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Z' search in 2f final states with ILC 500 GeV

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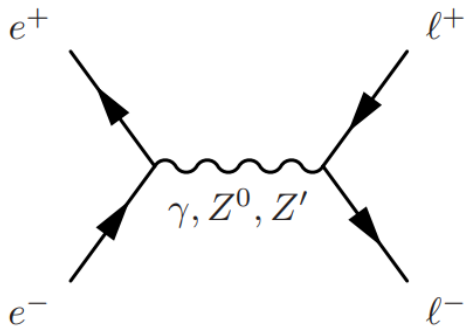
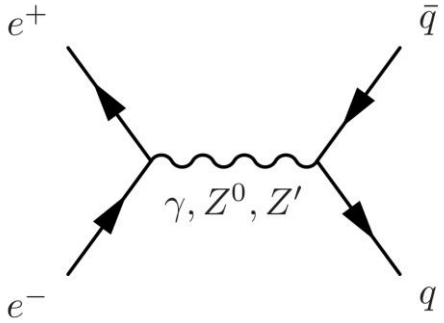
2-fermion $e^+e^- \rightarrow f^+f^-$ event

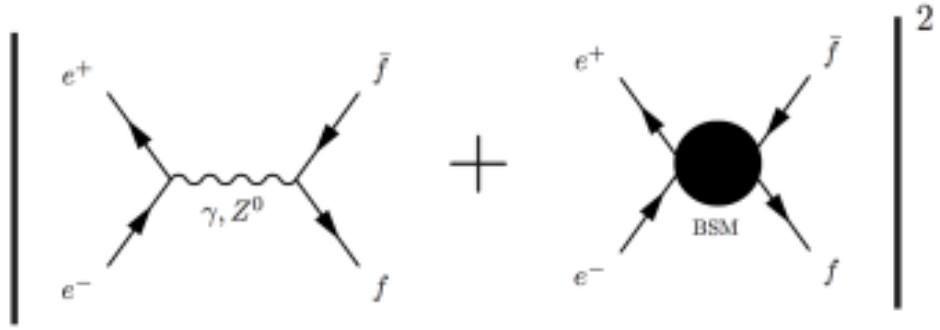
- $e^+e^- \rightarrow f^+f^-$: The production of fermionic pairs is sensitive to the production of heavy gauge bosons (Z'). In the presence of new physics mediated by new particles, total and differential cross section can be deviated from the standard model as shown in the interference diagram below.



2 lepton process



2 quark process



Feynman diagram of fermion pair production when the new physics (Beyond Standard Model : BSM) is included

Event selection

- I have conducted mu and tau event selection and have used the results to evaluate the Z' new physics search.

Evaluation of Z' new physics search by mu & tau event

Z'model	SSM	ALR	χ	ψ	η
5-sigma	6.24 TeV	8.35 TeV	6.08 TeV	3.16 TeV	3.53 TeV

5-sigma = discovery reach

Z'model	SSM	ALR	χ	ψ	η
2-sigma	9.84 TeV	13.18 TeV	9.60 TeV	4.96 TeV	5.55 TeV

2-sigma = 95% CL lower limit

Particle ID

- This time, I use Particle ID to select events.

- **μ event selection with the ILD 500 GeV full simulation.**
- **Signal Event**:
  - 2f_Z_leptonic (μ) (true $mass$ ≥450 GeV)
- **Background Event**:
  - 2f_Z_leptonic (signal true $mass$ <450 GeV)
  - 2f_Z_leptonic (τ)
  - 2f_Z_bhabhag
  - 4f_WW_leptonic
  - 4f_ZZ_leptonic
  - 4f_singleZee_leptonic
  - 4f_singleZsingleWMix_leptonic
  - 4f_ZZWWMix_leptonic
  - 4f_singleW_leptonic
  - 4f_singleZnunu_leptonic

2f Background
2f Bhabha Background
4f leptonic Background

- **Polarization** **Luminosity**
- e^-: −80% , e^+: +30% 1600 fb^{-1} each

Particle ID for mu

- Clustering (muon & FSR photon)
- Opening angle: $\cos(angle) \leq -0.95$
- Energy: $Energy \geq 450\ GeV$
- Particle ID condition: if either of the two jets is muon

		signal	2f _z_BG	2f_bha_BG	P4f_BG
No clustering & cut →	original	781,215	4,249,717	44,105,837	10,184,055
Include other cuts & clustering	Without PID	716,569(100%)	20,985(100%)	5,465,710(100%)	136,737(100%)
	With PID	711,788(99%)	13,140(63%)	38,296(0.7%)	41,736(31%)

Event selection

- I have conducted mu and tau event selection and have used the results to evaluate the Z' new physics search.

- In addition to these, I will include electron and quark events in this evaluation.

Use below events for qq event selection

- $quark$ **event selection with the ILD 500 GeV full simulation.**
- **Signal Event**:
  - 2f_z_hadronic(true mass≥450 GeV)
- **Background Event**:
  - 2f_z_hadronic(true mass<450 GeV) — 2f Background
  - 4f_ww_hadronic
  - 4f_zzwwmix_hadronic
  - 4f_zz_hadronic

  — 4f hadronic Background
  - 4f_singleW_semileptonic
  - 4f_singleZee_semileptonic
  - 4f_singleZnunu_semileptonic
  - 4f_singleWW_semileptonic
  - 4f_singleZZ_semileptonic

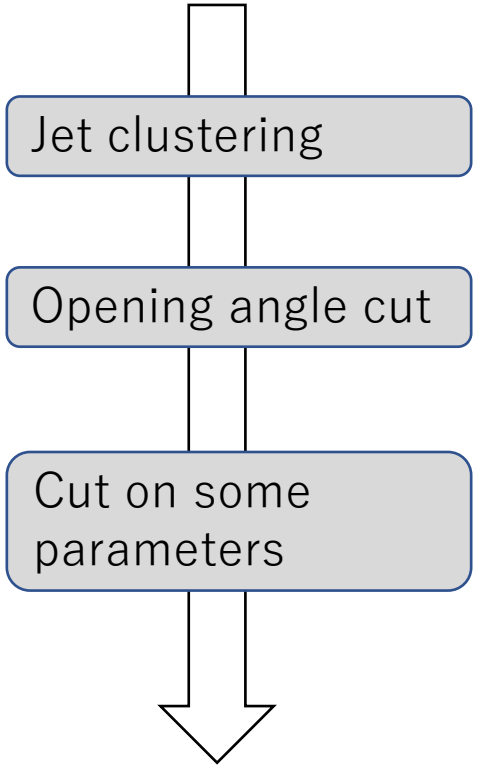
  — 4f semileptonic Background
- **Polarization**
- $e^-: -80\%\,, e^+: +30\%$

Luminosity

$1600\ \mathrm{fb}^{-1}$ each

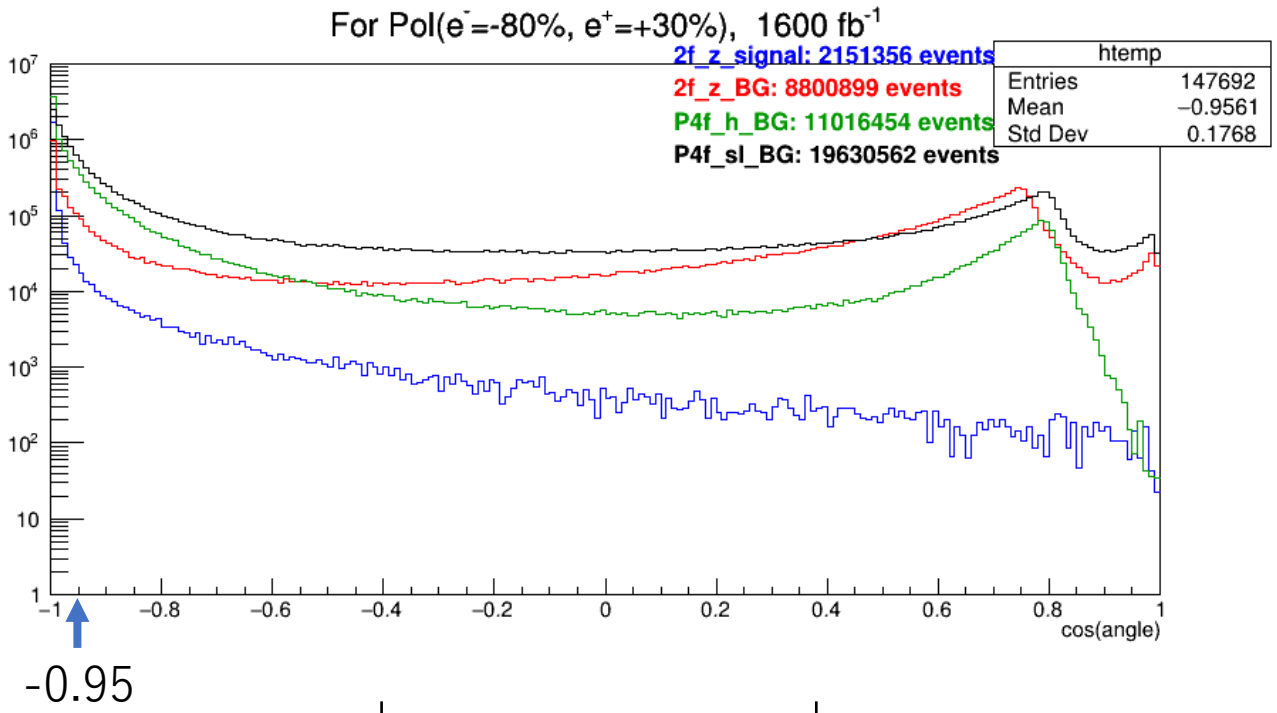
qq event selection

the ILD 500 GeV full simulation data



Evaluation of Z' new physics search

- Opening angle cut:
- $\cos(angle) \leq -0.95$



	signal	2f BG	4f_h_BG	4f_sl_BG
No cut	2,151,356(100%)	8,800,899(100%)	11,016,453(100%)	19,630,562(100%)
With OP angle	1,916,598(89%)	1,588,215(18%)	6,394,654(58%)	6,588,209(34%)

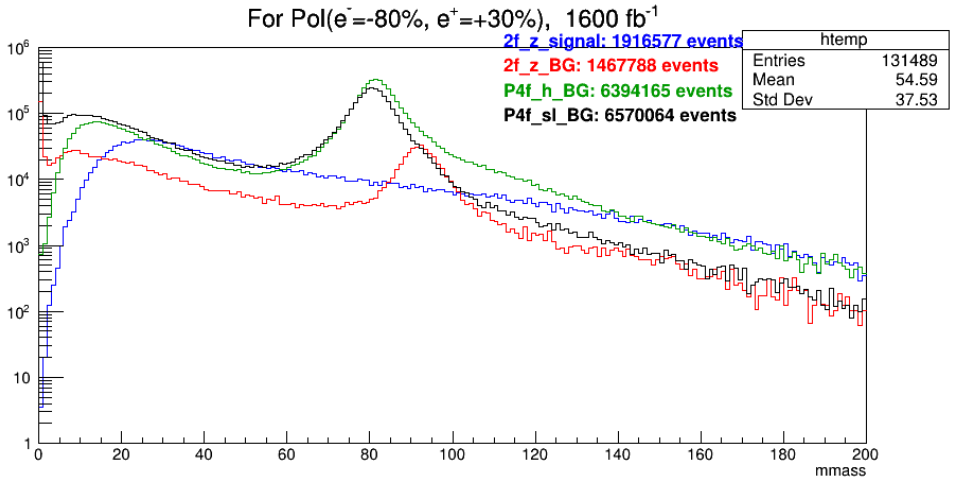
- **Goal:** The signal should be 60-70% and the number of background events should be less than the signal.

Cut on some parameters

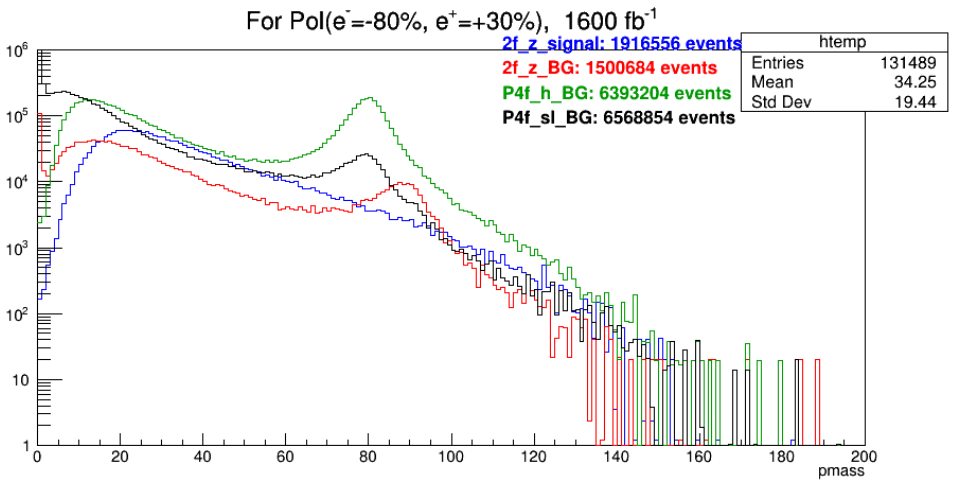
- Additional cut conditions: Mass (jet), y23, y34

Jet mass plot

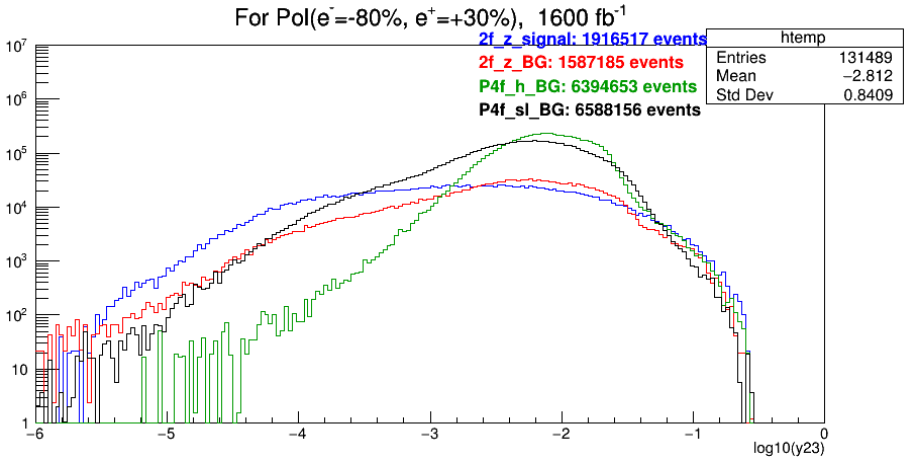
The first one



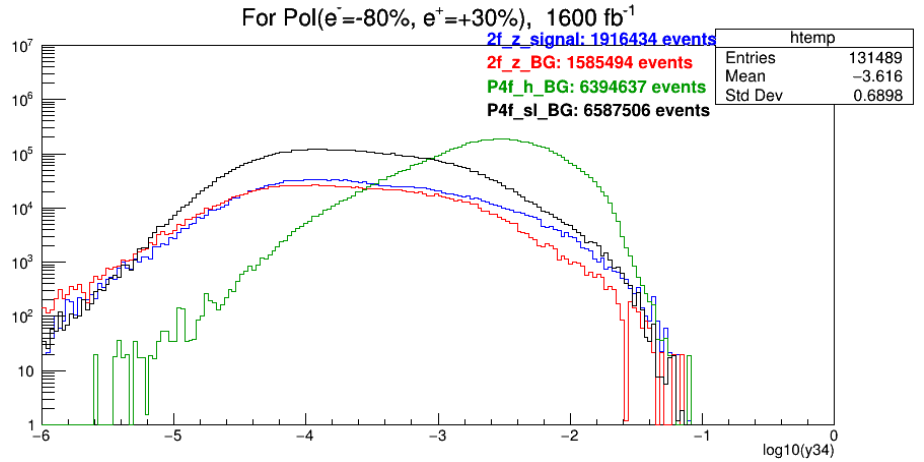
The second one



y23



y34



Cut on some parameters

- The best cut condition among several combinations is

  mmass(first jet) <= 80 & log10(y34)<=-3.0
- but the number of 4f semileptonic BG events is still too large, so I will cut this.

Cut condition: mmass(first jet) <= 80 & log10(y34)<=-3.0

	signal	**2f BG**	**4f_h_BG**	**4f_sl_BG**
No cut	2,151,356(100%)	8,800,899(100%)	11,016,453(100%)	19,630,562(100%)
With mass, OP angle cut	1,329,022(62%)	747,675(8%)	701,049(6%)	3,614,268(18%)

Conclusion

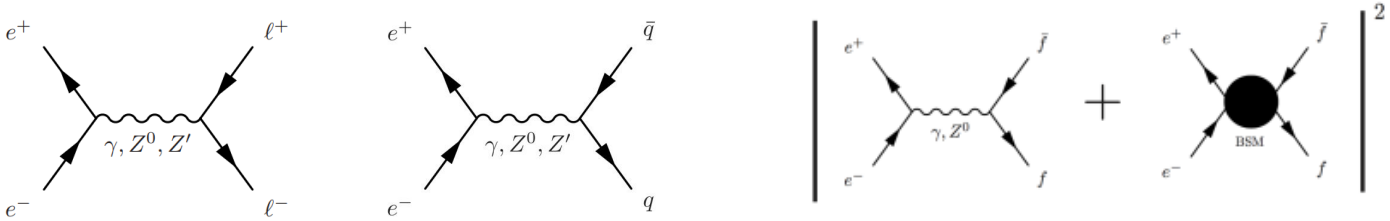
- qq event selection was conducted, but the number of background events could not be reduced significantly, so the multivariate analysis will be conducted.

- I also checked whether Particle ID is working, using mu events.
- Particle ID is working well.

backup

2-lepton $e^+e^- \rightarrow l^+l^-$ event

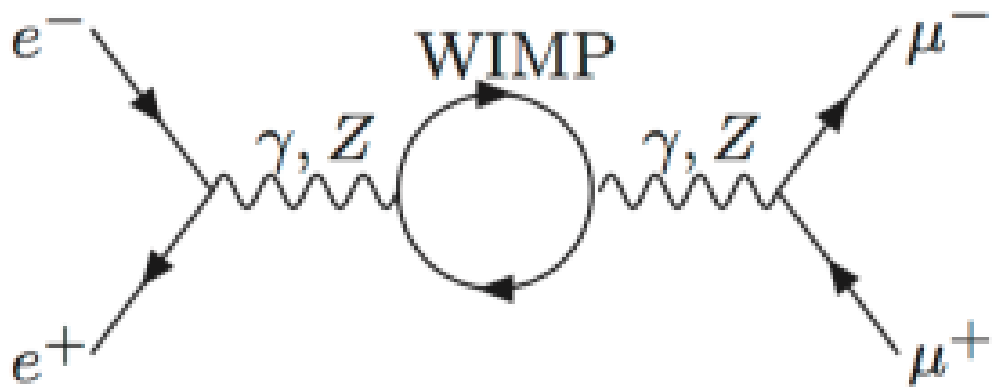
- $e^+e^- \rightarrow l^+l^-(l = \mu, \tau)$: The production of fermionic pairs is sensitive to the production of heavy gauge bosons (Z'). In the presence of new physics mediated by new particles, the first power term of the interference can be seen as a shift, as in right Figure.



- In the Gauge Higgs Unification (GHU) model, Higgs particles are part of an extra-dimensional component of the gauge potential, which is represented by a variation of the Aharonov-Bohm (AB) phase (θ_H) in the fifth dimension.

2-lepton $e^+e^- \rightarrow l^+l^-$ event

- There is a general method to investigate the $e^+e^- \rightarrow f\bar{f}$ misalignment due to WIMPs.
- If we introduce the WIMP(χ) into the 2-fermion final state process ($e^+e^- \rightarrow f\bar{f}$) analyzed so far and assume a diagram that includes the loop $Z \rightarrow \chi\chi \rightarrow Z$, the coupling constant changes.



Definition of signal events

- I separate signal events into signal and background by mass.
- This mass corresponds to the Z* mass in the Feynman diagram.
- If Z* mass is small, the contribution of heavy new particles such as Z' that interfere with Z* will be small.
- When calculating the Z' model, Z* is assumed to be 500 GeV (not including ISR and other effects), so if low Z* contribution is included, the result will be different from what we expect.

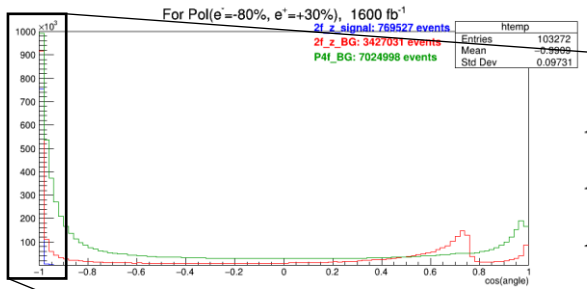
- So I drop the low mass events as background.

Opening angle cut

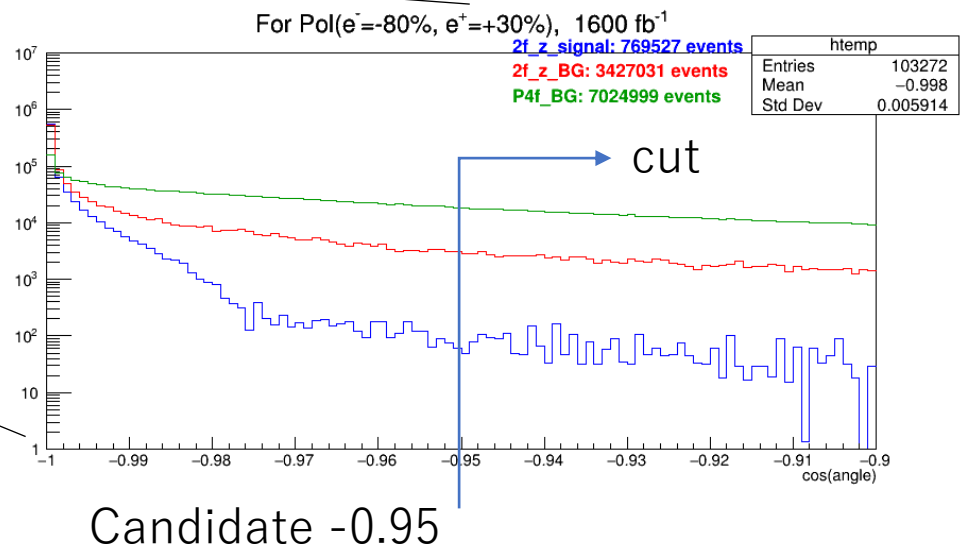
The angle between the signal jets is almost 180 degrees.
→An event near 180 degrees is considered a signal (2 fermion) event.

For mu event

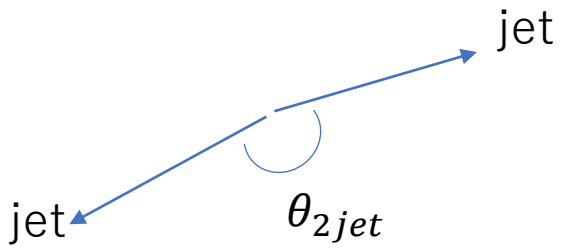
overall



Around 180°



Candidate -0.95

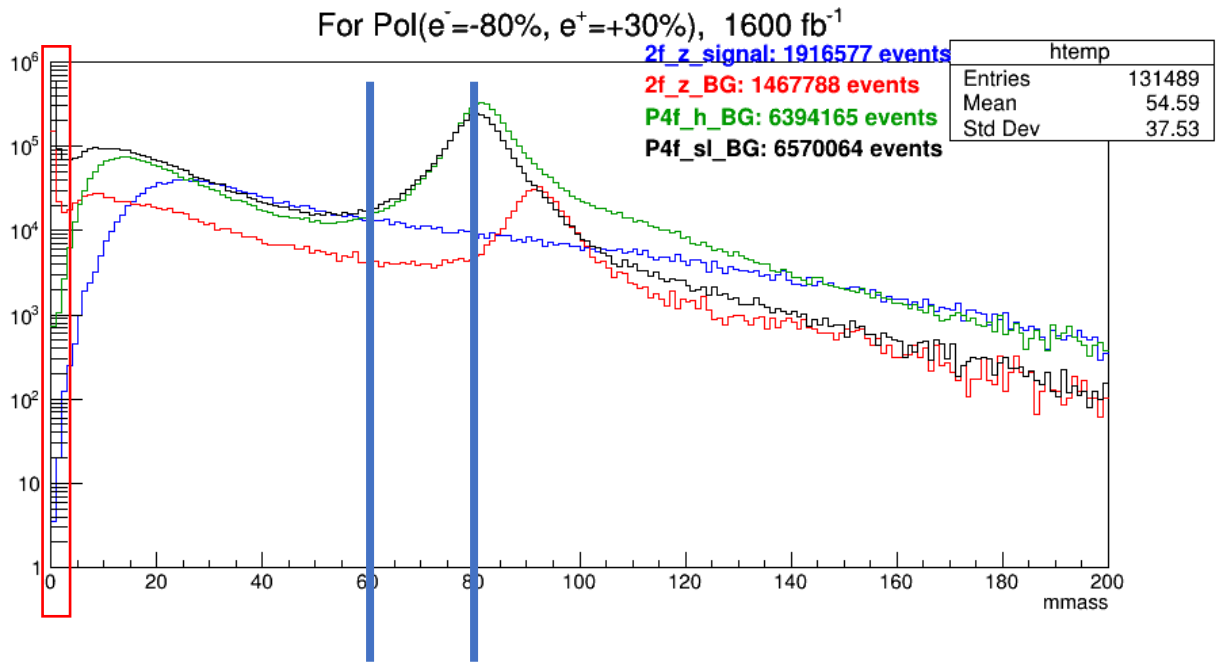


qq event selection

- With Opening angle: $\cos(angle) \leq -0.95$

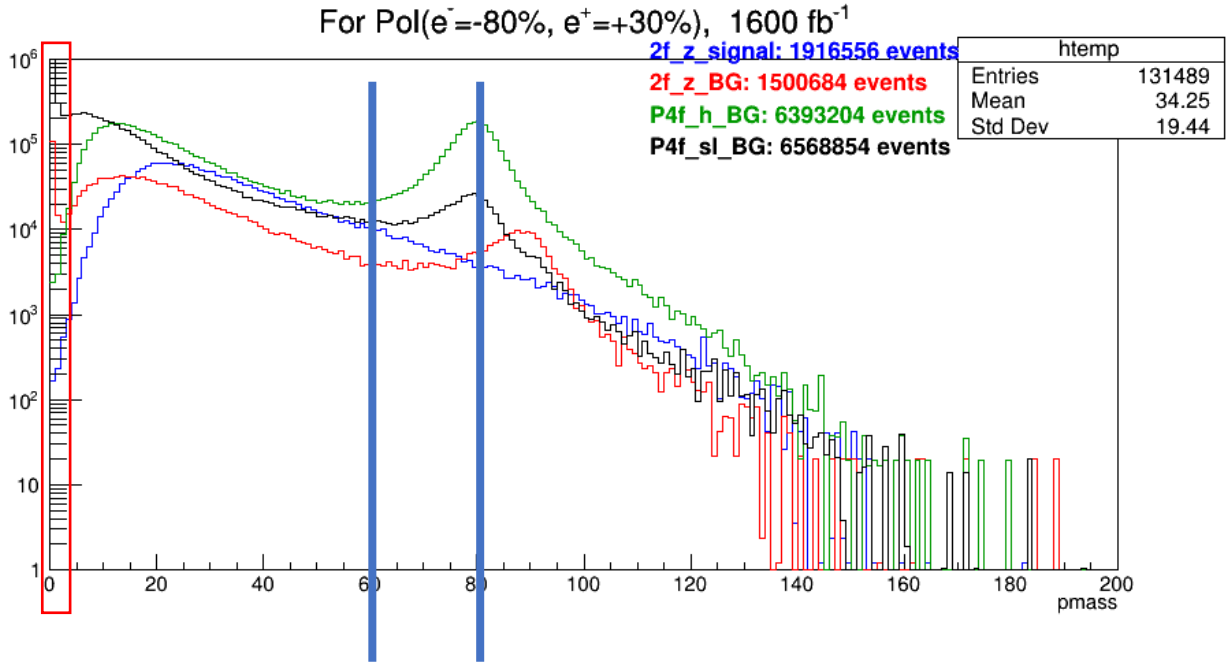
Jet mass plot

First jet



Cut condition
1 < mmass <= 60 or 80 GeV

Second jet

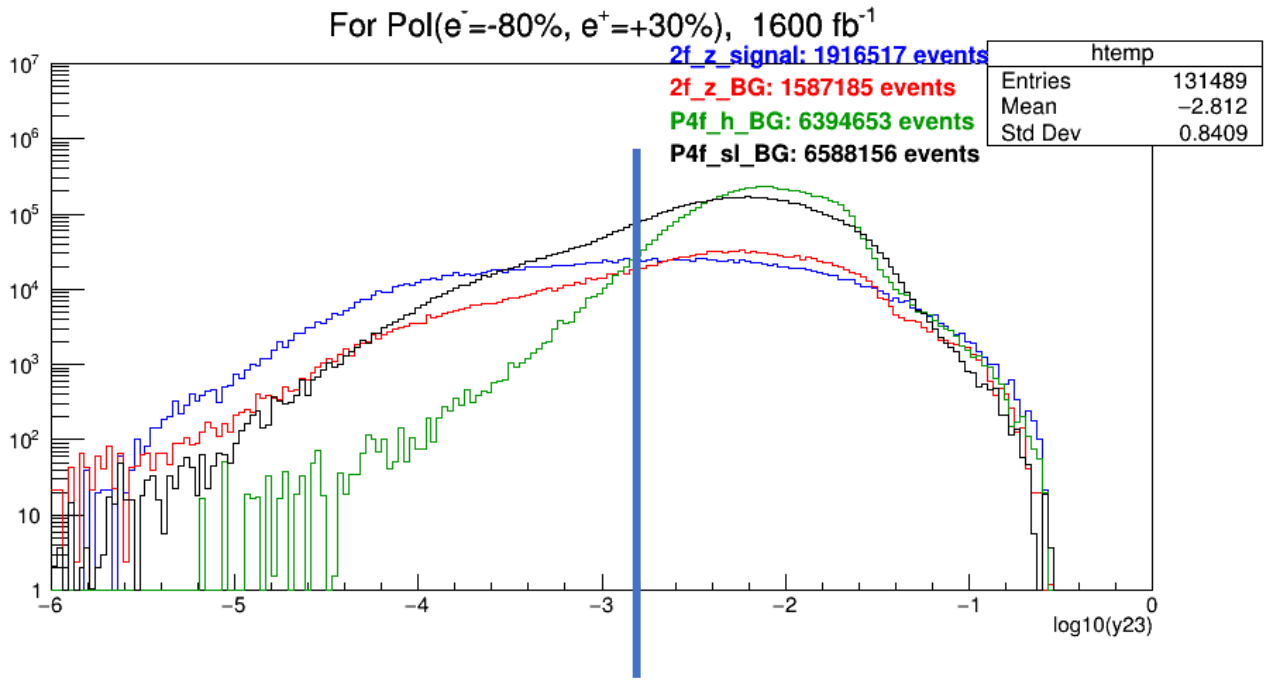


Cut condition
1 < pmass <= 60 or 80 GeV

qq event selection

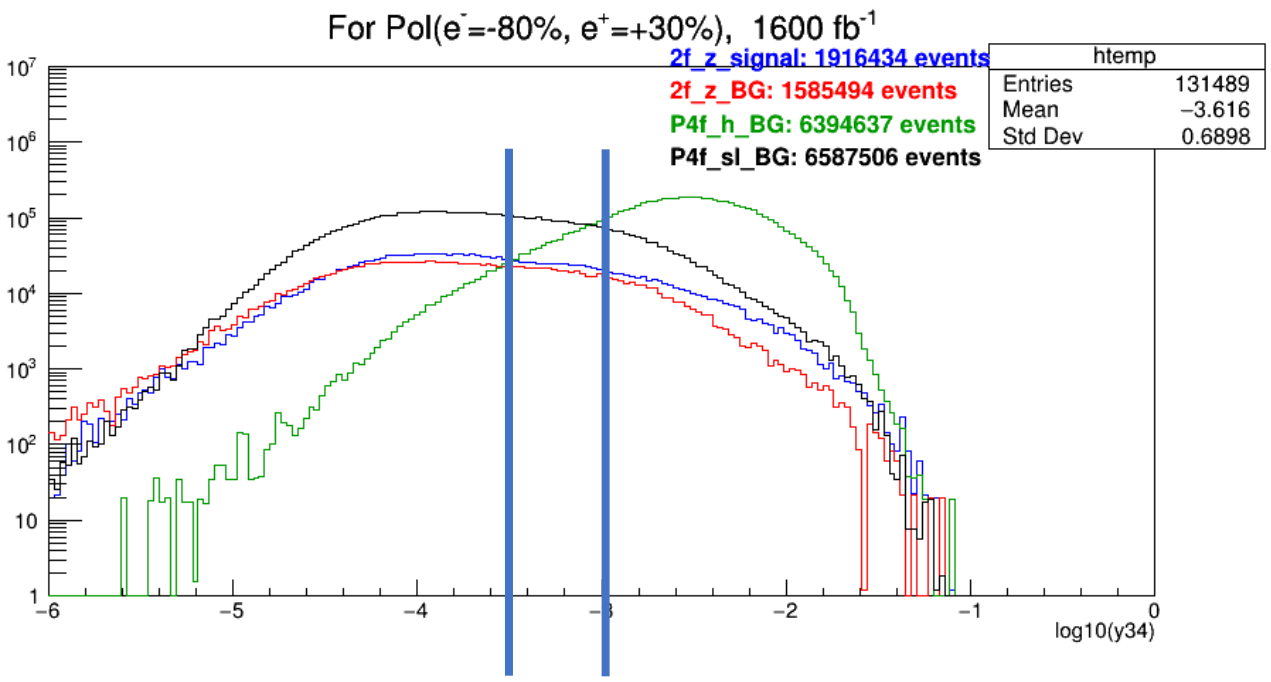
- With Opening angle: $\cos(angle) \leq -0.95$

y23



Cut condition
log10(y23) <= -2.8

y34



Cut condition
log10(y34) <= -3.0 or -3.5

qq event selection

- Jet mass cut with Opening angle cut: $\cos(angle) \leq -0.95$

First jet

1 < mmass <= 60 GeV

	signal	2f BG	4f_h_BG	4f_sl_BG
No cut	2,151,356(100%)	8,800,899(100%)	11,016,453(100%)	19,630,562(100%)
With mass, OP angle cut	1,272,931(59%)	786,796(9%)	1,865,450(17%)	2,751,771(14%)

1 < mmass <= 80 GeV

	signal	2f BG	4f_h_BG	4f_sl_BG
No cut	2,151,356(100%)	8,800,899(100%)	11,016,453(100%)	19,630,562(100%)
With mass, OP angle cut	1,497,172(70%)	869,734(10%)	3,382,997(31%)	4,212,822(21%)

Second jet

1 < pmass <= 60 GeV

	signal	2f BG	4f_h_BG	4f_sl_BG
No cut	2,151,356(100%)	8,800,899(100%)	11,016,453(100%)	19,630,562(100%)
With mass, OP angle cut	1,713,454(80%)	1,184,916(13%)	3,995,870(36%)	4,620,594(24%)

1 < pmass <= 80 GeV

	signal	2f BG	4f_h_BG	4f_sl_BG
No cut	2,151,356(100%)	8,800,899(100%)	11,016,453(100%)	19,630,562(100%)
With mass, OP angle cut	1,846,892(86%)	1,264,701(14%)	5,321,984(48%)	4,938,367(25%)

qq event selection

- With Opening angle: $\cos(angle) \leq -0.95$

y23

log10(y23) <= -2.8

	signal	2f BG	4f_h_BG	4f_sl_BG
No cut	2,151,356(100%)	8,800,899(100%)	11,016,453(100%)	19,630,562(100%)
With y23, OP angle cut	936,400(44%)	426,342(5%)	183,726(2%)	1,166,883(6%)

y34

log10(y34) <= -3.0

	signal	2f BG	4f_h_BG	4f_sl_BG
No cut	2,151,356(100%)	8,800,899(100%)	11,016,453(100%)	19,630,562(100%)
With y34, OP angle cut	1,539,170(72%)	1,339,581(15%)	1,156,958(11%)	5,524,699(28%)

log10(y34) <= -3.5

	signal	2f BG	4f_h_BG	4f_sl_BG
No cut	2,151,356(100%)	8,800,899(100%)	11,016,453(100%)	19,630,562(100%)
With y34, OP angle cut	1,135,346(53%)	1,003,140(11%)	262,340(2%)	4,004,374(20%)

Number of events of mu event background without and with PID

	Without pid	With pid
2f_bha-eLpR	5195782.0	36418.0
2f_bha-eRpL	269929.0	1878.0
P4f_sznu-eLpR	0.0	0.0
P4f_sznu-eRpL	0.0	0.0
P4f_ww-eLpR	1622.0	1417.0
P4f_ww-eRpL	0.0	0.0
P4f_zzorww-eLpR	0.0	0.0
P4f_zzorww-eRpL	0.0	0.0
P4f_zz-eLpR	554.0	546.0
P4f_zz-eRpL	32.0	31.0
P4f_sw-eLpR	33779.0	28949.0
P4f_sw-eRpL	0.0	0.0
P4f_sze-eLpR	77318.0	10064.0
P4f_sze-eRpL	4291.0	540.0
P4f_szeorsw-eLpR	19139.0	189.0
P4f_szeorsw-eRpL	2.0	0.0