and GEANT4

An outlook on the next few years

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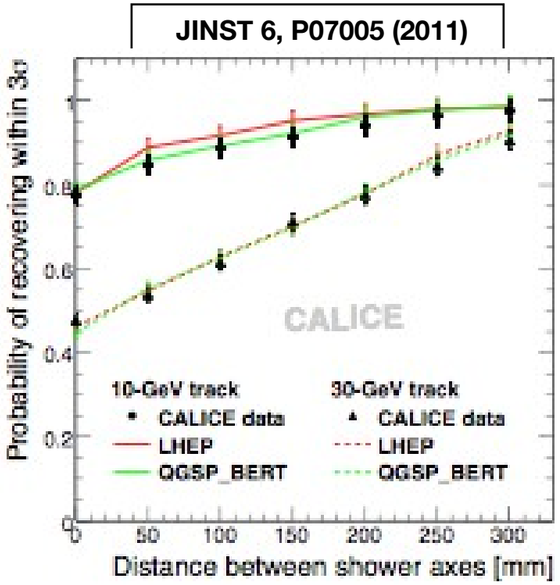
Virtual LPCC Workshop – November 2020

CALICE "History"

Physics Prototypes

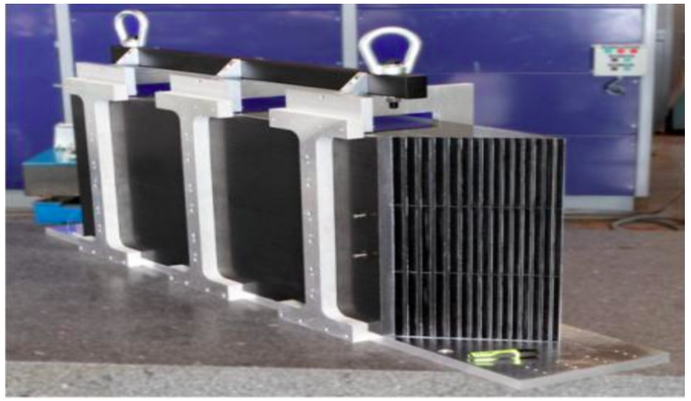
2003 - 2012



- Proof of principle of granular calorimeters
- Large scale combined beam tests
- **Validation of G4 Physics lists**

Technological Prototypes

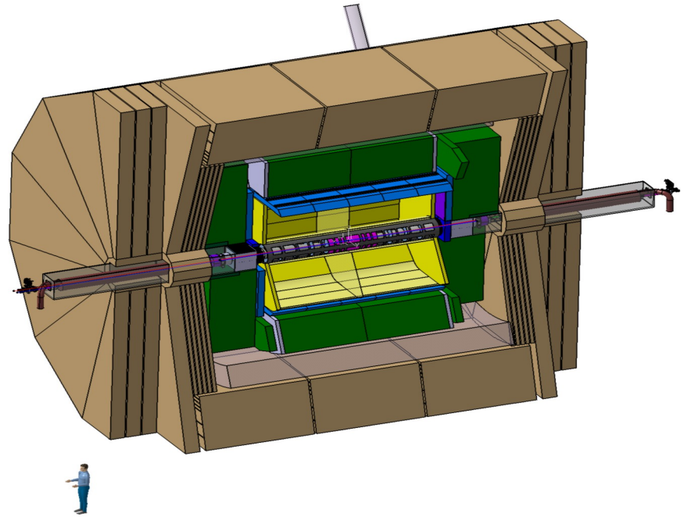
2010 - ...



- Engineering challenges
- Higher granularity
- Better sensitivity (lower noise)

Current period

Higgs factory detector

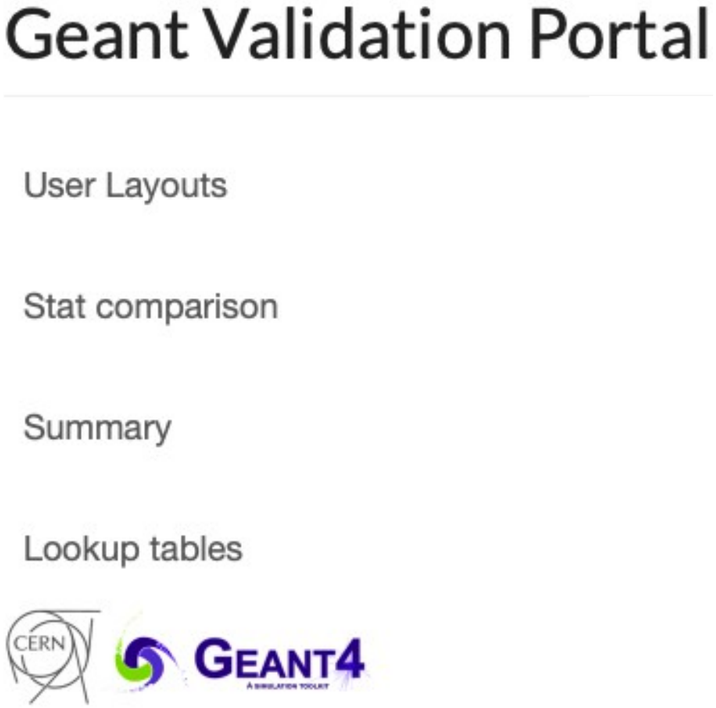


- The goal
  - Typically 10^8 calorimeter cells
- Compare:
  - ATLAS LAr ~10^5 cells
  - CMS HGCAL ~10^7 cells

Where are we?

- Data analyses of physics prototype and first technological prototypes data are about to come to an end
- Lots on emphasis on solving technological challenges in recent years
- Further technological prototypes are getting mature
- At the eve of new round of large scale combined beam tests
  - Will be conducted over next 2-3 three years
  - Discussion on “physics program” with G4 team highly desirable

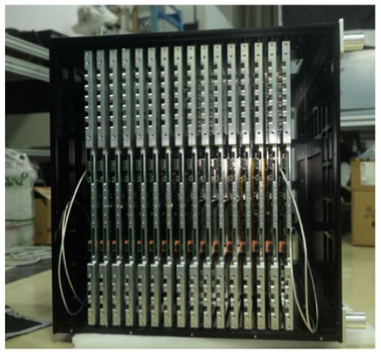
CALICE and GEANT4 Versions



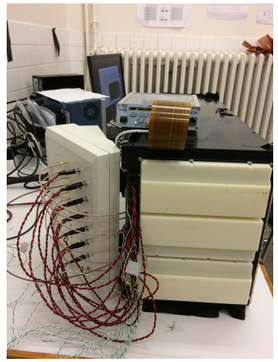
https://geant-val.cern.ch

- CALICE results present comparisons with older GEANT4 physics lists (v10.1 at best)
  - Note that CALICE analyses are often sophisticated, which makes it difficult to keep up with the G4 development cycle
- CALICE will make an effort to change this for new analyses
  - Not possible and reasonable anymore for analyses with physics prototypes
- The GEANT4 validation would be/could be a very useful tool to validate new GEANT4 versions at an early stage
  - Effort started in 2017/18 with SiECAL (physics prototype) data
  - Seems to be ready but is hibernating since Spring 2018
  - It is clearly worthwhile to resume this
  - Requires manpower on both (i.e. CALICE and GEANT4) sides

(Main) Technological prototypes

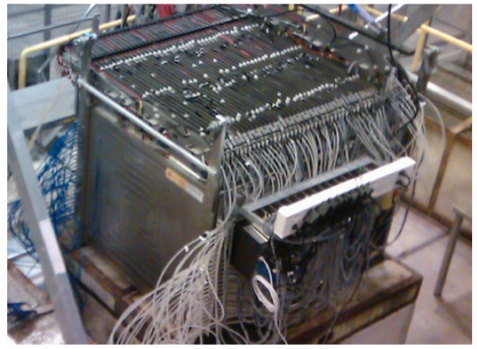


ScECAL



SiECAL

AHCAL



SDHCAL

Name	Sensitive Material	Absorber Material	Resolution	Pixel size/mm^3	~Layer size**/cm^3	~Layer depth/X_0	~Layer depth/λ_I	# of Pixels/ layer	# of layers	Comment
ScECAL	Scintillator	W-Cu Alloy	Analogue, 12bit	5x45x2	23x22x0.5	0.73	0.03	210	32	2x16 x and y strips
SiECAL	Si	W	Analogue, 12bit	5.5x5.5x 0.3 (0.5, 0.65)	18x18x 0.24 (-0.63)	0.6-1.6	0.02-0.06	1024	≥22	Can be run in different configs.
AHCAL	Scintillator	Fe*/W	Analogue, 12bit	30x30x3	72x72x2/ 1.4	1/2.9	0.11	576	38	Running with Fe and W
SDHCAL	Gas	Fe*	Semi-digital 2bit	10x10x6	100x100x 2.6	1.1	0.12	9216	48	

*Stainless Steel

**Only absorber + sensitive material for z direction, air gaps, electronics discarded here (would add 5-10%)

Scope of analyses

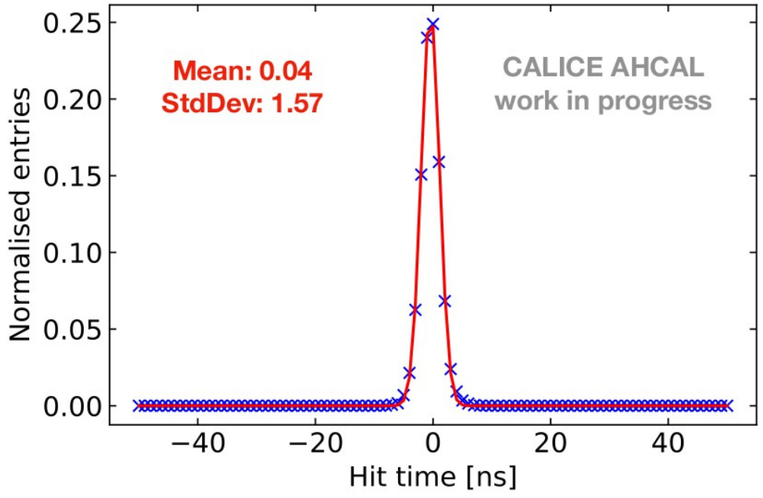
- CALICE will of course continue to extract and present “classical” calorimetric observables
  - Be also reminded that CALICE Calorimeters are a sequence of thin targets
- The rich amount of information has to be further exploited
  - I am sure we have only seen the tip of the iceberg
- The CALICE programme will follow the trend in terms of instrumentation but also in terms of analysis techniques
  - See next slides

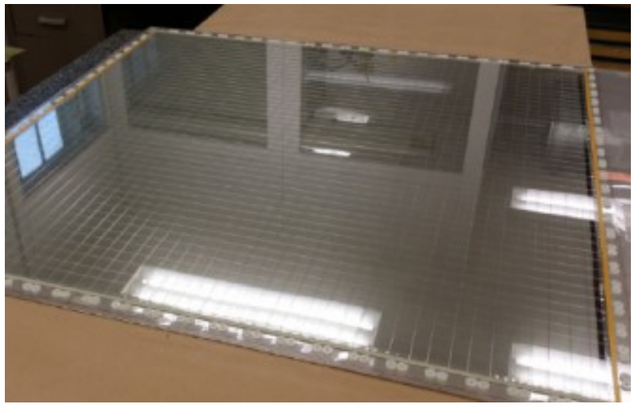
Trends I - Timing

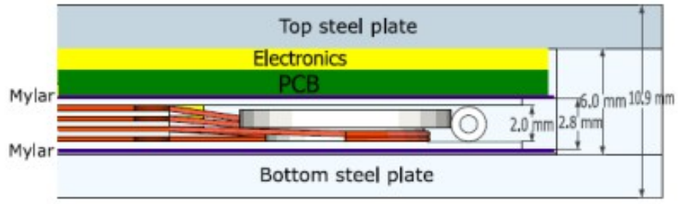
Pioneered by LHC Experiments, timing detectors are/will be also under scrutiny by CALICE Groups

Hit time resolution:
Results from 2018 beam test of AHCAL with muons

Clock frequency 5 MHz,
Powering pulsing

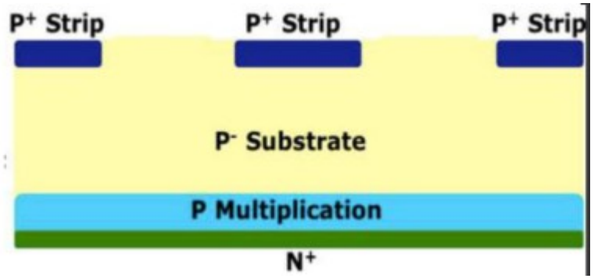






Under development:
GRPC with PETIROC
- < 20ps time jitter
- Developed for CMS Muon upgrade

Inverse APD as LGAD?



Inverse APD
by Hamamatsu

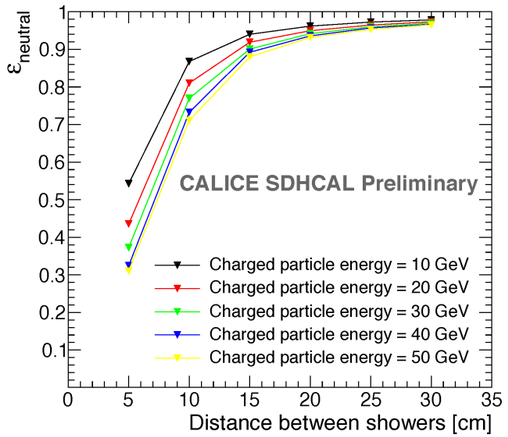
Gain ~ 50

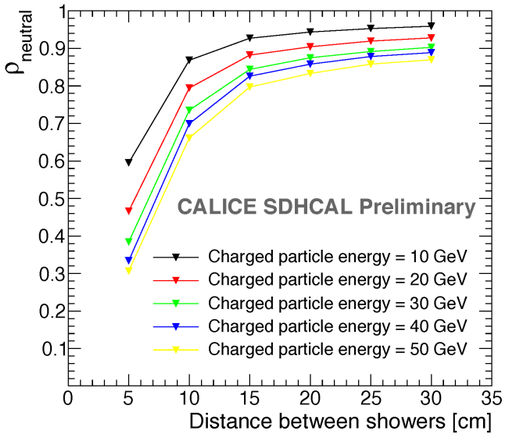
Timing – Key questions

- Particle flow is driving concept for most of the detector designs for Higgs factories
- Introducing timing for Higgs factories may assist PFA but has implications for detector design
- What is better?
  - Excellent timing of the order of 10-30ps in a few layers at e.g. the beginning of a calorimeter or
  - Average timing of the order of 100-200ps in the entire detector
- Guidance has to come from GEANT4 simulations that implement properly the time structure of hadronic showers
- The specific needs for timing would trigger dedicated hardware developments
- Given current hardware constraints CALICE will be able to validate G4 physics list at the 500ps - 1ns level
  - With large prototypes
  - Maybe better with smaller dedicated setups

Trends II – More studies on particle separation

SDHCAL: Separation of 10 GeV neutral hadron from charged hadron [CALICE-CAN-2015-001]

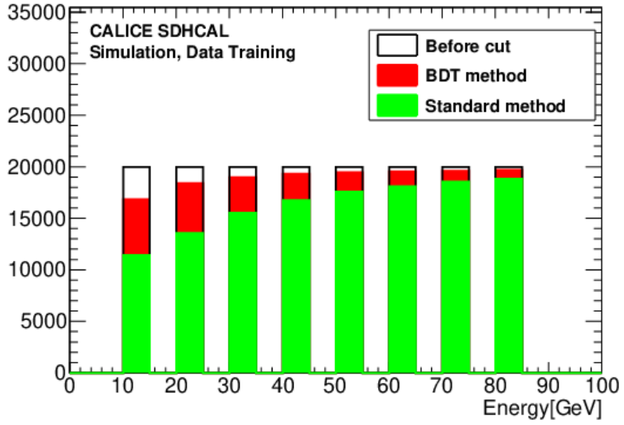


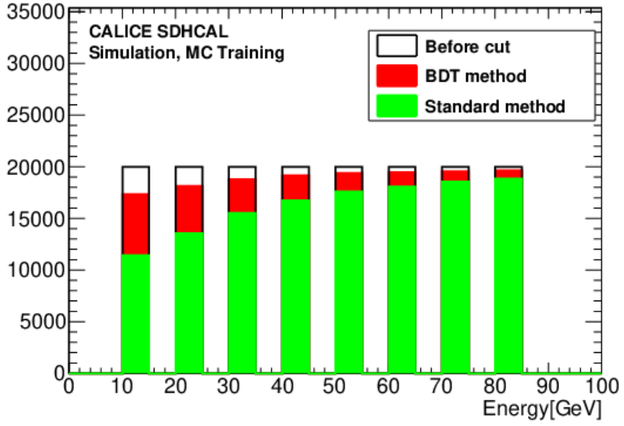


More than 90% efficiency (ε) and purity (ρ) for distances ≥ 15 cm

SDHCAL: Multi-variate analysis for Particle ID

[arxiv:2004.02972, accepted by JINST]

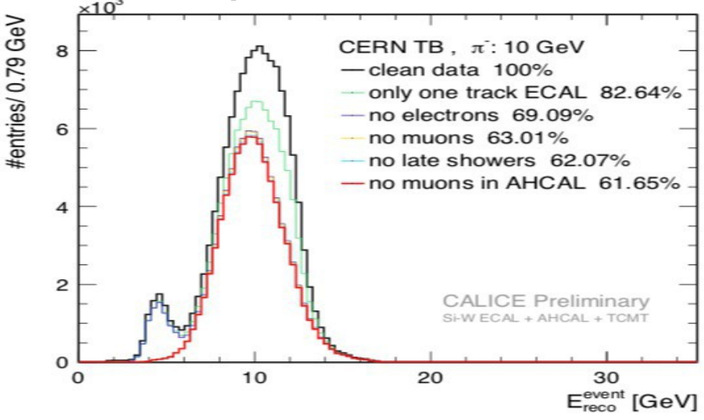




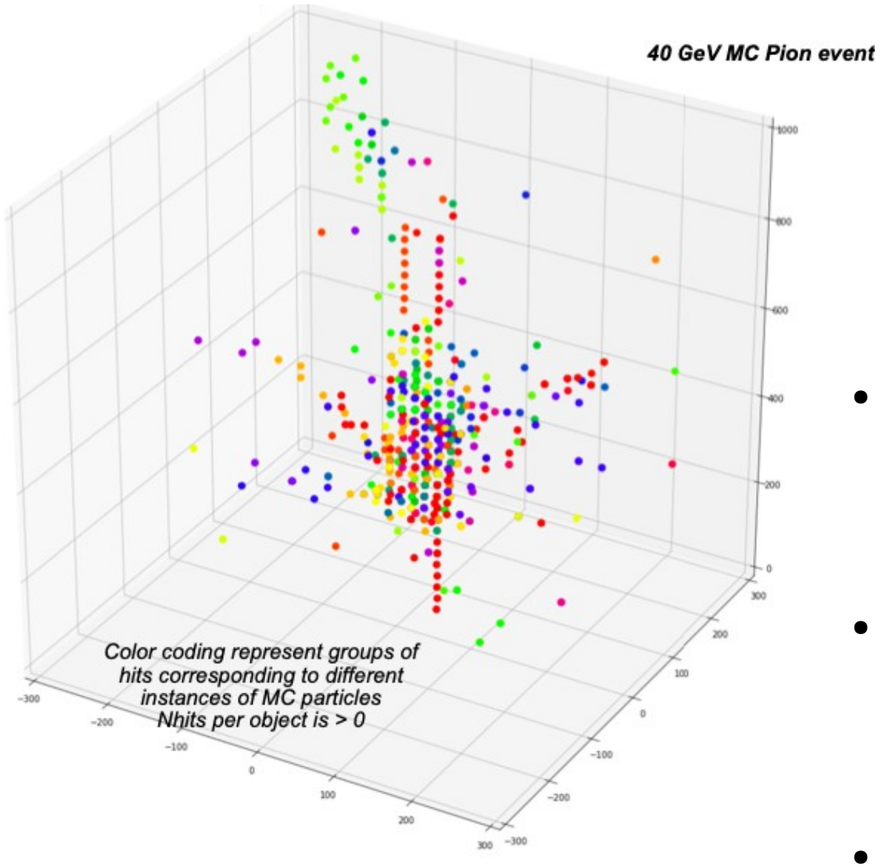
BDT enhance pion selection efficiency at small energies

SiW ECAL: Tracking capabilities to select single π-events

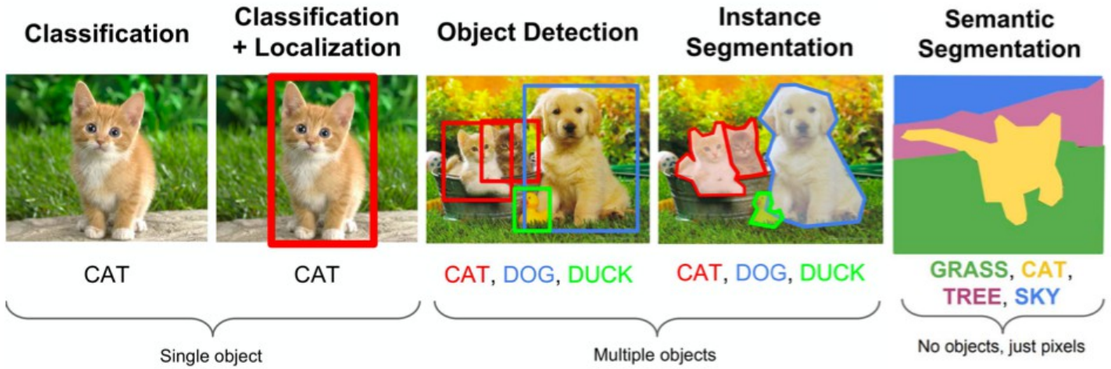
[CALICE-CAN-2017-002]



Trends III – Analysing hadronic showers with ML



Images V. Bocharnikov



- CALICE data are excellent “playground” for application of machine learning and computer vision algorithms
  - Shower substructure
  - Particle identification and separation
- This is attractive in particular for young generation of physicists (and beyond)
  - Often (if not always) first steps are made with G4 simulated events
  - Can the algorithms be mislead by “wrong” models of hadronic showers?
- How to address a meaningful comparison with data?
  - Sophisticated combination of information

Summary

- CALICE continues to produce and analyse data with highly granular calorimeters
  - Four large scale technological prototypes are available and will (continue to) take data in coming years
- Comparison with GEANT4 physics lists is essential pillar of CALICE Mission
  - Recommendation in ECFA Review 2018 of CALICE
    - *"...., the committee recommends that the CALICE collaboration continues to analyse the rich set of data that has been and will be collected in a number of test beam campaigns with prototypes of different technologies and to publish the results. These data are a crucial input for an improved understanding of hadronic showers. The exploitation of these data shall be continued in close collaboration with the GEANT4 team to contribute to an improved modelling of hadronic interactions, which is also of interest beyond high energy physics applications."*
  - Awareness that "transition" to more recent GEANT4 versions has to be made
- Timing will become a topic in coming years
- Granularity implies opportunities for the application of modern algorithms
  - Best strategy for meaningful comparisons?

Backup