AFB studies at 500 GeV

ILD Top/HF group meeting 20/12/21

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Observables for BSM studies

- Forward-backward asymmetry:

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

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

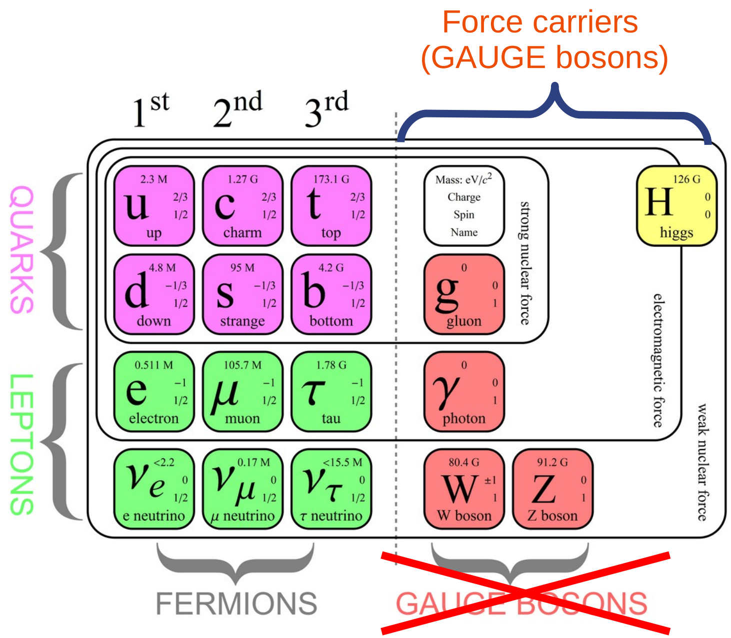
$$N = L \cdot \sigma \cdot \epsilon$$

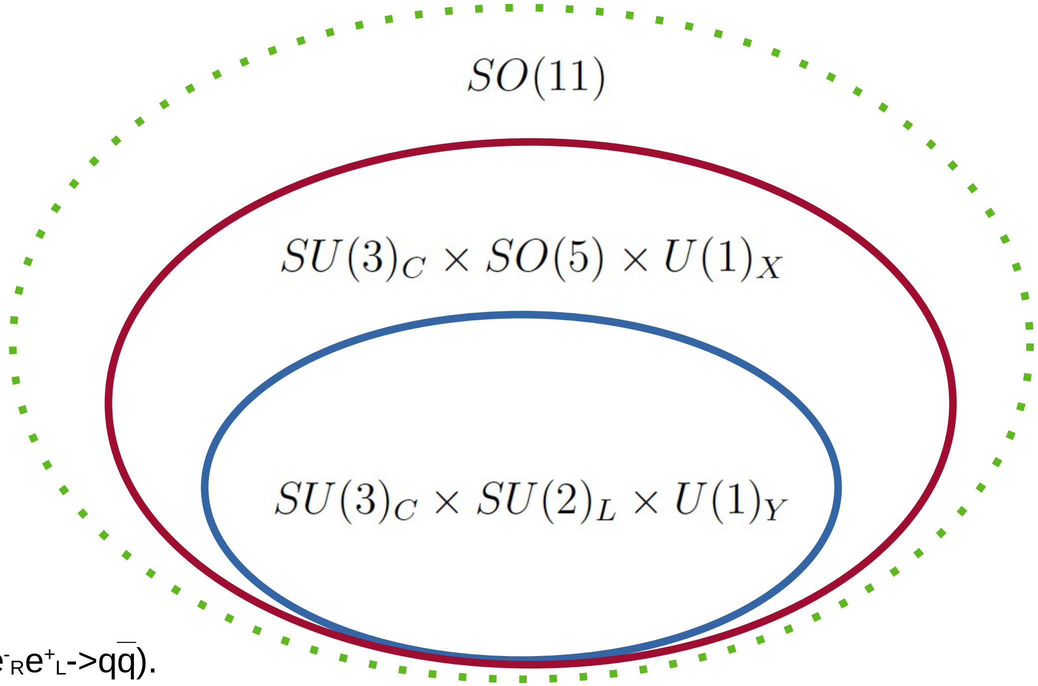
- Experimental definition:
  - Reduce bias from systematic errors from the luminosity and efficiency w.r.t. the cross-section observable

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

Gauge-Higgs Unification (GHU) Models

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



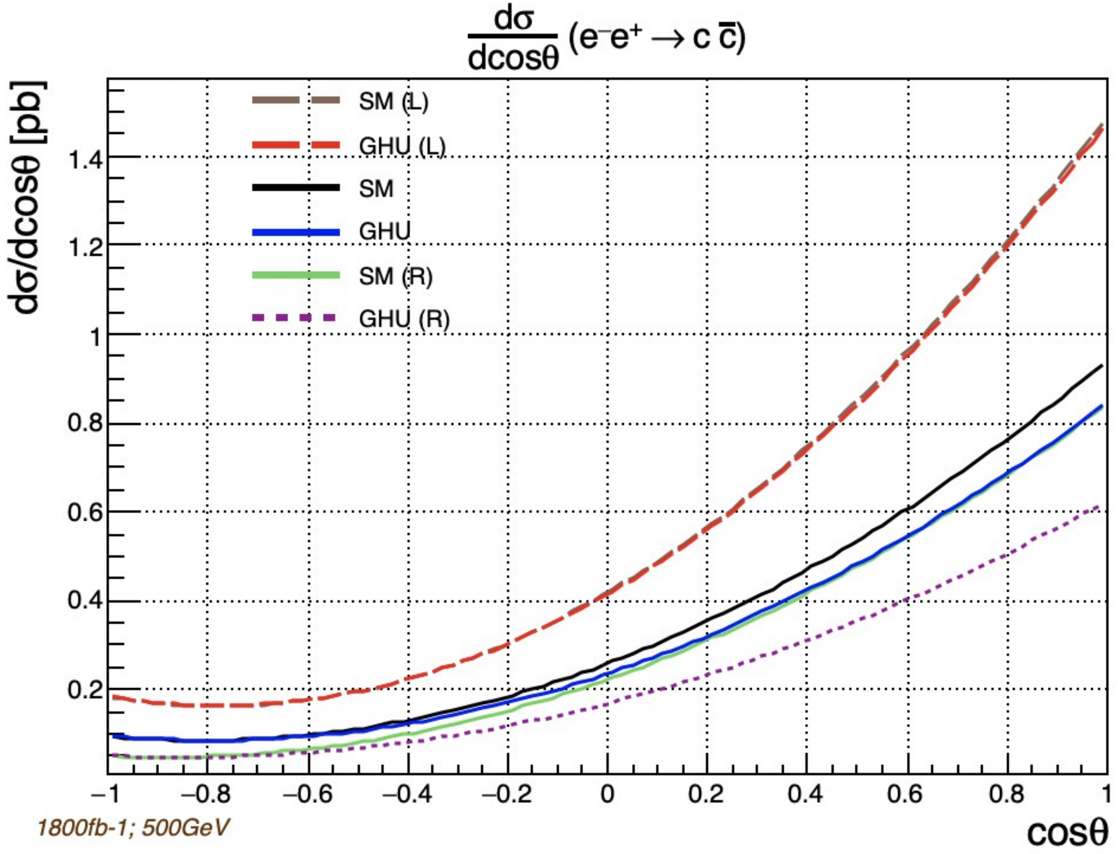


- A-Models[1]: Stronger deviations in the right-handed case ($e^-_R e^+_L \to q\bar{q}$).
- B-Models[2]: Stronger deviations in the left-handed case ($e^-_L e^+_R \to q\bar{q}$).
  - The gauge group of GHU is also related to Grand Unification Theory (GUT), embedded in the SO(11) group.

[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

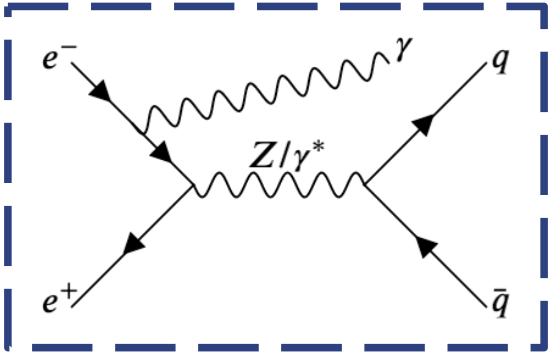
- A-Model cross-section deviation examples (c-quark) 500 GeV:

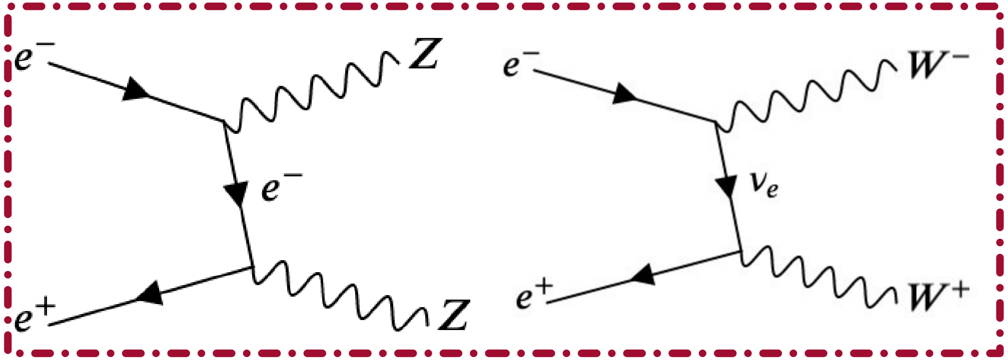


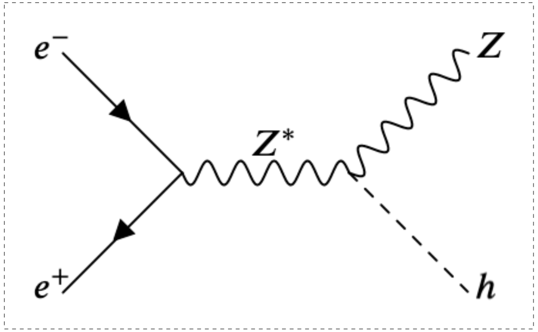
New physics hide in the forward region of the detector

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







Preselection for 250 GeV

Cuts:
- K_{reco} < 35 GeV
- m_{2jets} > 140 GeV
- Charged N pfos
- Photon veto
- Y_{23} < 0.015

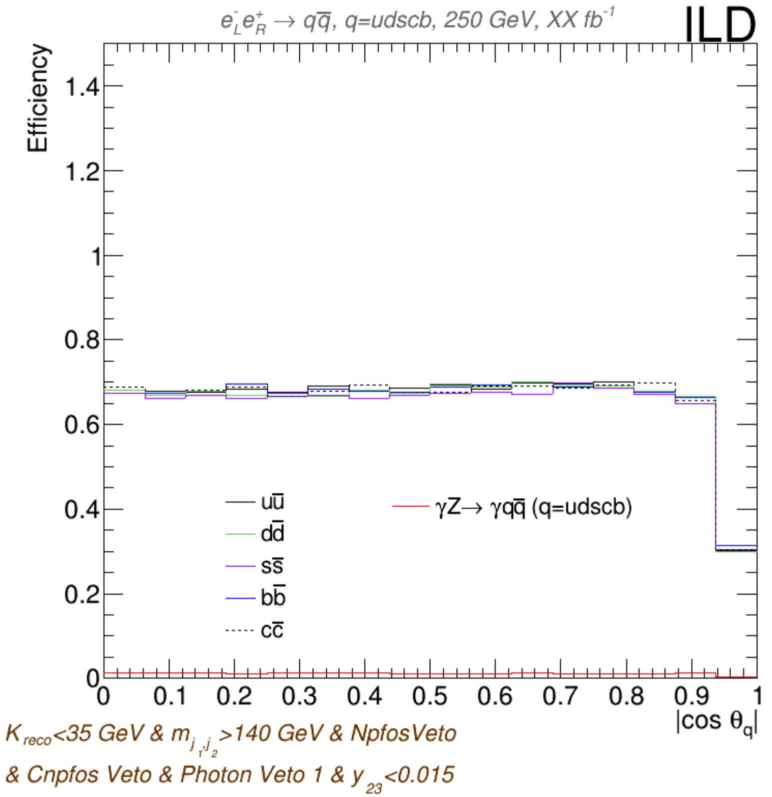
VLC Algorithm parameters:
- R = 1.0
- γ = 0.0
- β = 1.0

R	Efficiencies (%) $b\bar{b}$	$c\bar{c}$	$q\bar{q}$ (uds)	ISR	S/B
1.0	64.7	64.6	64.3	0.9	23.7
	68.3	68.5	68.1	1.1	28.1

← |cosθ| < 0.9

Total efficiency of the preselection for the different quark flavours and radiative return for the chosen configuration (γ=0). The second row is for |cosθ| < 0.9

Re-adapting this preselection is the first step to take for an analysis at 500 GeV



Efficiency of the preselection for the different quark flavours vs the angular distribution of the two jet system (new samples, final configuration)

Samples (500 GeV)

$e_L p_R$

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

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

	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

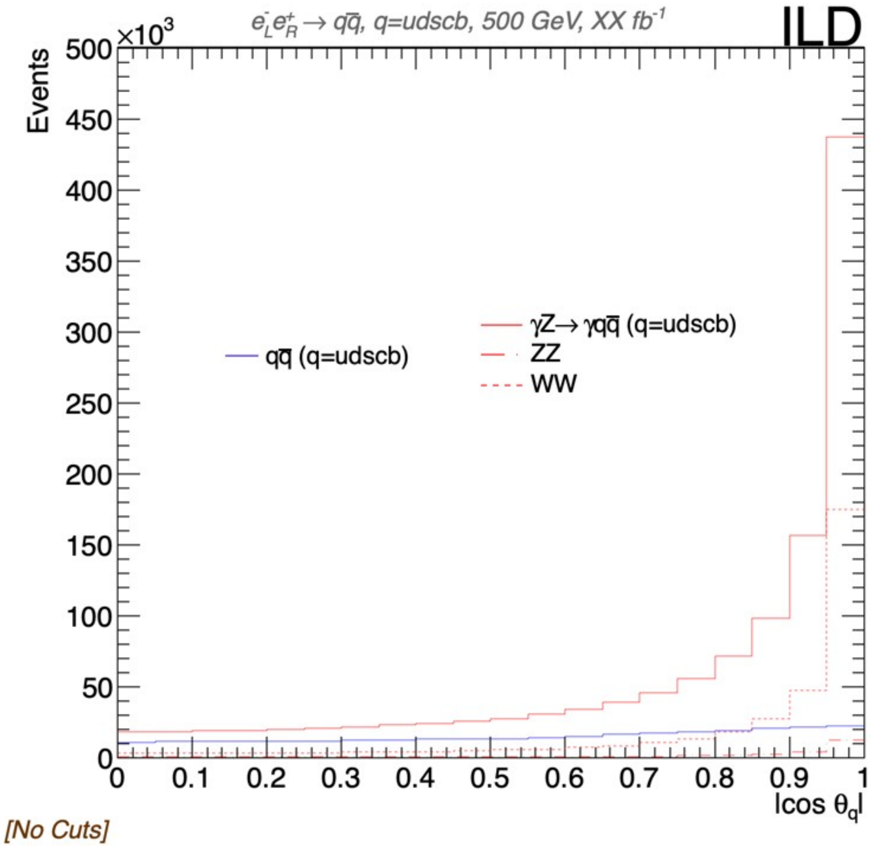
$e_R p_L$

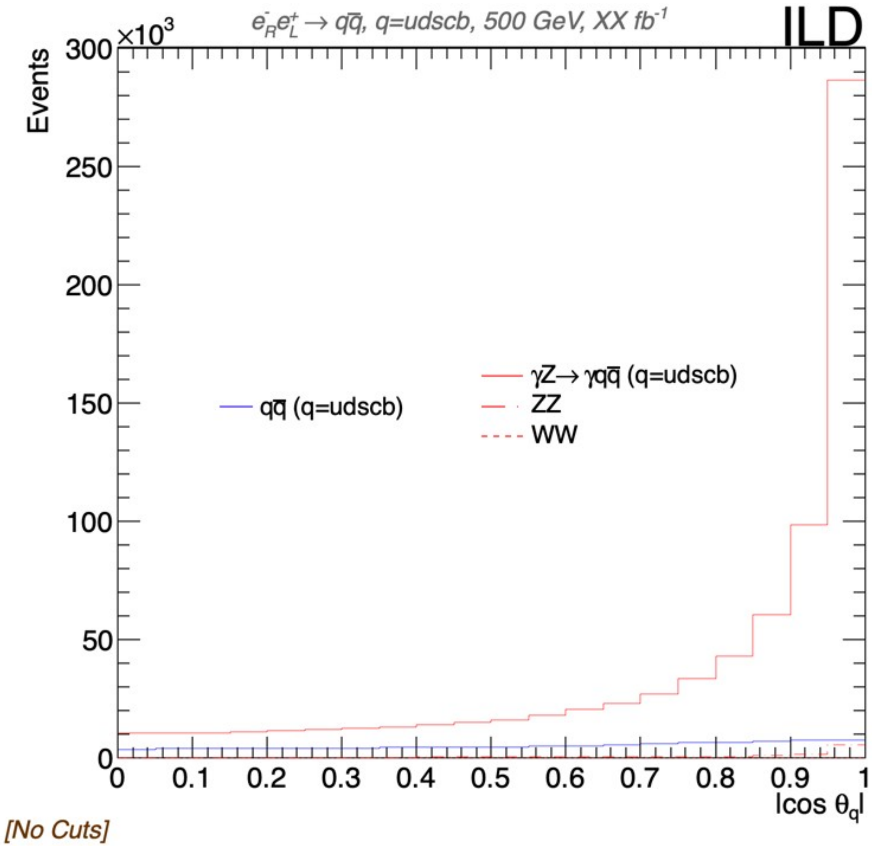
Luminosity (fb^{-1})		
$q\bar{q}$ + ISR	WW	ZZ
47.0	500	72.5

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

	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

Samples (500 GeV)





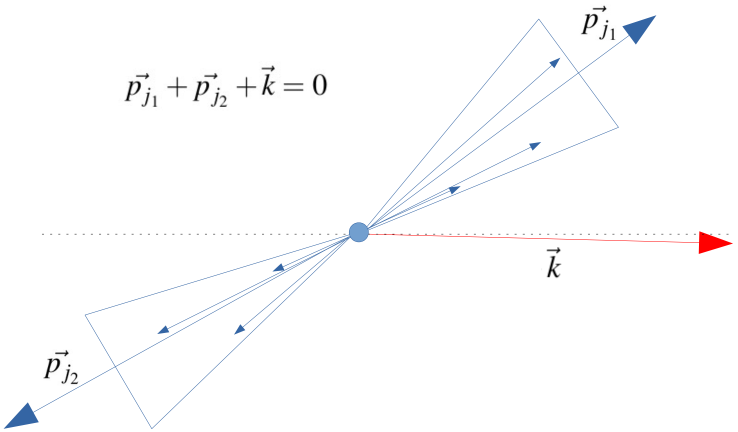
Optimization of the cuts: K_{reco}

- 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 ($m_{jets} << p_{jets}$):

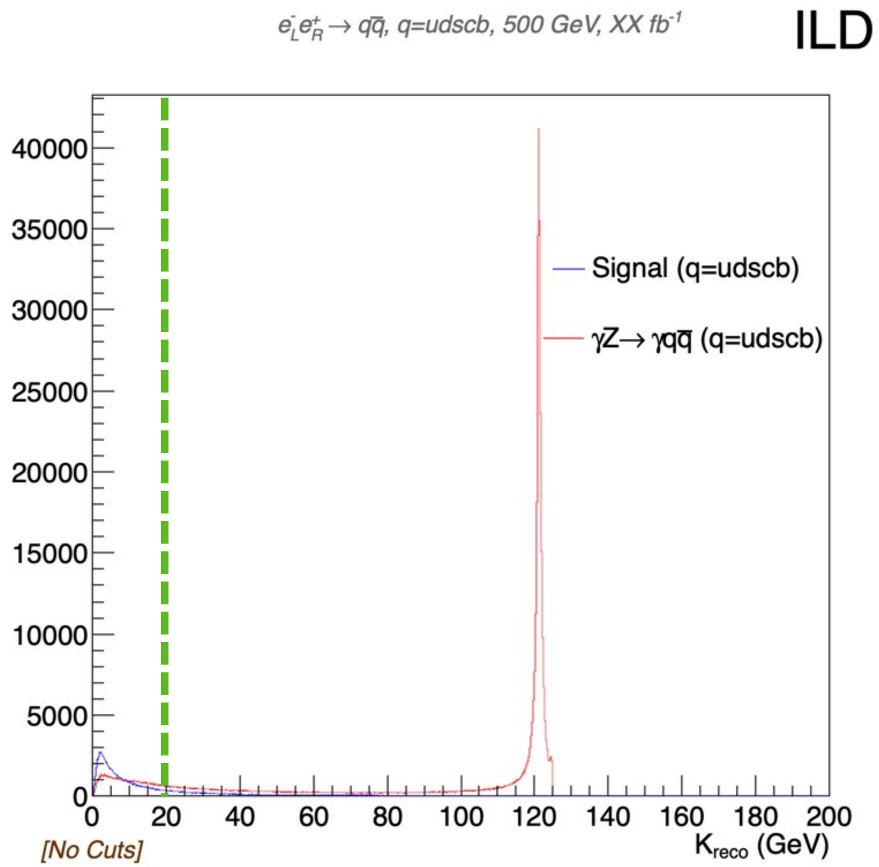
$$|\vec{k}| \approx K_{reco} = \frac{250\,\mathrm{GeV} \cdot \sin\Psi_{acol}}{\sin\Psi_{acol} + sin\theta_1 + sin\theta_2}$$

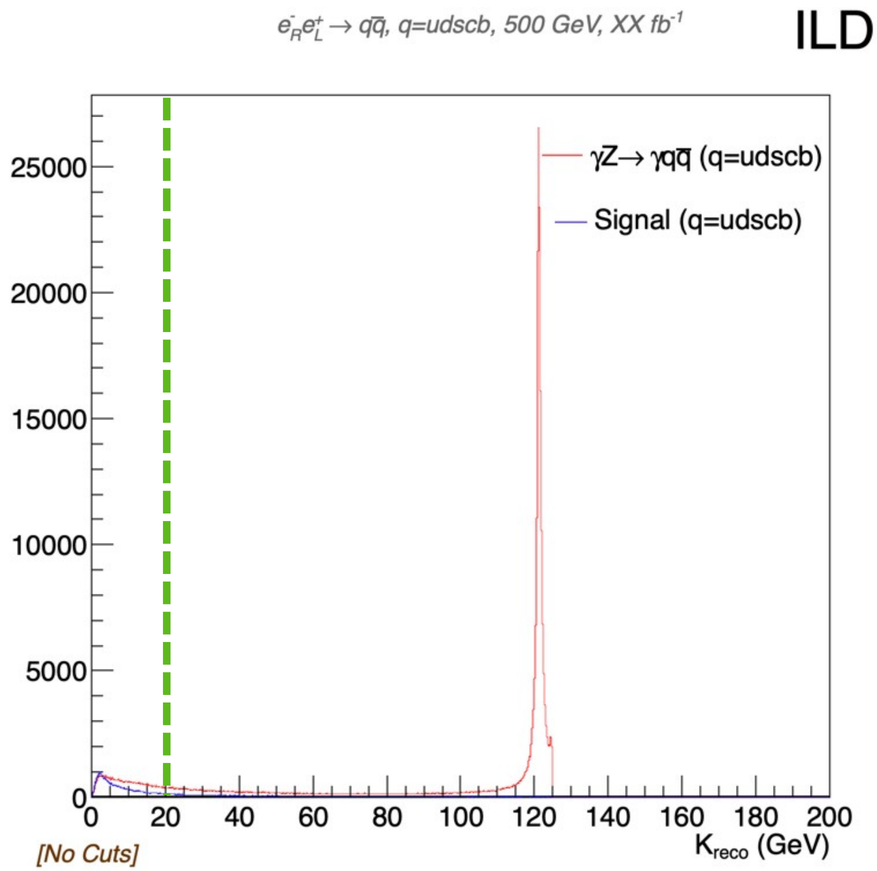


Kinematics of a two jets system reconstruction with ISR

Cut 1 (K_{reco} < 20)

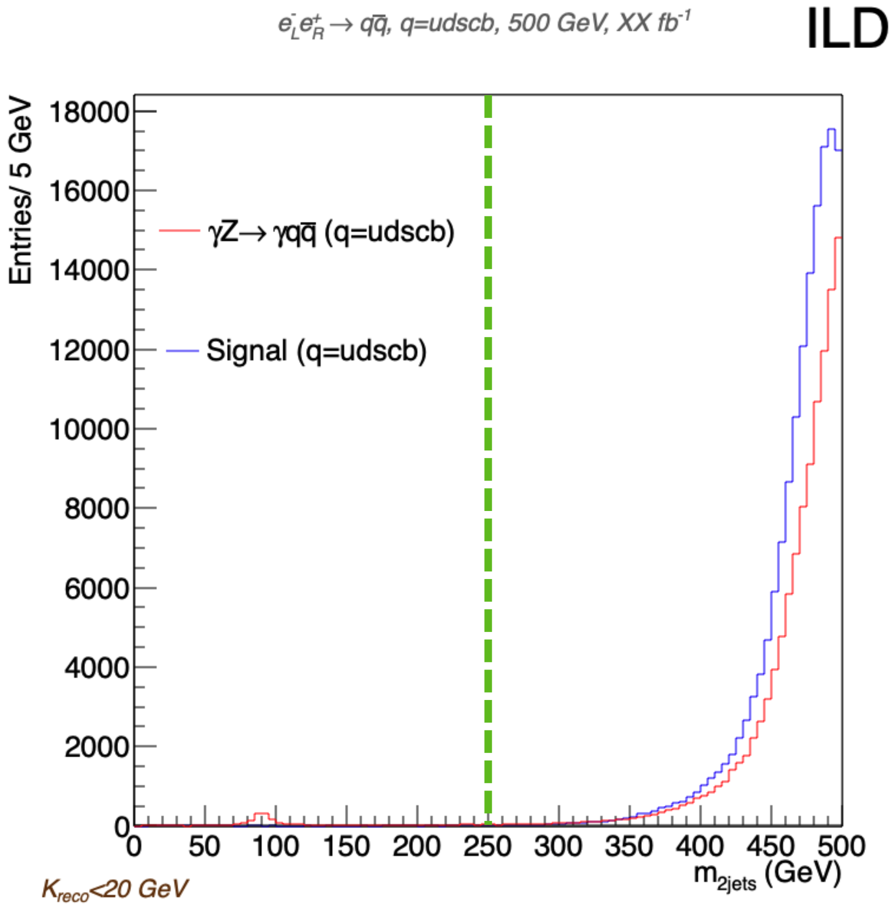
•



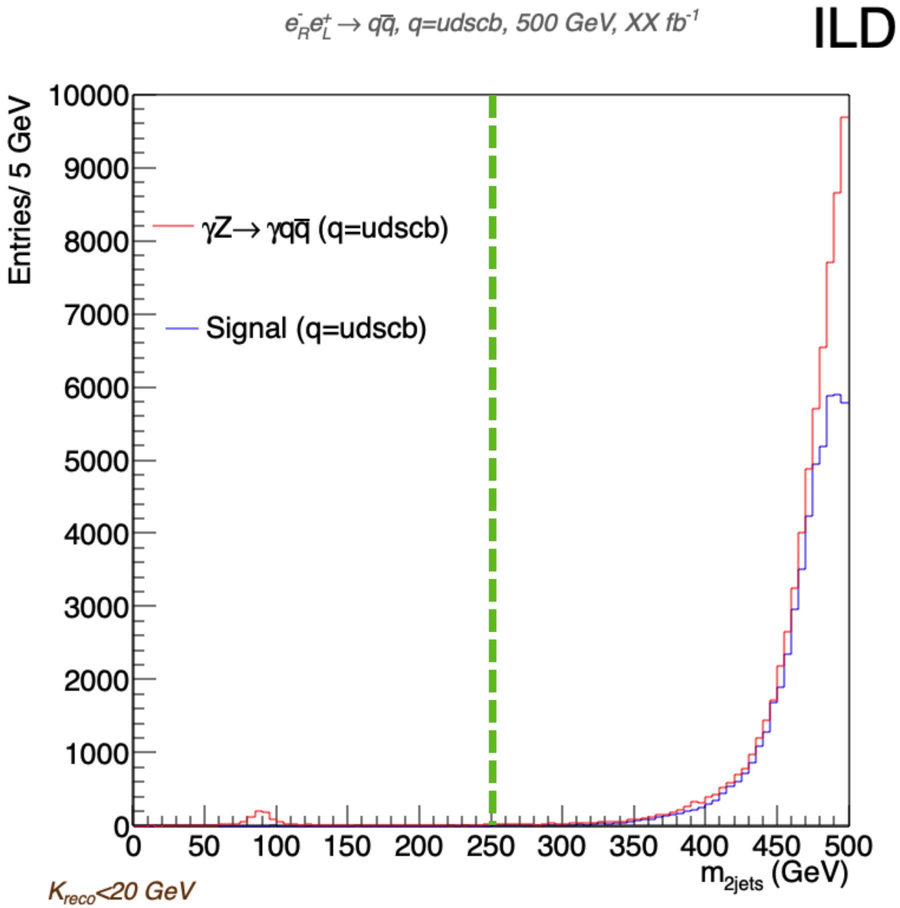


Cut2 mjj > 250

- .



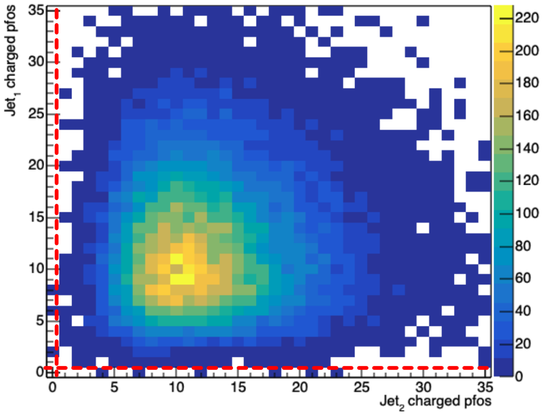
$e^-_L e^+_R \to q\bar{q}$, q=udscb, 500 GeV, XX fb^{-1}
ILD
Entries/ 5 GeV
$\gamma Z \to \gamma q\bar{q}$ (q=udscb)
Signal (q=udscb)
m_{2jets} (GeV)
K_{reco}<20 GeV



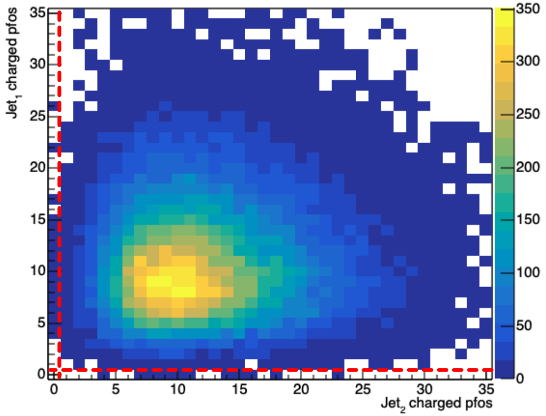
$e^-_R e^+_L \to q\bar{q}$, q=udscb, 500 GeV, XX fb^{-1}
ILD
Entries/ 5 GeV
$\gamma Z \to \gamma q\bar{q}$ (q=udscb)
Signal (q=udscb)
m_{2jets} (GeV)
K_{reco}<20 GeV

Cut 3 – n charge pfos > 0.5 ($e_L p_R$)

$b\bar{b}$

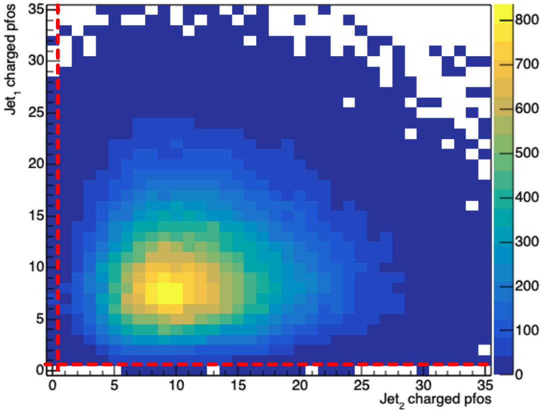


$c\bar{c}$

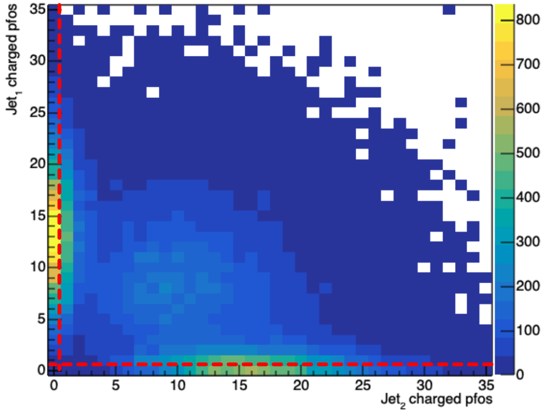


q=u,d,s

$q\bar{q}$

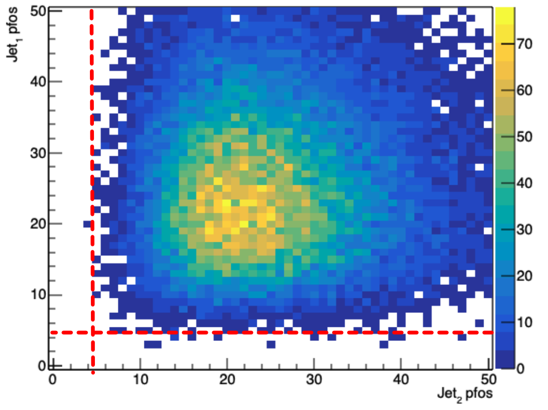


ISR

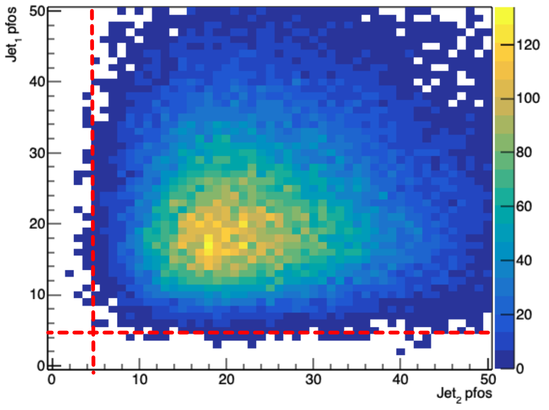


Cut 4 – n neutral pfos > 4.5 ($e_L p_R$)

$b\bar{b}$

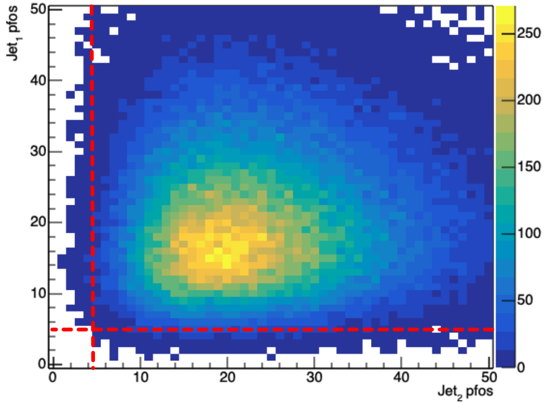


$c\bar{c}$

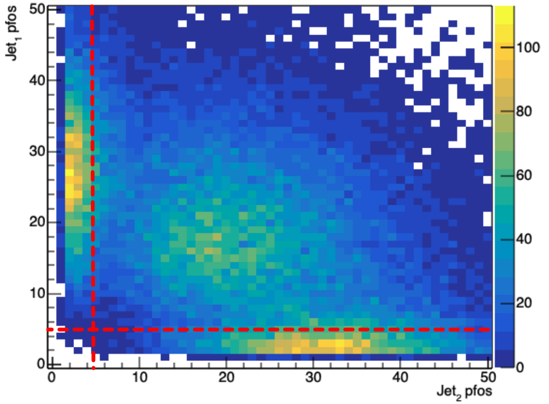


q=u,d,s

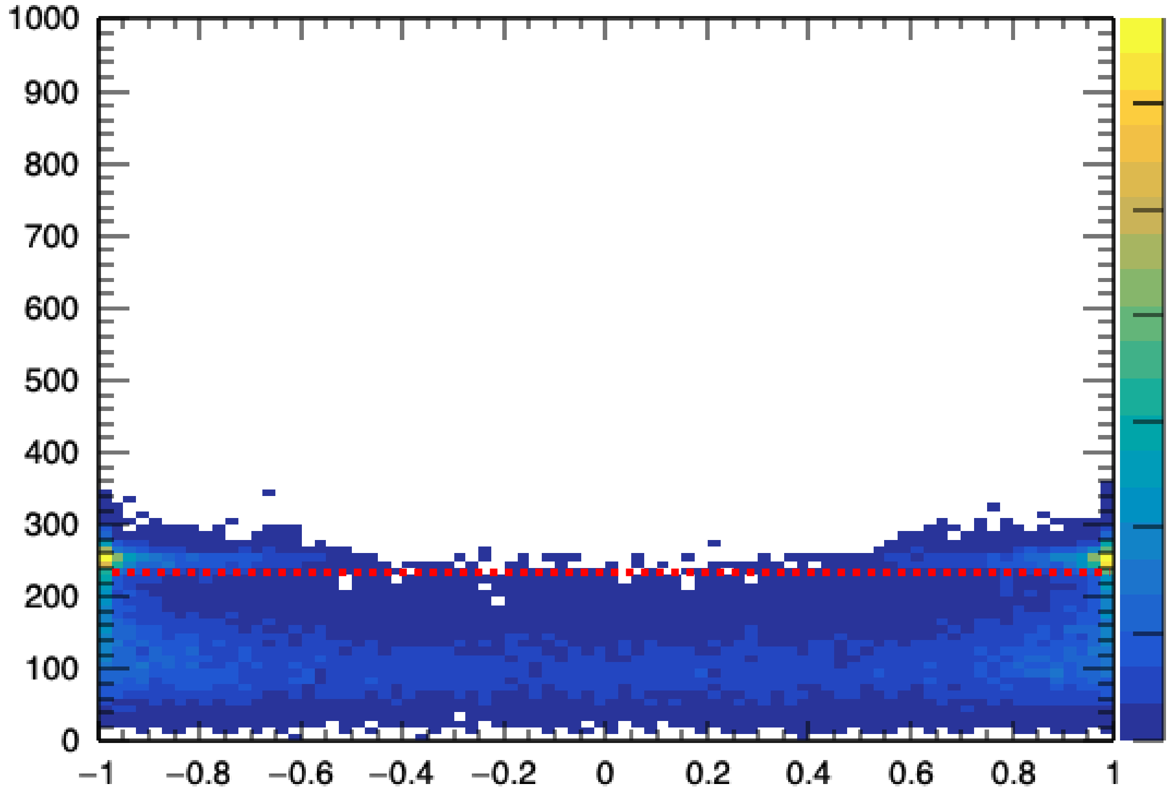
$q\bar{q}$



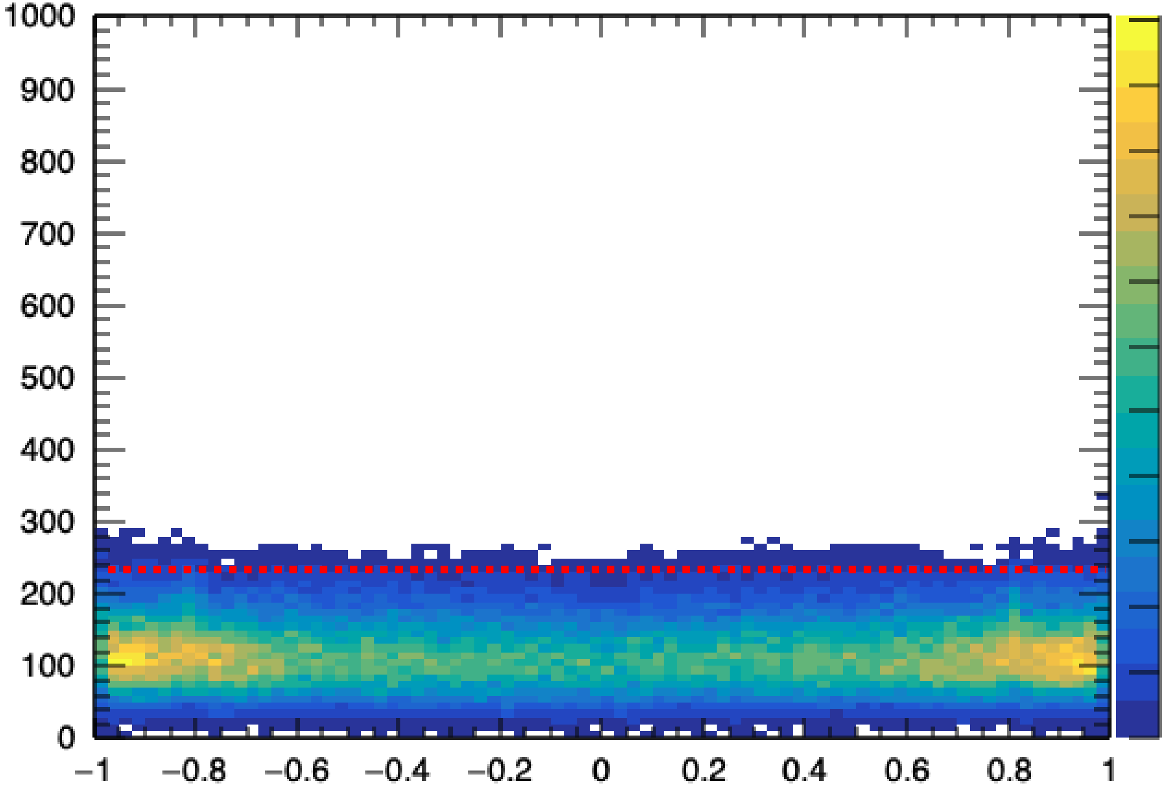
ISR



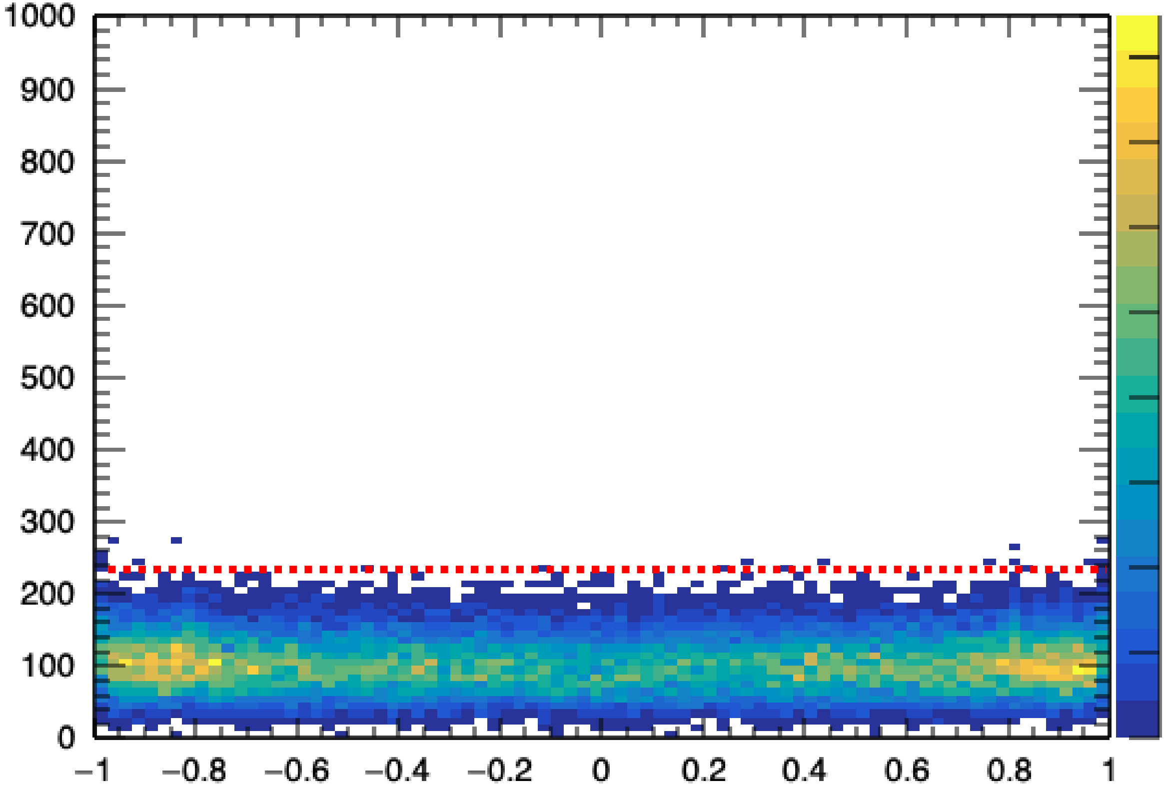
Cut 5 – photon veto ($e_L p_R$)-ISR



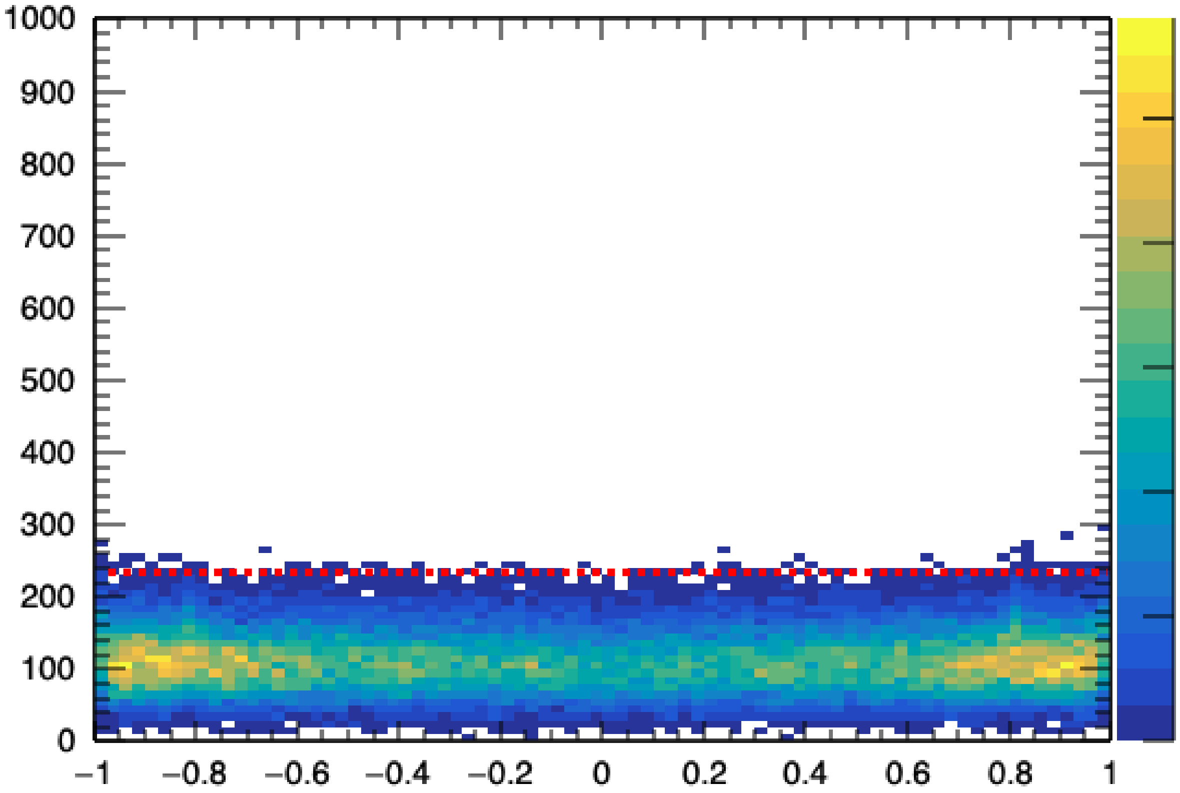
Cut 5 – photon veto ($e_L p_R$)-$q\bar{q}$



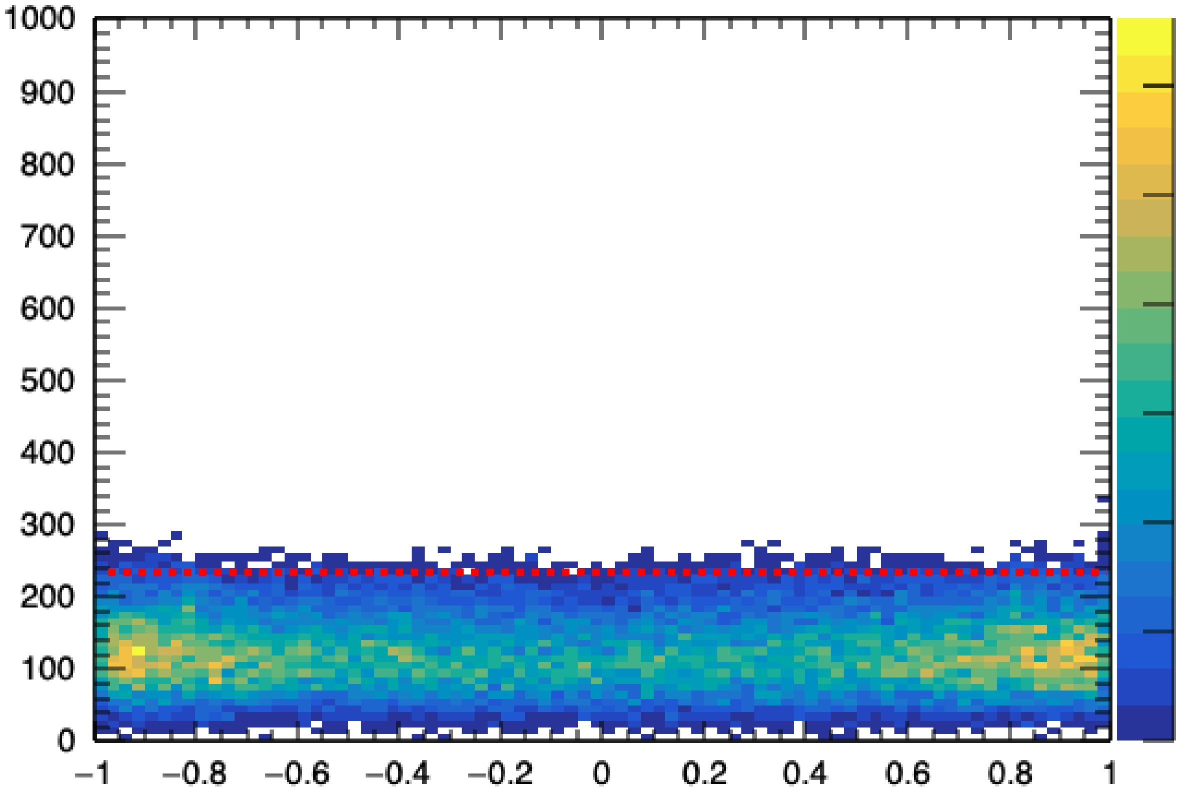
Cut 5 – photon veto ($e_L p_R$)-$b\bar{b}$



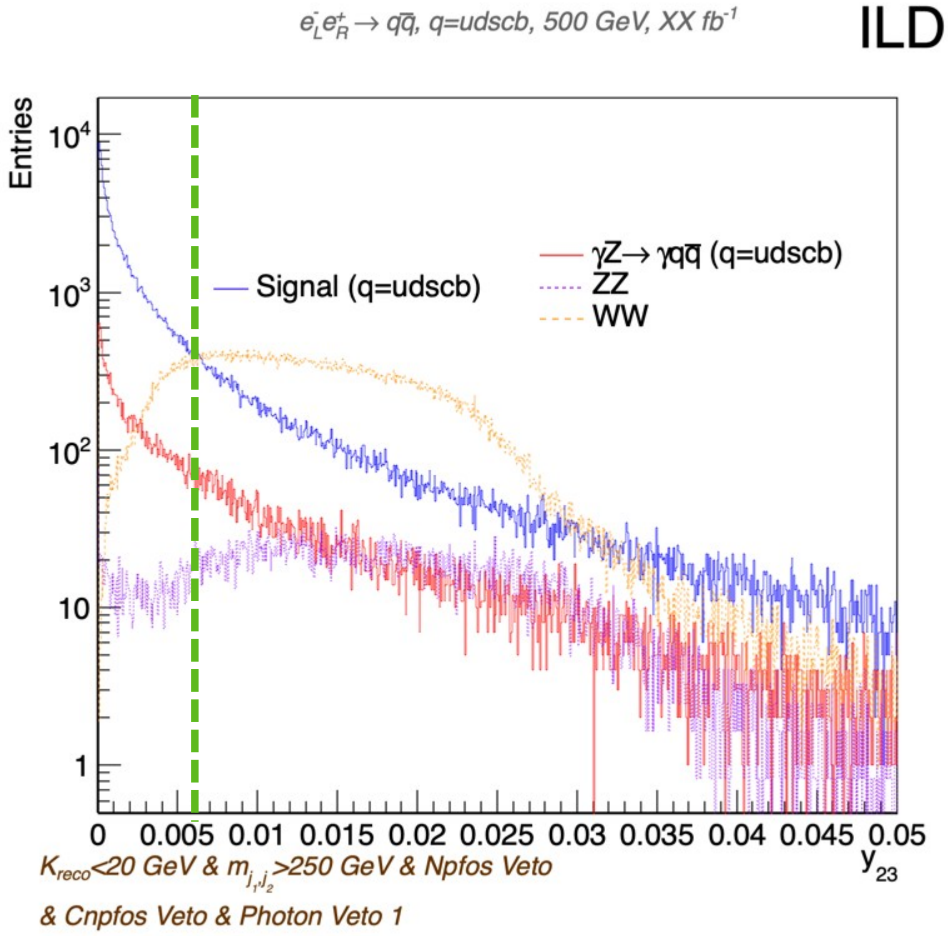
Cut 5 – photon veto ($e_L p_R$)-$c\bar{c}$



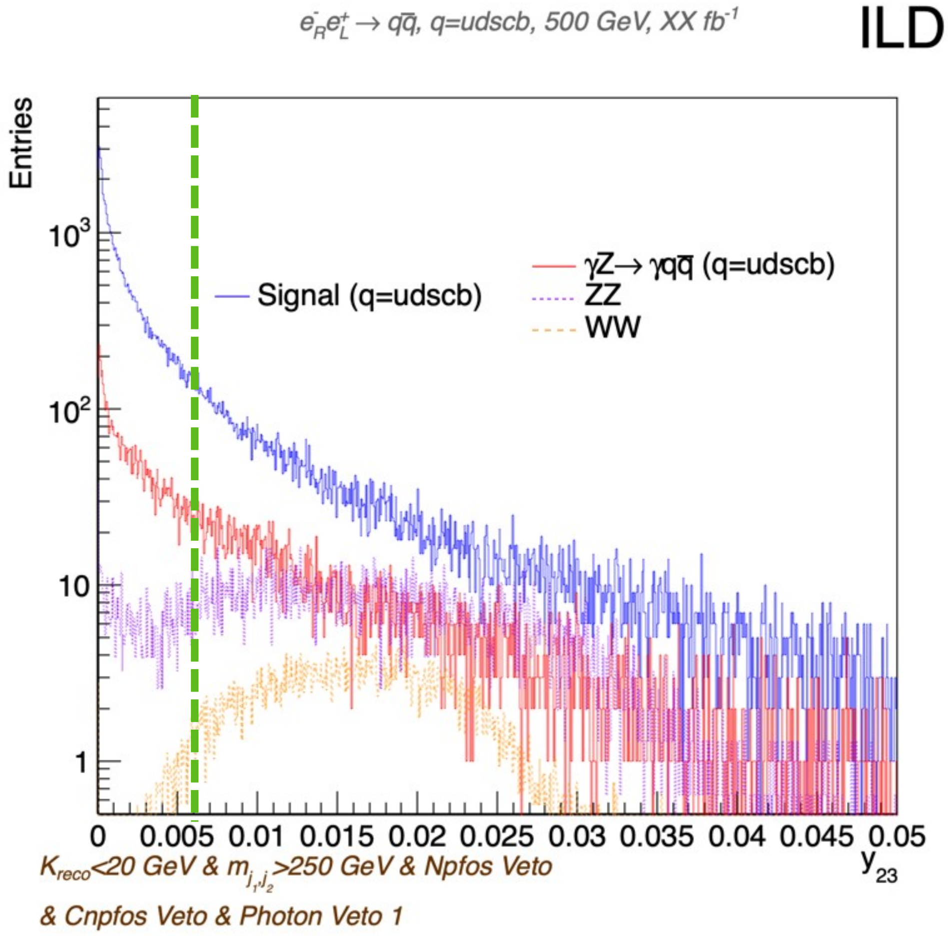
Cut 5 – photon veto ($e_L p_R$)-$s\bar{s}$



Cut 6 – y23



$e^-_L e^+_R \to q\bar{q}$, q=udscb, 500 GeV, XX fb^{-1}
ILD
Entries
Signal (q=udscb)
$\gamma Z \to \gamma q\bar{q}$ (q=udscb)
ZZ
WW
y_{23}
K_{reco}<20 GeV & m_{j_1,j_2}>250 GeV & Npfos Veto
& Cnpfos Veto & Photon Veto 1



$e^-_R e^+_L \to q\bar{q}$, q=udscb, 500 GeV, XX fb^{-1}
ILD
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ZZ
WW
y_{23}
K_{reco}<20 GeV & m_{j_1,j_2}>250 GeV & Npfos Veto
& Cnpfos Veto & Photon Veto 1

Overview (Efficiency)

$e_L p_R$

	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

Overview (Background/signal)

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$e_L p_R$

	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! (ISR)

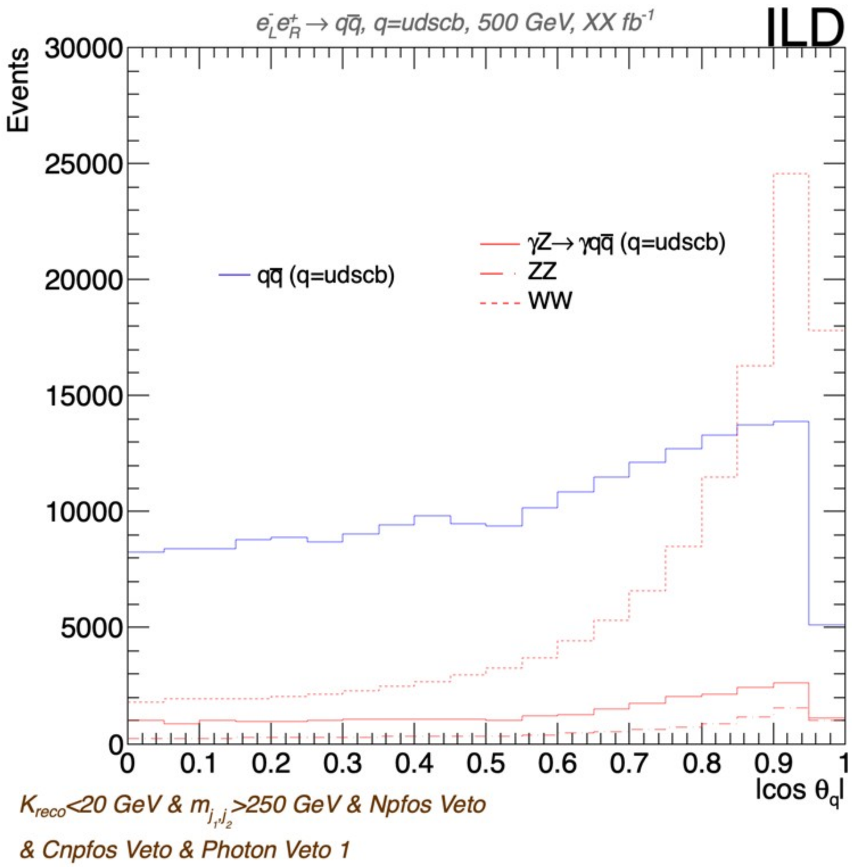
Too high! (WW)

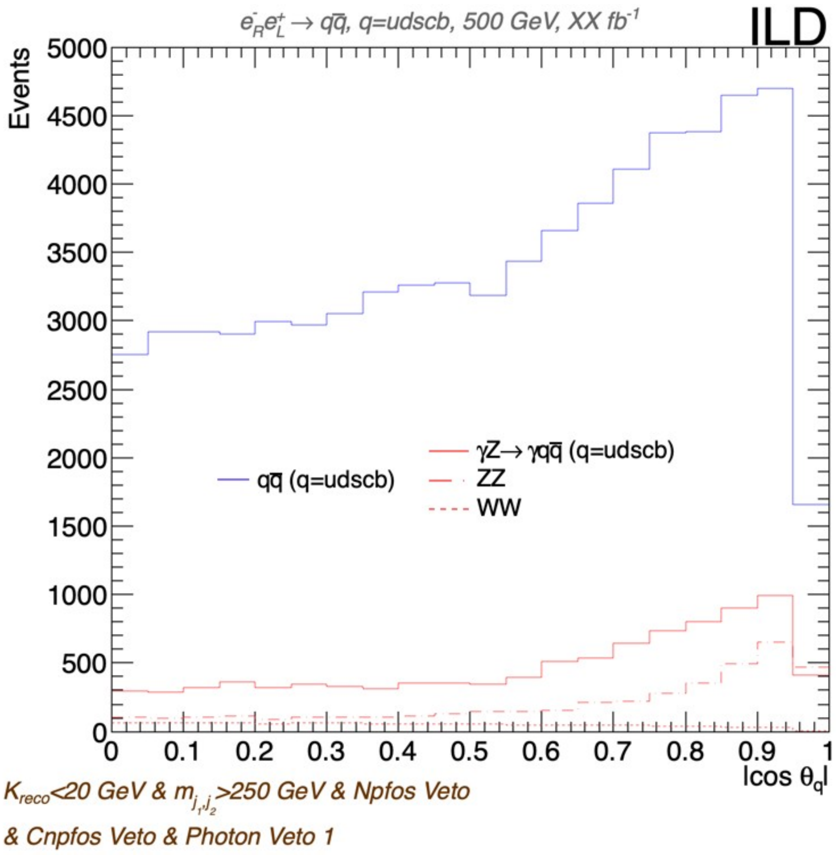
$e_R p_L$

	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

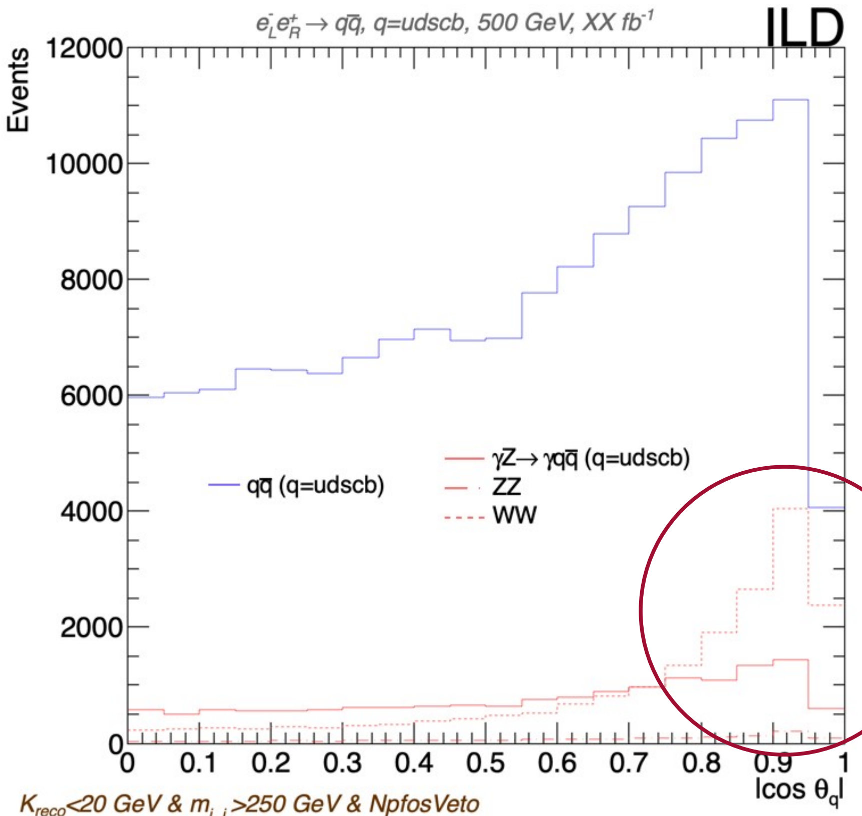
X2 than at 250 GeV! (ISR)

Overview (Angular profile – Cut 5)

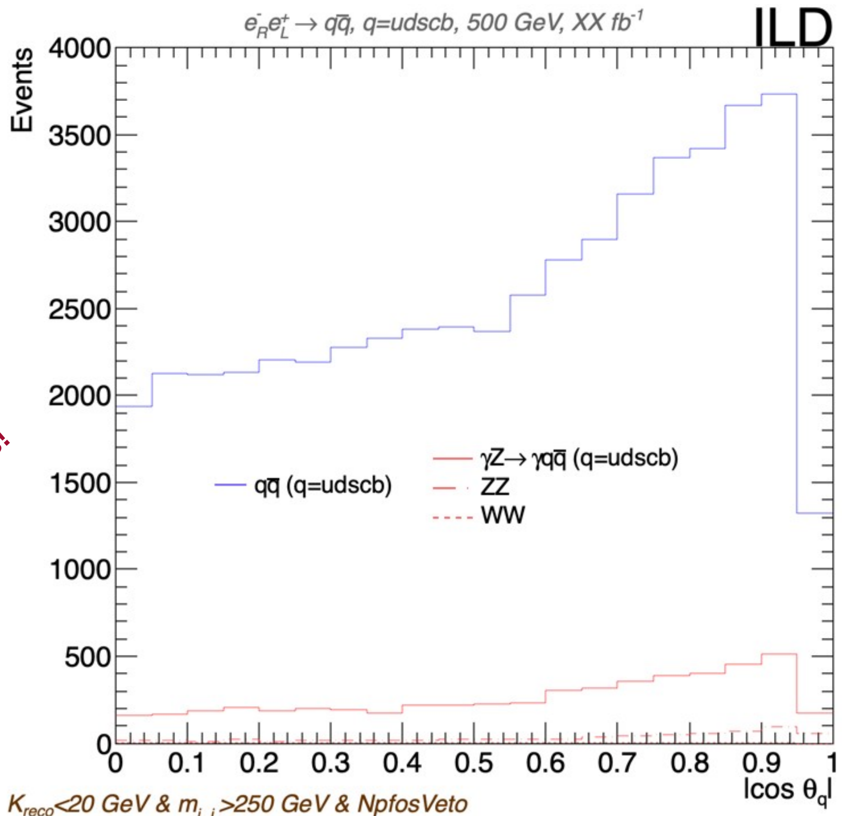




Overview (Angular profile – Cut 6)



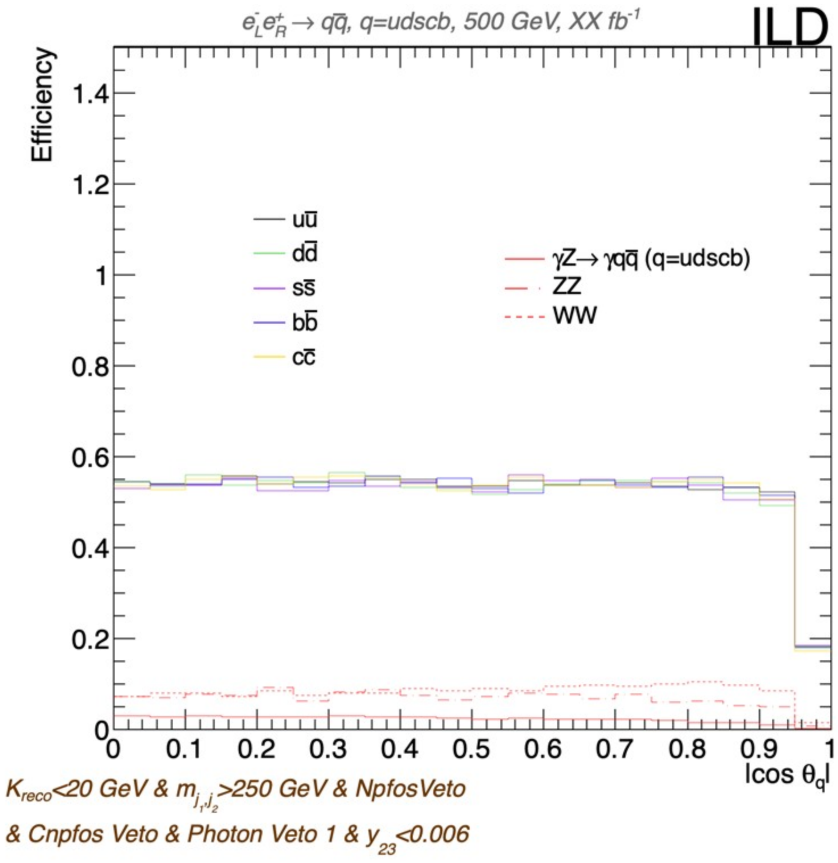
May look like new physics!

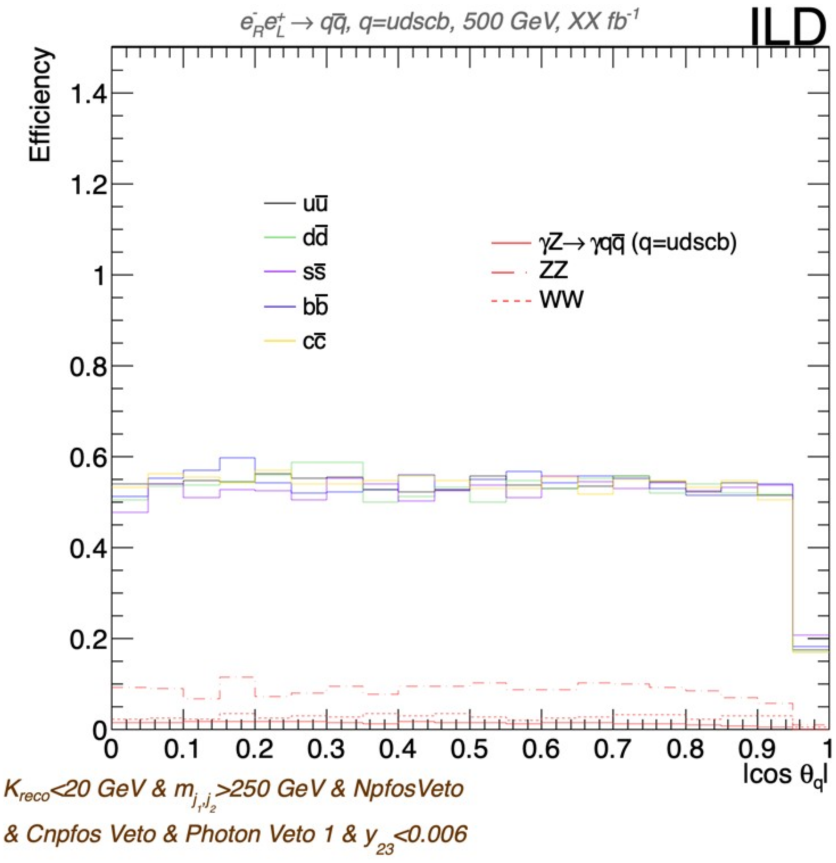


K_{reco}<20 GeV & $m_{j_1 j_2}$>250 GeV & NpfosVeto & Cnpfos Veto & Photon Veto 1 & y_{23}<0.006

K_{reco}<20 GeV & $m_{j_1 j_2}$>250 GeV & NpfosVeto & Cnpfos Veto & Photon Veto 1 & y_{23}<0.006

Overview (efficiency)





Conclusion and next steps

- Some *good* first steps have been taken to study A_{FB} at 500 GeV.

- Yet, the B/S is not good enough for $e_L p_R$, we want to refine the preselection process using other variables: Sphericity, oblateness, thrust, etc.

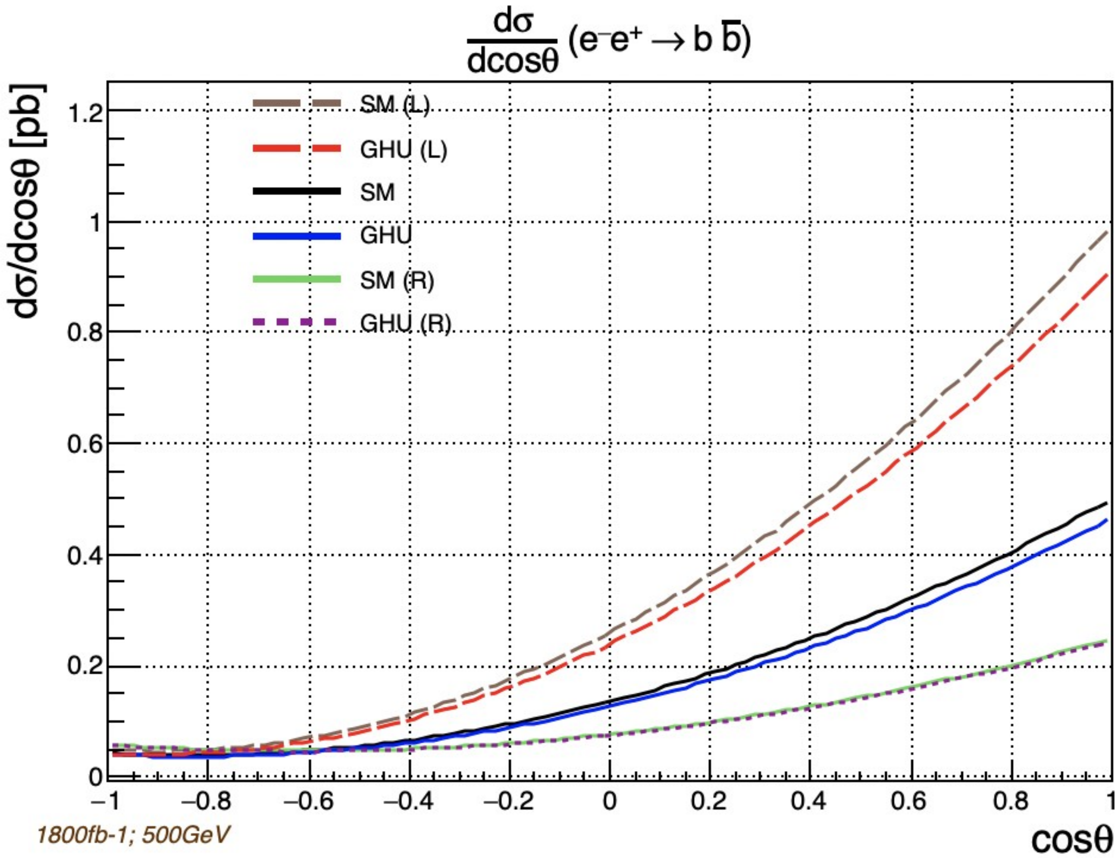
- After the preselection process finishes -> Flavour tagging at 500 GeV.

- Final goal: Obtain efficiencies and systematic errors for a complete study of EW couplings at 500 GeV (including an update of GHU phenomenology)
  - Newer and bigger samples will be needed for a good realistic study!

Back-Up slides

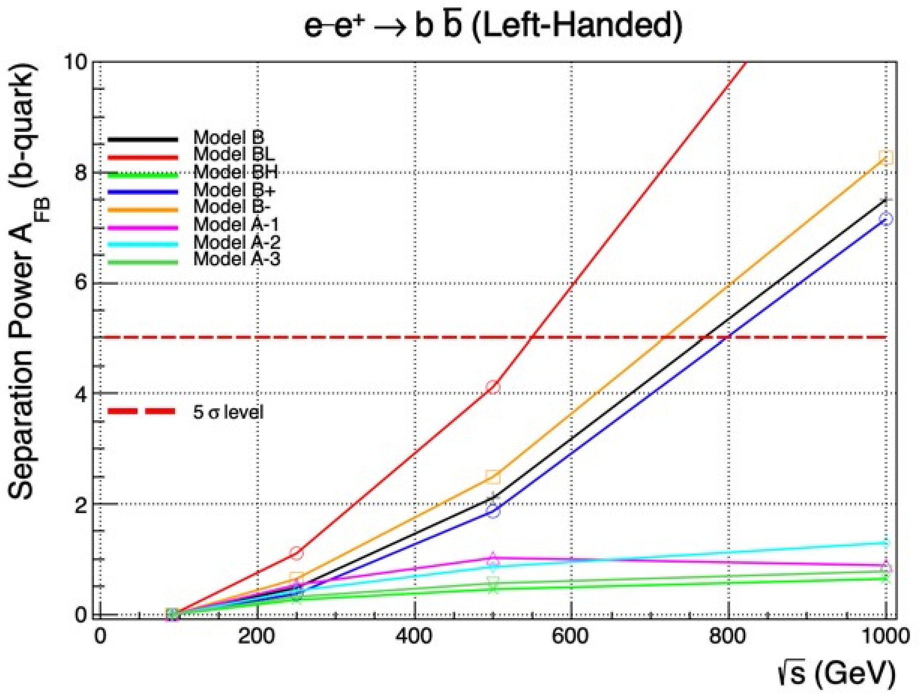
Gauge-Higgs Unification (GHU) Models

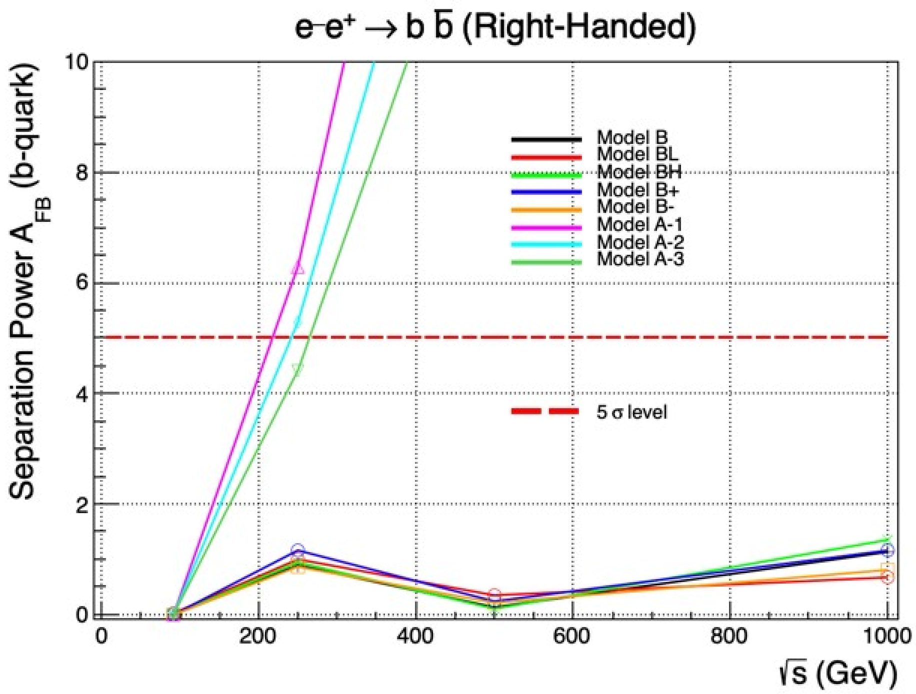
- B-Model cross-section deviation examples (b-quark) 500 GeV:



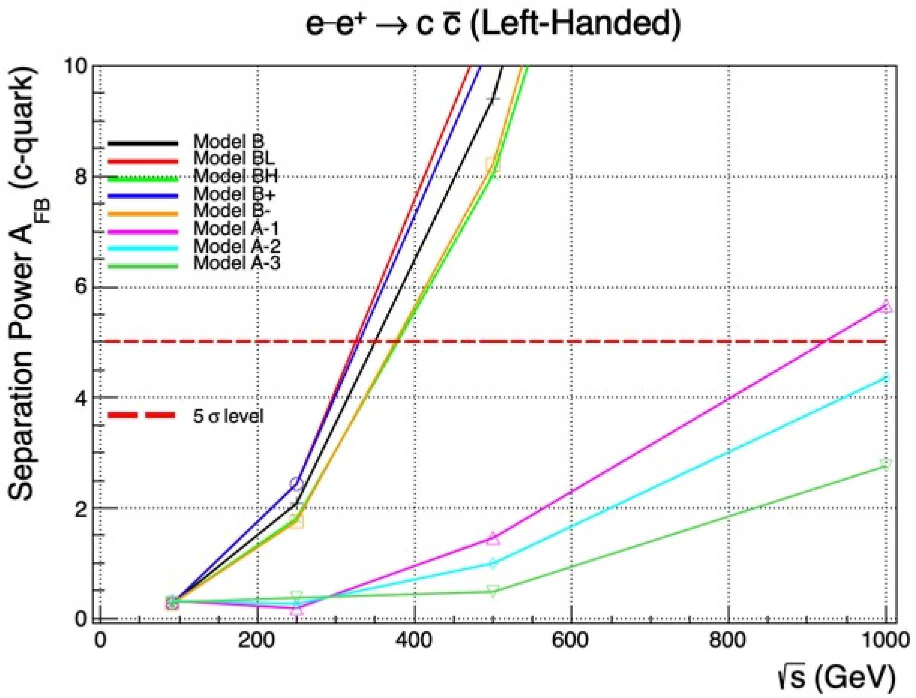
New physics hide in the forward region of the detector

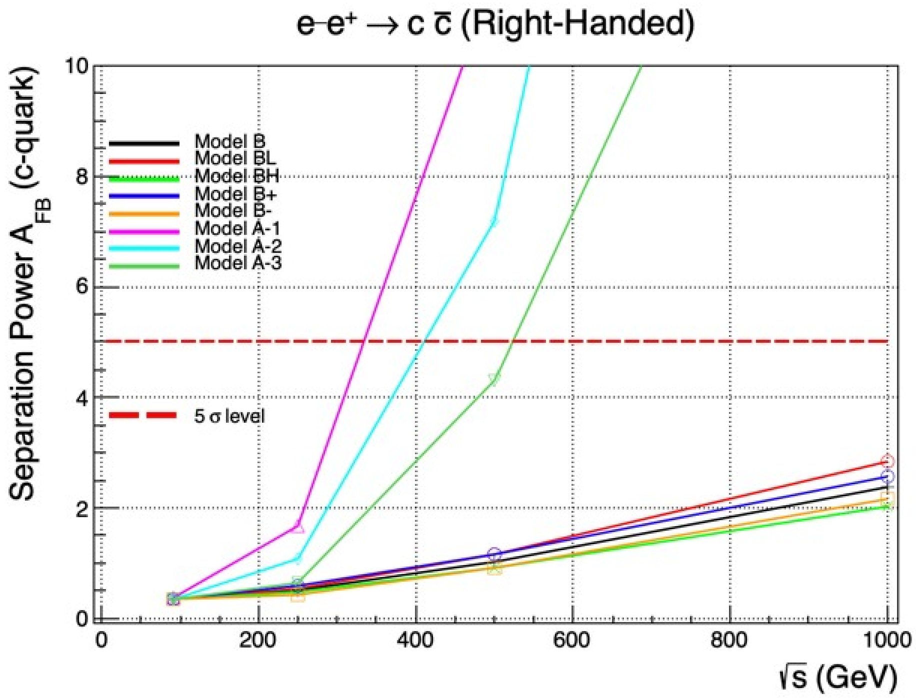
Prospects for b-quark in GHU (A_{FB})





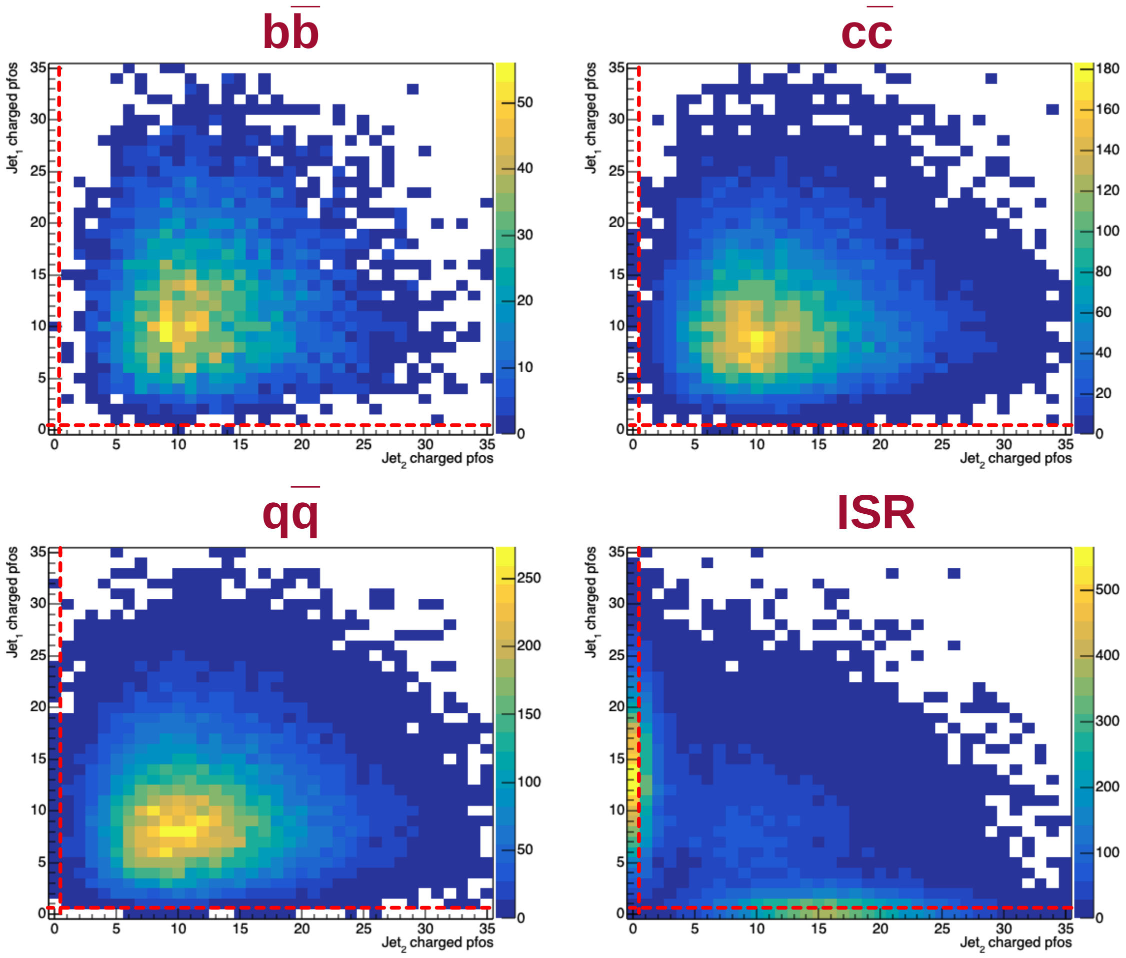
Prospects for c-quark in GHU (A_{FB})





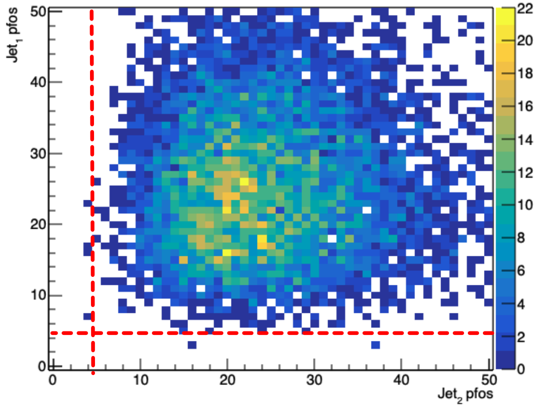
Cut 4 – n charge pfos > 0.5 (eR)

q=u,d,s

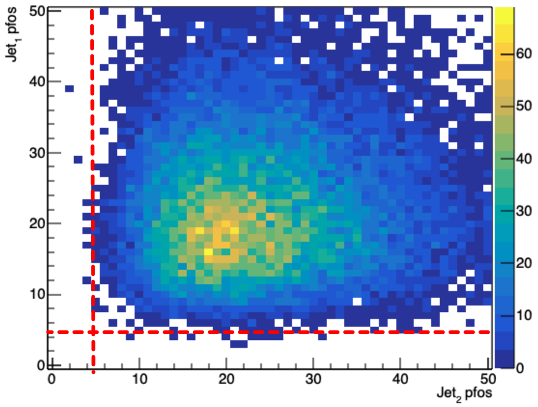


Cut 4 – n neutral pfos > 4.5 (eL)

$b\bar{b}$

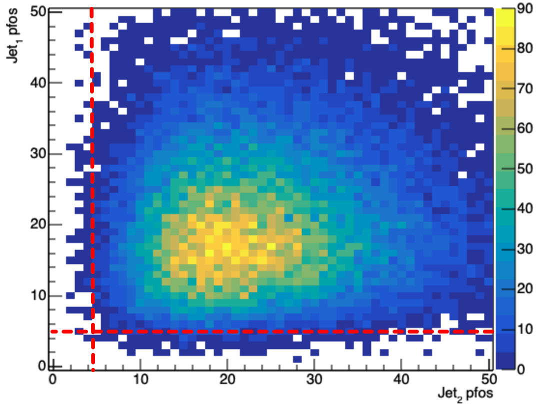


$c\bar{c}$

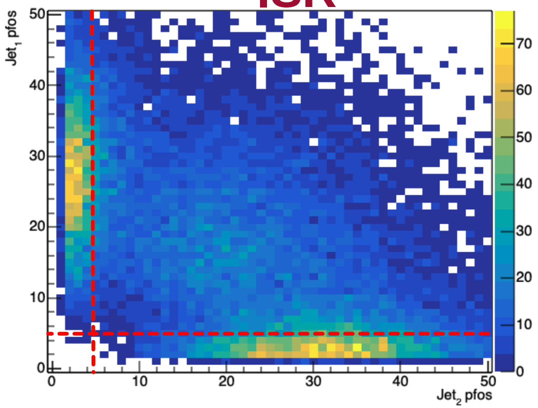


q=u,d,s

$q\bar{q}$



ISR



Optimization of the cuts: VLC algorithm

- Definitions

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

$$d_{iB} = E_i^{2\beta}\sin^{2\gamma}\theta_{iB},$$

- We played with the parameters R and γ:
  - R: (0.5, 0.7, 1.0, 1.3, 1.6)
  - γ : (0.0, 0.5, 1.0)
- We kept β=1

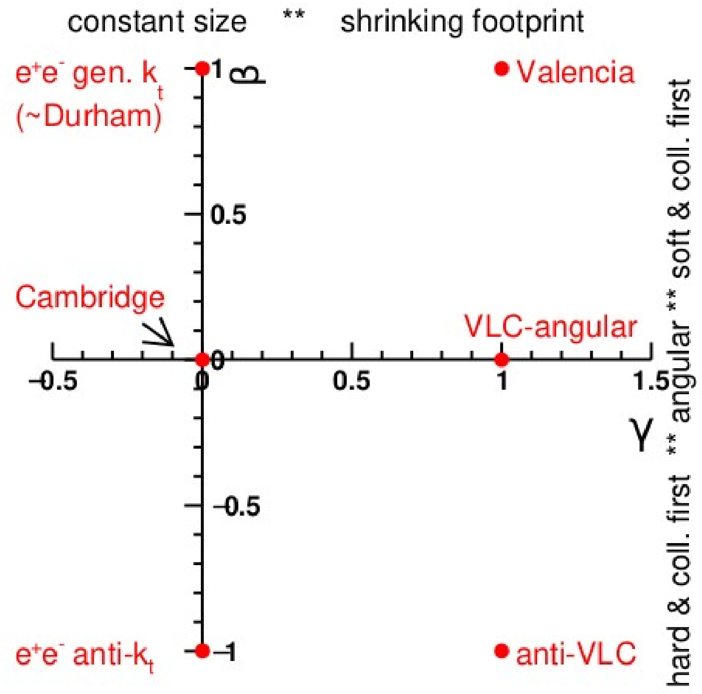
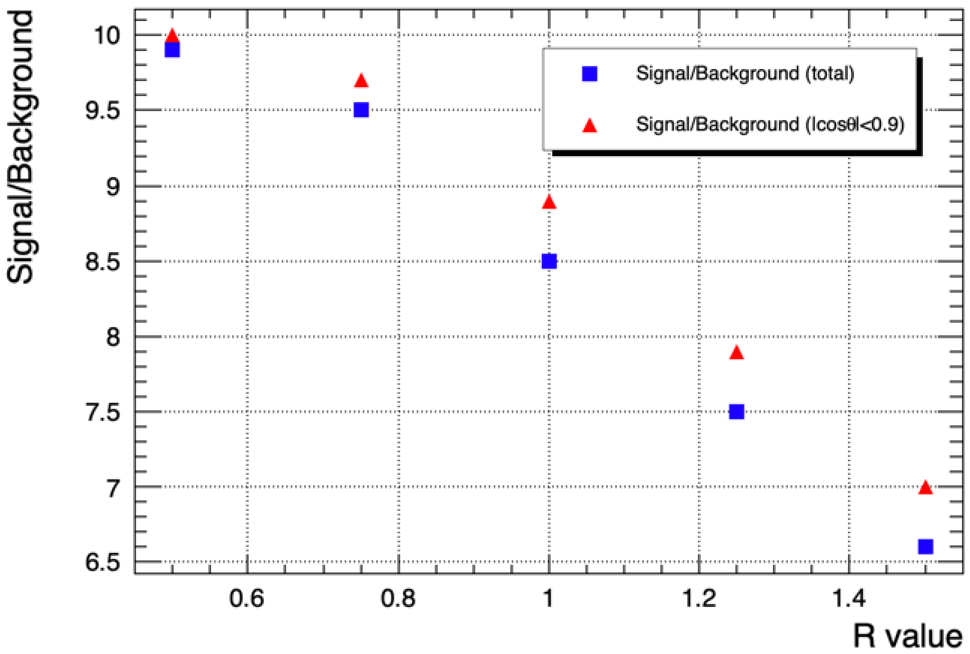


Diagram of the parameter space spanned by exponents γ and β. [1]

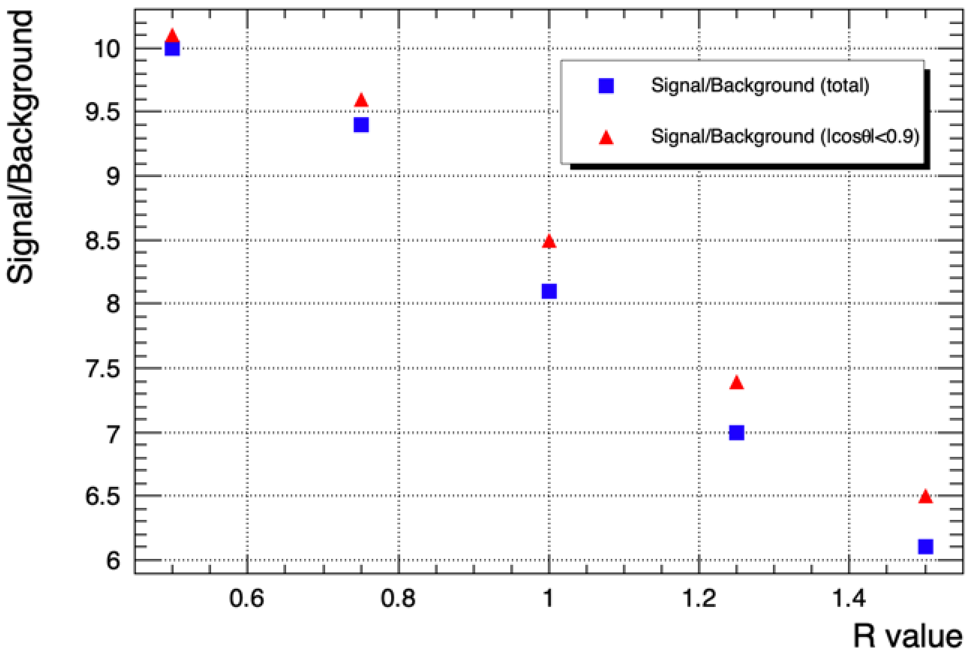
[1] M. Boronat et al. (arXiv:1607.05039)

VLC Algorithm optimization - R (*S/B*)

eL

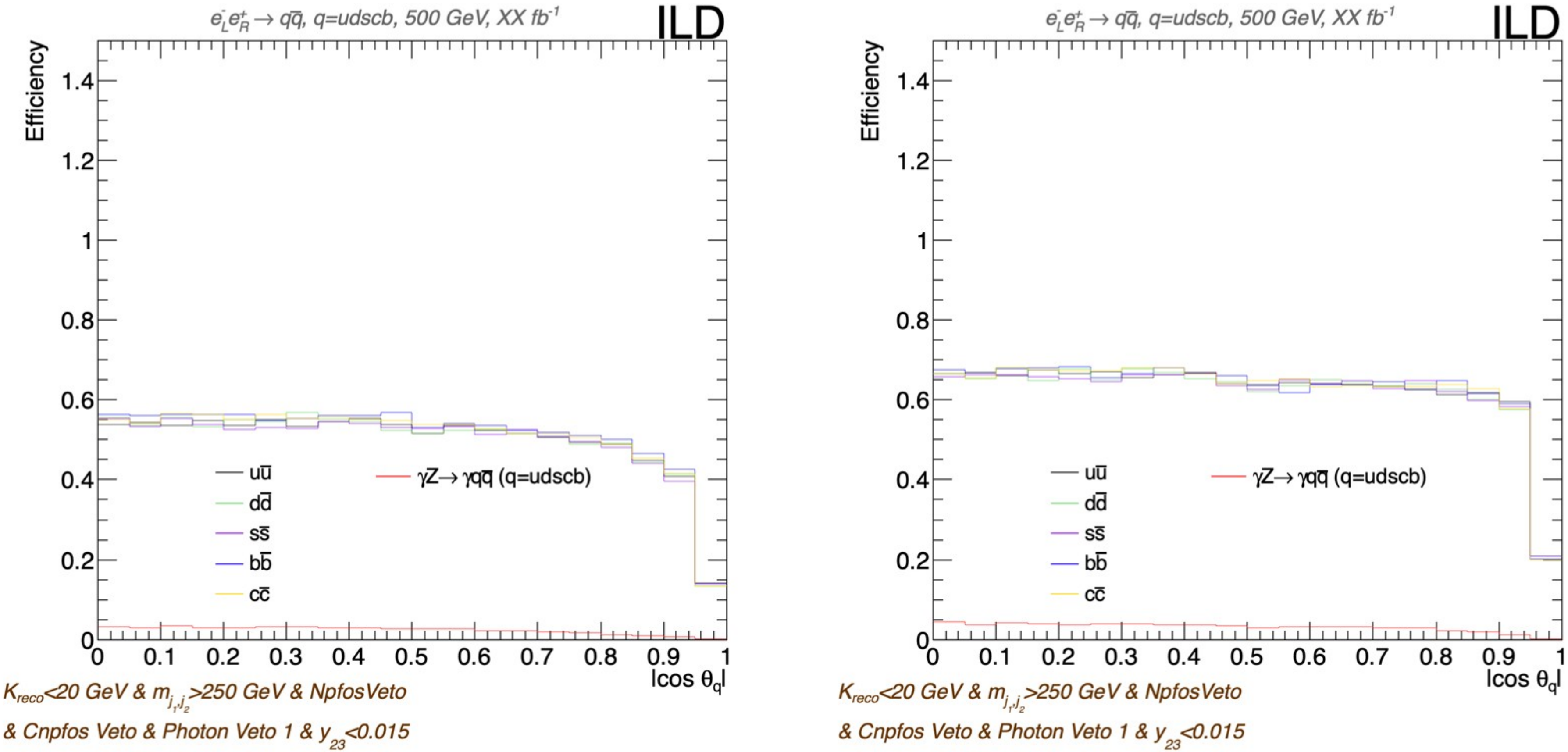


eR



VLC Algorithm optimization – R (angular)

- Some angular effects appear as we lower R. Plots for R=0.5 and 1.0 in the left-handed case:



VLC Algorithm optimization – ɣ (angular)

- Some angular effects appear as we increase ɣ. Plots for ɣ=0 and 1.0 in the left-handed case: