Multi-object identification with Dual-Readout Calorimeter at future e^+e^- colliders

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Proposed future lepton colliders will measure observables, such as various Higgs couplings, Higgs total width, and top quark mass, at an unprecedented precision [1–4]. Primary production processes, such as ZH and $t\bar{t}$ production processes, studied at the future lepton colliders will be probed in multi-jet final states. Therefore, a clean reconstruction and identification of hadronic decays of W, Z, H, and top quark including off-shell W^* and Z^* of intermediate Higgs decay products are expected to be important to the physics program of the future lepton colliders.

More specifically, correct identification of multi-objects from ZH production that produces a large multiplicity of jets in various decay channels will be important to the sensitivities to the Higgs couplings and total width measurements through proper disentanglement between various Higgs decay channels and also via background suppression [5]. The top quark mass measurement via the threshold scan of the $t\bar{t}$ production will also rely on correct identification of the top quark and the W boson candidates among the high number of jet multiplicities.

One of the most difficult correct jet assignments will be between the hadronically decaying W and Z boson. If the calorimeter systems deployed in the experiments perform sufficiently well such that jet energy resolution of $\sigma_E/E \approx 3\%$ (which corresponds to $30\%/\sqrt{E}$ at 100 GeV) is achieved then the hadronic decays of W and Z bosons can be separated [1]. Also, in processes that produce multiple of the same objects, the combinatorial backgrounds could be reduced if the jet energy resolution is sufficiently well-performing.

Dual-Readout Calorimetry (DRC) has been developed by RD52/DREAM Collaboration in the last 20 years and has been shown that through parallel and independent readout of scintillation and Cherenkov light, the fluctuation in the electromagnetic fraction of hadronic showers can be canceled to achieve an excellent jet energy resolution [6]. It has been noted as a promising candidate calorimetry to achieve the desired $30\%/\sqrt{E}$ jet energy resolution performance [2–4]. Such

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high-quality hadronic energy measurements provided by DRC exceed the minimal requirements of future lepton collider experiments of the desired $30\%/\sqrt{E}$ jet energy resolution performance [2–4] and has been proposed as the calorimeter of the IDEA detector concept published in Conceptual Design Reports of CEPC and FCC-ee projects [2, 4]. DRC will provide the sufficient jet resolution that leads to a clean reconstruction of W, Z, H, and top quark resonances including off-shell W^* and Z^* bosons from Higgs boson decay and play a key role in the precise reconstruction and identification of multi-jets at the future lepton collider experiments.

In this letter, we suggest to make studies on the effect of such high performing jet energy resolution calorimetry in multi-object identification and ultimately the impact to the physics measurements such as the Higgs couplings and top quark mass measurement. The study will also explore various methods, such as kinematic likelihood fits or machine-learning-based techniques, of correct identification of multi-object reconstruction. The studies should also compare the impact on the final measurements of various observables of interest of future lepton colliders between different levels of achievable jet energy resolution. A similar kind of study has been carried out for certain Higgs decay channels in Ref. [7]. Such a study will inform the community and help in making the calorimetry design choice.

A non-exhaustive list of topics include:

- Multi-jet signatures from ZH processes and the impact of high-quality jet energy resolution on Higgs couplings or the Higgs total width measurements.
- Multi-jet signatures from $t\bar{t}$ and the impact of high-quality jet energy resolution on the suppression of the irreducible single-top background.
- Multi-jet signatures from WW, and ZZ processes.
- Assessing the impact of high-quality jet energy resolution when applying kinematic likelihood fit or machine learning techniques in improving object assignments and suppression of combinatorial backgrounds.
- Varying jet energy resolution and reassessing impacts on above measurements.

The topic of study will range across a few frontier such as, **IF6**, **EF1**, **EF2**, **EF3**, and **EF4**.

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