Charge ID

- I use charge ID results to calculate zprime mass limit in bb and cc.
- I use this as a reference.

ILD-PHYS-PUB-2023-001, June 2023,

"Experimental methods and prospects on the measurement of electroweak b and c-quark observables at the ILC operating at 250 GeV"

Efficiency $\varepsilon_{Cat.X}$ distribution

- For $c\bar{c}$
  - Cat.1 ->K-method
  - Cat.2 ->Vtx-method
  - Cat.3 ->Method in which one of the jets had no measurement of the charge using K-method but had it with Vtx-method
- For $b\bar{b}$
  - Cat.1 ->Vtx-method
  - Cat.2 ->K-method
  - Cat.3->Method in which one of the jets had no measurement of the charge using Vtx-method but had it with K-method

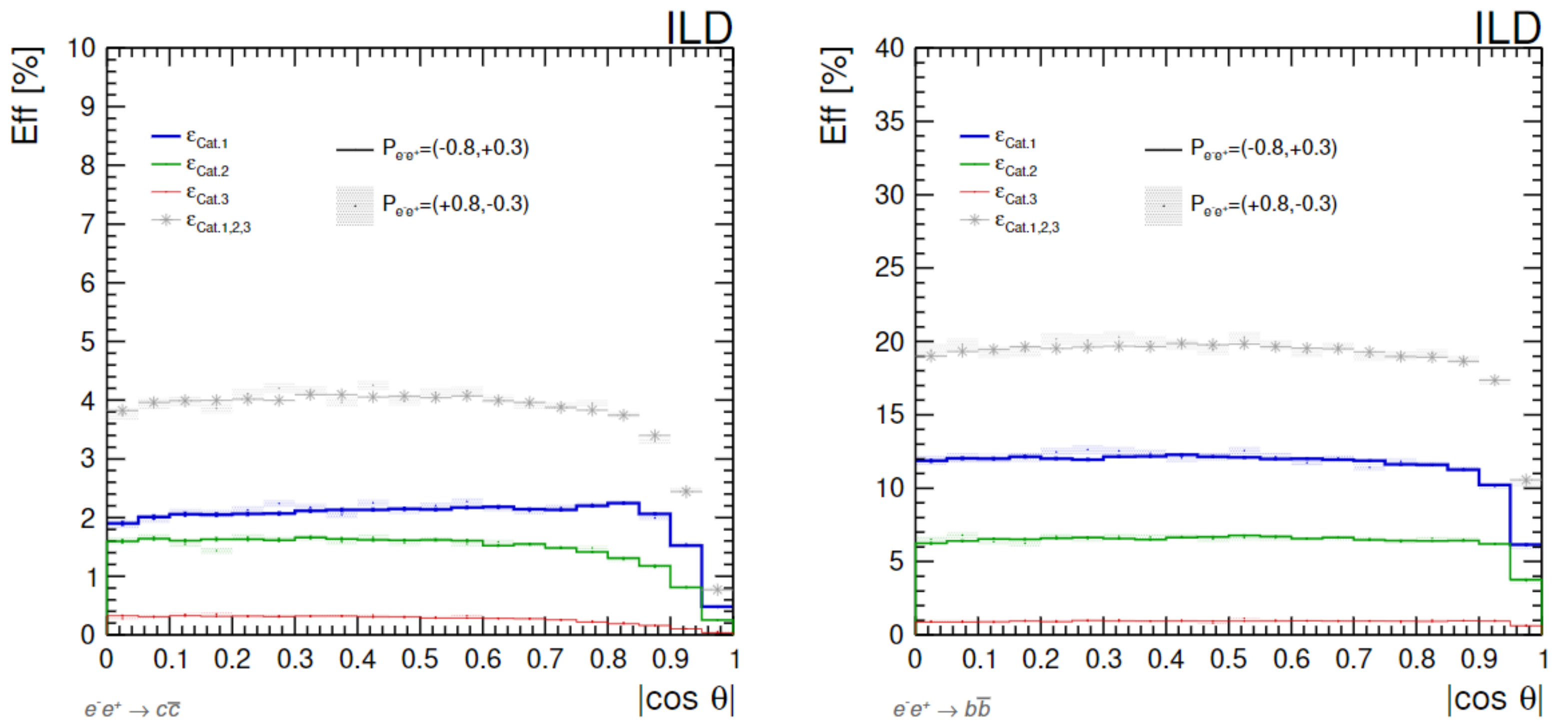

Figure 18: Distribution of the different selection efficiencies for $c\bar{c}$ (left) and $b\bar{b}$ (right) for the A_{FB} measurement, as described in Eq. 22. For the $c\bar{c}$ ($b\bar{b}$) case, the $Cat.1$ corresponds to only the K-method (Vtx-method) applied and $Cat.2$ to only the Vtx-method (K-method) applied.

Total efficiency (gray line) is used to find the zprime mass limit.

Calculate efficiency (costheta-dependent)

- Efficiency(costheta-dependent) for each bin of bb,cc events
- For bb event,

$$efficiency\_angle = \frac{\#\ of\ (true\ bb\ )\ w/eventcut}{\#\ of\ (true\ bb\ )\ w/o\ eventcut} \times \frac{\#\ of\ predicted\ bb}{\#\ of\ predicted\ total} \times Charge\ ID\ efficiency$$

The below case is used as the 1bin case.

$$efficiency\_1bin = \frac{\#\ of\ (true\ bb\ )\ w/eventcut}{\#\ of\ (true\ bb\ )\ w/o\ eventcut} \times \frac{\#\ of\ predicted\ bb}{\#\ of\ predicted\ total} \times (1 - Charge\ ID\ efficiency)$$

- Since the angle-dependent range is from -0.9 to 0.9, but the charge ID efficiency is from 0 to 0.9.
- So, I calculate the angle-dependent efficiency in this range and use the same value for the -0.9 to 0 range.

- I calculate the same way for number of background events.

Mass limit for bb

1bin & angle (with Charge ID)

```
===============================================
Ecm =500 [GeV]
SSM: M(5) = 4.31409 [TeV] M(2) = 6.05246 [TeV]
angle: M(5) = 2.69937 [TeV] M(2) = 3.78336 [TeV]
1bin: M(5) = 5.03988 [TeV] M(2) = 8.19033 [TeV]

===============================================
Ecm =500 [GeV]
ALR: M(5) = 1.78208 [TeV] M(2) = 2.45438 [TeV]
angle: M(5) = 1.3354 [TeV] M(2) = 1.79494 [TeV]
1bin: M(5) = 1.99279 [TeV] M(2) = 3.18321 [TeV]

===============================================
Ecm =500 [GeV]
chi: M(5) = 2.84672 [TeV] M(2) = 3.95397 [TeV]
angle: M(5) = 1.86292 [TeV] M(2) = 2.54522 [TeV]
1bin: M(5) = 3.29768 [TeV] M(2) = 5.31323 [TeV]

===============================================
Ecm =500 [GeV]
psi: M(5) = 1.80812 [TeV] M(2) = 2.49743 [TeV]
angle: M(5) = 1.2342 [TeV] M(2) = 1.66725 [TeV]
1bin: M(5) = 2.0801 [TeV] M(2) = 3.33138 [TeV]

===============================================
Ecm =500 [GeV]
eta: M(5) = 1.58703 [TeV] M(2) = 2.17248 [TeV]
angle: M(5) = 1.15382 [TeV] M(2) = 1.54333 [TeV]
1bin: M(5) = 1.79082 [TeV] M(2) = 2.83971 [TeV]
```

"model name" mass limit for angle + 1bin and mass limit in each case

1bin only (No Charge ID)

```
===============================================
Ecm =500 [GeV]
SSM: M(5) = 5.05972 [TeV] M(2) = 8.22287 [TeV]

===============================================
Ecm =500 [GeV]
ALR: M(5) = 1.99059 [TeV] M(2) = 3.17969 [TeV]

===============================================
Ecm =500 [GeV]
chi: M(5) = 3.31222 [TeV] M(2) = 5.33668 [TeV]

===============================================
Ecm =500 [GeV]
psi: M(5) = 2.08022 [TeV] M(2) = 3.33161 [TeV]

===============================================
Ecm =500 [GeV]
eta: M(5) = 1.7985 [TeV] M(2) = 2.85464 [TeV]
```

Mass limit for cc

1bin & angle (with Charge ID)

```
=============================================
Ecm =500 [GeV]
SSM: M(5) = 3.64362 [TeV] M(2) = 5.09955 [TeV]
angle: M(5) = 3.35435 [TeV] M(2) = 4.69629 [TeV]
1bin: M(5) = 3.28304 [TeV] M(2) = 5.32016 [TeV]

=============================================
Ecm =500 [GeV]
ALR: M(5) = 3.2932 [TeV] M(2) = 4.61607 [TeV]
angle: M(5) = 3.10067 [TeV] M(2) = 4.35332 [TeV]
1bin: M(5) = 2.78294 [TeV] M(2) = 4.50451 [TeV]

=============================================
Ecm =500 [GeV]
chi: M(5) = 1.96116 [TeV] M(2) = 2.70934 [TeV]
angle: M(5) = 1.86537 [TeV] M(2) = 2.57585 [TeV]
1bin: M(5) = 1.63275 [TeV] M(2) = 2.5902 [TeV]

=============================================
Ecm =500 [GeV]
psi: M(5) = 1.75443 [TeV] M(2) = 2.40728 [TeV]
angle: M(5) = 1.65998 [TeV] M(2) = 2.27744 [TeV]
1bin: M(5) = 1.50334 [TeV] M(2) = 2.35333 [TeV]

=============================================
Ecm =500 [GeV]
eta: M(5) = 1.82679 [TeV] M(2) = 2.51223 [TeV]
angle: M(5) = 1.72028 [TeV] M(2) = 2.36653 [TeV]
1bin: M(5) = 1.58671 [TeV] M(2) = 2.4868 [TeV]
```

mass limit for angle + 1bin
and mass limit in each case

1bin only (No Charge ID)

```
=============================================
Ecm =500 [GeV]
SSM: M(5) = 4.01106 [TeV] M(2) = 6.51063 [TeV]

=============================================
Ecm =500 [GeV]
ALR: M(5) = 3.45473 [TeV] M(2) = 5.60182 [TeV]

=============================================
Ecm =500 [GeV]
chi: M(5) = 1.9736 [TeV] M(2) = 3.15851 [TeV]

=============================================
Ecm =500 [GeV]
psi: M(5) = 1.8201 [TeV] M(2) = 2.88201 [TeV]

=============================================
Ecm =500 [GeV]
eta: M(5) = 1.93457 [TeV] M(2) = 3.06962 [TeV]
```

χ^2 for bb

```
==============================================
Ecm =500 [GeV]
SSM: M(5) = 4.31409 [TeV] M(2) = 6.05246 [TeV]
angle: M(5) = 2.69937 [TeV] M(2) = 3.78336 [TeV]
1bin: M(5) = 5.03988 [TeV] M(2) = 8.19033 [TeV]

==============================================
Ecm =500 [GeV]
ALR: M(5) = 1.78208 [TeV] M(2) = 2.45438 [TeV]
angle: M(5) = 1.3354 [TeV] M(2) = 1.79494 [TeV]
1bin: M(5) = 1.99279 [TeV] M(2) = 3.18321 [TeV]

==============================================
Ecm =500 [GeV]
chi: M(5) = 2.84672 [TeV] M(2) = 3.95397 [TeV]
angle: M(5) = 1.86292 [TeV] M(2) = 2.54522 [TeV]
1bin: M(5) = 3.29768 [TeV] M(2) = 5.31323 [TeV]

==============================================
Ecm =500 [GeV]
psi: M(5) = 1.80812 [TeV] M(2) = 2.49743 [TeV]
angle: M(5) = 1.2342 [TeV] M(2) = 1.66725 [TeV]
1bin: M(5) = 2.0801 [TeV] M(2) = 3.33138 [TeV]

==============================================
Ecm =500 [GeV]
eta: M(5) = 1.58703 [TeV] M(2) = 2.17248 [TeV]
angle: M(5) = 1.15382 [TeV] M(2) = 1.54333 [TeV]
1bin: M(5) = 1.79082 [TeV] M(2) = 2.83971 [TeV]
```

1bin & angle (with Charge ID)

```
 chi2_angle = 42.9909
 chi2_1bin = 30.9084
chi2 = 73.8994 ndf = 40
==============================================
Ecm =500 [GeV]
SSM: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = 38.216
 chi2_1bin = 2.63567
chi2 = 40.8517 ndf = 40
==============================================
Ecm =500 [GeV]
ALR: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = 38.9348
 chi2_1bin = 7.09886
chi2 = 46.0336 ndf = 40
==============================================
Ecm =500 [GeV]
chi: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = 38.1609
 chi2_1bin = 2.76687
chi2 = 40.9277 ndf = 40
==============================================
Ecm =500 [GeV]
psi: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = 38.1133
 chi2_1bin = 2.39511
chi2 = 40.5084 ndf = 40
==============================================
Ecm =500 [GeV]
eta: M(5) = 5 [TeV] M(2) = 5 [TeV]
```

1bin only (No Charge ID)

```
 chi2_angle = No Use
 chi2_1bin = 31.3686
 chi2 = 31.3686 ndf = 2
==============================================
Ecm =500 [GeV]
SSM: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = No Use
 chi2_1bin = 2.63276
 chi2 = 2.63276 ndf = 2
==============================================
Ecm =500 [GeV]
ALR: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = No Use
 chi2_1bin = 7.18849
 chi2 = 7.18849 ndf = 2
==============================================
Ecm =500 [GeV]
chi: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = No Use
 chi2_1bin = 2.76707
 chi2 = 2.76707 ndf = 2
==============================================
Ecm =500 [GeV]
psi: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = No Use
 chi2_1bin = 2.40372
 chi2 = 2.40372 ndf = 2
==============================================
Ecm =500 [GeV]
eta: M(5) = 5 [TeV] M(2) = 5 [TeV]
```

χ^2 for cc

Each chi square value is "calculated chi2" + "ndf".

1bin & angle (with Charge ID)

```
 chi2_angle = 49.9328
 chi2_1bin = 7.11491
chi2 = 57.0477 ndf = 40
=============================================
Ecm =500 [GeV]
SSM: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = 46.7909
 chi2_1bin = 4.61892
chi2 = 51.4098 ndf = 40
=============================================
Ecm =500 [GeV]
ALR: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = 39.0199
 chi2_1bin = 2.27406
chi2 = 41.2939 ndf = 40
=============================================
Ecm =500 [GeV]
chi: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = 38.607
 chi2_1bin = 2.17943
chi2 = 40.7865 ndf = 40
=============================================
Ecm =500 [GeV]
psi: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = 38.7112
 chi2_1bin = 2.22636
chi2 = 40.9376 ndf = 40
=============================================
Ecm =500 [GeV]
eta: M(5) = 5 [TeV] M(2) = 5 [TeV]
```

1bin only (No Charge ID)

```
 chi2_angle = No Use
 chi2_1bin = 13.5185
 chi2 = 13.5185 ndf = 2
=============================================
Ecm =500 [GeV]
SSM: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = No Use
 chi2_1bin = 8.29543
 chi2 = 8.29543 ndf = 2
=============================================
Ecm =500 [GeV]
ALR: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = No Use
 chi2_1bin = 2.61767
 chi2 = 2.61767 ndf = 2
=============================================
Ecm =500 [GeV]
chi: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = No Use
 chi2_1bin = 2.41935
 chi2 = 2.41935 ndf = 2
=============================================
Ecm =500 [GeV]
psi: M(5) = 5 [TeV] M(2) = 5 [TeV]

 chi2_angle = No Use
 chi2_1bin = 2.54317
 chi2 = 2.54317 ndf = 2
=============================================
Ecm =500 [GeV]
eta: M(5) = 5 [TeV] M(2) = 5 [TeV]
```

Back up

quark flavor tagging

- To evaluate the new physics search, we make a cos theta distribution for each signal quark.
- To do this, I first conduct flavor tagging on the signals and separate them into b, c, and others.

After event cut

predicted flavor

true flavor	qq(u,d,s)	cc	bb	others
qq(u,d,s)	**2,661,403**	83,956	36,887	34,311
cc	266,296	**834,452**	89,949	10,348
bb	13,535	21,423	**705,974**	5,104

Flavor tagging is performed on the two jets of reconstituted particles
and events are used if the respective flavors match,
events that do not match are others.

- Number of background event
- 2f BG + 4f BG + 2f signal(Not signal flavor)
- BG for bb event
- BG=signal(true flavor qq,cc & predicted bb)+2fBG(predicted bb)+4fBG(predicted bb)

- Number of signal event
- SIG=Signal(predicted bbの中のtrue flavorがbb)

Without Charge ID

5-sigma mass limit (TeV)

Z' model	l	b	c	q
SSM	4.7	5.1	4.1	6.3
ALR	6.4	2.0	3.5	2.8
Chi	4.6	3.3	2.0	3.2
Psi	2.4	2.1	1.8	1.6
Eta	2.7	1.8	2.0	1.9

Upper limit for the mass of Z' that can be detected in $e^+e^- \to f\bar{f}$ measurements of ILCs with CMS energy of 500 GeV with a misalignment of more than 5 σ.
If the upper limit of mass is lowered by adding a channel, the value of the upper limit before the addition is used.

Z' model	$b+c$	$b+c$ (original)	$b+c+q$	$b+c+q$ (original)	$l+b+c$	$l+b+c$ (original)	$l+b+c+q$	$l+b+c+q$ (original)
SSM	**5.3**	5.3	**6.7**	6.7	**5.3**	5.3	**6.5**	6.0
ALR	**3.5**	3.4	**3.6**	3.6	**6.4**	6.4	**6.4**	6.4
Chi	**3.3**	3.3	**3.7**	3.7	**4.7**	4.7	**4.8**	4.8
Psi	**2.2**	2.2	**2.3**	2.3	**2.6**	2.6	**2.6**	2.6
Eta	**2.1**	2.1	**2.3**	2.3	**2.8**	2.8	**2.8**	2.8

Without Charge ID

2-sigma mass limit (TeV)

Z' model	l	b	c	q
SSM	6.6	8.9	7.0	10.9
ALR	8.8	3.4	6.0	4.8
Chi	6.4	5.7	3.4	5.4
Psi	3.3	3.6	3.1	2.6
Eta	3.7	3.1	3.3	3.2

Upper limit for the mass of Z' that can be detected in $e^+e^- \to f\bar{f}$ measurements of ILCs with CMS energy of 500 GeV with a misalignment of more than 2σ.
If the upper limit of mass is lowered by adding a channel, the value of the upper limit before the addition is used.

Z' model	$b+c$	$b+c$ **(original)**	$b+c+q$	$b+c+q$ **(original)**	$l+b+c$	$l+b+c$ **(original)**	$l+b+c+q$	$l+b+c+q$ **(original)**
SSM	**8.9**	8.2	**10.9**	10.1	**8.9**	7.3	**10.9**	8.3
ALR	**6.0**	5.3	**6.0**	5.5	**8.9**	8.9	**8.8**	8.8
Chi	**5.7**	5.0	**5.7**	5.5	**6.5**	6.5	**6.6**	6.6
Psi	**3.6**	3.4	**3.6**	3.4	**3.6**	3.5	**3.6**	3.5
Eta	**3.3**	3.3	**3.4**	3.4	**3.8**	3.8	**3.9**	3.9