English

Systematic study of $e^+e^- \to t\bar{t}$ at the ILC using full simulation of the ILD Detector and determination of anomalous electroweak coupling of top quarks

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2019

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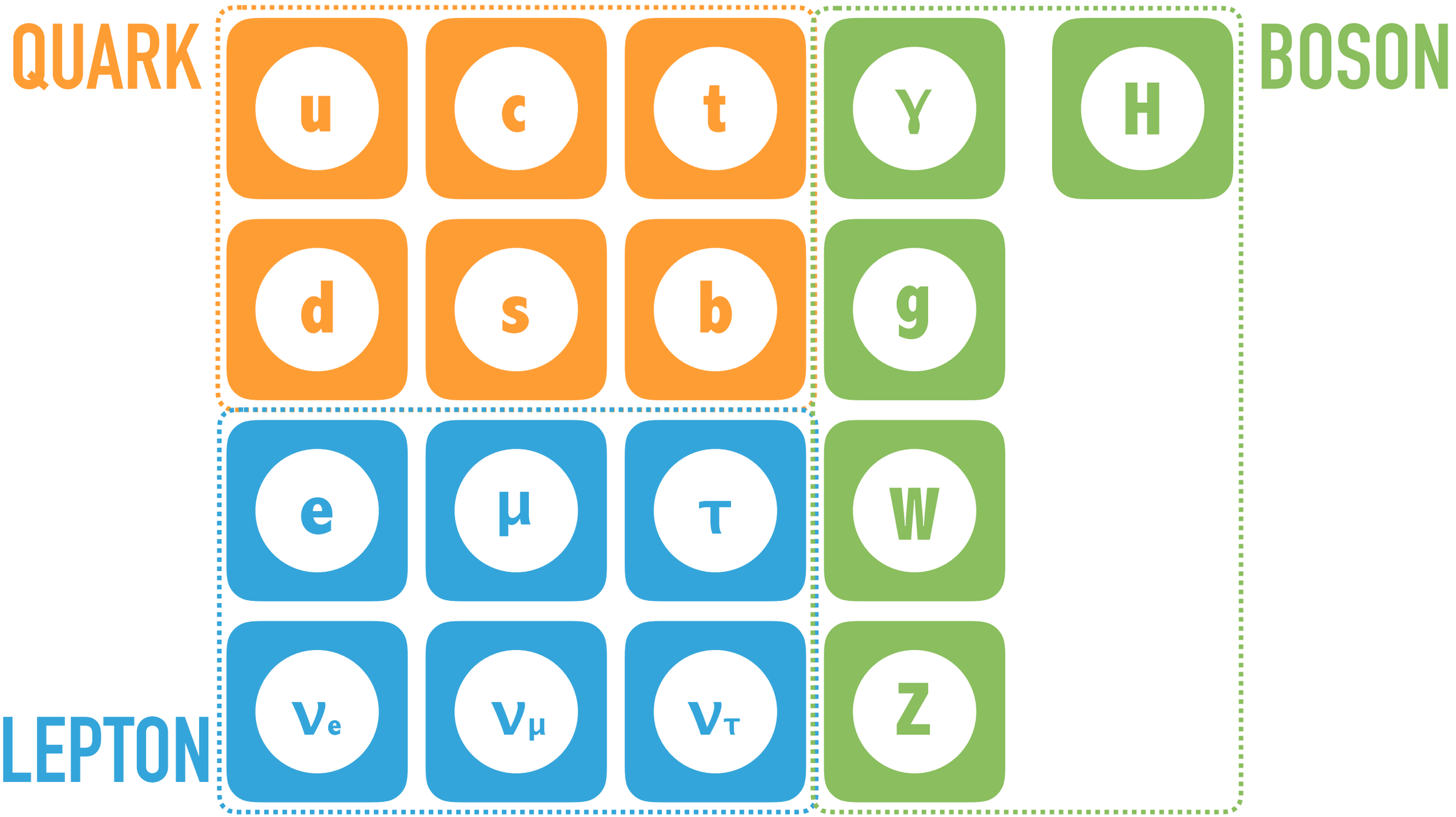
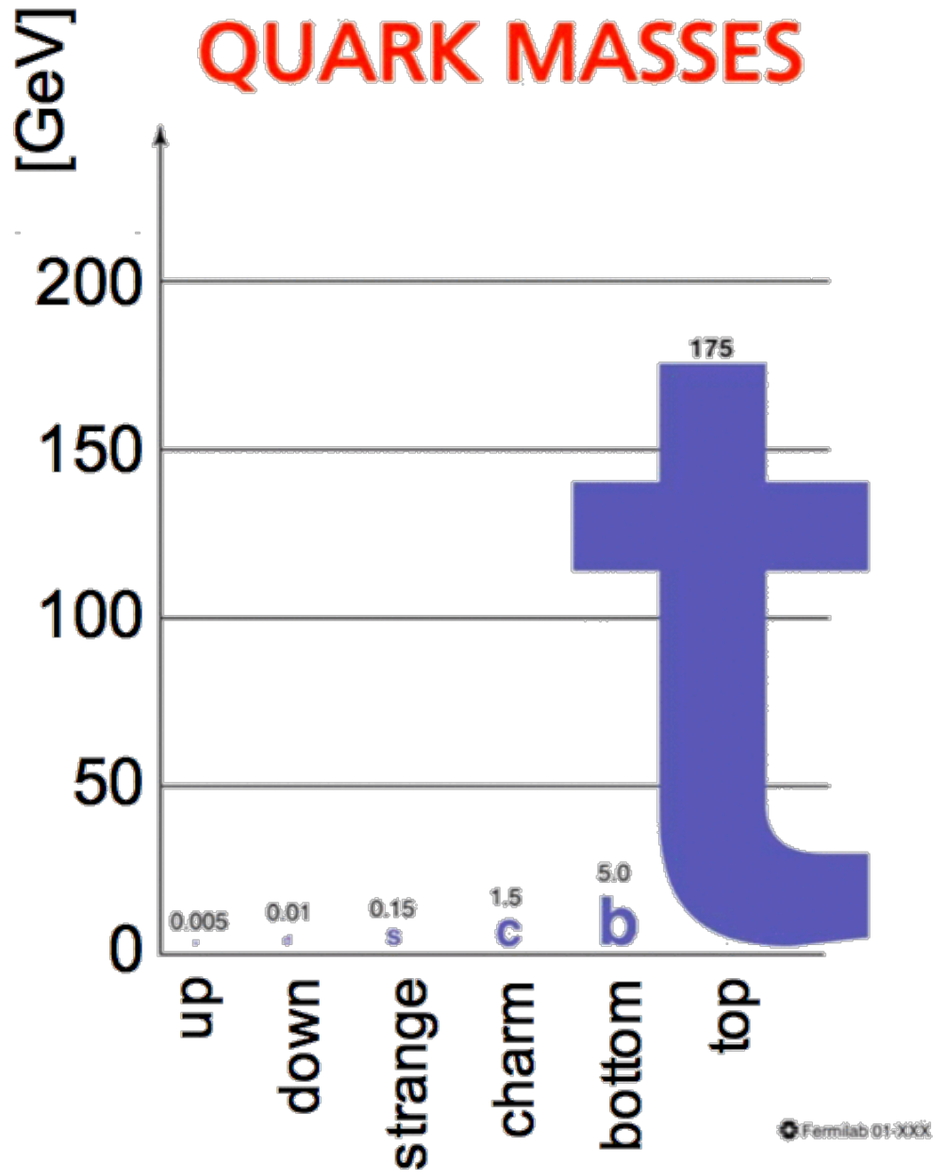
標準模型



Top Quark

Top Quark

- Mass ~175 GeV
- Spin 1/2
- Charge 2/3

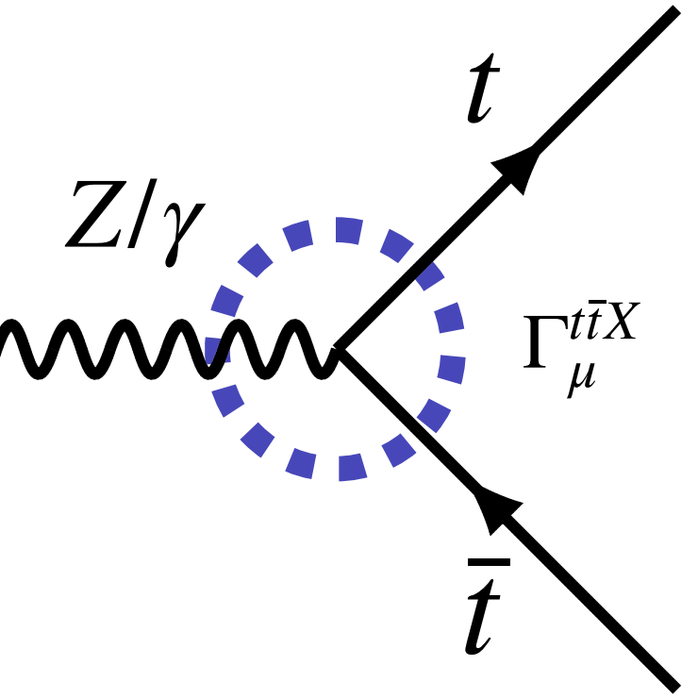


- Mass of the top quark is close to the vacuum expectation value of the electroweak symmetry breaking.
- Due to its massiveness, top quark decays before its hadronization.
- Since the discovery of the top quark, it has only been studied in the hadron colliders, such as LHC and Tevatron.
  → Precision studies at the lepton collider is now expected.

トップ対と Z/γ の結合

$$\Gamma_{\mu}^{t\bar{t}X}(k^2,q,\bar{q}) = ie\left[\gamma_\mu\left(\tilde{F}_{1V}^{X}(k^2)+\gamma_5\tilde{F}_{1A}^{X}(k^2)\right)+\frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\nu\left(i\tilde{F}_{2V}^{X}(k^2)+\gamma_5\tilde{F}_{2A}^{X}(k^2)\right)\right]$$

$$(X = Z,\gamma)$$



The couplings between pair of top and Z^0/γ are parametrized in terms of form factors.

A_{FB}^{t} is the measure for the level of the parity violation.

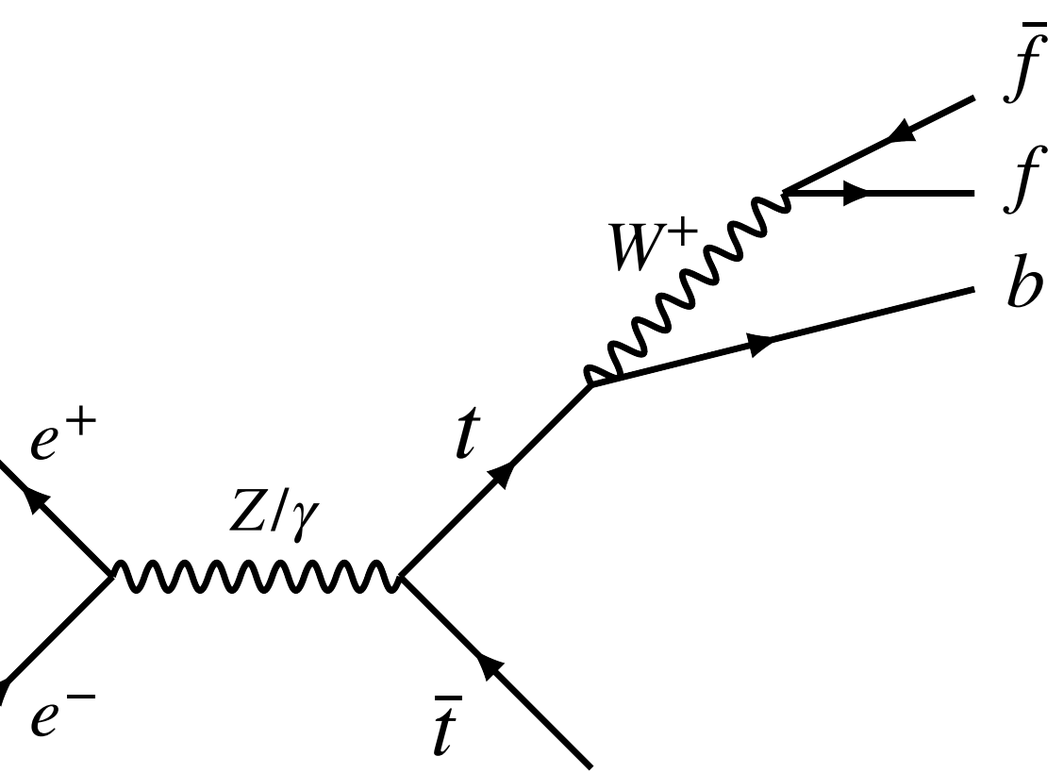
$$(A_{FB}^{t})_I = \frac{-3\beta F_{1A}^{I}(F_{1V}^{I}+F_{2V}^{I})}{2[(1+\frac{1}{2\gamma^2})(F_{1V}^{I})^2+(\beta F_{1A}^{I})^2+3F_{1V}^{I}F_{2V}^{I}]}$$

$$\sigma_I = 2\left(\frac{4\pi\alpha^2}{3s}\right)N_c\beta\left[\left(1+\frac{1}{2\gamma^2}\right)(F_{1V}^{I})^2+(\beta F_{1A}^{I})^2+3F_{1V}^{I}F_{2V}^{I}\right]$$

*At the tree level Standard Mode, $F_2 = 0$

本研究の目標

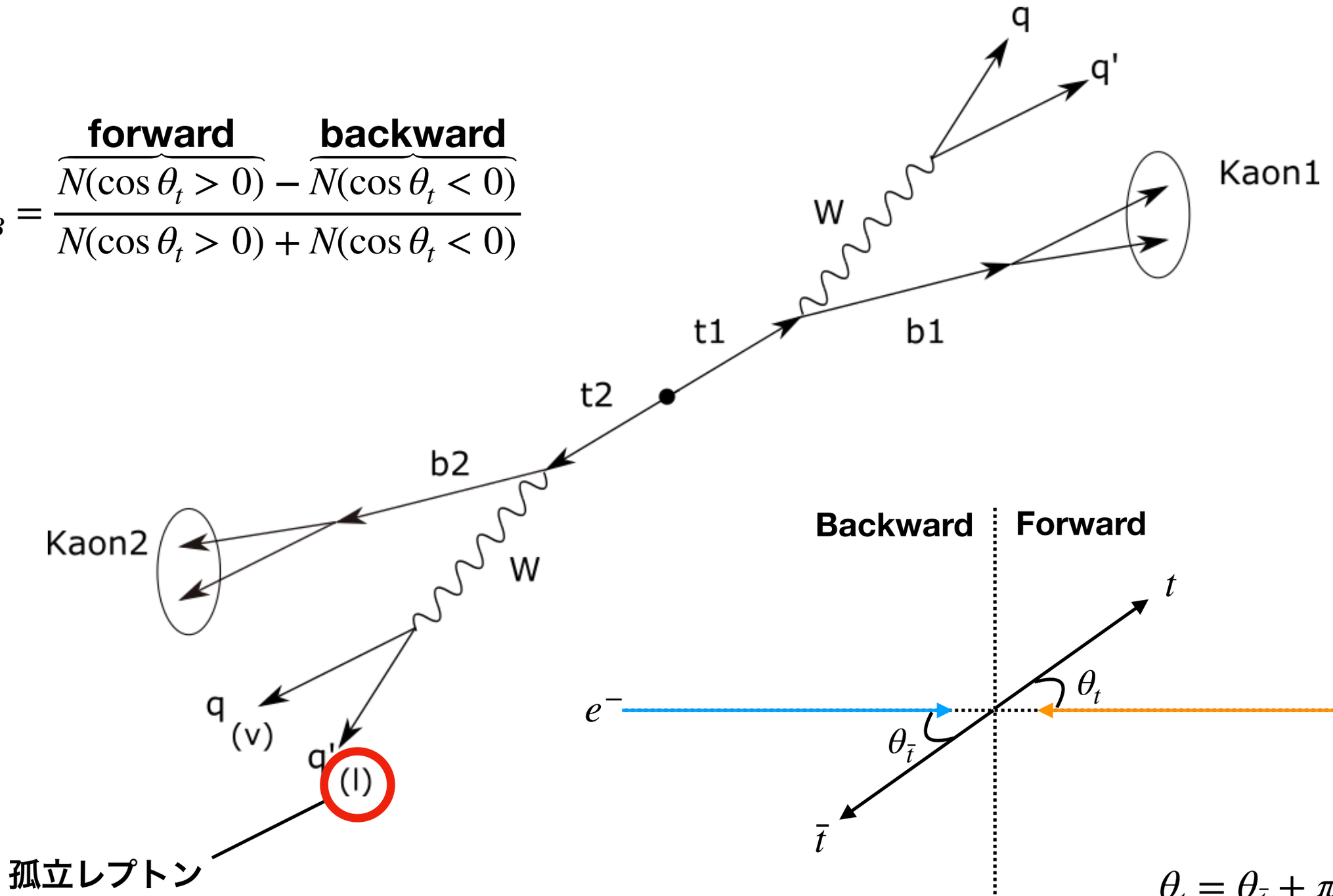
	終状態	Jet 数	崩壊率
Full Leptonic	$t\bar{t} \to (b\ell\bar{\nu})(\bar{b}\bar{\ell}\nu)$	2 jets + 2ℓ	10.5%
Semi Leptonic	$t\bar{t} \to (b\ell\bar{\nu})(\bar{b}q\bar{q}')$	4 jets + 1ℓ	43.8%
Full Hadronic	$t\bar{t} \to (bq\bar{q}')(\bar{b}q\bar{q}')$	6 jets	45.7%



- In the pre-studies, analysis method for the full-leptonic and semi-leptonic channel has been established.
- Through analysis on the semi-leptonic analysis, particularly aimed for the detector optimization.
- This thesis explores the analysis technique for the full-hadronic channel, which has 6 jets as final states.

トップ対の生成

$$A_{FB}^{t} = \frac{\overbrace{N(\cos\theta_t > 0)}^{\textbf{forward}} - \overbrace{N(\cos\theta_t < 0)}^{\textbf{backward}}}{N(\cos\theta_t > 0) + N(\cos\theta_t < 0)}$$



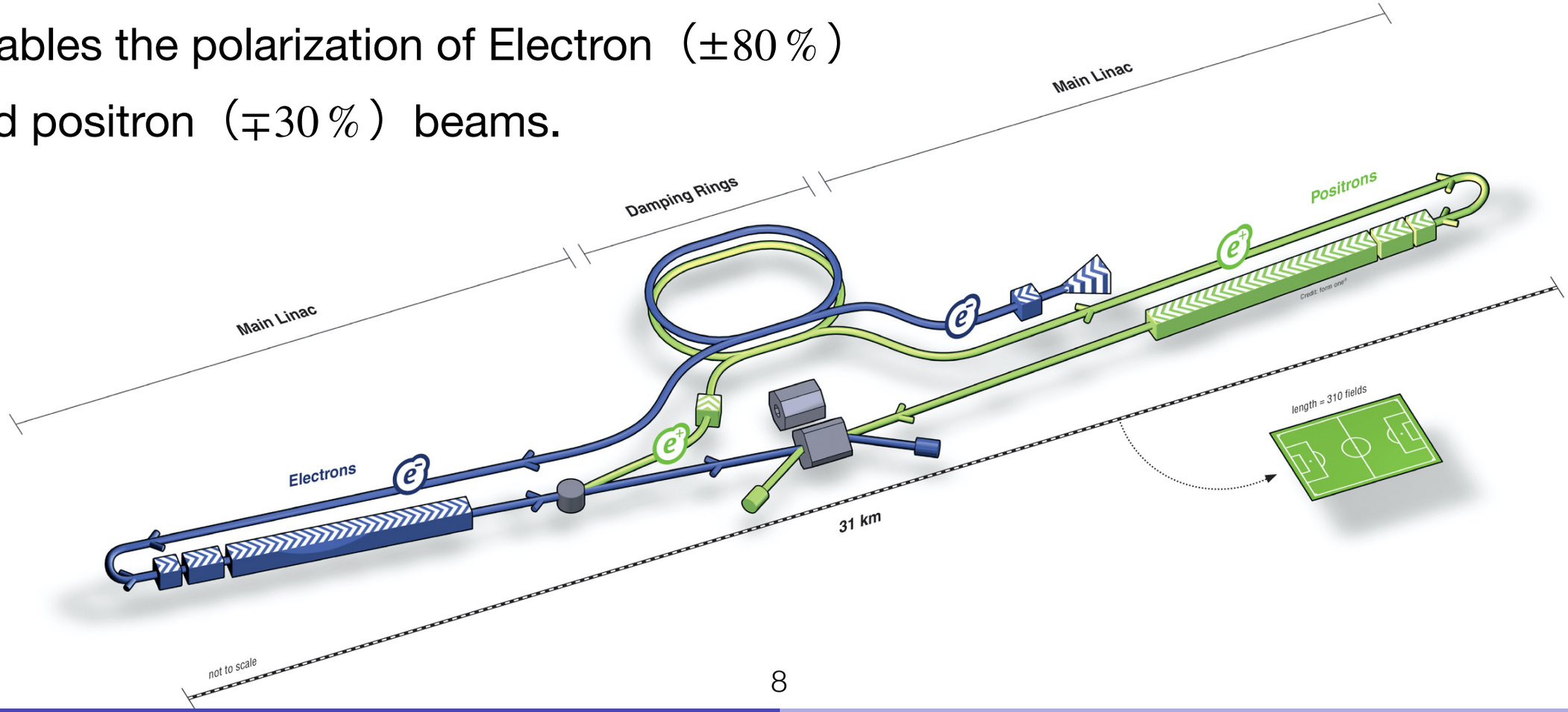
International Linear Collider

International Linear Collider (ILC)

- e^+e^- linear collider
- Cleaner events compared to the hadron colliders
- $\sqrt{s} = 250 \sim 500$ GeV （500 GeV for this study）
- Enables the polarization of Electron （$\pm 80\,\%$）and positron （$\mp 30\,\%$） beams.

Expected Physics

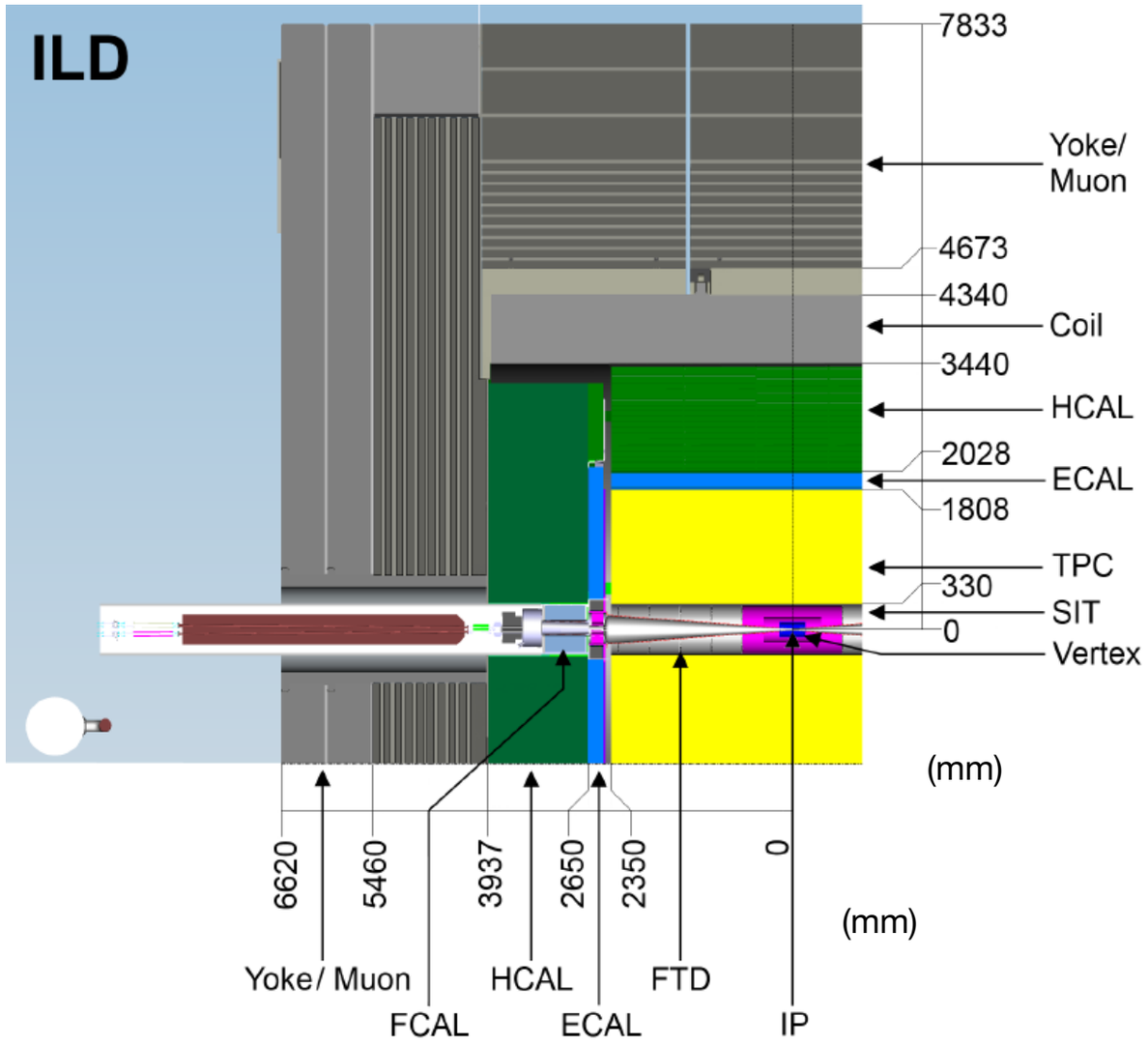
- Precision measurements of Higgs boson.
- Dark matter search
- Precision measurements of top quark.
- etc…



International Large Detector

International Large Detector (ILD)

- The detector mounted on the ILC
- It is designed to allow the precision measurement of the properties of top quark, and be sensitive to the physics beyond the Standard Model.



Reconstruction Flow

Isolated Lepton

↓

Jet Reconstruction

↓

Vertex Reconstruction

↓

Top Reconstruction

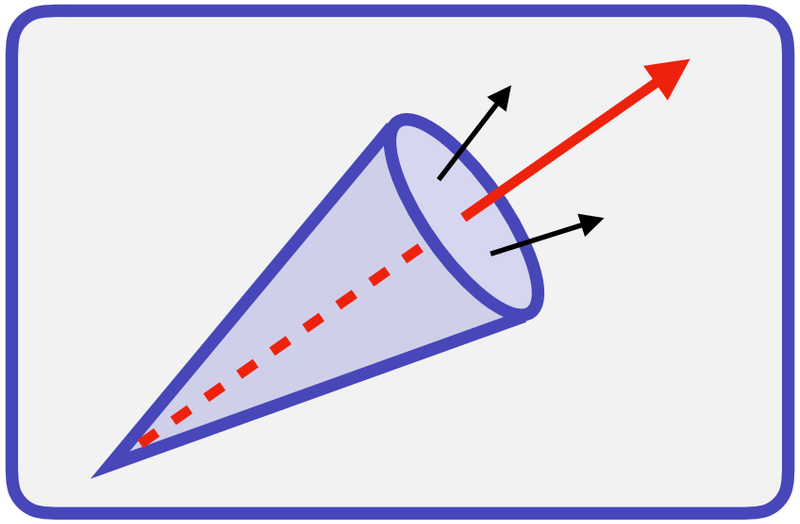
Isolated Lepton Definition

- Semi-leptonic only
- Identify e, μ (τ not included)
- Creates cone around the energetic leptons.

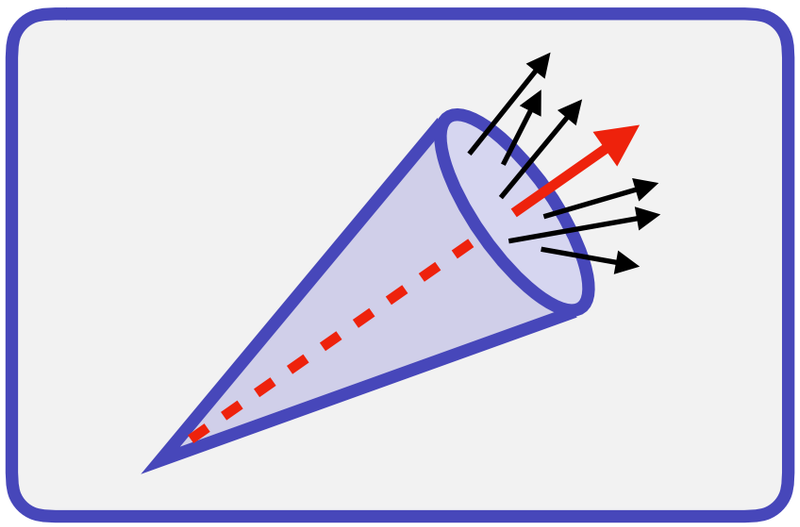
Cut

- $p_{track} > 5\ GeV$
- $\cos\theta_{cone} = 0.98$

With Isolated Lepton



Without Isolated Lepton



Reconstruction Flow

Isolated Lepton

↓

Jet Reconstruction

↓

Vertex Reconstruction

↓

Top Reconstruction

Jet Definition（Generalized k_T algorithm for e^+e^- collisions）

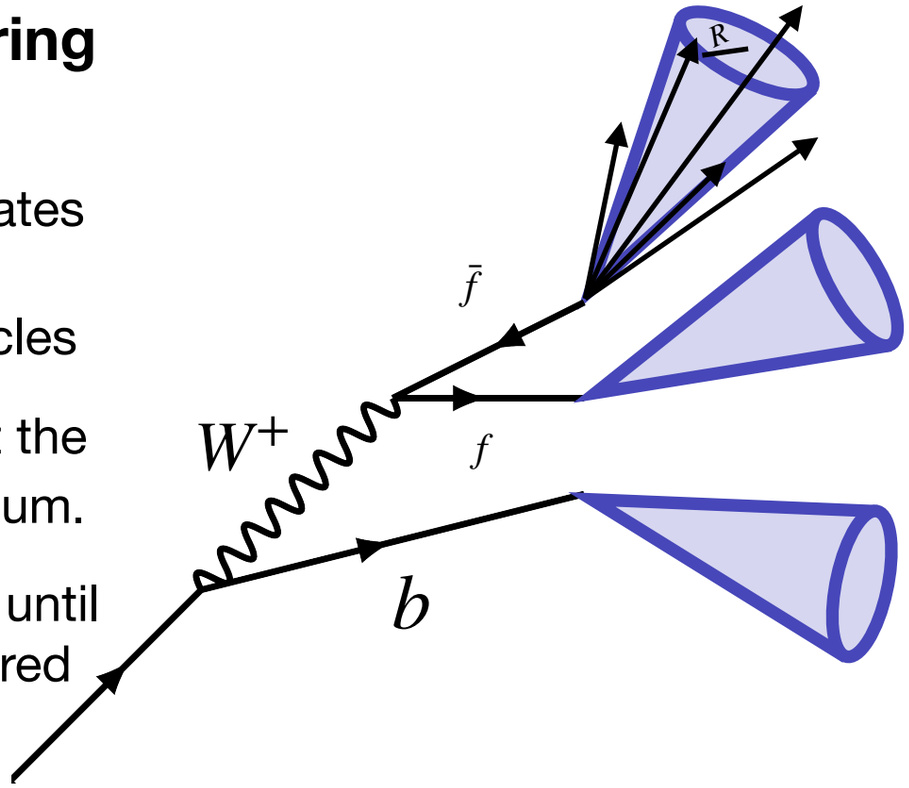
$$d_{ij} = \min(E_i^2, E_j^2)\frac{(1-\cos\theta_{ij})}{(1-\cos R)}$$

$$d_{iB} = E_{iB}^2$$

$E_{i,j}$: energy of particles
$\cos\theta_{ij}$: separation angle
R : cone radius (=1.5)

Flow of jet clustering

1. The algorithm calculates the d_{ij}, d_{iB} for each combination of particles
2. Selects d_{ij}, d_{iB} so that the value become minimum.
3. Repeat step 1 and 2 until the number of clustered jets become 4 or 6.



Reconstruction Flow

Isolated Lepton

↓

Jet Reconstruction

↓

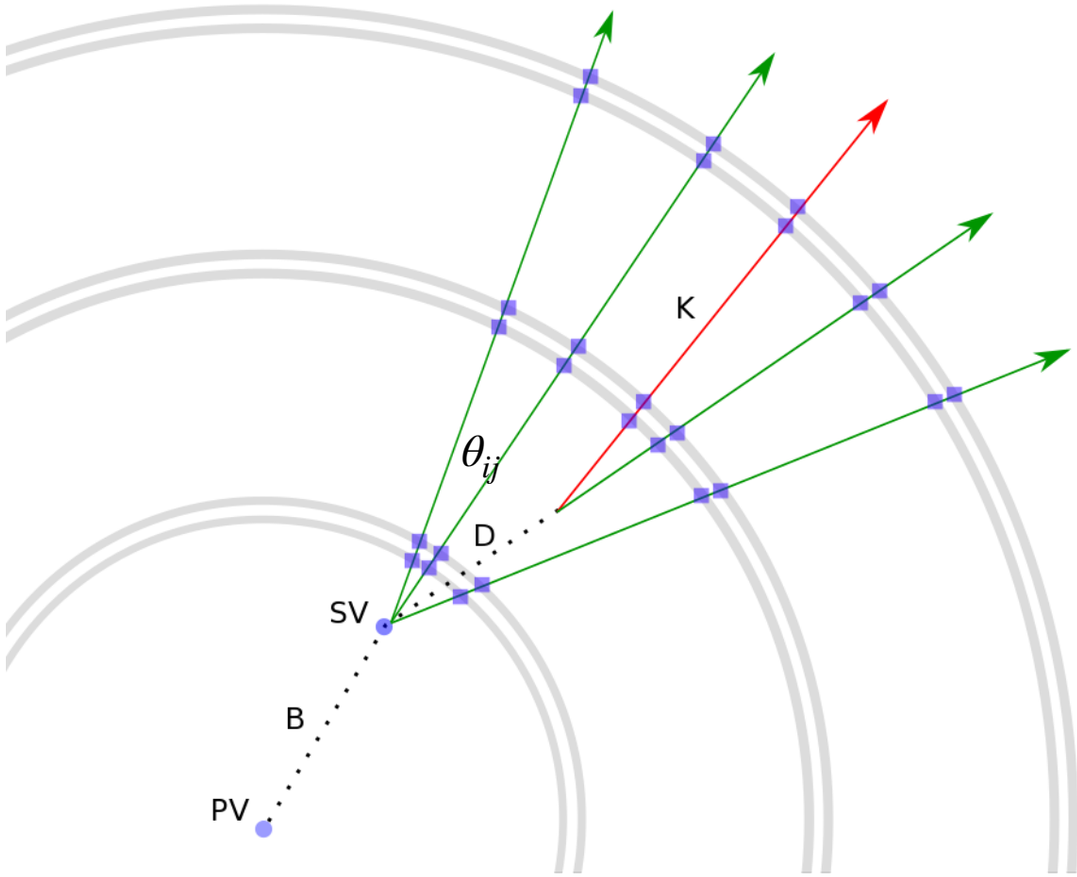
Vertex Reconstruction

↓

Top Reconstruction

Secondary Vertex Reconstruction

- After the hadronization, B hadrons will decay at the point away from the primary vertex (PV), called secondary vertex (SV)
- Using the vertex information and multivariable analysis, the algorithm calculates the likelihood of b for each jets called b-tag.



Reconstruction Flow

Isolated Lepton

Jet Reconstruction

Vertex Reconstruction

Top Reconstruction

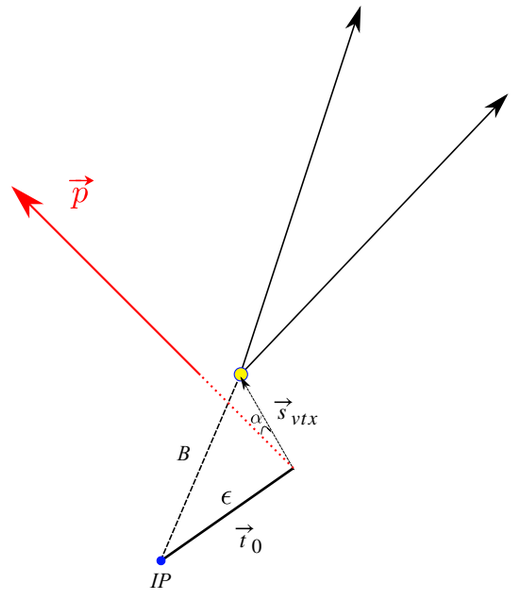
Track will not be associated to the secondary vertex

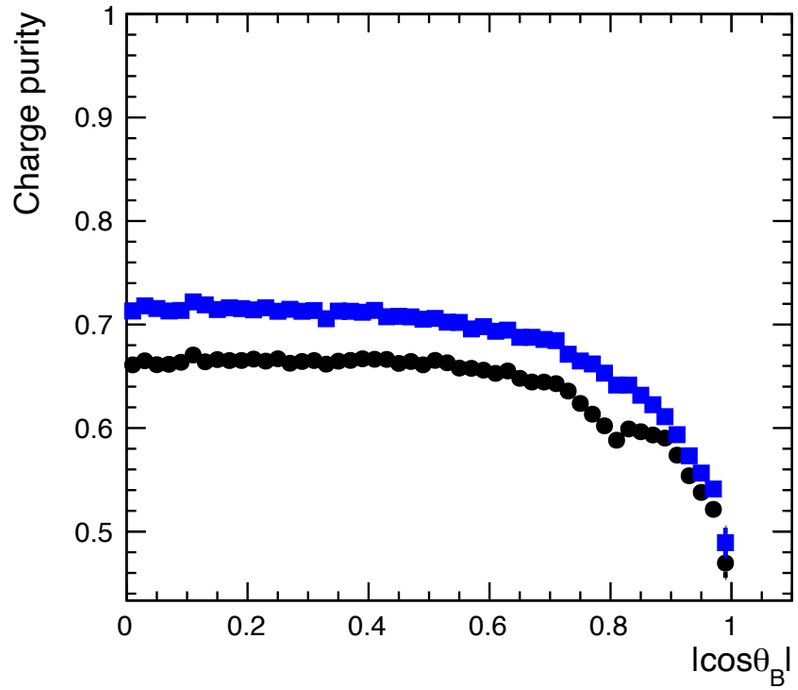
- Low momentum ($P_{trak} < 4$ GeV)
- Small offset ($\epsilon < 0.5$ mm)

Track Recovery

Applies the cut to ϵ and α and computes the SV parameters.

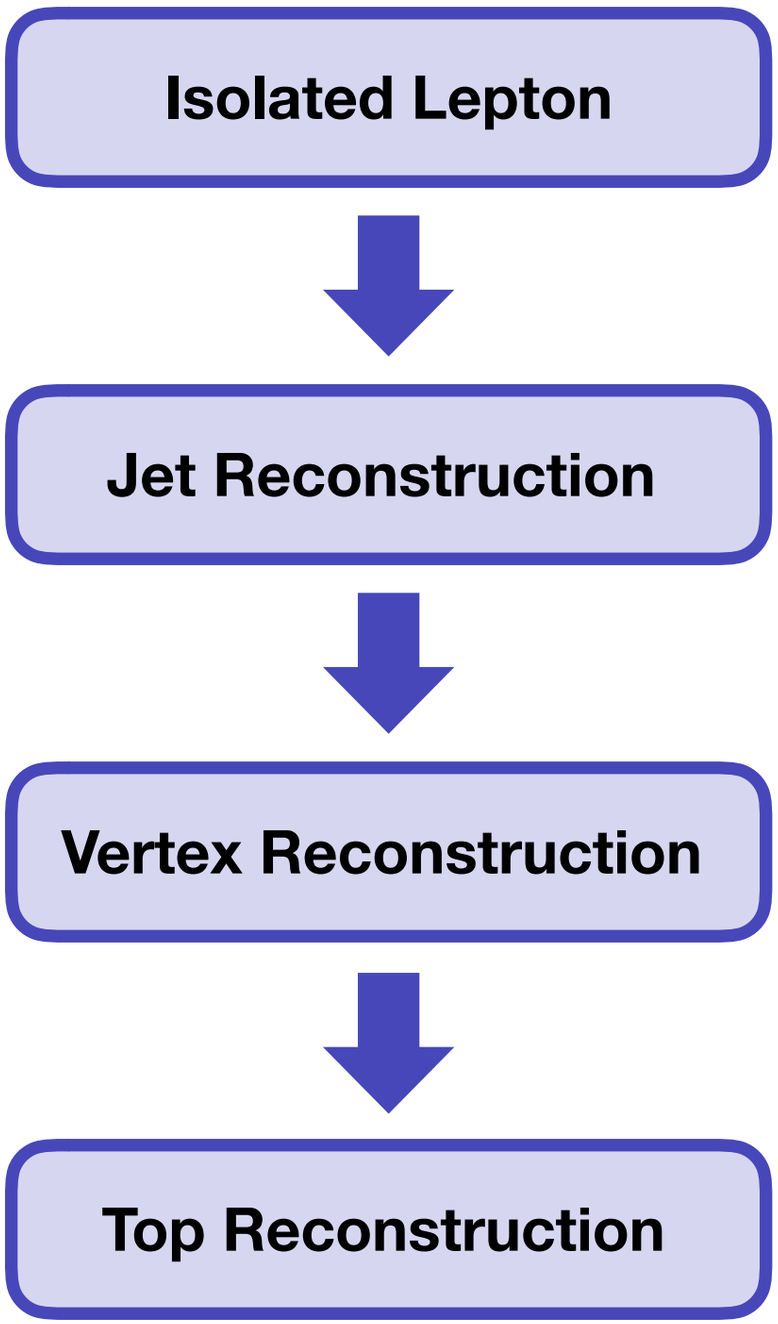
- $\epsilon/\sigma > 2 + 25\sqrt{\alpha}$
- $\alpha < 0.08$





$$\textbf{Charge Purity} = \frac{\textbf{\# of correctly reconstructed b charge}}{\textbf{\# of reconstructed b-jets}}$$

Reconstruction Flow



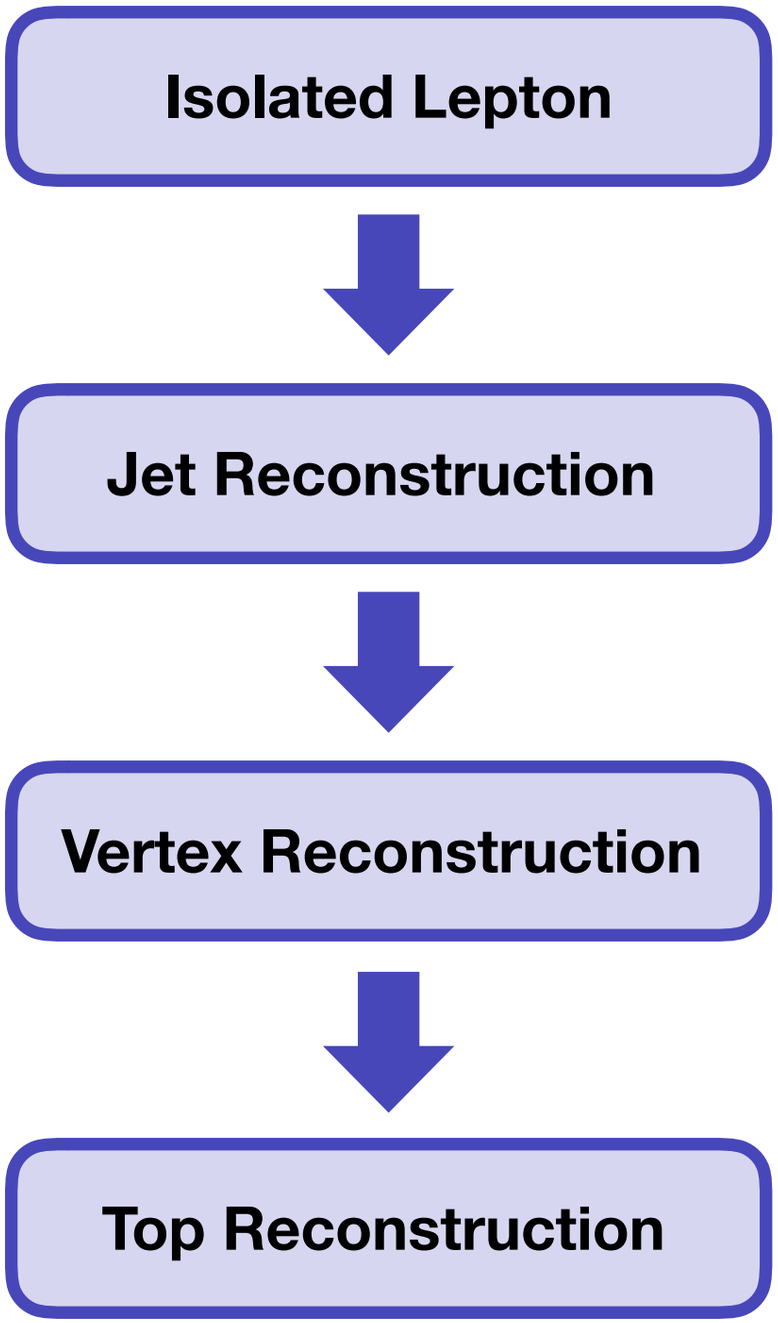
Difference Semi-Leptonic and Full-Hadronic

	Semi-Leptonic	Full-Hadronic
Isolated Lepton	$P_{lep} > 5$ GeV	0
N jets	4	6
$W^{\pm}$ reco	isoLep + q jet	q jet + q jet

Cuts

種類	カット
b-tag	0.8 < b-tag < 0.3
Thrust	Thrust > 0.9
M_{had} (GeV)	180 < M_{had} < 420
Top mass (GeV)	120 < M_{top} < 270
$W^{\pm}_{had}$ mass (GeV)	50 < M_W < 270

Reconstruction Flow



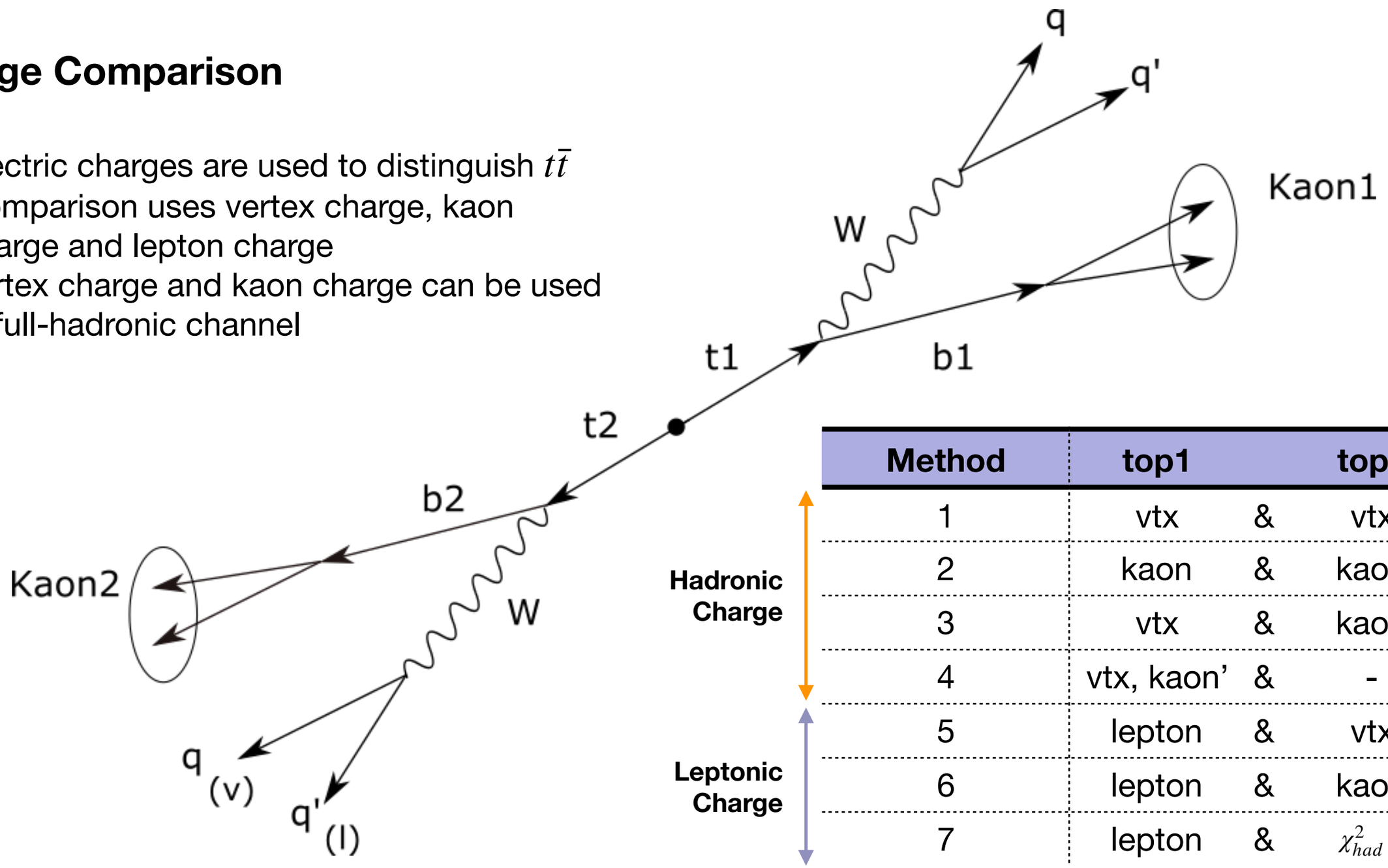
Selection Efficiencies

Cuts	Semi-Leptonic		Full-Hadronic	
	eLpR	eRpL	eLpR	eRpL
Isolated Lepton	95.1%	94.1%	-	-
b-tag	83.9%	84.9%	72.1%	71.4%
Thrust	83.9%	84.9%	72.1%	71.4%
M_{had} (GeV)	80.8%	82.2%	70.1%	69.6%
Top / $W^{\pm}_{had}$ mass (GeV)	75.8%	77.6%	66.7%	66.5%

Charge Measurement

Charge Comparison

- Electric charges are used to distinguish $t\bar{t}$
- Comparison uses vertex charge, kaon charge and lepton charge
- vertex charge and kaon charge can be used in full-hadronic channel



	Method	top1		top2
Hadronic Charge	1	vtx	&	vtx
	2	kaon	&	kaon
	3	vtx	&	kaon
	4	vtx, kaon’	&	-
Leptonic Charge	5	lepton	&	vtx
	6	lepton	&	kaon
	7	lepton	&	χ^2_{had}

$$\chi^2_{had} = \frac{\gamma_t^{had} - 1.435}{\sigma_{\gamma_t}} + \frac{\cos\theta_{Wb} - 0.23}{\sigma_{\cos\theta_{Wb}}} + \frac{p_b^* - 68}{\sigma_{p_b^*}}$$

Standard Model Background

Process	$\sigma_{unpol.}$	σ_{eLpR}	σ_{eRpL}
$t\bar{t}$	572	1564	724
$u\bar{u} + d\bar{d} + c\bar{c} + s\bar{s}$	2208	6032	2793
$b\bar{b}$	372	1212	276
γZ^0	11185	25500	19126
WW	6603	26000	150
Z^0Z^0	422	1106	582
Z^0WW	40	151	8.7
$Z^0Z^0Z^0$	1.1	3.2	1.22

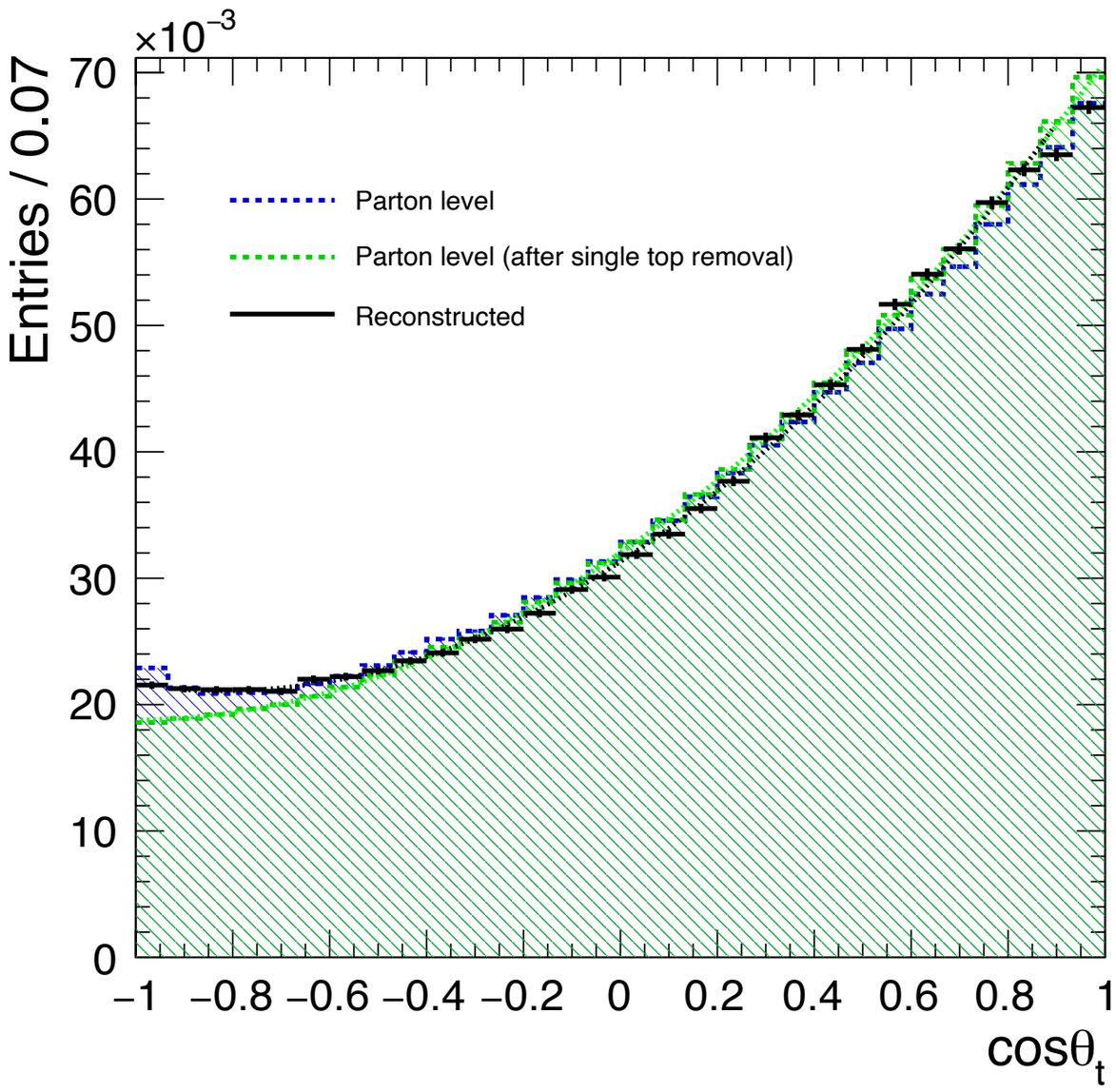
(fb)

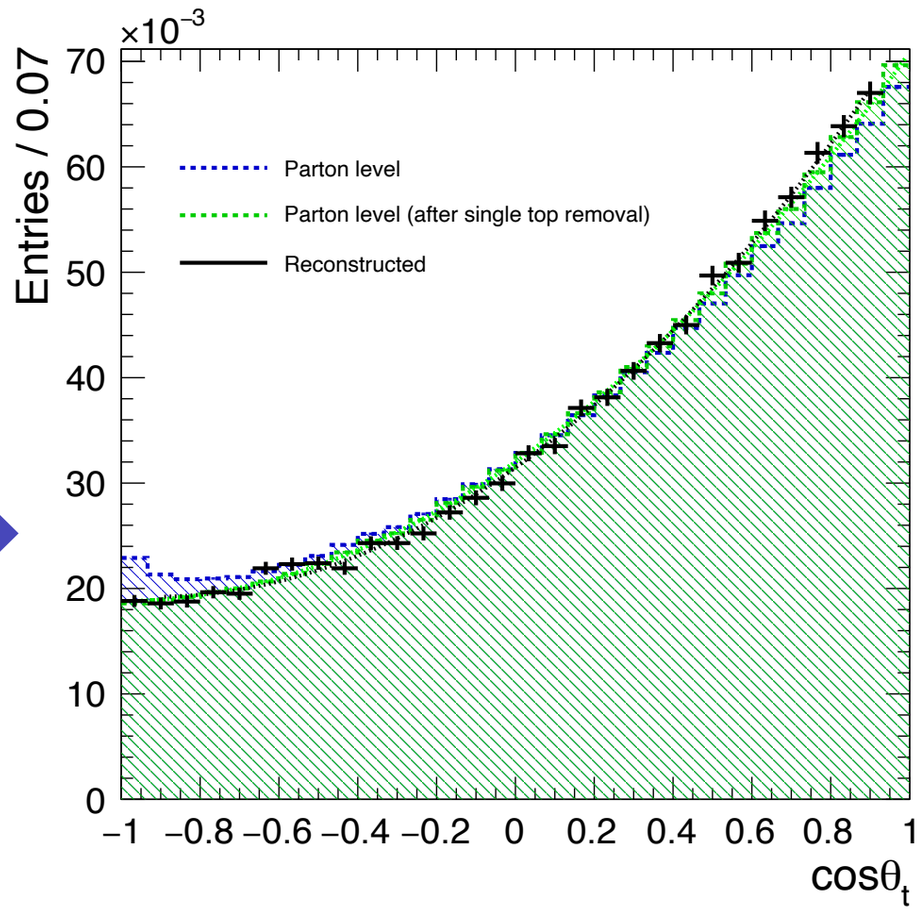
	eLpR
Isolated Lepton	51.1%
b-tag	1.10%
Thrust	1.10%
M_{had} (GeV)	0.619%
Top / $W^{\pm}_{had}$ mass (GeV)	0.435%

- Focused on the backgrounds that contain similar signature to the $t\bar{t}$ events.
- Most of the events are removed after the b-tag cuts and finally the top and W mass cuts attenuates the background down to 0.4%

Top Polar Angle (semi-leptonic)

偏極100%（左巻き）の場合





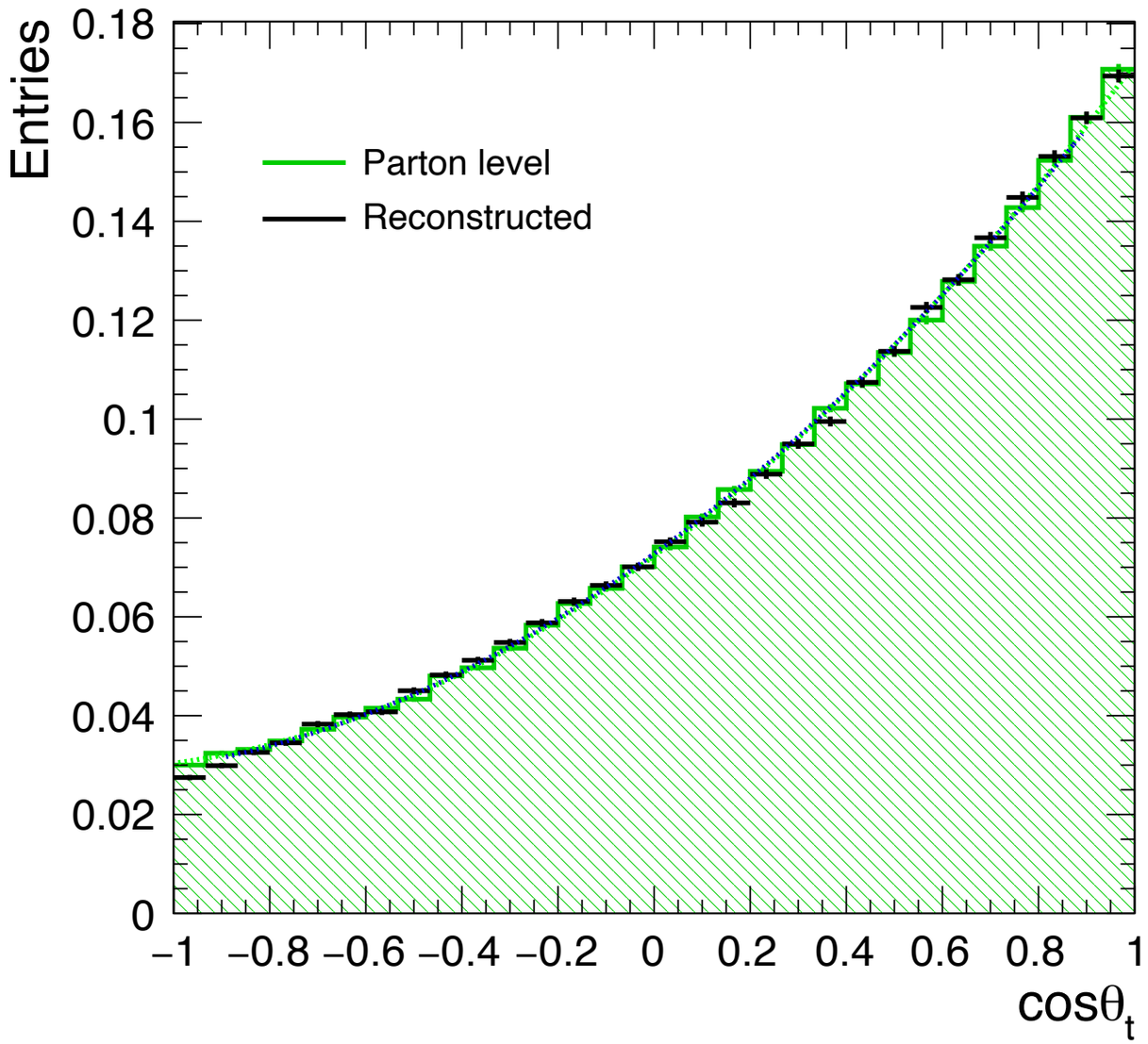
Method 1のみを使用

→ Single top由来のイベントの影響が弱まる

Top Polar Angle (semi-leptonic)

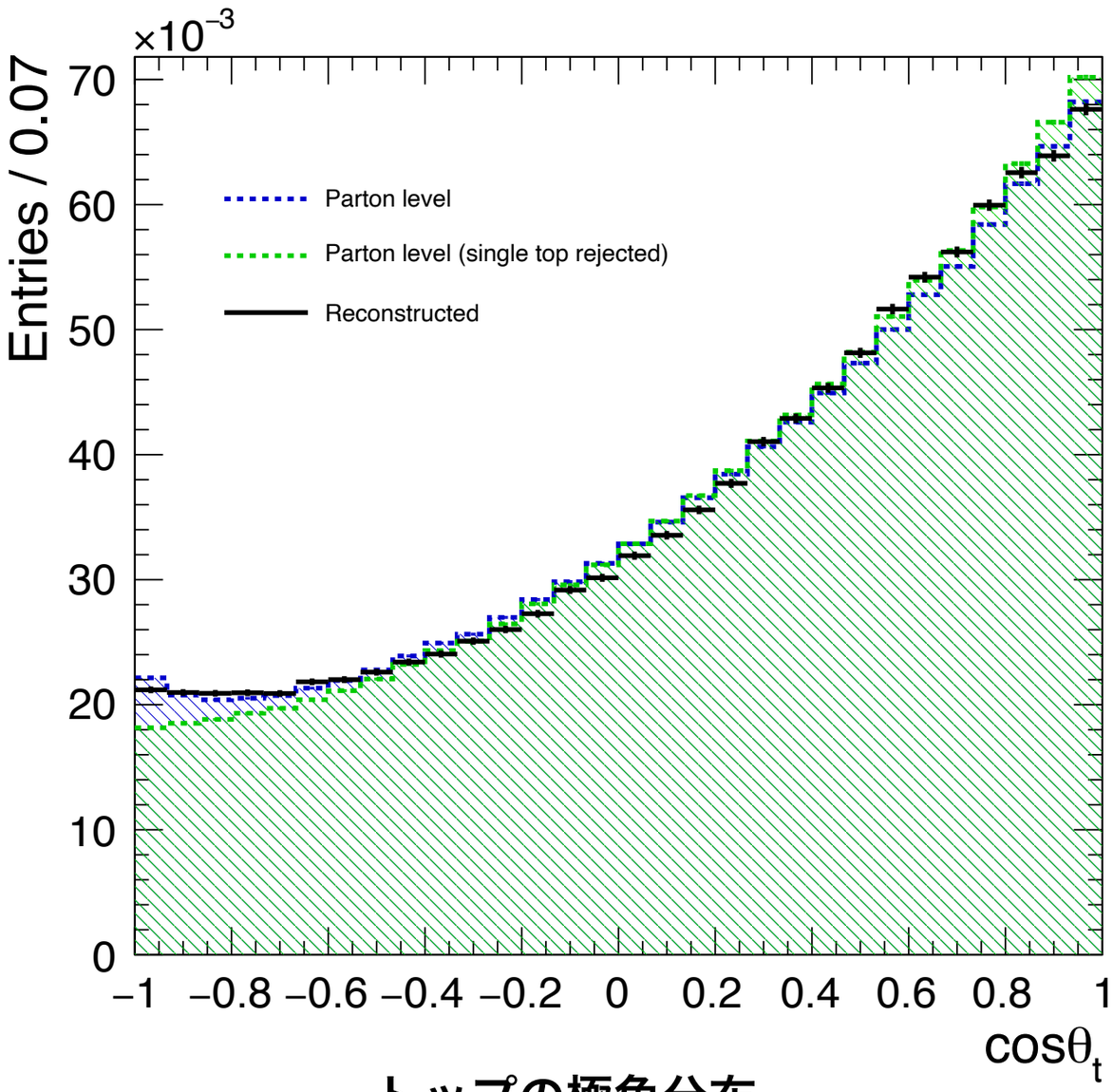
偏極100%（右巻き）の場合

- V-A結合により、偏極が右巻きの場合は　W　はトップの運動方向と同じ方向に出てくる。
- 再構成されたトップの運動方向は　W　由来の孤立レプトンの方向とほぼ同一となる。
- 孤立レプトンはエネルギーが高い為、b-jetなどよりも同定しやすい。



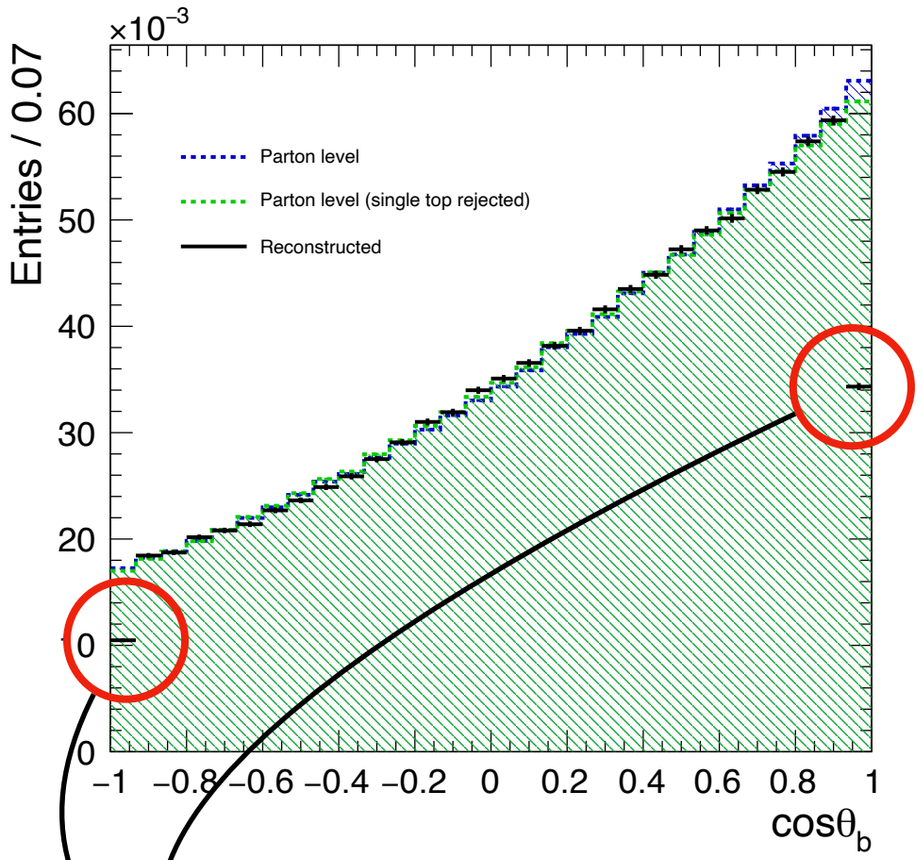
Polar Angle Distribution (semi-leptonic)

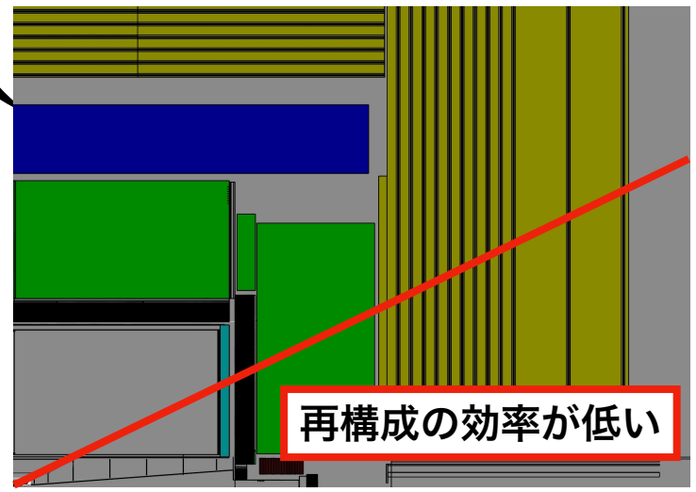
$(\mathscr{P}_{e^-}, \mathscr{P}_{e^+}) = (-0.8, +0.3)$ の場合



トップの極角分布

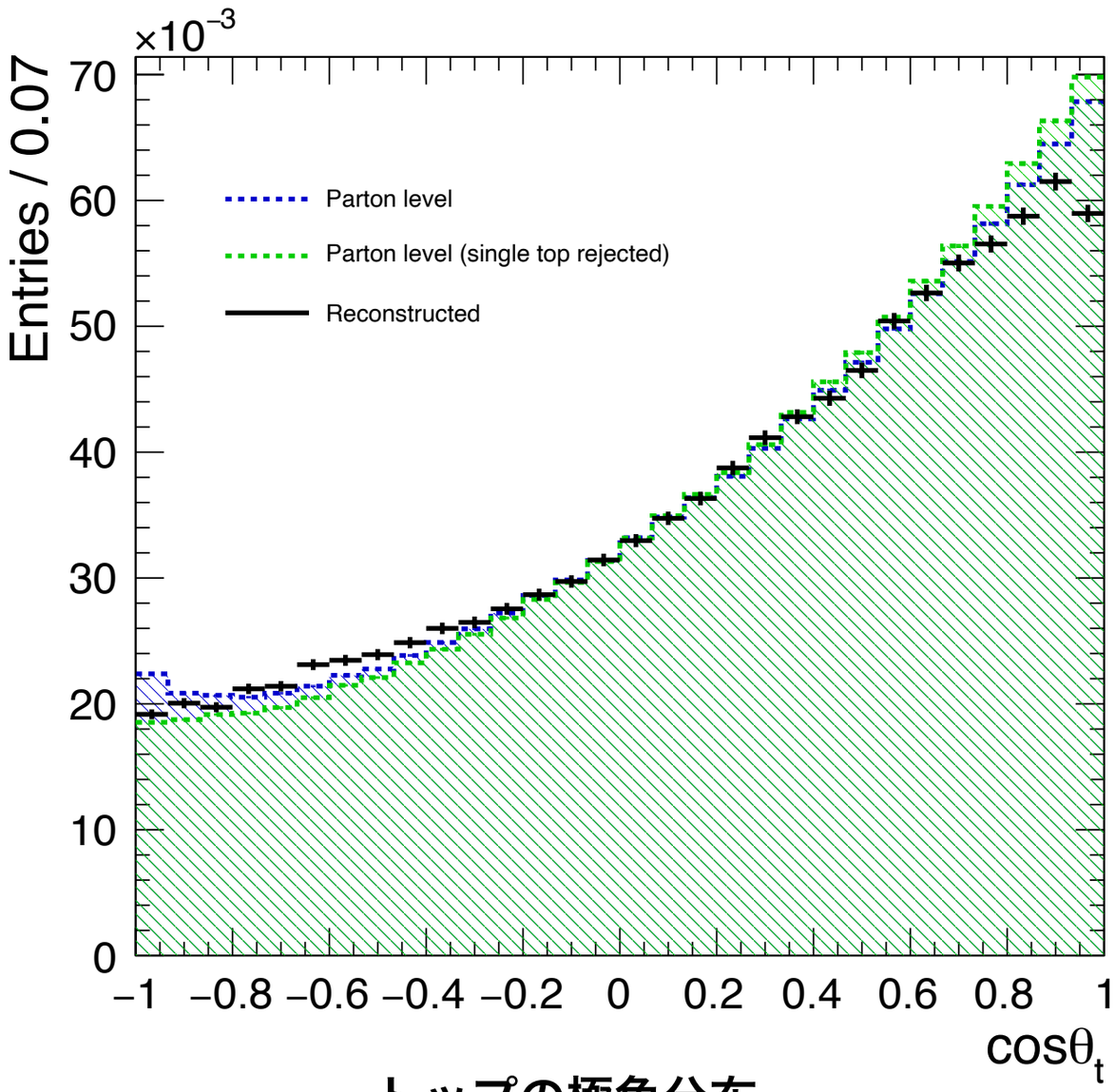
bの極角分布





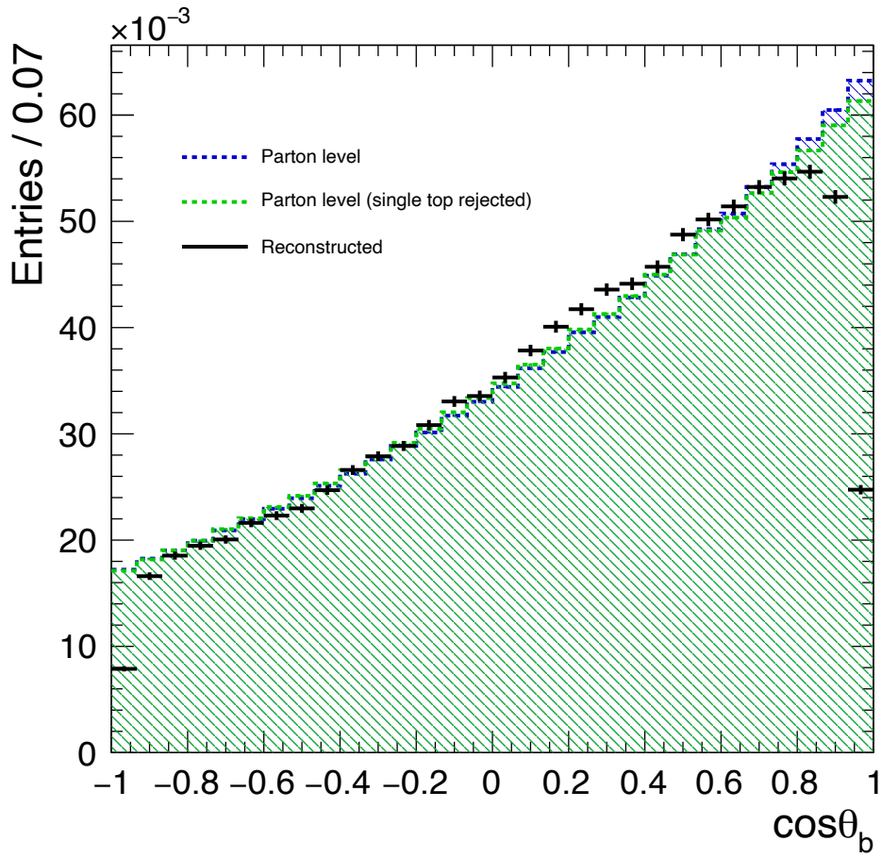
Polar Angle Distribution (full-hadronic)

$(\mathscr{P}_{e^-}, \mathscr{P}_{e^+}) = (-0.8, +0.3)$ の場合



トップの極角分布

bの極角分布



A_{FB} Calculation

Semi-leptonic 過程

$(\mathscr{P}_{e^-}, \mathscr{P}_{e^+})$	(-0.8, +0.3)	(+0.8, -0.3)
$A^t_{FB,gen}$	0.364	0.409
$A^t_{FB,reco}$	0.345	0.369
$\delta_{A^t_{FB}}$	0.0025	0.0020
Efficiency	34.6%	64.1%

Full-hadronic 過程

$(\mathscr{P}_{e^-}, \mathscr{P}_{e^+})$	(-0.8, +0.3)	(+0.8, -0.3)
$A^t_{FB,gen}$	0.359	0.409
$A^t_{FB,reco}$	0.322	0.369
$\delta_{A^t_{FB}}$	0.0028	0.0058
Efficiency	34.6%	32.5%

Semi-leptonic 過程 （先行研究*）

	(-0.8, +0.3)	(+0.8, -0.3)
$\delta_{A^t_{FB}}$	0.0059	0.0055
Efficiency	30.8%	30.8%

* Rouene, *Top Quark Production at ILC*, 124

まとめ

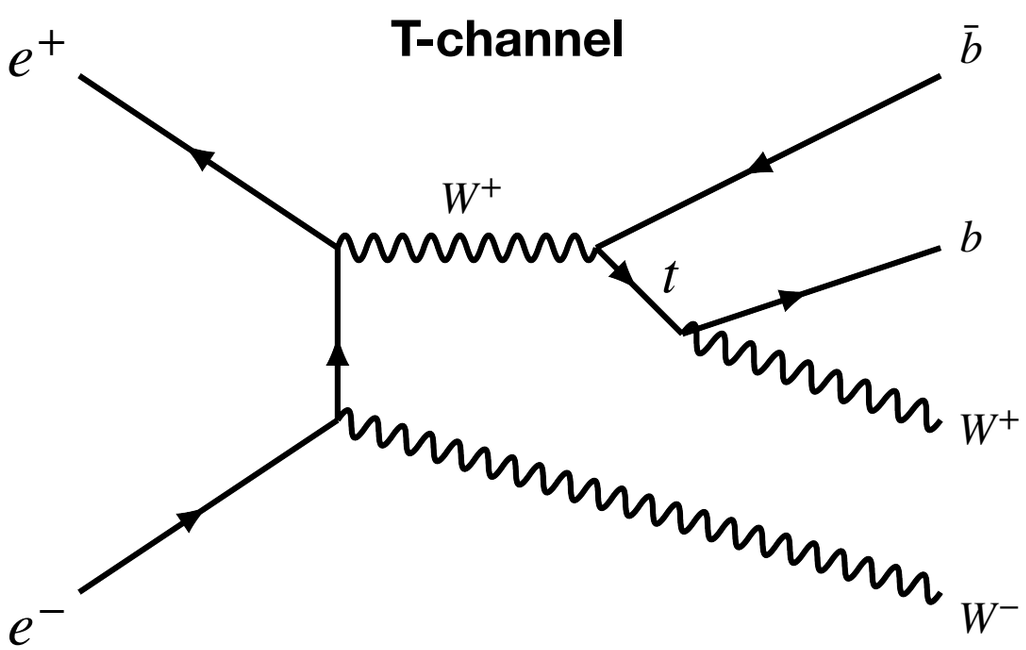
- Reconstruction of top quark using $\sqrt{s} = 500$ GeV samples was presented, along with calculation of A_{FB}^{t} which demonstrated the ILC's capability to measure its value with uncertainty up to $\delta_{A_{FB}^{t}} = \pm 0.002$.
- The full-hadronic channel of $t\bar{t}$ decay was analyzed for the first time.

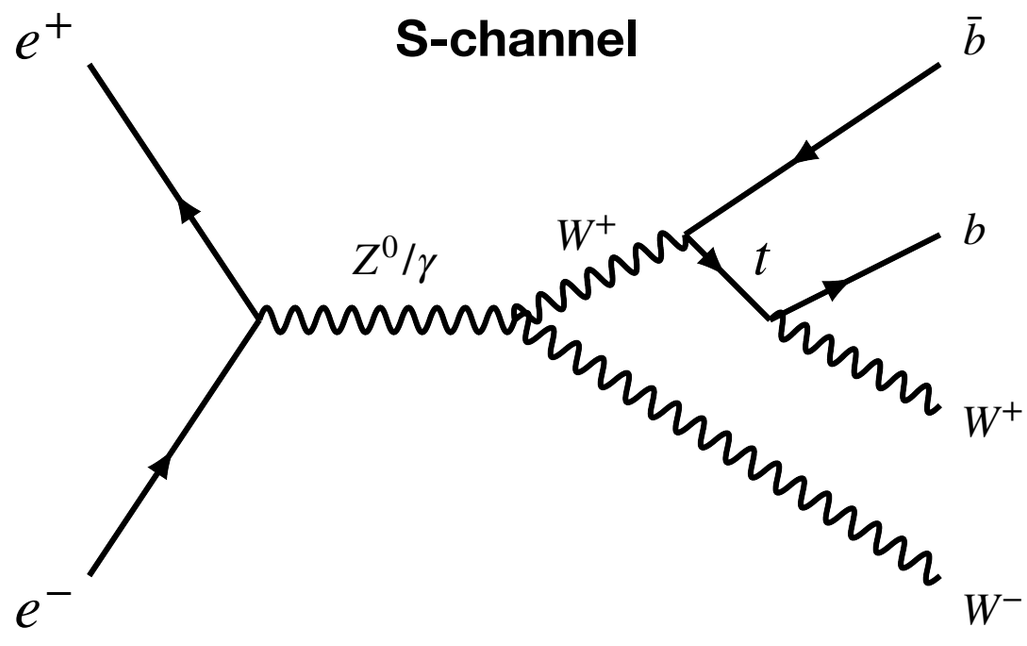
Future Prospects

- Apply the weights to the method used for the charge comparison by computing charge identification efficiencies for each methods.
- Form factor calculation using A_{FB}^{t} that was obtained in this analysis.

Backup Slides

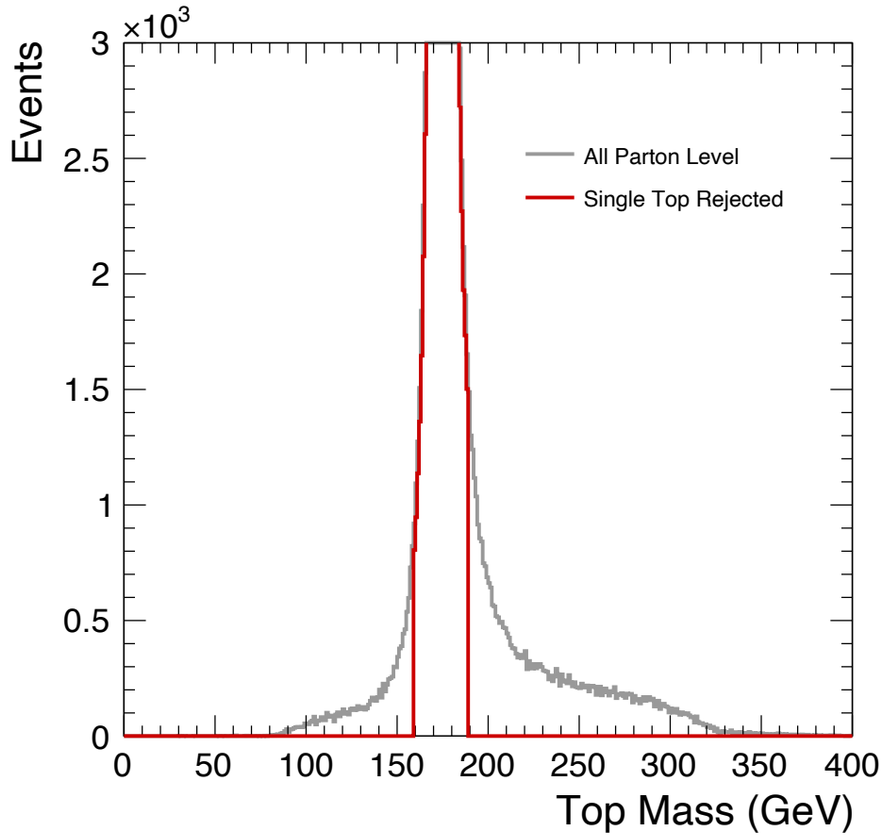
Single Topの背景事象





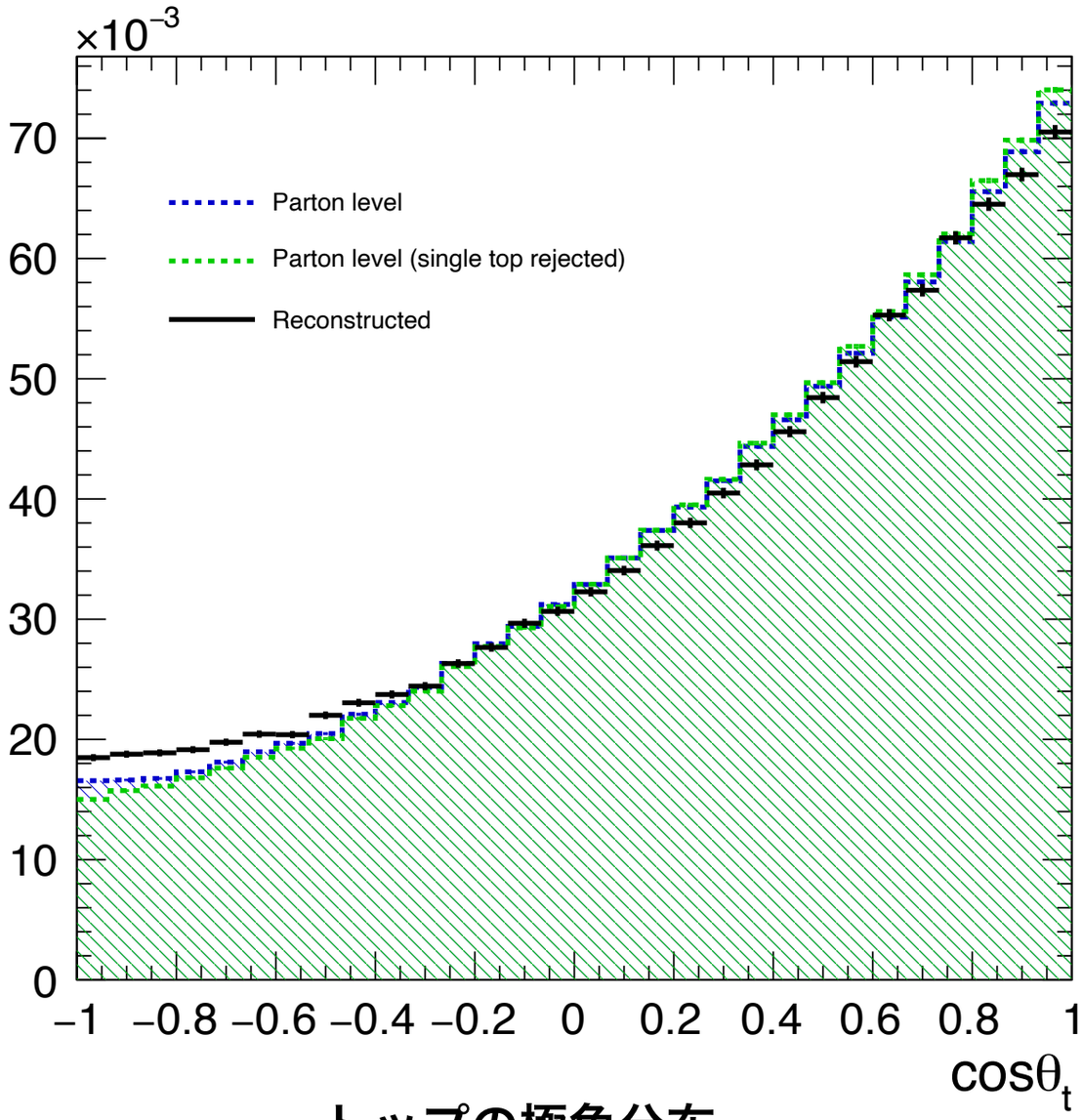
- Similar to the $t\bar{t}$ events, it has $b\bar{b}W^+W^-$as final state
- Difficult to eliminate these events from the reconstruction
  →set a cut to the generator information

  $|m_{Wb} - 174| < 15$ GeV
- 12% of all events are from the single top events.



Polar Angle Distribution (semi-leptonic)

$(\mathscr{P}_{e^-}, \mathscr{P}_{e^+}) = (+0.8, -0.3)$ **の場合**



トップの極角分布

bの極角分布