LHC TeV 物理实验进展

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（代表ATLAS和CMS中国组）

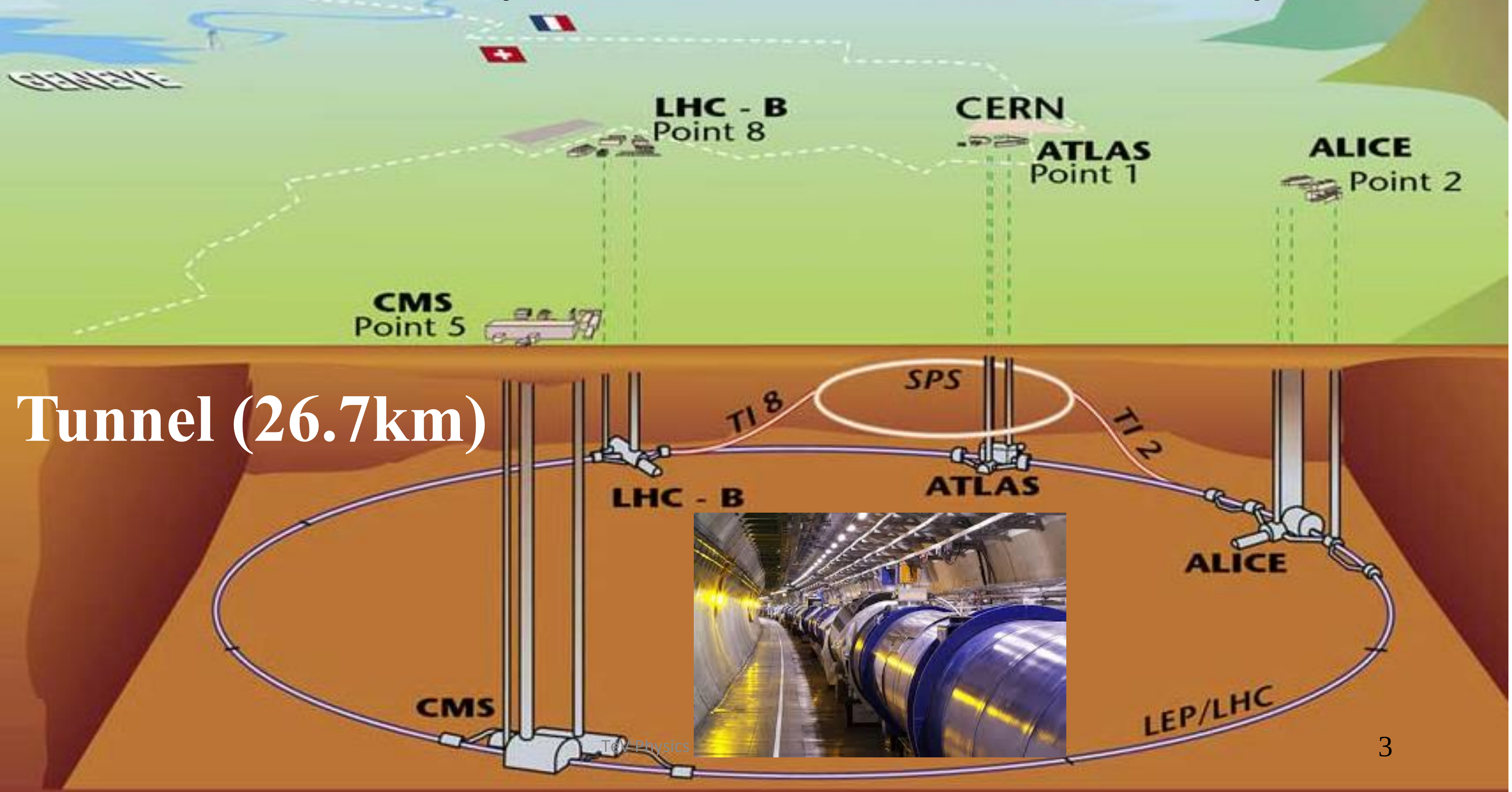
第十二届全国粒子物理学术会议
中国科学技术大学，2016年8月22-26日

报告提纲

- 介绍LHC、ATLAS和CMS实验
- 标准模型精确测量
  - 双玻色子截面
  - 顶夸克对截面
- 希格斯物理
  - Run1 希格斯粒子的发现和性质测量
  - Run2 重新发现希格斯粒子
  - 寻找和测量希格斯的各种衰变产物和性质
- 超出标准模型新物理寻找
  - 高质量的共振态粒子
  - 超对称粒子
  - 暗物质粒子
  - 重夸克粒子，…
- 结语

欧洲核子研究中心大型强子对撞机

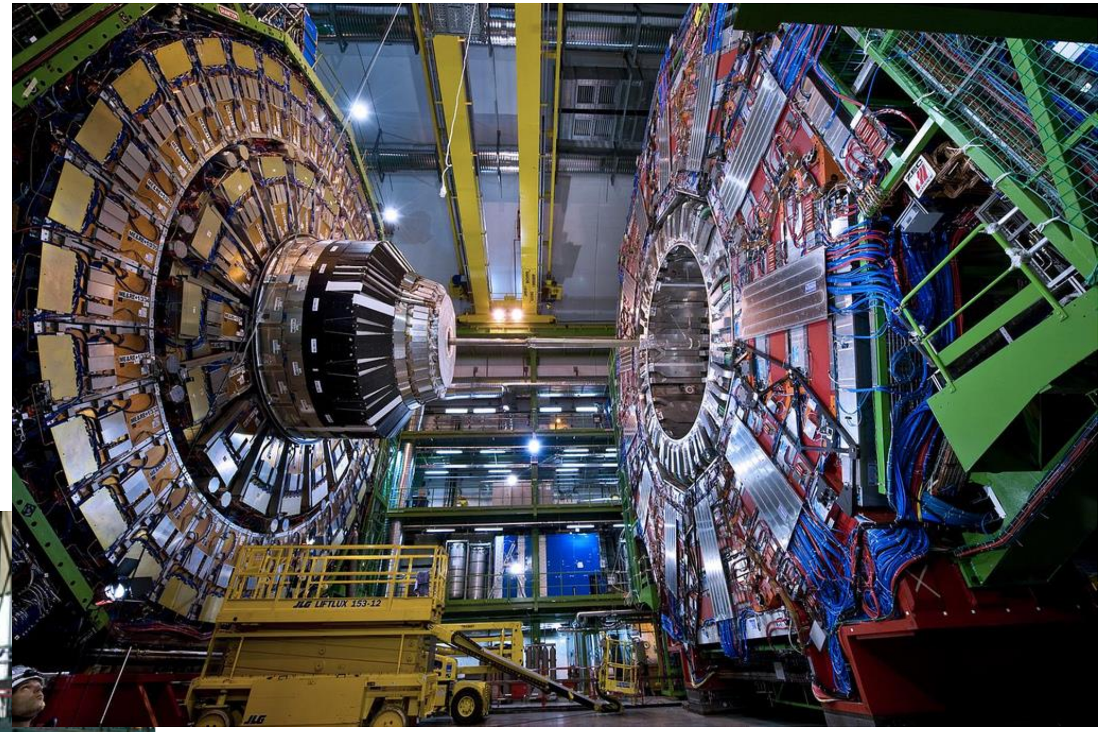
LHC is the world's largest collider (7-13 TeV)
ATLAS Collaboration (40 countries, 180 institutions, ~ 3000)
CMS Collaboration (41 counties, 184 institutions, ~2900)

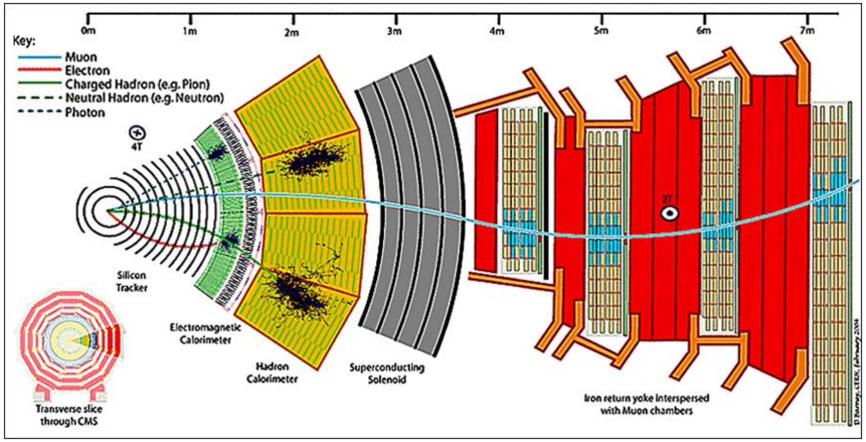


Tunnel (26.7km)

CMS 探测器

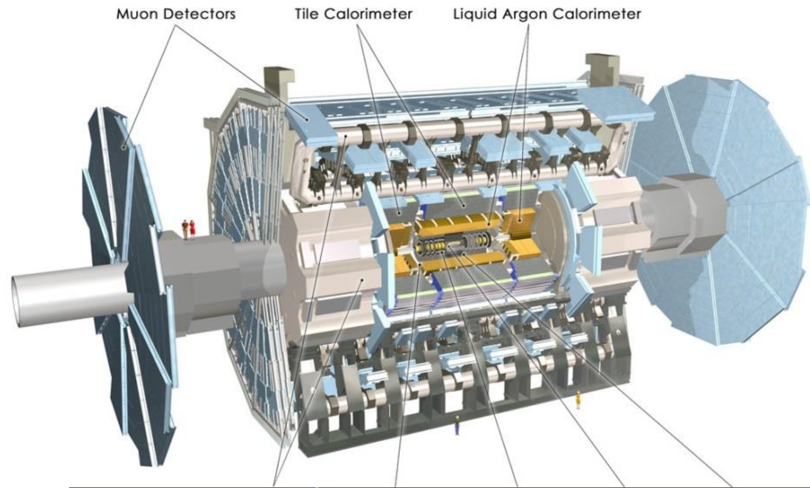
CMS-中国组(32人)
- 高能所
- 北大
- 北航
- 清华

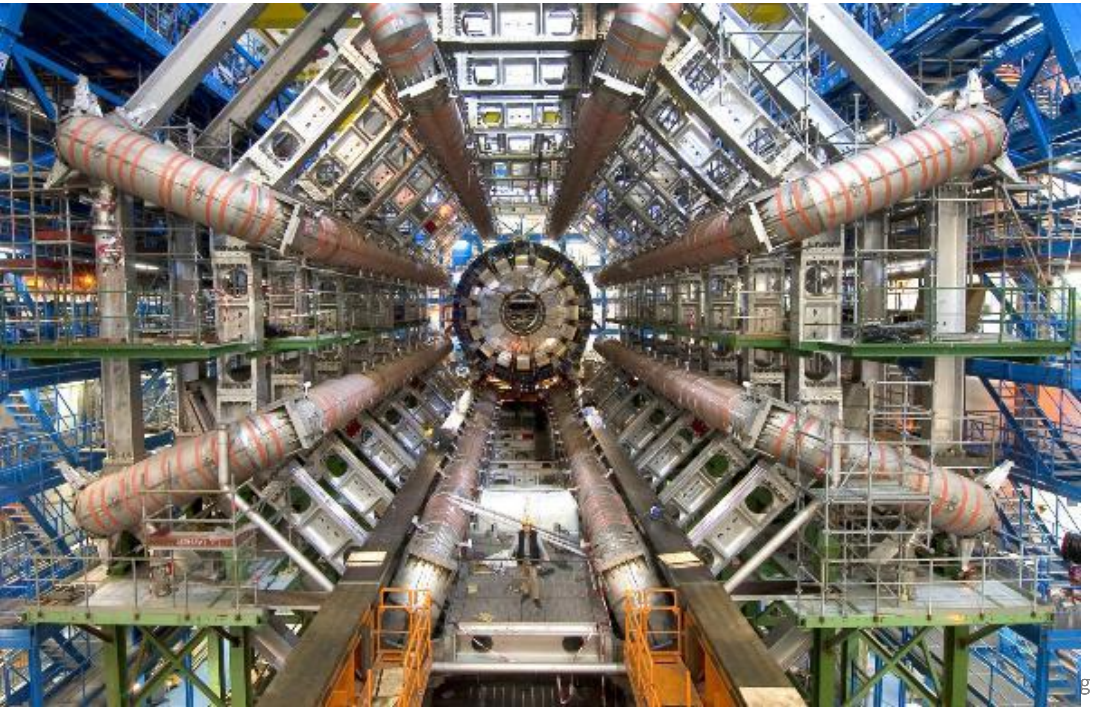


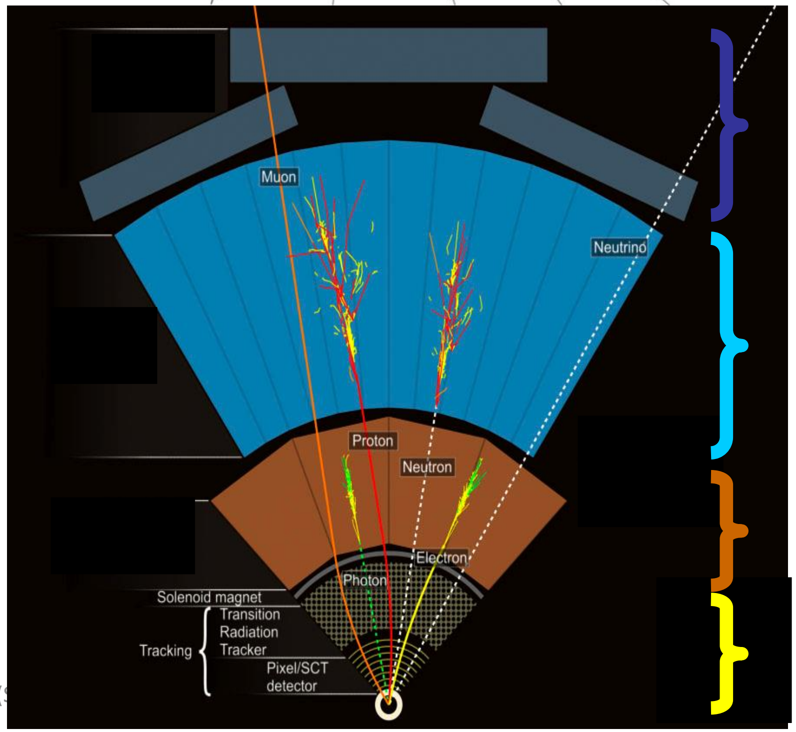


ATLAS 探测器

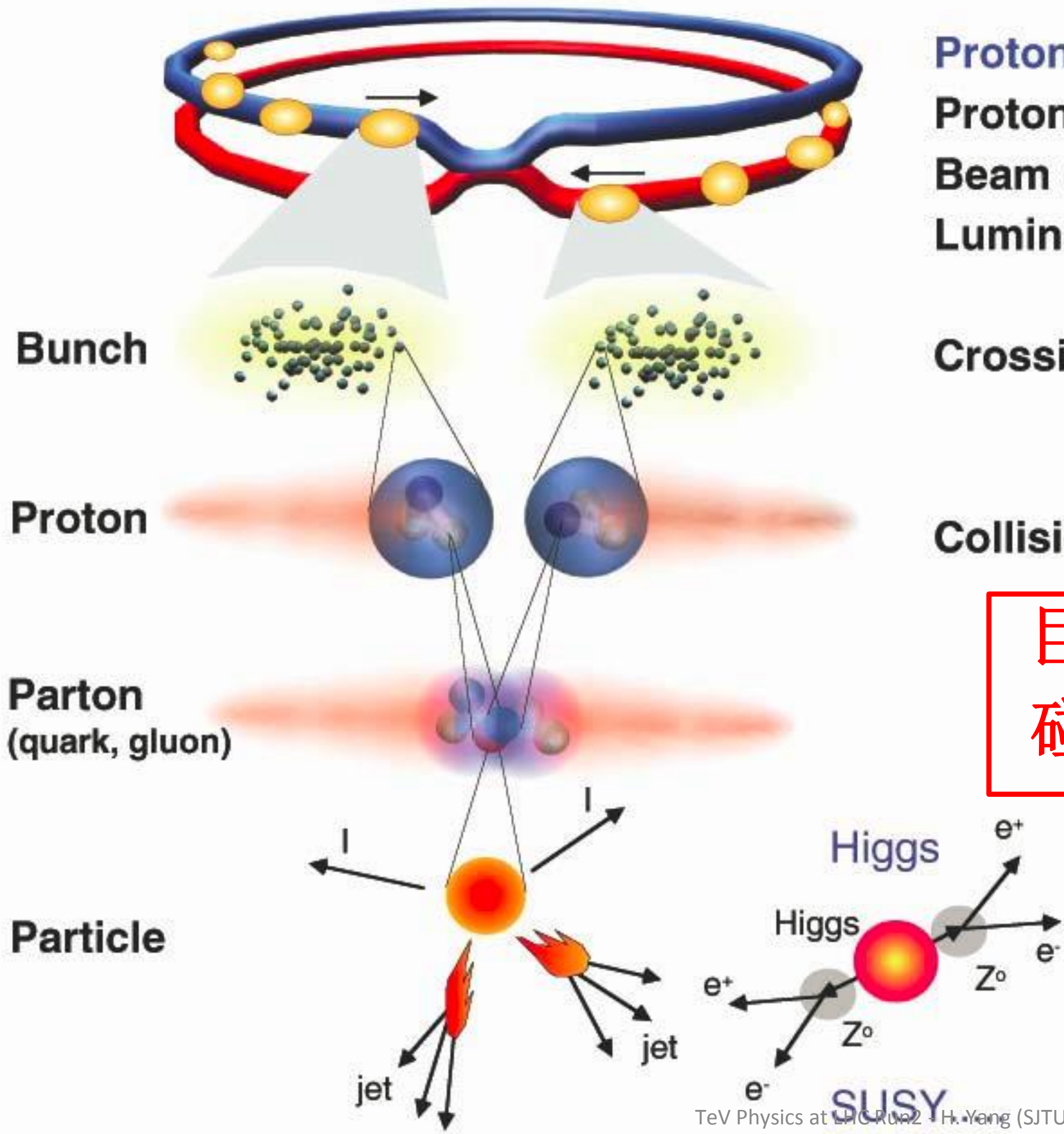
ATLAS-中国组（51人）
- 高能所、南大、清华
- 科大、山大、交大







欧洲核子研究中心大型强子对撞机



Proton-Proton	2835 bunch/beam
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	10^{34} cm^{-2} s^{-1}
Crossing rate	40 MHz
Collisions ≈	10^{7} - 10^{9} Hz

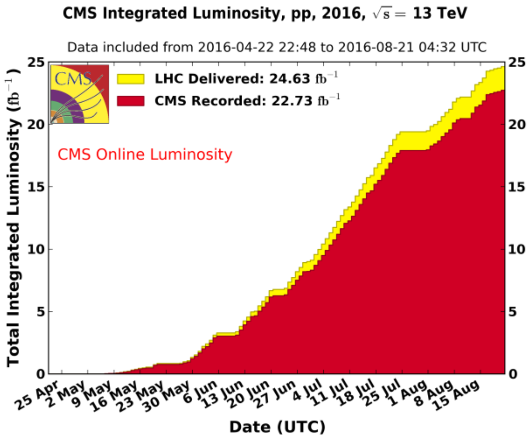
巨大挑战：从10万亿次碰撞中挑选一个希格斯

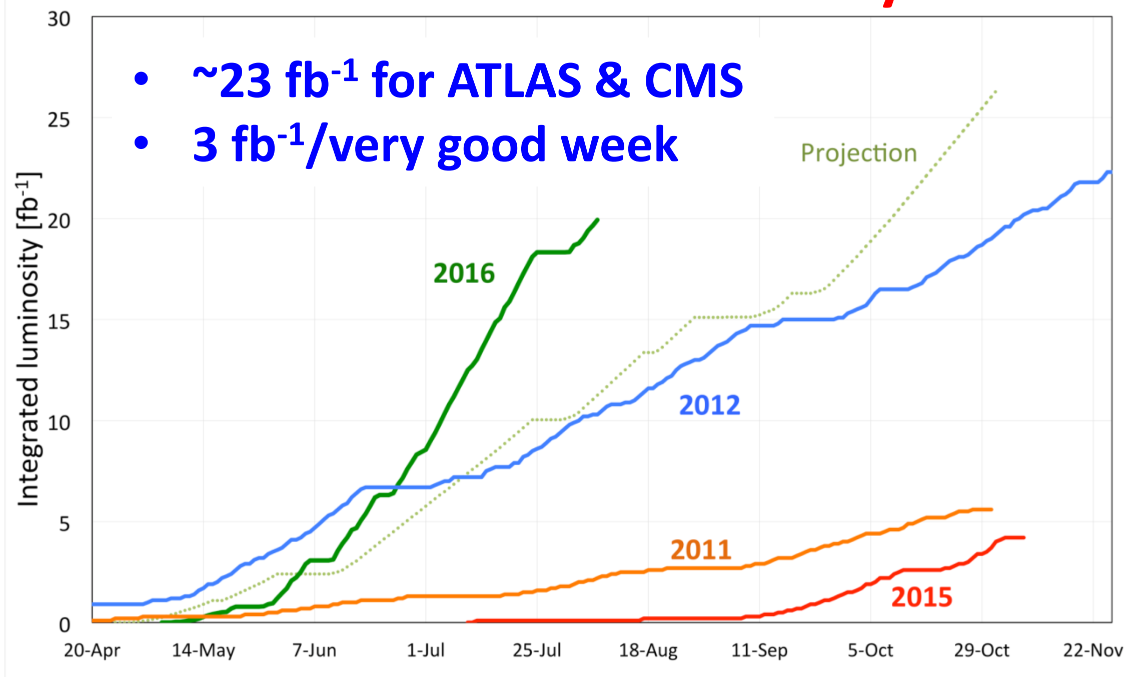
Selection of 1 in 10,000,000,000,000

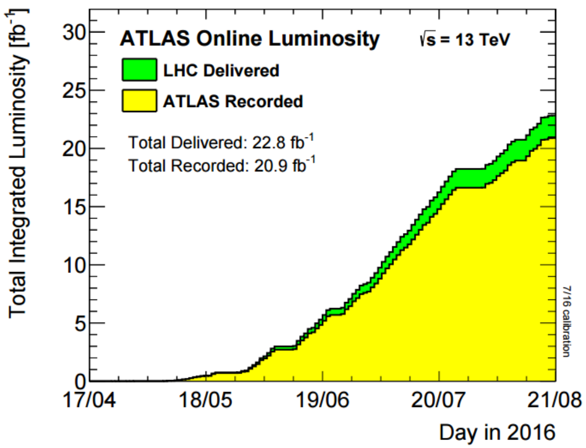
LHC 积分亮度

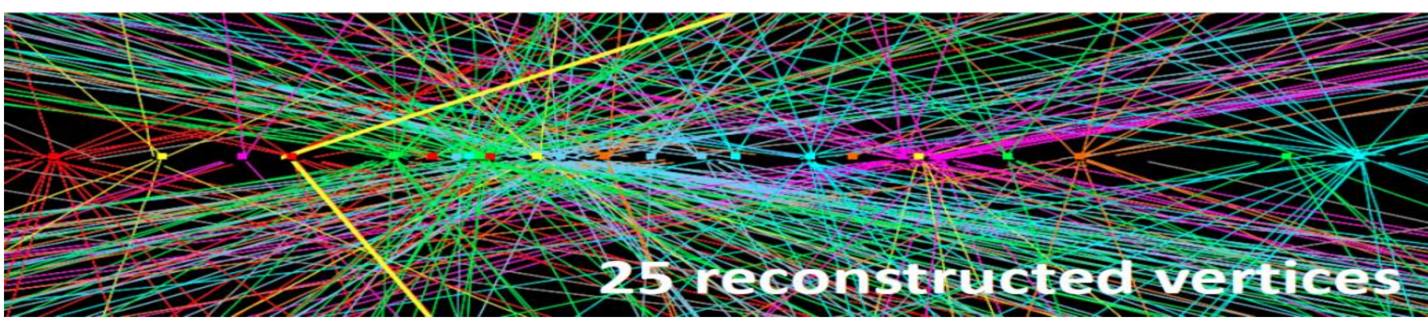
Peak Luminosity: 1.2 x 10^{34} $cm^{-2}s^{-1}$

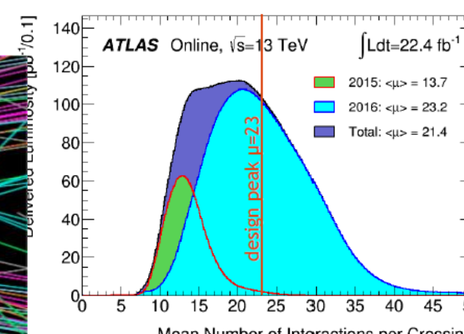
> 90% of data usable for analysis





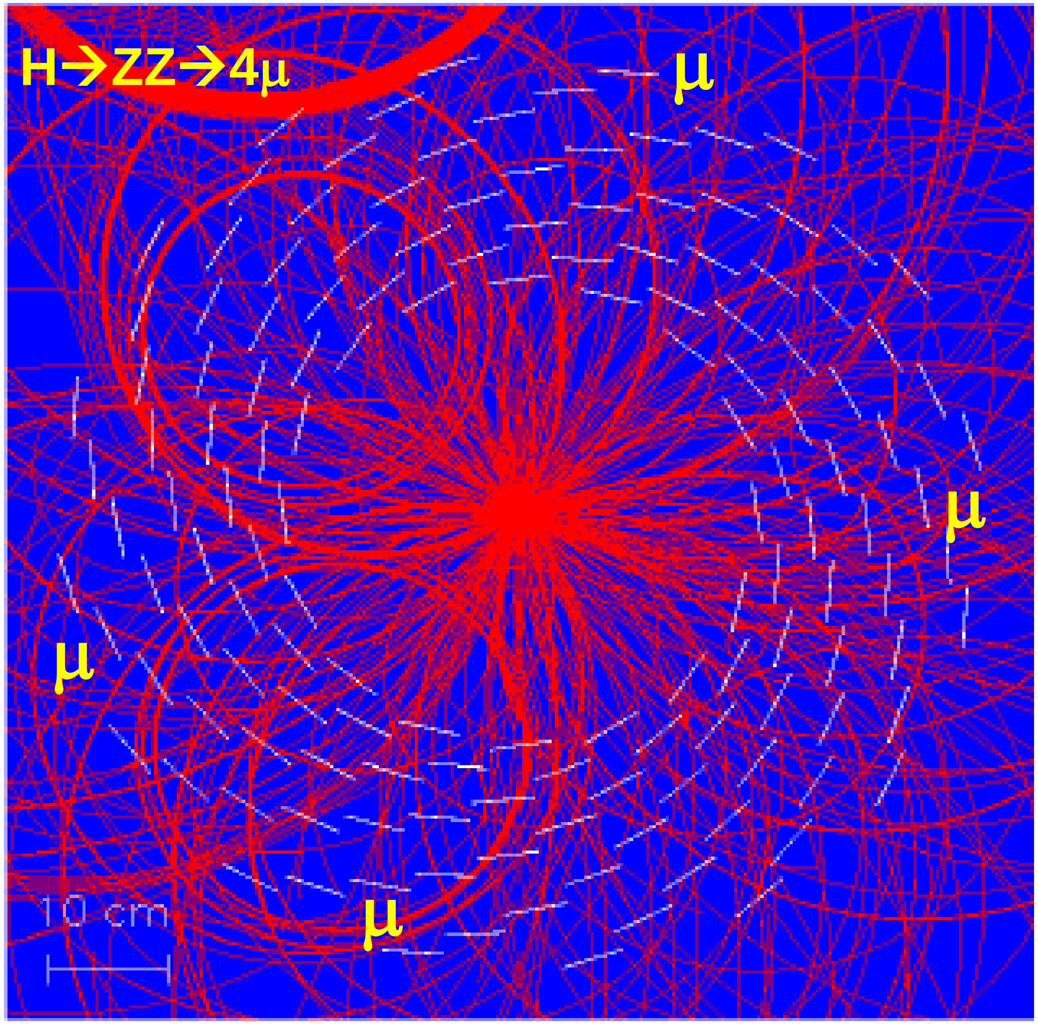






Pileup often above LHC design in 2016

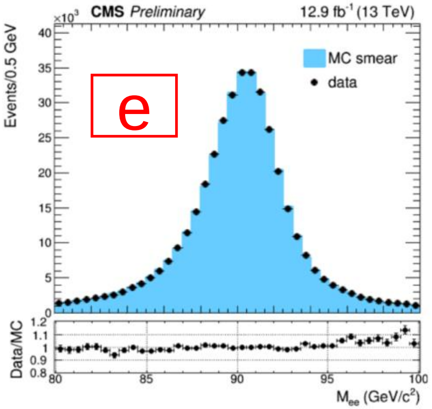
大量的事例堆积对探测器信号读出、粒子重建和鉴别造成巨大的挑战！

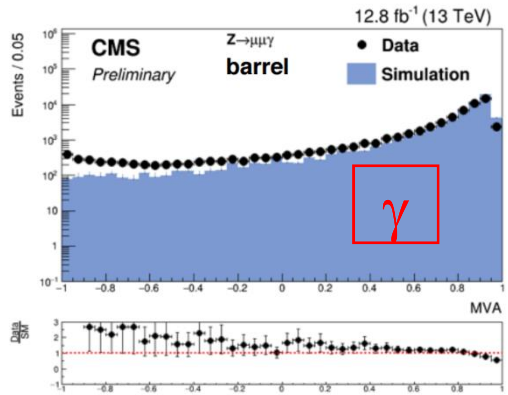


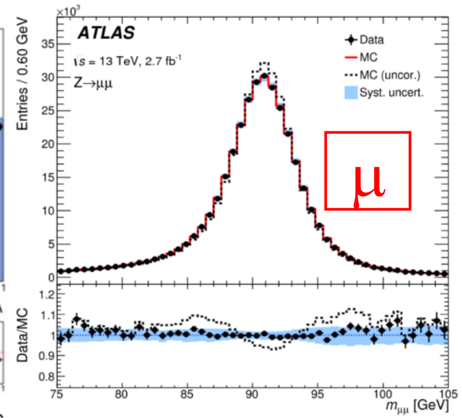
采用多变量
MVA-BDT
方法提高粒子鉴别效率和事例识别

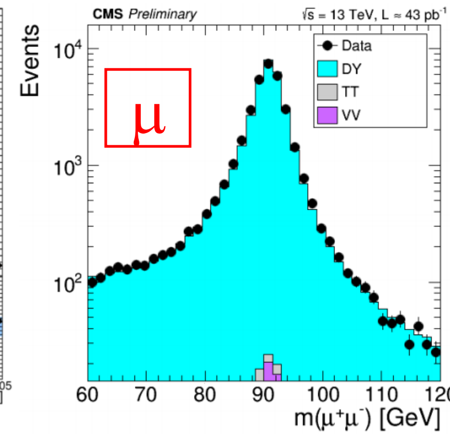
探测器性能-粒子鉴别

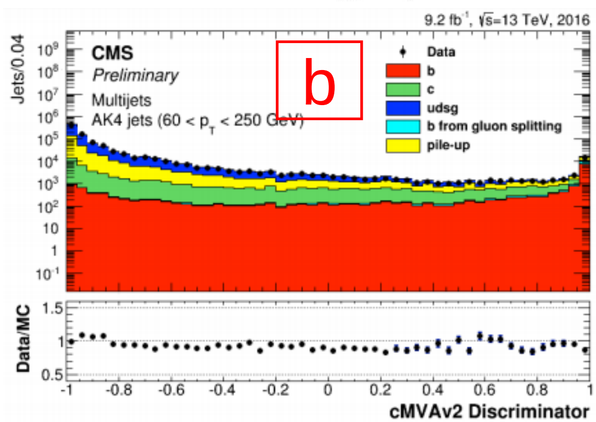
ATLAS-CONF-2015-041, ATL-PHYS-PUB-2016-015
Eur. Phys. J. C (2016) 76:292
CMS-DP-2015-015, CMS-DP-2016-015/042/049

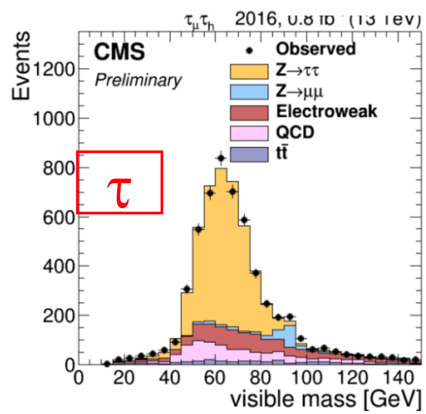




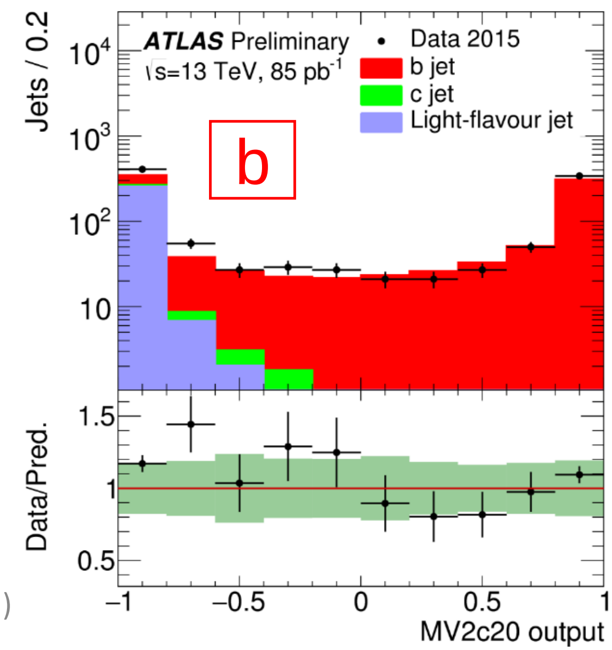


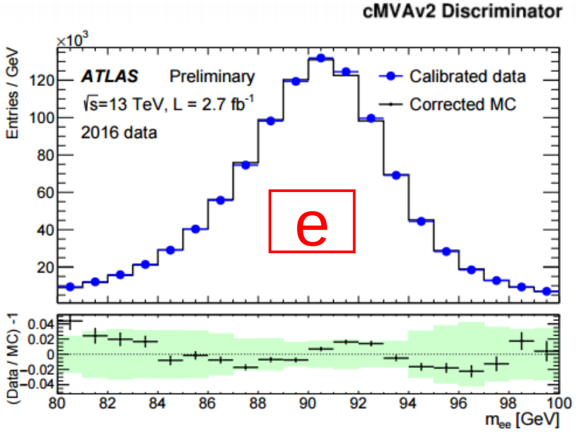


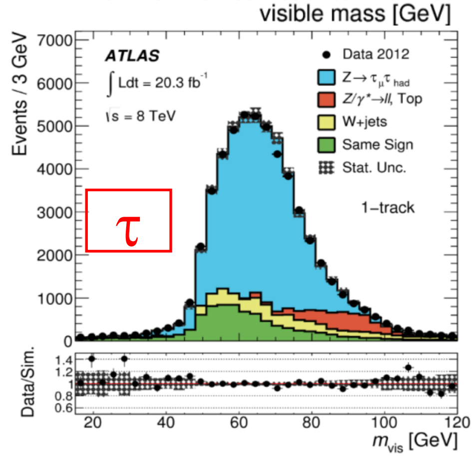




e, γ, τ, b粒子的鉴别采用多变量MVA-BDT方法。

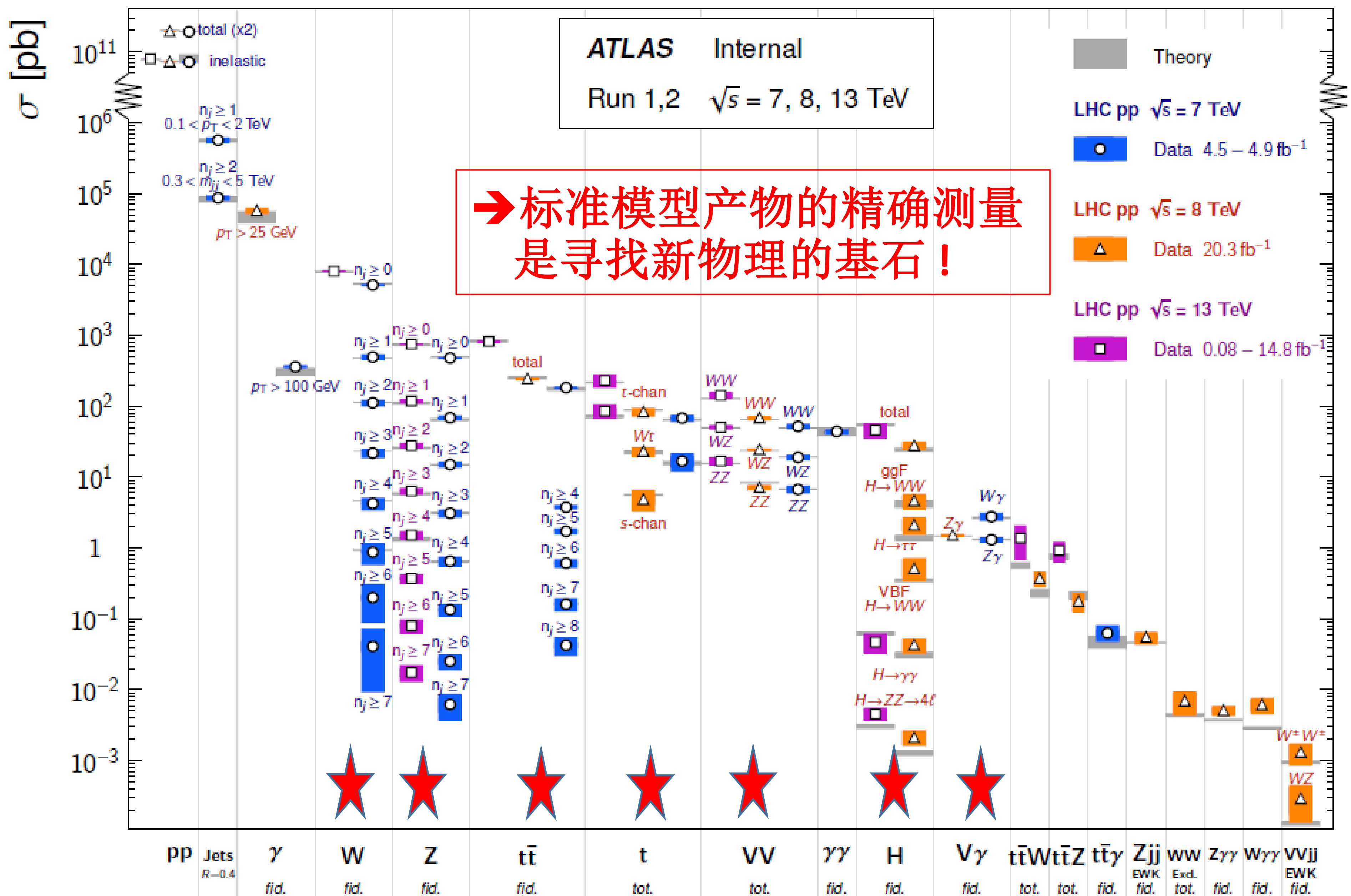






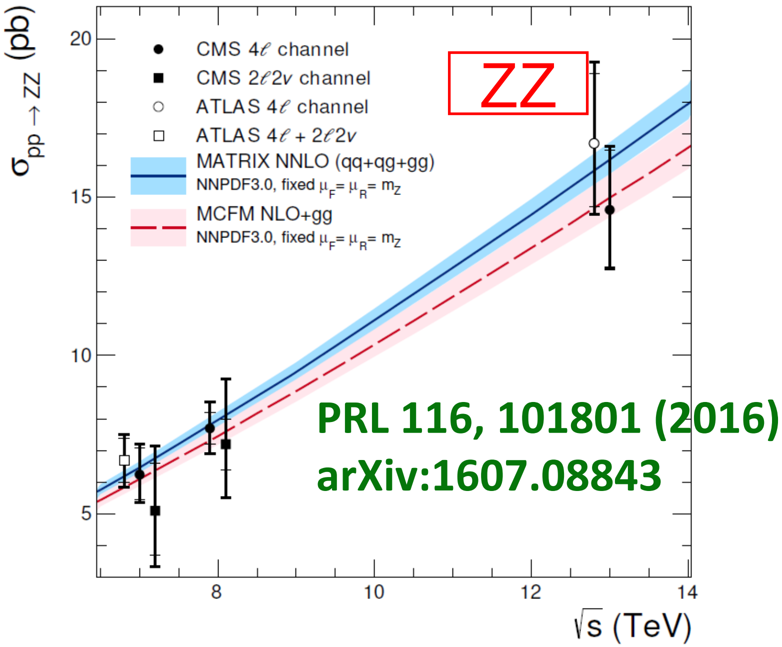
Standard Model Production Cross Section Measurements

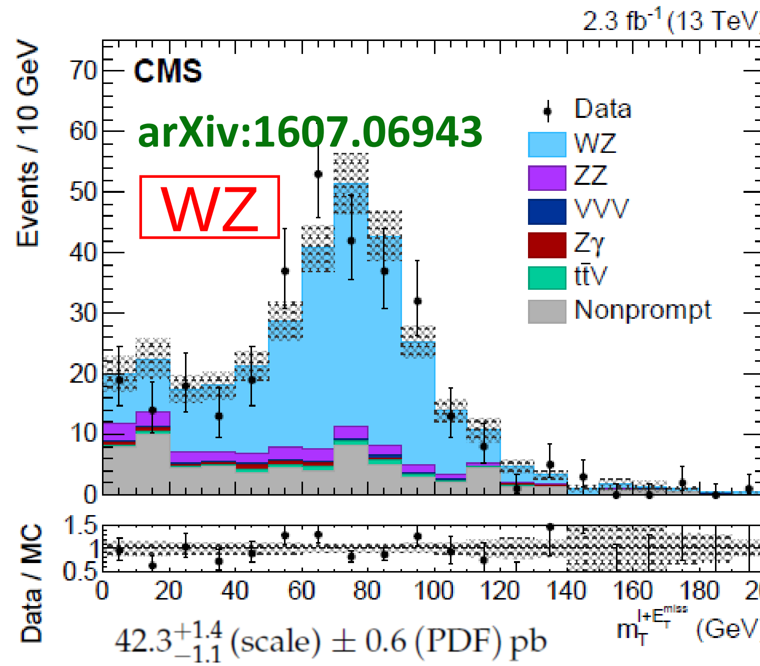
Status: August 2016

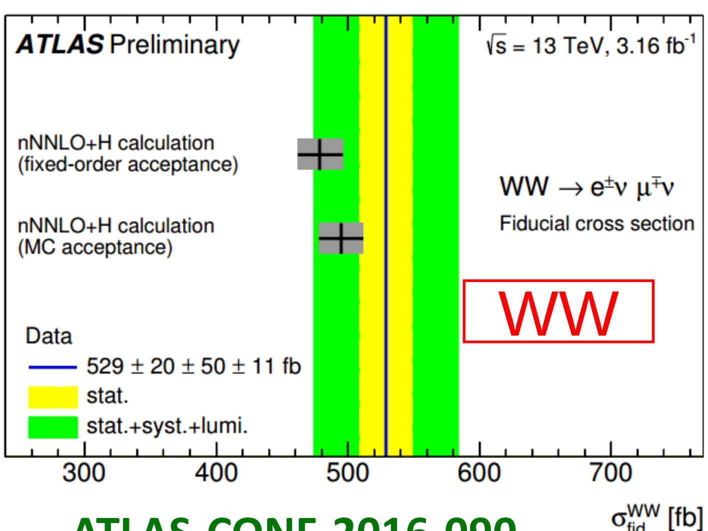


双玻色子截面

ATLAS-CONF-2016-043/090
arXiv:1607.06943
arXiv:1607.08843

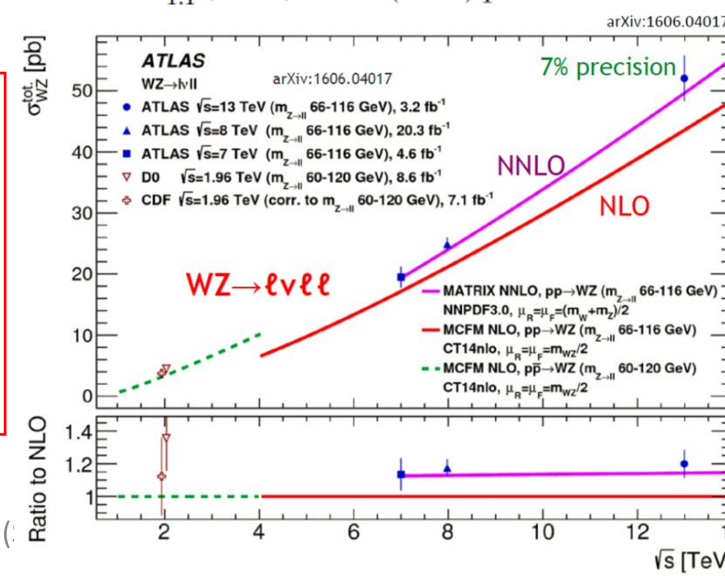




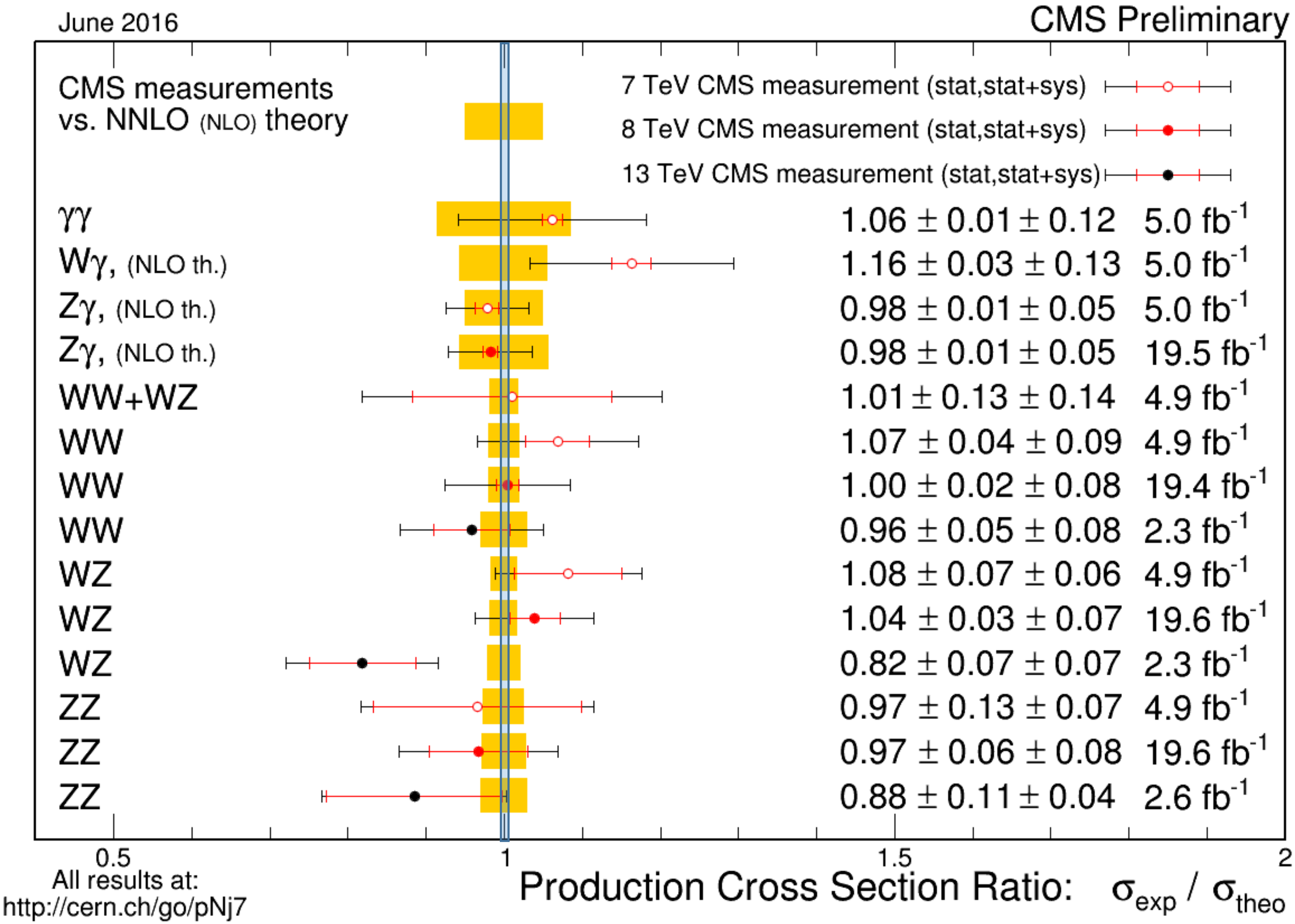


ATLAS-CONF-2016-090

➔ **WZ: ~20% correction for NNLO Which describes data better than NLO**



标准模型截面测量

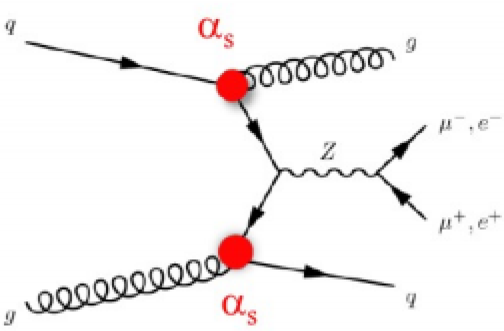


June 2016
CMS Preliminary
CMS measurements
vs. NNLO (NLO) theory
7 TeV CMS measurement (stat,stat+sys)
8 TeV CMS measurement (stat,stat+sys)
13 TeV CMS measurement (stat,stat+sys)
γγ
Wγ, (NLO th.)
Zγ, (NLO th.)
Zγ, (NLO th.)
WW+WZ
WW
WW
WW
WZ
WZ
WZ
ZZ
ZZ
ZZ
1.06 ± 0.01 ± 0.12 5.0 fb-1
1.16 ± 0.03 ± 0.13 5.0 fb-1
0.98 ± 0.01 ± 0.05 5.0 fb-1
0.98 ± 0.01 ± 0.05 19.5 fb-1
1.01 ± 0.13 ± 0.14 4.9 fb-1
1.07 ± 0.04 ± 0.09 4.9 fb-1
1.00 ± 0.02 ± 0.08 19.4 fb-1
0.96 ± 0.05 ± 0.08 2.3 fb-1
1.08 ± 0.07 ± 0.06 4.9 fb-1
1.04 ± 0.03 ± 0.07 19.6 fb-1
0.82 ± 0.07 ± 0.07 2.3 fb-1
0.97 ± 0.13 ± 0.07 4.9 fb-1
0.97 ± 0.06 ± 0.08 19.6 fb-1
0.88 ± 0.11 ± 0.04 2.6 fb-1
0.5
1
1.5
2
All results at:
http://cern.ch/go/pNj7
Production Cross Section Ratio: σexp / σtheo

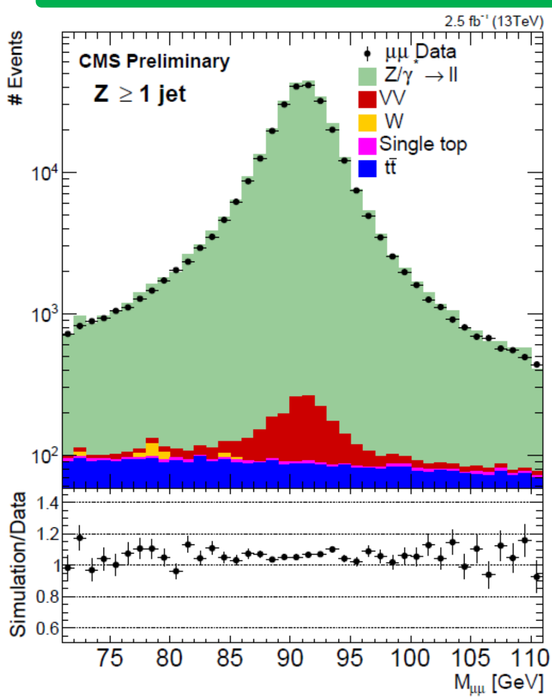
W/Z + Jets 截面

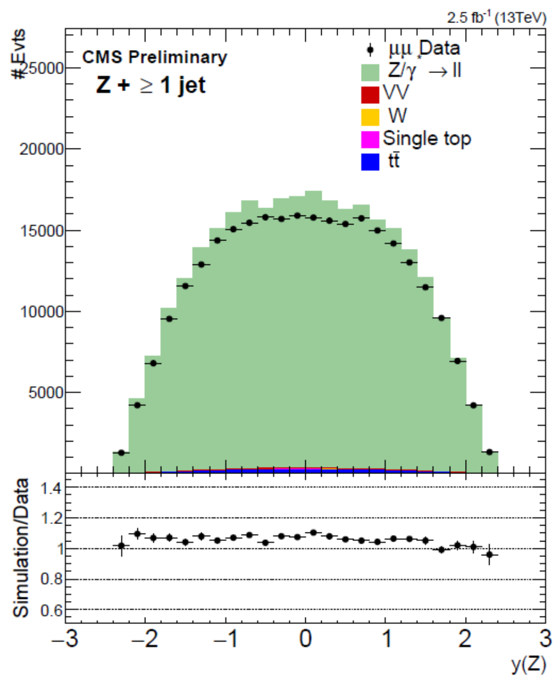
CMS-PAS-SMP-15-010
CMS-PAS-SMP-16-005

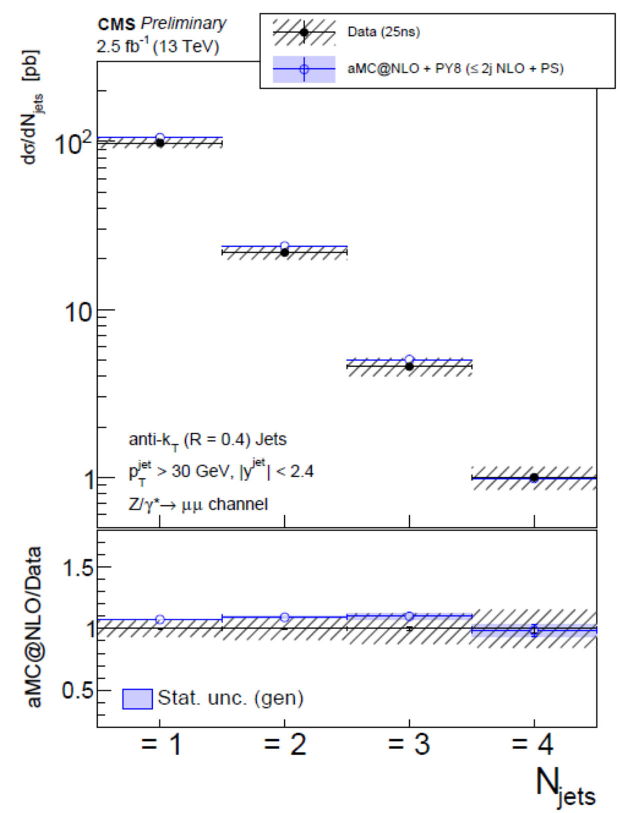
- Dominated by QCD interaction → abundant production
- Measurement is test of perturbative QCD (pQCD)
- Sensitive to PDFs models
- Large background to BSM and Higgs searches



北大参与W/Z+jets截面的测量，
张冯望东作Preapproval报告





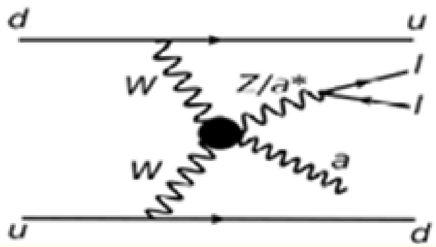


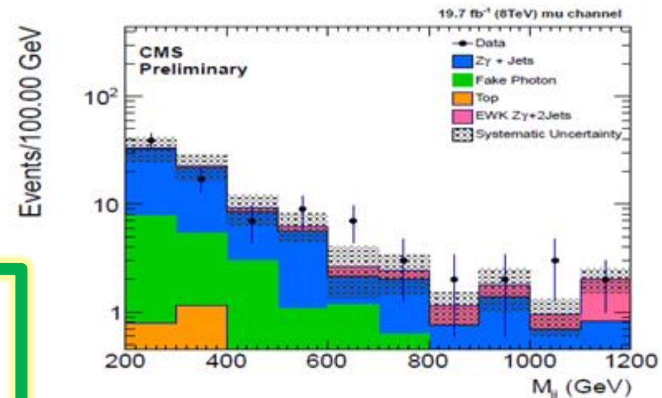
VBS / VBF

CMS-PAS-SMP-13-012
CMS-PAS-SMP-14-011/018
ATLAS-CONF-2016-053, PRL113,141803

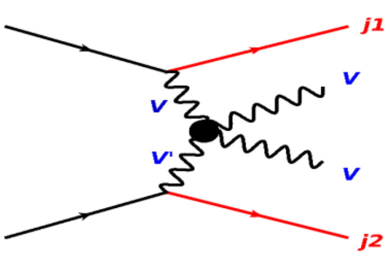
北大担任X→VBS (Wγjj, Zγjj)，VBF (Wjj)
多个分析负责人，多个Approval 报告。

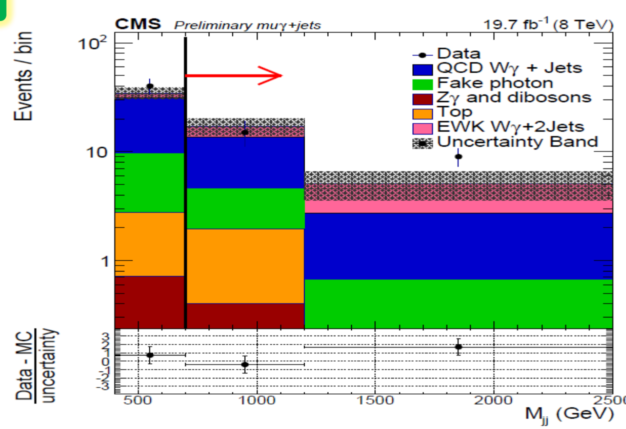
科大韩良，刘明辉，张广义参与VBF WW→lvlv分析工作，多个Approval 报告。
科大刘建北参与VBS same-sign WWjj分析(4.5σ)发表1篇PRL。
【详见刘明辉报告】



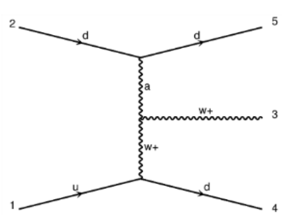


VBS Zγjj
张冯望东、张照茹报告

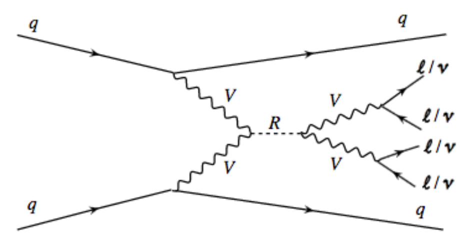




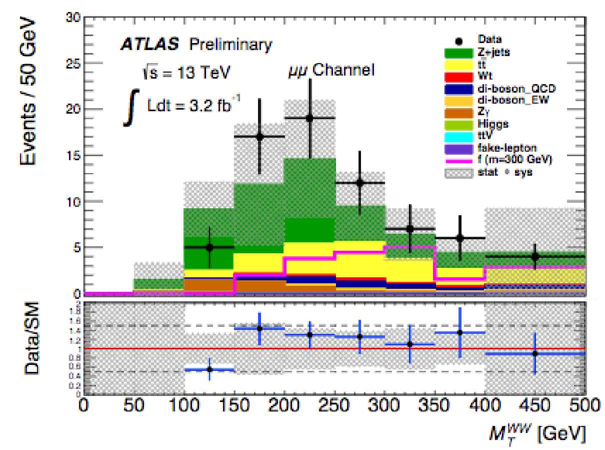
VBS Wγjj
【详见杨大能报告】



VBF Wjj 北大
李晶、邹伟、刘帅



ATLAS-CONF-2016-053



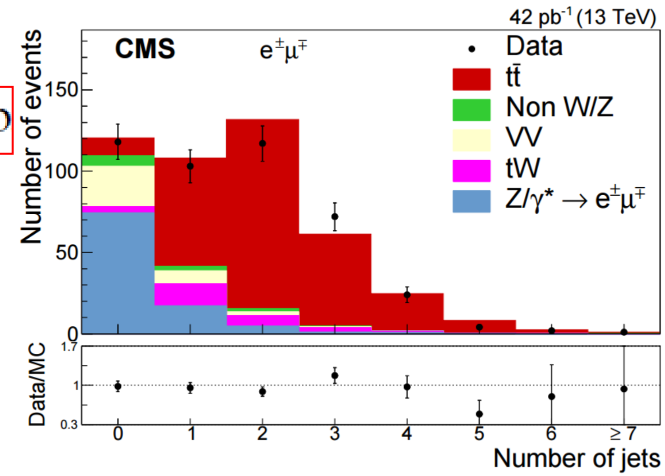
ATLAS-CONF-2016-005
PRL 116 (2016) 052002
CMS-PAS-TOP-16-006

LHC: a Top quark factory

→ tt → bbWW → bb eμνν (OS-eμ)

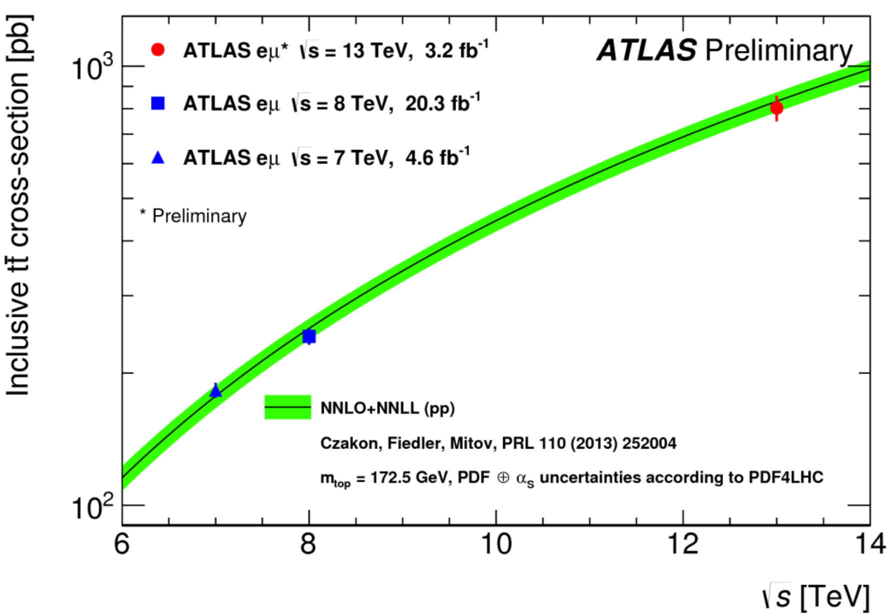
$\sigma_{t\bar{t}} = 803 \pm 7\ (\text{stat}) \pm 27\ (\text{syst}) \pm 45\ (\text{lumi}) \pm 12\ (\text{beam})\ \text{pb}$

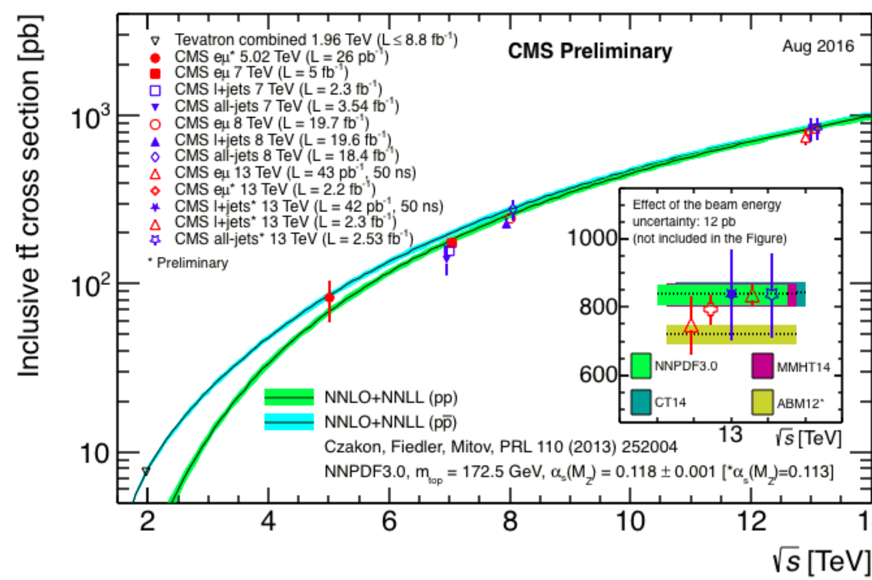
CMS: $746 \pm 58(\text{stat}) \pm 53(\text{syst}) \pm 36\ (\text{lumi})$ pb



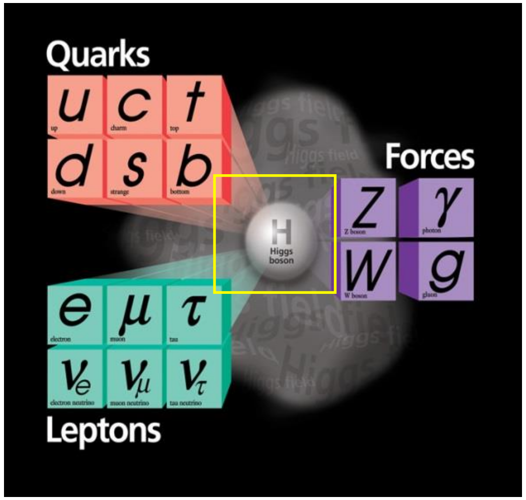
→ Measured cross section agrees well with NNLO+NNLL theoretical prediction

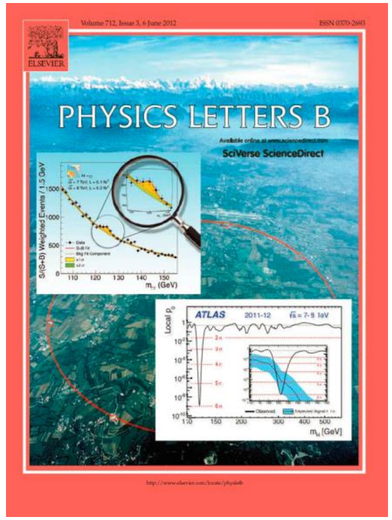
$$\sigma_{t\bar{t}}^{\text{NNLO+NNLL}} = 832^{+40}_{-46}\ \text{pb}$$





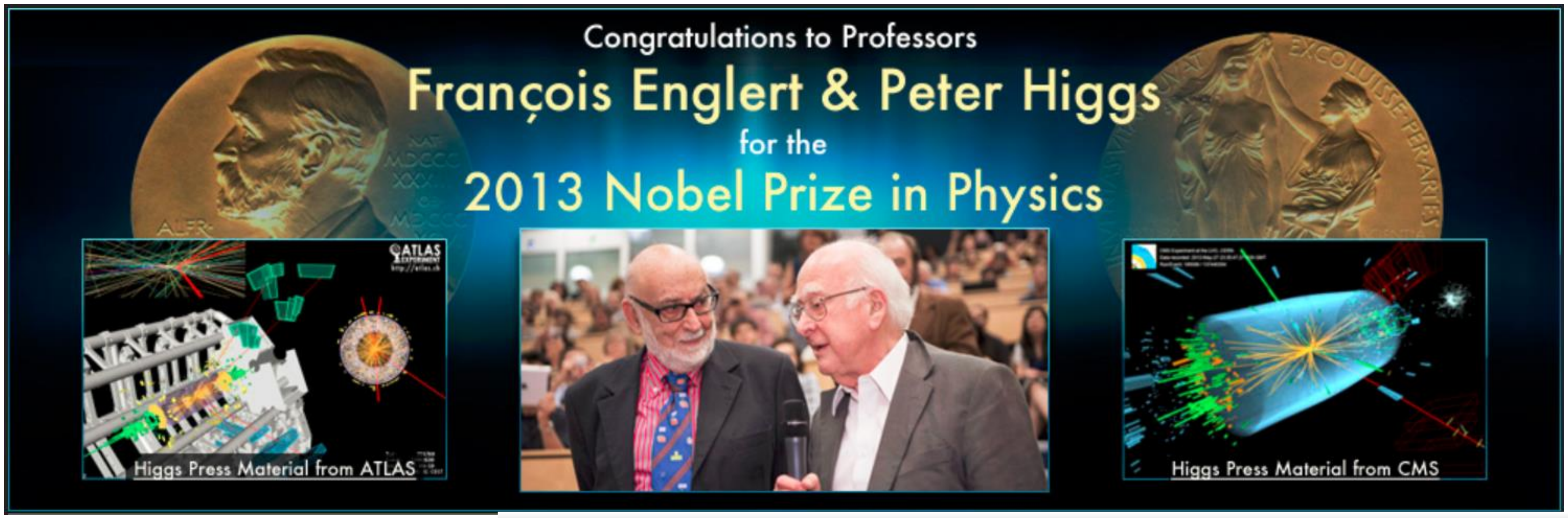
希格斯玻色子的发现（2012）





PLB 716 (2012) 1-29 (ATLAS)

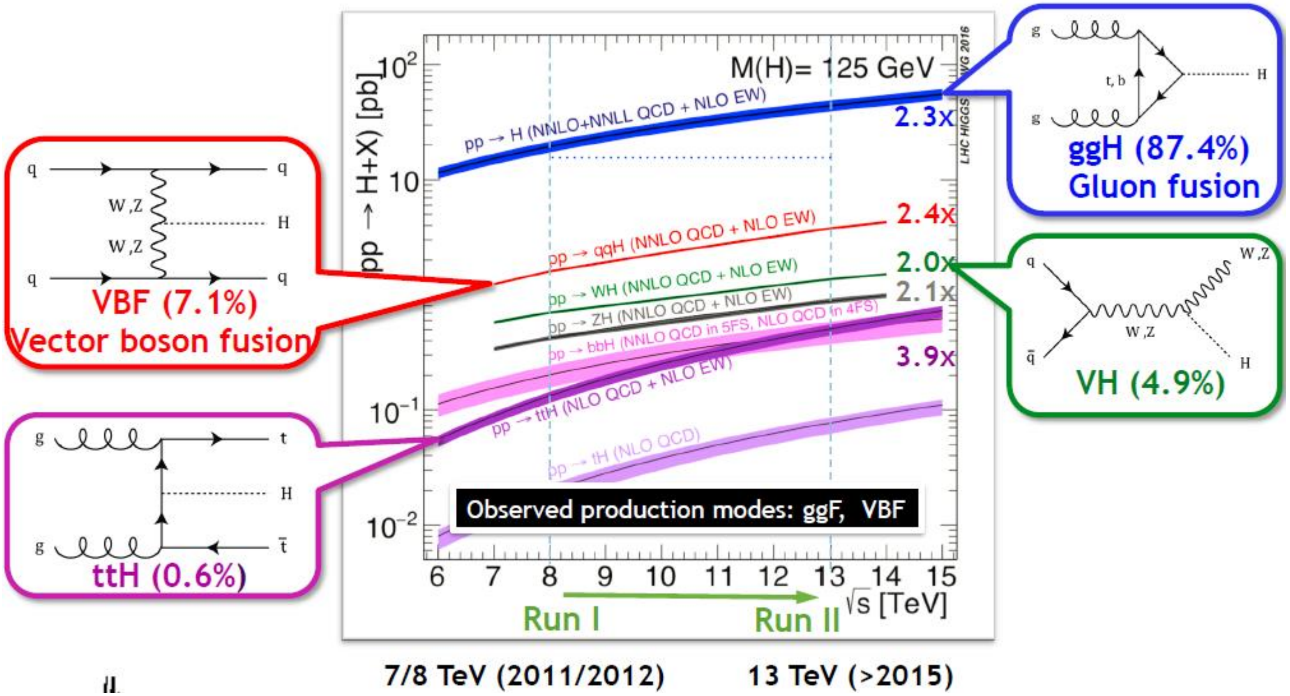
PLB 716 (2012) 30-61 (CMS)

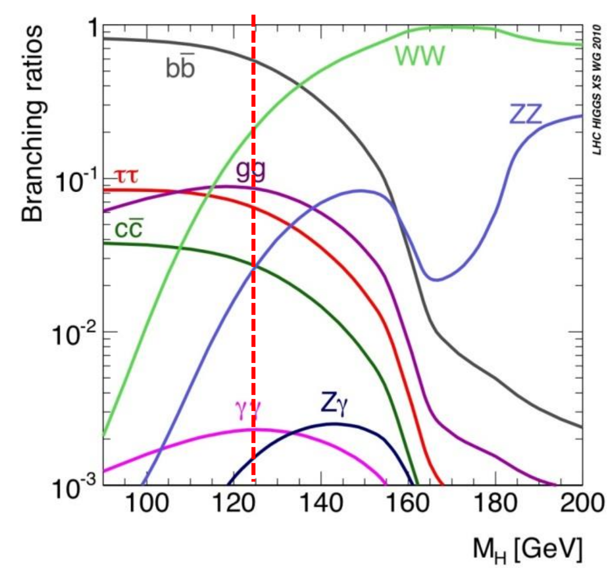


希格斯联合分析

- 联合ATLAS 和 CMS 两大实验组的数据进行测量，提高统计量和减少统计误差，高能所陈明水担任CMS联合分析组召集人。
  - ATLAS datasets: 4.5/fb at 7 TeV, 20.3/fb at 8 TeV
  - CMS datasets: 5.1/fb at 7 TeV, 19.7/fb at 8 TeV

【详见陈明水报告】

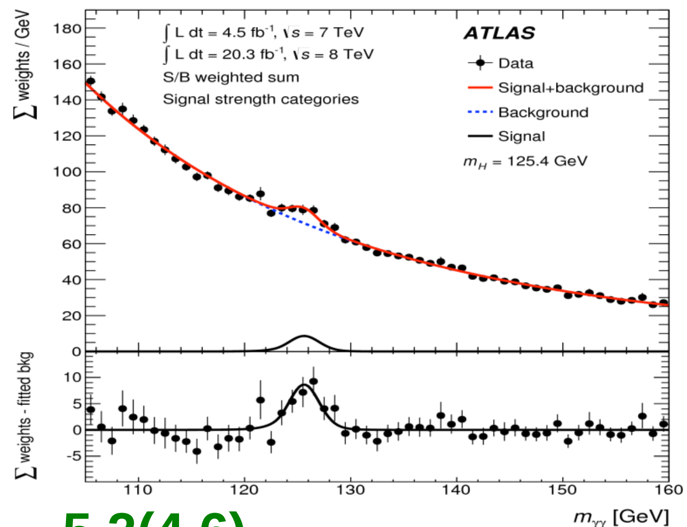




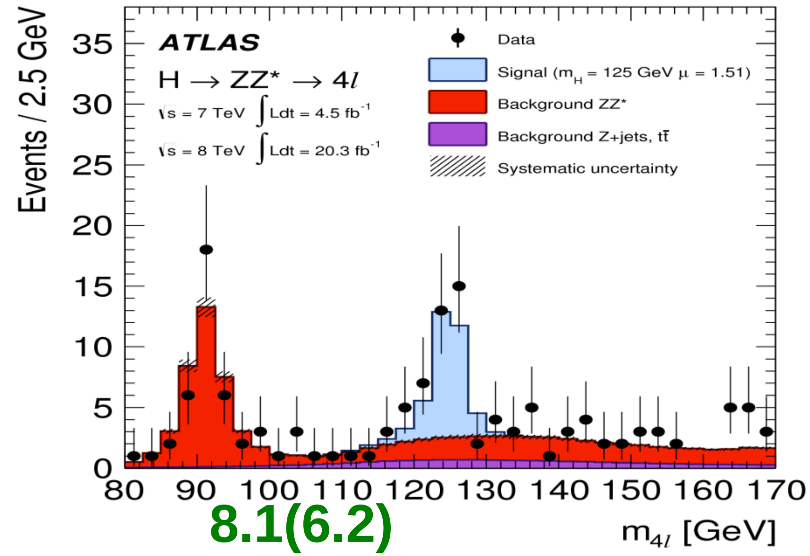
希格斯粒子的发现

ATLAS

obs(expected) significance

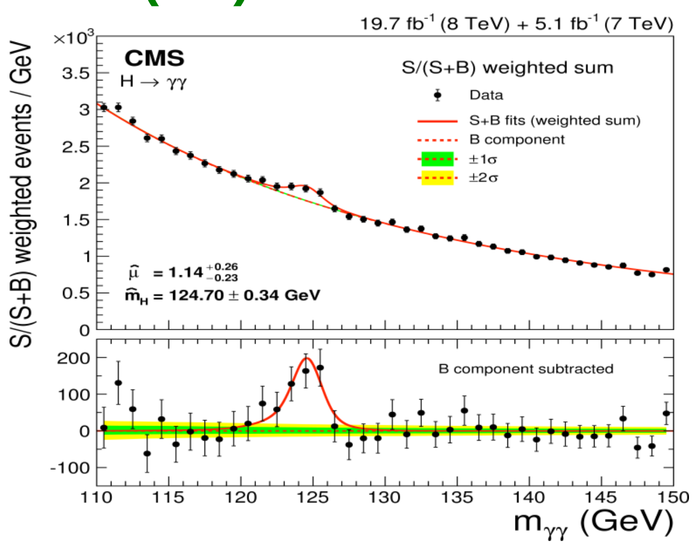


5.2(4.6)

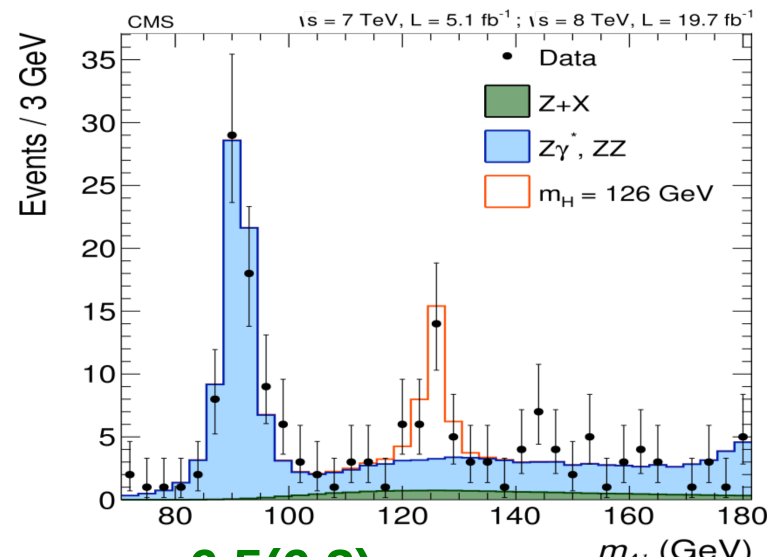


8.1(6.2)

CMS

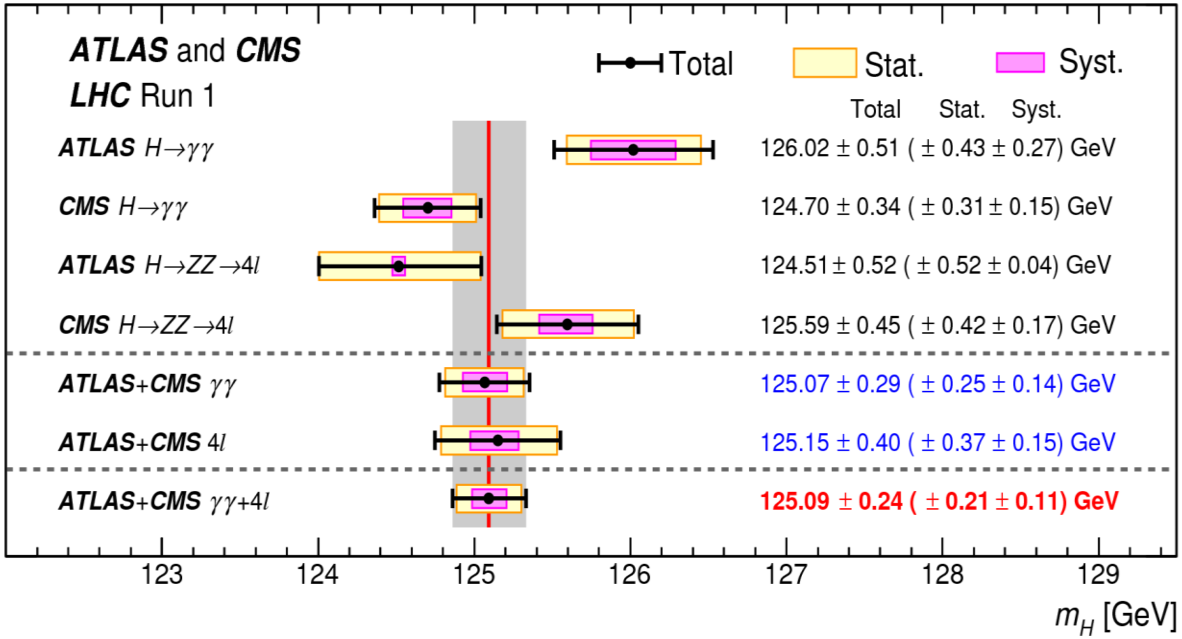


5.6(5.3)



6.5(6.3)

希格斯粒子的质量



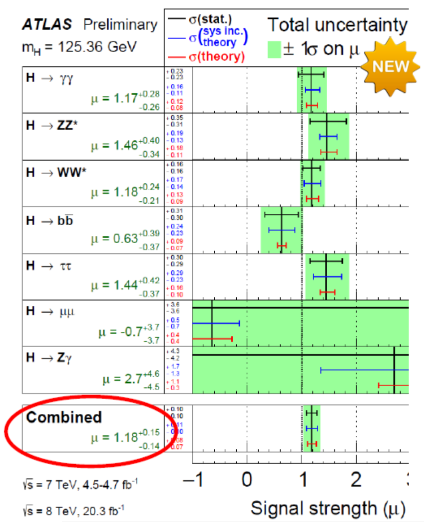
PRL114 (2015) 191803

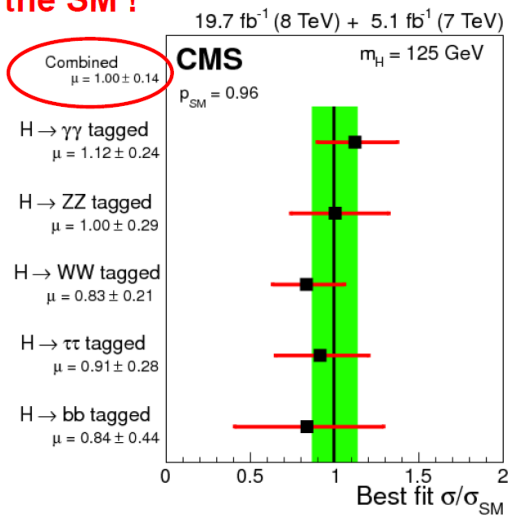
- 为了提高测量精度，CMS和ATLAS对希格斯质量进行联合测量，希格斯质量的测量精度达到千分之二的水平。
- 论文被PRL杂志选为封面介绍

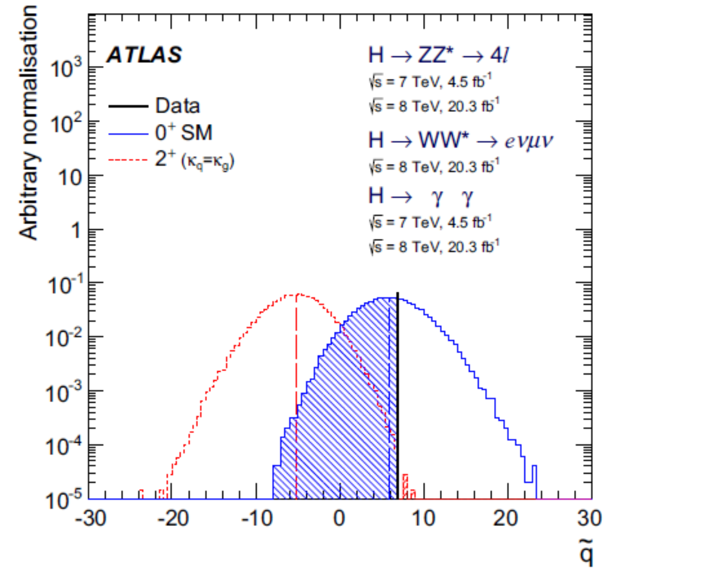
希格斯粒子的性质

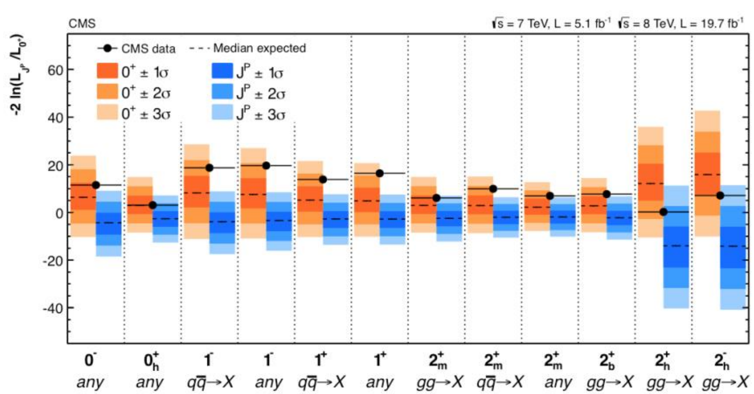
- **Higgs Strength μ = 1.09 ± 0.14**
- **Spin/Parity: 0^+**
- **Couplings: agree with SM predictions**

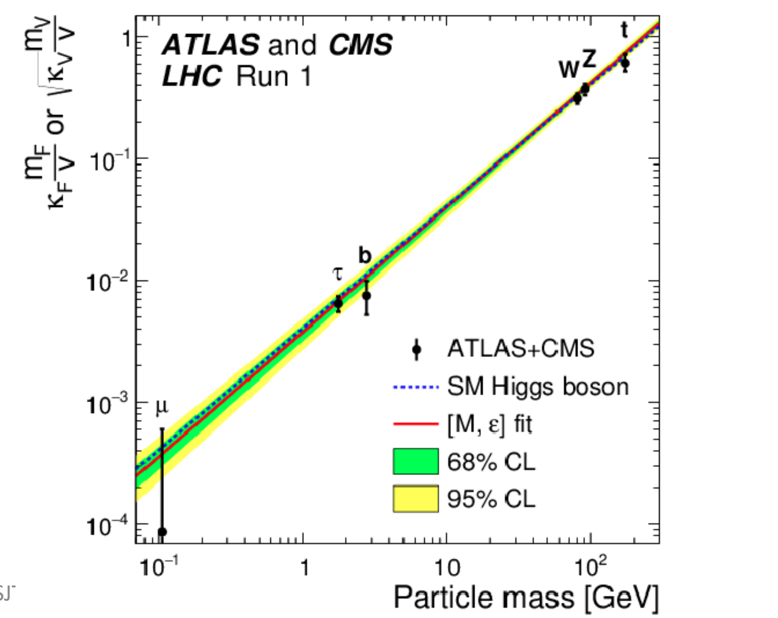
- **Results are consistent with the SM !**











LHC Run2 Physics

LHC Run2 Priorities on Higgs:

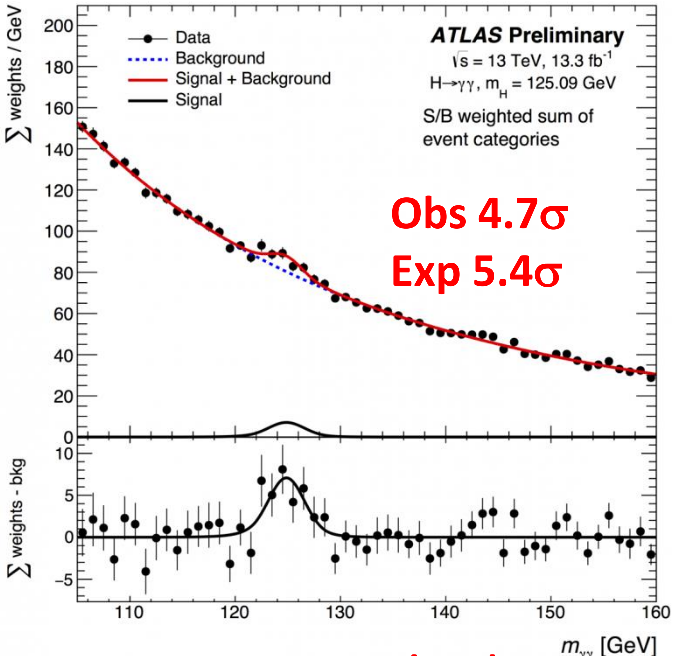
- Re-discovery SM Higgs
- Search for VBF, VH, ttH Higgs
- Search for H→bb, ττ to study Yukawa couplings
- Search for rare decays eg. H→Zγ, μμ
- Use Higgs as a tool to find new physics

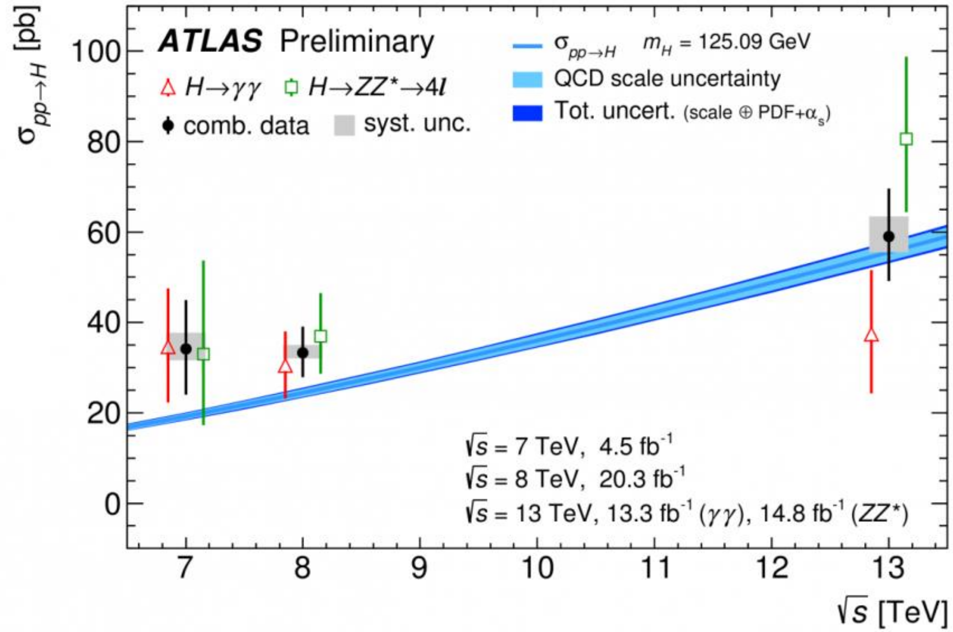
	Untagged	VBF	VH	ttH
H→γγ	✓	✓	✓	✓
H→ZZ→4l	✓	✓	✓	✓
H→WW→2l2ν	✓	✓	✓	✓
H→ττ	✓	✓	✓	✓
H→bb			✓	✓
H→μμ	✓	✓		

Decay mode	Branching fraction [%]
$H \to bb$	57.5 ± 1.9
$H \to WW$	21.6 ± 0.9
$H \to gg$	8.56 ± 0.86
$H \to \tau\tau$	6.30 ± 0.36
$H \to cc$	2.90 ± 0.35
$H \to ZZ$	2.67 ± 0.11
$H \to \gamma\gamma$	0.228 ± 0.011
$H \to Z\gamma$	0.155 ± 0.014
$H \to \mu\mu$	0.022 ± 0.001

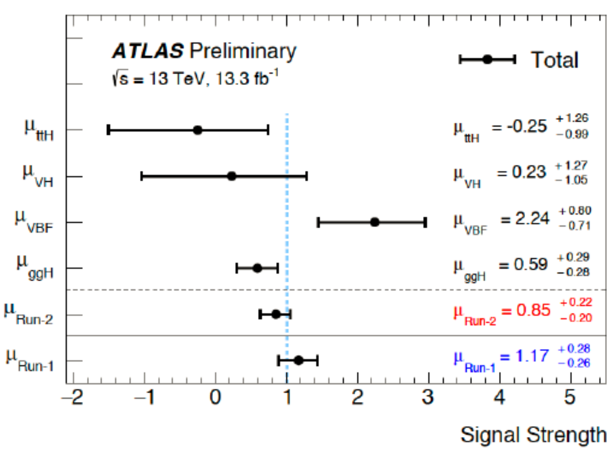
Re-discover Higgs → γγ

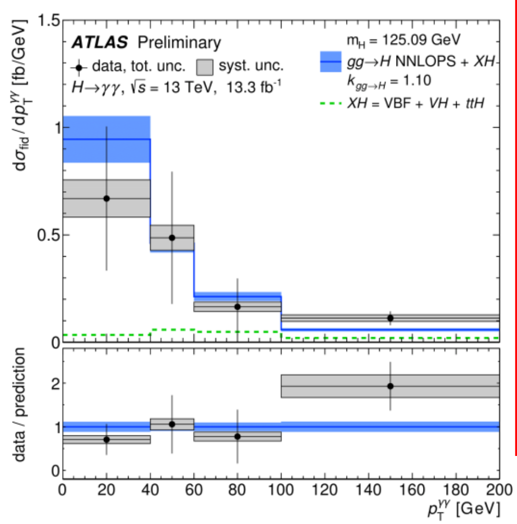
ATLAS-CONF-2016-067
ATLAS-CONF-2016-081
ATLAS-CONF-2016-068





13 categorisation: 4(ggF) 2(VBF), 5(VH), 2(ttH)



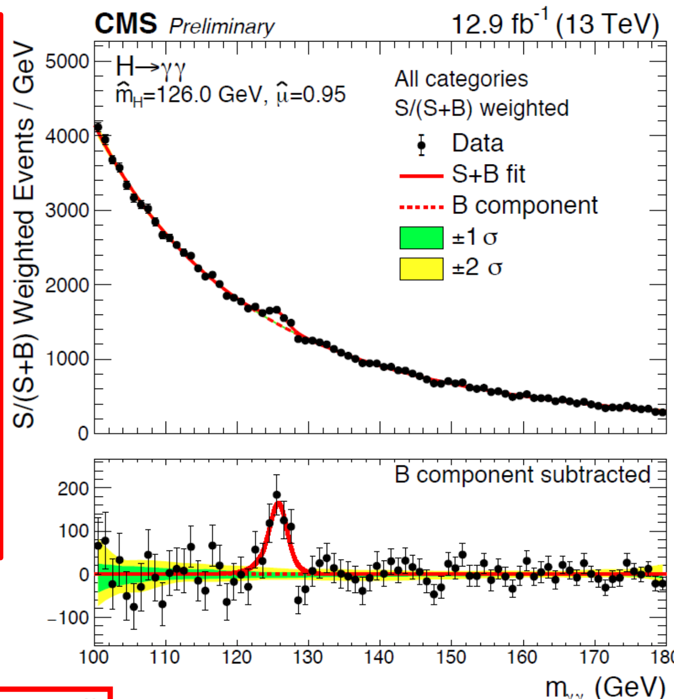


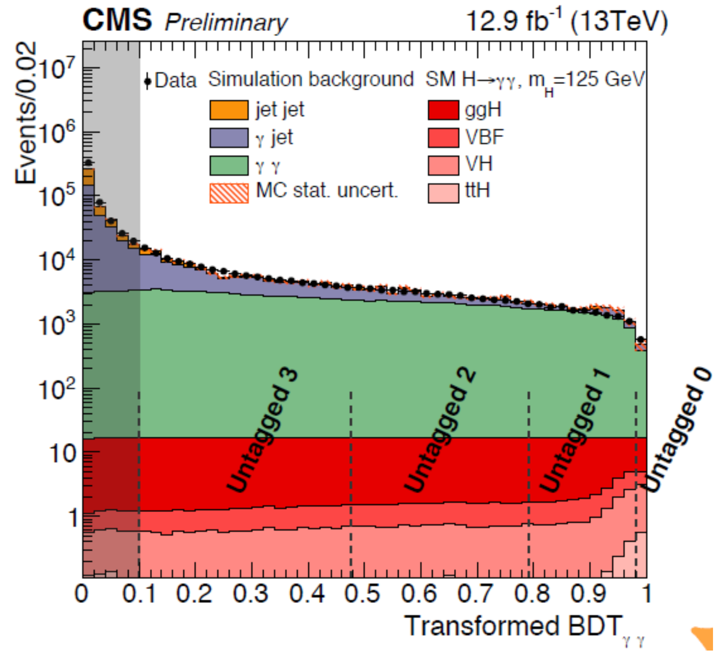
- 高能所金山、黄燕萍、彭聪在LHC实验率先开展H→γγ 截面测量研究，在该分析中发挥主导作用，担任Editor，发表多篇文章和 Conf-Note。
- 上海交大王子瑞、杨海军参与VH(H→γγ)事例选择和优化，光子isolation。

Re-discover Higgs → γγ

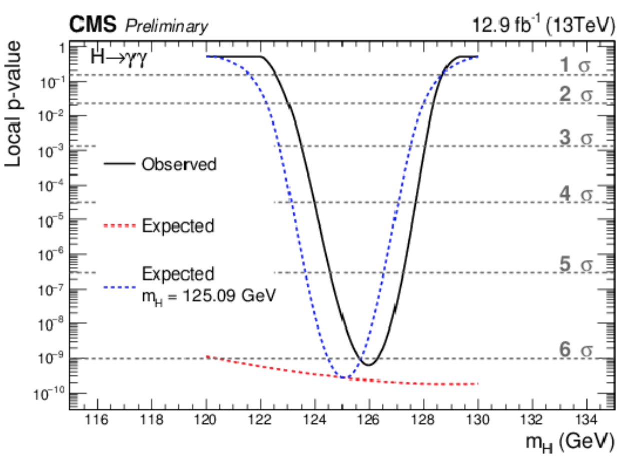
CMS-PAS-HIG-16-020

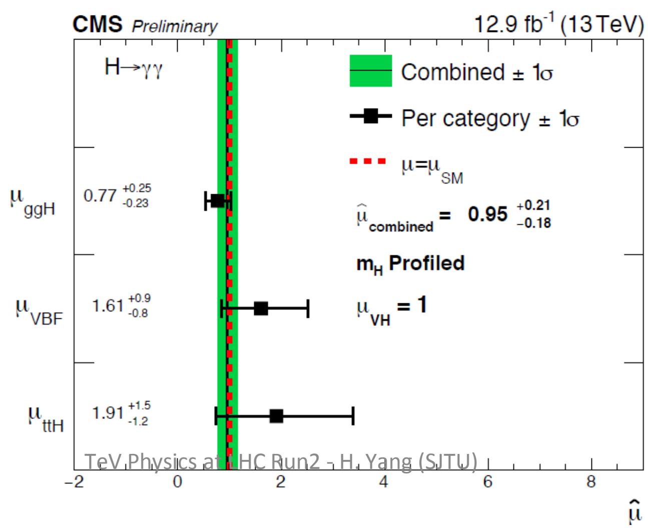
➔ H→双光子末态观察到5.6σ，信号强度和截面测量与标准模型吻合。
➔高能所参与光子鉴别及Z→μμγ检验，陶军全担任论文Editor之一。
【详见陶军全报告】

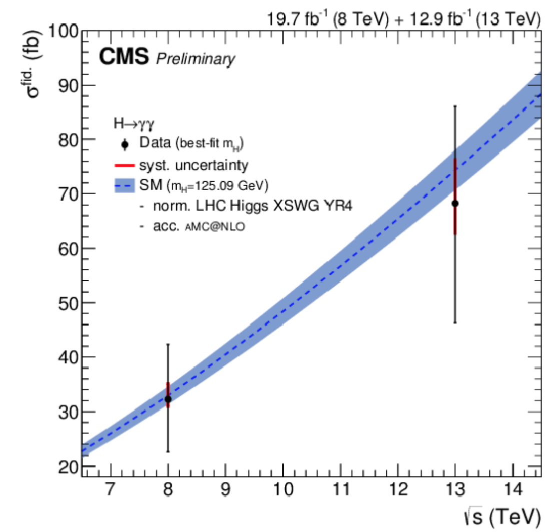




5.6σ observed (6.2σ expected)





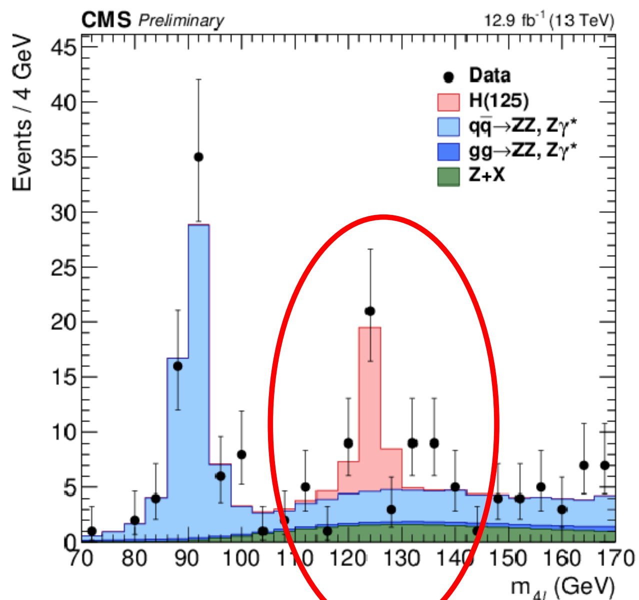


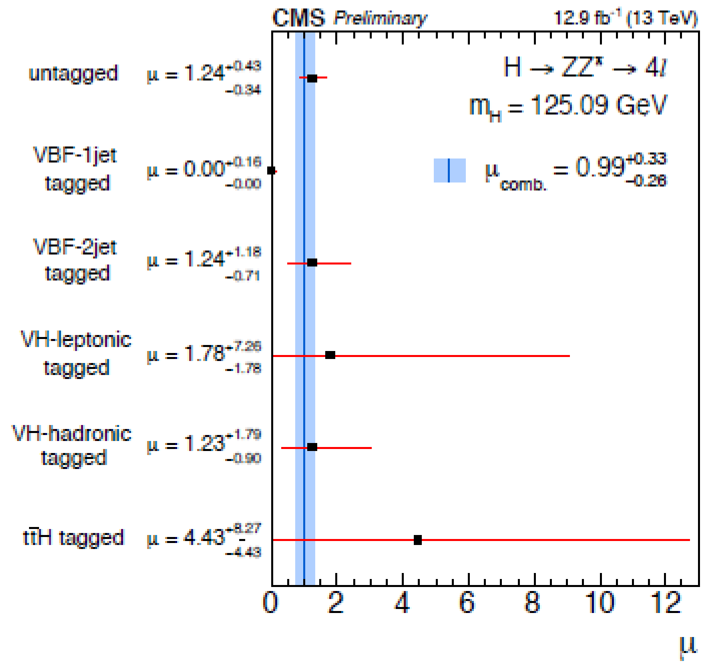
Re-discover Higgs → ZZ* →4l

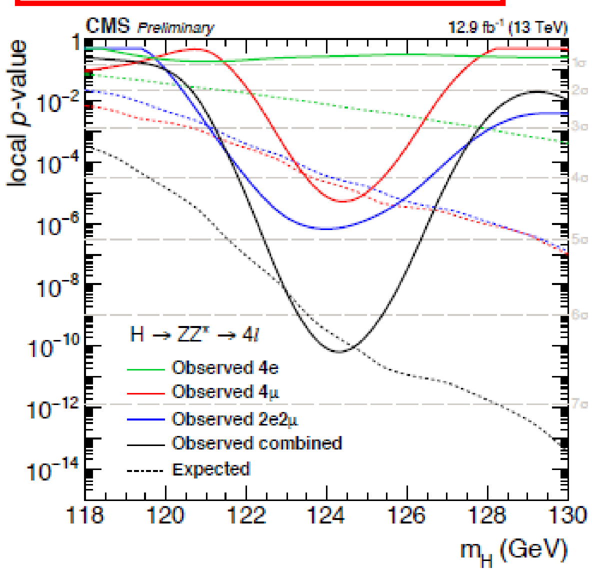
CMS-PAS-HIG-16-033

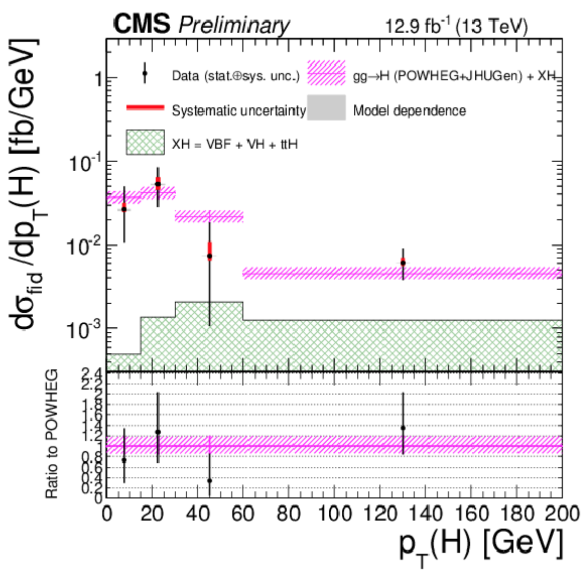
➔高能所陈明水、成瞳光、Ahmad、Roko参与希格斯质量、产生截面的测量。多次作preapproval报告【详见Muhammad, Ahmad报告】

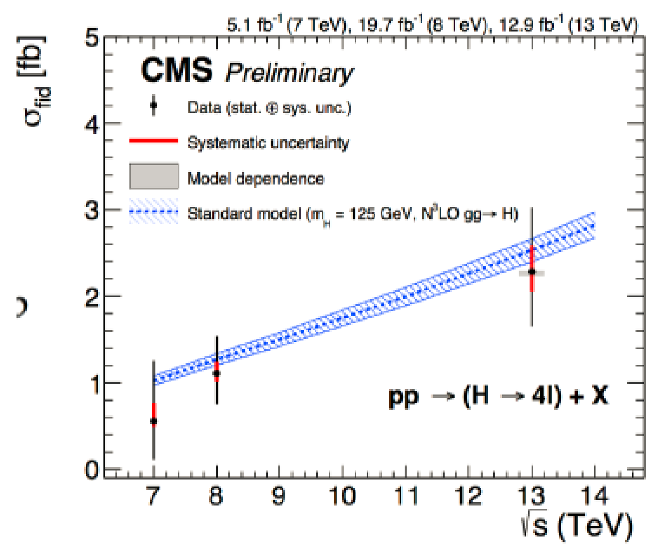
at m_H = 125.09 GeV
6.2σ obs. (**6.5σ** exp.)





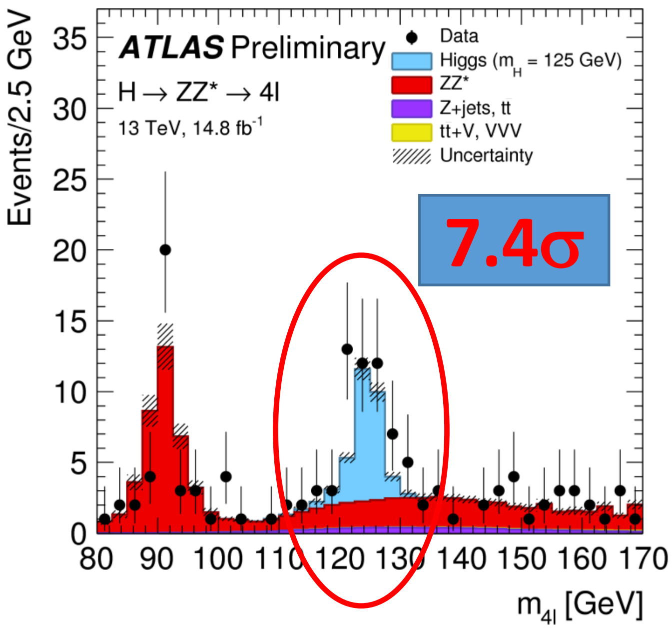






Re-discover Higgs → ZZ* →4l

ATLAS-CONF-2016-079

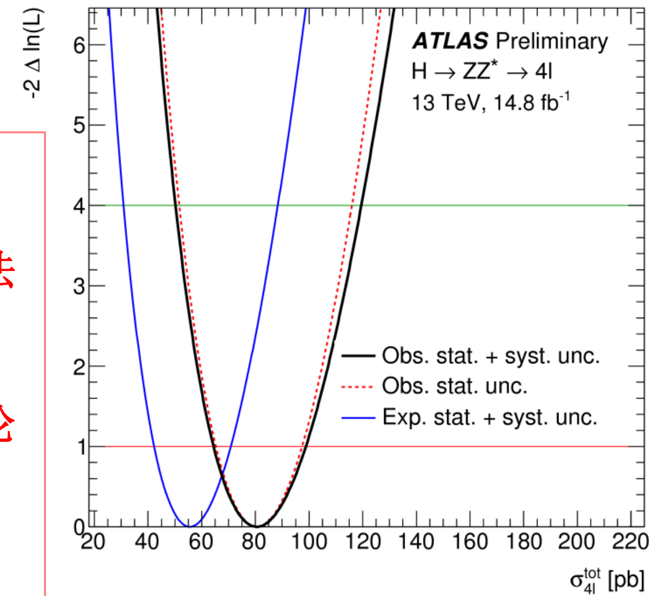


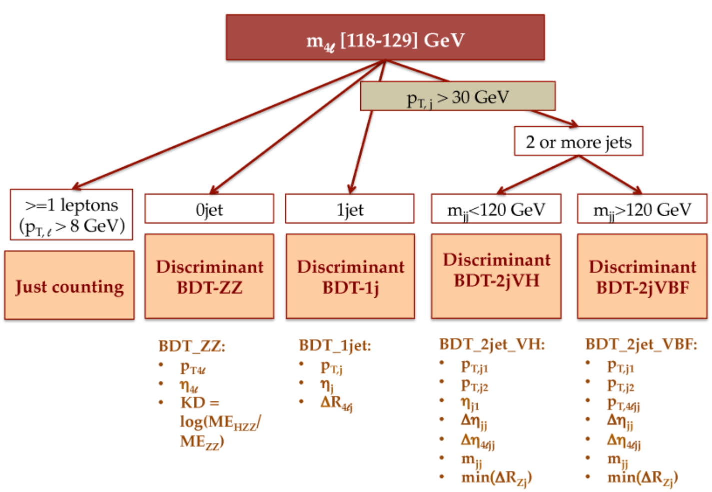
$$\sigma_{\mathrm{tot,SM}} = 55.5^{+3.8}_{-4.4}\ \mathrm{pb.}$$

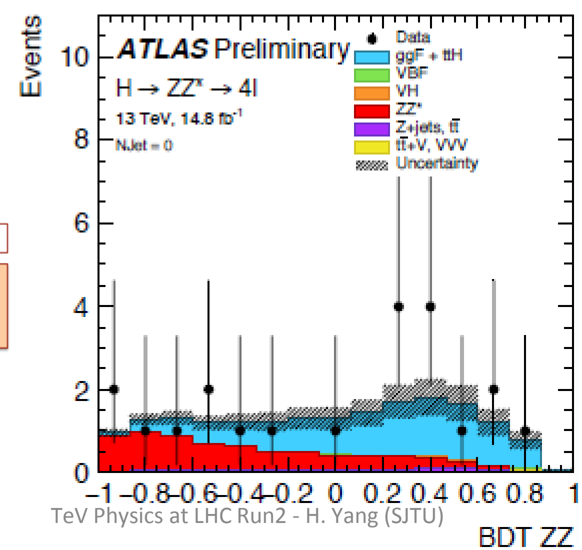
$$\sigma_{\mathrm{tot}} = 81^{+18}_{-16}\ \mathrm{pb}$$

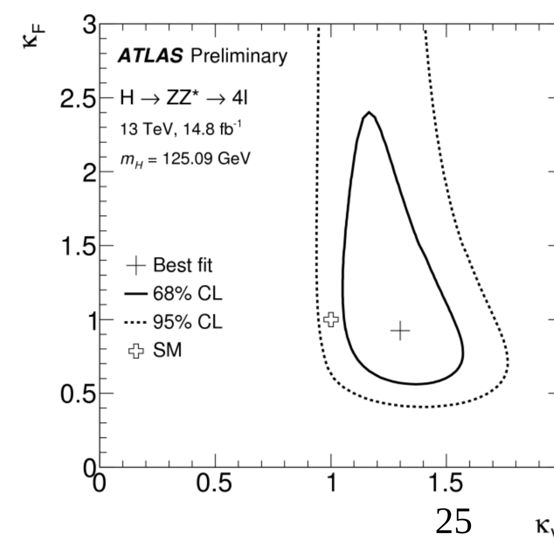
科大李冰、徐来林、赵政国，交大杨海军在 **ATLAS Run1** 参与**H→ZZ***的分析，用**BDT**方法提高信噪比，测量自旋和宇称等，首次提出用**Z→4l**刻度希格斯质量，担任**4**篇**Higgs**论文的编辑之一。

Run2主要参与**VBF** 事例的选择优化，截面测量等。







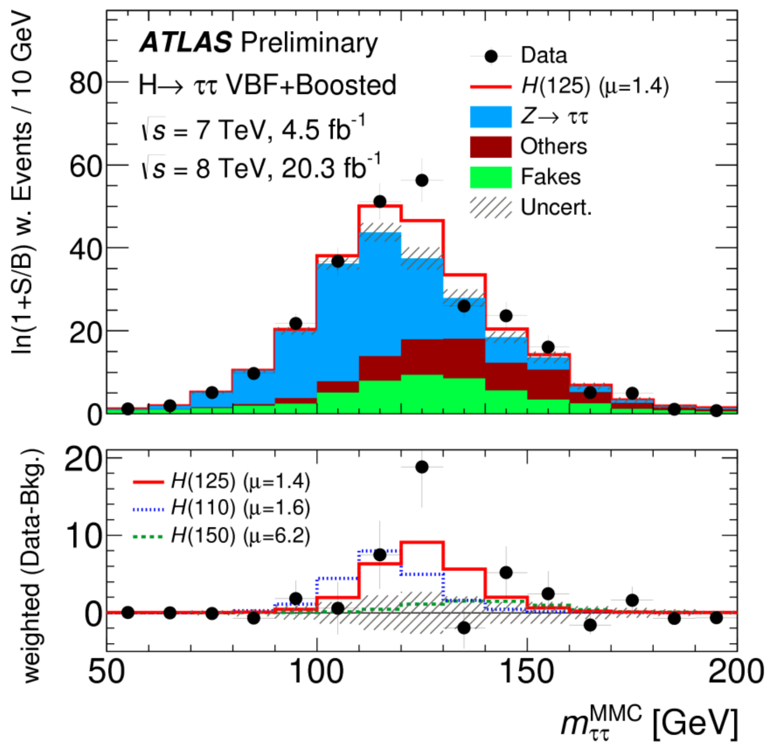


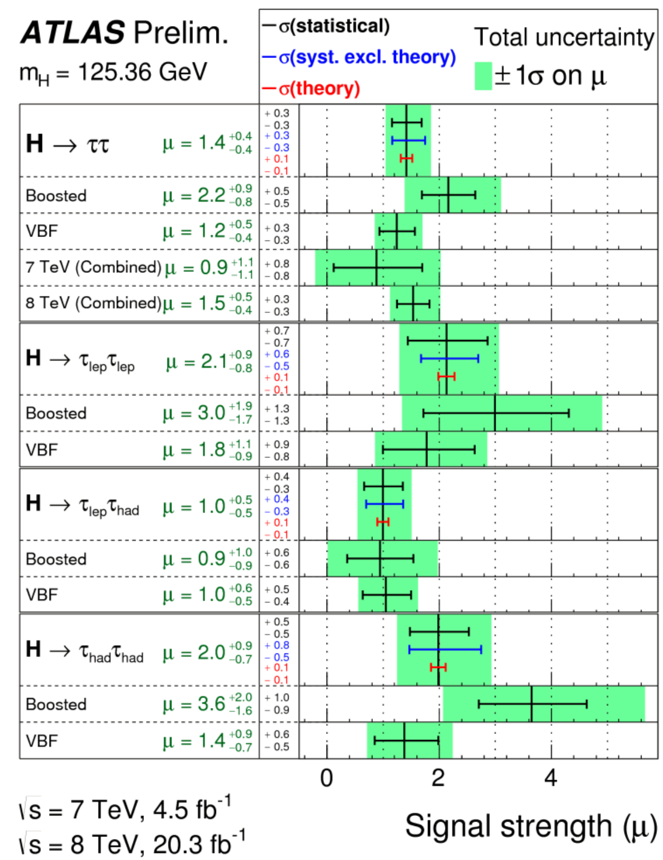
Search for Higgs→ττ

JHEP04 (2015) 117

- H->ττ是研究希格斯粒子汤川耦合非常重要的衰变，对判定新粒子是否为标准模型希格斯粒子具有重要意义。
- 清华陈新担任H→ττ双轻子衰变道的Contact 和Editor，做出了重要贡献。
- Run2数据在继续分析中。

H→ττ 信号强度 (Run1), ATLAS: 4.5σ , CMS: 3.4σ; 联合信号强度: 5.5σ (exp 5σ)



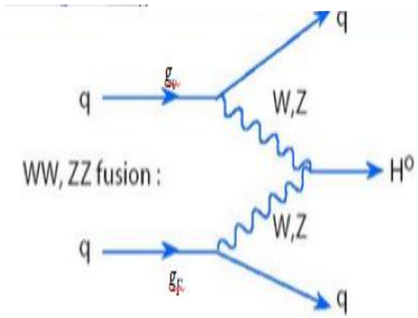


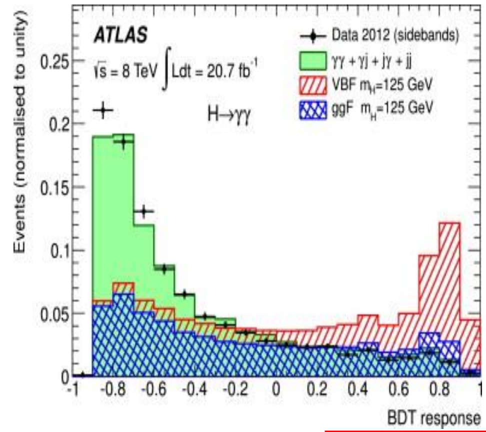
Search for VBF Higgs

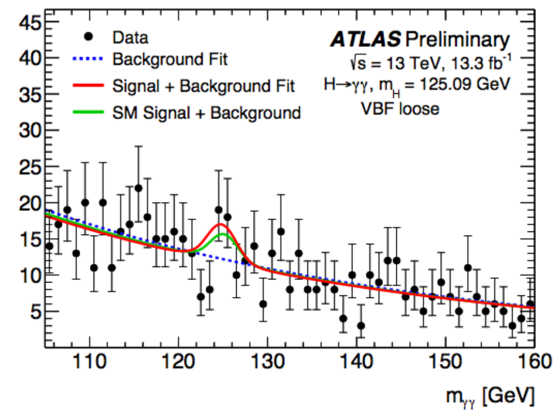
ATLAS-CONF-2016-068
ATLAS-CONF-2016-063

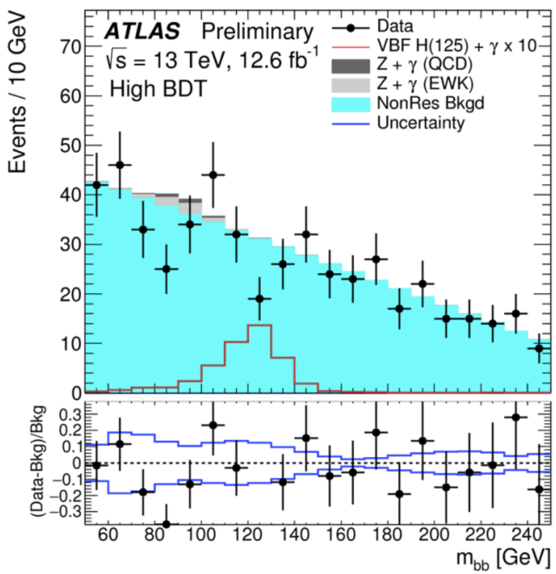
- VBF 是希格斯粒子产生的第二大机制，能否在实验上观测到VBF Higgs是希格斯发现后重要研究课题之一。
- 高能所方亚泉、章宇、娄辛丑率先提出多变量方法BDT分析VBF H→γγ。担任分析的Contact和文章editor，发挥主导作用，已发表多篇文章和Conf-Note。

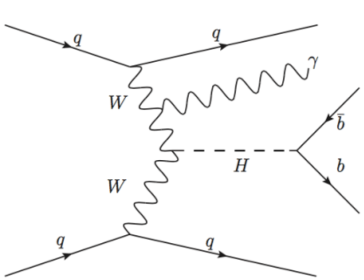
$$\mu_{\mathrm{VBF}} = 2.10^{+0.89}_{-0.79} = 2.10^{+0.84}_{-0.76}\,(\mathrm{stat.})\,^{+0.29}_{-0.22}\,(\mathrm{syst.})\,^{+0.08}_{-0.04}\,(\mathrm{theory})$$











- 目前唯一可以区分WWH 与ZZH的贡献的分析是H(→bb)γ，
- 高能所梁志均, Javier Llorente Merino 率先提出该分析，并担任分析的Contact，給Approval报告，发挥主导作用。【详见梁志均报告】

Search for VH, H→bb

ATLAS-CONF-2016-091

- 测量H->bb衰变分支比和汤川耦合
- 按照末态轻子，喷注数和运动学划分信号区， 采用BDT降低本底。

➔ 科大李昌樵、陈程、刘衍文 (b-tagging, CxAOD，BDT分析，统计分析)

➔ 山大马延辉、马连良 (WH→lνbb, b-tagging, top本底估计)

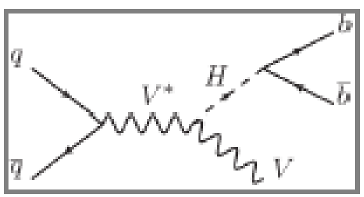
➔ 高能所单连友参与WH→WWW*分析

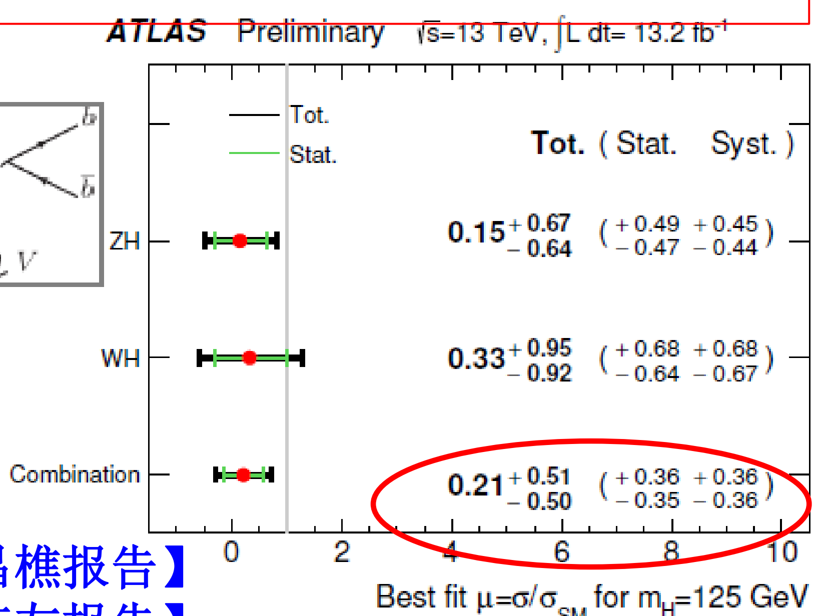
➔ 南大王超、陈申见 (A→ZH)

➔ 交大Nataliia、郭军、杨海军 (ZH→ννbb分析)

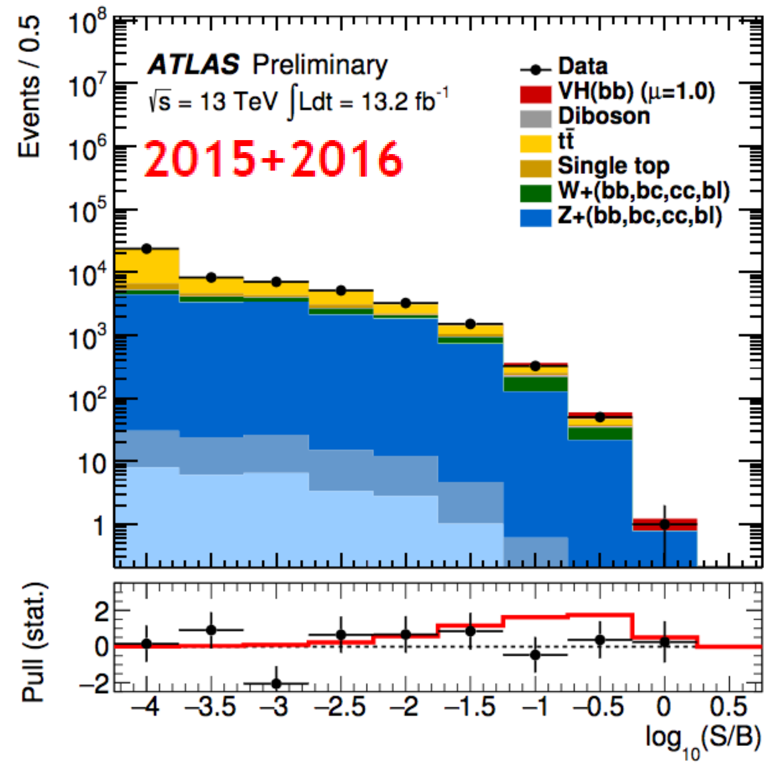
Run1: ATLAS+CMS combined
H→bb 2.6σ (exp. 3.7σ)

Run2: 13 TeV (2015+2016)
Z→ll, W→lv, Z→νν
ATLAS 0.4σ (exp. 1.9σ)





【详见李昌樵报告】
【详见单连友报告】

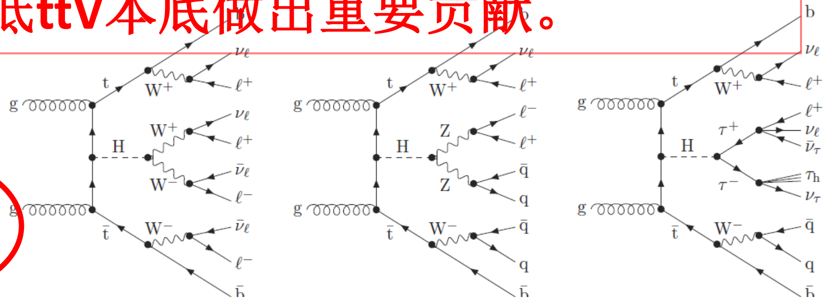


Search for ttH

CMS-PAS-HIG-16-022/004
CMS-PAS-HIG-15-008

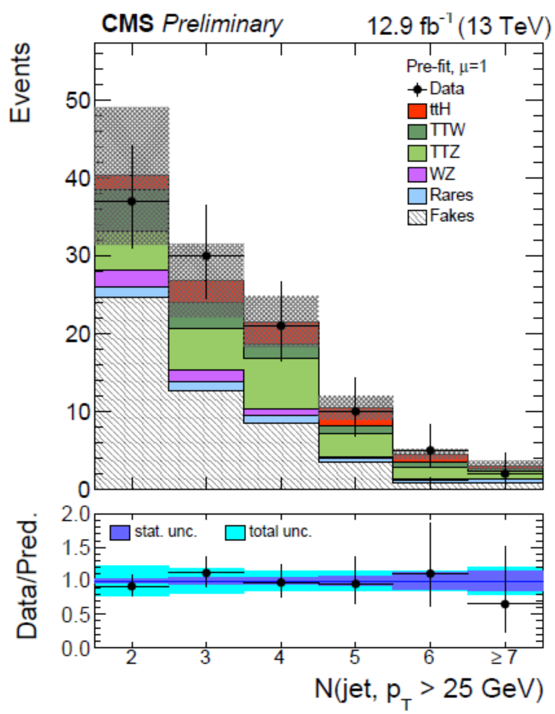
- ➢ 寻找ttH, H→WW, ZZ,ττ 多轻子信号 → 直接检验 Higgs-top 的汤川耦合.
- → 高能所Francesco, Aniello, 李秉恒，张华桥，廖红波主导分析，担任editor。
- → 北大李晶等参与Matrix Element 方法压低ttV本底做出重要贡献。

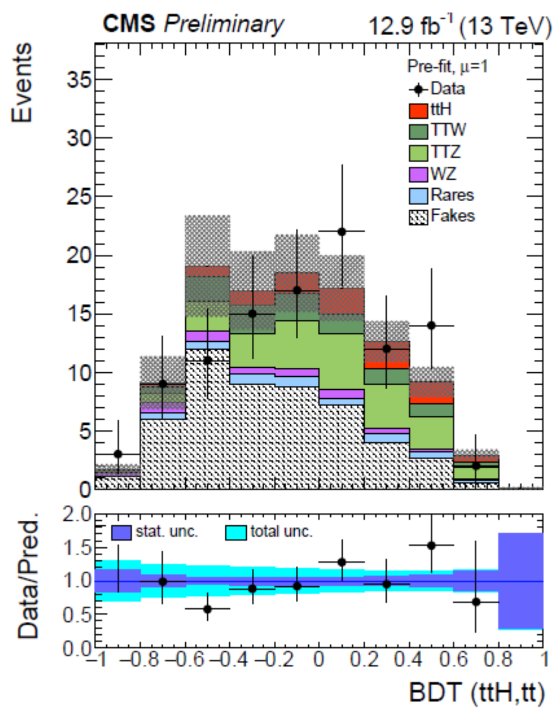
Category	Obs. limit	Exp. limit $\pm 1\sigma$	Best fit $\mu \pm 1\sigma$
Same-sign dileptons	4.6	$1.7^{+0.9}_{-0.5}$	$2.7^{+1.1}_{-1.0}$
Trileptons	3.7	$2.3^{+1.2}_{-0.7}$	$1.3^{+1.2}_{-1.0}$
Combined categories	3.9	$1.4^{+0.7}_{-0.4}$	$2.3^{+0.9}_{-0.8}$
Combined with 2015 data	3.4	$1.3^{+0.6}_{-0.4}$	$2.0^{+0.8}_{-0.7}$

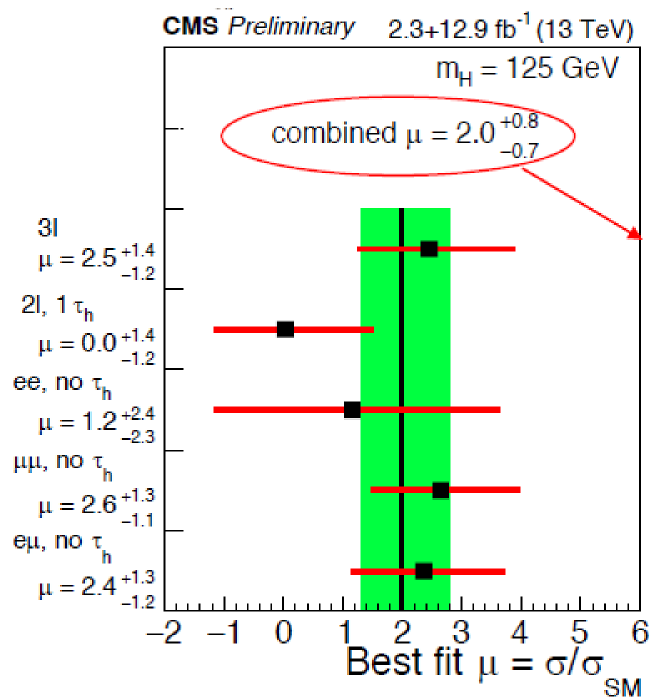


four leptons, three leptons, and two same-sign leptons

【详见张华桥报告】







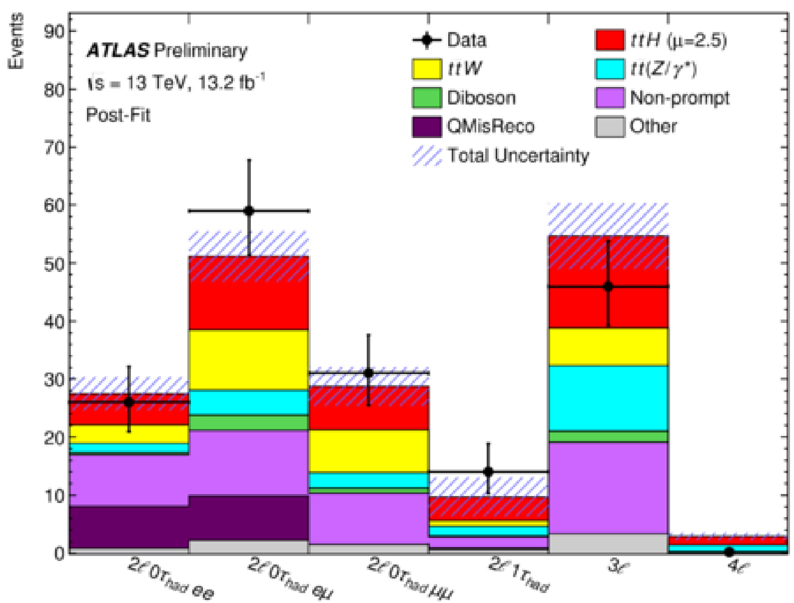
Search for ttH

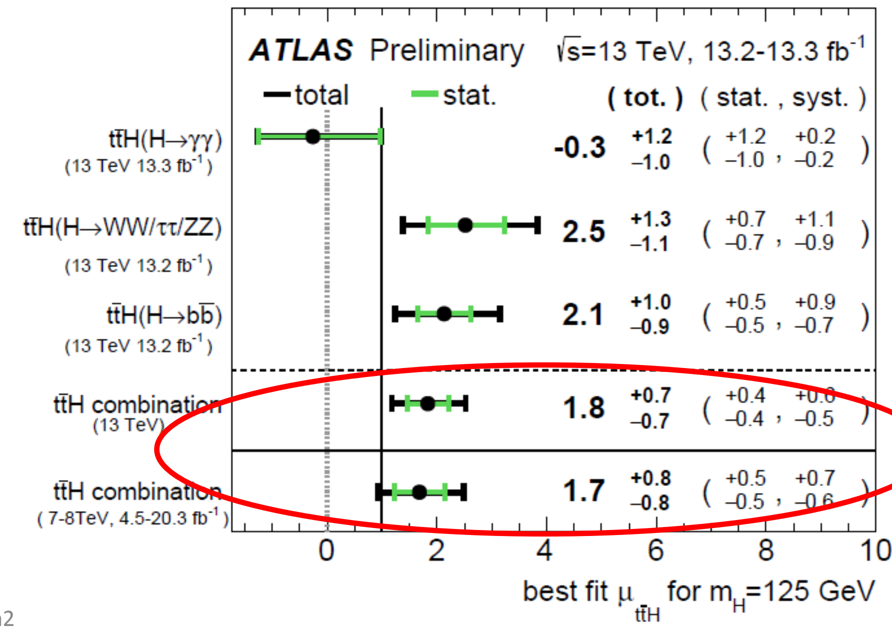
ATLAS-CONF-2016-058
ATLAS-CONF-2016-068

➔ ATLAS combining ttH in γγ, multi-lepton (decay from H➔WW, ZZ, ττ), bb states, obs (exp) significance of 2.8σ (1.8σ).

- ❑ 山大王超、马连良、冯存峰主要贡献：ttH, H➔WW, 3轻子末态分析。
- ❑ 高能所朱宏博，交大胡舒旸、李亮参与 ttH, H➔bb数据分析

Channel	Significance	
	Observed [σ]	Expected [σ]
$t\bar{t}H$, $H \to \gamma\gamma$	−0.2	0.9
$t\bar{t}H$, $H \to (WW, \tau\tau, ZZ)$	2.2	1.0
$t\bar{t}H$, $H \to b\bar{b}$	2.4	1.2
$t\bar{t}H$ combination	2.8	1.8

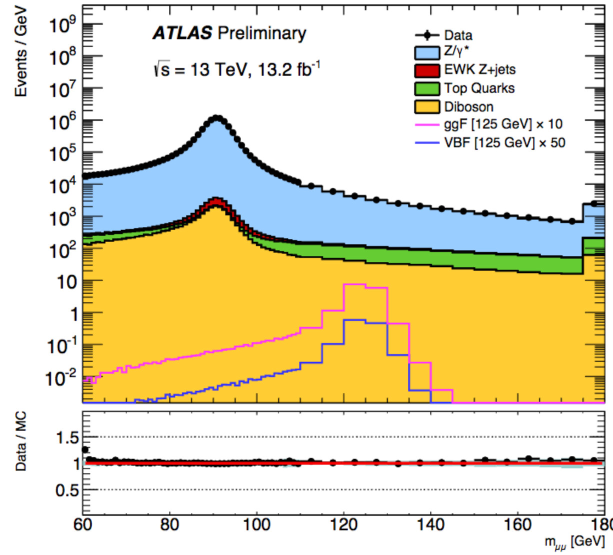


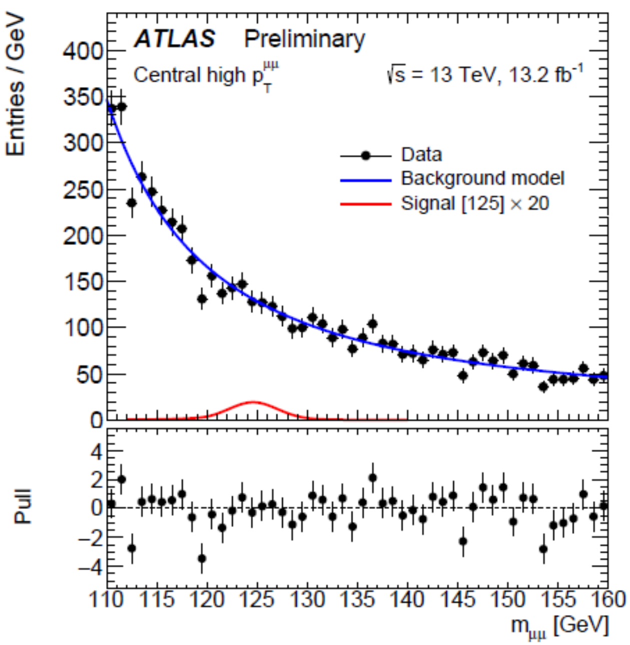


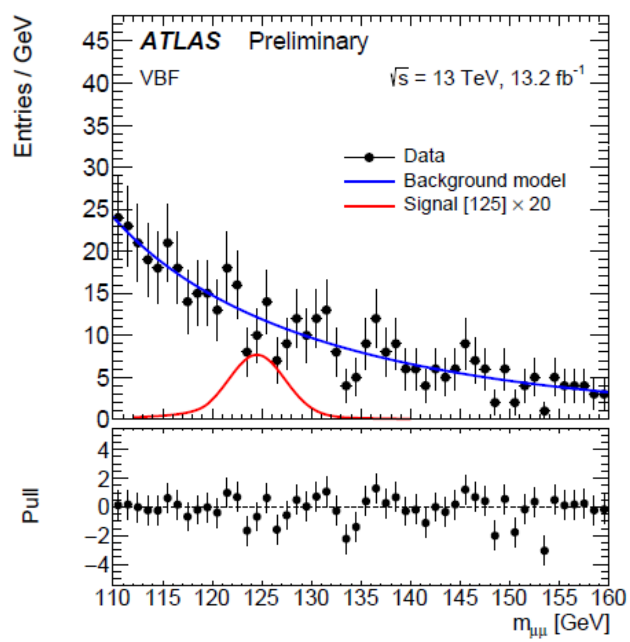
Run2

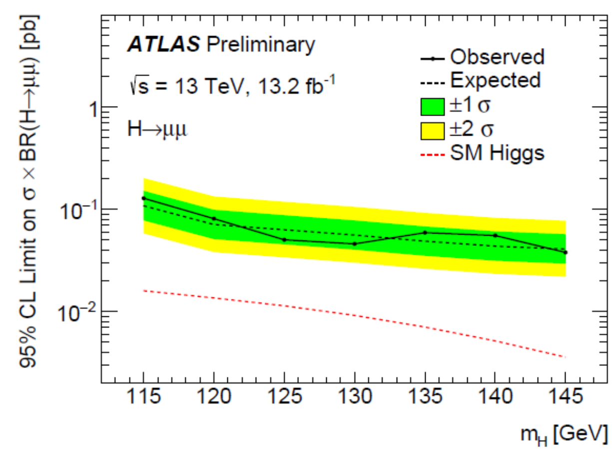
Search for Higgs → μμ

- ➔ 希格斯稀有衰变，末态干净，测量希格斯与第二代费米子mu子的耦合，ggF (6个信号区) 和 VBF(1个信号区)
- ➔ 测量(预期)截面上限 95% CL 是 4.4 (5.5) x σ_{SM}.
- ➔ 科大刘彦麟和赵政国主要参与VBF信号区BDT优化，结果的图形展示等。



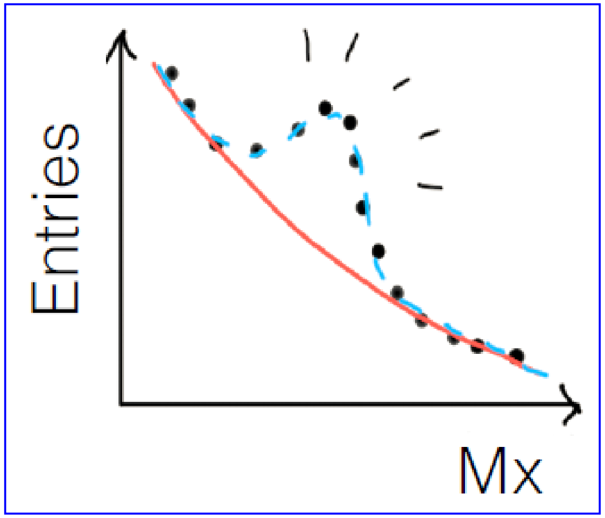


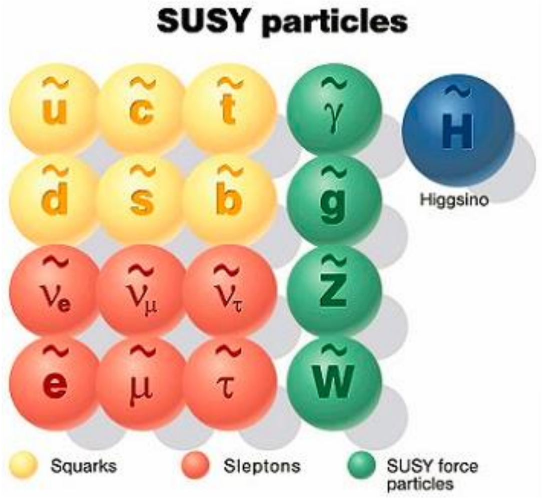




Search for New Physics

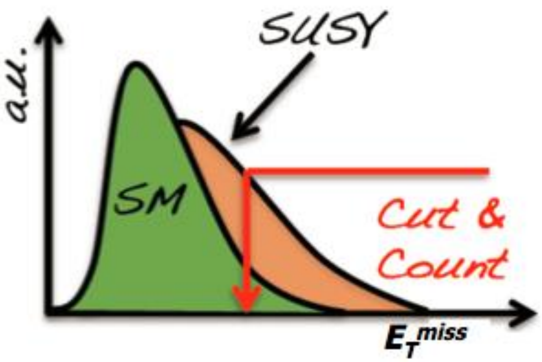
- ✓ X → di-photon
- ✓ X → Z+photon
- ✓ X → di-lepton
- ✓ X → di-jets
- ✓ X → di-boson
- ✓ X → hh





- ✓ SUSY Particles
- ✓ Dark Matter
- ✓ Heavy Quarks
- ✓ Majorana neutrino

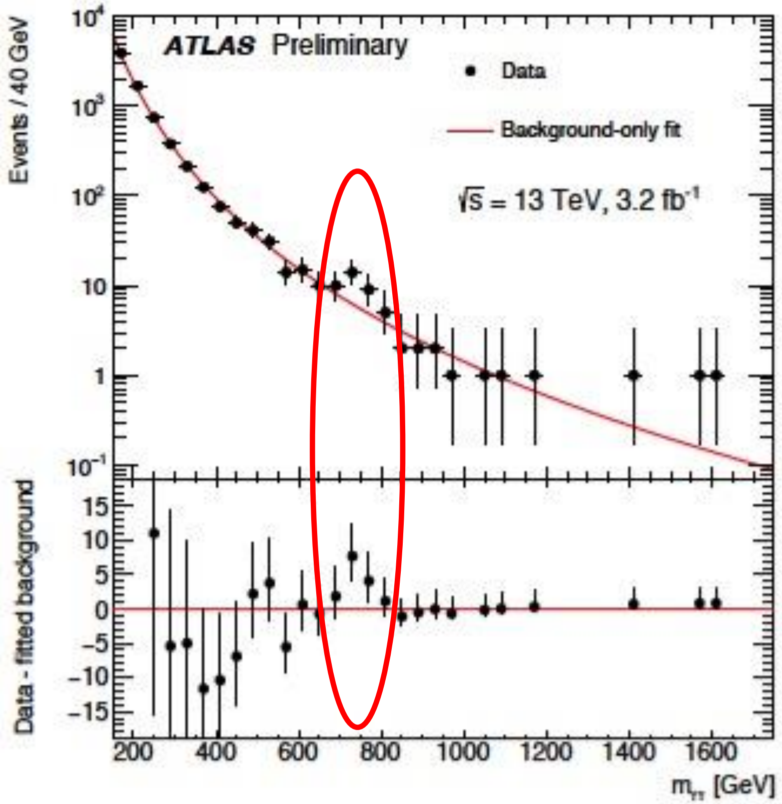
… …

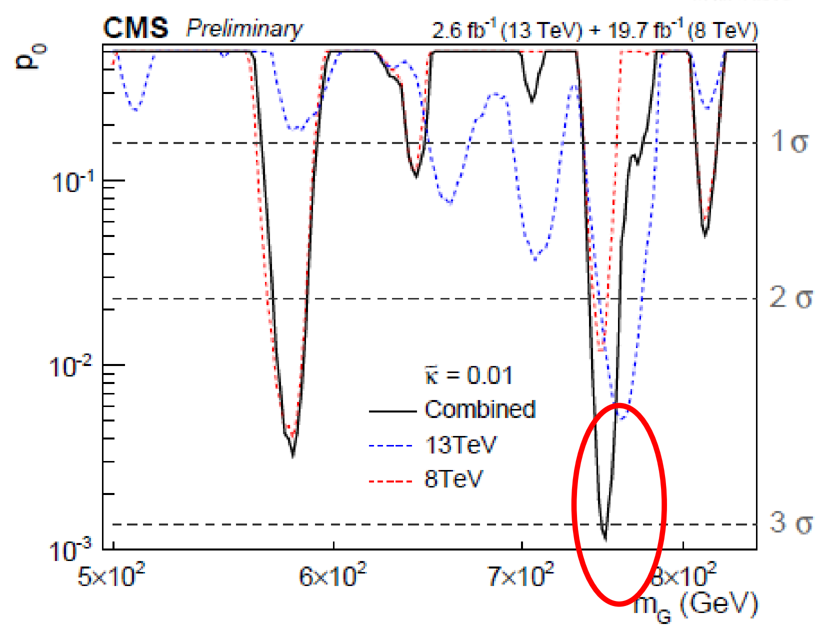


*Search for X → γγ

ATLAS-CONF-2016-018
arXiv:1606.03833
CMS-PAS-EXO-15-004

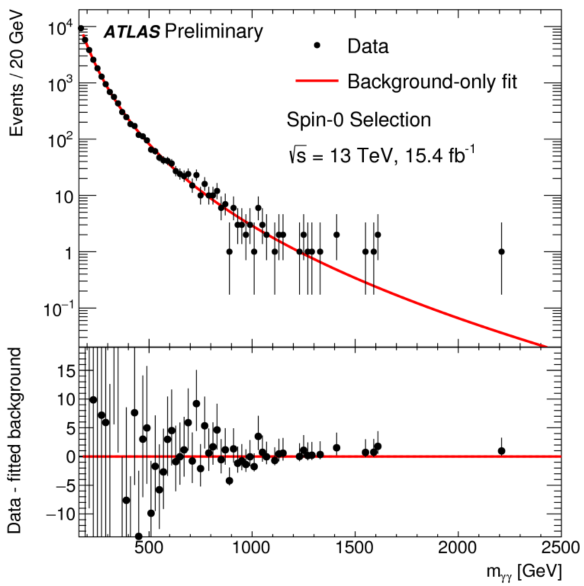
- 寻找高质量共振态粒子，2015年在LHC实验数据中ATLAS和CMS观测到750GeV附近分别约有3.4 σ和 3.0σ超出，引起了理论家的广泛兴趣！

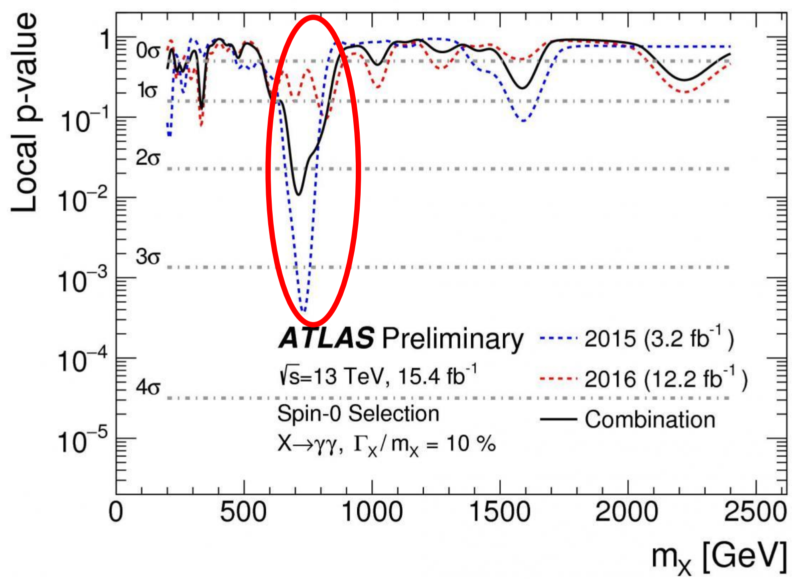




*Search for X → γγ

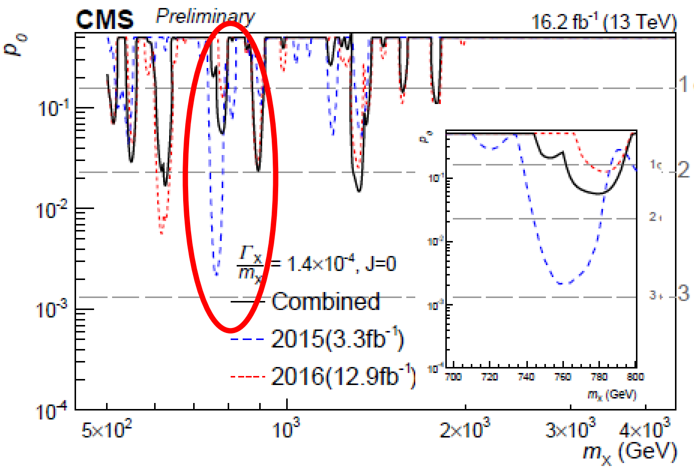
ATLAS-CONF-2016-018/059
arXiv:1606.03833
CMS-PAS-EXO-16-027



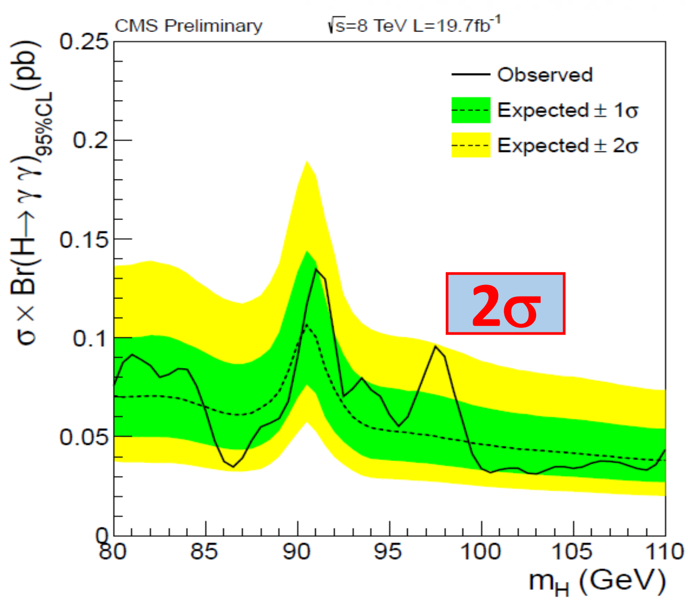


ATLAS和CMS最新的Run2数据中都没有观测到750GeV 附近有显著超出！

- 高能所金山、黄燕萍、彭聪、冉坤林、韩朔、方亚泉、章宇、娄辛丑等做出重要贡献，包括本底估计、多喷注分类、CR研究和统计分析等。
- 交大王子瑞、杨海军参与光子isolation研究



TeV



❖ 高能所CMS组主导低质量双光子分析，范嘉伟完成主要分析，给preapproval报告。

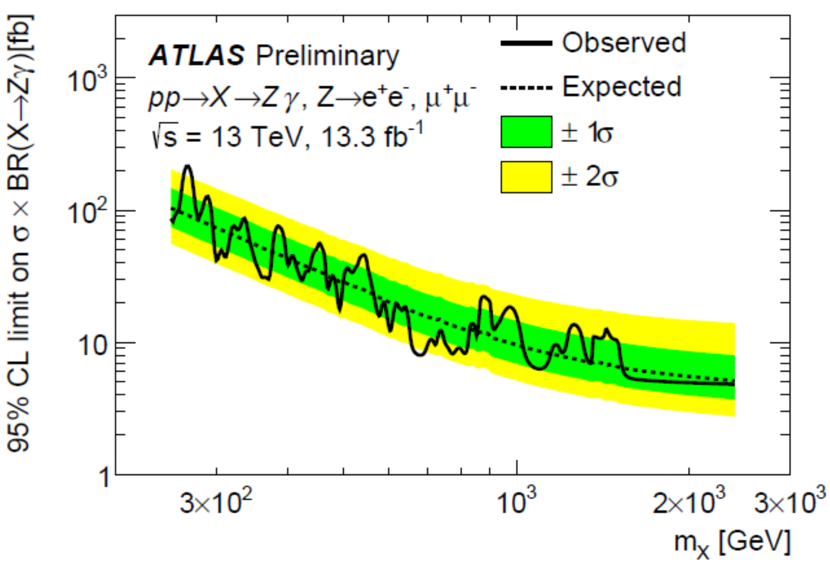
*Search for X → Zγ

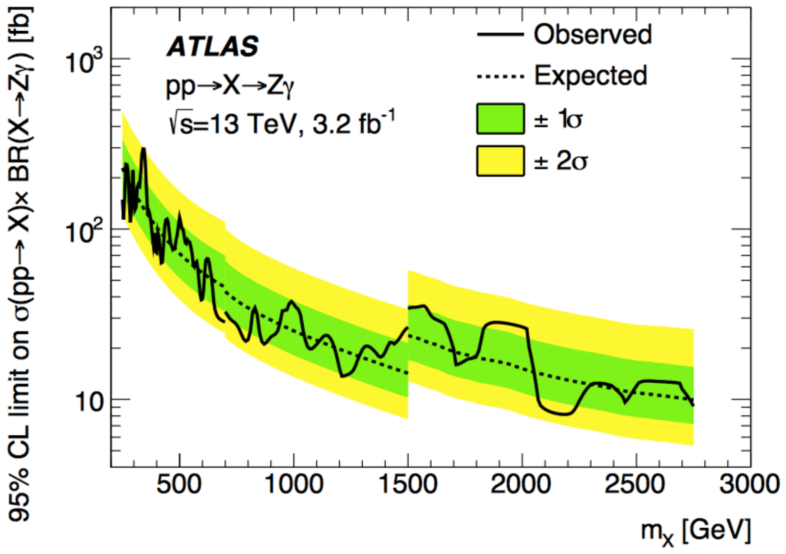
ATLAS-CONF-2016-044
arXiv:1607.06363

- Zγ末态有可能发现类似Higgs粒子的高质量的新粒子。
- 高能所金山、黄燕萍、韩朔主导完成了Z→ee,μμ分析的全过程，事例选择，信号显著性优化，信号建模，本底组成分析，系统误差、统计分析。
- 担任Contact editor 发挥主导作用，已投送1篇 (arXiv:1607.06363)

✓ 高能所梁志均、孙小虎、方亚泉分析Z→di-jet末态，主要贡献：估计本底；信号效率的误差估计；统计分析。

● 担任分析的Contact，文章editor，給 approval talk, 在该分析中发挥主导作用。已投送一篇 PLB (arXiv:1607.06363)



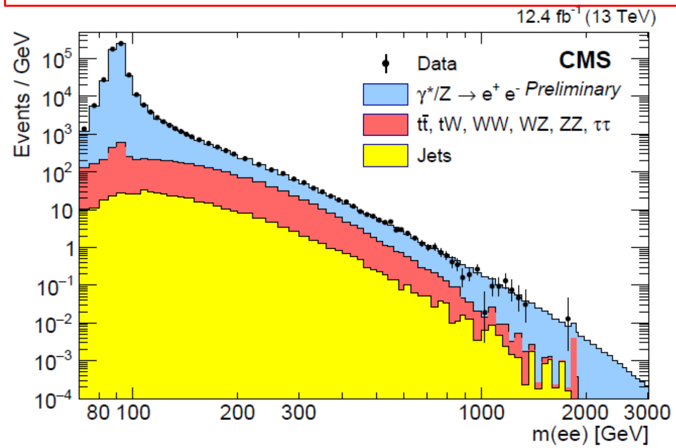


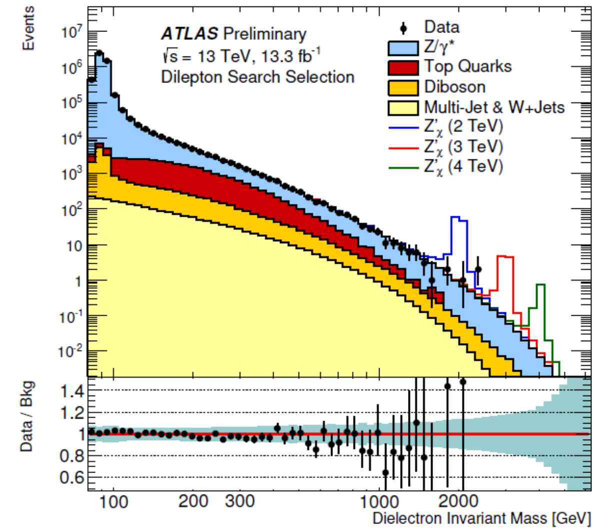
Search for di-lepton resonance

ATLAS-CONF-2016-045
CMS-PAS-EXO-16-031

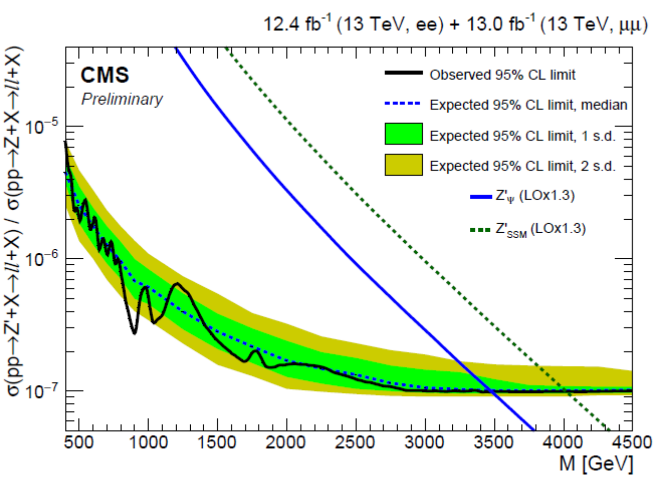
➔北航方文兴、高旭阳、沈成平、袁丽参与 Z’➔ee分析，并作Approval 报告。
➔高能所Romeo担任Z’➔ττ分析contact.
【详见袁丽报告】

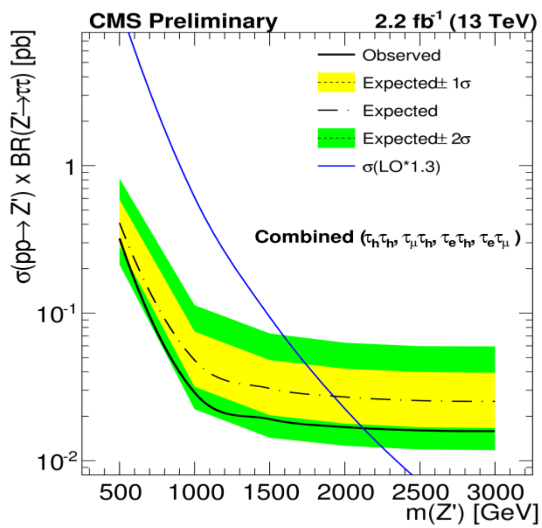
科大刘彦麟和赵政国主导 Z’➔μμ全部分析工作。

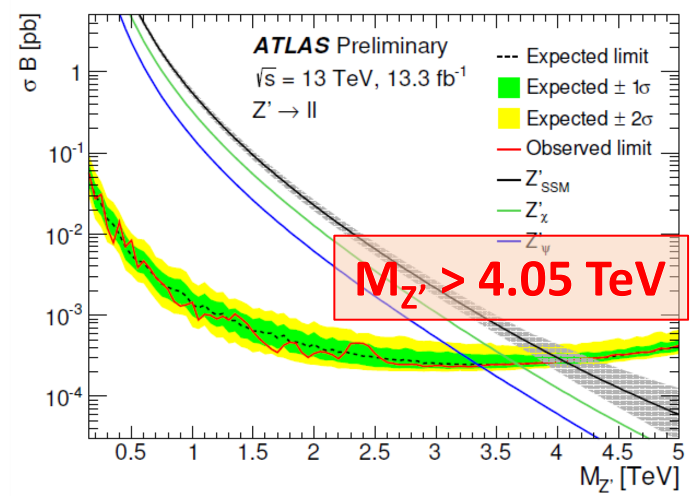




高能双轻子末态对很多新物理灵敏。
扩展规范群：额外的U(1)对称性预言Z’。
最新质量下限4.05 TeV.





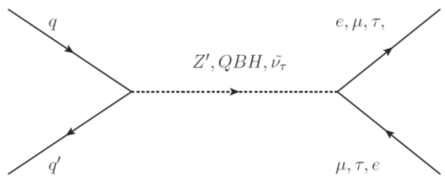


Search for LFV di-lepton Resonance

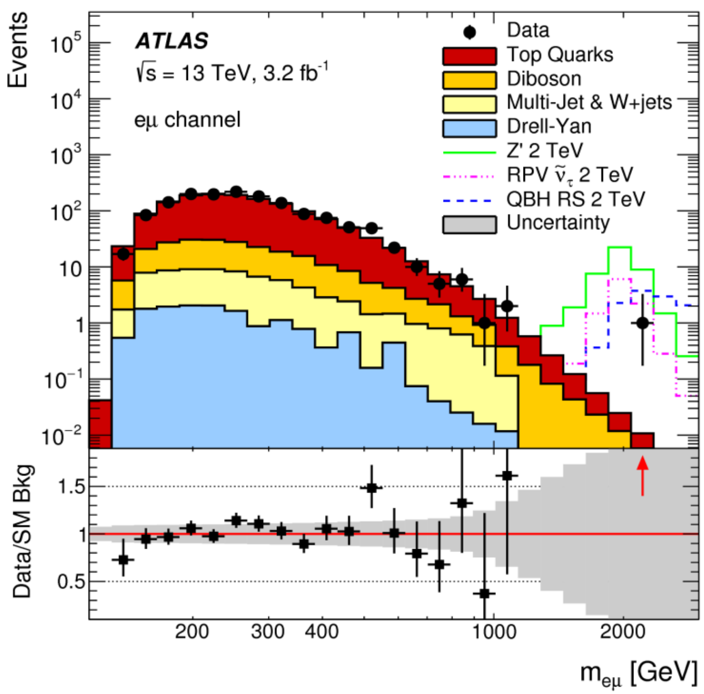
arXiv:1607.08079

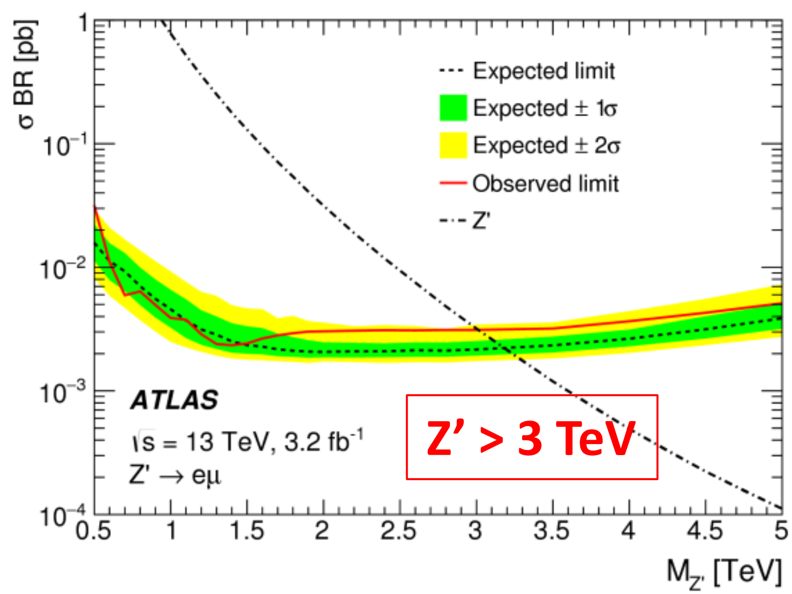
- ❑ 通过轻子味不守恒的双轻子末态（ eμ, eτ, μτ ）寻找新物理，譬如： **SSM Z’, RPV SUSY scalar tau neutrino, QBH**。
- ❑上海交大(Marc Bret、郭军、杨海军)和科大(刘明辉、李全印、韩良)主导整个分析，担任分析Contact和论文编辑，多个Approval报告，投送一篇文章EPJC(arXiv:1607.08079)。

【详见郭军报告】



Model	Expected Limit [TeV]			Observed Limit [TeV]		
	$e\mu$	$e\tau$	$\mu\tau$	$e\mu$	$e\tau$	$\mu\tau$
Z'	3.2	2.7	2.6	3.0	2.7	2.6
RPV SUSY $\tilde{\nu}_\tau$	2.5	2.1	2.0	2.3	2.2	1.9
QBH ADD $n = 6$	4.6	4.1	3.9	4.5	4.1	3.9
QBH RS $n = 1$	2.5	2.2	2.1	2.4	2.2	2.1

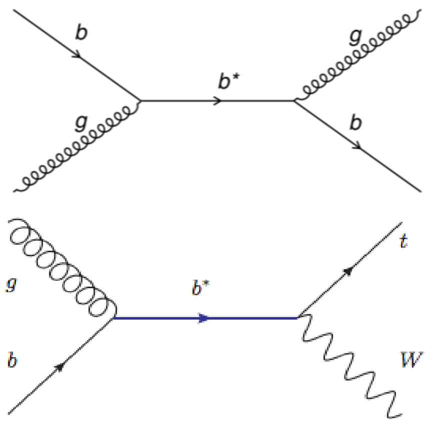


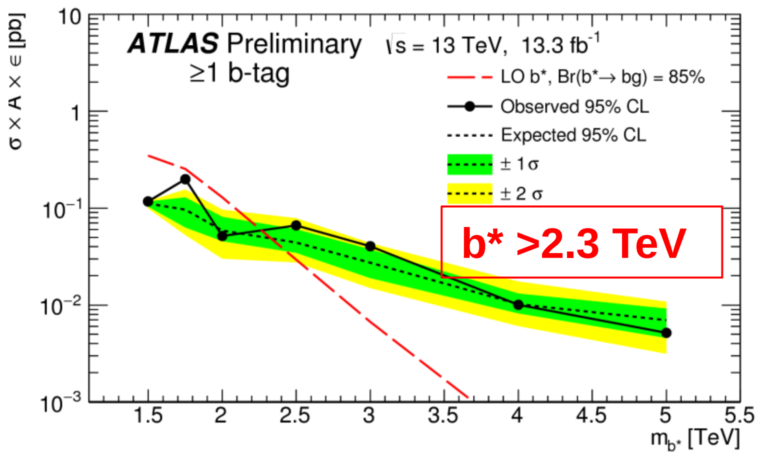


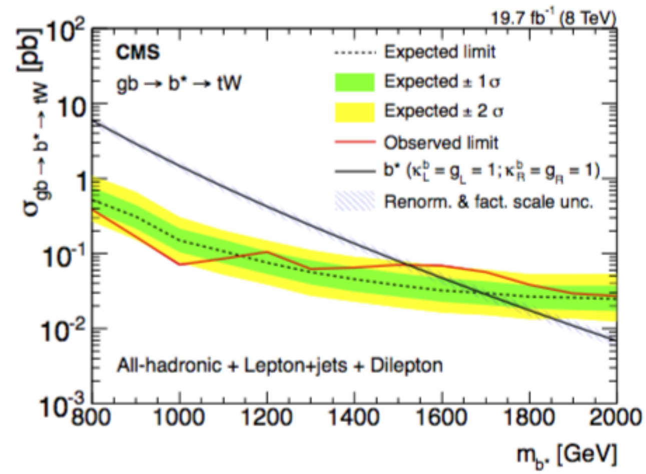
Search for X→Di-jet resonance

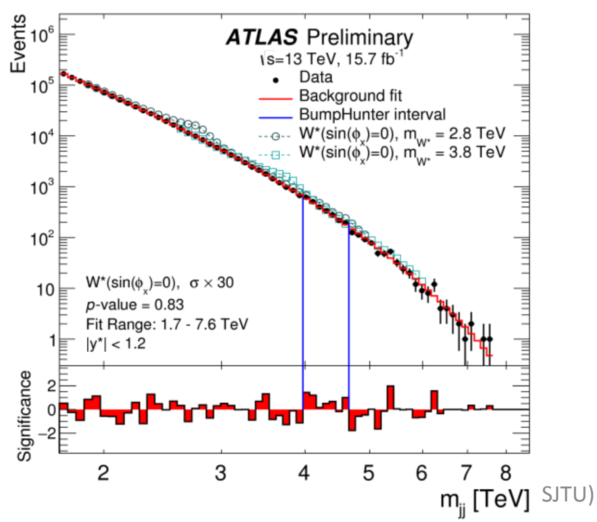
ATLAS-CONF-2016-060
ATLAS-CONF-2016-031
ATLAS-CONF-2016-069

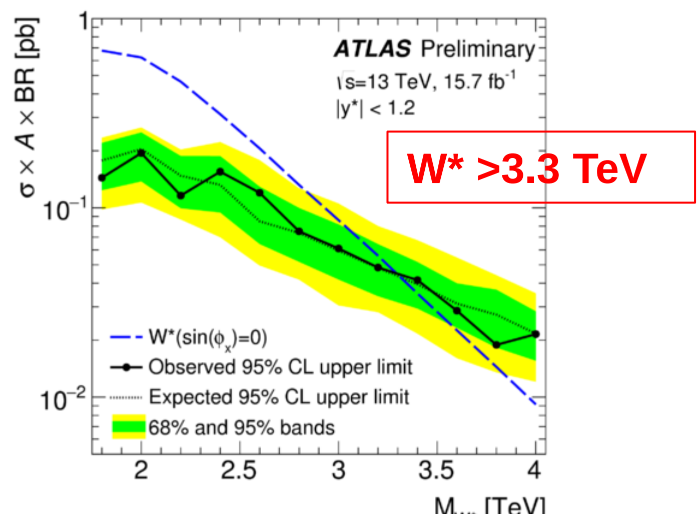
➔清华Nishu，周宁参与 Z’→bb，b*→gb分析，担任Contact Editor, 多个Approval报告，发表论文一篇PLB759(2016)229，两篇Conf-note.
➔高能所张华桥担任CMS激发态b*分析Contact，给Approval报告，发表在JHEP01(2016)166。











➔山大张登峰和祝成光参与激发态W*→jj的分析, 发表1篇Conf-note.

Search for X→WW, WZ, WH

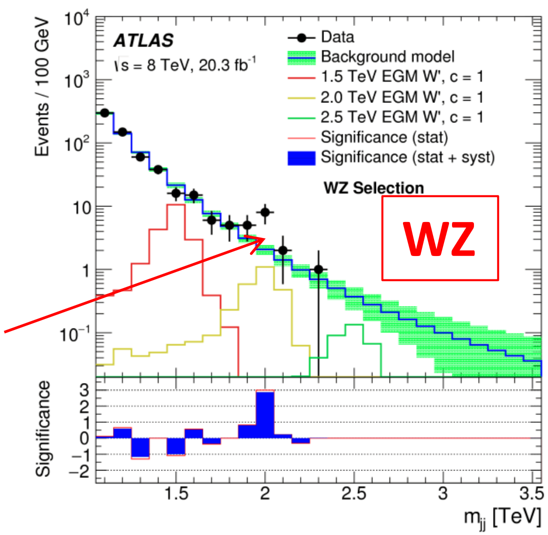
CMS-PAS-B2G-16-020/004
JHEP 1510 (2015) 144
EPJC76 (2016) 237

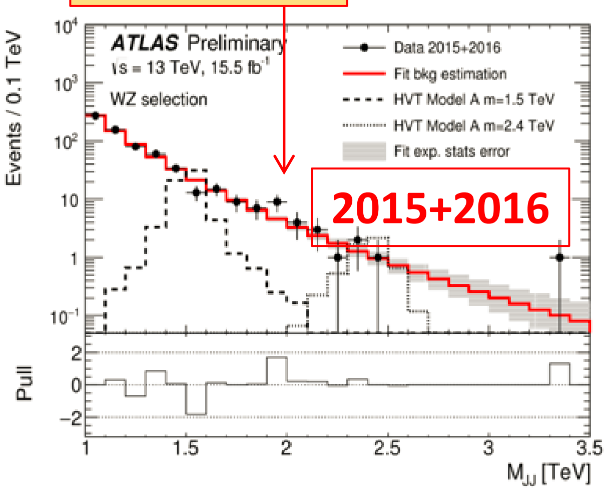
北大主导X→WW, WZ, heavy Higgs 物理分析，李强、王蒙蒙、刘帅、徐子骏，黄璜、王群、邹伟、李俊昊等，担任多个分析负责人，多个Approval 报告。【详见李强、黄璜报告】

JHEP12 (2015)055
ATL-COM-2016-055
ATLAS-CONF-2016-082

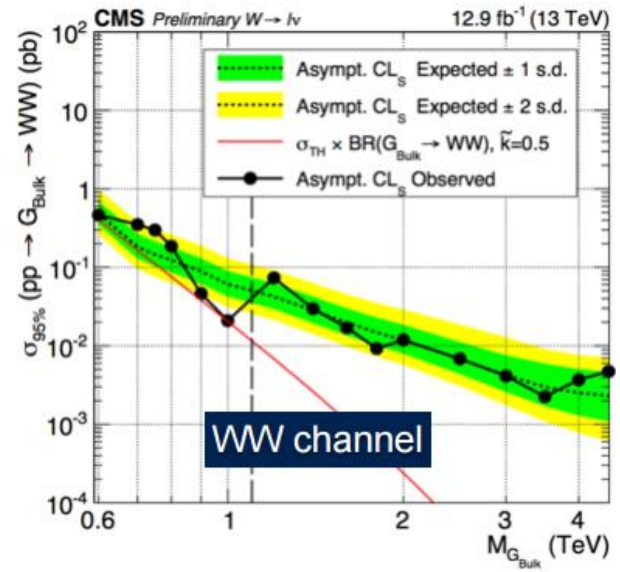
Excess not confirmed in Run2

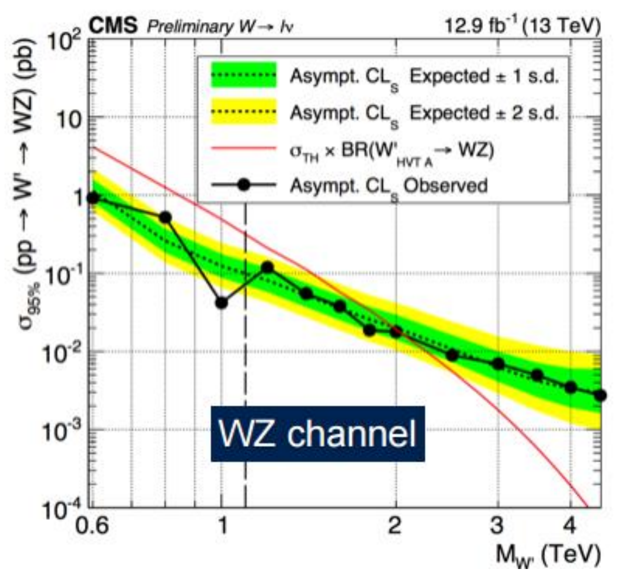
m= 2TeV
3.4σ local
2.5σ global





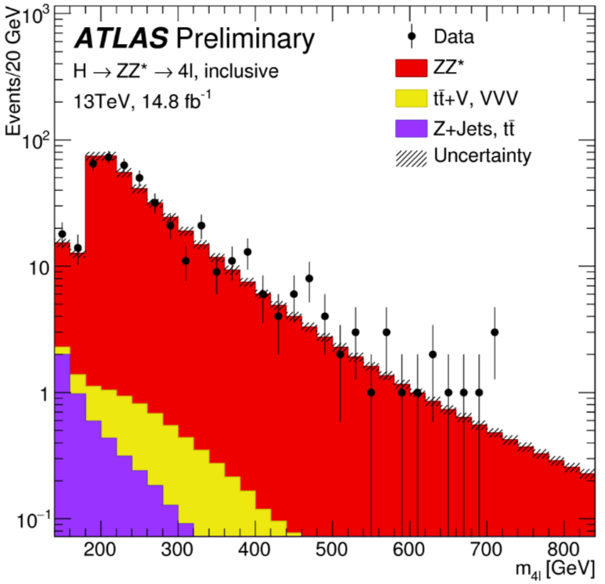
科大郭毅成和赵政国参与 事例选择优化、 信号接收度和控制样本。

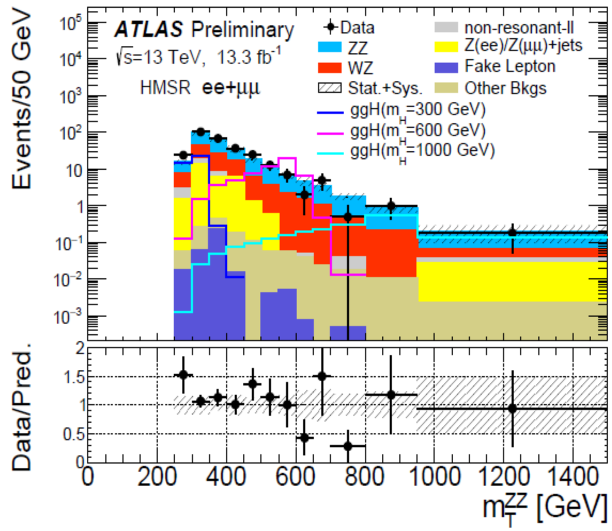




Search for Heavy H →ZZ

ATLAS-CONF-2016-079/056
EPJC76(2016)45
CMS-PAS-HIG-16-033





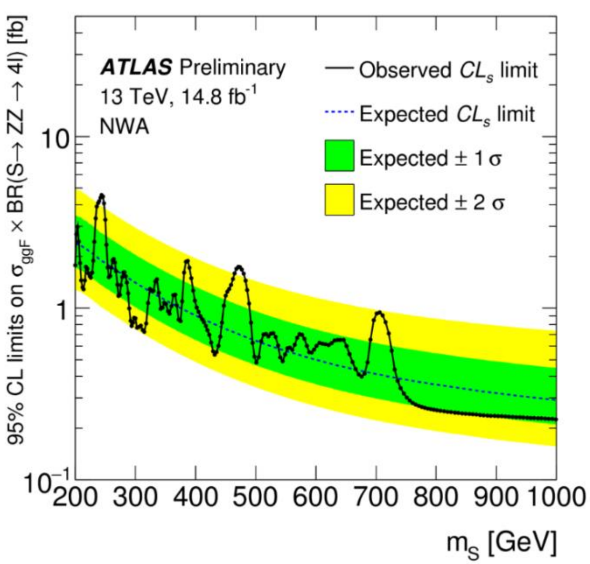
➔山大刘波和冯存峰参与 **ATLAS H→ZZ*→2l2ν**，作 **Approval** 报告。

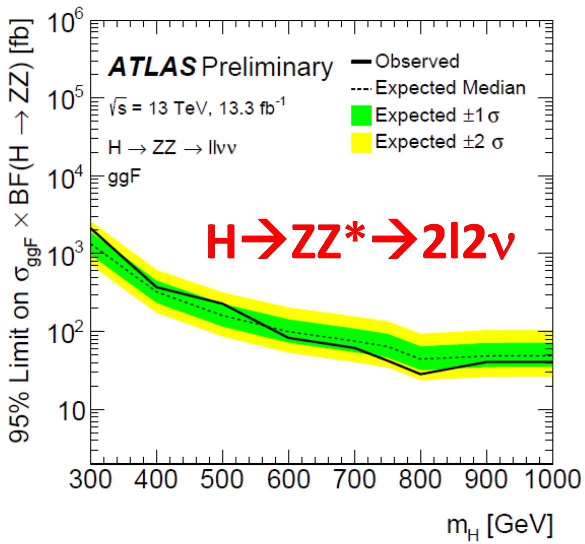
➔南京大学李依宸、王超、陈申见等参与高质量希格斯衰变**WW/ZZ**的寻找。

➔高能所陈明水、成瞳光担任**CMS H→ZZ**高质量共振态分析**Contact**。

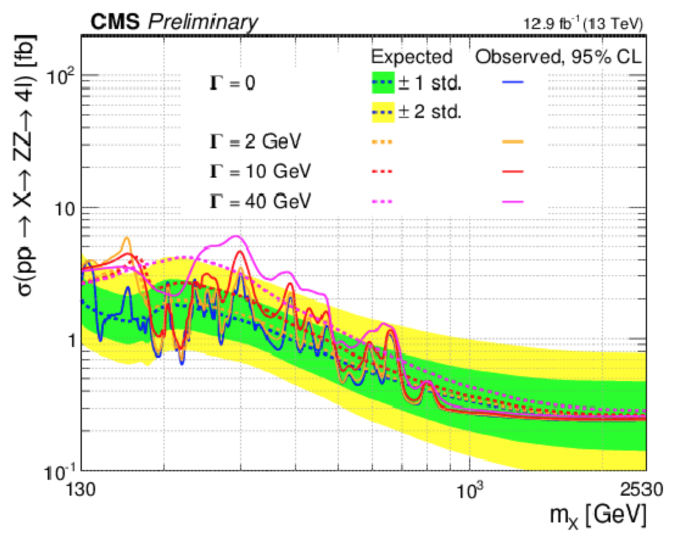
H→ZZ*→4l

【详见成瞳光报告】





H→ZZ*→2l2ν



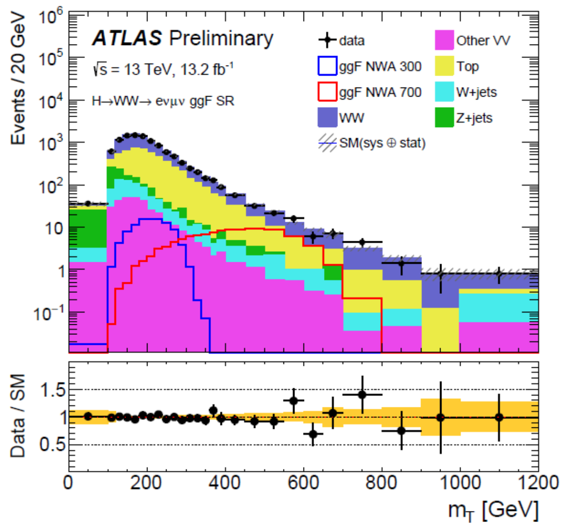
Search for H → WW

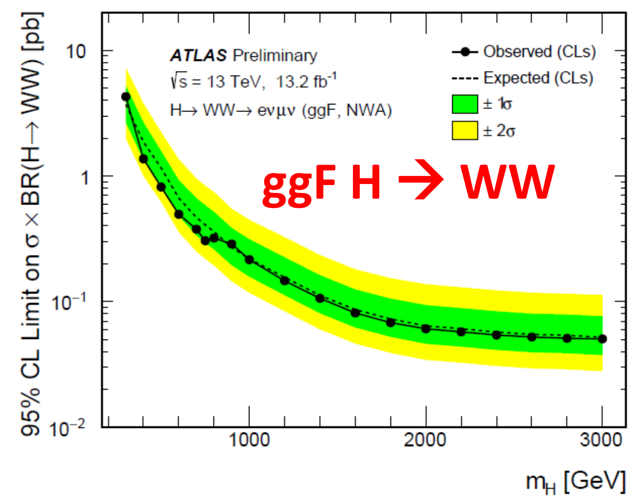
ATLAS-CONF-2016-085
ATLAS-CONF-2016-074
ATLAS-CONF-2016-021
ATLAS-CONF-2016-089

➔ 寻找超出标准模型的重希格斯粒子(末态lνlν)，检验NWA/LWA两种模型。
科大韩坤霖，胡启鹏，朱莹春参与系统误差研究，W+jet本底估计。
山大赵永柯、宋维民、马连良、张学尧主导H→WW→eνμν分析，负责事例优化，信号区间和本底控制区间定义，主要本底误差估计等，担任编辑和作Approval报告。

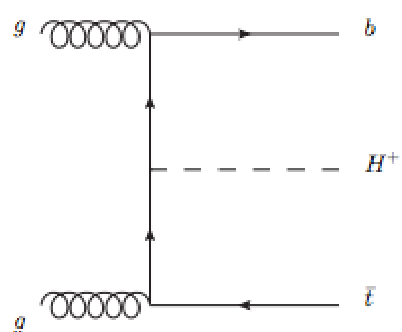
没有发现BSM超重希格斯粒子的迹象

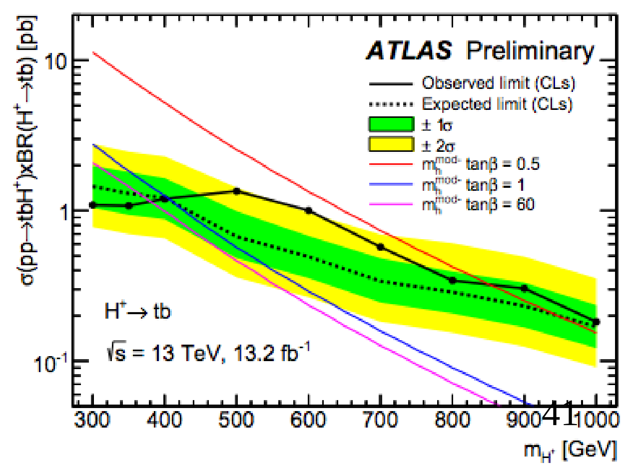
【详见赵永柯报告】





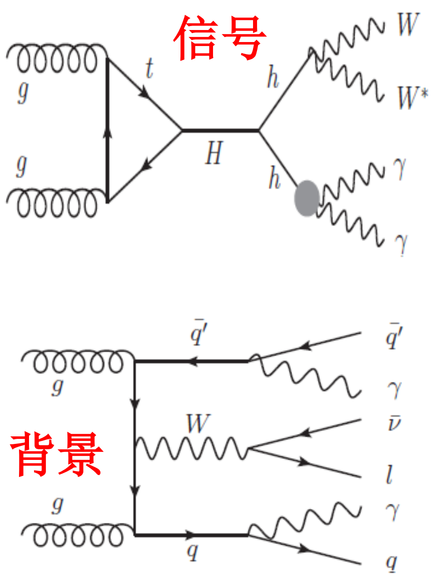
➔ H+ → tb → e(mu) + jets
➔ Split signal regions by Njets
- CR: 4j2b, 4j>=3b, 5j2b, >=6j2b
- SR: 5j3b, 5j>=4b, >=6j3b, >=6j>=4b
- Use HT_had in CR, BDT in SR
➔ 山大杨轩、冯存峰参与分析

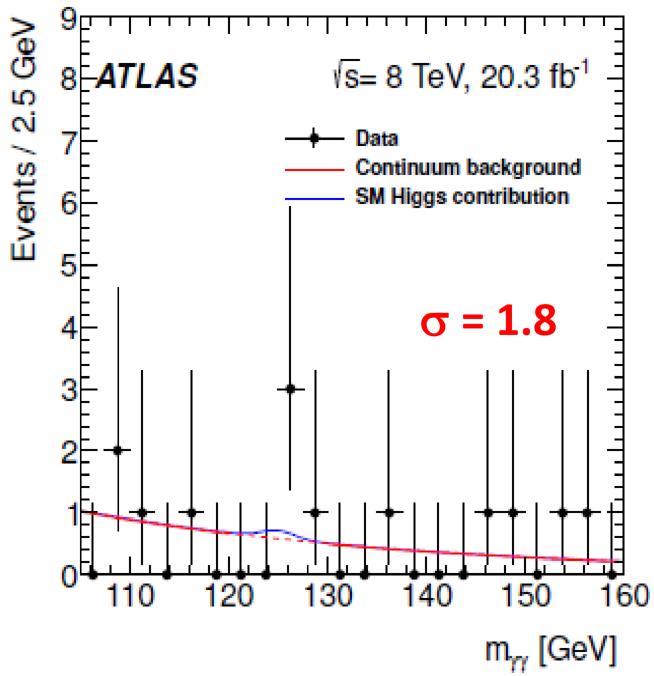


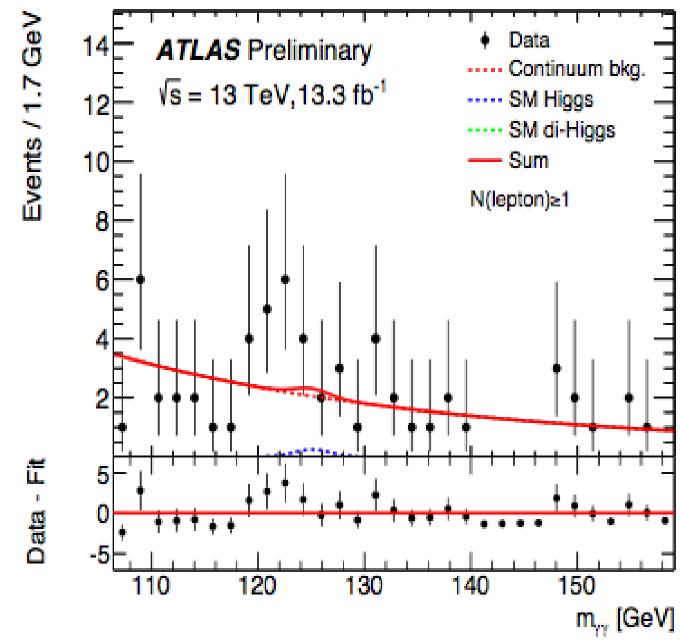


Search for H→hh→WWγγ

ATLAS-CONF-2016-071
PLB755 (2016) 509
PRD92, 092004 (2015)





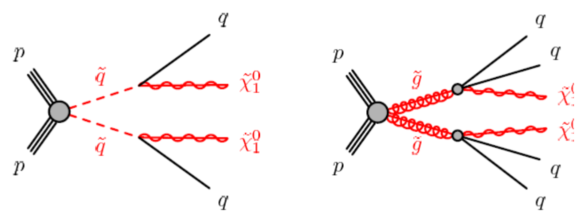


- 高能所方亚泉、孙小虎、娄辛丑、李奇、周茂森和交大李亮等提出寻找重希格斯衰变到两个希格斯粒子，并进一步衰变到双光子和两个W玻色子 (W全轻子或者半轻子衰变)。
- 在RUN1分析中，高能所提出和主导该课题，并完成半轻子衰变道分析，观测到1.8σ，发表文章两篇。
- Run2，高能所主导完成hh分析，担任编辑。【详见方亚泉报告】

Jets + MET (无轻子)

ATLAS-CONF-2016-078

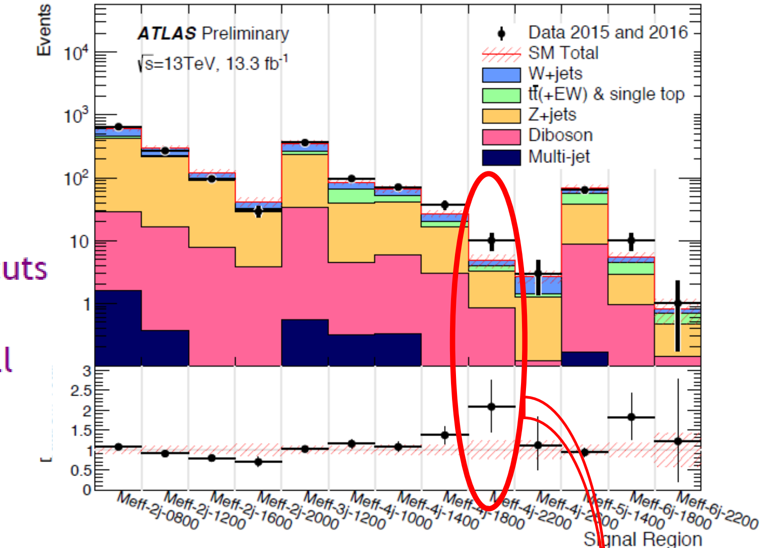
The large expected cross section predicted for ‘strong’ SUSY makes gluino and squarks the primary target for early searches.

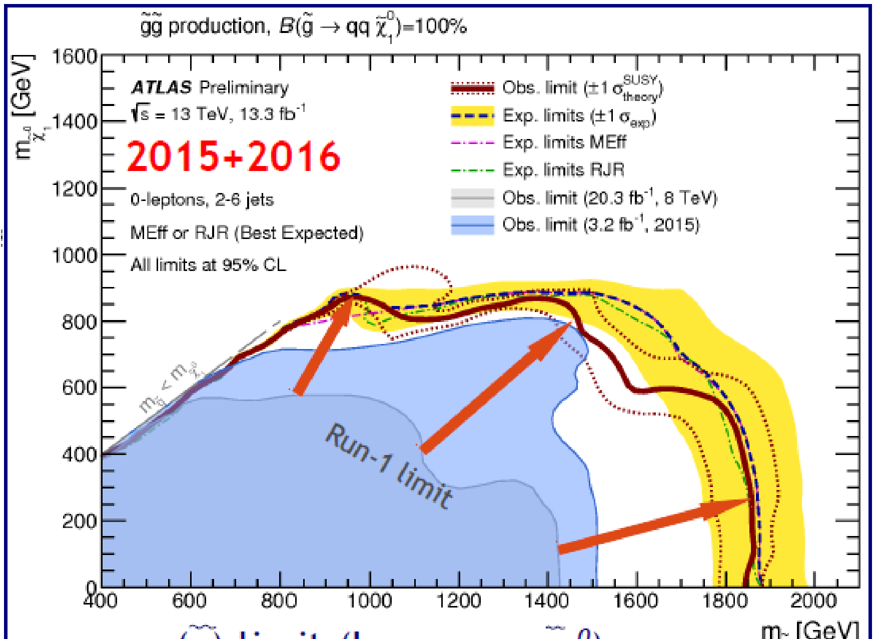


Total of 30 signal regions:

- 13 shown with different m_{eff} cuts
- Largest excess 1.6σ
- No significant excesses overall

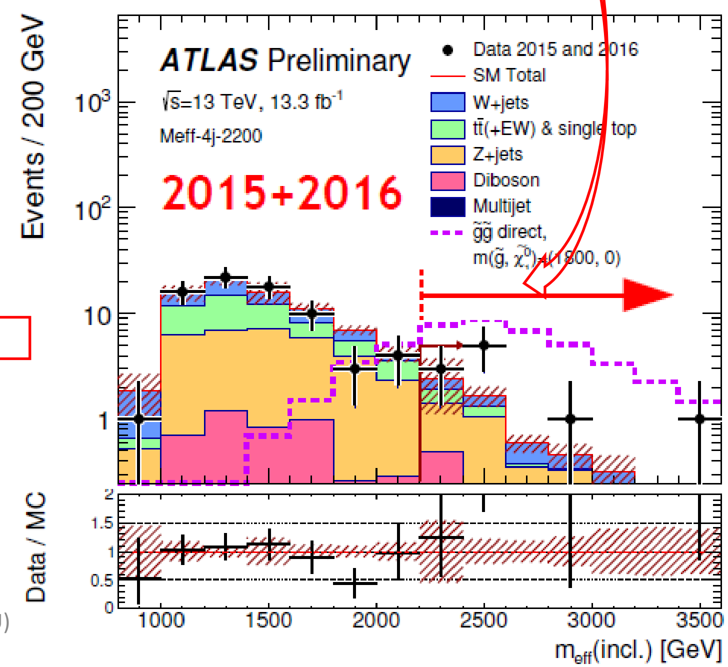
$$m_{eff} = E_T^{miss} + \Sigma\,|p_T(\text{jet})|$$





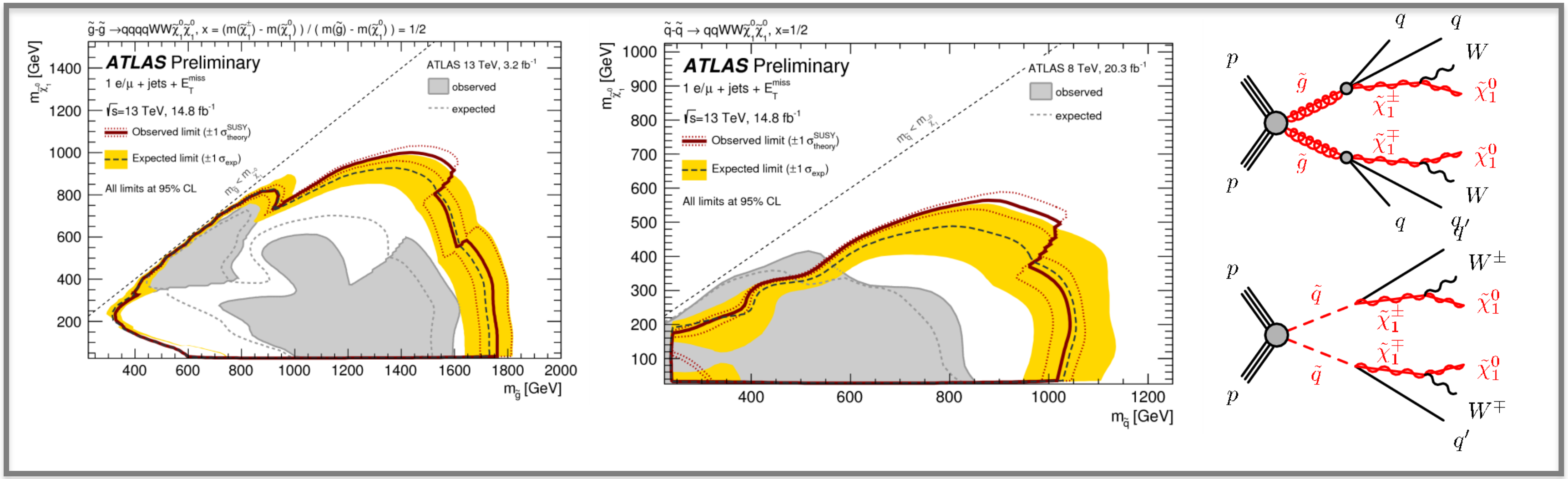
m(g̃) limit (low-mass $\tilde{\chi}_1^0$)

(Run-1) 1.4 TeV → 1.86 TeV



单轻子末态SUSY粒子的寻找

- 强SUSY产生过程，产生截面很大，本底压制较好，是对撞初期的重要课题。
- 基于Run1和2015年的Run2数据，已发表3篇文章和2篇CONF note。
- 基于13TeV 2015＋2016的数据，发表1篇 ATLAS-CONF-2016-054 。
  - → Gluino (squark) masses up to 1.8 TeV (1.1 TeV) are excluded for low neutralino masses (≤ 400 or ≤ 300 GeV)
- 高能所组成员担任该课题的联系人、编辑和通讯作者，给了approval报告，做了主导贡献。 主要参与人： 庄胥爱、金山、徐达、程华杰



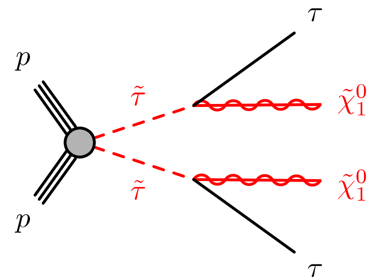
双轻子末态 SUSY 粒子寻找

ATLAS-CONF-SUSY-2016-08
PRD 93, 052002 (2016)
ATLAS-CONF-2016-037

stau 的直接寻找结果

Phys. Rev. D 93, 052002 (2016)

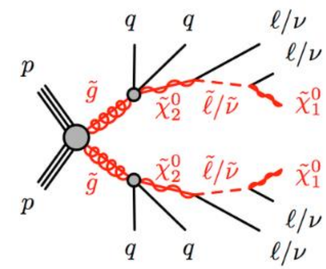
【详见庄胥爱报告】

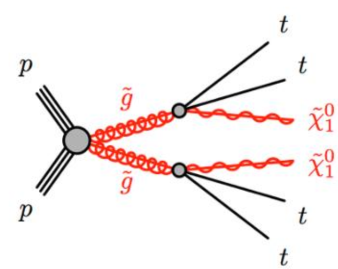


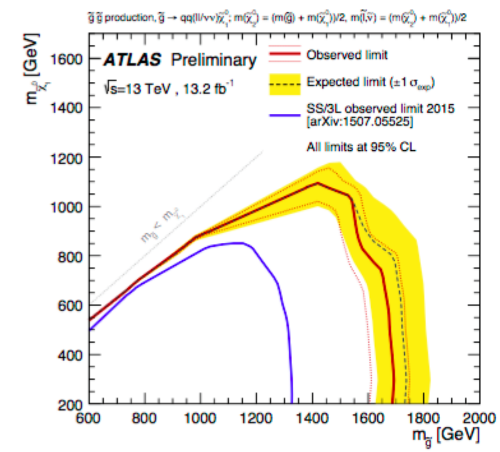
- 高能所庄胥爱、金山、徐达、程华杰、张鹏等提出stau寻找原创性课题，并主导完成了该课题的全部分析。担任该课题的联系人和编辑，给了approval报告，已发表3篇文章。

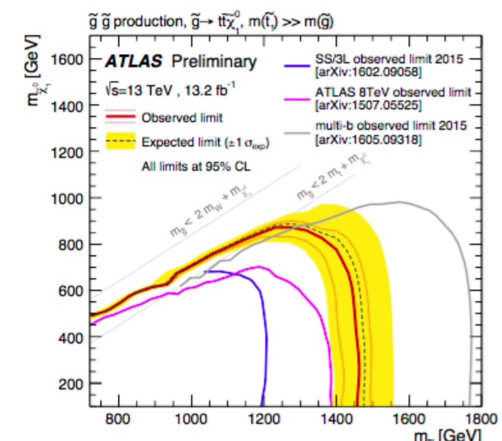
➔ 电荷同号两轻子末态 SUSY 粒子寻找

- 该分析由于要求两个轻子同号，本底比较小，对新物理的寻找非常敏感，是热门的课题。基于2015年数据，已发表1篇文章和1篇CONF note。
- 高能所庄胥爱、金山、任欢 、刘洋主要负责信号区的定义，本底的估计，给Approval 报告。
- 基于2015＋2016的Run2数据， Gluino mass <1.3-1.7 TeV and LSP mass < 850-1100 GeV are excluded for gluino pair production







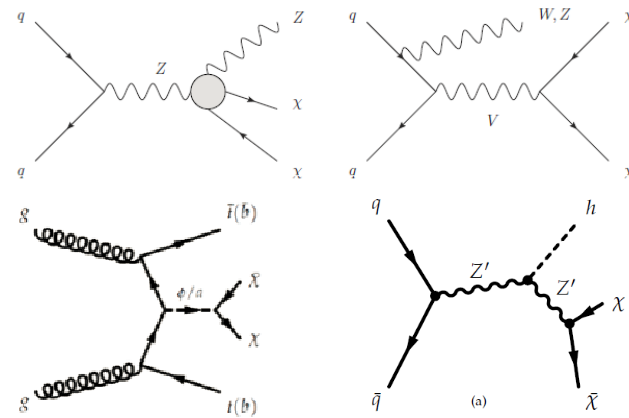


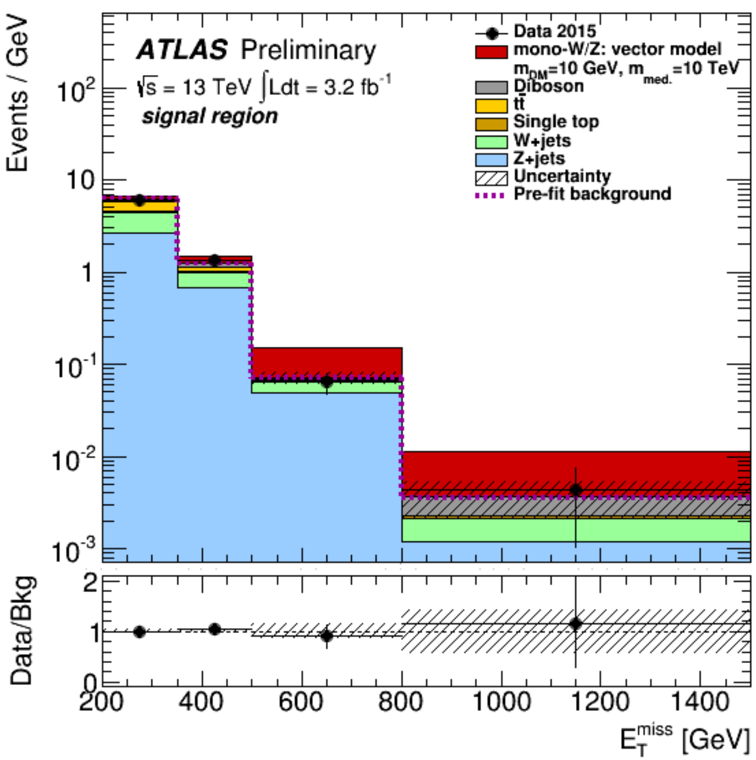
寻找暗物质粒子(DM+W/Z)

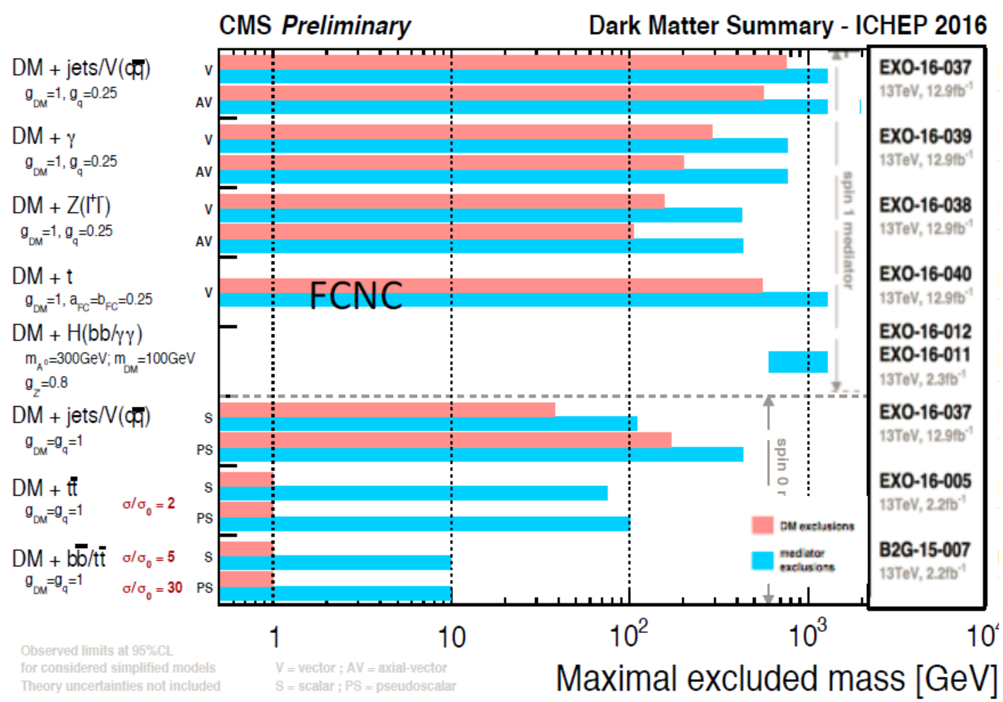
ATLAS-CONF-2016-086
ATLAS-CONF-2015-080

- ❑ 寻找策略：通过暗物质粒子和 jet, photon, W/Z, Higgs等伴随产生。
- ❑ 特征：末态产物 有大的横向动量失衡 MET。
- ❑ 清华周宁、Bibhuti等主导 mono-W/Z分析。

【详见周宁报告】





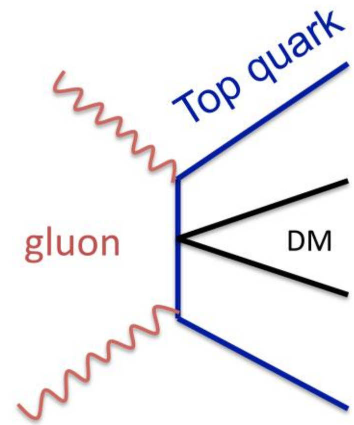


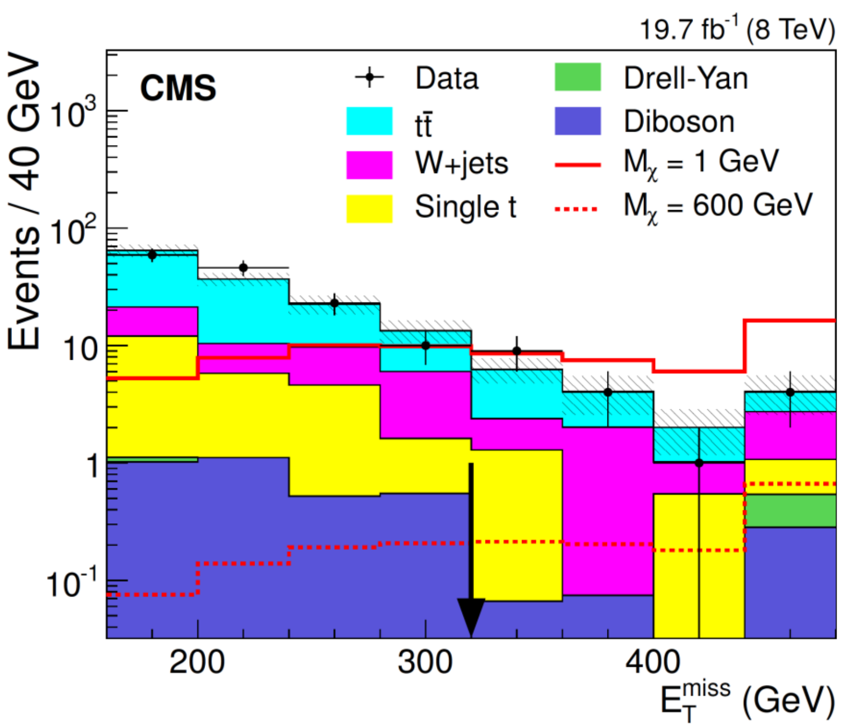
TeV Physics

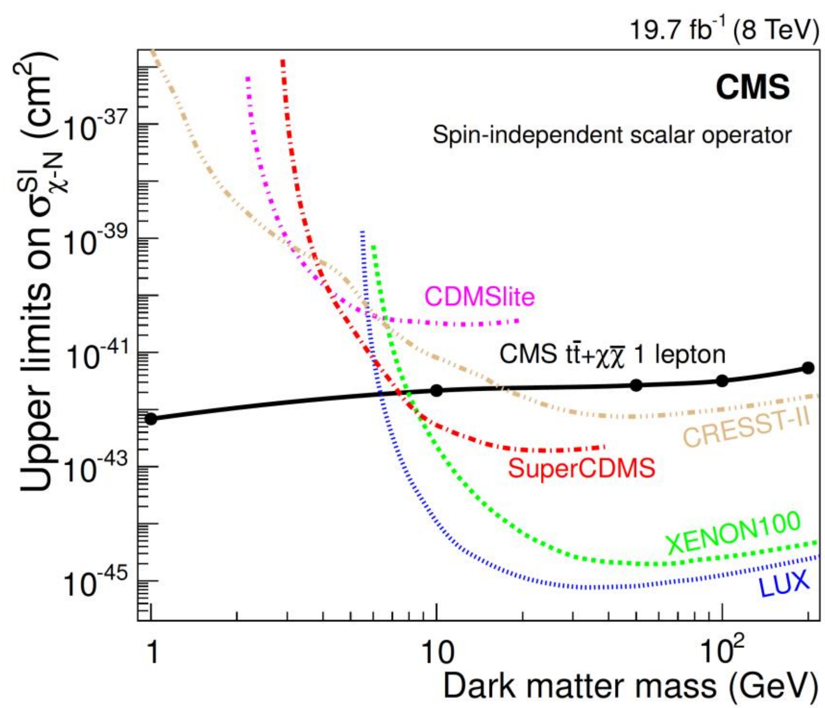
暗物质粒子寻找 (DM+tt)

CMS-B2G-13-004
CMS-B2G-14-004
JHEP06 (2015) 121

- 首次在CMS实验组寻找DM+顶夸克对产生
- 对低质量(<10GeV)的暗物质探测比较敏感
- 上海交大的杨勇主导该分析，担任Contact和论文的Editor。转到ATLAS实验组开展类似的暗物质粒子寻找。



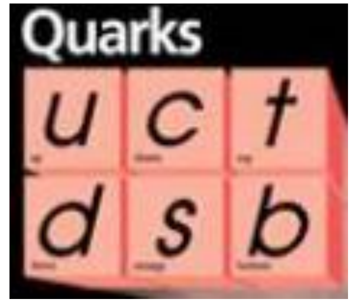




Search for Heavy Quarks

CMS-PAS-B2G-16-001
PRD91, 112011 (2015)
JHEP 08 (2015) 105

➔ 高能所主导CMS单个类矢量夸克寻找，用2015年数据分析Z→ll道，廖红波、Aniello担任Contact和Editor。



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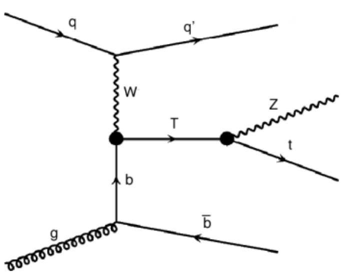
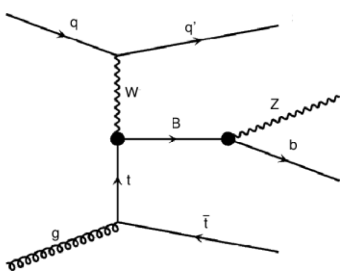
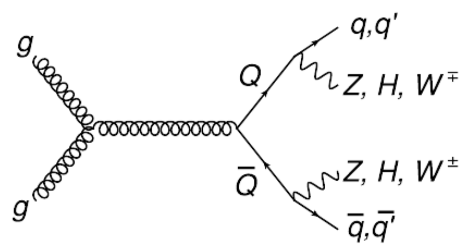
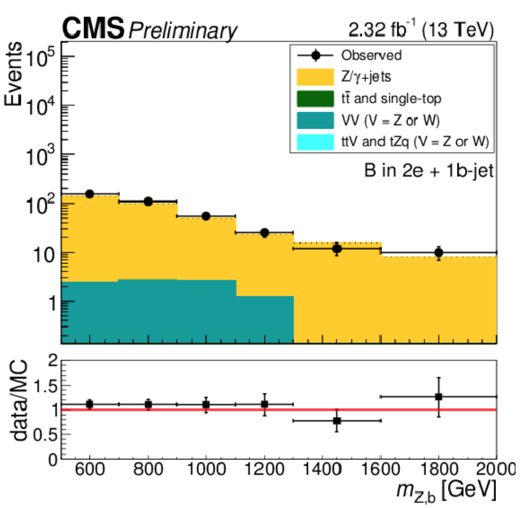
B

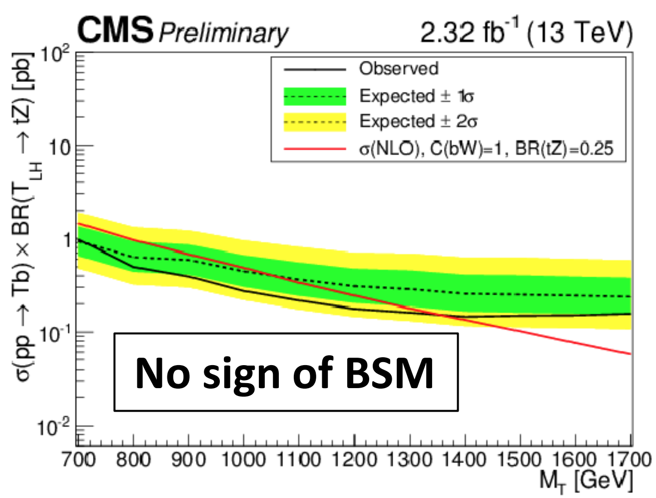
上海交大郭军主导ATLAS类矢量重夸克对产生寻找，担任Contact 和Editor。用8TeV, 20/fb，l+jet末态分析，95%CL排除质量小于800 GeV重夸克，发表2篇论文：
PRD91, 112011 (2015)
JHEP 08 (2015) 105



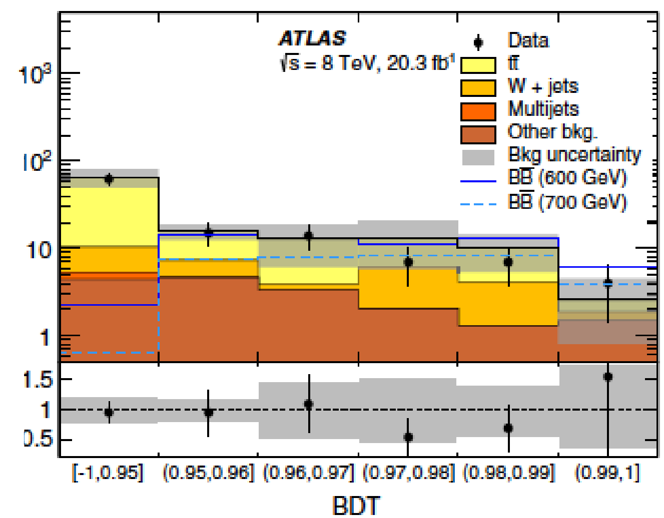








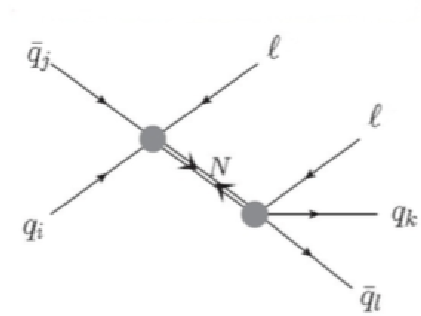
No sign of BSM

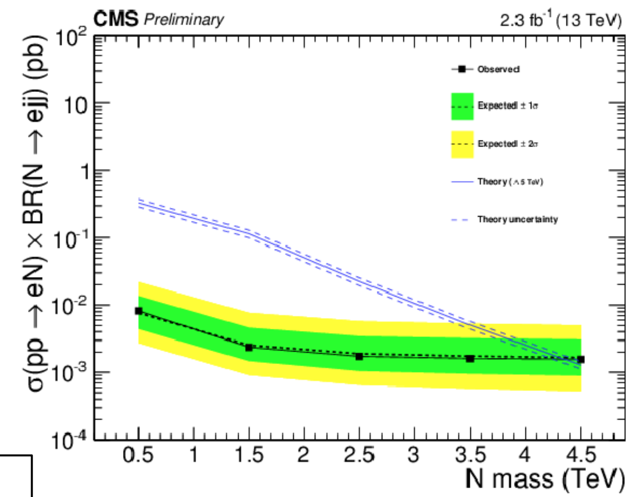


Search for Majorana Neutrino

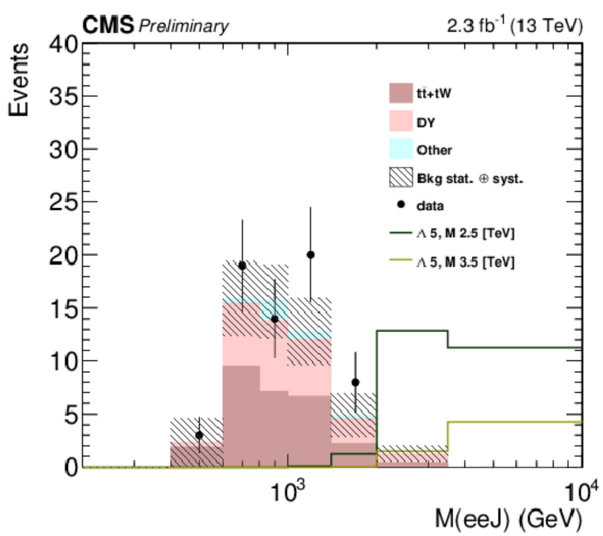
CMS-PAS-EXO-16-026

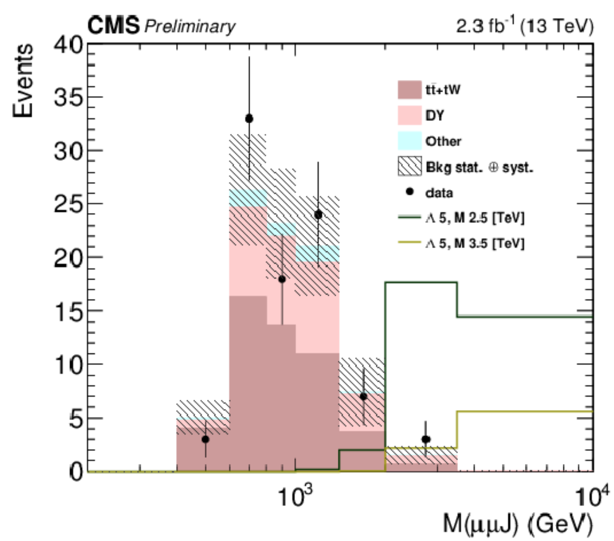
- ❑ 寻找重 Majorana 中微子与轻子协同产生，重中微子衰变到一对同味轻子(e or μ)和两个夸克。
- ❑ 2015年数据没有发现超出标准模型迹象。
- ❑ 高能所张华桥、Romeo担任分析的Contact和Editor。【详见王峰报告】

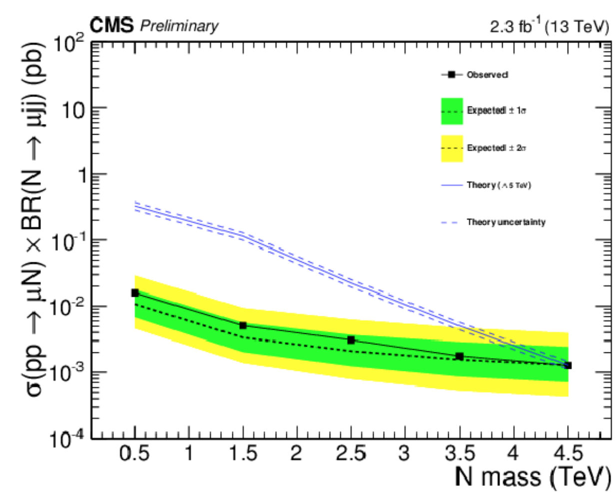




No sign of BSM



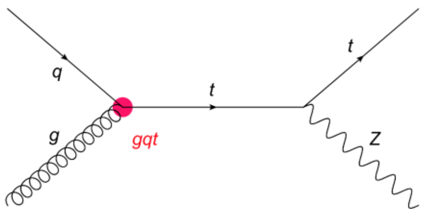


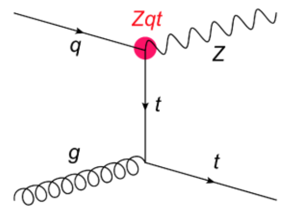


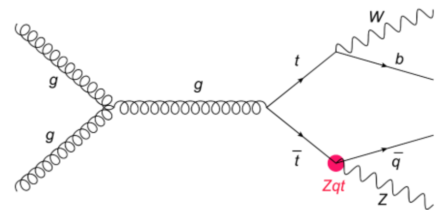
Search for Single top + Z

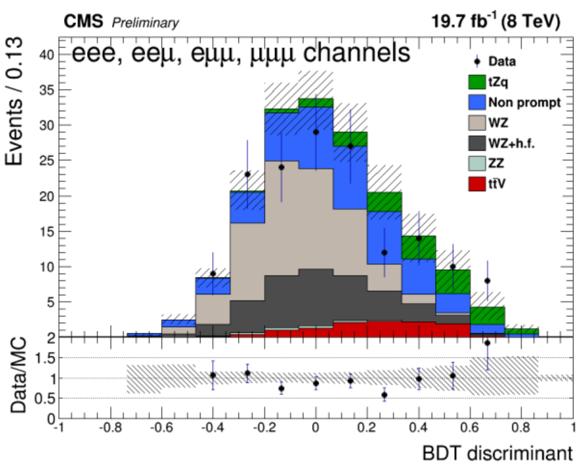
高能所张华桥、Duncan等参与tZ分析，作Approval报告。

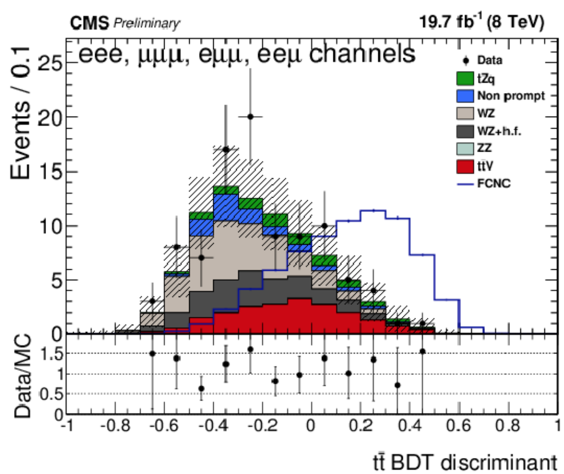
A search for the production of a single top quark in association with a Z boson
Can Identify the expected SM process and Search for FCNC interactions

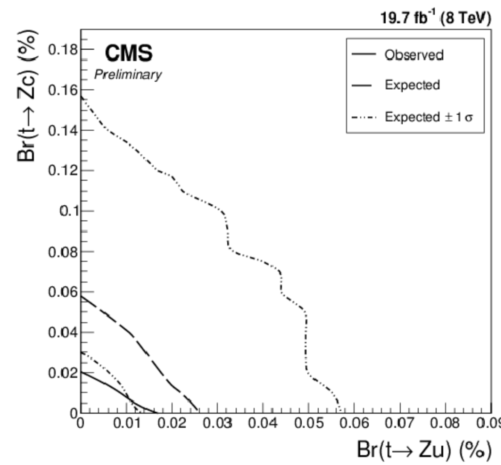








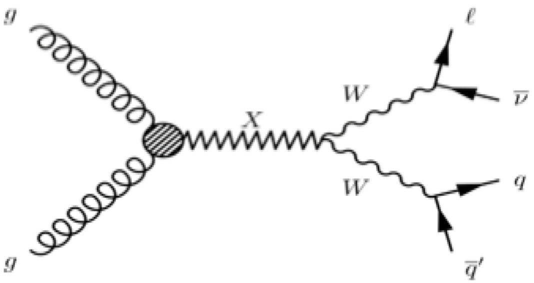


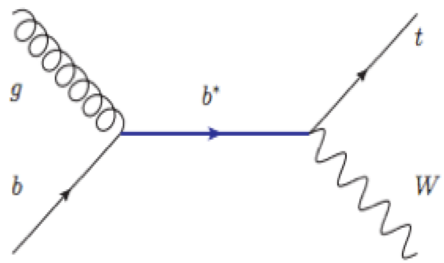


A moderate excess of events compatible with SM tZq production is observed, and the corresponding cross section is measured to be $\sigma(\mathrm{tZq} \rightarrow \ell\nu \mathrm{b}\ell^+\ell^-\mathrm{q}) = 10^{+8}_{-7}$ fb with a significance of 2.4 σ. No presence of FCNC production of tZ(q) is observed and exclusion limits at 95% confidence level on the branching ratios of a top quark decaying to a Z boson and an up or a charm quark are found to be $(\mathrm{t} \rightarrow \mathrm{Zu}) < 0.017\%$ and $\mathcal{B}(\mathrm{t} \rightarrow \mathrm{Zu}) < 0.020\%$, respectively.

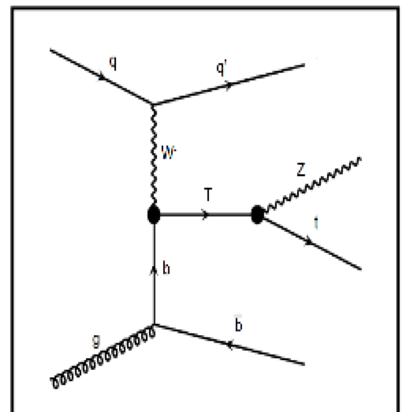
新物理寻找@CMS

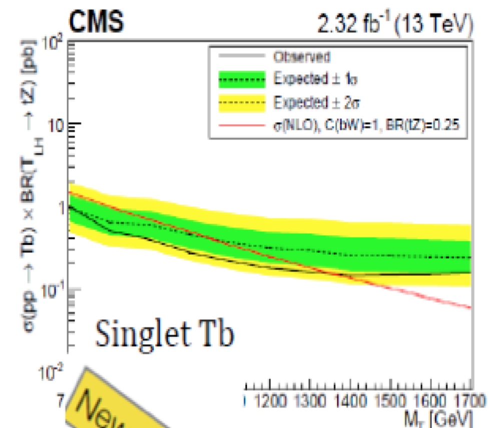
新物理寻找：过去2年主导8个分析





Run1 激发态底夸克的寻找 负责人
Run2 T'→ tZ 负责人
Run2 Majorana 中微子 负责人
Run2 Z' → ll Approval



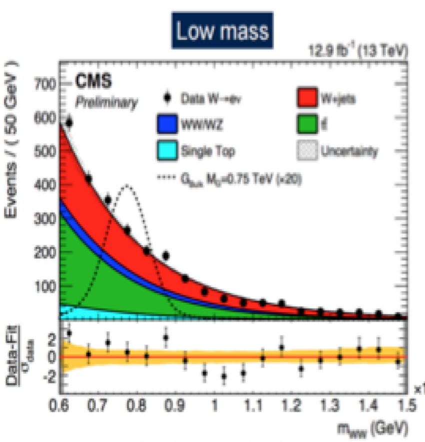


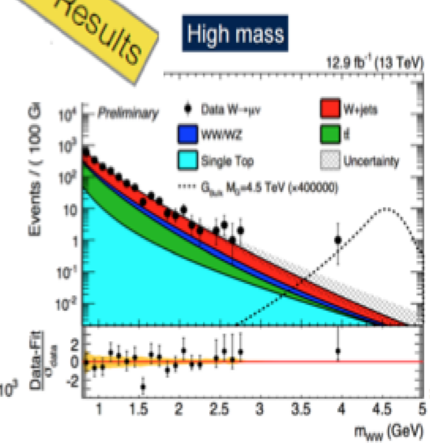
New Results

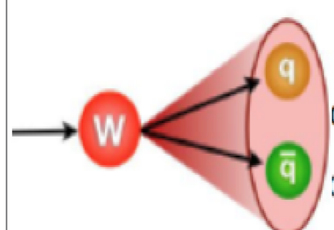
VV共振态寻找 Run2 2015/2016

EXO-15-002 0.8-4TeV Approval
B2G-16-004 0.6-1TeV Preapproval
B2G-16-020 0.6-4.5TeV 负责人
HIG-16-033/034 负责人

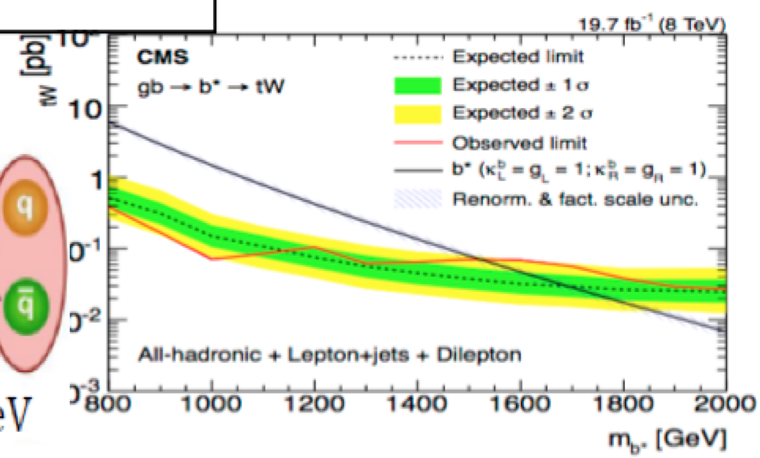
New Results



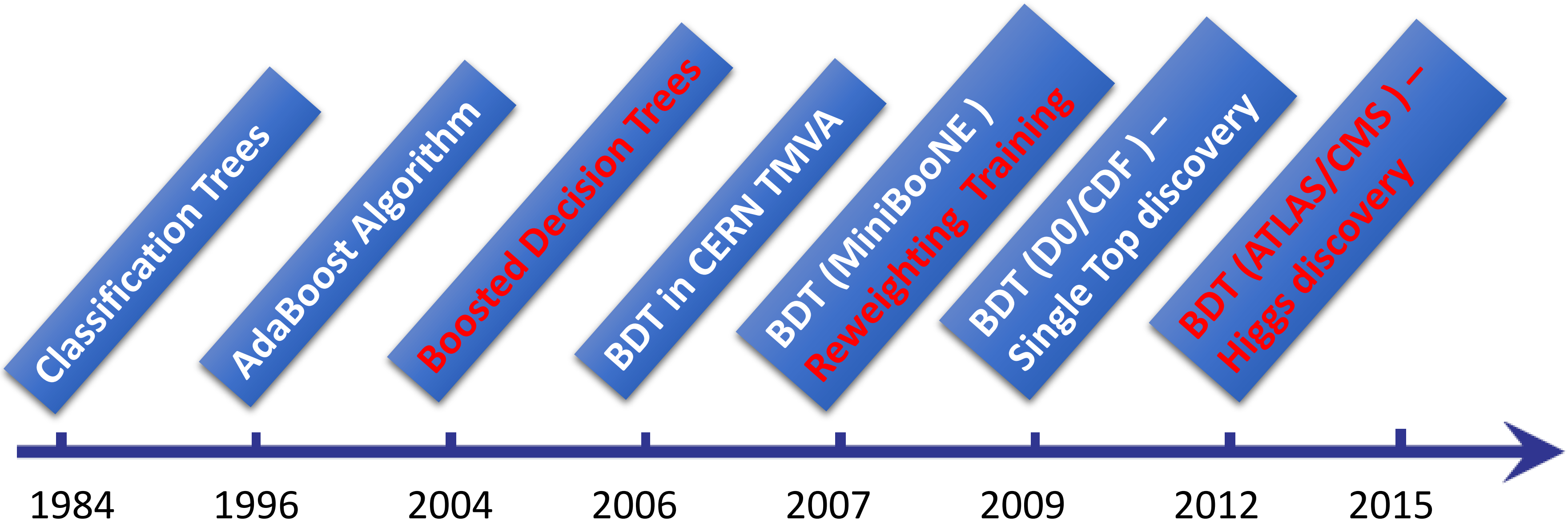




$p_T > \sim 200$ GeV



Boosted Decision Trees (BDT)



➔1984. L. Breiman, J.H. Friedman, R.A. Olshen, C.J.Stone, "Classification and Regression Trees", Wadsworth, 1984. **(首次提出 Classification Trees概念)**

➔ 1996. Ref: Y. Freund, R.E. Schapire, "Experiments with a new boosting algorithm", Proceedings of COLT, ACM Press, New York, 1996, pp. 209-217. **(首次提出AdaBoost算法)**

➔2004. 本人和Byron P. Roe, Ji Zhu首次把Boosting算法和Decision Trees结合，提出Boosted Decision Trees (BDT)，作为通讯作者发表4篇论文，为BDT应用于粒子物理实验数据分析做出了开创性的贡献。BDT广泛应用于希格斯粒子的发现和性质测量及新物理寻找等。

➔应用于ATLAS, CMS, LHCb, MiniBooNE, CDF, D0, BarBar, BESIII, AMS, IceCube, PandaX 等等.

Boosted Decision Trees (BDT)

- ➔ **2004/8/30, arXiv:physics/0408124, [Nucl.Instrum.Meth. A543 (2005) 577-584]**
  Byron P. Roe, **Hai-Jun Yang*,** Ji Zhu, Yong Liu, Ion Stancu, Gordon McGregor,
  "Boosted Decision Trees as an Alternative to Artificial Neural Networks for Particle Identification"
- ➔ **2005/8/8, arXiv:physics/0508045, [Nucl.Instrum.Meth. A555 (2005) 370-385]**
  Hai-Jun.Yang*, Byron P. Roe, Ji Zhu,
  "Studies of Boosted Decision Trees for MiniBooNE Particle Identification"
- ➔ **2006/10/31, arXiv:physics/0610276, [Nucl. Instrum. & Meth. A 574 (2007) 342-349]**
  Hai-Jun Yang*, Byron P. Roe, Ji Zhu,
  "Studies of Stability and Robustness for Artificial Neural Networks and Boosted Decision Trees"
- ➔ **2007/8/27, arXiv:0708.3635, [JINST3:P04004,2008]**
  Hai-Jun Yang*, Tiesheng Dai, Alan Wilson, Zhengguo Zhao, Bing Zhou,
  "A Multivariate Training Technique with Event Reweighting"

➔ **美国物理学会会长Homer A. Neal 教授对此高度评价**

> I should comment further on his contributions to ATLAS. His work on the new analysis tool BDT had a very broad impact on several of the Large Hadron Collider analyses done at Fermilab and at CERN over the past ten years. The first evidence of nw physics at Fermilab experiments (D0 and CDF), and final discovery of the Higgs boson at CERN by the ATLAS and CMS experiments all heavily used the advanced analysis tool, BDT, developed by Dr. Yang. This is an advanced statistical analysis tool that permits researchers to extract the underlying physics signature from large background for discovery. Indeed. This tool developed by Dr. Yang was essential in the discovery of the Higgs Boson and will be continue to be used in searching for new physics beyond the standard model in particle physics experiments.

结束语

非常感谢ATLAS和CMS组成员提供大量最新的研究成果。近几年中国组研究队伍和实力显著提升，在众多重要物理课题中担任负责人和论文编辑！

LHC TeV实验测量目前与标准模型预期相吻合！
随着Run2数据显著增加，我们期待发现
希格斯粒子之外的新物理！

LHCP国际会议将于2017年5月15-20日在上海举办，
欢迎大家踊跃参加，http://lhcp2017.physics.sjtu.edu.cn/

谢谢大家，请继续关注！

Backup Slides

ATLAS 中国组 （ATLAS Chinese Cluster）

- **六个单位组成（按英文字母排序）：**
  - **Institute of High Energy Physics (高能所)**
    金山（万人、杰青）、娄辛丑（千人）、庄胥爱（百人）、方亚泉（青千）、朱宏博（青千）、黄燕萍（青千）、梁志军（百人）、史欣（青千）、Joao Costa （外专千人）、吕峰、单连友、徐达
  - **Nanjing University (南大)**
    陈申见、祁鸣
  - **Shandong University (山大)**
    张学尧、马连良（青千）、冯存峰、祝成光
  - **Shanghai Jiao Tong University （上海交大）**
    杨海军（青千）、李亮（青千）、郭军（青千）、杨勇（青千）
  - **Tsinghua University （清华）**
    陈新（青千）、周宁（青千）
  - **University of Science and Technology of China (科大)**
    赵政国（院士、千人）、韩良（杰青、百人）、蒋一、刘衍文、刘建北（青千）、彭海平（杰青、百人）、朱莹春、刘明辉

人员队伍一览

高能所：

职工 10人：陈和生 陈国明 卞建国 王 征 陈明水（百人）
张华桥（青千） 陶军全 孟祥伟 陈 晔 廖红波（百人）

博士后 8人：朱世海（已出站） Roko Plestina (克罗地亚，已出站）
F. Romeo （意大利）A. Spiezia （意大利） D. Lagget （英国）
成瞳光 吴梦晴 王伟

在读学生 5人：沈玉乔 张思靓 李秉桓 S. Masood A. Muhammad （巴基斯坦） 毕业学生6人：范嘉伟, 肖虹，梁松，汪先友，王健，藏京京

北大：

教职 5人： 冒亚军 班勇 钱思进 王大勇（北大百人） 李强

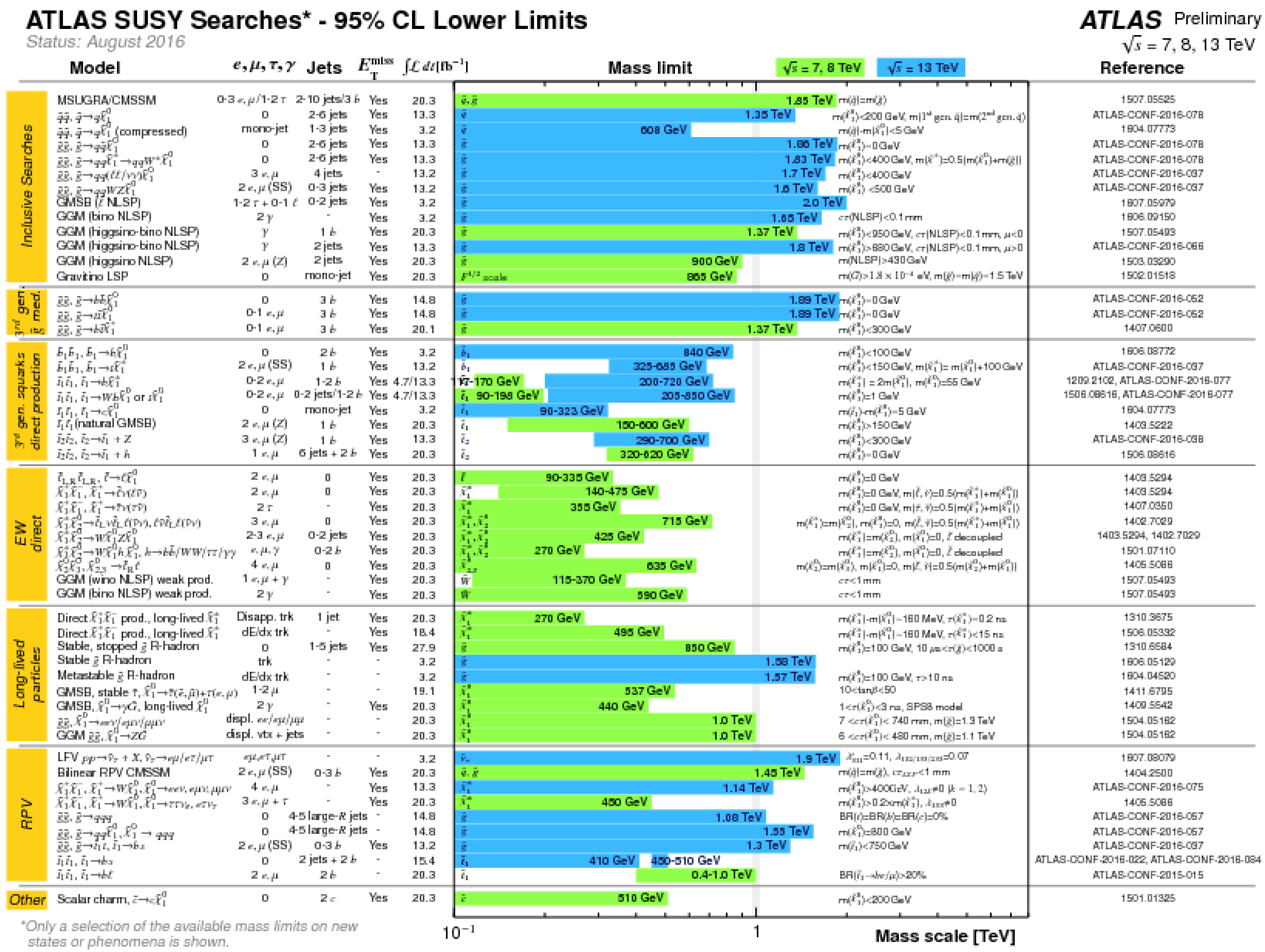
学生 13人：徐子骏、王蒙蒙、张照茹、张冯望东、李晶、杨大能、陈耿、王群、李俊昊、黄璜、袁晓庆、李林蔚、黄迁明

毕业学生11人： 李文博 郭逸飞、郭爽、朱博、滕海云、张琳琳、邹伟、刘帅、马妙钟，郭威、温一闻

北航：沈成平，袁丽，学生：方文兴、高旭阳

清华：王义

ATLAS SUSY Searches



ATLAS Exotics Searches* - 95% CL Exclusion

Status: August 2016

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 20.3)\ \text{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\text{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	3.2	M_D 6.58 TeV	$n = 2$	1604.07773
	ADD non-resonant $\ell\ell$	2 e, μ	–	–	20.3	M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\rightarrow \ell q$	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	15.7	M_{th} 8.7 TeV	$n = 6$	ATLAS-CONF-2016-069
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \rightarrow \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2 γ	–	–	3.2	G_{KK} mass 3.2 TeV	$k/\overline{M}_{Pl} = 0.1$	1606.03833
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	1 e, μ	1 J	Yes	13.2	G_{KK} mass 1.24 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-062
	Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	–	4 b	–	13.3	G_{KK} mass 360-860 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-049
	Bulk RS $g_{KK} \rightarrow tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	g_{KK} mass 2.2 TeV	BR = 0.925	1505.07018
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 4 j	Yes	3.2	KK mass 1.46 TeV	Tier (1,1), BR($A^{(1,1)} \rightarrow tt$) = 1	ATLAS-CONF-2016-013
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	–	–	13.3	Z' mass 4.05 TeV		ATLAS-CONF-2016-045
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	19.5	Z' mass 2.02 TeV		1502.07177
	Leptophobic $Z' \rightarrow bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	SSM $W' \rightarrow \ell\nu$	1 e, μ	–	Yes	13.3	W' mass 4.74 TeV		ATLAS-CONF-2016-061
	HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	0 e, μ	1 J	Yes	13.2	W' mass 2.4 TeV	$g_V = 1$	ATLAS-CONF-2016-082
	HVT $W' \rightarrow WZ \rightarrow qqqq$ model B	–	2 J	–	15.5	W' mass 3.0 TeV	$g_V = 3$	ATLAS-CONF-2016-055
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel			3.2	V' mass 2.31 TeV	$g_V = 3$	1607.05621
	LRSM $W'_R \rightarrow tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \rightarrow tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	15.7	Λ 19.9 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2016-069
	CI $\ell\ell qq$	2 e, μ	–	–	3.2	Λ 25.2 TeV	$\eta_{LL} = -1$	1607.03669
	CI $uutt$	2(SS)/$\geq$3 e,μ	$\geq$1 b, $\geq$1 j	Yes	20.3	Λ 4.9 TeV	$\lvert C_{RR}\rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	≥ 1 j	Yes	3.2	m_A 1.0 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 250$ GeV	1604.07773
	Axial-vector mediator (Dirac DM)	0 e, μ, 1 γ	1 j	Yes	3.2	m_A 710 GeV	g_q=0.25, g_χ=1.0, $m(\chi) < 150$ GeV	1604.01306
	$ZZ\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 550 GeV	$m(\chi) < 150$ GeV	ATLAS-CONF-2015-080
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	$\geq$1 b, $\geq$3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \rightarrow Ht + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	T mass 855 GeV	T in (T,B) doublet	1505.04306
	VLQ $YY \rightarrow Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	20.3	Y mass 770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ $BB \rightarrow Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 735 GeV	isospin singlet	1505.04306
	VLQ $BB \rightarrow Zb + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $QQ \rightarrow WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
	VLQ $T_{5/3}T_{5/3} \rightarrow WtWt$	2(SS)/$\geq$3 e,μ	$\geq$1 b, $\geq$1 j	Yes	3.2	$T_{5/3}$ mass 990 GeV		ATLAS-CONF-2016-032
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	–	3.2	q^* mass 4.4 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.05910
	Excited quark $q^* \rightarrow qg$	–	2 j	–	15.7	q^* mass 5.6 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2016-069
	Excited quark $b^* \rightarrow bg$	–	1 b, 1 j	–	8.8	b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \rightarrow Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	2 e, μ	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \rightarrow ee$	2 e (SS)	–	–	13.9	$H^{\pm\pm}$ mass 570 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow ee$)=1	ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1509.08059

$\sqrt{s} = 8$ TeV $\sqrt{s} = 13$ TeV

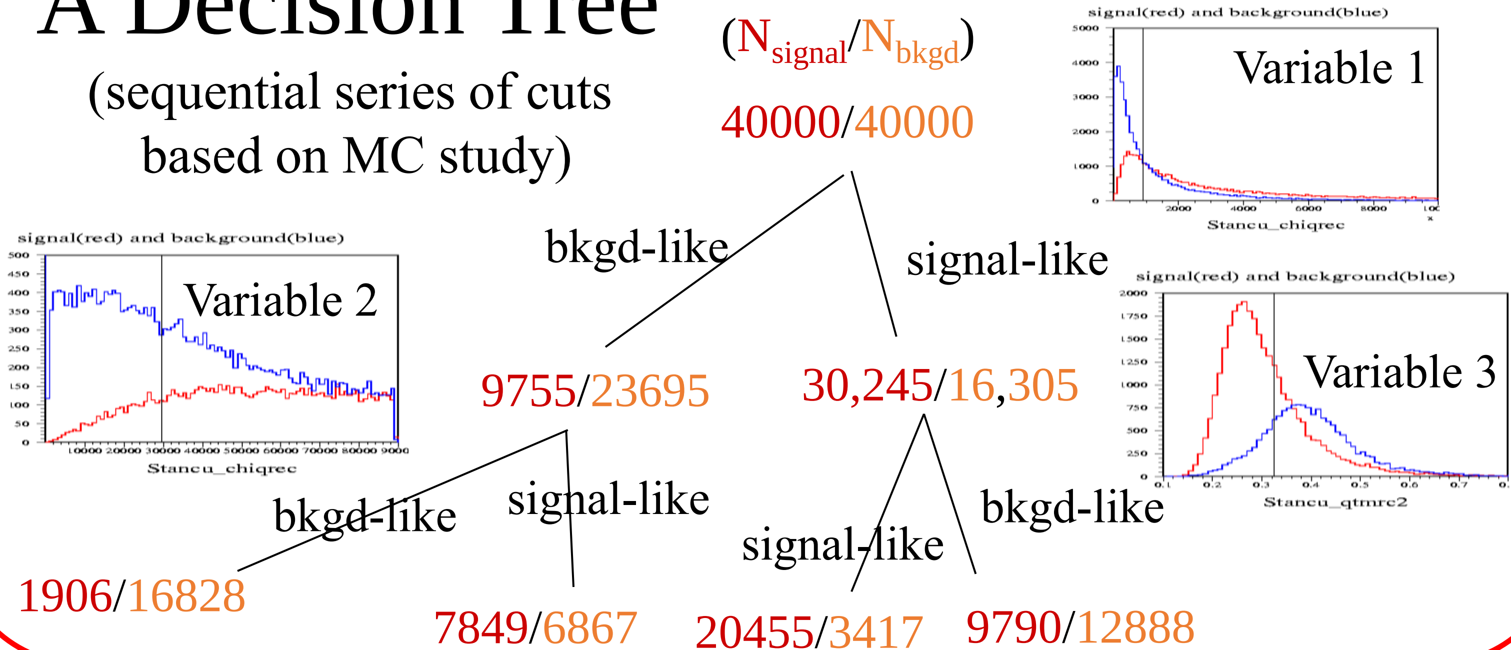
Mass scale [TeV]: 10^{-1}, 1, 10

*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.

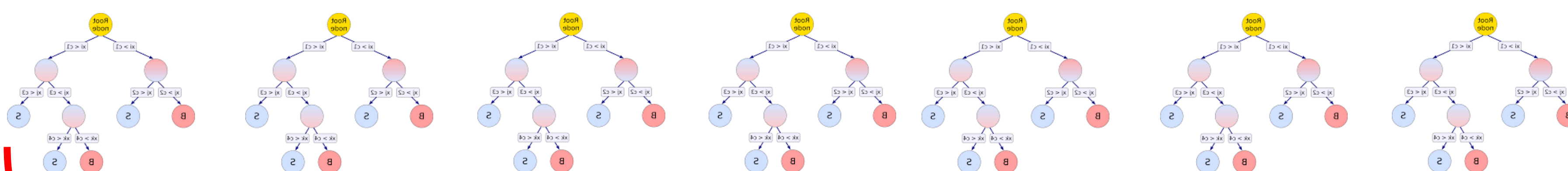
†Small-radius (large-radius) jets are denoted by the letter j (J).

A Decision Tree

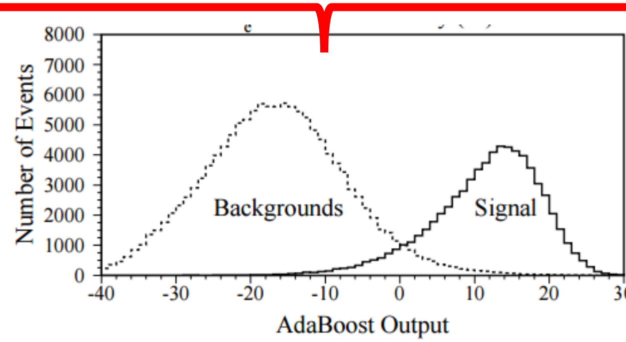
(sequential series of cuts
based on MC study)



通过Boosting 算法不断提高误判事例的权重，产生一系列Decision Trees



把每个事例在所有Decision Trees获得的积分累加，通过"Majority vote"方法提高性能和稳定性。



通过Boosting不断提高误判事例的权重，使得这些难以区分的事例在后续的Decision Trees获得的正确区分，提高效率。

Boosted Decision Trees (BDT)

CERN TMVA 软件包收入，http://tmva.sourceforge.net/

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Nuclear Instruments and Methods in Physics Research A 543 (2005) 577–584
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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Boosted decision trees as an alternative to artificial neural networks for particle identification

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Studies of boosted decision trees for MiniBooNE particle identification

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Available online 4 October 2005

Abstract

Boosted decision trees are applied to particle identification in the MiniBooNE experiment operated at Fermi National Accelerator Laboratory (Fermilab) for neutrino oscillations. Numerous attempts are made to tune the boosted decision trees, to compare performance of various boosting algorithms, and to select input variables for optimal performance.
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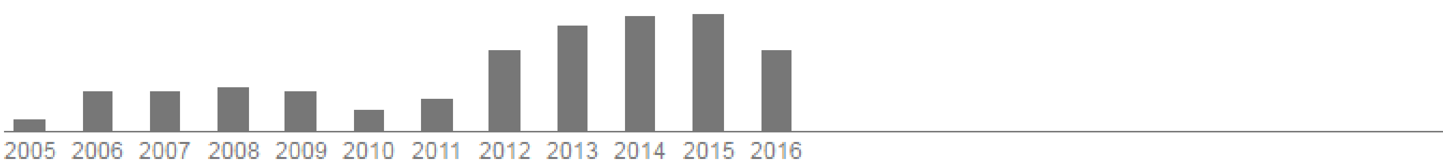
PACS: 29.85.+c; 02.70.Uu; 07.05.Mh; 14.60.Pq



has been widely used in data analysis of High Energy Physics experiments in the last decade. The use of the ANN technique usually gives better

MiniBooNE experiment [1] at Fermi National Accelerator Laboratory. The MiniBooNE experiment is designed to confirm or refute the evidence for $\nu_\mu \to \nu_e$ oscillations at $\Delta m^2 \simeq 1\,eV^2/c^4$ found by the LSND experiment [2]. It is a crucial experiment which will imply new physics beyond

Initial comparisons of these techniques with artificial neural networks (ANN) using the MiniBooNE MC

procedure that combines many "weak" classifiers to achieve a final powerful classifier. In the present work numerous trials are made to tune the boosted decision trees, and comparisons are made for various algorithms. For a large number of discriminant variables, several

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CMS phase II upgrade in China

一级径迹触发升级

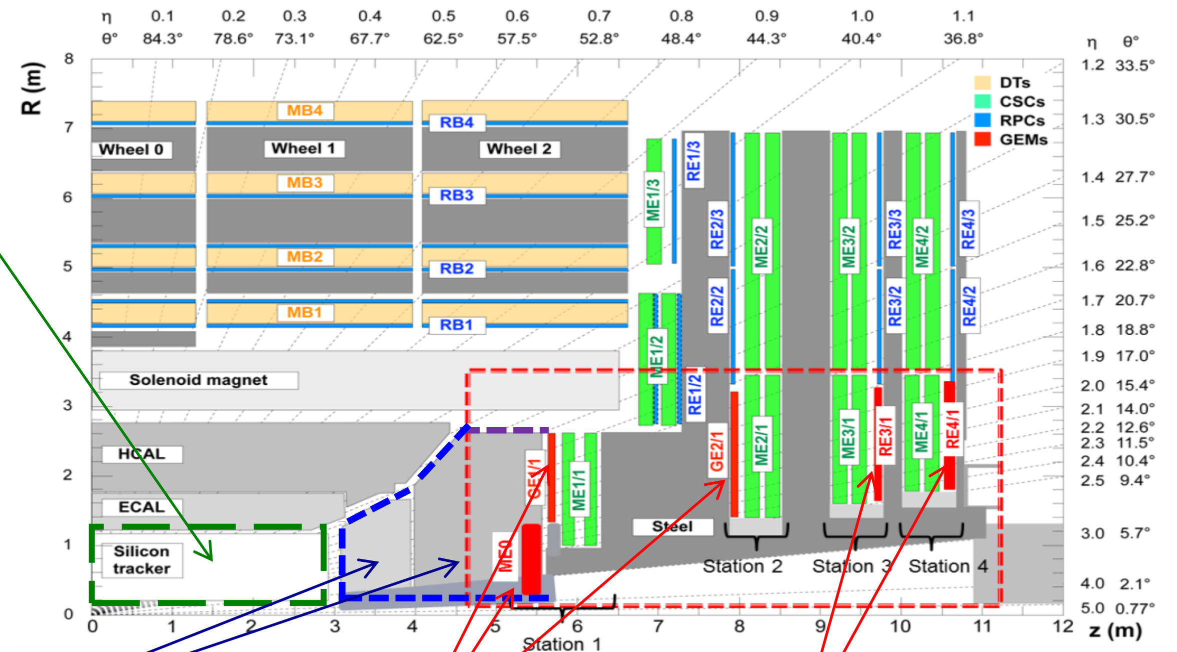
高能所：触发插件

- 寻迹插件研制
- 高速数据传输插件研制
- xTCA架构的智能控制

端盖量能器升级

高能所：硅模块

- 硅传感器性能研究
- 硅传感器模块组装设计与质量控制
- 实验束性能测试与分析



端盖μ探测器升级

北京大学：GEM

- 大面积读出PCB、GEM膜的研制与生产
- 前段电子学和数据获取系统的开发和研制
- 探测器组装，测试

端盖μ探测器升级

清华大学：MRPC

- 自主产权低电阻玻璃
- 梯形高计数率玻璃MRPC研制
- 实验束流测试

科技部重大研发项目首期共投入1800万

近两年进展总结@CMS实验

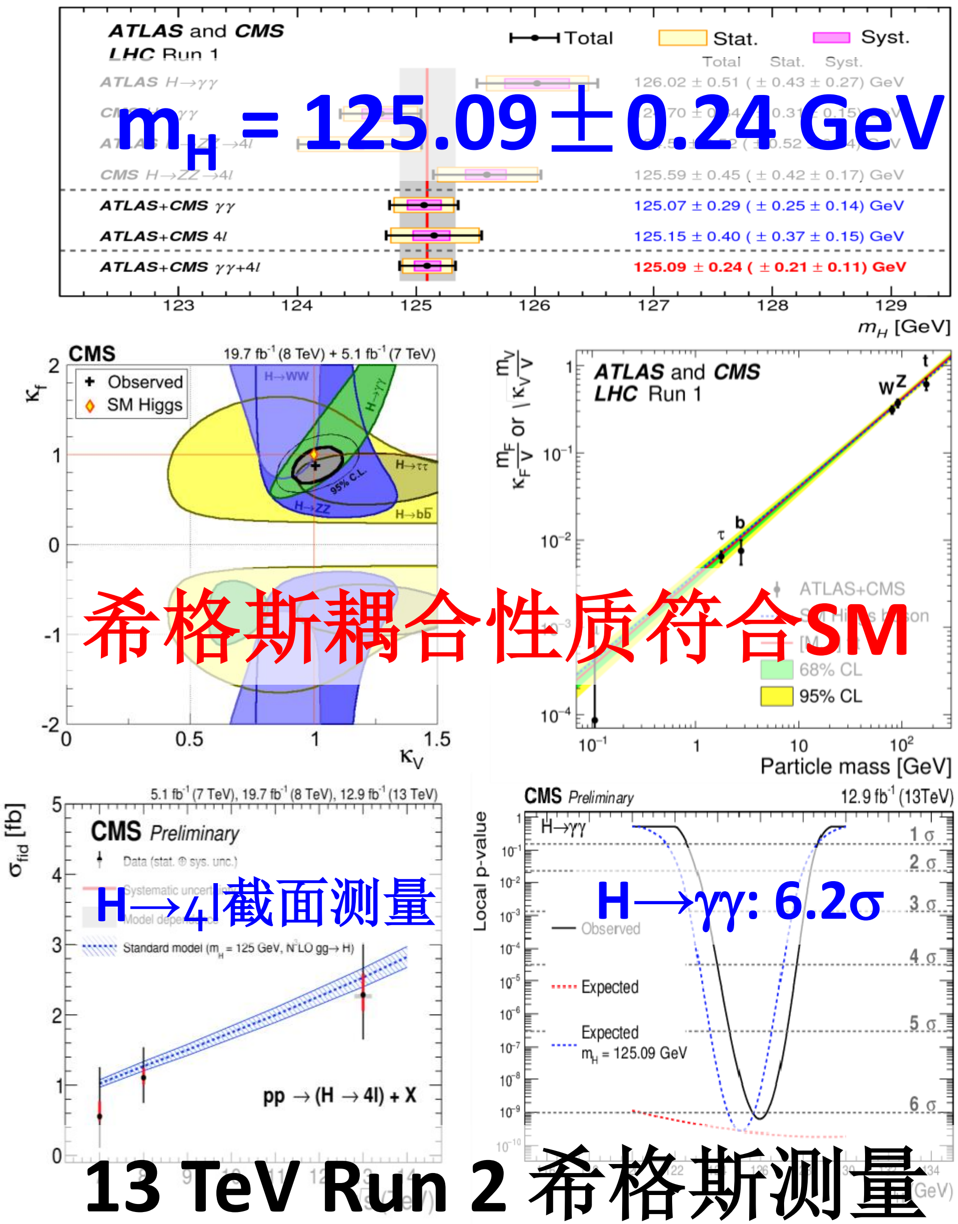
- 实验队伍进一步壮大：高能所、北大、清华、北航
- 共发表有重要贡献的合作组**文章25篇，**有重要贡献Conf. Note (PAS) **29篇**
  - **Contact editors: ～12篇**
  - 高引文章 100+
- 在合作组中活跃度/显示度大幅提升，多人担任L3协调人
  - **高能所陈明水担任CMS希格斯联合分析及性质测量小组召集人(2014-2015), LHCHXSWG 希格斯性质组召集人 (2016.01-)**
  - **北大李强担任CMS 蒙卡产生子 MEG小组召集人(2015.10-)**
- **国际会议报告及海报51人次**

近2年高引论文 (InSpireHEP)

1. **488次,** Combined Measurement of the Higgs Boson Mass in pp Collisions at s√=7 and 8 TeV with the ATLAS and CMS Experiments, Phys.Rev.Lett. 114 (2015) 191803
2. **415次,** Measurement of the properties of a Higgs boson in the four-lepton final state, Phys.Rev. D89 (2014) 092007
3. **413次,** Precise determination of the mass of the Higgs boson and tests of compatibility of its couplings with the standard model predictions using proton collisions at 7 and 8 TeV, Eur.Phys.J. C75 (2015) 212
4. **295次,** Observation of the diphoton decay of the Higgs boson and measurement of its properties, Eur.Phys.J. C74 (2014) 3076
5. **173次,** Invisible Higgs production, VBF and ZH channels combination, Eur. Phys. J. C 74 (2014) 2980
6. **166次,** Search for new diboson resonances in semi-leptonic final states with boosted topology, JHEP 08 (2014) 174
7. **140次,** Constraints on the spin-parity and anomalous HVV couplings of the Higgs boson in proton collisions at 7 and 8 TeV, Phys.Rev. D92 (2015) 012004
8. **129次,** Search for a Higgs boson in the mass range from 145 to 1000 GeV decaying to a pair of W or Z bosons, JHEP 1510 (2015) 144
9. **124次,** Evidence for the direct decay of the 125 GeV Higgs boson to fermions, Nature Phys. 10 (2014) 557-560

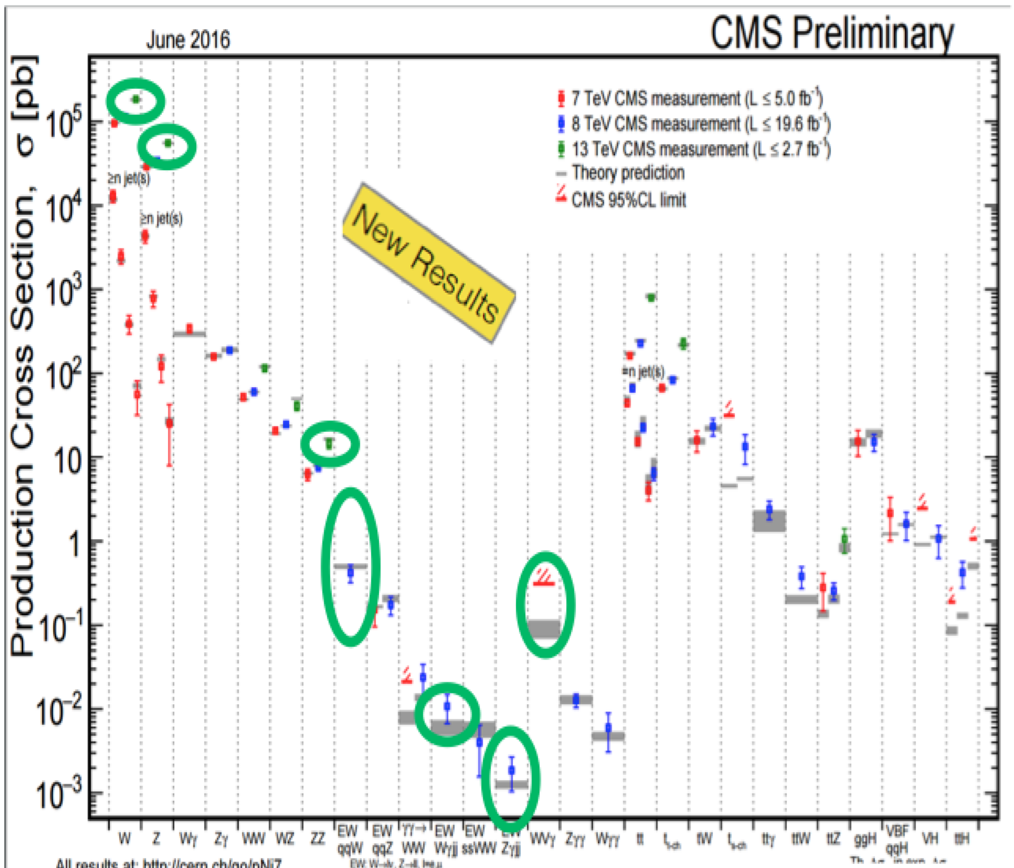
希格斯的性质测量@CMS实验

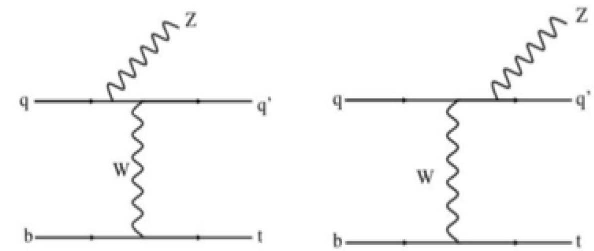
- 中国组在**双光子**和**四轻子**末态多个分析中有重要贡献
  - 光子ID、四轻子道质量测量、产生截面、统计分析等
- 同时在综合所有末态**的希格斯联合分析**中起主要作用
  - 在CMS 125 GeV的希格斯粒子性质研究中发挥了核心作用
  - 担任CMS、LHC Higgs combination多篇文章联系人、编辑等
- **Run 2** 继续在以上分析上发挥重要作用，并已加入**ttH多个末态**物理分析



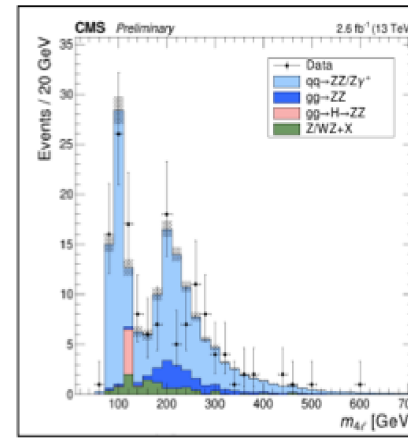
标准模型测量@CMS

标准模型测量:过去2年主导主导7个分析



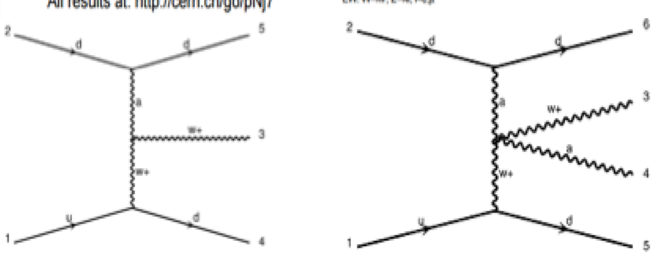


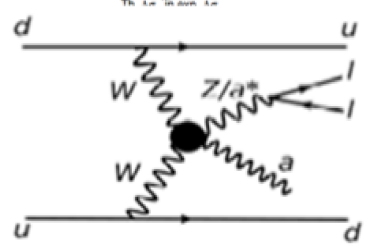
Run1 TZq
中国组Preapproval
2015 Run2 ZZ→4l
中国组Preapproval

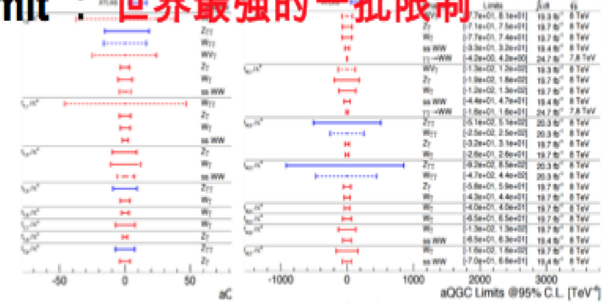


Run2 W/Z+jets
中国组Preapproval
Run1 EWK W+2Jets
中国组负责
Run1 VBS Zγjj，VBS Wγjj
中国组负责

aQGC limit ：世界最强的一批限制







PROSPECTS

CMS-FTR-15-002

What can we expect from HL-LHC (>2024)?

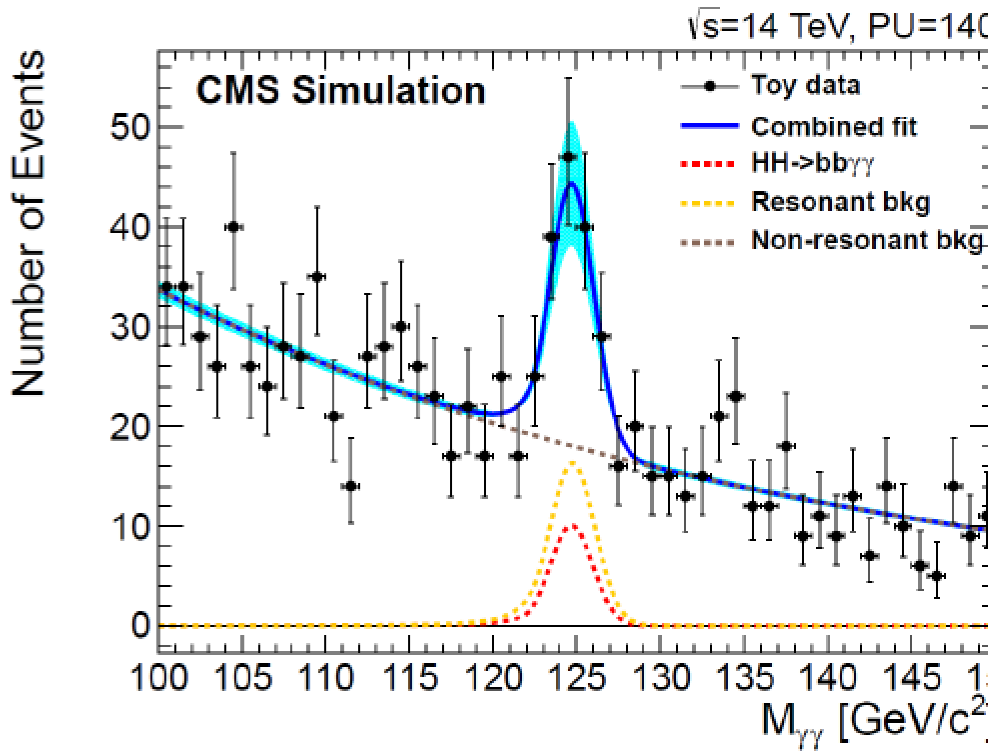
Main focus is on SM non-resonant production since most the BSM should be already constrained.

- **Study performed by CMS on bbττ, bbγγ and bbWW channels**

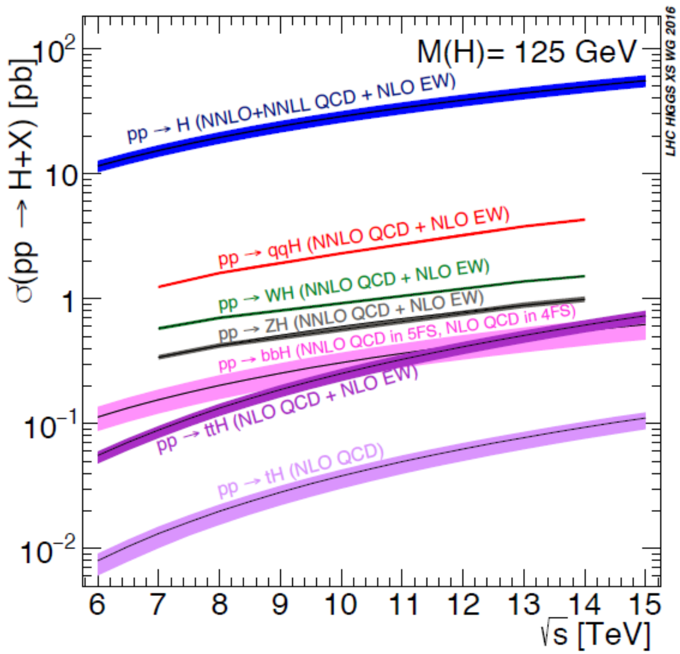
  HL-LHC operating condition assumed → 3000 fb^{-1}
  Delphes simulation used.
  Simplified Run1 analysis flow followed.
  Phase II Upgrade conditions included.

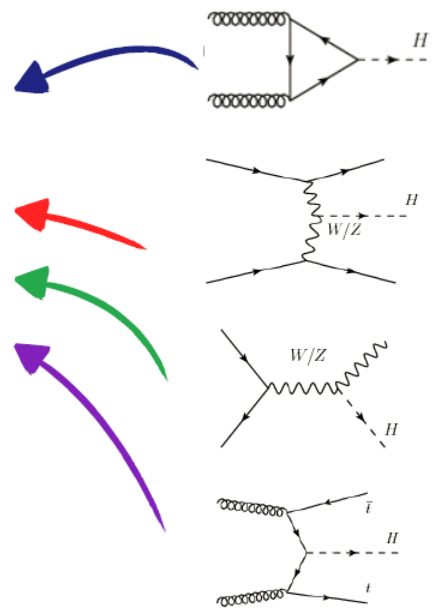
Combining **bbττ and bbγγ:** the expected significance for Higgs boson pair production is 1.9 standard deviation.

The bbbb final state promises the largest potential for improvement but still not investigated → waiting for first result on 13TeV data.



希格斯粒子的产生机制和衰变





@13TeV ggH 87% m_H=125 GeV — (N3LO QCD + NLO EW)

@13TeV VBF 7% m_H=125 GeV

@13TeV VH 4% m_H=125 GeV — (NNLO QCD + NLO EW)

@13TeV ttH/bbH 2% m_H=125 GeV — (NLO QCD + NLO EW)

- ➔ **ggH, ttH, bbH – Yukawa coupling**
- ➔ **VBF, VH – Gauge coupling**

Production cross section

@m_H=125 GeV

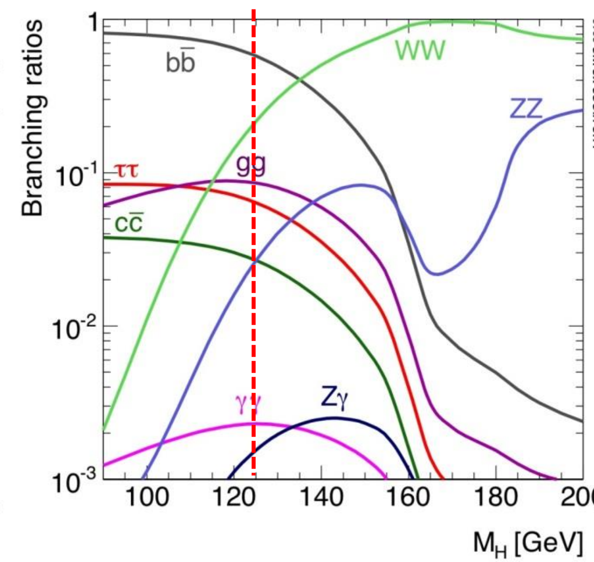
19.3 pb @7 TeV

24.5 pb @8 TeV

55.7 pb @13 TeV

62.7 pb @14 TeV

Decay mode	Branching fraction [%]
$H \to bb$	57.5 ± 1.9
$H \to WW$	21.6 ± 0.9
$H \to gg$	8.56 ± 0.86
$H \to \tau\tau$	6.30 ± 0.36
$H \to cc$	2.90 ± 0.35
$H \to ZZ$	2.67 ± 0.11
$H \to \gamma\gamma$	0.228 ± 0.011
$H \to Z\gamma$	0.155 ± 0.014
$H \to \mu\mu$	0.022 ± 0.001



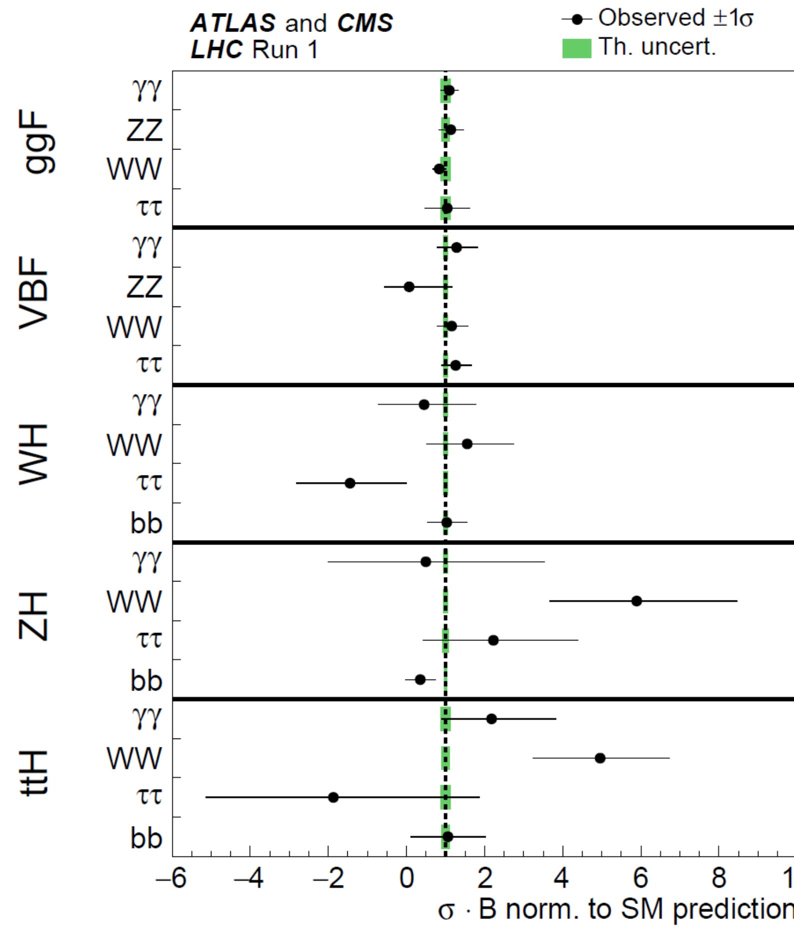
希格斯联合分析

arXiv:1606.02266

- ➔ 希格斯衰变到双玻色子末态H➔γγ, ZZ, WW， 单一末态独立超过5σ！
- ➔ 综合ATLAS和CMS实验结果， H➔ ττ 达到5.5σ, VBF Higgs 产生达到5.4σ！

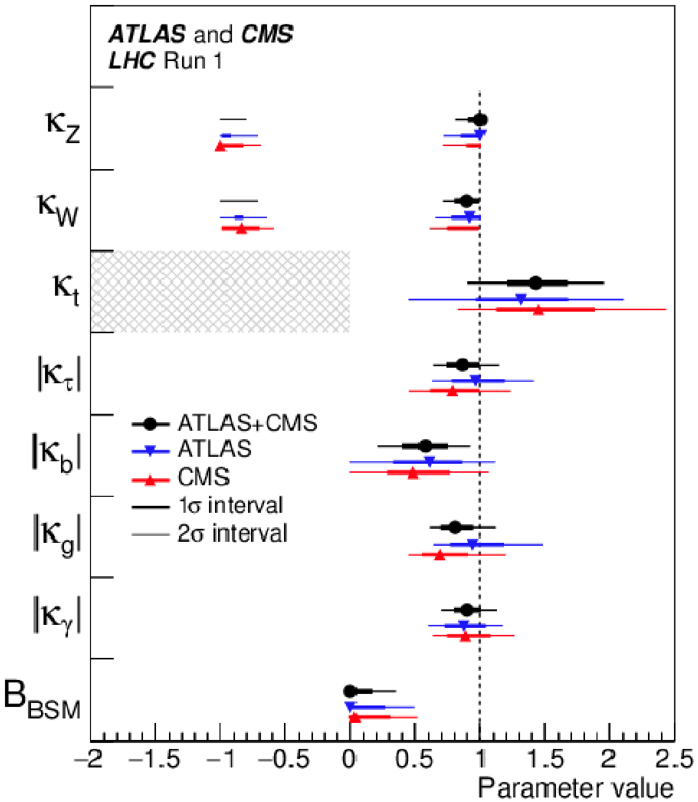
Channel	References for individual publications		Signal strength [μ] from results in this paper (Section 5.2)		Signal significance [σ]	
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
$H \to \gamma\gamma$	[91]	[92]	$1.14^{+0.27}_{-0.25}$ $\left(^{+0.26}_{-0.24}\right)$	$1.11^{+0.25}_{-0.23}$ $\left(^{+0.23}_{-0.21}\right)$	5.0 (4.6)	5.6 (5.1)
$H \to ZZ$	[93]	[94]	$1.52^{+0.40}_{-0.34}$ $\left(^{+0.32}_{-0.27}\right)$	$1.04^{+0.32}_{-0.26}$ $\left(^{+0.30}_{-0.25}\right)$	7.6 (5.6)	7.0 (6.8)
$H \to WW$	[95,96]	[97]	$1.22^{+0.23}_{-0.21}$ $\left(^{+0.21}_{-0.20}\right)$	$0.90^{+0.23}_{-0.21}$ $\left(^{+0.23}_{-0.20}\right)$	6.8 (5.8)	4.8 (5.6)
$H \to \tau\tau$	[98]	[99]	$1.41^{+0.40}_{-0.36}$ $\left(^{+0.37}_{-0.33}\right)$	$0.88^{+0.30}_{-0.28}$ $\left(^{+0.31}_{-0.29}\right)$	4.4 (3.3)	3.4 (3.7)
$H \to bb$	[100]	[101]	$0.62^{+0.37}_{-0.37}$ $\left(^{+0.39}_{-0.37}\right)$	$0.81^{+0.45}_{-0.43}$ $\left(^{+0.45}_{-0.43}\right)$	1.7 (2.7)	2.0 (2.5)
$H \to \mu\mu$	[102]	[103]	$-0.6^{+3.6}_{-3.6}$ $\left(^{+3.6}_{-3.6}\right)$	$0.9^{+3.6}_{-3.5}$ $\left(^{+3.3}_{-3.2}\right)$		
ttH production	[77,104,105]	[107]	$1.9^{+0.8}_{-0.7}$ $\left(^{+0.7}_{-0.7}\right)$	$2.9^{+1.0}_{-0.9}$ $\left(^{+0.9}_{-0.8}\right)$	2.7 (1.6)	3.6 (1.3)

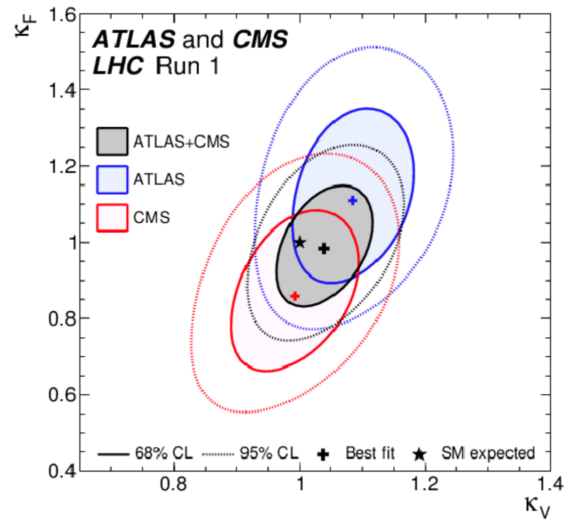
Production process	Measured significance (σ)	Expected significance (σ)
VBF	5.4	4.6
WH	2.4	2.7
ZH	2.3	2.9
VH	3.5	4.2
ttH	4.4	2.0
Decay channel		
$H \to \tau\tau$	5.5	5.0
$H \to bb$	2.6	3.7

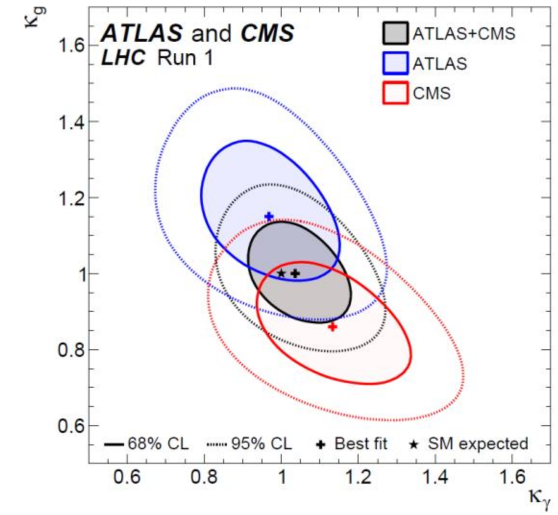


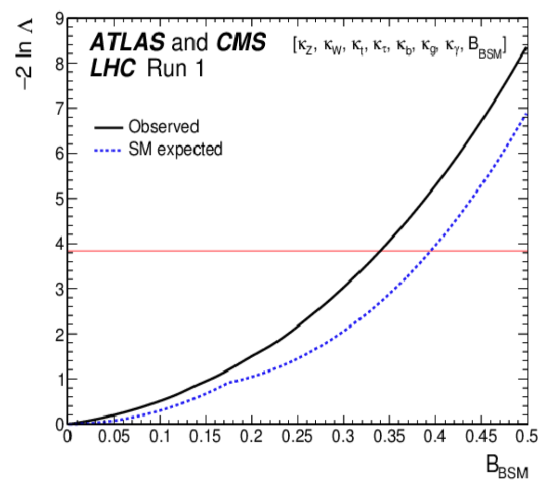
希格斯粒子的耦合强度

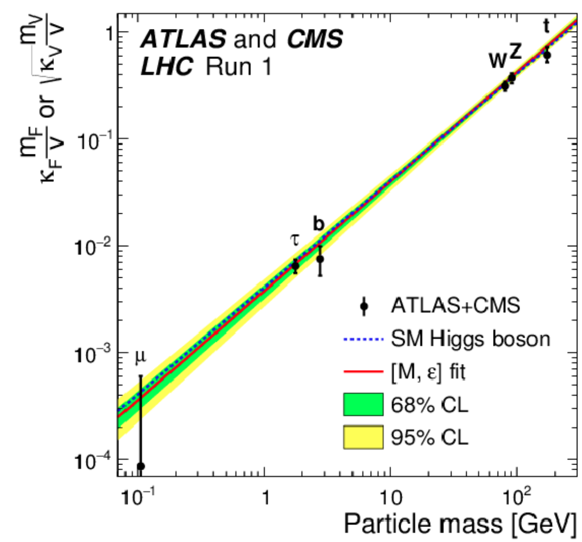
- 目前LHC Run1的实验数据表明希格斯粒子的耦合强度与标准模型预言一致。







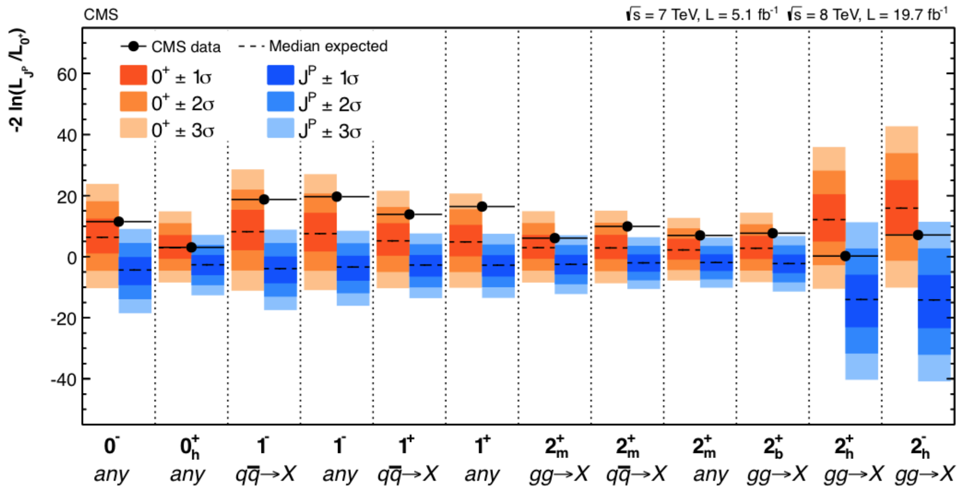


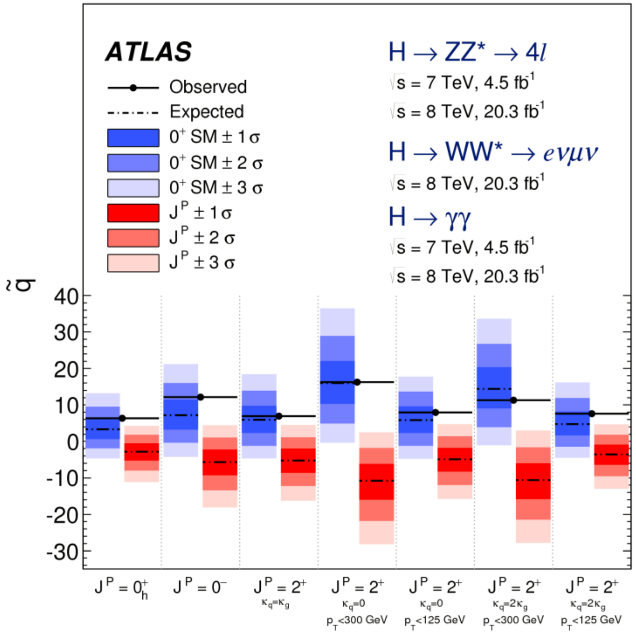


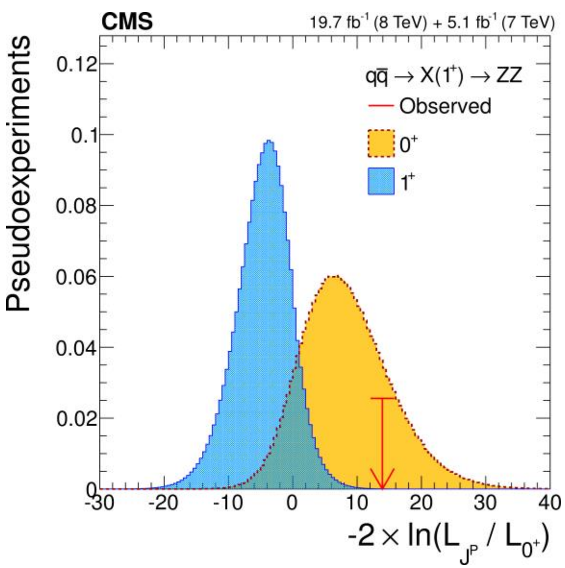
希格斯自旋和宇称

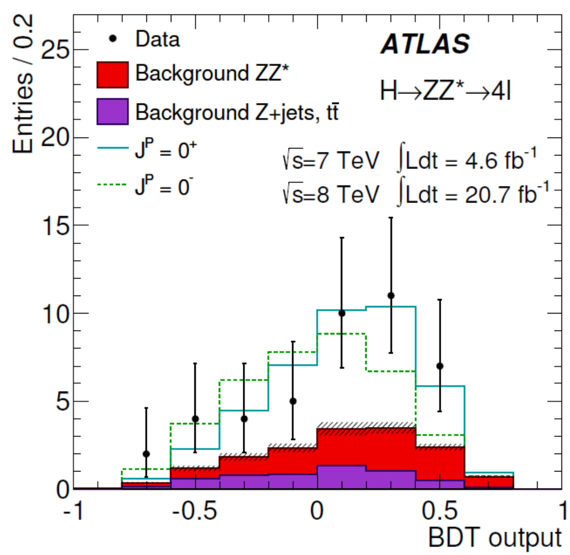
EPJC75, 476 (2015)
PRD89(2014)092007

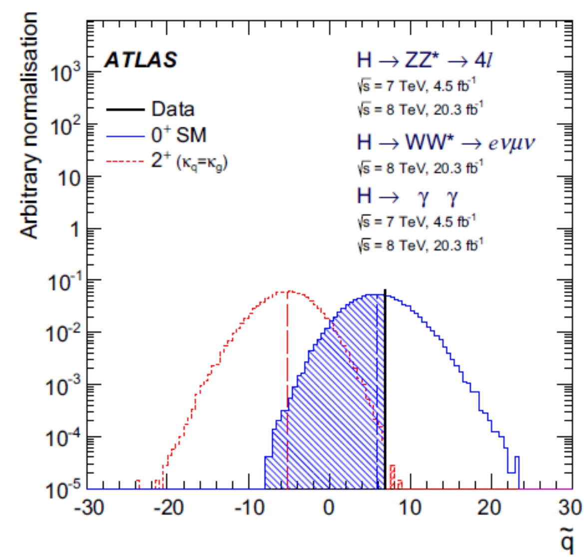
- 综合双玻色子末态（VV），希格斯的自旋和宇称与标准模型预言吻合，而其他各种组合以99.9%的置信度被排除！











H→ diphoton analysis

HIGG-2016-08 (3.2/fb)

IHEP: Y. Huang, S. Jin, C. Peng, Y. Zhang
SJTU: Z. Wang, H. Yang

HIGG-2016-09 (13.3/fb)

IHEP: Yanping Huang, Shan Jin, Cong Peng, Yu Zhang, Yaquan Fang, Xinchou Lou, Huijun Zhang
SJTU: Zirui Wang, Haijun Yang

Search for new phenomena in diphoton events with the ATLAS detector at $\sqrt{s}$ = 13 TeV

HIGG-2016-08

Version: 1.0

Analysis Team

[*email:* atlas-higg-2016-08-editors@cern.ch]

L. Barak, J. Beacham, C. Becot, N. Berger, Q. Buat, L. Carminati, R. Carbonne, M. Chelstowska, K. Cranmer, M. Delmastro, M. Fanti, L. Fayard, C. Goudet, T. Guillemin, K. Grevtsov, E. Gross, F. Hamnett, A. Hard, H. Hayward, Y. Huang, K. Iordanidou, S. Jin, X. Ju, R. Lafaye, S. Laplace, B. Lenzi, A. Loginov, T. Meideck, F. Malek, S. Manzoni, G. Marchiori, S. Mazza, C. Meyer, D. Nole, J. Ocariz, J. Parsons, C. Peng, E. Petit, X. Poveda Torres, N. Proklova, R. Reed, L. Roos, M. Saimpert, B. Sheff, Y-T. Shen, J. Stark, K. Tackmann, B. Trocmé, R. Turra, G. Unal, M. Villaplana, A. Vallier, J.-B. de Vivie de Regie, H. Yang, Y. Yap, Z. Wang, F. Wang, I. Wingerter-Seez, S.L. Wu, Y. Zang

ATLAS EXPERIMENT

ATLAS Paper Draft

Measurement of fiducial, differential and production cross sections in the $H \to \gamma\gamma$ decay channel with $13.3\ \text{fb}^{-1}$ of 13 TeV proton-proton collision data

HIGG-2016-09

Version: 2.5

To be submitted to:

Supporting internal notes

$H \to \gamma\gamma$ and $H \to Z\gamma$ selection and performance: https://cds.cern.ch/record/2196102
Fiducial and differential cross sections: https://cds.cern.ch/record/2150683
Couplings analysis: https://cds.cern.ch/record/2137502

Comments are due by: 2nd August 2016

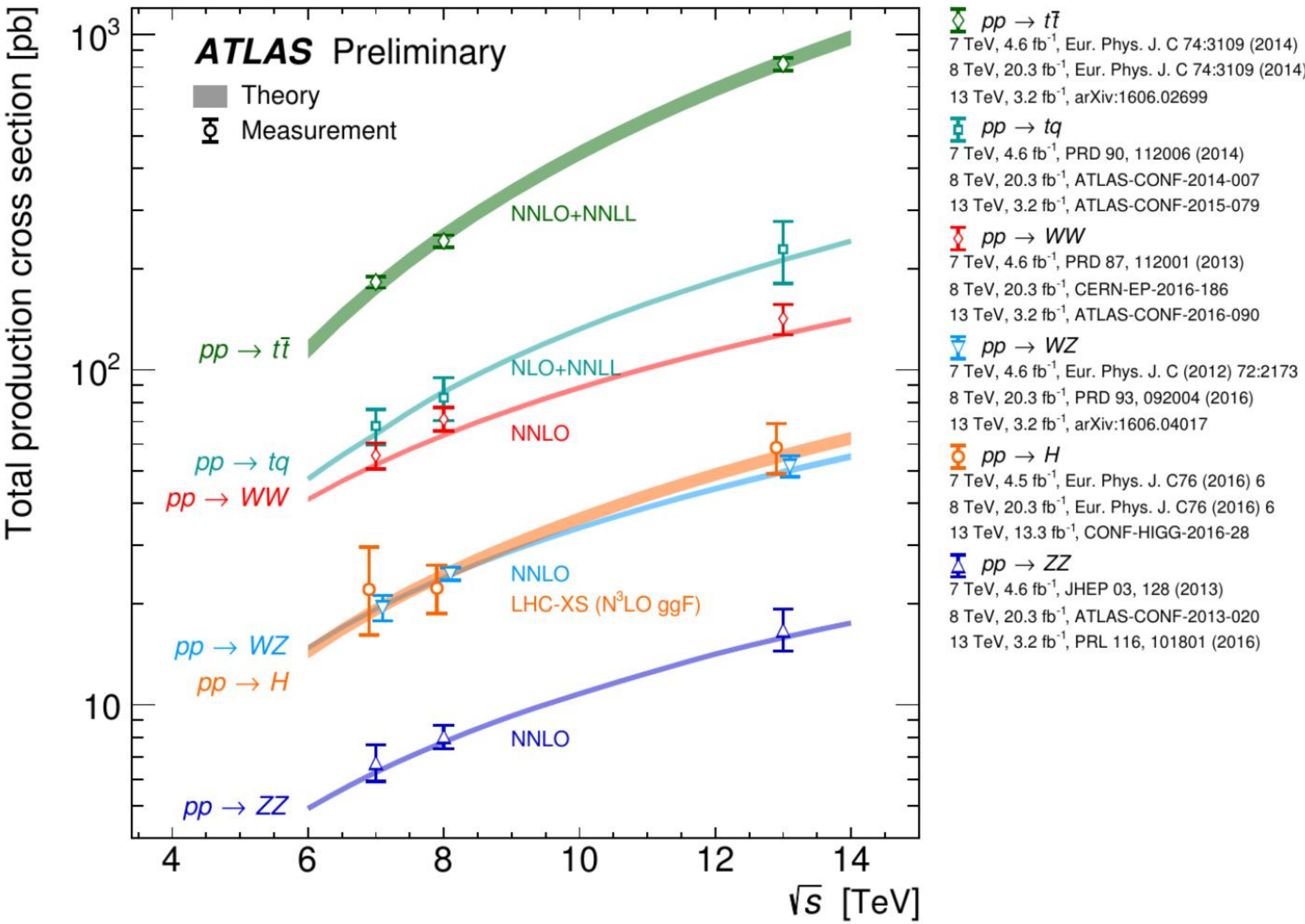
Analysis Team

[*email:* atlas-conf-higg-2016-09-editors@cern.ch>]

Maria Josefina Alconada Verzini, Liron Barak, Cyril Becot, Nicolas Berger, Florian Urs Bernlochner, Leonardo Carminati, Leonor Cerda Alberich, Magda Anna Chelstowska, Diane Cinca, David Delgove, Marco Delmastro, Tulay Cuhadar Donszelmann, Maria Teresa Dova, Johannes Erdmann, Marc Escalier, Yaquan Fang, Marcello Fanti, Louis Fayard, Luca Fiorini, Rob Fletcher, Daniel Fournier, Dag Gillberg, Christophe Goudet, Kirill Grevtsov, Thibault Guillemin, Shuo Han, Andrew Hard, Yanping Huang, Joey Huston, Shan Jin, Deepak Kar, Kevin Kröninger, Jim Lacey, Bertrand Laforge, Tanner Lange, Sandrine Laplace, Bruno Lenzi, Kaicheng Li, Shell-May Liao, Andrey Loginov, Alvaro Lopez Solis, Xinchou Lou, Alizeh Maqbool, Giovanni Marchiori, Bruce Mellado Garcia, Simone Michele Mazza, Stephen Menary, Chris Meyer, Khilesh Mistry, Fernando Monticelli, Isabel Nitsche, Jose Ocariz, Chad Pelwan, Cong Peng, Elisabeth Petit, Andrew Pilkington, Ivan Pogrebnyak, Jianming Qian, Michaela Queitsch-Maitland, Kunlin Ran, Nathan Peter Readioff, Robert Reed, James Robinson, Xifeng Ruan, Nick Styles, Kerstin Tackmann, Tony Thompson, Paul Louis Tipton, Kehinde Gbenga Tomiwa, Ruggero Turra, Guillaume Unal, Jared Vasquez, Marion Villenave, Jean-Baptiste de Vivie, Stefan von Buddenbrock, Jin Wang, Zirui Wang, Brig Williams, Sau Lan Wu, Haijun Yang, Hongtao Yang, Huijun Zhang, Yu Zhang

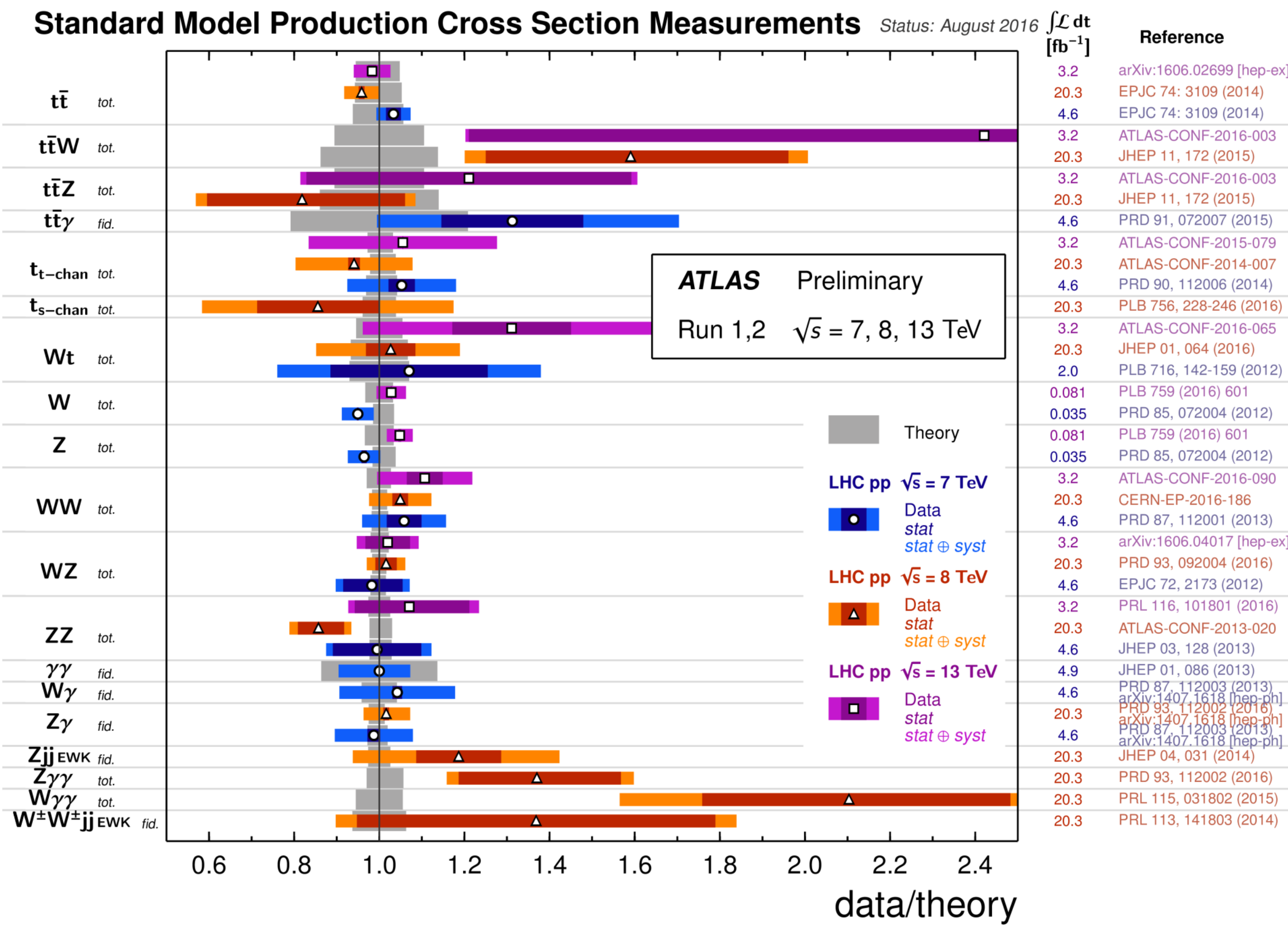
Run:

标准模型截面测量



Total production cross section [pb]
ATLAS Preliminary
Theory
Measurement
NNLO+NNLL
NLO+NNLL
NNLO
NNLO
LHC-XS (N^{3}LO ggF)
NNLO
$pp \to t\bar{t}$
$pp \to tq$
$pp \to WW$
$pp \to WZ$
$pp \to H$
$pp \to ZZ$
$\sqrt{s}$ [TeV]
$pp \to t\bar{t}$
7 TeV, 4.6 fb^{-1}, Eur. Phys. J. C 74:3109 (2014)
8 TeV, 20.3 fb^{-1}, Eur. Phys. J. C 74:3109 (2014)
13 TeV, 3.2 fb^{-1}, arXiv:1606.02699
$pp \to tq$
7 TeV, 4.6 fb^{-1}, PRD 90, 112006 (2014)
8 TeV, 20.3 fb^{-1}, ATLAS-CONF-2014-007
13 TeV, 3.2 fb^{-1}, ATLAS-CONF-2015-079
$pp \to WW$
7 TeV, 4.6 fb^{-1}, PRD 87, 112001 (2013)
8 TeV, 20.3 fb^{-1}, CERN-EP-2016-186
13 TeV, 3.2 fb^{-1}, ATLAS-CONF-2016-090
$pp \to WZ$
7 TeV, 4.6 fb^{-1}, Eur. Phys. J. C (2012) 72:2173
8 TeV, 20.3 fb^{-1}, PRD 93, 092004 (2016)
13 TeV, 3.2 fb^{-1}, arXiv:1606.04017
$pp \to H$
7 TeV, 4.5 fb^{-1}, Eur. Phys. J. C76 (2016) 6
8 TeV, 20.3 fb^{-1}, Eur. Phys. J. C76 (2016) 6
13 TeV, 13.3 fb^{-1}, CONF-HIGG-2016-28
$pp \to ZZ$
7 TeV, 4.6 fb^{-1}, JHEP 03, 128 (2013)
8 TeV, 20.3 fb^{-1}, ATLAS-CONF-2013-020
13 TeV, 3.2 fb^{-1}, PRL 116, 101801 (2016)

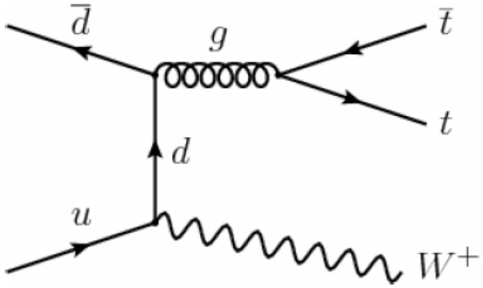
标准模型截面测量

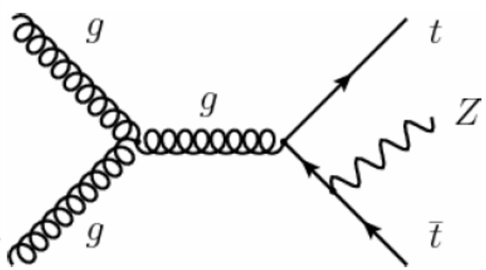

Standard Model Production Cross Section Measurements
Status: August 2016
∫ℒ dt [fb⁻¹]
Reference
tt̄ tot.
tt̄W tot.
tt̄Z tot.
tt̄γ fid.
t t−chan tot.
t s−chan tot.
Wt tot.
W tot.
Z tot.
WW tot.
WZ tot.
ZZ tot.
γγ fid.
Wγ fid.
Zγ fid.
Zjj EWK fid.
Zγγ tot.
Wγγ tot.
W±W±jj EWK fid.
ATLAS Preliminary
Run 1,2 √s = 7, 8, 13 TeV
Theory
LHC pp √s = 7 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 8 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 13 TeV
Data
stat
stat ⊕ syst
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
data/theory
3.2 arXiv:1606.02699 [hep-ex]
20.3 EPJC 74: 3109 (2014)
4.6 EPJC 74: 3109 (2014)
3.2 ATLAS-CONF-2016-003
20.3 JHEP 11, 172 (2015)
3.2 ATLAS-CONF-2016-003
20.3 JHEP 11, 172 (2015)
4.6 PRD 91, 072007 (2015)
3.2 ATLAS-CONF-2015-079
20.3 ATLAS-CONF-2014-007
4.6 PRD 90, 112006 (2014)
20.3 PLB 756, 228-246 (2016)
3.2 ATLAS-CONF-2016-065
20.3 JHEP 01, 064 (2016)
2.0 PLB 716, 142-159 (2012)
0.081 PLB 759 (2016) 601
0.035 PRD 85, 072004 (2012)
0.081 PLB 759 (2016) 601
0.035 PRD 85, 072004 (2012)
3.2 ATLAS-CONF-2016-090
20.3 CERN-EP-2016-186
4.6 PRD 87, 112001 (2013)
3.2 arXiv:1606.04017 [hep-ex]
20.3 PRD 93, 092004 (2016)
4.6 EPJC 72, 2173 (2012)
3.2 PRL 116, 101801 (2016)
20.3 ATLAS-CONF-2013-020
4.6 JHEP 03, 128 (2013)
4.9 JHEP 01, 086 (2013)
4.6 PRD 87, 112003 (2013) arXiv:1407.1618 [hep-ph]
20.3 PRD 93, 112002 (2016) arXiv:1407.1618 [hep-ph]
4.6 PRD 87, 112003 (2013) arXiv:1407.1618 [hep-ph]
20.3 JHEP 04, 031 (2014)
20.3 PRD 93, 112002 (2016)
20.3 PRL 115, 031802 (2015)
20.3 PRL 113, 141803 (2014)

Top pair + W/Z

CMS-PAS-TOP-16-017

ATLAS-CONF-2016-003





	ATLAS Obs (Exp)	CMS Obs (Exp)
ttZ (8TeV)	4.2 (4.5)	6.4 (5.7)
ttW (8TeV)	5.0 (3.2)	4.8 (3.5)
ttZ (13TeV)	-	3.9 (2.6)
ttW(13TeV)	-	4.6 (5.8)

➔ **CMS (12.9/fb)**

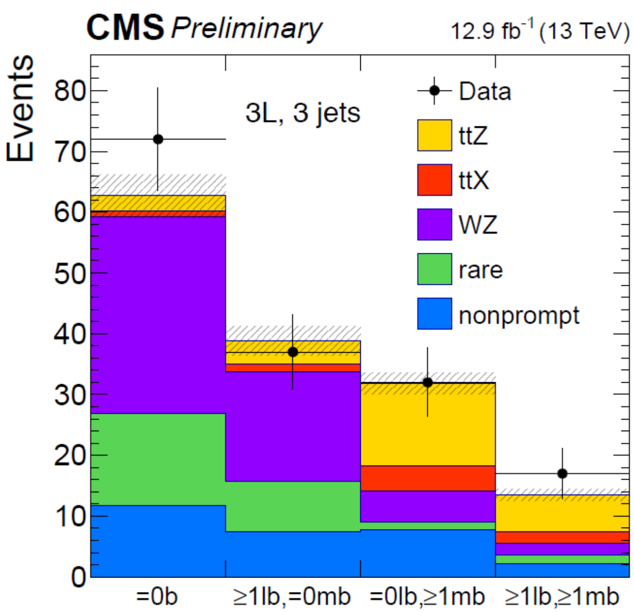
$$\sigma(\mathrm{pp} \to \mathrm{t\bar{t}Z}) = 0.70^{+0.16}_{-0.15}(\mathrm{stat.})\ ^{+0.14}_{-0.12}(\mathrm{sys.})\ \mathrm{pb}$$

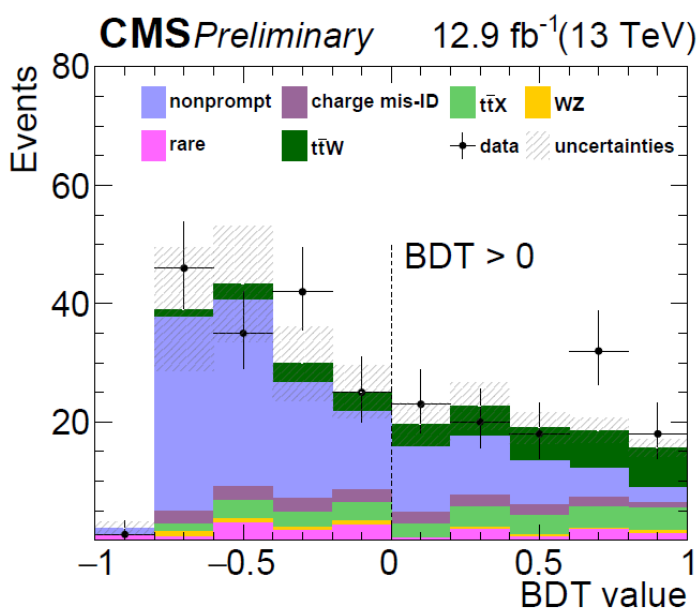
$$\sigma(\mathrm{pp} \to \mathrm{t\bar{t}W}) = 0.98\ ^{+0.23}_{-0.22}(\mathrm{stat.})\ ^{+0.22}_{-0.18}(\mathrm{sys.})\ \mathrm{pb}$$

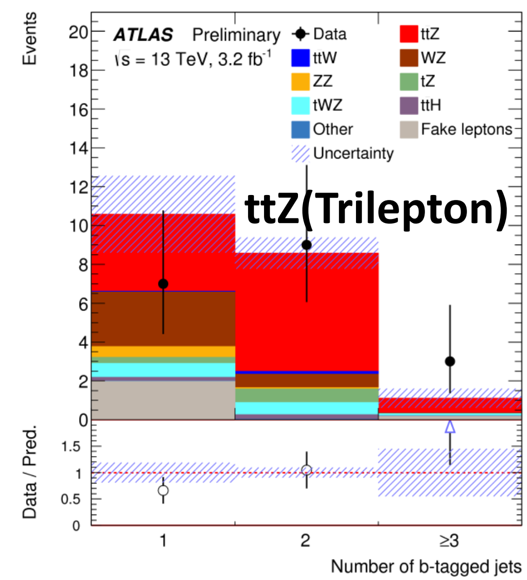
ATLAS (3.2/fb)

$$\sigma_{t\bar{t}Z} = 0.9 \pm 0.3\ \mathrm{pb}$$

$$\sigma_{t\bar{t}W} = 1.4 \pm 0.8\ \mathrm{pb}$$



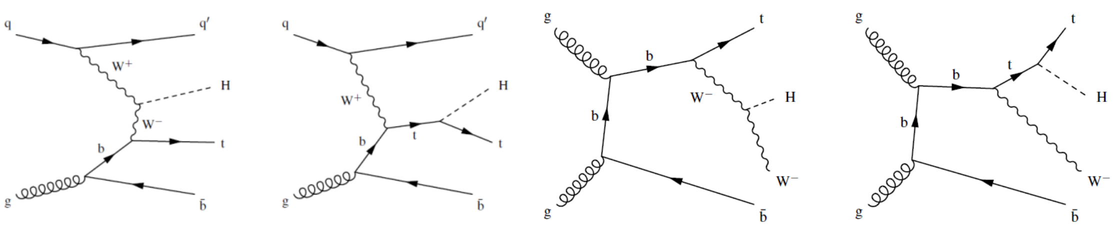




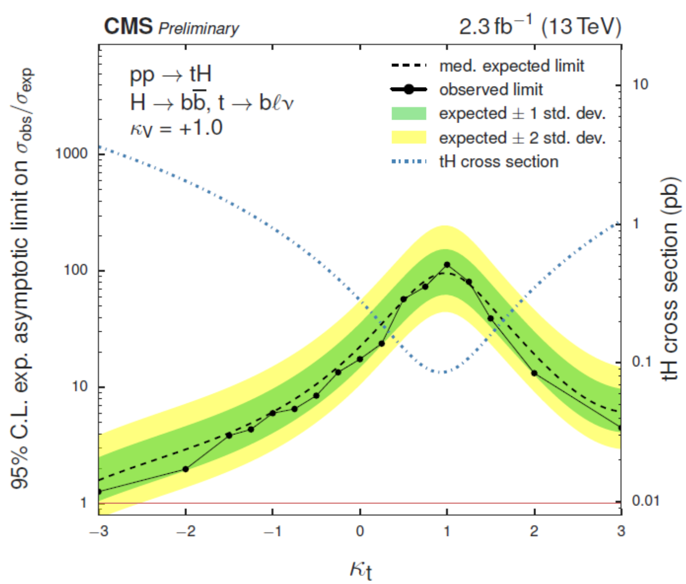
Search for tH, H→bb

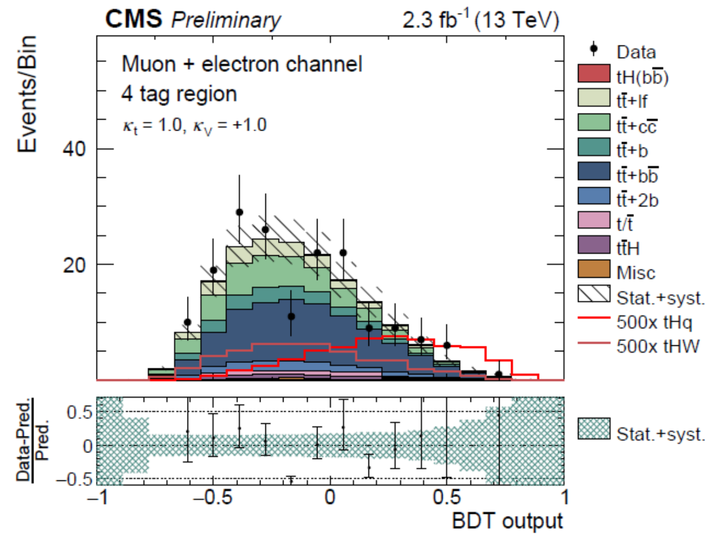
CMS-PAS-HIG-16-019

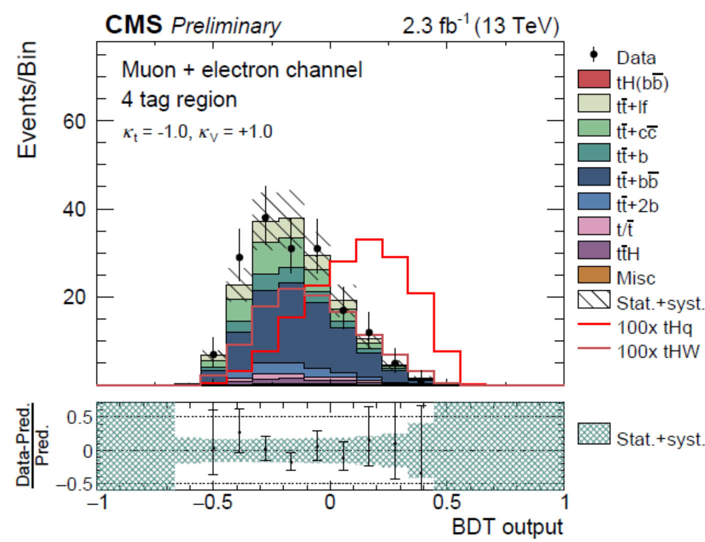
- → **tH production is sensitive to Yukawa coupling magnitude and sign of k_t, at 13 TeV,**
- ➢ **SM predict: tHq (71fb) and tHW (16fb)**
- ➢ **ITC predicts: tHq (739fb) and tHW (147fb)**
- → **The obs (exp) 95% CL upper limit for ITC scenario is 6 (6.4) times the predicted cross section.**



	Region	Observed Limit	Median
SM scenario	3 tag	124.0	114.3
	4 tag	195.8	174.6
	Combination	**113.7**	**98.6**
ITC scenario	3 tag	7.4	7.4
	4 tag	9.2	10.0
	Combination	**6.0**	**6.4**

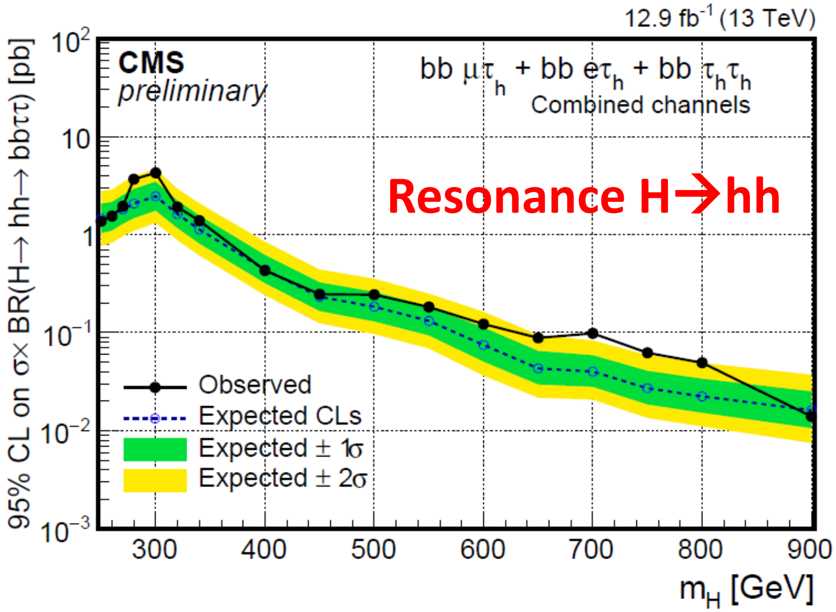


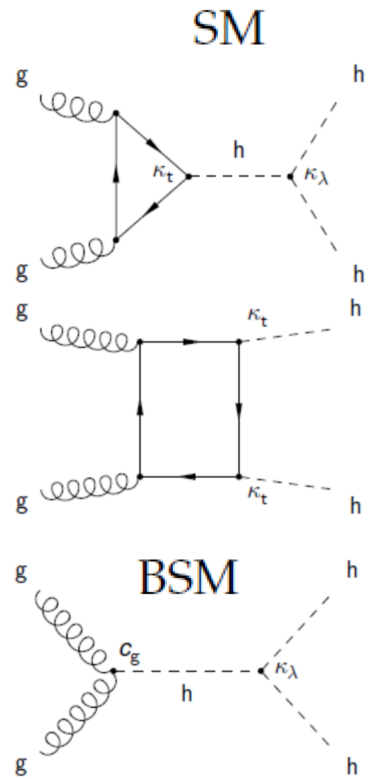


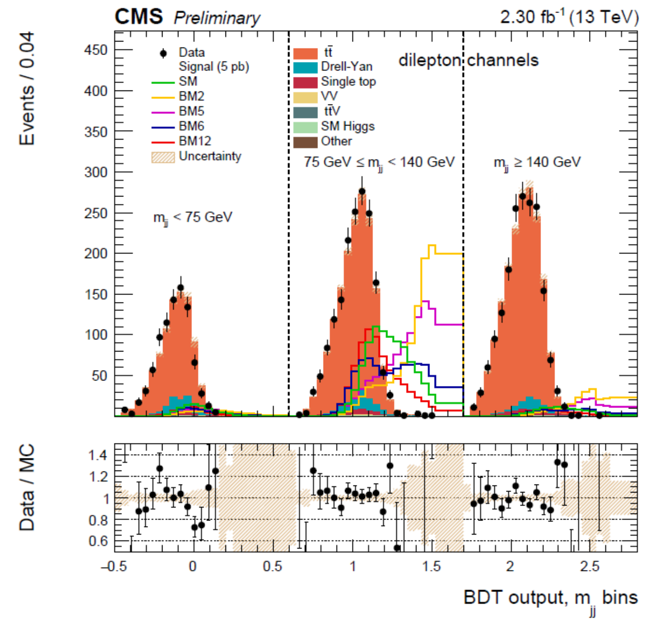


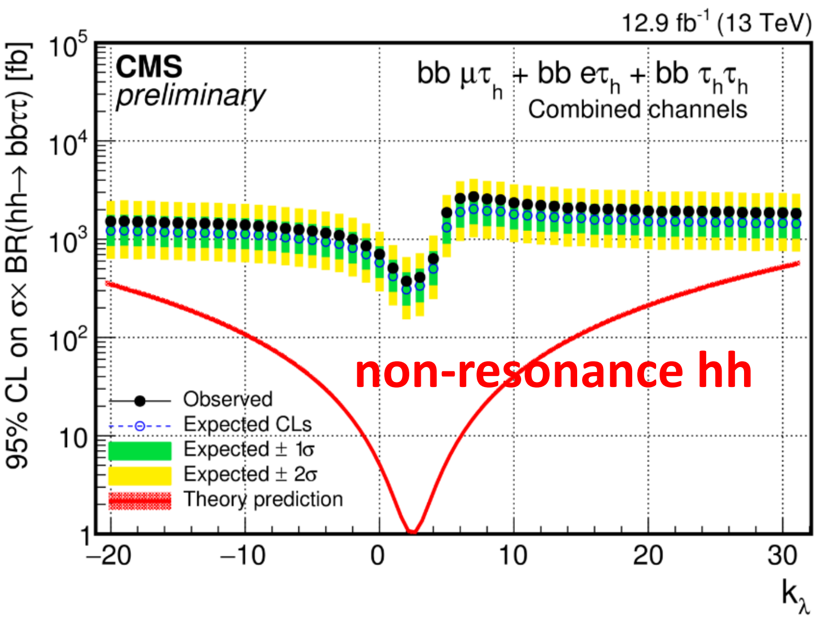
Search for hh → bbττ, bblνlν

CMS-PAS-HIG-16-028
CMS-PAS-HIG-16-029
CMS-PAS-HIG-16-024

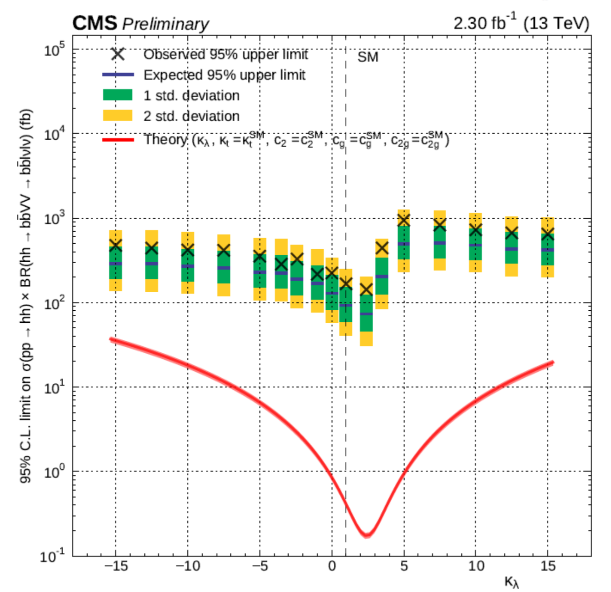








➔For SM hh, 95%CL observed limit < 166.7fb, about 400 × σ_{SM}

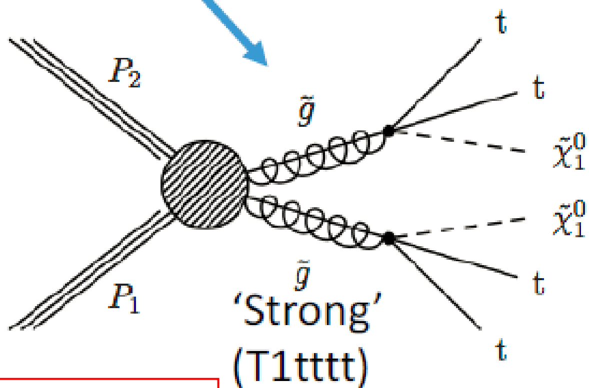


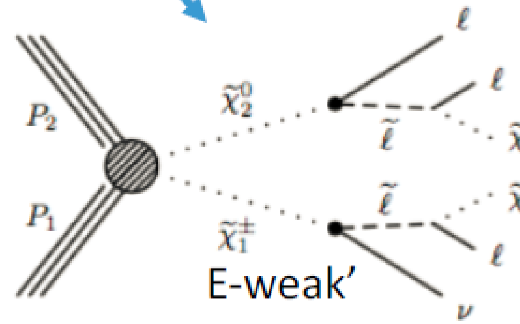
Search for SUSY

CMS-PAS-SUS-16-022
CMS-PAS-SUS-16-024

Clean signature for complex final states: selecting on the jet activity we can be sensitive to 'strong' SUSY productions or Electroweak SUSY production

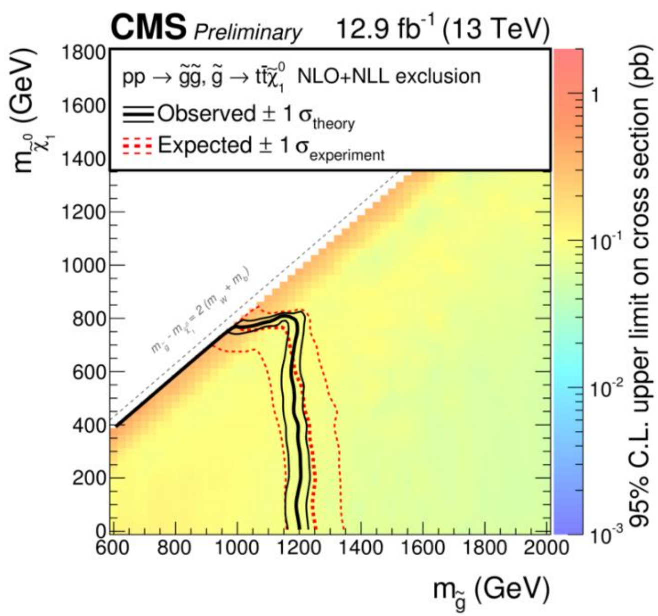
Example of two SUSY production

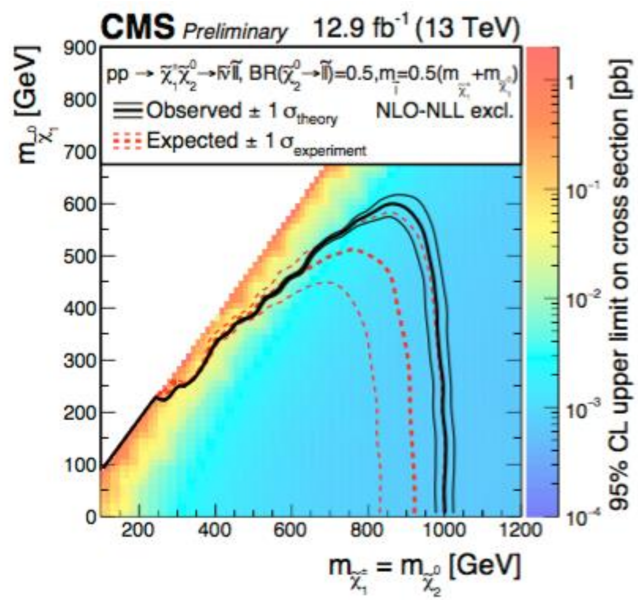


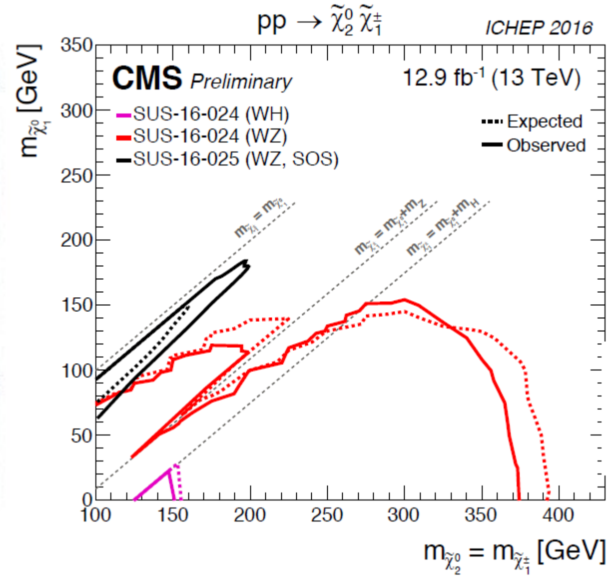


32 search regions

118 different search regions

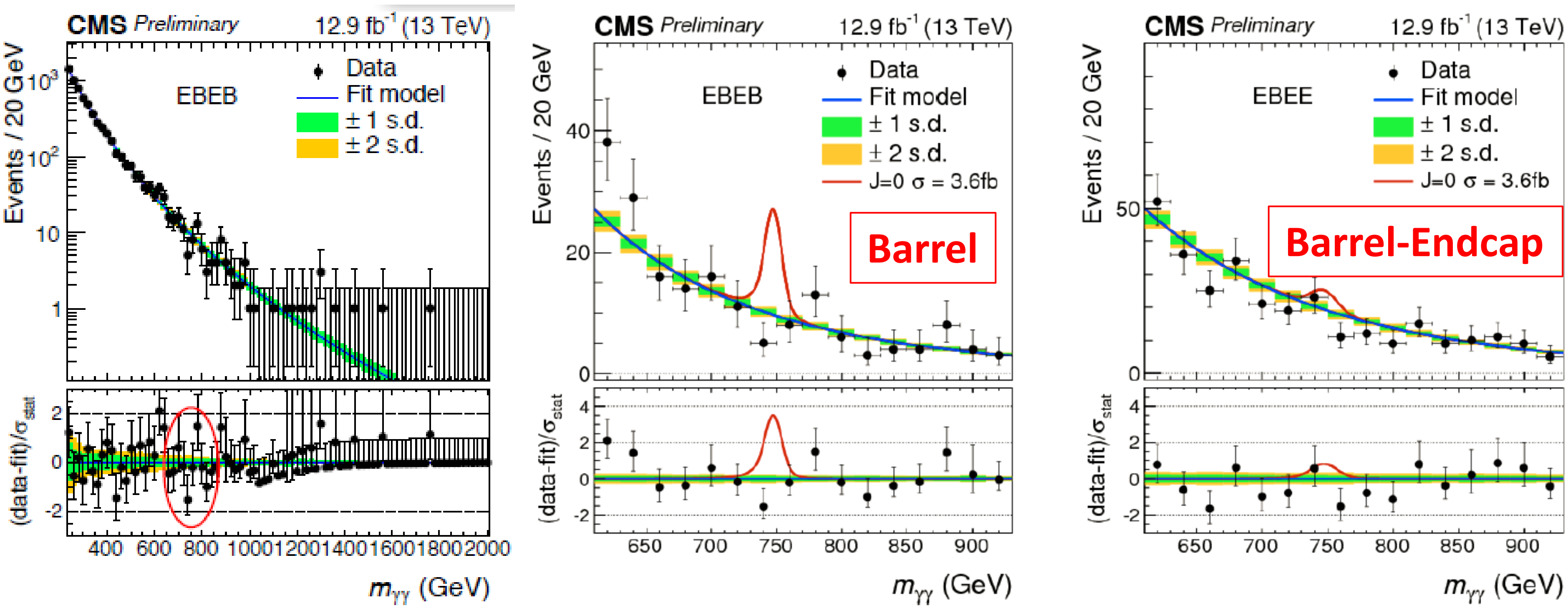


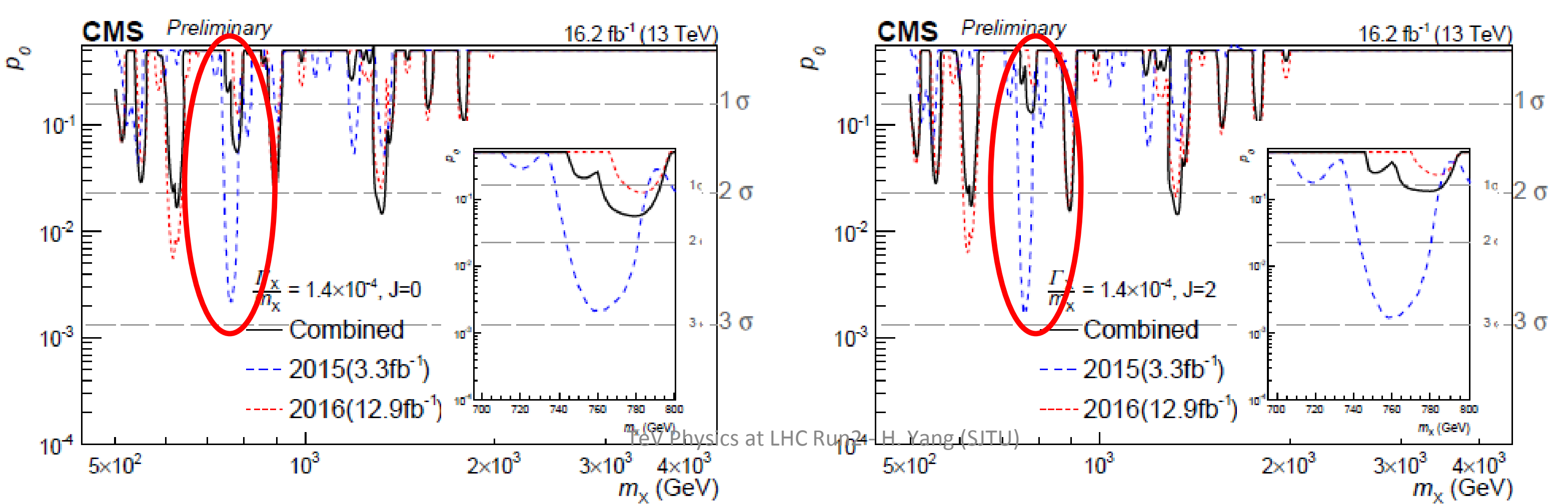




*Search for resonance X → γγ

CMS-PAS-EXO-16-027



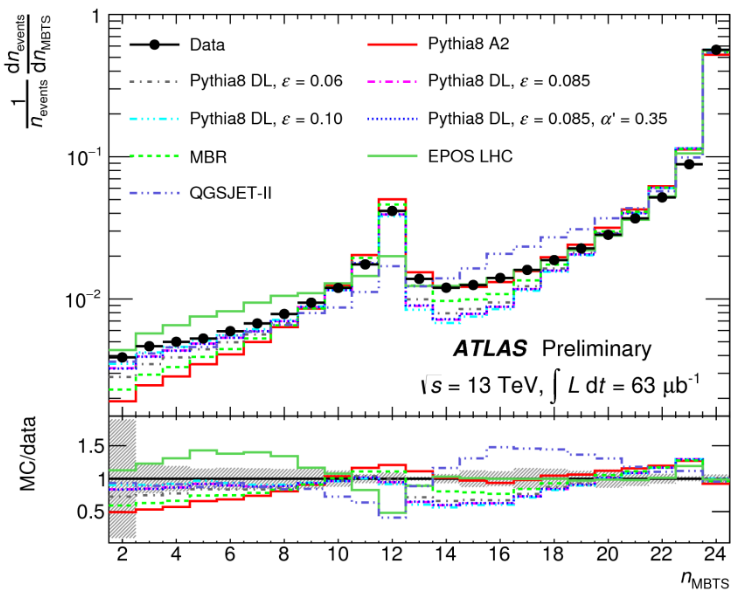


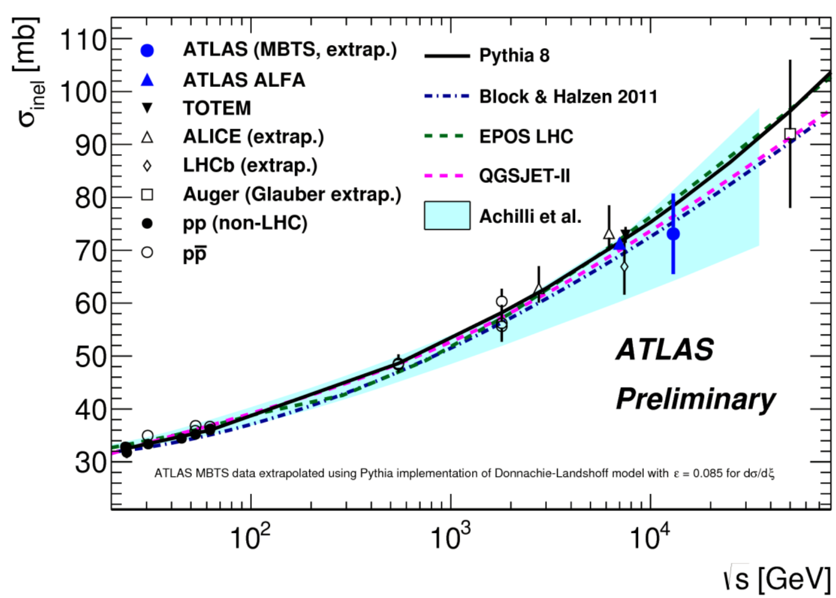
Inelastic pp Cross Section

- Using low pileup dataset ($\mu < 0.05$)
- Analysis with new MBTS scintillators ($2.1 < |\eta| < 3.9$)
- Result dominated by luminosity uncertainty (~9%)
- 4.2M events selected in 63 μb^{-1}, estimated 1% background

N_{MBTS} above threshold
(Data vs. MCs)

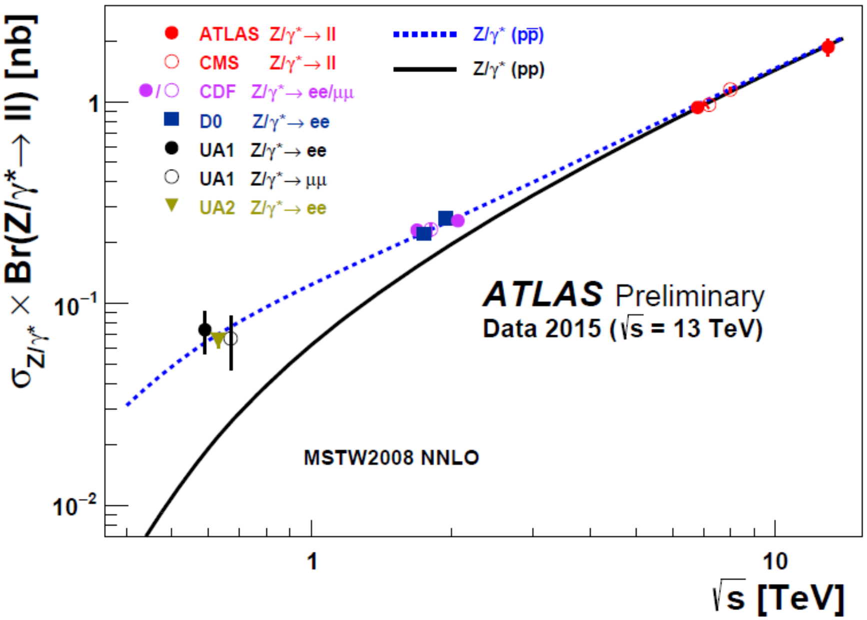
$$73.1 \pm 0.9\,(\text{exp.}) \pm 6.6\,(\text{lum.}) \pm 3.8\,(\text{extr.})\ \text{mb}$$

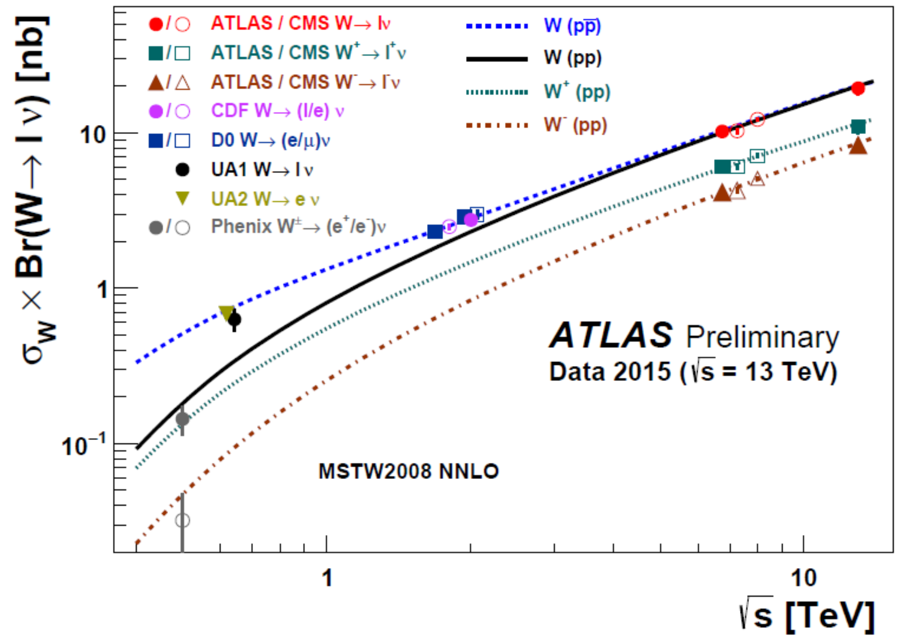


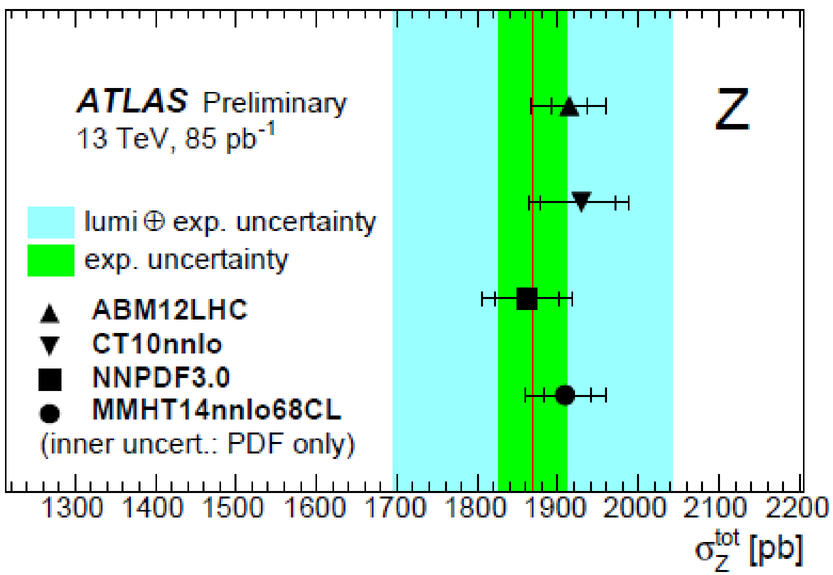


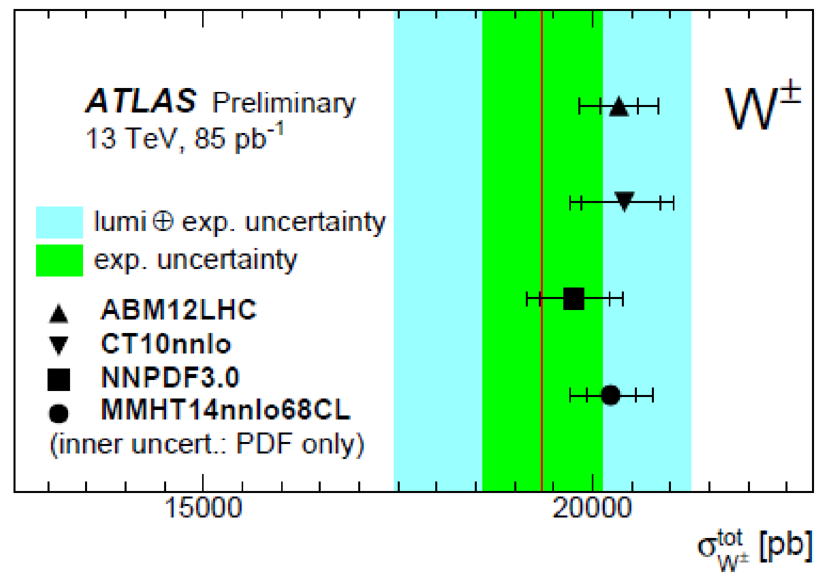
ATLAS-CONF-2015-039

W/Z Cross Section







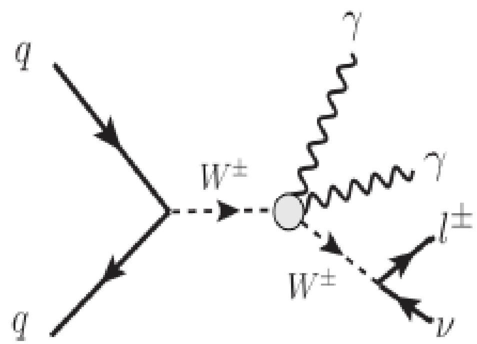


PRL 115 (2015) 031802

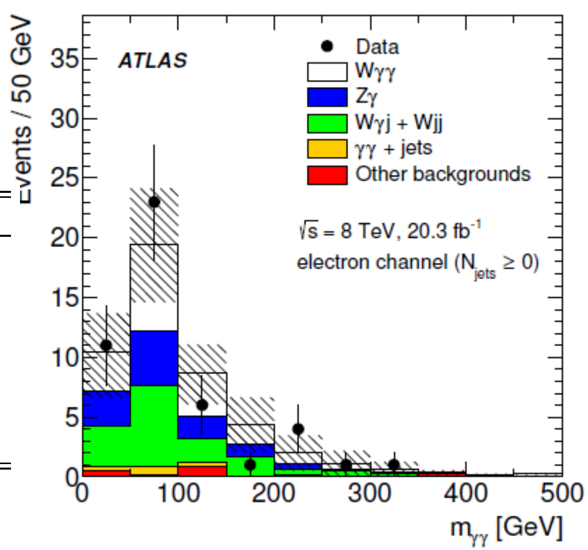
Evidence of Wγγ production

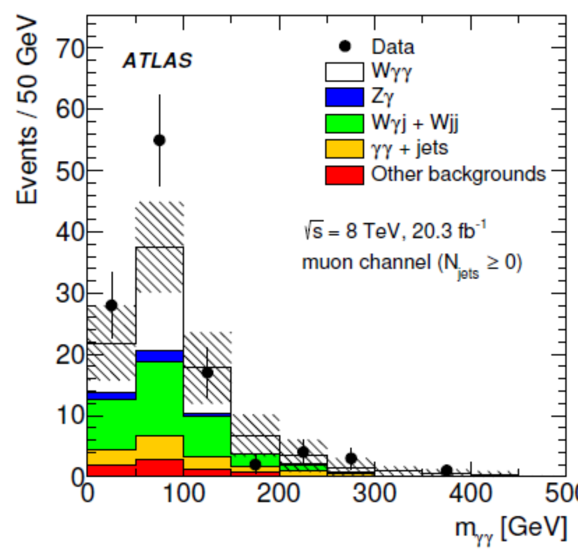
- **Tri-boson production with relative large cross section**
  - Final state: lepton + Etmiss + two photons
  - Main backgrounds : Wγj+Wjj
  - Sensitive to the WWγγ aQGC
- **First time have 3σ evidence of Wγγ**

	σ^{fid} [fb]	σ^{MCFM} [fb]
Inclusive ($N_{\text{jet}} \geq 0$)		
$\mu\nu\gamma\gamma$	$7.1\ ^{+1.3}_{-1.2}$ (stat.) ± 1.5 (syst.) ± 0.2 (lumi.)	
$e\nu\gamma\gamma$	$4.3\ ^{+1.8}_{-1.6}$ (stat.) $^{+1.9}_{-1.8}$ (syst.) ± 0.2 (lumi.)	2.90 ± 0.16
$\ell\nu\gamma\gamma$	$6.1\ ^{+1.1}_{-1.0}$ (stat.) ± 1.2 (syst.) ± 0.2 (lumi.)	
Exclusive ($N_{\text{jet}} = 0$)		
$\mu\nu\gamma\gamma$	3.5 ± 0.9 (stat.) $^{+1.1}_{-1.0}$ (syst.) ± 0.1 (lumi.)	
$e\nu\gamma\gamma$	$1.9\ ^{+1.4}_{-1.1}$ (stat.) $^{+1.1}_{-1.2}$ (syst.) ± 0.1 (lumi.)	1.88 ± 0.20
$\ell\nu\gamma\gamma$	$2.9\ ^{+0.8}_{-0.7}$ (stat.) $^{+1.0}_{-0.9}$ (syst.) ± 0.1 (lumi.)	

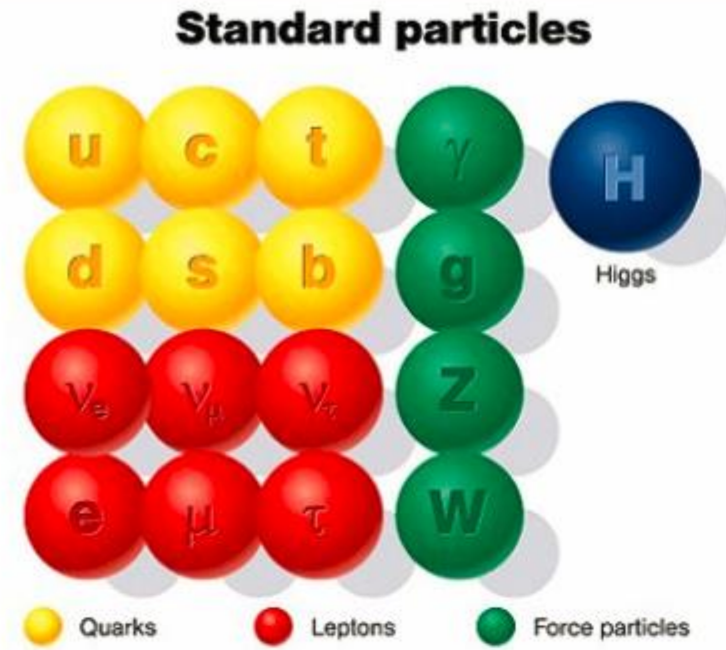


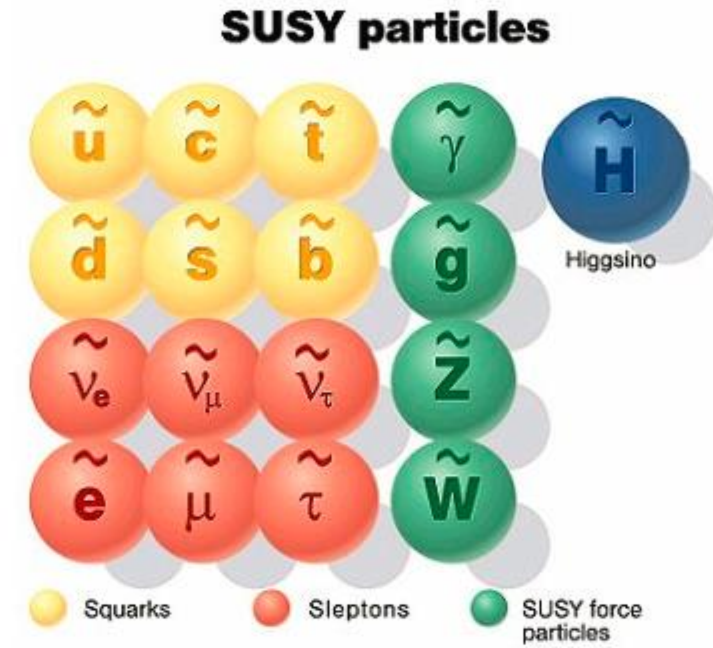
Definition of the fiducial region
$p_{\text{T}}^{\ell} > 20$ GeV, $p_{\text{T}}^{\nu} > 25$ GeV, $\lvert\eta_\ell\rvert < 2.5$
$m_{\text{T}} > 40$ GeV
$E_{\text{T}}^{\gamma} > 20$ GeV, $\lvert\eta^\gamma\rvert < 2.37$, iso. fraction $\epsilon_{\text{h}}^{\text{p}} < 0.5$
$\Delta R(\ell,\gamma) > 0.7$, $\Delta R(\gamma,\gamma) > 0.4$, $\Delta R(\ell/\gamma, \text{jet}) > 0.3$
Exclusive: no anti-k_t jets with $p_{\text{T}}^{\text{jet}} > 30$ GeV, $\lvert\eta^{\text{jet}}\rvert < 4.4$





Standard Model and Supersymmetry





- **Standard Model (SM)**

  Very successful description of phenomena at TeV scale, but some shortcomings:

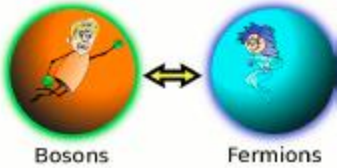
  - ❑ Hierarchy problem
  - ❑ Can not unify gauge couplings
  - ❑ No dark matter (DM)
  - ❑ …

- **Supersymmetry (SUSY)**

  Unique extension of Poincar spacetime symmetry

  - ❑ Moderate the hierarchy probler
  - ❑ Grand unification of gaug couplings
  - ❑ Provide excellent DM candidate
  - ❑ …

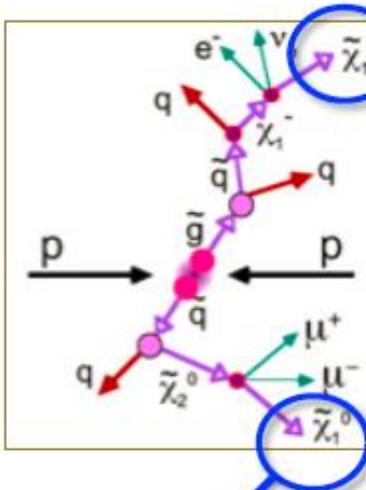
SUSY Introduction

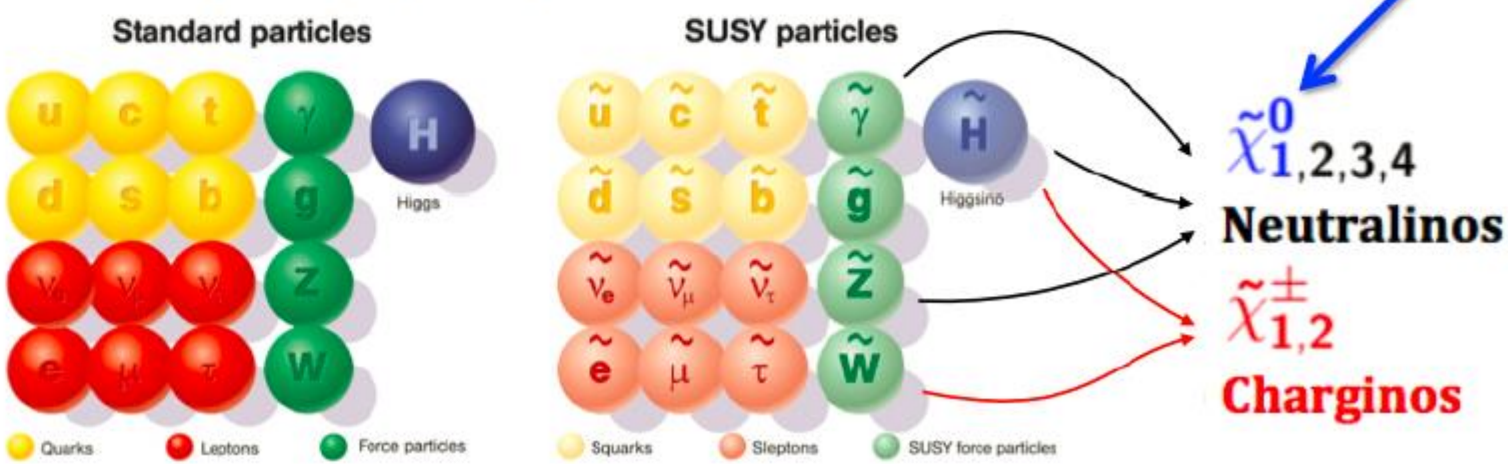


- **A symmetry which unified fermions (matter) and bosons (forces)** –> A fundamental theory
- **Conserved R parity (RPC):** (originally introduced for stability of proton) $R = (-1)^{3(B-L)+2S}$

  R=+1 (SM)
  R=-1 (SUSY)

  - SUSY particles produced/annihilated in pairs
  - Lightest SUSY particle (LSP) stable (DM candidate)
  - Typical signature: jets/leptons/photons + **MET**
- **Violated R parity (RPV)**: no Dark Matter candidate





Search for stop pair

ATLAS-CONF-2016-007

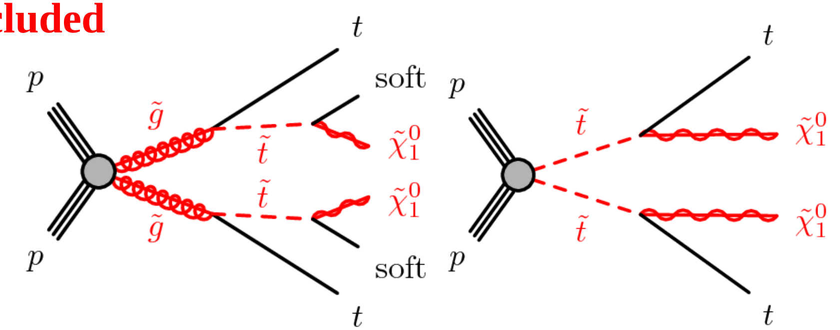
➔ SUSY is a natural solution to the hierarchy problem. If R-parity is conserved, SUSY particles are produced in pairs and LSP is stable. The stop is expected to be light due to it's large contribution to the Higgs mass radiative correction.

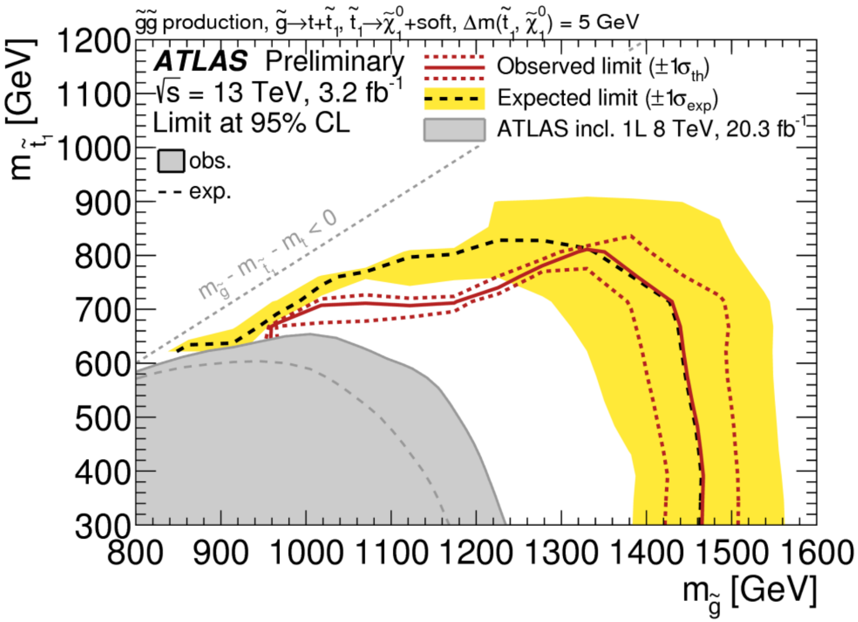
➔ **Scenario #1**: Gluino-mediated pair production, assuming 100% BR via stop➔c+neutralino, and mass splitting of 5 GeV. **M_{Gluino} < 1460 GeV is excluded**

➔**Scenario #2:** direct pair production of stop

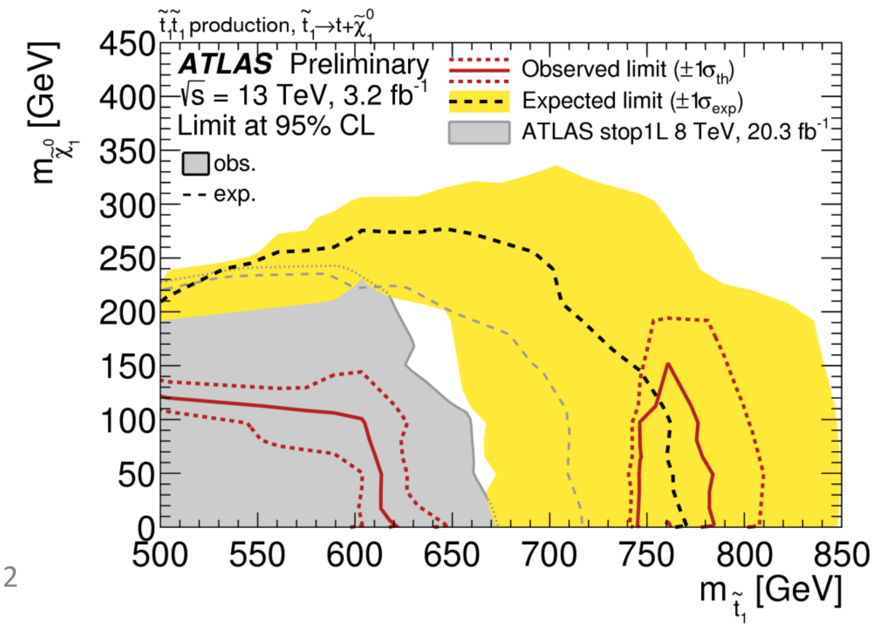
(➔ top + neutralino), **excludes stop mass from**

745 to 780 GeV for a massless neutralino at 95% CL.





Run2

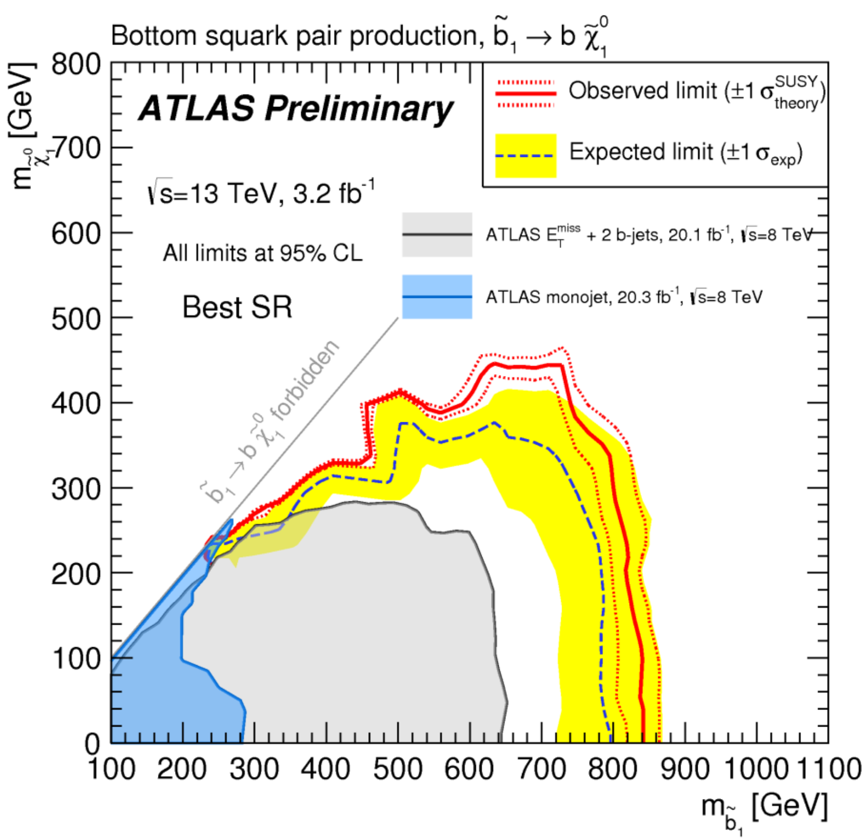


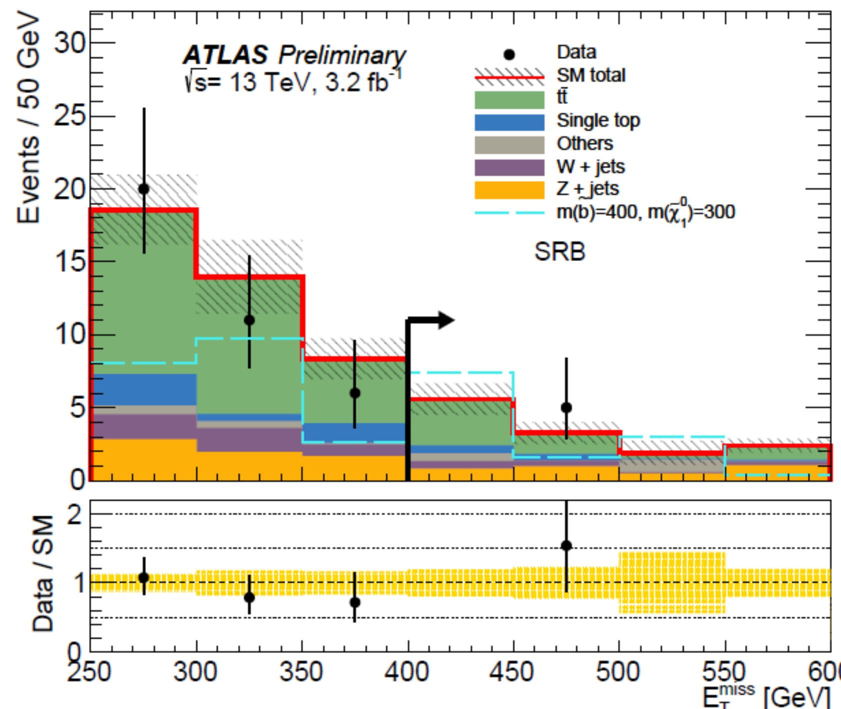
Search for sbottom pair

ATLAS-CONF-2015-066

- Search for bottom squarks pair decaying exclusively as b-quark and LSP neutralino. The signature has 2 b-jets and large MET. $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$
- Bottom squark mass < 800 GeV are excluded for neutralino mass below 360 GeV at 95% CL.

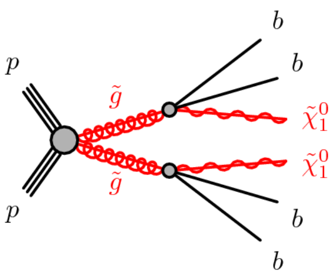
Signal channel	$\langle \epsilon A \sigma \rangle_{obs}^{95}$ [fb]	S_{obs}^{95}	S_{exp}^{95}
SRA250	2.74	8.8	$15.8^{+6.3}_{-4.4}$
SRA350	1.90	6.1	$8.1^{+3.7}_{-2.3}$
SRA450	1.16	3.7	$4.4^{+2.6}_{-1.0}$
SRB	1.57	5.0	$8.5^{+3.9}_{-2.4}$

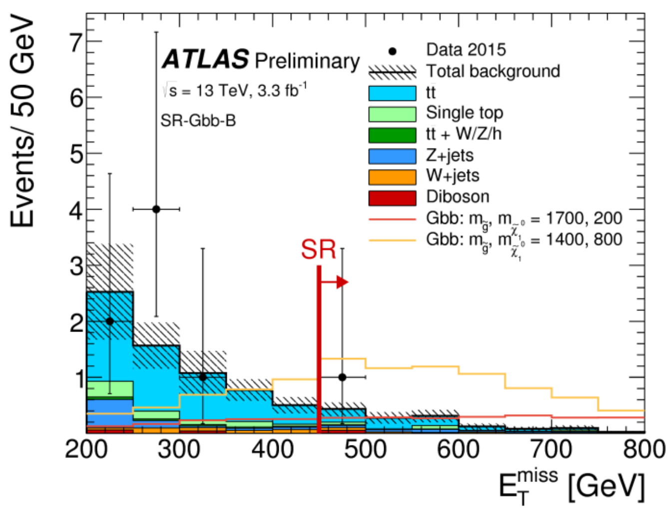


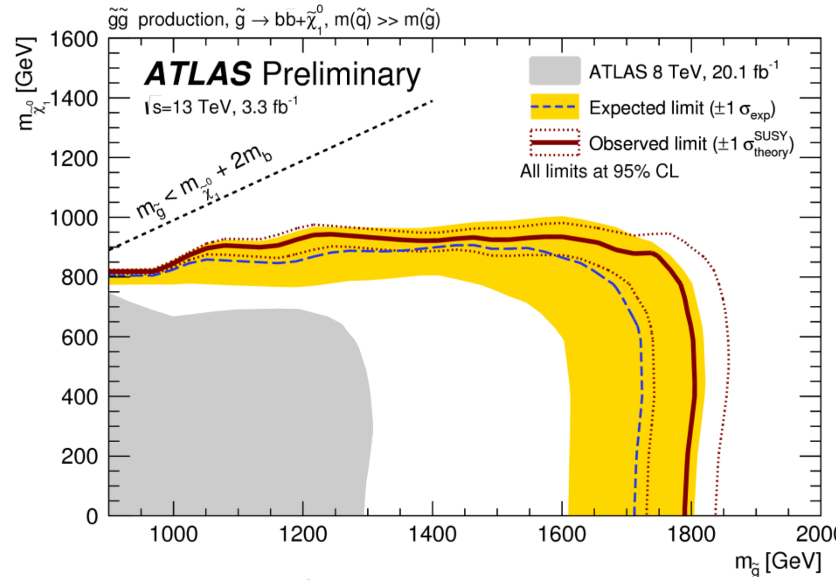


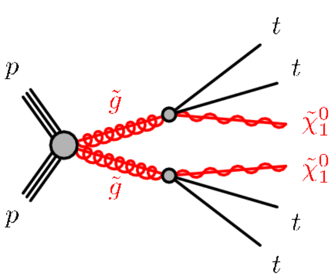
Search for gluino pair

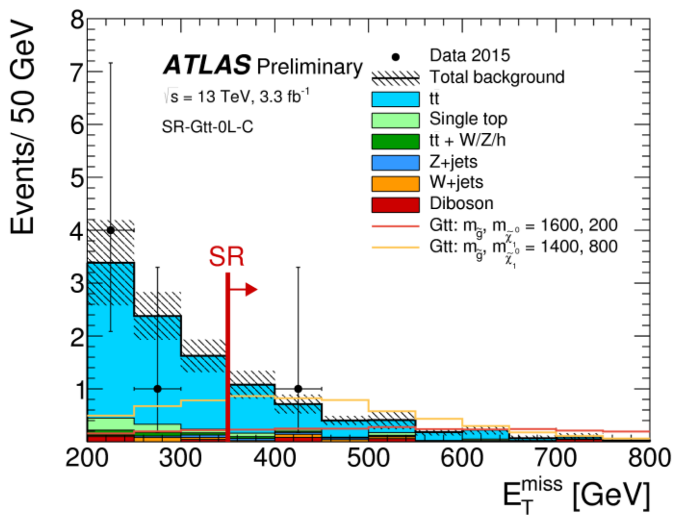
ATLAS-CONF-2015-067

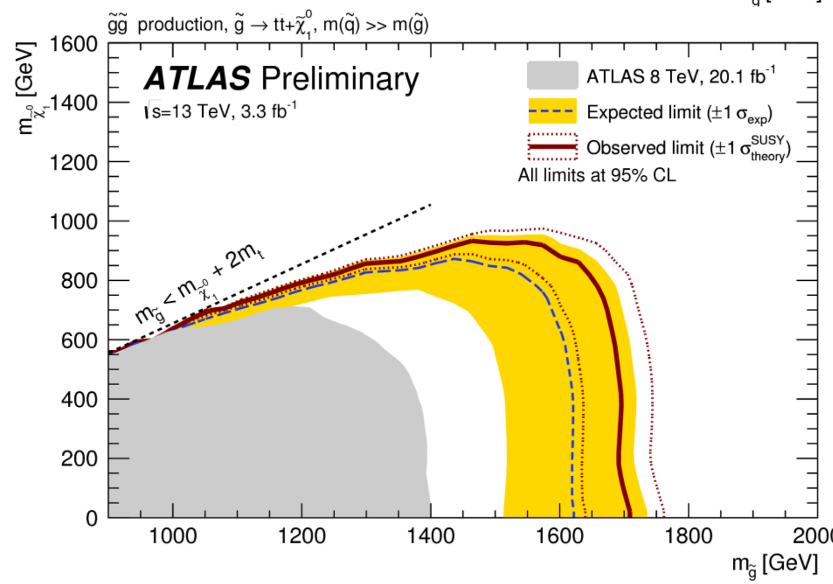






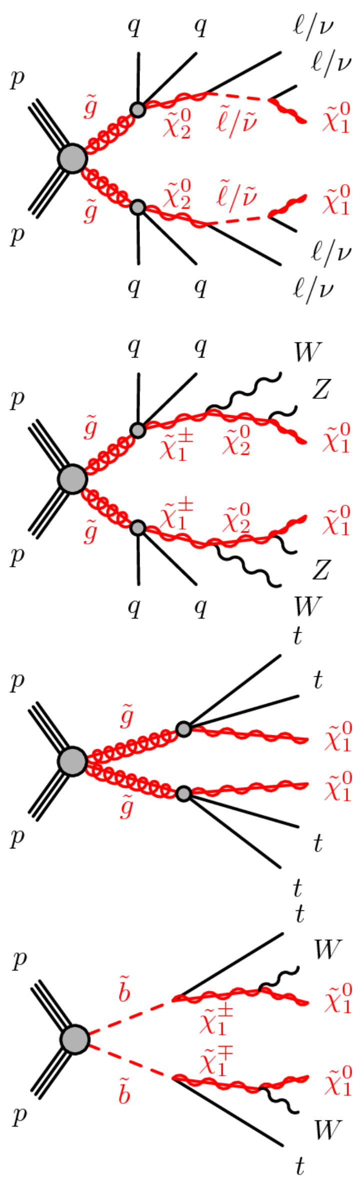


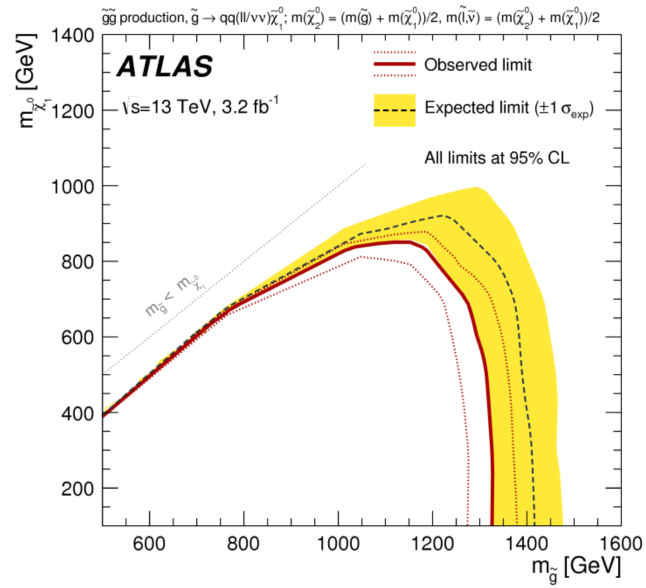


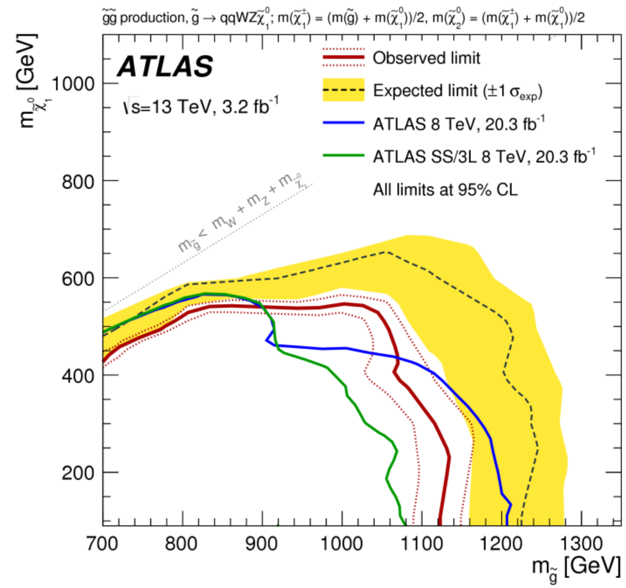


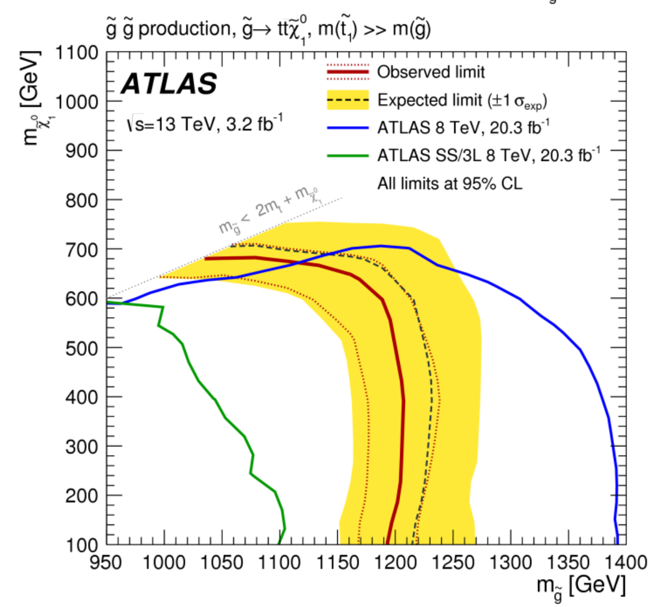
Search for SUSY Gluino and sbottom

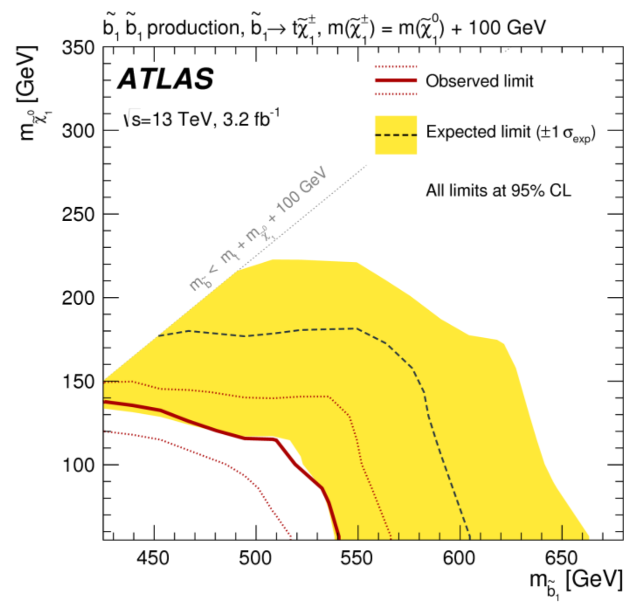
arXiv:1602.09058







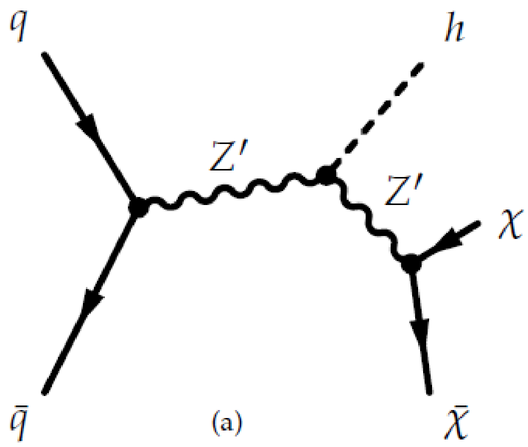




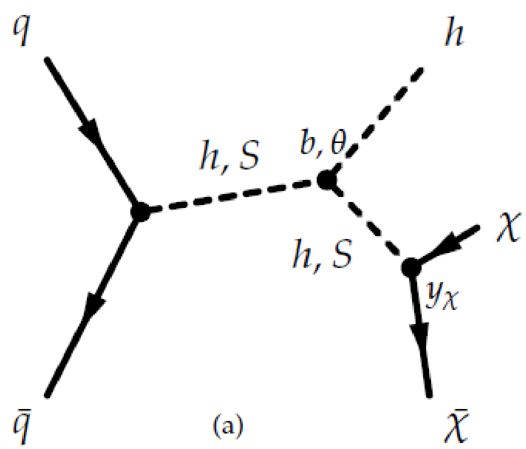
Search for Higgs + DM

ATLAS-CONF-2015-059

- ❑ To search for Dark Matter (MET) associated with a Higgs boson.



(a)



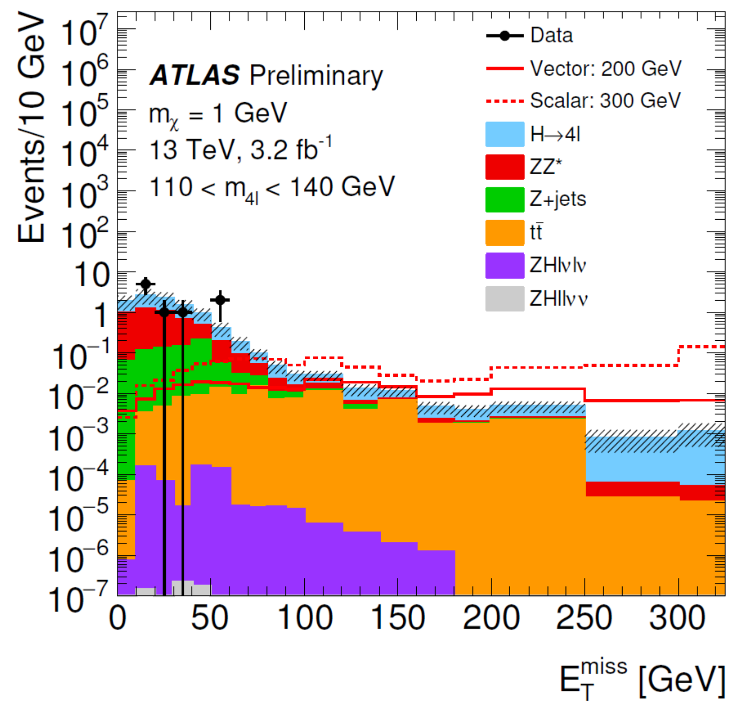
(a)

No significant excess is found in search for Higgs boson with large MET.

Vector mediator hZ’

Scalar mediator hS

Process	High-E_T^{miss} category ($E_T^{miss} > 100$ GeV)	Low-E_T^{miss} category ($E_T^{miss} < 100$ GeV)
$H \to ZZ^* \to 4\ell$	$(2.1 \pm 0.6) \cdot 10^{-2}$	4.9 ± 0.5
ZZ^*	$(0.7 \pm 0.4) \cdot 10^{-2}$	4.4 ± 0.4
Z+jets and $t\bar{t}$	$(3.1 \pm 1.2) \cdot 10^{-2}$	0.8 ± 0.5
$ZH(\ell\nu\ell\nu)$	$(1.2 \pm 0.6) \cdot 10^{-5}$	$(5.8 \pm 0.8) \cdot 10^{-4}$
$ZH(\ell\ell\nu\nu)$	$(1.3 \pm 0.8) \cdot 10^{-7}$	$(8.2 \pm 1.5) \cdot 10^{-7}$
Total background	$(5.9 \pm 1.6) \cdot 10^{-2}$	10.1 ± 1.0
Vector mediator signal $m_\chi = 1$ GeV, $m_{med} = 200$ GeV	$(9.7 \pm 3.3) \cdot 10^{-2}$	$(1.3 \pm 0.6) \cdot 10^{-1}$
Scalar mediator signal $m_\chi = 1$ GeV, $m_{med} = 300$ GeV	0.41 ± 0.14	0.44 ± 0.09
Data	0	0



Search for W' → $\ell\nu$

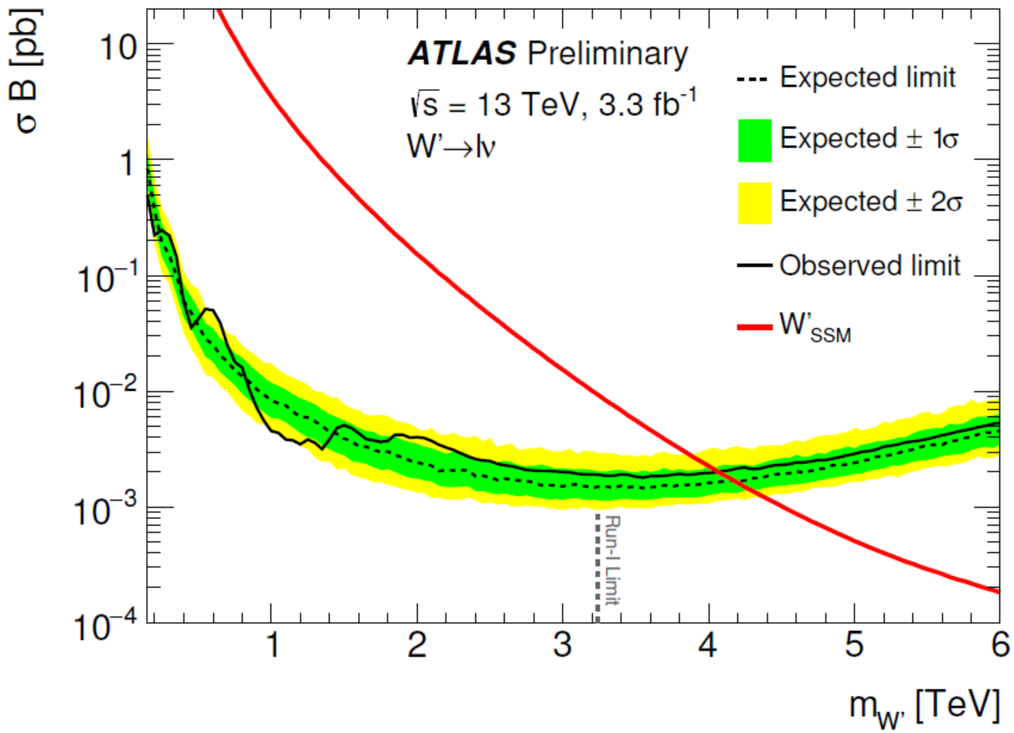
ATLAS-CONF-2015-063

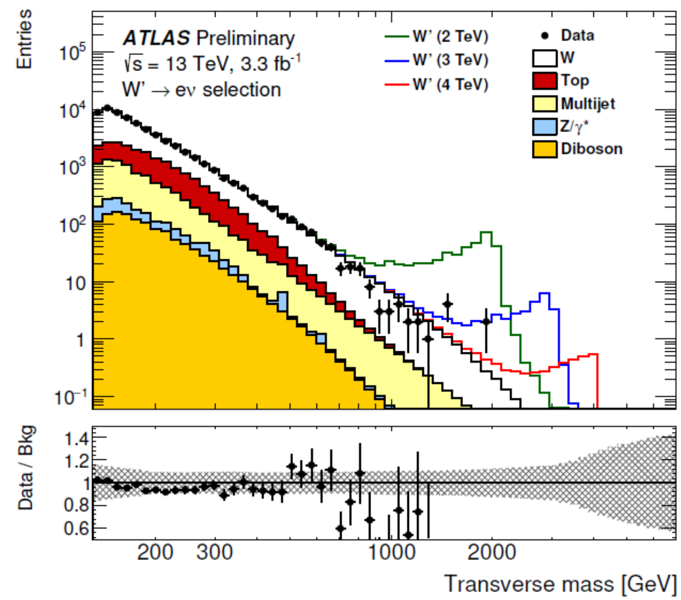
- ❑ BSM models predict new spin-1 boson (SSM W'), it is heavier version of the SM W boson.

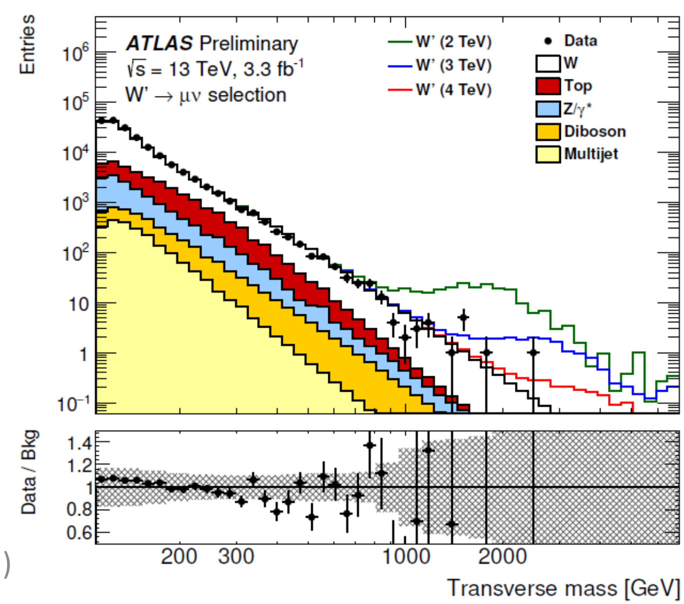
$W' \rightarrow \ell\nu$ channel

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

Decay	$m_{W'}$ limit [TeV] Expected	Observed
$W' \rightarrow e\nu$	4.03	3.98
$W' \rightarrow \mu\nu$	3.66	3.42
$W' \rightarrow \ell\nu$	4.18	4.07







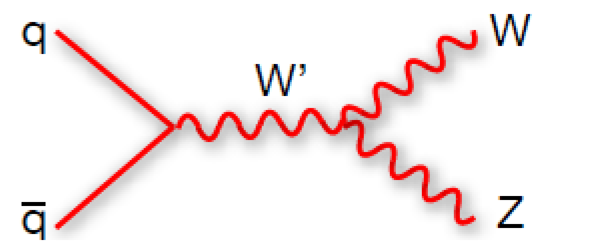
A bit about the models...

Slide borrowed from V. Cavaliere...

Charged (WZ)

Sequential Standard Model (W', spin-1)

- Trilinear W'WZ coupling set by Extended Gauge Model: ~ $(M_W/M_{W'})^2$



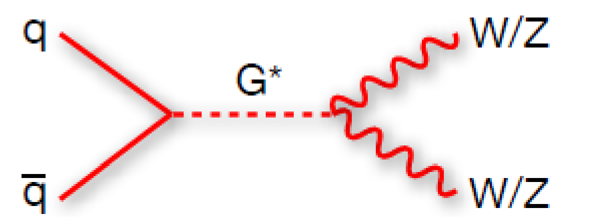
Neutral (WW,ZZ,HH)

Randall-Sundrum graviton (RS G*, spin-2)

- Traditional benchmark model with extra dimensions

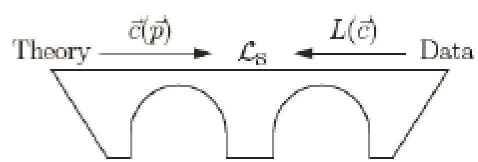
Bulk RS graviton (Bulk G*, spin-2)

- Graviton couples more with heavy particles (W, Z, t)
- Smaller σ, but larger branching ratio to WW, ZZ



Minimal Walking Technicolor (R_1,R_2, charged and neutral)

- Technicolor with minimal ingredients, can decay to ZH and WH



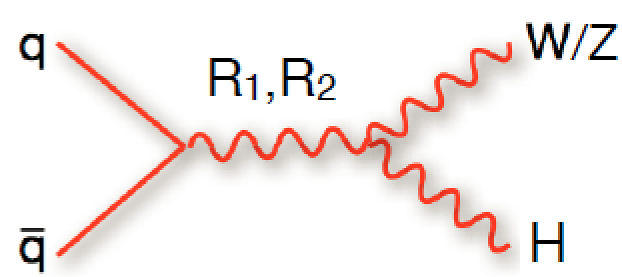
HVT (Simplified Lagrangian)

Model A

- weakly coupled vector resonances from extension of the gauge group

Model B

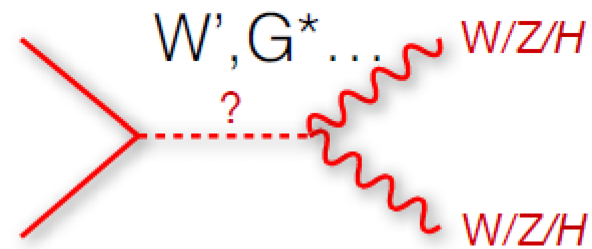
- produced in a strong scenario e.g. composite higgs model



Search for Diboson Resonance

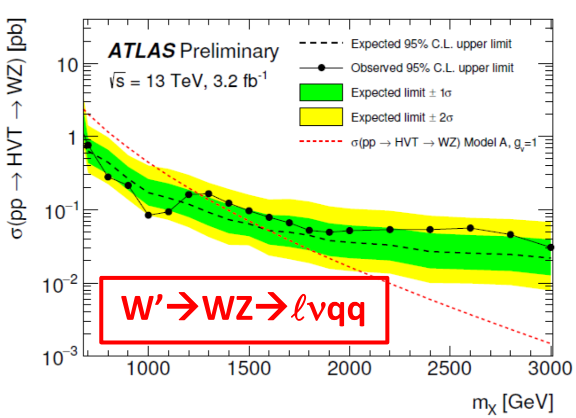
ATLAS-CONF-2015-071
ATLAS-CONF-2015-075

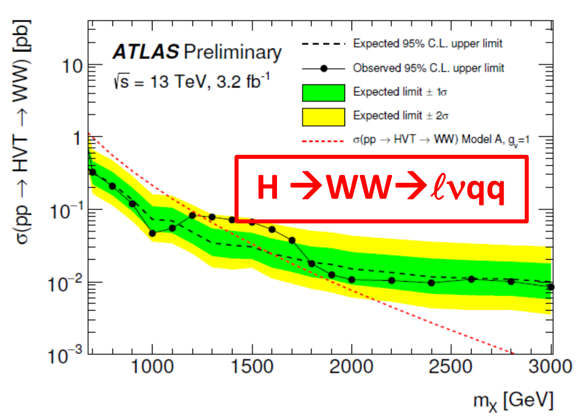
- ❑ **Search for heavy resonances in diboson final states (eg. $\ell\ell qq$, $\nu\nu qq$, $\ell\nu qq$, qqqq), well-motivated extensions to the SM and has very rich phenomenology. LHC Run1 observed some excess which needs cross check using 13 TeV data at Run2**
  - Heavy Vector Triplet (HVT) model A, BR(W'→ WZ) ~ 2%
  - Kaluza-Klein (KK) modes in Randall-Sundrum(RS) graviton model, BR(G*→ZZ)~ 8-10%
  - Generator: MadGraph5 2.2.2 (NNPDF23LO)

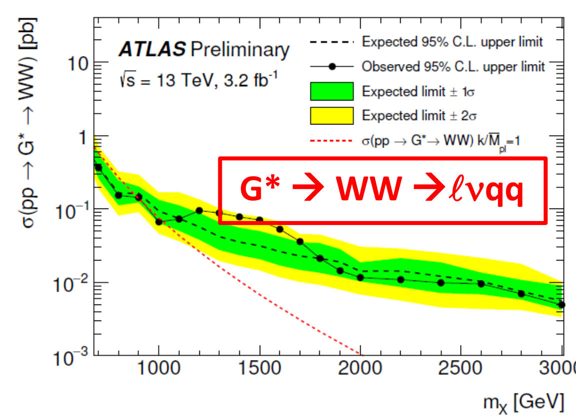


- ❑ **Two heavy Higgs-like boson hypotheses are tested (H→WW→ $\ell\nu qq$):**
  - ❑ Narrow Width Assumption (NWA, SM Higgs width of 4MeV) ,
  - ❑ Large Width Assumption (LWA, 5-15% of heavy Higgs mass)

- ❑ **No evidence is observed, masses below 1060 GeV and 1250 GeV are excluded at 95% CL for spin-2 RS G*→WW and H→WW. Upper limits on $\sigma \times$ BR(H→WW) with NWA/LWA $\in$ [0.02, 0.3]pb**

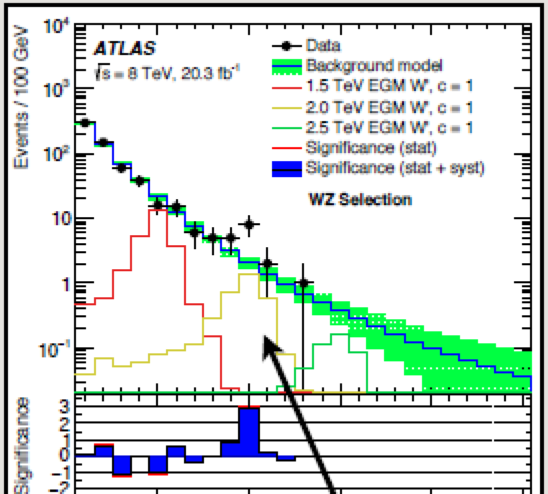


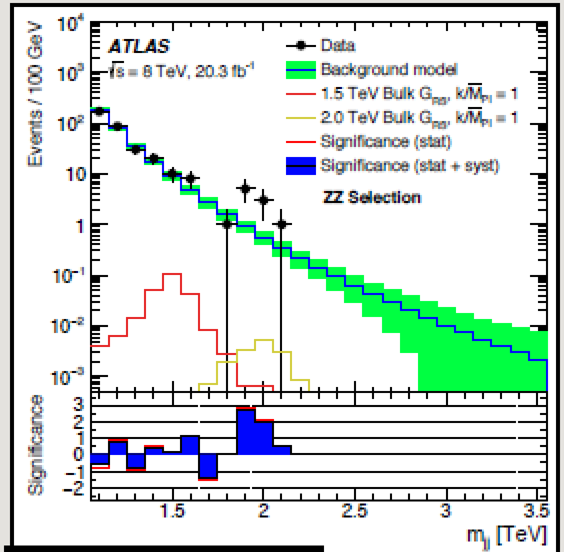


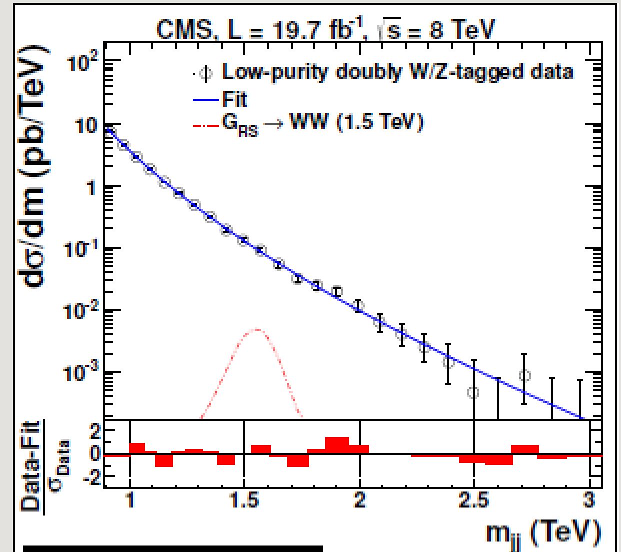


ZZ & WZ & WW → *qqqq*

Dijet boosted final state:
Identification of di-boson state is through the use of tagging techniques







3.4σ local excess in WZ channel (2.5σ global)!

arxiv.1506.00962

arxiv.1405.1994

ATLAS

Dedicated selection for all 3 channels based on W/Z jet mass requirements (26 GeV windows), implying **statistical overlap** between channels

2 large **CA** R=1.2 jets with n_{trk} < 30 are required in the events, satisfying boson tagging requirements (grooming & filtering). Extra topology requirements are used to reduce QCD backgrounds

CMS

Require 2 **CA** R=0.8 jets in the events along with topology requirements to reduce backgrounds

Jets are W/Z-tagged based on a combination of pruned mass and subjettiness requirements
Separate events into 1/2 tag category, and use same **HP/LP** classification as in the *llqq* analysis