Latest results from the LHC

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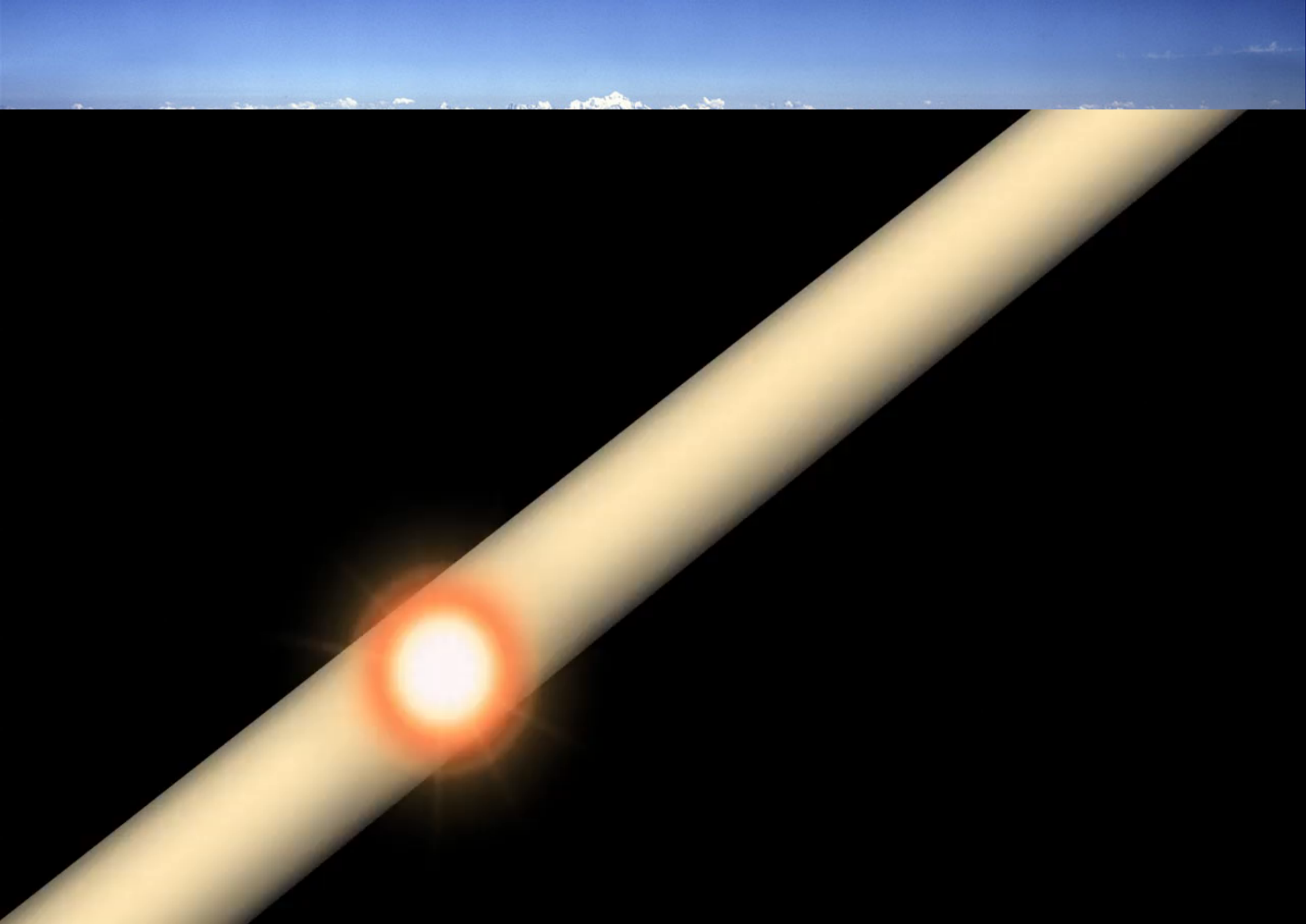
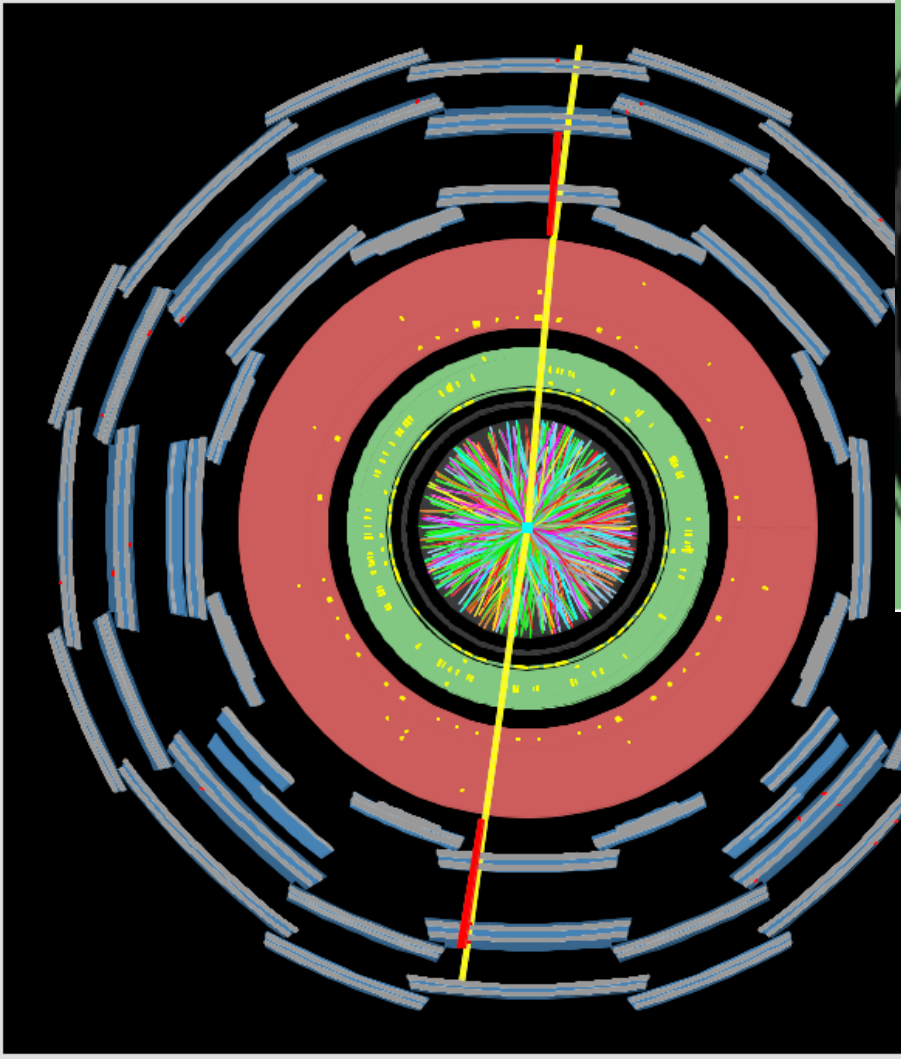
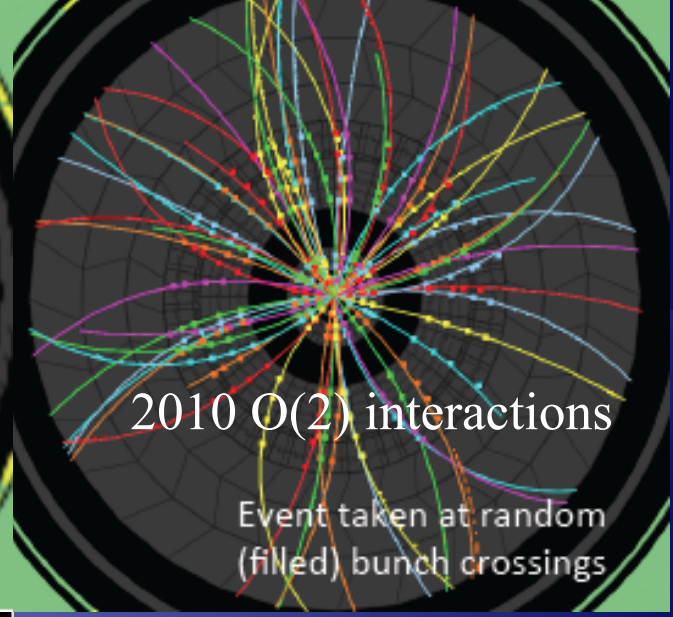
Seoul National University

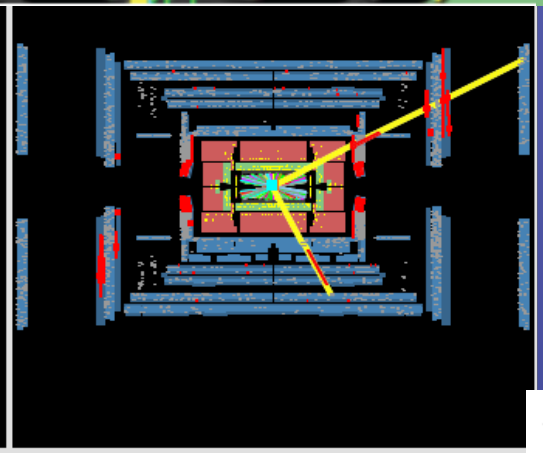
On behalf of ATLAS & CMS

r Institute 2013, Aug 17-23 2013

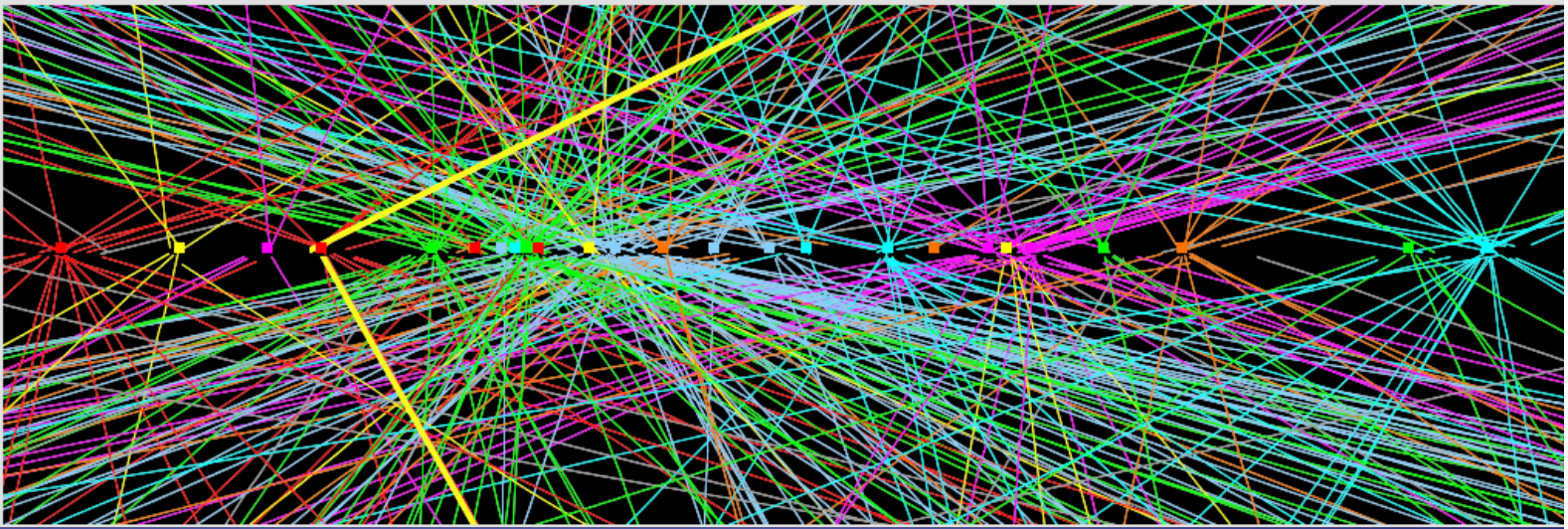


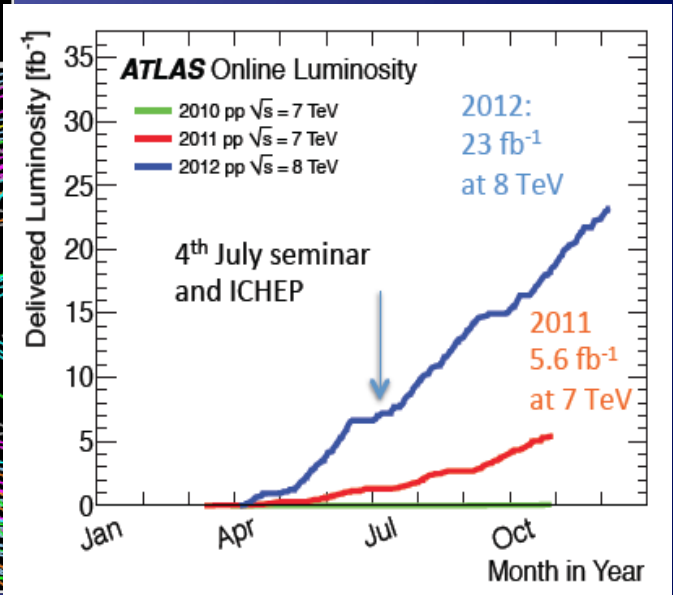




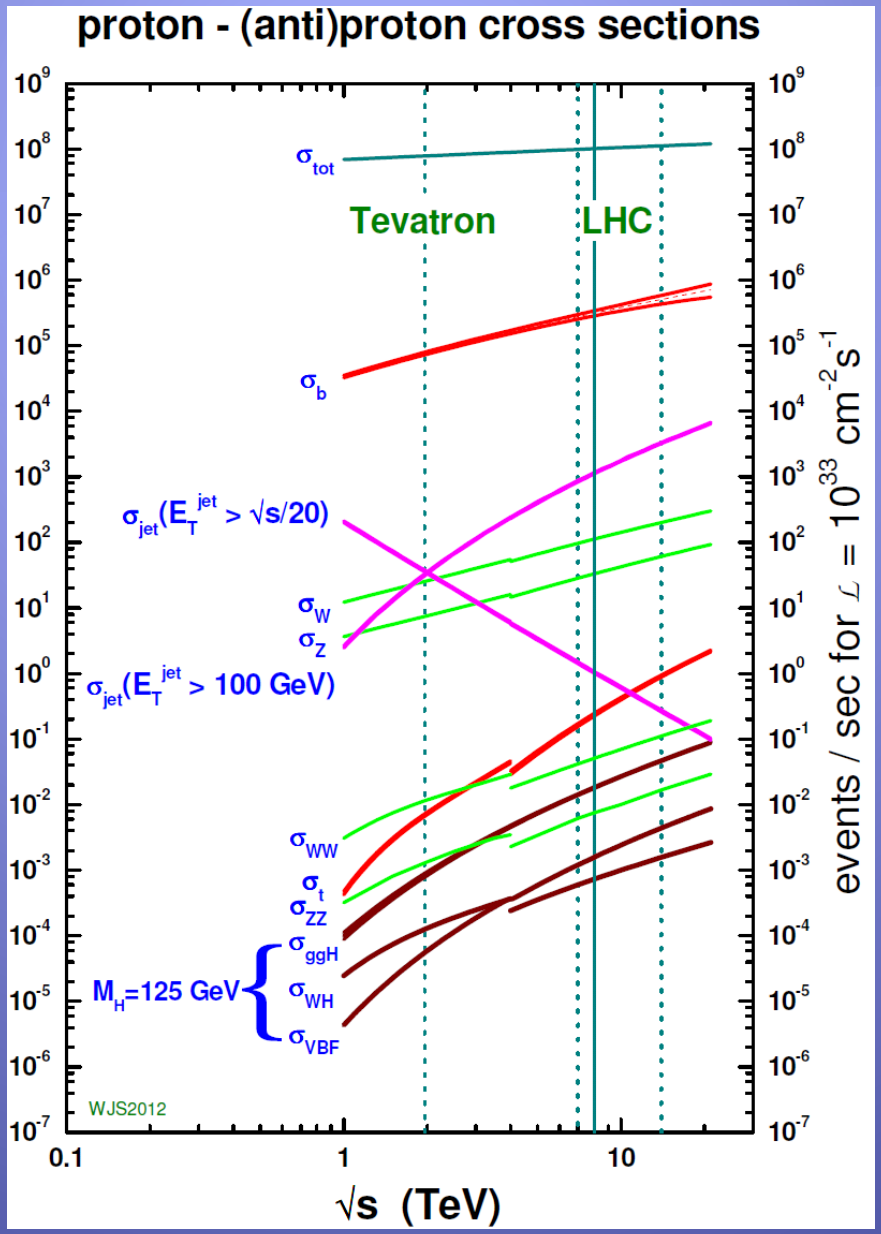


- 400M collision evts/s (400 saved)
- 5×10^9 saved out of 10^{14} evts





LHC Program



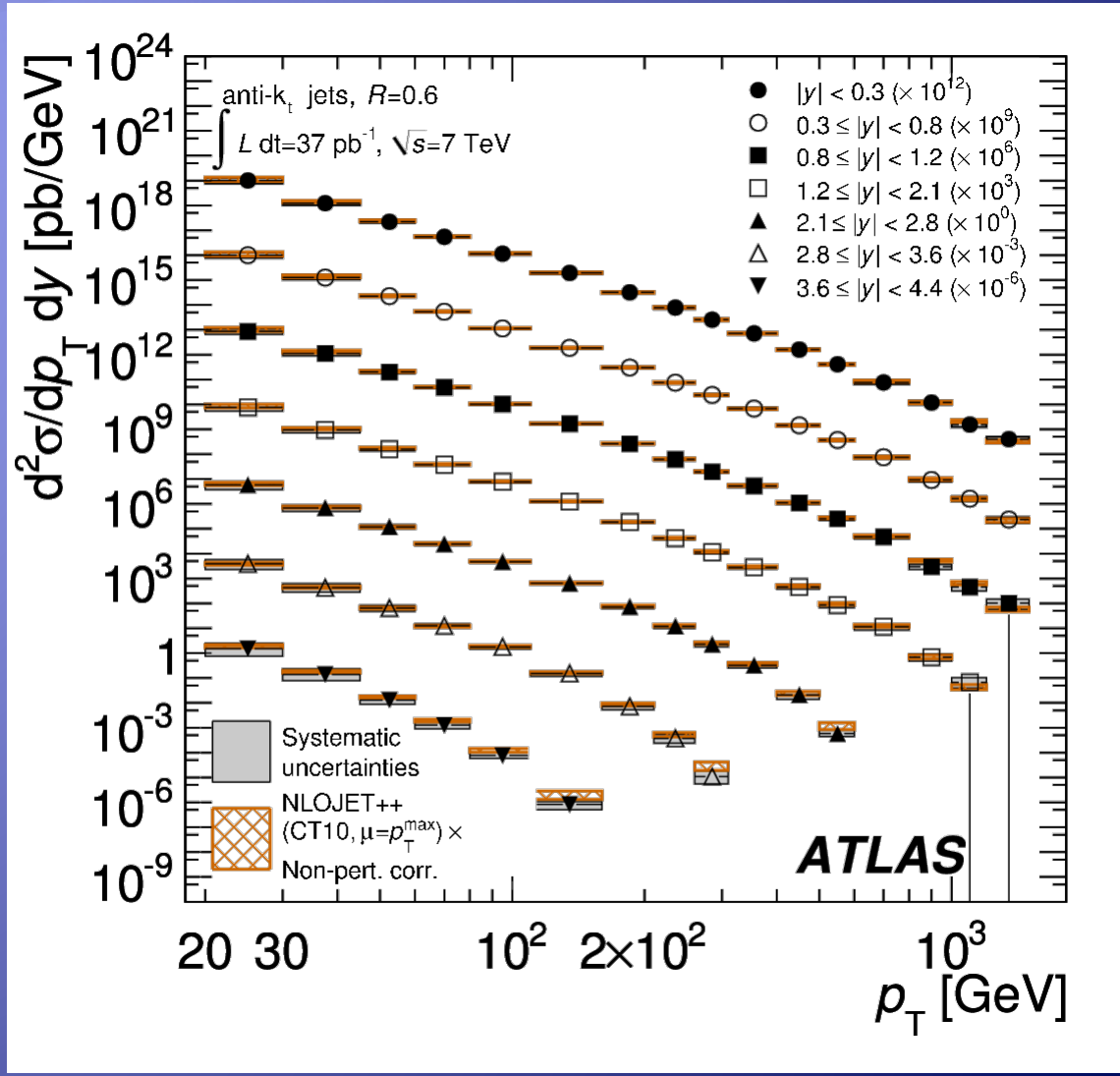
- **Measurements**
  - Jets (~1-100μb)
  - W, Z (~10nb)
  - Top (~100pb)
- **Discovery**
  - Higgs (~10pb)
- **Searches**
  - Exotics
  - SUSY

Measurements

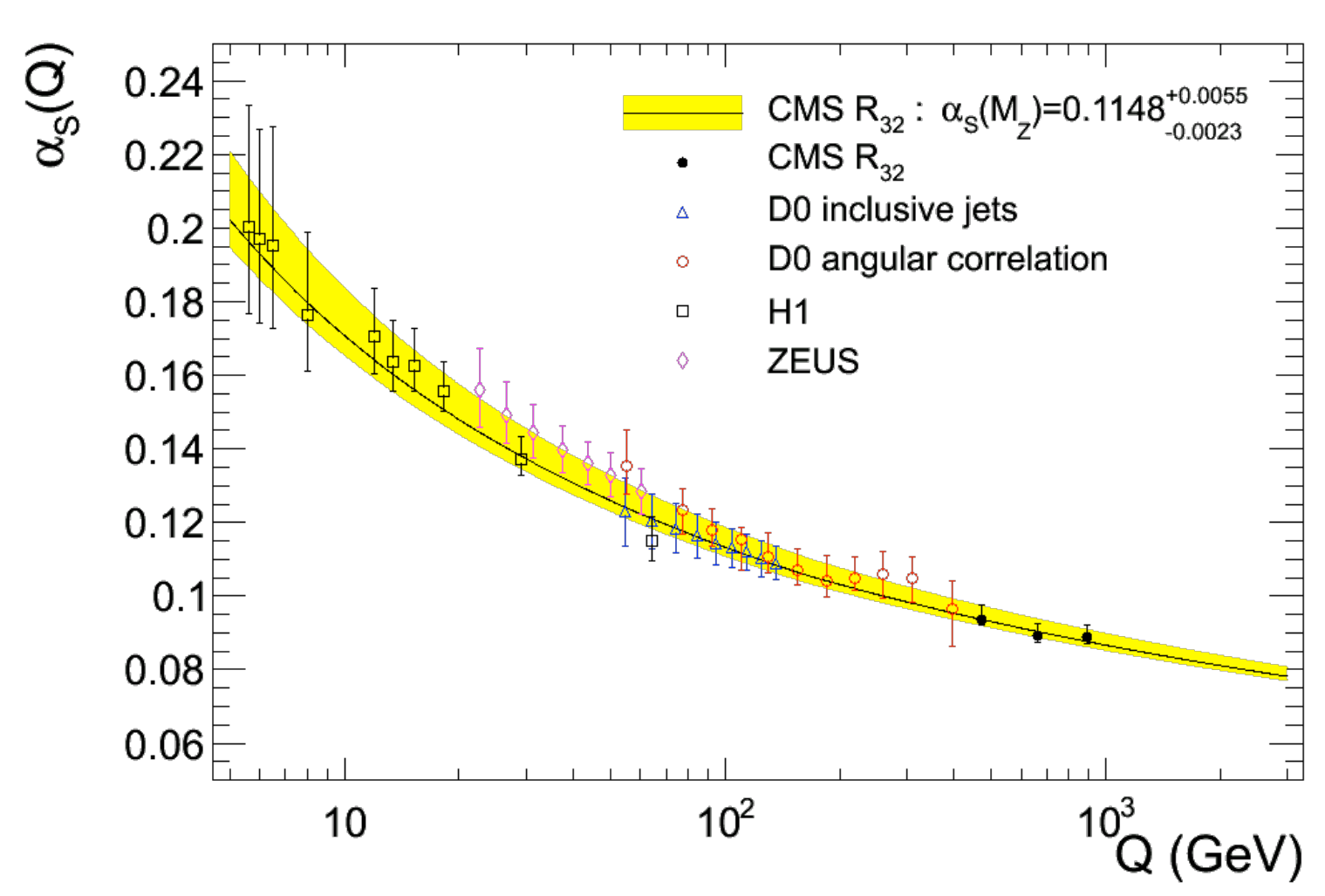
Jets at the highest scales

- Highest transverse momentum jets at the TeV scale

  arXiv:1009.5908 (EPJC),
  arXiv:1112.6297 (PRD)
  arXiv:1106.0208 (PRL)

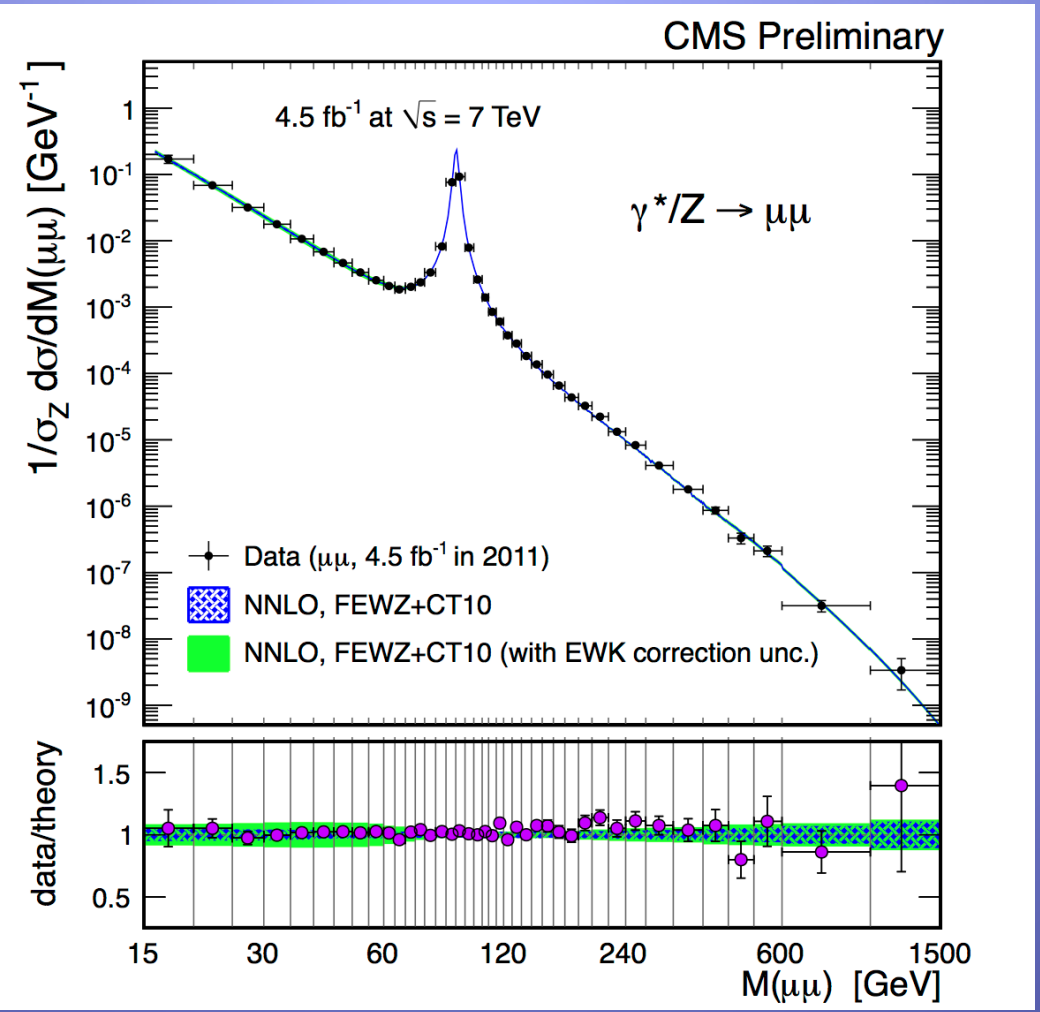


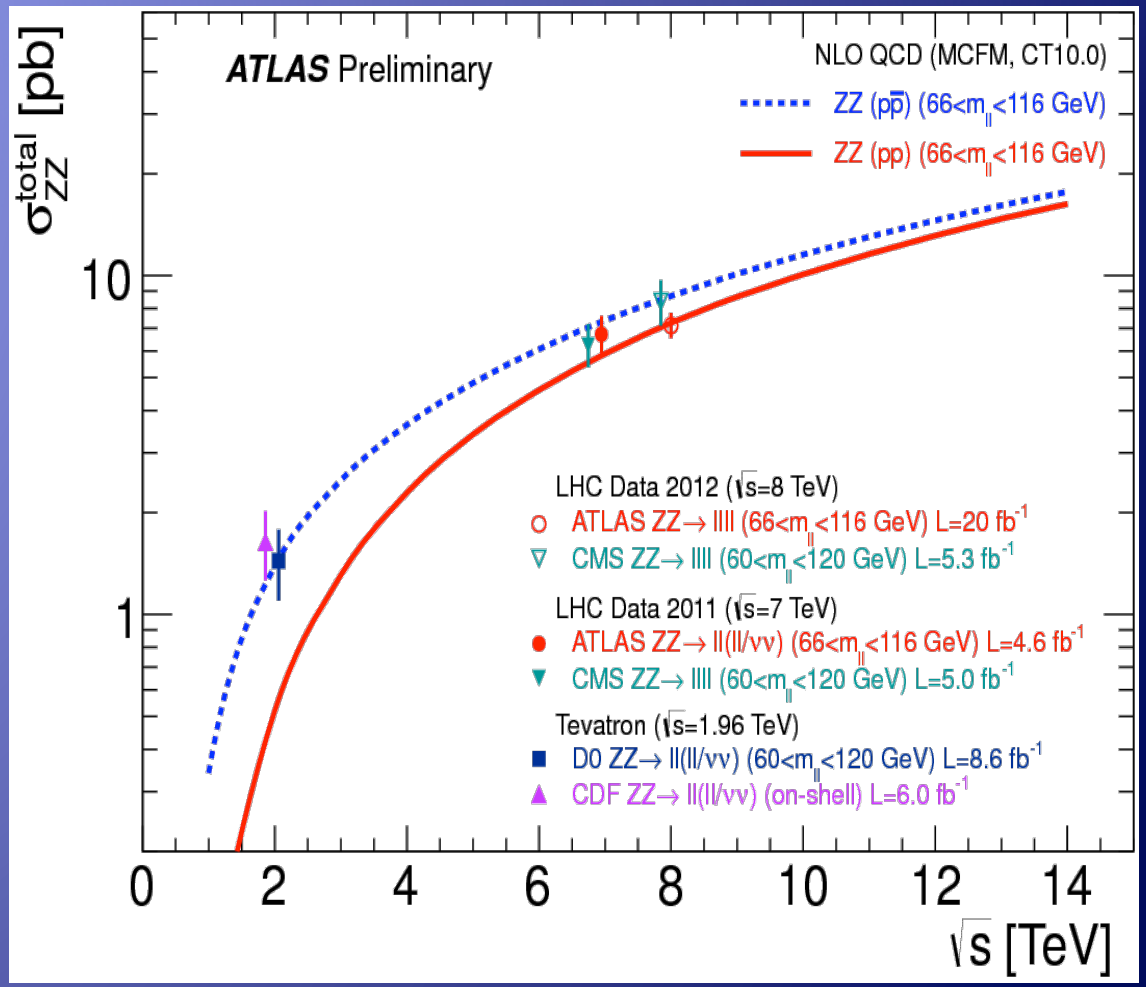
Running of the strong coupling



arXiv:1304.7498

Leptons: Z, ZZ

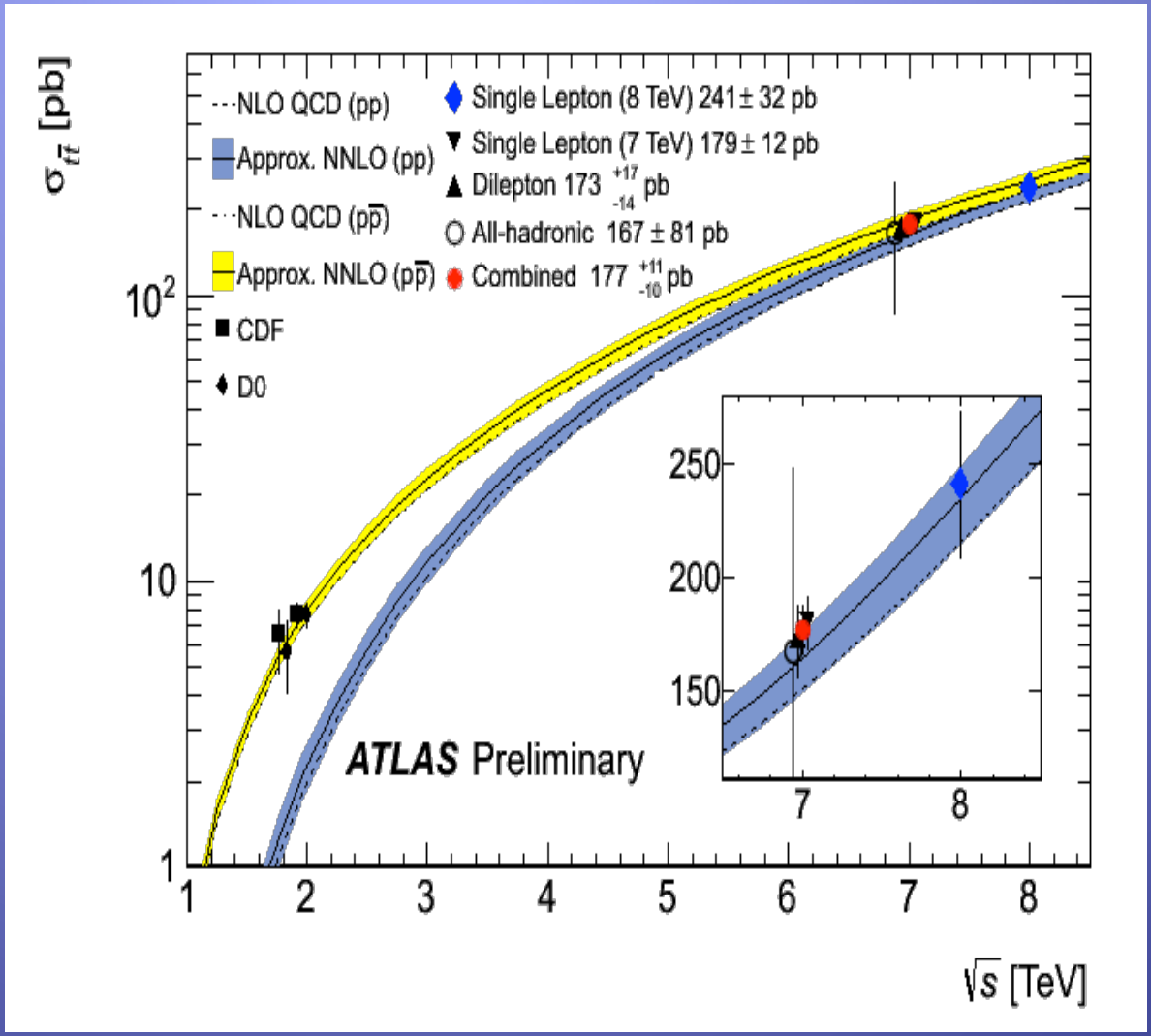


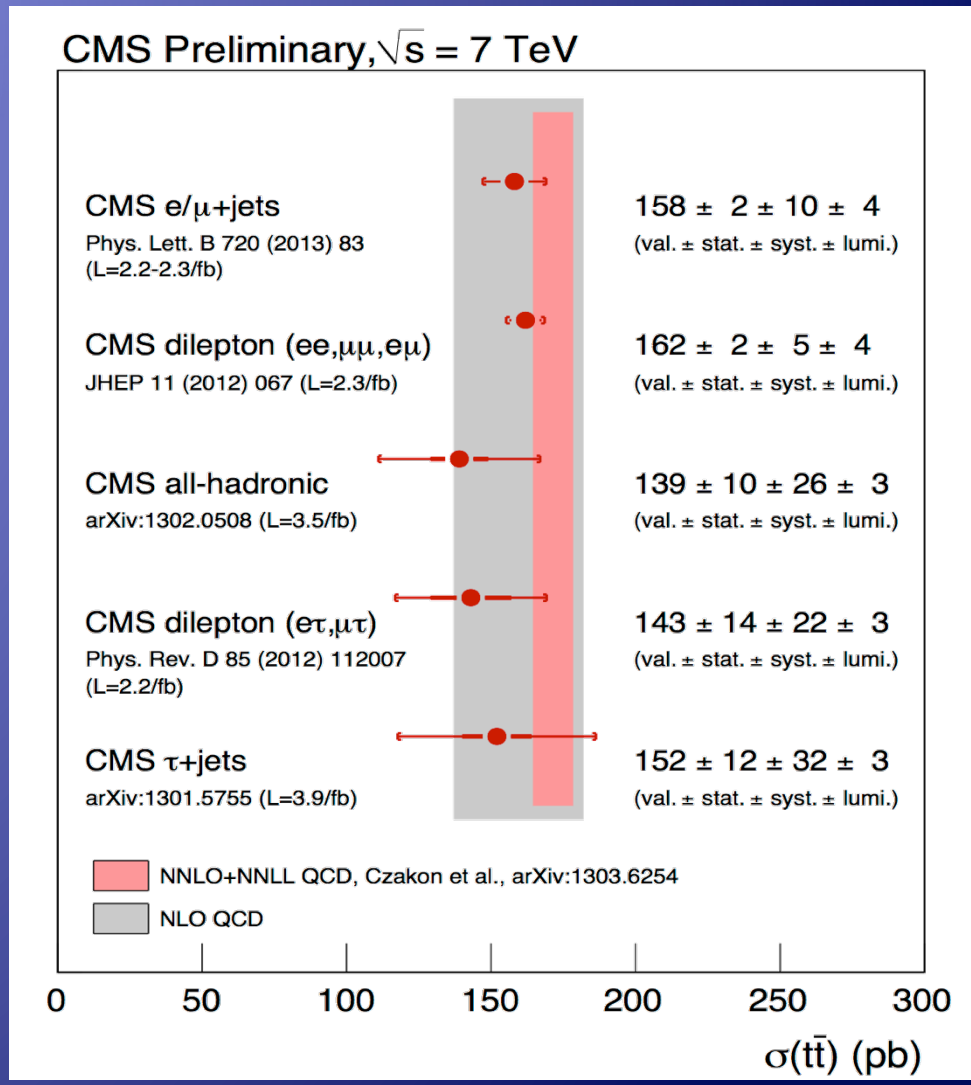


CMS PAS SMP-12-025

Top Productions

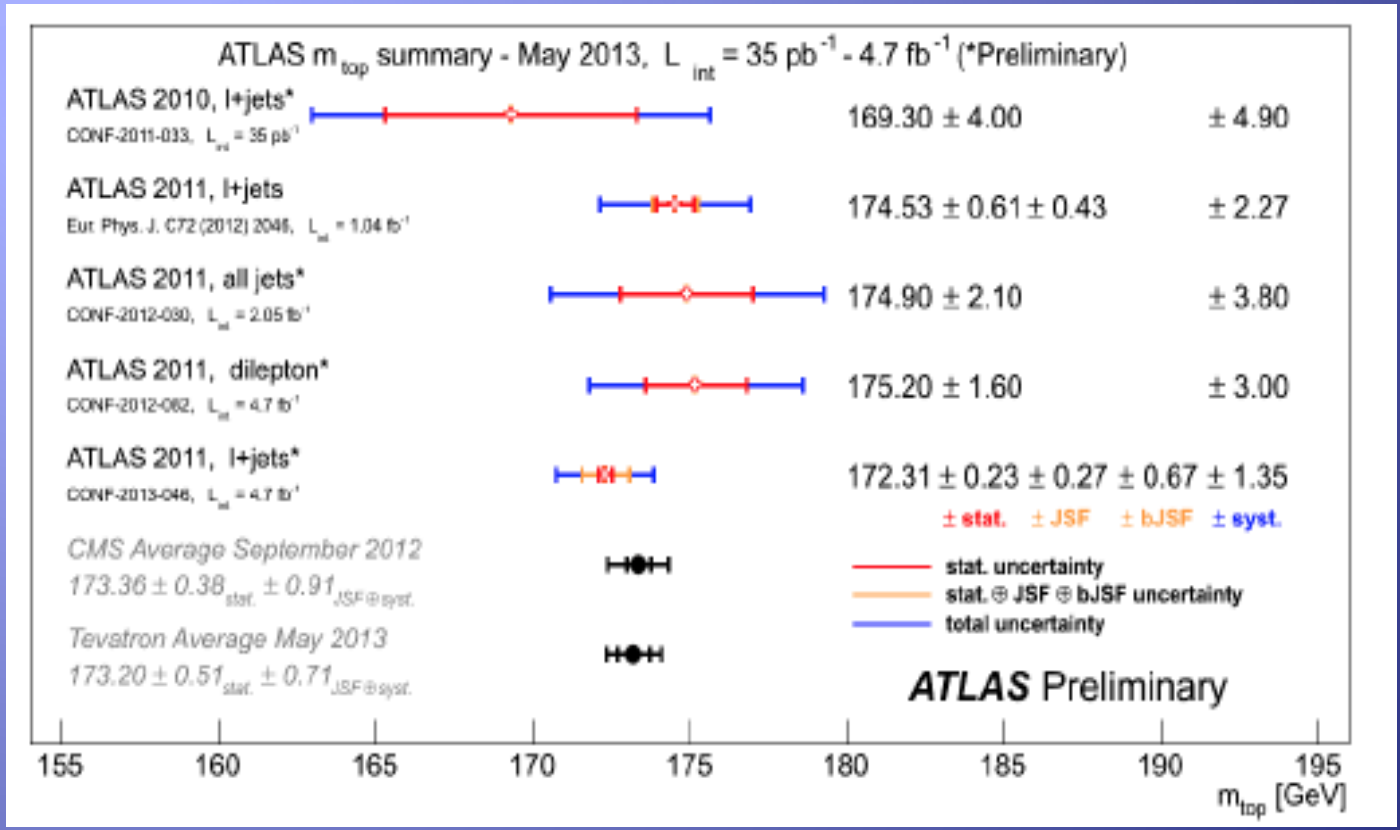
- Use multivariable techniques and b-jet identification
- 4% precision in dilepton channel





Top Mass

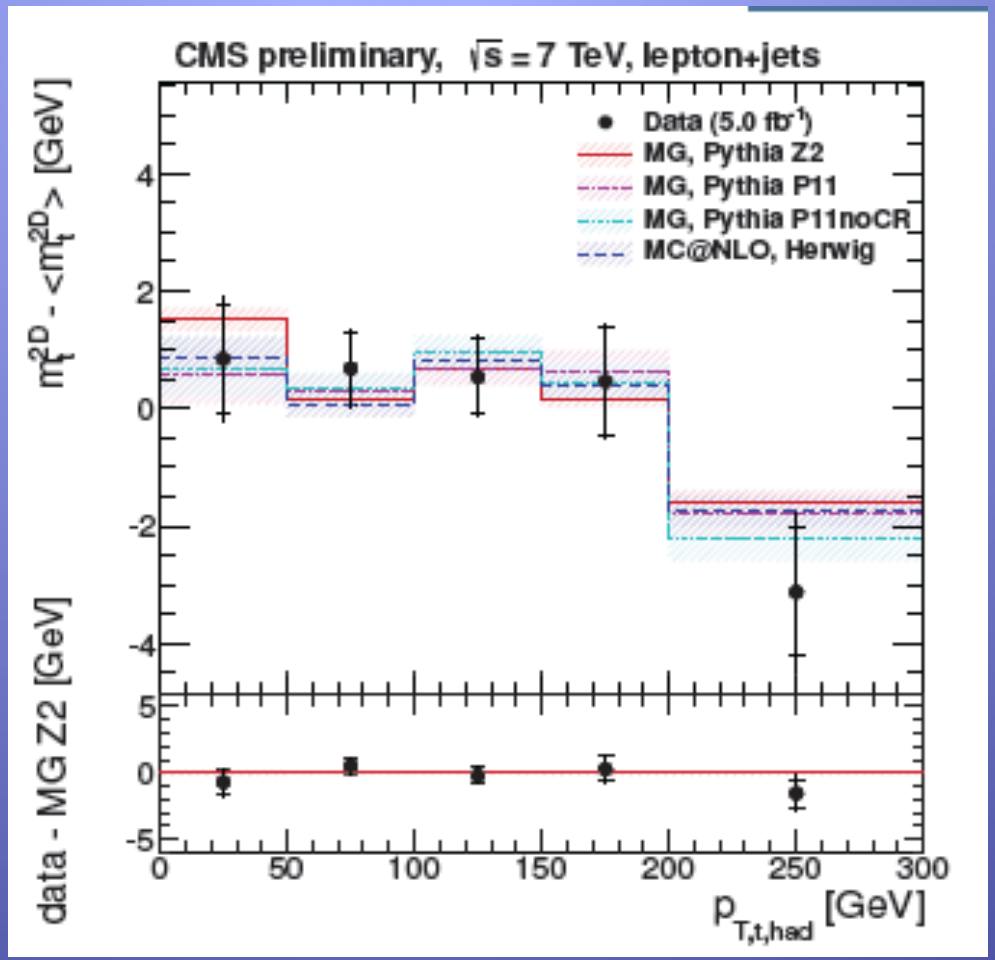
- Fundamental parameter of the SM physics (+beyond)

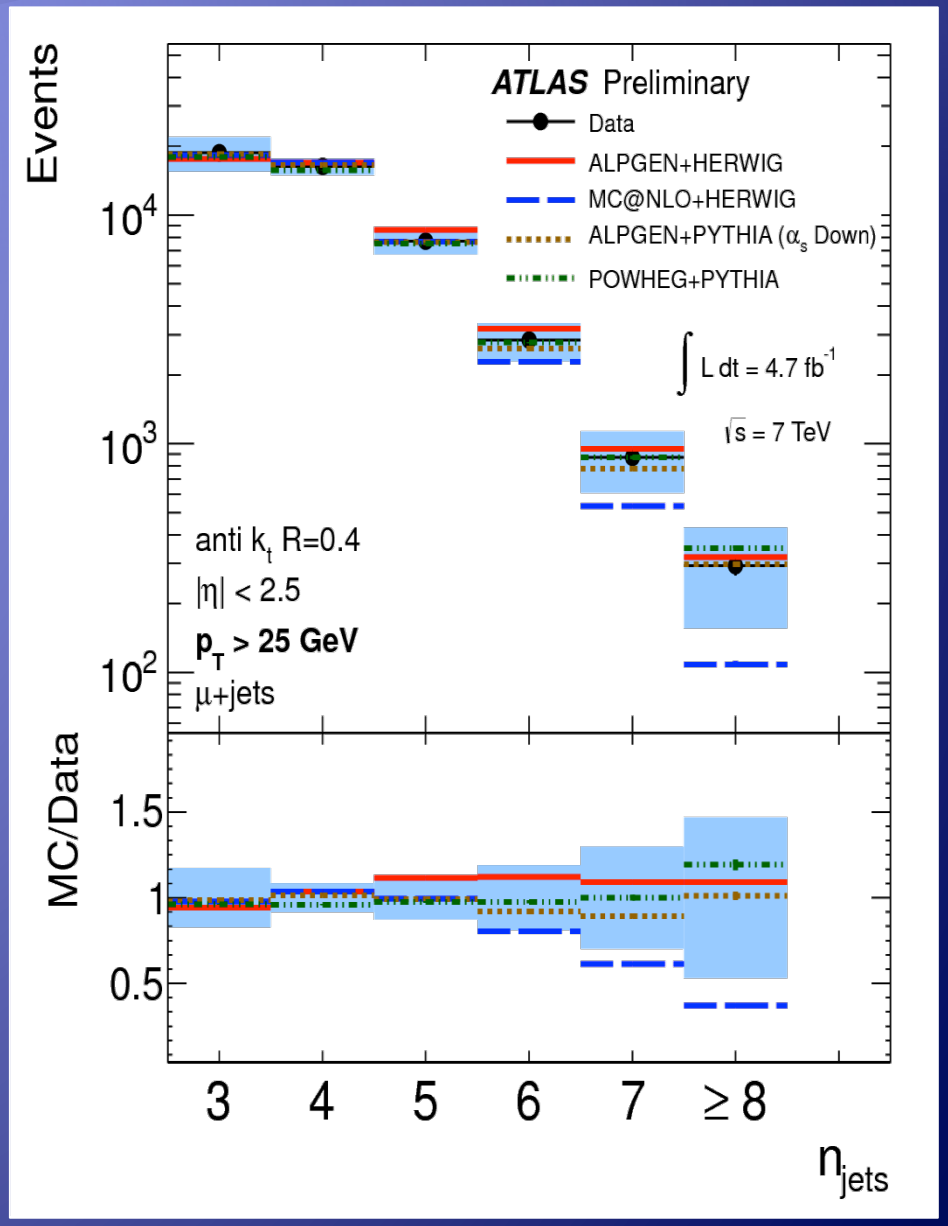


- Impressive precision: LHC (0.6%), Tevatron (0.5%); need to worry about what mass they measured

Differential Measurements

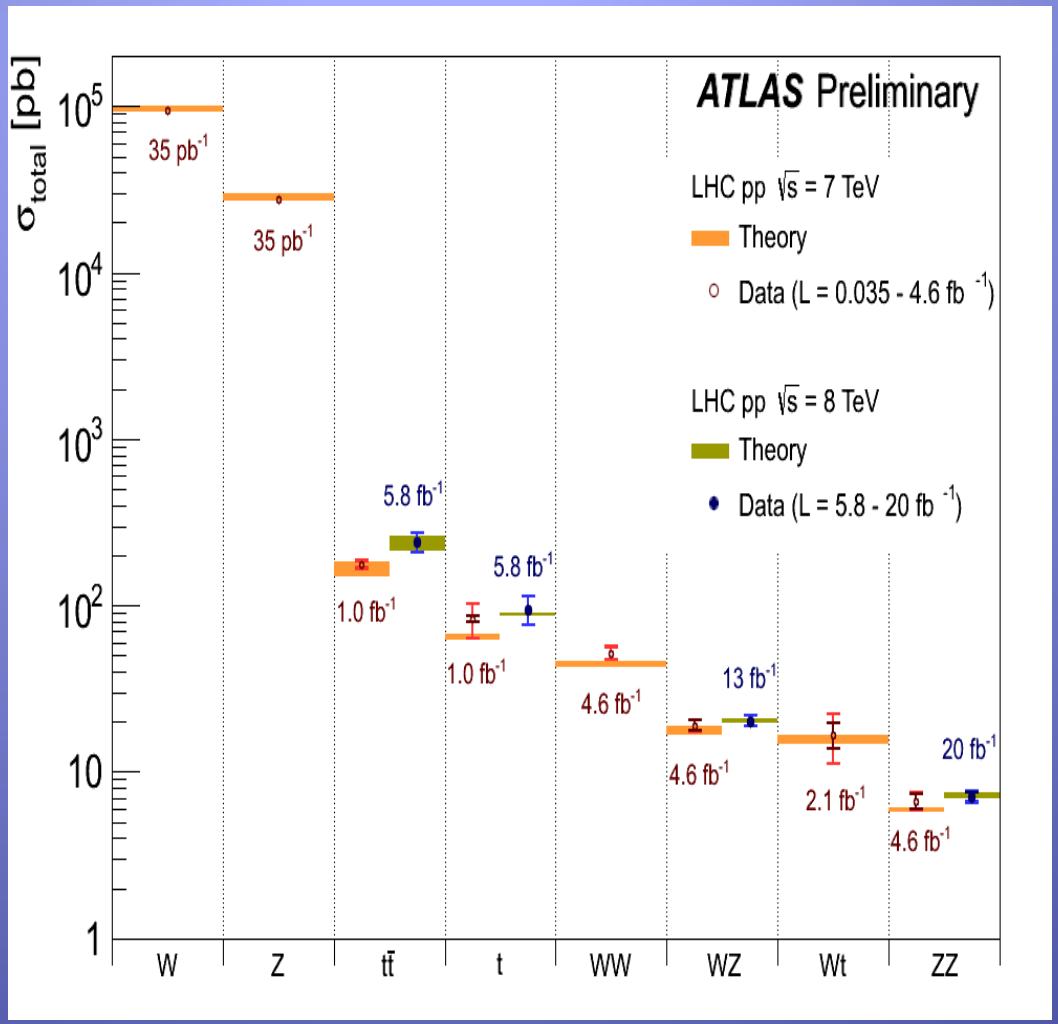
m_t - $\langle m_t \rangle$ as pt(top)

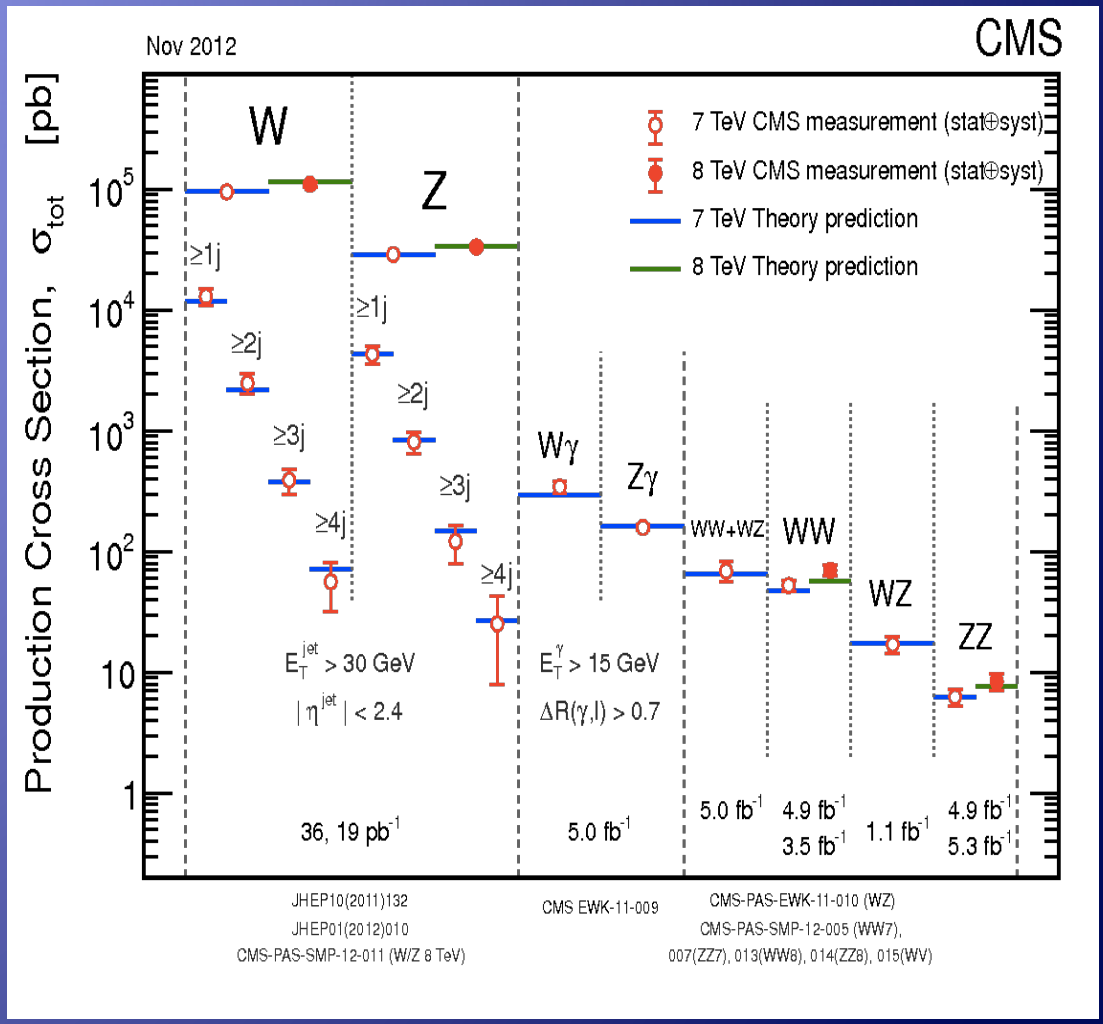




SM processes understood?

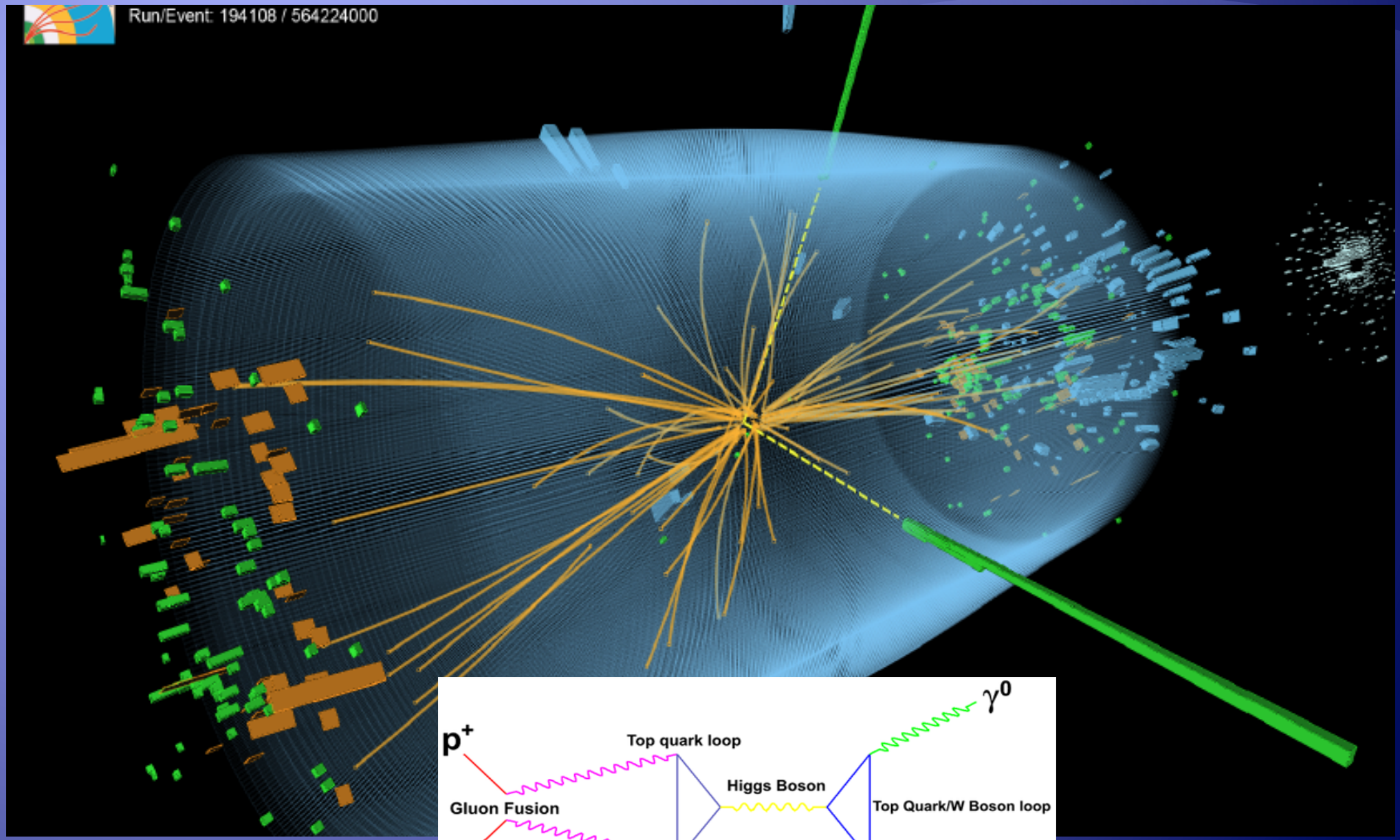
- ATLAS: Yes!!!
- CMS: Yes!!!



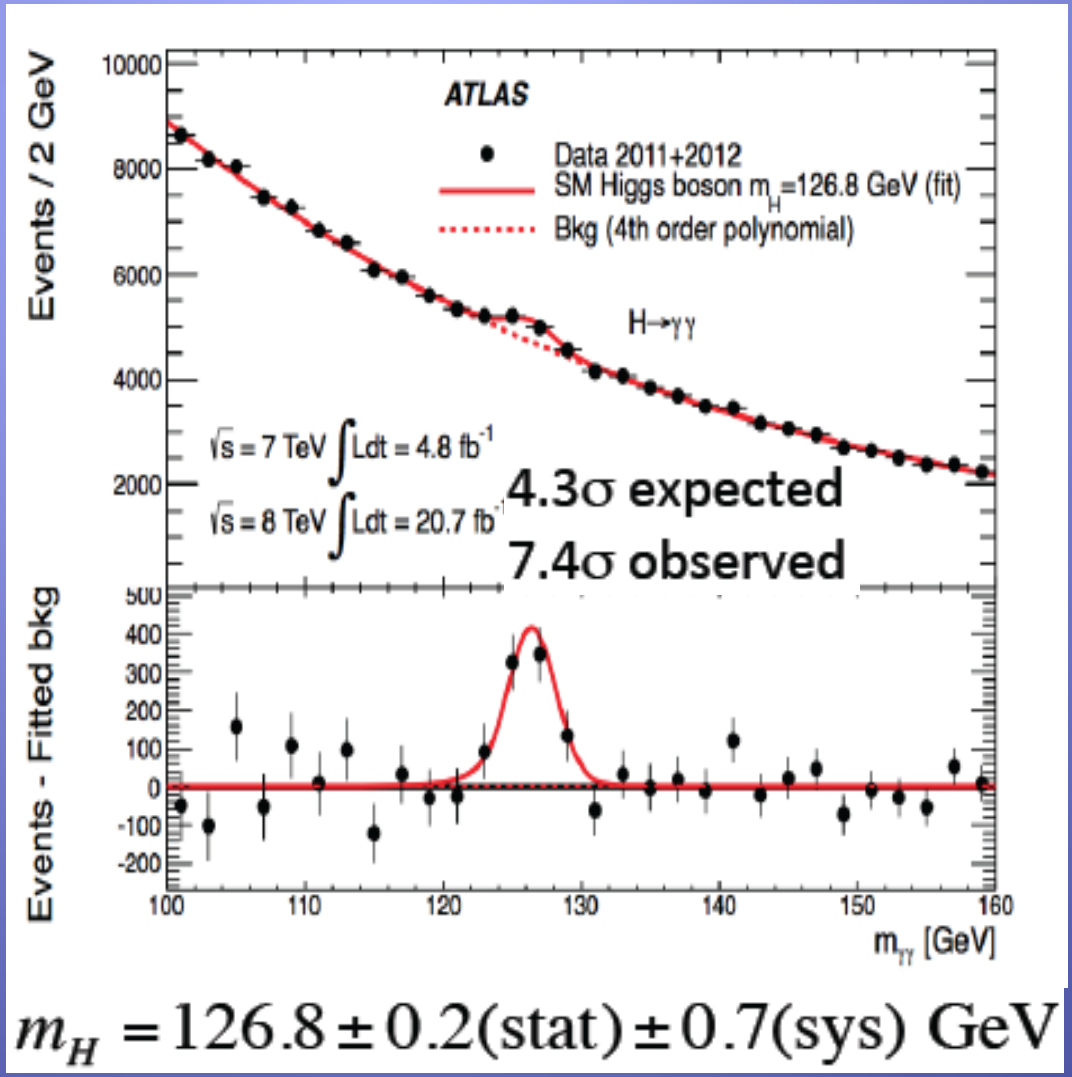


Discovery

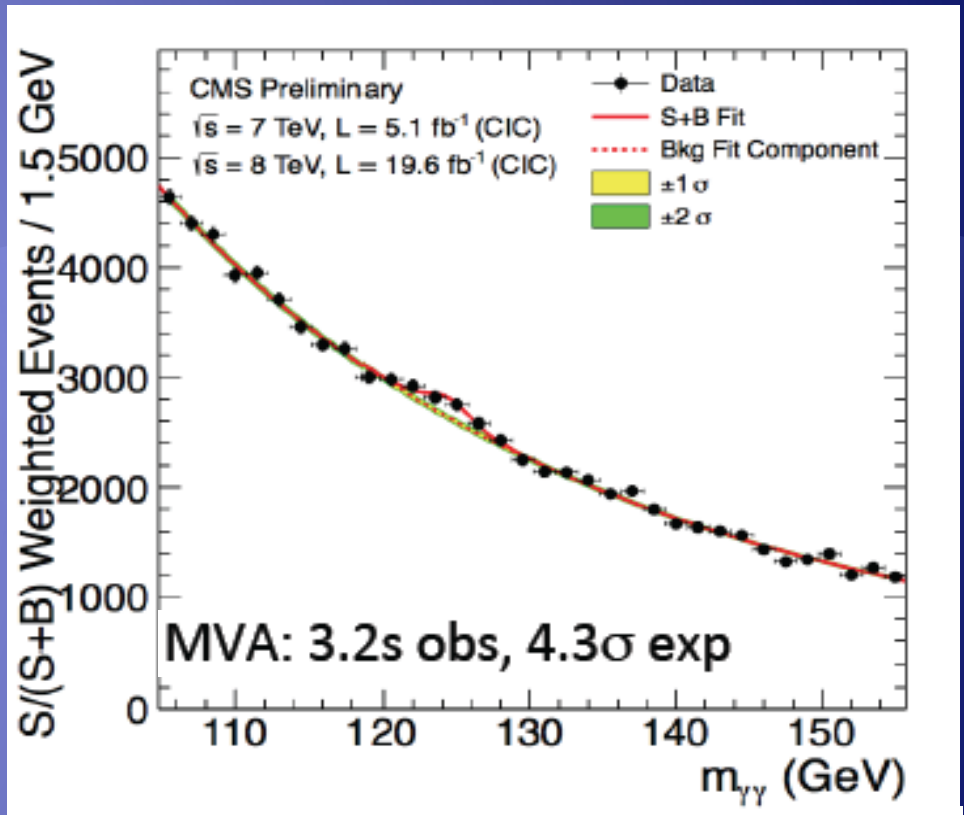
A Higgs boson Discovery

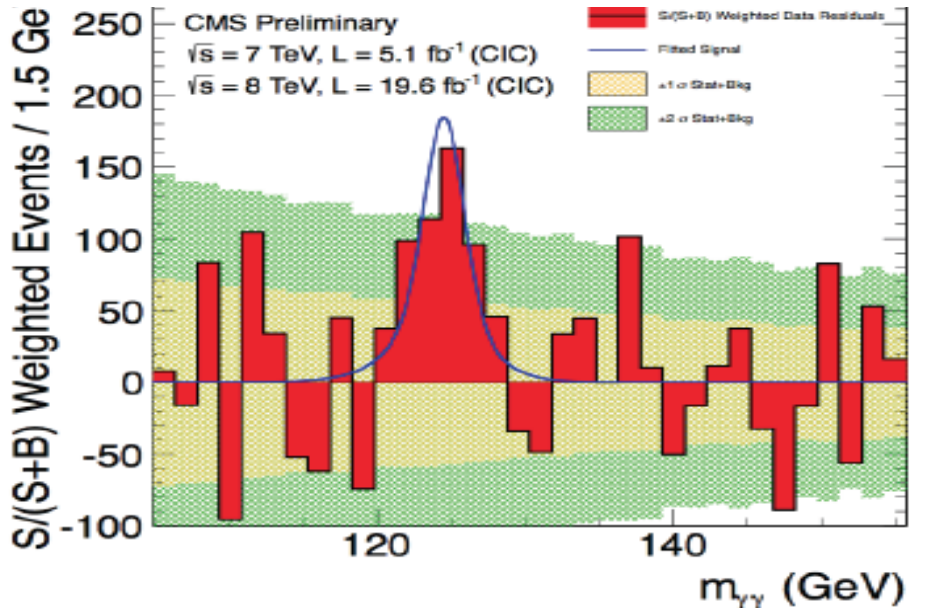


H→γγ discovery



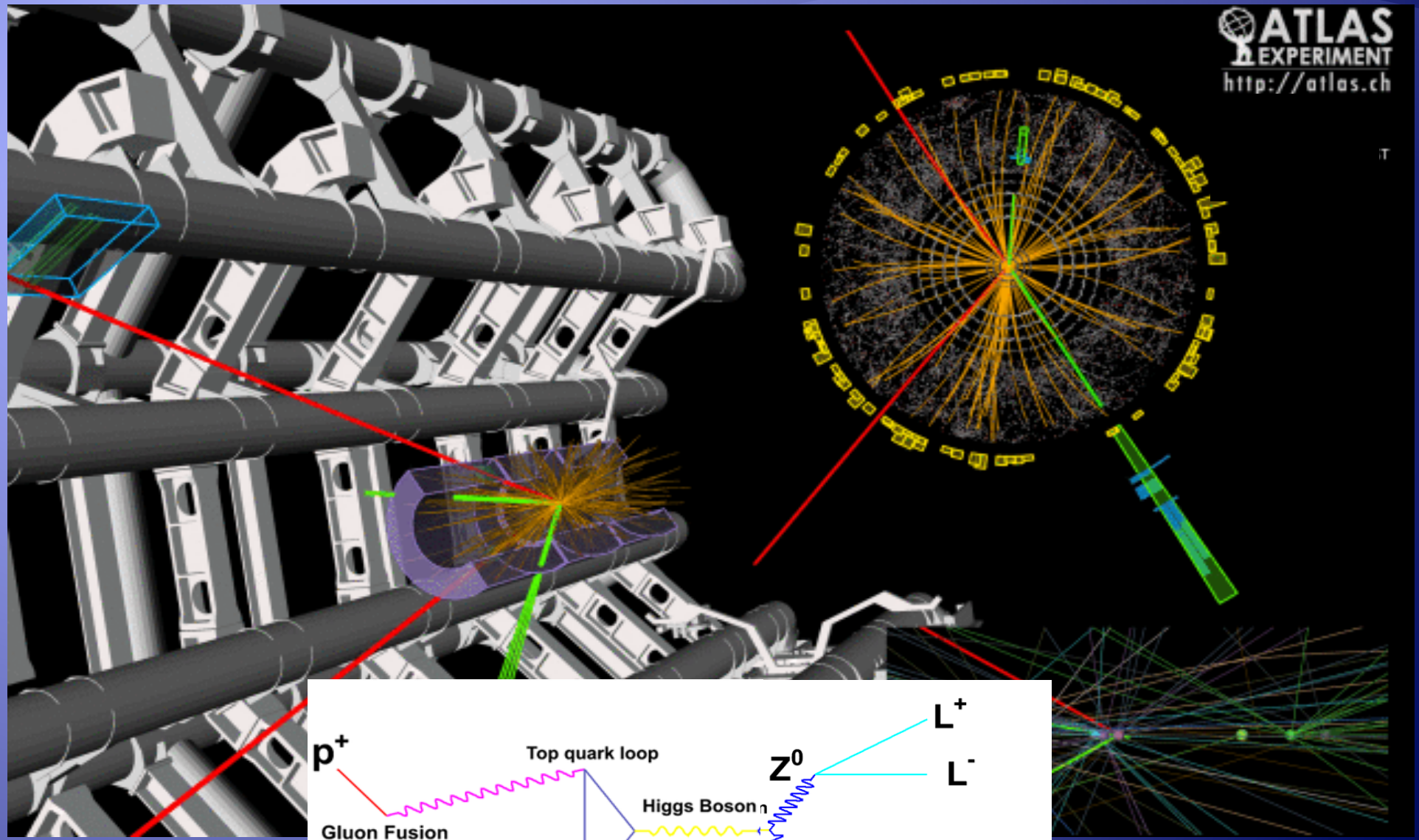
$m_H = 126.8 \pm 0.2(\text{stat}) \pm 0.7(\text{sys})$ GeV



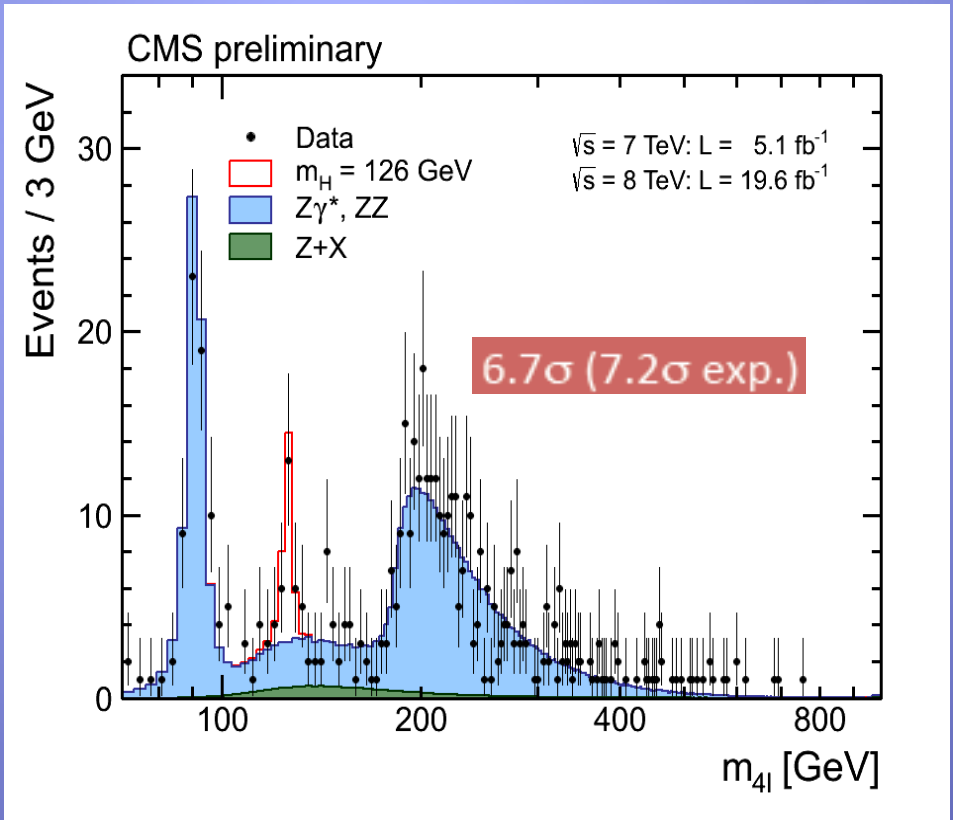


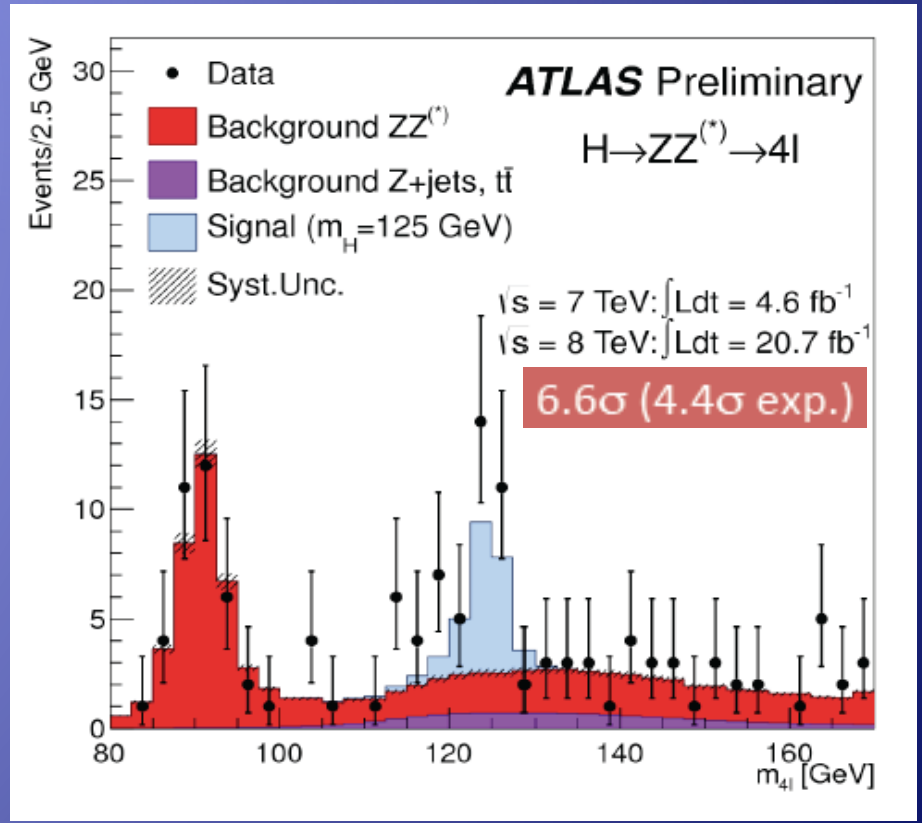
$m_H = 125.4 \pm 0.5(\text{stat}) \pm 0.6(\text{sys})$ GeV

A Higgs boson discovery



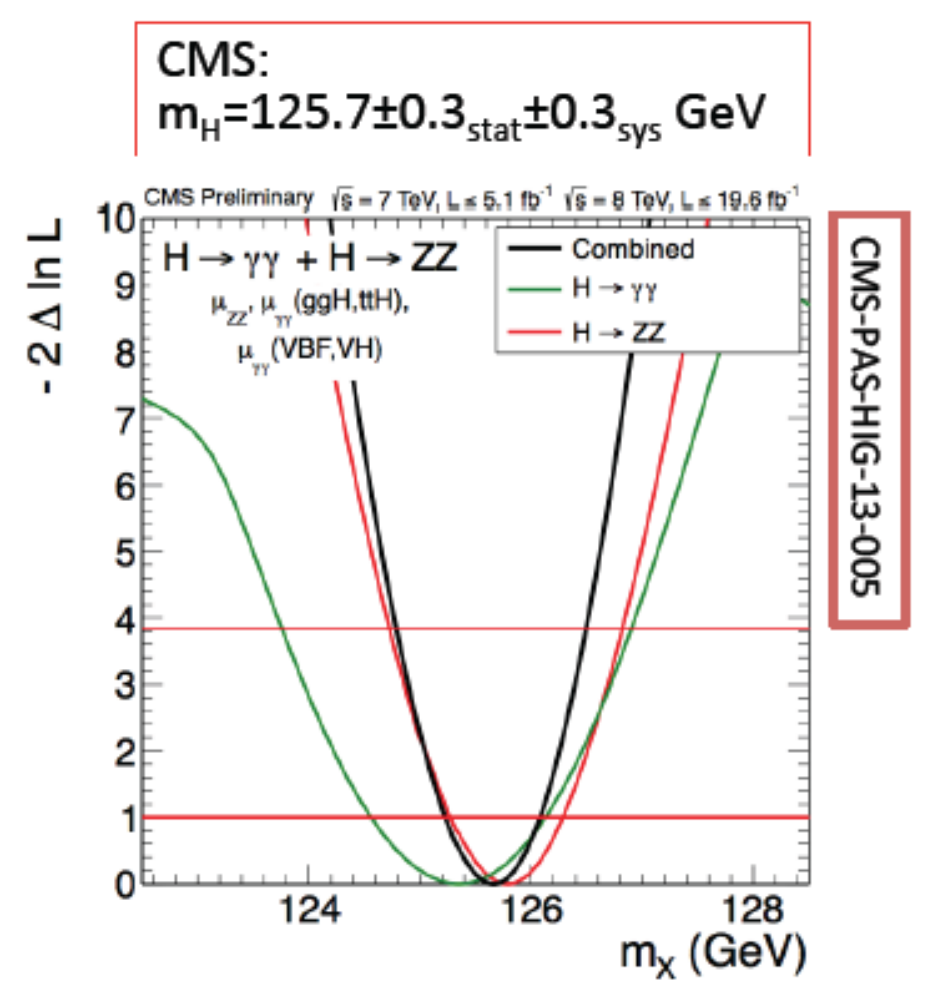
$H \rightarrow ZZ^{*} \rightarrow 4\ell$ discovery (golden channel)

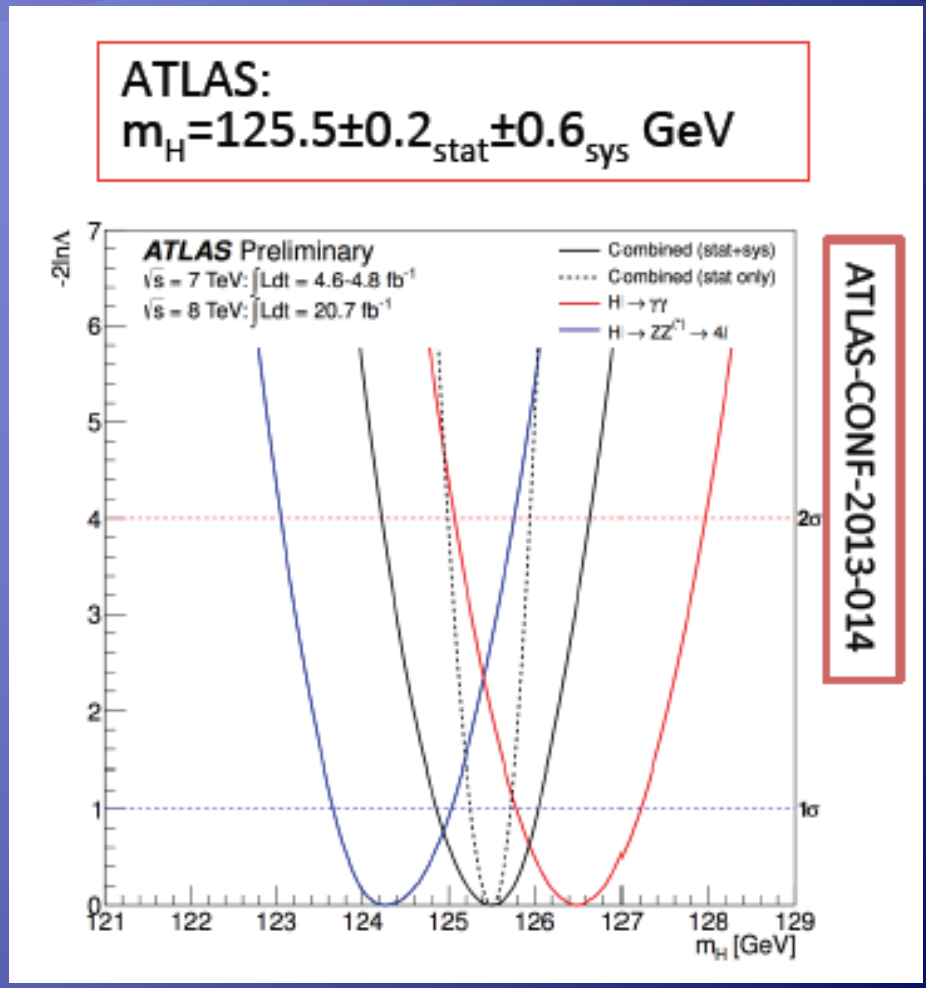




- **CMS: e,μ,τ channels : m(ll), opening angle**
- **ATLAS: e,μ channels : m(ll)**

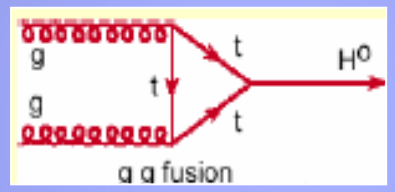
Mass Combination

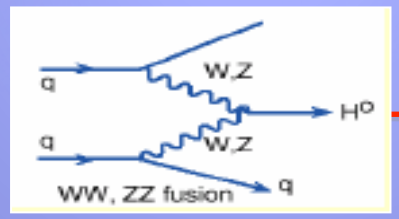


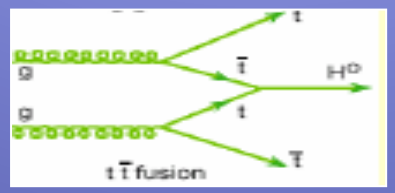


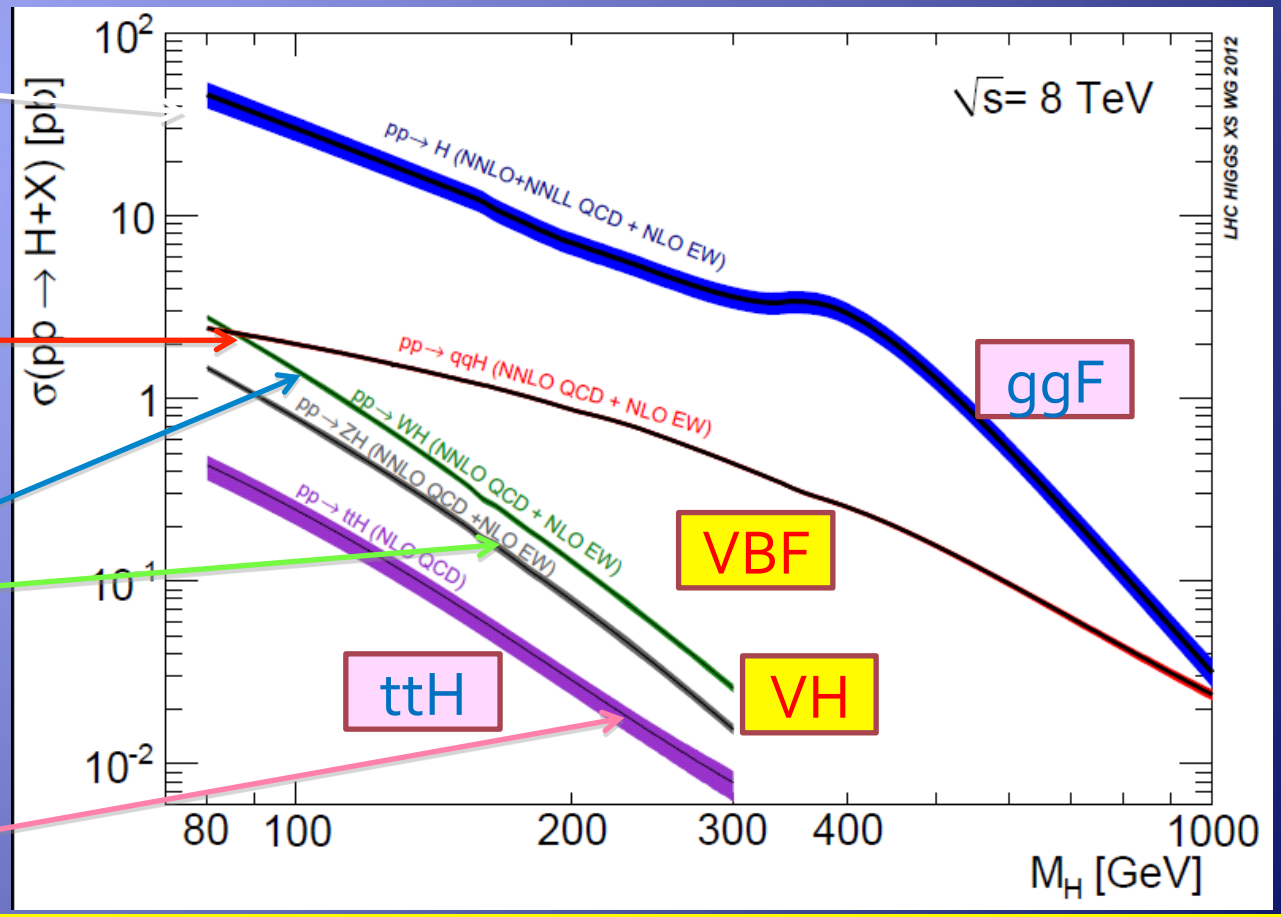
- Slight tension in ATLAS γγ and ZZ masses
- Which Higgs have we discovered?

SM Higgs productions



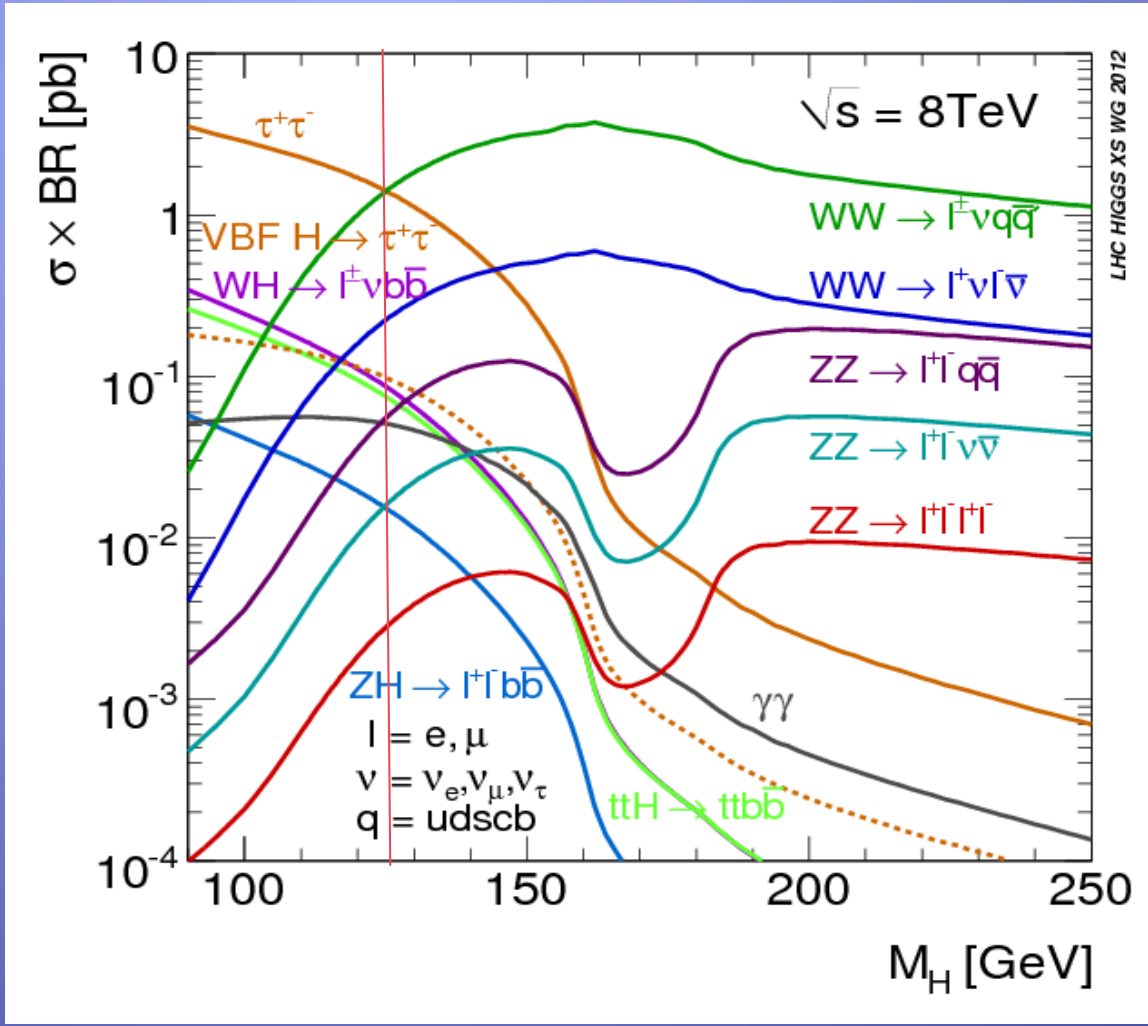






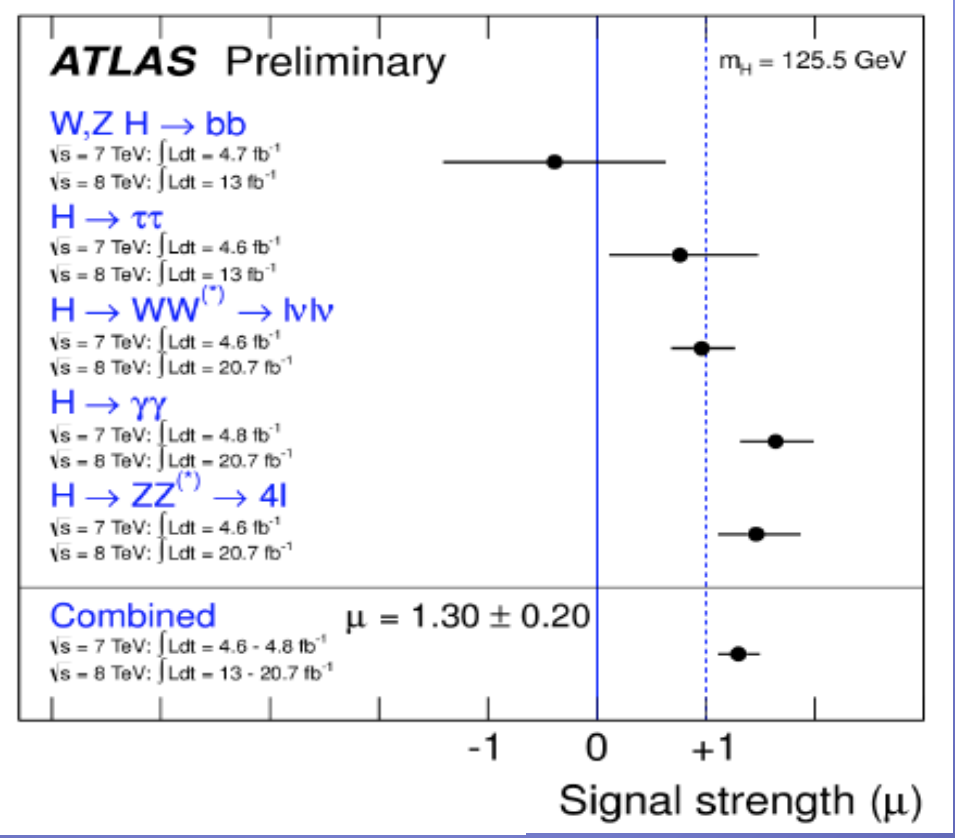
gg→H: σ =O(10) pb, gluon-gluon fusion @125 GeV
VV→H: σ =O(1) pb, vector boson fusion

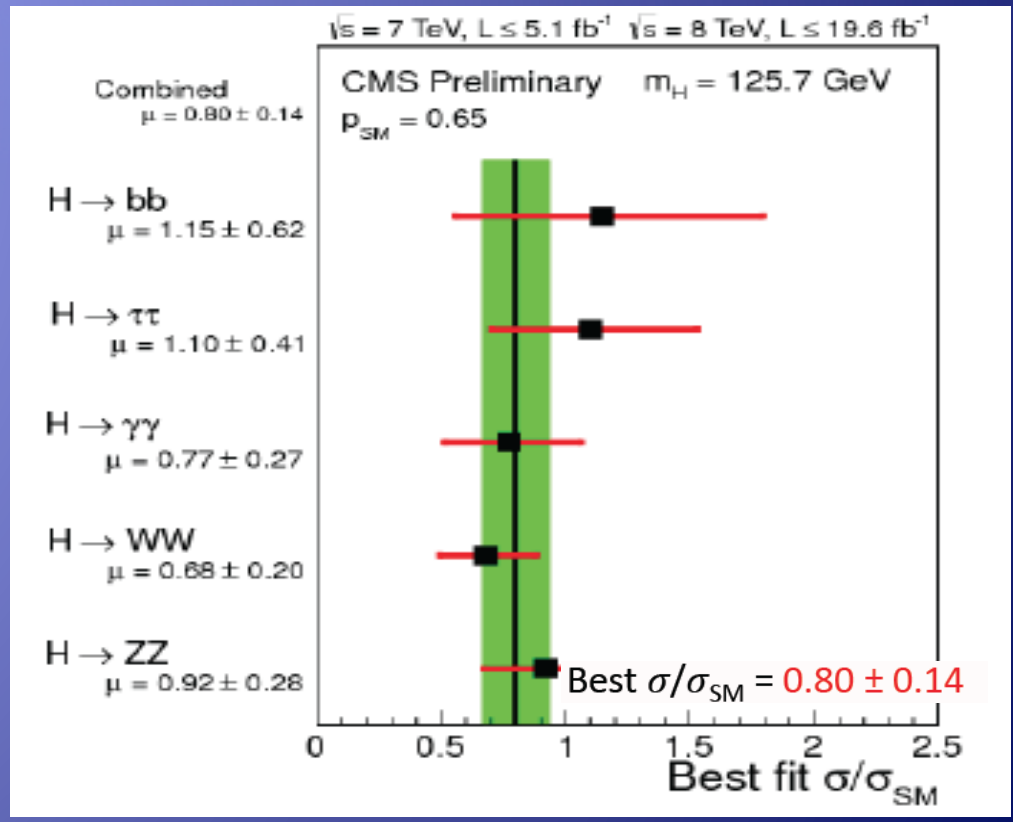
SM Higgs decays



- 1.5 pb for $\tau\tau$; very difficult
- 0.25 pb for $WW^* \rightarrow \ell\nu\ell\nu$: only m_t
- 0.1 pb for VBF $\tau\tau$, $WH \rightarrow \ell\nu bb$, $ZZ^* \rightarrow \ell\ell qq$, $\ell\ell\nu\nu$: only m_t
- 0.05 pb for $H \rightarrow \gamma\gamma$: mass: ok, but S/B<<1
- 0.003 pb $H \rightarrow ZZ^* \rightarrow 4\ell$: "gold-plate" mode
- 0.004 pb $H \rightarrow \mu\mu$: huge DY bkgds

Higgs: signal strengths

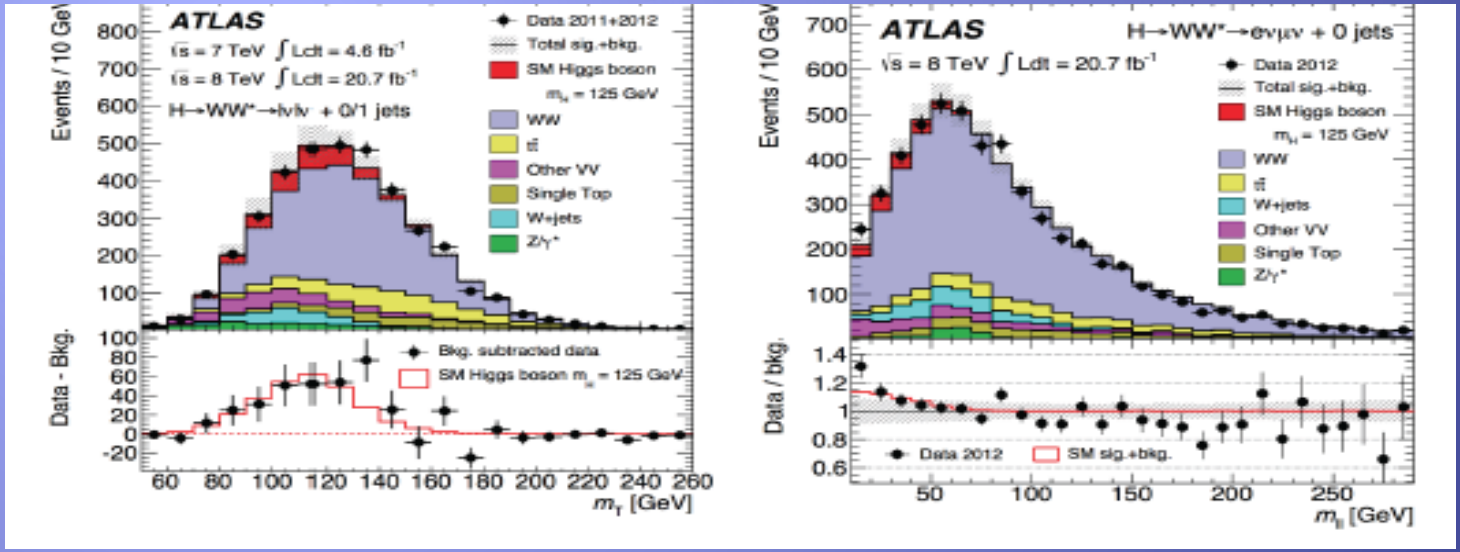




- Higgs signal strengths (to fermion and bosons) are consistent with the SM predictions

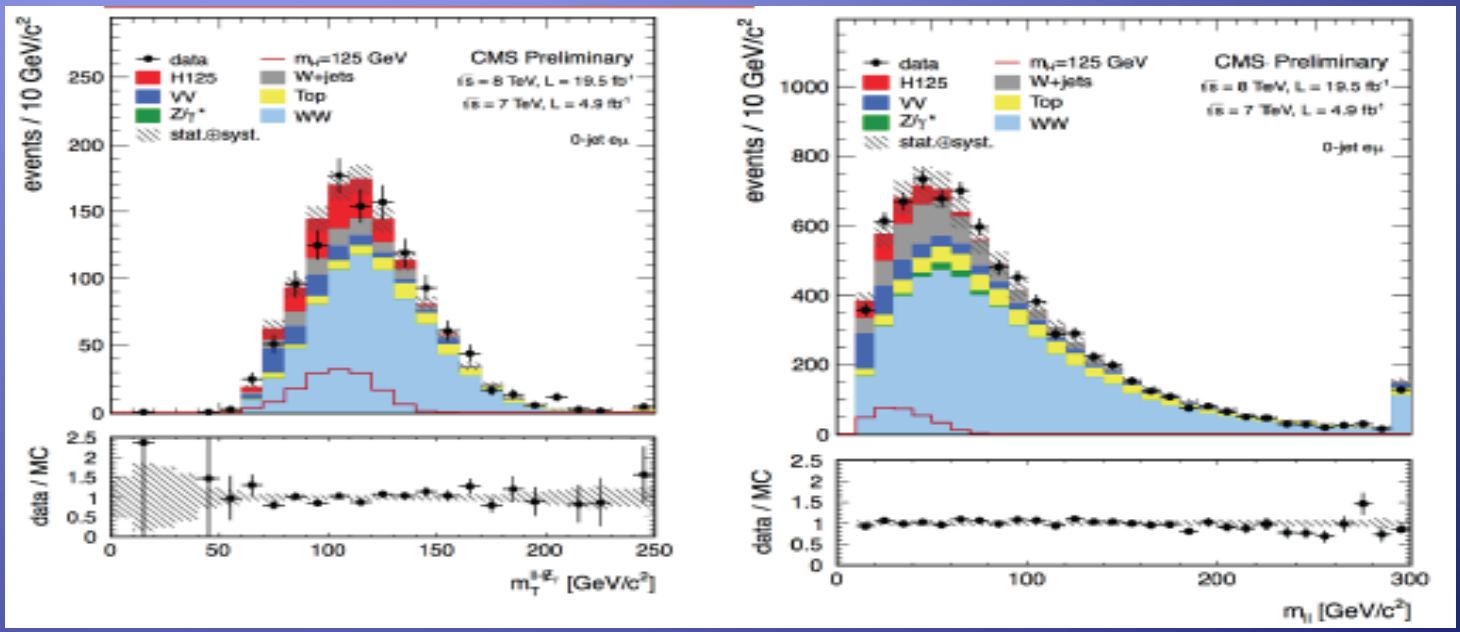
H→WW (→lνlν)

- 2 hi-pt leptons



ATLAS:use m_T

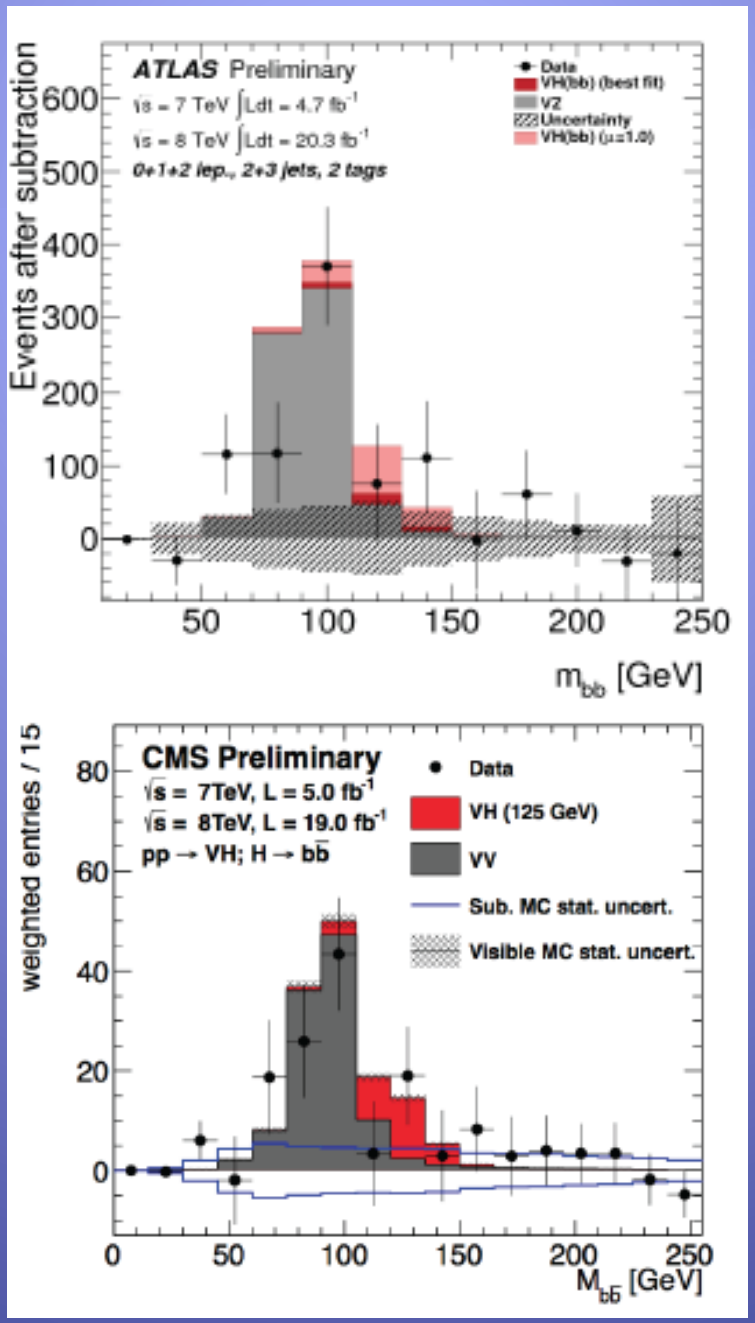
$$\mu = 0.99^{+0.31}_{-0.28}$$

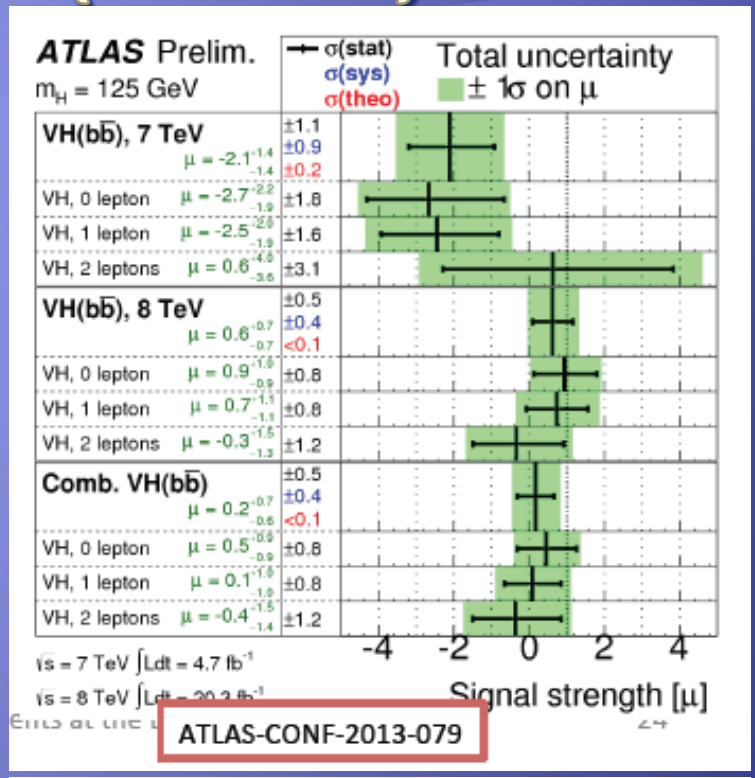


CMS:
use m_T & m(ll)

$$\mu = 0.68 \pm 0.20$$

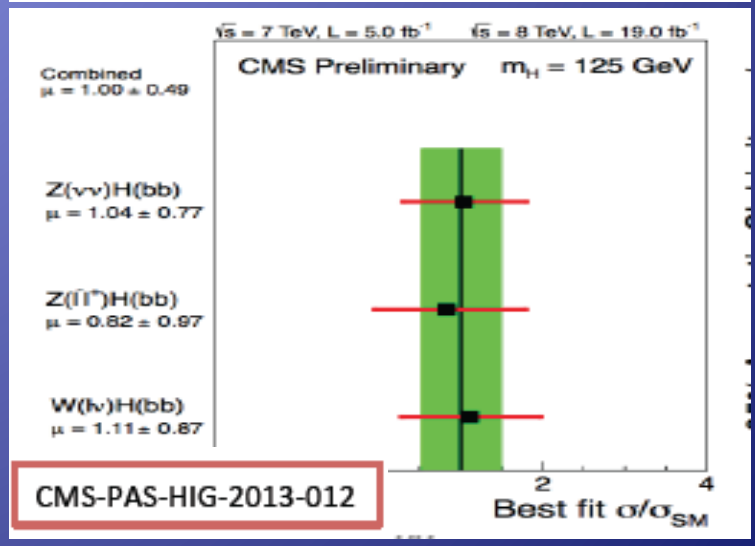
VH(→bb)





ATLAS-CONF-2013-079

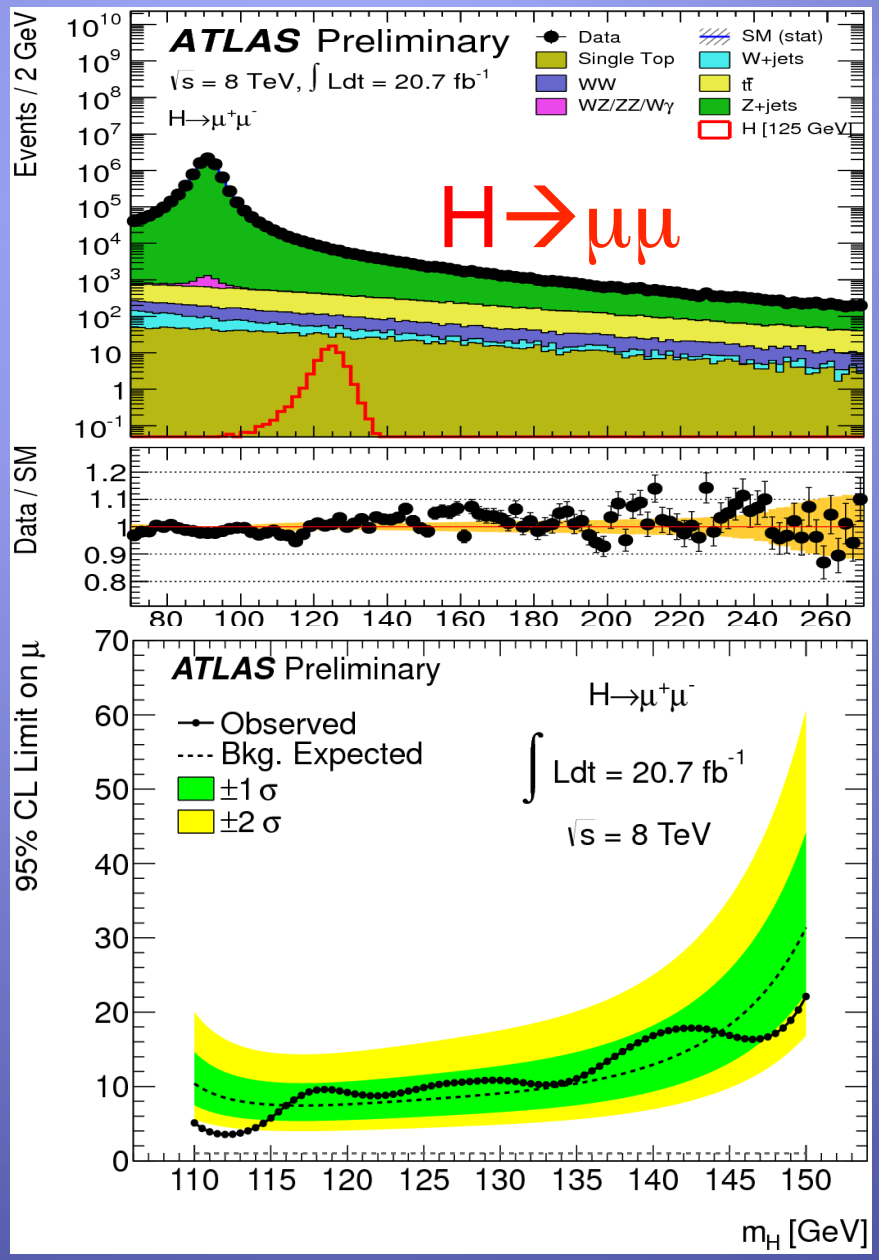
$$\mu = 0.2^{+0.7}_{-0.6}$$

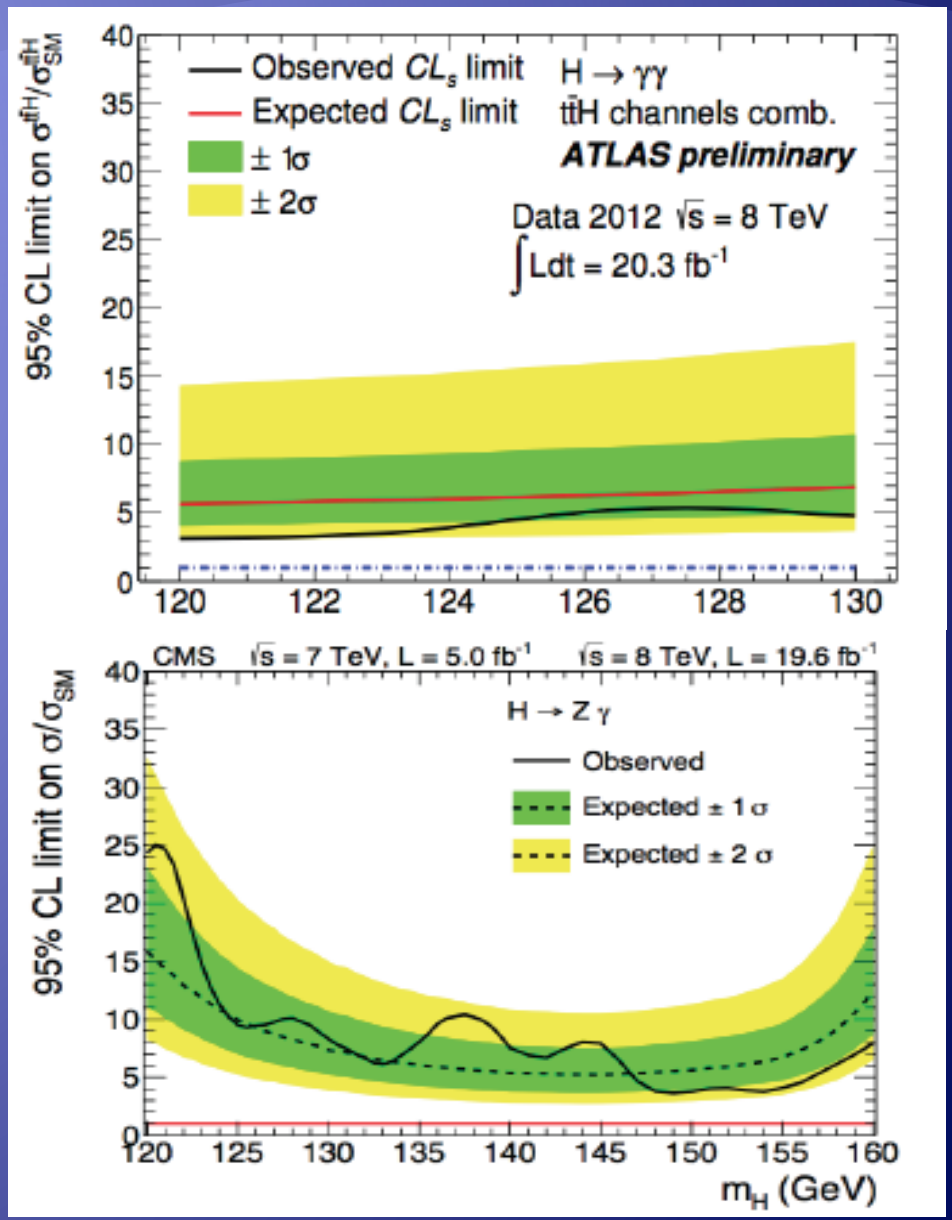


CMS-PAS-HIG-2013-012

$$\mu = 1.0 \pm 0.5$$

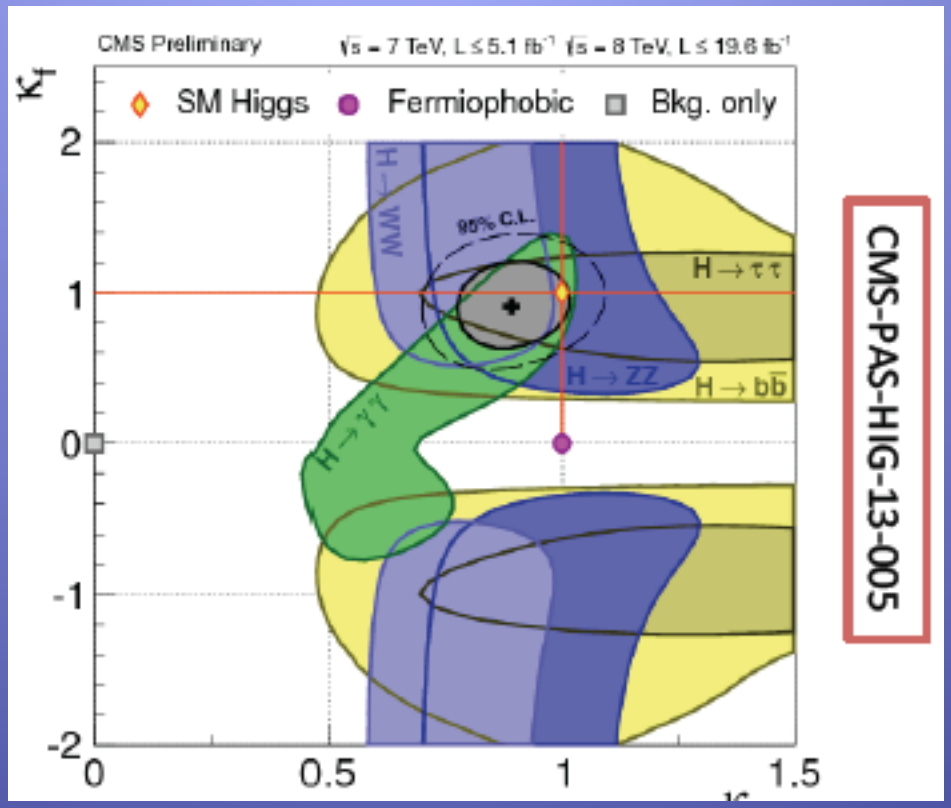
Other Higgs decays

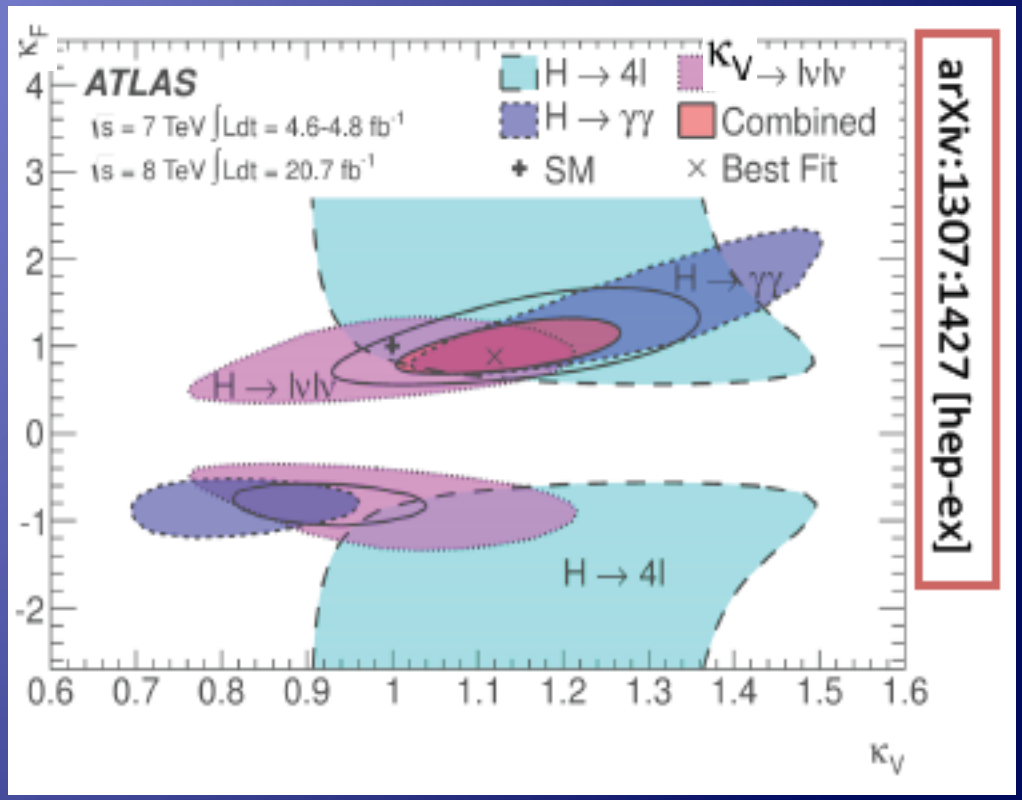




Higgs Couplings

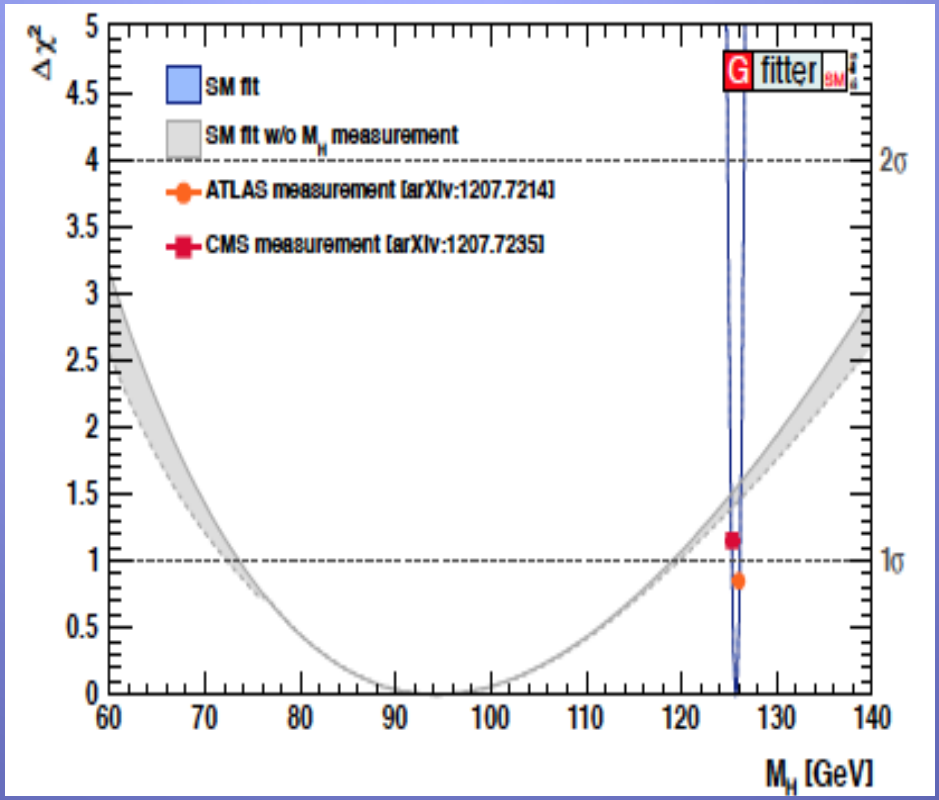
- ATLAS and CMS are compatible with the SM at the 10% level
- Assumption:
  - One Higgs resonance with narrow width
  - 2-parameter bench-mark model with only fermion (κ_F) and vector coupling (κ_V) modifiers

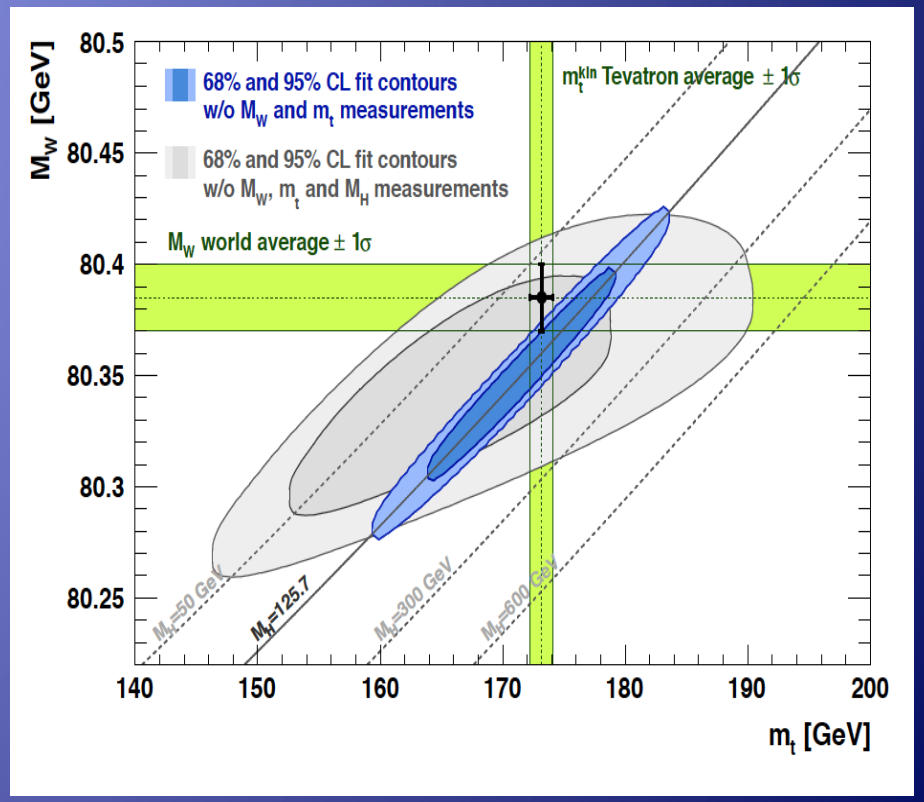




Higgs, top, W masses

- Consistency of the precise electroweak data (W, top masses) against Higgs mass





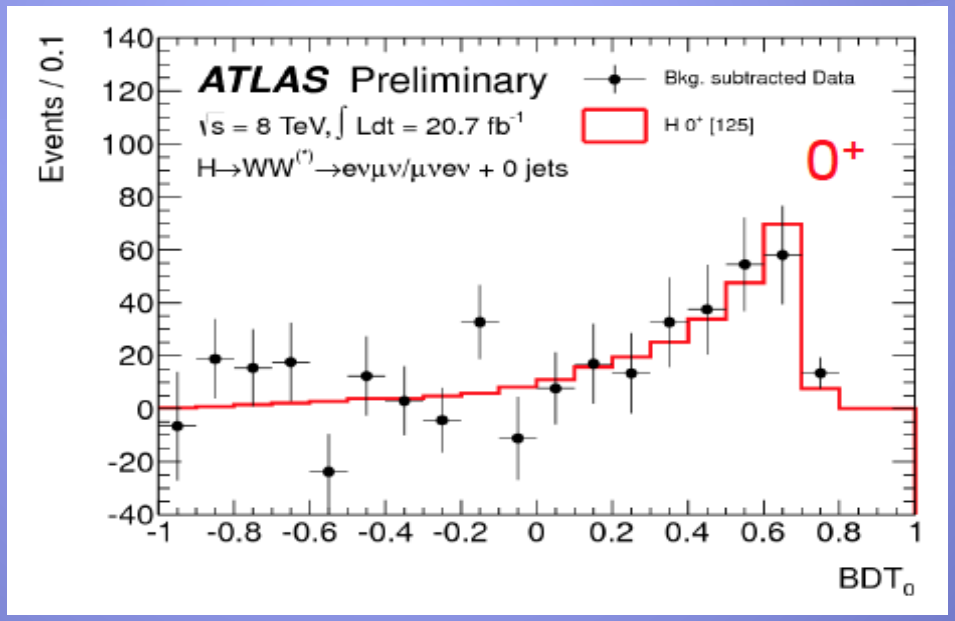
$m_H = 94^{+25}_{-22}$ GeV (indirect) from the EWK fit; consistent within 1.3σ

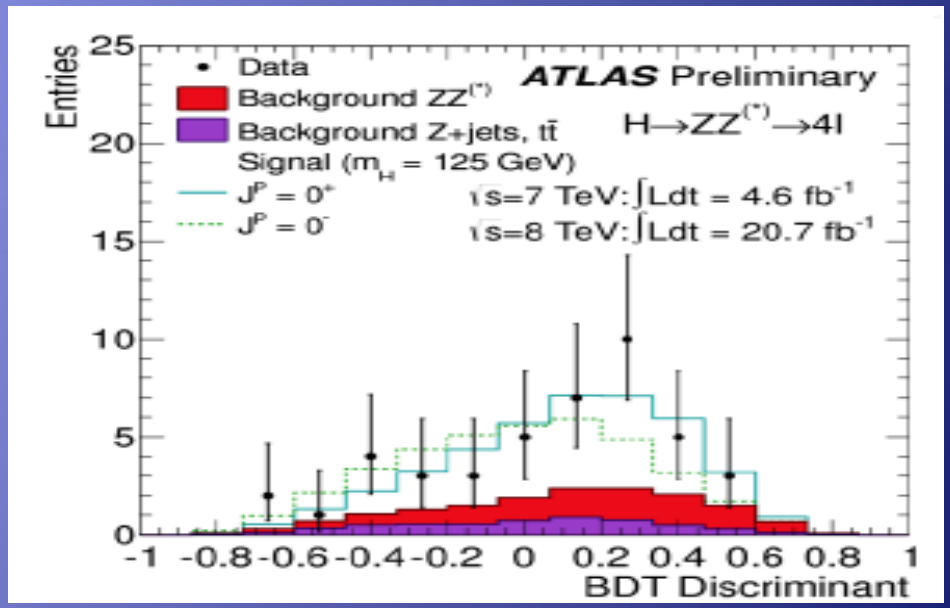
$m_t = 173.2 \pm 0.9$ GeV (direct) from Tevatron

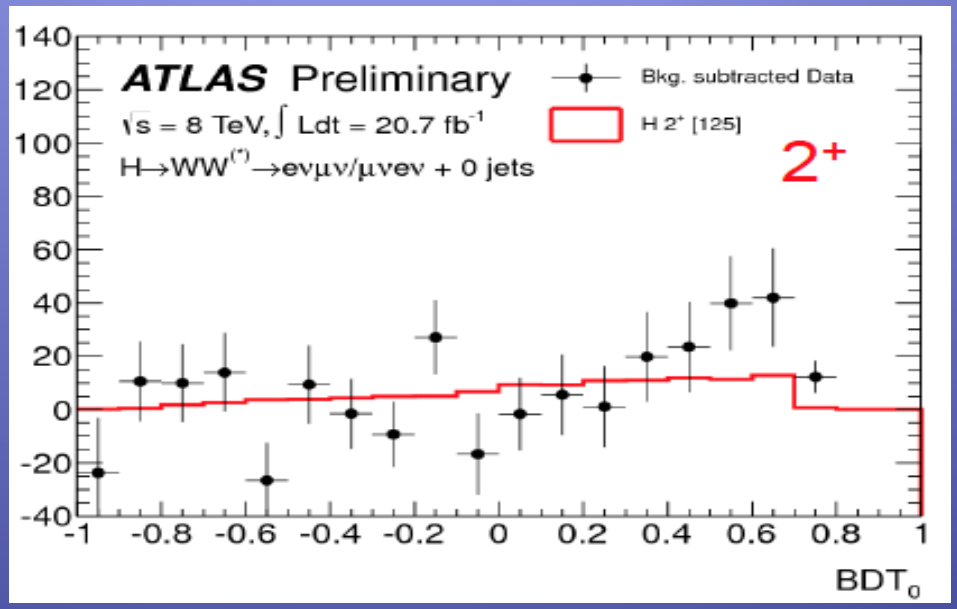
$= 175.8^{+2.7}_{-2.4}$ GeV (indirect) fromt the EWK fit

LHC : 173.2 ± 1.0 GeV (direct)

Higgs Spin



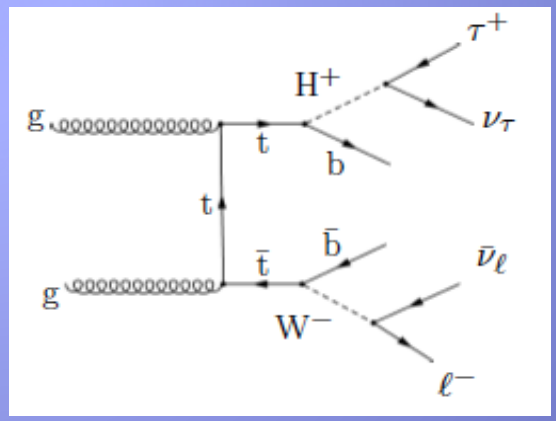


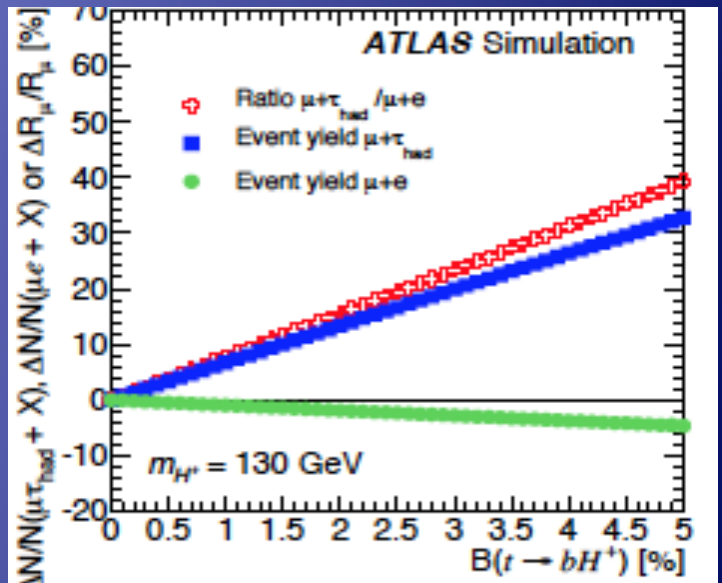


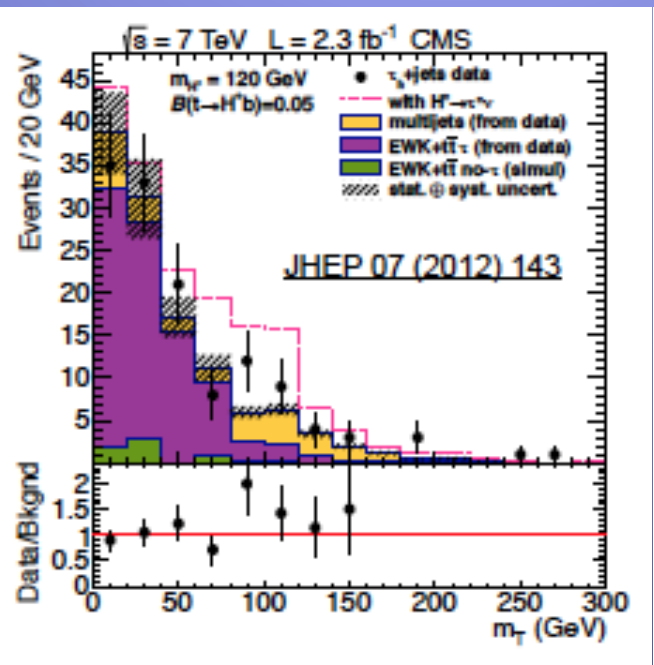
- Combined channels using $H \to WW^* \to e\nu\mu\nu$, $H \to ZZ^* \to 4l$, $H \to \gamma\gamma$, almost full statistics
  - Data strongly favor the $J^P = 0^+$ hypothesis
  - $J^P = 2^+$ hypothesis is excluded with CL>99.9%

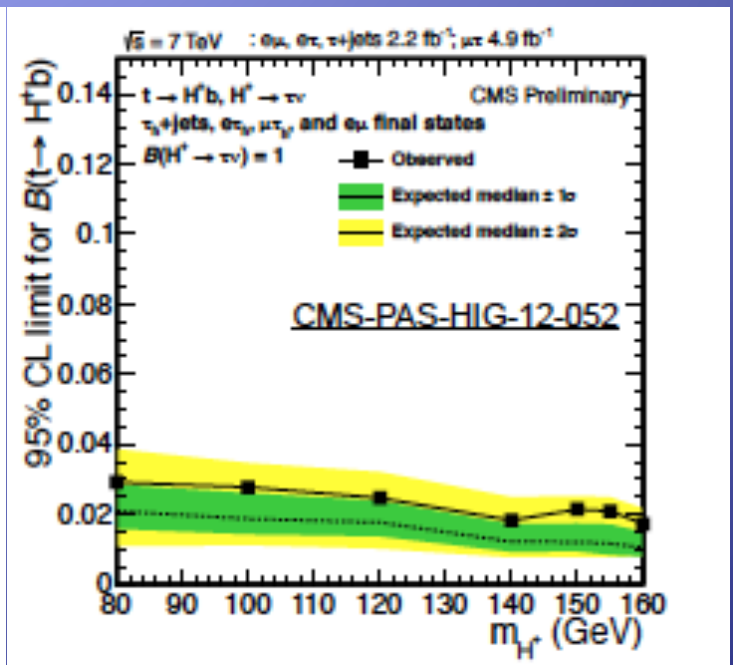
Searches for Charged Higgs

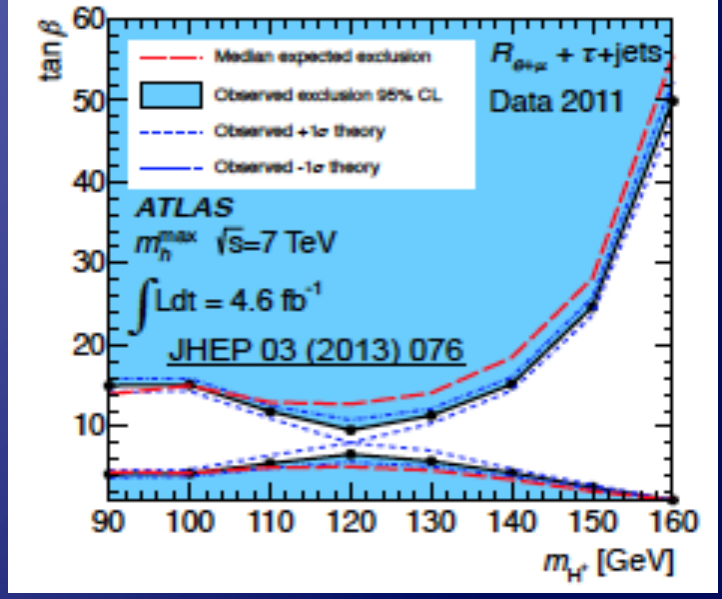
- $H^{\pm}$ (H^0, h^0, A^0, $H^{\pm}$) is predicted by the Beyond SM
- Searches for $H^+ \rightarrow \tau\nu$ in ttbar events





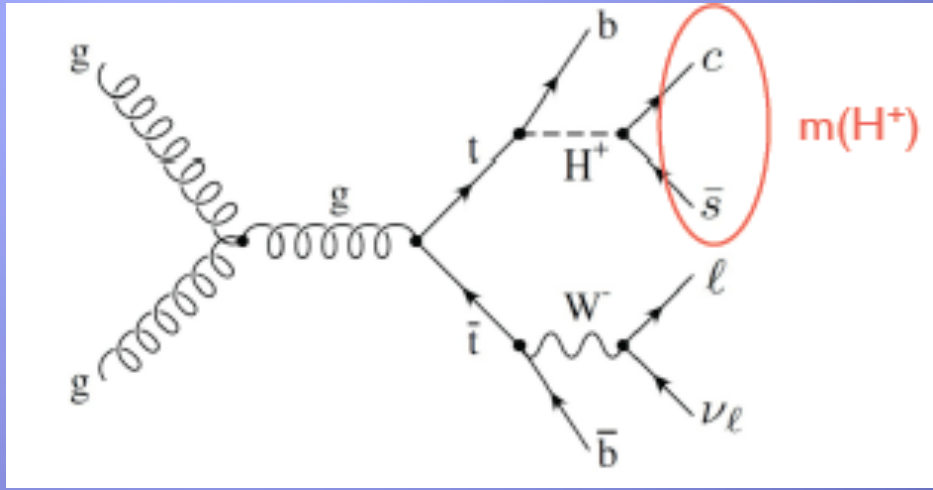


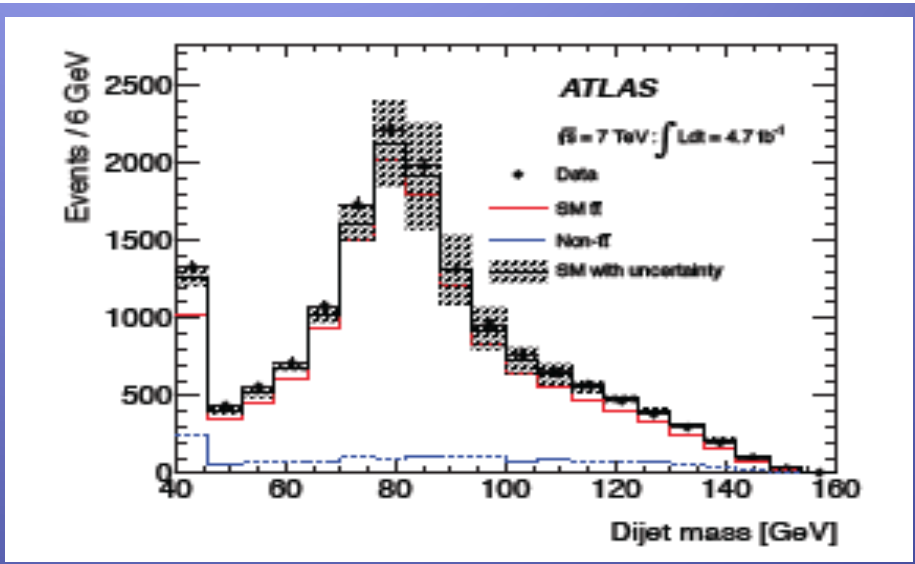


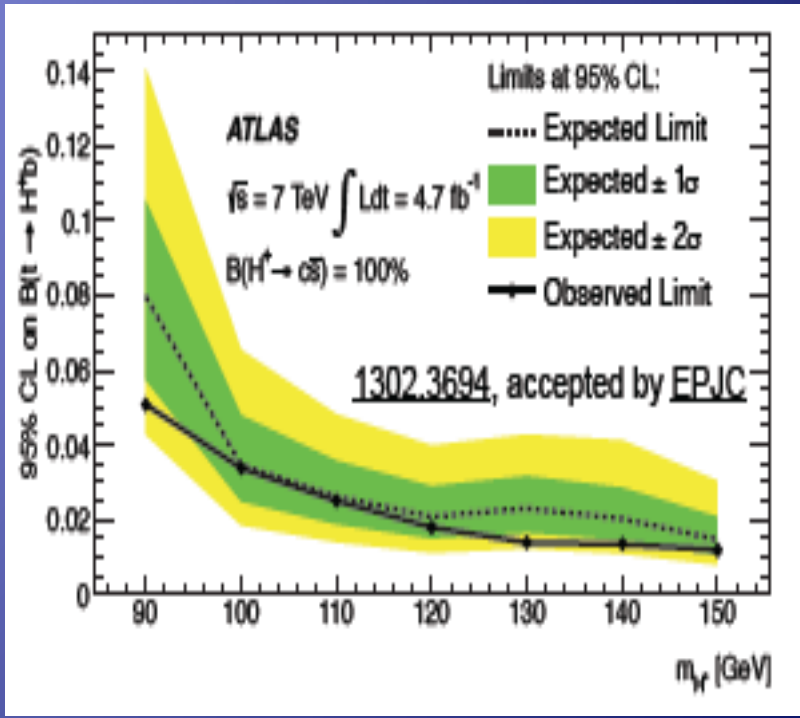


Searches for Charged Higgs

- Searches for $H^+ \rightarrow cs$: look for a second peak in m(jj)







Higgs Summary

- Experiments transited from discovery to precision phase
- First measurements of the new boson couplings (boson and fermion) are all in agreement with SM predictions
- Different spin/parity hypotheses were tested and the SM-predicted hypothesis, 0^+ , has strong preference
- More data needed to determine the Yukawa couplings in the quark and lepton sectors (especially, ttH, H($\mu\mu$)), and to search for BSM Higgs

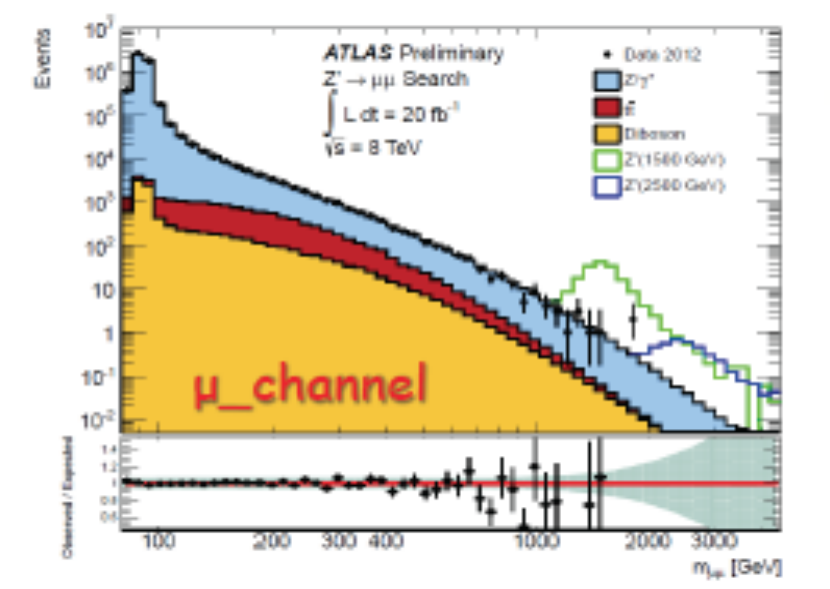
Searches

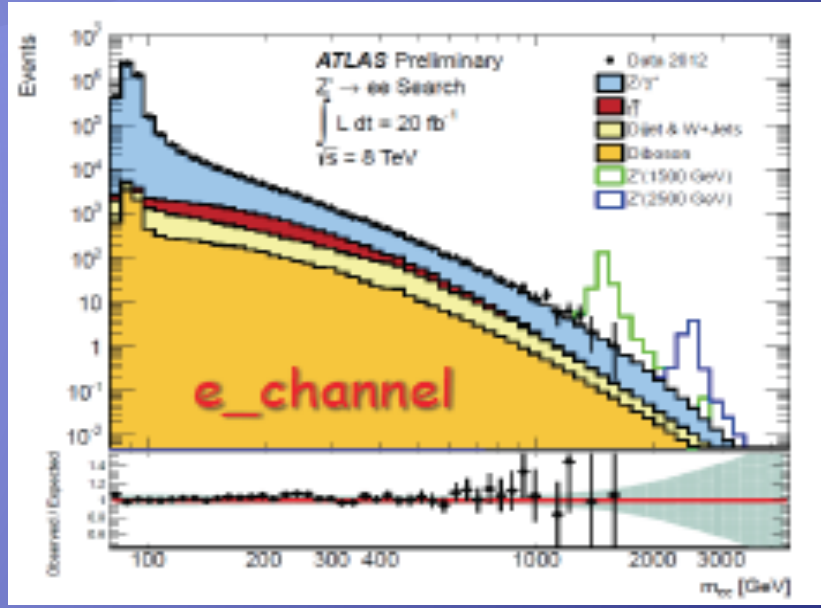
Exotics

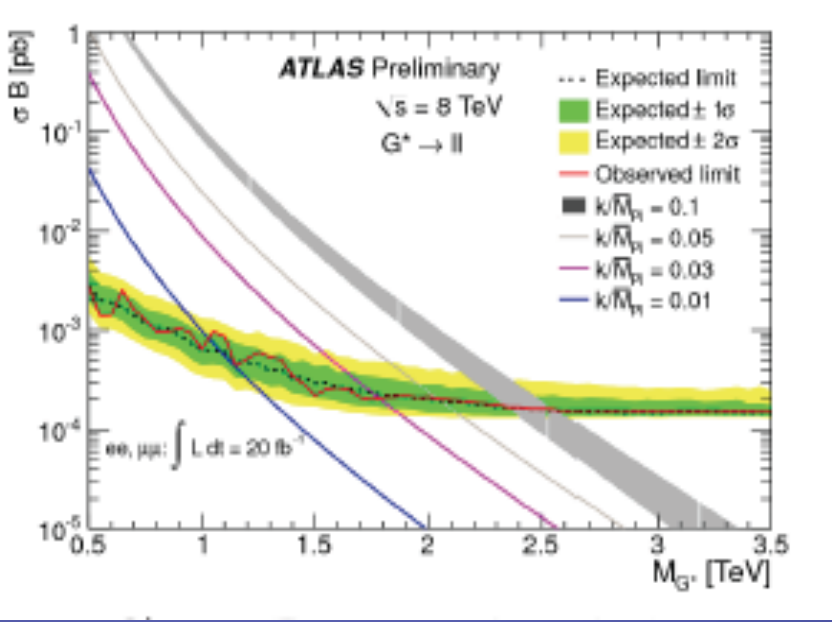
- Even with a SM-like Higgs discovery, still many questions unsolved by the SM: either SUSY or exotic model?

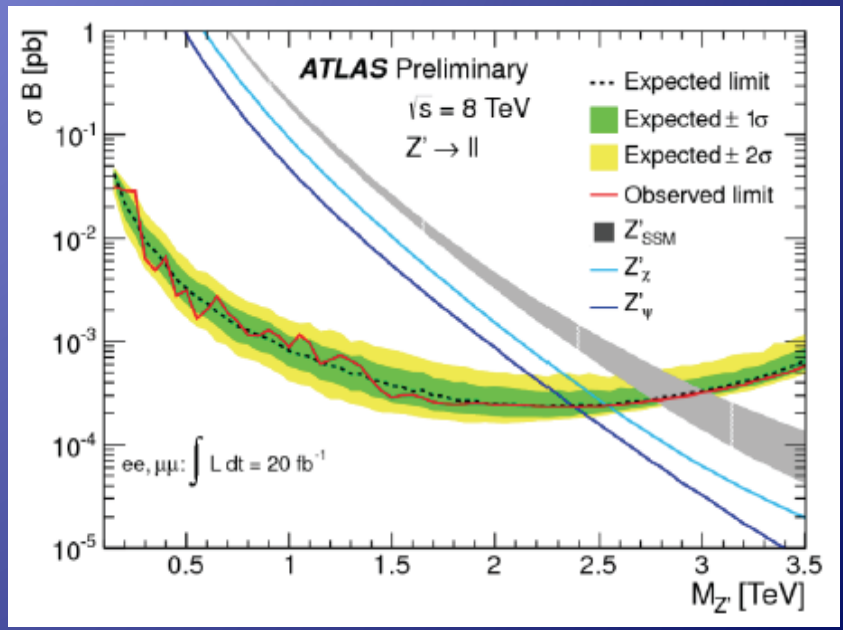
- Strategy
  - Pursue signature-driven analyses; search for resonances (dilepton, ttbar, heavy quark, diboson), and signatures for slow-moving, long-lived particles etc
  - Interpret in specific models to obtain limits on masses, scales

Dilepton resonance

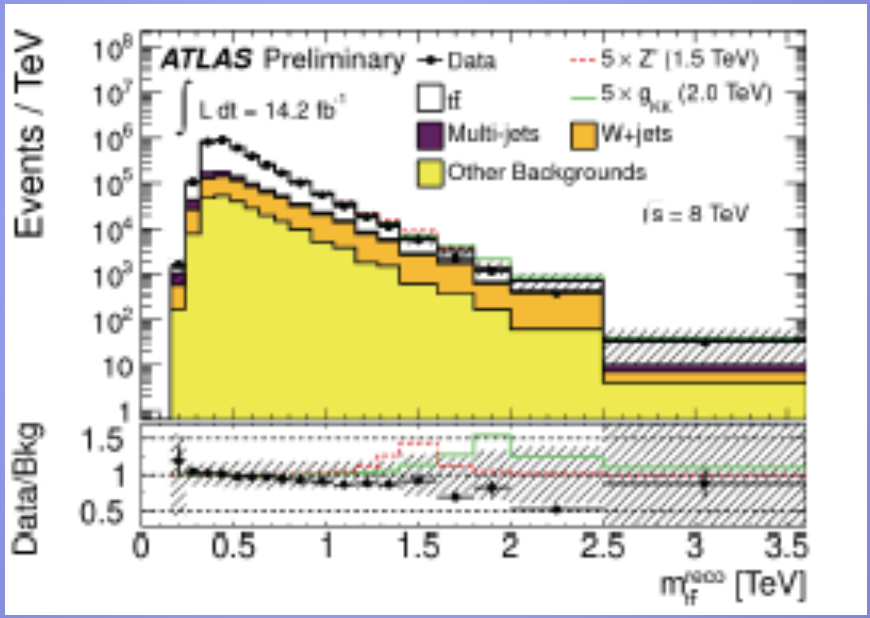


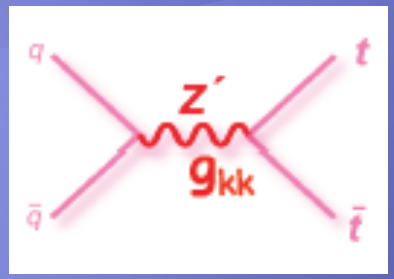






ttbar resonance

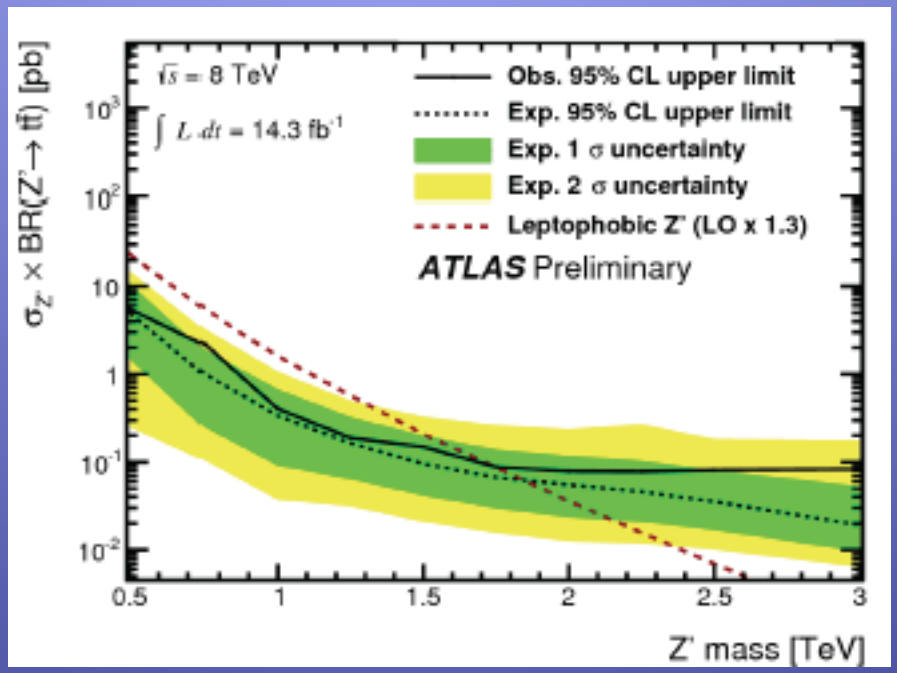


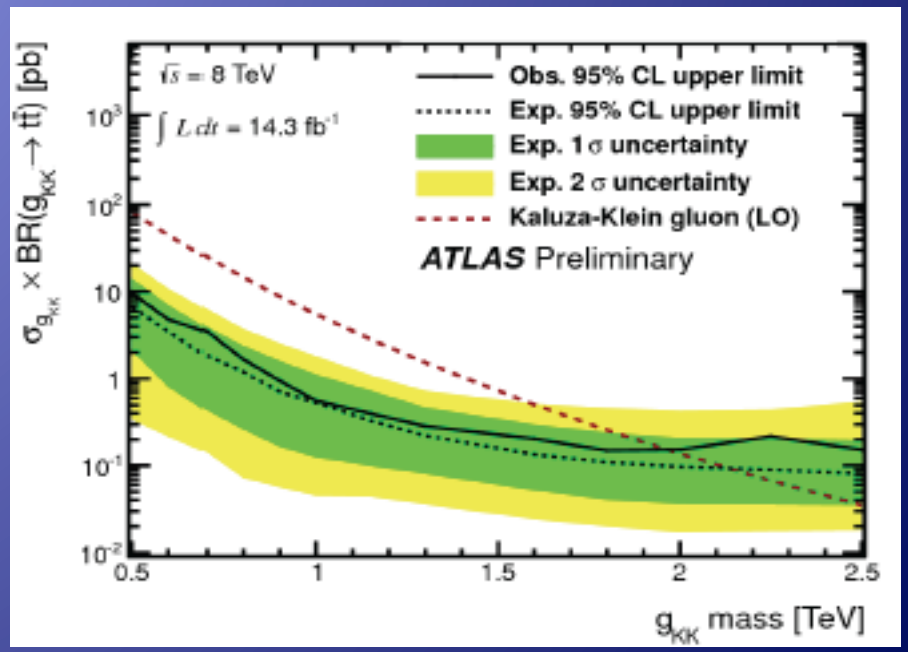


Leptophobic Z': narrow width 1%
KK gluon: broad width 10%

Exlusion @95% CL limit (Bayesian)

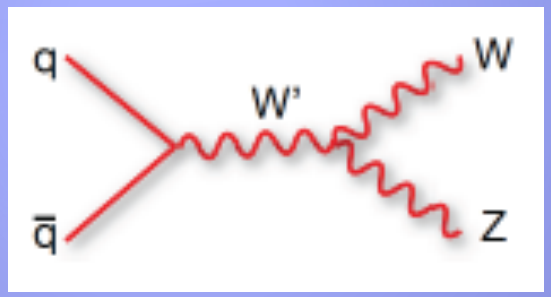
- 0.5 TeV < $m_{Z'}$ <1.74 TeV
- 0.5 TeV < mg_{KK}< 2.07 TeV

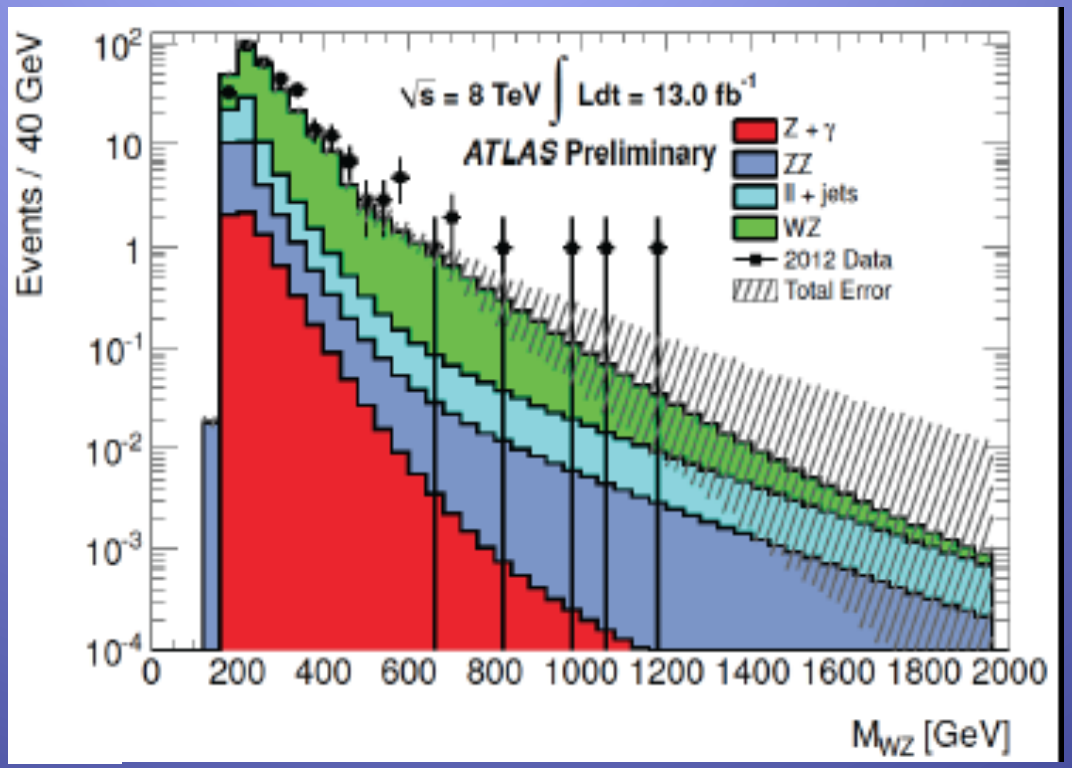




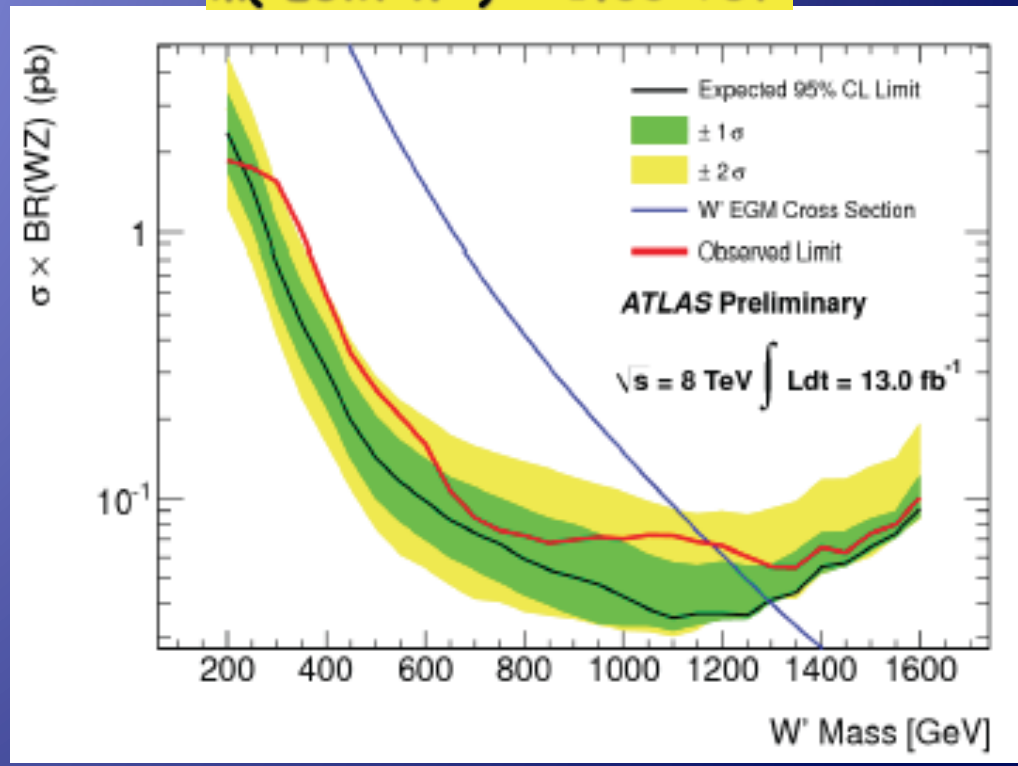
Diboson resonance

- W' in the Extended Gauge Model (EGM)





m(EGM W´) > 1.30 TeV

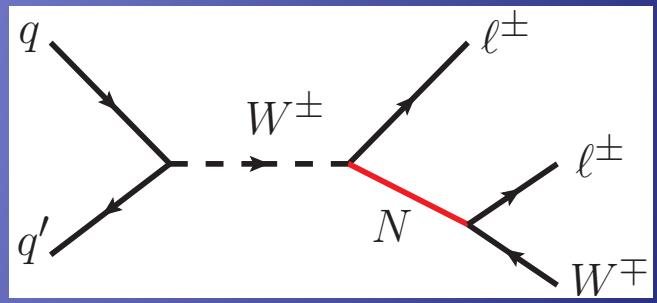


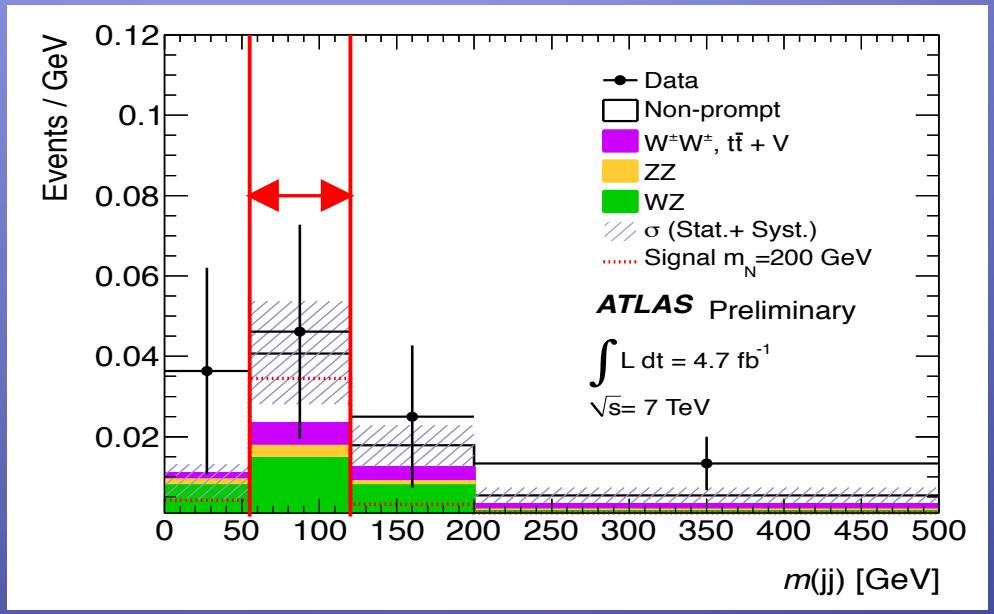
Heavy Neutrino

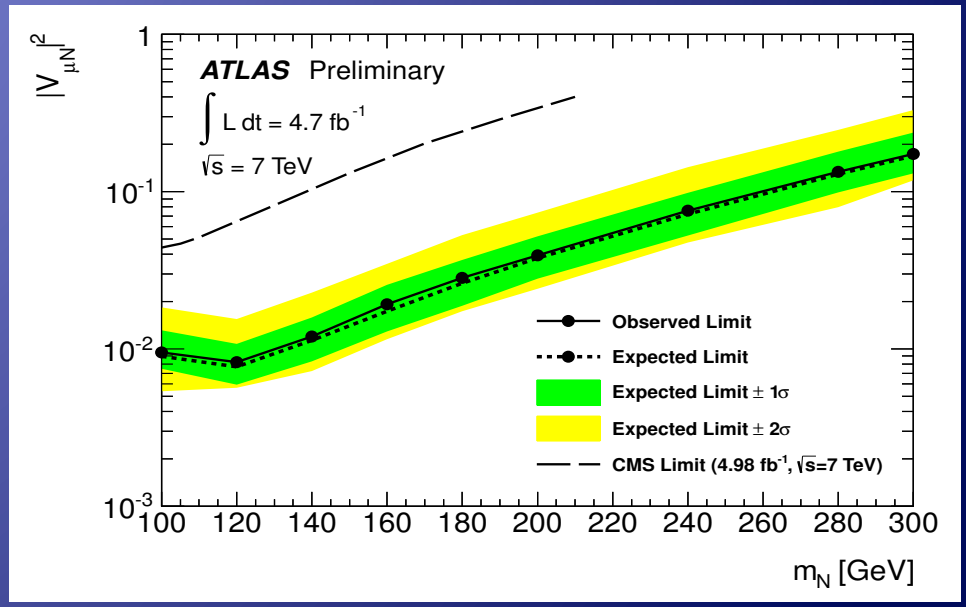
- Neutrino oscillations requires non-zero neutrino mass and right-handed neutrinos:
  - Type-I seasaw mechanism: 100 – 500 GeV

$$m_\nu^{\text{light}} \sim \frac{m_e^2}{m_N} \sim 0.1 \text{ eV}$$

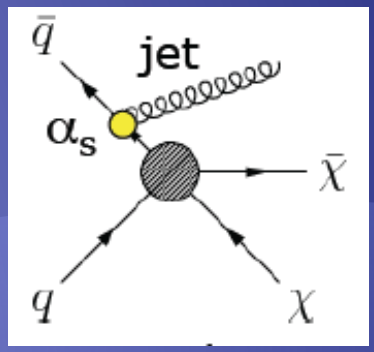
  - The Majorana nature of the heavy neutrino: lepton number violation (same sign leptons)
  - Same-sign with two jets, but no MET

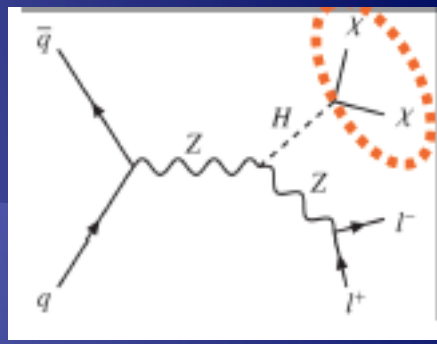






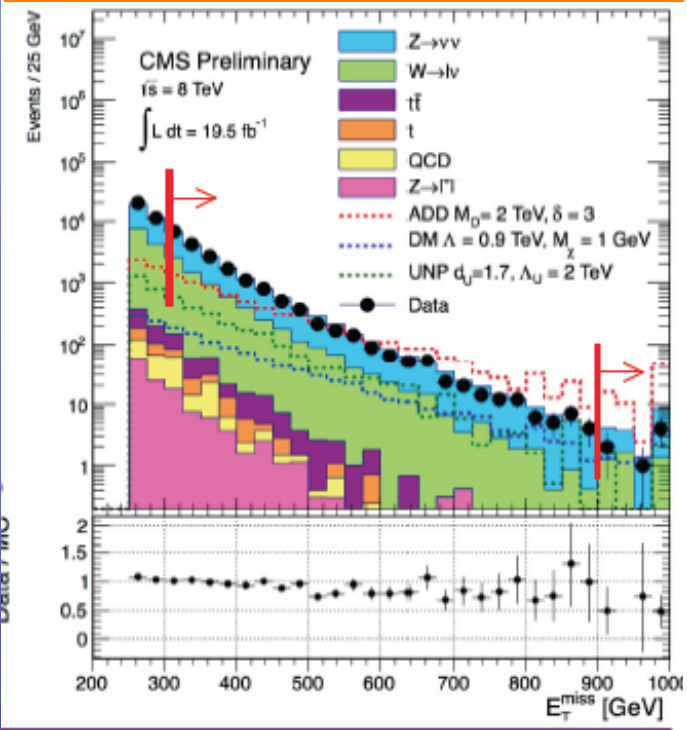
Dark Matter



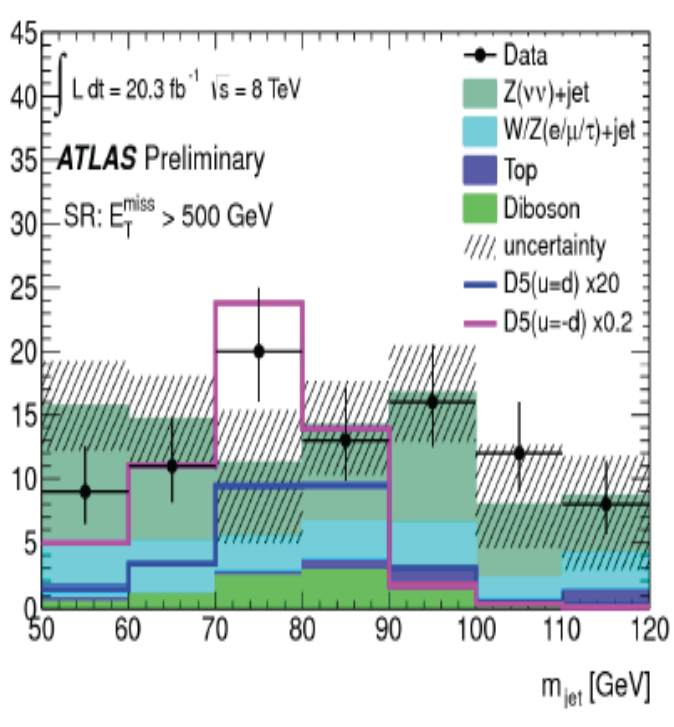


- Searches in the context of Effective Field theory and large extra dimension
- Direct production
  - X(=q/g,g,W/Z) is radiated from incoming quark/gluon

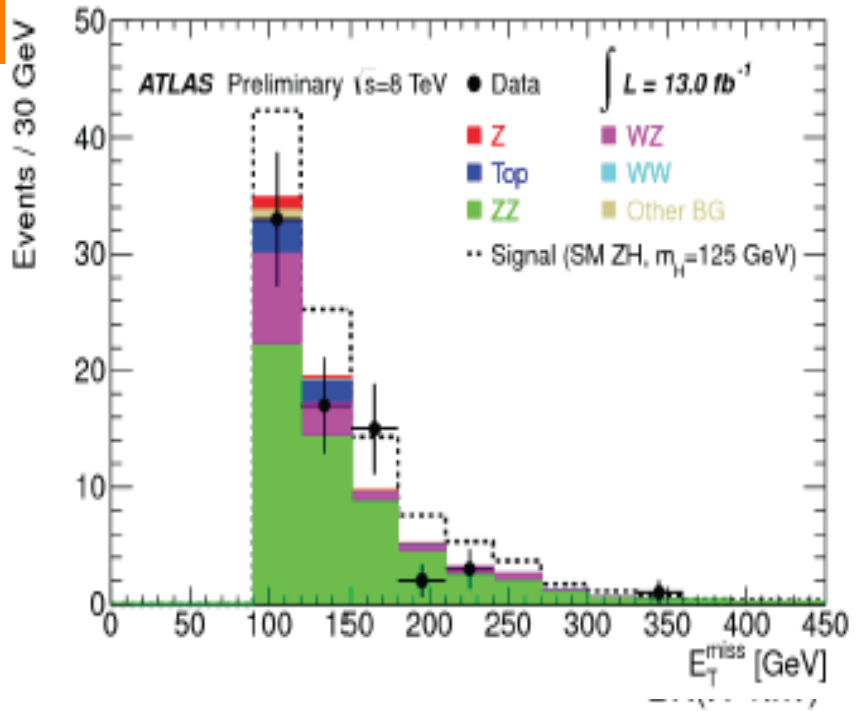
Mono-jets + missing Et



Mono-W/Z + missing Et



Higgs decay to DM

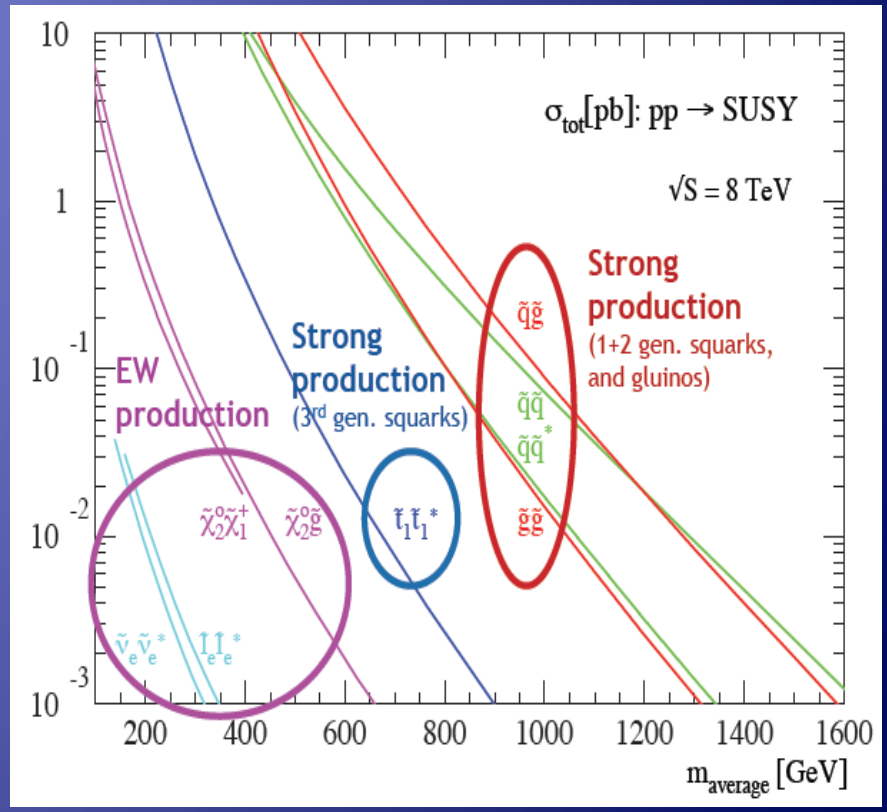


BR<65%(ATLAS),75%(CMS)

SUSY

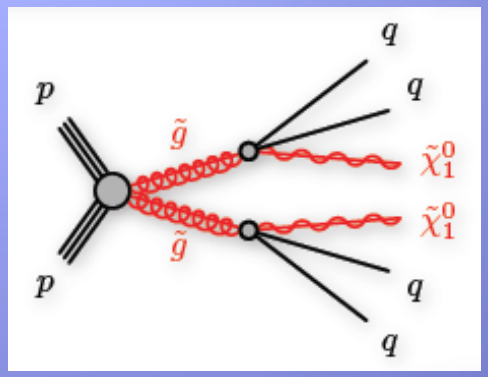
- SUSY particles (Sparticle) decay in b/c-jets, lepton, τ, photons, invisible (MET)

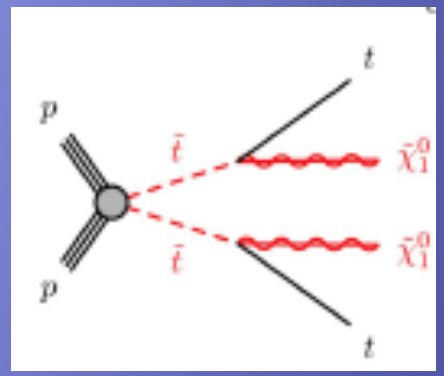
- Search strategies are based on two signatures, their cross section and luminosities
- R-parity conserving signature
  - Sparticles produced in pairs, each decays to LSP (WIMP)
  - Stable LSP→ MET
- R-parity violating signature
  - Single Sparticle production
  - LSP decay: resonances or multijets/multileptons

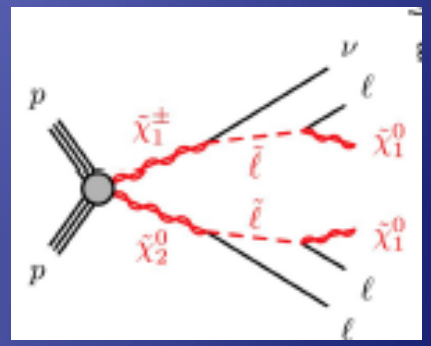


Search for SUSY

- Searches in three major areas
  - Inclusive (1st-2nd) squarks and gluinos
  - 3rd generation squarks
  - charginos and neutralinos

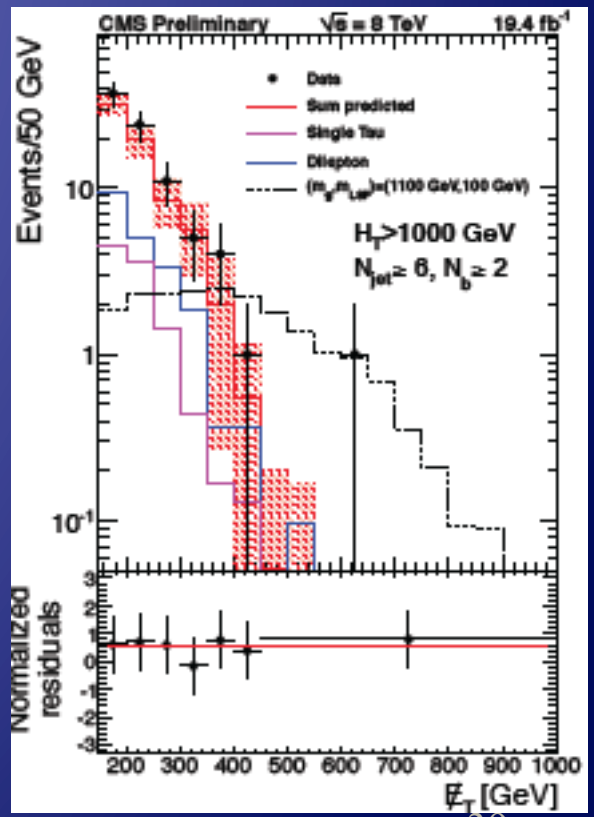


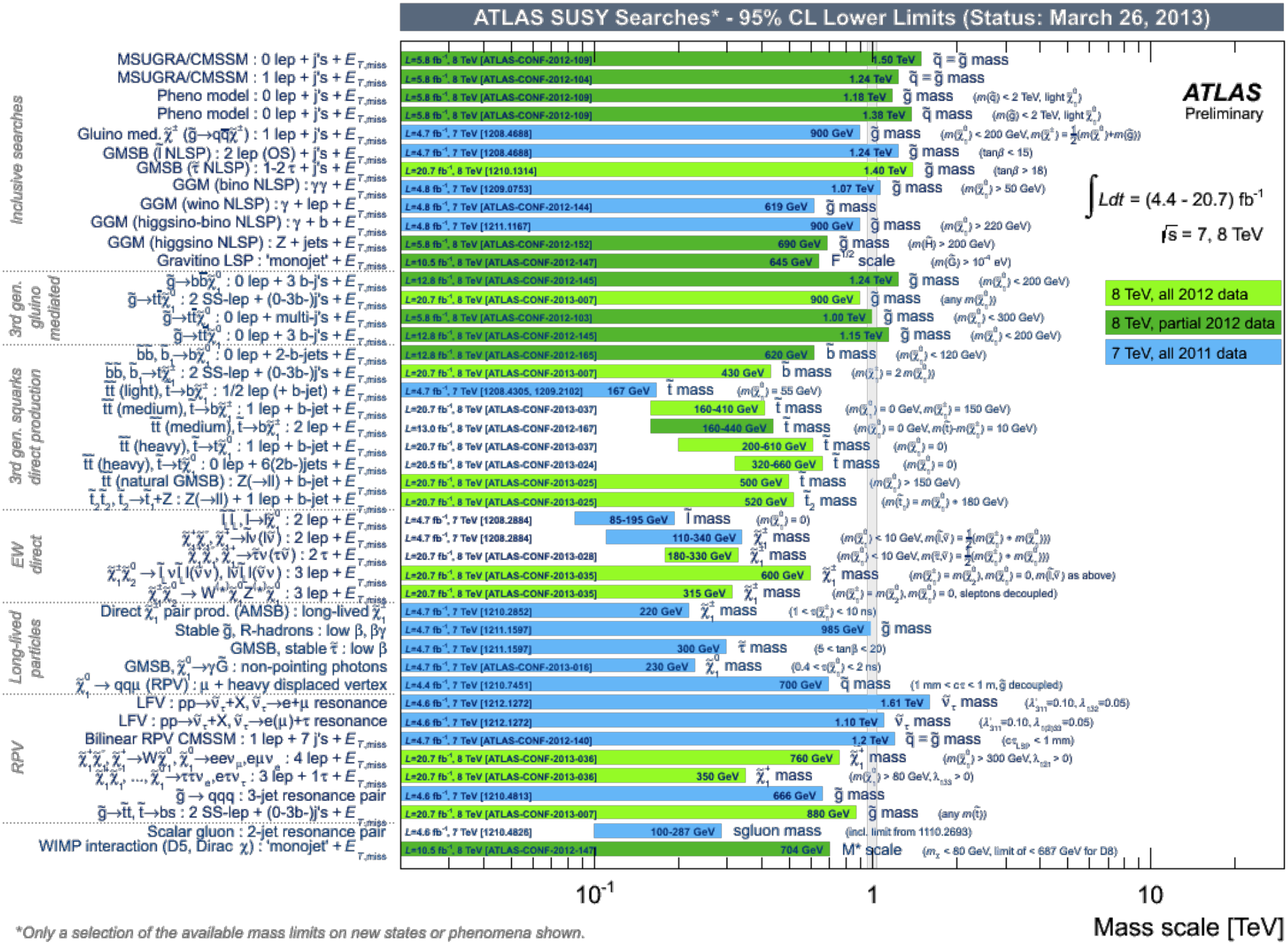




- No signal observed

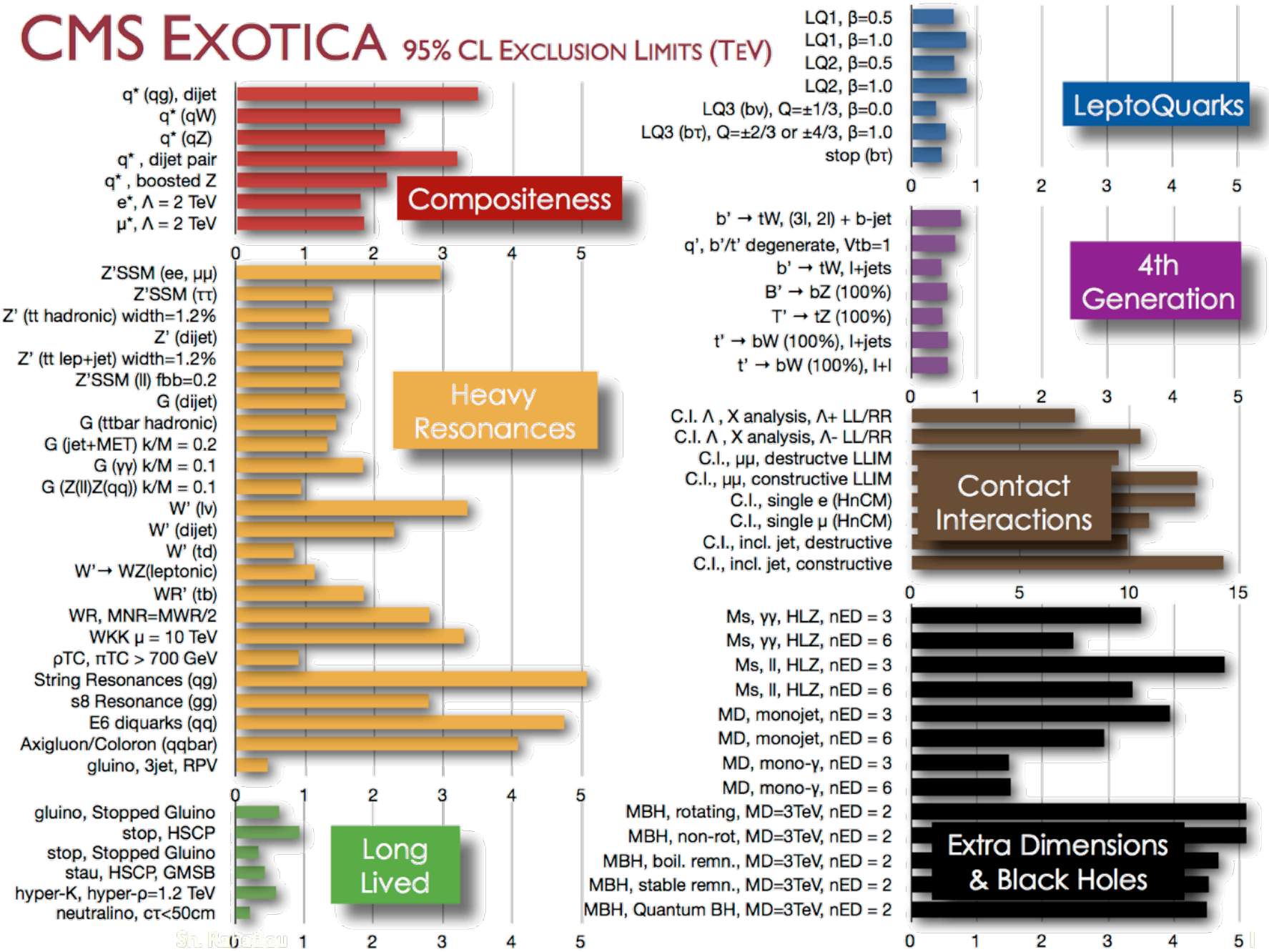
$$m(\tilde{g}) < 1300 \text{ GeV}$$
$$m(\tilde{q}) < 1400 \text{ GeV}$$
$$m(\tilde{b}) < 650 \text{ GeV}$$
$$m(\tilde{t}) < 680 \text{ GeV}$$
$$m(\tilde{\ell}_L) < 300 \text{ GeV}$$
$$m(\chi^{\pm} = \chi^0)_{\text{light } \tilde{t}} < 650 \text{ GeV}$$
$$m(\chi^{\pm} = \chi^0)_{\text{heavy } \tilde{t}} < 340 \text{ GeV}$$

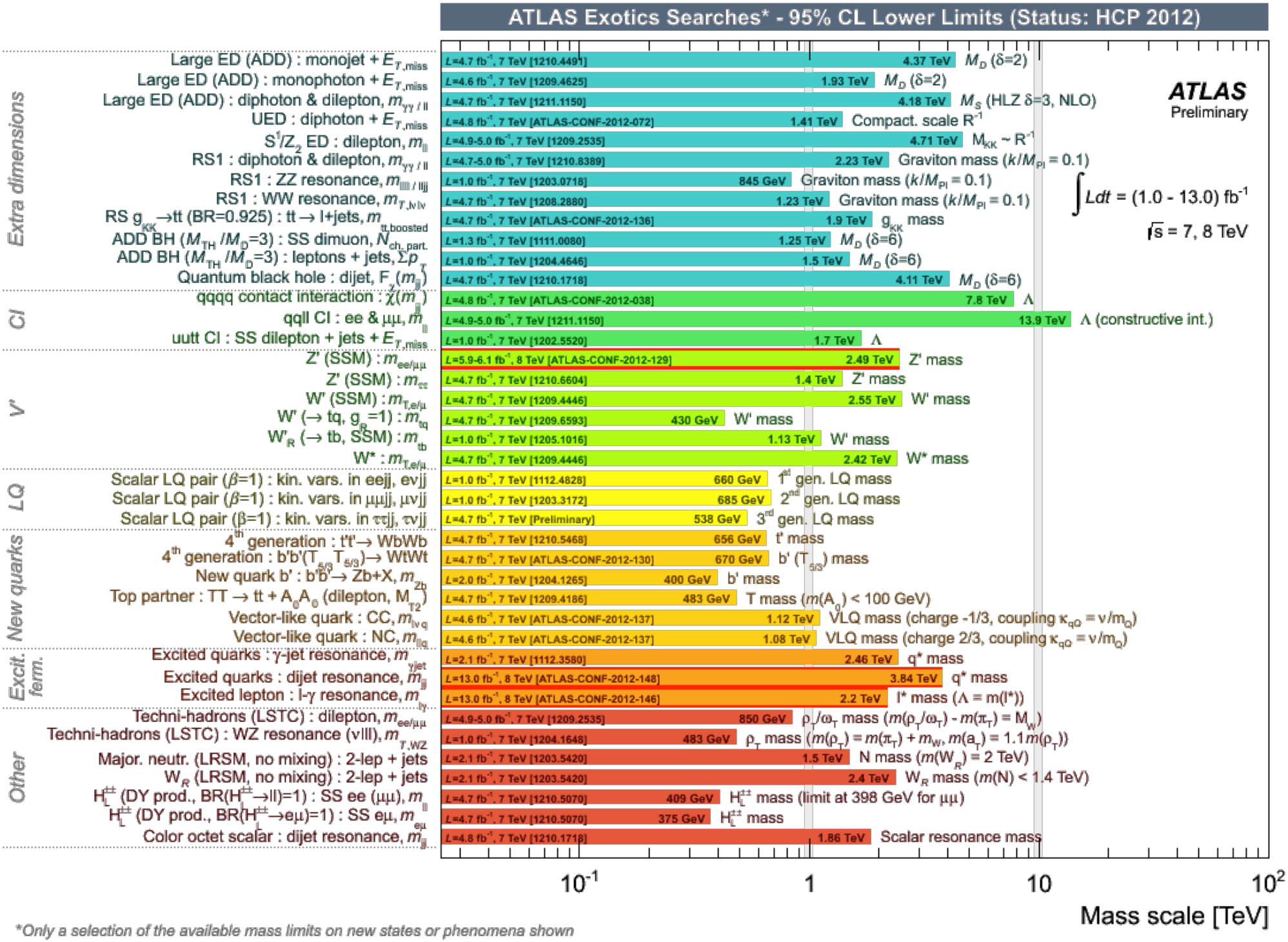




*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

CMS EXOTICA 95% CL EXCLUSION LIMITS (TEV)





*Only a selection of the available mass limits on new states or phenomena shown

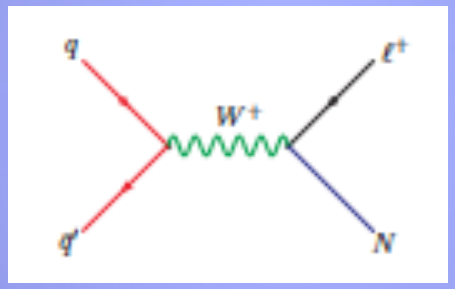
Summary & outlook

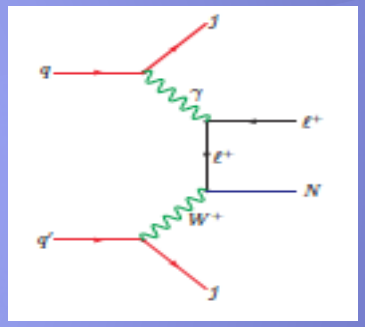
- LHC and experiments have made fabulous performance, leading to the discovery of a Higgs particle and precision tests on the Standard Model at the unprecedented level even in Run 1 phase

- No hints of new physics yet!!, but many limits on new physics have been pushed to much higher scale, still 2011,2012 data are actively being analyzed in many new physics area

- With coming 13-14 TeV collision with 70-100/fb data, LHC physics reach at TeV mass scale will be greatly extended at Run 2

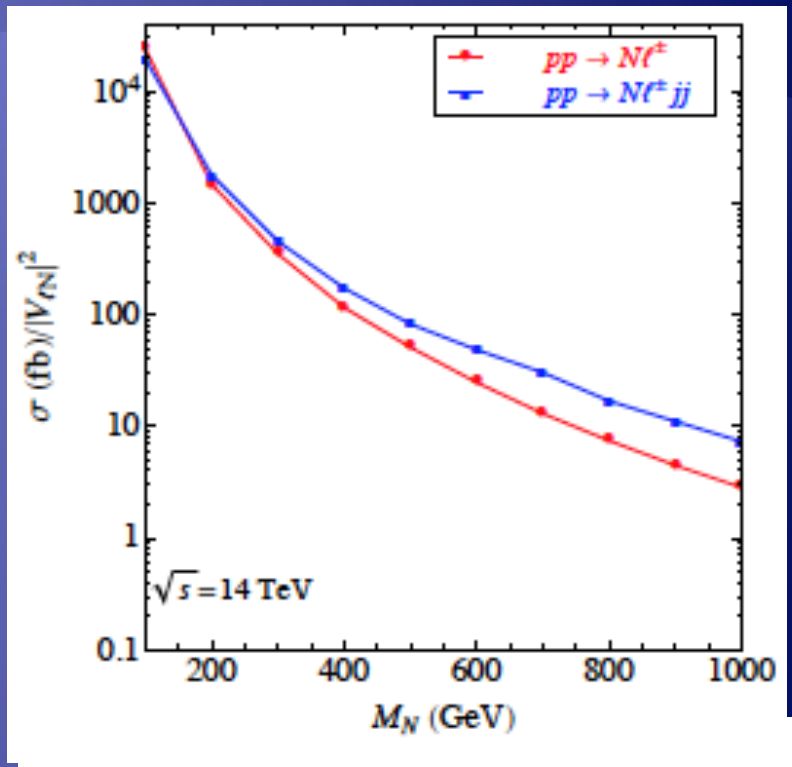
Heavy Neutrinos





s-ch. : W exchanage

t-ch. : W-γ fusion



- t-ch W-g fusion is found to be significant: arXiv:1308.2209[hep-ph]
- Effect becomes larger at 14 TeV