PROCEEDINGS OF SCIENCE

IDEA Dual-Readout Calorimeter Simulation

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The IDEA Experiment envisaged at future e^+e^- circular colliders (FCC-ee and CEPC) is currently under design and optimization with dedicated full-simulation investigations. We review the design of the IDEA fully-projective fiber-based dual-readout calorimeter simulation. Particular attention is given to general and fundamental limitations of calorimeters operating at colliders, together with the path for the reconstruction of events with complex topologies. Through the study of the distinction between γ and π^0, we illustrate the outstanding particle identification capabilities given by a millimeter shower sampling coupled to modern convolutional neural networks.

**** The European Physical Society Conference on High Energy Physics (EPS-HEP2021), ****
**** 26-30 July 2021 ****
**** Online conference, jointly organized by Universität Hamburg and the research center DESY ****

[*] Speaker

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PoS(EPS-HEP2021)777

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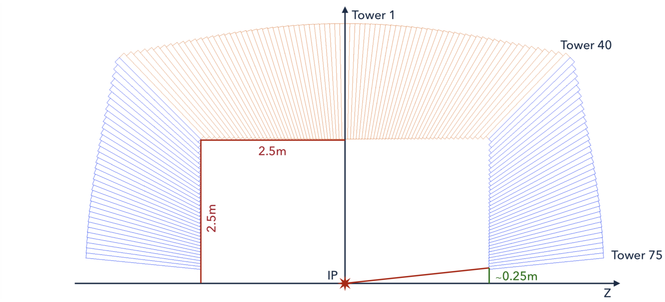
1. Detector studies

At future e^+e^- circular colliders, the majority of final-state topologies are two- and four-jet ones. An elegant approach to properly reconstruct such events is to fully absorb each particle within jets in a highly granular calorimeter with a response approximately equal for all particle species. To achieve that, the IDEA experiment adopts a fiber-sampling longitudinally-unsegmented dual-readout calorimeter. This design has been reproduced with a Geant4 application, illustrated in fig. 1. The detector response is calibrated with electron beams and, for both single hadrons and jets, the energy is reconstructed with the dual-readout formula [1].



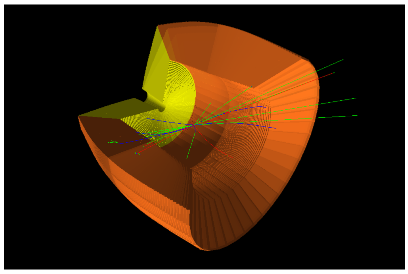


Figure 1: Sketch of the IDEA tower-based dual-readout calorimeter structure (left). Artistic view of a simulated $e^+e^- \to jj$ event showering in the IDEA calorimeter (right).

By exploiting the scintillation signal in scintillating fibers and the Cherenkov signal in clear plastic fibers, it is possible to measure the electromagnetic fraction on an event-by-event basis and correct the calorimeter response for its degree of non compensation ($h/e \neq 1$) [1]. This has proven to be beneficial in suppressing energy response variations when absorbing different hadron species. Fig. 2 shows, for instance, the simulated energy distribution as reconstructed by the IDEA Calorimeter for 100 GeV π^-, K^-, n and p. It clearly indicates that the residual response variations are kept below 1%, while ATLAS quotes differences of $\simeq$ 5% in the response to $\pi^\pm$ and p [2], and this difference increases to $\simeq$ 10% in the case of the CMS Forward Calorimeter for energies below 100 GeV [3]. Simulations also indicate that the dual-readout correction leads to a superior jet energy resolution, as indicated by fig. 3, which shows the W, Z and H bosons masses as reconstructed with the IDEA Calorimeter.
The IDEA Calorimeter design can also be combined with a dual-readout crystal electromagnetic

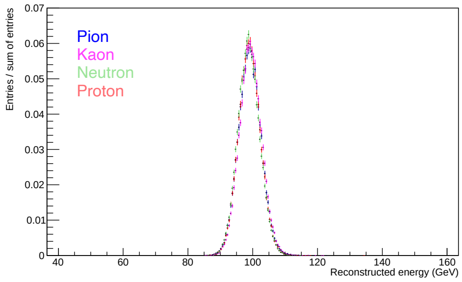


Figure 2: 100 GeV π^-, k^-, n and p energy as reconstructed with the IDEA Calorimeter. Energies are not corrected for the longitudinal shower leakage. Image from [4].

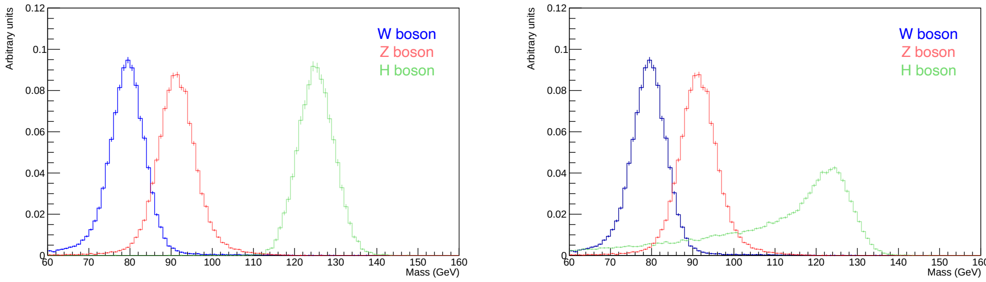


Figure 3: W, Z and H bosons invariant masses as reconstructed with the IDEA Calorimeter through the processes $e^+e^- \to ZH$ and $H \to \chi_1^0\chi_1^0$ $Z \to jj$, $e^+e^- \to W^+W^-$ and $W^+ \to \mu\nu$ $W^- \to jj$, $e^+e^- \to ZH$ and $H \to b\bar{b}$ $Z \to \nu\nu$. Excluding and including b semileptonic decay, left and right respectively. Image from [4].

section. This configuration highly improves the electromagnetic energy resolution and leads to a better isolation of γ in jets, thus opening the possibility to adopt Particle-Flow-Like approaches for jet reconstruction. First results in this respects were presented at this Conference and indicate a further improvement in the jet energy resolution [5].
Here, for sake of brevity and to add something new, we will report on the recent results on particle identification exploiting the fiber calorimeter transverse granularity.

2. γ/π^0 identification with neural networks

In the current calorimeter simulation, each fiber is coupled to a dedicated Silicon PhotoMultiplier and the fiber-to-fiber pitch considered is 1.5 mm. This solution guarantees a millimetric transverse shower sampling leading to some spectacular results. Fig. 4 shows the integrated charge at each SiPM, obtained with the Cherenkov signals only, for 40 GeV γ or π^0 induced shower when the primary particle is shot from the interaction point. Such detailed information is certainly useful when coupled to modern convolutional neural networks for pattern identification in images.
To distinguish between γ and π^0 with energies ranging from 1 to 80 GeV, the information from the shower sampling, as shown in fig. 4, was used as input to a VGG [6] and a Residual neural network [7]. The training was performed over 50 epochs on 24000 events. Fig. 5 (left) shows the distribution of the activation neuron values corresponding to the π^0 detection, after the training phase,

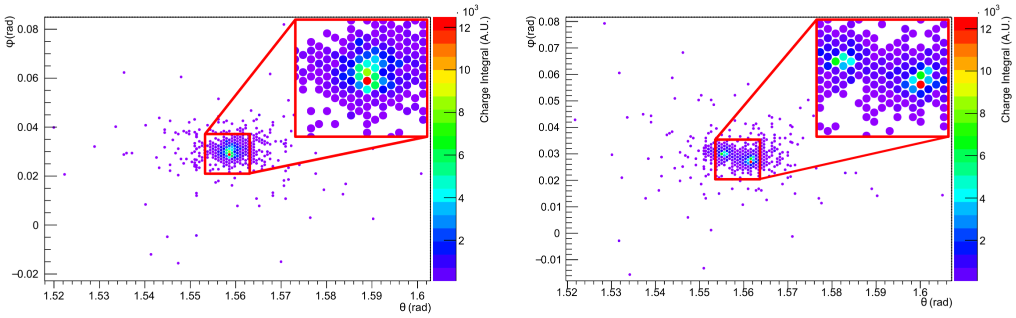


Figure 4: 40 GeV γ (left) and π^0 (right) shower as sampled and reconstructed by the IDEA Calorimeter Cherenkov fibers.

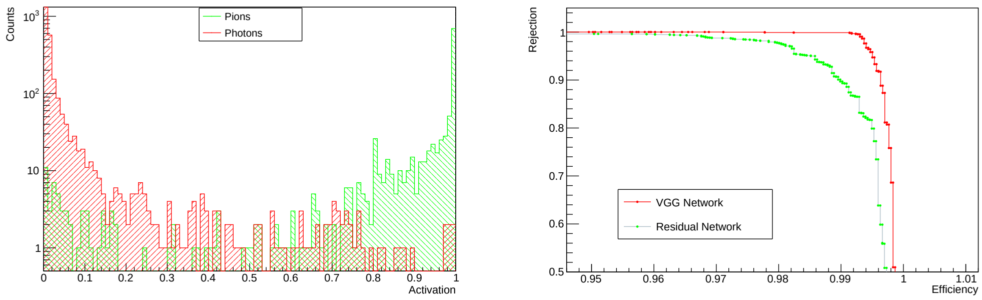


Figure 5: Distribution of the π^0 activation neuron, after the training phase, for the VGG neural network for π^0 and γ events separately (left). ROC curve for π^0 identification and γ rejection for the VGG and the Residual neural networks exploiting the IDEA Calorimeter millimetric shower sampling (right).

for two data sets containing exclusively π^0 or γ events. By changing the threshold for identifying a π^0, it is possible to estimate the efficiency in π^0 detection as a function of the γ rejection. This curve, known as the ROC curve, is shown in fig. 5 (right). Both neural networks can achieve a π^0 identification efficiency of 99% with a γ rejection of $\simeq$ 85% and $\simeq$ 99.9% for the Residual and the VGG, respectively.

Acknowledgements

We would like to thank the Organizers and the Local Committee of the EPS2021 Conference.

References

[1] S. Lee, M. Livan, R. Wigmans, Dual-readout calorimetry, Rev. Mod. Phys. 90 (2018) 025002.

[2] P. Adragna, et. al., Nucl. Instrum. Methods Phys. Res. A606 (2009) 362.

[3] N. Akchurin, et al., Nucl. Instrum. Methods Phys. Res. A408 (1998) 380.

[4] L. Pezzotti, *Particle Detectors R&D: Dual-Readout Calorimetry for Future Colliders and MicroMegas Chambers for the ATLAS New Small Wheel Upgrade*, University of Pavia, PhD Thesis, 2021.

[5] M. T. Lucchini, *Combining Dual-Readout Crystals and Fibers in a Hybrid Calorimeter for the IDEA Experiment*, EPS2021 Proceedings.

[6] K. Simonyan and A. Zisserman *Very Deep Convolutional Networks for Large-Scale Image Recognition*, arXiv:1409.1556v6, 2015.

[7] K. He, et al., *Deep Residual Learning for Image Recognition*, arXiv:1512.03385v1, 2015.