Measurement of top quark CKM elements at FCC-ee

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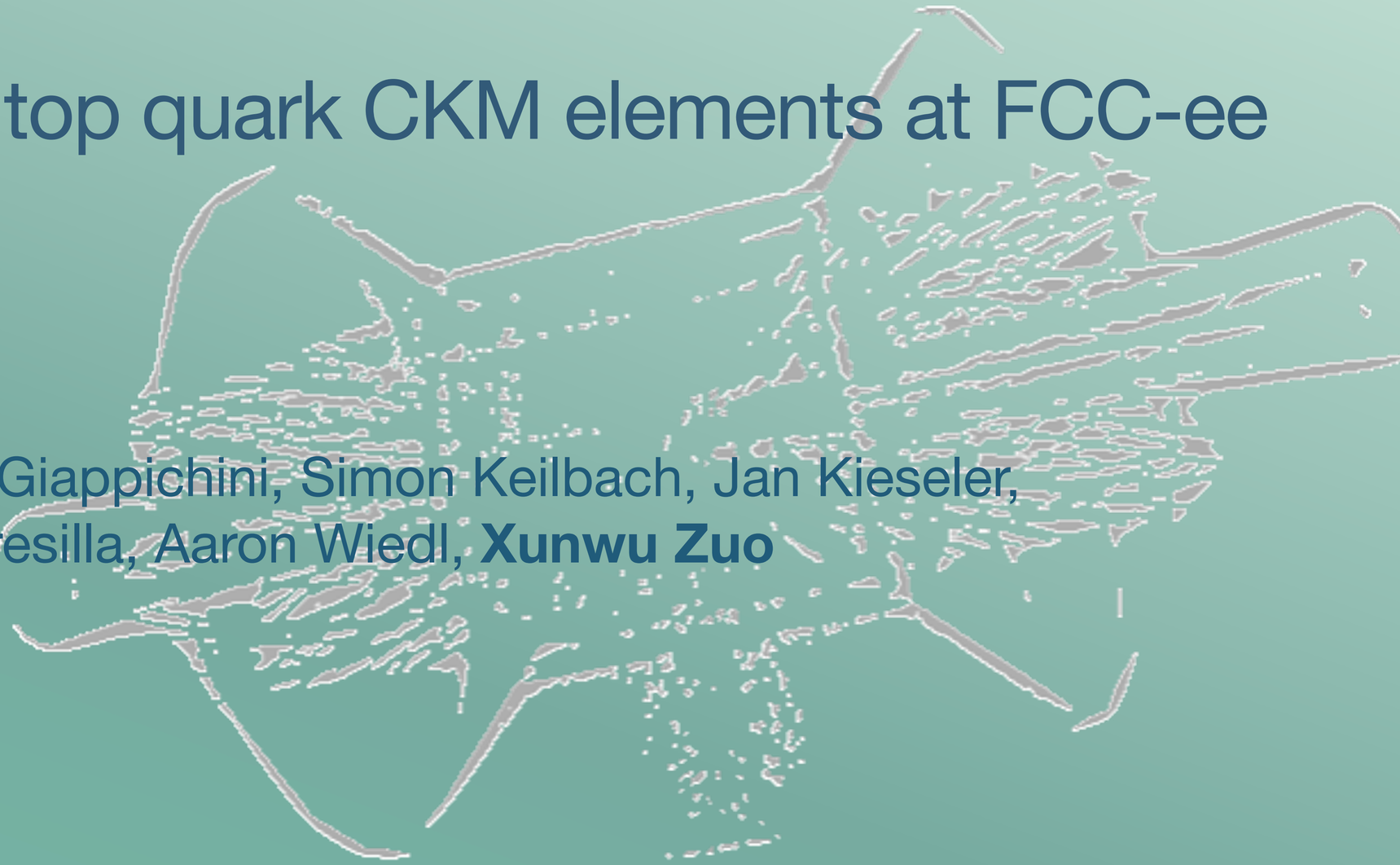


$|V_{ts}|$ introduction

Current measurements on $|V_{ts}|$

- PDG value: $|V_{ts}| = (41.5 \pm 0.9) \times 10^{-3}$
  - From $B_s^0 - \bar{B}_s^0$ mixing, mediated via t-W box diagrams
  - Assume no NP in the loop
  - Dominated by theory uncertainty from lattice QCD
- Also keep $|V_{cb}|$ in mind
  - Inclusive $(42.2 \pm 0.5) \times 10^{-3}$ vs exclusive $(39.8 \pm 0.6) \times 10^{-3}$ (6% tension)

Potential at e^+e^- colliders

- Model-independent direct measurement
- FCC-ee expects $2 \times 10^6 \times 2 \times |V_{ts}|^2 \sim$ 6400 cases of $t \to Ws$
  - s-tagging is the core
  - Limited by statistical uncertainty

FCC project

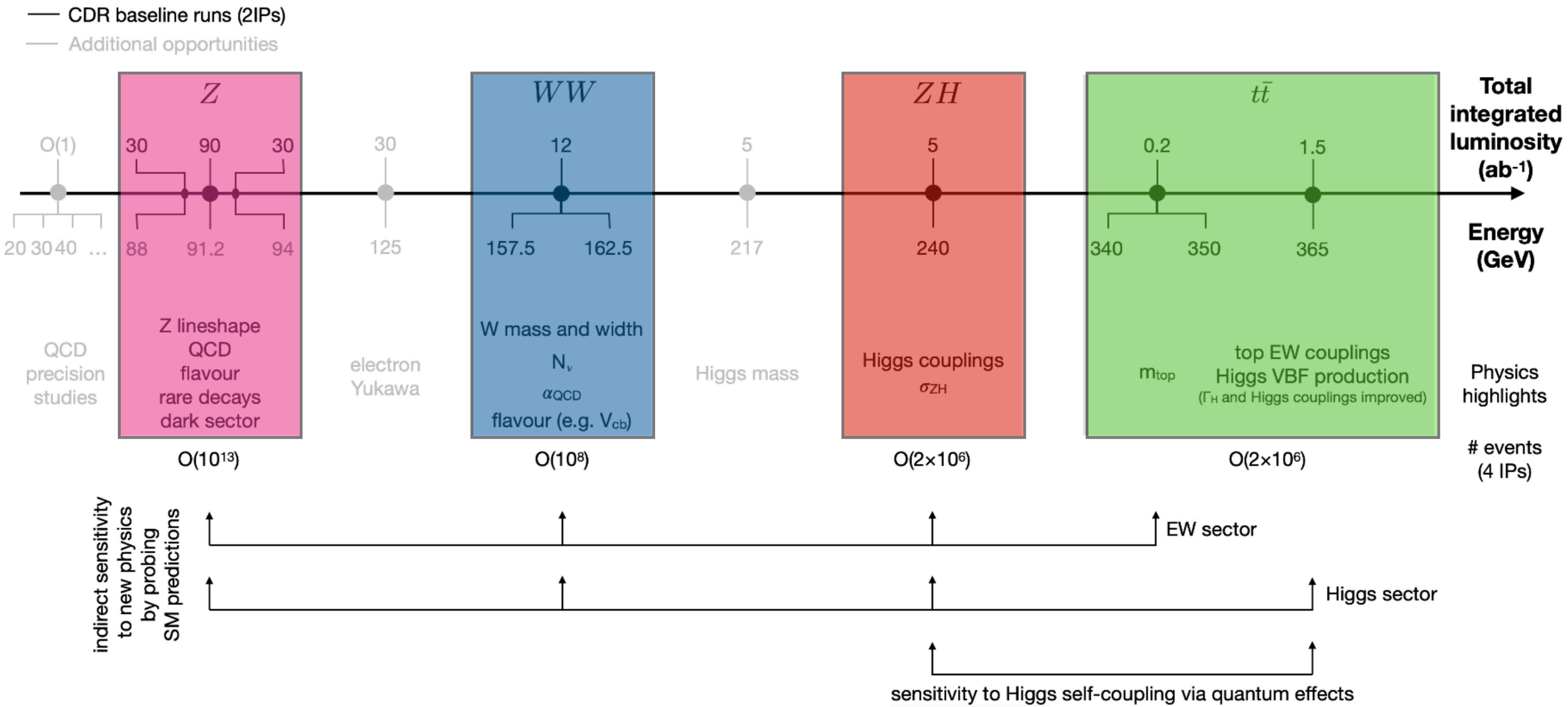
New infrastructure

- 90.7 km tunnel
- 8 surface points
- 4 experimental sites
- Deepest shaft 400 m, average 240 m

Two stages

- FCC-ee (~15 years)
- FCC-hh (>20 years)

FCC-ee program



jet clustering

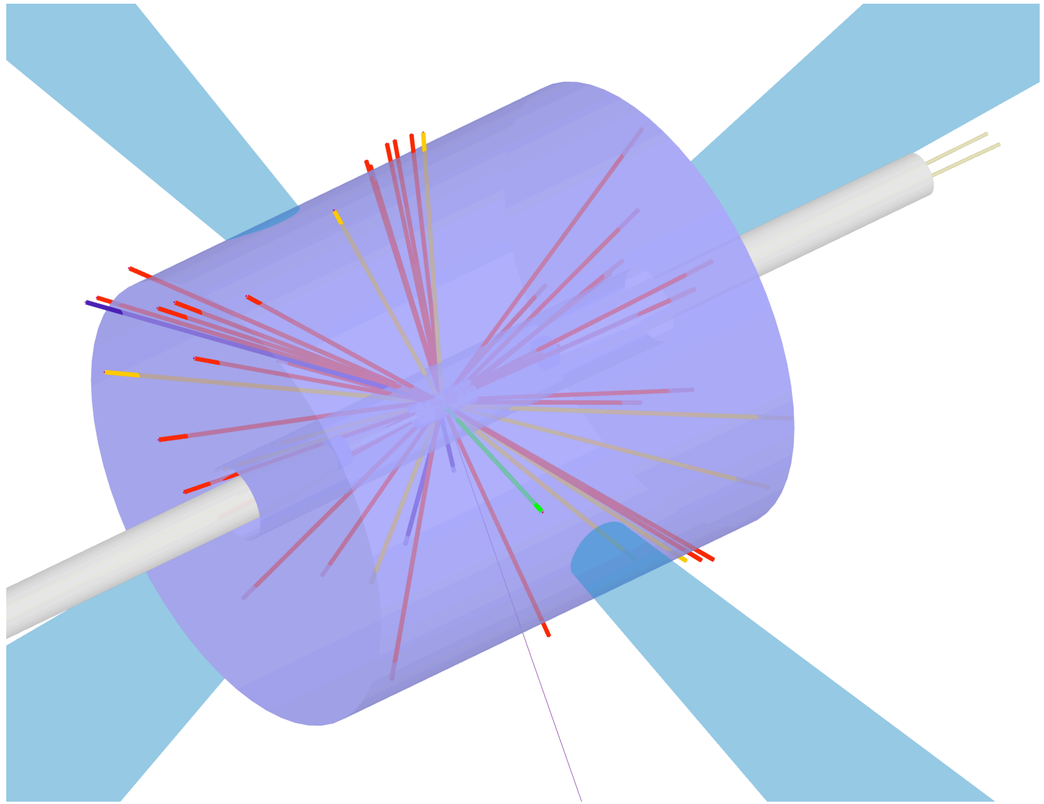
Crucial ingredient of this analysis

- Correctly categorize dileptonic, semi-leptonic, fully hadronic $t\bar{t}$ decays
- Well-defined jets for flavor tagging

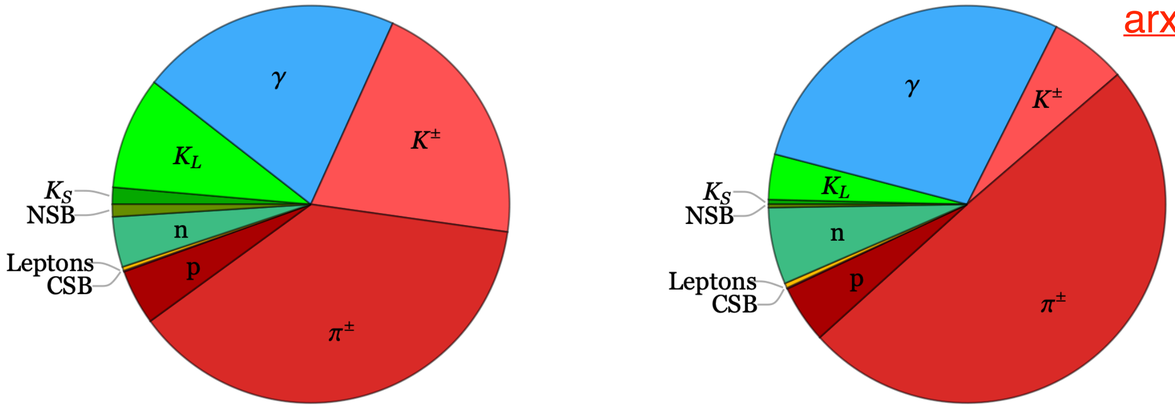
Two types considered

- Exclusive clustering (fixed number of jets in events)
  - subjet distance $d_{ij} = 2\text{min}(E_i^2, E_j^2)(1 - \cos\theta_{ij})$
- Inclusive clustering (roughly fixed cone size)
  - subjet distance $d_{ij} = \text{min}(E_i^{2p}, E_j^{2p})\dfrac{1 - \cos\theta_{ij}}{1 - \cos R}$
  - merge i, j until $\forall\ d_{ij} > E_i^{2p}$

Inclusive jet with R=0.5 as nominal choice in this work



Strange jet tagging



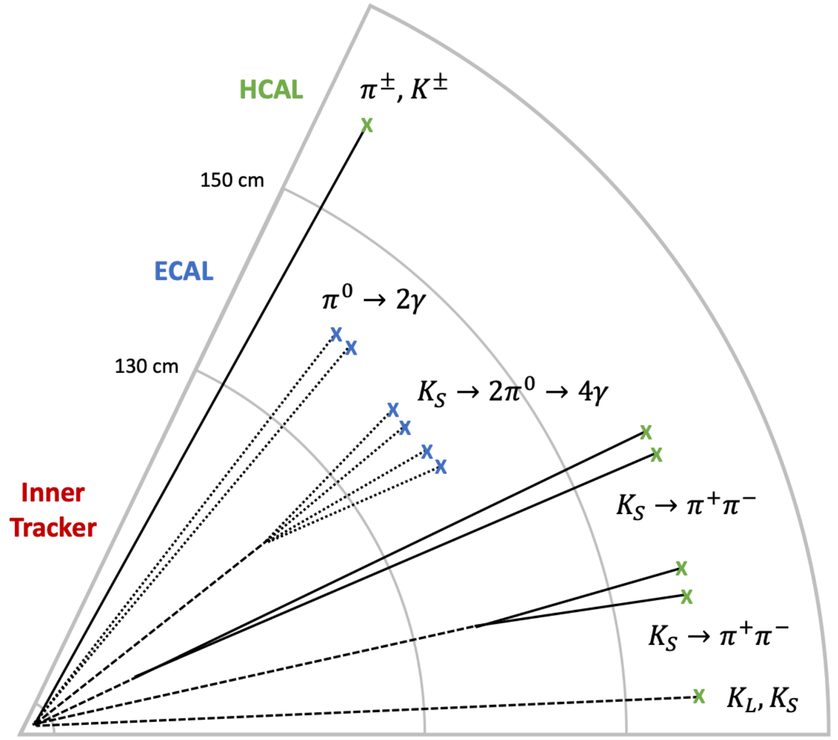
Momentum fraction

Strange $p_T = 45\,\mathrm{GeV}$ Down $p_T = 45\,\mathrm{GeV}$

arxiv:2003.09517

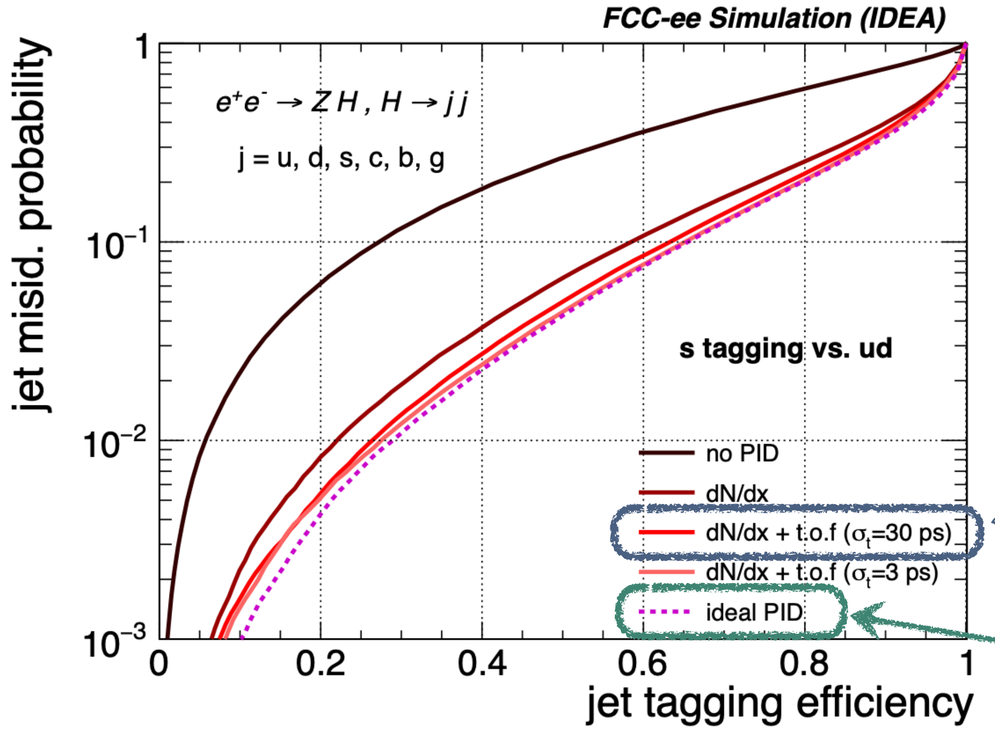
- Higher fraction of momentum carried by **kaons**
  - K^+/π^+ separation is the key
- Neutral kaons and s-baryons are long-lived
  - $c\tau(b/c) \approx 0.5$ mm, $c\tau(s) \approx 50$ mm
  - Depends on reco efficiency of highly displaced vertices

Not to scale



s-baryons Λ, Σ, Ξ have $c\tau \approx 1 - 10$ cm

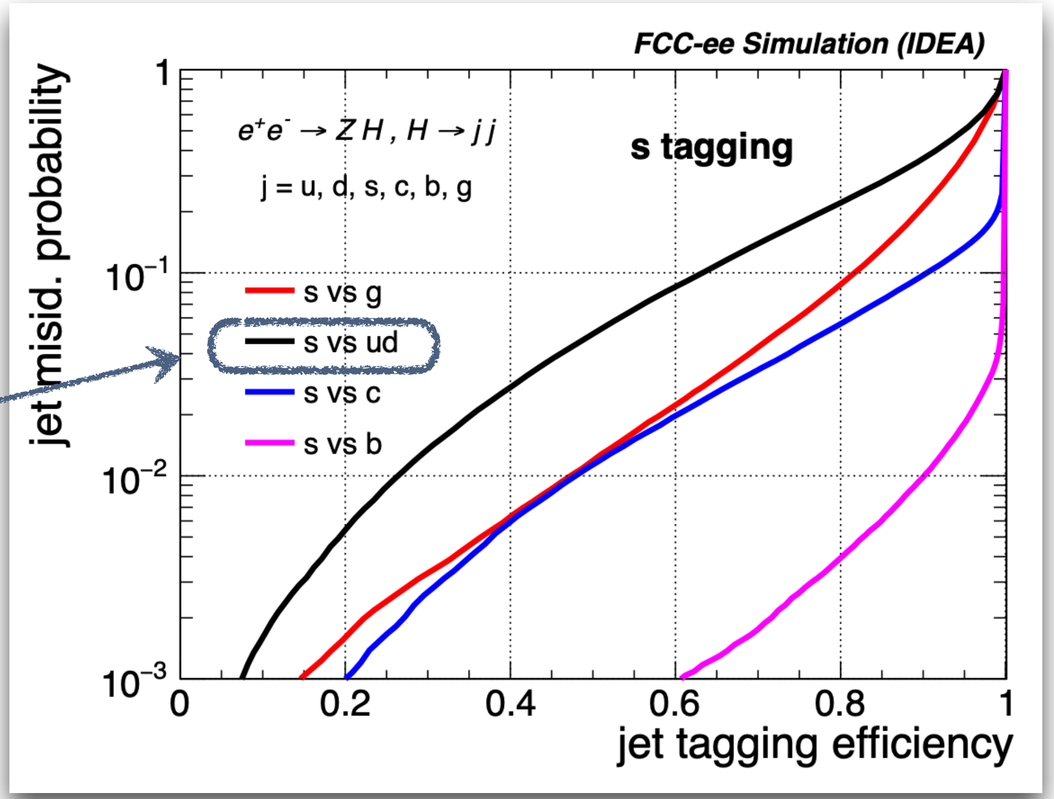
Strange tagging at FCC-ee



Nominal performance

gen PID info

EPJC 82, 646 (2022)



- Most improvement from dN/dx
- With nominal design (dN/dx, $\sigma(\text{TOF}) = 30$ ps), already close to perfect PID
- Limited natural separation between s and ud

	Eff (**s**)	Mistag (**g**)	Mistag (**ud**)	Mistag (**c**)	Mistag (**b**)
Loose	90%	20%	40%	10%	1%
Medium	80%	9%	20%	6%	0.4%

Samples and selection

Samples

- Signal: all decay modes of $t\bar{t} \rightarrow WbWs$
- Backgrounds: $t\bar{t} \rightarrow WbWb$, Z, WW, ZZ, Higgs, WWZ

Event selection

- Require exactly 1 s-tagged jet and 1 b-tagged jet
- Further divide into 6 **categories** based on **number of objects:** e, μ, and tagged jets
  - **1 dileptonic category**
  - **2 semileptonic categories:** $W \rightarrow ud$ **and** $W \rightarrow cs$
  - **3 fully hadronic categories:** $WW \rightarrow udud$, $WW \rightarrow udcs$, $WW \rightarrow cscs$

e/μ selection

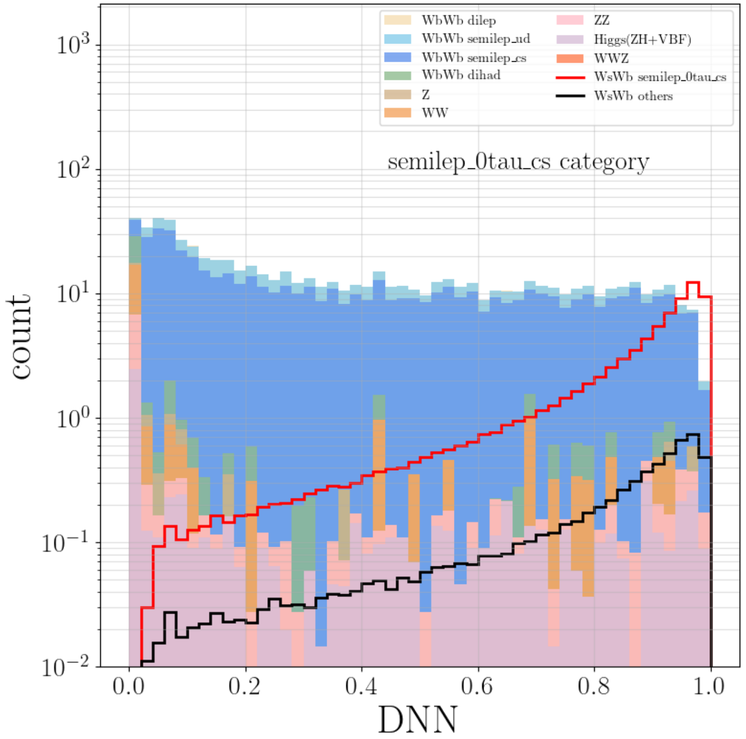
- $p_\ell > 20$ GeV
- $\text{Iso}_{R<0.5} < 0.25$

jet selection

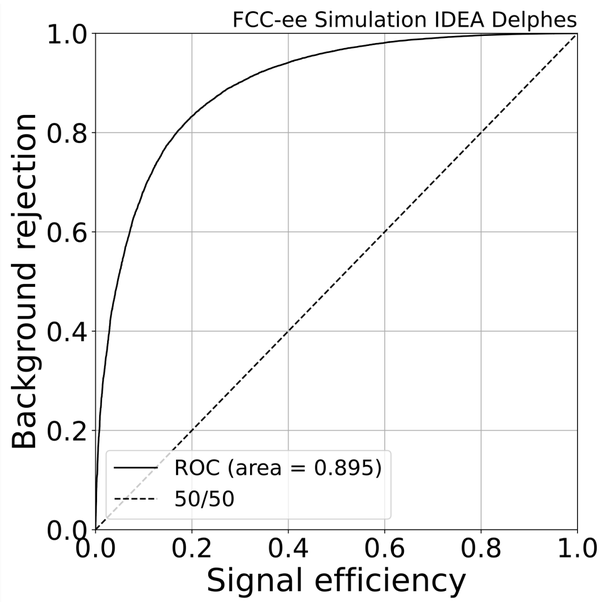
- ee_gen_kt R=0.5
- $E_J > 15$ GeV
- $m_J < 50$ GeV
- τ-score < 0.5
- flavor tag if score > 0.5

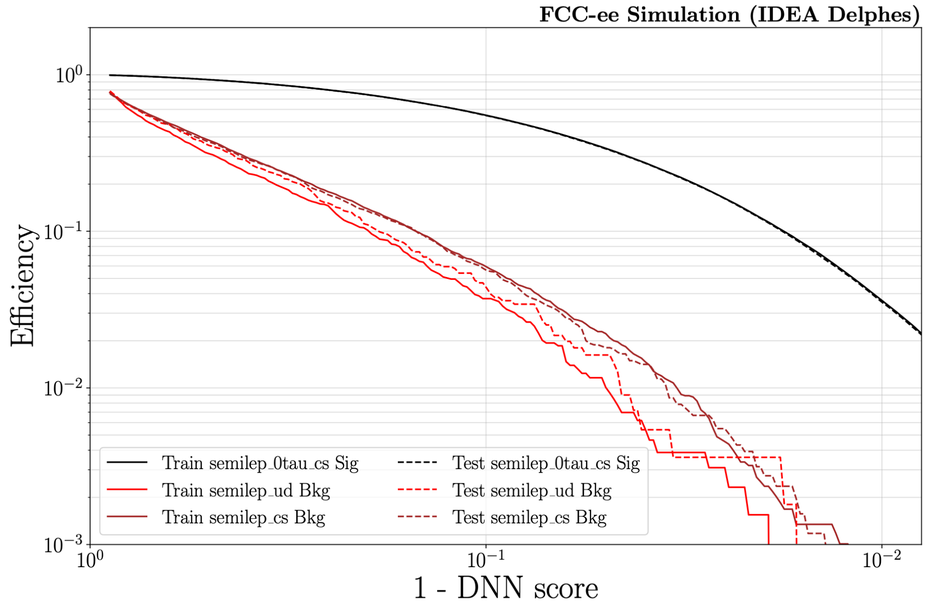
DNN training

- Fully connected 3 hidden layers (#inputs -> 2*#inputs -> 4*#inputs -> 8 -> 1)
- For tt processes (sig and bkg), independent events for training, testing, and statistical analysis
- For other bkgs, training and testing events are also used for analysis.
- DNN performance consistent with previous analysis, but more reliable



example plots in semilep_0tau_cs category





Results

- Binned likelihood fit on DNN output with Asimov dataset
- Only take categories without taus. —> Not affected by bkg issue
- Consider 1% bkg norm uncertainty to be the nominal case
- **6.3% relative uncertainty on $\mathscr{B}(t \to Ws)$**

Fit config	Free bkg	bkg ±20%	bkg ±5%	bkg ±2%	bkg ±1%
category					
dilep_0tau	14.5%	12.4%	12.0%	11.9%	11.8%
semilep_0tau_ud	13.2%	10.8%	10.2%	9.9%	9.7%
semilep_0tau_cs	30.3%	18.9%	18.3%	17.8%	17.7%
dihad_ud_only	25.4%	20.2%	19.8%	19.1%	18.6%
dihad_udcs	32.4%	26.0%	25.6%	24.7%	24.1%
dihad_cs_only	108%	83.1%	78.4%	76.5%	76.2%
combined	6.8%	6.6%	6.5%	6.4%	6.3%

Conclusions and outlook

Measurement of $\mathcal{B}(t \to Ws)$ at 365 GeV

- First opportunity for model-independent measurement of $|V_{ts}|$
- Nominal precision $\sigma(t \to Ws)$ = 6.3%, $\sigma(|V_{ts}|)$ = 3.1%

Outlook

- Simultaneous measurement of $\mathcal{B}(t \to Ws)$ and $\mathcal{B}(t \to Wb)$
- Benchmark for jet clustering and flavor tagging performance
- Rich discussion in pheno interpretation

Backups

Sample considered

Sig: SM **t -> Ws** decay

- wzp6_ee_SM_tt_tWsTWb_tlepTall_ecm365
- wzp6_ee_SM_tt_tWsTWb_tlightTall_ecm365
- wzp6_ee_SM_tt_tWsTWb_theavyTall_ecm365
- wzp6_ee_SM_tt_tWbTWs_tallTlep_ecm365
- wzp6_ee_SM_tt_tWbTWs_tallTlight_ecm365
- wzp6_ee_SM_tt_tWbTWs_tallTheavy_ecm365

Bkg: SM **t -> Wb** samples

- wzp6_ee_SM_tt_tlepTlep_noCKMmix_keepPolInfo_ecm365
- wzp6_ee_SM_tt_thadThad_noCKMmix_keepPolInfo_ecm365
- wzp6_ee_SM_tt_tlepThad_noCKMmix_keepPolInfo_ecm365
- wzp6_ee_SM_tt_thadTlep_noCKMmix_keepPolInfo_ecm365

Bkg: other SM processes

WW

- p8_ee_WW_ecm365

Z

- p8_ee_Zbb_ecm365
- wzp6_ee_tautau_ecm365

ZZ

- p8_ee_ZZ_ecm365

Higgs

- wzp6_ee_bbH_ecm365
- wzp6_ee_ccH_ecm365
- wzp6_ee_ssH_ecm365
- wzp6_ee_qqH_ecm365
- wzp6_ee_tautauH_ecm365
- wzp6_ee_mumuH_ecm365
- wzp6_ee_eeH_ecm365
- wzp6_ee_nunuH_ecm365

WWZ

- wzp6_ee_WWZ_Zbb_ecm365

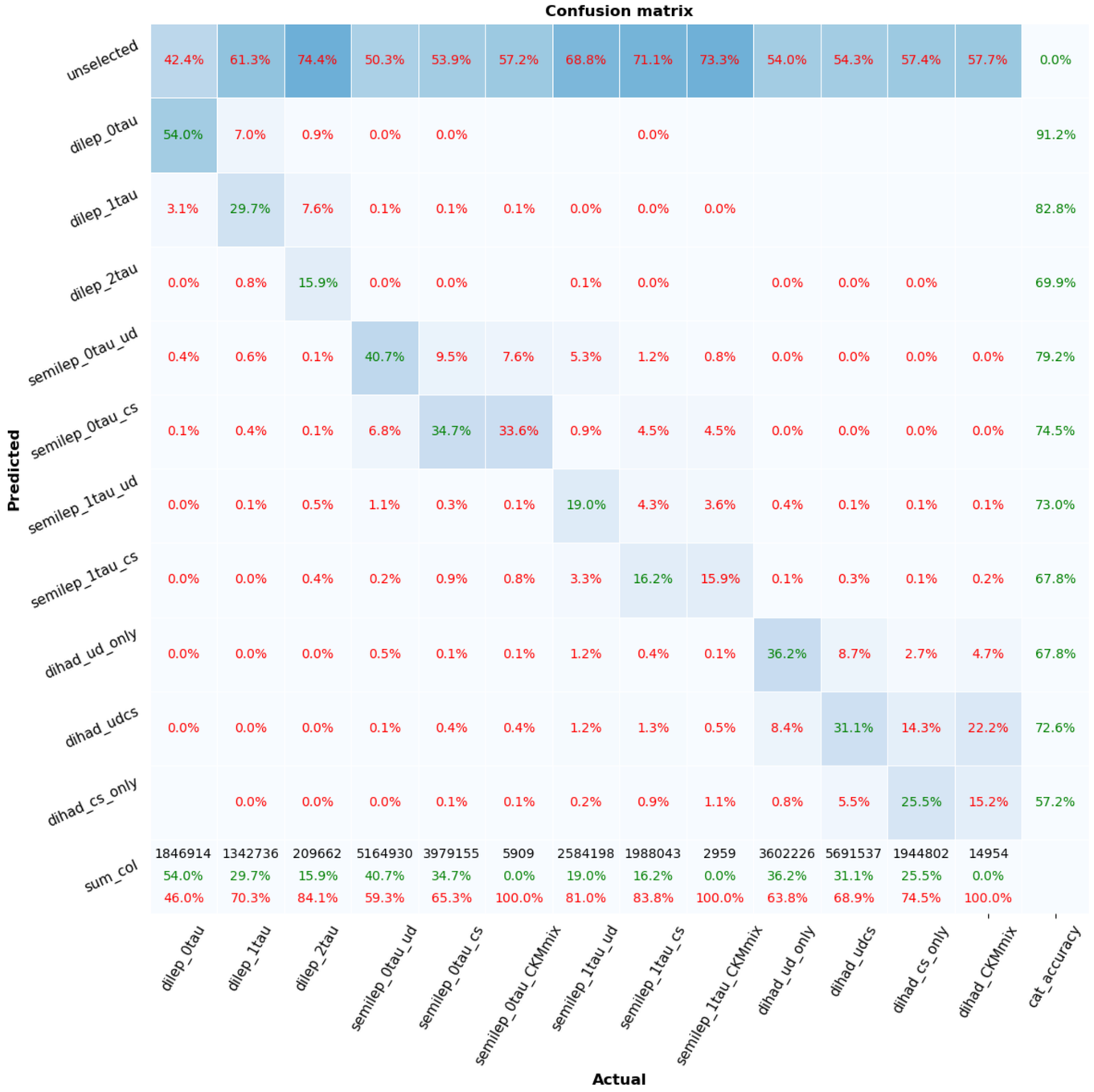
Signal efficiency

x axis: truth of decay

y axis: reco selection category

- Each cell shows fraction per column (truth), reflecting acceptance and reconstruction efficiency
- Last column is the fraction of diagonal yield wrt its row. I.e. the accuracy of reco categories.

Full yield table and discussion in backup

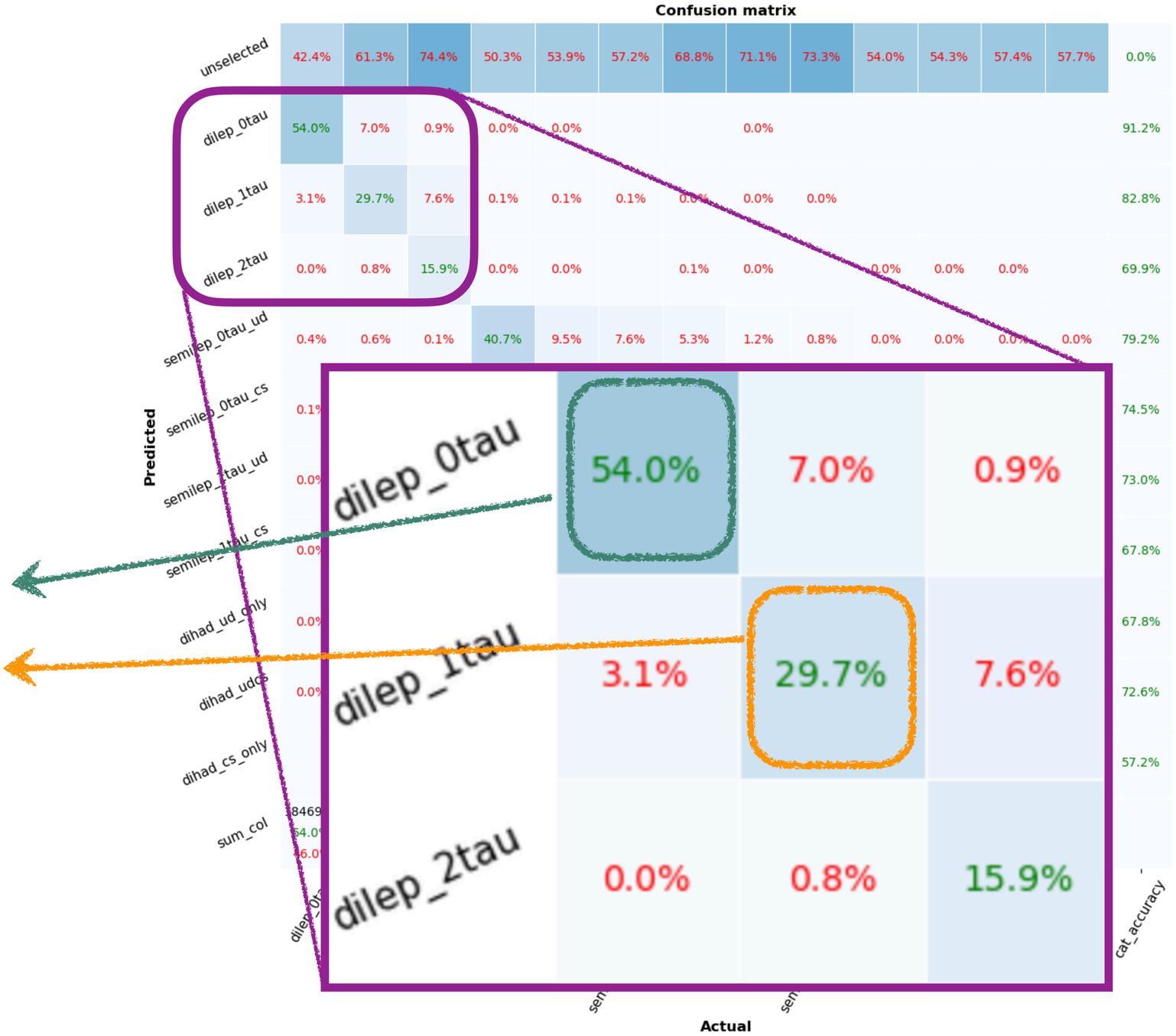


Signal efficiency

x axis: truth of decay

y axis: reco selection category

- Each cell shows fraction per column (truth), reflecting acceptance and reconstruction efficiency
  - ϵ(2 leptons) = 75%, ϵ(2 jets) = 71%
  - $\epsilon(\tau_h) \sim 50\%$



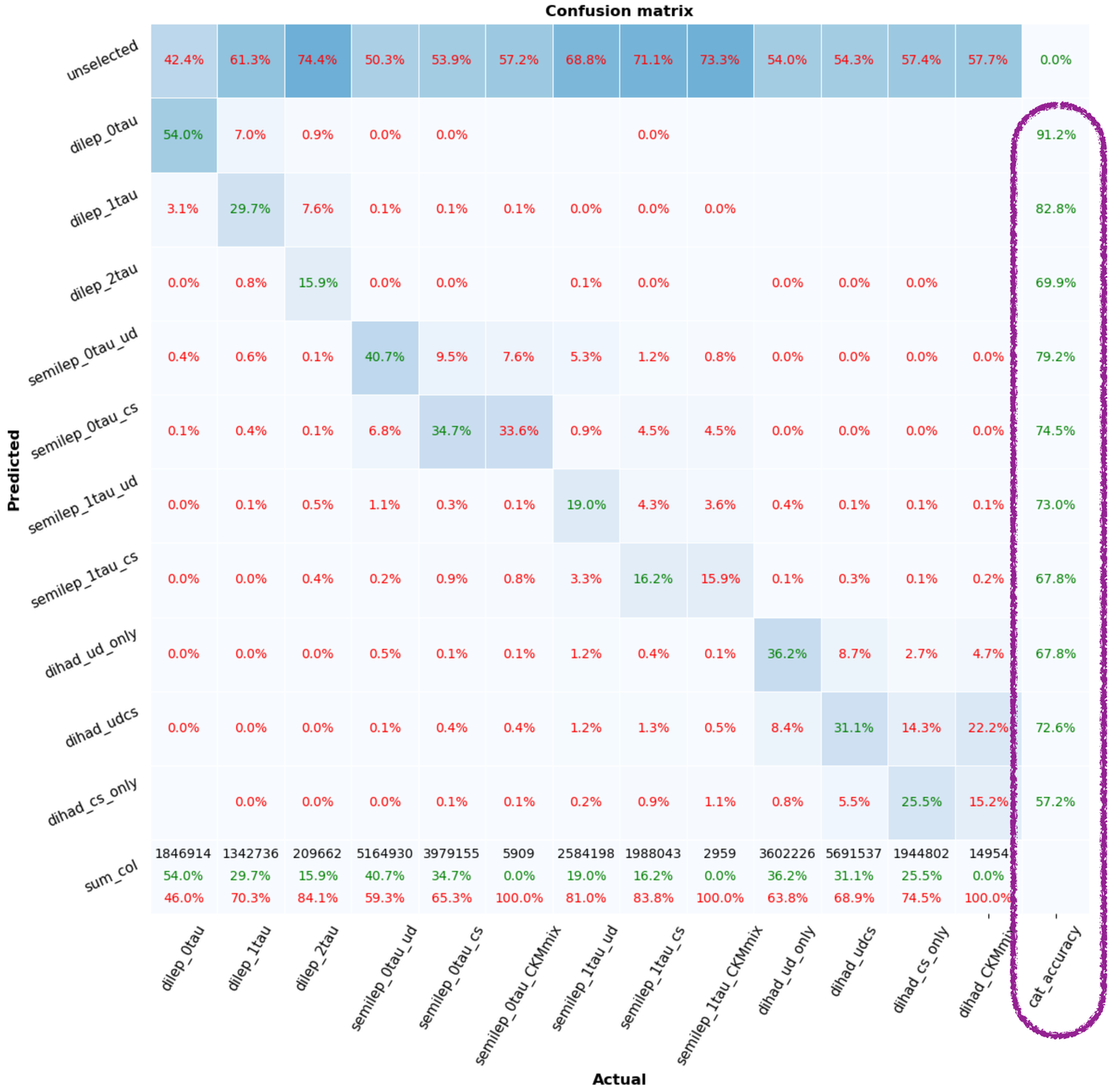
Full yield table and discussion in backup

Signal efficiency

x axis: truth of decay

y axis: reco selection category

- Last column is the fraction of diagonal yield wrt its row. I.e. the accuracy of reco categories.
  - Selected events match the target decay modes well



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