LHC Results (HIGGS) II

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TAE SCHOOL FOR HIGH ENERGY PHYSICS BENASQUE, SEPTEMBER 2014

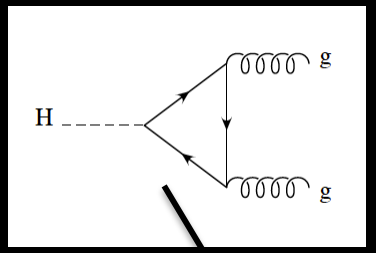
Outline for Today…

J^{PC}

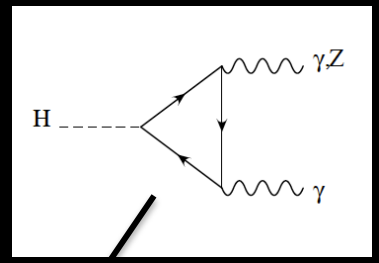
- **Other (Bronze) Channels**
- **Detailed study on Couplings**
- **Higgs width**
- **Invisibly decaying Higgs**
- **Higgs and Vacuum Stability**
- **Hierarchy Problem & SUSY**
- **Search for other Higgs**
- **Exotics to keep an eye on**
- **What to expect in 2015 -- ?**

Disclaimer: completely unbalanced set of results from CMS and ATLAS

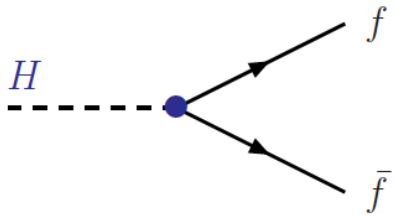
Higgs Couplings to SM



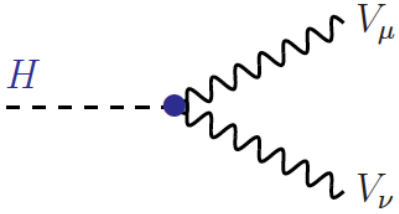
and via loops..



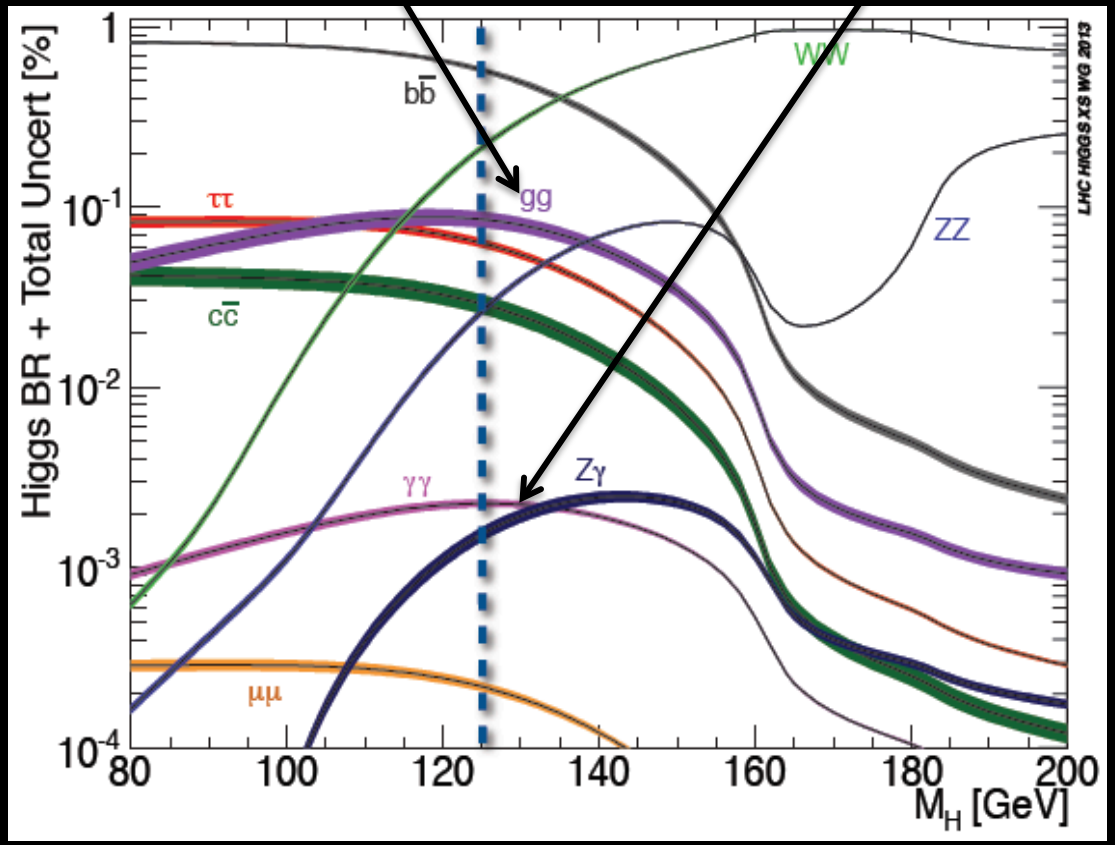
Couplings proportional to masses of particles
→ This determines the phenomenology

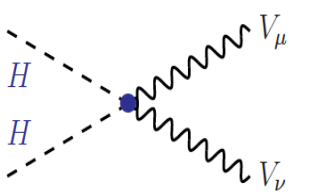


$$g_{Hff} = m_f/v$$

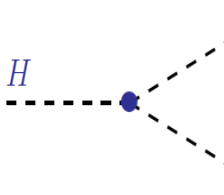


$$g_{HVV} = 2M_V^2/v$$

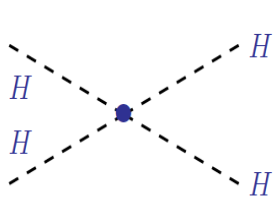




$$g_{HHVV} = 2M_V^2/v^2$$



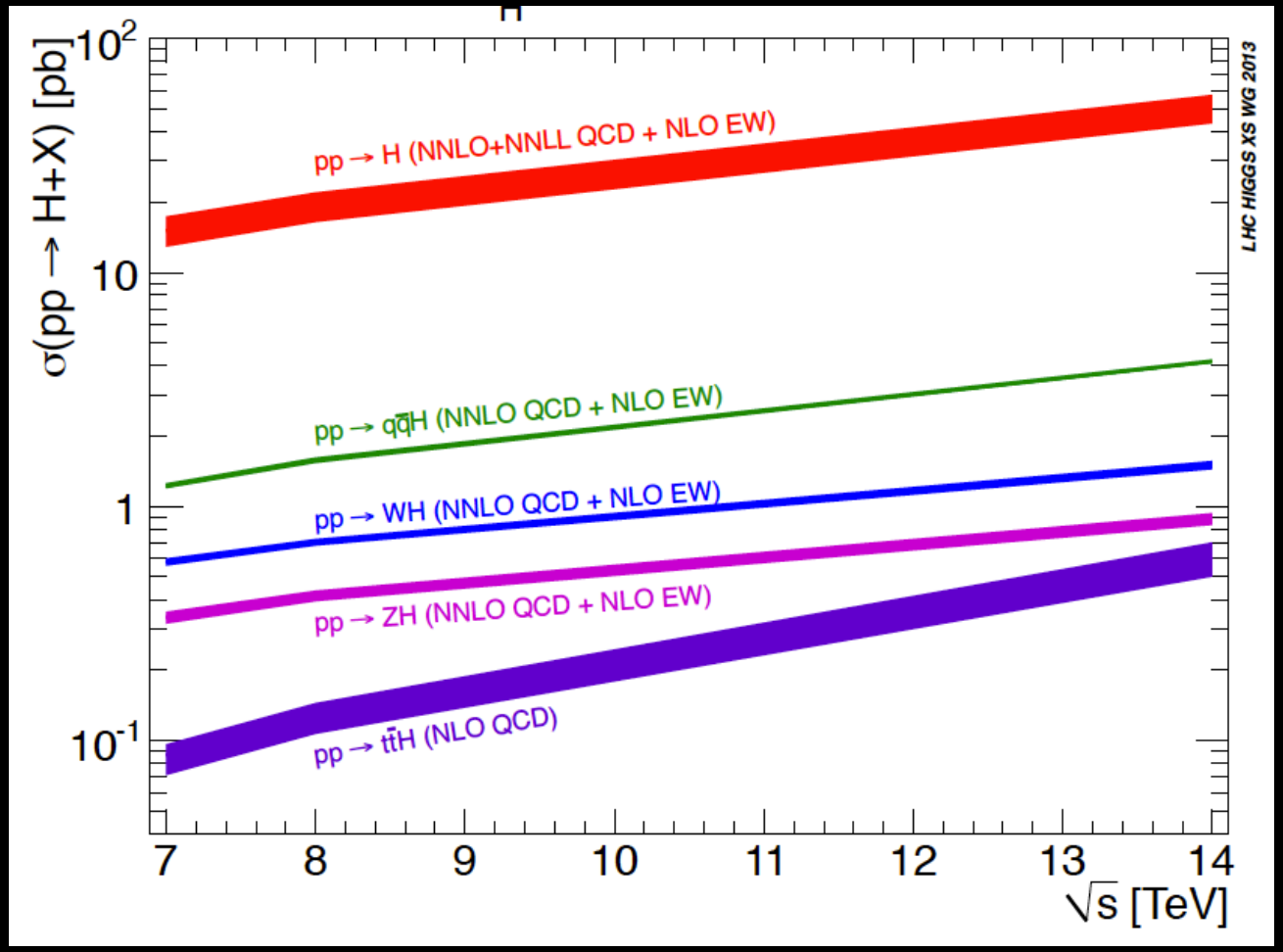
$$g_{HHH} = 3M_H^2/v$$



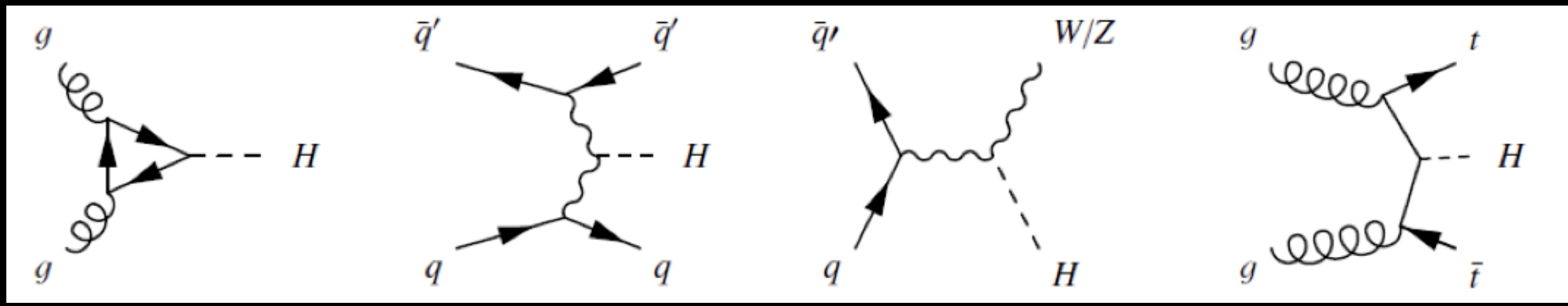
$$g_{HHHH} = 3M_H^2/v^2$$

Higgs Production (LHC)

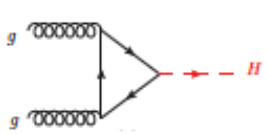
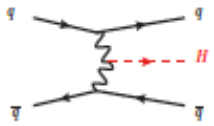
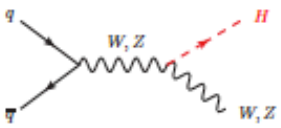
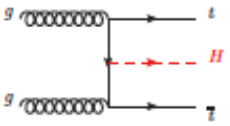
For a Higgs of 125 GeV



Decreasing cross section →



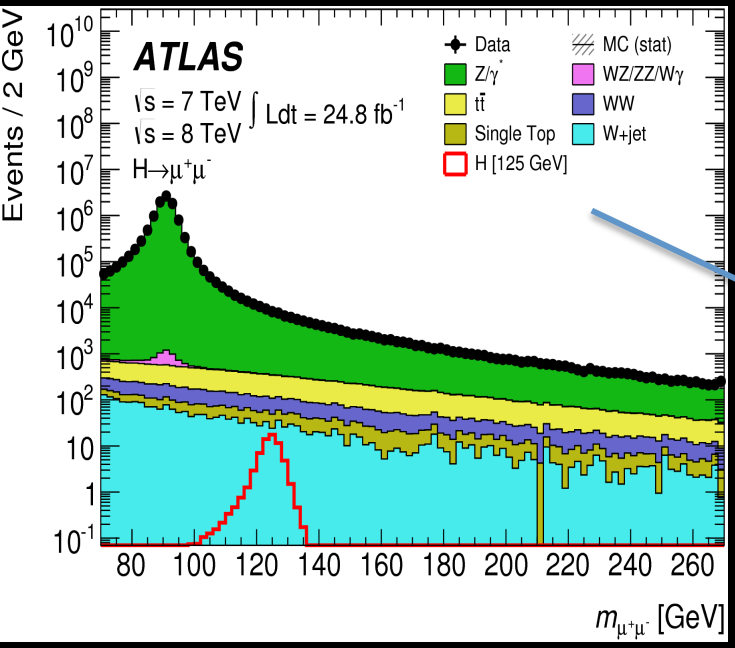
Higgs Program in a Glance

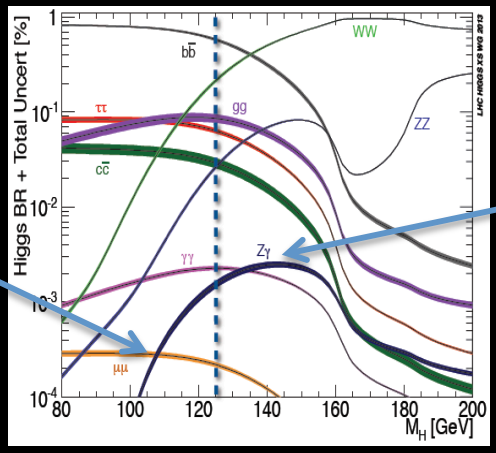
Channel categories	ggF 	VBF 	VH 	ttH 
γγ	✓	✓	✓	✓
ZZ (llll)	✓	✓	✓	✓
WW (lnln)	✓	✓	✓	✓
ττ		✓	✓	✓
bb		✓	✓	✓
Zγ	✓	✓		
μμ	✓	✓		
Invisible	✓	✓	✓	

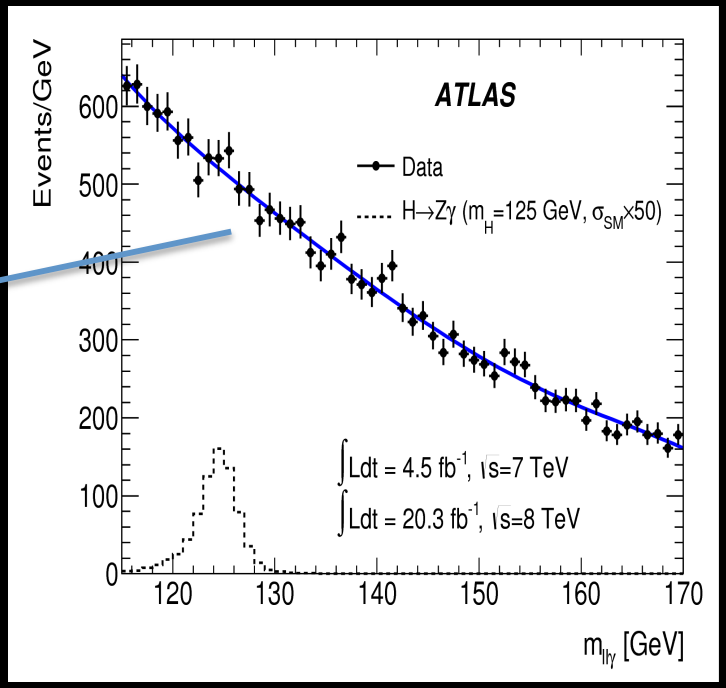
Large Backgrounds

Rare Decays

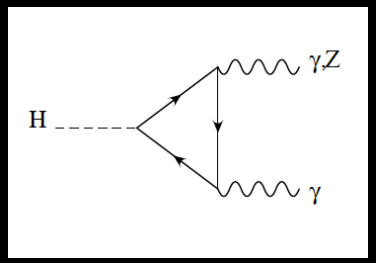
Rare Decays



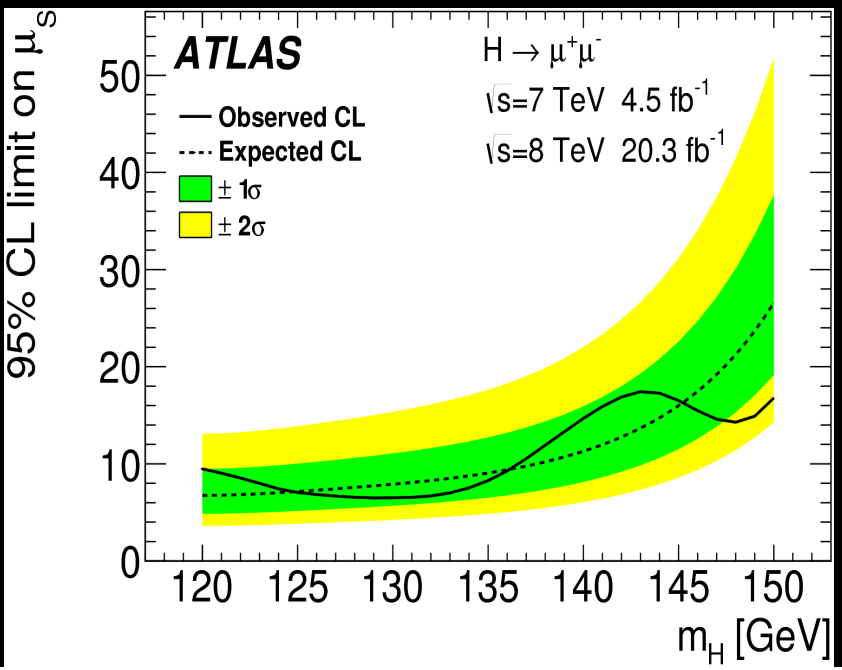


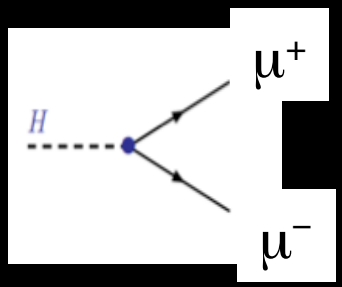


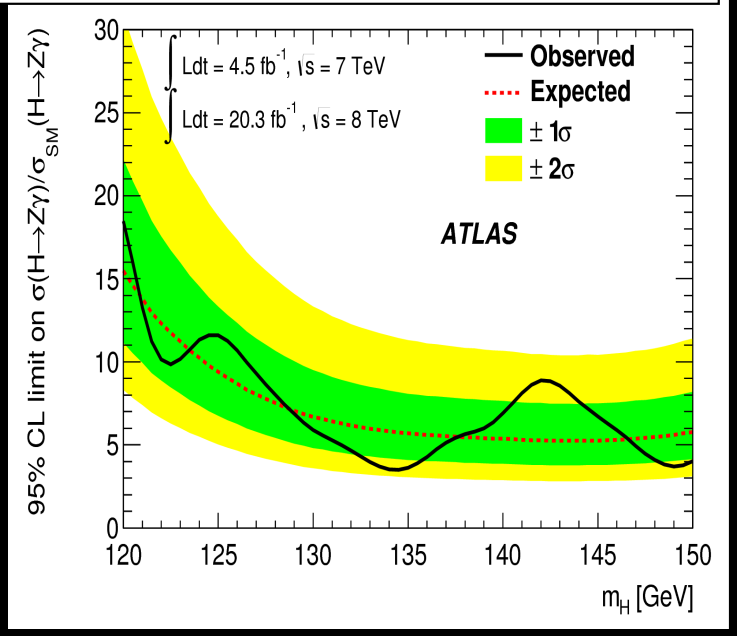
$$\sigma \mathrm{Br}_{\mu\mu}/\sigma^{SM} < 7 \text{ @ } 95\% \text{ CL}$$



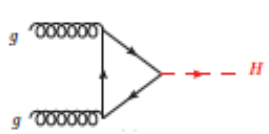
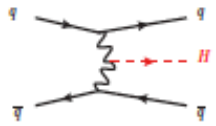
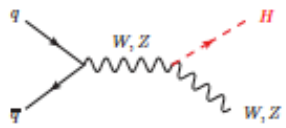
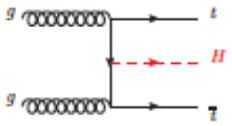
$$\sigma \mathrm{Br}_{Z\gamma}/\sigma^{SM} < 11 \text{ @ } 95\% \text{ CL}$$







Global Understanding

Channel categories	ggF 	VBF 	VH 	ttH 
γγ	✓	✓	✓	✓
ZZ (llll)	✓	✓	✓	✓
WW (lnln)	✓	✓	✓	✓
ττ		✓	✓	✓
bb		✓	✓	✓
Zγ	✓	✓		
μμ	✓	✓		
Invisible	✓	✓	✓	

Detailed Study of Couplings

$$n^{c}_{signal} = (\sum_{i} \mu_i \sigma_{i,SM} \times A^{c}_{if} \times \varepsilon^{c}_{if}) \times \mu_f \times B_{f,SM} \times \mathcal{L}$$

$$i \in \{ggH, VBF, VH, ttH\}$$

$$f \in \{\gamma\gamma, WW, ZZ, bb, \tau\tau\}$$

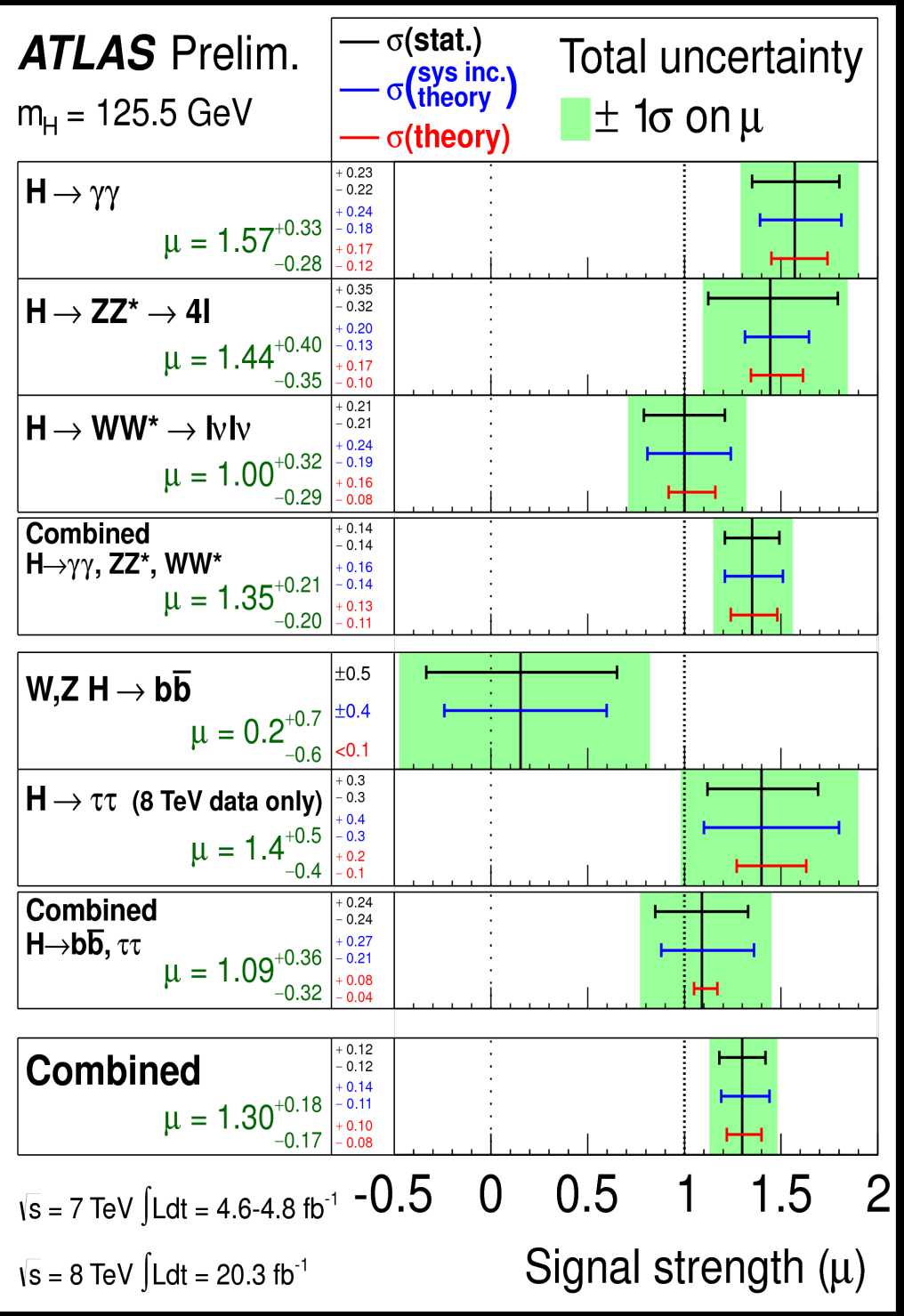
Taking some assumptions

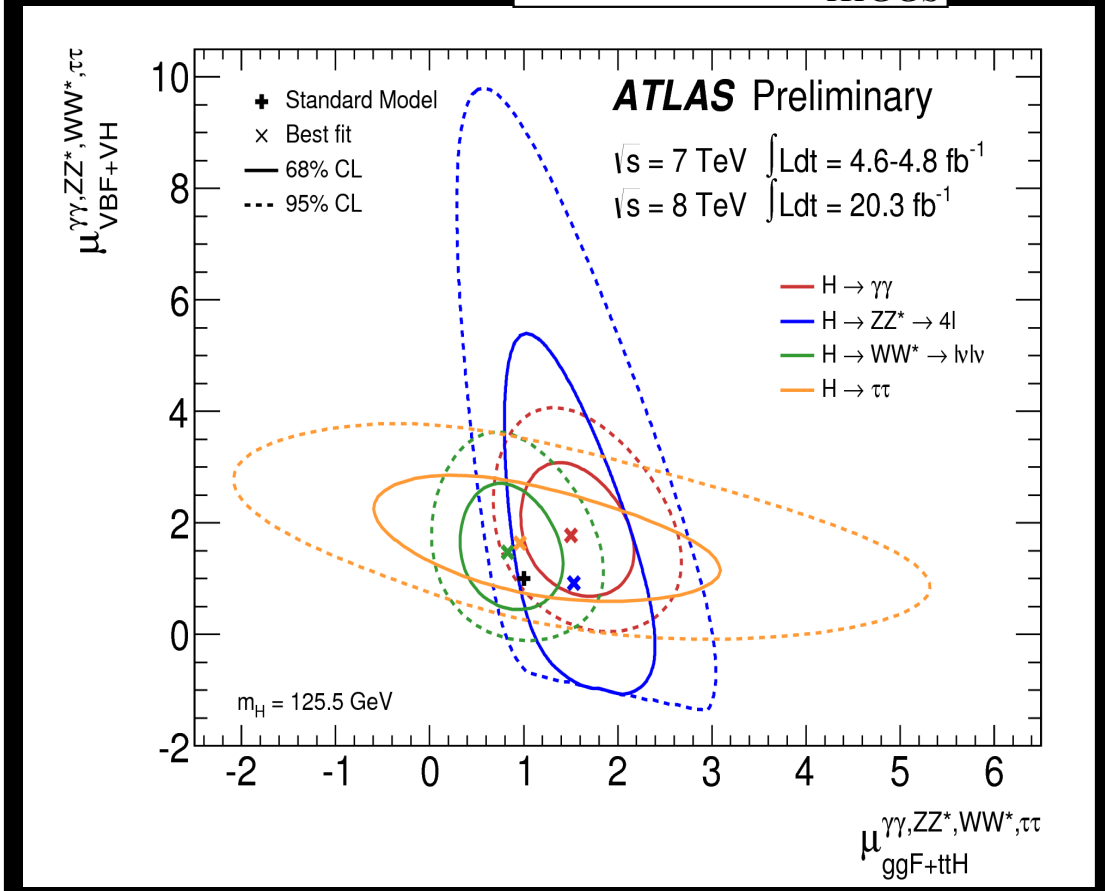
$$(\mu_{ggH+ttH} = \mu_{ggH} = \mu_{ttH})$$

$$(\mu_{VBF+VH} = \mu_{VBF} = \mu_{VH})$$

Higgs Couplings

$$\sigma^{visible} = \mu\sigma^{SM}_{HIGGS}$$

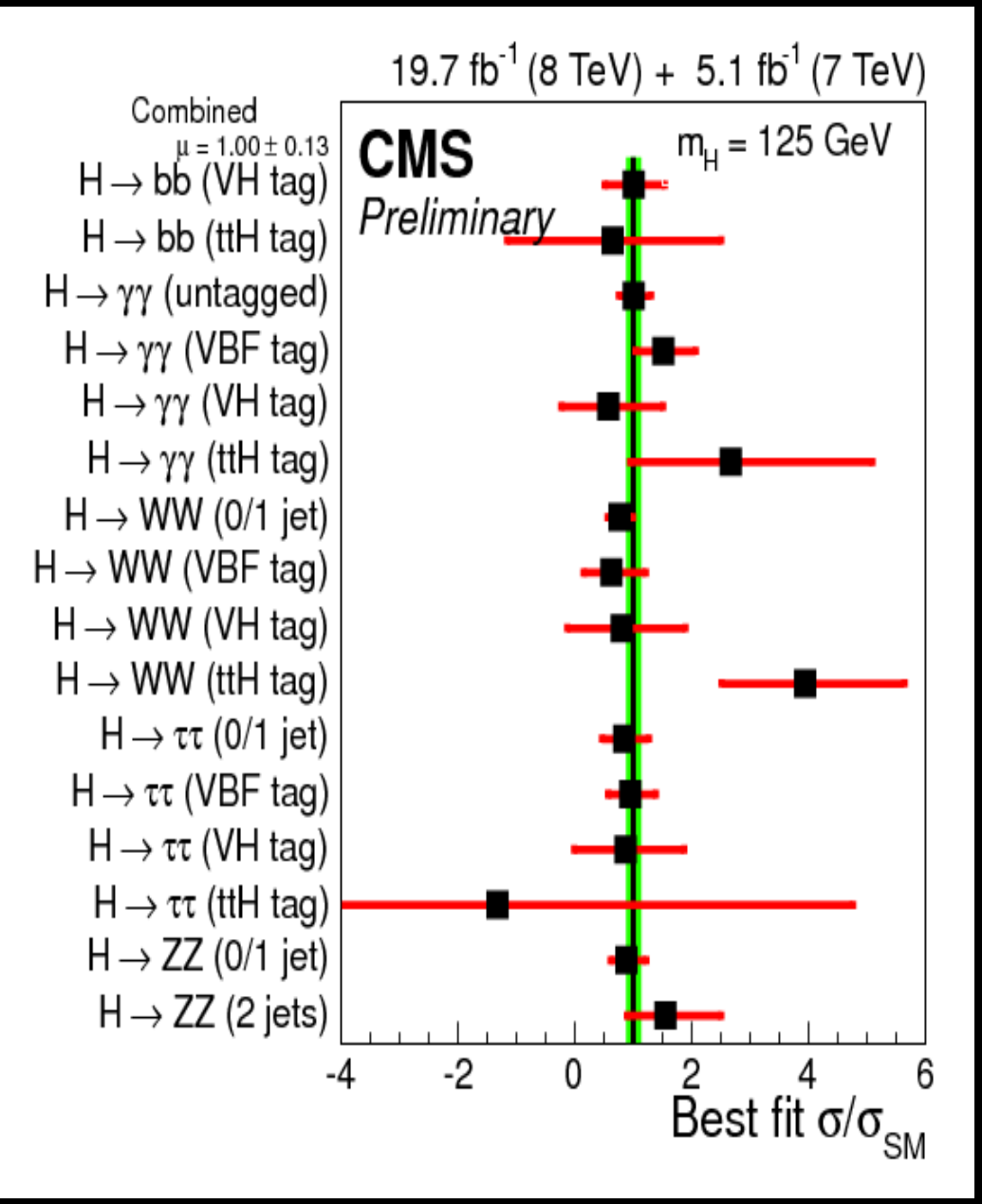


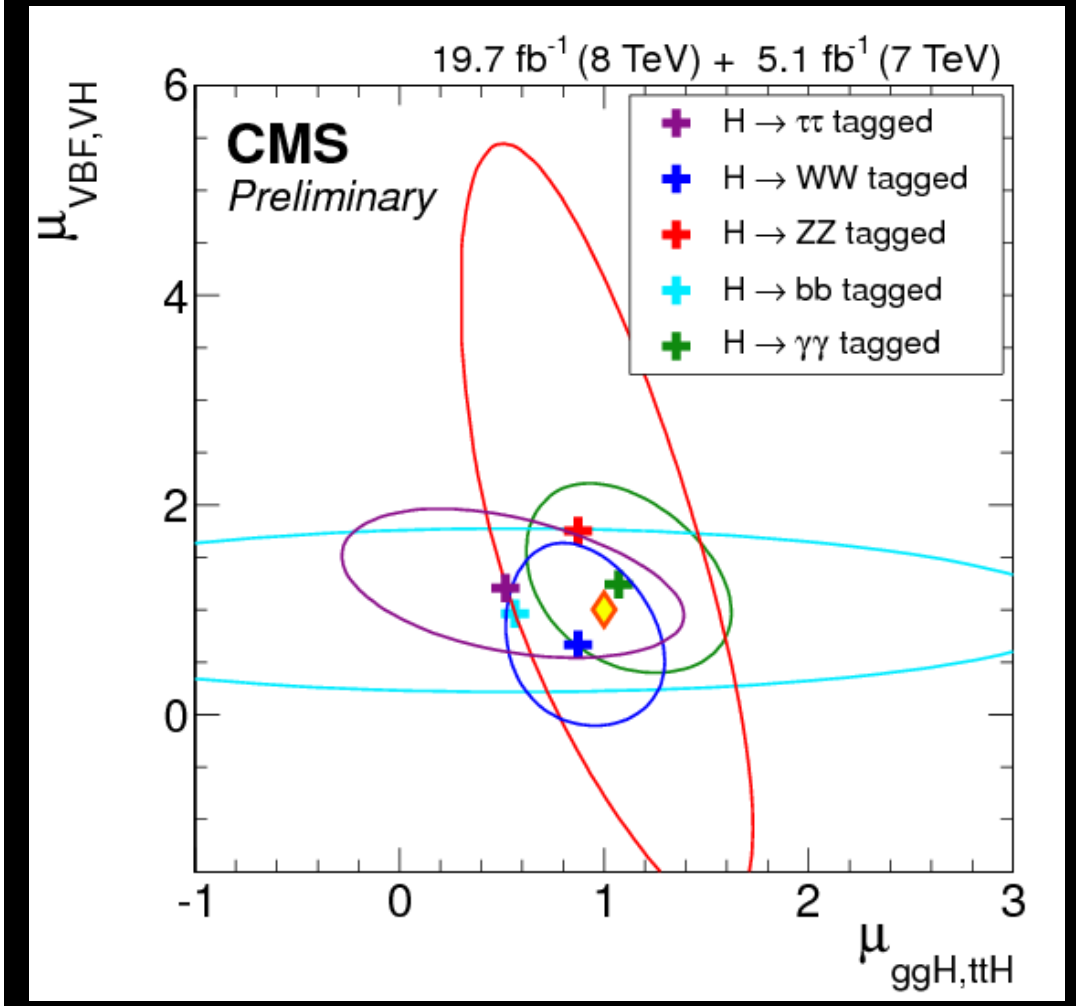


Within the uncertainty of the data all looks consistent with a SM Higgs

$$\sigma/\sigma^{SM}_{HIGGS} = 1.00 \pm 0.13$$

Higgs Couplings





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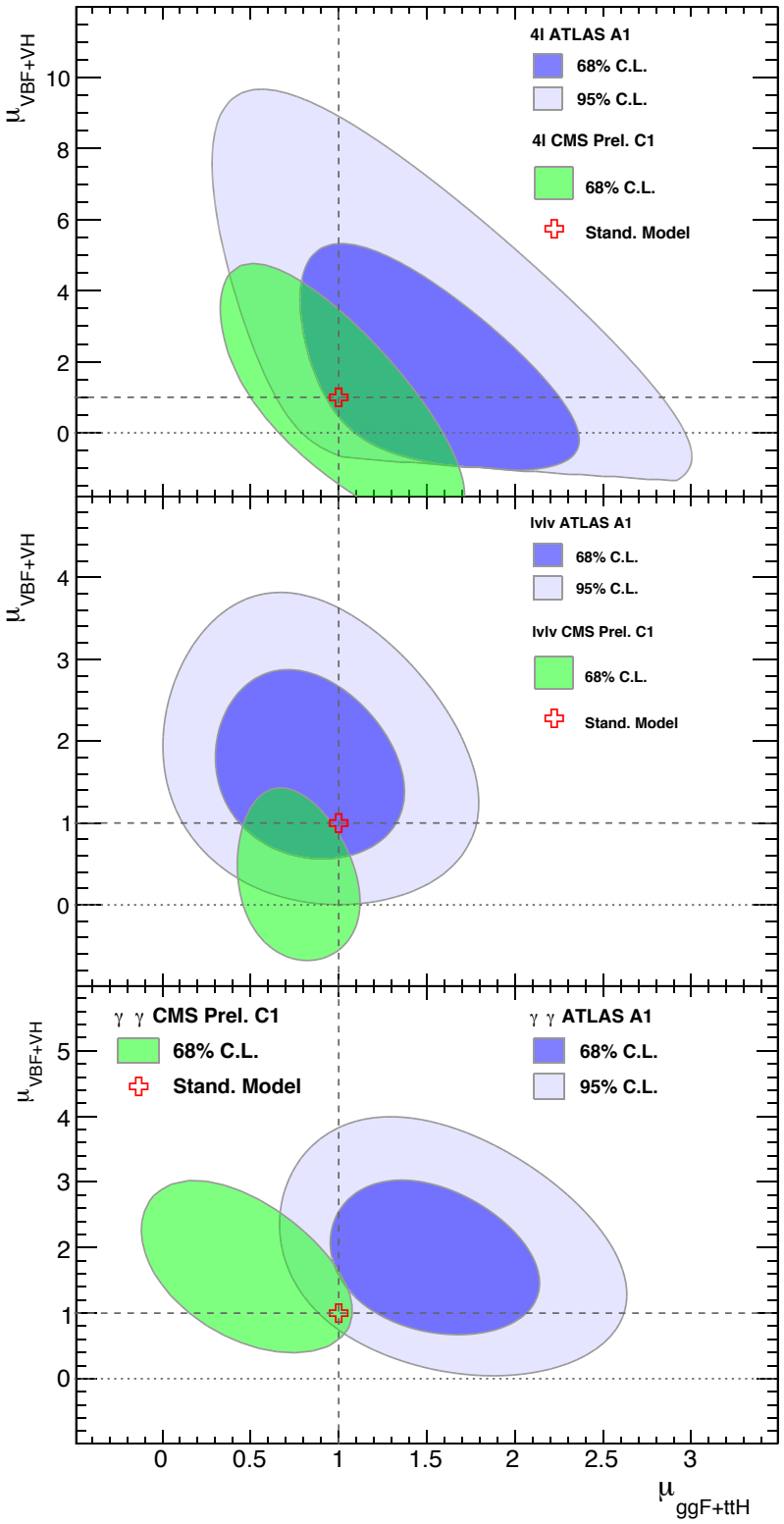
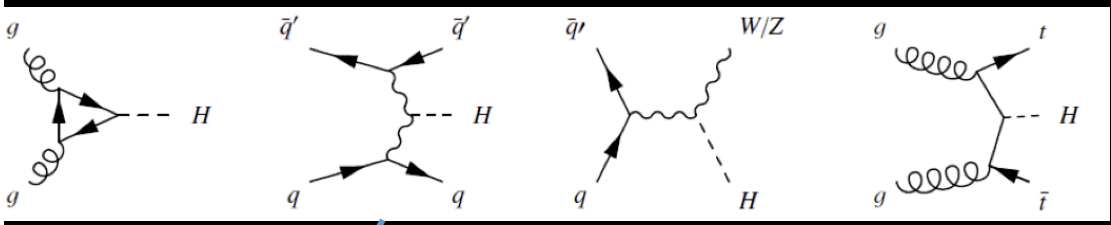


ATLAS vs CMS



$$\rho_{VBF,ggH+ttH} = 1.1^{+0.4}_{-0.3}$$ ATLAS

$$\rho_{VBF+VH,ggH+ttH} = 1.1^{+0.4}_{-0.3}$$ ATLAS

$$\rho_{VBF+VH,ggH+ttH} = 1.7^{+0.7}_{-0.5}$$ CMS

Both experiments show consistency

VBF process confirm beyond 3σ

Using EFT Lagrangian in Global Fit

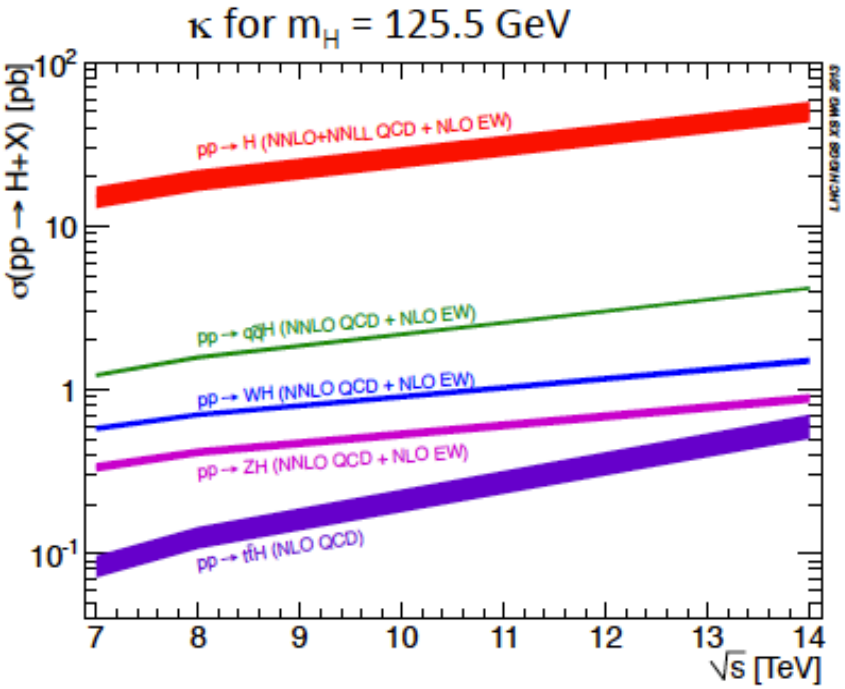
$$\mathcal{L} = \kappa_3 \frac{m_H^2}{2v} H^3 + \kappa_Z \frac{m_Z^2}{v} Z_\mu Z^\mu H + \kappa_W \frac{2m_W^2}{v} W_\mu^+ W^{-\mu} H$$
$$+ \kappa_g \frac{\alpha_s}{12\pi v} G^a_{\mu\nu} G^{a\mu\nu} H + \kappa_\gamma \frac{\alpha}{2\pi v} A_{\mu\nu} A^{\mu\nu} H + \kappa_{Z\gamma} \frac{\alpha}{\pi v} A_{\mu\nu} Z^{\mu\nu} H$$
$$+ \kappa_{VV} \frac{\alpha}{2\pi v} \left(\cos^2\theta_W Z_{\mu\nu} Z^{\mu\nu} + 2\, W^+_{\mu\nu} W^{-\mu\nu} \right) H$$
$$- \left(\kappa_t \sum_{f=u,c,t} \frac{m_f}{v} f\bar{f} + \kappa_b \sum_{f=d,s,b} \frac{m_f}{v} f\bar{f} + \kappa_\tau \sum_{f=e,\mu,\tau} \frac{m_f}{v} f\bar{f} \right) H.$$

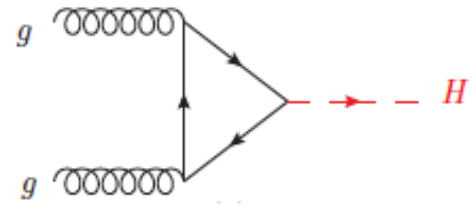
Global EFT analysis using scale factors κ_k that modify SM couplings

$$k \in \{Z, W, f, g, \gamma, Z\gamma\}$$

One can build the relationships between different scale factors according to the different processes…

Higgs Production Modes



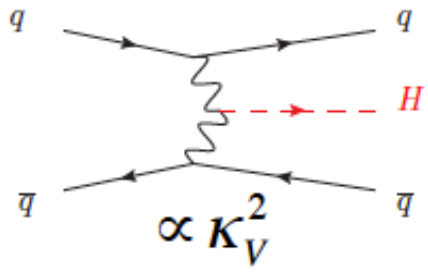


Gluon fusion process

NNnLO ~O(10%)

~0.5 M events produced

$$\kappa_g \propto 1.\times 06\kappa_t^2 - 0.07\times\kappa_t\kappa_b + 0.01\times\kappa_b^2$$



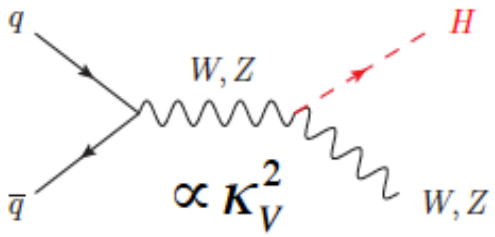
$\propto \kappa_V^2$

Vector Boson Fusion

NLO TH uncertainty ~O(5%)

Two forward jets and a large rapidity gap

~40 k events produced

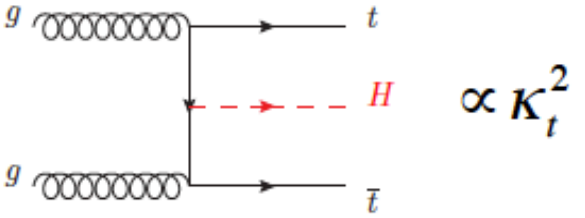


$\propto \kappa_V^2$

W and Z Associated Production

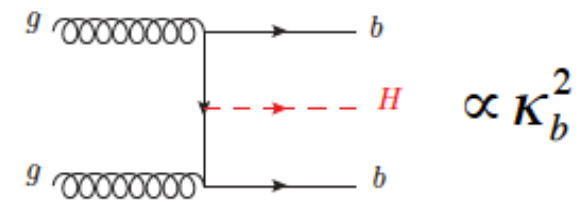
NNLO TH uncertainty ~O(5%)

~20 k events produced



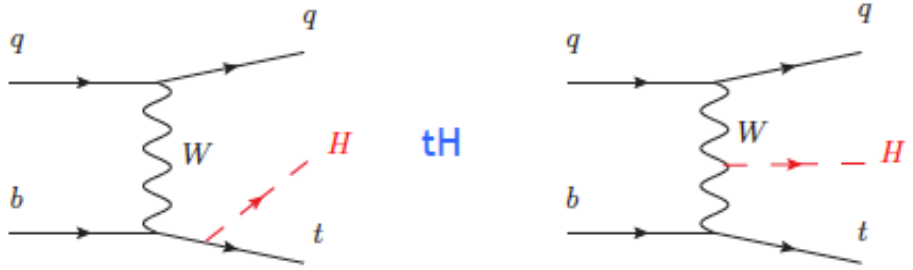
$\propto \kappa_t^2$

Top Assoc. Prod. ~3 k evts produced



$\propto \kappa_b^2$

B-quark Assoc. Prod. ~5 k evts produced

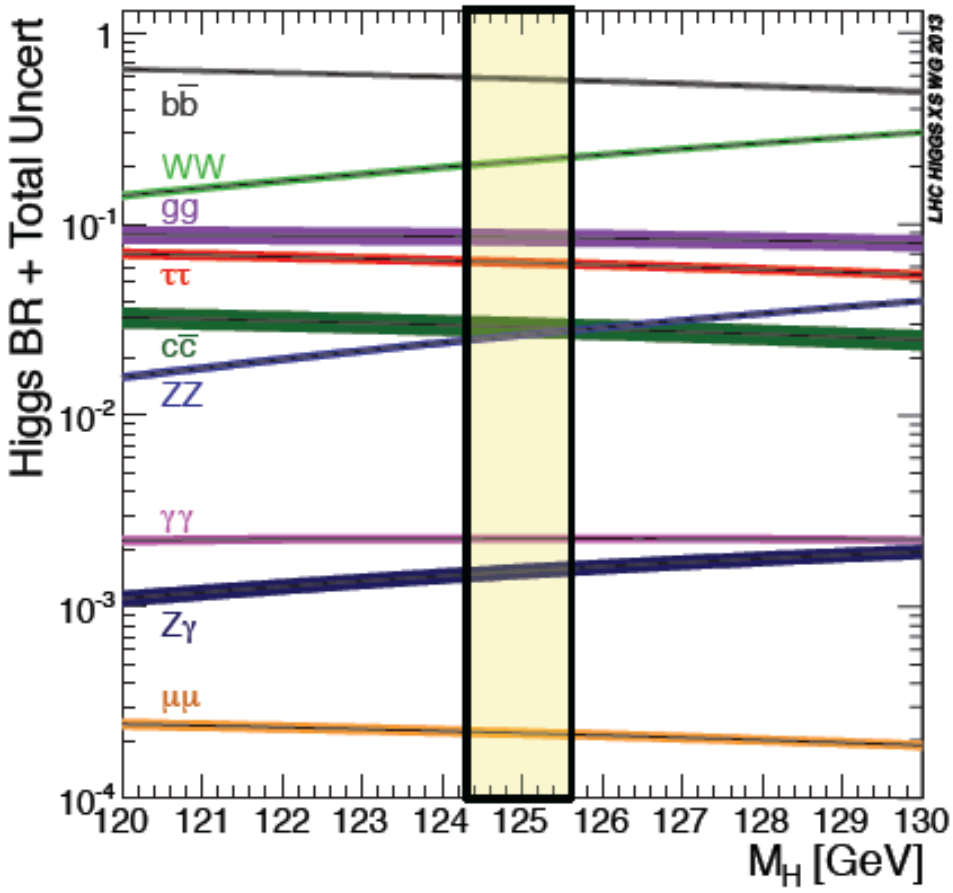


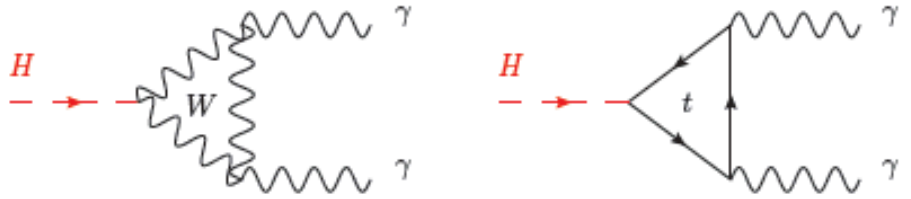
tH

$$\propto 3.3\times\kappa_W^2 - 5.1\times\kappa_t\kappa_W + 2.8\times\kappa_t^2$$

Higgs Decay Channels

- Dominant: bb (57%) $\propto \kappa_b^2 / \kappa_H^2$
- WW channel (22%) $\propto \kappa_W^2 / \kappa_H^2$
- ττ channel (6.3%) $\propto \kappa_\tau^2 / \kappa_H^2$
- ZZ channel (3%) $\propto \kappa_Z^2 / \kappa_H^2$
- cc channel (3%) $\propto \kappa_c^2 / \kappa_H^2$
  Extremely difficult
- The γγ channel (0.2%) $\propto \kappa_\gamma^2 / \kappa_H^2$





$$\kappa_\gamma \propto 1.6 \times \kappa_W^2 - 0.7 \times \kappa_t \kappa_W + 0.1 \times \kappa_t^2$$

(when assuming no BSM charged in the loop)

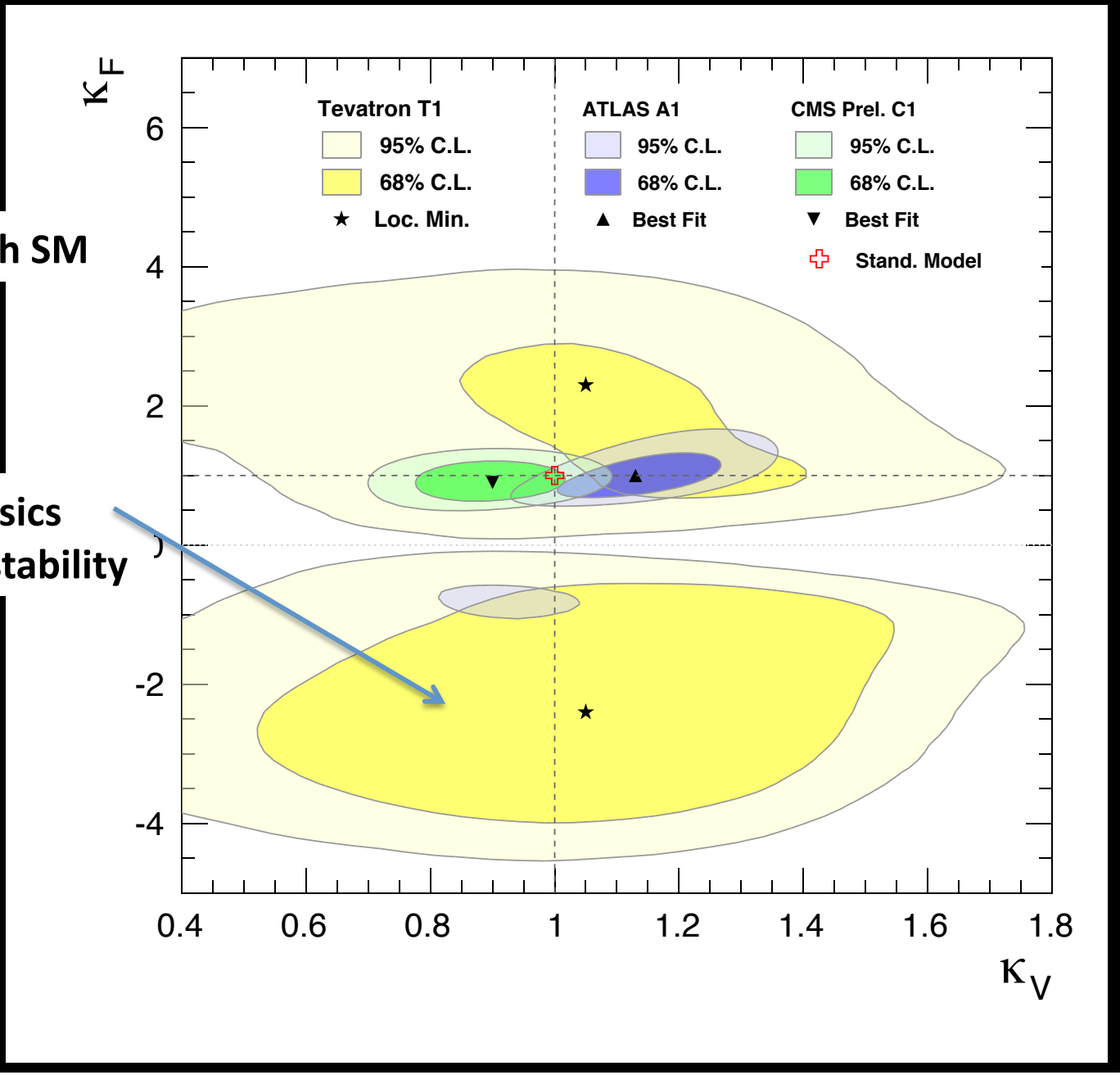
- The Zγ (0.2%) $\kappa_{Z\gamma} \propto 1.12 \times \kappa_W^2 - 0.15 \times \kappa_t \kappa_W + 0.03 \times \kappa_t^2$
- The μμ channel (0.02%) $\propto \kappa_\mu^2 / \kappa_H^2$

As in PDG (Aug 2014)

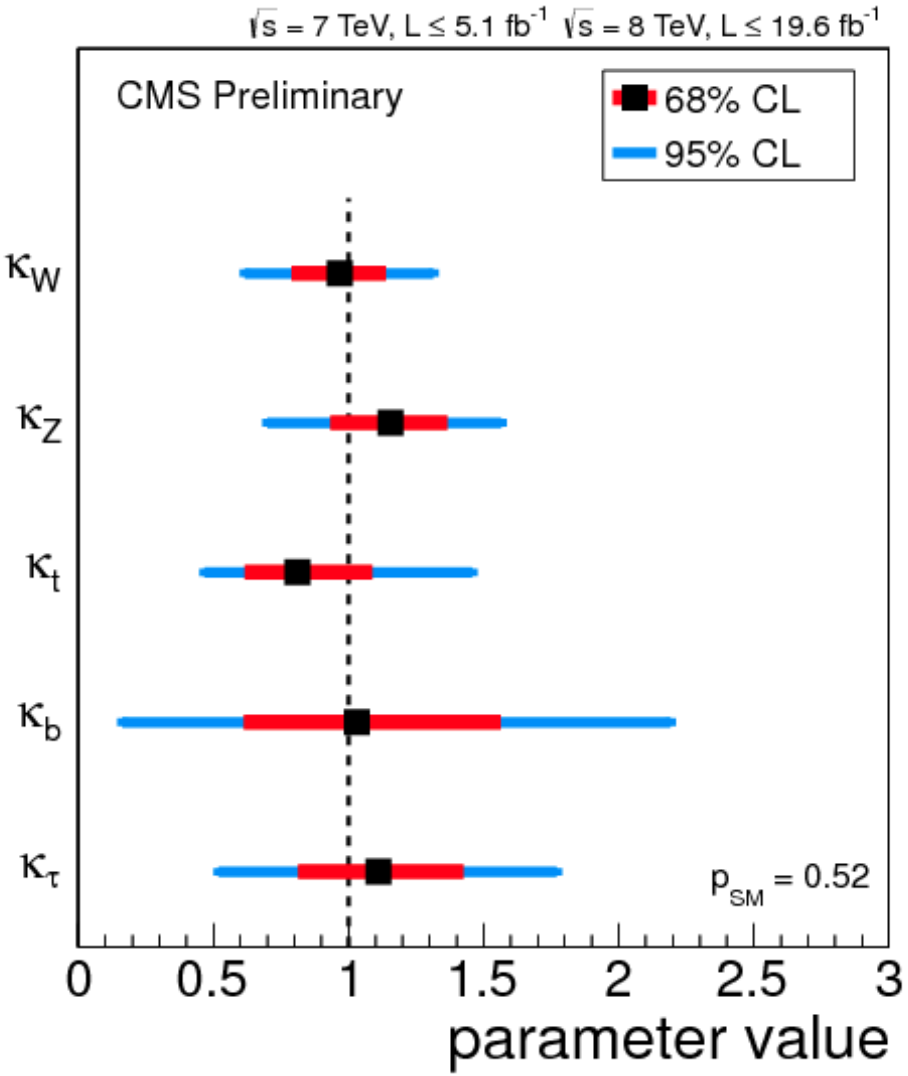
Relative Couplings to fermions/bosons

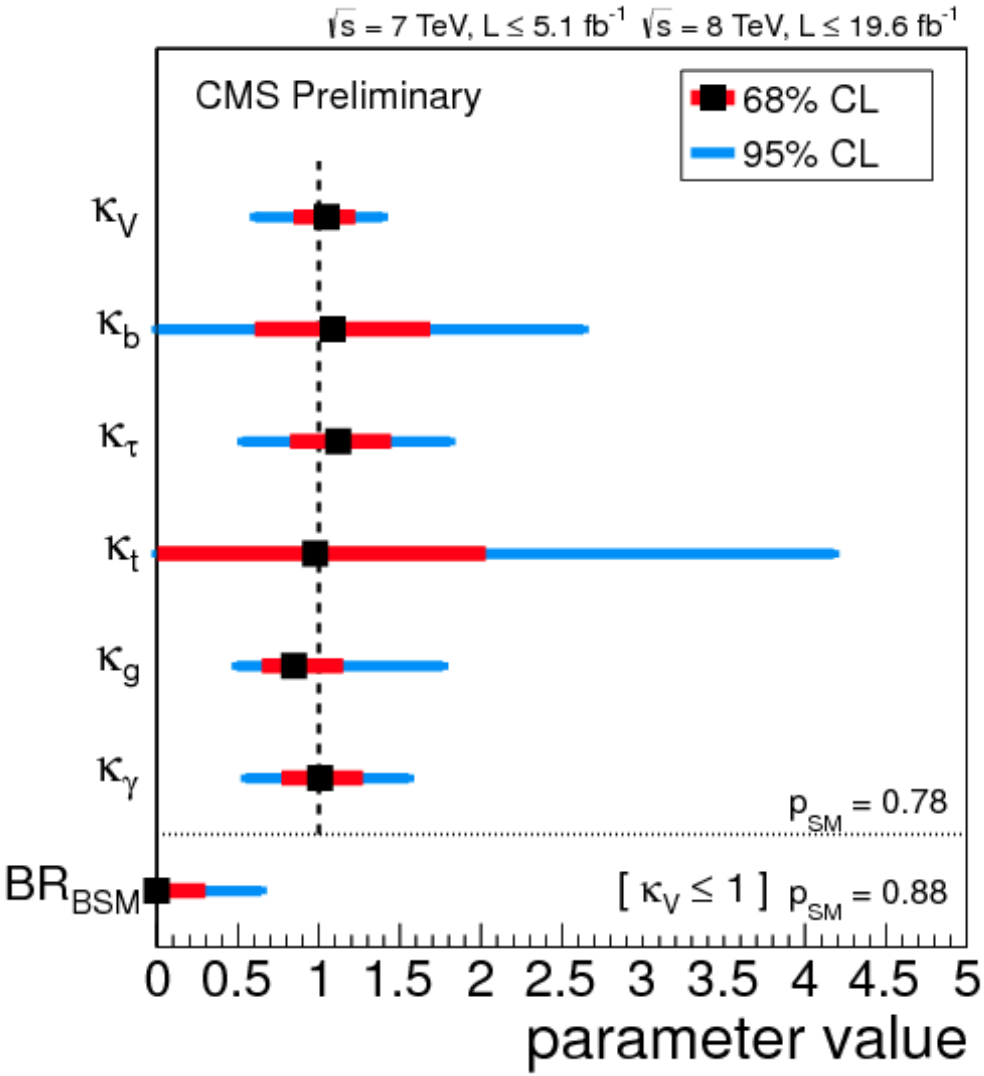
Best fit consistent with SM

That would imply new physics and compromise vacuum stability

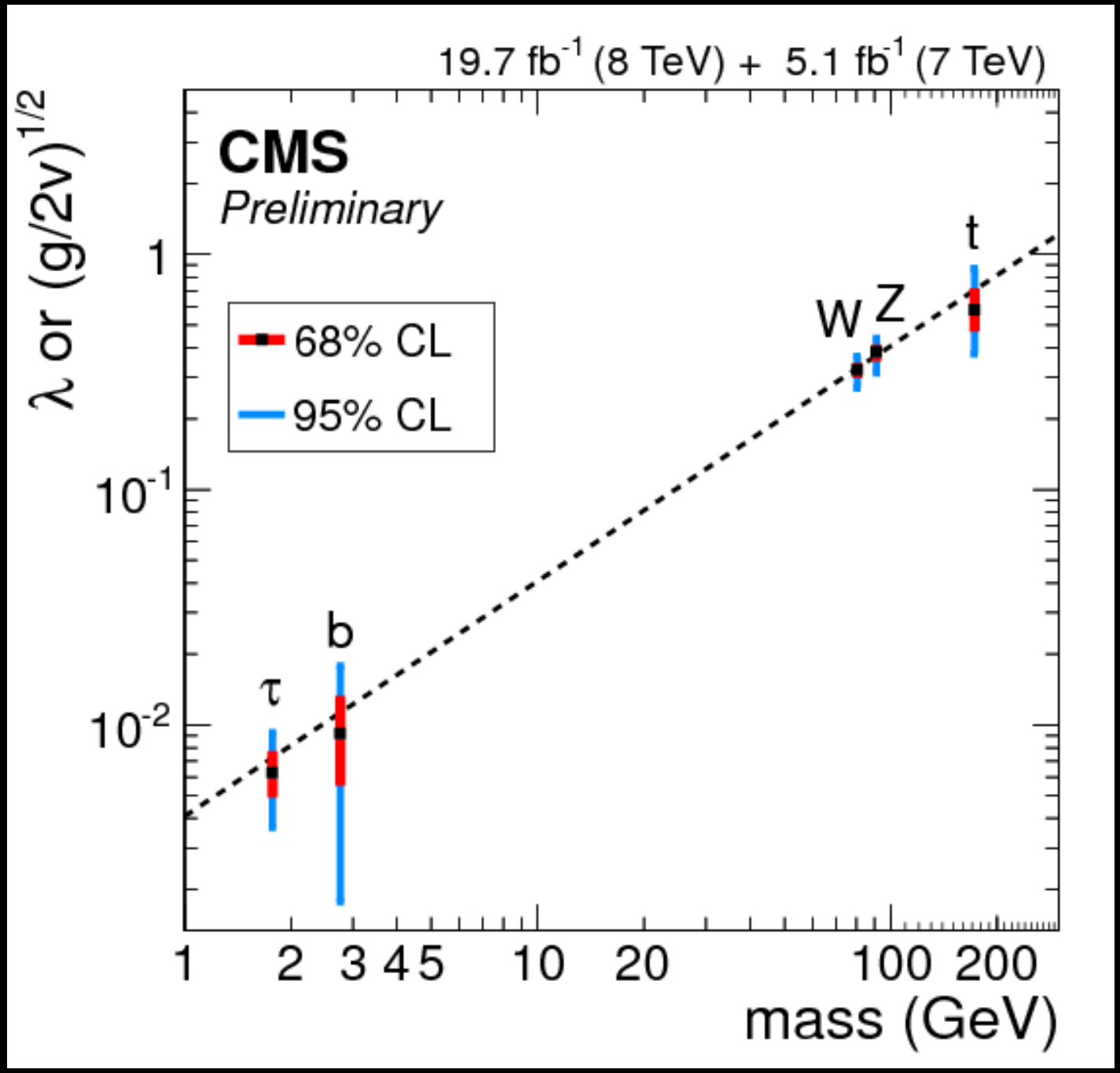


So close to 1…


√s = 7 TeV, L ≤ 5.1 fb-1 √s = 8 TeV, L ≤ 19.6 fb-1
CMS Preliminary
68% CL
95% CL
κW
κZ
κt
κb
κτ
p_SM = 0.52
0 0.5 1 1.5 2 2.5 3
parameter value

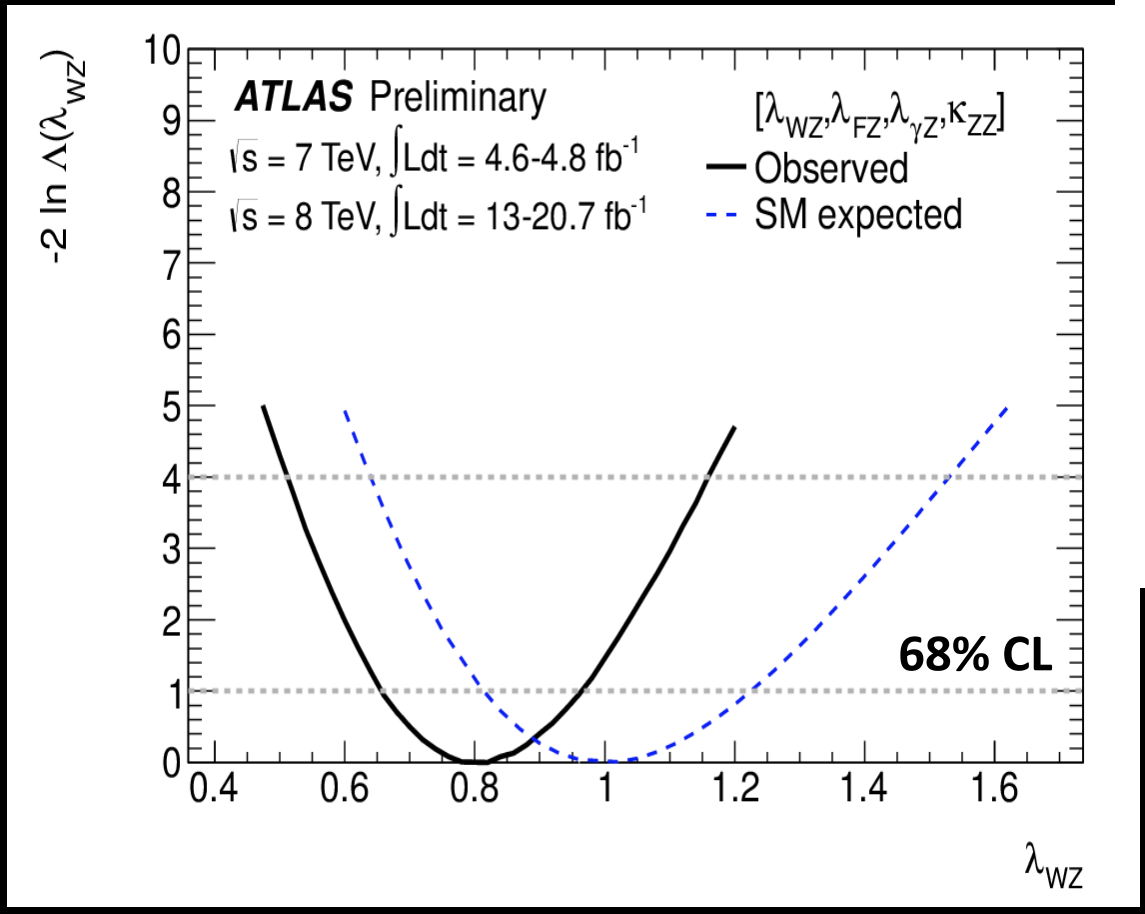

√s = 7 TeV, L ≤ 5.1 fb-1 √s = 8 TeV, L ≤ 19.6 fb-1
CMS Preliminary
68% CL
95% CL
κV
κb
κτ
κt
κg
κγ
BR_BSM
p_SM = 0.78
[κV ≤ 1] p_SM = 0.88
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
parameter value

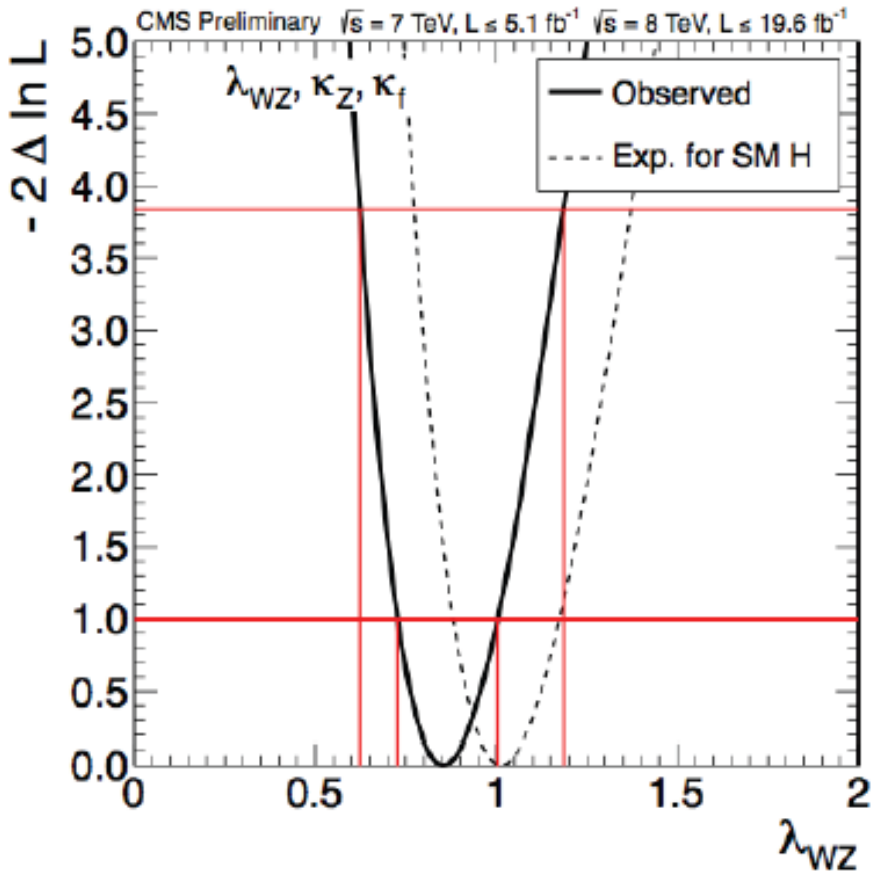
Higgs Couplings vs mass



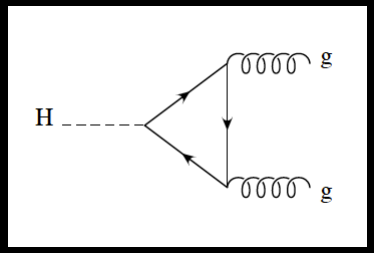
Custodial Symmetry (W/Z ratio)

$$\lambda_{WZ} = \kappa_W / \kappa_Z$$

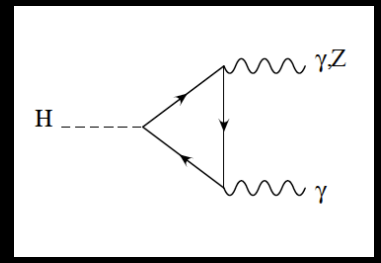


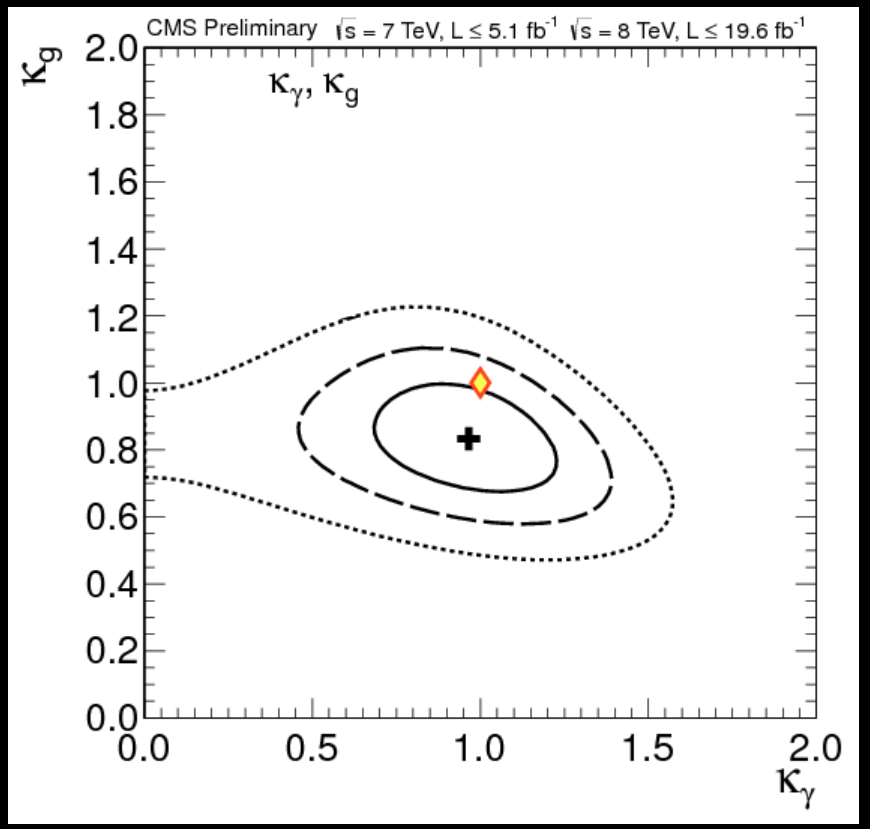


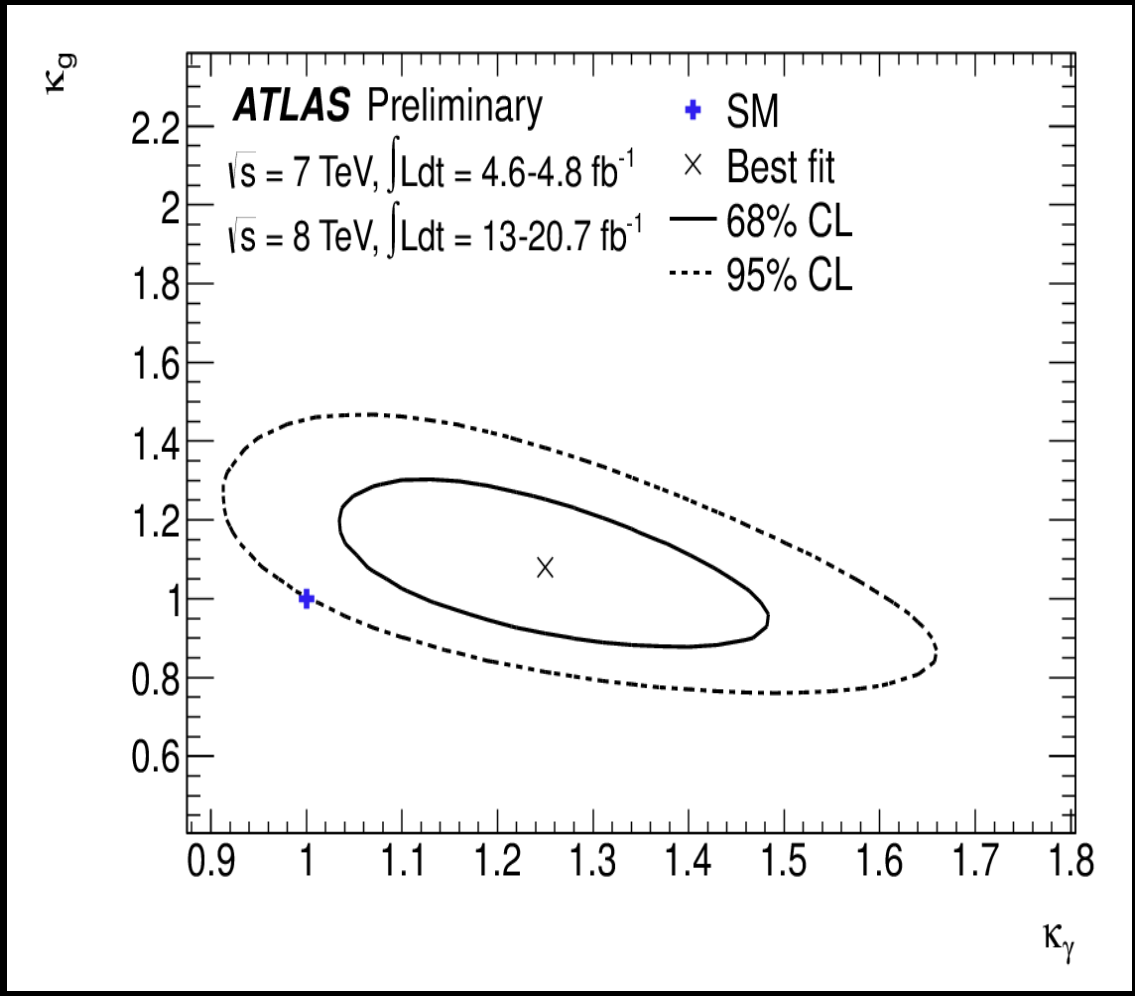
Consistent with SM $\rho = 1$



New Physics in Loops ?







Some tension in the γγ loop in ATLAS

H → γγ

Diphoton selection

$t\bar{t}H$ leptonic

$t\bar{t}H$ hadronic

VH dilepton
$(ZH \to \ell\ell H)$

VH one-lepton
$(WH \to \ell\nu H)$

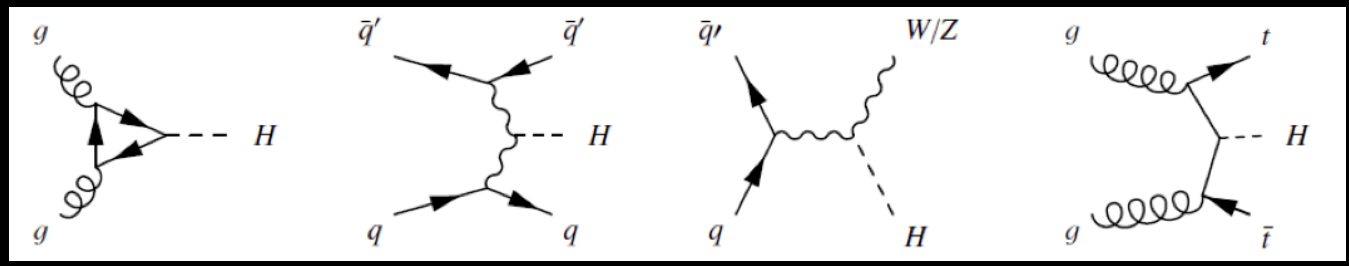
VH $E_{\mathrm{T}}^{\mathrm{miss}}$
$(ZH \to \nu\nu H;\ WH \to \ell\nu H)$

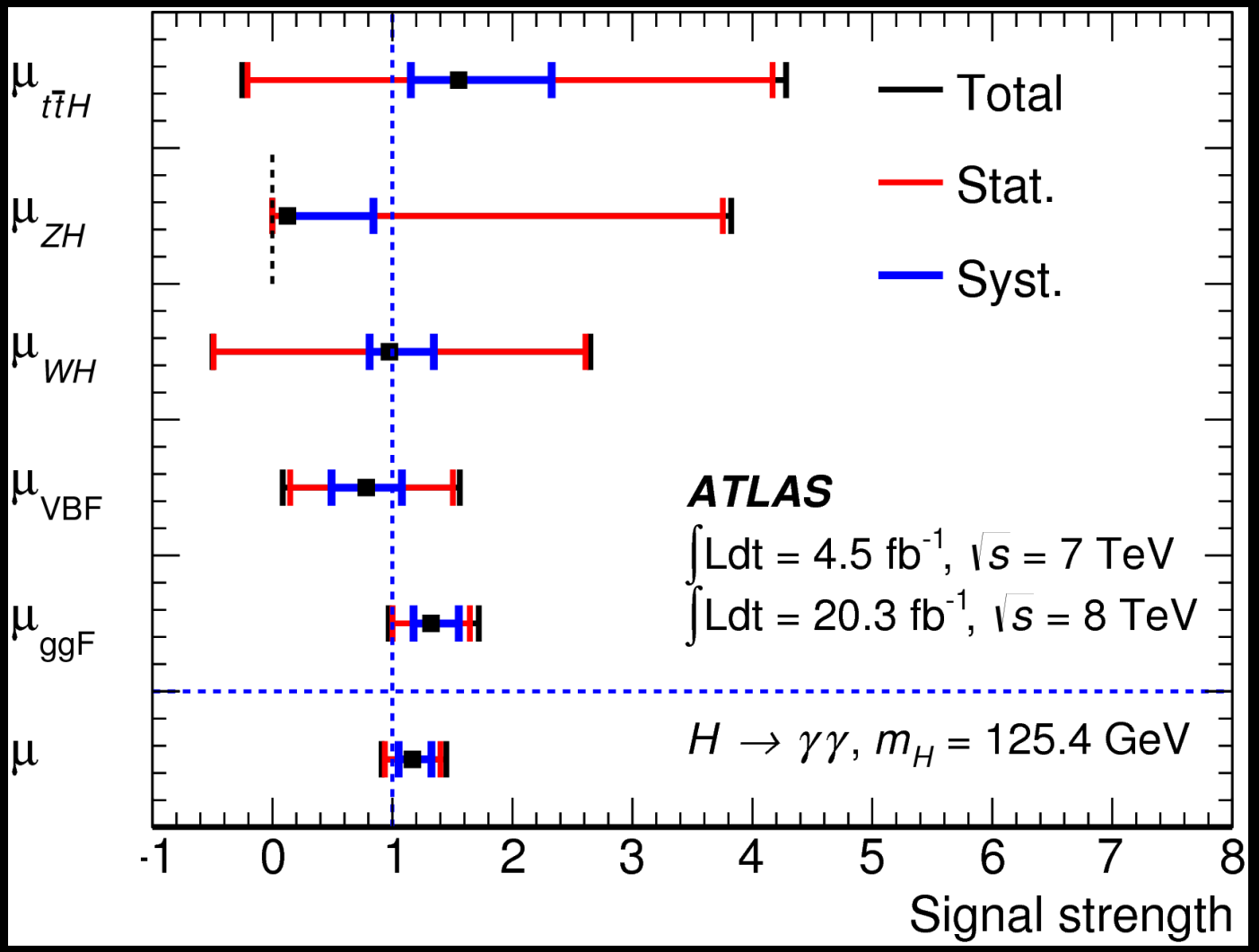
VH hadronic
$(WH \to jjH;\ ZH \to jjH)$

VBF tight
$(qqV \to jjH)$

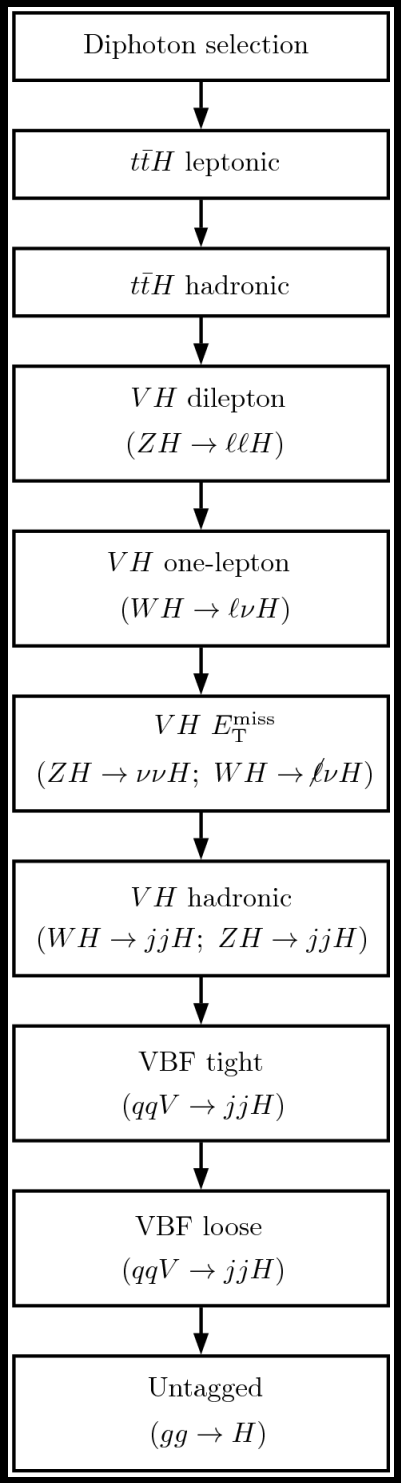
VBF loose
$(qqV \to jjH)$

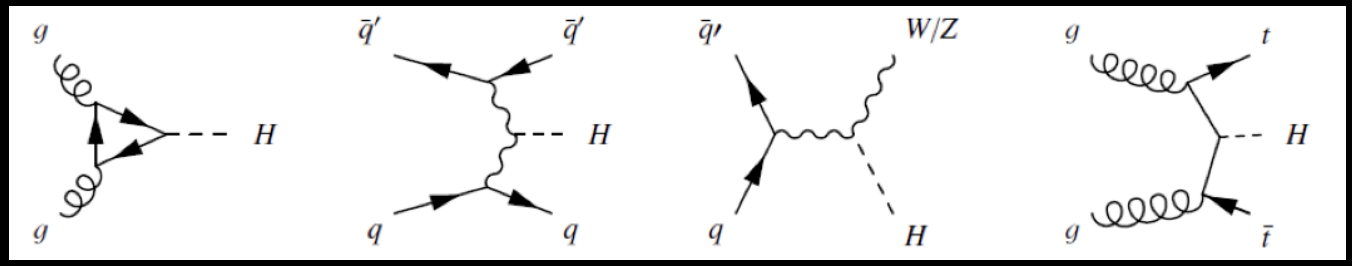
Untagged
$(gg \to H)$

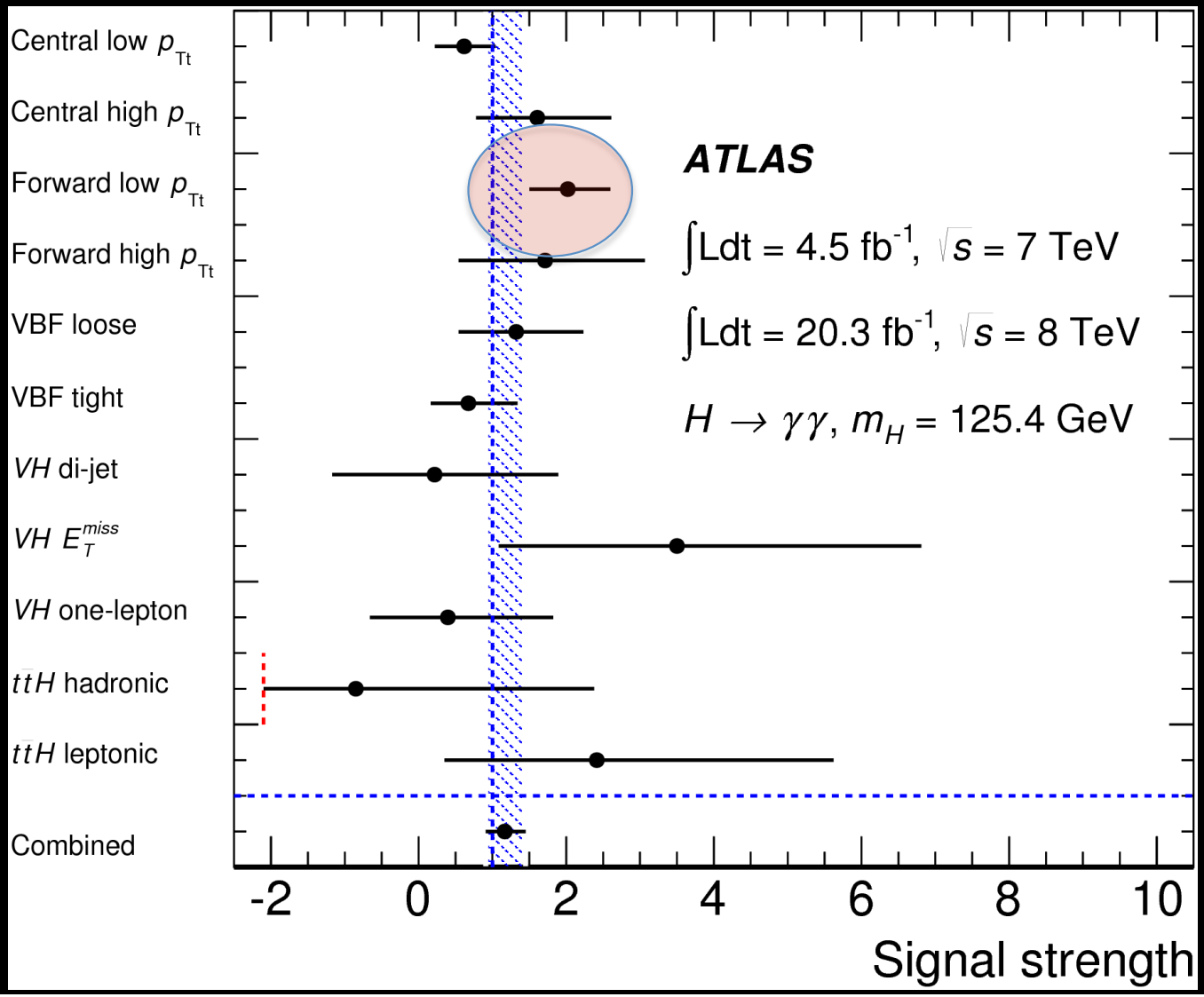




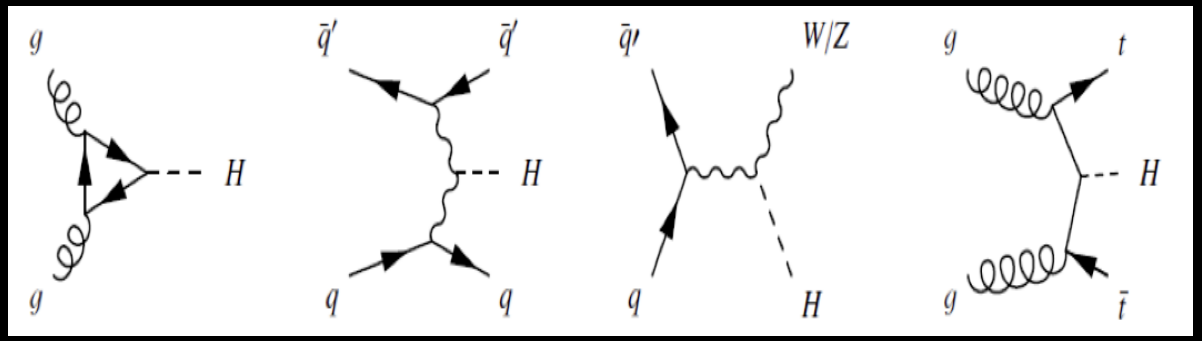
H → γγ


Diphoton selection
$t\bar{t}H$ leptonic
$t\bar{t}H$ hadronic
VH dilepton
$(ZH \to \ell\ell H)$
VH one-lepton
$(WH \to \ell\nu H)$
VH $E_{\mathrm{T}}^{\mathrm{miss}}$
$(ZH \to \nu\nu H;\ WH \to \ell\nu H)$
VH hadronic
$(WH \to jjH;\ ZH \to jjH)$
VBF tight
$(qqV \to jjH)$
VBF loose
$(qqV \to jjH)$
Untagged
$(gg \to H)$

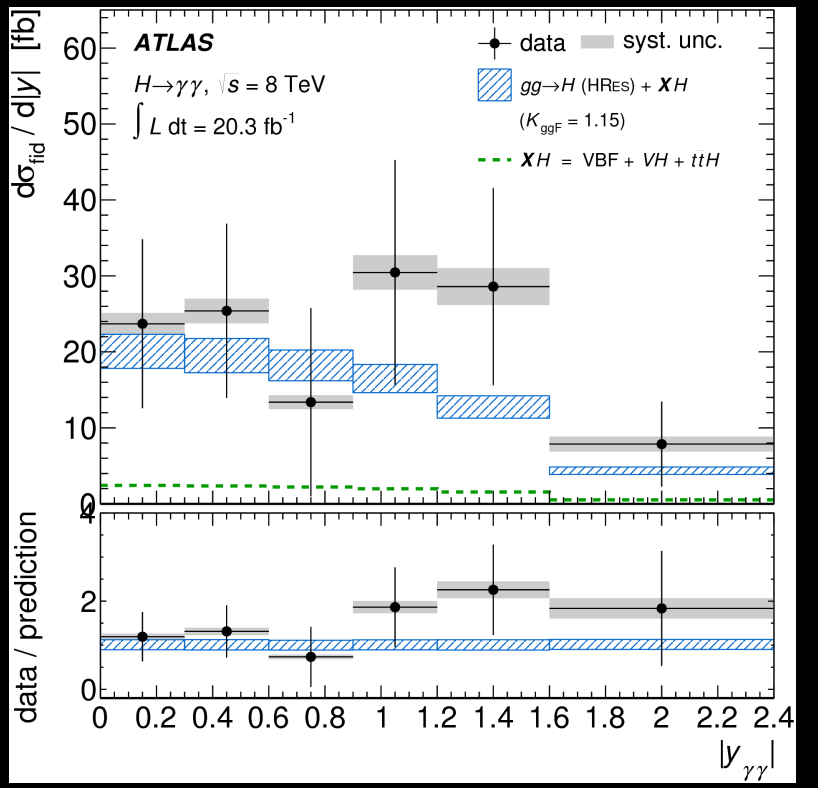

g
g
H
$\bar{q}'$
q
$\bar{q}'$
q
H
$\bar{q}'$
q
W/Z
H
g
g
t
$\bar{t}$
H

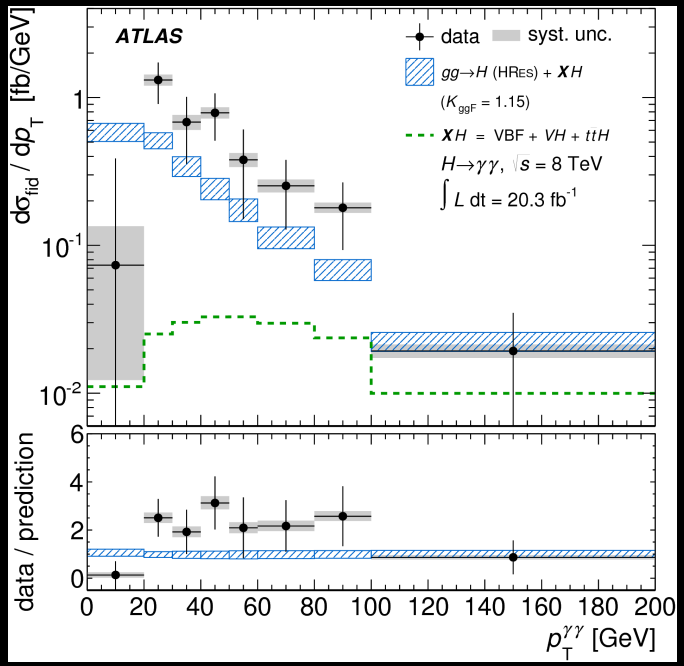

Central low p_{Tt}
Central high p_{Tt}
Forward low p_{Tt}
Forward high p_{Tt}
VBF loose
VBF tight
VH di-jet
VH E_T^{miss}
VH one-lepton
$t\bar{t}H$ hadronic
$t\bar{t}H$ leptonic
Combined
ATLAS
$\int$Ldt = 4.5 fb^{-1}, $\sqrt{s}$ = 7 TeV
$\int$Ldt = 20.3 fb^{-1}, $\sqrt{s}$ = 8 TeV
$H \to \gamma\gamma$, m_H = 125.4 GeV
-2
0
2
4
6
8
10
Signal strength

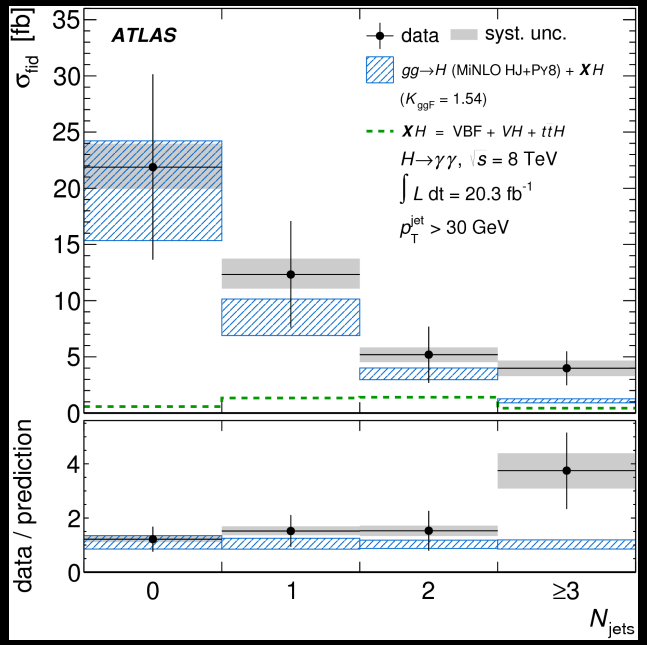
Going differential…

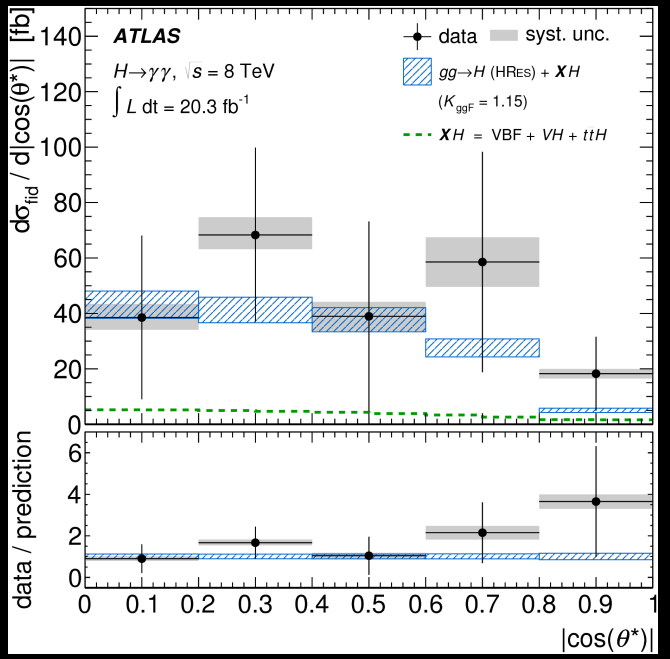


Some excess at low $p_T^{\gamma\gamma}$ and large $Y_{\gamma\gamma}$



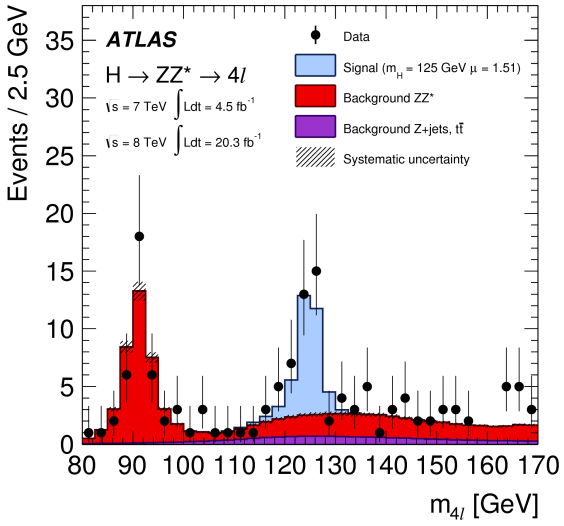


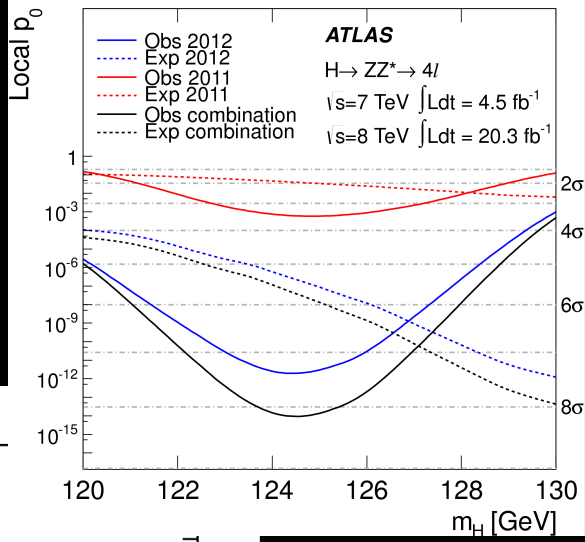


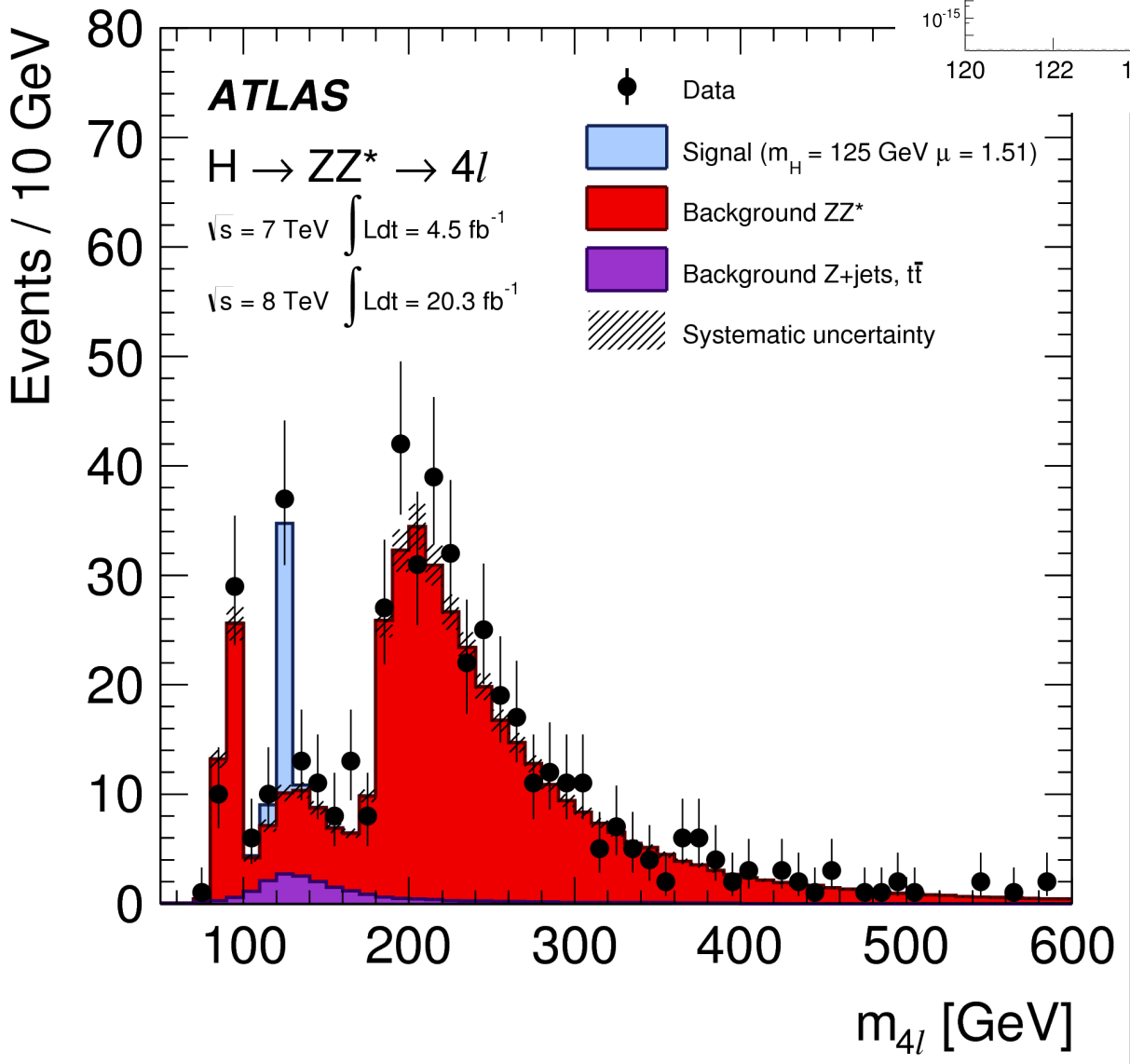


H → ZZ* → 4l

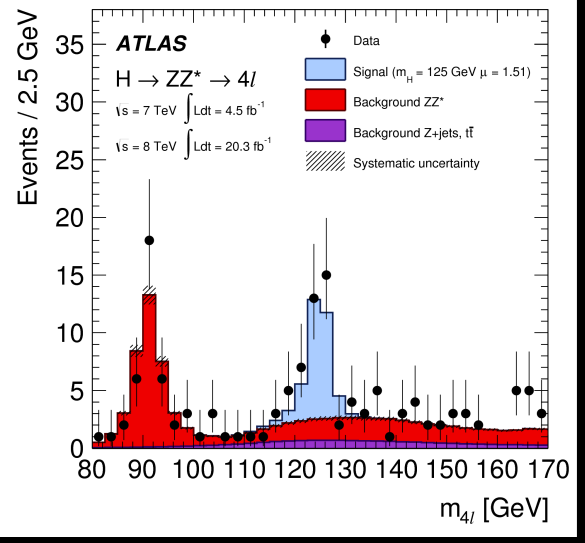
Run I Combination (ATLAS)

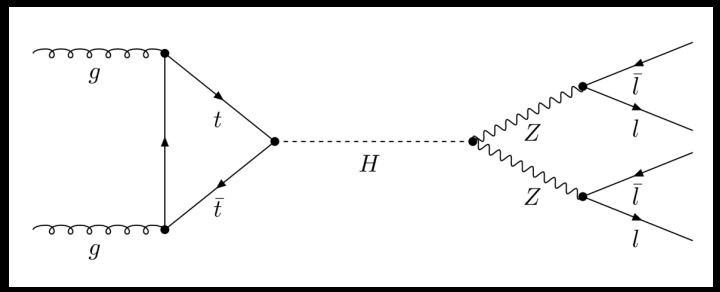


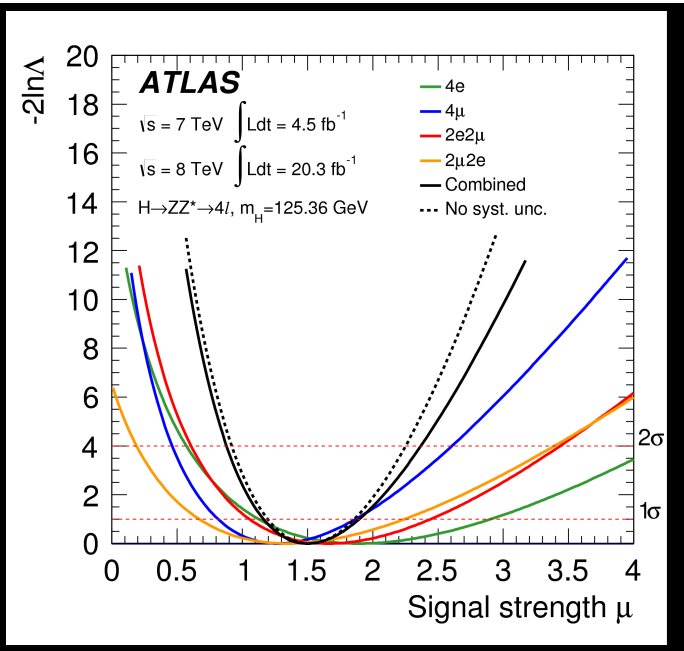


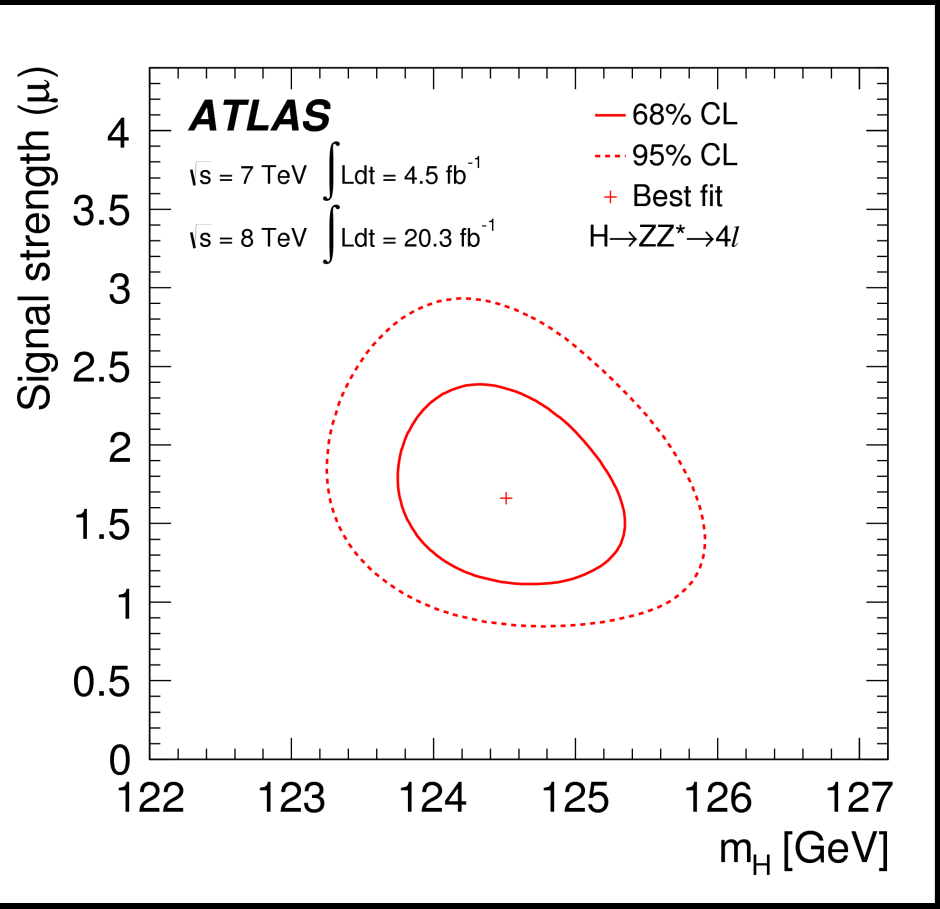


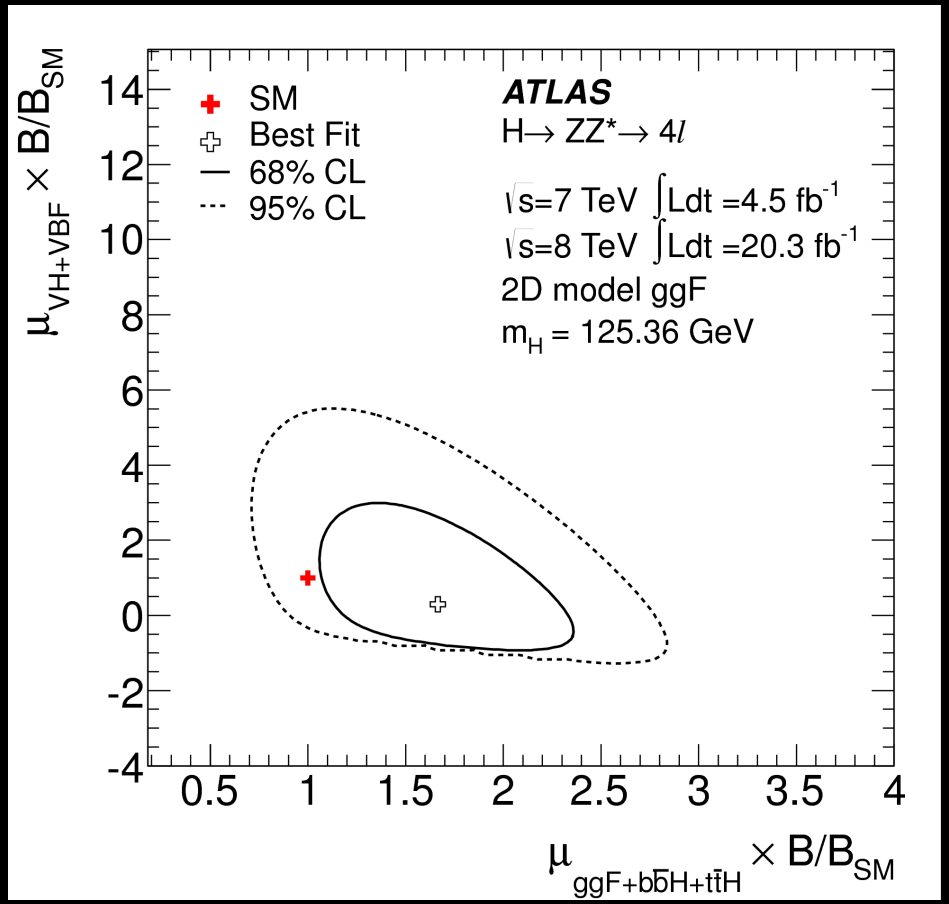
H → ZZ* → 4l


ATLAS
H → ZZ* → 4l
√s = 7 TeV ∫Ldt = 4.5 fb-1
√s = 8 TeV ∫Ldt = 20.3 fb-1
Data
Signal (mH = 125 GeV μ = 1.51)
Background ZZ*
Background Z+jets, tt̄
Systematic uncertainty
Events / 2.5 GeV
m4l [GeV]

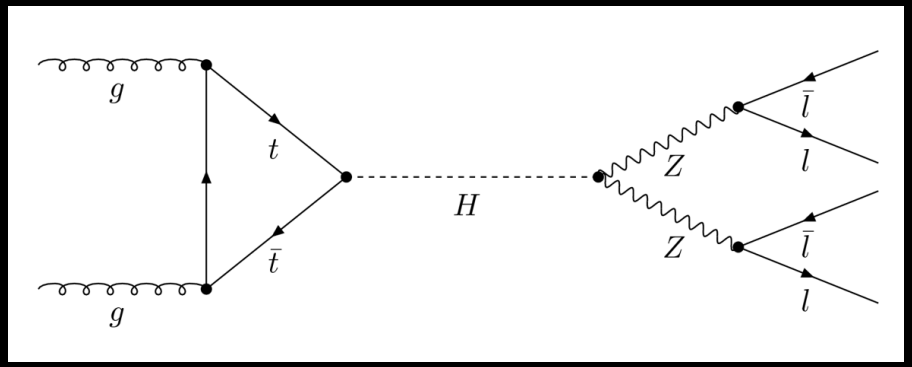

g
g
t
t̄
H
Z
Z
l̄
l
l̄
l

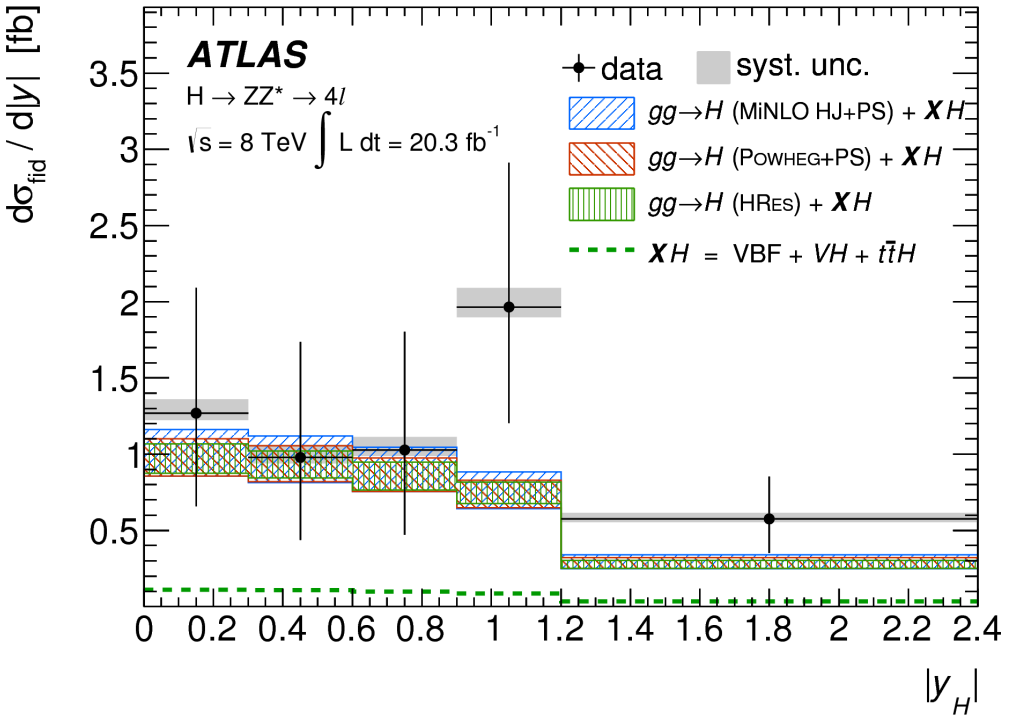

ATLAS
√s = 7 TeV ∫Ldt = 4.5 fb-1
√s = 8 TeV ∫Ldt = 20.3 fb-1
H→ZZ*→4l, mH=125.36 GeV
4e
4μ
2e2μ
2μ2e
Combined
No syst. unc.
-2lnΛ
2σ
1σ
Signal strength μ


ATLAS
√s = 7 TeV ∫Ldt = 4.5 fb-1
√s = 8 TeV ∫Ldt = 20.3 fb-1
68% CL
95% CL
Best fit
H→ZZ*→4l
Signal strength (μ)
mH [GeV]

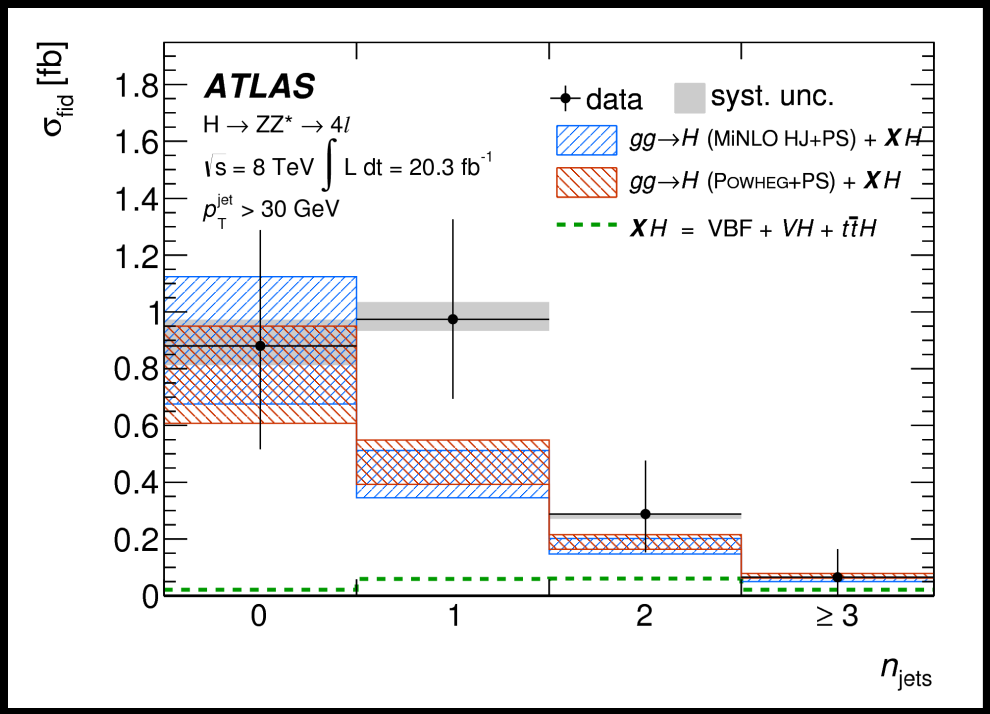

SM
Best Fit
68% CL
95% CL
ATLAS
H→ ZZ*→ 4l
√s=7 TeV ∫Ldt =4.5 fb-1
√s=8 TeV ∫Ldt =20.3 fb-1
2D model ggF
mH = 125.36 GeV
μVH+VBF × B/BSM
μggF+bb̄H+tt̄H × B/BSM

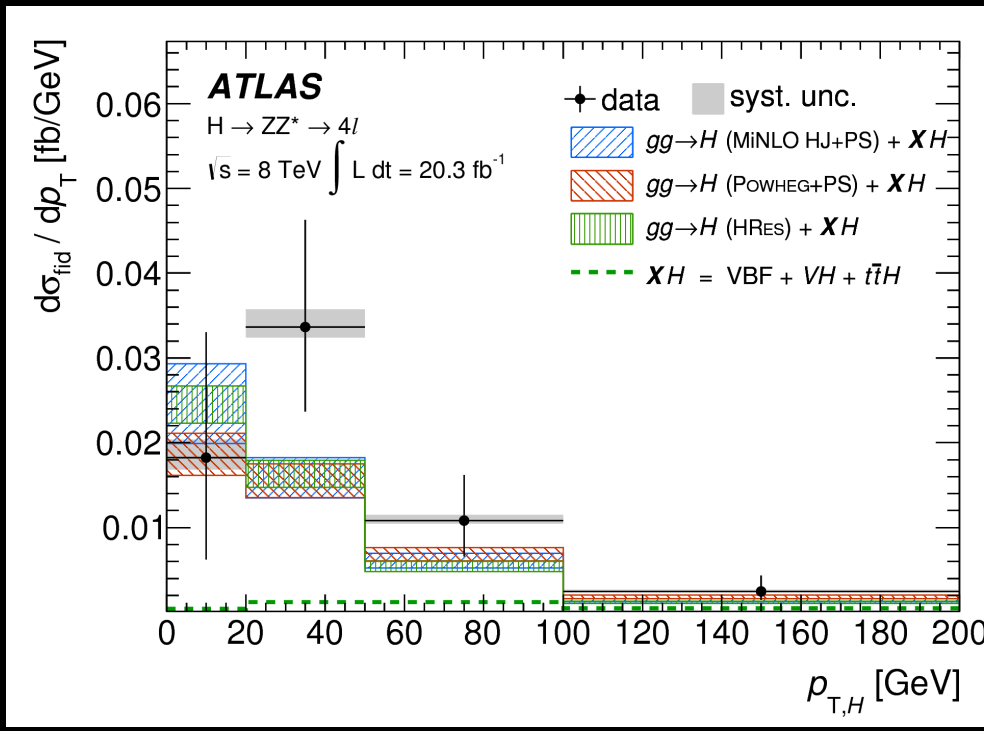
Going Differential...

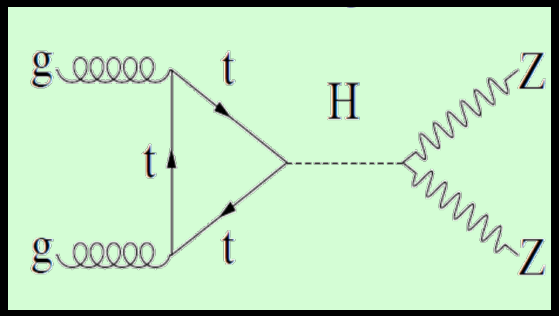




Reasonable within the limited statistics







Higgs width

Sensitive to small contributions

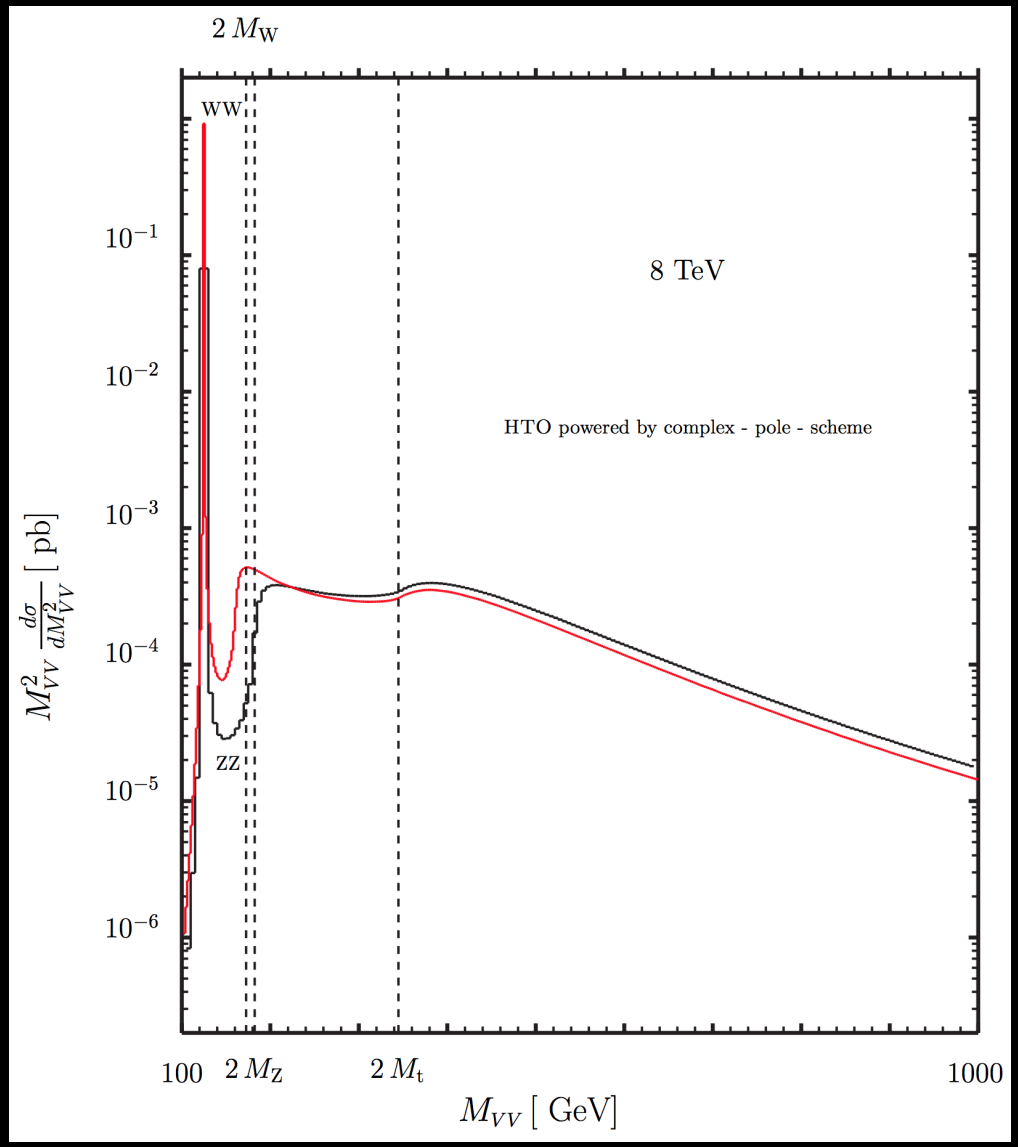
$$\Gamma_H\,(SM) \;=\; 4.2\ \text{MeV}$$

$$\frac{d\sigma_{gg\to H\to ZZ}}{dm^2_{ZZ}} \sim \frac{g^2_{ggH}g^2_{HZZ}}{(m^2_{ZZ}-m^2_H)^2+m^2_H\Gamma^2_H}$$

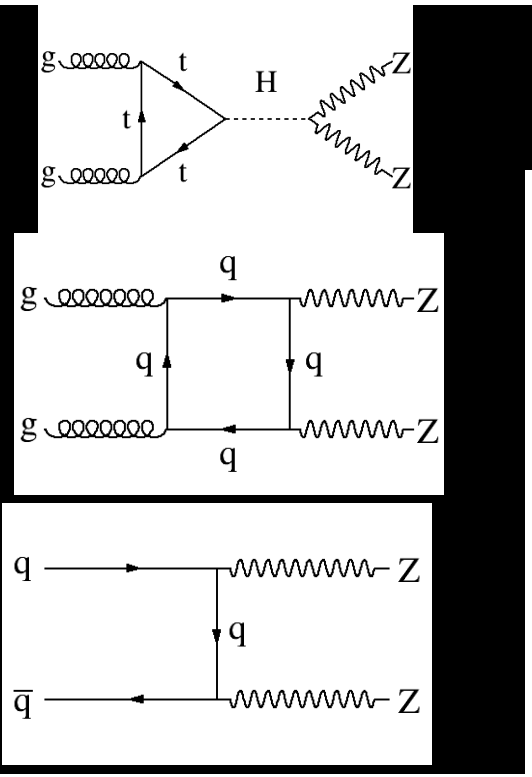
$$\sigma^{\text{on-shell}}_{gg\to H\to ZZ} \sim \frac{g^2_{ggH}g^2_{HZZ}}{m_H\Gamma_H}$$

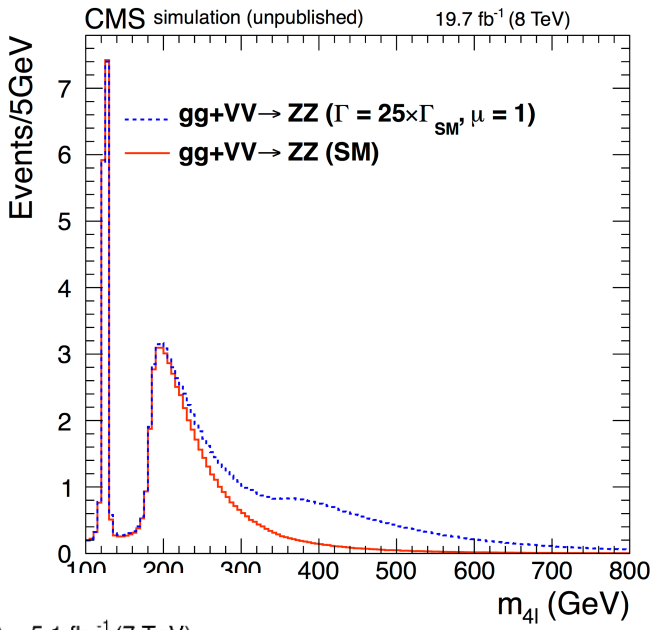
$$\sigma^{\text{off-shell}}_{gg\to H\to ZZ} \sim \frac{g^2_{ggH}g^2_{HZZ}}{(2m_Z)^2}$$

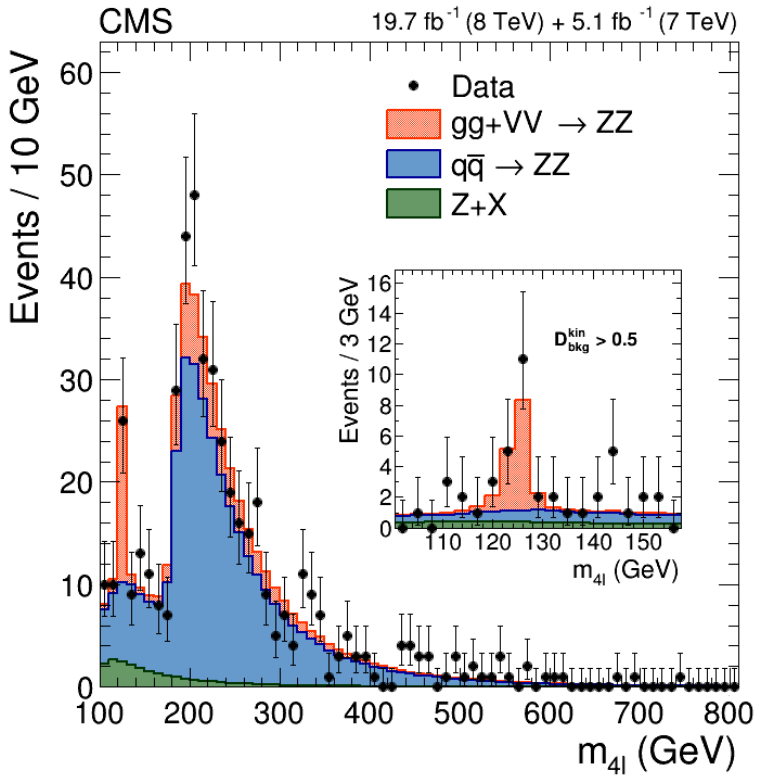
$$\frac{\sigma^{\text{off-shell}}_{gg\to H\to ZZ}}{\sigma^{\text{on-shell}}_{gg\to H\to ZZ}} \sim \Gamma_H$$

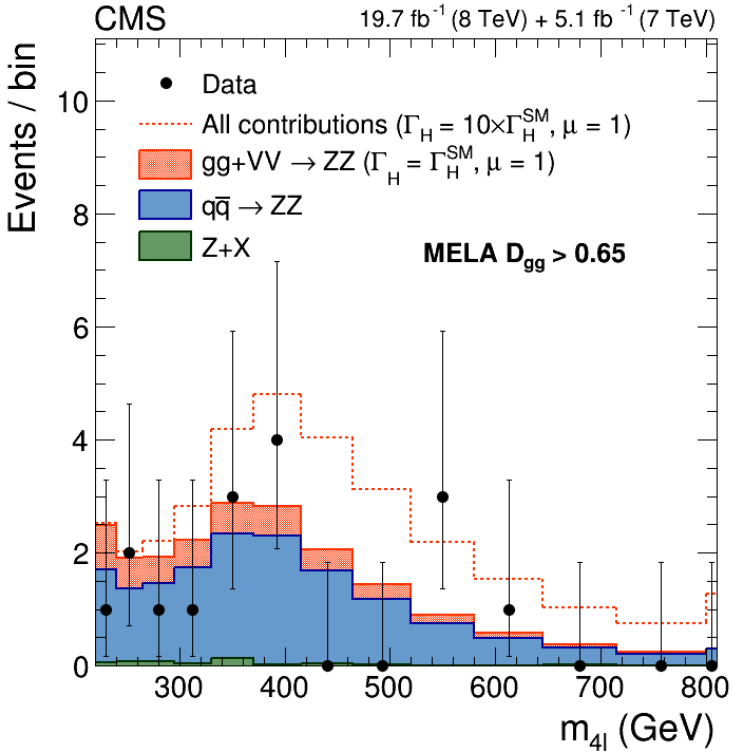


Off-Shell Higgs

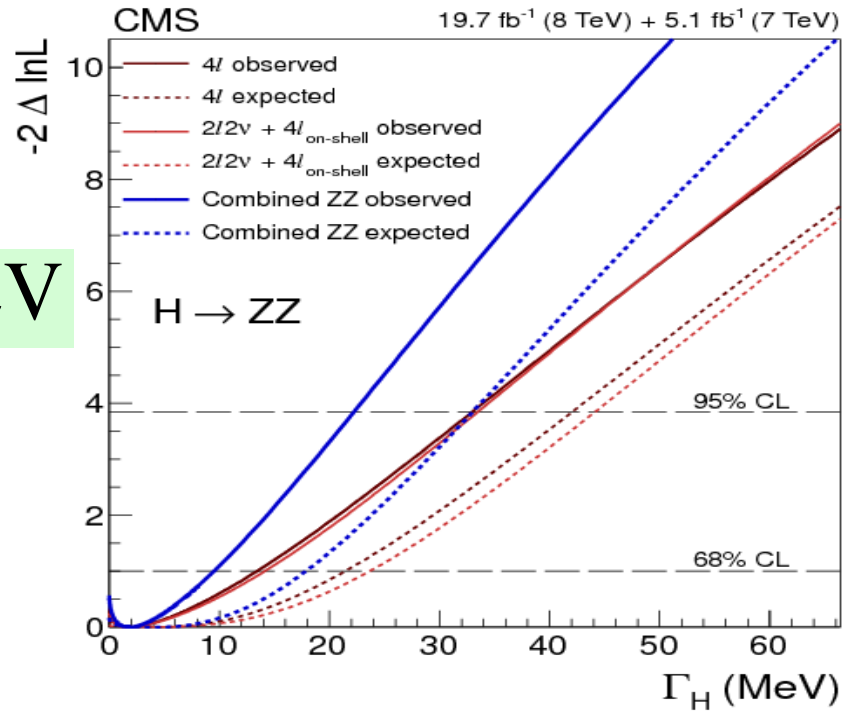






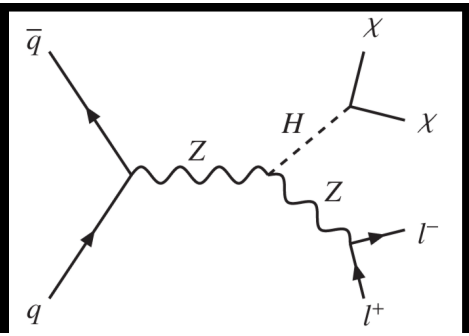


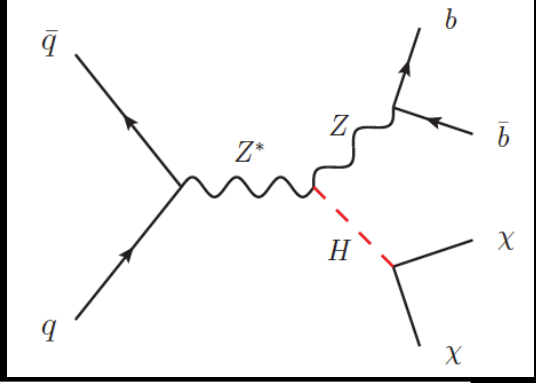
$\Gamma_{4l} < 3$ GeV



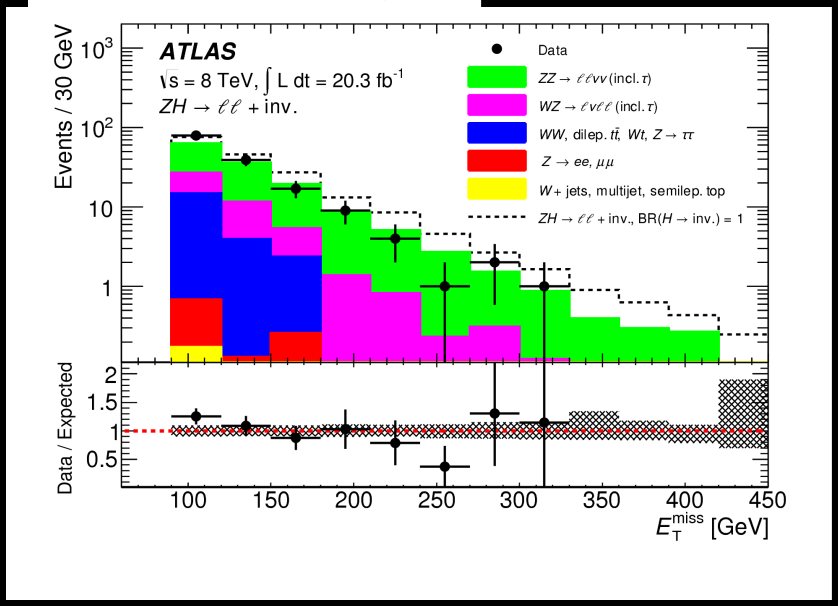
Invisibly decaying Higgs

Invisible Higgs

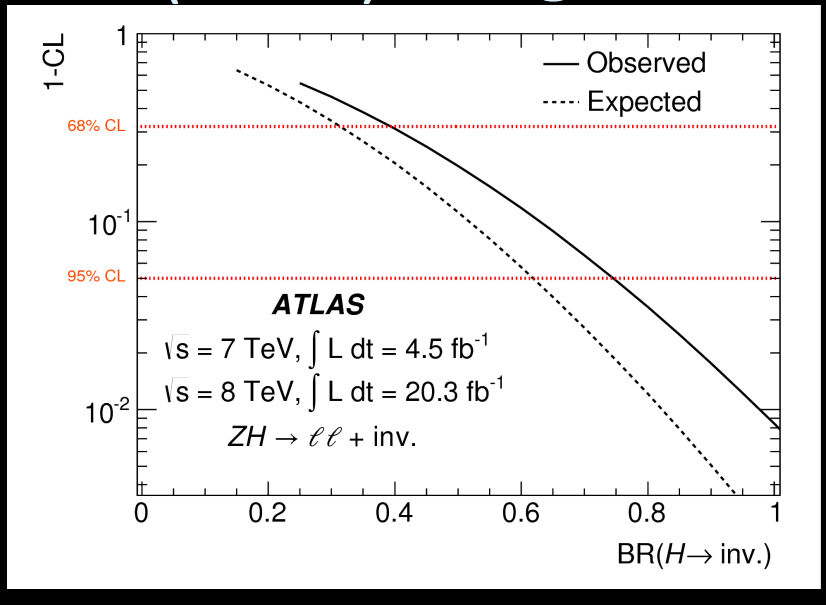


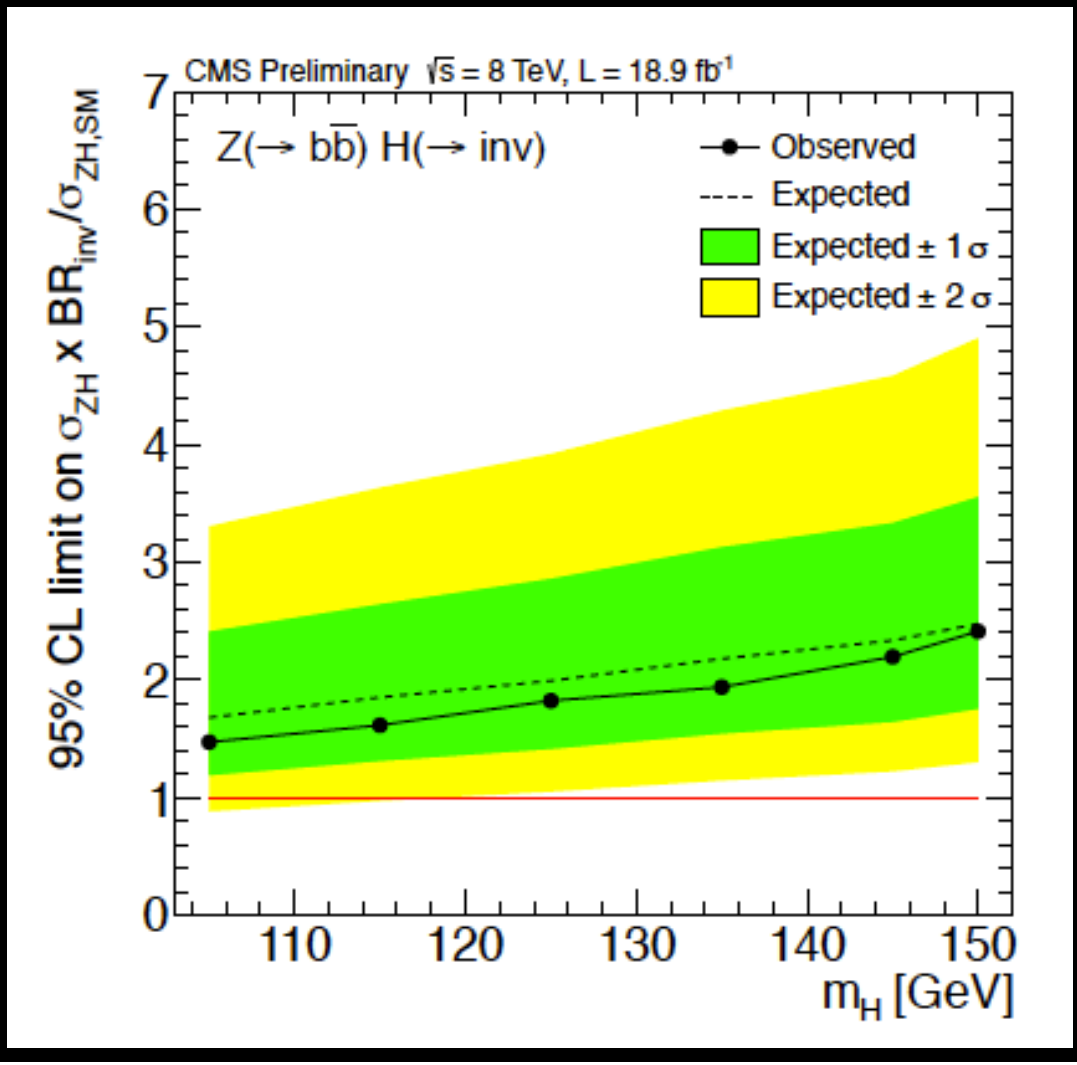


$\sigma \mathrm{Br}_{\mathrm{inv}} / \sigma^{SM} < 1.8$ @ 95% CL

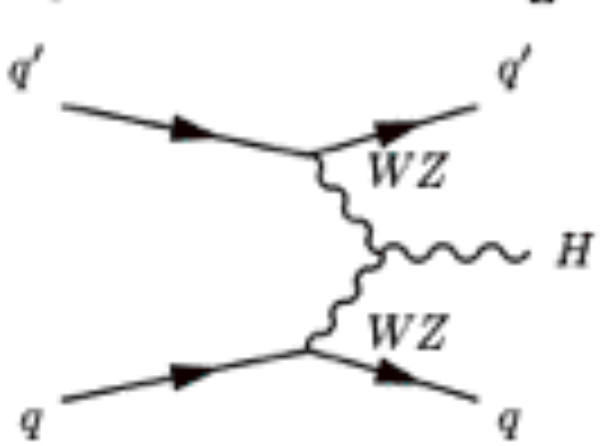


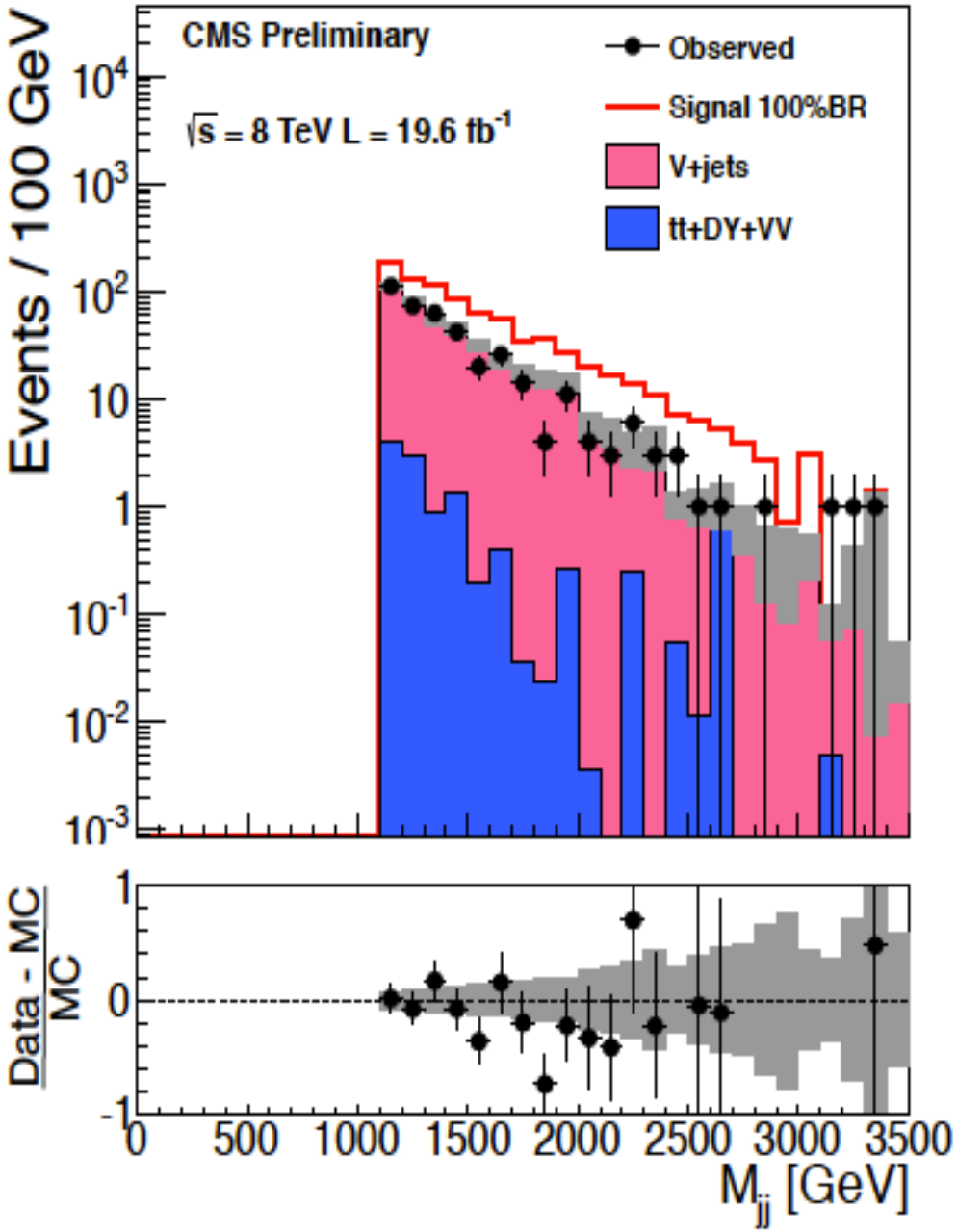
BR (invisible) < 75% @ 95% CL

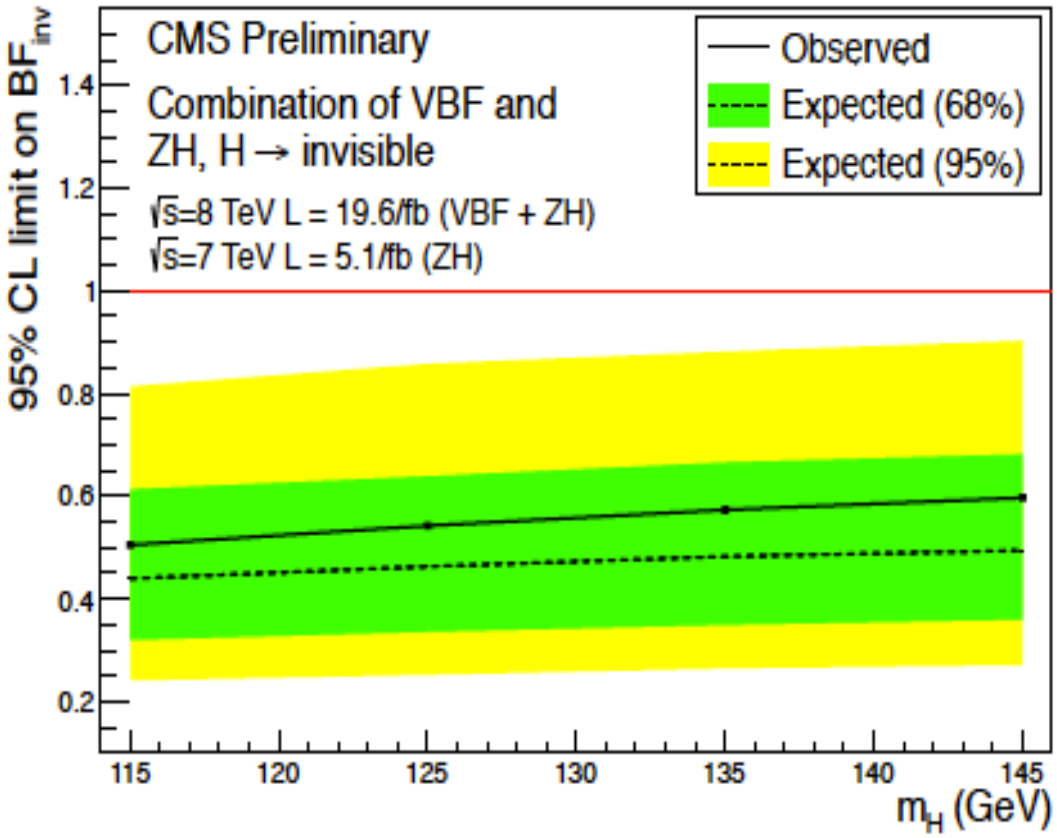




Invisible Higgs





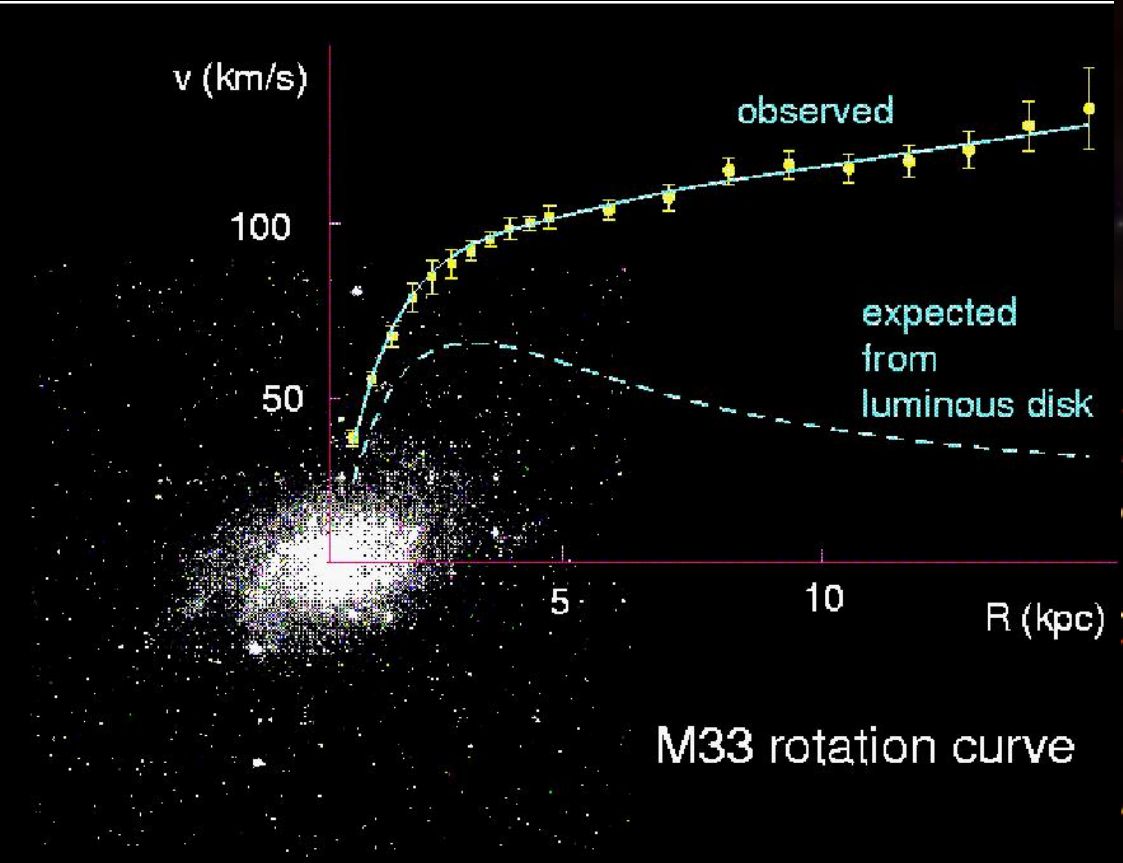


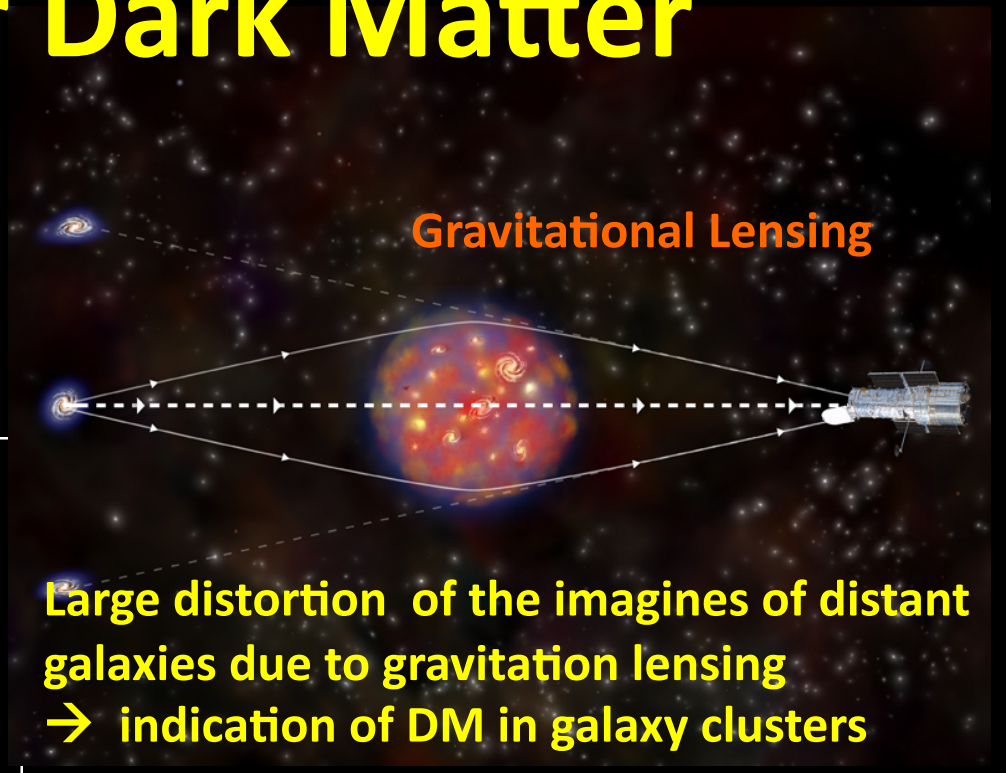
BR (invisible) < 69% @ 95% CL

Evidence for Dark Matter

The rotation of the stars around the center of the galaxies is not consistent with the amount of mass observed
$(L/M\ ratio)_{SUN}$

Spherical dark matter halo



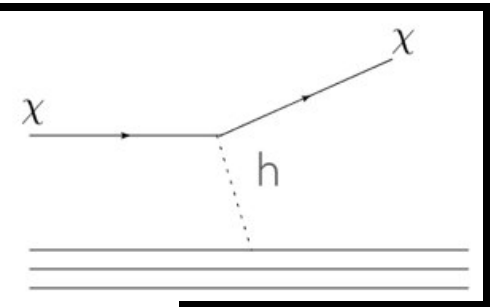


Gravitational Lensing

Large distortion of the imagines of distant galaxies due to gravitation lensing
→ indication of DM in galaxy clusters

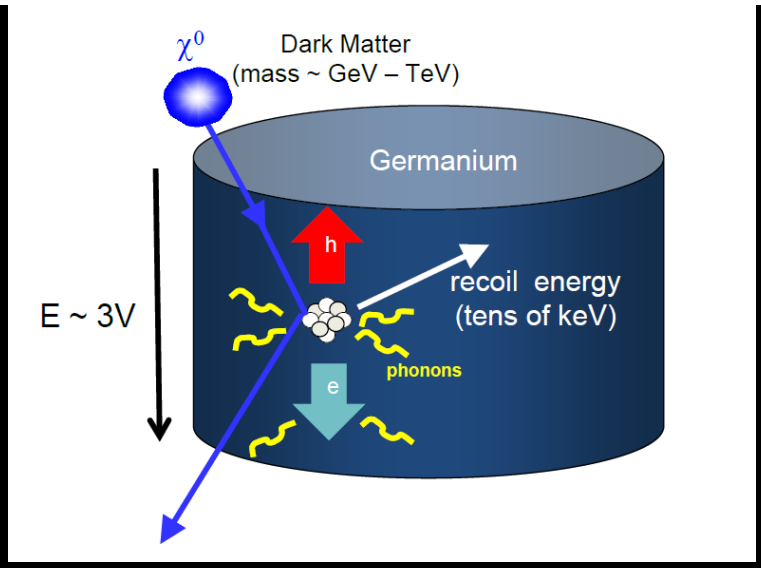
Collisions of clusters of galaxies

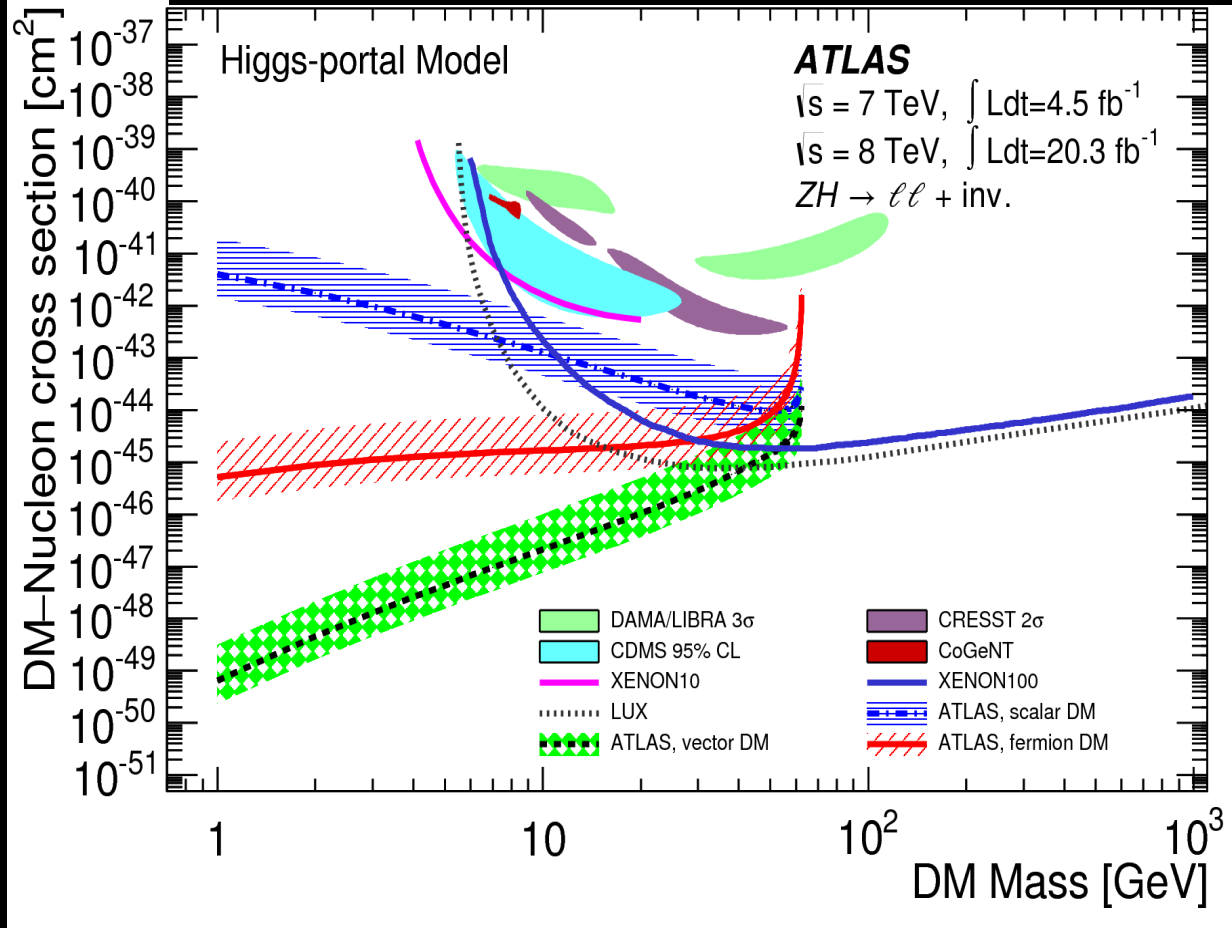
Considered the ultimate demonstration of the presence of Dark Matter since this does not involve Newton's Law

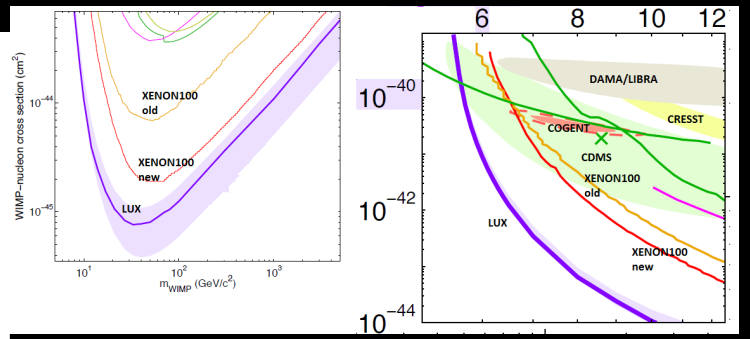


Higgs Portal

The limits on invisibly decaying Higgs can be re-interpreted in the context of SM – DM interactions via light Higgs mediators



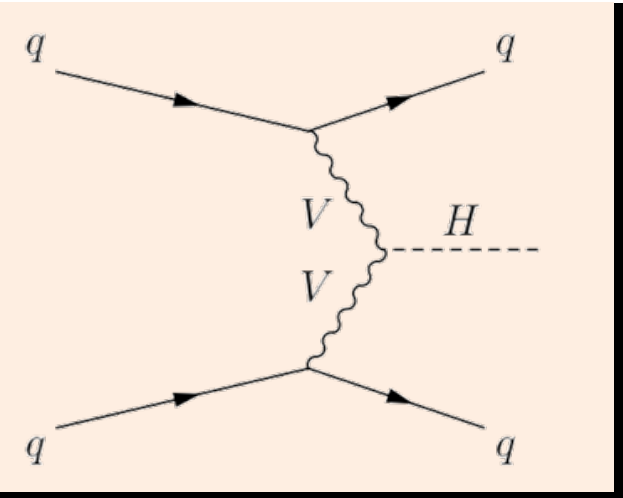


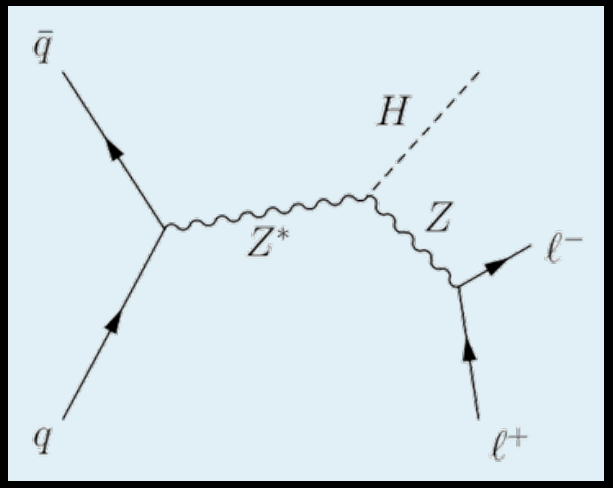


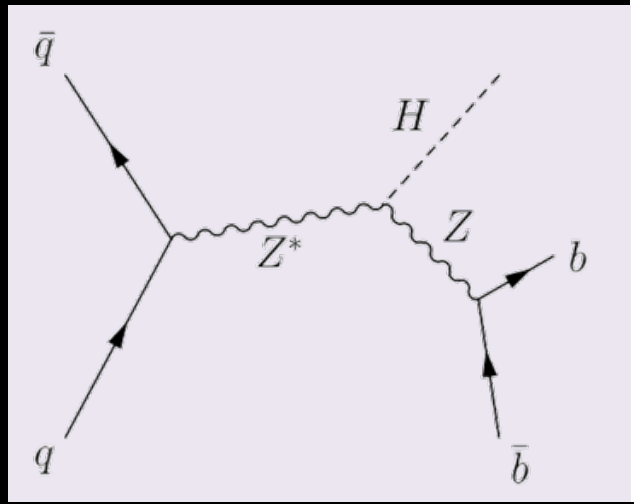
Note the LHC results provide unique access to light DM range (< 10 GeV)

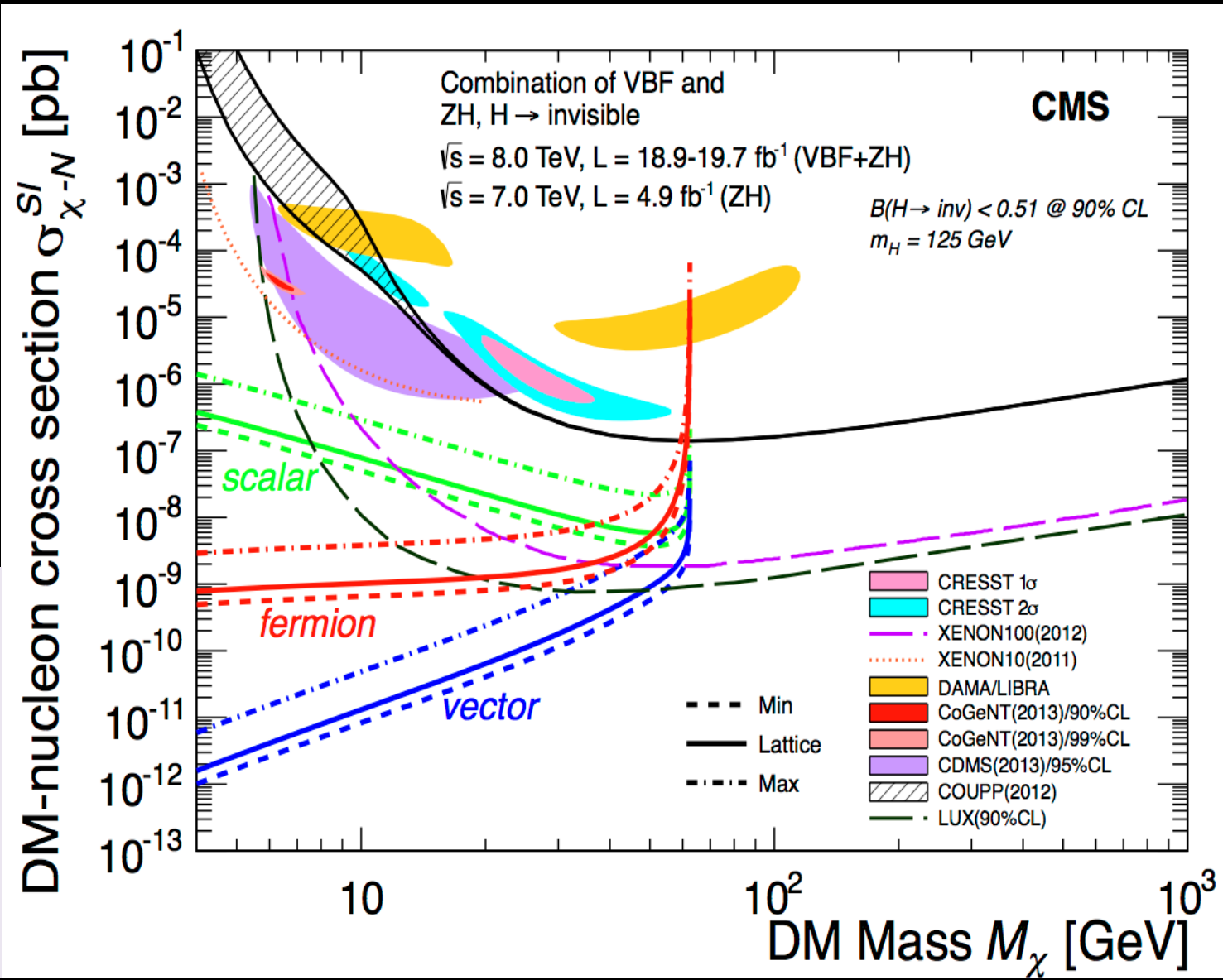
Higgs Portal

Assuming different kind of DM – Higgs Interactions

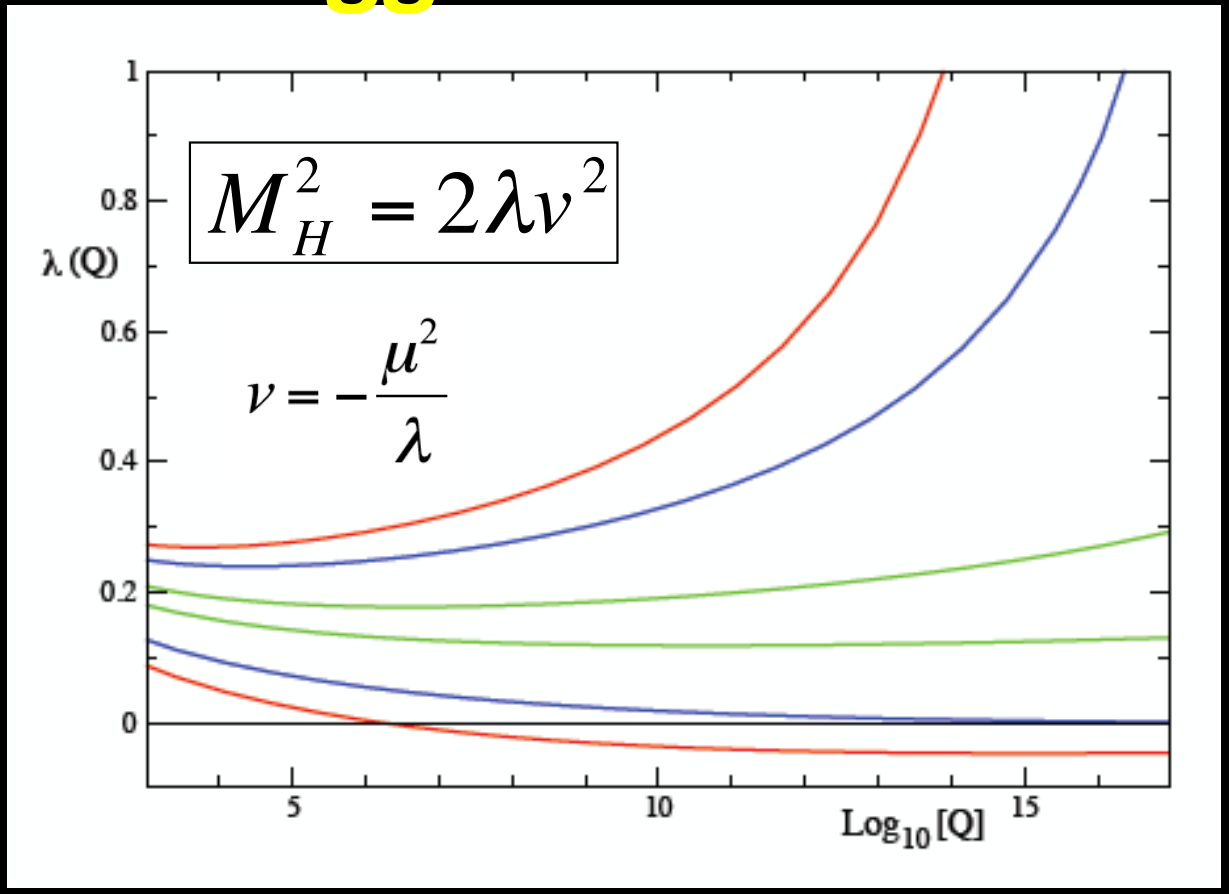




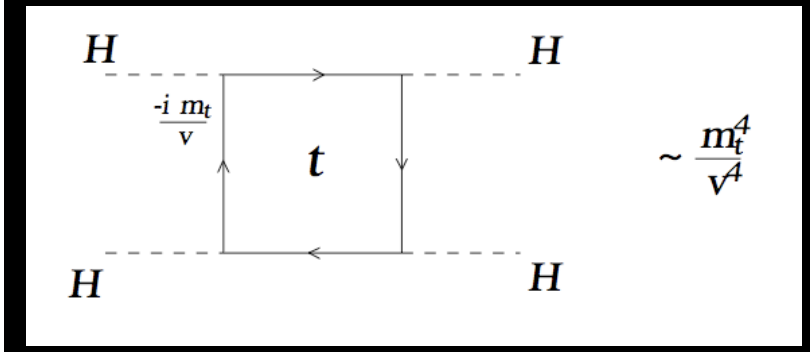




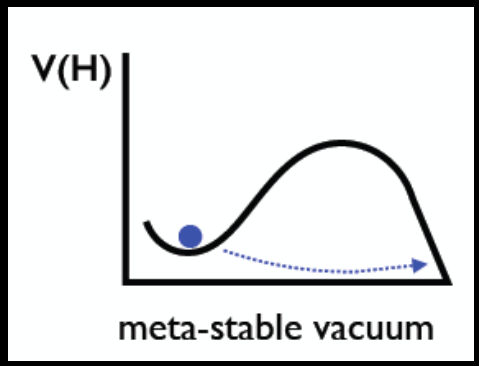
Higgs mass and Vacuum Stability



If too large it becomes non-perturbative



If too negative destabilizes the EWK vacuum

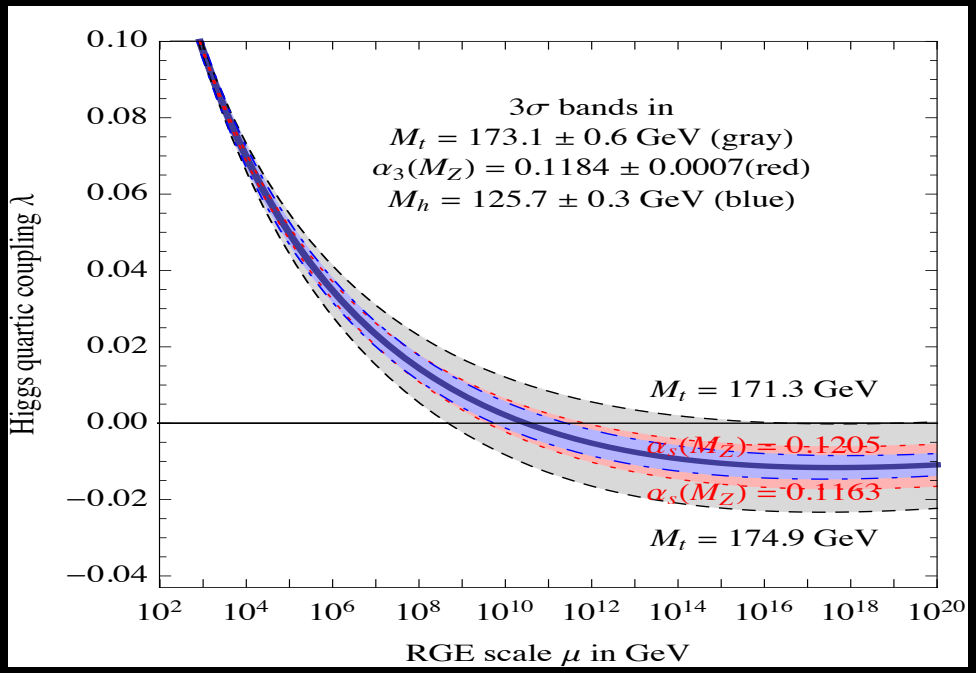


$$M_H \approx 125 \text{ GeV} \rightarrow \lambda \approx 0.13$$

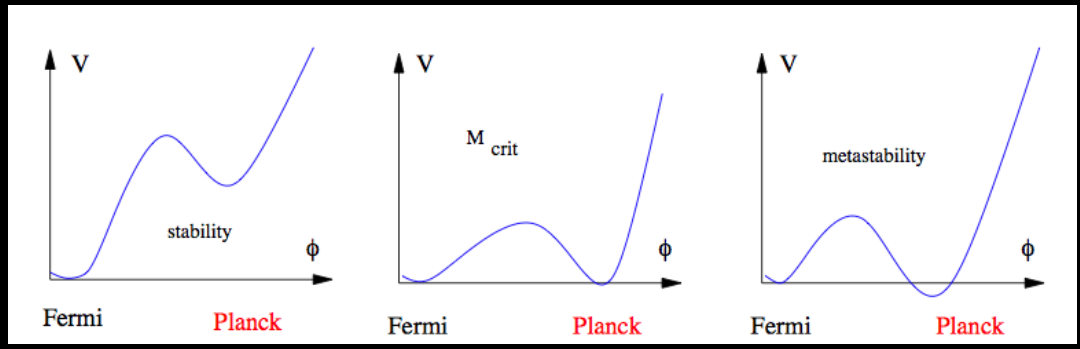
$$32\pi^2 \frac{d\lambda}{dt} = 24\lambda^2 - (3g'^2 + 9g^2 - 24y_t^2)\lambda + \frac{3}{8}g'^4 + \frac{3}{4}g'^2 g^2 + \frac{9}{8}g^4 - 24y_t^4 + \cdots$$

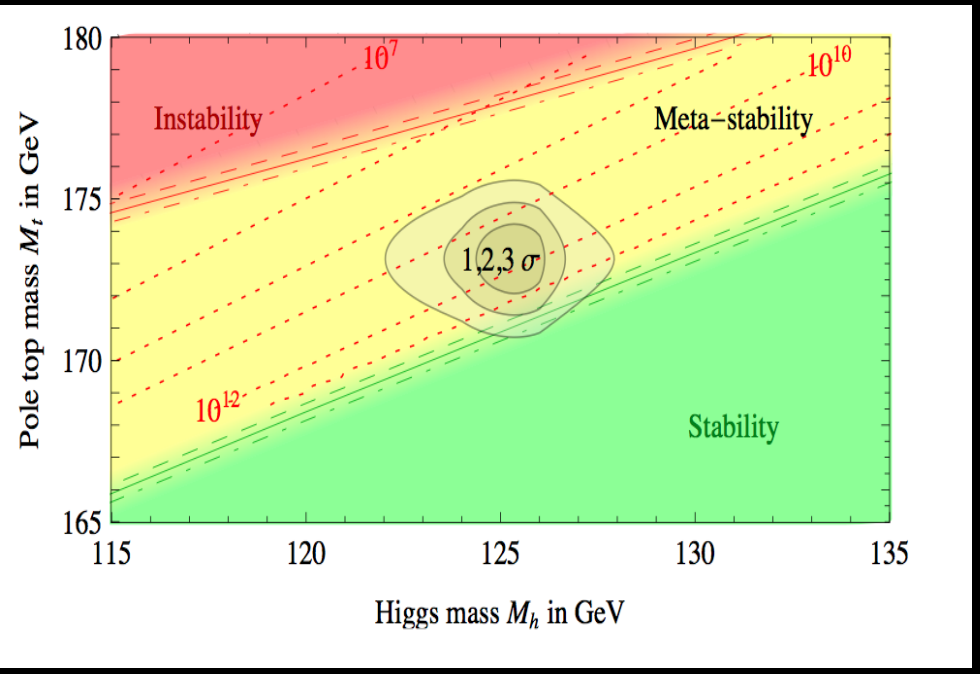
$(t = \ln(Q^2/Q_0^2),\ y_t = m_t/v \rightarrow$ top quark Yukawa coupling).

Higgs vs Vacuum Stability



$$\lambda(\Lambda) = \lambda(v) - \frac{3}{4\pi^2} y_t^2 \log\left(\frac{\Lambda^2}{v^2}\right)$$





What this really means ?

Large dependence on top and Higgs masses
Assumes no BSM physics enters in the RGE

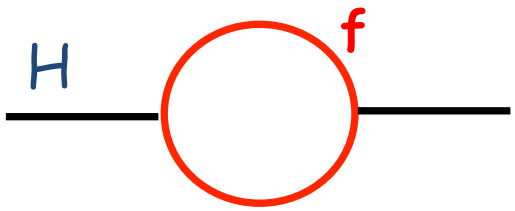
This really means that the SM is consistent all the way to the Planck scale..

Do not worry .. Lifetime probably larger than the age of the Universe.

Hierarchy Problem

From EWK to Planck scale ?

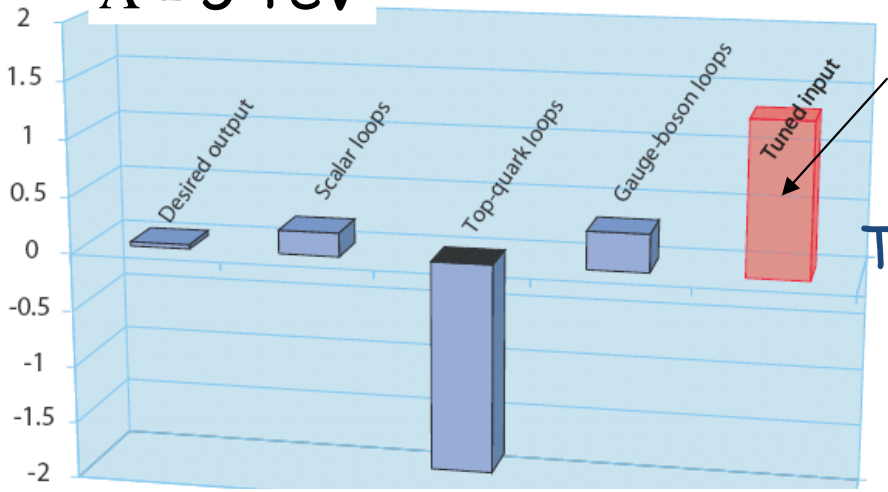
$$< H > = 174\ GeV \rightarrow m_H^2 \approx O(-100\ GeV^2)$$



$$\Delta m_H^2 = \frac{|\lambda_f|^2}{16\pi^2}[-2\Lambda_{UV}^2 + 6m_f^2 \ln(\Lambda_{UV}/m_f) + \ldots]$$

if $\Lambda_{UV} \approx M_{planck}$ → fine tuning in 10^{30} !!

Λ = 5 TeV

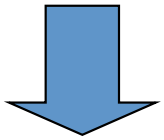


relative contributions to ΔM_H^2

(taken from C. Quigg, hep-ph/0704.2232)

Already a serious problem at 5 TeV scale
(cancellation among top, gauge and Higgs loops)

This kind of conspiracy has name in Physics...



SuperSymmetry ?

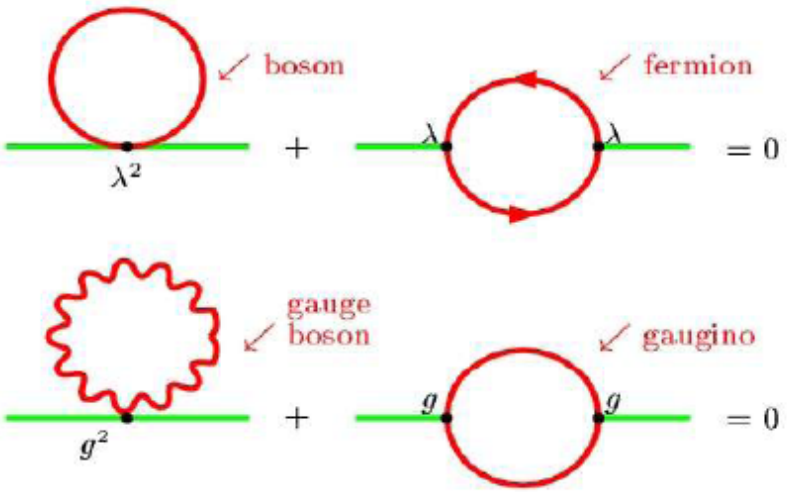
SuperSymmetry in 30"

- Fermion/Boson symmetry

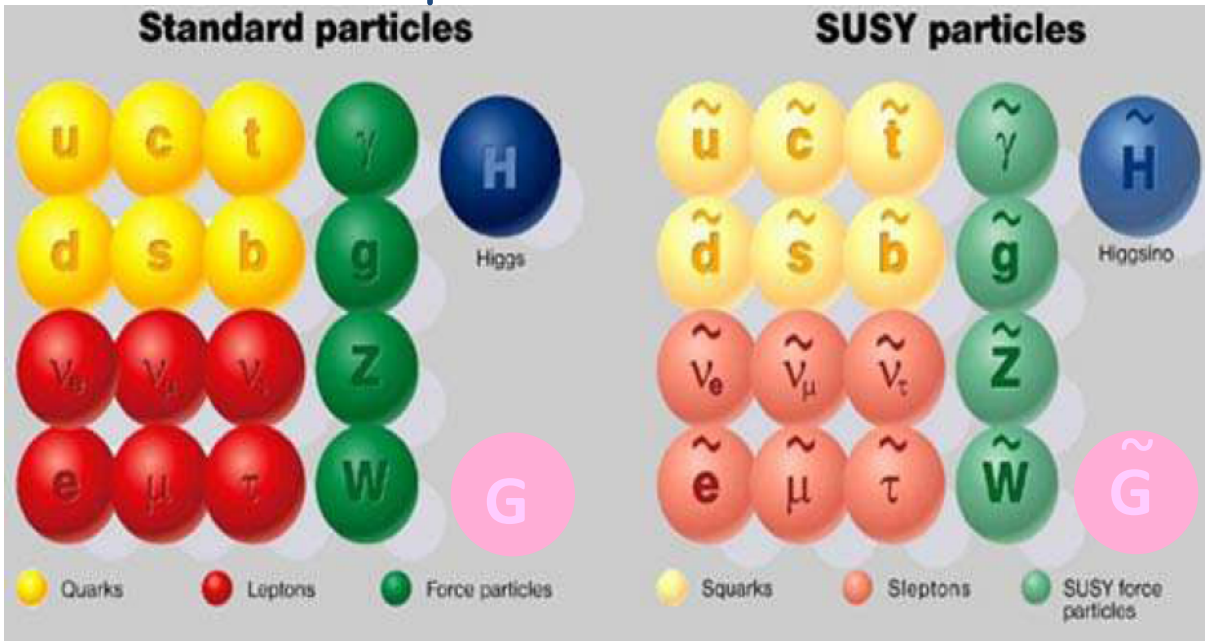
$$Q\,|\,\text{fermion}\,> = |\,\text{boson}\,>$$

$$Q\,|\,\text{boson}\,> = |\,\text{fermion}\,>$$

- Exact cancellation between fermion & boson loops for Higgs



Double Spectra of Particles



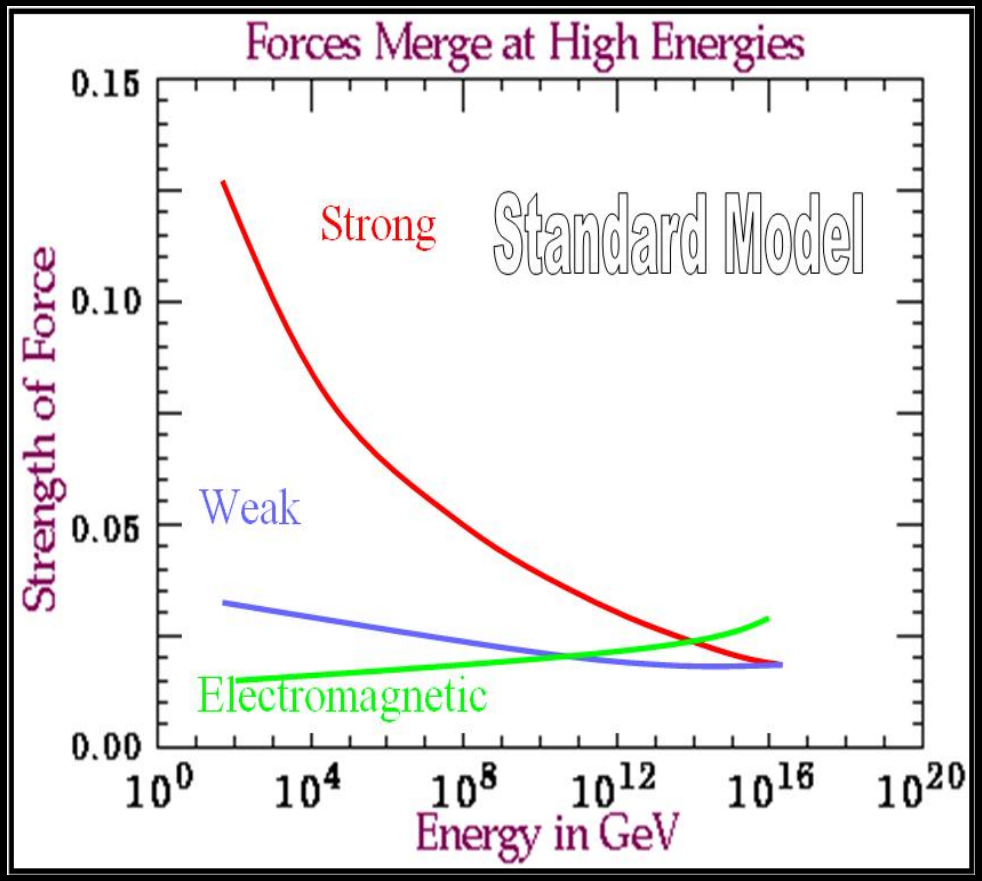
..will mix to form mass eigenstates..

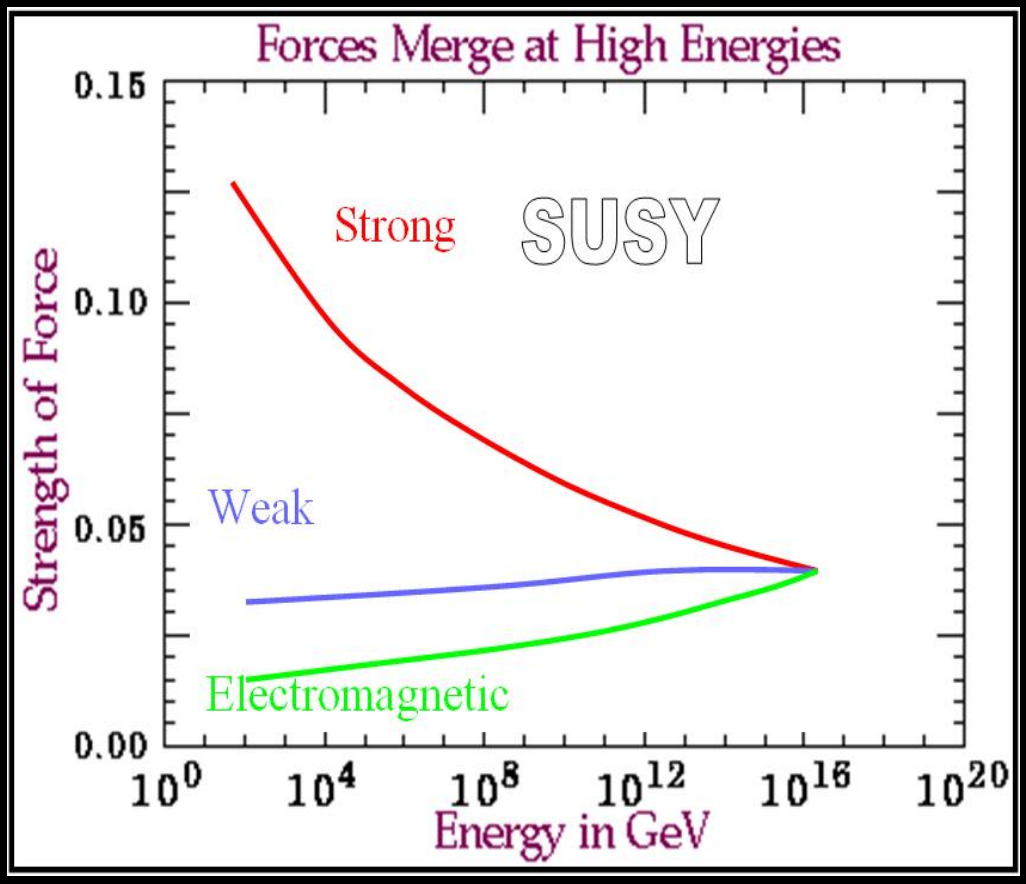
Higgs sector with 2 doublets

$$H_U, H_D \longrightarrow h, H, A, H^{\pm}$$

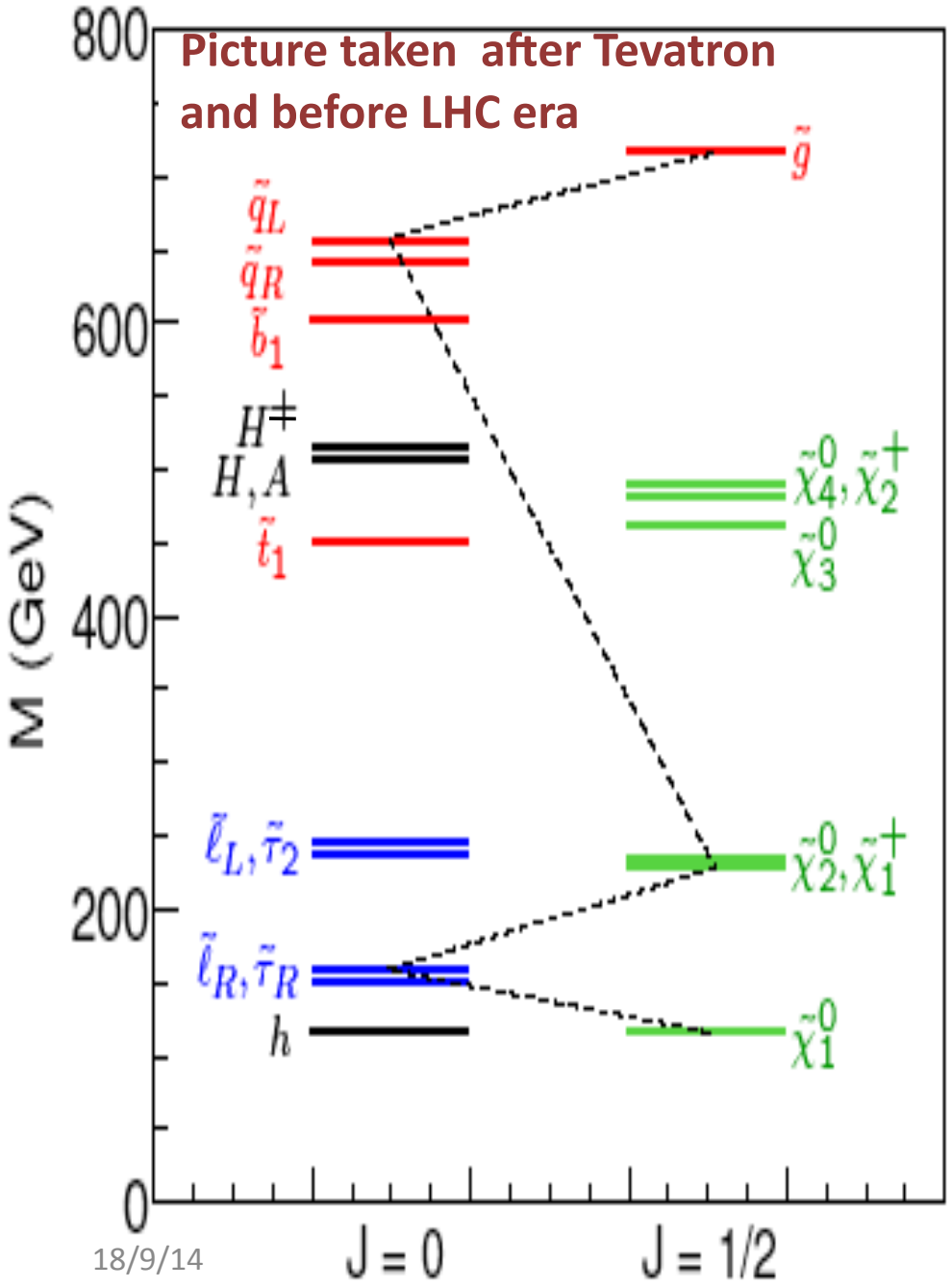
..SUSY must be broken..... model-dependent phenomenology

Unification of Forces…

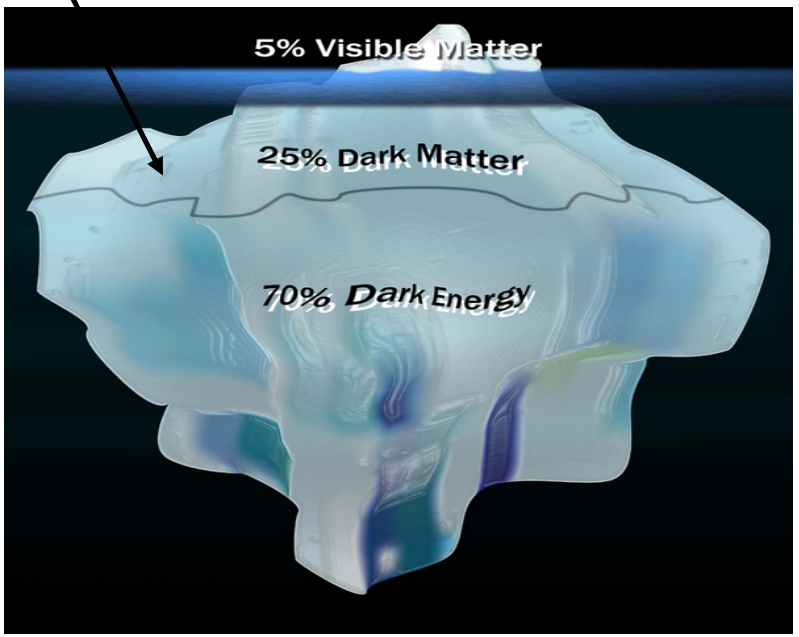




SUSY candidate for Dark Matter



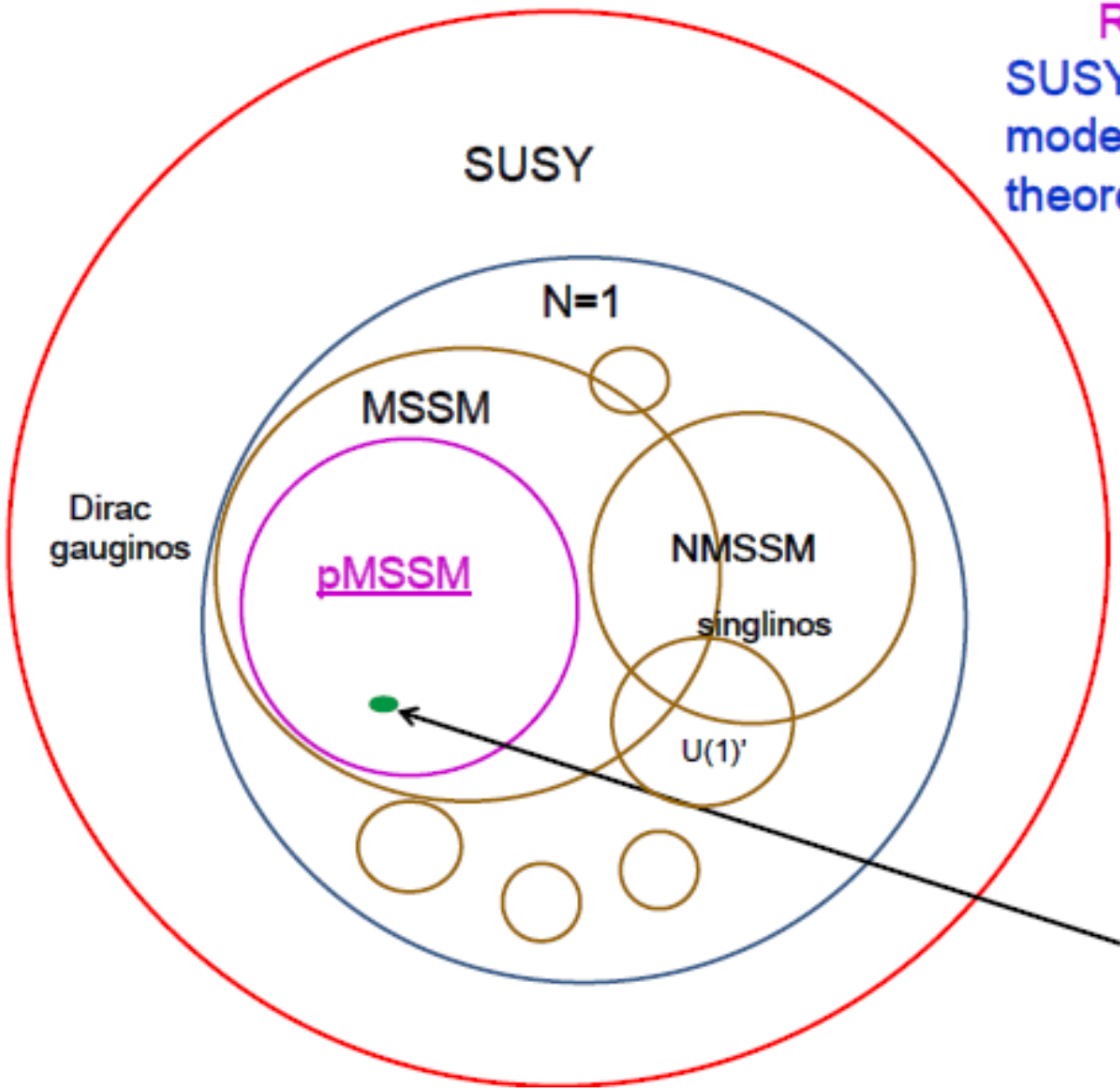
1. Squarks and Gluinos are heavy
2. mixing of third generation leads to light stop and sbottom
3. χ_1^0 good candidate for Dark Matter



4. One higgs is very light (< 135 GeV)

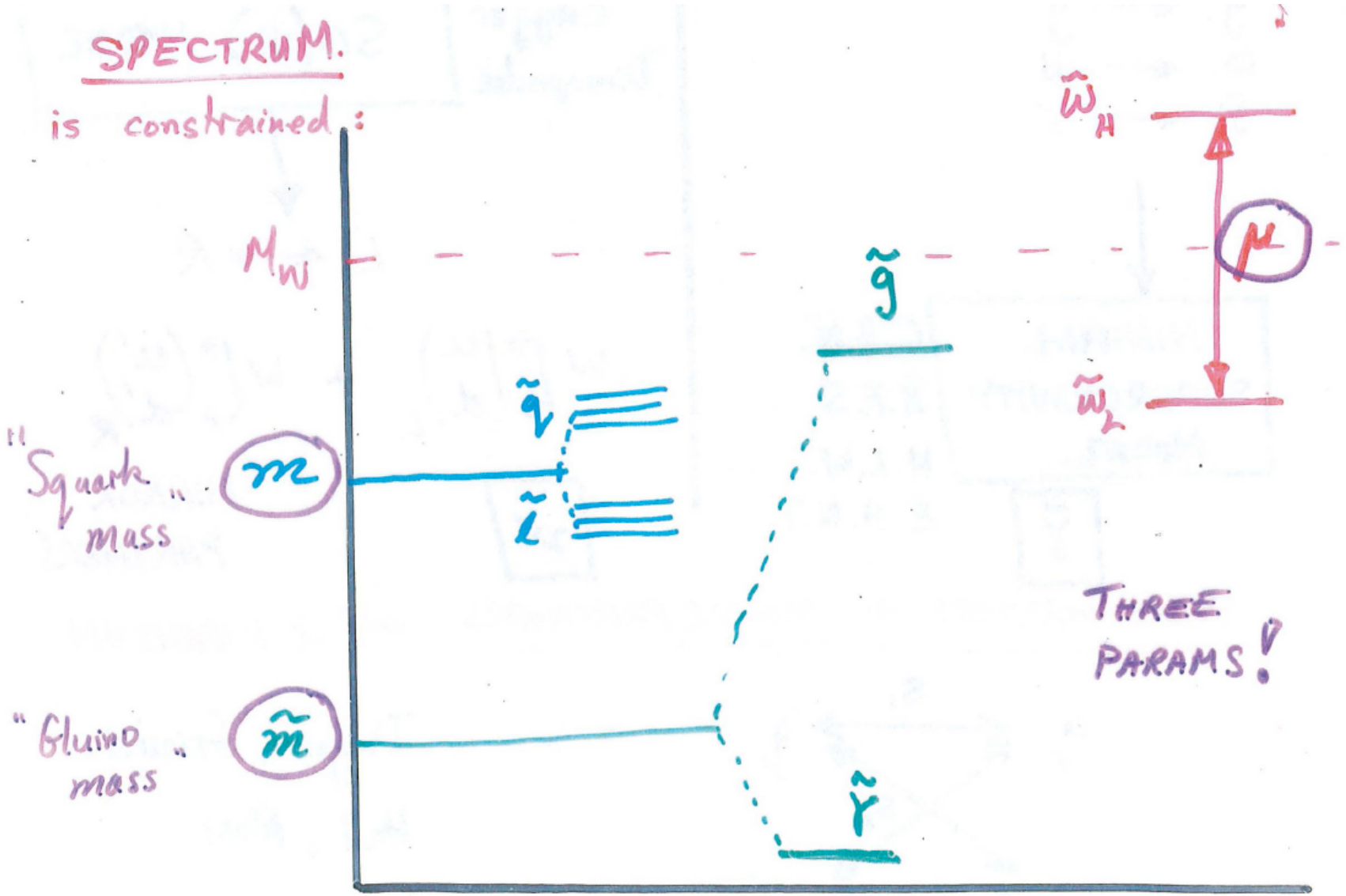
Taken from T. Rizzo

SUSY ZOO

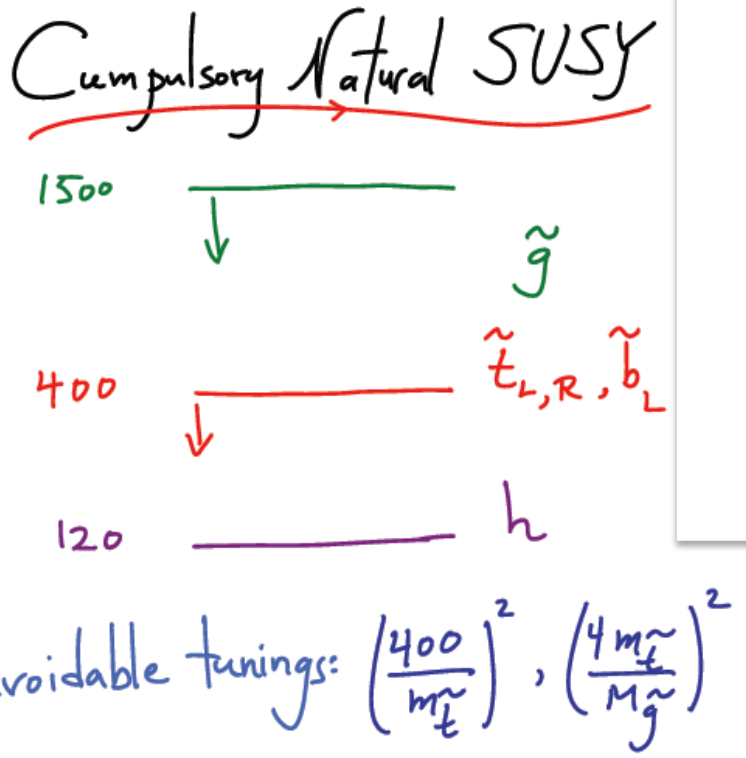


Reminder:
SUSY is *not* a single model but a very large theoretical framework

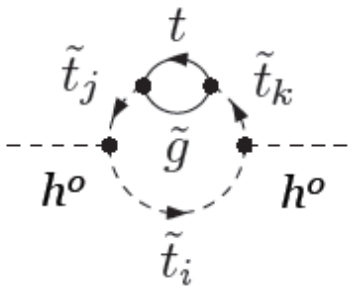
"Natural SUSY in 1984"



“Natural SUSY 2012”



N. Arkani-Hamed talk at CERN Oct. 2012



$$\frac{m_H^2}{2} = -|\mu|^2 + \ldots + \delta m_H^2$$

$$\delta m_H^2\big|_{stop} \cong -\frac{3y_t^2}{8\pi^2}\left(m_{Q_3}^2 + m_{U_3}^2 + |A_t|^2\right)\ln\left(\frac{\Lambda}{TeV}\right)$$

$$\delta m_H^2\big|_{gluino} \cong -\frac{2y_t^2}{\pi^2}\left(\frac{\alpha_s}{\pi}\right)|M_3|^2 \ln^2\left(\frac{\Lambda}{TeV}\right)$$

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{t}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_t & \sin\theta_t \\ -\sin\theta_t & \cos\theta_t \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix}$$

→ Light higgsinos

→ Light stop (t_1 < 1 TeV)

→ Light gluinos (< 1-2 TeV)

One light stop and sbotton ….rest of sparticles can be decoupled….

$$\begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix} \quad \tilde{t}_R \quad \tilde{b}_R$$

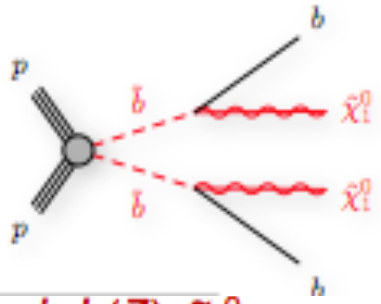
(same weak isospin multiplet)

Direct Stop/Sbottom

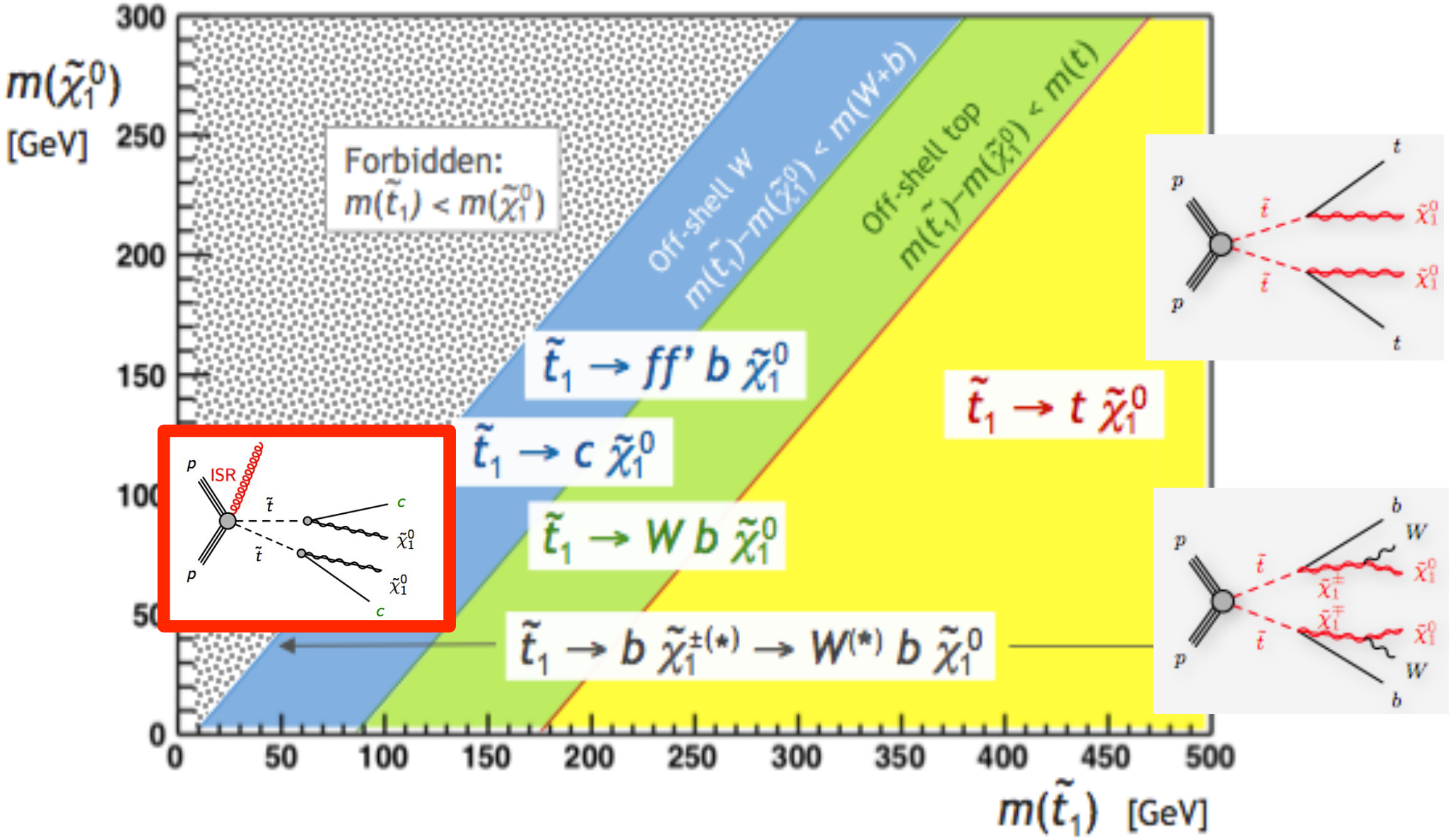
$\tilde{b}_1 \rightarrow b\,\tilde{\chi}_1^0$

$\tilde{b}_1 \rightarrow t\,\tilde{\chi}_1^{\pm}$

$\tilde{b}_1 \rightarrow b\,\tilde{\chi}_2^0 \rightarrow b\,h(Z)\,\tilde{\chi}_1^0$

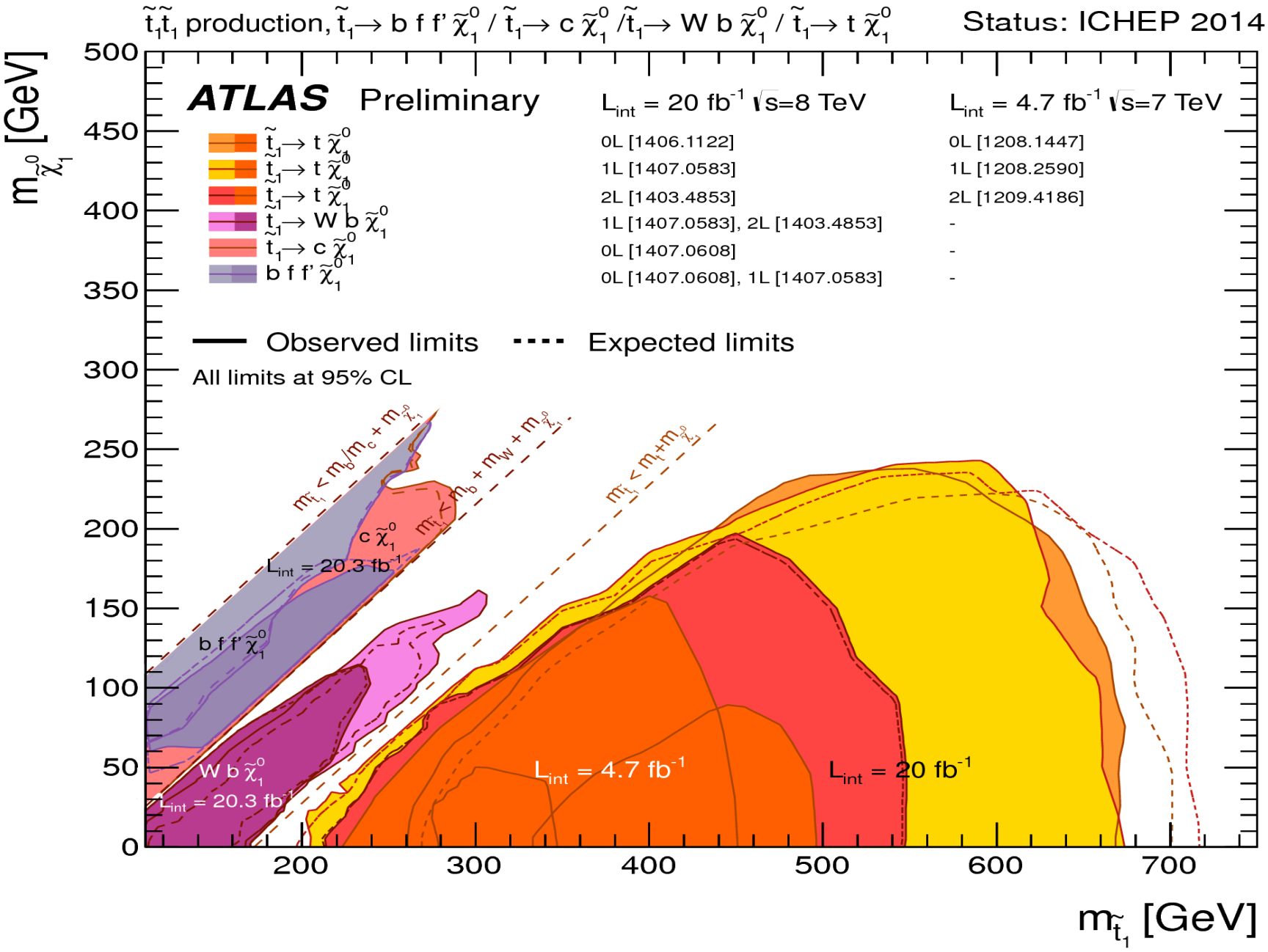


In the scenario with TeV gluinos / squarks (1st/2nd generations)
All the attention is put now in searches for stop/sbottom
Multiple channels according to the decays



Summary Searches for Stop

(different mass hierarchies, simplified models)



Hard to believe in SUSY if the Higgs sector stays with just h_0

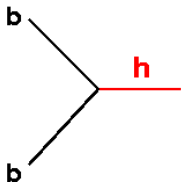
…Looking for extra Higgs particles ….

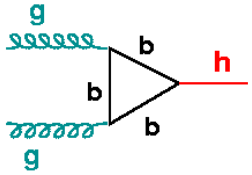
MSSM Higgs

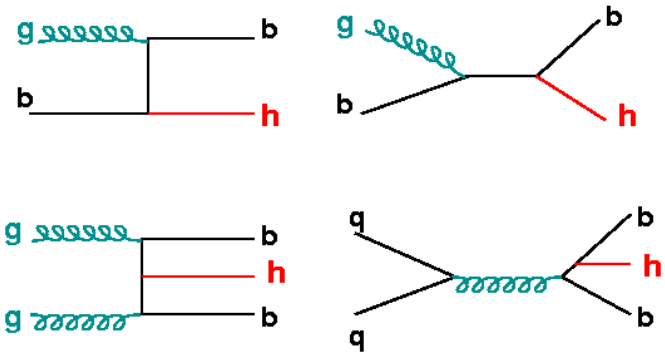
$H_U, H_D \longrightarrow$ h,H,A and $H^{\pm}$

$\tan\beta = < H_U > / < H_D >$

$M(h) < 135$ GeV





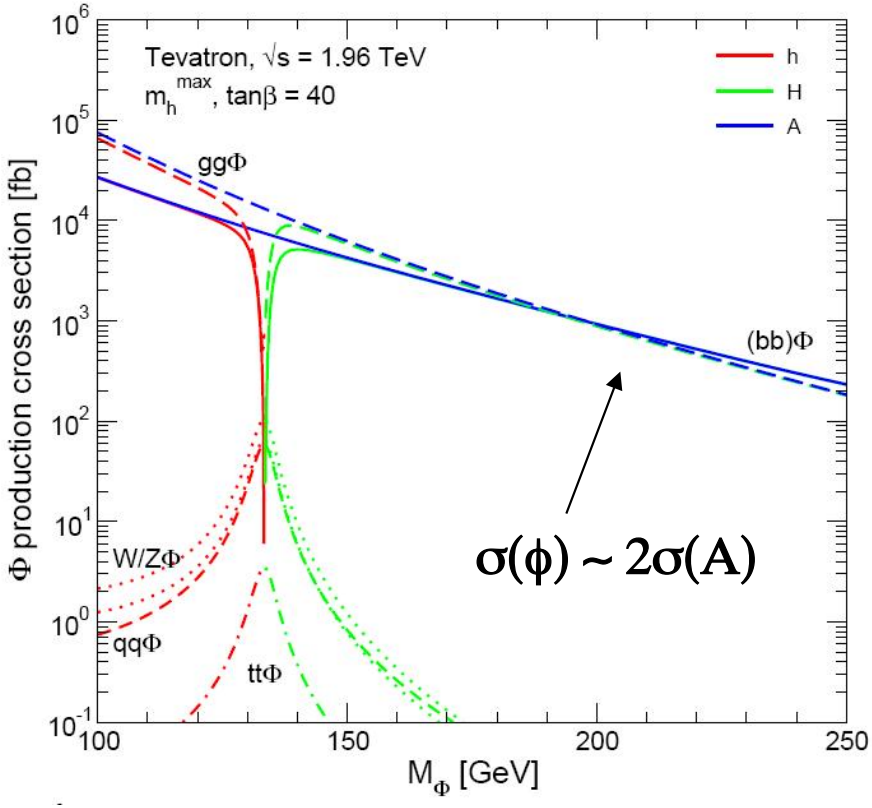


Tree level : M_A and $\tan\beta$ as parameters

MSSM Higgs production cross section boosted compared to SM at large tanβ

$$\sigma(b\bar{b}A) \times \mathrm{BR}(A \to b\bar{b}) \simeq \sigma(b\bar{b}A)_{\mathrm{SM}} \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{9}{(1+\Delta_b)^2+9}$$

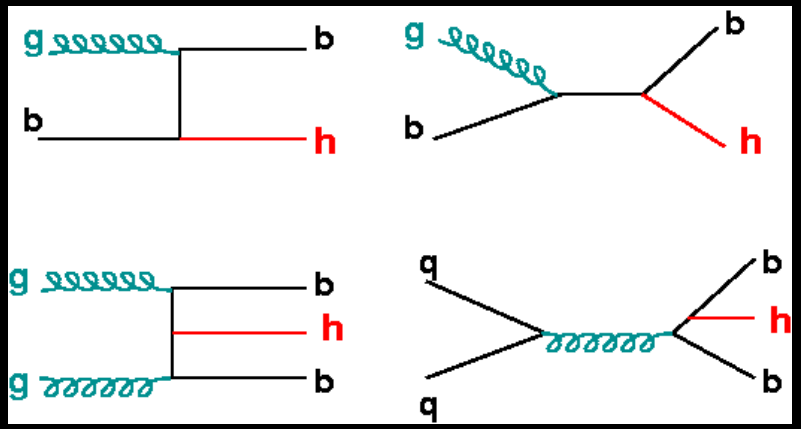
$$\sigma(gg, b\bar{b} \to A) \times \mathrm{BR}(A \to \tau^+\tau^-) \simeq \sigma(gg, b\bar{b} \to A)_{\mathrm{SM}} \frac{\tan^2\beta}{(1+\Delta_b)^2+9},$$

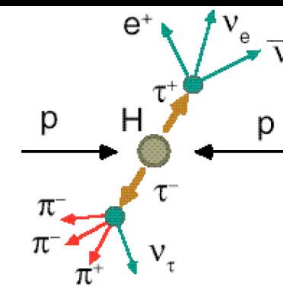


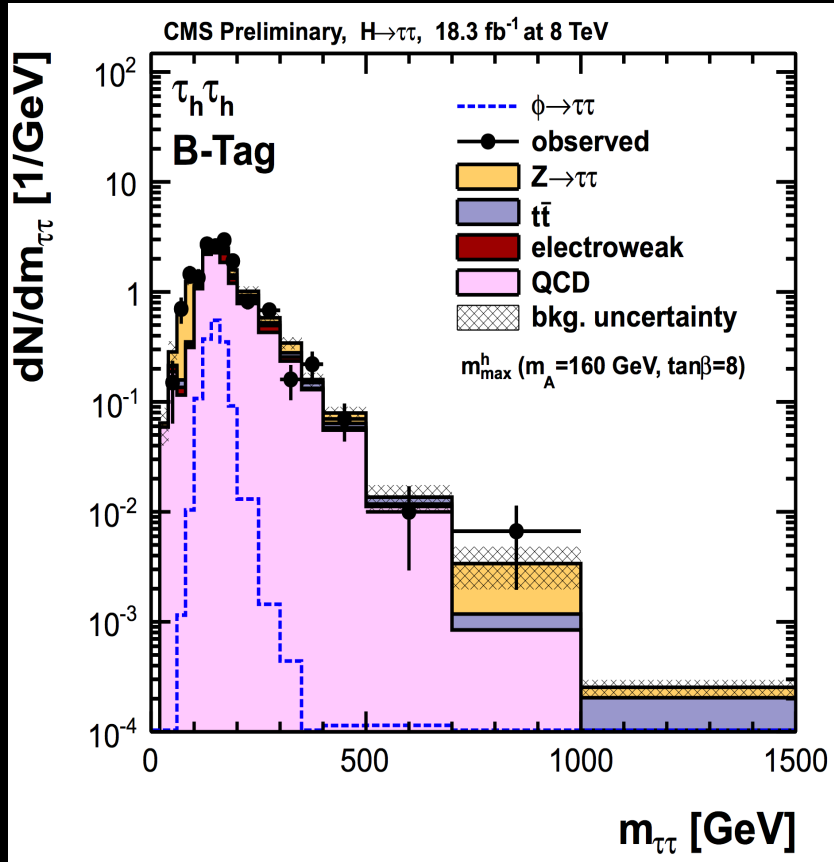
At low masses

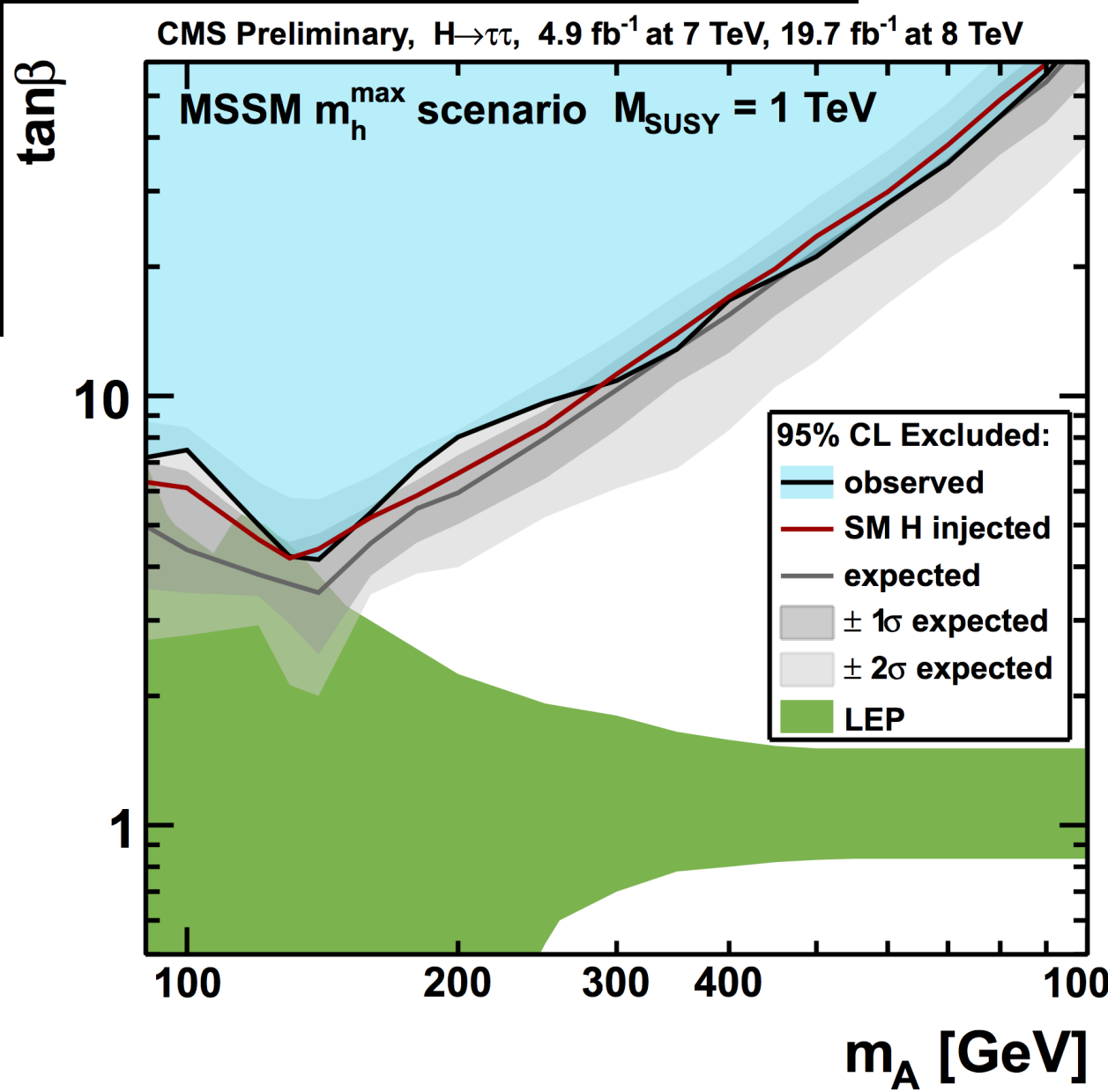
Br(h → bb) ~ 90% , Br(h → ττ) ~ 10%

MSSM Neutral Higgs

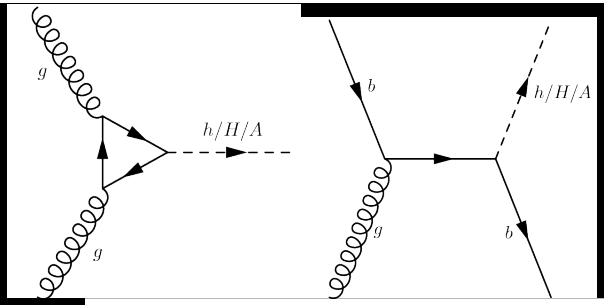


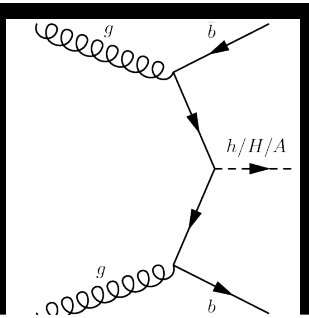


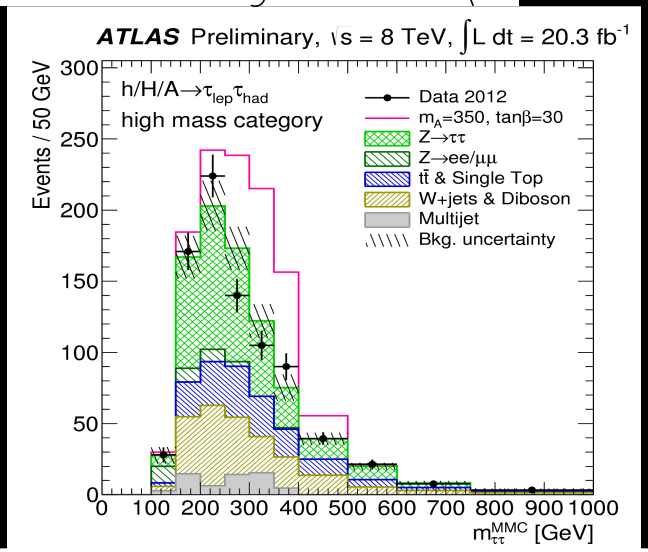


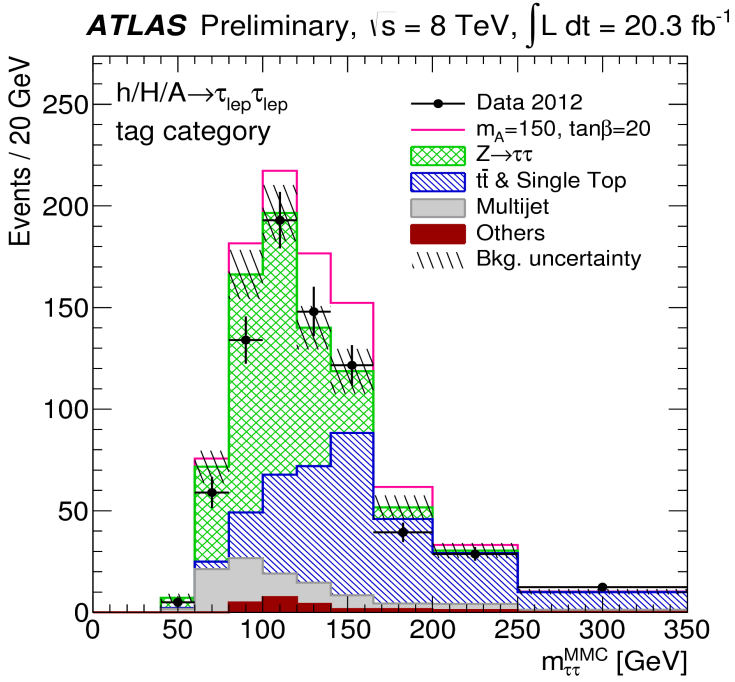


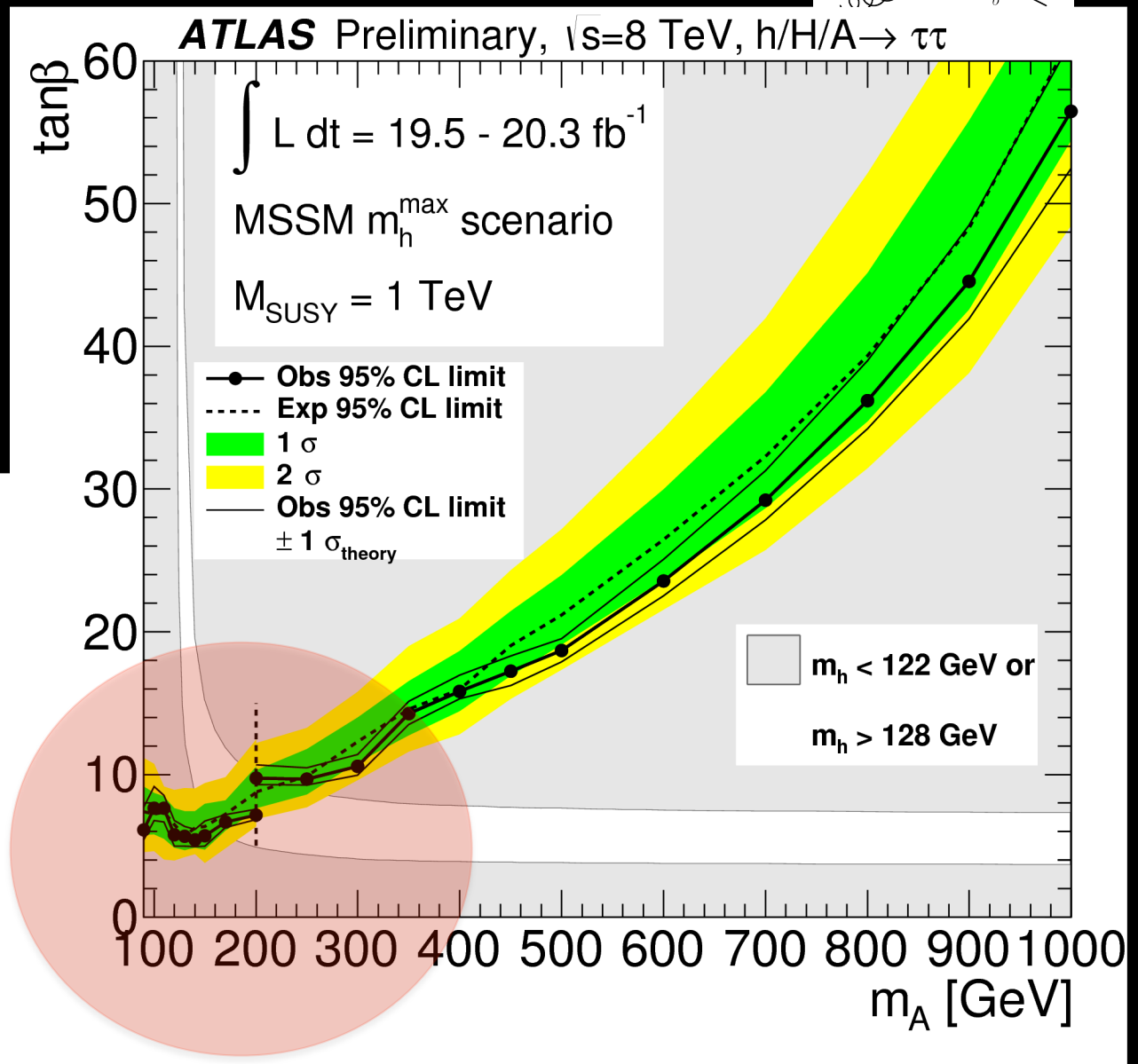
MSSM Neutral Higgs





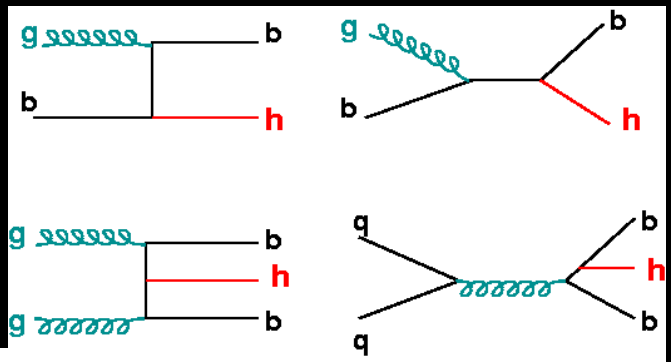


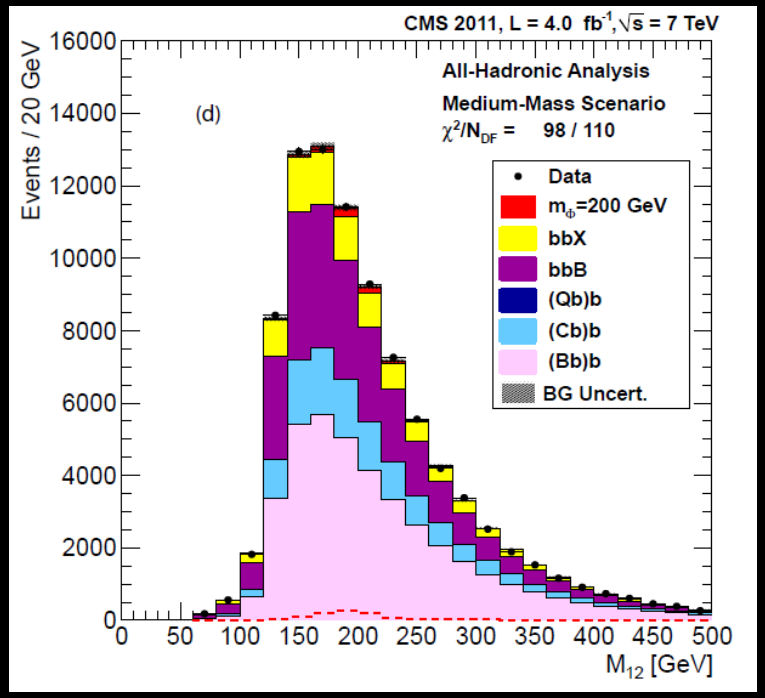


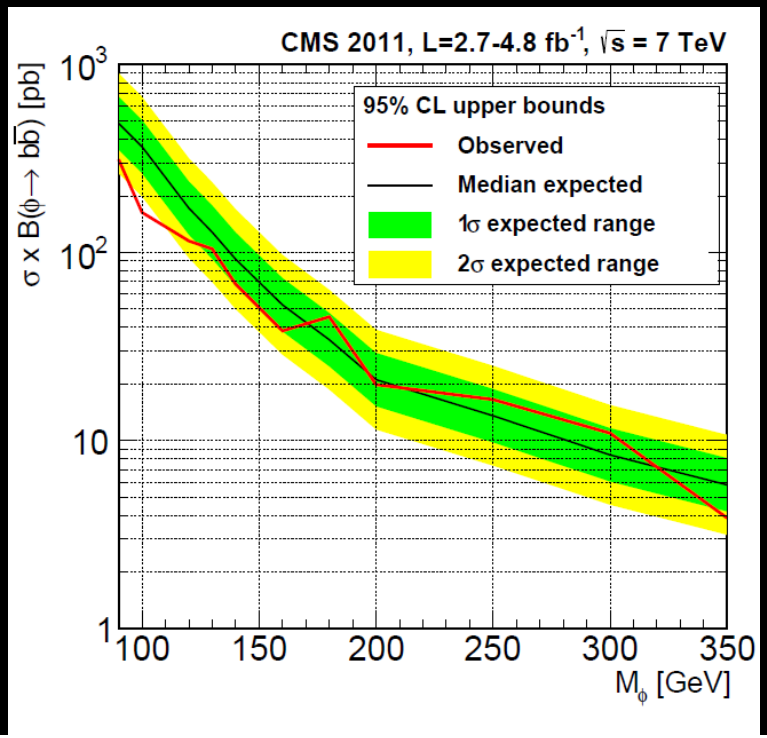


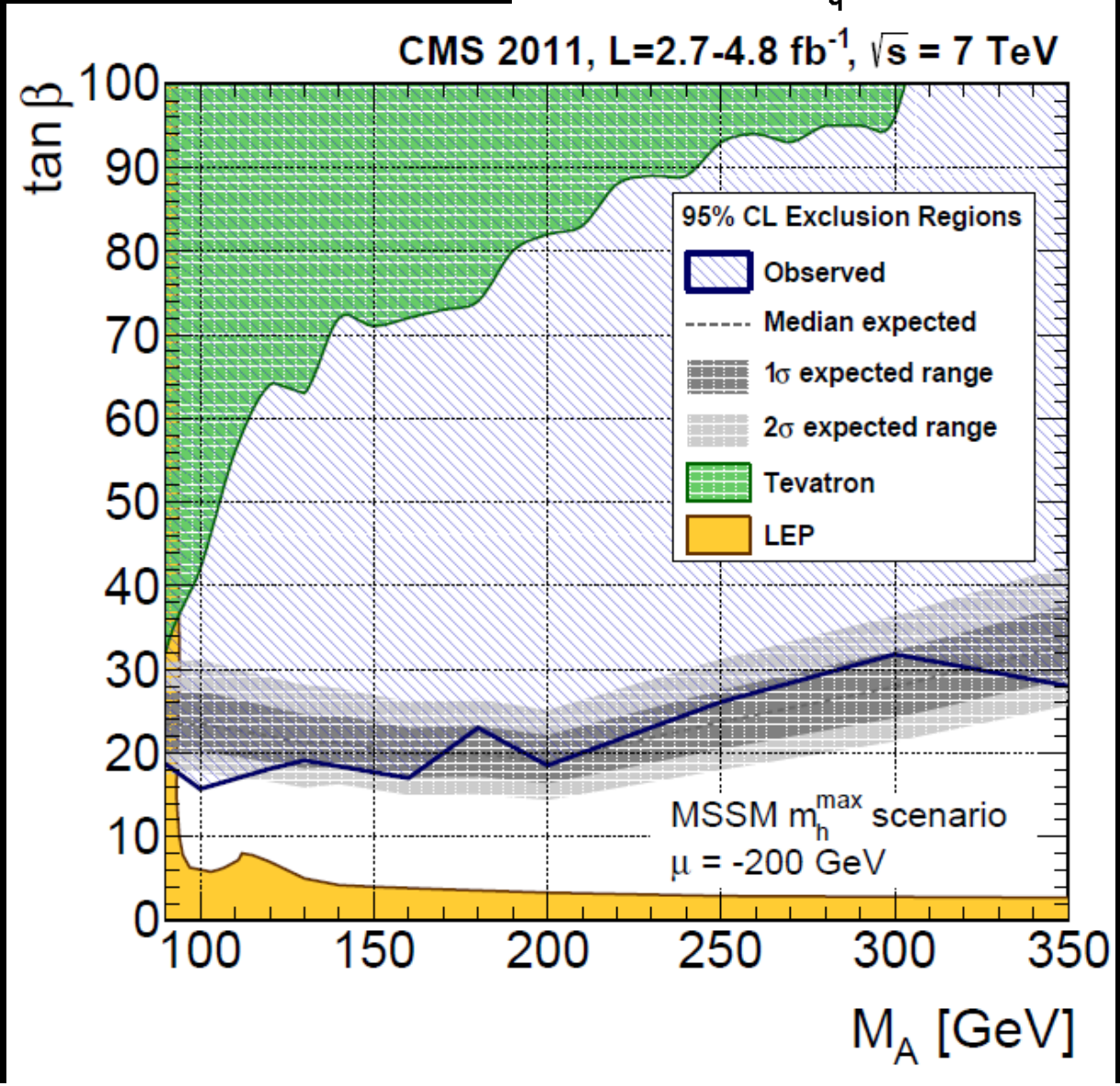
MSSM Higgs

$h \rightarrow bb$

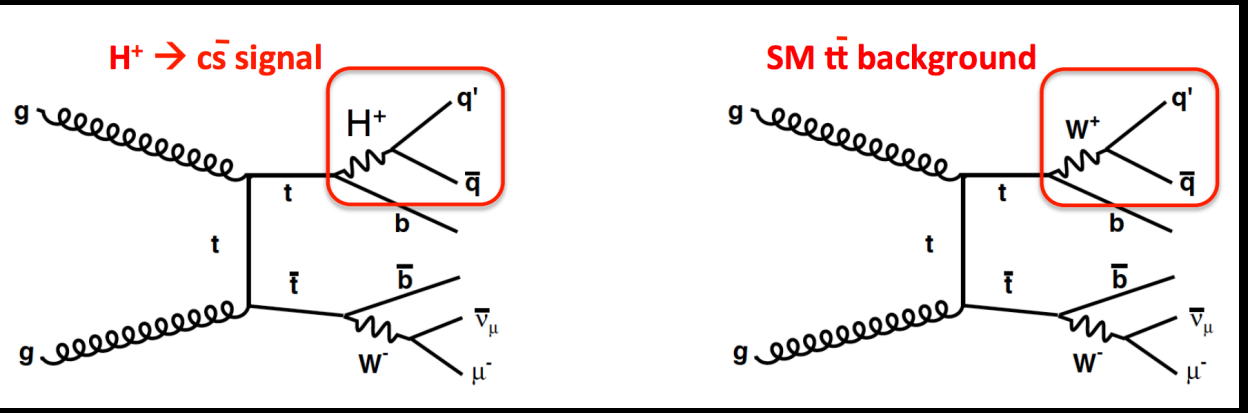




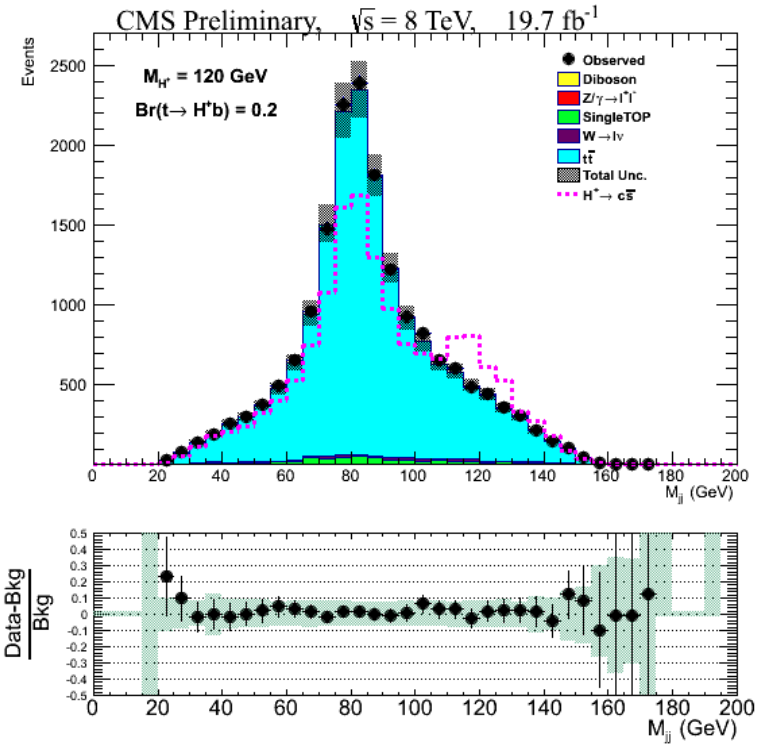


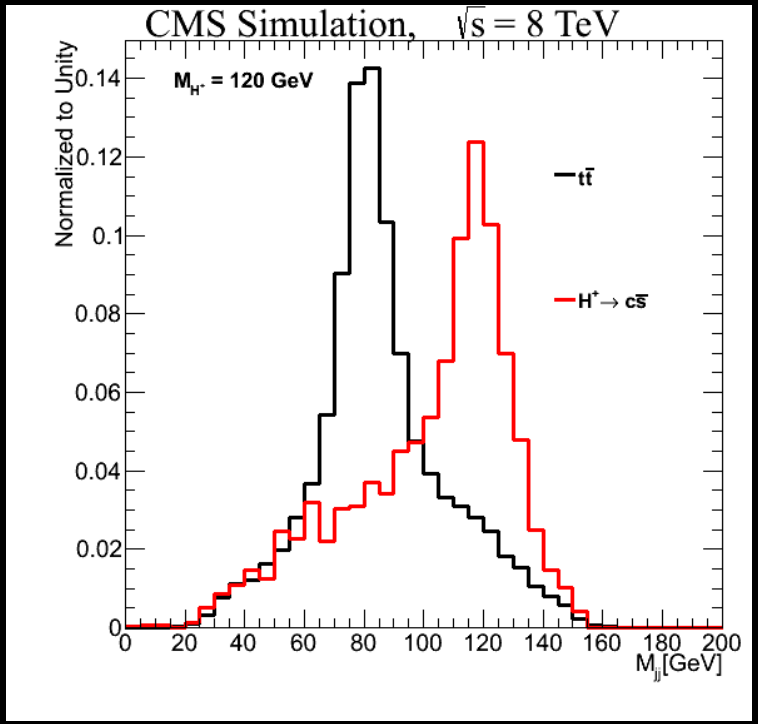


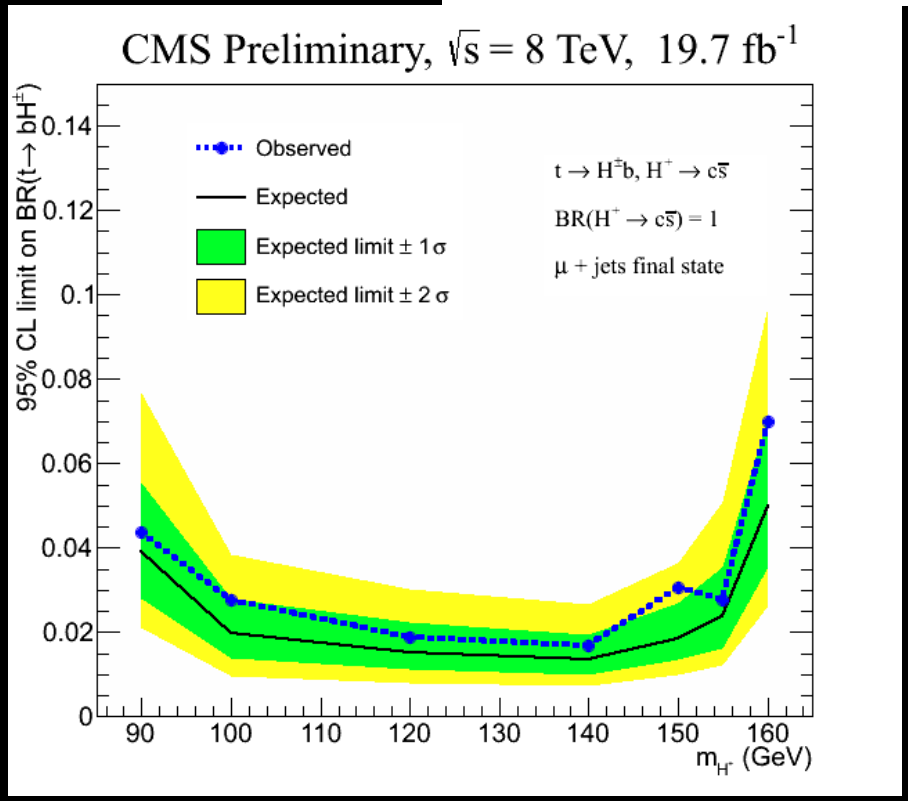
$H^+ \rightarrow c\bar{s}$

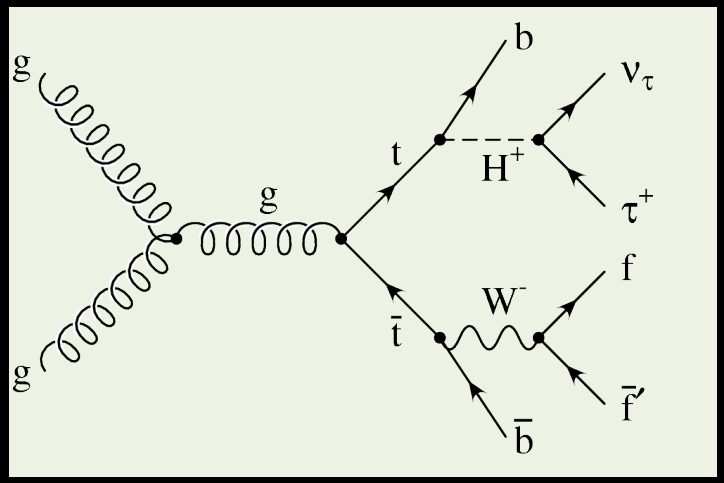


Expressed in terms of limits on BR in top decays

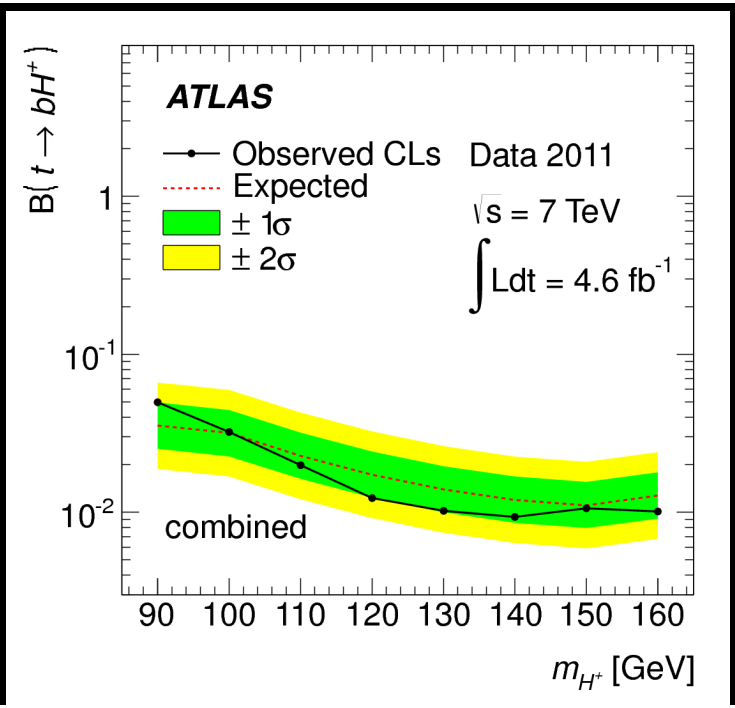






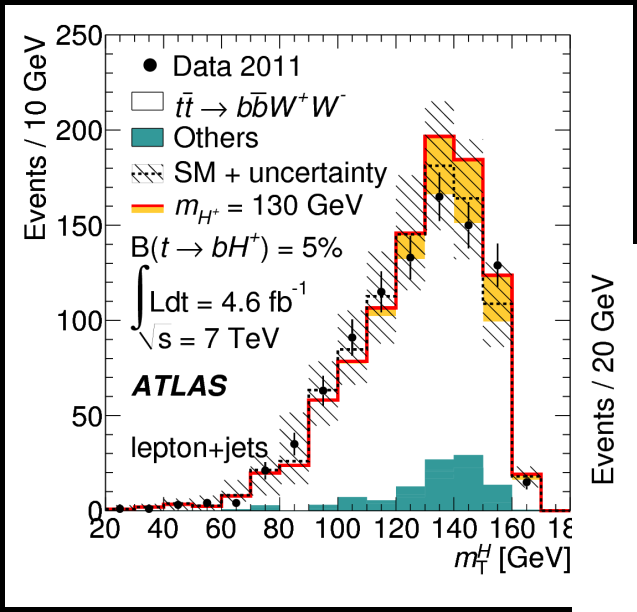


$H^+ \rightarrow \tau\nu$

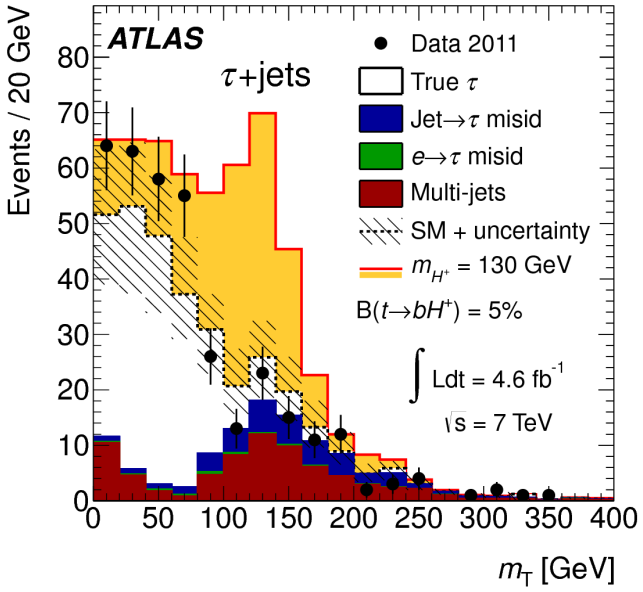


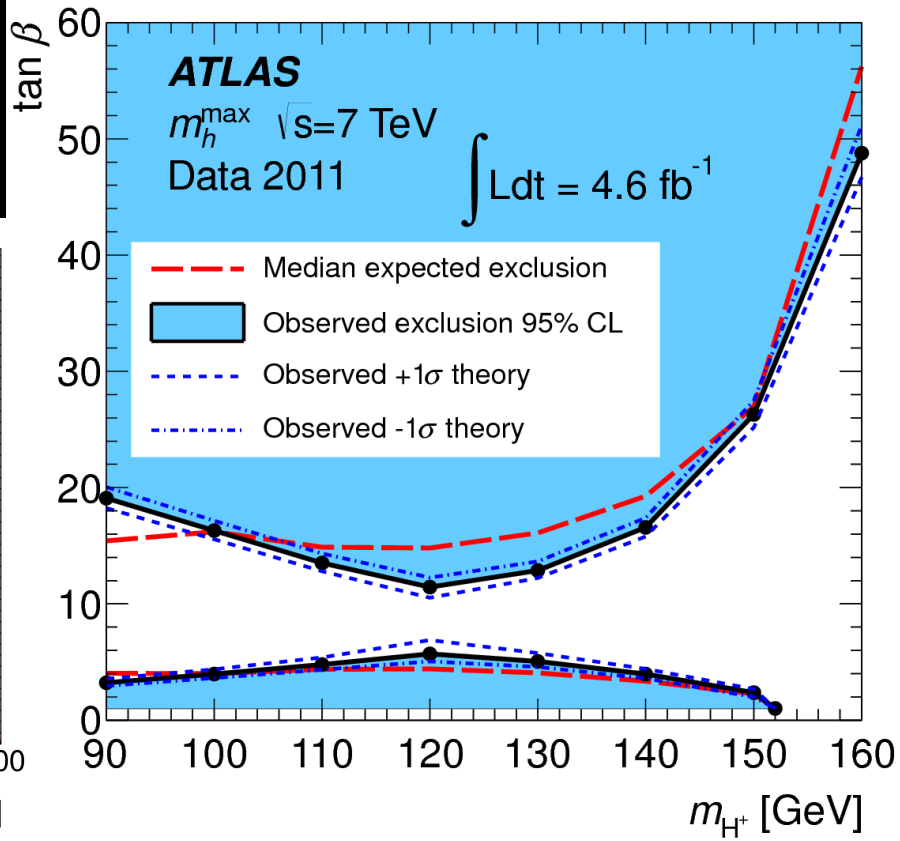
Limits on top BR and SUSY MSSM parameters

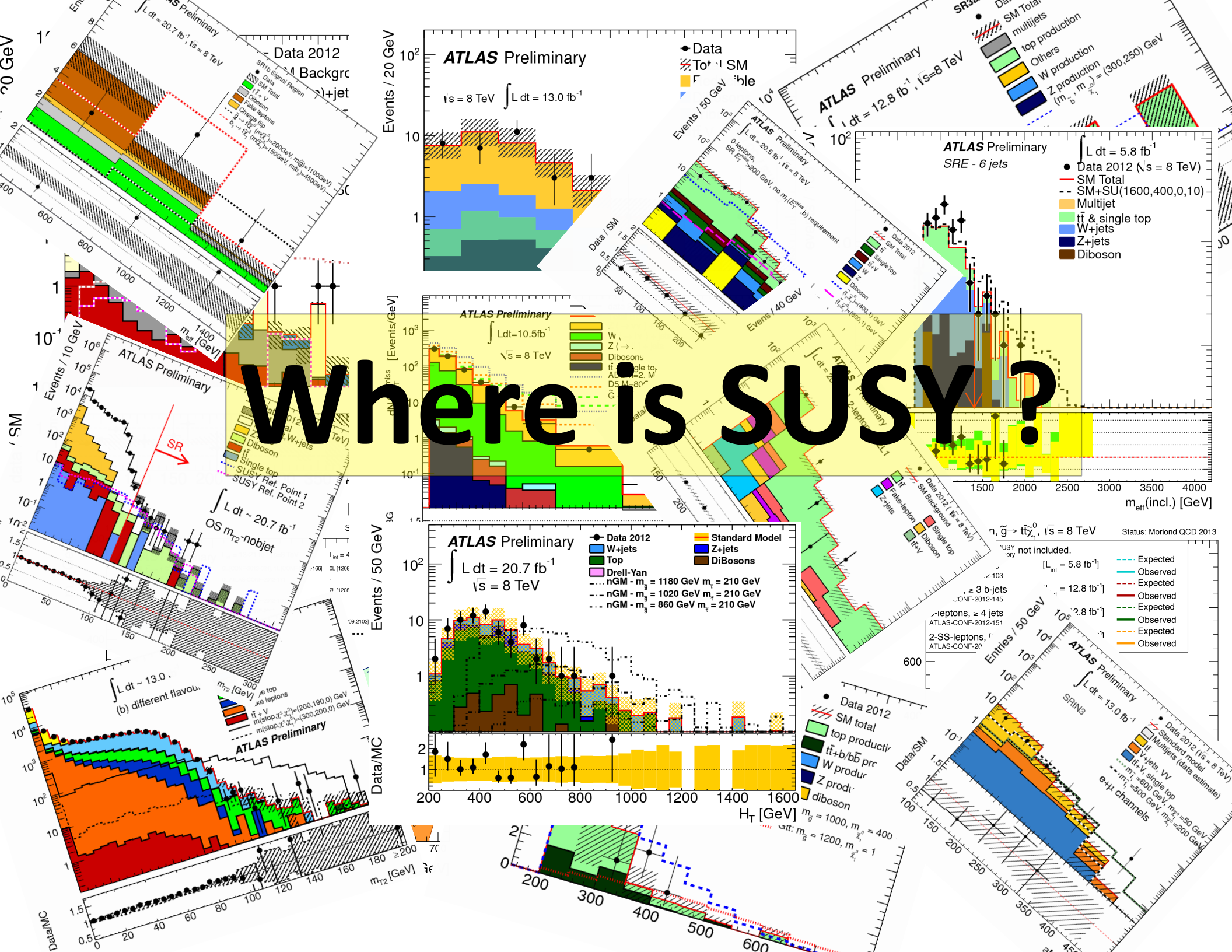
lepton + jets

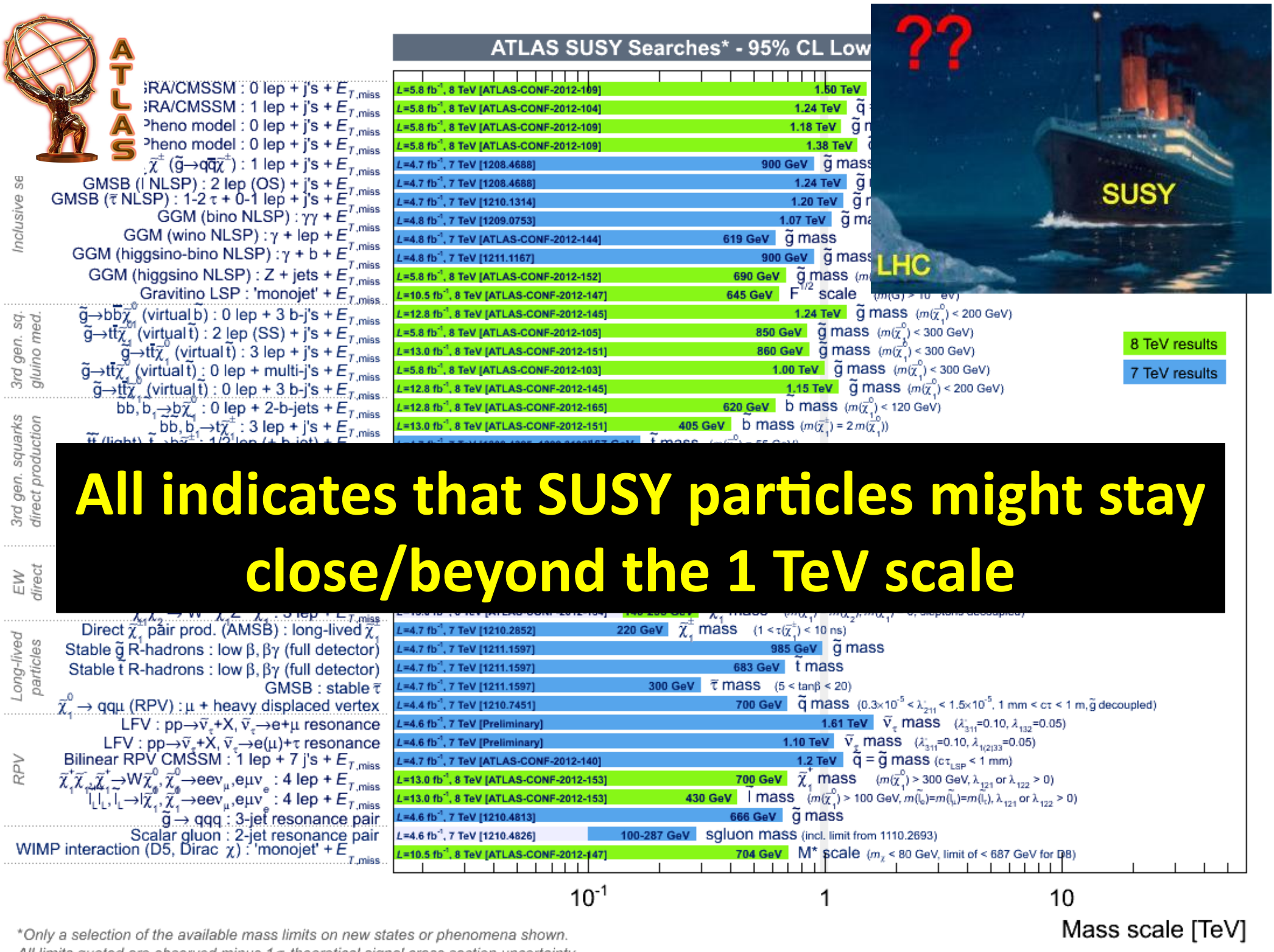


Tau-ID + jets

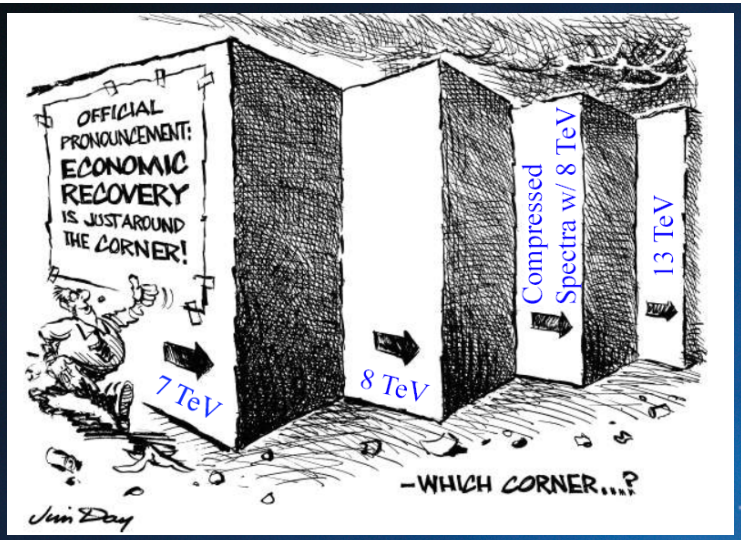




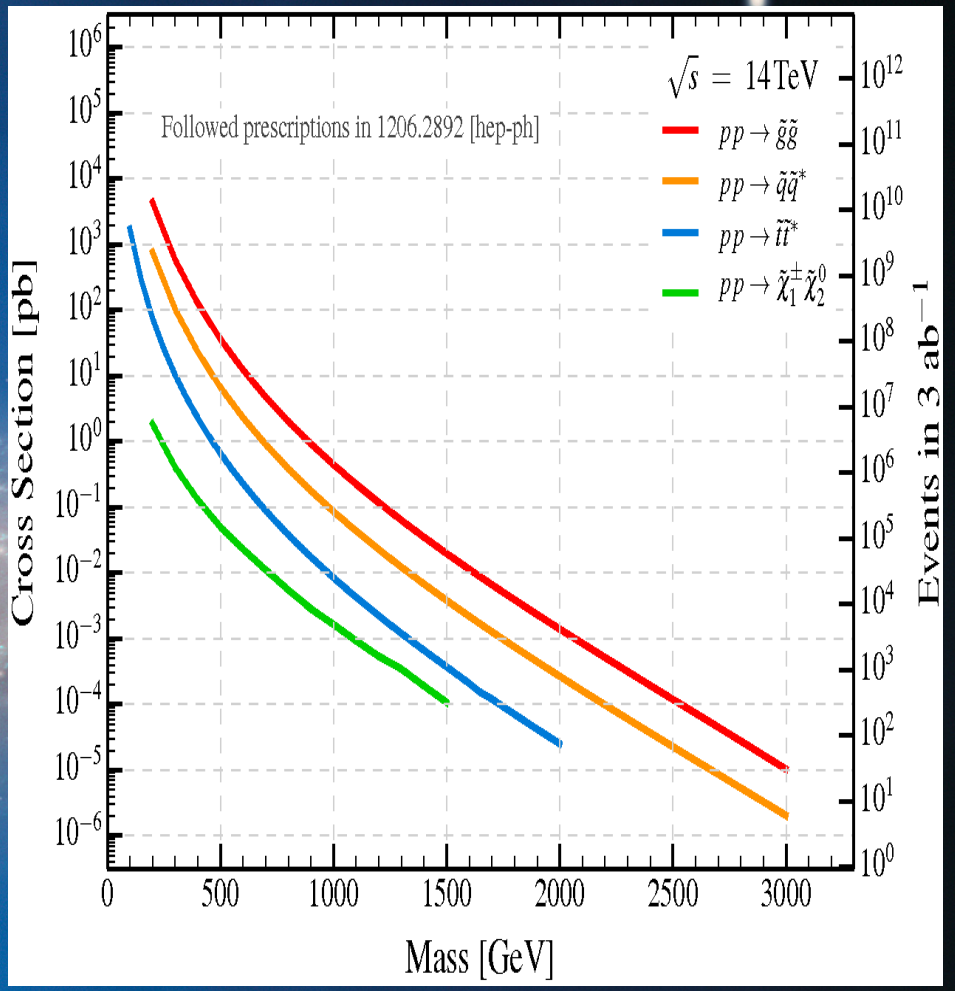

Where is SUSY?



*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.



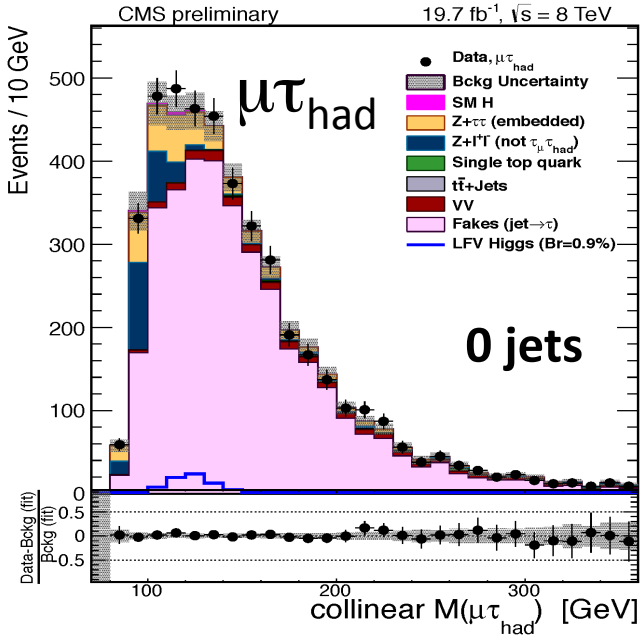
?

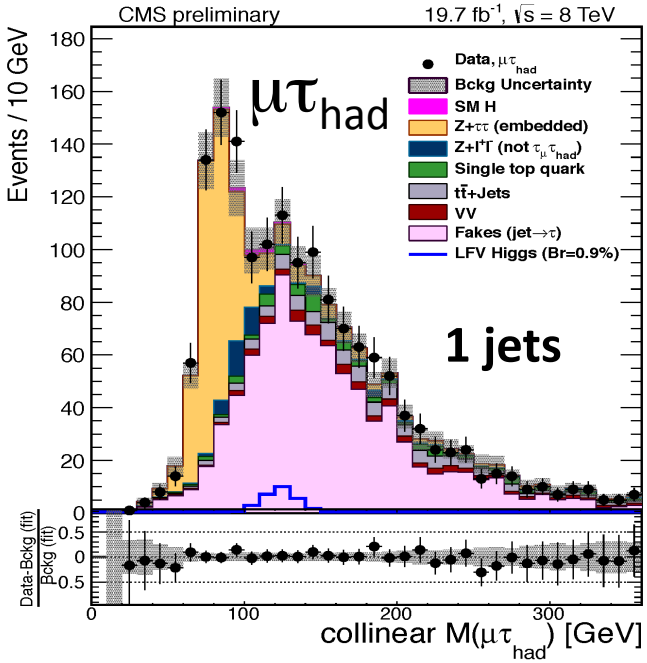


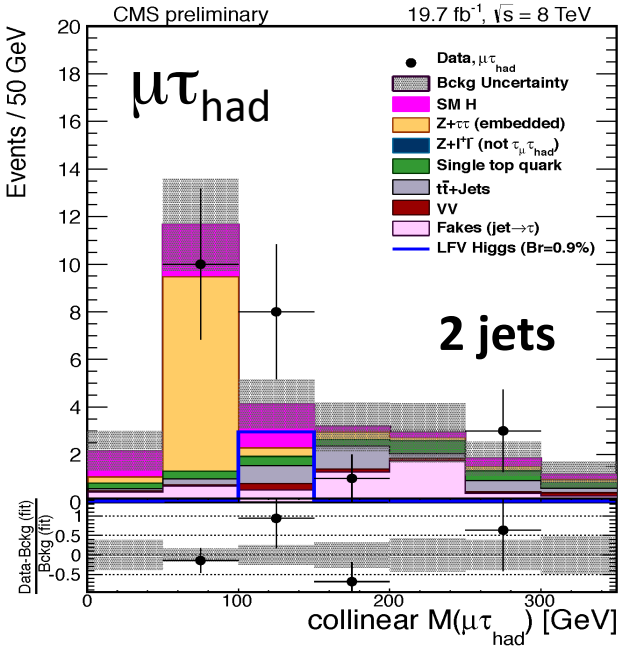
The discovery of New Phyiscs requires more energy and more data ……

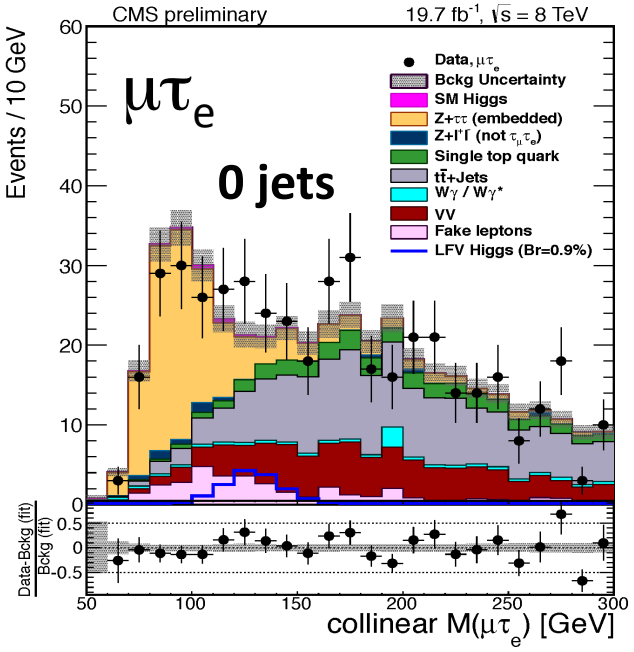

BUMP

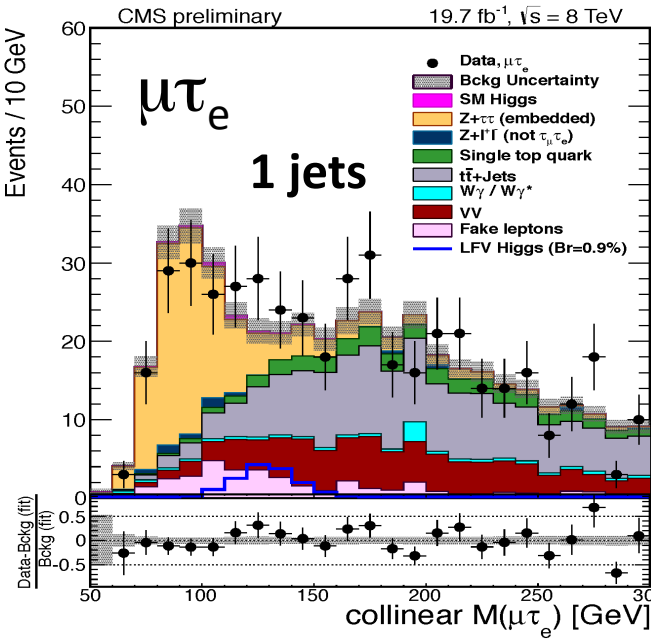
LFV H → μτ

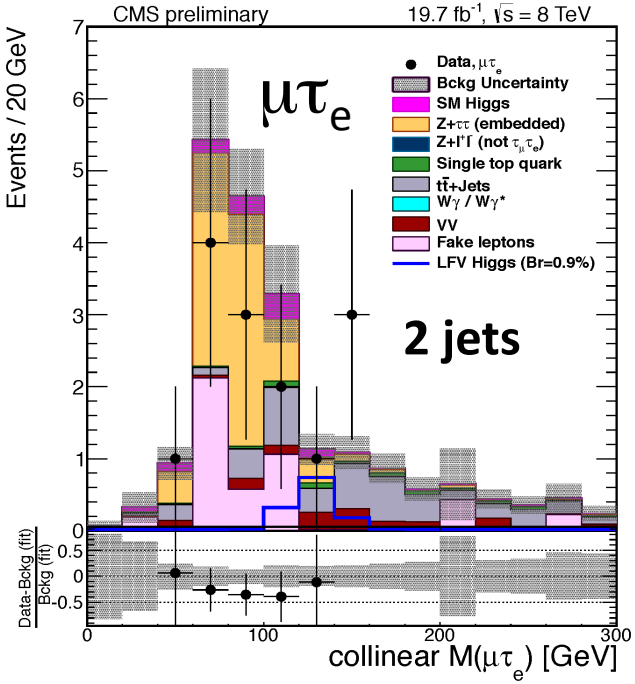

CMS preliminary
19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV
$\mu\tau_{had}$
0 jets
Data, $\mu\tau_{had}$
Bckg Uncertainty
SM H
Z+ττ (embedded)
Z+l$^+$l$^-$ (not $\tau_\mu\tau_{had}$)
Single top quark
tt̄+Jets
VV
Fakes (jet→τ)
LFV Higgs (Br=0.9%)
Events / 10 GeV
Data-Bckg (fit) / Bckg (fit)
collinear M($\mu\tau_{had}$) [GeV]


CMS preliminary
19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV
$\mu\tau_{had}$
1 jets
Data, $\mu\tau_{had}$
Bckg Uncertainty
SM H
Z+ττ (embedded)
Z+l$^+$l$^-$ (not $\tau_\mu\tau_{had}$)
Single top quark
tt̄+Jets
VV
Fakes (jet→τ)
LFV Higgs (Br=0.9%)
Events / 10 GeV
Data-Bckg (fit) / Bckg (fit)
collinear M($\mu\tau_{had}$) [GeV]

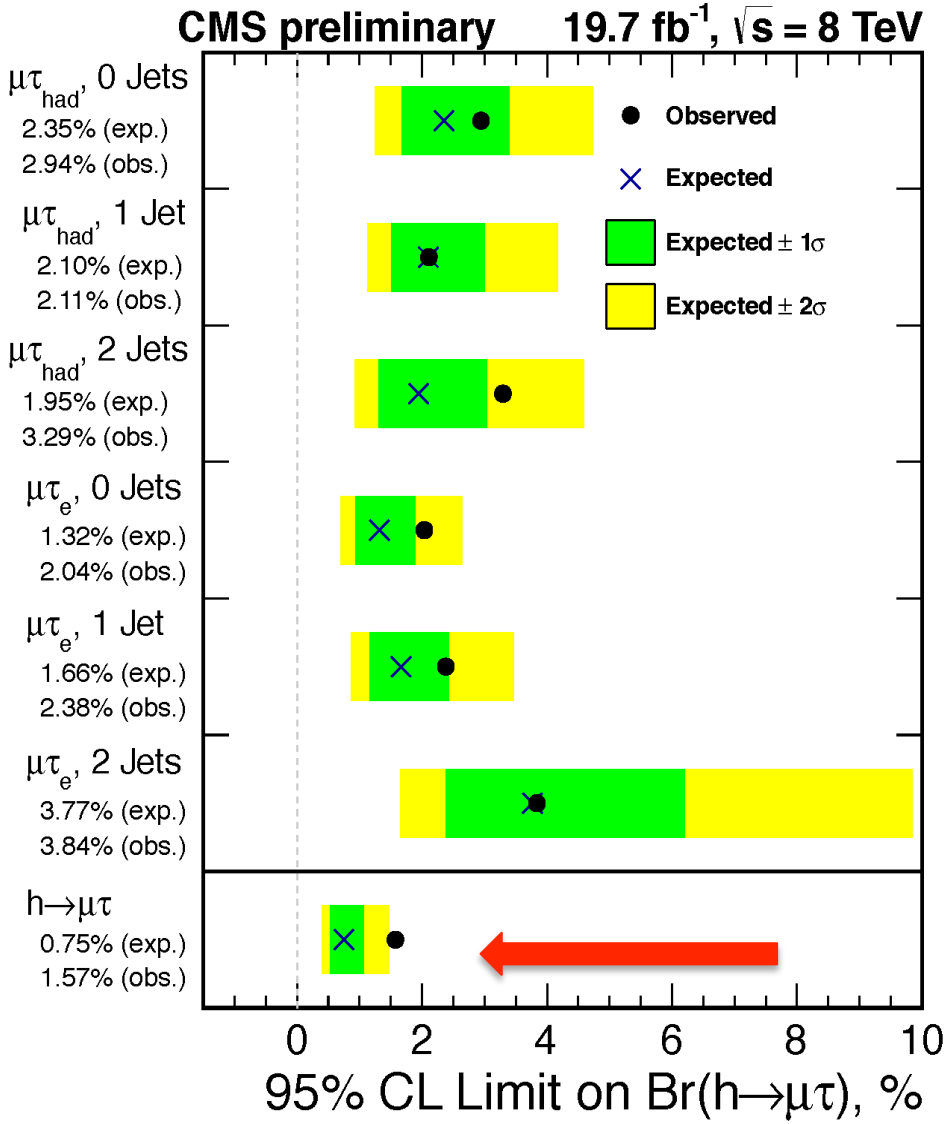

CMS preliminary
19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV
$\mu\tau_{had}$
2 jets
Data, $\mu\tau_{had}$
Bckg Uncertainty
SM H
Z+ττ (embedded)
Z+l$^+$l$^-$ (not $\tau_\mu\tau_{had}$)
Single top quark
tt̄+Jets
VV
Fakes (jet→τ)
LFV Higgs (Br=0.9%)
Events / 50 GeV
Data-Bckg (fit) / Bckg (fit)
collinear M($\mu\tau_{had}$) [GeV]

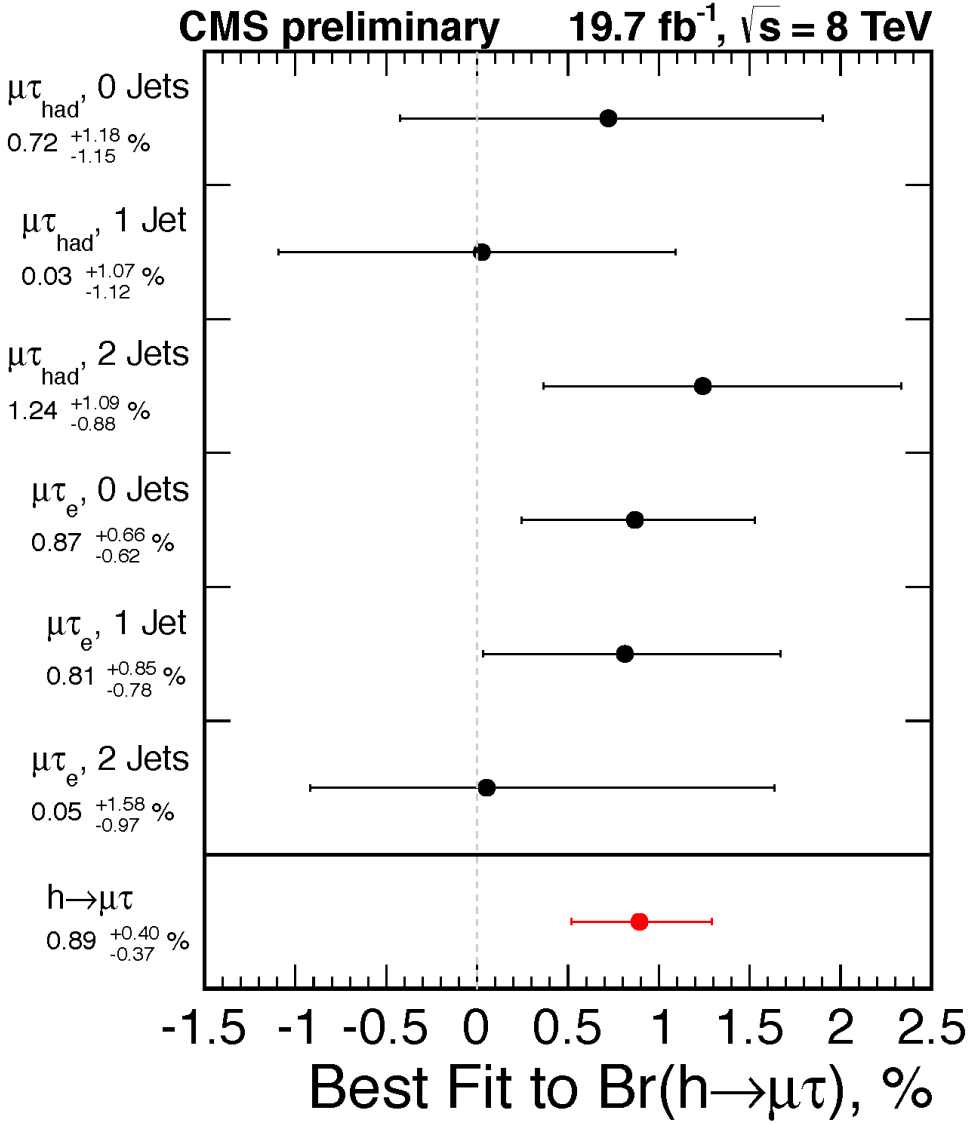

CMS preliminary
19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV
$\mu\tau_e$
0 jets
Data, $\mu\tau_e$
Bckg Uncertainty
SM Higgs
Z+ττ (embedded)
Z+l$^+$l$^-$ (not $\tau_\mu\tau_e$)
Single top quark
tt̄+Jets
Wγ / Wγ*
VV
Fake leptons
LFV Higgs (Br=0.9%)
Events / 10 GeV
Data-Bckg (fit) / Bckg (fit)
collinear M($\mu\tau_e$) [GeV]


CMS preliminary
19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV
$\mu\tau_e$
1 jets
Data, $\mu\tau_e$
Bckg Uncertainty
SM Higgs
Z+ττ (embedded)
Z+l$^+$l$^-$ (not $\tau_\mu\tau_e$)
Single top quark
tt̄+Jets
Wγ / Wγ*
VV
Fake leptons
LFV Higgs (Br=0.9%)
Events / 10 GeV
Data-Bckg (fit) / Bckg (fit)
collinear M($\mu\tau_e$) [GeV]


CMS preliminary
19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV
$\mu\tau_e$
2 jets
Data, $\mu\tau_e$
Bckg Uncertainty
SM Higgs
Z+ττ (embedded)
Z+l$^+$l$^-$ (not $\tau_\mu\tau_e$)
Single top quark
tt̄+Jets
Wγ / Wγ*
VV
Fake leptons
LFV Higgs (Br=0.9%)
Events / 20 GeV
Data-Bckg (fit) / Bckg (fit)
collinear M($\mu\tau_e$) [GeV]

LVF Higgs → μτ



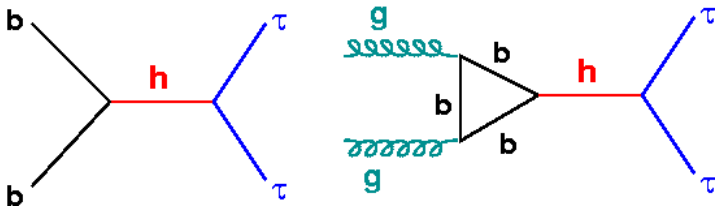


An excess at the level of 2.5σ

ATLAS looking at the same channel as we speak..

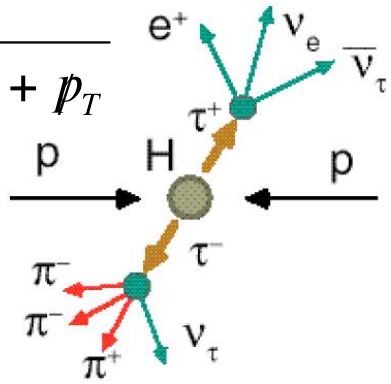
This is one reason to have two (expensive) experiments

(let me show you one example…)



$\phi \to \tau\tau$

$$m_{vis} = \sqrt{p_{\tau_1}^{vis} + p_{\tau_2}^{vis} + \not{p}_T}$$



As shown in LP2007

...idates

...ne hadronic or leptonic (CDF) decay

One leptonic decay (opposite charge)

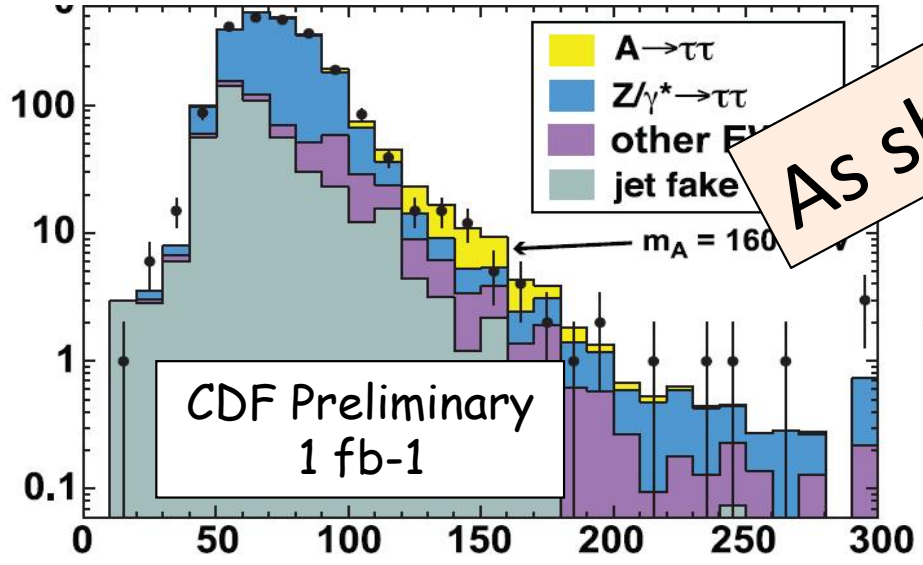
(CDF: e,μ) (D0: μ)

small excess in CDF eτ+μτ channel (<2σ effect)

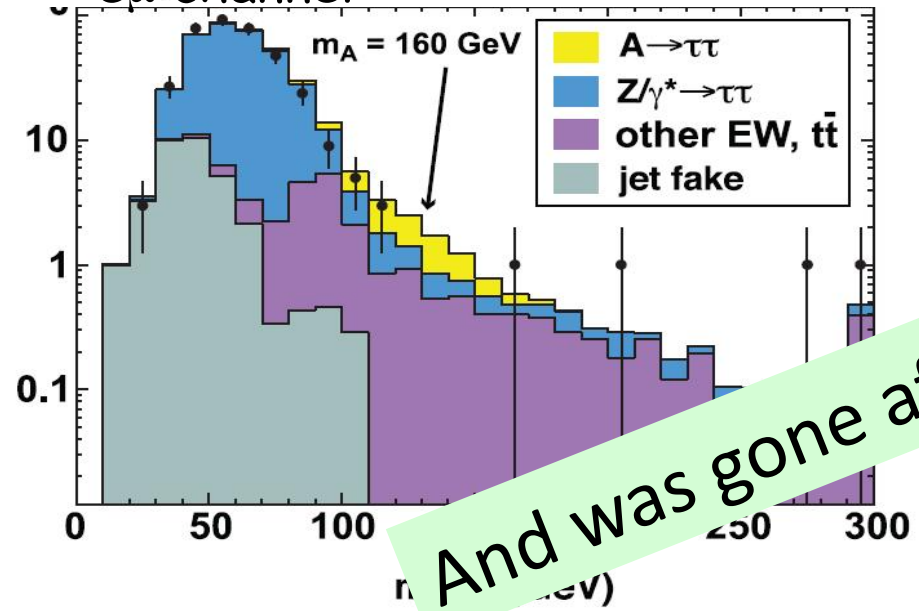
Not observed in CDF eμ channel

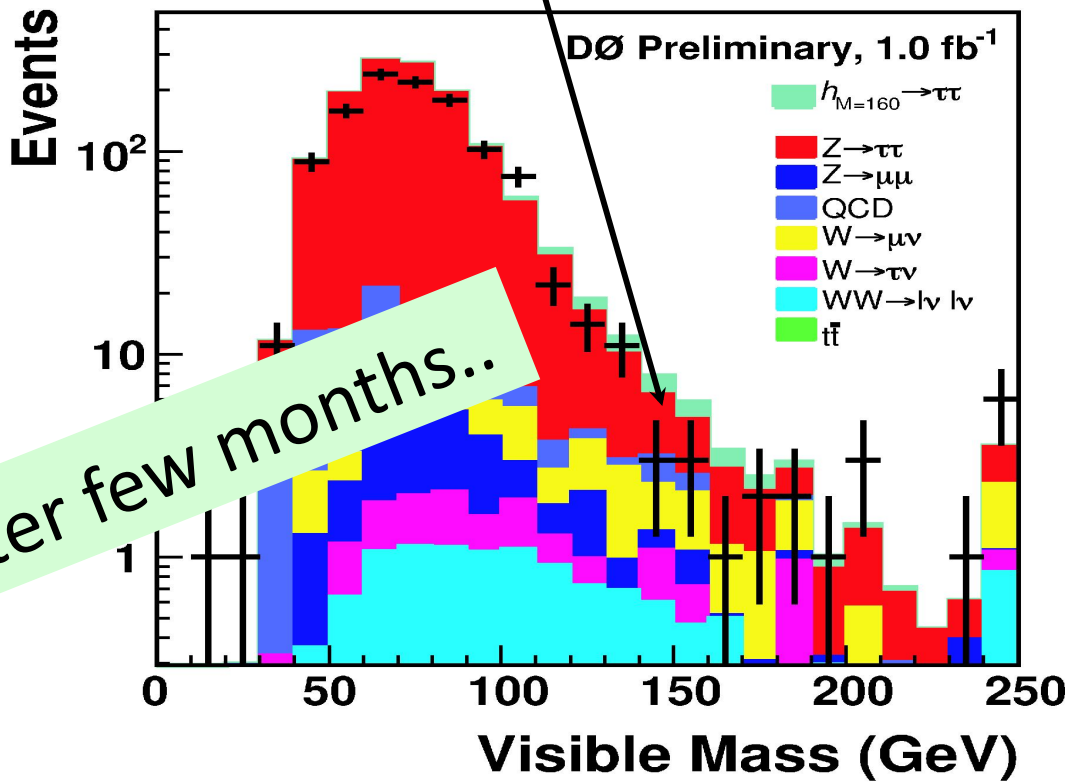
Followed by a D0 deficit in same region

eτ,μτ channel



eμ channel

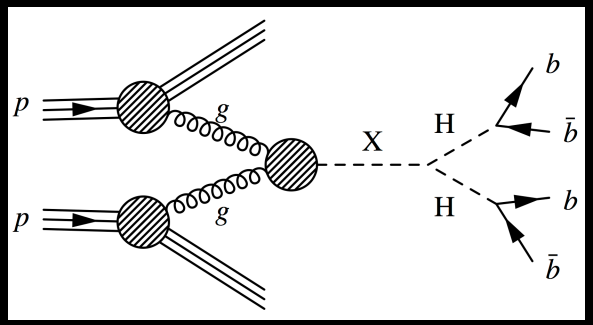


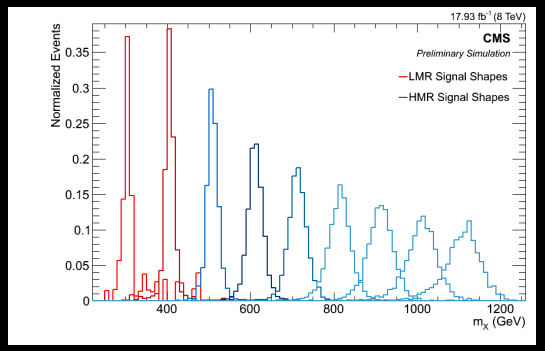


And was gone after few months..

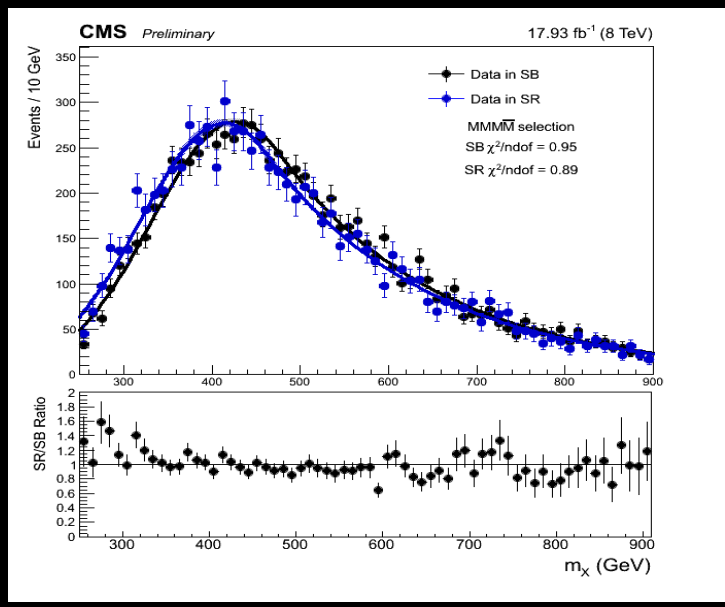
X → HH (→ bbbb)

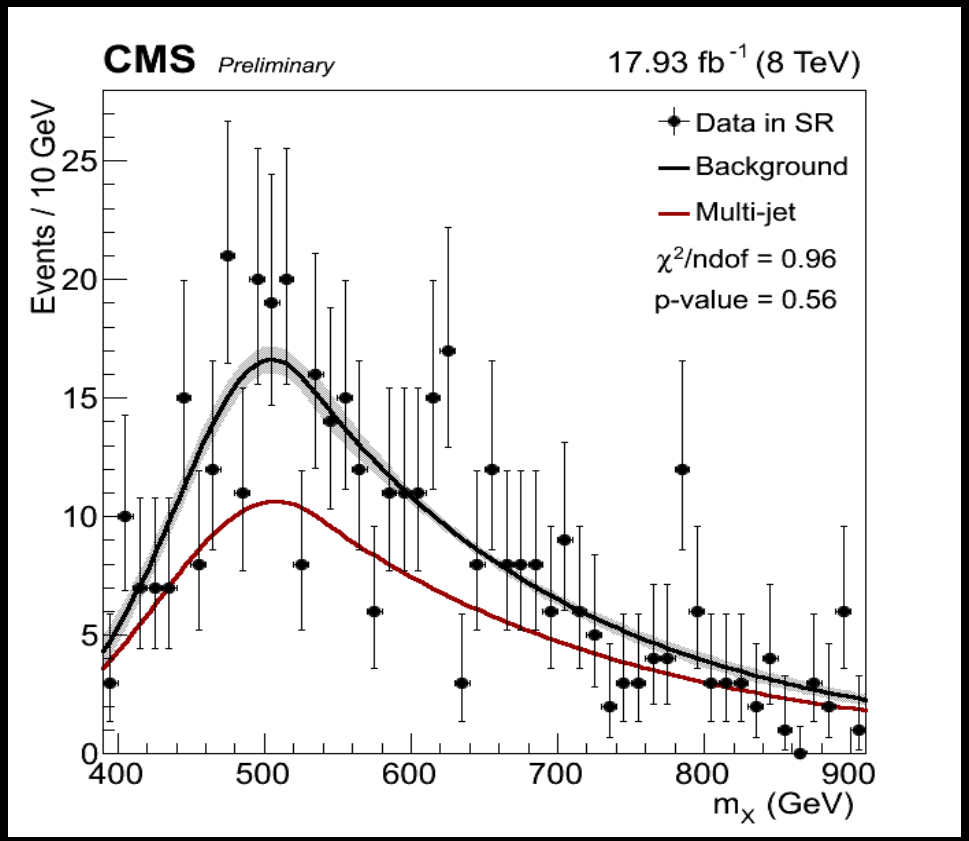
3-b control region

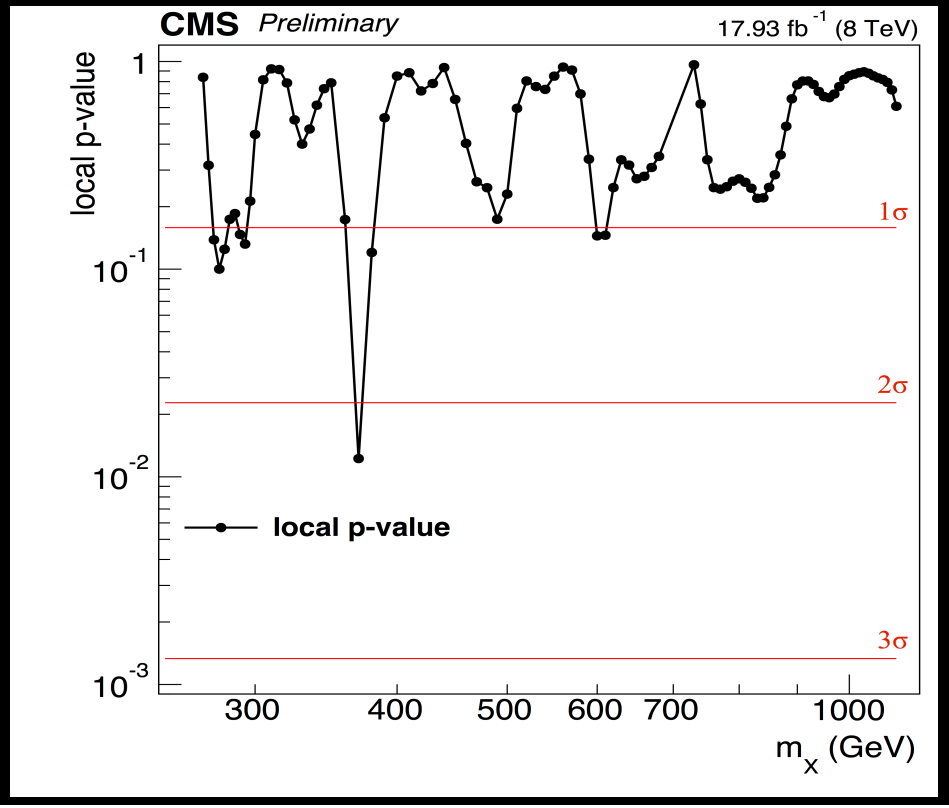




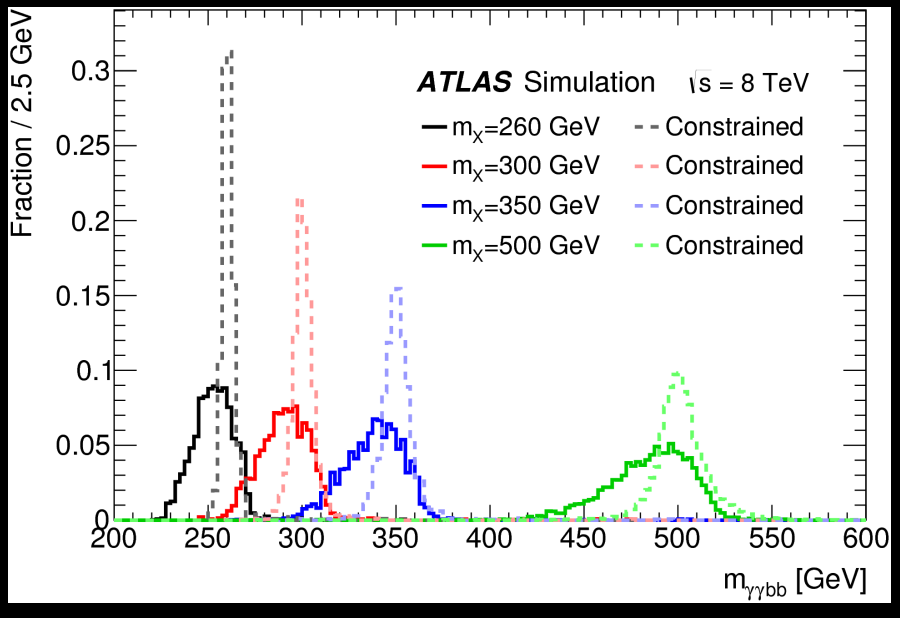
Very difficult analysis
(huge QCD and ttbar)

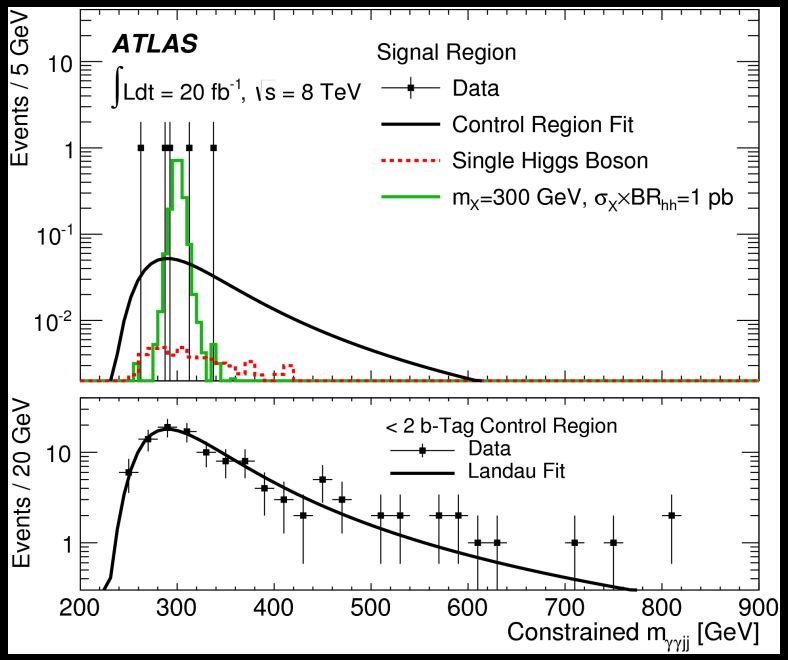


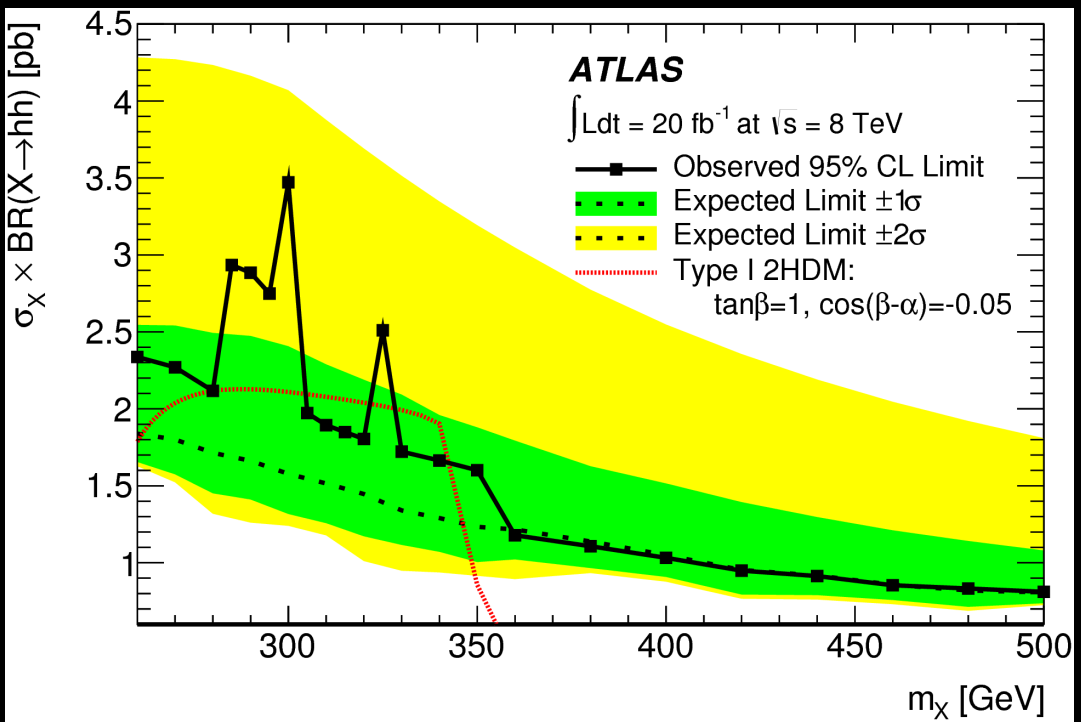


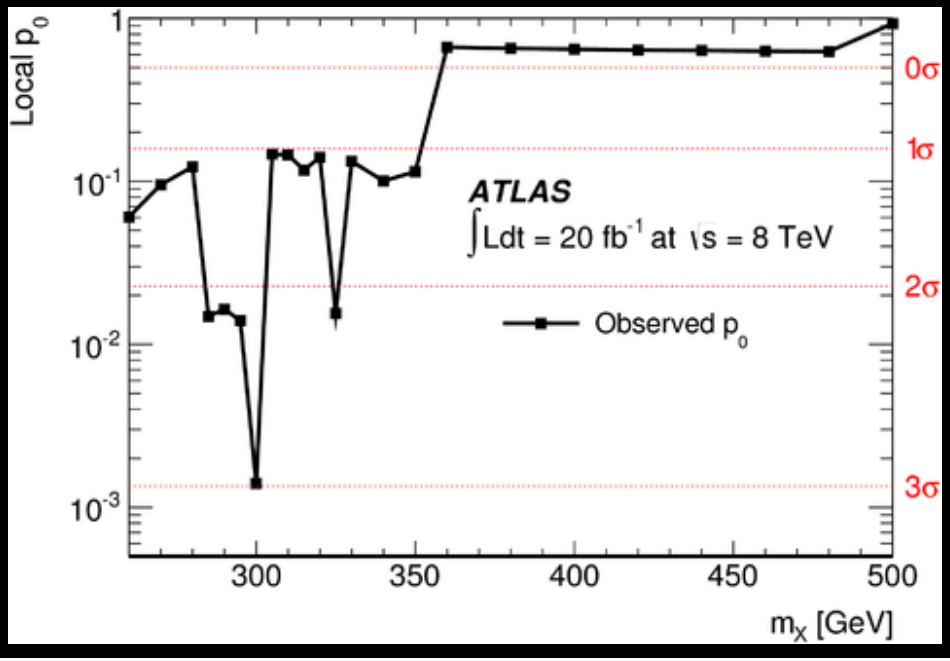


X → HH (γγ bb)


ATLAS Simulation √s = 8 TeV
m_X=260 GeV Constrained
m_X=300 GeV Constrained
m_X=350 GeV Constrained
m_X=500 GeV Constrained
Fraction / 2.5 GeV
m_γγbb [GeV]


ATLAS
∫Ldt = 20 fb⁻¹, √s = 8 TeV
Signal Region
Data
Control Region Fit
Single Higgs Boson
m_X=300 GeV, σ_X×BR_hh=1 pb
Events / 5 GeV
< 2 b-Tag Control Region
Data
Landau Fit
Events / 20 GeV
Constrained m_γγjj [GeV]


ATLAS
∫Ldt = 20 fb⁻¹ at √s = 8 TeV
Observed 95% CL Limit
Expected Limit ±1σ
Expected Limit ±2σ
Type I 2HDM:
tanβ=1, cos(β-α)=-0.05
σ_X × BR(X→hh) [pb]
m_X [GeV]


ATLAS
∫Ldt = 20 fb⁻¹ at √s = 8 TeV
Observed p_0
Local p_0
0σ
1σ
2σ
3σ
m_X [GeV]

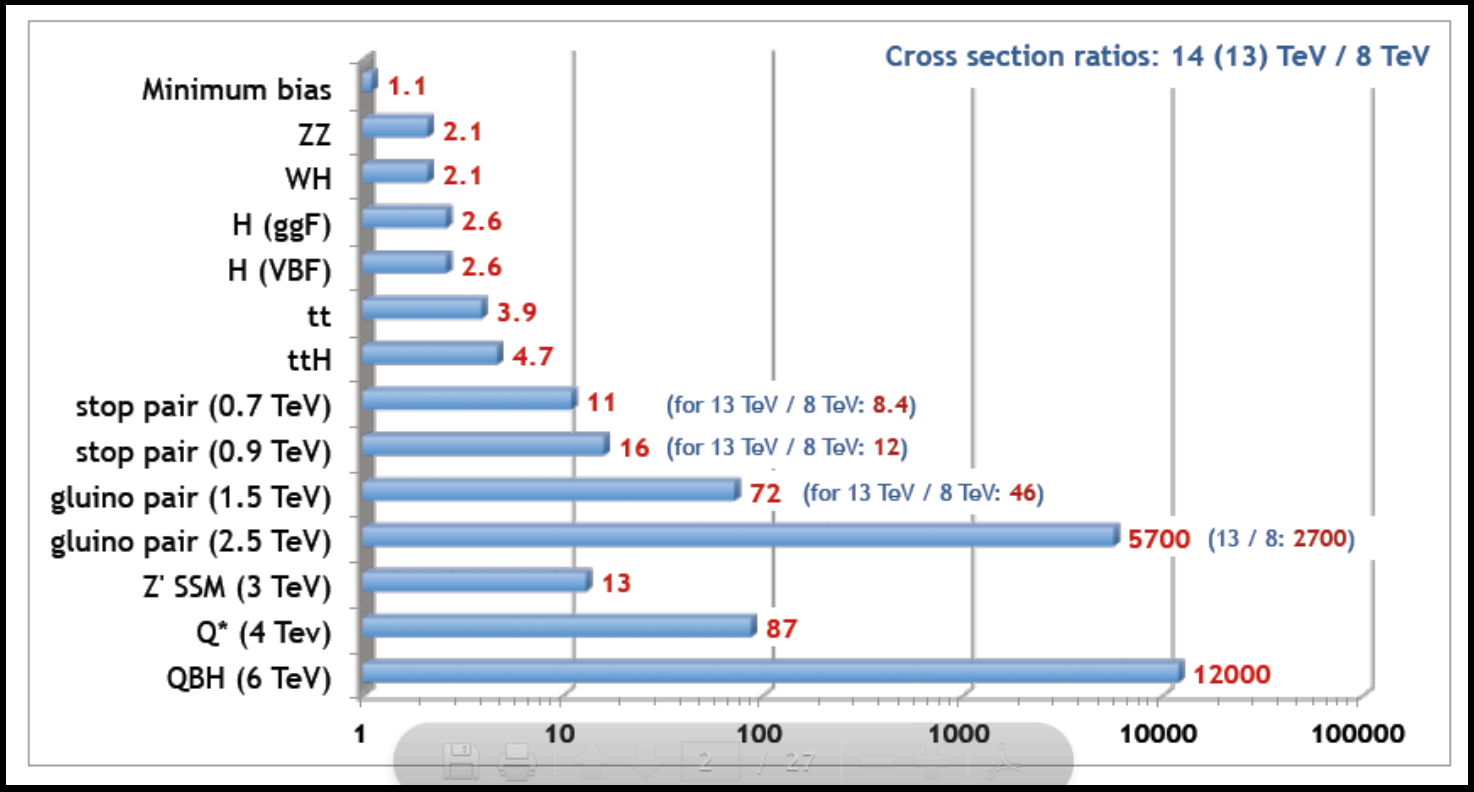
Only more data will tell

LHC beyond Run I

LHC in 2015

HL-LHC

The physics gain 8 TeV → 13 TeV



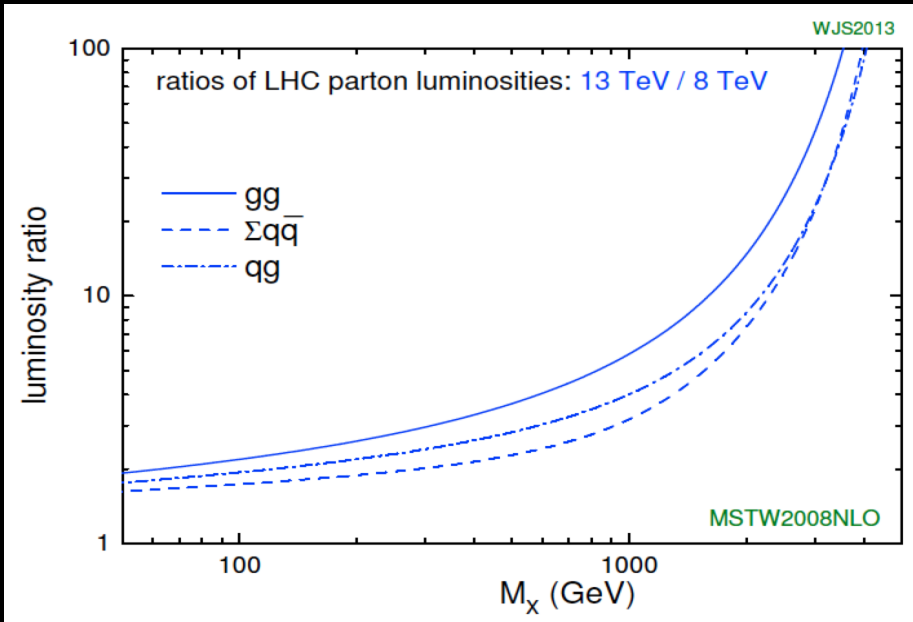
Consider this an optimistic view as it does not include realities as

Background composition
Pileup
Data Validation
MC simulation
……..

NO surprising.. this is just PDFs

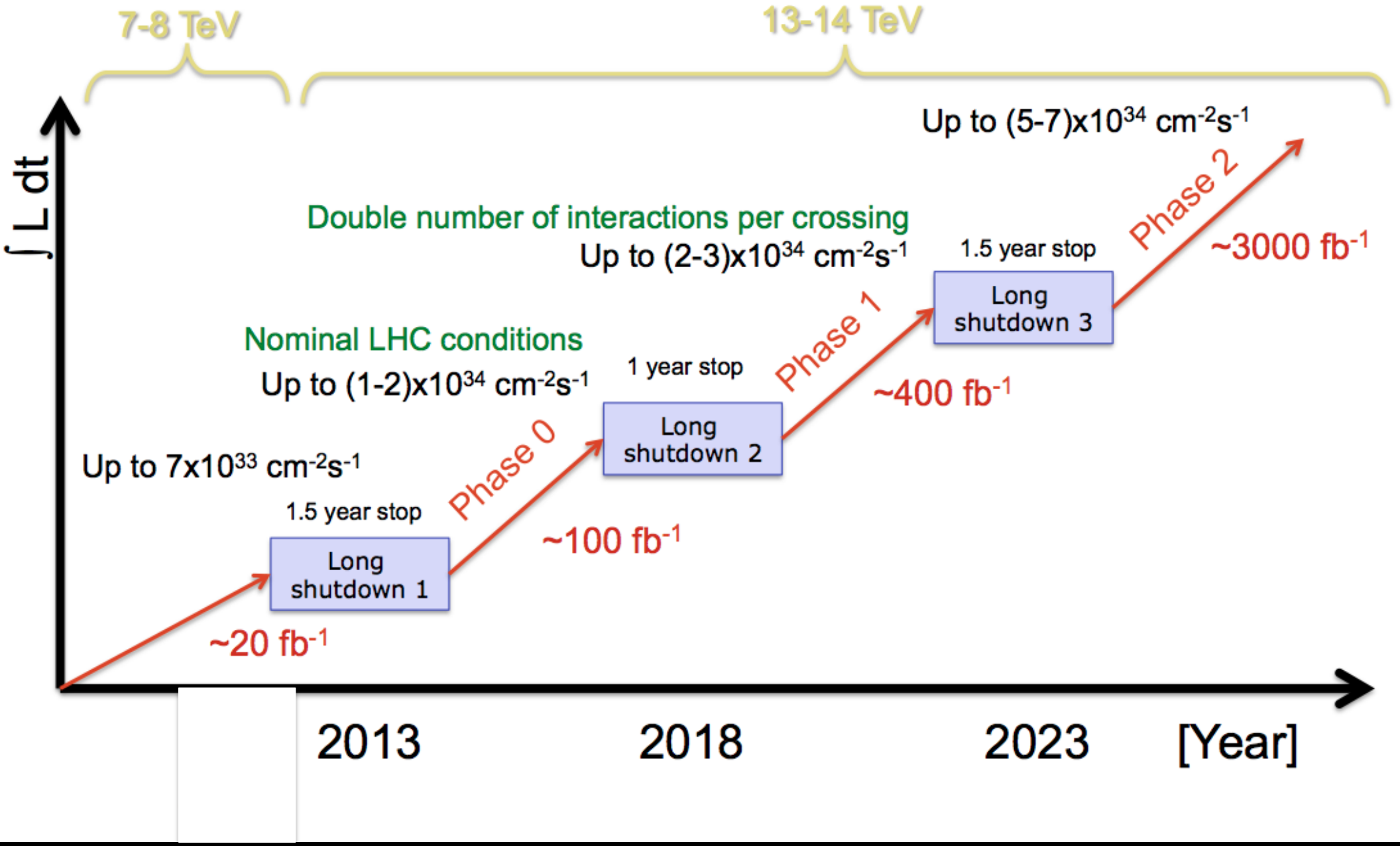
But tells you nicely what we already know

- Huge improvement at the edge of phase space
- Searches should be priority 1 in first 6-12 months



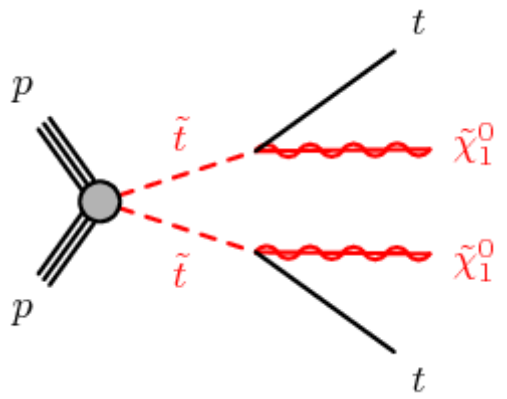
LHC Plan

Producción
174M Higgs

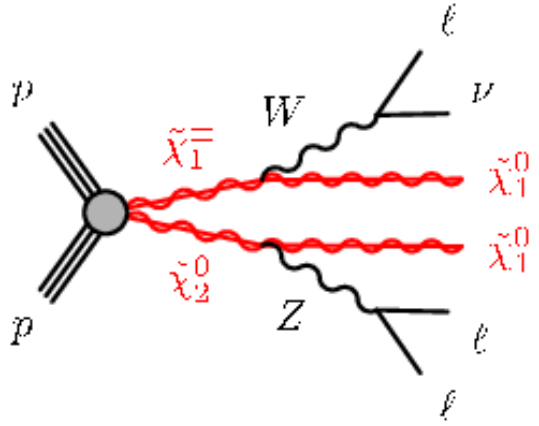


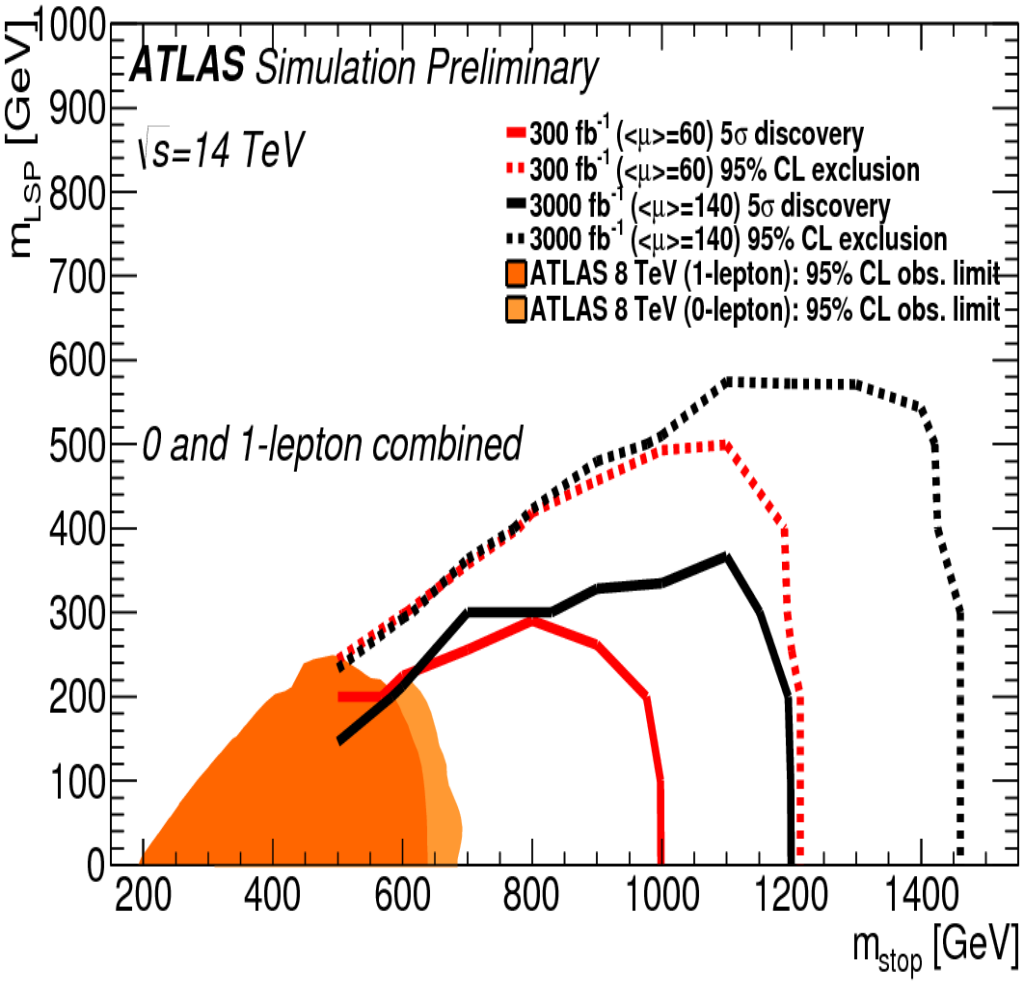
ATL-PHYS-PUB-2013-011

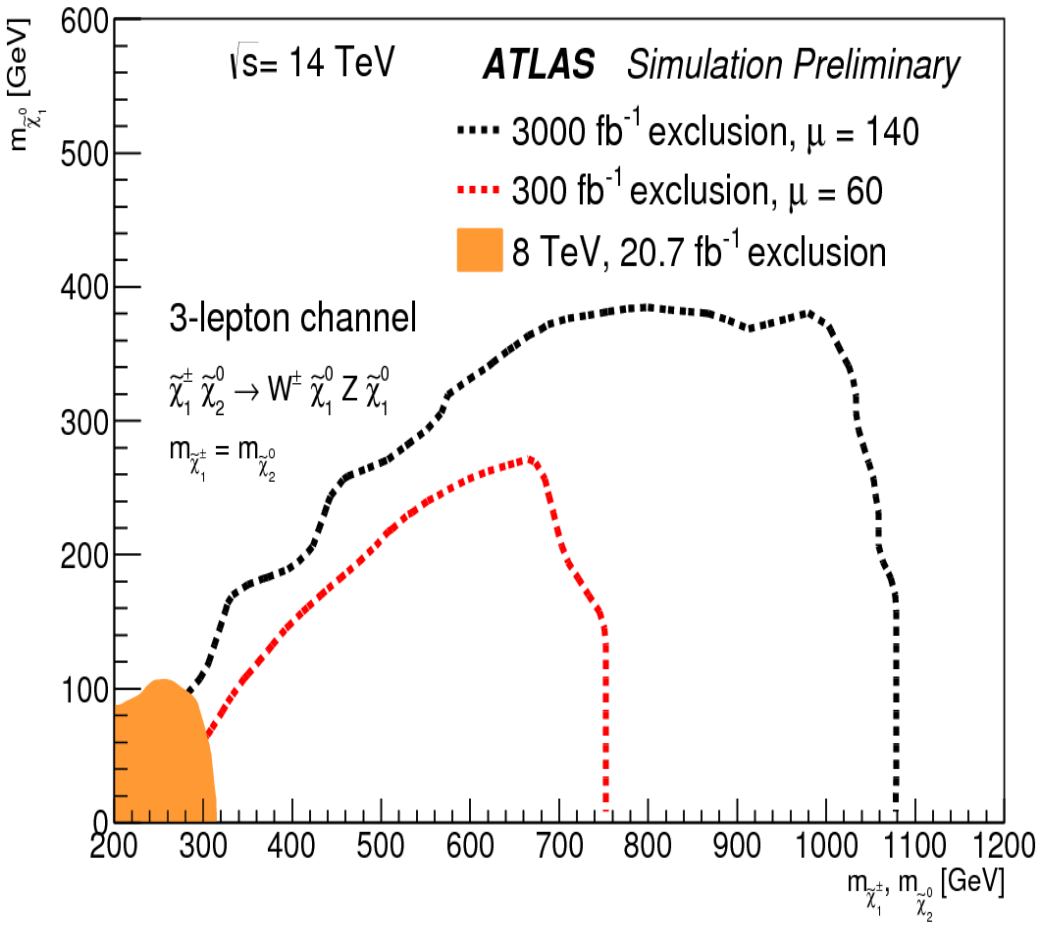
14 TeV Prospects



Will be in the position to "kill natural SUSY"

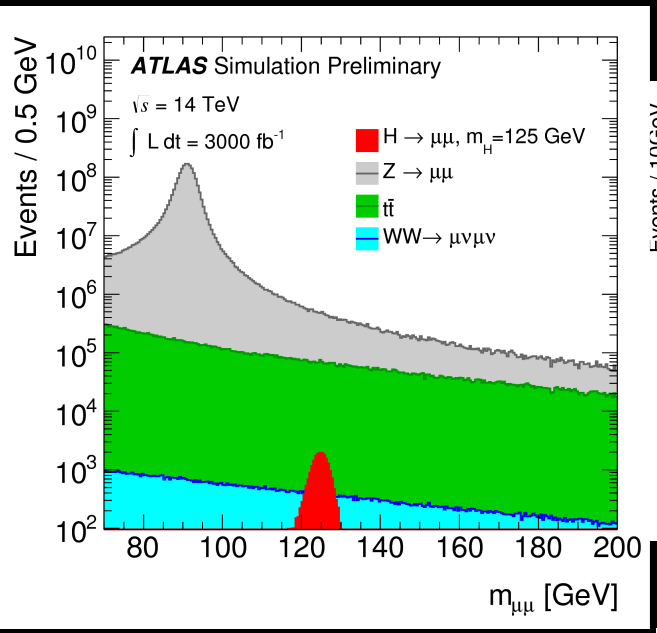


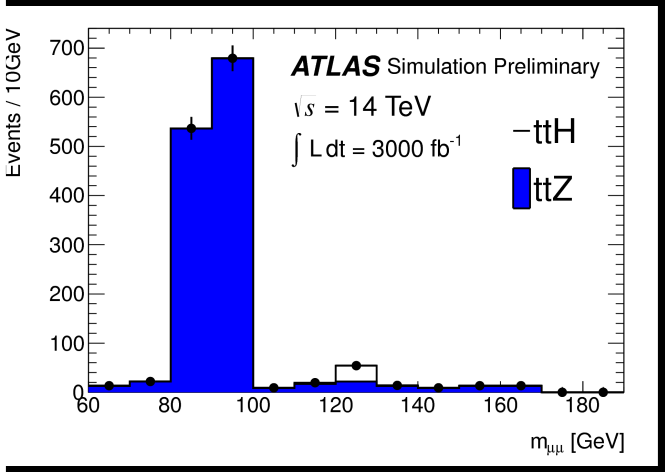


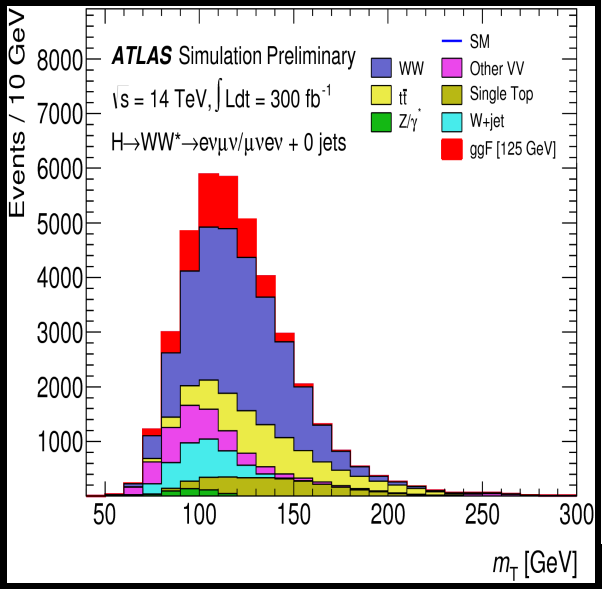


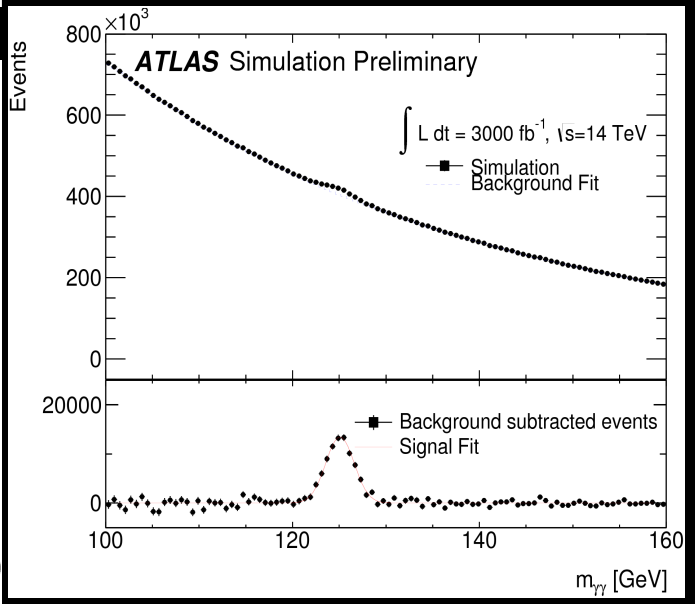
Higgs signal strength

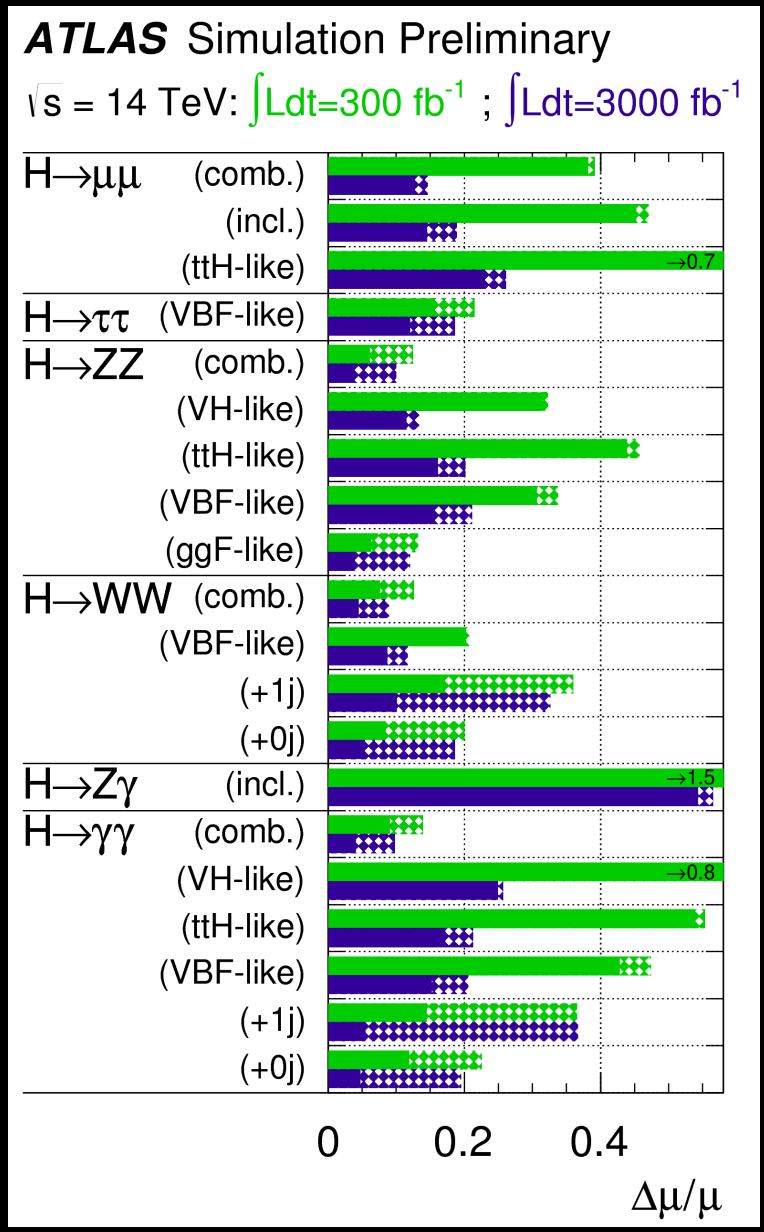
10 – 20 % accuracy after long time





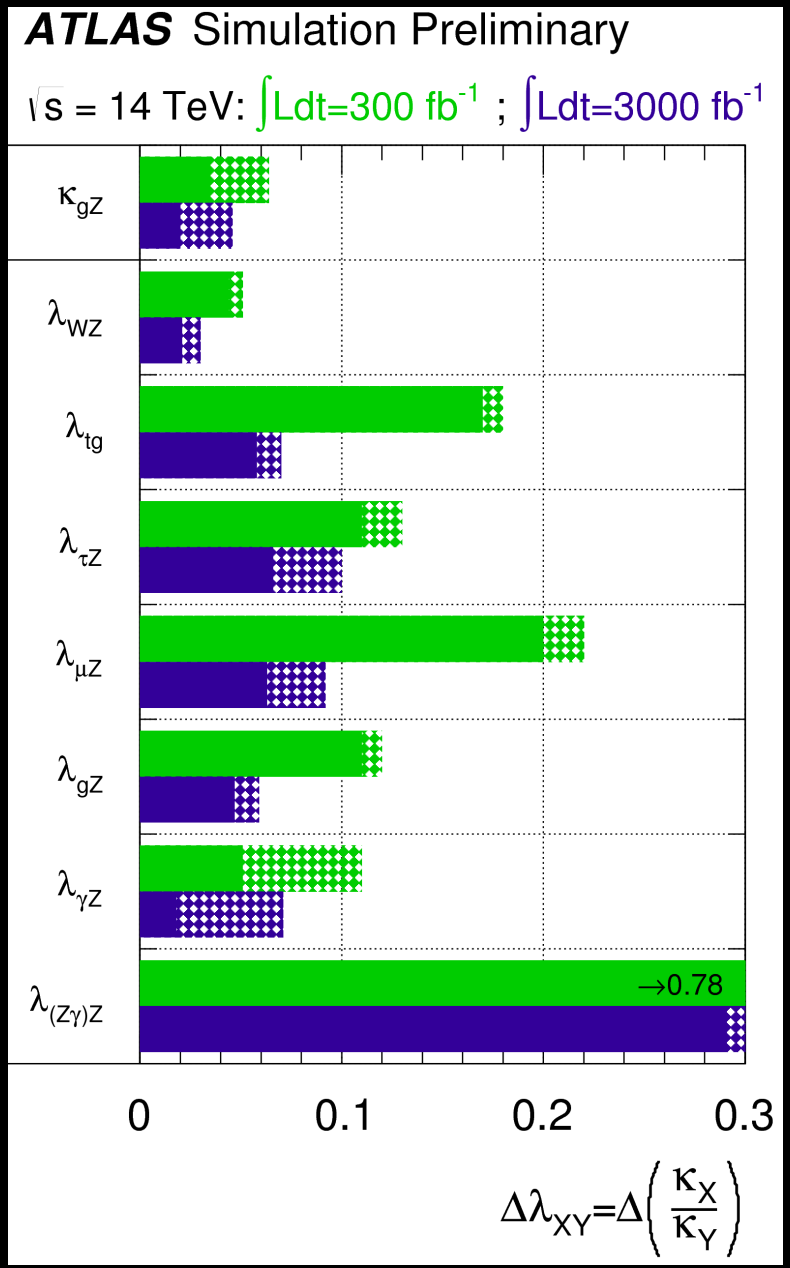


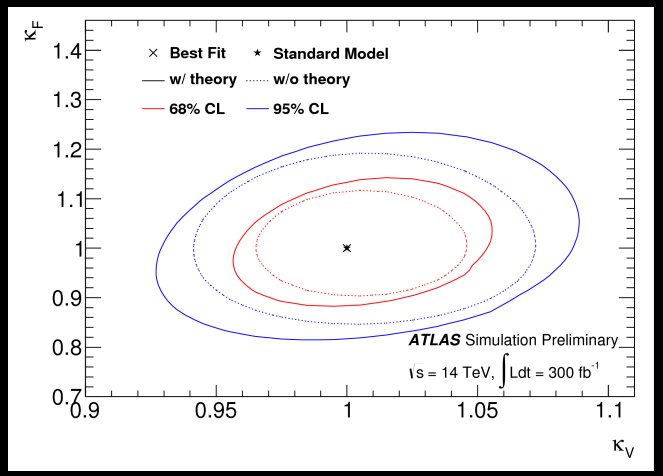


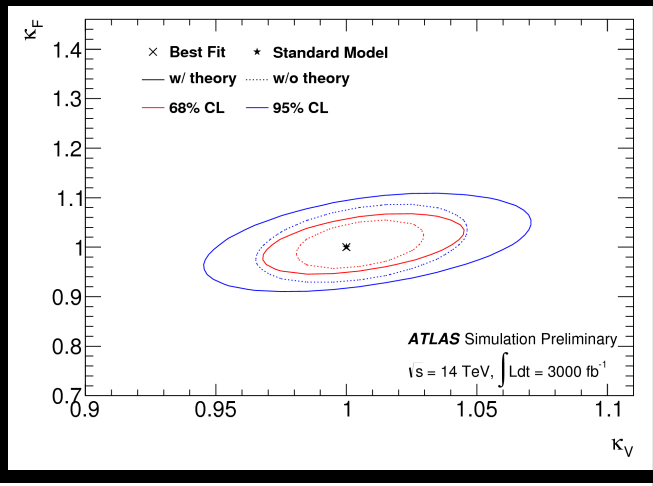


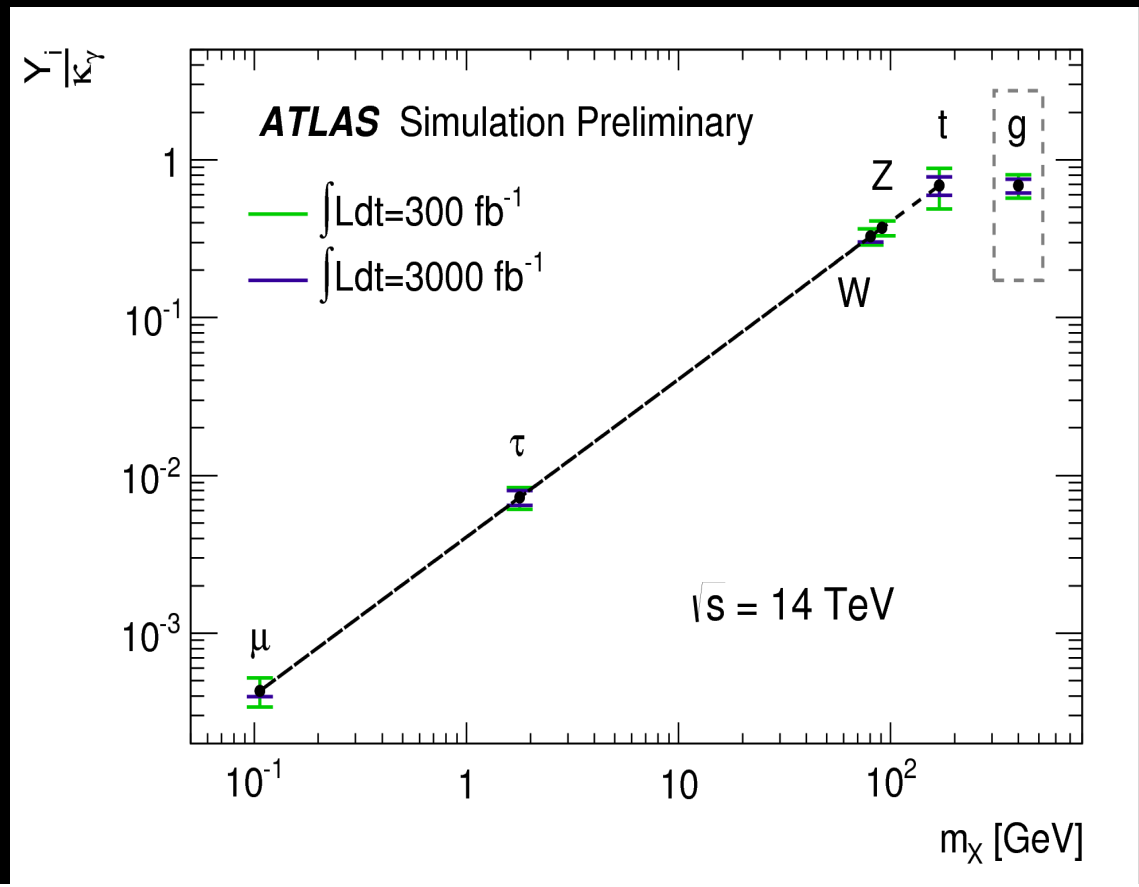
Higgs Couplings

5-10% accuracy on couplings

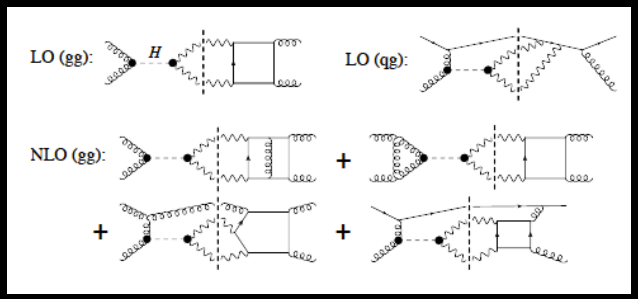








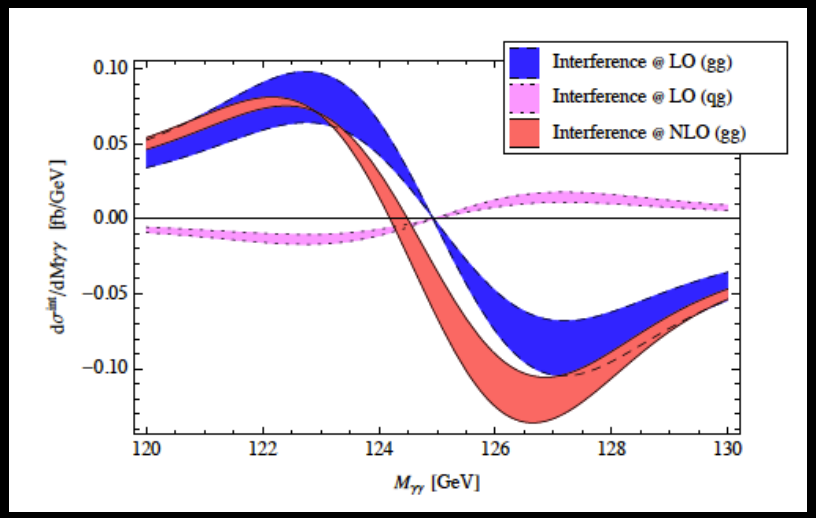
Higgs width

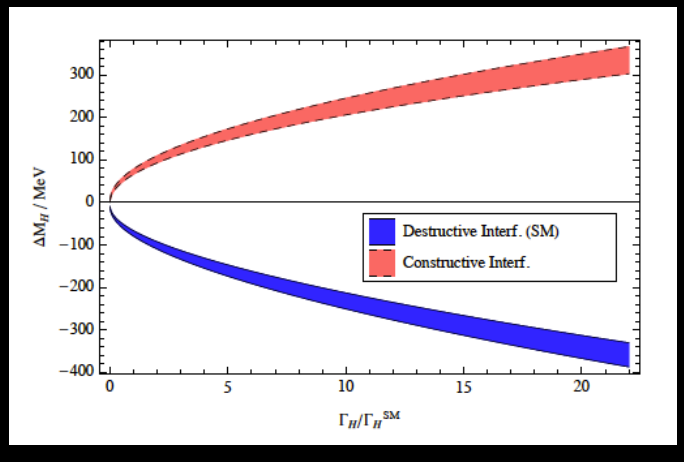


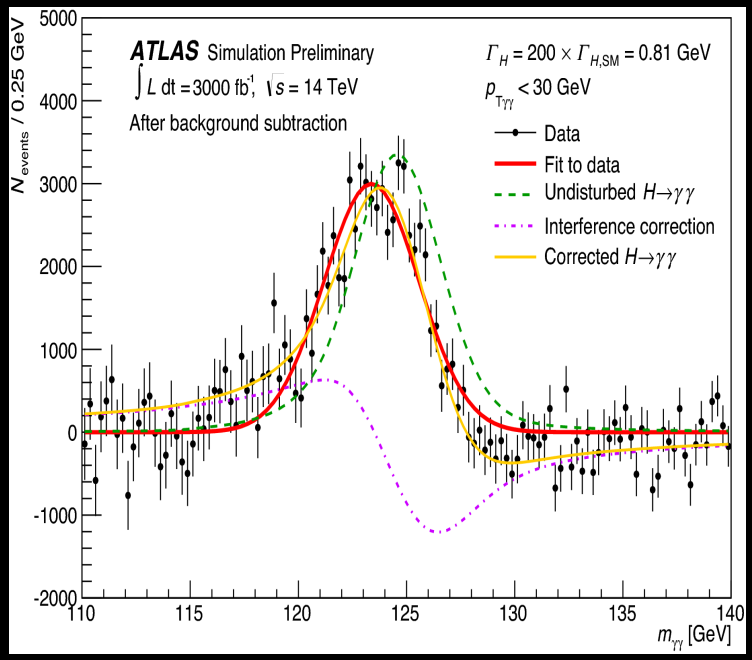
Lance J. Dixon[1] and Ye Li[1]

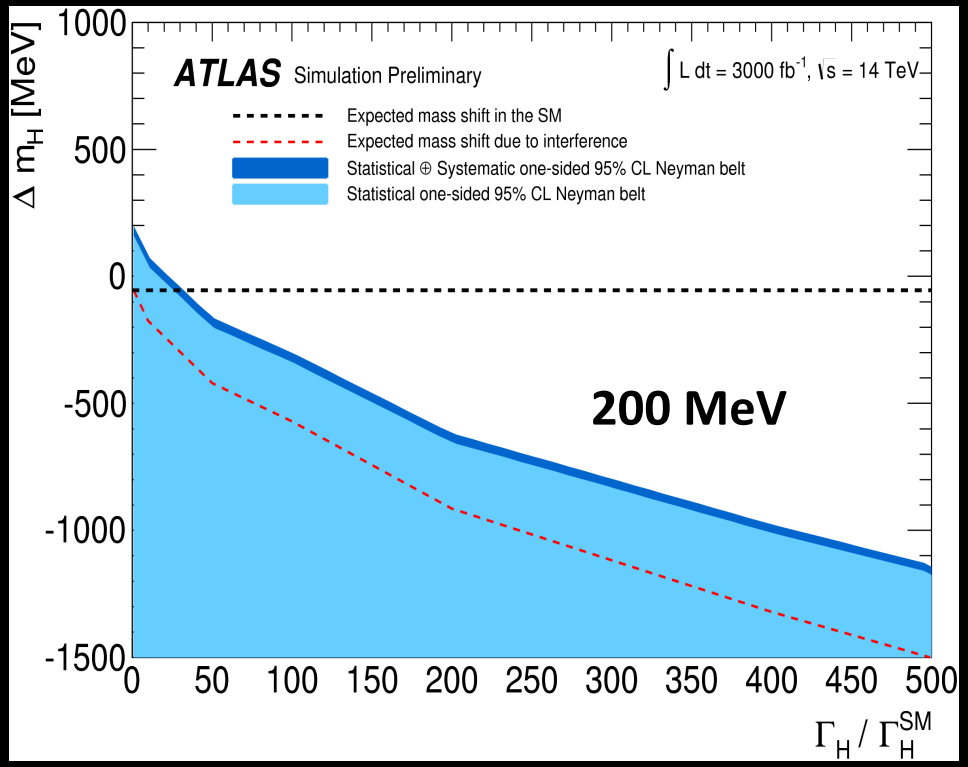
Bounding the Higgs Boson Width Through Interferometry

$$\frac{d\sigma^{\rm sig}}{dM_{\gamma\gamma}} = \frac{S}{(M_{\gamma\gamma}^2 - m_H^2)^2 + m_H^2\Gamma_H^2},$$
$$\frac{d\sigma^{\rm int}}{dM_{\gamma\gamma}} = \frac{(M_{\gamma\gamma}^2 - m_H^2)R + m_H\Gamma_H I}{(M_{\gamma\gamma}^2 - m_H^2)^2 + m_H^2\Gamma_H^2}.$$

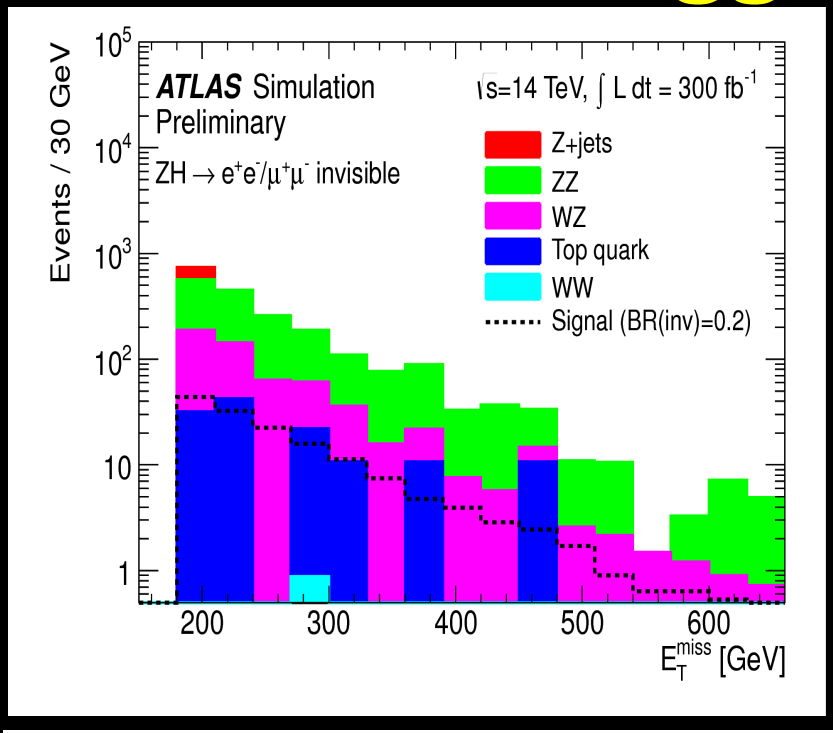


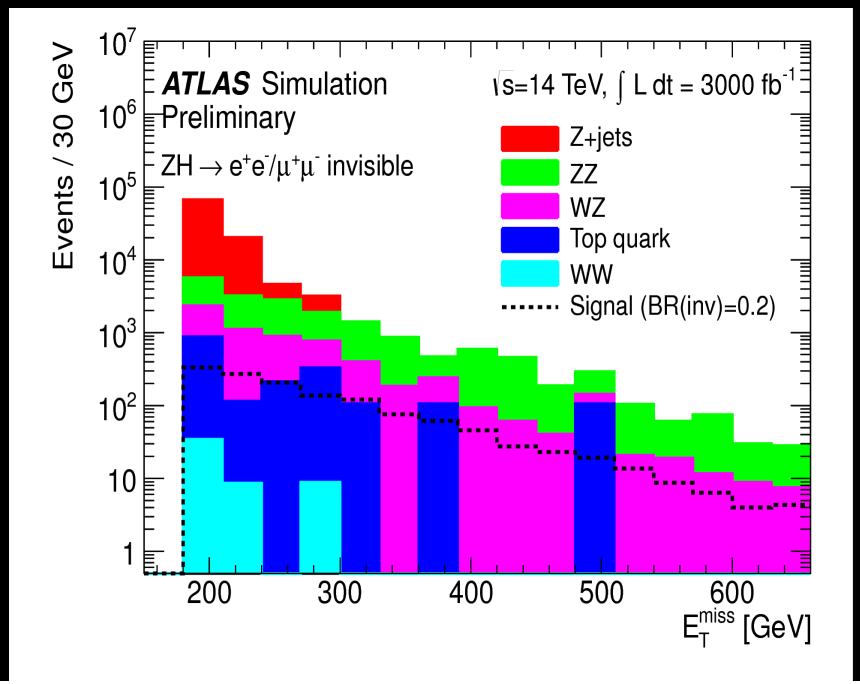


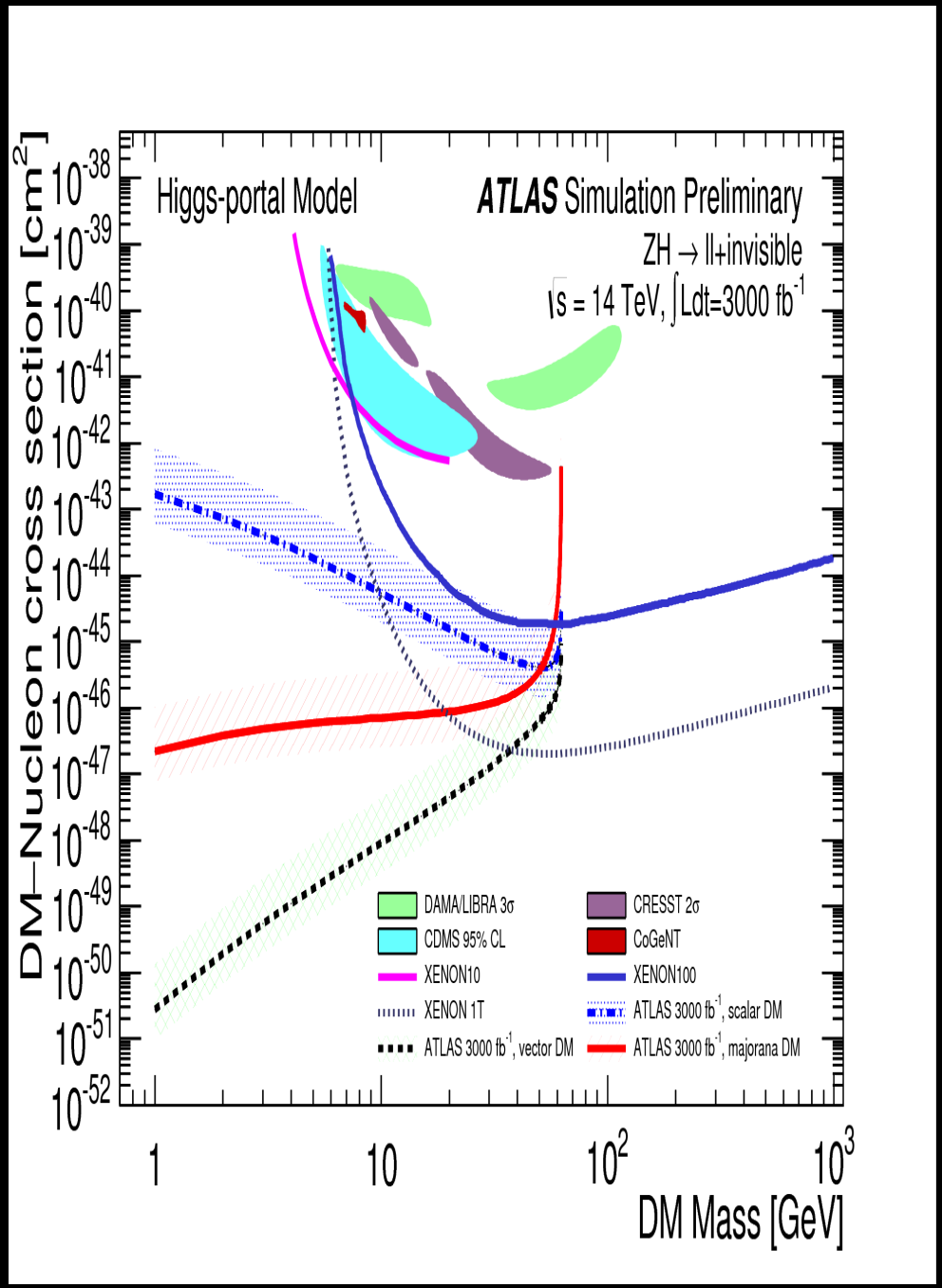




Higgs Portal to DM







Final Notes

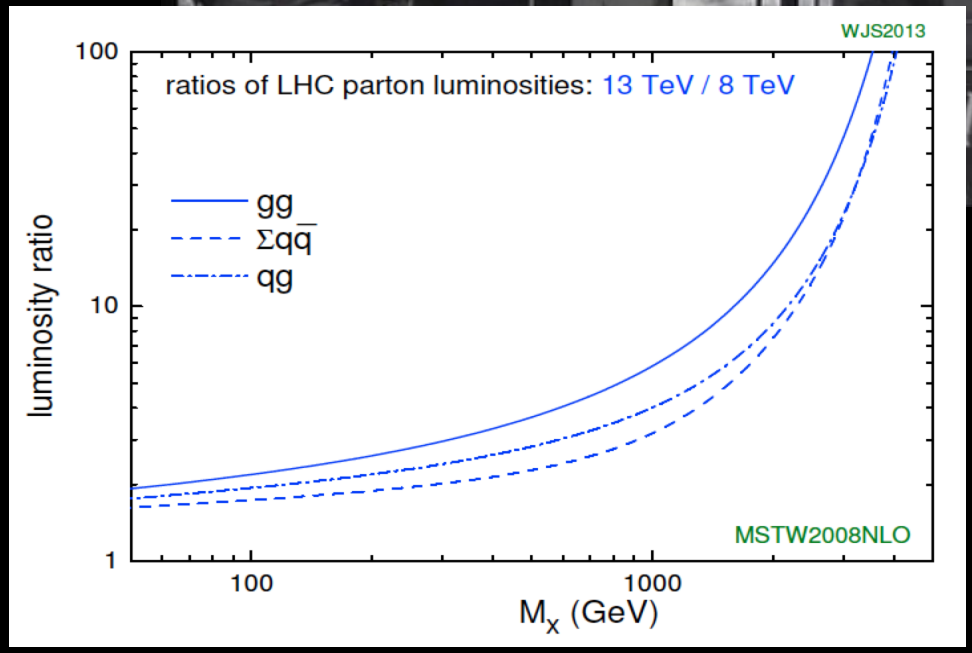
More energy and more data !

El LHC will almost double
the centre-of-mass energy
in 2015

8 TeV → 13 TeV

(about 20 fb-1 in 2015…my guess)

Cross section for stop (0.9 TeV mass) pair production @ 13 TeV = 12 x @ 8 TeV



Ready for a new discovery ?

WE NEED YOU TO JOIN US