$WH \to WWW^{*}$@ATLAS

单 连友

ATLAS@IHEP

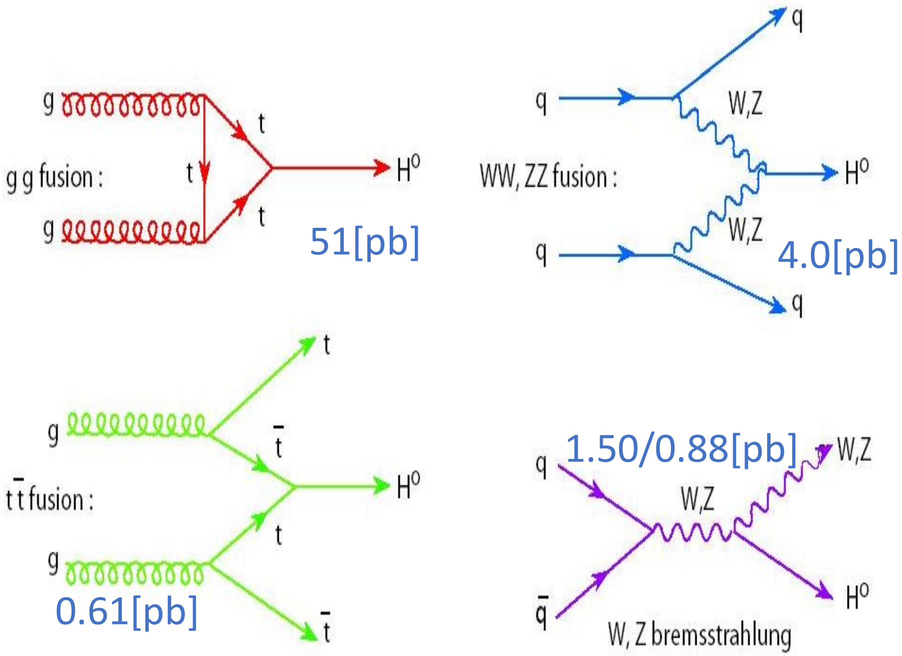
12’th 全国粒子物理学术会议， Aug 22, 合肥

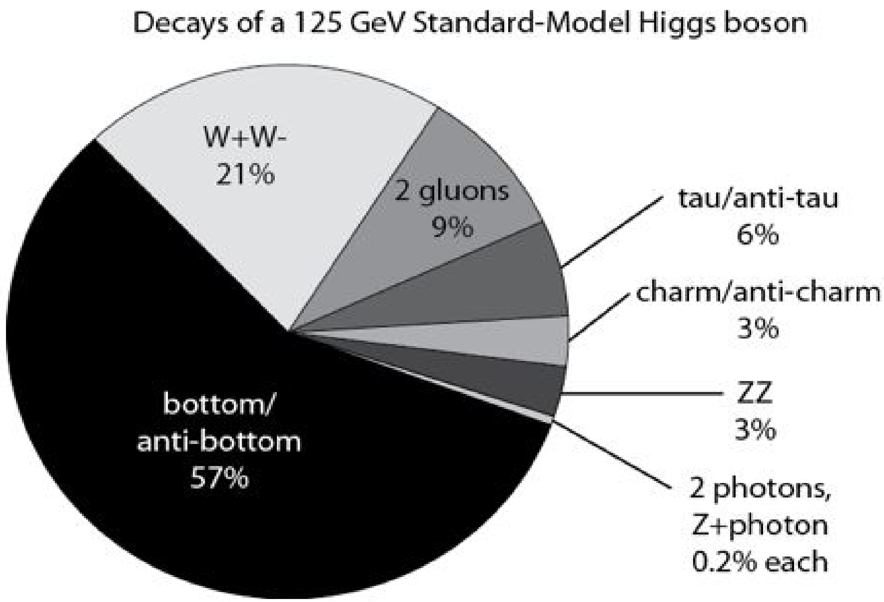
提纲

- 物理引言
- RunI 物理分析及结果
- 讨论

物理引言

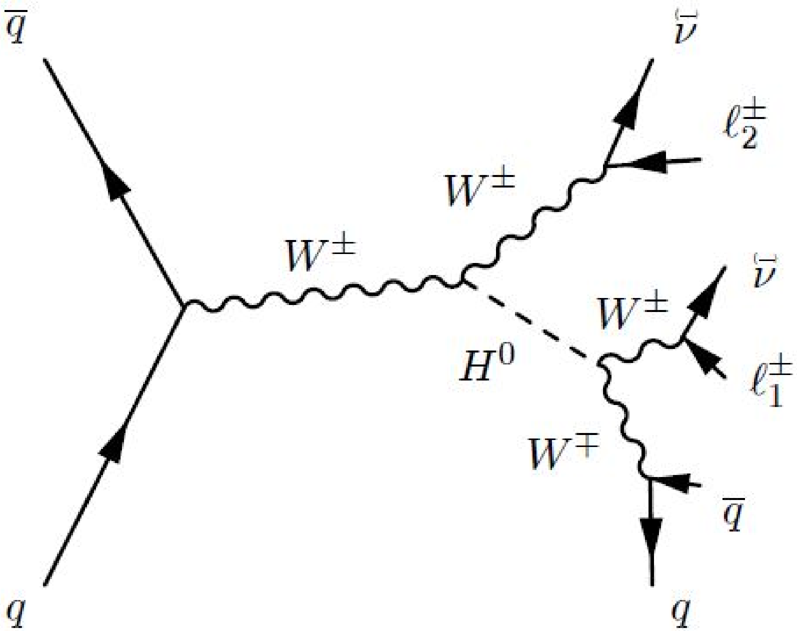
- 125GeV Higgs discovered at LHC
  - VH is one of the four mechanism
    - Decay to WW* is a big fraction

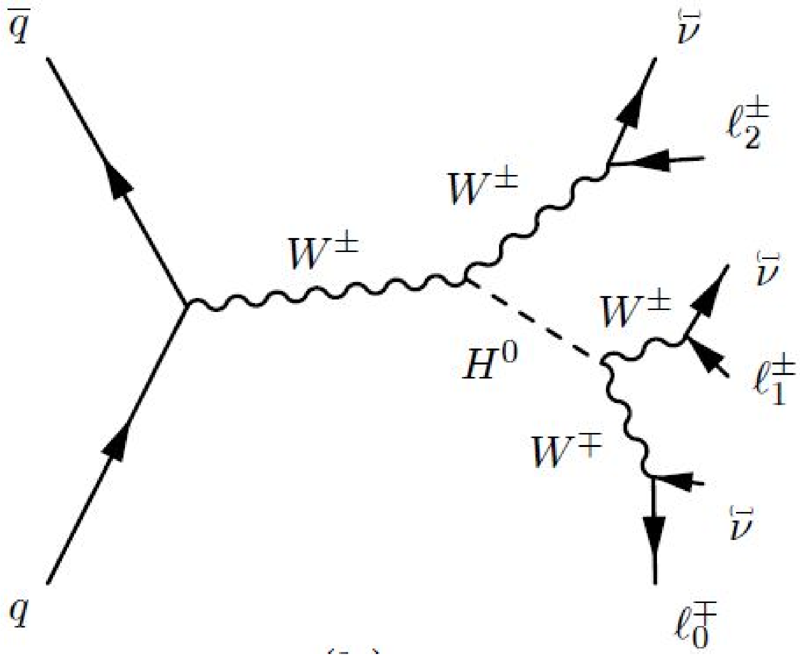




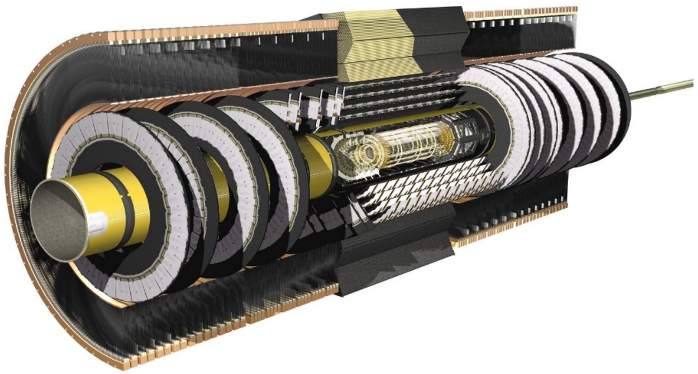
$WH \rightarrow WWW^{*}$

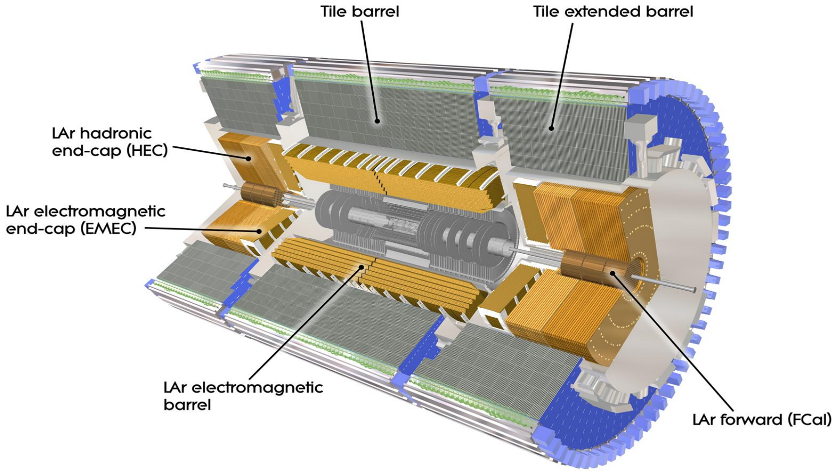
- Only HWW coupling enter the entire progress
  - $\mu_{WH} = {\sigma_{pp\rightarrow WH} * Br(H\rightarrow WW^{*})}\Big/{\sigma^{SM}_{pp\rightarrow WH} * Br^{SM}(H\rightarrow WW^{*})} = {\kappa_W^2 * \kappa_W^2}\Big/{\kappa_H^2}$

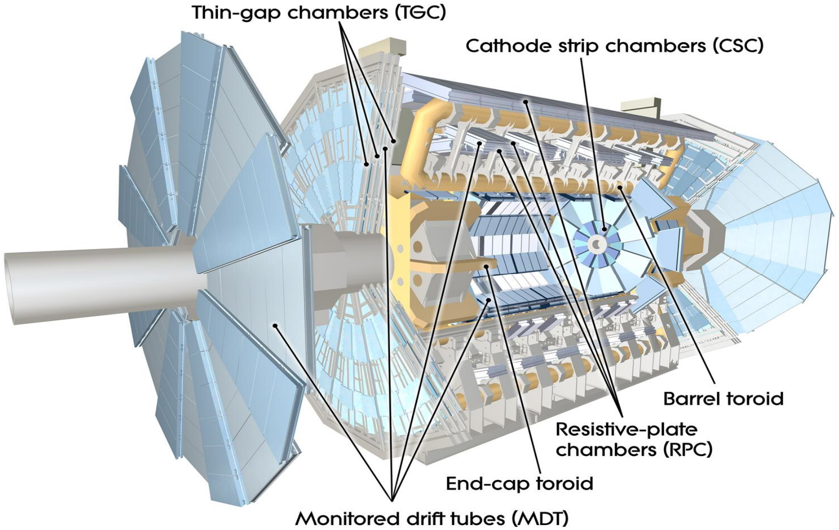


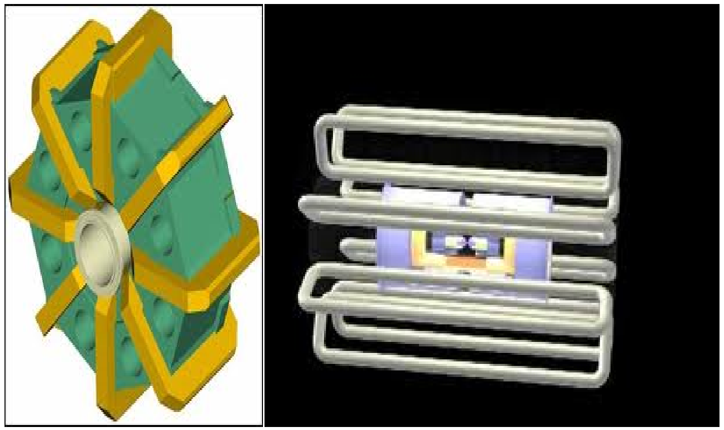


The Atlas




Tile barrel
Tile extended barrel
LAr hadronic end-cap (HEC)
LAr electromagnetic end-cap (EMEC)
LAr electromagnetic barrel
LAr forward (FCal)


Thin-gap chambers (TGC)
Cathode strip chambers (CSC)
Barrel toroid
Resistive-plate chambers (RPC)
End-cap toroid
Monitored drift tubes (MDT)



Run I analysis

- 4.5/fb at 7TeV + 20.3/fb 8TeV since 2012 to 2013
  - JHEP 08 2015 (137)
- Data samples
- Objects reconstruction & selection
- Events selection
- Background modelling
- Systematics
- Results

Data samples

Process	Generator	$\sigma(\times\mathrm{Br})$ [pb]	Cross-section normalisation	
Higgs boson				
VH $(H\to WW^*)$	PYTHIA [25, 26] v8.165, v6.428	0.24, 0.20	NNLO QCD + NLO EW	
VH $(H\to\tau\tau)$	PYTHIA v8.165, v6.428	0.07, 0.06	NNLO QCD + NLO EW	
$gg\to H$ $(H\to WW^*)$	POWHEG-BOX [27–30] v1.0 (r1655)+ PYTHIA v8.165, v6.428	4.1, 3.3	NNLO+NNLL QCD + NLO EW	
VBF $(H\to WW^*)$	POWHEG-BOX [31] v1.0 (r1655)+ PYTHIA v8.165, v6.428	0.34, 0.26	NNLO QCD + NLO EW	5
$t\bar{t}H$ $(H\to WW^*)$	PYTHIA v8.165	0.028, 0.019	NLO	
Single boson				
$Z/\gamma^*(\to\ell\ell)$+jets $(m_{\ell\ell}>10$ GeV)	ALPGEN [32] v2.14 + HERWIG [33] v6.52	16540, 12930	NNLO	
HF $Z/\gamma^*(\to\ell\ell)$+jets $(m_{\ell\ell}>30$ GeV)	ALPGEN v2.14 + HERWIG v6.52	126, 57	NNLO	4
VBF $Z/\gamma^*(\to\ell\ell)$ $(m_{\ell\ell}>7$ GeV)	SHERPA [34] v1.4.1	5.3, 2.8	LO	
Top-quark				
$t\bar{t}$	POWHEG-BOX [35] v1.0 (r2129)+PYTHIA v6.428	250, 180	NNLO+NNLL	
	MC@NLO [36] v4.03			2
$t\bar{t}W/Z$	MADGRAPH [37] v5.1.5.2, v5.1.3.28 +PYTHIA v6.428	0.35, 0.25	LO	
tqb	ACERMC [38] v3.8 +PYTHIA v6.428	88, 65	NNLL	
tb, tW	POWHEG-BOX [39, 40] v1.0 (r2092)+ PYTHIA v6.428	28, 20	NNLL	
tZ	MADGRAPH v5.1.5.2, v5.1.5.11 +PYTHIA v6.428	0.035, 0.025	LO	
Dibosons				
$WZ/W\gamma^*(\to\ell\ell\nu)(m_{\ell\ell}>7$ GeV)	POWHEG-BOX [41] v1.0 (r1508)+PYTHIA v8.165, v6.428	12.7, 10.7	NLO	
$WZ/W\gamma^*(\to\ell\ell\nu)$(min. $m_{\ell\ell}<7$ GeV)	SHERPA v1.4.1	12.2, 10.5	NLO	
other WZ	POWHEG-BOX [41] v1.0 (r1508) + PYTHIA v8.165	21.2, 17.2	NLO	
$q\bar{q}/gg\to Z^{(*)}Z^{(*)}(\to\ell\ell\ell\ell,\ell\ell\nu\nu)$ $(m_{\ell\ell}>4$ GeV)	POWHEG-BOX [41] v1.0 (r1556) +PYTHIA v8.165, v6.428	1.24, 0.79	NLO	
$q\bar{q}/gg\to Z^{(*)}Z^{(*)}(\to\ell\ell\ell\ell,\ell\ell\nu\nu)$ (min. $m_{\ell\ell}<4$ GeV)	SHERPA v1.4.1	7.3, 5.9	NLO	
other $q\bar{q}/gg\to ZZ$	POWHEG-BOX [41] v1.0 (r1556) + PYTHIA v8.165	6.9, 5.7	NLO	
$gg\to Z^{(*)}Z^{(*)}$	gg2ZZ [42] v3.1.2 + HERWIG v6.52 (8 TeV only)	0.59	LO	1
$q\bar{q}/gg\to WW$	POWHEG-BOX [41] v1.0 (r1556) + PYTHIA v6.428	54, 45	NLO	
	SHERPA v1.4.1 (for 2ℓ-DFOS 8 TeV only)	54	NLO	
$gg\to WW$	gg2WW [43] v3.1.2 + HERWIG v6.52	1.9, 1.1	LO	
VBS WZ, $ZZ(\to\ell\ell\ell\ell,\ell\ell\nu\nu)$ $(m_{\ell\ell}>7$ GeV), WW	SHERPA v1.4.1	1.2, 0.88	LO	
$W\gamma$ $(p_T^{\gamma}>8$ GeV)	ALPGEN v2.14 +HERWIG v6.52	1140, 970	NLO	
$Z\gamma$ $(p_T^{\gamma}>8$ GeV)	SHERPA v1.4.3	960, 810	NLO	
Tribosons				
$WWW^*, ZWW^*, ZZZ^*, WW\gamma^*$	MADGRAPH v5.1.3.33, v5.1.5.10 + PYTHIA v6.428	0.44, 0.18	NLO	3

Objects reconstruction & selection

- PriVtx with maximal pt2 from tracks >= 0.4GeV
- Medium muons pT>15GeV (combined from MS to ID)
- Electrons pT>15GeV upon likelihood identification
  - 3L : very tight low pt & loose if pt > 20 GeV
  - 2L : very tight low pt & medium if pt > 25 GeV
- dR = 0.2 isolation in both traker and Calo for muon & electrons
- AntiKt4 jet from topological cluster
  - 25GeV pt cut within |eta|=2.4, JVF cut against Pileup
- Leptons overlap (dR~0.1) and lepton-jet overlap (dR~0.3) are removed
- Calo-based MET is compensated with possible track pt

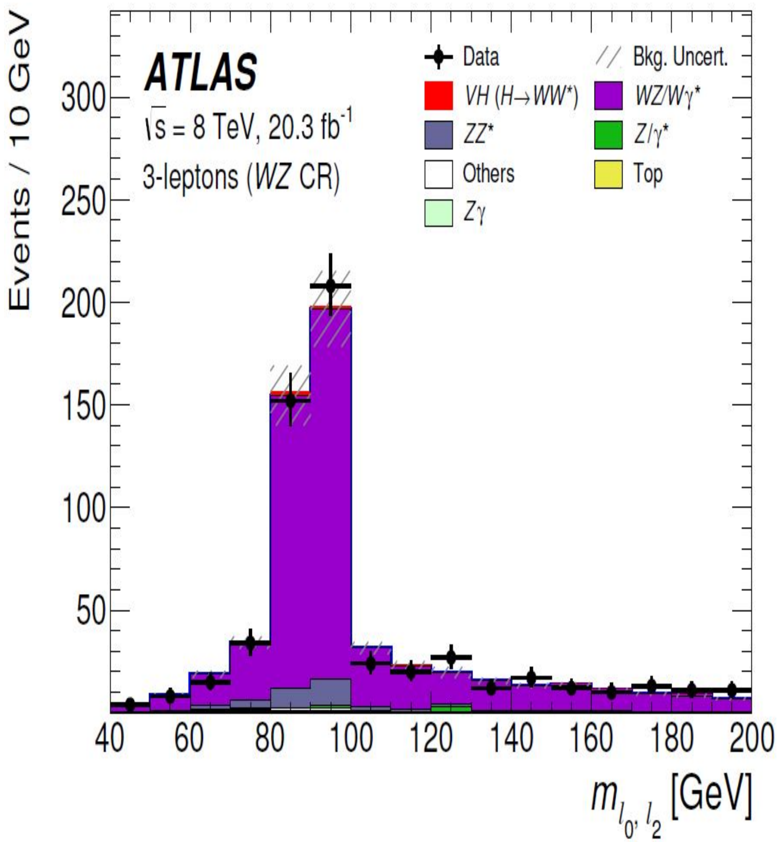
Events selection

Channel	3ℓ			2ℓ	
Category	3SF	1SFOS	0SFOS	SS2jet	SS1jet
Trigger	single-lepton triggers			lepton & dilepton triggers	
Num. of leptons	3	3	3	2	2
$p_{\mathrm{T,leptons}}$ [GeV]	> 15	> 15	> 15	$> 22, 15$	$> 22, 15$
Total lepton charge	± 1	± 1	± 1	± 2	± 2
Num. of SFOS pairs	2	1	0	0	0
Num. of jets	≤ 1	≤ 1	≤ 1	2	1
$p_{\mathrm{T\,jets}}$ [GeV]	> 25 (30)	> 25 (30)	> 25 (30)	> 25 (30)	> 25 (30)
Num. of b-tagged jets	0	0	0	0	0
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 30	> 30	—	> 50	> 45
$p_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 20	> 20	—	—	—
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	> 25	> 25	—	> 15	> 15
Min. $m_{\ell\ell}$ [GeV]	> 12	> 12	> 6	> 12 $(ee, \mu\mu)$ > 10 $(e\mu)$	> 12 $(ee, \mu\mu)$ > 10 $(e\mu)$
Max. $m_{\ell\ell}$ [GeV]	< 200	< 200	< 200	—	—
$m_{4\ell}$ [GeV]	—	—	—	—	—
$p_{\mathrm{T},4\ell}$ [GeV]	—	—	—	—	—
$m_{\tau\tau}$ [GeV]	—	—	—	—	—
$\Delta R_{\ell_0\ell_1}$	< 2.0	< 2.0	—	—	—
$\Delta\phi_{\ell_0\ell_1}$ [rad]	—	—	—	—	—
m_{T} [GeV]	—	—	—	—	> 105 $(m_{\mathrm{T}}^{\mathrm{lead}})$
Min. $m_{\ell_i j(j)}$ [GeV]	—	—	—	< 115	< 70
Min. $\phi_{\ell_i j}$ [rad]	—	—	—	< 1.5	< 1.5
Δy_{jj}	—	—	—	—	—
$\lvert m_{jj} - 85 \rvert$ [GeV]	—	—	—	—	—

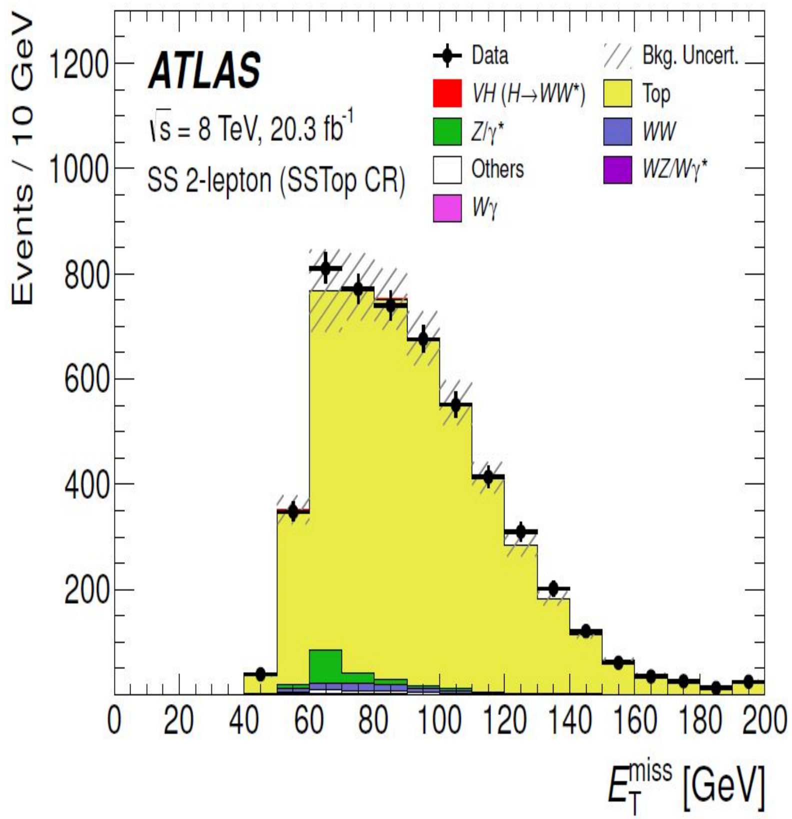
- Split signal regions
  - Signal characteristics
  - Optimization
- Xcheck
  - Divide & govern
- BDT adopted for 3l

$(m_{\ell_0\ell_1}, m_{\ell_0\ell_2})$, $\Delta R_{\ell_0\ell_1}$, $E_{\mathrm{T}}^{\mathrm{miss}}$, and $p_{\mathrm{T}}^{\mathrm{miss}}$

Background modelling



Channel	4ℓ	3ℓ	2ℓ	
Category	2SFOS, 1SFOS	3SF, 1SFOS, 0SFOS	DFOS	SS2jet, SS1jet
Process				
$WZ/W\gamma^*$	—	$1.08^{+0.08}_{-0.06}$	—	0.94 ± 0.10
ZZ^*	$1.03^{+0.11}_{-0.10}$	$1.28^{+0.22}_{-0.20}$	—	—
OS WW	—	—	—	0.80 ± 0.33
$W\gamma$	—	—	—	1.06 ± 0.12
$Z\gamma$	—	$0.62^{+0.15}_{-0.14}$	—	—
Z/γ^*	—	$0.80^{+0.68}_{-0.53}$ (μ-misid)	$0.90^{+0.18}_{-0.16}$	0.86 ± 0.30
		$0.33^{+0.12}_{-0.11}$ (e-misid)		
Top	—	$1.36^{+0.34}_{-0.30}$	$1.05^{+0.16}_{-0.14}$	1.04 ± 0.08



Backgrounds seem well understood, estimated and controlled

Systematics

Uncertainties on the signal strength μ_{VH} (%)

Signal theoretical uncertainties	$\Delta\mu_{VH}/\mu_{VH}$ +	-
VH acceptance	11	7
Higgs boson branching fraction	7	4
QCD scale	1.6	0.7
PDF and α_S	3.2	1.5
VH NLO EW corrections	2.5	1.2
Background theoretical uncertainties		
QCD scale	10	9
PDF and α_S	2.3	2.0
VVV K-factor	3.0	3.0
MC modelling	7.5	6.9

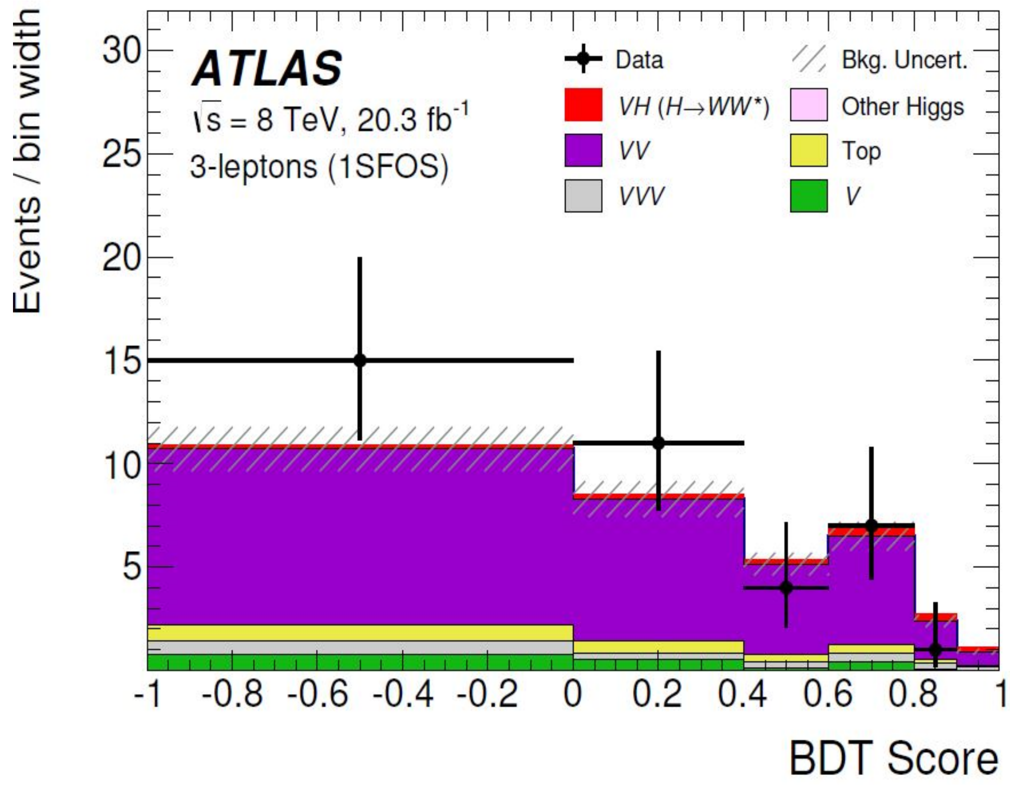
Experimental uncertainties		
Jet	14	9
E_T^{miss} soft term	3.4	2.3
Electron	4.8	2.9
Muon	4.8	3.2
Trigger efficiency	1.7	0.9
b-tagging efficiency	4.7	3.2
Fake factor	14	12
Charge mis-assignment	1.1	1.0
Photon conversion rate	0.8	0.7
Pile-up	3.0	1.9
Luminosity	5.4	3.3
MC statistics	8	8
CR statistics	18	15
ggF SR statistics	5.5	4.4
VBF SR statistics	1.9	1.5
ggF+VBF CR statistics	10	9

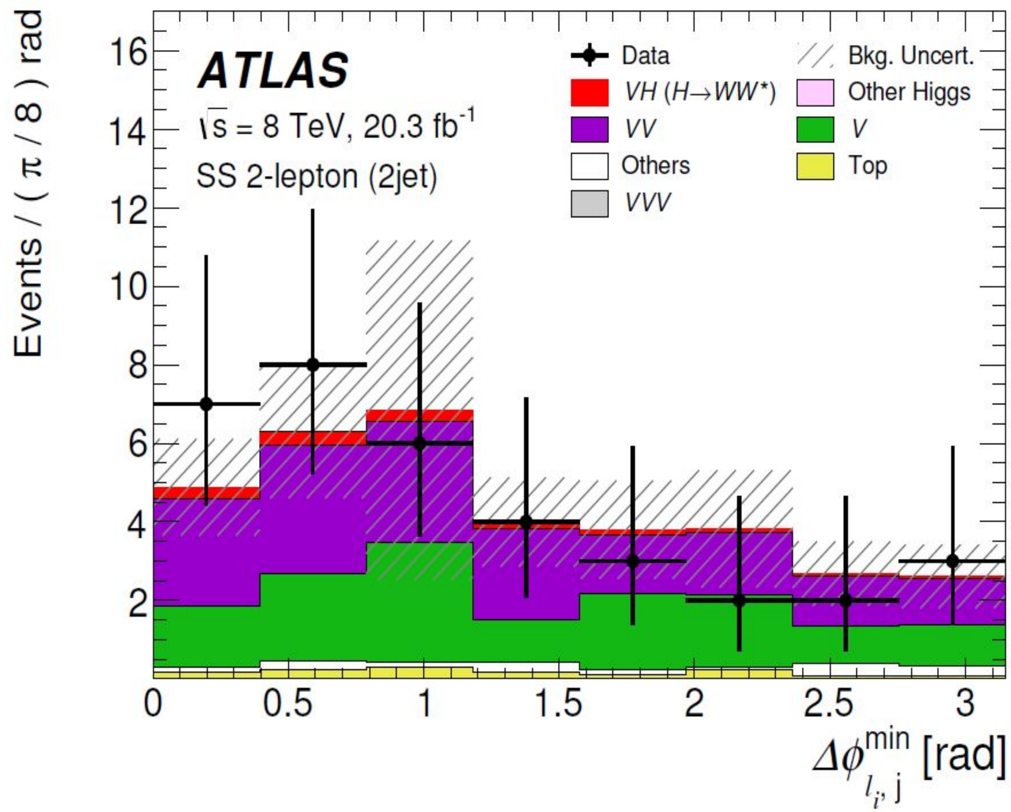
The variation in signal strength is proportional to that of event yields => relative rank

Results -- Event yields

Process	3ℓ			2ℓ	
Category	3SF	1SFOS	0SFOS	SS2jet	SS1jet
Higgs boson					
VH $(H \to WW^*)$	0.73±0.10	1.61±0.18	1.43±0.16	1.04±0.18	2.04±0.30
VH $(H \to \tau\tau)$	0.057±0.011	0.152±0.023	0.248±0.035	0.036±0.008	0.27±0.04
ggF	0.076±0.015	0.085±0.018	—	—	—
VBF	—	—	—	—	—
ttH	—	—	—	—	—
Background					
V	0.22±0.16	1.9±0.6	0.37±0.15	8±4	15±5
VV	19±3	28±4	4.7±0.6	11.2±2.1	26±4
VVV	0.8±0.3	2.2±0.7	2.93±0.29	—	0.47±0.05
Top	0.91±0.26	2.4±0.6	3.7±0.9	0.75±0.19	1.3±0.5
Others	—	—	—	0.71±0.30	0.60±0.24
Total	22±4	34±6	11.7±1.8	21±5	44±6
Observed events	22	38	14	25	62

Result -- distributions



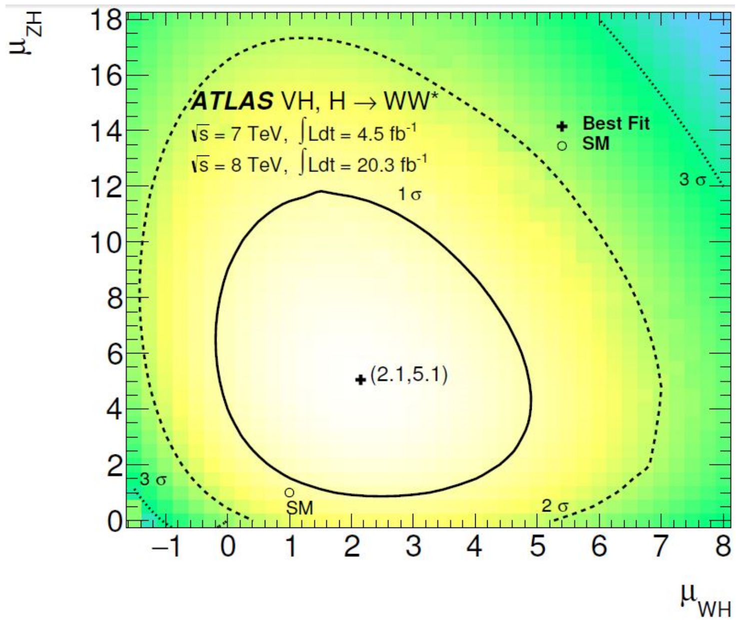


MC simulation and Bckg-estimation agree well to data !

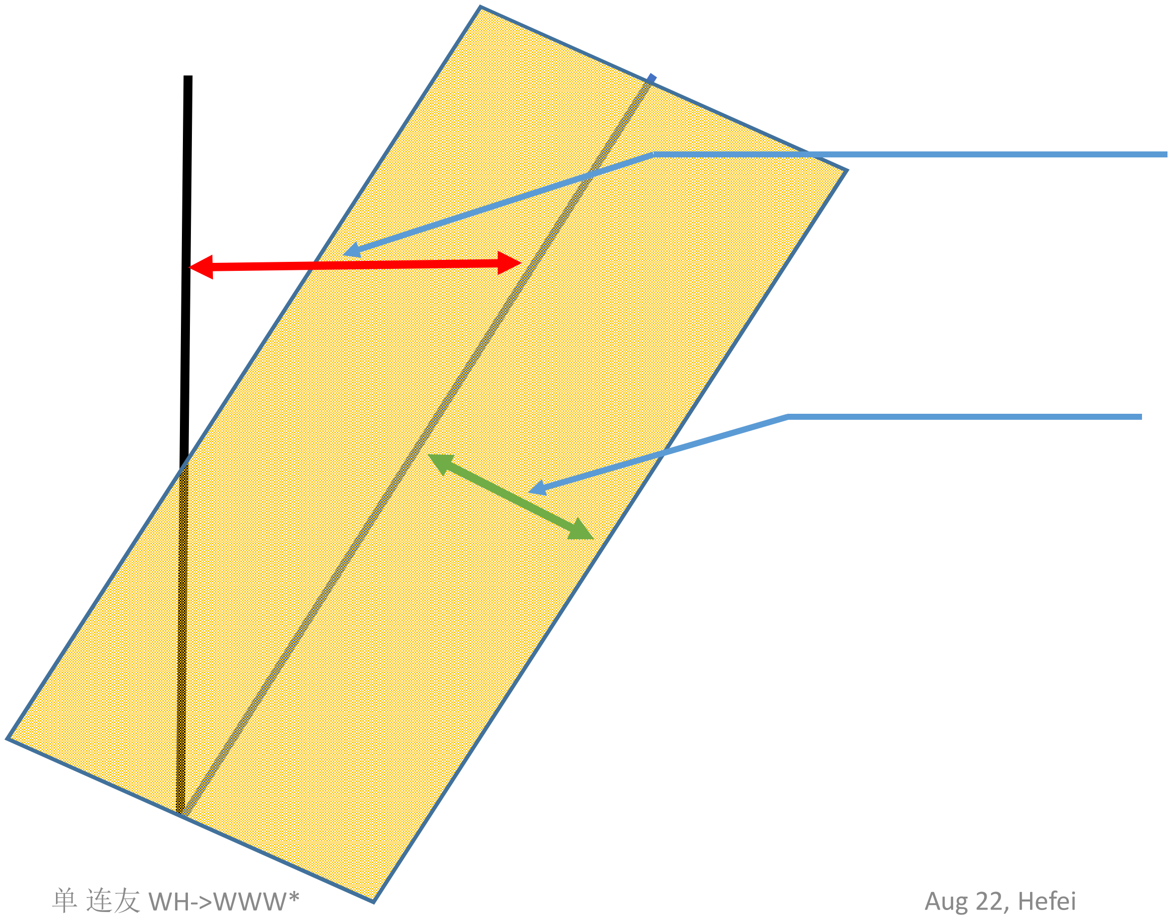
Results – significance & strength

- Likelihood fit : $$q_{\mu} = -2\ln\frac{\mathcal{L}(\mu,\hat{\boldsymbol{\theta}}_{\mu})}{\mathcal{L}_{\max}}$$
- Signal strength $$\mu_{WH} = 2.1^{+1.5}_{-1.3}\,(\mathrm{stat.})^{+1.2}_{-0.8}\,(\mathrm{sys.})$$
- Significance $Z_0 = 2.1(0.66)$ with $m_H = 125.36$ GeV
- Also with ggF and VBF combined
  - As backgrounds
  - strength correlated
  - experimental uncertainties correlated

$$\mathrm{Br}(H\to WW^*) = \frac{\kappa_V^2\Gamma_{\mathrm{SM}}(H\to WW^*)}{\kappa_F^2\Gamma_{\mathrm{SM}}(H\to f\bar{f}) + \kappa_F^2\Gamma_{\mathrm{SM}}(H\to gg) + \kappa_V^2\Gamma_{\mathrm{SM}}(H\to VV)}$$



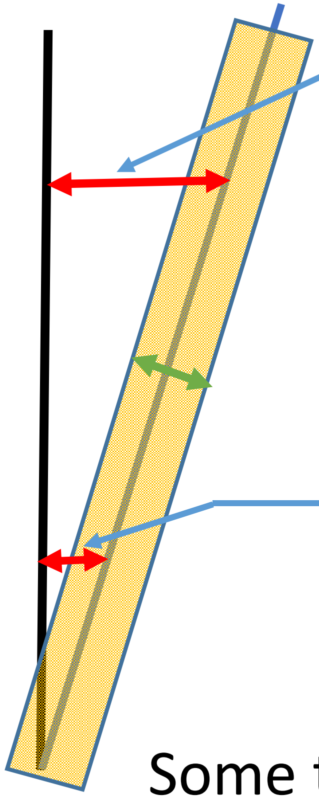
讨论：measurement of Higgs coupling ?



- $\kappa_W - 1 \in [0, 1]$
- Uncertainties
  - Statistical (luminosity)
  - Experimental
  - Theoretical
  - $50\% \sim 20\%$ at LHC

讨论： more precise measurements at CEPC

---but neither NP model ruled out nor unique NP model established ?



- $\kappa_X - 1 \in [\,0,\ \ 0.5\,]$
- Uncertainties
  - Luminosity
  - Detectors/softwares
  - Theoretical
  - 5% at CEPC ?

- If sufficiently big deviation observed
  - Which model is demanded ?
    - SUSY ? Little Higgs ? … ?
  - Uniquely ?

- If sufficiently small deviation confirmed
  - Which model will be ruled out ?
    - SUSY ? Little Higgs ? … ?

Some theoretical explorations or summary are expected as a guide