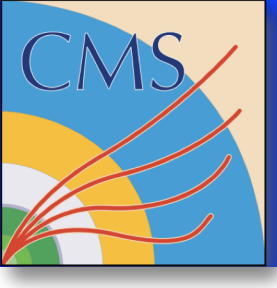


ATLAS和CMS实验最新成果和进展

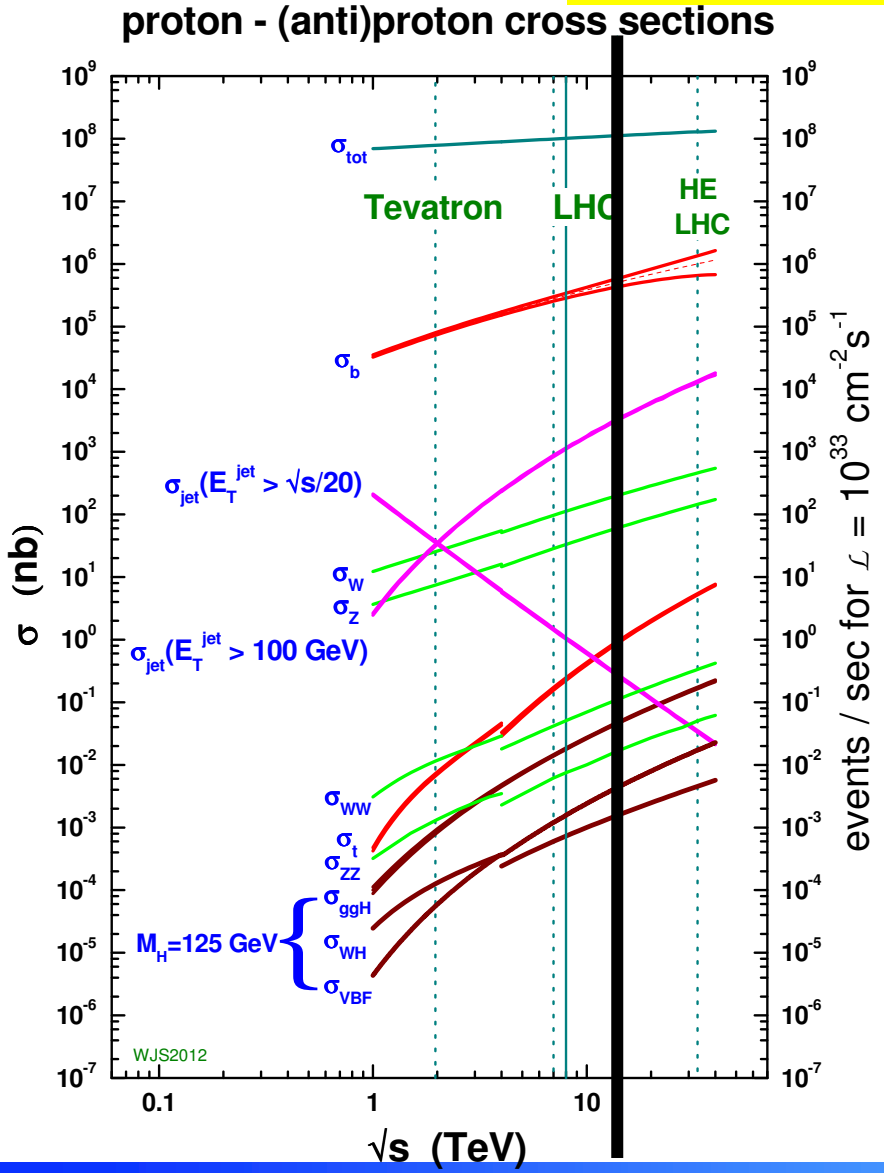
张华桥(IHEP, Beijing)

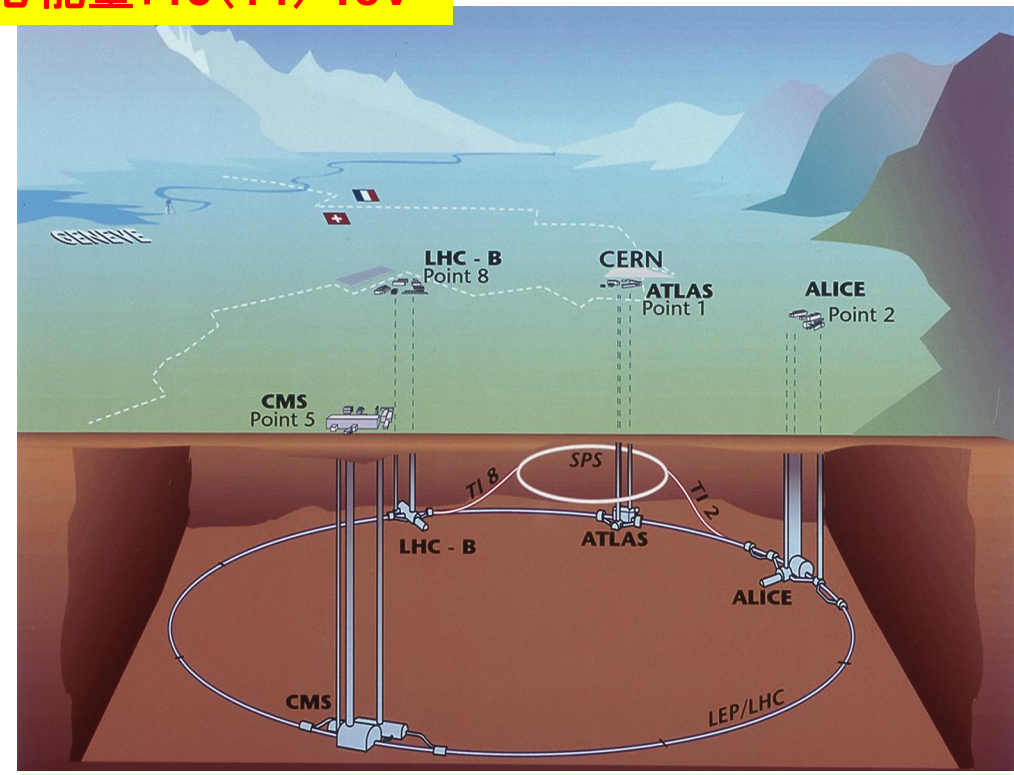
22,Nov,2018@Beijing, China

中科院粒子物理卓越中心年会

LHC: a discovery machine of energy frontier

运行（设计）质心能量：13（14） TeV





Large Hadron Collider (LHC):

A machine that has highest Ecm that mankind ever made

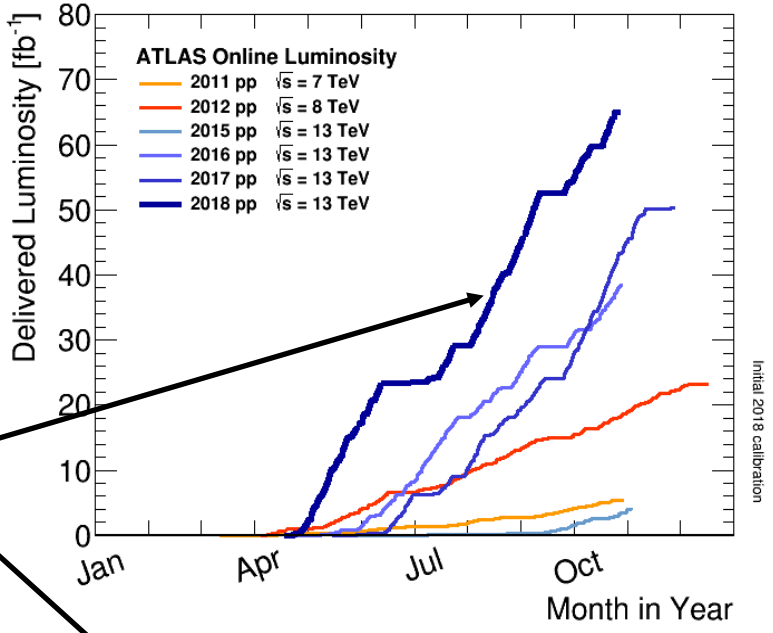
Located at CERN, 27km tunnel, 14 TeV E_{cm}

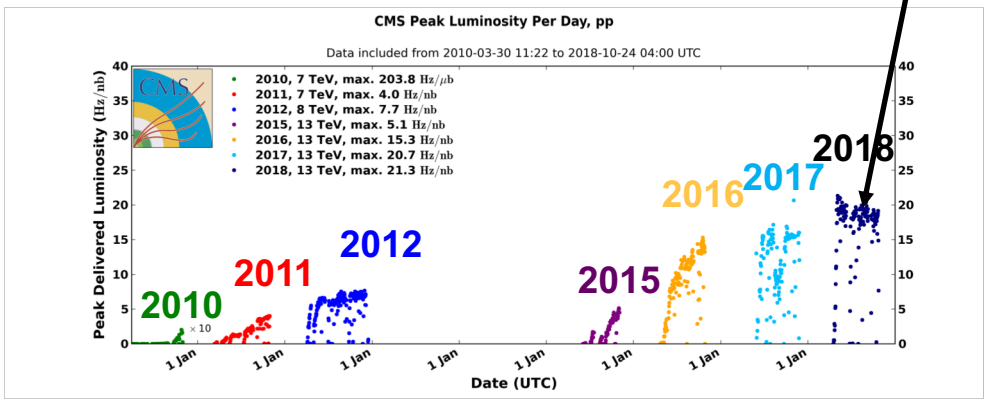
Data taking status: Big Success

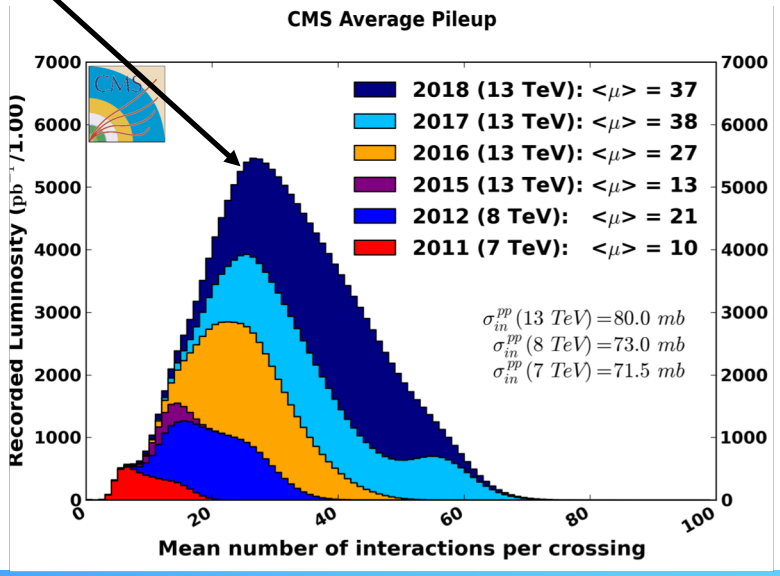
- Data taken from 2010-2018
  - 7TeV → 8 TeV → 13 TeV
- Integrated Luminosity (Delivered)

	7TeV	8TeV	13TeV	2018
ATLAS	5.5 fb^{-1}	22.8fb^{-1}	158fb^{-1}	**65.0fb^{-1}**
CMS	6.1 fb^{-1}	23.3fb^{-1}	163fb^{-1}	**68.2fb^{-1}**

2018年积分亮度增加了~50%





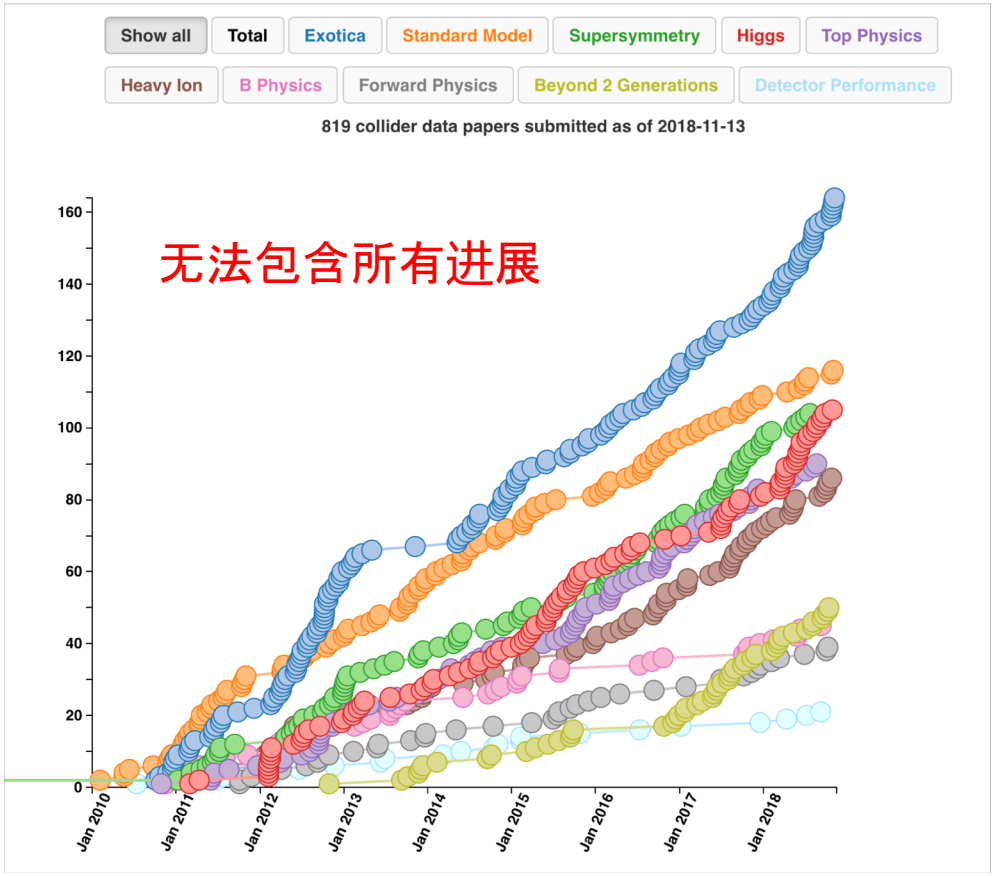


* >94% of detector channels active

A year with rich physics outcome

Papers From CDS*	All papers	2018/1/1-11/15
ATLAS	807	**89**
CMS	846	**117**

- Similar number of CONF/PAS notes with preliminary results



165 exotica

116SM

104 SUSY

105 Higgs

91 Top

86 HI

51 B2G

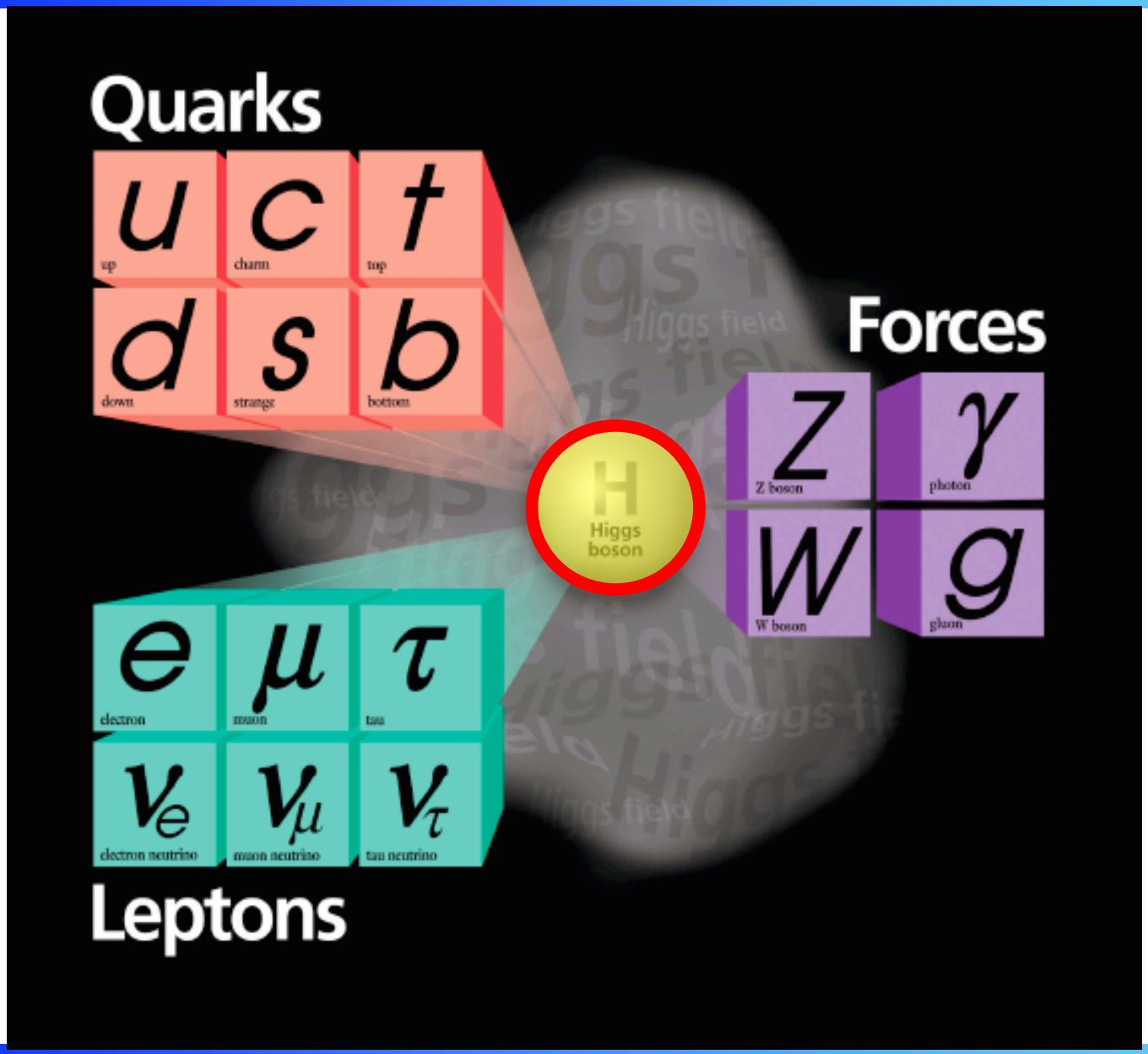
45 Bphysics

39 Forward physics

21 performance

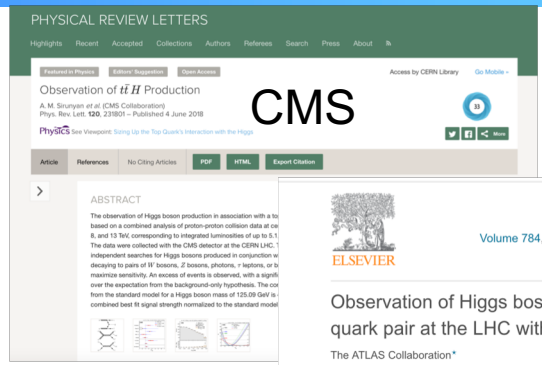
中国ATLAS/CMS组活跃在除重离子组之外所有的物理组

2018: A Year of Higgs couplings

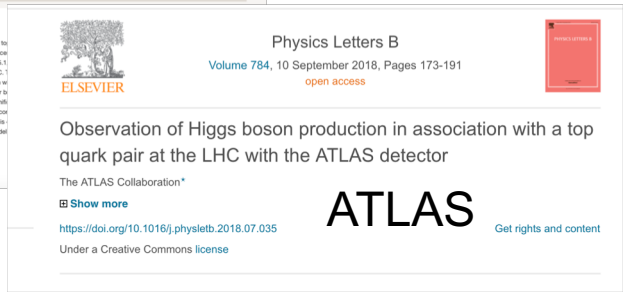


Observation of …

- Higgs interaction with top quark:
  - Interaction with Heaviest particle
  - CERN Press release
  - Media/news/view point…

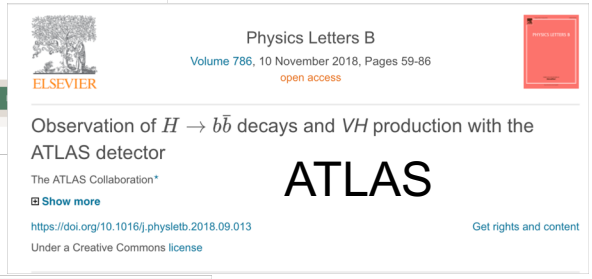


2018/6（9）



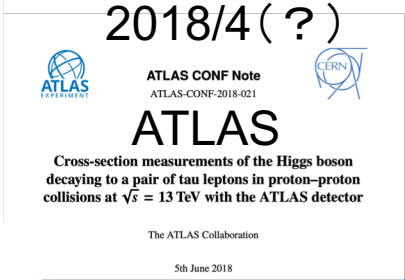
- Higgs decay to bottom quark
  - The largest decay mode
  - CERN Press release
  - Media/news/view point…

2018/9（10）



- Higgs Decay to tau pairs
  - First obs. H-f coupling;
  - Confirmation take longer

2018/4（？）

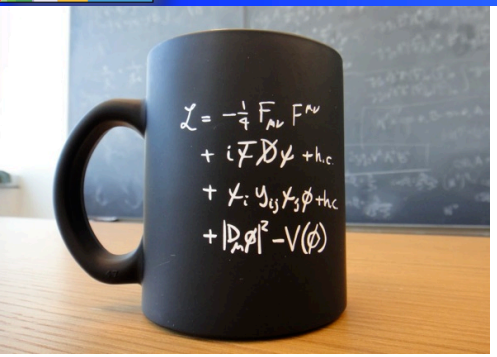


ATLAS/CMS以observation命名的希格斯文章屈指可数

中国人在这三个发现中均做关键/显著贡献

ATLAS/CMS进

Higgs Physics: Measurement of interactions



希格斯粒子：基本粒子的质量起源

与玻色子耦合

- Higgs 机制
- 2012年发现
  希格斯时发现

2013年诺贝尔奖

与费米子耦合

- **第五种力**
- **最近一年发现三种**(第三代)

决定原子的半径，真空是否稳定，（宇宙的命运）

与自己自耦合

- 第六种力
- LHC取数到2035年发现？

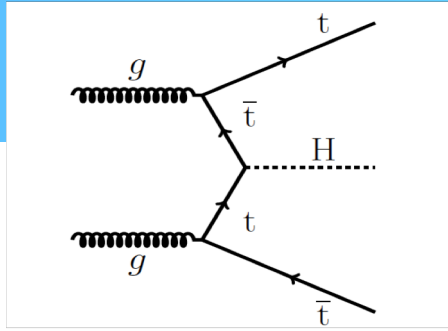
宇宙是否存在相变

LHC质子-质子对撞决定了难以精确测量

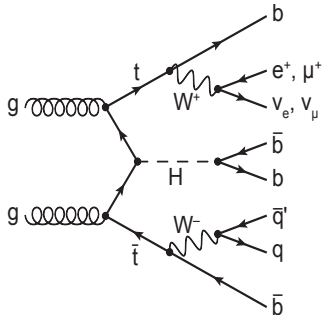
CEPC ILC FCC hh ee he

How to hunt ttH

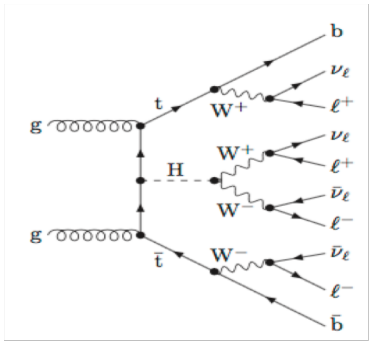
- 每产生100个希格斯粒子中仅有一个ttH
- 未态复杂：有8-10个末态粒子，组合众多



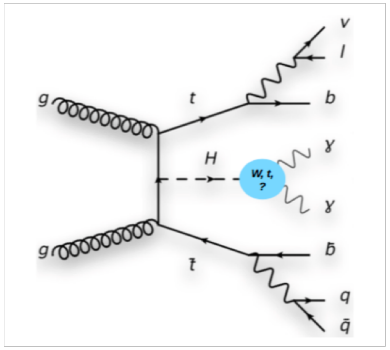
Higher cross-section ⟵ ⟶ Higher purity



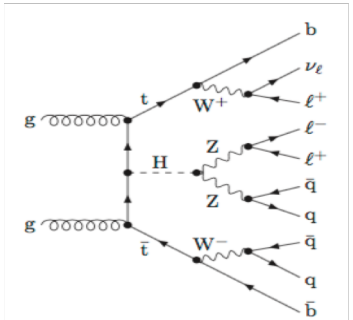
arXiv:1804.03682



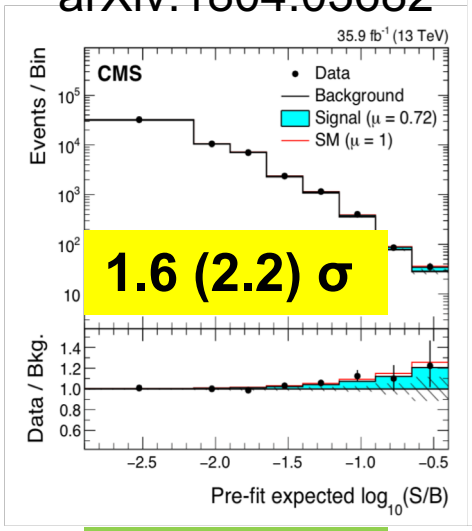
JHEP 08 (2018) 066



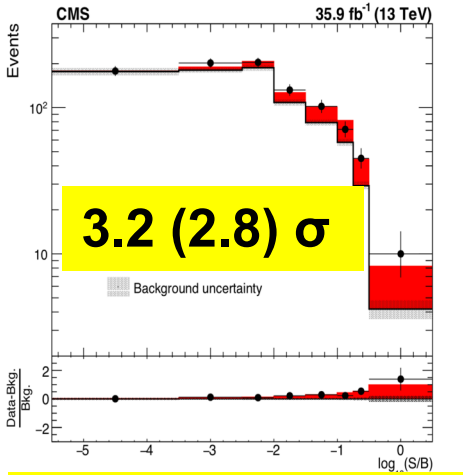
arXiv:1804.02716



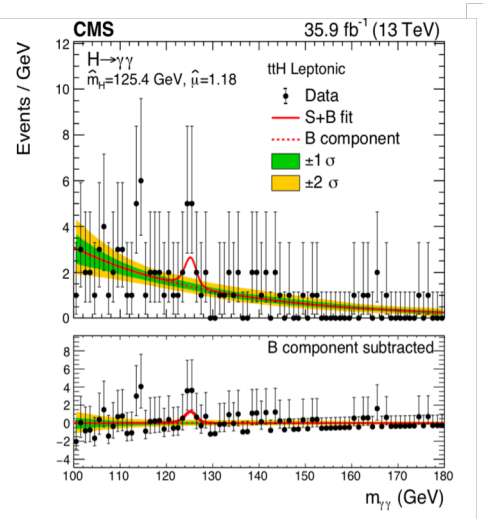
JHEP11(2017)047

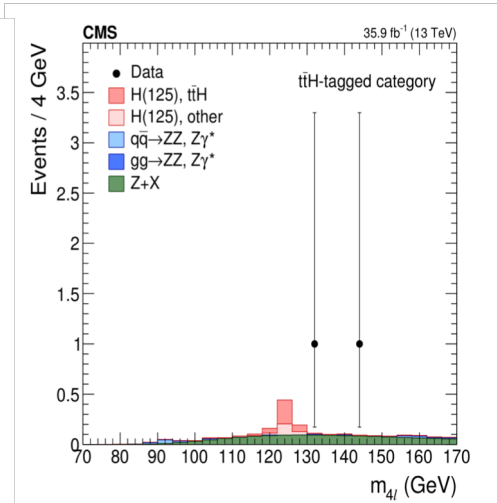


IHEP/SJTU



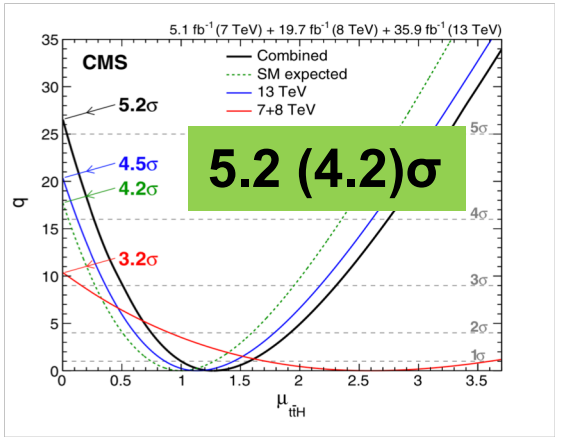
IHEP pre-approval
PKU/SDU/USTC

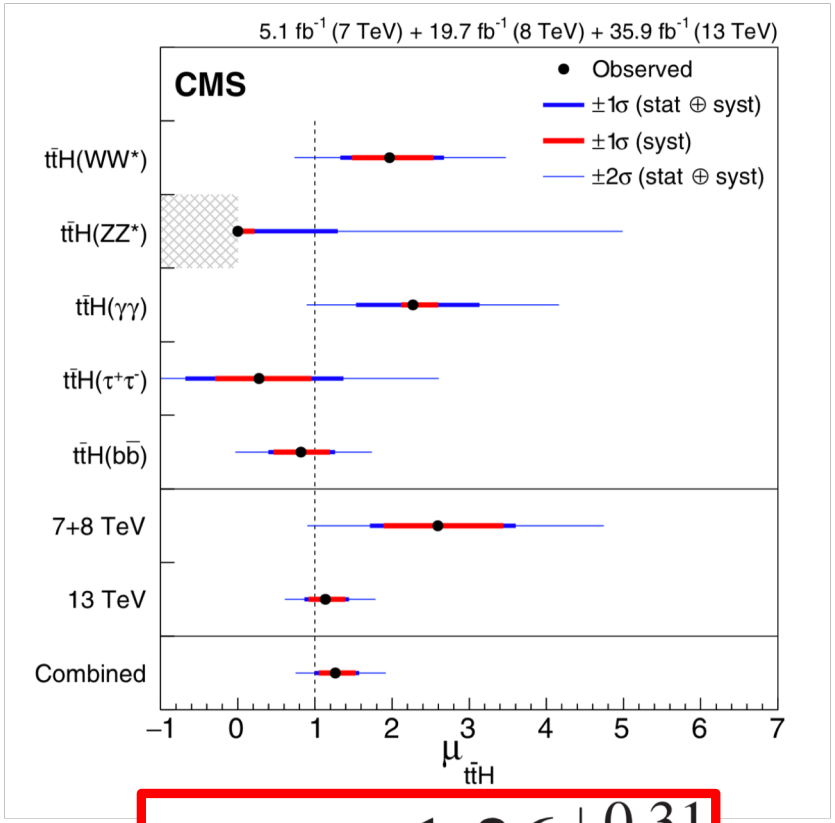




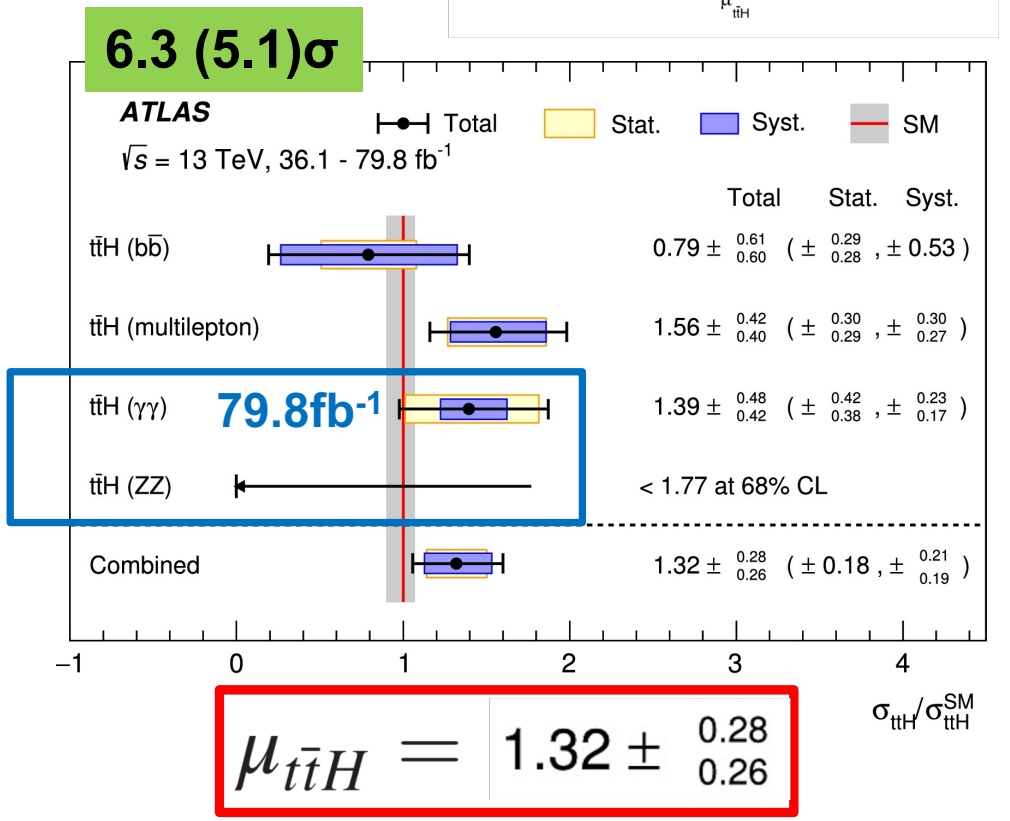
Observation of ttH

- Combination of ttH,H→WW/ ττ /bb/γγ/ZZ
  - CMS: 7TeV + 8TeV + 13 TeV(35.9 fb^{-1}),5.2 σ
  - ATLAS: 13 TeV (35.9 fb^{-1} – 79.8 fb^{-1}),6.3 σ
- Simultaneous ML fit to all decay modes/Ecm





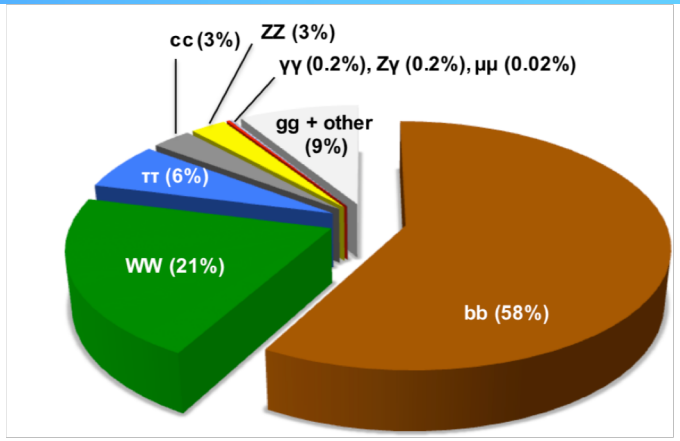
$$\mu_{t\bar{t}H} = 1.26^{+0.31}_{-0.26}$$



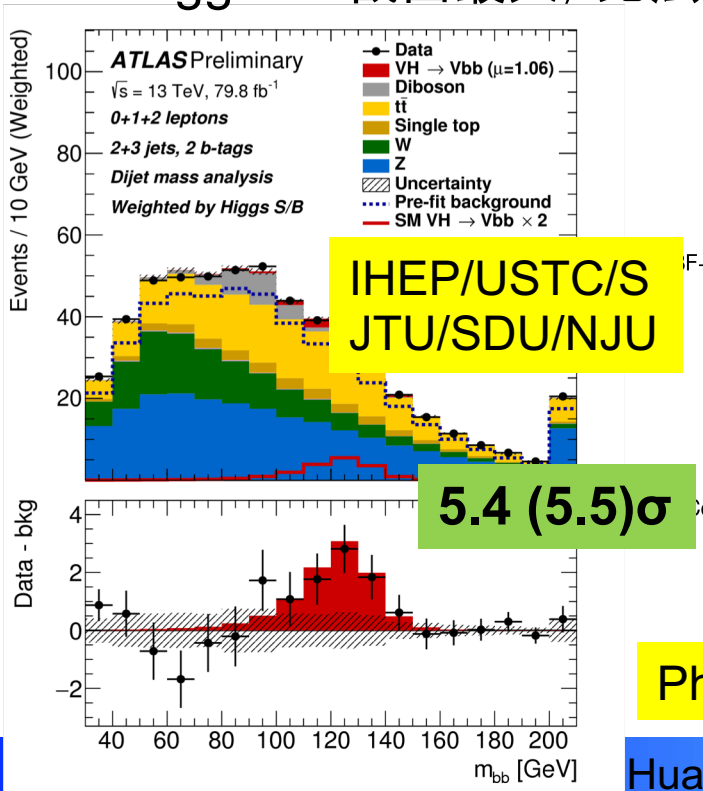
$$\mu_{t\bar{t}H} = 1.32 \pm \begin{matrix}0.28\\0.26\end{matrix}$$

Observation of Higgs decay to bottom quarks

- Higgs Largest decay mode
- Search with 4 productions modes
  - VH,H→bb; 最灵敏的道
  - ttH+tH,H→bb; 截面最小的道
  - VBF H, H→bb;截面小，本底大
  - ggF H：截面最大，无法区分本底，H→bb boosted;

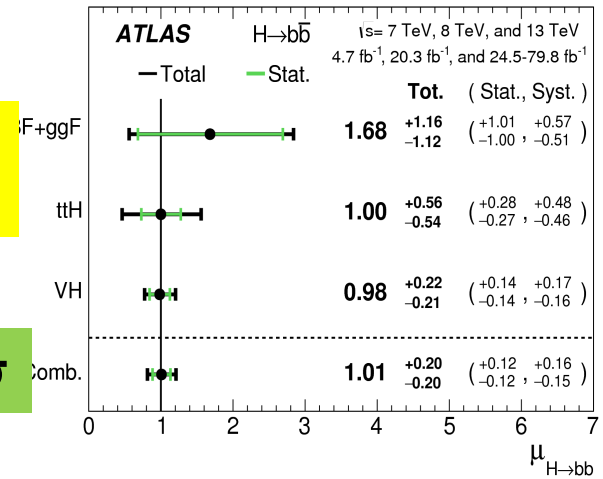


$$\mu = 1.04 \pm 0.20$$

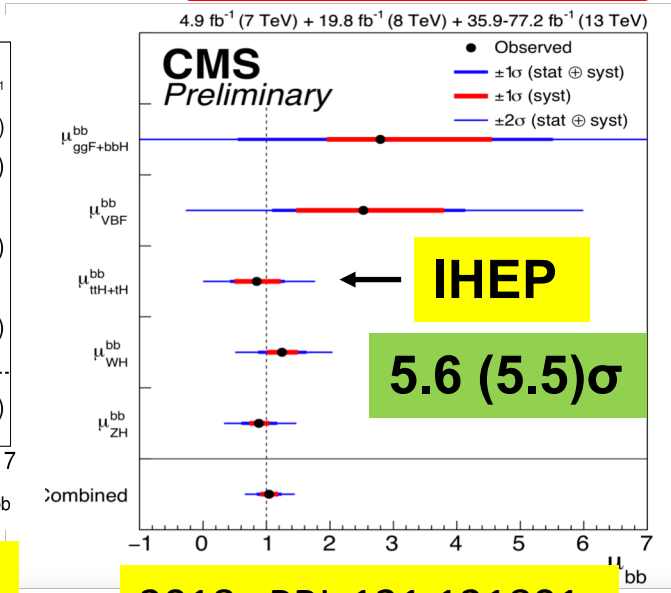


IHEP/USTC/SJTU/SDU/NJU

5.4 (5.5)σ



Phys. Lett. B 786 (2018) 59



IHEP

5.6 (5.5)σ

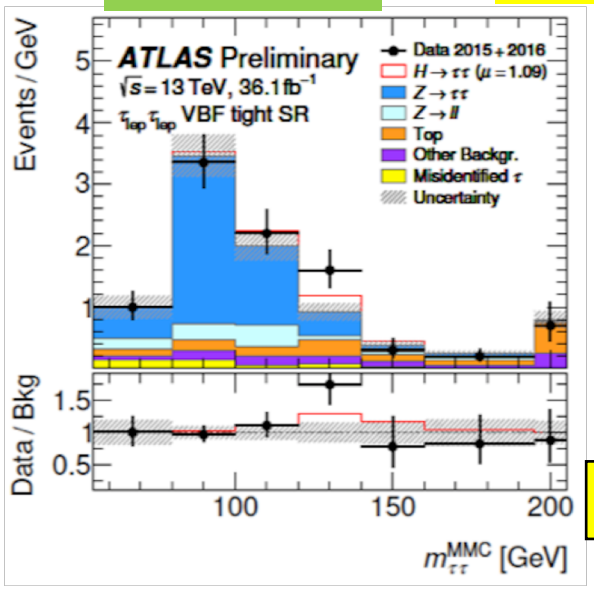
2018, PRL 121.121801

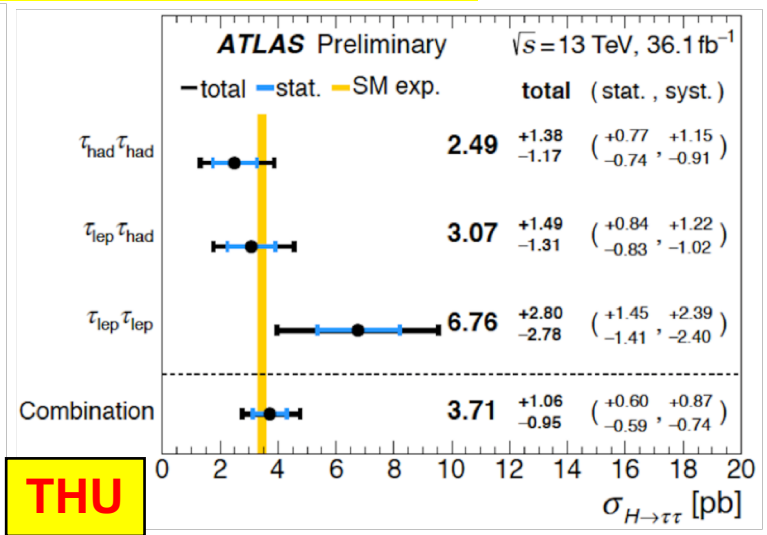
Observation of H→ττ

- Strong (relatively to other leptons) coupling to Higgs
- Large background dominated by Z→ ττ
- Search H→ ττ in the production mode of ggH,VBF,VH（ttH)

6.4 (5.4)σ

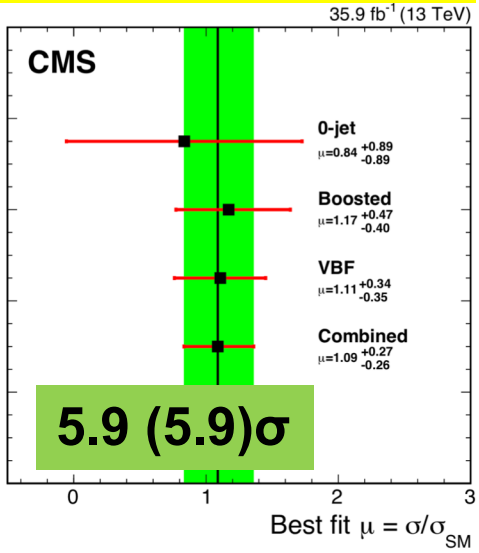
ATLAS-CONF-2018-021





THU

PLB 779 (2018) 283



5.9 (5.9)σ

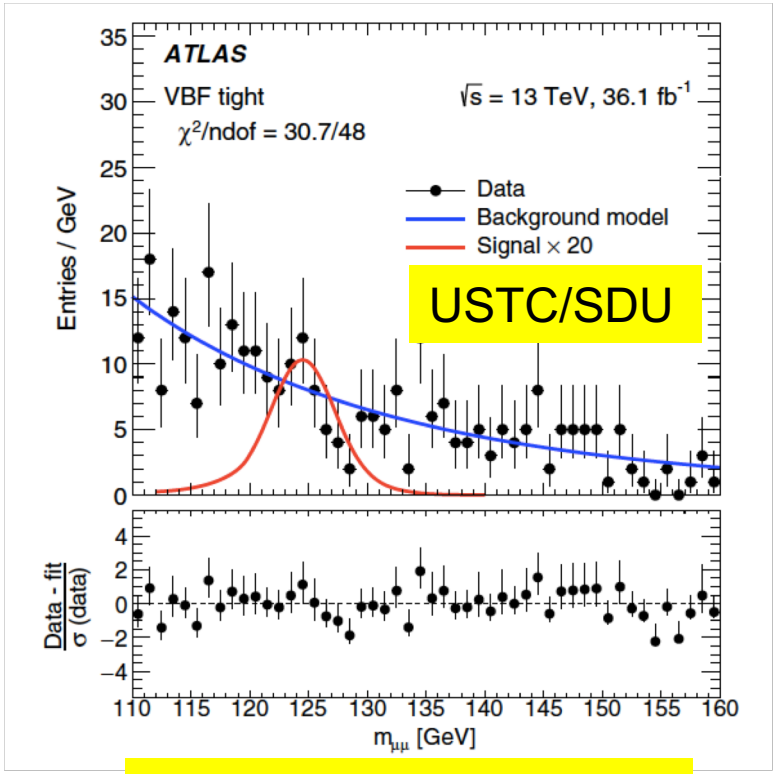
$$\sigma_{ggH} = 3.0 \pm 1.0(\text{stat})^{+1.6}_{-1.2}(\text{sys}) \text{ pb}$$

$$\sigma_{VBF} = 0.28 \pm 0.09(\text{stat})^{+0.11}_{-0.09}(\text{sys}) \text{ pb}$$

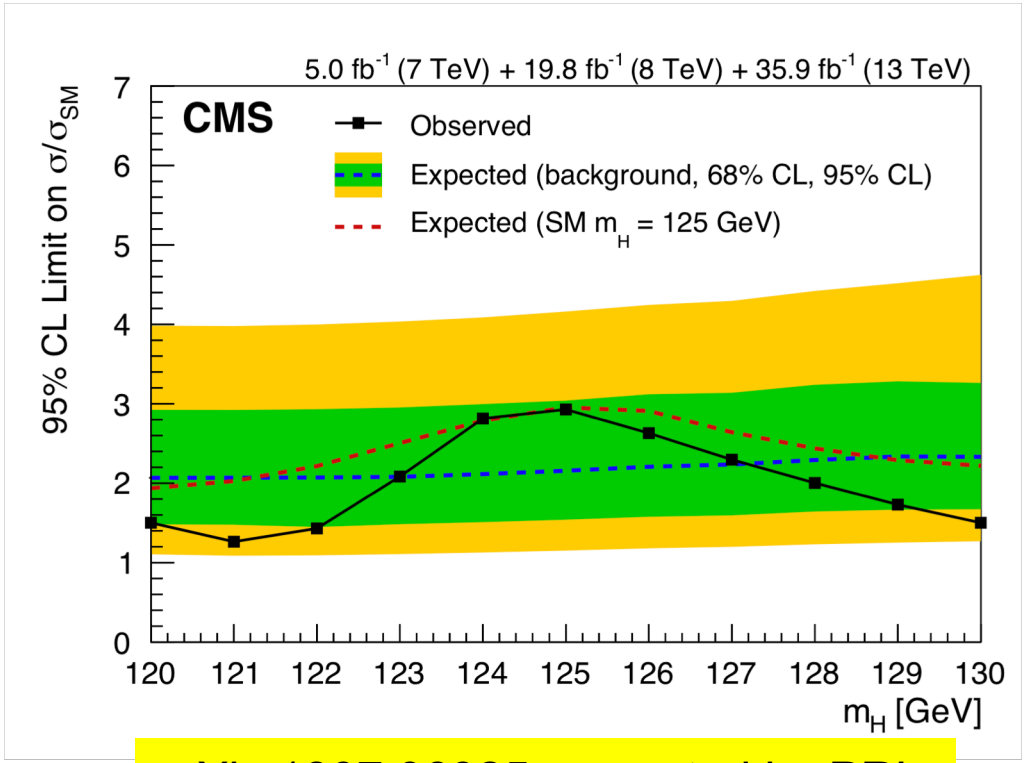
$$\mu = 1.09^{+0.27}_{-0.26}$$

Search for H→$\mu\mu$

- 下一个问题：Higgs couples to 2nd generation?
- Very small decay BR (0.02%)
- Overwhelming by DY background (cat. And BDT used)
- Getting close for access assume SM: <2.92 SM@95%



PRL 119 (2017) 051802

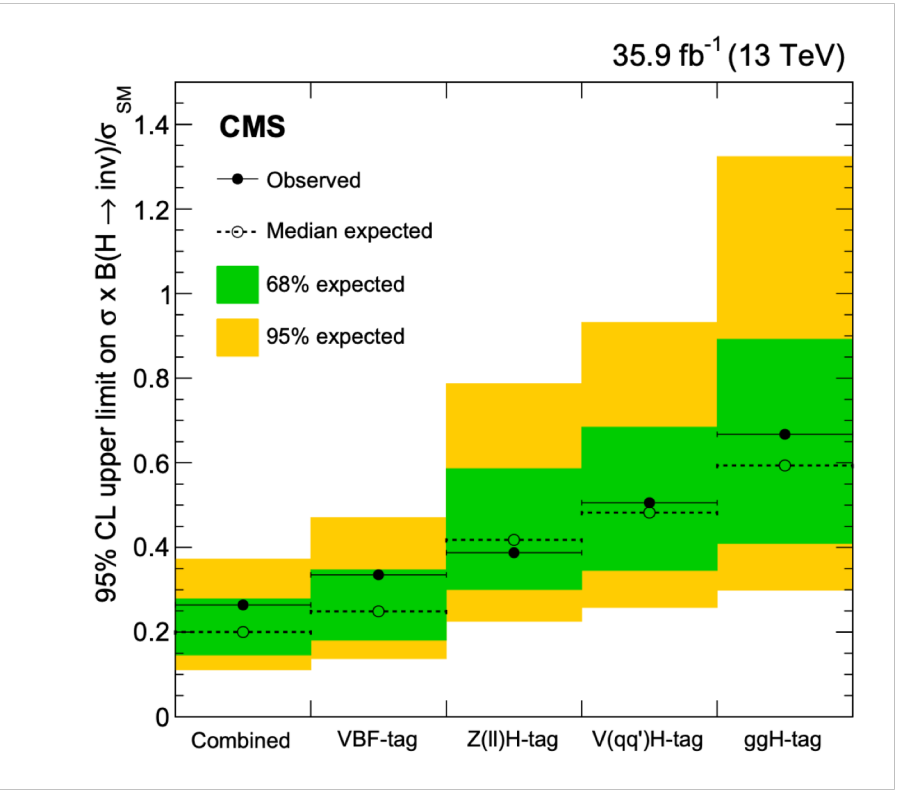


arXiv:1807.06325; accepted by PRL

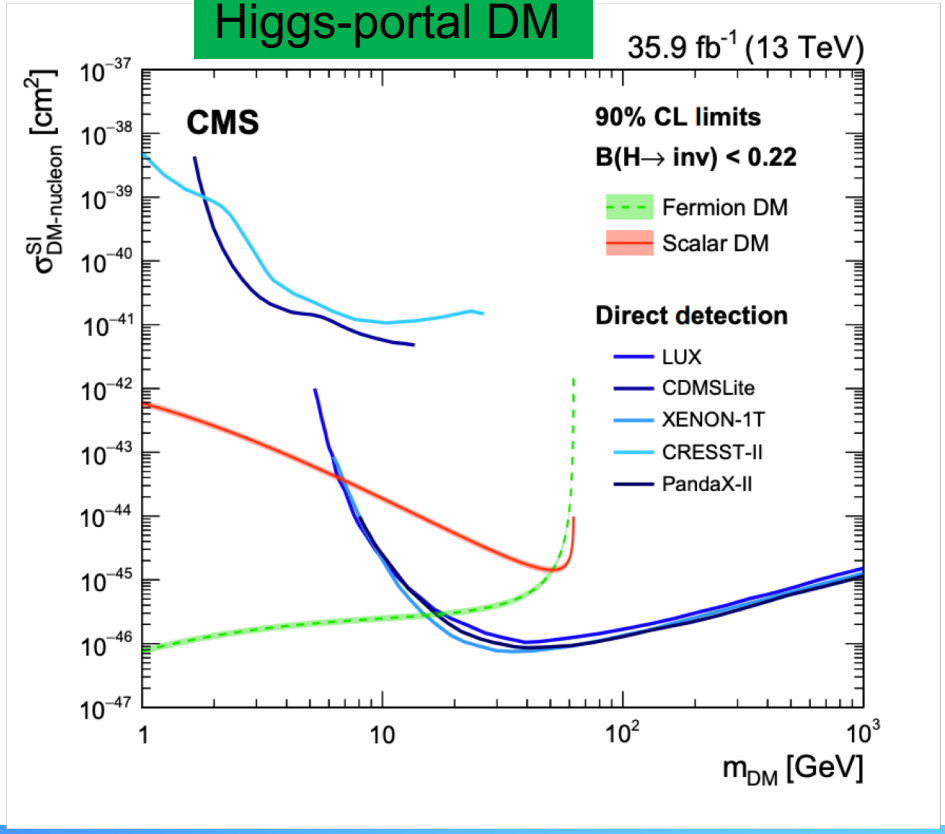
Search for H→inv.

- SM pred. H→inv. Br: <0.1%
- Enhanced from BSM, ex: DM
- Br<0.26 (0.20) @ 95%

arXiv:1809.05937
submitted to PLB

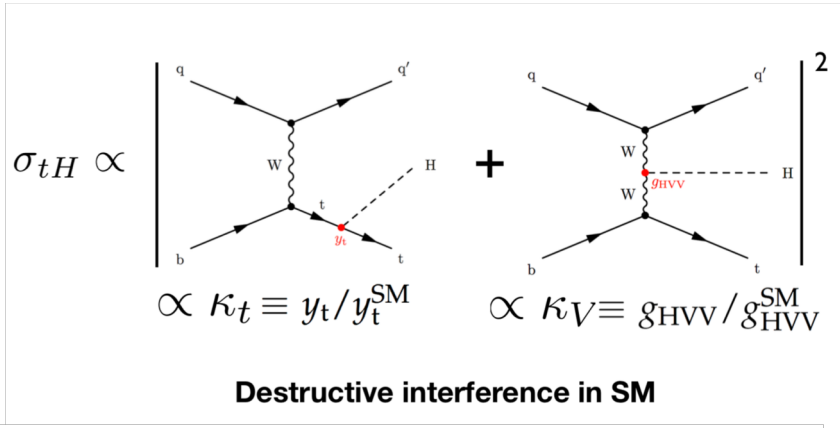


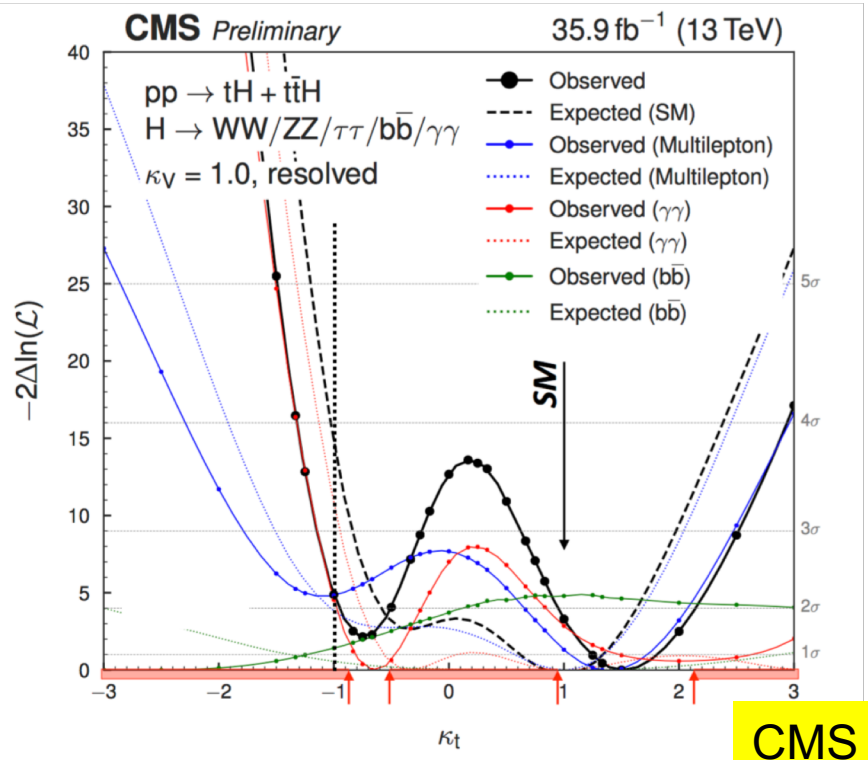
Higgs-portal DM

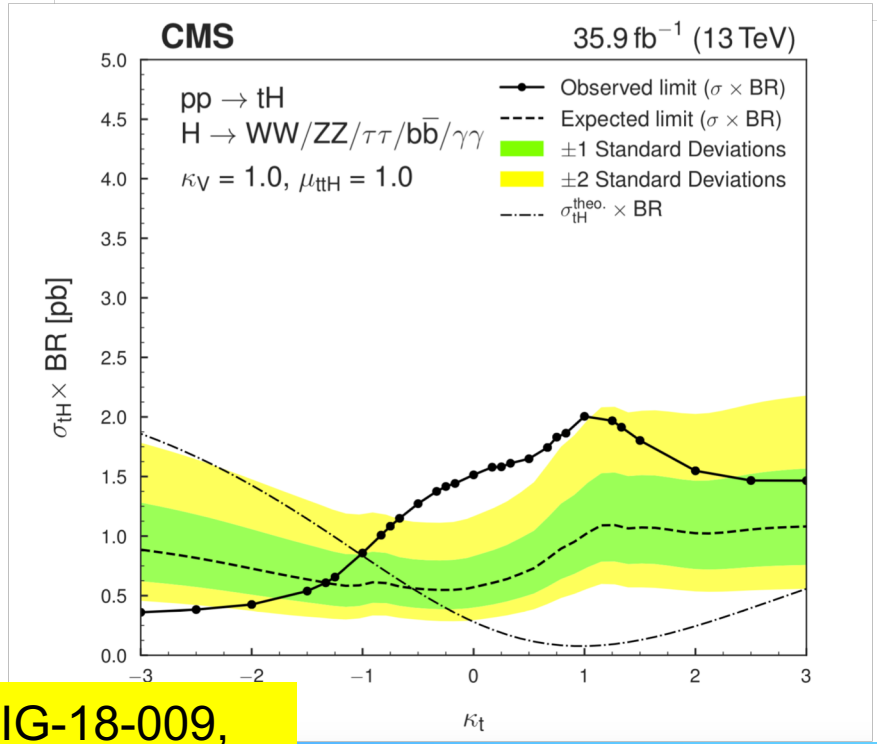


tHq searches

- Sensitive to Yt/gHVV
- Search in H→multi-lepton/bb/$\gamma\gamma$
- Data favors SM phase at 1.5(4)σ
- tHq+ttH about 2 σ within SM pred.





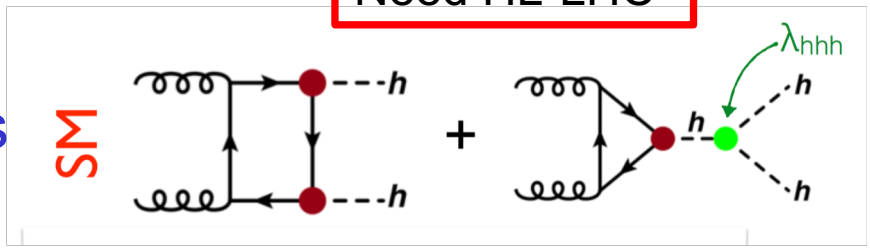


CMS PAS HIG-18-009, about to submit to PRD

Double Higgs: next big target?

- Production w/w.o. Higgs self coupling
  - Probe Higgs self coupling
- Searched with multiple final states

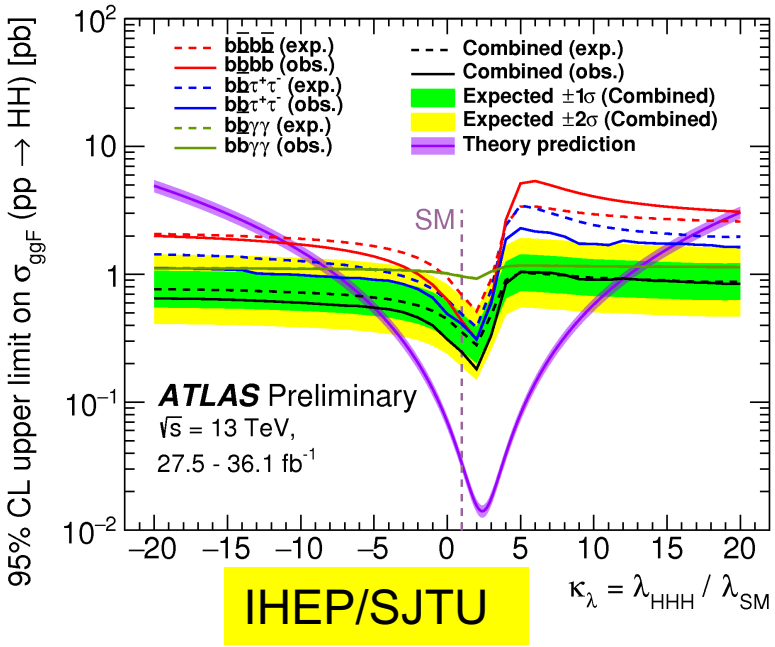
Need HL-LHC



bbbb	bbWW	bbττ	bbγγ
34%	25%	7%	0.26%

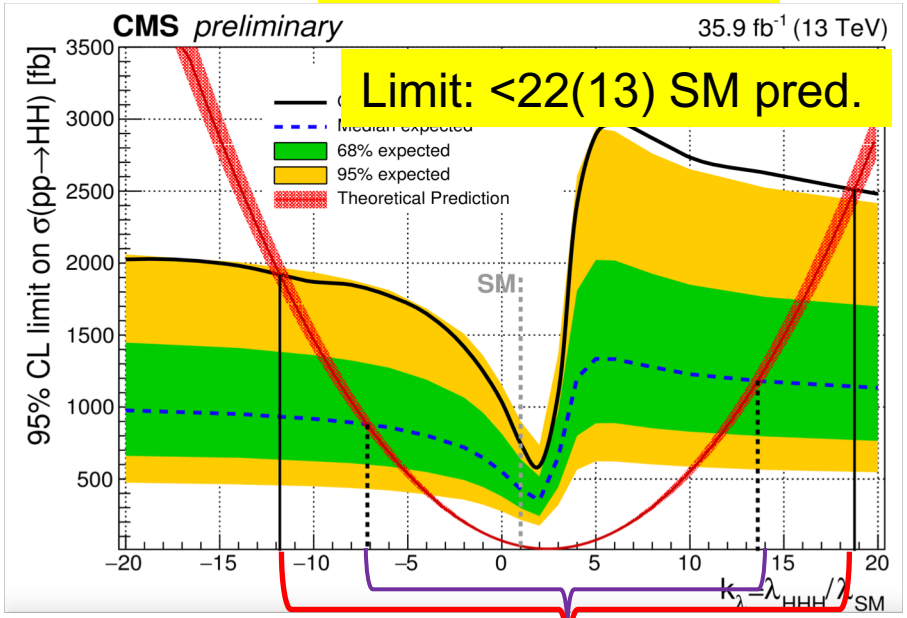
purity

ATLAS-CONF-2018-043



IHEP/SJTU

HIG PAS 2017-030



Limit: <22(13) SM pred.

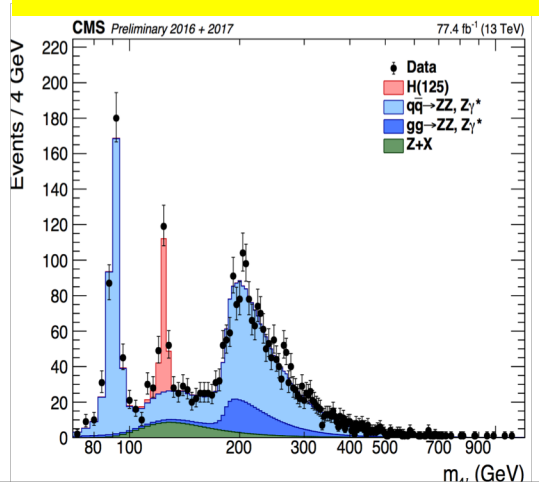
Obv. (**exp**) limit on self coupling

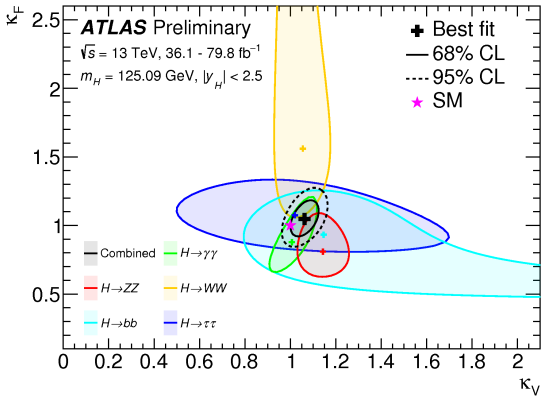
Re-establish H→WW/ZZ/γγ

- Observed decay channel at beginning of Higgs discovery(2012)
  - Mass/CP/Width/X-section accurate measurements

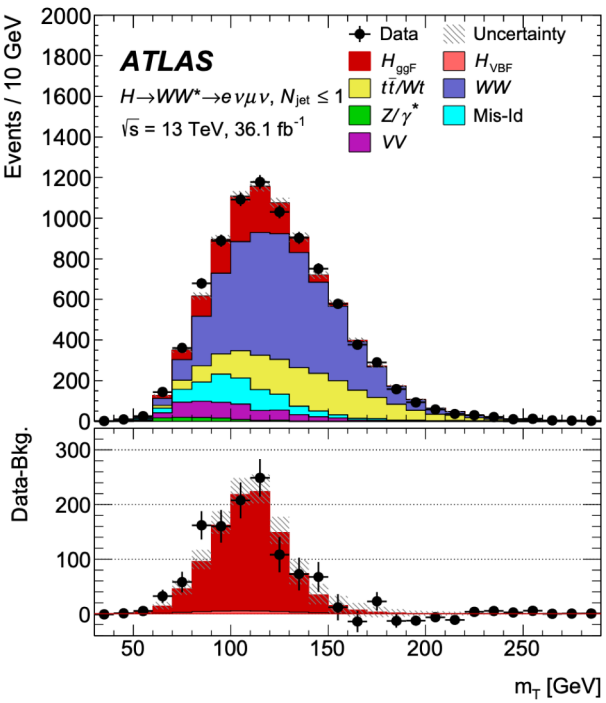
IHEP/USTC/NJU/SDU…

CMS PAS HIG-18-001

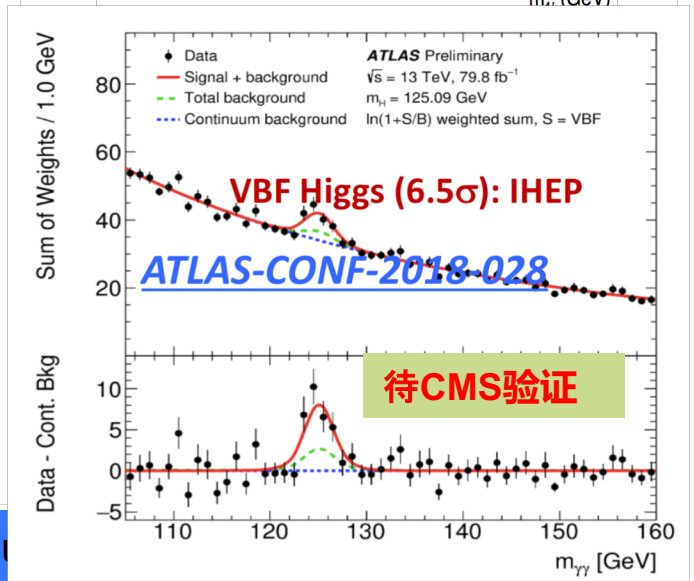


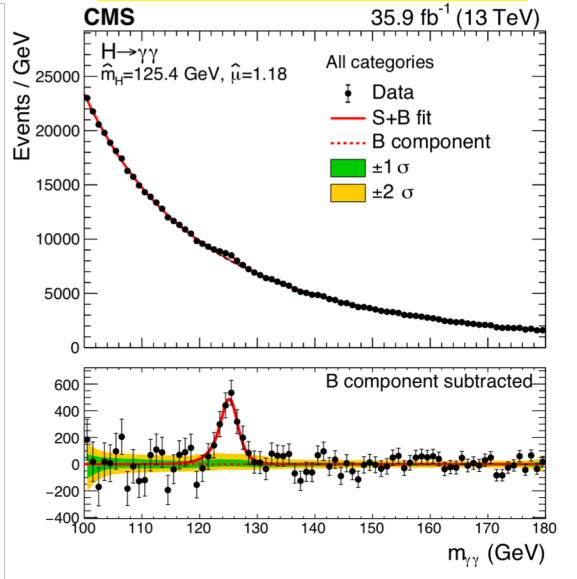


arXiv:1808.09054



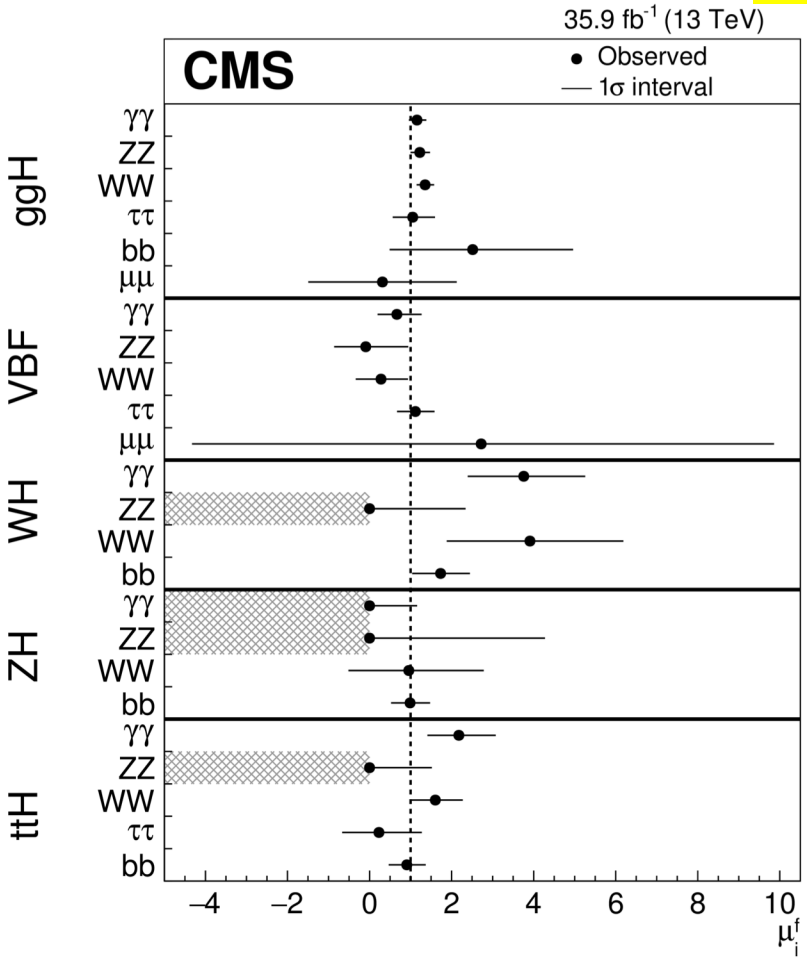
arXiv: 1804.02716

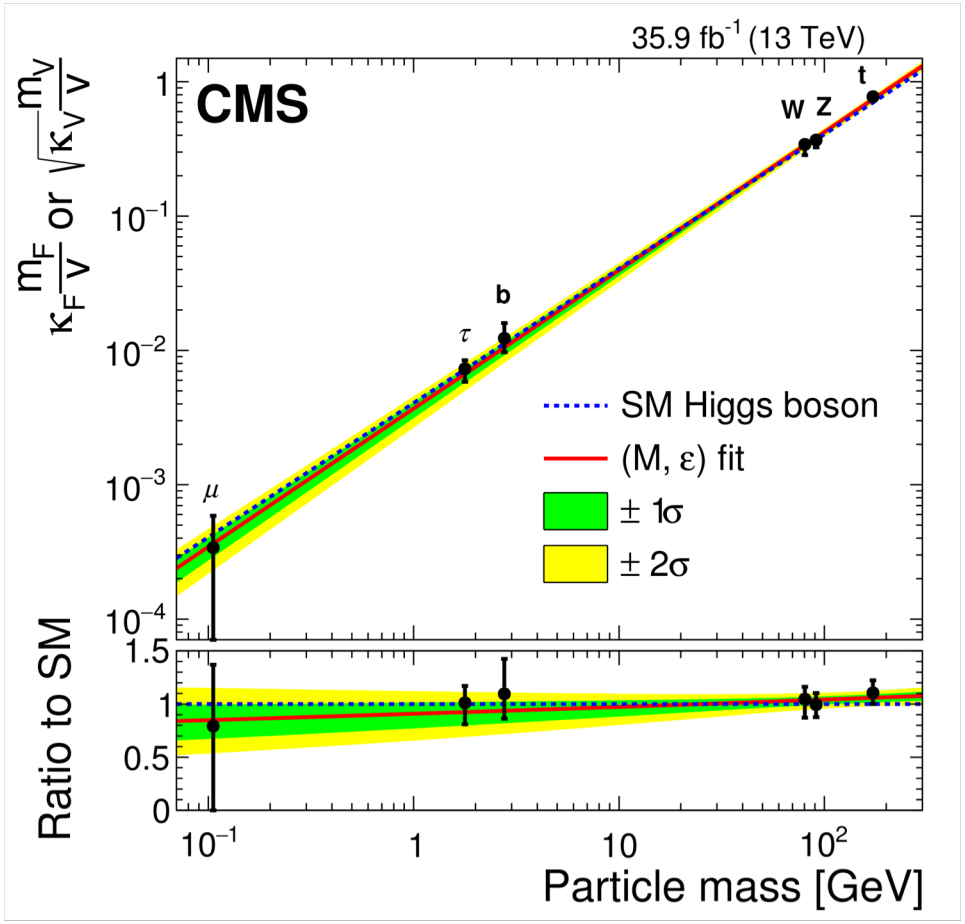




Higgs: More and more SM Like

arXiv:1809.10733

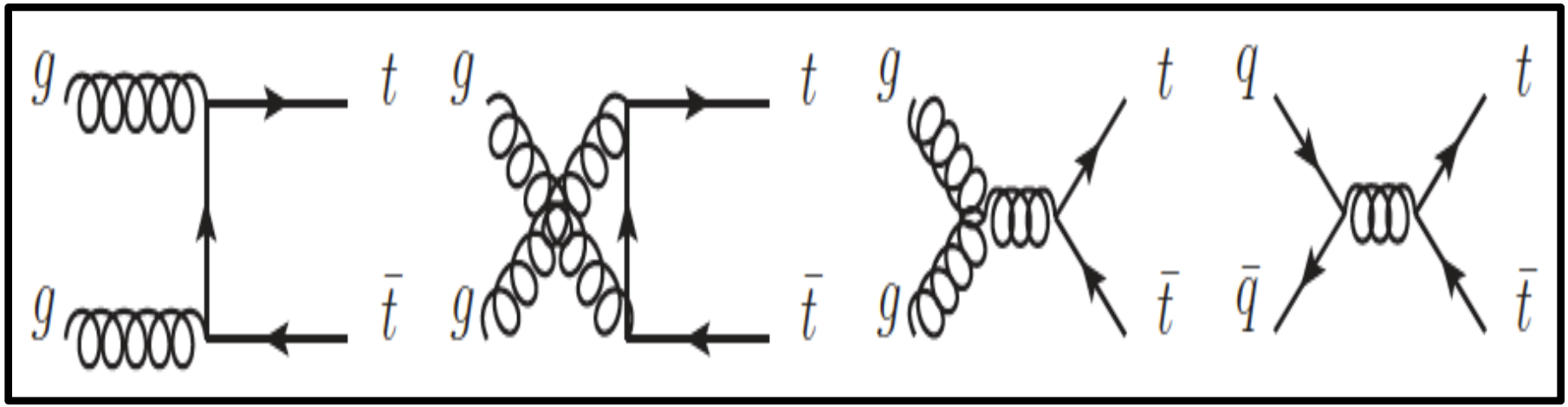


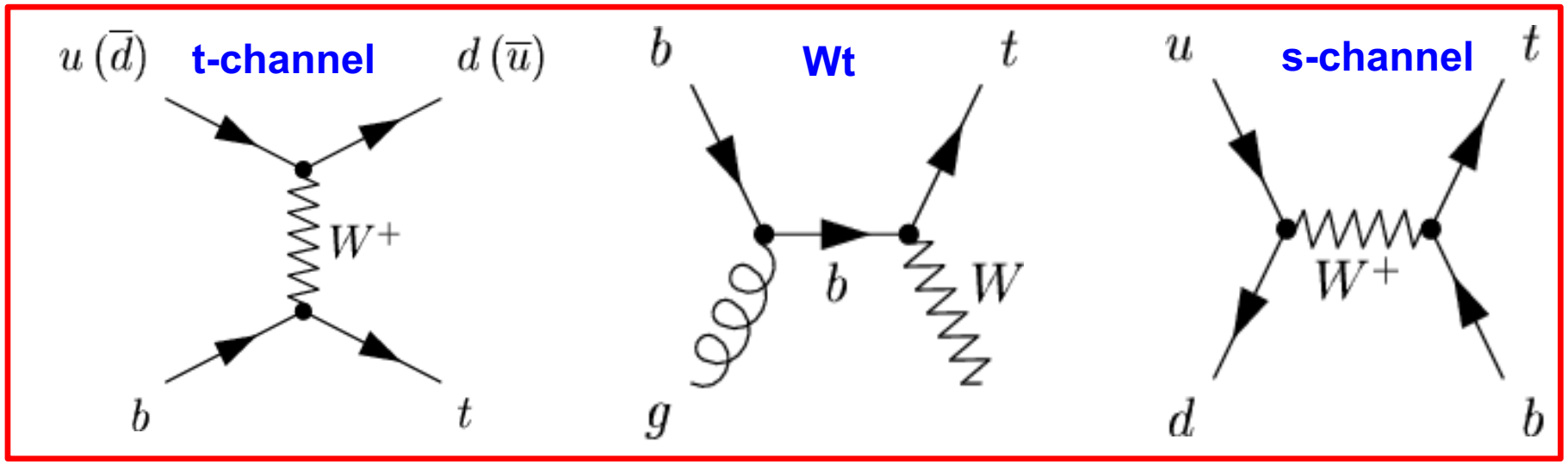


需要更多的数据，或者正负电子对撞机进行精确测量

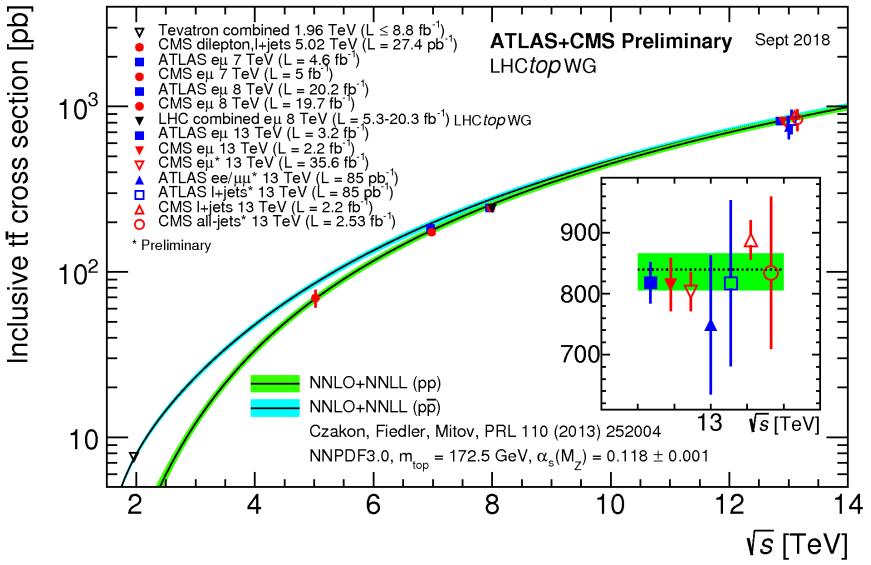
更多的未知需要来发现

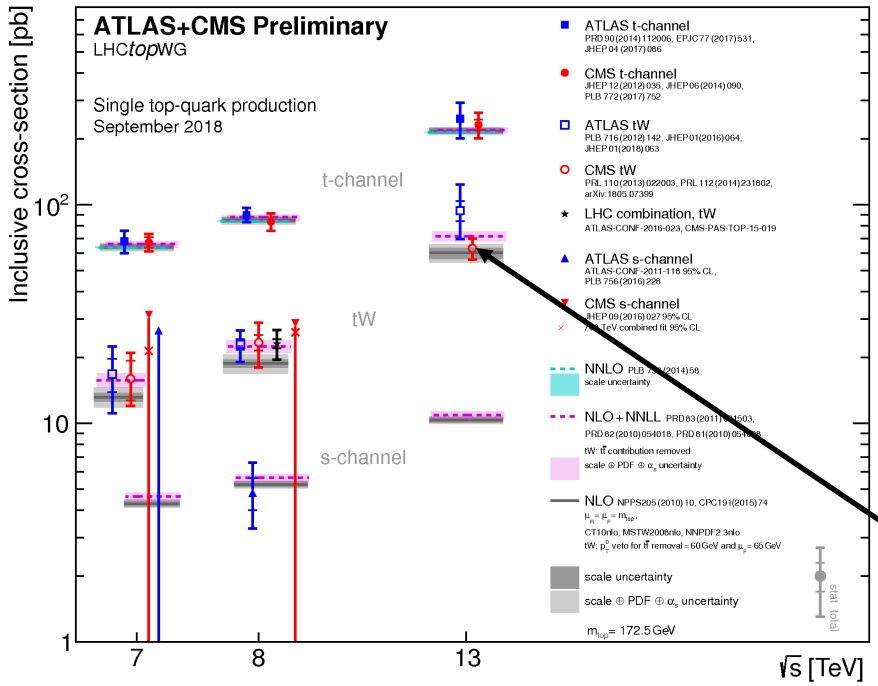
- 最重的基本粒子
- LHC有可以预计的未来最大的top样本：重要性日渐凸显





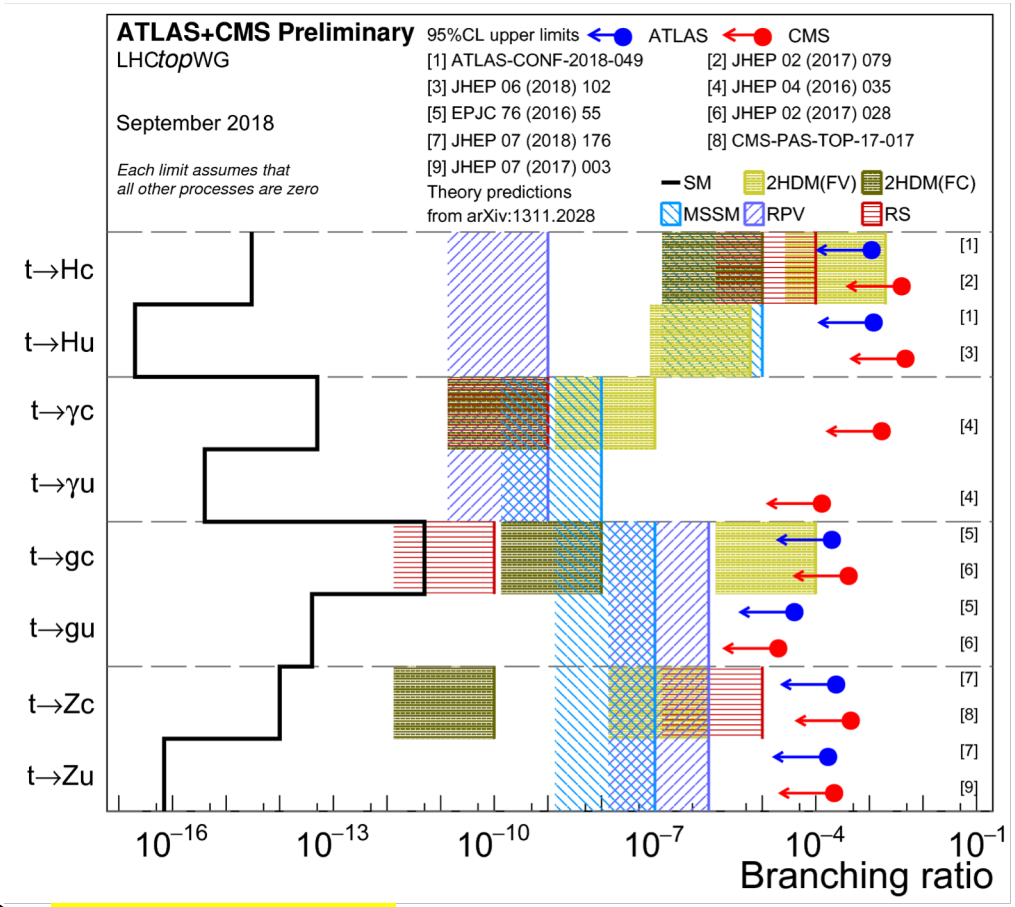
Top quark production and decays





Almost 100% decay to tW

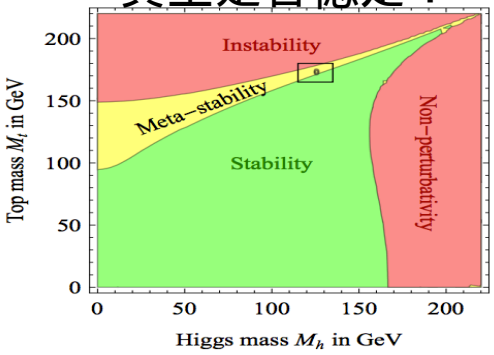
Rare decay not yet sensitive to SM



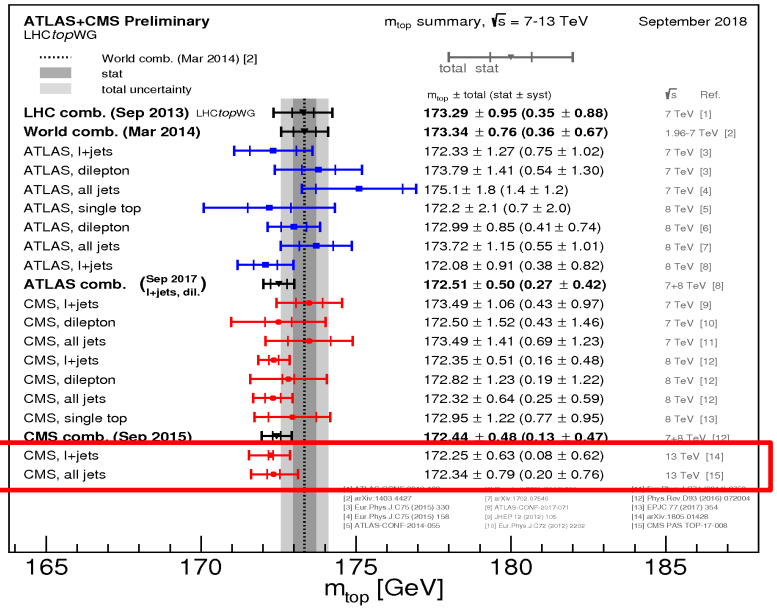
IHEP: contact

Top quark physics: A probe to SM at extreme accuracy

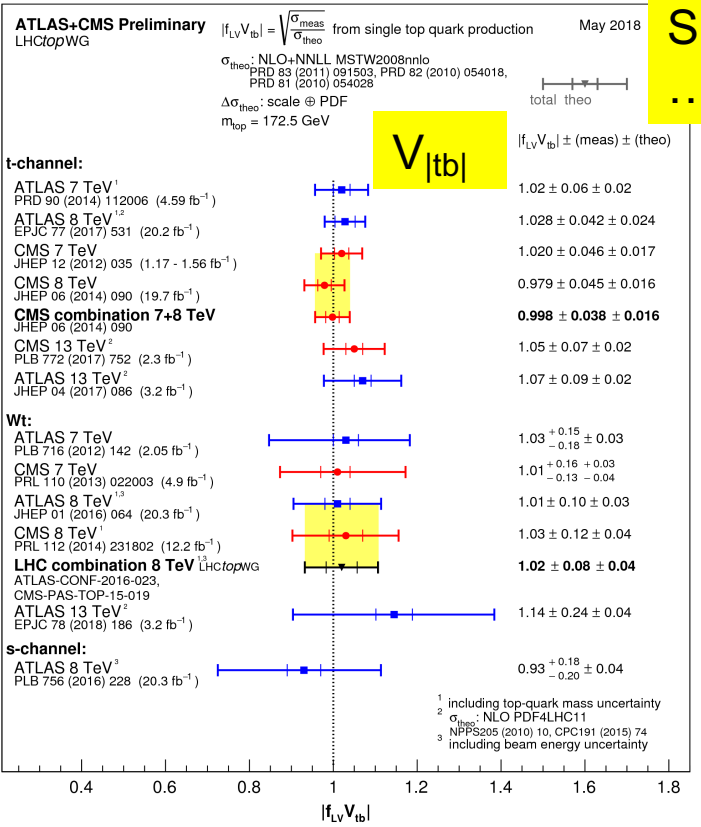
真空是否稳定？



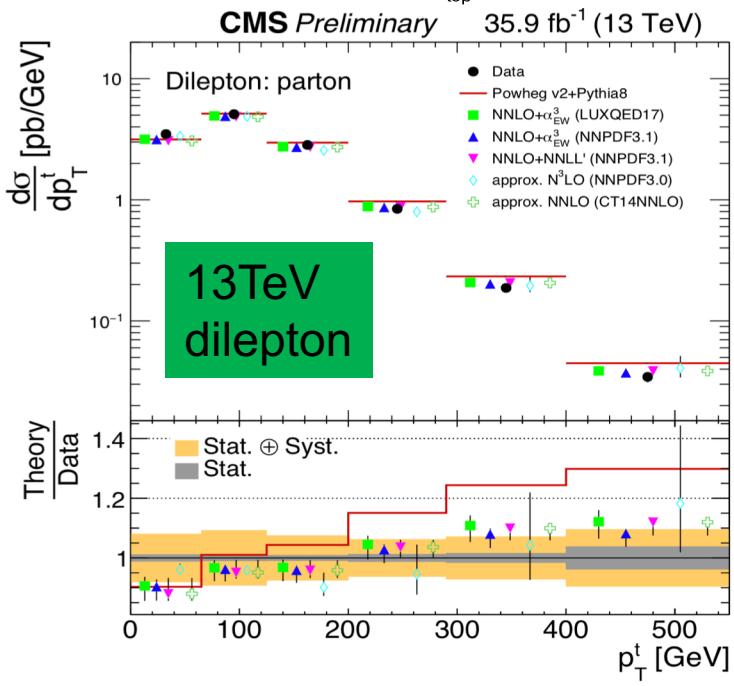
最精确的 top quark质量测量



IHEP
SDU
…



$V_{|tb|}$



13TeV
dilepton

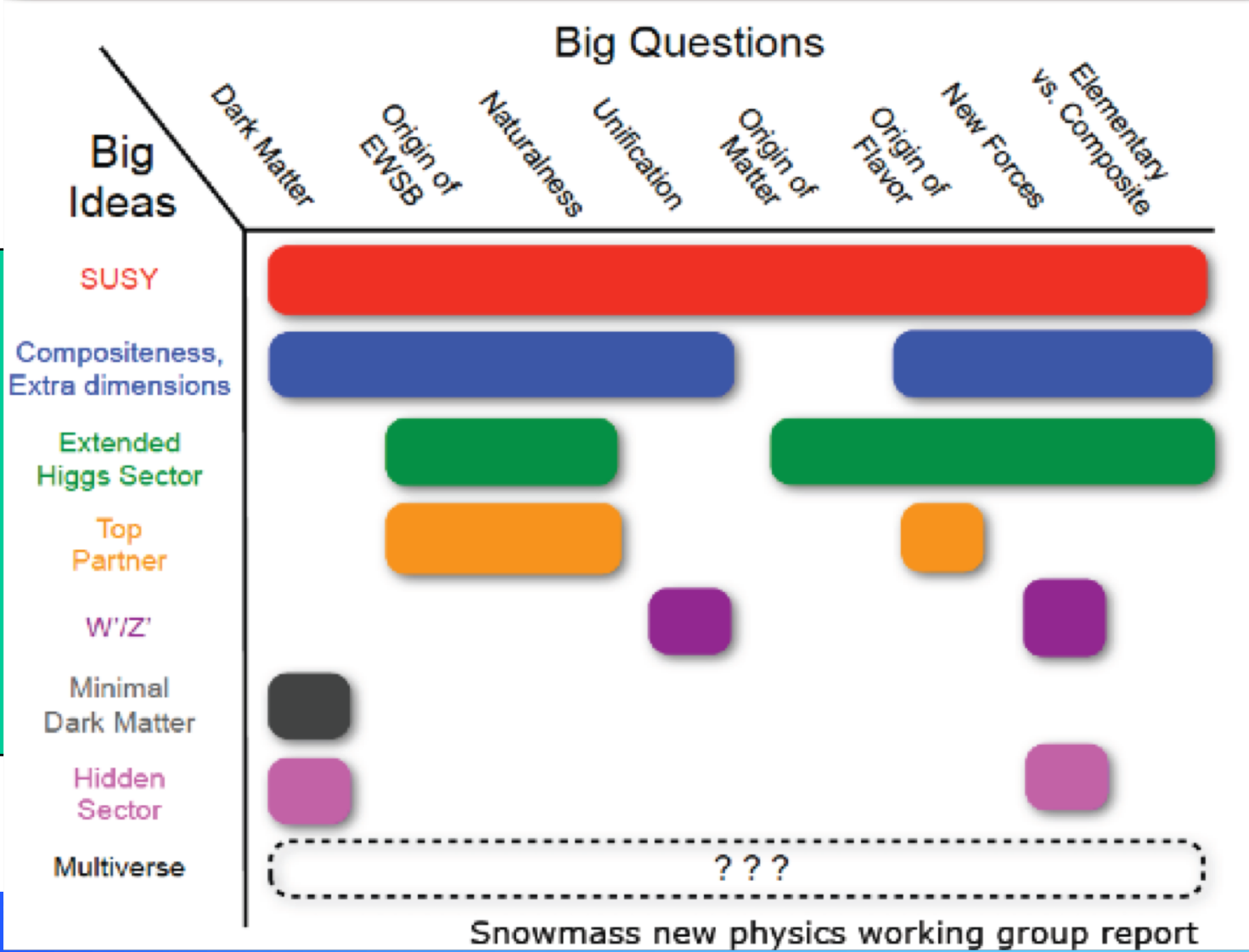
arXiv:1811.06625,
submitted to JHEP

顶夸克pt需要理论描述的修正

LHC, a discover machine

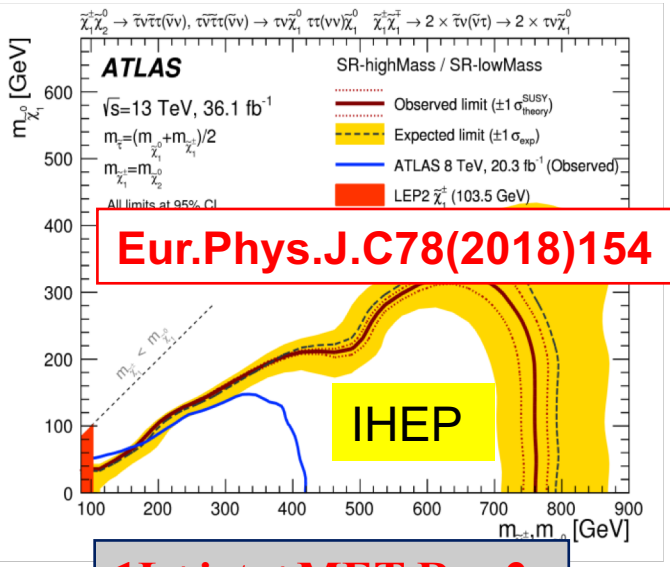
- **Discover Higgs boson**
- **系统性寻找新物理最合适的地方**

中国ATLAS/CMS组正在寻找的模型



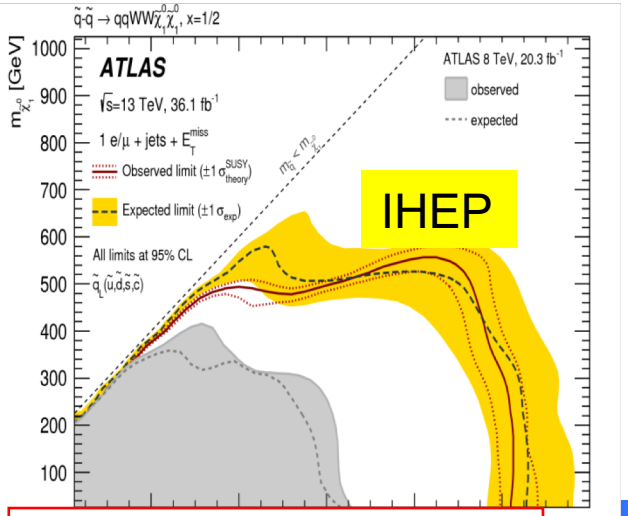
SUSY searches

EWK-2tau Run2

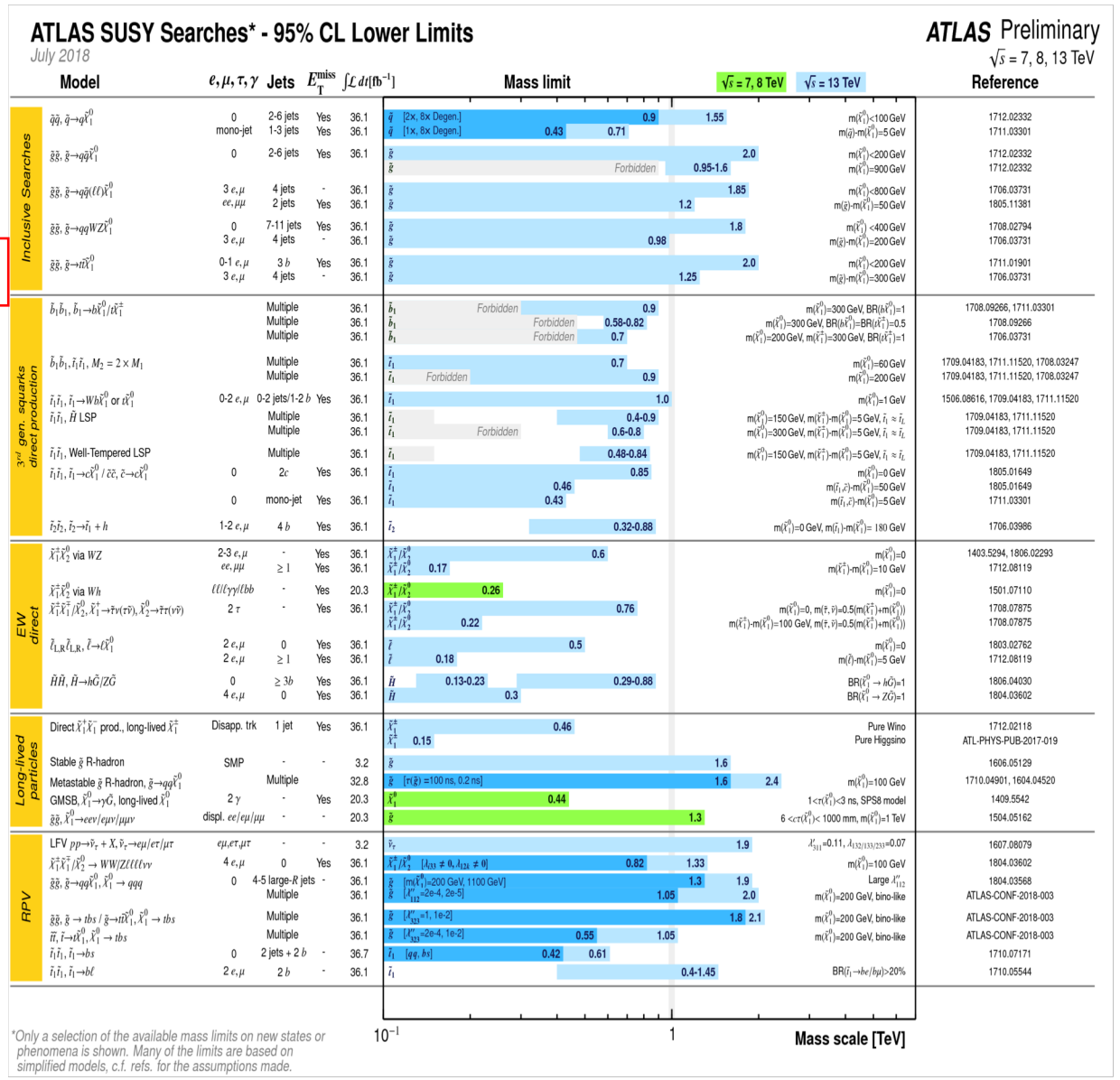


Eur.Phys.J.C78(2018)154

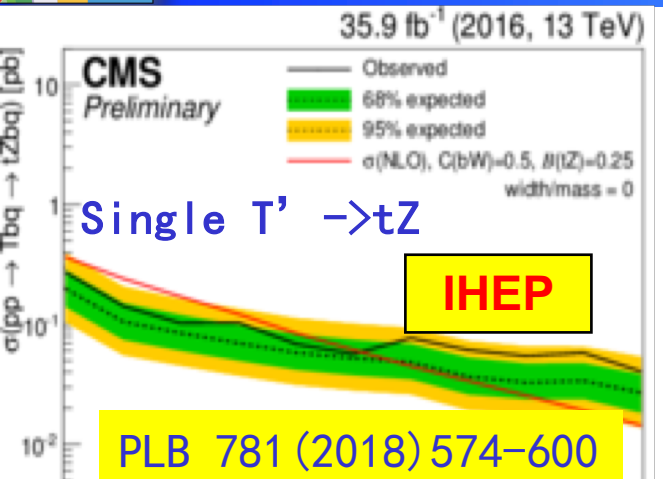
1L+jets+MET Run2



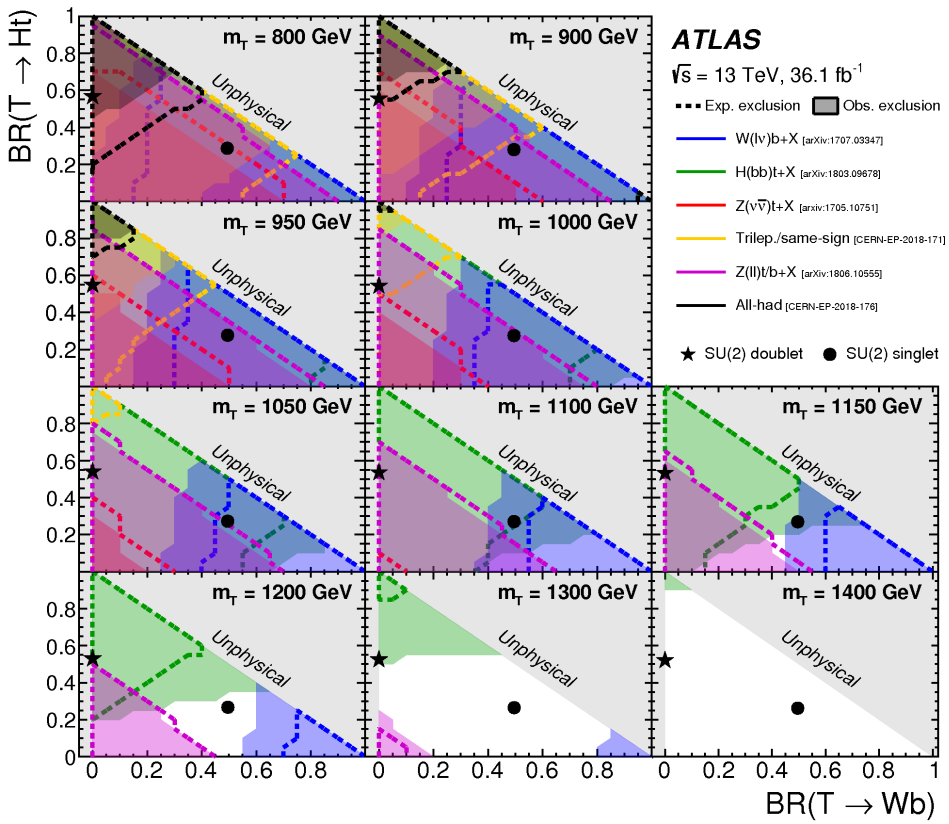
Phys.Rev.D96(2017)112010

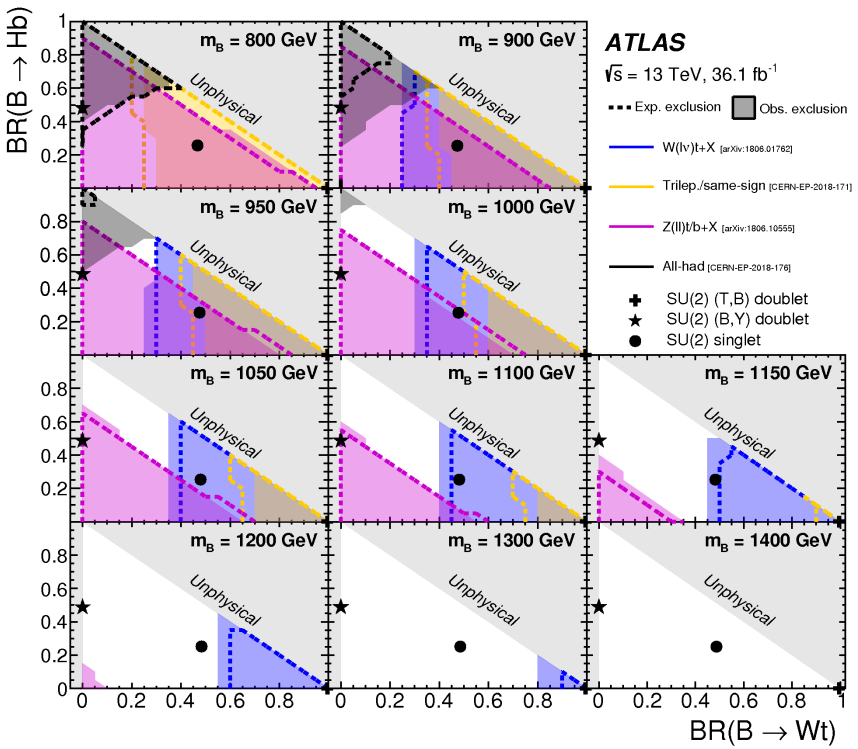


Top partner searches



PLB 781 (2018) 574–600

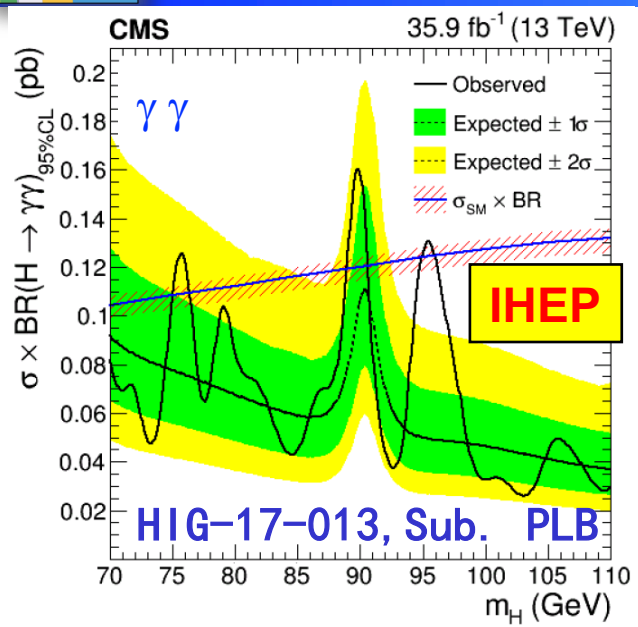


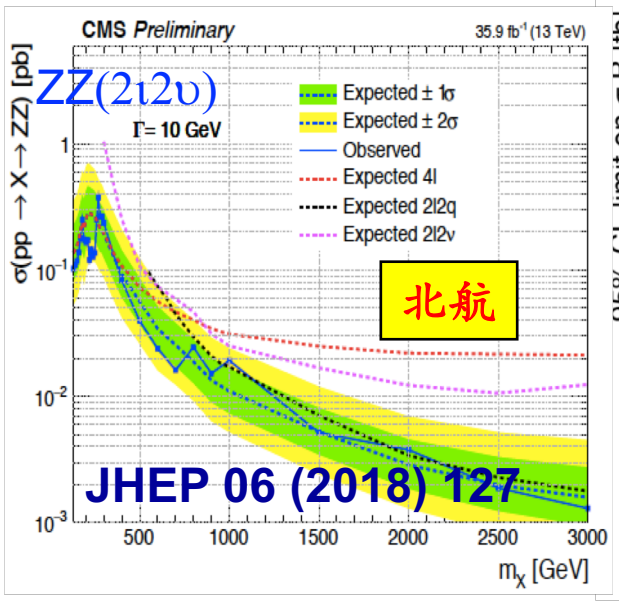


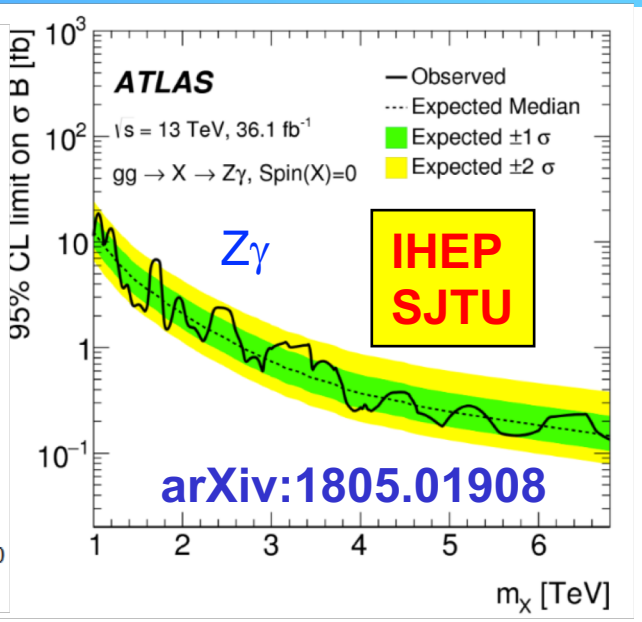
arXiv:1808.02343

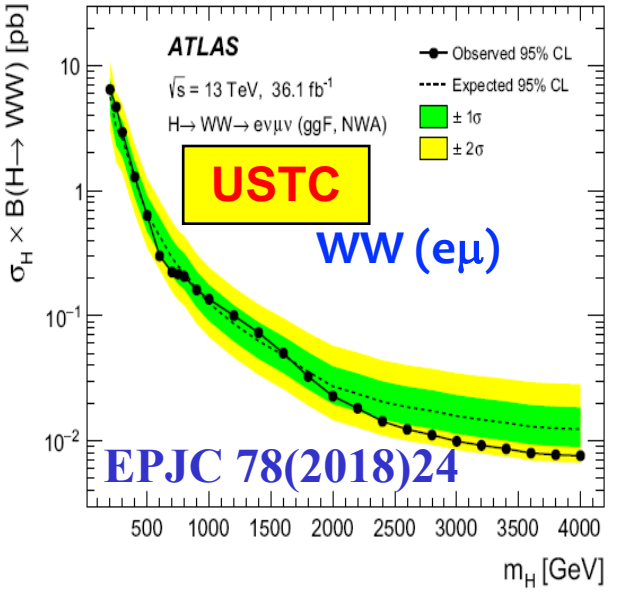
- No signal in single nor pair production (yet)

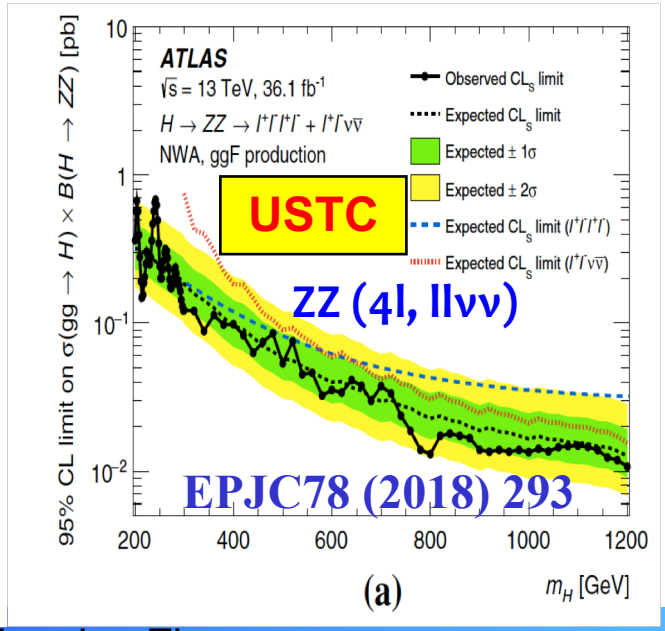
Higgs like resonances

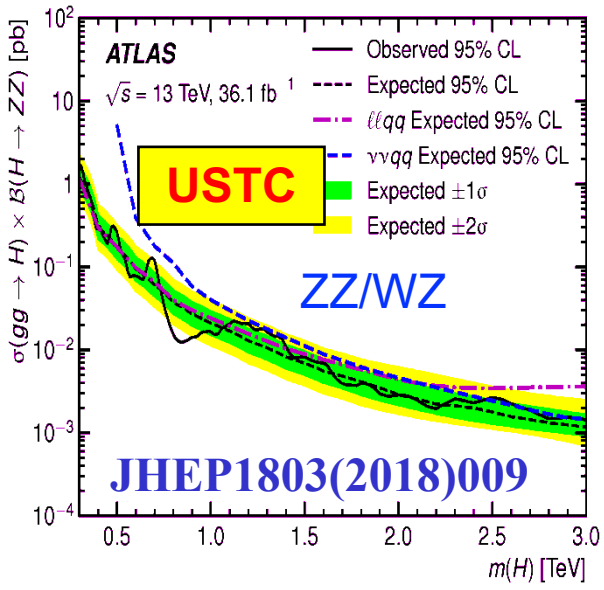




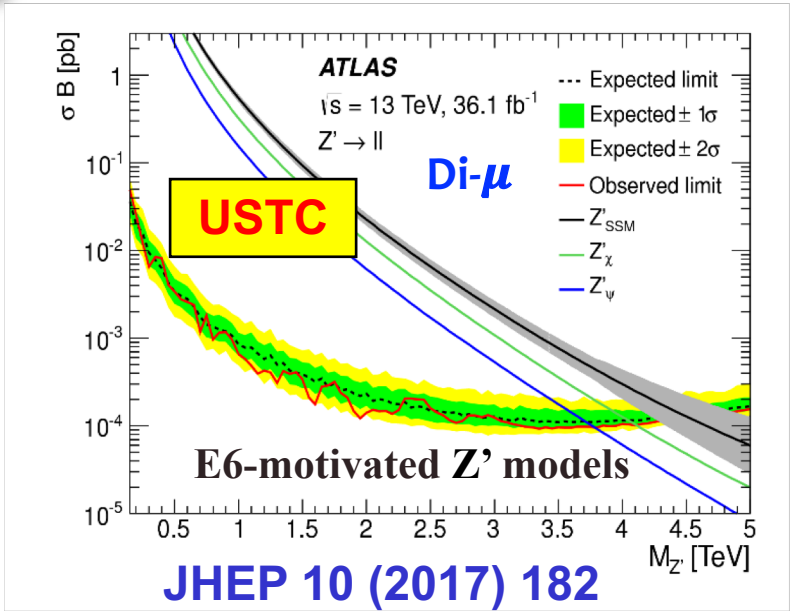




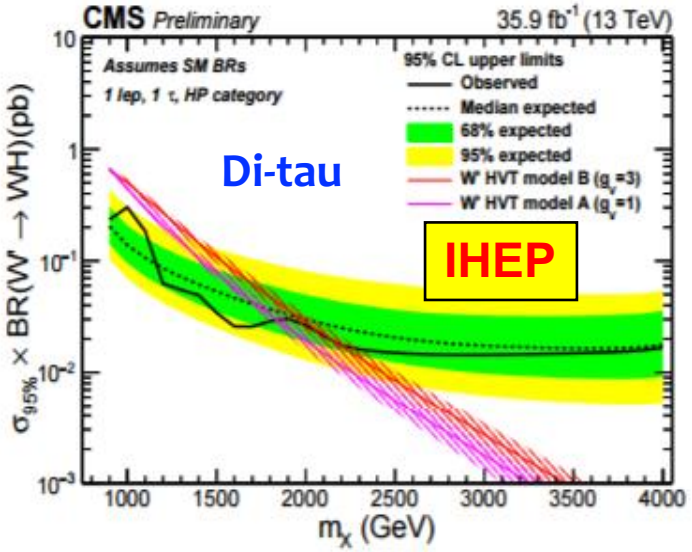




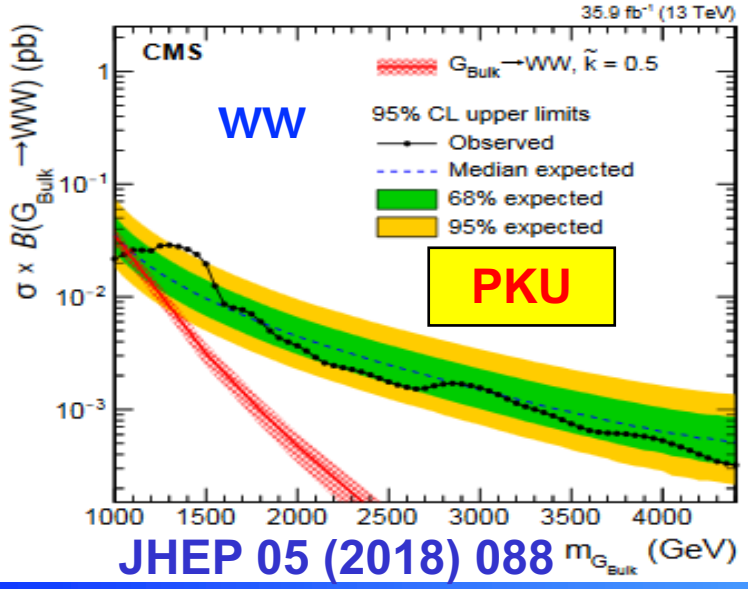
Heavy resonance (W'/Z'…)



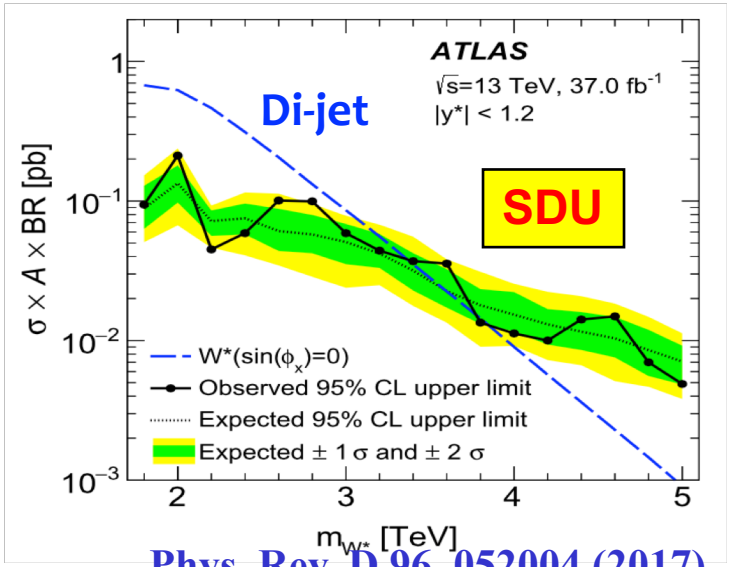
JHEP 10 (2017) 182



arXiv:1808.01365



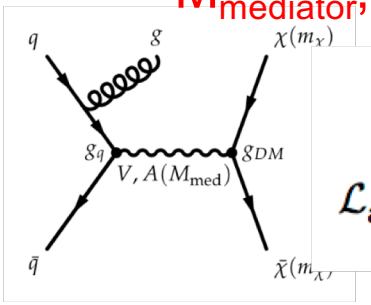
JHEP 05 (2018) 088



Phys. Rev. D 96, 052004 (2017)

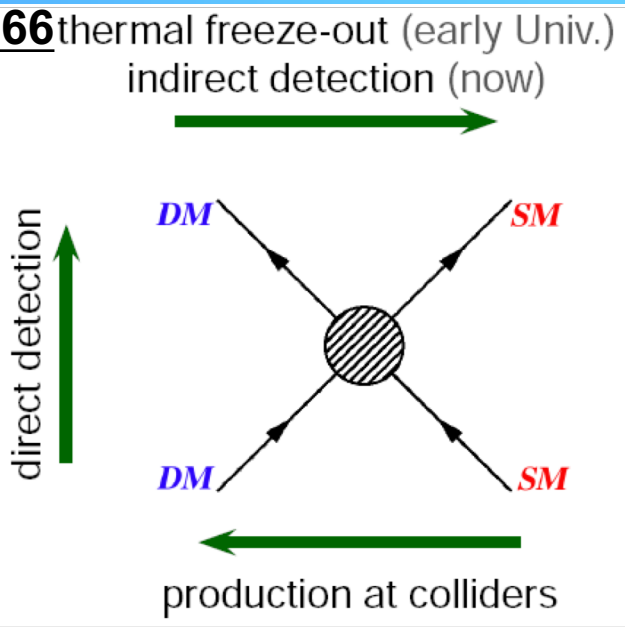
Dark mater bench mark model at LHC

- Keep the mediator information **arXiv:1507.00966**
- Simplified model with parameters of
  - $M_{mediator}$, M_χ, g_q, g_χ

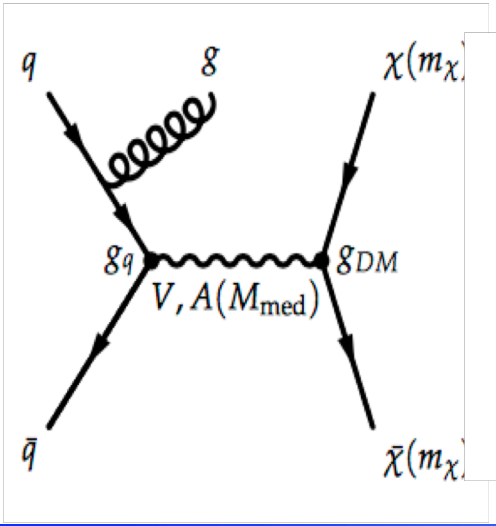


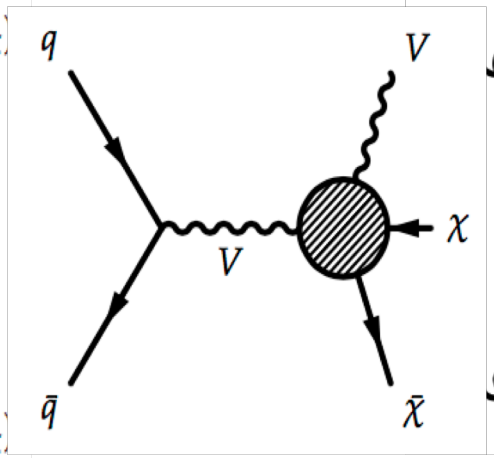
$$\mathcal{L}_{\text{vector}} = g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu q + g_\chi Z'_\mu \bar{\chi}\gamma^\mu \chi$$

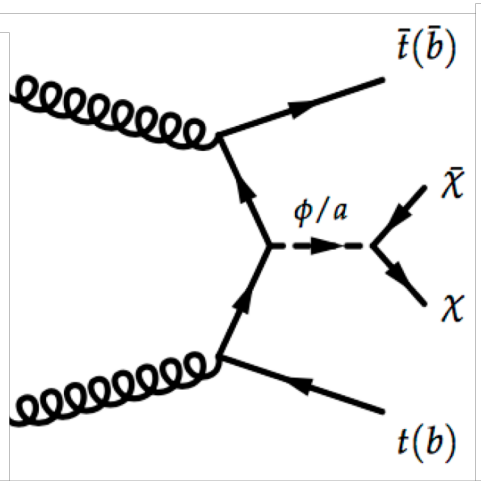
$$\mathcal{L}_{\text{axial-vector}} = g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu\gamma^5 q + g_\chi Z'_\mu \bar{\chi}\gamma^\mu\gamma^5 \chi$$

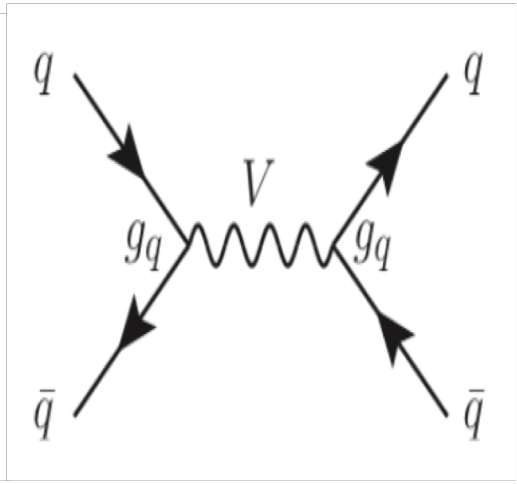


- Searches with MET + X or mediator





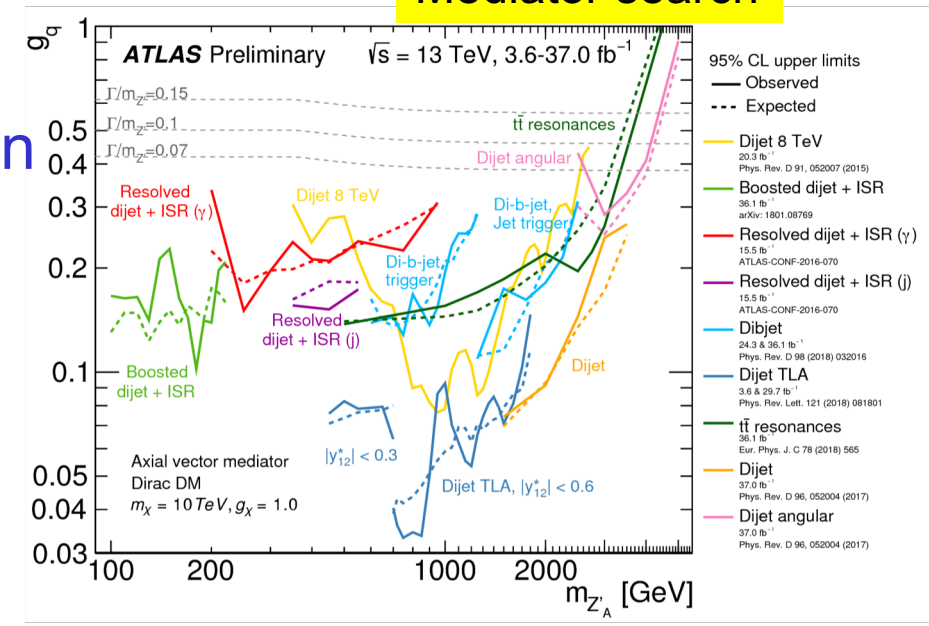


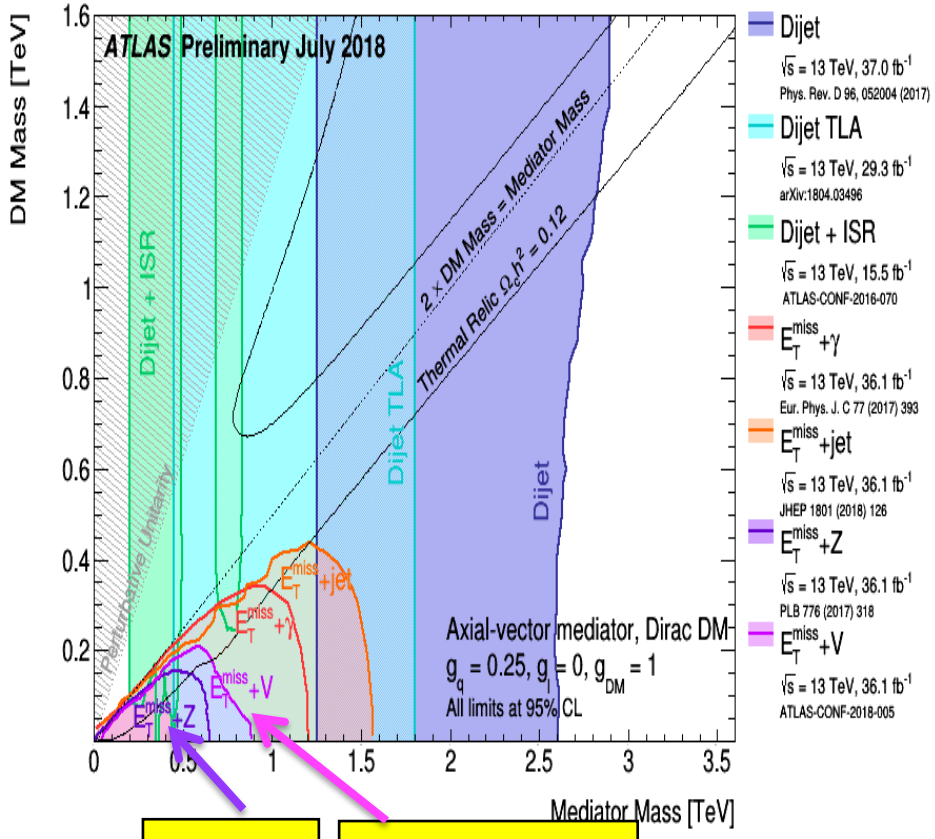


Dark matter searches

- No sign of DM (mediator) yet
- Sensitive comparable/better than direct searches (model dep.)

Mediator search

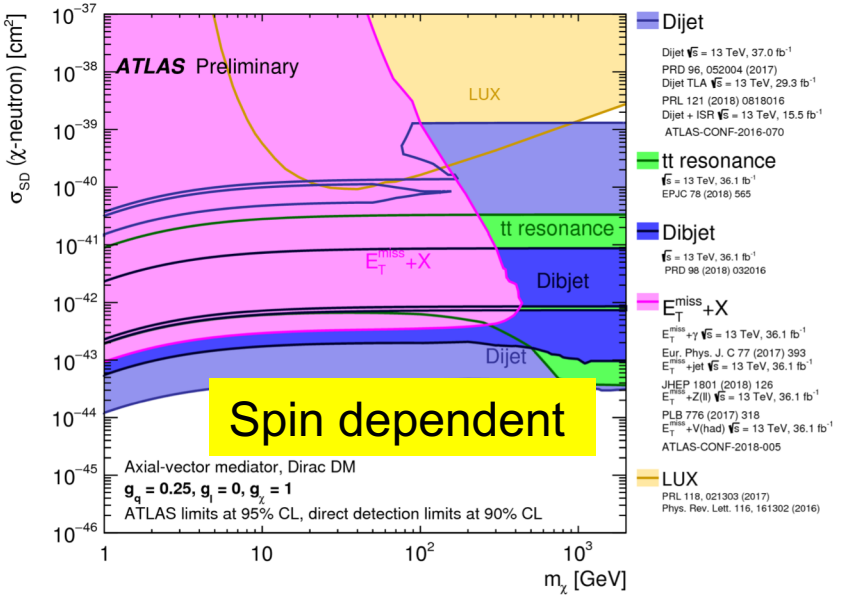




USTC

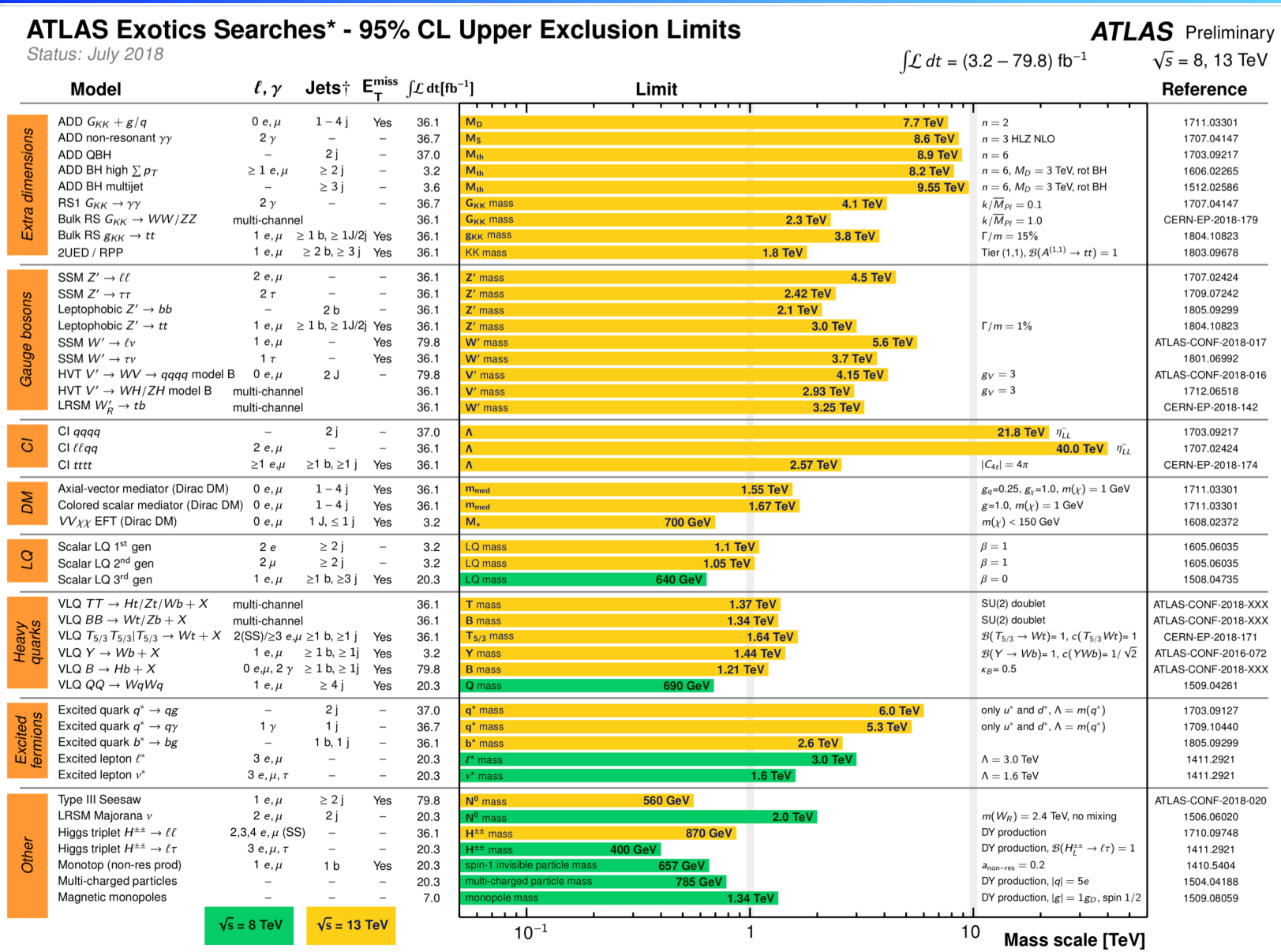
SJTU, NJU

ATLAS-CONF-2018-051



Spin dependent

No new physics (yet)

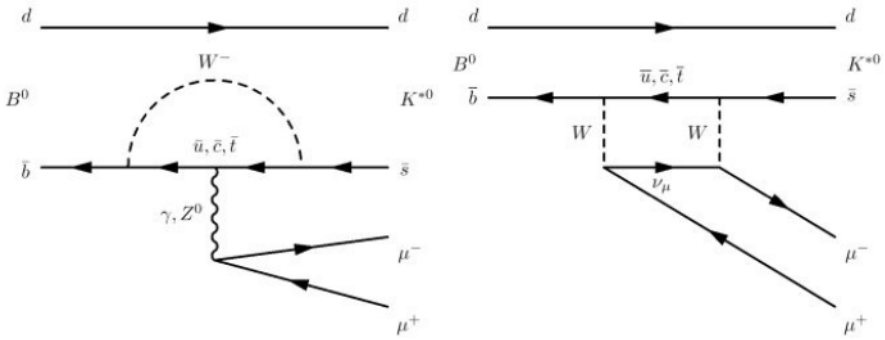


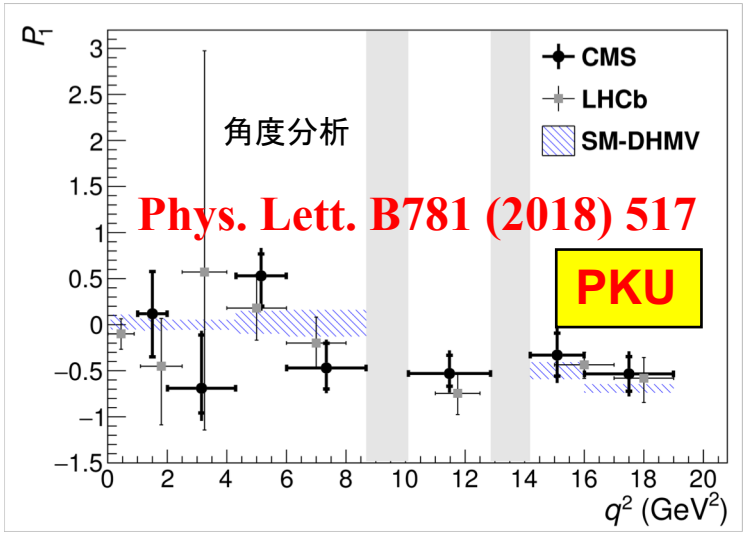
*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

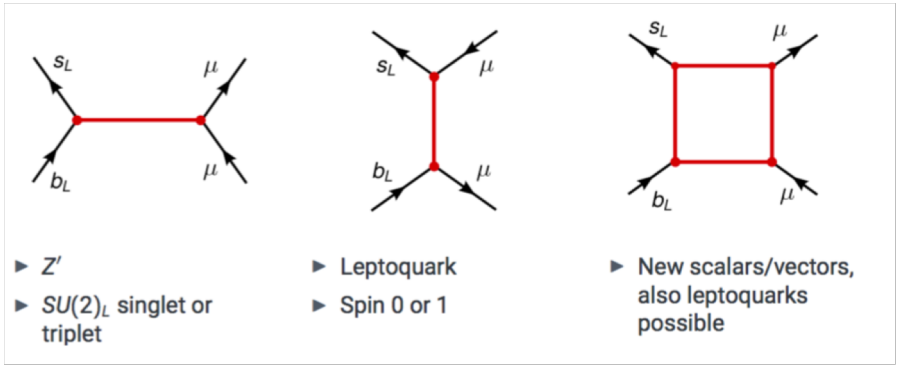
B物理：B → K(*)μ⁺ μ⁻的测量和角度分析

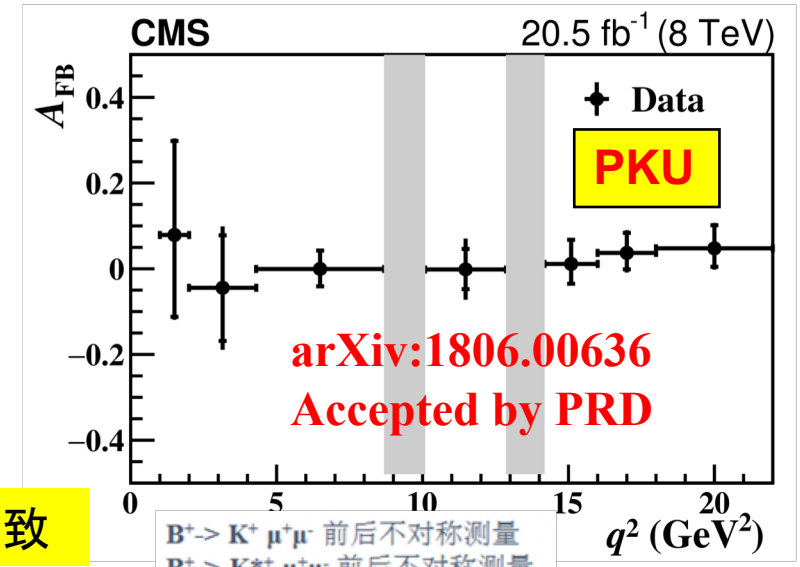
味道改变中性流过程，对新物理极敏感





“B 介子反常”=> 多种新物理模型





测量的分布与标准模型一致

总结

Higgs

- 2018 LHC发现了三种希格斯粒子与费米子的相互作用
  - 全部为第三代（夸克/轻子）
  - 中国ATLAS/CMS组作出了众多关键性的贡献

新物理

- 目前为止未发现新物理的显著证据
  - 中国ATLAS/CMS参与了大部分主流新物理模型的寻找

- 标准模型特别是顶夸克物理的精确测量将越来越重要

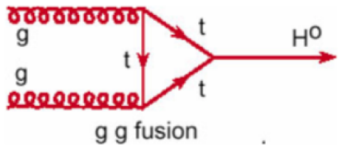
- ATLAS/CMS 仅收集了计划数据的 1/20
  - 将会产生更多的物理成果

CMS成果： http://cms-results.web.cern.ch/cms-results/public-results/publications/
ATLAS成果： https://twiki.cern.ch/twiki/bin/view/AtlasPublic/

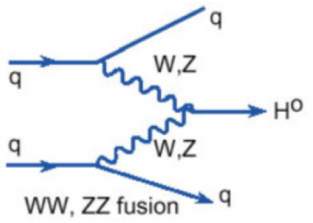
Backup

Higgs production at LHC

	ggF	VBF	WH	ZH	bbH	ttH	tHq	tHW
8 TeV	19.5	1.60	0.70	0.42	0.20	0.13	0.019	0.0012
13 TeV	44.1	3.78	1.37	0.88	0.49	0.51	0.074	0.0029
ratio	2.3	2.4	2.0	2.1	2.5	3.9	3.9	2.4

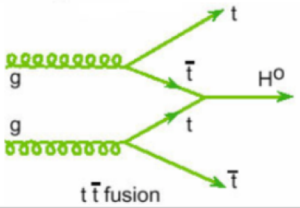


g g fusion

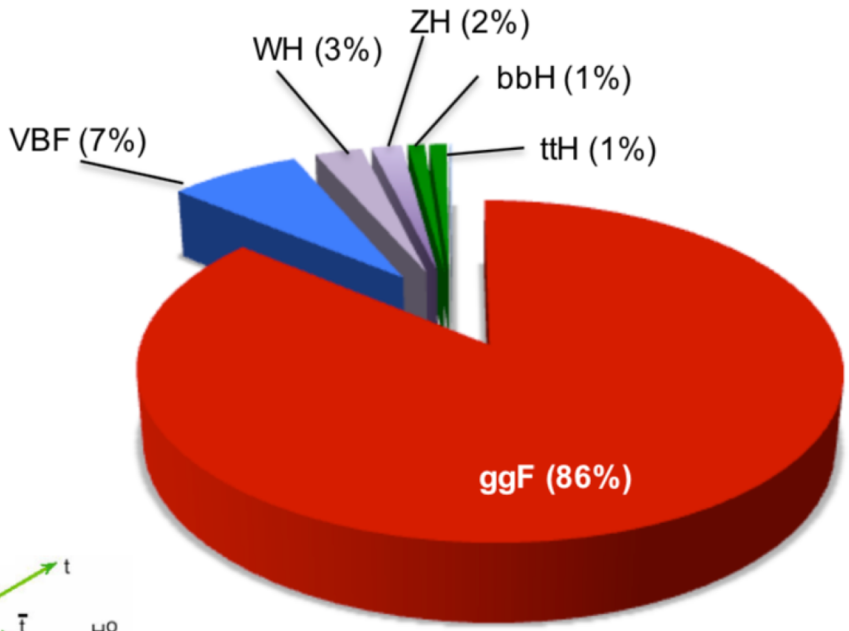


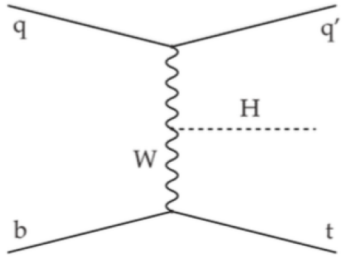
WW, ZZ fusion

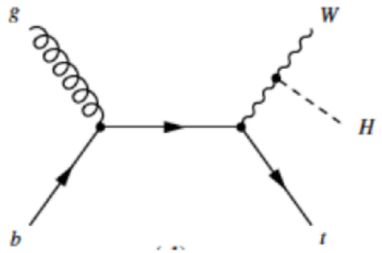
W, Z bremsstrahlung



t t̄ fusion

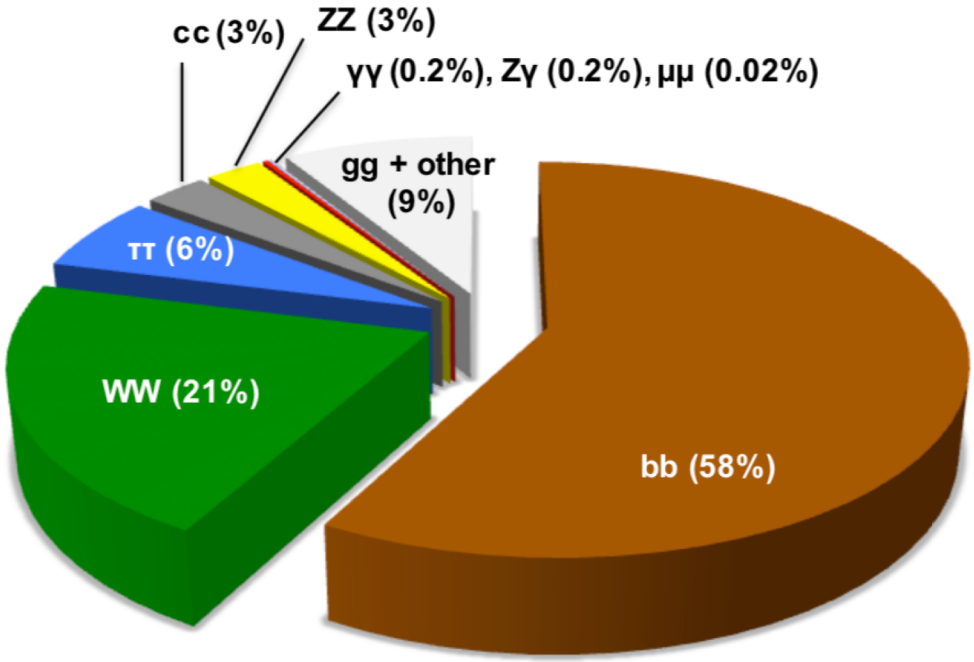


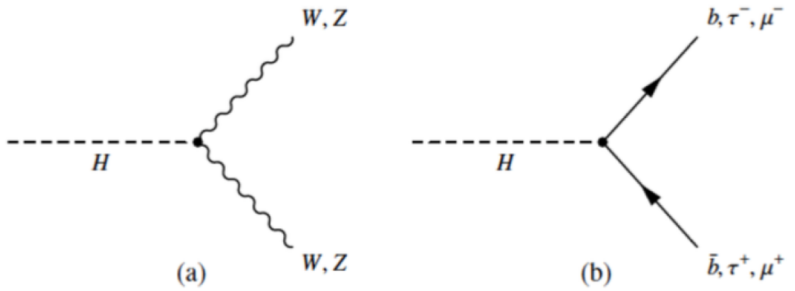


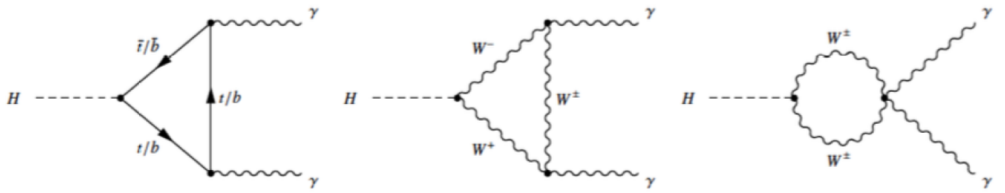


Higgs Decays

	bb	WW	ττ	cc	ZZ	γγ	Zγ	μμ	gg + …
all	58%	21%	6.3%	2.9%	2.6%	0.23%	0.15%	0.022%	9%
leptonic		0.76%			0.012%		0.09%		







Observation of ttH

4th June 2018, LHCP/PRL and others…

PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press About

Featured in Physics | Editors' Suggestion | Open Access | Access by CERN Library | Go Mobile »

Observation of $t\bar{t}H$ Production

A. M. Sirunyan *et al.* (CMS Collaboration)
Phys. Rev. Lett. **120**, 231801 – P

Physics See Viewpoint: Sizing Up

Phys. Rev. Lett. 120, 231801

33 More

Article | References | No Citing Articles | PDF | HTML | Export Citation

ABSTRACT

The observation of Higgs boson production in association with a top quark-antiquark pair is reported, based on a combined analysis of proton-proton collision data at center-of-mass energies of $\sqrt{s} = 7$, 8, and 13 TeV, corresponding to integrated luminosities of up to 5.1, 19.7, and 35.9 fb^{-1}, respectively. The data were collected with the CMS detector at the CERN LHC. The results of statistically independent searches for Higgs bosons produced in conjunction with a top quark-antiquark pair and decaying to pairs of W bosons, Z bosons, photons, τ leptons, or bottom quark jets are combined to maximize sensitivity. An excess of events is observed, with a significance of 5.2 standard deviations, over the expectation from the background-only hypothesis. The corresponding expected significance from the standard model for a Higgs boson mass of 125.09 GeV is 4.2 standard deviations. The combined best fit signal strength normalized to the standard model prediction is $1.26^{+0.31}_{-0.26}$.

您现在的位置：首页 > 新闻动态 > 高能新闻 > 2018年高能新闻

CMS实验发现ttH物理过程，高能所CMS组作出关键贡献

2018-06-05 | 文章来源：粒子天体中心 | 【大 中 小】

6月4日，《物理评论快报》（Physical Review Letters，简称PRL）以编辑推荐的方式发表了欧洲核子研究中心大型强子对撞机（LHC）上CMS合作组首次发现ttH物理过程的文章（Phys. Rev. Lett. 120, 231801），高能所CMS组张华桥、李秉桓，Francesco Romeo小组在该项研究中最灵敏的ttHWW末态作出了关键性贡献并做合作组预审核报告；同时，张华桥小组和廖红波、Aniello Spiez、Joshuha Thomas-Wilsker小组联合在ttHbb末态也做出重要贡献。此项发现直接证明了希格斯粒子和顶夸克存在一种全新的汤川相互作用，对理解费米子的质量起源有着里程碑式的意义。

希格斯粒子于2012年7月在LHC上ATLAS和CMS实验发现后，理论上就预测存在两种新的相互作用力：希格斯粒子和费米子的汤川耦合作用，以及希格斯粒子的自耦合作用。此次CMS实验仅分析了2016年之前取得的数据，发现的ttH产生截面与标准模型预测相比稍微超出，但在2倍误差

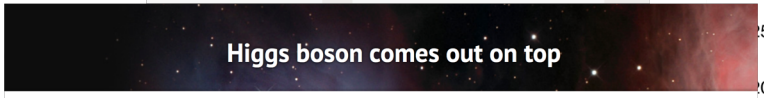
Physics ABOUT BROWSE PRESS COLLECTIONS

PHYSICAL REVIEW JOURNALS 125 YEARS

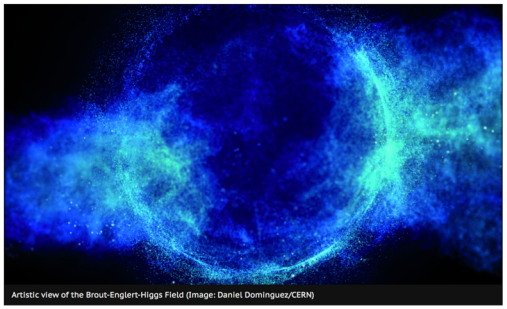
Viewpoint: Sizing Up the Top Interaction with the Higgs

Matthew Reece, Department of Physics, Harvard University, 17 Oxford St, Cambrid

June 4, 2018 • *Physics* 11, 56



Posted by Kate Kahle on 4 Jun 2018. Last updated 4 Jun 2018, 16:35.



New results from the ATLAS and CMS experiments at the Large Hadron Collider (LHC) reveal how strongly the Higgs boson interacts with the heaviest known elementary particle, the top quark.

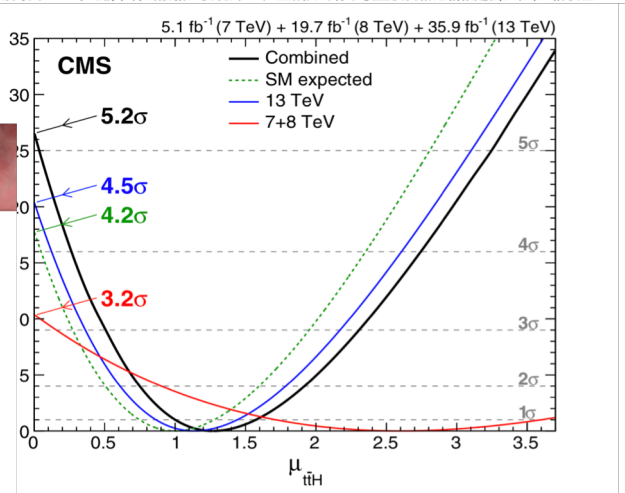
The Higgs boson interacts only with massive particles, yet it was initially discovered in its decay to two

The Higgs boson reveals its affinity for the top quark

04 Jun 2018

New results from the ATLAS and CMS experiments at the LHC reveal how strongly the Higgs boson interacts with the heaviest known elementary particle, the top quark, corroborating our understanding of the Higgs and setting constraints on new physics.

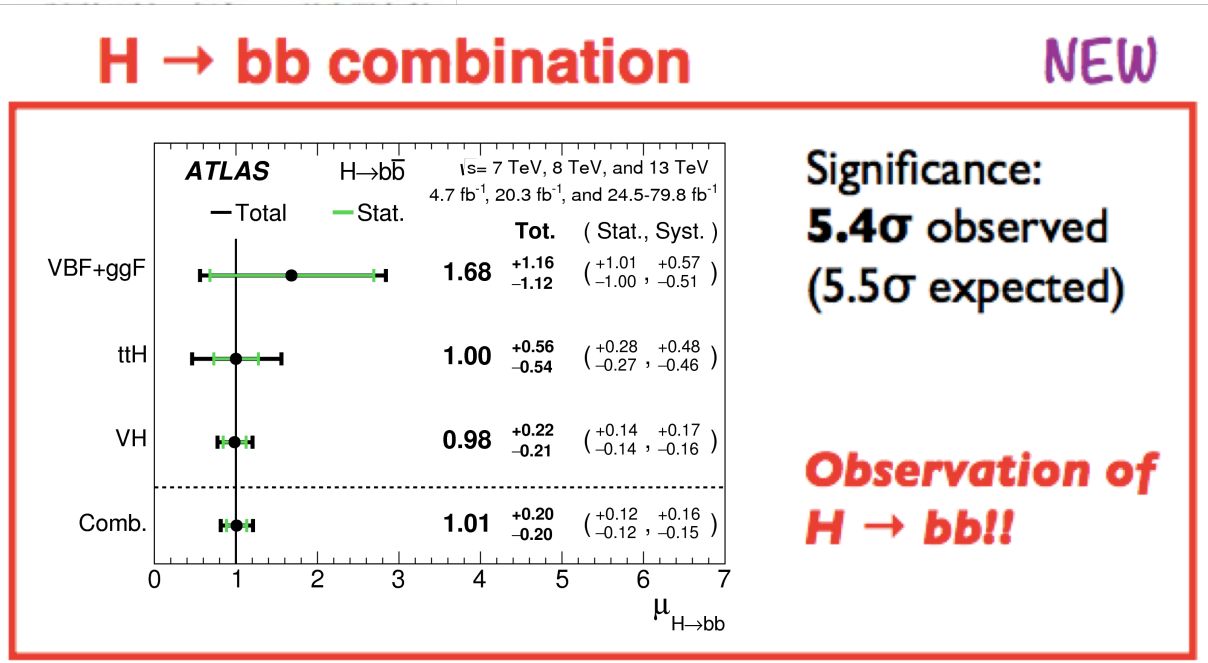
Geneva, 4 June 2018. The Higgs boson interacts only with massive particles, yet it was discovered in its decay to two massless photons. Quantum mechanics allows the Higgs to fluctuate for a very short time into a top quark and a top anti-quark, which promptly annihilate each other into a photon pair. The probability of this process occurring varies with the strength of the interaction (known as coupling) between the Higgs boson and top quarks. Its measurement allows us to indirectly infer the value of the Higgs-top coupling. However,



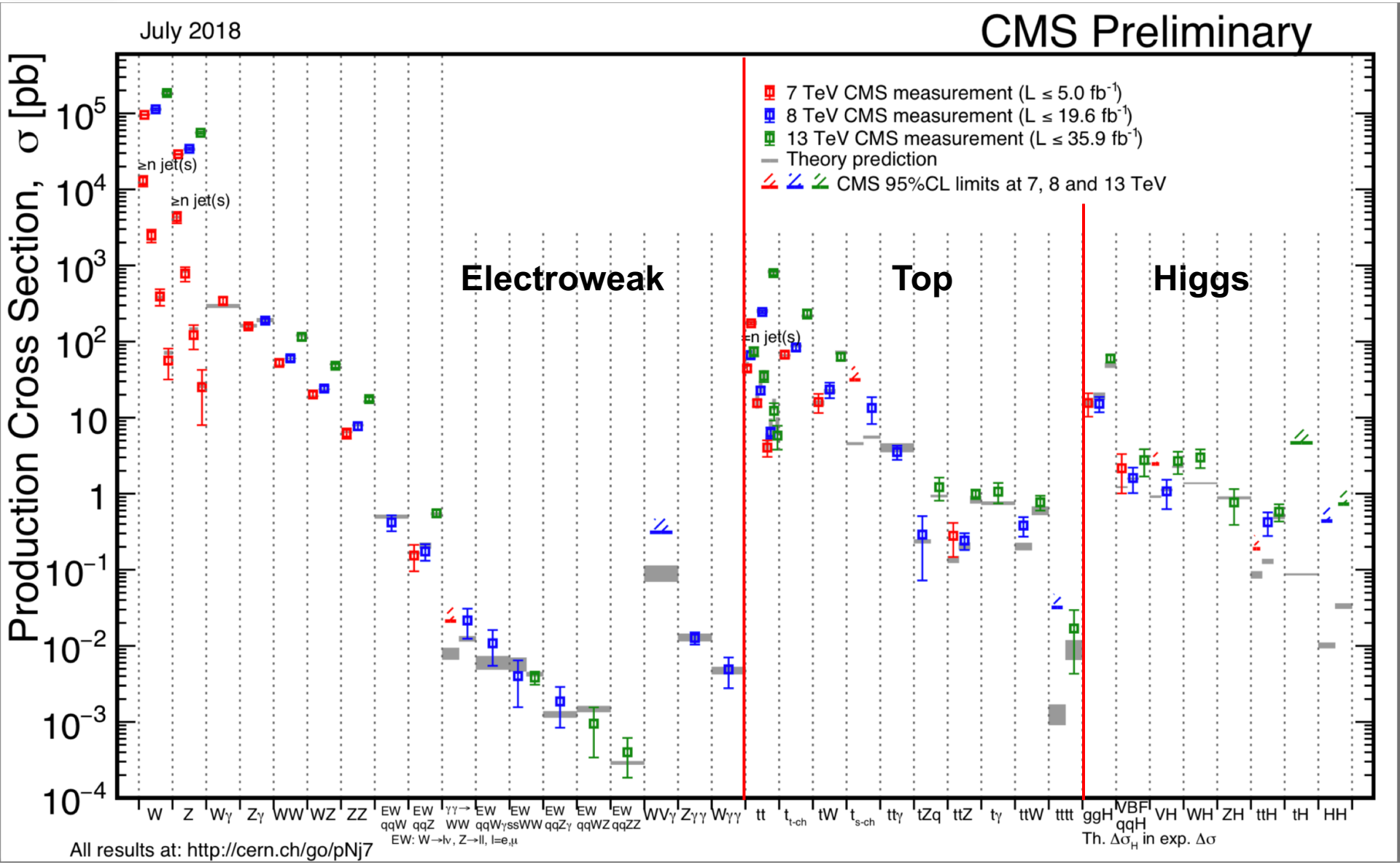
H→bb observation in ICHEP2018

- ATLAS presented H→bb observation in ICHEP2018 (5.4σ)
- China Science Daily reported this news in its front page
  - NJU,USTC,SDU and SJTC made key contribution to VH(bb) analysis
  - IHEP made key contribution to VBF H(bb) analysis
- CMS confirmed H→bb observation in Vitnam2018 (5.6σ)

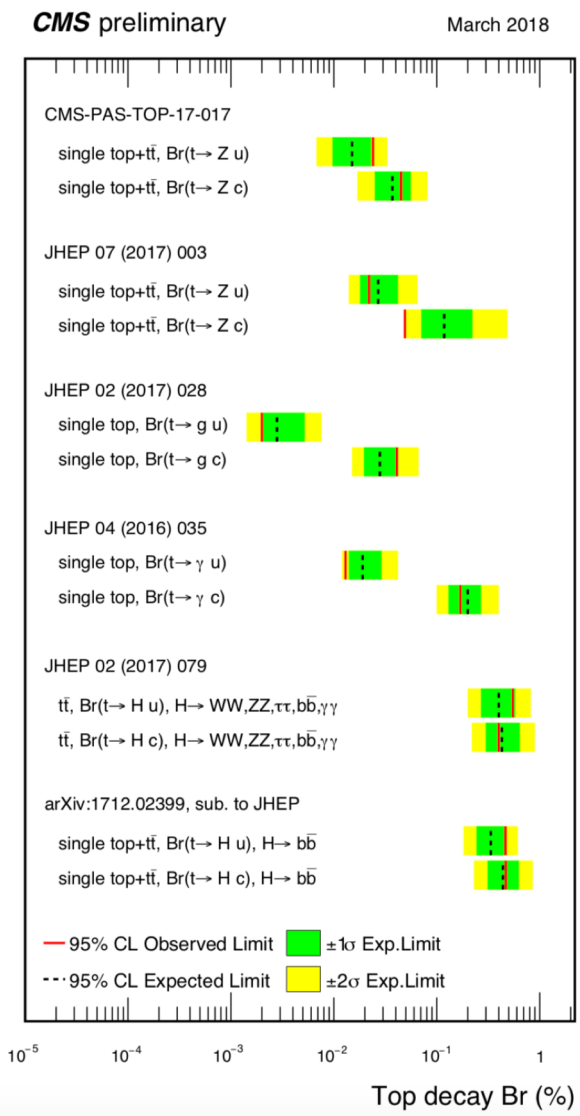

中国科学报
CHINA SCIENCE DAILY
7082
2018年7月11日 星期三 今日8版
ATLAS 首次发现希格斯粒子最主要衰变过程
中国科学家作出关键贡献
我国最大盐湖资源环境信息数据库建成
含有我国近千个盐湖基本数据

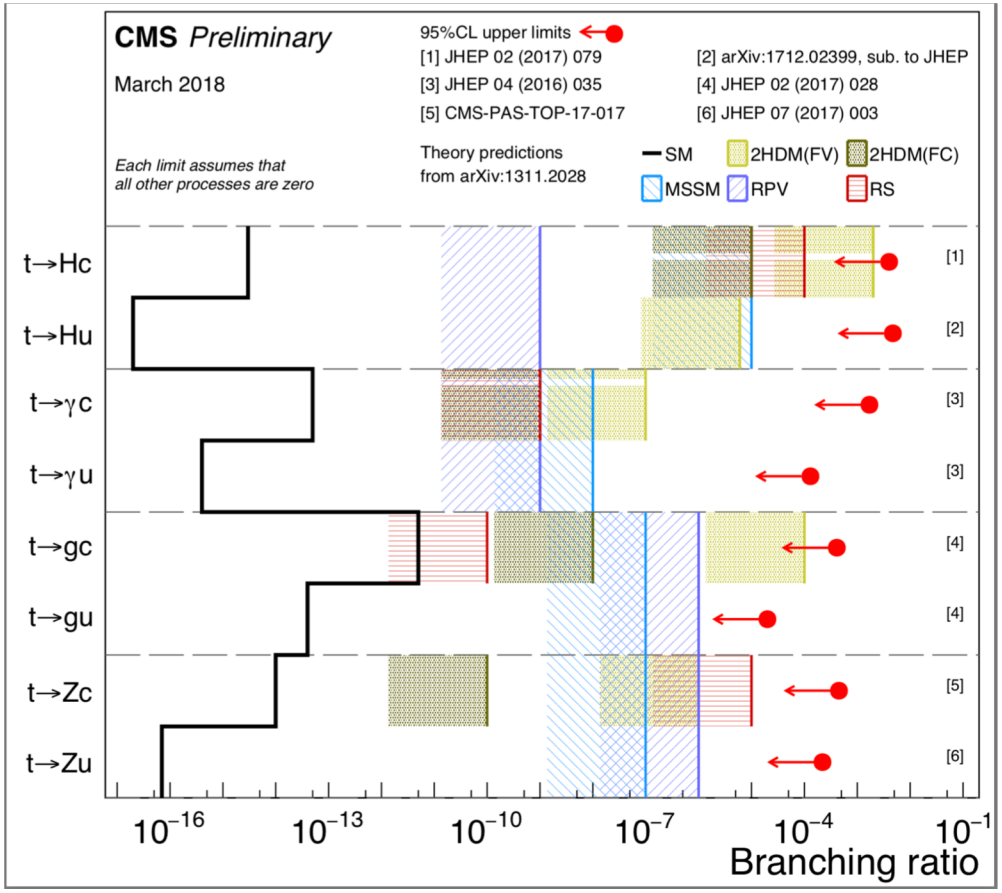


Overview of cross section measurement

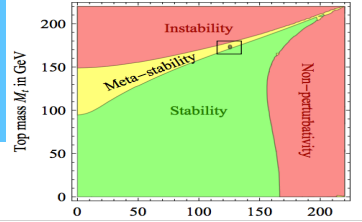


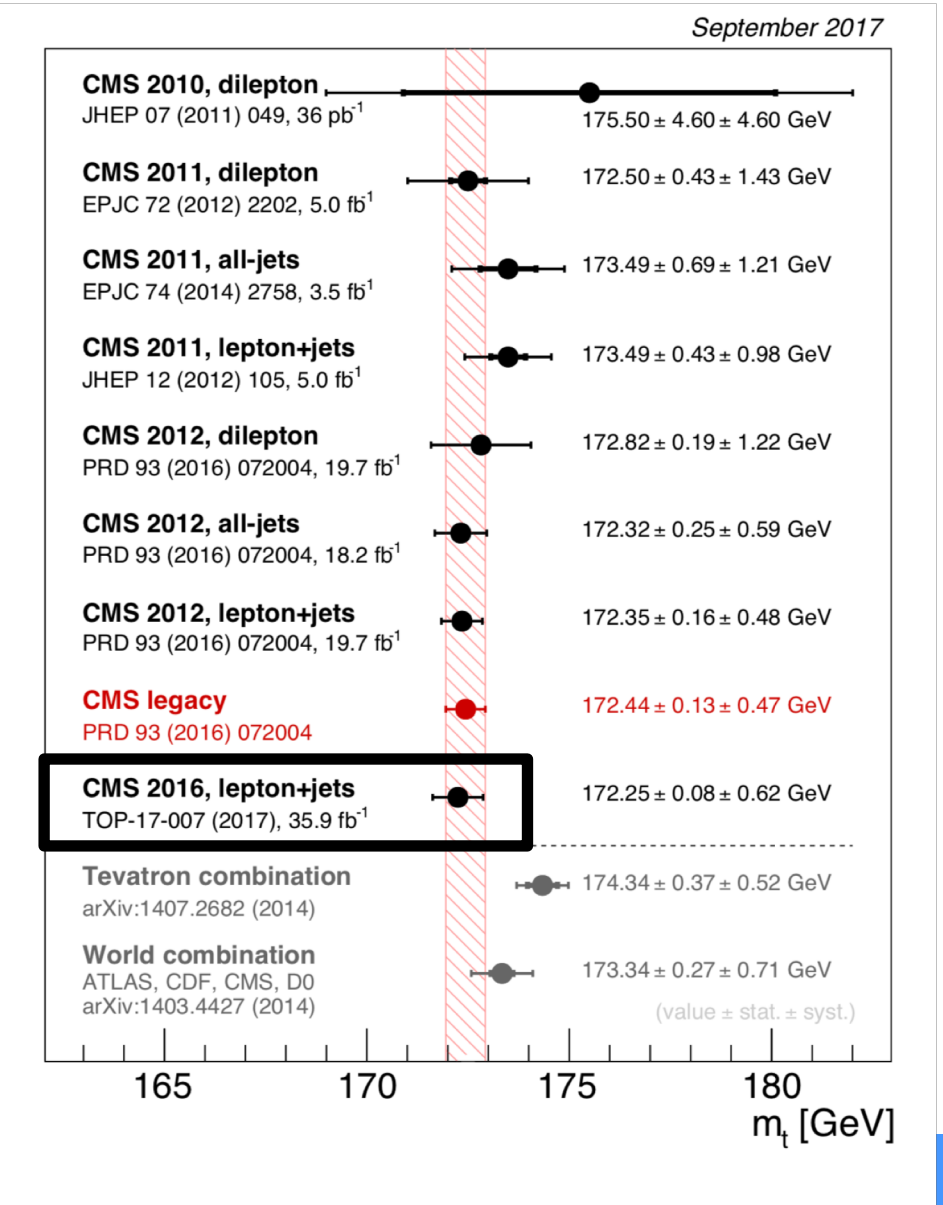
Top rare decay

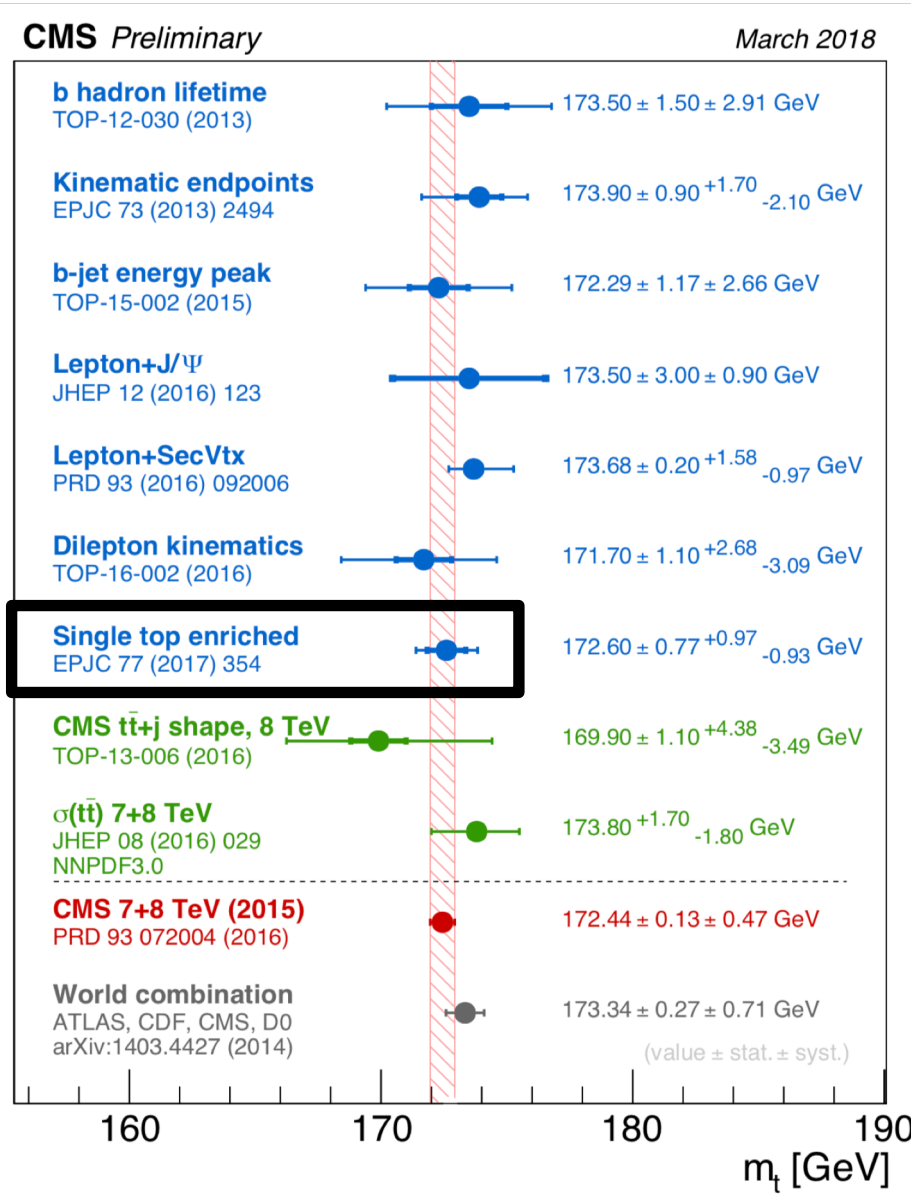




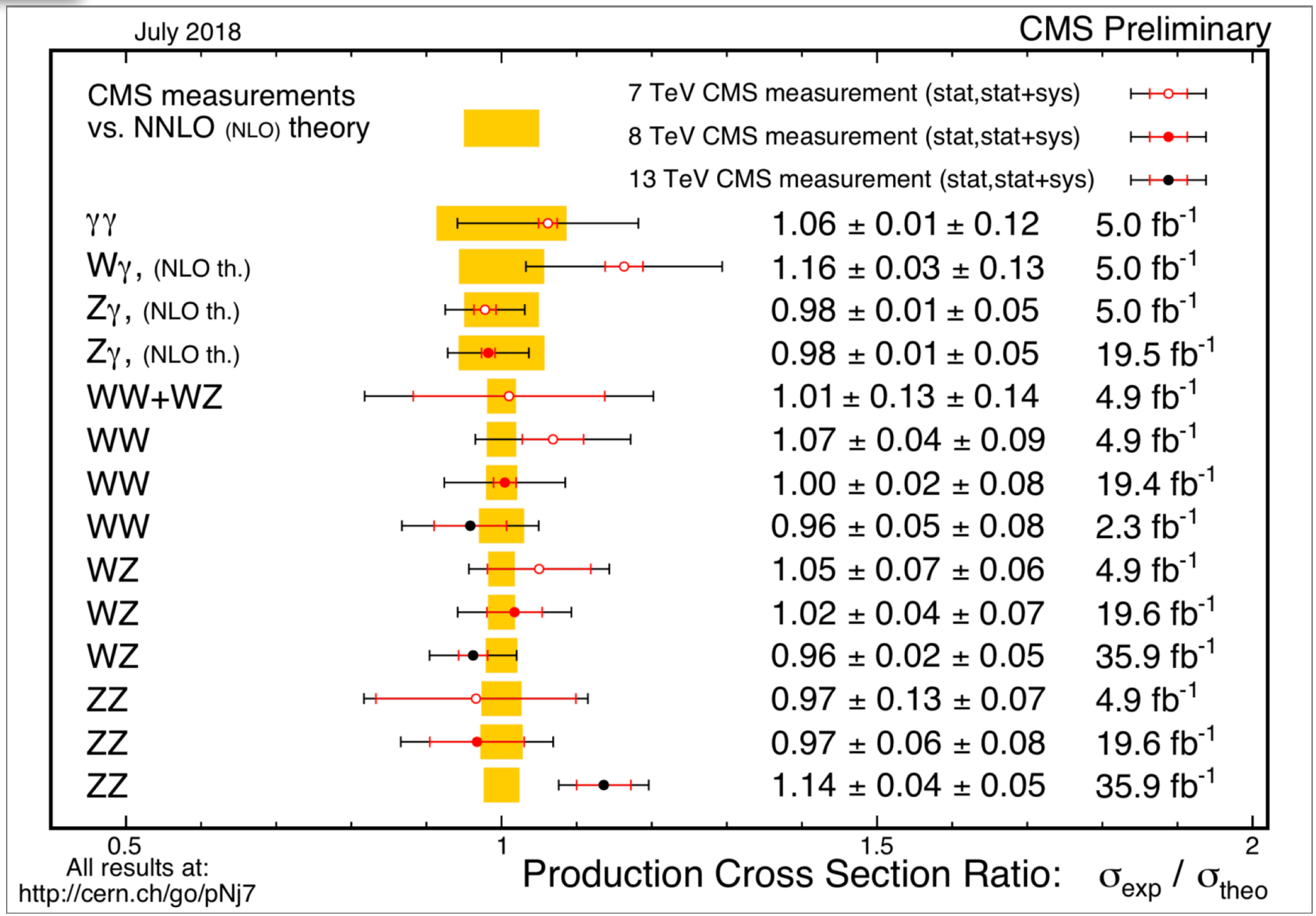
Top mass


Instability
Meta−stability
Stability
Non−perturbativity
Top mass M_t in GeV
200
150
100
50
0
0
50
100
150
200

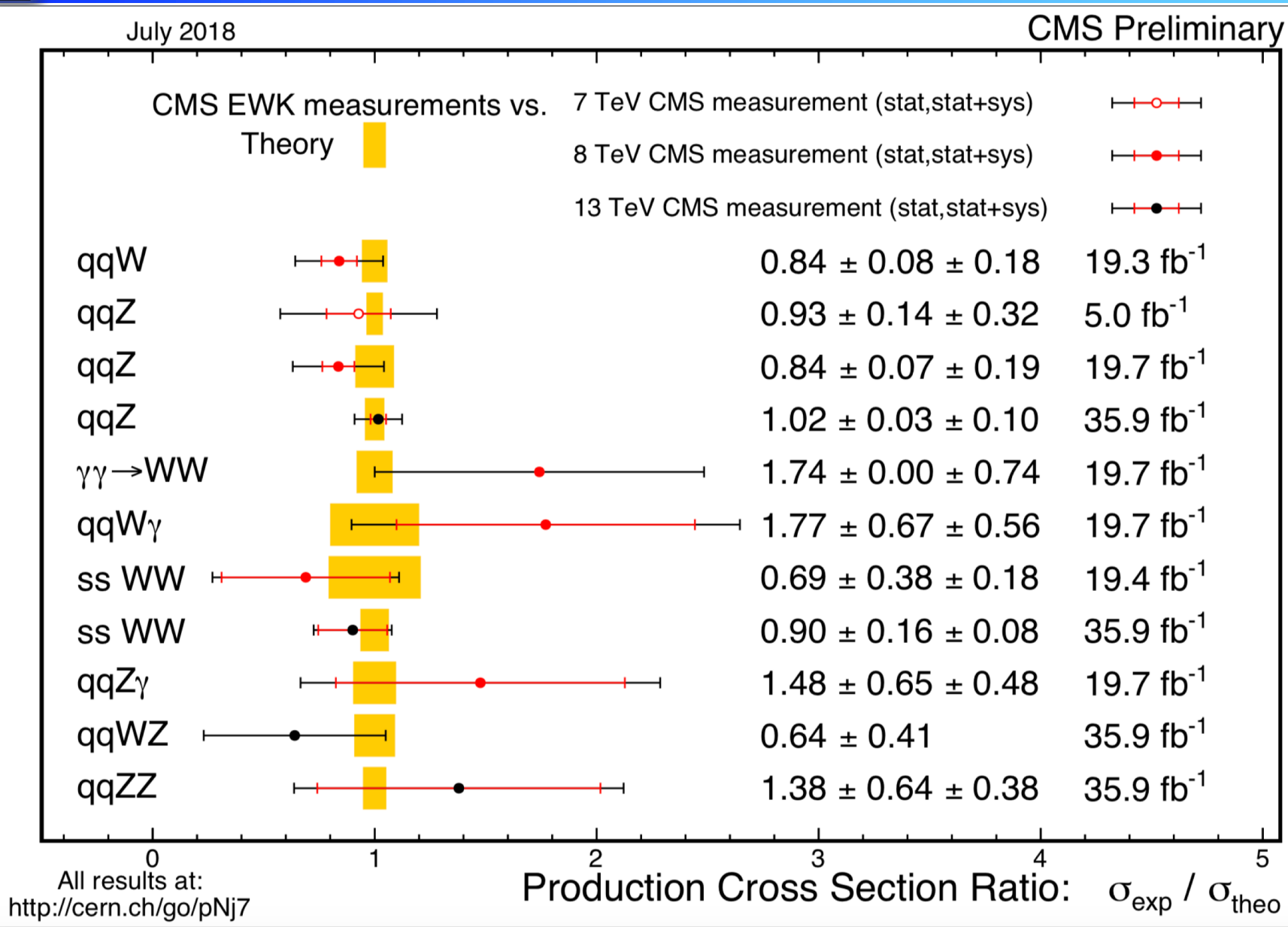

September 2017
CMS 2010, dilepton
JHEP 07 (2011) 049, 36 pb^{-1}
175.50 ± 4.60 ± 4.60 GeV
CMS 2011, dilepton
EPJC 72 (2012) 2202, 5.0 fb^{-1}
172.50 ± 0.43 ± 1.43 GeV
CMS 2011, all-jets
EPJC 74 (2014) 2758, 3.5 fb^{-1}
173.49 ± 0.69 ± 1.21 GeV
CMS 2011, lepton+jets
JHEP 12 (2012) 105, 5.0 fb^{-1}
173.49 ± 0.43 ± 0.98 GeV
CMS 2012, dilepton
PRD 93 (2016) 072004, 19.7 fb^{-1}
172.82 ± 0.19 ± 1.22 GeV
CMS 2012, all-jets
PRD 93 (2016) 072004, 18.2 fb^{-1}
172.32 ± 0.25 ± 0.59 GeV
CMS 2012, lepton+jets
PRD 93 (2016) 072004, 19.7 fb^{-1}
172.35 ± 0.16 ± 0.48 GeV
CMS legacy
PRD 93 (2016) 072004
172.44 ± 0.13 ± 0.47 GeV
CMS 2016, lepton+jets
TOP-17-007 (2017), 35.9 fb^{-1}
172.25 ± 0.08 ± 0.62 GeV
Tevatron combination
arXiv:1407.2682 (2014)
174.34 ± 0.37 ± 0.52 GeV
World combination
ATLAS, CDF, CMS, D0
arXiv:1403.4427 (2014)
173.34 ± 0.27 ± 0.71 GeV
(value ± stat. ± syst.)
165
170
175
180
m_t [GeV]


CMS Preliminary
March 2018
b hadron lifetime
TOP-12-030 (2013)
173.50 ± 1.50 ± 2.91 GeV
Kinematic endpoints
EPJC 73 (2013) 2494
173.90 ± 0.90 $^{+1.70}_{-2.10}$ GeV
b-jet energy peak
TOP-15-002 (2015)
172.29 ± 1.17 ± 2.66 GeV
Lepton+J/Ψ
JHEP 12 (2016) 123
173.50 ± 3.00 ± 0.90 GeV
Lepton+SecVtx
PRD 93 (2016) 092006
173.68 ± 0.20 $^{+1.58}_{-0.97}$ GeV
Dilepton kinematics
TOP-16-002 (2016)
171.70 ± 1.10 $^{+2.68}_{-3.09}$ GeV
Single top enriched
EPJC 77 (2017) 354
172.60 ± 0.77 $^{+0.97}_{-0.93}$ GeV
CMS tt̄+j shape, 8 TeV
TOP-13-006 (2016)
169.90 ± 1.10 $^{+4.38}_{-3.49}$ GeV
σ(tt̄) 7+8 TeV
JHEP 08 (2016) 029
NNPDF3.0
173.80 $^{+1.70}_{-1.80}$ GeV
CMS 7+8 TeV (2015)
PRD 93 072004 (2016)
172.44 ± 0.13 ± 0.47 GeV
World combination
ATLAS, CDF, CMS, D0
arXiv:1403.4427 (2014)
173.34 ± 0.27 ± 0.71 GeV
(value ± stat. ± syst.)
160
170
180
190
m_t [GeV]

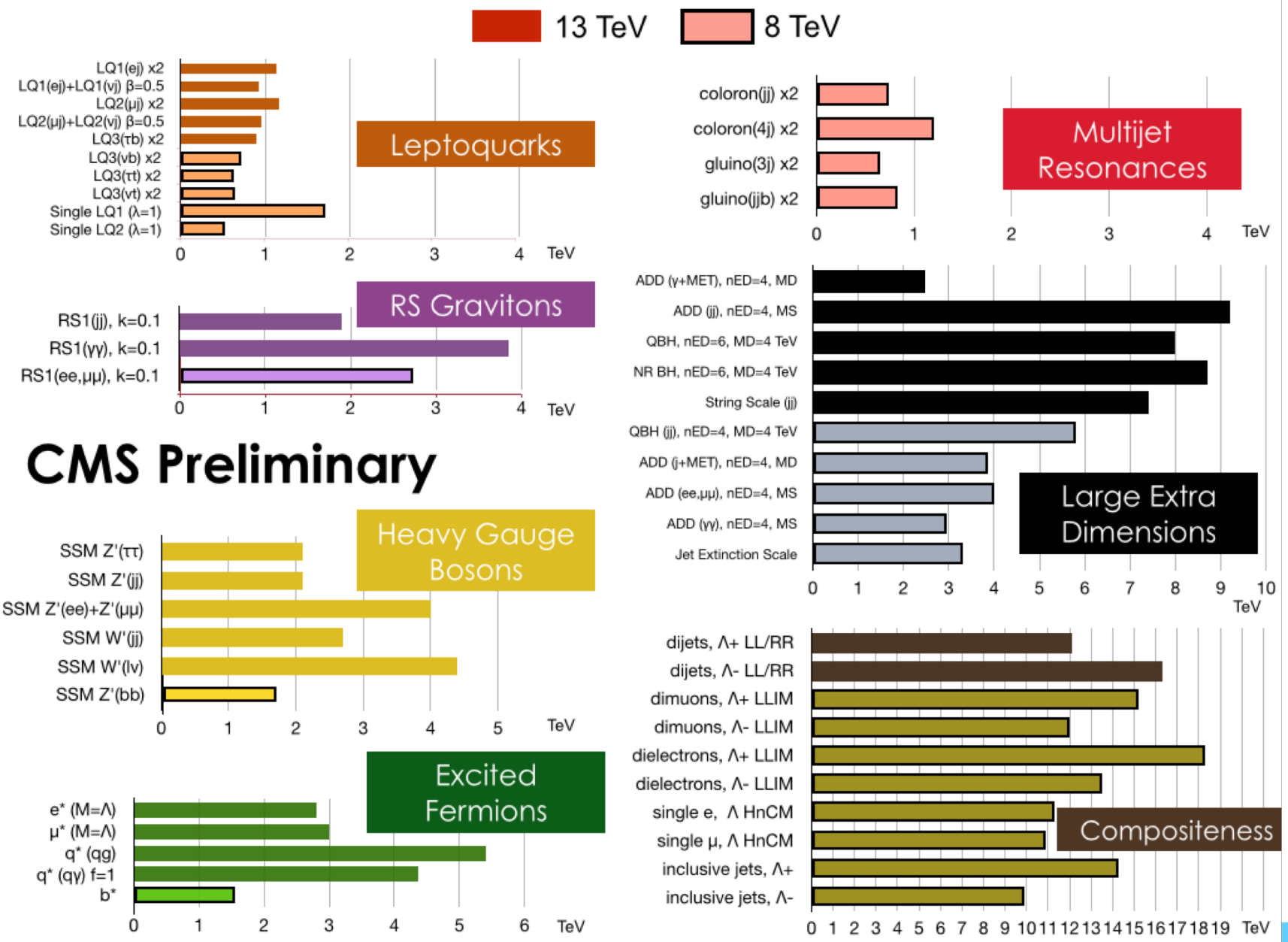
Diboson production measurements



Electroweak process

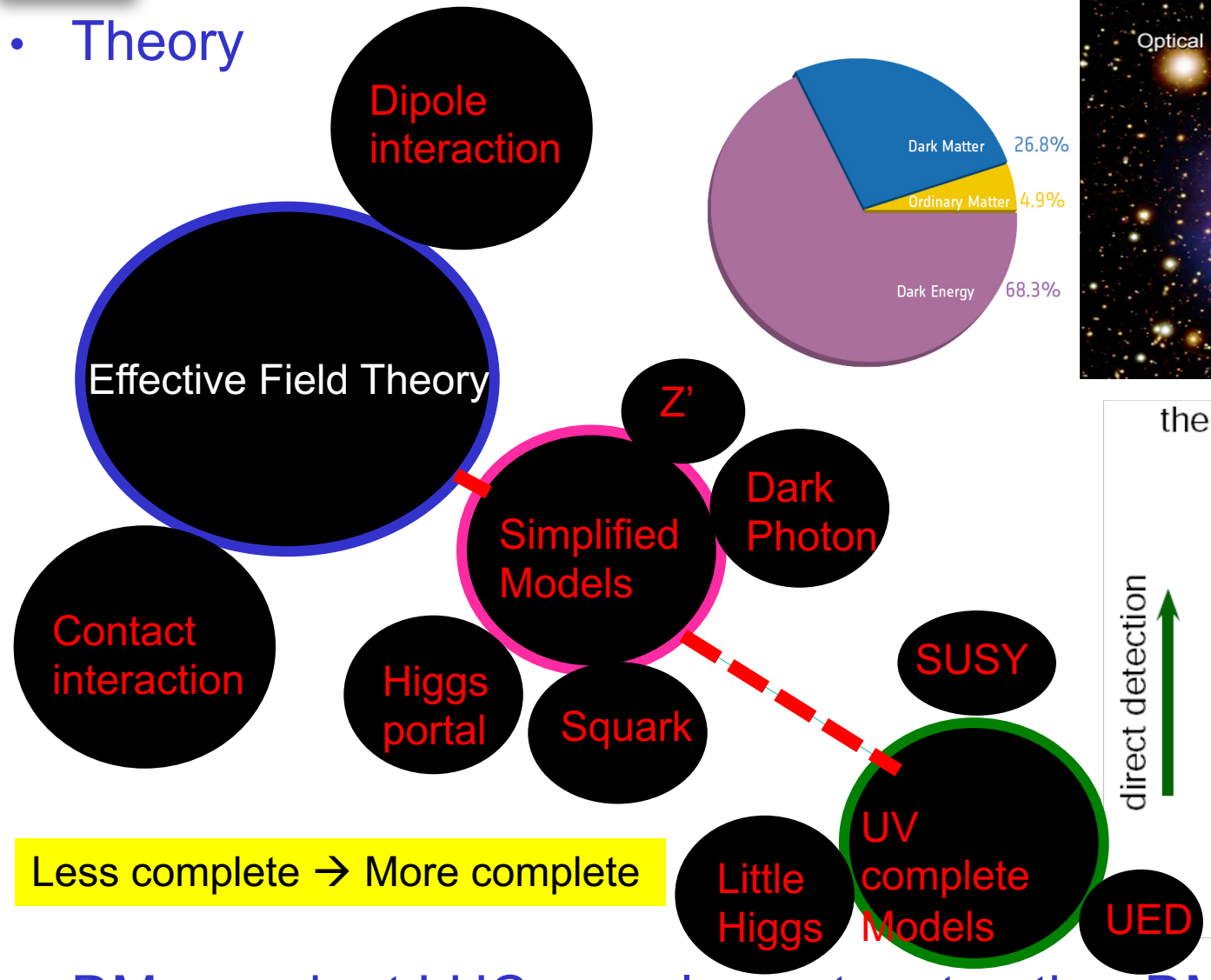


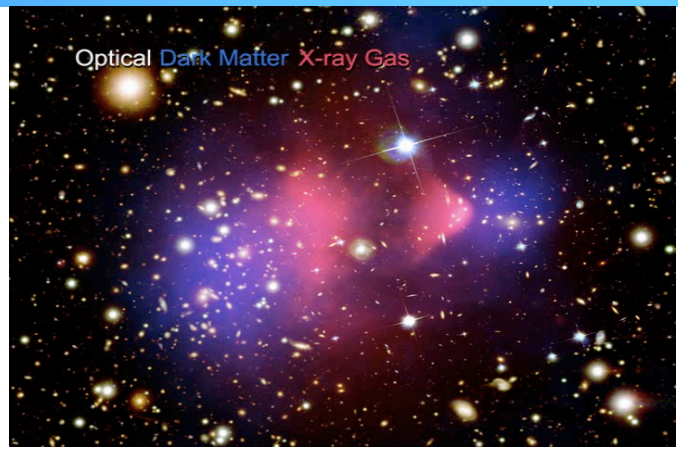
Summary of BSM searches

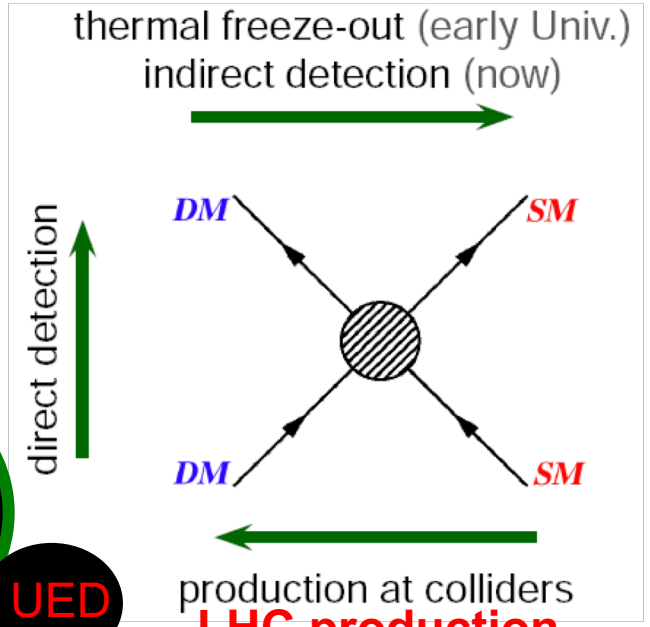


Dark mater searches

- Theory







- DM search at LHC complementary to other DM searches