LHC ATLAS 実験

佐藤構二 宇宙史センター構成員会議 2019年6月3日(月)









円周27km 陽子を最大7 TeVまで加速して正面衝撃

LHCの長期将来計画



Accelerator LS2 Upgrades

 2019-2020: Long Shutdown (LS2) preparing for Run 3 in 2021-2023.

Key Plans for LS2 Accelerator Upgrades

https://home.cern/news/news/accelerators/key-plans-next-two-years-lhc

- Preparation for HL-LHC, as well as Run 3 and maintenance.
- More intense, concentrated beam, with new Linac accelerating Hinstead of proton.
 - Replace Linac 2 with new Linac 4.
 - Upgrade Booster injection.
 - New RF system in SPS.
- Bring beam energy up to 7 TeV.
 - Consolidate the diodes providing current to dipole magnets
- ~20 magnet replacements, install new lifts, ...





ーレリノス位于、保牛理論、ドリノリオーリ、BAフノ、超対称任、新初理保系 オン衝突…

ATLAS LS2 Upgrades



New Muon Small Wheel

For L1 Trigger



FTK Upgrade – new track trigger in L2 trigger. TDAQ Upgrade

Improvement on Jet and MET triggers, too.

Nucl.Instrum.Meth. 825 (2016) 374-378

Luminosities in Run 2



Run 1	$E_{CM}(\mathrm{TeV})$	integ lumi [fb ⁻¹]
2011	7	5
2012	8	21

 $E_{CM} = 13 (TeV)$

Run 2	Peak lumi E34 cm ⁻² s ⁻¹	Days pp physics	Recorded integ lumi [fb ⁻¹]	Good for Physics [fb ⁻¹] 累積
2015	0.5	56	3.9	3.2
2016	1.4	122	36.0	36
2017	1.9	150	46.9	80
2018	2.1	152	65.0	139

Full Run 2 Dilepton Resonance Search



No significant excess, set limit on production cross section of heavy particle.



Full Run 2 Dijet Resonance Search





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Full Run 2 ATLAS-CONF-2019-008 Chargino and Slepton Searches Final states: $2\ell + missing E_T$

- ullet
- Use stransverse mass M_{T2}

m(x⁰) [GeV]



Supersymmetry Searches

ATLAS SUSY Searche

	<u> </u>	J	
s* - 95% CL L	ower Limits		ATLAS Preliminary
			$\sqrt{s} = 13 \text{ TeV}$

A	6	ro	h	20	10
VI	a	10		20	19

	Model	Si	gnatur	e ∫∠	<i>dt</i> [fb ⁻¹]]		Mas	s limit						Reference
S	$ ilde{q} ilde{q}, ilde{q}{ ightarrow} q ilde{\chi}_1^0$	0 e, μ mono-jet	2-6 jets 1-3 jets	E_T^{miss} E_T^{miss}	36.1 36.1	 <i>q</i> [2×, 8× <i>q</i> [1×, 8× 	× Degen.] × Degen.]	I	0.43	0.9 0.71	1.55		$\mathfrak{m}(ilde{\chi}^0_1){<}100{ m GeV}$ $\mathfrak{m}(ilde{q}){-}\mathfrak{m}(ilde{\chi}^0_1){=}5{ m GeV}$		1712.02332 1711.03301
arche	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q \bar{q} \tilde{\chi}_1^0$	0 <i>e</i> , <i>µ</i>	2-6 jets	$E_T^{\rm miss}$	36.1	יסטי אסט				Forbidden	0.95-1.	2.0	m($ ilde{\mathcal{X}}_1^0$)<200 GeV m($ ilde{\mathcal{X}}_1^0$)=900 GeV		1712.02332 1712.02332
/e Se	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}(\ell\ell)\tilde{\chi}^0_1$	3 е, µ ее, µµ	4 jets 2 jets	E_T^{miss}	36.1 36.1	σαι σαι					1.2	1.85	m($ ilde{\mathcal{X}}_1^0 angle < 800 Ge \m(ilde{\mathcal{X}}_1^0 angle = 50 Ge \$		1706.03731 1805.11381
nclusi	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qqWZ\tilde{\chi}_1^0$	0 e,μ 3 e,μ	7-11 jets 4 jets	E_T^{miss}	36.1 36.1	ĩg ig				0.98		1.8	m(${ ilde \chi}^0_1)$ <400 Ge\ m(${ ilde g}$)=200 Ge\		1708.02794 1706.03731
4	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t t \tilde{\chi}_1^0$	0-1 e,μ 3 e,μ	3 <i>b</i> 4 jets	E_T^{miss}	79.8 36.1	100 100					1.25	2.25	$m(\tilde{\chi}_{1}^{0}) < 200 \text{ GeV}$ $m(\tilde{g})-m(\tilde{\chi}_{1}^{0}) = 300 \text{ GeV}$	TA	LAS-CONF-2018-041 1706.03731
	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_1^0 / i \tilde{\chi}_1^{\pm}$		Multiple Multiple Multiple		36.1 36.1 36.1	$egin{array}{c} & & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & & \ & & \ & & & \ & \ & \ & \ $	Fo	orbidden	Forbidden Forbidden	0.9 0.58-0.82 0.7		$m(\tilde{\chi}^0_1)=20$	$m(\tilde{\chi}_{1}^{0})=300 \text{ GeV}, BR(b\tilde{\chi}_{1}^{0})=1$)=300 GeV, BR(b\tilde{\chi}_{1}^{0})=BR(b\tilde{\chi}_{1}^{0})=0.5 0 GeV, $m(\tilde{\chi}_{1}^{\pm})=300 \text{ GeV}, BR(t\tilde{\chi}_{1}^{\pm})=1$	17	08.09266, 1711.03301 1708.09266 1706.03731
uarks	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_2^0 \rightarrow b h \tilde{\chi}_1^0$	0 <i>e</i> , <i>µ</i>	6 <i>b</i>	$E_T^{\rm miss}$	139	${ar b_1\ ar b_1}$	Forbidden		0.23-0.48	C	.23-1.35	Δn	$h(\tilde{\chi}_{2}^{0}, \tilde{\chi}_{1}^{0}) = 130 \text{ GeV}, m(\tilde{\chi}_{1}^{0}) = 100 \text{ GeV}$ $\Delta m(\tilde{\chi}_{2}^{0}, \tilde{\chi}_{1}^{0}) = 130 \text{ GeV}, m(\tilde{\chi}_{1}^{0}) = 0 \text{ GeV}$		SUSY-2018-31 SUSY-2018-31
en. squ t produ	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow W b \tilde{\chi}_1^0 \text{ or } t \tilde{\chi}_1^0$ $\tilde{t}_1 \tilde{t}_1$, Well-Tempered LSP	0-2 e,µ 0)-2 jets/1-2 Multiple	$b E_T^{miss}$	36.1 36.1	$\tilde{\iota}_1$ $\tilde{\iota}_1$				1.0 0.48-0.84		$m(\tilde{\chi}_1^0)=15$	$m(\tilde{\chi}_1^0)=1 \text{ GeV}$ io GeV, $m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0)=5 \text{ GeV}$, $\tilde{t}_1 \approx \tilde{t}_2$	1506.086 17	16, 1709.04183, 1711.11520 09.04183, 1711.11520
^d g	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{\tau}_1 bv, \tilde{\tau}_1 \rightarrow \tau \tilde{G}$	$1 \tau + 1 e, \mu, \tau$	2 jets/1 b	E_T^{miss}	36.1	\tilde{t}_1					1.16		m(Ť₁)=800 Ge\		1803.10178
бő	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c \tilde{\chi}_1^0 / \tilde{c} \tilde{c}, \tilde{c} \rightarrow c \tilde{\chi}_1^0$	0 <i>e</i> , µ	2 c	$E_T^{\rm miss}$	36.1	č ř.			0.46	0.85			$m(\tilde{\chi}_{1}^{0})=0 \text{ GeV}$ $m(\tilde{\iota}, \tilde{\iota})-m(\tilde{\nu}_{2}^{0})=50 \text{ GeV}$		1805.01649 1805.01649
		0 <i>e</i> , <i>µ</i>	mono-jet	$E_T^{\rm miss}$	36.1	\tilde{t}_1			0.43				$m(\tilde{t}_1,\tilde{c})-m(\tilde{t}_1^0)=5$ GeV		1711.03301
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + h$	1-2 e, µ	4 <i>b</i>	$E_T^{\rm miss}$	36.1	\tilde{t}_2				0.32-0.88		m	$(\tilde{\chi}_{1}^{0})=0$ GeV, m $(\tilde{\iota}_{1})-m(\tilde{\chi}_{1}^{0})=180$ GeV		1706.03986
	${ ilde \chi}_1^\pm { ilde \chi}_2^0$ via WZ	2-3 e, μ ee, μμ	≥ 1	E_T^{miss} E_T^{miss}	36.1 36.1	$\begin{array}{c} \tilde{\chi}_1^\pm/\tilde{\chi}_2^0\\ \tilde{\chi}_1^\pm/\tilde{\chi}_2^0 \end{array}$	0.17			0.6			$m(\tilde{\chi}_{\perp}^{0})=0$ $m(\tilde{\chi}_{\perp}^{\pm})-m(\tilde{\chi}_{\perp}^{0})=10$ GeV	14	03.5294, 1806.02293 1712.08119
-	$\tilde{\chi}_{1}^{\pm}\tilde{\chi}_{1}^{\mp}$ via WW	2 <i>e</i> , <i>µ</i>		E_T^{miss}	139	$\tilde{\chi}_{1}^{\pm}$			0.42				$m(\tilde{\chi}_1^0)=0$	TA	LAS-CONF-2019-008
	$\tilde{\chi}_{1}^{\pm}\tilde{\chi}_{2}^{0}$ via Wh	0-1 e,μ	2 b	E_T^{miss}	36.1	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$				0.68			$m(\tilde{\chi}_1^0)=0$		1812.09432
sc <	$\tilde{\chi}_1^{+} \tilde{\chi}_1^{+}$ via $\tilde{\ell}_L / \tilde{v}$	2 <i>e</i> , µ		E_T^{miss}	139	$\tilde{\chi}_1^{\pm}$				1.0			$m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\chi}_{1}^{\pm})+m(\tilde{\chi}_{1}^{0}))$	AT	LAS-CONF-2019-008
EV dire	$\tilde{\chi}_{1}^{\pm}\tilde{\chi}_{1}^{+}/\tilde{\chi}_{2}^{0}, \tilde{\chi}_{1}^{+} \rightarrow \tilde{\tau}_{1}\nu(\tau\tilde{\nu}), \tilde{\chi}_{2}^{0} \rightarrow \tilde{\tau}_{1}\tau(\nu\tilde{\nu})$	2 τ		E_T^{miss}	36.1	$\begin{array}{c} \tilde{\chi}_1^{\pm} / \tilde{\chi}_2^0 \\ \tilde{\chi}_1^{\pm} / \tilde{\chi}_2^0 \end{array}$	0.22			0.76		$m\langle \tilde{\chi}_1^{\pm} \rangle - m\langle \tilde{\chi}_1^0 \rangle = 0$	$m(\tilde{\chi}_{1}^{0})=0, m(\tilde{\tau}, \tilde{\nu})=0.5(m(\tilde{\chi}_{1}^{\pm})+m(\tilde{\chi}_{1}^{0}))$ 100 GeV, $m(\tilde{\tau}, \tilde{\nu})=0.5(m(\tilde{\chi}_{1}^{\pm})+m(\tilde{\chi}_{1}^{0}))$		1708.07875 1708.07875
-	$\epsilon_{\mathrm{L,R}} \tilde{\ell}_{\mathrm{L,R}}, \tilde{\ell} \to \ell \tilde{\chi}_1^0$	2 e,μ 2 e,μ	0 jets ≥ 1	E_T^{miss} E_T^{miss}	139 36.1	Ĩ Ĩ	0.18			0.7			$m(\tilde{\ell})=0$ $m(\tilde{\ell})-m(\tilde{\chi}_{1}^{0})=5$ GeV	TA	LAS-CONF-2019-008 1712.08119
	ĤĤ, Ĥ→hĜ/ZĜ	0 e,μ 4 e,μ	$\geq 3 b$ 0 jets	E_T^{miss} E_T^{miss}	36.1 36.1	Ĥ Ĥ	0.13-0.23	0.3		0.29-0.88			$BR(\tilde{\chi}^0_1 \to h\tilde{G})=1$ $BR(\tilde{\chi}^0_1 \to Z\tilde{G})=1$		1806.04030 1804.03602
-lived cles	$\operatorname{Direct} \tilde{\chi}_1^+ \tilde{\chi}_1^- \text{ prod., long-lived } \tilde{\chi}_1^\pm$	Disapp. trk	1 jet	$E_T^{\rm miss}$	36.1		5		0.46				Pure Wind Pure Higgsind	ATI	1712.02118 PHYS-PUB-2017-019
arti	Stable g R-hadron		Multiple		36.1	ĝ						2.0		19	02.01636,1808.04095
Lo P	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow qq \tilde{\chi}_1^0$		Multiple		36.1	$\tilde{g} = [\tau(\tilde{g}) =$	=10 ns, 0.2 ns]					2.05 2.4	m(𝑋 μ)=100 GeV	17	10.04901,1808.04095
	LFV $pp \rightarrow \tilde{v}_{\tau} + X, \tilde{v}_{\tau} \rightarrow e\mu/e\tau/\mu\tau$	εμ,ετ,μτ			3.2	$\tilde{\nu}_{\tau}$						1.9	$\lambda'_{311}=0.11, \lambda_{132/133/233}=0.07$		1607.08079
	$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp} / \tilde{\chi}_2^0 \rightarrow WW/Z\ell\ell\ell\ell\nu\nu$	4 e, µ	0 jets	E_T^{miss}	36.1	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0 = [\lambda$	$l_{i33} \neq 0, \lambda_{12k} \neq 0$)]		0.82	1.33		m(𝑋10)=100 GeV		1804.03602
>	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qq \tilde{\chi}^0_1, \tilde{\chi}^0_1 \rightarrow qqq$	4-	5 large- <i>R</i> je Multiple	ts	36.1 36.1	$\tilde{g} = [m(\tilde{\chi}_1^0)]$ $\tilde{g} = [\chi_{112}''] = 2$	=200 GeV, 1100 2e-4, 2e-5]	GeV]		1.0	1.3 5	1.9 2.0	Large $\lambda_{112}^{\prime\prime}$ m($\tilde{\chi}_{1}^{0}$)=200 GeV, bino-like	TA	1804.03568 LAS-CONF-2018-003
ВF	$\tilde{t}\tilde{t}, \tilde{t} \rightarrow t \tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow t b s$		Multiple		36.1	$\tilde{g} = [\lambda''_{323} = 2$	2e-4, 1e-2]		0.	55 1.0	5		$m(\tilde{\chi}_1^0)$ =200 GeV, bino-like	TA	LAS-CONF-2018-003
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow bs$		2 jets + 2 b		36.7	$\tilde{t}_1 = [qq, bs]$	r]		0.42	0.61					1710.07171
	$t_1 t_1, t_1 \rightarrow q\ell$	2 e,μ 1 μ	2 <i>b</i> DV		36.1 136	$\tilde{t}_1 = \tilde{t}_1 = [1e-10]$)< <i>λ′</i> <1e-8, 3 _{23k} <1e-8, 3	$10 < \lambda'_{23k}$	<3e-9]	1.0	0.4-1.45 1.	6	$BR(\tilde{i}_1 \rightarrow be/b\mu) > 20\%$ $BR(\tilde{i}_1 \rightarrow q\mu) = 100\%, \cos\theta_i = 10\%$	TA	1710.05544 LAS-CONF-2019-006 1 1
															<u> </u>
						 1	I	I			1				

標準理論の大成功

Stand	dard Model Tota	al Production Cross	s Seci	tion Meas	uremen ∖····-	ts March 2019	∫£ dt [fb ⁻¹]	Reference
рр	$\sigma = 96.07 \pm 0.18 \pm 0.91$ mb (data) COMPETE HPR1R2 (theory)				Ă '	4	50×10 ⁻⁸	PLB 761 (2016) 158
•	COMPETE HPR1R2 (theory) $c = 190.1 \pm 0.2 \pm 6.4 \text{ pb} (data)$	AILAS Preliminary	y	<u>+</u>	0	9	8×10 ⁻⁸	Nucl. Phys. B, 486-548 (20
N	$\sigma = 98.71 \pm 0.028 \pm 2.191 \text{ nb} (data)$, P		E I	0.081	PLB 759 (2016) 601
	$DYNNLO + CT14NNLO (theory)$ $\sigma = 58.43 \pm 0.03 \pm 1.66 \text{ pb} (data)$	Run 1,2 $\sqrt{s} = 7,8,13$	3 TeV	Ŷ		2	4.6	EPJC 77 (2017) 367
7	DYNNLO+CT14 NNLO (theory) $\sigma = 34.24 \pm 0.03 \pm 0.92$ nb (data)			Ļ			3.2	JHEP 02 (2017) 117
Z	DYNNLO+CT14 NNLO [*] (theory) $\sigma = 29.53 \pm 0.03 \pm 0.77$ nb (data)					Ê	20.2	JHEP 02 (2017) 117
	DYNNLO+CT14 NNLO (theory) $\sigma = 818 \pm 8 \pm 35 \text{ pb} \text{ (data)}$	4	Ŷ			P	4.6	JHEP 02 (2017) 117
Ŧ	top++ NNLO+NLL (theory) $\sigma = 242.9 \pm 1.7 \pm 8.6 \text{ pb} \text{ (data)}$, ^Ļ				X I	3.2	FEB / 61 (2016) 136
L	$\sigma = 182.9 \pm 3.1 \pm 6.4 \text{ pb} (\text{data})$	d [†]				1	20.2	EPIC 74: 3109 (2014)
	$\sigma = 247 \pm 6 \pm 46 \text{ pb (data)}$	Y					4.0	IHEP 04 (2017) 086
	NLO+NLL (theory) $\sigma = 89.6 \pm 1.7 + 7.2 - 6.4 \text{ pb} (data)$, P					20.3	EPJC 77 (2017) 531
t–cnan	$\sigma = 68 \pm 2 \pm 8 \text{ pb} \text{ (data)}$	<u>م</u>				L	4.6	PBD 90, 112006 (2014)
	$\sigma = 142 \pm 5 \pm 13 \text{ pb (data)}$	Y					3.2	PLB 773 (2017) 354
۸/۱۸/	NNLO (theory) $\sigma = 68.2 \pm 1.2 \pm 4.6$ pb (data)	× ۲					20.3	PLB 763, 114 (2016)
	$\sigma = 51.9 \pm 2 \pm 4.4 \text{ pb} (\text{data})$	<u>لم</u>				5	4.6	PRD 87, 112001 (2013)
	$\sigma = 57 + 6 - 5.9 + 4 - 3.3 \text{ pb} (\text{data})$	ň				ň	36.1	ATLAS-CONF-2017-047
-	$\sigma = 27.7 \pm 3 + 2.3 - 1.9 \text{ pb (data)}$	<u>ه</u> -					20.3	EPJC 76, 6 (2016)
•	$\sigma = 22.1 + 6.7 - 5.3 + 3.3 - 2.7 \text{ pb} (data)$	6					4.5	EPJC 76, 6 (2016)
	$\sigma = 94 \pm 10 + 28 - 23 \text{ pb} \text{ (data)}$	E	_	Theory			3.2	JHEP 01 (2018) 63
Vt	$\sigma = 23 \pm 1.3 + 3.4 - 3.7 \text{ pb (data)}$	▲		,, ,			20.3	JHEP 01, 064 (2016)
•••	$\sigma = 16.8 \pm 2.9 \pm 3.9 \text{ pb (data)}$	D	1.14	$rac{1}{2}$ nn $\sqrt{r} = 7 TeV$,		2.0	PLB 716, 142-159 (2012)
	$\sigma = 51 \pm 0.8 \pm 2.3 \text{ pb} \text{ (data)}$ MATRIX (NNLO) (theory)			$-$ pp $v_s = r rev$		6	36.1	arXiv: 1902.05759 [hep-ex]
NZ	$\sigma = 24.3 \pm 0.6 \pm 0.9 \text{ pb (data)}$	Å	0	Data		4	20.3	PRD 93, 092004 (2016) PLB 761 (2016) 179
	$\sigma = 19 + 1.4 - 1.3 \pm 1 \text{ pb (data)}$ MATRIX (NNLO) (theory)	Ó		SIAI		d	4.6	EPJC 72, 2173 (2012) PLB 761 (2016) 179
	$\sigma = 17.3 \pm 0.6 \pm 0.8 \text{ pb (data)}$ Matrix (NNLO) & Sherpa (NLO) (theory)			51ai ⊕ 5y51		Ь	36.1	PRD 97 (2018) 032005
ZZ	$\sigma = 7.3 \pm 0.4 + 0.4 - 0.3 \text{ pb} \text{ (data)}$	~~	LHO	C pp √s = 8 TeV			20.3	JHEP 01, 099 (2017)
	$\sigma = 6.7 \pm 0.7 + 0.5 - 0.4 \text{ pb} \text{ (data)}$	Ó.		Data			4.6	JHEP 03, 128 (2013) PLB 735 (2014) 311
s-chan	$\sigma = 4.8 \pm 0.8 \pm 1.6 - 1.3 \text{ pb}$ (data) NLO+NNL (theory)			stat			20.3	PLB 756, 228-246 (2016)
T) A /	$\sigma = 870 \pm 130 \pm 140 \text{ fb} \text{ (data)}$ Madgraph5 + aMCNLO (theory)			stat ⊕ syst			36.1	arXiv:1901.03584
tvv	$\sigma = 369 + 86 - 79 \pm 44$ fb (data) MCFM (theory)		LHO	Cpp √s = 13 Te	v		20.3	JHEP 11, 172 (2015)
I 7	$\sigma = 950 \pm 80 \pm 100$ fb (data) Madgraph5 + aMCNLO (theory)			Data			36.1	arXiv:1901.03584
ιZ	$\sigma = 176 + 52 - 48 \pm 24 \text{ fb (data)}$ HELAC-NLO (theory)			stat			20.3	JHEP 11, 172 (2015)
Ζj	$\sigma = 620 \pm 170 \pm 160$ fb (data) NLO+NLL (theory)			stat ⊕ syst			36.1	PLB 780 (2018) 557
NWW	σ = 0.68 + 0.16 - 0.15 + 0.16 - 0.15 pb (Sherpa 2.2.2 (theory)	data)					79.8	STDM-2017-22
NWZ	$\sigma = 0.49 \pm 0.14 + 0.14 - 0.13$ pb (data) Sherpa 2.2.2 (theory)						79.8	STDM-2017-22
			ب استنت	<u></u> W	$V^{\mu u}$ Lilii			
	10^{-4} 10^{-3} 10^{-2} 10	$^{-1}$ 1 10 ¹ 10 ² 10 ³	10^{4}	$10^5 10^6$	10 ¹¹ 0.5	1.0 1.5 2.0		
				— Ги		to/theory		
				σ [[buj dal	a/meory		
4					\rightarrow	•		

ヒッグス粒子発見の発表



2012年7月4日 LHC加速器の ATLAS/CMS両実験が発見を報告

2013年 アングラール、ヒッグス がノーベル物理学賞を受賞



全Run 1データでのアップデー

2012年夏の結果



Higgs Peaks - Run 1 vs Run 2



$H \rightarrow \gamma \gamma$ 、生成過程ごとの解析-CONF-2018-028





キネマティックスによって、生成過程ごとのサブ チャンネルを解析する。



Process	Result	Uncert	Uncertainty [fb] SM prediction				
$(y_H <2.5)$	[fb]	Total (Stat.	Exp. Theo.)	[fb]			
ggF	98	+15 -14 (±11	+9 +4 -8 -3	102 +5			
VBF	11.2	+3.4 (+2.6	+1.3 +1.9)	8.0 ± 0.2			
VH	4.9	+2.7 (+2.4	+1.0 +0.6)	4.5 ± 0.2			
Тор	1.5	+0.6 (+0.5	±0.2 +0.2	1.3 ± 0.1			

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(c)

(d)

ヒッグス粒子の性質(標準理論の計算)

• 生成断面積



	$\sigma(14 \text{TeV}) / \sigma(8 \text{TeV})$
gg→H	2.6 (M _X =M _H)
qq→qqH	2.6 (probes high M _X)
qq→VH	2.1 (M _X =M _V +M _H)
gg→ttH	4.7 (phase space+M _X)









Figure 3: Leading-order Feynman diagrams of Higgs boson production via the $q\bar{q}/gg \rightarrow t\bar{t}H$ and $q\bar{q}/gg \rightarrow bbH$ processes.

ヒッグス粒子の性質(標準理論の計算)



さまざまな生成・崩壊モード

 さまざまな測定を行い、標準 理論を検証できる。

重心エネルギー8 TeV⇒13 TeV

- ・ 生成断面積は、2-5倍。
- Run2では、たくさん作って 様々なチャンネルで精密測定
 歩する。





Figure 6: Leading-order Feynman diagrams of Higgs boson decays to a pair of photons.

• 崩壊分岐比 (*m_H*= 125 GeV)

	<u> </u>									
$H \rightarrow b\overline{b}$		$H o au^+ au^-$		$H ightarrow \mu^+ \mu^-$		$H ightarrow c \overline{c}$				
57.7%		6.32%	% 0.0		022%	2.91%				
H ightarrow gg	H	$\rightarrow \gamma \gamma$	$H \rightarrow$	γZγ	$H \to W$	W	$H \rightarrow ZZ$	Γ _H [MeV]		
8.6%	0	.23%	0.1	.5%	21.5%		2.64%	4.07		

<u>Run1での信号の有意度</u>

ATLAS、CMS個別

Channel	References for		Signal stre	ength [μ]	Signal significance $[\sigma]$				
	individual pu	blications	from	from results in this paper (Section 5.2)					
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS			
$H \rightarrow \gamma \gamma$	[51]	[52]	$1.15^{+0.27}_{-0.25}$	$1.12_{-0.23}^{+0.25}$	5.0	5.6			
			$\binom{+0.26}{-0.24}$	$\binom{+0.24}{-0.22}$	(4.6)	(5.1)			
$H \to Z Z \to 4\ell$	[53]	[54]	$1.51^{+0.39}_{-0.34}$	$1.05^{+0.32}_{-0.27}$	6.6	7.0			
			$\binom{+0.33}{-0.27}$	$\binom{+0.31}{-0.26}$	(5.5)	(6.8)			
$H \rightarrow WW$	[55, 56]	[57]	$1.23^{+0.23}_{-0.21}$	$0.91^{+0.24}_{-0.21}$	6.8	4.8			
			$\binom{+0.21}{-0.20}$	$\binom{+0.23}{-0.20}$	(5.6)	(5.6)			
$H \rightarrow \tau \tau$	[58]	[59]	$1.41^{+0.40}_{-0.35}$	$0.89^{+0.31}_{-0.28}$	4.4	3.4			
			$\binom{+0.37}{-0.33}$	$\binom{+0.31}{-0.29}$	(3.3)	(3.7)			
$H \rightarrow bb$	[38]	[39]	$0.62^{+0.37}_{-0.36}$	$0.81^{+0.45}_{-0.42}$	1.7	2.0			
			$\binom{+0.39}{-0.37}$	$\binom{+0.45}{-0.43}$	(2.7)	(2.5)			
$H \rightarrow \mu \mu$	[60]	[61]	-0.7 ± 3.6	0.8 ± 3.5					
			(±3.6)	(±3.5)					
ttH production	[28, 62, 63]	[65]	1.9 ^{+0.8} -0.7	$2.9^{+1.0}_{-0.9}$	2.7	3.6			
			$\binom{+0.72}{-0.66}$	(^{+0.88} (-0.80)	(1.6)	(1.3)			

3σ:"兆候が見えた" 5σ:"発見した"

- メインの生成・崩壊過程の 多くはRun 1で発見がす んだ。
- ttH生成、 $H \rightarrow bb$ はRun2 で検証していく。
- LHC Run 2では、一個一 個の過程の理解を確立し、 精密測定に入っていく。

ATLAS-CONF-2015-044

Production process	Measured significance (σ)	Expected significance (σ)
VBF	5.4_	4.7
WH	2.4	2.7
ZH	2.3	2.9
VH	3.5	4.2
ttH	4.4	2.0
Decay channel		
$H \rightarrow \tau \tau$	5.5	5.0
$H \rightarrow bb$	2.6	3.7

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Observation of ttH production

- Top quarkの湯川カップリングを直接測定
- · Combination of analyses with decays:
 - $-H \rightarrow \gamma \gamma$ (79.8 fb⁻¹)
 - $-H \rightarrow WW/ZZ \rightarrow leptons$ (36.1 fb⁻¹)
 - $-H \rightarrow \overline{b}b$ (36.1 fb⁻¹) \leftarrow 本多D論(2018)

Candidate eventのS/B分布 測定された信号強度



g 0000000 t

Phys. Lett. B 786 (2018) 59

Observation of $H \rightarrow b\overline{b}$

bottom quarkの湯川カップリング

log (S/B)

- Combination of processes:
 - $-ZH \rightarrow (\nu\nu)(bb)$
 - $WH \to (\ell \nu)(bb)$
 - $\, ZH \to (\ell\ell)(bb)$





5.3 σ Observation (expected sensitivity: 4.8 σ) ²³

Search for $H \rightarrow \mu\mu$

- 第3世代(*t*, *b*, *t*)との湯川カップリングは確認できた。
- 第2世代粒子との湯川カップリングの発見を目指す
 - VBFに特化した信号領域を定義して解析感度を向上



Combined Higgs Boson Couphing PF-2019-005 Measurement

Analysis	Integrated luminosity (fb ⁻¹)
$H \rightarrow \gamma \gamma$ (including $t\bar{t}H, H \rightarrow \gamma \gamma$)	79.8
$H \rightarrow ZZ^* \rightarrow 4\ell$ (including $t\bar{t}H, H \rightarrow ZZ^* \rightarrow 4\ell$)	79.8
$H \rightarrow WW^* \rightarrow e \nu \mu \nu$	36.1
$H \rightarrow \tau \tau$	36.1
$VH, H \rightarrow b\bar{b}$	79.8
VBF, $H \rightarrow b\bar{b}$	24.5 - 30.6
$H \rightarrow \mu \mu$	79.8
$t\bar{t}H, H \rightarrow b\bar{b}$ and $t\bar{t}H$ multilepton	36.1
$H \rightarrow \text{invisible}$	36.1
Off-shell $H \to ZZ^* \to 4\ell$ and $H \to ZZ^* \to 2\ell 2\nu$	36.1

Coambined Higgs Boson Coupling-2019-005 Measurement

ATLAS Preliminary Hotal	Stat. — Syst. II SM
$\sqrt{s} = 13 \text{ TeV}, 24.5 - 79.8 \text{ fb}^{-1}$	
$m_{H} = 125.09 \text{ GeV}, y_{H} < 2.5$	
$P_{SM} = 7176$	Total Stat. Syst.
ggFγγ 📥	$0.96 \pm 0.14 (\pm 0.11, -0.08)$
ggF ZZ 🙀	$1.04 \stackrel{+0.16}{_{-0.15}} (\pm 0.14, \pm 0.06)$
ggF WW 📥	1.08 ± 0.19 (± 0.11 , ± 0.15)
ggF ττ ι	$0.96 \begin{array}{c} +0.59 \\ -0.52 \\ -0.36 \end{array} , \begin{array}{c} +0.46 \\ -0.38 \\ -0.38 \end{array})$
ggF comb.	$1.04 \pm 0.09 (\pm 0.07, \pm 0.07) = -0.06$
VBF γγ μ	$1.39 \begin{array}{c} +0.40 \\ -0.35 \end{array} \begin{pmatrix} +0.31 \\ -0.30 \end{pmatrix} , \begin{array}{c} +0.26 \\ -0.19 \end{pmatrix}$
VBF ZZ	$2.68 \begin{array}{c} +0.98 \\ -0.83 \end{array} \begin{pmatrix} +0.94 \\ -0.81 \end{pmatrix} + \begin{array}{c} +0.27 \\ -0.20 \end{pmatrix}$
VBF WW I	$0.59 \begin{array}{c} \pm 0.36 \\ -0.35 \end{array} (\begin{array}{c} \pm 0.29 \\ -0.27 \end{array} , \begin{array}{c} \pm 0.21 \end{array})$
VBF TT I	$1.16 \begin{array}{c} +0.58 \\ -0.53 \end{array} \begin{pmatrix} +0.42 \\ -0.40 \end{array}, \begin{array}{c} +0.40 \\ -0.35 \end{array} \end{pmatrix}$
VBF bb	\rightarrow 3.01 $^{+1.67}_{-1.61}($ $^{+1.63}_{-1.57},$ $^{+0.39}_{-0.36})$
VBF comb.	$1.21 \begin{array}{c} +0.24 \\ -0.22 \end{array} \begin{pmatrix} +0.18 \\ -0.17 \end{array} , \begin{array}{c} +0.16 \\ -0.13 \end{array}$
VH γγ 📫	$1.09 \begin{array}{c} +0.58 \\ -0.54 \end{array} \begin{pmatrix} +0.53 \\ -0.49 \end{array}, \begin{array}{c} +0.25 \\ -0.22 \end{array} \end{pmatrix}$
VH ZZ	$0.68 \begin{array}{c} +1.20 \\ -0.78 \end{array} \begin{pmatrix} +1.18 \\ -0.77 \end{pmatrix}, \begin{array}{c} +0.18 \\ -0.11 \end{pmatrix}$
VH bb 🙀 🔤	$1.19 \begin{array}{c} +0.27 \\ -0.25 \\ -0.17 \\ -0.17 \\ -0.18 \end{array} + \begin{array}{c} +0.20 \\ -0.18 \\ -0.18 \\ -0.18 \end{array}$
VH comb.	$1.15 \begin{array}{c} +0.24 \\ -0.22 \end{array} (\pm 0.16 , \begin{array}{c} +0.17 \\ -0.16 \end{array})$
ttH+tH γγ 🛑	$1.10 \begin{array}{c} +0.41 \\ -0.35 \\ -0.33 \\ -0.14 \end{array}$
ttH+tH VV	$1.50 \begin{array}{c} +0.59 \\ -0.57 \end{array} \begin{pmatrix} +0.43 \\ -0.42 \end{pmatrix} , \begin{array}{c} +0.41 \\ -0.38 \end{pmatrix}$
ttH+tH tt +	$1.38 \begin{array}{c} +1.13 \\ -0.96 \\ -0.76 \\ -0.76 \\ -0.79 \end{array}$
ttH+tH bb	$0.79 \begin{array}{c} \pm 0.60 \\ -0.59 \end{array} (\pm 0.29 , \pm 0.52)$
ttH+tH comb.	$1.21 \stackrel{+0.26}{_{-0.24}} (\pm 0.17, \stackrel{+0.20}{_{-0.18}})$
	$= (\sigma \times R)/(\sigma \times R)$
2 0 2 4	6 8 $\mu = (0 \land D)/(0 \land D)$

Parameter normalized to SM value

Coambined Higgs Boson Courphing -2019-005 Measurement



Process	Value		Uncertainty [pb]				SM pred.	Signif	icance
$(y_H <2.5)$	[pb]	Total	Stat.	Exp.	Sig. th.	Bkg. th.	[pb]	obs.	(exp.)
ggF	46.5	±4.0	±3.1	±2.2	±0.9	±1.3	44.7 ± 2.2	-	
VBF	4.25	+0.84	+0.63	+0.35	+0.42	+0.14 -0.11	3.515 ± 0.075	6.5 (5.3)	
WH	1.57	+0.48 -0.46	+0.34 -0.33	+0.25	+0.11 -0.07	±0.20	1.204 ± 0.024	3.5 (2.7)	$\int_{5.3(4.7)}$
ZH	0.84	+0.25 -0.23	±0.19	±0.09	+0.07 -0.04	±0.10	$0.797^{+0.033}_{-0.026}$	3.6 (3.6)	5.5 (4.7)
tīH+tH	0.71	+0.15 -0.14	±0.10	±0.07	+0.05 -0.04	+0.08 -0.07	$0.586^{+0.034}_{-0.049}$	5.8 (5.4)	

Higgs Coupling Measurement

$$\begin{split} L_{\rm h} &= \frac{1}{2} (\partial^{\,\mu} h) (\partial_{\mu} \, h) + \frac{M_{\rm h}^{\,2}}{2} \, h^{\,2} - \frac{M_{\rm h}^{\,2}}{2v} \, h^{\,3} - \frac{M_{\rm h}^{\,2}}{8v^2} \, h^{\,4} \\ &+ \left(M_{\rm W}^{\,2} W_{\mu}^{\,+} W^{\,-\mu} + \frac{1}{2} \, M_{\rm Z}^{\,2} Z_{\mu} Z^{\,\mu} \right) \left(1 + \frac{h}{v} \right)^2 \\ &- \sum_{f} m_{f} \, \bar{f} \, f \left(1 + \frac{h}{v} \right). \end{split}$$

(19) $\begin{array}{c} & & \\ g_F = \sqrt{2} \frac{m_f}{v} \\ g_V = 2 \frac{m_V^2}{v} \end{array}$



ヒッグス結合、Run 1結果との比較



Parameter value

Heavy Triple Gauge Boson Production

- Test of non-Aberian gauge structure.
- SM predicts small cross sections:





Decay channel	Significance			
Decay channel	Observed	Expected		
WWW combined	3.3 <i>o</i>	2.4 <i>o</i>		
$WWW \rightarrow \ell \nu \ell \nu q q$	4.3 σ	1.7σ		
$WWW \rightarrow \ell \nu \ell \nu \ell \nu$	1.0σ	2.0σ		
WVZ combined	2.9σ	2.0σ		
$WVZ \rightarrow \ell \nu q q \ell \ell$	-	1.0σ		
$WVZ \rightarrow \ell \nu \ell \nu \ell \ell / q q \ell \ell \ell \ell$	3.5σ	1.8σ		
VVV combined	4.0σ	3.1 <i>o</i>		

$\sigma_{WWW} = 0.50 \text{ pb}, \sigma_{WWZ} = 0.29 \text{ pb}.$

Vector Boson Scattering Processes

- Vector boson scattering involves
 - Triple and Quadratic Gauge Couplings
 - Higgs restores unitarity at high energies



Vector Boson Scattering Processes





ATLAS-CONF-2018-030

arXiv:1812.09740

VBSは、ちょうどプロセスが発見に達したところ。 これから、ヒッグスとの干渉について、精密検証を行う。

ヒッグス自己結合測定

- DiHiggs事象を探して解析する。
- DiHiggsは、2つのダイヤグラムの干 渉が起こる。









Expected event yields for $\frac{\lambda_{HHH}}{\lambda^{SM}} = 1$

Decay Channel	Branching Ratio	Total Yield (3000 fb ⁻¹)
$b\overline{b} + b\overline{b}$	33%	40,000
$b\overline{b} + W^+W^-$	25%	31,000
$b\overline{b} + \tau^+\tau^-$	7.3%	8,900
$ZZ + b\overline{b}$	3.1%	3,800
$W^+W^-+\tau^+\tau^-$	2.7%	3,300
$ZZ + W^+W^-$	1.1%	1,300
$\gamma\gamma + b\overline{b}$	0.26%	320
$\gamma\gamma + \gamma\gamma$	0.0010%	1.2

Run 2でのDihiggs探索結果 まずはDihiggs事象を探している。 Dihiggs事象の生成断面積に対する上限 自己相互結合に対する制限 10² 35% CL upper limit on σ_{gg_F} (pp → HH) [pb] bbbb (exp.) bbbb (obs.) bbt*† (exp. bbt*† (obs.) ATLAS Preliminary Observed Combined (exp.) Combined (obs.) Expected √s = 13 TeV, 27.5 - 36.1 fb⁻ Expected ±10 (Combined) Expected ± 1a Expected ±20 (Combined) σ_{ove}^{SM} (pp \rightarrow HH) = 33.4 fb Expected ± 2σ bbyy (exp. 10 Theory prediction Obs. Exp. Exp. stat. SM HH→ bbbb 12.9 20.7 18.5 $HH \rightarrow b \overline{b} T^{+}T$ 12.6 14.6 11.9 ATLAS Preliminary √s = 13 TeV. HH→ bbyy 20.4 26.3 25.1 27.5 - 36.1 fb⁻¹ Combined -5 6.7 10.4 9.2 -20 -15 -10 0 5 10 15 $\kappa_{\lambda} = \lambda_{HHH} / \lambda_{SM}$ 10 20 30 40 50 60 70 $-5.0 < \kappa_{\lambda} < 12.1 at 95\%$ CL. 95% CL upper limit on σ_{qqF} (pp \rightarrow HH) normalized to σ_{qqF}^{SM} 10³ bbbb (exp.) Combined (exp.) bbbb (obs.) — Combined (obs.) bbt*r (exp.) 10² Expected ±1 σ (Combined) bb⊤⁺⊤ (obs.) Expected ±2σ (Combined) bbyy (exp.) $S \rightarrow hh$ 事象の探索として、 bbyy (obs.) hMSSM (tan $\beta = 2$) 10 同じデータを解釈することも できる:

(e.g. S=heavy Higgs)





tanß October 2018 tan β 40 H/A→ττ Is = 13 TeV, 36.1 fb⁻¹ 30 40 JHEP 01 (2018) 055 $H^{\scriptscriptstyle +}{\rightarrow}\tau\nu$ 30 s = 13 TeV, 36.1 fb 20 ATLAS JHEP 09 (2018) 139 $H^+ \rightarrow tb$ 20 s = 13 TeV, 36.1 fb arXiv:1808.03599 [hep-ex] 95% CL_s exclusions $H \rightarrow ZZ \rightarrow 4 I/I v v$ 10 s = 13 TeV, 36.1 fb Eur. Phys. J. C (2018) 78: 293 $H^+ \rightarrow \tau v.tb$ Observed, vv 10 $gg \rightarrow A \rightarrow Zh$ s = 13 TeV, 36.1 fb hMSSM JHEP 03 (2018) 174 Expected, vv $H \rightarrow WW \rightarrow h/h$ ATLAS Preliminary √s = 13 TeV 1s = 13 TeV, 36.1 fb⁻¹ Eur. Phys. J. C 78 (2018) 24 3 hMSSM, 95% CL limits Observed, tb $H \rightarrow hh \rightarrow 4b$, 36.1 fb⁻¹ 4 — Observed \rightarrow bb $\gamma\gamma/\tau\tau$, 2 3 $\rightarrow WW\gamma\gamma$ Expected, tb --- Expected s = 8 TeV, 20.3 fb Phys. Rev. D92, 092004 (2015) $H \rightarrow hh \rightarrow bb \gamma\gamma$ 2 s = 13 TeV, 3.2 fb ATLAS-CONF-2016-004 h couplings [$\kappa_v, \kappa_u, \kappa_d$] s = 13 TeV, 36.1 - 79.8 fb 0.6 ATLAS-CONF-2018-031 300 400 200 1000 2000 200 400 600 800 1200 1400 1000 m₄ [GeV] m_{µ⁺} [GeV]

<u>JHEP 11 (2018) 085</u>

結論

- LHCは2015~2018年のRun 2を終えた。
 - 2019–2020はアップグレードのシャットダウン。
- シャットダウン中はフルRun 2の139 fb⁻¹データセットを解析する。(すでにいくつかの解析が出ている)
 - これまで公表されてきた物理結果は、36 fb⁻¹(2015+2016)、80 fb⁻¹(2015-2017)を使ってきた。
- Run 2のデータで、標準理論を厳しく検証、新物理を探索し続ける。



バックアップ

LAr trigger readout: Super Cells



(box: minimal readout element)

ity: trigger tower \Rightarrow 10 Super Cells (SCs)

cells in each layer

Super Cells

▶ Trigger tower \Rightarrow 10 Super Cells (SCs)



	Elementary Cell	Trigge	r Tower	Su	per Cell
Layer (barrel)	$[\Delta \eta \times \Delta \phi]$	$[n_\eta \times n_\phi]$	$[\Delta \eta \times \Delta \phi]$	$[n_\eta \times n_\phi]$	$[\Delta \eta \times \Delta \phi]$
Presampler (layer 0)	0.025 × 0.1	4 × 1		4 × 1	0.1 × 0.1
Front (layer 1)	0.003125 × 0.1	32 × 1	01~01	8 × 1	0.025 × 0.1
Middle (layer 2)	0.025 × 0.025	4 × 4	0.1 × 0.1	1 × 4	0.025 × 0.1
Back (layer 3)	0.05 × 0.025	2 × 4		2 × 4	0.1 × 0.1

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$H \rightarrow \gamma \gamma$ Event Categories_{TLAS-CONF-2018-028}

Category label	Selection
ttH lep BDT1	$N_{\text{lep}} \ge 1$, $N_{b-\text{jet}} \ge 1$, BDT _{uHlep} > 0.987
ttH lep BDT2	$N_{\text{lcp}} \ge 1$, $N_{b-\text{jet}} \ge 1$, 0.942 < BDT _{utHlcp} < 0.987
ttH lep BDT3	$N_{\text{lep}} \ge 1$, $N_{b-\text{jet}} \ge 1$, 0.705 < BDT _{ttHlep} < 0.942
ttH had BDT1	$N_{\text{lep}} = 0$, $N_{\text{jets}} \ge 3$, $N_{b-\text{jet}} \ge 1$, $\text{BDT}_{\text{ttHhad}} > 0.996$
ttH had BDT2	$N_{\text{lep}} = 0$, $N_{\text{jets}} \ge 3$, $N_{b-\text{jet}} \ge 1$, 0.991 < BDT _{ttHhad} < 0.996
ttH had BDT3	$N_{\text{kep}} = 0$, $N_{\text{jets}} \ge 3$, $N_{b-\text{jet}} \ge 1$, 0.971 < BDT _{ttHhad} < 0.991
ttH had BDT4	$N_{\text{kep}} = 0$, $N_{\text{jets}} \ge 3$, $N_{b-\text{jet}} \ge 1$, 0.911 < BDT _{ttHhad} < 0.971
VH dilep	$N_{\rm lep} \ge 2$, 70 GeV $\le m_{\ell\ell} \le 110$ GeV
VH lep High	$N_{\rm kep} = 1$, $ m_{e\gamma} - 89 {\rm GeV} > 5 {\rm GeV}$, $p_{\rm T}^{\ell + E_{\rm T}^{\rm min}} > 150 {\rm GeV}$
VH lep Low	$N_{\text{lep}} = 1$, $ m_{e\gamma} - 89 \text{ GeV} > 5 \text{ GeV}$, $p_T^{\ell + E_T^{\text{mins}}} < 150 \text{ GeV}$, E_T^{minss} significance > 1
VH MET High	$150 \text{ GeV} < E_T^{\text{miss}} < 250 \text{ GeV}, E_T^{\text{miss}} \text{ significance } > 9 \text{ or } E_T^{\text{miss}} > 250 \text{ GeV}$
VH MET Low	$80 \text{ GeV} < E_{\text{T}}^{\text{miss}} < 150 \text{ GeV}, E_{\text{T}}^{\text{miss}} \text{ significance} > 8$
qqH BSM	$N_{\text{jets}} \ge 2$, $p_{\text{T,j1}} > 200 \text{GeV}$
VH had BDT tight	$60 \text{GeV} < m_{jj} < 120 \text{GeV}, \text{ BDT}_{VH} > 0.78$
VH had BDT loose	$60 \text{ GeV} < m_{jj} < 120 \text{ GeV}, 0.35 < \text{BDT}_{VH} < 0.78$
VBF high-p _T ^{Hjj} BDT tight	$ \Delta \eta_{jj} > 2$, $ \eta_{\gamma\gamma} - 0.5(\eta_{j1} + \eta_{j2}) < 5$, $p_{T}^{Hjj} > 25 \text{GeV}$, BDT _{VBF} > 0.47
VBF high-p _T ^{Hjj} BDT loose	$ \Delta \eta_{jj} > 2$, $ \eta_{\gamma\gamma} - 0.5(\eta_{j1} + \eta_{j2}) < 5$, $p_T^{Hjj} > 25 \text{ GeV}$, $-0.32 < \text{BDT}_{VBF}^{high} < 0.47$
VBF low-p _T ^{Hjj} BDT tight	$ \Delta \eta_{jj} > 2$, $ \eta_{\gamma\gamma} - 0.5(\eta_{j1} + \eta_{j2}) < 5$, $p_T^{Hjj} < 25 \text{GeV}$, $BDT_{VBP}^{low} > 0.87$
VBF low-p _T ^{Hjj} BDT loose	$ \Delta \eta_{jj} > 2$, $ \eta_{\gamma\gamma} - 0.5(\eta_{j1} + \eta_{j2}) < 5$, $p_T^{Hjj} < 25 \text{ GeV}$, $0.26 < \text{BDT}_{VBF}^{low} < 0.87$
ggF 2J BSM	$N_{\text{jets}} \ge 2, \ p_{\text{T}}^{\gamma\gamma} \ge 200 \text{GeV}$
ggF 2J High	$N_{\text{jets}} \ge 2, \ p_{\text{T}}^{\gamma\gamma} \in [120, 200] \text{ GeV}$
ggF 2J Med	$N_{\text{jets}} \ge 2, \ p_{\text{T}}^{\gamma\gamma} \in [60, 120] \text{ GeV}$
ggF 2J Low	$N_{\text{jets}} \ge 2, p_T^{\gamma\gamma} \in [0, 60] \text{ GeV}$
ggF 1J BSM	$N_{\text{jets}} = 1, \ p_T^{\gamma\gamma} \ge 200 \text{GeV}$
ggF 1J High	$N_{\text{jets}} = 1, \ p_{\text{T}}^{27} \in [120, 200] \text{ GeV}$
ggF 1J Med	$N_{\text{jets}} = 1, \ p_{\text{T}}^{27} \in [60, 120] \text{ GeV}$
ggF 1J Low	$N_{\text{jets}} = 1, \ p_{\text{T}}^{\gamma\gamma} \in [0, 60] \text{ GeV}$
ggF 0J Fwd	$N_{\text{jets}} = 0$, one photon with $ \eta > 0.95$
ggF 0J Cen	$N_{\text{jets}} = 0$, two photons with $ \eta \le 0.95$

Top Spin Correlation



Parton level $\Delta \phi(l^+, \bar{l})/\pi$ [rad/ π]

- $t\bar{t} \to (Wb)(Wb) \to (e\nu b)(\mu\nu b)$
- eとμの間の角度相関。
- SM(NLO QCD)の予言値よりも 強い相関がみられた。
- テンプレート・フィット $n_i = f_{SM} \cdot n_{spin} + (1 - f_{SM}) \cdot n_{nospin}$ フィット結果: $f_{SM} = 1.250 \pm 0.026 \pm 0.063$
- SMからのずれ: 3.2σ (syst込み)

Overview of VBS measurements @ the LHC



Recent update:

Channel	Final state	Observed (expected) significance	Recent measurements	Experimental Challenges
VBS W [±] W [±]	l [±] l [±] יע jj	5.5 (5.7) σ <mark>NEW</mark>	CMS @13 TeV ATLAS @13 TeV	"golden channel": first observation of VBS in this channel, very good EW/QCD ratio, mostly experimental backgrounds
VBS W [±] Z	Шv jj	1.9 (1.0) σ NEW	CMS @13 TeV ATLAS @13 TeV	similar cross section as ssWW, but larger QCD backgrounds, reasonable reconstruction of final state (m_T^{WZ})
VBS ZZ	ші	2.7 (1.6) σ	CMS @13 TeV	very clean channel, reconstruction of final state, low background but small cross section
VBS W [±] V	l±vjj jj	only BSM interpretation @8 TeV		large backgrounds, but promising when looking for BSM effects in boosted topology
$\frac{VBS}{\gamma\gamma \rightarrow W^+W^-}$	llvv jj	3.4 (2.8) σ	ATLAS & CMS @8 TeV	huge backgrounds (dileptonic ttbar), no sensitivity to BSM EWSB
VBS Wγ/Zγ	Ινγ ϳϳ / ΙΙνγ ϳϳ	2.7 (1.5) σ / 3.0 (2.1) σ	CMS @8 TeV	higher statistics due to photon, but no sensitivity to BSM EWSB

Today's focus:

• Measurement in fully leptonic final states in VBS $W^{\pm}W^{\pm}jj$ and $W^{\pm}Zjj$ with the ATLAS detector @13 TeV

Stefanie Todt - TU Dresden - VBS at ATLAS 3 / 11

Stefanie Todt at Corfu2018

VBSは、ちょうどプロセスが発見に達したところ。 これから、ヒッグスとの干渉について、精密検証を行う。

High Luminosity LHC (HL-LHC)

10000

