AFB studies at 500 GeV

ILD Top/HF group meeting 20/12/21

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Observables for BSM studies

- Forward-backward asymmetry:

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

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

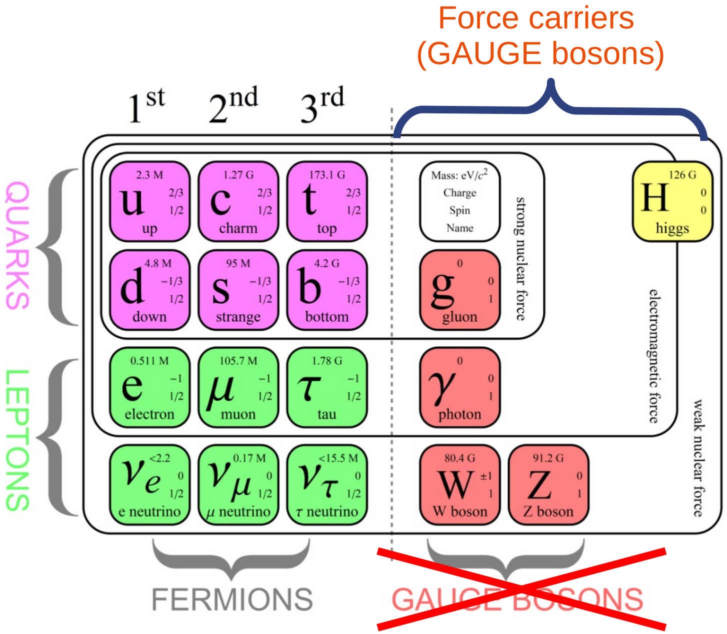
$$N = L \cdot \sigma \cdot \epsilon$$

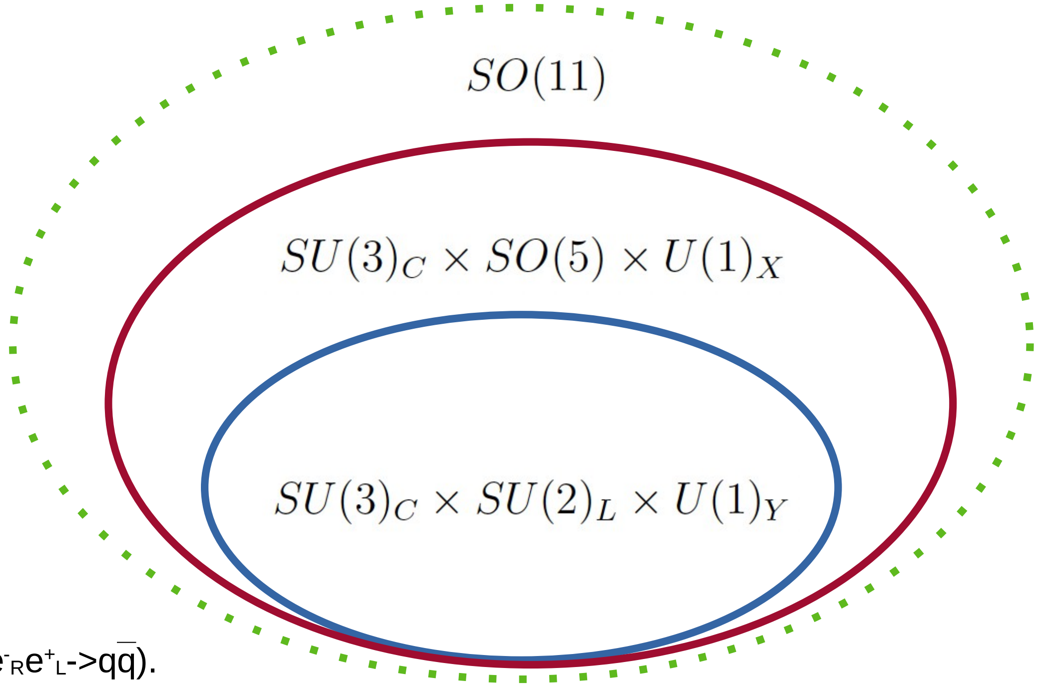
- Experimental definition:
  - Reduce bias from systematic errors from the luminosity and efficiency w.r.t. the cross-section observable

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

Gauge-Higgs Unification (GHU) Models

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



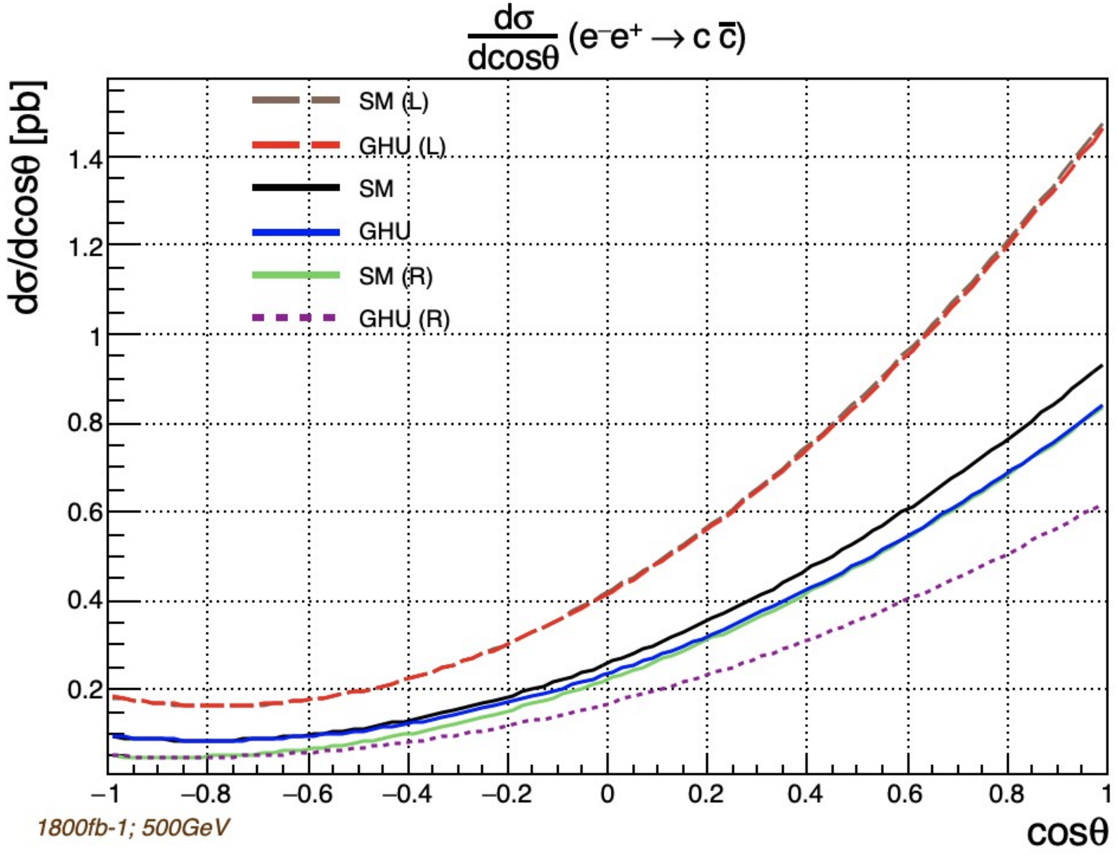


- A-Models[1]: Stronger deviations in the right-handed case ($e^-_R e^+_L \to q\bar{q}$).
- B-Models[2]: Stronger deviations in the left-handed case ($e^-_L e^+_R \to q\bar{q}$).
  - The gauge group of GHU is also related to Grand Unification Theory (GUT), embedded in the SO(11) group.

[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

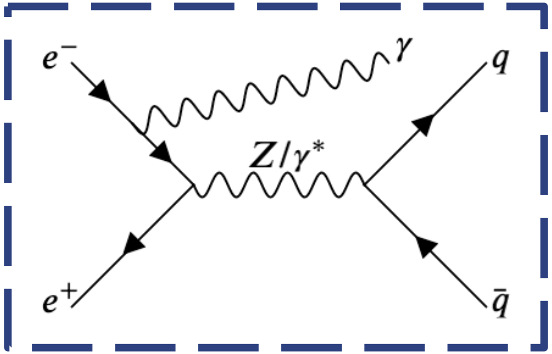
- A-Model cross-section deviation examples (c-quark) 500 GeV:

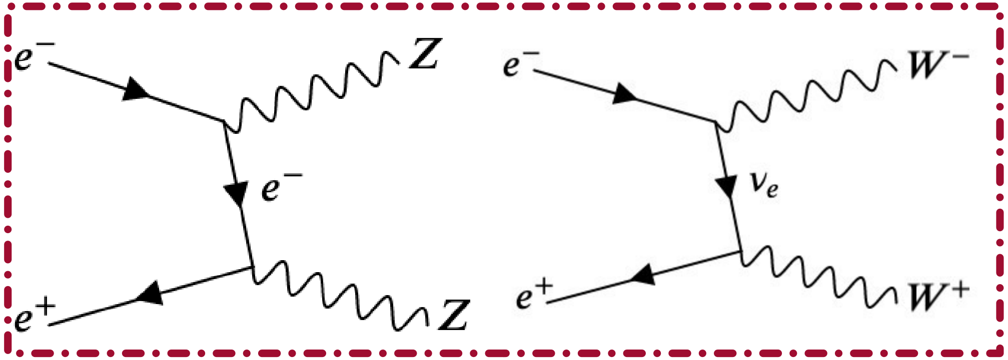


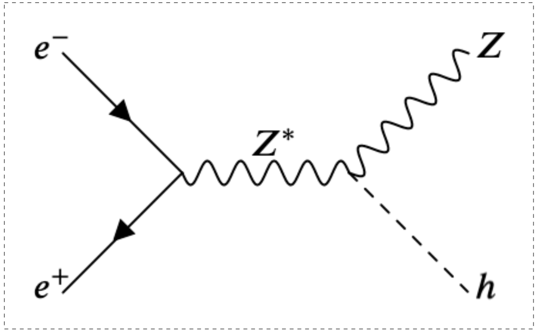
New physics hide in the forward region of the detector

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







Preselection for 250 GeV

Cuts:

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

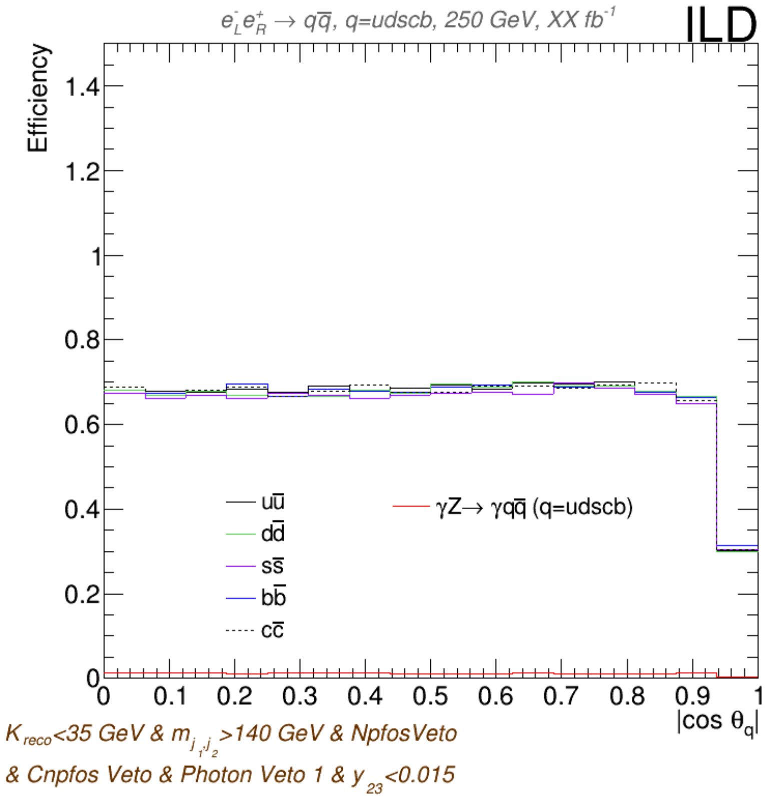
VLC Algorithm parameters:

- 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



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

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

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

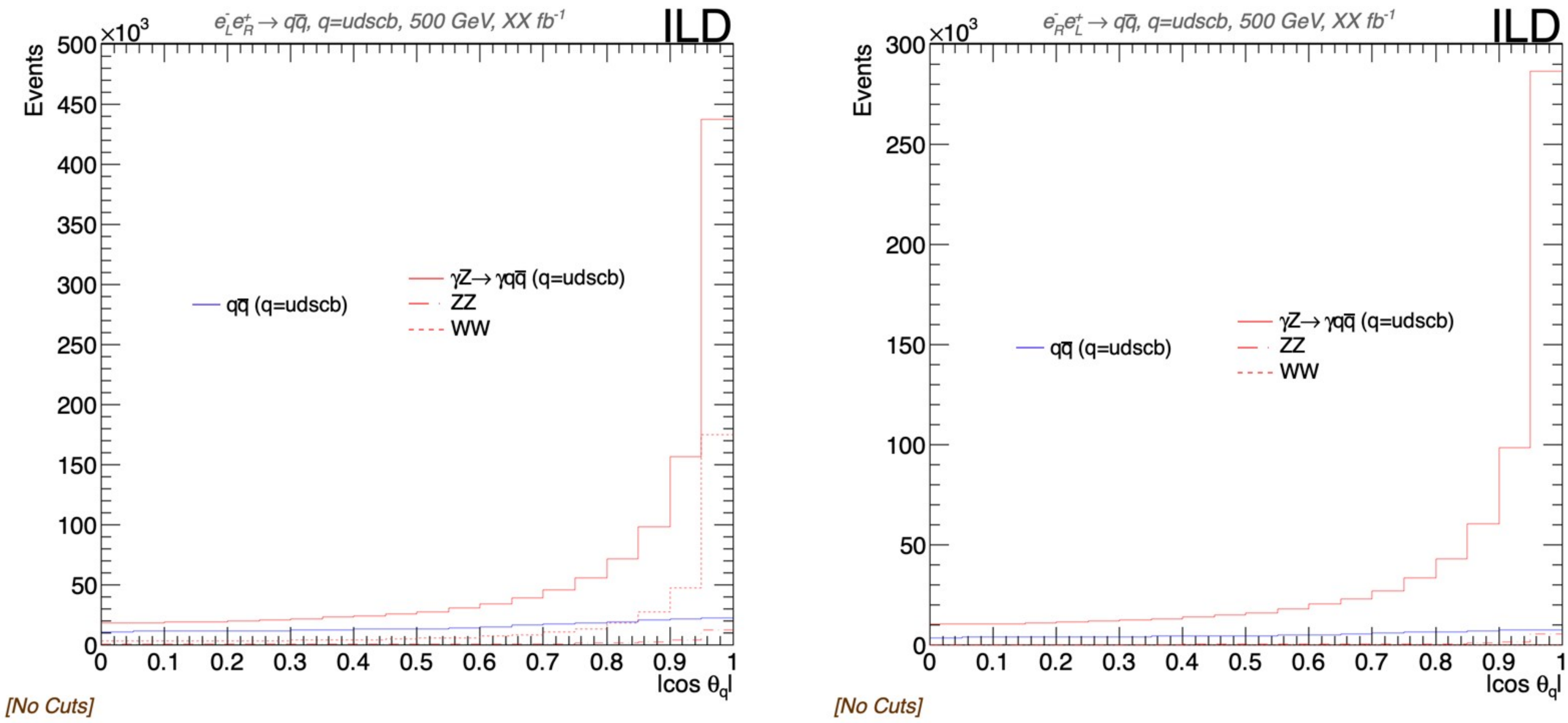
$e_R p_L$

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)



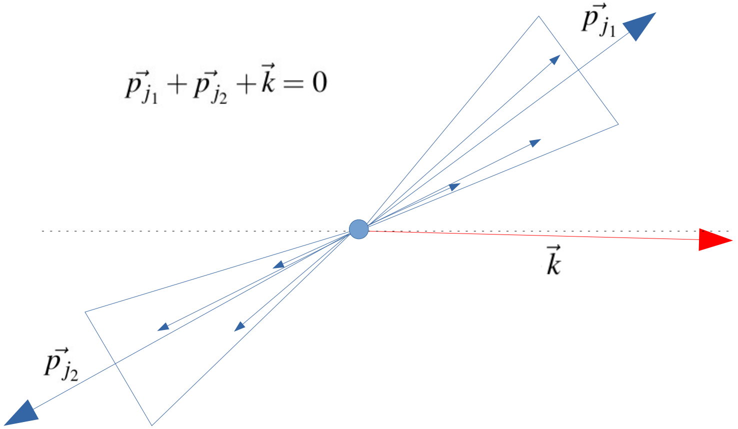
Optimization of the cuts: K_{reco}

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

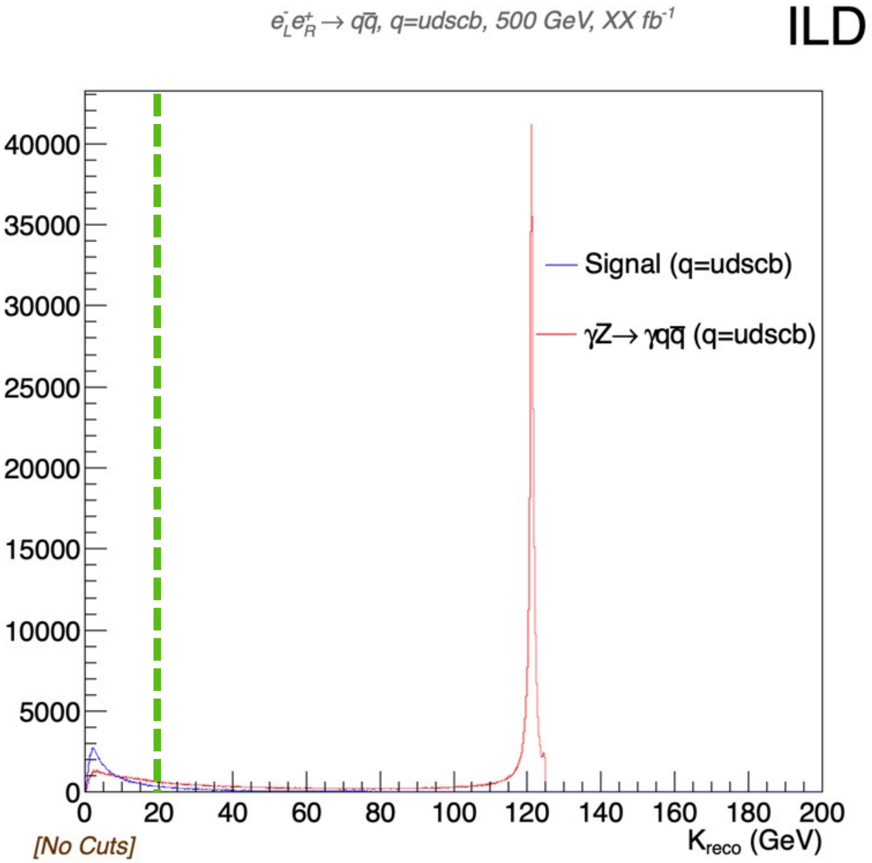
$$|\vec{k}| \approx K_{reco} = \frac{250\,\text{GeV} \cdot \sin\Psi_{acol}}{\sin\Psi_{acol} + sin\theta_1 + sin\theta_2}$$

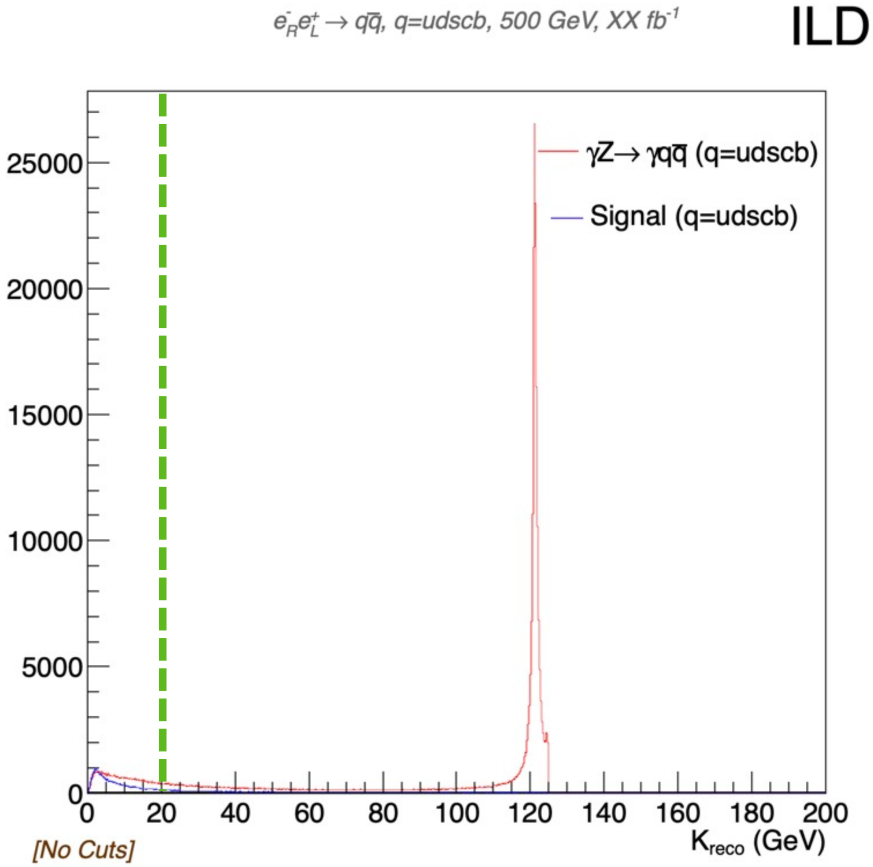


Kinematics of a two jets system reconstruction with ISR

Cut 1 (K_{reco} < 20)

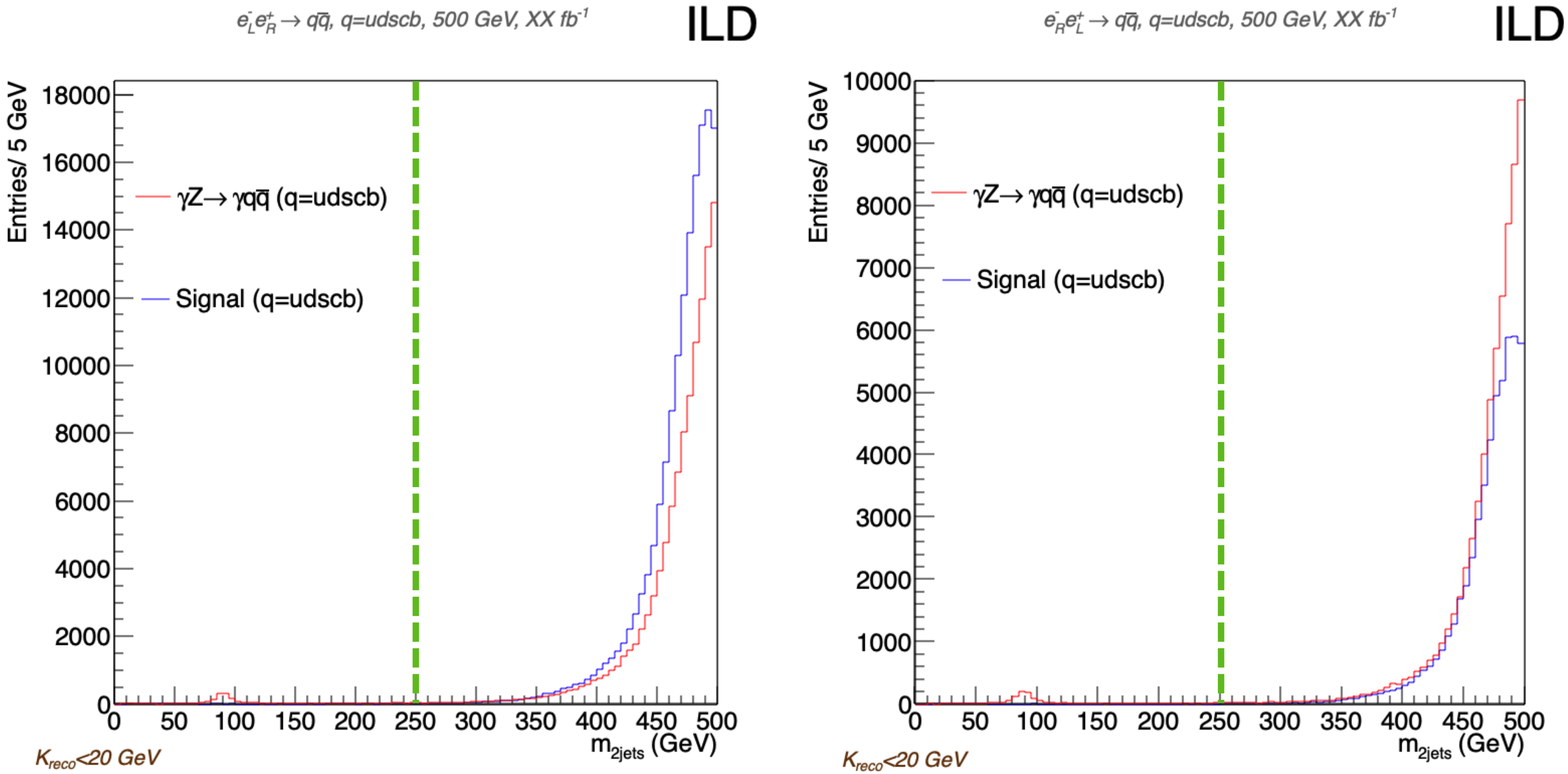
•





Cut2 mjj > 250

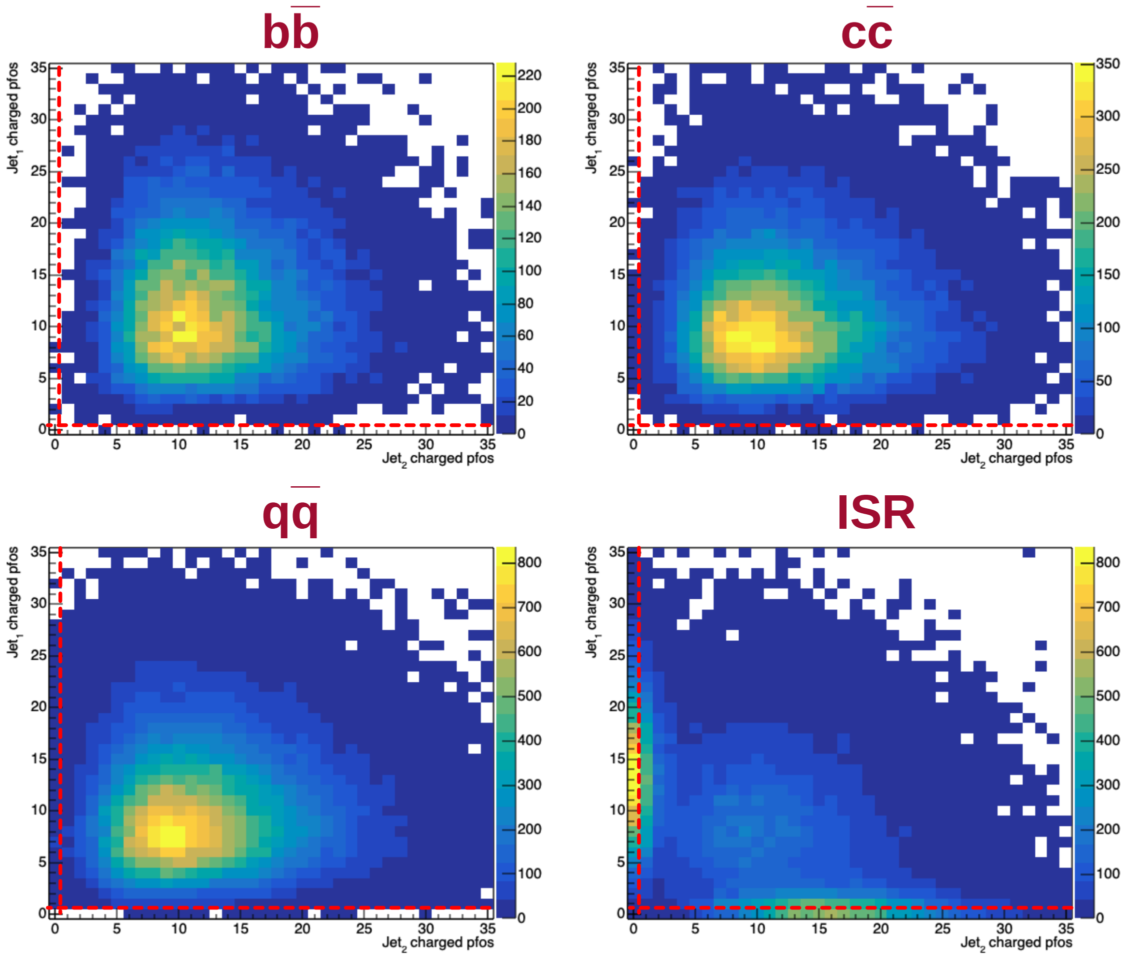
- .



$e^-_L e^+_R \to q\bar{q}$, 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

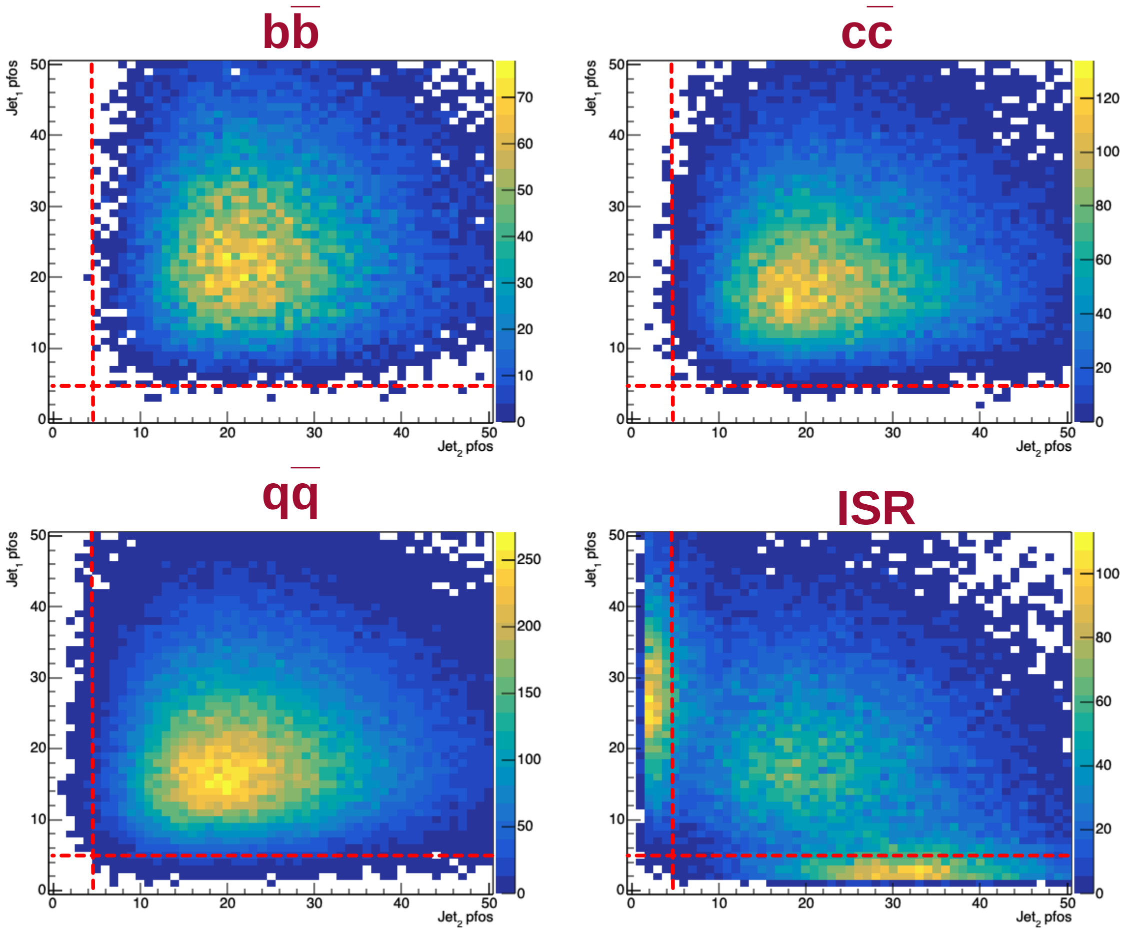
Cut 3 – n charge pfos > 0.5 ($e_L p_R$)

q=u,d,s

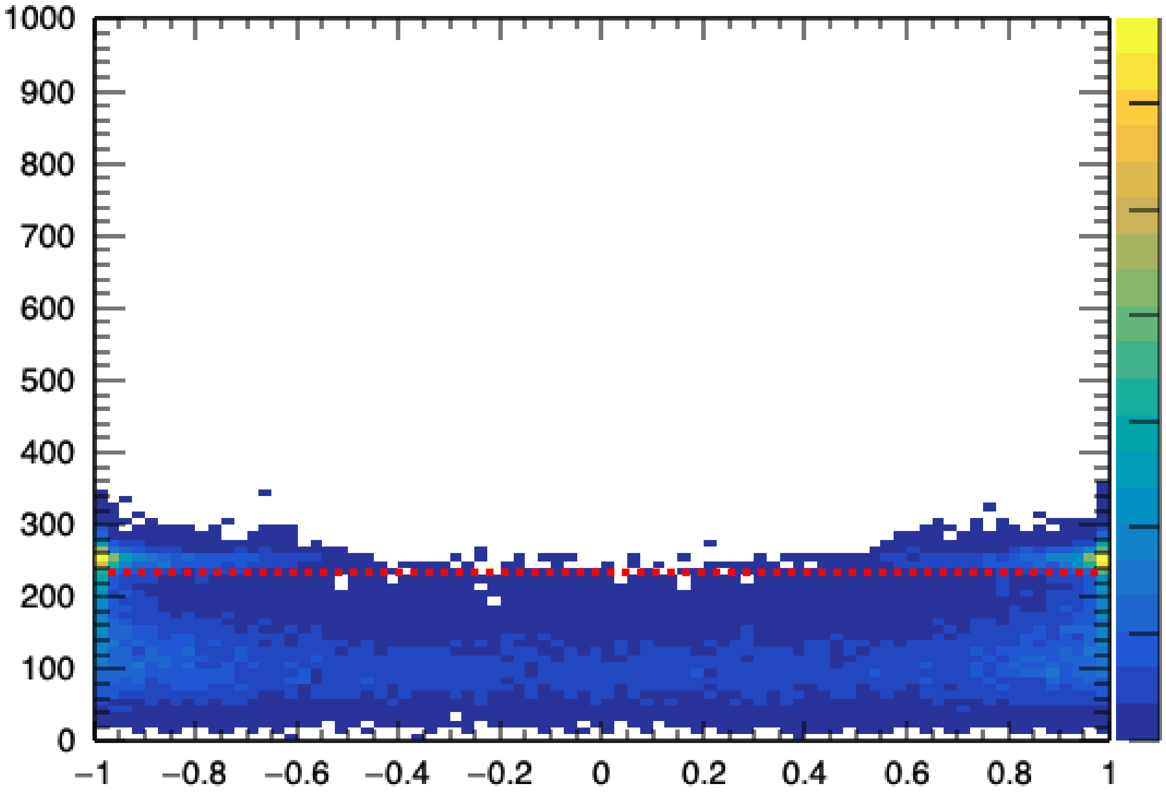


Cut 4 – n neutral pfos > 4.5 ($e_L p_R$)

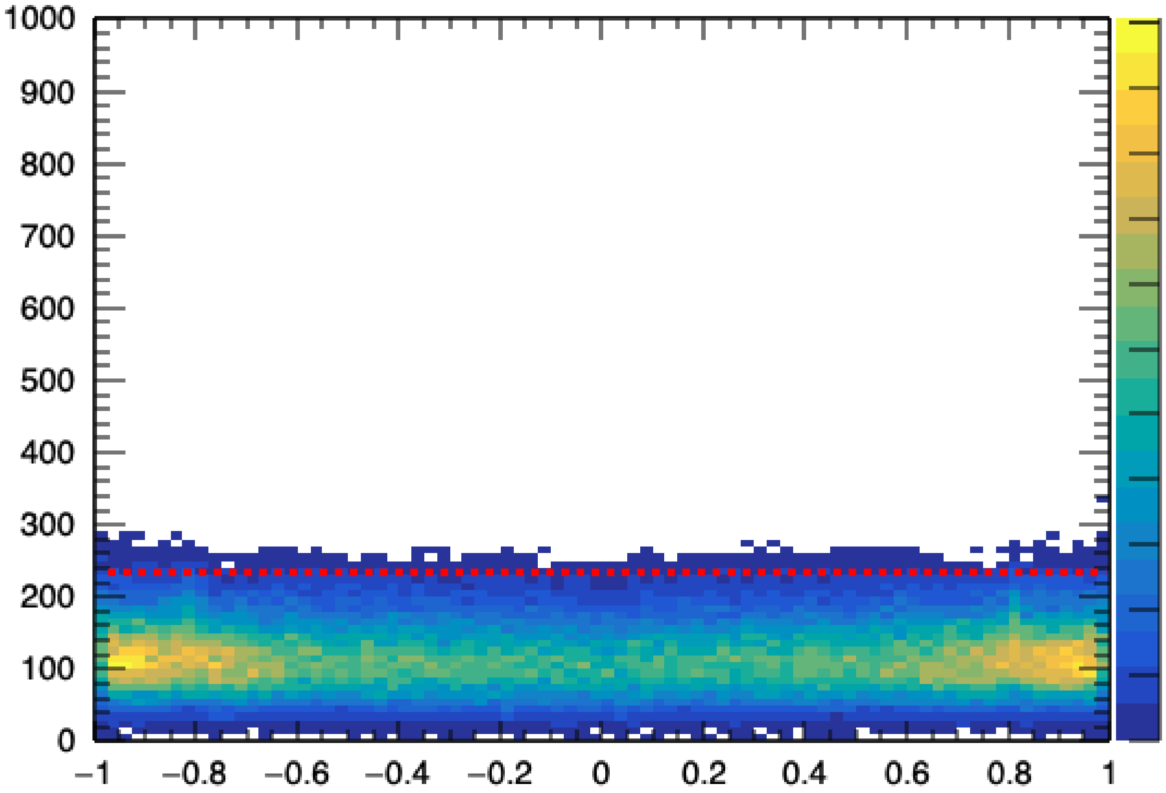
q=u,d,s



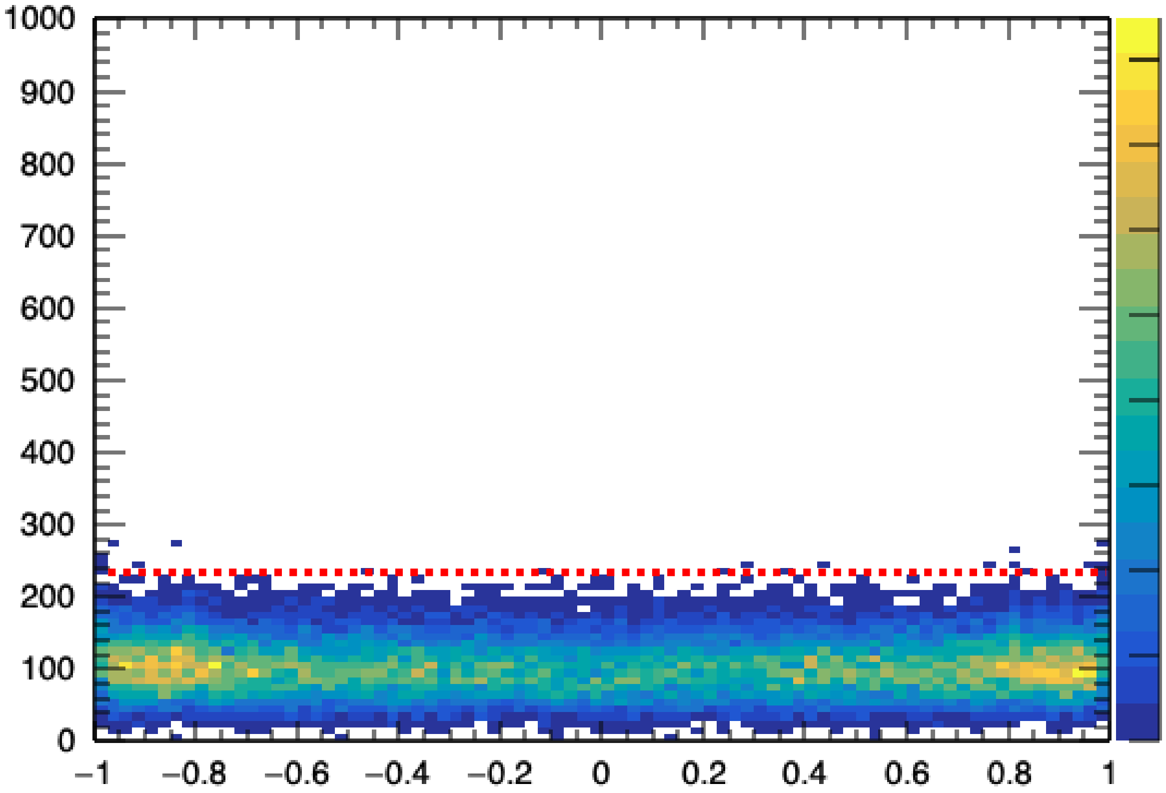
Cut 5 – photon veto ($e_L p_R$)-ISR



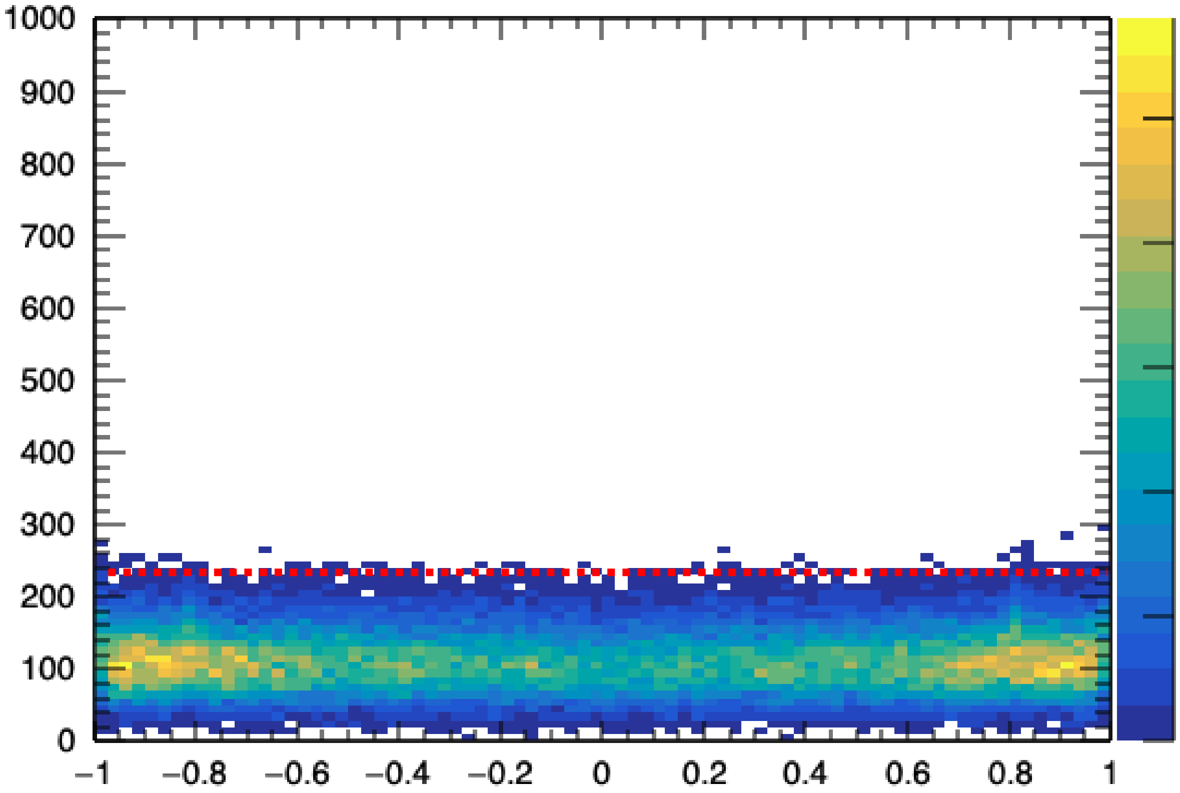
Cut 5 – photon veto ($e_L p_R$)-$q\bar{q}$



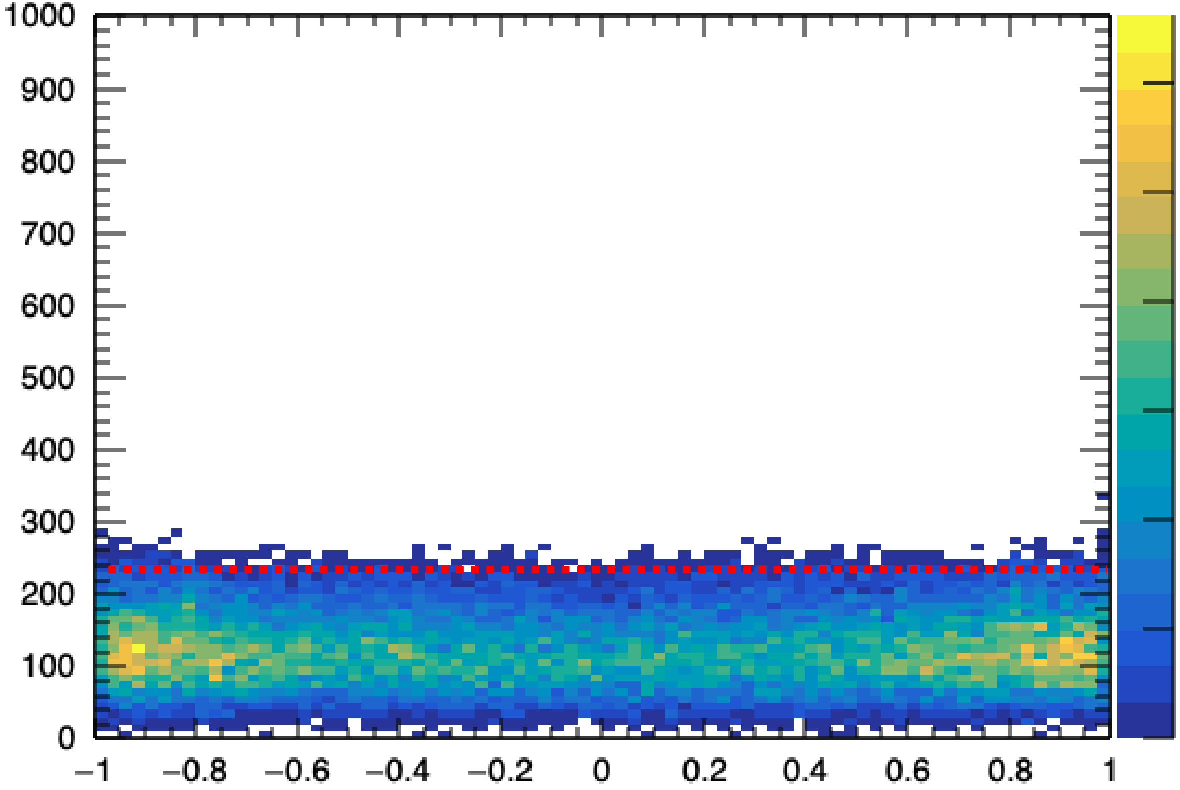
Cut 5 – photon veto ($e_L p_R$)-$b\bar{b}$



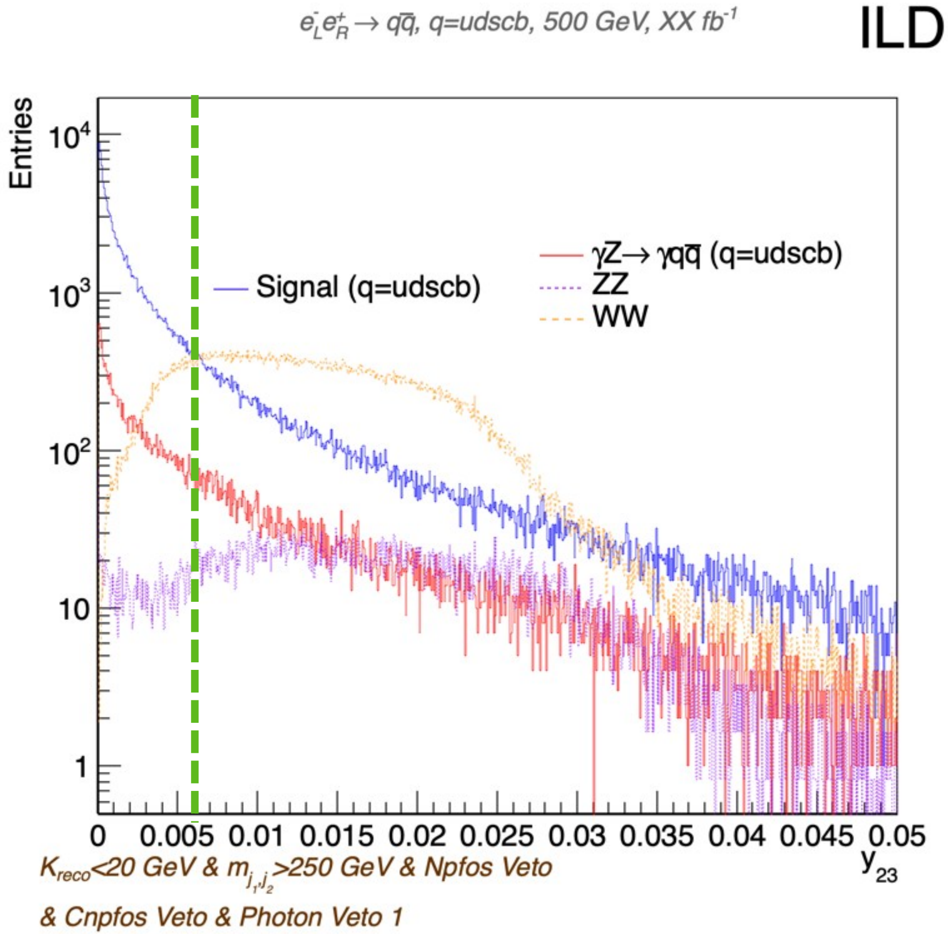
Cut 5 – photon veto ($e_L p_R$)-$c\bar{c}$



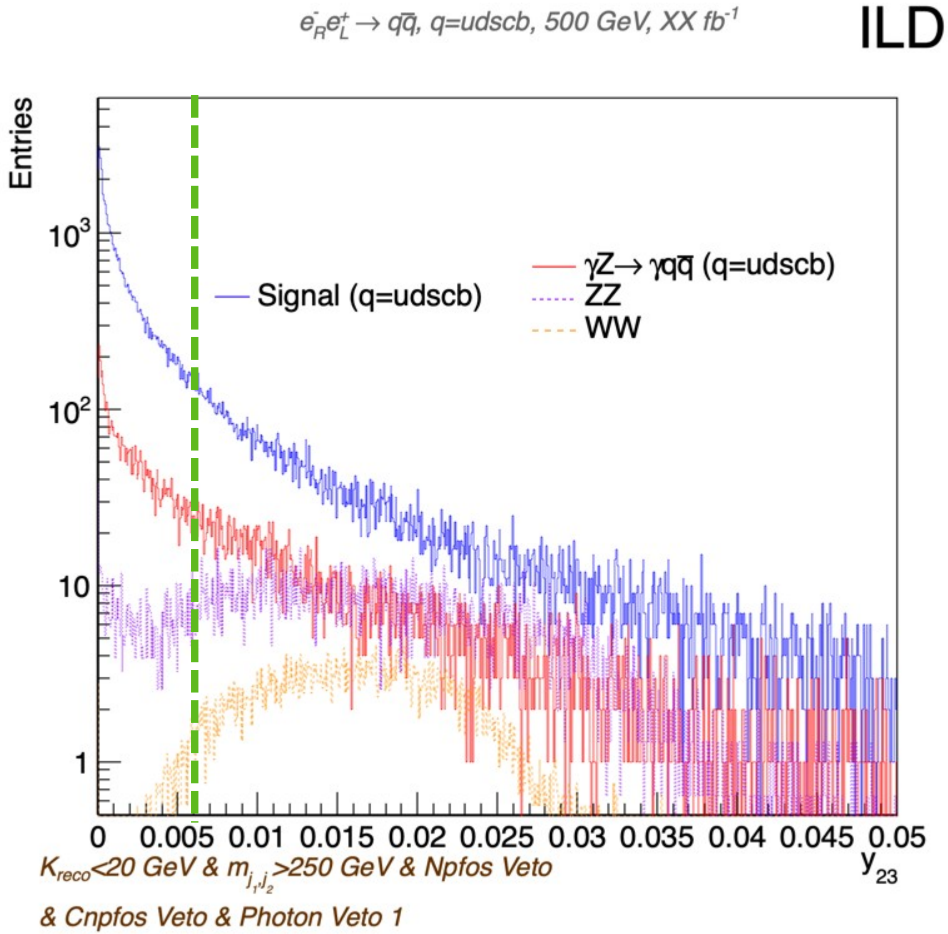
Cut 5 – photon veto ($e_L p_R$)-$s\bar{s}$



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
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

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)

$e_L p_R$

	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!

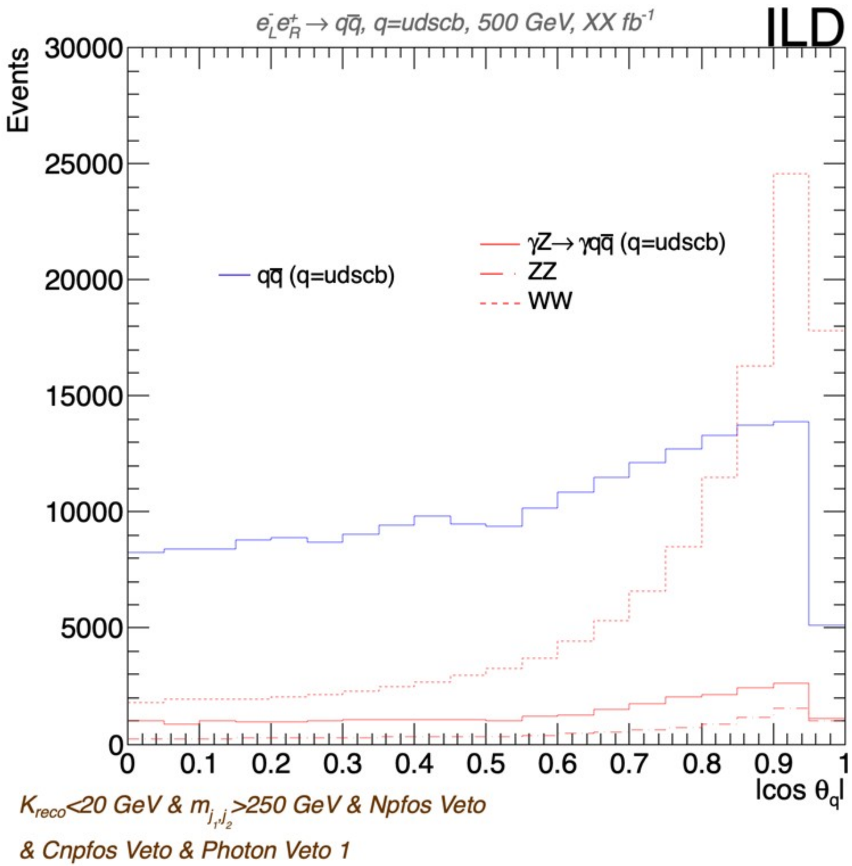
Too high!

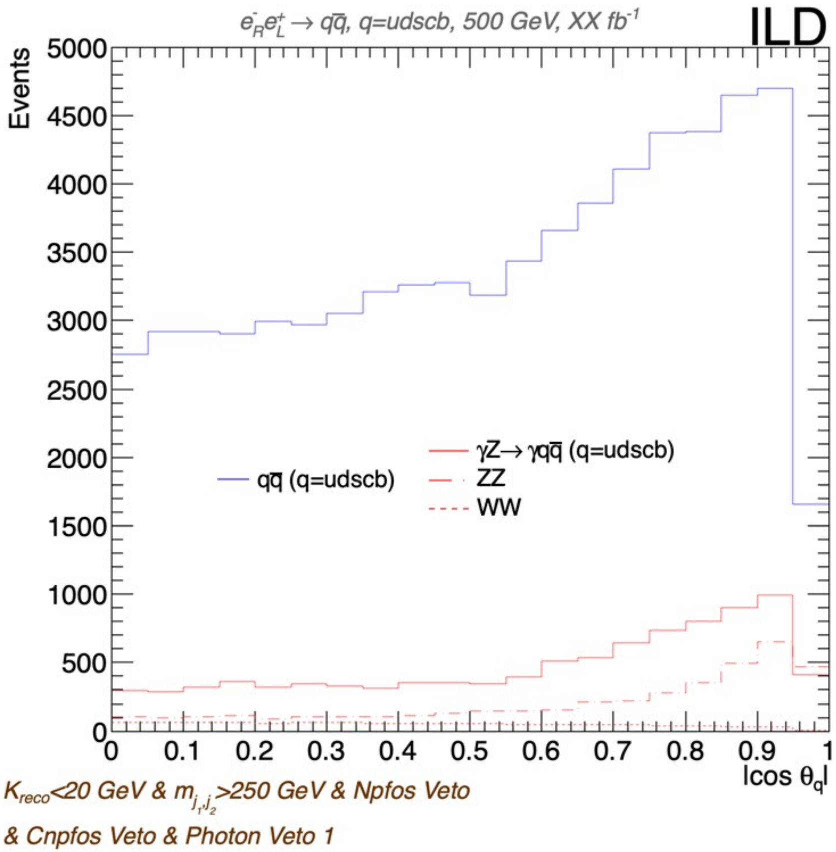
$e_R p_L$

	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

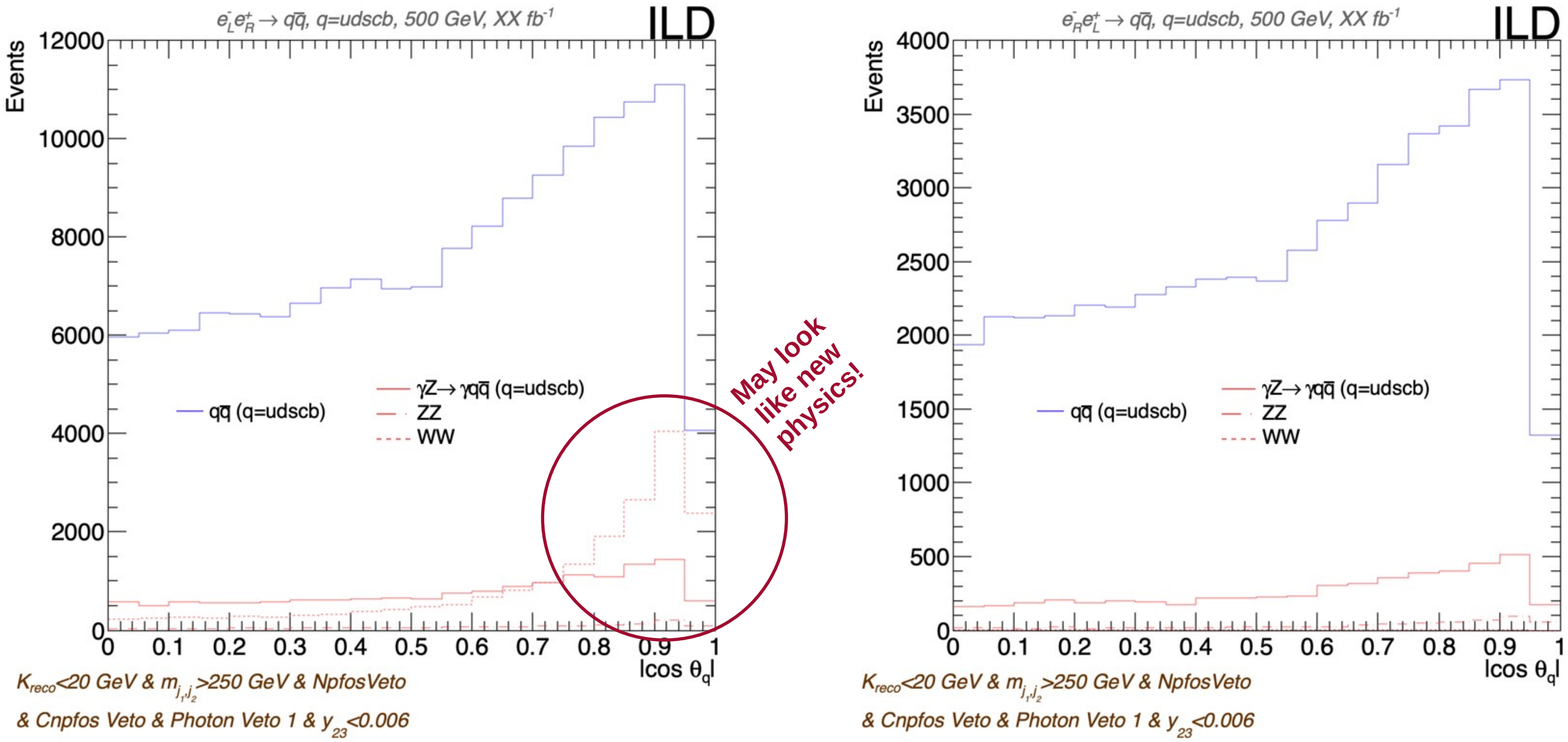
X2 than at 250 GeV!

Overview (Angular profile – Cut 5)

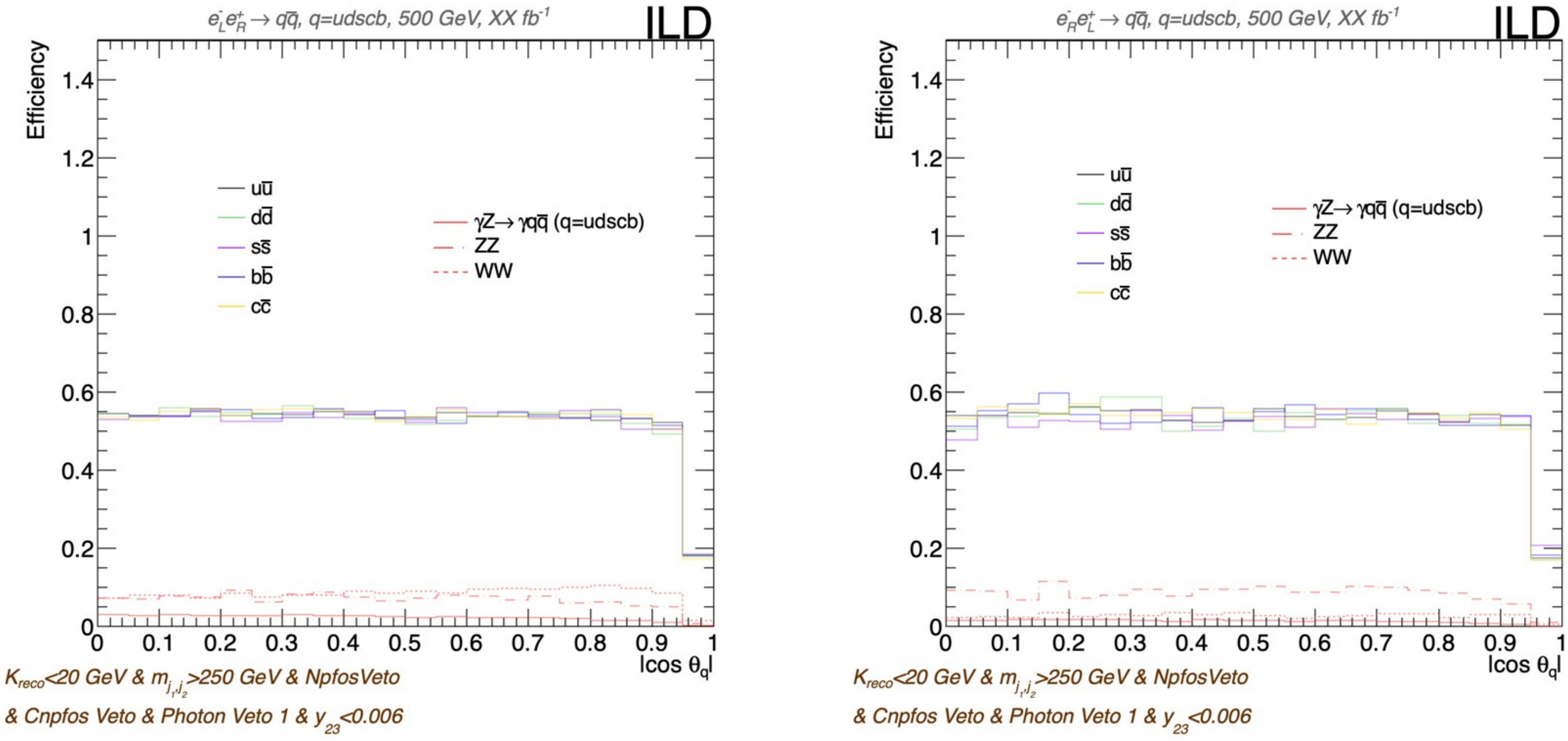




Overview (Angular profile – Cut 6)



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.

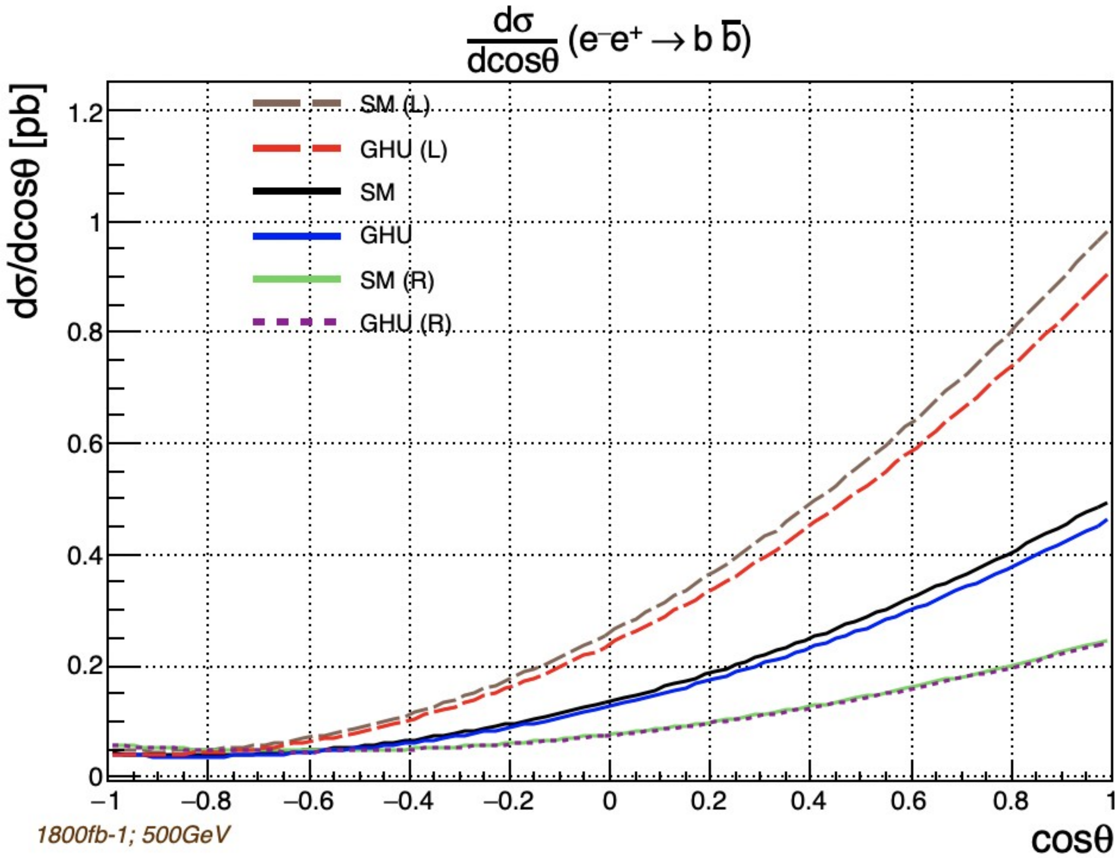
- After the preselection process finishes -> Flavour tagging at 500 GeV.

- 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

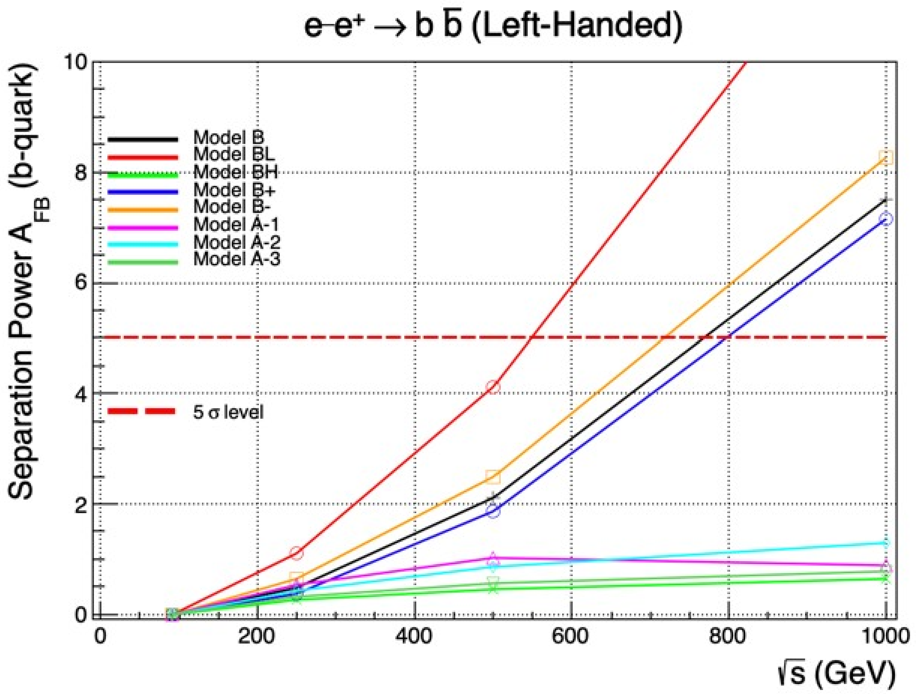
Gauge-Higgs Unification (GHU) Models

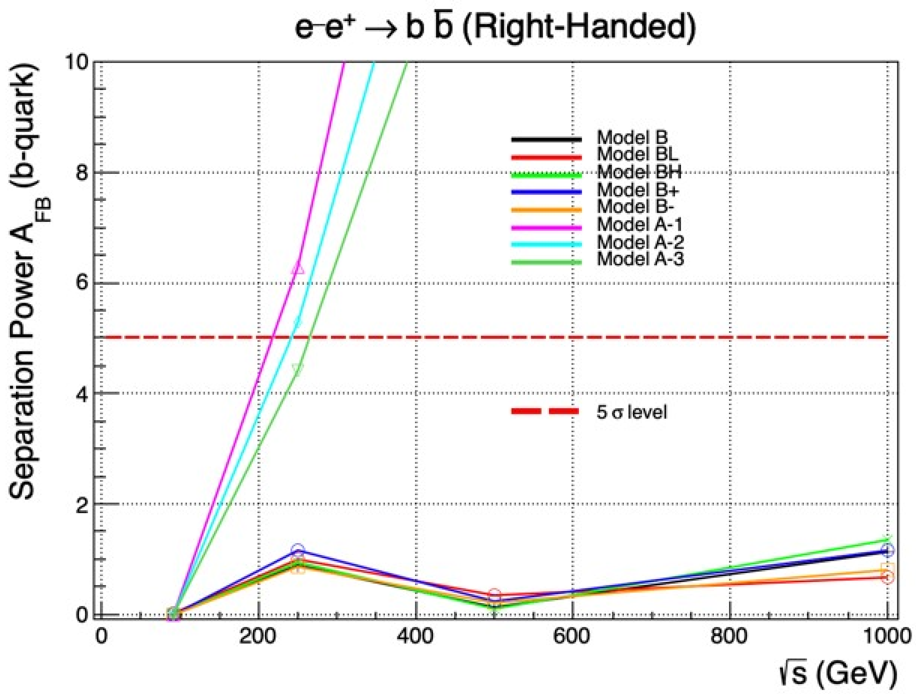
- B-Model cross-section deviation examples (b-quark) 500 GeV:



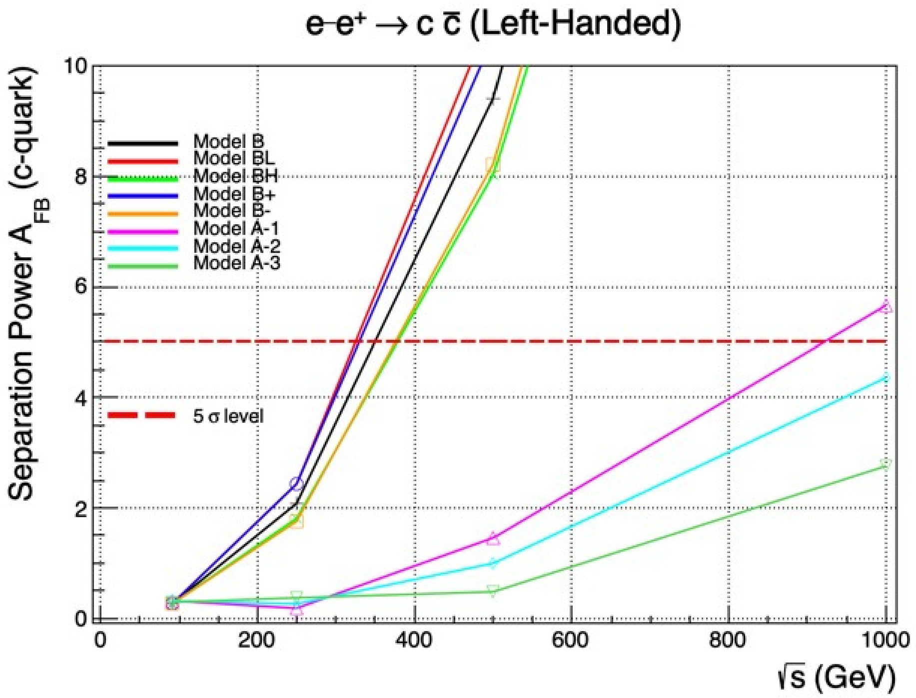
New physics hide in the forward region of the detector

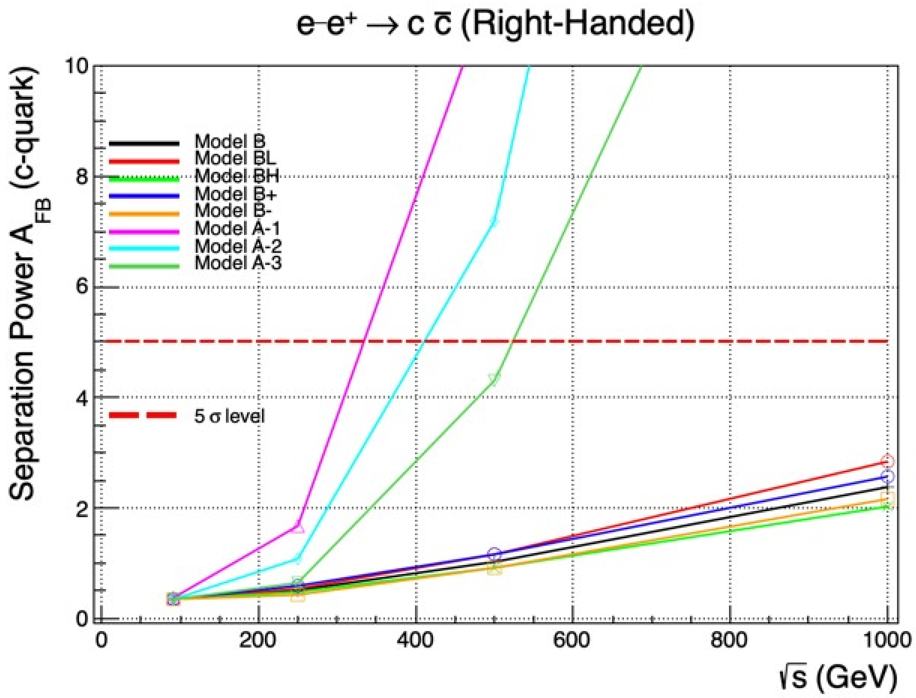
Prospects for b-quark in GHU (A_{FB})





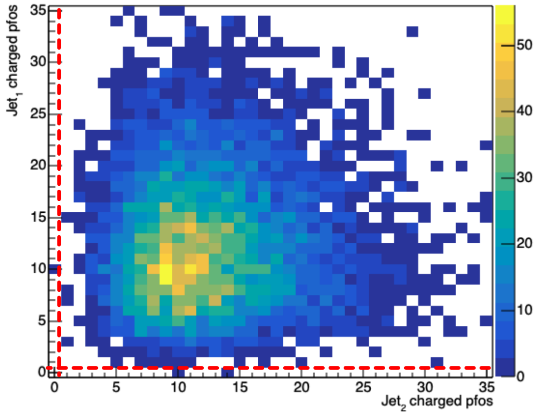
Prospects for c-quark in GHU (A_{FB})



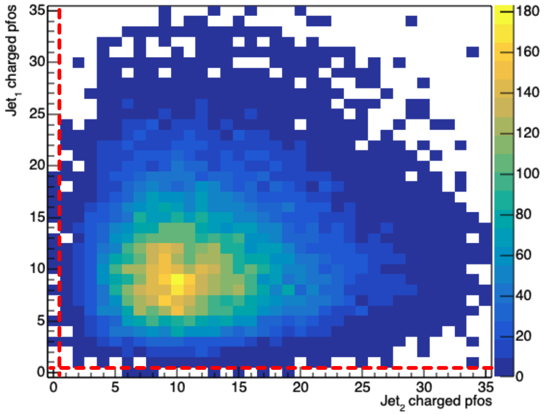


Cut 4 – n charge pfos > 0.5 (eR)

$b\bar{b}$

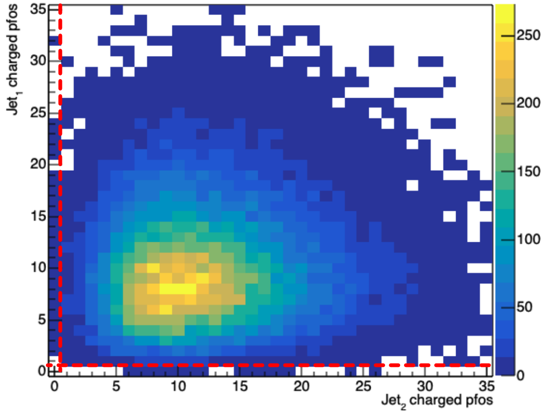


$c\bar{c}$

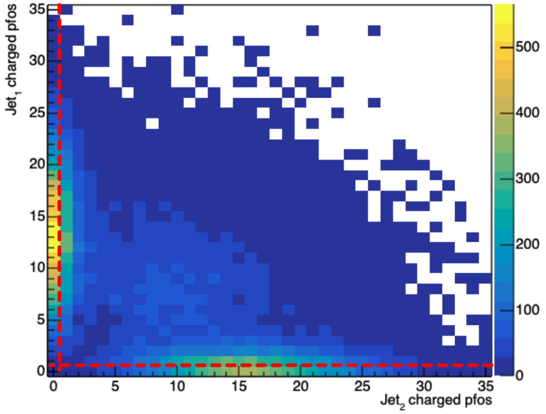


q=u,d,s

$q\bar{q}$

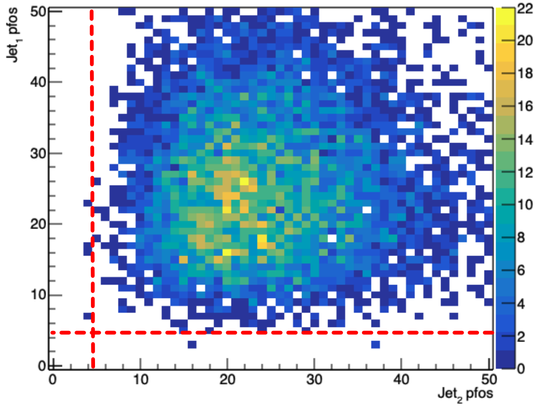


ISR

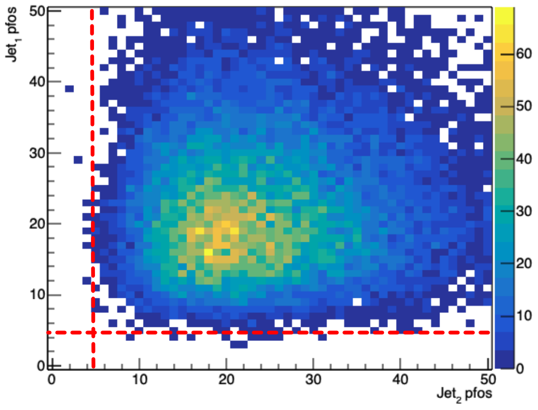


Cut 4 – n neutral pfos > 4.5 (eL)

$b\bar{b}$

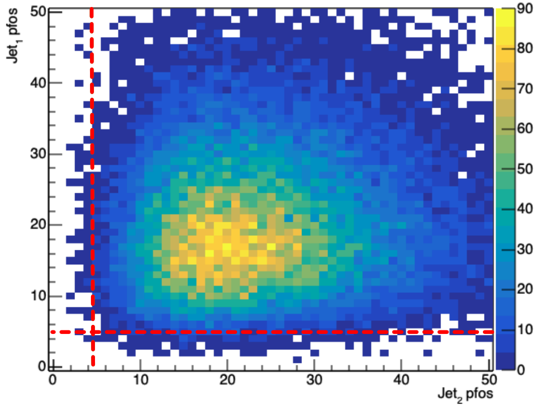


$c\bar{c}$

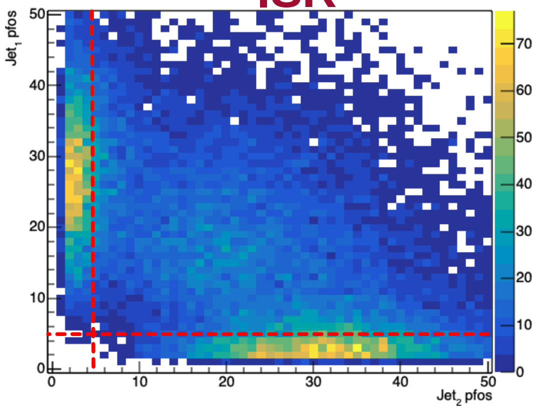


q=u,d,s

$q\bar{q}$



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

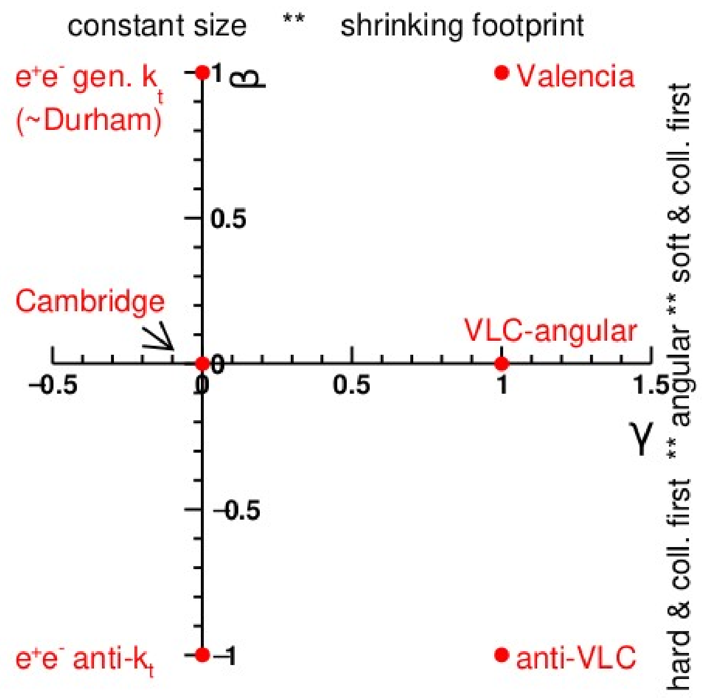
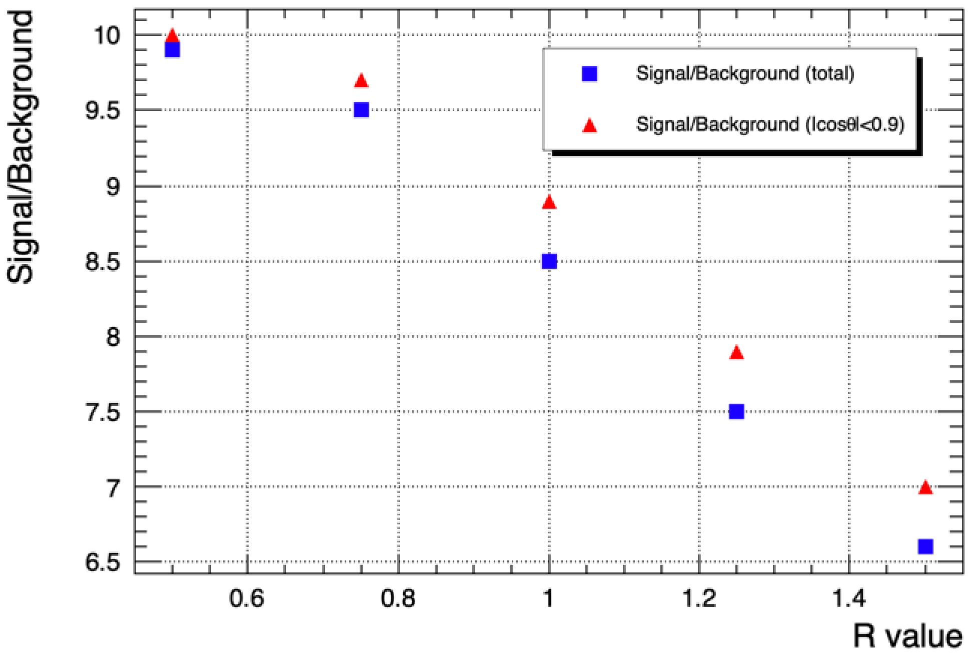


Diagram of the parameter space spanned by exponents γ and β. [1]

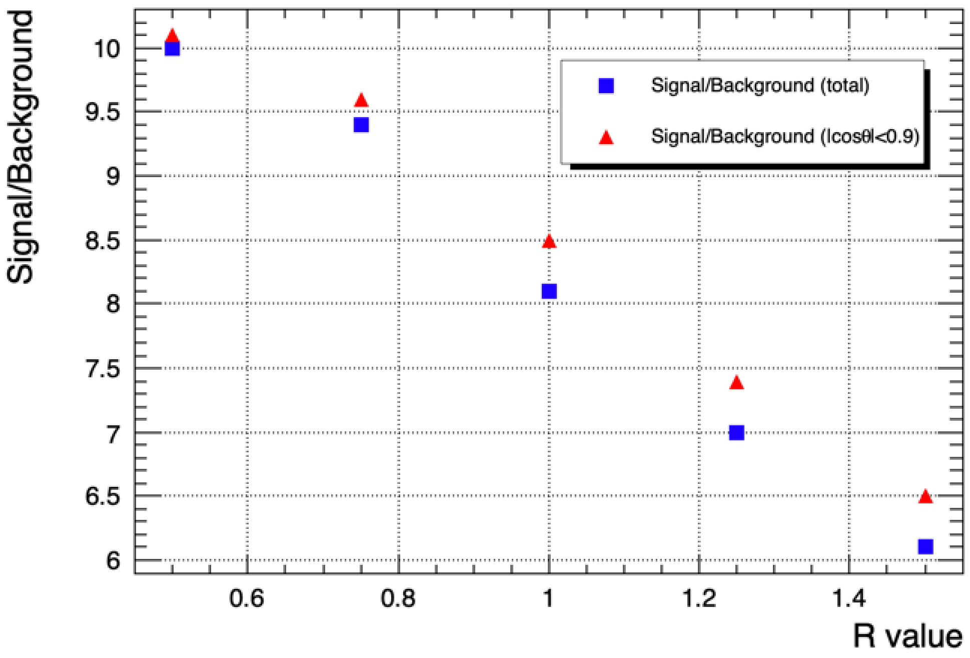
[1] M. Boronat et al. (arXiv:1607.05039)

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

e_L

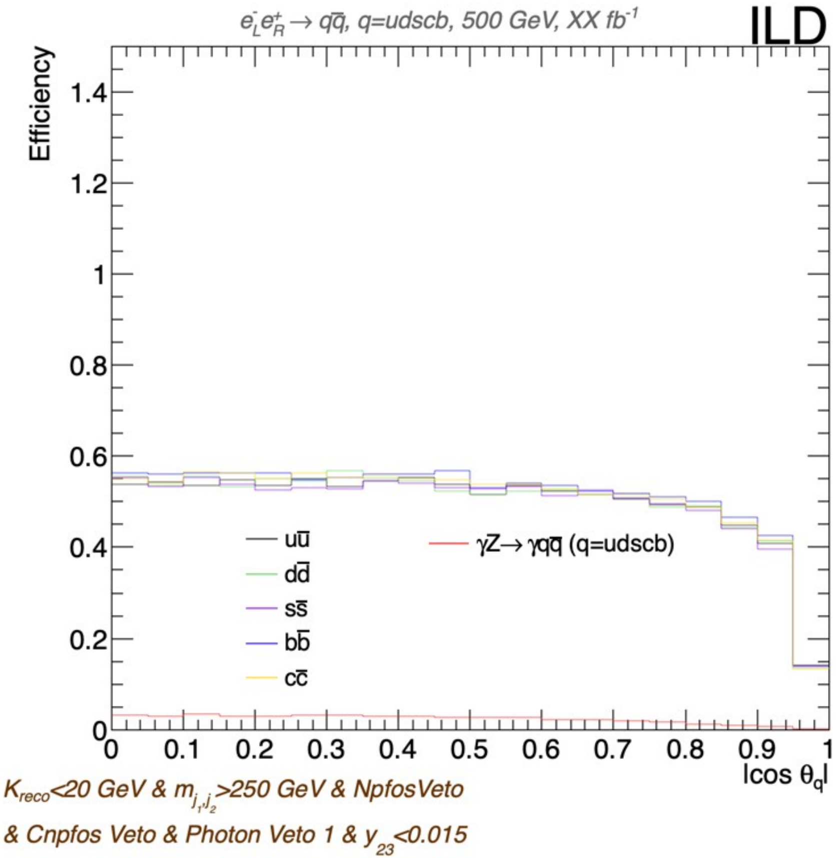


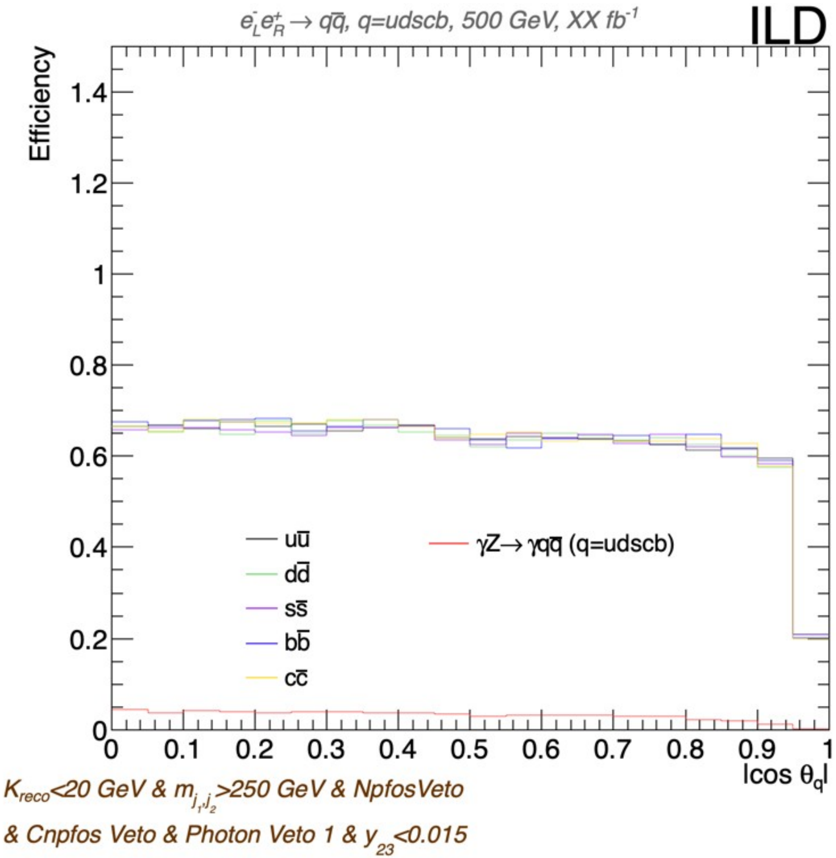
e_R



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: