Overview of Physics with CMS

Tariq Aziz

DHEP Annual Meeting
April 7-8, 2016

TIFR, Mumbai

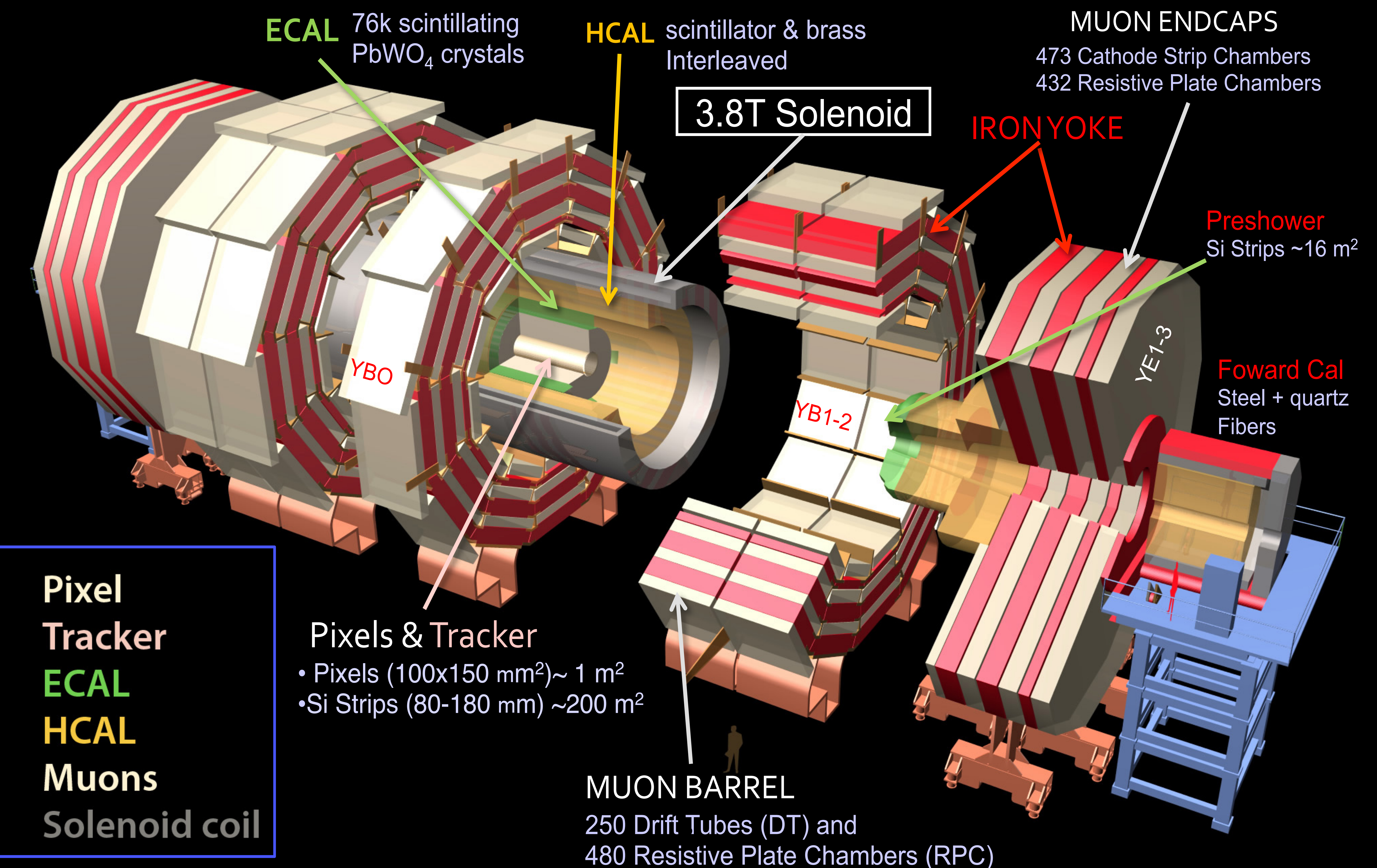
Introduction

Physics at 7-8 TeV CM Energy of LHC

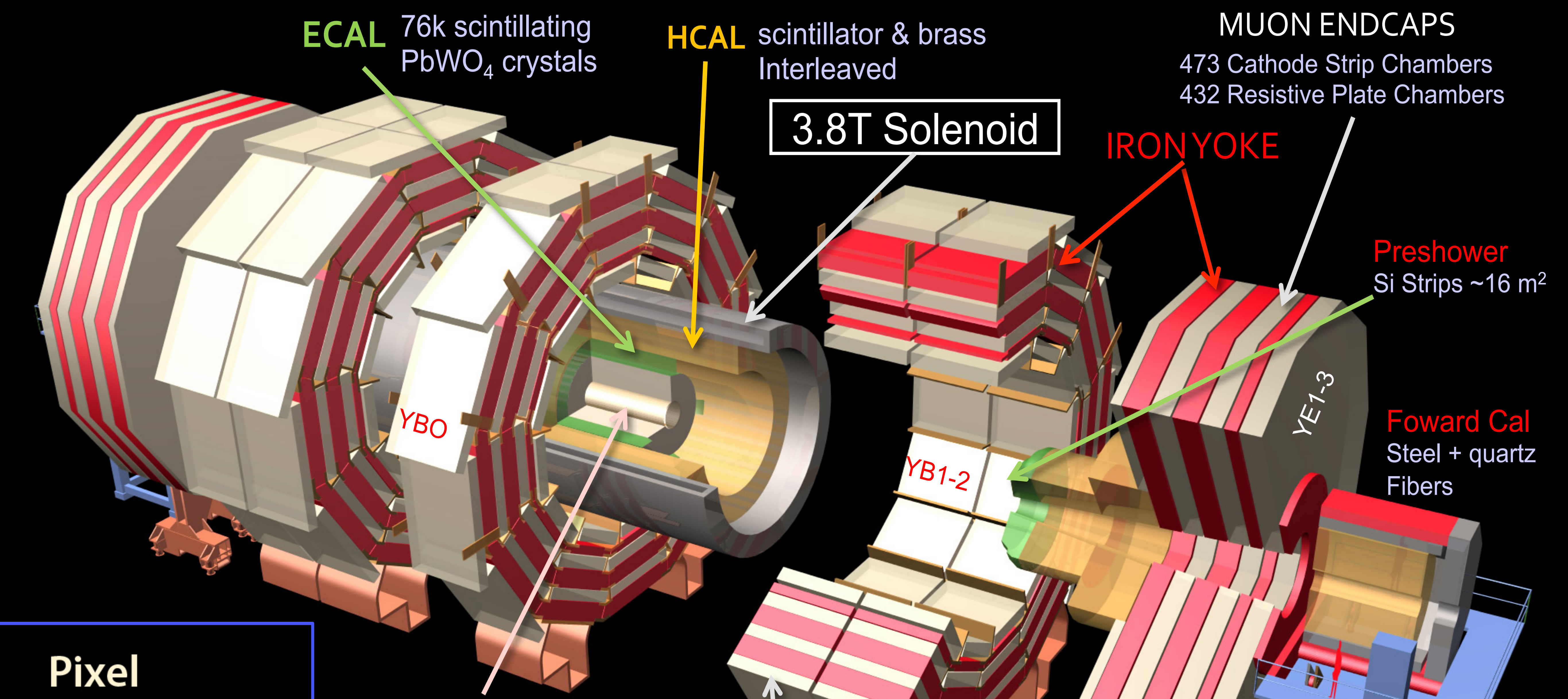
Physics at 13 TeV   CM Energy of LHC

SM & Beyond

Compact Muon Solenoid (CMS) experiment



Compact Muon Solenoid (CMS) experiment



Some of the hard-to-believe facts:

Total weight 14 000 ton, diameter 15 m and length 28.7m

In total there are about ~100 000 000 electronic channels

Each channel checked 40 000 000 times per second (collision rate is 40 MHz)

An online trigger selects events and reduces the rate from 40MHz to 100 Hz

Amount of data of just one collision >1 500 000 Bytes

TIFR joined the CMS Collaboration in 1994

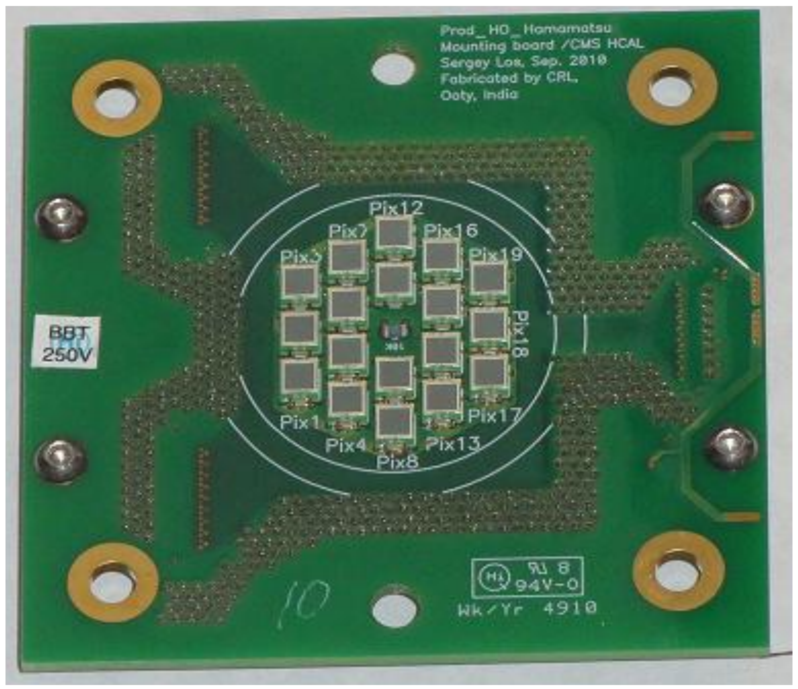
Participation in hardware, software, data taking and physics

Major contribution in building Outer Hadron Calorimeter- HO

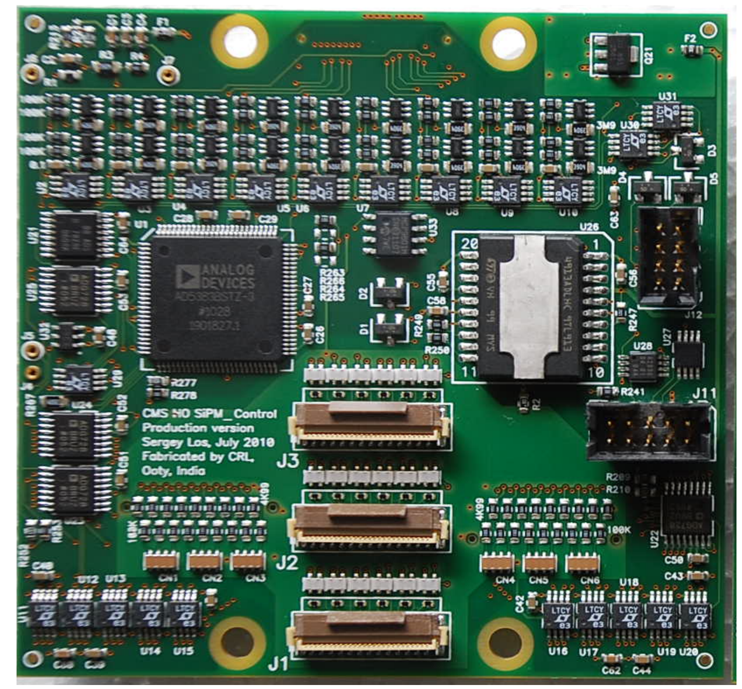
TIFR+PU

Recent HO Upgrade — Readout

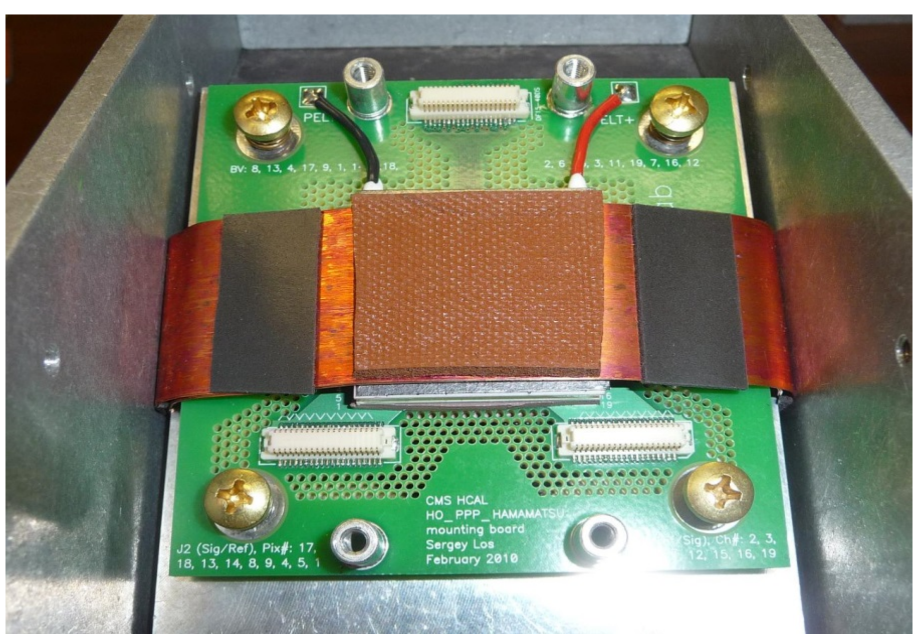
SiPM based HO Readout upgrade -- Module Assembly by TIFR

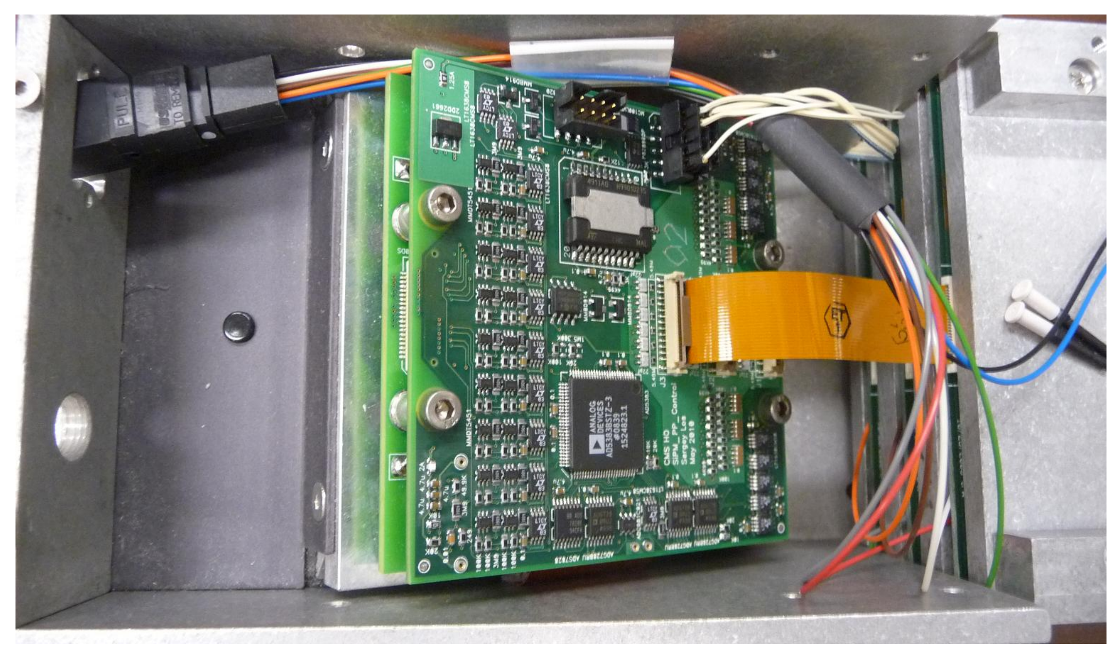


SiPM Mounting Board



SiPM Control Board



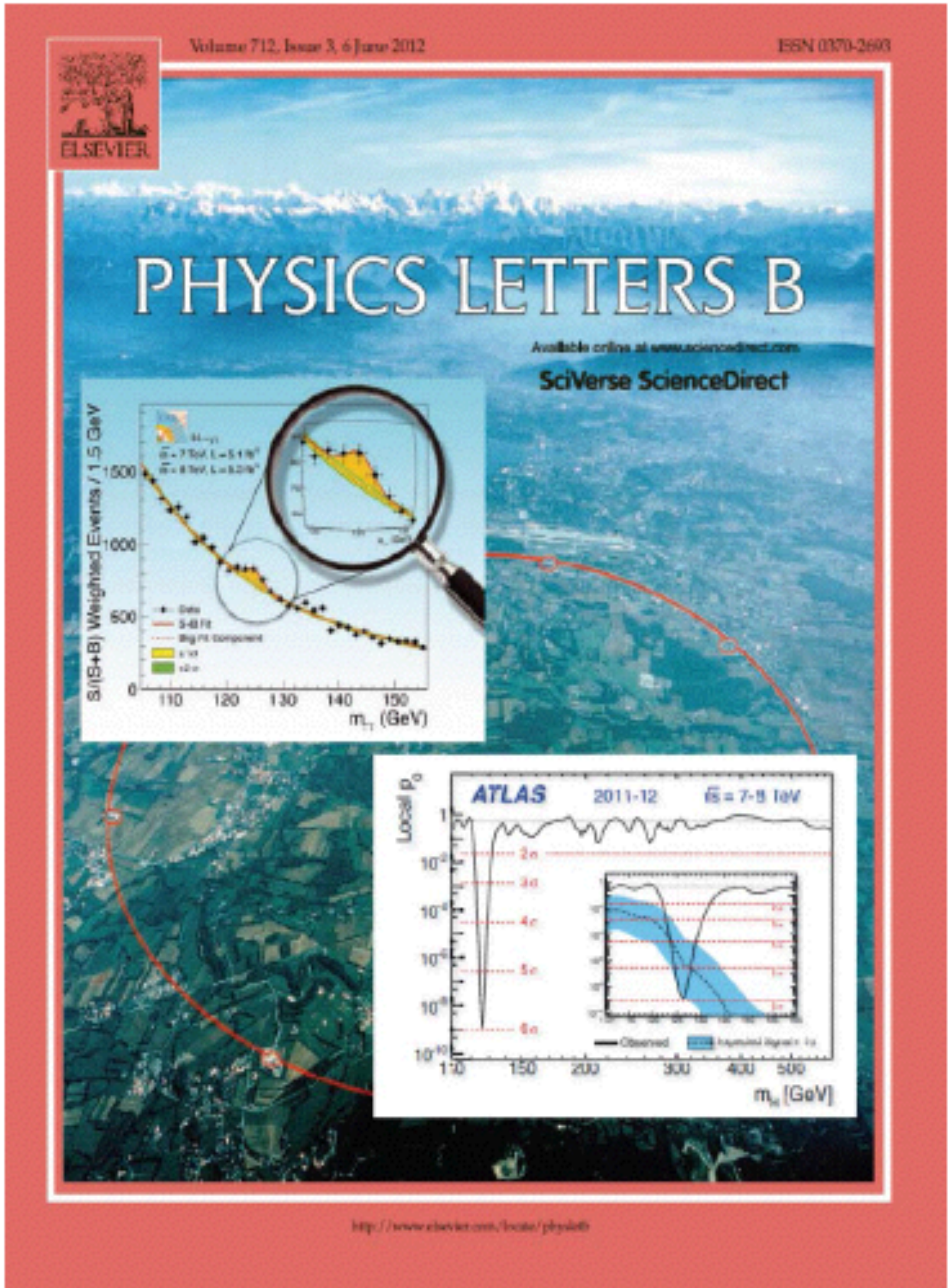


160 SiPM control boards and mounting boards- commissioned at CERN

pp collision data collected at 7 TeV, 8 TeV and 13 TeV (most recent)

Some Results

July 2012 Revolution



Peer-reviewed papers:

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC.

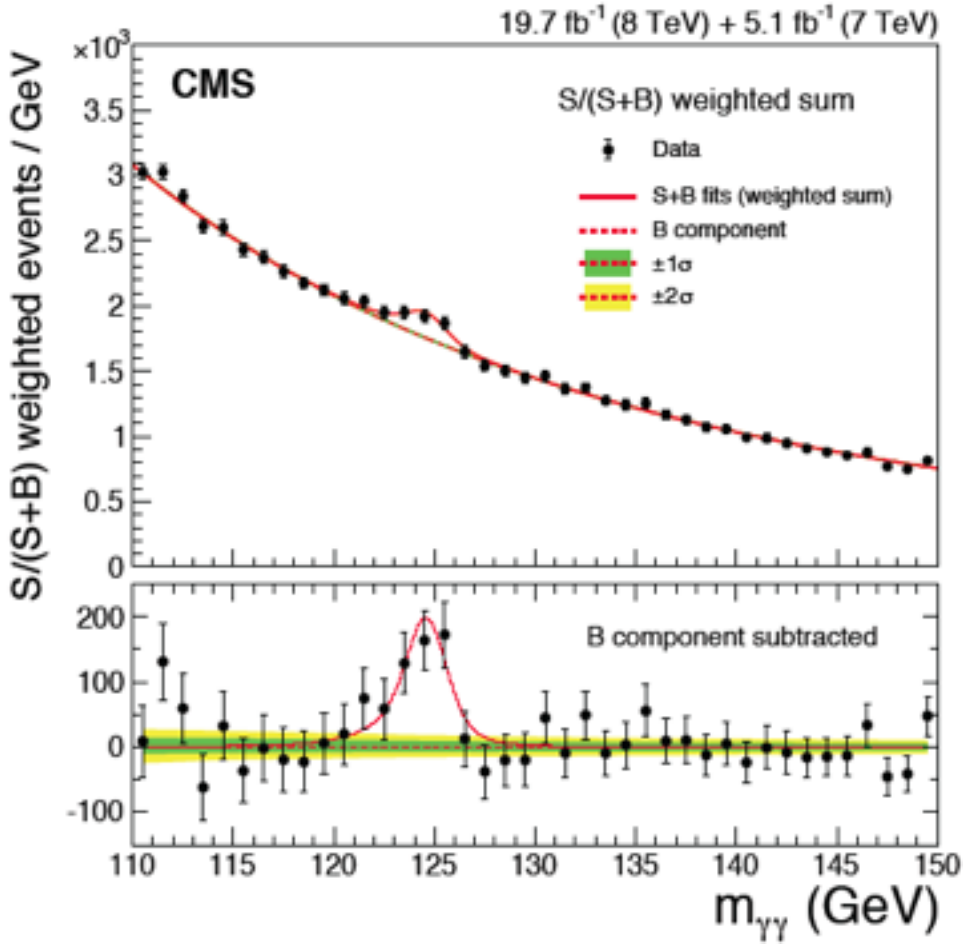
"…compatible with the production and decay of the Standard Model Higgs boson."

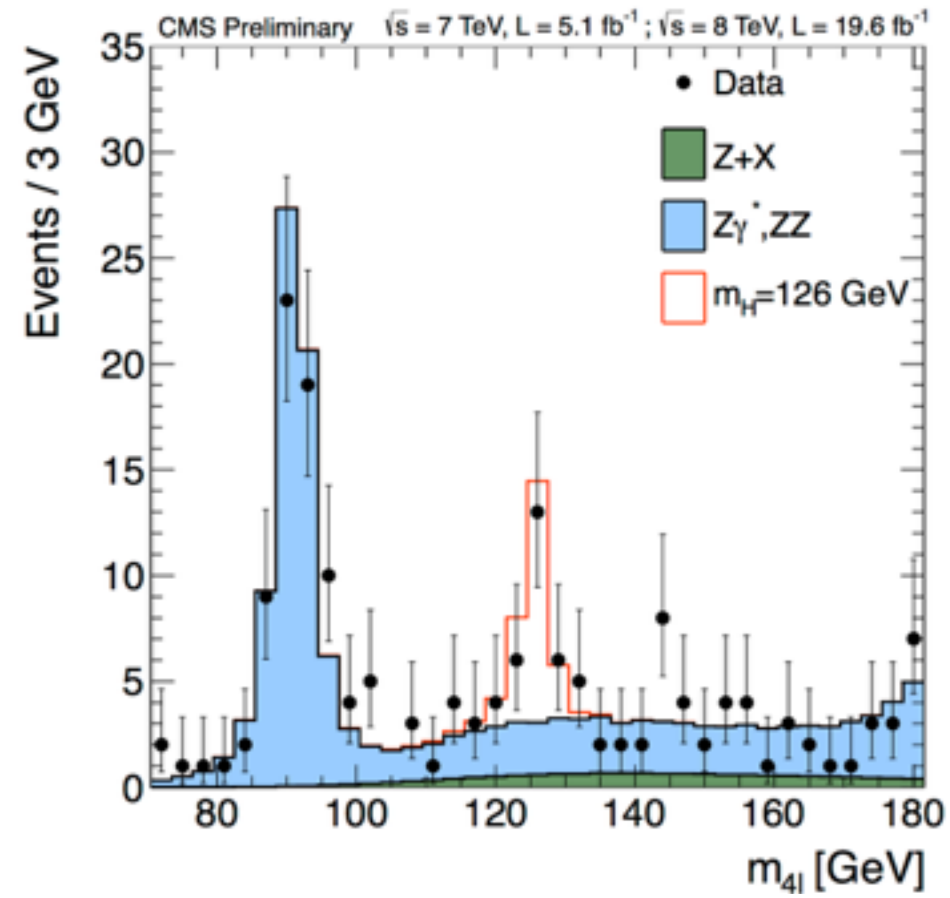
Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC

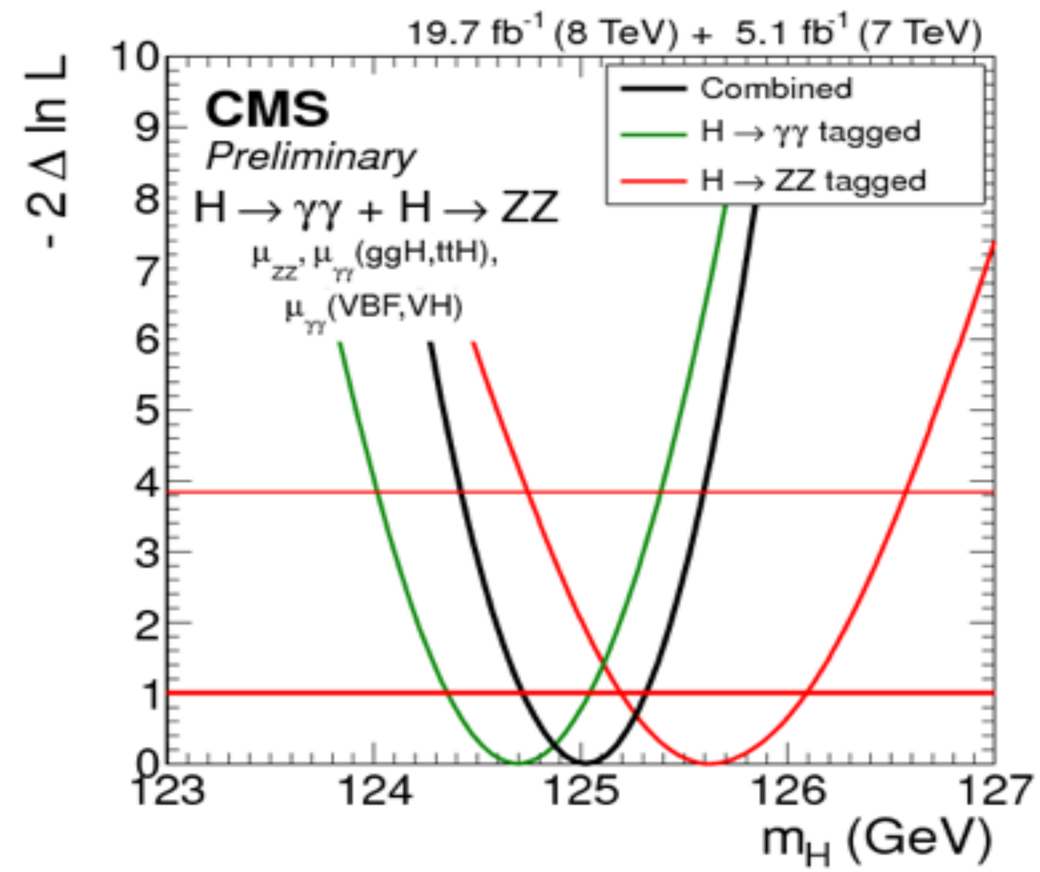
"..consistent, within uncertainties, with expectations for the standard model Higgs boson."

Higgs →$\gamma\gamma$

Higgs→ZZ→ 4-leptons





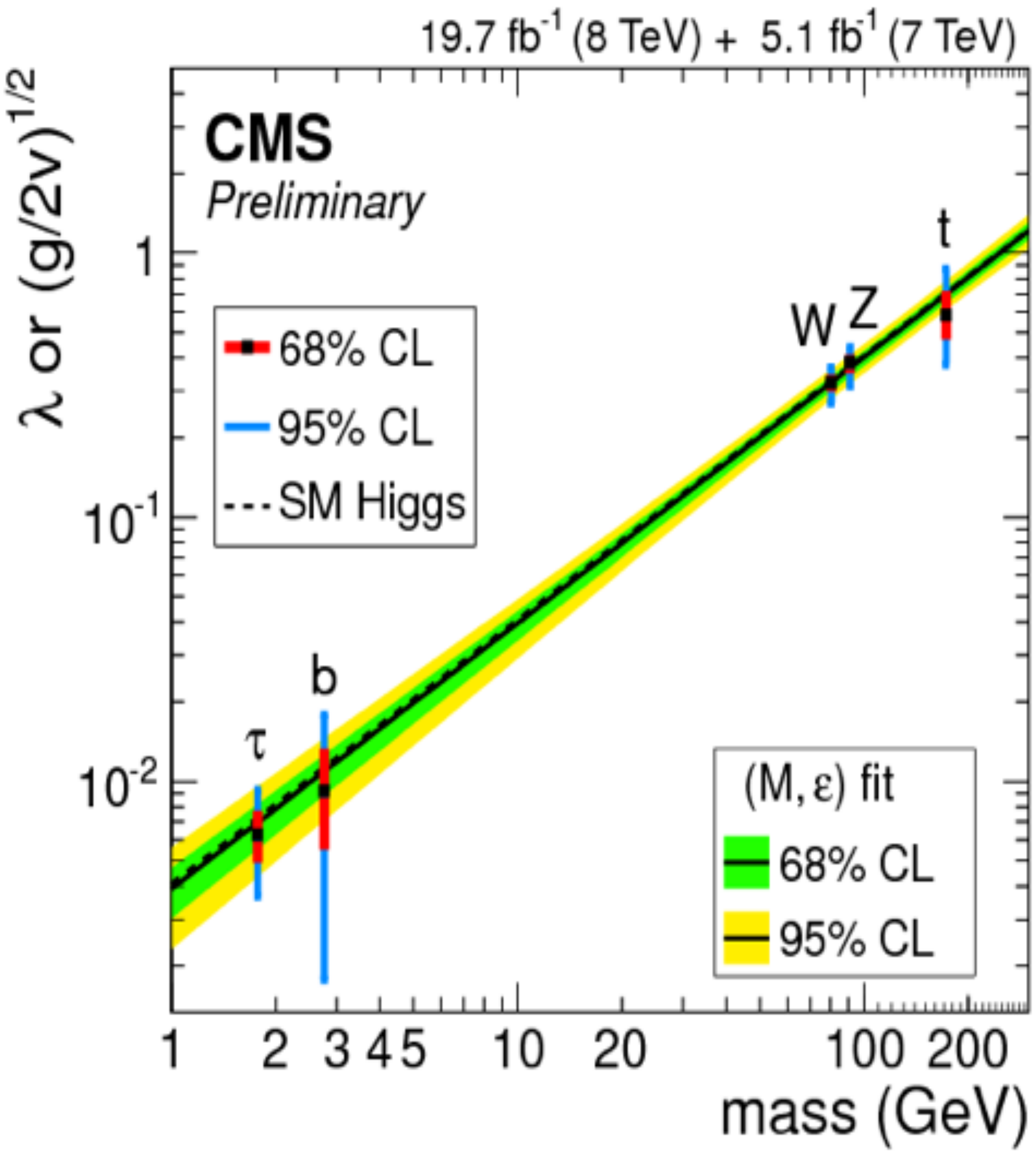


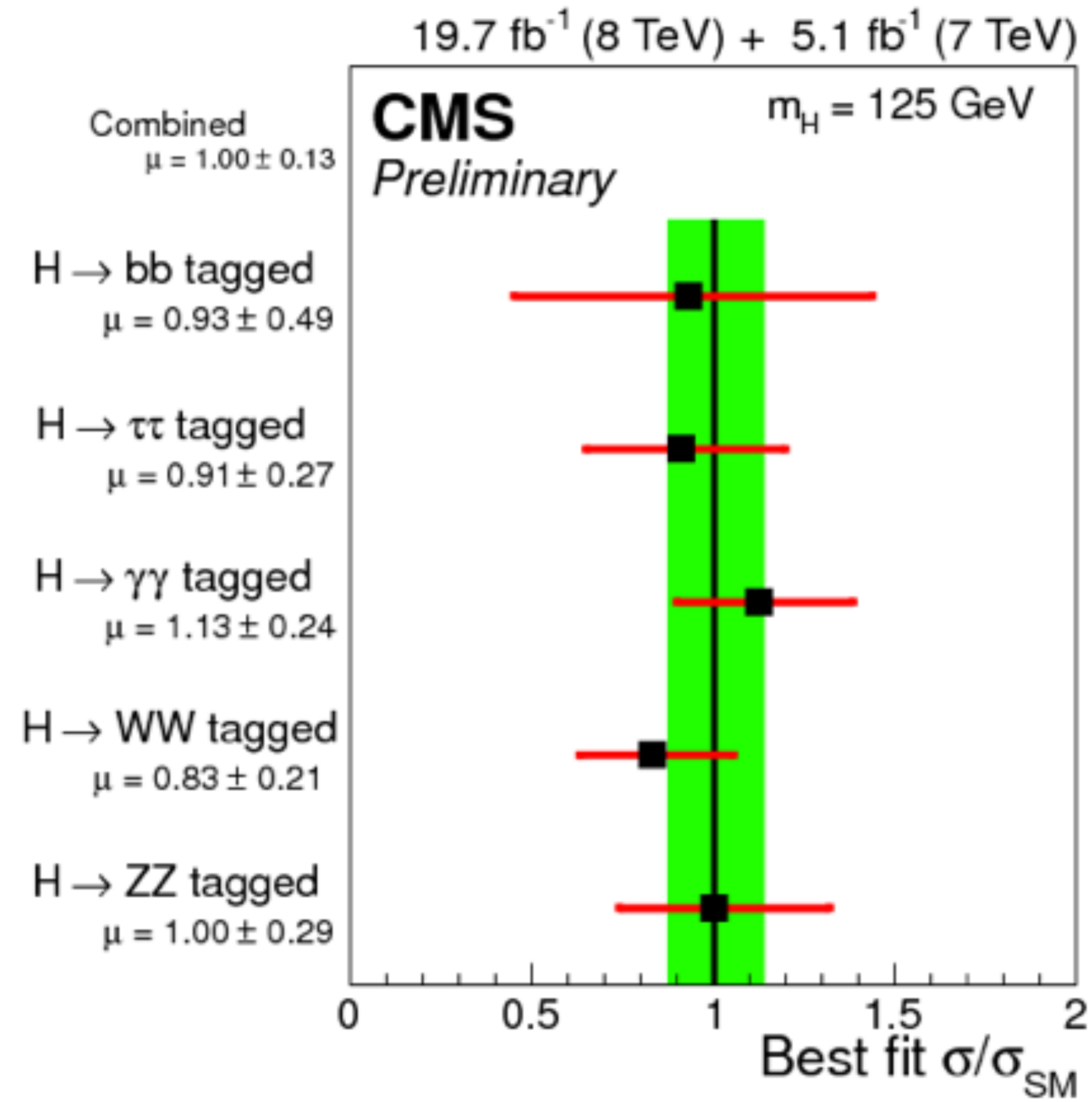
$$m_H = 125.03^{+0.26}_{-0.27}\ (\text{stat})\ ^{+0.13}_{-0.15}\ (\text{syst})\ \text{GeV}$$

Higgs mass now a precision game

Higgs Couplings

Signal Strength with respect to SM





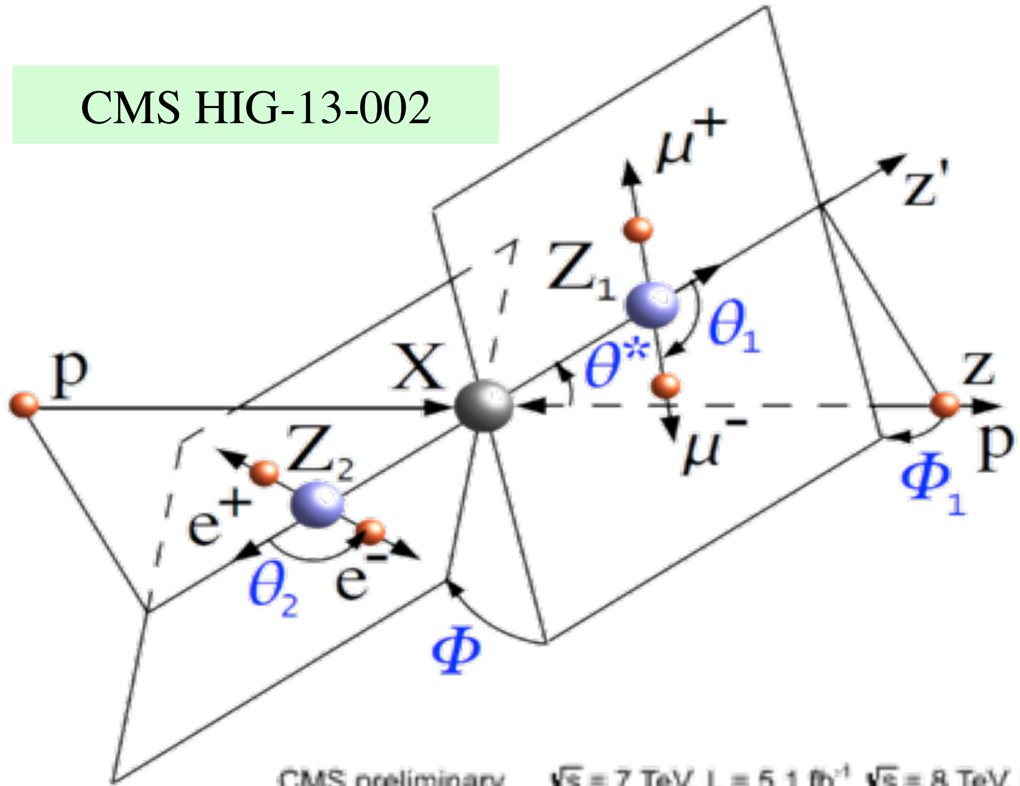
All consistent with SM Higgs

What about Spin and Parity?

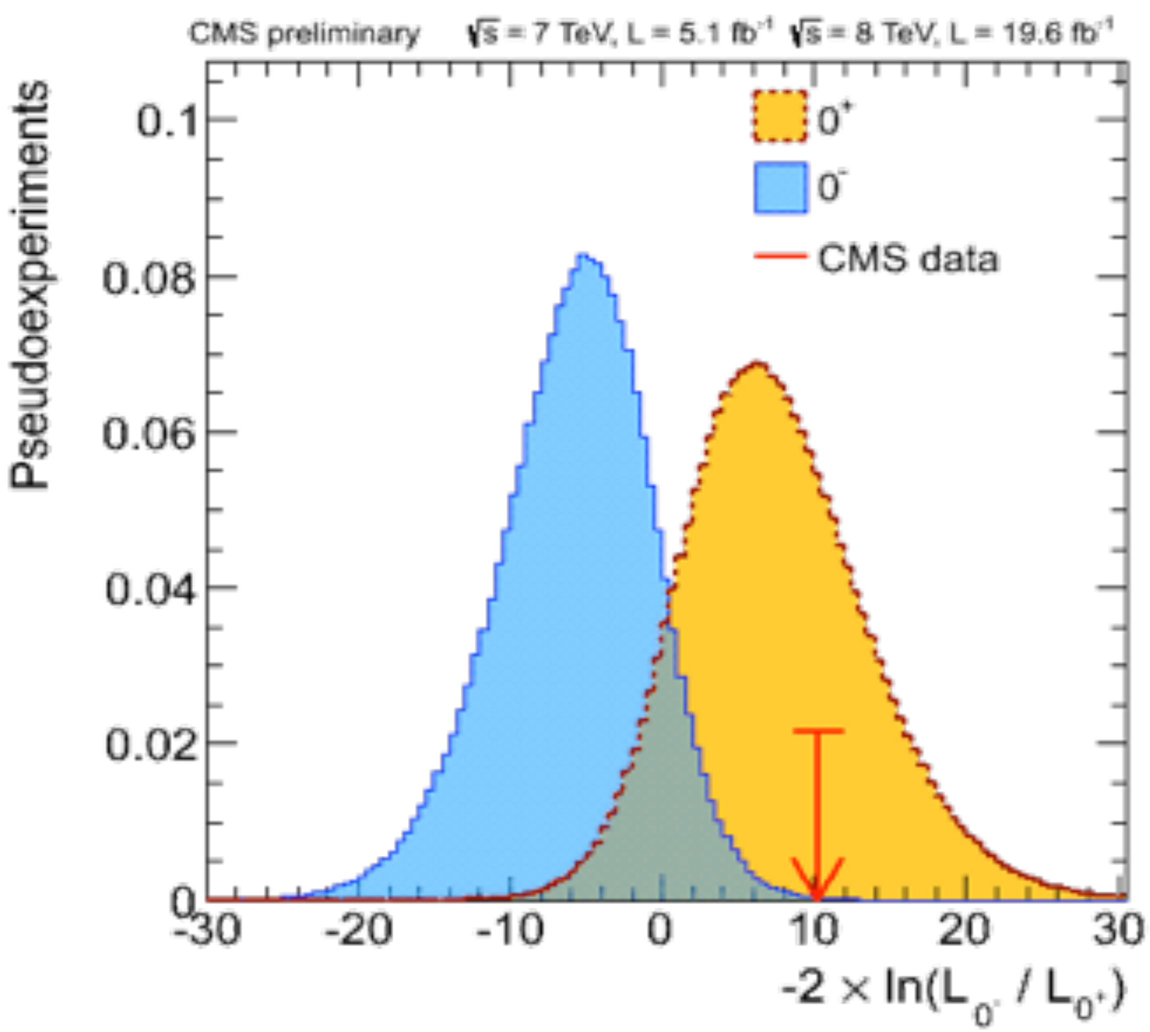
Is it Scalar ?   and the right one?

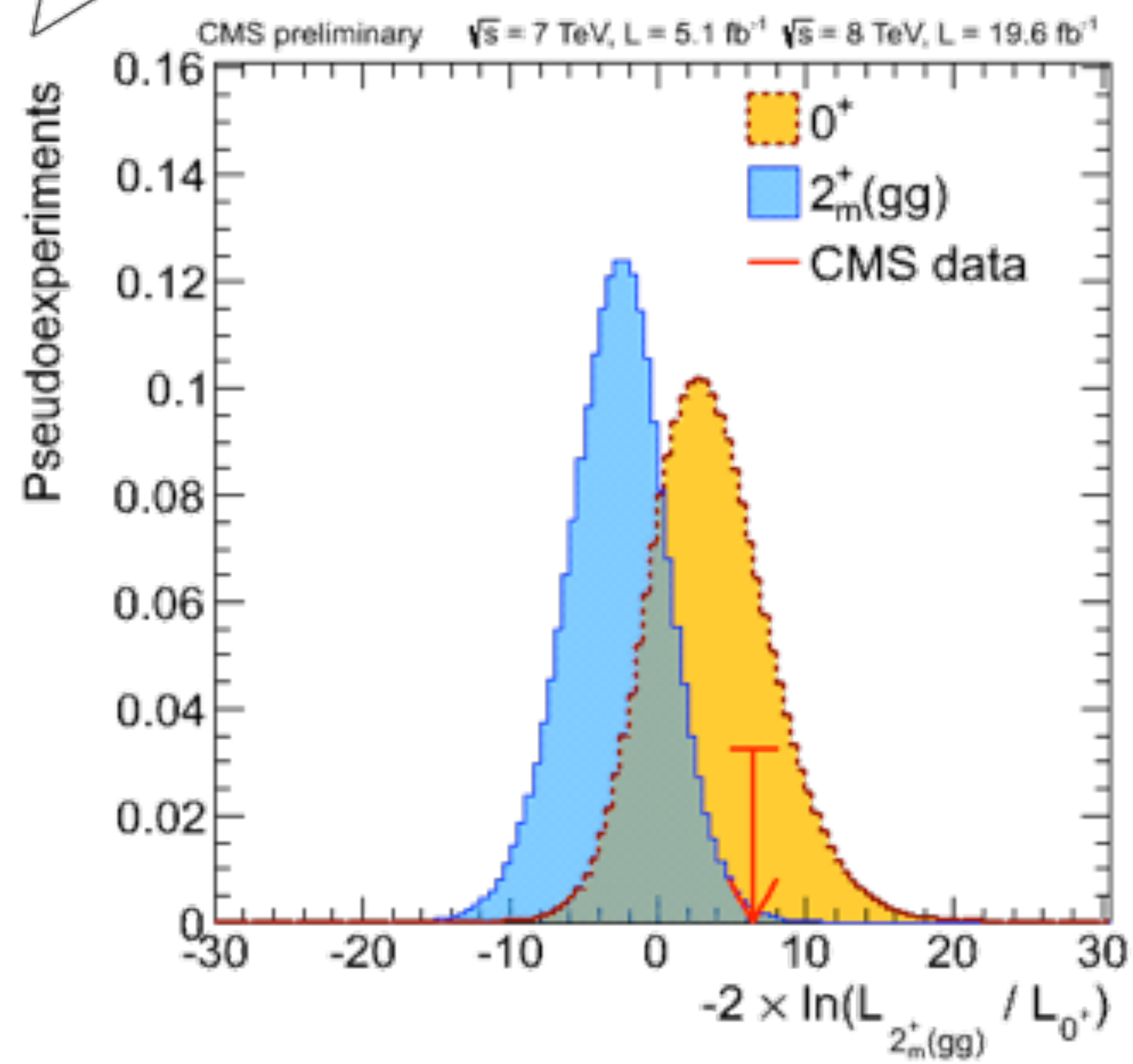
Higgs → ZZ*→4-leptons

CMS HIG-13-002



Use 5 angles and two masses



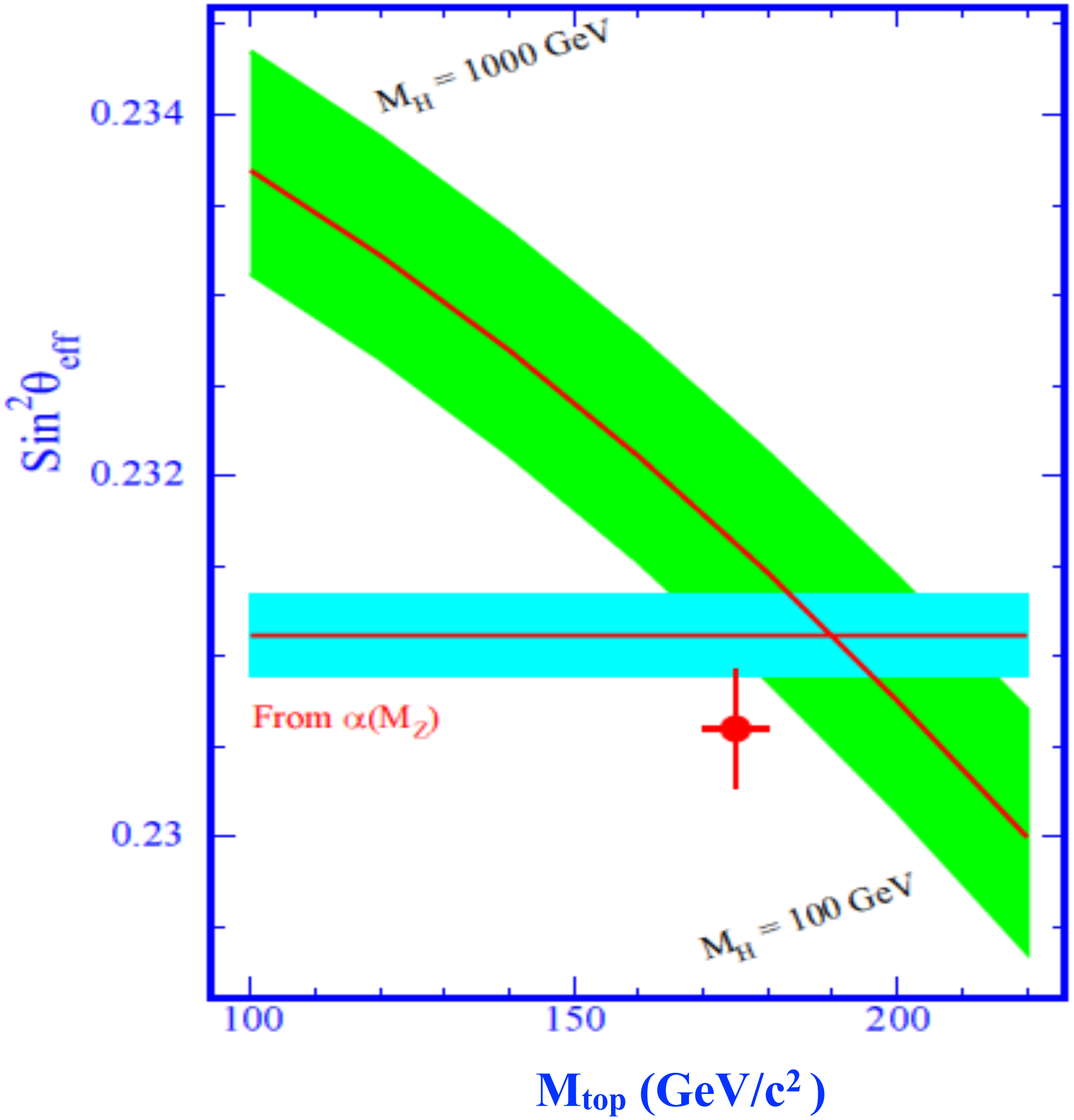


0^+ favoured over others

Independently CMS and ATLAS experiments have established that the observed 125 GeV object is indeed SM Higgs boson

What could be the consequences ?

Observation in 1997



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ASYMMETRY MEASUREMENTS AT LEP/SLC REVISITED

TARIQ AZIZ*
Tata Institute of Fundamental Research, Bombay 400005, India

Received 4 September 1997

Recent status

$\sin^2\theta_{\rm eff}^{\rm lept}$ of 0.23113 ± 0.00021

$M_t = 173.20 \pm 0.87$ GeV/c^2

[a]The relationship between M_Z and $\sin^2\theta_{\rm eff}$ is given as[4]:

$$M_Z^2 \cos^2\theta_{\rm eff} \sin^2\theta_{\rm eff} = \frac{\pi}{\sqrt{2}G_F}\frac{\alpha}{1-\Delta r_{\rm eff}} = \frac{\pi\alpha_{\rm eff}(M_Z)}{\sqrt{2}G_F},$$

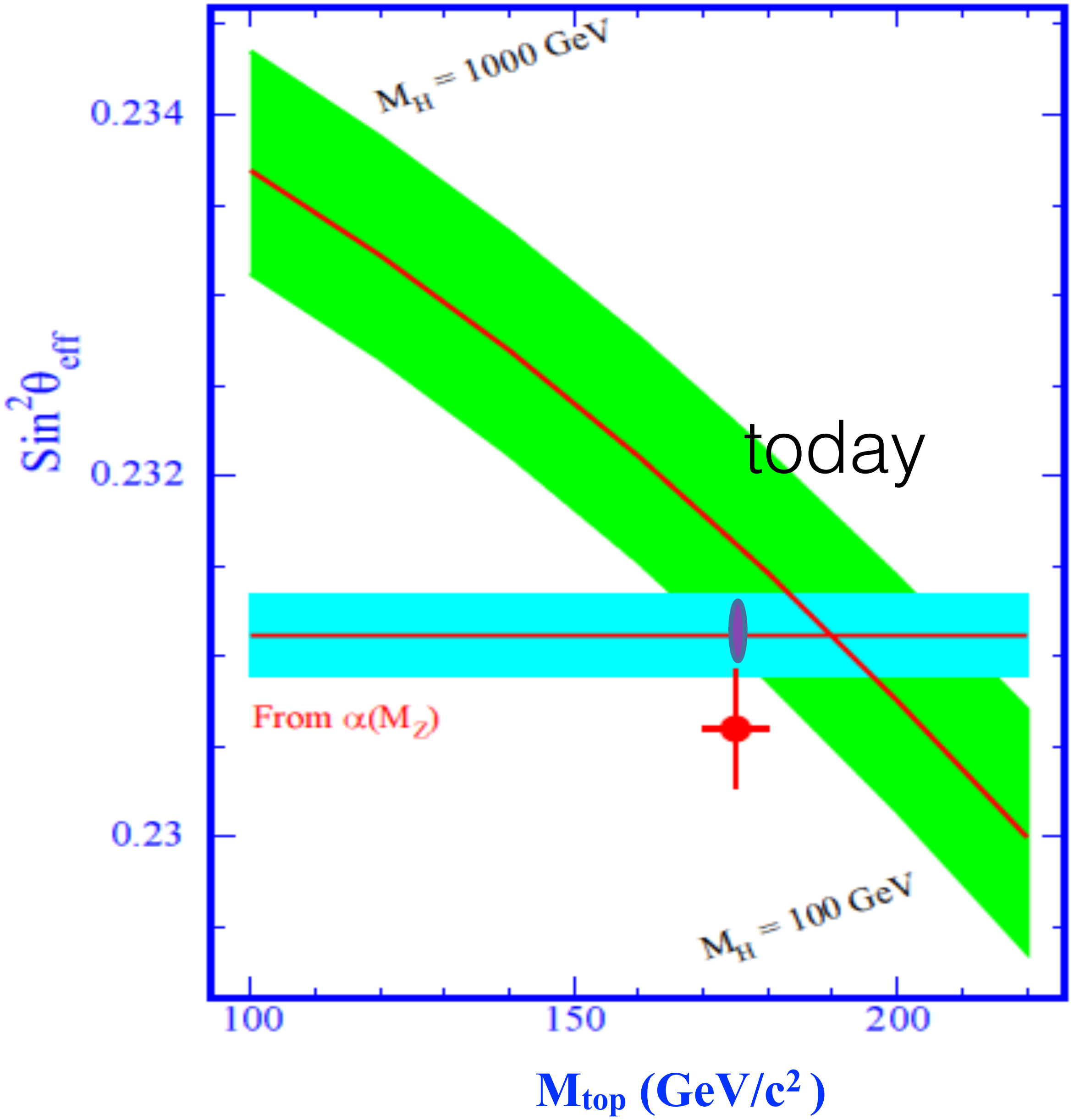
where

$$\Delta r_{\rm eff} = \Delta\alpha + \Delta r_W .$$

Here $\Delta\alpha$ represents the effect due to running of QED coupling, α, in going from low energy to Z mass scale and Δr_W is the effective weak radiative correction mainly due to top and Higgs in the Z propagator and some other nonleading effects. From now on if the mass scale is not specified, α refers to $\alpha(m_e)$. The best estimate of α at Z mass scale is $\alpha(M_Z) = 1/(128.896 \pm 0.090)$.[5]

In this letter $\sin^2\theta_{\rm eff}$ always corresponds to $\sin^2\theta_{\rm eff}^{\rm lepton}$ even when extracted using quark asymmetries.

Observation in 1997



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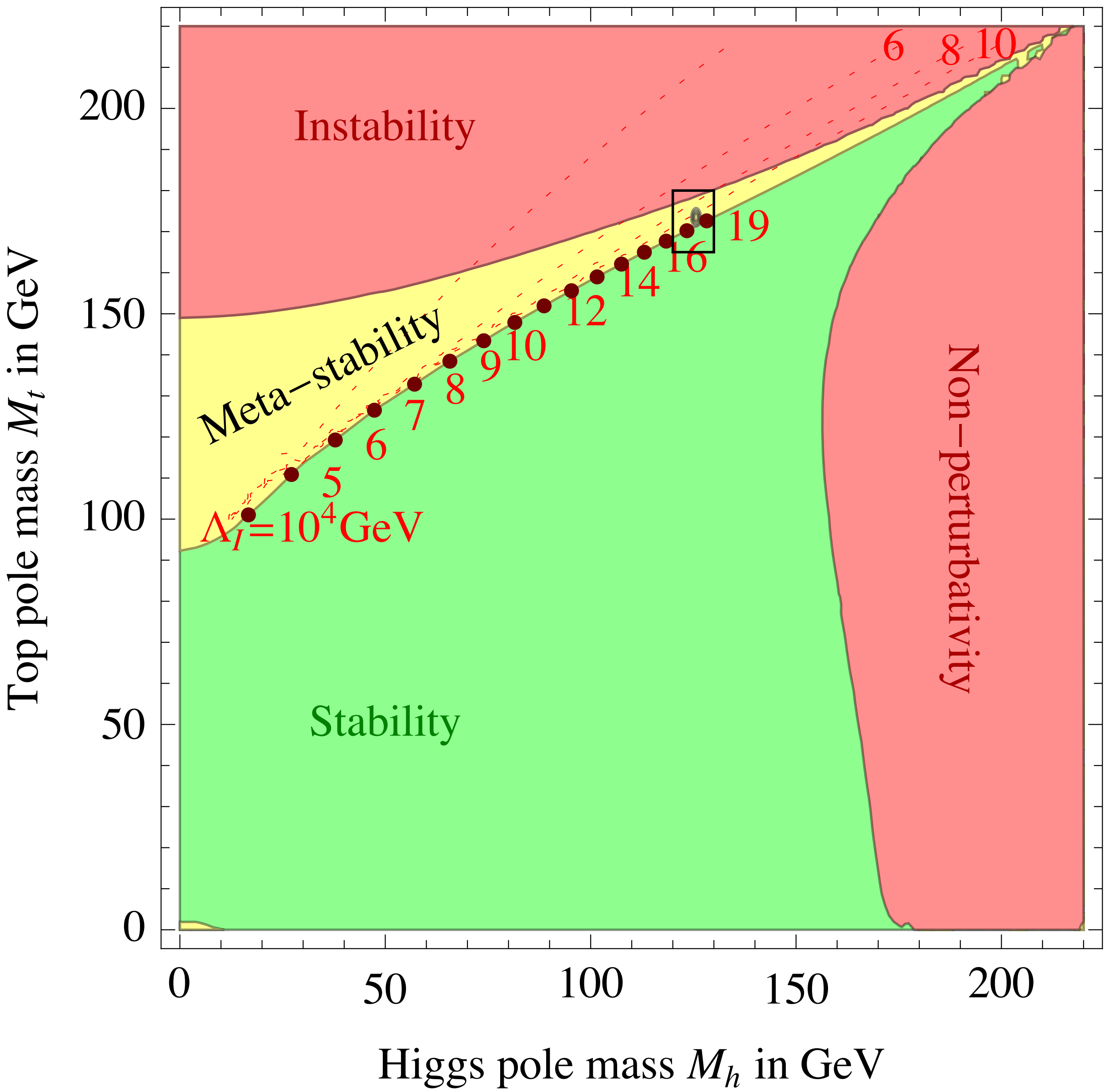
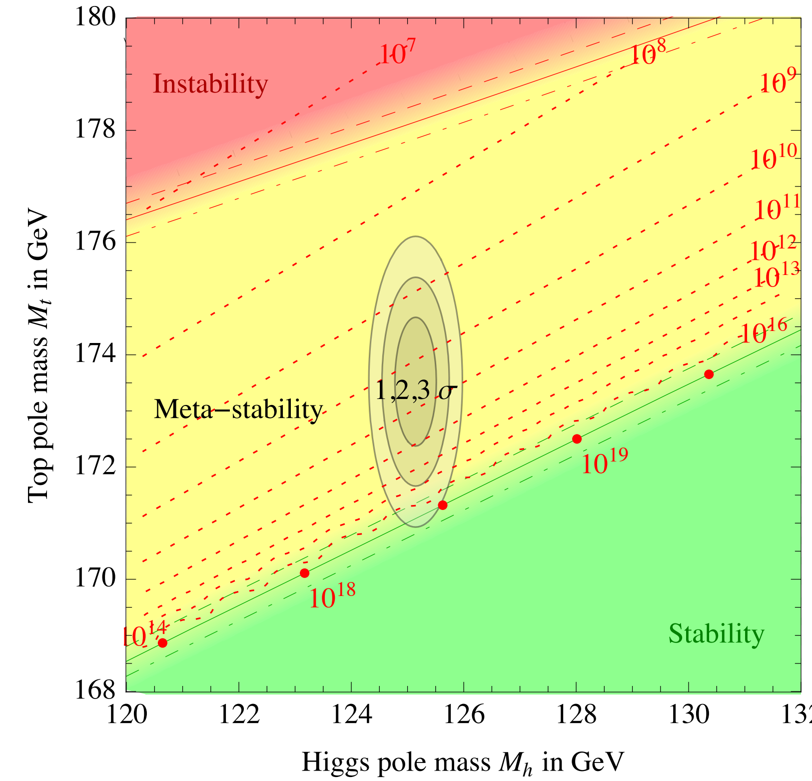
(M_t , M_H) : (173 , 125) GeV/c^2

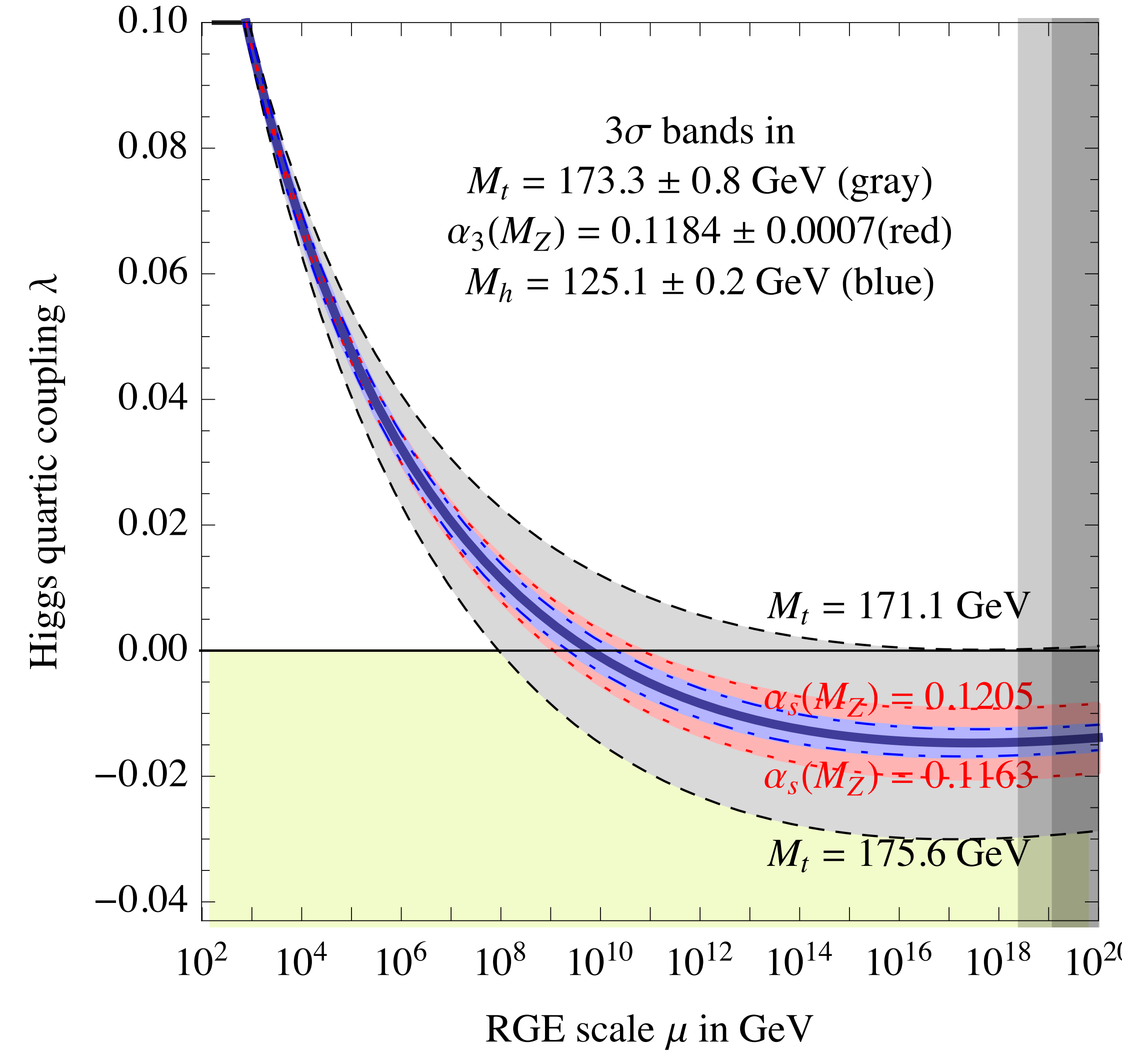
Interesting point in Top-Higgs space

arXiv:1307.3536 V4, Sept 20, 2014

Living at the edge: Proximity to criticality







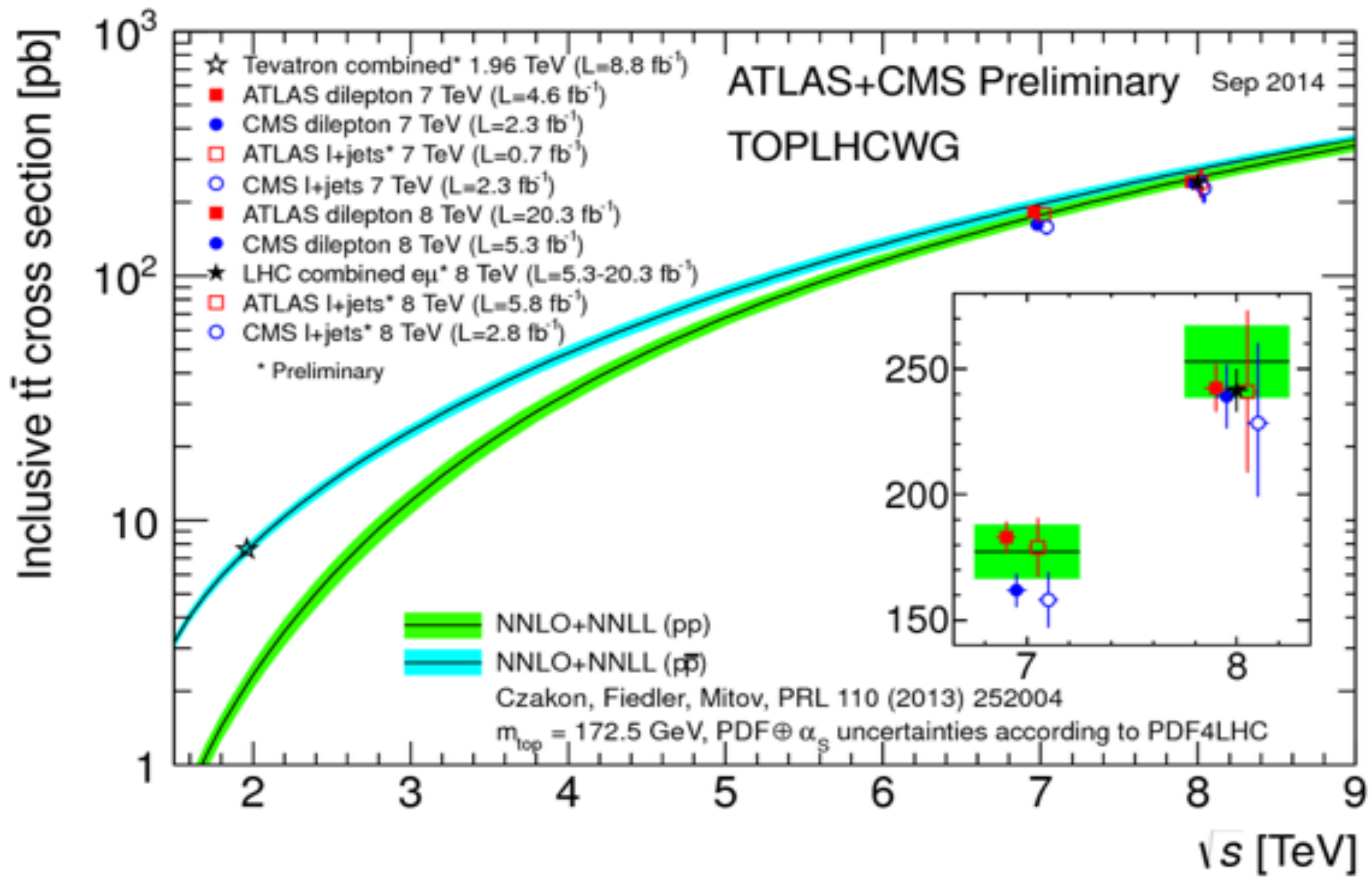
Measured M_h and M_t appear special, they place SM vacuum in near critical condition, at the border between stability and metastability

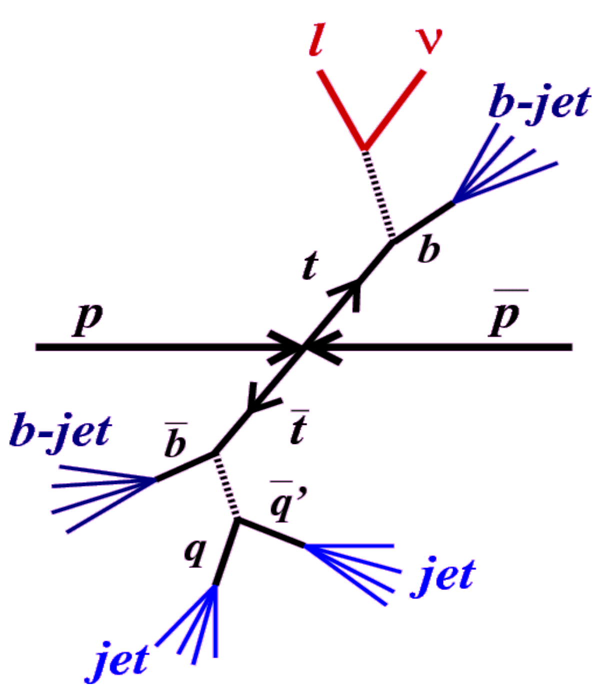
We need more focus on Top Quark,

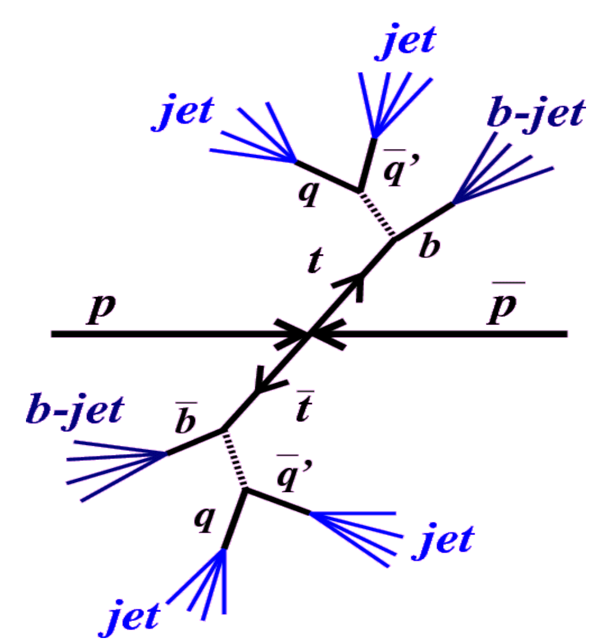
Might be more special than we thought

LHC is a Top Quark Factory

Top Quark Production Cross Section and Mass

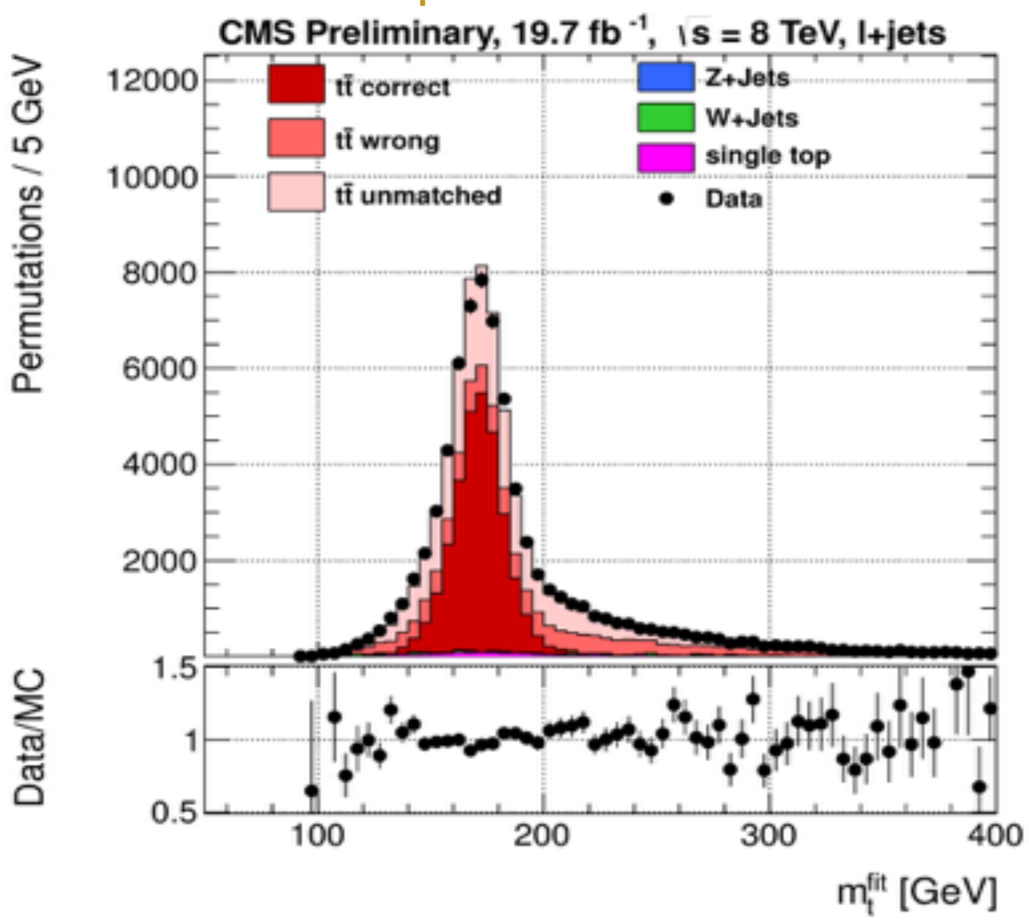




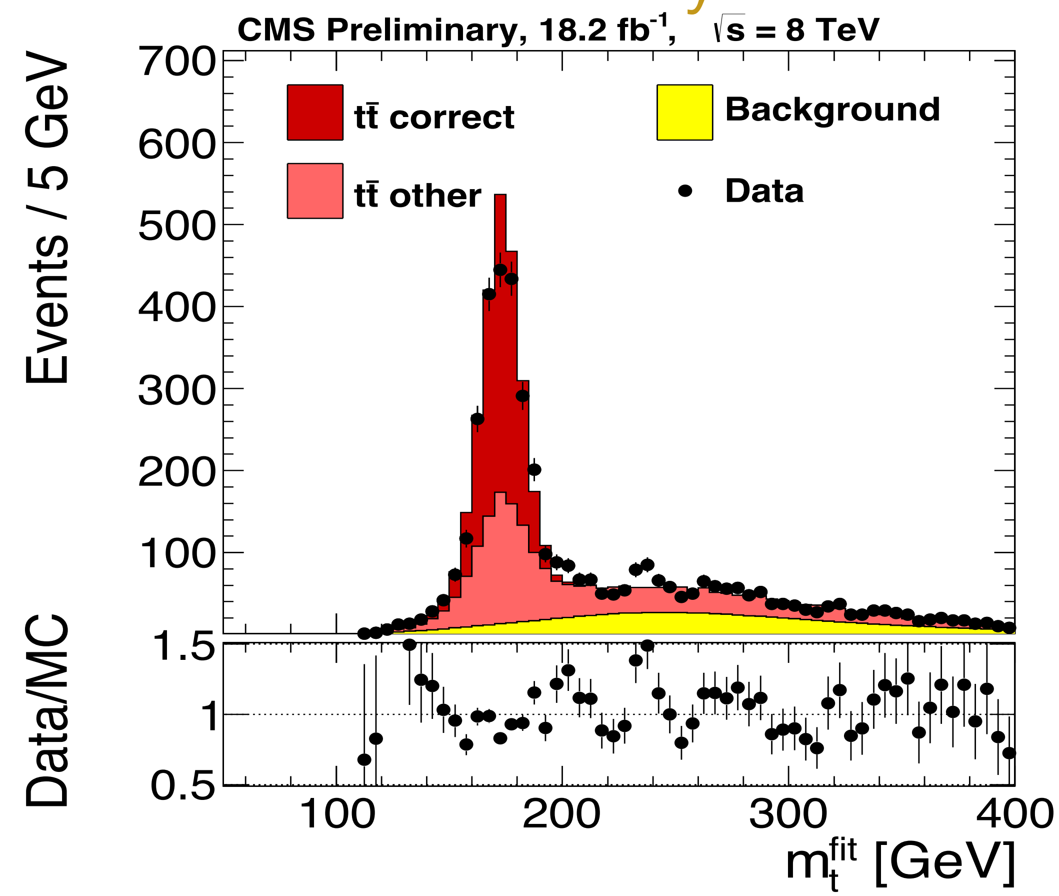


top quark mass measurement

semileptonc



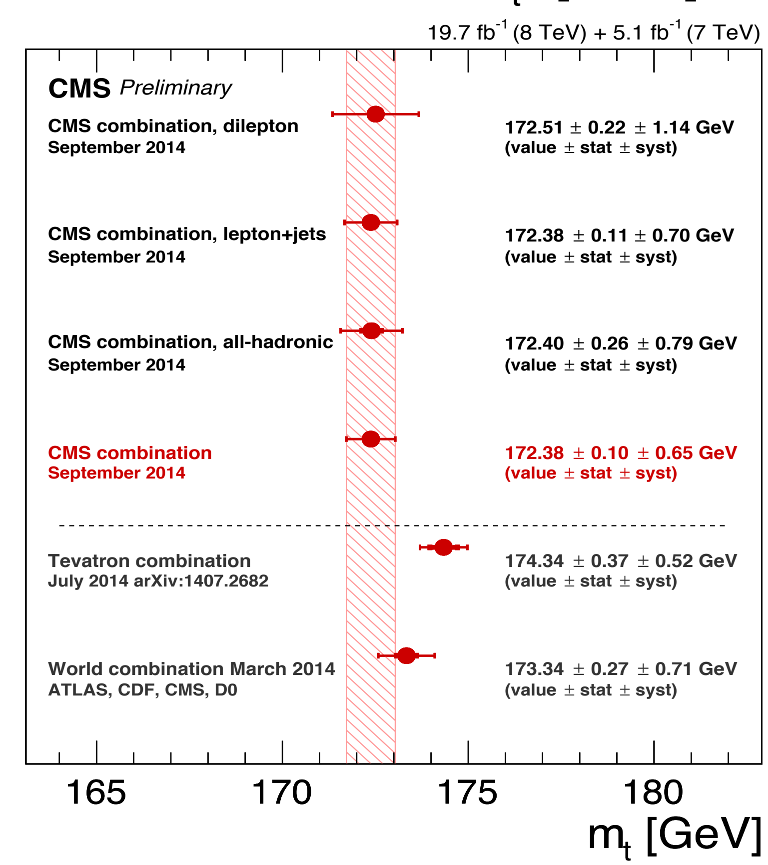
fully hadronic



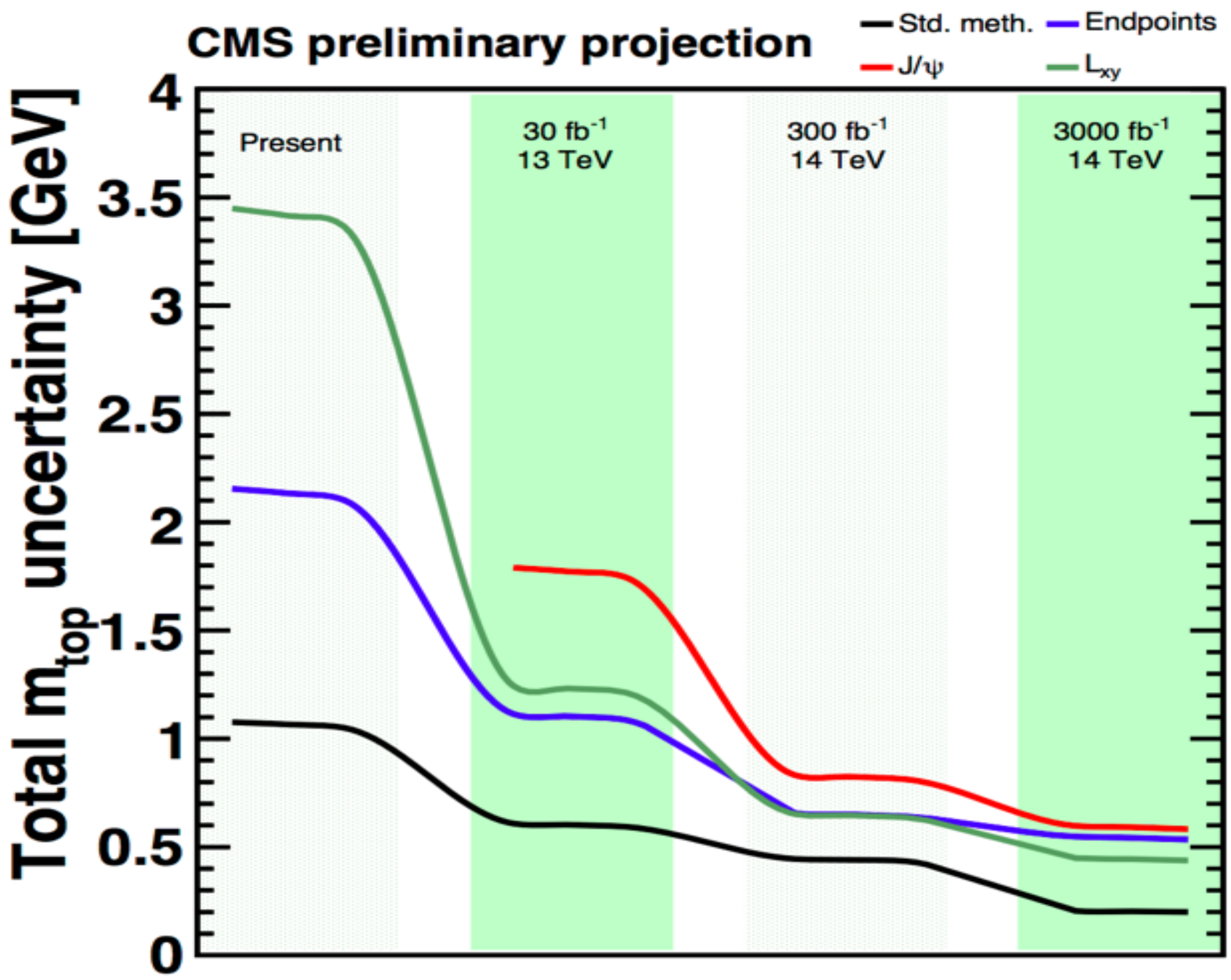
$$m_t = 172.38 \pm 0.10\,(\text{stat.}) \pm 0.65\,(\text{syst.})\,\text{GeV}$$

CMS alone as good as world average

top mass crucial to decide between meta stable or stable region



How well can CMS measure top mass in future ?

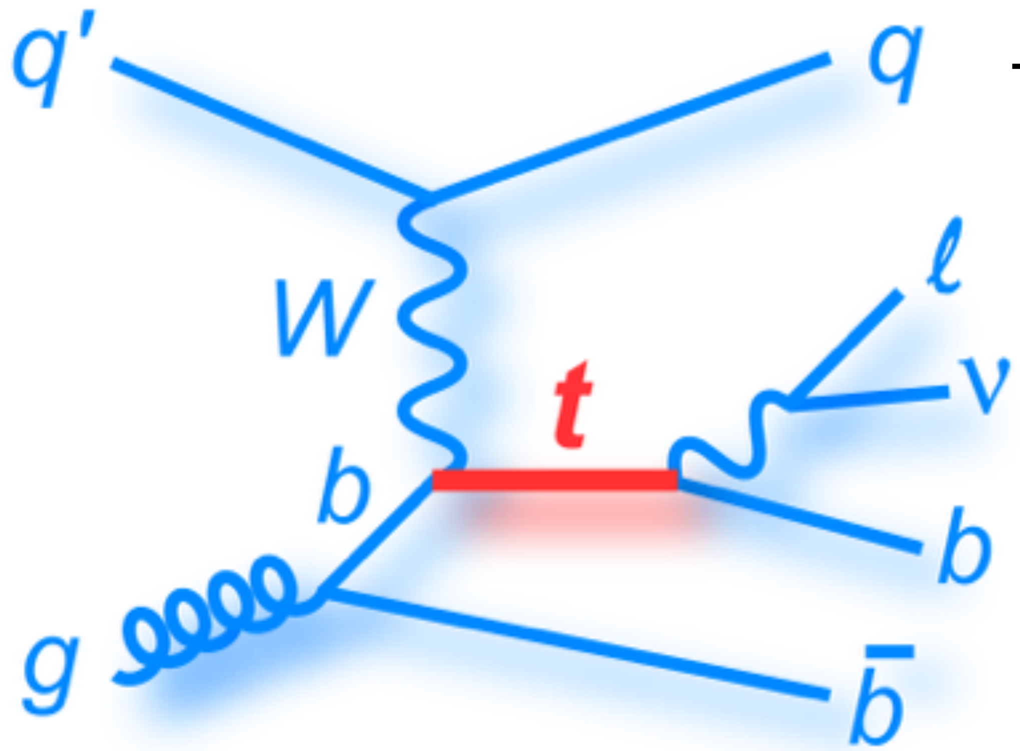


t-channel Single Top production

Soureek Mitra -Thesis- Poster

Measurement of $|V_{tb}|$ and
top quark polarisation,
Test of SM and new physics,
Constrain u/d PDF via σ_t / σ_{tbar}

$t \rightarrow bW \rightarrow b\mu\nu$ decay channel



→ Light jet with high |η|

→ μ only in this analysis

→ Missing Energy

→ b-jet: high p_T, central

→ 2nd b-jet: low p_T, broad |η| X

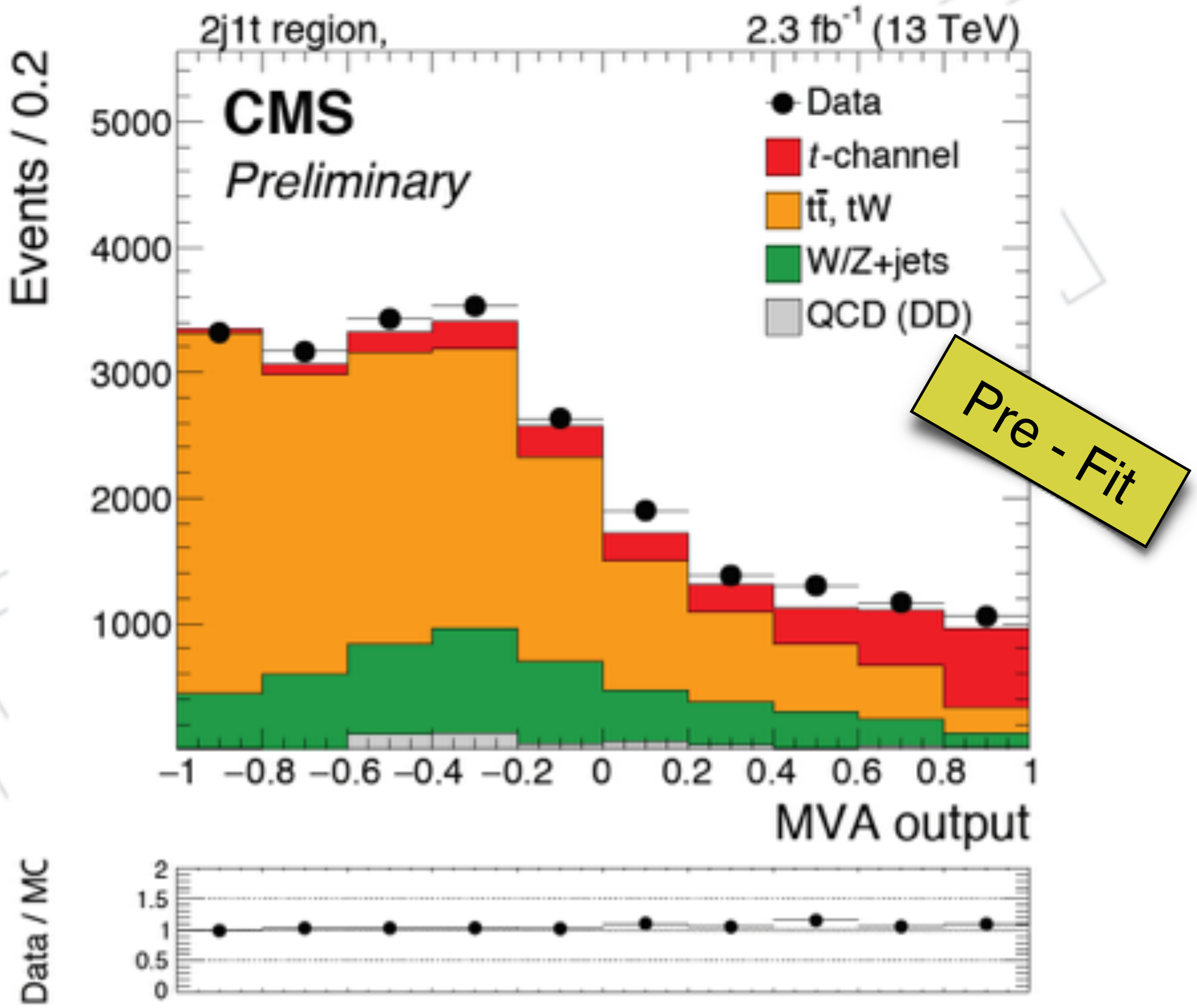
Top reconstruction:

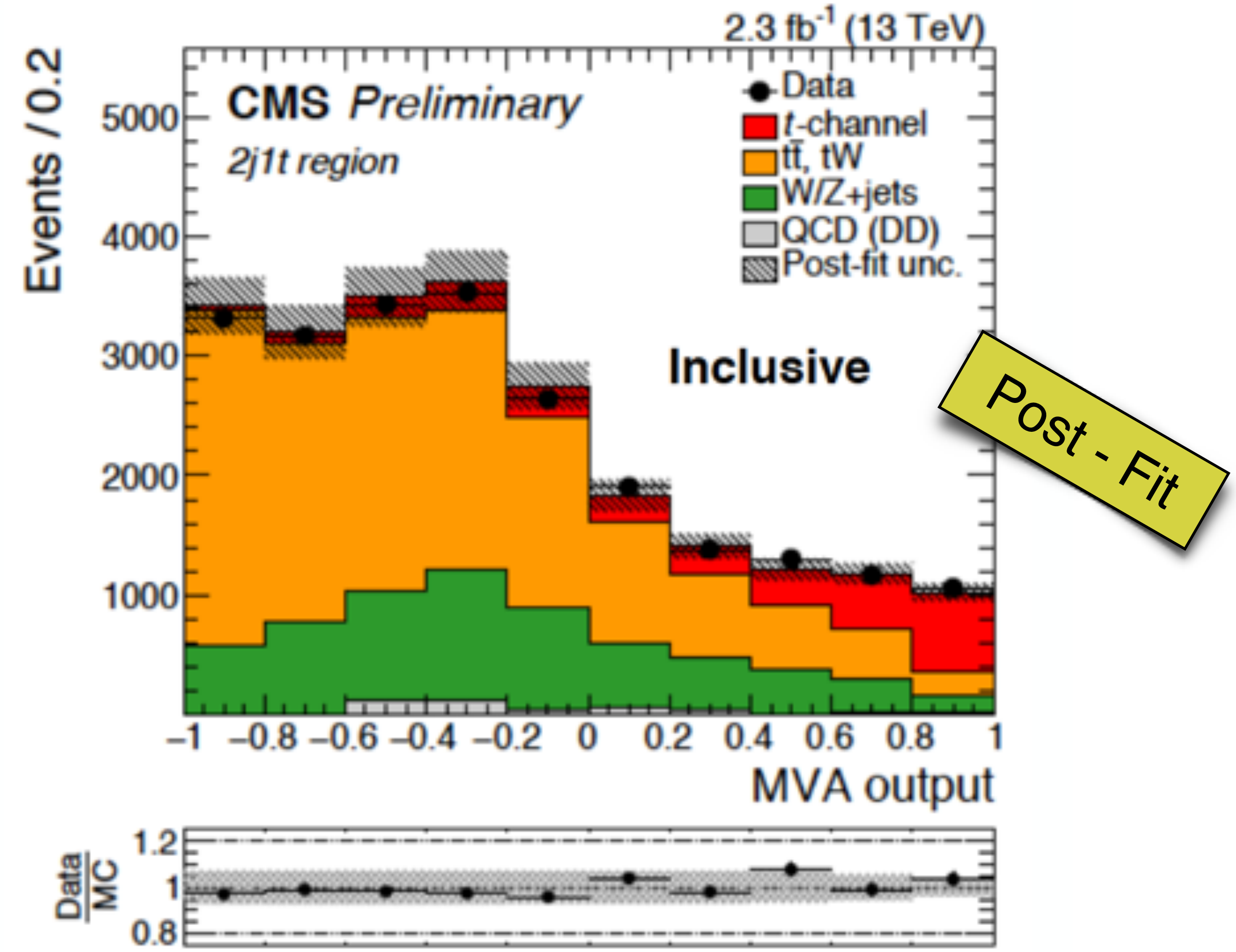
- Reconstruct W from $\mu\nu$

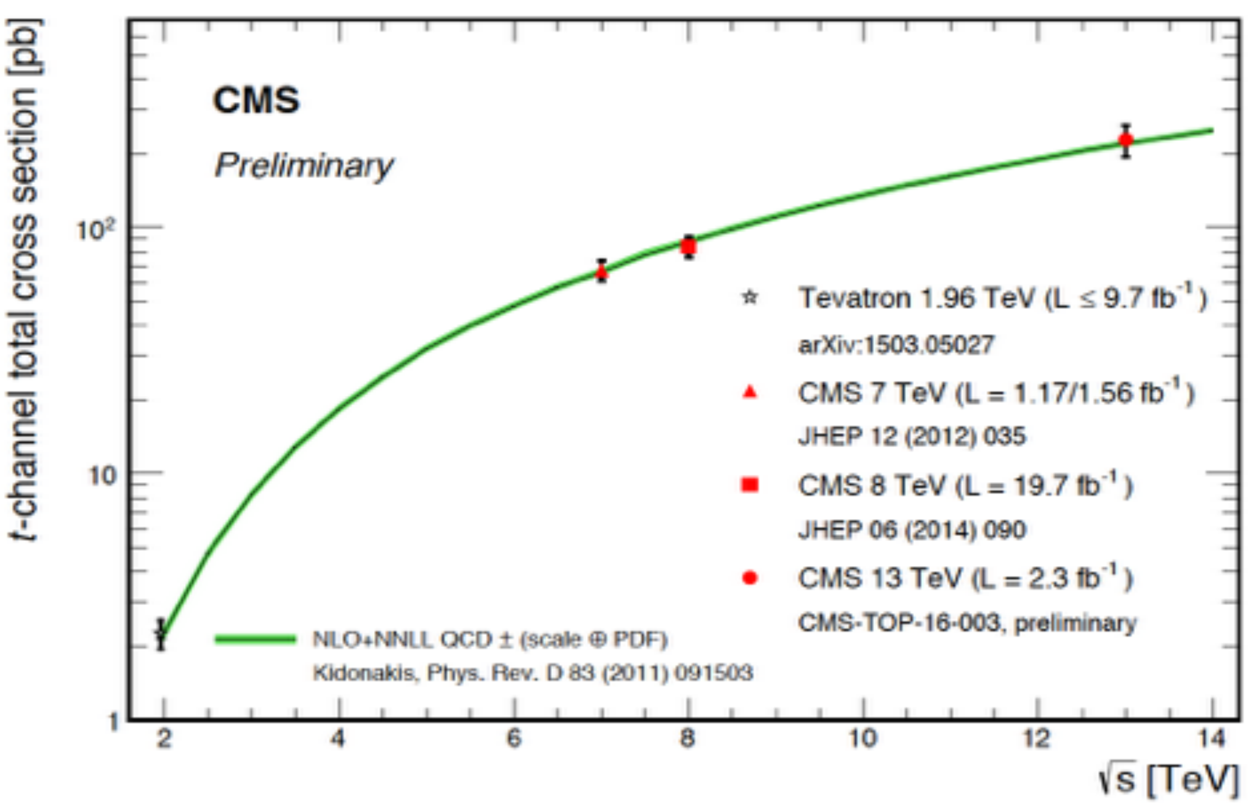
→ use m_W=80.4 GeV (PDG mass) constraint to resolve $p_{Z,\nu}$

- Add W candidate to b-jet to get top

Single top at 13 TeV







$$\sigma_{t\text{-ch.}} = 227.8 \pm 9.1\,(\text{stat.}) \pm 14.0\,(\text{exp.})\,^{+28.7}_{-27.7}\,(\text{theo.}) \pm 6.2\,(\text{lumi.})\,\text{pb} = 227.8^{+33.7}_{-33.0}\,\text{pb}$$

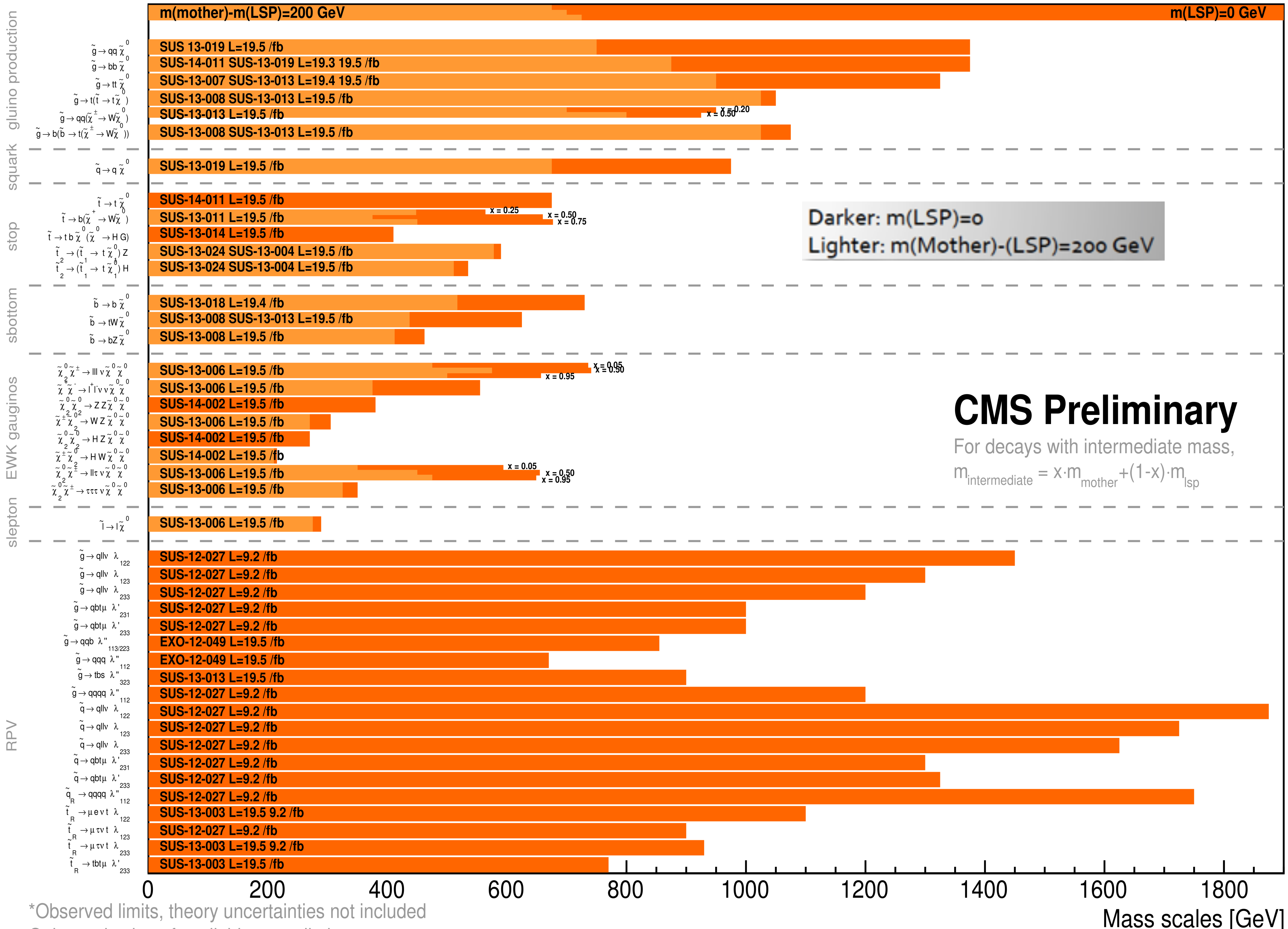
Soureek Mitra -Thesis- Poster

Search for New Physics

Many possibilities, many searches

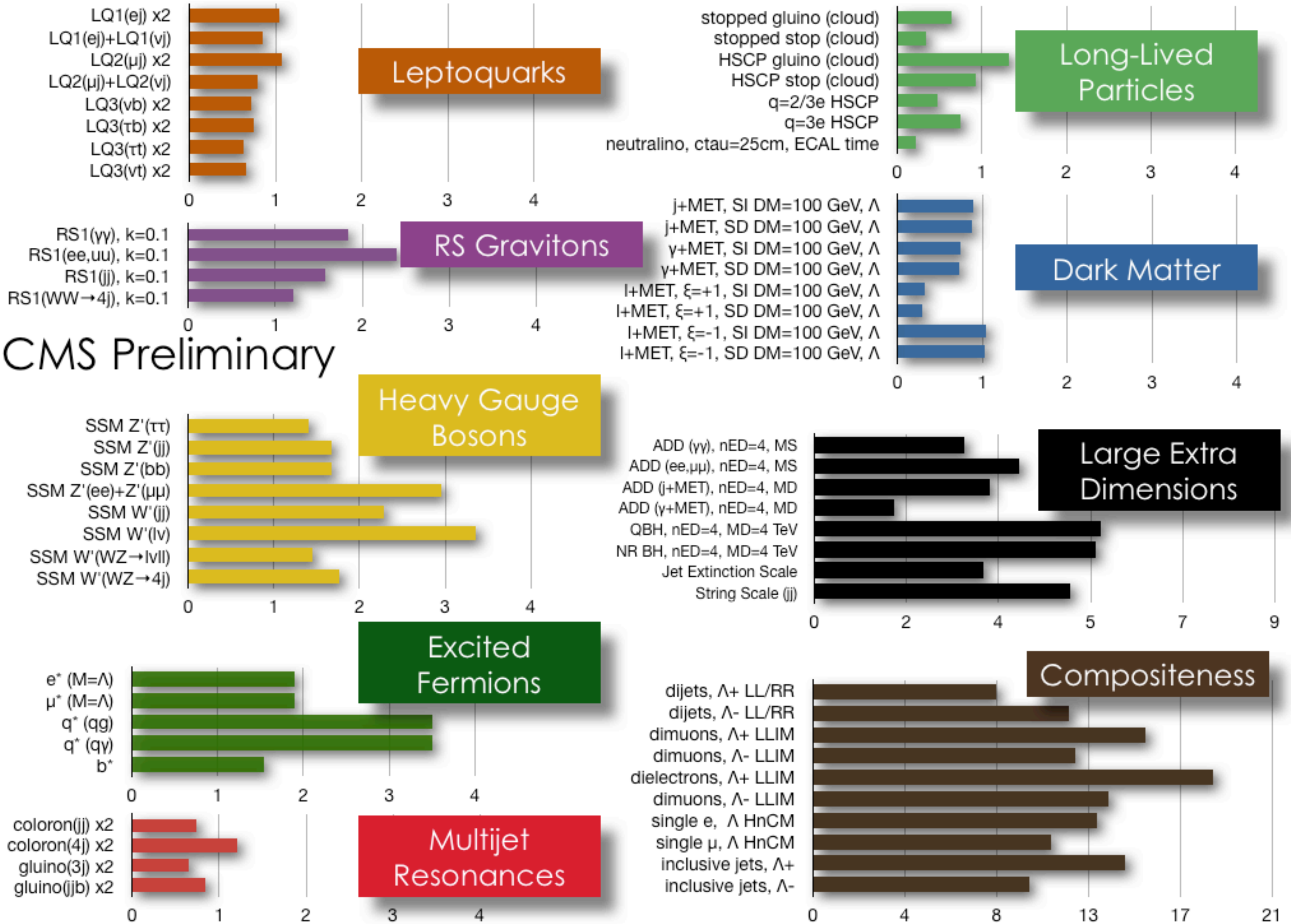
Summary of CMS SUSY Results* in SMS framework

ICHEP 2014



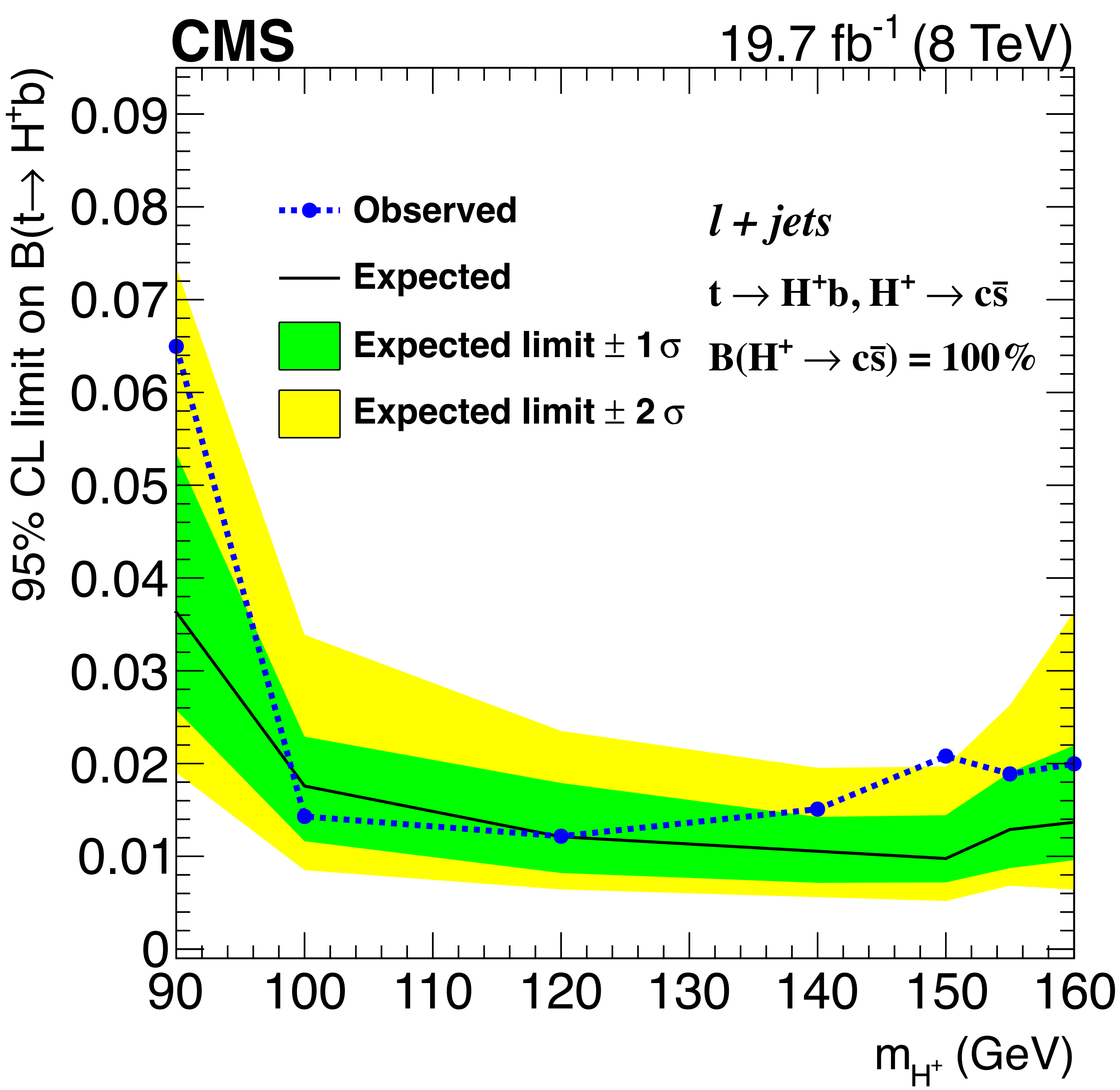
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

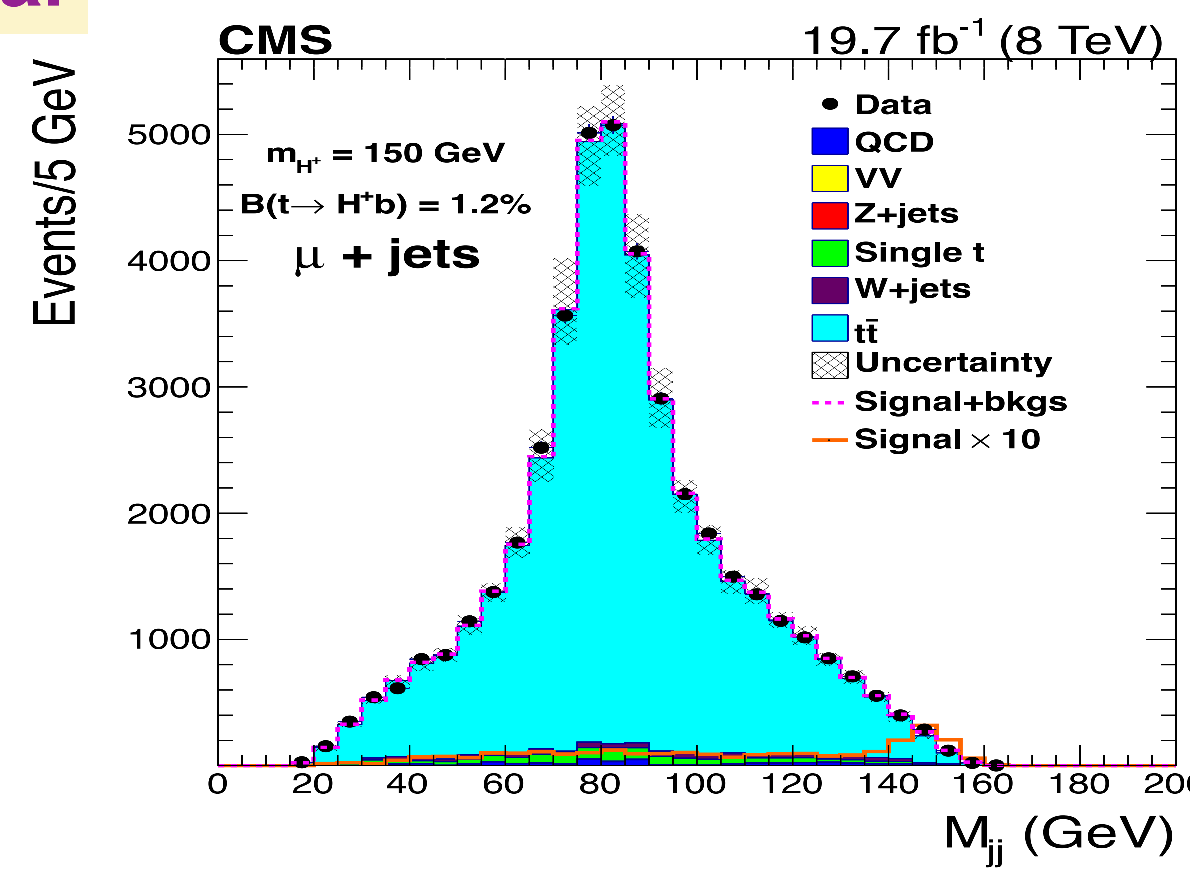
Other new physics scenarios

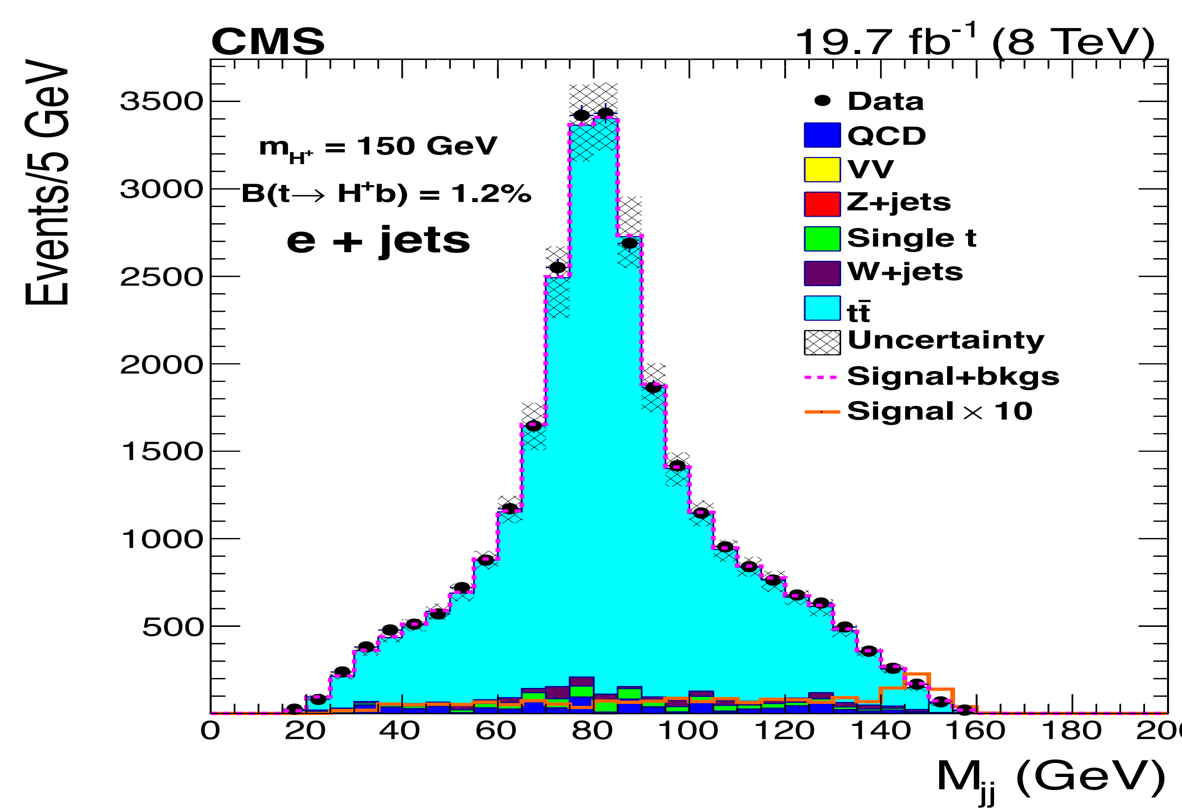


Search for Charged Higgs boson in top pair events decaying to c s-bar

Thesis- G.Kole





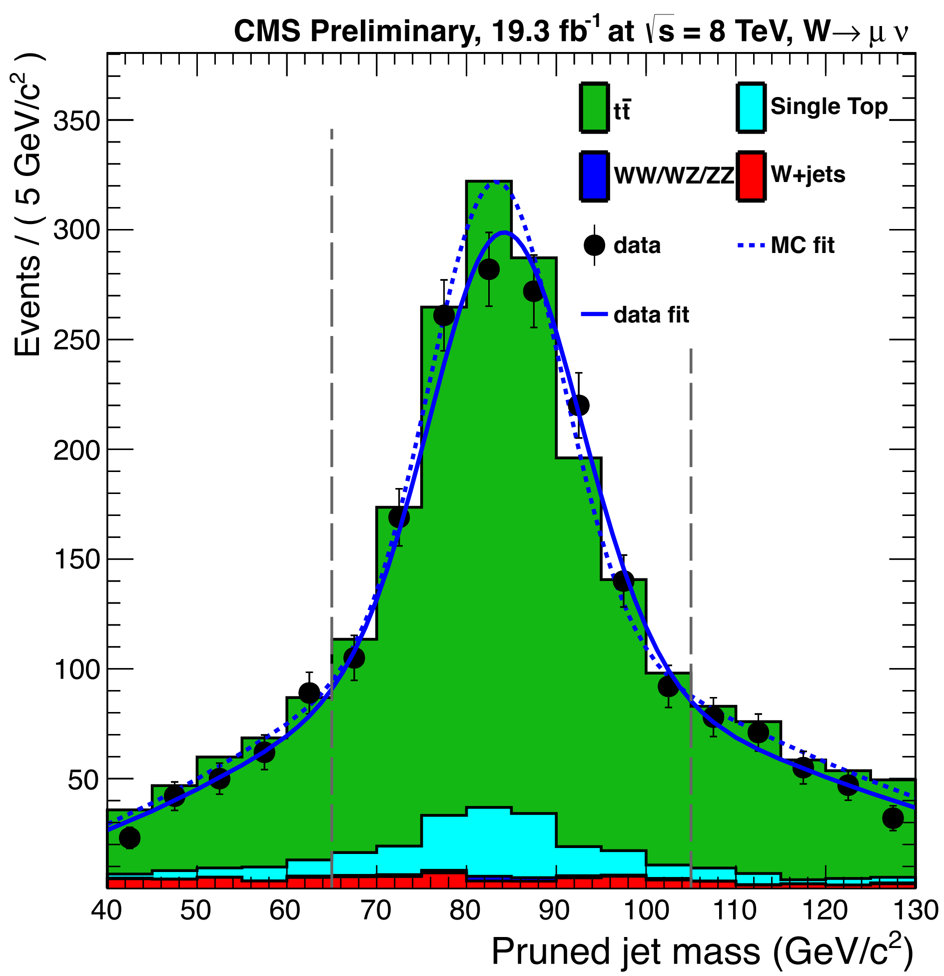


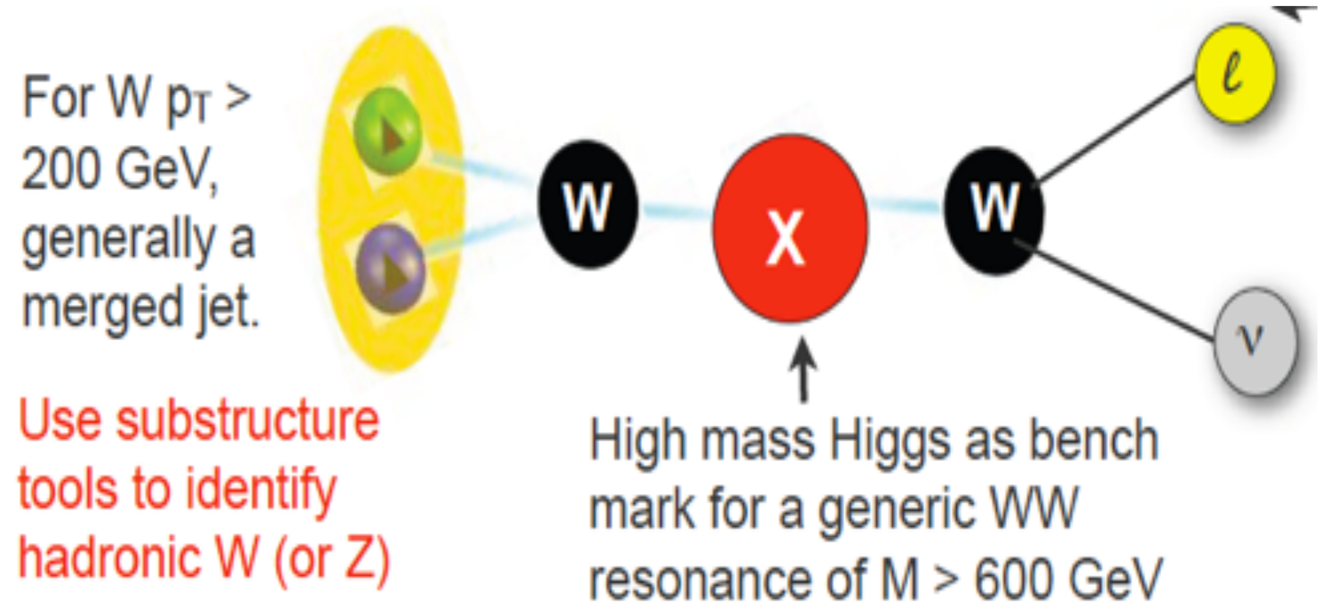
most restrictive limit to date

Going beyond H(125) -extended higgs sector

Thesis- B.Parida

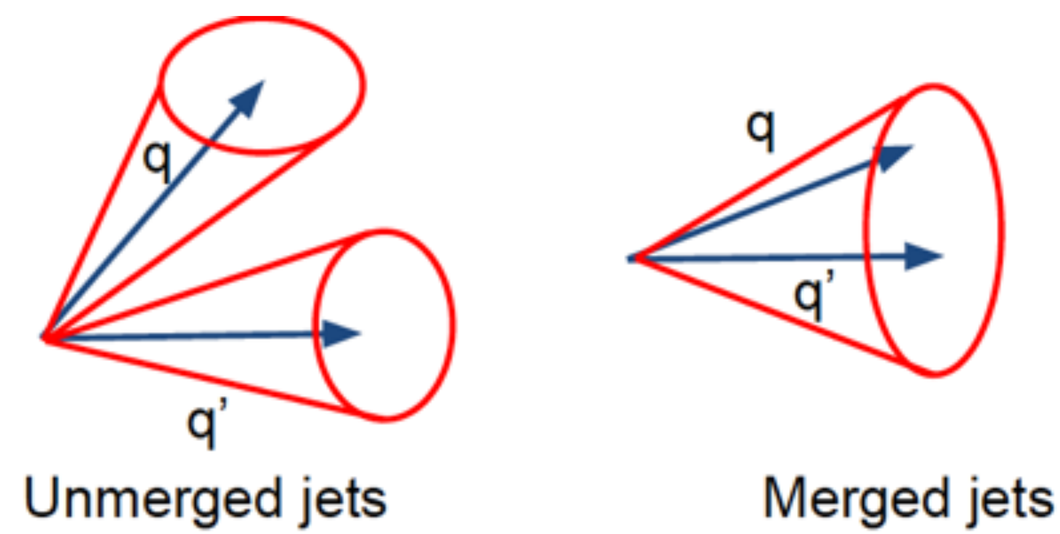
Search for Higgs (-like) boson in the high mass region (600-1000 GeV)





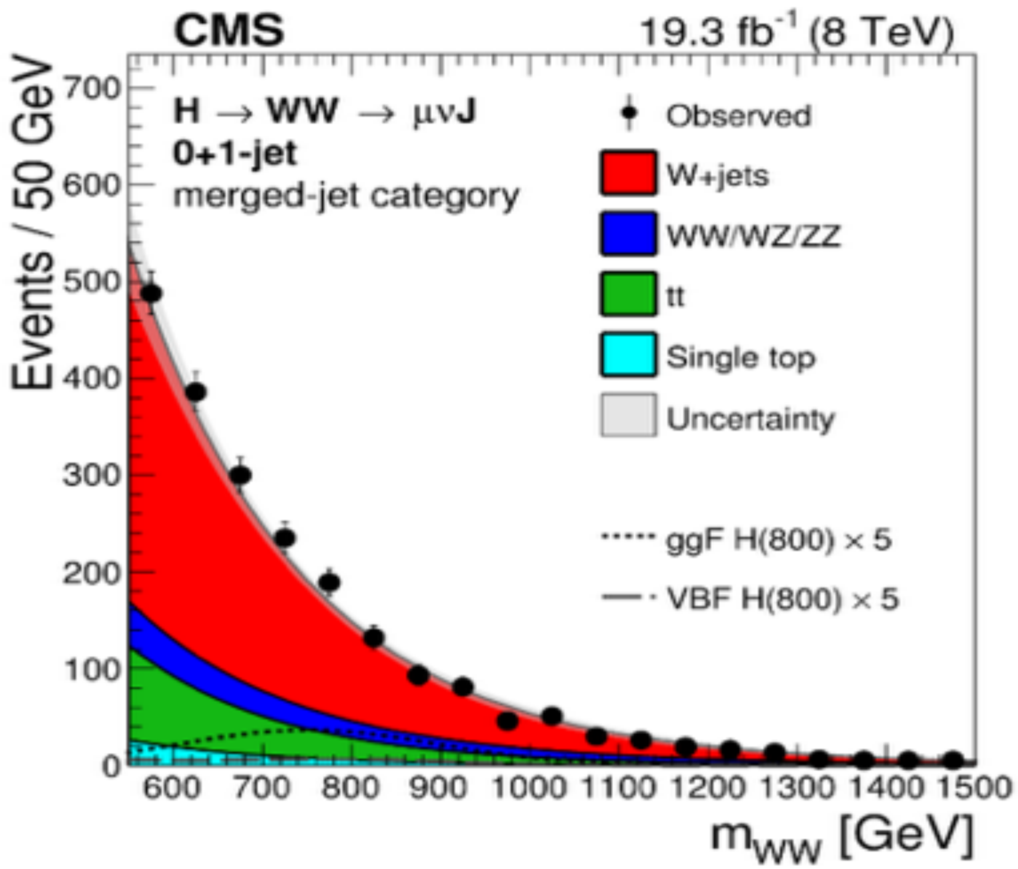
Low boost

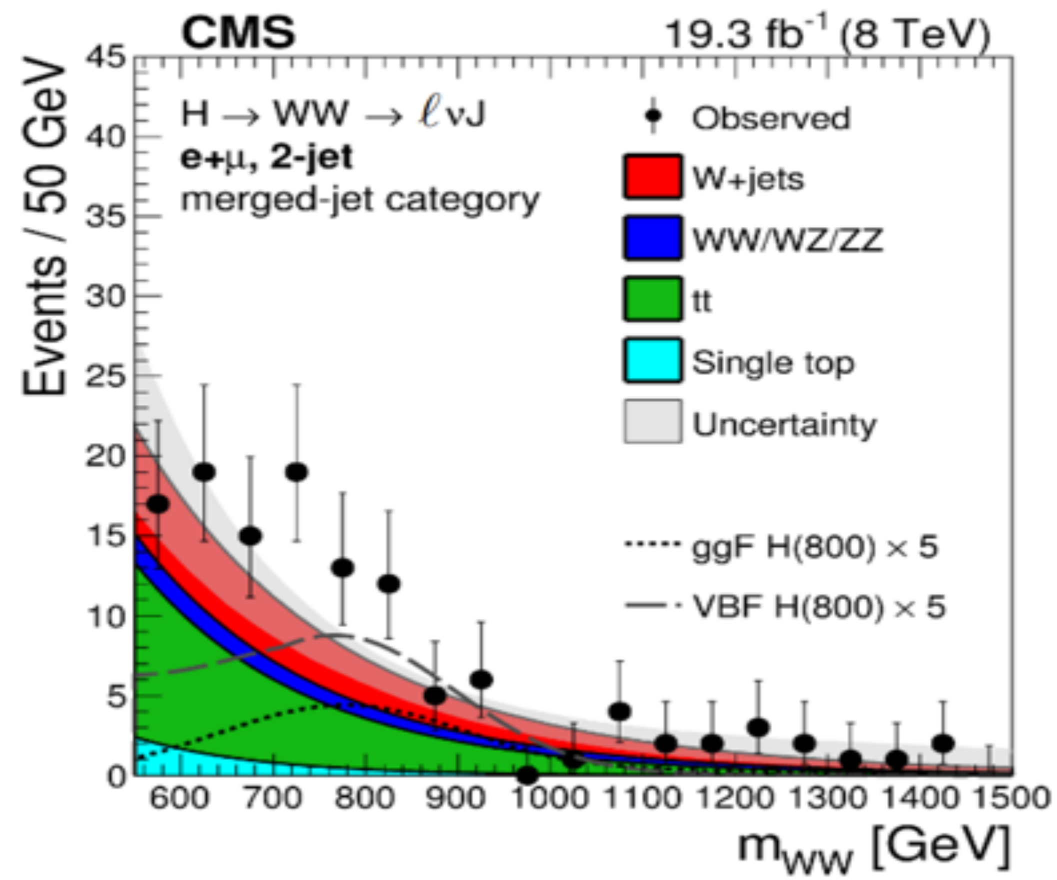
High boost

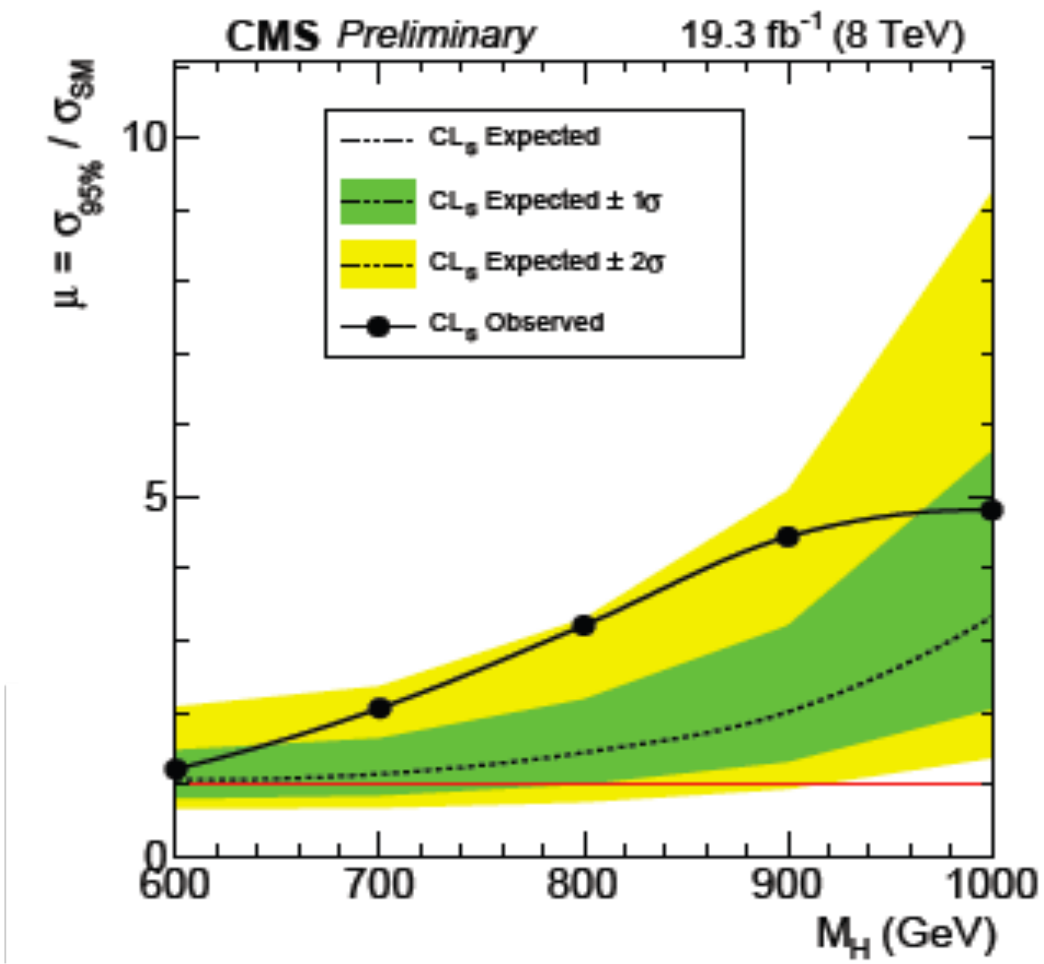


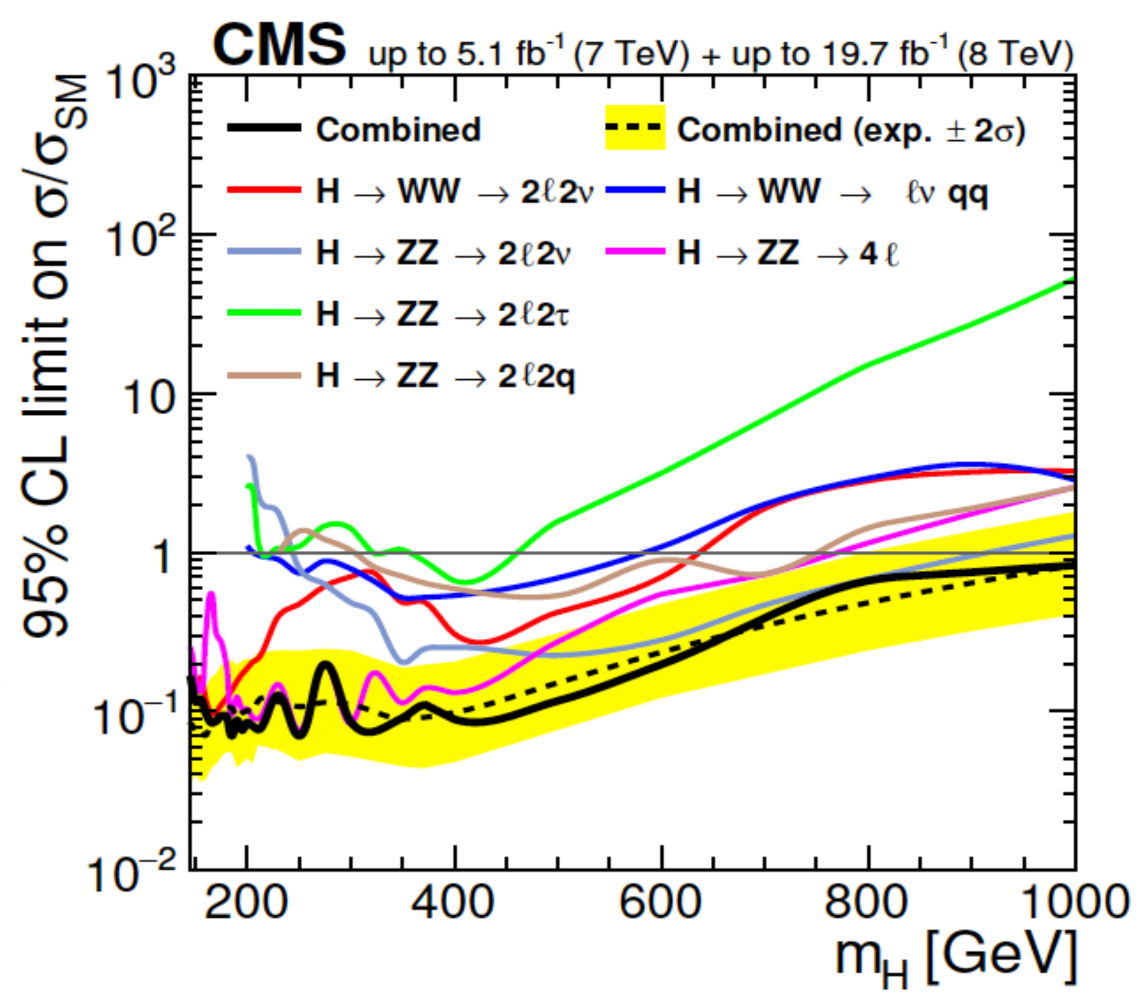
Decays to WW → **lν** qq' and pruned jet mass (m_J)reconstructed as three body mass ($m_{l\nu J}$)

Merged Jets Leading to One fat jet


CMS
19.3 fb-1 (8 TeV)
H → WW → μνJ
0+1-jet
merged-jet category
Observed
W+jets
WW/WZ/ZZ
tt
Single top
Uncertainty
ggF H(800) × 5
VBF H(800) × 5
Events / 50 GeV
mWW [GeV]

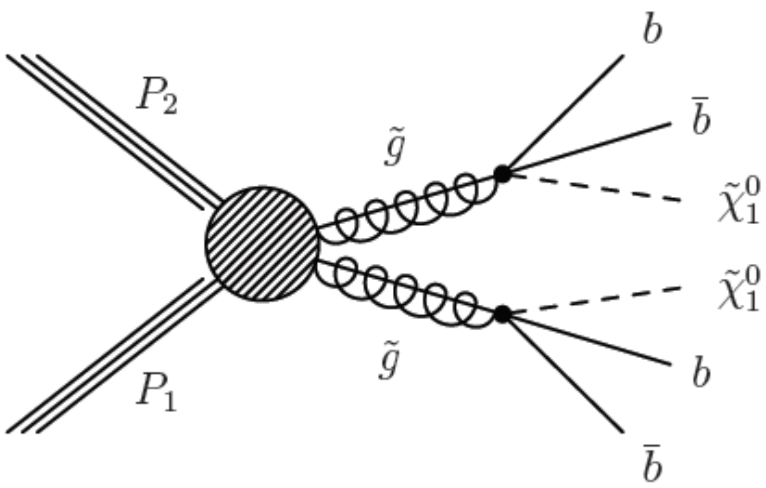

CMS
19.3 fb-1 (8 TeV)
H → WW → ℓνJ
e+μ, 2-jet
merged-jet category
Observed
W+jets
WW/WZ/ZZ
tt
Single top
Uncertainty
ggF H(800) × 5
VBF H(800) × 5
Events / 50 GeV
mWW [GeV]

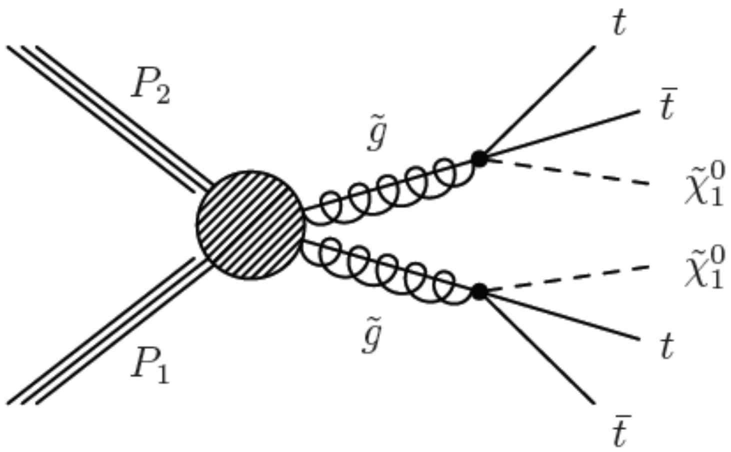

CMS Preliminary
19.3 fb-1 (8 TeV)
CLs Expected
CLs Expected ± 1σ
CLs Expected ± 2σ
CLs Observed
μ = σ95% / σSM
MH (GeV)

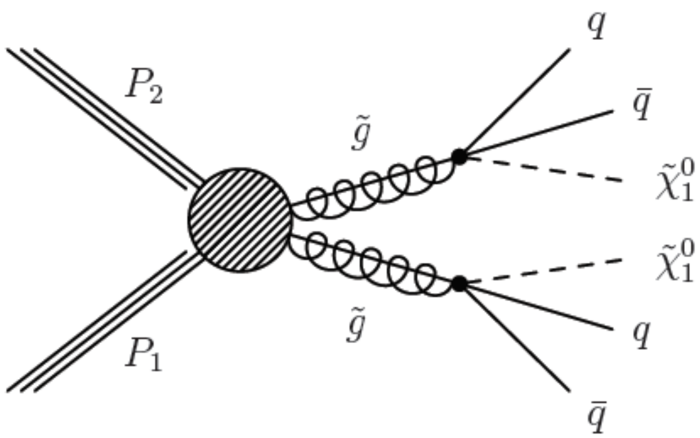

CMS
up to 5.1 fb-1 (7 TeV) + up to 19.7 fb-1 (8 TeV)
Combined
Combined (exp. ± 2σ)
H → WW → 2ℓ2ν
H → WW → ℓν qq
H → ZZ → 2ℓ2ν
H → ZZ → 4ℓ
H → ZZ → 2ℓ2τ
H → ZZ → 2ℓ2q
95% CL limit on σ/σSM
mH [GeV]

Search for SUSY in multi-jets at 13 TeV

Gluino production



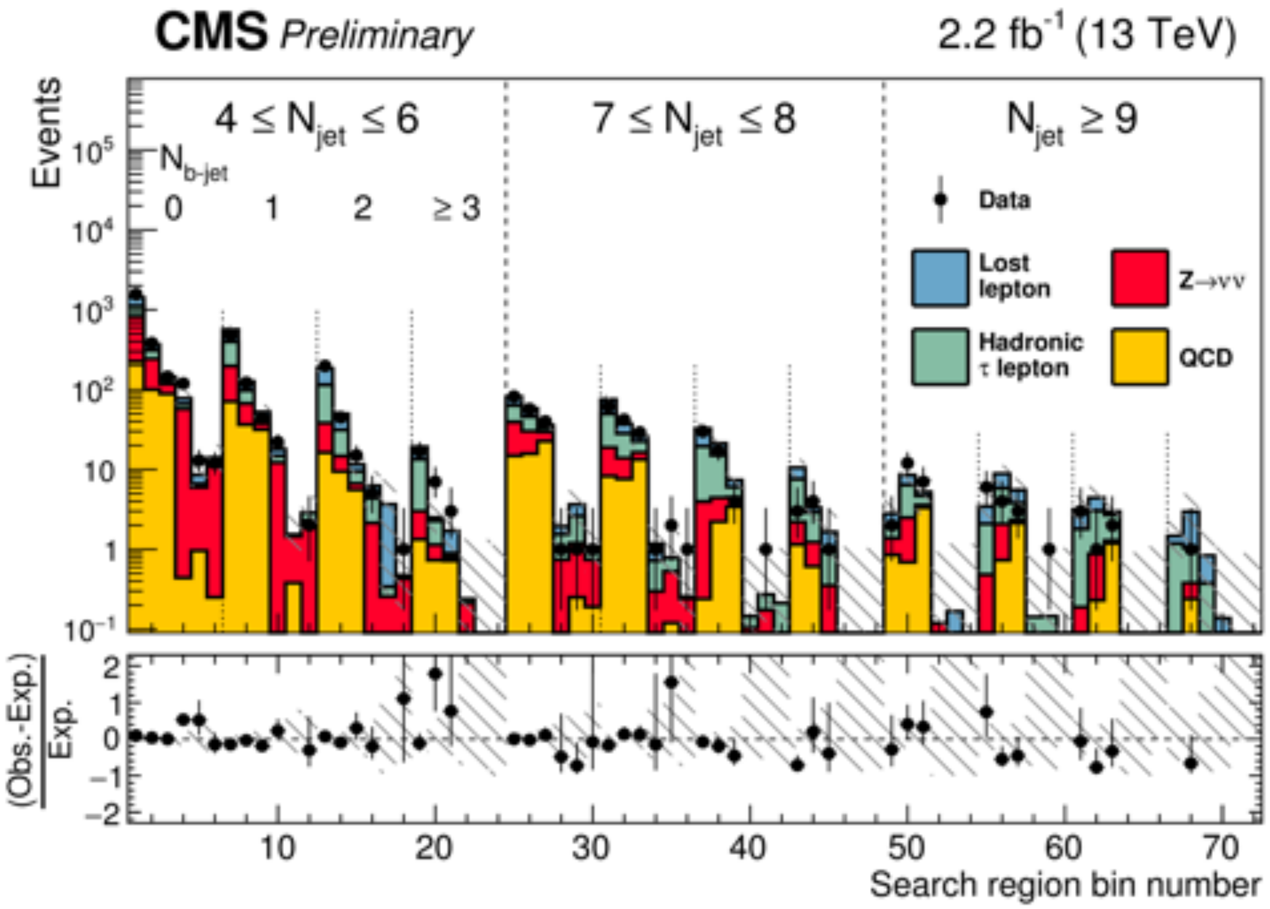


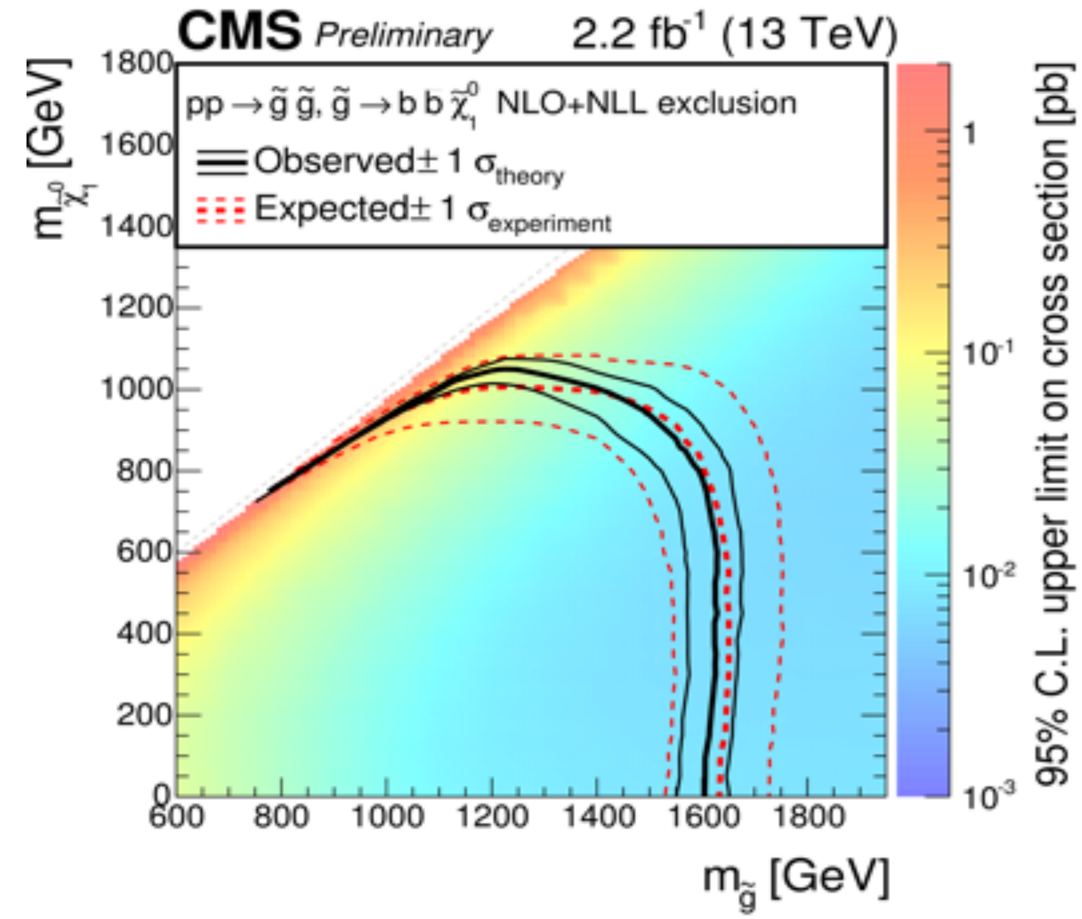


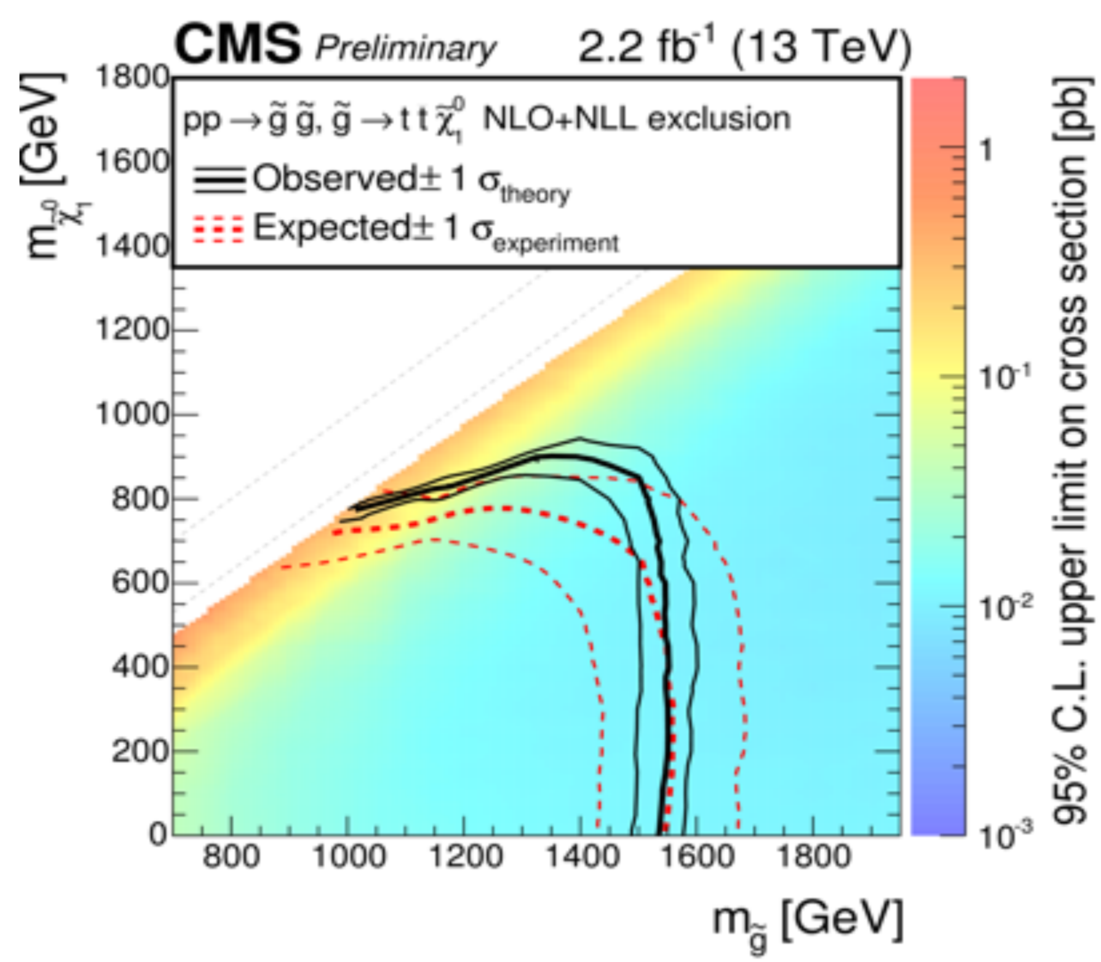
Search performed in the bins H_T, H_T^{miss}, N_{jet}, $N_{b\text{-}jet}$

Sensitive to models with large and small m_{gluino} - m_{LSP}

Probe new territory with early data







- Exclude gluino mass from 1.44 to 1.60 TeV
- Run1 limits were between1.15 and 1.28 TeV

Search for Lepto-Quarks at 13 TeV

Poster by Muzamil Bhat

Study of Ratio of W^{+}+jets/W^{-}+jets to probe Parton Distribution Functions

Poster by Bajrang Sutar

Search for Exotic Charged Charmonium-like States in CMS

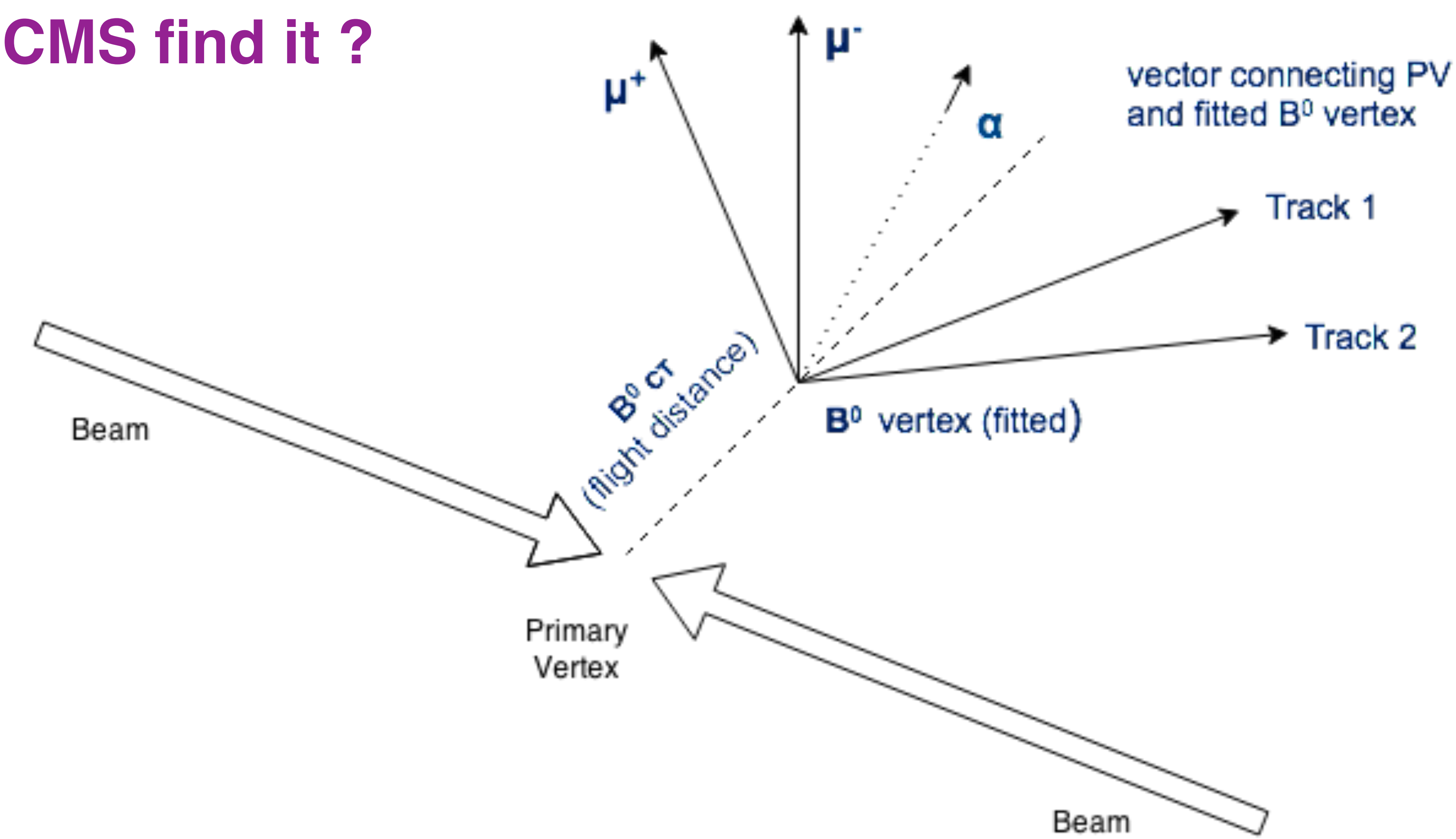
Potentially interesting for exotic quark content- tetra quark?

Discovery of the Z(4430)± in the ψ'π spectrum in the decay B0 → ψ' Kπ by Belle (2007)

Nairit - Thesis-poster

Not confirmed by BABAR, confirmed by LHCb

Can CMS find it ?



Very complex analysis- Could be equally rewarding

Some Remarks

Higgs mass measurement already precision game. Beyond any doubt Higgs is a fundamental scalar.

Great improvement in Top quark studies by CMS, moving towards much better precision in mass, cross section and couplings.

No significant anomaly so far from 7-8 TeV LHC data. BSM physics yet to show up! Next stage at 13-14 TeV LHC may be more exciting.

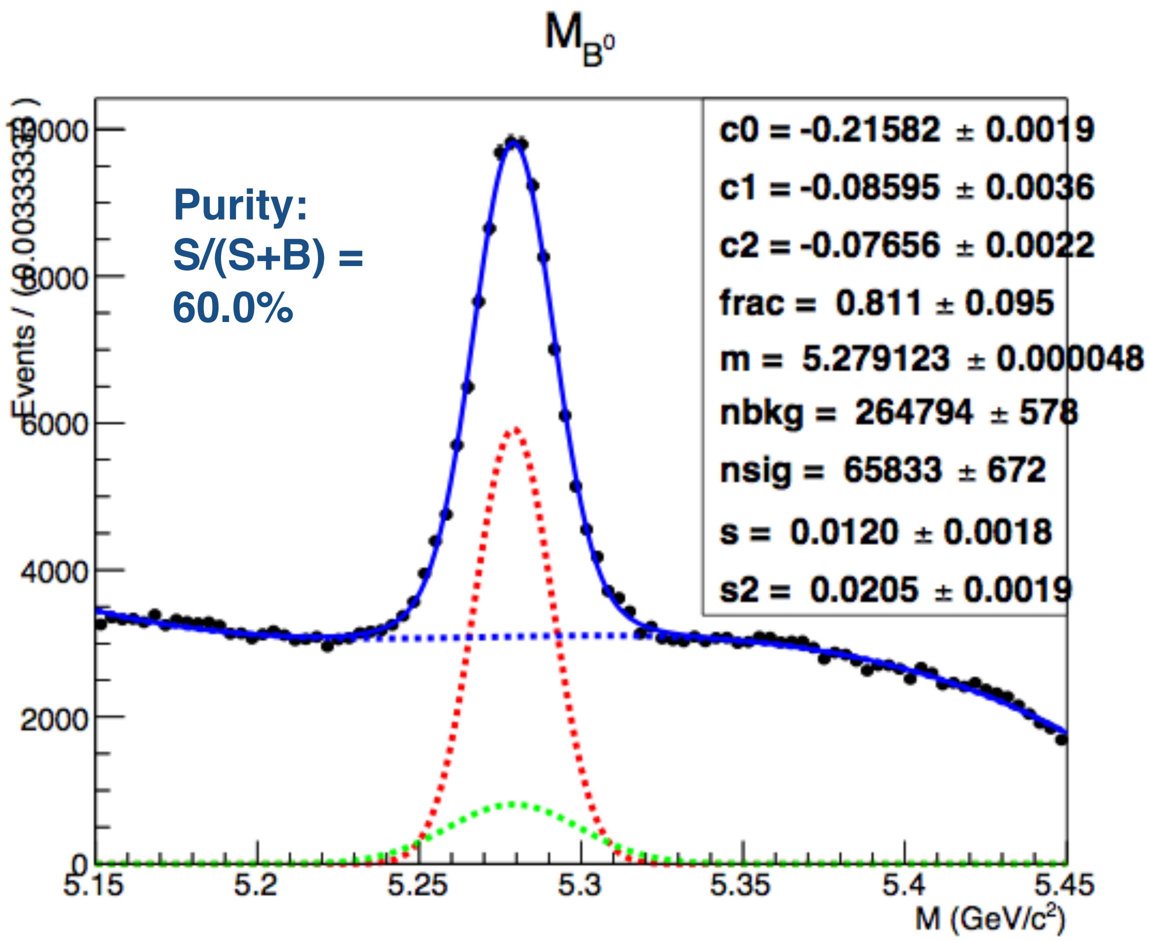
Maintain the detector and keep collecting data.

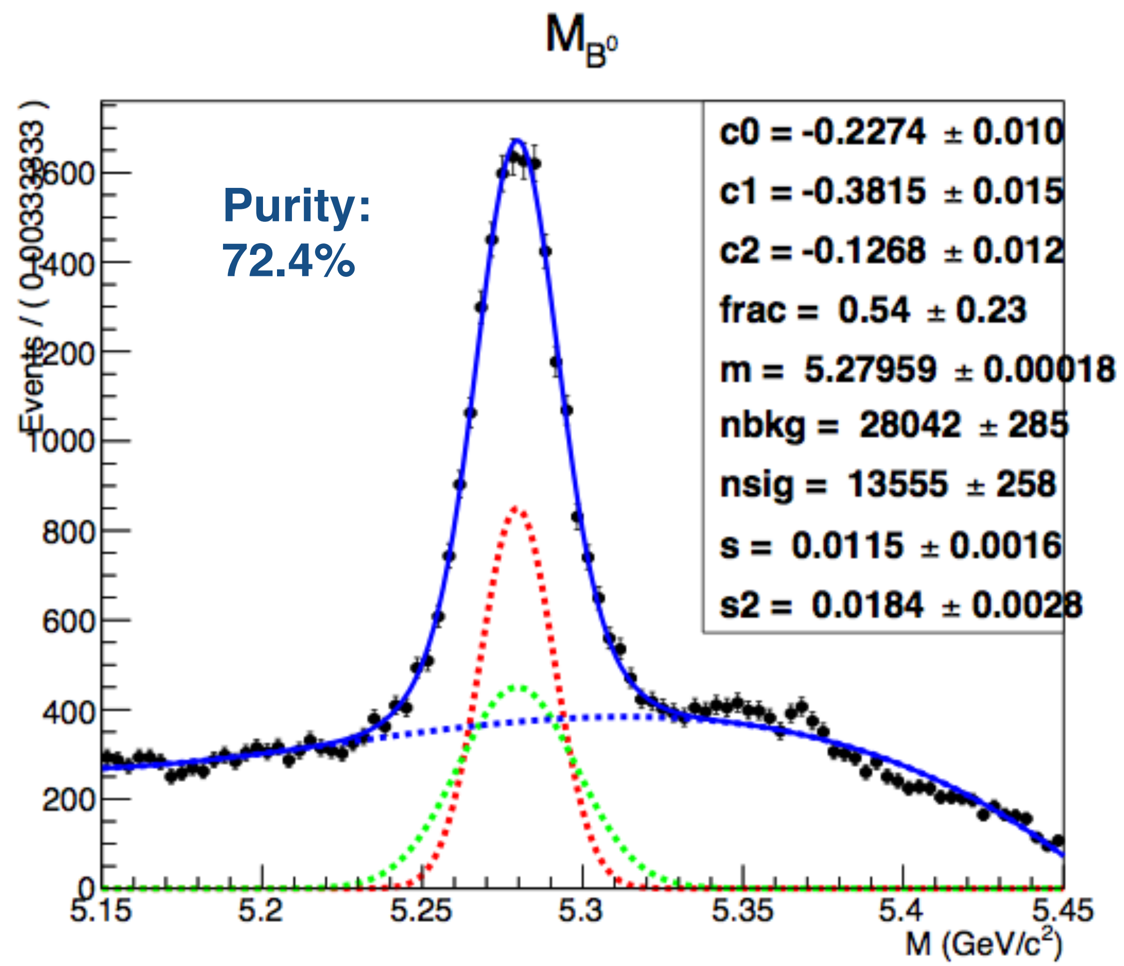
Adventure has just begun, long journey ahead, Vast territory to explore.

Backup

Charmonium-like charged states potentially interesting for exotic quark content —- tetra-quark?

$B^0 \rightarrow J/\psi(\text{or } \psi') K\pi$





with harder selection better purity

Amplitude Analysis Formalism

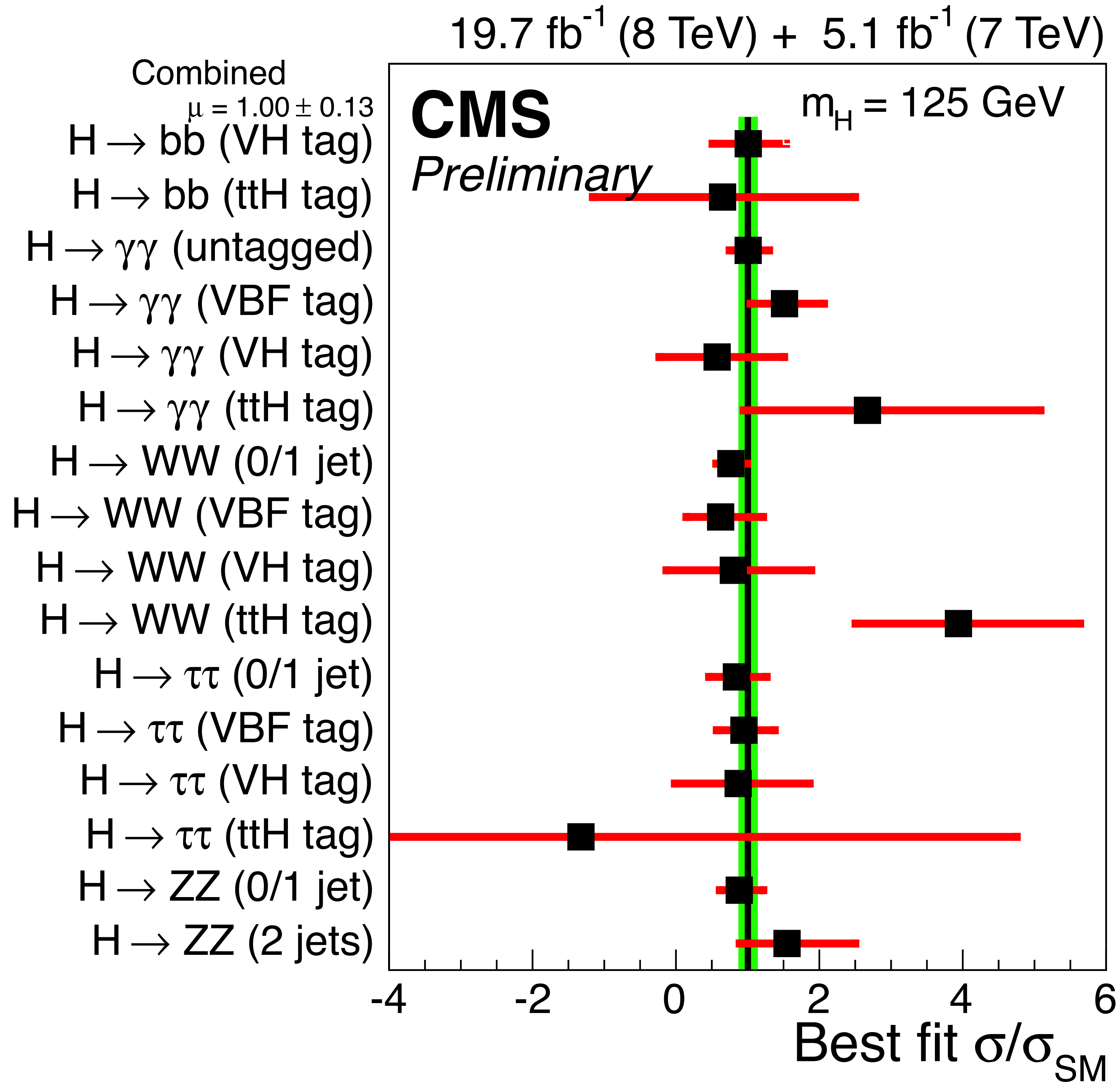
- The amplitude of the decay $B^0 \to J/\psi\ K\pi$ is represented by the sum of Breit-Wigner contributions for several intermediate two-body states
- $K*0(800)$, $K*(892)$, $K*(1410)$, $K*0(1430)$, $K*2(1430)$, $K*(1680)$, $K*3(1780)$, $K*0(1950)$,$K*2(1980)$, $K*4(2045)$
- The idea is to show that the fit to data where amplitudes of all these resonances add up and interfere is not good enough, a new intermediate resonance $B^0 \to Z(4430)K$, $(Z(4430) \to J/\psi\pi)$ is needed

Parameter space = $\Phi = (M^2_{K\pi}, M^2_{J/\psi\pi}, \theta_{J/\psi}, \varphi).$

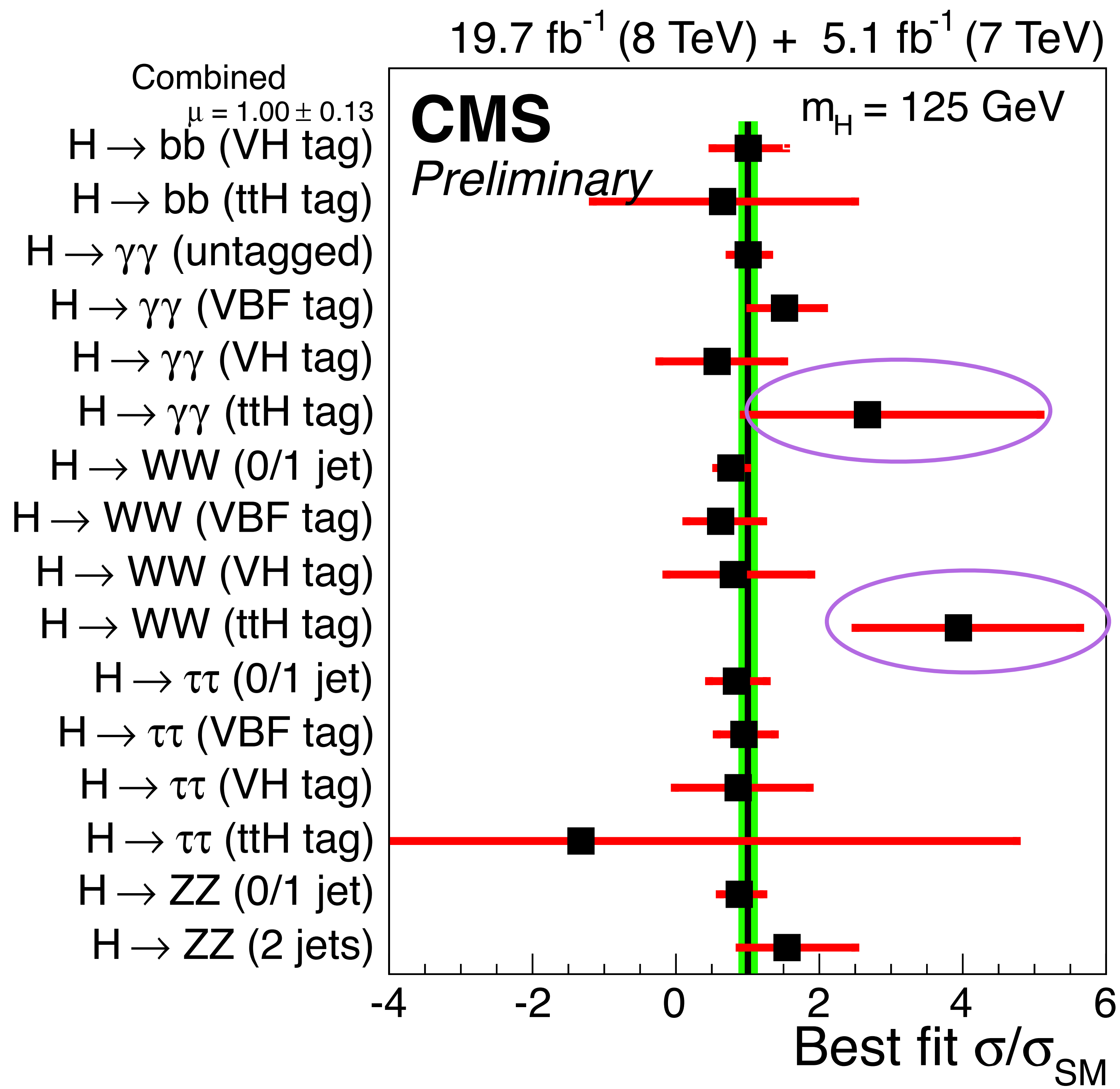
There is good potential to find evidence

Finally we would like to add that taking all the electroweak measurements together, including W boson mass, we see a converging trend of all the measurements such that $\sin^2\theta_{\rm eff}$ remains close to $\simeq 0.2311$, within the overlapping band shown in Fig. 3. In the coming years when SLD improves its $\sin^2\theta_{\rm eff}$ measurements significantly and LEP and Tevatron have improved the W mass measurements further, this will become clear. However from Fig. 3, one finds that the effects of weak radiative corrections in $\sin^2\theta_{\rm eff}$ are least visible for such a situation. In fact we end up with a twofold ambiguity because such a value of $\sin^2\theta_{\rm eff}$ can also be obtained by simply running $\alpha_{\rm QED}$ up to Z mass scale as shown by the overlapping bands. This is a puzzling situation and one may ask the question: why should nature want the weak correction around this scale to be least visible. For example, a significantly light top quark or pretty more massive than the observed would have been perfectly fine with the SM leading to significantly larger or smaller value of $\sin^2\theta_{\rm eff}$. The proximity of the data with the zone made by overlapping bands in Fig. 3 is intriguing and deserves special attention.

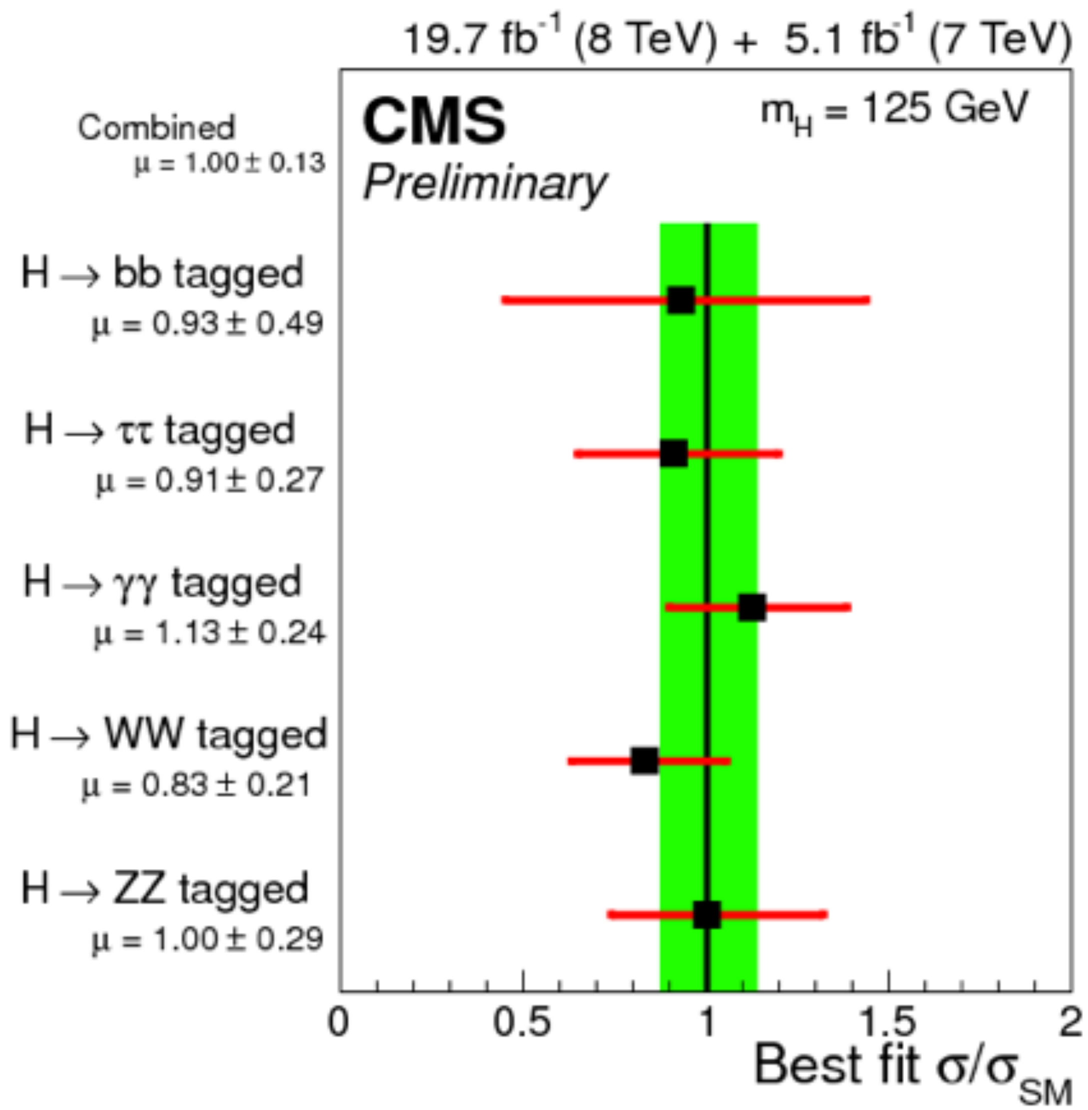
Signal strength classified with different tags

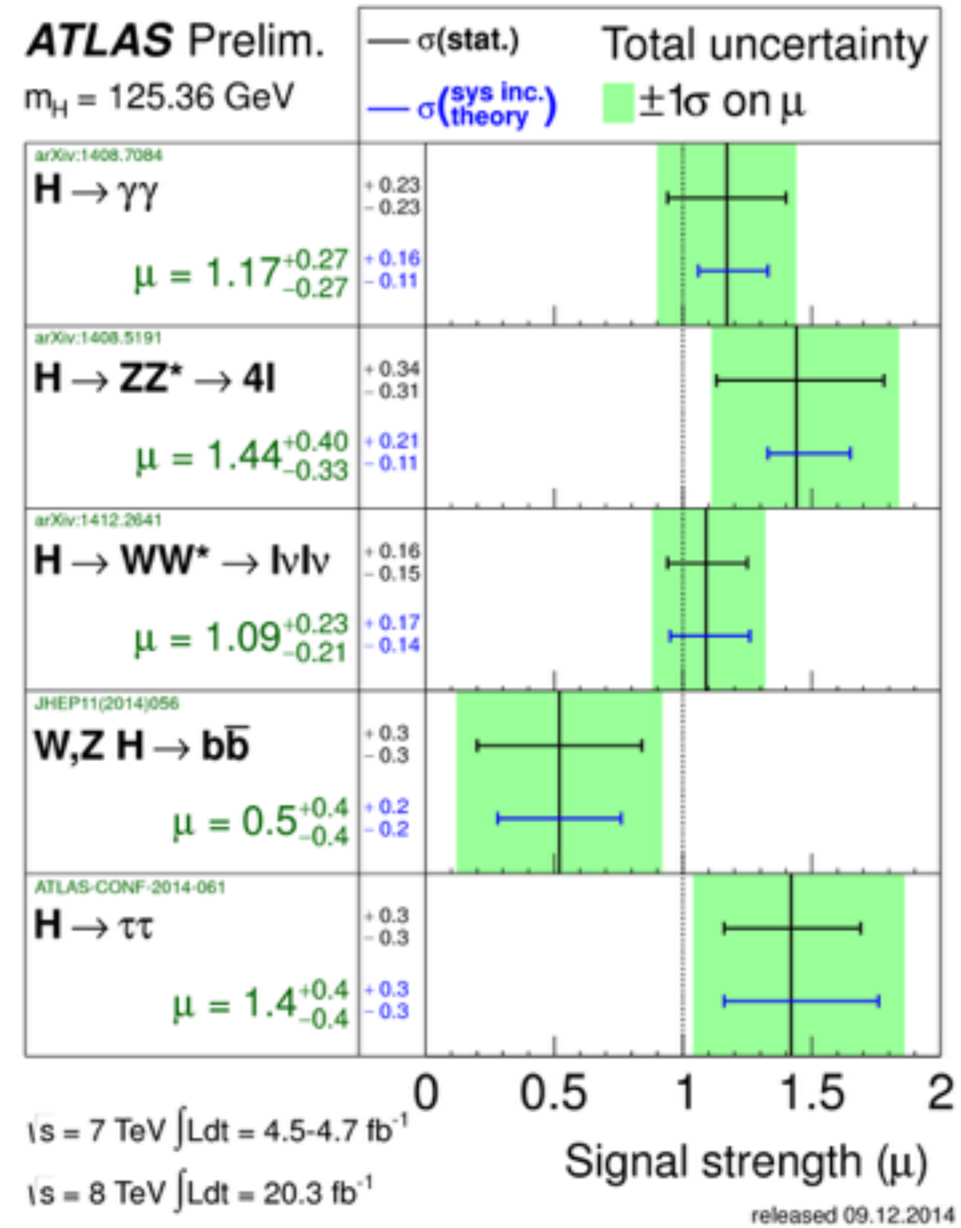


Signal strength classified with different tags



Higgs Signal Strength with respect to SM





CMS: $\mu = 1.00 \pm 0.09\,(\text{stat}) \pm 0.07\,(\text{syst}) \pm 0.08\,(\text{theory})$

ATLAS: $\mu = 1.30 \pm 0.12\,(\text{stat}) \pm 0.09\,(\text{syst}) \pm 0.10\,(\text{theory})$

ATLAS to be updated

Result

$$\sigma_{t\text{-ch.}} = 227.8 \pm 9.1\,(\text{stat.}) \pm 14.0\,(\text{exp.})\,{}^{+28.7}_{\;27.7}\,(\text{theo.}) \pm 6.2\,(\text{lumi.})\,\text{pb} = 227.8\,{}^{+33.7}_{\;33.0}\,\text{pb}$$

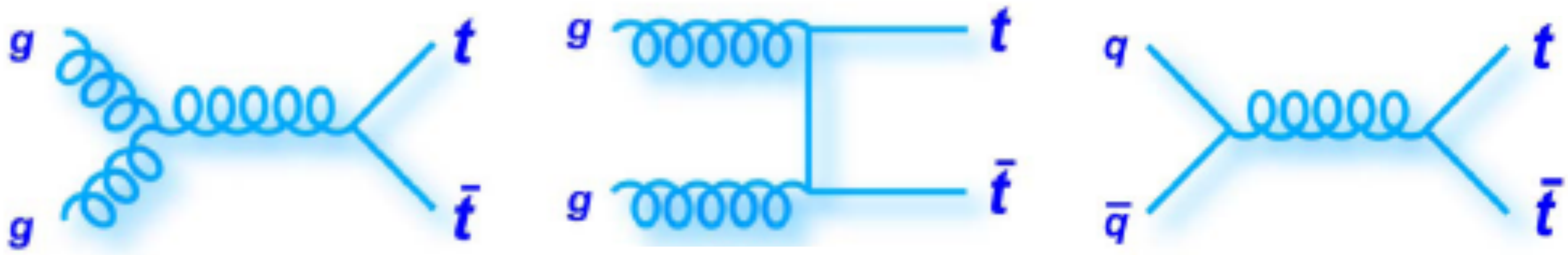
$$|V_{tb}| >> |V_{td}|, |V_{ts}|$$

$$\sigma_{t-ch.} = 216.99^{+6.62}_{-4.64}(scale) \pm 6.16(PDF)pb$$

$$|f_{LV}V_{tb}| = \sqrt{\frac{\sigma^{meas}_{t-ch}}{\sigma^{th}_{t-ch}}}$$

$$|f_{LV}V_{tb}| = 1.02 \pm 0.07(exp.) \pm 0.02(theo.)$$

Top Quark Pair Production at LHC



Isolated leptons (e , μ or τ)

Isolation (including PU subtraction)

Calibrations and efficiencies from dilepton resonances (Z, ϒ, J/ψ)

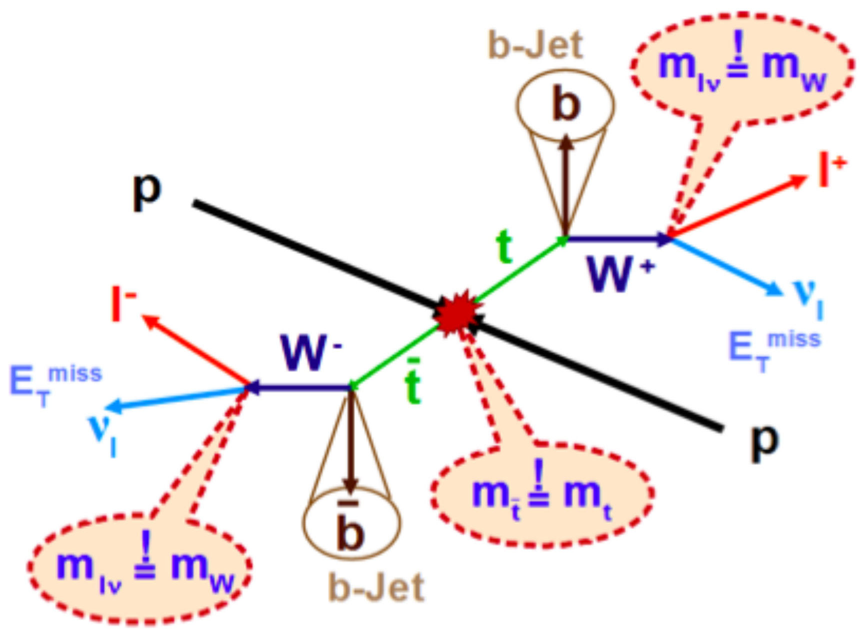
b-tagging

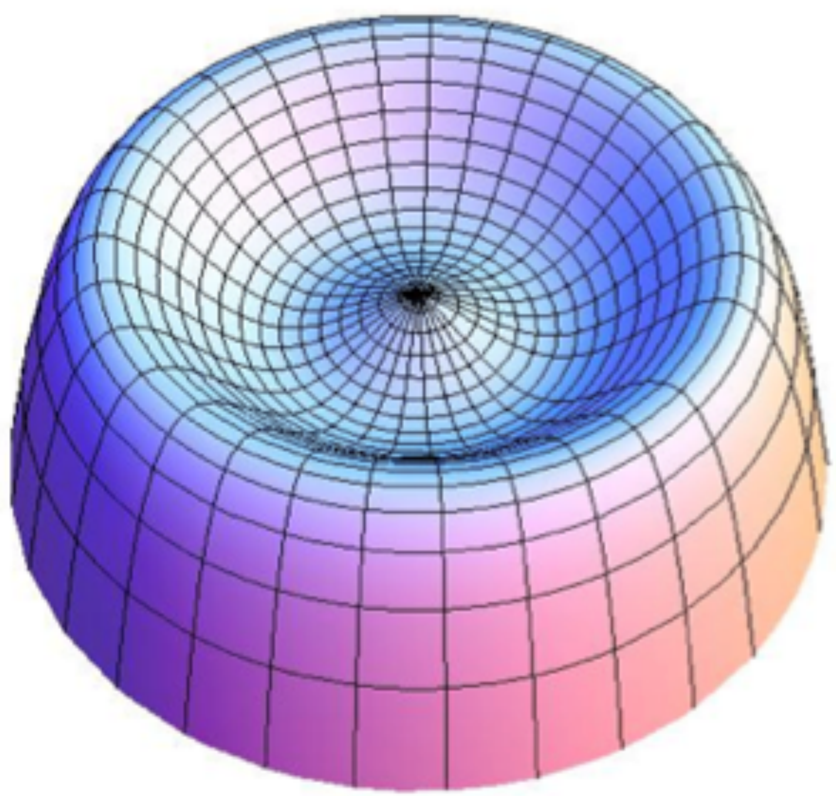
Combination of several techniques (vertex, impact parameter, track distributions within jets)

Jet and missing E_T

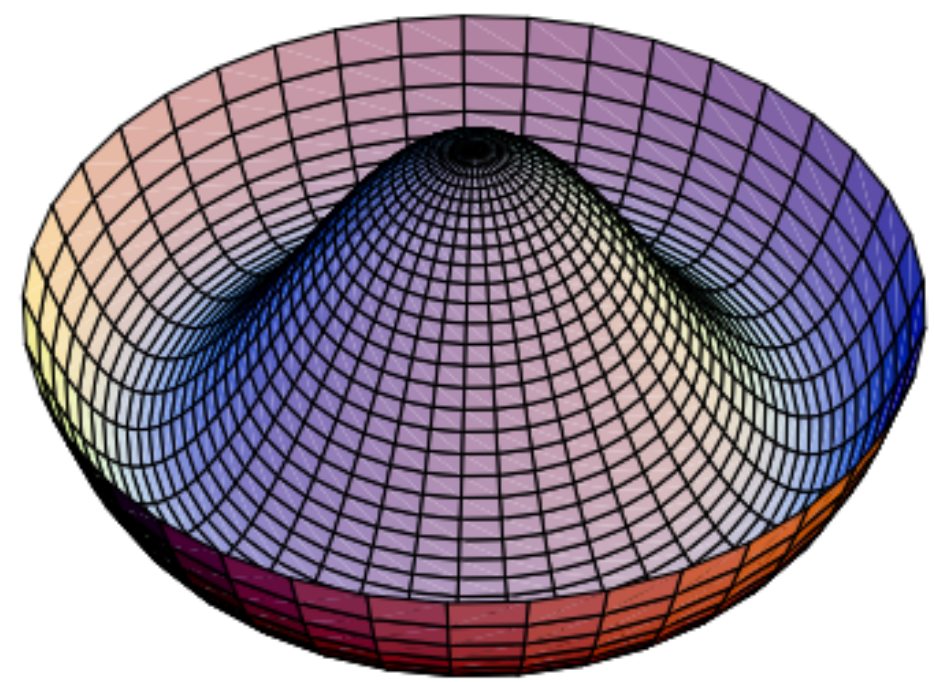
Optimal resolution and scale

Pile-up subtraction based on charged component





metastable vacuum



stable vacuum

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$$V \equiv (\sqrt{2}G_\mu)^{-1/2} \quad = \quad 246.21971 \pm 0.00006\,\text{GeV}$$

Fermi constant for μ decay

$$\frac{1}{\tau_\mu} = \frac{G_\mu^2 m_\mu^5}{192\pi^3} F(\frac{m_e^2}{m_\mu^2})(1+\Delta q)(1+\frac{3m_\mu^2}{5M_W^2})$$

Relevant for ttH
top Yukawa coupling