Hadron Collider Physics III: PPP-II Lecture 13 (FS 2012)

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29.5.2012

15.5.2012 Introduction: Why we want(ed) the LHC?

15.5.2012 From "low" Q^2 pp physics to W, Z and other medium Q^2 LHC questions and answers.

22.5.2012 QCD, TOP and "known"(?) SM physics at the LHC, status and perspectives.

29.5.2012 Higgs@LHC and searches for new phenomena, status and perspectives.

29.5.2012 "Some kind of PPP2 "Summary": The next few years at the LHC.

Hadron Collider Physics:
PPP-II Lecture 12 (29.5.2012)

- Searching for the Higgs and Supersymmetry at the LHC, some basic ideas.
- No signs for supersymmetry so far!
- Higgs search expectations in 2007 and the 2011 ATLAS/CMS results.
- Some topics for the LHC from 2015 onwards.
- Options for future collider physics?

Searching for Higgs, Supersymmetry etc at the LHC: some basic ideas (I)

- QCD multi jet events with high transverse momentum dominate everything else also because of very large uncertainties from the jet energy measurements!
  High p_t b-jet tagging in multi jet events provides significant QCD jet background reduction

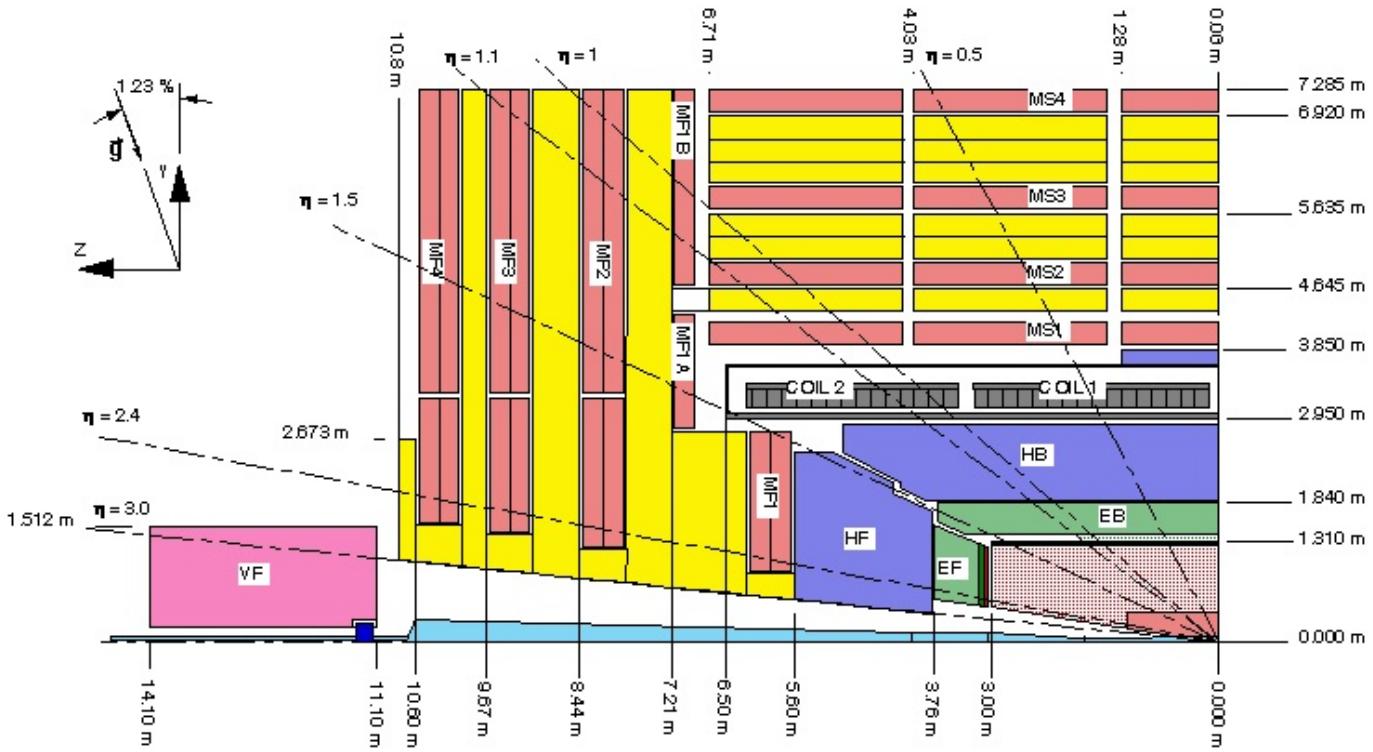
- high p_t isolated electrons and muons (what about τ decay products) are a clean sign for W and $(\gamma, Z)^*$ production (sign of electroweak cross sections).

- "isolated" and large missing transverse momentum is a clear sign for "neutrino" like production (sign of weak interaction).

- Other helpful requirements:
  - Invariant mass peaks ($H \to \gamma\gamma$ and $H \to ZZ \to 4\ell$)
  - Jet Veto (zero jets) or multi-jet large transverse mass events
  - all above combined

Searching for Higgs, Supersymmetry etc at the LHC: some basic ideas (II)

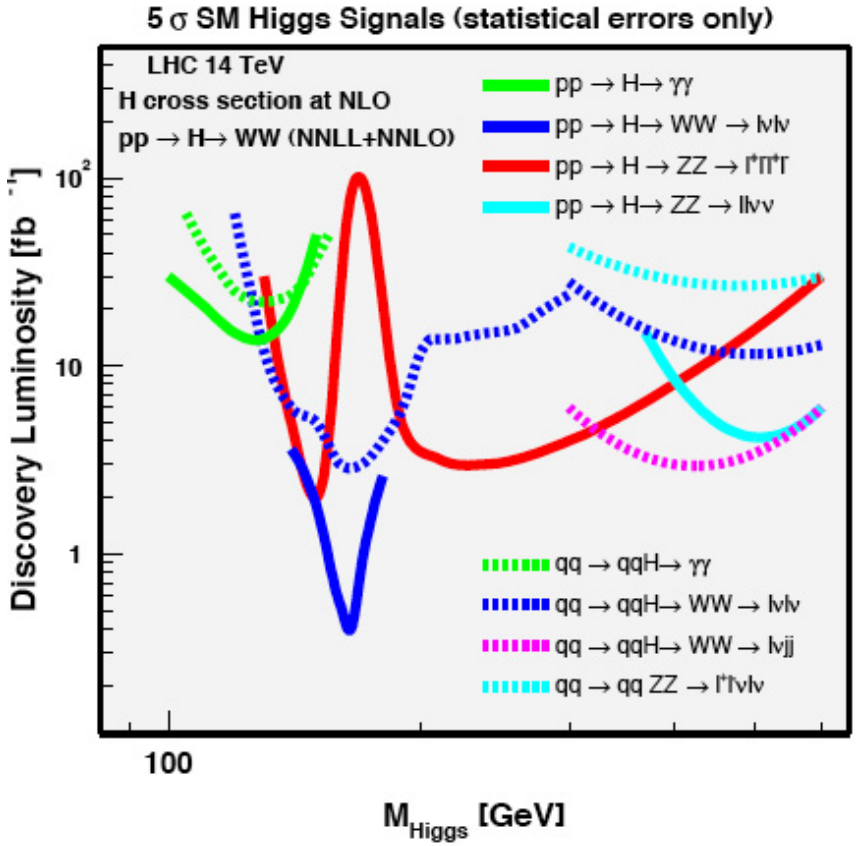
R-Z view of the CMS detector:
Excellent electron and muon identification and "complete calorimeter coverage" up to $|\eta| < 5$.



more at http://cms.web.cern.ch/cms/Detector/WhatCMS/index.html

Searching for Higgs, Supersymmetry etc at the LHC: some basic ideas (III)

Production: (1) gluon-gluon fusion channel ($gg \to$ Higgs) and (2) vector-boson fusion channel ($qq \to qq$ Higgs). strong background reduction due to two extra forward jets!



Plot based on "optimistic" (and realistic!) simulations from ATLAS and CMS for the LHC with 14 TeV (at 7 TeV one needs about a factor $\sqrt{2}$ more luminosity)

Searching for Higgs, Supersymmetry etc at the LHC: some basic ideas (IV)

a possible 5 sigma signal depends on the Higgs mass:
(exclusions of a Standard Model Higgs require only about 1/6 of the discovery luminosity! ($(2/5)^2$ if there are no background fluctuations!).

1. $\mathrm{M_H}$ **= 114-140 GeV:** $H \to \gamma\gamma$
   extremely difficult and at least 30 fb^{-1} required for a signal!

2. $\mathrm{M_H}$ **= 135-155 GeV:** $H \to ZZ^* \to$ **4 charged leptons**
   plus $H \to WW^* \to \ell\nu\ell\nu$
   significant signals already with 10-20 fb^{-1} possible!

3. $\mathrm{M_H}$ **= 155-180 GeV:** $H \to WW \to \ell\nu\ell\nu$
   a significant signal already with only 0.5-1 fb^{-1} possible!

4. $\mathrm{M_H}$ **= 180-400 GeV:** $H \to ZZ \to$ **4 charged leptons**
   significant signals with about 5-10 fb^{-1} possible,

5. $\mathrm{M_H}$ **= 350-700 GeV:** $qqH \to qqWW \to qq\ell\nu qq$
   plus $H \to ZZ \to$ **4 charged leptons plus** $H \to ZZ \to \ell^+e^-\nu\nu$
   significant signals already with 10 fb^{-1} possible.

Searching for Higgs, Supersymmetry etc at the LHC: some basic ideas (V)

The 2012 timeline for the LHC to 2016 and the Higgs etc search

2010 Start of the experiments at 7 TeV
collected 0.05 fb^{-1}/experiment

2011 Stable high quality data taking at 7 TeV with about 5 fb^{-1}/experiment
During the summer 2011 first significant Higgs (exclusions) with more than 1 fb^{-1}..
a SM Higgs in the mass range from 150-400 GeV can not exist! (a small excess around 145 GeV was reported).
ATLAS and CMS presented their first full 2011 data (on 13.12.2011). A small excess near 125 GeV reported.
March 2012: remaining allowed SM Higgs mass range: 122 GeV to 127 GeV!

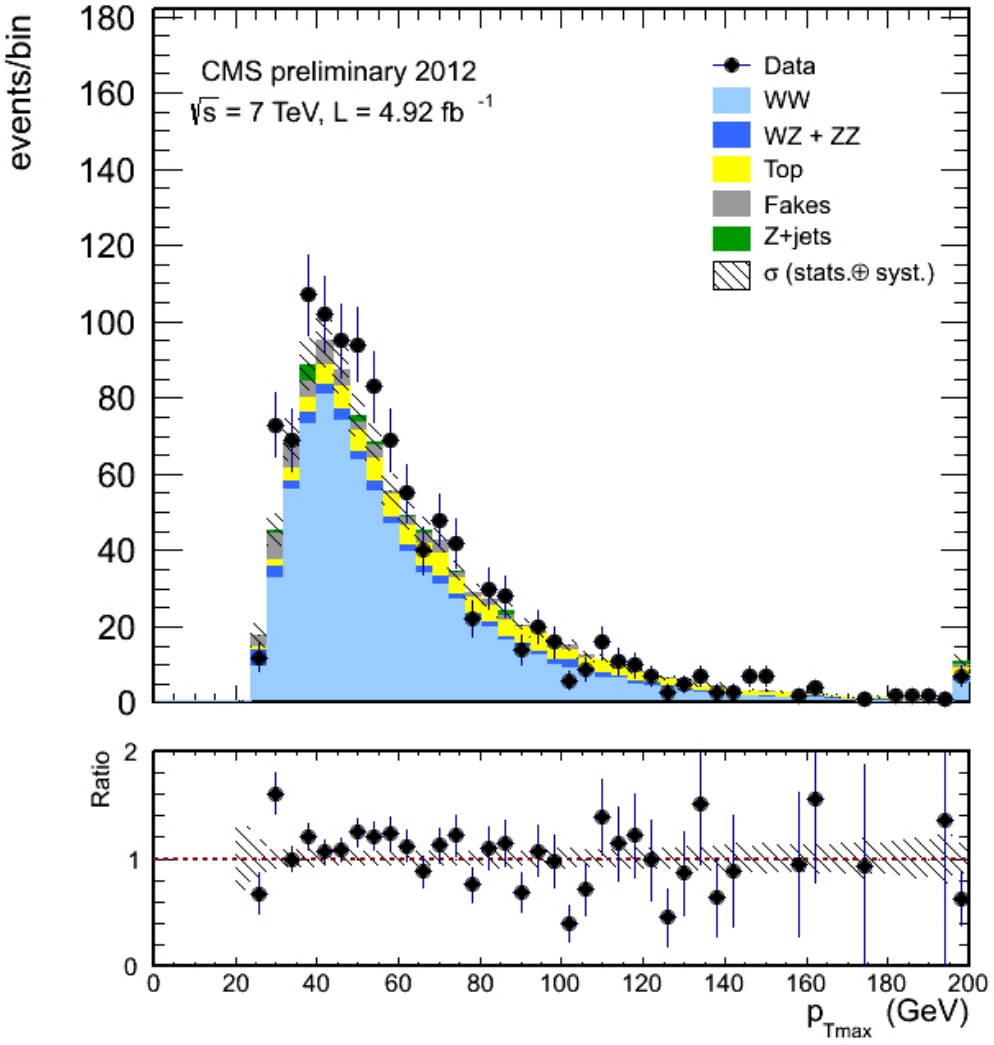
2012 Stabile data taking at 8 TeV (goal 15 fb^{-1} and 5 fb^{-1} for the summer conferences) Data should be sufficient to reach sufficient sensitivity to exclude the existence of SM Higgs or find a significant hint near 125 GeV.
Expect also some improvements in "exotic physics" exclusions, but not signals!

2013 / 2014 repair of the LHC to reach 14 TeV design collision energy in 2015.

2015 /2016 expected luminosity a few 10 fb^{-1}/year
Final words about the exclusion/existence of a SM Higgs like signal!
Supersymmetry and other searches up to masses of about 2 TeV.

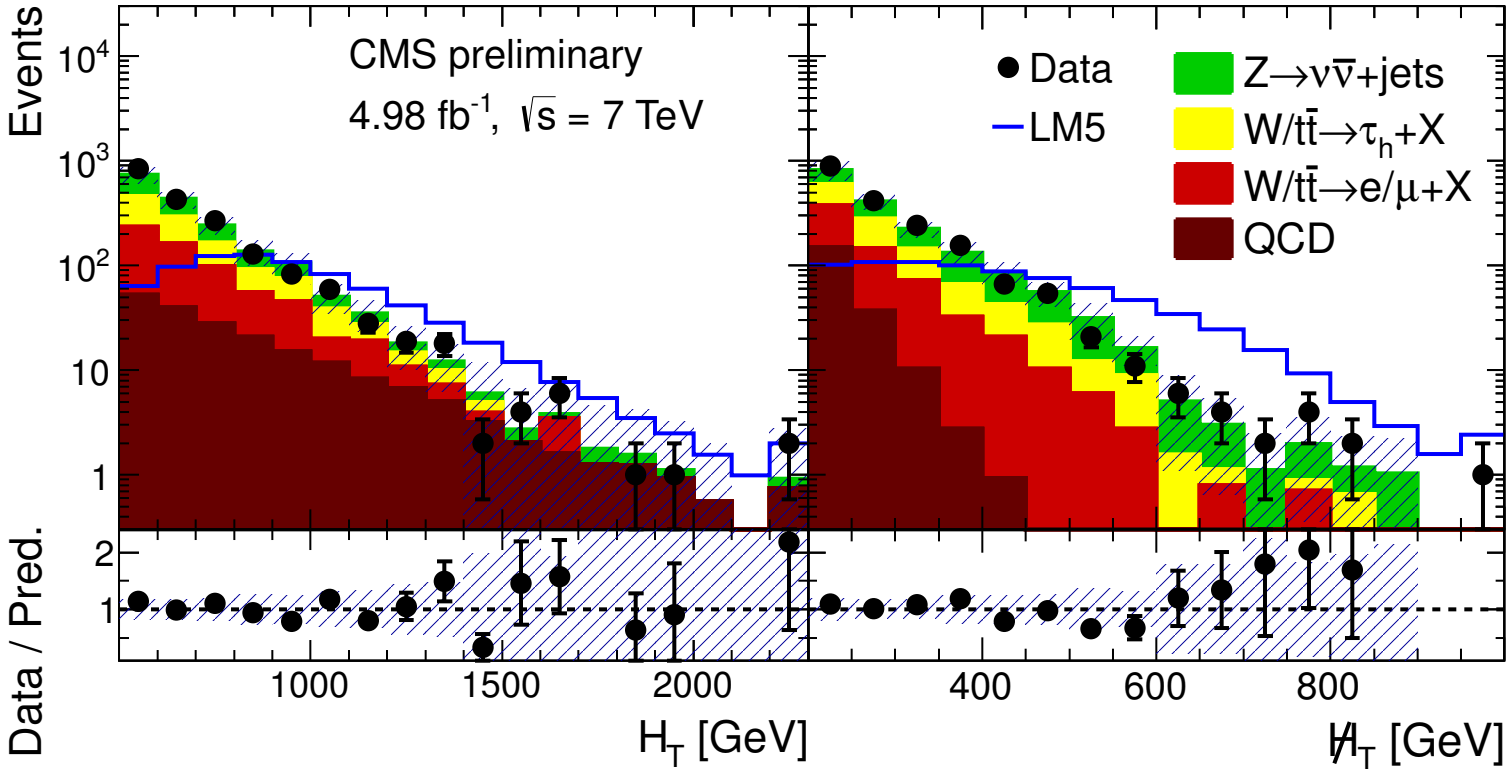
Reminder: known SM processes at the LHC

"All" in excellent agreement with theoretical expectations
$\rightarrow$ lots of hypothetical new types of exotic physics signatures excluded already!
not much "phase space" left for easy discoveries!
Even WW (and WZ, ZZ) are in good agreement (so far) with theory



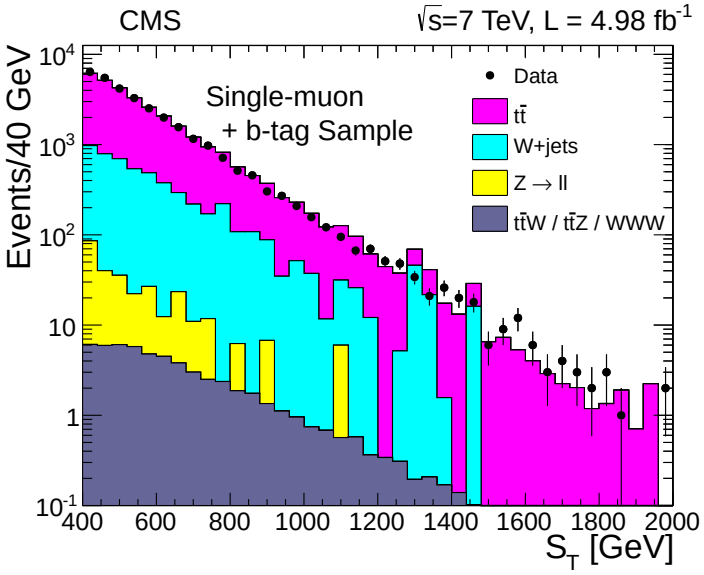
No signs for supersymmetry yet (I)

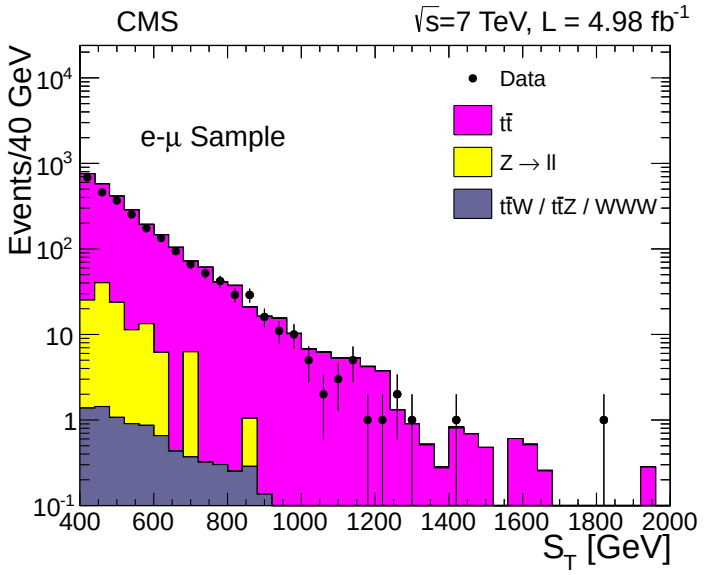
Signature for superymmetric particles:
High mass and high p_t jets (leptons) plus large missing momentum.



No signs for supersymmetry yet (II)

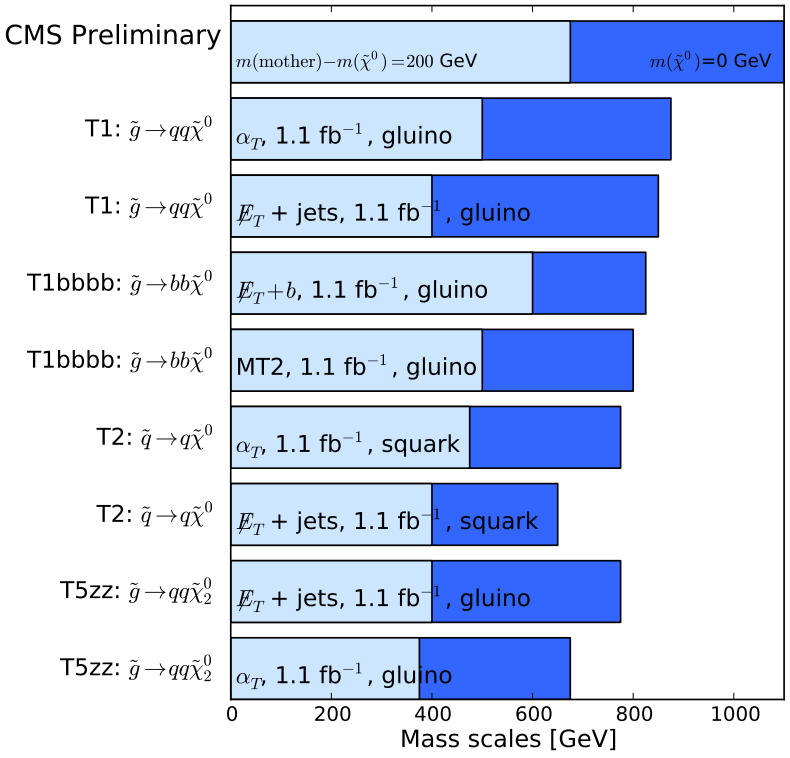
Some more "difficult" susy signatures:
b-flavored jets with high mass, plus 1 or 2 leptons plus missing transverse energy

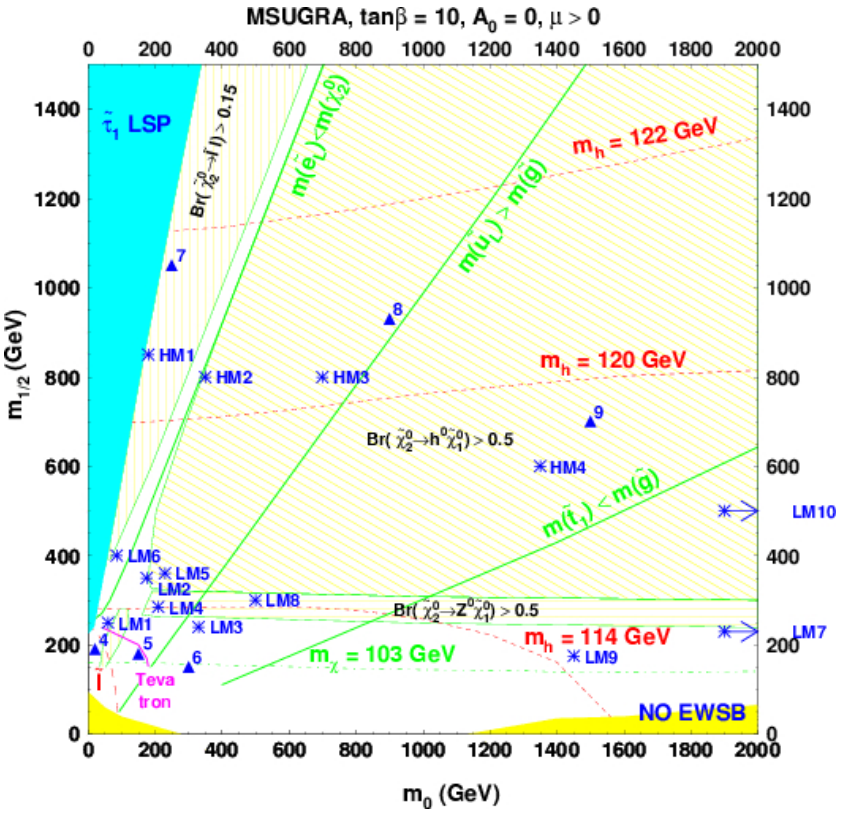




No signs for supersymmetry yet (III)

Results: "complicated" exclusion plots
the right hand plot is the "ultimate" 14 TeV 5 sigma discovery potential.





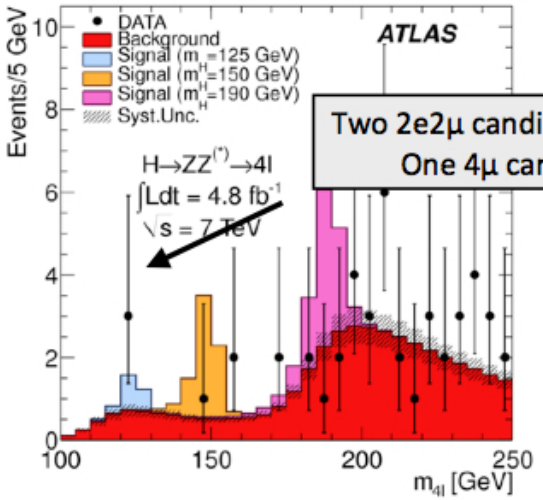
Higgs searches with the 2011 LHC data (Ia)

ATLAS, R.Bernhard (March 2012)

$H \to ZZ^{(*)} \to 4l$

8

- Very clean: four leptons (e or μ); "golden" channel
- Good four-lepton mass resolution needed to separate signal from irreducible continuum ZZ background (σ_{mH}/m_H ~1.5-2% at m_H = 130 GeV)
  - Above 350 GeV natural width dominates
- High lepton reconstruction efficiency down to low p_T (7 GeV)



- Lepton performance well modeled by the simulation, independent of pileup

Two 2e2μ candidates: m_{4l}=123.6, 124.3 GeV
One 4μ candidate: m_{4l}=124.6 GeV

Event yields in full mass range

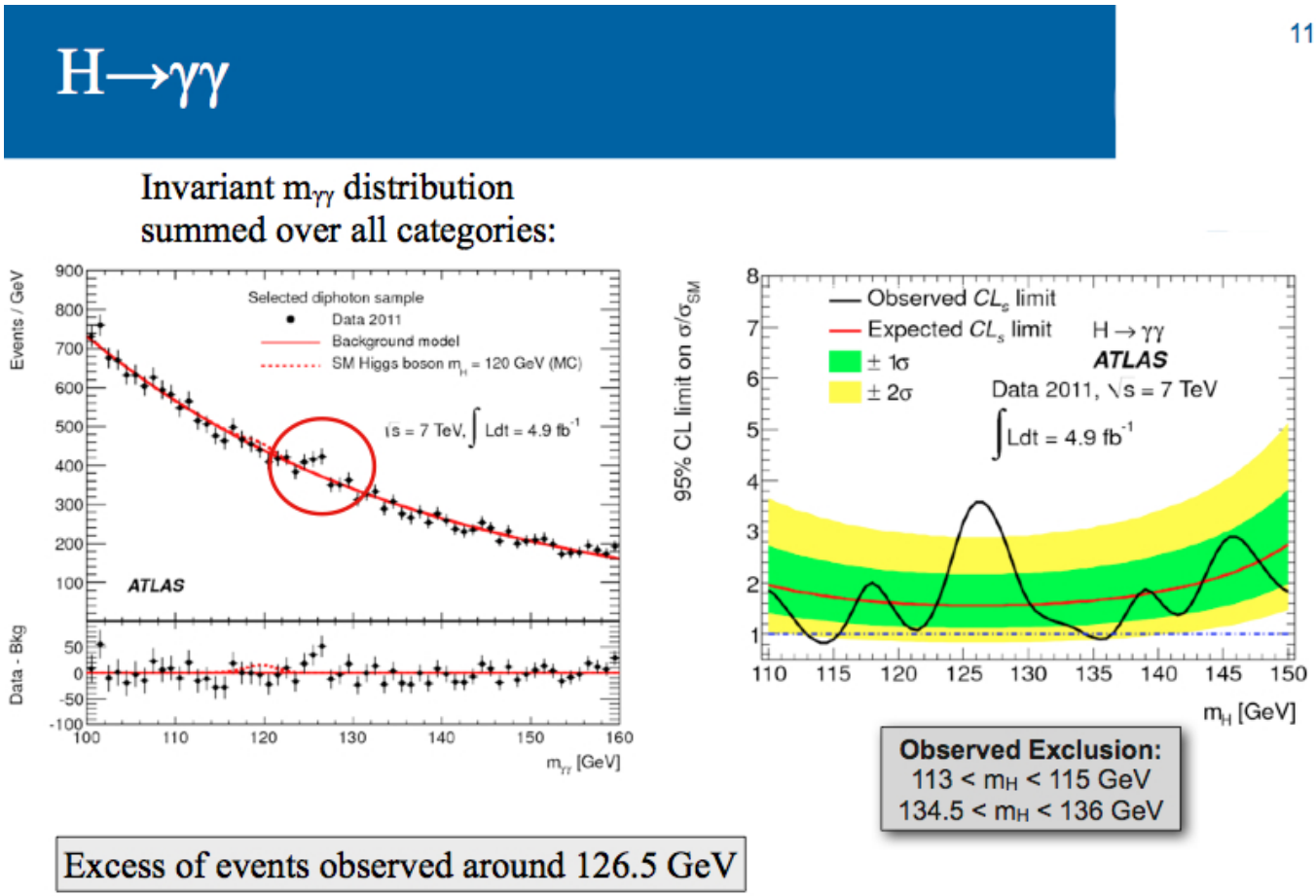
	4μ	2e2μ	4e
Expected	18.6±2.8	29.7±4.5	13.4±2.0
Observed	24	30	17

submitted to Physics Letters B, arXiv:1202.1415

source: http://moriond.in2p3.fr/QCD/2012/MorQCD12Prog.html

Higgs searches with the 2011 LHC data (Ib)

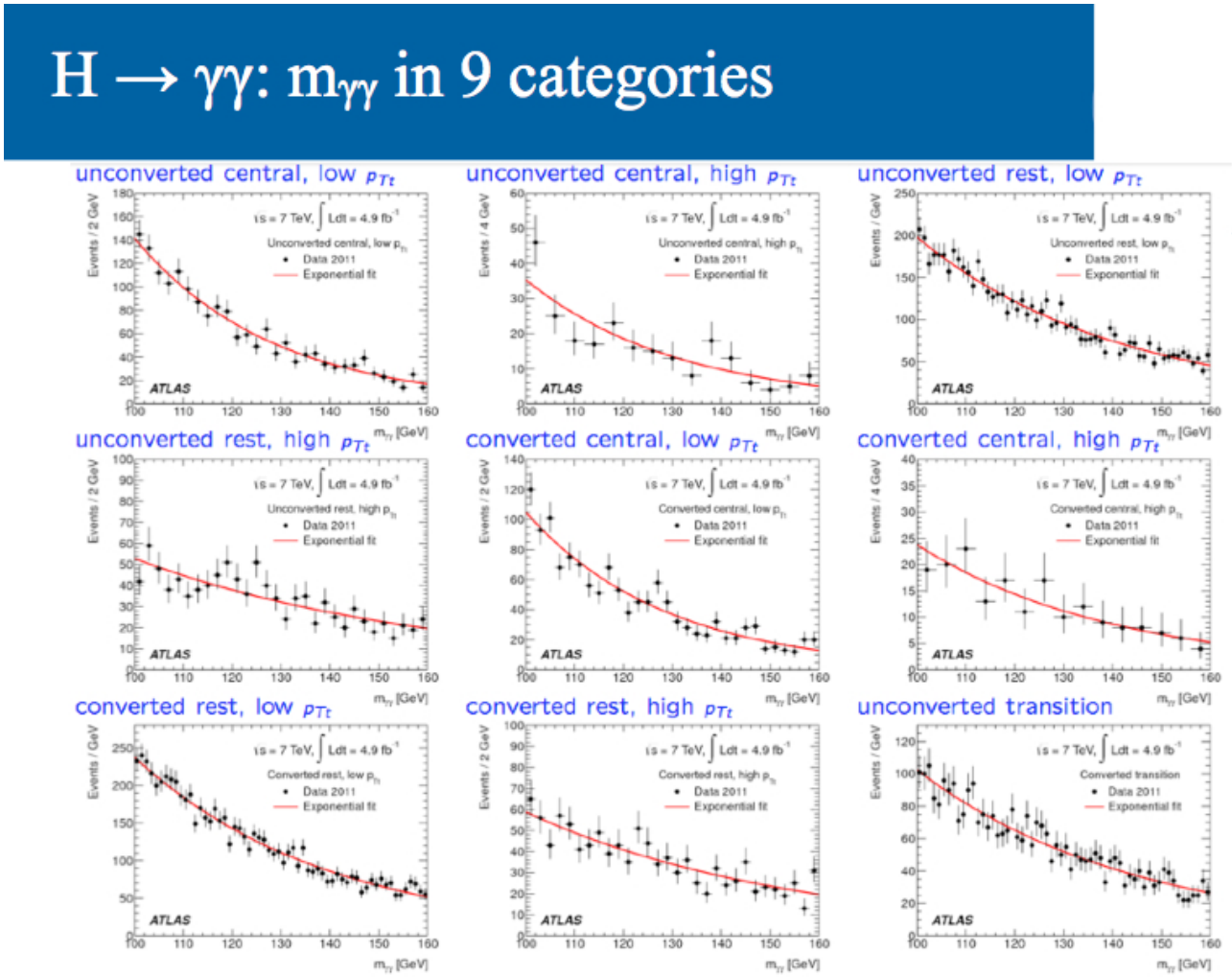
ATLAS, R.Bernhard (March 2012)



source: http://moriond.in2p3.fr/QCD/2012/MorQCD12Prog.html

Higgs searches with the 2011 LHC data (Ic)

ATLAS, R.Bernhard (March 2012)



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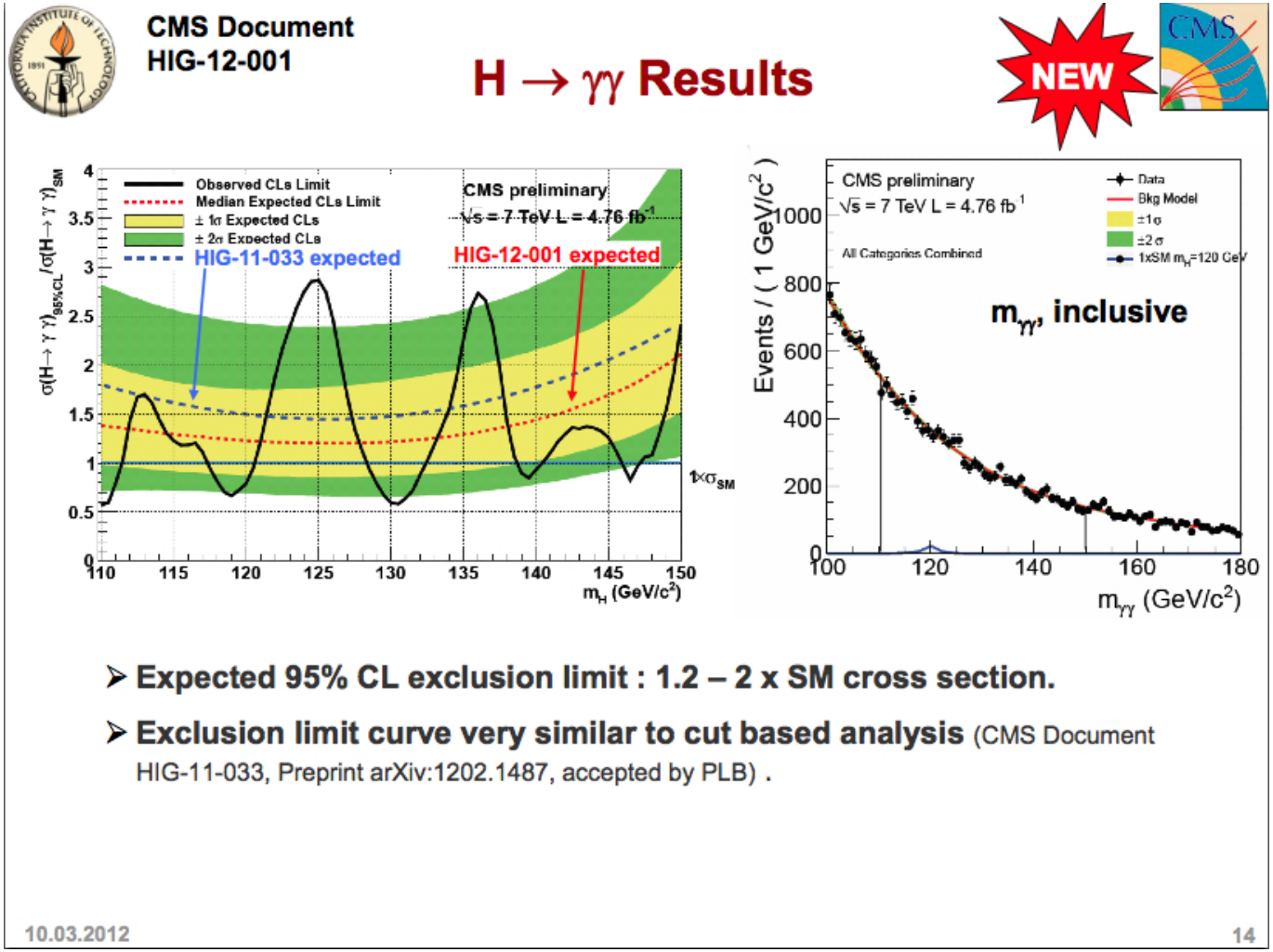
Higgs searches with the 2011 LHC data (IIa)

CMS, A. Bornheim (March 2012)



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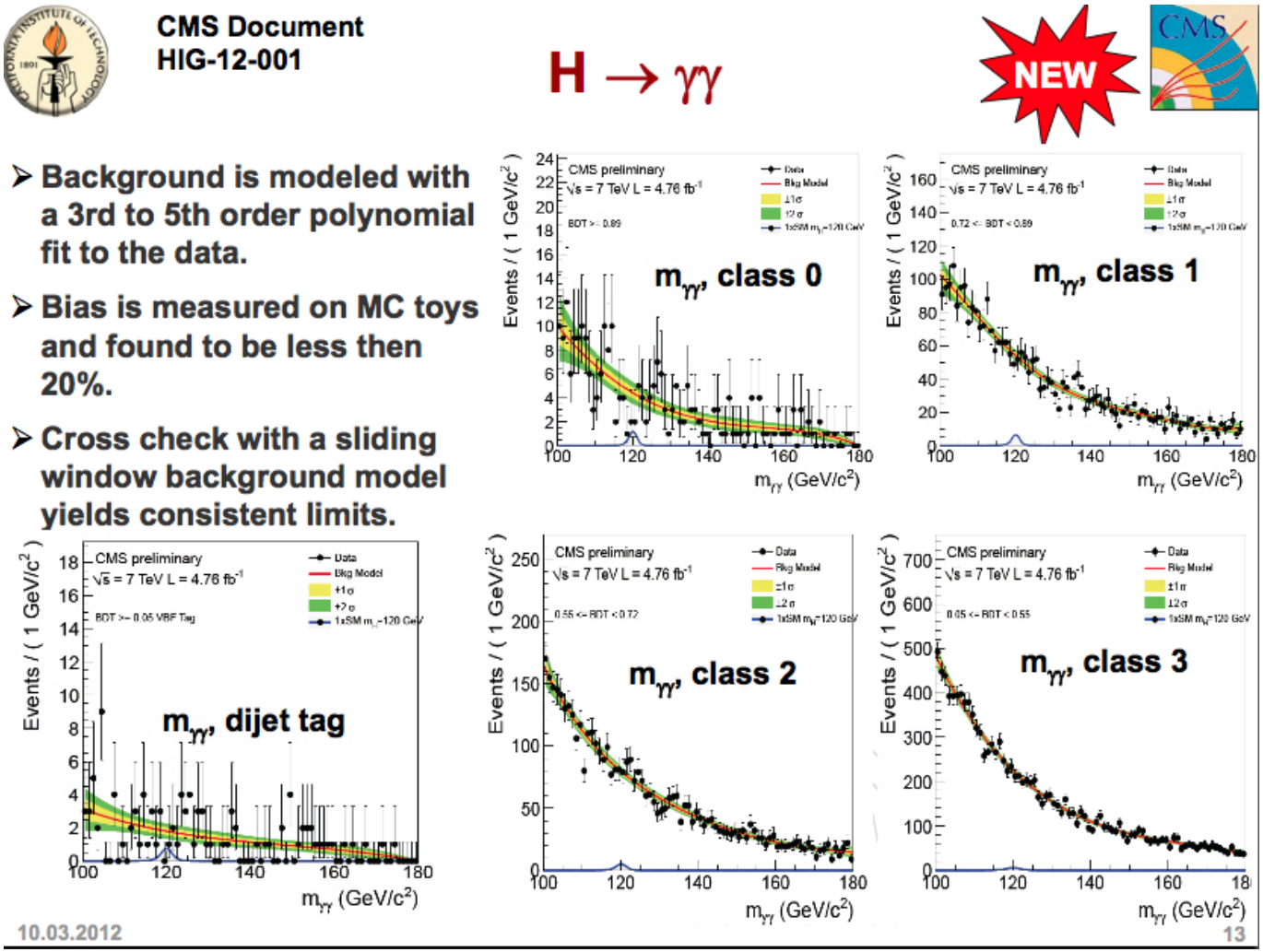
Higgs searches with the 2011 LHC data (IIb)

CMS, A. Bornheim (March2012)



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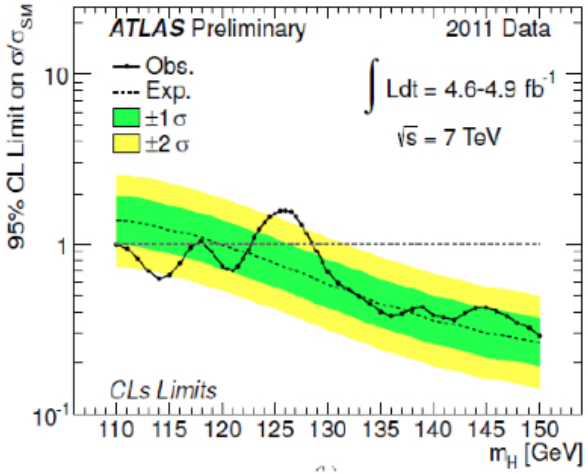
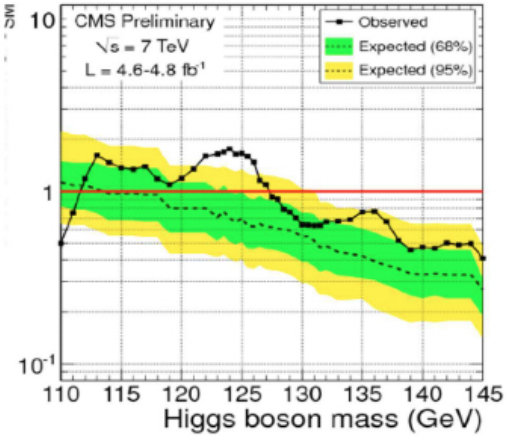
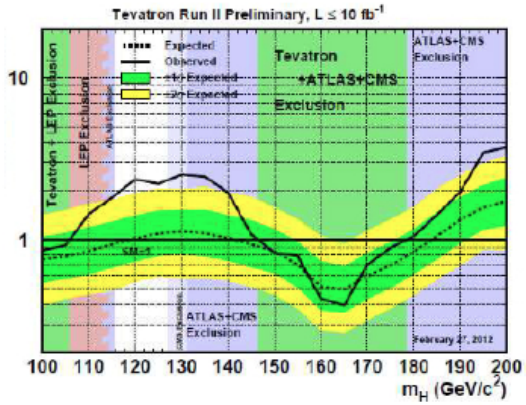
Higgs searches with the 2011 LHC data (III)

G. Altarelli Moriond conference (March 2012)







The Higgs

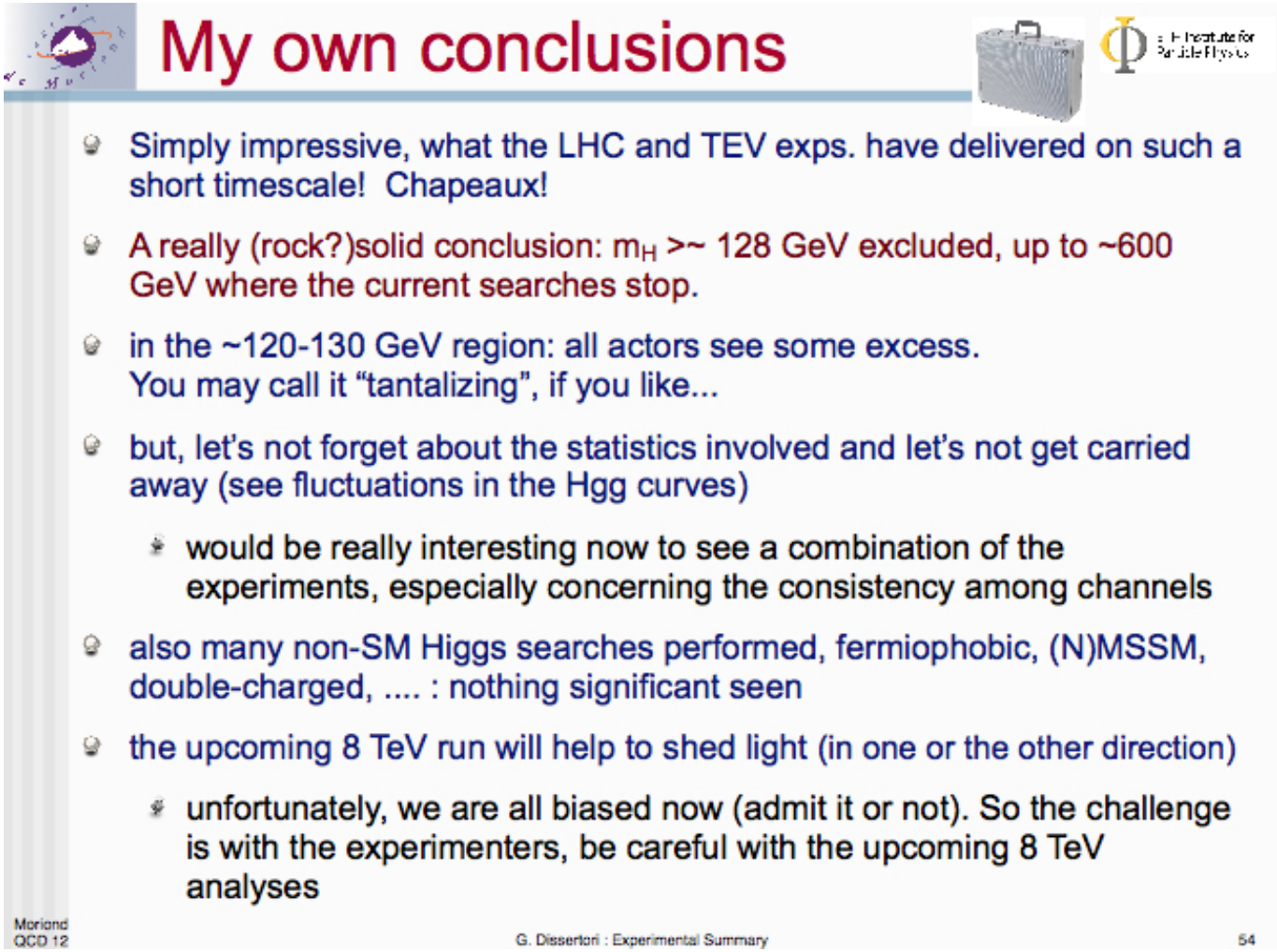
95% exclusion
ATLAS:
110-117.5, 118.5-122.5, 129-539 GeV
CMS:
127.5- 600 GeV

All experiments see some excess
at ~ 122 - 128 GeV

source: http://moriond.in2p3.fr/QCD/2012/MorQCD12Prog.html

Higgs searches with the 2011 LHC data (IVa)

G. Dissertori, experimental summary (Moriond conference March 2012)



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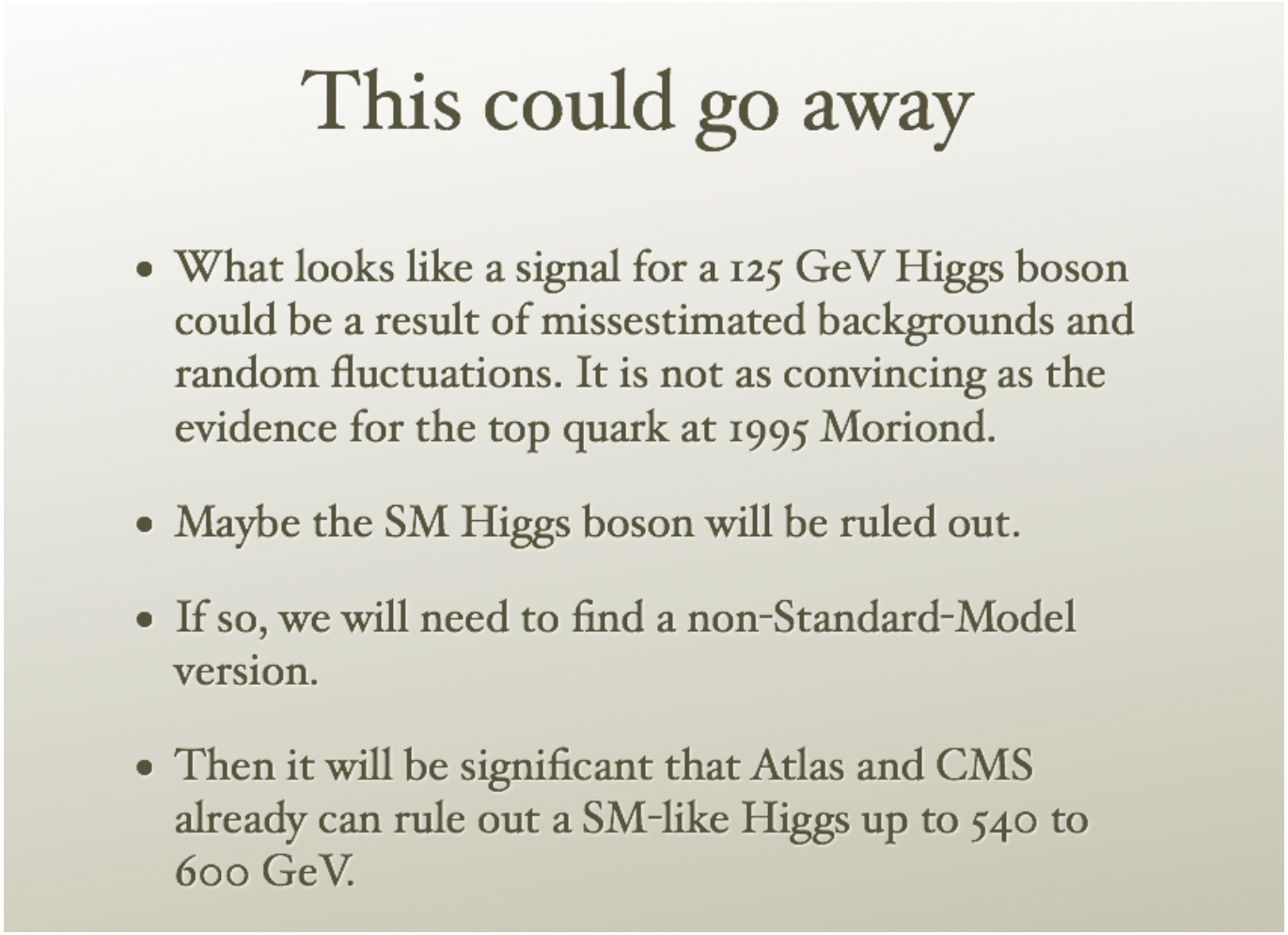
Higgs searches with the 2011 LHC data (IVb)

D. Soper, theoretical summary (Moriond conference March 2012)



source: http://moriond.in2p3.fr/QCD/2012/MorQCD12Prog.html

Higgs searches with the 2011 LHC data (V)

fact: The search for $H \to \gamma\gamma$ in both ATLAS and CMS gives a small excess (significance about 2 sigma) for a mass between 123 GeV and 127 GeV. But:

- The ATLAS / CMS excesses are near 126 GeV / 124GeV
  not at the same mass!

- both experiments find an excess of about 100-120 events for a background of 1800 $\pm$ 45 events.
  For a SM Higgs we would expect only about 60-70 events.
  The "Excess" is too large
  (other signatures at this mass are not really sensitive!)

- In the best case: a SM Higgs can be hidden in the excess.

- For the summer (and end of) 2012 we expect a factor of 2-4 more data:
  - If a SM Higgs does not exist and if we do not find new fluctuations a SM Higgs can be excluded during the 2012 running period.
  - If the SM Higgs exists with a mass between 120-128 GeV, both experiments should obtain about 2-3 sigma signals during 2012.

Summary and outlook

Searches for "Beyond the known SM" at the 7/8 TeV ℓHC demonstrated:

- Excellent agreement between theoretical calculations and experiments even in "extreme" phase space regions.
- Small differences between experiment and theory can all be understood because of missing higher order theory calculations.
- Many exotic (esoteric?) models excluded now.
- Little "room" left to observe supersymmetric surprises during 2012.
- In my view: also little "room" left for Higgs discovery in 2012.
- The LHC program till early 2020ies seems to be "clear", but... What are the prospects of (in?) particle physics during the coming decades?
  ... see next slide

Outlook: Future Colliders?

- LEP discussions started "seriously" in 1979 and the physics program started in 1989
- It took 25 years from the first SSC/LHC discussions to the first LHC physics
- Are there limits for future collider projects (technology/size/finance/)?
- We can be sure that without new fundamental ideas/questions/results from the LHC: without new physics discoveries at the LHC → difficult even to define the future steps!