ATLAS EXPERIMENT
Run: 281411
Event: 312608026
2015-10-11 18:40:58 CEST

ATLAS Higgs to Dimuon

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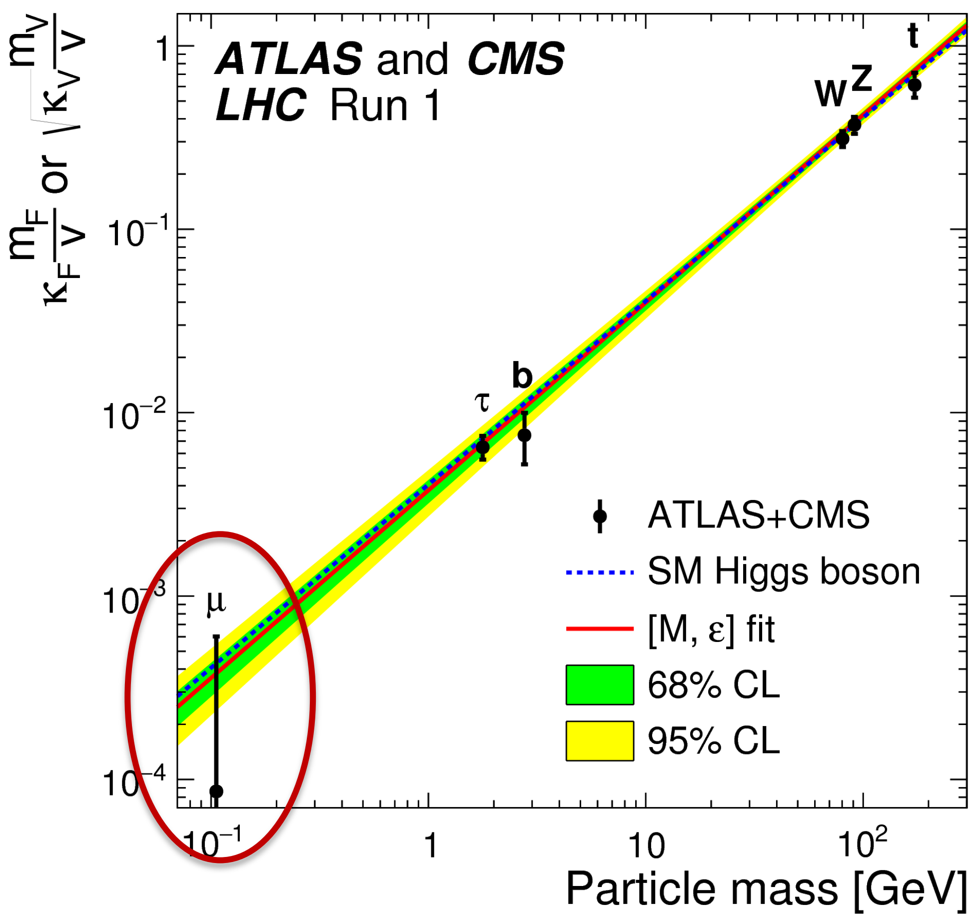
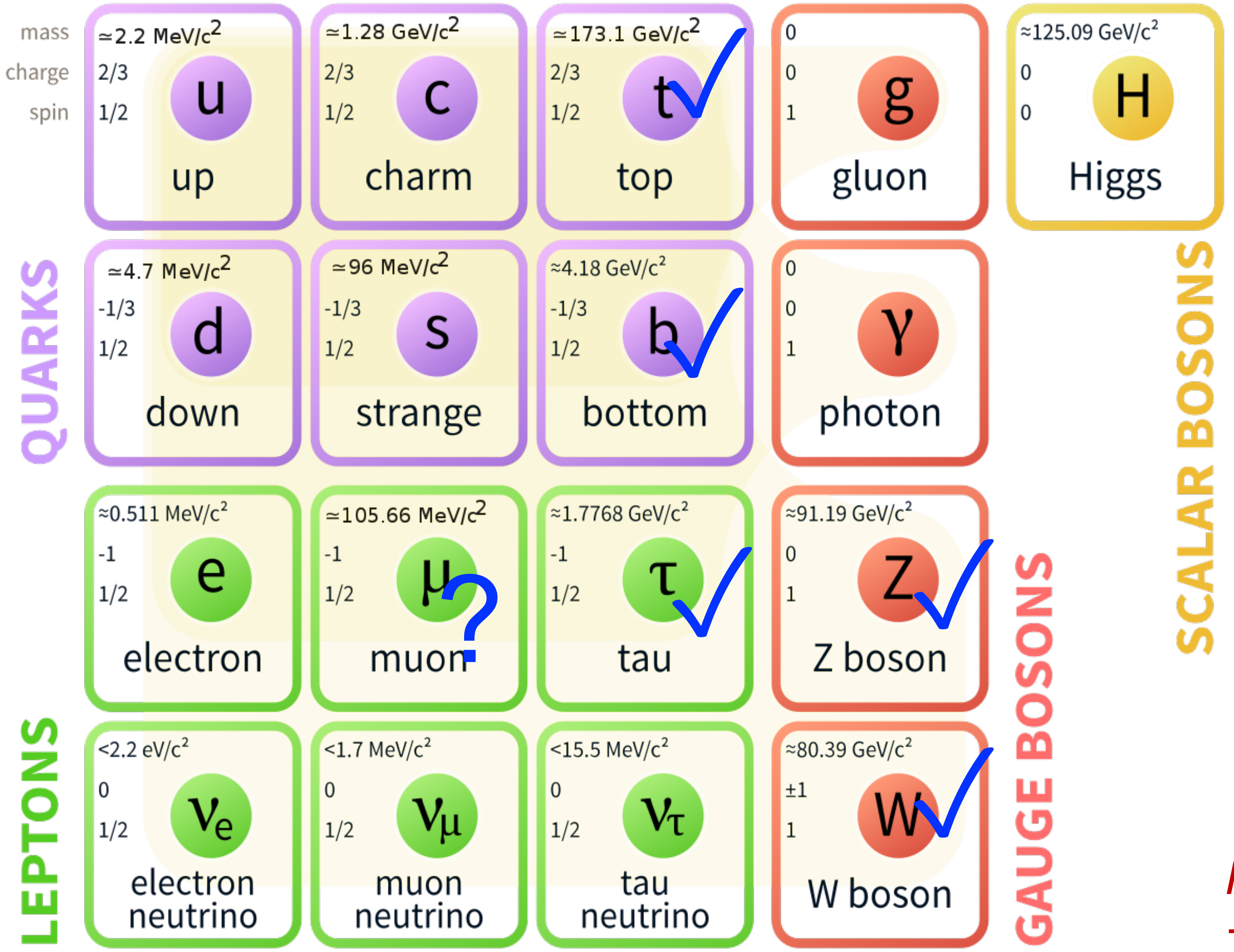
希格斯粒子和缪子的耦合

- 希格斯粒子和W/Z玻色子、希格斯粒子和τ费米子的耦合已经在LHC一期被观测到。最近，希格斯粒子与底夸克的耦合、希格斯粒子和顶夸克的耦合也已经被LHC观测到。在图中，唯一没有被观测到的是希格斯粒子和缪子的耦合。
- 目前观测到的都是希格斯和第三代费米子的耦合。这个道可以用来探测希格斯粒子和第二代费米子的耦合。

JHEP 08 (2016) 045

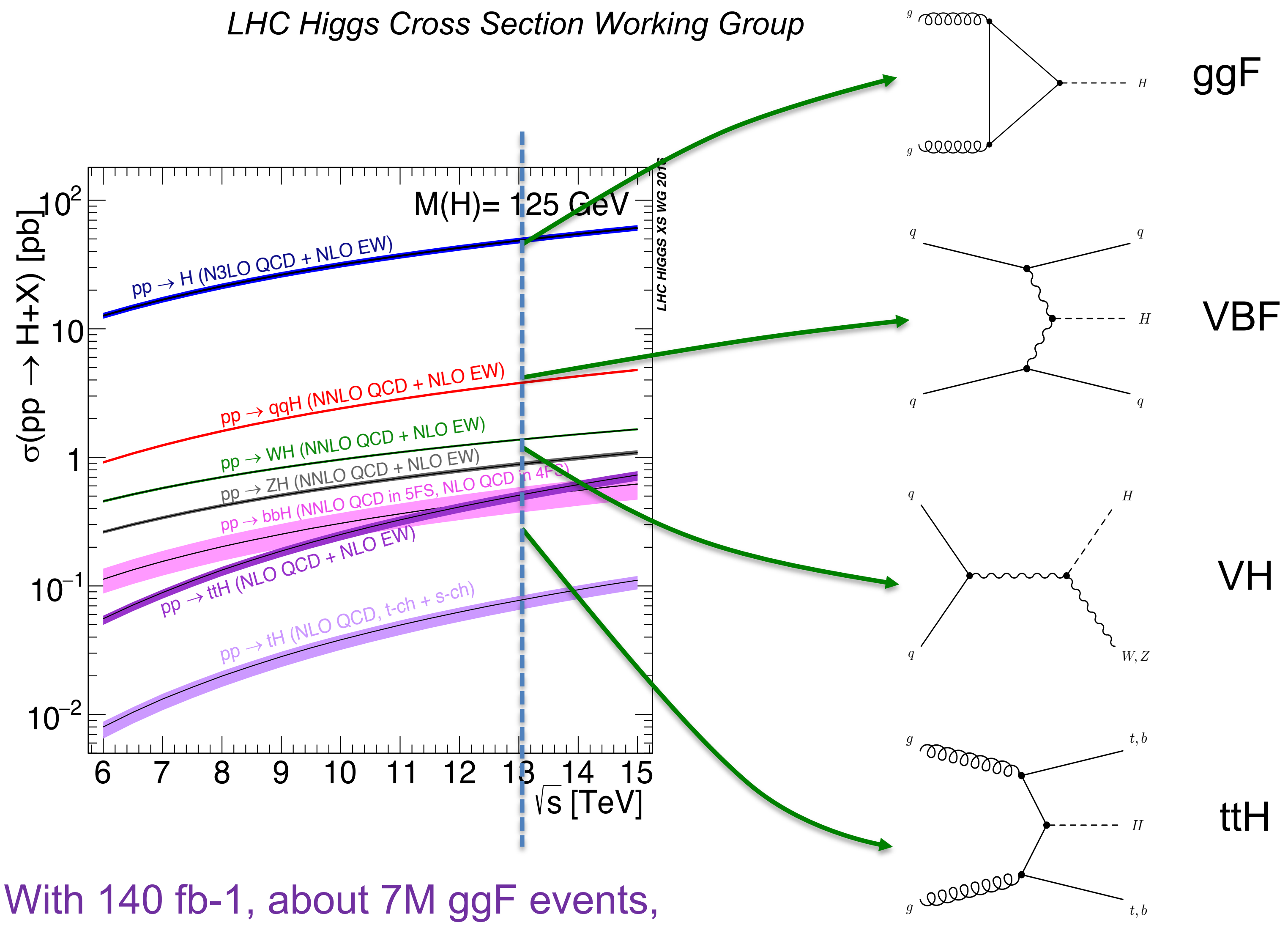


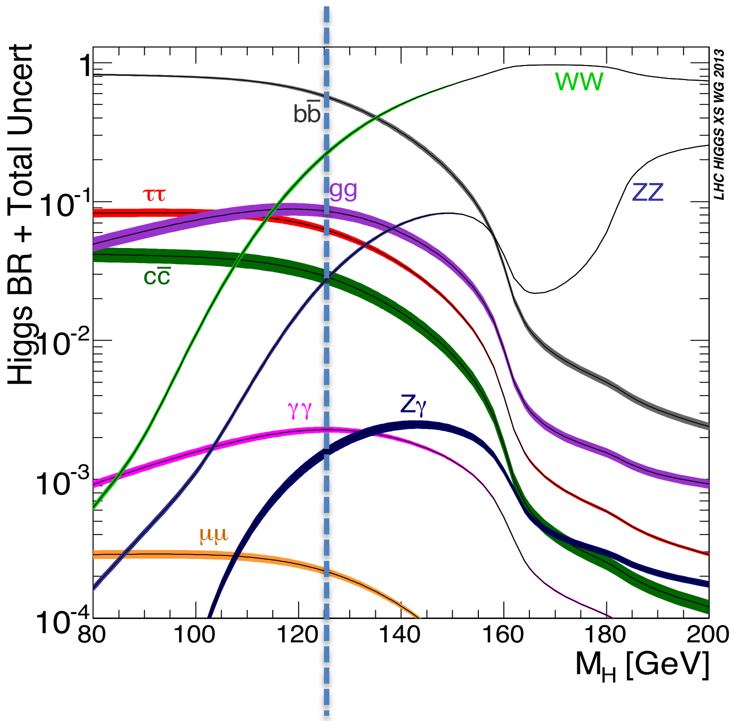
Higgs粒子只跟有质量的基本粒子耦合



H→cc：CEPC or FCC-ee
+理解Higgs的势（triple Higgs coupling）

LHC上希格斯玻色子的产生和衰变





m_H=125 GeV

Higgs decays	**BR** [%]
$H \to bb$	57.8
$H \to WW$	21.4
$H \to gg$	8.19
$H \to \tau\tau$	6.27
$H \to ZZ$	2.62
$H \to cc$	2.89
$H \to \gamma\gamma$	0.227
$H \to Z\gamma$	0.153
$H \to \mu\mu$	0.022

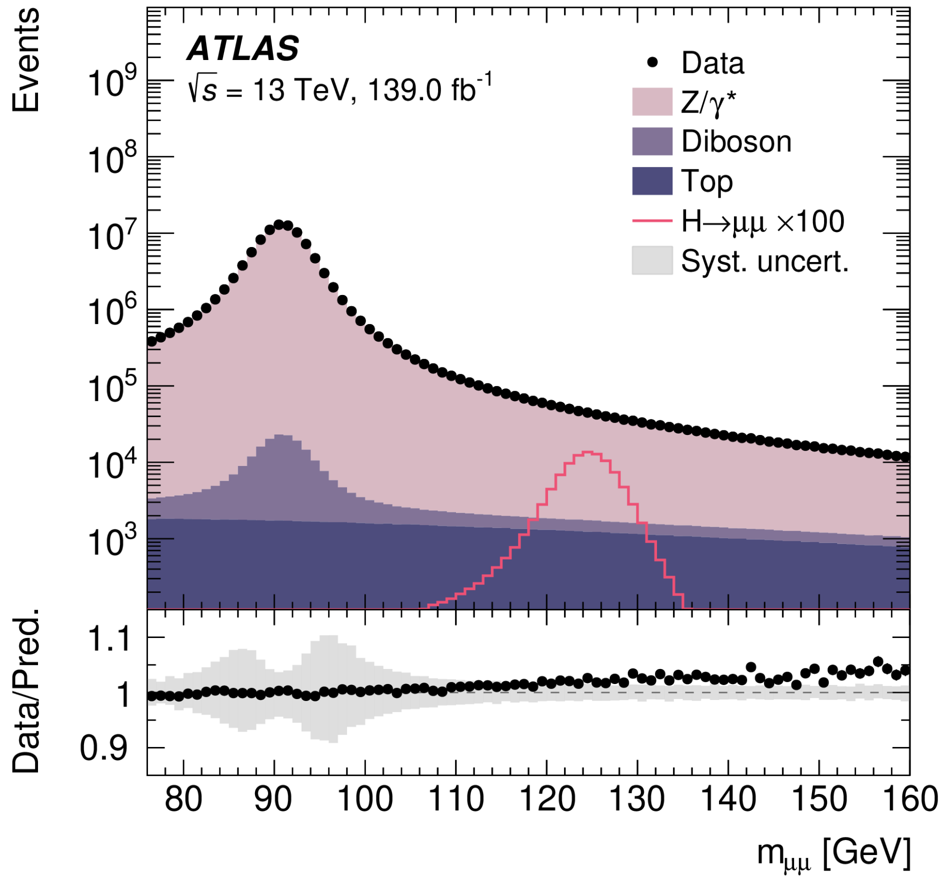
With 140 fb-1, about 7M ggF events,
520K VBF, 350K VH and 70K ttH events

Higgs to μμ

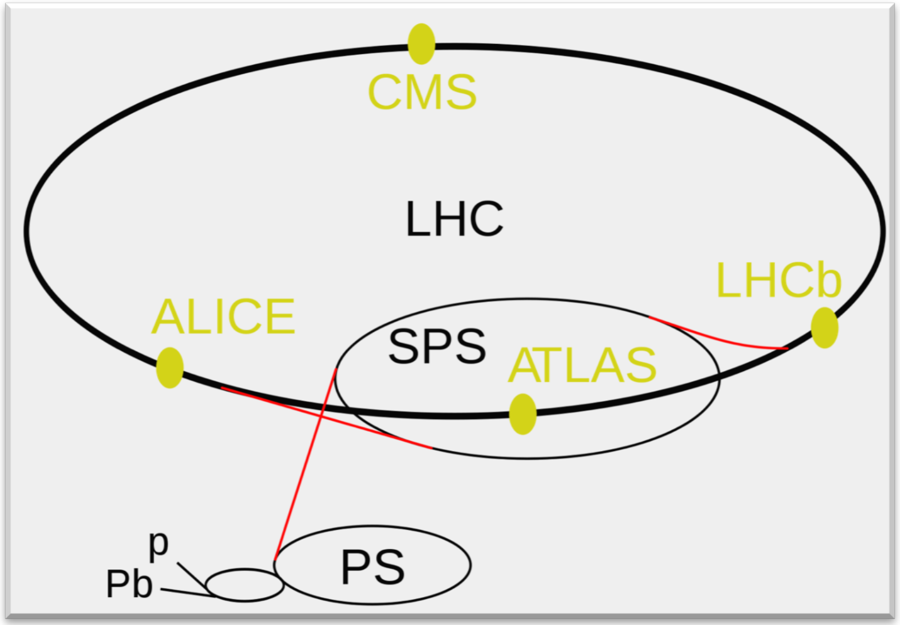
- The Higgs cross section at 13 TeV is about 55 pb. With 140 fb-1 data, ~8 million Higgs boson have been produced. 1540 of them decay to μμ

arXiv:2007.07830

Why it is so difficult to find H->μμ?

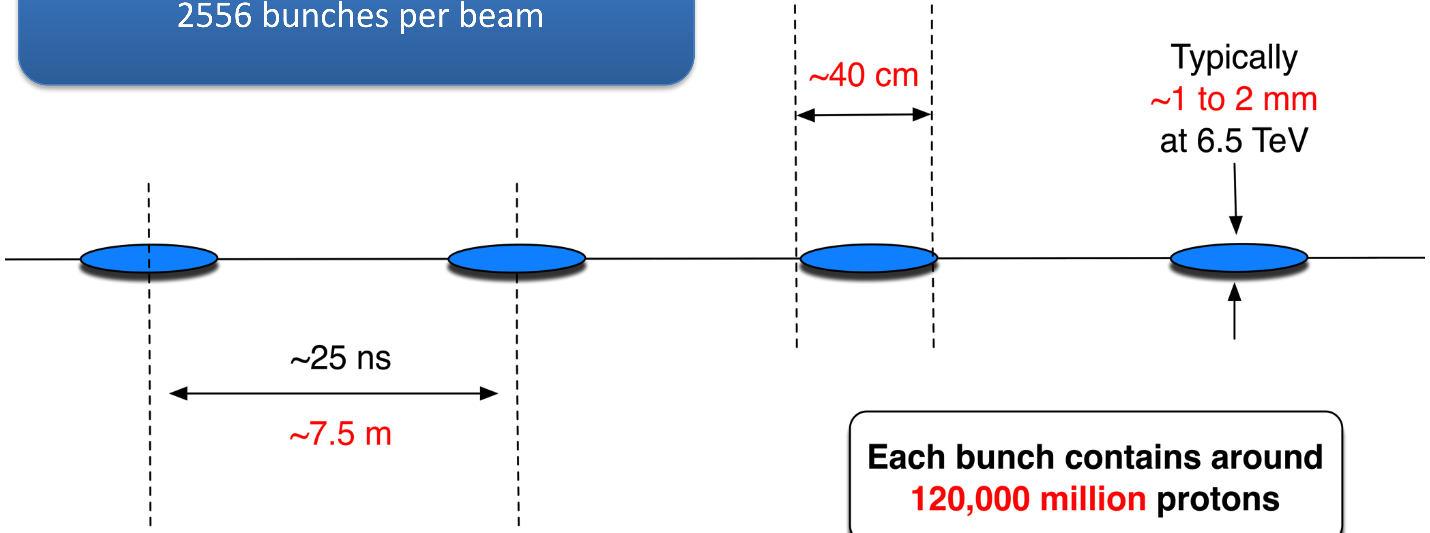


大型强子对撞机二期（LHC）

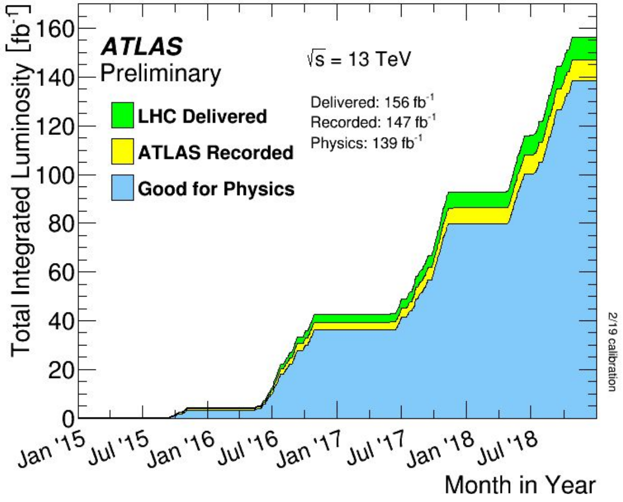


- 两个束流，每个束流：2808 bunches
- 每个bunch：1.15×10^{11} 个质子
- Bunch之间的时间间隔：25 纳秒
  Bunch的对撞次数：每秒4千万次
- 二期对撞能量13TeV

In 2017 the LHC is operating with 2556 bunches per beam



Each bunch contains around 120,000 million protons

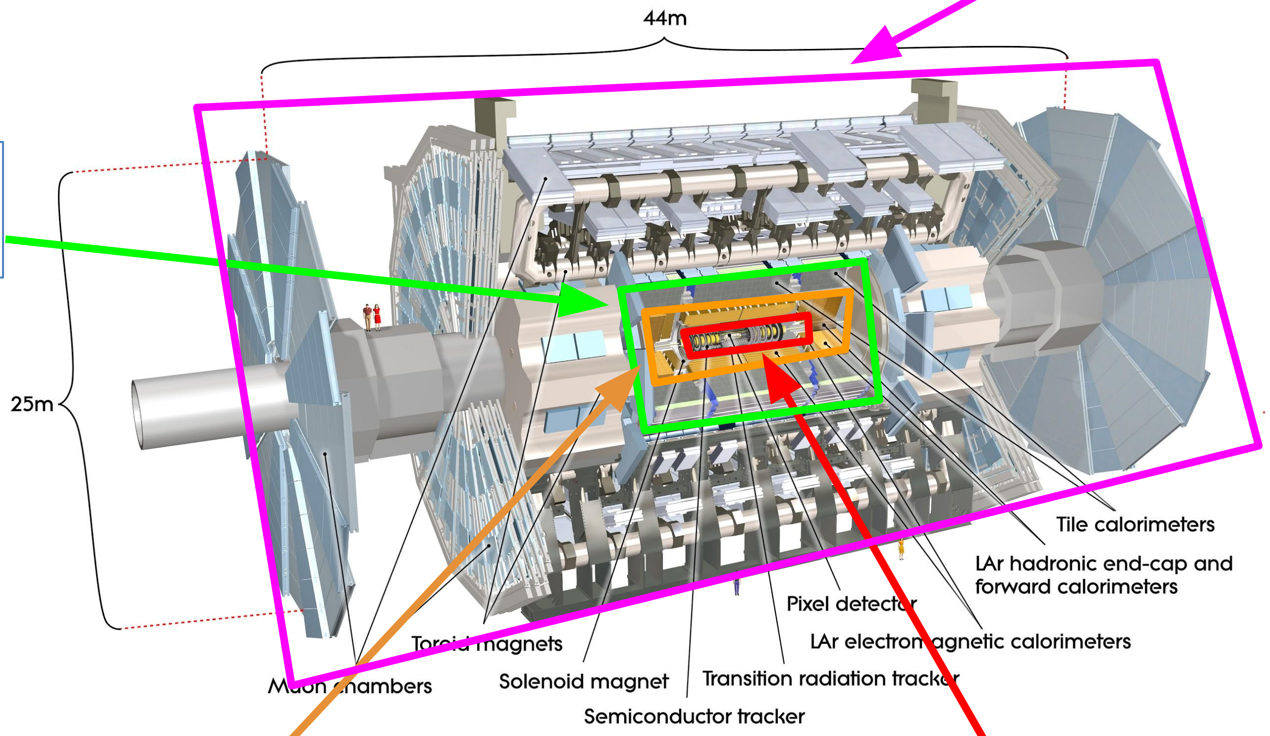


ATLAS 探测器 7000吨，长44米，高25米

ATLAS合作组：~3000人

缪子谱仪（|η|<2.7）

强子量能器（|η|<4.9）
Scintillator/Steel



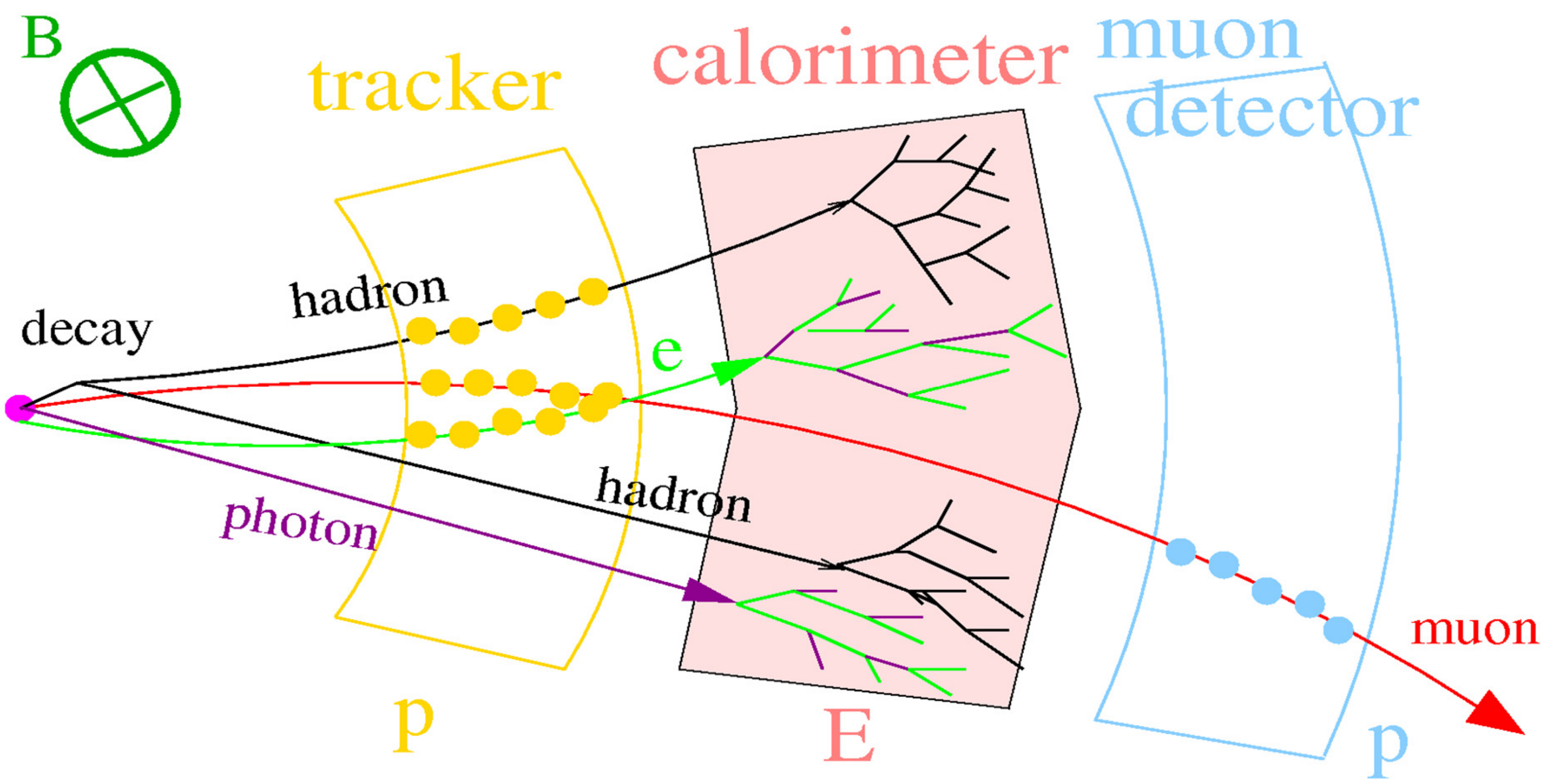
电磁量能器（|η|<3.2）
LAr/Pb

内部径迹探测器（|η|<2.5）
2T Solenoid
Pixels, SCT and TRT

缪子

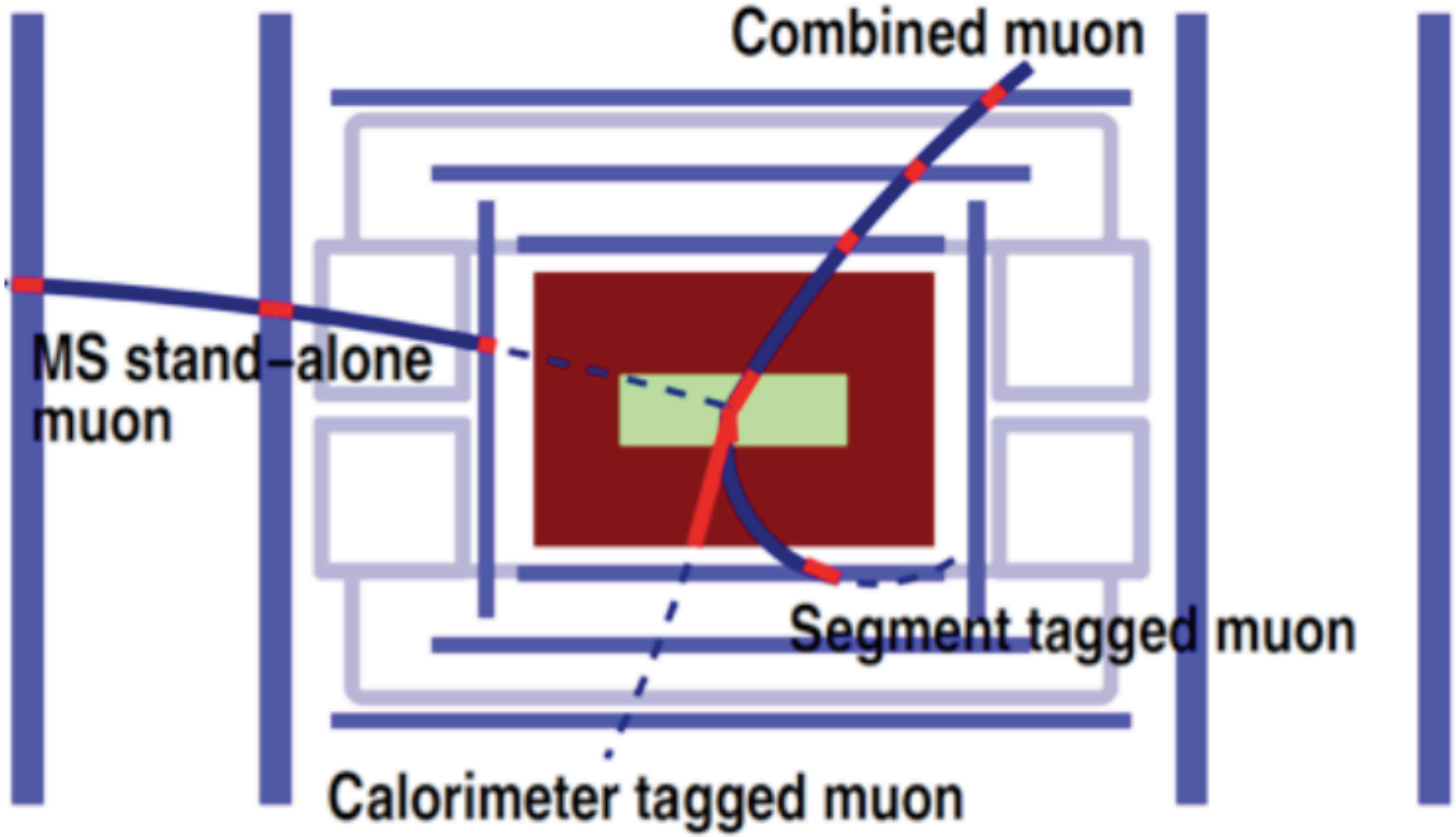
质量：105.6MeV

最小电离化粒子



- 缪子在inner tracker中留下径迹
- 缪子在量能器留下很少的能量
- 缪子在缪子谱仪中留下径迹

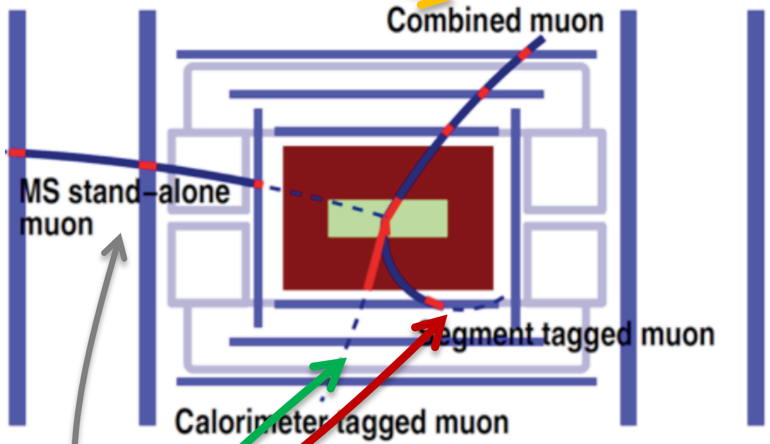
ATLAS Muon


Combined muon
MS stand–alone
muon
Segment tagged muon
Calorimeter tagged muon

ATLAS Muon

Combined muon:

- 组合了内部径迹探测器中的径迹和缪子探测器中的径迹
- 误判率最低的缪子



Segment tagged muon：

- 内部探测器的径迹+缪子探测器的segment
- 小动量的缪子

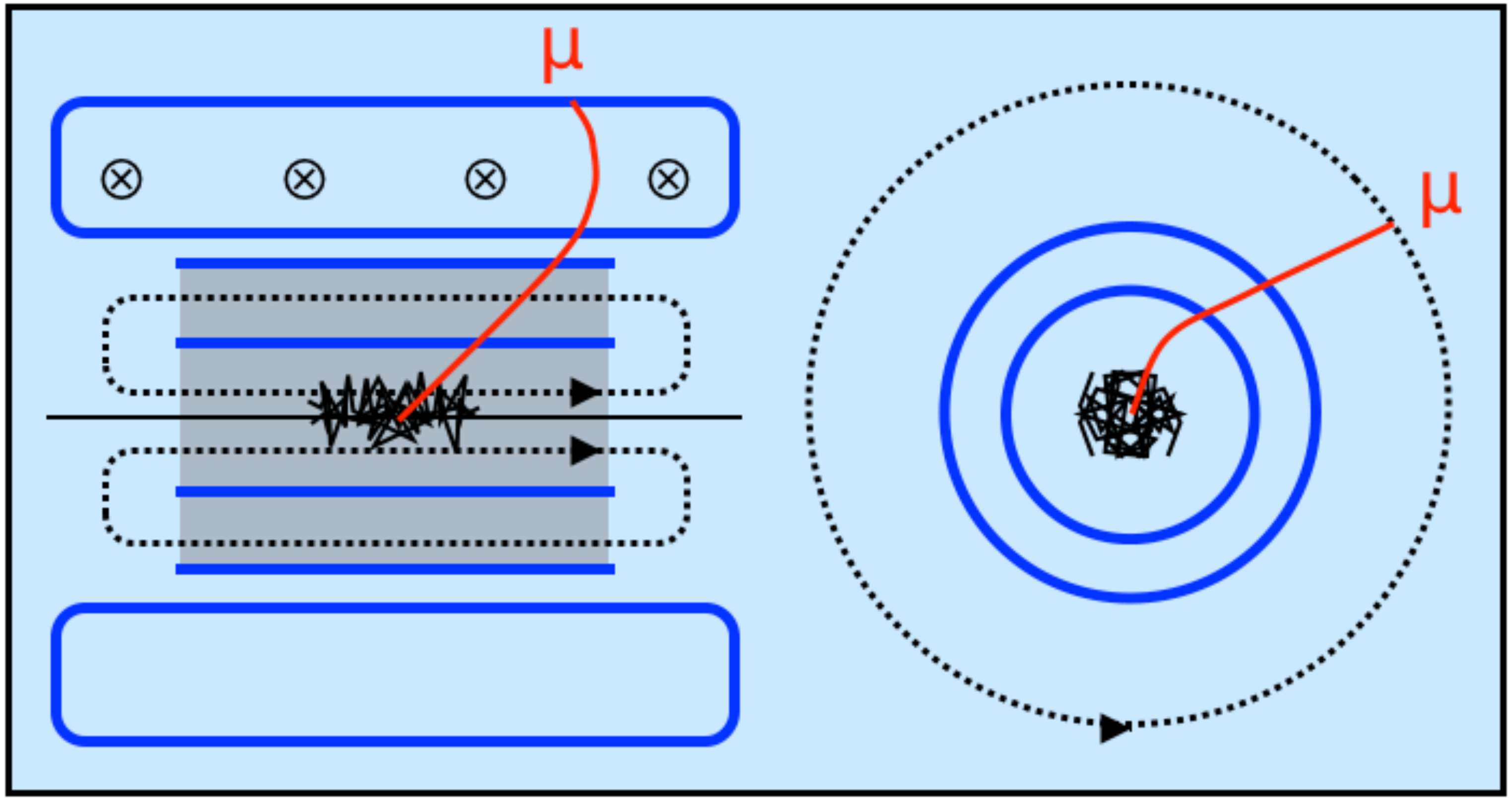
Calorimeter tagged muon：

- 内部探测器的径迹+量能器
- 有些方向缪子探测器没有覆盖

Track only in MS：

- 只有缪子探测器中的径迹
- 前端没有内部探测器覆盖

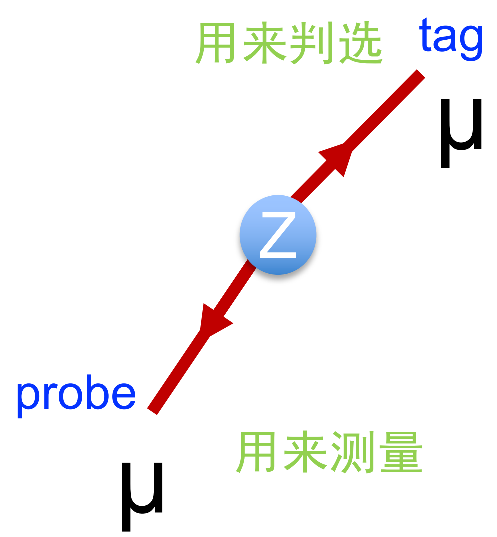
缪子谱仪中的径迹重建

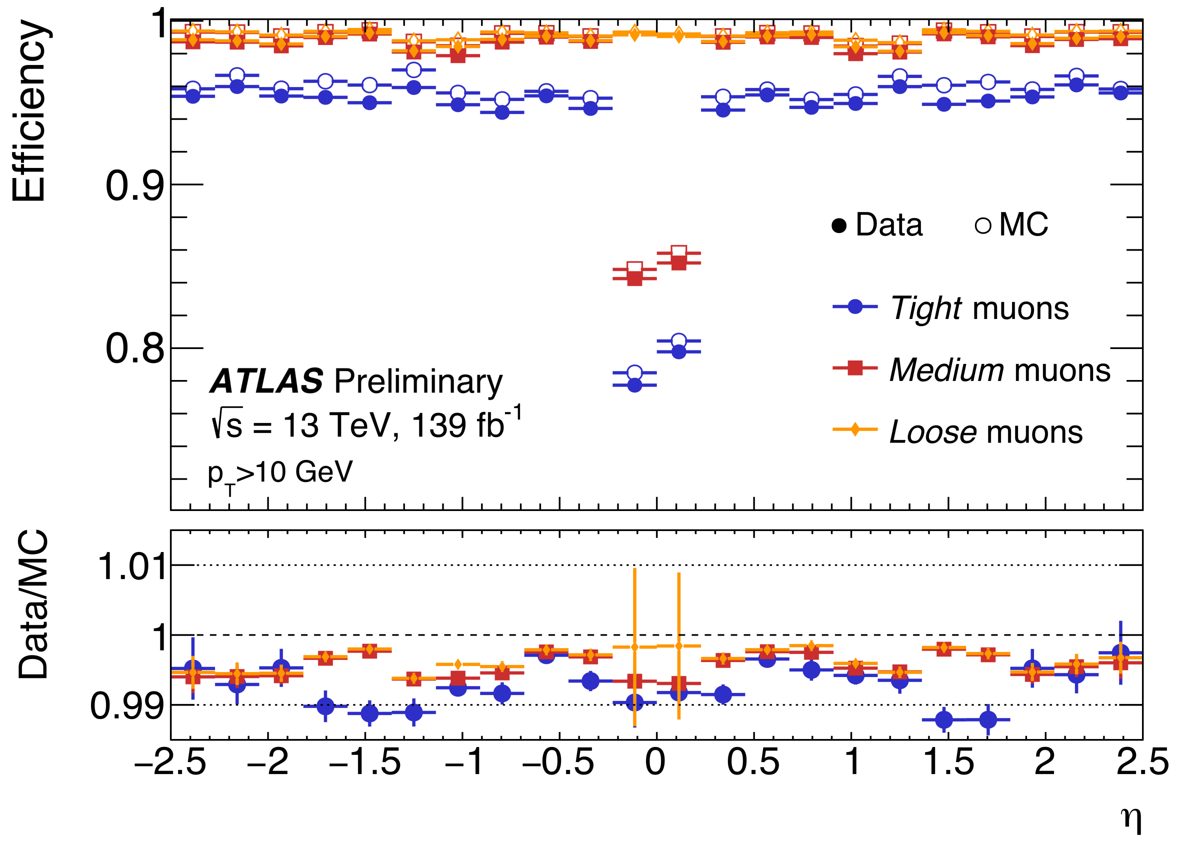


ATLAS：在x-y平面，缪子的径迹是直线

缪子的刻度

利用Z→μμ sample





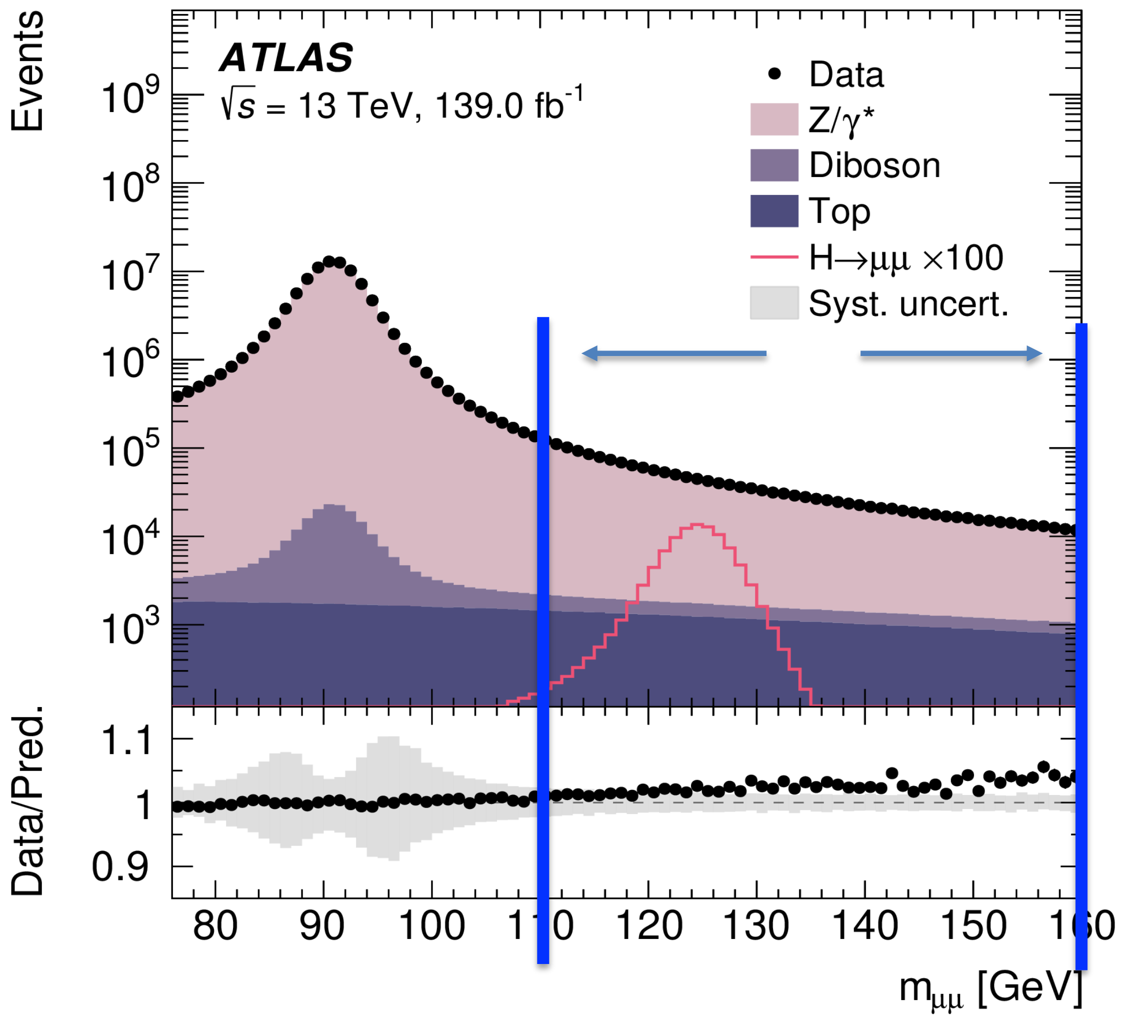
- Within the ID acceptance |η| < 2.5, the *Medium working point* accepts only CB muons.
- The *Loose* selection working point accepts all the muons passing the *Medium* WP. In addition, it includes CT and ST muons in the range |η| < 0.1

Analysis Strategy

- Signal has good $m_{\mu\mu}$ resolution. Background $m_{\mu\mu}$ is smooth
- Use analytic functions to model signal and background.
- Fully data-driven method

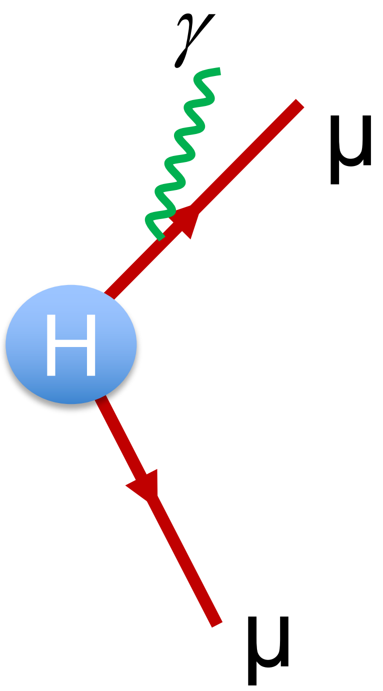
- ggF, VBF, VH and ttH signal processes are considered.
- Dominant background is Drell-Yan process

arXiv:2007.07830

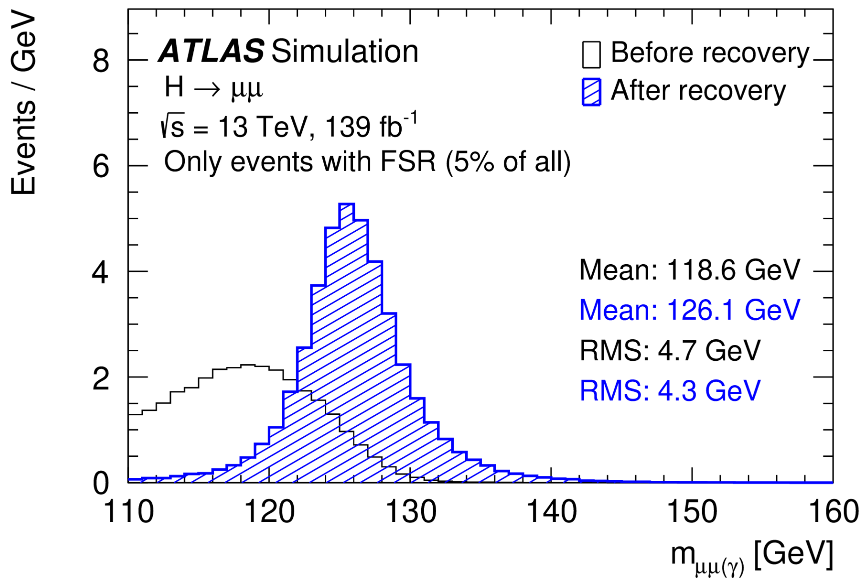


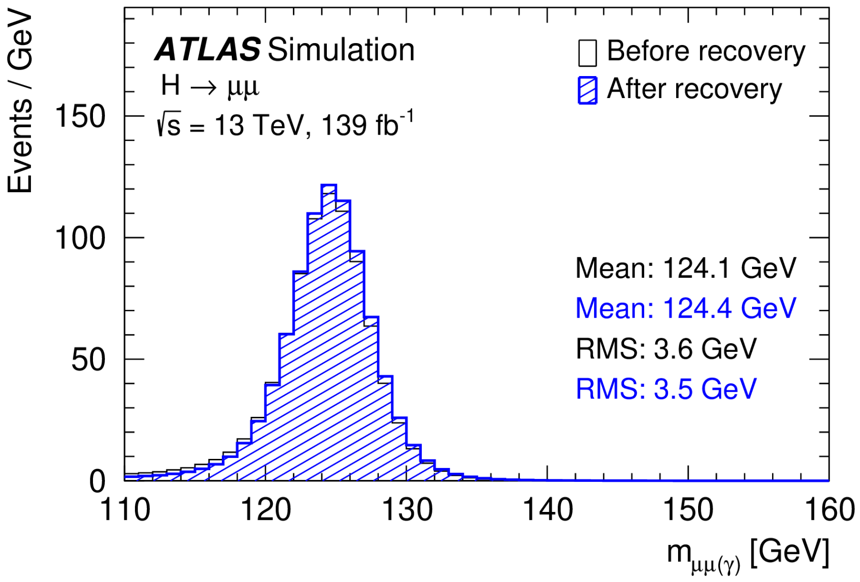
Muon QED Final State Radiation

- Add FSR photon to $m_{\mu\mu}$ calculation to improve the $m_{\mu\mu}$ resolution



arXiv:2007.07830

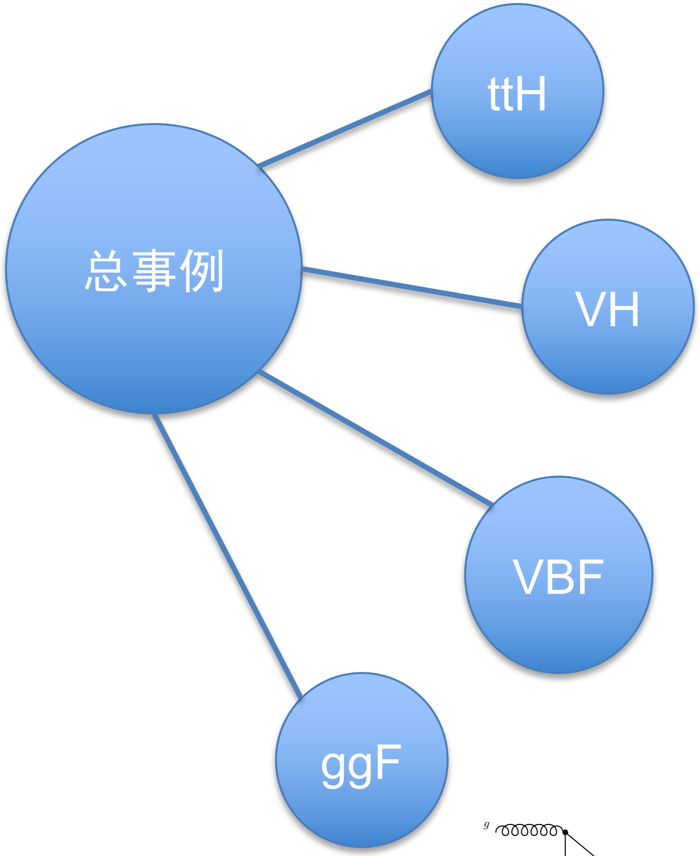


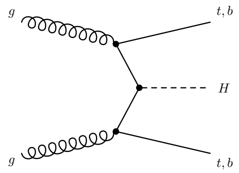


3% improvement in signal width

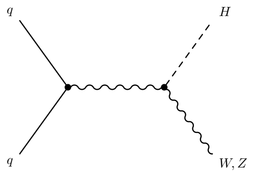
Categorization

面向不同的production mode设计不同的判选条件

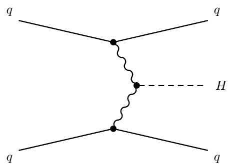




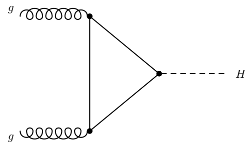
3/4 leptons, at least one bjet



3/4 leptons, no bjet



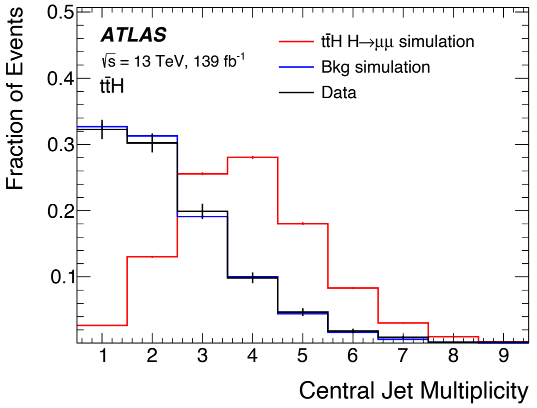
2 leptons, no bjet

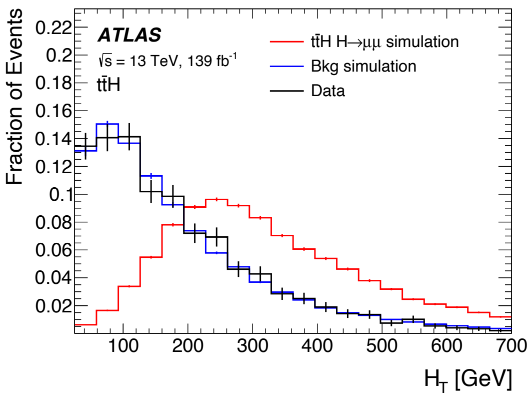


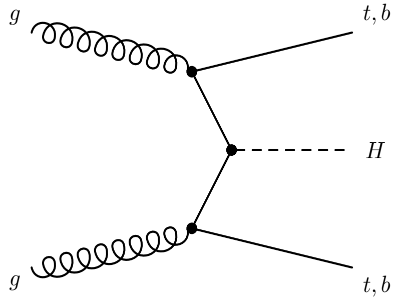
2 leptons, no bjet

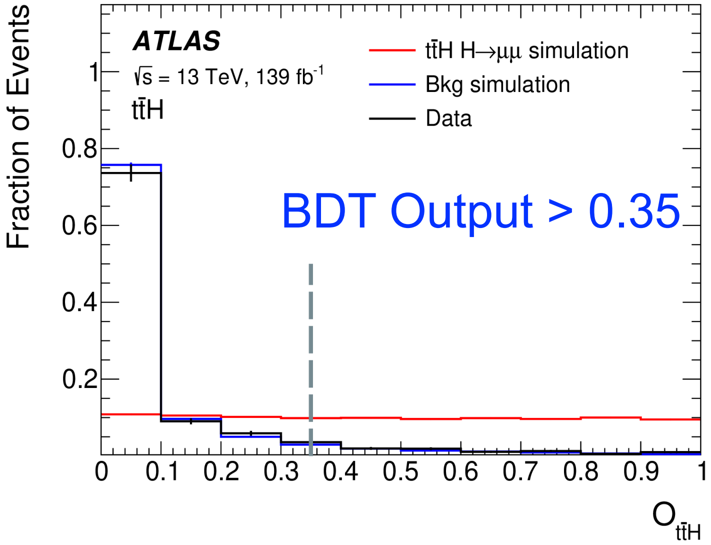
ttH Category

- Use BDT (implemented in `XGBoost` package) to further suppress backgrounds
- Leading two muons as H->mumu
- 12 variables are used for the BDT
- Main background is ttZ. Expected signal: 1.2 events

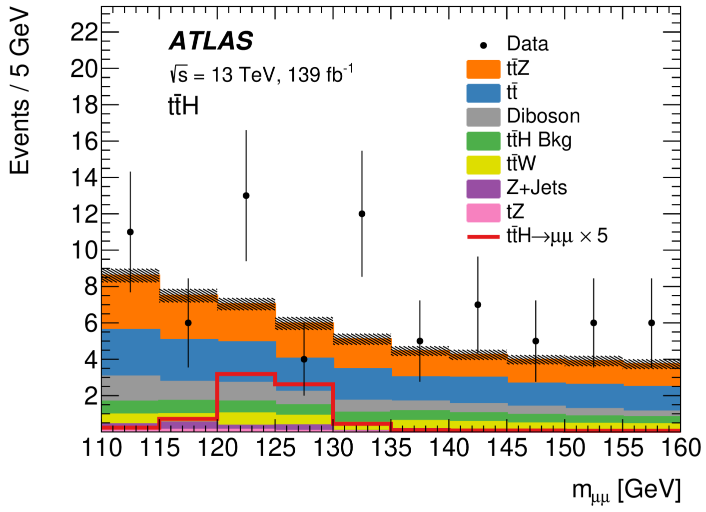








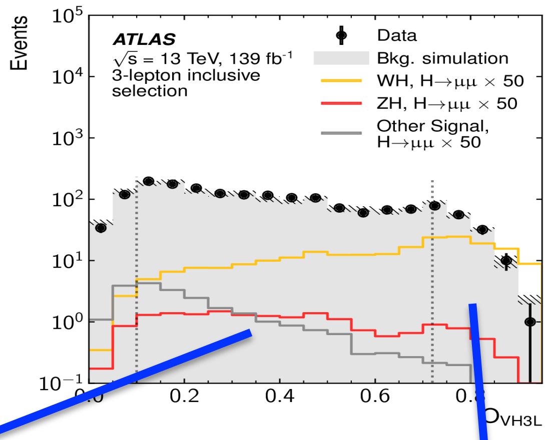
After BDT selection

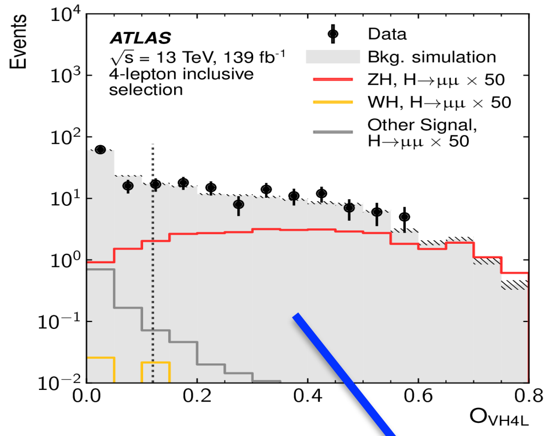


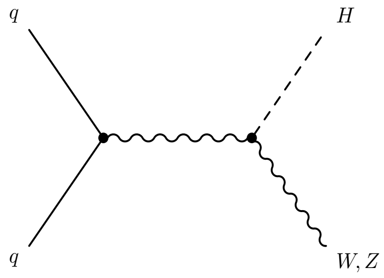
VH Categories

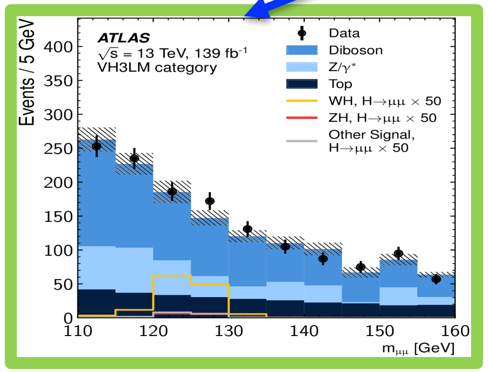
- WH/ZH, (H→μμ). Expected signal: 4.7 events
- Two BDTs: one BDT for 3 lepton (8 variables) and another BDT for 4 lepton (7 variables)

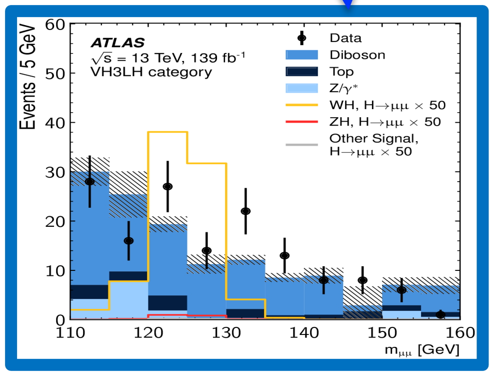
Main background: diboson

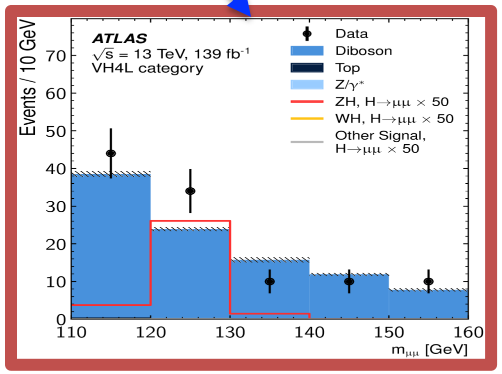




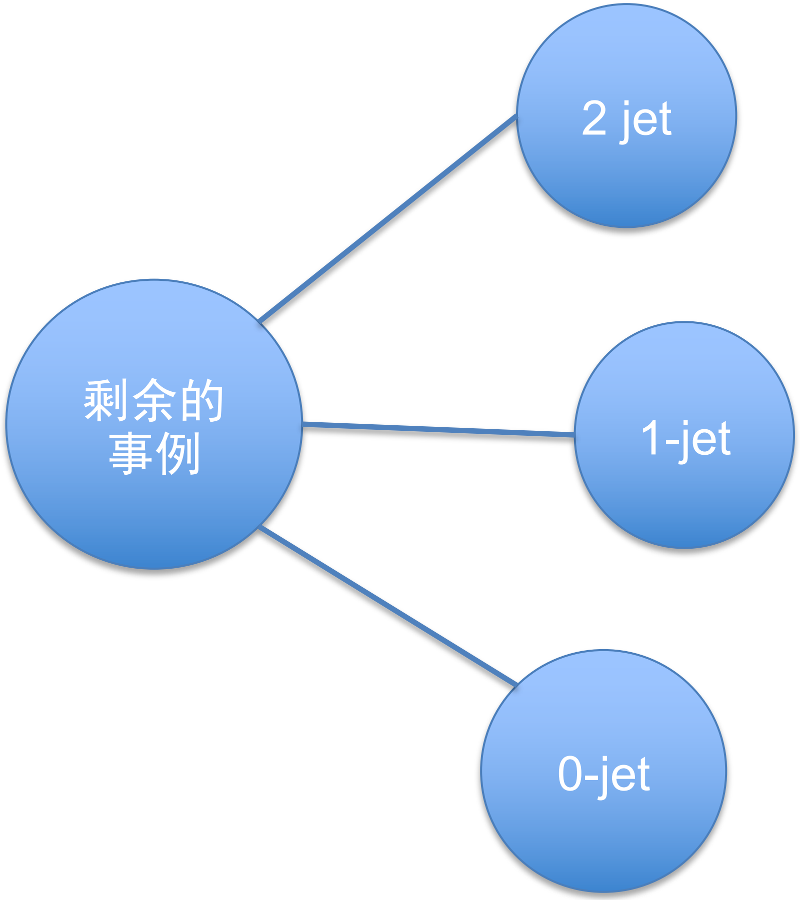


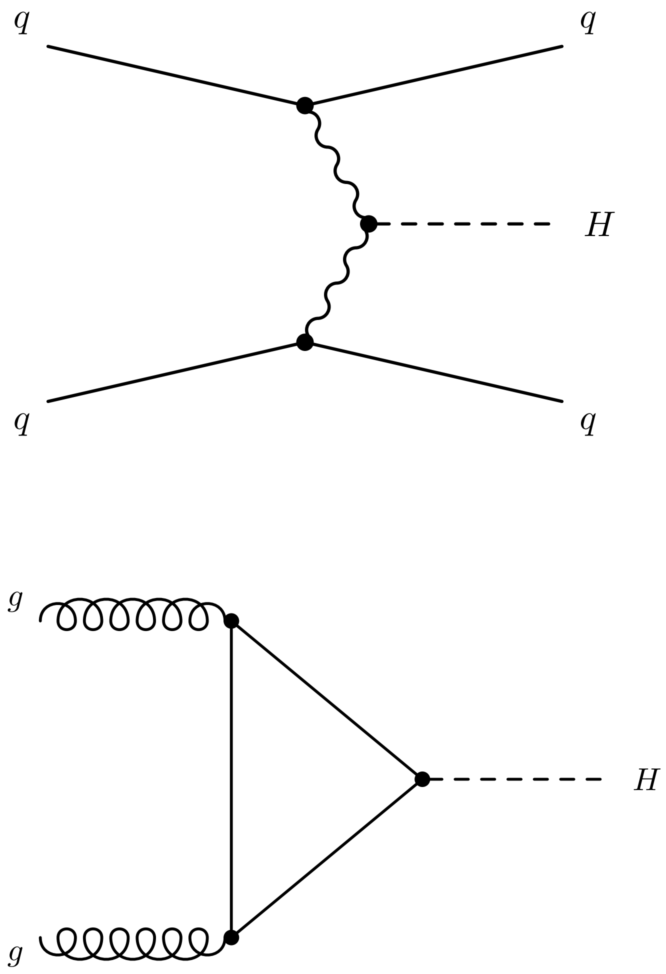




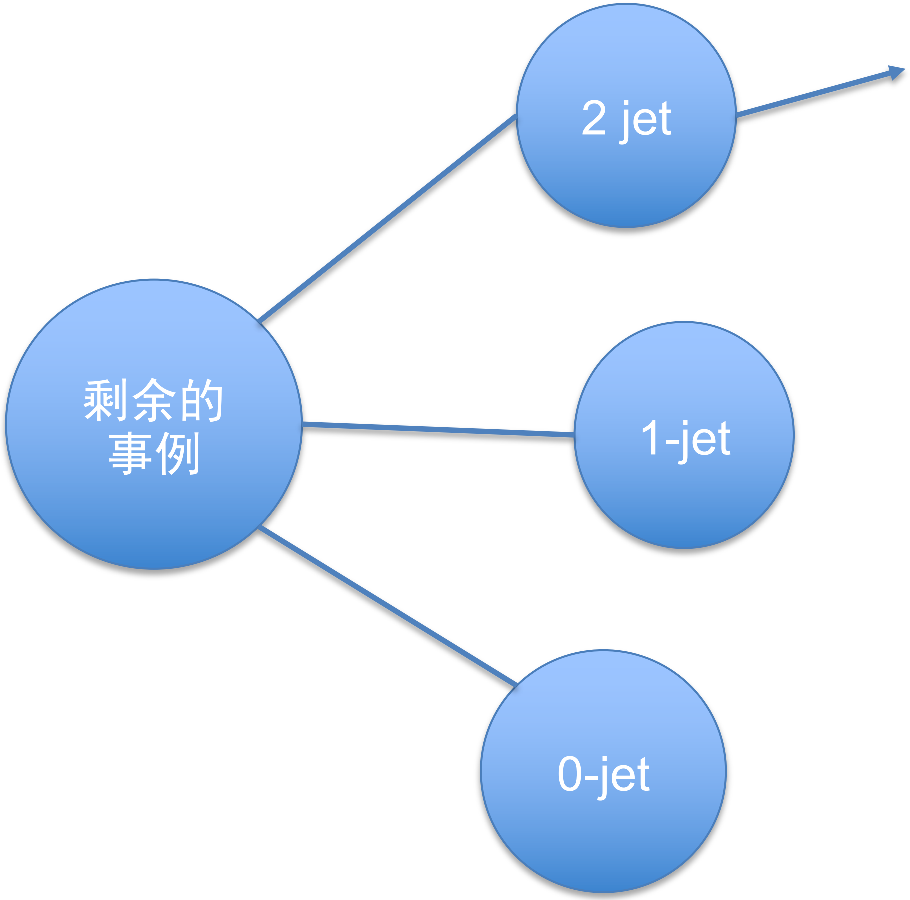


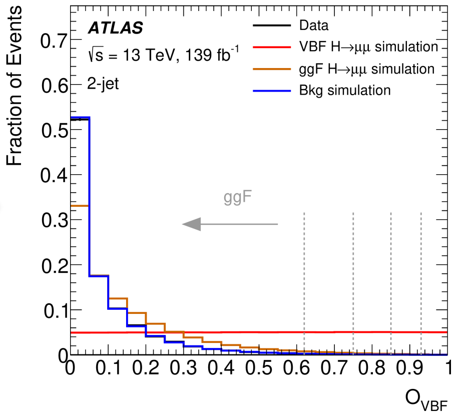
VBF/ggF Categories



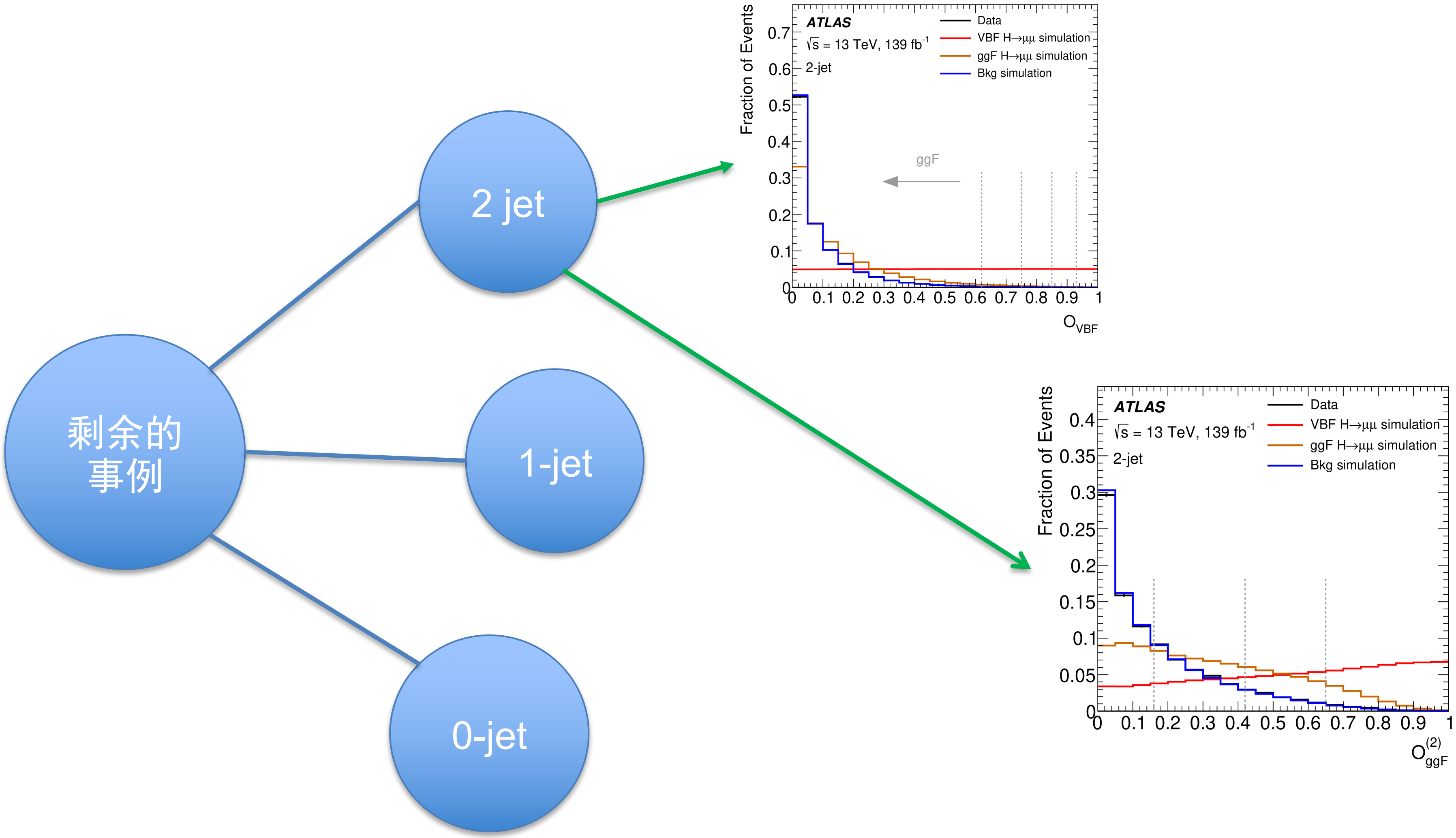


VBF/ggF Categories

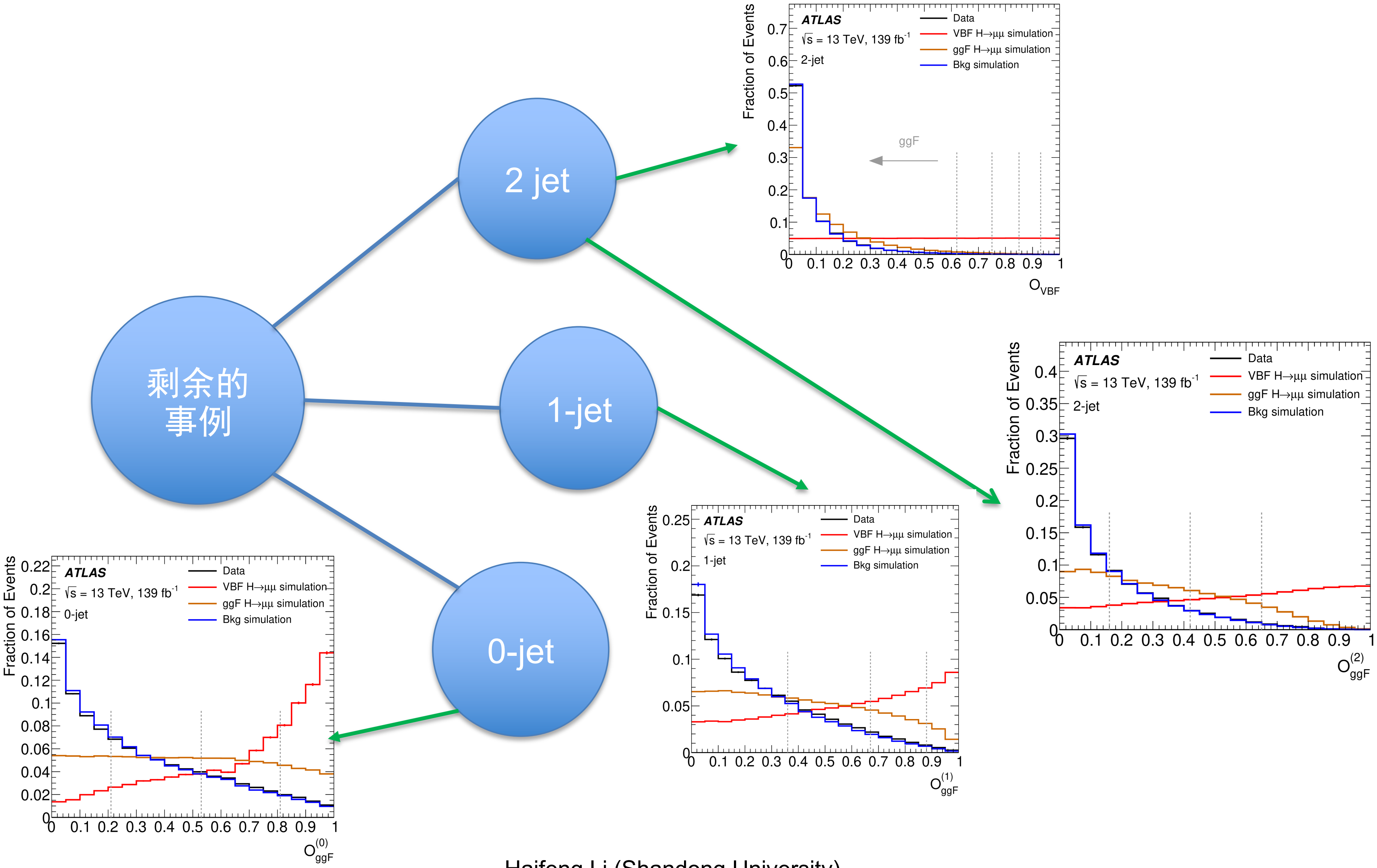




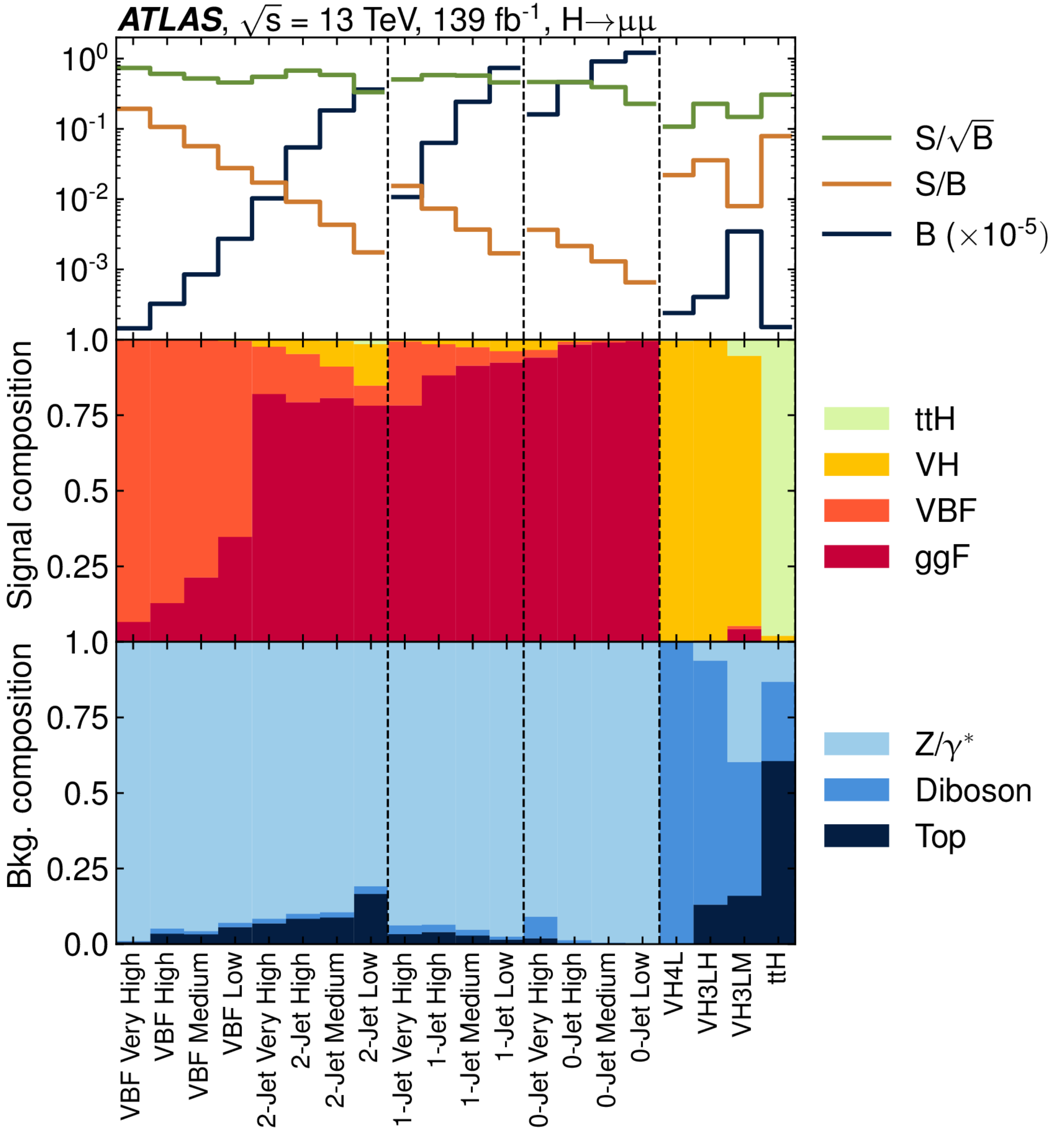
VBF/ggF Categories



VBF/ggF Categories

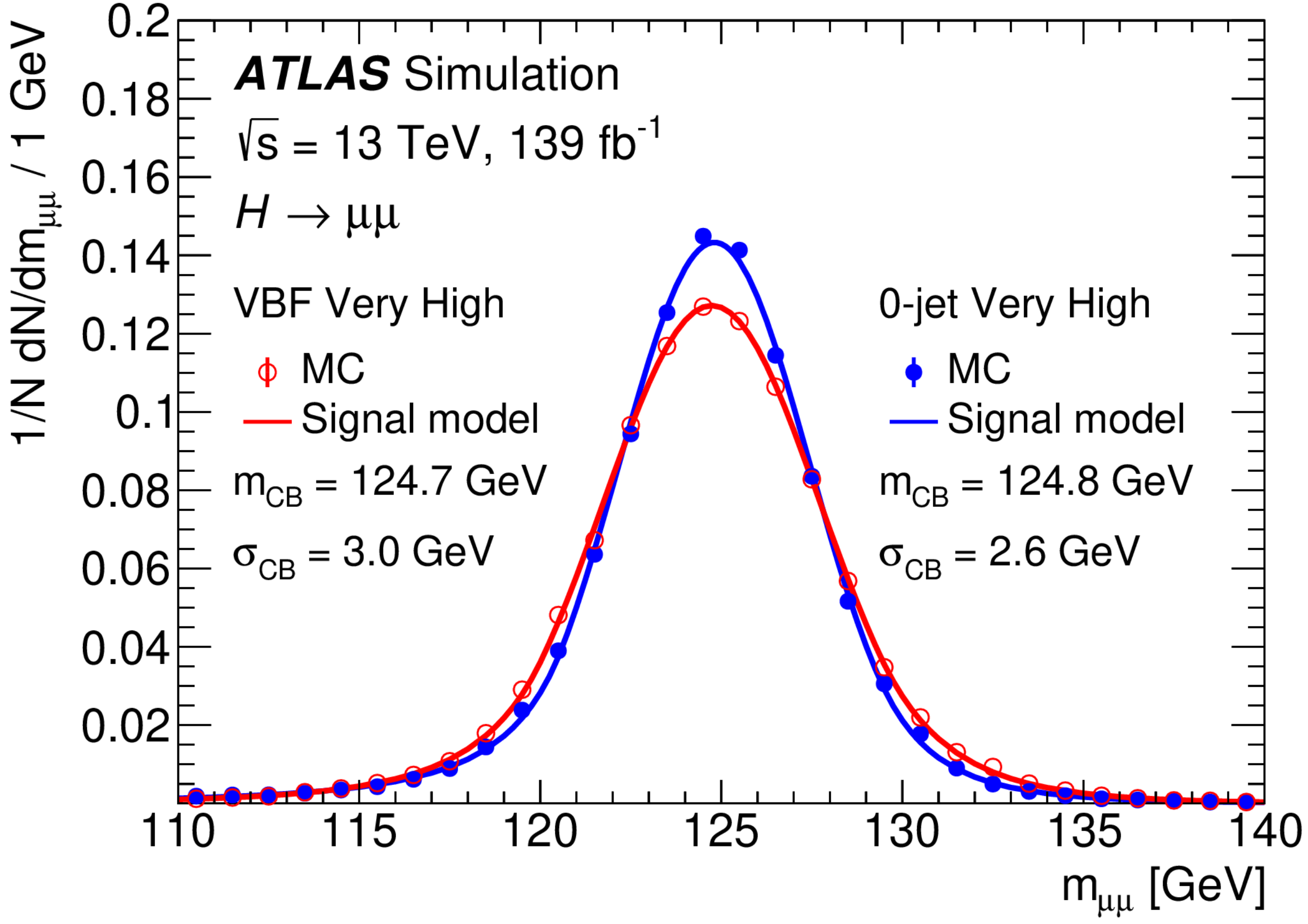


20 categories in total



Signal Modeling

- Double-sided Crystal-Ball function



Background Modeling

Proposed model with two components: [fix] x [floating]

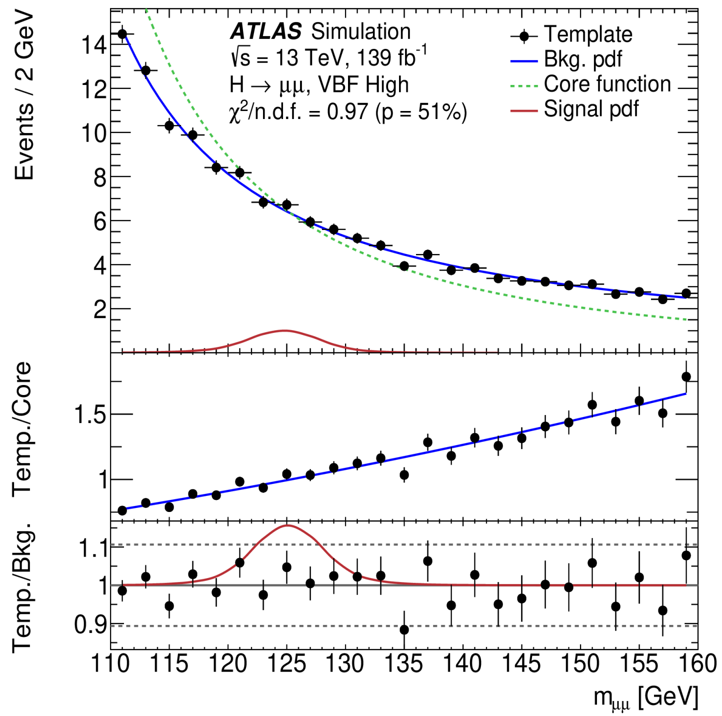
- Fixed part (physics motivated): LO 2→2 Drell-Yan analytic lineshape
  - m(μμ) resolution effect included by smearing with Gaussian
- Floating part:

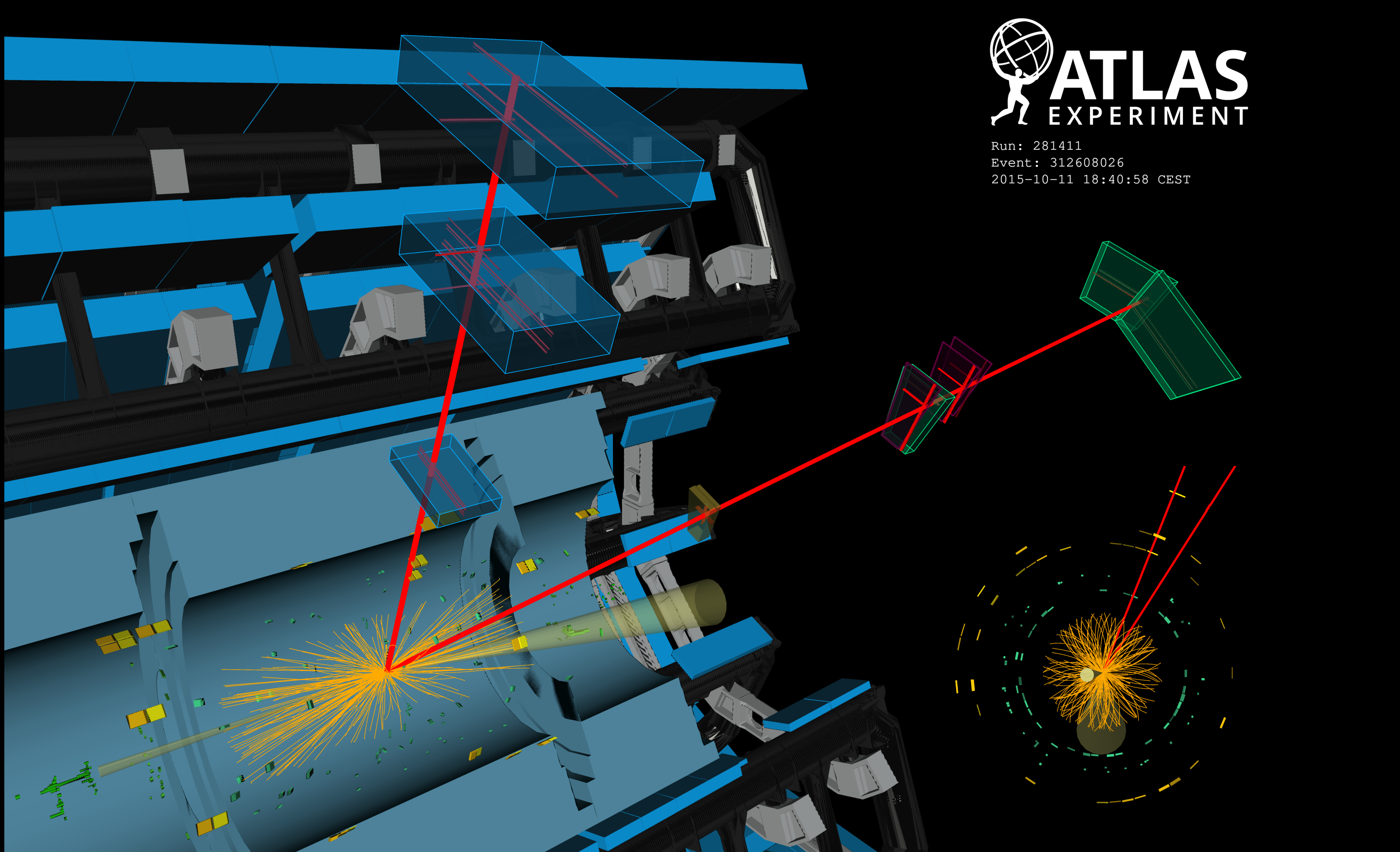
Simultaneous fit with 20 categories to extract signal strength

Category	Empirical Function
VBF Very High	Epoly1
VBF High	Power0
VBF Medium	Power0
VBF Low	Power0
2-jet Very High	Power1
2-jet High	Epoly2
2-jet Medium	Power1
2-jet Low	Epoly3
1-jet Very High	Epoly2
1-jet High	Epoly2
1-jet Medium	Power1
1-jet Low	Power1
0-jet Very High	Power1
0-jet High	Power1
0-jet Medium	Power1
0-jet Low	Epoly3
VH4L	Power1
VH3LH	Epoly2
VH3LM	Epoly3
$t\bar{t}H$	Power0

Chosen with high-stat DY fast simulated samples

Function	Expression
PowerN	$m_{\mu\mu}^{(a_0+a_1 m_{\mu\mu}+a_2 m_{\mu\mu}^2+...+a_N m_{\mu\mu}^N)}$
EpolyN	$\exp(a_1 m_{\mu\mu} + a_2 m_{\mu\mu}^2 + ... + a_N m_{\mu\mu}^N)$





ATLAS
EXPERIMENT
Run: 281411
Event: 312608026
2015-10-11 18:40:58 CEST

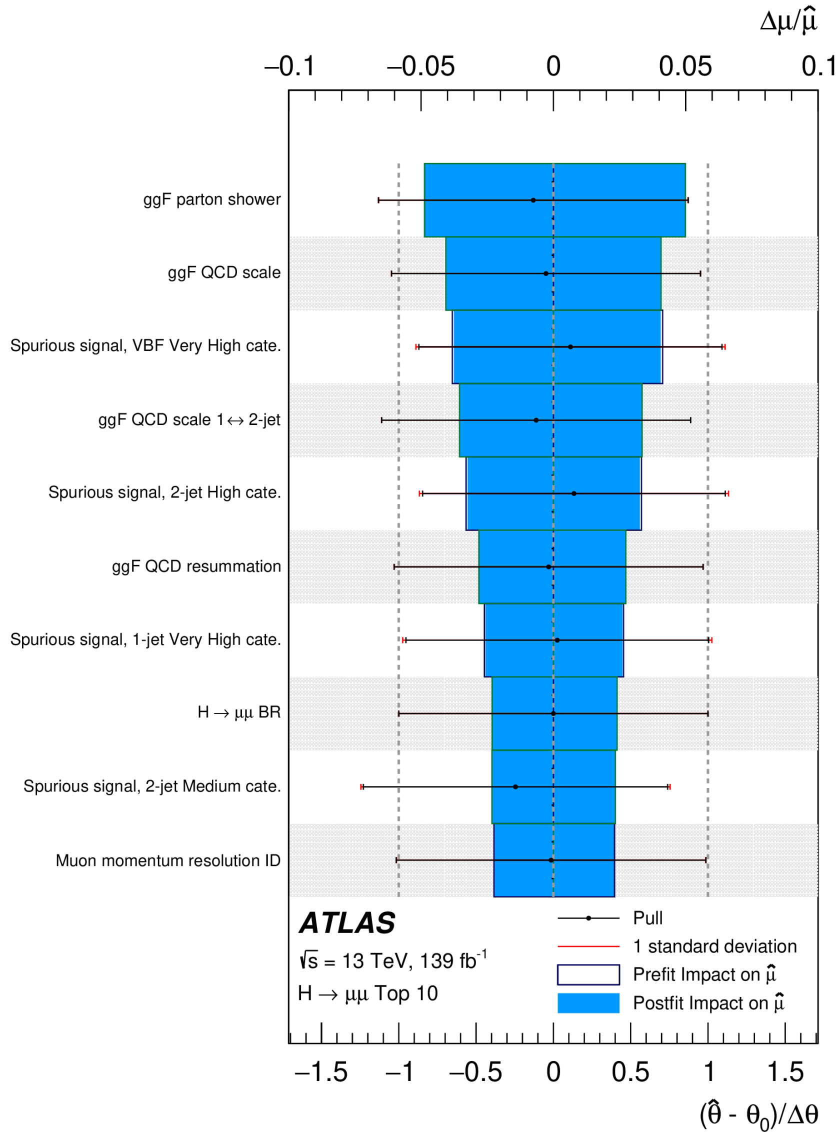
结果

Event Yields

Events within $m_{\mu\mu}$ = 120–130 GeV

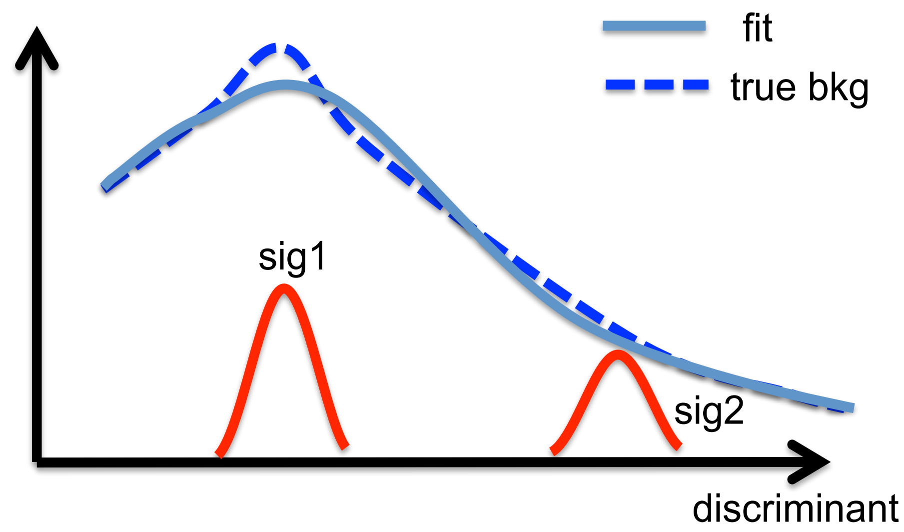
Category	Data	S_{SM}	S	B	$S/\sqrt{B}$	S/B [%]
VBF Very High	15	2.81 ± 0.27	3.3 ± 1.7	14.5 ± 2.1	0.86	22.6
VBF High	39	3.46 ± 0.36	4.0 ± 2.1	32.5 ± 2.9	0.71	12.4
VBF Medium	112	4.8 ± 0.5	5.6 ± 2.8	85 ± 4	0.61	6.6
VBF Low	284	7.5 ± 0.9	9 ± 4	273 ± 8	0.53	3.2
2-jet Very High	1030	17.6 ± 3.3	21 ± 10	1024 ± 22	0.63	2.0
2-jet High	5433	50 ± 8	58 ± 30	5440 ± 50	0.77	1.0
2-jet Medium	18 311	79 ± 15	90 ± 50	$18\,320 \pm 90$	0.66	0.5
2-jet Low	36 409	63 ± 17	70 ± 40	$36\,340 \pm 140$	0.37	0.2
1-jet Very High	1097	16.5 ± 2.4	19 ± 10	1071 ± 22	0.59	1.8
1-jet High	6413	46 ± 7	54 ± 28	6320 ± 50	0.69	0.9
1-jet Medium	24 576	90 ± 11	100 ± 50	$24\,290 \pm 100$	0.67	0.4
1-jet Low	73 459	125 ± 17	150 ± 70	$73\,480 \pm 190$	0.53	0.2
0-jet Very High	15 986	59 ± 11	70 ± 40	$16\,090 \pm 90$	0.55	0.4
0-jet High	46 523	99 ± 13	120 ± 60	$46\,190 \pm 150$	0.54	0.3
0-jet Medium	91 392	119 ± 14	140 ± 70	$91\,310 \pm 210$	0.46	0.2
0-jet Low	121 354	79 ± 10	90 ± 50	$121\,310 \pm 280$	0.26	0.1
VH4L	34	0.53 ± 0.05	0.6 ± 0.3	24 ± 4	0.13	2.6
VH3LH	41	1.45 ± 0.14	1.7 ± 0.9	41 ± 5	0.27	4.2
VH3LM	358	2.76 ± 0.24	3.2 ± 1.6	347 ± 15	0.17	0.9
$t\bar{t}H$	17	1.19 ± 0.13	1.4 ± 0.7	15.1 ± 2.2	0.36	9.2

系统误差

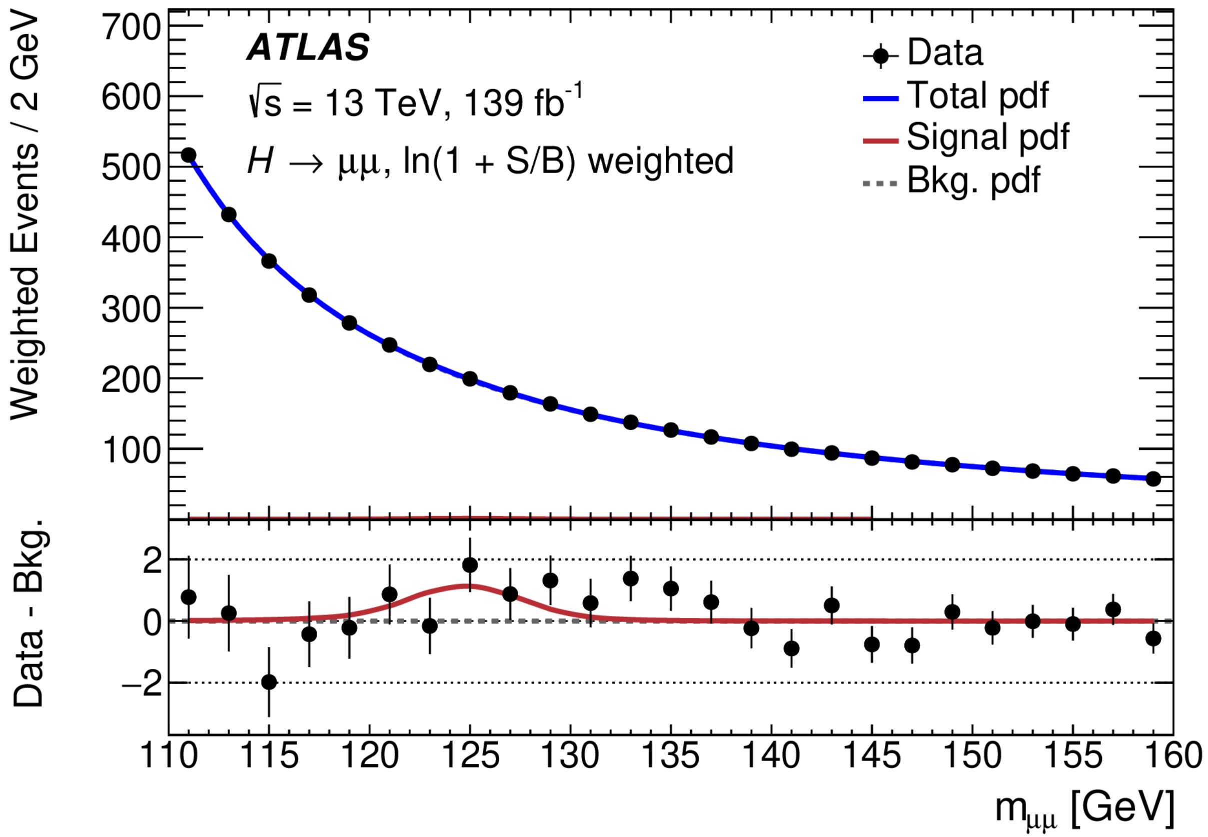


Main systematic uncertainties

- Theory uncertainties on the signal
- Spurious signal systematic per category
- Experimental uncertainties on muon



统计结果



Significance: 2.0σ (1.7σ expected)

Best fit: μ = 1.2 ±0.6

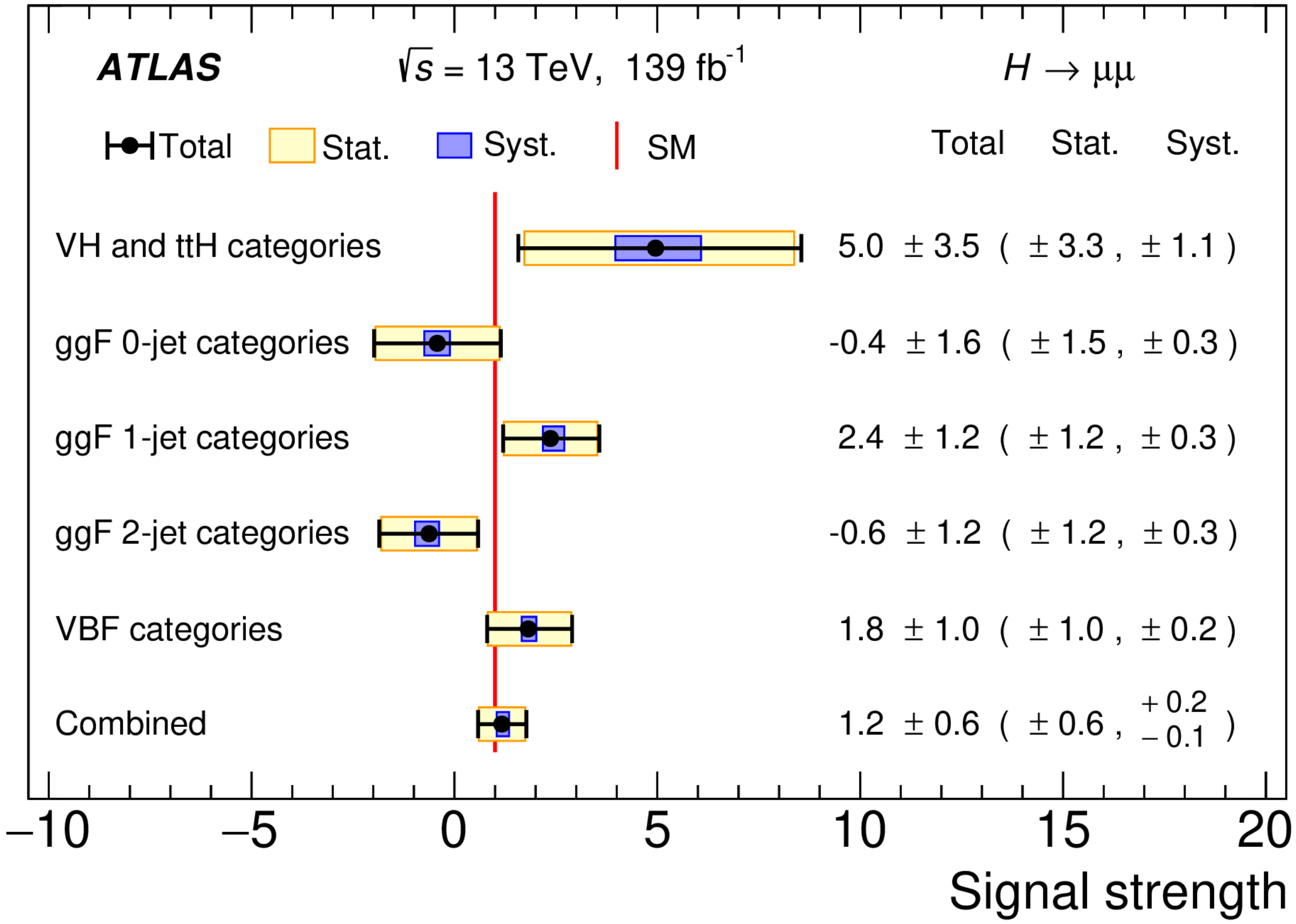
Data statistics: ±0.58

Signal theory syst.: +0.13 -0.08

Signal experiment syst.: +0.07-0.03

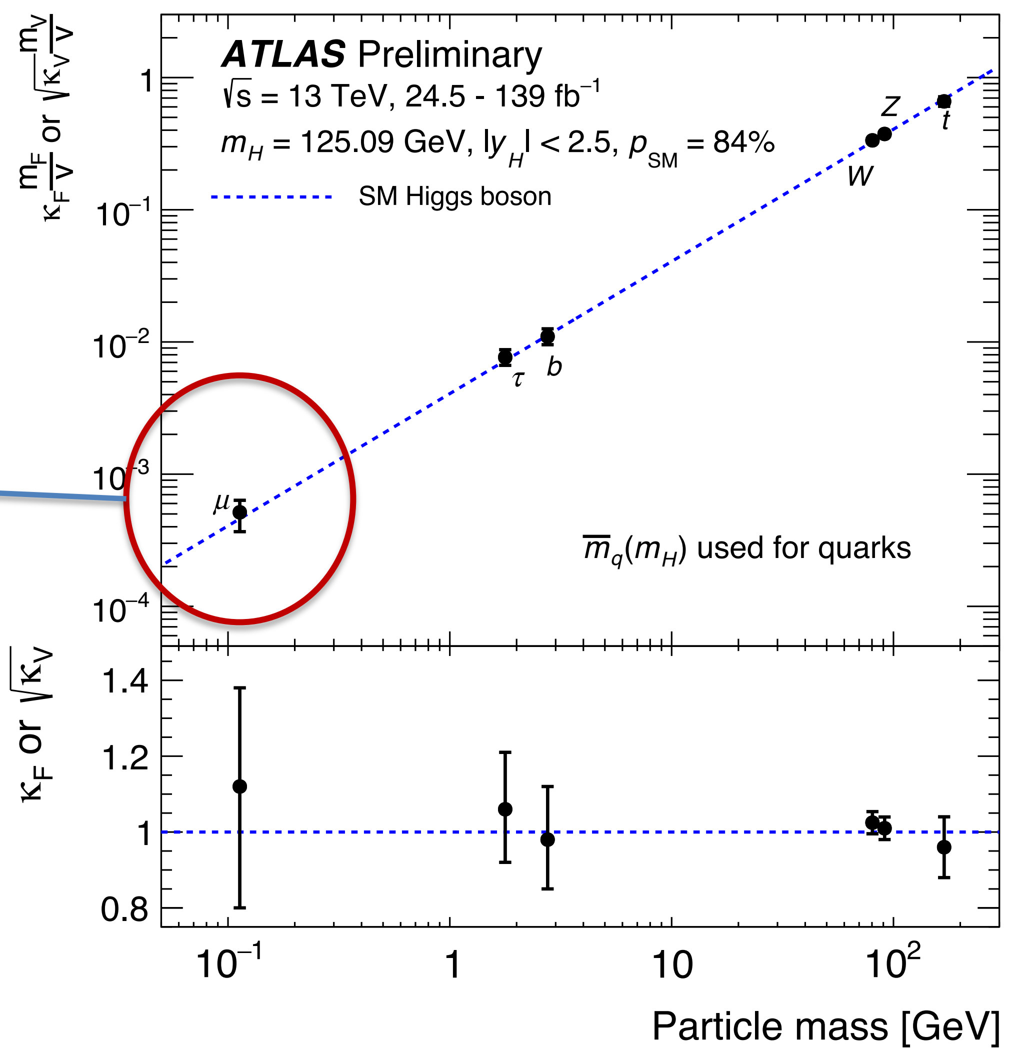
Spurious signal syst.: ±0.10

Signal Strength in Different Categories



Higgs Couplings

ATLAS-CONF-2020-027



Updated with 139 fb^{-1}

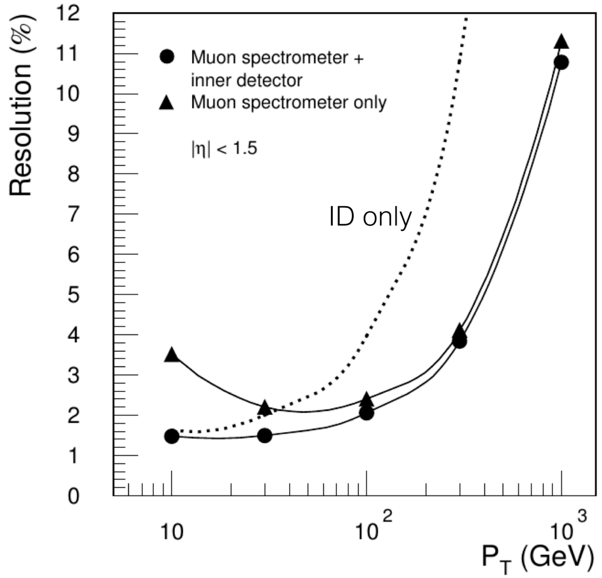
总结

- H->mumu is used to probe the Higgs coupling to second generation fermions
- H->mumu search with full run2 data. Observed significance: 2σ (1.7σ expected)
- Best-fit combined signal strength: $\mu = 1.2 \pm 0.6$

Outlook:

- Need more data to understand the coupling between Higgs boson and muons
- LHC Run 3 will start Feb 2022

Backup

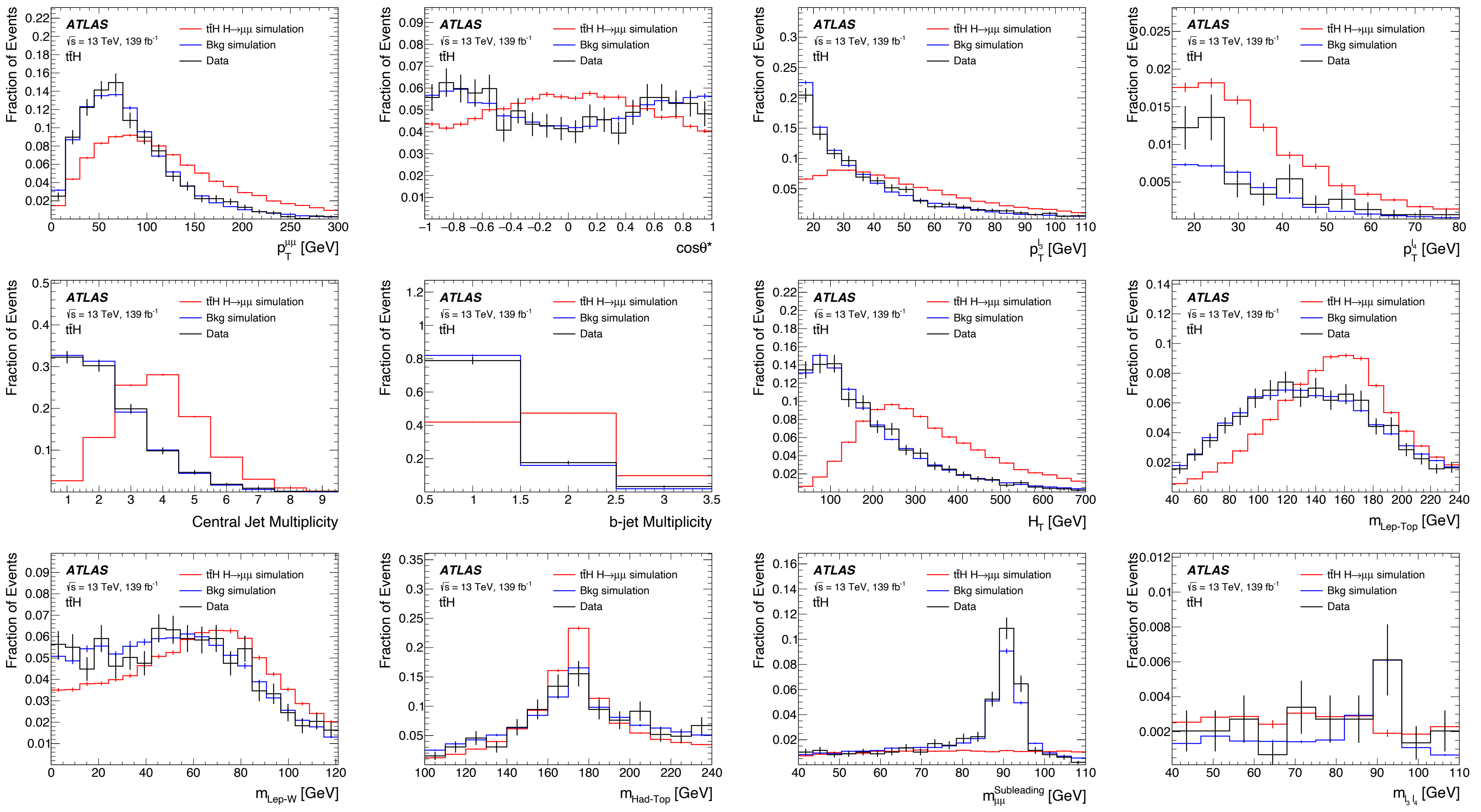


- Most $H \rightarrow \mu\mu$ signal have muon pT between 50 GeV and 100 GeV.
- Sensitivity to signal is proportional to the $1/\sqrt{\sigma}$

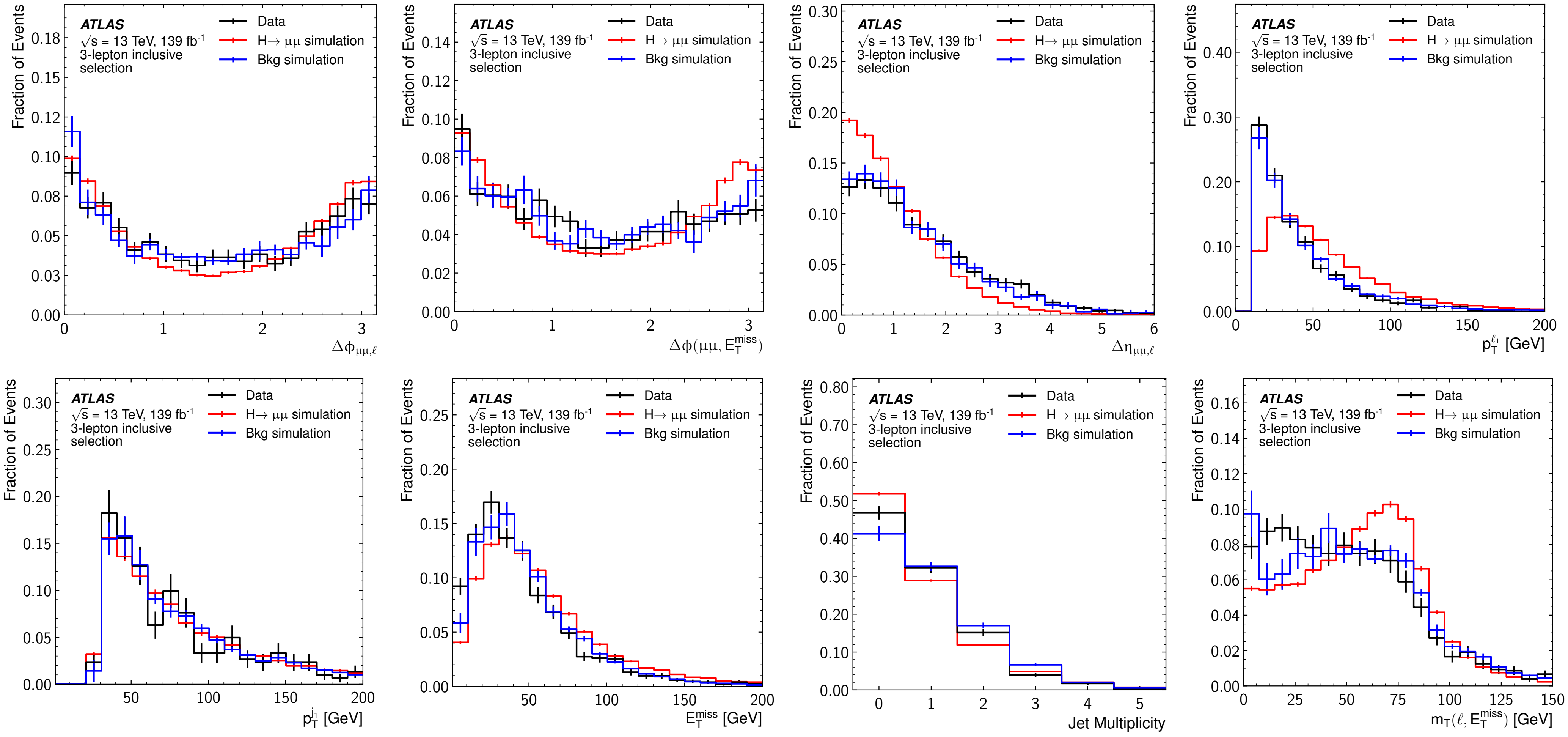
$$\frac{S}{\sqrt{B}} \sim \frac{1}{\sqrt{\sigma}}$$

Improving the dimuon mass resolution is the key to find $H \rightarrow \mu\mu$ signal at LHC

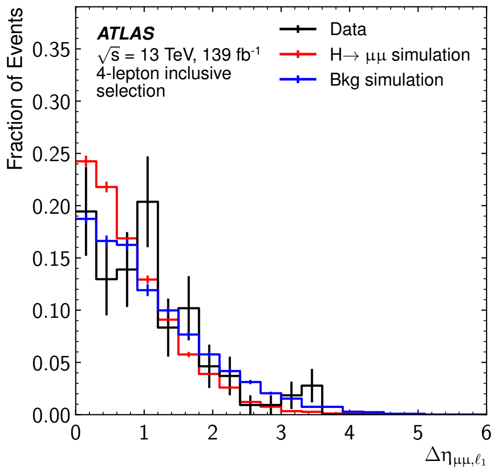
ttH training 变量

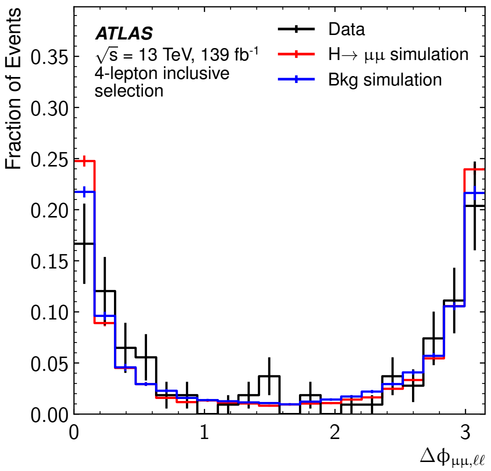


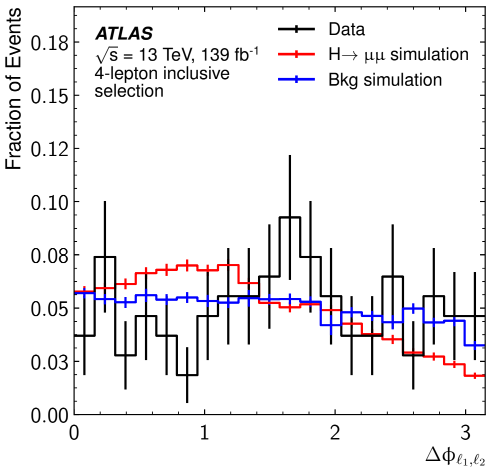
VH 3-lepton training 变量

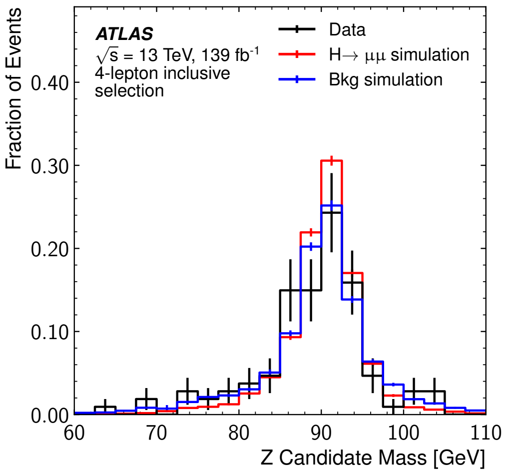


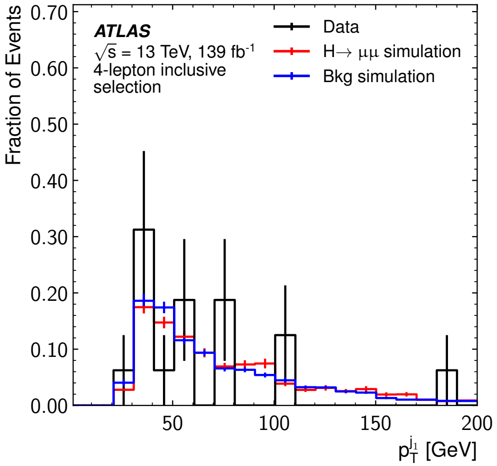
VH 4-lepton training 变量

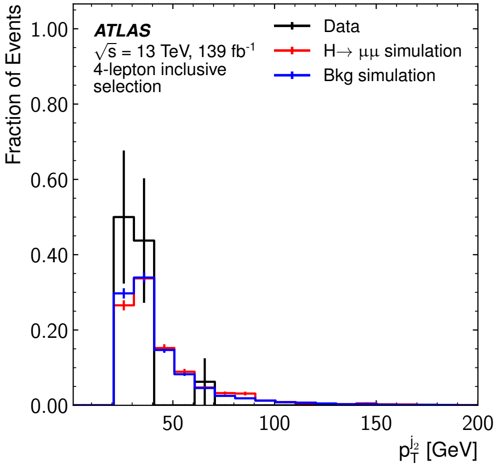


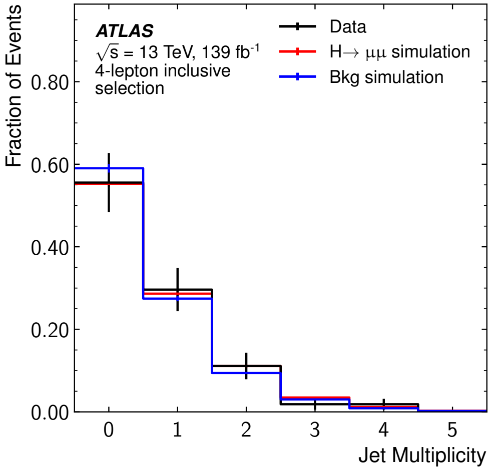




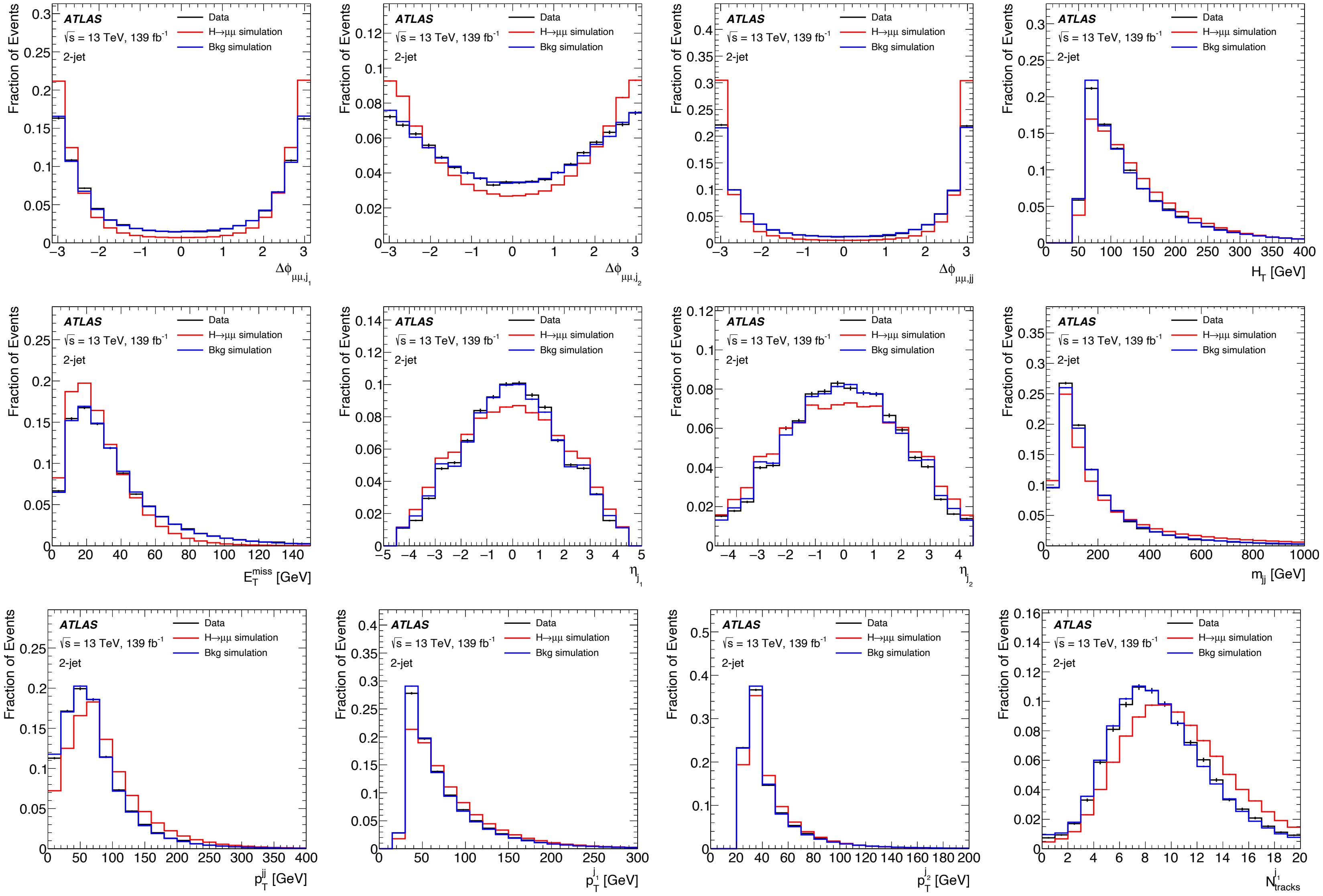




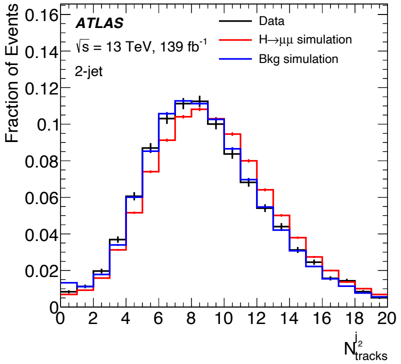


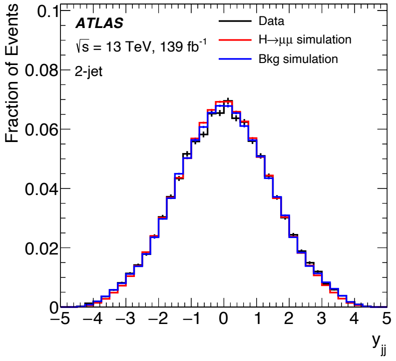


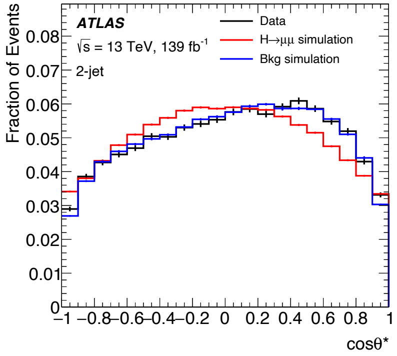
2-jet training 变量

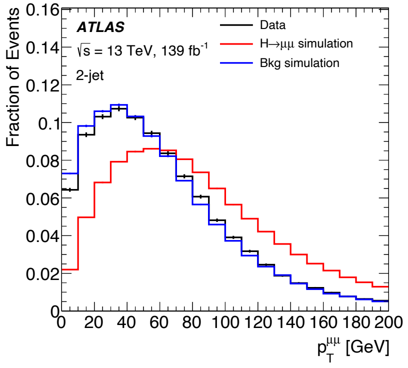


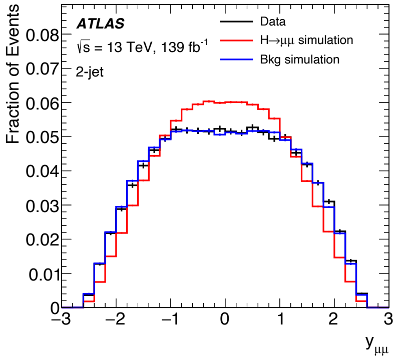
2-jet training 变量



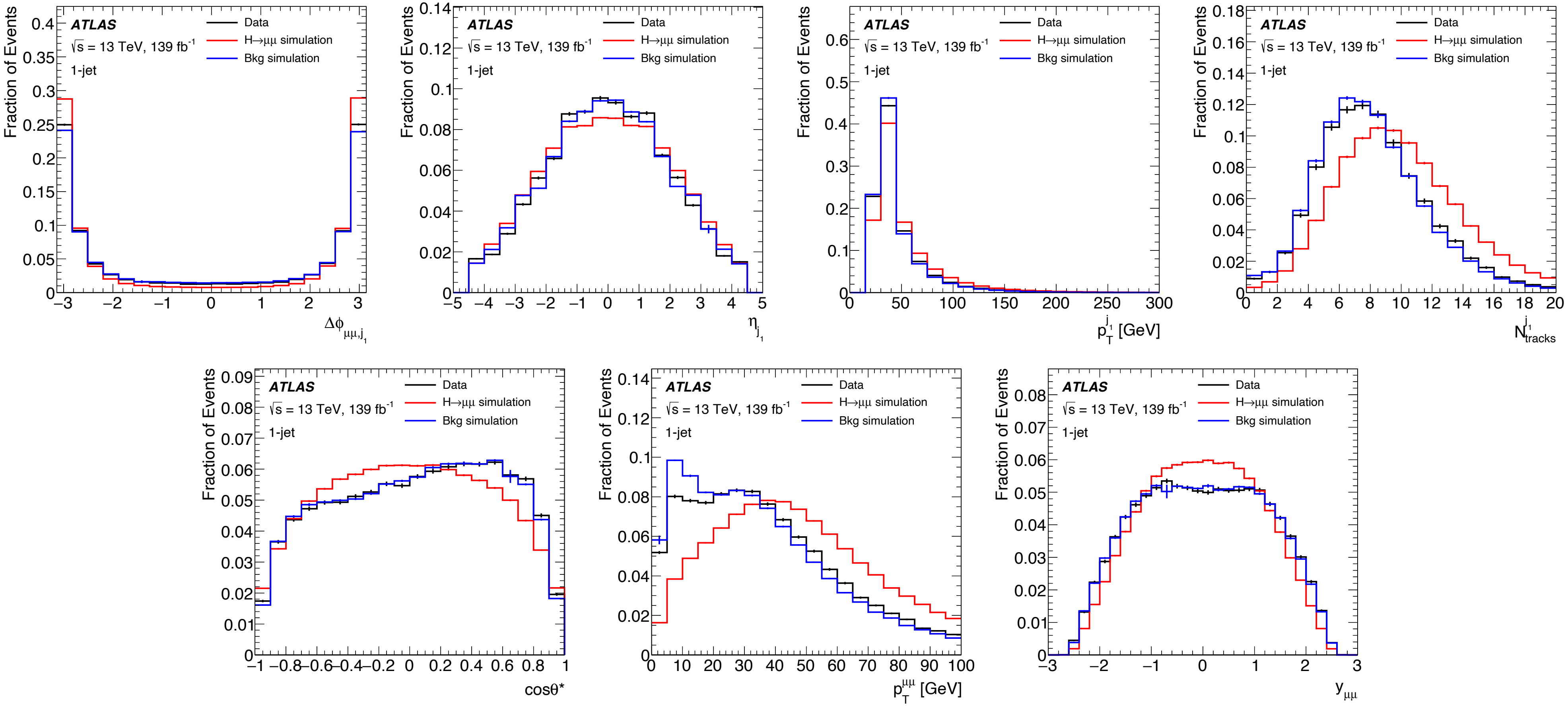




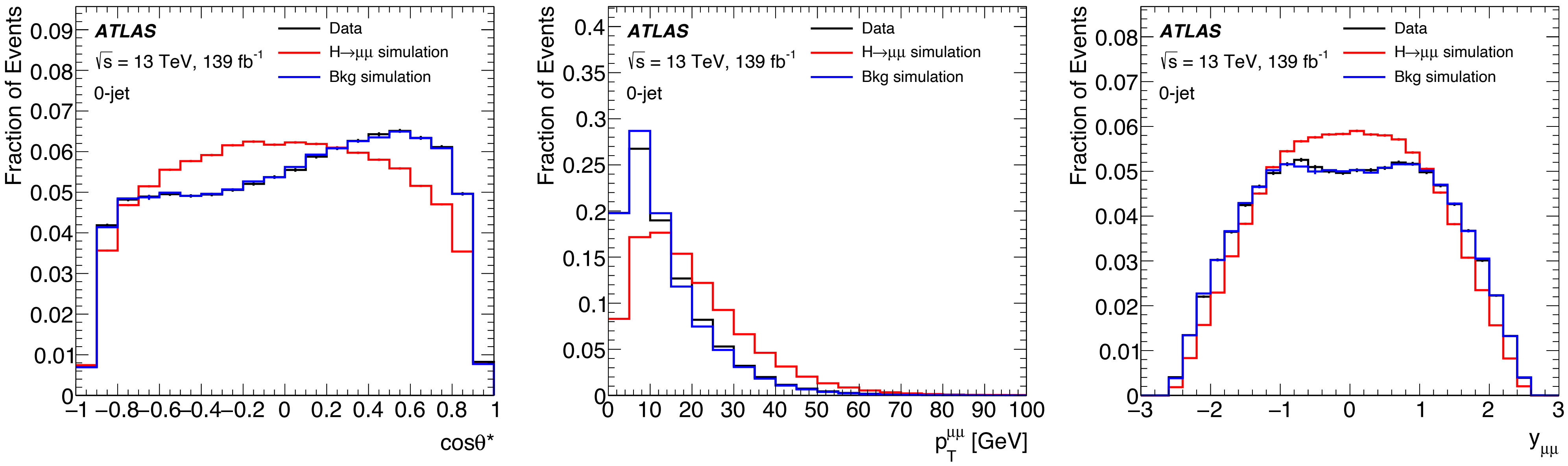




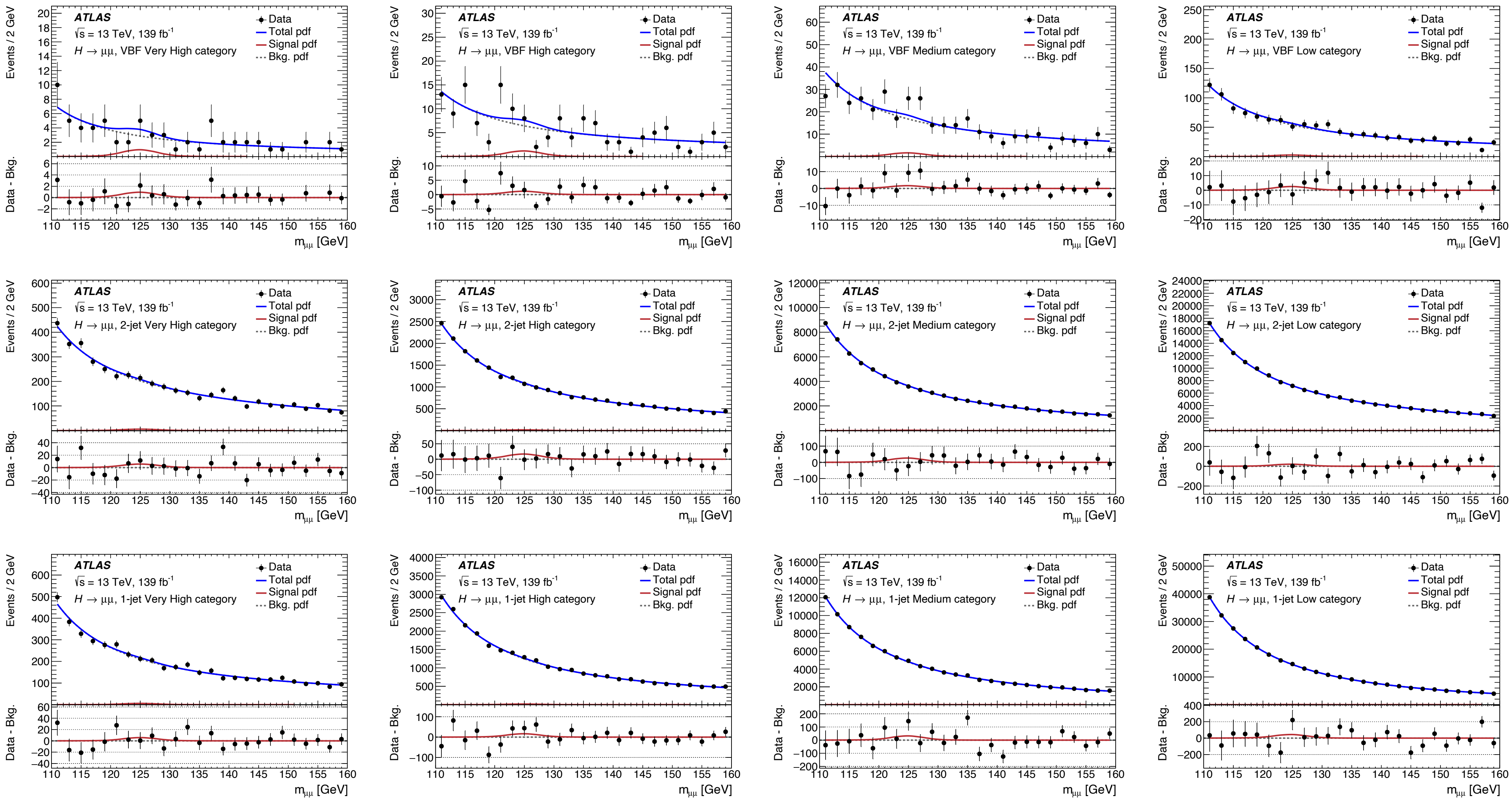
1-jet training 变量



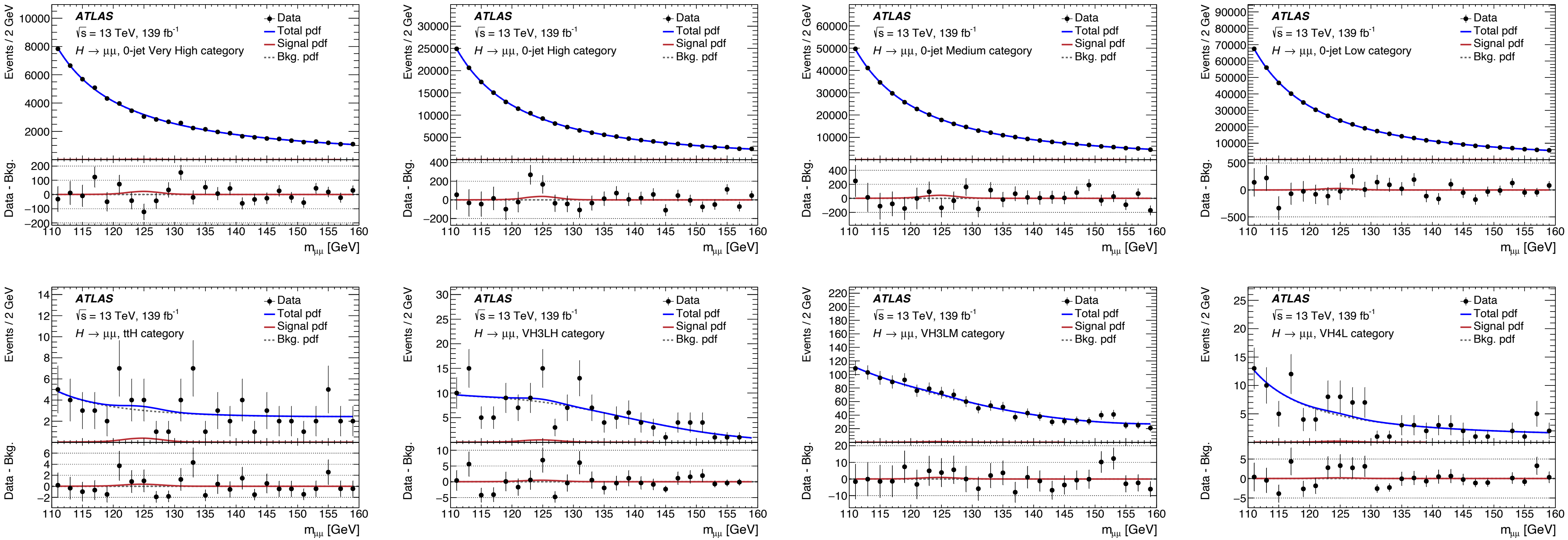
0-jet training 变量



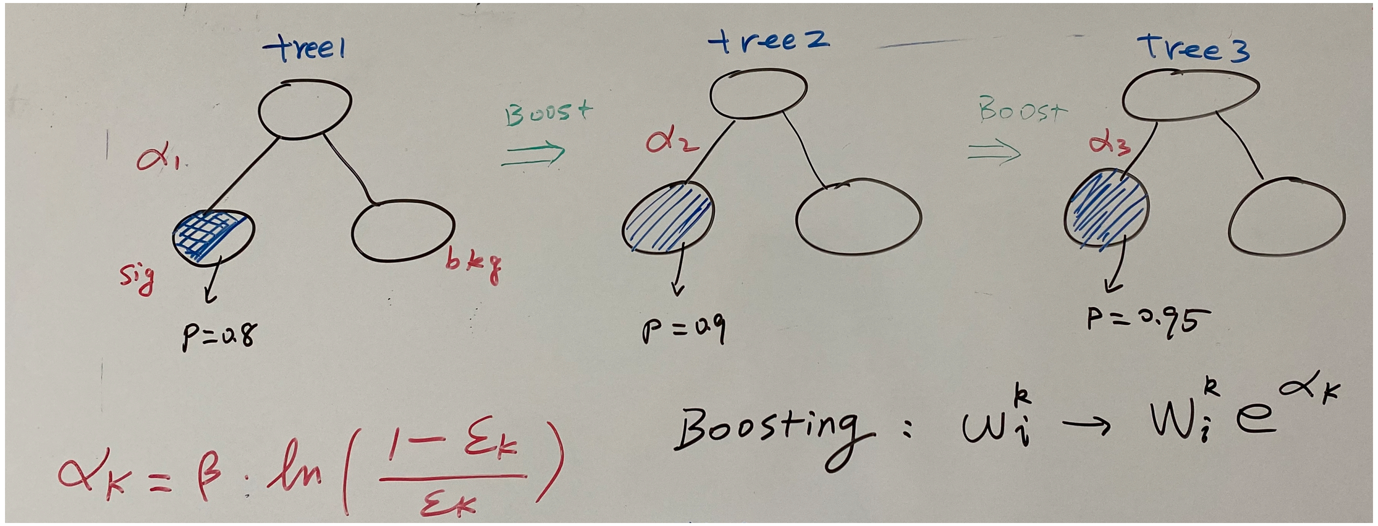
Signal plus background fits with μ=1.2

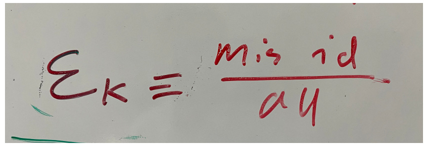


Signal plus background fits with μ=1.2



Boosted Decision Trees





Here β=1