ttH analysis at CMS

张华桥 （高能物理研究所）

10th, Nov 2014, LHC-mini workshop at HangZhou

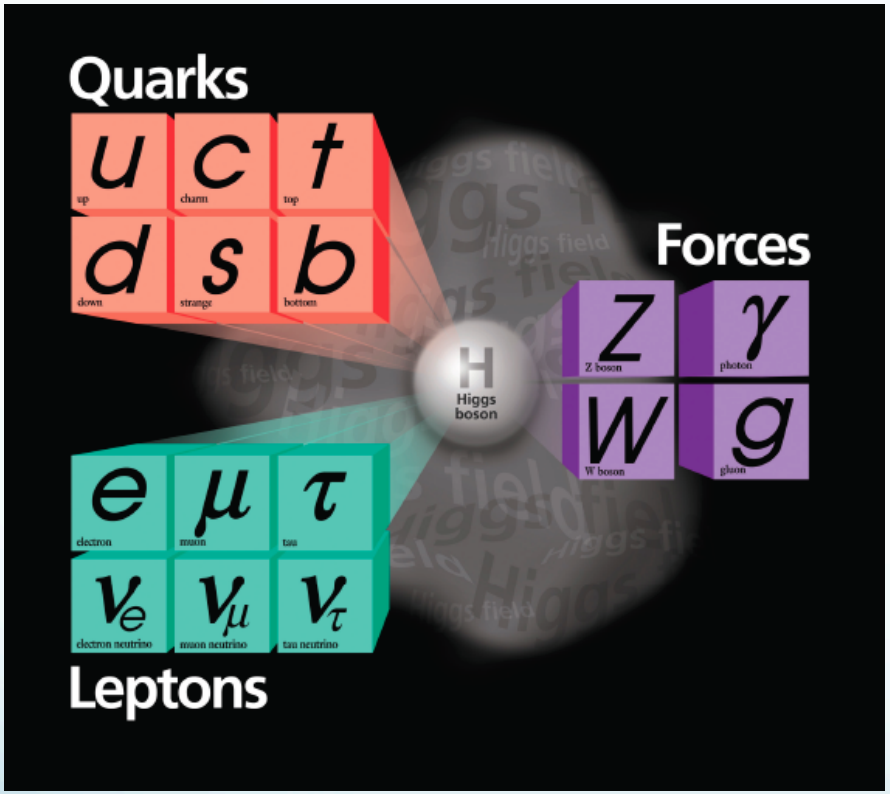
Latest CMS ttH results: JHEP09(2014)087

Outline

- Motivation
- Experimental Setup
- Analysis results of ttH at CMS
- Perspective of ttH for LHC run II
- ttH analysis at IHEP-CMS group

The Big Picture (1)

- A Higgs is discovered in July 2012: Is this THE Higgs?



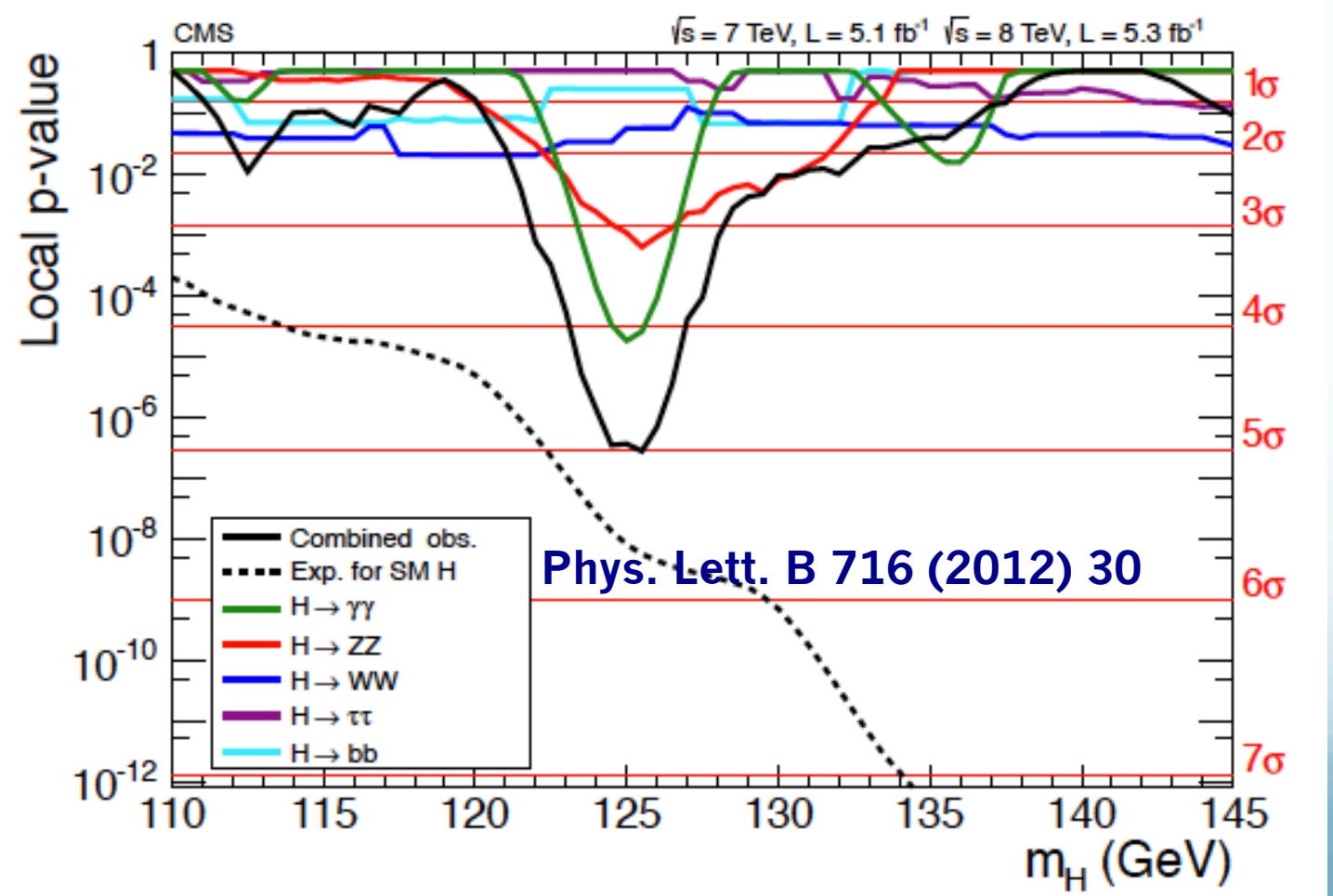
基本粒子的质量起源问题
Nobel Prize 2013: Higgs

- Extend our understanding of interactions from 4 to 6

电，磁，强，弱， 汤川，Higgs自相互作用

The big picture (2)

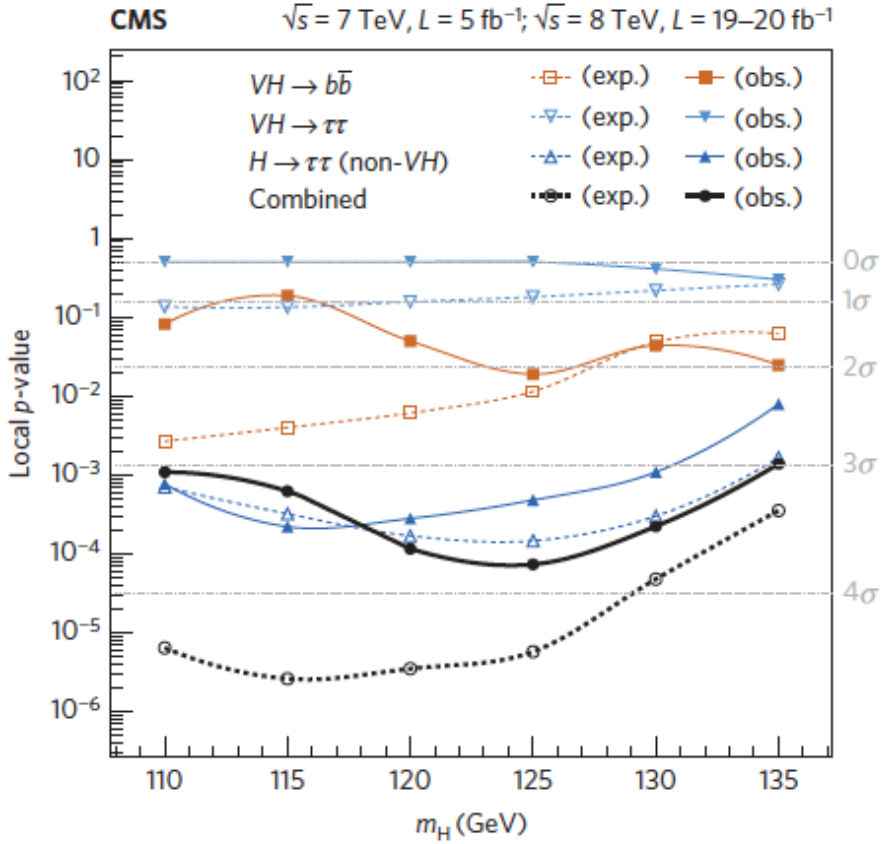
- Discovery dominated by Higgs decay to bosons/ gamma

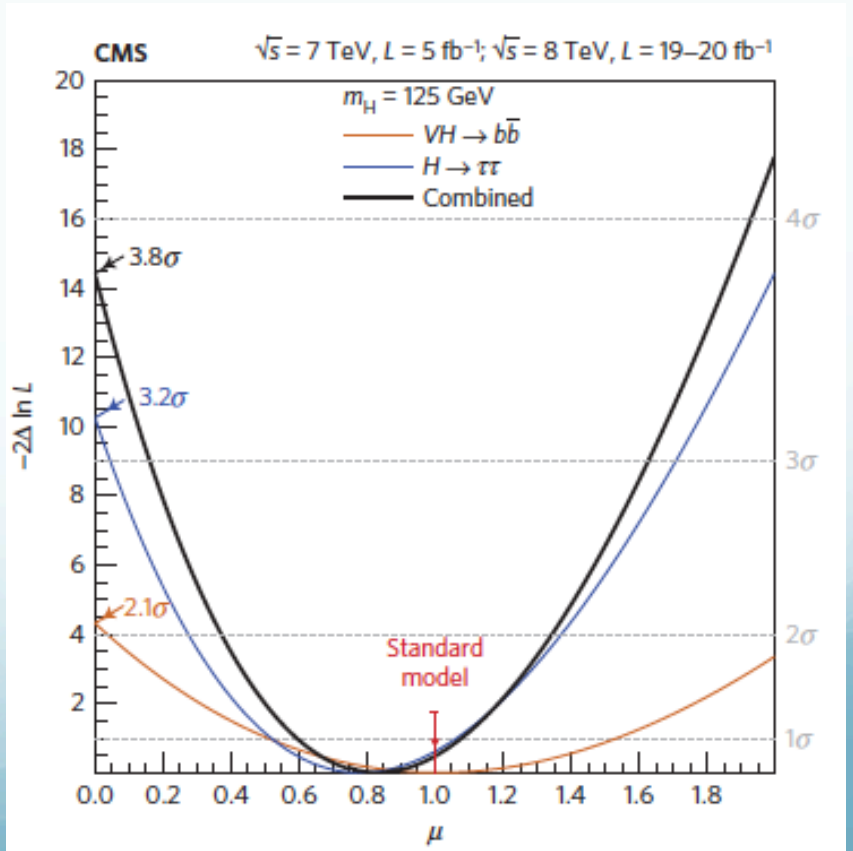


The big picture (3)

- Evidence of Higgs couples to fermions:
  Nature Phys. 10 (2014) 557-560

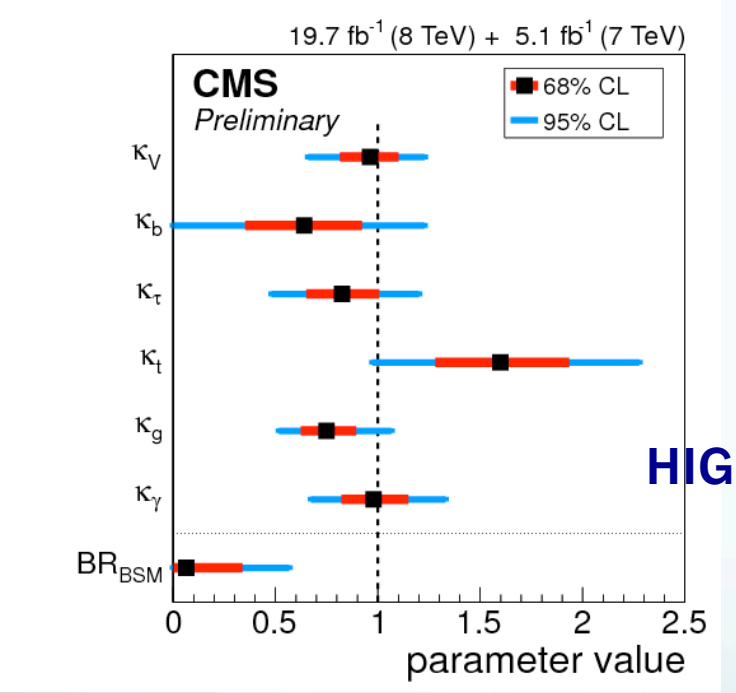
- Our world: Fermions seems do gain mass from Higgs



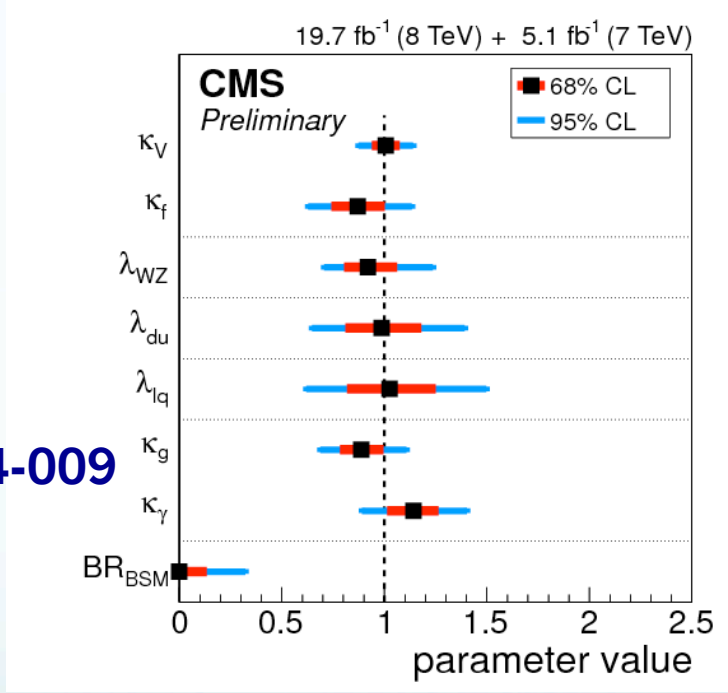


The big picture (4)

- Tests of Higgs properties: So far agrees with SM hypothesis of coupling（spin/parity）



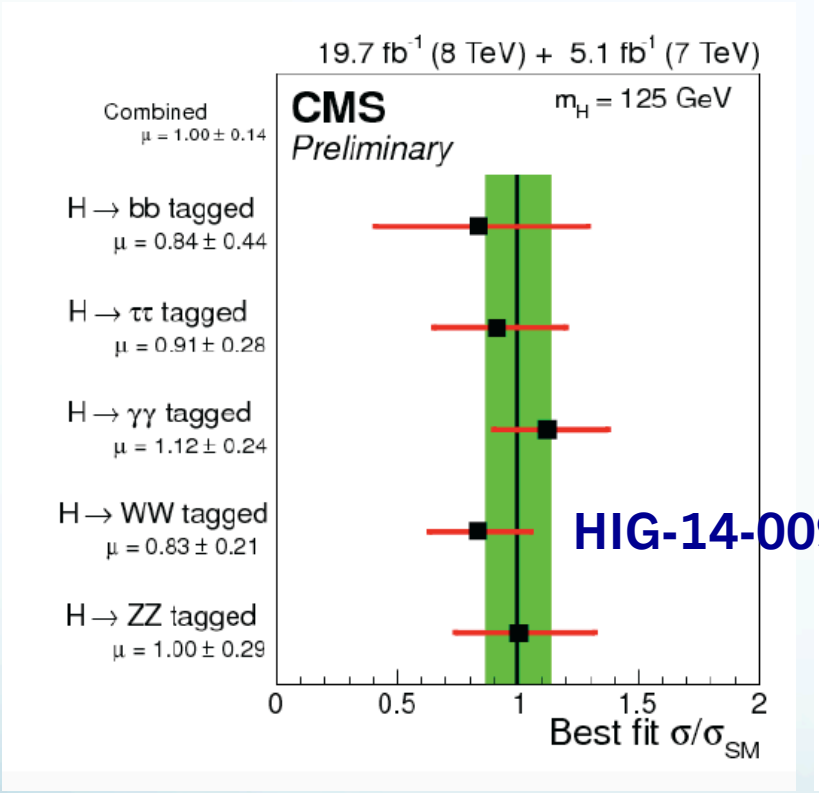
HIG-14-009



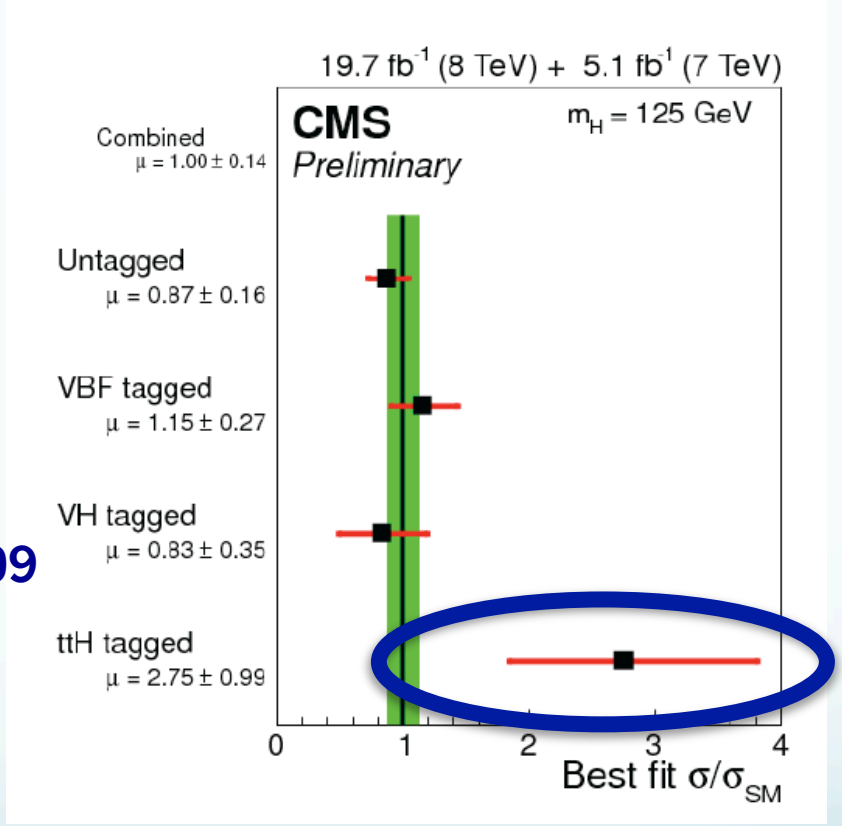
- We know this not is the whole story
  - Neutrino masses, dark mater, dark energy…

The big picture (5)

- What current data tell us: 2.0 sigma deviation of ttH



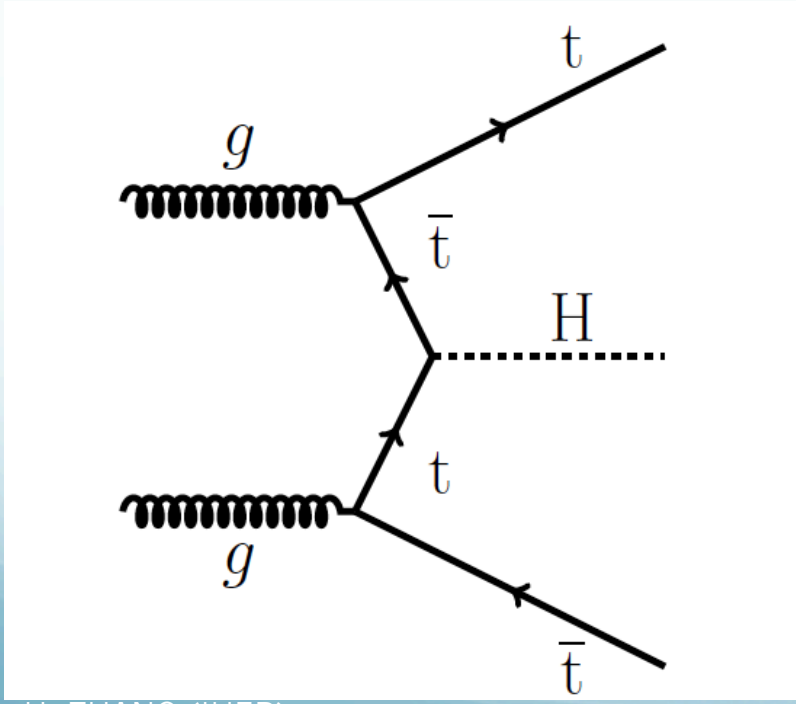
HIG-14-009

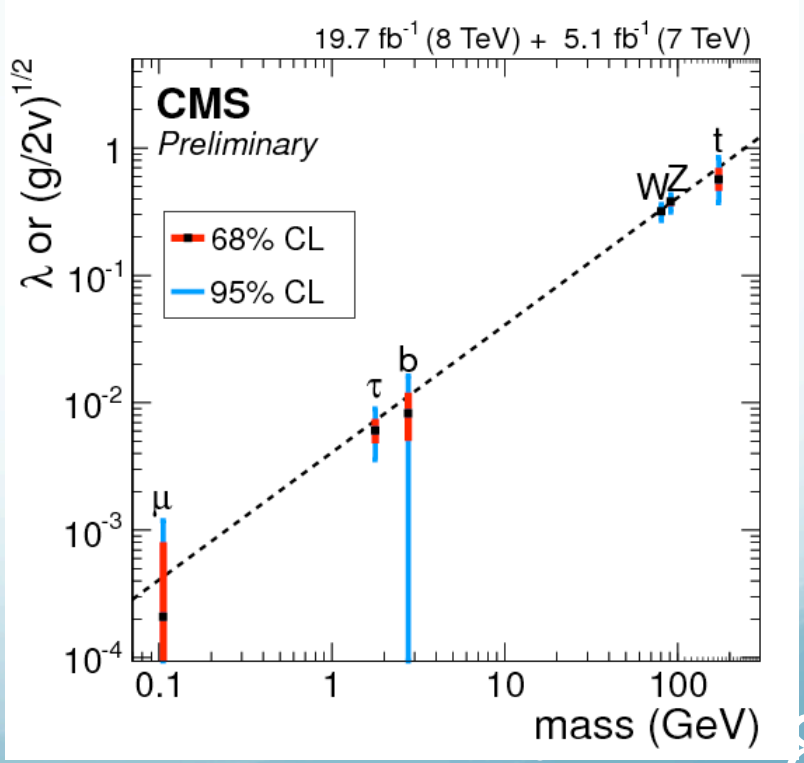


- If you want to know more, see my next slides...

Why ttH (experimental view)

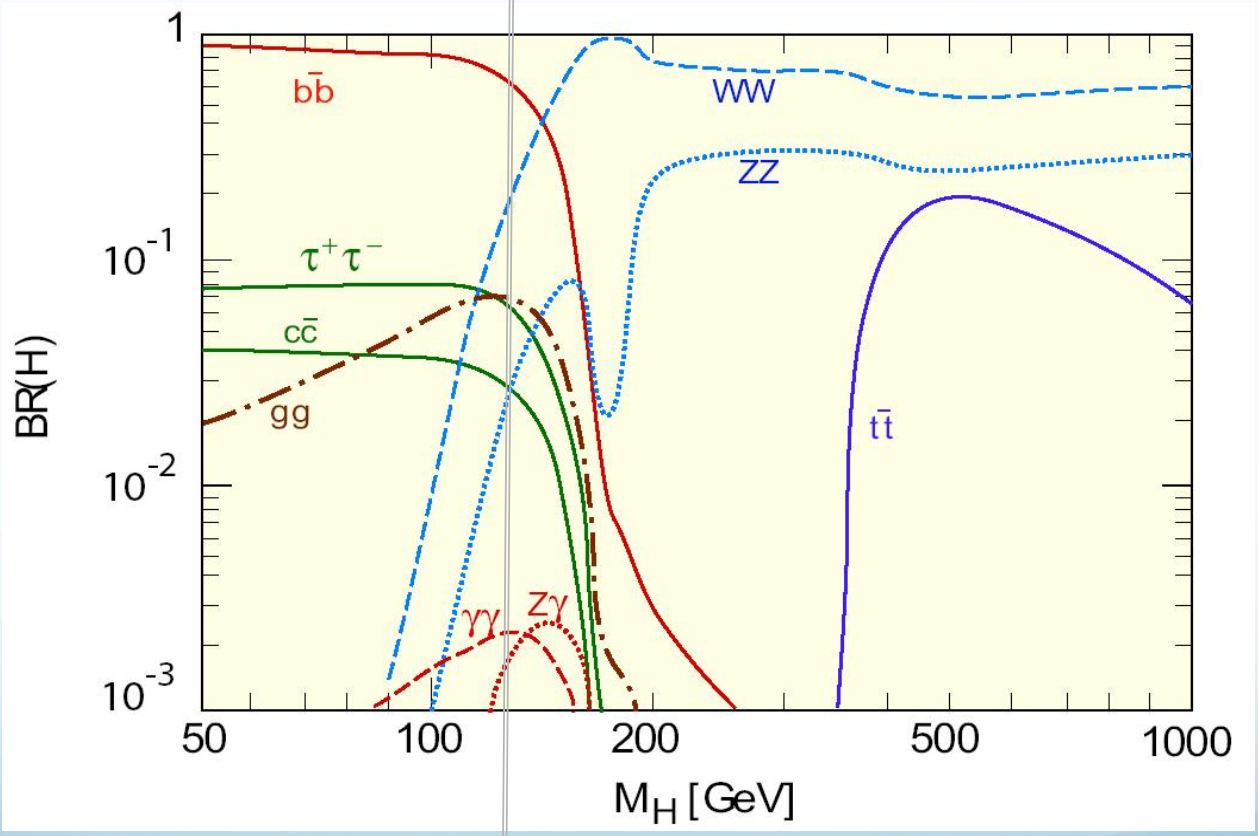
Top-Higgs Yukawa coupling appears in Higgs production and decay loop contributions
Direct measurement
Largest coupling to Fermion
The only one that could possible direct measure at LHC



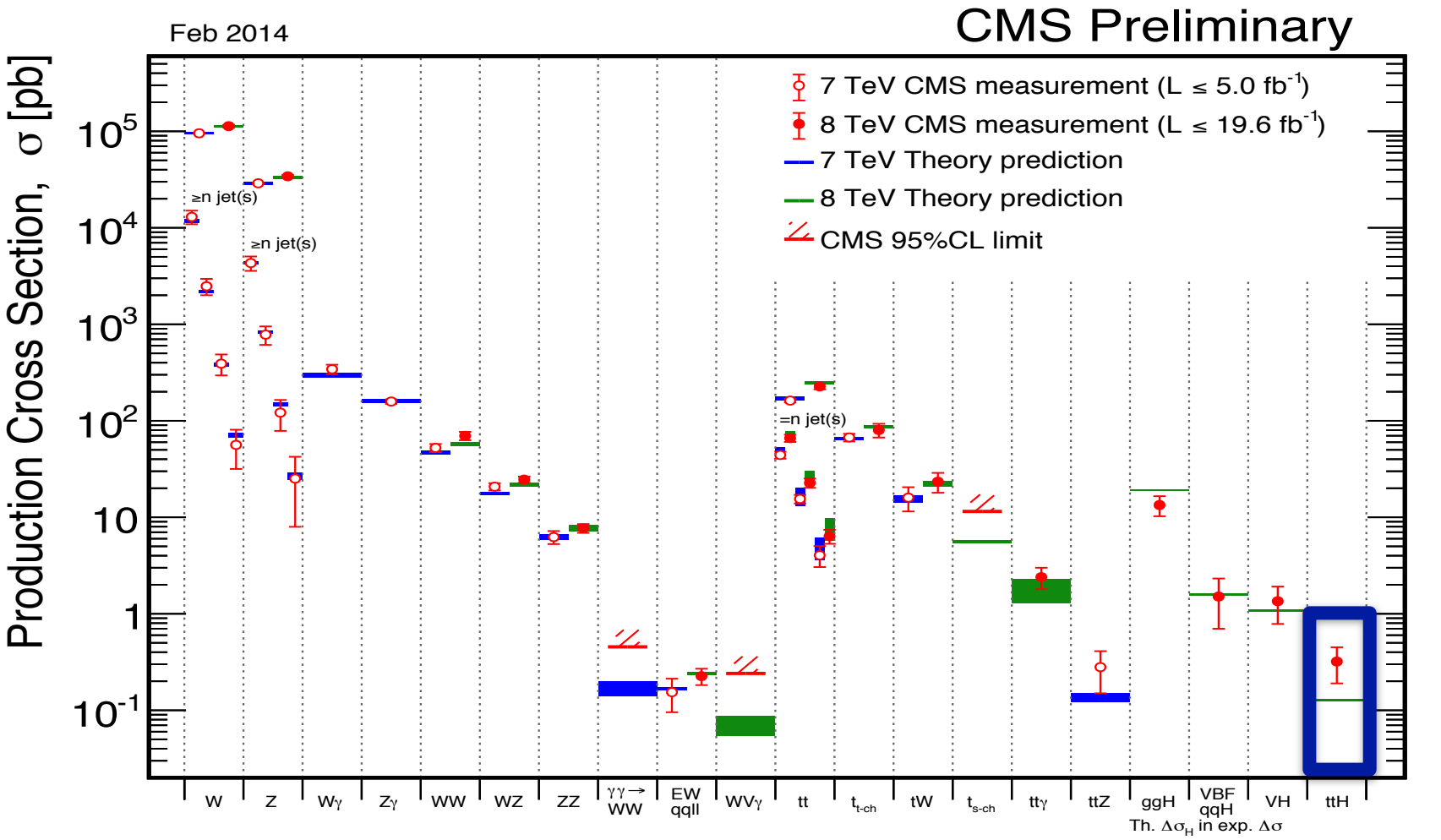


Analysis channels of ttH (1)

- Higgs decay modes:
  - Lots of final states to be analyzed: large room for contributions



Analysis channels of ttH (2)



- But: Very challenge

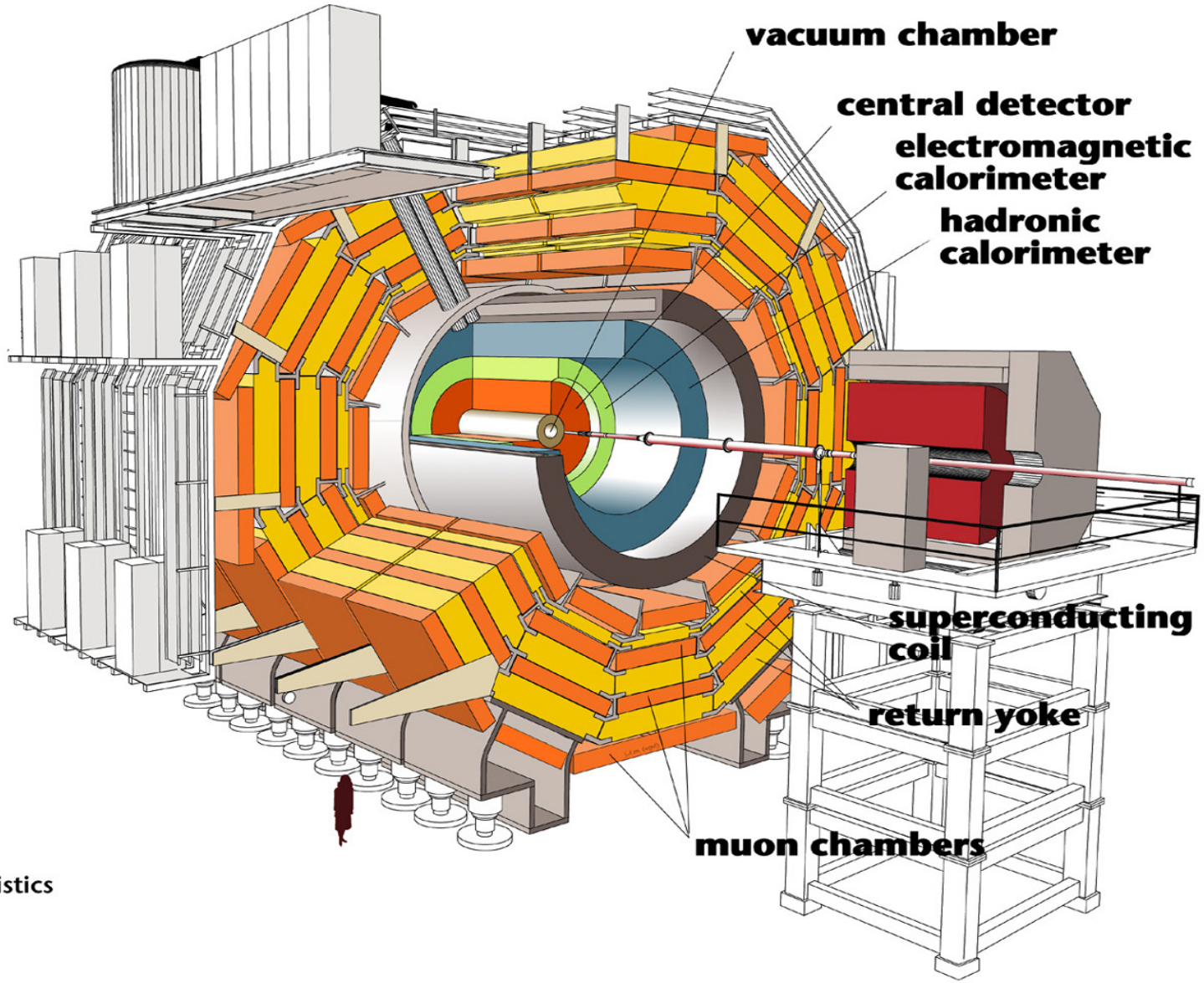
Experimental setup

大型强子对撞机（LHC）
位于欧洲核子研究中心（CERN）

ATLAS/CMS物理目标：
1.寻找希格斯粒子
2.寻找超出标准模型的新物理

- 周长27km，跨越瑞士法国国境，总投资40亿美元
- 世界能量最高最大的加速器，设计质心系能量14TeV（14×10^{12}eV）

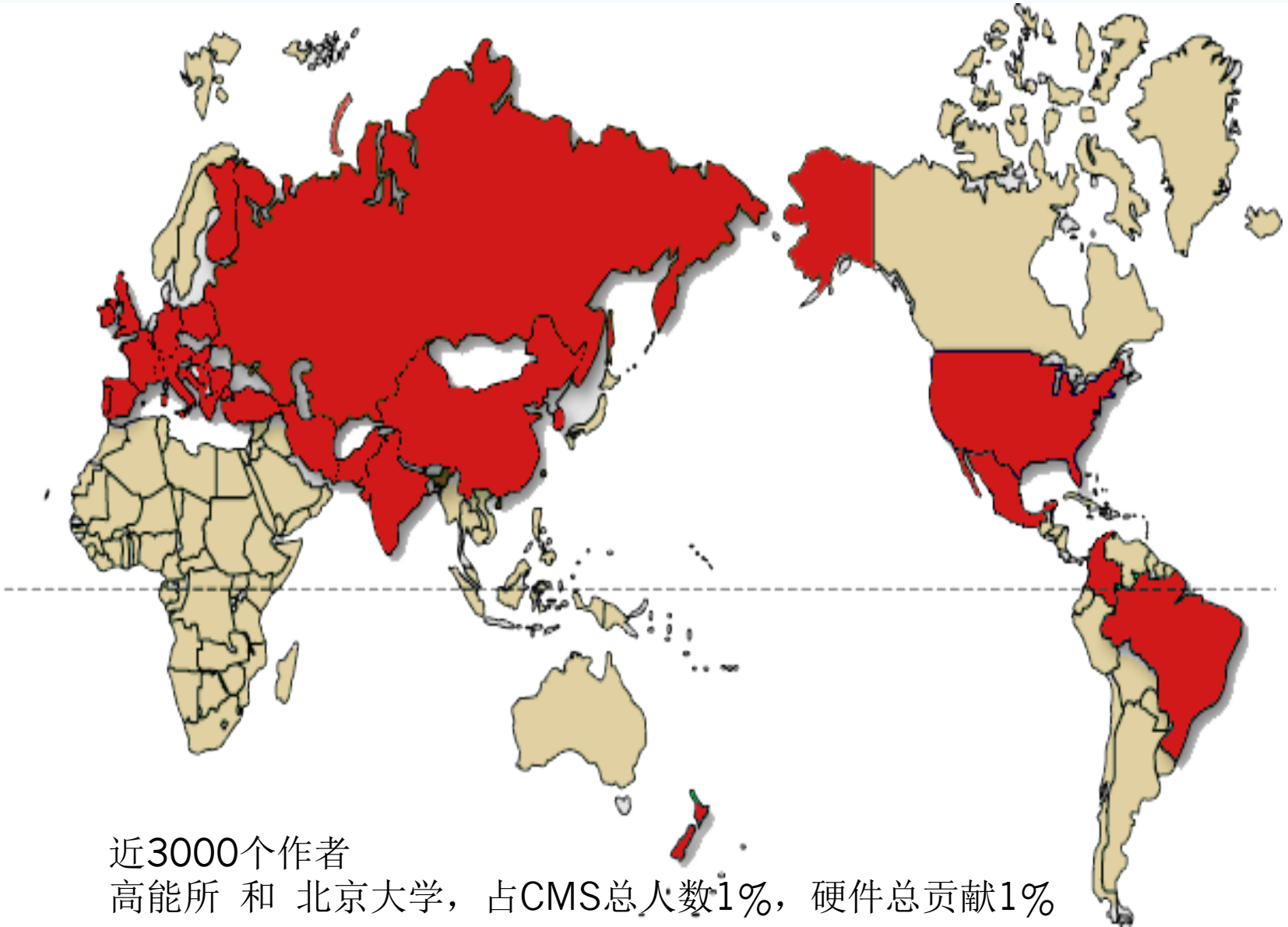
CMS detector



Detector characteristics

Width:	22m
Diameter:	15m
Weight:	14'500t

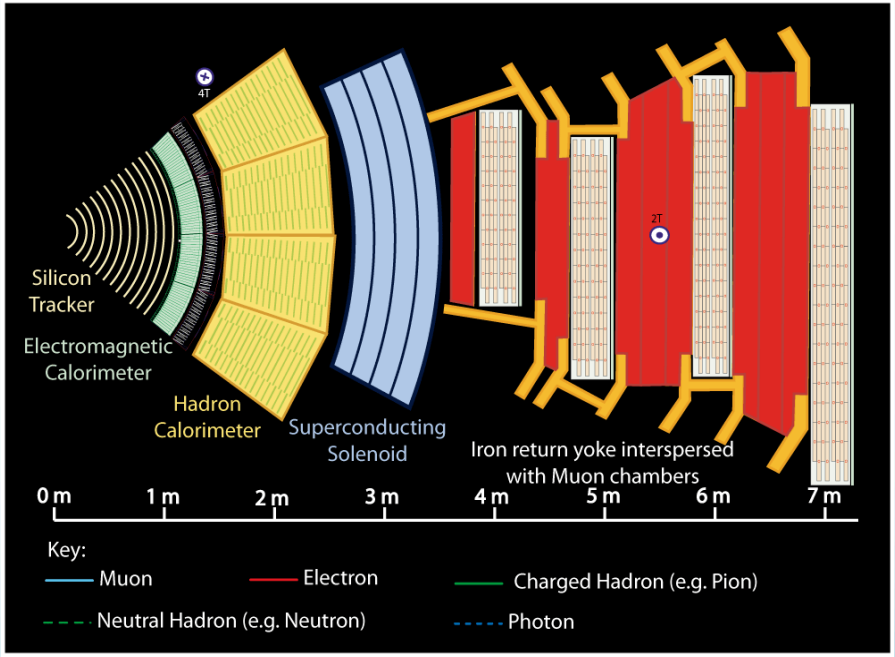
CMS collaboration



近3000个作者
高能所 和 北京大学，占CMS总人数1%，硬件总贡献1%

Particle Flow Reconstruction

- Particle Flow (Follow)
  - Optimally combines the information from all CMS sub-detectors to reconstruct and identify each individual particle
    - Charged hadrons
    - Neutral hadrons
    - Photons
    - Electrons
    - Muons
- Jet Energy/Resolution
- Missing Transverse Energy



ttH analysis results at CMS

ttH analysis at CMS

H → Photons H → γγ	Leptonic ($t\bar{t}H \to \ell\nu jjbb\gamma\gamma$, $t\bar{t}H \to \ell\nu\ell\nu bb\gamma\gamma$)
	Hadronic ($t\bar{t}H \to jjjjbb\gamma\gamma$)

H → Hadrons H → $b\bar{b}$ H → $\tau_h\tau_h$ H → WW	Lepton + Jets ($t\bar{t}H \to \ell\nu jjbbbb$)
	Dilepton ($t\bar{t}H \to \ell\nu\ell\nu bbbb$)
	Hadronic τ ($t\bar{t}H \to \ell\nu\tau_h[\nu]\tau_h[\nu]jjbb$)

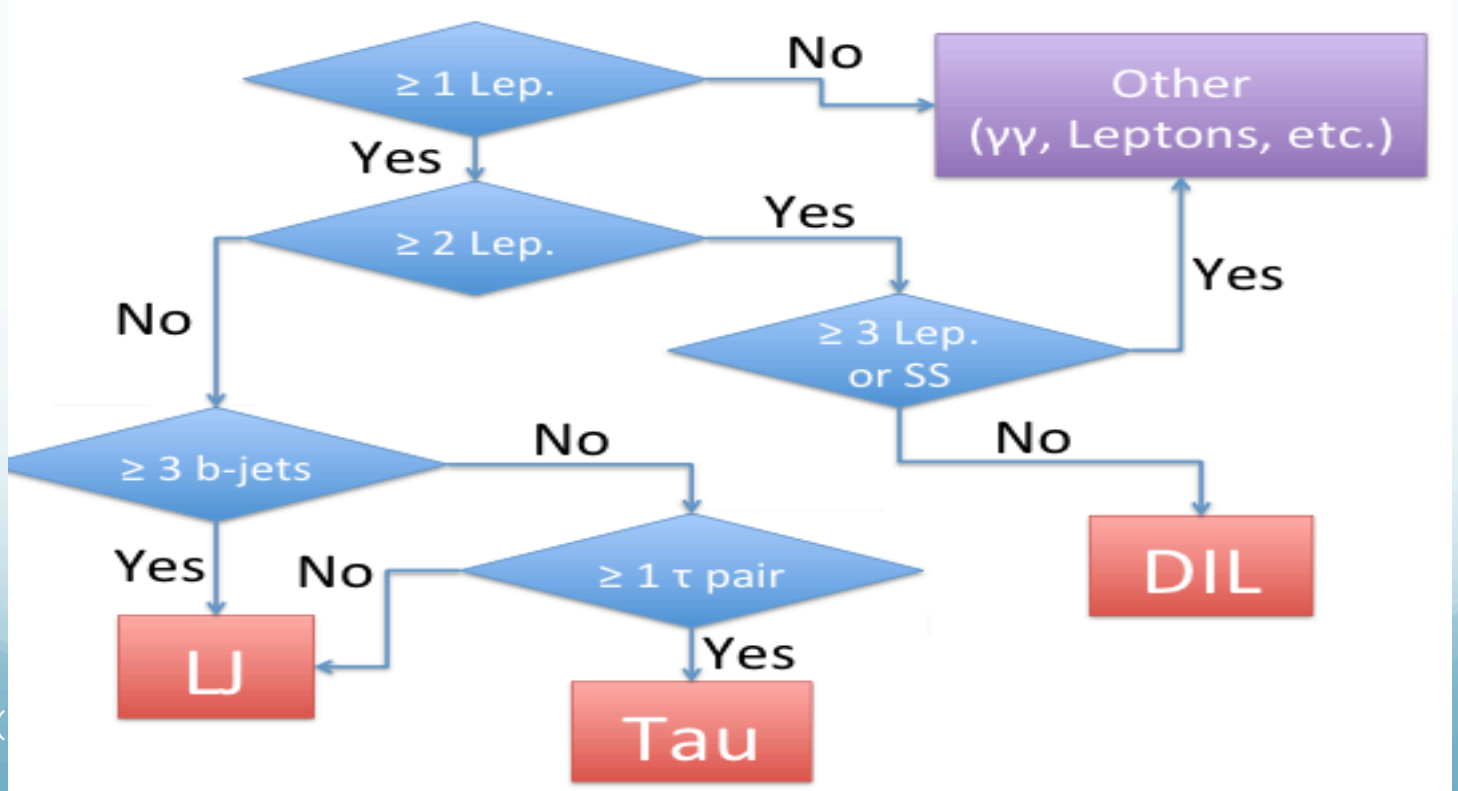
H → Leptons H → WW H → ττ H → ZZ	Same-Sign Dilepton ($t\bar{t}H \to \ell^{\pm}\nu\ell^{\pm}[\nu]jjj[j]bb$)
	3 Lepton ($t\bar{t}H \to \ell\nu\ell[\nu]\ell[\nu]j[j]bb$)
	4 Lepton ($t\bar{t}H \to \ell\nu\ell\nu\ell[\nu]\ell[\nu]bb$)

Simulation samples for ttH

Process	Generator
ttH	Pythia
gg → H → ϒϒ	Powheg+Pythia
qqbar→qqbarH→ϒϒ	Powheg+Pythia
tt+jets(ttbb/ttcc/ttb/tt+lf)	MadGraph+Pythia
ttW/Z	MadGraph+Pythia
Single top	Powheg+pythia
W/Z+jets	MadGraph+Pythia
Diboson	MadGraph+Pythia
WWZ	MadGraph+Pythia
WWW	MadGraph+Pythia
tt+gamma+jets	MadGraph+Pythia
ttWW	MadGraph+Pythia

ttH,H→Hadron

H → Hadrons $H \to b\bar{b}$ $H \to \tau_h\tau_h$ $H \to WW$	Lepton + Jets ($t\bar{t}H \to \ell\nu jjbbbb$)	Single Lepton	1 e/μ, $p_T > 30$ GeV $\geq$4 jets + $\geq$2 b-tags, $p_T > 30$ GeV
	Dilepton ($t\bar{t}H \to \ell\nu\ell\nu bbbb$)	Dilepton	1 e/μ, $p_T > 20$ GeV 1 e/μ, $p_T > 10$ GeV $\geq$3 jets + $\geq$2 b-tags, $p_T > 30$ GeV
	Hadronic τ ($t\bar{t}H \to \ell\nu\tau_h[\nu]\tau_h[\nu]jjbb$)	Single Lepton	1 e/μ, $p_T > 30$ GeV 2 τ_h, $p_T > 20$ GeV $\geq$2 jets + 1-2 b-tags, $p_T > 30$ GeV



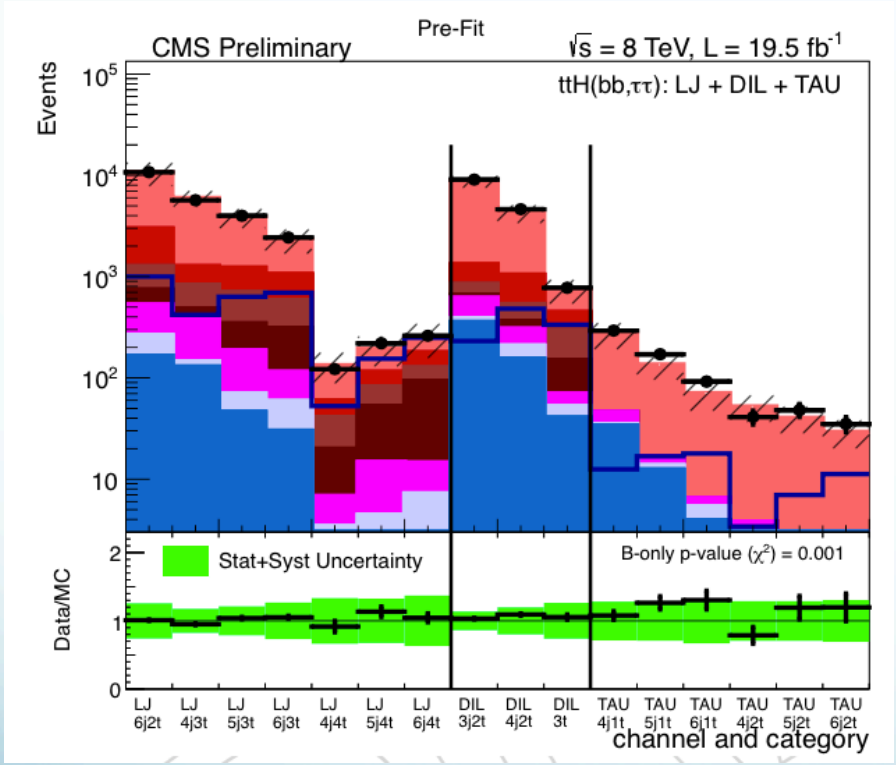
Challenges

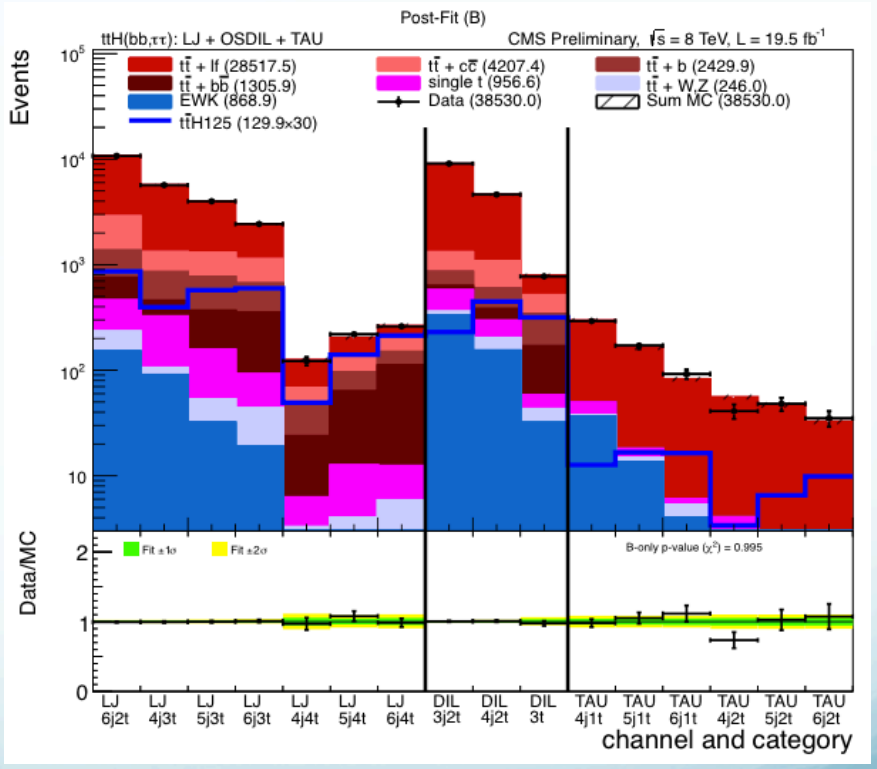
- Very small signal over large background
  - The largest S/B is <3%, tt+jets > 90%
- No sharp peak due to un-perfect jet energy resolution
  - Can not use only one discriminate variable to separate ttH to backgrounds

	≥6 jets + 2 b-tags	4 jets + 3 b-tags	5 jets + 3 b-tags	≥6 jets + 3 b-tags	4 jets + 4 b-tags	5 jets + ≥4 b-tags	≥6 jets + ≥4 b-tags
$t\bar{t}H(125.6\,GeV)$	28.5 ± 2.5	12.4 ± 1.0	18.1 ± 1.5	18.9 ± 1.5	1.5 ± 0.2	4.4 ± 0.4	6.7 ± 0.6
$t\bar{t}$+lf	7140 ± 310	4280 ± 150	2450 ± 130	1076 ± 74	48.4 ± 10.0	54 ± 12	44 ± 11
$t\bar{t}$+b	570 ± 170	364 ± 94	367 ± 98	289 ± 87	20.0 ± 5.5	28.6 ± 8.0	33 ± 10
$t\bar{t} + b\bar{b}$	264 ± 59	123 ± 29	193 ± 42	232 ± 49	15.8 ± 3.6	45.2 ± 9.7	86 ± 18
$t\bar{t} + c\bar{c}$	2420 ± 300	690 ± 130	800 ± 130	720 ± 110	29.7 ± 5.6	55 ± 11	81 ± 13
$t\bar{t}$+W/Z	85 ± 11	15.0 ± 2.0	20.9 ± 2.8	24.7 ± 3.3	1.0 ± 0.2	2.1 ± 0.4	4.7 ± 0.8
Single t	236 ± 18	213 ± 17	101.7 ± 10.0	47.7 ± 6.7	2.8 ± 1.4	7.5 ± 3.8	6.7 ± 2.6
W/Z+jets	75 ± 27	46 ± 30	13 ± 12	7.7 ± 8.8	1.1 ± 1.2	0.9 ± 1.0	0.3 ± 0.8
Diboson	4.5 ± 1.0	5.4 ± 0.9	2.0 ± 0.5	1.0 ± 0.4	0.2 ± 0.2	0.1 ± 0.1	0.2 ± 0.1
Total bkg	10790 ± 200	5730 ± 110	3935 ± 74	2394 ± 65	119.0 ± 8.2	193.4 ± 10.0	256 ± 16
Data	10724	5667	3983	2426	122	219	260

Analysis strategy (1)

1. Divide events into 16 different categories according to Number of jets and number of b-tagged jets

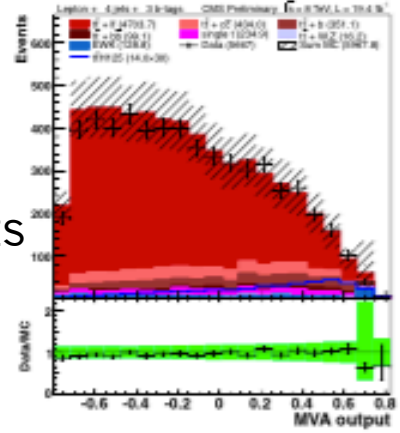


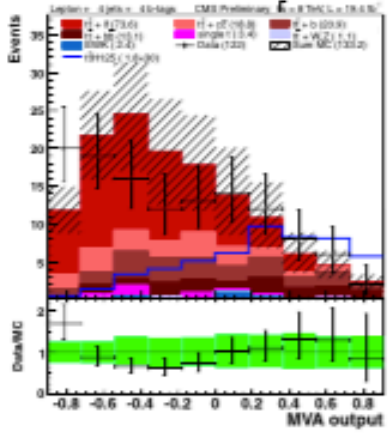


Analysis strategy (2)

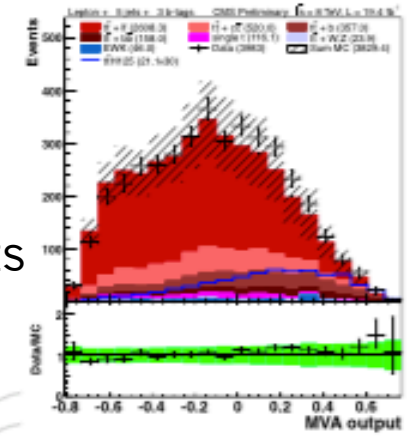
1. In each jet bin, use BDT to separate ttH signal from background➔ BDT response distribution
2. Here take ttH,H→bb single lepton analysis for example, same done for dilepton and tau final states

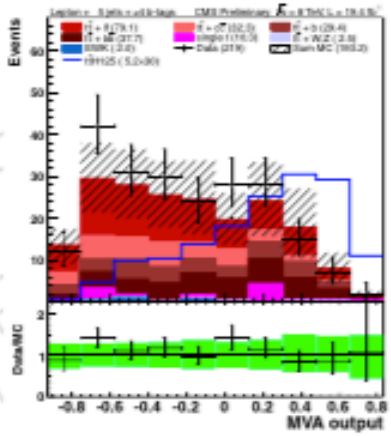
4 Jets



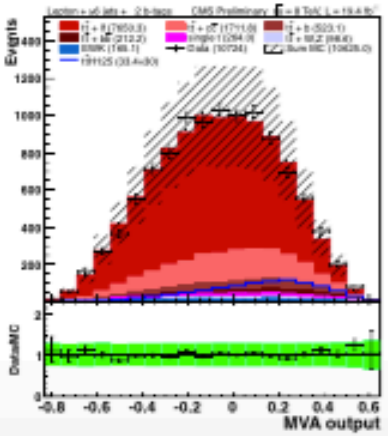


5 Jets

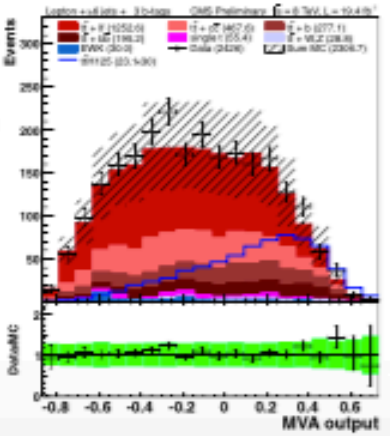




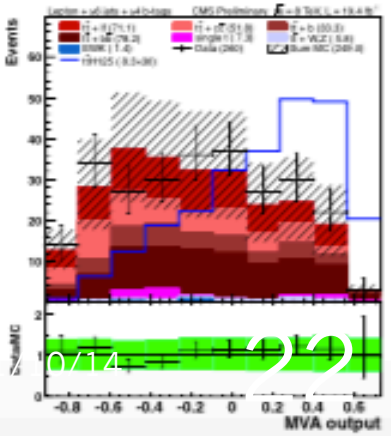
2 bjet



3 bjet



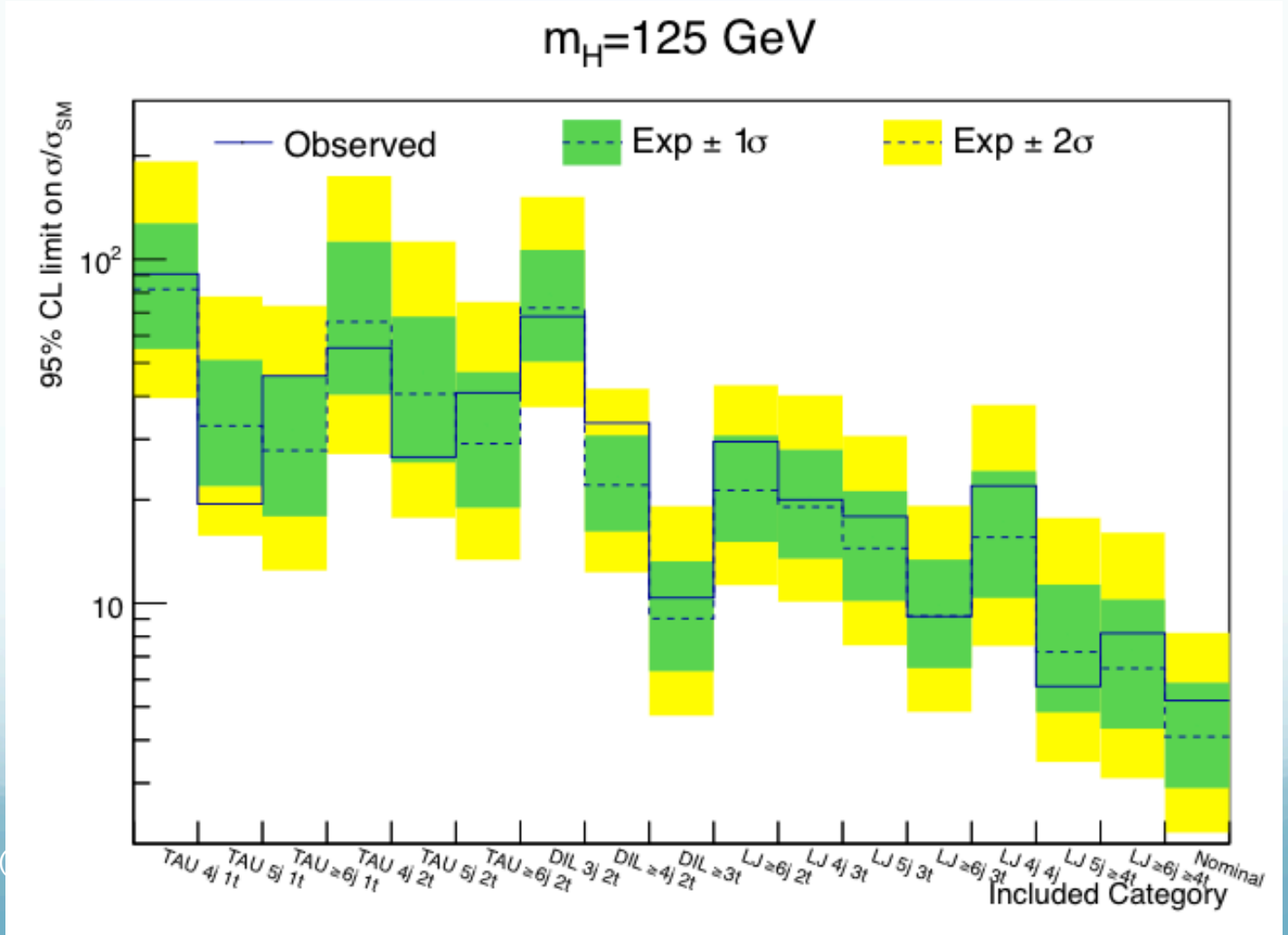
>=4 bjet



>=6 Jets

Analysis strategy (3)

1. Fit all BDT distribution of different categories simultaneously



ttH,H→diphoton

Leptonic ($t\bar{t}H \to \ell\nu jjbb\gamma\gamma$, $t\bar{t}H \to \ell\nu\ell\nu bb\gamma\gamma$)	Diphoton	2 γ, $p_T > m_{\gamma\gamma}/2\,(25)$ GeV for 1st (2nd) $\geq$1 e/μ, $p_T > 20$ GeV $\geq$2 jets + $\geq$1 b-tags, $p_T > 25$ GeV
Hadronic ($t\bar{t}H \to jjjjbb\gamma\gamma$)	Diphoton	2 γ, $p_T > m_{\gamma\gamma}/2\,(25)$ GeV for 1st (2nd) 0 e/μ, $p_T > 20$ GeV $\geq$4 jets + $\geq$1 b-tags, $p_T > 25$ GeV

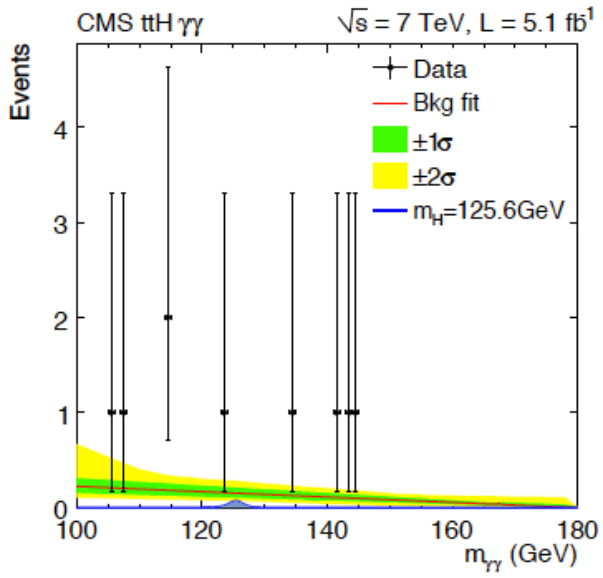
Challenges

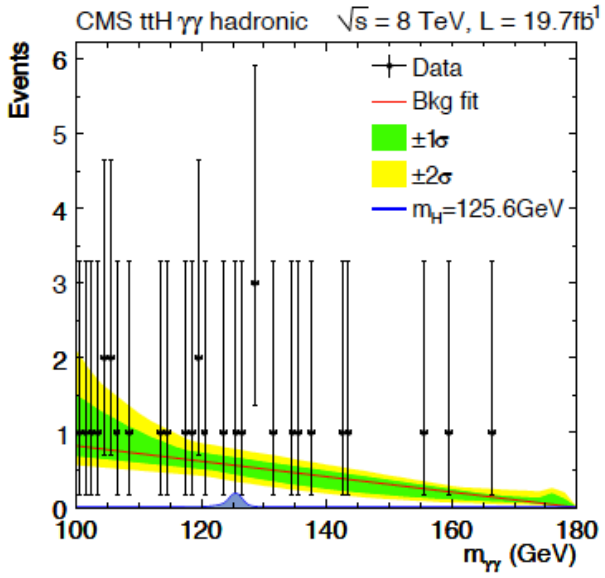
- Very small expected signal due to small H→ diphoton Branching ratio

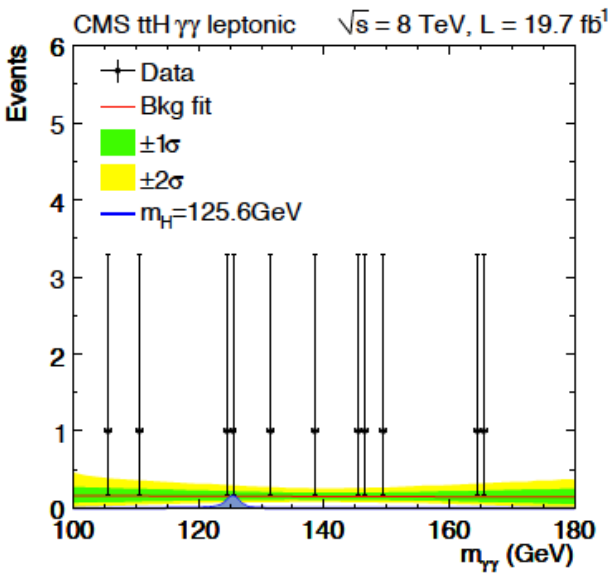
	7 TeV	8 TeV	
	All decays	Hadronic channel	Leptonic channel
$t\bar{t}H$	0.21	0.51	0.45
$gg \rightarrow H$	0.01	0.02	0
VBF H	0	0	0
WH/ZH	0.01	0.01	0.01
Total H	0.23	0.54	0.46
Data	9	32	11

Analysis Strategy

- Fit the Higgs mass spectrum (Very good Higgs peak)







ttH,H→multi-leptons

H → Leptons H → WW H → ττ H → ZZ	Same-Sign Dilepton ($t\bar{t}H \to \ell^{\pm}\nu\ell^{\pm}[\nu]jjj[j]bb$)	Dilepton	2 e/μ, $p_T > 20$ GeV $\geq$4 jets + $\geq$1 b-tags, $p_T > 25$ GeV
	3 Lepton ($t\bar{t}H \to \ell\nu\ell[\nu]\ell[\nu]j[j]bb$)	Dilepton, Trielectron	1 e/μ, $p_T > 20$ GeV 1 e/μ, $p_T > 10$ GeV 1 e(μ), $p_T > 7(5)$ GeV $\geq$2 jets + $\geq$1 b-tags, $p_T > 25$ GeV
	4 Lepton ($t\bar{t}H \to \ell\nu\ell\nu\ell[\nu]\ell[\nu]bb$)	Dilepton, Trielectron	1 e/μ, $p_T > 20$ GeV 1 e/μ, $p_T > 10$ GeV 2 e(μ), $p_T > 7(5)$ GeV $\geq$2 jets + $\geq$1 b-tags, $p_T > 25$ GeV

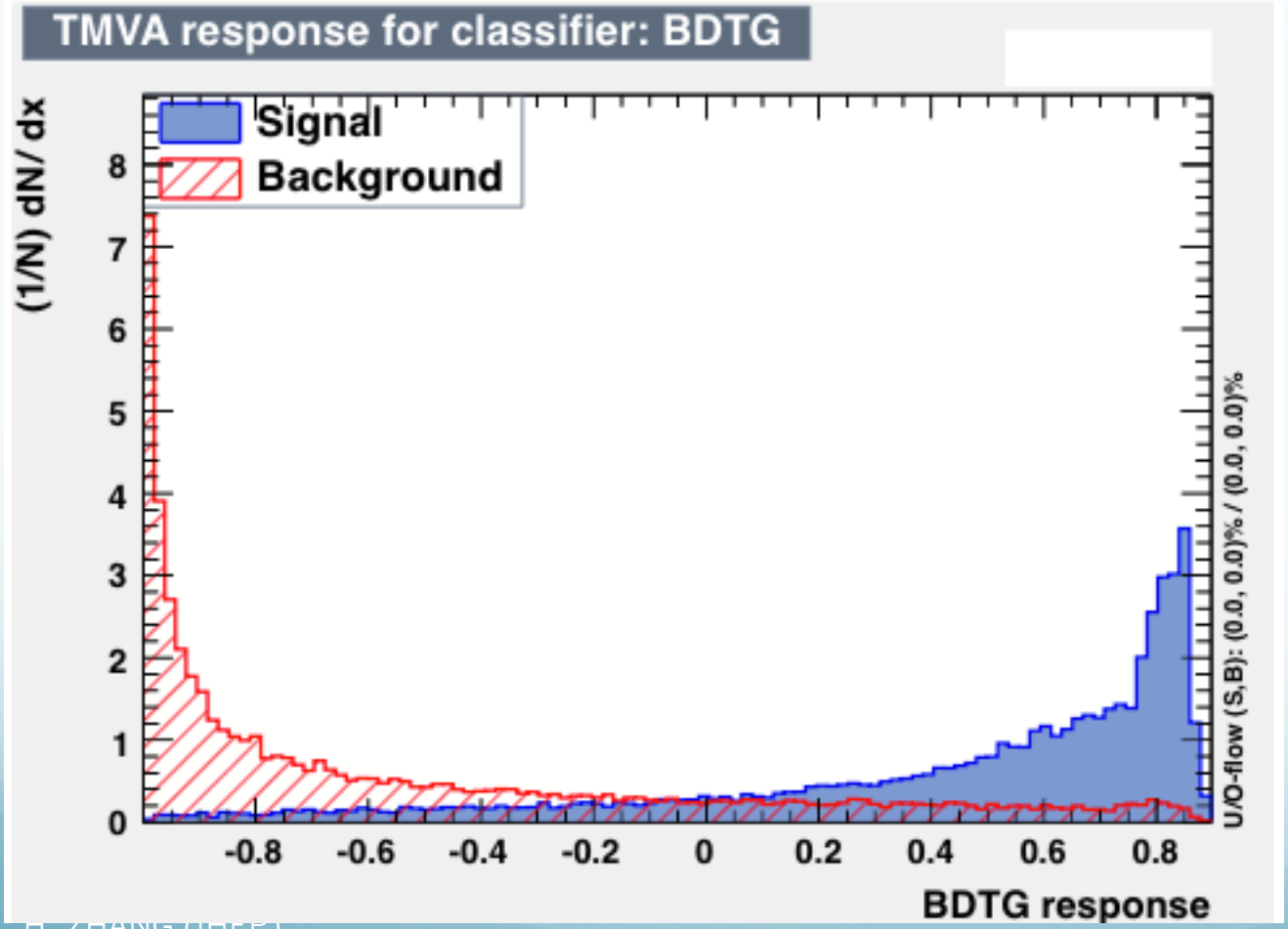
challenges

- Non Prompt leptons (40-65% bkg)

	ee	$e\mu$	$\mu\mu$	3ℓ	4ℓ
$t\bar{t}H$, $H \to WW$	1.0 ± 0.1	3.2 ± 0.4	2.4 ± 0.3	3.4 ± 0.5	0.29 ± 0.04
$t\bar{t}H$, $H \to ZZ$	—	0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.09 ± 0.02
$t\bar{t}H$, $H \to \tau\tau$	0.3 ± 0.0	1.0 ± 0.1	0.7 ± 0.1	1.1 ± 0.2	0.15 ± 0.02
$t\bar{t}W$	4.3 ± 0.6	16.5 ± 2.3	10.4 ± 1.5	10.3 ± 1.9	—
$t\bar{t}Z/\gamma^*$	1.8 ± 0.4	4.9 ± 0.9	2.9 ± 0.5	8.4 ± 1.7	1.12 ± 0.62
$t\bar{t}WW$	0.1 ± 0.0	0.4 ± 0.1	0.3 ± 0.0	0.4 ± 0.1	0.04 ± 0.02
$t\bar{t}\gamma$	1.3 ± 0.3	1.9 ± 0.5	—	2.6 ± 0.6	—
WZ	0.6 ± 0.6	1.5 ± 1.7	1.0 ± 1.1	3.9 ± 0.7	—
ZZ	—	0.1 ± 0.1	0.1 ± 0.0	0.3 ± 0.1	0.47 ± 0.10
Rare SM bkg.	0.4 ± 0.1	1.6 ± 0.4	1.1 ± 0.3	0.8 ± 0.3	0.01 ± 0.00
Non-prompt	7.6 ± 2.5	20.0 ± 4.4	11.9 ± 4.2	33.3 ± 7.5	0.43 ± 0.22
Charge misidentified	1.8 ± 0.5	2.3 ± 0.7	—	—	—
All signals	1.4 ± 0.2	4.3 ± 0.6	3.1 ± 0.4	4.7 ± 0.7	0.54 ± 0.08
All backgrounds	18.0 ± 2.7	49.3 ± 5.4	27.7 ± 4.7	59.8 ± 8.0	2.07 ± 0.67
Data	19	51	41	68	1

Analysis strategy (1)

- To get rid of prompt leptons
  - BDT used to separate prompt and non-prompt leptons



IP3D
Charge Pt
Neutral Pt
DeltaR(lep, jet)
Ratio (PtLep/PtJet)
JetCSV
...

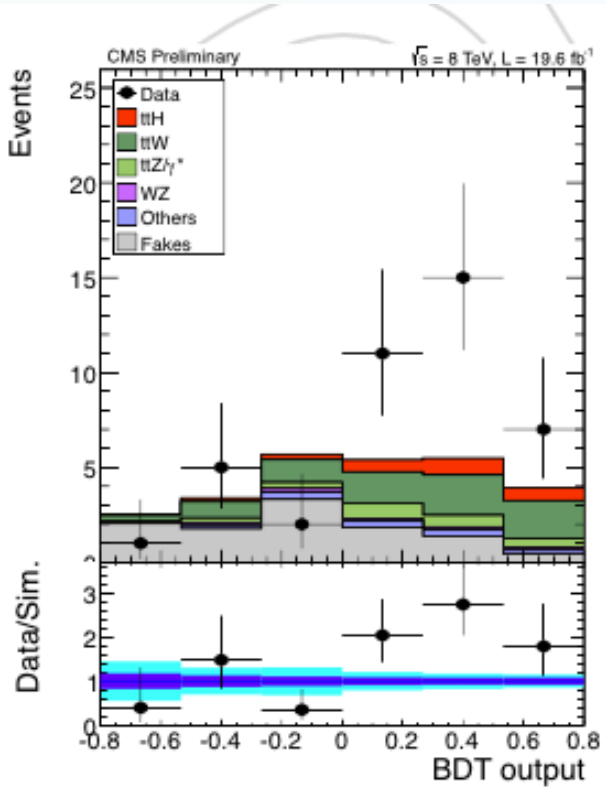
IHEP going to add 6 more categories of variables

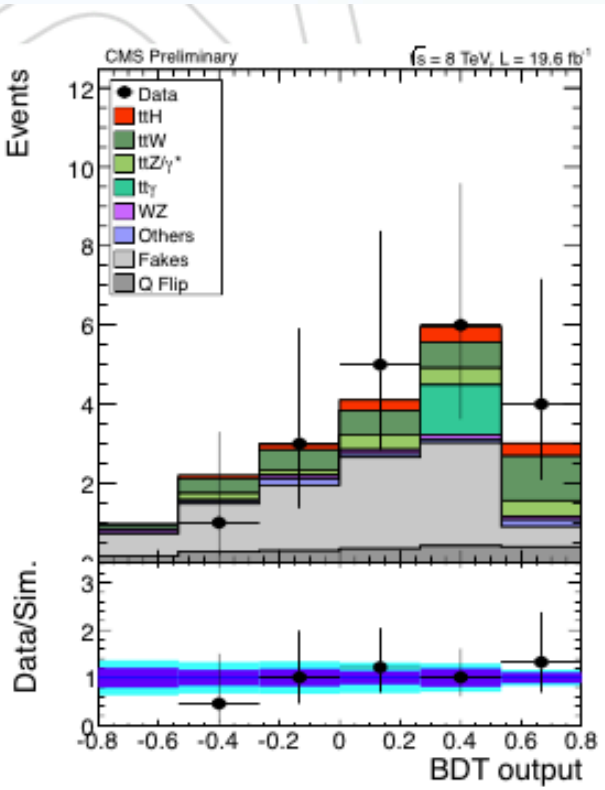
Analysis strategy (2)

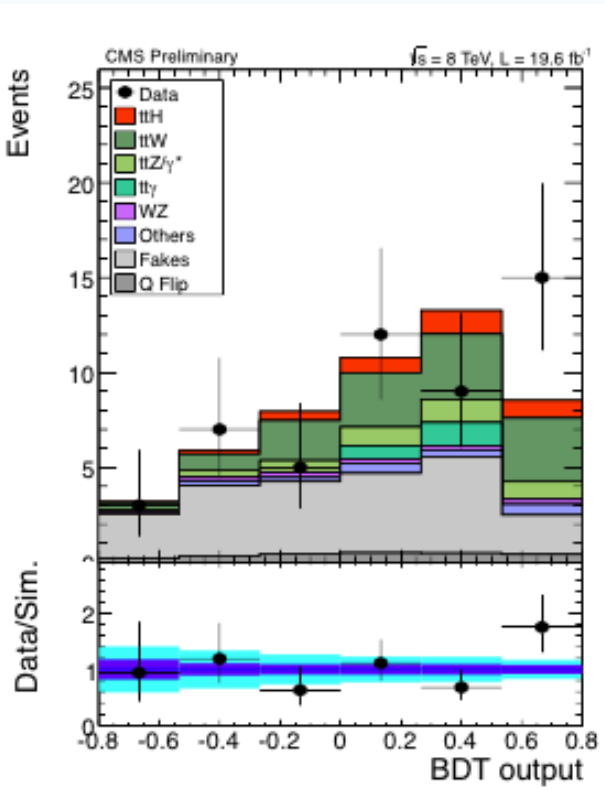
- To separate signal to backgrounds

Pt (lep2)
Eta (lep2)
Min DeltaR(lep2, Jets)

Mt(lep1, MET)
St(jets,leptons,MET)
VecPtSum(jets, lepton, MET)

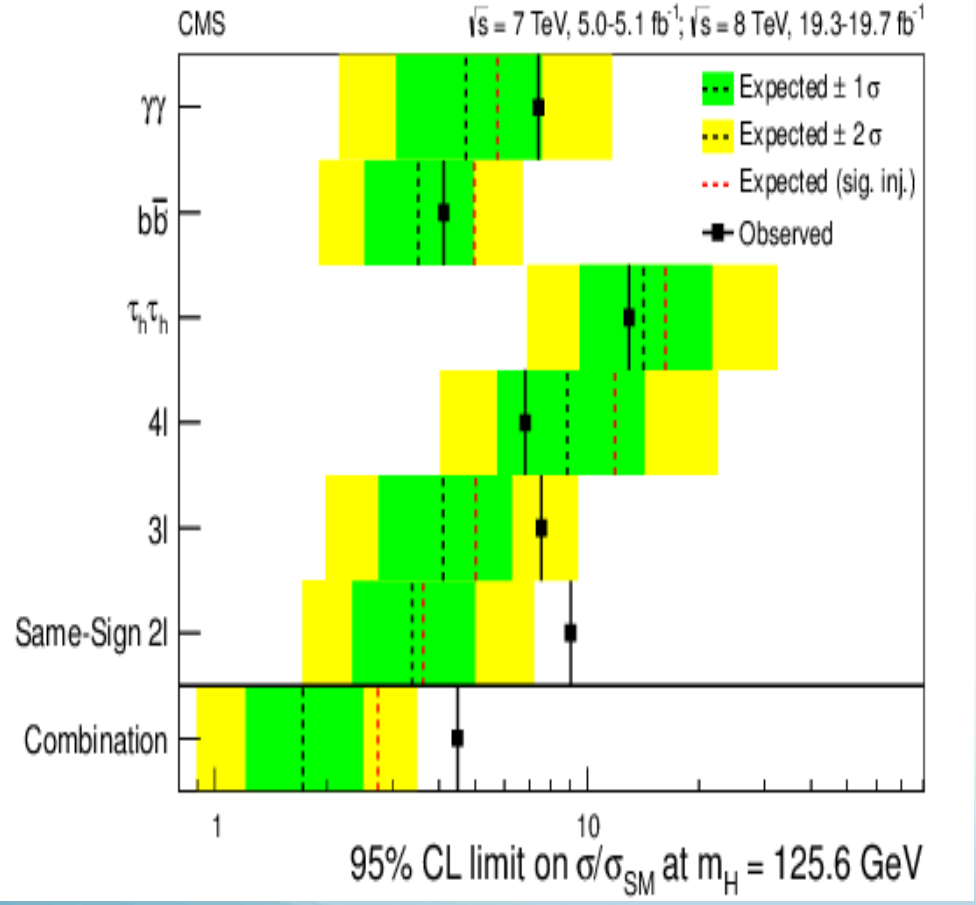


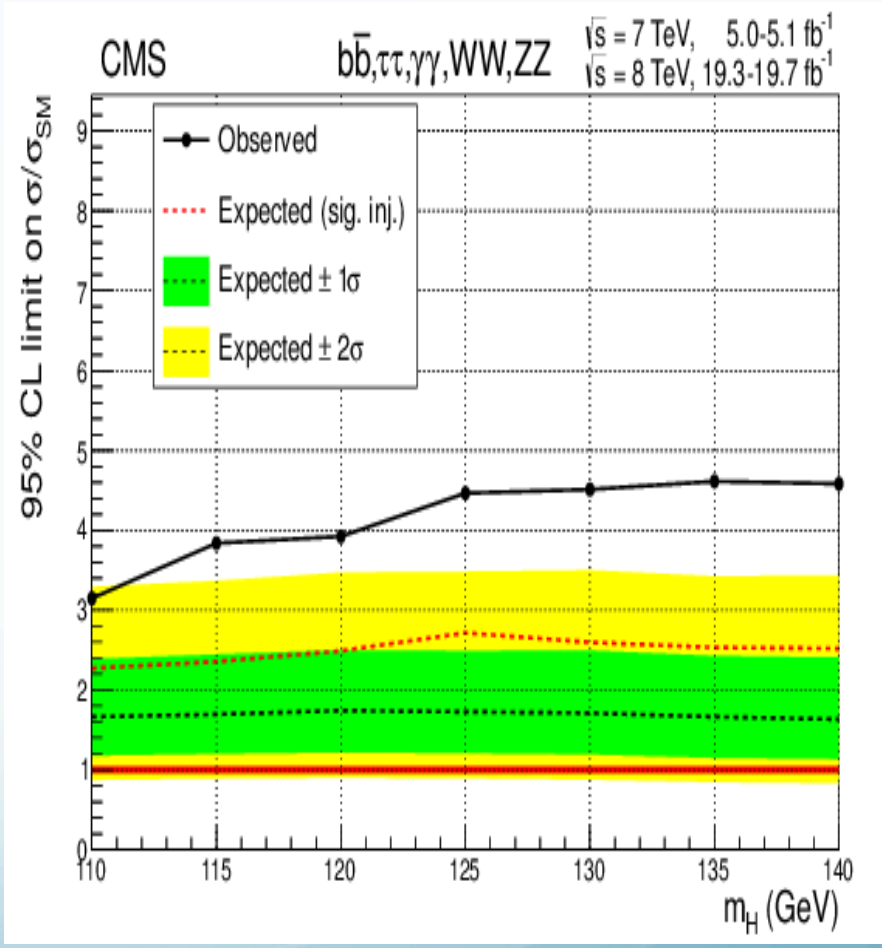




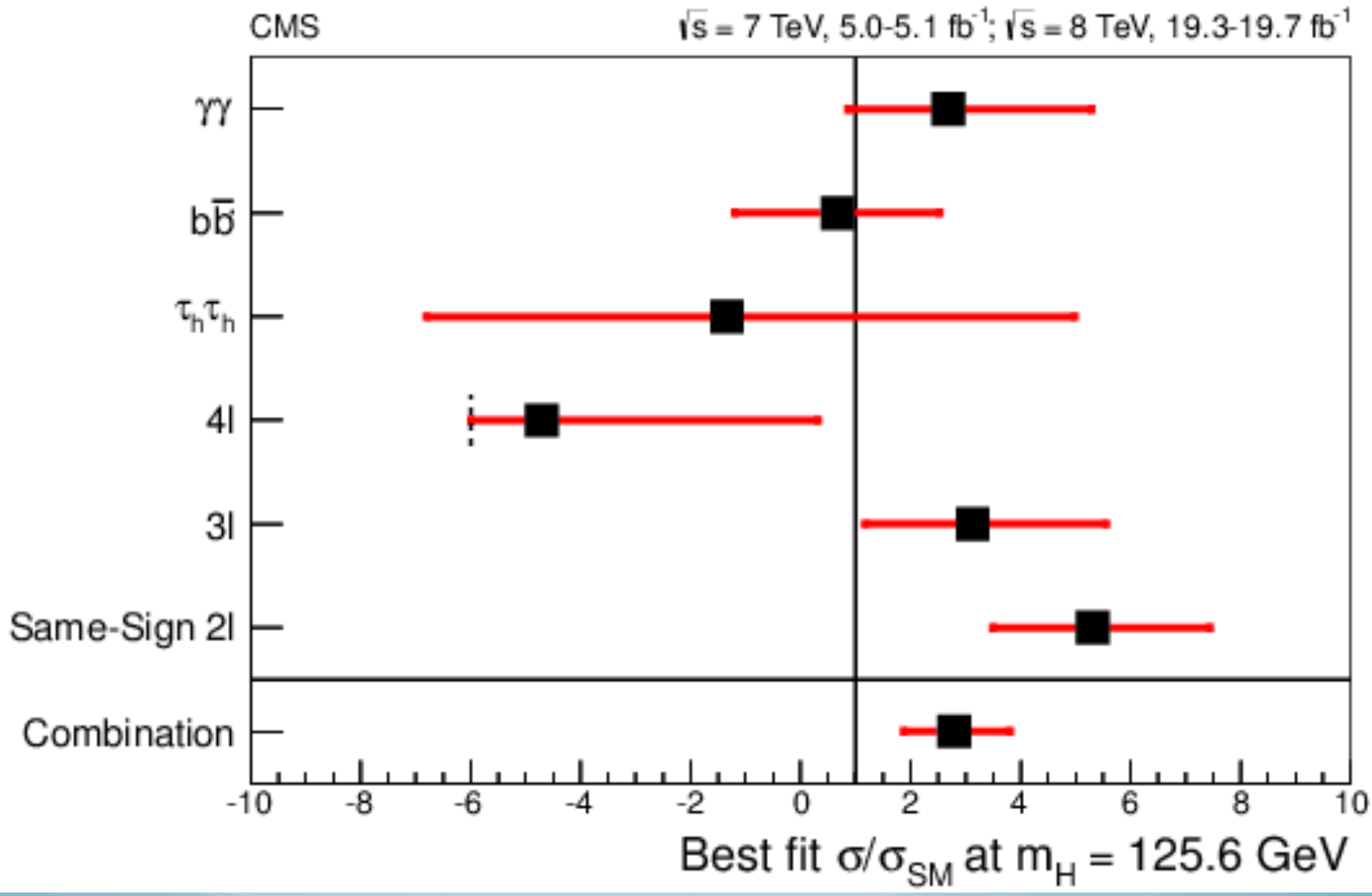
Then Fit these BDT distribution to get signal

ttH limit result

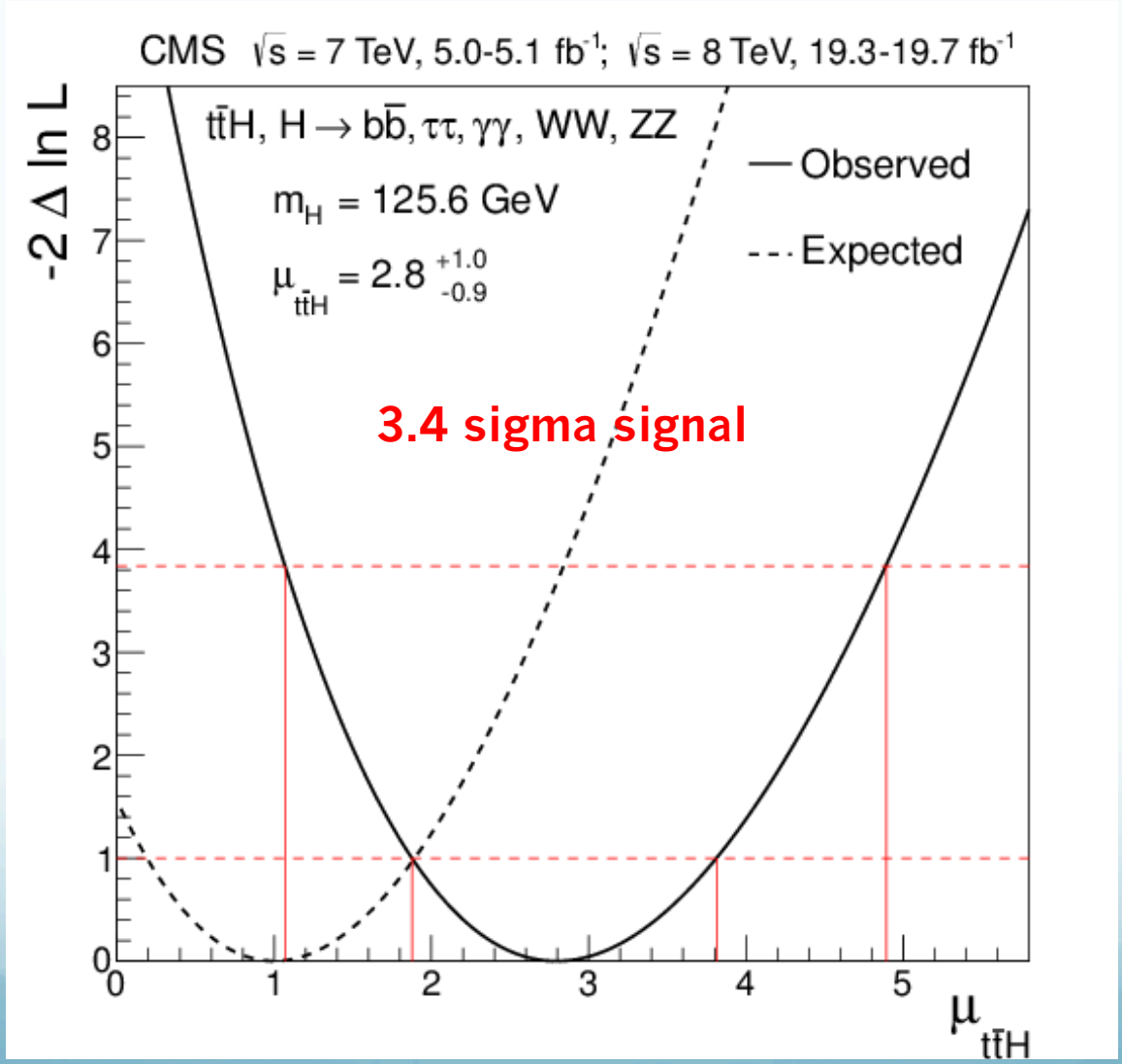




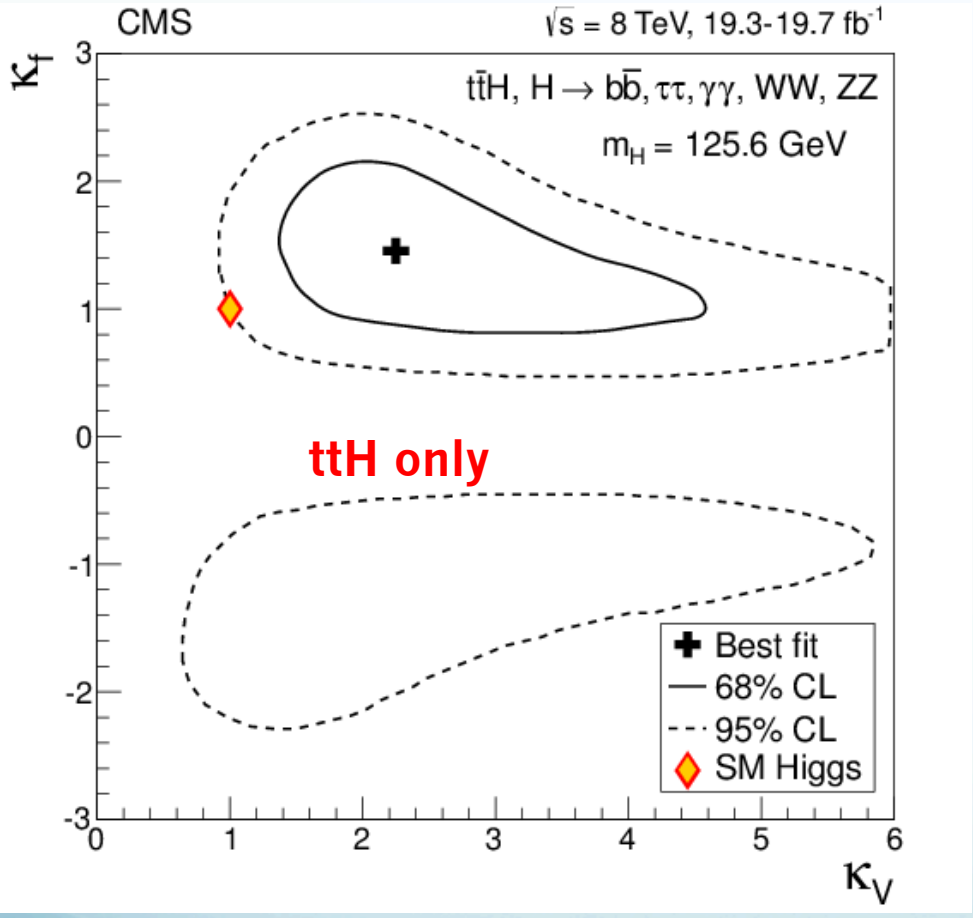
Individual Measurement

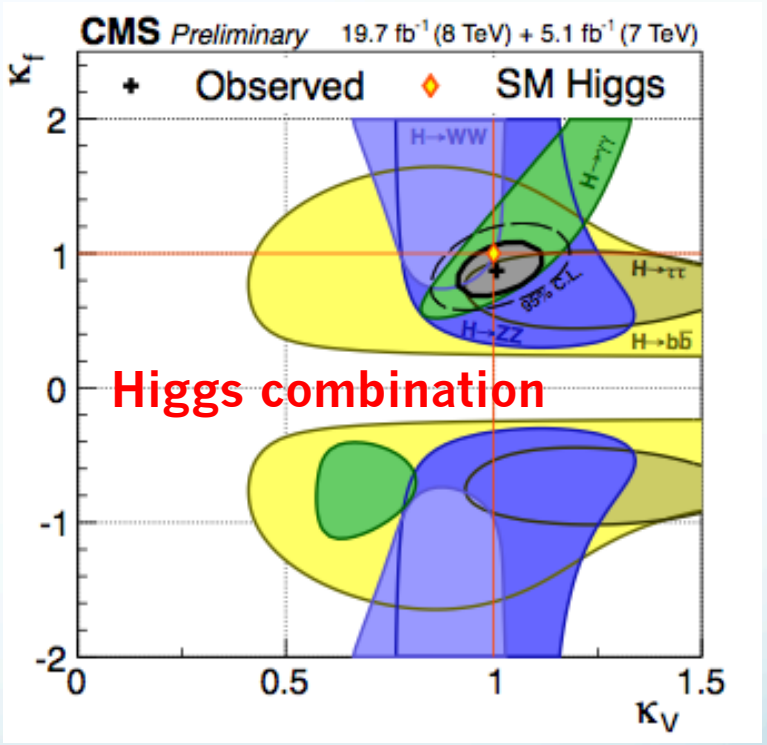


Combined measurement



Interpretation of results





ttH searches @ LHC run II

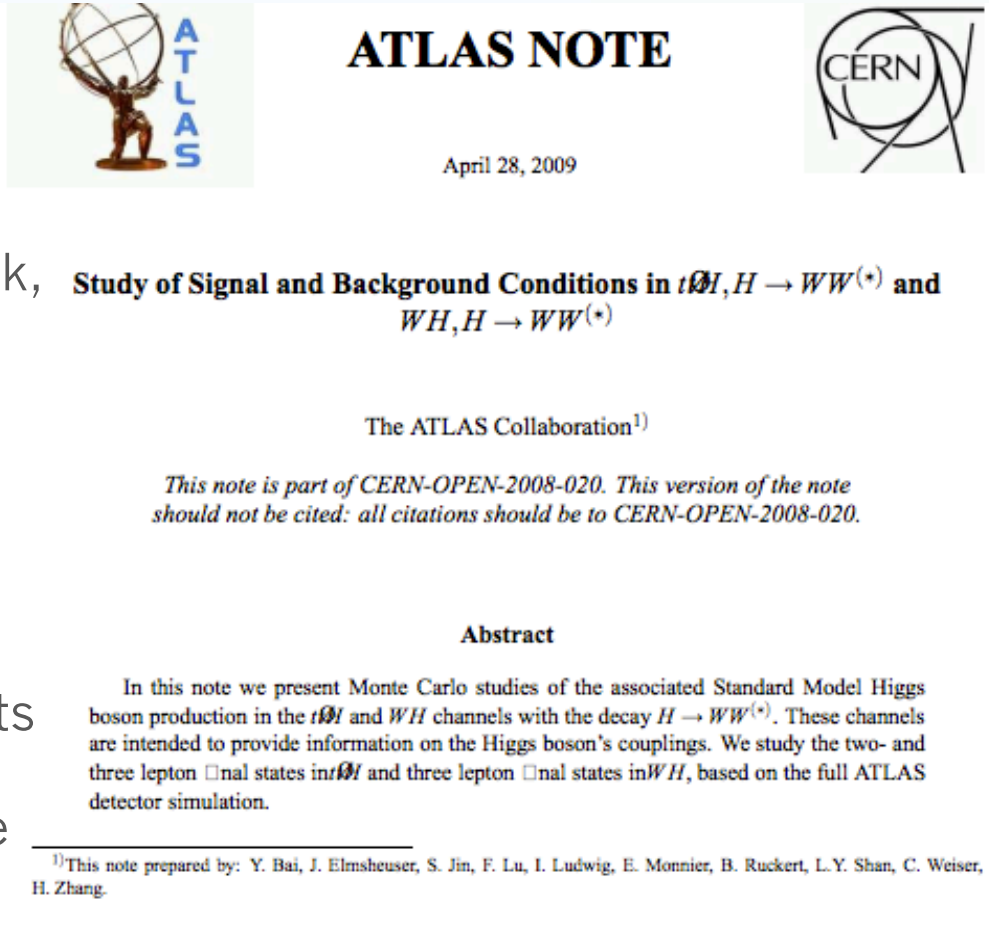
- ttH,H->bb: very interesting at 13/14 TeV
  - ttH increase 4.7 times, 1.4 times more than ttbar
  - Run II 13/14 TeV, 100-300 fb-1
    - ➔23.5-70.5 times more signal !!
    - 3.4 sigma at 8 TeV with 20 fb-1:➔ same systematics with get 5 sigma with ~25 fb-1 @ 14 TeV: several weeks

fb	ttH(NLO)	WH(NNLO)	ZH(NNLO)	ttbar
14 TeV	611	1522	969	833000
8 TeV	130	697	394	248000
7 TeV	86	579	335	159000
14/8 TeV	4.7	2.2	2.5	3.4

ttH analysis at IHEP-CMS group

Chinese ttH efforts

- Chinese ATLAS ttH efforts
  - Long history：IHEP collaborate with Marseille
    - My Ph.D thesis in 2008: ttH,H→WW ATLAS CSC book, full simulation results just before data taken, at that time I am the editor of ttH, H→WW analysis
  - Now:
    - (Shan Jin) Hongbo ZHU, LianYou Shan (IHEP)
    - Liang Li (SJU): boost objects of ttH
    - CMS ttH @ IHEP: next slide



ATLAS NOTE

April 28, 2009

Study of Signal and Background Conditions in $t\bar{t}H, H \to WW^{(*)}$ and $WH, H \to WW^{(*)}$

The ATLAS Collaboration[1)]

This note is part of CERN-OPEN-2008-020. This version of the note should not be cited: all citations should be to CERN-OPEN-2008-020.

Abstract

In this note we present Monte Carlo studies of the associated Standard Model Higgs boson production in the $t\bar{t}H$ and WH channels with the decay $H \to WW^{(*)}$. These channels are intended to provide information on the Higgs boson's couplings. We study the two- and three lepton final states in $t\bar{t}H$ and three lepton final states in WH, based on the full ATLAS detector simulation.

[1)] This note prepared by: Y. Bai, J. Elmsheuser, S. Jin, F. Lu, I. Ludwig, E. Monnier, B. Ruckert, L.Y. Shan, C. Weiser, H. Zhang.

ttH, (Top – Higgs coupling measurement) is very interesting to Chinese experimental physicist

ttH: IHEP-CMS group

- Man power:
  - Francesco Romeo (post-doc,100% based at CERN), Huaqiao ZHANG, Binghuan Li(1st Year Ph.D)
- Contribution to ttH analysis key points for Run II
  - Lepton isolation using tracking information (new information and better performance, implementing to the analysis package)
  - B-tagging related event shape variables separate ttbb/ ttH,H→bb (new information from detector, study on going)
  - Reconstruction of Higgs mass
    - New idea to reconstruct higgs mass

IHEP CMS analysis topics

- IHEP CMS group:
  - B physics
  - H→ diphoton
  - H→ZZ/combination
  - Top quark related analysis
  - SUSY/exotica...
- IHEP CMS top quark related analysis
  - Search single exited bottom quark decay to tW
    - 4 Analysis + combination, Preapproval this week
  - Single top tW → lepton+jets
  - ttH
  - ...

Summary

- ttH channel is very interesting from both theory and experimental point of view
- CMS ttH already get 3.4 sigma evidence of ttH production
  - Expected to observe more than 5 sigma in LHC run II (in next year or tow)
- It is time to prepare this important analysis adventure
  - Many Chinese LHC experimental colleagues interested to/ already participate in ttH efforts
- Comments and Suggestion on how to get significant contribution to ttH are open