Strange Quark as a Probe for new physics in the Higgs sector

So far, only Higgs Boson couplings to the 3rd generation demonstrated…
Is Yukawa coupling really universal between families?
Could current flavour anomalies have origin in the Higgs sector?

Snowmass 2021 - EF01 Meeting - Jan 12th, 2022

CERN

Valentina Maria Martina Cairo & Matthew Basso

LoI for Snowmass 2021

- ***Strange Quark as a probe for new physics in the Higgs Sector***

  - Study **Higgs** boson couplings to light quarks, in particular to the **strange quark**
    - Very rare in the SM
      - $BR(H \to s\bar{s}) \cong 10^{-4}$
    - Powerful channel to investigate the big questions in the previous page!

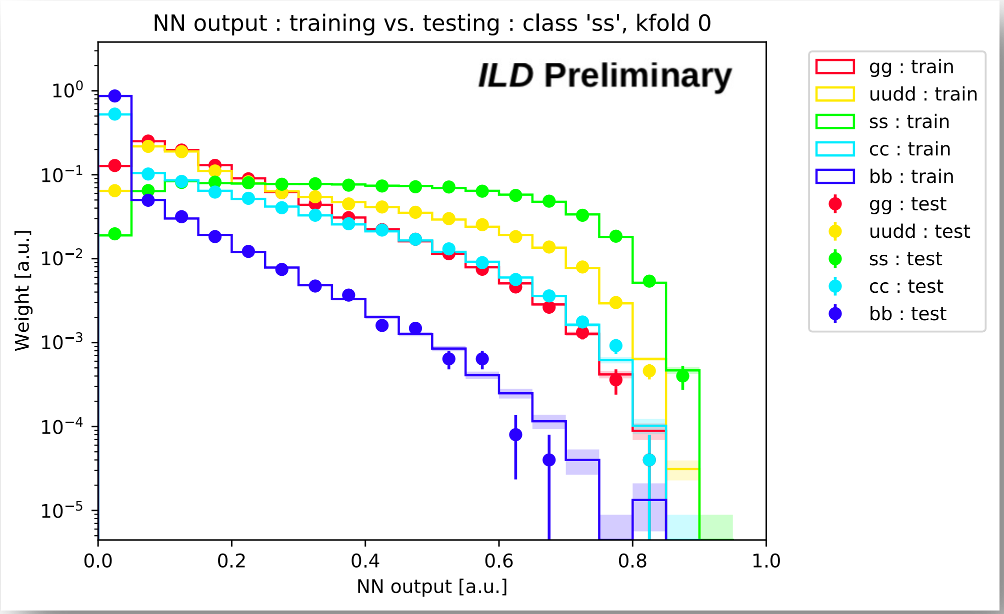
  - Calls for **lepton colliders** and dedicated **detector technologies** and **reconstruction techniques**!

- Somewhat related to the Instrumentation Frontier LoI on 4D Tracking

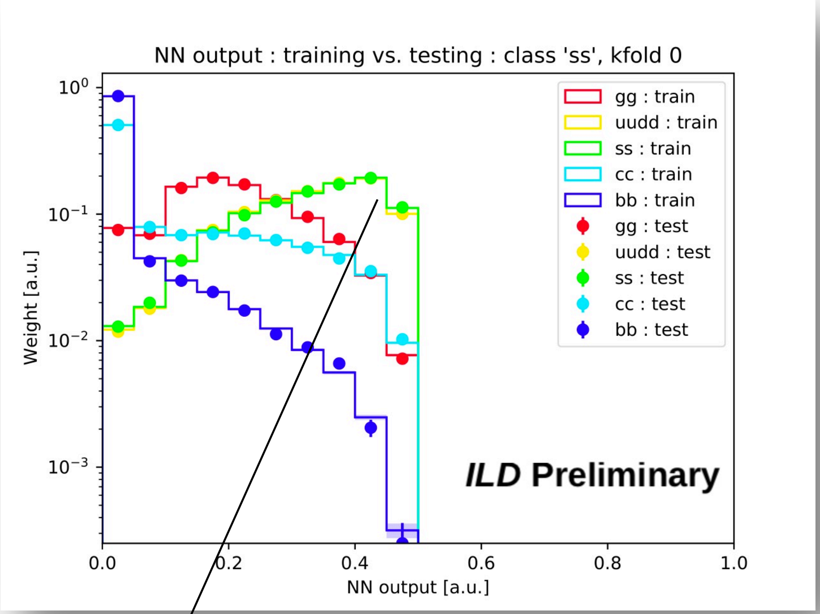
- Most recent presentations: ILCx 2021, Higgs 2021, SiDOptimizationMeeting
- **Studies performed in ILD, but of general applicability**

Performance Recap: Strange Tagger with & without PID

With (truth) PID



Without PID



No discrimination between s and u/d without PID!

PID is a crucial ingredient for discriminating strange from up/down initiated jets!

Recap: Analysis Overview and Results

Define Signal/Bkg

- Signal: Z(inv)H(ss)
- Bkg: Z(inv)H(bb,cc,gg), Z(qq), ZZ(qqqq), WW

Select Events

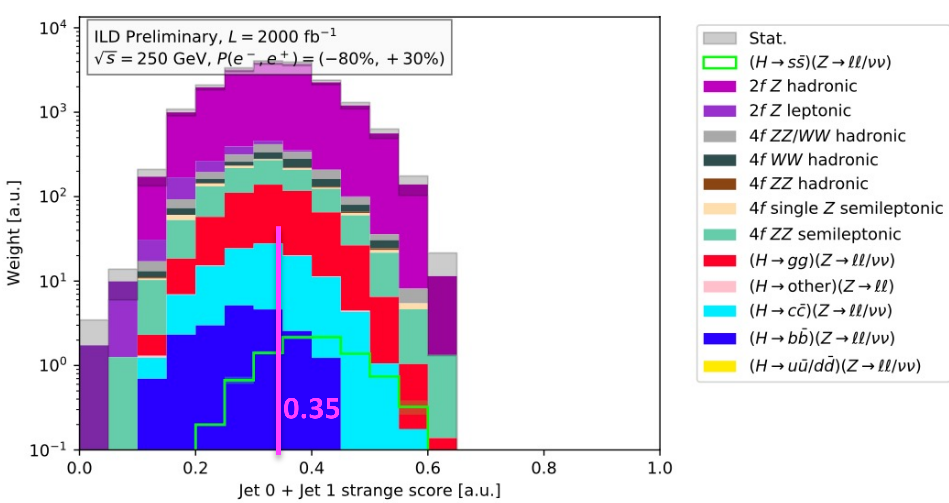
Most powerful cut on M_{jj} (see previous talks for more details)

Build Signal discriminant

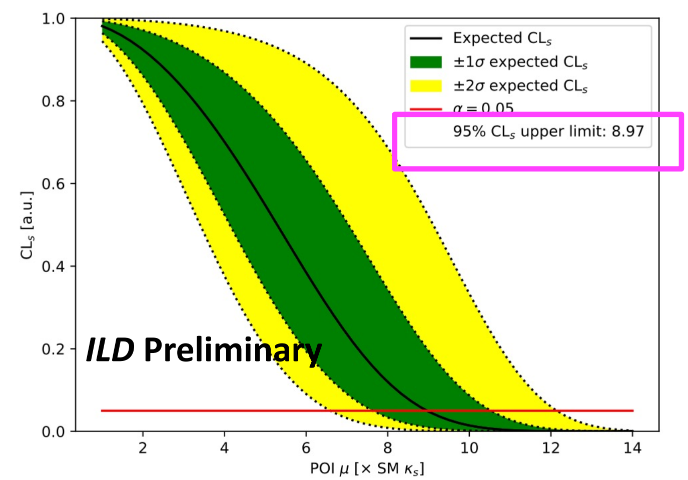
Sum of leading and sub-leading **strange-jet score**

s-Yukawa coupling

Probe various BSM regimes



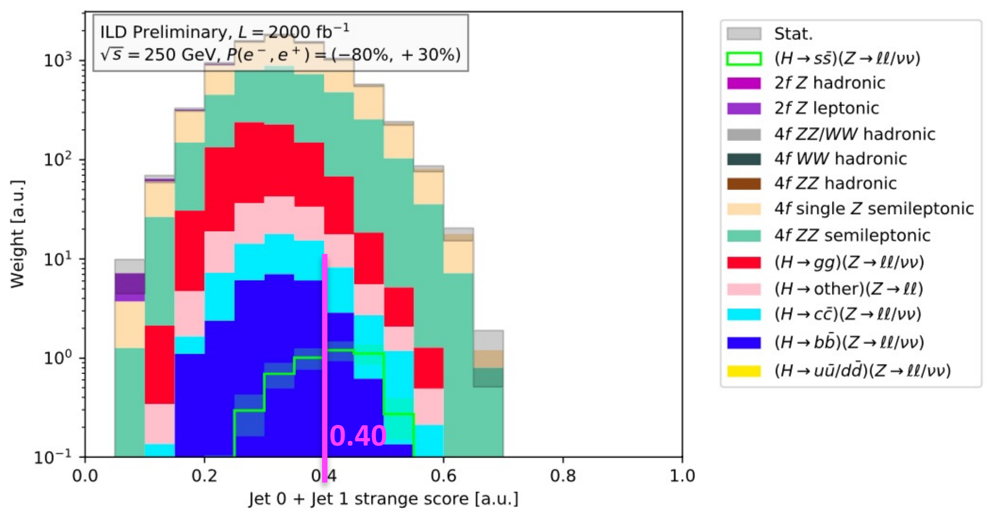
(a) $Z \to \nu\bar{\nu}$ channel



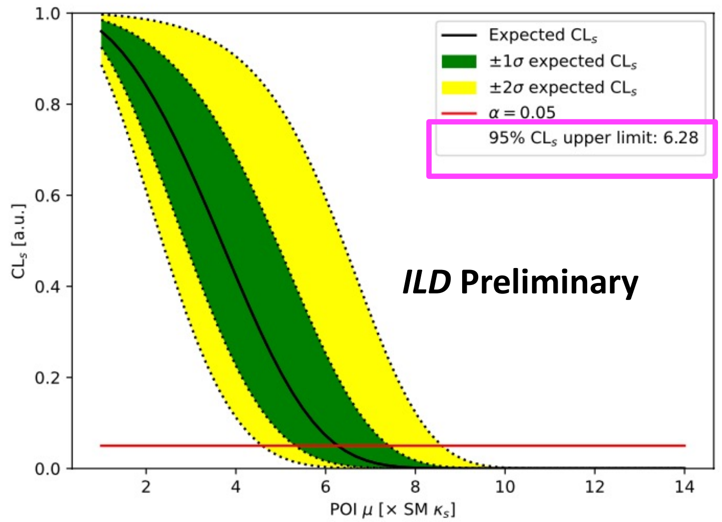
(a) $Z \to \nu\bar{\nu}$ channel

Update: Analysis Overview and Results

- Added leptonic channel to signal: Z(inv)H(ss) **+ Z(ll)H(ss)**
  - >= 2 leptons are required, other analysis cuts adjusted too
- We now have a 2-category analysis with ~doubled significance!



(b) $Z \to \ell\ell$ channel



(b) $Z \to \ell\ell$ channel

Update: Analysis Overview and Results

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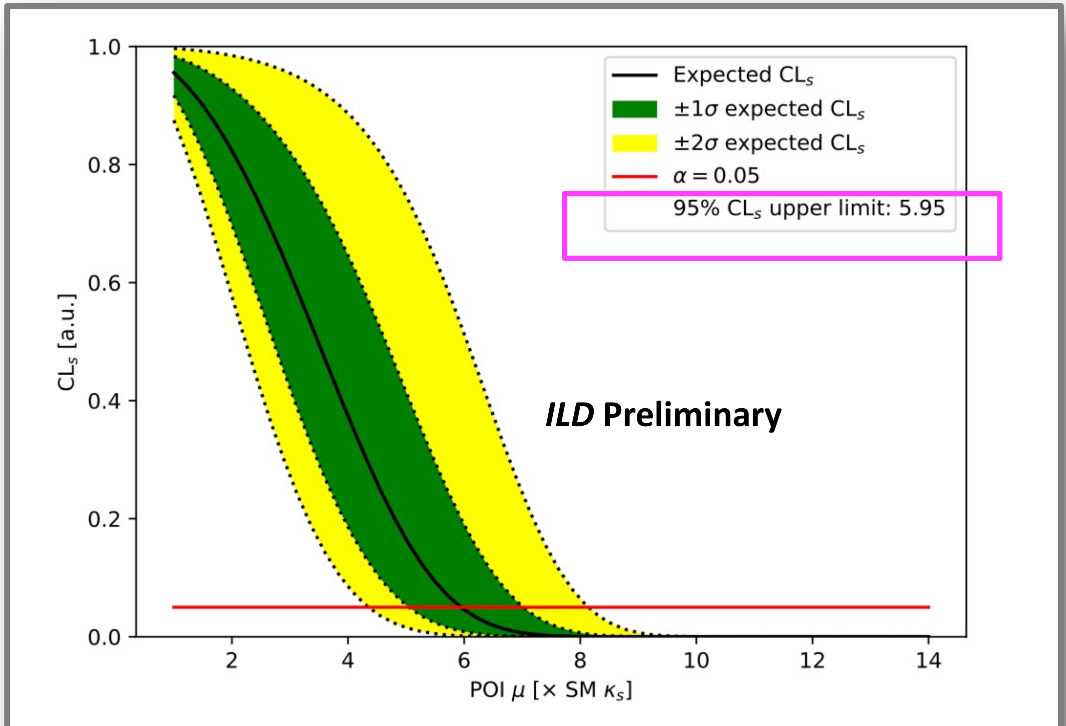
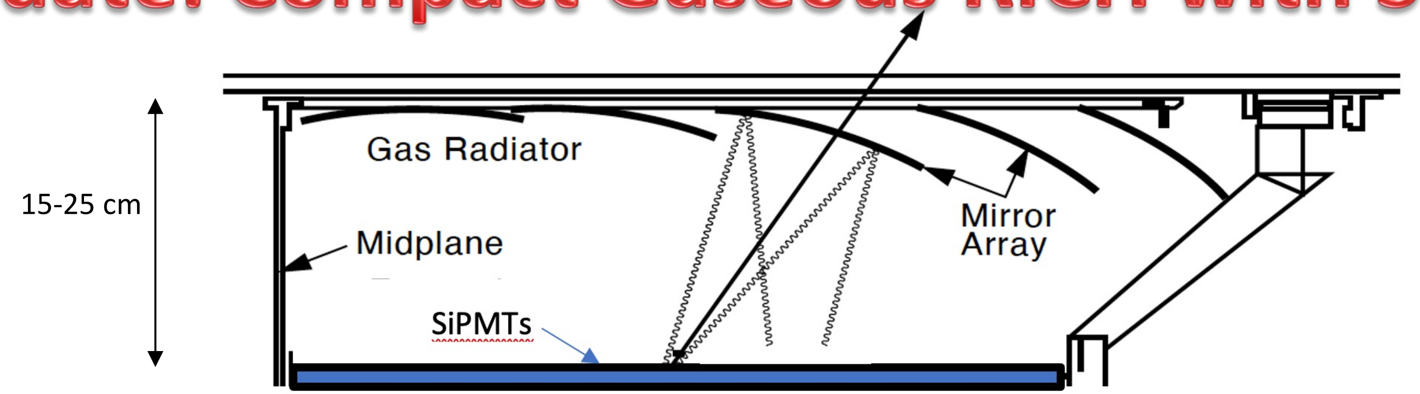


(c) Combined

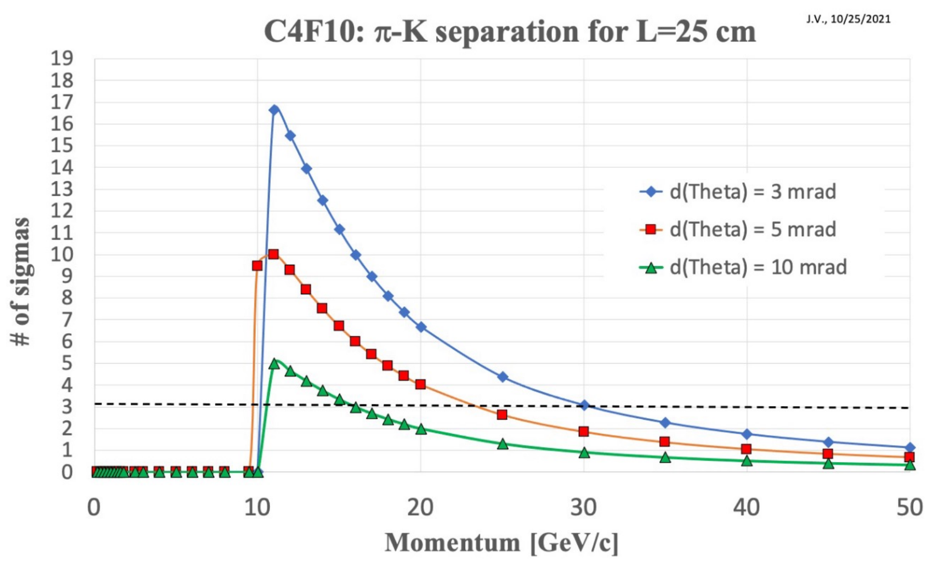
Update: Compact Gaseous RICH with SiPMTs



- Reach of PID performance depends on the **Cherenkov angle resolution**
  - Effects of chromaticity, bending of tracks, pixel size, tracking precision, noise, etc.)

# of sigmas = $\dfrac{\theta_\pi - \theta_K}{\sigma_\theta/\sqrt{N}}$

σ_θ is total Cherenkov angle resolution



We should try to keep the Cherenkov error below the 5 mrad level!

Publication plans

Measurement prospects for Higgs decays to strange quark pairs with the future International Large Detector at the International Linear Collider

The paper is organized as follows:

- Section 2 describes the International Large Detector, a proposed detector at the ILC and the detector used for the contained studies;
- Section 3 describes the Monte Carlo samples included in the study;
- Section 4 describes the development and validation of a jet flavour tagger using a neural network;
- Section 5 describes the application of the jet flavour tagger to a SM $h \to s\bar{s}$ analysis with ILD at the $\sqrt{s} = 250\,\mathrm{GeV}$ ILC run;
- Section 6 describes a detector proposal which would maximize particle identification (PID) at high momenta and thus boost strange tagging performance.
- Section 7 describes the conclusions and next steps.

- **Preliminary draft being written** (currently ~30 pages)
    - Analysis documentation ~complete, detector part to be added
- **Discussion with ILD community** in the coming weeks to agree on review procedure (the detector part is not ILD-related), then upload on arxiv

- **Wish list:**
    - Final results with no PID info or partial PID for certain momentum thresholds
    - H->cs results (work has started, but might not arrive on time)
        - The BSM aspects will still be highlighter by saying how much we are reducing the phase space for new physics leading to enhancements of H->ss rate→allows for later interpretations
            - Get in touch with theory colleagues to expand the discussion about interpretations

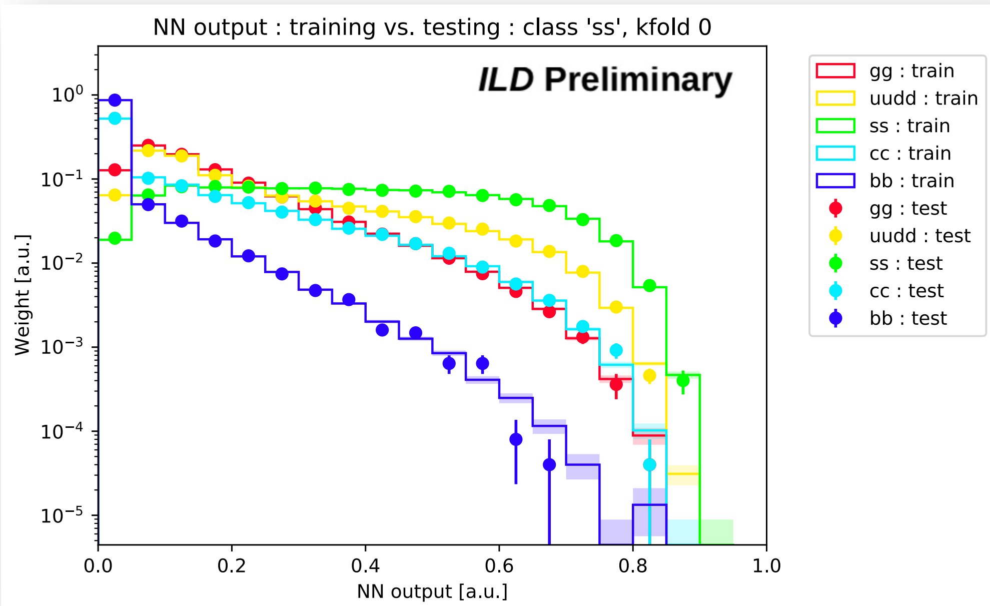
Thanks for your attention!

Valentina Cairo

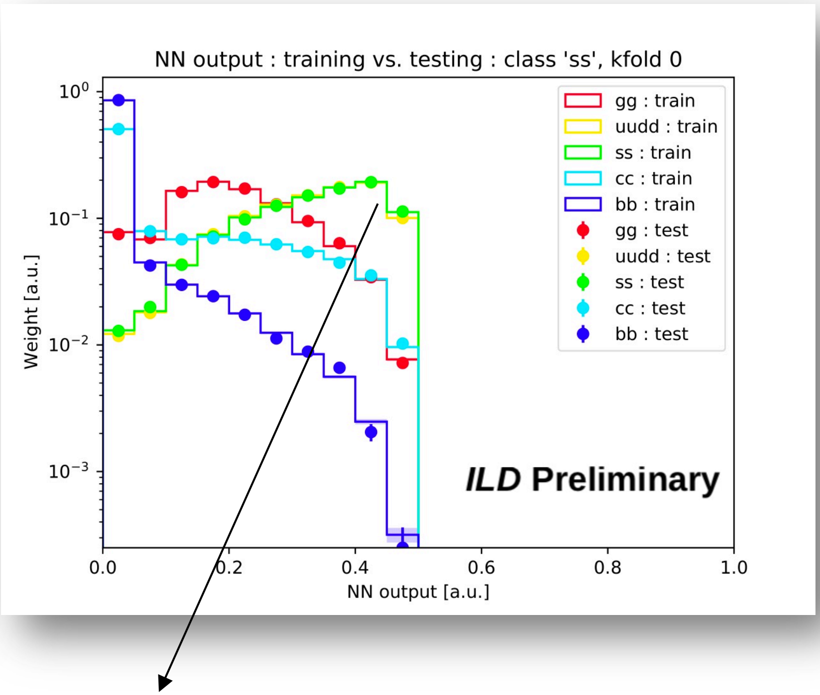
CERN

Performance: Strange Tagger with & without PID

With (truth) PID



Without PID



No discrimination between s and u/d without PID!

PID is a crucial ingredient for discriminating strange from up/down initiated jets!

Event Selection

Table 3: Kinematic selections for $Z \to \nu\bar{\nu}$ and $Z \to \ell\ell$ channels of the $h \to s\bar{s}$ analysis. The selections are grouped into categories serving specific purposes.

Category	Selection	$Z \to \nu\bar{\nu}$	$Z \to \ell\ell$
Object counting	Number of leptons, N_{leptons}	0	≥ 2
	Number of jets, N_{jets}	≥ 2	≥ 2
	Leading 2 leptons are SFOS[2]	–	True
$2f$ Z rejection	Leading jet momentum, p_{j_0}	$\in [40, 110]$ GeV	$\in [60, 110]$ GeV
	Subleading jet momentum, p_{j_1}	$\in [30, 80]$ GeV	$\in [30, 75]$ GeV
	Dijet mass, M_{jj}	$\in [120, 140]$ GeV	$\in [115, 145]$ GeV
	Dijet energy, E_{jj}	$\in [125, 155]$ GeV	$\in [130, 160]$ GeV
	Missing mass, M_{miss}	$\in [75, 120]$ GeV	–
	Dijet/missing-p^{μ} angular separation, $\Delta R_{jj,\text{miss}}$[3]	$\in [3.1, 4.0]$[4]	–
	Dijet azimuthal separation, $\Delta\phi_{jj}$	> 1.25	> 1.75
	Leading lepton momentum, p_{ℓ_0}	–	$\in [40, 90]$ GeV
	Subleading lepton momentum, p_{ℓ_1}	–	$\in [20, 60]$ GeV
	Dilepton mass, $M_{\ell\ell}$	–	$\in [70, 100]$ GeV
	Dilepton energy, $E_{\ell\ell}$	–	$\in [85, 115]$ GeV
$h \to b\bar{b}/c\bar{c}$ rejection	Leading jet LCFIPlus BTag score, $\text{score}_b^{j_0}$	< 0.20	< 0.1
	Subleading jet LCFIPlus BTag score, $\text{score}_b^{j_1}$	< 0.20	< 0.1
	Leading jet LCFIPlus CTag score, $\text{score}_c^{j_0}$	< 0.35	< 0.3
	Subleading jet LCFIPlus CTag score, $\text{score}_c^{j_1}$	< 0.35	< 0.3
$4f$ VV rejection	$2 \to 3$ jet transition variable, y_{23}	< 0.010	< 0.050
	$2 \to 3$ jet transition variable, y_{34}	< 0.002	< 0.005
$h \to gg$ rejection	Number of PFOs in event, $N_{\text{PFOs}}^{\text{event}}$	$\in [30, 60]$	$\in [20, 80]$
	Number of PFOs in leading jet, $N_{\text{PFOs}}^{j_0}$	$\in [10, 40]$	$\in [5, 50]$
	Number of PFOs in subleading jet, $N_{\text{PFOs}}^{j_1}$	$\in [9, 37]$	$\in [5, 50]$

Cut Flows

Table 4: Cutflow for the $Z \to \nu\bar{\nu}$ channel selections described in Table 3. Shown are the central values in the yields as well as the Poisson counting uncertainties on those yields. The signal (background) efficiency is defined as the ratio of the $h(\to s\bar{s})Z(\to \ell\ell/\nu\bar{\nu})$ (all non-$h(\to s\bar{s})Z(\to \ell\ell/\nu\bar{\nu})$) yields at a given cut value to the yields at "No cut". The sum-of-weights per process is normalised to the SM cross-section.

ILD Preliminary, $\mathcal{L} = 2000$ fb^{-1}, $\sqrt{s} = 250$ GeV, $P(e^-, e^+) = (-80\%, +30\%)$

	$(H \to s\bar{s})(Z \to \ell\ell/\nu\nu)$	$(H \to gg)(Z \to \ell\ell/\nu\nu)$	$(H \to u\bar{u}/d\bar{d})(Z \to \ell\ell/\nu\nu)$	$(H \to c\bar{c})(Z \to \ell\ell/\nu\nu)$	$(H \to b\bar{b})(Z \to \ell\ell/\nu\nu)$	$(H \to \text{other})(Z \to \ell\ell)$	2f Z hadronic	4f ZZ hadronic	4f WW hadronic
No cut	64.51 ± 1.14	26095.47 ± 35.08	0.13 ± 0.0	8860.89 ± 16.64	175695.3 ± 176.22	31773.76 ± 46.82	255931062.5 ± 50827.22	2810119.87 ± 1054.69	29732839.84 ± 7731.14
No leptons	48.29 ± 0.6	19695.06 ± 27.73	0.13 ± 0.0	6675.43 ± 11.18	131811.89 ± 167.15	6268.25 ± 20.66	$253692442.95 \pm 50604.44$	2795922.02 ± 1052.03	29604798.82 ± 7714.47
≥ 2 jets	48.29 ± 0.6	19695.06 ± 27.73	0.13 ± 0.0	6675.43 ± 11.18	131811.89 ± 167.15	6216.23 ± 20.58	$253692331.92 \pm 50604.43$	2795922.02 ± 1052.03	29604798.82 ± 7714.47
$p_{T_{jj}} \in [40, 110]$ GeV	47.41 ± 0.59	19512.14 ± 27.58	0.13 ± 0.0	6591.48 ± 11.07	130386.65 ± 166.35	4719.6 ± 17.93	157498040.21 ± 39872.4	2508108.58 ± 996.41	25394290.9 ± 7144.85
$p_{j_1} \in [30, 80]$ GeV	43.65 ± 0.54	18516.51 ± 26.82	0.12 ± 0.0	6286.23 ± 10.71	122931.01 ± 161.78	3704.24 ± 15.88	$107287881.34 \pm 32908.66$	1005428.35 ± 630.87	6120566.28 ± 3513.13
$M_{jj} \in [120, 140]$ GeV	32.05 ± 0.38	13381.62 ± 22.26	0.09 ± 0.0	4197.13 ± 8.2	69510.76 ± 123.28	1176.03 ± 8.95	8471483.31 ± 9247.29	16096.54 ± 79.82	217286.18 ± 660.91
$E_{jj} \in [125, 155]$ GeV	31.54 ± 0.37	13195.22 ± 22.09	0.09 ± 0.0	4138.2 ± 8.13	68431.89 ± 122.37	1130.0 ± 8.77	3115326.57 ± 5607.72	8724.87 ± 58.77	103011.37 ± 455.06
$M_{\text{miss}} \in [75, 120]$ GeV	29.66 ± 0.36	12431.98 ± 21.42	0.09 ± 0.0	3897.6 ± 7.86	64672.67 ± 119.07	1014.35 ± 8.31	1269359.28 ± 3579.54	4371.34 ± 41.6	46621.77 ± 306.14
$\Delta R_{jj,\text{min}} \in [3.1, 4.0]$	25.27 ± 0.31	10708.0 ± 19.88	0.07 ± 0.0	3358.7 ± 7.3	55705.28 ± 110.51	866.91 ± 7.68	212330.4 ± 1464.0	3092.75 ± 34.99	36683.09 ± 271.56
$\Delta\phi_{jj} > 1.25$	23.84 ± 0.31	9939.25 ± 19.15	0.07 ± 0.0	3163.72 ± 7.08	52405.74 ± 107.21	779.39 ± 7.28	190315.06 ± 1386.03	2789.54 ± 33.23	32543.98 ± 255.78
$\text{score}^{j_0}_{b\text{-tag}} < 0.20$	23.07 ± 0.31	9064.62 ± 18.28	0.07 ± 0.0	2455.55 ± 6.2	4481.42 ± 31.41	601.51 ± 6.4	127610.22 ± 1134.95	1554.49 ± 24.81	28047.04 ± 237.45
$\text{score}^{j_1}_{b\text{-tag}} < 0.20$	22.26 ± 0.3	8505.84 ± 17.7	0.07 ± 0.0	1920.09 ± 5.46	477.27 ± 10.28	493.89 ± 5.8	111106.29 ± 1059.02	1259.98 ± 22.33	24117.0 ± 220.18
$\text{score}^{j_0}_{c\text{-tag}} < 0.35$	21.34 ± 0.28	8037.73 ± 17.19	0.06 ± 0.0	681.96 ± 3.26	245.28 ± 7.36	370.8 ± 5.02	95642.05 ± 982.56	1077.1 ± 20.65	18413.91 ± 192.4
$\text{score}^{j_1}_{c\text{-tag}} < 0.35$	20.61 ± 0.27	7627.12 ± 16.73	0.06 ± 0.0	279.98 ± 2.07	139.46 ± 5.56	281.77 ± 4.38	87597.02 ± 940.33	974.58 ± 19.64	13237.51 ± 163.13
$y_{23} < 0.010$	13.45 ± 0.23	2783.47 ± 10.11	0.04 ± 0.0	157.85 ± 1.53	59.82 ± 3.65	9.74 ± 0.81	31443.27 ± 563.38	113.61 ± 6.71	1055.38 ± 46.06
$y_{34} < 0.002$	11.64 ± 0.22	1508.06 ± 7.44	0.03 ± 0.0	128.67 ± 1.39	42.88 ± 3.1	2.32 ± 0.4	24306.71 ± 495.33	47.11 ± 4.32	492.51 ± 31.47
$N^{\text{event}}_{\text{PFOs}} \in [30, 60]$	9.71 ± 0.19	460.46 ± 4.07	0.03 ± 0.0	96.57 ± 1.18	21.42 ± 2.2	1.23 ± 0.29	18351.16 ± 430.39	21.38 ± 2.91	241.23 ± 22.02
$N^{j_0}_{\text{PFOs}} \in [10, 40]$	9.44 ± 0.19	445.06 ± 4.0	0.03 ± 0.0	94.58 ± 1.17	21.19 ± 2.19	1.23 ± 0.29	17149.96 ± 416.07	20.58 ± 2.85	233.19 ± 21.65
$N^{j_1}_{\text{PFOs}} \in [9, 37]$	9.15 ± 0.19	431.49 ± 3.94	0.03 ± 0.0	92.25 ± 1.16	19.56 ± 2.1	1.23 ± 0.29	16100.17 ± 403.13	20.19 ± 2.83	223.14 ± 21.18

	4f ZZ/WW hadronic	2f Z leptonic	4f ZZ semileptonic	4f single Z semileptonic	Total bkg.	Sig. eff.	Bkg. eff.
No cut	24177280.41 ± 5691.47	42428003.91 ± 8571.75	1676158.94 ± 817.92	2539817.83 ± 1016.32	$359537773.37 \pm 52458.49$	1.00e+00	1.00e+00
No leptons	24073642.64 ± 5679.26	18721739.44 ± 5693.99	851521.55 ± 582.98	1011752.12 ± 641.45	$330916318.59 \pm 51835.17$	7.49e-01	9.20e-01
≥ 2 jets	24073642.64 ± 5679.26	17830382.5 ± 5556.78	851521.55 ± 582.98	1011750.09 ± 641.45	$330024796.57 \pm 51820.27$	7.49e-01	9.18e-01
$p_{T_{jj}} \in [40, 110]$ GeV	20720712.03 ± 5268.93	3973417.2 ± 2623.16	689124.99 ± 524.45	407773.91 ± 407.23	$211352725.23 \pm 40950.73$	7.35e-01	5.88e-01
$p_{j_1} \in [30, 80]$ GeV	5224597.83 ± 2645.74	522979.7 ± 951.67	508522.82 ± 450.51	150690.35 ± 247.55	$120991148.43 \pm 33225.25$	6.77e-01	3.37e-01
$M_{jj} \in [120, 140]$ GeV	174691.55 ± 483.79	50982.87 ± 297.14	71310.19 ± 168.71	19882.33 ± 89.92	9110030.46 ± 9291.41	4.97e-01	2.53e-02
$E_{jj} \in [125, 155]$ GeV	83133.43 ± 333.74	45493.21 ± 280.68	44520.23 ± 133.3	15399.87 ± 79.14	3502536.49 ± 5646.85	4.89e-01	9.74e-03
$M_{\text{miss}} \in [75, 120]$ GeV	37363.09 ± 223.74	36735.72 ± 252.22	24247.55 ± 98.38	11056.09 ± 67.05	1511801.18 ± 3612.64	4.60e-01	4.20e-03
$\Delta R_{jj,\text{min}} \in [3.1, 4.0]$	29230.48 ± 197.9	15476.7 ± 163.71	15023.41 ± 77.44	881.28 ± 18.93	383382.34 ± 1517.66	3.92e-01	1.07e-03
$\Delta\phi_{jj} > 1.25$	25899.73 ± 186.28	13228.88 ± 151.36	13633.66 ± 73.77	749.11 ± 17.45	345471.96 ± 1436.28	3.70e-01	9.61e-04
$\text{score}^{j_0}_{b\text{-tag}} < 0.20$	22362.65 ± 173.09	8958.37 ± 124.55	9276.43 ± 60.85	621.41 ± 15.9	215056.84 ± 1181.5	3.58e-01	5.98e-04
$\text{score}^{j_1}_{b\text{-tag}} < 0.20$	19759.41 ± 162.71	6572.01 ± 106.68	7567.38 ± 54.96	541.7 ± 14.84	182343.2 ± 1100.95	3.45e-01	5.07e-04
$\text{score}^{j_0}_{c\text{-tag}} < 0.35$	16643.03 ± 149.33	2673.83 ± 68.05	5892.26 ± 48.49	492.49 ± 14.15	150191.86 ± 1016.24	3.31e-01	4.18e-04
$\text{score}^{j_1}_{c\text{-tag}} < 0.35$	14368.05 ± 138.75	1451.21 ± 50.13	4338.87 ± 41.61	447.76 ± 13.49	130764.01 ± 967.07	3.20e-01	3.64e-04
$y_{23} < 0.010$	1302.29 ± 41.77	1314.4 ± 47.71	1130.72 ± 21.24	165.52 ± 8.2	39549.56 ± 569.4	2.08e-01	1.10e-04
$y_{34} < 0.002$	637.75 ± 29.23	1286.69 ± 47.2	806.23 ± 17.94	122.82 ± 7.07	29393.42 ± 499.89	1.80e-01	8.17e-05
$N^{\text{event}}_{\text{PFOs}} \in [30, 60]$	337.63 ± 21.27	438.13 ± 27.55	619.44 ± 15.72	95.16 ± 6.22	20693.55 ± 432.73	1.50e-01	5.75e-05
$N^{j_0}_{\text{PFOs}} \in [10, 40]$	329.59 ± 21.01	349.81 ± 24.61	591.5 ± 15.36	69.95 ± 5.33	19316.11 ± 418.24	1.46e-01	5.37e-05
$N^{j_1}_{\text{PFOs}} \in [9, 37]$	324.23 ± 20.84	309.98 ± 23.17	559.17 ± 14.94	57.34 ± 4.83	18147.92 ± 405.23	1.42e-01	5.05e-05

Cut Flows

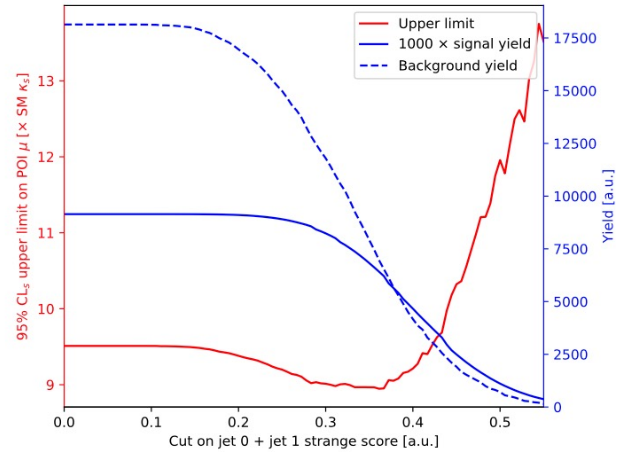
Table 5: Cutflow for the $Z \to \ell\ell$ channel selections described in Table 3. Shown are the central values in the yields as well as the Poisson counting uncertainties on those yields. The signal (background) efficiency is defined as the ratio of the $h(\to s\bar{s})Z(\to \ell\ell/\nu\bar{\nu})$ (all non-$h(\to s\bar{s})Z(\to \ell\ell/\nu\bar{\nu})$) yields at a given cut value to the yields at "No cut". The sum-of-weights per process is normalised to the SM cross-section.

ILD Preliminary, $\mathcal{L} = 2000$ fb^{-1}, $\sqrt{s} = 250$ GeV, $P(e^-, e^+) = (-80\%, +30\%)$

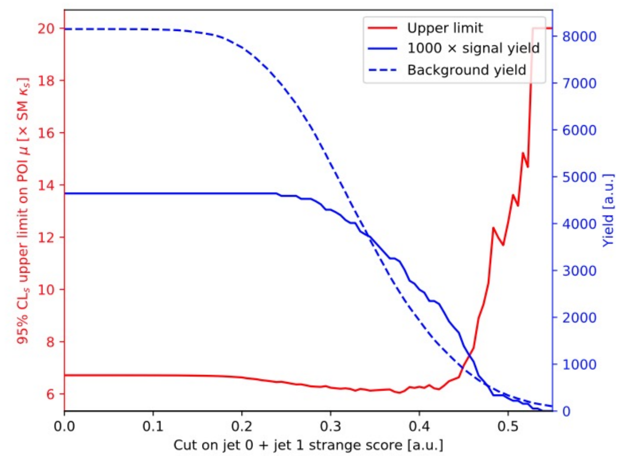
	$(H \to s\bar{s})(Z \to \ell\ell/\nu\nu)$	$(H \to gg)(Z \to \ell\ell/\nu\nu)$	$(H \to u\bar{u}/d\bar{d})(Z \to \ell\ell/\nu\nu)$	$(H \to c\bar{c})(Z \to \ell\ell/\nu\nu)$	$(H \to b\bar{b})(Z \to \ell\ell/\nu\nu)$	$(H \to \text{other})(Z \to \ell\ell)$	2f Z hadronic	4f ZZ hadronic
No cut	64.51 ± 1.14	26095.47 ± 35.08	0.13 ± 0.0	8860.89 ± 16.64	175695.3 ± 176.22	31773.76 ± 46.82	2559331062.5 ± 50827.22	2810119.87 ± 1054.69
≥ 2 leptons	12.55 ± 0.86	5094.72 ± 19.19	0.0 ± 0.0	1725.93 ± 10.98	34414.35 ± 48.59	20045.48 ± 37.27	19713.87 ± 446.09	87.09 ± 5.87
Leading 2 leptons are SFOS	12.22 ± 0.85	5029.16 ± 19.06	0.0 ± 0.0	1703.55 ± 10.9	33915.11 ± 48.24	17026.98 ± 34.35	11870.72 ± 346.16	55.02 ± 4.67
≥ 2 jets	12.22 ± 0.85	5029.16 ± 19.06	0.0 ± 0.0	1703.55 ± 10.9	33915.11 ± 48.24	16930.03 ± 34.25	11870.72 ± 346.16	55.02 ± 4.67
$p_{j_0} \in [60, 110]$ GeV	11.95 ± 0.84	4571.55 ± 18.17	0.0 ± 0.0	1595.44 ± 10.55	30236.02 ± 45.55	6539.54 ± 21.29	6308.84 ± 252.35	46.71 ± 4.3
$p_{j_1} \in [30, 75]$ GeV	11.5 ± 0.82	4375.06 ± 17.78	0.0 ± 0.0	1538.03 ± 10.36	28689.22 ± 44.37	5140.28 ± 18.88	3664.18 ± 192.32	17.81 ± 2.66
$M_{jj} \in [115, 145]$ GeV	9.81 ± 0.76	3691.65 ± 16.32	0.0 ± 0.0	1264.68 ± 9.39	22453.12 ± 39.25	3706.97 ± 16.03	504.71 ± 71.38	1.19 ± 0.69
$E_{jj} \in [130, 160]$ GeV	9.63 ± 0.75	3546.02 ± 16.0	0.0 ± 0.0	1182.85 ± 9.09	20125.91 ± 37.16	3513.65 ± 15.6	363.39 ± 60.56	1.19 ± 0.69
$\Delta\phi_{jj} > 1.75$	8.33 ± 0.7	3122.06 ± 15.01	0.0 ± 0.0	1066.59 ± 8.63	18087.03 ± 35.23	2964.88 ± 14.33	312.92 ± 56.2	1.19 ± 0.69
$p_{\ell_0} \in [40, 90]$ GeV	8.28 ± 0.7	3083.46 ± 14.92	0.0 ± 0.0	1053.16 ± 8.57	17864.64 ± 35.01	2923.97 ± 14.23	80.75 ± 28.55	0.4 ± 0.4
$p_{\ell_1} \in [20, 60]$ GeV	8.23 ± 0.7	3033.43 ± 14.8	0.0 ± 0.0	1034.14 ± 8.5	17531.96 ± 34.68	2874.49 ± 14.11	60.56 ± 24.73	0.0 ± 0.0
$M_{\ell\ell} \in [70, 100]$ GeV	7.71 ± 0.67	2871.04 ± 14.39	0.0 ± 0.0	978.1 ± 8.26	16618.67 ± 33.76	2726.42 ± 13.74	40.38 ± 20.19	0.0 ± 0.0
$E_{\ell\ell} \in [85, 115]$ GeV	7.66 ± 0.67	2843.63 ± 14.32	0.0 ± 0.0	967.53 ± 8.22	16436.56 ± 33.57	2694.88 ± 13.66	40.38 ± 20.19	0.0 ± 0.0
$\text{score}^{j_0}_{b\text{-tag}} < 0.1$	6.74 ± 0.63	2435.67 ± 13.26	0.0 ± 0.0	570.02 ± 6.31	810.59 ± 7.45	1883.22 ± 11.42	30.28 ± 17.48	0.0 ± 0.0
$\text{score}^{j_1}_{b\text{-tag}} < 0.1$	6.08 ± 0.6	2145.87 ± 12.44	0.0 ± 0.0	332.25 ± 4.81	76.16 ± 2.28	1416.5 ± 9.9	20.19 ± 14.28	0.0 ± 0.0
$\text{score}^{j_0}_{c\text{-tag}} < 0.3$	5.96 ± 0.59	2055.37 ± 12.18	0.0 ± 0.0	129.61 ± 3.01	53.15 ± 1.91	1209.79 ± 9.15	20.19 ± 14.28	0.0 ± 0.0
$\text{score}^{j_1}_{c\text{-tag}} < 0.3$	5.79 ± 0.58	1972.93 ± 11.93	0.0 ± 0.0	60.36 ± 2.05	40.25 ± 1.66	1042.23 ± 8.5	20.19 ± 14.28	0.0 ± 0.0
$y_{23} < 0.050$	5.49 ± 0.57	1623.21 ± 10.82	0.0 ± 0.0	53.38 ± 1.93	36.75 ± 1.59	512.04 ± 5.95	20.19 ± 14.28	0.0 ± 0.0
$y_{34} < 0.005$	4.75 ± 0.53	1160.13 ± 9.15	0.0 ± 0.0	46.48 ± 1.8	31.19 ± 1.46	119.85 ± 2.88	20.19 ± 14.28	0.0 ± 0.0
$N^{\text{event}}_{\text{PFOs}} \in [20, 80]$	4.7 ± 0.53	755.14 ± 7.38	0.0 ± 0.0	43.81 ± 1.75	27.63 ± 1.38	99.07 ± 2.62	20.19 ± 14.28	0.0 ± 0.0
$N^{j_0}_{\text{PFOs}} \in [5, 50]$	4.64 ± 0.52	722.43 ± 7.21	0.0 ± 0.0	42.9 ± 1.73	26.62 ± 1.35	94.92 ± 2.56	20.19 ± 14.28	0.0 ± 0.0
$N^{j_1}_{\text{PFOs}} \in [5, 50]$	4.64 ± 0.52	711.51 ± 7.16	0.0 ± 0.0	42.42 ± 1.72	26.41 ± 1.34	93.82 ± 2.55	20.19 ± 14.28	0.0 ± 0.0

	4f WW hadronic	4f ZZ/WW hadronic	2f Z leptonic	4f ZZ semileptonic	4f single Z semileptonic	Total bkg.	Sig. eff.	Bkg. eff.
No cut	29732839.84 ± 7731.14	24177280.41 ± 5691.47	42428003.91 ± 8571.75	1676158.94 ± 817.92	2539817.83 ± 1016.32	3595377773.37 ± 52458.49	1.00e+00	1.00e+00
≥ 2 leptons	800.08 ± 40.1	625.69 ± 28.95	17934724.21 ± 5573.02	425681.95 ± 412.19	599633.62 ± 493.82	19042559.54 ± 5628.32	1.95e-01	5.30e-02
Leading 2 leptons are SFOS	482.46 ± 31.14	353.71 ± 21.77	17683936.61 ± 5533.92	420043.13 ± 409.45	573238.66 ± 482.83	18747667.32 ± 5581.25	1.89e-01	5.21e-02
≥ 2 jets	482.46 ± 31.14	353.71 ± 21.77	16688722.84 ± 5375.94	420043.13 ± 409.45	573238.66 ± 482.83	17752356.61 ± 5424.65	1.89e-01	4.94e-02
$p_{j_0} \in [60, 110]$ GeV	379.94 ± 27.64	285.38 ± 19.55	235006.12 ± 637.94	344790.79 ± 370.96	385873.61 ± 396.14	1015645.88 ± 877.12	1.85e-01	2.82e-03
$p_{j_1} \in [30, 75]$ GeV	104.53 ± 14.5	66.99 ± 9.47	10650.29 ± 135.81	233165.14 ± 305.06	243602.82 ± 314.75	531025.84 ± 500.62	1.78e-01	1.48e-03
$M_{jj} \in [115, 145]$ GeV	6.03 ± 3.48	5.36 ± 2.68	2658.24 ± 67.85	41899.98 ± 129.32	61397.77 ± 158.02	137599.51 ± 231.44	1.52e-01	3.83e-04
$E_{jj} \in [130, 160]$ GeV	6.03 ± 3.48	4.02 ± 2.32	1948.22 ± 58.08	35088.82 ± 119.35	52414.55 ± 146.0	118804.28 ± 211.15	1.49e-01	3.30e-04
$\Delta\phi_{jj} > 1.75$	2.01 ± 2.01	2.68 ± 1.89	1078.88 ± 43.22	27193.48 ± 104.18	41553.26 ± 130.0	95393.31 ± 185.84	1.29e-01	2.65e-04
$p_{\ell_0} \in [40, 90]$ GeV	0.0 ± 0.0	0.0 ± 0.0	464.11 ± 28.35	23032.62 ± 95.88	34281.36 ± 118.07	82792.75 ± 162.72	1.28e-01	2.30e-04
$p_{\ell_1} \in [20, 60]$ GeV	0.0 ± 0.0	0.0 ± 0.0	349.81 ± 24.61	21456.08 ± 92.54	29659.81 ± 109.83	76008.52 ± 153.42	1.28e-01	2.11e-04
$M_{\ell\ell} \in [70, 100]$ GeV	0.0 ± 0.0	0.0 ± 0.0	296.13 ± 22.65	16918.05 ± 82.17	21311.83 ± 93.1	61768.32 ± 133.96	1.20e-01	1.72e-04
$E_{\ell\ell} \in [85, 115]$ GeV	0.0 ± 0.0	0.0 ± 0.0	162.78 ± 16.79	10095.83 ± 63.48	14714.61 ± 77.36	47963.86 ± 110.86	1.19e-01	1.33e-04
$\text{score}^{j_0}_{b\text{-tag}} < 0.1$	0.0 ± 0.0	0.0 ± 0.0	133.35 ± 15.2	7093.62 ± 53.21	10389.54 ± 65.0	23353.01 ± 89.41	1.04e-01	6.49e-05
$\text{score}^{j_1}_{b\text{-tag}} < 0.1$	0.0 ± 0.0	0.0 ± 0.0	105.64 ± 13.53	5994.44 ± 48.91	8752.64 ± 59.66	18849.77 ± 81.37	9.43e-02	5.24e-05
$\text{score}^{j_0}_{c\text{-tag}} < 0.3$	0.0 ± 0.0	0.0 ± 0.0	100.44 ± 13.19	5458.81 ± 46.68	8047.85 ± 57.21	17081.16 ± 77.94	9.23e-02	4.75e-05
$\text{score}^{j_1}_{c\text{-tag}} < 0.3$	0.0 ± 0.0	0.0 ± 0.0	96.98 ± 12.96	5126.74 ± 45.23	7591.15 ± 55.56	15956.63 ± 75.68	8.97e-02	4.44e-05
$y_{23} < 0.050$	0.0 ± 0.0	0.0 ± 0.0	96.98 ± 12.96	4121.35 ± 40.56	6027.86 ± 49.51	12497.25 ± 68.02	8.51e-02	3.47e-05
$y_{34} < 0.005$	0.0 ± 0.0	0.0 ± 0.0	96.98 ± 12.96	3292.77 ± 36.25	4516.22 ± 42.86	9288.55 ± 60.17	7.36e-02	2.58e-05
$N^{\text{event}}_{\text{PFOs}} \in [20, 80]$	0.0 ± 0.0	0.0 ± 0.0	50.22 ± 9.33	3141.5 ± 35.41	4292.95 ± 41.78	8435.21 ± 57.94	7.28e-02	2.34e-05
$N^{j_0}_{\text{PFOs}} \in [5, 50]$	0.0 ± 0.0	0.0 ± 0.0	39.83 ± 8.31	3088.82 ± 35.11	4206.32 ± 41.36	8246.68 ± 57.27	7.20e-02	2.29e-05
$N^{j_1}_{\text{PFOs}} \in [5, 50]$	0.0 ± 0.0	0.0 ± 0.0	39.83 ± 8.31	3056.09 ± 34.93	4160.37 ± 41.13	8155.28 ± 56.98	7.20e-02	2.27e-05

Sensitivity scan



(a) $Z \to \nu\bar{\nu}$ channel



(b) $Z \to \ell\ell$ channel

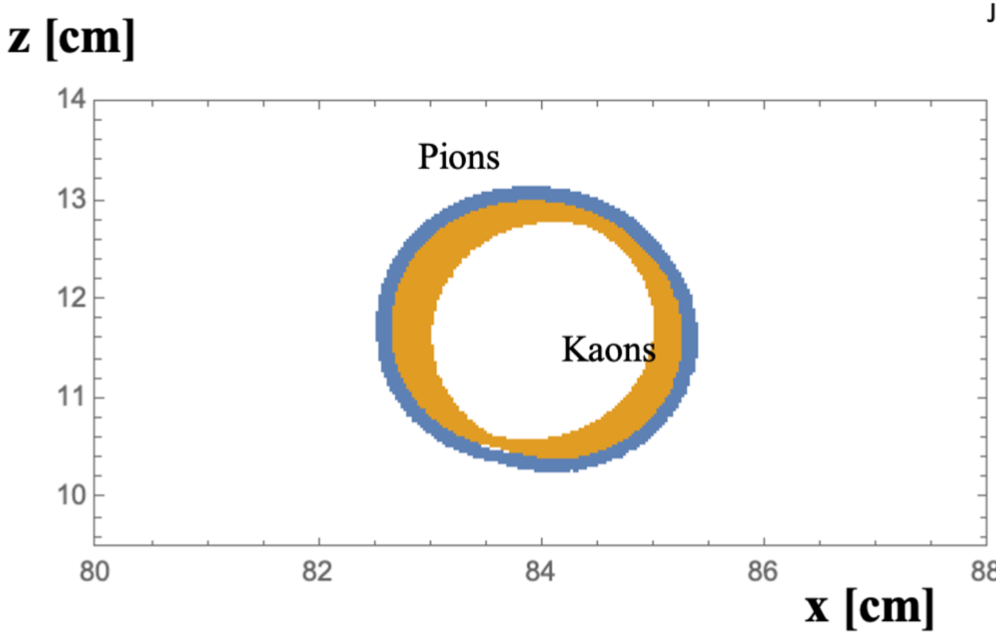
Figure 13: Scans of the 95% CL$_s$ upper limit for the Higgs-strange coupling strength modifier κ_s, obtained by varying the choice of the lower thresholds on the discriminants shown in Figure 12. Also shown are the signal (i.e., $h(\to s\bar{s})Z(\to \ell\ell/\nu\bar{\nu})$) and background (i.e., non-$h(\to s\bar{s})Z(\to \ell\ell/\nu\bar{\nu})$) yields in the resulting regions.

Gaseous RICH with SiPMTs – performance

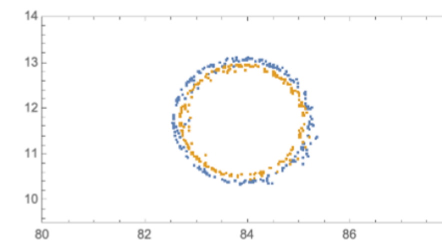
Pion and Kaon rings at SiPMT detector for $\theta_{dip} = 86^o$

J.V., 11/8/2021

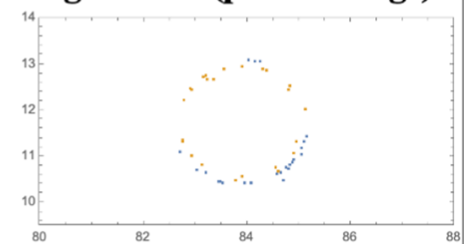
B = 5 Tesla,
P = 20 GeV/c pions
Pt = 19.951 GeV/c
Pz = 1.3973 GeV/c
Theta = 86°
Phi = 90°
R-helix=13.3 meters
θ_C (Pions)= 0.0532 rad
θ_C (Kaons)= 0.0471 rad
Npe (Pions) ~ 16
Npe (Kaons) ~ 12-13
C_4F_{10} gas
$L_{radiator}$ = 25 cm



10 tracks (pi & K rings):



Single track (pi & K rings):



- **Plot all {xfinal[i] & zfinal[i]} 2D-hits in detector plane, no cuts, no fitting.**

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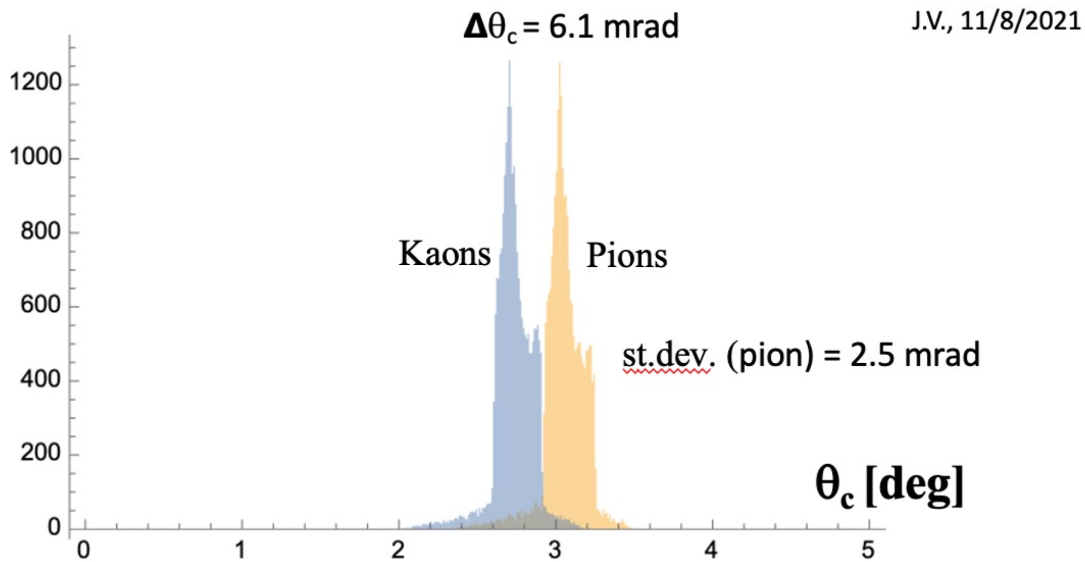
Gaseous RICH with SiPMTs – performance

Cherenkov angle distributions for $\theta_{dip} = 86^o$

B = 5 Tesla,
P = 20 GeV/c pions
Pt = 19.951 GeV/c
Pz = 1.3973 GeV/c
Theta = 86°
Phi = 90°
R-helix=13.3 meters
θ_C (Pions)= 0.0532 rad Kaons
θ_C (Kaons)= 0.0471 rad
Npe (Pions) ~ 16
Npe (Kaons) ~ 12-13
C_4F_{10} gas
$L_{radiator}$ = 25 cm



- **For each hit detector plane calculate r[i] = Sqrt{(xfinal[i] - x_0)^2 + (zfinal[i) - z_0)^2}, then for each entry calculate θ_c[i] = r[i]/25 for Pion and Kaon and plot them; no cuts.**
- **Calculate mean and standard deviation of each distributions.**
- **Distributions are not Gaussian. Clearly, one needs to fit circles with weighting.**

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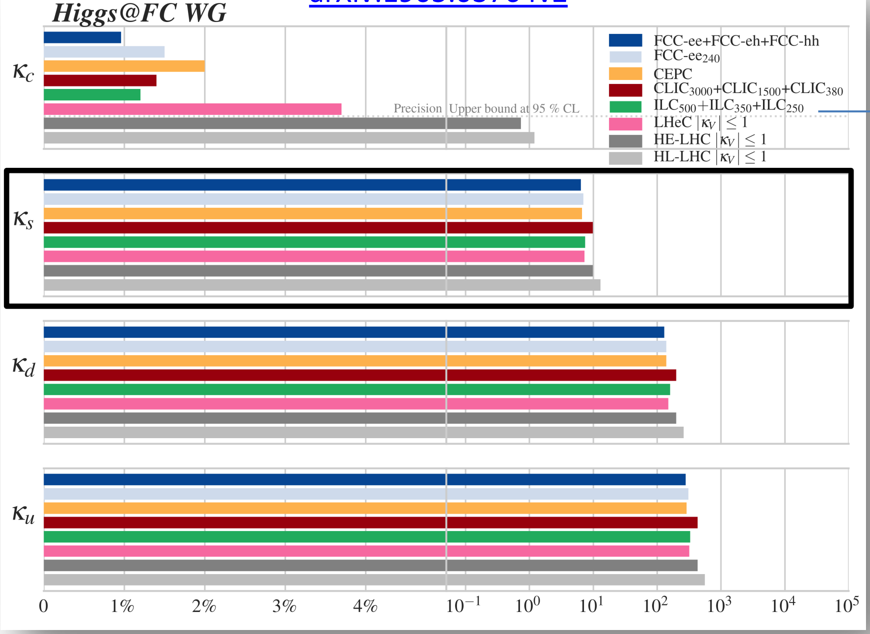
Comparison with existing projections

- Discovery measurement seems ***unlikely*** – looking at tagger with truth PID
  - For 30% signal efficiency, need 10,000x better background rejection
  - Set limits on coupling strength modifier κs at **O(6) x SM prediction** using 2000 fb-1 of data at √s = 250 GeV
- Sensitivity is ***limited*** but more promising than previous projections derived from unitarity bounds or exclusive Higgs decays

arXiv:1905.03764v2



Based on all the ILC stats, while we considered only the 250 GeV scenario for now