AFB studies at 500 GeV (update)

ILD Top/HF group meeting 25/01/22

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Observables for BSM studies

- Forward-backward asymmetry:

$$A_{\mathrm{FB}} = \frac{\int_0^1 \frac{d\sigma}{d\cos\theta} d\cos\theta - \int_{-1}^0 \frac{d\sigma}{d\cos\theta} d\cos\theta}{\int_{-1}^1 \frac{d\sigma}{d\cos\theta} d\cos\theta}$$

- From theory to experiment, i.e., from cross-section to events:

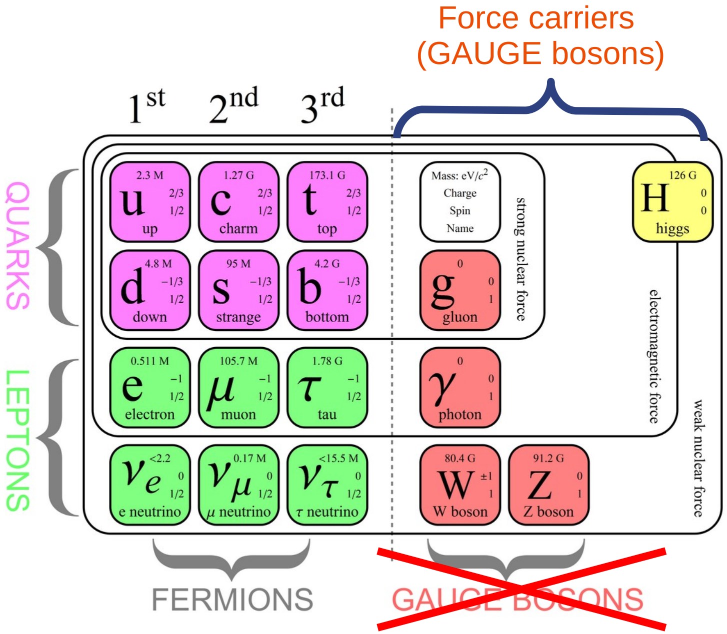
$$N = L \cdot \sigma \cdot \epsilon$$

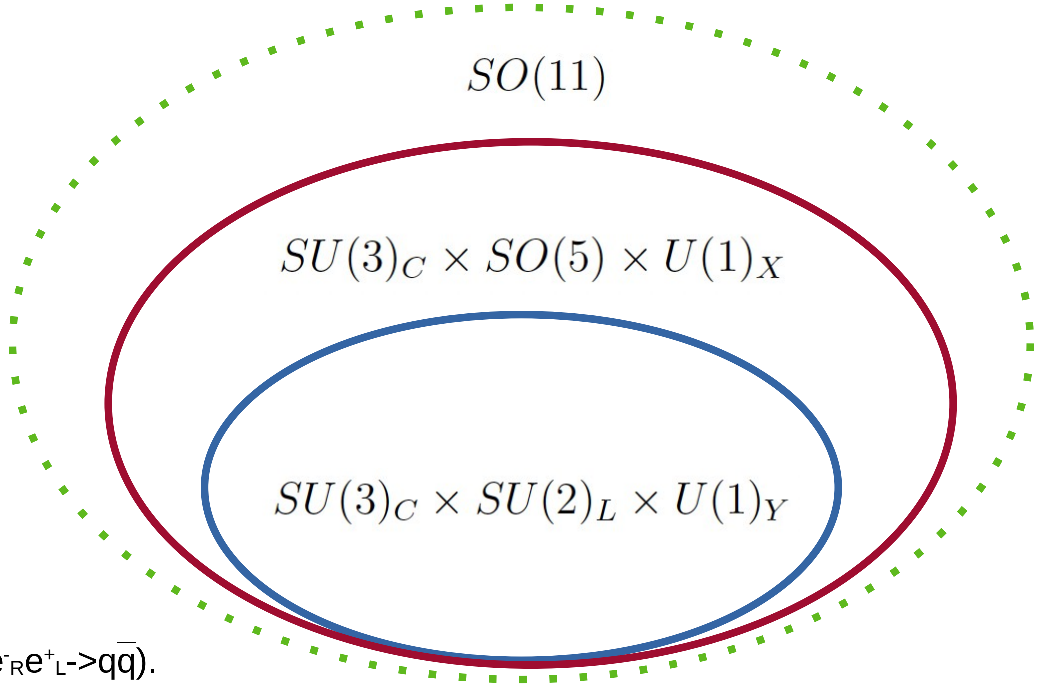
- Experimental definition:
  - Reduce bias from systematic errors from the luminosity and efficiency w.r.t. the cross-section observable

$$A_{FB}^{Exp} = \frac{N_F - N_B}{N_{Total}}$$

Gauge-Higgs Unification (GHU) Models

- The GHU unified all the force carriers under a single gauge group:



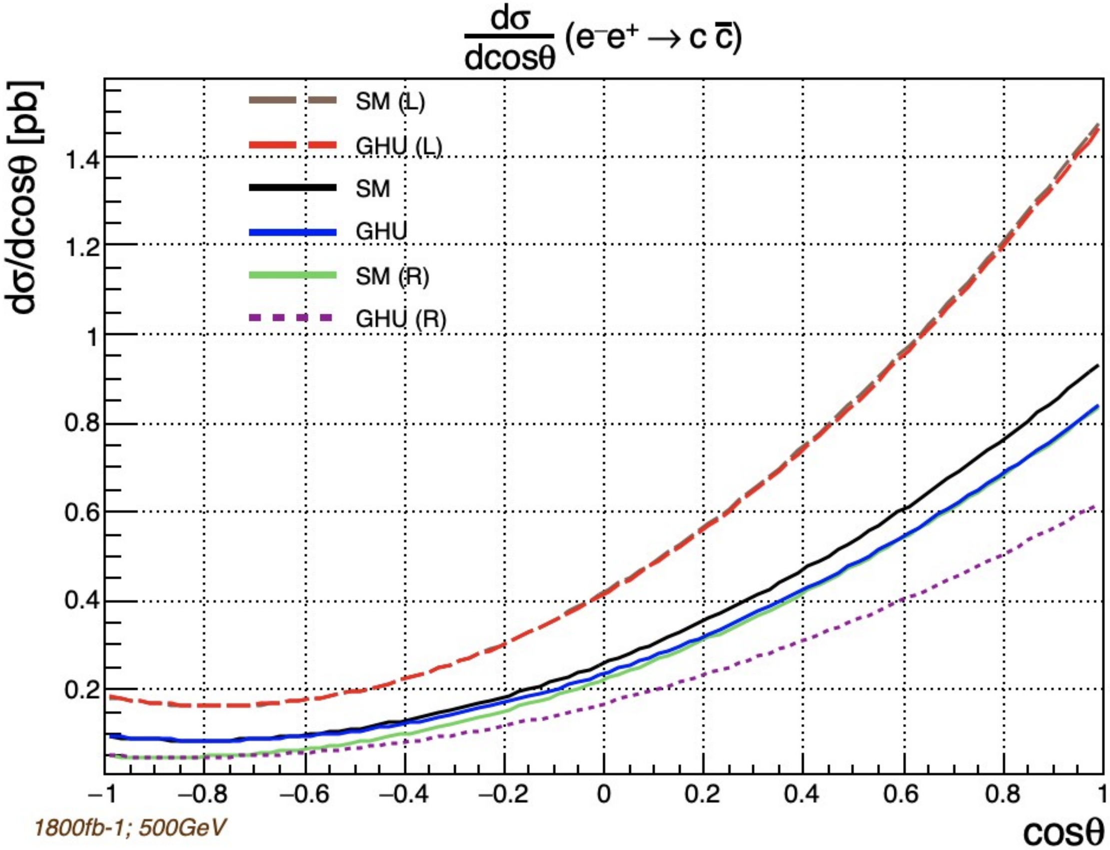


- A-Models[1]: Stronger deviations in the right-handed case ($e^-_R e^+_L \to q\bar{q}$).
- B-Models[2]: Stronger deviations in the left-handed case ($e^-_L e^+_R \to q\bar{q}$).
  - The gauge group of GHU is also related to Grand Unification Theory (GUT), embedded in the SO(11) group.

[1] Shuichiro Funatsu, Hisaki Hatanaka, Yutaka Hosotani, Yuta Orikasa, and Naoki Yamatsu. *Fermion pair production at e-e+ linear collider experiments in GUT inspired gauge-Higgs unification*. Phys. Rev. D, 102(1):015029, 2020.
[2] Shuichiro Funatsu, Hisaki Hatanaka, Yutaka Hosotani, and Yuta Orikasa. *Distinct signals of the gauge-Higgs unification in e-e+ collider experiments*. Phys. Lett. B, 775:297–302, 2017.

Gauge-Higgs Unification (GHU) Models

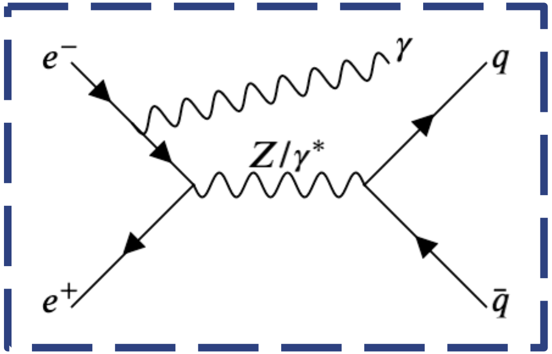
- A-Model cross-section deviation examples (c-quark) 500 GeV:

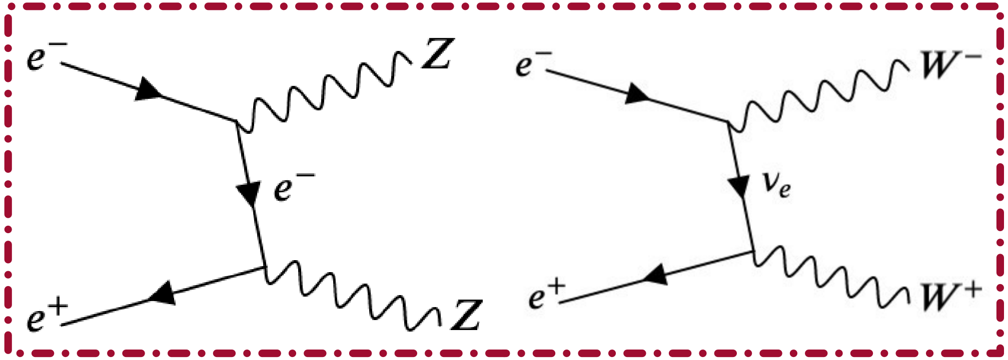


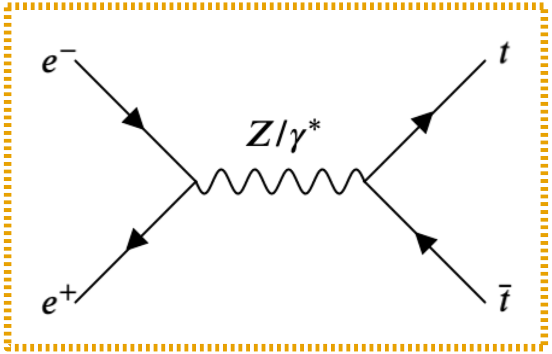
New physics hide in the forward region of the detector

Preselection of $q\bar{q}$ signals

- Once we have the reconstructed pfos of the events with different targets:
  - We cluster the signal in jets (VLC algorithm):
    - The algorithm packs together the PFOs into two jets.
    - Signal is expected in a back-to-back topology (but not the backgrounds!)
      - Most of the background is **radiative return ($\gamma q\bar{q}$)**
      - And most of the data is background!
        - x3 for $e^-_L e^+_R$ and x6 for $e^-_R e^+_L$ at 250 GeV
        - x4 for $e^-_L e^+_R$ and x7 for $e^-_R e^+_L$ at 500 GeV
  - Then we apply different cuts to the signal to remove the background processes







Summary from the last meeting ($e_L p_R$)

Cuts:

- K_{reco} < 20 GeV
- m_{2jets} > 250 GeV
- Charged N pfos > 0.5
- Neutral N pfos > 4.5
- Photon veto (E<240 GeV; $|\cos\theta_q|$<0.97)
- y23<0.006

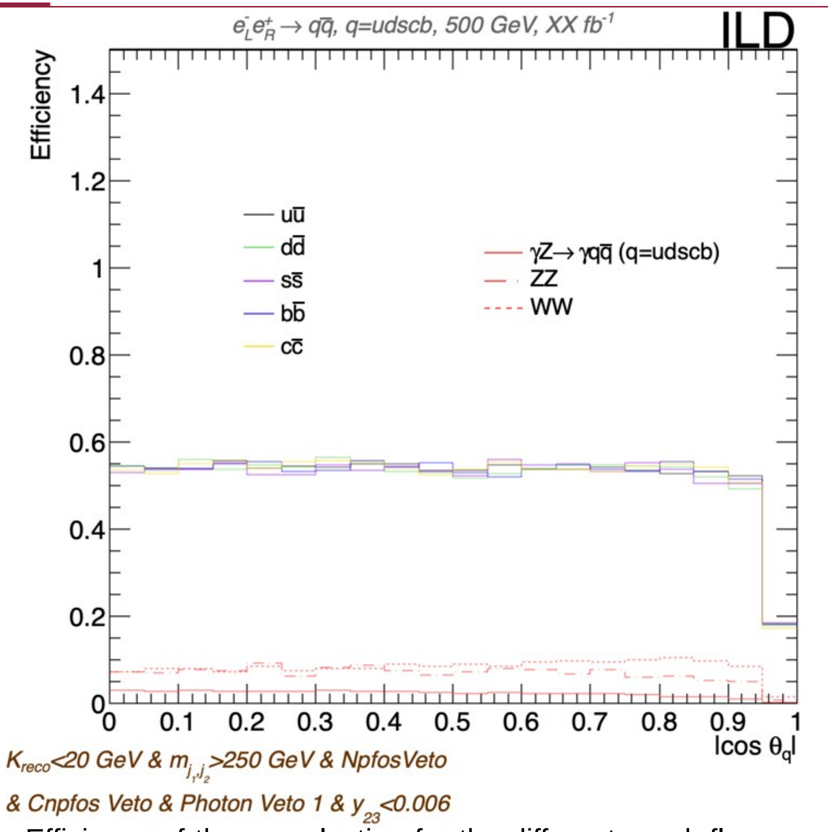
VLC Algorithm parameters:

- R = 1.0
- γ = 0.0
- β = 1.0

	Background/Signal		
	ISR	WW	ZZ
No Cut	4.044	1.193	0.106
+ Cut 1	0.871	0.784	0.059
+ Cut 2	0.863	0.784	0.059
+ Cut 3	0.243	0.785	0.059
+ Cut 4	0.182	0.787	0.059
+ Cut 5	0.134	0.615	0.051
+ Cut 6	0.102	0.123	0.009

X2 than at 250 GeV!

Too high!



Efficiency of the preselection for the different quark flavours vs the angular distribution of the two jet system (up to cut 6)

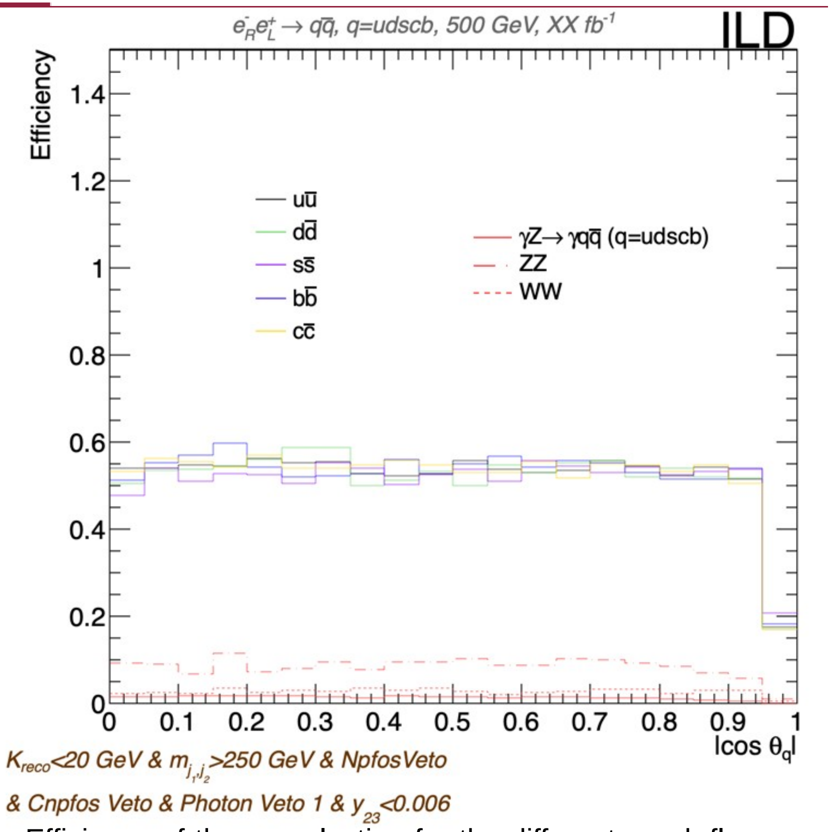
Summary from the last meeting ($e_R p_L$)

Cuts:
- K_{reco} < 20 GeV
- m_{2jets} > 250 GeV
- Charged N pfos > 0.5
- Neutral N pfos > 4.5
- Photon veto (E<240 GeV; $|\cos\theta_q|$<0.97)
- y23<0.006

VLC Algorithm parameters:
- R = 1.0
- γ = 0.0
- β = 1.0

	Background/Signal		
	ISR	WW	ZZ
No Cut	7.416	0.016	0.127
+ Cut 1	1.597	0.014	0.072
+ Cut 2	1.582	0.014	0.072
+ Cut 3	0.350	0.014	0.072
+ Cut 4	0.227	0.014	0.073
+ Cut 5	0.140	0.015	0.062
+ Cut 6	0.103	0.001	0.013

X2 than at 250 GeV!



Efficiency of the preselection for the different quark flavours vs the angular distribution of the two jet system (up to cut 6)

Samples (500 GeV)

$e_L p_R$

Luminosity (fb^{-1})			
$q\bar{q}$ + ISR	WW	ZZ	$t\bar{t}_1$
46.4	49.0	56.6	7704.9

Cross-Section (fb)			
$q\bar{q}$ + ISR	WW	ZZ	$t\bar{t}_1$
32470.5	7680	680.2	165.0

$e_R p_L$

Luminosity (fb^{-1})			
$q\bar{q}$ + ISR	WW	ZZ	$t\bar{t}_1$
47.0	500	72.5	8354.1

Cross-Section (fb)			
$q\bar{q}$ + ISR	WW	ZZ	$t\bar{t}_1$
17994.7	33.5	271.9	63.7

$e_L p_R$: K_{ISR}<20 GeV

	Cross-Section (fb)				
	$b\bar{b}$	$c\bar{c}$	$s\bar{s}$	$u\bar{u}$	$d\bar{d}$
$q\bar{q}$	1051.6	1633.1	1051.5	1643.5	1058.2
ISR	5391.9	4933.3	5389.0	4951.9	5366.6
Ratio	5.1	3	5.1	3	5.1

$e_R p_L$: K_{ISR}<20 GeV

	Cross-Section (fb)				
	$b\bar{b}$	$c\bar{c}$	$s\bar{s}$	$u\bar{u}$	$d\bar{d}$
$q\bar{q}$	226.6	733.0	221.7	732.8	224.1
ISR	3233.5	3092.5	3222.5	3075.0	3243
Ratio	14.2	4.2	14.5	4.2	14.5

$e_L p_R$: K_{ISR}<70 GeV

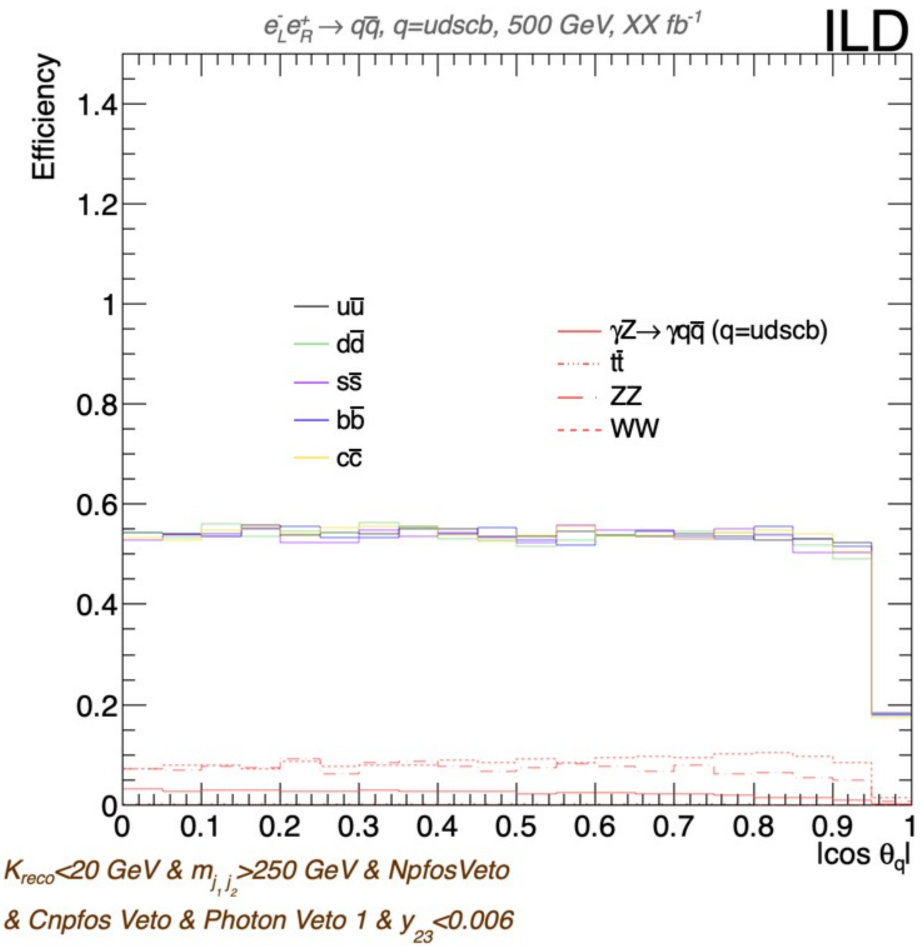
	Cross-Section (fb)				
	$b\bar{b}$	$c\bar{c}$	$s\bar{s}$	$u\bar{u}$	$d\bar{d}$
$q\bar{q}$	1231.3	1917.3	1232.2	1923.5	1239.9
ISR	5212.2	4649.1	5208.4	4671.8	5184.9
Ratio	4.2	2.4	4.2	2.4	4.2

$e_R p_L$: K_{ISR}<70 GeV

	Cross-Section (fb)				
	$b\bar{b}$	$c\bar{c}$	$s\bar{s}$	$u\bar{u}$	$d\bar{d}$
$q\bar{q}$	264.7	857.9	260.1	857.5	263.7
ISR	3185.4	2967.7	3184.1	2950.3	3203.5
Ratio	12.0	3.5	12.2	3.4	12.1

1: There are 4 different samples (for different processes), this is the average number for each of them

We stepped back to study K_{reco}



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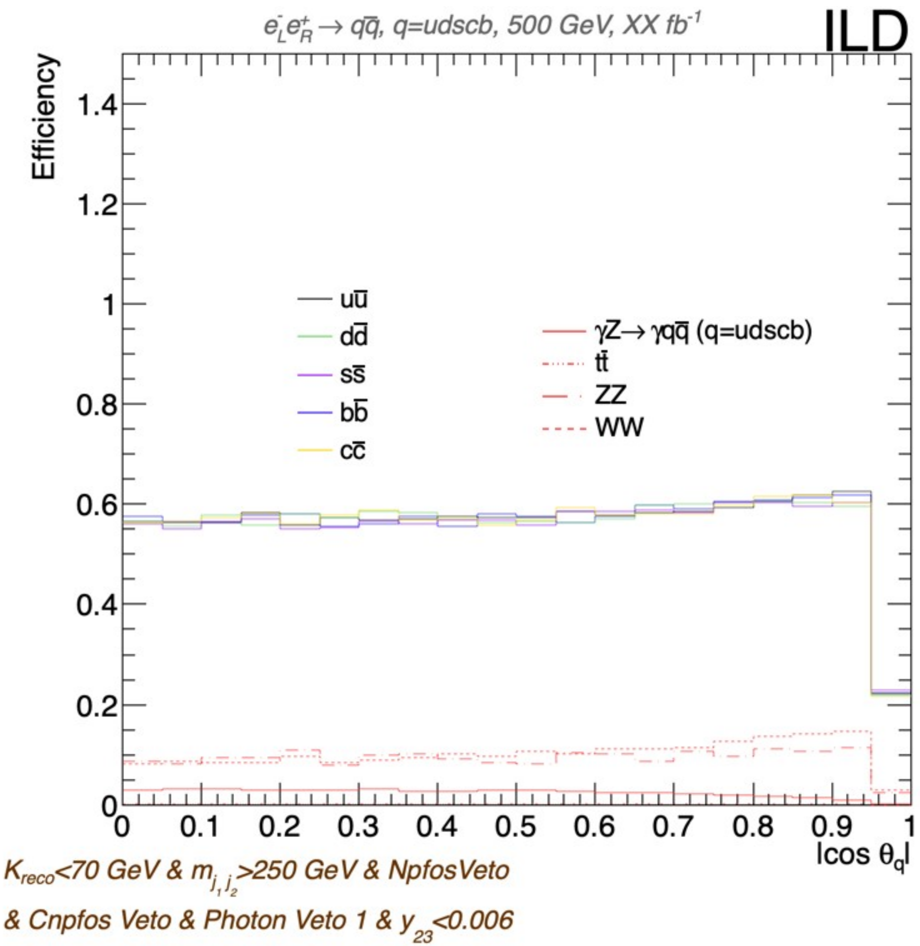


We stepped back to study K_{reco}

K_{reco} < 20 GeV

	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
No cut	100	100	100	4.04	1.19	0.11	0.11
+ Cut 1	70.9	70.5	70.8	0.87	0.78	0.06	0.007
+ Cut 2	70.8	70.5	70.8	0.86	0.78	0.06	0.007
+ Cut 3	70.7	70.4	70.5	0.24	0.79	0.06	0.007
+ Cut 4	70.7	70.3	70.0	0.20	0.79	0.06	0.007
+ Cut 5	68.5	68.1	67.6	0.14	0.61	0.05	0.007

We stepped back to study K_{reco}

K_{reco} < 70 GeV

	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
No cut	100	100	100	3.30	1.19	0.11	0.11
+ Cut 1	94.6	94.3	94.3	0.95	1.07	0.09	0.062
+ Cut 2	94.2	94.1	94.2	0.91	1.07	0.09	0.057
+ Cut 3	94.1	93.9	93.7	0.24	1.07	0.09	0.058
+ Cut 4	94.0	93.8	93.0	0.18	1.07	0.09	0.058
+ Cut 5	90.0	89.6	88.6	0.11	0.69	0.07	0.060

Higher statistic
+
Higher flavour differences

Similar B/S

We retouched the cuts for K_{reco}=70 ($e_L p_R$)

Cuts:

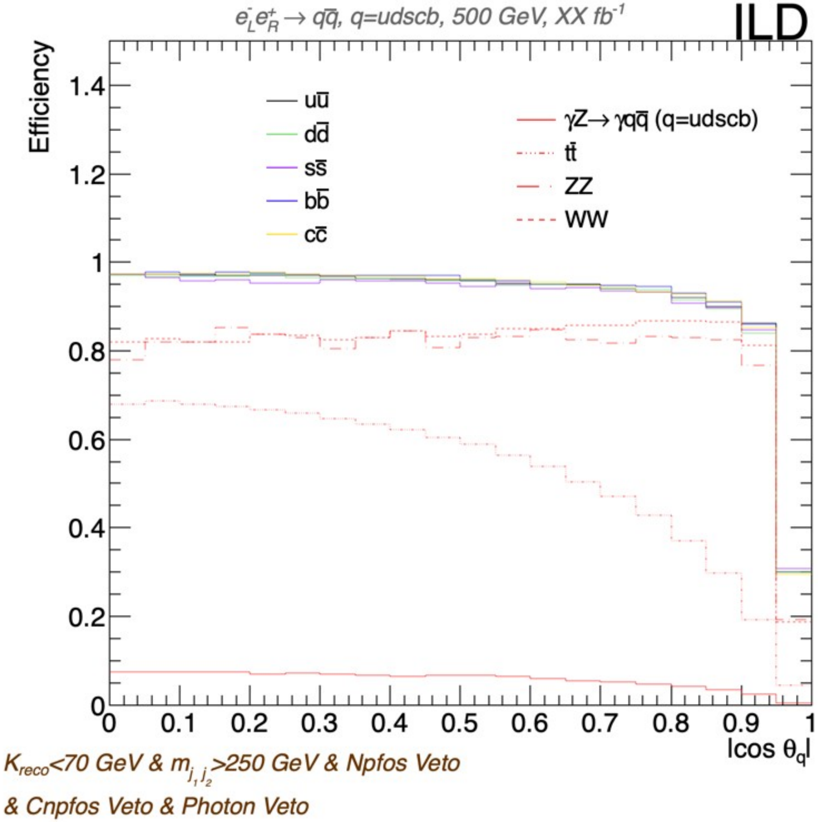
- K_{reco} < 70 GeV
- m_{2jets} > 250 GeV
- Charged N pfos > 0.5
- Neutral N pfos > 3.5
- Photon veto

VLC Algorithm parameters:

- R = 1.0
- γ = 0.0
- β = 1.0

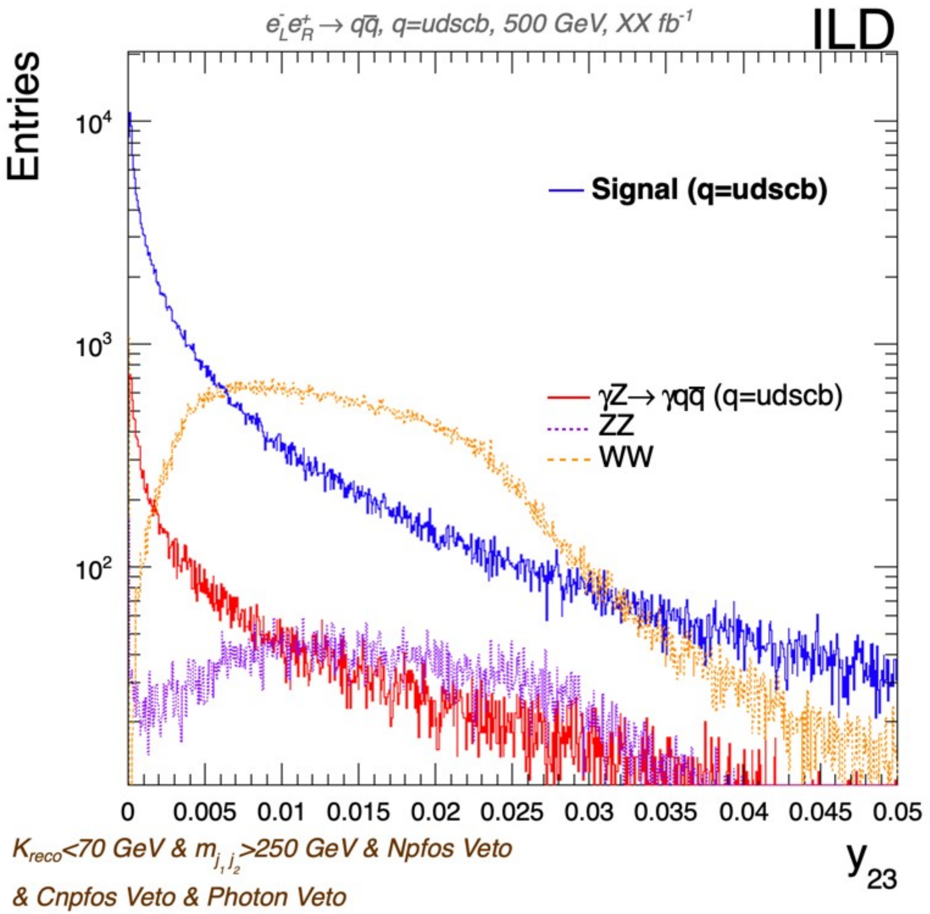
	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
No cut	100	100	100	3.30	1.02	0.09	0.09
+ Cut 1	94.6	94.3	94.3	0.95	0.92	0.08	0.05
+ Cut 2	94.2	94.1	94.2	0.91	0.91	0.08	0.05
+ Cut 3	94.1	93.9	93.7	0.24	0.91	0.08	0.05
+ Cut 4	94.1	93.8	93.4	0.19	0.91	0.08	0.05
+ Cut 5	90.1	89.7	89.1	0.11	0.59	0.06	0.05

Rebalanced

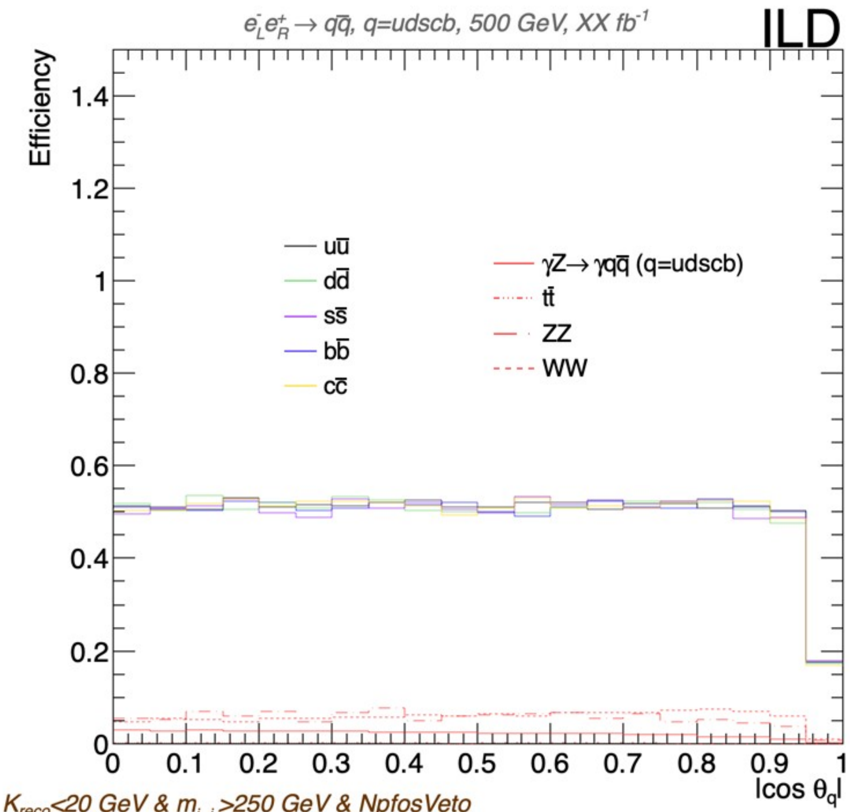


Now, we carry on the analysis looking in the $e_L p_R$ case

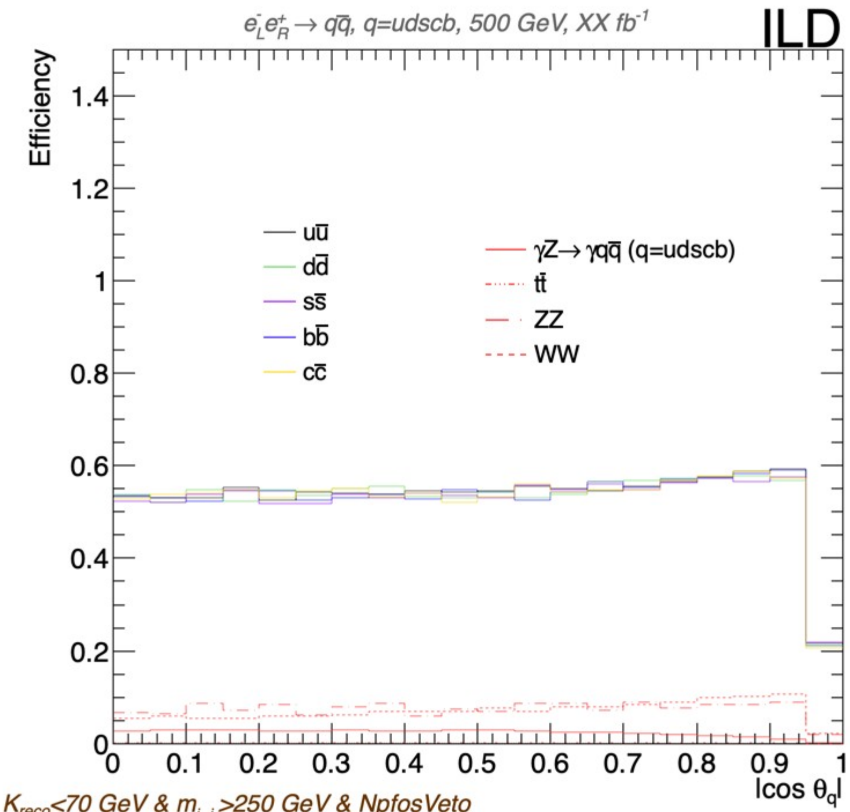
Looking for a sixth cut (y_{23})



Cut y_{23}<0.005 for K_{reco}=20 & 70 GeV



K_{reco}<20 GeV & $m_{j_1j_2}$>250 GeV & NpfosVeto & Cnpfos Veto & Photon Veto & y_{23}<0.005



K_{reco}<70 GeV & $m_{j_1j_2}$>250 GeV & NpfosVeto & Cnpfos Veto & Photon Veto & y_{23}<0.005

Cut y_{23}<0.005 for K_{reco}=20 & 70 GeV

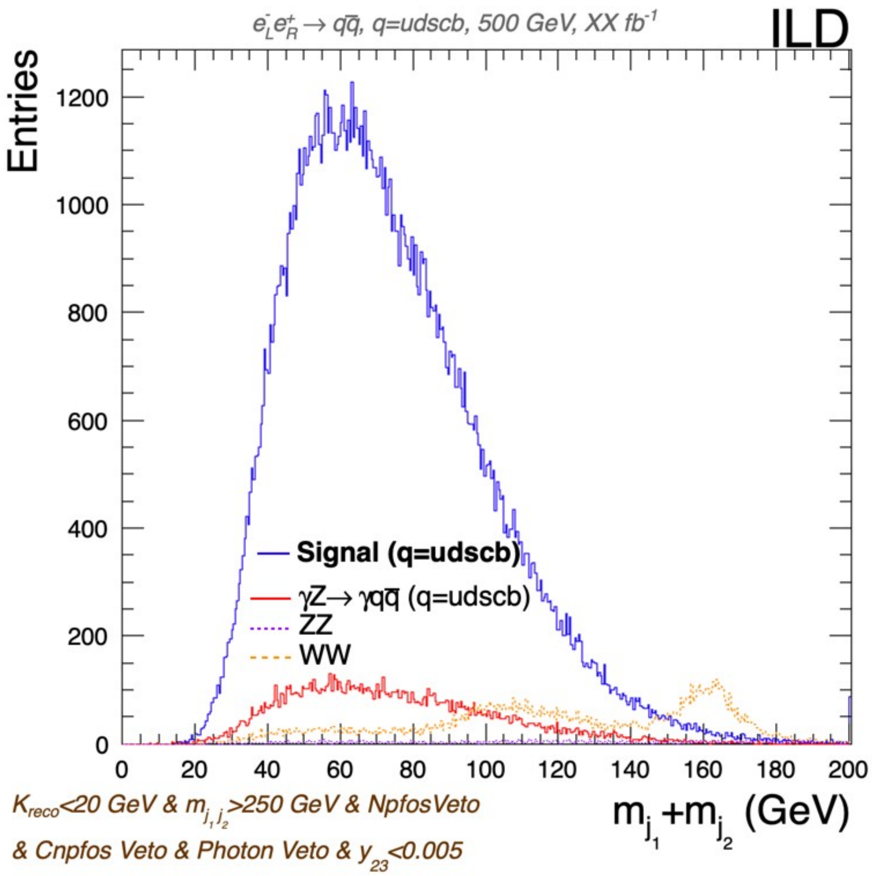
K_{reco}<20 GeV

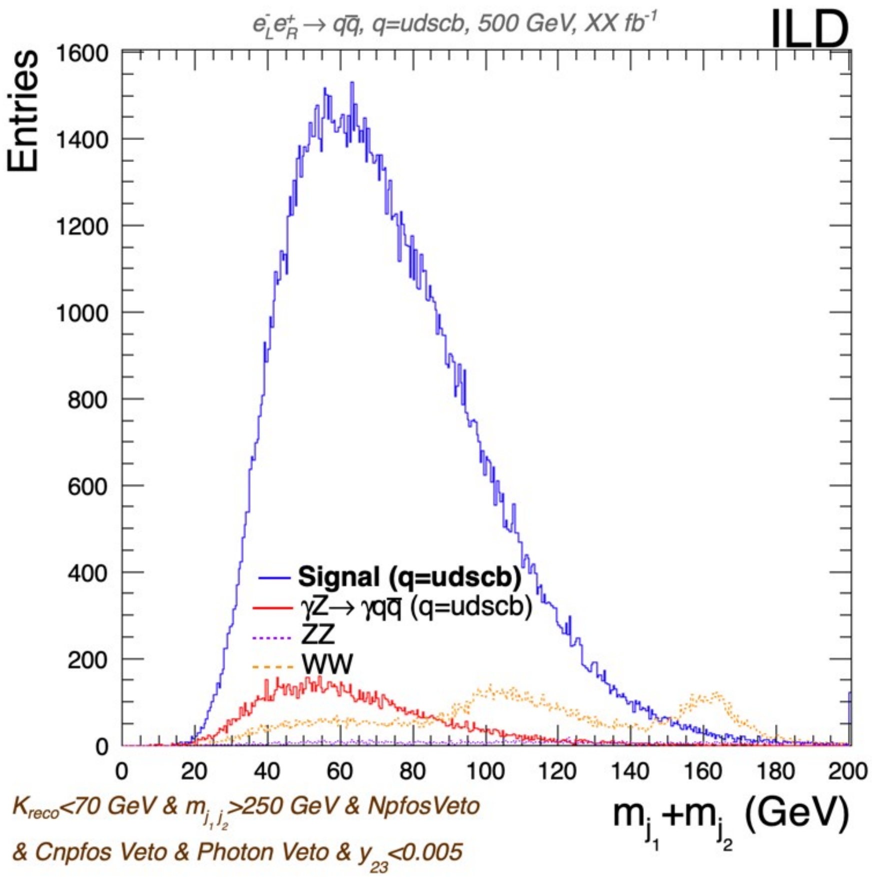
	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
$y_{23}<0.005$	48.6	48.7	48.7	0.10	0.09	0.007	0.0001

K_{reco}<70 GeV

	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
$y_{23}<0.005$	52.9	52.6	52.6	0.08	0.11	0.010	0.0002

Looking for a seventh cut ($m_{j1}+m_{j2}$)





Seventh cut: $m_{j1}+m_{j2}$ (k_{reco}<20 GeV)

	Efficiency (%)			Background/Signal			
$m_{j_1}+m_{j_2}$<X GeV	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
120	45.9	45.9	45.8	0.10	0.05	0.004	2e-06
130	47.0	47.1	47.1	0.10	0.05	0.004	3e-06
140	47.6	47.8	47.8	0.10	0.06	0.005	5e-06 ←
150	48.0	48.3	48.2	0.10	0.06	0.005	8e-06

|cos(θ)|<0.9

	Efficiency (%)			Background/Signal			
$m_{j_1}+m_{j_2}$<X GeV	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
120	48.4	48.5	48.3	0.10	0.04	0.003	2e-06
130	49.5	49.9	49.7	0.10	0.04	0.004	4e-06
140	50.2	50.6	50.5	0.10	0.05	0.004	6e-06 ←
150	50.6	51.1	50.9	0.10	0.05	0.004	9e-06

Seventh cut: $m_{j1}+m_{j2}$ (k_{reco}<70 GeV)

$m_{j_1}+m_{j_2}$<X GeV	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
120	49.7	49.5	49.5	0.08	0.07	0.006	4e-06
130	50.8	50.8	50.9	0.08	0.08	0.007	7e-06
140	51.5	51.6	51.7	0.08	0.08	0.007	9e-06 ←
150	51.9	52.0	52.1	0.10	0.08	0.007	1e-05

|cos(θ)|<0.9

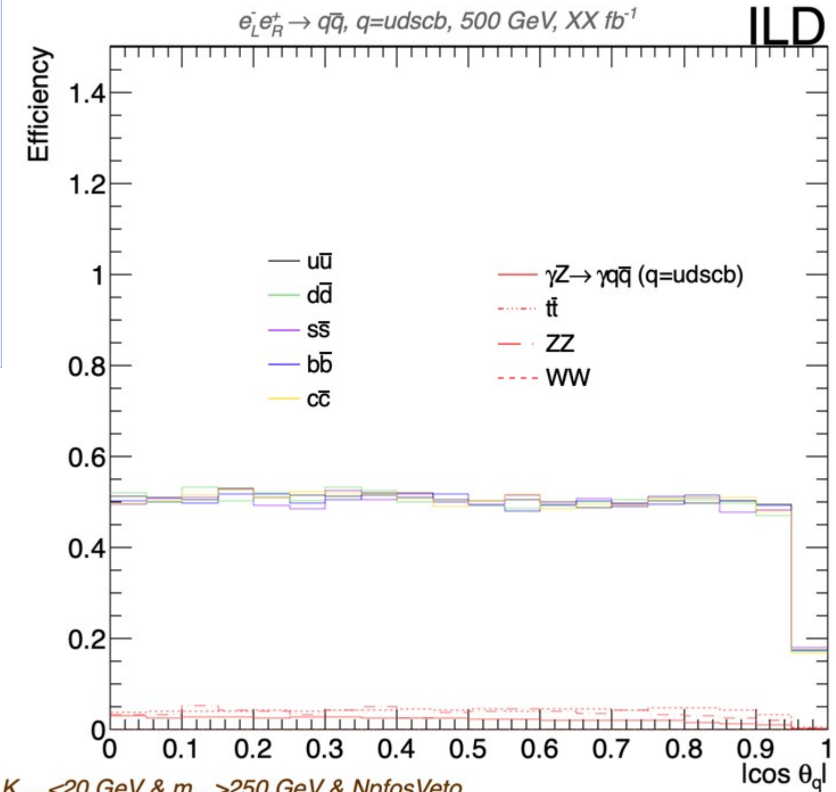
$m_{j_1}+m_{j_2}$<X GeV	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
120	51.7	51.8	51.7	0.08	0.04	0.004	3e-06
130	52.9	53,2	53.1	0.08	0.05	0.005	7e-06
140	53.7	53.9	53.9	0.08	0.05	0.005	8e-06 ←
150	54.1	54.4	54.4	0.08	0.05	0.005	1e-05

Final selection for K_{reco}=20 GeV ($e_L p_R$)

Cuts:
- K_{reco} < 20 GeV
- m_{2jets} > 250 GeV
- Charged N pfos > 0.5
- Neutral N pfos > 3.5
- Photon veto
- y_{23} < 0.005
- $m_{j1}+m_{j2}$ < 140 GeV

VLC Algorithm parameters:
- R = 1.0
- γ = 0.0
- β = 1.0

	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
No cut	100	100	100	4.04	1.19	0.11	0.11
+ Cut 1	70.9	70.5	70.8	0.87	0.78	0.06	0.007
+ Cut 2	70.8	70.5	70.8	0.86	0.78	0.06	0.007
+ Cut 3	70.7	70.4	70.5	0.24	0.79	0.06	0.007
+ Cut 4	70.7	70.4	70.0	0.20	0.79	0.06	0.007
+ Cut 5	68.5	68.1	67.6	0.14	0.61	0.05	0.007
+ Cut 6	48.6	48.7	48.7	0.10	0.09	0.007	1e-04
+ Cut 7	47.6	47.8	47.8	0.10	0.06	0.005	5e-06



K_{reco}<20 GeV & $m_{j_1j_2}$>250 GeV & NpfosVeto & Cnpfos Veto & Photon Veto & y_{23}<0.005 & $m_{j_1}+m_{j_2}$<140 GeV

Final selection for K_{reco}=20 GeV ($e_R p_L$)

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- Charged N pfos > 0.5
- Neutral N pfos > 3.5
- Photon veto
- y_{23} < 0.005
- ($m_{j1}+m_{j2}$ < 140 GeV) Not needed

VLC Algorithm parameters:

- R = 1.0
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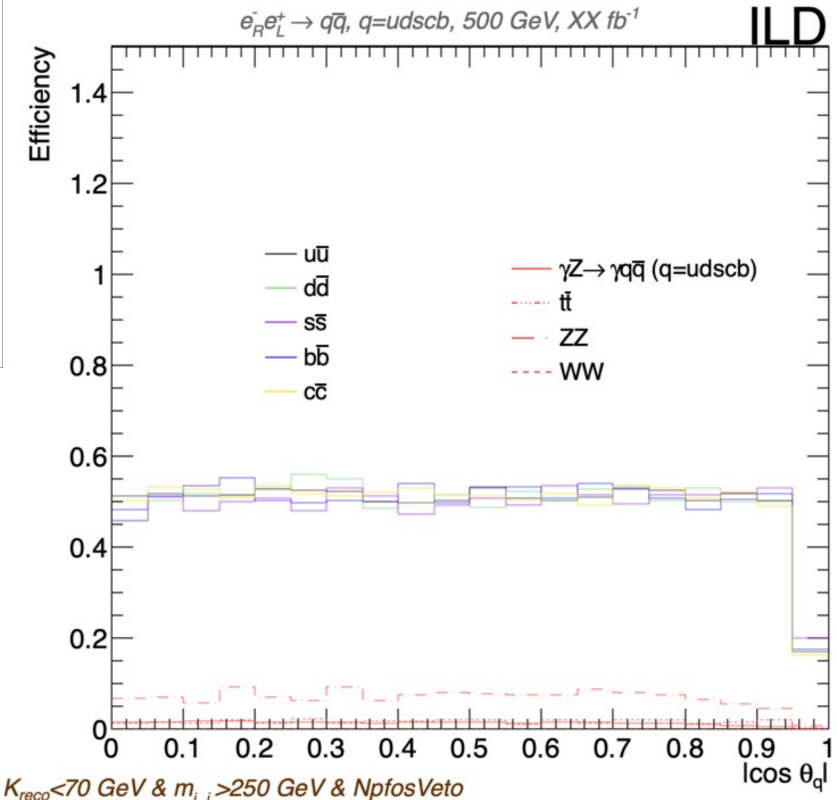
	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
No cut	100	100	100	7.42	0.02	0.13	0.11
+ Cut 1	70.6	70.7	71.0	1.60	0.01	0.07	0.008
+ Cut 2	70.5	70.7	71.0	1.58	0.01	0.07	0.008
+ Cut 3	70.5	70.6	70.7	0.35	0.01	0.07	0.008
+ Cut 4	70.5	70.6	70.5	0.26	0.01	0.07	0.008
+ Cut 5	68.4	68.3	67.9	0.15	0.01	0.06	0.008
+ Cut 6	48.8	48.9	48.6	0.10	5e-04	0.01	8e-05
~~+ Cut 7~~	47.7	48.0	47.8	0.10	2e-04	0.007	4e-06



Final selection for K_{reco}=70 GeV ($e_L p_R$)

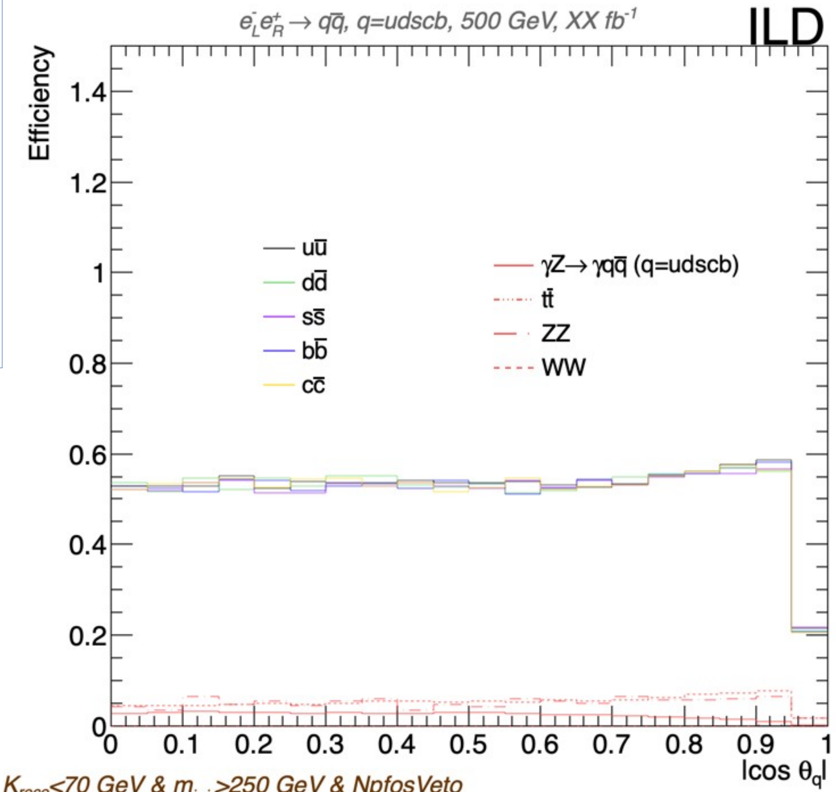
Cuts:

- K_{reco} < 70 GeV
- m_{2jets} > 250 GeV
- Charged N pfos > 0.5
- Neutral N pfos > 3.5
- Photon veto
- y_{23} < 0.005
- $m_{j1}+m_{j2}$ < 140 GeV

VLC Algorithm parameters:

- R = 1.0
- γ = 0.0
- β = 1.0

	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
No cut	100	100	100	3.30	1.02	0.09	0.09
+ Cut 1	94.6	94.3	94.3	0.95	0.92	0.08	0.05
+ Cut 2	94.2	94.1	94.2	0.91	0.91	0.08	0.05
+ Cut 3	94.1	93.9	93.7	0.24	0.91	0.08	0.05
+ Cut 4	94.1	93.8	93.4	0.19	0.91	0.08	0.05
+ Cut 5	90.1	89.7	89.1	0.11	0.59	0.06	0.05
+ Cut 6	52.6	52.5	52.6	0.08	0.11	0.01	2e-04
+ Cut 7	51.5	51.6	51.7	0.08	0.08	0.007	9e-06



K_{reco}<70 GeV & $m_{j_1 j_2}$>250 GeV & NpfosVeto & Cnpfos Veto & Photon Veto & y_{23}<0.005 & $m_{j_1}+m_{j_2}$<140 GeV

We have to check this weird behavior at high angles with new samples

Final selection for K_{reco}=70 GeV ($e_L p_R$)

Cuts:

- K_{reco} < 70 GeV
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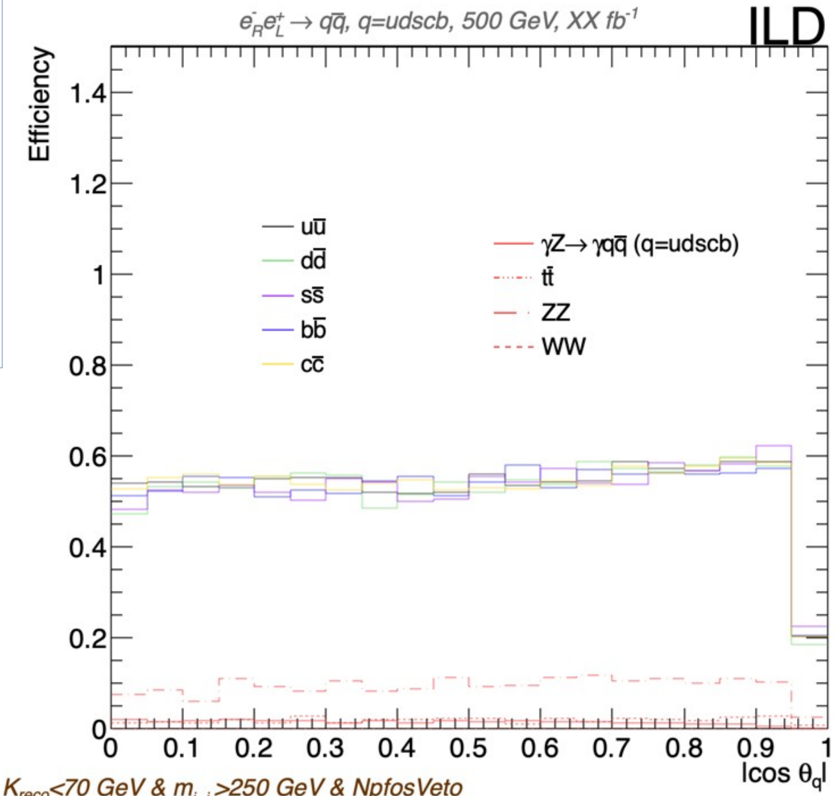
	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
No cut	100	100	100	6.19	0.01	0.11	0.10
+ Cut 1	93.9	94.4	94.3	1.75	0.01	0.09	0.06
+ Cut 2	93.6	94.3	94.2	1.68	0.01	0.09	0.06
+ Cut 3	93.6	94.0	93.7	0.37	0.01	0.09	0.06
+ Cut 4	93.5	94.0	93.4	0.28	0.01	0.09	0.06
+ Cut 5	89.5	89.9	89.2	0.13	0.01	0.07	0.06
+ Cut 6	52.1	52.6	52.5	0.09	5e-04	0.01	1e-04
~~+ Cut 7~~	51.0	51.7	51.6	0.09	3e-04	0.01	5e-06

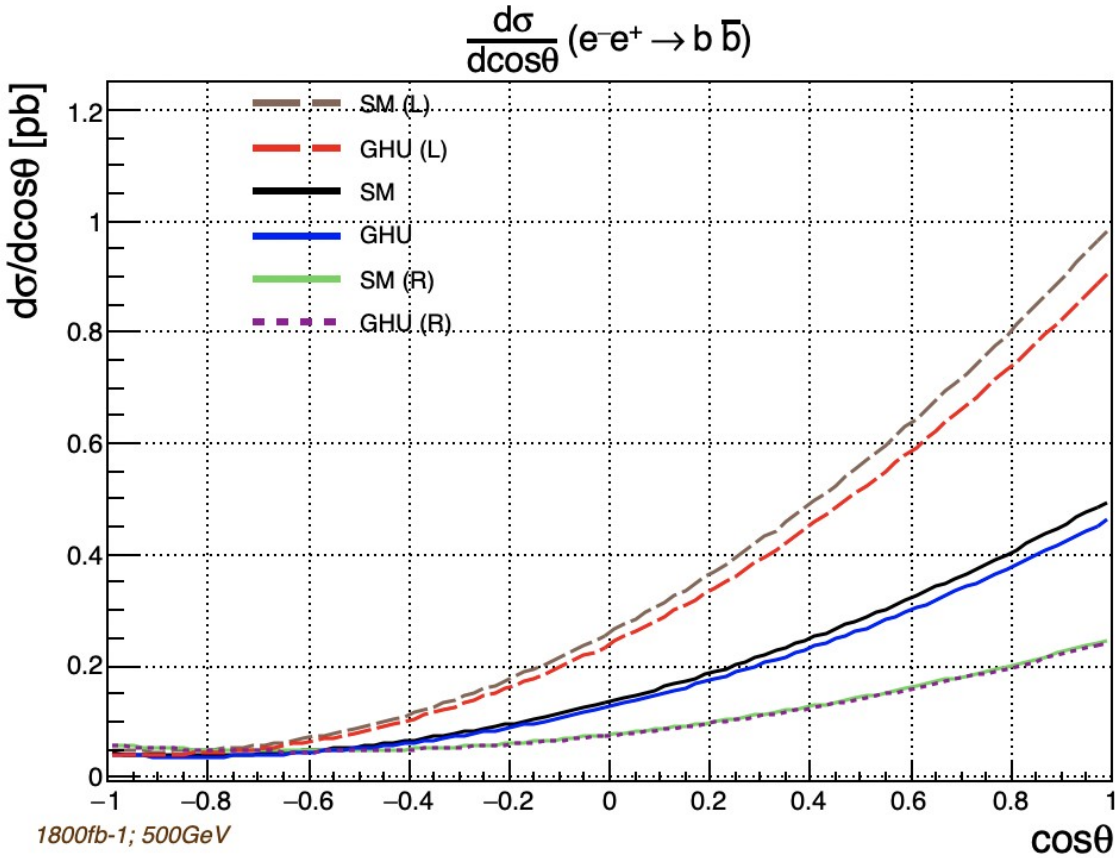


K_{reco}<70 GeV & $m_{j_1 j_2}$>250 GeV & NpfosVeto & Cnpfos Veto & Photon Veto & y_{23}<0.005

Back-Up slides

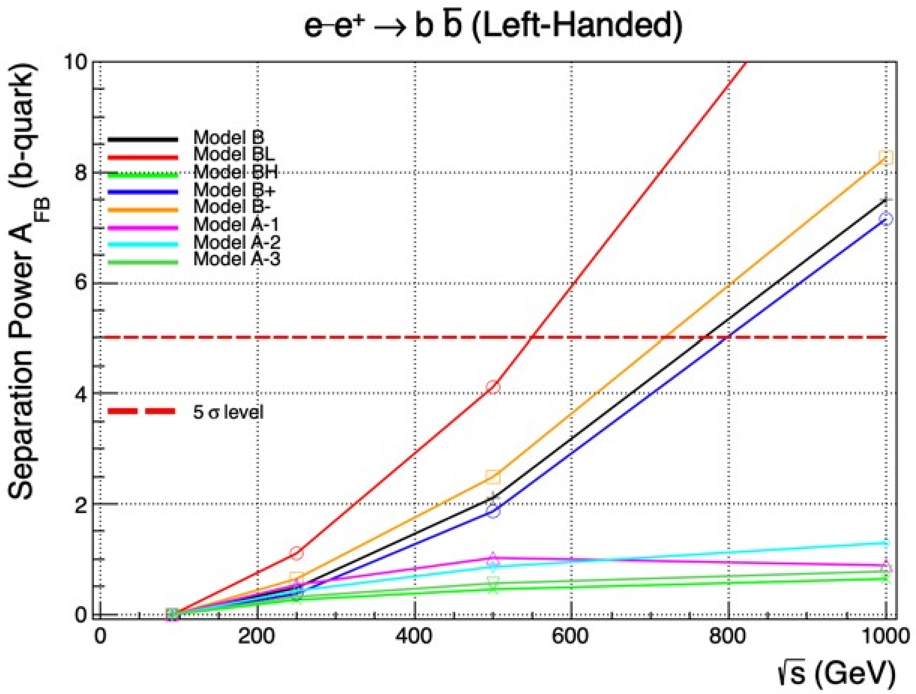
Gauge-Higgs Unification (GHU) Models

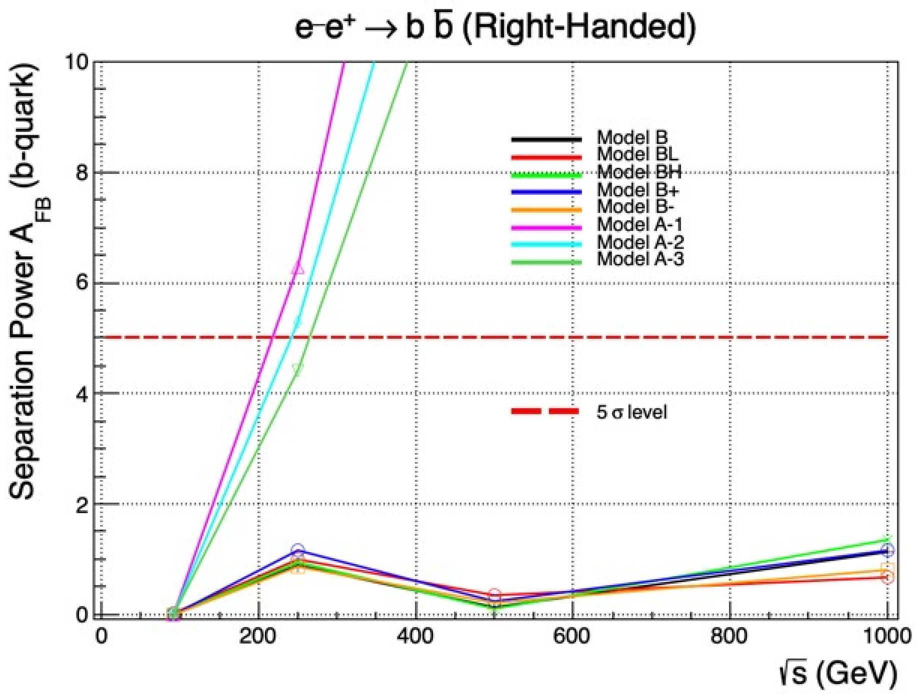
- B-Model cross-section deviation examples (b-quark) 500 GeV:



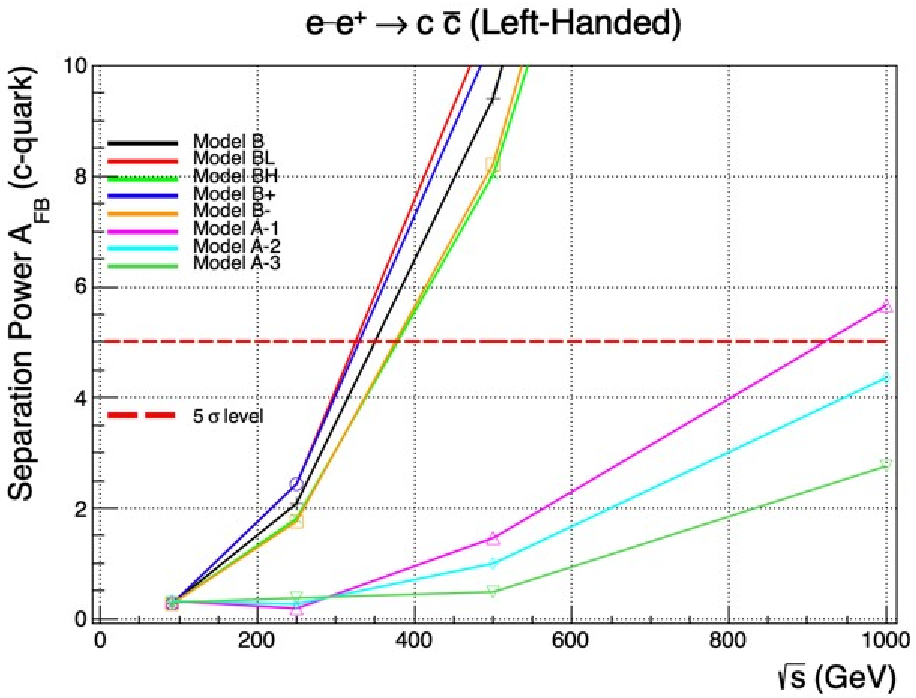
New physics hide in the forward region of the detector

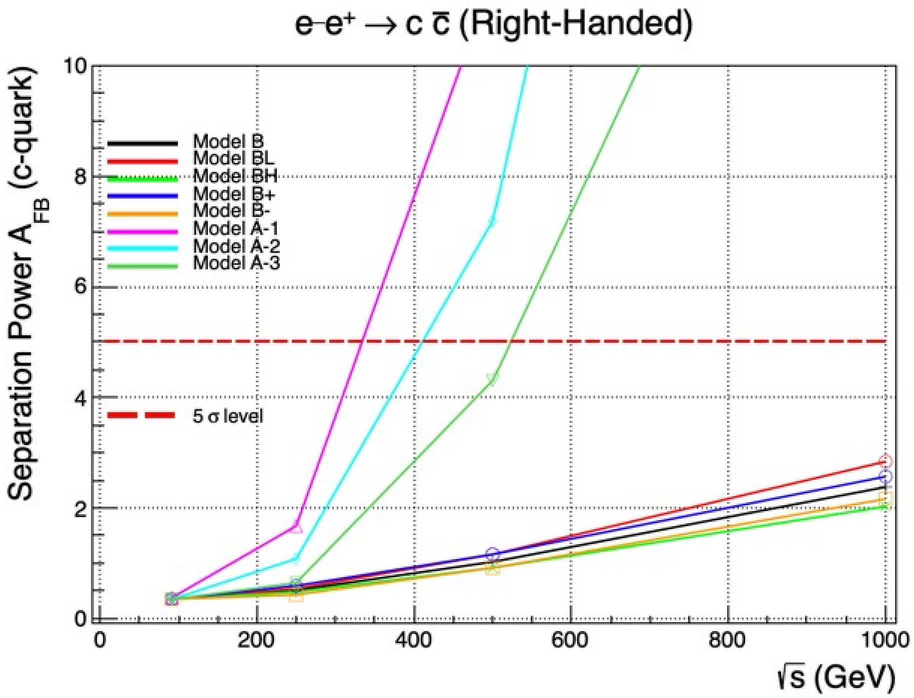
Prospects for b-quark in GHU (A_{FB})





Prospects for c-quark in GHU (A_{FB})





Efficiency up to cut 6 (previous meeting)

$e_L p_R$

	Efficiency (%)					
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ
Cut 1	70.9	70.5	70.8	15.2	46.5	39.3
+ Cut 2	70.8	70.5	70.8	15.1	46.4	39.3
+ Cut 3	70.7	70.4	70.5	4.2	46.4	39.2
+ Cut 4	70.7	70.3	70.0	3.2	46.3	39.1
+ Cut 5	68.5	68.0	67.3	2.2	34.9	32.5
+ Cut 6	51.1	51.2	50.9	1.3	5.3	4.3

$e_R p_L$

	Efficiency (%)					
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ
Cut 1	70.6	70.7	71.0	15.3	63.8	40.4
+ Cut 2	70.5	70.7	71.0	15.1	63.7	40.3
+ Cut 3	70.5	70.6	70.7	3.3	63.7	40.3
+ Cut 4	70.4	70.6	70.2	2.2	63.6	40.1
+ Cut 5	68.3	68.2	67.6	1.28	62.8	33.0
+ Cut 6	51.4	51.3	50.9	0.7	2.7	5.1

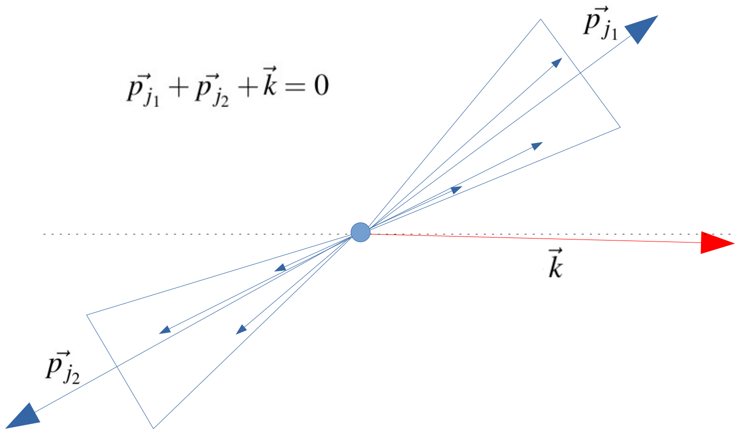
Optimization of the cuts: K_{reco}

- K_{reco} is a good estimator of E_γ:
  - Definition of acolinearity:

$$\sin\Psi_{acol} = \frac{\vec{p_{j_1}} \times \vec{p_{j_2}}}{|\vec{p_{j_1}}| \cdot |\vec{p_{j_1}}|}$$

  - Momentum of the collinear photon in the ultrarrelativistic limit ($m_{jets} << p_{jets}$):

$$|\vec{k}| \approx K_{reco} = \frac{250\,\mathrm{GeV} \cdot \sin\Psi_{acol}}{\sin\Psi_{acol} + sin\theta_1 + sin\theta_2}$$

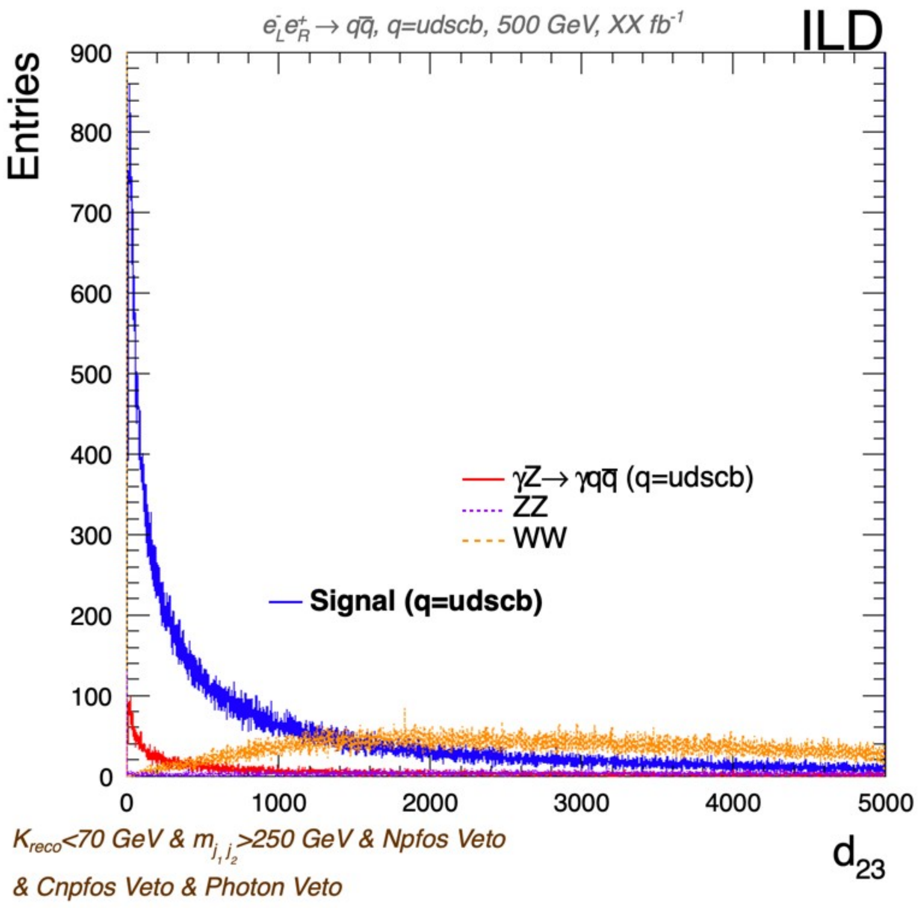


Kinematics of a two jets system reconstruction with ISR

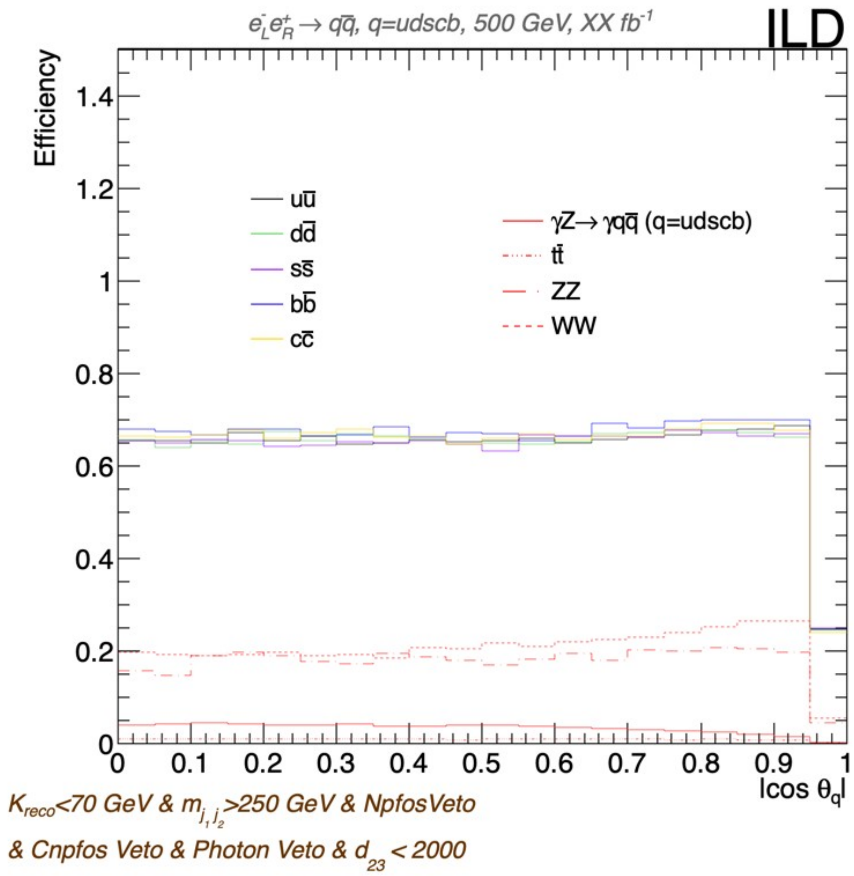
Samples (500 GeV)

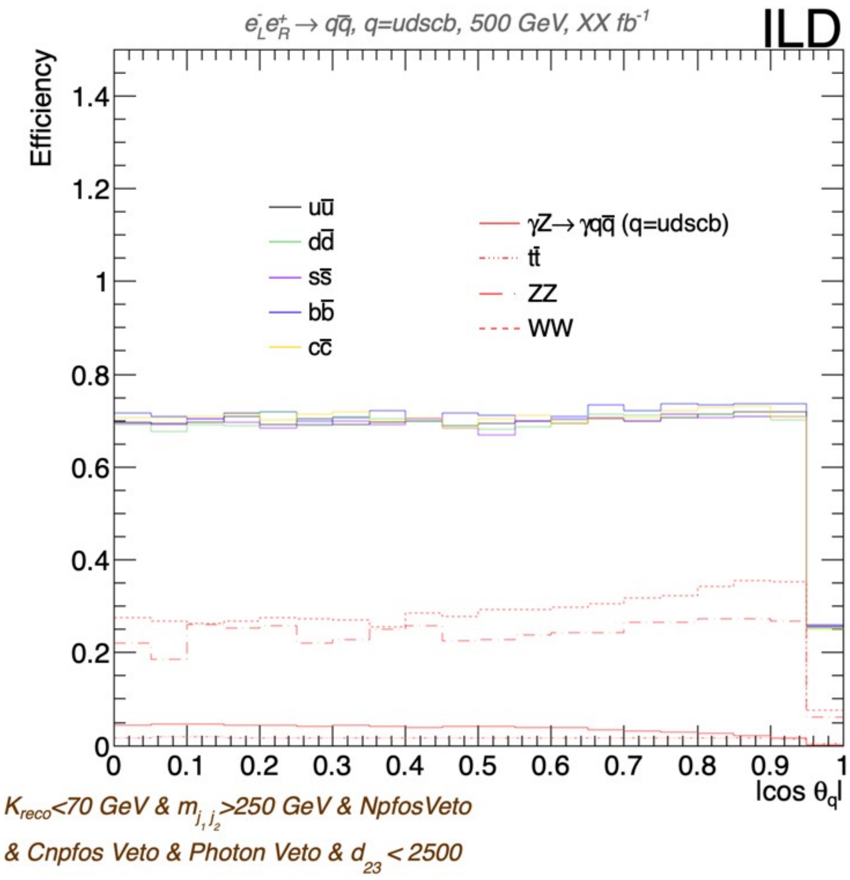
- The samples names are:
  - $q\bar{q}$+ISR: 2f_hadronic
  - WW: 4f_WW_hadronic
  - ZZ: 4f_ZZ_hadronic
  - $t\bar{t}$:
    - 6f_ttbar_yycyyc
    - 6f_ttbar_yycyyu
    - 6f_ttbar_yyuyyc
    - 6f_ttbar_yyuyyu

Looking for a sixth cut (d_{23})

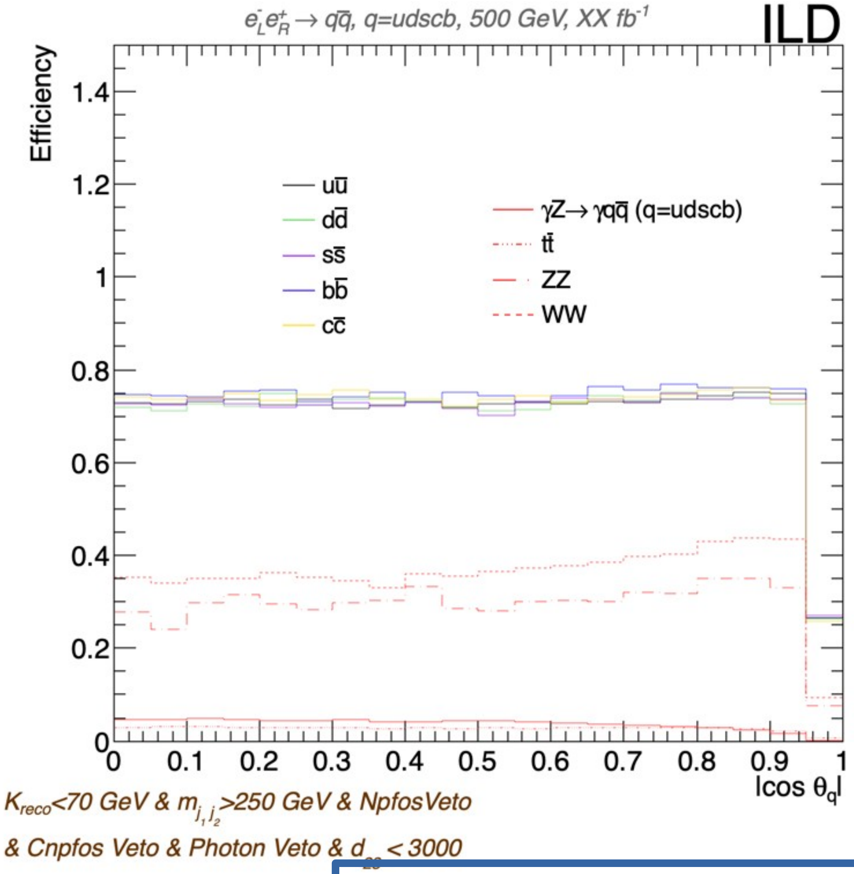


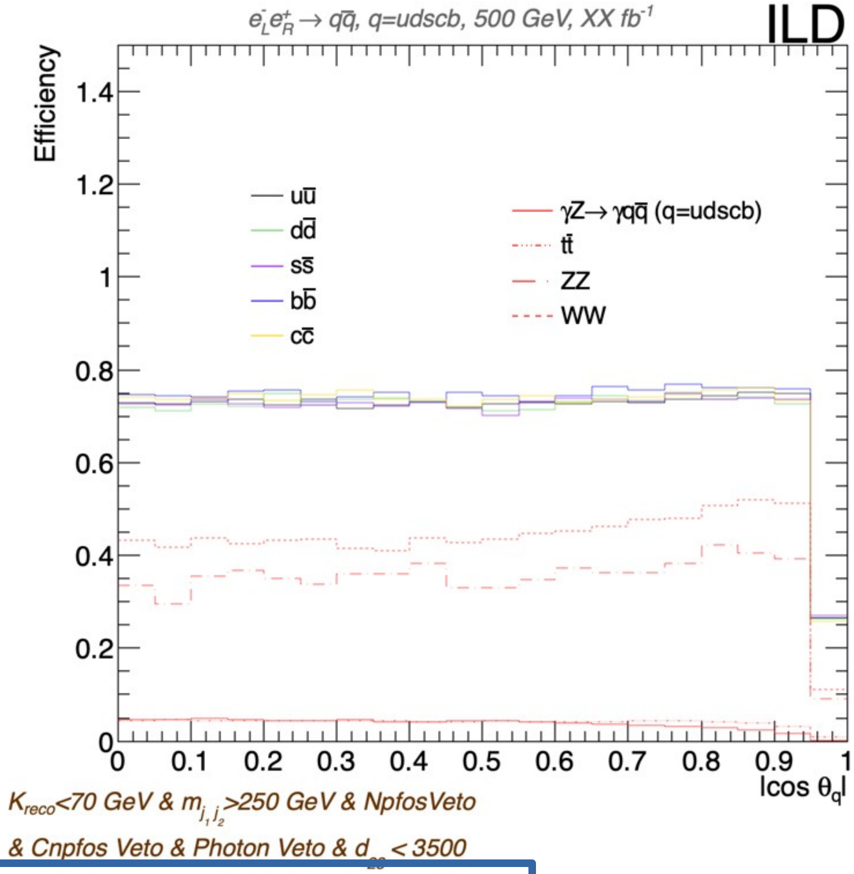
Looking for a sixth cut (d_{23})





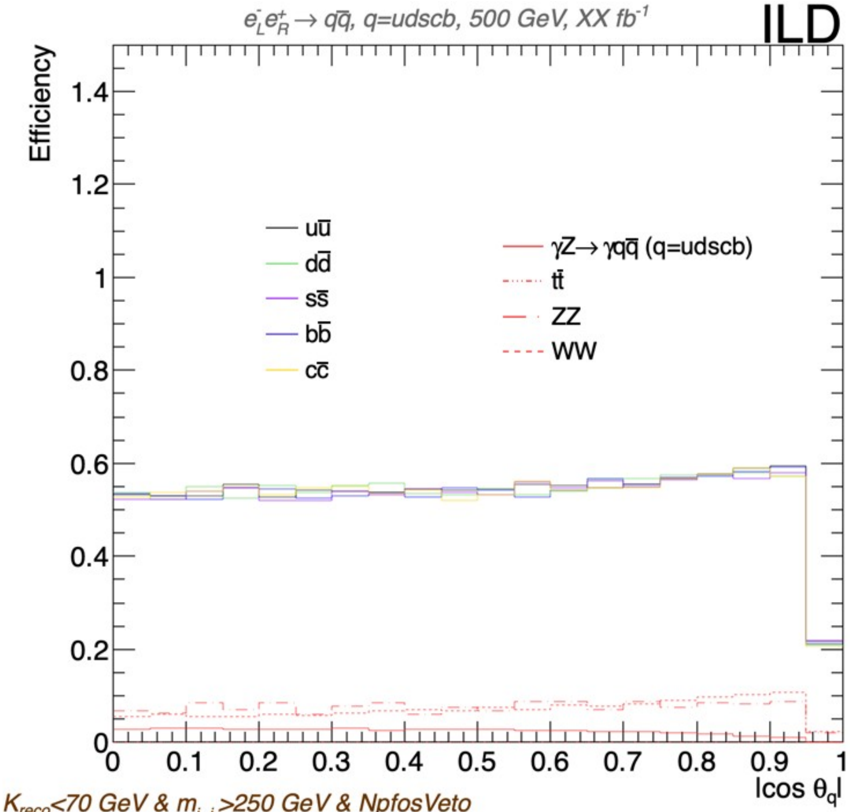
Looking for a sixth cut (d_{23})



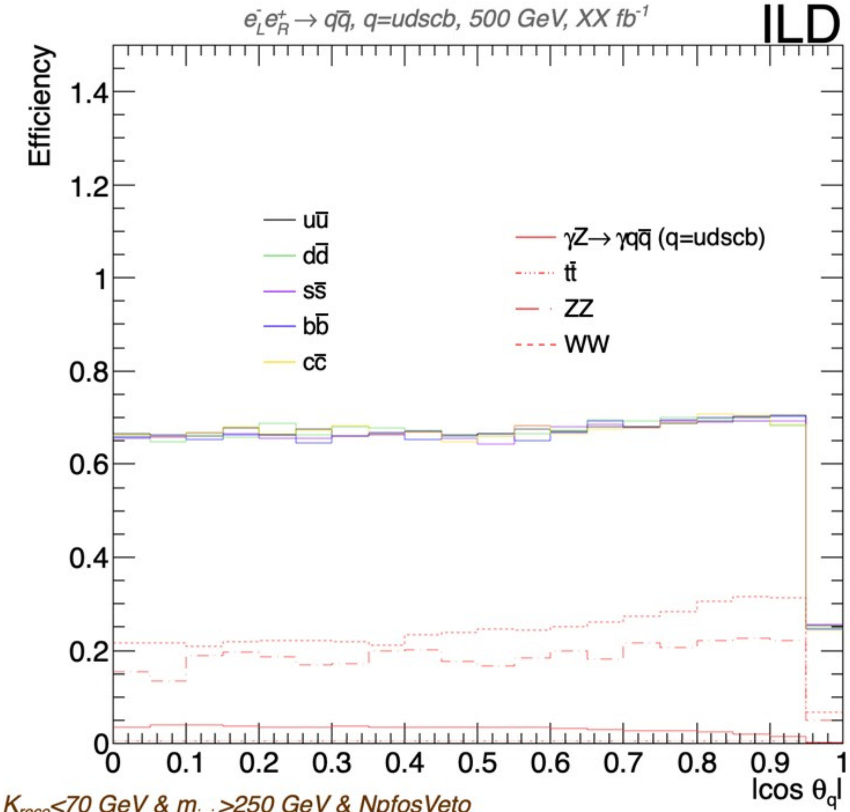


d_{23} always induce flavour dependance

Looking for a sixth cut (y_{23})



K_{reco}<70 GeV & $m_{j_1 j_2}$>250 GeV & NpfosVeto & Cnpfos Veto & Photon Veto & $y_{23} < 0.005$



K_{reco}<70 GeV & $m_{j_1 j_2}$>250 GeV & NpfosVeto & Cnpfos Veto & Photon Veto & $y_{23} < 0.01$

Low y_{23} induces a positive slope

Looking for a sixth cut (y_{23})

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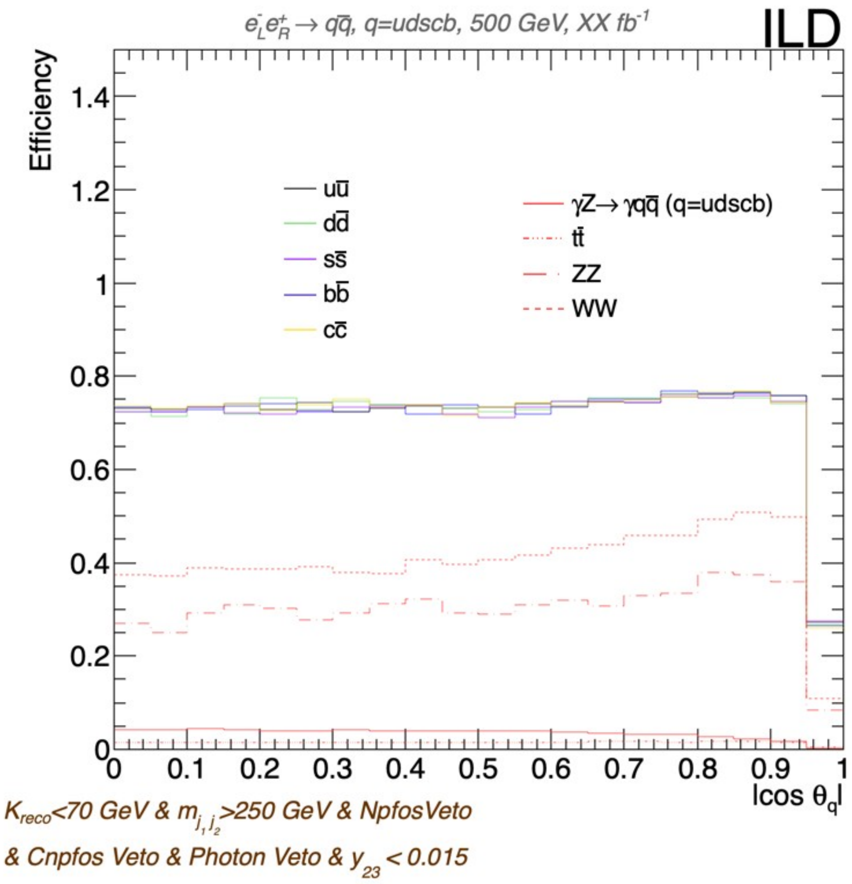
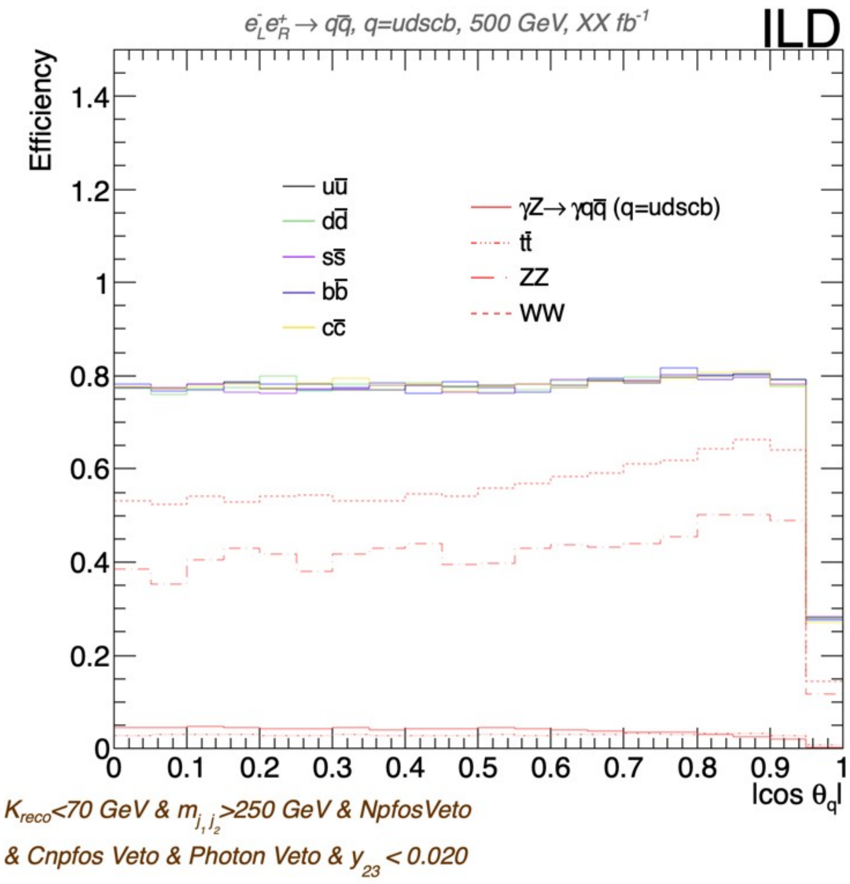
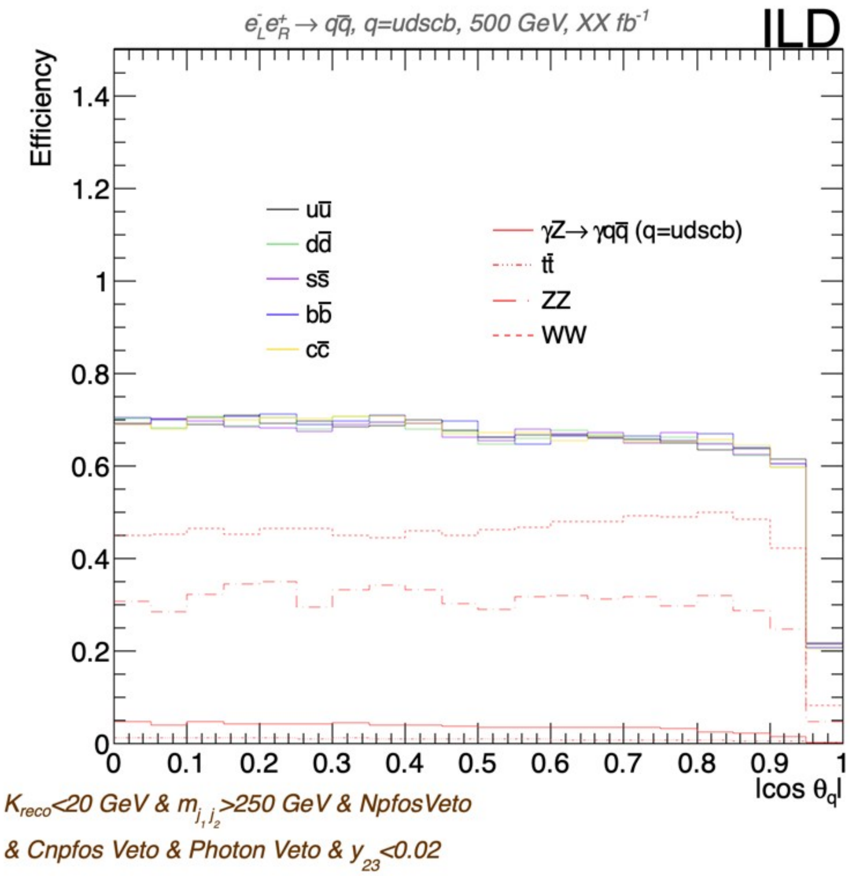
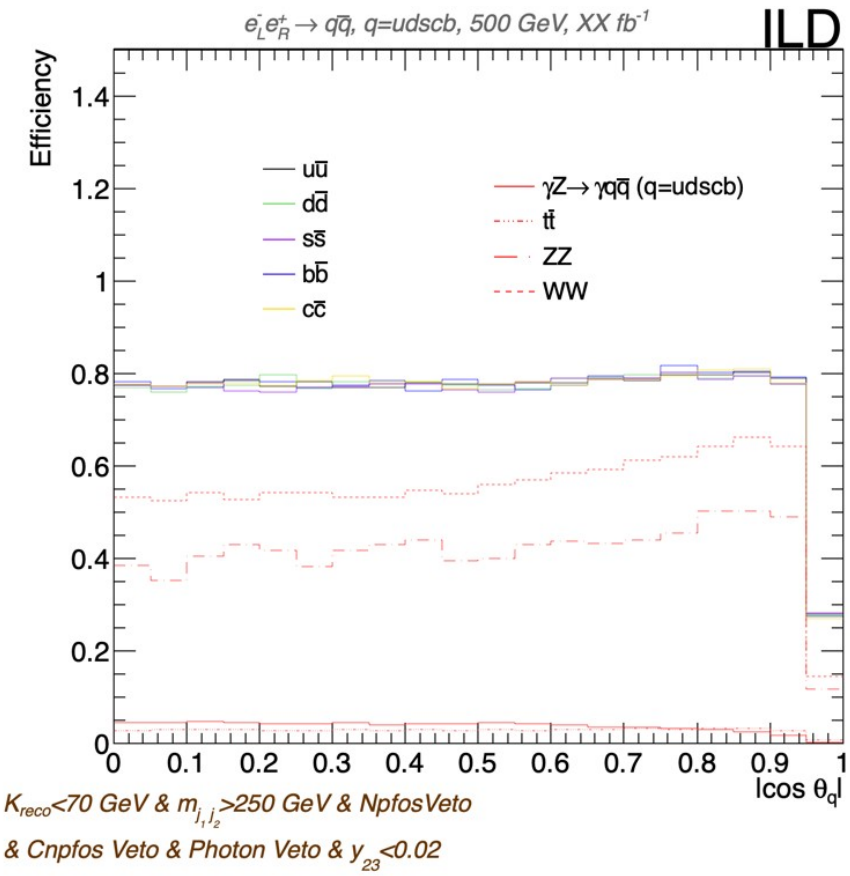




High y_{23} barely reduces background

Cut y_{23}<0.02 for K_{reco}=20 & 70 GeV





Cut y_{23}<0.02 for K_{reco}=20 & 70 GeV

K_{reco}<20 GeV

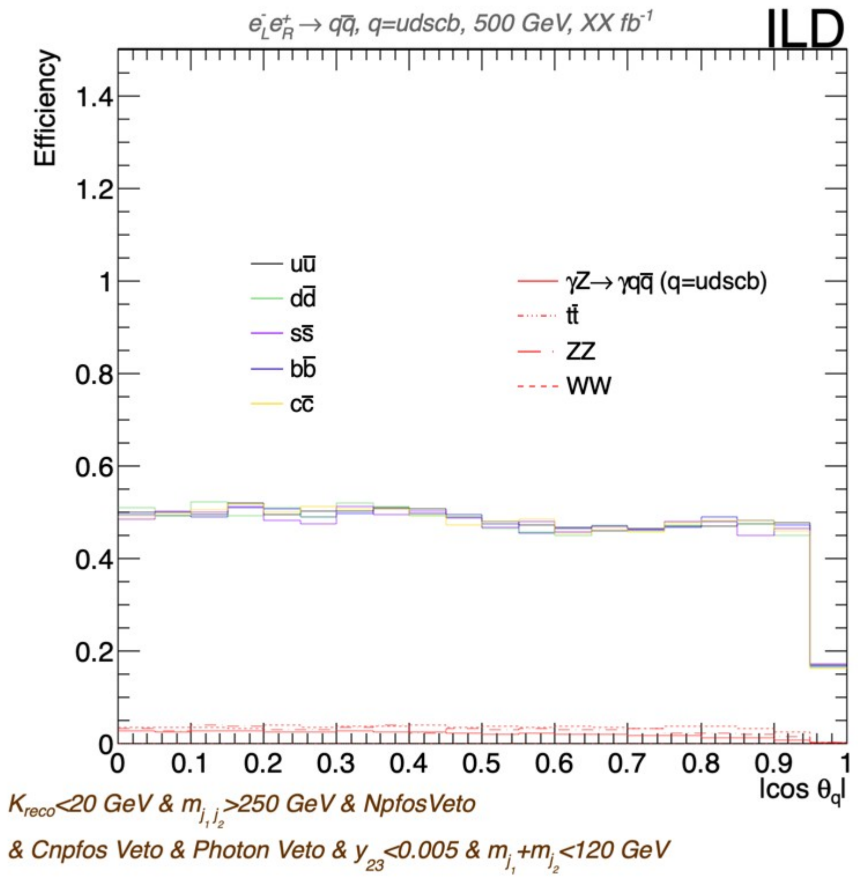
	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
$y_{23}<0.020$	63.7	63.4	63.2	0.13	0.52	0.034	0.001

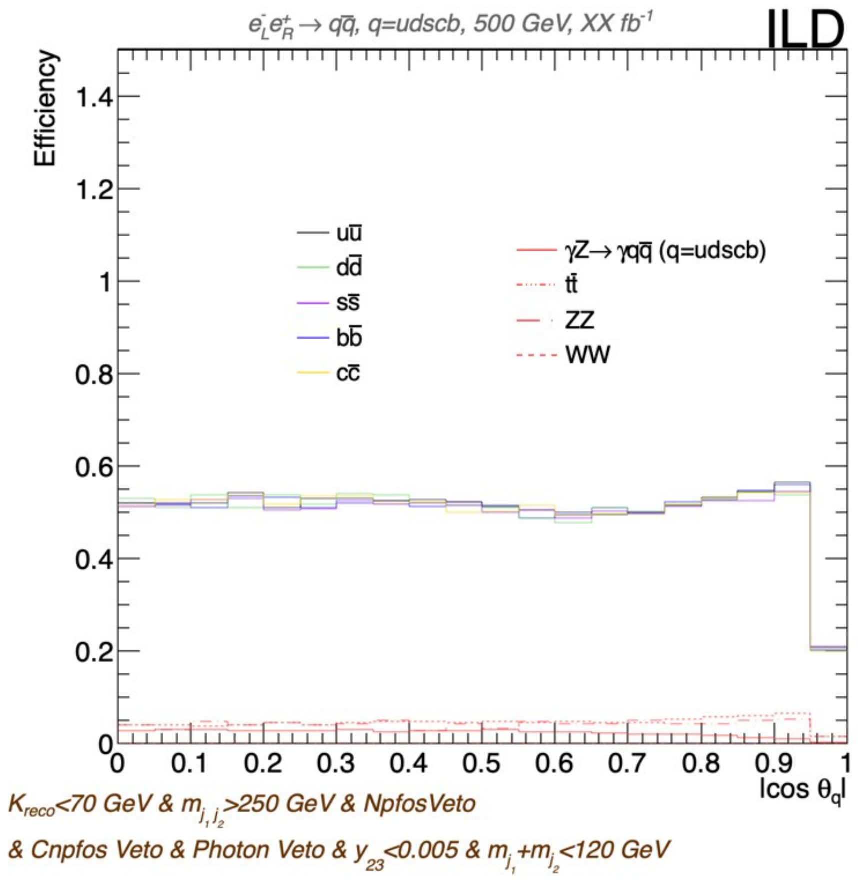
K_{reco}<70 GeV

	Efficiency (%)			Background/Signal			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$	ISR	WW	ZZ	$t\bar{t}$
$y_{23}<0.020$	74.7	74.5	74.3	0.09	0.52	0.04	0.0034

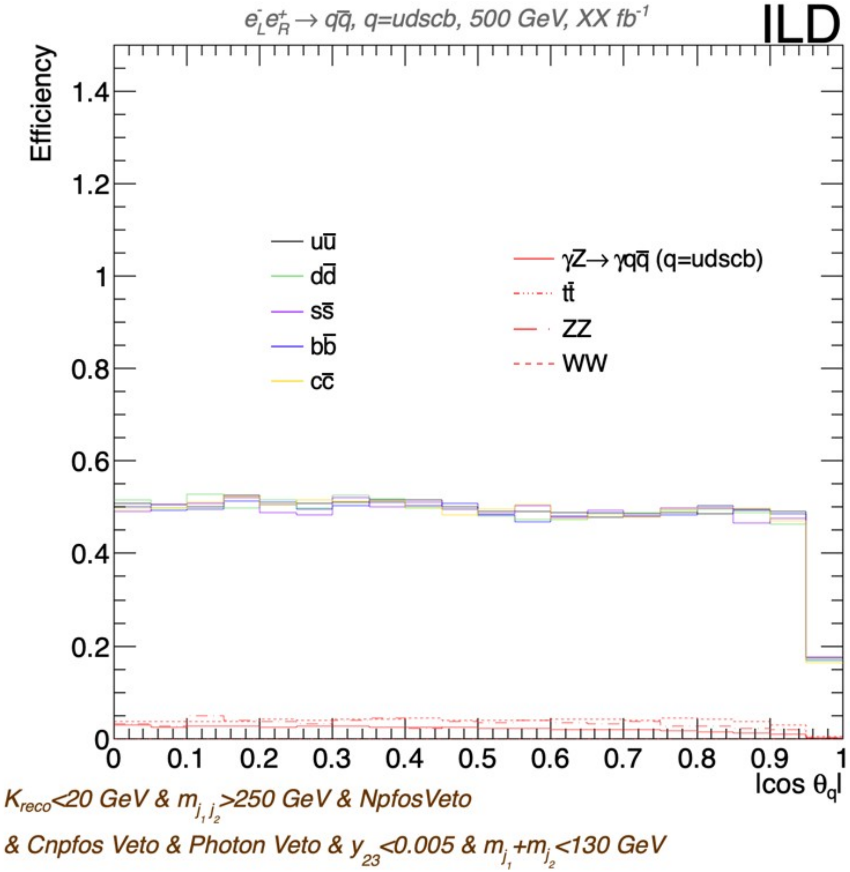
If we try to remove the slope using a milder cut in y_{23} we left way too much background

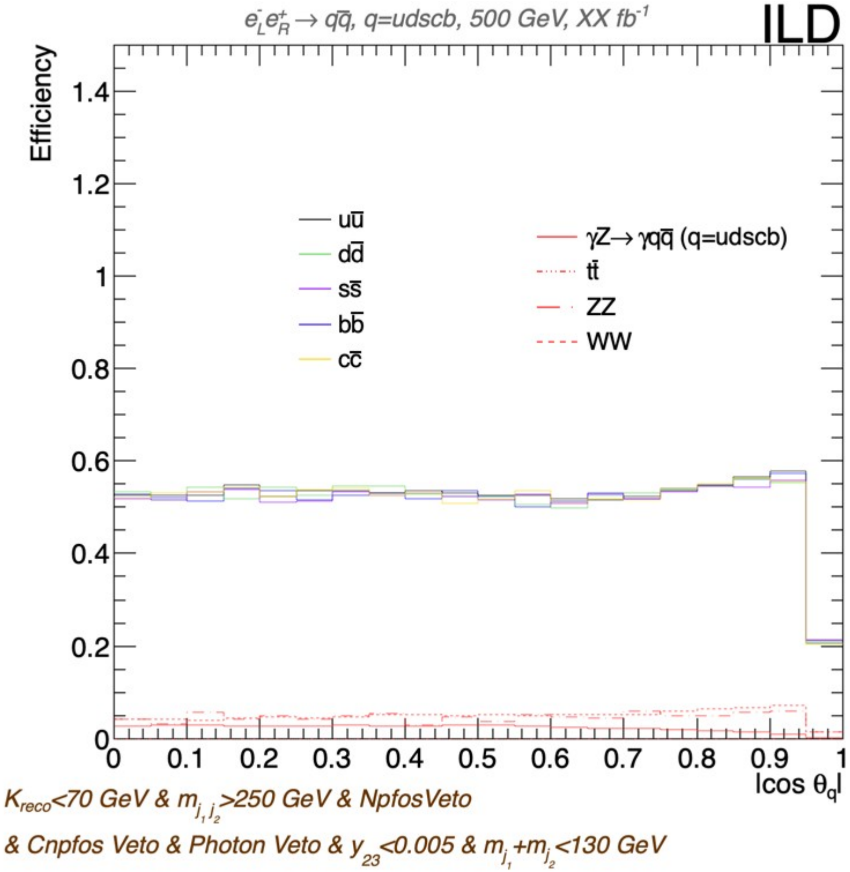
Seventh cut: $m_{j1}+m_{j2}<120$ GeV



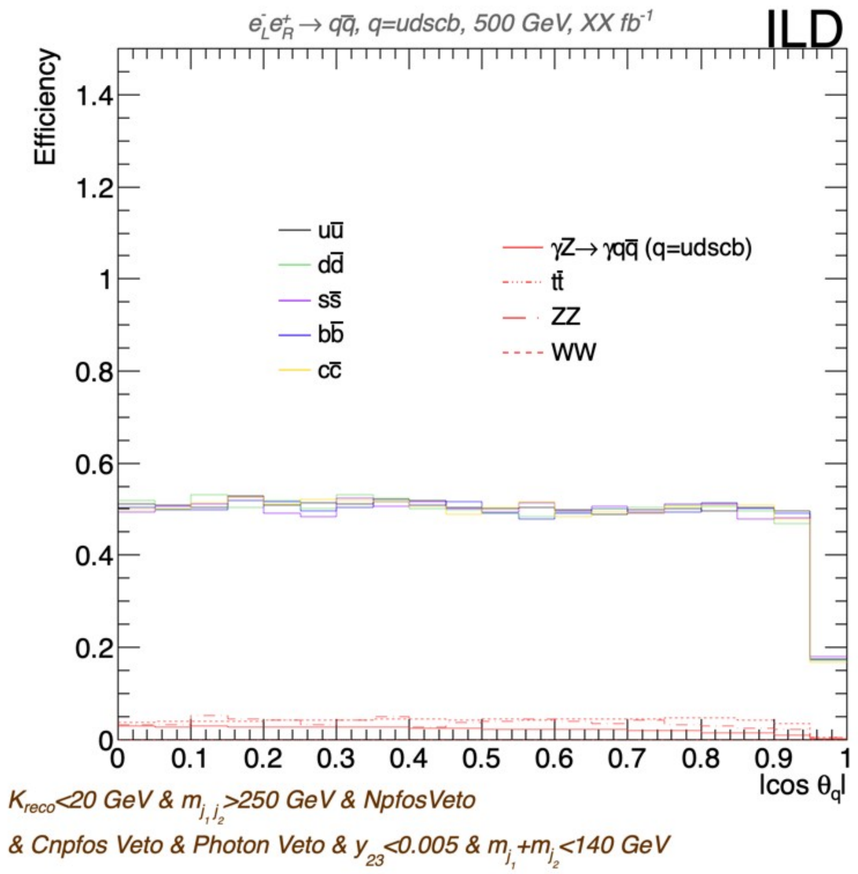


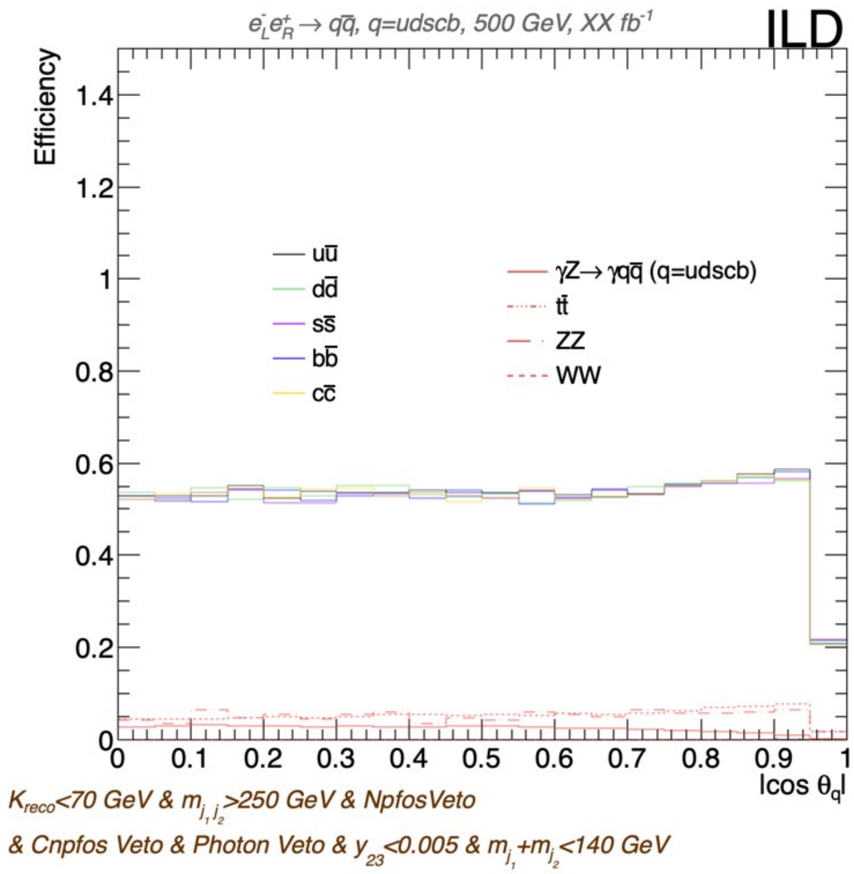
Seventh cut: $m_{j1}+m_{j2}<130$ GeV





Seventh cut: $m_{j1}+m_{j2}<140$ GeV





Seventh cut: $m_{j1}+m_{j2}<150$ GeV