ILD contribution for H → ss ECFA focused study

T. Suehara (ICEPP, U. Tokyo)

1 e+e− → Zh with h → ss (Z → anything) at √s = 240..250 GeV

HtoSS, HTE

Theoretical, phenomenological and MC generator targets

Expanding the BSM interpretations of the studies that have already been performed or developing new simulation-based analyses targeting specific BSM scenarios would enlarge the physics case for strange tagging at future ...

- Detailed un... measureme...
- BSM mode... 37];
- BSM mode... states including strange quarks, e.g., 2HDM $H^+ \to cs$ BR ≈ 50%;
- $s\bar{s}$ vs. $b\bar{b}$ in BSM models: gain from $s\bar{s}$;
- BSM flavour structure and $h \to s\bar{s}$ signal.

- extraction of h-ss coupling strength
- BSM!

Target physics observables

Several ...

- e... s... d...
- p...
- fl... n...

- ee->Zh with h->ss at all energies
- projected precision on BR and diff. x-sec
- Flavour changing decays

Target analysis techniques

The performed proof-of-concept studies [49, 51] showed that to improve the results there will be a large need for more powerful background rejection techniques as well as a potentially more global approach in the extraction of the Higgs couplings. Two areas of particular interest will be:

- diboson background suppression;
- signal extraction (fit discriminant variables, counting experiments, etc.).

Target methods to be developed

In collaboration with the Reconstruction and Detector groups, the impact from the following features will have to be evaluated when estimating the analysis sensitivity re...

- control of strange-tagging related systematic uncertainties;
- reconstruction of in-flight decays, e.g., $K^0_S \to \pi^+\pi^-$;
- strangeness-tagging with ML techniques and compared with ...
- s vs $\bar{s}$ separation;
- complementarity of particle identification (ID) techniques for ... (from dN/dx, dE/dx, ToF, RICH);
- understanding the contribution from $g \to s\bar{s}$ (from single jets) ... analysis sensitivity.

- strange tagging
- in-flight decays
- PID techniques
- g->ss

Target detector performance aspects

The obtained results will inform the community on two crucial aspects:

- dependence of the precision on physics observables on particle ID, strange-tagging, and reconstruction capabilities;
- technology benchmarks for sub-detectors.

Generation and Simulation needs

Full simulation samples will be needed to perform the studies list... $\sqrt{s}$ = 240/250 GeV and 350/380/550 GeV are available as indic... motivation. In the years to come, it will be important to iterate wi... and fragmentation uncertainties in order to account for more real...

- fragmentation uncertainties
- ....

List of active works (ongoing and planned)

- ILD: Comprehensive H → ss paper exists, including discussion on additional RICH on detector (maybe good to replace with latest strange tagging) arxiv:2203.07535
- ILD: Ongoing work with DNN (ParticleNet/Par. Transformer)
  - For us: first result targeted at March (JPS) or July (LCWS)
- IDEA: strange tagging with ParticleNet etc. gives good results, real H → ss analysis to be done? arxiv:2202.03285
- CEPC: work ongoing based on ParticleNet arxiv:2310.03440
- Others?

What to do in ILD?

- Establish strange tagging algorithm: by ~ middle 2024
  - Probably DNN-based, PID input important (CPID?)
  - Should also include charge ID
  - Consideration of systematic effects
- Dependence on detector performance
  - dE/dx (pixel TPC? Difference with drift chamber in FCC?)
  - Timing (some model needed for physics analysis)
  - Cherenkov? (ambitious for ECFA timescale?)
- Physics analysis based on the algorithm (250 GeV and higher)
  - Separation of b/c/s/ud/g (gluon tag is also important)
- Other BSM contributions?
  - $H \rightarrow bs$?

Backup

Slides from Paestum workshop

H → ss: target by organizers (1)

Theoretical, phenomenological and MC generator targets

- BSM models predicting deviations in $h \to s\bar{s}$, e.g. SUSY
- BSM models predicting for example charged Higgs boson with large branching ratios in final states including strange quarks, e.g. 2HDM $H^+ \to cs$ BR $\approx 50\%$
- $s\bar{s}$ vs. $b\bar{b}$ in BSM models: gain from $s\bar{s}$?
- flavor assumptions in EFTs: decouple 3rd from 1st/2nd family? Partially looked at in the context of the Spontaneous Flavour Violating framework.

No serious model discovered so far?

TBD?

No serious model discovered so far?

Works exist

Target physics observables

- $e^+e^- \to Zh$ with $h \to ss$ ($Z \to$ anything) at $\sqrt{s} = 240/250$ GeV (higher center of mass energies still unexplored)
- projected precision on branching fraction, and differential cross-section in $\cos\theta_s$
- Flavour changing decays are very rare in the SM , for example BR($h \to bs$) $\simeq 10^{-7}$. NP models, which can be encapsulated by an EFT, allow larger values.

Done with some concepts: to be collected and compared?

TBD?

Target methods to be developed

- charged hadron ID from dN/dx, dE/dx, ToF, RICH, study complementarity in momentum reach.
- reconstruction of in-flight decays, e.g. $K^0_S \to \pi^+\pi^-$
- strangeness-tagging
- s vs $\bar{s}$ separation
- control of strange-tagging related systematic uncertainties

Work in progress

TBD?

Some works exist, some ongoing

TBD (some ongoing)?

TBD?

H → ss: target by organizers (2)

Target analysis techniques

- diboson background suppression
- signal extraction (fit discriminant variables, counting experiement etc)

Done in ILD study, more to come?

Target detector performance aspects

- dependence of the precision on physics observables on particle ID and reconstruction capabilities

Some works exist, more to come?

MC samples needed

full SM and $e^+e^- \to f\bar{f}h$ at $\sqrt{s} = 240/250$ GeV and 350...380 GeV available in general samples listed in Section

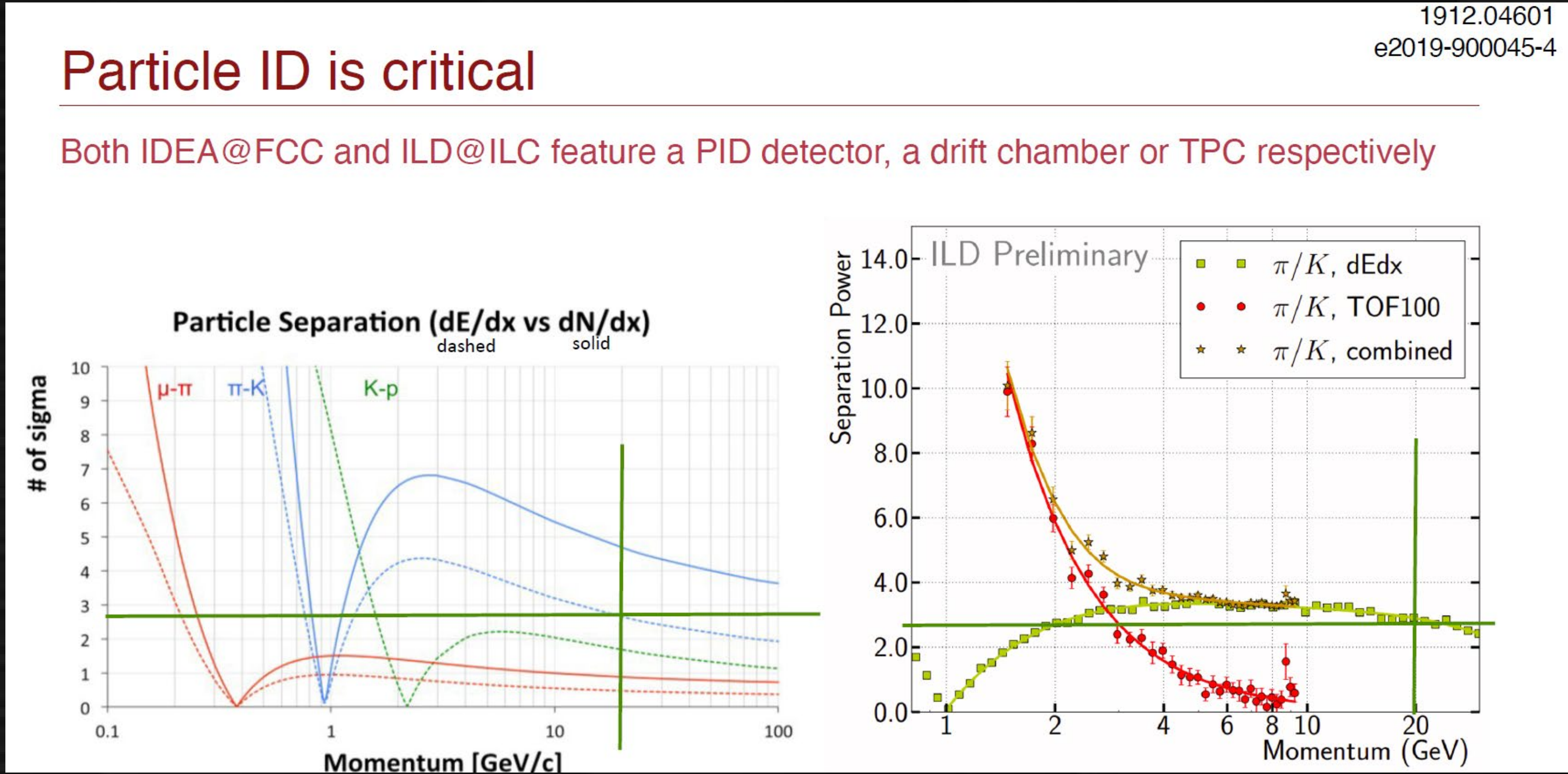
Existing tools / examples

- similar ILD analysis for $h \to b\bar{b}/c\bar{c}/s\bar{s}$: https://github.com/ILDAnaSoft/ILDbench_Hbbccgg
- similar SiD analysis ...
- similar CLICdp analysis ...
- similar IDEA analysis ...
- similar CLD analysis ...

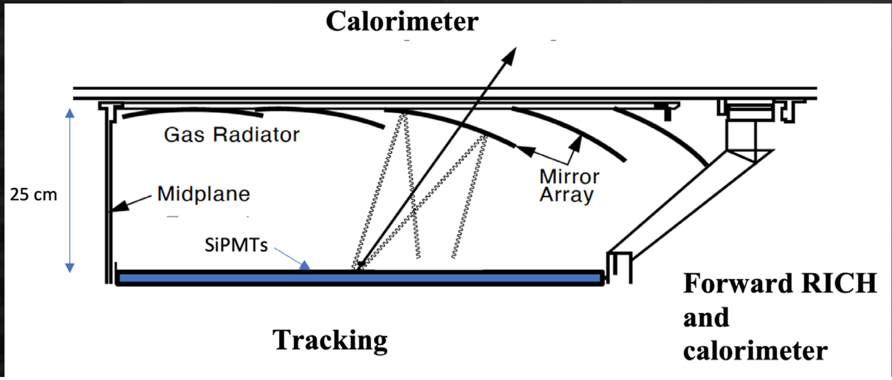
Common topics

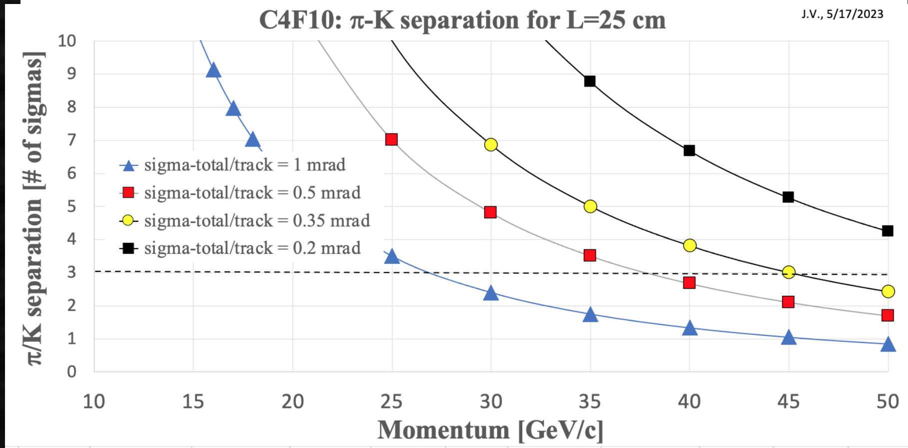
- Demonstration of technologies
(dE/dx or dN/dx, large-scale picosec timing detectors, RICH)
  - Clarify difference of the performance between detector concepts
- Reconstruction algorithm
  - GNN/Transformer seems promising, dependence on detector performance to be seen
  - Common framework to use ML-based algorithm to analysis
  - Difference between fast and full sim identified
- Physics analysis – comparison of results
- Interpretation (BSM sensitivity?)

Difference on PID (e.g. ILD and FCCee)



arXiv: 2307.01929





How the performance should be validated? Detector prototype available?
Picosec detectors at calorimeter practical? Power consumptions?
RICH to be included? Impact on detector design/performance?
Other technologies?

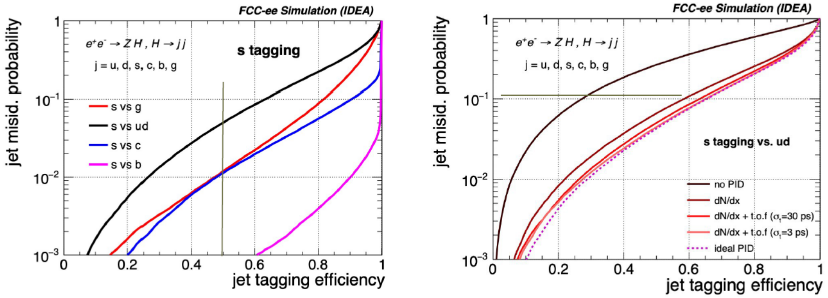
Current status of strange tagging

PRD 101 056019 (2020)
EPJ C 82 646 (2022)
L. Gouskos @FCC week

Strange tagging performance 1/2

IDEA-like detector and Particle cloud graph neural network (fast sim)

- Both TOF and dN/dx ($3\sigma < 30$ GeV) included as inputs
- No PID to PID with dN/dx → at fixed mistag, efficiency doubles



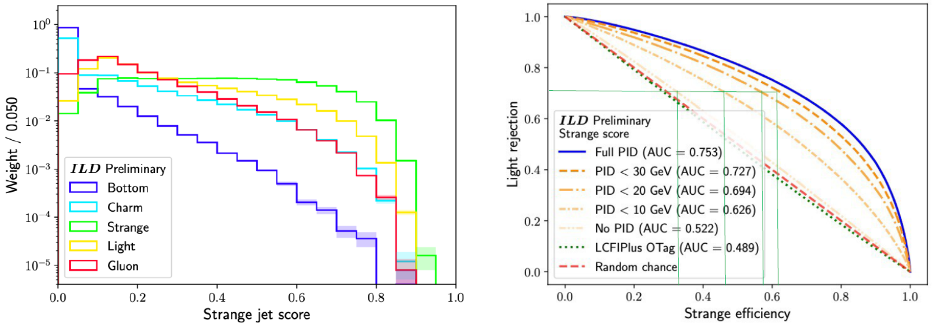
WP	Eff (s)	Mistag (g)	Mistag (ud)	Mistag (c)	Mistag (b)
Loose	90%	20%	40%	10%	1%
Medium	80%	9%	20%	6%	0.4%

2203.07535

Strange tagging performance 2/2

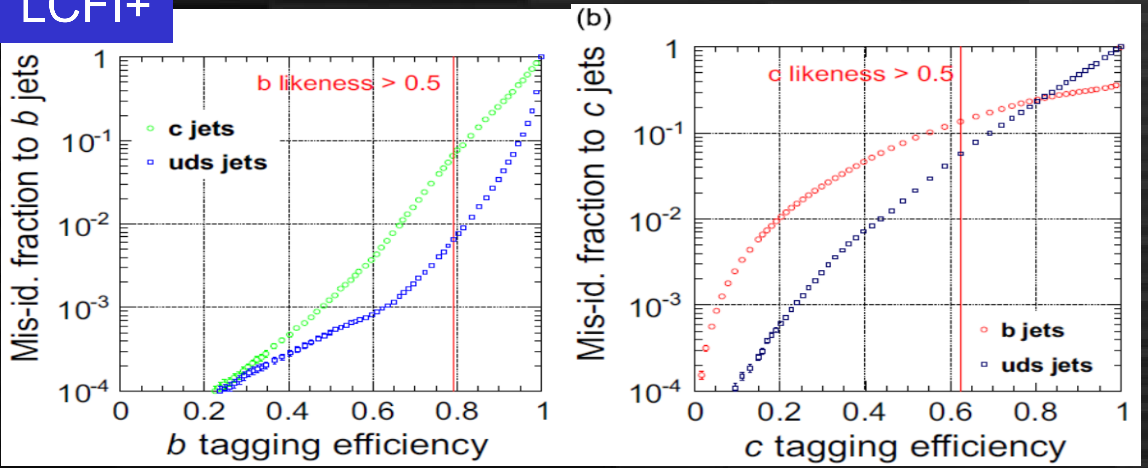
ILD-like detector with full simulation and Recurrent NN

- Includes PDG-based PID → assuming perfect detector capability
- At 50% s-tag efficiency, 90% background rejection
- No PID to PID < 10 (30) GeV → at fixed mistag, 1.5x (2x) efficiency

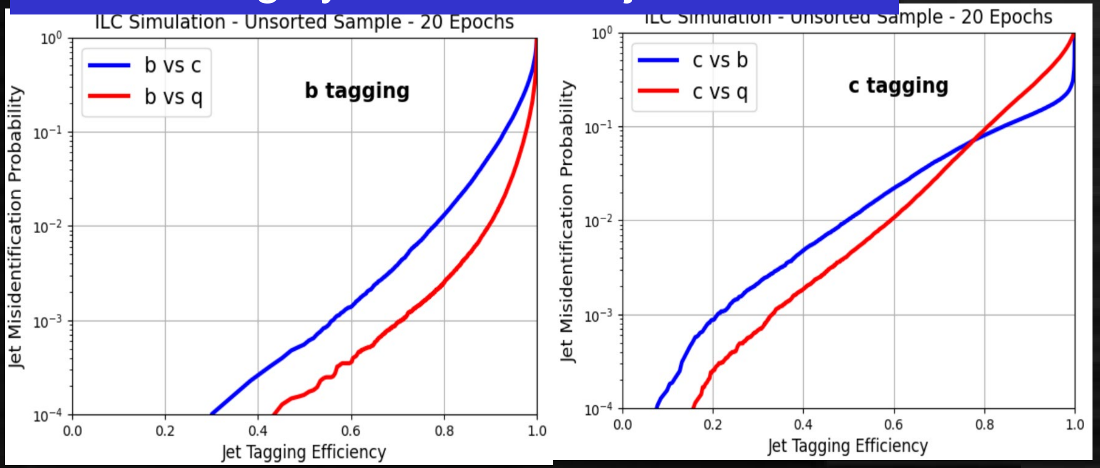


ILD: b/c tagging with Particle Transformer
strange tagging to be investigated

LCFI+



ParT – roughly 10x better rejection ratio



Analyses to be compared

- Strange tag need to be fixed first
  - DNN-based tagger seems to be baseline
  - Need to incorporate into (common?) analysis framework
- Analyses are usually difficult to compare
  - Detector different
  - Simulation details different
  - Analysis method different

  Difficult to disentangle those – common framework / analysis would help (to be discussed)

Issues on H → ss (apart from strange tag)

- Higgs with other decays (bb/cc/gg): main background
  - Need to clarify Z/W background for some channels though
- Separation of H → bb/cc is relatively easy
  (H → bb: clear signature,
  H → cc: statistically less demanding)
  → the critical part is discrimination of H → gg/ss
  (if we ignore H → light quarks / exotic)
- "Gluon tagging" may be rather essential
  - Included in the current tagger (in part of multiclass)
  - Different from e^+e^- → ss (where strange tag is essential)

Investigating more issues

- Jet charge of strange?
- Exotic decay of Higgs like H → bs?
- Differential cross section of H → ss?
- Decay of K0 short?
- Heavy Higgs decay e.g. H^+ → cs?
- Systematic effects?
  - Esp. serious for DNN-based algorithms

Interpretation?

- Theory colleagues would propose way to go…
  - Sorry, not available today

- Some quasi-personal comments:
  - Physics case for H → ss is not very strong
    (not the first 2nd generation quark, not easy to reach SM…)
    Worthwhile to separate from 1st generation in case of large deviation?
  - How about H → bs, H^+ → cs, other exotics?

Caterina's summary

Conclusions and next steps

s-tagging & PID would allow for a complete exploration of the 2nd generation Yukawa couplings

- First simulations with some assumptions on detector performance show promise to test κ_s
- Moving forward we want to:
  - map this into phenomenological targets
    - i.e. BSM models predicting deviations in $h \to ss$, or $h \to cs$
  - refine the analysis for $e^+e^- \to Zh$ with $h \to ss$ $(Z \to X)$ at 240/250 GeV
    - higher center of mass energies still unexplored
  - study detector benchmarks:
    - the complementarity in momentum reach of charged hadron ID from dN/dx, dE/dx, ToF, RICH
    - reconstruction of in-flight decays, $K^0_S \to \pi^+\pi^-$
    - strangeness-tagging and s/sbar separation
    - ***Important to evaluate simultaneously other Higgs benchmarks***

Theoretical, phenomenological and MC generator targets

Expanding the BSM interpretations of the studies that have already been performed or developing new simulation-based analyses targeting specific BSM scenarios would enlarge the physics case for strange tagging at future colliders. In particular, we welcome studies in the following areas:

- Detailed understanding of how to extract the Higgs-strange coupling strength from a BR($h \to s\bar{s}$) measurement, given contributions from Dalitz decays, e.g, $h \to g^*(\to s\bar{s})g$ or $h \to \gamma^*(\to s\bar{s})\gamma$.
- BSM models predicting deviations in $h \to s\bar{s}$, e.g., SUSY or composite Higgs — see Refs. [36, 37];
- BSM models predicting, for example, charged Higgs bosons with large branching ratios in final states including strange quarks, e.g., 2HDM $H^+ \to cs$ BR $\approx 50\%$;
- $s\bar{s}$ vs. $b\bar{b}$ in BSM models: gain from $s\bar{s}$;
- BSM flavour structure and $h \to s\bar{s}$ signal.

Target physics observables

Several physics quantities will be investigated:

- $e^+e^- \to Zh$ with $h \to ss$ ($Z \to$ anything) at $\sqrt{s} = 240/250$ GeV (this has been the only target so far, but it will be relevant to explore also higher centre-of-mass energies, which, in turn, enable different Higgs production modes);
- projected precision on the branching fraction and the differential cross-section in $\cos\theta_s$;
- flavour-changing decays are very rare in the SM, for example, BR($h \to bs$) $\simeq 10^{-7}$. New physics models, which can be encapsulated by an EFT, allow larger values.

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The obtained results will inform the community on two crucial aspects:

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Generation and Simulation needs

Full simulation samples will be needed to perform the studies listed above. Samples for $e^+e^- \to f\bar{f}h$ at $\sqrt{s} = 240/250$ GeV and $350/380/550$ GeV are available as indicated in the general samples listed in the motivation. In the years to come, it will be important to iterate with simulation experts on $s\bar{s}$ correlations and fragmentation uncertainties in order to account for more realistic systematic uncertainties.

Existing tools / examples

There are several existing tools and analysis codes available. At the time of writing, this includes examples for ILC and FCC-ee. However, due to ongoing developments, in case you would like to get actively engaged, please contact us directly (see below), such that we can point you to the up-to-date tools and code repositories.