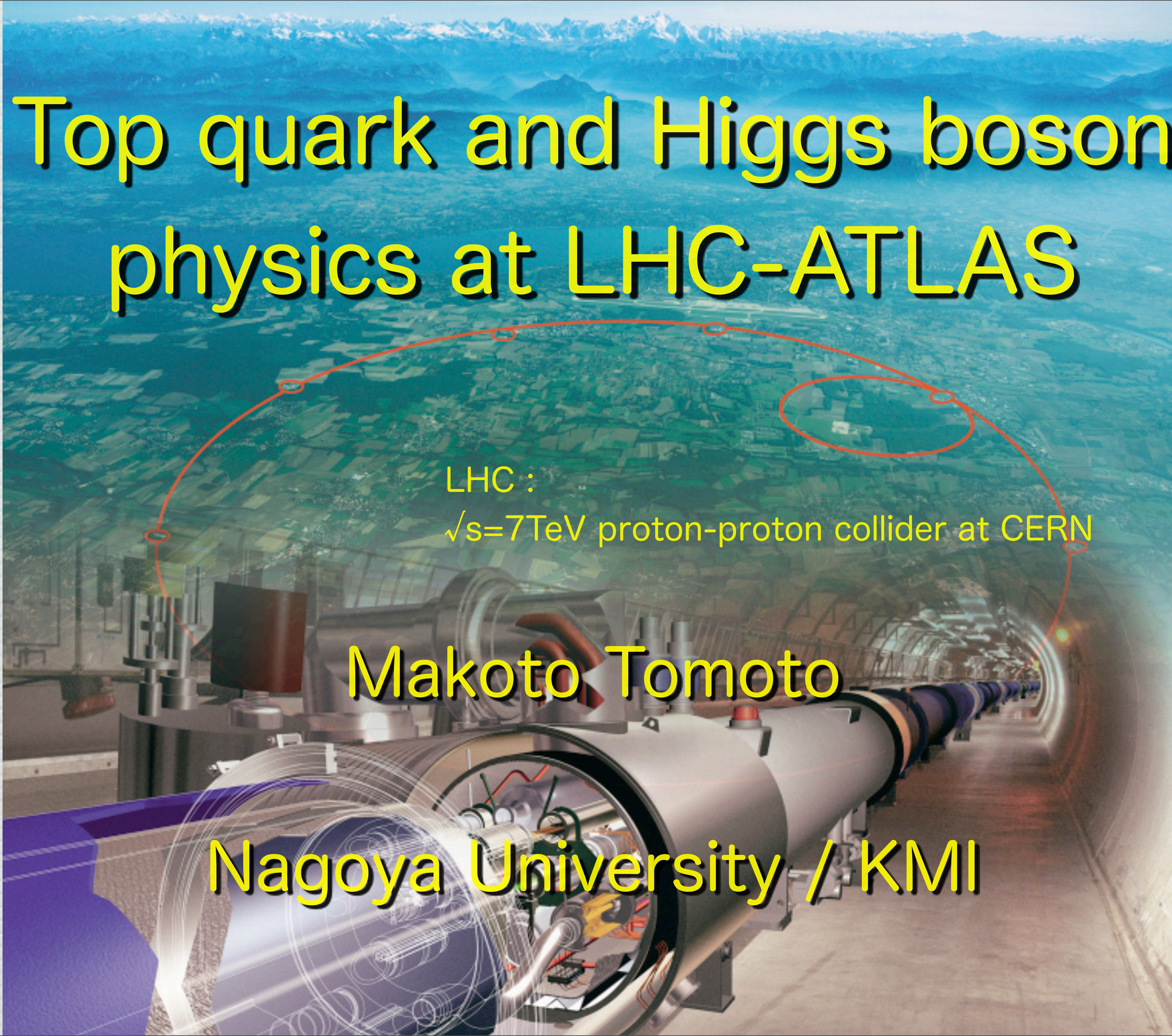
Top quark and Higgs boson physics at LHC-ATLAS



LHC :
√s=7TeV proton-proton collider at CERN

Makoto Tomoto

Nagoya University / KMI

Outline

(1) Motivation to Higgs boson and top quark physics

(2) ATLAS detector

(3) The latest results of the top quark physics

① top pair production cross section in dilepton final state

Measurement of the top-quark pair production cross-section in pp collisions at √s = 7 TeV in dilepton final states with ATLAS (ATLAS-CONF-2011-100)

Measurement of the top quark pair production cross-section based on a statistical combination of measurements of dilepton and single-lepton final states at √s = 7 TeV with the ATLAS detector (ATLAS-CONF-2011-108)

② top pair production cross section in τ-μ final state

Measurement of the top quark pair production cross section in pp collisions at √s = 7 TeV in μ+τ final states with ATLAS (ATLAS-CONF-2011-119)

③ W boson polarization in top quark decays

Measurement of the W boson polarisation in top quark decays in 0.70 fb^{-1} of pp collisions at √s = 7 TeV with the ATLAS detector (ATLAS-CONF-2011-122)

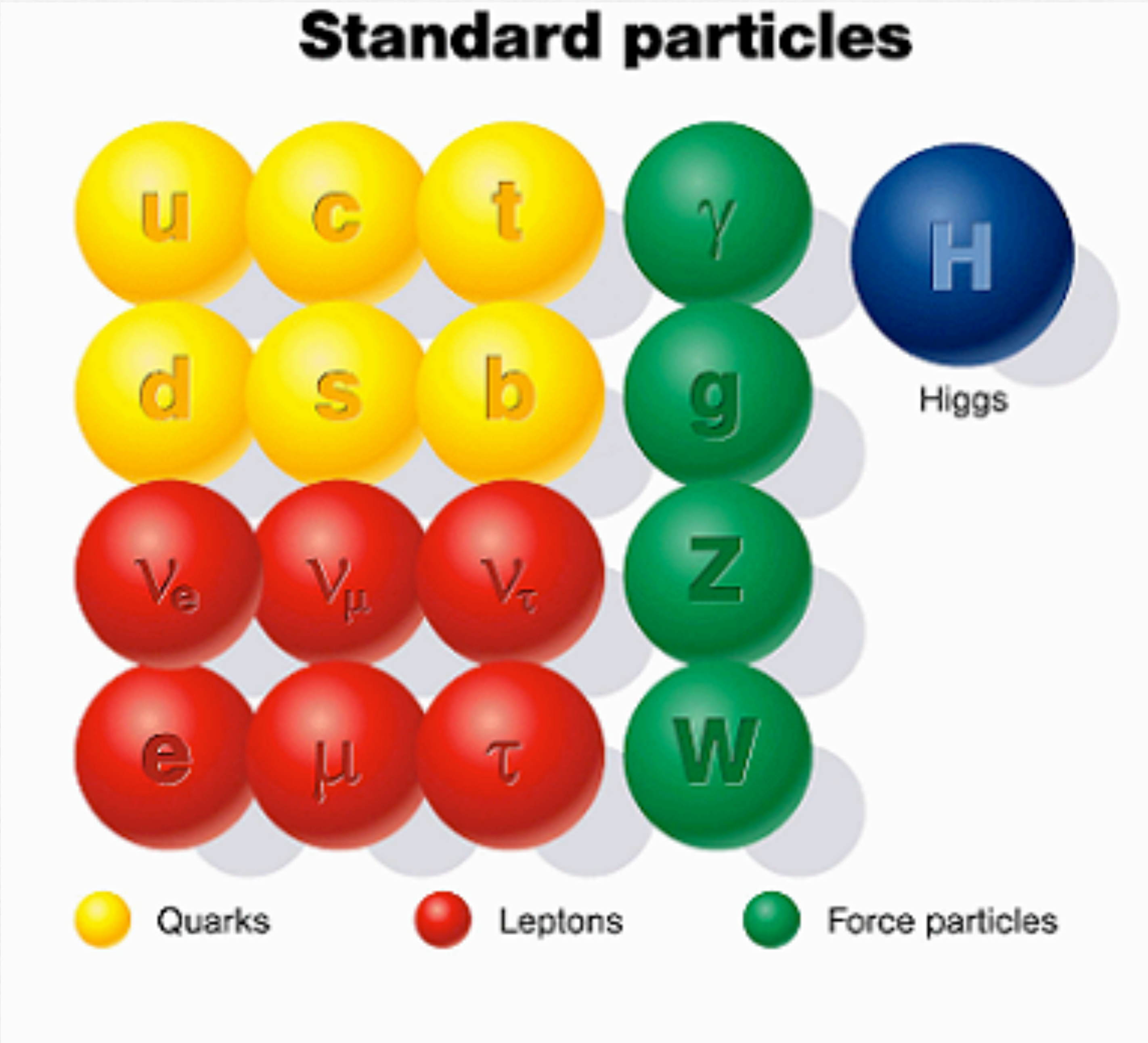
(4) The latest results of the Higgs boson searches

(5) Summary

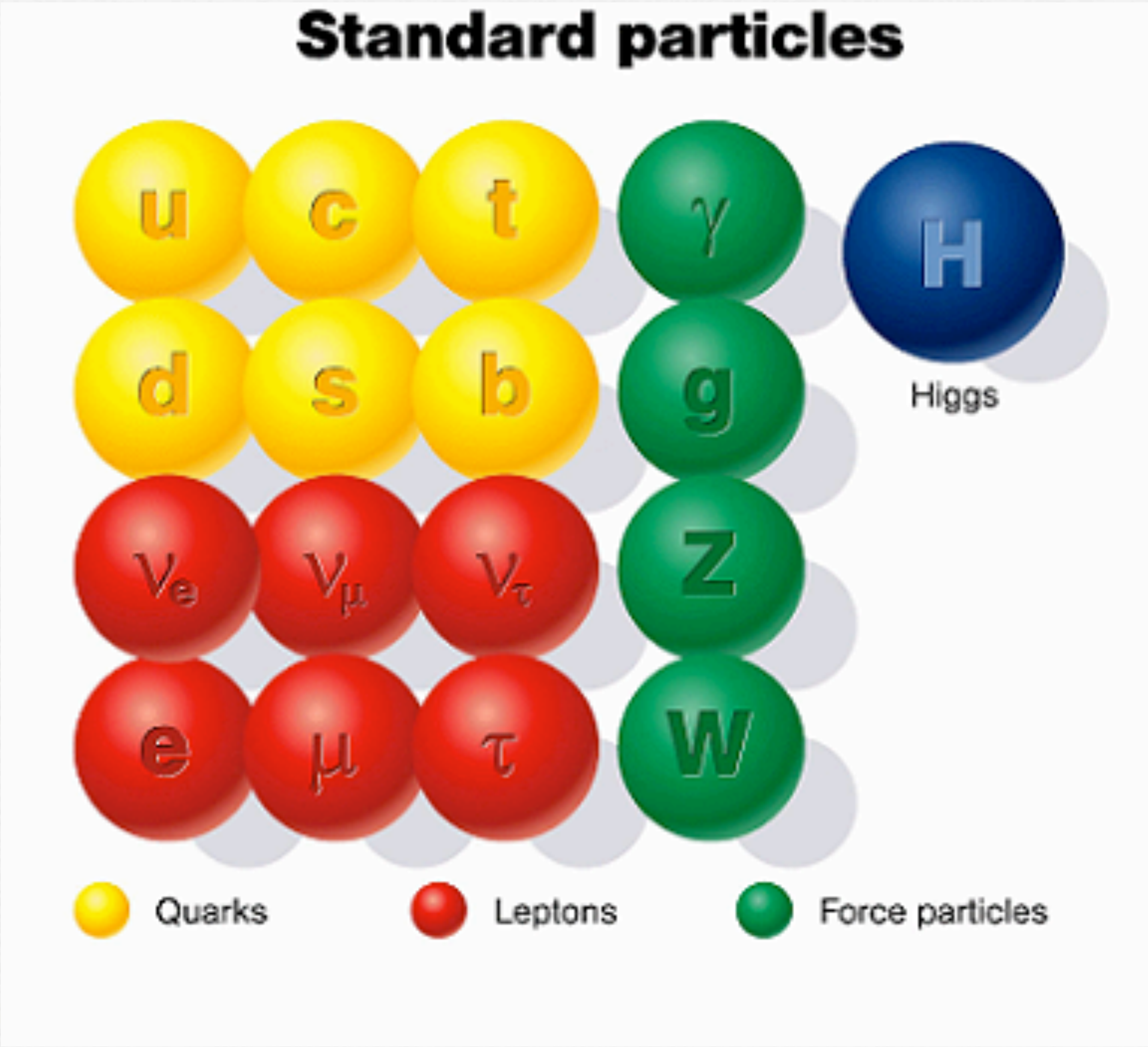
Motivation to

Top quark physics
&
Higgs boson physics

Standard Model

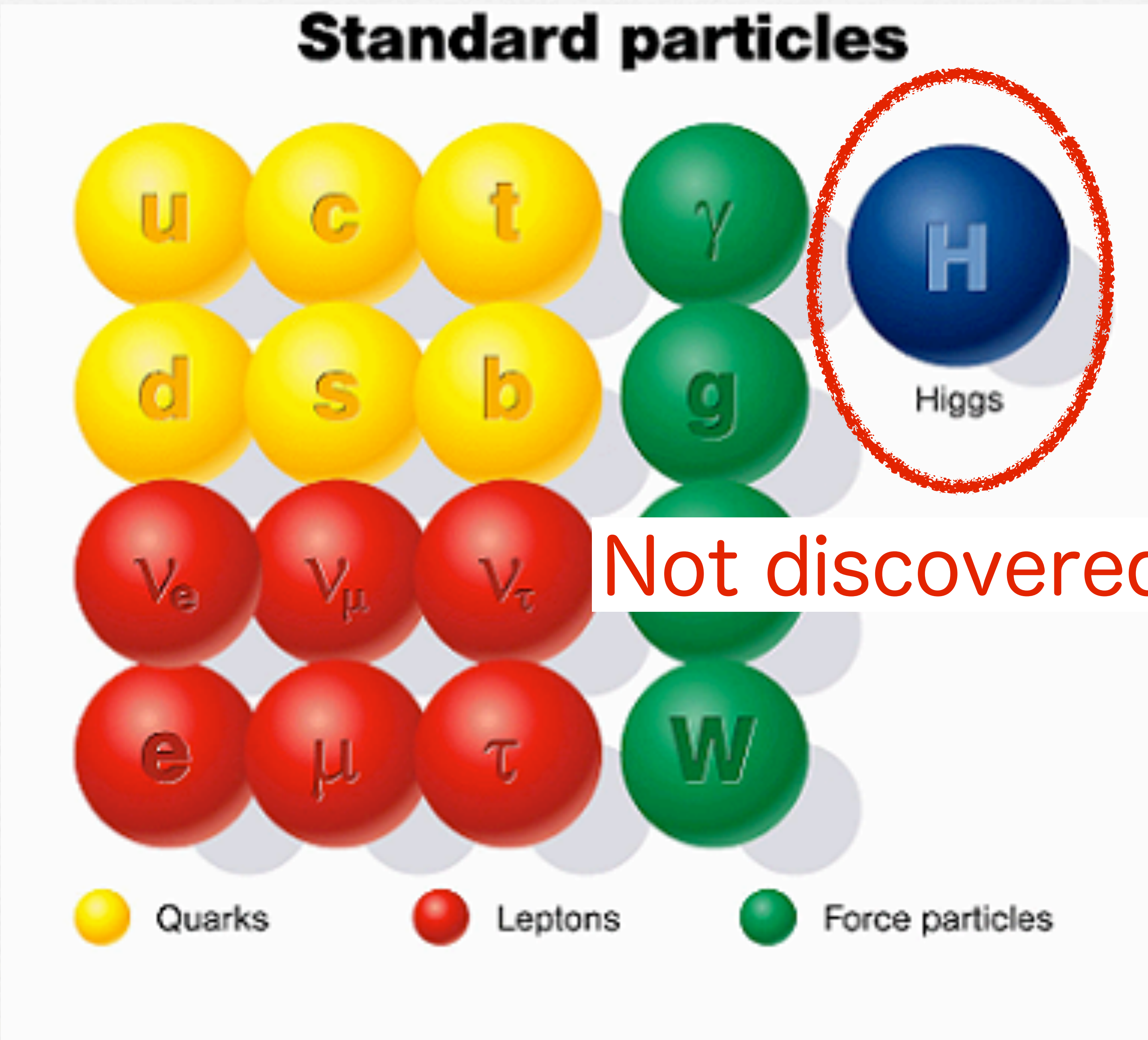


Standard Model



1897 : electron
1900 : γ-ray
1932 : positron
1937 : muon
1956 : neutrino
1962 : ν_e and ν_μ
1969 : u,d,s quarks (parton model)
1974 : charm quark
1975 : τ lepton
1977 : bottom quark
1979 : gluon
1983 : W and Z bosons
1995 : top quark
2000 : ν_τ

Standard Model



Not discovered yet

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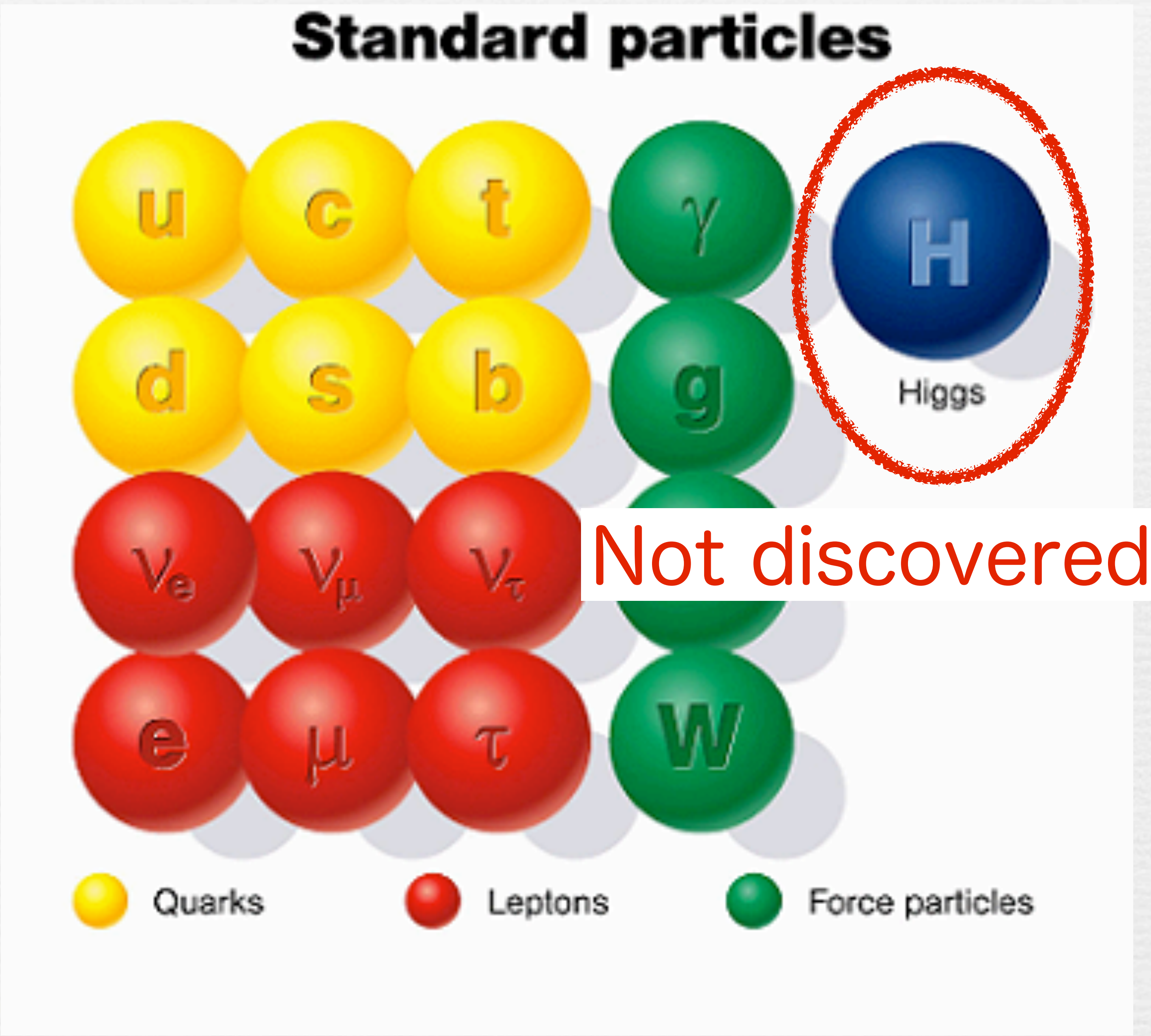

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2012 ? : Higgs boson !?

Higgs boson

- Standard Model...quantum+relativity+gauge principle
  - The mass of the elementary particles should be 0
    - Gauge boson mass : Gauge symmetry

$$m^2 A^\mu A_\mu \rightarrow m^2 (A^\mu + \partial^\mu \Lambda)(A_\mu + \partial_\mu \Lambda) \neq m^2 A^\mu A_\mu$$

    - Fermion mass : Gauge + chiral symmetry

$$m\bar{\psi}\psi = m(\bar{\psi}_R + \bar{\psi}_L)(\psi_R + \psi_L) = m(\bar{\psi}_R \psi_L + \bar{\psi}_L \psi_R)$$

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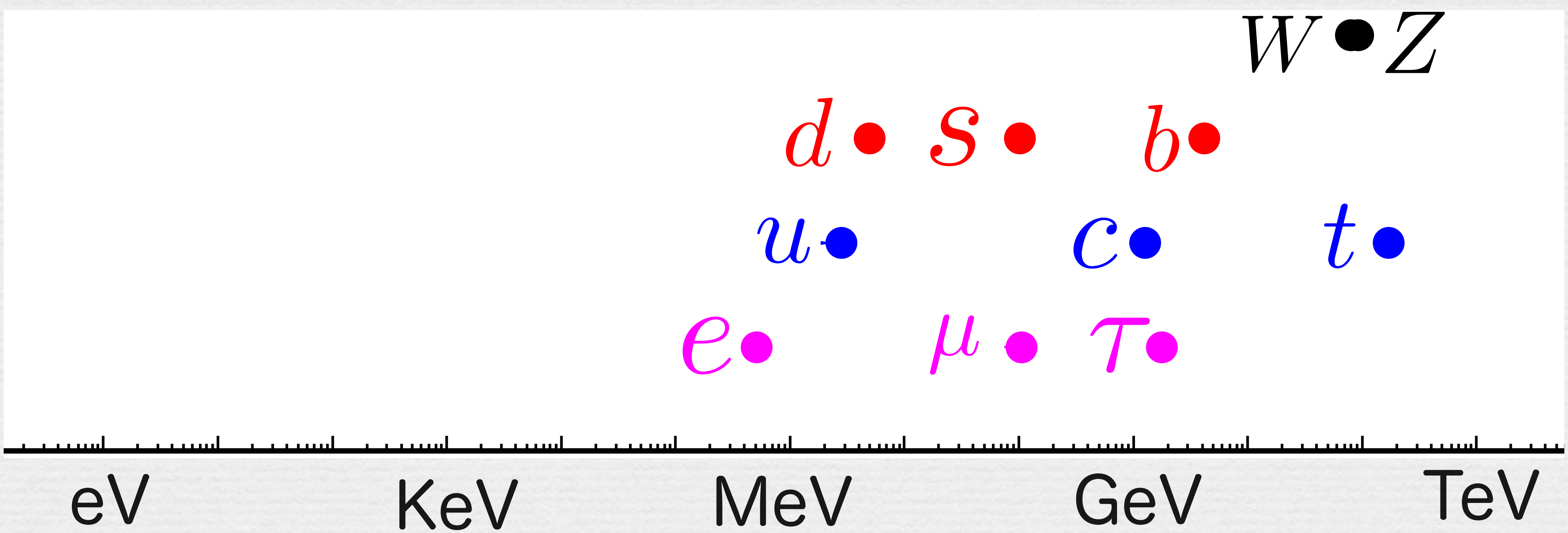

Higgs boson

- Standard Model...quantum+relativity+gauge principle
  - Higgs mechanism→Higgs boson ... d be 0
  - O(100GeV) : LHC experiments
  - Fermion mass : Gauge + chiral symmetry

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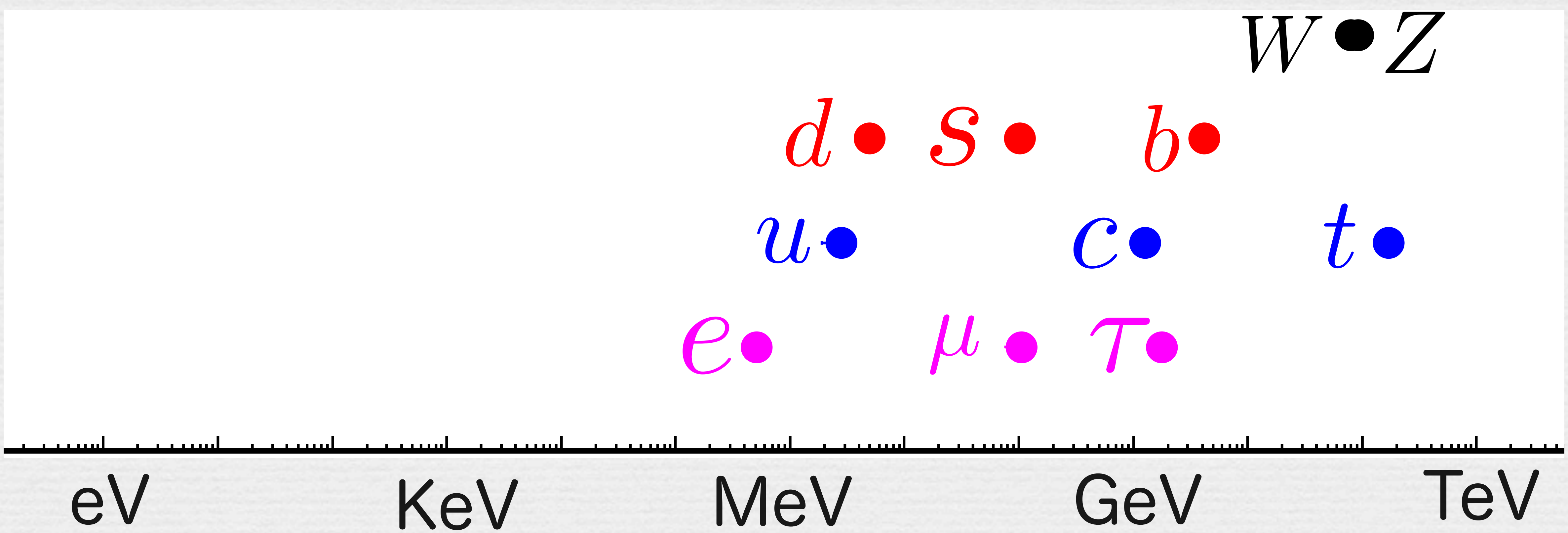

Higgs boson

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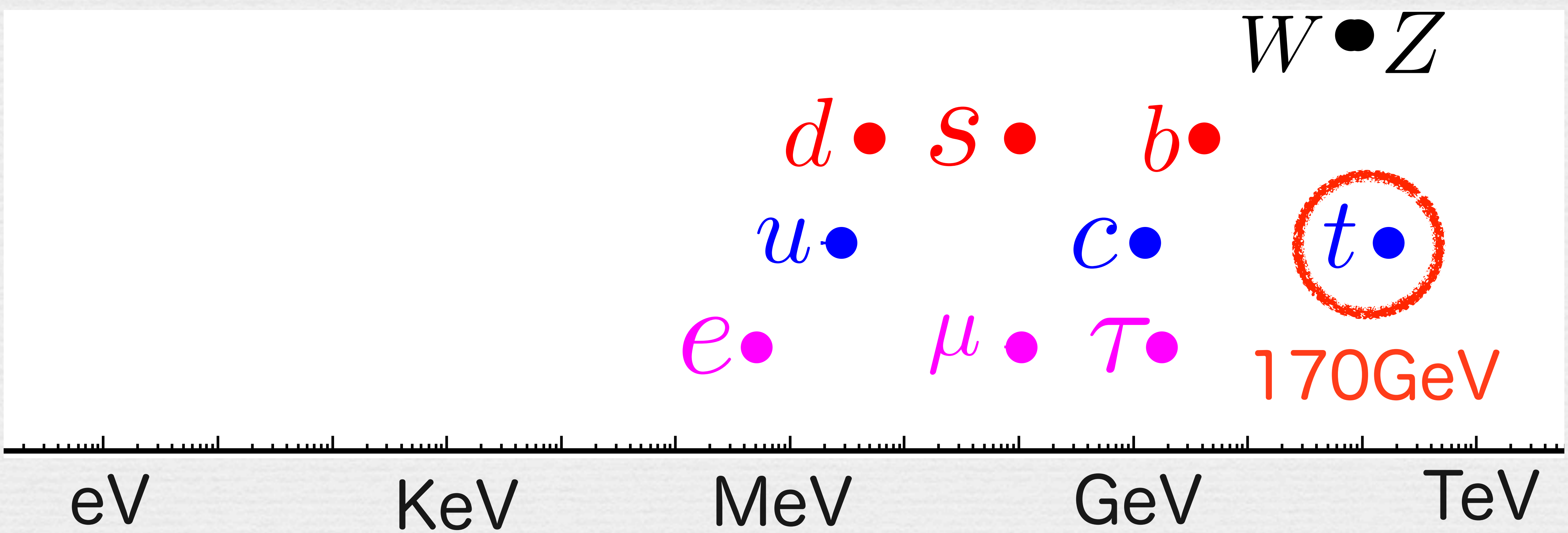
  - Higgs mechanism→Higgs boson
    - O(100GeV) : LHC experiments

Origin of the mass :

Heaviest top quark becomes important

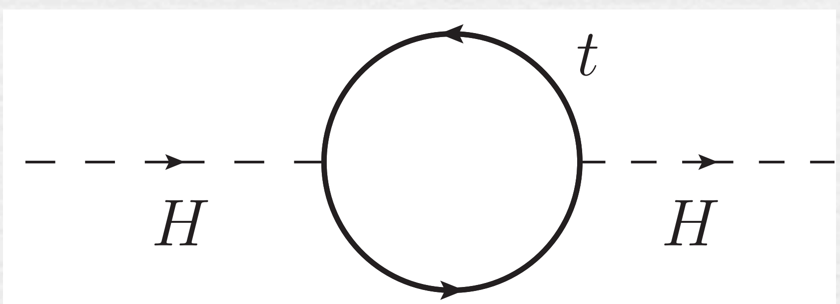


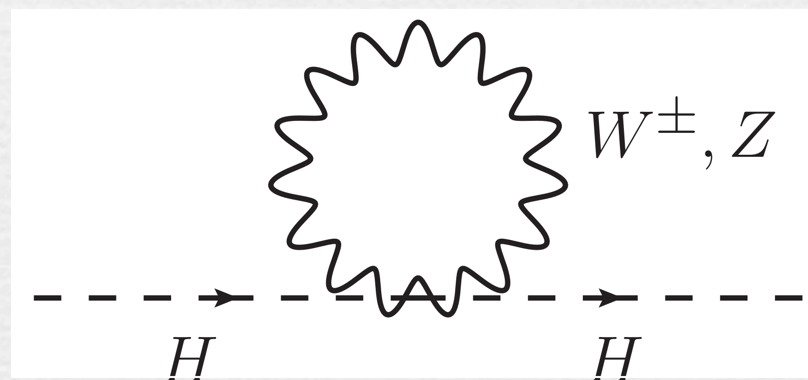
Quadratic divergence

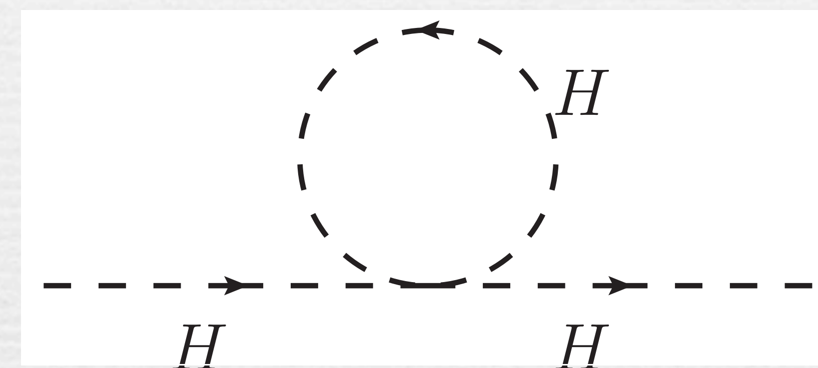
If Higgs boson exists ... We can expect the new physics

Scalar Higgs boson causes the quadratic divergence

$$m_H^2 = (m_H^0)^2 + \delta m_H^2$$







$$\begin{aligned} \delta m_H^2 &\sim -y_t^2 \Lambda^2 \\ &\sim -m_t^2 \Lambda^2 \end{aligned}$$

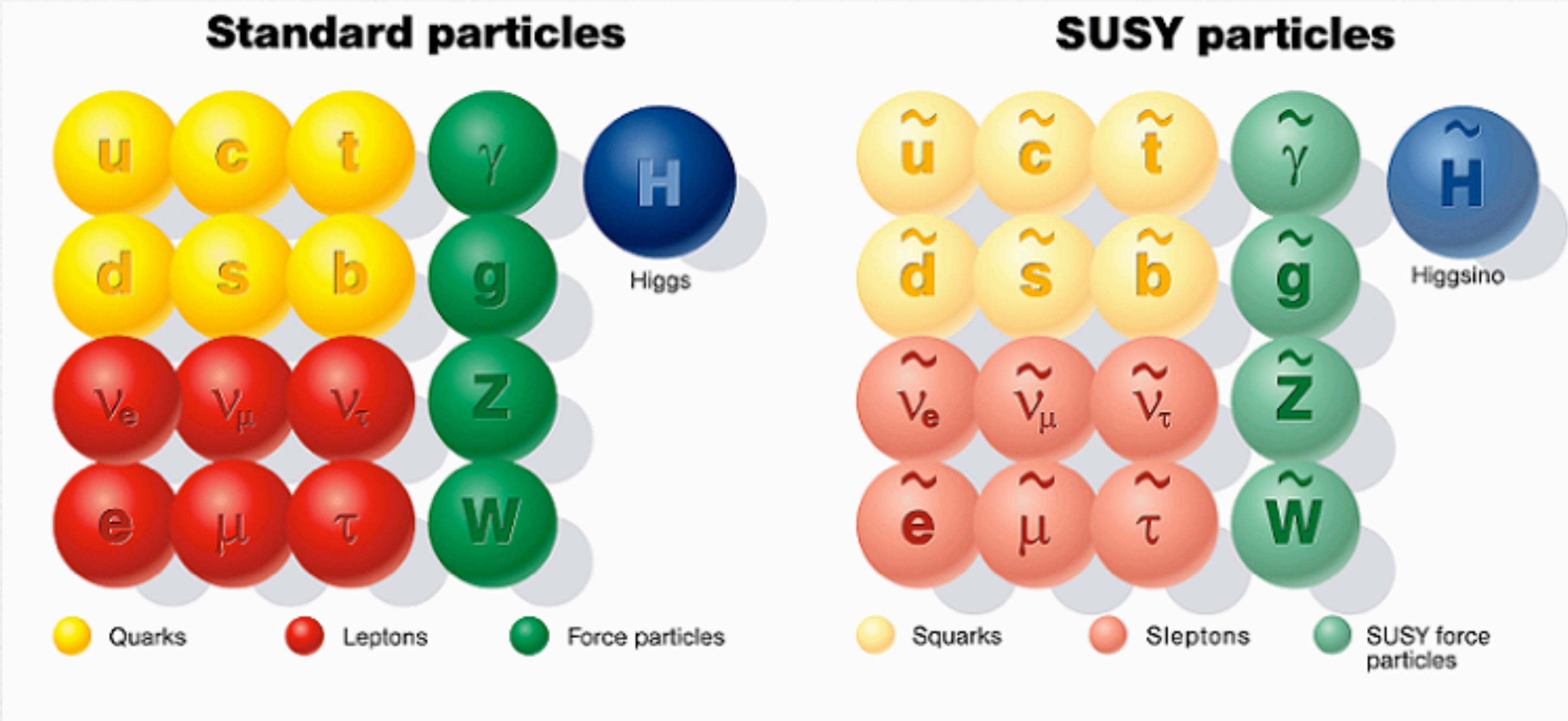
$$\begin{aligned} \delta m_H^2 &\sim g^2 \Lambda^2 \\ &\sim m_{W/Z}^2 \Lambda^2 \end{aligned}$$

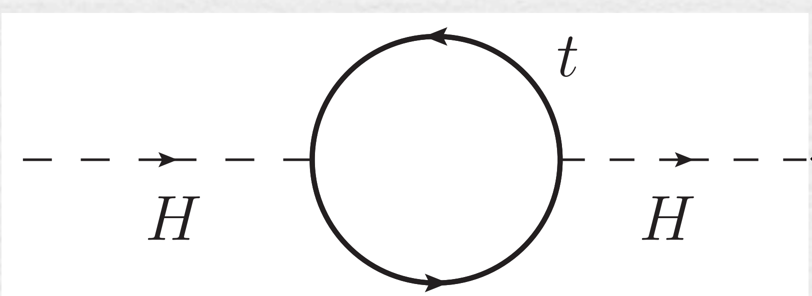
$$\begin{aligned} \delta m_H^2 &\sim \lambda \Lambda^2 \\ &\sim m_H^2 \Lambda^2 \end{aligned}$$

New physics which cancels top quark loop is seriously needed

New physics is needed to cancel these divergences out

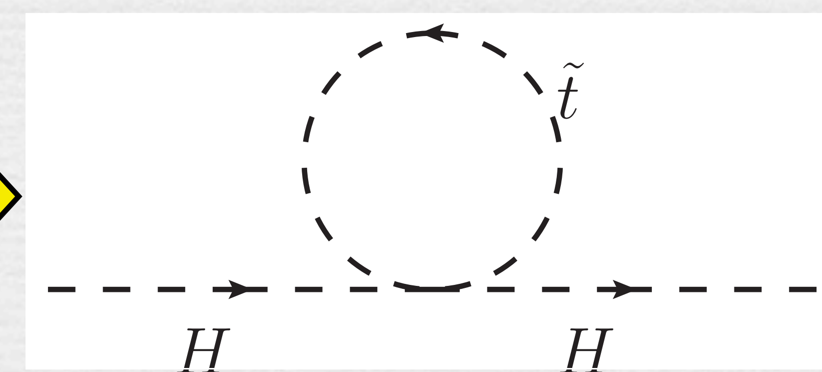
Example of new physics : SUSY





top quark

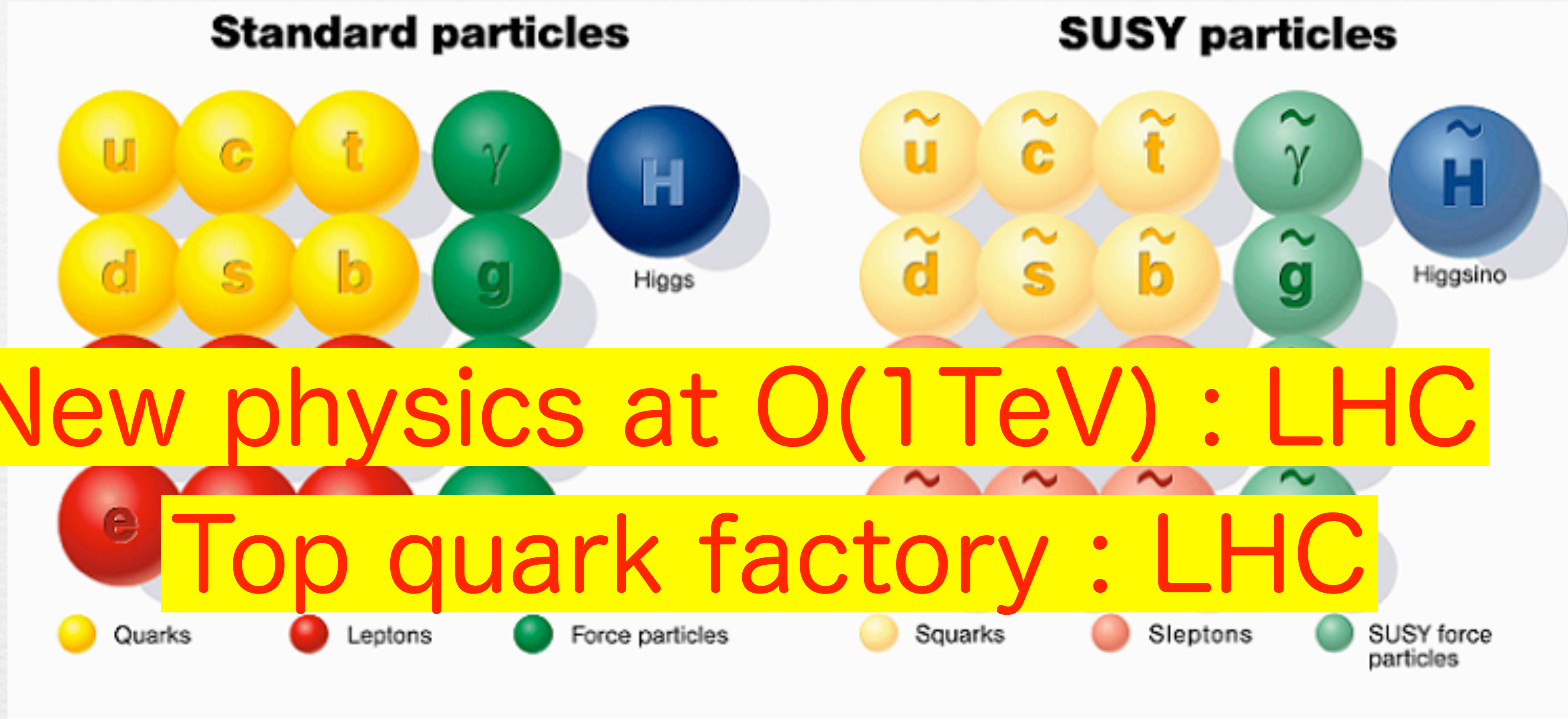
Cancel out



top quark partner

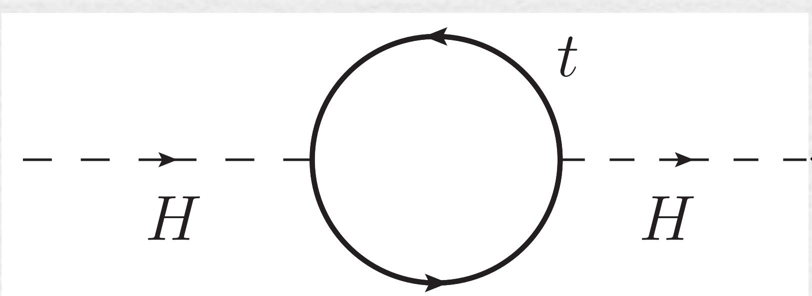
Search for the top quark partner using top quark

Example of new physics : SUSY



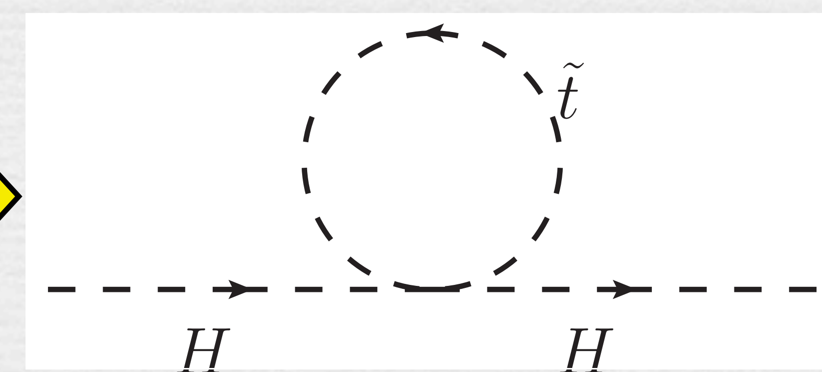
New physics at O(1TeV) : LHC

Top quark factory : LHC



top quark

Cancel out



top quark partner

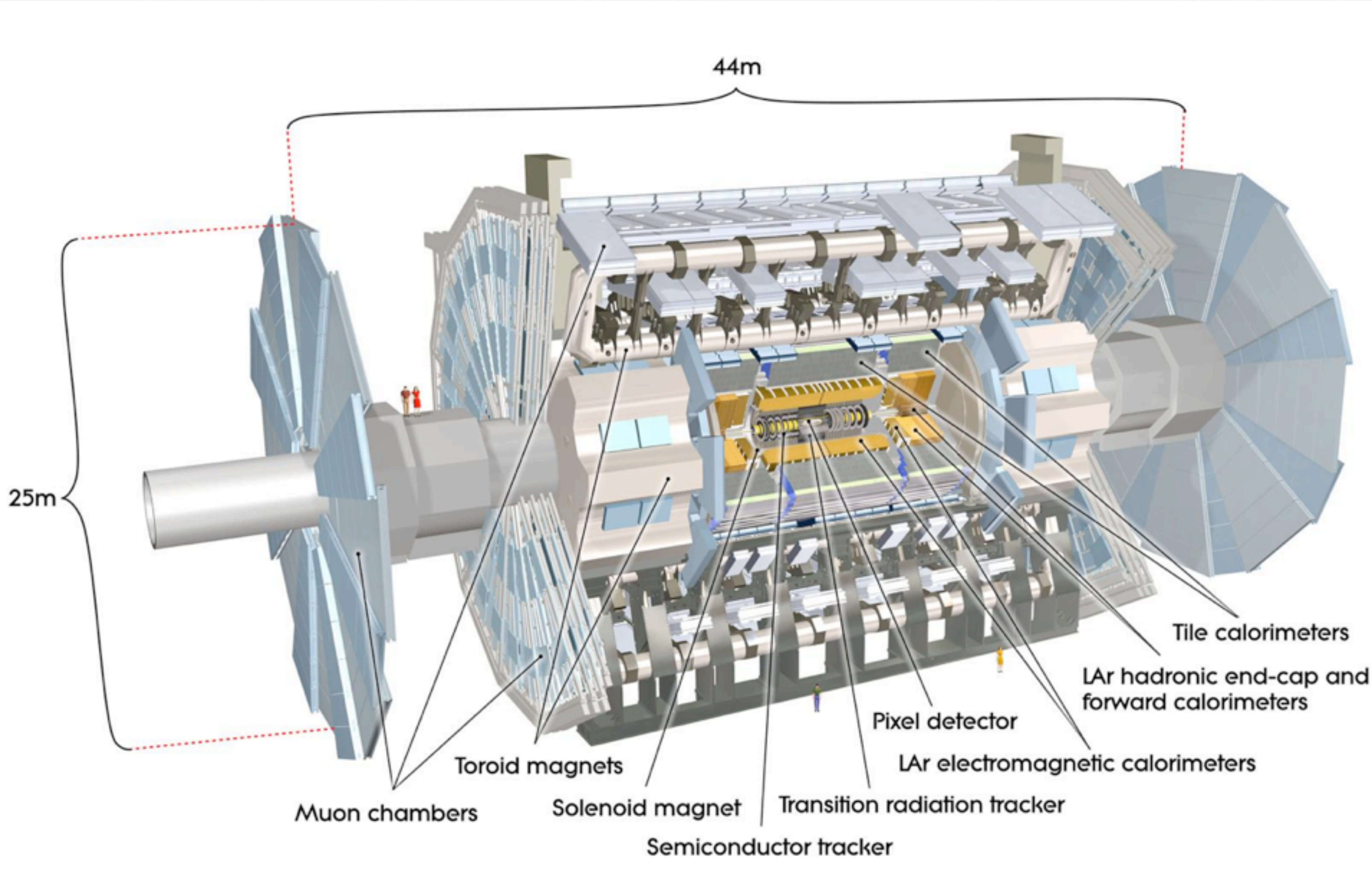
Search for the top quark partner using top quark

LHC-ATLAS

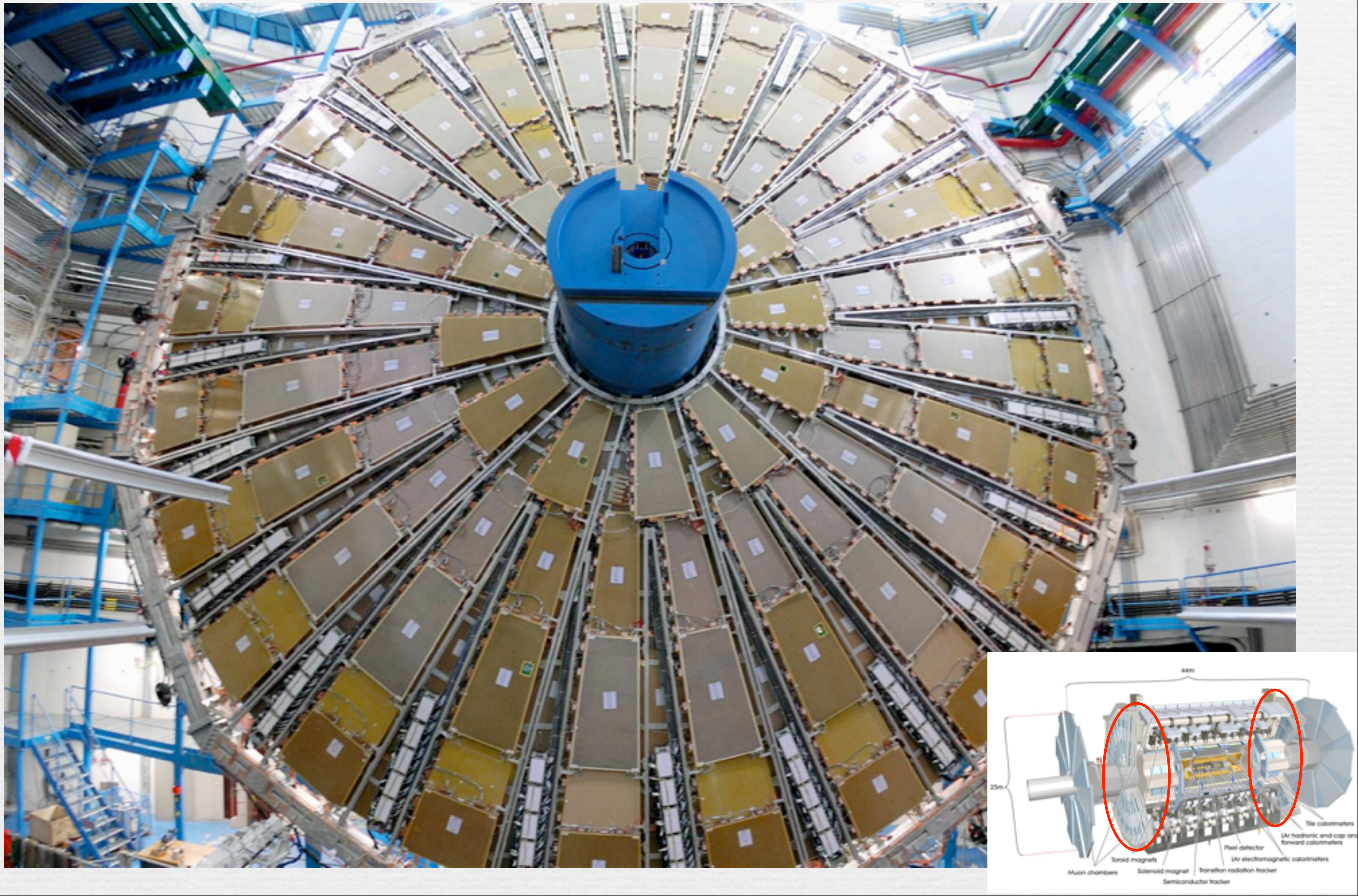
LHC-ATLAS detector

2T Solenoid Magnet + Toroidal Magnet

7000 tons, 160M channels



Nagoya group's contribution



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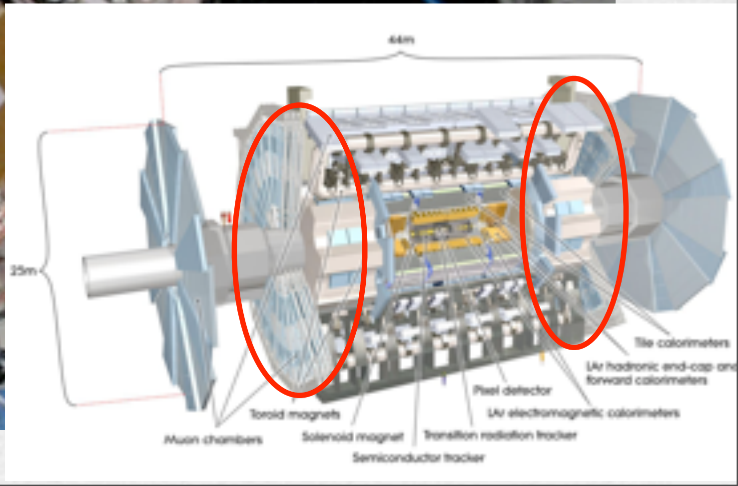
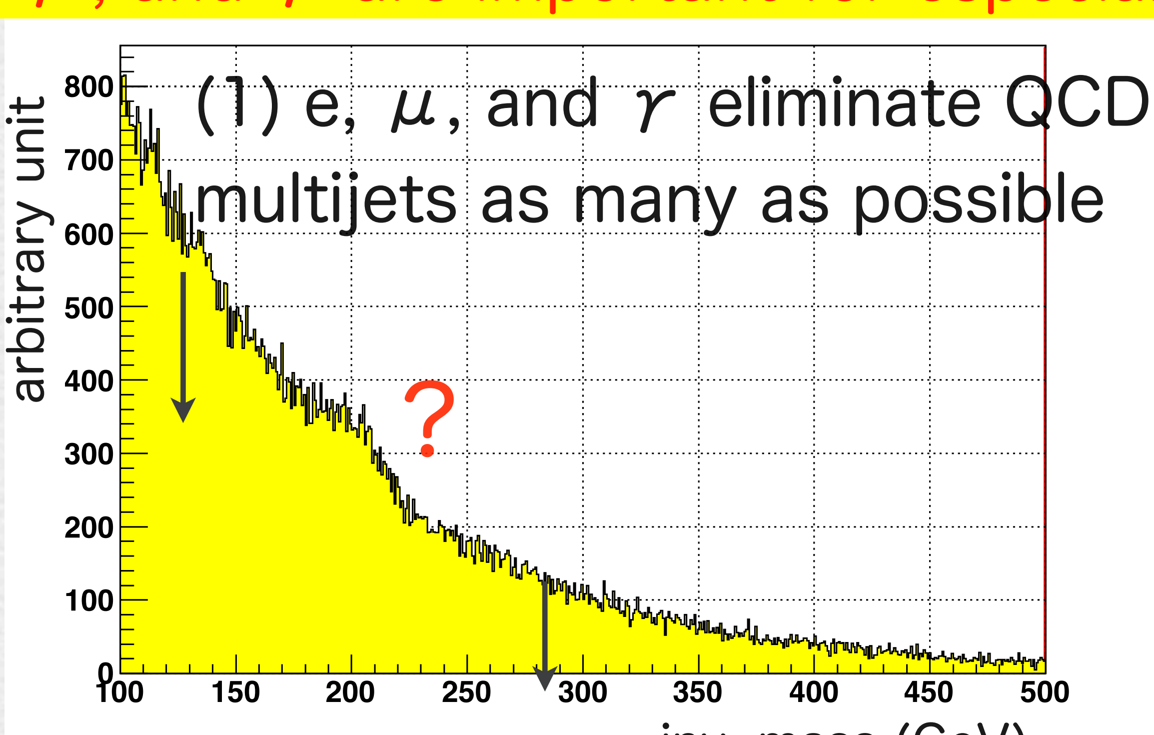
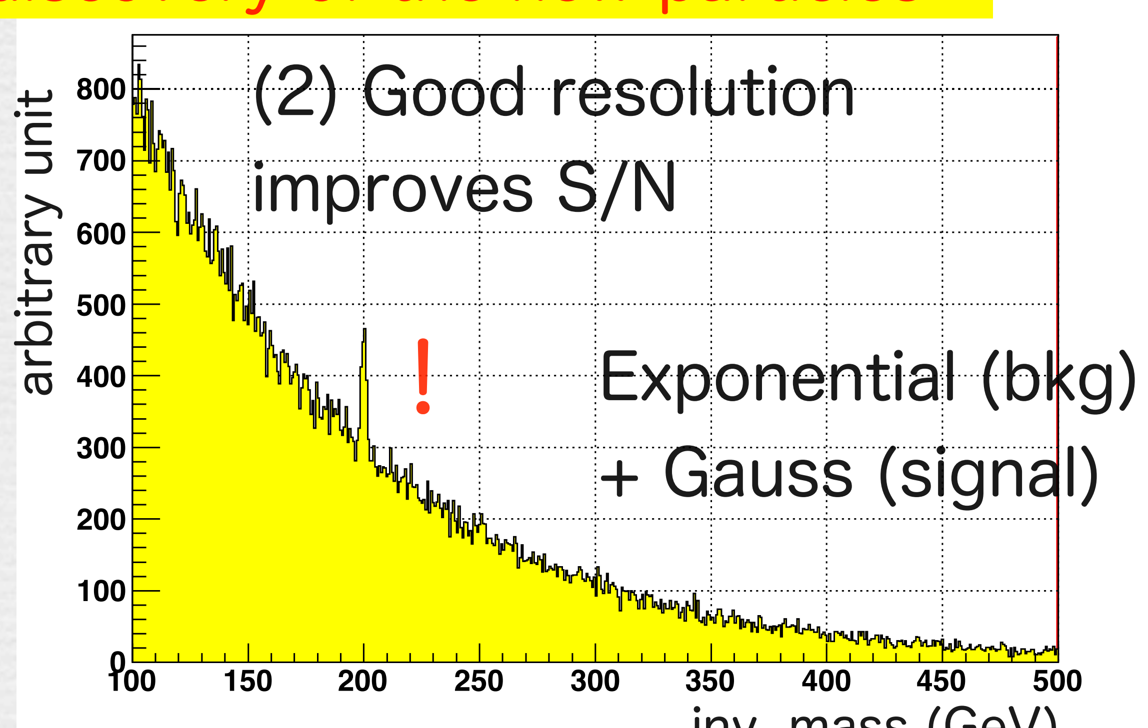


ATLAS detector specification

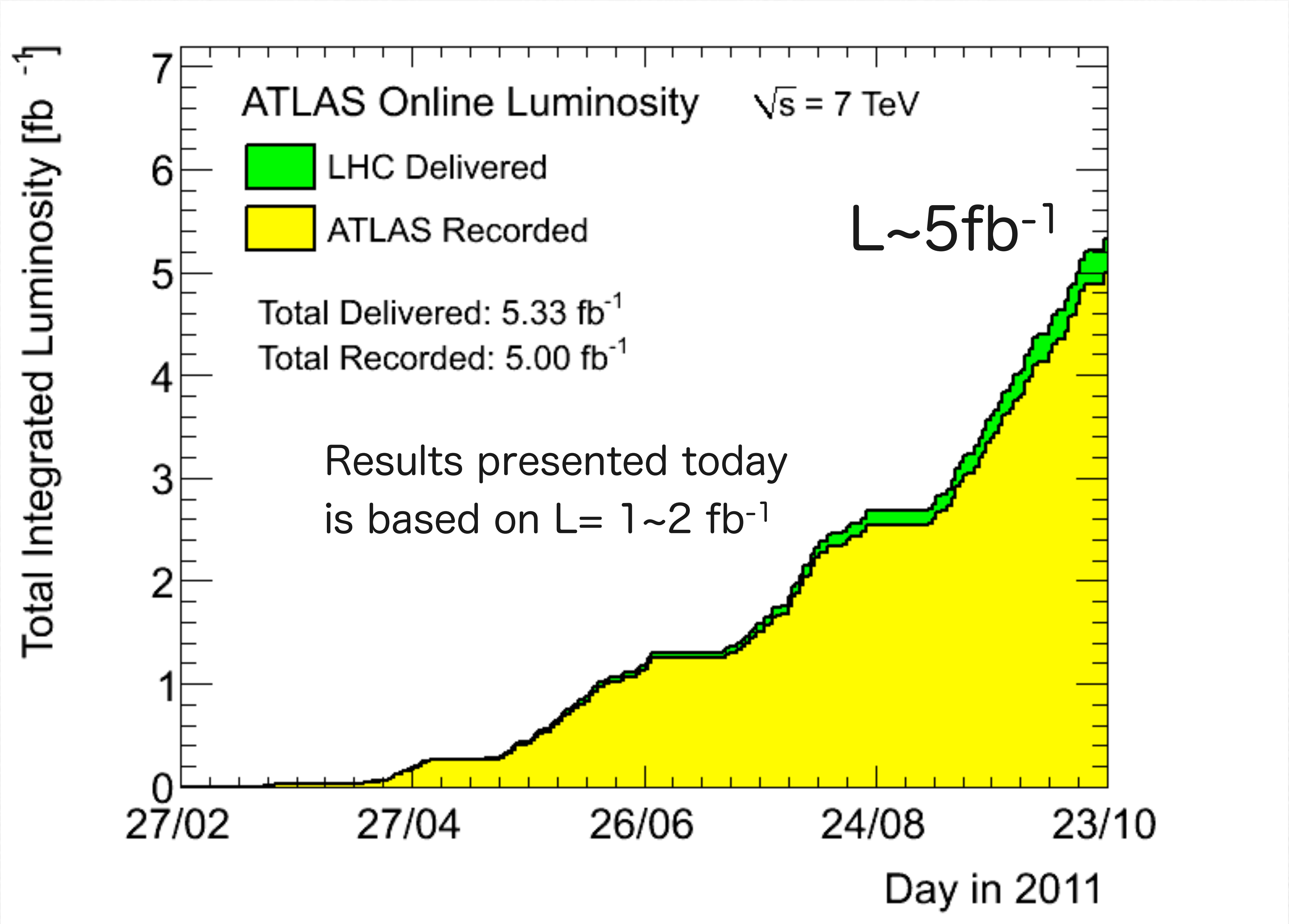
Detector	technology	Resolution	resolution @100GeV
Tracker	Si-pixel/strip, transition radiation tracker	$\frac{\sigma(p_T)}{p_T} = 0.05\% \times p_T + 1\%$	6%
EM cal	Pb+LAr	$\frac{\sigma(E)}{E} = \frac{10\%}{\sqrt{E}} + 0.7\%$	1.5%
Had cal	Fe+scintillator, Cu+LAr, Cu +W+LAr	$\frac{\sigma(E)}{E} = \frac{50\%}{\sqrt{E}} + 3\%$	8%
muon	drift tube, RPC, TGC	$\frac{\sigma(p_T)}{p_T} = 0.01\% \times p_T + 2\%$	2-3%

e, μ, and γ are important for especially discovery of the new particles

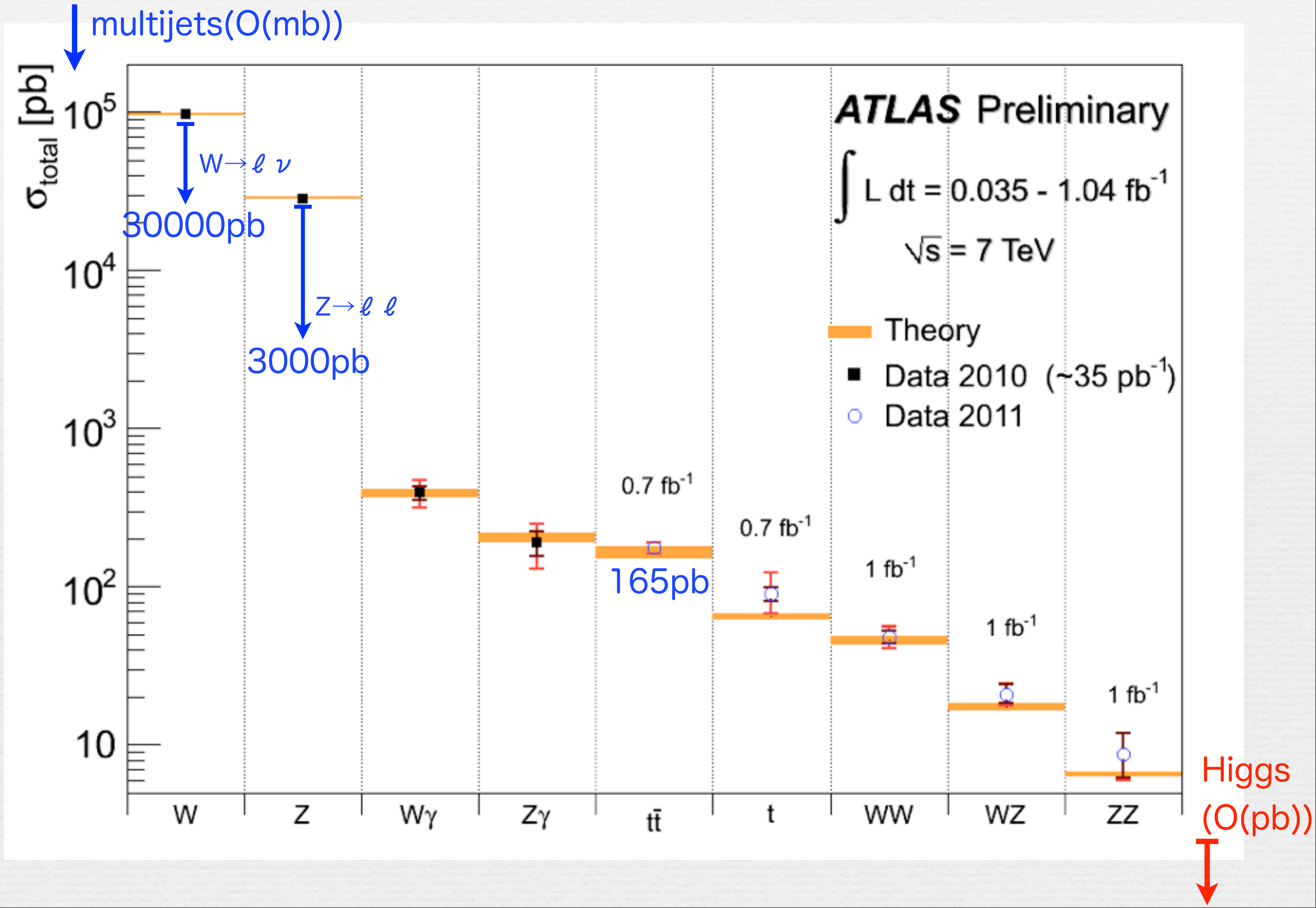




Luminosity


ATLAS Online Luminosity
√s = 7 TeV
LHC Delivered
ATLAS Recorded
L~5fb-1
Total Delivered: 5.33 fb-1
Total Recorded: 5.00 fb-1
Results presented today
is based on L= 1~2 fb-1
Total Integrated Luminosity [fb-1]
0
1
2
3
4
5
6
7
27/02
27/04
26/06
24/08
23/10
Day in 2011

SM processes

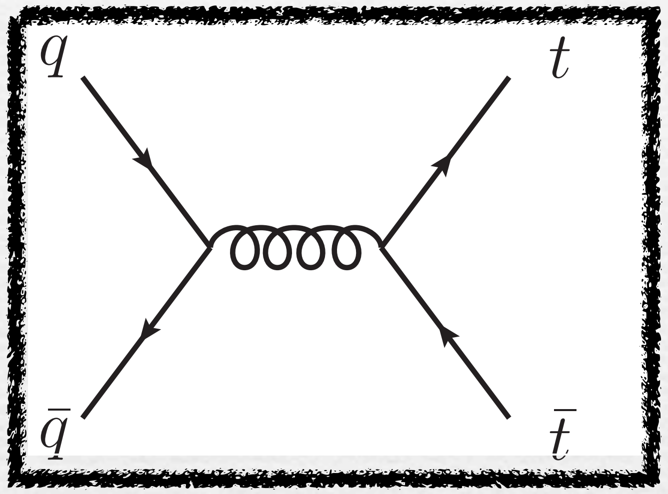


Top quark physics

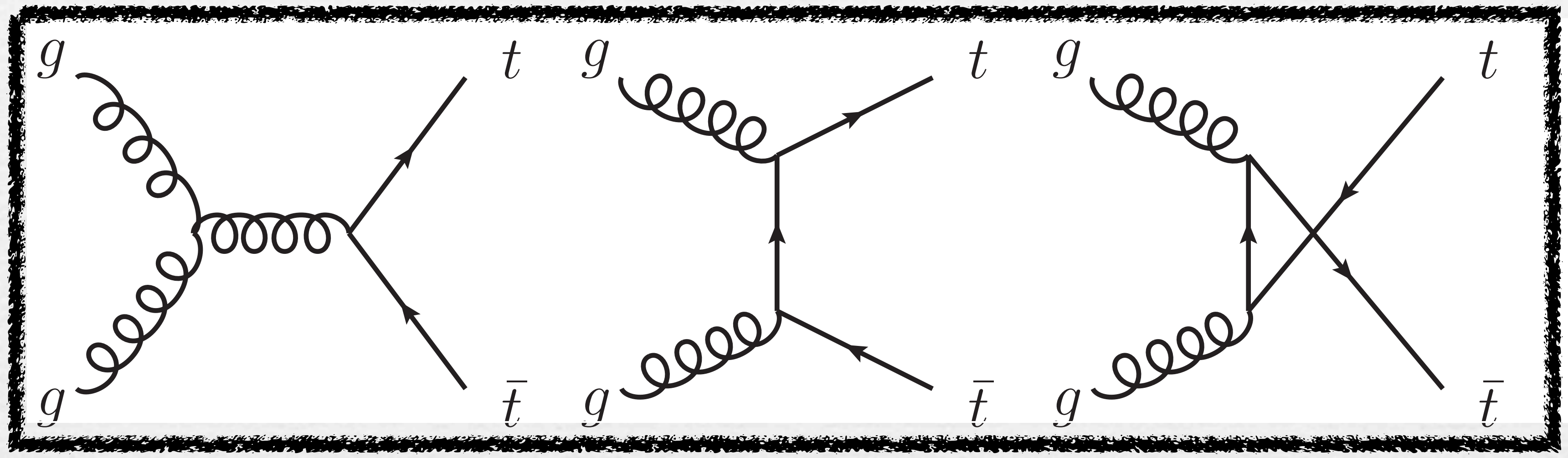
Top quark physics

In the SM,

Top quark pair is produced by strong interaction via:



+



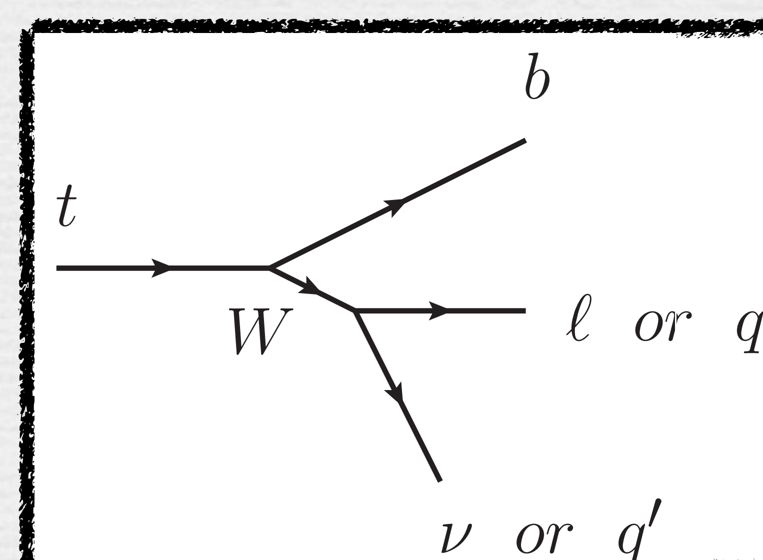
Cross section (@NNLO) : $\sigma_{t\bar{t}} = 165^{+11}_{-16} pb$ ... 8×10^5 $t\bar{t}$

@ 5 fb^{-1}

Top quark decays into b-quark and W boson before hadronization

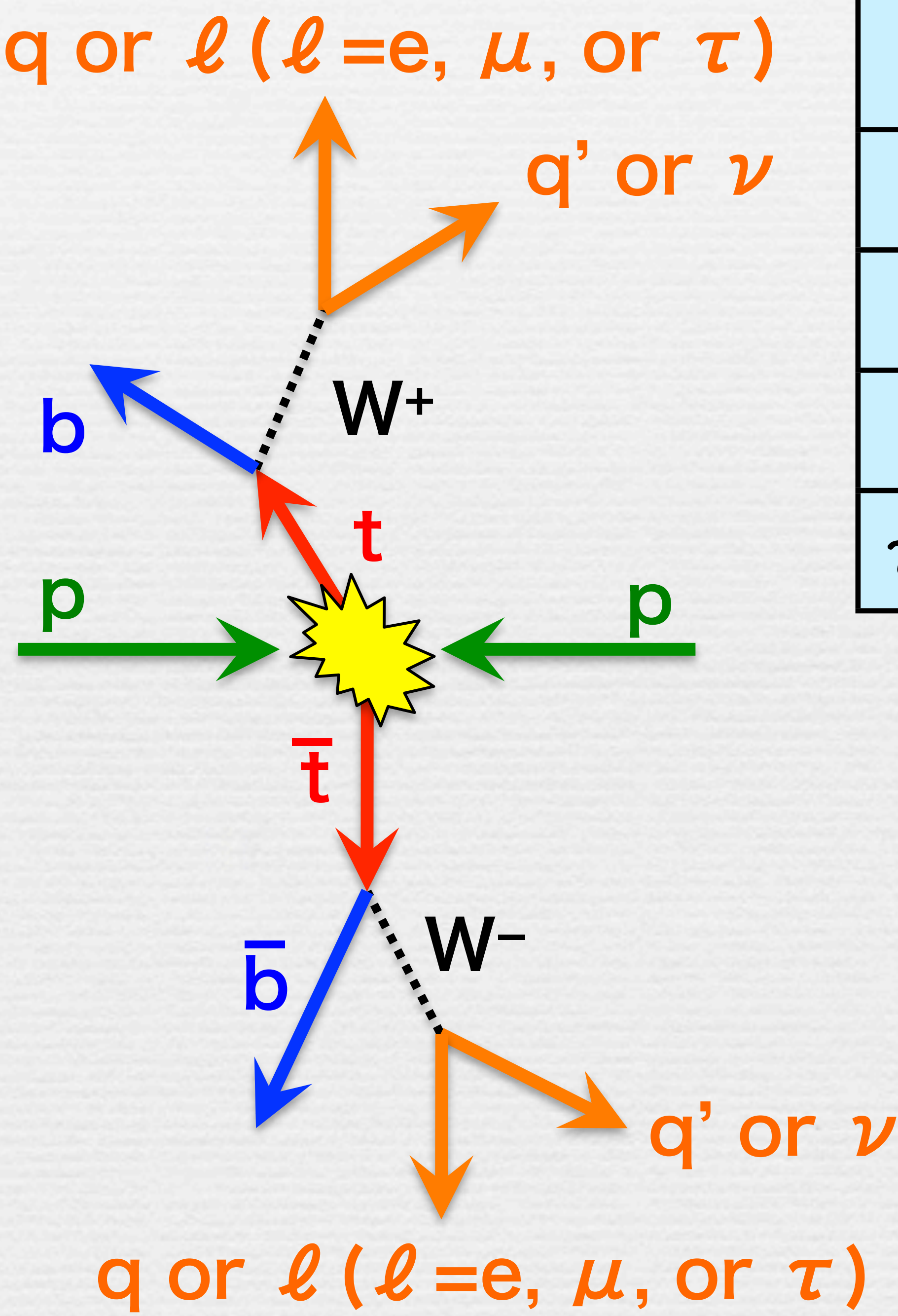
$\tau_t \sim 4 \times 10^{-25} s \ll 1/\Lambda_{QCD} \sim 3 \times 10^{-24} s$

$Br(t \to bW^+) \sim 100\%$



$t\bar{t}$ production kinematics

$Br(t \rightarrow bW^+) \sim 100\%$ Final state depends on W decays



	Final state	Branching fraction
All jets	2 b-jets, 4 jets	46%
1 lepton	2 b-jets, 2 jets, 1 lepton, E_T^{miss}	34%
2 lepton	2 b-jets, 2 leptons, E_T^{miss}	6%
τ channel	2 b-jets, τ, lepton or jets, E_T^{miss}	14%

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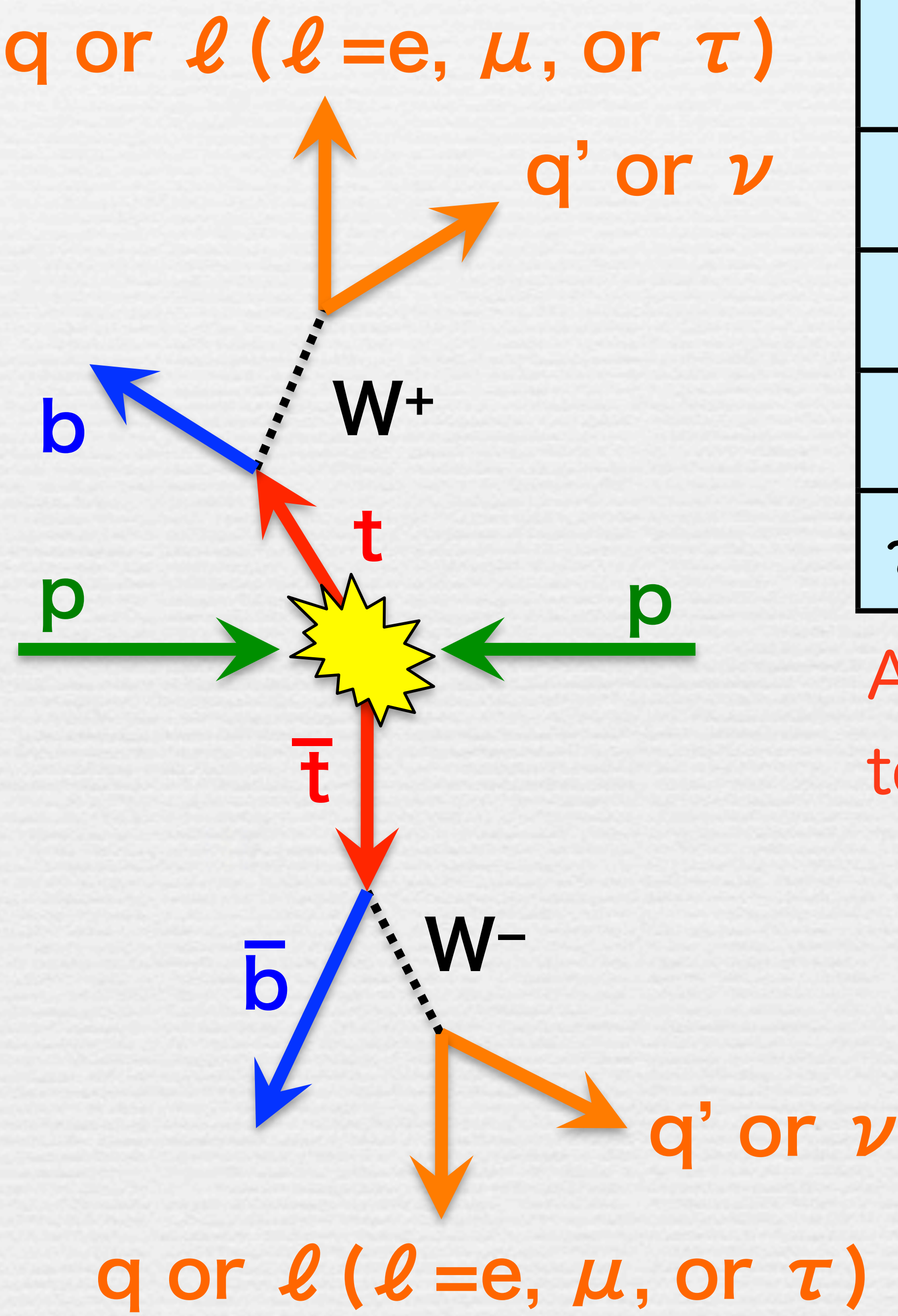

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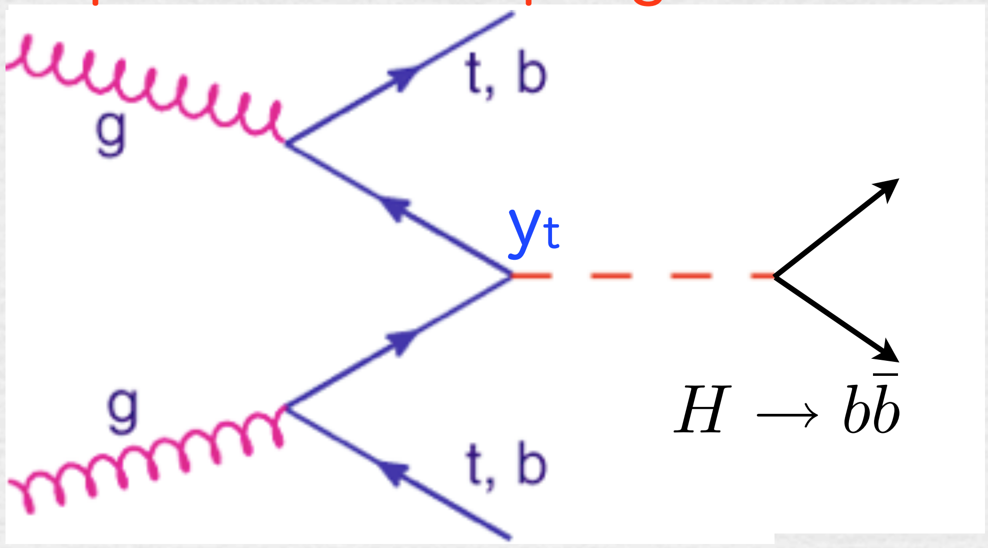
Associated production of the Higgs with top quark pair, toward top Yukawa coupling measurement

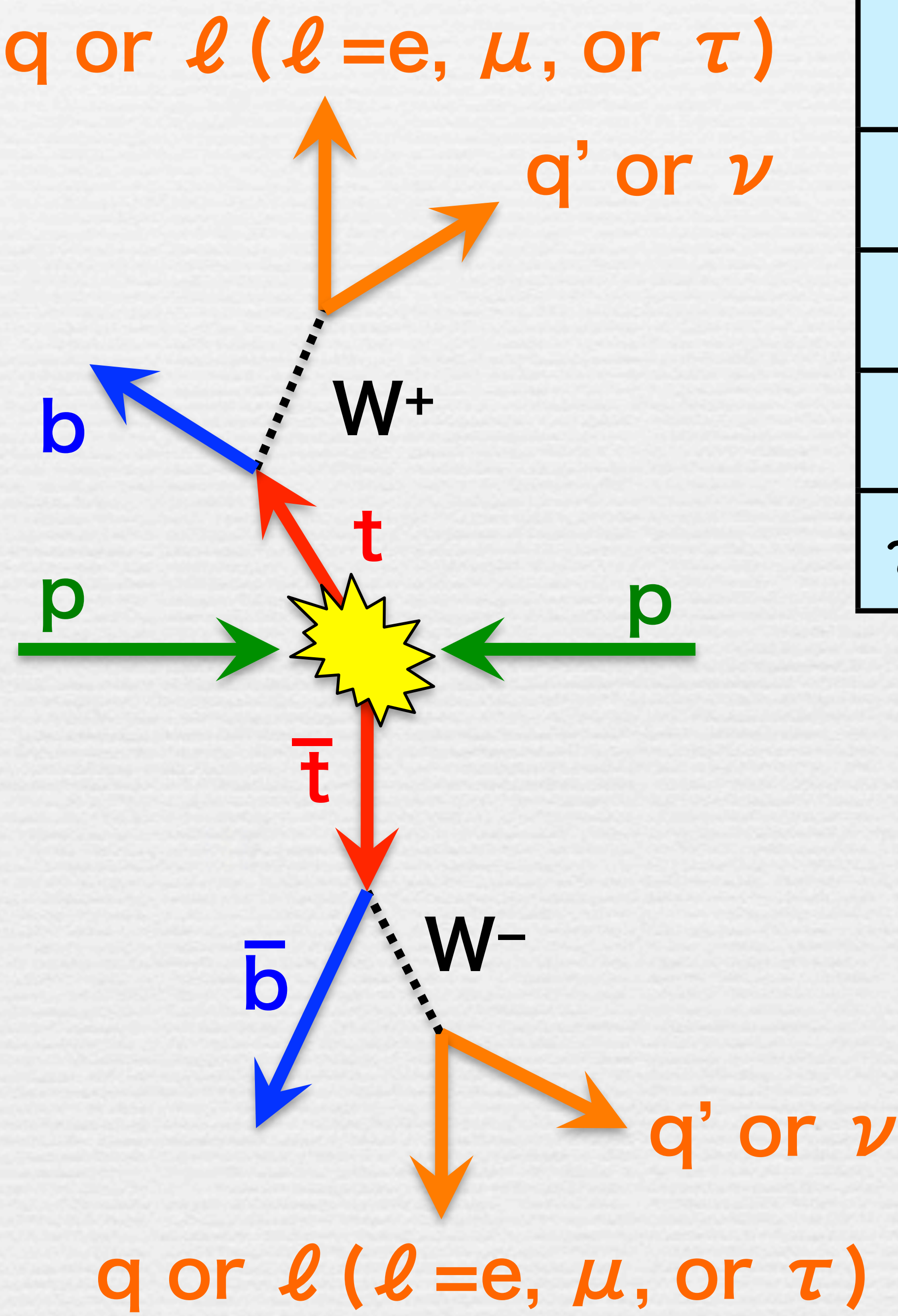


top quark pair + 2 b-jets

Understanding ttbar + (b-) jets is important

$t\bar{t}$ production kinematics

$Br(t \rightarrow bW^{+}) \sim 100\%$ Final state depends on W decays



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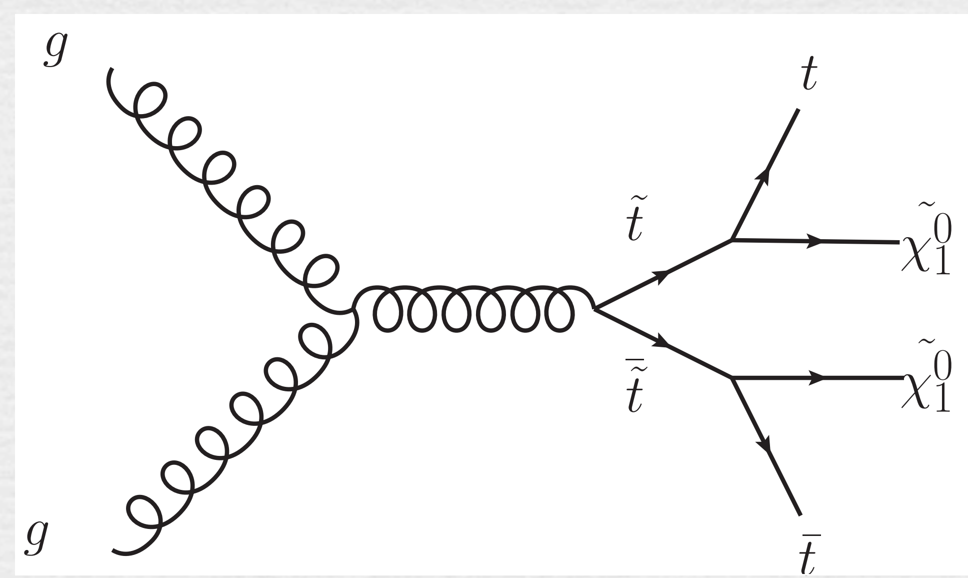
top quark partner search (ex. stop search)



top quark pair + E_T^{miss}

$t\bar{t}$ production kinematics

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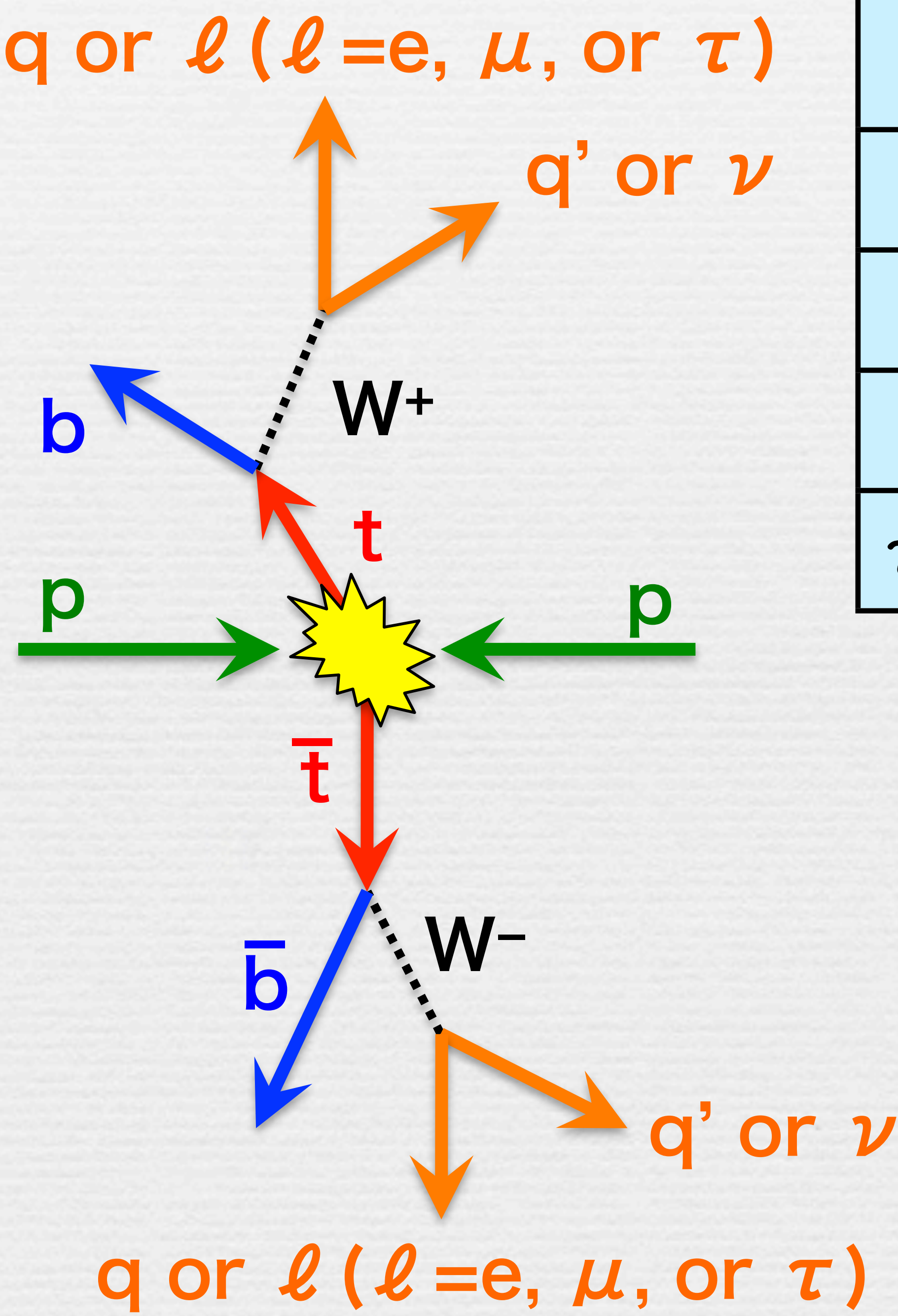

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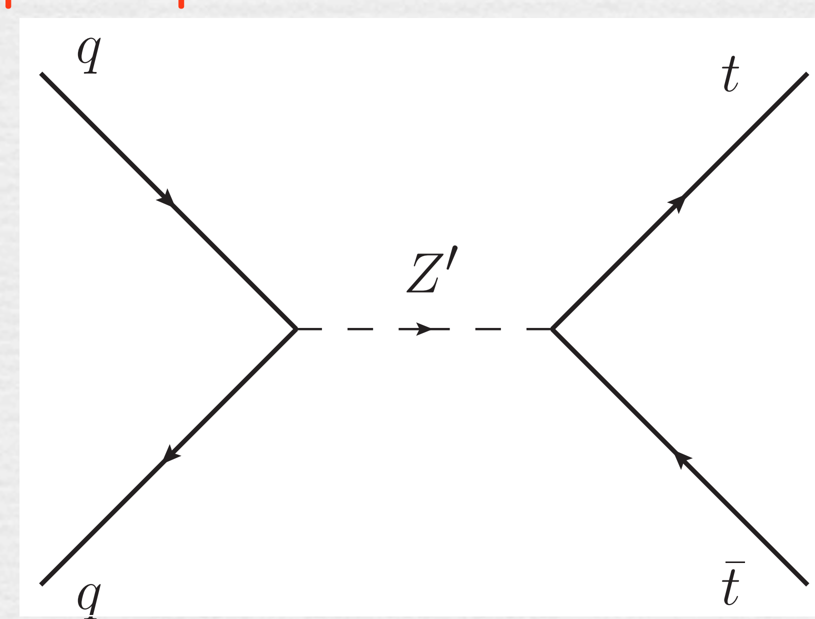
top quark pair from new resonance

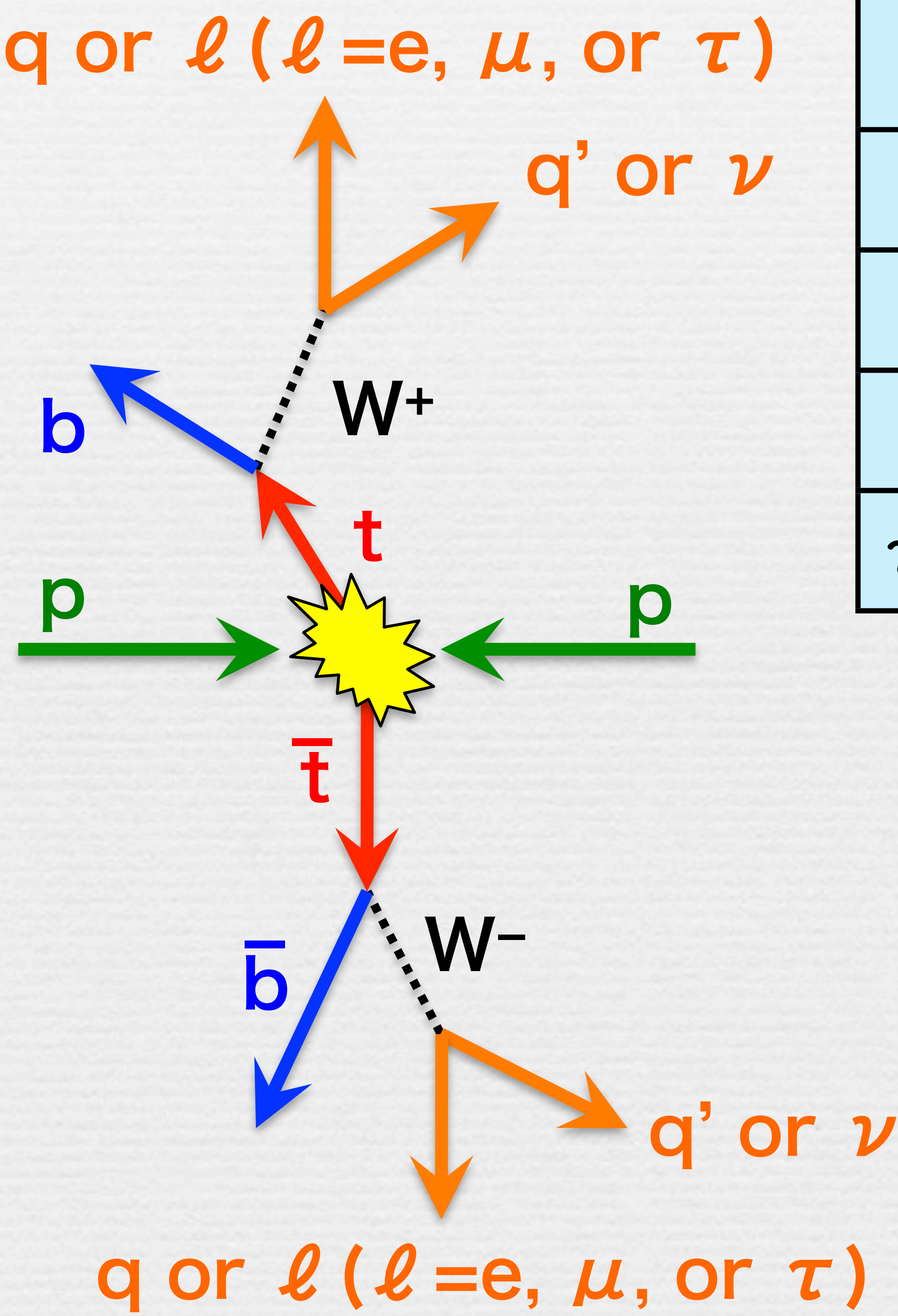


M_{tt},

σ_{tt} after collision energy exceeds Z' mass

$t\bar{t}$ production kinematics

$Br(t \to bW^+) \sim 100\%$ Final state depends on W decays



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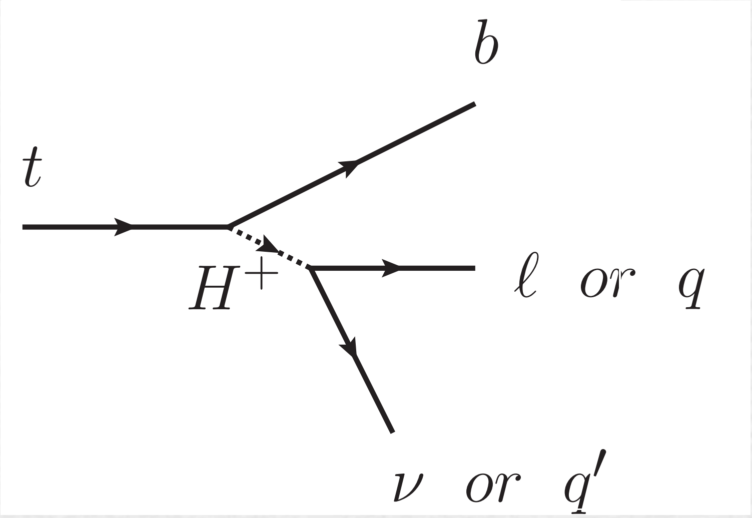
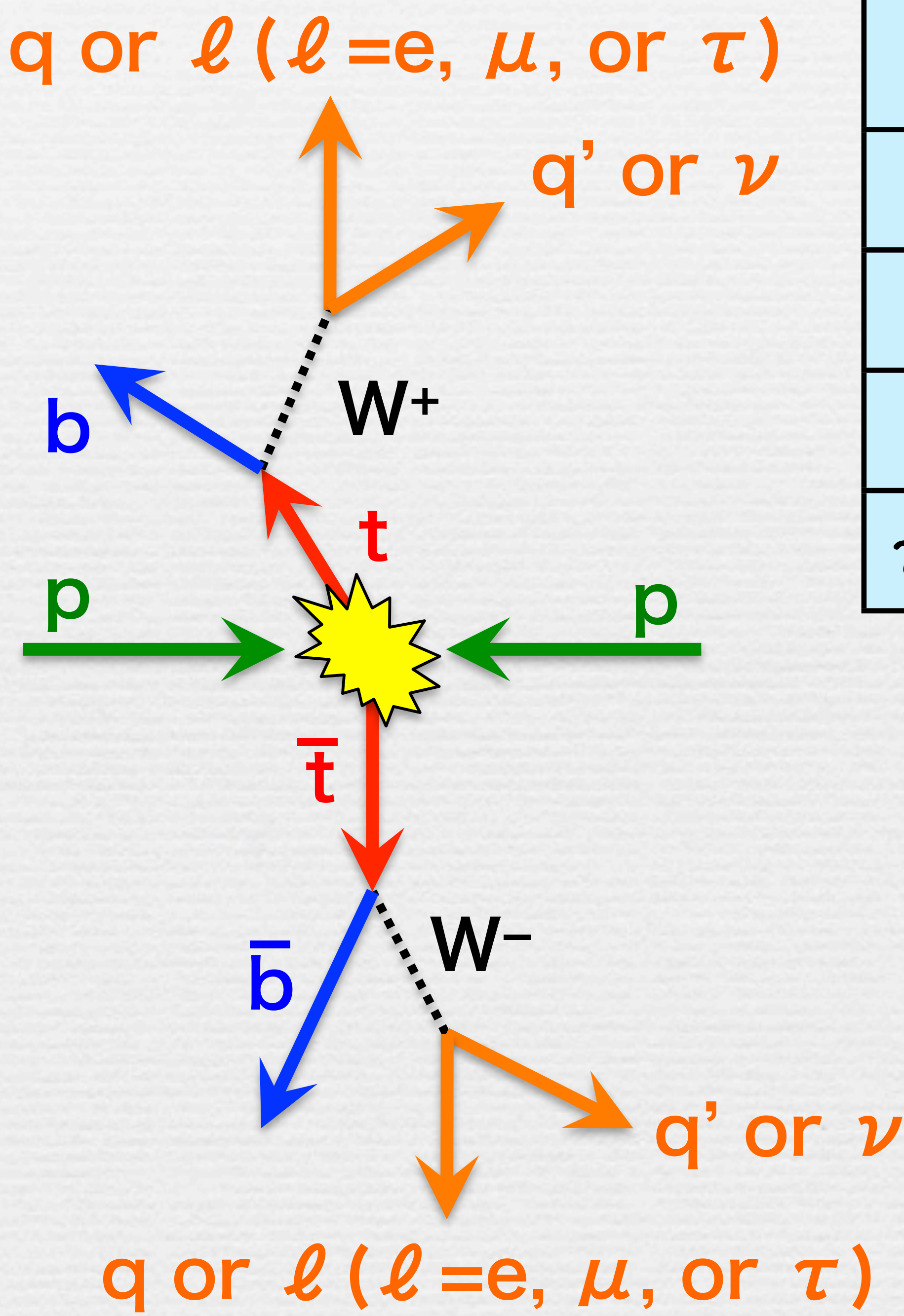
New particles from top quark decay



Enhancement of specific decay channel

$t\bar{t}$ production kinematics

$Br(t \to bW^+) \sim 100\%$ Final state depends on W decays



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It is crucial to measure the cross-section and the branching fraction with

(1) several decay channels,
(2) several associated productions,
(3) several $\sqrt{s}$

It is also important to check the kinematic distributions of the decay products

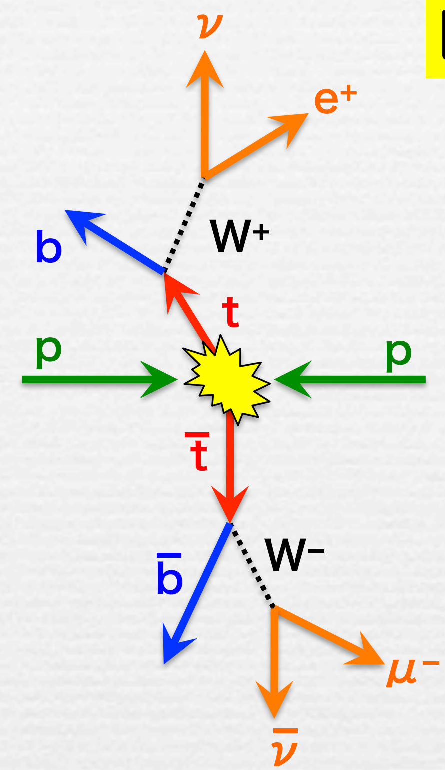
$t\bar{t}$ production cross section in 2-lepton

L=700pb^{-1}

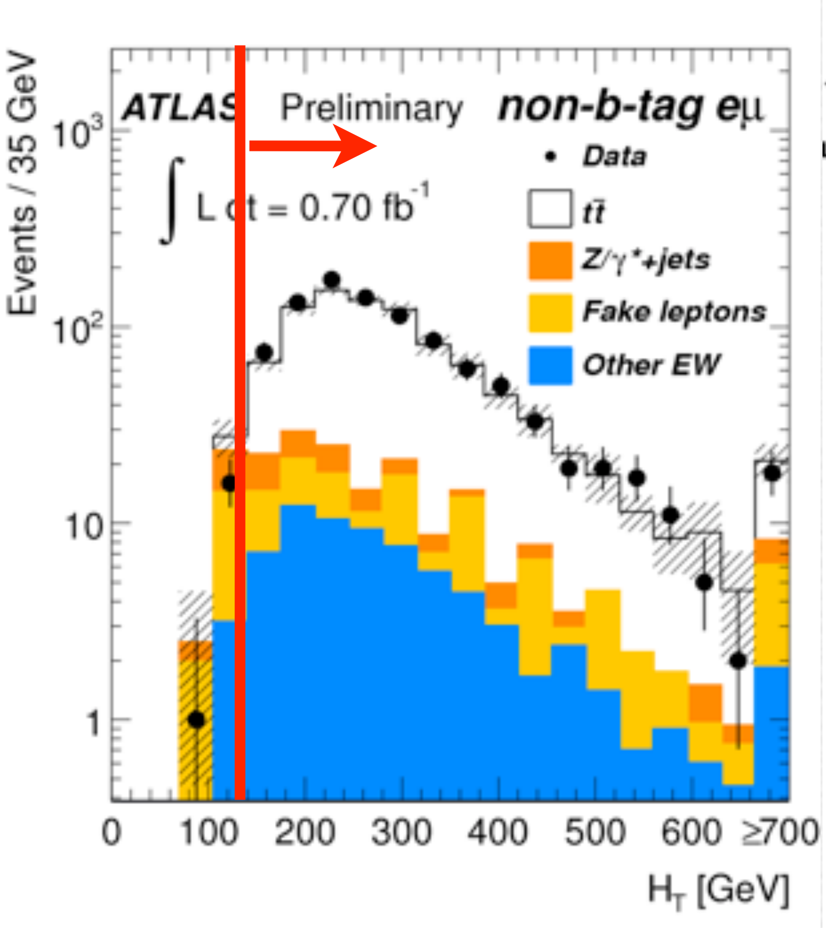
Event selection

- 2 leptons (ee/$\mu\mu$/eμ)
- At least 2 jets
- E_T^{miss} > 60 GeV, Z veto $|M_Z - M_{ll}|$>10GeV (ee/$\mu\mu$)
- $H_T = \Sigma pT$(leptons, jets) > 130 GeV (eμ)

Backgrounds : Z+jets, W+jets

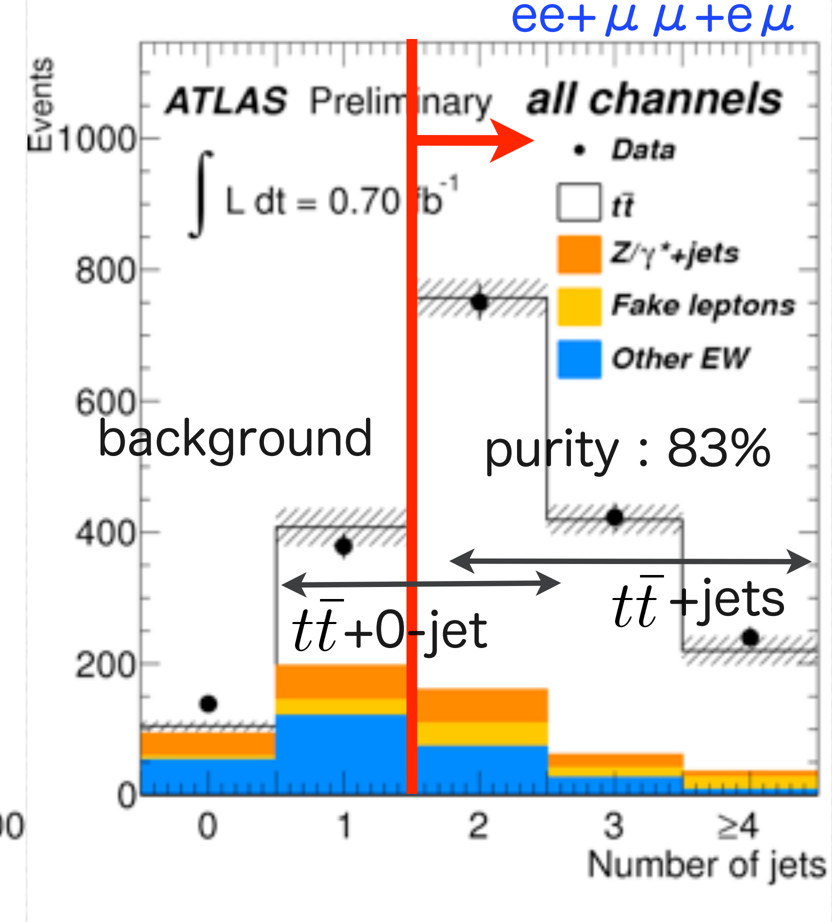


HT distribution for eμ channel

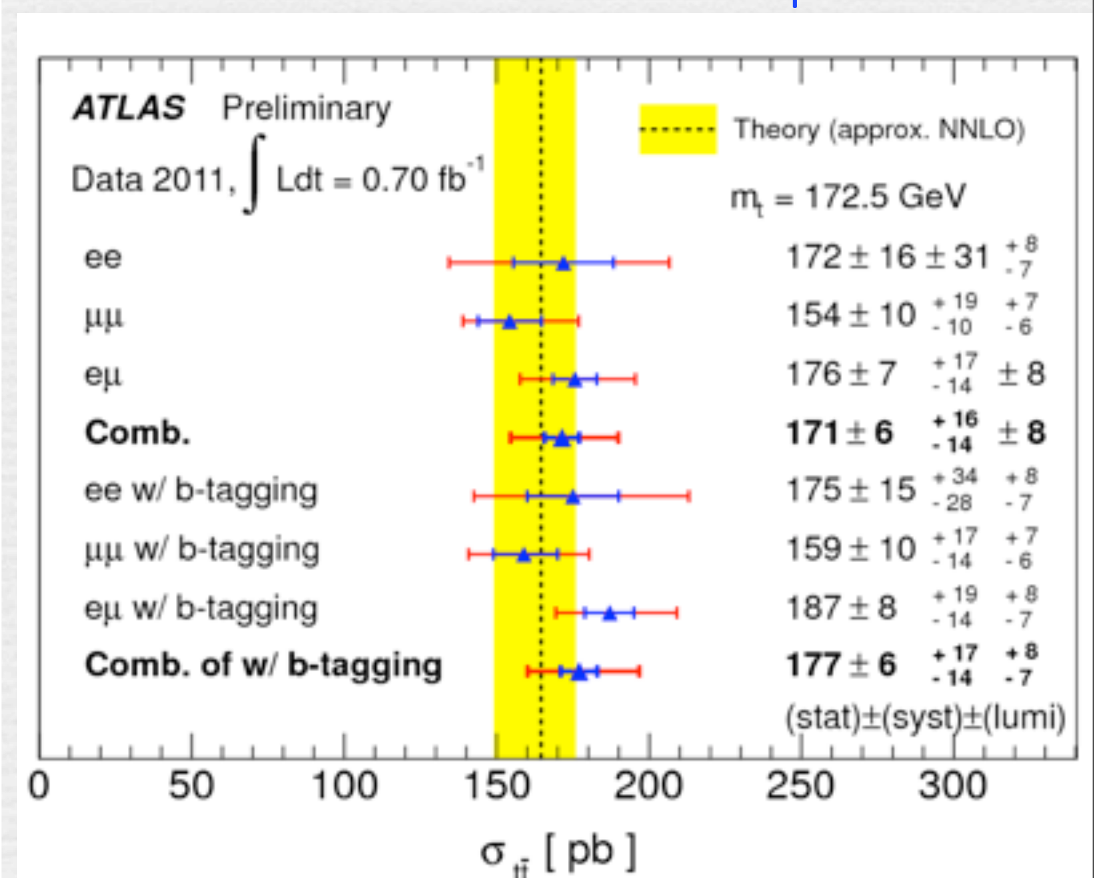


number of jets distribution

ee+$\mu\mu$+eμ



Cross section of the dilepton



consistent with SM prediction

$t\bar{t}$ cross section in τ - μ + X

L=1fb^{-1}

Sensitive to charged Higgs

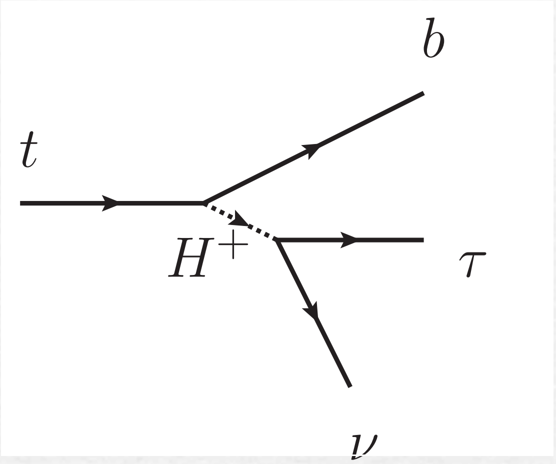
Event selection:

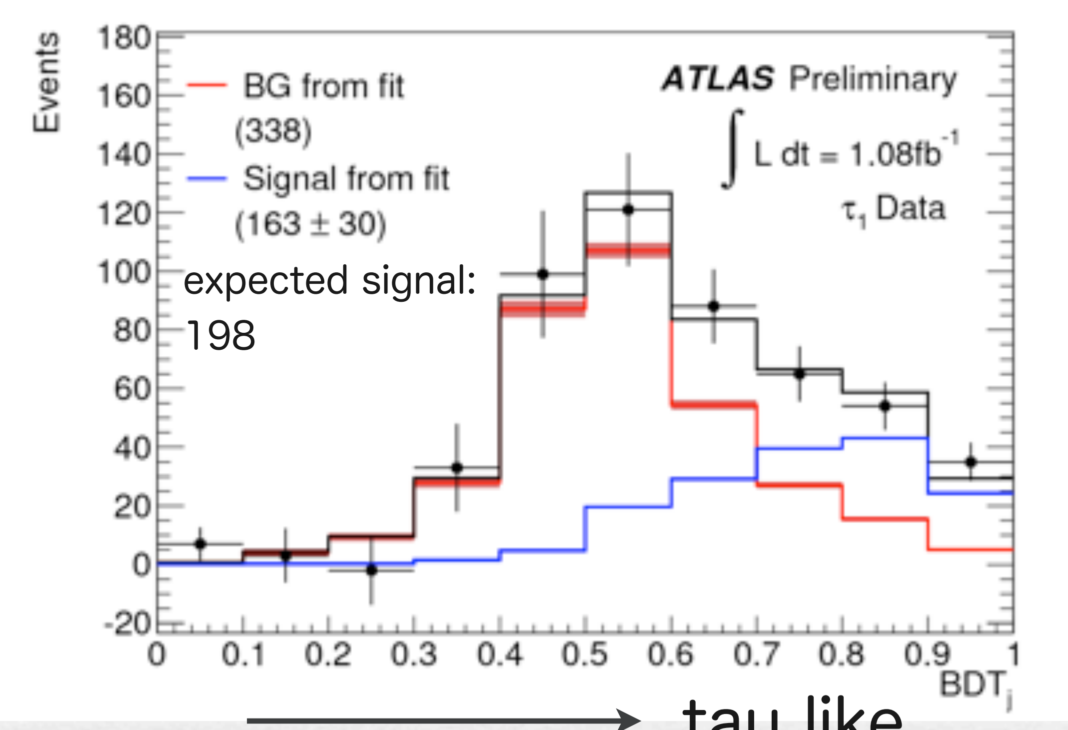
One μ

≧ 2 jets (≧ 1 jet is b-jet)

E_T^{miss} > 30 GeV

$H_T = \Sigma pT(\mu$, jets, $E_T^{miss})$





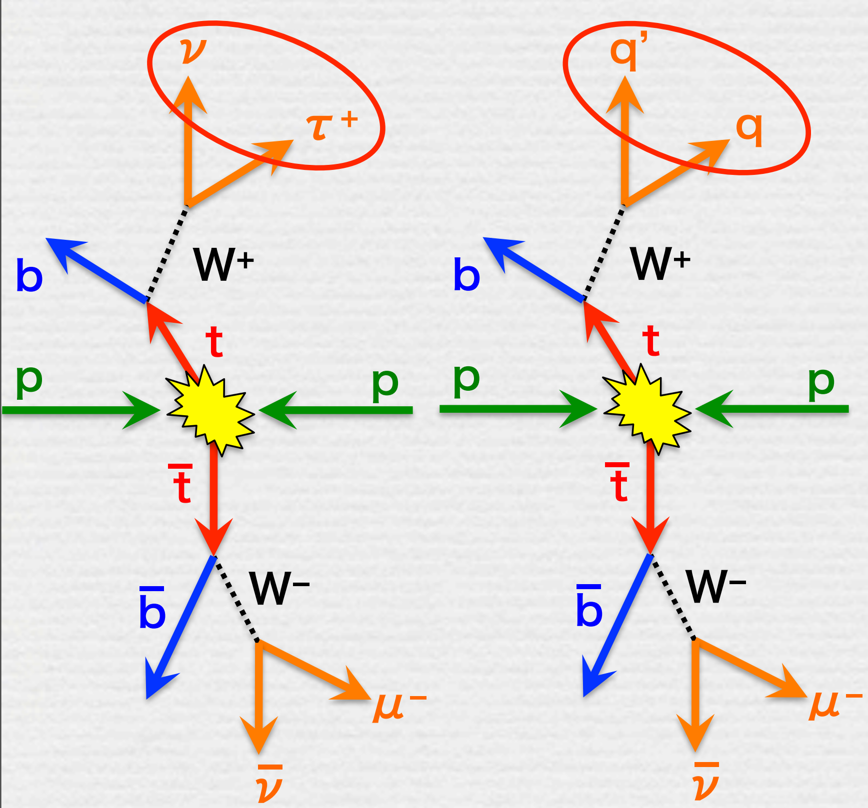
Background : $t\bar{t}$ (1 lepton)

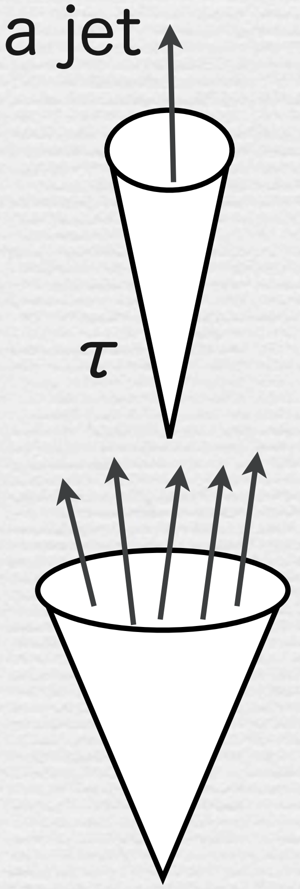
Only τ id can discriminate signal from bkg

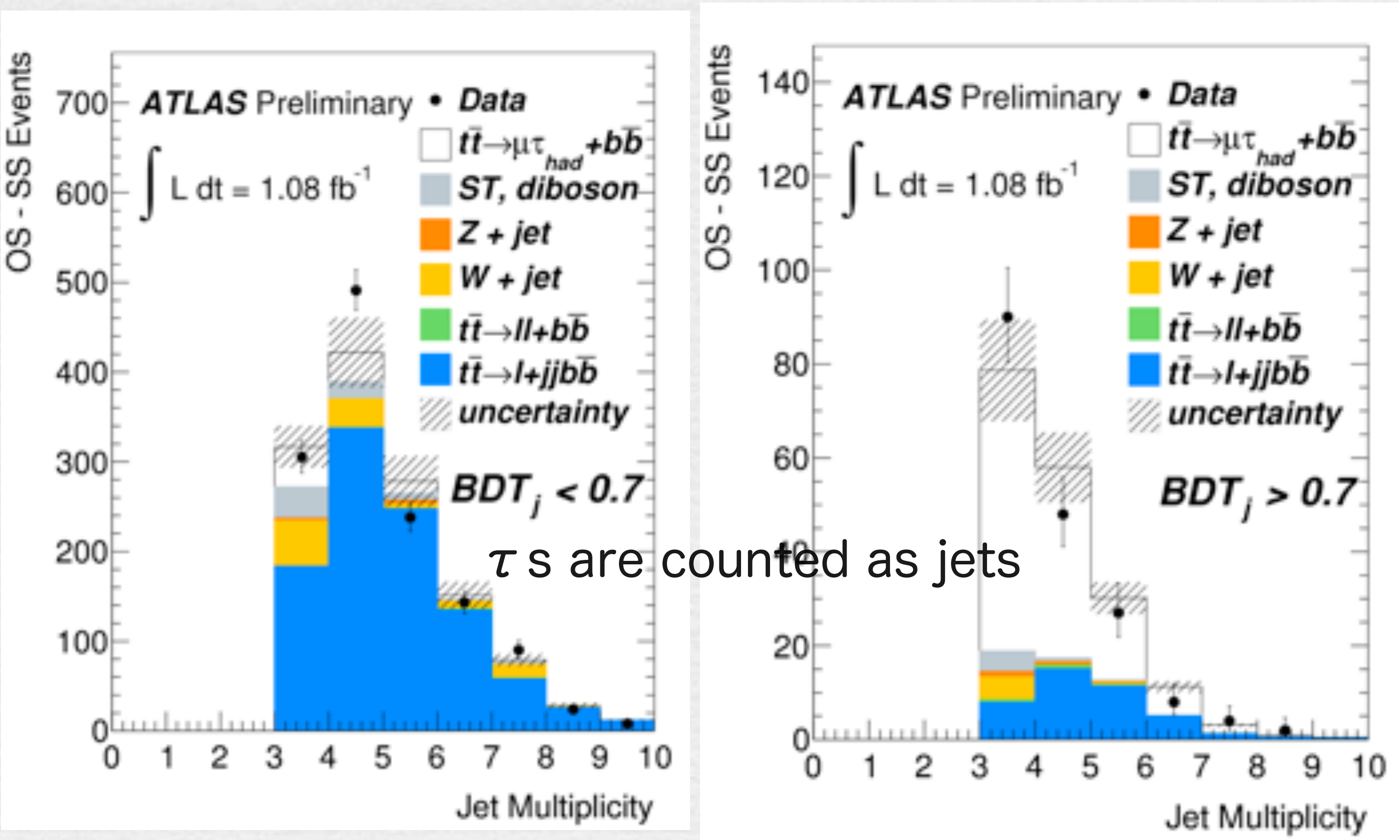
Boosted Decision Tree (BDT) multivariate analysis :

Narrow jet cone, Low N_{trk} in a jet

$$\sigma_{t\bar{t}} = 142 \pm 21 \pm^{20}_{16} \pm 5 \quad \text{pb}$$

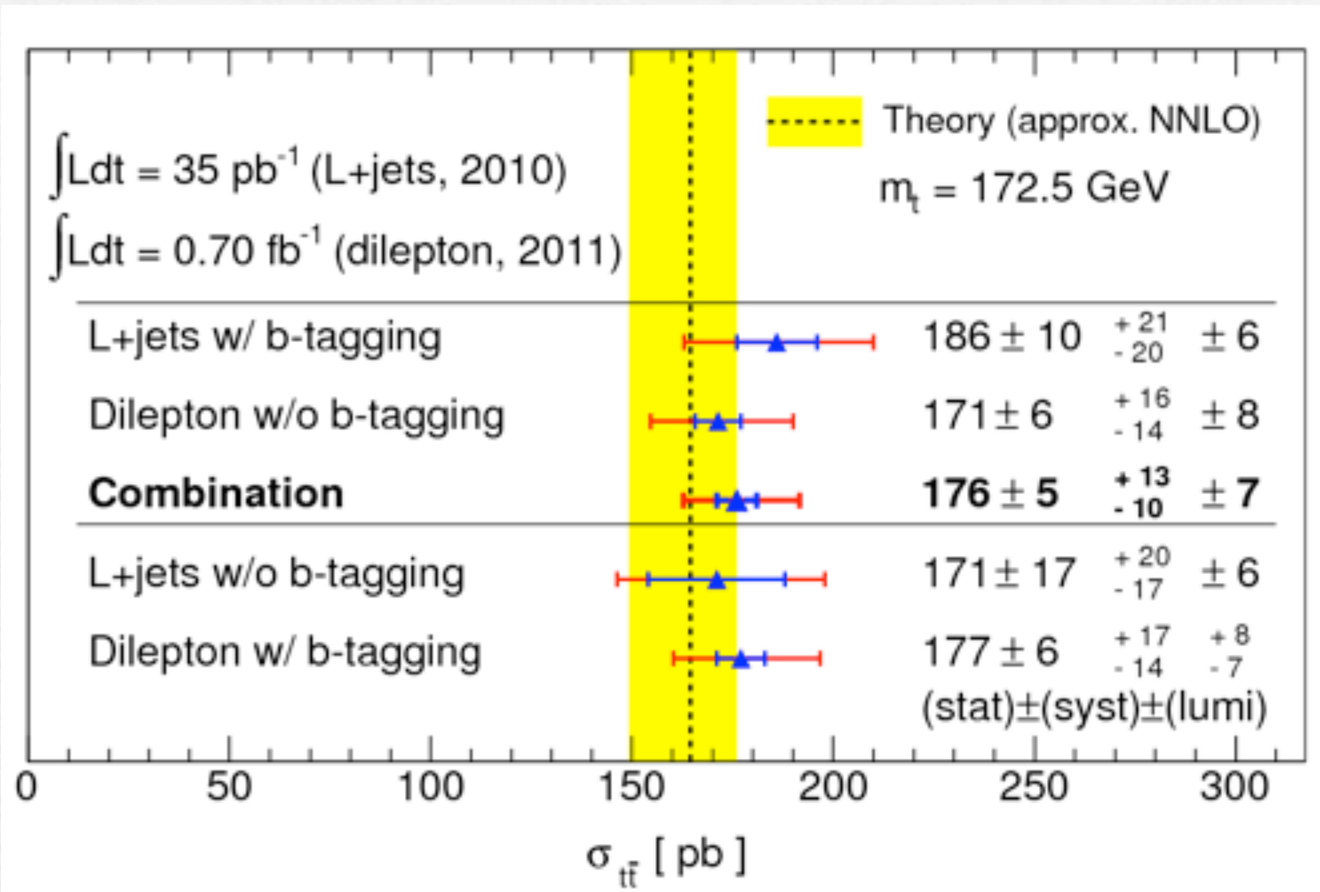


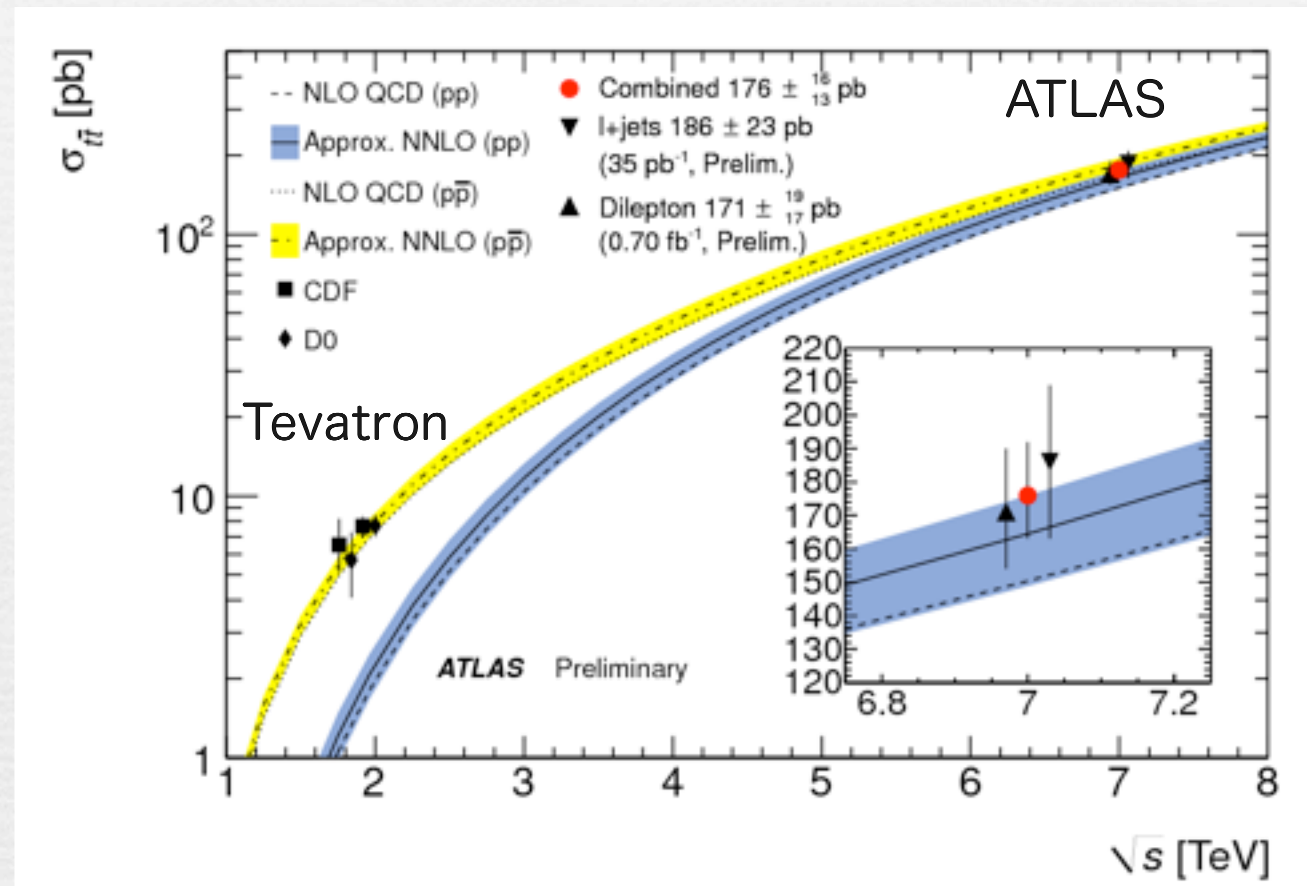


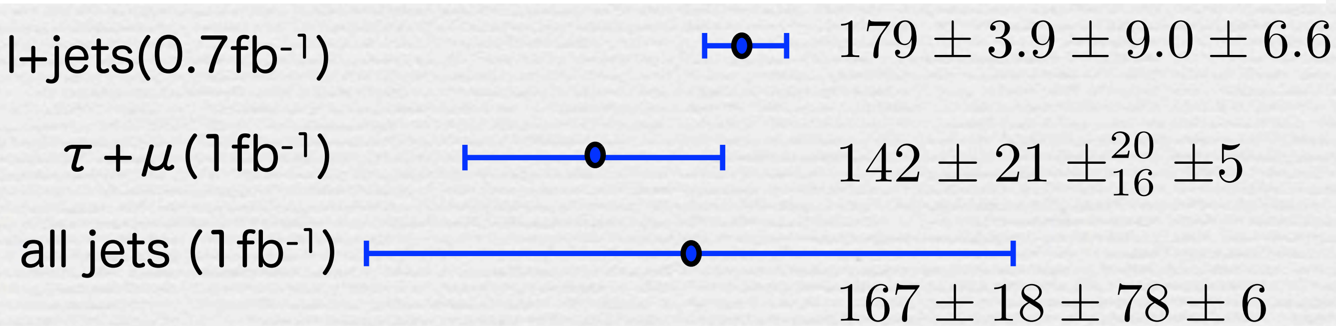


τ s are counted as jets

$t\bar{t}$ production cross section







All channels are consistent with SM

QCD is effective theory from 1TeV to 7 TeV proton collision

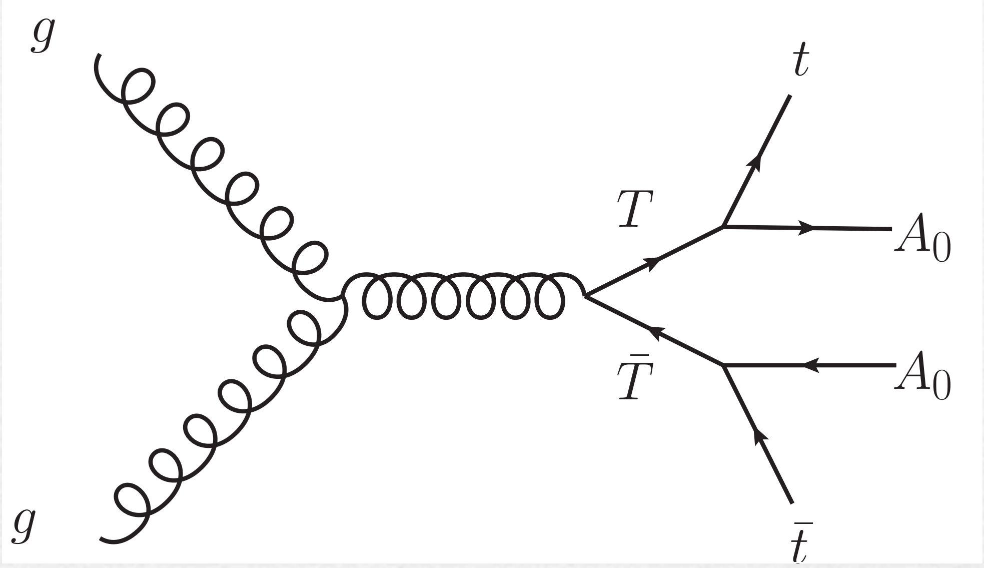
Experimental uncertainty is now comparable with theoretical uncertainty

ttbar+E_T^{miss}

L=1fb^{-1}

Search for the exotic top quark partner (SUSY, little Higgs, UED, 4th gen...)

SUSY: T is scalar top $\tilde{t}\bar{\tilde{t}} \rightarrow t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0$



Event selections:

1-lepton selection (1 lepton, ≧4 jets)

E_T^{miss} > 100GeV, m_T>150GeV

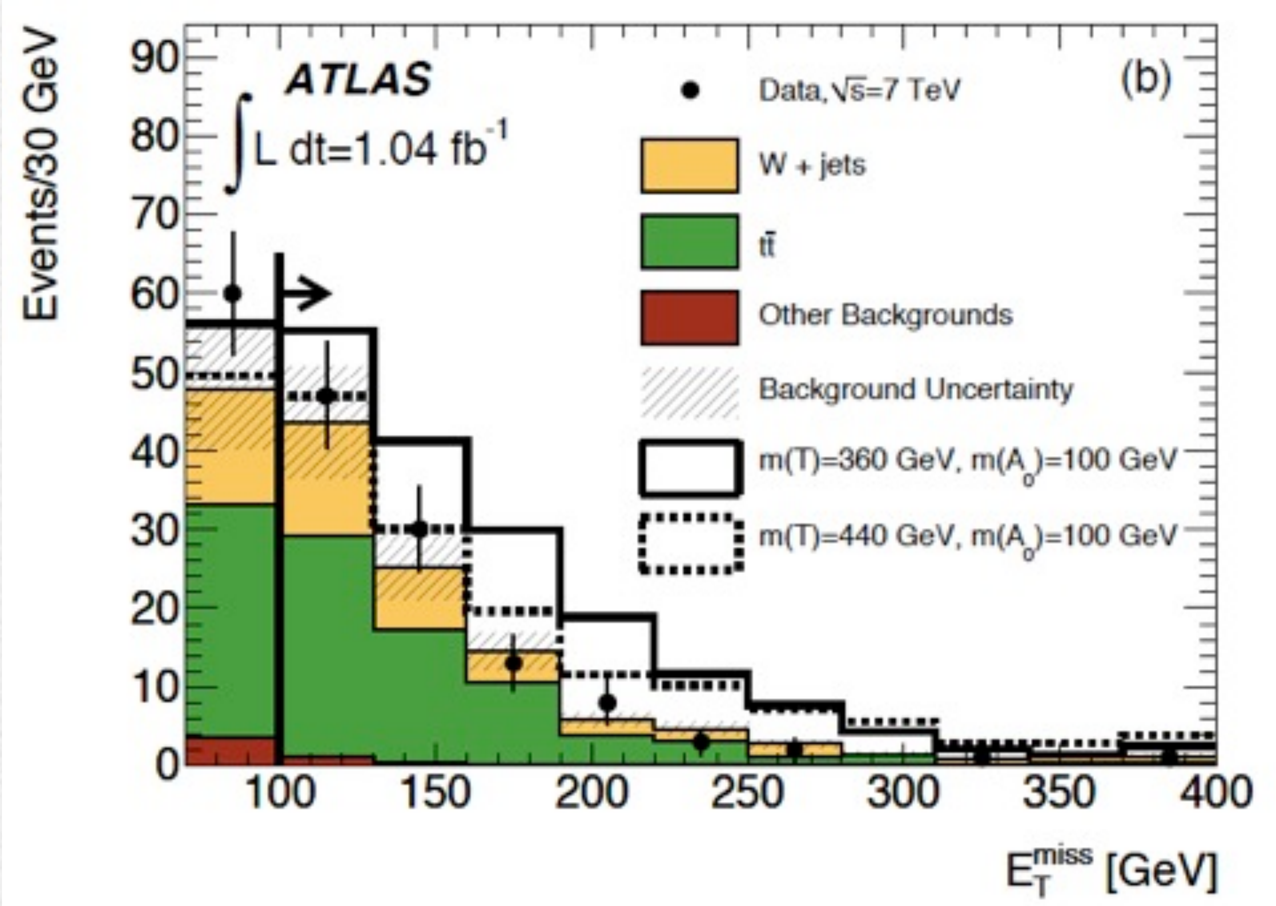
$$m_T = \sqrt{2p_T^\ell E_T^{miss}(1-\cos(\phi^\ell - \phi^{E_T^{miss}}))}$$

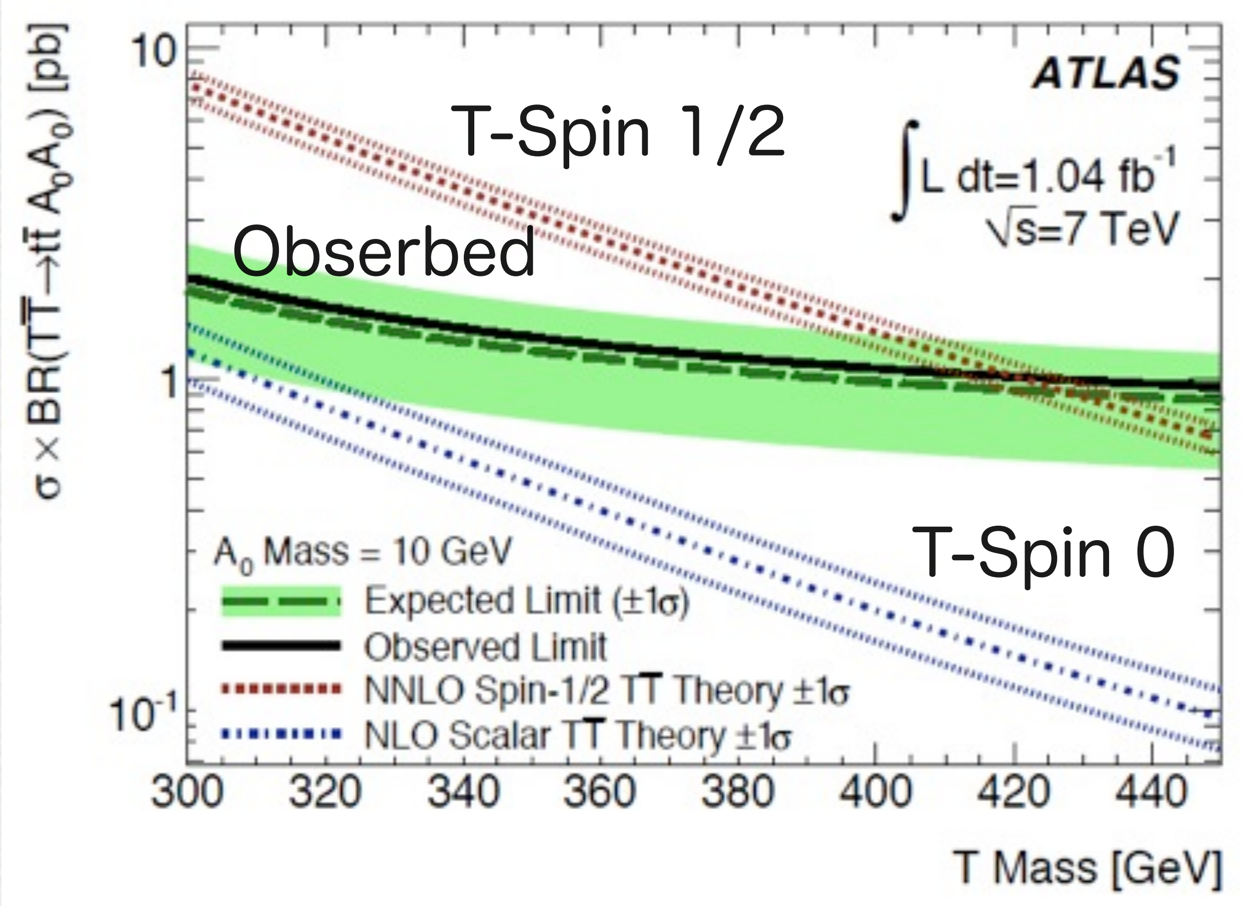
Backgrounds:

top quark pair 2 lepton, W+jets

T-spin 1/2

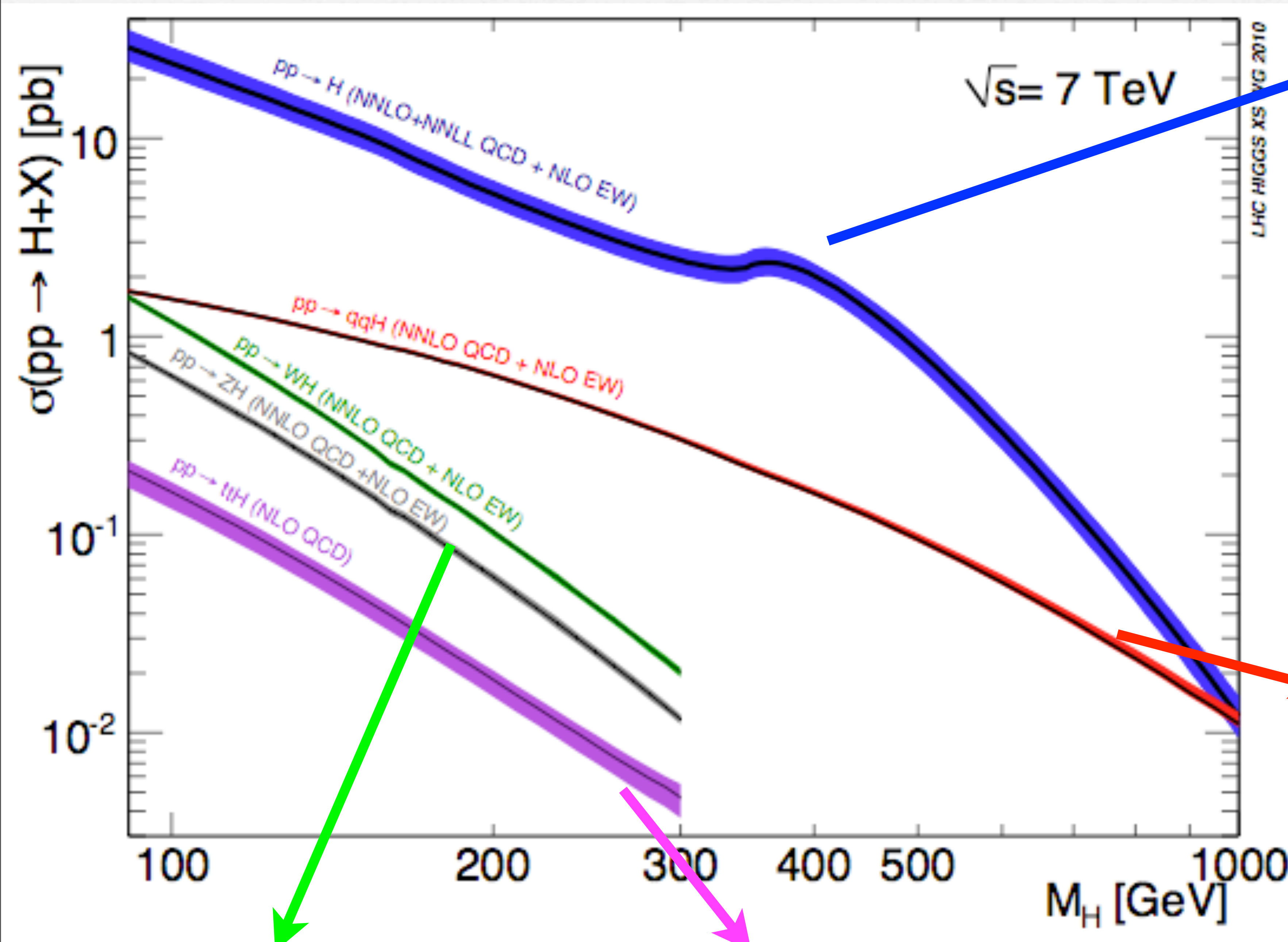
Exclude M_T<420GeV @ A0=10GeV



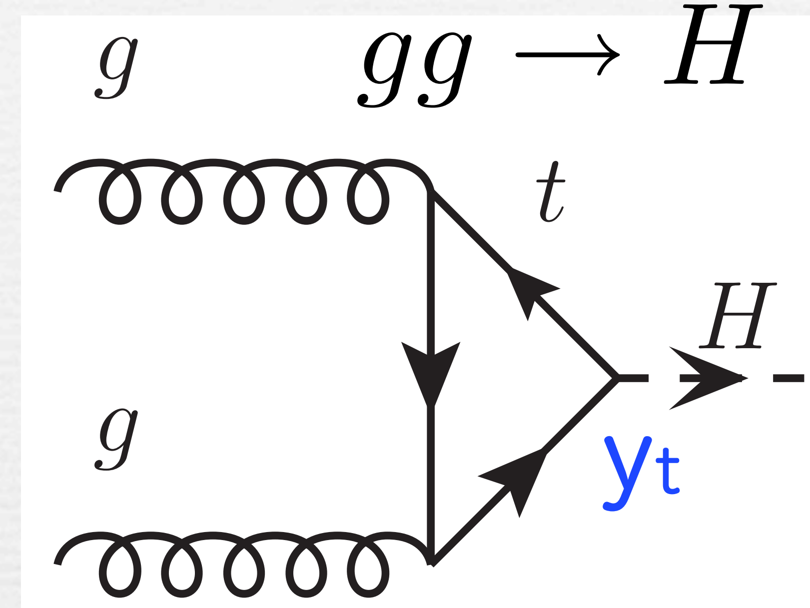


Higgs boson searches

Higgs production

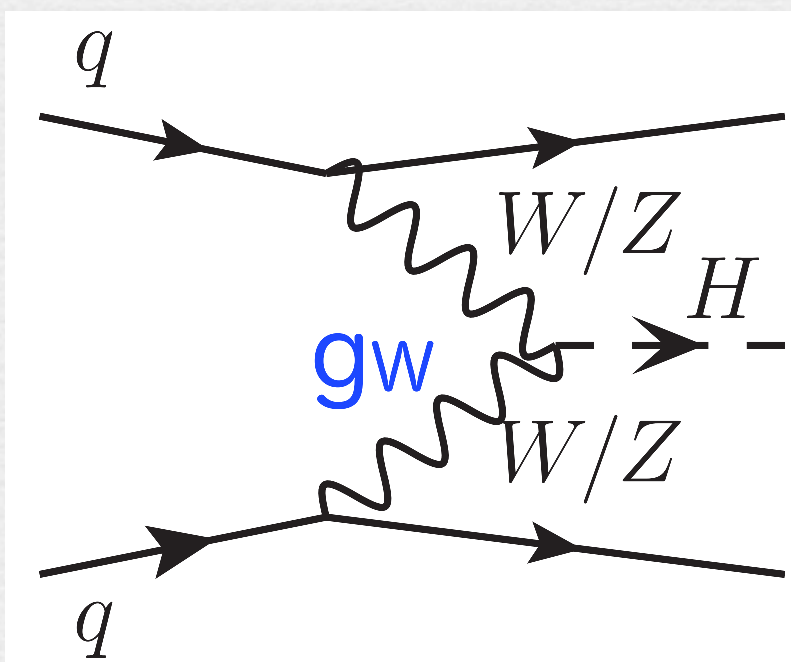


gluon fusion

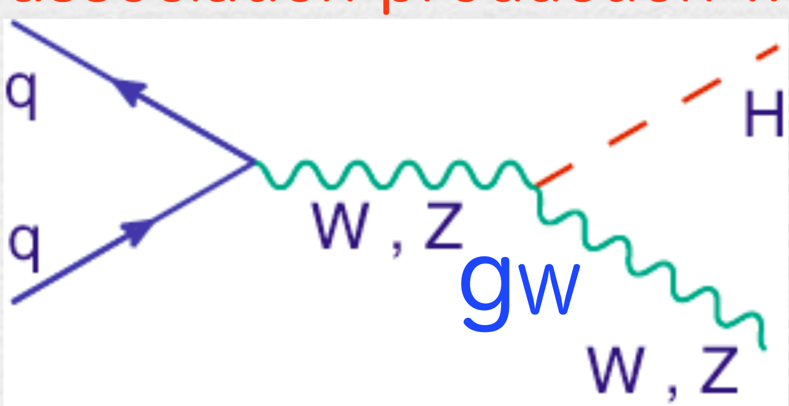


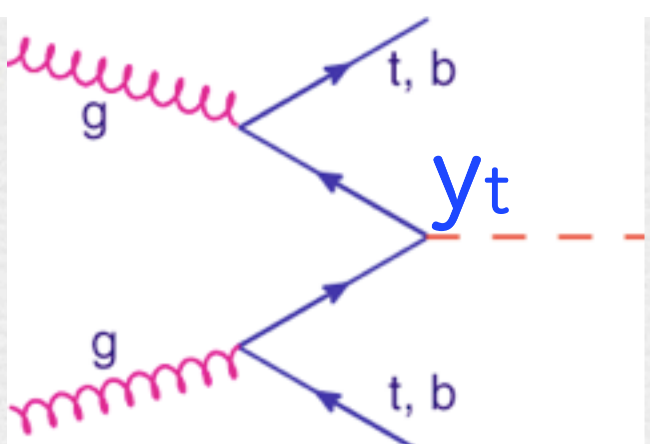
W/Z boson fusion

$qq \to Hqq$



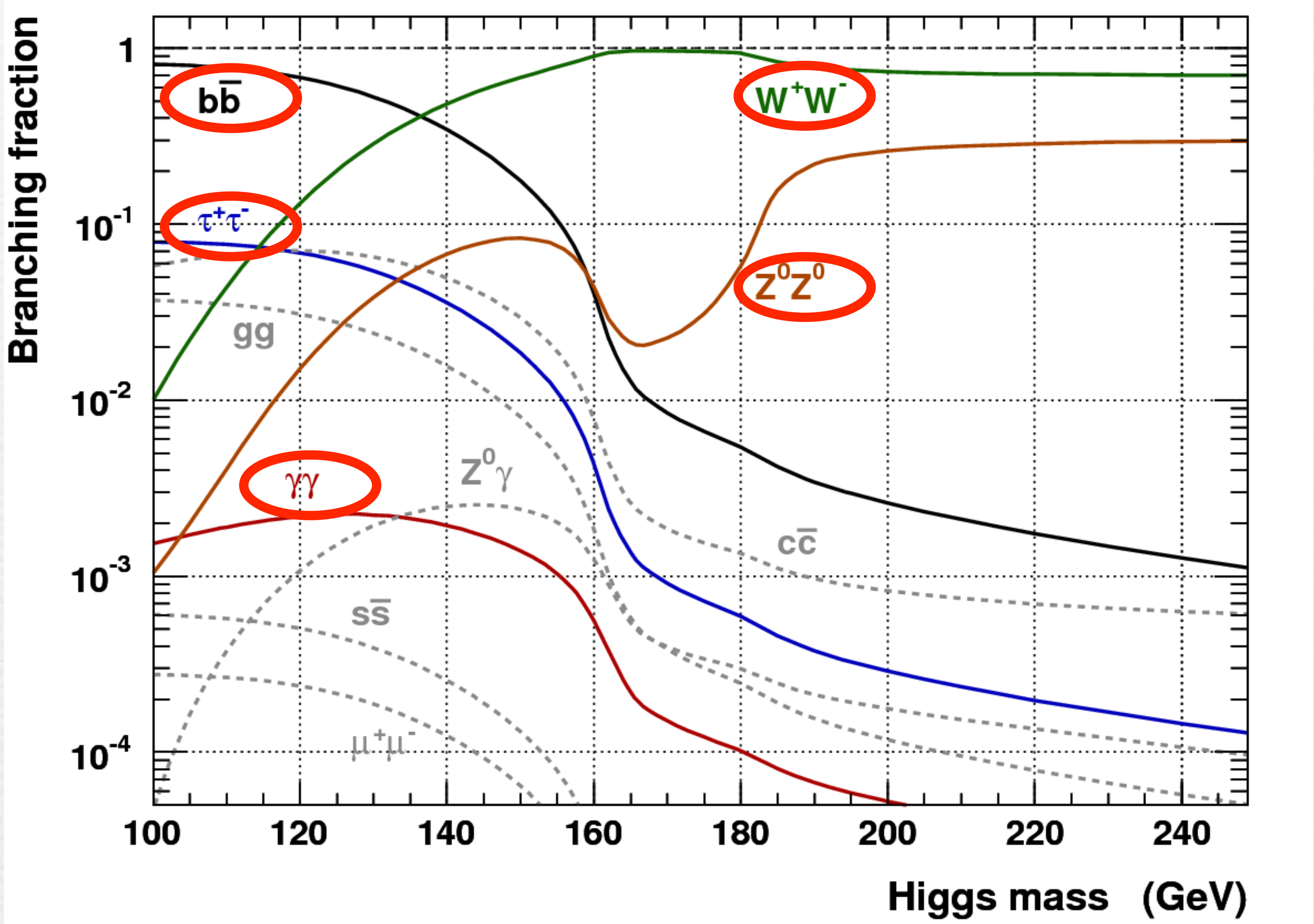
association production with W/Z

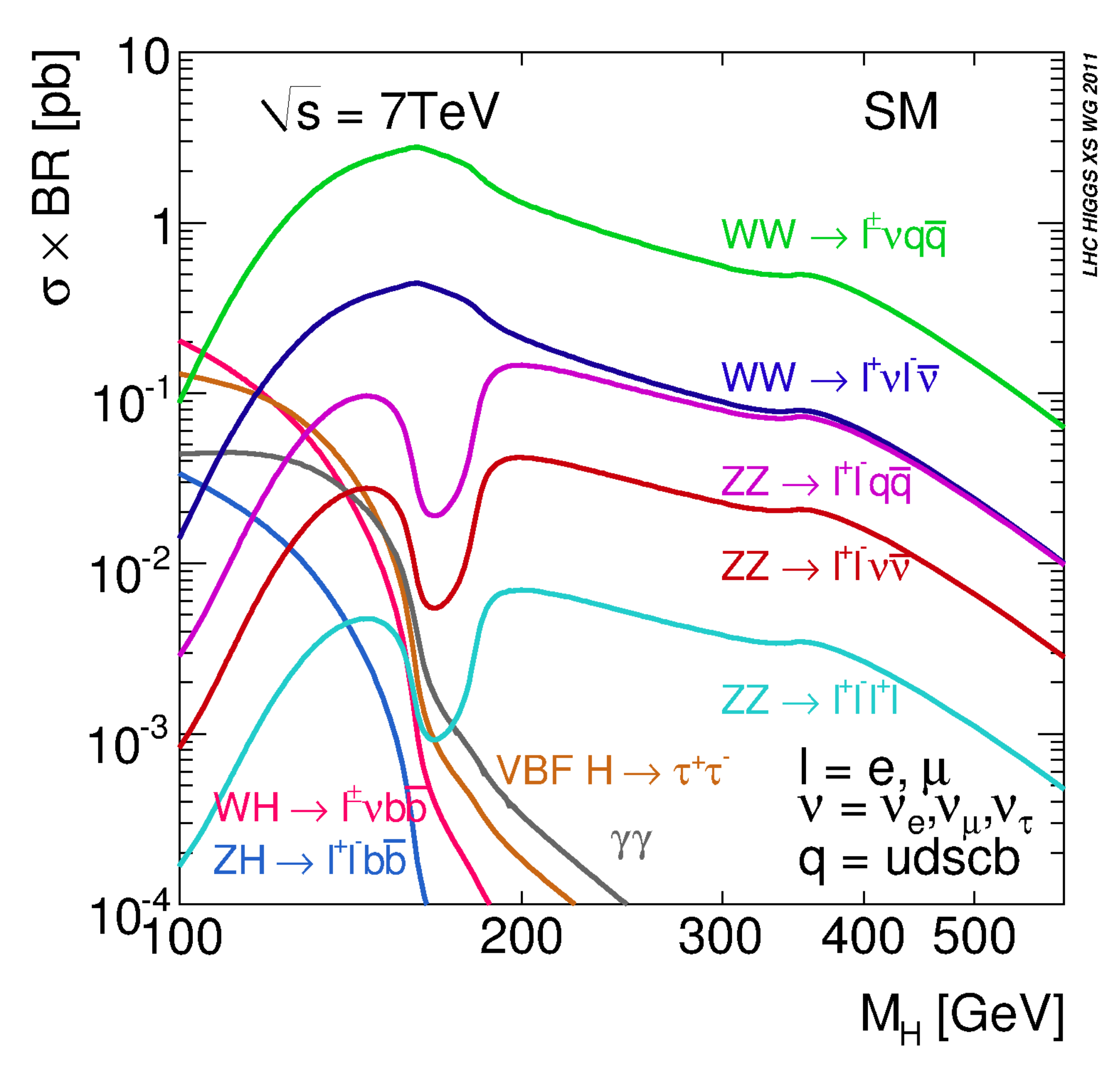




association production with t/b

Higgs Decay





M_H<130GeV

$H \to b\bar{b}, \quad H \to \tau^-\tau^+$

$H \to \gamma\gamma$ M(2γ)

130GeV<M_H<200GeV

$H \to WW^{(*)} \to \ell^-\bar{\nu}\ell^+\nu$ Cannot reconstruct Higgs mass

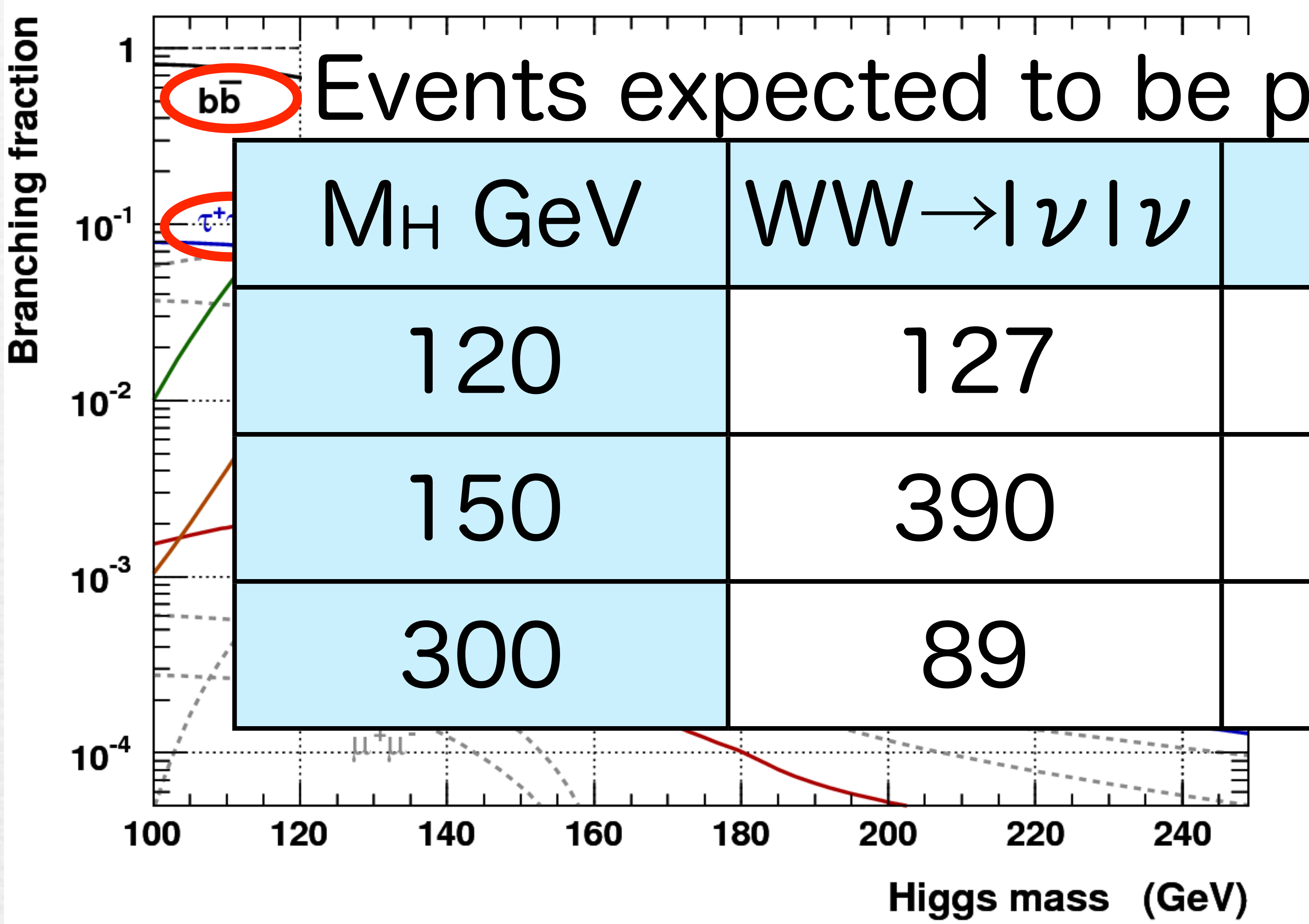
M_H>200GeV

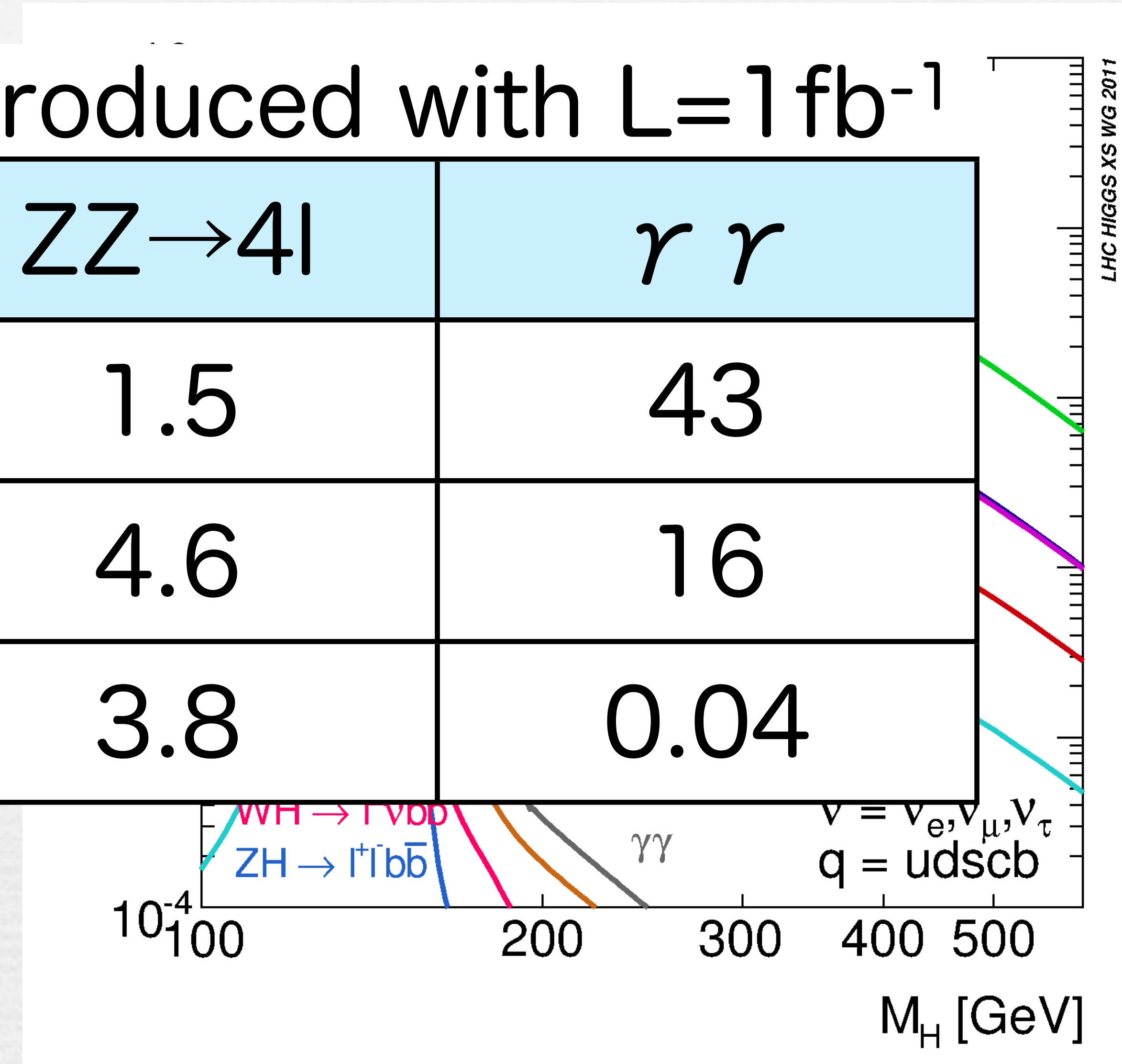
$H \to ZZ^{(*)} \to \ell^+\ell^- jj$ M(2ℓ 2j)

$H \to ZZ^{(*)} \to \ell^+\ell^-\nu\bar{\nu}$ M(2ℓ +p_T^{miss})

$H \to ZZ^{(*)} \to \ell^+\ell^-\ell^+\ell^-$ M(4ℓ)

Higgs Decay





Events expected to be produced with $L=1\,fb^{-1}$

M_H GeV	$WW \to l\nu l\nu$	$ZZ \to 4l$	$\gamma\gamma$
120	127	1.5	43
150	390	4.6	16
300	89	3.8	0.04

M_H<130GeV

$H \to b\bar{b}, \quad H \to \tau^-\tau^+$

$H \to \gamma\gamma$ M(2γ)

130GeV<M_H<200GeV

$H \to WW^{(*)} \to \ell^-\bar{\nu}\ell^+\nu$ Cannot reconstruct Higgs mass

M_H>200GeV

$H \to ZZ^{(*)} \to \ell^+\ell^- jj$ M(2ℓ 2j)

$H \to ZZ^{(*)} \to \ell^+\ell^-\nu\bar{\nu}$ M(2ℓ +p_T^{miss})

$H \to ZZ^{(*)} \to \ell^+\ell^-\ell^+\ell^-$ M(4ℓ)

H→WW search

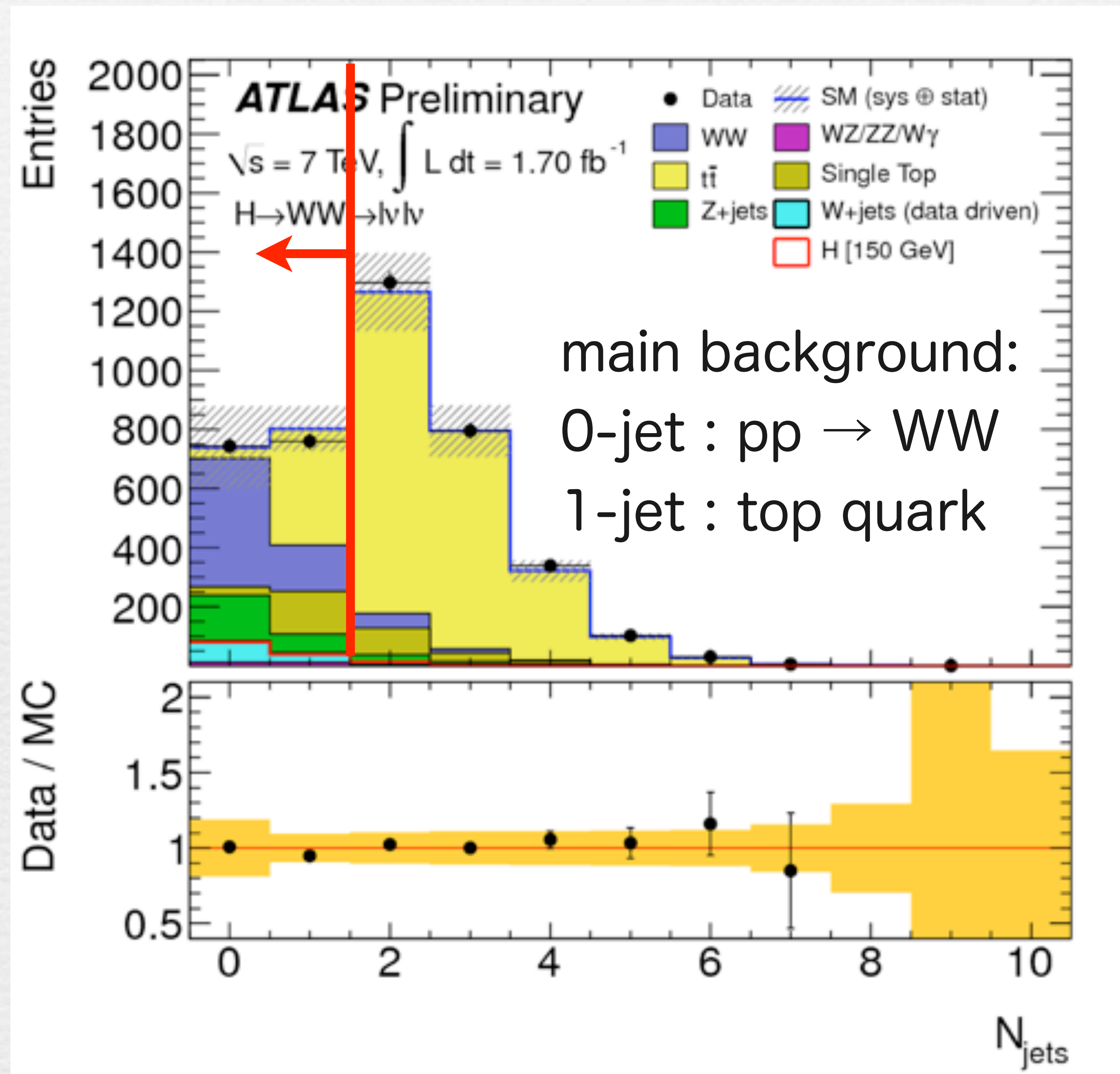
L=1.7fb^{-1}

Event selection

Opposite sign 2 good leptons

Large E_T^{miss}

Selections for WW+0jet and 1jet are optimized independently



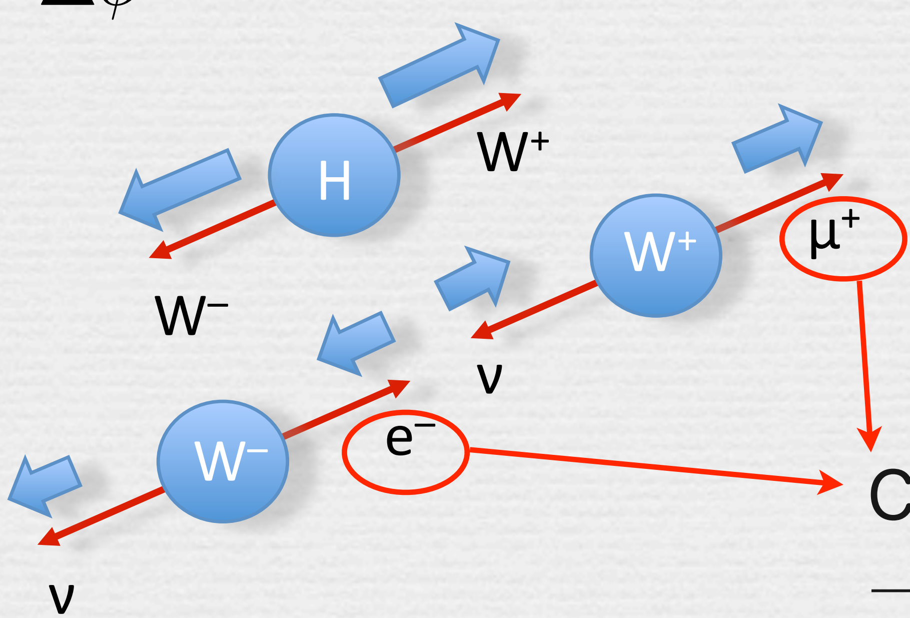
Higgs mass cannot be reconstructed.

transverse mass of $\ell\,\nu\,\ell\,\nu$ system

$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - (p_T^{\ell\ell} + p_T^{miss})^2}$$

spin correlation of $\ell\,\nu\,\ell\,\nu$ system

$$\Delta\phi^{\ell\ell}$$

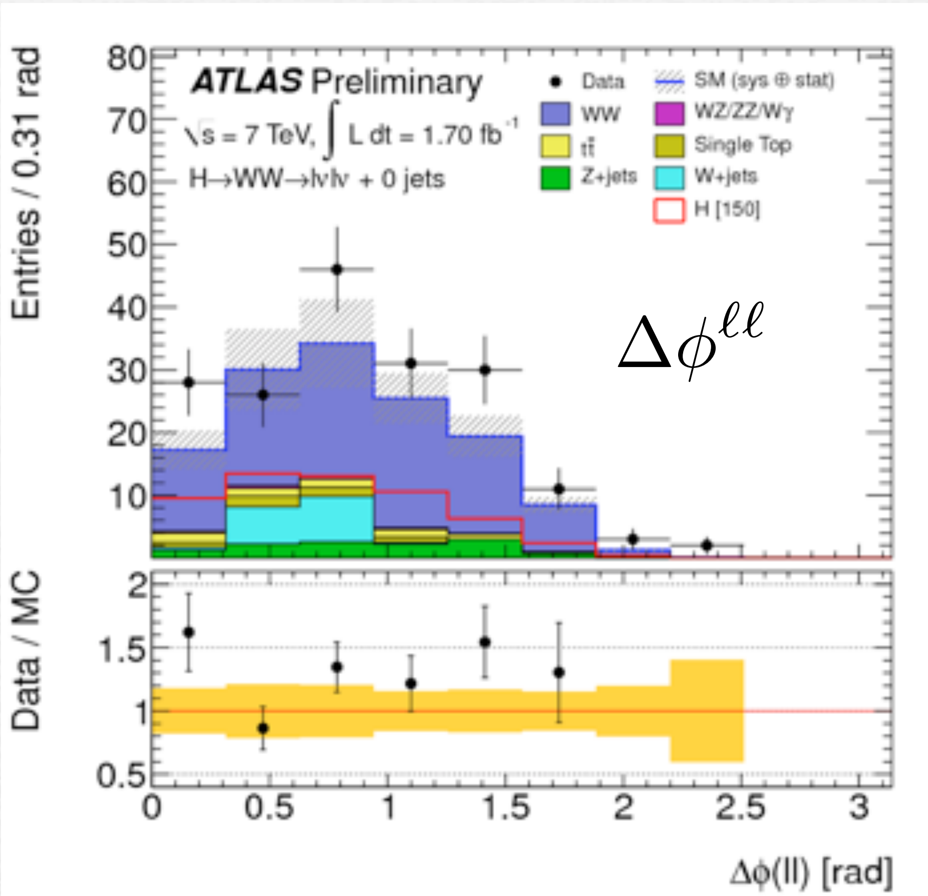


Charged leptons tend to decay to the similar direction

→ Narrow $\Delta\phi^{\ell\ell}$

H→WW search

L=1.7fb^{-1}



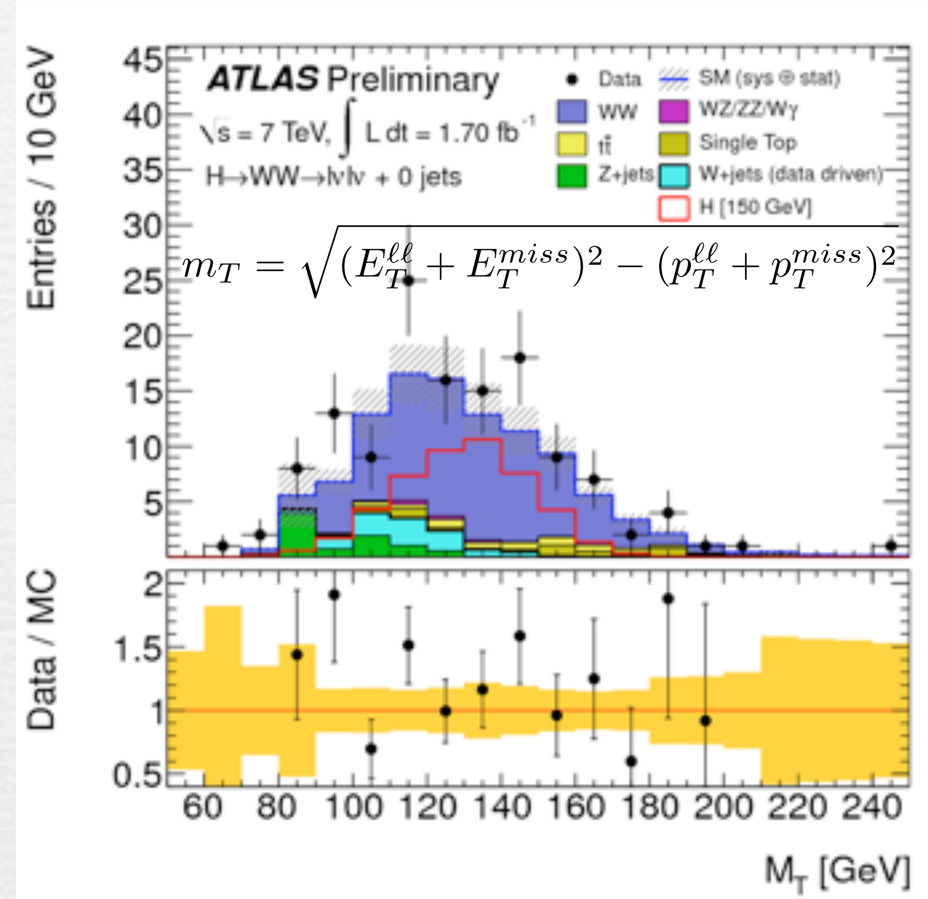
WW+0-jet

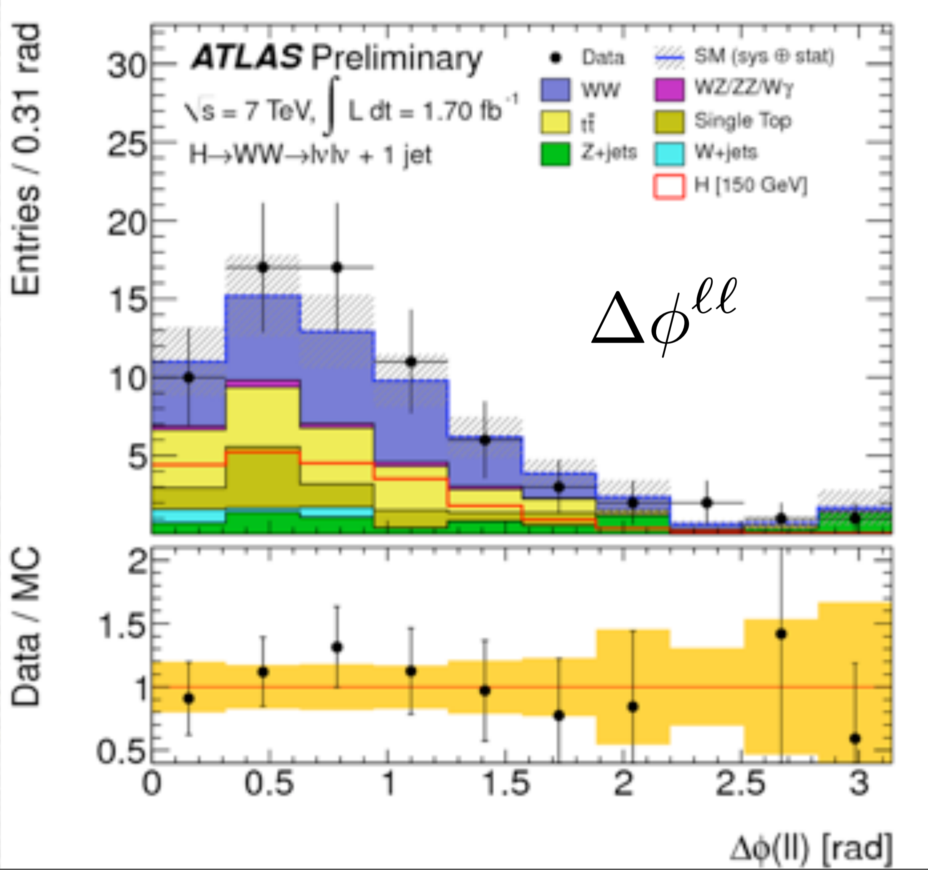
Observed data : 70

expected :

background : 53±9

signal : 34±7





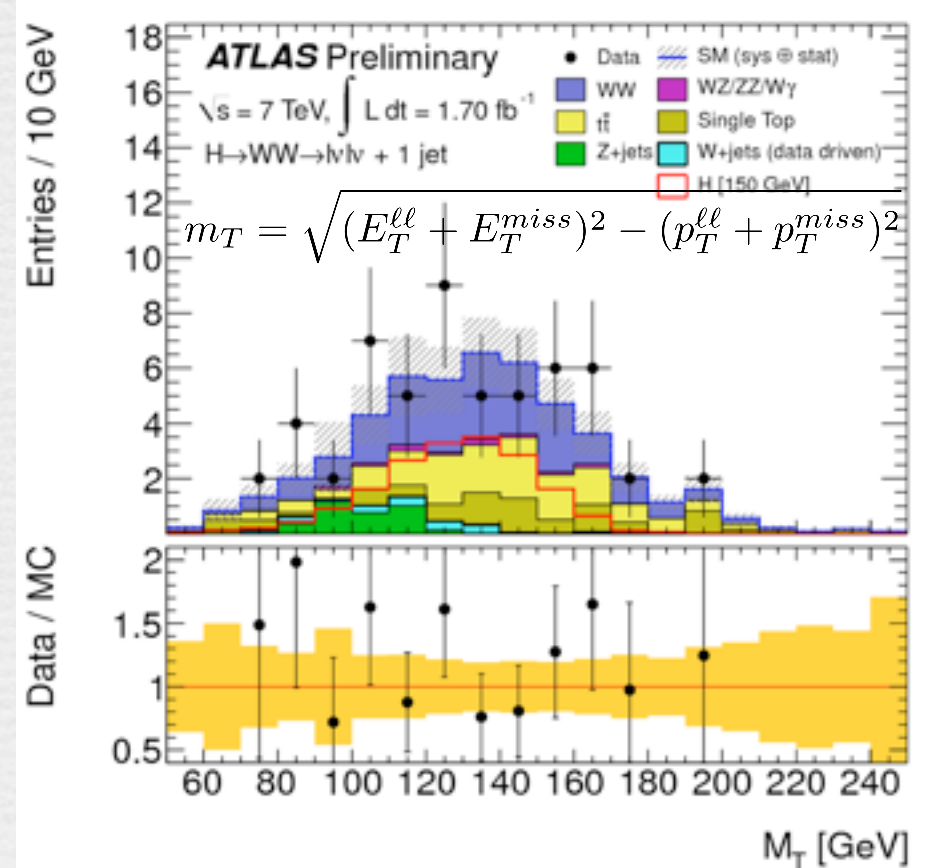
WW+1-jet

Observed data : 23

expected :

background : 23±4

signal : 12±3



$H \to \gamma\gamma$ search

$L = 1.1 fb^{-1}$

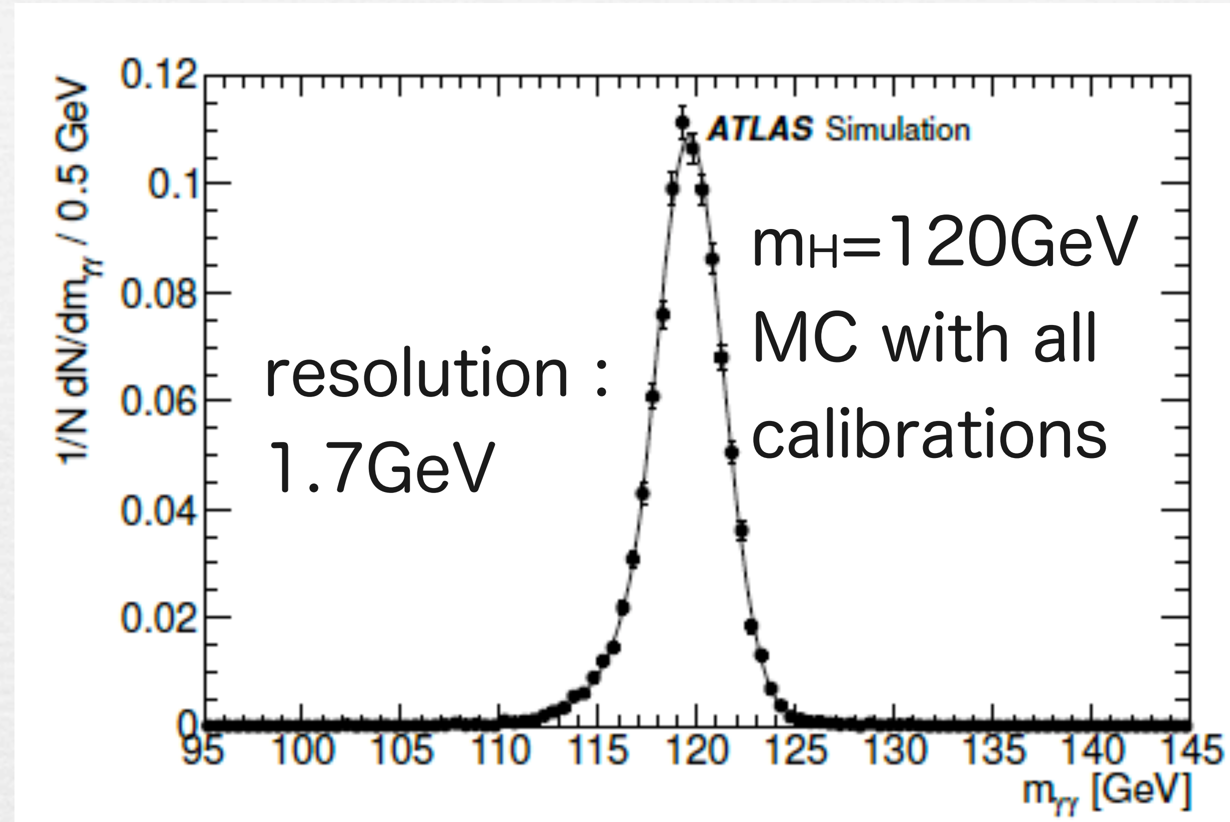
Event selection

2 good γs (p_T >40GeV, 25GeV)

Good resolution $\sigma(M_{\gamma\gamma})$=1.7GeV

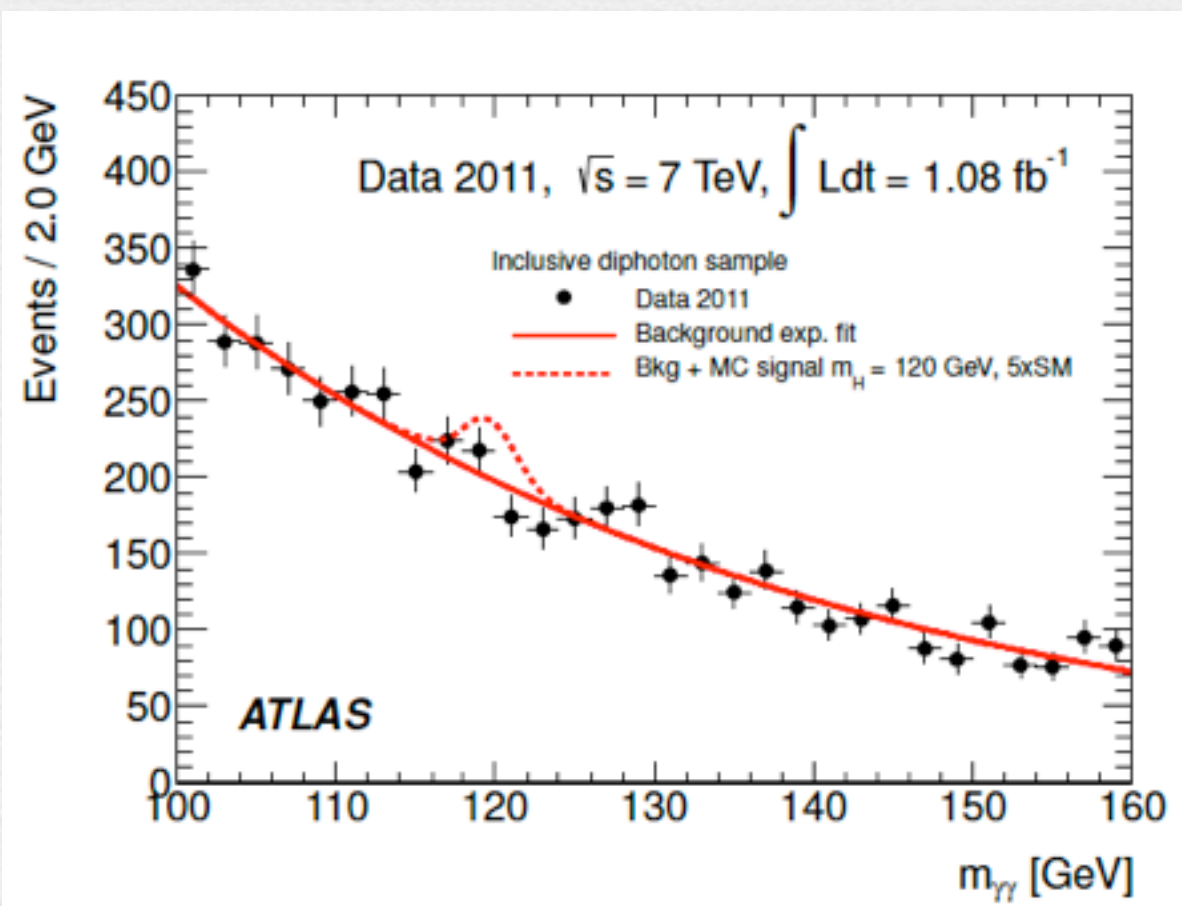
In spite of small $Br(H \to \gamma\gamma) = 2\times10^{-3}$

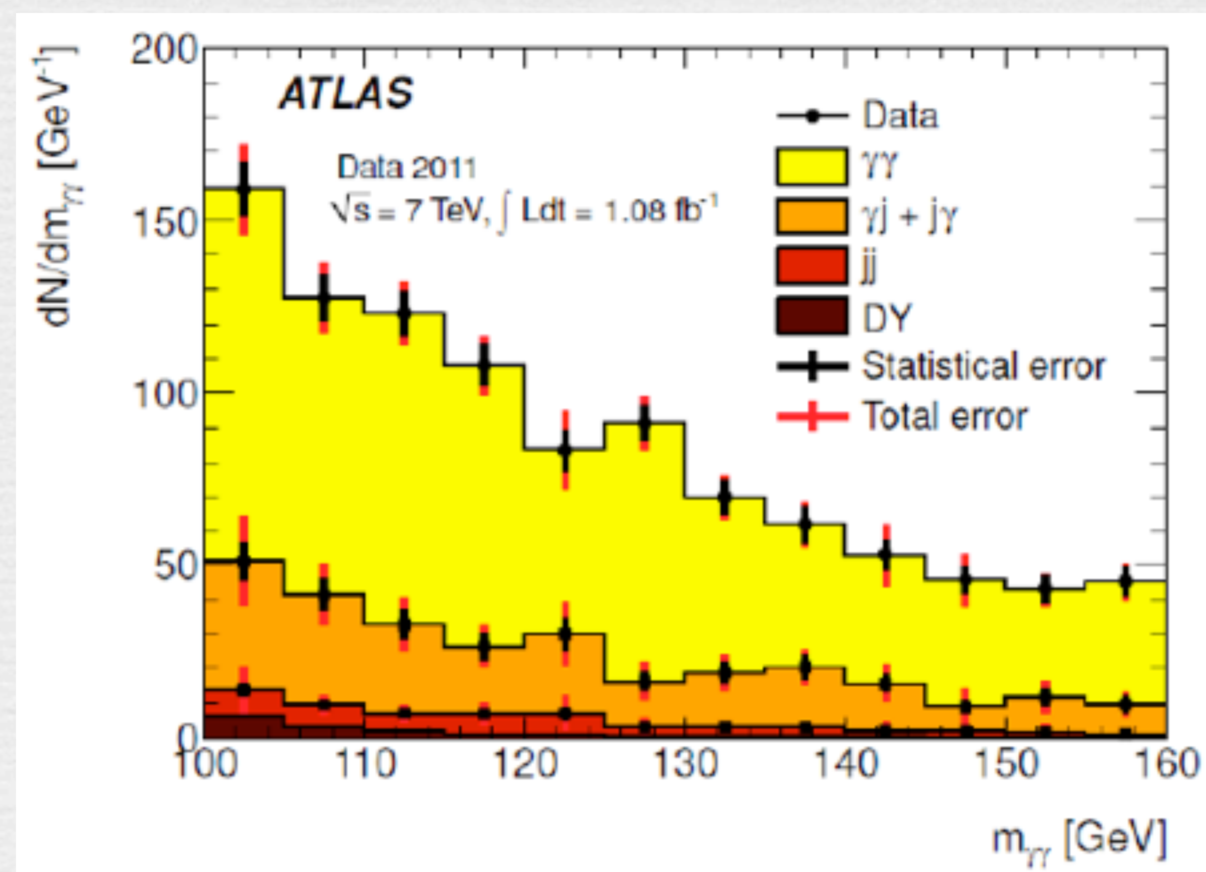
this channel is the best for low mass Higgs



Backgrounds are extracted from the fit of the side band → exponential

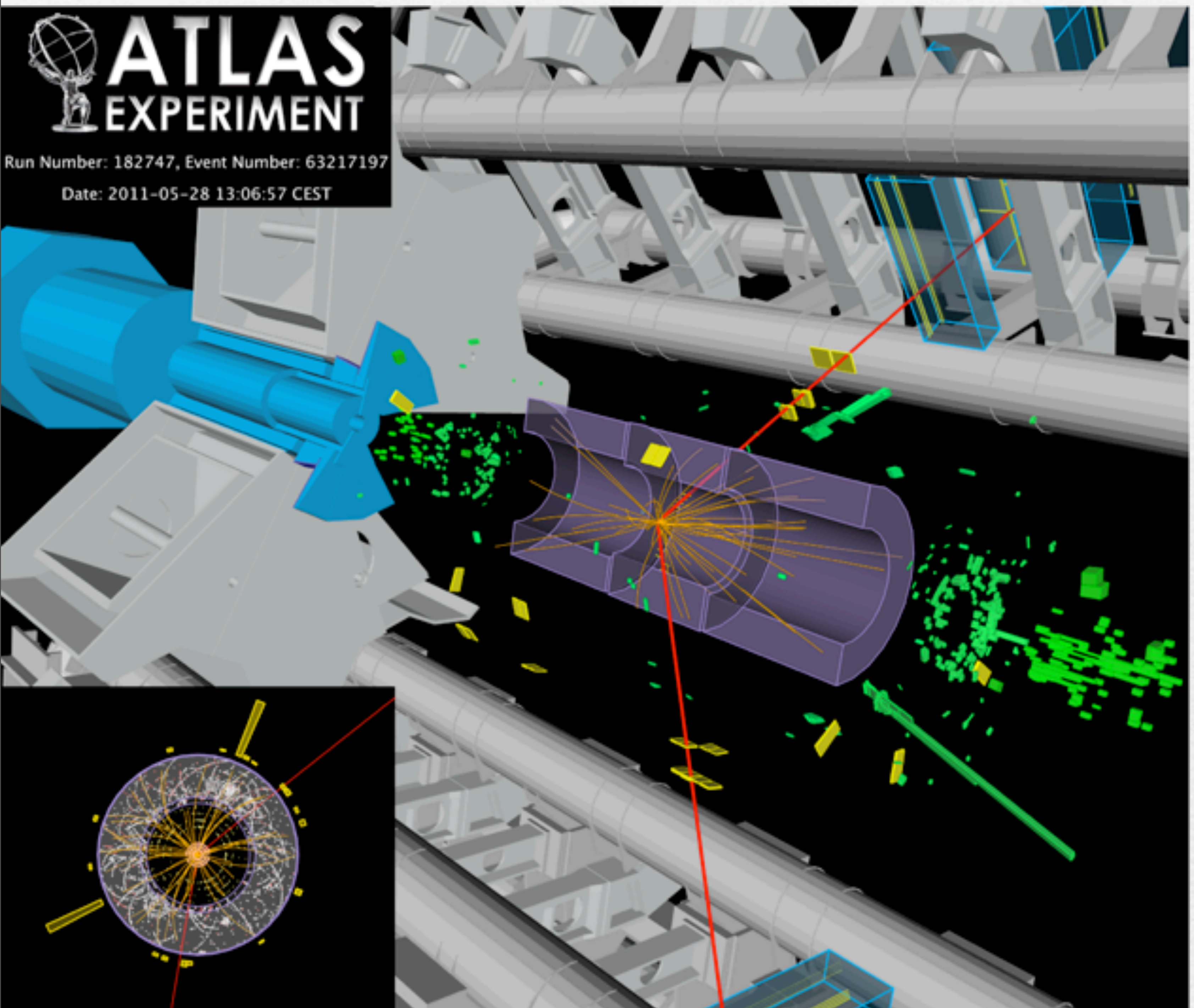
70% : $pp \to \gamma\gamma$, 30% : jet(π^0) faking γ

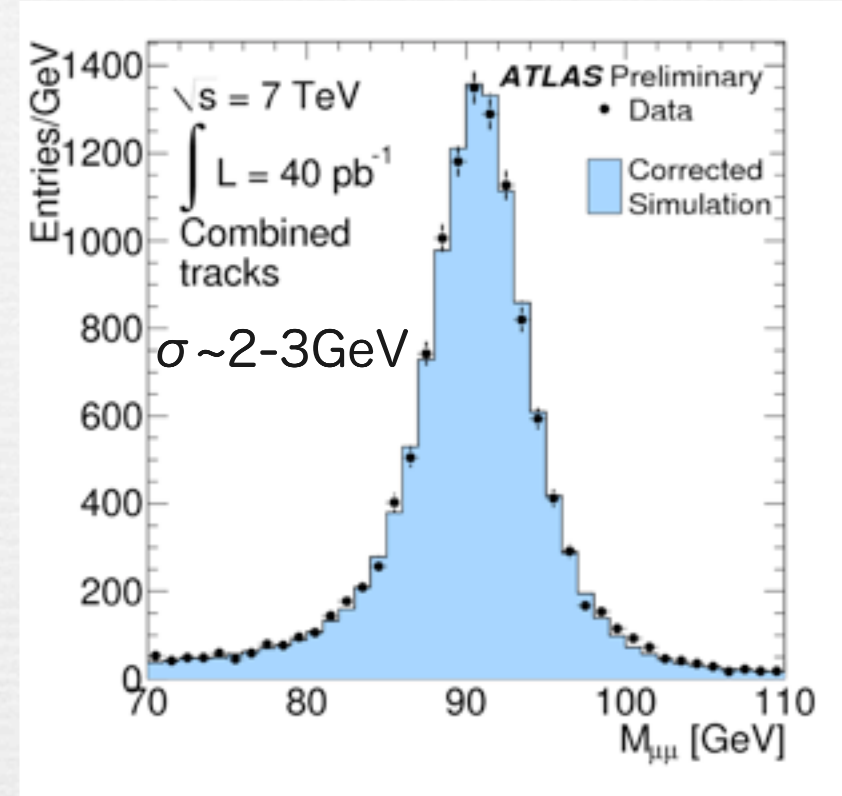


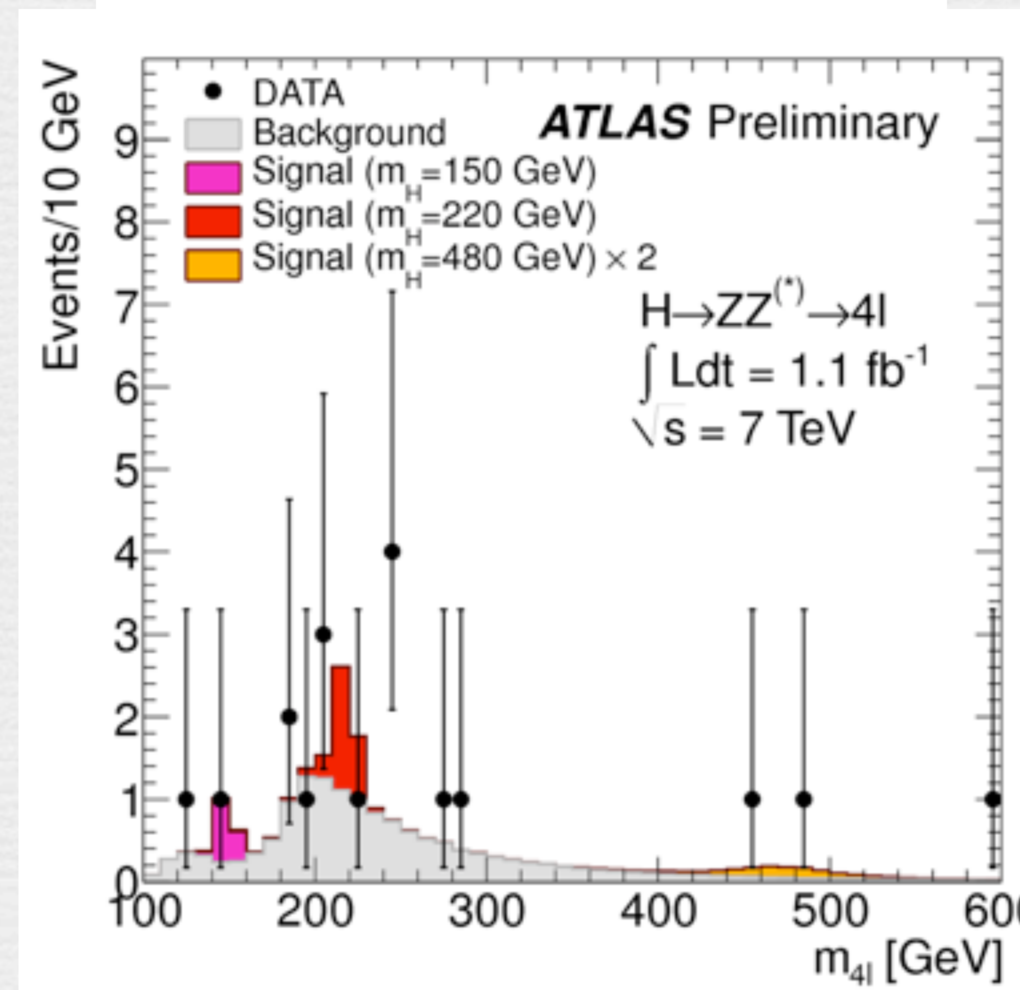


H→ZZ→4 leptons search

L=2fb^{-1}







High mass Higgs search in H → ZZ

L=1fb^{-1}

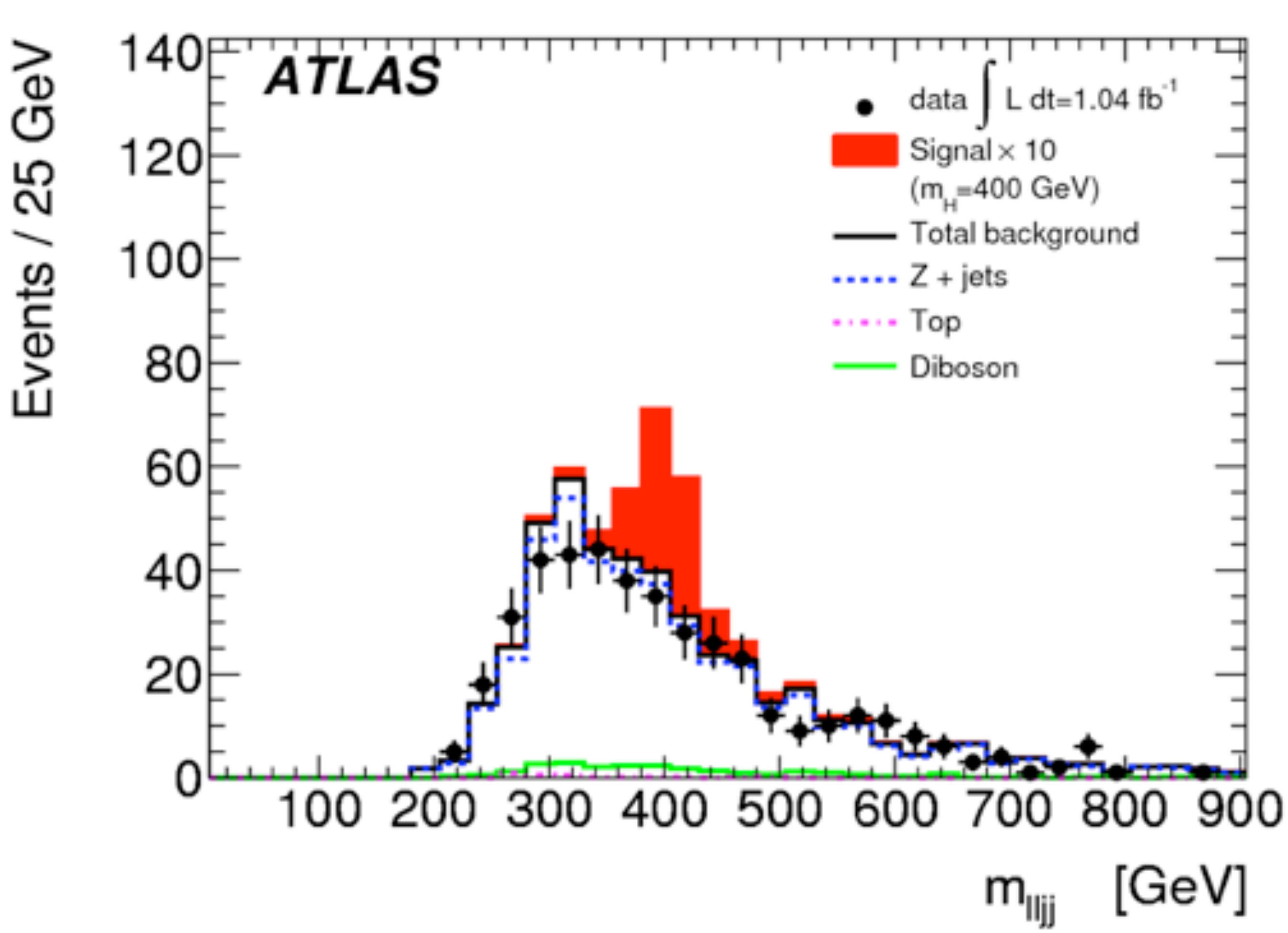
Γ_H (~m_H^3) becomes broader at for heavy Higgs

→ good lepton resolution cannot help very much

cross section × Br (Z→ℓ ℓ) becomes too small

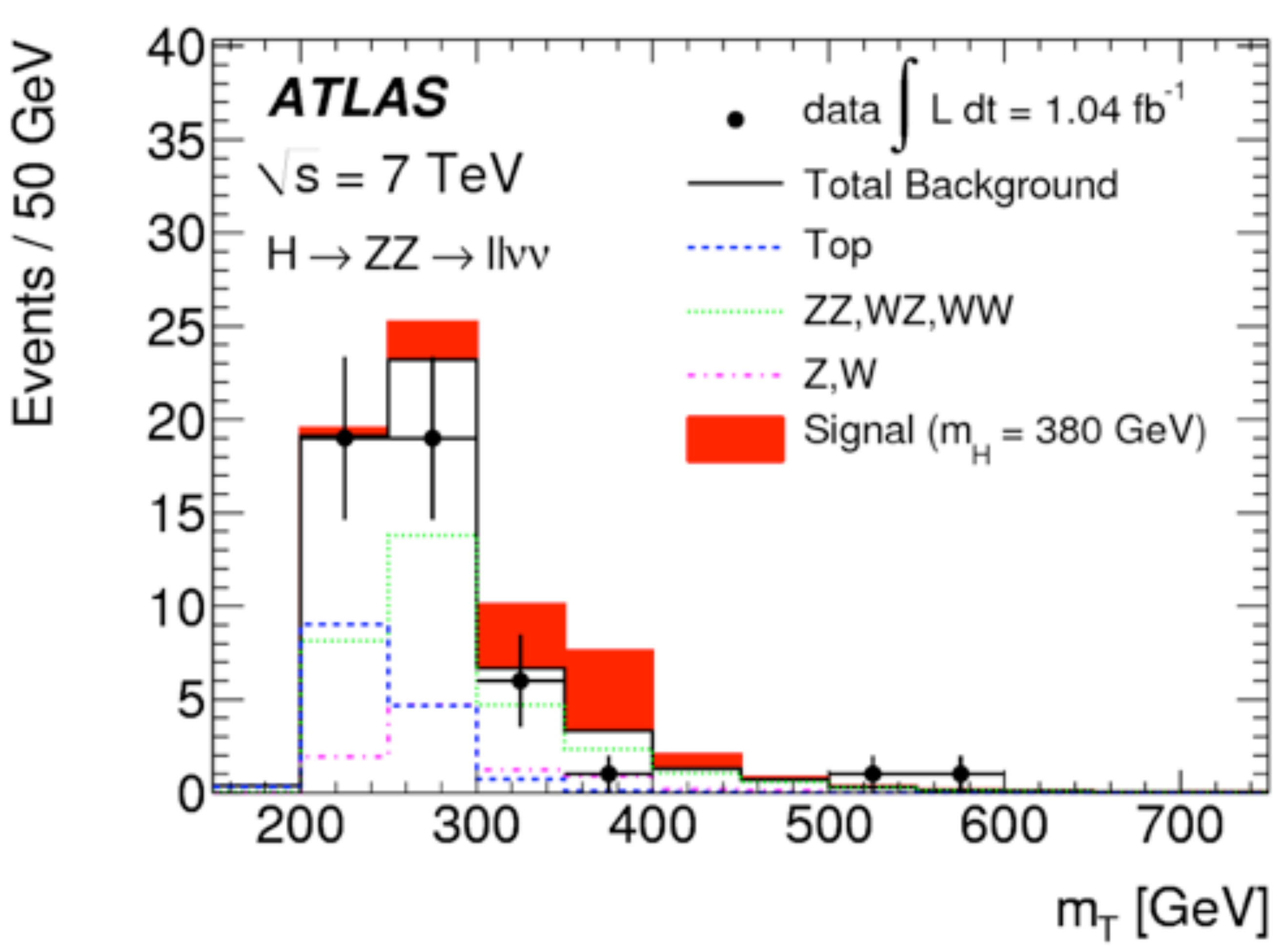
H→ZZ→ℓ ℓ jj

m_{lljj}



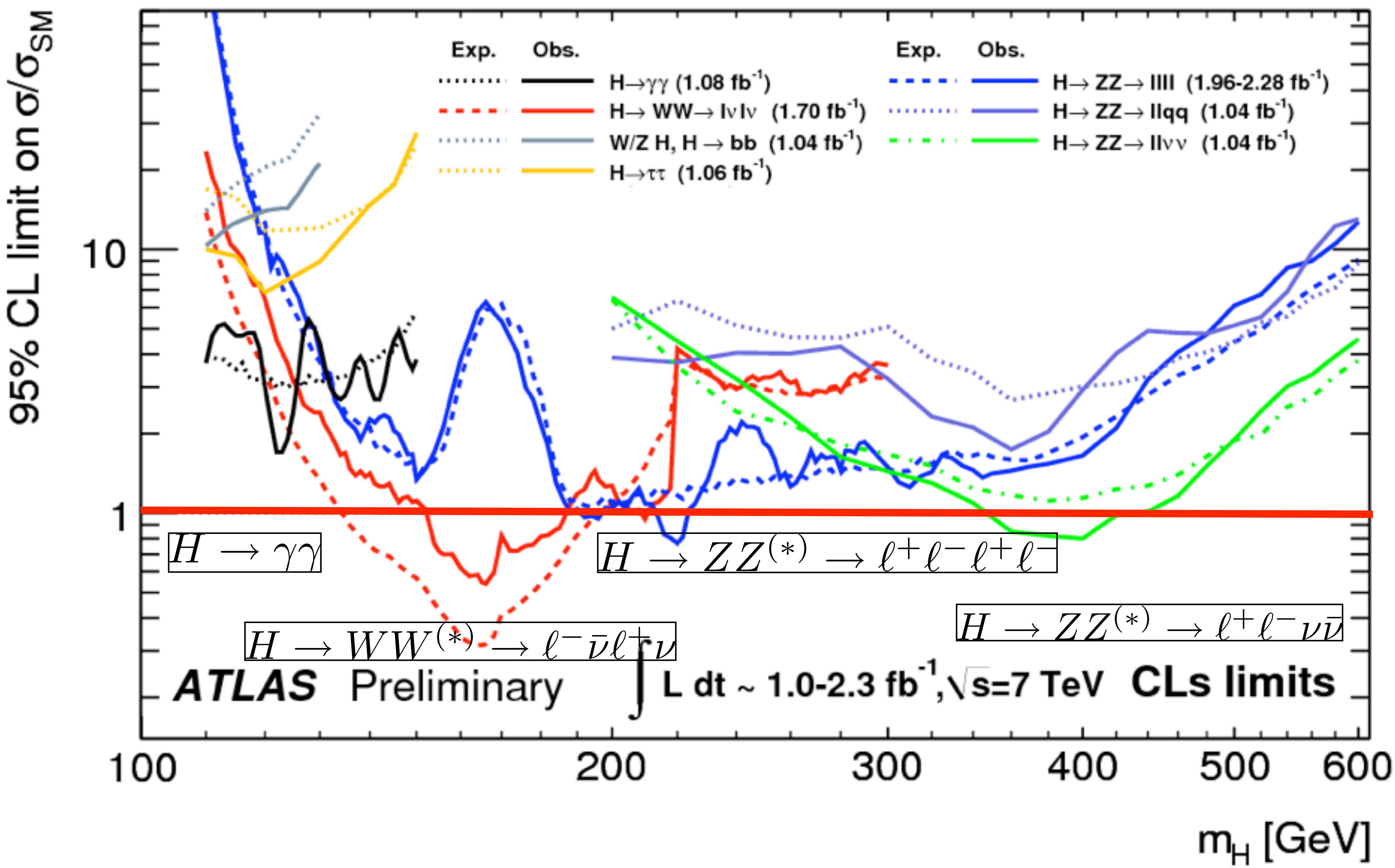
H→ZZ→ℓ ℓ ν ν

$$m_T^2 \equiv \left[\sqrt{m_Z^2+|\boldsymbol{p_T^{\mu}}|}+\sqrt{m_Z^2+|\boldsymbol{p_T^{miss}}|}\right]^2-\left[\boldsymbol{p_T^{\ell\ell}}+\boldsymbol{p_T^{miss}}\right]^2$$

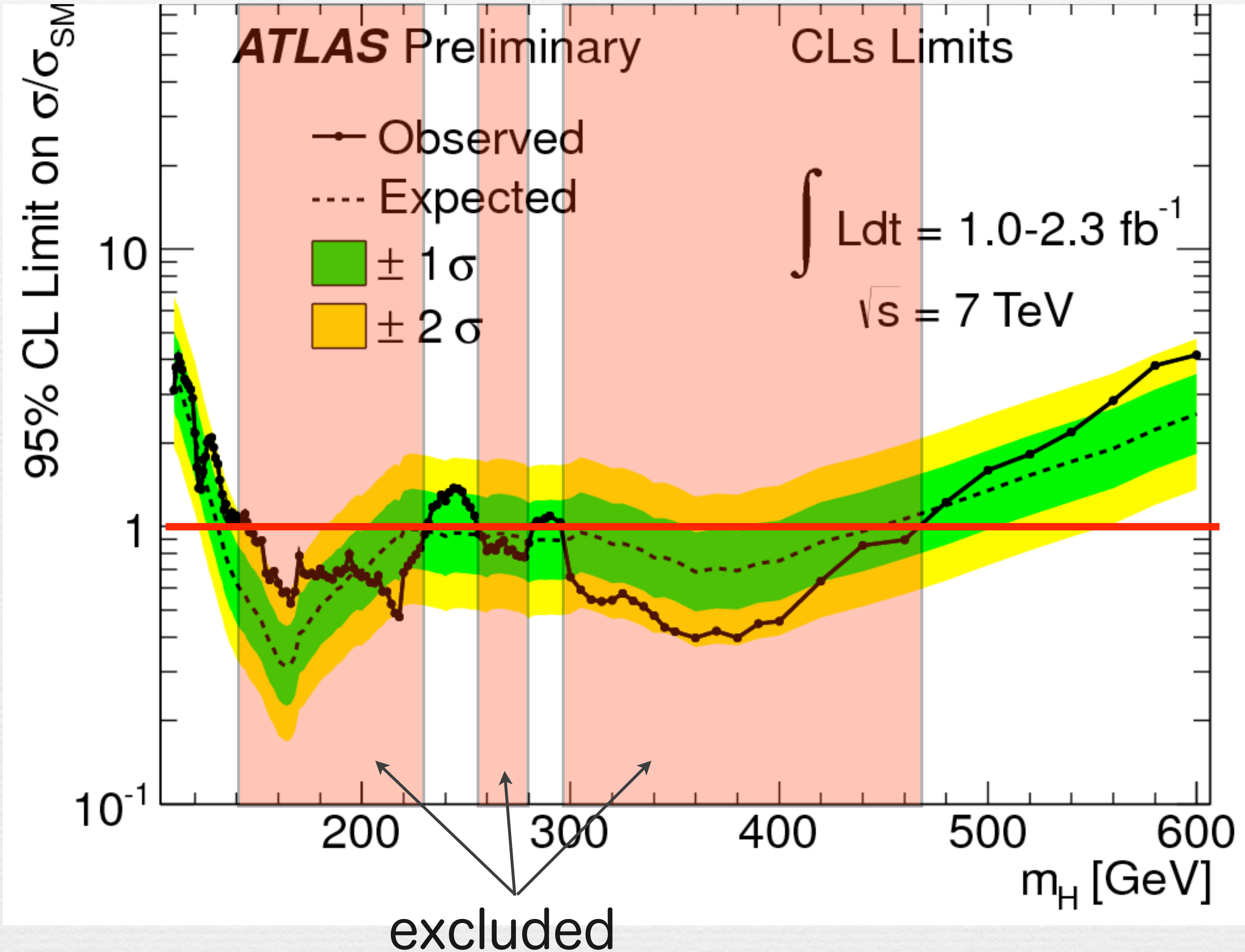


Higgs searches

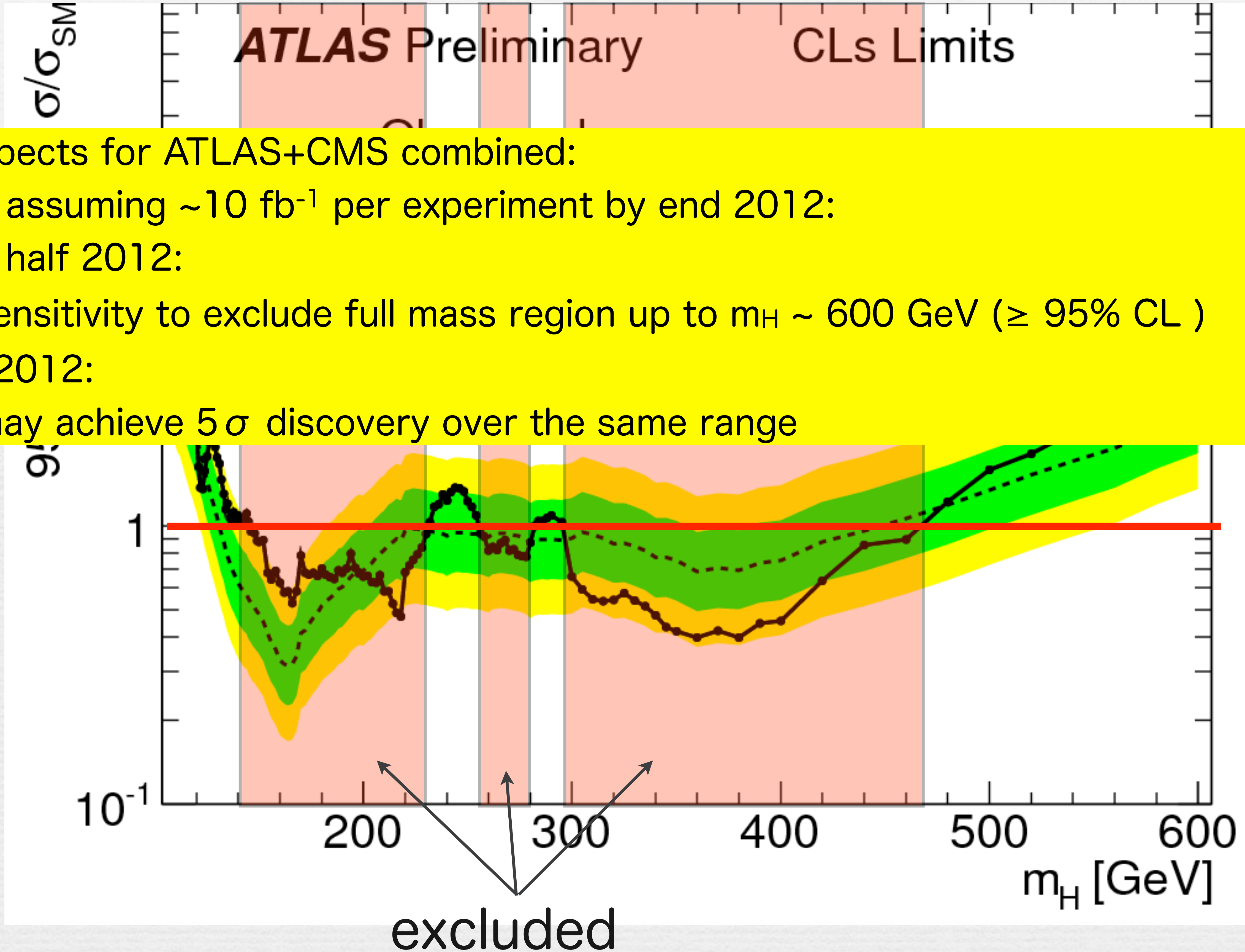
(95% CL limit on σ)/σ_{SM}



Combination



Combination



Prospects for ATLAS+CMS combined:

With assuming ~10 fb^{-1} per experiment by end 2012:

First half 2012:

sensitivity to exclude full mass region up to m_H ~ 600 GeV (≥ 95% CL)

End 2012:

may achieve 5σ discovery over the same range

Summary

LHC-ATLAS is running very well

Precise measurement of the top quark has begun

- The uncertainties of inclusive cross-section measurement is better than level of 10%
- New physics search using top quark has begun

No excess of the Higgs boson has been seen yet

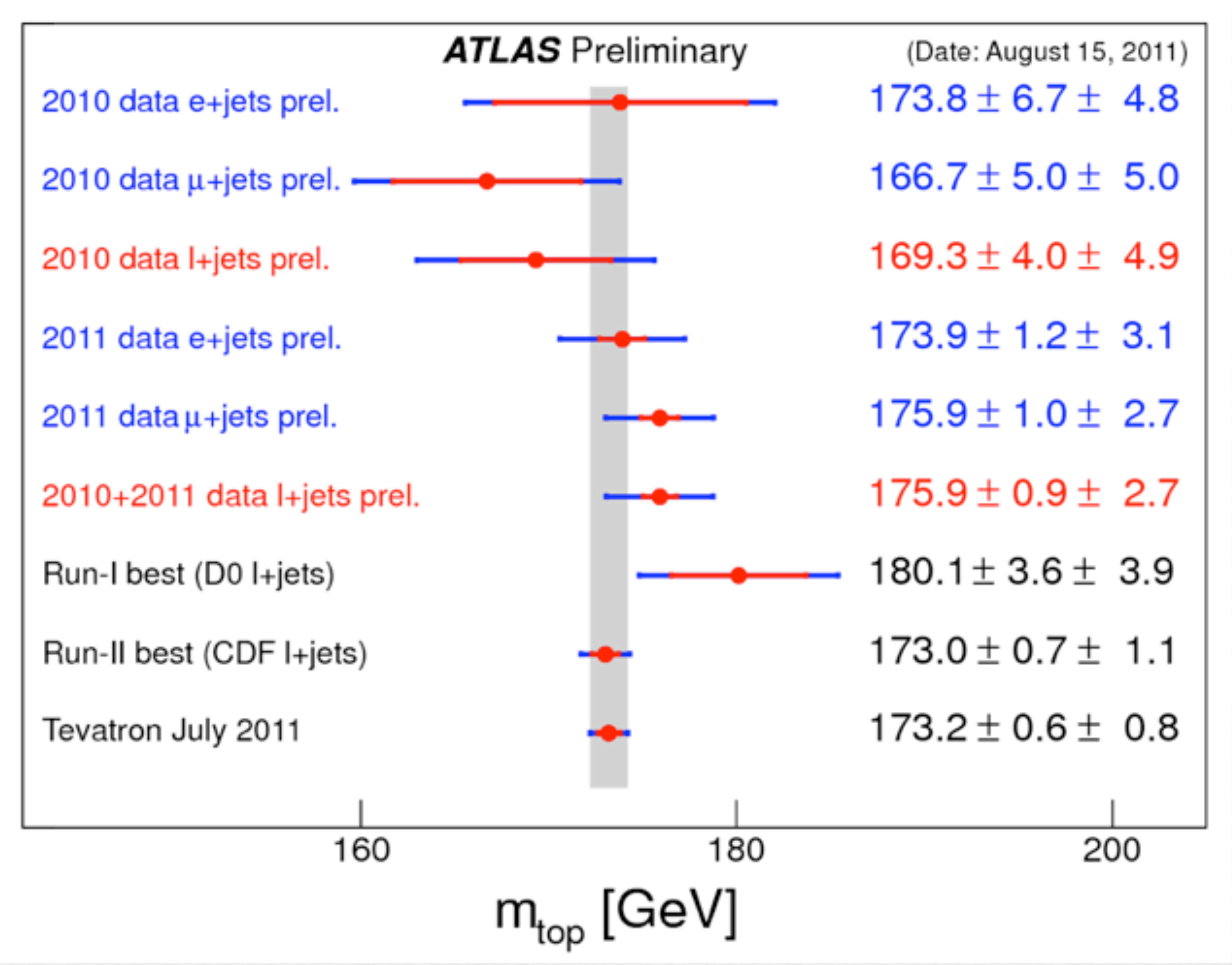
- Exclude 146-466 GeV, except 232-256, 282-296 GeV
- End of 2012 (for ATLAS+CMS combined), we may achieve 5σ discovery over m_H<600 GeV

2012 will be year of the Higgs !

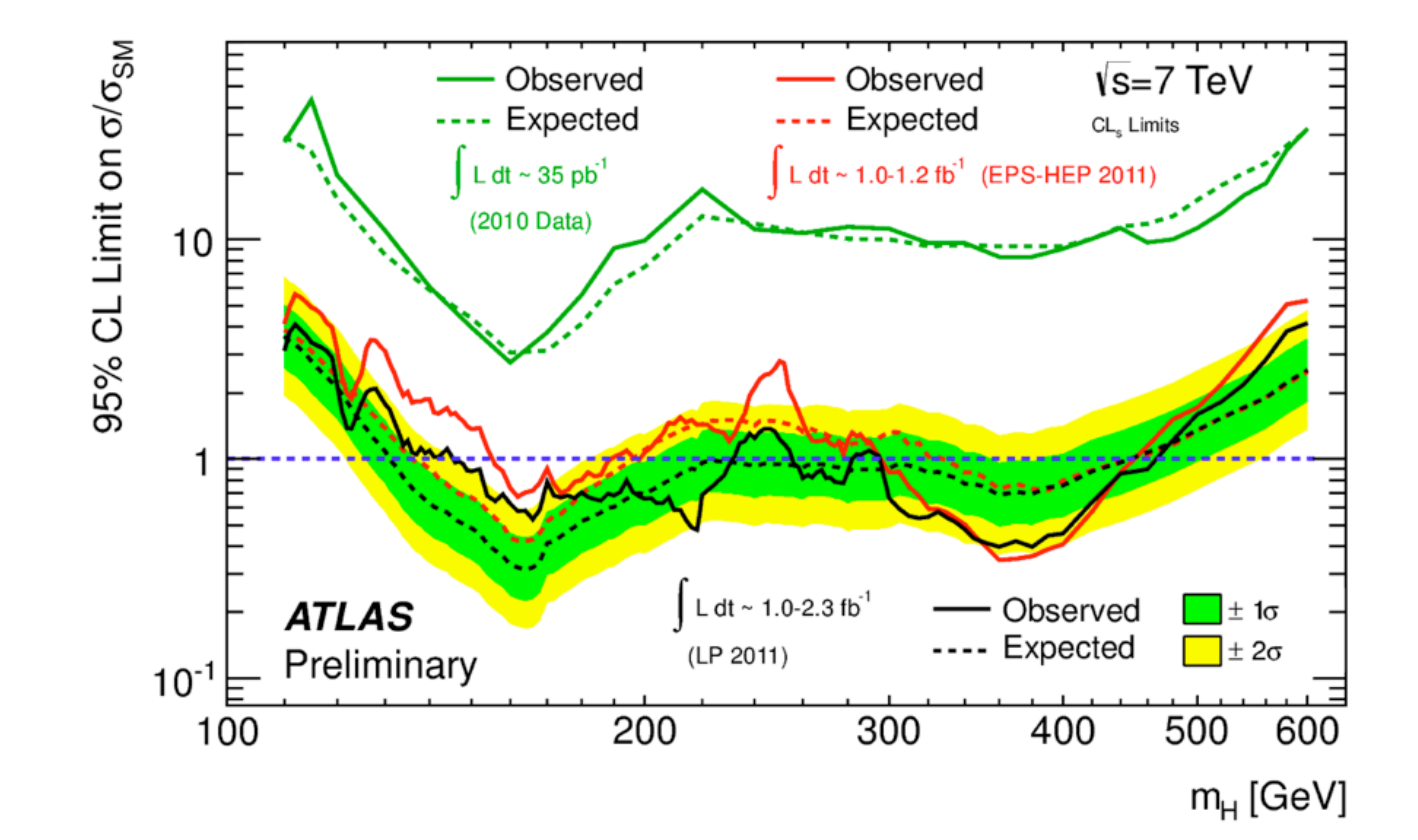
→ top quark physics becomes more important

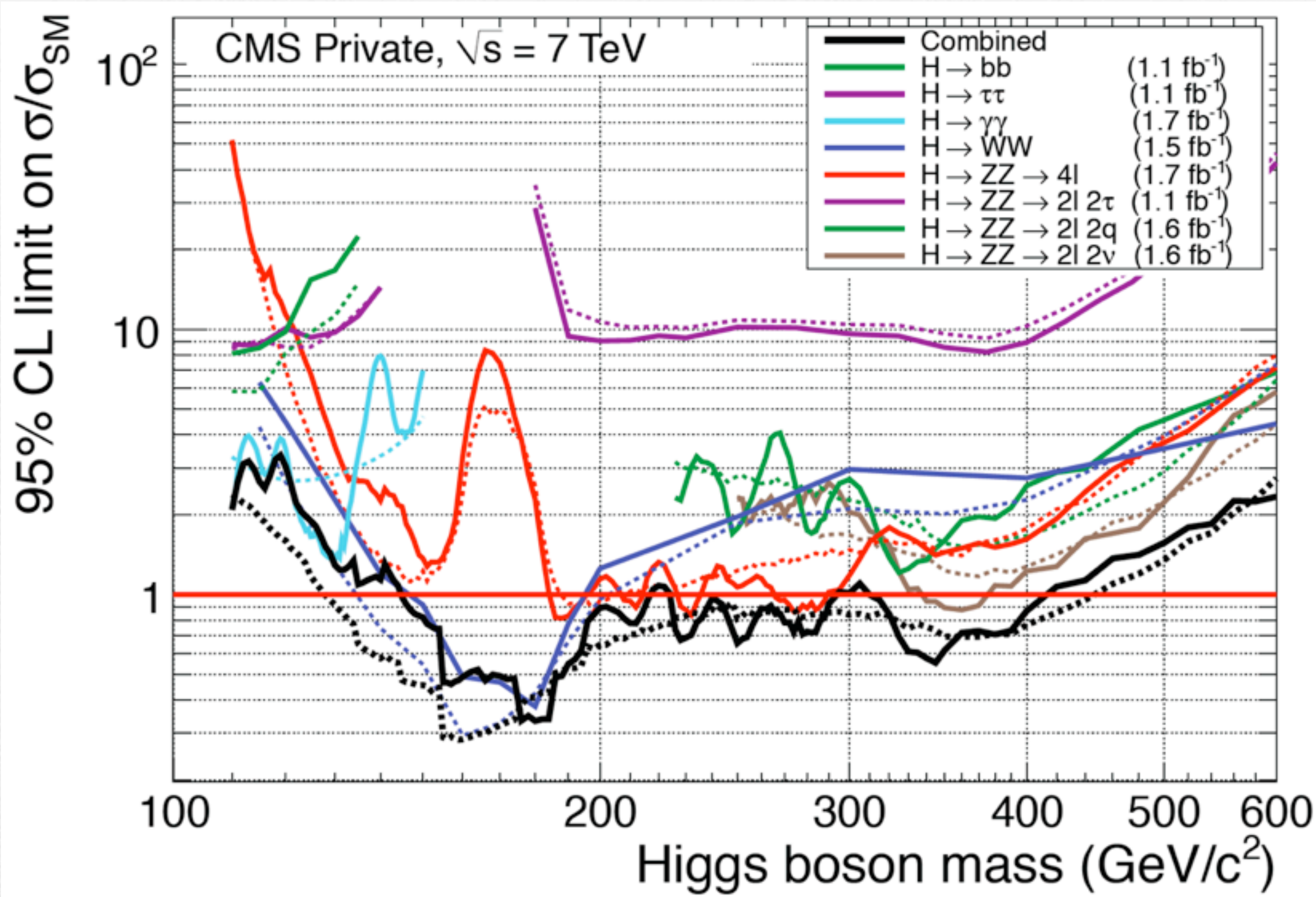
Backup

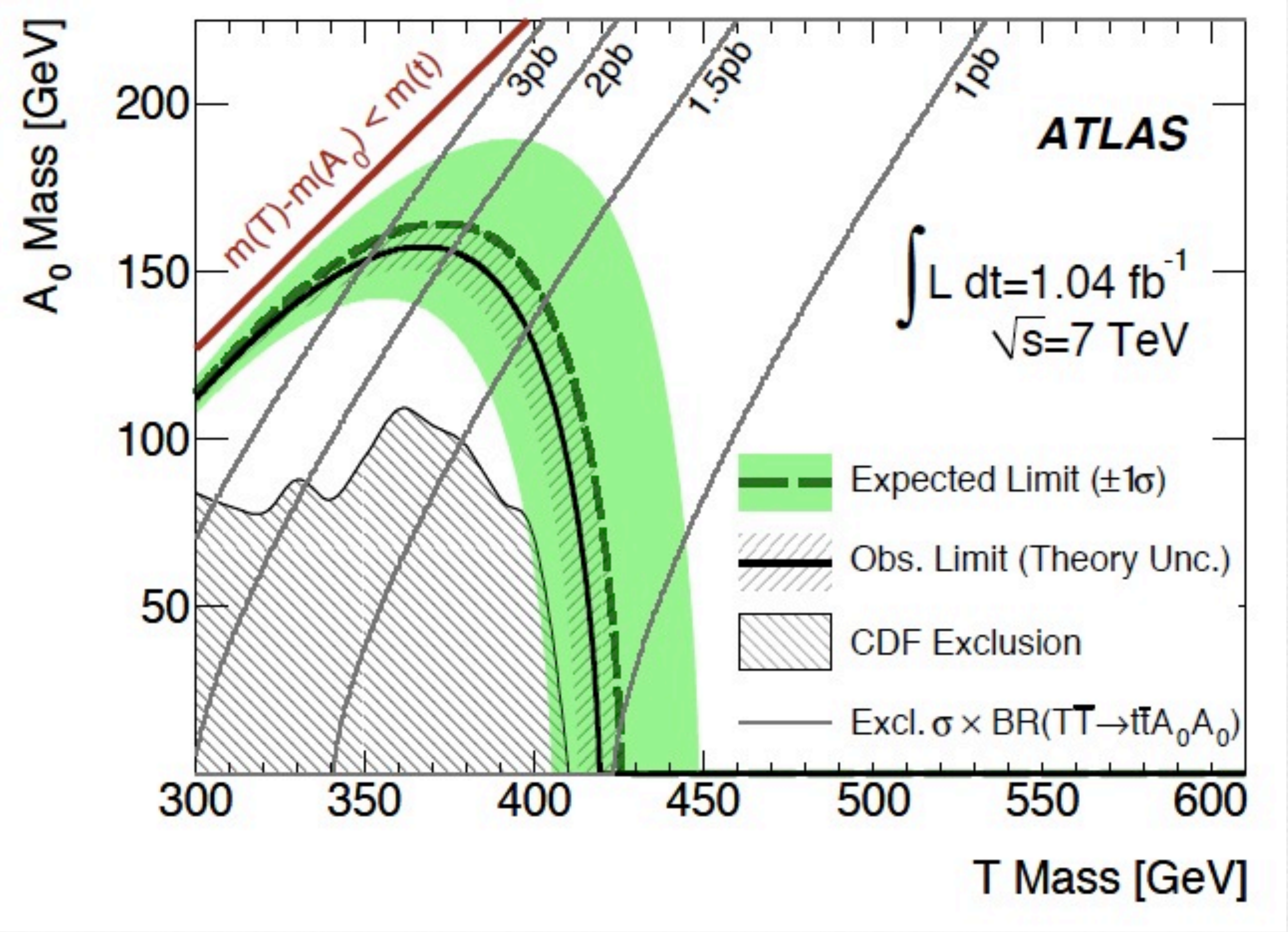
Top quark mass



Combination

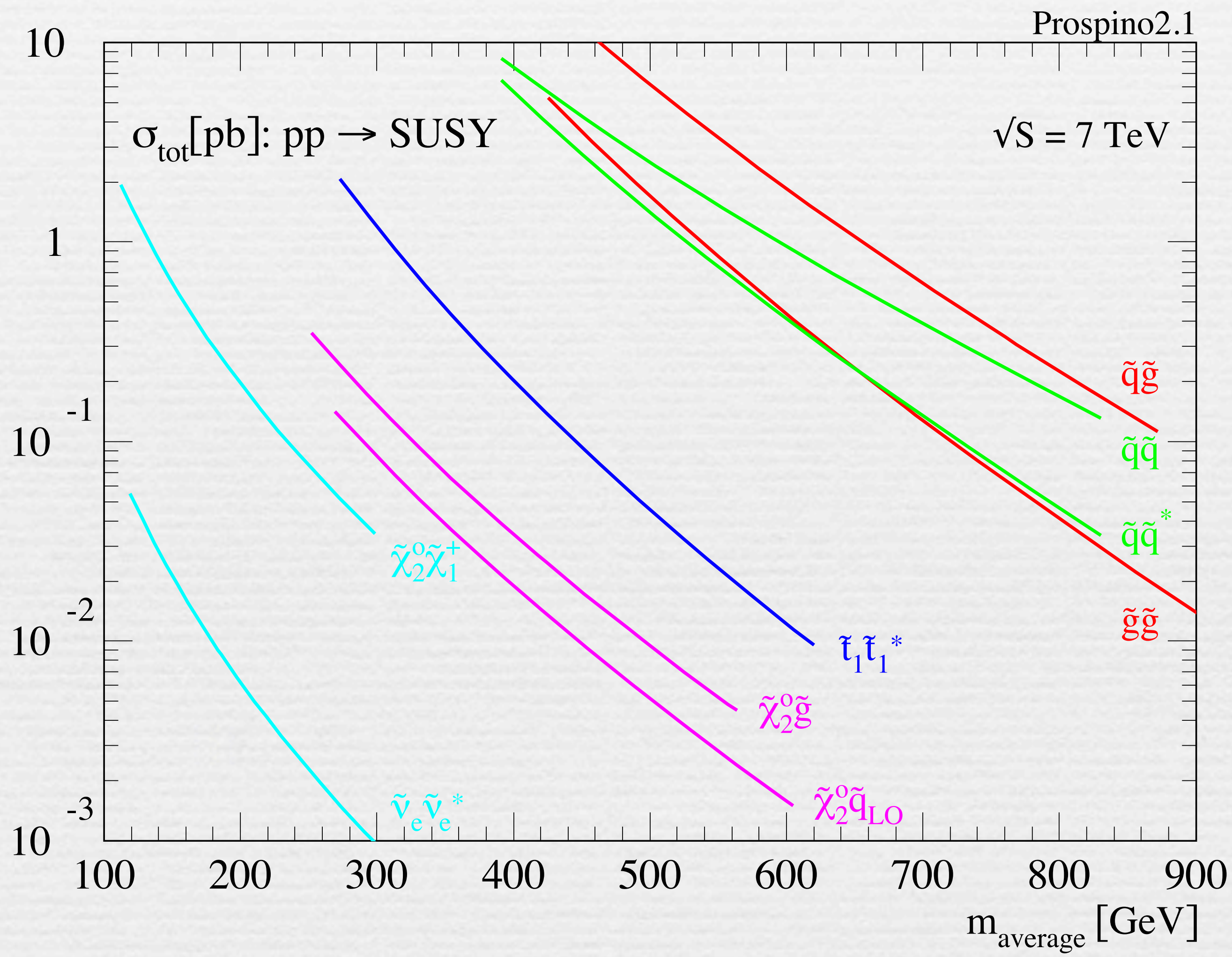


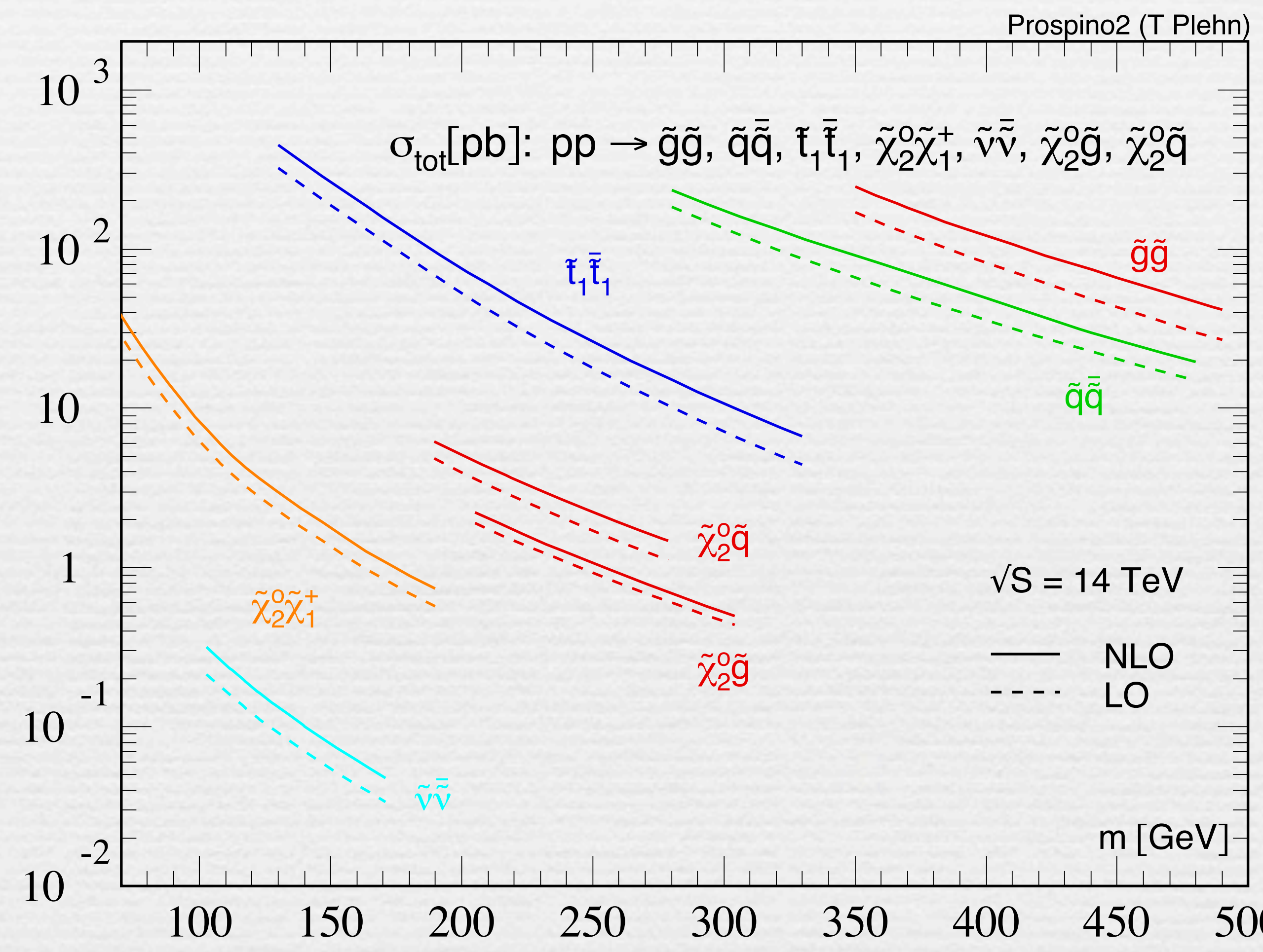

CMS Private, $\sqrt{s}$ = 7 TeV
95% CL limit on σ/σ_{SM}
Higgs boson mass (GeV/c^2)
Combined
$H \to bb$ (1.1 fb^{-1})
$H \to \tau\tau$ (1.1 fb^{-1})
$H \to \gamma\gamma$ (1.7 fb^{-1})
$H \to WW$ (1.5 fb^{-1})
$H \to ZZ \to 4l$ (1.7 fb^{-1})
$H \to ZZ \to 2l\,2\tau$ (1.1 fb^{-1})
$H \to ZZ \to 2l\,2q$ (1.6 fb^{-1})
$H \to ZZ \to 2l\,2\nu$ (1.6 fb^{-1})
10^2
10
1
100
200
300
400
500
600



ATLAS
m(T)-m(A$_0$) < m(t)
3pb
2pb
1.5pb
1pb
$\int L\,dt = 1.04\ fb^{-1}$
$\sqrt{s} = 7$ TeV
Expected Limit (±1σ)
Obs. Limit (Theory Unc.)
CDF Exclusion
Excl. $\sigma \times BR(T\bar{T} \rightarrow t\bar{t}A_0A_0)$
A_0 Mass [GeV]
T Mass [GeV]
200
150
100
50
300
350
400
450
500
550
600

SUSY production



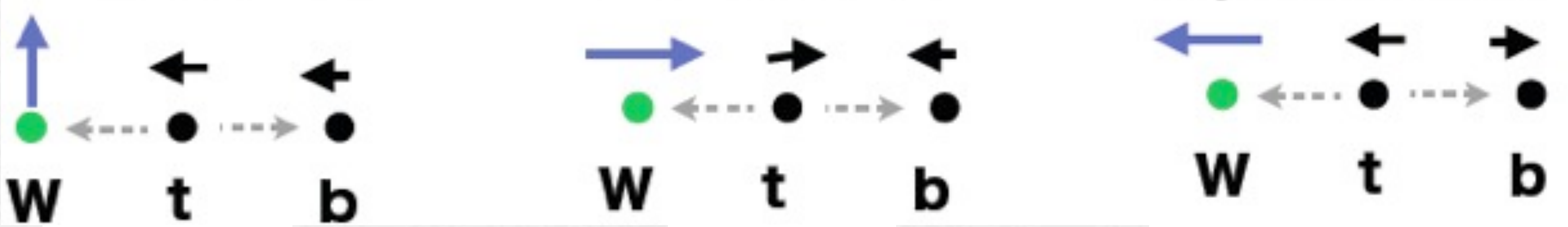


W boson helicity

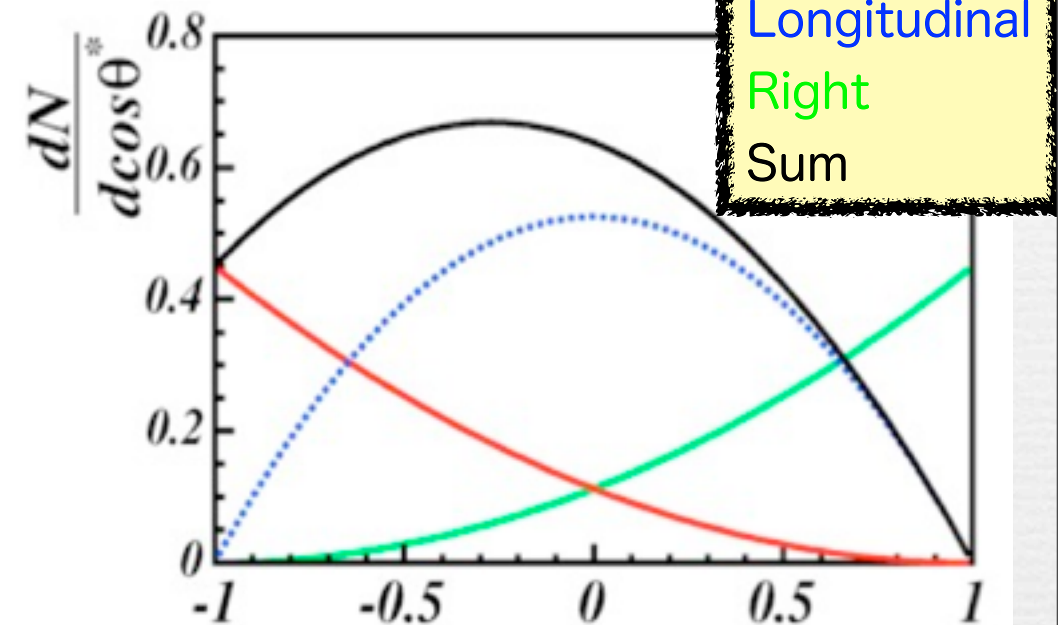
L=700pb^{-1}

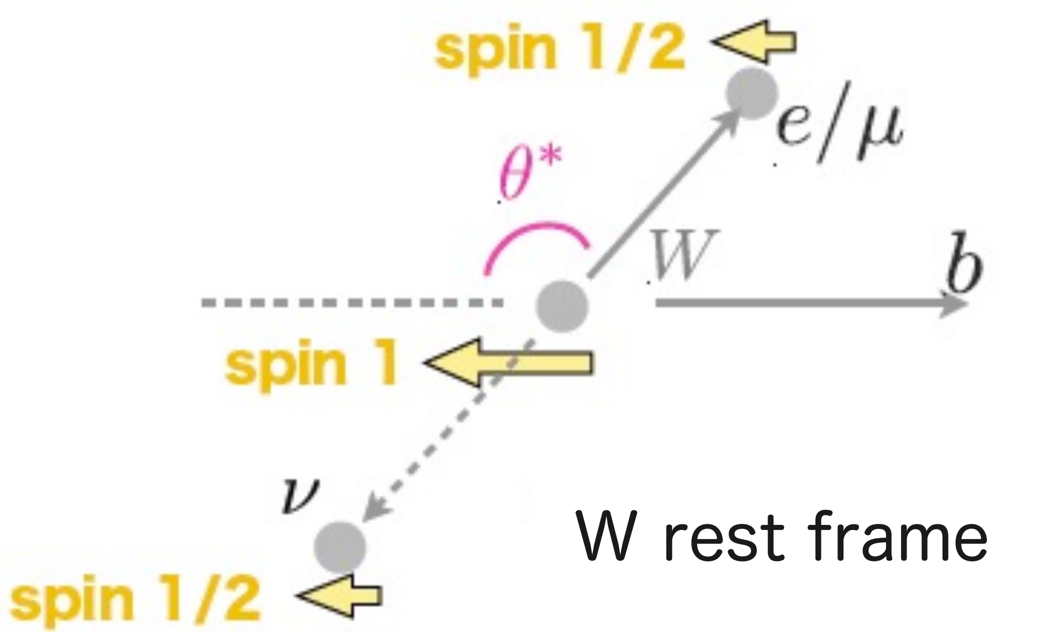
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1+\cos\theta^*)^2\, F_R + \frac{3}{8}(1-\cos\theta^*)^2\, F_L + \frac{3}{4}\left(1-\cos^2\theta^*\right) F_0$$

In V-A interaction of the SM



F_0 : 0.7 F_L: 0.3 F_R : Forbidden





$$F_0 = 0.68 \pm 0.12$$
$$F_L = 0.32 \pm 0.09$$
$$F_R = 0.00 \pm 0.06$$