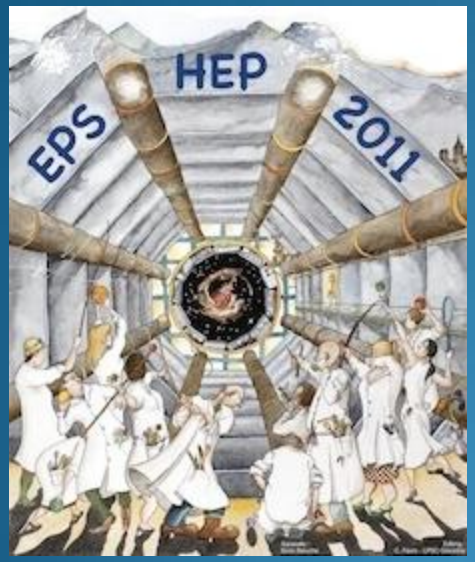
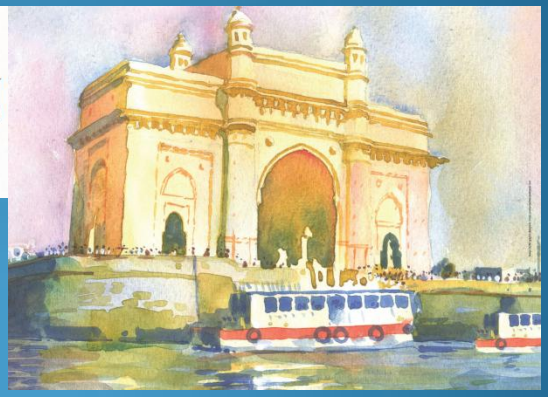
Highlights from Summer Conferences



Higgs and Super-Symmetry Results

LEPTON PHOTON 2011
XXV International Symposium on Lepton and Photon Interactions at High Energies
22-27 August, 2011

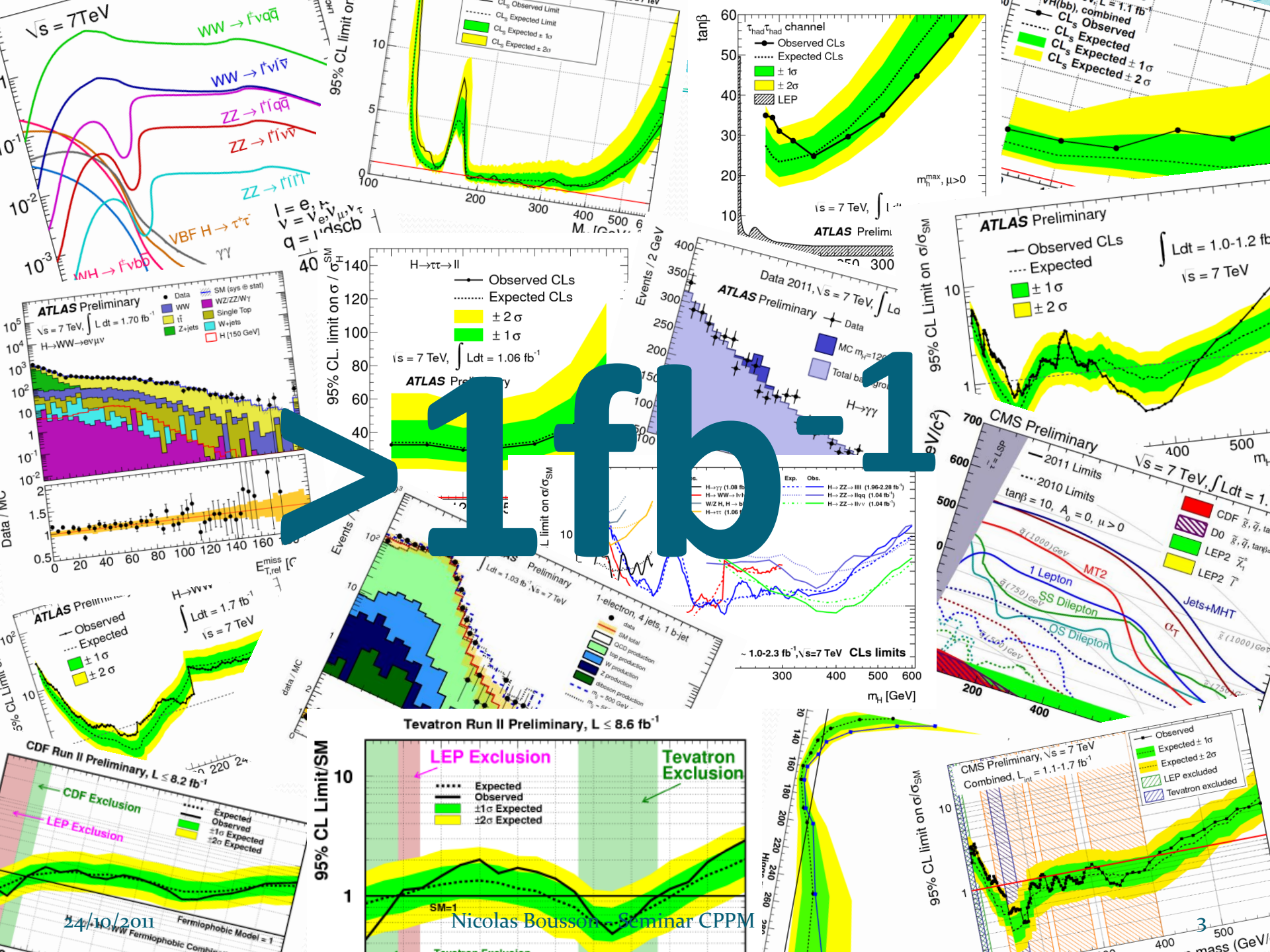


Nicolas Bousson

Centre de Physique des Particules de Marseille

In case you are not aware, no Higgs nor SuSy particles were seen this summer…

…But a lot of nice results were shown! ☺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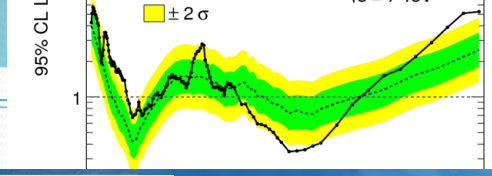
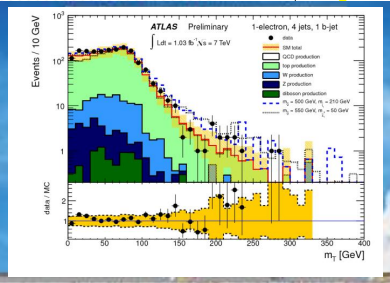
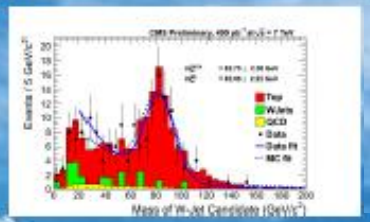


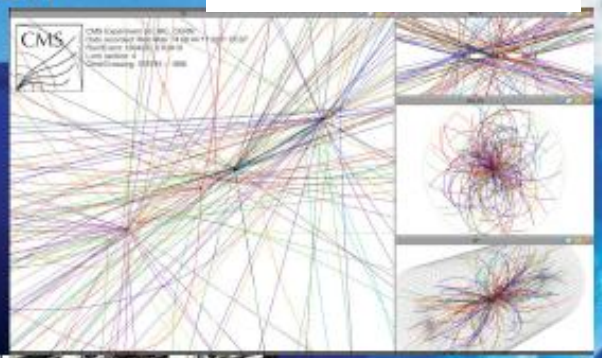
←This talk!



Physics Analysis



Calibration



Simulation

Reconstruction

R&D

Trigger
DAQ

Commissioning

Magnets

Installation
Construction

LHC

Credit: H.Bachacou

Outline

In 15 min, try to understand ONE "yellow/green" plot

Then show the most important results about Higgs searches

And about SuperSymmetry searches

Starting point: Describing the data

Before asking any statistical question, one must have a **model** for the data, *i.e.* the full structure **P(data|Θ,ν)**

Observable	Likelihood
n : measured number of events	Poisson $L(n;s,b) = e^{-(s+b)}\frac{(s+b)^n}{n!}$ b : expected background
n_i, i=1..N_{bins} : measured events in each bin.	Multi-Dim Poisson $L(n;s,f_i,b_i) = \prod_{i=1}^{N_{bins}} e^{-(sf_i+b_i)}\frac{(sf_i+b_i)^{n_i}}{n_i!}$ f_i : fraction of signal in each bin b_i : expected background in each bin
x_i, i=1..N_{events} : parameter values for each event	Extended Likelihood $L(\mathbf{x}_i;s,b) = e^{-(s+b)}\prod_{i=1}^{N_{events}} sP_S(\mathbf{x}_i) + bP_B(\mathbf{x}_i)$ P_S, P_B : PDFs for x in signal and background

Credit: N.Berger

- Holding parameters fixed gives a PDF for data
- Holding data fixed gives a "likelihood function" for parameters

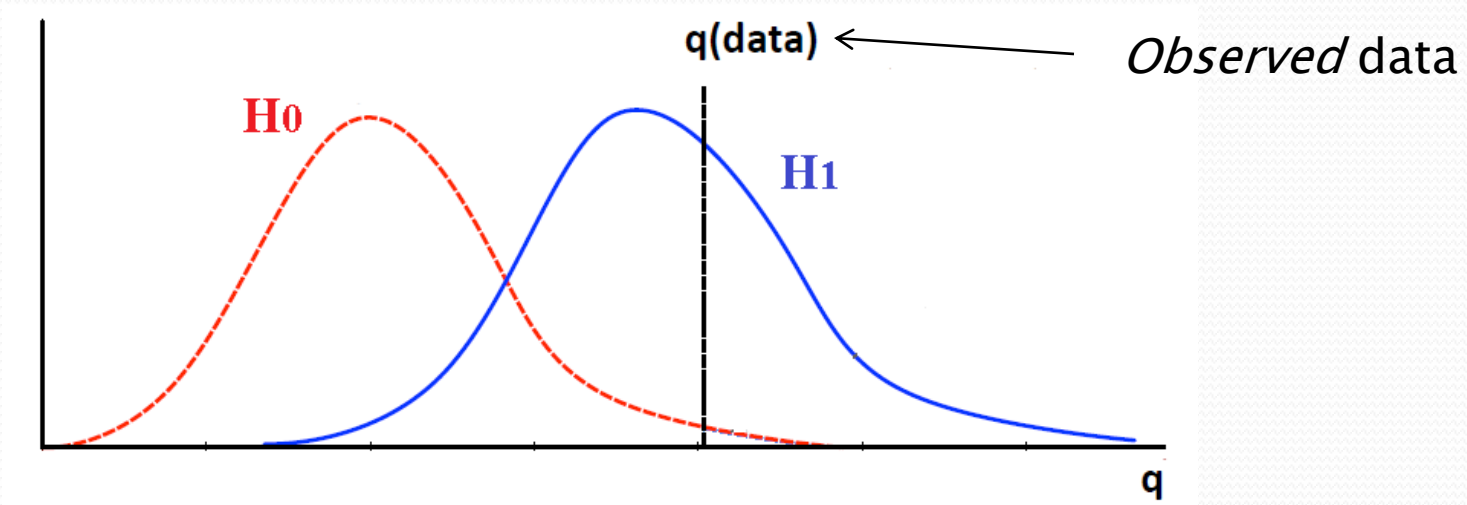
→This is where physics knowledge/ understanding come in

→ Should be easy to compute (generation of pseudo-data)

The test statistics and its distribution

The **"test statistic" q** is a single number that quantifies the entire experiment

→It is built from the model in order to discriminate as well as possible different hypothesis
(can be number of events, or likelihood ratios etc…)



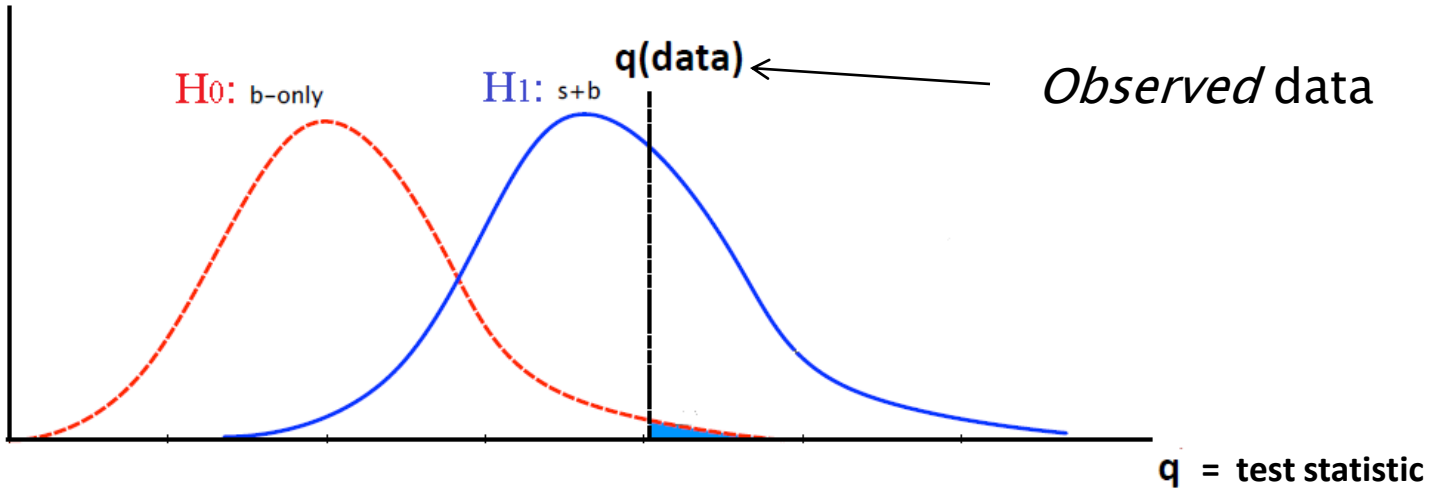
Distributions obtained from
known form or pseudo-experiments

Discovery ?

Discovery is a "Hypothesis test" in the Frequentist setup

→ One tests: **a "null" hypothesis H_0** against **an "alternate" H_1**

Ex: H_0=background H_1=signal+background



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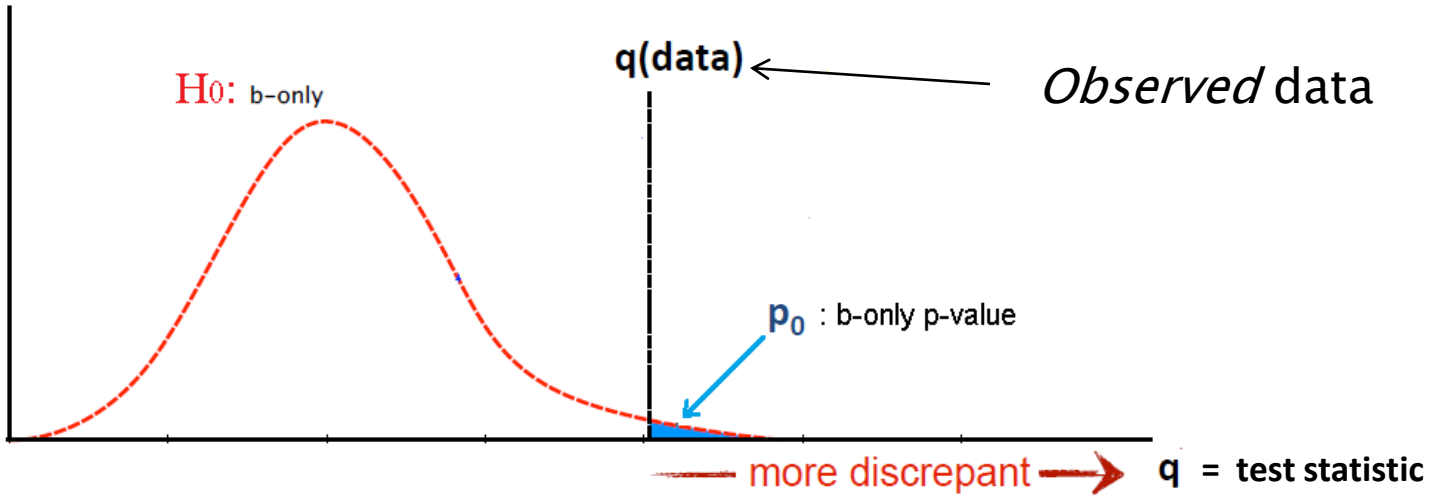


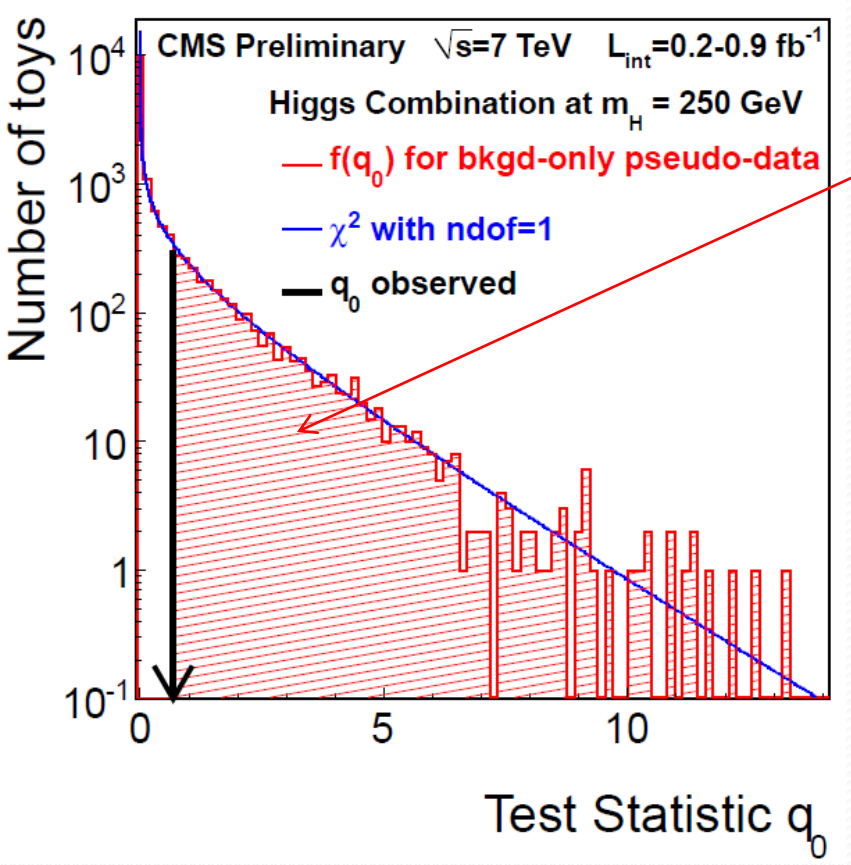
→ Blue area is the fraction of the time that, if H0 were true and the experiments were repeated many times, one would obtain data as far away (or further) from H0 as the observed data

(typically referred as "Type I error", α, CLb, p_0 or b-only p-value)

If p_0 is < α, then reject H_0 ! (5σ means $\alpha=2.9\ 10^{-7}$)

Discovery ?

In practice: Do we see the Higgs?



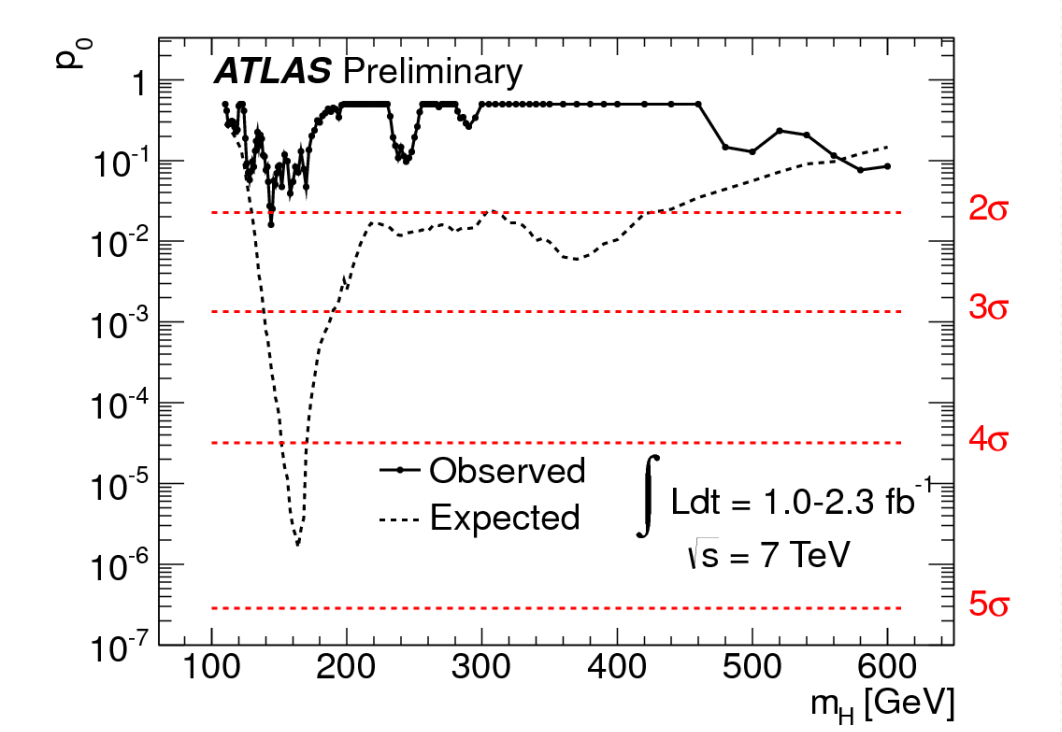
p_0 here is ~0.18

Means that the probability to exclude the background-only hypothesis while it is true is ~18%

→ We cannot exclude the SM(without Higgs) for mH=250GeV

Discovery ?

What about all the hypothetical Higgs masses ?



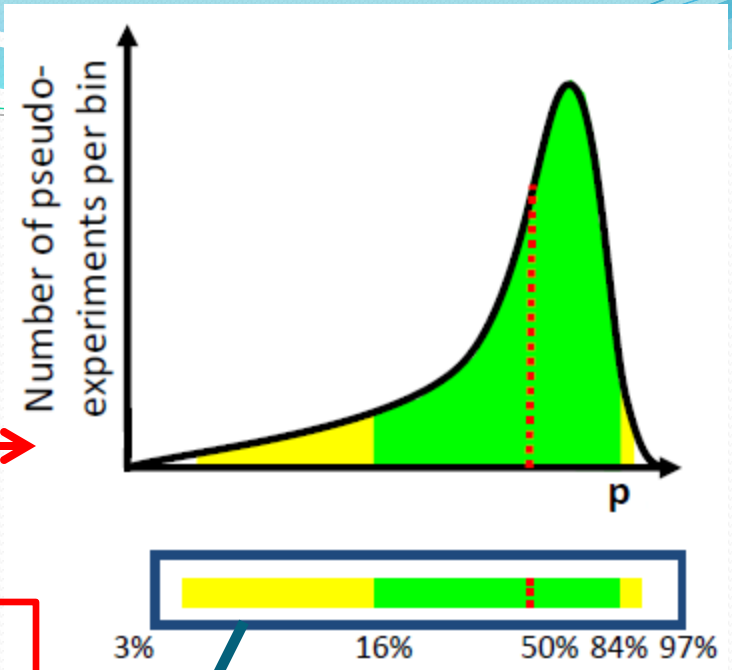
→Observed curve compatible with the background-only hypothesis over all the Higgs mass range (no more than a 2.1σ discrepancy)

→Expected curve here is what we would expect in the hypothesis of the SM Higgs boson production. How is it built?

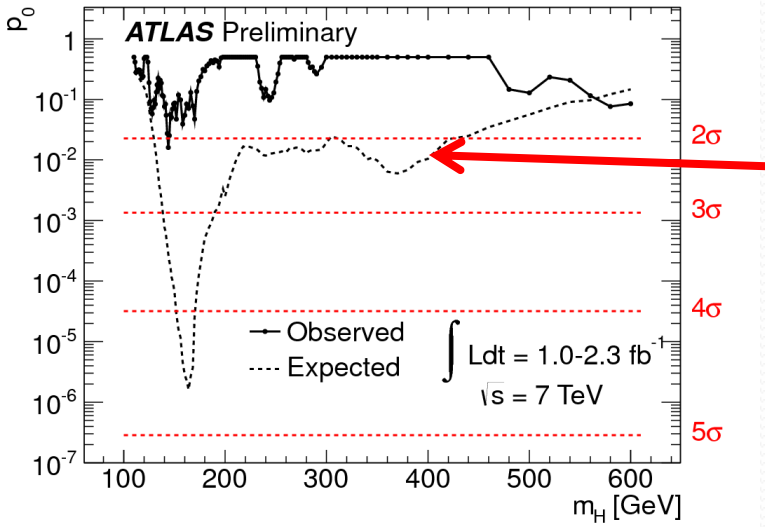
Expected result band

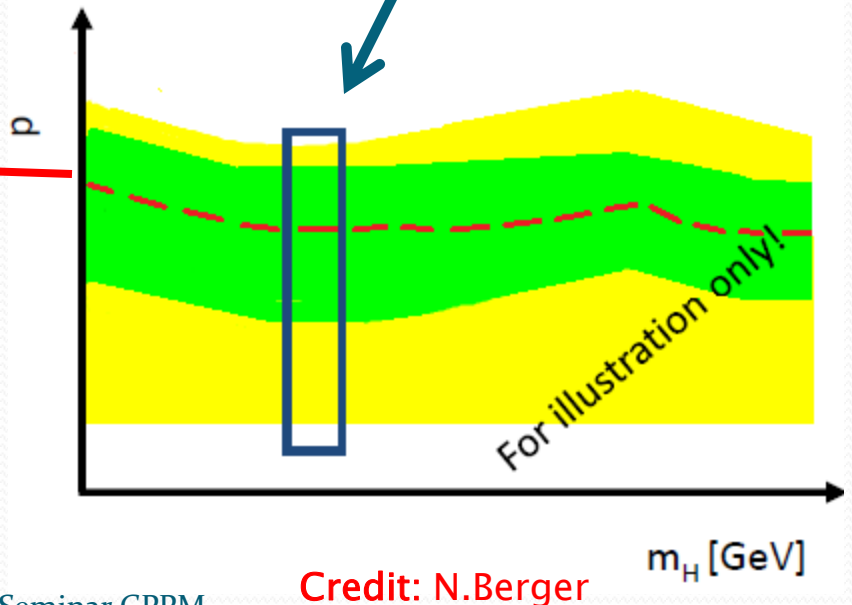
How to compute *expected* results?

→ Generate pseudo-experiments in the hypothesis of the SM Higgs production
→Compute the p-value for each
→Get median and quantiles of distribution



→Repeat for all mass points and interpolate





Credit: N.Berger

Limit-setting

So far, from observed data test statistic we derived a probability (CL, or p-value) related to the compatibility of the data with a given hypothesis

In some sense, the hypothesis was 'fixed' while CL was left 'floating'

E.g.: H_0: b-only vs alt. s+b with mH=250GeV ➡ p_0=18%

→ We can extract more information by reverting this situation:

We would like to know what is the hypothesis for which the compatibility with the observed data is lower than a given CL (typically 5%)?

For this, one first defines:

μ = quantity of signal (usually σ/σ_{SM})

→ Signal hypothesis : $\mu > 0$

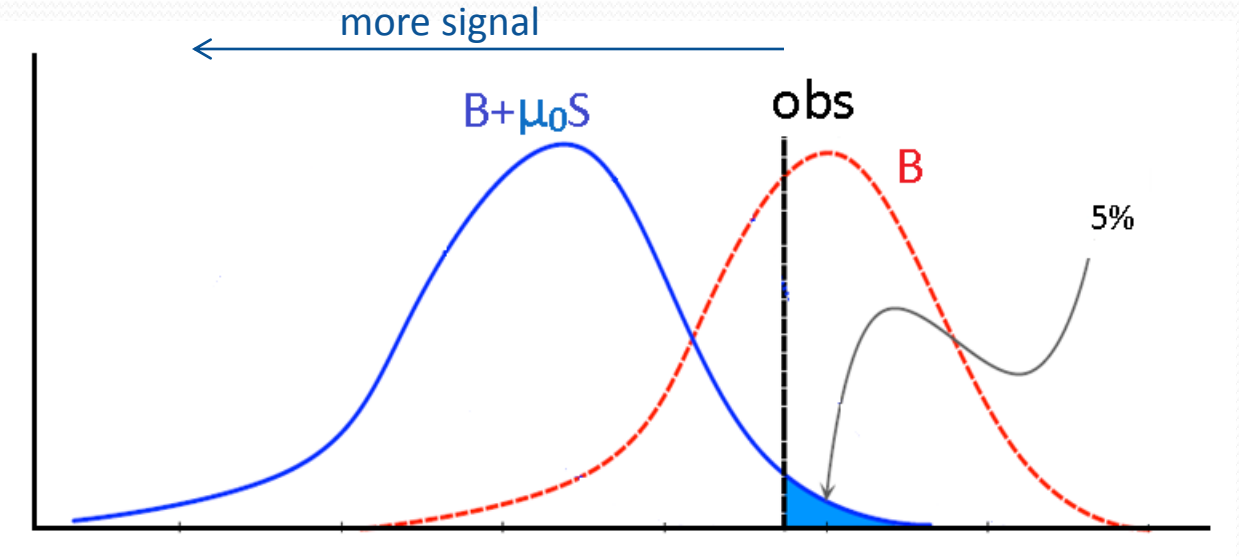
→ Background hypothesis : $\mu = 0$

Limit-setting

$\mu = \sigma/\sigma_{SM}$

Formally one tests: H_0: $B+\mu_0 S$ vs H_1: $B+\mu S$, $\mu<\mu_0$ ("one-sided" alternative)

Goal: Find the signal strength μ_0 that gives a p-value of 0.05



Credit: K.Cranmer

Limit-setting

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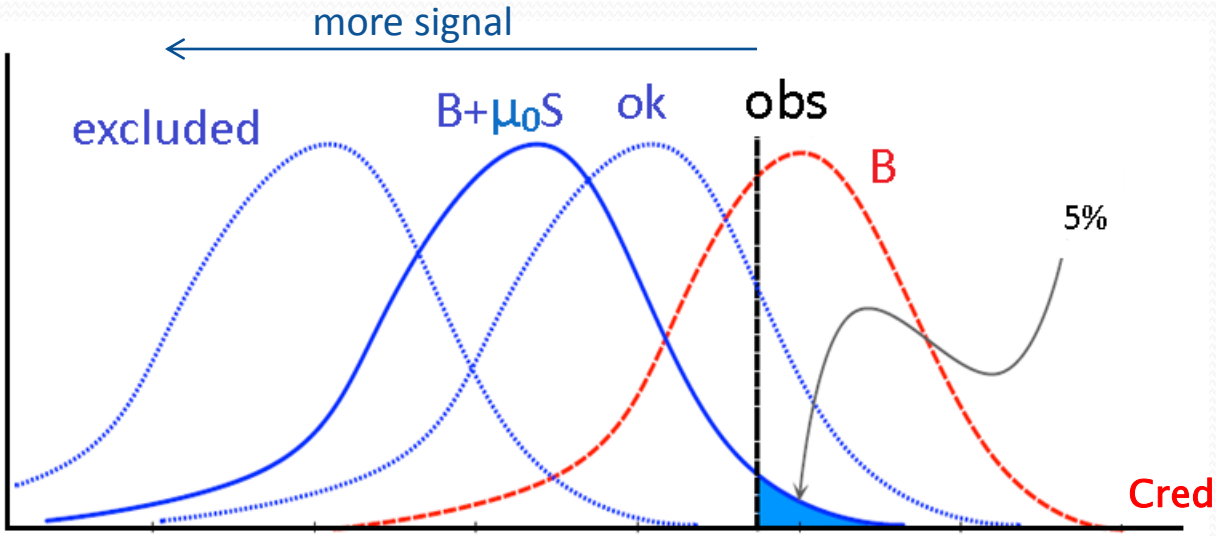


Credit: K. Cranmer

By construction:

$\mu>\mu_0$ is rejected because $p<0.05$

$[0, \mu_0]$ is 95% confidence interval

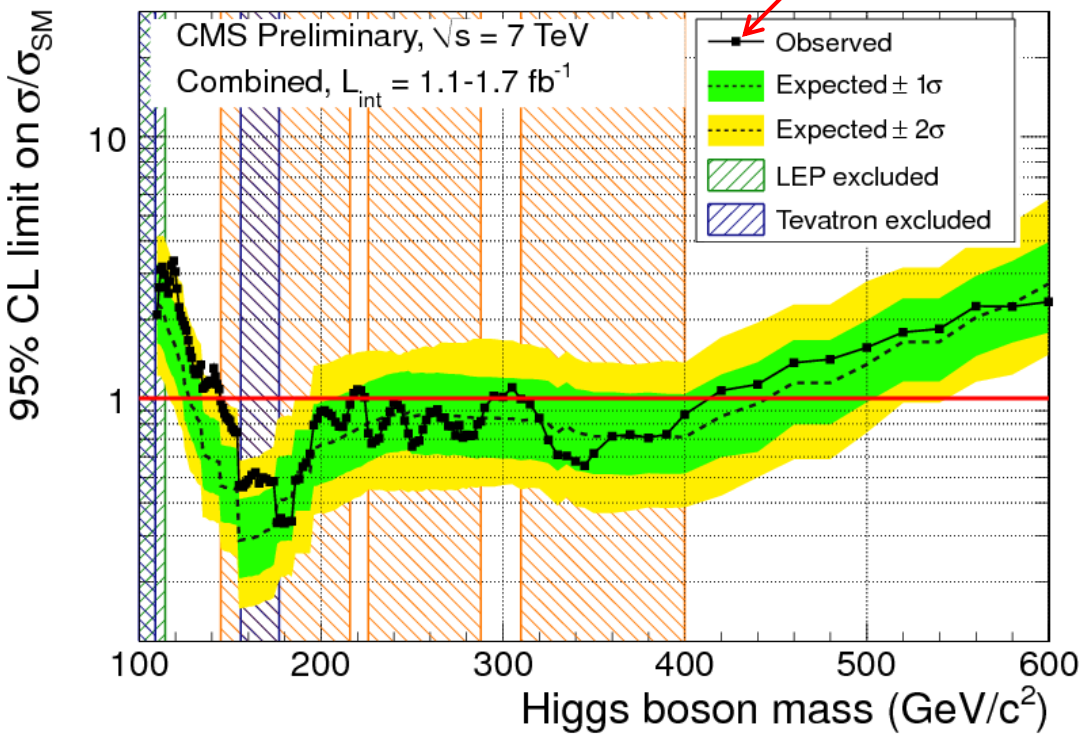
μ_0 is a 95% CL upper limit on the signal strength

For practical determination of μ_0 : c.f. back-up slides

Higgs upper limits

95% CL upper limit on the signal strength μ

$\mu = \sigma/\sigma_{SM}$



Remarks:

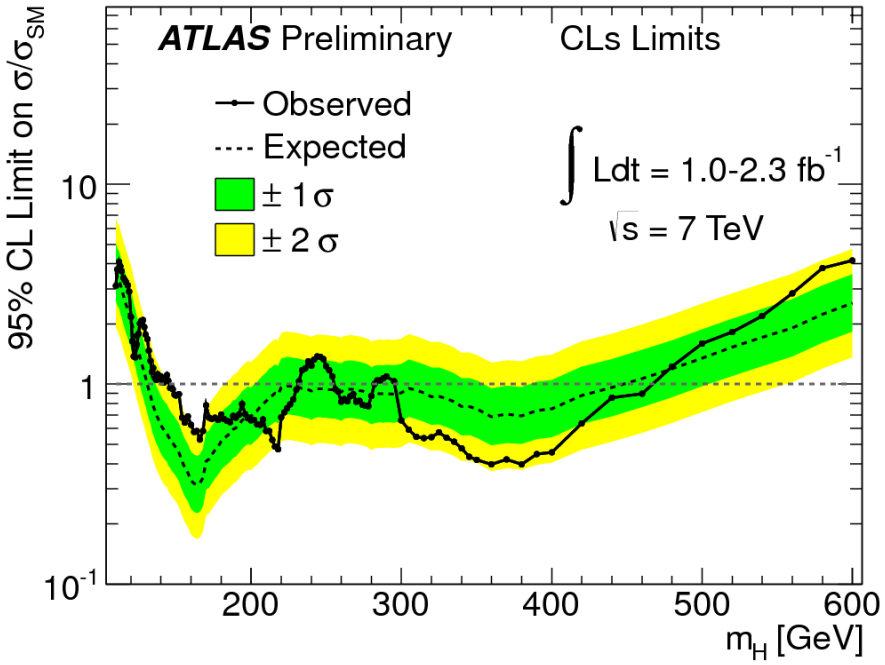
- The y axis is the signal strength μ (normalized to the SM one), not a CL!
- This plot does not show the CL, but the values of μ that gives CL=95%
- When **limit curve** goes below y=1:

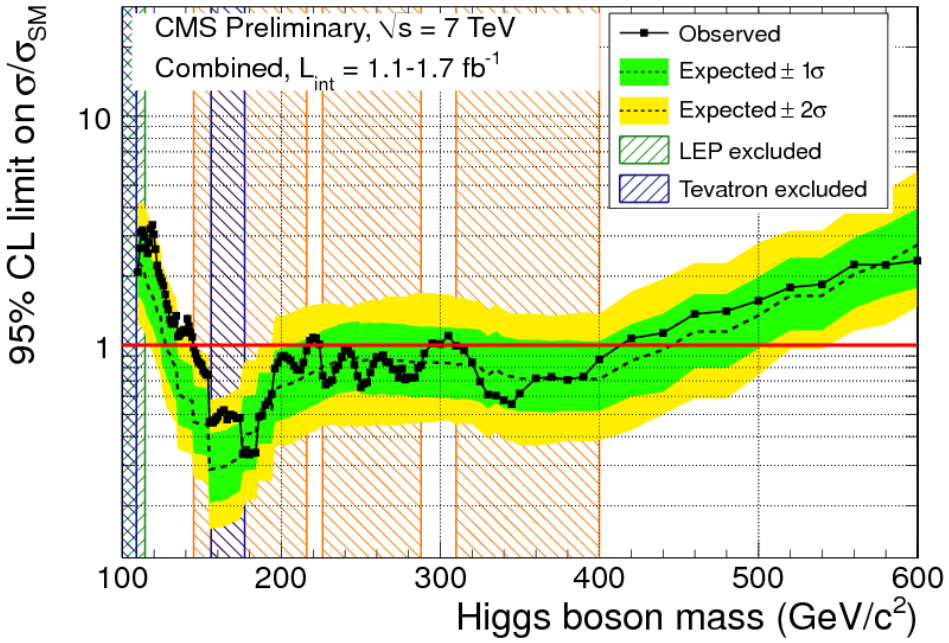
  the SM Higgs boson production (μ=1) is excluded at 95% CL
- The yellow/green band is the expectation from MC in the background-only hypothesis , i.e. SM without Higgs (how to built it is detailed in back-up slides)

Higgs upper limits

ATLAS

Expected exclusion: 131– 450 GeV
Observed exclusion: 146 – 232 GeV, 256 – 282 GeV, 296 – 466 GeV

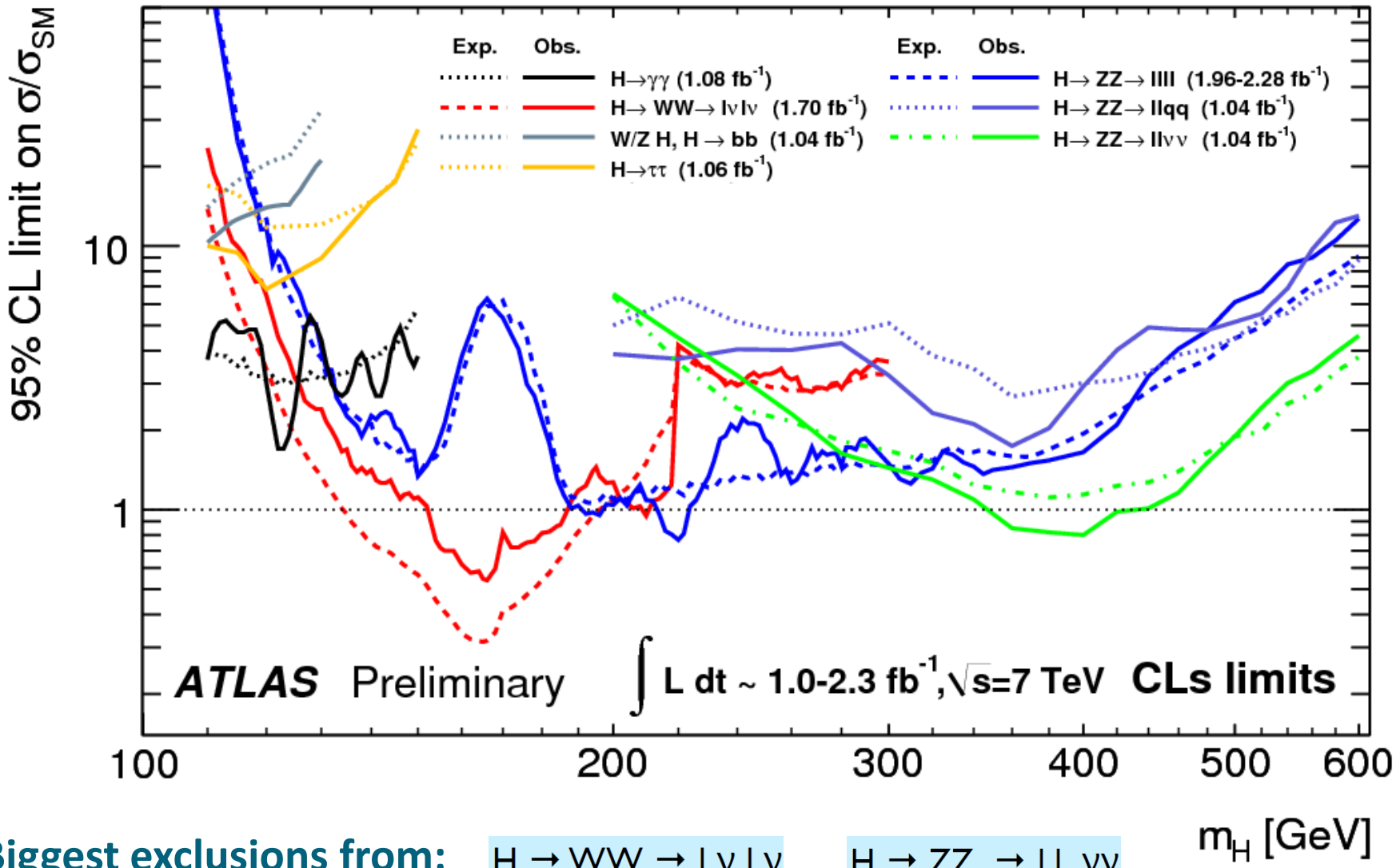




CMS

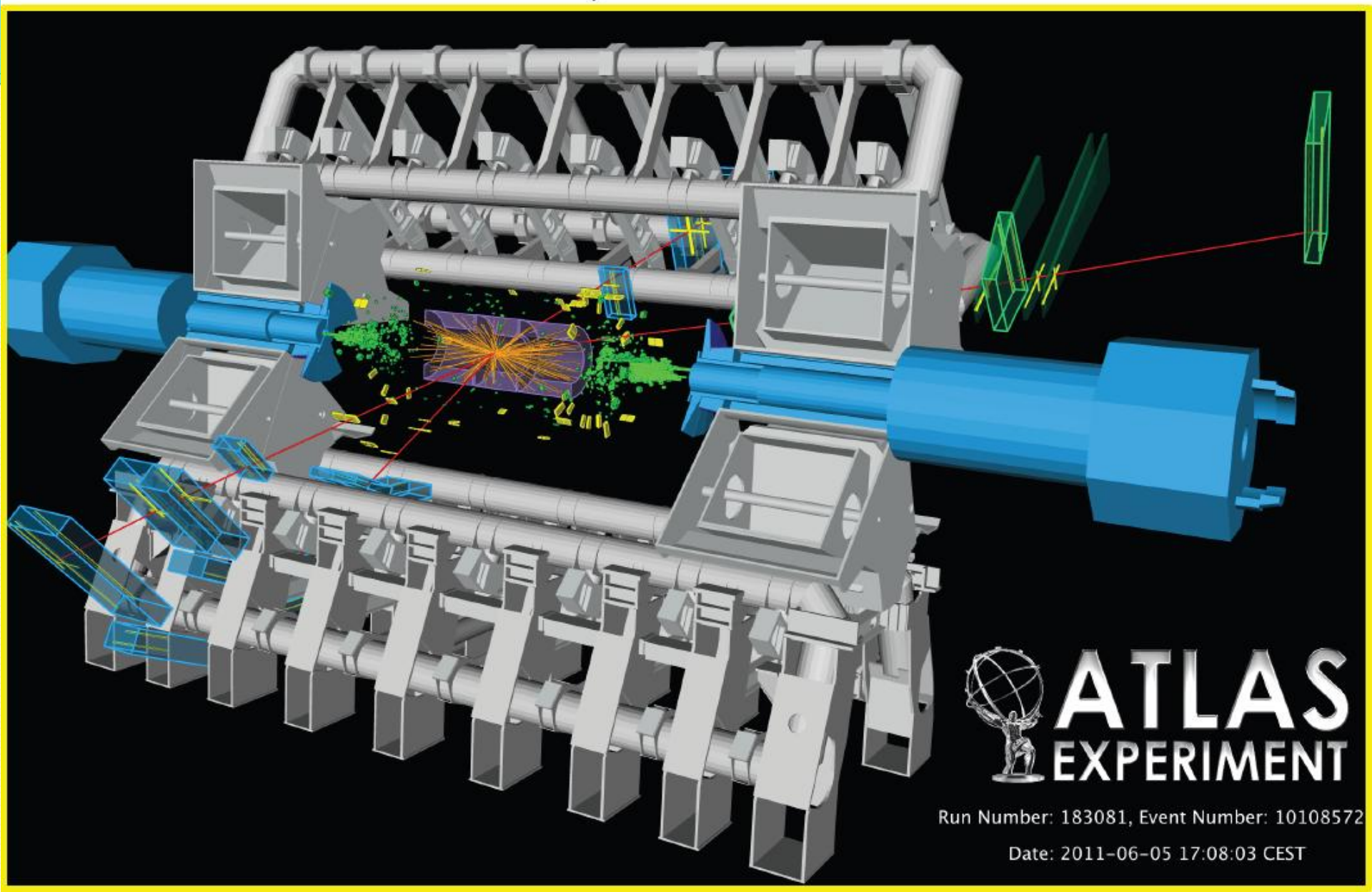
Standard Model Higgs excluded at 95% CL in the mass ranges : 145-216, 226-288 and 310-400 GeV
(expected exclusion : 144-440 GeV)

Individual channels



Biggest exclusions from: $H \rightarrow WW \rightarrow l\nu l\nu$ $H \rightarrow ZZ \rightarrow ll\nu\nu$

4 muon candidate, at mass 143.5 GeV



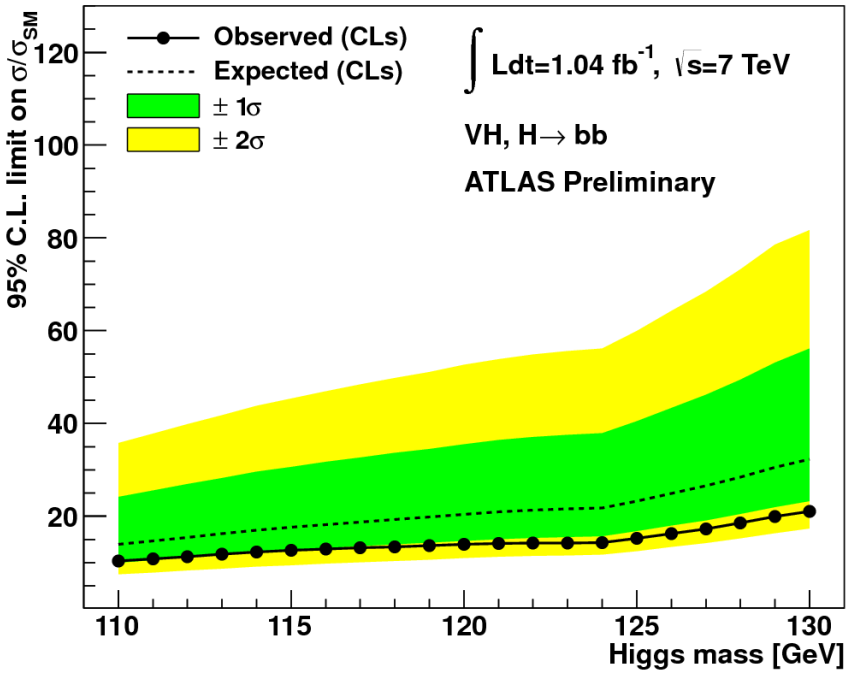
Zoom at low Higgs mass

$H \rightarrow b\bar{b}$

110 GeV < m_H < 130 GeV 1.04 /fb

ZH → llbb **WH → lνbb**

W/Z associated. Largest branching fraction at low mass, but huge backgrounds.



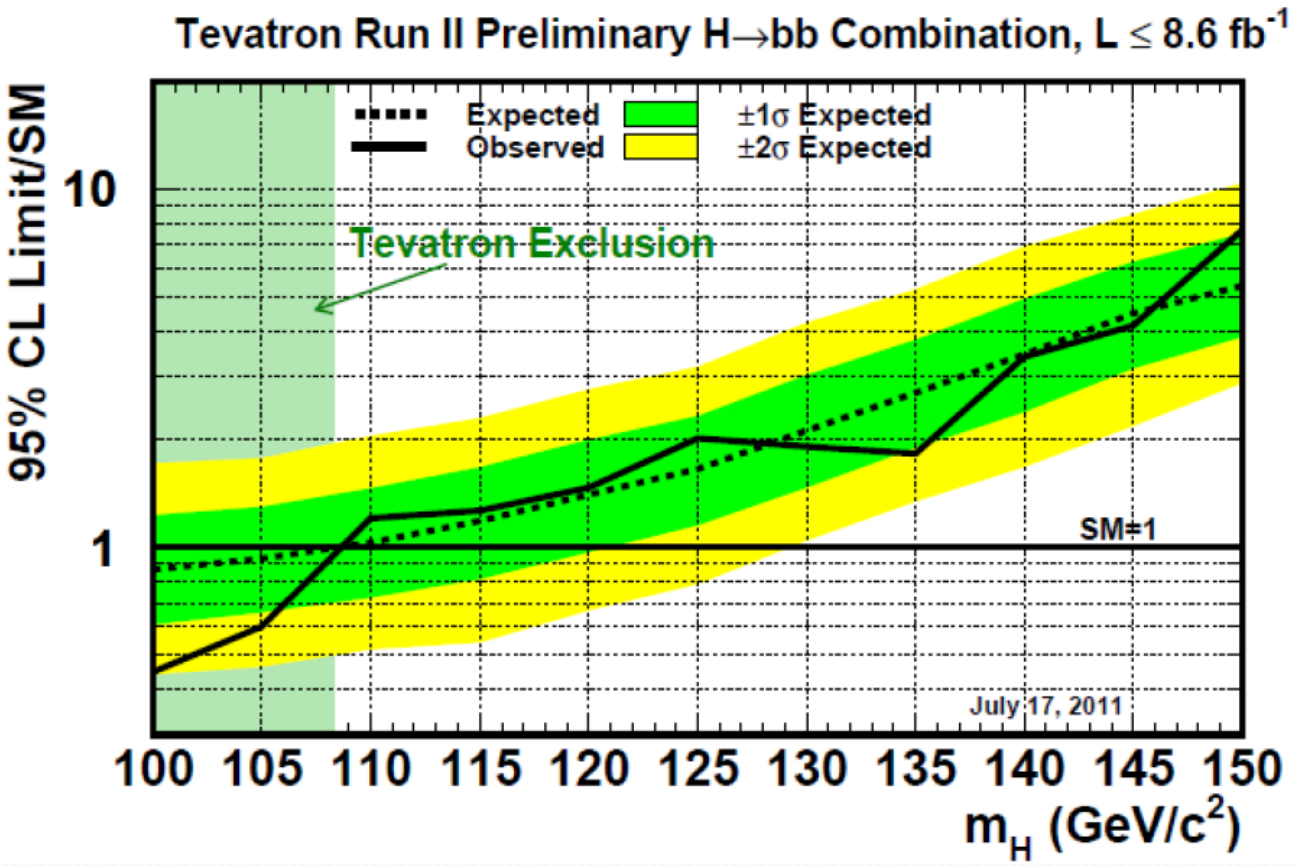
	Data	Total BG	m_H=120 GeV
ZH	329	325±8±28	1.6
WH	1 888	1 877±14±147	4.5

Dominant systematic uncertainties:

Jet energy scale: 2-7 %
Jet energy resolution: 5-12 %
B-tagging efficiency: 5-14 %
Mistagging rate: 8-12 %

Future: Boosted Higgs at high p_T, use jet substructure

H→ bbar Tevatron combination



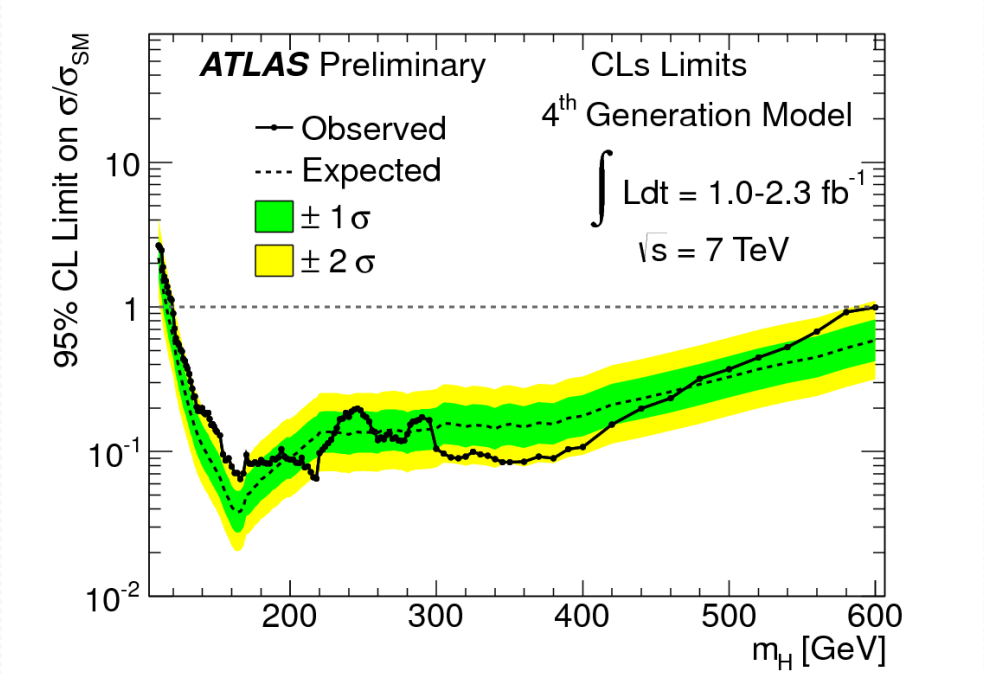
@ mH=110-120 GeV
Sensitivity is almost
1xσ(SM)

@ mH=130-140 GeV
Sensitivity is ~2-3xσ(SM)

Tevatron is seeking to achieve SM sensitivity for all interesting mass regions using full data set (~10fb^{-1}) !

Upper limits in the framework of a heavy 4th generation of fermions

In SM4, the Higgs production cross-section is strongly enhanced



Assumes m_{u4} and m_{d4} ~600GeV

→ Exclude Higgs masses between 120 and 600 GeV

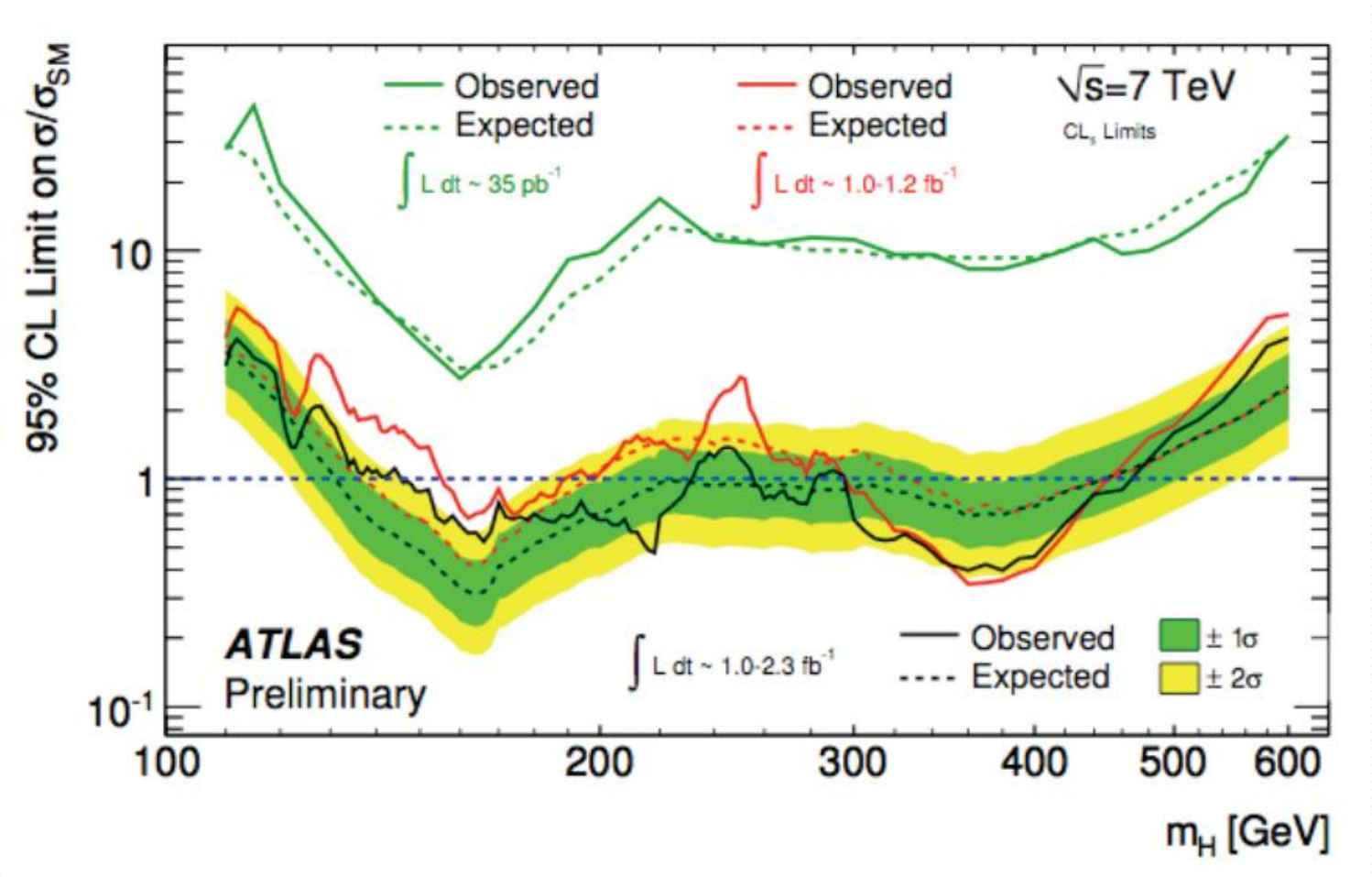
Possible interpretation: To find the Higgs in this range would kill 4th Gen.

Important condition: true only with perturbative couplings!

Interesting implication: If we don't find the Higgs, 4G condensates could play its role !

Higgs upper limits

Evolution with integrated luminosity



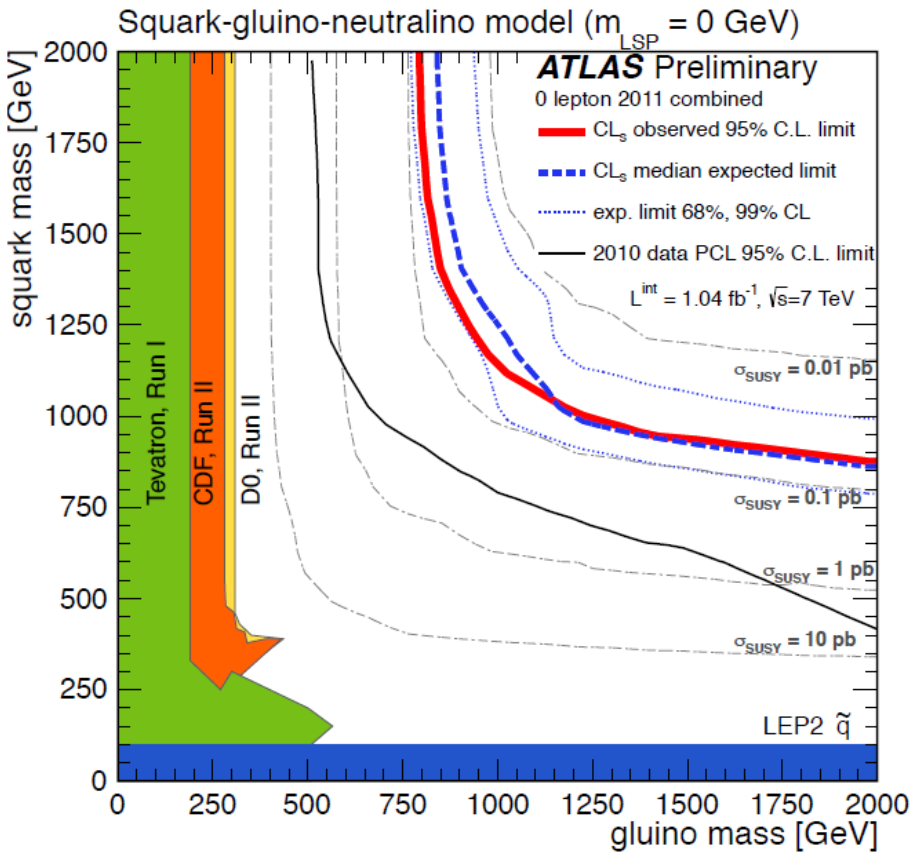
N.B.: More channels were also added with time

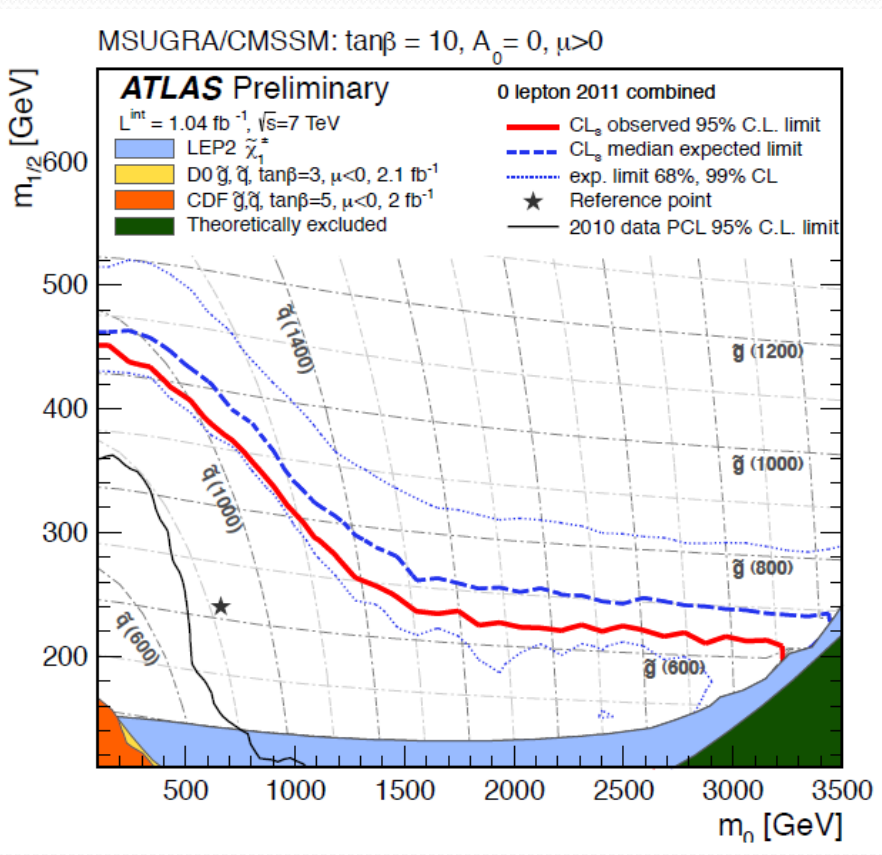
Searches for SUSY particles

Jets + Missing E_T

$$\tilde{q} \rightarrow q\tilde{\chi}_1^0$$
$$\tilde{g} \rightarrow qq\tilde{\chi}_1^0$$

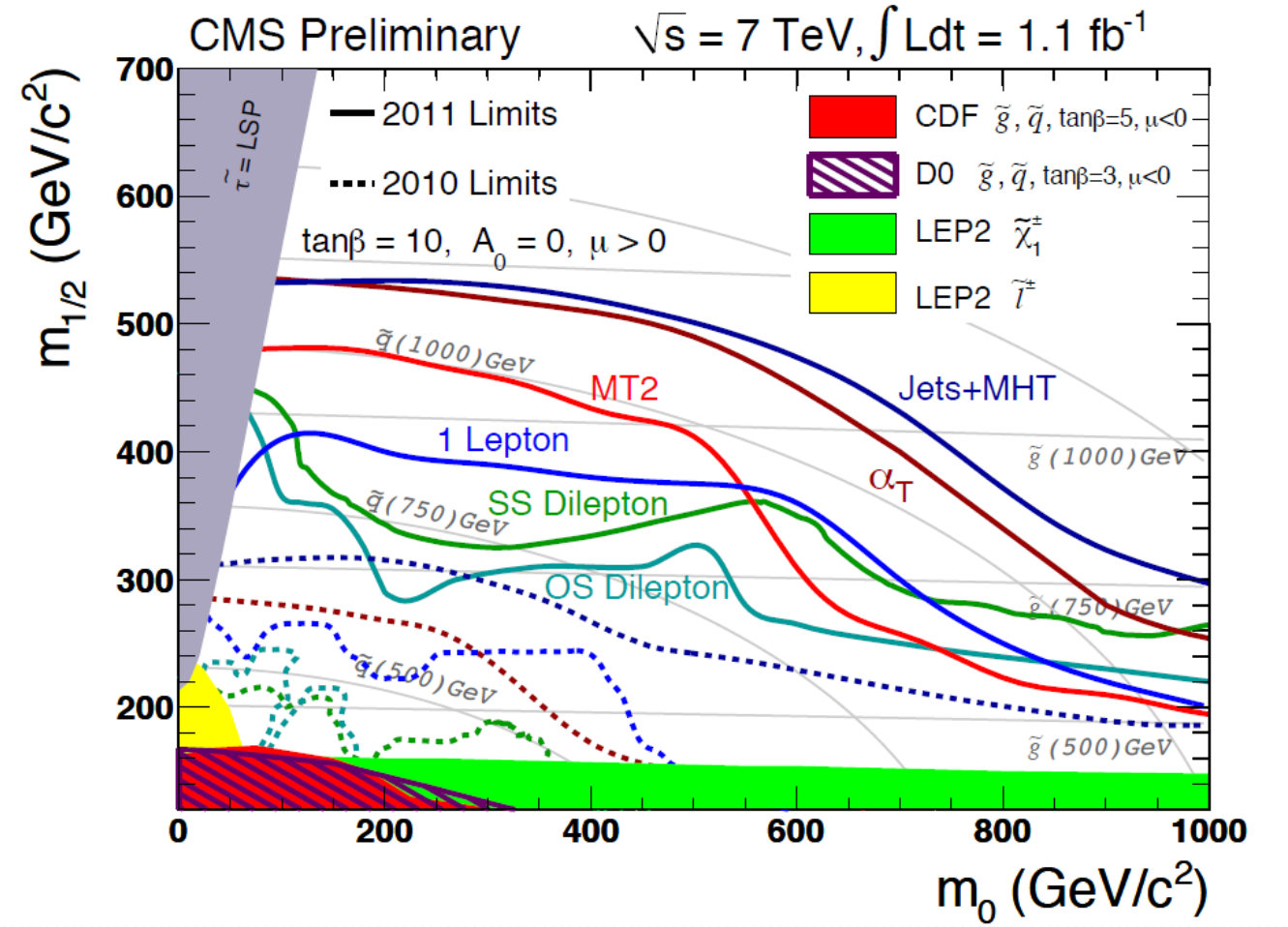
Exclude up to ~ 1 TeV for m(squark) = m(gluino)





Searches for SUSY particles

Lepton(s) + Jets + Missing ET



Conclusions and perspectives

Between 1 and ~2 fb^{-1} were analyzed during the summer conferences

No Higgs significant excess found by ATLAS or CMS
Almost all masses between 144 GeV and 466 GeV are excluded @95% CL

- With ~4-5fb-1 per experiment, could achieve 95% CL limit sensitivity for ~all mass range after combining ATLAS+CMS
- 5σ combined discovery possible for ~10-15fb-1 per experiment, except maybe at low mass (~115GeV)

SUSY as we expected it starts to be in trouble…
Excluded @95% CL up to m~1TeV

Thanks for your attention!

Questions?

Acknowledgments

Huge thanks to these nice lectures:

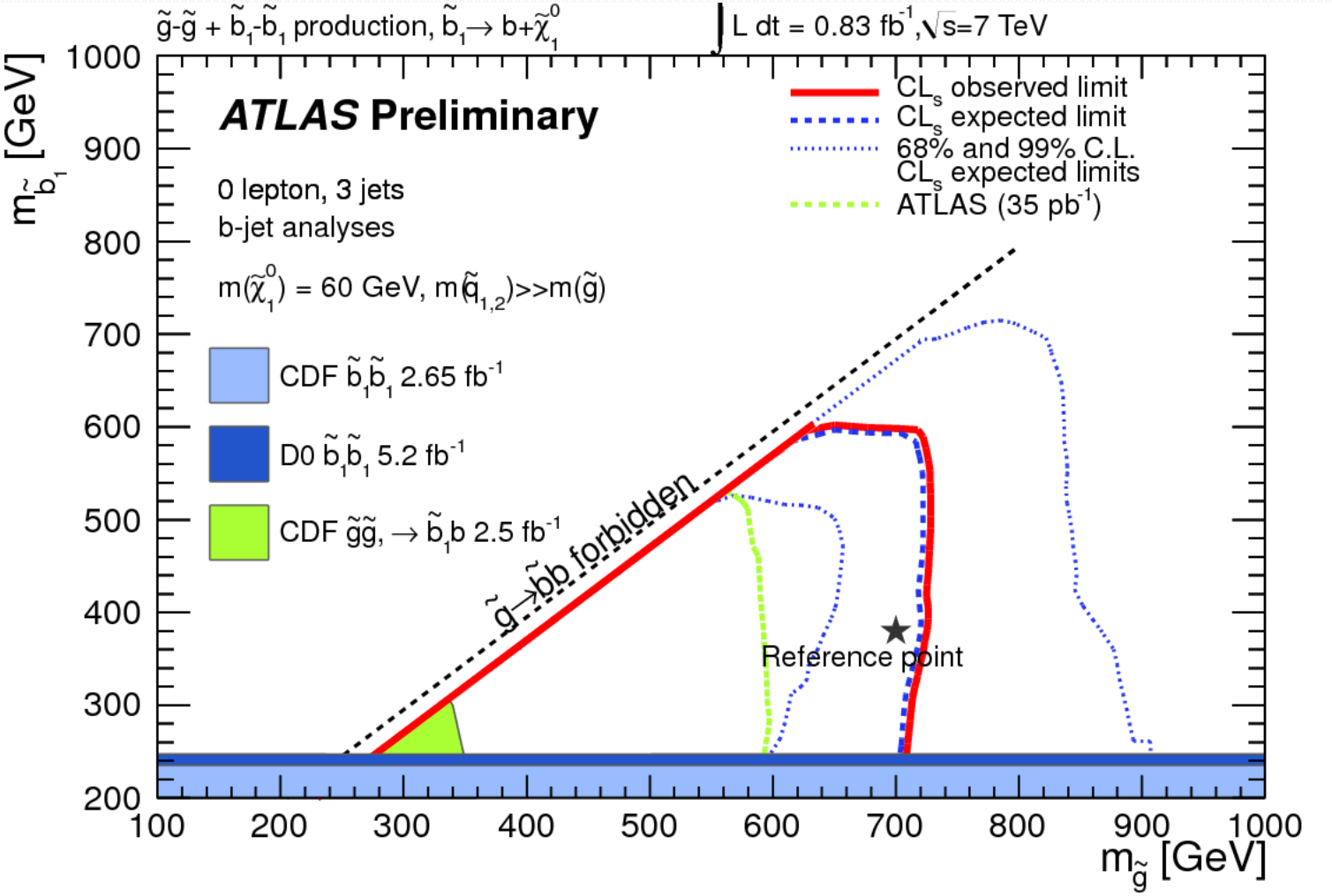
http://indico.cern.ch/conferenceDisplay.py?confId=48425
By Kyle Cranmer

https://indico.cern.ch/getFile.py/access?contribId=35&sessionId=12&resId=1&materialId=slides&confId=147821
By Nicolas Berger

Bonus slides

Searches for SUSY particles

b-Jets + lepton + Missing E_T

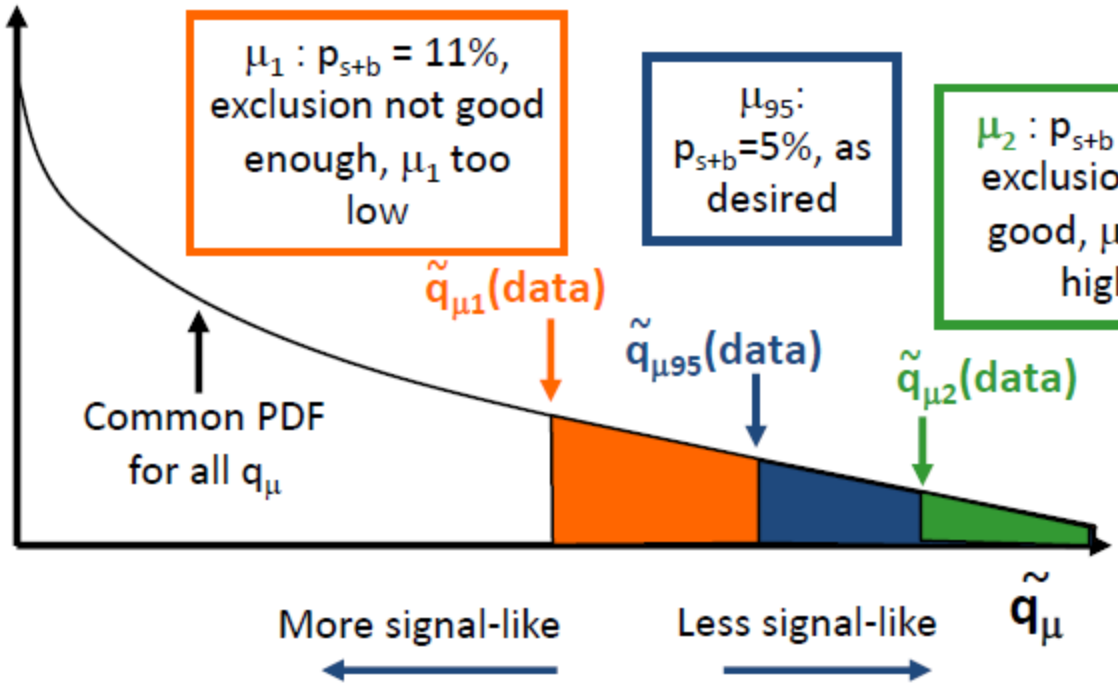


The inversion problem

Credit: N.Berger

We want to compute the value μ_{95} for which the p_{s+b} = 5% (95% CL exclusion)

→ Every statistic q_μ has the same distribution, assume it known



→ Need to consider various signal hypotheses: not just B and S+B, but also all the μS+B

→ Obtain μ_{95} either by interpolation or an iterative method

Inversion in practice

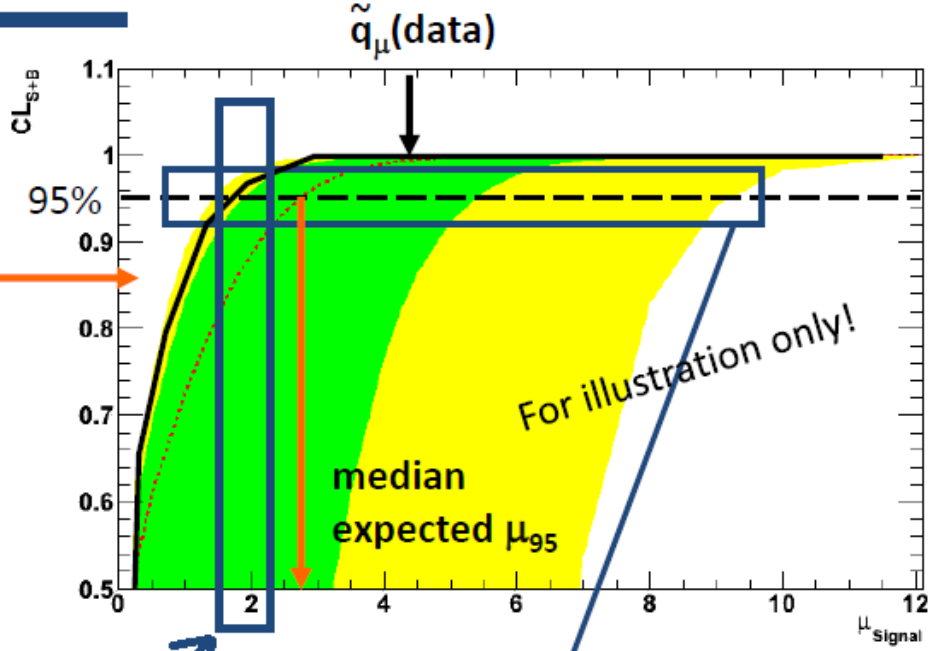
Credit: N.Berger

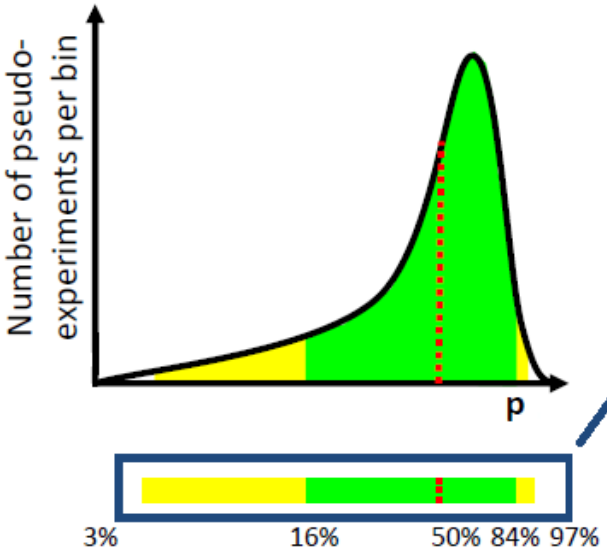
In practice, the inversion procedure can be done as follows:

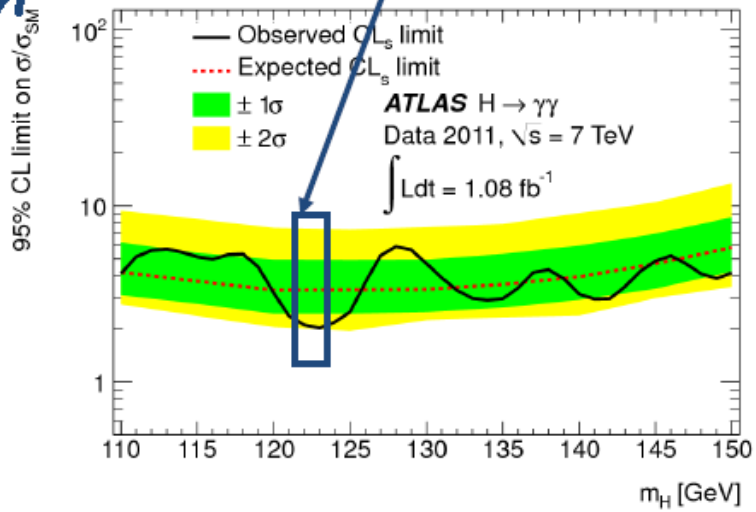
→ define a set of μ values to scan (here 0-12 with varying step sizes)

→ Compute p_{s+b} for each μ values
Can be both observed and expected

→ Find crossing with 95%







The Profile-likelihood statistic

Credit: N.Berger

$$q_0 = 2\log\frac{L(data;\hat{\mu})}{L(data;\mu=0)}$$

μ = quantity of signal (usually σ/σ_{SM})

→ **Signal** hypothesis : **μ > 0**

→ **Background** hypothesis : **μ = 0**

μ fixed to 0 : background hypo

hat = best-fit value.
μ is allowed to float ⇒ signal hypo

$$q_0 = \begin{cases} 2\log\dfrac{L(data;\hat{\mu})}{L(data;\mu=0)} & \hat{\mu} \geq 0 \\ 0 & \hat{\mu} < 0 \end{cases}$$

→ force μ<0 region to q_0=0
⇒ perfect agreement with background

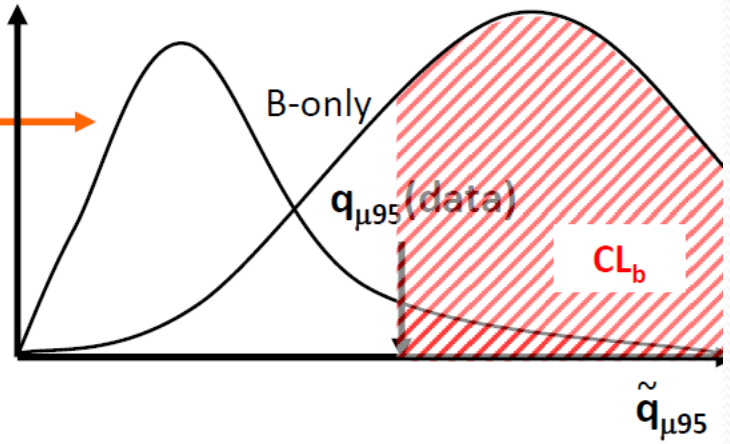
Statistic for exclusion

→ Similar to case of discovery, but adapt q that adapts to the hypothesis: when testing the μ hypothesis, consider q_μ:

$$\tilde{q}_\mu = \begin{cases} 2\log\dfrac{L(data;\hat{\mu})}{L(data;\mu)} & 0 < \hat{\mu} < \mu \\ 0 & \hat{\mu} \geq \mu \\ 2\log\dfrac{L(data;0)}{L(data;\mu)} & \hat{\mu} < 0 \end{cases}$$

CL_s

Symptom of sensitivity problems: "**Power of test**" (a.k.a. CL_b) becoming small



Since we can identify these cases, try to correct for them to avoid spurious exclusion claims.

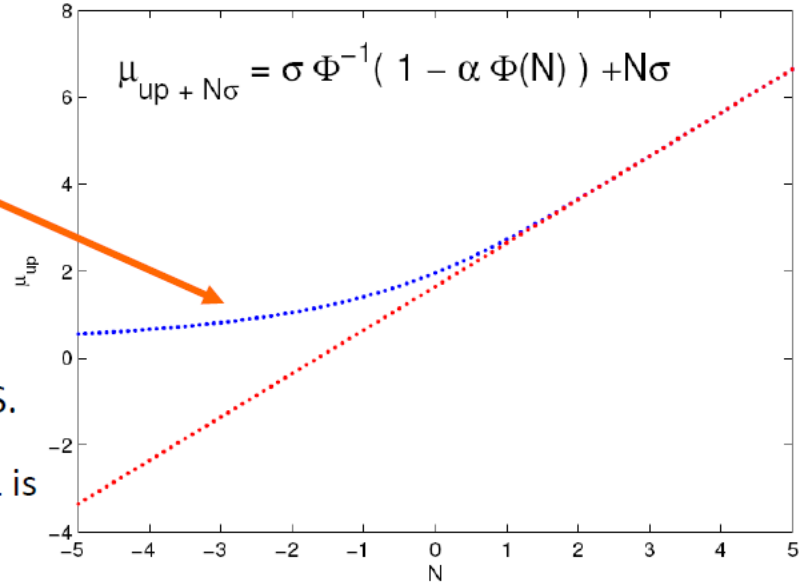
$=p_{s+b}$

CL_s

→ use $CL_s = CL_{s+b}/CL_b$ to set the limits.

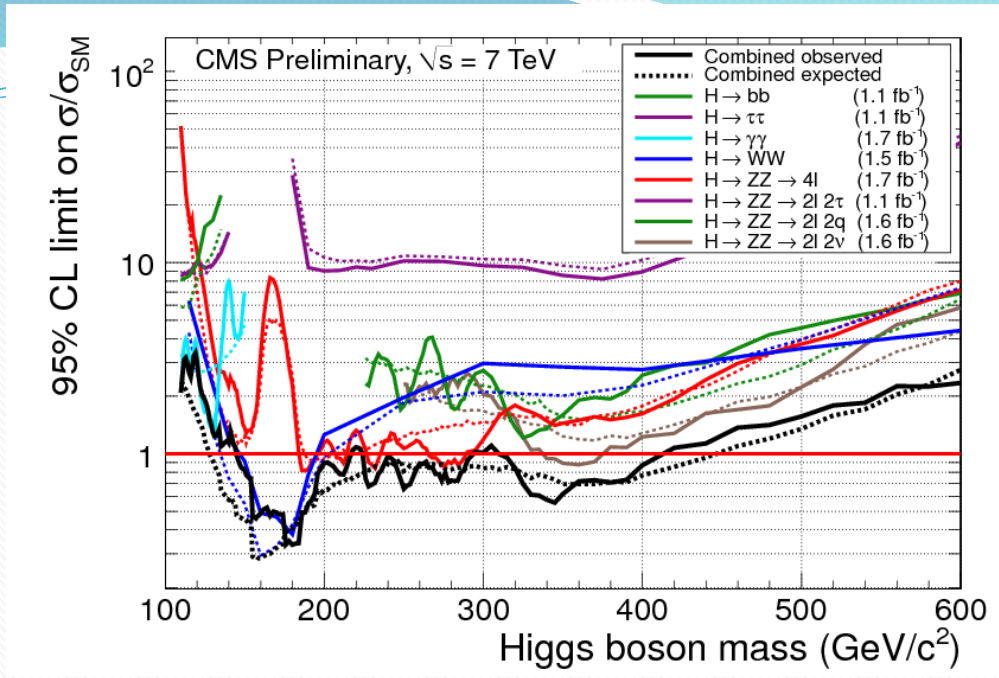
→ for data compatible with bkg hypo, $CL_b \approx 1$ and nothing changes

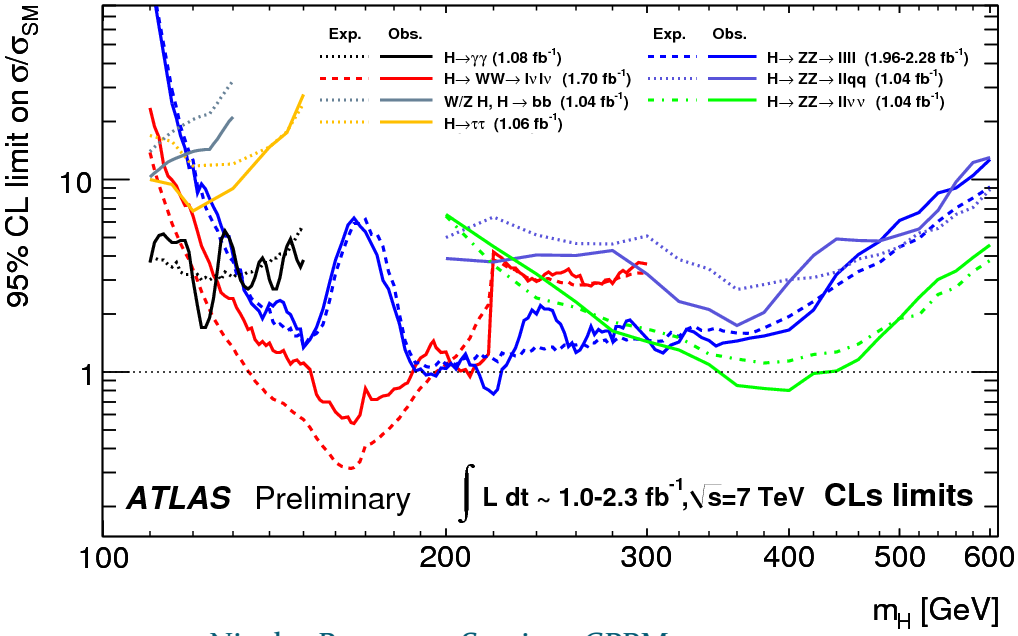
→ if $CL_b << 1$, then $CL_s >> CL_{s+b}$ and prevents too-good limits.

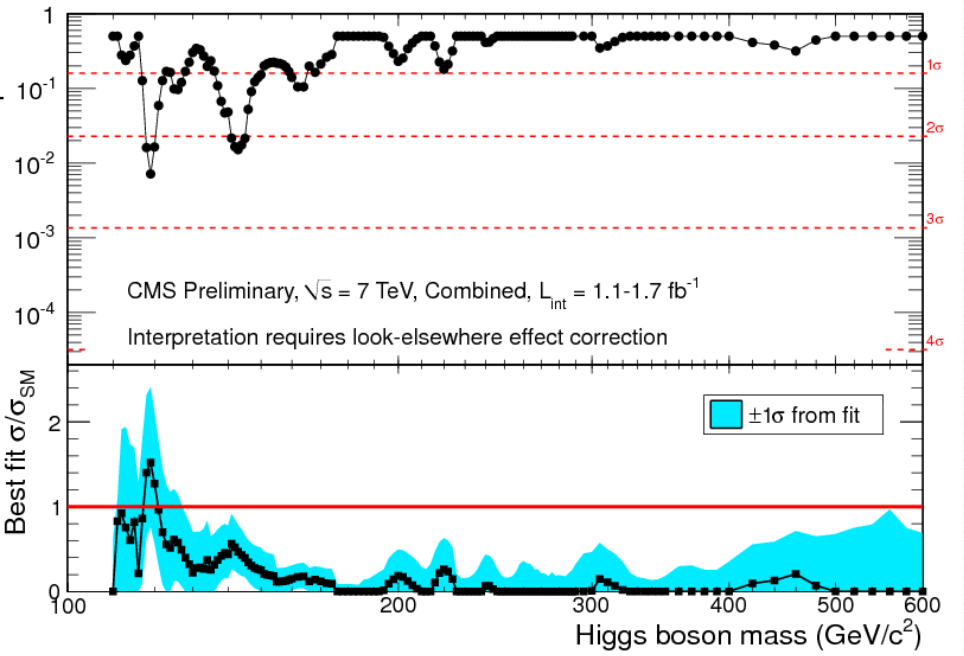


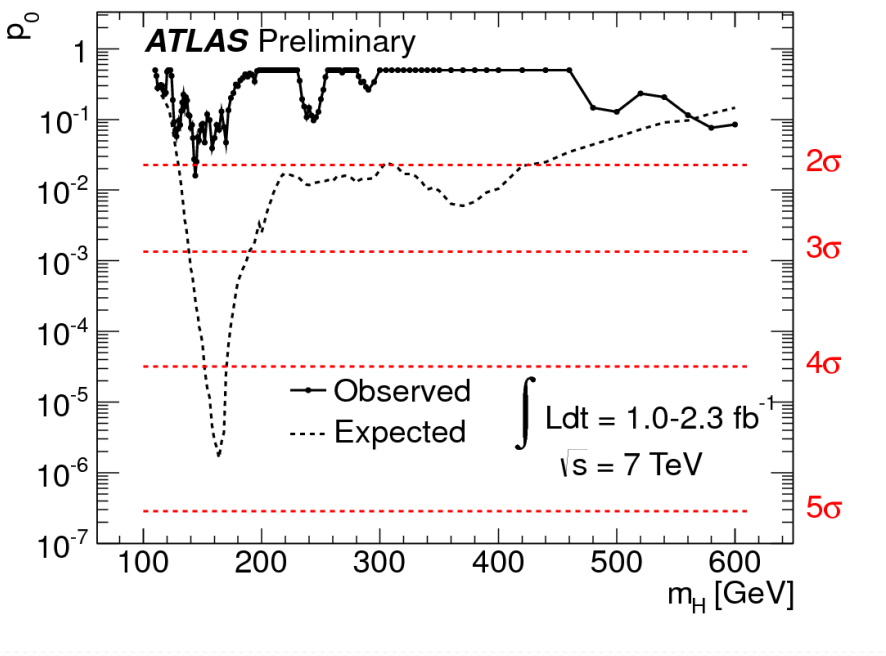
After some initial hesitation, CL_s is now the recommended method for limit-setting in ATLAS.

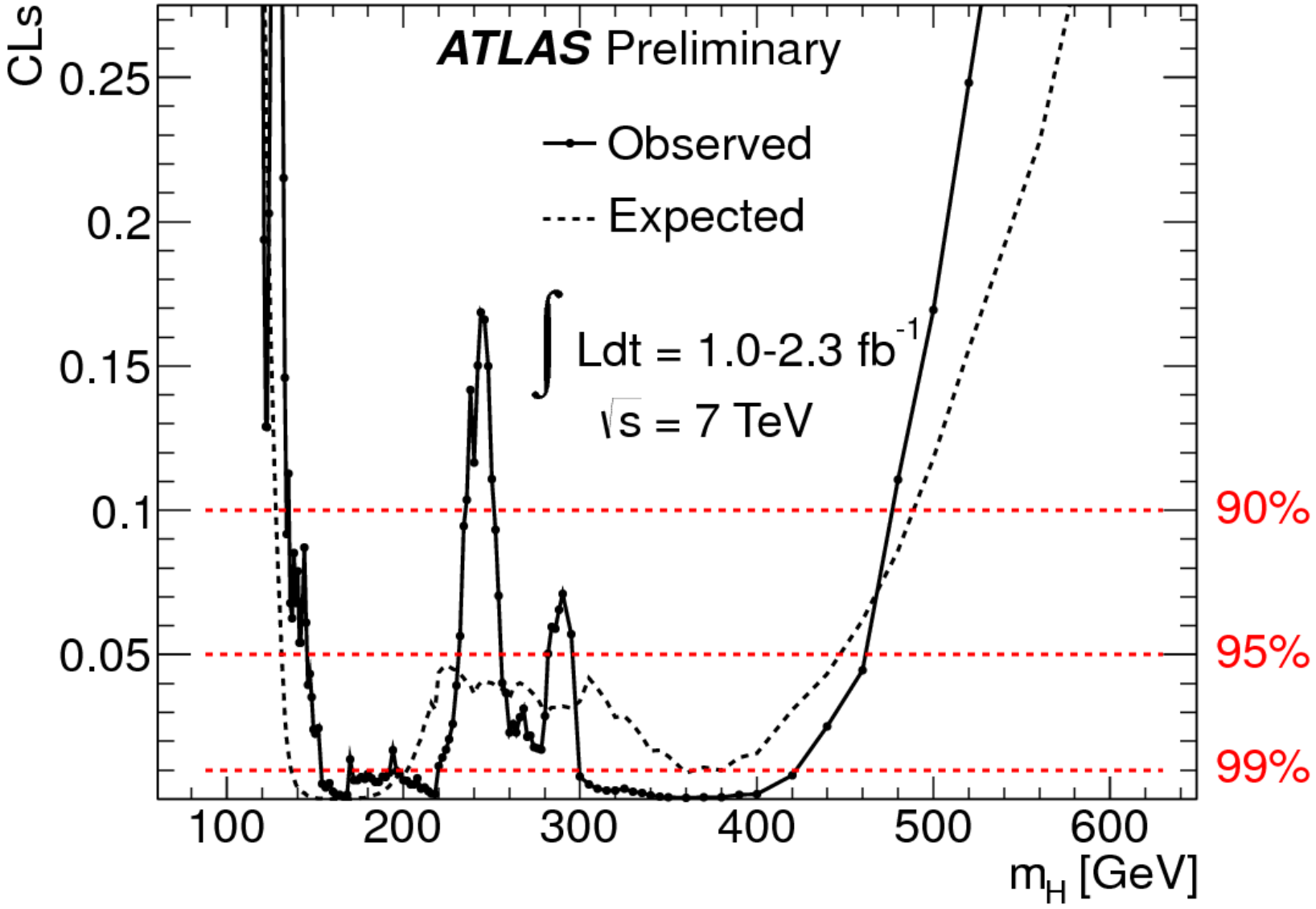
→ A side effect is "**overcoverage**" (e.g. 95% CL is in fact 98%) but it can't be avoided.


CMS Preliminary, √s = 7 TeV
Combined observed
Combined expected
H → bb (1.1 fb⁻¹)
H → ττ (1.1 fb⁻¹)
H → γγ (1.7 fb⁻¹)
H → WW (1.5 fb⁻¹)
H → ZZ → 4l (1.7 fb⁻¹)
H → ZZ → 2l 2τ (1.1 fb⁻¹)
H → ZZ → 2l 2q (1.6 fb⁻¹)
H → ZZ → 2l 2ν (1.6 fb⁻¹)
95% CL limit on σ/σSM
Higgs boson mass (GeV/c²)


Exp. Obs.
H→γγ (1.08 fb⁻¹)
H→ WW→ lνlν (1.70 fb⁻¹)
W/Z H, H → bb (1.04 fb⁻¹)
H→ττ (1.06 fb⁻¹)
Exp. Obs.
H→ ZZ→ llll (1.96-2.28 fb⁻¹)
H→ ZZ→ llqq (1.04 fb⁻¹)
H→ ZZ→ llνν (1.04 fb⁻¹)
95% CL limit on σ/σSM
ATLAS Preliminary
∫ L dt ~ 1.0-2.3 fb⁻¹, √s=7 TeV CLs limits
mH [GeV]


CMS Preliminary, √s = 7 TeV, Combined, L_int = 1.1-1.7 fb^-1
Interpretation requires look-elsewhere effect correction
±1σ from fit
Best fit σ/σ_SM
Higgs boson mass (GeV/c^2)
1σ
2σ
3σ
4σ

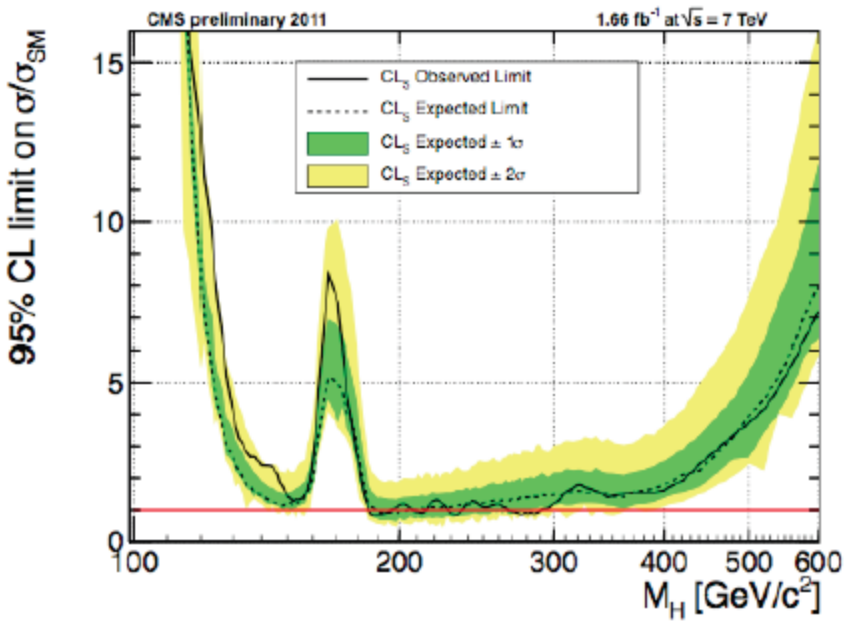

ATLAS Preliminary
p_0
Observed
Expected
∫ Ldt = 1.0-2.3 fb^-1
√s = 7 TeV
m_H [GeV]
2σ
3σ
4σ
5σ

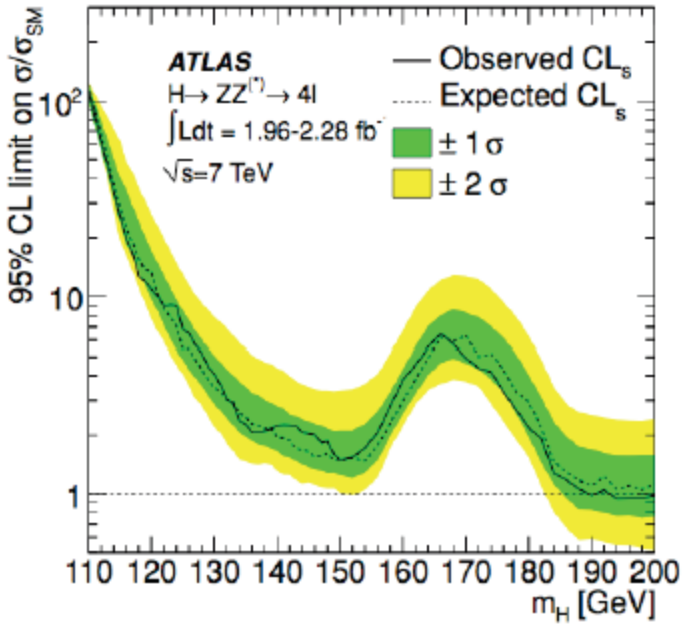

ATLAS Preliminary
Observed
Expected
∫ Ldt = 1.0-2.3 fb-1
√s = 7 TeV
CLs
0.25
0.2
0.15
0.1
0.05
90%
95%
99%
100
200
300
400
500
600
mH [GeV]

CMS sensitivity currently ~40-50% better at low mass

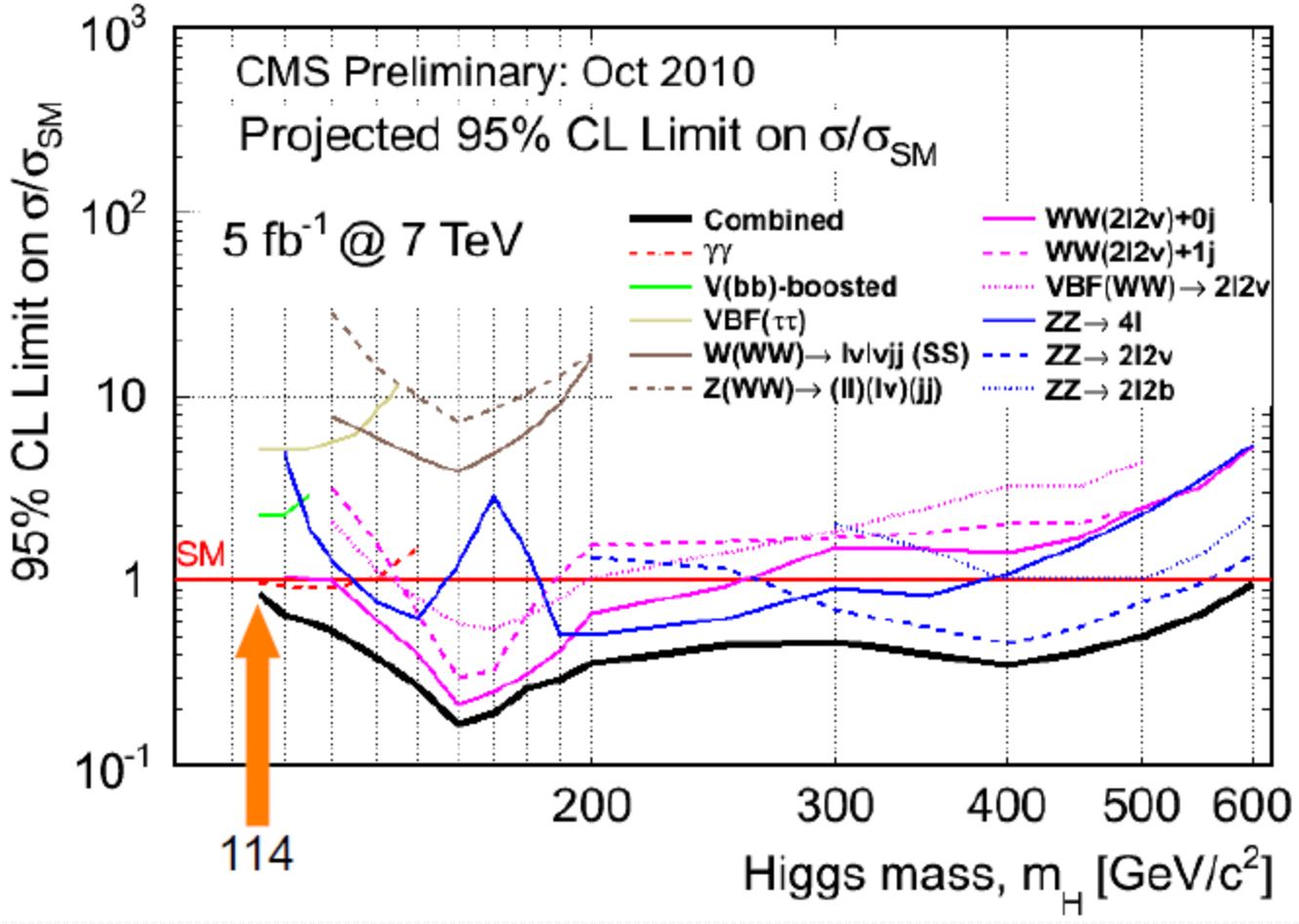
Credit: G.Unal

Mostly from higher signal efficiency (especially in electron channel) (with somewhat larger expected background) and also better mass resolution

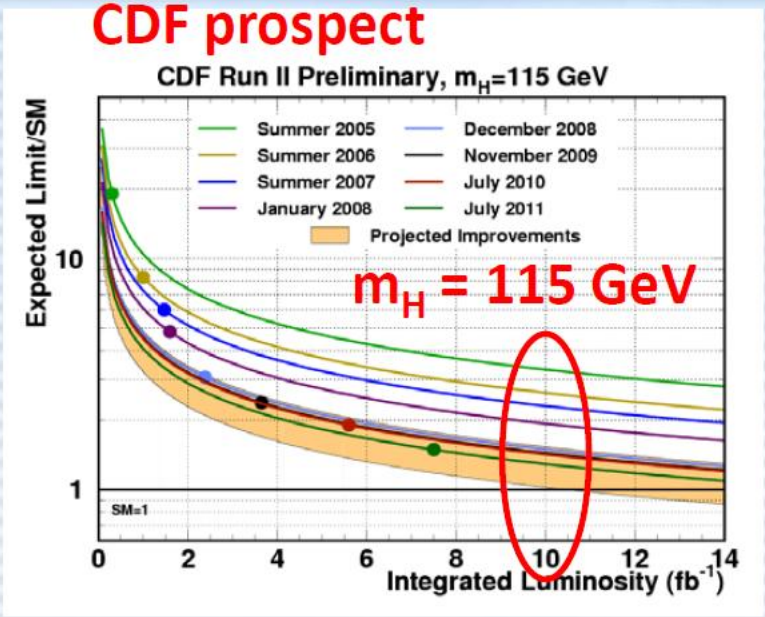




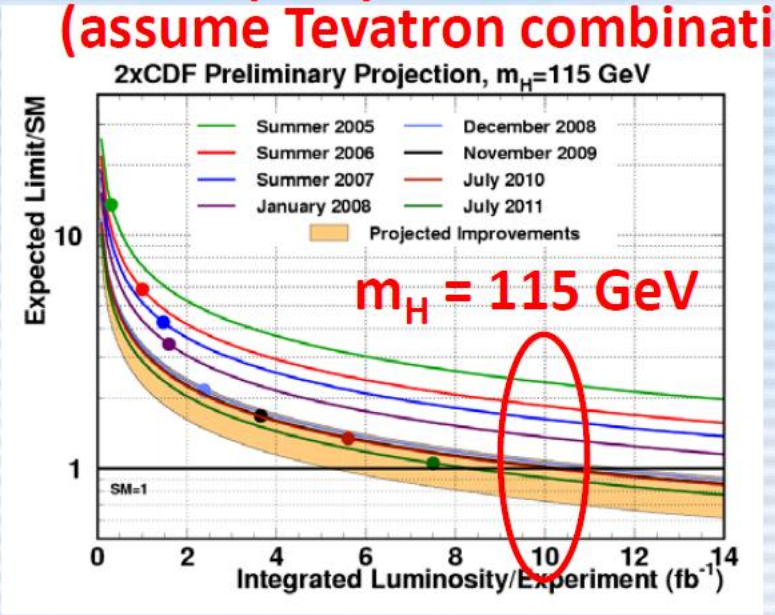
Projected Exclusion with 5 fb^{-1} @ 7 TeV



CDF prospect



CDFx2 prospect (assume Tevatron combination)



Credit: Y.Nagai

Credit: H.Bachacou

Supersymmetry: Summary

- SUSY in its most hoped for incarnation is starting to be in trouble
  - → Of course we will continue looking and increasing our reach
- What if SUSY were hiding? (e.g. no Missing E_T)
  - → "Split", "low-MET", "squashed", "mashed?"
  - → Even if very soft cascade at tree level, Initial State Radiation still creates MET, but this needs to be studied further
- With >1 fb^{-1}, other SUSY prod. mechanisms open up → exclusive chargino/neutralino and 3rd generation production