Higgs Rare and BSM Decays from ATLAS

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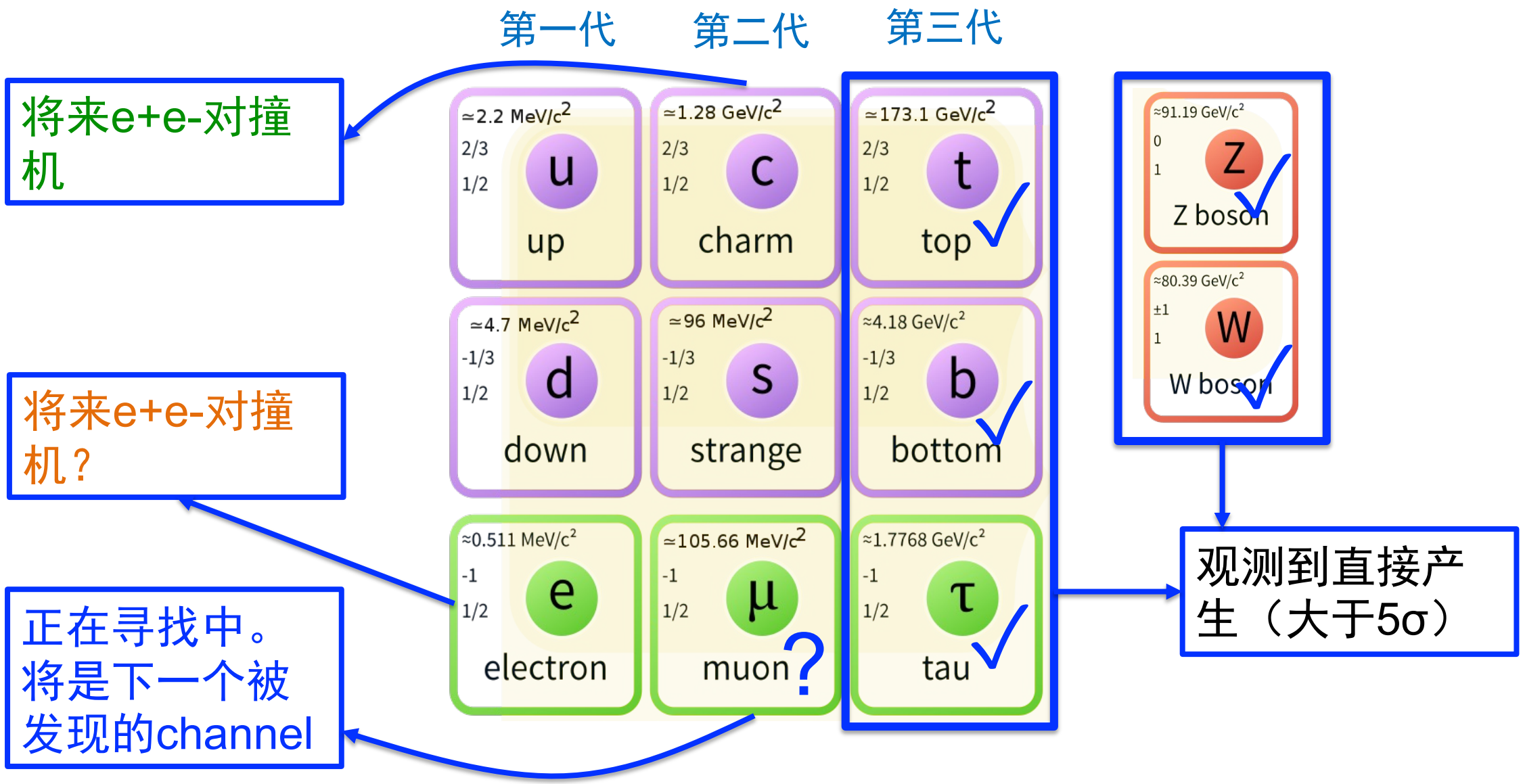
2024年8月14日，高能物理大会，青岛

希格斯粒子只和有质量的基本粒子发生相互作用



$H \to \mu\mu$

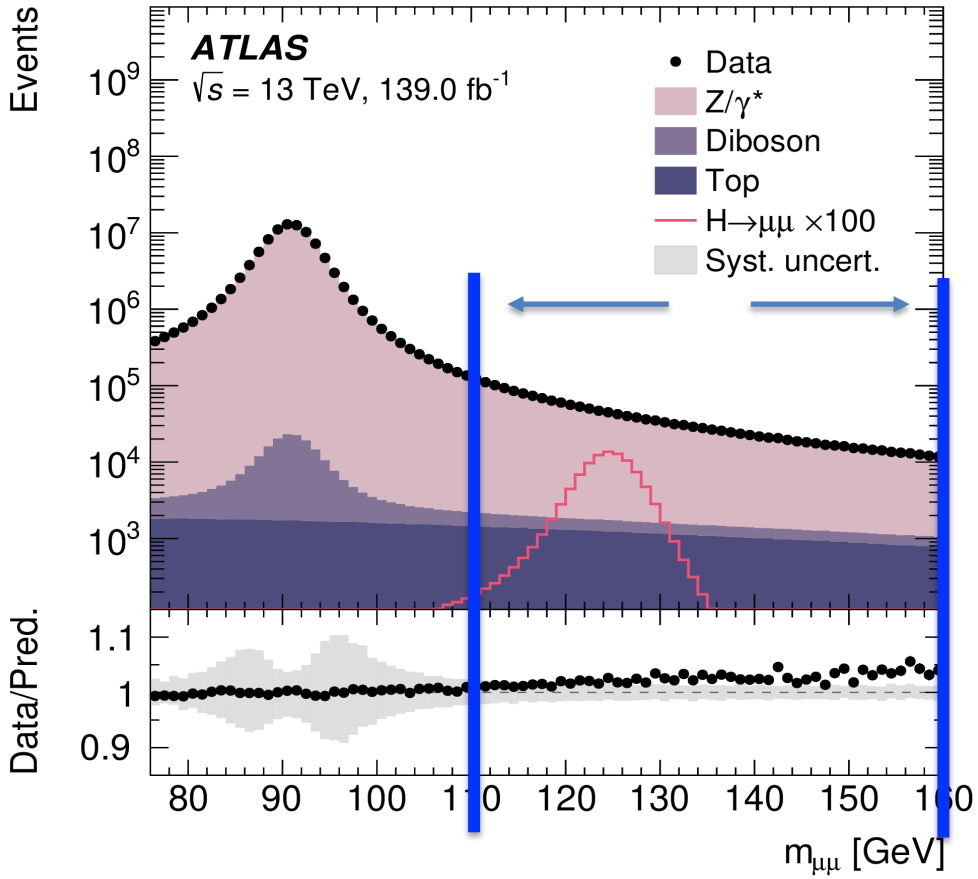
Phys. Lett. B 812 (2021) 135980

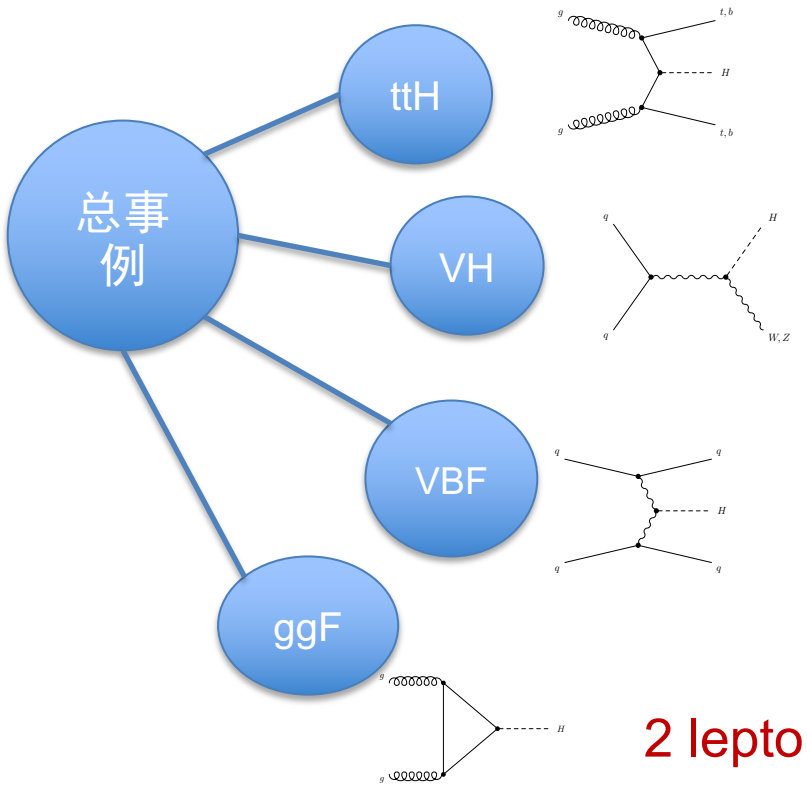
H→μμ

Phys. Lett. B 812 (2021) 135980

最大的本底是Drell-Yan过程
BR(H→μμ)=0.02%

13 TeV 希格斯粒子的产生截面约为 55 pb。积分亮度为140 fb^{-1}的数据中, 有大约8百万个希格斯粒子产生。其中1540个衰变到双缪子（μμ）





3/4 leptons, at least one bjet

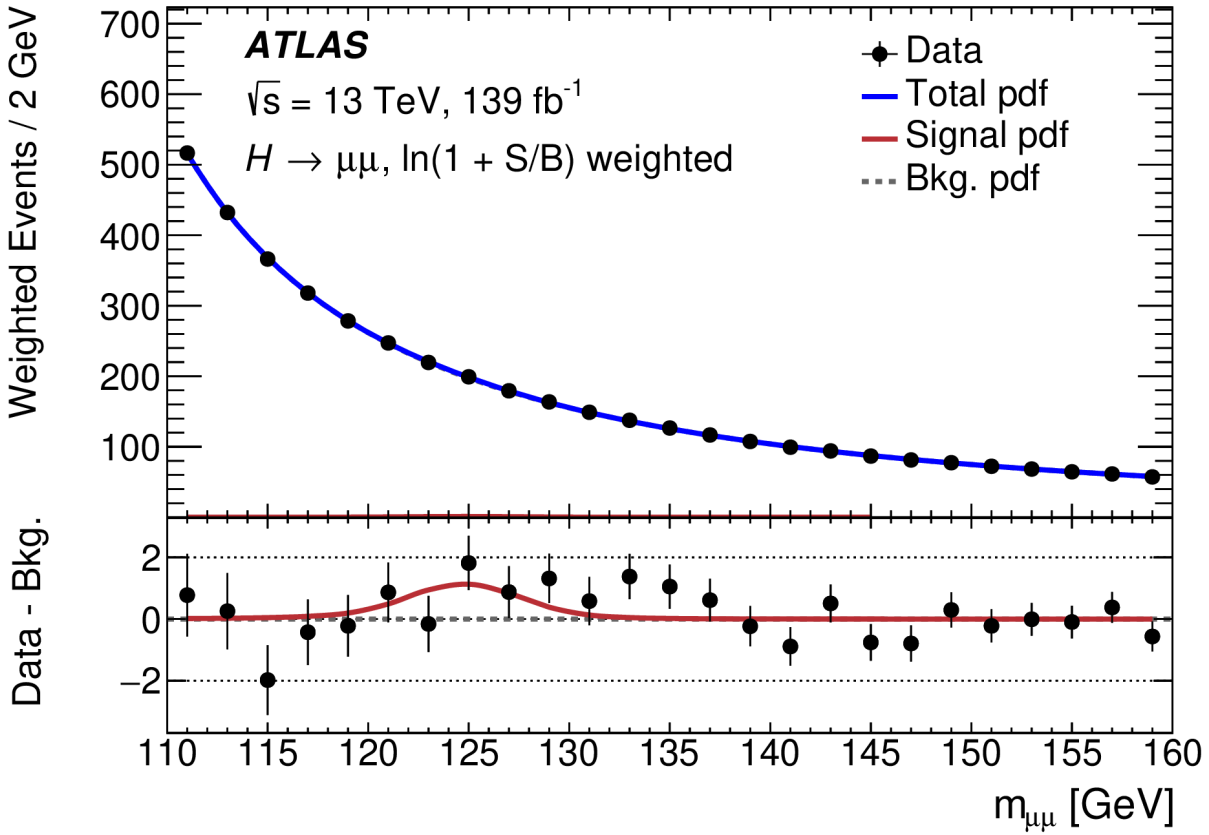
3/4 leptons, no bjet

2 leptons, no bjet

2 leptons, no bjet

H→μμ

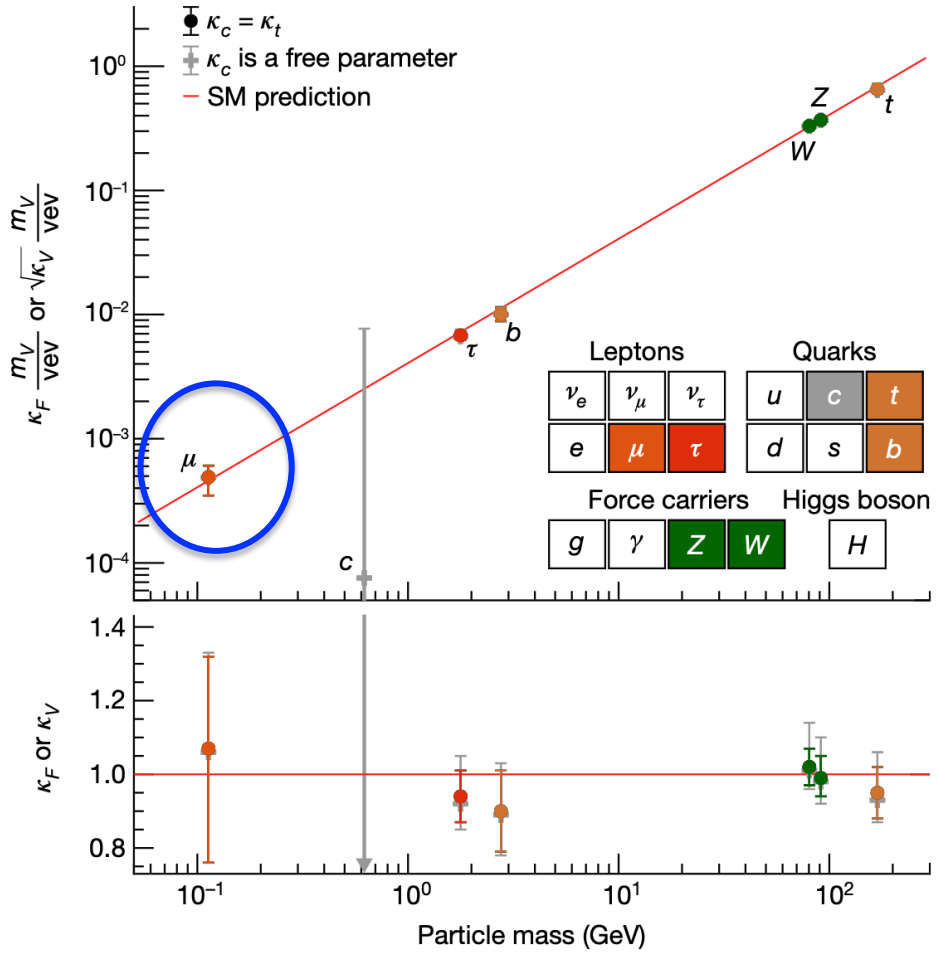
Phys. Lett. B 812 (2021) 135980



Significance: 2.0σ (1.7σ expected)

Best fit: μ = 1.2 ±0.6

Nature 607, 52–59 (2022)



Personal note: 12 years ago

```
/*
 * @author Haifeng Li <Haifeng.Li@cern.ch>
 * @date   Sep 03, 2012
 * @usage  Fitting macro for H -> mu mu background.
 */

// ROOT
#include "TTree.h"
#include "TH1D.h"
#include "TRandom.h"
#include "
#include "
#include

// RooFit
#ifndef _
#include
#endif
#include
#include
#include "RooDataHist.h"
#include "RooGaussian.h"
#include "RooPlot.h"
#include "RooGenericPdf.h"
#include "RooMinuit.h"
//Local
#include "util/plotFit.h"


using namespace RooFit ;
```

A twelve-year query for the Higgs coupling to second generation fermion

```
// model
RooWorkspace* w = new RooWorkspace("w","w");
w->import(mll);

// Working version for [105, 160]
//w->factory("EXPR::bkgPDF('exp( a2*pow((mll-97), 0.2) )', mll, a2[-1

//
//w->factory("EXPR::bkgPDF('(a1*mll + a2*(2*mll*mll -1 ) + a3*(4*mll*

//
//w->factory("EXPR::bkgPDF('exp( a1*pow((mll-100), 0.2) + (a2)*(2*pow


// H->gamma gamma
//w->factory("EXPR::bkgPDF('exp( a1*(mll-100)/100.+a2*(mll-100)*(mll-

w((mll-100

w((mll-100

, -1., 1],
., 1], pol
2., 2], pol

//w->factory("RooPolynomial::poly_bg(mll, {poly_c1[1, 0., 10], poly_c
//w->factory("EXPR::exp_bg('exp( a2*pow((mll-97), a3) )', mll, a2[-1,
//w->factory("PROD::bkgPDF( exp_bg ,  poly_bg)");



//w->factory("Chebychev::poly_bg(mll, {poly_c1[-7.44E-3, -1., 1], pol
//w->factory("RooExponential::exp_bg( mll, a2_bg[-0.1,-0.5,-0.001])"
//w->factory("SUM::bkgPDF(  frac_bg[0.6, 0.01, 0.9]*exp_bg ,  poly_bg


// Working version
w->factory("Chebychev::poly_bg(mll, {poly_c1[-0.7969, -1., 1], poly_c
w->factory("RooExponential::exp_bg( mll, a2_bg[-0.1584,-0.5,-0.001])"
w->factory("SUM::bkgPDF(  frac_bg[0.382, 0.01, 0.9]*exp_bg ,  poly_bg
```

Gavin Salam, the future of HEP

- LHC will reach 5σ sensitivity for $H \to \mu\mu$ in the coming years (if it is SM-like), offering first proof that particles other than 3rd generation also get their mass from Yukawa mechanism
- that will be a crucial step on the way from 3rd generation Yukawas to 1st
- it deserves a big event with the world's press to announce it

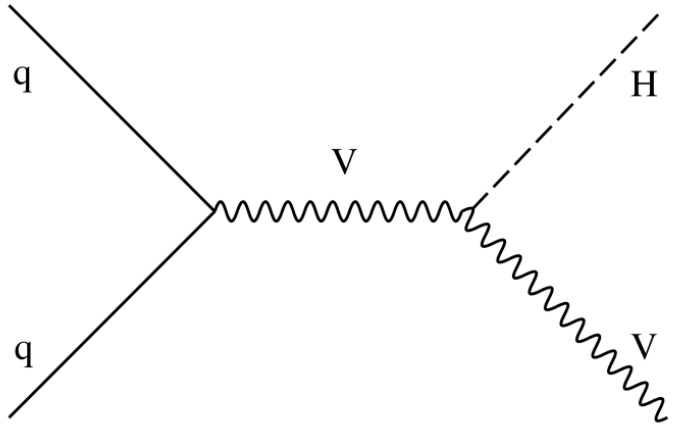
H→cc

ATLAS-CONF-2024-010

H→cc分析策略

ATLAS-CONF-2024-010

Similar to H→bb, VH events are used to suppress QCD background for H→cc （利用vector boson来触发探测器）

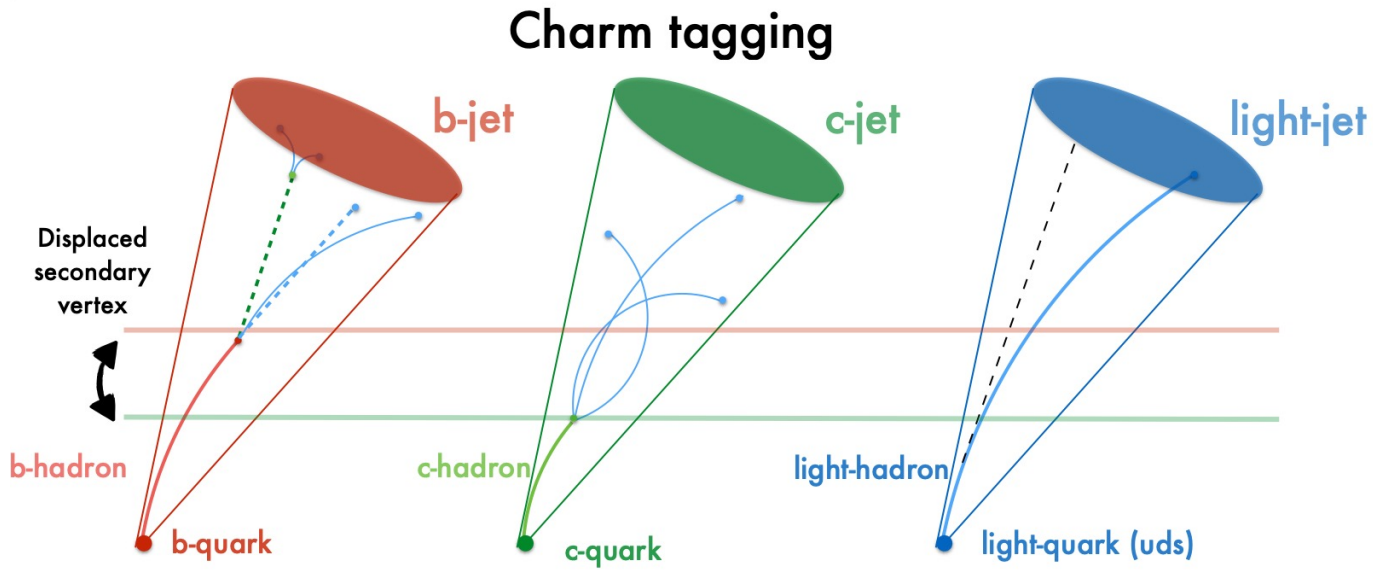


Use V (W/Z) leptonic decays

- 0-lepton: Z(→$\nu\nu$) H(→cc)
- 1-lepton: W(l±ν)H(→cc)
- 2-lepton: Z(l+l-)H(→cc)

Charm-jet tagging: vary challenging

- The decay length of the D hadron will be smaller than the decay length of B hadron
- Use Deep Neural Networks to combine different discriminate variables for c-jet tagging

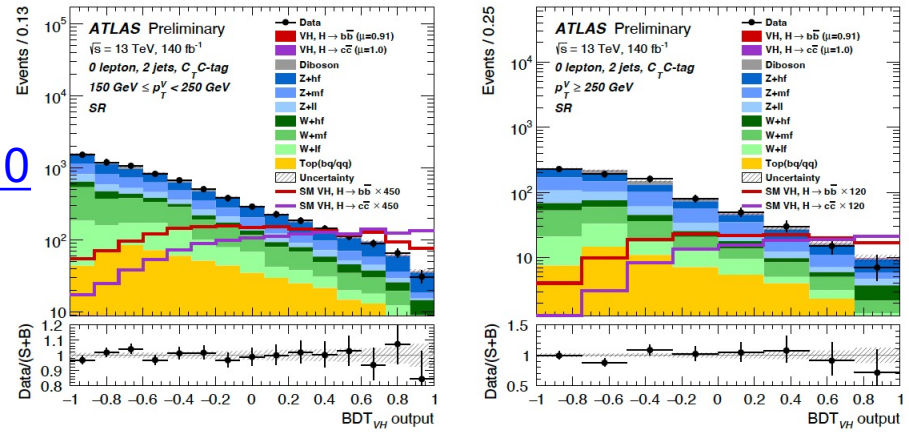


H→cc

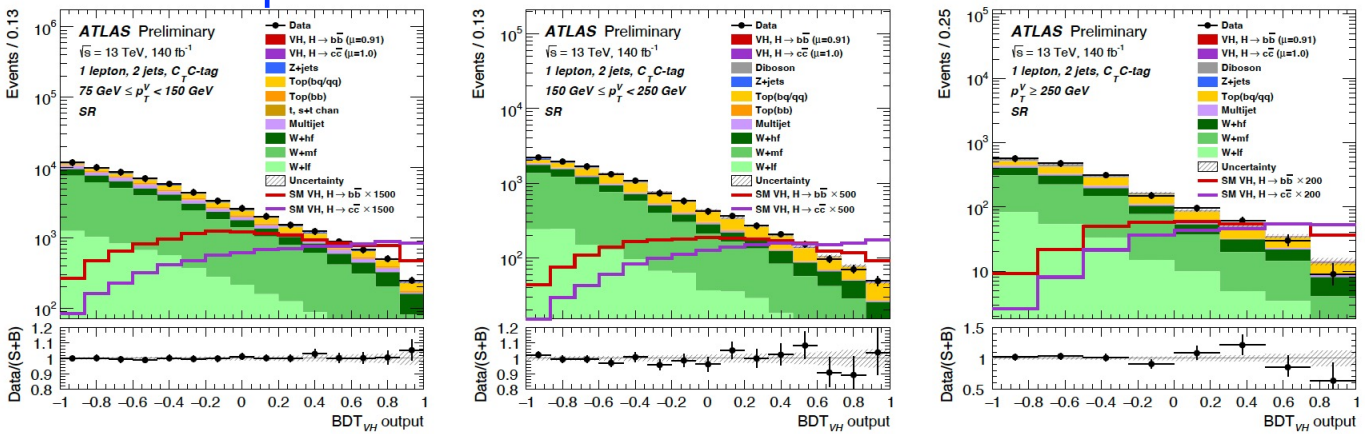
- Main backgrounds are W/Z+jet, top, VZ (Z→cc)
- ATLAS recently reanalyzed the previous published results (Eur. Phys. J. C 82 (2022) 717) with CONF note, ATLAS-CONF-2024-010
- Main changes are,
  - Better flavor jet tagging (DL1r with DNN), Eur. Phys. J. C (2023) 83
  - Use BDT to discriminate VH(cc) boost
  - *etc.*

0 lepton

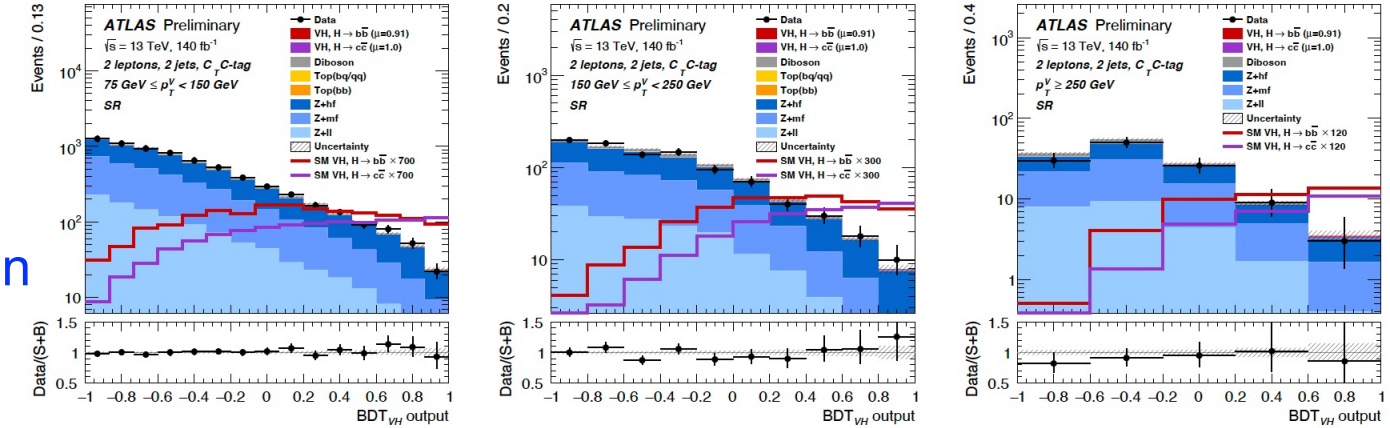
ATLAS-CONF-2024-010



1 lepton



2 lepton

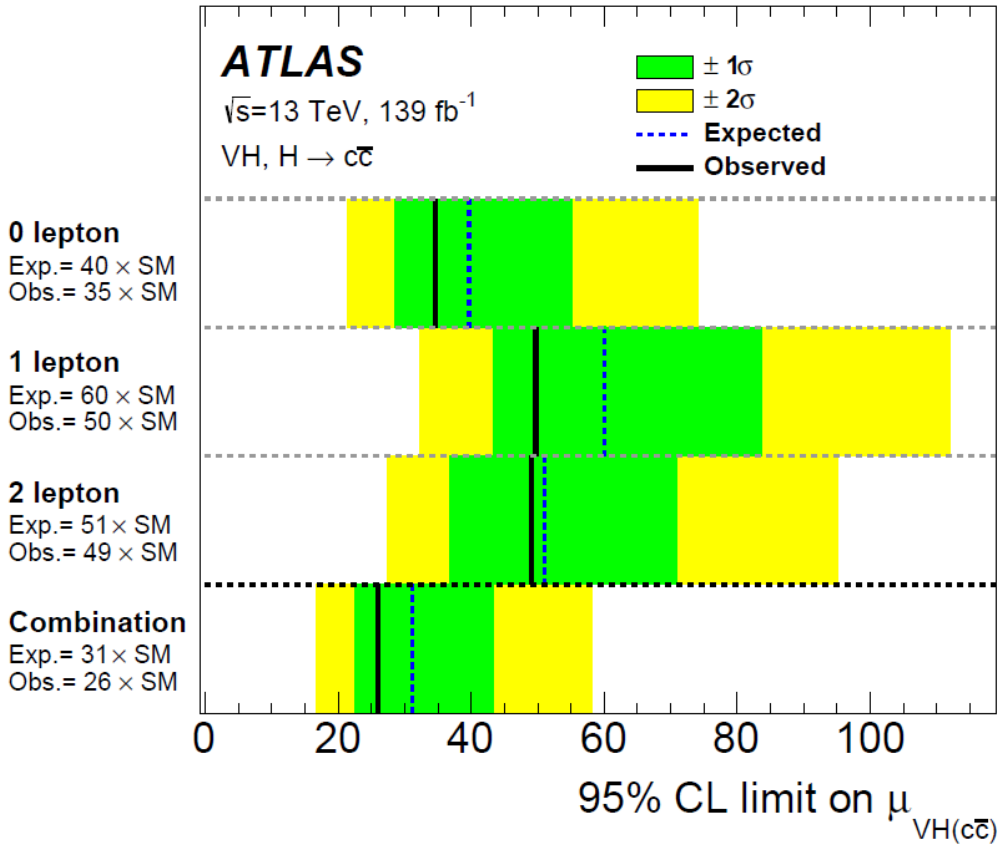


H→cc

ATLAS-CONF-2024-010

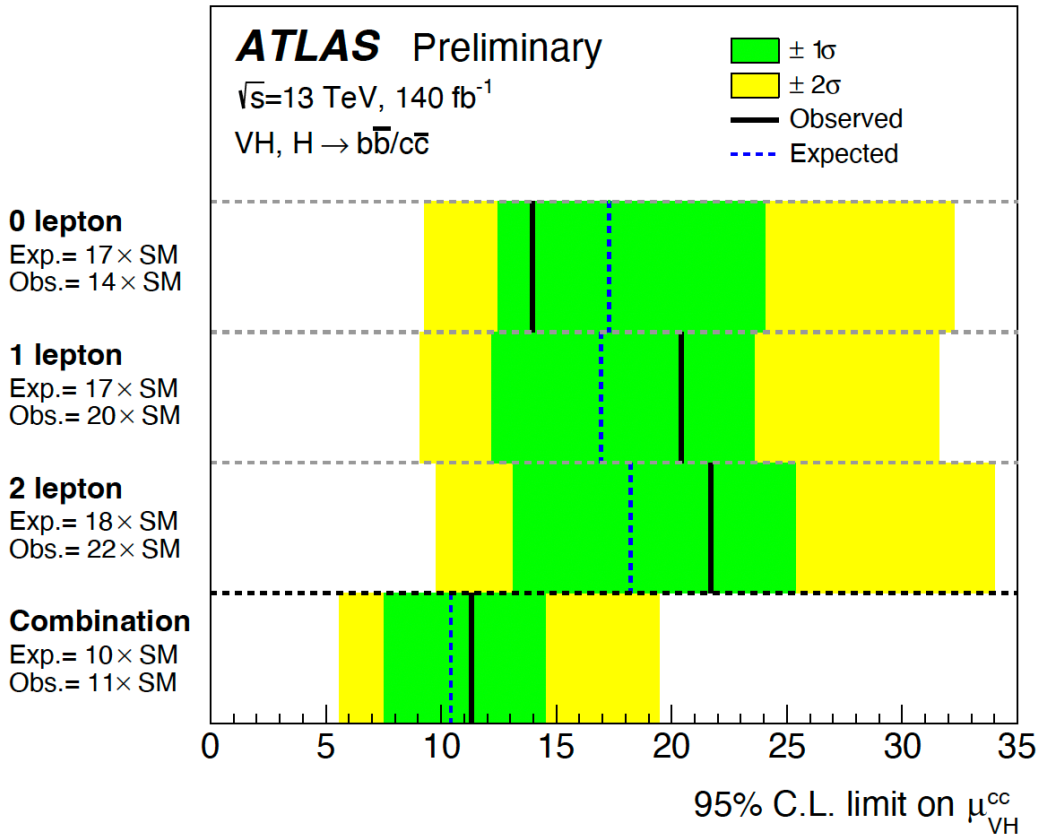
旧结果

Eur. Phys. J. C 82 (2022) 717



Expected upper limit on signal strength: 31

新结果



Expected upper limit on signal strength: 10

Will need 14000 fb^{-1} to reach SM sensitivity

$H \to Z\gamma$

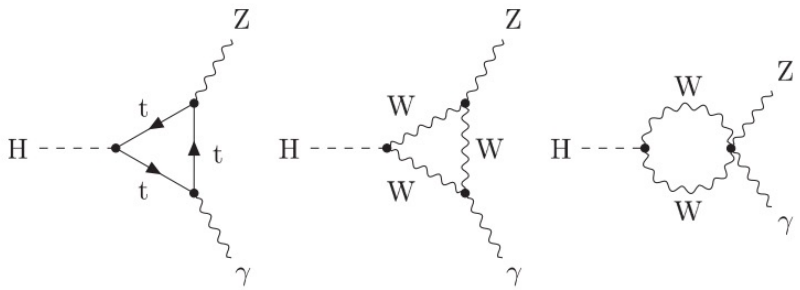
Phys. Lett. B 809 (2020) 135754

Phys. Rev. Lett. **132**, 021803 (2024)

H→Zγ

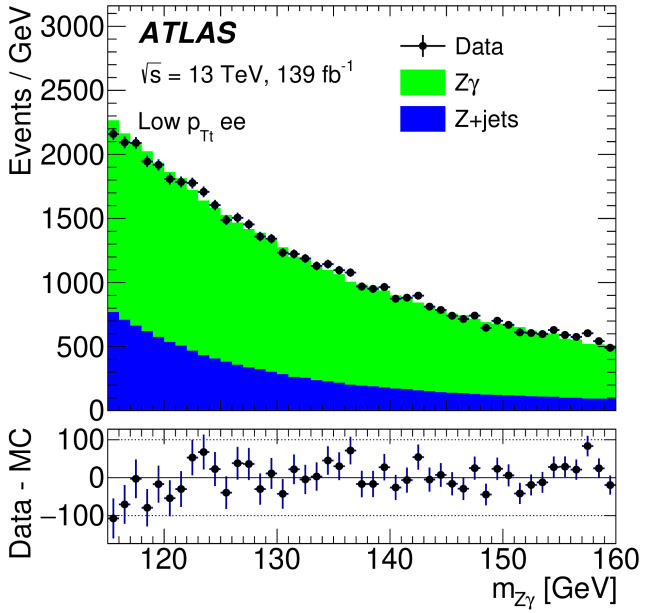
arXiv:2005.05382

Phys. Lett. B 809 (2020) 135754



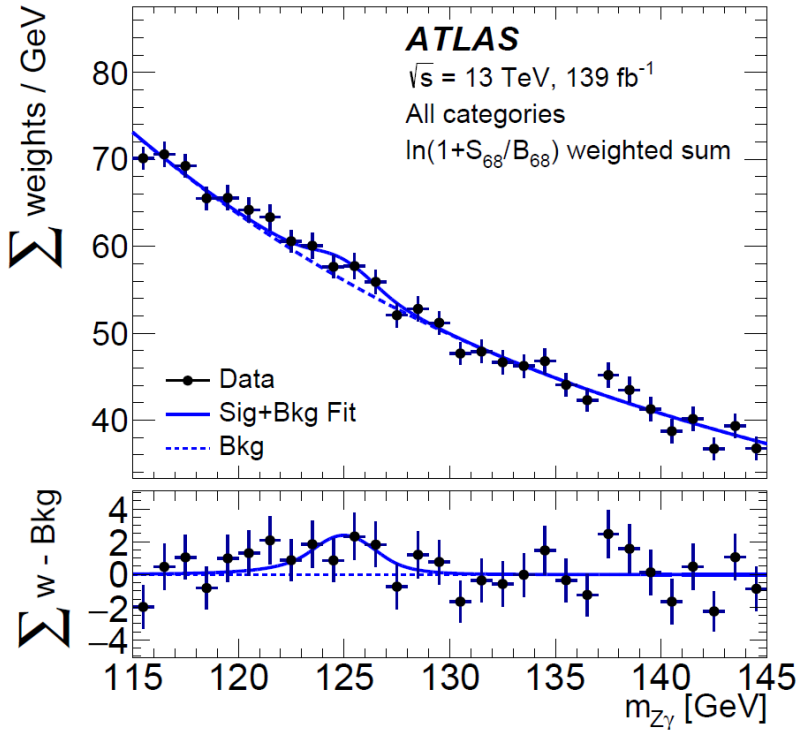
- Higgs boson can not couple to photon directly. H→Zγ through loop
- Main background: non-resonant production of $Z\gamma$. A smaller contribution from Z+jets
- Fit to $m_{Z\gamma}$ spectra. Signal modeling is using MC template. Background modelling is using analytic functions

Br(H→Zγ): ~1.5×10^{-3}

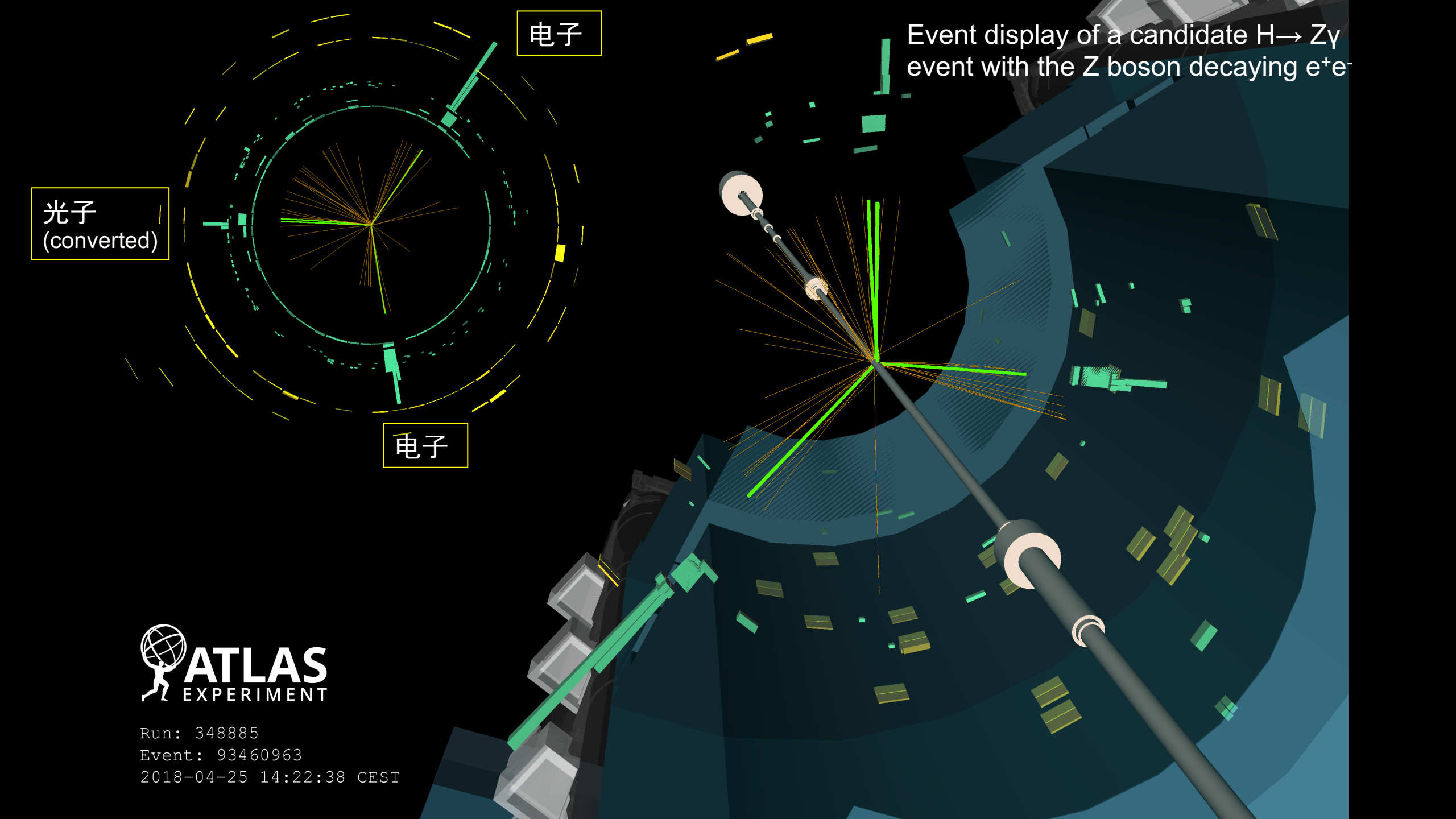


Category	μ	Significance
VBF-enriched	$0.5^{+1.9}_{-1.7}$ ($1.0^{+2.0}_{-1.6}$)	0.3 (0.6)
High relative p_T	$1.6^{+1.7}_{-1.6}$ ($1.0^{+1.7}_{-1.6}$)	1.0 (0.6)
High p_{Tt} ee	$4.7^{+3.0}_{-2.7}$ ($1.0^{+2.7}_{-2.6}$)	1.7 (0.4)
Low p_{Tt} ee	$3.9^{+2.8}_{-2.7}$ ($1.0^{+2.7}_{-2.6}$)	1.5 (0.4)
High p_{Tt} $\mu\mu$	$2.9^{+3.0}_{-2.8}$ ($1.0^{+2.8}_{-2.7}$)	1.0 (0.4)
Low p_{Tt} $\mu\mu$	$0.8^{+2.6}_{-2.6}$ ($1.0^{+2.6}_{-2.5}$)	0.3 (0.4)
Combined	$2.0^{+1.0}_{-0.9}$ ($1.0^{+0.9}_{-0.9}$)	2.2 (1.2)

不同category的显著度



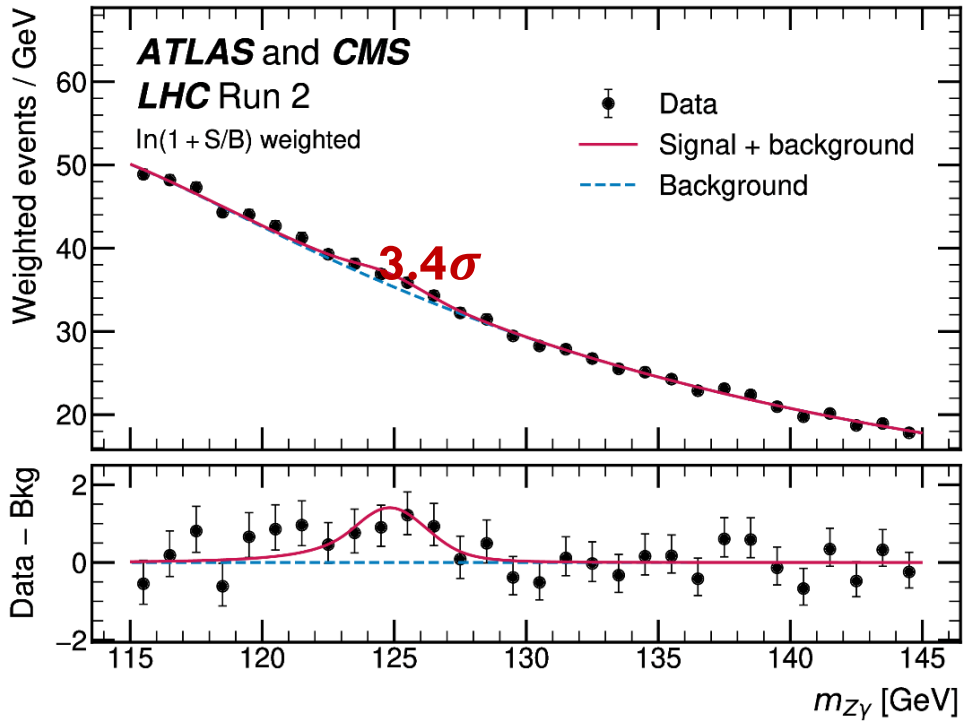
The observed (expected) significance: 2.2σ (1.2σ)

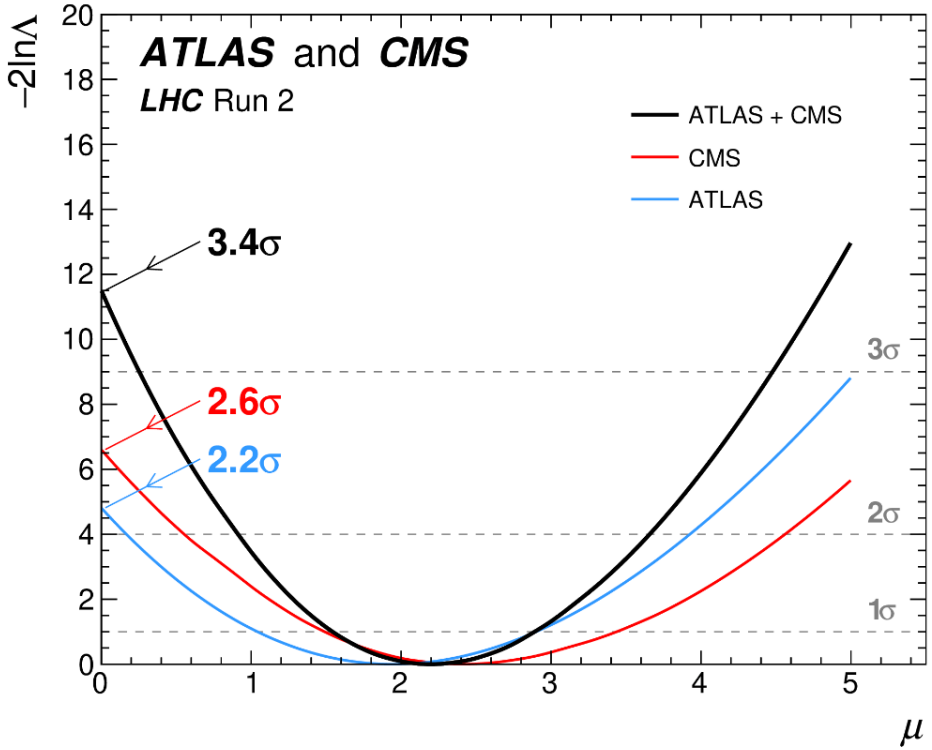

电子
光子
(converted)
电子
Event display of a candidate H→ Zγ
event with the Z boson decaying e+e-
ATLAS
EXPERIMENT
Run: 348885
Event: 93460963
2018-04-25 14:22:38 CEST

H→Zγ: ATLAS+CMS combined

arXiv:2309.03501

Phys. Rev. Lett. **132**, 021803 (2024)





CMS observed (expected) significance is 2.7σ (1.2σ) JHEP 05 (2023) 233

Observed (SM expected) significance: 3.4σ (1.6σ)

Evidence for H→Zγ at the LHC

H→ee and lepton flavor violation decays

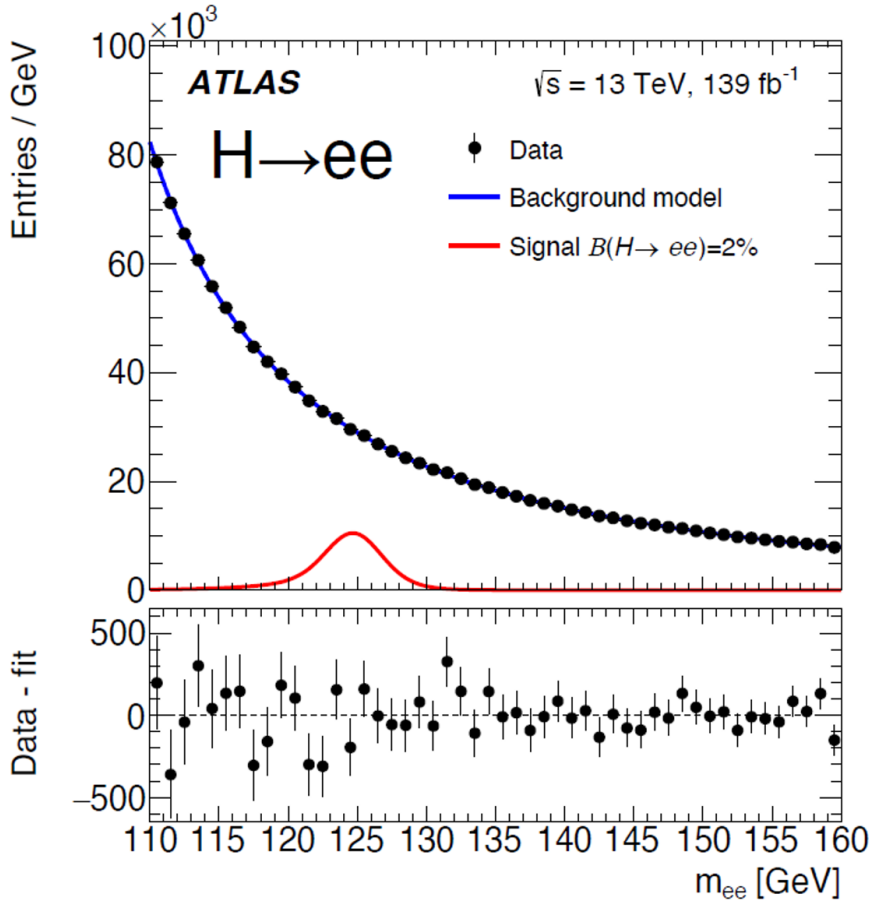
Phys. Lett. B 801 (2020) 135148

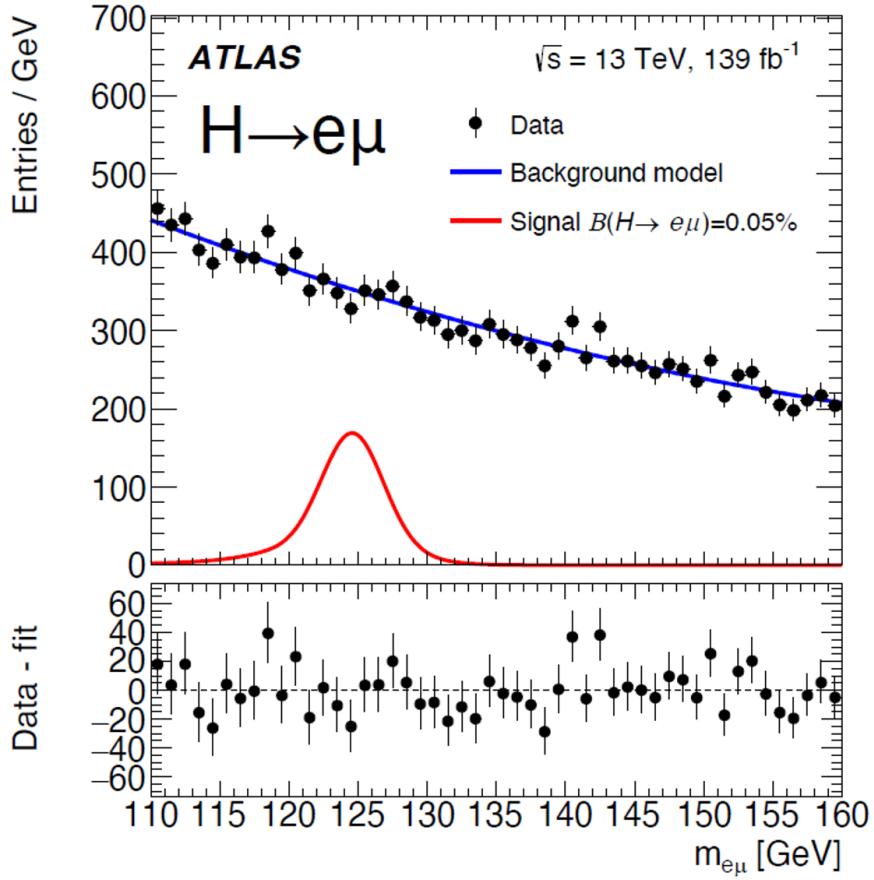
JHEP 07 (2023) 166

H→ee and H→eμ

arXiv:1909.10235

Phys. Lett. B 801 (2020) 135148





H→eμ: probe lepton flavor violation

Observed (expected) upper limit at the 95% confidence level on the branching fraction Br(H→ee) is $3.6\times10^{-4}(3.5\times10^{-4})$ and on Br(H→eμ) is 6.1×10^{-5} (5.8×10^{-5})

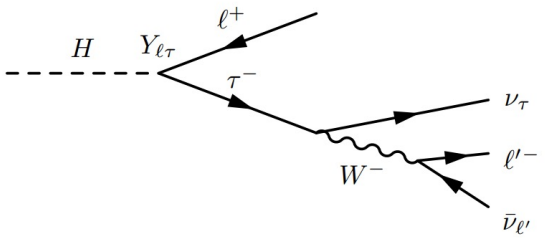
H→eτ and H→μτ

arXiv:2302.05225

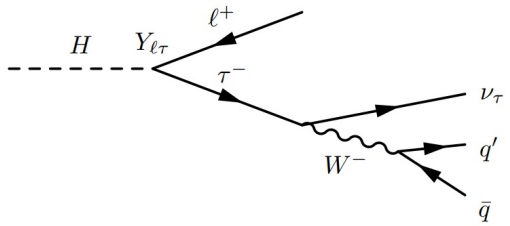
JHEP 07 (2023) 166

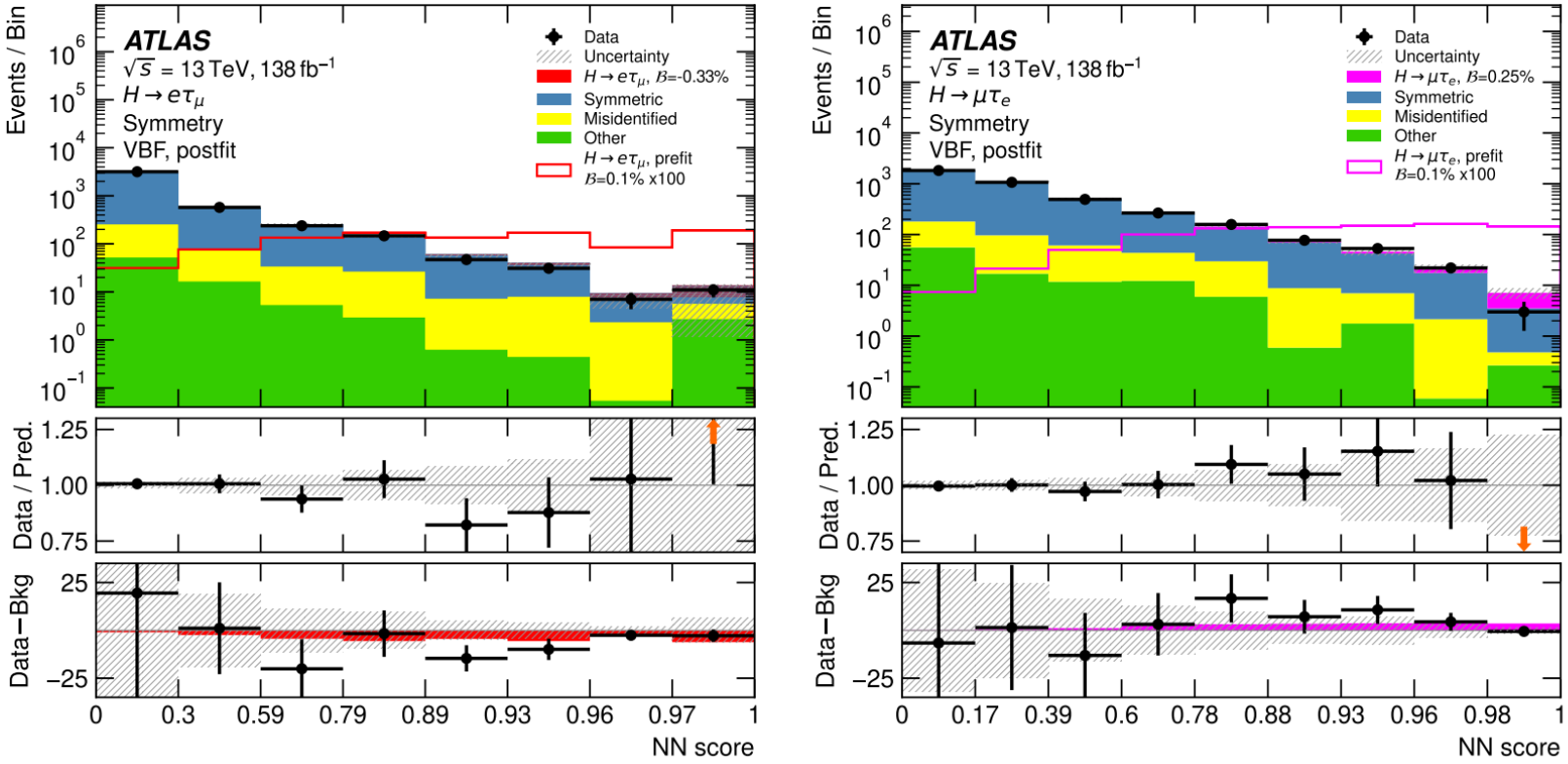
Probe lepton flavor violation (LFV) decays of the Higgs boson

Leptonic τ



Hadronic τ





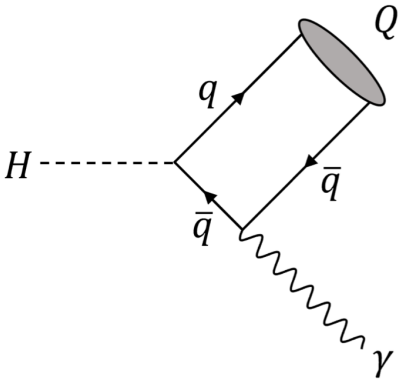
The observed (expected) upper limits set on the branching ratios at 95% confidence level, B($H \to e\tau$) < 0.20% (0.12%) and B($H \to \mu\tau$) < 0.18% (0.09%)

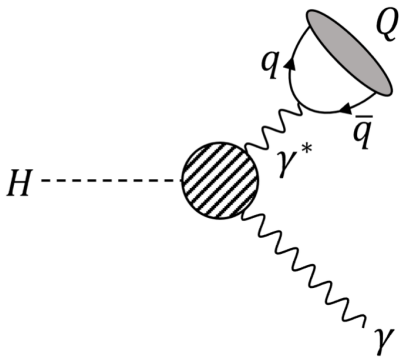
$H \to Q + \gamma$

Eur. Phys. J. C 83 (2023) 781

H→J/ψ /ψ2S + γ

arXiv:2208.03122

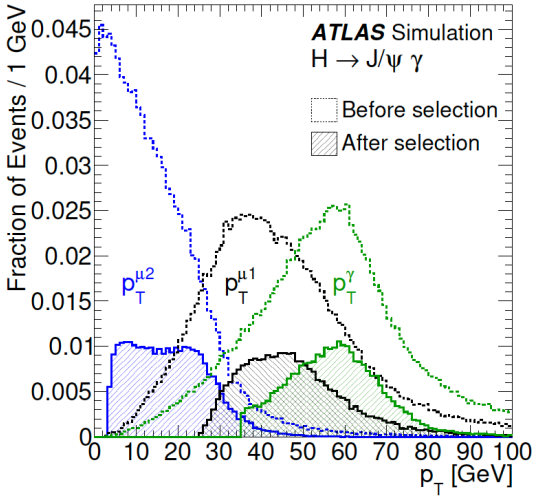


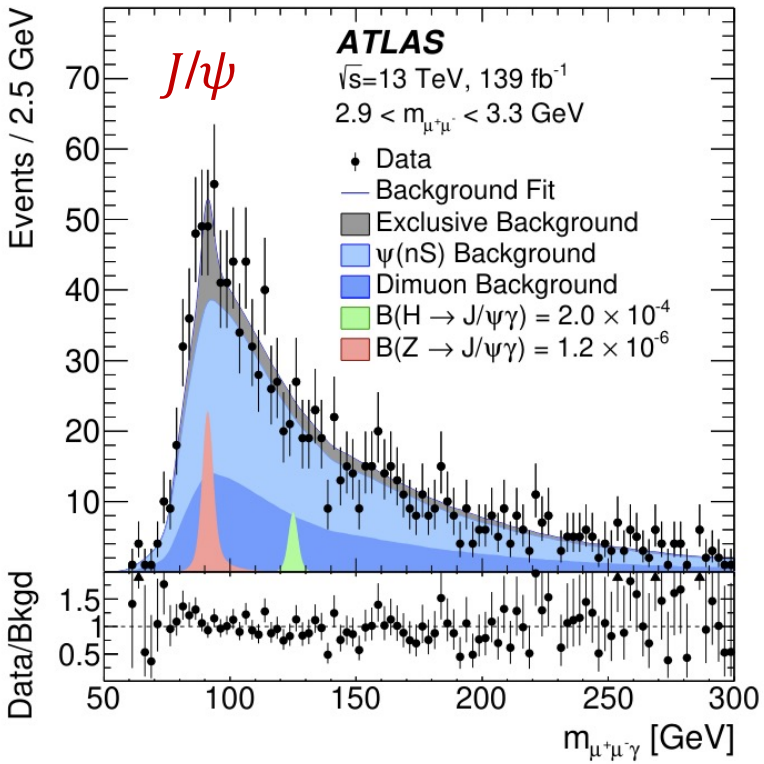


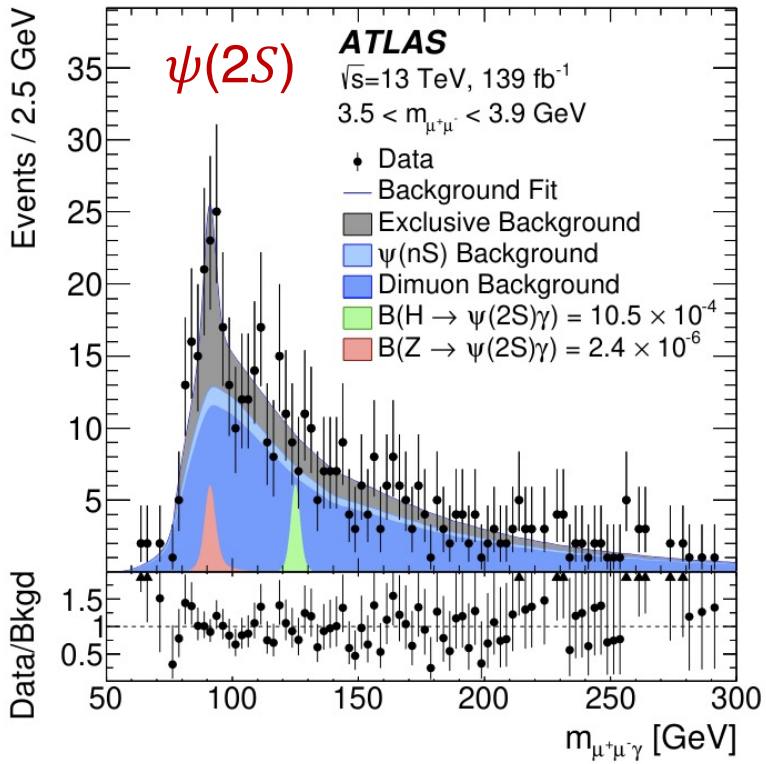
To access c-quark Yukawa coupling indirectly

Eur. Phys. J. C 83 (2023) 781

From MC







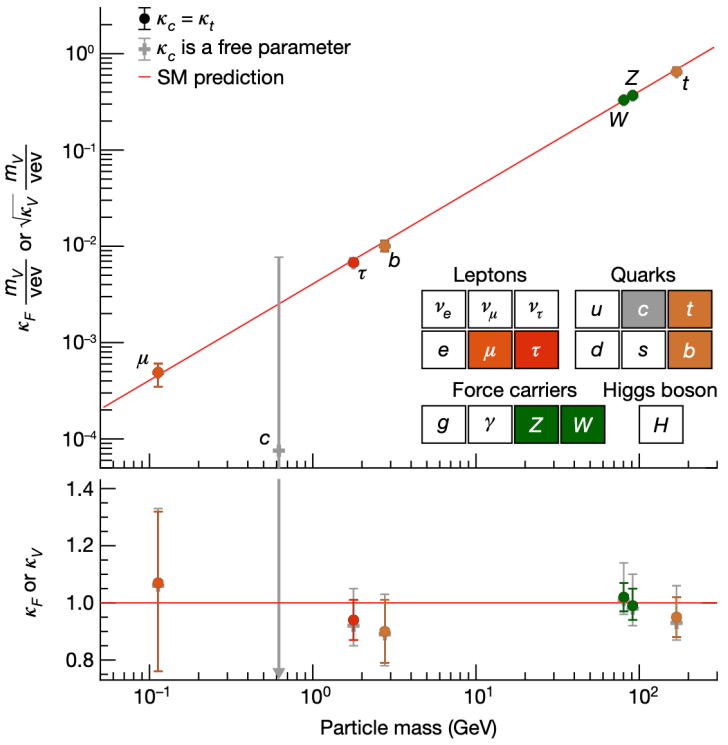
Upper limits on the branching fractions of the Higgs boson decays into J/ψγ, ψ(2S)γ are found to be 2.0×10^{-4}, 10.5×10^{-4}

总结

- H→μμ search with full run2 data by ATLAS. Observed significance: 2σ (1.7σ expected). Best-fit combined signal strength: μ = 1.2 ±0.6

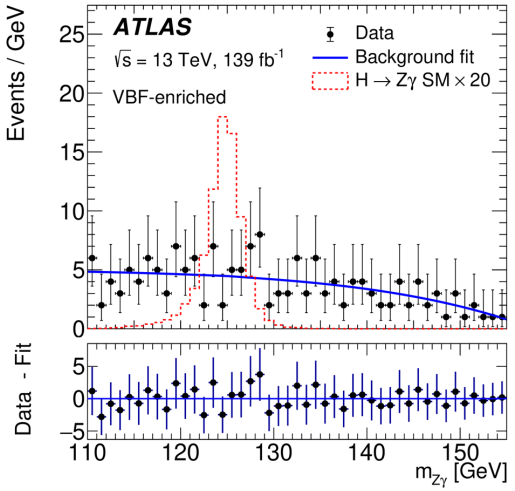
第十届中国LHC物理会议 (CLHCP2024) 将由山东大学承办
会议日期：2024年11月14日至11月17日
会议地点：山东省青岛市鳌山湾
会议网址：https://indico.ihep.ac.cn/event/22941/

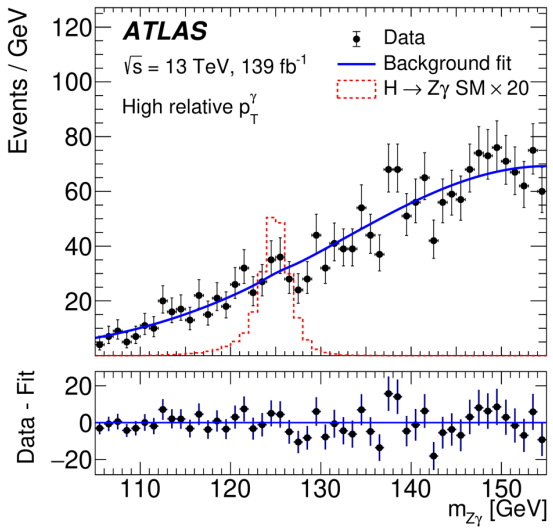
- First evidence of H→Zγ from ATLAS&CMS. Observed result is 1.9σ away from the SM Higgs prediction
- ATLAS VH(→cc) measurement has been improved significantly. Hard to reach to SM sensitivity but will provide smaller confidence interval for charm-Higgs Yukawa coupling

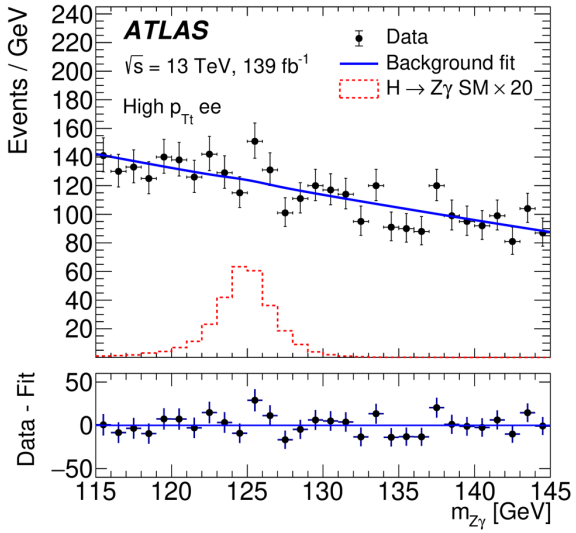


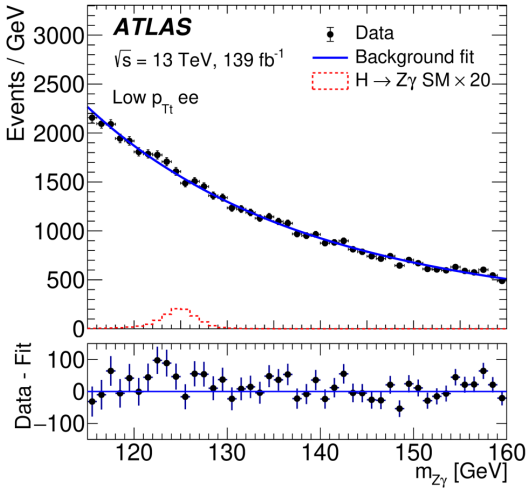
Peter Higgs (29 May 1929 – 8 April 2024)

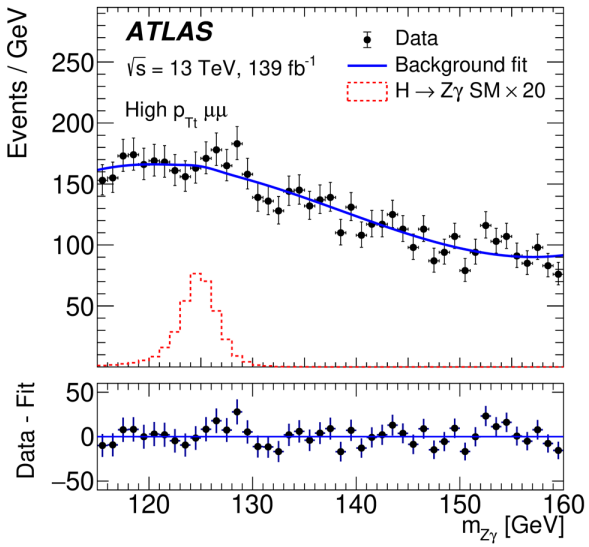
ATLAS H→Zγ：不同category的数据

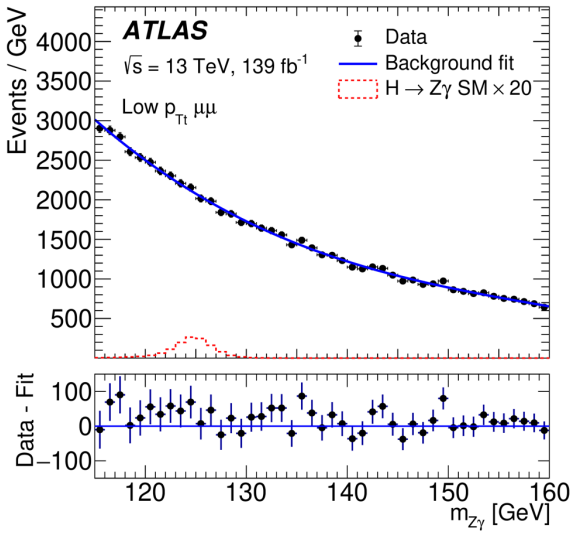






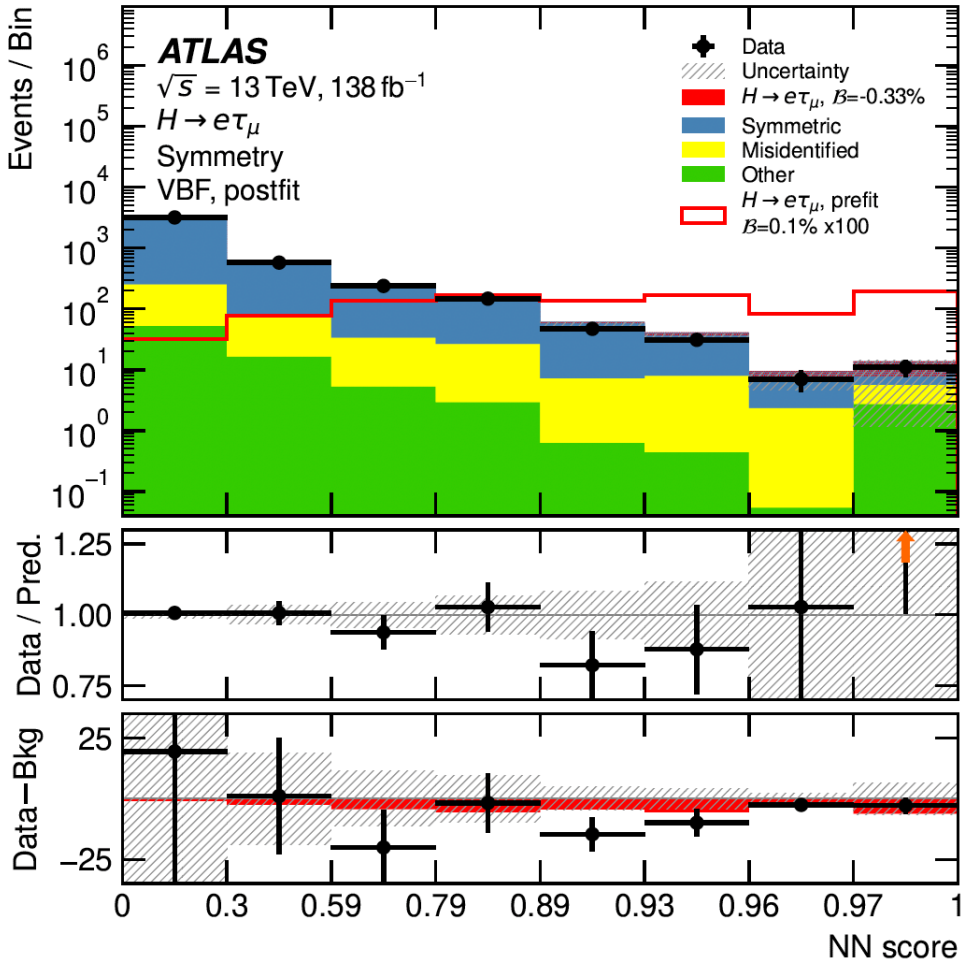






H→eτ and H→μτ：本底估计方法

H→eτ, VBF



Symmetry method: Data-driven method where the main backgrounds in one channel are estimated using the data yields in the other channel [Phys. Rev. D 90, 015025 (2014)]

H→J/ψ /ψ2S + γ：本底

- **Exclusive background**: the first is an exclusive contribution originating from $\mu+\mu-\gamma$ events produced via the Drell–Yan process, where a highly energetic photon typically arises from final-state radiation
- **Inclusive background**: the second, which is the dominant background, is an inclusive contribution mostly from multi-jet and γ+jet events involving dimuon or Q production