

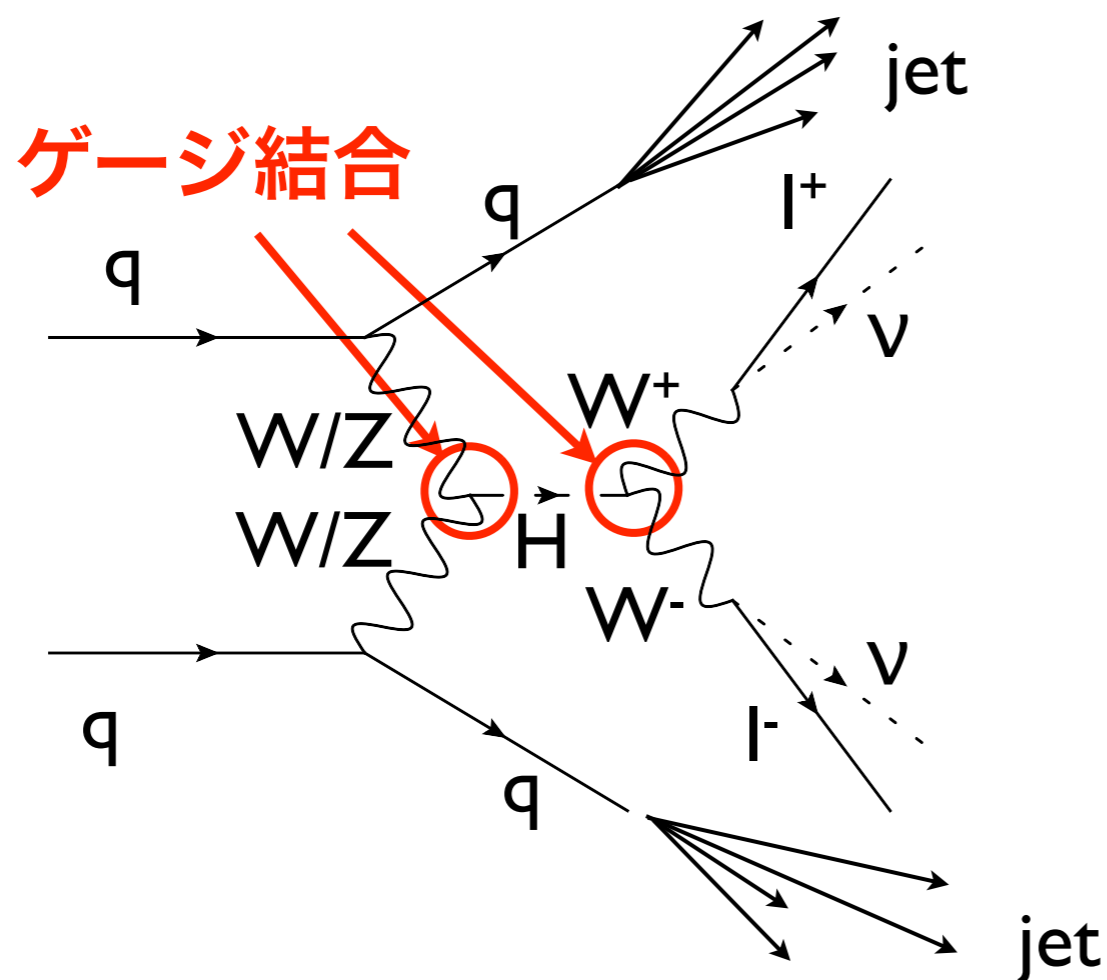
LHC-ATLAS実験における VBF $H \rightarrow WW \rightarrow l\nu l\nu$
を用いたヒッグス粒子の探索

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イントロダクション (I)

- Vector Boson Fusion (VBF) Higgs \rightarrow $WW \rightarrow l\nu l\nu$

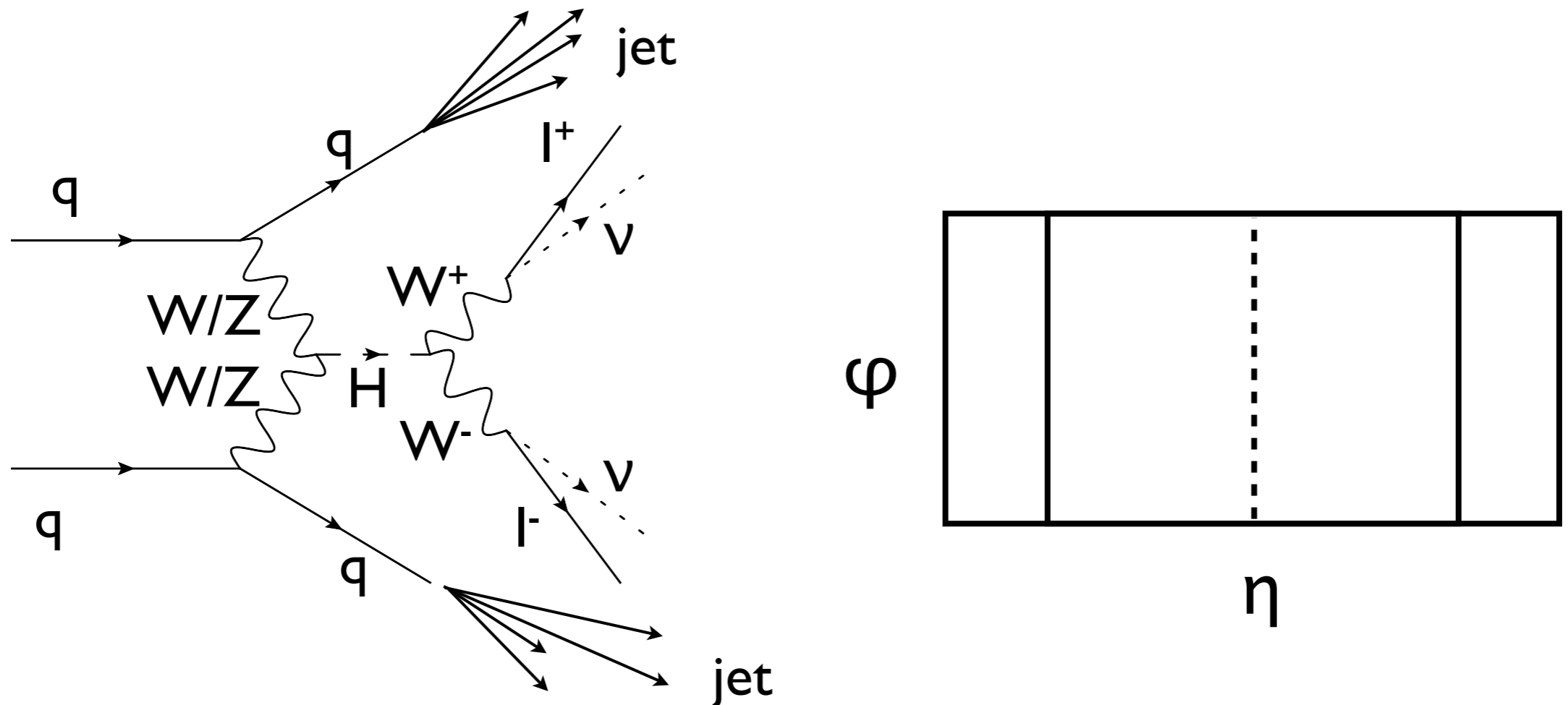


- ヒッグスの生成・崩壊過程に湯川結合が関与しない
 - ヒッグスとゲージボソンの結合定数を綺麗に測定ができる

今後のヒッグス探索で重要なチャンネル

イントロダクション (2)

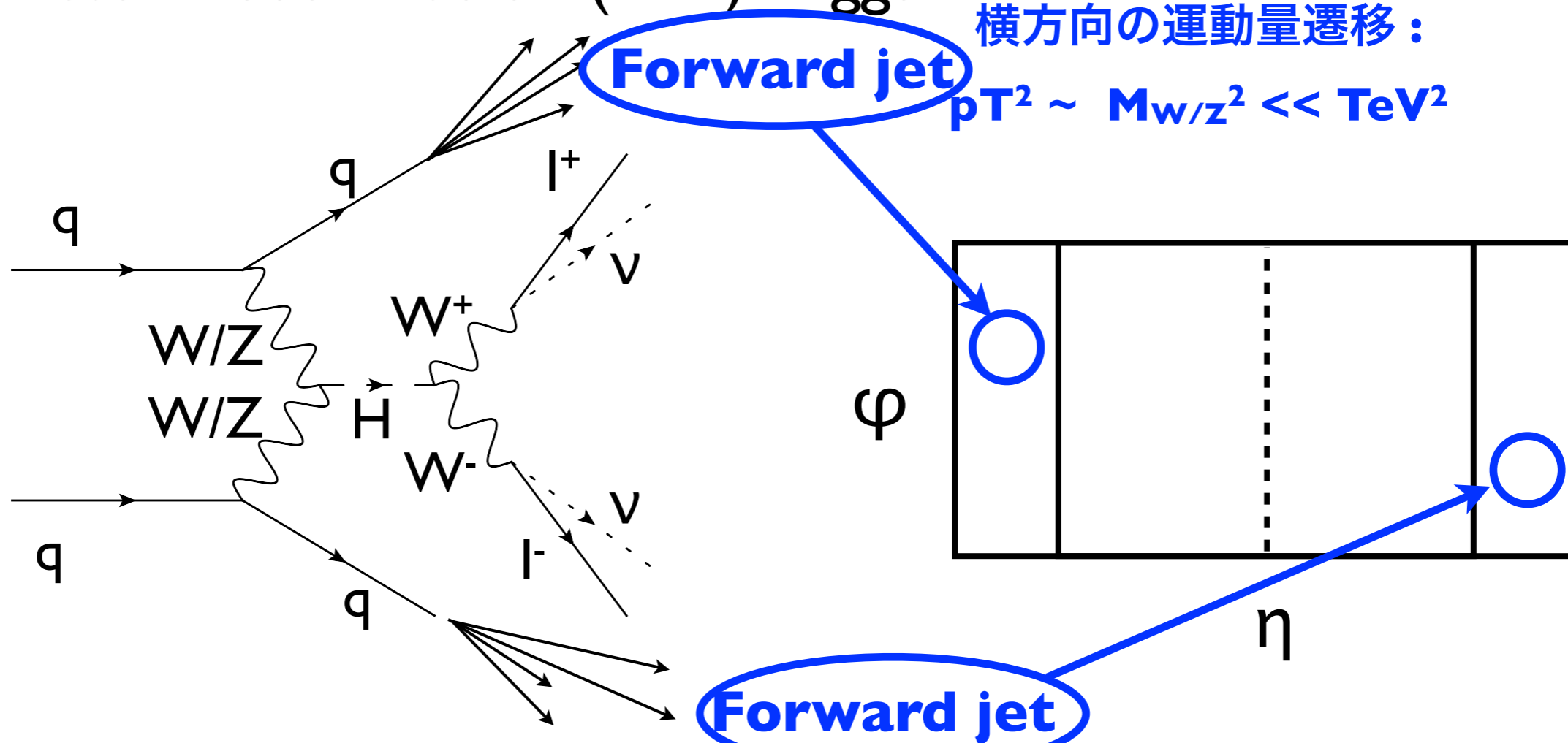
- Vector Boson Fusion (VBF) Higgs \rightarrow $WW \rightarrow l\nu l\nu$



- 終状態に多くの特徴
 - Two jets with high momentum in forward region
 - No color flow between quark lines : No central jets
 - Higgs boson decay products in the central region

イントロダクション (2)

- Vector Boson Fusion (VBF) Higgs \rightarrow $WW \rightarrow l\nu l\nu$
 横方向の運動量遷移：
 $p_T^2 \sim M_{W/Z}^2 \ll \text{TeV}^2$



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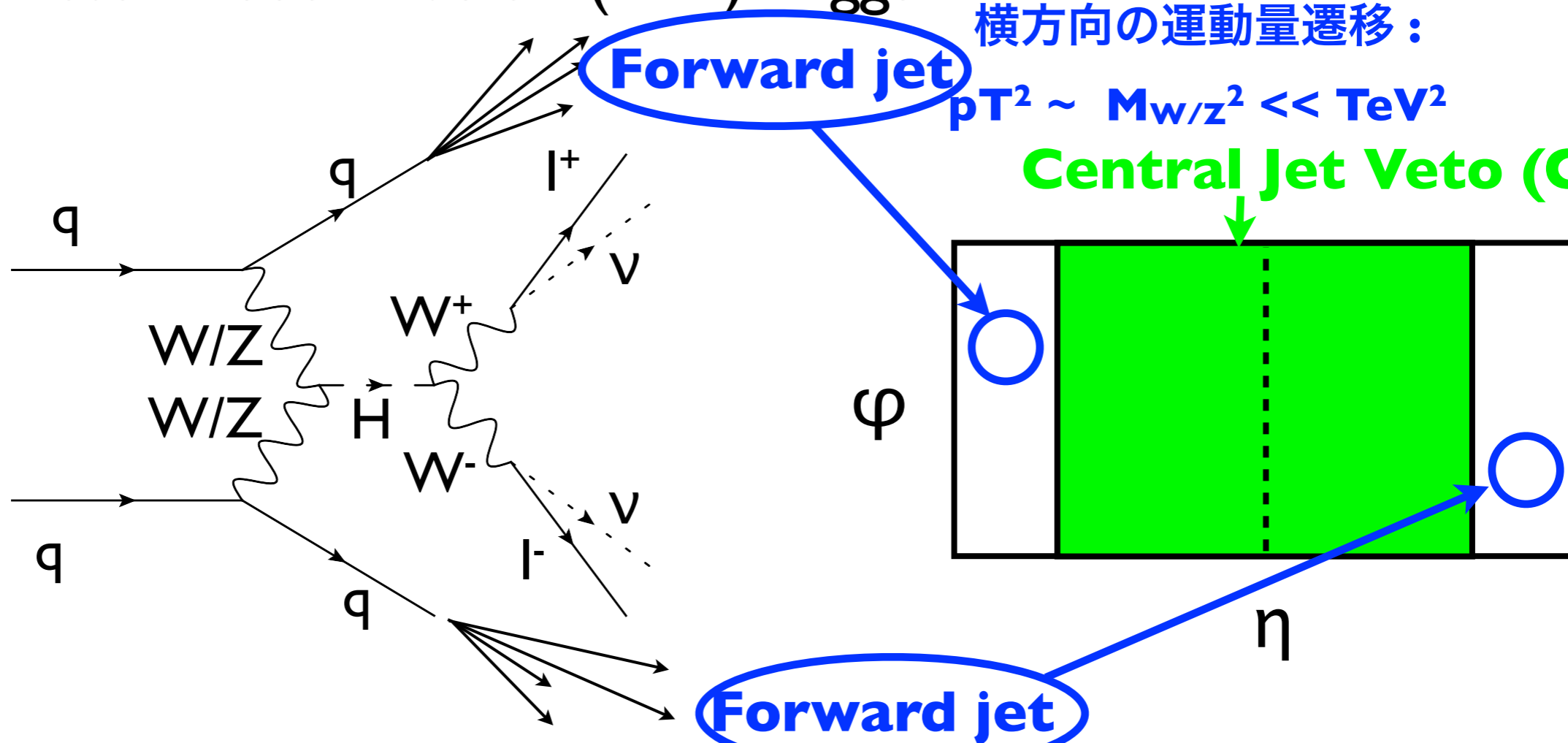
イントロダクション (2)

- Vector Boson Fusion (VBF) Higgs \rightarrow $WW \rightarrow l\nu l\nu$

横方向の運動量遷移:

$$p_T^2 \sim M_{W/Z}^2 \ll \text{TeV}^2$$

Central Jet Veto (CJV)



- 終状態に多くの特徴

- Two jets with high momentum in forward region
- No color flow between quark lines : No central jets
- Higgs boson decay products in the central region

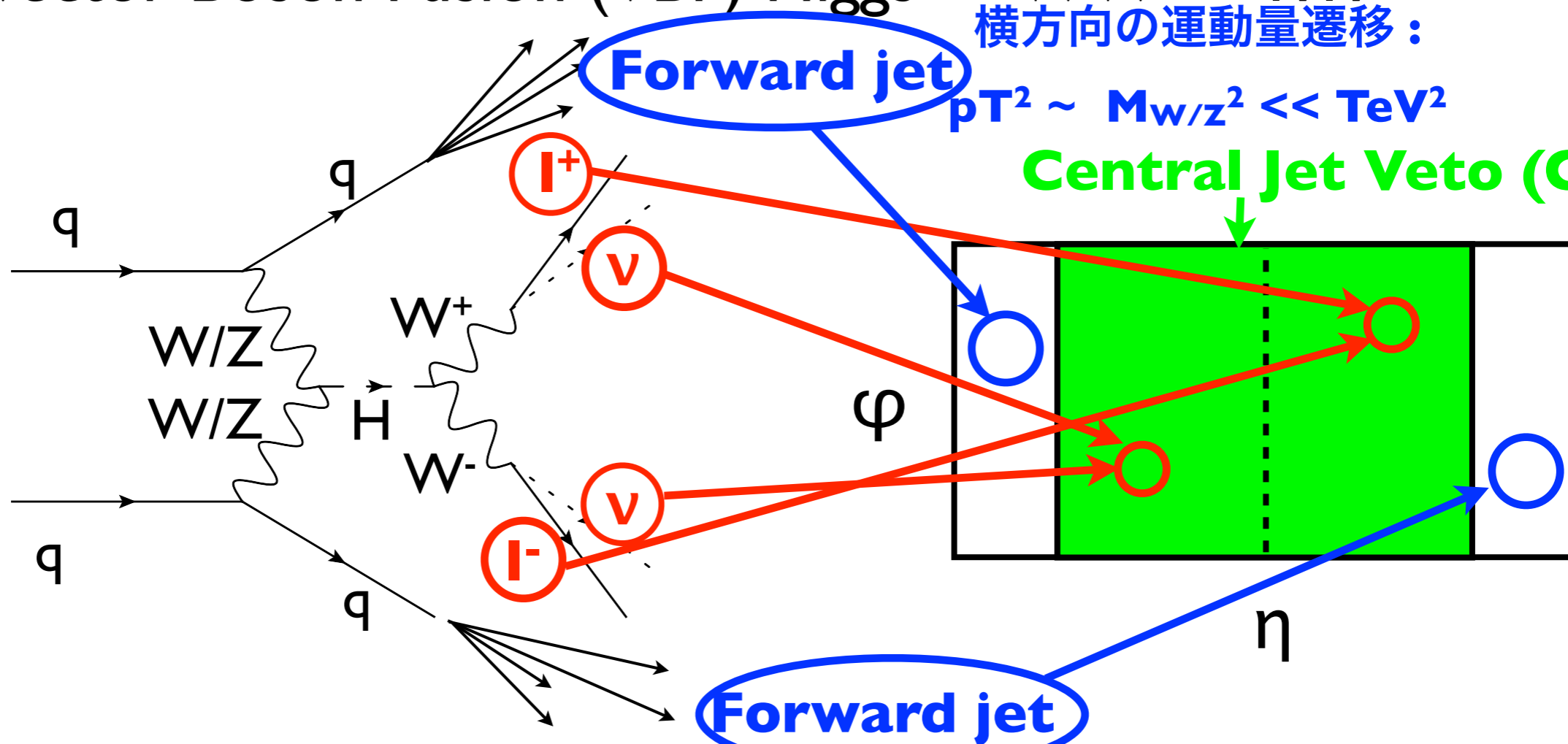
イントロダクション (2)

- Vector Boson Fusion (VBF) Higgs \rightarrow $WW \rightarrow l\nu l\nu$

横方向の運動量遷移:

$$p_T^2 \sim M_{W/Z}^2 \ll \text{TeV}^2$$

Central Jet Veto (CJV)



- 終状態に多くの特徴

S/B が非常に良い

- Two jets with high momentum in forward region
- No color flow between quark lines : No central jets
- Higgs boson decay products in the central region

研究の目的

- 現在の事象選択後の事象数

- ee/e μ / $\mu\mu$ channel (8TeV, 5.8 fb⁻¹)

Statistical error only

Signal	Total Background
0.4 \pm 0.0	0.7 \pm 0.3

- 統計量が圧倒的に少ないという問題

➡ 感度を保ち（／増加させ）かつ、統計も稼ぐ事を
目的とした事象選択の最適化をする必要がある

- 新しい事象選択の導入
- 既存の事象選択の最適化

今回のトークの内容

シグナルと背景事象

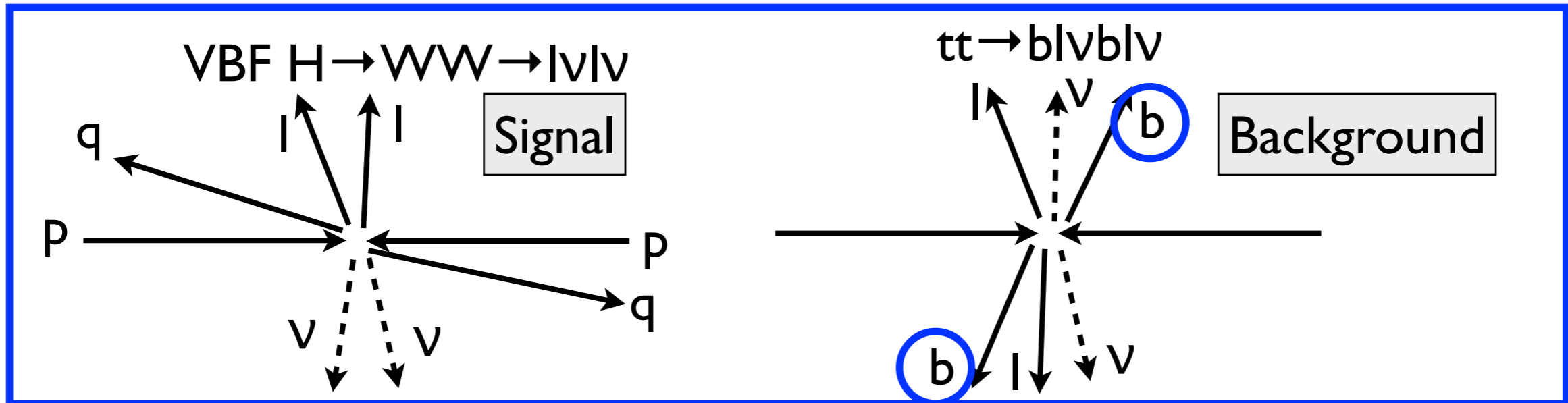
- 現在の事象選択後の事象数 (July 2012)

Statistical error only

Signal	Total Background (BG)						
VBF	ggF	WW	WZ/ZZ/W γ	$t\bar{t}$	Single top	Z+jets	W+jets
0.4 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0

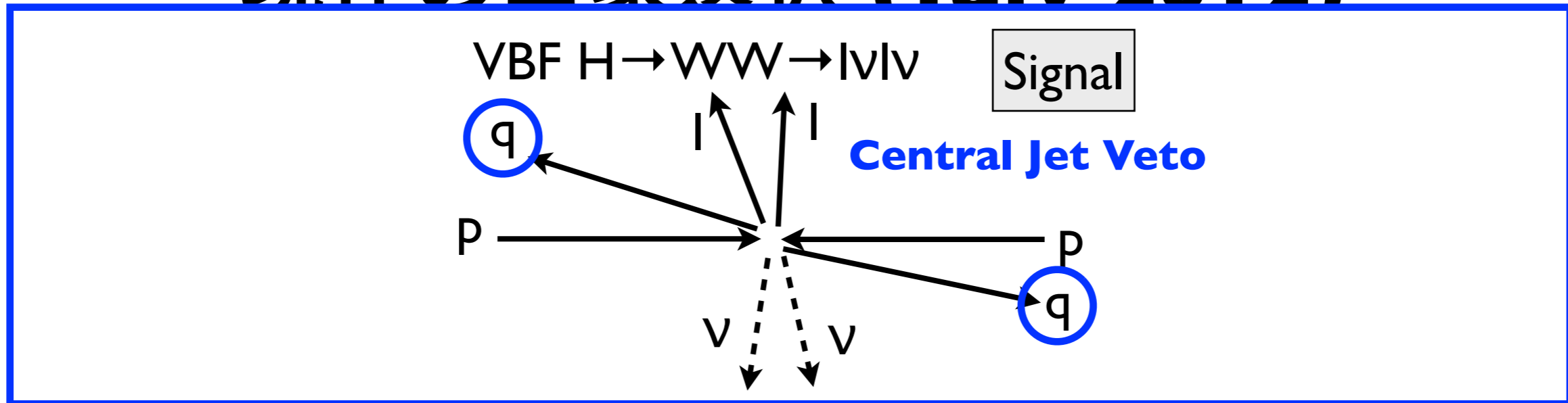
現在の事象選択 (July 2012)

- Preselections (missing ET cuts and so on.)
- VBF analysis selections
 - Number of jets ≥ 2
 - Number of b-jets $= 0$ (b-jet veto)
 - $\Delta y(jj) > 3.8$ (y : Rapidity)
 - Central leading jet $p_T < 20\text{GeV}$ (CJV)
 - $M_{jj} > 500\text{ GeV}$
 - $p_T(\text{total}) < 30\text{ GeV}$
 - Z to $\tau\tau$ veto
 - $M_{ll} < 80\text{ GeV}$
 - $\Delta\phi(ll) < 1.8$
 - $0.75 * M_H < M_T < M_H$ (M_H : Higgs mass)



- Number of b-jets == 0 (b-jet veto) → **Reduce top BG**
- $\Delta y(jj) > 3.8$ (y : Rapidity)
- Central leading jet $p_T < 20 \text{ GeV}$ (CJV)
- $M_{jj} > 500 \text{ GeV}$
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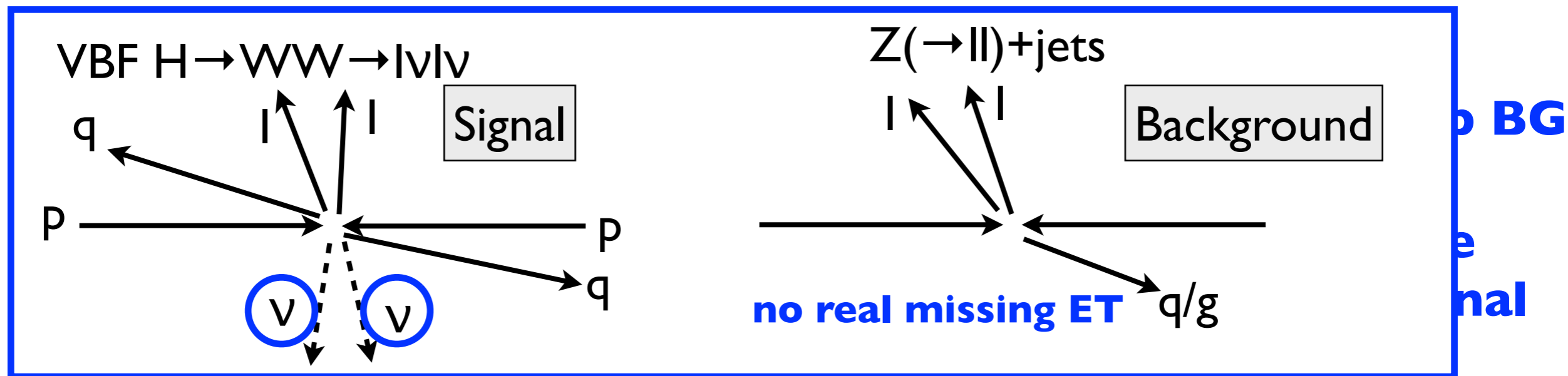
現在の事象選択 (July 2012)



- $\Delta y(jj) > 3.8$ (y : Rapidity)
- Central leading jet $p_T < 20\text{GeV}$ (CJV) } **Enhance VBF signal**
- $M_{jj} > 500\text{ GeV}$
- $p_T(\text{total}) < 30\text{ GeV}$
- Z to $\tau\tau$ veto
- $M_{ll} < 80\text{ GeV}$
- $\Delta\phi(ll) < 1.8$
- $0.75 * M_H < M_T < M_H$ (M_H : Higgs mass)

現在の事象選択 (July 2012)

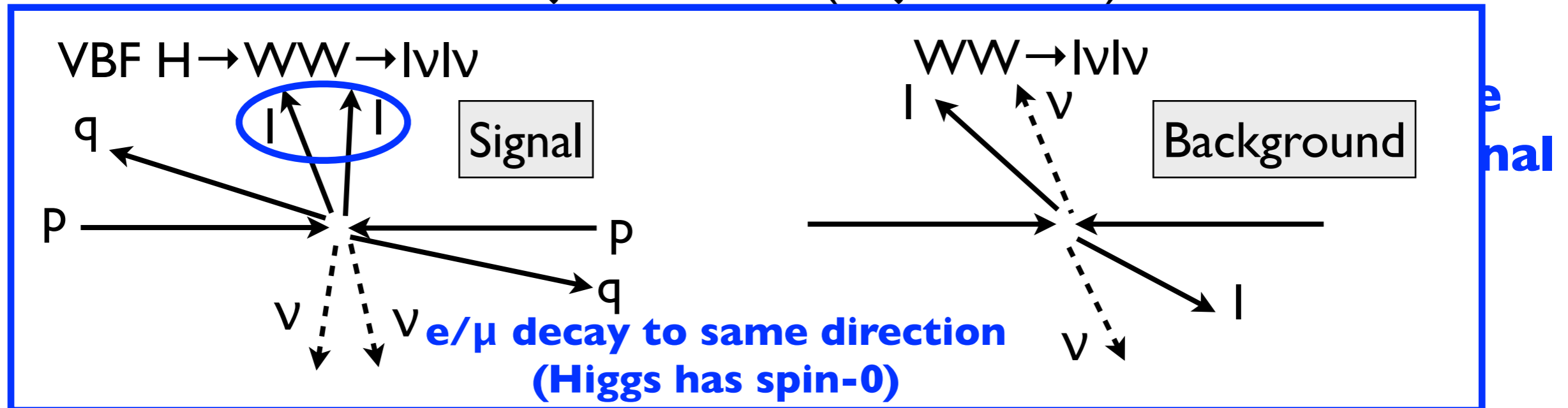
- Preselections (missing ET cuts and so on.)
- VBF analysis selections



- $p_T(\text{total}) < 30 \text{ GeV} \rightarrow$ **Reduce fake missing ET events**
- Z to $\tau\tau$ veto
- $M_{ll} < 80 \text{ GeV}$
- $\Delta\phi(ll) < 1.8$
- $0.75 * M_H < M_T < M_H$ (M_H : Higgs mass)

現在の事象選択 (July 2012)

- Preselections (missing ET cuts and so on.)
- VBF analysis selections
 - Number of jets ≥ 2
 - Number of b-jets $= 0$ (b-jet veto) \rightarrow **Reduce top BG**



- $M_{ll} < 80 \text{ GeV}$
 - $\Delta\varphi(ll) < 1.8$
 - $0.75 * M_H < M_T < M_H$ (M_H : Higgs mass)
- Enhance higgs signal**

現在の事象選択 (July 2012)

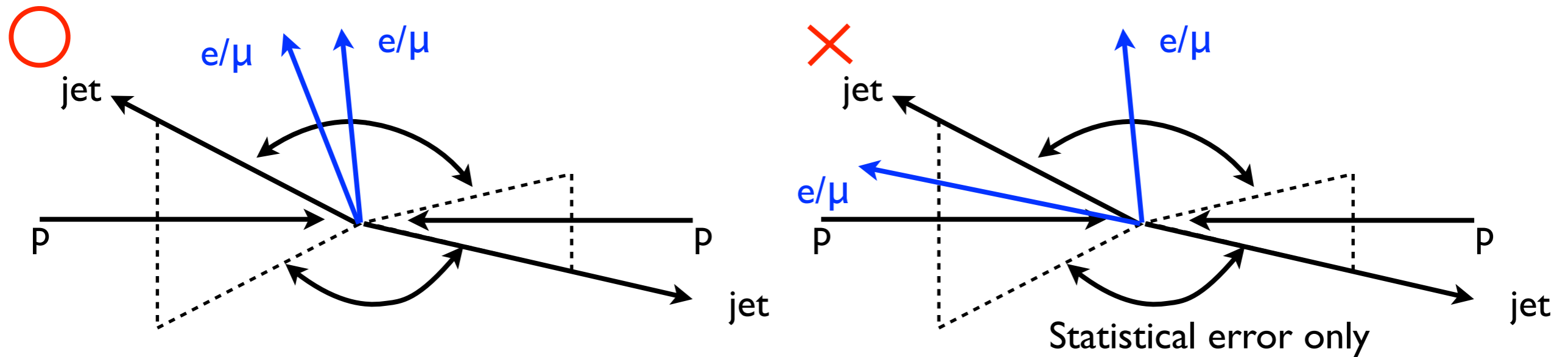
- Preselections (missing ET cuts and so on.)
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 - Number of jets ≥ 2
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 - $\Delta y(jj) > 3.8$ (y : Rapidity)
 - Central leading jet $p_T < 20 \text{ GeV}$ (CJV) \rightarrow **Enhance VBF signal**
 - $M_{jj} > 500 \text{ GeV}$
 - $p_T(\text{total}) < 30 \text{ GeV} \rightarrow$ **Reduce fake missing ET events**
 - Z to $\tau\tau$ veto
 - $M_{ll} < 80 \text{ GeV}$
 - $\Delta\phi(ll) < 1.8$
 - $0.75 * M_H < M_T < M_H$ (M_H : Higgs mass) \rightarrow **Enhance higgs signal**

最適化するべき事象選択

新しい事象選択の導入

- Outside Lepton Veto (OLV) を事象選択に導入
 - 2本の荷電レプトンが2本のジェットの間にある
 - $\eta(\text{jet1}) < \eta(\text{leptons}) < \eta(\text{jet2})$

CMS はすでに導入している



After MT cut	Signal	Total Background		S/\sqrt{B}
	VBF	ggF	others	
w/o OLV	0.4 ± 0.0	0.1 ± 0.0	0.6 ± 0.3	0.5 ± 0.1
w/ OLV	0.4 ± 0.0	0.1 ± 0.0	0.5 ± 0.2	0.6 ± 0.1

OLV を導入することで、背景事象だけを除去できる

既存の事象選択の最適化

- 2つの significance を感度の指標として用いた
 - S/\sqrt{B} に背景事象の統計、系統の不定性を含めた significance

$$Sig. = \frac{S}{\sqrt{B + \Delta B^2}}$$

S : signal

B : background

$\Delta B : \Delta B^2 = \Delta B(\text{stat.})^2 + \Delta B(\text{sys.})^2$

- Punzi significance

$$Sig. = \frac{S}{a/2 + \sqrt{B}}$$

S : signal

B : background

a : a = 3 is assumed

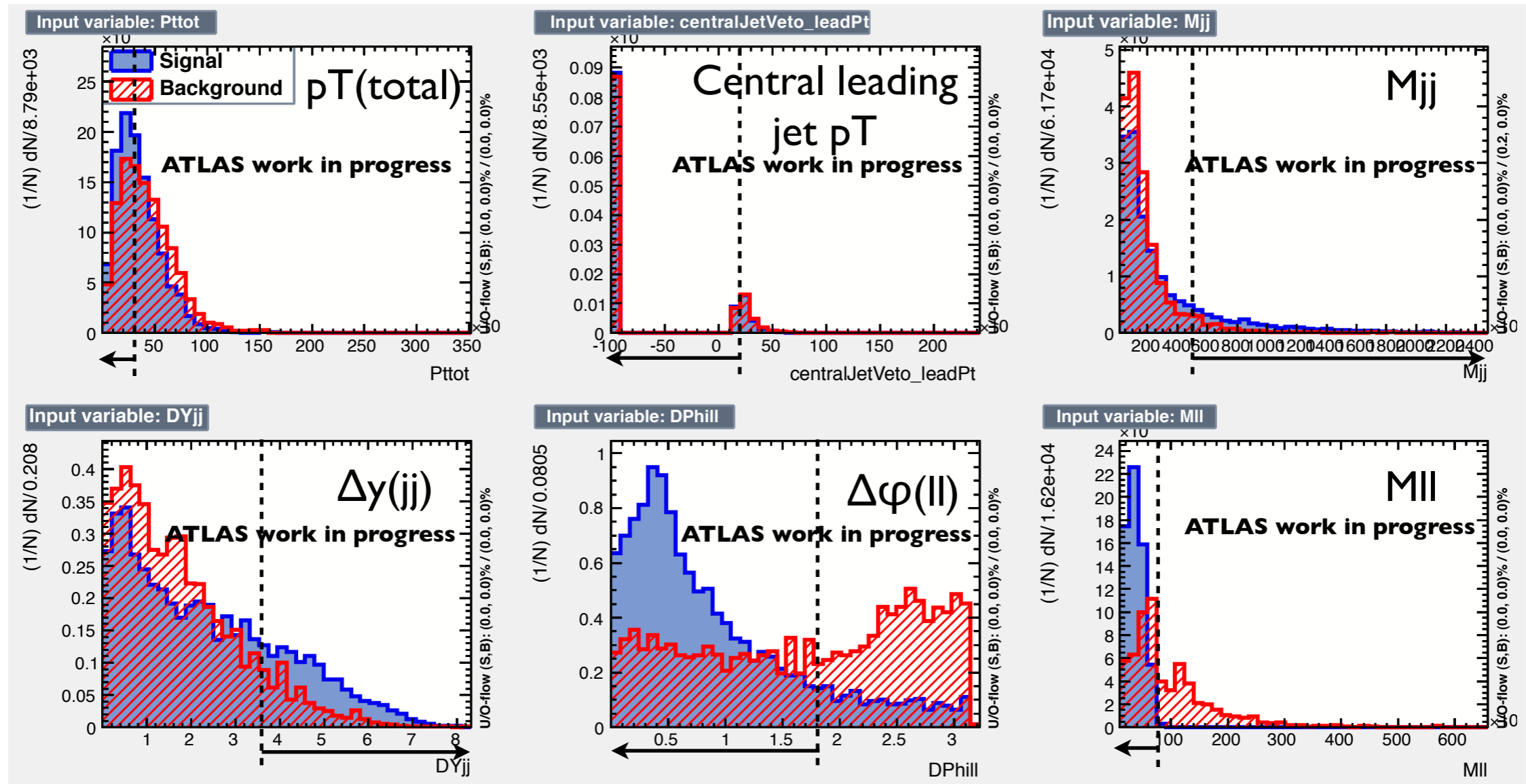
❖ B ~ 0 でも機能する

Systematics Uncertainty

	Signal	BG
Jet Energy Resolution	1.2 %	-
Jet Energy Scale	10 %	6.1 %
missing ET	2.2 %	4.8 %
B-tag efficiency	-	8.2 %

最適化する変数

- Variables after the below selections
 - Preselection, # of jets ≥ 2 , b-jet veto and Z to $\tau\tau$ veto

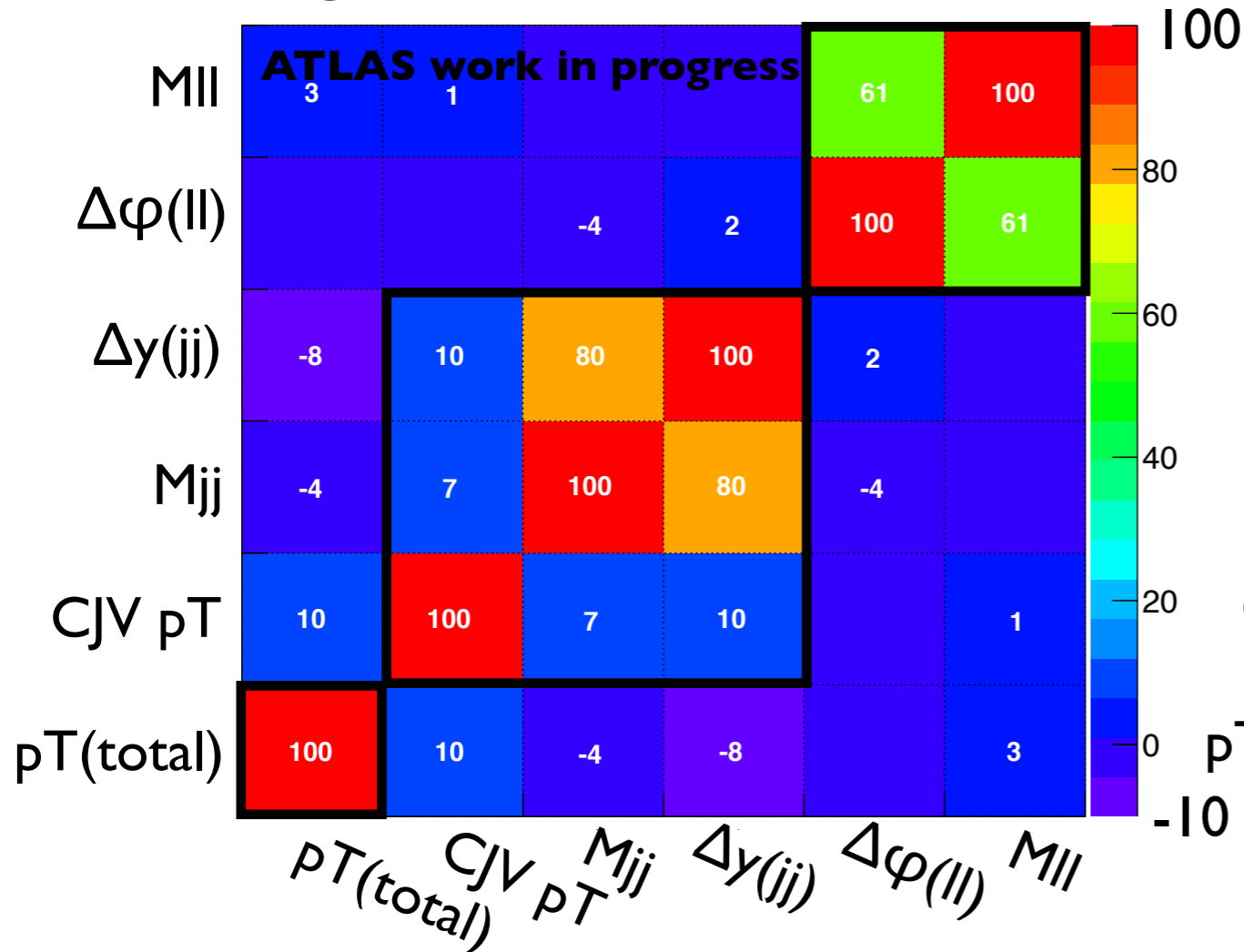


ほとんどの変数で、Signal と Background の分離が良い

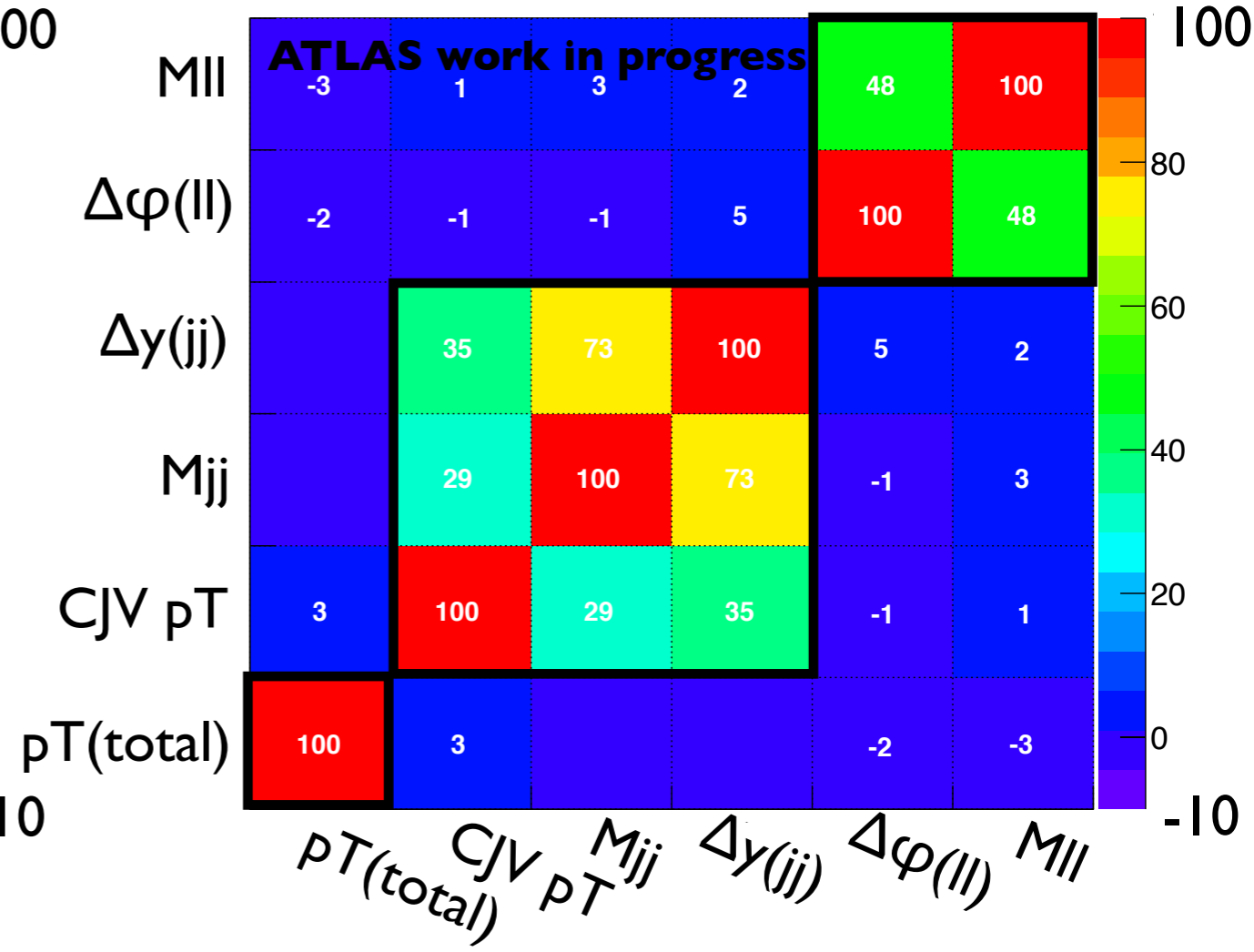
変数同士の相関

- Correlation Matrix for signal and background

Signal



Background



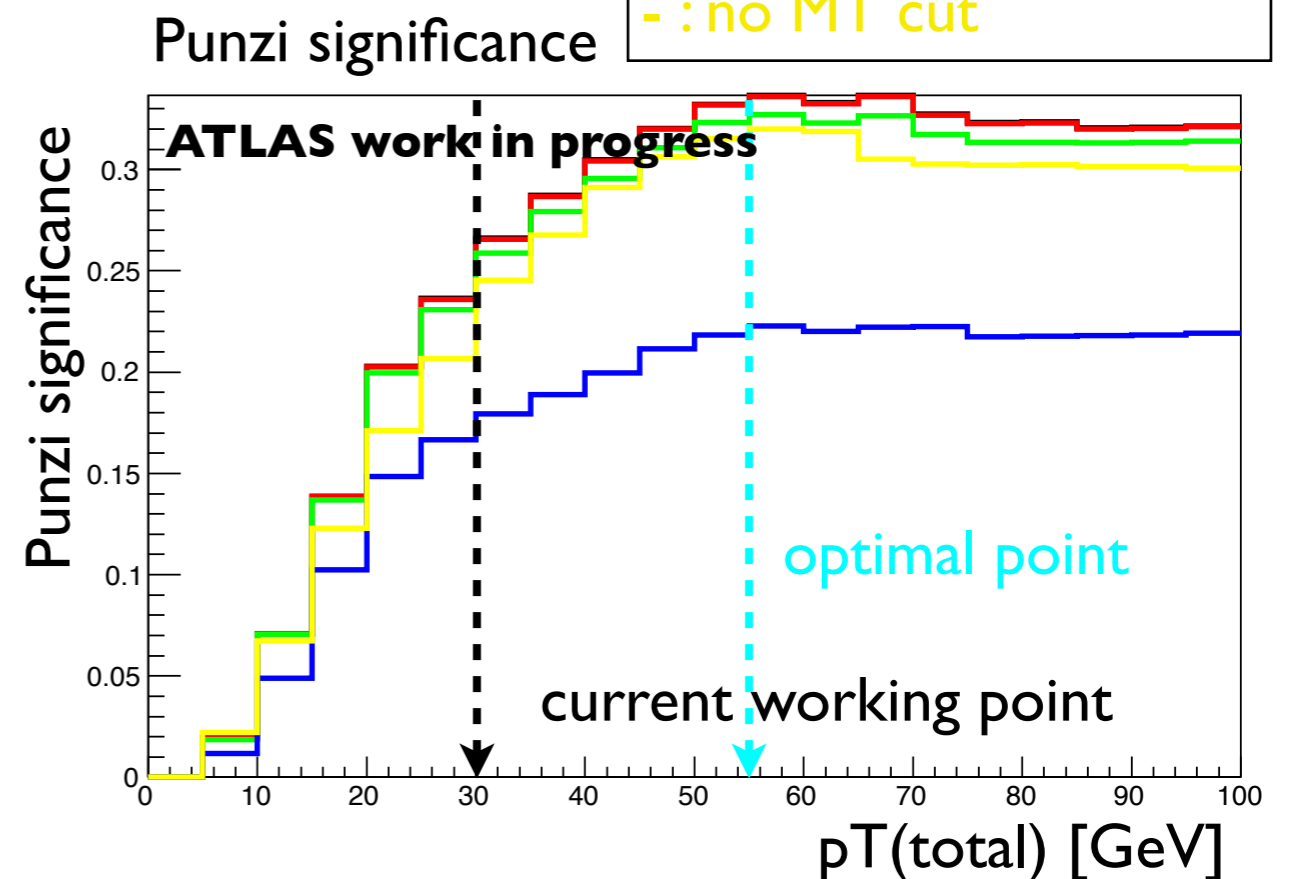
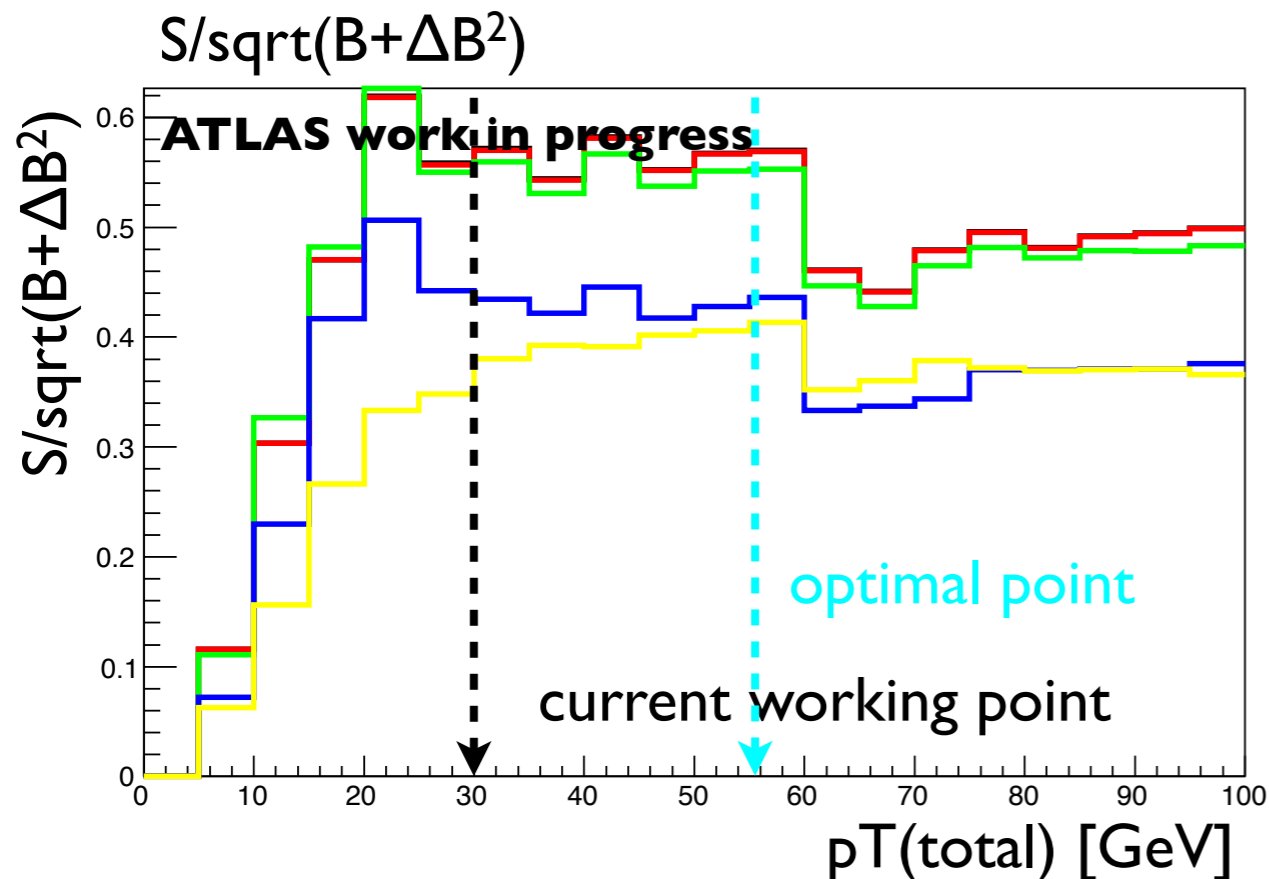
**pT(total), Dijets variables, Dilepton variables の
3つのグループで、事象選択を別々に最適化**

pT(total) の最適化

- Significance after all selections

$\Delta y(jj) : 3.8$, CJV pT : 20 GeV, $M_{jj} : 500$ GeV, pTtotal : scanned,
 $M_{ll} : 80$ GeV, $\Delta\phi(ll) : 1.8$, MT : scanned

- : MT < 125 GeV
 - : 30 < MT < 125 GeV
 - : 60 < MT < 125 GeV
 - : 95 < MT < 125 GeV
 - : no MT cut



pT(total) cut は、統計の影響が少なく、

感度が高い pT(total) < 55 GeV に決めた。

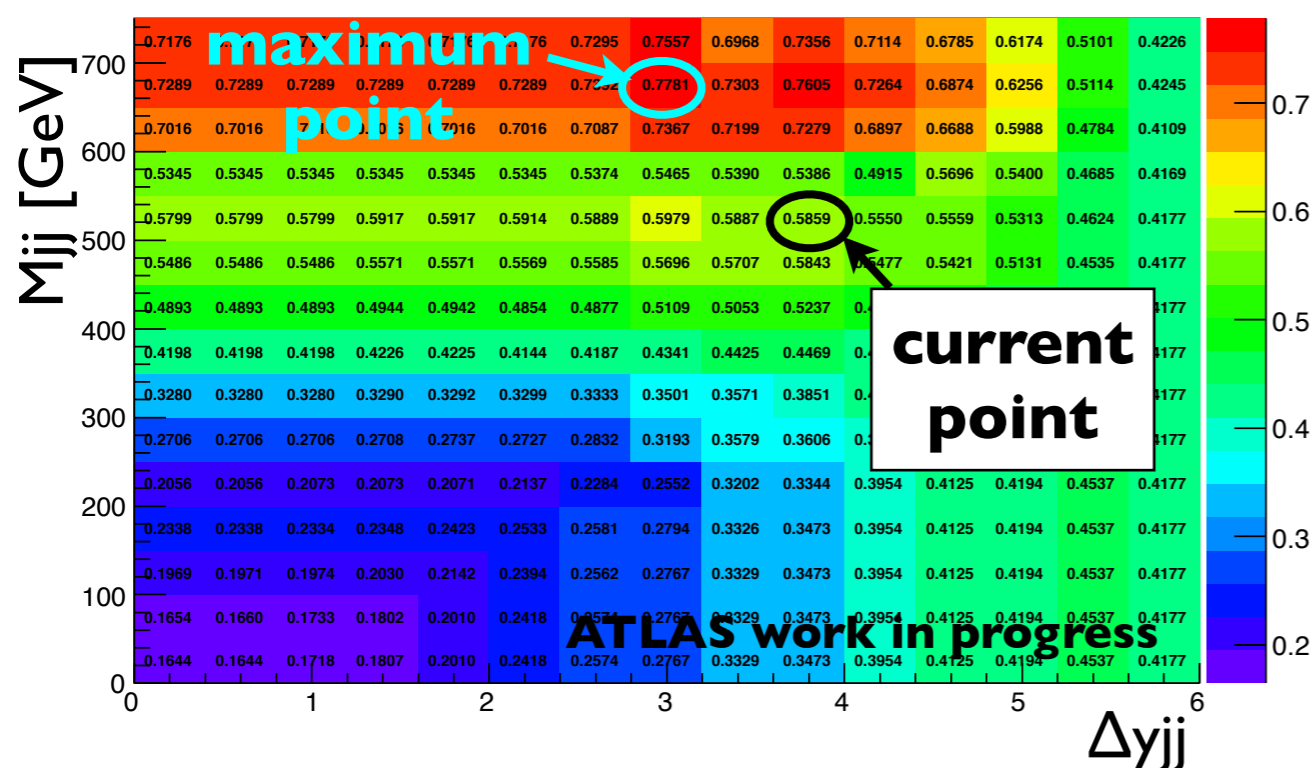
M_T cut は、感度が一番高い M_T < M_H に決めた。

Dijet 変数の最適化

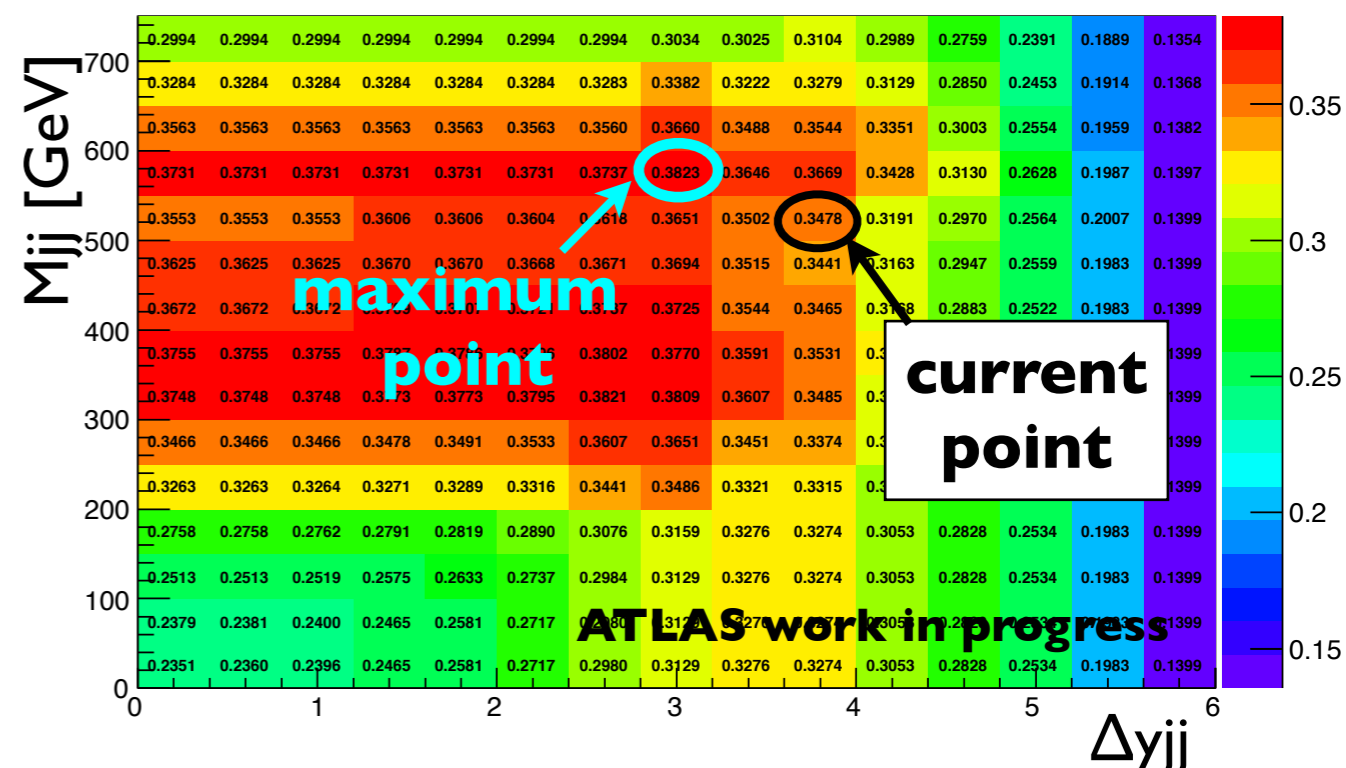
- Significance after all selections

$\Delta y(jj)$: scanned, CJV p_T : scanned (20 GeV), M_{jj} : scanned, p_{Ttotal} : 55 GeV,
 M_{ll} : 80 GeV, $\Delta\phi(ll)$: 1.8, M_T : scanned ($M_T < 125$ GeV)

$S/\sqrt{B+\Delta B^2}$



Punzi significance



$\Delta y(jj)$, CJV cut は、感度が一番高い

$\Delta y(jj) > 2.8$ 、Central leading jet $p_T < 20$ GeVに決めた。

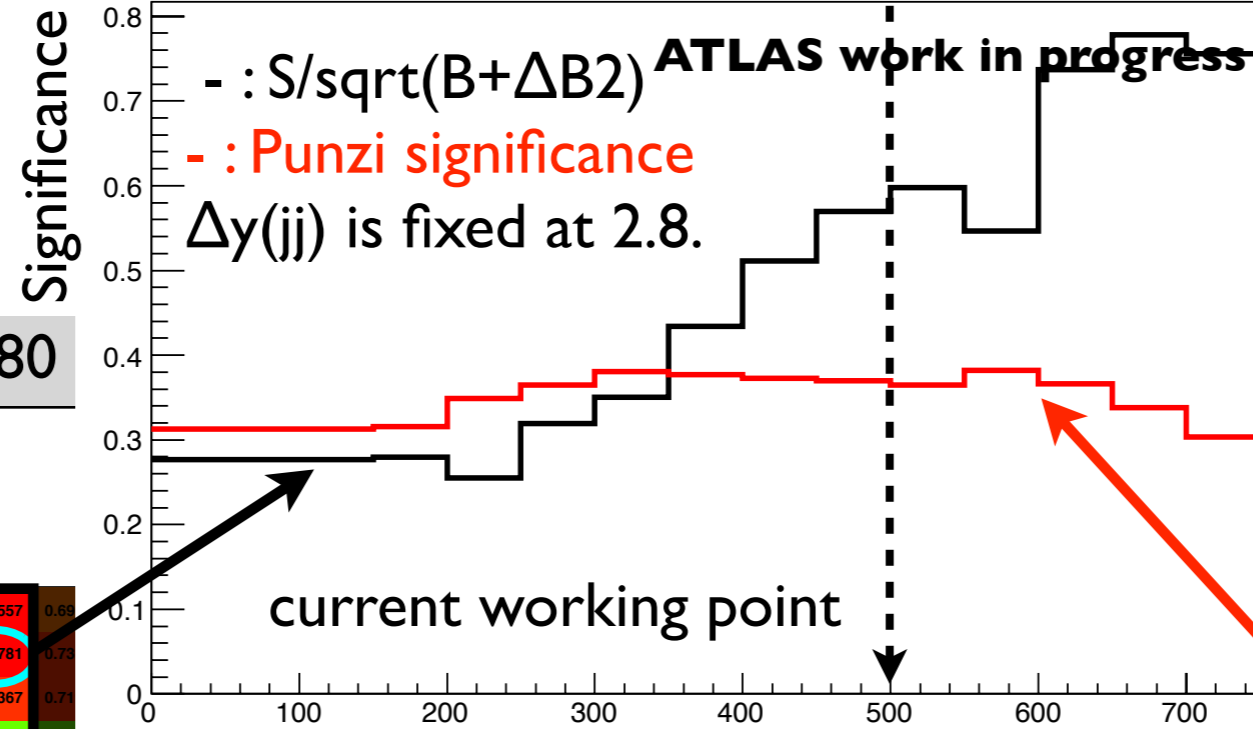
M_{jj} cut は統計の影響が少ない $M_{jj} > 500$ GeV に決めた。

DiJet 変数の最適化

- Significance

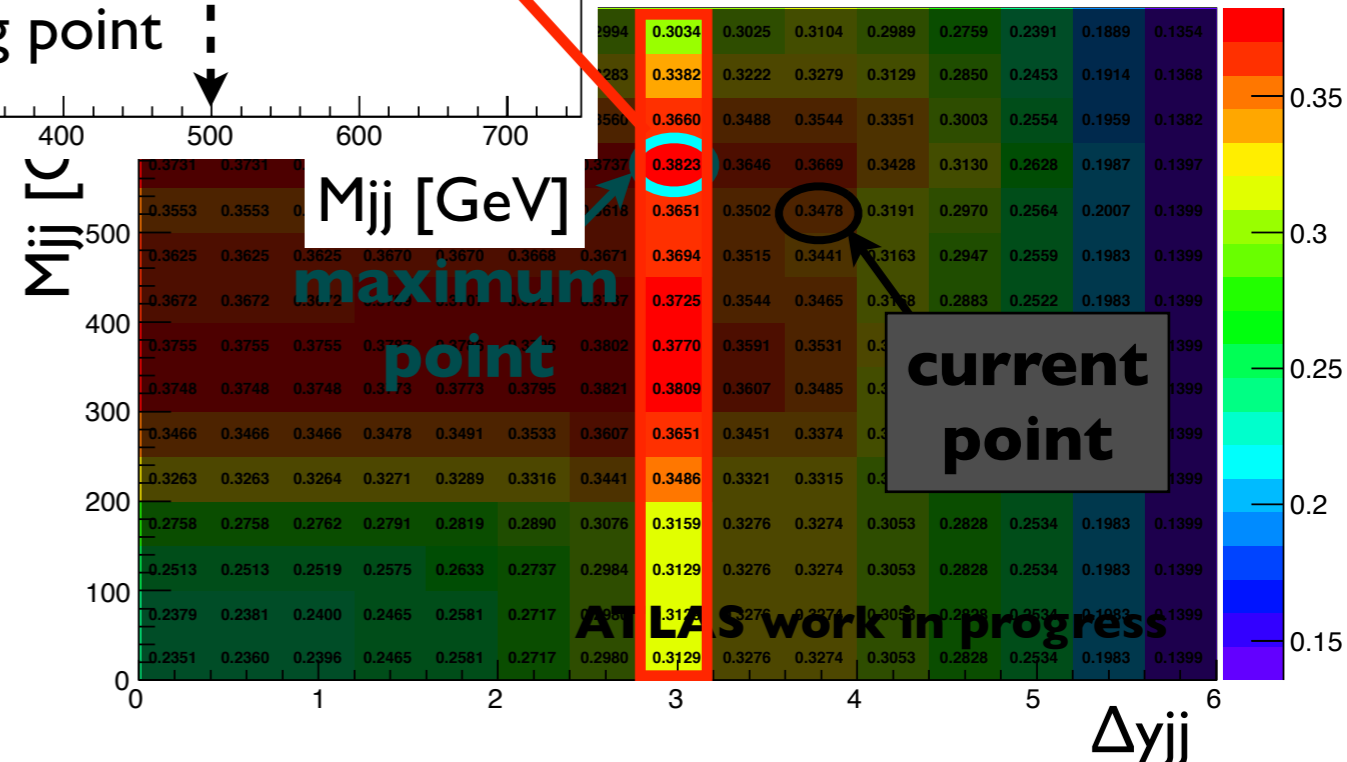
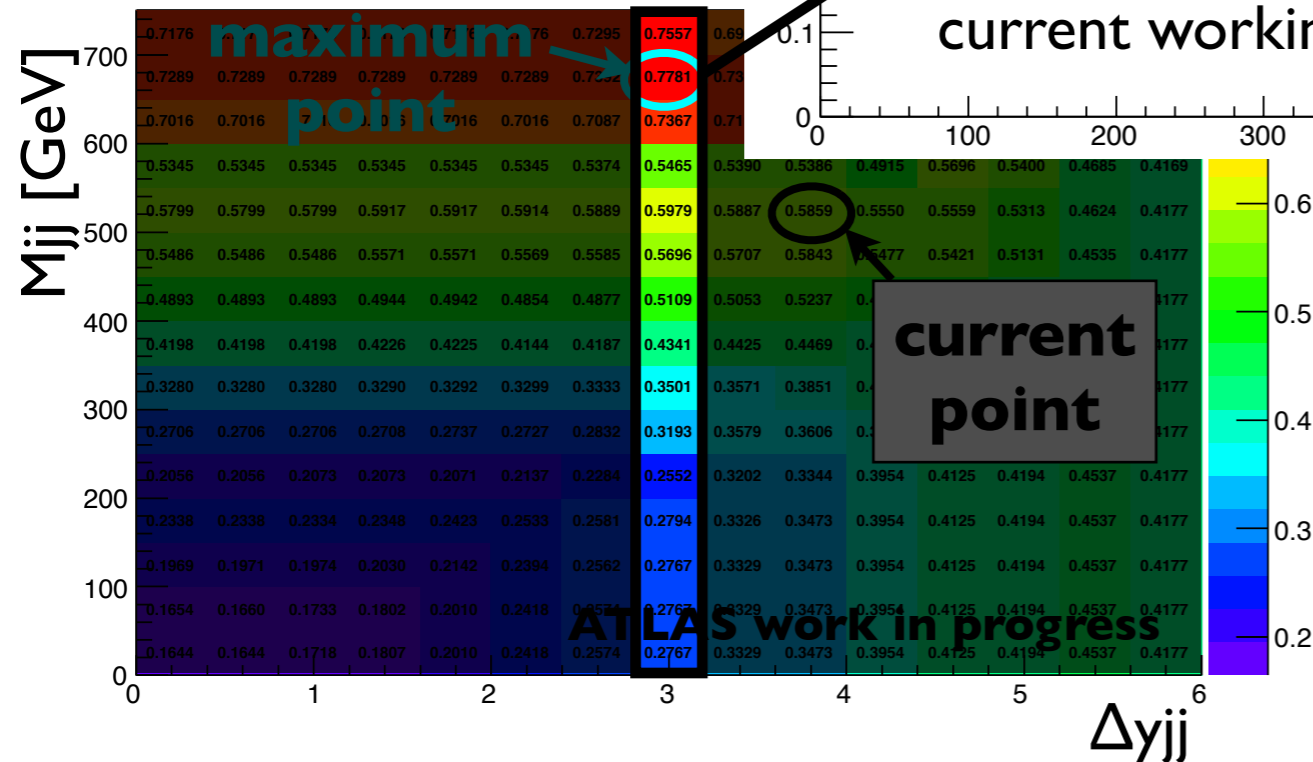
$\Delta y(jj)$: scanner

$M_{jj} > 80$



al : 55 GeV,
)

$S/\sqrt{B+\Delta B^2}$



$\Delta y(jj)$, CJV cut は、感度が一番高い

$\Delta y(jj) > 2.8$ 、Central leading jet $p_T < 20$ GeVに決めた。

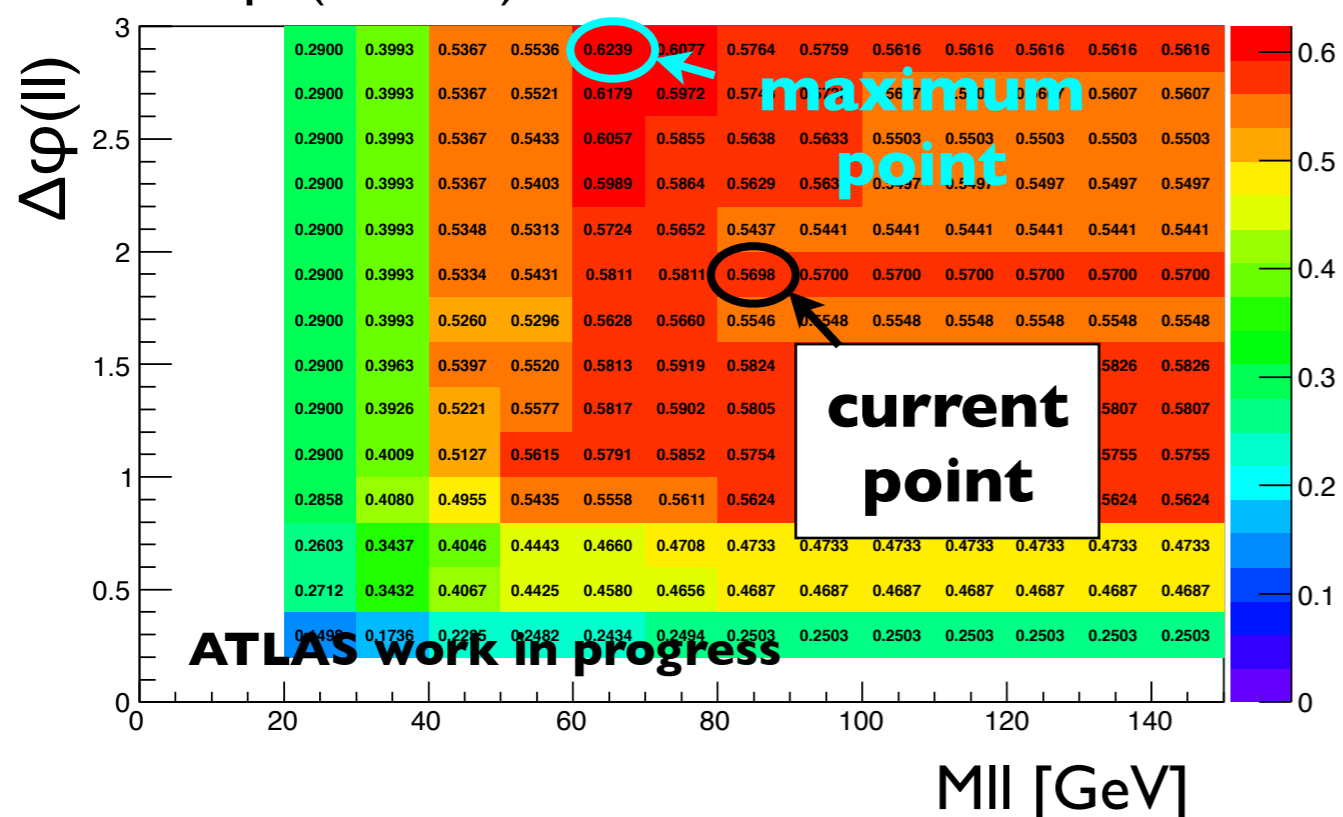
M_{jj} cut は統計の影響が少ない $M_{jj} > 500$ GeV に決めた。

Dilepton 変数の最適化

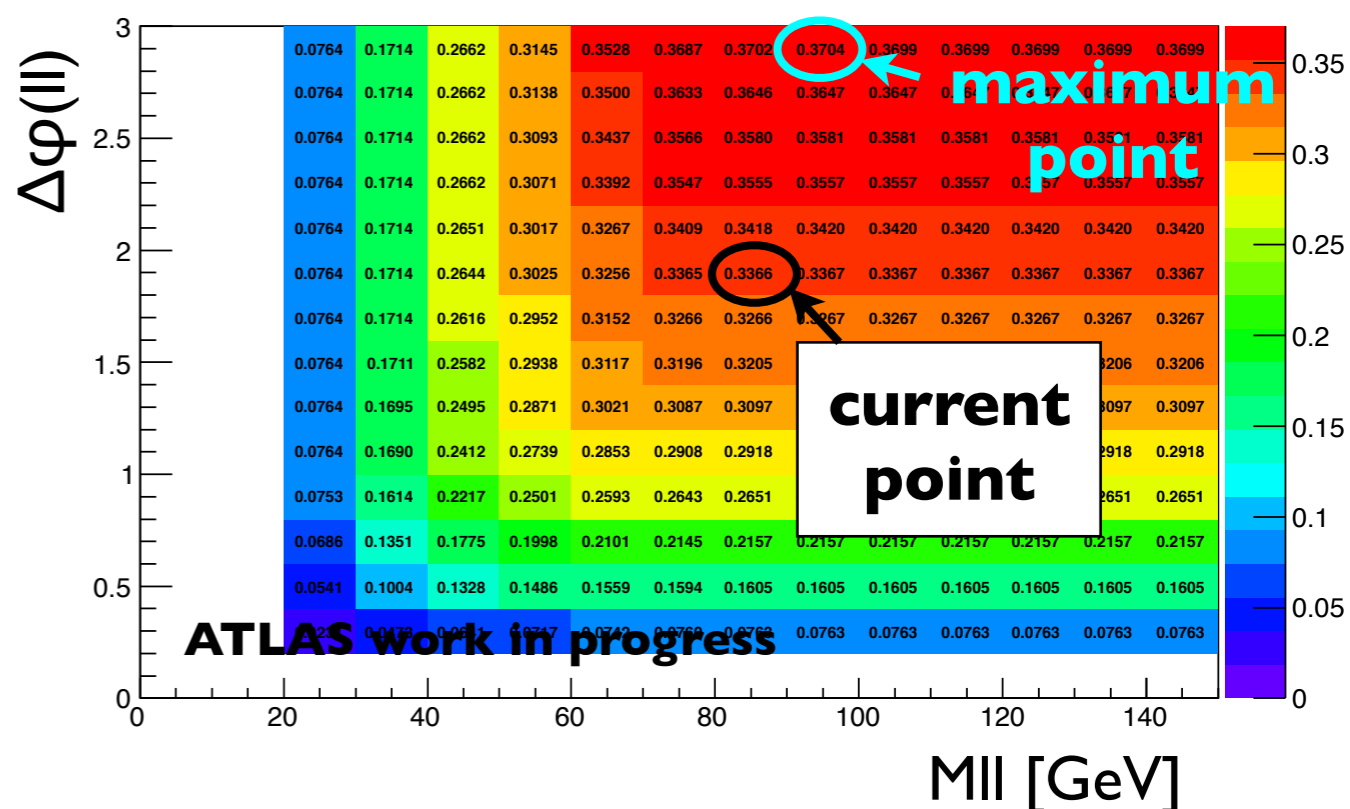
- Significance after all selections

$\Delta y(jj) : 3.8$, $CJV pT : 20 \text{ GeV}$, $M_{jj} : 500 \text{ GeV}$, $pT_{total} : 55 \text{ GeV}$,
 $M_{II} : \text{scanned}$, $\Delta\phi(II) : \text{scanned}$, $MT : \text{scanned} (MT < 125 \text{ GeV})$

$S/\sqrt{B+\Delta B^2}$



Punzi significance



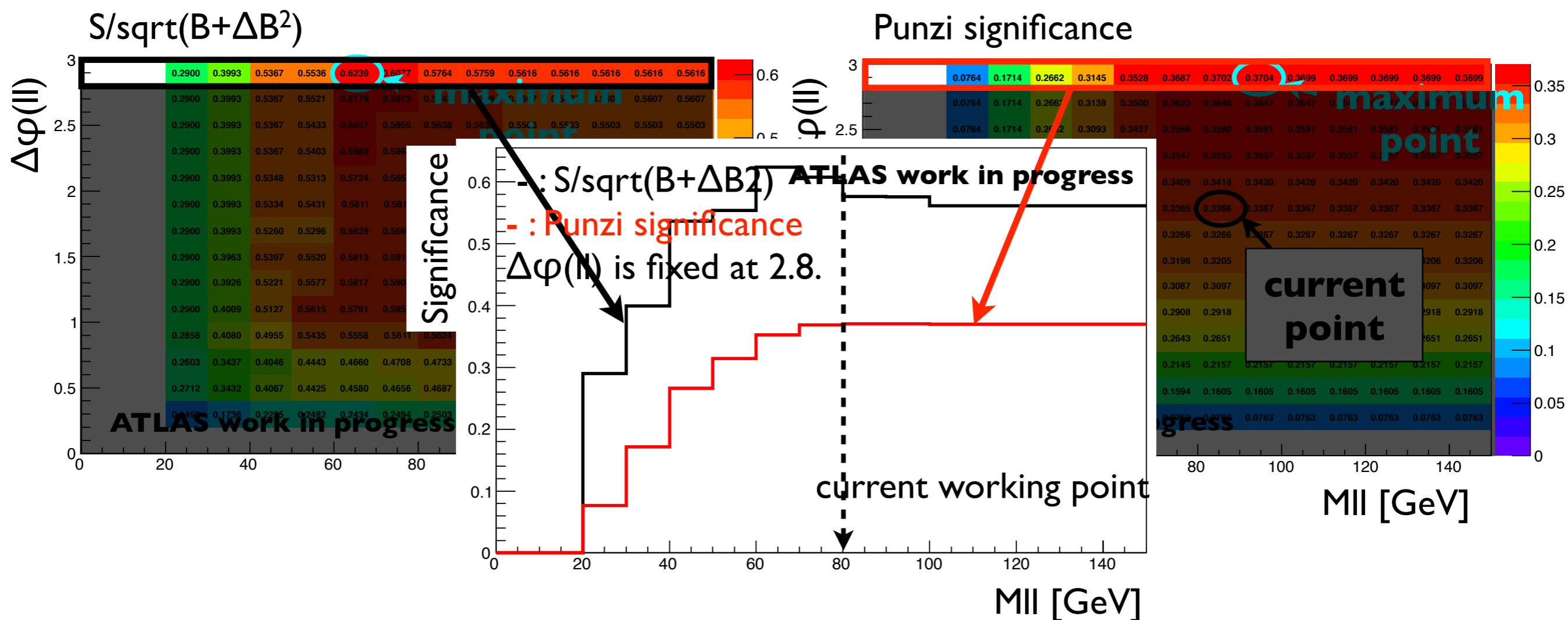
$\Delta\phi(II)$ cut は感度が一番高い $\Delta\phi(II) < 2.8$ に決めた。

M_{II} cut は $M_{II} < 80 \text{ GeV}$ に決めた。

Dilepton 変数の最適化

- Significance after all selections

$\Delta y(jj) : 3.8$, $CJV pT : 20 \text{ GeV}$, $M_{jj} : 500 \text{ GeV}$, $pT_{total} : 55 \text{ GeV}$,
 $M_{II} : \text{scanned}$, $\Delta\phi(II) : \text{scanned}$, $MT : \text{scanned} (MT < 125 \text{ GeV})$



$\Delta\phi(II)$ cut は感度が一番高い $\Delta\phi(II) < 2.8$ に決めた。

M_{II} cut は $M_{II} < 80 \text{ GeV}$ に決めた。

事象選択の最適化のまとめ

- 最適化前後での事象選択 最適化した事象選択

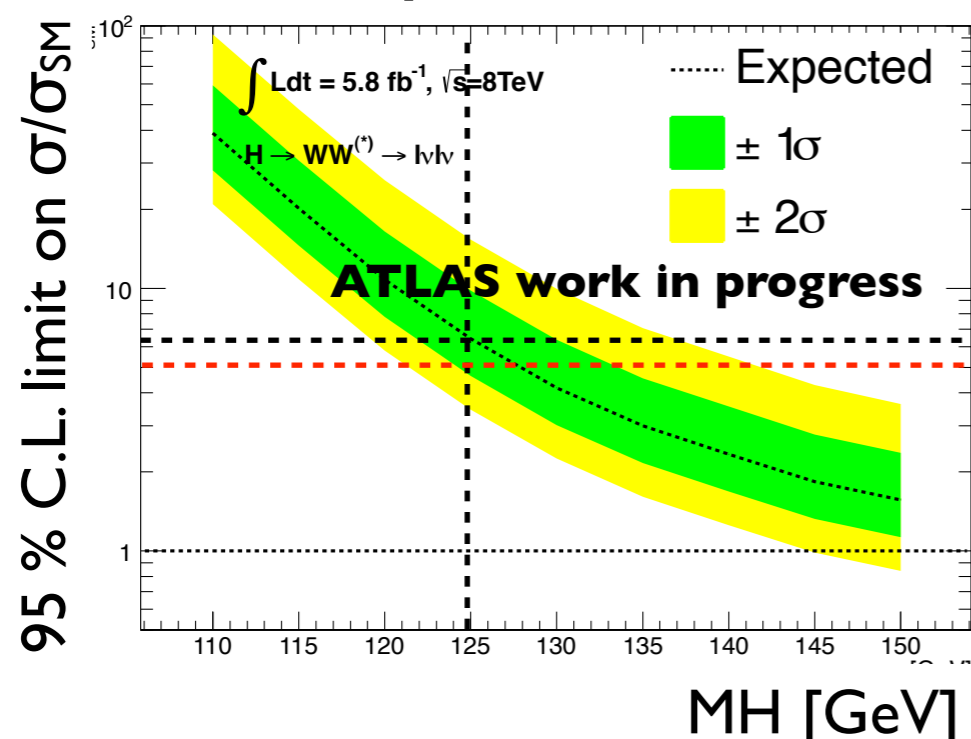
Event selections	Old	New
Number of jets	≥ 2	≥ 2
Number of b-jets	$= 0$	$= 0$
Outside Lepton Veto	\times	\circ
$\Delta y(jj)$	> 3.8	> 2.8
Central leading jet p_T	$< 20 \text{ GeV}$	$< 20 \text{ GeV}$
M_{jj}	$> 500 \text{ GeV}$	$> 500 \text{ GeV}$
$p_T(\text{total})$	$< 30 \text{ GeV}$	$< 55 \text{ GeV}$
Z to $\tau\tau$ veto	\circ	\circ
M_{ll}	$< 80 \text{ GeV}$	$< 80 \text{ GeV}$
$\Delta\phi(ll)$	< 1.8	< 2.8
M_T	$> 0.75 \times M_H \ \&\& \ < M_H$	$< M_H$

事象選択の最適化の結果

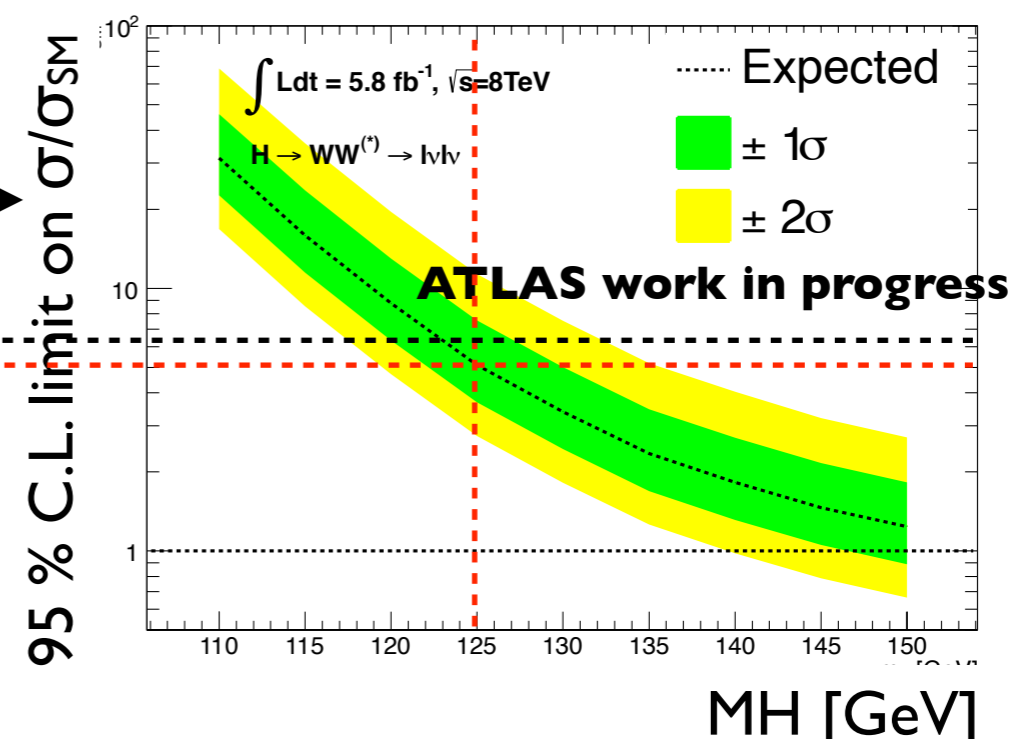
- 最適化前後での事象選択後の事象数 (8 TeV, 5.8 fb⁻¹)
Statistical error only

After MT cut	Signal	Total Background		S/√B
	VBF	ggF	others	
最適化前	0.4 ± 0.0	0.1 ± 0.0	0.6 ± 0.3	0.5 ± 0.1
最適化後	1.1 ± 0.0	0.3 ± 0.0	1.6 ± 0.4	0.9 ± 0.1

- The expected 95% CL upper limit on cross section



$$\sigma = 6.4 \times \sigma_{\text{SM}} \text{ at } 125 \text{ GeV}$$



$$\sigma = 5.1 \times \sigma_{\text{SM}} \text{ at } 125 \text{ GeV}$$

事象選択の最適化を行うことで感度が上がった

まとめと結論

- VBF Higgs \rightarrow WW \rightarrow $l\bar{l}l\bar{l}$ 解析において、ヒッグス粒子の探索を行なっている。
 - ヒッグスとゲージボソンの結合定数を綺麗に測定ができる。
- 事象選択の最適化を行った。
 - ➡ **狙い通り、感度は上がり、かつ統計量も増加した。**
- 更なる事象選択の最適化
 - Sub-leading lepton の p_T を下げる。

backup

- Pre-event selections
 1. Leading lepton $p_T > 25$ GeV
 2. Opposite charged leptons
 3. $M_{ll} > 10$ GeV for em and me, 15 GeV for ee and mm
 4. $|M_{ll} - M_Z| > 15$ GeV
 5. $M_{ETRel} > 20$ GeV for em and me, 45 GeV for ee and mm

- Electron selection(/ low pT mode)
 1. Author 1 or 3
 2. $ET > 15 \text{ GeV}$ (/ $ET > 10 \text{ GeV}$)
 3. $|\eta_{cl}| < 2.47$ excl. $1.37 < |\eta_{cl}| < 1.52$
 4. `el_OQ&I446 == 0`
 5. Tight++
 6. $z0 * \sin\theta < 0.4 \text{ mm}$
 7. $d0 / \sigma d0 < 3$
 8. $Etcone30 / ET < 0.16$
 9. $Ptcone40 / ET < 0.12$ for $ET < 25 \text{ GeV}$, 0.16 for $ET > 25 \text{ GeV}$ (/ $Ptcone40 / ET < 0.06$ for $ET < 15 \text{ GeV}$, 0.12 for $15 \text{ GeV} < ET < 25 \text{ GeV}$, 0.16 for $ET > 25 \text{ GeV}$)
 10. $dr(e, mu) < 0.1$, $dr(e, e) < 0.1$

- Muon selection (/ low pT mode)
 1. Staco combined muon
 2. $|\eta| < 2.5$
 3. $pT > 15\text{GeV}$ (/ $pT > 10\text{ GeV}$)
 4. MCP ID selection (Pixel, SCT, TRT...)
 5. $z0 \cdot \sin\theta < 1\text{ mm}$
 6. $d0/\sigma d0 < 3$
 7. $Etcone30 < 0.014 \cdot pT - 0.15$ && $Etcone30 < 0.2$
 8. $Ptcone30/pT < 0.01 \cdot pT - 0.105$ && $Ptcone30/pT < 0.15$ (/ $Ptcone40/pT < 0.05$ for $pT < 15\text{ GeV}$, $Ptcone30/pT < 0.01 \cdot pT - 0.105$ && $Ptcone30/pT < 0.15$ for $pT > 15\text{ GeV}$)

- Jet selection
 1. $|\eta| < 4.5$
 2. $p_T > 25 \text{ GeV}$ for $|\eta| < 2.5$, $p_T > 30 \text{ GeV}$ for $|\eta| > 2.5$
 3. $|j_{vtxf}| > 0.5$
 4. $dr(j, e) < 0.3$
 5. $dr(j, \mu) < 0.3$
- b-jet
 1. MVI 85%
 2. $p_T > 25 \text{ GeV}$
 3. $|\eta| < 2.5$
- Trigger
 - EF_e24vhi_medium I
 - EF_e60_medium I
 - EF_mu24i_tight
 - EF_mu36_tight

• Cutflow for all channel (MC only)

	Signal [125 GeV]	ggf [125 GeV]	vbf [125 GeV]	WW	WZ/ZZ/W γ	$t\bar{t}$	Single Top	Z+jets	W+jets	Total Bkg.
blinding	321.20 \pm 1.10	286.76 \pm 1.08	27.09 \pm 0.12	5996.77 \pm 18.67	4409.93 \pm 18.52	30376.81 \pm 49.10	3096.20 \pm 29.72	4094337.11 \pm 2326.73	5769.98 \pm 53.93	4143986.81 \pm 2328.21
lepton p_T	267.89 \pm 1.01	238.16 \pm 0.99	23.27 \pm 0.11	5692.13 \pm 18.17	3856.91 \pm 16.72	28766.64 \pm 47.75	2921.80 \pm 28.78	4012466.04 \pm 2310.11	5769.98 \pm 53.93	4059473.50 \pm 2311.55
OS leptons	267.26 \pm 1.00	237.94 \pm 0.98	23.25 \pm 0.11	5678.21 \pm 18.15	2885.53 \pm 13.60	28701.65 \pm 47.70	2895.95 \pm 28.33	4006809.18 \pm 2308.58	4864.15 \pm 53.27	4051834.66 \pm 2309.97
$m_{\ell\ell} > 12, 10$ GeV	262.56 \pm 1.00	233.60 \pm 0.98	22.95 \pm 0.11	5664.50 \pm 18.13	2862.85 \pm 13.51	28649.23 \pm 47.66	2891.23 \pm 28.30	4003217.29 \pm 2308.44	4576.83 \pm 53.02	4047861.92 \pm 2309.82
Scale factors		NF = 1.07		NF = 1.05	NF = 1.05					
Z veto (for $ee, \mu\mu$)	259.83 \pm 0.99	231.68 \pm 0.97	22.79 \pm 0.11	5391.67 \pm 18.26	1147.57 \pm 9.64	26711.04 \pm 47.08	2710.30 \pm 28.08	361057.06 \pm 603.97	1986.16 \pm 26.47	399003.80 \pm 607.38
$E_{T,rel}^{miss} > 45, 25$ GeV	131.82 \pm 0.71	119.89 \pm 0.70	9.34 \pm 0.07	2822.34 \pm 13.16	341.23 \pm 5.80	13204.90 \pm 33.09	1450.92 \pm 20.54	6910.97 \pm 79.29	370.28 \pm 7.62	25100.65 \pm 89.83
Z validation region (incl)	132.65 \pm 0.71	117.74 \pm 0.69	11.60 \pm 0.08	3435.71 \pm 14.11	2274.32 \pm 12.08	17435.74 \pm 37.13	1732.11 \pm 21.82	3650553.31 \pm 2230.54	3387.68 \pm 47.56	3678818.87 \pm 2231.54
Top validation region (incl)	12.36 \pm 0.22	9.70 \pm 0.21	1.97 \pm 0.03	165.49 \pm 3.17	43.08 \pm 1.99	11373.43 \pm 30.30	1010.99 \pm 16.87	402.75 \pm 19.21	99.48 \pm 4.50	13095.22 \pm 40.08
Scale factors		NF = 1.07		NF = 0.92	NF = 0.92					
0j: jet veto	73.74 \pm 0.54	72.09 \pm 0.54	0.83 \pm 0.02	1946.36 \pm 11.04	189.54 \pm 4.52	237.51 \pm 4.10	138.19 \pm 5.73	5049.62 \pm 67.75	180.00 \pm 4.97	7741.23 \pm 69.33
0j: $p_{T,\ell\ell} > 45, 30$ GeV	68.29 \pm 0.52	66.73 \pm 0.52	0.77 \pm 0.02	1672.06 \pm 10.23	157.62 \pm 4.12	215.68 \pm 3.91	127.86 \pm 5.52	665.02 \pm 22.64	140.86 \pm 2.90	2979.09 \pm 26.23
0j: $m_{\ell\ell} < 50$ GeV	56.56 \pm 0.48	55.32 \pm 0.47	0.64 \pm 0.02	426.56 \pm 5.28	51.36 \pm 2.37	39.88 \pm 1.78	26.66 \pm 2.63	252.98 \pm 6.75	46.85 \pm 1.57	844.28 \pm 9.57
0j: $\Delta\phi_{\ell\ell} < 1.8$	54.62 \pm 0.47	53.40 \pm 0.47	0.62 \pm 0.02	412.61 \pm 5.19	49.93 \pm 2.34	39.22 \pm 1.76	26.50 \pm 2.63	232.65 \pm 6.38	41.43 \pm 1.48	802.32 \pm 9.24
0j: $0.75 \cdot m_H \leq m_T \leq m_H$	34.13 \pm 0.37	33.58 \pm 0.37	0.38 \pm 0.01	174.23 \pm 3.38	19.58 \pm 1.45	11.10 \pm 0.88	5.98 \pm 1.10	139.96 \pm 4.92	27.44 \pm 1.18	378.29 \pm 6.41
0j: Z validation region	62.85 \pm 0.50	61.41 \pm 0.50	0.78 \pm 0.02	2332.21 \pm 11.75	993.06 \pm 7.45	272.14 \pm 4.54	151.88 \pm 6.23	2872389.56 \pm 1960.26	2355.41 \pm 40.10	2878494.27 \pm 1960.74
0j: WW control region	0.10 \pm 0.02	0.08 \pm 0.02	0.00 \pm 0.00	750.09 \pm 6.45	64.29 \pm 2.62	130.97 \pm 2.96	75.53 \pm 4.12	159.91 \pm 14.14	45.62 \pm 1.64	1226.41 \pm 16.64
Scale factors		NF = 0.91		NF = 1.09	NF = 1.09					
1j: one jet	37.69 \pm 0.38	33.45 \pm 0.37	3.53 \pm 0.04	549.38 \pm 5.25	108.71 \pm 3.15	2509.85 \pm 14.56	740.16 \pm 14.67	1406.65 \pm 35.86	88.72 \pm 3.61	5403.47 \pm 42.00
1j: b-jet veto	32.08 \pm 0.35	28.52 \pm 0.34	3.03 \pm 0.04	463.41 \pm 4.78	84.31 \pm 2.77	532.00 \pm 6.83	174.30 \pm 7.45	1173.12 \pm 32.90	66.42 \pm 2.90	2493.55 \pm 34.98
1j: $p_{T,tot} < 30$ GeV	18.52 \pm 0.27	16.71 \pm 0.26	1.54 \pm 0.03	292.19 \pm 3.86	46.87 \pm 2.15	214.78 \pm 4.40	93.18 \pm 5.52	313.28 \pm 18.82	27.69 \pm 1.82	987.99 \pm 20.66
1j: $Z \rightarrow \tau\tau$ veto	18.46 \pm 0.27	16.67 \pm 0.26	1.53 \pm 0.03	285.10 \pm 3.82	44.97 \pm 2.10	206.08 \pm 4.32	89.94 \pm 5.44	287.37 \pm 17.50	26.77 \pm 1.77	940.23 \pm 19.41
1j: $m_{\ell\ell} < 50$ GeV	14.42 \pm 0.24	13.05 \pm 0.23	1.21 \pm 0.03	62.08 \pm 1.77	14.84 \pm 1.27	39.00 \pm 1.97	19.85 \pm 2.51	79.43 \pm 6.65	10.30 \pm 1.02	225.49 \pm 7.76
1j: $\Delta\phi_{\ell\ell} < 1.8$	13.34 \pm 0.23	12.07 \pm 0.22	1.13 \pm 0.03	56.75 \pm 1.69	13.64 \pm 1.22	37.56 \pm 1.92	19.17 \pm 2.47	54.08 \pm 4.56	8.35 \pm 0.84	189.55 \pm 5.97
1j: $0.75 \cdot m_H \leq m_T \leq m_H$	7.81 \pm 0.17	7.14 \pm 0.17	0.62 \pm 0.02	19.68 \pm 1.00	4.11 \pm 0.62	9.59 \pm 0.94	5.82 \pm 1.31	28.55 \pm 2.29	3.61 \pm 0.52	71.35 \pm 3.08
1j: Z validation region	42.24 \pm 0.40	37.11 \pm 0.39	4.11 \pm 0.05	807.84 \pm 6.72	769.19 \pm 7.29	2672.29 \pm 14.36	805.40 \pm 14.57	584278.29 \pm 917.06	658.38 \pm 21.24	589991.38 \pm 917.59
1j: WW control region	0.05 \pm 0.01	0.03 \pm 0.01	0.00 \pm 0.00	156.91 \pm 2.97	19.34 \pm 1.37	116.85 \pm 3.16	48.50 \pm 3.78	53.11 \pm 8.60	8.43 \pm 0.86	403.14 \pm 10.47
1j: Top control region	3.08 \pm 0.11	2.74 \pm 0.11	0.26 \pm 0.01	59.06 \pm 1.95	13.09 \pm 1.17	768.84 \pm 7.84	311.94 \pm 9.04	61.37 \pm 8.37	8.87 \pm 1.32	1223.16 \pm 14.84
$E_{T,rel}^{miss} > 45, 20$ GeV	131.82 \pm 0.71	119.89 \pm 0.70	9.34 \pm 0.07	2822.34 \pm 13.16	341.23 \pm 5.80	13204.90 \pm 33.09	1450.92 \pm 20.54	6910.97 \pm 79.29	370.28 \pm 7.62	25100.65 \pm 89.83
Scale factors				NF = 1.04	NF = 1.04					
$\geq 2j$: at least two jets	20.39 \pm 0.26	14.35 \pm 0.24	4.97 \pm 0.05	214.83 \pm 3.40	42.98 \pm 1.81	10510.37 \pm 29.58	581.57 \pm 13.41	454.70 \pm 20.28	101.56 \pm 4.51	11906.00 \pm 38.74
$\geq 2j$: b-jet veto	13.89 \pm 0.21	9.76 \pm 0.20	3.56 \pm 0.04	147.35 \pm 2.77	26.17 \pm 1.39	540.04 \pm 6.93	68.92 \pm 4.68	296.46 \pm 16.22	27.80 \pm 2.14	1106.75 \pm 18.63
$\geq 2j$: Outside-lepton veto	6.07 \pm 0.12	3.18 \pm 0.11	2.81 \pm 0.04	31.87 \pm 1.23	7.05 \pm 0.76	157.39 \pm 3.75	18.07 \pm 2.46	69.07 \pm 7.61	3.77 \pm 0.97	287.21 \pm 9.01
$\geq 2j$: $\Delta Y_{jj} > 2.4$	4.82 \pm 0.10	2.16 \pm 0.09	2.65 \pm 0.04	20.96 \pm 1.00	4.49 \pm 0.59	93.26 \pm 2.91	12.32 \pm 2.07	38.26 \pm 5.61	2.63 \pm 0.71	171.93 \pm 6.79
$\geq 2j$: CJV (20 GeV)	3.82 \pm 0.09	1.52 \pm 0.08	2.30 \pm 0.04	16.00 \pm 0.87	3.55 \pm 0.51	51.04 \pm 2.14	9.18 \pm 1.84	27.12 \pm 4.85	1.36 \pm 0.50	108.25 \pm 5.72
$\geq 2j$: $m_{jj} > 300$ GeV	2.84 \pm 0.07	0.82 \pm 0.06	2.02 \pm 0.03	9.34 \pm 0.65	1.56 \pm 0.33	25.05 \pm 1.46	5.77 \pm 1.51	6.75 \pm 2.13	0.71 \pm 0.39	49.17 \pm 3.10
$\geq 2j$: $p_{T,tot} < 55$ GeV	2.60 \pm 0.06	0.69 \pm 0.05	1.91 \pm 0.03	8.48 \pm 0.61	1.06 \pm 0.27	20.77 \pm 1.34	4.34 \pm 1.22	3.86 \pm 1.81	0.50 \pm 0.35	39.01 \pm 2.67
$\geq 2j$: $Z \rightarrow \tau\tau$ veto	2.56 \pm 0.06	0.68 \pm 0.05	1.88 \pm 0.03	8.16 \pm 0.60	1.06 \pm 0.27	19.87 \pm 1.31	4.01 \pm 1.18	3.86 \pm 1.81	0.43 \pm 0.34	37.38 \pm 2.63
$\geq 2j$: $m_{\ell\ell} < 90$ GeV	2.56 \pm 0.06	0.68 \pm 0.05	1.88 \pm 0.03	4.64 \pm 0.45	0.70 \pm 0.23	9.25 \pm 0.93	2.17 \pm 0.98	3.61 \pm 1.79	0.21 \pm 0.30	20.59 \pm 2.32
$\geq 2j$: $\Delta\phi_{\ell\ell} < 2.8$	2.50 \pm 0.06	0.67 \pm 0.05	1.82 \pm 0.03	4.29 \pm 0.43	0.69 \pm 0.23	8.44 \pm 0.91	2.17 \pm 0.98	2.26 \pm 1.17	0.21 \pm 0.28	18.07 \pm 1.86
$\geq 2j$: $0.75 \cdot m_H \leq m_T \leq m_H$	1.35 \pm 0.05	0.37 \pm 0.04	0.98 \pm 0.02	0.96 \pm 0.21	0.25 \pm 0.14	1.56 \pm 0.39	0.17 \pm 0.17	1.51 \pm 1.15	-0.03 \pm 0.14	4.42 \pm 1.26
$\geq 2j$: Z validation region	27.56 \pm 0.30	19.23 \pm 0.28	6.71 \pm 0.06	295.66 \pm 3.99	512.07 \pm 6.10	14491.32 \pm 33.93	774.83 \pm 15.00	193885.46 \pm 540.07	373.88 \pm 14.25	210333.22 \pm 541.58
$\geq 2j$: Top control region	6.64 \pm 0.15	4.67 \pm 0.14	1.46 \pm 0.03	68.90 \pm 2.02	17.61 \pm 1.21	9559.81 \pm 27.88	489.55 \pm 12.17	163.90 \pm 12.62	76.80 \pm 3.96	10376.57 \pm 33.25
$\geq 2j$: Top control region (fit)	0.26 \pm 0.02	0.05 \pm 0.02	0.20 \pm 0.01	0.56 \pm 0.19	0.13 \pm 0.11	20.51 \pm 1.22	1.81 \pm 0.95	0.00 \pm 0.00	0.13 \pm 0.16	23.15 \pm 1.57

- **Poisson significance**

$$Sig. = \sqrt{2((s + b)\ln(1 + \frac{s}{b}) - s)}$$