Strange Tagging and $H \to s\bar{s}$ @ ILD

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EF01
Working Group Meeting

September 15th 2021

U.S. DEPARTMENT OF ENERGY Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Our Snowmass LoI

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

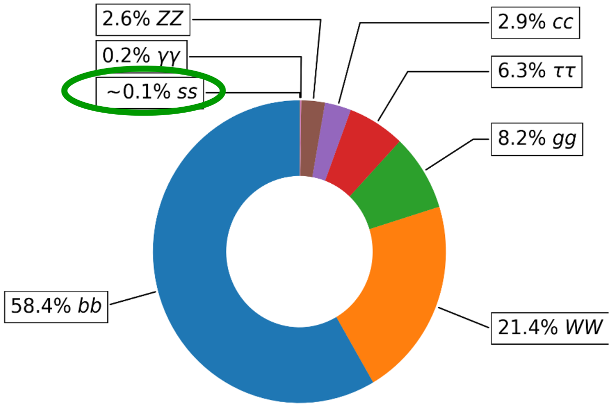
"More specifically, in the context of Snowmass 2021, we propose to study the feasibility of the measurement of Higgs boson couplings to light quarks, in particular to strange quarks, as of paramount importance to complete the understanding of the Higgs sector. The emphasis will be put on future lepton colliders since the branching ratio for h $\rightarrow s\bar{s}$ is below the level of 10-3 [6] in the SM and the measurement requires a large number of Higgs bosons in a very clean environment, but important information on the usage of advanced 4D tracking capabilities can also be learned in the HL-LHC context. This study strongly aims at motivating the development of strange tagging techniques and at providing requirements to future tracking algorithms and timing detectors performance."

- **In line with the ILC Study Questions for Snowmass 2021**: https://arxiv.org/pdf/2007.03650.pdf

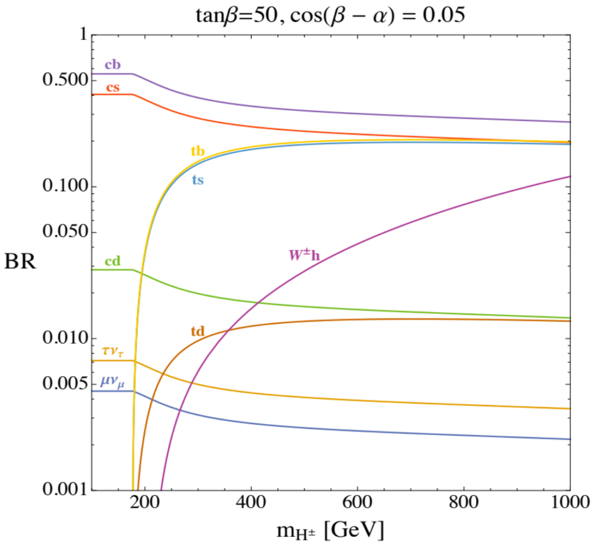
- Somewhat related to the IF LoI on 4D Tracking

Goals

- Develop a **strange tagger** using ILD@ILC and apply the tagger to a simple SM H→ss or BSM H→cs analysis
- Derive sensitivity of the ILC to the strange Yukawa coupling
- **H→ss**: likely to remain out of experimental reach unless enhanced relative to SM expectations
- **H→cs**: BSM models allow for the 1st & 2nd generation fermion masses to be an additional source of EW symmetry breaking, resulting in a "SM" Higgs doublet (125 GeV) and a "heavy" Higgs doublet
  - Charged heavy Higgs can undergo flavour violating decays (e.g., cs) – both **s/c-tagging** can help here



$\sqrt{s}$ = 13 TeV, m_H = 125 GeV

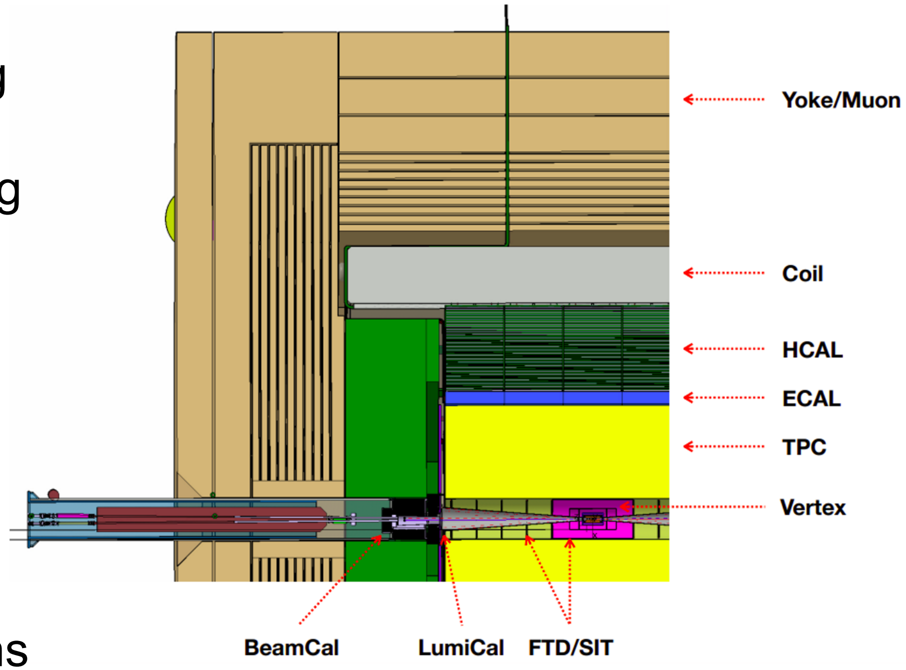


Charged heavy Higgs branching ratios. Taken from Fig. 6 of 1610.02398.

International Large Detector (ILD) @ ILC

ILD @ ILC

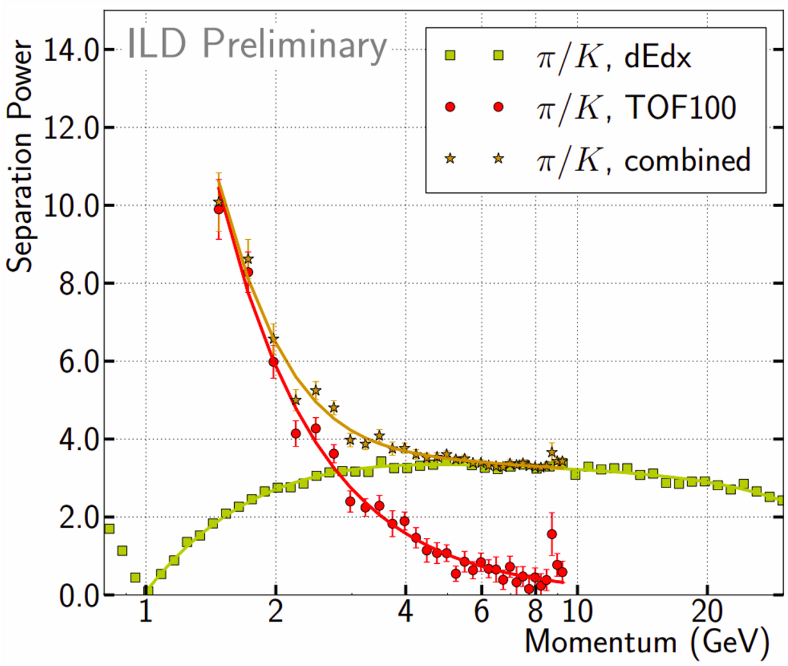
- Detector overview: 1912.04601
- 3 double-layer pixel detectors for vertexing
- Time projection chamber (TPC) for tracking with inner/outer Si layers
- Low material assists in low-p tracking
- High granularity sampling calorimeters for particle flow reconstruction
- Challenge is reconstructing neutral hadrons
- Precise EM/hadronic design still under study
- Tracking/calorimetry contained in 3.5 T field



ILD detector quadrant. Taken from Fig. 1 of 1912.04601.

ILD @ ILC

- Good impact parameter resolution, secondary vertexing
  - Pertinent to b/c-tagging
- For strange versus up/down (“light”) quark tagging, there’s a need for kaon tagging
  - TPC provides dE/dx, Si detectors on either side of TPC provide time-of-flight (TOF) measurement
  - TOF works best at low p (< 10 GeV), expect dE/dx to work better for kaon tagging (where p > 10 GeV)
- ILD already provides BDT scores for b/c-taggers and an other (“o”) tagger per jet – these can be utilized



ILD separation power for pions and kaons using dE/dx and TOF (100 ps resolution). Taken from Fig. 3 of [1912.04601](1912.04601).

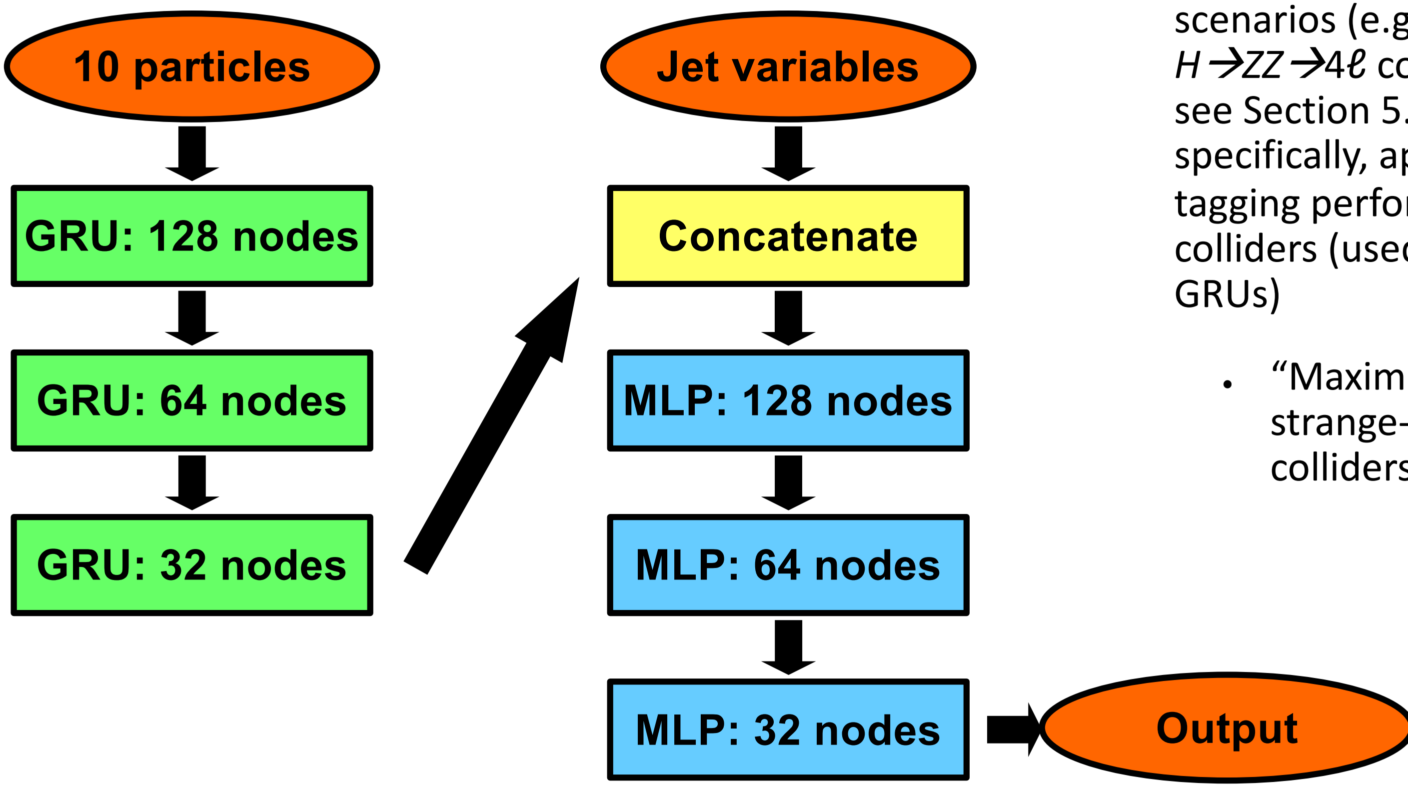
Strange Tagger

Multiclassifier tagger and inputs

- Use a ***multiclassifier* tagger**, which assigns probabilities to the possible flavours of a jet simultaneously
- Train on **ILD-reconstructed *H->qq/gg* samples** (*qq* = *uu*, *dd*, *ss*, *cc*, *bb*) with $\sqrt{s}$ = 250 GeV and $P_L[e^-]$ = -100% and $P_R[e^+]$ = +100%
  - *Unskimmed*, except for $N_{jets} \geq 2$, $N_{leptons} = 0$, and truth $H \rightarrow qq/gg$ cuts

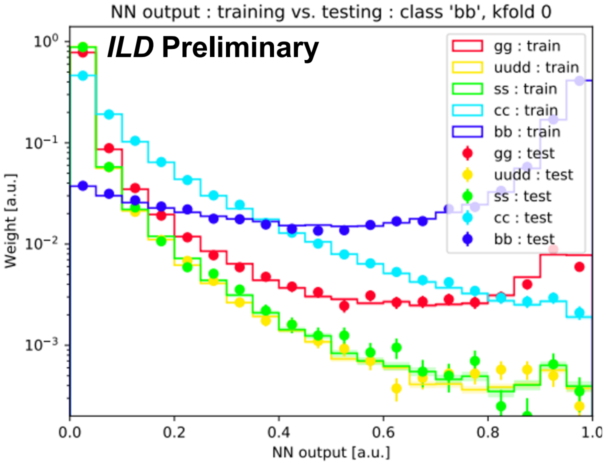
- Use **per-jet level inputs** as well as variables on the **10 leading particles** in each jet (with kinematics re-defined relative to the jet axis and re-normalized relative to jet momentum)
  - Jets:
    - momentum p, pseudorapidity η, polar angle ϕ, mass m, b/c-tagger scores, $N_{particles}$
  - Particles:
    - p, η, ϕ, m, charge, **truth** electron/muon/pion/kaon/proton likelihoods (0 or 1, using PDG ID **– *dE/dx* and TOF likelihoods in ILD samples have a bug – not used in current analysis, opted for truth info instead**)

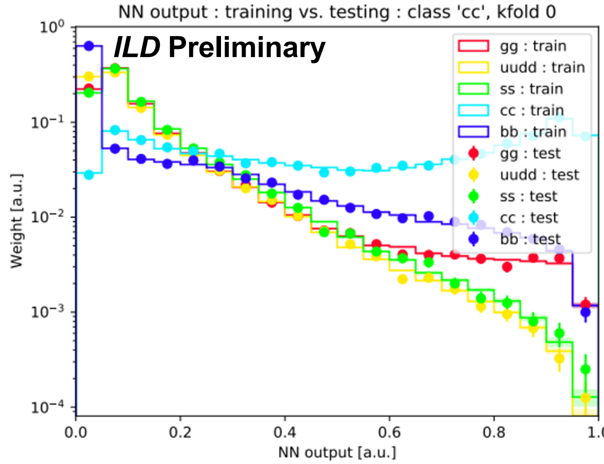
Tagger architecture

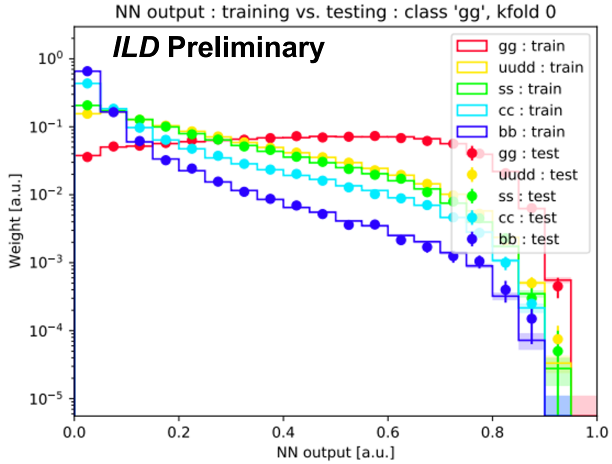


- Architecture shows up in many different HEP measurement scenarios (e.g., recent ATLAS $H \rightarrow ZZ \rightarrow 4\ell$ couplings measurement, see Section 5.2 of 2004.03447); specifically, applied even to strange tagging performance at **hadron** colliders (used LSTMs instead of GRUs)
  - "Maximum performance of strange-jet tagging at hadron colliders" (2011.10736)

Performance: b, c, and g jets

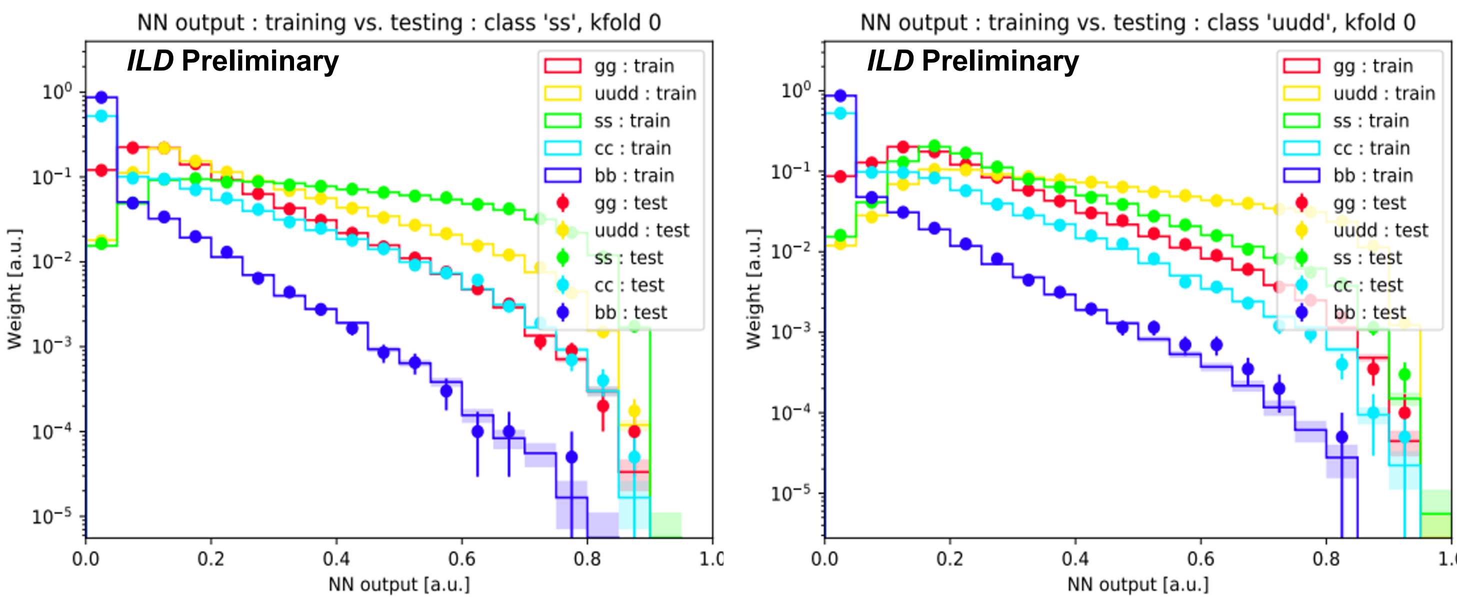






- MVA likely returning *b*/*c*-tagger scores – should do just as well or better than input BDT scores
- Reasonable discrimination of gluon jets

Performance: s and u/d jets



- Separation of *s* and *u*/*d* is **possible** with using truth likelihoods
- At 50% strange tagging efficiency, we have **90%** background rejection over **70%** for LCFIPlus Otag (see ROC curves in back-up and LCWS2021 talk)

$H \rightarrow s\bar{s}$ analysis

Analysis overview

SLAC

- Analysis performed on the same flavour tag samples as for training (500K events per flavour) as well as 2f_Z_hadronic and 4f_ZZ_hadronic samples (1.5M events each) – currently missing W-fusion signal (~10x smaller xs) and WW background
  - Cross sections assume $\sqrt{s}$ = 250 GeV and $P_L[e^-] = -80\%$, $P_R[e^+] = +30\%$
  - Accordingly, use the cross sections decorated onto the miniDSTs and multiply by BR[$H \rightarrow$inv] * BR[$H \rightarrow qq/gg$], BR[$Z \rightarrow$had], or BR[$Z \rightarrow$had]^2
    - N.B.: BR[$H \rightarrow ss$], BR[$H \rightarrow uu$], and BR[$H \rightarrow dd$] **aren't available**, so we take BR[$H \rightarrow cc$] and scale using **ratios of quark masses squared**
      - BR[$H \rightarrow ss$] ~ 2E-4, BR[$H \rightarrow uu$] ~ 2E-6, BR[$H \rightarrow dd$] ~ 5E-7
  - Multiply cross sections by integrated luminosity of **2000 fb^{-1}** to yield events
    - Could consider adding the 500 GeV int. lumi but it implies additional sample production, not easy for the time being

Analysis cuts

- Preliminary selection:
  - Leading and subleading jet momenta, $p_j > 30$ GeV
  - Dijet mass, $M_{jj} \in [120, 140]$ GeV
  - Dijet energy, $E_{jj} \in [125, 160]$ GeV
  - Missing mass, $M_{\text{miss}} \in [75, 120]$ GeV
  - Angular separation, $\Delta R_{jj,\text{miss}} = \sqrt{(\Delta\phi_{jj,\text{miss}}^2 + \Delta\eta_{jj,\text{miss}}^2)} < 4$
    - During last week ILD meeting, suggestion to use angular variable between jets as well, not added yet
  - Leading and subleading LCFIPlus tagger scores, $\text{score}^b_j < 0.2$ && $\text{score}^c_j < 0.35$
  - Number of PFOs per event, $N_{\text{PFOs}}/\text{event} \in [30, 60]$
  - Number of PFOs per jet, $N_{\text{PFOs}}/\text{jet} \in [10, 40]$

Suggested also to look at the scale at which the event goes from 2->3 / 3->4 jets) to reduce 4-jet events from eg WW, ZZ

Cutflow

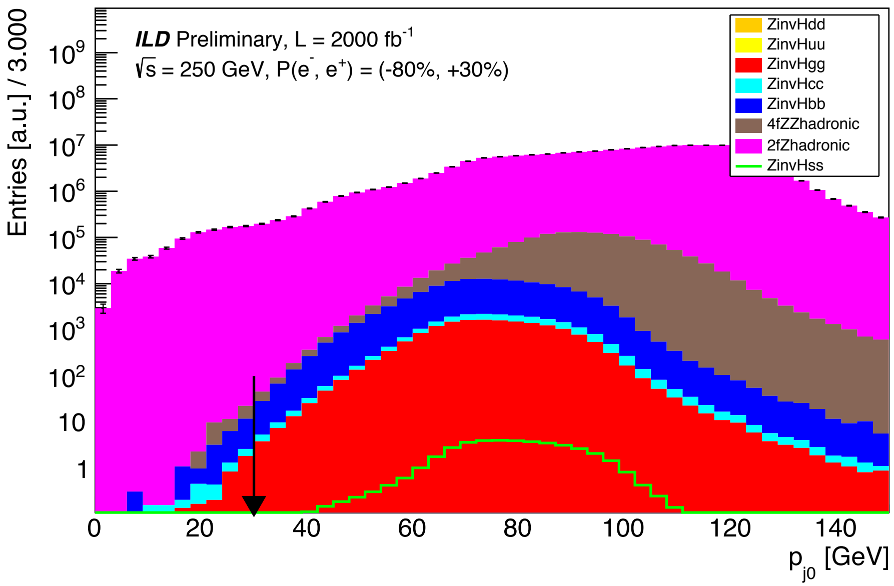
$\mathcal{L}$= 2000 fb^{-1}

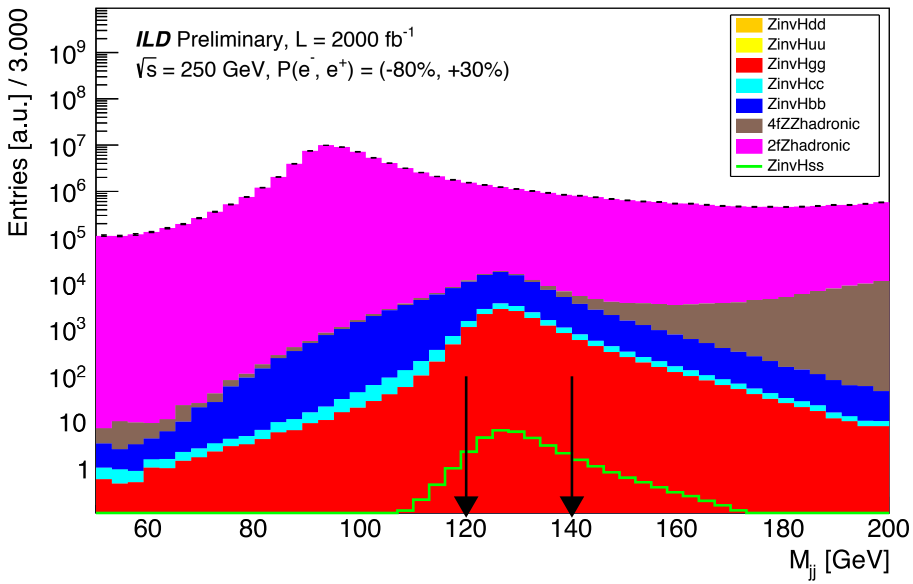
ILD Preliminary, $\sqrt{s} = 250$ GeV, $P(e^-, e^+) = (-80\%, +30\%)$

	$(H \to s\bar{s})(Z \to \nu\nu)$	$(H \to gg)(Z \to \nu\nu)$	$(H \to u\bar{u}/d\bar{d})(Z \to \nu\nu)$	$(H \to c\bar{c})(Z \to \nu\nu)$	$(H \to b\bar{b})(Z \to \nu\nu)$	$Z \to q\bar{q}$	$ZZ \to q\bar{q}q\bar{q}$	Sig. eff.	Bkg. eff.
No cut	42.65 ± 0.06	17254.17 ± 24.41	0.59 ± 0.0	5858.77 ± 8.29	116168.67 ± 164.29	$176876516.6 \pm 161411.64$	1342206.08 ± 1338.33	1.00e+00	1.00e+00
No leptons	42.55 ± 0.06	17225.89 ± 24.39	0.59 ± 0.0	5846.08 ± 8.28	115535.31 ± 163.84	$175328405.19 \pm 160703.71$	1335436.33 ± 1334.95	9.98e-01	9.91e-01
≥ 2 jets	42.55 ± 0.06	17225.89 ± 24.39	0.59 ± 0.0	5846.08 ± 8.28	115535.31 ± 163.84	$175328405.19 \pm 160703.71$	1335436.33 ± 1334.95	9.98e-01	9.91e-01
$p_{j0}, p_{j1} > 30$ GeV	39.46 ± 0.06	16424.08 ± 23.81	0.55 ± 0.0	5619.05 ± 8.12	109492.68 ± 159.5	$131310044.43 \pm 139074.89$	1331247.44 ± 1332.86	9.25e-01	7.44e-01
$M_{jj} \in [120, 140]$ GeV	29.75 ± 0.05	12459.56 ± 20.74	0.42 ± 0.0	3883.41 ± 6.75	63849.78 ± 121.8	7424895.55 ± 33070.82	8041.49 ± 103.59	6.97e-01	4.21e-02
$E_{jj} \in [125, 160]$ GeV	29.62 ± 0.05	12401.25 ± 20.69	0.42 ± 0.0	3862.38 ± 6.73	63407.65 ± 121.38	4027593.77 ± 24356.93	6111.86 ± 90.31	6.94e-01	2.31e-02
$M_{\text{miss}} \in [75, 120]$ GeV	27.56 ± 0.05	11614.11 ± 20.02	0.39 ± 0.0	3612.75 ± 6.51	59551.31 ± 117.63	867590.51 ± 11304.65	2105.79 ± 53.01	6.46e-01	5.30e-03
$\Delta R_{jj,\text{miss}} < 4$	23.82 ± 0.05	10039.07 ± 18.62	0.34 ± 0.0	3124.94 ± 6.05	51512.9 ± 109.4	151865.16 ± 4729.65	1537.31 ± 45.29	5.58e-01	1.22e-03
$\text{score}^b/\text{jet} < 0.2$	22.2 ± 0.04	8593.49 ± 17.22	0.32 ± 0.0	1917.39 ± 4.74	551.1 ± 11.32	88968.53 ± 3620.08	689.92 ± 30.34	5.20e-01	5.65e-04
$\text{score}^c/\text{jet} < 0.35$	20.72 ± 0.04	7745.04 ± 16.35	0.3 ± 0.0	302.77 ± 1.88	179.83 ± 6.46	73060.25 ± 3280.5	548.47 ± 27.05	4.86e-01	4.59e-04
$N_{\text{PFOs}}/\text{event} \in [30, 60]$	13.93 ± 0.03	854.7 ± 5.43	0.2 ± 0.0	146.28 ± 1.31	44.14 ± 3.2	33584.15 ± 2224.16	64.05 ± 9.25	3.27e-01	1.95e-04
$N_{\text{PFOs}}/\text{jet} \in [10, 40]$	12.53 ± 0.03	778.96 ± 5.19	0.18 ± 0.0	136.34 ± 1.26	39.96 ± 3.05	26955.7 ± 1992.62	56.05 ± 8.65	2.94e-01	1.57e-04

- Largest **decrease** in signal efficiency at M_{jj} cut
  - Provides one of the strongest handles on reducing 2f_Z_hadronic, however
- Net result: 30% signal efficiency, 0.016% background efficiency
  - *H→bb s/b* ~ 0.0007 @ No cut can be compared to that in the 4-jet channel, 0.00077 (see extra slides)

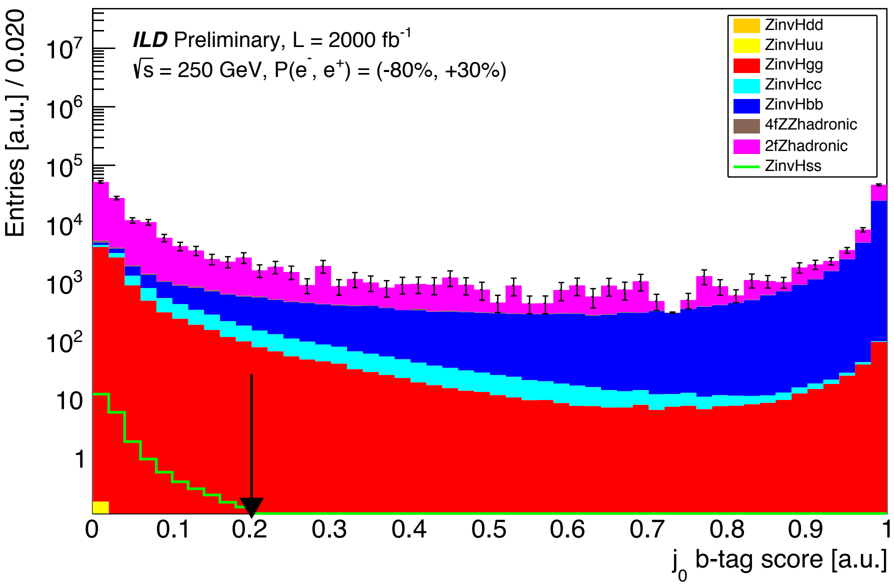
Histograms: pj0 & Mjj

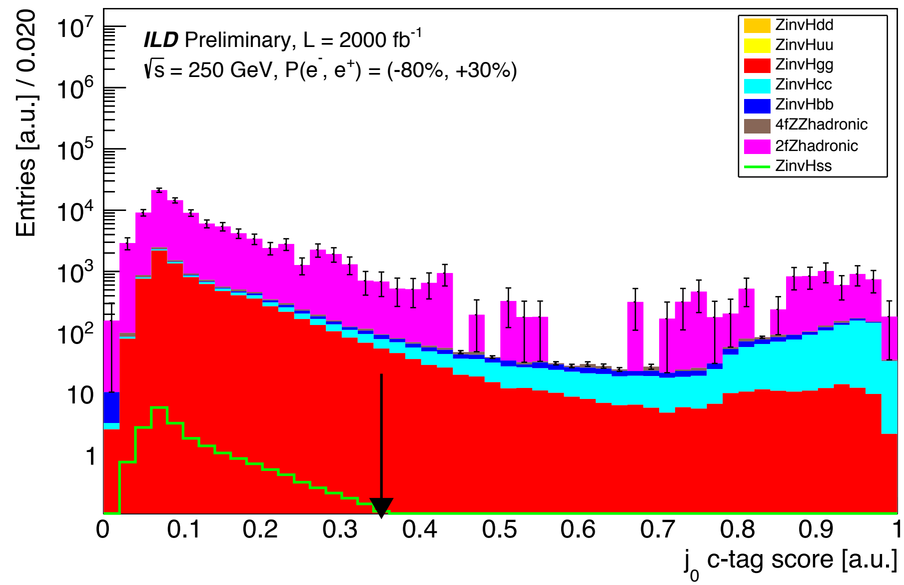




****Unstacked green line is signal****

Histograms: b- & c-tagger scores

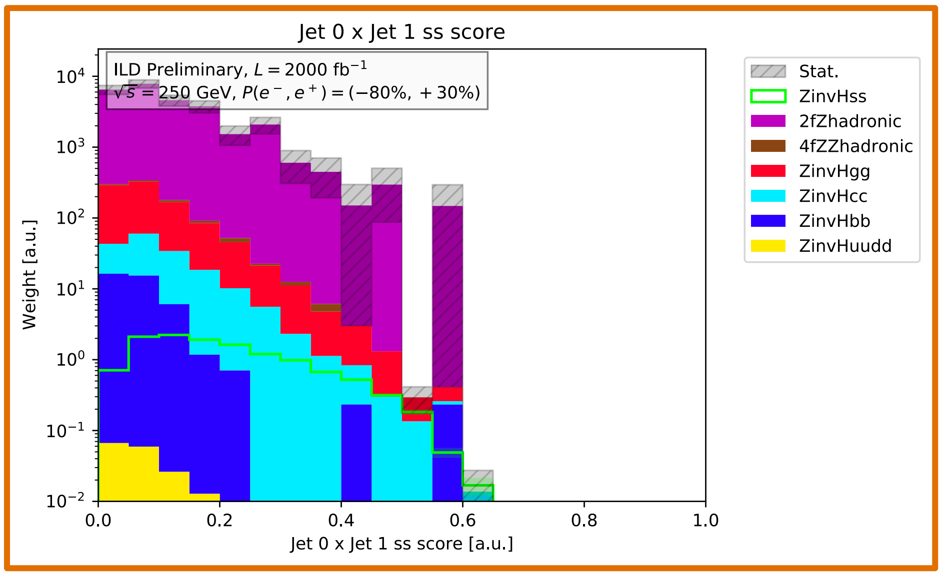


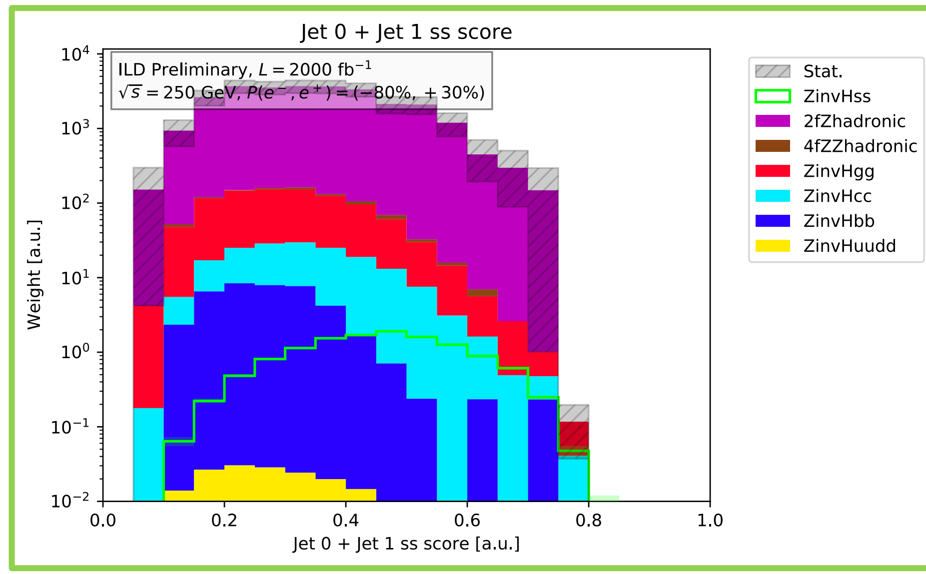


****Unstacked green line is signal****

Signal discriminant

- Using the **product** or the **sum** of leading and subleading strange scores as a discriminant

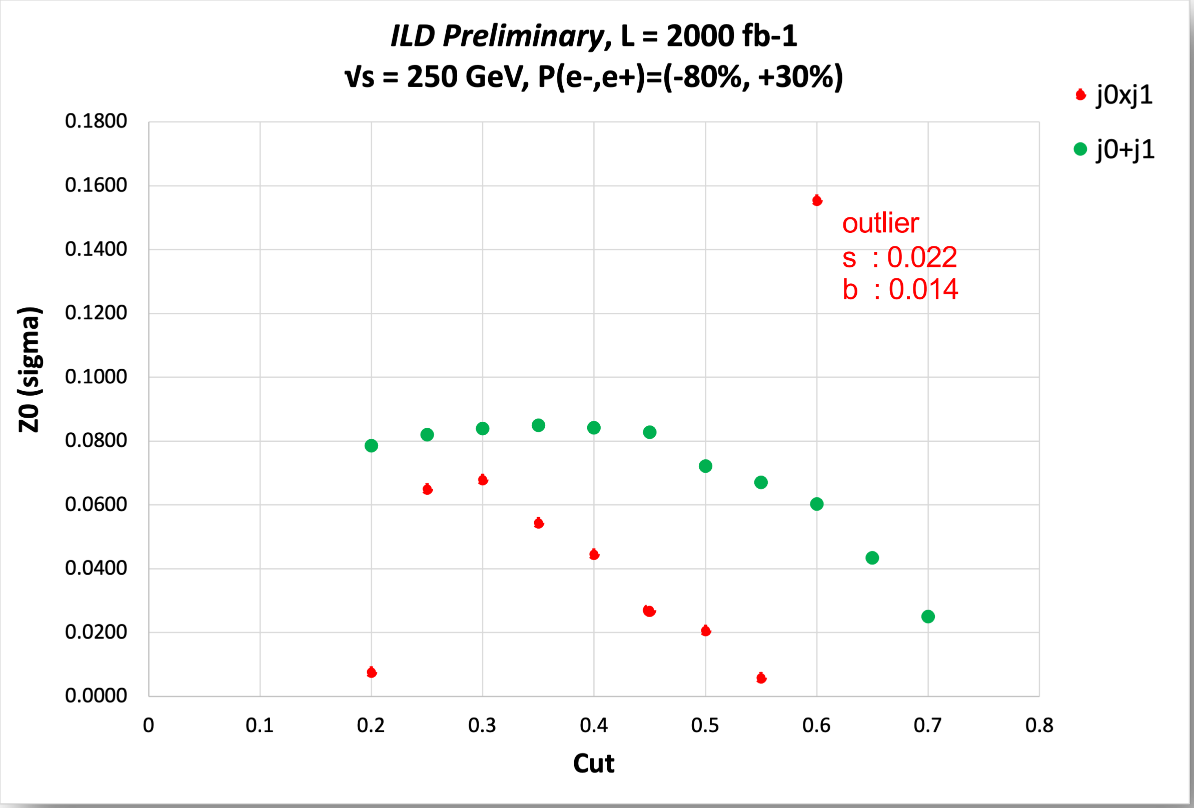




Signal discriminant (2)

- Yields for different cuts:
  - Using asymptotic significance assuming Asimov data (neglecting MC stats):

$$Z_0 = \sqrt{(2 * ((s + b) * \ln(1 + s / b) - s))}$$



Better sensitivity achieved from the sum of the score

Discussion

- Discovery measurement seems ***unlikely***, as expected, even after using truth info in the tagger – set limits instead?
  - Try a BDT using tagger scores and cut-and-count variables? May not be possible, time-wise
- Any gains in the analysis would come from reducing the 2f_Z_hadronic background
  - Tricky, as even now we only keep <10 raw events per 15,000 raw events when processing this background (similar for 4f_ZZ_hadronic)
  - Ongoing discussion on whether to enlarge sample statistics

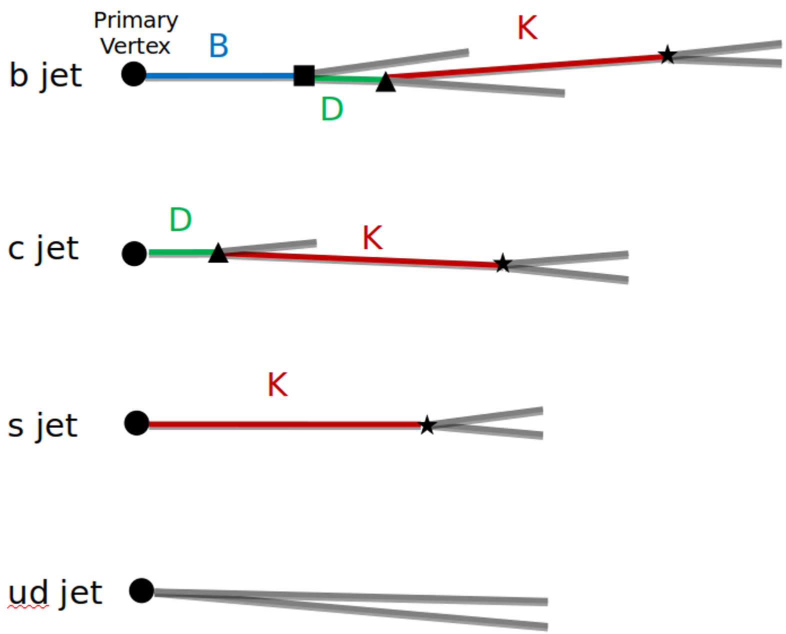
Summary

- Presented progress towards strange tagging with ILD and a *H→ss* analysis
  - Sensitivity is ***limited*** – we are looking at the best case scenario in terms of tagger (save other architectures), analysis cuts could be better optimized more, however
  - We are also happy to scale the results to other scenarios
  - Having MCs for a 2HDM *H→cs* decay could provide prospects for BSM scenarios with enhanced yields
    - Flavour tagger has good performance for c-jets
  - Write up what has been done as a contribution to Snowmass 2021
    - Other analysis could benefit from the usage of this strange tagger!

Extra Slides

Jet Types

Discriminants



Charged Kaon track

- Zero track impact parameter w.r.t. primary vertex
- Momentum fraction relative to the jet momentum carried by the leading Kaon
    - (Longitudinal vs transverse components?)

V^0 (K_S^0,Λ^0)

- Vertex momentum & displacement must point in the same direction
- Mean vertex distance smaller compared to b/c

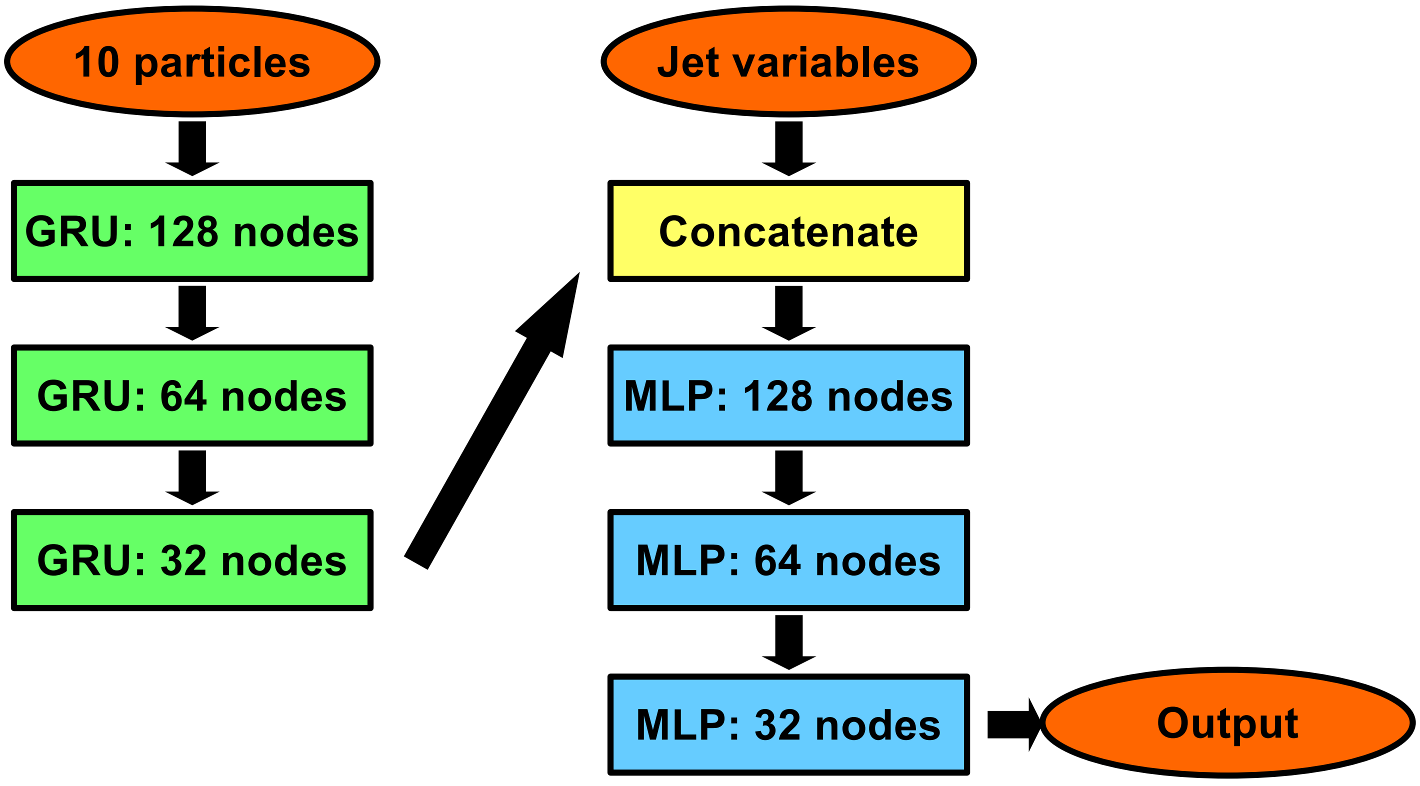
+ the usual b/c discriminants (vertex mass, impact parameter for all tracks, etc.)

Remember to normalize the discriminants to make them boost invariant (as much as possible)

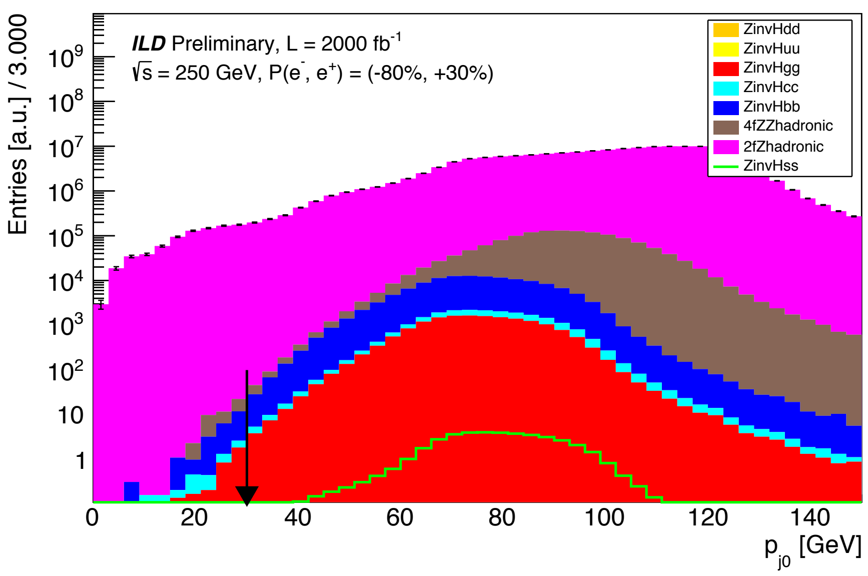
Taken from Slide 5 of Tomohiko Tanabe's 2020/11/24 presentation.

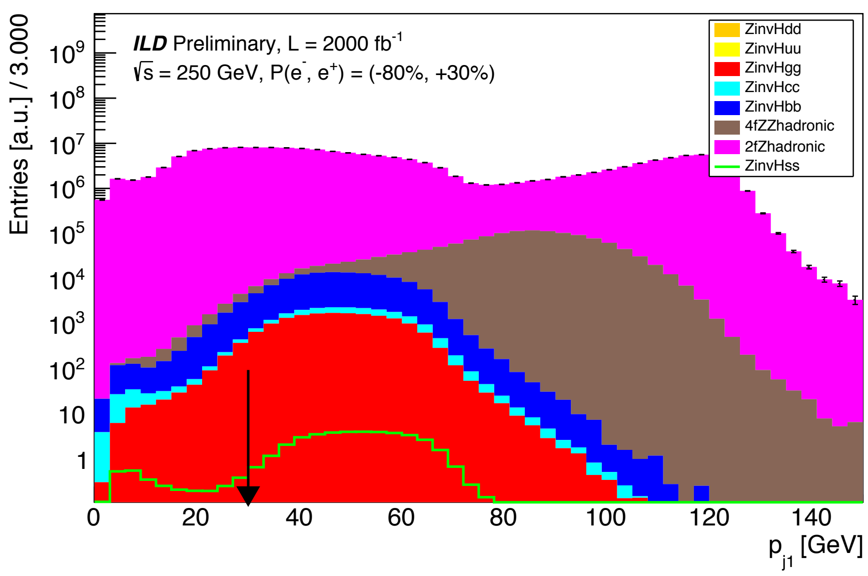
5

Tagger architecture: pictorially



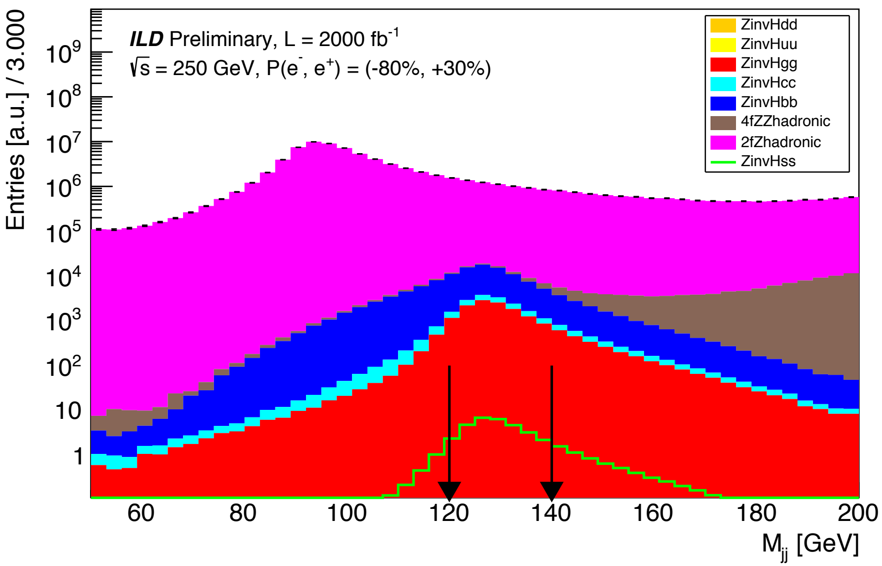
Histograms: pj0 and pj1

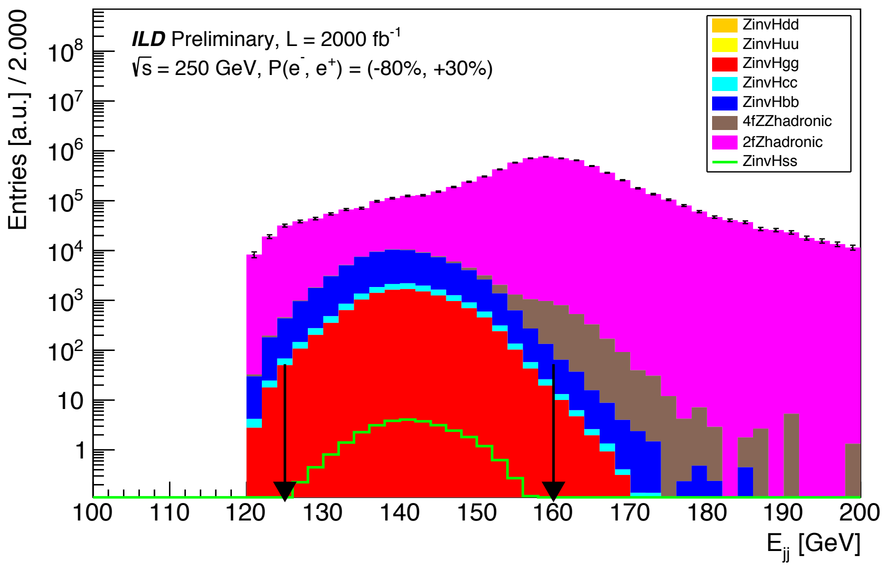




****Unstacked green line is signal****

Histograms: Mjj and Ejj





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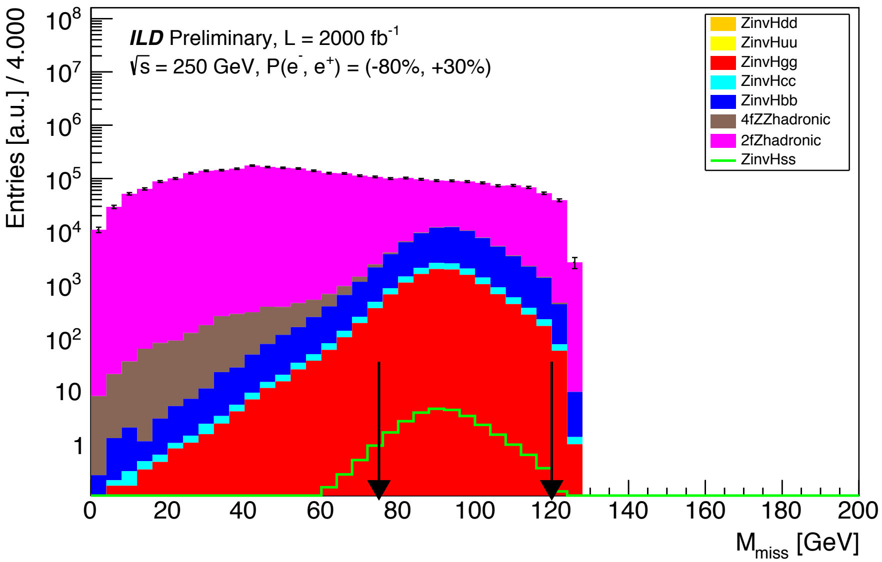
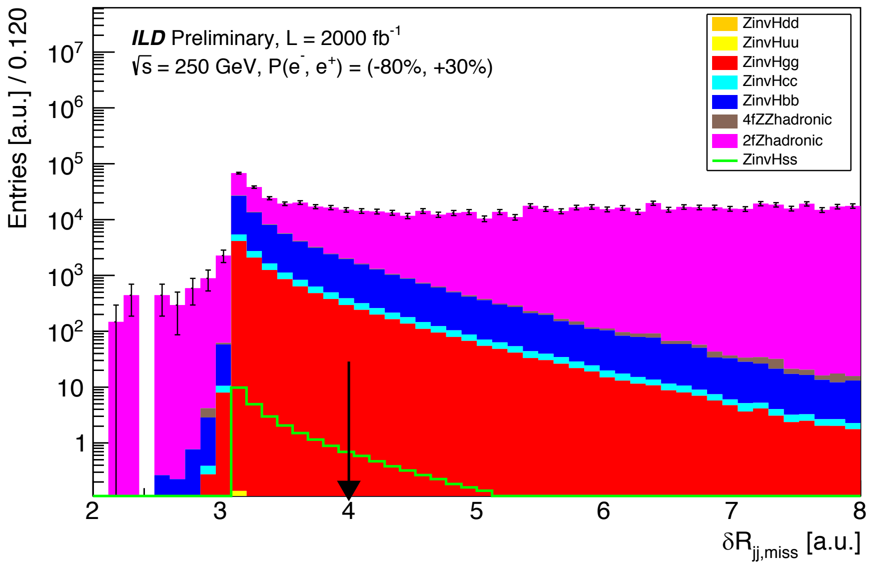
Histograms: Mmiss and ΔRjj,miss





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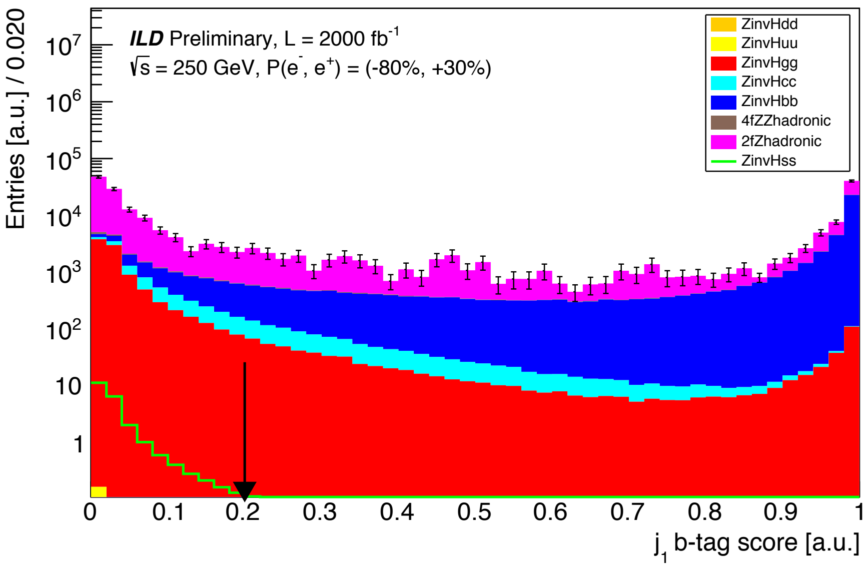
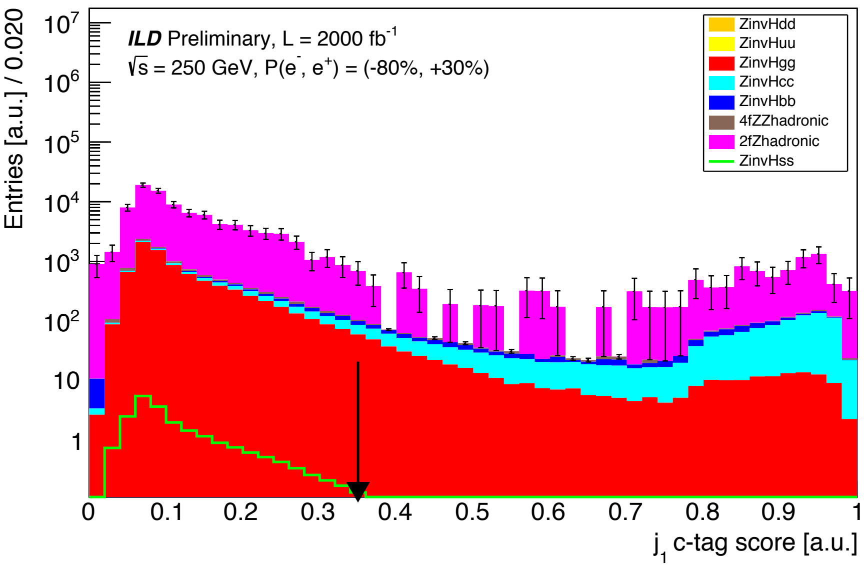
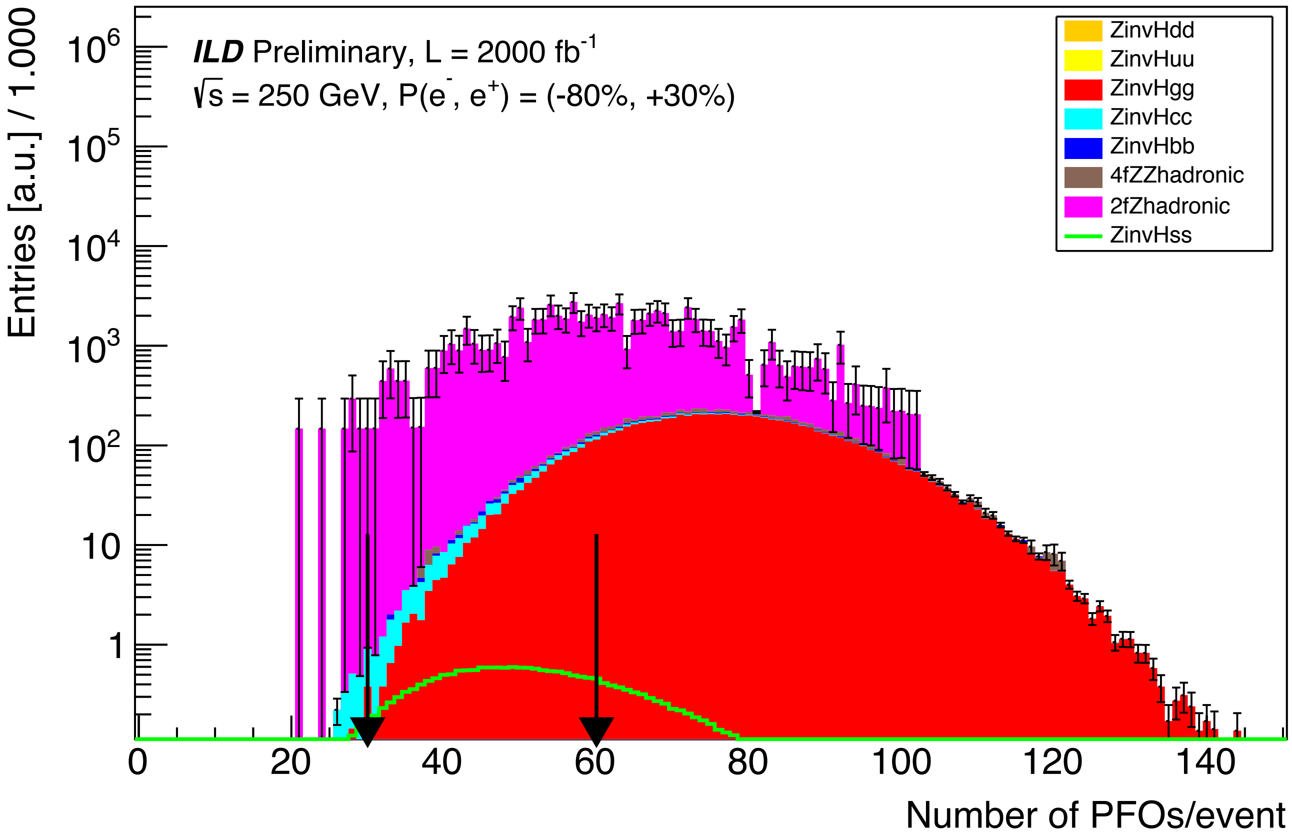
Histograms: b- & c-tagger scores



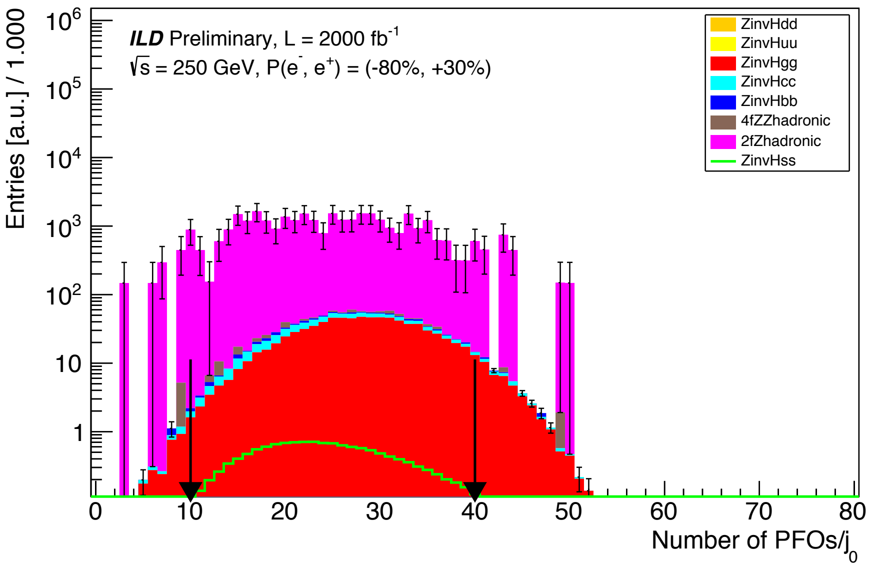


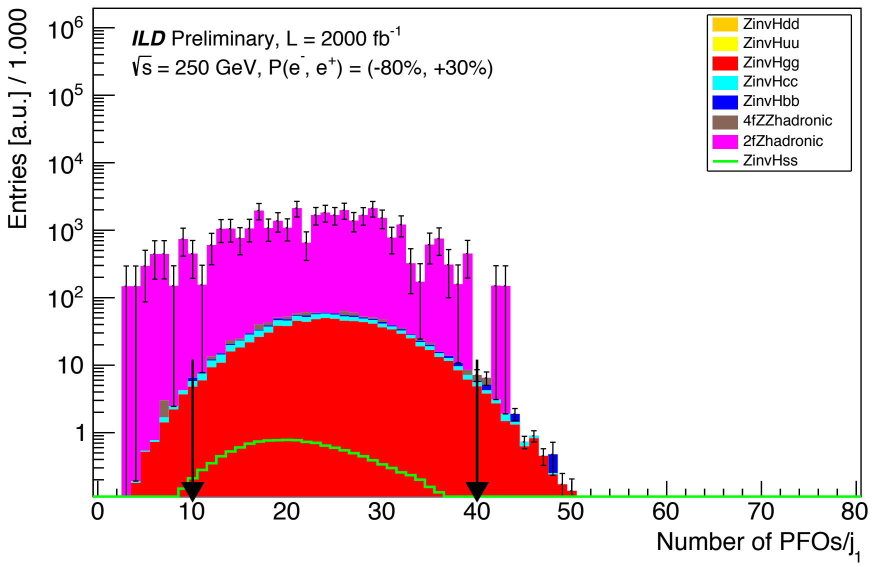
****Unstacked green line is signal****

Histograms: NPFOs/event



Histograms: NPFOs/jet





****Unstacked green line is signal****

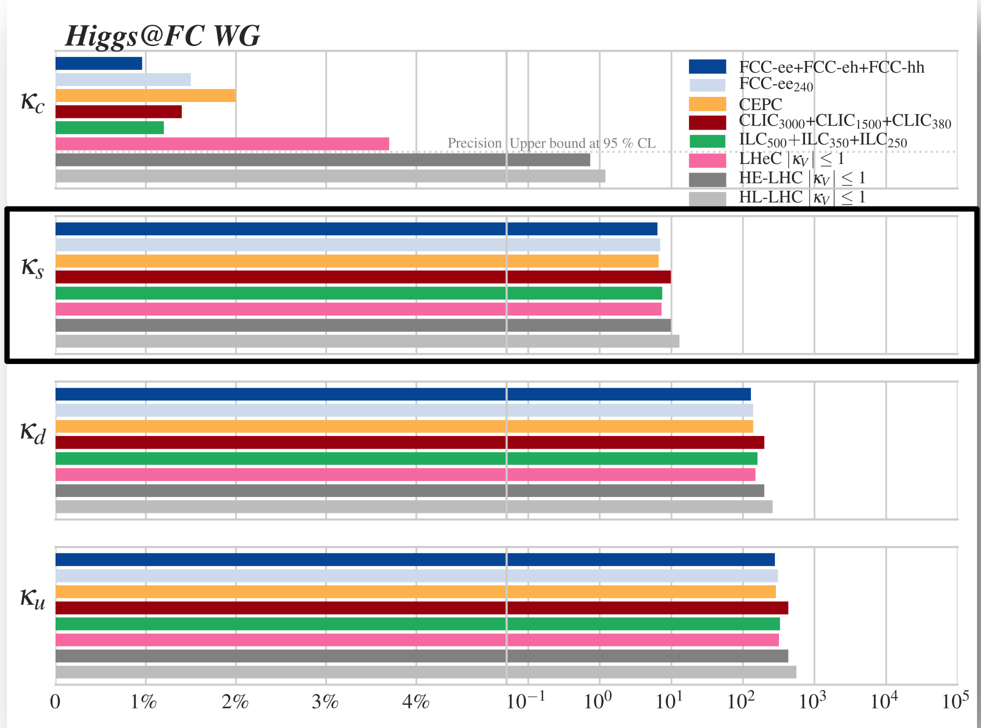
Signal discriminant (2)

j0 x j1:
Cut: 0.2
s : 5.5654785096412525
b : 5253.939919094857
Z0 : 0.07676854538565478
Cut: 0.25
s : 3.9403779269196093
b : 3728.830329093824
Z0 : 0.06451713959512251
Cut: 0.3
s : 2.7415917753241956
b : 1644.0106210620702
Z0 : 0.06759737625722617
Cut: 0.35
s : 1.7592644195538014
b : 1042.245556926145
Z0 : 0.054478354764755384
Cut: 0.4
s : 1.0887995637021959
b : 594.2361149458384
Z0 : 0.04465148158251319
Cut: 0.45
s : 0.566939894342795
b : 443.92903776872777
Z0 : 0.026902202768505058
Cut: 0.5
s : 0.2524129586527124
b : 148.01879303174542
Z0 : 0.020741007866406074
Cut: 0.55
s : 0.07083354517817497
b : 147.72465044426963
Z0 : 0.00582743974151281
Cut: 0.6
s : 0.021902027539908886
b : 0.013714998960494995
Z0 : 0.15548956770016534

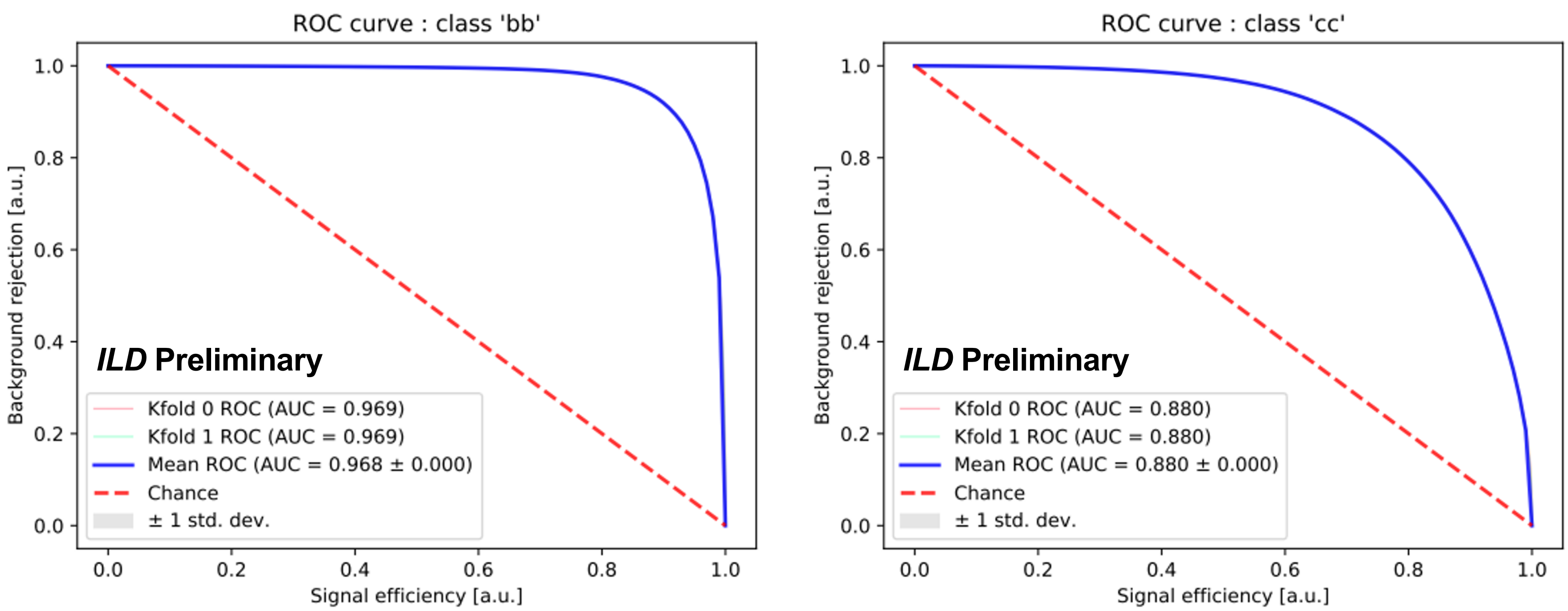
j0 + j1:
Cut: 0.2
s : 12.242391029838473
b : 24256.373724540405
Z0 : 0.07859895706194787
Cut: 0.25
s : 11.75890307186637
b : 20571.76969071827
Z0 : 0.08197654633491663
Cut: 0.3
s : 10.947859286679886
b : 17024.09735365923
Z0 : 0.08389780949113125
Cut: 0.35
s : 9.810693963780068
b : 13326.963469873936
Z0 : 0.08497298080156246
Cut: 0.4
s : 8.271826807060279
b : 9660.45653458523
Z0 : 0.08414738944817839
Cut: 0.45
s : 6.574709334061481
b : 6314.407373362772
Z0 : 0.08272464629857522
Cut: 0.5
s : 4.666403093840927
b : 4183.467504632149
Z0 : 0.07213289177636732
Cut: 0.55
s : 3.065837964299135
b : 2088.717378884584
Z0 : 0.06706611758544637
Cut: 0.6
s : 1.8046592578757554
b : 894.4982530597899
Z0 : 0.06031974977244867
Cut: 0.65
s : 0.9168394939042628
b : 445.62633642762626
Z0 : 0.043416925775766405
Cut: 0.7
s : 0.3047961258562282
b : 148.42523148232203
Z0 : 0.025009616775977003

Existing bounds

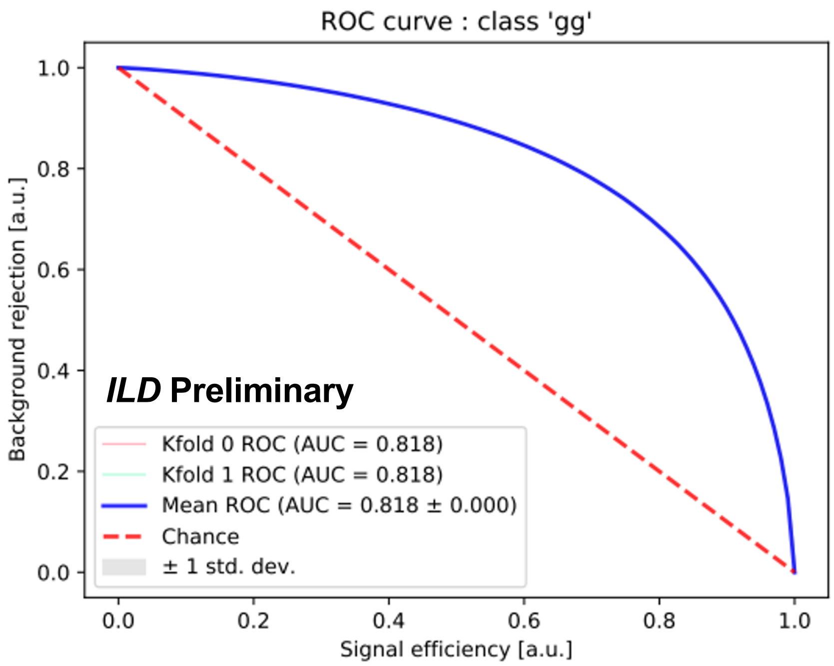
arXiv:1905.03764v2



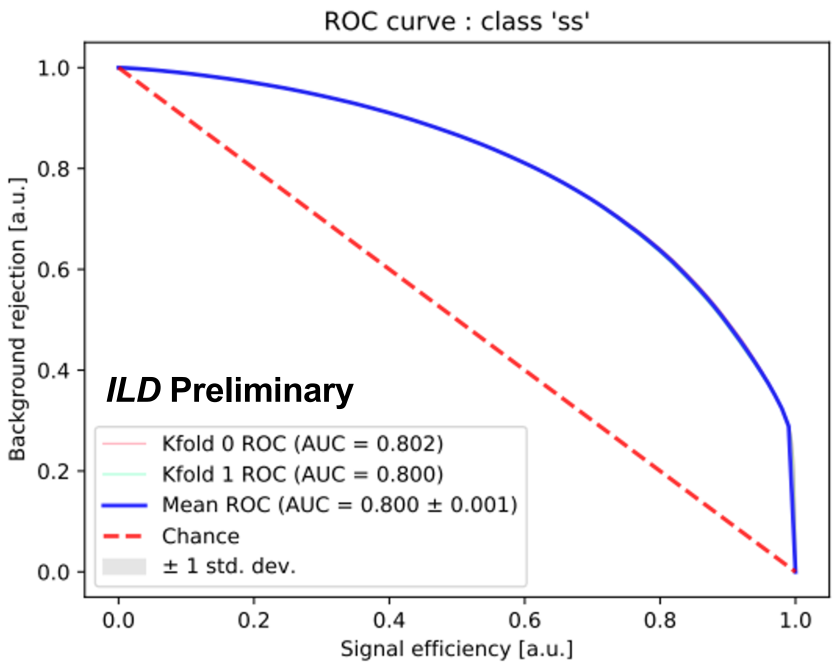
ROC curves: b and c jets

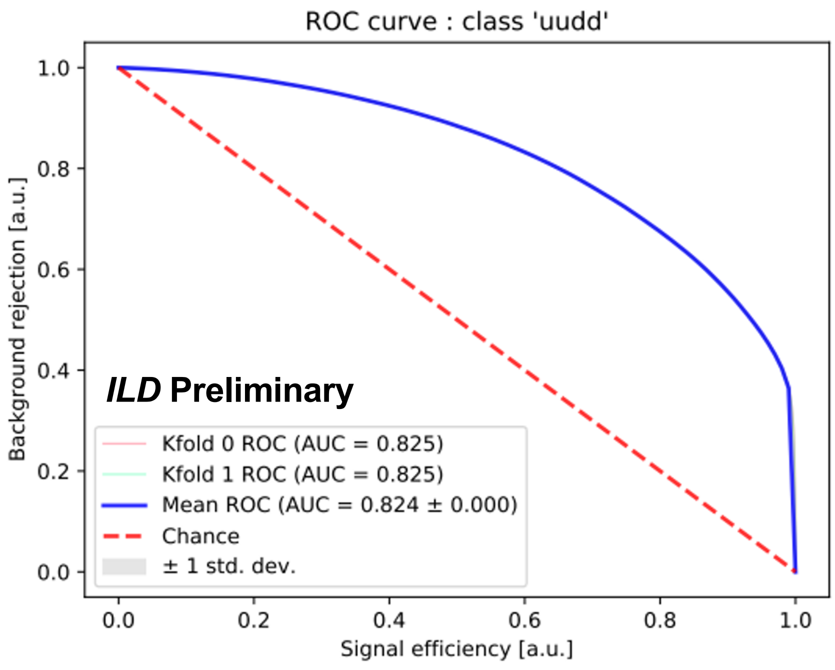


ROC curves: g jets



ROC curves: s and u/d jets





e+e- cross sections

Table 2: Cross-sections and number of generated MC samples on the Higgs production processes and the major SM background processes for both $\sqrt{s} = 250$ and 500 GeV. The cross-sections given in the table are set to be each operation beam polarization states: $P(e^-, e^+) = (-80\%, +30\%)$ and $P(e^-, e^+) = (+80\%, -30\%)$, whereas the number of MC samples are given with fully beam polarization states: $P(e^-, e^+) = P^L_{e^-} P^R_{e^+} = (-100\%, +100\%)$. The eeH(s) and eeH(t) denote the s-channel ZH process and the t-channel ZZ-fusion processes. $2f\_l$ and $2f\_h$ in the table indicate that the final state has a lepton pair such as charged leptons or neutrinos, and a quark pair like $u\bar{u}$, $d\bar{d}$ except $t\bar{t}$. $4f\_l$ and $4f\_h$ are the same indication with $2f\_l$ or $2f\_h$, that means a final state has two lepton pairs or two quark pairs. $4f\_sl$ shows that a final state has a lepton pair and a quark pair. At $\sqrt{s} = 500$ GeV $6f$ is included in the SM backgrounds, where possible diagrams of 6 fermions in a final state are considered such as $t\bar{t}$ and a fermion pair with two W bosons and two fermion pairs with the Z boson.

$\sqrt{s}$=250 GeV	operation polarization		fully polarization			
	Cross-section (fb)		MC sample			
$P(e^-, e^+)$	$(-80\%, +30\%)$	$(+80\%, -30\%)$	$P^L_{e^-} P^R_{e^+}$	$P^R_{e^-} P^L_{e^+}$	$P^L_{e^-} P^L_{e^+}$	$P^R_{e^-} P^R_{e^+}$
eeH(s)	10.7	7.14	$4.00 \cdot 10^4$	$1.00 \cdot 10^4$	0	0
eeH(t)	0.71	0.52	$1.00 \cdot 10^4$	$1.00 \cdot 10^4$	3992	3992
$\mu\mu H$	10.4	7.03	$4.00 \cdot 10^4$	$1.00 \cdot 10^4$	0	0
qqH	210.2	141.9	$5.45 \cdot 10^5$	$2.94 \cdot 10^5$	0	0
$\nu\nu H$ (s)	61.6	41.6	$12.8 \cdot 10^4$	$6.50 \cdot 10^4$	0	0
$\nu\nu H$ (t)	15.4	0.93	$12.8 \cdot 10^4$	$6.50 \cdot 10^4$	0	0
$2f\_l$	$3.82 \cdot 10^4$	$3.49 \cdot 10^4$	$2.63 \cdot 10^6$	$2.13 \cdot 10^6$	$5.03 \cdot 10^5$	$5.03 \cdot 10^5$
$2f\_h$	$7.80 \cdot 10^4$	$4.62 \cdot 10^4$	$1.75 \cdot 10^6$	$1.43 \cdot 10^6$	0	0
$4f\_l$	$6.03 \cdot 10^3$	$1.47 \cdot 10^3$	$2.25 \cdot 10^6$	$9.80 \cdot 10^4$	$2.73 \cdot 10^5$	$2.73 \cdot 10^5$
$4f\_sl$	$1.84 \cdot 10^4$	$2.06 \cdot 10^3$	$4.04 \cdot 10^6$	$3.56 \cdot 10^5$	$9.78 \cdot 10^4$	$9.78 \cdot 10^4$
$4f\_h$	$1.68 \cdot 10^4$	$1.57 \cdot 10^3$	$2.38 \cdot 10^6$	$2.42 \cdot 10^5$	0	0

Table 2, taken from page 62 of Tomohisa Ogawa's thesis

H→bb analysis: histograms

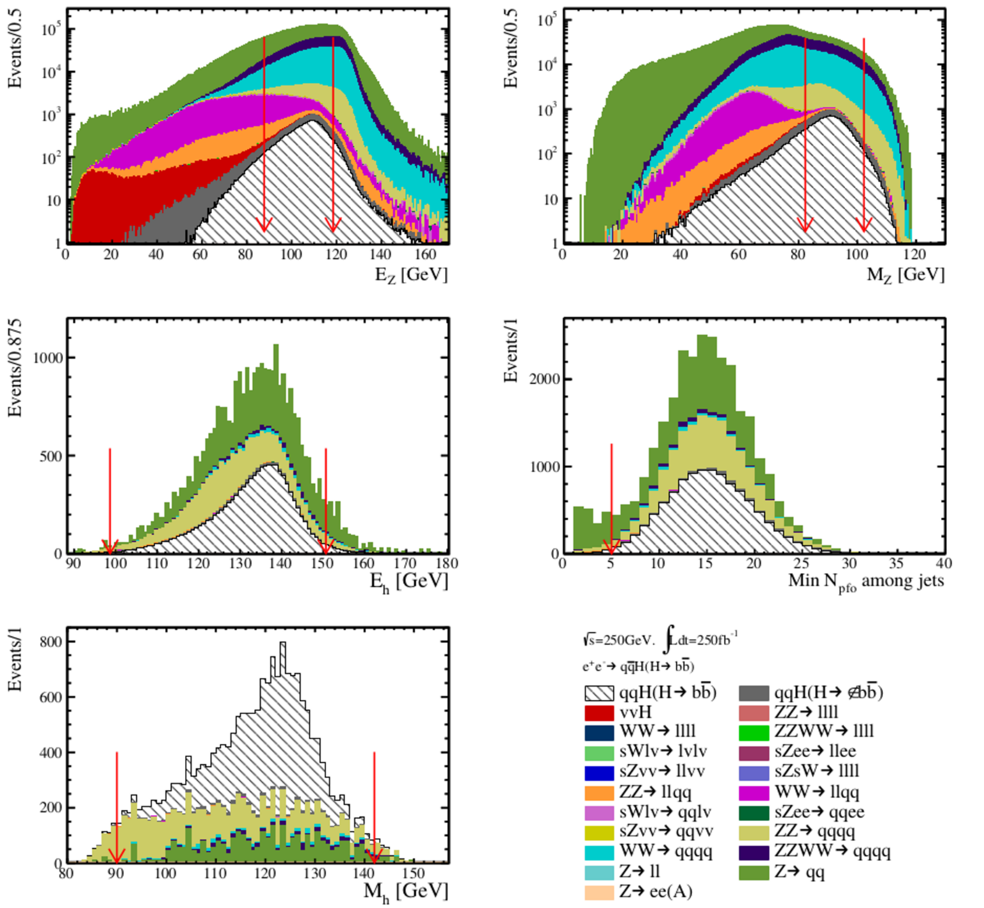


Figure 66: The distributions show each observable used for the background suppression assuming 250 fb^{-1} with $P(e^-, e^+)$= (-80%,+30%). The explanation of the observables are given in the text. Red arrows on each plot indicate the cut values applied to each observable as the background suppression.

Figure 66, taken from page 87 of Tomohisa Ogawa's thesis

H→bb analysis: cutflow

Table 4, taken from page 89 of Tomohisa Ogawa's thesis

Table 4: The expected number of remaining signal and background events after each cut for the $Zh \to q\bar{q}b\bar{b}$ at $\sqrt{s}$=250 GeV, with with both of the beam polarization states: P(e^-, e^+)= (-80%,+30%) and (+80%,-30%). The integrated luminosity of 250 fb^{-1} is assumed. The signal efficiency ϵ and significance S_{sig} are also given in the table.

$\sqrt{s}$=250 GeV   P(e^-, e^+)= (-80%,+30%)

Cut variables	$q\bar{q}b\bar{b}$	ϵ	$q\bar{q}H(H \notin b\bar{b})$	$2f$	$4f$	S_{sig}
No cut	30372	100	22175	$2.9 \cdot 10^7$	$1.02 \cdot 10^7$	-
$N_{isolep} = 0$	30314	99.8	17492	$2.6 \cdot 10^7$	$6.9 \cdot 10^6$	5.28
$N_{pfo} \in [55,\ 170]$	30218	99.5	15141	$6.0 \cdot 10^6$	$4.4 \cdot 10^6$	9.37
$E_Z \in [87.75,\ 118.50]$ GeV	25712	84.7	11365	$3.3 \cdot 10^6$	$2.8 \cdot 10^6$	10.35
$M_Z \in [82.29,\ 102.29]$ GeV	18658	61.4	7572	$3.8 \cdot 10^5$	$1.0 \cdot 10^6$	15.62
$b\text{-}tag \in [1.25,\ 2.0]$	11203	36.9	381	9364	8454	65.76
$E_H \in [98.67,\ 150.67]$ GeV	10909	35.9	368	8242	7998	66.21
Min $N_{pfo} \in [5,\ 40]$	10841	35.7	358	6932	7792	67.81
$-\log y_{32} \in [0.5, 3.62]$	10409	34.3	349	3917	7453	70.53
$-\log y_{43} \in [1.8, 5.52]$	10065	33.2	346	2921	7027	71.15
thrust $T \in [0.5,\ 0.89]$	9966	32.8	345	2520	7004	71.39
$M_H \in [90,\ 142]$ GeV	9907	32.6	335	2419	6382	72.43

Meeting the ILD community

Inputs and outputs

- Outputs: could imagine the network provides bottom, charm, strange, and light output scores
  - **Multiclassifier** provides more freedom for output class
- Jets: p4, ILD tagger scores (b-, c-, o-, and category?), ...
  - **Anything else which is sensible/useful to include?**
- Tracks (jet constituent particles): p4, momentum / jet momentum, dE/dx (+ uncertainty?), different PID likelihoods, ...
  - **Anything else?**

We really invite you to read this!

More in Jan's talk!

We found out in the meeting that dE/dx is bugged in the current version of the ILD ntuples! ☹

Tagger architecture(s)

- Possible architectures from the literature include:
  - "Maximum performance of strange-jet tagging at **hadron** colliders" (2011.10736 – published in November 2020)
    - {Recurrent neural network for track inputs} + {jet inputs} -> Concatenate -> multilayer perceptron (MLP) -> output
    - Could also use MLP on the jet inputs prior to concatenation
  - "ParticleNet: Jet Tagging via Particle Clouds" (1902.08570)
    - Proposed for flavour tagging at FCC-ee (see talk here)
    - *Complex*: represent particles in jet as a graph and apply EdgeConv (1801.07829) units to relationships between a given particle and its nearest neighbours

Maximum performance of strange tagging at colliders: https://arxiv.org/pdf/2011.10736.pdf

Name	Selection criteria	Input variables
Universal detector	$\tau > 0$	E, η, ϕ, m (4-momentum) r_0, η_0, ϕ_0 (origin) τ (lifetime in lab system) q (charge)
Universal detector excluding beampipe	$\tau > 0$ $r_f > 10\,\text{mm}$	E, η, ϕ, m (4-momentum), r_i, η_i, ϕ_i (initial measurement), τ (lifetime in lab system), q (charge)
Infinite tracker	$\tau > 0$ $r_f > 10\,\text{mm}$ $q \neq 0$	p, η, ϕ (4-momentum minus mass) r_i, η_i, ϕ_i (initial measurement) τ (lifetime in lab system) q (charge)
Finite tracker	$\tau > 0$ $r_f > 10\,\text{mm}$ $q \neq 0$ $r_0 < 1\,\text{m}$	p, η, ϕ (4-momentum minus mass) r_i, η_i, ϕ_i (initial measurement) τ (lifetime in lab system) q (charge)
Cherenkov tracker	$\tau > 0$ $r_f > 10\,\text{mm}$ $q \neq 0$ $r_0 < 1\,\text{m}$	p, η, ϕ, m (4-momentum) r_i, η_i, ϕ_i (initial measurement) τ (lifetime in lab system) q (charge)
Calorimeter without ECAL/HCAL separation	$\tau > 0$ $r_0 < 1\,\text{m}$ $r_f > 1\,\text{m}$ no ν	E, η, ϕ (3-momentum)
Calorimeter with ECAL/HCAL separation	$\tau > 0$ $r_0 < 1\,\text{m}$ $r_f > 1\,\text{m}$ no ν	E, η, ϕ (3-momentum), particle category (γ/e, μ, other)
Finite tracker, no $0 \to +-$ decays	$\tau > 0$ $r_f > 10\,\text{mm}$ $r_0 < 1\,\text{m}$ $q \neq 0$ no charged particles from neutral decays	p, η, ϕ, m (4-momentum) r_i, η_i, ϕ_i (initial measurement) τ (lifetime in lab system) q (charge)
Finite tracker, only $0 \to +-$ decays	$\tau > 0$ $r_f > 10\,\text{mm}$ $r_0 < 1\,\text{m}$ $q \neq 0$ only charged particles from neutral decays	p, η, ϕ, m (4-momentum) r_i, η_i, ϕ_i (initial measurement) τ (lifetime in lab system) q (charge)

Table 1. List of all considered detector scenarios as a combination of ideal detector components. The second column shows the selection requirements imposed on the particles used as input to the neural networks, where τ means the lifetime of the particles, r_0 is the radial distance between the primary vertex and the point where the particle is created, and r_f is the radial distance between the primary vertex and the decay vertex. The third column describes the variables that are used as inputs to the neural network. If the variable carries a subscript 0, it refers to the spacepoint of creation, and if it carries a subscript i, it refers to the spacepoint of initial measurement.

– 6 –

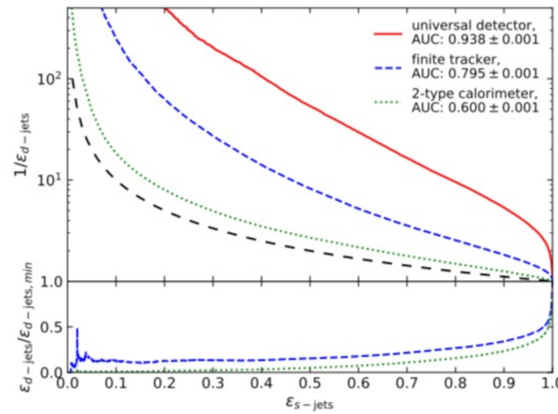


Figure 14. ROC curves illustrating the classification power of the neural networks in the universal-detector, finite-tracker, and ECAL/HCAL-separated calorimeter ("2-type calorimeter") scenarios. The signal is composed of s-jets, and the background is composed of d-jets. The dashed line illustrates a ROC curve for the case of no separation. The ratio beneath the ROC curves shows the efficiency for d-jets in one scenario ($\varepsilon_{d\text{-jets}}$) divided by the efficiency for d-jets in the scenario with the best separation power shown in the ROC curve ($\varepsilon_{d\text{-jets,min}}$). The efficiencies are evaluated on the test sample and the uncertainty in the area under the curve is the statistical uncertainty associated with that sample.

- Assuming an ideal detector that can perfectly measure all jet constituents ("universal collider detector"), s- and d-jets can be separated well. This means that the fragmentation of s- and d-jets shows promising differences that may be explored in an s-tagging algorithm, but that the maximum achievable performance of an s-tagger is by far not as good as for example achieved for b-tagging algorithms (see back-up for comparison)
- The comparison also shows that the information measured in a perfect tracker may be much more valuable for s-tagging than the energy deposits measured in electromagnetic and hadronic calorimeters.
- Interestingly, the addition of an ideal Cherenkov detector to the tracking scenario does not yield a large improvement.

Possible FCC Collaborators

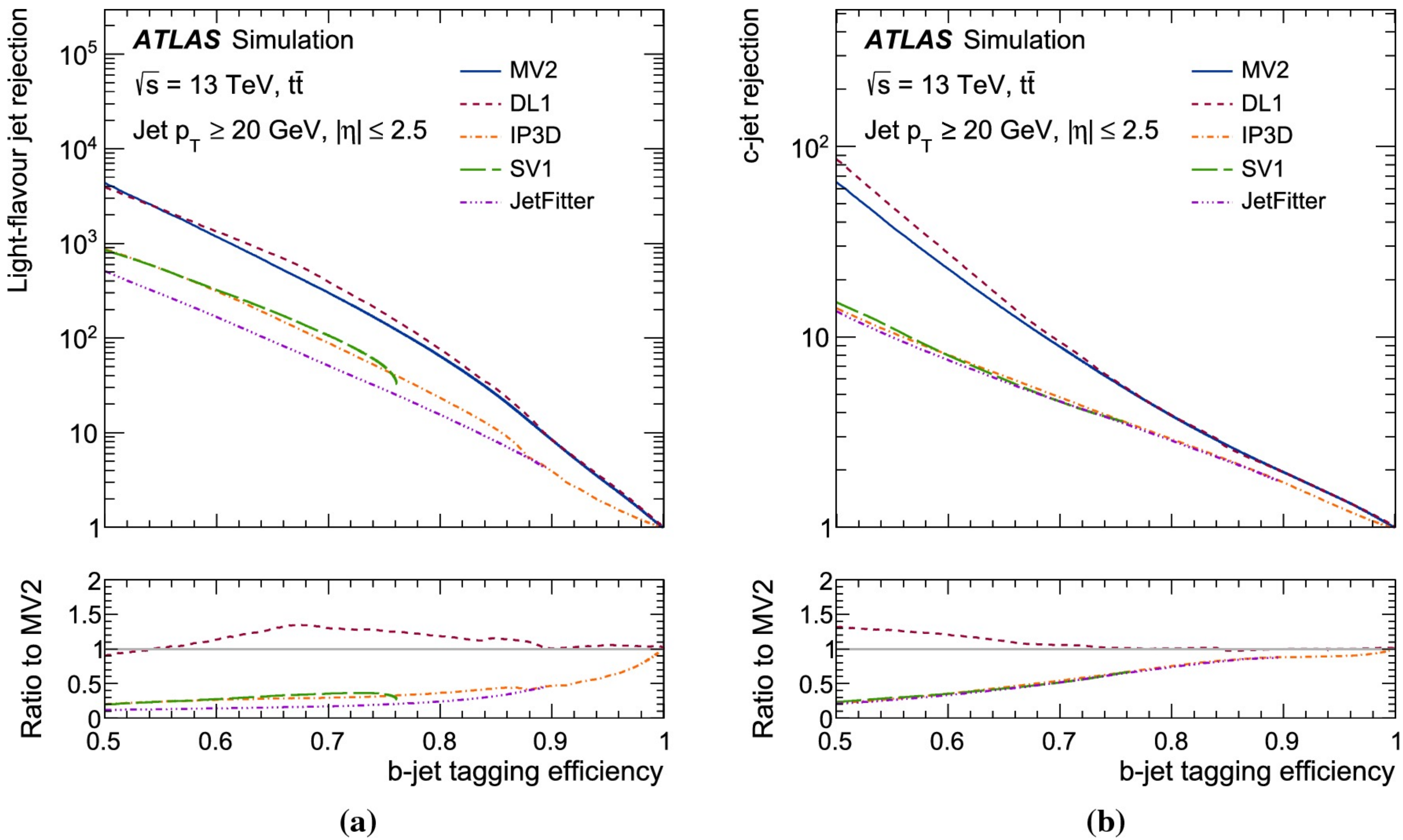
- David D'Enterria gave a talk during one of the EF1 meetings on ***Electron Yukawa from s-channel in e^+e^- → Higgs production at FCC-ee*** and during the talk he mentioned that he was working also on H->ss, so we got in touch with him to explore possible collaborations

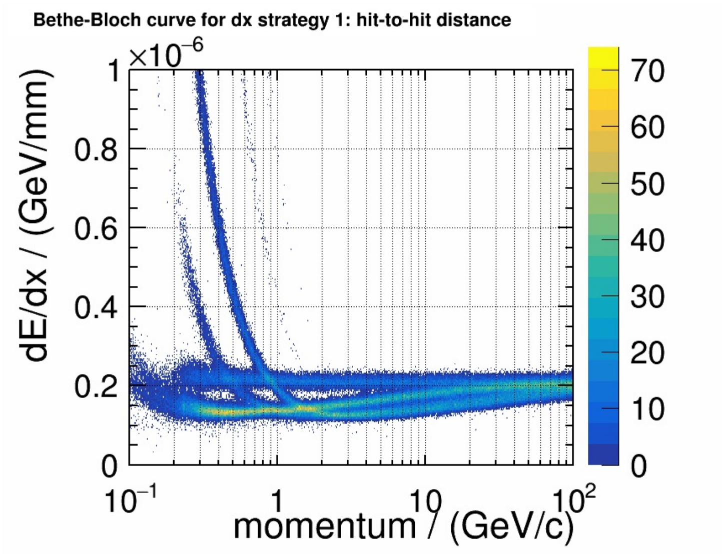
- Their focus would be on the exclusive **H->phi+gamma** decay, rather than the full h->ssbar with jet reconstruction
  - *One expects a handful of such rare decay events with the ~1.5 million Higgs expected at the **FCC-ee***
  - *This direct decay interferes with the (more probable)* ***H->gamma gamma*->gamma phi channel****, and one needs to disentangle the dependence of the yields on k_gamma and k_s (the k_gamma coupling should be known with good accuracy...).*
  - *There are phenomenological studies for the LHC* (in fact we has cited the one from the ATLAS Collaboration), *but neither of us recalled them for e+e-.*
  - He proposed to take a closer look at it and try to estimate the actual sensitivity to k_s
  - If potentially relevant, and if we are interested in that channel, we carry out together a simulation analysis...
    - Main signal and background samples needed would be the ones mentioned above

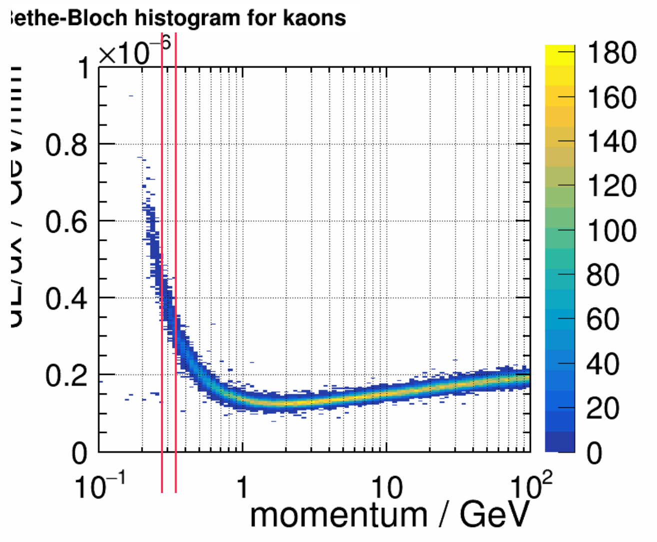
Possible FCC Collaborators

- Recent Updates from David:
- For orientation, in order to obtain bounds coming close to the SM kappa_s/kappa_b ~ 0.02 expectation, one needs **H->phi+gamma** measurements with a 1% uncertainty (corresponding to -0.04 < kappa_s/kappa_b < 0.08).
- With 1.5e6 Higgs expected at the FCC-ee and a BR(H->phi+gamma) = 2.3e-6, we only expect 3.5 signal events (on top of probably small backgrounds).
- So, any measurement of the decay will have, at least, a 50% statistical uncertainty. This would imply to set limits about 2 < kappa_s/kappa_b < 4, i.e. **more than 100 times the SM prediction**...
- Summary: **No strong motivation right now on running a simulation for this rare final state**. But it's worth to **quote this generic result in** a couple of lines **in any document that may be produced**, because people keep asking.
- David is happy to produce those lines if needed

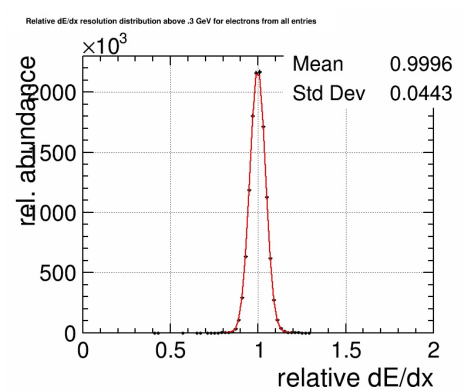
https://link.springer.com/article/10.1140/epjc/s10052-019-7450-8/figures/2

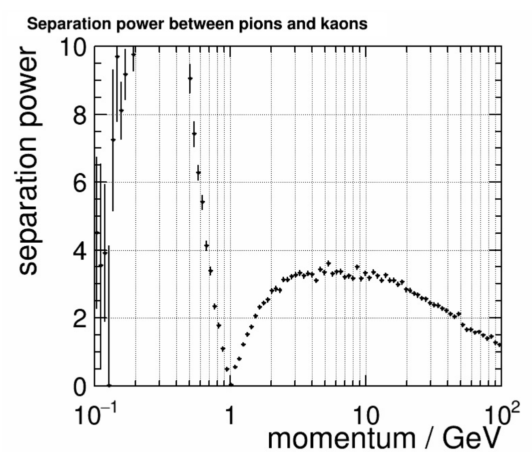




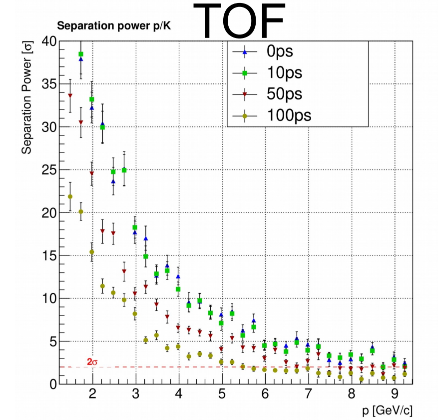


Single particles

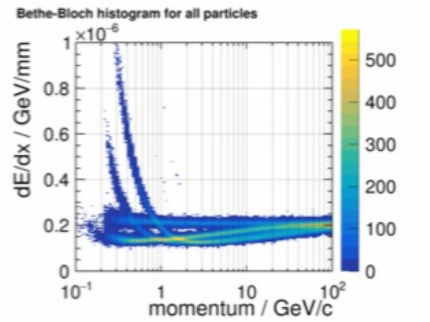


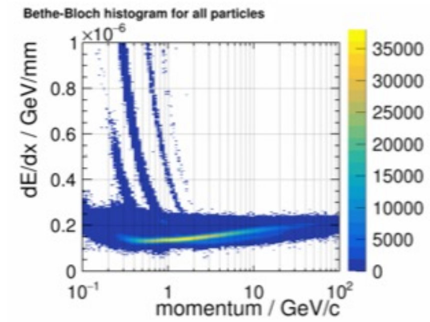


TOF



Comparison: dE/dx for single particles vs. 6f-t$\bar{t}$ events





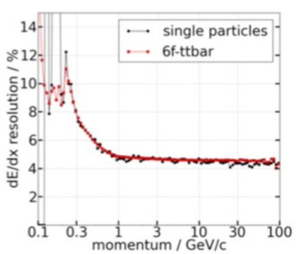
	l5 single	l5 6f-tt	s5 single	s5 6f-tt
electrons	4.3 %	4.5 %	5.3 %	5.4 %
muons	4.5 %	4.8 %	5.4 %	5.7 %
pions	4.5 %	4.6 %	5.5 %	5.6 %
kaons	4.6 %	4.7 %	5.5 %	5.7 %
protons	4.6 %	4.7 %	5.5 %	5.7 %

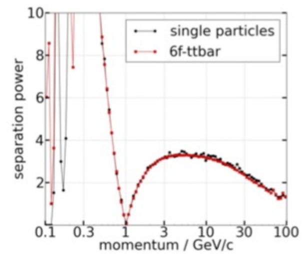
Uli Einhaus | PID with dE/dx and TOF at ILD | 10.01.2019 | Page 9

https://agenda.linearcollider.org/event/8067/contributions/43101/attachments/34181/52634/2019_01_10_LCTPC_Col_Meeting.pdf

SLAC

Resolution & π/K-separation in single comp. to $t\bar{t}$





ILD

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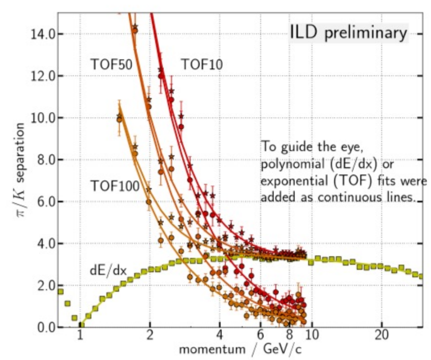

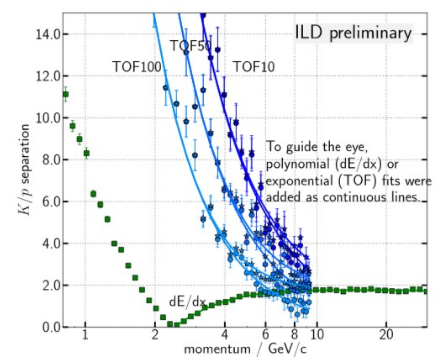

ILD

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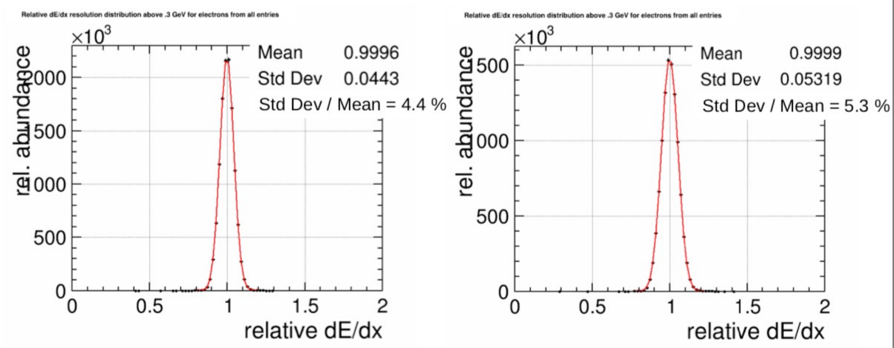
DESY.

https://agenda.linearcollider.org/event/8067/contributions/43101/attachments/34181/52634/2019_01_10_LCTPC_Col_Meeting.pdf

SLAC

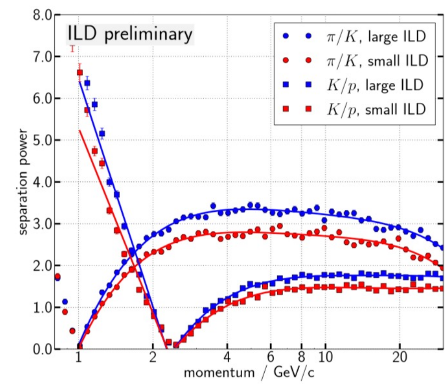
dE/dx: Resolution



Testbeam results, extrapolation to ILD:
4.2 % large, 4.8 % small (GridGEM)
4.7 % large, 5.4 % small (AsianGEM)

Uli Einhaus | PID with dE/dx and TOF at ILD | 10.01.2019 | Page 7

Combined Plots: dE/dx in Large vs. Small ILD



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Sukeerthi Dharani

Particle Identification using Time of Flight

Goal: Use arrival time at ECAL to determine particle ID

$$\beta = \frac{l_{\text{track}}}{t_{\text{arrival}}}$$

l_{track}: From momentum & curve in B field

t_{arrival}: Time of first hit from 10 closest hits in ECal

- Test on $t\bar{t}$ events
- Charged Particles : p, κ, pi, μ, e
- **Time resolution:** 0 ps,10 ps, 50 ps
- Cuts: filter only particles hitting barrel, omit particles that spiral inside TPC
- Processors: First hit & Closest hits

https://agenda.linearcollider.org/event/7972/contributions/41753/attachments/33290/50855/ParticleID-TOF.pdf

Sukeerthi Dharani

Particle Identification using Time Of Flight

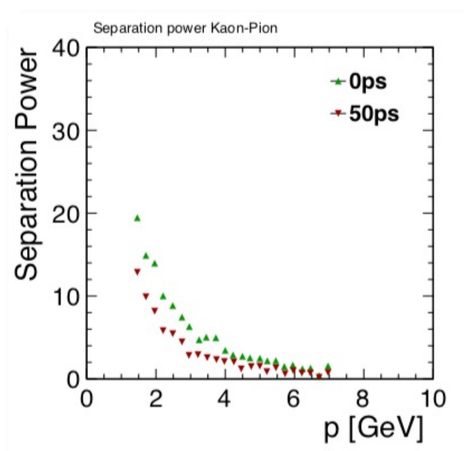
Particle-ID for low-p hadrons

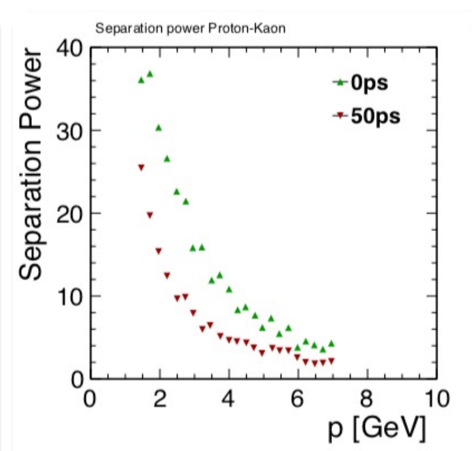
Separation power (between particle i and j):

Gaussian fit $\Rightarrow$ μ_i: Mean for particle type i

σ_i: Std. dev. for particle type i

$$S = \frac{|\mu_i - \mu_j|}{\sqrt{(\sigma_i^2 + \sigma_j^2)/2}}$$



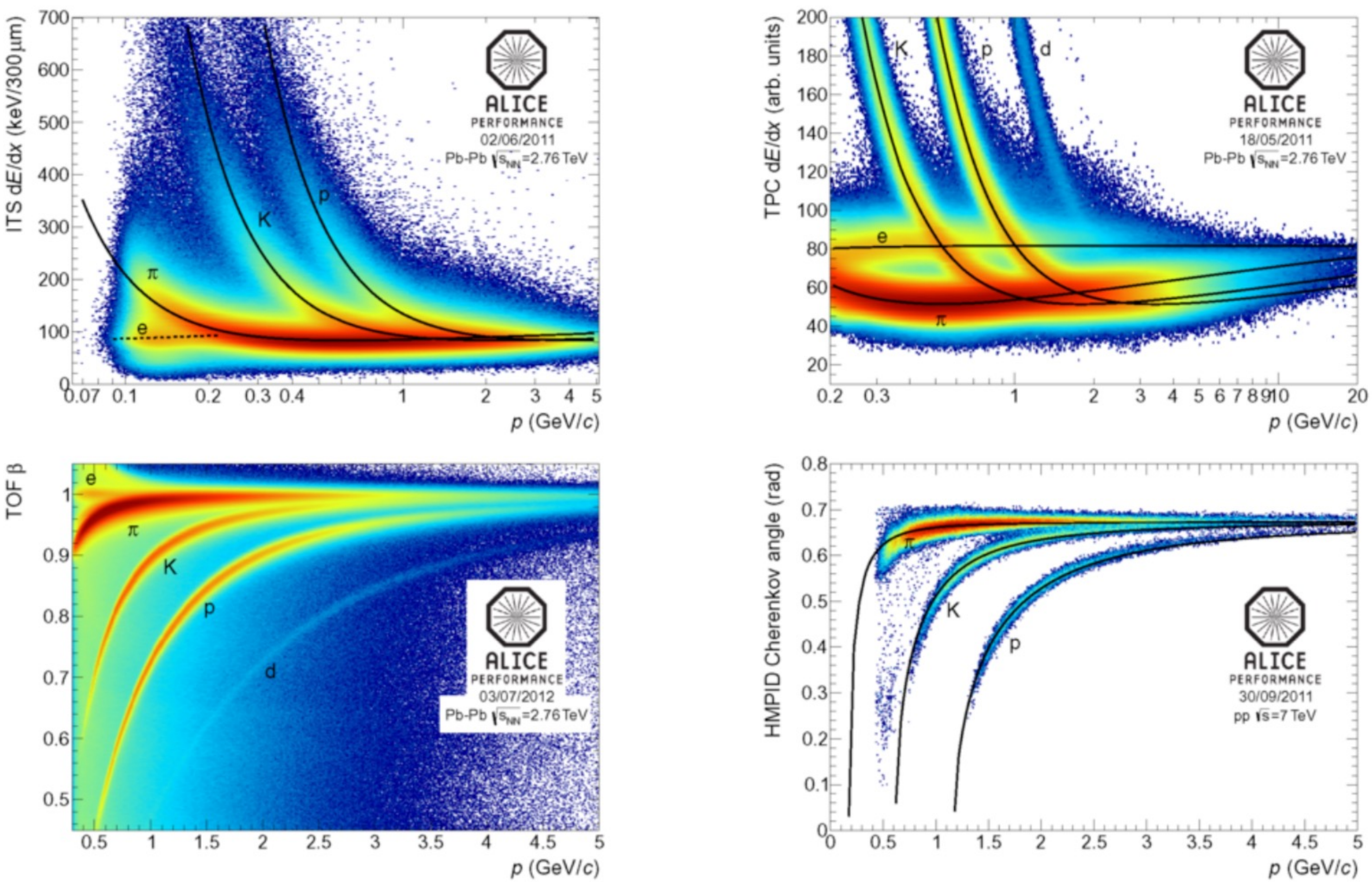


$\Rightarrow$ TOF usable for **low-p hadron ID** $\longrightarrow K - p$ up to 6GeV $\longrightarrow K - \pi$ up to 3.5GeV @ **50ps single hit resolution**

DESY. | Particle Identification using Time of Flight | Sukeerthi Dharani | June 13, 2018 | Page 7/8

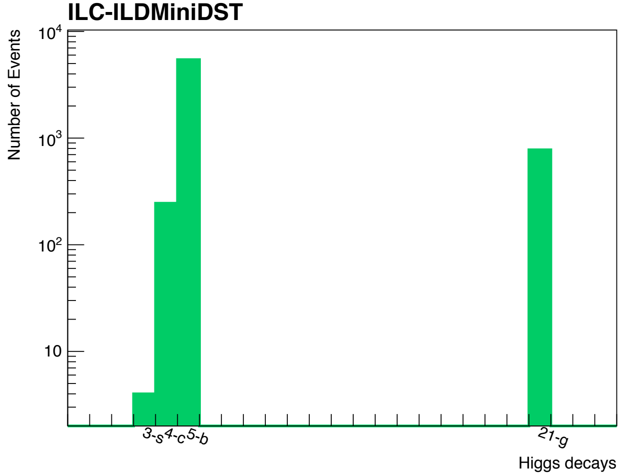
https://www.researchgate.net/publication/257190213_Identified_charged_hadron_production_measured_with_ALICE_at_the_LHC

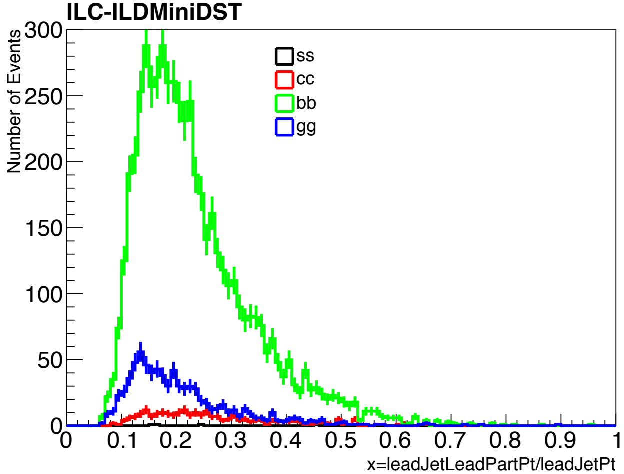
M. Ivanov / Nuclear Physics A 904–905 (2013) 162c–169c



Some more details

```
root [12] tree->Scan("leadJetLeadPartPdgId", "leadJetLeadPartPdgId>3000")
************************
   Row    leadJetLe *
************************
   474      3122 *    Λ
  1204      3122 *
  1797      3122 *
  2027      3122 *
  2116      3322 *    Ξ0
  2223      3122 *
  2567      3112 *
  2860      3122 *
  2994      3122 *
  3889      3122 *
  3930      3122 *
  4593      3222 *    Σ+
  5143      3122 *
  5148      3122 *
  5315      3122 *
  5346      3122 *
  5759      3122 *
  6264      3122 *
************************
==> 18 selected entries
```



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************************
   Row    leadJetLe *
************************
  1180       211 *   π+
  1911       211 *
  4446       321 *   K +
  5532      -211 *
************************
==> 4 selected entries
```

BR

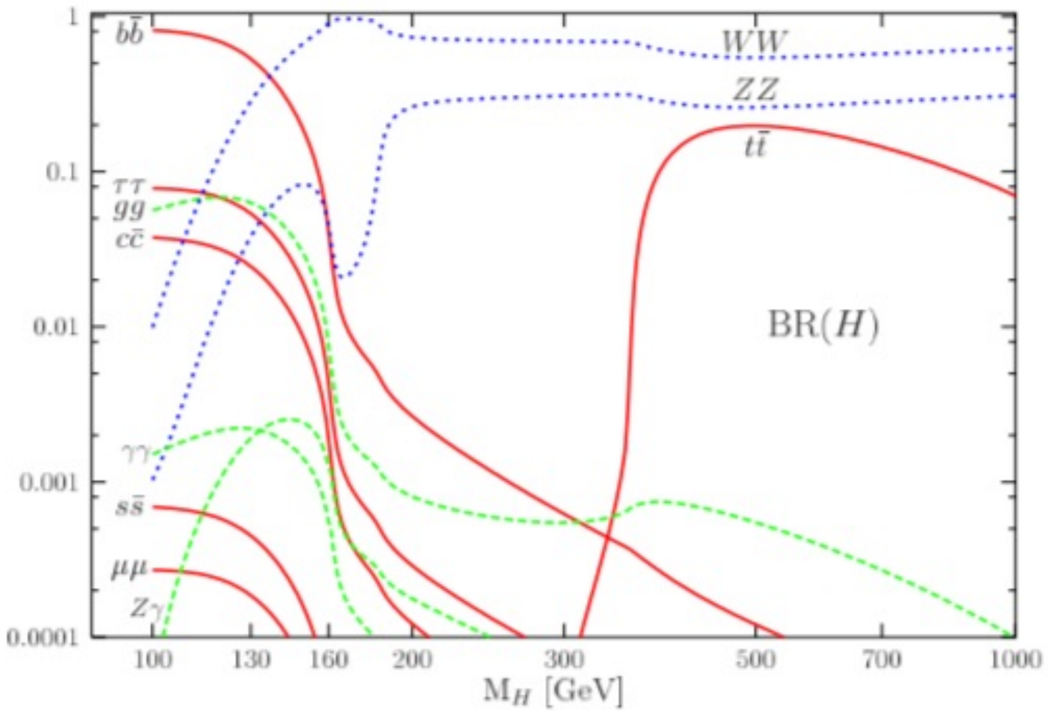

Fig. 1 From [5]: The decay branching ratios of the SM Higgs boson as a function of its mass.

[5] "*Electroweak Symmetry Breaking at the LHC*", A. Djouadi, R.M. Godbole, https://link.springer.com/chapter/10.1007%2F978-81-8489-295-6_5, https://arxiv.org/abs/0901.2030