Advanced reconstruction and simulation techniques for highly granular calorimeters

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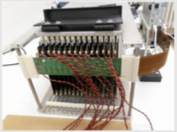
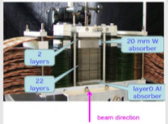
Introduction - outline

- Software for simulation and reconstruction in future colliders and prototypes
- Some aspects of advanced reconstruction techniques in CALICE prototypes
- Example of Machine Learning applications for hadronic shower simulations

Prototypes

Si-W ECAL	(ALICE FoCAL)	[Scint-W ECAL]	AHCAL	SDHCAL
				
0,5×0,5 cm² ×15 (→30) Si layers + W	0,003×0,003 cm² × 24 MIMOSA layers + W	0,5×4,5 cm² ×30 Scint+SiPM lay. + SS	3×3 cm² × 38 Scint+SiPM lay. + SS	1×1 cm² × 48 layers GRPC + SS

(Table by V. Boudry)

CALICE prototypes are the motivation of the baseline choices of most of the future detectors proposals for Higgs factories.

See two previous talks by A. Irles and I. Laktineh.

Simulation landscape

Packages and frameworks used across detector concepts and prototypes

Generation, det. sim. $\rightarrow$ Digi, Reco. $\rightarrow$ High level Reco, PID

- Whizard
- G4/dd4hep
- (Geometry def.: lcgeo)
- Delphes, SGV

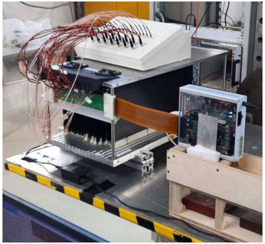
- Pandora
- Arbor
- Garlic

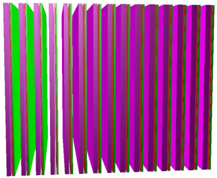
- Jet clustering, flavor tagging
- MarlinKinFit

Frameworks: Marlin, Gaudi
Event models: LCIO, EDM4HEP

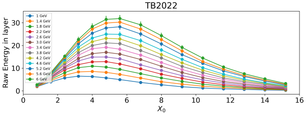
SiW ECAL prototype - simulation

Simulate the prototype in TB conditions

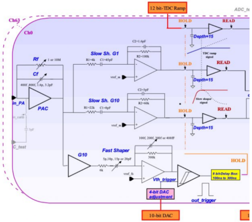


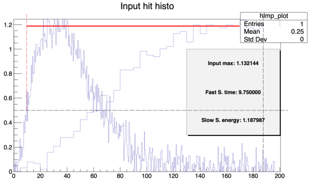


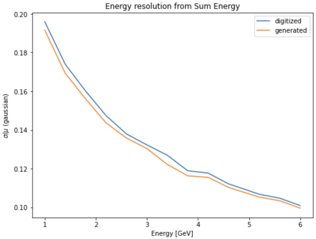
Profiles, linearity, resol.



Digitization: Sim hits $\rightarrow$ conversion $\rightarrow$ shaping $\rightarrow$ noise



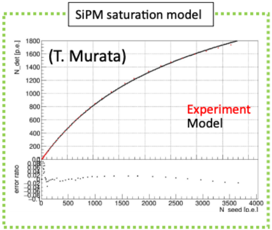




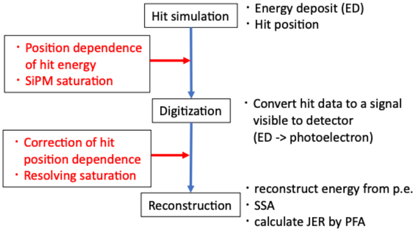
ScW ECAL

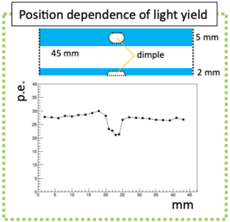
ILD simulation with realistic effects

- **SiPM saturation**
  ➡ Simple saturation model → Saturation model based on recent measurement using UV LED
- **Position dependence of light yield**
  ➡ Scale energy deposit according to position dependence of light yield



Simulation flows



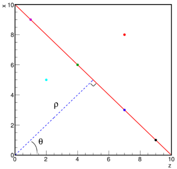


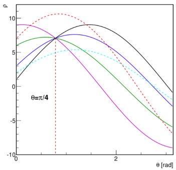
21 Apr. 2022 CALICE collaboration meeting 2022 5

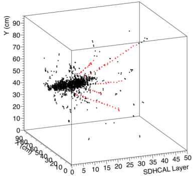
(Slide from R. Masuda.)

SDHCAL: Hough transform*

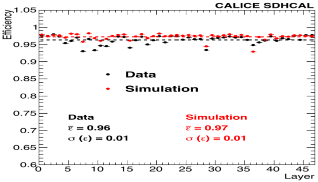
High granularity: extract tracks (Hough transform), control calorimeter in situ

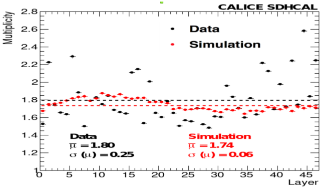






$$\rho_{xz} = z\, sin(\theta) + x\, cos(\theta)$$





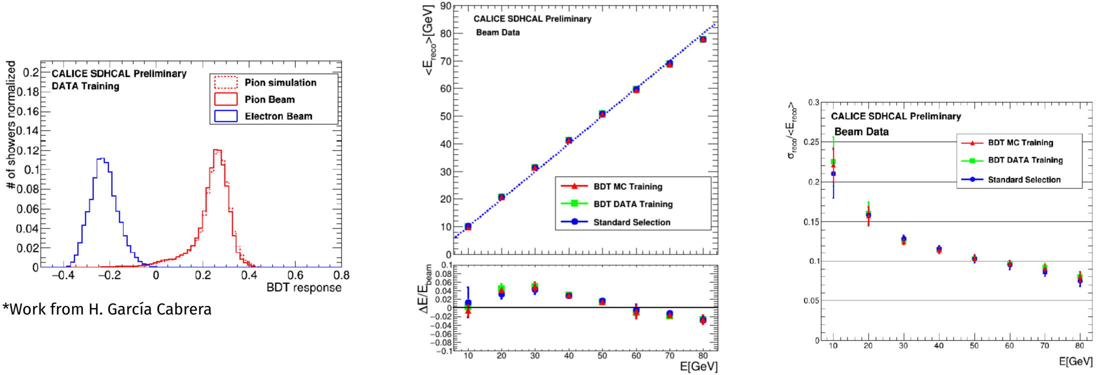
Excellent agreement in efficiency & multiplicity for μ (cosmics and beam).
Excellent agreement Data/MC.

*Work from H. García Cabrera

SDHCAL BDTs for hadron selection*

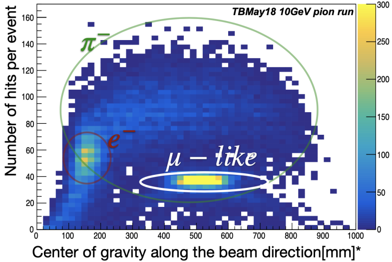
BDTs used for rejecting e and μ contamination in hadronic showers, as an alternative to a cut-based method.

- Use information from shower position, density and shape as input for BDT.
- Train BDTs for separating μ-e and μ-π.



*Work from H. García Cabrera

AHCAL PID with BDTs*

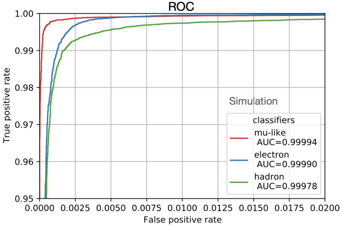


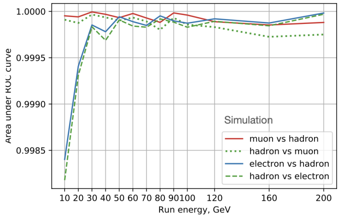
$$* \, z_{CoG} = \frac{\sum_{i=1}^{N_{hits}} z_i \cdot E_i}{E_{sum}}$$

- Identify contamination in TB data
- Learn discrimantive variables
- Data preparation: clustering - track finding
- BDT setup:
  - Generate MC e, μ and π @ 10-200 GeV
  - 50/50 Train/test ratio
  - One classifier per particle type

BDTs show high identification power over full energy range

*Slide adapted from L. Emberger and V. Bocharnikov





CycleGAN for the AHCAL*

No neutral hadron showers measured with the AHCAL, can only be simulated

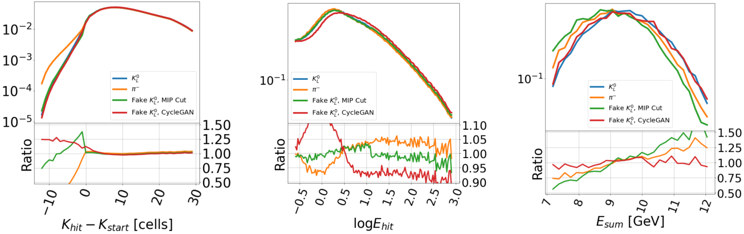
Use Cycle-Consistent Adversarial Networks → artificial K_L^0 hadron showers

CycleGANs

- Convert data: domain A → domain B
- Use: image class conversion
- Input: examples of A & B (not matched)

Hadron shower challenging

- Modify CycleGAN
- kNN graph as input
- Vector output



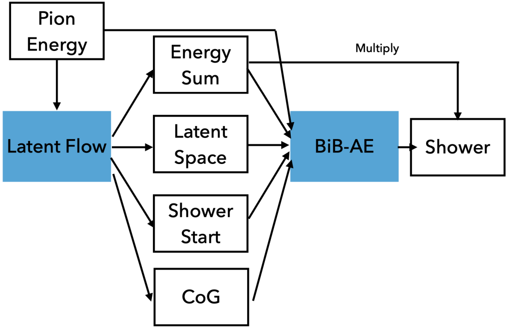
- Good performance overall
- Consistent $K_{hit} - K_{start}$ distribution
- Hit energy dist. must shift to higher energies
- PID validation (not shown) produces similarly distinguishable showers

* Work from Jack Rolph

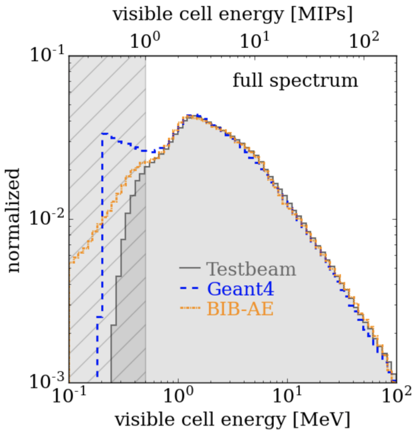
Generative models for TB simulation

Simulation solution using normalizing flow and (BIB) Auto-Encoders

- Trained using real AHCAL beam test data
- Much faster than Geant4
- Some observables: “better” than G4



* Work from Sascha Diefenbacher



Conclusions

- Many software tools in place for simulation and reconstruction, both for detector concept and prototypes.
- Exploiting high granularity in reconstruction: noise, imperfections, models.
- G4 Validation.
- Timing developments ongoing.
- Machine Learning used in hadronic shower reconstruction and simulation shows promising results.

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Sources

- Masuda for the ScW-ECAL (LCWS'21)
- Ryunosuke Masuda for the ScW-ECAL (CALICE meeting 22)
- Héctor García Cabrera - SDHCAL (LCWS'21)
- Lorentz Emberger - AHCAL (LCWS'21)
- Jack Rolph – AHCAL (CALICE Meeting Sept 2021)
- Jack Rolph (CALICE Meeting Sept 2020)
- Sascha Diefenbacher - Generative Models for Shower simulation on TB data
- Lorenzo Pezzotti's GEANT4 talk (Calice Meeting April 2022)