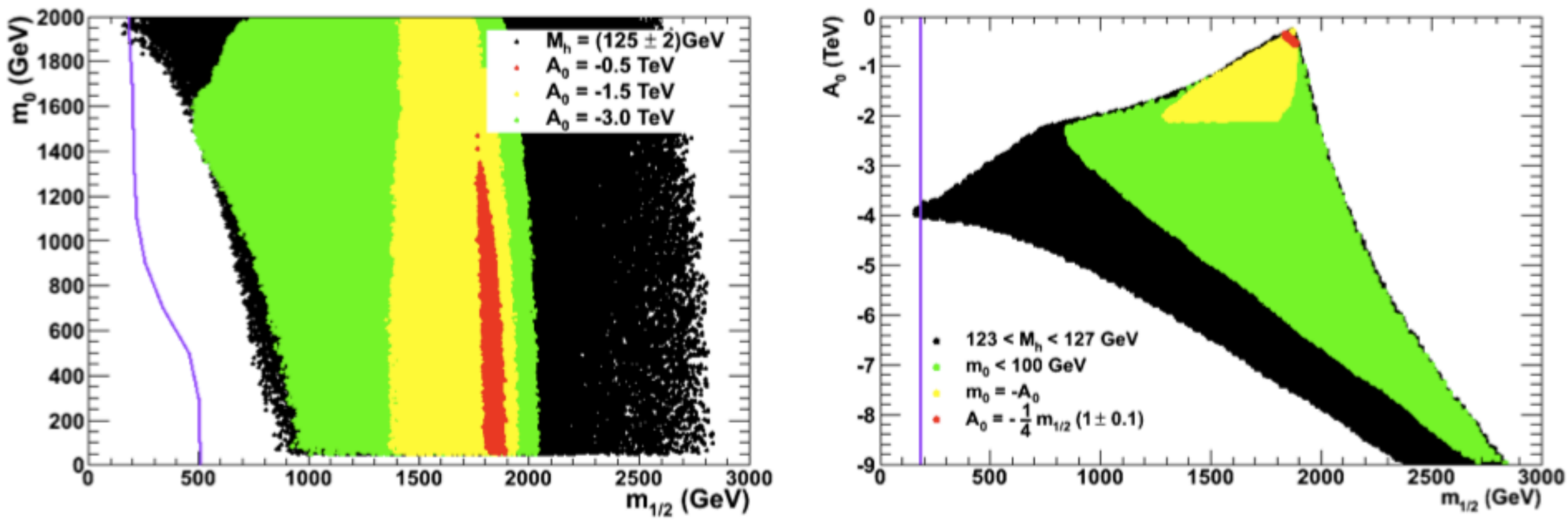


Figure 4: Contours in which $123 < M_h < 127$ GeV, resulting of a full scan of the mSUGRA parameter but for particular choices of the inputs A_0 (left) and m_0 (right). The lower bound from LHC searches of SUSY strongly interacting particles in the fully hadronic channel with 1 fb^{-1} data [24] is shown by a continuous line.

Higgs as a way to constrain SUSY

Example: "split" and "high-scale" SUSY

http://lanl.arxiv.org/pdf/1112.3028.pdf

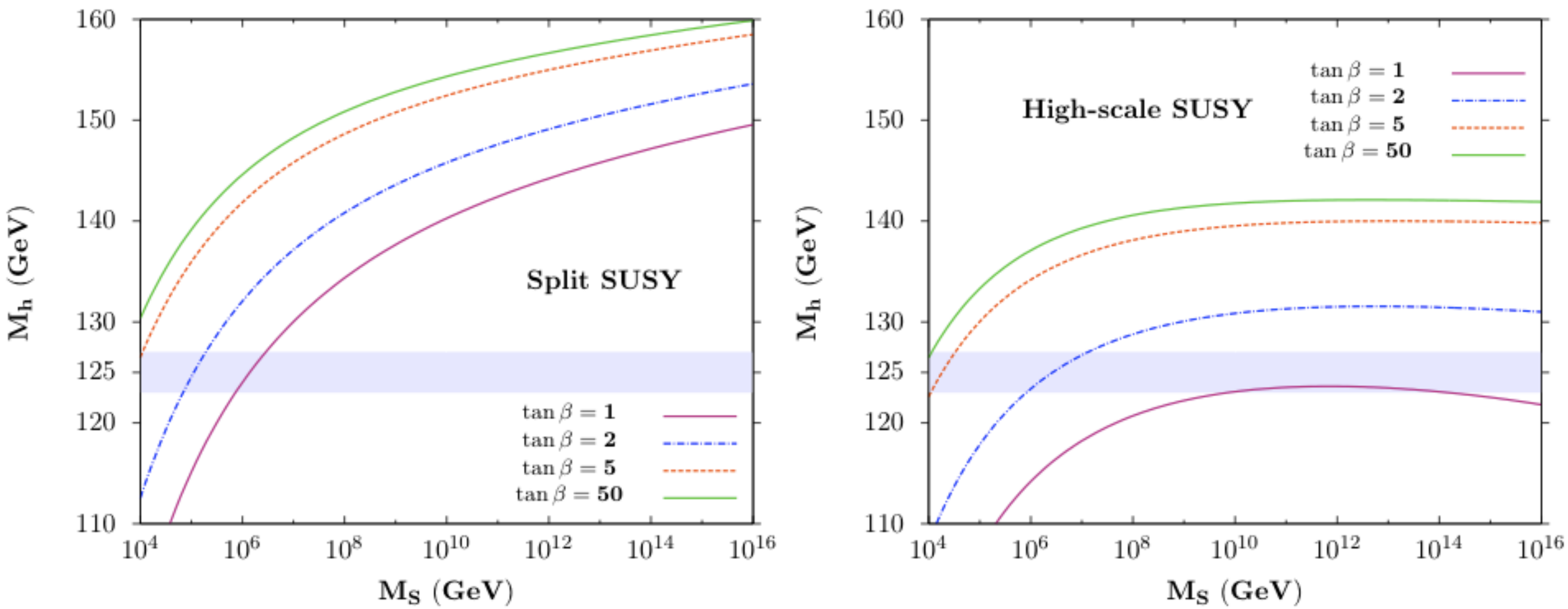
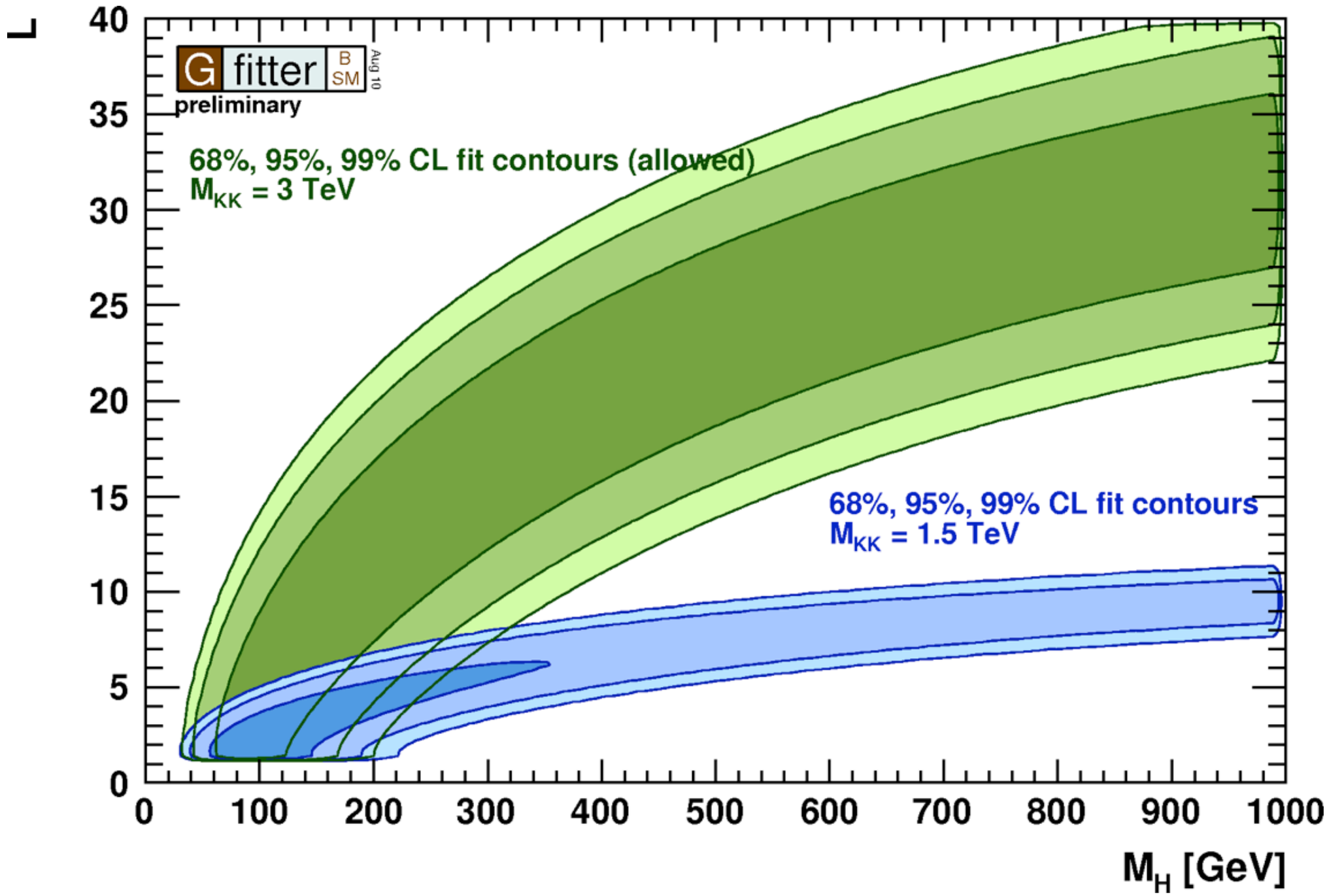


Figure 5: The value of M_h as a function of M_S for several values of $\tan\beta = 1, 2, 5, 50$ in the split SUSY (left) and high–scale SUSY (right) scenarios.

Higgs as a way to constrain RS graviton models

Example: constraints on warp factor from Higgs mass measurement

http://gfitter.desy.de



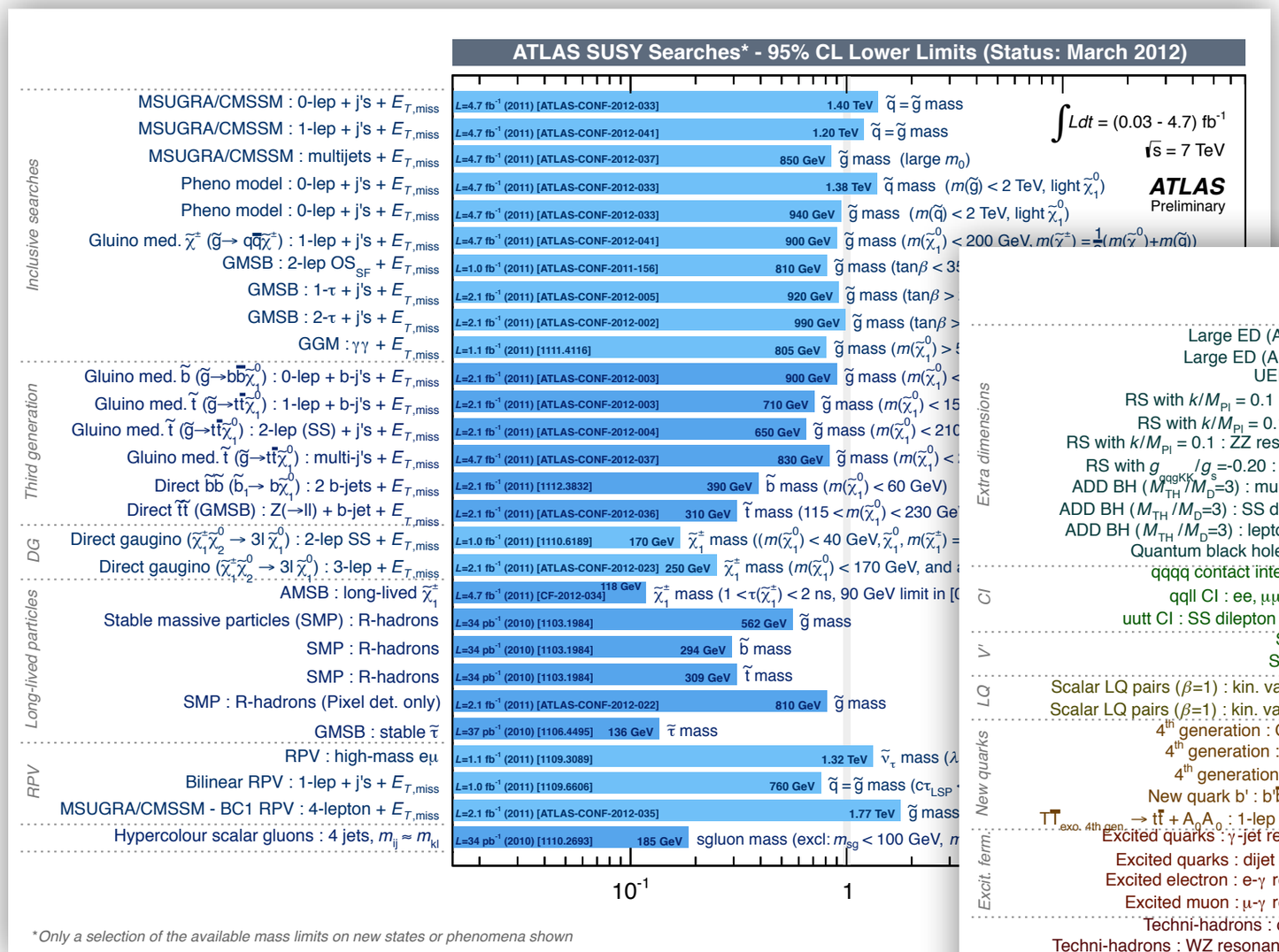
It is assumed that the effects of new physics only appear through vacuum polarisation and therefore lead to modified oblique parameters. Most of the effects on electroweak precision observables can be parametrised by three gauge self-energy parameters (S, T, U) introduced by Peskin and Takeuchi [Phys.Rev.D46, 381-409(1992)].

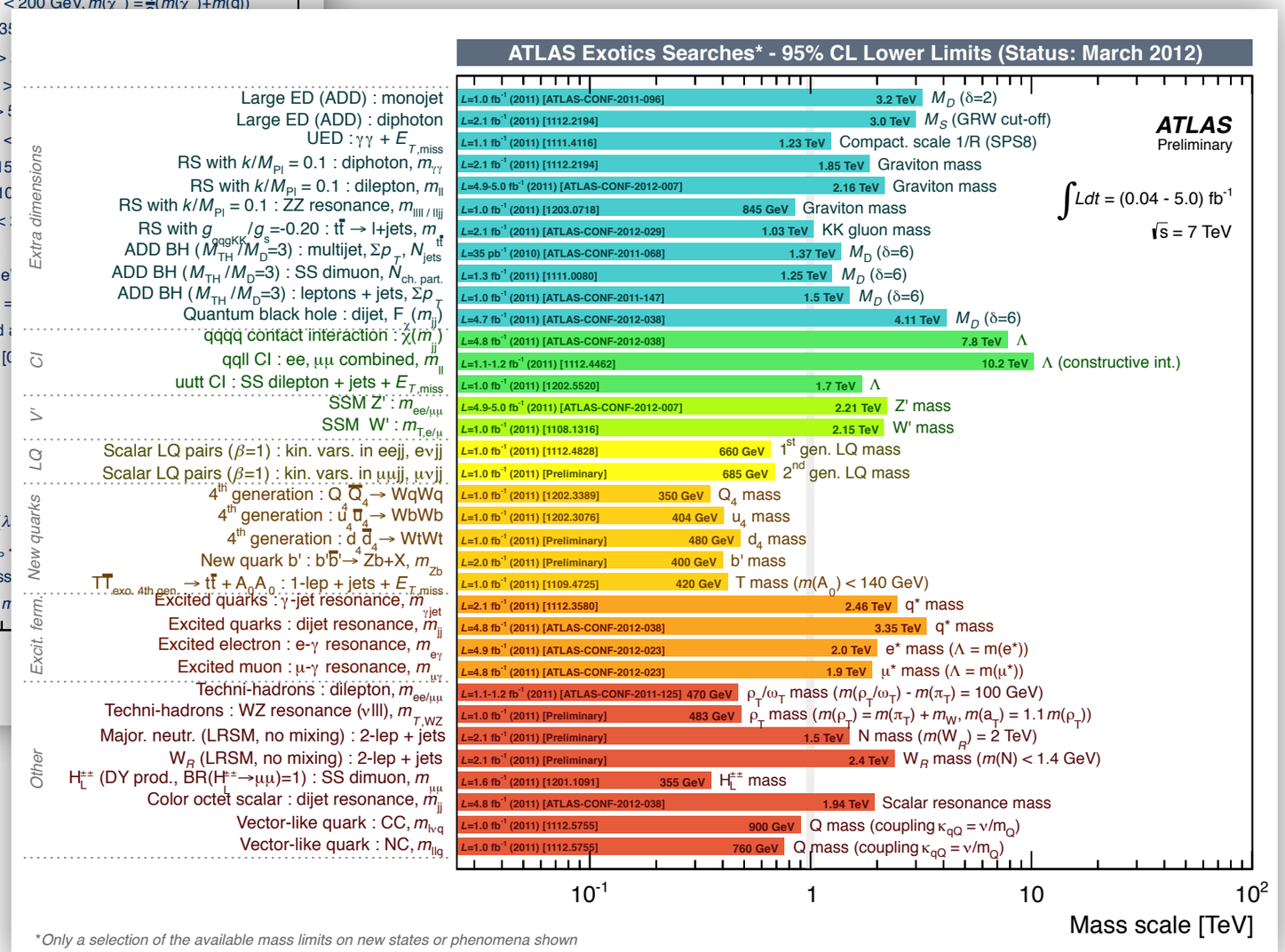
BSM physics outside the Higgs sector

If Higgs is not found, where is the BSM physics hiding?

Continuing refrain from phenomenologists (c.f. SEARCH 2012): existing searches are not general enough

- *Finite resources => focus on some fashionable subset of models*
- *Theoretical prejudices => prefer scenarios with attractive properties*
- *Search results interpreted in terms of a handful of models, or sometimes provided in various "model-independent" ways (often not model independent or hard for theory to interpret)*





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- *Example: photon+jet searches—17 year gap...*

PRL 72 (3004) (1994)

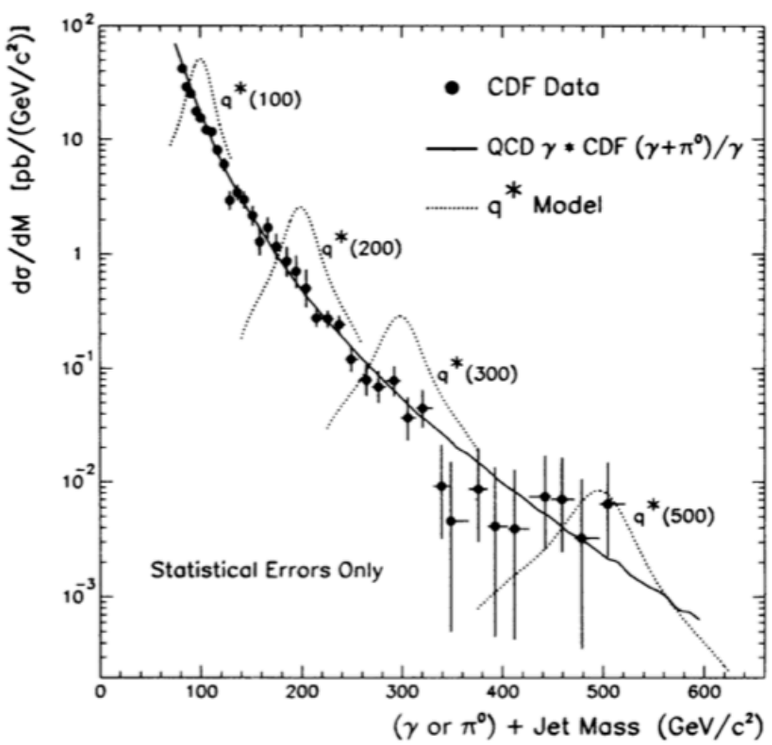
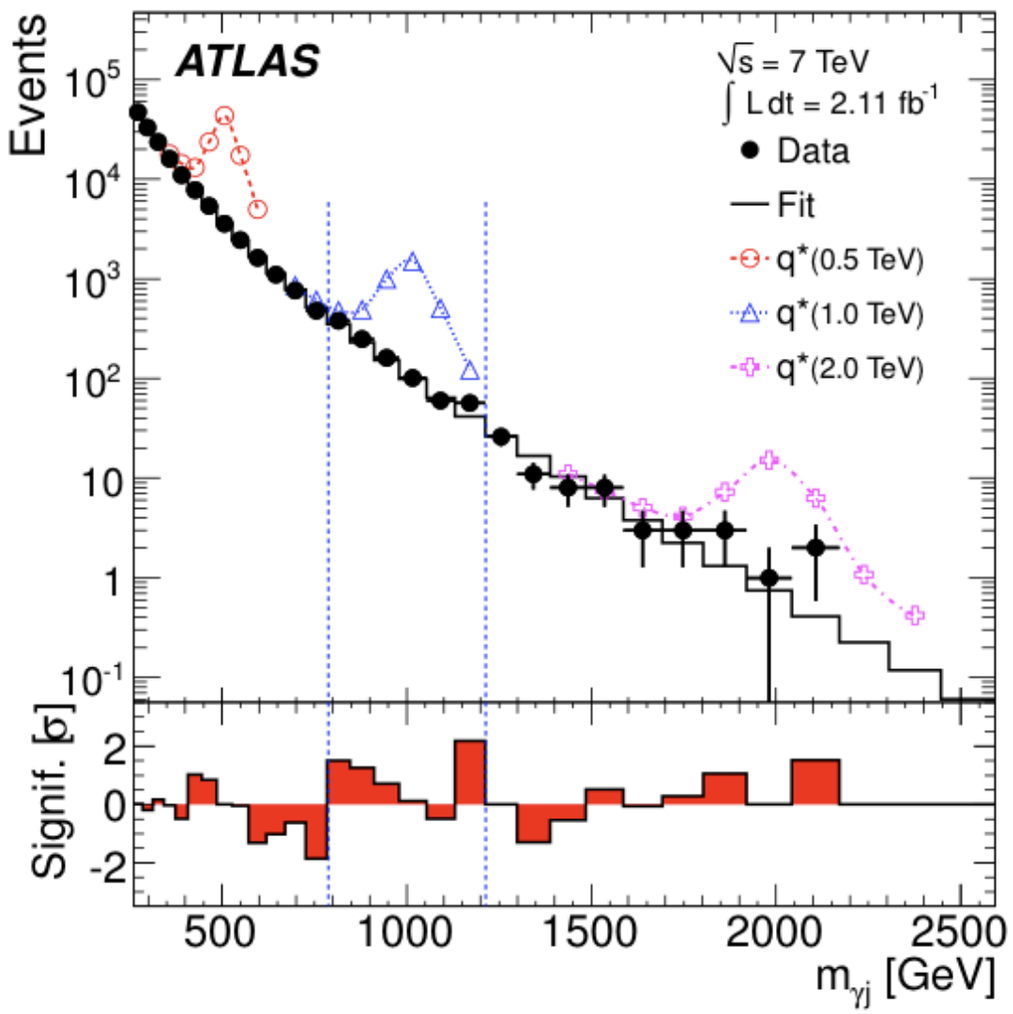


FIG. 1. The photon candidate + leading jet invariant mass distribution (points) compared to an estimate of the QCD background (solid curve) and excited quark signal at four different q^* mass values (dotted curves). Corrected for acceptance and efficiency except for the cuts $|\eta_\gamma| < 0.9$ and $|\cos\theta^*| < \frac{2}{3}$.

arXiv:1112.3580 (2011)



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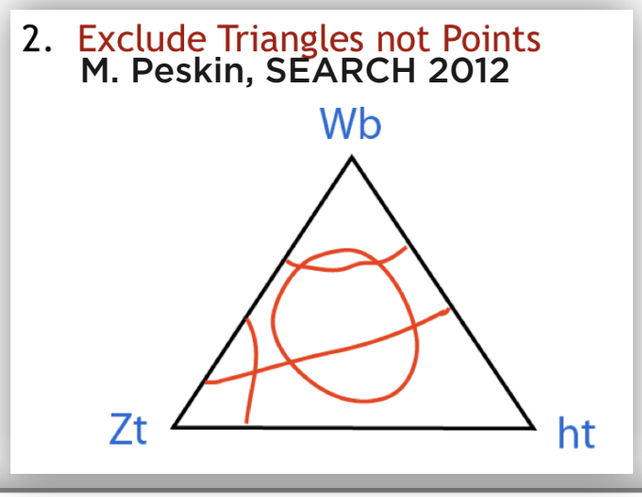
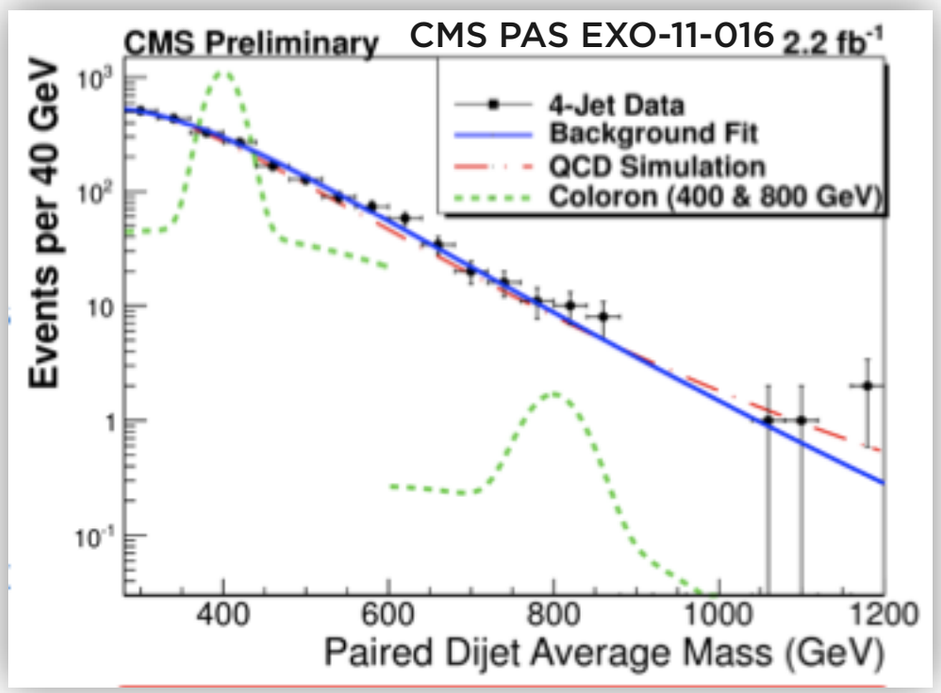
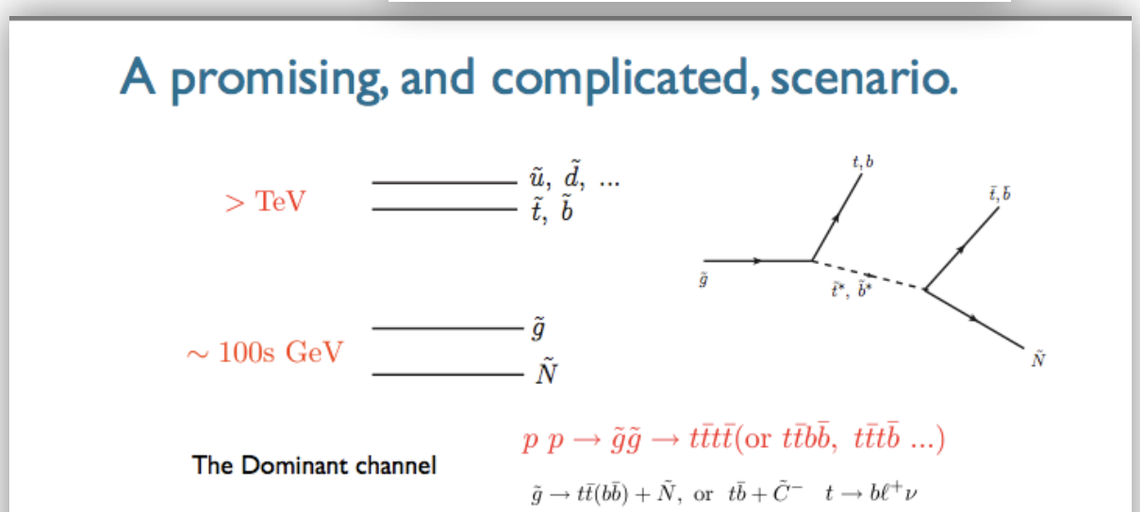
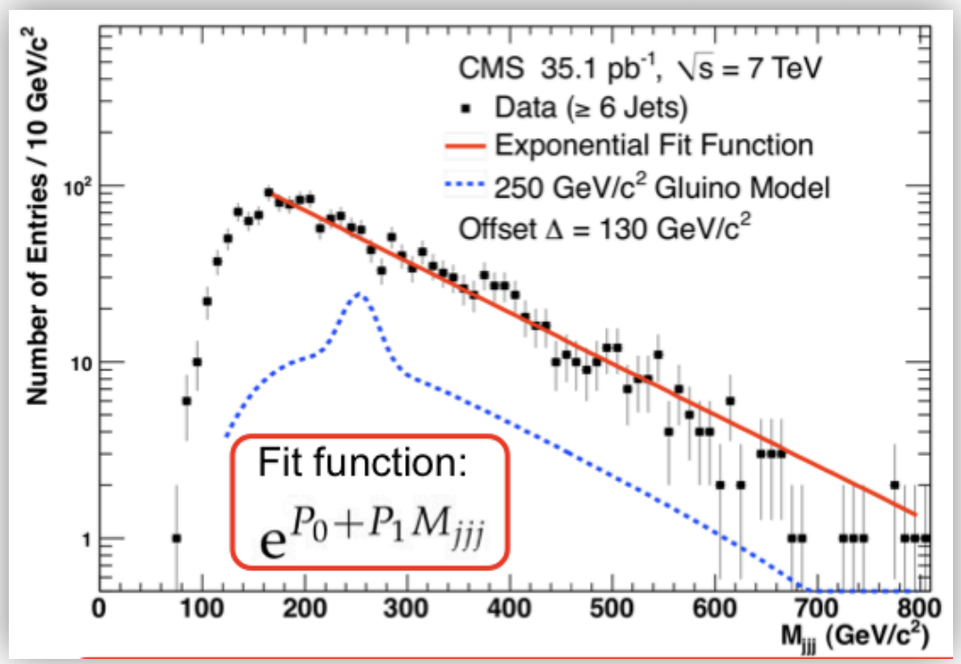
- *Example: more complicated decay topologies*





PRL 107, 101801 (2011)





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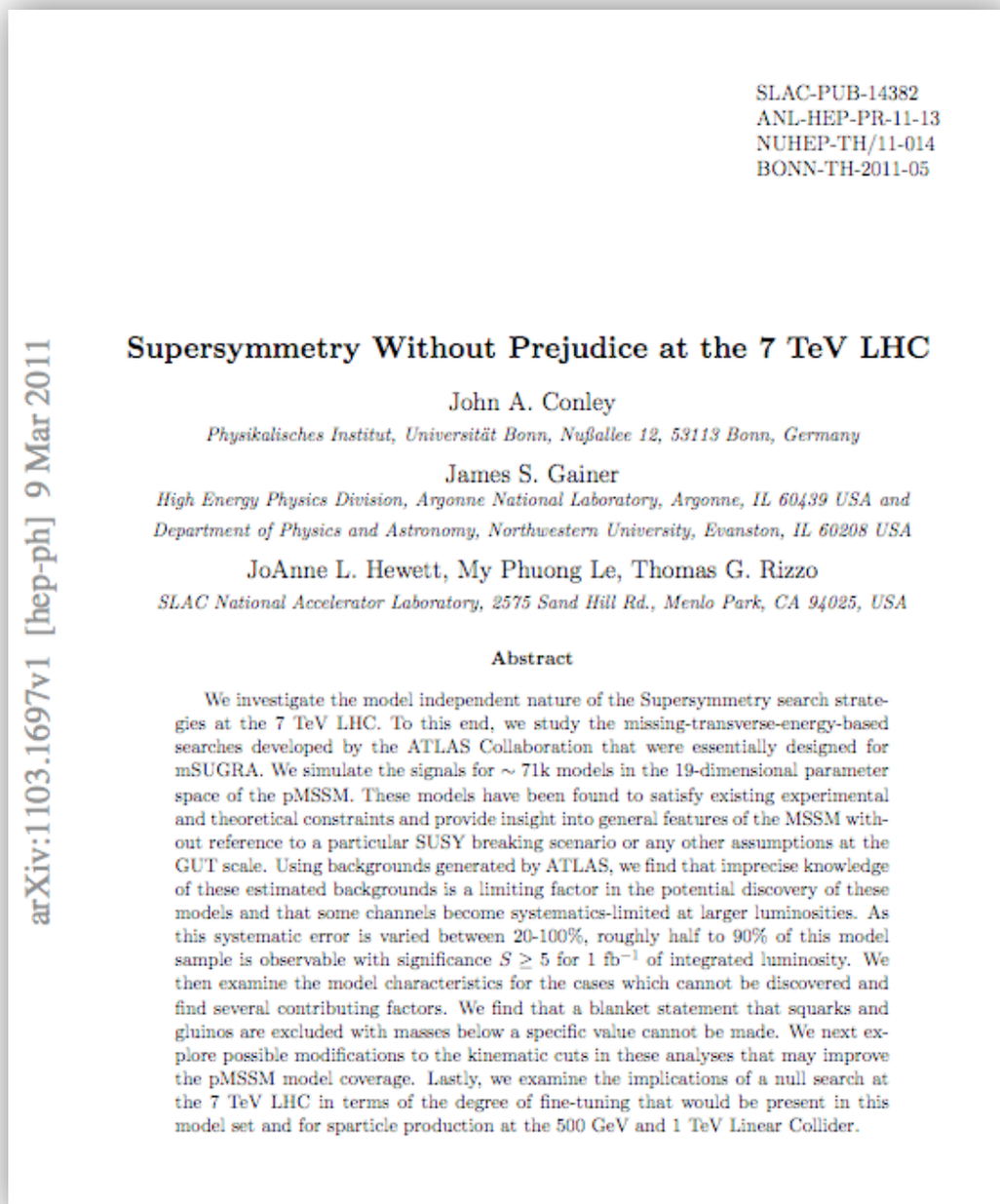
- *Search results interpreted in terms of a handful of models, or sometimes provided in various "model-independent" ways (often not model independent or hard for theory to interpret)*
- *Example: debate over how to re-interpret mSUGRA and other searches in terms of less-restrictive SUSY scenarios*
  - *"Supersymmetry Without Prejudice"*



SLAC-PUB-14382
ANL-HEP-PR-11-13
NUHEP-TH/11-014
BONN-TH-2011-05

arXiv:1103.1697v1 [hep-ph] 9 Mar 2011

Supersymmetry Without Prejudice at the 7 TeV LHC

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Abstract

We investigate the model independent nature of the Supersymmetry search strategies at the 7 TeV LHC. To this end, we study the missing-transverse-energy-based searches developed by the ATLAS Collaboration that were essentially designed for mSUGRA. We simulate the signals for ~ 71k models in the 19-dimensional parameter space of the pMSSM. These models have been found to satisfy existing experimental and theoretical constraints and provide insight into general features of the MSSM without reference to a particular SUSY breaking scenario or any other assumptions at the GUT scale. Using backgrounds generated by ATLAS, we find that imprecise knowledge of these estimated backgrounds is a limiting factor in the potential discovery of these models and that some channels become systematics-limited at larger luminosities. As this systematic error is varied between 20-100%, roughly half to 90% of this model sample is observable with significance $S \geq 5$ for 1 fb^{-1} of integrated luminosity. We then examine the model characteristics for the cases which cannot be discovered and find several contributing factors. We find that a blanket statement that squarks and gluinos are excluded with masses below a specific value cannot be made. We next explore possible modifications to the kinematic cuts in these analyses that may improve the pMSSM model coverage. Lastly, we examine the implications of a null search at the 7 TeV LHC in terms of the degree of fine-tuning that would be present in this model set and for sparticle production at the 500 GeV and 1 TeV Linear Collider.

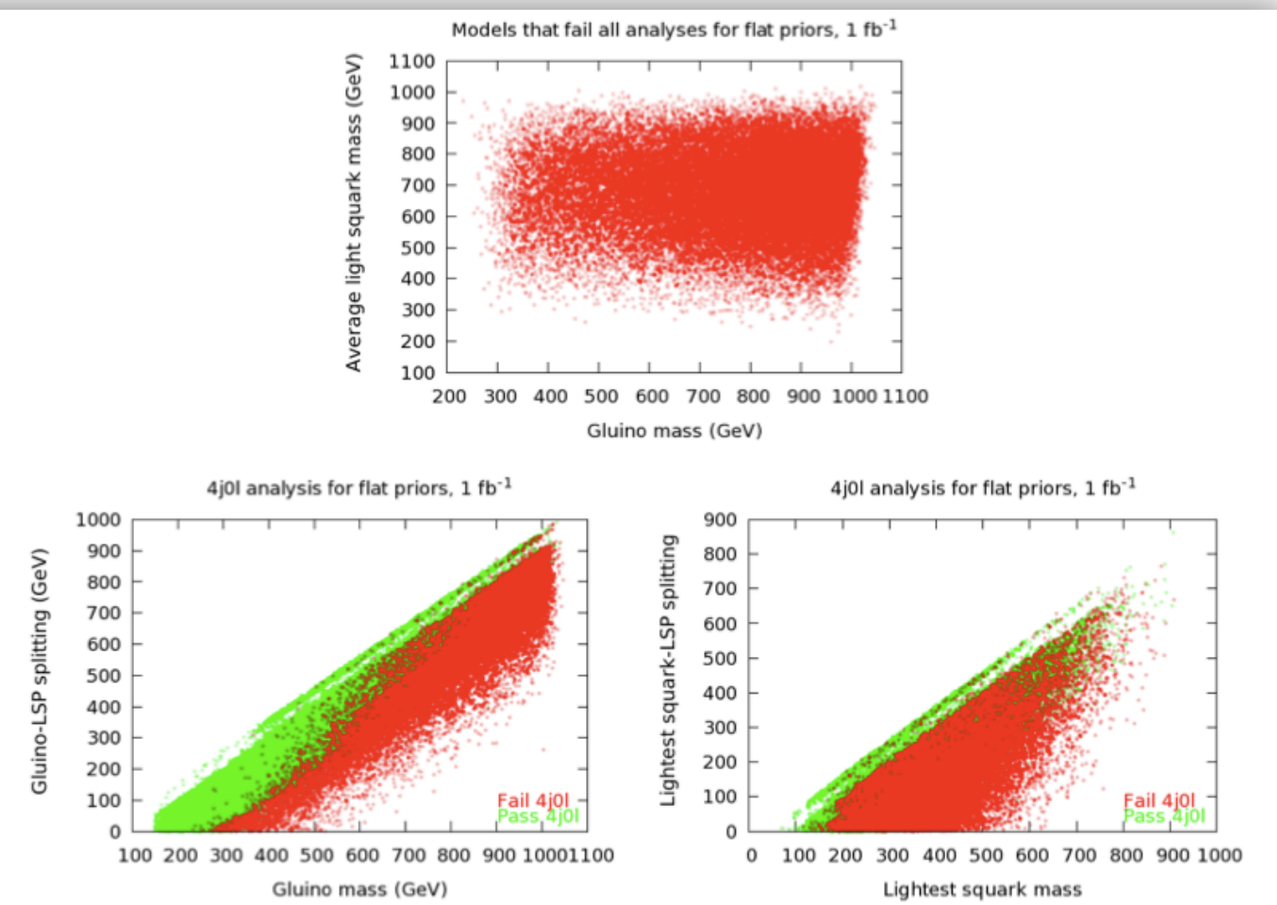


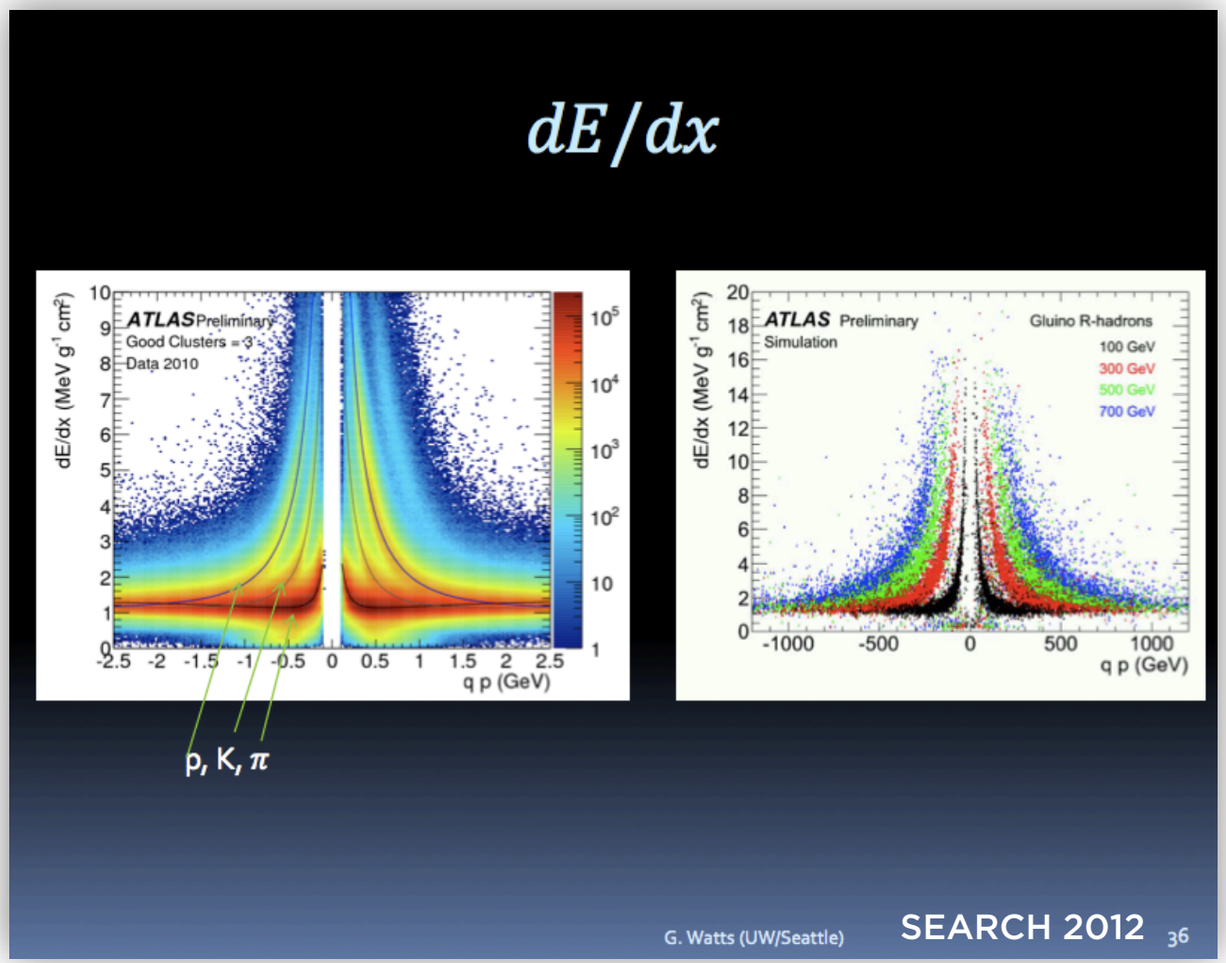
Figure 14: (Top) Flat prior models that are unobservable in all of the $E_T^{\rm miss}$-based search analyses in the average light squark -gluino mass plane. (Bottom) Flat prior models that pass(green) or fail(red) the 4j0l analysis in the gluino(lightest squark) mass vs gluino-LSP(lightest squark-LSP) mass splitting plane in the left(right) panel. $\mathcal{L} = 1$ fb^{-1} and $\delta B = 50\%$ have again been assumed.

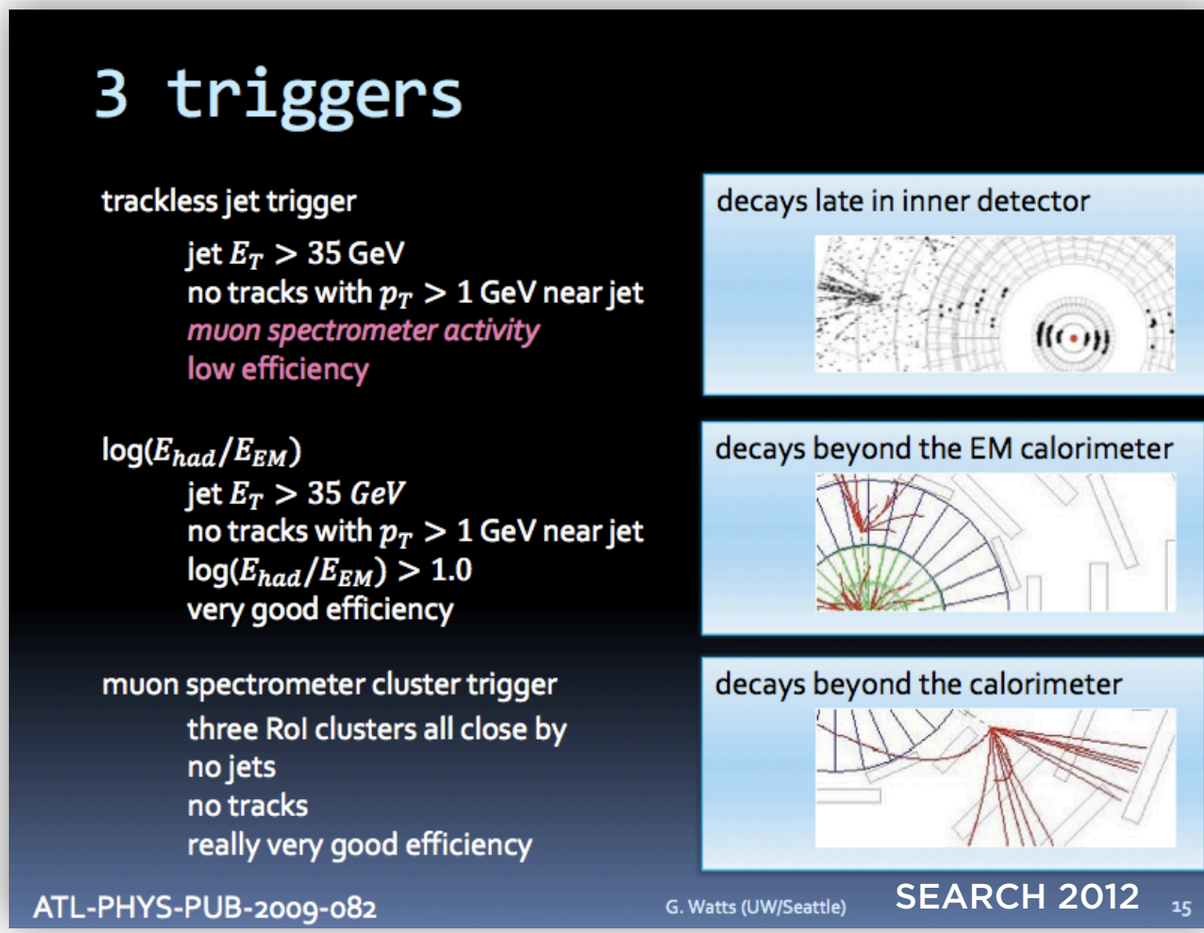
BSM physics outside the Higgs sector

If Higgs is not found, where is the BSM physics hiding?

Continuing refrain from phenomenologists (c.f. SEARCH 2012): existing searches are not general enough

- *Finite resources => focus on some fashionable subset of models*
- *Theoretical prejudices => prefer scenarios with attractive properties*
- *Search results interpreted in terms of a handful of models, or sometimes provided in various "model-independent" ways (often not model independent or hard for theory to interpret)*
- *Example:* ***non-prompt, late-decaying or slow/highly ionizing tracks; late jets, out of time energy***





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- *Search results interpreted in terms of a handful of models, or sometimes provided in various "model-independent" ways (often not model independent or hard for theory to interpret)*
- *Example:* ***pathologically wacky final states (e.g. charge-shifting R hadrons)***

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Odd Tracks at Hadron Colliders

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New physics that exhibits irregular tracks such as kinks, intermittent hits or decay in flight may easily be missed at hadron colliders. We demonstrate this by studying viable models of light, $\mathcal{O}(10\ \mathrm{GeV})$, colored particles that decay predominantly inside the tracker. Such particles can be produced at staggering rates, and yet may not be identified or even triggered on at the LHC, unless specifically searched for. In addition, the models we study provide an explanation for the original measurement of the anomalous charged track distribution by CDF. The presence of irregular tracks in these models reconcile that measurement with the subsequent reanalysis and the null results of ATLAS and CMS. Our study clearly illustrates the need for a comprehensive study of irregular tracks at the LHC.

INTRODUCTION

A large variety of new physics scenarios feature the presence of charged particles with peculiar properties, that can lead to a systematic mis-reconstruction of their tracks by the standard algorithms. These properties can induce mismeasurements of the p_T or even a failure to reconstruct tracks. One of the simplest examples is a particle that decays in flight inside the tracker, but in the following we list other possibilities and refer to them generically as New Odd Tracks (NOTs). The systematic mis-reconstruction of NOTs implies that such theories may evade detection, even if they are produced at surprisingly high rates. Consequently, particles of this kind can be very light, and may require dedicated studies for discovery. In this note we argue that there are viable models with very light colored states that would have gone unnoticed. As a motivating example, we consider an anomaly in a recent measurement based on minimum bias events, and provide viable explanations using NOTs.

In [1] the single charged particle inclusive distribution was measured by the CDF collaboration. The measurement was found to be inconsistent with the QCD prediction at high p_T [2-4] by a factor of 10^4. Subsequent measurements by ATLAS [5] and CMS [6] found no evidence for an anomaly at high p_T. Most recently, CDF released an erratum [7] where they changed their track selection to remove the high-p_T tracks they had previously measured. While the original result could in principle come from an experimental mismeasurement/unaccounted for background, there is an intriguing possibility that it was due to new physics that can also account for all subsequent findings.

The main difference between the original CDF analysis and the subsequent reanalysis lies in demanding a higher track quality. Unfortunately, the reanalysis does not quantitatively find a SM explanation of the original excess tracks, which are simply removed by the quality cut. The measurements by ATLAS and CMS also require much more stringent track quality cuts than the original CDF measurement. To address the original anomaly, together with the null results, one is therefore required to introduce new particles which appear fundamentally different in the tracker, i.e. NOTs. The more stringent cuts on the CDF data reconcile the apparent tension, however, they do so at the cost of losing the sensitivity to new physics of this kind.

The models presented are interesting in their own right. The take-home message, however, is not the specific model. Rather, we stress the existence of a large variety of theories that exhibit NOTs, which would be misinterpreted or even missed at the LHC unless specifically searched for. Our work aims, in part, at motivating additional studies to ensure NOTs will not escape detection.

NEW ODD TRACKS

Before discussing specific models, we briefly discuss the spectrum of possibilities for theories that exhibit NOTs. It is useful to classify the possible effects of new physics on standard track signatures. Typically, a given model exhibits more than one signature, which may simplify its identification [8]:

- **Kinks**. Tracks that appear to change direction, without a secondary vertex. Typically produced by one-prong decays.
- **Displaced vertices**. Tracks appearing to emanate not from the PV.
- **Anomalous** dE/dx. Tracks may have lower or higher ionization loss. Standard Heavy Stable Charged Particle (HSCP) searches typically look for the latter.
- **Anomalous timing**. Slowly moving tracks as measured via the timing module at the calorimeter, but

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Macroscopic Strings and "Quirks" at Colliders

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Abstract

We consider extensions of the standard model containing additional heavy particles ("quirks") charged under a new unbroken non-abelian gauge group as well as the standard model. We assume that the quirk mass m is in the phenomenologically interesting range 100 GeV–TeV, and that the new gauge group gets strong at a scale $\Lambda < m$. In this case breaking of strings is exponentially suppressed, and quirk production results in strings that are long compared to Λ^{-1}. The existence of these long stable strings leads to highly exotic events at colliders. For $100\ \mathrm{eV} \lesssim \Lambda \lesssim \mathrm{keV}$ the strings are macroscopic, giving rise to events with two separated quirk tracks with measurable curvature toward each other due to the string interaction. For $\mathrm{keV} \lesssim \Lambda \lesssim \mathrm{MeV}$ the typical strings are mesoscopic: too small to resolve in the detector, but large compared to atomic scales. In this case, the bound state appears as a single particle, but its mass is the invariant mass of a quirk pair, which has an event-by-event distribution. For $\mathrm{MeV} \lesssim \Lambda \lesssim m$, the strings are microscopic, and the quirks annihilate promptly within the detector. For colored quirks, this can lead to hadronic fireball events with $\sim 10^3$ hadrons with energy of order GeV emitted in conjunction with hard decay products from the final annihilation.

New requirements for new physics

Exhaust easy options for BSM physics => grow more desperate => give up prejudices

- *"Naturalness", simplicity, triggerable leptons, etc.*
- *Examples:*
  - *why does SUSY need to supply a dark matter candidate? (give up R-parity)*
  - *why does DM need to consist of a single type of particle? (SM does not)*
  - *why should BSM physics be easy to trigger on?*

FTK

Since exact nature of BSM physics is unknown, trigger flexibility is vital.

ATLAS is preparing a Level "1.5" trigger upgrade to provide near-offline quality tracking for the Level 2 trigger algorithms.

Within 100 us of each Level 1 accept, FTK will perform $p_T > 1$ GeV tracking over the entire silicon system for the start of HLT processing. It divides tracking into two stages:

- *Coarse pattern recognition with an associative memory*
- *Full-resolution FPGA track search and fits*

Designed to handle Phase I pile-up (3x design luminosity)

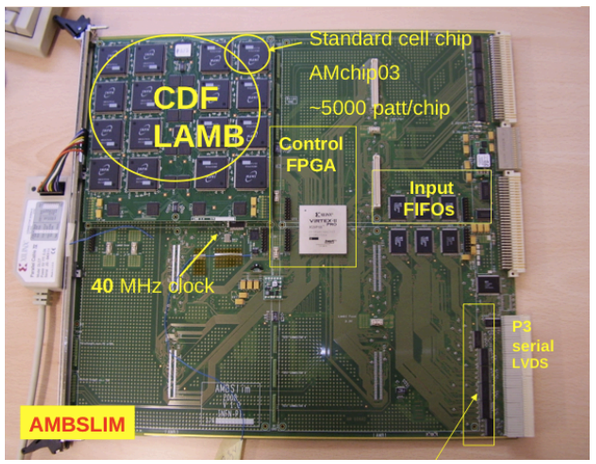
Associative memory "road finding"

Analyze a large sample of tracks and construct a frequency-ordered list of all hit patterns generated by the tracks in the detector. Look for each of these patterns in every event.

- Group consecutive silicon channels into "superstrips" (SS) to reduce the number of unique patterns needed for high efficiency and the size of training track sample.
- Partition silicon detectors into 11 "logical layers."
- Result for high-pileup configuration is typically order 1 billion coarse-granularity hit patterns for $p_T > 1$ GeV tracks over the entire detector (smaller for early system).

The associative memory (AM) chip

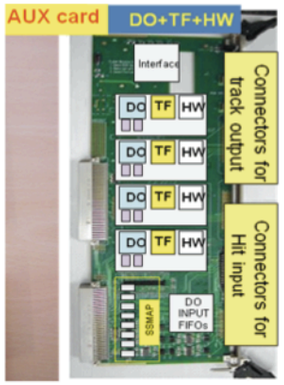
- Store each pattern in one cell of memory in a set of custom ASICs. Each cell compares its pattern to silicon data flowing through a common bus.
- When readout is complete, the AM stage is complete; pattern recognition occurs at the silicon readout speed.



FPGA "track fitting"

Within each identified pattern ("road"), fit all full resolution hit combinations and apply a chi^2 cut.

- Linearize the track fit: average track parameters for each combination of modules + first order correction for each hit—excellent approximation suitable for FPGAs with embedded DSPs.
- Full combinations have exactly one hit in each of the logical layers
- "Majority" roads/combinations have one logical layer with no hit.
- 1 fit/ns



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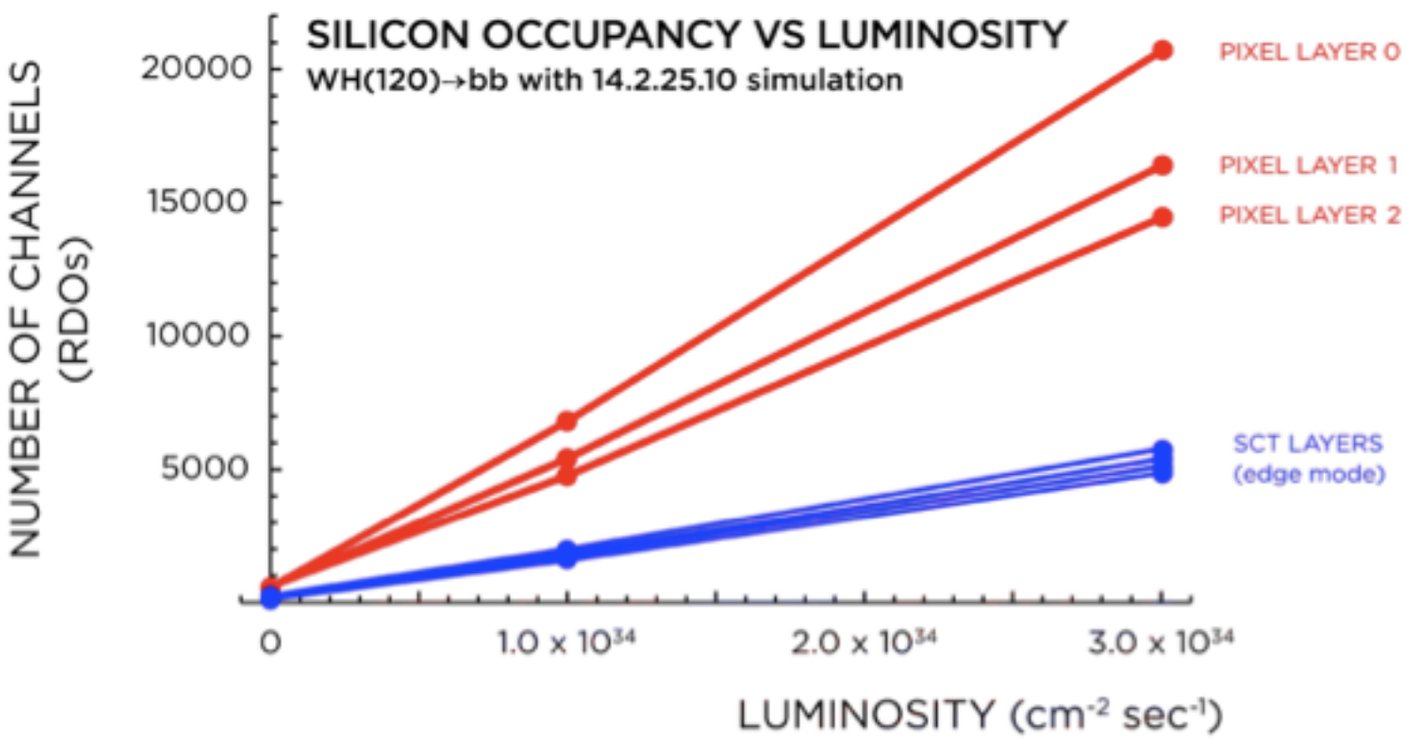
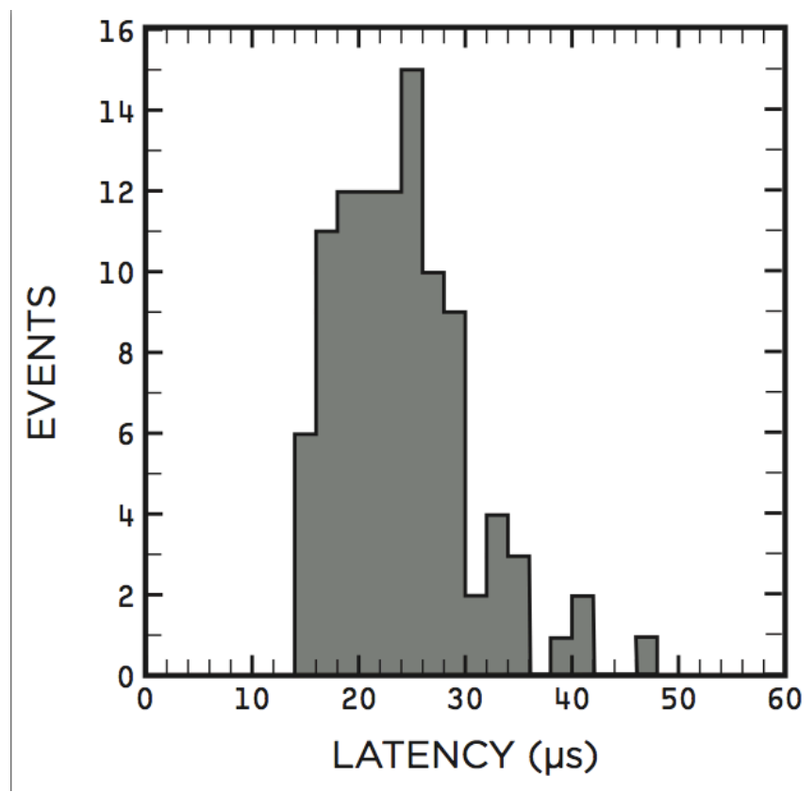
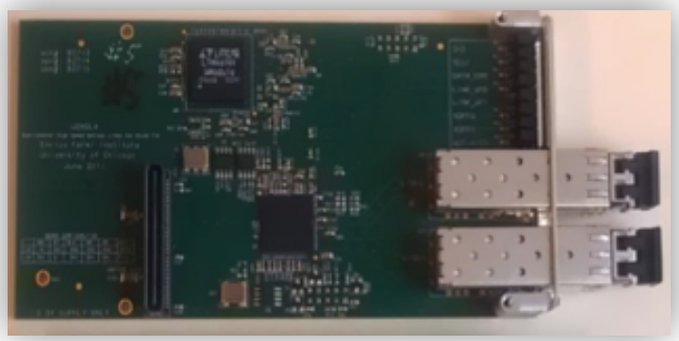
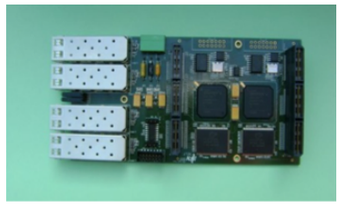


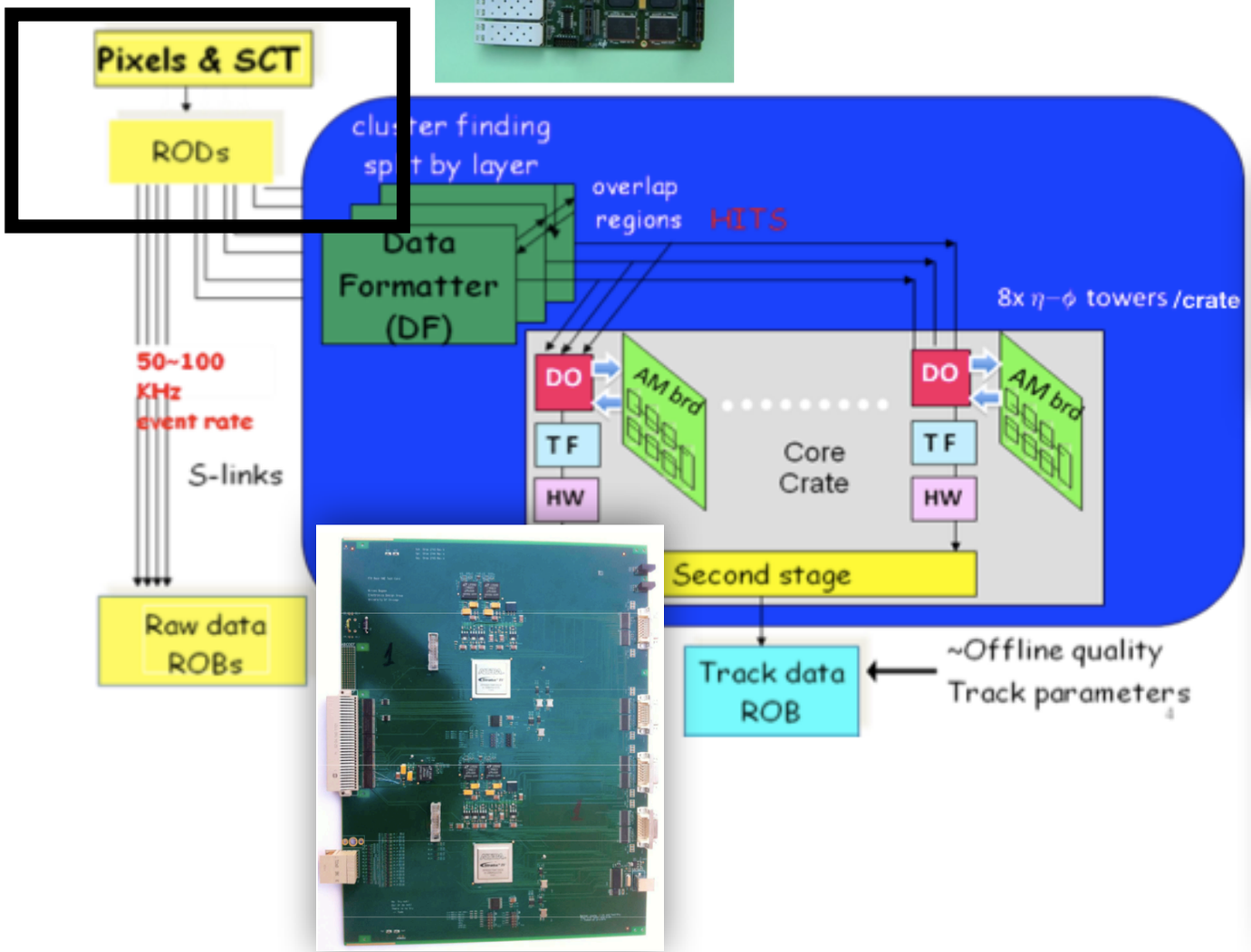
Figure 2.1: The number of ROD output hits from each silicon layer in the barrel vs. luminosity.

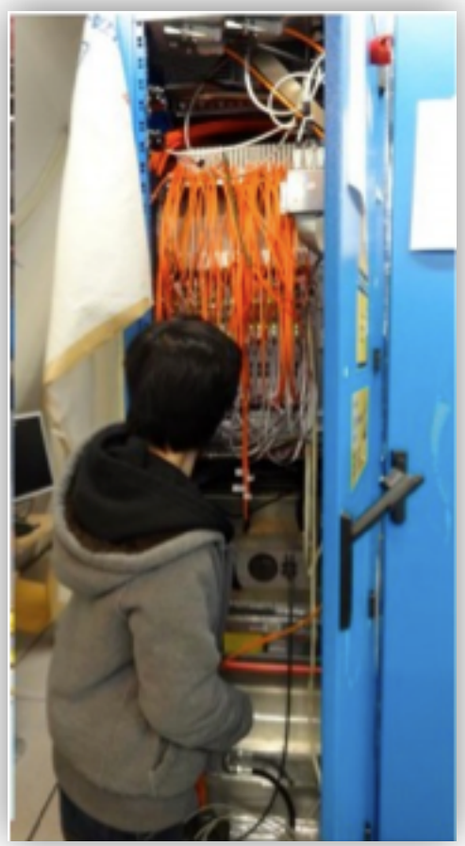


FTK









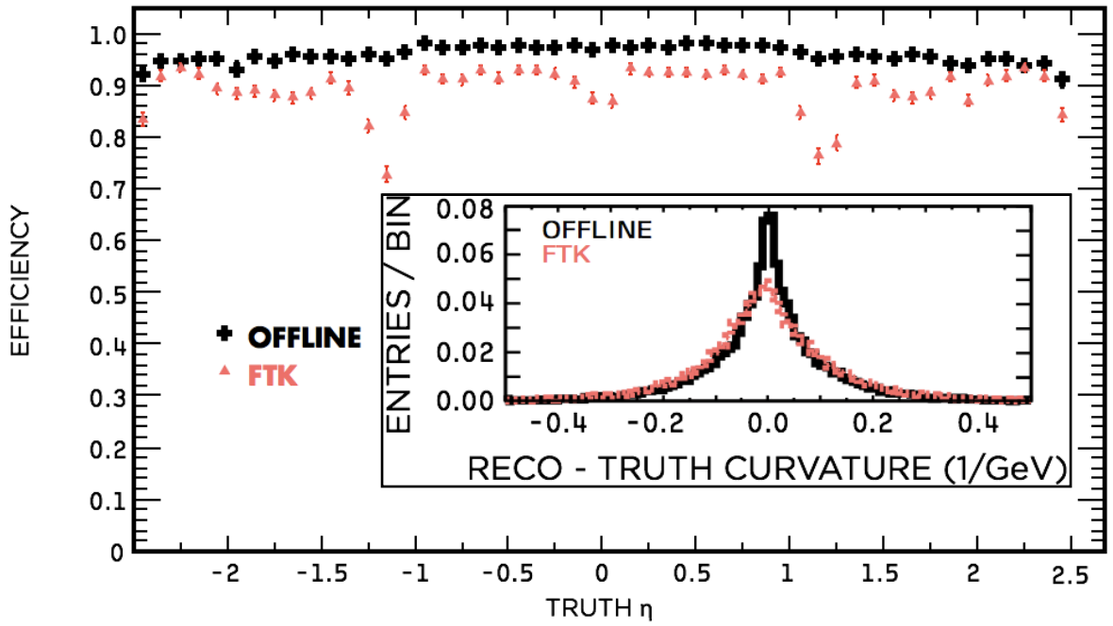
Prototype being built at ATLAS Point 1 for parasitic commissioning

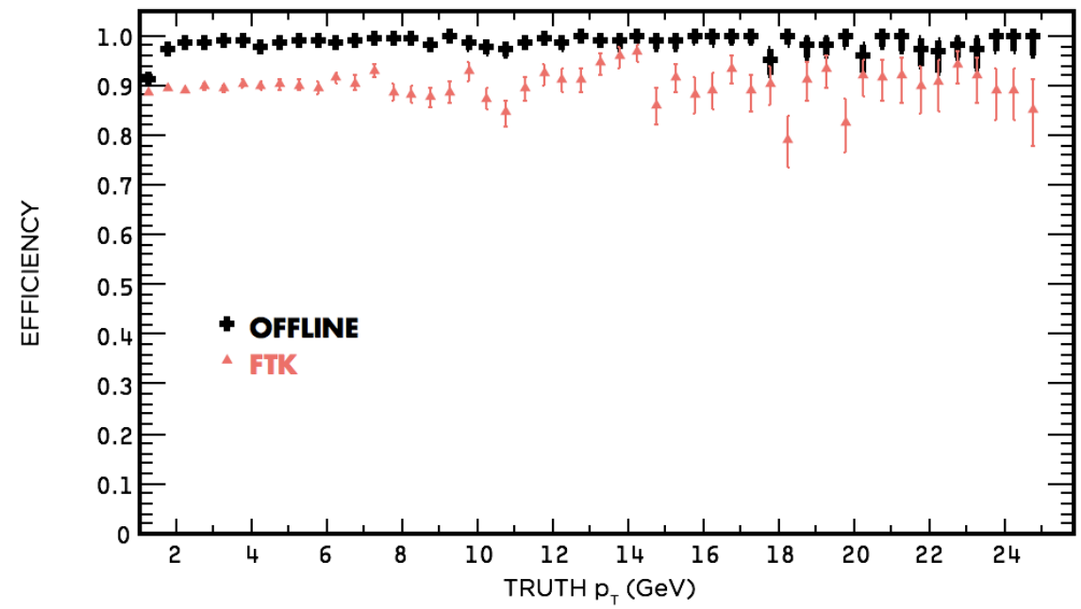
Replace HOLAs for RODs in existing detectorwith ones that have two outputs:
- *ROS : standard behavior*
- *FTK : Can exert flow control when FTK is enabled*

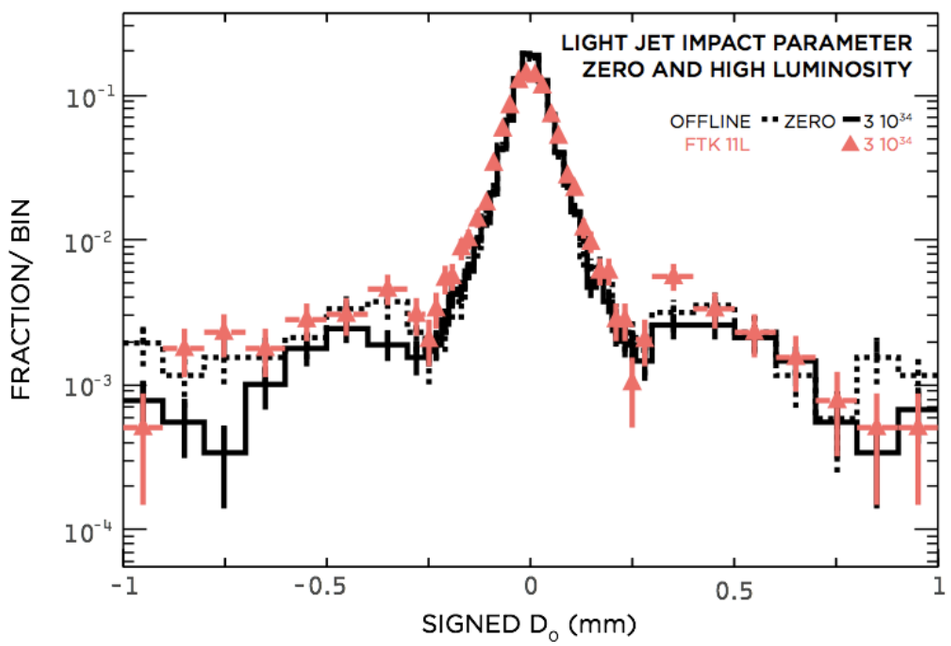
Produced and tested all replacements boards at Chicago in Nov/December
32 installed and tested at P1 since January; remainder during long shutdown.

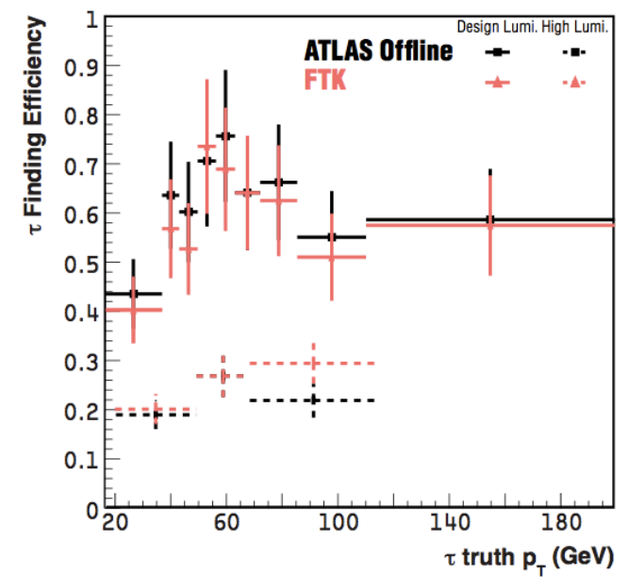
Goal is to prototype and test all components by Summer 2013. Full system ASAP.

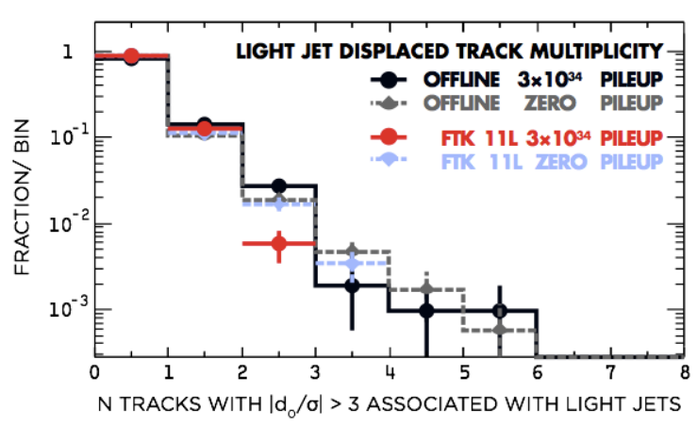
FTK—Performance Figures from 2010 Technical Proposal

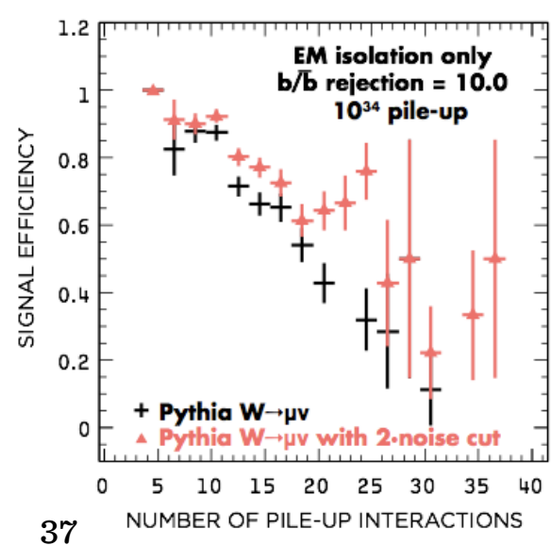


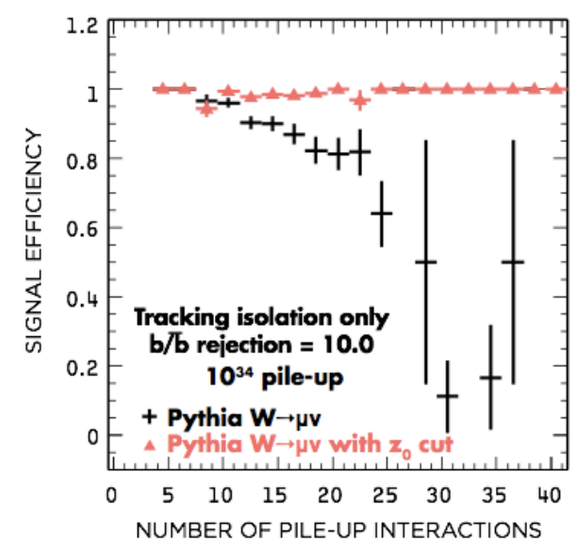












Summary

- *Higgs physics is beginning to place important constraints on BSM physics scenarios.*
  - *2012 "Precision" measurements of properties may be the most interesting measurements for the next few years.*

- *Traditional BSM strategies need to evolve*
  - *Exhaust easy options for BSM physics => grow more desperate => give up prejudices for direct searches*

Additional Slides

Diphoton systematics

Signal event yield	
Photon reconstruction and identification	$\pm 11\%$
Effect of pileup on photon identification	$\pm 4\%$
Isolation cut efficiency	$\pm 5\%$
Trigger efficiency	$\pm 1\%$
Higgs boson cross section (scales)	$^{+12}_{-8}\%$
Higgs boson cross section (PDF+α_s)	$\pm 8\%$
Higgs boson p_{T} modeling	$\pm 1\%$
Luminosity	$\pm 3.9\%$
Signal mass resolution	
Calorimeter energy resolution	$\pm 12\%$
Photon energy calibration	$\pm 6\%$
Effect of pileup on energy resolution	$\pm 3\%$
Photon angular resolution	$\pm 1\%$
Signal mass position	
Photon energy scale	± 0.7 GeV
Signal category migration	
Higgs boson p_{T} modeling	$\pm 8\%$
Conversion rate	$\pm 4.5\%$
Background model	$\pm (0.1 - 7.9)$ events

How did the sensitivity projections do?

- *ATLAS ZZ: projected ~0.5 bkg + 1.5 signal at 130 GeV, vs. 9.3 bkg + 2.65 signal actual.*

ATLAS, arXiv:1202.1415

Table 3: The expected numbers of background events, with their systematic uncertainty, separated into "Low-$m_{4\ell}$" ($m_{4\ell} < 180$ GeV) and "High-$m_{4\ell}$" ($m_{4\ell} \geq 180$ GeV) regions, compared to the observed numbers of events. The expectations for a Higgs boson signal for five different m_H values are also given.

	$\mu^+\mu^-\mu^+\mu^-$		$e^+e^-\mu^+\mu^-$		$e^+e^-e^+e^-$	
	Low-$m_{4\ell}$	High-$m_{4\ell}$	Low-$m_{4\ell}$	High-$m_{4\ell}$	Low-$m_{4\ell}$	High-$m_{4\ell}$
Int. Luminosity	4.8 fb^{-1}		4.8 fb^{-1}		4.9 fb^{-1}	
$ZZ^{(*)}$	2.1 ± 0.3	16.3 ± 2.4	2.8 ± 0.6	25.2 ± 3.8	1.2 ± 0.3	10.4 ± 1.5
$Z +$ jets and $t\bar{t}$	0.16 ± 0.06	0.02 ± 0.01	1.4 ± 0.5	0.17 ± 0.08	1.6 ± 0.7	0.18 ± 0.08
Total Background	2.2 ± 0.3	16.3 ± 2.4	4.3 ± 0.8	25.4 ± 3.8	2.8 ± 0.8	10.6 ± 1.5
Data	3	21	3	27	2	15
$m_H = 130$ GeV	1.00 ± 0.17		1.22 ± 0.21		0.43 ± 0.08	
$m_H = 150$ GeV	2.1 ± 0.4		2.9 ± 0.4		1.12 ± 0.18	
$m_H = 200$ GeV	4.9 ± 0.7		7.7 ± 1.0		3.1 ± 0.4	
$m_H = 400$ GeV	2.0 ± 0.3		3.3 ± 0.5		1.49 ± 0.21	
$m_H =$						

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M_H(GeV)	120	130	140	150	165	170	180	190
SM ZZ	0.090	0.094	0.083	0.089	0.121	0.147	0.376	0.981
top & Z+jets	0.005	0.004	0.005	0.004	0.005	0.005	0.003	0.003
Total background	0.095	0.098	0.088	0.093	0.126	0.152	0.379	0.984
Signal	0.105	0.319	0.595	0.713	0.185	0.192	0.458	1.49
M_H(GeV)	200	220	240	260	300	400	500	600
SM ZZ	1.29	1.18	0.92	0.89	0.72	0.48	0.49	0.39
Signal	1.60	1.46	1.25	1.08	0.88	0.67	0.29	0.13

Table 11: Estimated number of events in the signal region for the signal and the major backgrounds at an integrated luminosity of 1 fb^{-1} for $\sqrt{s} = 7$ TeV after the full event selection in $H \to ZZ \to 4l$ (the $4e$, $2e2\mu$ and the 4μ final states are summed) .

Production Cross Section

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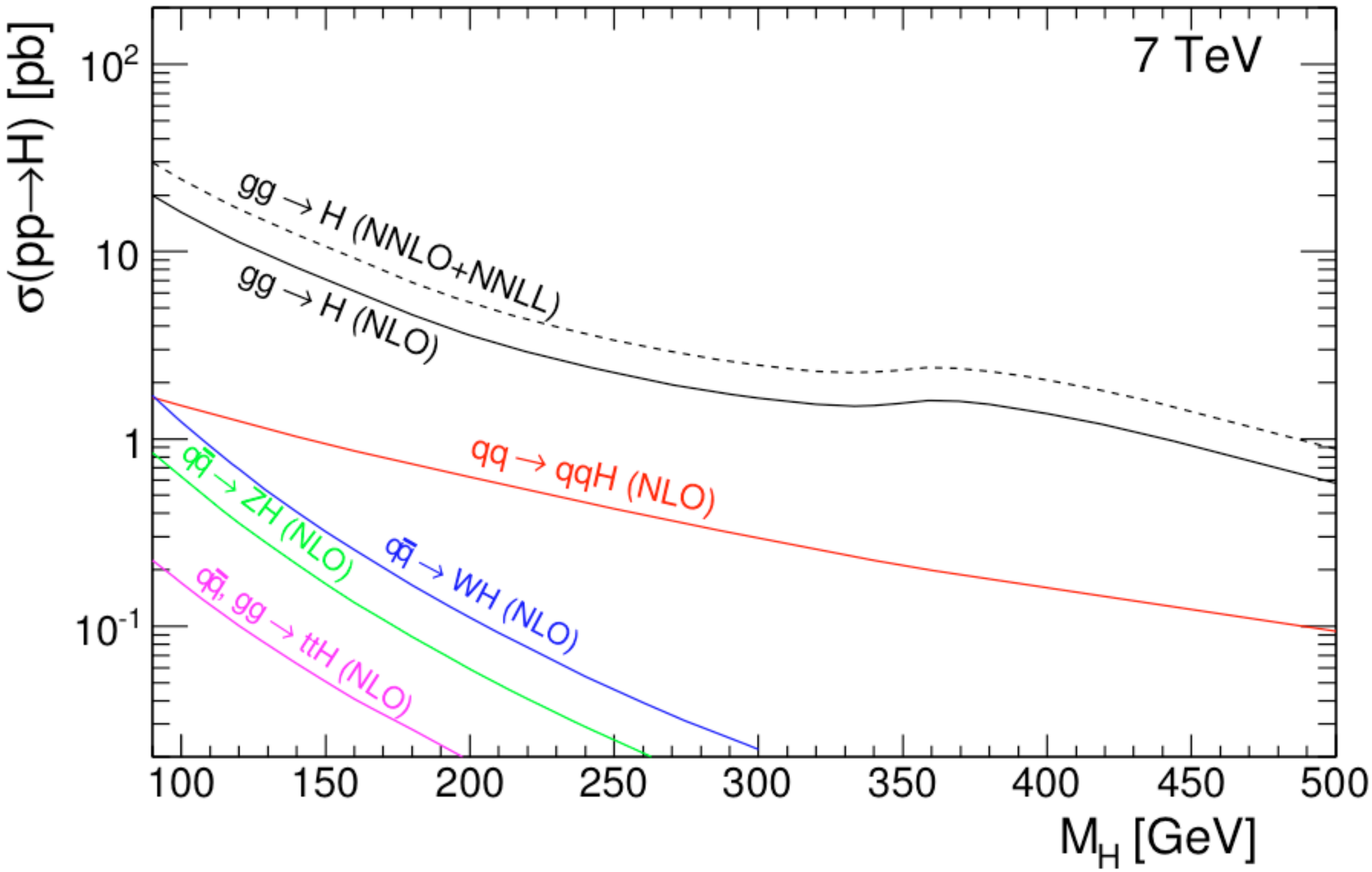

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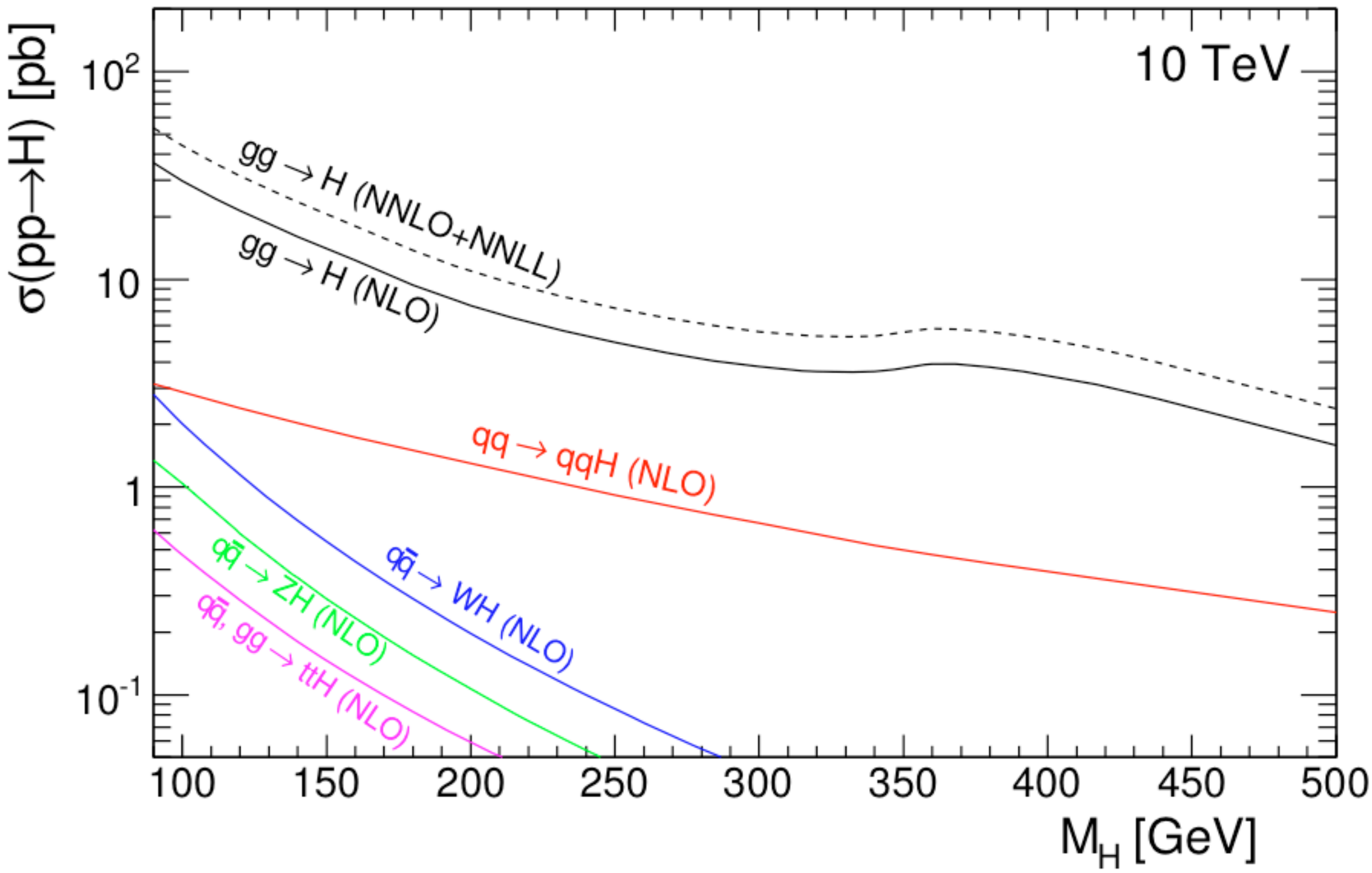

Production Cross Section

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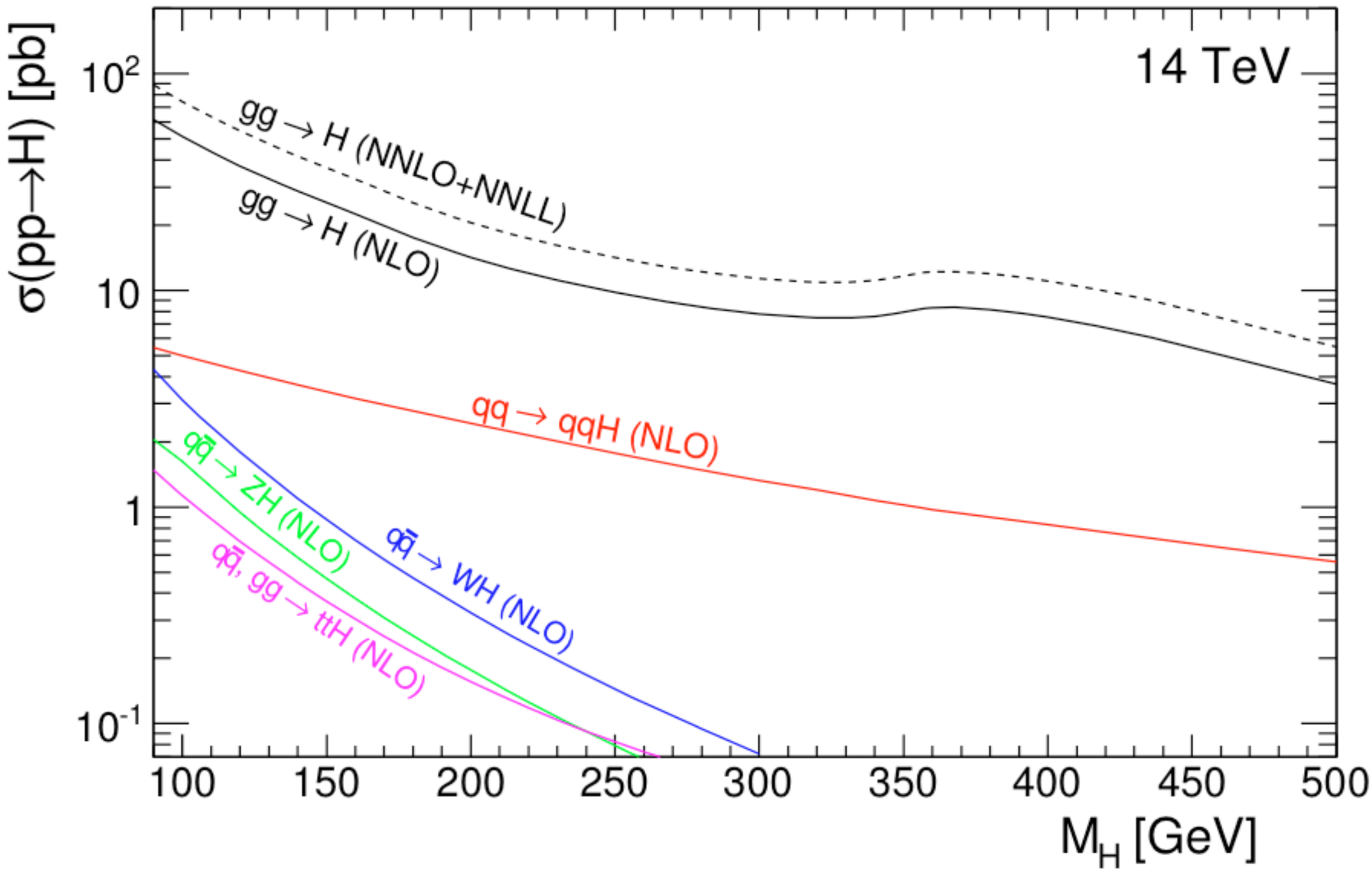
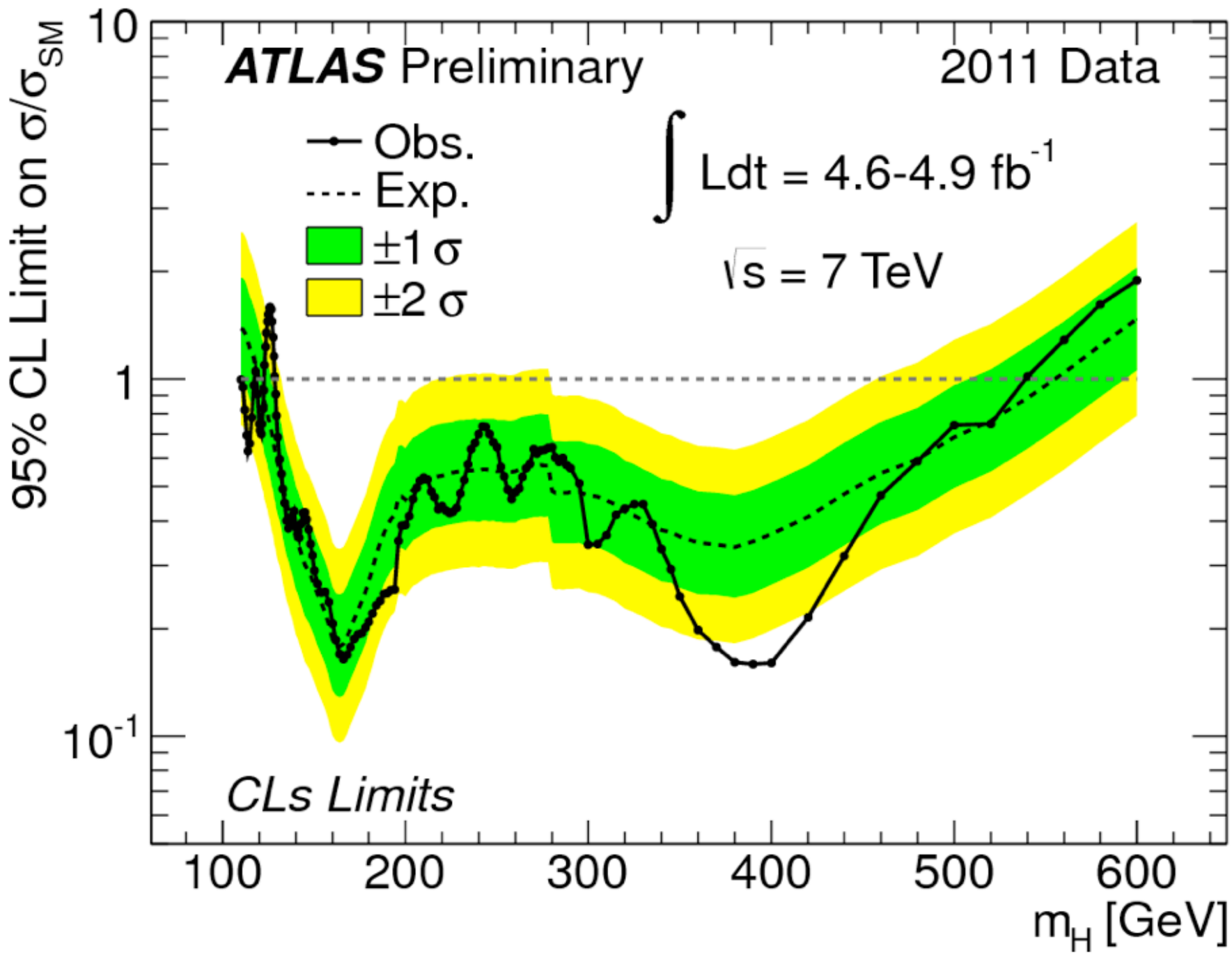


Higgs in 2012



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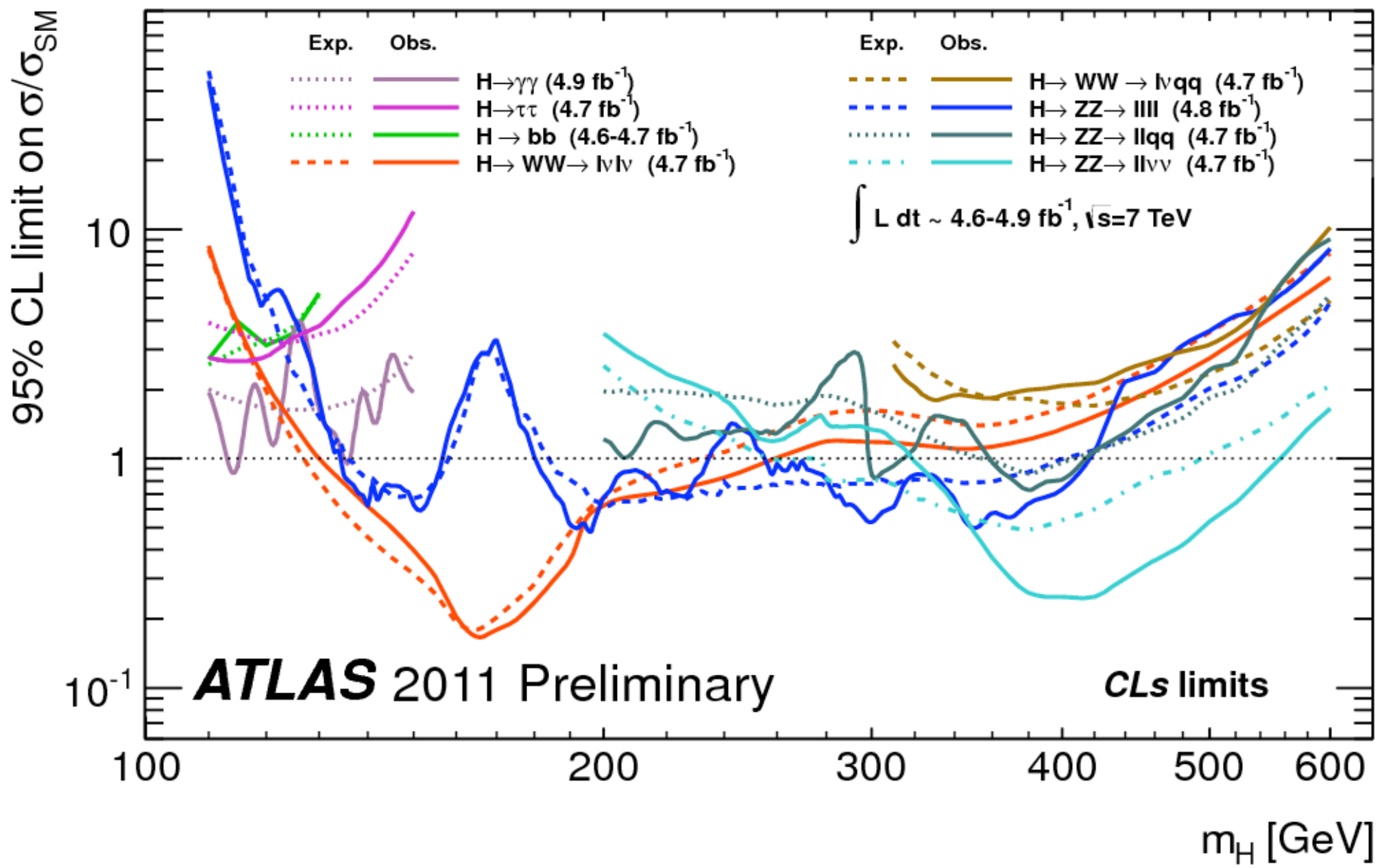


Estimated Sensitivity with 20/fb?

ATL-PHYS-PUB-2010-009

(from last time)
Many caveats to predictions: effect of pile-up on each channel, different signal to background, no new channels or other improvements, etc.

Naively: assuming 8 TeV analysis has the same sensitivity as at 7 TeV, sqrt(L=(5+15)/fb) improvement suggests anywhere from complete exclusion to (if we're extremely unlucky) m_H>~122 GeV

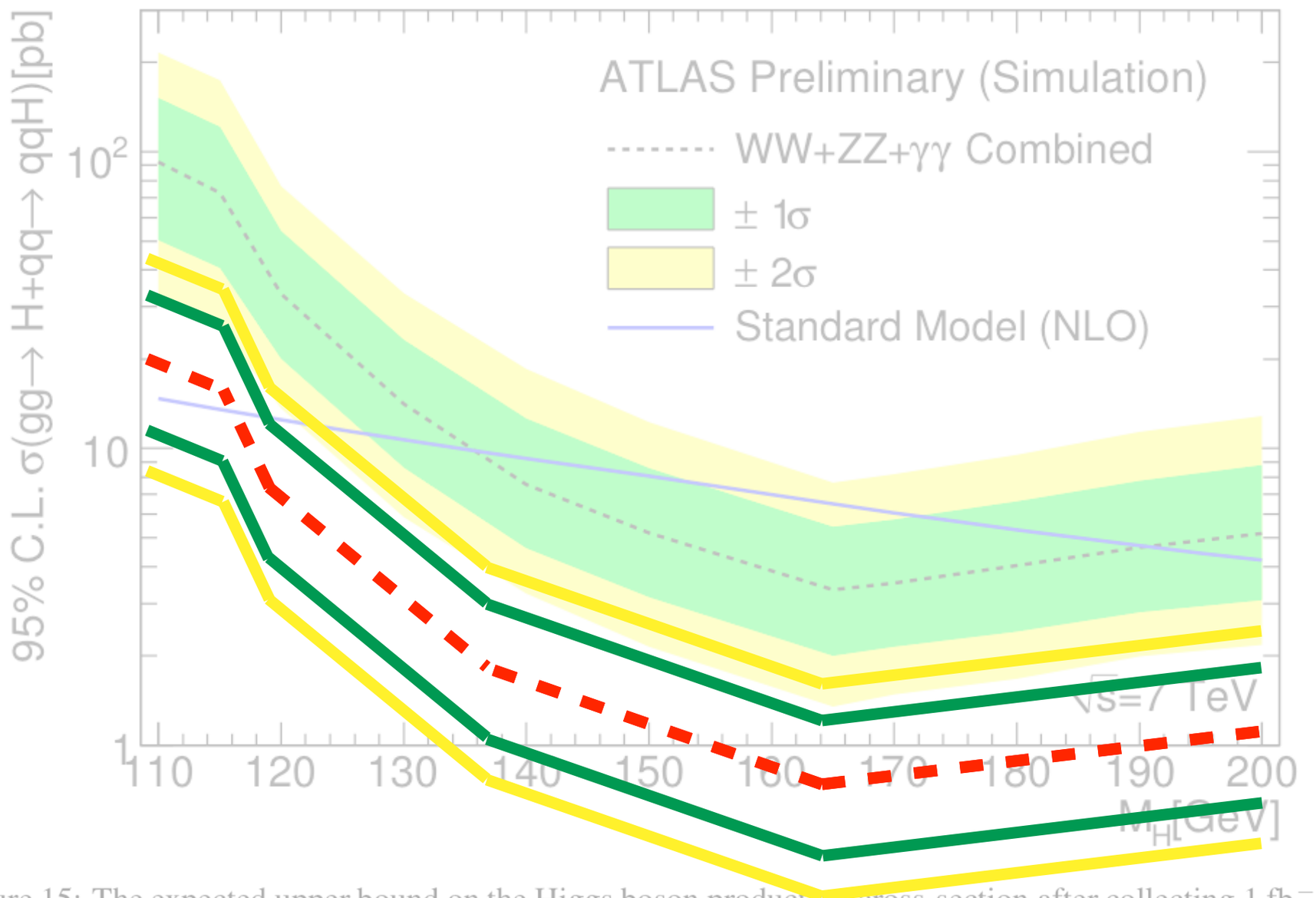


Figure 15: The expected upper bound on the Higgs boson production cross-section after collecting 1 fb^{-1} of integrated luminosity in 7 TeV collisions with the ATLAS detector: on the top plot, the limit is normalised to the NLO prediction of the SM cross-section and on the bottom plot, it is normalised to an absolute cross-section. The green and yellow bands represent the range in which we expect the limit will lie, depending upon the data. Only the $H \to WW \to ll\nu\nu$, $H \to ZZ \to 4l$ and $H \to \gamma\gamma$ channels are included in these plots. It is expected that in the low mass region, the addition of $H \to b\bar{b}$ and $H \to \tau\tau$ will improve this result. The expected limit in high mass region above $M_H \sim 200$ GeV is obtained from the $H \to ZZ \to 4l$ only as shown in Fig. 10; the limit in the high mass region will be improved with the addition of the $H \to ZZ \to llbb$ and $H \to ZZ \to ll\nu\nu$ channels.

Estimated Sensitivity with 20/fb?

ATL-PHYS-PUB-2010-009

@ 20/fb + 20/fb

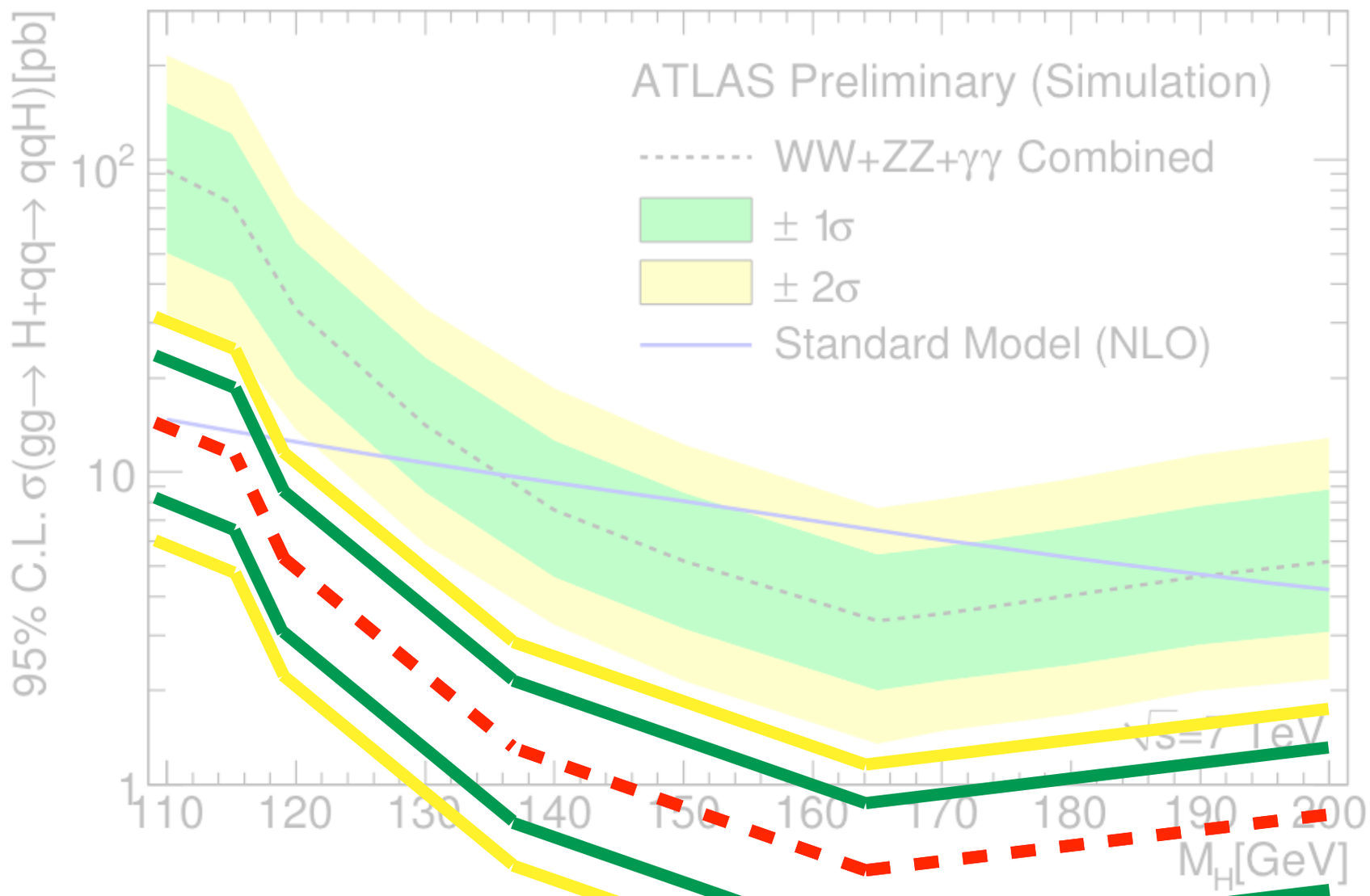


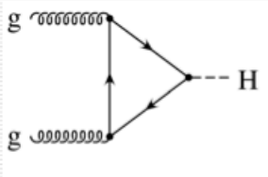
Figure 15: The expected upper bound on the Higgs boson production cross-section after collecting 1 fb^{-1} of integrated luminosity in 7 TeV collisions with the ATLAS detector: on the top plot, the limit is normalised to the NLO prediction of the SM cross-section and on the bottom plot, it is normalised to an absolute cross-section. The green and yellow bands represent the range in which we expect the limit will lie, depending upon the data. Only the $H \to WW \to ll\nu\nu$, $H \to ZZ \to 4l$ and $H \to \gamma\gamma$ channels are included in these plots. It is expected that in the low mass region, the addition of $H \to b\bar{b}$ and $H \to \tau\tau$ will improve this result. The expected limit in high mass region above $M_H \sim 200$ GeV is obtained from the $H \to ZZ \to 4l$ only as shown in Fig. 10; the limit in the high mass region will be improved with the addition of the $H \to ZZ \to llbb$ and $H \to ZZ \to ll\nu\nu$ channels.

http://lanl.arxiv.org/pdf/1112.3028.pdf

Standard Model Higgs

- SM fermion couplings to Higgs are fixed

$$L_Y = -m_f\left(\overline{\Psi}_L\Psi_R + \overline{\Psi}_R\Psi_L\right)\left(1+\frac{H}{v}\right)$$



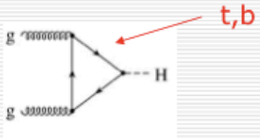
Largest contribution is top loop

b-loop contributes ~2-5%

Extremely sensitive to BSM Physics

SM calculations in great shape

- Dominant production mode is gg→H



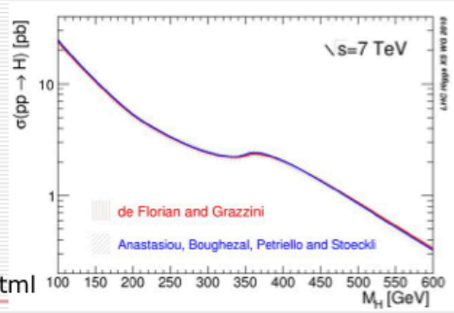
- NNLO in heavy M_{top} limit (checked in M_H/M_{top} expansion)
- Exact t,b loops at NLO
- N^3LL resummation
- EW and mixed EW/QCD corrections

Precise predictions allow us to trust error estimates

Scale uncertainty for gg→H

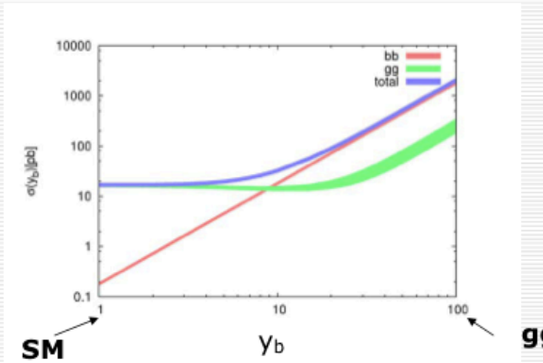
- Scale uncertainty O(6-8%) for M_H~ 100-300 GeV
- Slightly different approaches
  - ABPS
    - Exact NLO/NNLO in large M_t limit
    - No resummation
    - EFT estimate of EW/QCD
  - dFG
    - NNLO for large M_t+NNLL
    - Exact t/b to NLO
    - Exact EW

Online calculator:
http://theory.fi.infn.it/grazzini/hcalculators.html



The Role of b-loops

- K factor for b loops smaller than for top loops
- b loops are 2-5% of SM gg→H



[Anastasiou, Buehler, Herzog, Lazopoulos]

Vector

- Discover
  - 2nd la
- VBF: H→
- Probes ne

Higgs C

- Gluon fermio
  - If fe by ~
- New cl

- gg →H, M_H=120 GeV, (+20%, -15%) uncertainty at 7 TeV
  - Scale & PDF/α_s uncertainties roughly equal