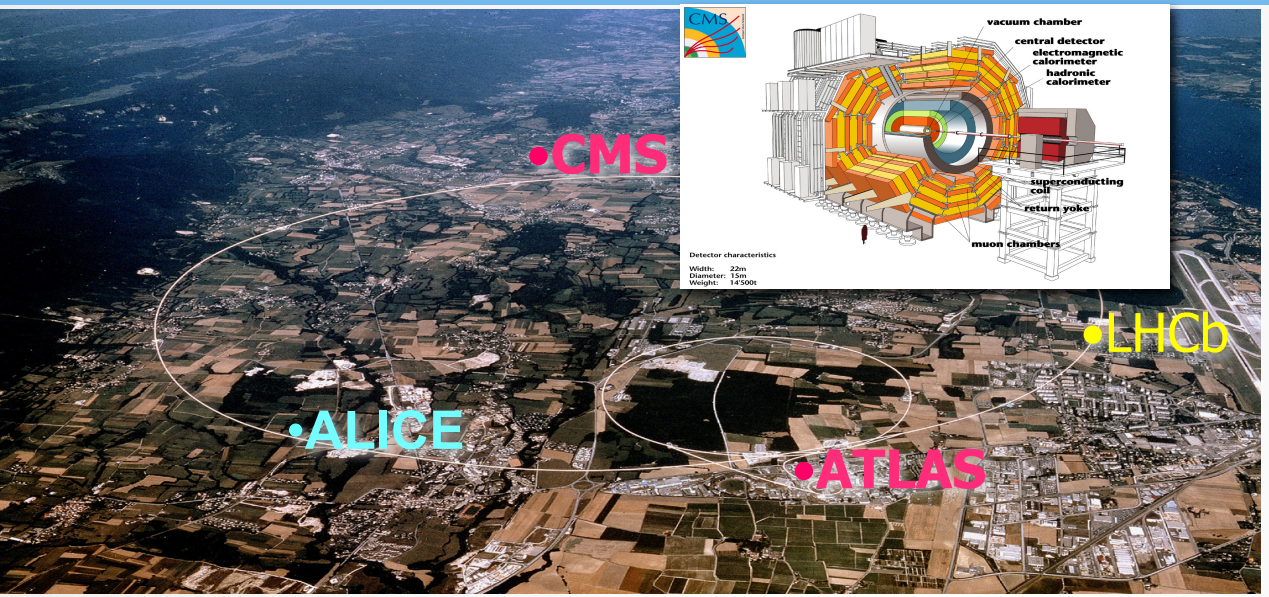
CMS中国组2021年研究进展

袁 丽

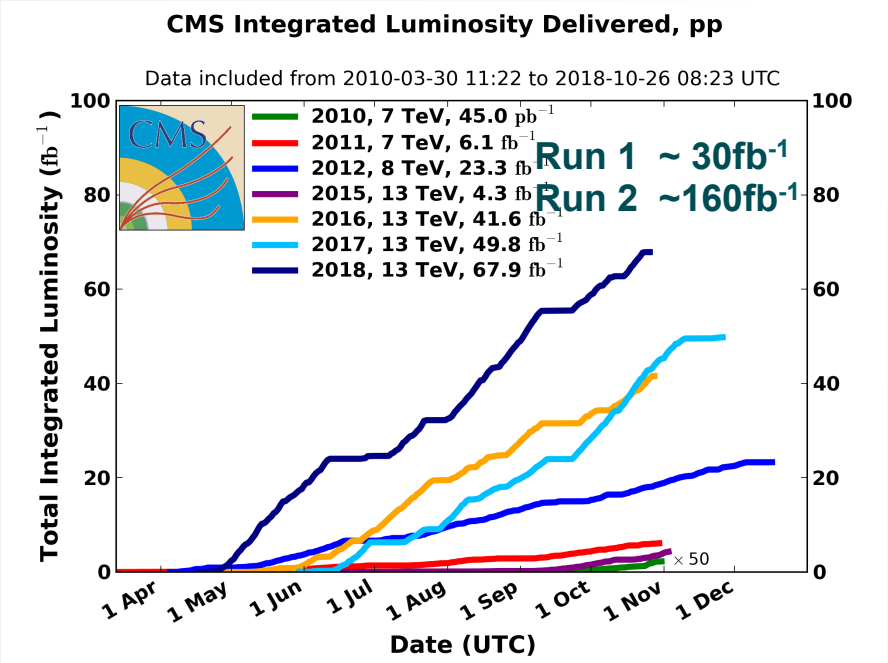
谨代表CMS中国组

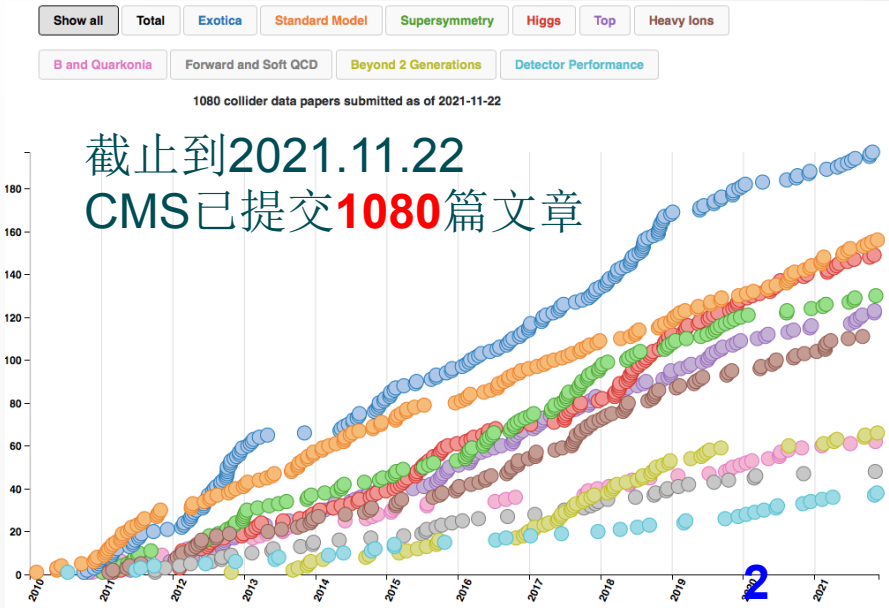
2021. 11. 25

CMS合作组



- CMS探测器：
  - 实现多重物理目标
  - 长～22米，直径～15米的圆柱型探测器
  - ～14500吨，相当于2个埃菲尔铁塔的重量





中国组参与CMS人数

单位	职工人数	博士后人数	学生人数	总人数	Authors
高能所	19	8	13	40	15
北大	5	4	21	30	12
北航	2	2	3	7	4
清华/南师大	5	5	24	34	7
中山大学	1	1	3	5	2
浙江大学	3	0	5	8	2
复旦大学	2	3	1	6	4
总数	37	23	70	130	46

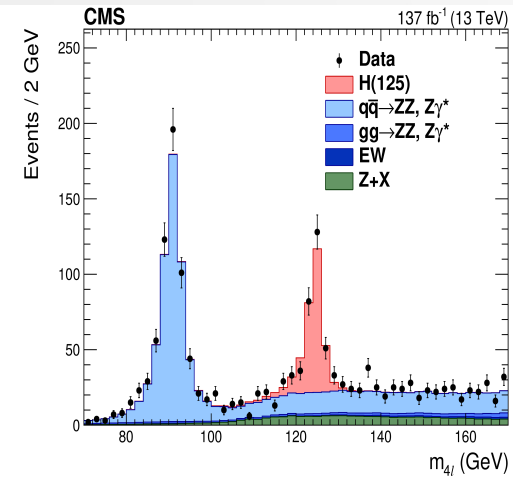
文章签名人数占CMS总签名人数2. 2%

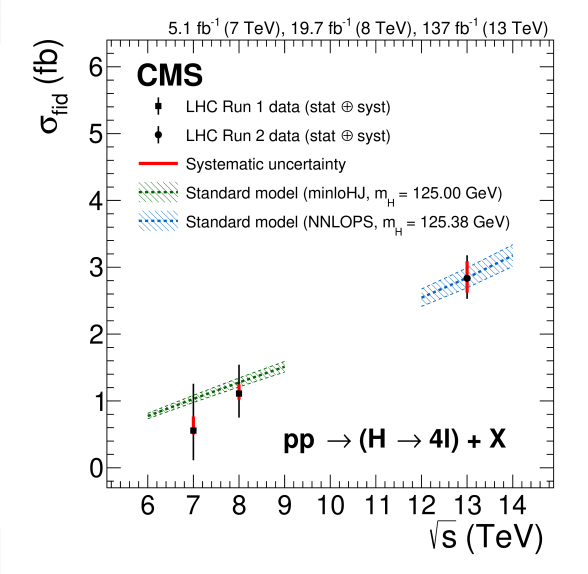
CMS中国组参与的物理分析

Highlights:

1. 希格斯粒子性质测量
2. 精确检验标准模型
3. 新粒子寻找

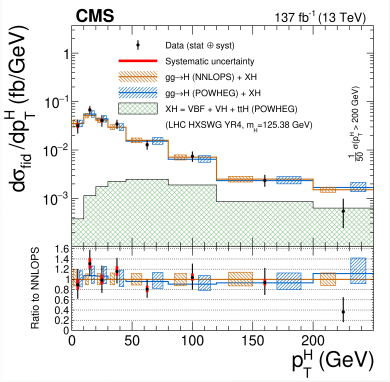
希格斯产生截面测量: H→ZZ→4l

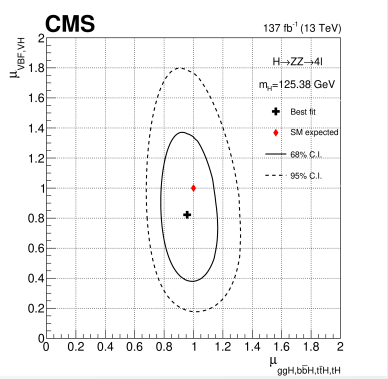




CMS-PAS-HIG-19-001

EPJC 81 (2021) 488



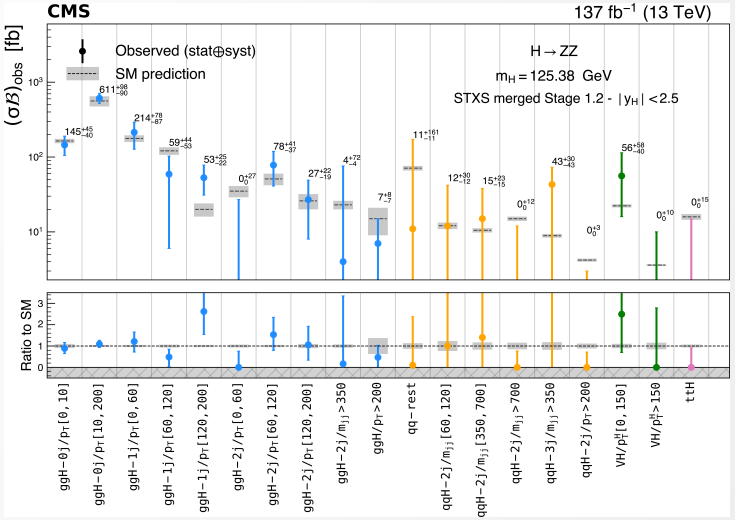


- 利用Full Run 2数据测量总截面、微分截面等

  Inclusive fiducial $\sigma = 2.84^{+0.23}_{-0.22}$ (stat) $^{+0.26}_{-0.21}$ (syst) fb

  – 精度为12%

- 中国组主要贡献：负责轻子的效率测量及蒙卡样本修正、独立分析框架检验、产生截面的全流程分析，并给予合作组Pre-approval报告



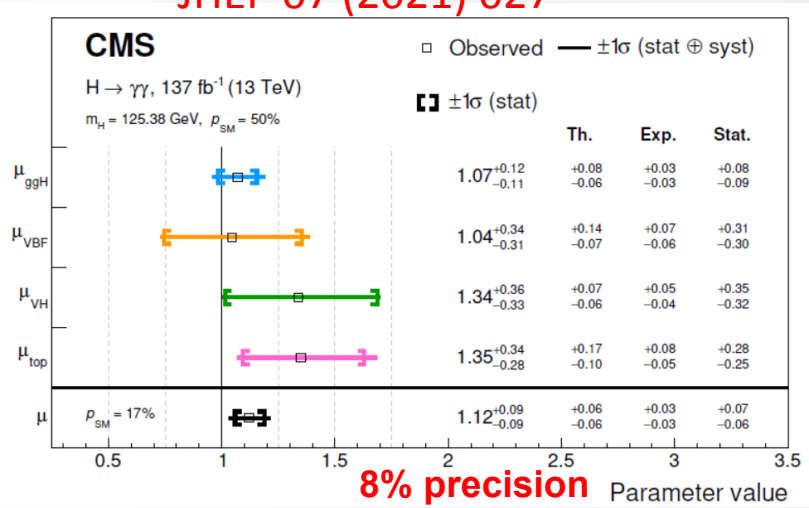
高能所、北航、浙大、清华

希格斯产生截面测量: H→γγ

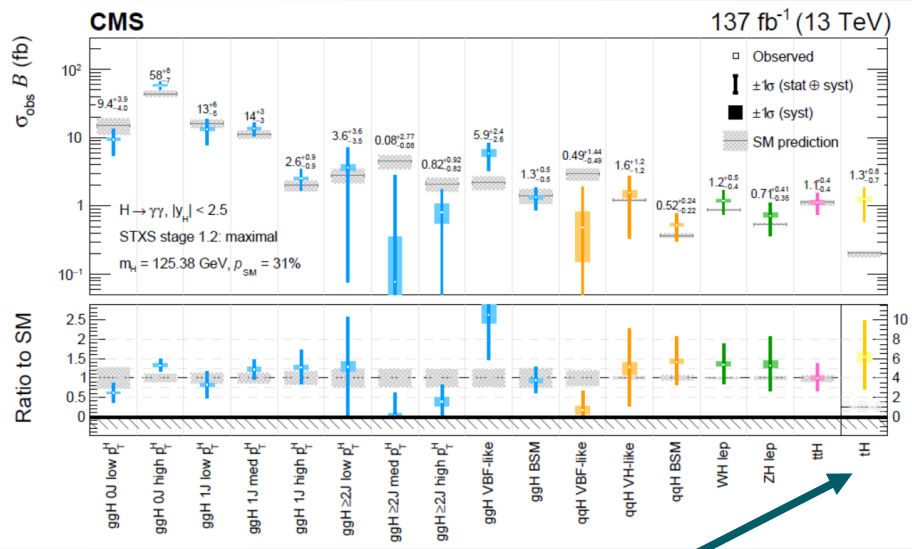
CMS-PAS-HIG-19-015

JHEP 07 (2021) 027

- 基于Run-2全部数据，测量了Higgs的信号强度和基于简化模式模板产生截面(STXS)：
  - **测量精度~8%**
  - **首次测量了tH的截面**
- 高能所在“common tools”分析，包括光子鉴别、MC样本模拟和修正、能量刻度、电子的排除等方面做出直接贡献，是CMS内部文章的编辑人之一和**Ultra-legacy数据分析common tools内部文章的主编辑**



8% precision

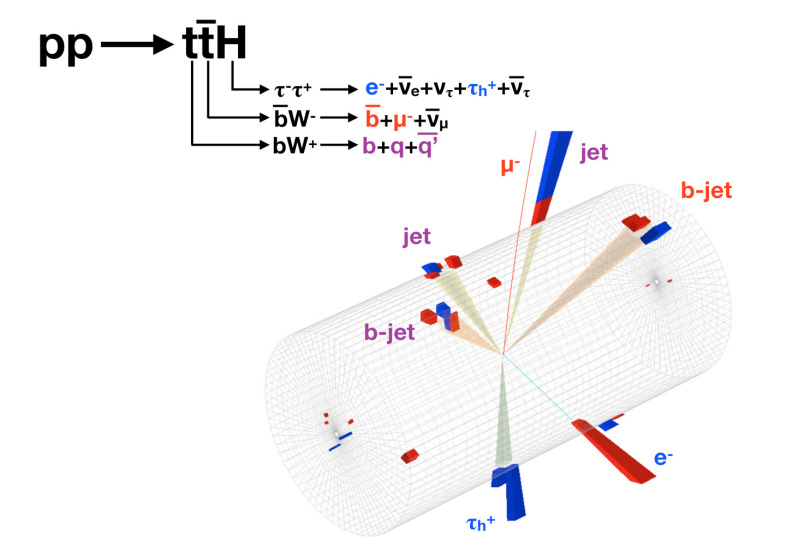


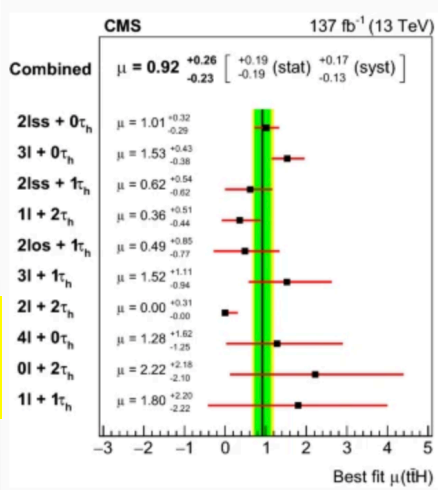
tH : 14obs.(8exp.)×σ_{SM}

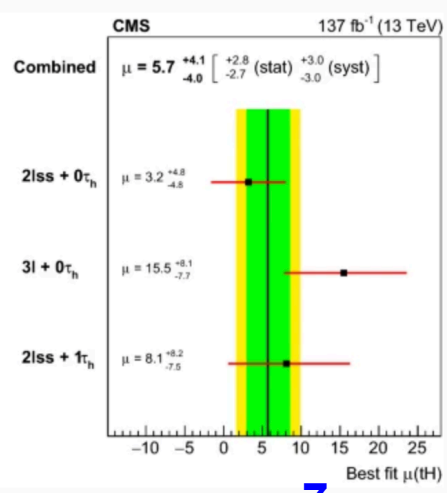
希格斯产生截面测量: ttH多轻子末态

- 利用139fb^{-1}的Run 2数据，发表ttH、tH截面测量结果
  - 最灵敏的ttH产率测量结果
  - 高能所改进了轻子鉴别，研发了Higgs-jet tagger等，主导的DNN分析方案被采纳
  - 高能所做unblinding报告

CMS-PAS-HIG-19-008
EPJC 81(2021) 378







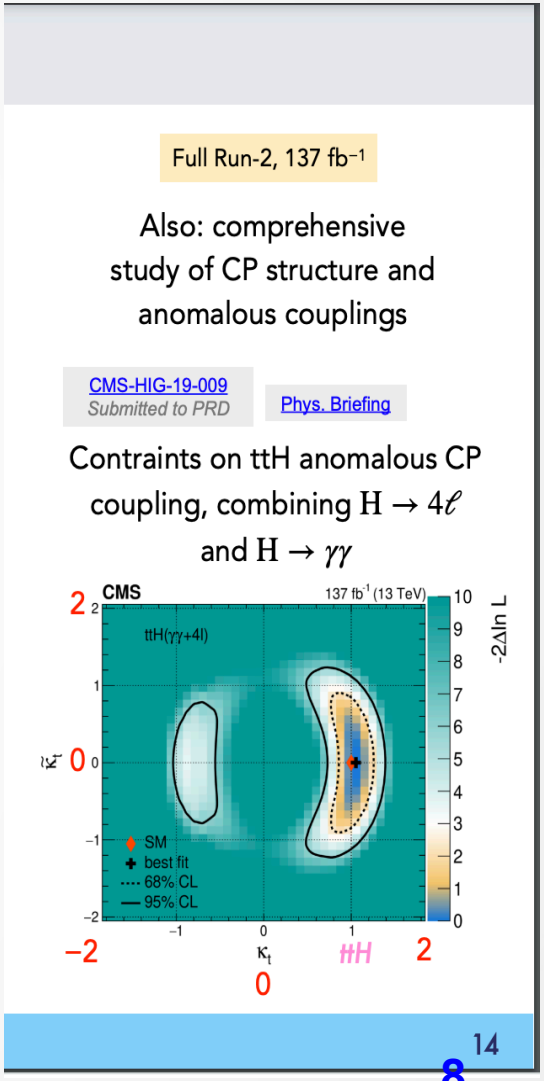
CMS实验组发表新闻通稿
“Higgs playing with top in singles and doubles”

希格斯反常耦合和EFT测量

CMS-PAS-HIG-19-009
PRD 104(2021) 052004

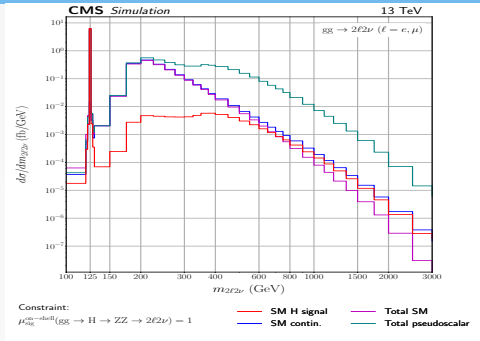
- 首次通过结合ttH, ggH共同测量H-tt作用的CP和EFT系数
- 在四轻子末态测量多个EFT算符系数，并与双光子结果结合
- 浙大担任分析联系人、文章编辑, 做approval报告
- LHCP 2021 CMS亮点工作之一

CMS实验组发表新闻通稿
“Higgs Scrutinizing production and decay kinematics of the Higgs boson using its golden decay channel”



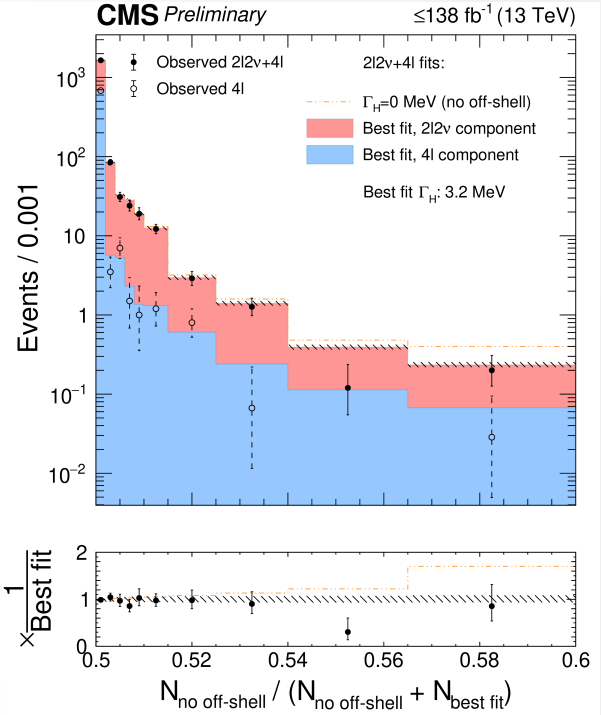
希格斯离壳事例研究: H→ZZ

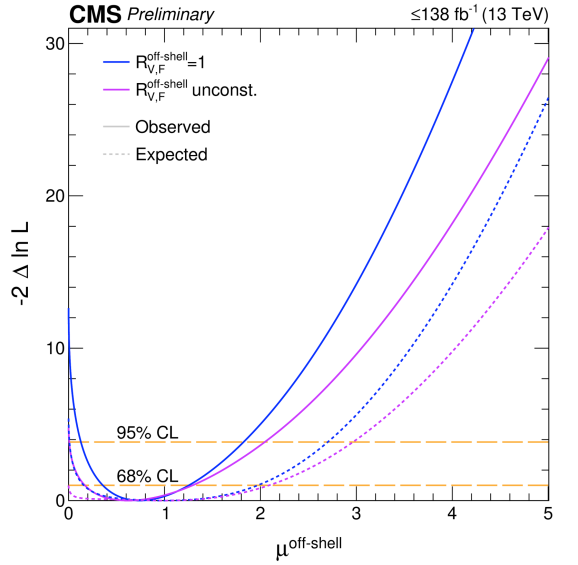
- 希格斯离壳事例仅为在壳事例~1/10
- 联合在壳事例和离壳事例间接测量希格斯宽度:
  - **首次观测到离壳事例的证据（3.6σ）**
  - **测得希格斯宽度 $3.2^{+2.4}_{-1.7}$ MeV**
- 北航担任该分析召集人、文章编辑，做pre-approval报告
- **Higgs2021 CMS亮点工作之一**

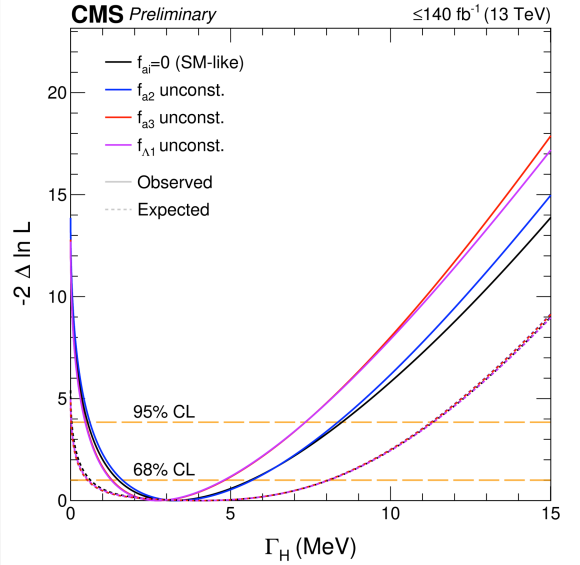


CMS-PAS-HIG-21-013

To be submitted to Nat.Phys.





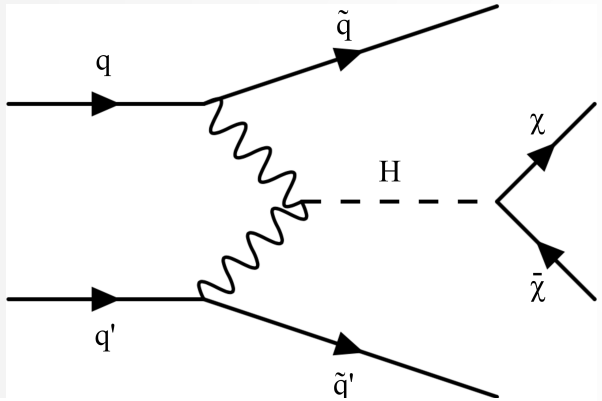


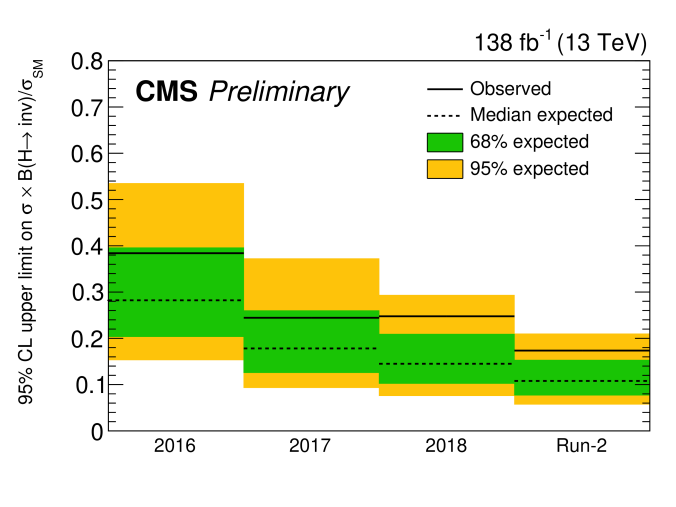
希格斯不可见衰变

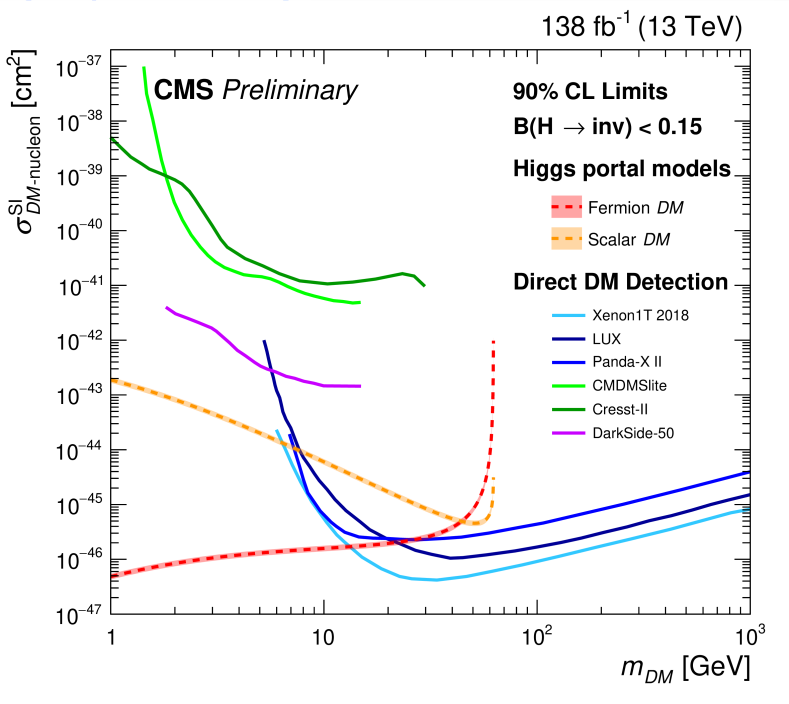
- 暗物质是否与希格斯相互作用？
  - Higgs boson could be a mediator between SM and DM sector
  - Detection would require it to recoil against a visible system

CMS-PAS-HIG-20-003

- 通过VBF产生过程来探测希格斯不可见衰变
- 高能所博后Vukasin做主要贡献（曾担任Analysis Contact）







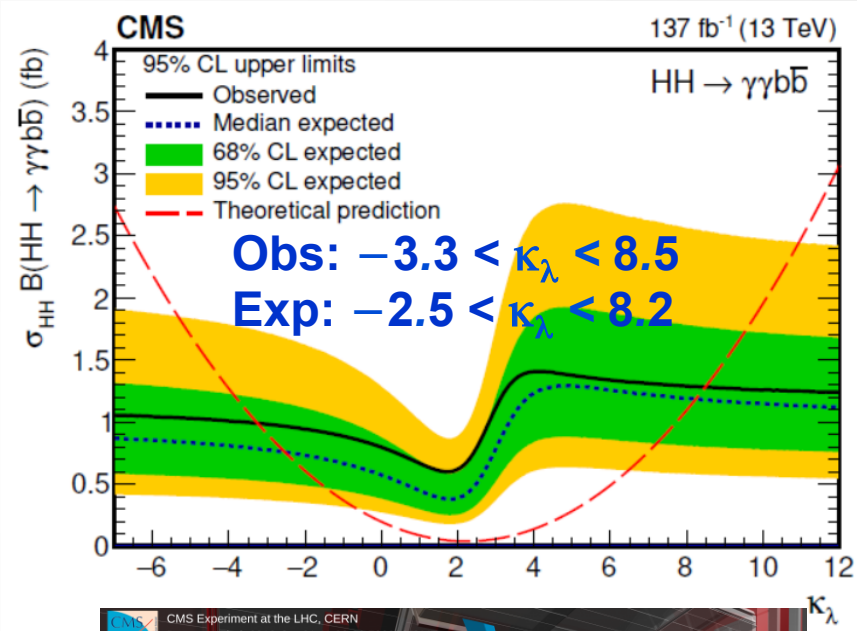
Observed (expected) 95% CL upper limit
Br(H → inv) = 0.17 (0.11)

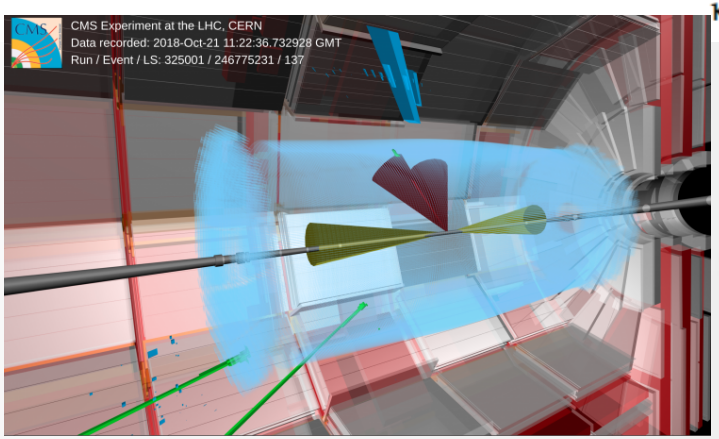
双希格斯的研究：HH→bbγγ

- 测量希格斯的自相互作用（自耦合）
- HH→bbγγ：希格斯自耦合测量最灵敏的物理道之一
  - large SM BR of HH→bb;
  - good mass resolution of H→γγ;
  - relatively low background rates
- 全部Run2数据
  - **5.2obs(7.7exp)×σ_{SM}**
  - 自耦合较强的限制：**$-3.3 < \kappa_\lambda < 8.5$** （结果公开时的最强限制）

CMS-PAS-HIG-19-018

JHEP 03(2021)257





高能所主要贡献：

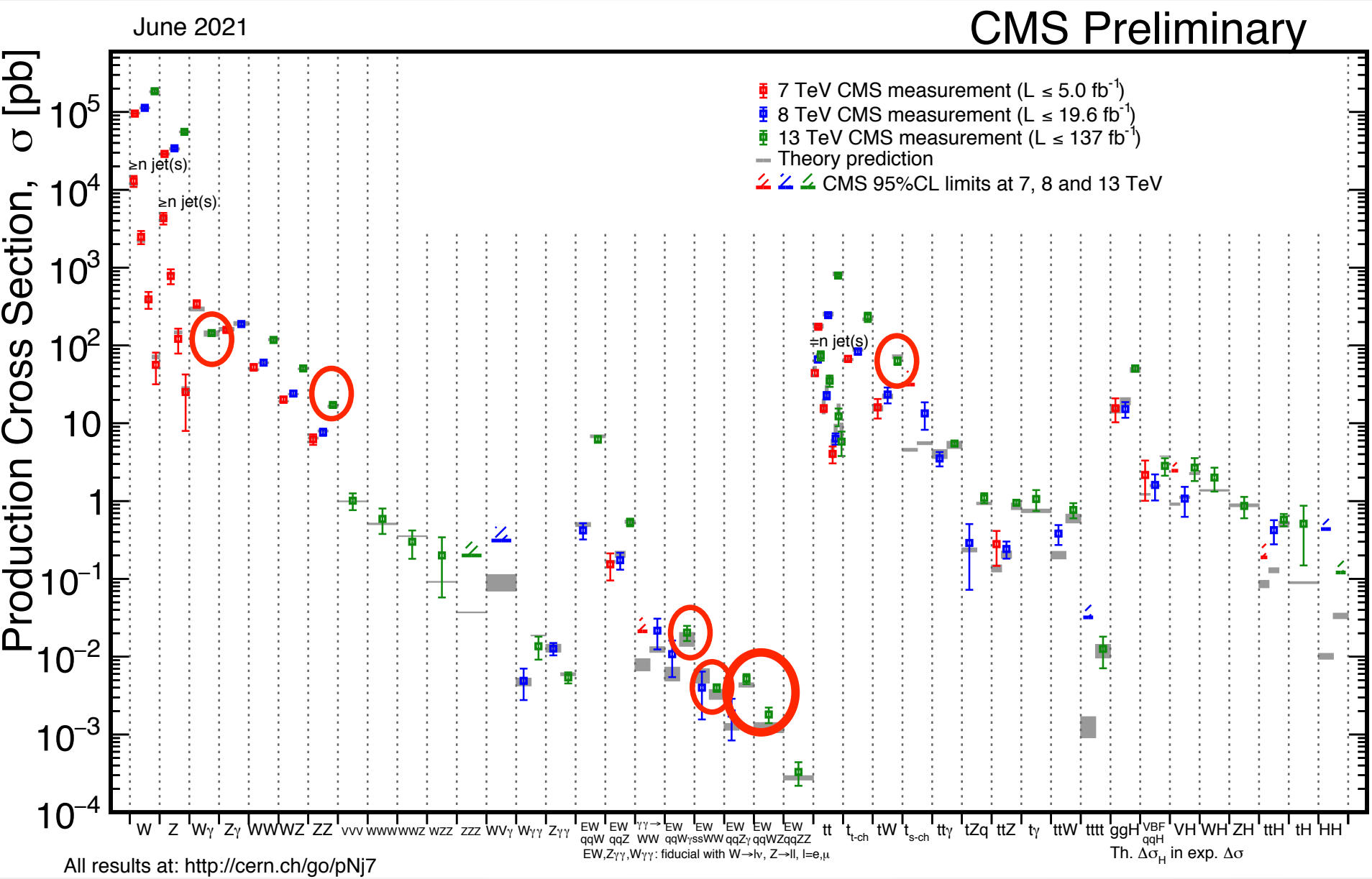
common tools, 包括光子刻度、鉴别、效率等；

信号及本底蒙卡样本模拟与验证；

博士后Fabio 作unblinding报告

获CMS新闻报道

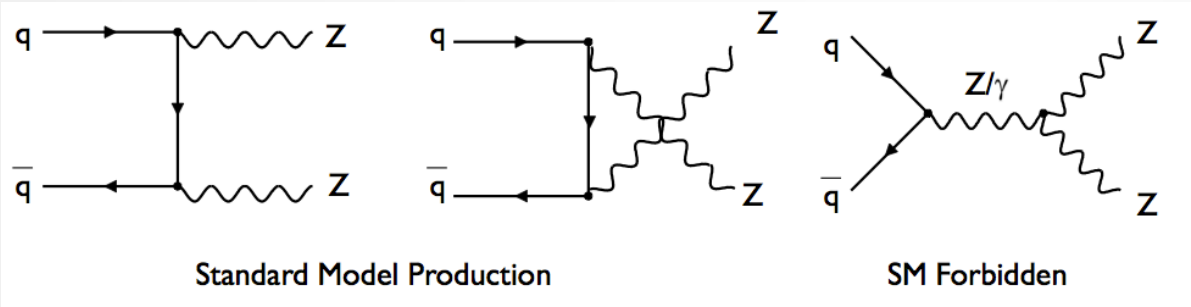
精确检验标准模型


June 2021
CMS Preliminary
Production Cross Section, σ [pb]
7 TeV CMS measurement (L ≤ 5.0 fb^{-1})
8 TeV CMS measurement (L ≤ 19.6 fb^{-1})
13 TeV CMS measurement (L ≤ 137 fb^{-1})
Theory prediction
CMS 95%CL limits at 7, 8 and 13 TeV
≥n jet(s)
≥n jet(s)
≠n jet(s)
W Z Wγ Zγ WW WZ ZZ VVV WWW WWZ WZZ ZZZ WVγ Wγγ Zγγ
EW qqW EW qqZ γγ→WW EW qqWγ EW ssWW EW qqZγ EW qqWZ EW qqZZ
tt $t_{t\text{-}ch}$ tW $t_{s\text{-}ch}$ ttγ tZq ttZ tγ ttW tttt ggH VBF qqH VH WH ZH ttH tH HH
EW,Zγγ,Wγγ: fiducial with W→lν, Z→ll, l=e,μ
Th. $\Delta\sigma_H$ in exp. Δσ
All results at: http://cern.ch/go/pNj7

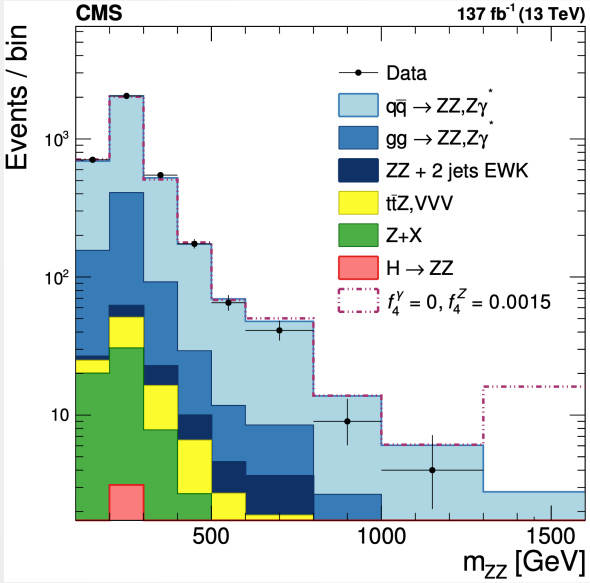
ZZ→4l截面测量

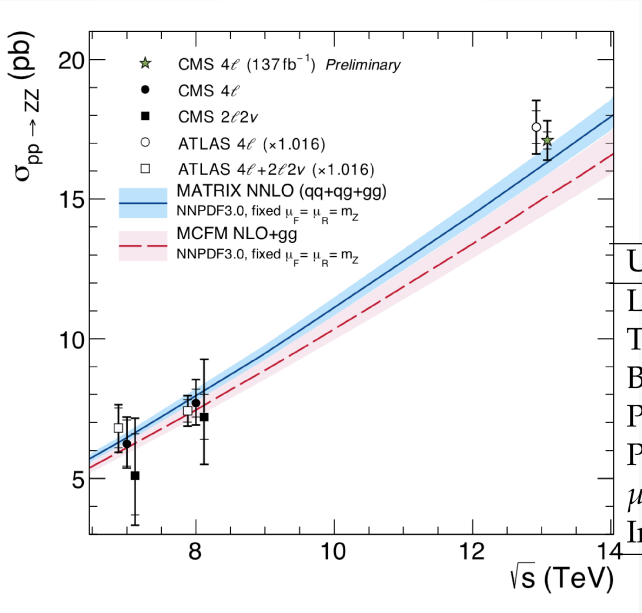
基于全部Run-2数据，标准模型过程ZZ截面测量并对反常三规范耦合进行约束。

CMS-PAS-SMP-19-001
EPJC 81 (2021) 200



Best limits to date on neutral aTGC ZZ and ZZZ couplings





高能所主要贡献是缪子的效率测量及蒙卡样本修正 -> 最主要的系统误差

Uncertainty	Range of values
Lepton efficiency	2–8%
Trigger efficiency	1–2%
Background	0.6–1.3%
Pileup	1%
PDF	1%
μ_R, μ_F	1%
Integrated luminosity	2.3% (2017) 2.5% (2018)

W+γ联合产生的精确测量

自7TeV文章之后，LHC一直没有成功完成该分析

- 高精度测量需要对复杂本底有很好的控制
- **对6维有效理论算符Cwww给出世界最好限制**
- 基于mlγ分布，得到Wγ的基准截面:
  - σ = 15.44 ±0.05 (stat) ±0.84 (exp) ±0.12 (theory) pb
- 理论截面:
  - MadGraph5_aMC@NLO 0+1 jets at NLO: 15.44 ±1.24 pb
  - POWHEG with "NLO competition" scheme: 22.45 ±3.21 pb

Description	Wgamma cross section
Contact Person	Andrew Michael Levin (PEKING-UNIV)
HN	SMP-19-002

Approval for SMP-19-002 : Wgamma cross section

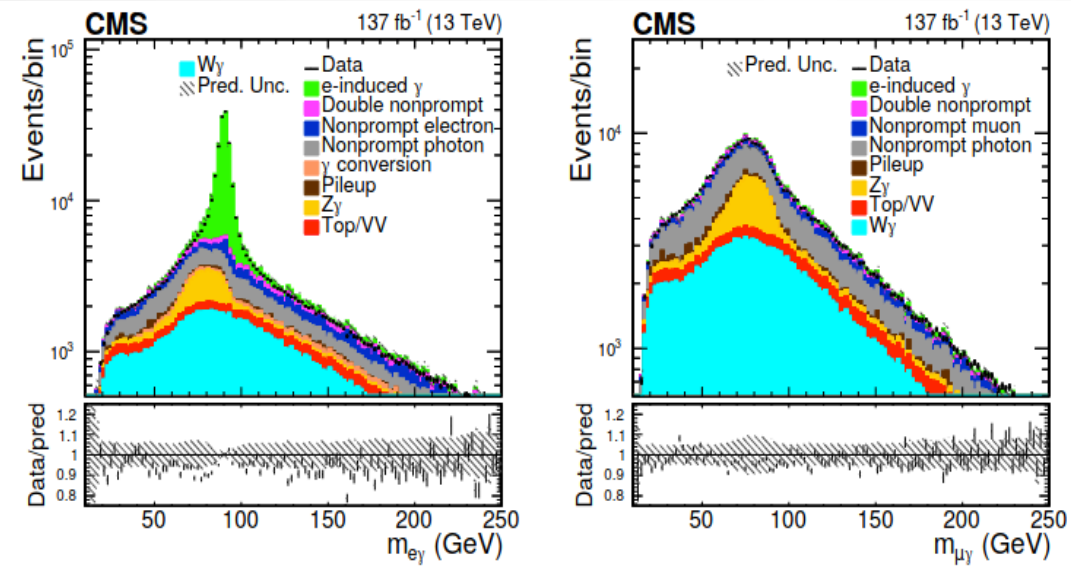
Speaker: Jie Xiao (Peking University (CN))

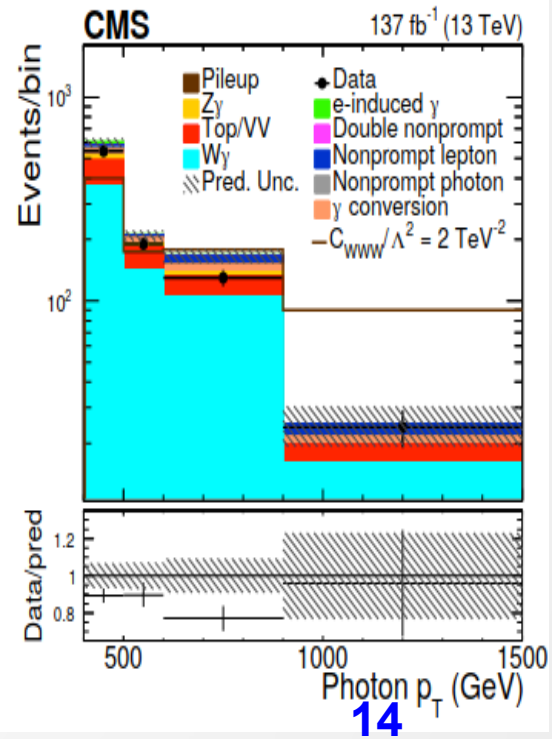
Full Run 2

CMS-PAS-SMP-19-002

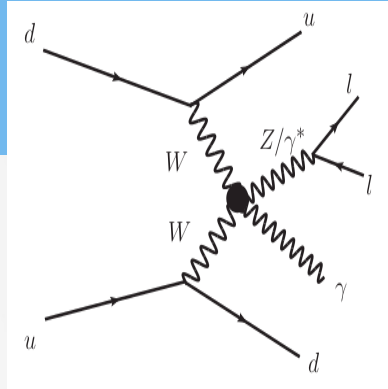
PRL 126(2021)252002

北大担任分析联系人，做Approval报告

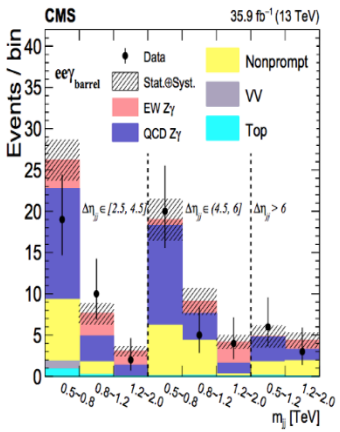




矢量玻色子散射： Z+γ



- 中性玻色子散射过程，对标准模型的深度检验。
- 利用Full Run2对撞数据，首次发现该过程。
- 北大、中山担任分析联系人、做pre-approval, approval 报告



CMS: arxiv: 2002.09902 for 13 TeV

8 TeV (19.7 fb^{-1}):

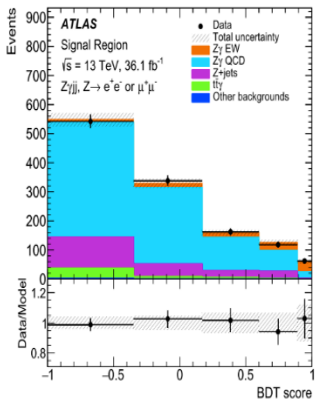
observed(expected) significance is **3.0σ (2.1σ)**.

13TeV (35.9fb^{-1}):

observed(expected) significance is **3.9σ (5.2σ)**.

aQGC limits and fiducial cross section are also reported

Combined observed(expected) significance is **4.7σ (5.5σ)**.



ATLAS: arxiv: 1910.09503 for 13 TeV

8 TeV (20.2 fb^{-1}):

observed(expected) significance is **2.0σ (1.8σ)**.

13 TeV (36.1fb^{-1}):

observed(expected) significance is **4.1σ (4.1σ)**

Fiducial cross section is also reported

Description	Zgamma + 2 jets production in EWK processes and aQGC
Contact Person	Fengwangdong Zhang (PEKING-UNIV)
HN	SMP-14-018

8TeV PLB 770 (2017) 380

Description	Zgamma vector boson scattering
Contact Person	Meng Lu (PEKING-UNIV)
HN	SMP-18-007

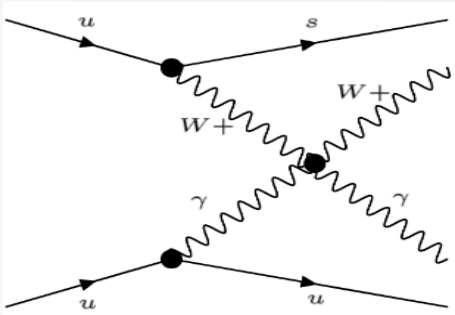
13TeV, 2016
JHEP 06 (2020) 076

Description	EW Zgamma plus 2 jets at 13 TeV full run 2
Contact Person	Ying An (PEKING-UNIV)
HN	SMP-20-016

Full Run2 SMP-20-016
PRD 104 (2021) 072001

矢量玻色子散射： W+γ

- **LHC首次发现该新型散射过程**
- 利用2016年13TeV对撞数据， 与8TeV数据联合
  - 给出预期(观测)敏感度4.8（5.3）倍标准偏差，
  - 对一批反常四规范玻色子耦合给出世界最强限制。
- 北大担任分析联系人，做pre-approval, approval报告
- Full Run2 分析即将进入预审核



Description	Wgamma + 2 jets production in EWK processes
Contact Person	Daneng Yang (PEKING-UNIV)
HN	SMP-14-011

8TeV JHEP 06 (2017) 106

Description	Wgamma vector boson scattering
Contact Person	Qianming Huang (PEKING-UNIV)
HN	SMP-19-008

13TeV, 2016
CMS-PAS-SMP-19-008
PLB 811(2020)135988

ELSEVIER

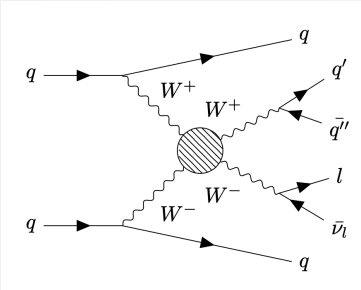
Physics Letters B
Volume 811, 10 December 2020, 135988

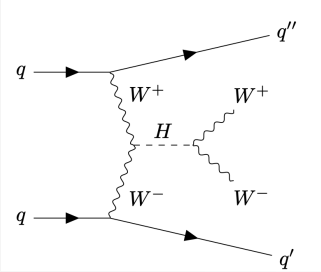
Observation of electroweak production of Wγ with two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV

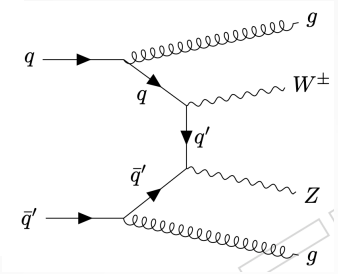
该分析在**LHCP2020**、**ICHEP2020**大会上作为**CMS**实验组的亮点工作之一得到展示。

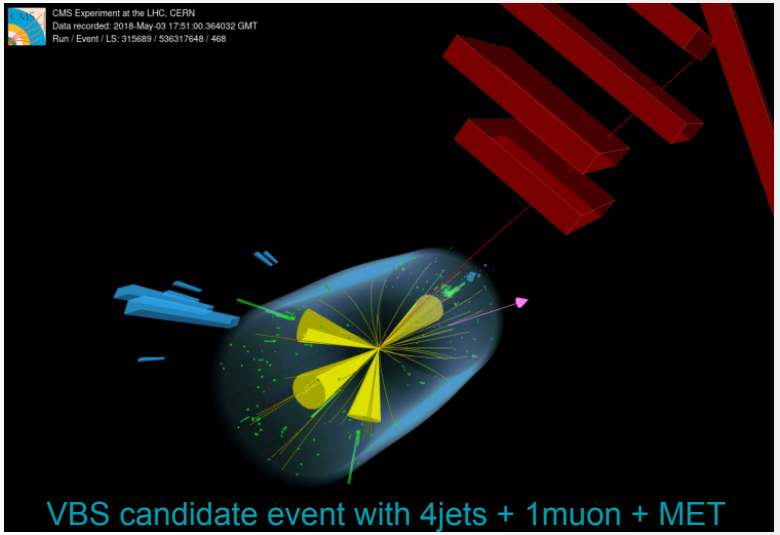
矢量玻色子散射： WW/WZ→lvqq

CMS-PAS-SMP-20-013

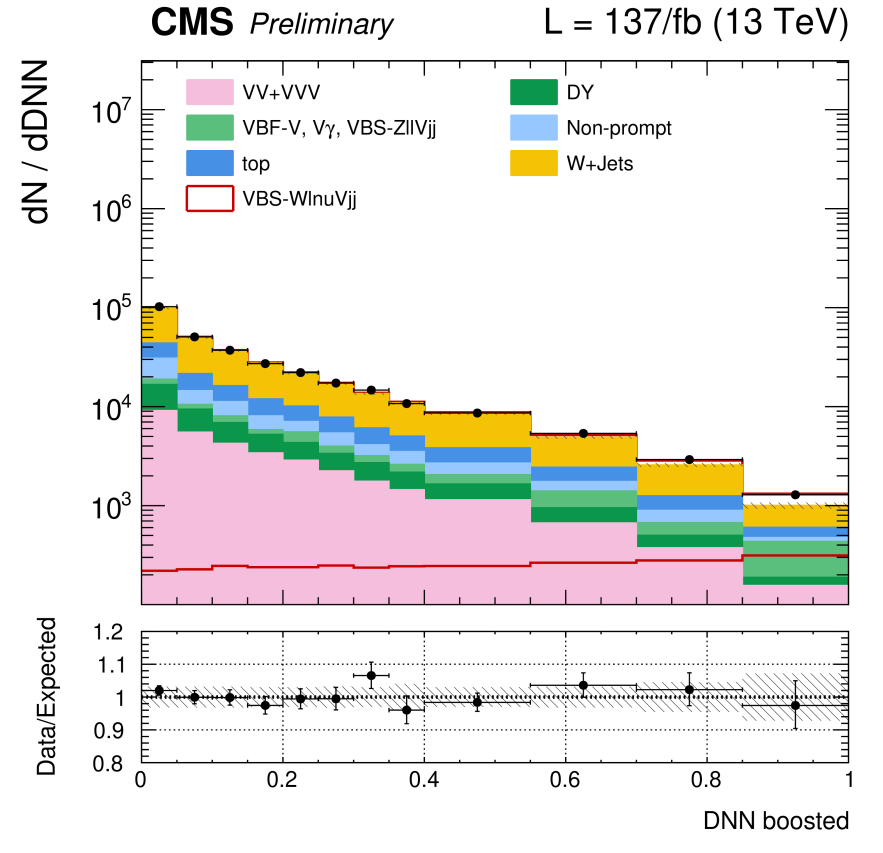








VBS candidate event with 4jets + 1muon + MET



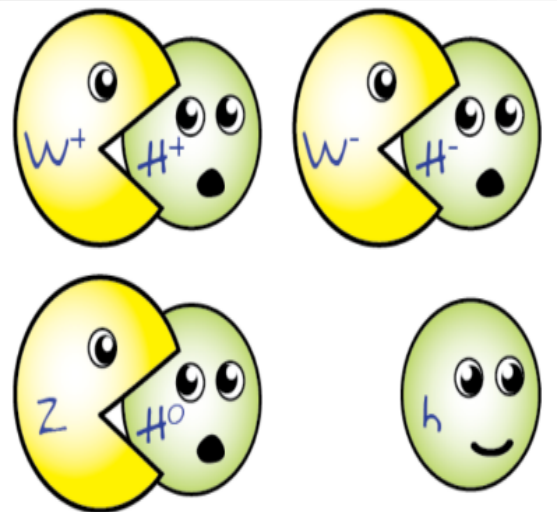
Observed (expected) EW signal significance

= 4.4 (5.1) σ

First evidence for the EW production of a WV (V = W or Z) pair plus two jets in the semileptonic channel

高能所博后Ram为主要分析人员之一

极化散射的首次测量



VOLUME 69, NUMBER 18 PHYSICAL REVIEW LETTERS 2 NOVEMBER 1992

On the Precise Formulation of the Equivalence Theorem

Hong-Jian He and Yu-Ping Kuang
CCAST (World Laboratory), P.O. Box 8730, Beijing 100080, China
and Institute of Modern Physics and Department of Physics, Tsinghua University, Beijing 100084, China[a]

Xiaoyuan Li
CCAST (World Laboratory), P.O. Box 8730, and Institute for Theoretical Physics–Academia Sinica, Beijing 100080, China
(Received 19 May 1992)

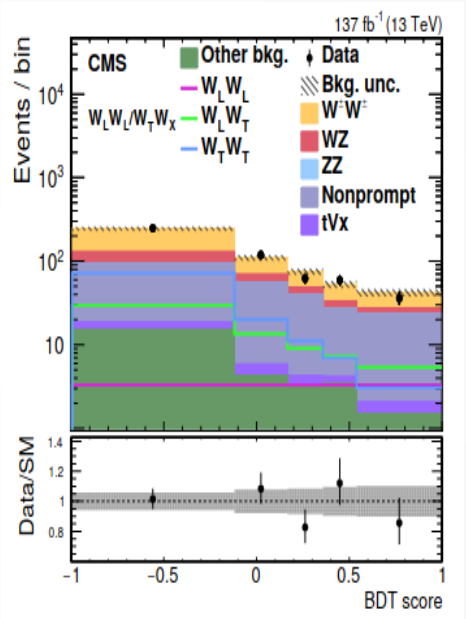
A systematic analysis of renormalization schemes and a general proof of the precise formulation of the equivalence theorem are given in the R_ξ gauge for both the $SU(2)_L$ and the $SU(2)\times U(1)$ theories. The precise formula for the modification factor C_{mod} is obtained, and a convenient particular scheme in which C_{mod} is exactly unity is proposed. C_{mod} in other schemes are discussed up to one loop in the heavy Higgs boson limit.

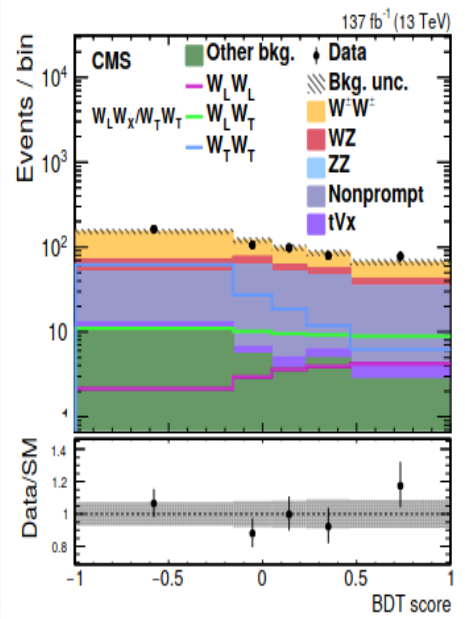
邝宇平院士、何红建教授、李小源教授 (1992):
Longitudinal weak boson scattering… is one of the most important processes to be studied at the Superconducting Super Collider and the CERN Large Hadron Collider. 纵向玻色子散射是LHC待研究的最重要的物理过程。

Approval of SMP-20-006 : Measurements of the scattering of polarized same-sign WW bosons

Speakers: Aram Apyan (Fermi National Accelerator Lab. (US)) , Mr Jie Xiao (Peking University (CN))

CMS-PAS-SMP-20-006
PLB 812(2020) 136018





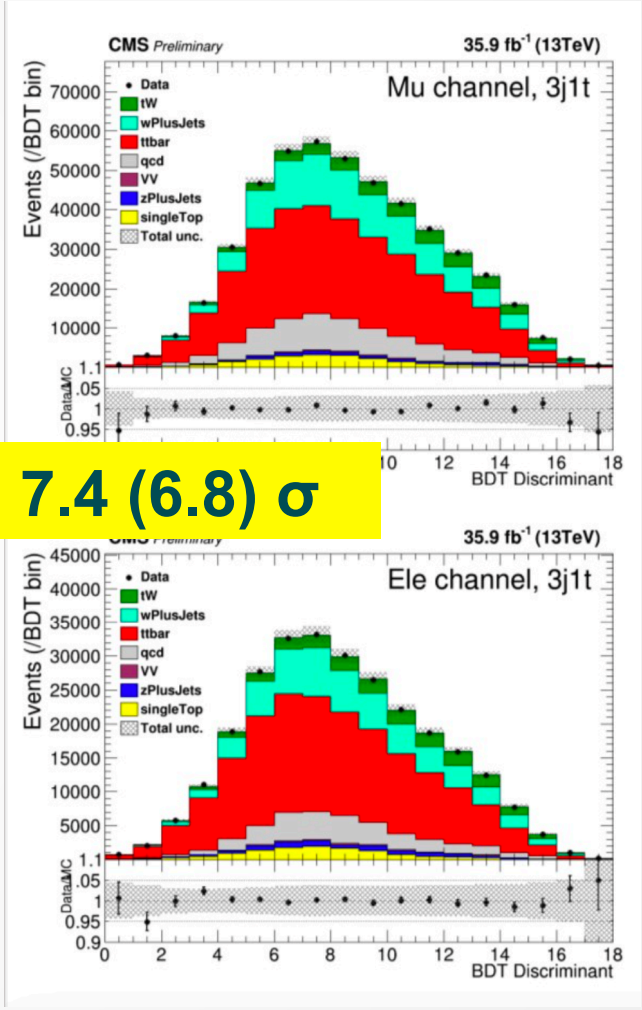
Process	$\sigma\mathcal{B}$ (fb)	Theoretical prediction (fb)
$W_L^\pm W_L^\pm$	$0.32^{+0.42}_{-0.40}$	0.44 ± 0.05
$W_X^\pm W_T^\pm$	$3.06^{+0.51}_{-0.48}$	3.13 ± 0.35
$W_L^\pm W_X^\pm$	$1.20^{+0.56}_{-0.53}$	1.63 ± 0.18
$W_T^\pm W_T^\pm$	$2.11^{+0.49}_{-0.47}$	1.94 ± 0.21

在半轻子道观测到tW

- 单顶夸克过程可以精确测量CKM矩阵元|Vtb|
- 课题组利用2016年13TeV 35.9 fb^{-1}的数据，独立完成了tW→b jj lv的信号强度与显著性的测量
  - 系统误差主导，分析难度极大
  - CMS首个tW半轻子道的分析
  - LHC首次观测到半轻子衰变的tW
  - 在LHC Top工作组作为CMS亮点工作汇报
  - 高能所担任分析联系人，并做预审核及审核报告

CMS-PAS-TOP-20-002

JHEP 11 (2011)111



7.4 (6.8) σ

tW cross section:

$89 \pm 4\ (\text{stat}) \pm 12\ (\text{syst})\ \text{pb}.$

新粒子的寻找

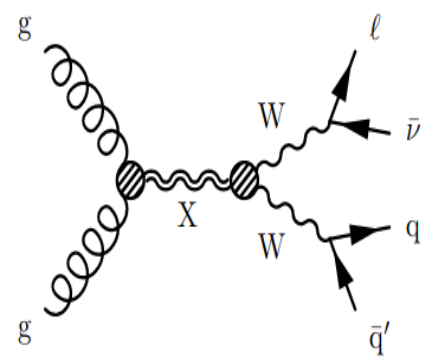
- 大质量粒子：
  - 双规范玻色子共振态
  - 三规范玻色子共振态
  - 类矢量夸克
  - 轻子夸克
  - 两轻子共振态
- 小质量粒子：
  - 通过希格斯奇异衰变寻找暗光子/类轴子

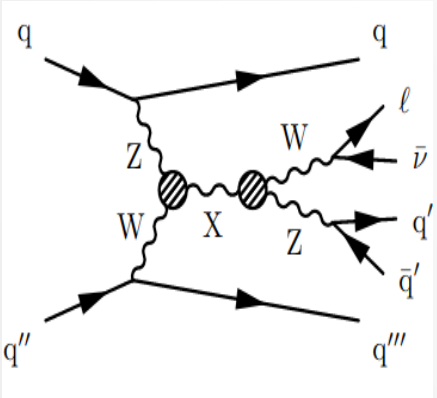
双规范玻色子共振态寻找: WW/WZ

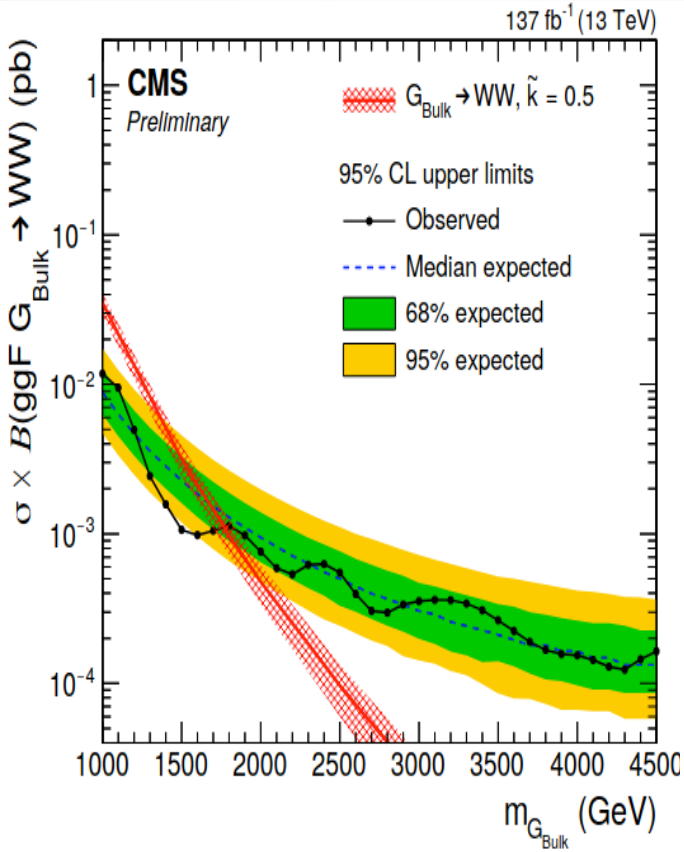
- 在新物理寻找上，北大参与推动了CMS上的Boosted Jet技术以及双玻色子共振态寻找。北大一直是WW/WZ分析的负责人。
- **Full Run2结果在2021年Moriond QCD上得到公开**
- **1TeV Graviton/W'的截面探测灵敏度均有显著提高。**

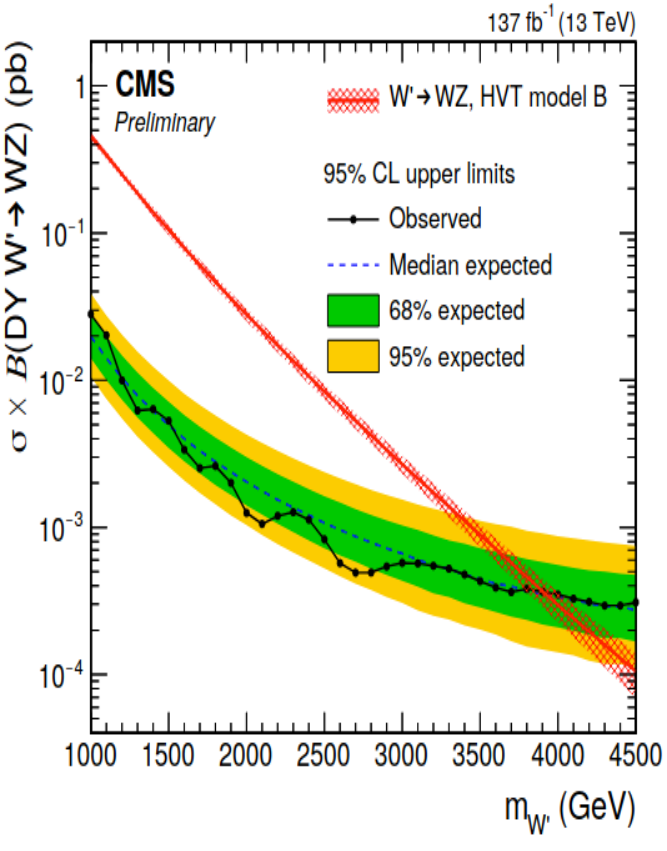
CMS-PAS-B2G-19-002

Submitted to PRD









三重规范玻色子共振态世界首次寻找

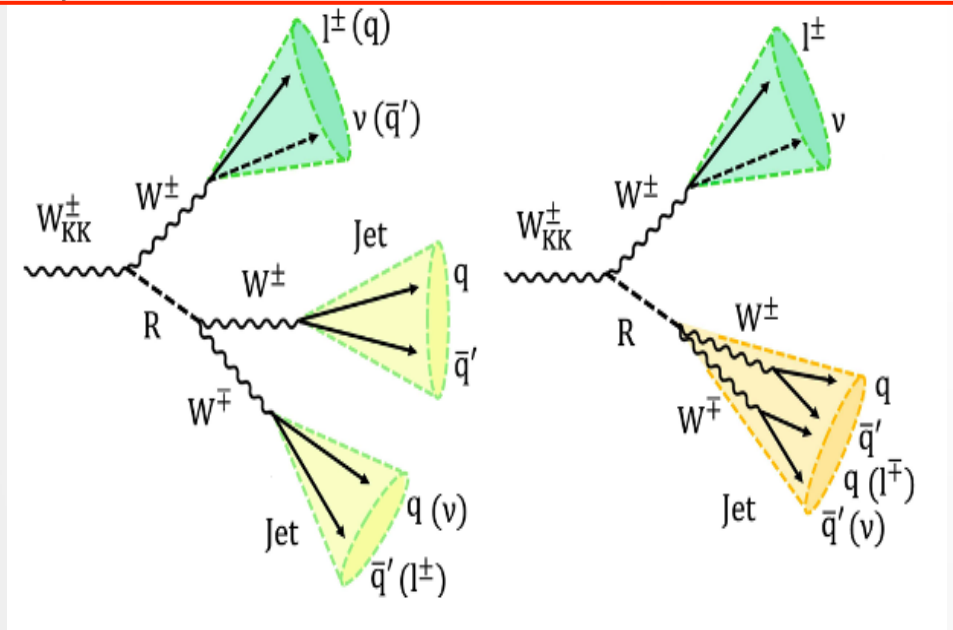
北大担当两个分析的负责人，建立了4夸克喷注的鉴别及校准技术，拓展了CMS新物理寻找路径。未来可以应用于：X->HH->8q, boosted H->WW

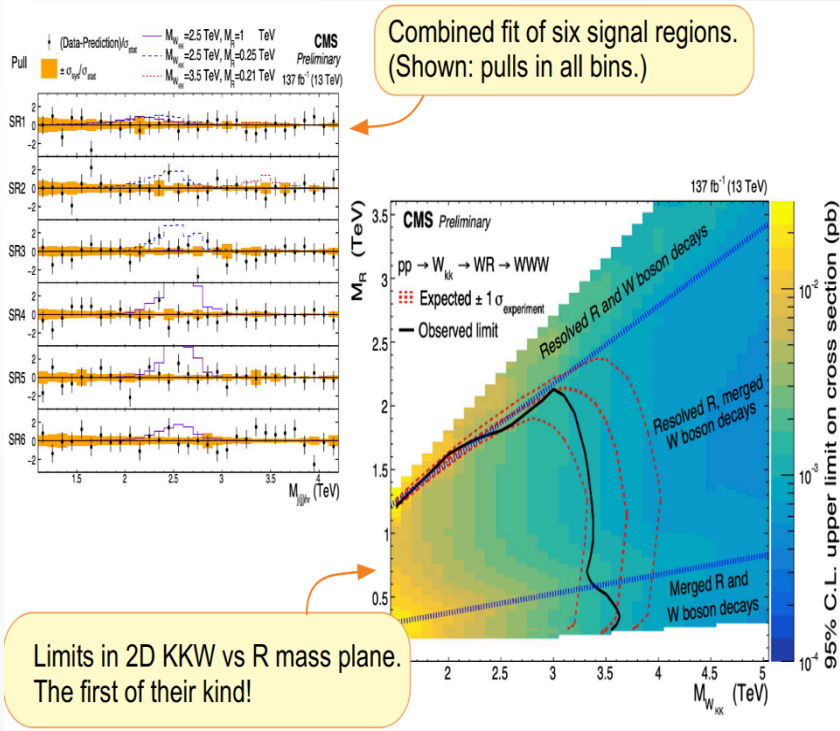
CMS发布新闻通稿予以报道

Moriond EW Wednesday: Moriond EWK - Wednesday: afternoon session

16:00 Approval of B2G-20-001: Search for resonances decaying into WVV in the single lepton final state

Speakers: Antonis Agapitos (Peking University (CN)), Qiang Li (Peking University (CN)), Xudong Lyu (Peking University (CN))



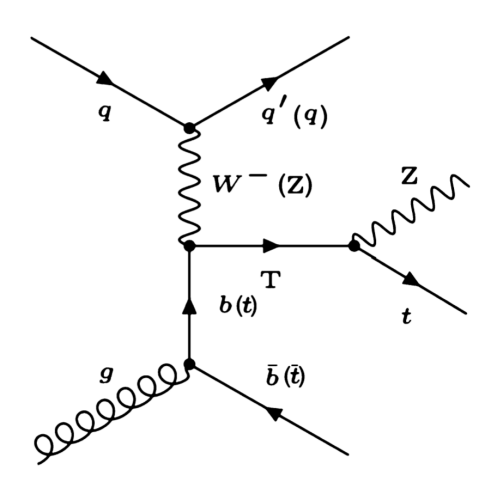


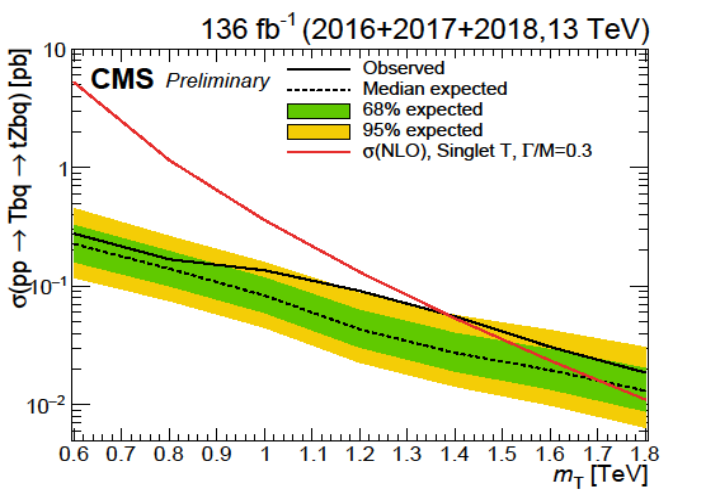
CMS-PAS-B2G-20-001 CMS-PAS-B2G-21-002 To be submitted to PRL+PRD

类矢量夸克T'->tZ寻找

- 很多新物理模型，如复合希格斯模型等通过引入质量较大的类矢量夸克，来抵消夸克对希格斯质量二次发散的贡献，从而解决希格斯质量的不自然性的问题
  - 高能所曾基于2015年和2016年13TeV数据独立完成双轻子末态分析，发表过两篇文章
- 双中微子末态分析已发表
  - 高能所担任分析联系人，并做预审核及审核报告

CMS-PAS-B2G-19-004
To be submitted to JHEP



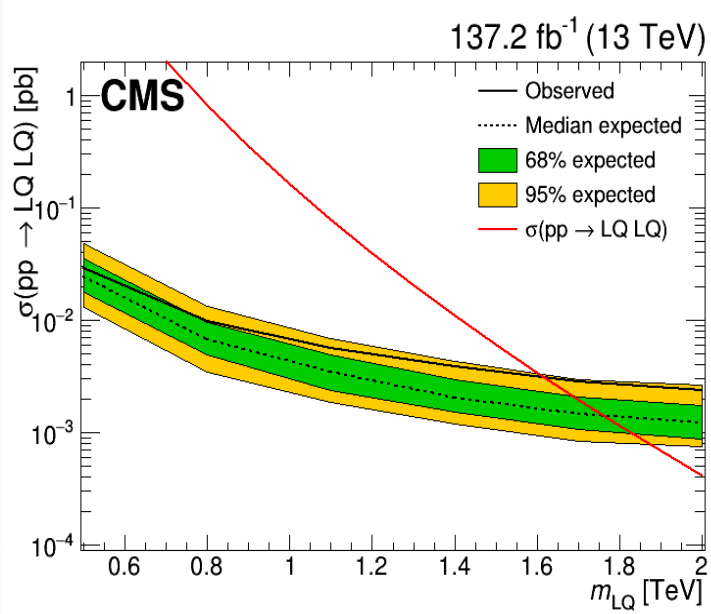


基于Z->νν新末态

轻子夸克的寻找

- 轻子夸克的存在被许多新物理模型预言，在LHC上进行了广泛的寻找；
- 可以解释当前一些实验上B介子的反常衰变。
- 基于Full Run2数据，在全新的顶夸克+陶子+中微子末态利用单个产生和对产生模式寻找轻子夸克；
  - 迄今最严的第三代轻子夸克的质量限制
  - 高能所成员担任分析联系人，文章编辑，做pre-approval报告

CMS-PAS-EXO-19-015
PLB 819 (2021) 136446



SEARCHES FOR NEW PHYSICS | NEWS

Leptoquarks and the third generation

10 November 2020

A report from the CMS experiment

CERN Courier

CERN News

News › News › Topic: Physics

Voir en français

CMS sets new bounds on the mass of leptoquarks

The bounds are some of the tightest yet on the existence of third-generation leptoquarks

18 DECEMBER, 2020 | By Ana Lopes

第三代轻子夸克质量下限设定

至少为0.98—1.73太电子伏特

科技日报

CMS合作组设定假设的第三代轻子夸克的质量下限。
图片来源：物理学家组织网

CERN Physicists Set Bounds on Mass of Hypothetical Leptoquarks

Dec 21, 2020 by News Staff / Source

Previous | Next

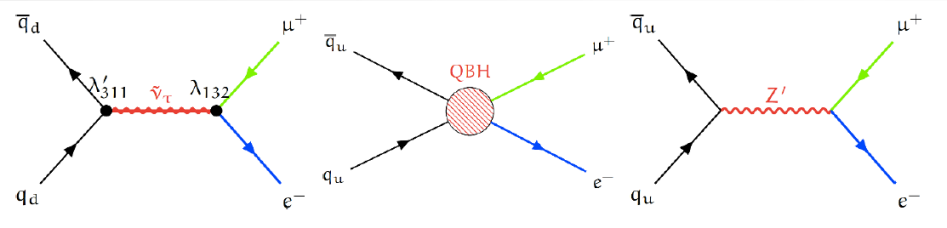
Published in

Physicists from the CMS (Compact Muon Solenoid) Collaboration at CERN's

在eμ, eτ, μτ末态寻找大质量的轻子味破缺过程

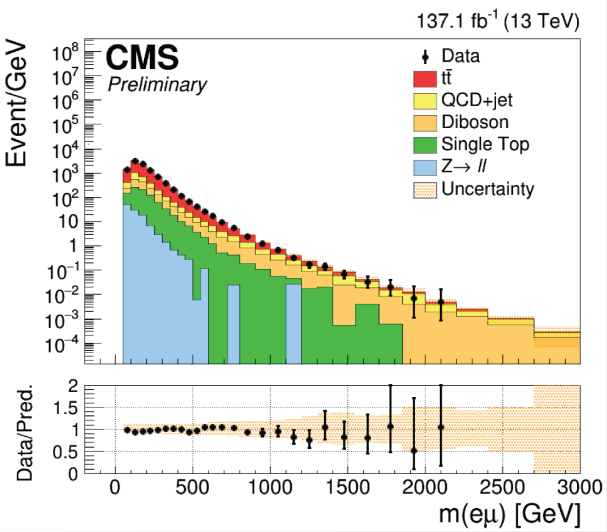
- 在标准模型中，带电荷轻子的味是守恒的，但一些超出标准模型理论(BSM)允许其被打破。
- 典型的存在轻子味破缺过程的理论模型包括R-parity violating (RPV), Microscopic quantum black holes (QBHs), 和 Gauge boson Z’ 等.

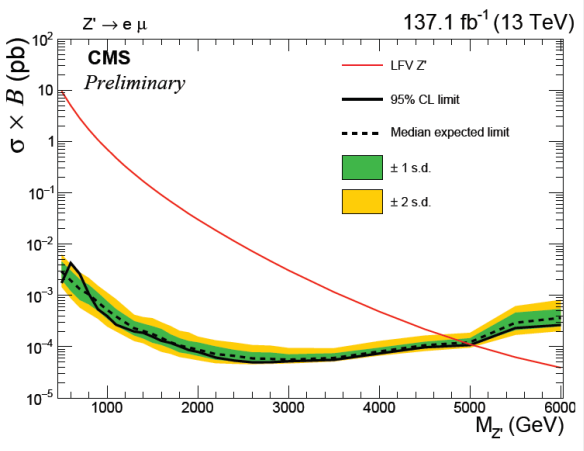
- 此分析使用CMS实验在Run2阶段积累的全部数据，在　末态寻找上述轻子味破缺过程的迹象。



- 复旦大学负责末态eμ的全部分析内容。

CMS-PAS-EXO-19-014



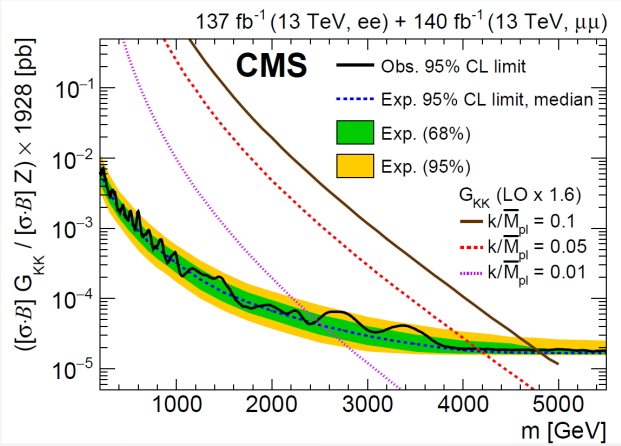


在轻子对末态寻找大质量玻色子

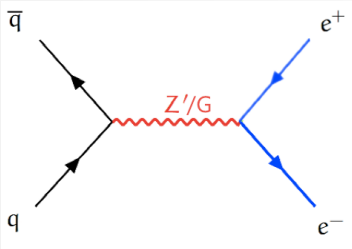
- 许多拓展标准模型理论的新物理模型，都预言在TeV量级存在大质量的规范玻色子，典型代表如：
  - The sequential standard model Z'_{SSM}.
  - The GUT mode Z'_{ψ}.

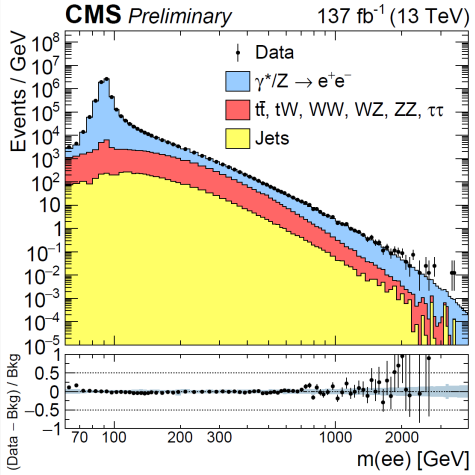
CMS-PAS-EXO-19-019

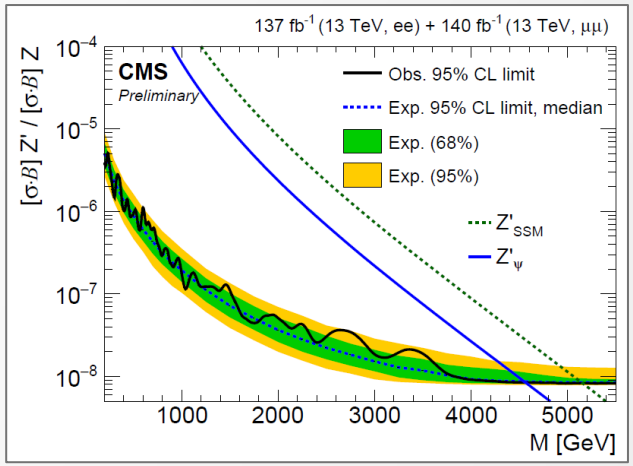
JHEP 07 (2021) 208



- 基于额外维理论的Randall-Sundrum（RS）模型也给出了自旋为2的引力子的描述，并预言其可以轻子化衰变到轻子对末态。





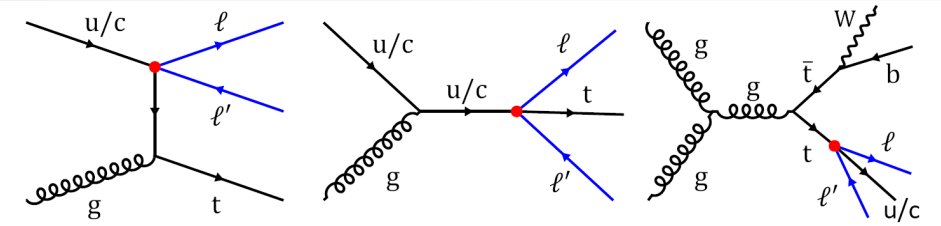


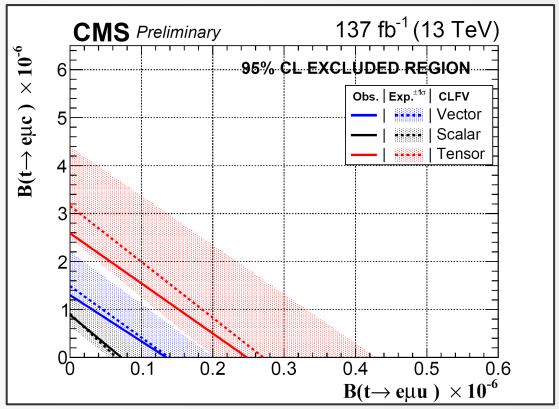
- 复旦大学在分析框架，触发效率测量，本底研究等方面做重要贡献。

在含顶夸克过程中寻找轻子味破缺现象

- LHC实验产生了大量的顶夸克(对)事例，为通过顶夸克寻找新物理提供了理想的实验平台。

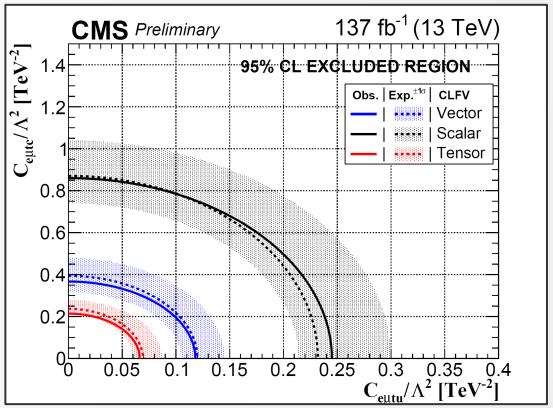
CMS-PAS-TOP-19-006





- 此分析寻找$e\mu$**tu**和$e\mu$**tc**这两个含有顶夸克的轻子味破缺过程。

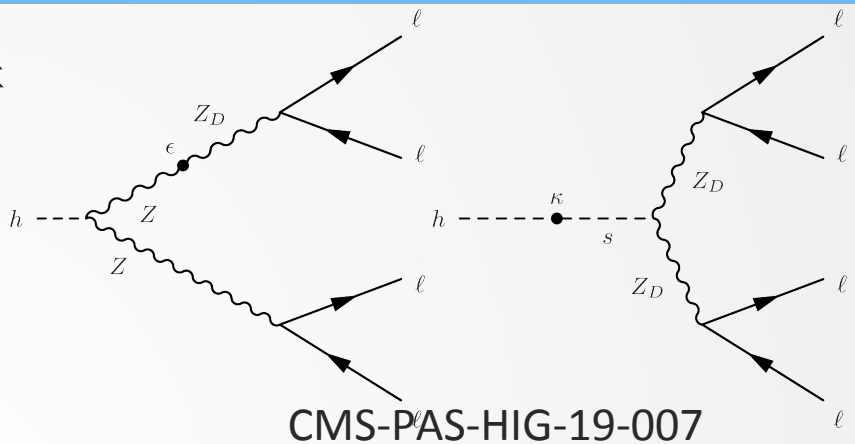
Vertex	Int. type	σ [fb] Exp.	σ [fb] Obs.	$C_{e\mu tq}/\Lambda^2$ [TeV^{-2}] Exp.	$C_{e\mu tq}/\Lambda^2$ [TeV^{-2}] Obs.	$\mathcal{B}\times10^{-6}$ Exp.	$\mathcal{B}\times10^{-6}$ Obs.
	Vector	7.02	6.78	0.12	0.12	0.14	0.13
		[5.33,10.21]		[0.10,0.14]		[0.11,0.20]	
		(3.39,12.33)		(0.08,0.16)		(0.07,0.24)	
$e\mu$tu	Scalar	5.63	6.25	0.23	0.24	0.06	0.07
		[4.79,9.38]		[0.21,0.33]		[0.05,0.11]	
		(3.75,12.12)		(0.19,0.34)		(0.04,0.14)	
	Tensor	10.01	9.18	0.07	0.06	0.27	0.25
		[7.51,15.90]		[0.06,0.09]		[0.20,0.43]	
		(4.59,19.24)		(0.04,0.09)		(0.12,0.52)	
	Vector	11.21	9.73	0.39	0.37	1.49	1.31
		[7.21,16.63]		[0.32,0.48]		[0.96,2.21]	
		(4.33,21.61)		(0.24,0.55)		(0.58,2.89)	
$e\mu$tc	Scalar	9.11	8.88	0.87	0.86	0.91	0.89
		[6.58,13.10]		[0.74,1.04]		[0.65,1.31]	
		(3.54,17.41)		(0.54,1.21)		(0.35,1.74)	
	Tensor	21.02	17.22	0.24	0.21	3.16	2.59
		[16.52,29.21]		[0.21,0.28]		[2.48,4.41]	
		(10.51,42.02)		(0.17,0.33)		(1.58,6.32)	



- 复旦大学在分析框架，触发效率，事例选择，信号抽取等方面做重要贡献。

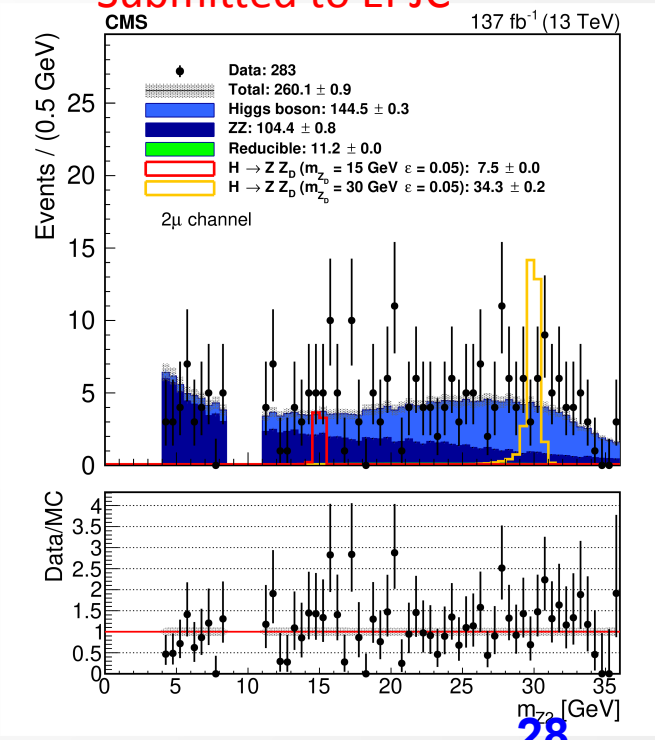
基于希格斯奇异衰变的新粒子寻找

- 基于H->ZZ->4l分析，寻找希格斯的奇异衰变模式、暗光子/类轴子寻找
  - H → ZX or H → XX
- 基于Run-2全部数据文章已提交EPJC (arXiv:2111.01299)
  - 对多种理论(暗光子模型、类轴子模型等)进行了约束
  - 中国组（高能所、清华）在分析框架、轻子效率测量、蒙卡样本修正等方面做了重要贡献



CMS-PAS-HIG-19-007

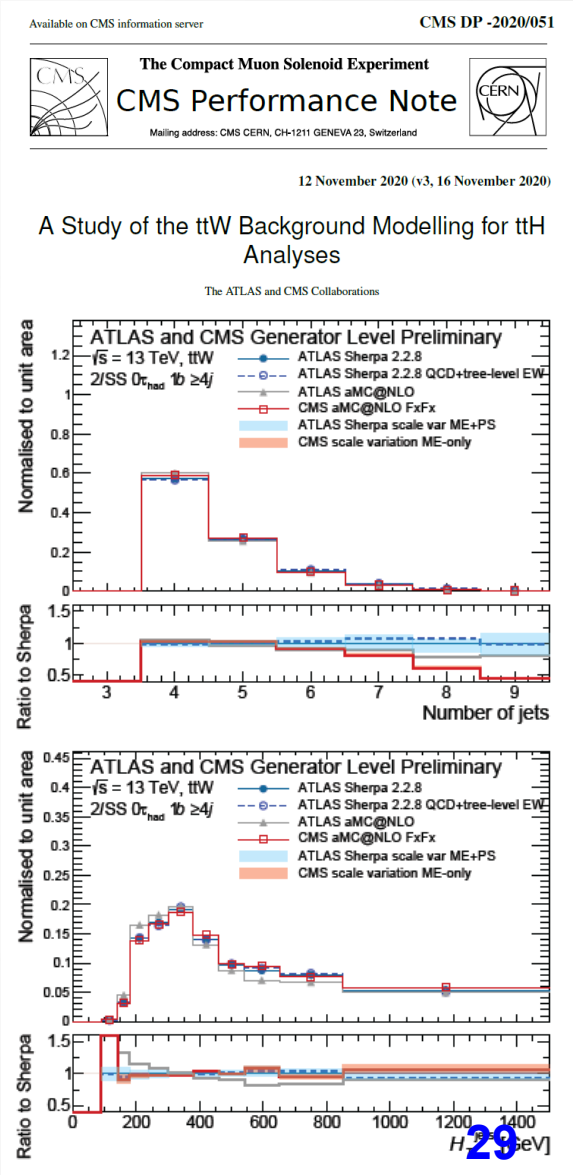
Submitted to EPJC



LHC希格斯截面研究: ttH本底模型研究

- 高能所博士后Joshuha为LHC希格斯工作组CMS ttH分组召集人
  - 研究对比和协调CMS及ATALS实验中ttH/tH相关的信号与本底使用的模型，及相关的主要理论误差
  - 目前已经完成对ttW本底模型、系统误差以及特征参量的研究
  - DP文章CMS-DP-2020-051发表为公开文集, Joshuha做审核报告
  - 未来将用于full Run2 ATLAS与CMS实验希格斯联合测量

CMS-DP-2020-051


Available on CMS information server

CMS DP -2020/051

The Compact Muon Solenoid Experiment

CMS Performance Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

12 November 2020 (v3, 16 November 2020)

A Study of the ttW Background Modelling for ttH Analyses

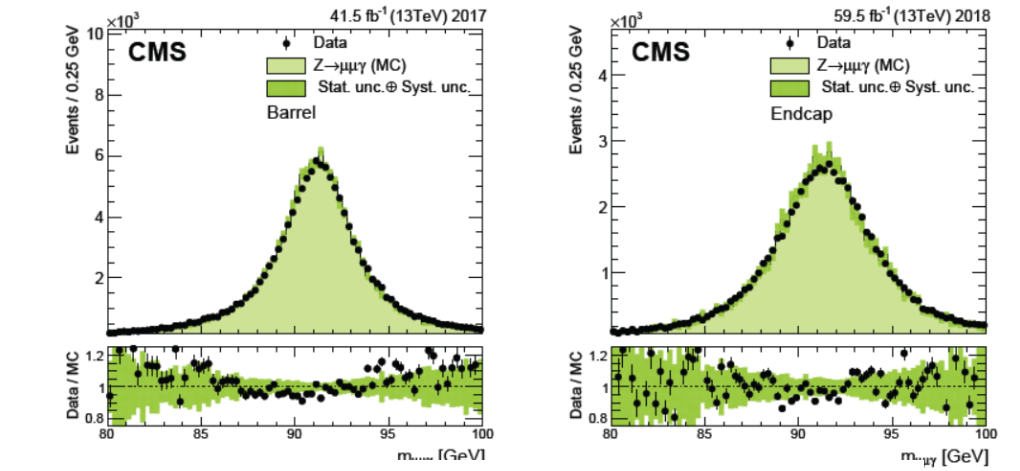
The ATLAS and CMS Collaborations

CMS Run2 电子和光子重建与鉴别

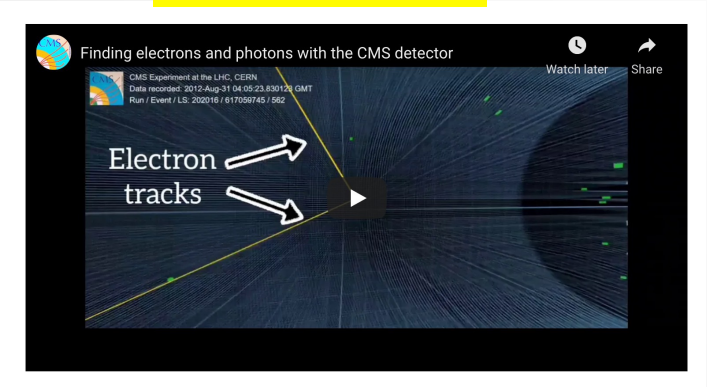
CMS-PAS-EGM-17-001
JINST 16(2021)P05014

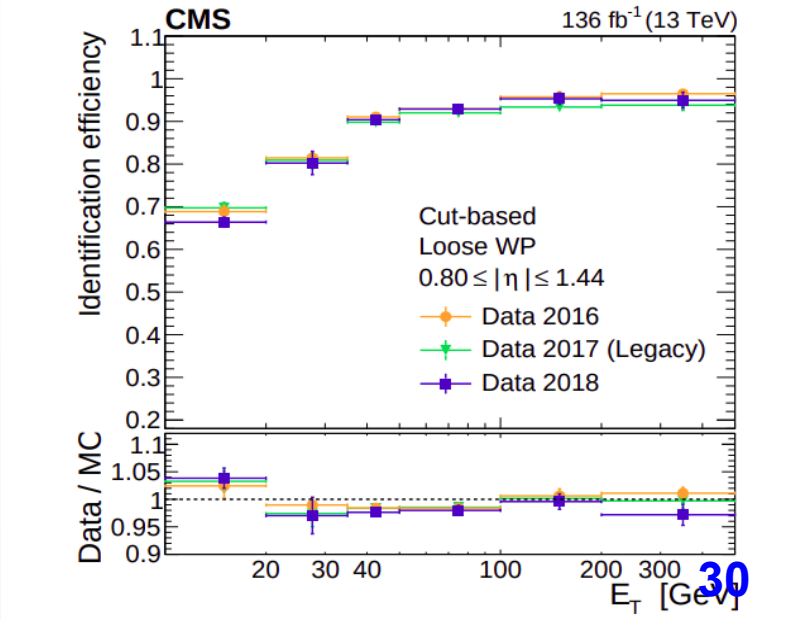
高能所做出重要贡献：

- 光子/电子鉴别组L3负责人
  光子/电子高阶触发组 L3负责人
- 负责2016-2018年数据光子能量刻度的验证、光子经典变量数据与MC的比对等
- 在光子/电子鉴别等多方面重要贡献，发展出电子鉴别和修正工具包，优化DNN鉴别等



获CMS新闻报道





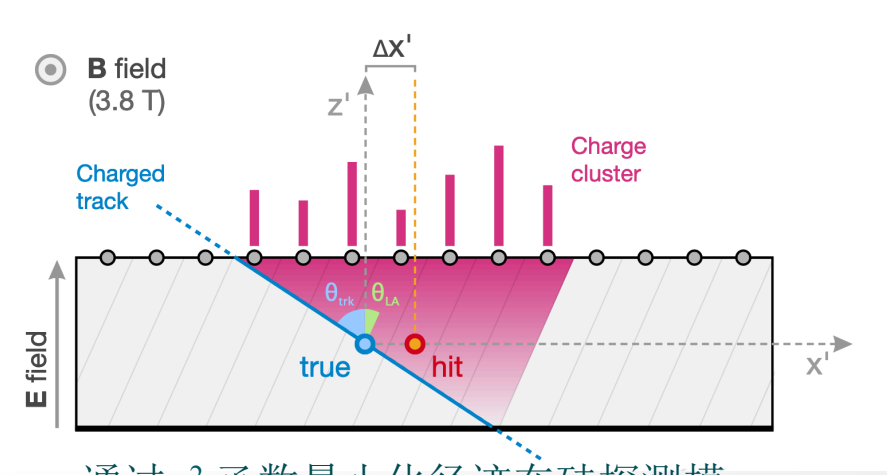
CMS径迹探测器 Run 2 矫正的策略和效果

TRK-20-001

To be submitted to NIM-A

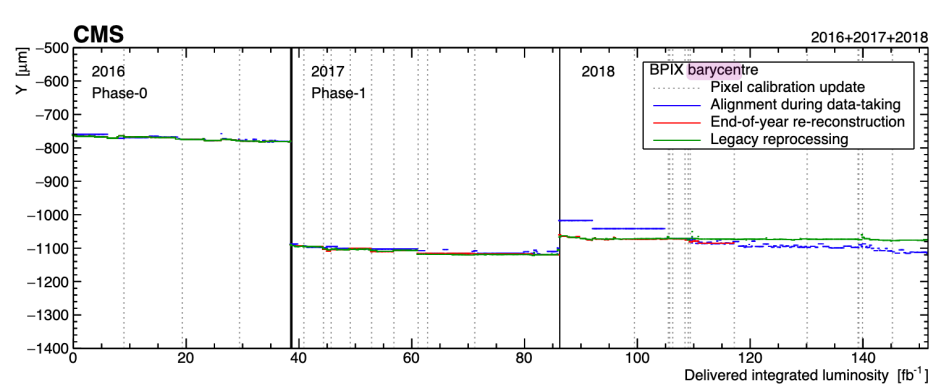
北航做出重要贡献:

- 负责研发软件模块用来监控硅像素径迹探测器不同子结构的几何中心随Run-2数据积累的变化:
  这些几何中心对CMS探测器打开/关闭、磁场的开/关以及辐照强度的累积有一定的灵敏度。



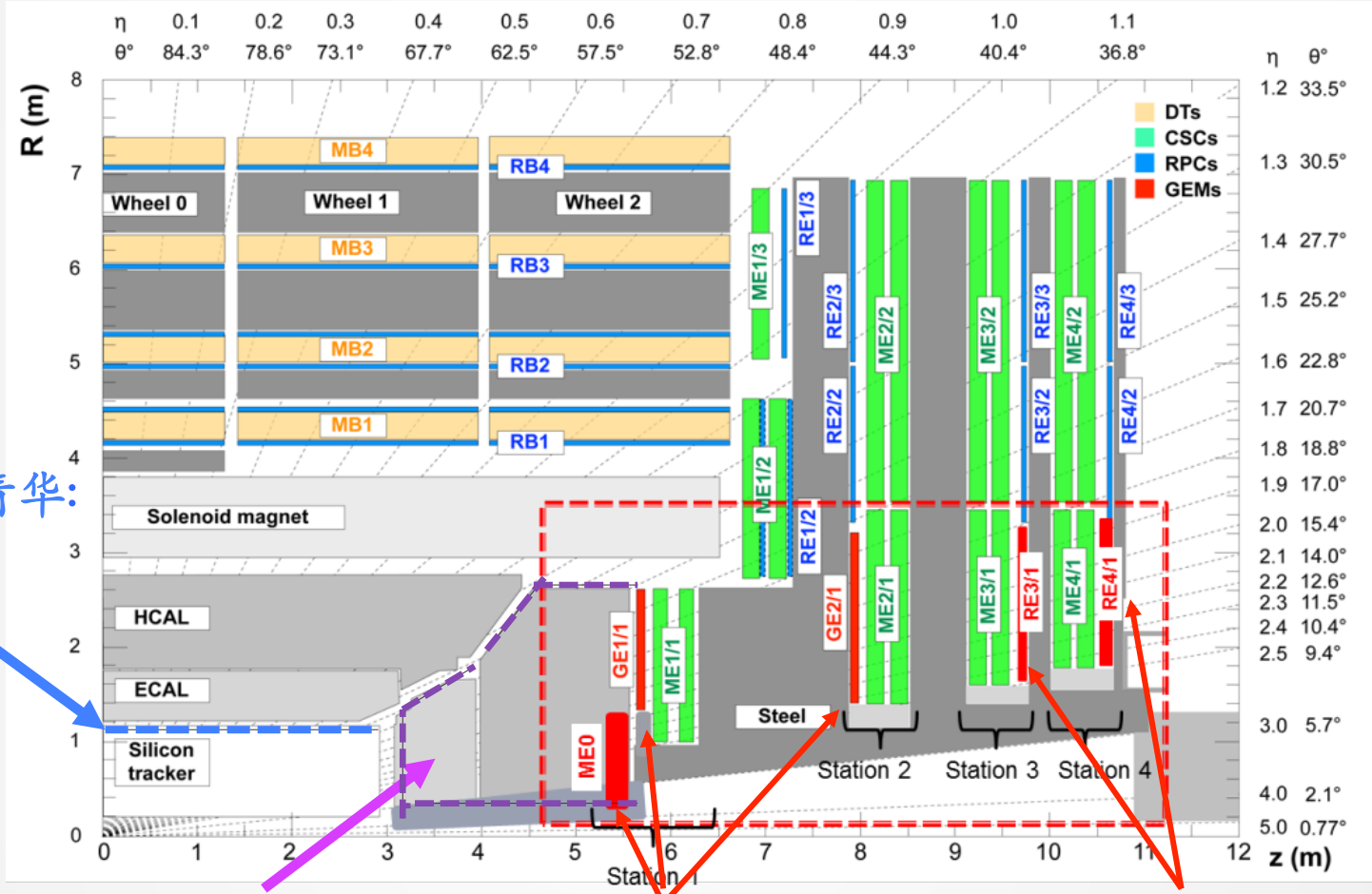
通过χ^2 函数最小化径迹在硅探测模块上的真实位置与预测未知的差别

- 曾担任Alignment and Calibration二级会议召集人，参与了2018年数据获取过程中刻度和矫正的管理



PIXEL桶部几何中心随着Run-2数据获取的变化

中国组参与phase II升级情况



北大/北航/清华:
MTD

高能所/清华/浙大/复旦:
HGCal

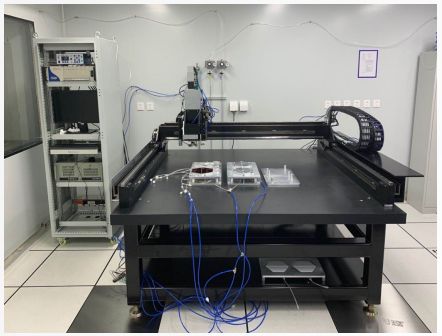
北大/中山/北航/清华:
GE1/1, GE2/1+ME0

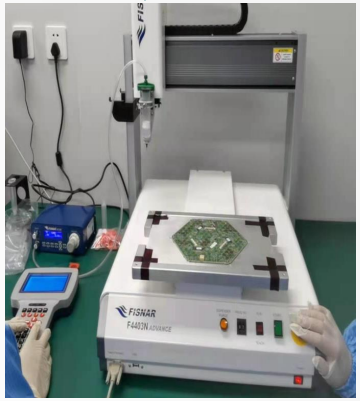
高能所:
muon-Trigger/backend

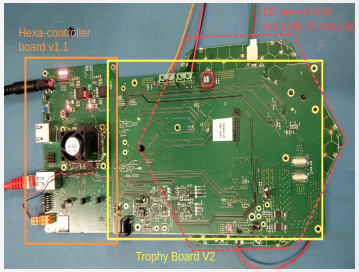
高粒度量能器升级亮点工作 （1）

通过CMS硅模块中心站点认证

- 在高能所建立了8寸硅模块生产工艺流程
  - 高度自动化的器件检测，系统集成，电子学绑定，模块封装，模块测试系统







- 完成了高粒度量能器硅模块集成站点认证
  - 即：生产两块正常工作的模块（见下页）

高能所通过了认证

高能所硅模块站点成员合影

- Silicon module assembly centres: 3 MACs qualified (UCSB, IHEP, and NTU), 2 are close (CMU and TTU), and TIFR now has a green light to order a centre
- SiPM market survey closed. Moulded tile prototyping well advanced. Machined cast tile prototypes made and under test, and tileboards development and test advancing well
- SiPM-on-Tile light yield results consolidated from different tests. Inputs collected for the optimization of the overall layout, and calibration procedure being studied for end-of-life with lower S/N
- Tilemodule assembly: automated tile wrapping and tilemodule assembly equipment is working in the TACs
- HGCROCv3 is under test and the analogue results very encouraging, some issues with new digital elements to be understood, and packaging has suffered delays
- ECON-T-P1 submitted. ECON-D design well advanced and reviews being planned. Schedule updated to be more realistic. ECON-T-P2 planned. ECON design and verification team stable. Looking how to further consolidate the depth of the team

(*) see additional material

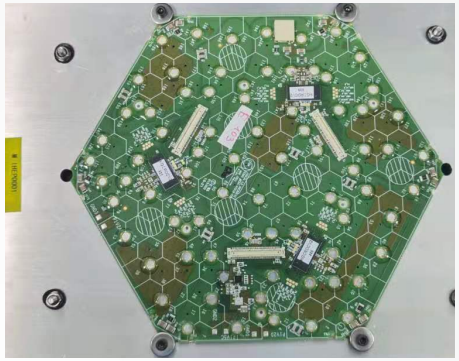
20 October 2021 61

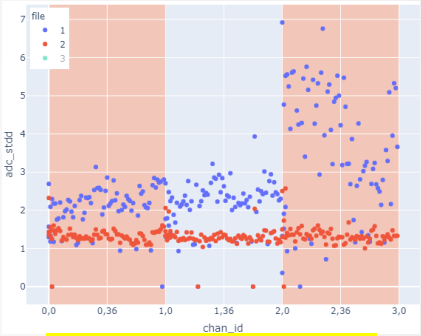
HGC项目经理在CMS二期升级组的报告

高粒度量能器升级亮点工作 （2）

证实了8寸硅模块可行性

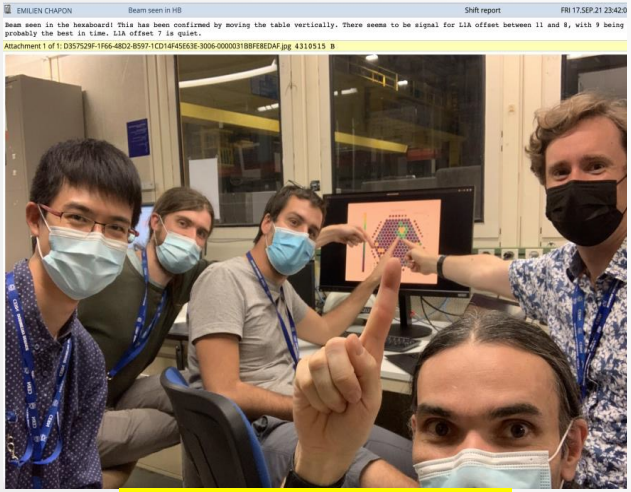
- 高能所成功制作两块8寸高粒度量能器硅模块
  - HGC首个正常工作的8寸硅模块
  - 采用最新HGC专用的前端ASIC
  - 噪声水平低（约2-3ADC）
  - 各项测试指标正常
  - 高能所新闻报道



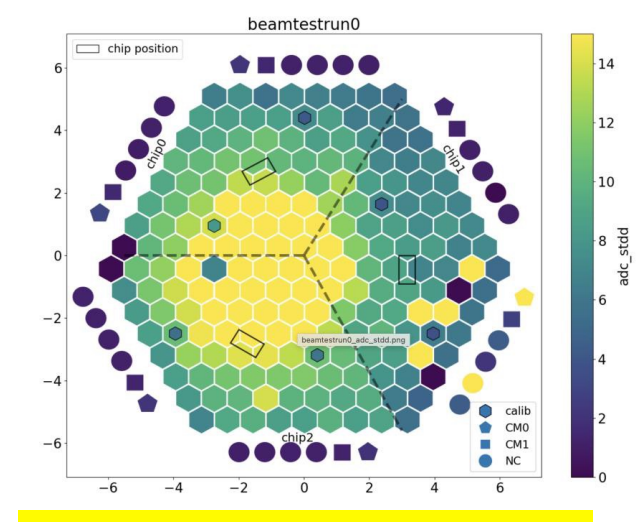


绑定前后噪声

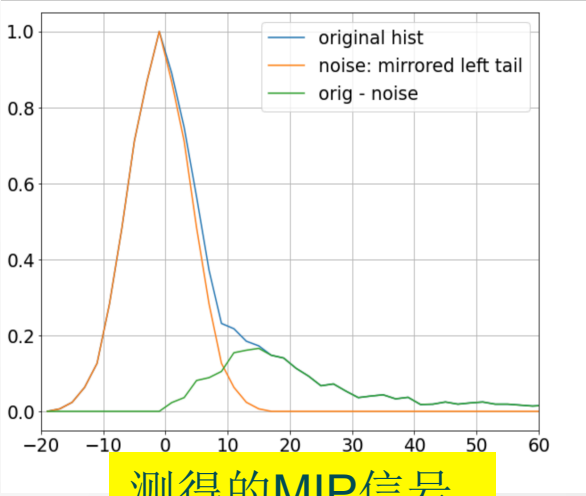
- 两块模块均在CERN进行了实验束测试验证
  - 2021年9月实验束测试高能所生产的IHEP module001
  - 2021年10月实验束测试高能所生产的IHEP module 002



第一次看到束流

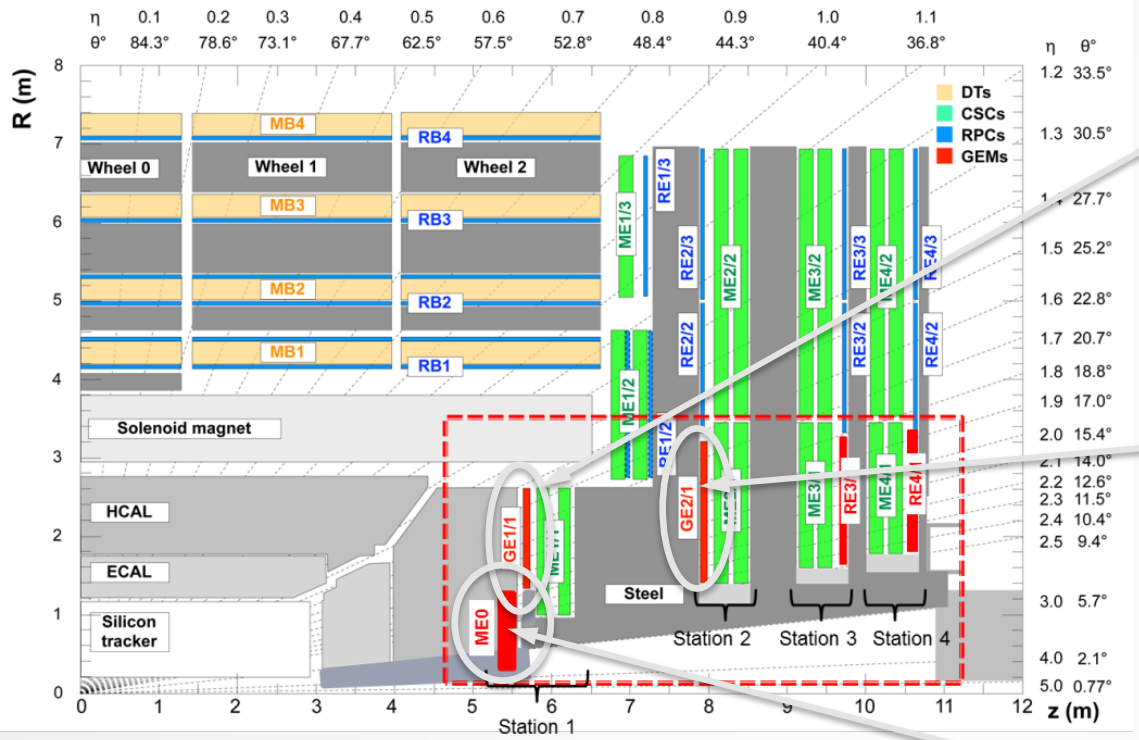


测得的束流粒子簇射信号



测得的MIP信号

CMS-GEM探测器PhaseII升级进展 （1）



中国组任务：

第一站内圈GE1/1 GEM：全部前端电子板GEB生产测试，在CERN的探测器组装测试、安装调试（ 2013-2021）→已完成

第二站内圈GE2/1 GEM：设计研发及生产测试全部GEB，在北大生产1/8 GEM探测器，在CERN进行组装测试、安装调试（ 2014-2024）

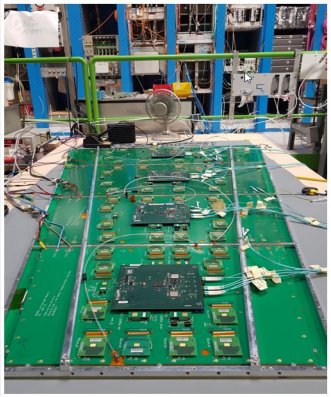
前向内圈ME0 GEM：设计研发及生产测试全部GEB，在北大生产~1/5 GEM探测器，在CERN进行组装测试、安装调试（ 2014-2026）

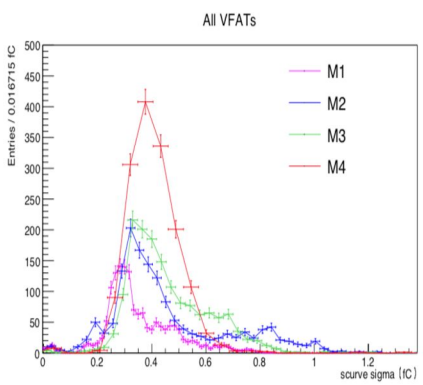
CMS-GEM升级参加单位：

北京大学、清华大学、中山大学、北京航空航天大学

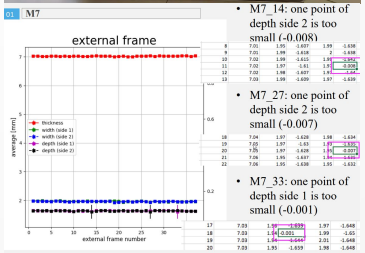
CMS-GEM探测器PhaseII升级进展 （2）

- **GEM探测器**前端电子学板GEB研发和生产
  - 设计、研发成功端部第二站全部8种型号GEM前端电子学板。样机经过CERN及美国初步测试达到要求：噪声<0.5fC，一小时实测误码率<10^{-13}。2021年10月开始批量生产。
  - 完成了第一版ME0 GEM前端电子学板设计并通过了合作组审核，在深圳鑫诺捷公司生产的样机已运到CERN和美国进行了测试，性能良好。
- 承担了在中国研制**GEM探测器**FR4内框架的任务，研制了样机并通过CERN测试和合作组评审。2021年6月完成全部~320块框架的批量生产并运到CERN。
- 对原尺寸第一站GEM探测器样机进行了高压性能、X射线增益等测试，达到CERN指标。→ **北京大学GEM批量生产测试基地建设完成，GEM探测器批量生产2022年2月开始。**





四种型号(M1-M4) GEB 2/1样机、测试平台和噪声测试结果。



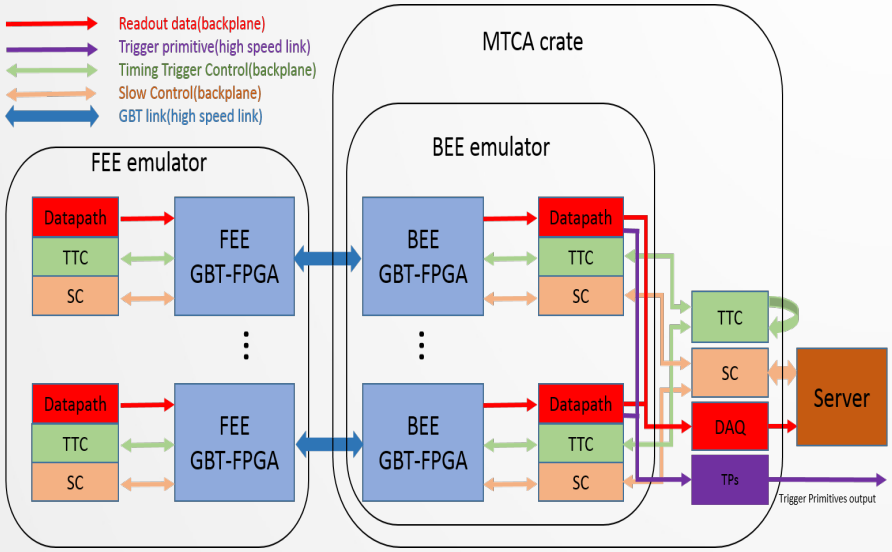
GE2/1 GEM探测器外框架及测试结果。

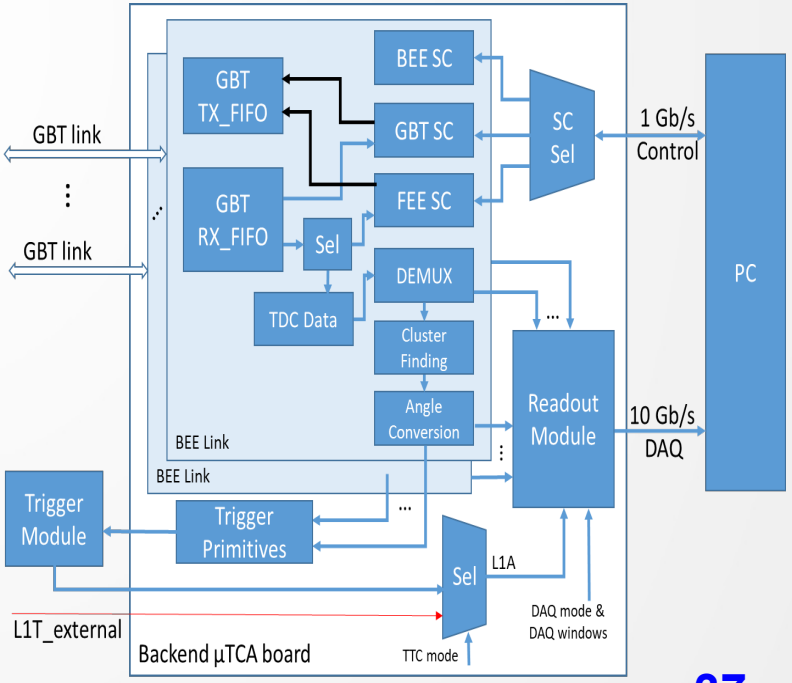
原尺寸第一站GEM探测器样机正在北大进行X射线增益测试

RPC后端触发电子学进展（1）

iRPC后端固件/软件开发

- 为验证后端触发电子学的功能，开发了iRPC前端电子学的模拟系统。
- 为节省FPGA逻辑资源，后端开发了基于数据驱动的读出方式，并完成了后端快/慢控制及触发预处理算法部分的固件开发。
- 后端触发电子学与iRPC模拟系统进行了联调，验证了后端触发电子学的功能。
  - 联调测试在北京实验室和CERN 904实验室进行。

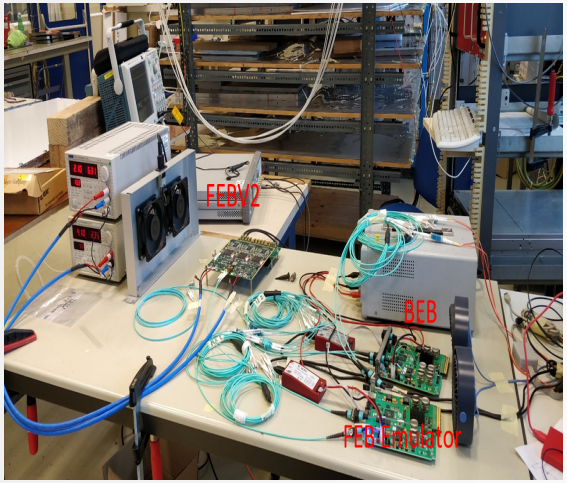




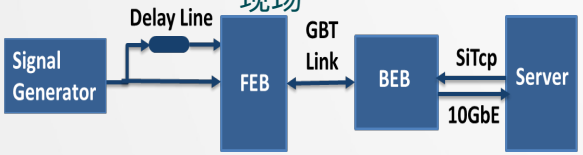
RPC后端触发电子学进展（2）

iRPC前端FEB与后端触发电子学联调测试

- iRPC前端FEB与后端触发电子学联调测试系统7月份在904搭建成功。
- 后端触发电子学与FEB基本功能测试在10月份完成，取得联调第一阶段成功。
- 10月份开始，后端触发电子学与FEB Injection系统联调取数，取得初步的数据分析结果，证明了后端触发电子学可以正确配置iRPC前端电子学并读取数据。



iRPC后端触发电子学与iRPC模拟系统，iRPC前端电子学在904联调现场

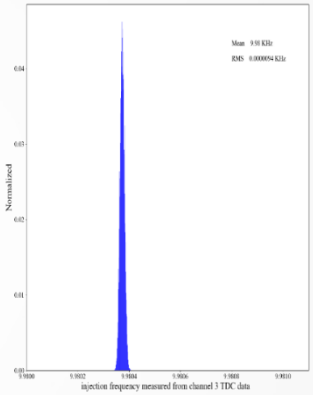


虚拟信号（信号发生器产生）时间信息测试系统结构图

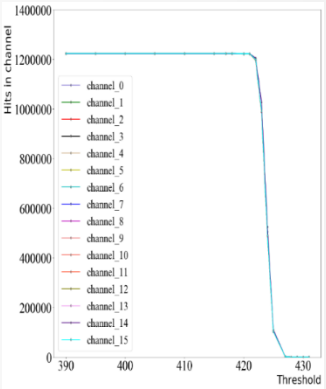
Injection信号参数

Injection信号扇出

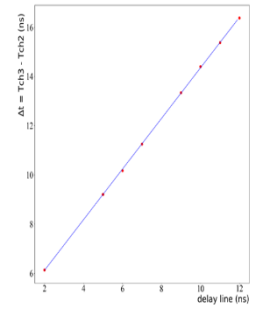
FEB Injection板



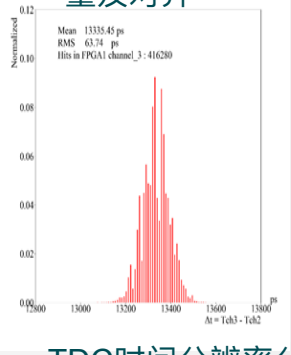
Injection信号频率测量



TDC通道S曲线测量及对齐



Injection信号加入延迟线后时间信息测量

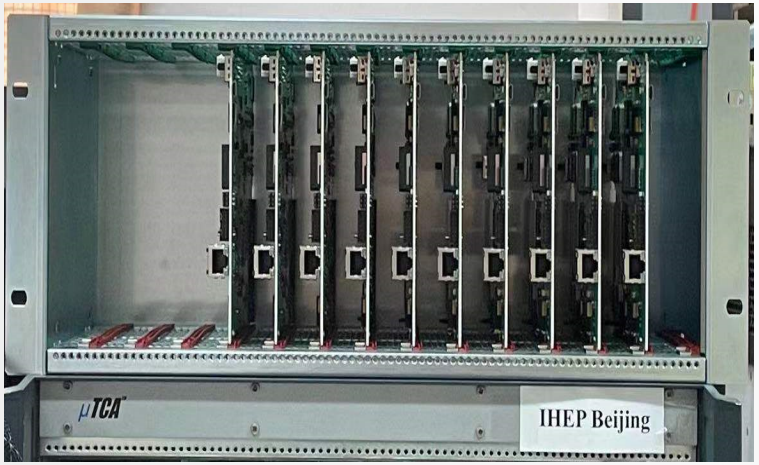


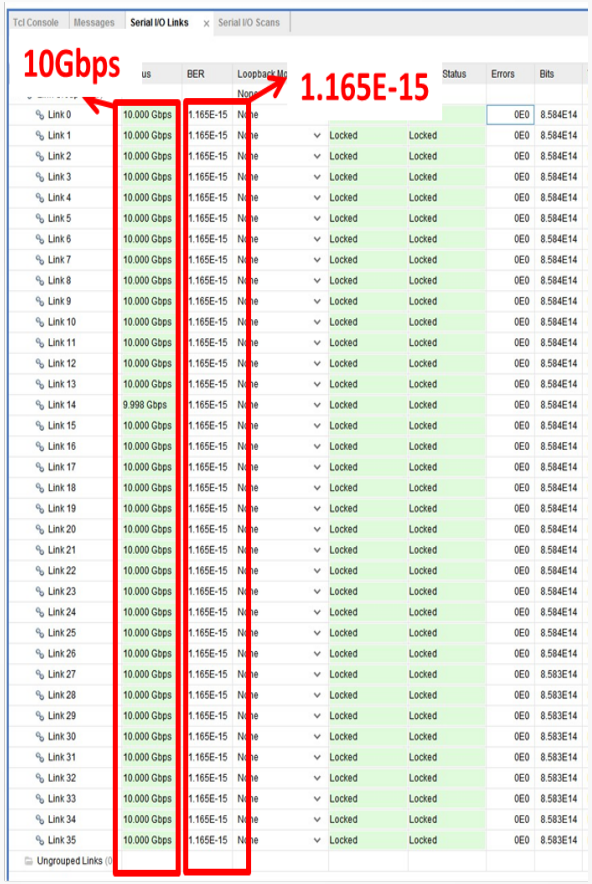
TDC时间分辨率分析

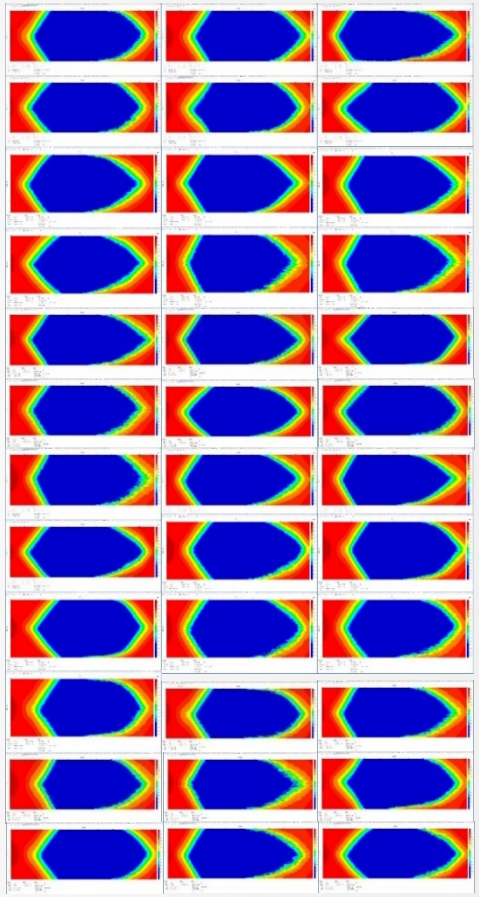
RPC后端触发电子学进展（3）

触发电子学板批量生产

- 按照Moun合作组新的计划，iRPC后端触发电子学MTC A部分在2022/2023年度进行安装。
- 本年度完成了后端触发电子学系统安装所需的触发电子学板的批量生产及性能测试。
- 准备发往CERN

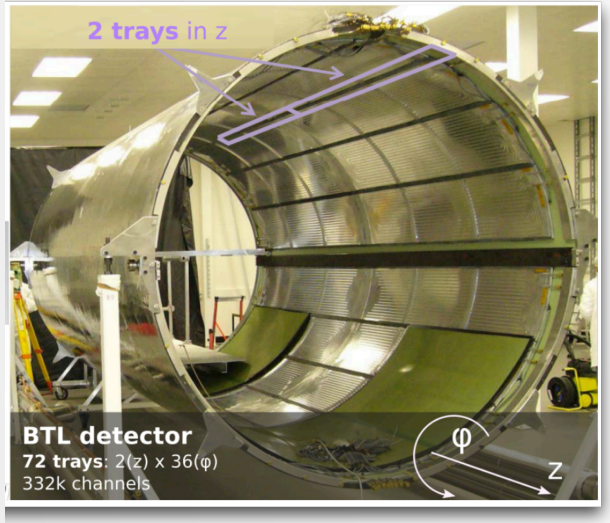


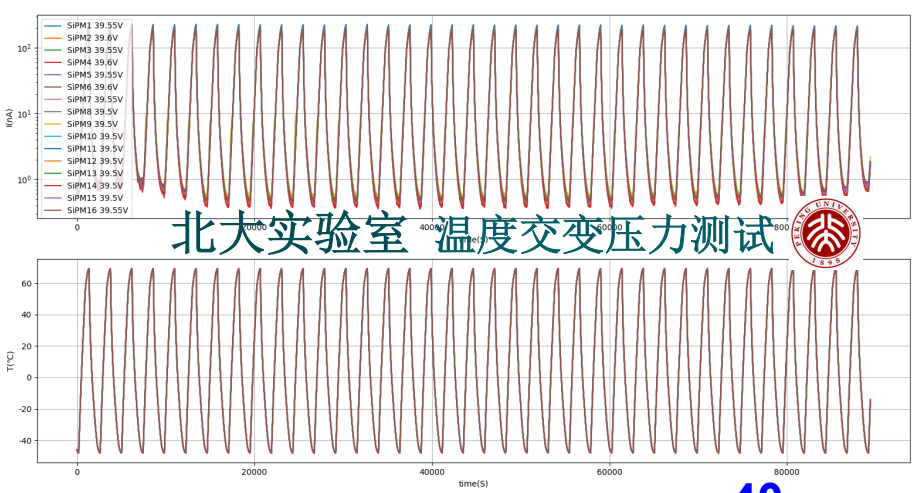




CMS超快时间探测器MTD的研制测试

- LHC升级到HL-LHC，每次对撞产生近200个顶点，事例堆积效应严重，极大的挑战实验测量精度
  - 为应对极为密集的对撞环境，在CMS上建设新型超快时间探测器MTD，拟将时间测量精度提高3个量级
- 2021年中国CMS组正式加入CMS超快时间探测器MTD的研制测试工作，国内单位包括北大、北航和清华
- 北大在加入MTD这短暂的半年内，积极与外方合作单位沟通，协调国内合作单位，搭建本地实验室，已经初步建成研制测试平台，并在sensor硅光电倍增器SiPM的研制测试等方面做出初步贡献





2021年发表的有中国组重要贡献的分析

序号	物理道	文章 / PAS号	中国组的贡献
1	RunII VBS ZZ->4l	CMS-PAS-SMP-20-001 PLB 812 (2021) 135992	**北大：** Loop induced ZZ, 反常耦合测量
2	RunII VBS Wγ	CMS-PAS-SMP-19-008 PLB 811（2020）135988	**北大：** 分析联系人，预审、审核报告
3	RunII VBS Zγ	CMS-PAS-SMP-20-016 PRD 104 (2021) 072001	**北大、中山：** 分析联系人，预审、审核报告
3	Polarized VBS (WW)	CMS-PAS-SMP-20-006 PLB 812(2020) 136018	北大：审核报告
4	WV/WH 共振态	CMS-PAS-B2G-19-002	**北大：** 分析联系人
5	WVV 共振态	CMS-PAS-B2G-20-001	**北大：** 分析联系人，预审、审核报告
6	WWW共振态(全强)	CMS-PAS-B2G-21-002	**北大：** 分析联系人，预审、审核报告
7	Wγ 截面测量	CMS-PAS-SMP-19-002 PRL 126(2021)252002	**北大：** 分析联系人，预审、审核报告
8	B+->K*+mumu 角分析	CMS-BPH-15-009 JHEP 04(2021)124	北大：选择条件与拟合优化
9	HZZ奇异耦合	CMS-PAS-HIG-19-009 PRD 104(2021) 052004	浙大：分析联系人，审核报告
10	HZZ截面测量	CMS-PAS-HIG-19-001 EPJC 81(2021) 488	高能所、北航、浙大、清华： 预审报告、多次做status report
11	HZZ offshell	CMS-PAS-HIG-21-013	北航： 分析召集人，文章编辑，预审报告

2021年发表的有中国组重要贡献的分析

序号	物理道	文章 / PAS号	贡献
12	H->gg截面测量	CMS-PAS-HIG-19-015 JHEP07(2021) 027	高能所：在分析框架、事例触发、光子鉴别、MC模拟修正、光子能量刻度、电子的排除以及效率等方面做出贡献，是CMS内部文章的编辑之一
13	HH (bbgg)	CMS-PAS-HIG-19-018 JHEP03(2021) 257	
14	ttH 多轻子道	CMS-PAS-HIG-19-008 EPJC 81（2021）378	高能所：主推的DNN方案成为新的分析基准，**unblinding报告**
15	T'->tZ寻找	CMS-PAS-B2G-19-004	高能所：分析联系人，预审、审核报告
16	ZZ4l截面及aTGC约束	CMS-PAS-SMP-19-001 EPJC 81(2021)200	高能所：负责缪子效率及其误差确定，独立分析框架检验
17	pPb对撞中Drell-Yan过程	CMS-PAS-HIN-18-003 JHEP05(2021)182	高能所：分析联系人，预审、审核报告
18	tW半轻衰变	CMS-PAS-TOP-20-002 JHEP 11(2021)111	高能所：分析联系人，预审、审核报告
19	H->4l过程中寻找暗光子、类轴子	HIG-19-007 Submitted to EPJC	高能所、清华：分析框架、轻子效率测量、蒙卡样本修正等方面做了重要贡献
20	VBS WV半轻子道证据	CMS-PAS-SMP-20-013	高能所博后为分析主力之一
21	VBF H不可见衰变	CMS-PAS-HIG-20-003	高能所博后作主要贡献，曾担任Analysis Contact
22	CMS电子和光子重建、鉴别性能研究	CMS-PAS-EGM-17-001 JINST 16(2021)P05014	高能所：负责光子能量刻度的验证、光子相关数据与MC的比对

2021年发表的有中国组重要贡献的分析

序号	物理道	文章 / PAS号	贡献
23	LFV寻找	CMS-PAS-EXO-19-014	复旦：负责emu末态全部分析内容
24	Z'->2l寻找	CMS-PAS-EXO-19-019 JHEP 07(2021)208	复旦：分析框架、触发效率测量、本底研究等方面做了重要贡献
25	利用顶夸克过程寻找LFV	CMS-PAS-TOP-19-006	复旦：分析框架、触发效率测量、事例选择、信号抽取等方面做了重要贡献
26	径迹探测器矫正性能	CMS-PAS-TRK-20-001	北航：曾担任AlCa二级召集人，开发软件模块监测硅像素探测器几何中心变化

2020.11 ~ 2021.11 发表有中国CMS组重要贡献的分析:

26 个 (paper 16 + PAS 10)

其中主导贡献（即担任分析联系人）的分析:

10 个 (paper 6 + PAS 4)

注： CMS的分析联系人每个分析只有一个！

2021发表有中国组成员单独署名文章：7 篇

单独署名文章:

Till Martini, Ren-Qi Pan, Markus Schulze, Meng Xiao, “Probing the CP structure of the top quark Yukawa coupling: Loop sensitivity vs. on-shell sensitivity”, arXiv: 2104.04277, Phys. Rev. D 104, 055045

E. Chapon et cl, Perspectives for quarkonium studies at the high-luminosity LHC, arXiv:2012.14161, DOI:https://doi.org/10.1016/j.ppnp.2021.103906 (In Press in *Progress in Particle and Nuclear Physics*, available online 1 September 2021)

J. Tao, Searches for additional Higgs bosons at the LHC, DOI: https://doi.org/10.22323/1.397.0077, PoS (LHCP2021) 077

Sitian Qian, Congqiao Li, Qiang Li, Fanqiang Meng, Jie Xiao, Tianyi Yang, Meng Lu, Zhengyun You, Searching for heavy leptoquarks at a muon collider, arXiv:2109.01265, accepted by JHEP.

Tianyi Yang, Sitian Qian, Zhe Guan, Congqiao Li, Fanqiang Meng, Jie Xiao, Meng Lu, Qiang Li, Longitudinally polarized ZZ scattering at the Muon Collider, arXiv:2107.13581, Phys.Rev.D 104 (2021) 9, 093003.

Meng Lu, Andrew Michael Levin, Congqiao Li, Antonios Agapitos, Qiang Li, Fanqiang Meng, Sitian Qian, Jie Xiao, Tianyi Yang, The physics case for an electron-muon collider, arXiv:2010.15144, Adv.High Energy Phys. 2021 (2021) 6693618

Congqiao Li, Ying An, Claude Charlot, Roberto Covarelli, Zhe Guan, and Qiang Li， Loop-induced ZZ production at the LHC: an improved description by matrix-element matching， Phys. Rev. D 102, 116003 (2020)

中国组代表CMS在国际会议报告Plenary 15 个

1. **Antonis Agapitos**, ATLAS + CMS Searches for Di/Triboson resonances (VV/VVV/Vh/Zy/Hy, 3y), LHCP2021, 7-12 Jun 2021,
2. Ying An, Electroweak production of Zγ and two jets at 13 TeV and constraints on EFTs, SM@LHC2021, 26-30 Apr 2021
3. Andrew Levin, Standard Model physics results at CMS, Moriond/QCD2021, 27 Mar-3 Apr 2021
4. Emilien Chapon, "Exotic phenomena in CMS", ECT workshop: Heavy Ions and New Physics (ECT-Heavy-Ions 2021), 20-21 May 2021, Villazzano (Italy)
5. Emilien Chapon, "Heavy flavour and correlations", VI-th International Conference on the Initial Stages of High-Energy Nuclear Collisions (Initial Stages 2021), 10-15 Jan 2021, Rehovot (Israel)
6. Fabio Monti, Resonant and non-resonant HH channel, SM@LHC2021: Standard Model at the LHC 2021, 26-30 Apr 2021, Video only (Virtual World)
7. Duncan Leggat, CMS Highlight talk 3: tW results, LHC-TOP2021: LHC TOP WG meeting, 19-21 May 2021, CERN, Video only (Virtual World)
8. Joshuha Thomas-Wilsker, Experimental results on tt+X, LHCP2021: 9th Edition of the Large Hadron Collider Physics Conference, 7-12 Jun 2021, Paris (Virtual World)
9. Junquan Tao, Searches for additional Higgs bosons at ATLAS+CMS, LHCP2021: 9th Edition of the Large Hadron Collider Physics Conference, 7-12 Jun 2021, Paris (Virtual World)

中国组代表CMS在国际会议报告Plenary 15 个

10. Andrew Levin, Precision measurements of diboson differential and total cross sections, MBI2021: Multi-Boson Interactions 2021, 23-27 Aug 2021
11. Searches for heavy BSM particles resulting in boosted final states at CMS, BOOST2021, 2-5 Aug 2021, Xudong Lyu
12. Boosted jet tagging in CMS, ML4Jets2021, 6-8 Jul 2021, Congqiao Li
13. Hongbo Liao , “Top quark physics at CMS ”, Lomonosov 2021, 19-25 Aug 2021 , Russia
14. Duncan Alexander Leggat, Measurement of tW production in lepton jets channel, TOP2021: 14th International Workshop on Top Quark Physics (TOP2021), 13-17 Sep 2021 (Online)
15. Ram Krishna Sharma, Standard Model and Electroweak Results from CMS, LISHEP2021: LISHEP Workshop on High Energy Physics, 6-8 Jul 2021, UERJ (Online)

中国组代表CMS在国际会议报告分会报告 20 个

1. Xuelong Qin, Angular analyses of B meson decays at CMS, FPCP2021, 7-11 Jun 2021
2. Hanwen Wang, Measurements on Higgs boson width and anomalous couplings with on-shell and off-shell production in ZZ->4l, FPCP2021, 7-11 Jun 2021
3. Xudong Lyu, Searches for heavy resonances decaying into Z, W, and Higgs bosons at CMS, Pheno2021, 24-26 May 2021
4. Jie Xiao, Searches for new physics in events with leptons in the final state in CMS, Pheno2021, 24-26 May 2021
5. Ying An, Vector Boson Scattering results from CMS, DIS2021, 12-16 Apr 2021
6. Jin Wang, “Calibration and Performance of the CMS Electromagnetic Calorimeter in LHC Run 2”, TIPP 2021 International Conference on Technology and Instrumentation in Particle Physics, May 24-28 2021, Canada (Online)
7. Hanwen Wang, Measurements on Higgs boson width and anomalous couplings with on-shell and off-shell production in ZZ decay channels at CMS experiment, TeVPA2021, 25-29 Oct, 2021
8. Xuyang Gao, Search for new physics in dilepton final states with CMS Run 2 data, TeVPA2021, 25-29 Oct, 2021,
9. Zebing Wang, Searches for Axion-like Particles at CMS, TeVPA2021, 25-29 Oct, 2021,
10. Qilong Guo, Searches for heavy resonances decaying into Z, W, and Higgs bosons at CMS, SUSY2021, 23-28 Aug 2021
11. Qun Wang, Vector boson associated with jets in CMS, EPS-HEP2021: European Physical Society Conference on High Energy Physics, 26-30 Jul 2021
12. Cheng Chen, Searches for heavy resonances decaying into Z, W, and Higgs bosons at CMS, EPS-HEP2021: European Physical Society Conference on High Energy Physics, 26-30 Jul 2021
13. Antonis Agapitos, ATLAS + CMS Searches for Di/Triboson resonances (VV/VVV/Vh/Zy/Hy,3y), LHCP2021, 7-12 Jun 2021,

中国组代表CMS在国际会议报告分会报告 20 个

14. Junquan Tao, Searches for additional Higgs bosons at ATLAS+CMS, LHCP2021: 9th Edition of the Large Hadron ColliderPhysics Conference, 7-12 Jun 2021, Paris (Virtual World)
15. M. A. Shahzad, Measurement of Higgs production and search for an additional SM-like Higgs boson in the diphoton decay channel with the CMS detector, Higgs2021: Higgs 2021 Conference, 18-22 Oct 2021, Stony Brook, NY (Virtual World)
16. Fabio Iemmi, Associated production of tt+HF at CMS, , EPS-HEP 2021, 26-30 Jul 2021, DESY;
17. Jin Wang, Higgs couplings and CP studies at ATLAS and CMS, CKM2021: 11th International Workshop on the CKM Unitarity Triangle, 22-26 Nov 2021, Univ. of Melbourne (Online)
18. Vukasin Milosevic, “Rare, Exotic, and Invisible Higgs Decays at CMS”, TeVPA2021, 24-29 Oct 2021, Chengdu (China)
19. Vukasin Milosevic, Searches for Higgs invisible, EPS-HEP2021: European Physical Society Conference on High Energy Physics, 26-30 Jul 2021, DESY and University of Hamburg (Online)
20. Taozhe Yu, Search for single T’ production in T’ ->tZ(ν ν) decay mode with CMS, 21-27 March, Moriond EW 2021

中国组代表CMS在国际会议报告Poster 2 个

1. Duncan Leggat, Measurement of tW production in the semileptonic channel in pp collisions at 13 TeV with CMS, LHCP2021: 9th Edition of the Large Hadron Collider Physics Conference, 7-12 Jun 2021, Paris (Virtual World)
2. Taozhe Yu, Posters@LHCC , Search for single T' production in T'->tZ(vv) decay mode at CMS , 18 Nov 2021, CERN, Geneva;

任CMS实验二/三级管理职位统计表

分组（二级）	人员	管理级别	所属三级分组	服务期限
软件计算组	李强	二级	-	2020.6-
RPC 触发组	刘振安	二级	-	2019.09-
Egamma ID group	Anshul Kapoor	三级	-	2020.9-
顶夸克物理组	J. Thomas-Wilsker	三级	ttX组召集人	2020.9-
物理性能以及数据集 PdmV	M. Ahmad	二级	-	2020.9-
物理性能以及数据集 DQM	J. Martins	二级	-	2020.9-
物理性能以及数据集PdmV	刘锦枫	三级	PPD	2021.01–
Egamma HLT group	Ram Krishna Sharma	三级		2020.10-
B2G分析组	Antonis Agapitos	三级	共振态组召集人	2020.9-
标准模型分析组	彭靖	三级	MC Contact	2019.6-
B2G 组	吕旭东	三级	MC Contact	2019.10-
希格斯物理组	肖朦	三级	Higgs联合分析和EFT组召集人	2020.09 -
LHC Higgs Combination工作组	陈明水		CMS负责人	2021.09-
L1触发组	Vukasin Milosevic	三级	DQM convener	2021.04-
TOP2021 IAC	Hongbo Liao			2021.09
Jetmet组	安莹	三级	DQM convener	2021.11-

任CMS实验二/三级管理职位统计表

物理分组（二级）	人员	管理级别	所属三级物理分组	服务期限
LHC Higgs物理工作组	J. Thomas-Wilsker	/	WG1 ttH	2019.06-
希格斯物理组	郭倩颖	/	HZZ MC联络人	2019.01-
产生子组	卢梦	/	Validation	2019.09-
B-Tagging组	王锦	/	MC联络人	2019.05-
希格斯物理组	王锦	/	Hgg MC联络人	2019.10-
希格斯物理组	王储	/	Hgg MC联络人	2020.10-
Jetmet组	郭启隆	三级	MC联络人	2020.10-
Jetmet组	李聪乔	三级	Upgrade联络人	2021.09-
标准模型分析组	安莹	三级	Electron Contact	2019.10-
产生子组	肖杰	三级	Validation	2020.9-
RPC电子学	赵京周	三级	RPC 触发组	2020. 9-
标准模型分析组	肖杰	三级	机器学习联络人	2020.06-
产生子组	Duncan Leggat		generator operator	2019.11-
顶夸克物理组	Duncan Leggat	三级	MC联络人	2021.01-
B物理组	胡震	三级	MC联络人	2021.01-
B物理组	J. Martins	三级	VFS	2021.01-

任CMS实验其它管理职位统计表

北大王群2020年获选担任Thesis Award Committee Member

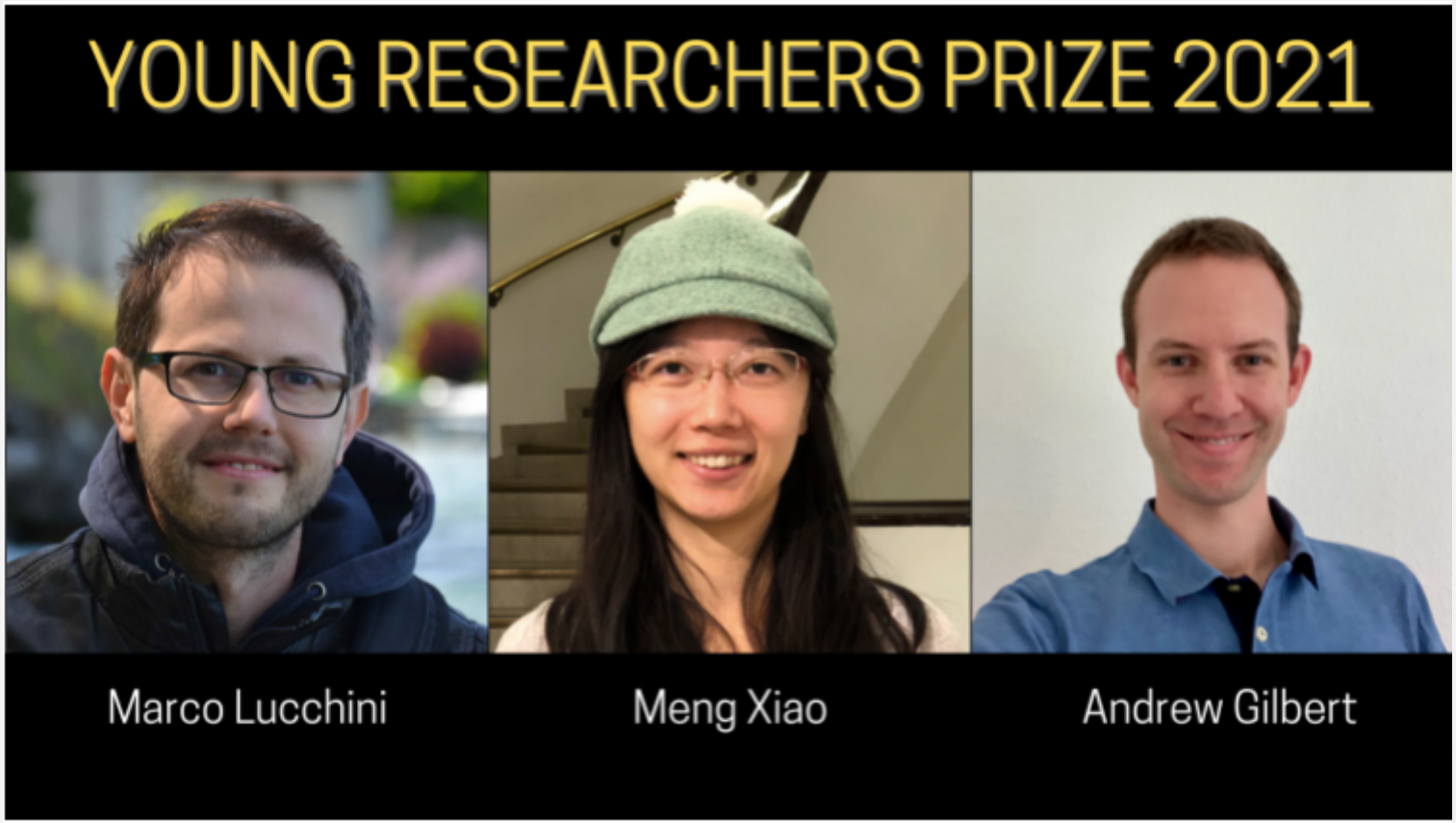
浙大肖朦2019.09至2021.09为CMS CB advisory board member(合作组顾问委员会)，2020.10至今为CMS diversity office member (多元委员会)

北大钱思进长期担当CMS Authorship Committee成员

高能所廖红波、北航袁丽2021年获选担任Conference Committee Member

获奖情况

- 浙大肖朦获得2021 CMS Young Researcher Prize



Congratulations to **Andrew Gilbert**, **Marco Luccini** and **Meng Xiao** for winning the CMS Young Researchers Prize for 2021!

https://cms.cern/news/cms-young-researchers-2021

CMS 2020 Award

The Compact Muon Solenoid Collaboration
confers on
Congqiao Li
Peking University
a
CMS 2020 Award
For
allowing the Legacy processing to benefit from the most recent framework developments in the area of parallelisation of event generators

The Collaboration Board Chairperson (Harrison B. Prosper)

The Experiment Spokesperson (Luca Malgeri)

February 1st, 2021

李聪乔(北大2019级博士生)　事例产生子多线程应用

For allowing the Legacy processing to benefit from the most recent framework developments in the area of parallelisation of event generators.

马妙钟(北大2015届博士生)　物理数据和蒙卡校准组的突出和领导贡献

For her leadership of and crucial contributions to the Physics Dataset and Monte Carlo Validation group, and in particular her invaluable impact on software release validation, data re-reconstruction and Monte Carlo production.

曲慧麟(北大2014届本科生，UCSB博士，现为CERN Fellow) 基于机器学习的探针

For deploying for production new tagger architectures as well as new inference engines, as well as important developments to speed up DeepTau inference.

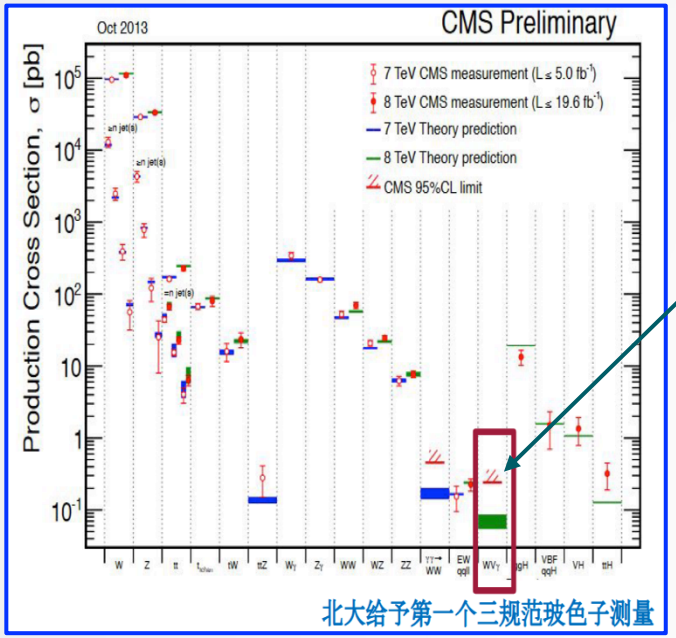
总 结

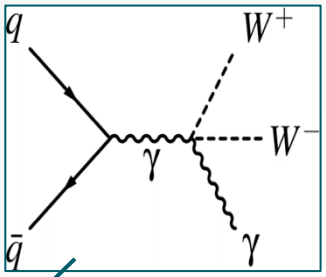
- CMS中国组工作努力，尽管没有突破标准模型，仍然在希格斯性质测量、新粒子寻找、标准模型检验三方面取得一批很好的成果，发表了有我方贡献的CMS文章16篇 (截止到目前，CMS2021年发表56篇)。
- Phase-2 升级工作，目前进展良好，升级经费获得了基金委、科技部的大力支持，但经费缺口依然较大，希望基金委、科技部能给予更多经费支持，以便完成中国组对CMS二期升级 1% 的贡献。

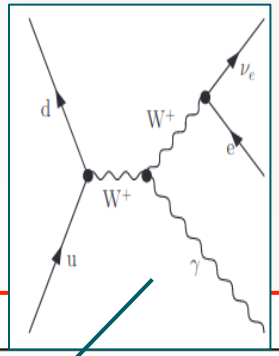
感谢基金委、科技部、科学院和兄弟单位长期大力支持！
请大家指正！

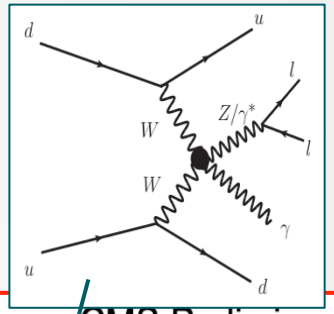
感谢您的批评指正

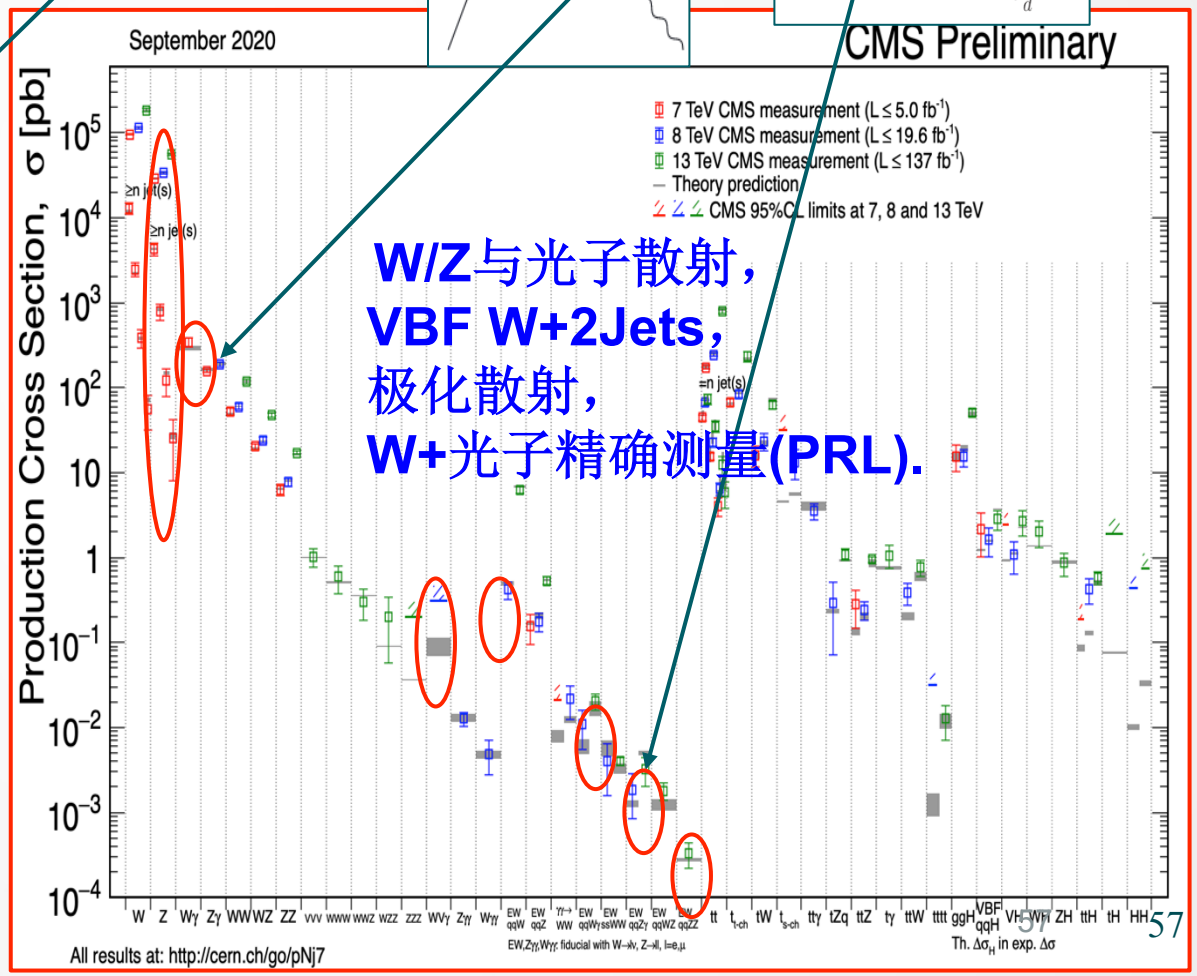
玻色子的散射和相互作用：stair to X











W/Z与光子散射，
VBF W+2Jets，
极化散射，
W+光子精确测量(PRL).

左图：**2013年版本**
北大给予三玻色子首次测量
右图：**2020年版本**
做出一批新发现、首次测量

全重味奇特强子态

- 早在上世纪八十年代，赵光达等理论学家预测了全粲四夸克态的存在
- CMS在2013年对Run 1数据在J/ψ J/ψ末态做了初步探索并有所斩获
- **清华(+南师)**CMS组目前正对此进行系统全面的研究。如Run 1的痕迹在Run2的海量数据中得到确认，将对全粲四夸克态的存在做出决定性的判定
- 目前LHCb在J/ψ J/ψ末态看到了新的结构。CMS将做独立无偏差的分析，并对LHCb结果进行检验
- **清华(+南师)、复旦** CMS组除在J/ψ J/ψ末态的研究以外，也在J/ψ ψ(2S)末态， J/ψ ϒ末态， ϒϒ末态等展开了系统研究，对全重味四夸克态进行前所未有的全面探测，预期未来几年取得突破性结果

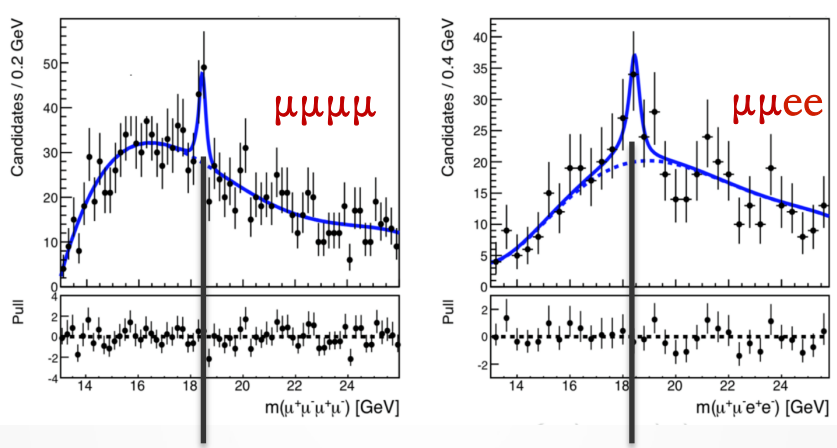
  – 8项分析同步推进
  – 第1篇(四夸克态cccc)预计年底前发出
  – 其它7篇预计未来1-2年内发出

$$\sigma^{\text{on-shell}} \propto \frac{g^2_{\text{prod}} g^2_{\text{dec}}}{\Gamma_{\text{H}}} \propto \mu_{\text{prod}}$$

$$\sigma^{\text{off-shell}} \propto \int \frac{g^2_{\text{prod}} g^2_{\text{dec}}}{\left(q^2_H - m^2_H\right)^2} dq^2_H \propto \mu_{\text{prod}} \cdot \Gamma_H$$

超出标准模型新物理

- 在 LHC Run 1 的数据中，在 μμμμ , μμee , μμγ等衰变道看到了新的结构，不变质量均在18 GeV 附近 (4b阈值之下)



- 阈值之下是否存在束缚态不确定
- 如果不是统计涨落，也可能是超出标准模型的新物理
- 清华(+南师)CMS组在JJ*，ϒϒ*末态开展了研究

Analysis	AN
Below 4c threshold search	AN-20-173
Below 4b threshold search	AN-19-244, AN-19-274

WZγ 三玻色子的测量

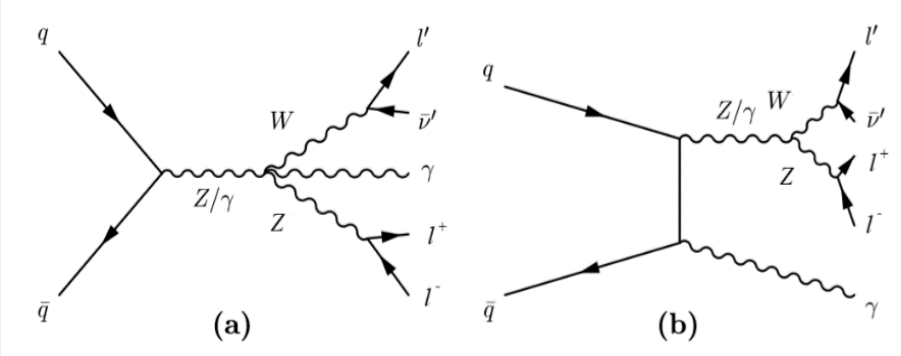
中山大学

		E_T^γ threshold [GeV]	Observed limit [fb]	Expected limit [fb]	SM Prediction σ_{theo} [fb]
Fully leptonic	$e\nu\mu\nu\gamma$	120	0.3	$0.3^{+0.3}_{-0.1}$	0.076 ± 0.004
Semileptonic	$e\nu jj\gamma$	200	1.3	$1.3^{+0.5}_{-0.3}$	0.057 ± 0.013
	$\mu\nu jj\gamma$	200	1.1	$1.1^{+0.5}_{-0.3}$	0.051 ± 0.011
	$\ell\nu jj\gamma$	200	0.9	$0.9^{+0.3}_{-0.2}$	0.054 ± 0.009

ATLAS，Eur. Phys. J. C (2017) 77:646

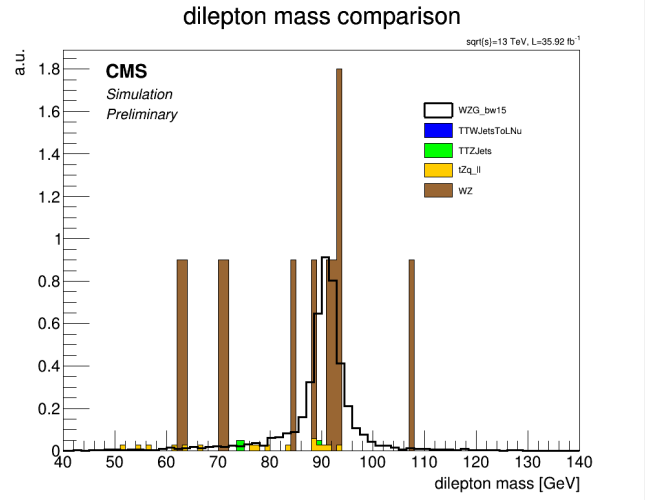
- 利用8TeV数据和半轻衰变模式中，已经测量了WZγ 散射截面
- 将利用纯轻衰变模式进行测量
- 分析正在进行中

pp→WZγ→lνl↑+ l↑− γ
(W↑± →l↑± +υ，Z→l↑+ +l↑−)
检验标准模型的电弱理论
对反常四规范玻色子耦合进行



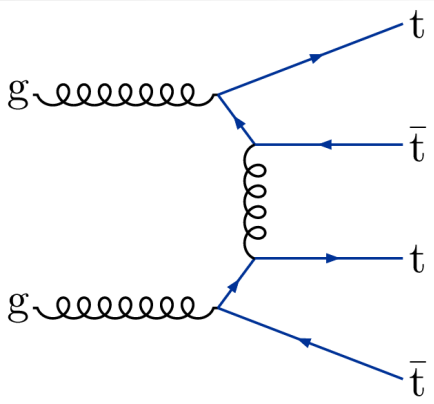
Quartic Gauge-boson Coupling　　Triple Gauge-boson Coupling

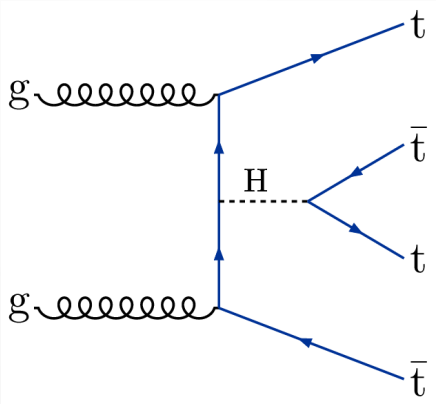
Phys. Rev. D 2013, 88, 015023.



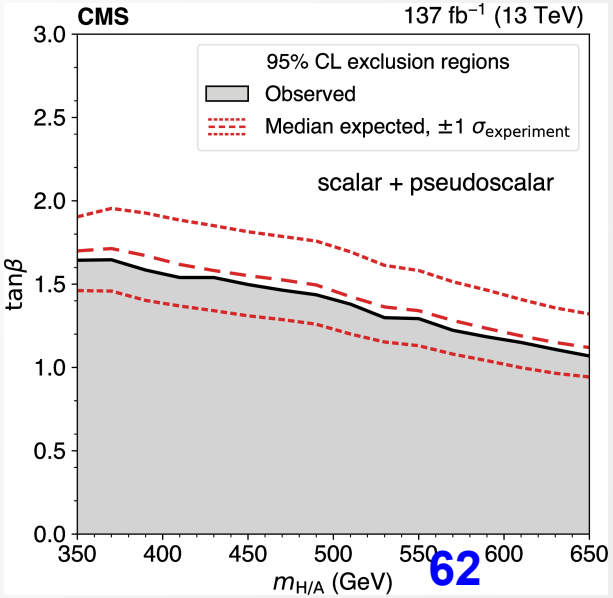
标准模型测量：4顶夸克产生截面测量

- 4 顶夸克的物理过程是标准模型允许的稀有衰变过程。
- 对顶夸克的汤川耦合强度和 CP 特性非常敏感，也会受到超出标准模型物理过程的影响（如重希格斯玻色子衰变到顶夸克对）。
- 在含有 tau 轻子的末态中寻找 4 顶夸克的产生过程，这是在之前的 ATLAS 和 CMS 分析中还没有尝试过的衰变模式。
- 预期可以增加 4 顶夸克产生截面测量的灵敏度，从而在 Run-3 阶段发现 4 顶夸克的产生过程并给出反应截面的测量结果。
- 复旦大川英希和高能所廖洪波做主导性贡献。





4顶夸克产生过程



希格斯自耦合性质研究

- 希格斯的自耦合即自相互作用是一种全新的基本相互作用，它的观测及测量有助于深入地理解弱电真空自发破缺机制，确定希格斯场参与的真空相变的形式。希格斯的自耦合研究是当前LHC和未来HL-LHC希格斯性质研究的重点。
  - 可以利用双希格斯粒子(HH)的产生过程直接探测希格斯的自耦合性质

- 高能所组目前在HH→$WW\gamma\gamma$， HH →bb$\gamma\gamma$分析以及双希格斯多衰变道联合分析中做出重要贡献
  - CMS实验上首个HH →WW$\gamma\gamma$分析，高能所主导全轻子及全强子衰变道的数据分析，以及半轻衰变道多变量分析方法的研究。
    - 预计明年发表1-2篇PAS
  - HH →bb$\gamma\gamma$末态是HH分析中最灵敏的衰变道之一，高能所成员负责蒙特卡罗（MC）样本的产生、光子MC模拟的修正研究、光子能量重建和刻度以及鉴别、电子排除效率以及数据与MC的修正因子的研究和应用。
    - Run2分析已经通过CMS内部审核，准备提交发表JHEP期刊文章
  - 利用全部双希格斯的衰变模式，最大化双希格斯产生过程的测量精度，高能所在当前双希格斯联合测量统计分析中做出重要贡献。
    - 预计明年发表一篇期刊文章