Hadronic Higgs Recoil Mass Study with ILD at 250GeV

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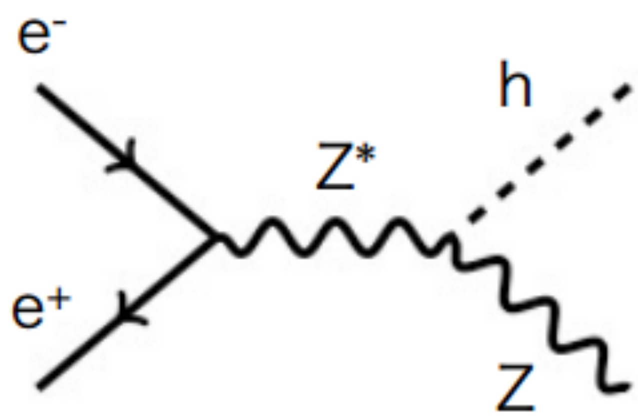
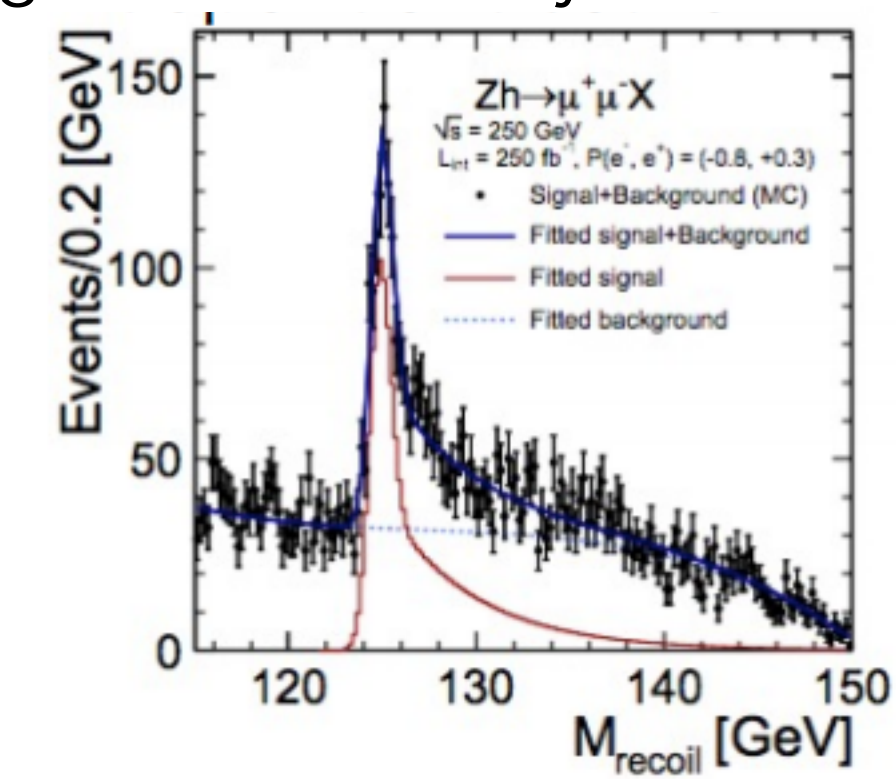
Overview - qqH channel



Using 4 momentum conservation,
we can calculate the mass of Higgs boson
without observing Higgs boson directly.



Especially in Z -> leptonic channel,
its mass distribution has quite high precision.
But, its BR is only ~3.4% for each generation.

In contrast, the branching ratio of **Z -> hadronic is ~70%**.

- **More statistics**

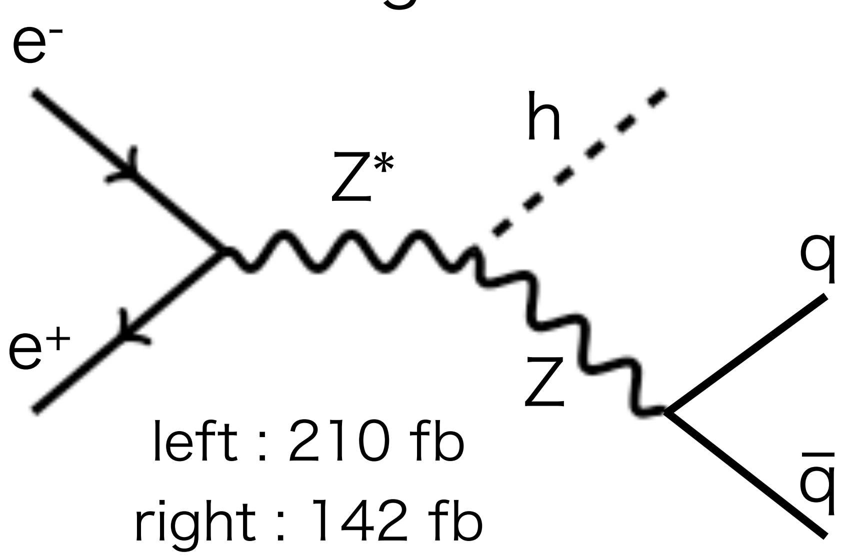
Model independent?

- **More background**

Data samples

Higgs mass	E_{CM}	Luminosity	Polarization	Detector
125 GeV	250 GeV	250 fb^{-1}	left: (-0.8, +0.3) right:(+0.8, -0.3)	ILD_DBD ver.

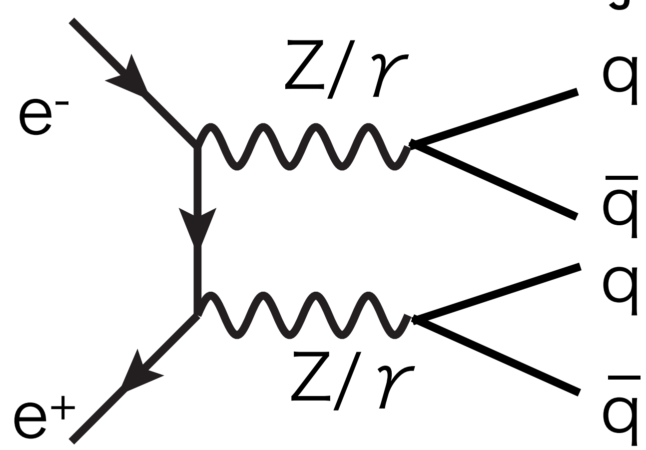
signal



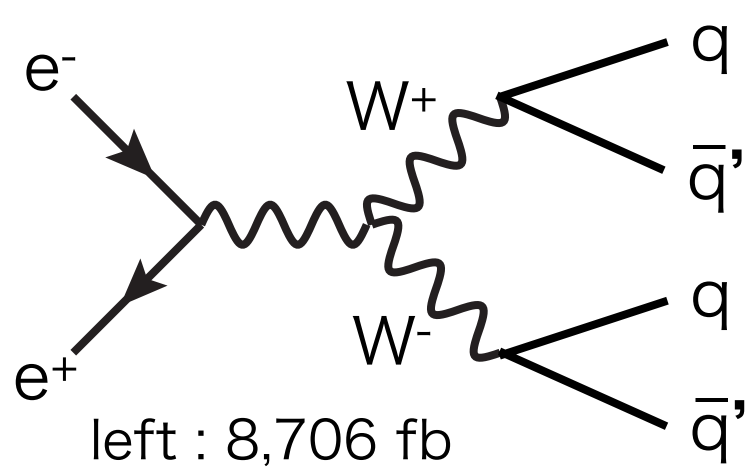
left : 210 fb
right : 142 fb

semi-leptonic events
are also considerable BG.

Major background

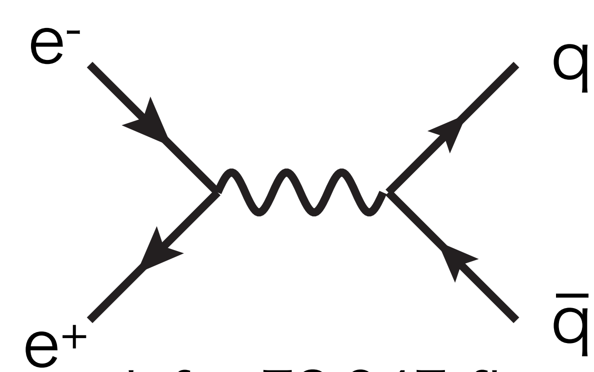


left : 841 fb
right : 403 fb



left : 8,706 fb
right : 600 fb

4 fermion



left : 78,047 fb
right : 46,214 fb

2 fermion

Analysis flow

- To improve jet clustering,
  - Initial state radiation
  - Isolated lepton
  - Hadronic tau jet were removed from events.
- Durham jet clustering was applied to the remaining events.

$$y = \frac{2\min(E_i^2, E_j^2)(1 - \cos\theta_{ij})}{Q^2}$$

- Forced 4 jet clustering, y threshold clustering were used.

Background reduction

- 4 fermion background - using forced 4 jet clustering,

- 2 fermion background - Thrust and Sphericity were used.

- S/N separation
  — reconstructed the mass of Z candidate 2-jet with y value clustering (y = 0.0025).
  — reconstructed the transverse momentum of Z candidate.
  — The distribution of Hadronic recoil mass.

- After applying these cuts,

	signal	4 fermion	2 fermion	others
% of events after cuts	46.2%	8.3%	1.4%	0.3%

Cut efficiency issue

- After applying cuts, tested cut efficiencies for each Higgs decay.

mode	After cuts (%)	diff./mean
H->all	46.2%	-----
H->bb (57.7%)	43.3%	-6.3%
H->WW(leptonic) (2.3%)	45.3%	-2.0%
H->WW(semi-leptonic) (9.5%)	46.9%	+1.4%
H->WW(hadronic) (9.8%)	54.4%	+17.7%
H->gg (8.6%)	55.2%	+19.5%
H->$\tau\tau$ (6.3%)	45.3%	-2.1%
H->ZZ (2.6%)	48.6%	+5.1%
H->cc (2.9%)	47.1%	+1.8%
H->invisible (ZZ->4n) (0.1%)	35.4%	-23.4%

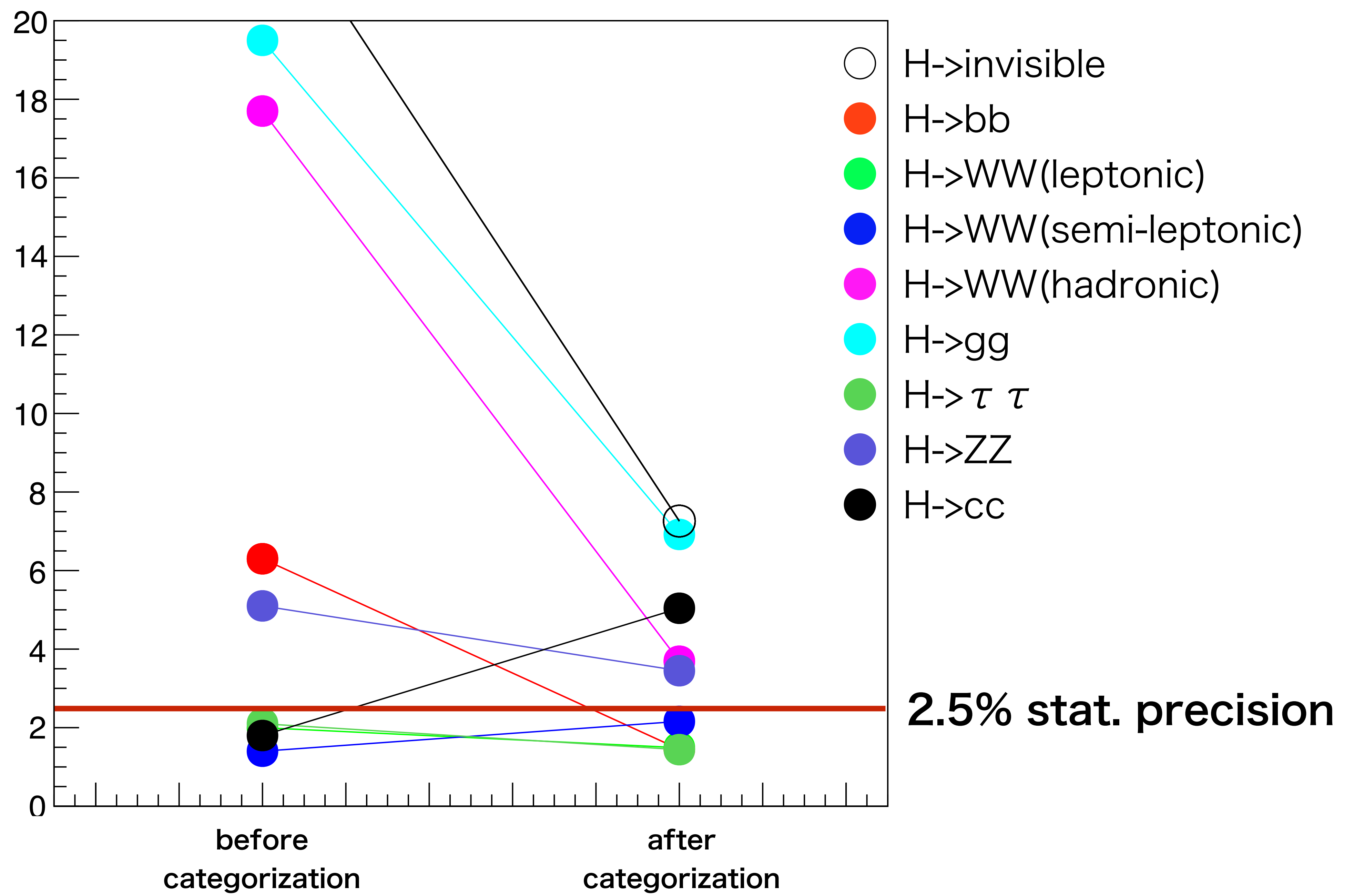
- The large inconsistency was found in H->gg, H->WW->4q and invisible.

Categorization (Reduction of inconsistency)

- The inconsistency of cut efficiency will affect the measurements of σ_{ZH}.
- This systematics uncertainty should be smaller than the statistical one.
- For reducing this inconsistency, the categorization is one of the powerful solution.
- Classify the whole event into the nine categories using number of isolated leptons, tau jets, b-tag (>0.6), c-tag (>0.6).
- Then, optimize the cut in each category.

Cut efficiency and Categorization

- After categorizing events and applying much optimized cuts,
- The efficiency inconsistency is at most ~ 7 %.



Two Luminosity case

polarization and Luminosity	significance σ_{ZH}	stat. precision σ_{ZH}	stat. precision g_{ZZH}	stat. precision g_{ZZH} (combined)
left (-0.8, +0.3) 250 fb^{-1}	**38.0σ**	**2.6%**	**1.3%**	**1.0%**
right (+0.8, -0.3) 250 fb^{-1}	**41.8σ**	**2.4%**	**1.2%**	**1.0%**
left (-0.8, +0.3) 1150 fb^{-1} (Lumi UP)	**81.5σ**	**1.2%**	**0.6%**	**0.5%**
right (+0.8, -0.3) 1150 fb^{-1} (Lumi UP)	**89.7σ**	**1.1%**	**0.6%**	**0.5%**

The effect of the different BR from SM

base	210.06	141.70	—	—
bb + 5% (57.7->62.7)	210.15	141.64	~0.0%	~0.0%
bb - 5% (57.7->52.7)	209.95	141.77	~0.0%	~0.0%
cc + 5% (2.9->7.9)	208.92	140.99	-0.5%	-0.5%
cc - 5% (2.9->0.0)	210.68	142.09	+0.3%	+0.3%
gg + 5% (8.6->13.6)	209.84	141.74	-0.1%	~0.0%
gg - 5% (8.6->3.6)	210.27	141.66	+0.1%	~0.0%
WW + 5% (21.6->26.6)	209.92	141.70	-0.1%	~0.0%
WW - 5% (21.6->16.6)	210.02	141.58	~0.0%	-0.1%
tau + 5% (6.3->11.3)	210.29	141.85	+0.1%	+0.1%
tau - 5% (6.3->1.3)	209.82	141.55	-0.1%	-0.1%
ZZ + 5% (2.6->7.6)	210.40	141.96	+0.2%	+0.2%
ZZ - 5% (2.6->0.0)	209.97	141.63	~0.0%	-0.1%
invisible + 5% (0.1->5.1)	210.29	142.34	+0.1%	+0.5%
invisible - 5% (0.1->0.0)	210.10	141.73	~0.0%	~0.0%

The different BR has only ~0.5 % effect on total cross section of ZH production.
This is much smaller than current stat. precision.

Stat. precision in the "worst case"

- If $\sigma_{tot} \times BR$ is not changed from SM, but g_{ZZH} is changed. The stat. precision of some major decay mode will suppressed.

- bb and tau tau mode were examined because these two decay mode mainly contribute the significance of σ_{tot}.

- Tau decay is not so serious problem for stat. precision.

- Still keep less than 4 % stat. precision in right polarization

	stat. precision of σZH	stat. precision of gZZH
$\sigma_{tot} \times BR_{bb} = SM$	left : 3.8% right : 3.0%	left : 1.9% right : 1.5%
$\sigma_{tot} \times BR_{\tau\tau} = SM$	left : 2.8% right : 2.6%	left : 1.4% right : 1.3%
$\sigma_{tot} \times BR_{\tau\tau} = SM$ $\sigma_{tot} \times BR_{bb} = SM$	left : 4.7% right : 3.5%	left : 2.3% right : 1.8%

350 GeV case

polarization and Luminosity	significance σ_{ZH}	stat. precision σ_{ZH}	stat. precision g_{ZZH}	stat. precision g_{ZZH} (combined)
350 GeV left (-0.8, +0.3) 333 fb^{-1}	**30.1 σ**	**3.3%**	**1.7%**	**1.4%**
350 GeV right (+0.8, -0.3) 333 fb^{-1}	**31.1 σ**	**3.2%**	**1.6%**	**1.3%**

The inconsistency of cut efficiency is about 10 %.

※ cut variables was slightly optimized from 250 GeV, but need more effort.

Summary and Prospects

summary

- Using categorization, the difference of cut efficiency is suppressed at most ~ 7 %.
- Stat. precision is about ~ 2.5 % which is almost the same as leptonic channel (ILC Higgs White paper's results)
- In worst case, the stat. precision is less than 4.0 % (σ_{ZH})

	significance	stat. precision
250 GeV (-0.8,+0.3) 250fb^{-1}	**38.0 σ**	**2.6%**
250 GeV (+0.8,-0.3) 250fb^{-1}	**41.8 σ**	**2.4%**
350 GeV (-0.8,+0.3) 333fb^{-1}	**30.1 σ**	**3.3%**
350 GeV (+0.8,-0.3) 333fb^{-1}	**31.1 σ**	**3.2%**

prospects

- cut optimization for 350 GeV (flavor tagging, cut variables…)
- Investigate the systematic uncertainty in both E_{CM}.

backup slides

Strategy to reduce inconsistency (Categorization)

- Categorization is a powerful tool to reduce difference of efficiency among Higgs decay modes.
  - Categorize events using number of jets, leptons, taus, etc.
  - Minimize the difference of efficiency in each category (decay modes with too small fraction in the category is negligible.)
  - Calculate partial cross section from each category
  - Combine all cross section from categories to get the total cross section of ZH production.

Categorization -1

To resolve efficiency inconsistent issue, we will categorize events using

- the number of tau jets (0, 1, and >= 2)
- the number of isolated lepton (0, 1, and >= 2)

$$\mathrm{N}^i = \sum_n \sigma_{\mathrm{tot}} \cdot \mathrm{BR}_n \cdot \theta_n^i \cdot \epsilon_n^i$$

$$\mathrm{n} = (\mathrm{b}, \mathrm{W}, \mathrm{g}, \tau, ...)$$

N^i is a number of events in category i, σ_{tot} is total cross section, BR_n is Higgs decay branching ratio, θ_n^i is fraction in category i, ϵ_n^i is cut efficiency for category i.

If the cut efficiency of each decay mode can be assumed to be the same as ϵ^i($= \epsilon_n^i$).

$$\frac{\mathrm{N}^i}{\epsilon^i} = \sigma_{\mathrm{tot}} \sum_n \mathrm{BR}_n \cdot \theta_n^i$$

Then we can get

$$\sum_i \frac{\mathrm{N}^i}{\epsilon^i} = \sigma_{\mathrm{tot}} \sum_n \sum_i \mathrm{BR}_n \cdot \theta_n^i = \sigma_{\mathrm{tot}}$$

Categorization

If the cut efficiency is not exactly the same,
we should consider the systematic effect caused by the difference.

$$\delta\epsilon_n^i = \epsilon_n^i - \epsilon^i$$

And the cross section is

$$\sigma_{\mathrm{tot}} = \frac{\sum_i \frac{\mathrm{N}^i}{\epsilon^i}}{1 + \sum_n \sum_i \mathrm{BR}_n \cdot \theta_n^i \cdot \frac{\delta\epsilon_n^i}{\epsilon^i}}$$

We want to keep systematic uncertainty is less than 1 % to do model independent analysis.

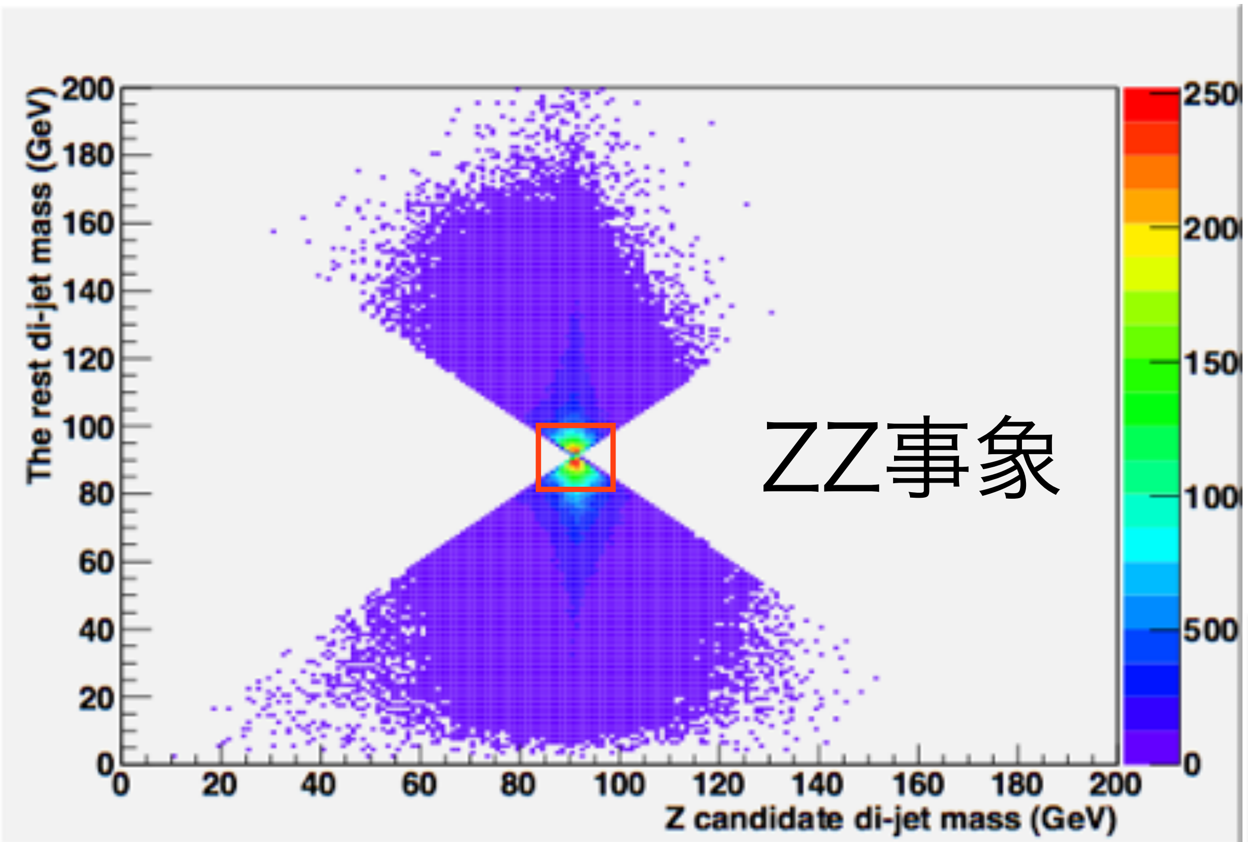
If we don't assume any models, we should keep $\theta_n^i \cdot \frac{\delta\epsilon_n^i}{\epsilon^i}$ << 1 %.

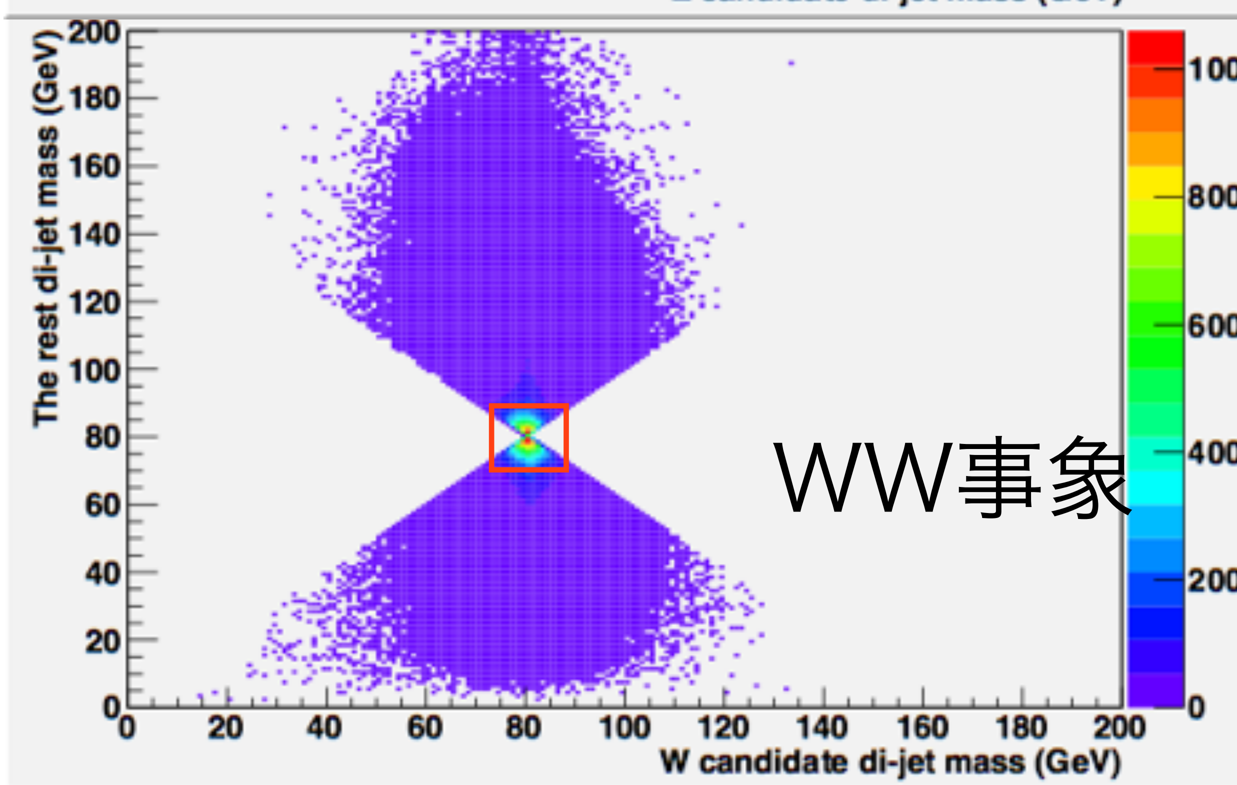
If we can assume SM like Higgs, we should keep $\mathrm{BR}_n \cdot \theta_n^i \cdot \frac{\delta\epsilon_n^i}{\epsilon^i}$ << 1 %.

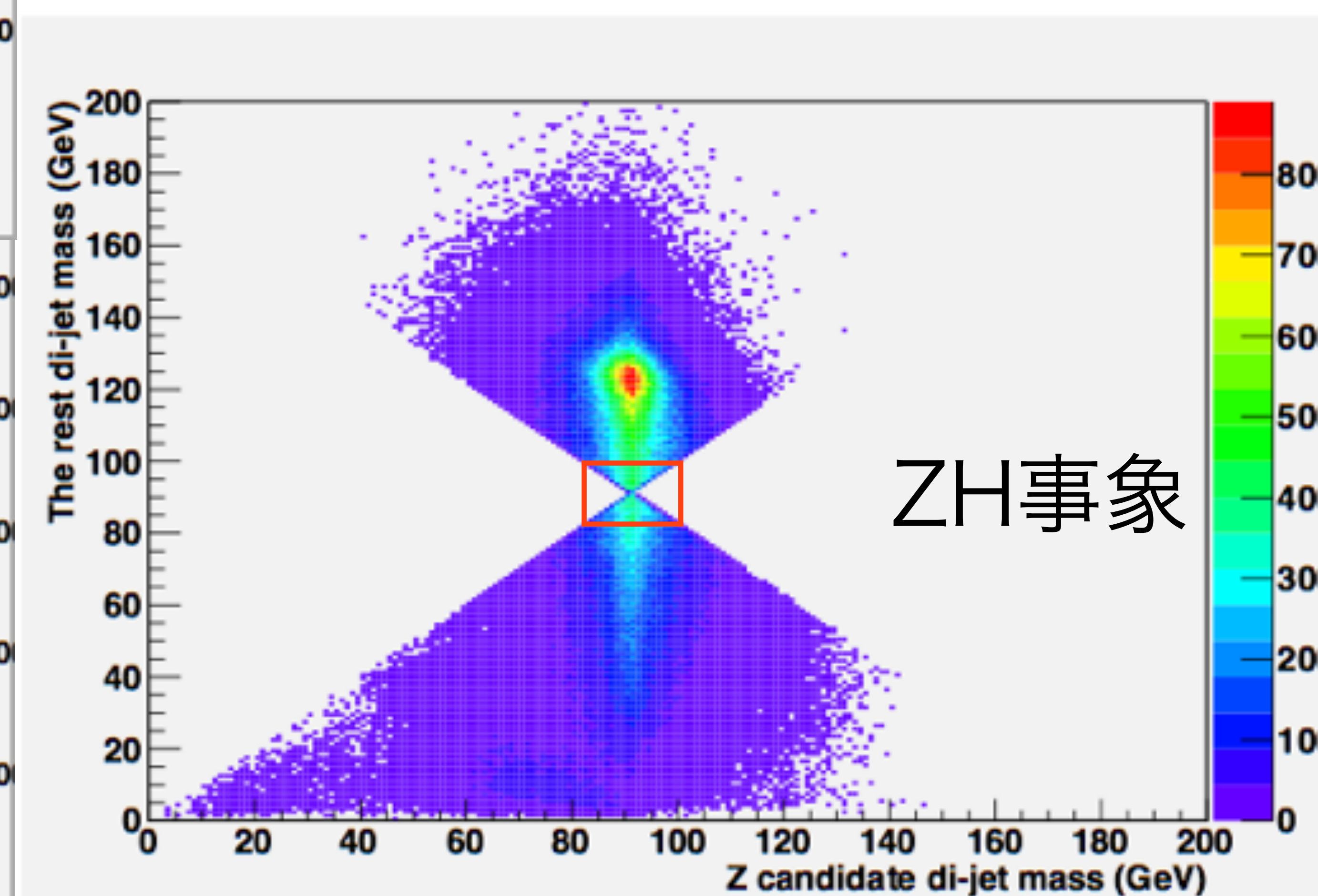
背景事象の低減 ①

- 4 fermion事象の低減 -> 各粒子の質量差を利用
  4つのジェットにクラスタリング -> 2つずつのジェットの組みで質量を再構成する

Z粒子 91GeV
W粒子 80GeV
ヒッグス粒子 125GeV







背景事象の低減 ②

- 2 fermion 事象の低減のために、
  SphericityとThrustによるカットを適用した

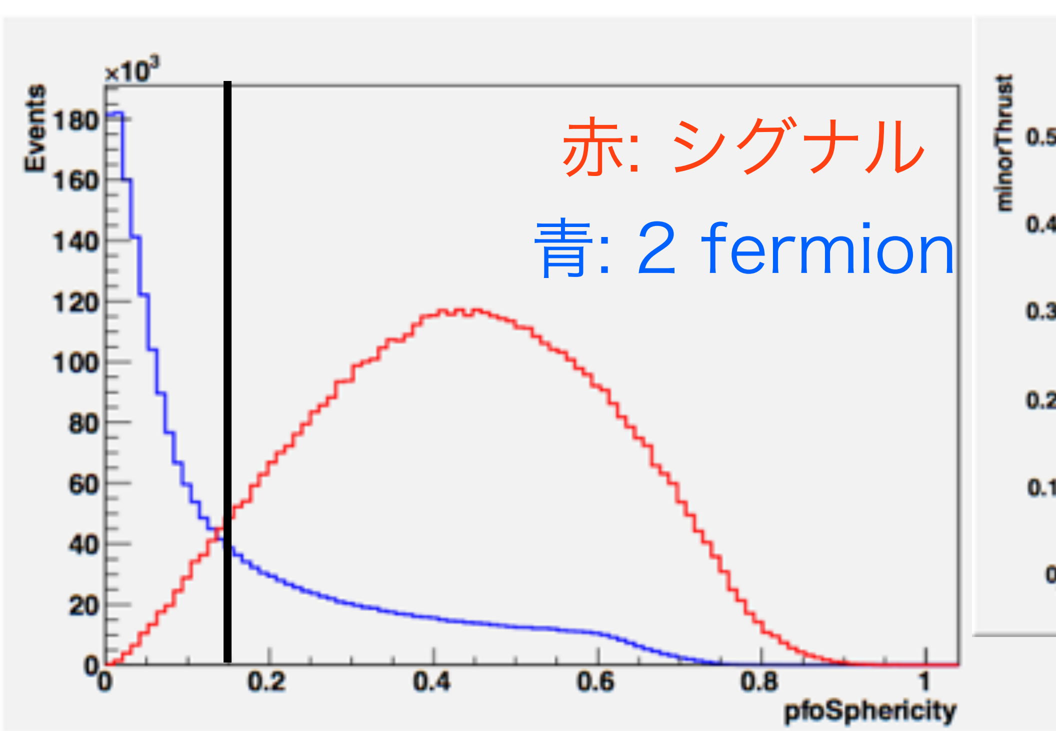
- Sphericity
  ー 観測された事象の球度を表す指標
  ~0で直線状　~1で球形

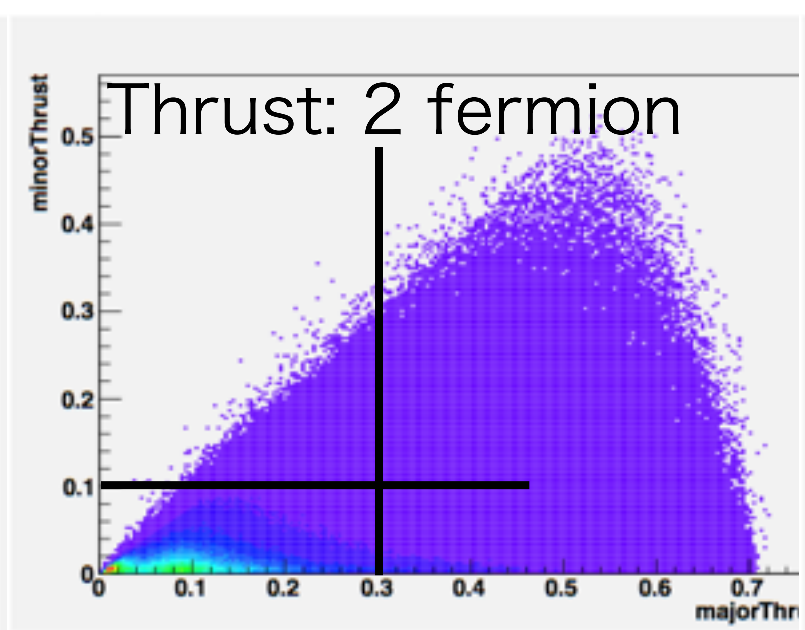
$$S^{ab} = \frac{\sum_i p_i^a p_i^b}{\sum_i p_i^2} \quad a, b = x, y, z$$

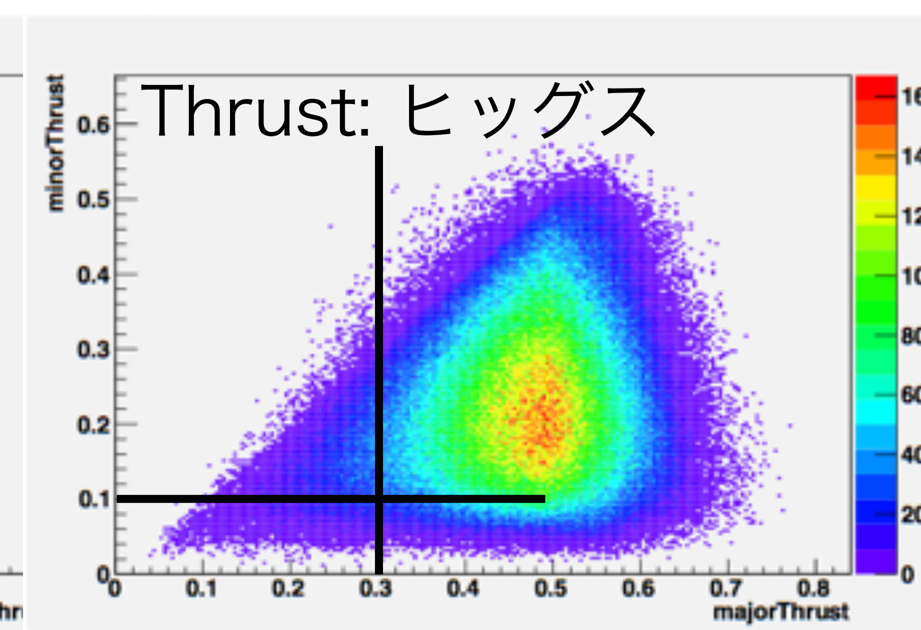
$$T_{major} = \max_{|\vec{n}'|=1, \vec{n}'\cdot\vec{n}=0} \frac{\sum_i |\vec{p}_i \cdot \vec{n}'|}{\sum_i |\vec{p}_i|}$$

- Major Thrust, Minor Thrust
  ー 事象のジェットの細さを表す指標
  Major Thrust ~ 0 で 3-jet未満、Minor Thrust ~ 0 で 4-jet未満

$$T_{minor} = \frac{\sum_i |\vec{p}_i \cdot \vec{n}''|}{\sum_i |\vec{p}_i|} \quad \text{with } \vec{n}''\cdot\vec{n} = \vec{n}''\cdot\vec{n}' = 0$$



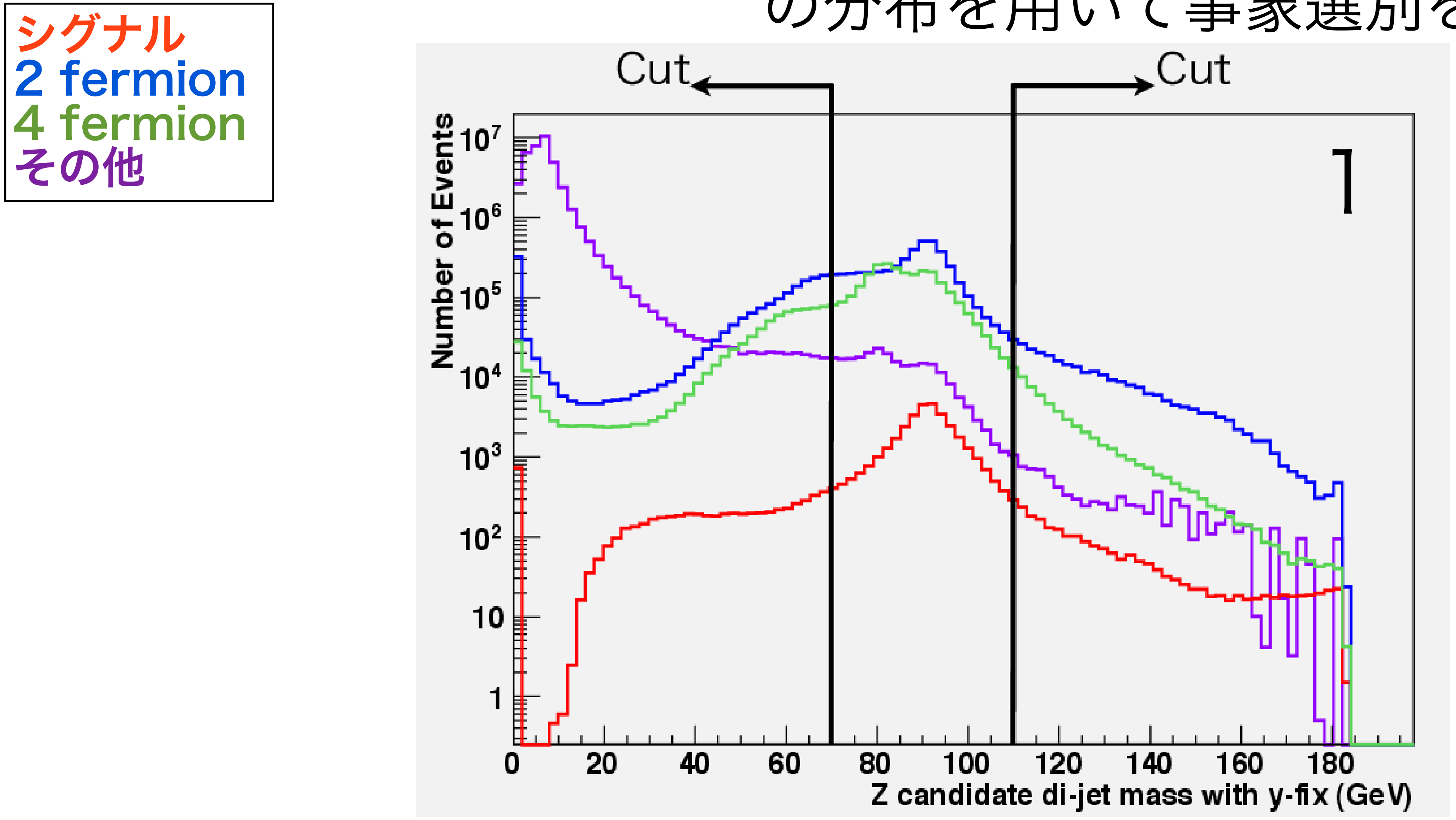




背景事象の低減 ③

- 背景事象と信号事象の更なる切り分けのために、
閾値を設定したジェットクラスタリングにおいて
  ・再構成されたZ粒子の質量　1
  ・再構成されたZ粒子の横方向運動量　2
  ・反跳質量　3

の分布を用いて事象選別をおこなった



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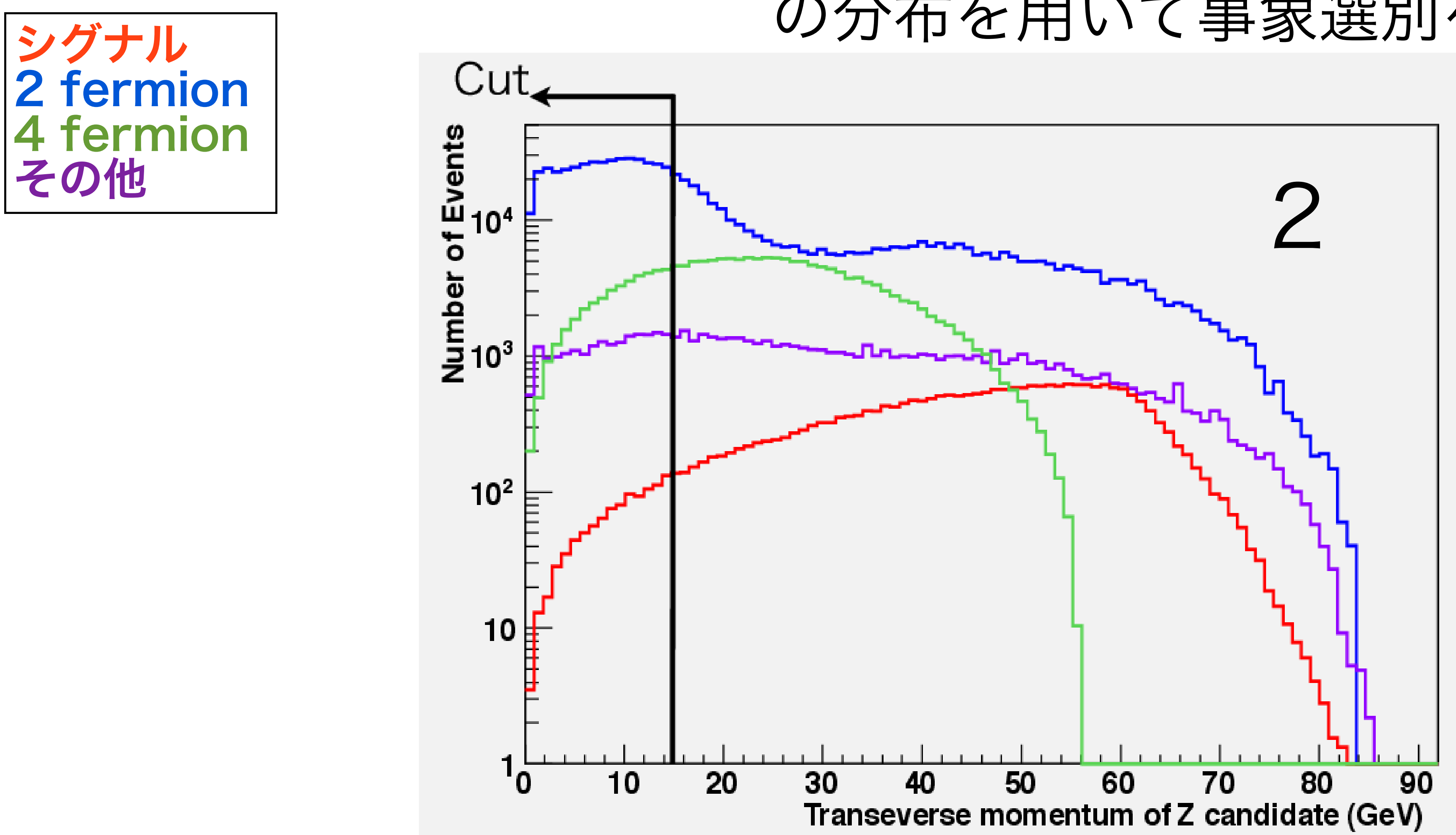

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  - 反跳質量 3

の分布を用いて事象選別をおこなった

シグナル
2 fermion
4 fermion
その他