US AHCAL Interests

Andy White

UNIVERSITY OF TEXAS ARLINGTON

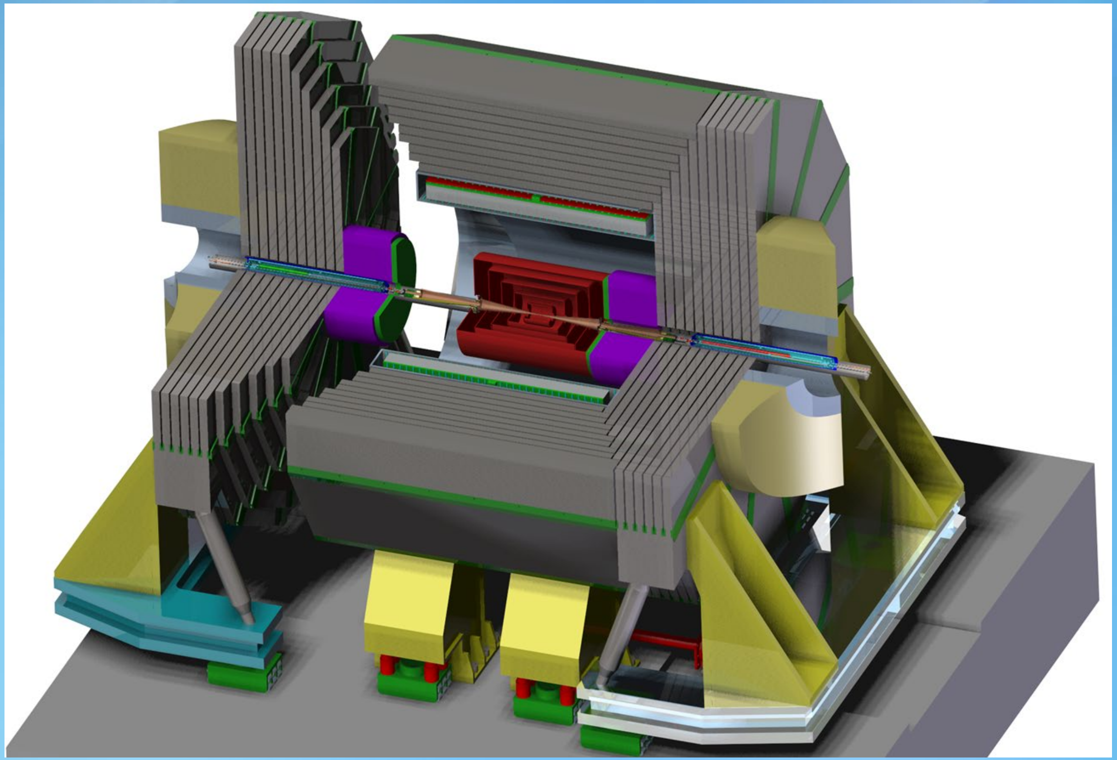
AHCAL

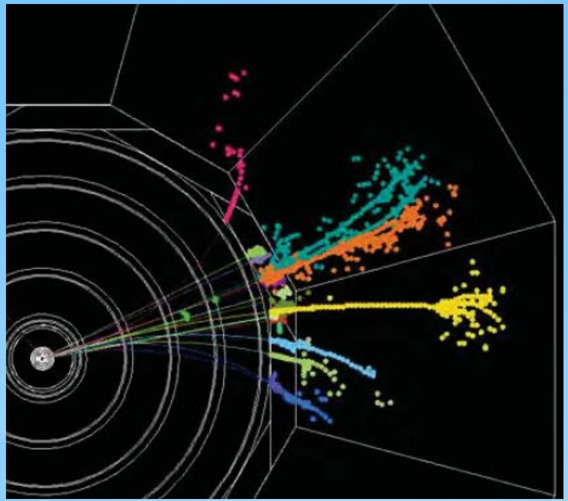
My interest in AHCAL is closely connected to the development of the SiD Detector Concept for the ILC.

In 2016 SiD changed technology for the HCal from RPC/Steel to Scintillator/SiPM/Steel.

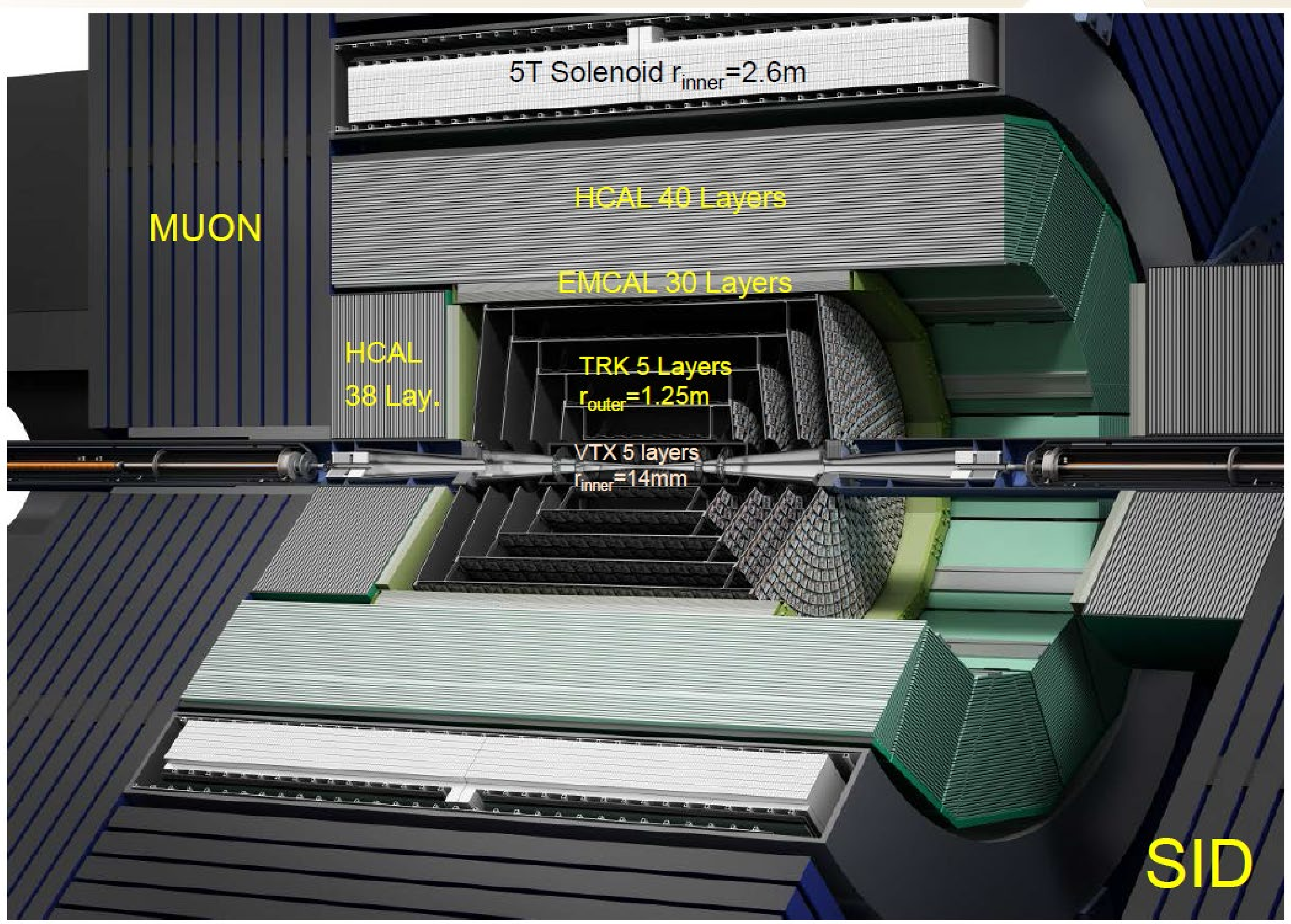
The application of this technology to SiD was developed until all support stopped, but we maintain a strong interest in pursuing it.

Today I will briefly review the SiD HCal design status and indicate further studies we would like to pursue.





The SiD Detector



The SiD Design Rationale

A compact, cost-constrained detector designed to make precision measurements and be sensitive to a wide range of new phenomena.

Design basics:

Robust silicon vertexing and tracking system – excellent momentum resolution, live for single bunch crossings.

Highly segmented “tracking” calorimeters optimized for Particle Flow.

Compact design with 5T field.

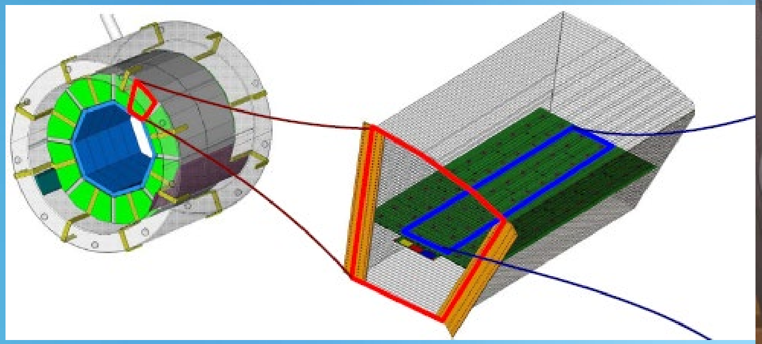
Iron flux return/muon identifier – component of SiD self-shielding.

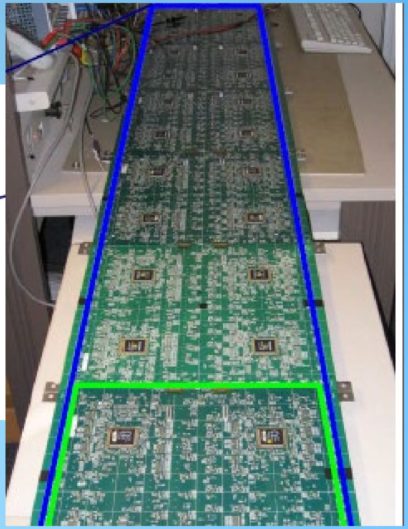
Detector is designed for rapid push-pull operation.

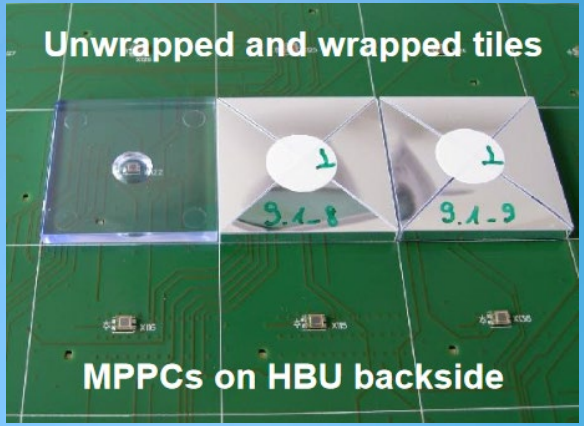
SiD – Required Physics Performance

Physics Process	Measured Quantity	Critical System	Critical Detector Characteristic	Required Performance
$H \to b\bar{b}, c\bar{c}, gg, \tau\tau$ $b\bar{b}$	Higgs branching fractions b quark charge asymmetry	Vertex Detector	Impact parameter $\Rightarrow$ Flavor tag	$\delta_b \sim 5\mu m \oplus 10\mu m/(p\sin^{3/2}\theta)$
ZH→$\ell^+\ell^-$X $\mu^+\mu^-\gamma$ $ZH + H\nu\bar{\nu}$ $\to \mu^+\mu^- X$	Higgs Recoil Mass Lumin Weighted E_{cm} BR (H →μμ)	Tracker	Charge particle momentum resolution, $\sigma(p_t)/p_t^2$ $\Rightarrow$ Recoil mass	$\sigma(p_t)/p_t^2 \sim few \times 10^{-5} GeV^{-1}$
ZHH $ZH \to q\bar{q}b\bar{b}$ ZH→ZWW* $\nu\bar{\nu}W^+W^-$	Triple Higgs Coupling Higgs Mass BR (H → WW*) σ(e+e- → νν W+W-)	Tracker & Calorimeter	Jet Energy Resolution, σ_E/E $\Rightarrow$ Di-jet Mass Res.	~3% for E_{jet} > 100 GeV $30\%/\sqrt{E_{jet}}$ for E_{jet} < 100 GeV
SUSY, eg. $\tilde{\mu}$ decay	$\tilde{\mu}$ mass	Tracker, Calorimeter	Momentum resolution, Hermiticity $\Rightarrow$ Event Reconstruction	Maximal solid angle coverage

SiD Hadron Calorimeter

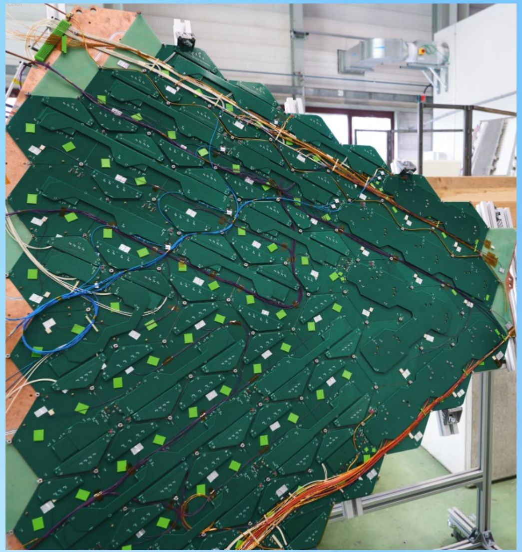


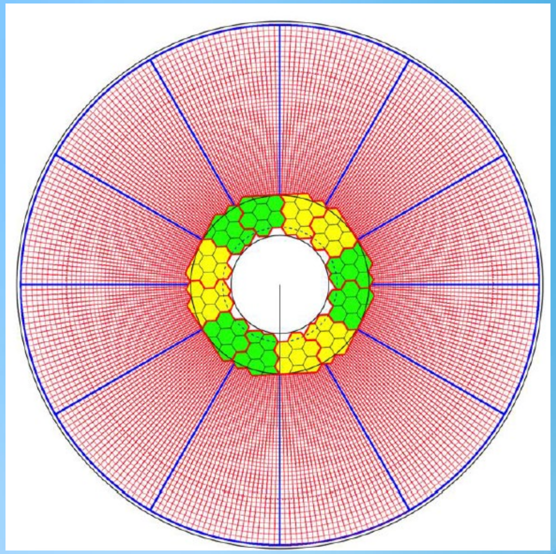


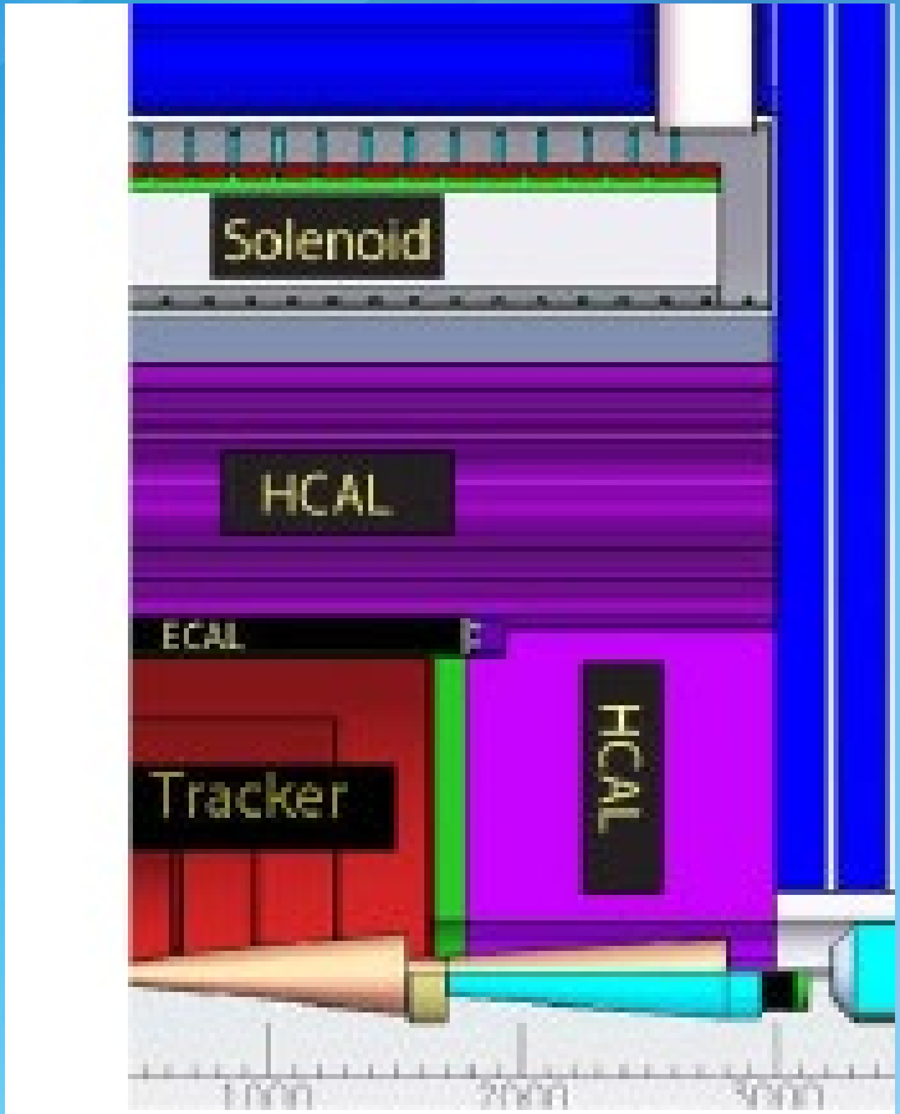


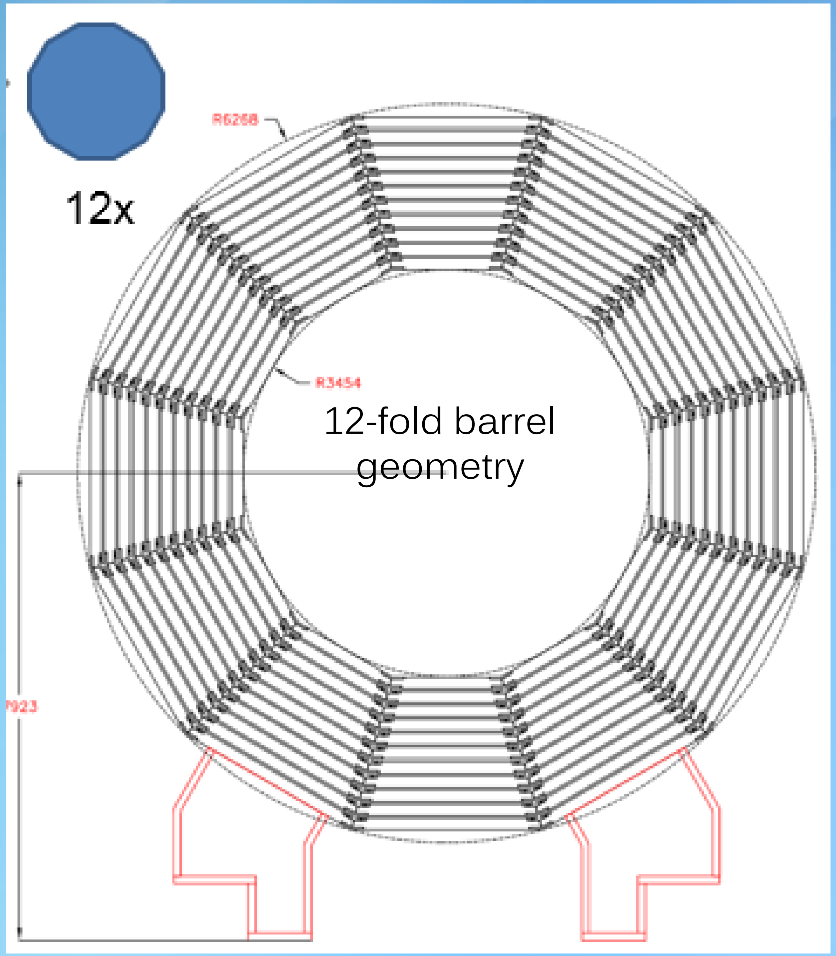
Baseline technology for the SiD HCal is Scintillator/SiPM/Steel
As for CALICE/DRD6/AHCAL

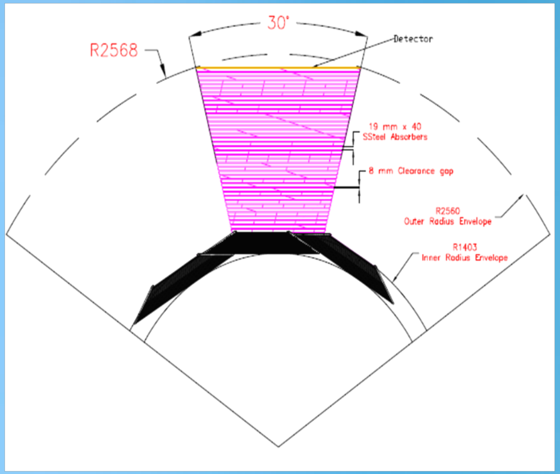
Similar issues for CMS HGCAL



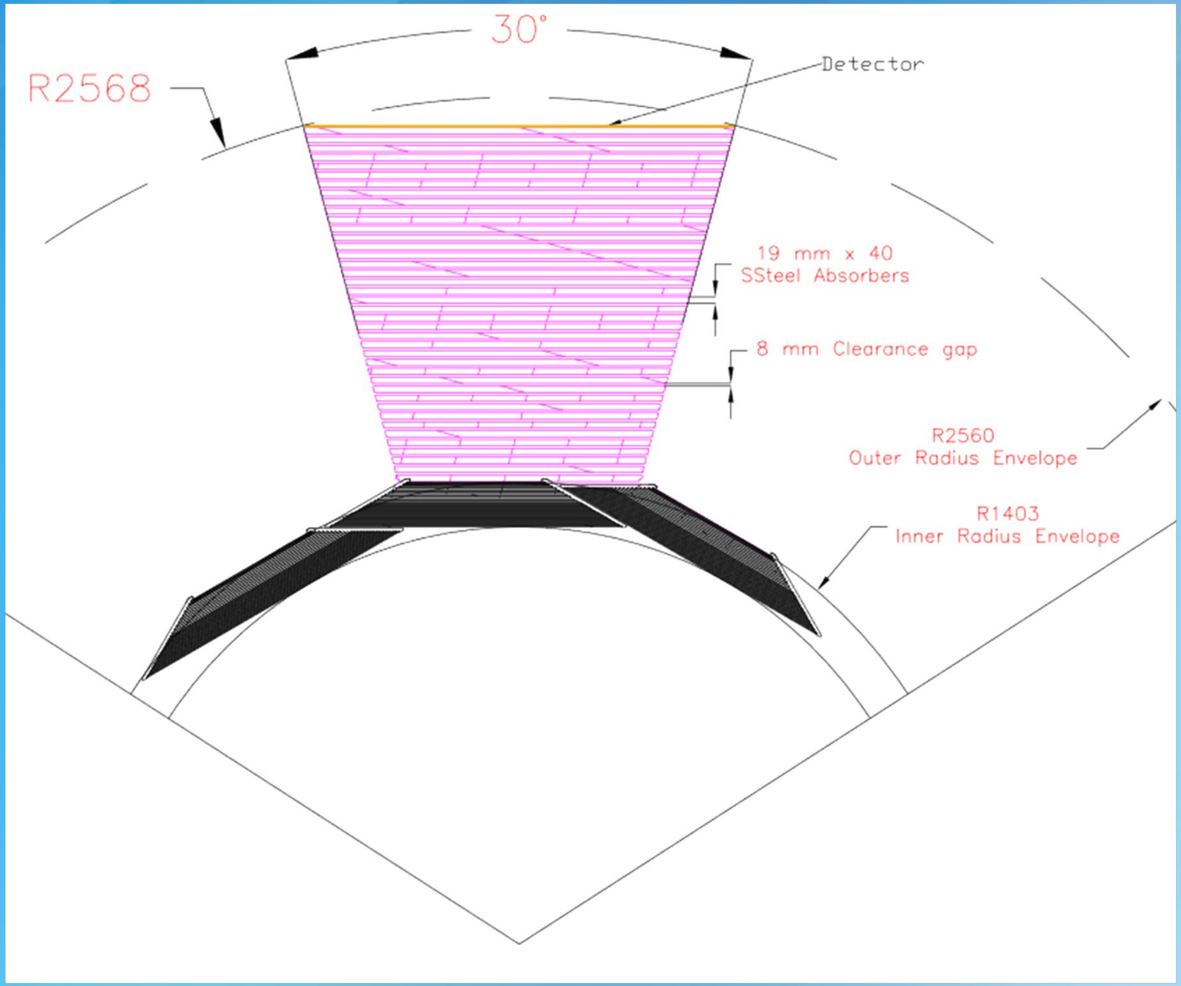


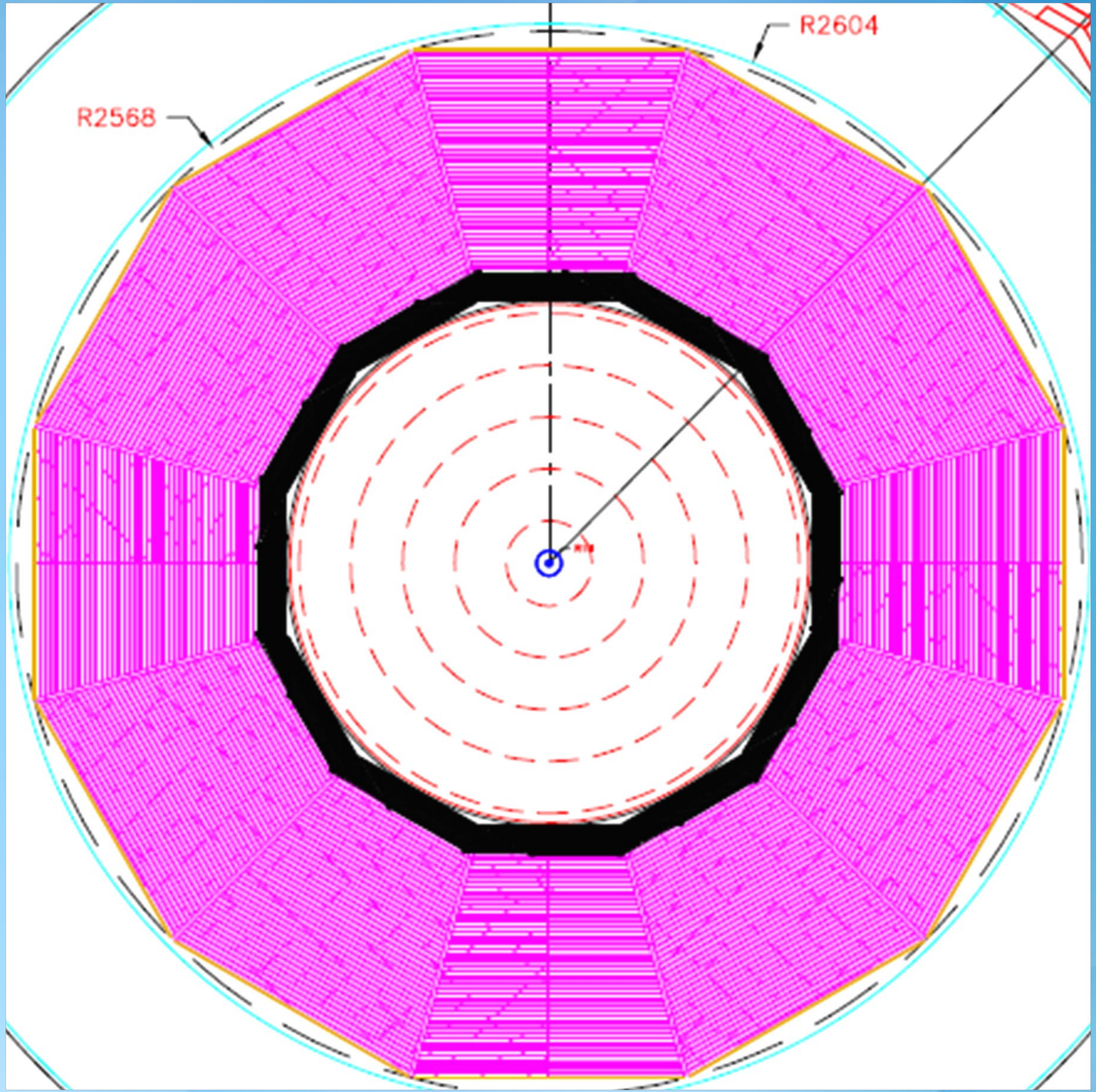






Marco Oriunno
(SLAC)

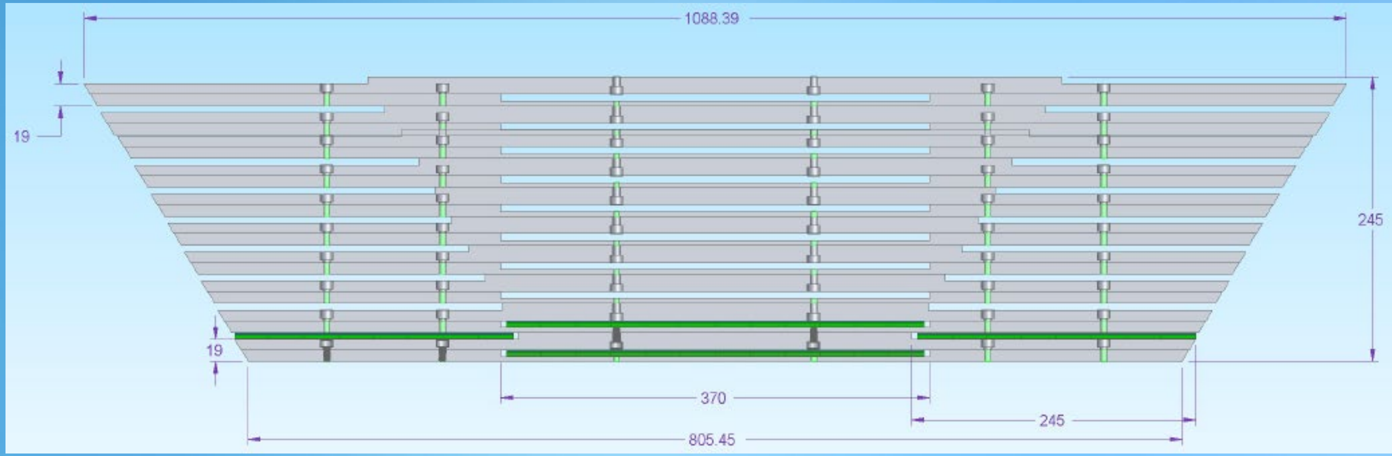




Marco Oriunno
(SLAC)

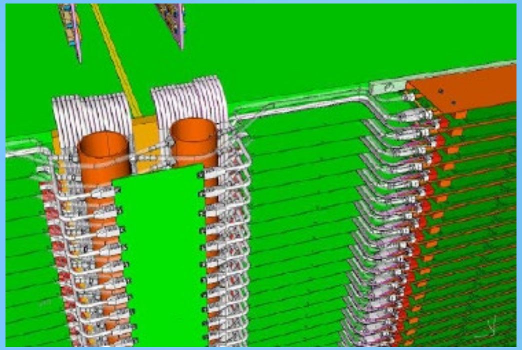
SiD Hadron Calorimeter

Initial SiD Hcal design ideas
(for barrel)

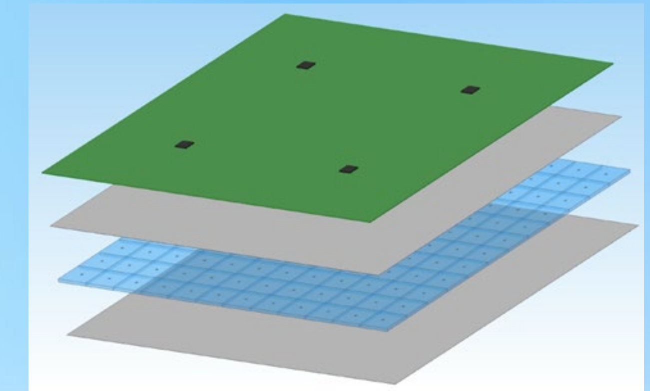


Marco Oriunno
(SLAC)

SiD Hadron Calorimeter

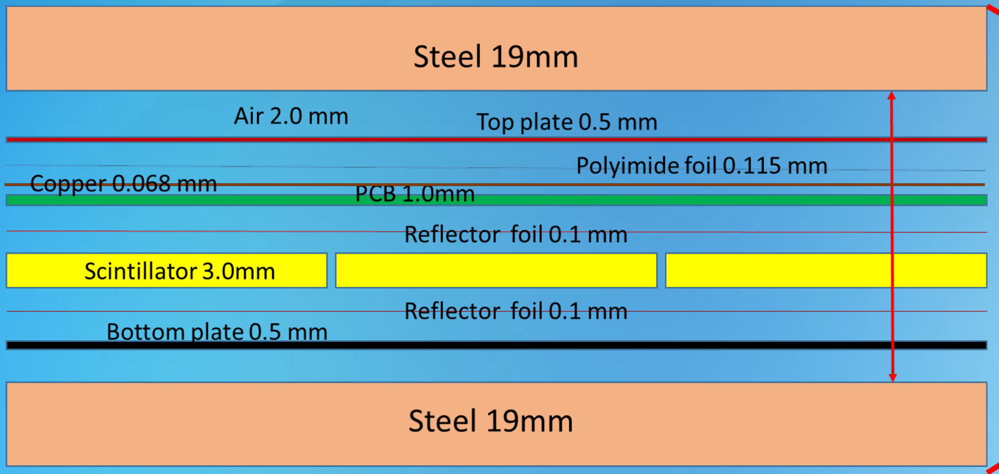


- Explored possible cooling schemes
- Heat load/extraction



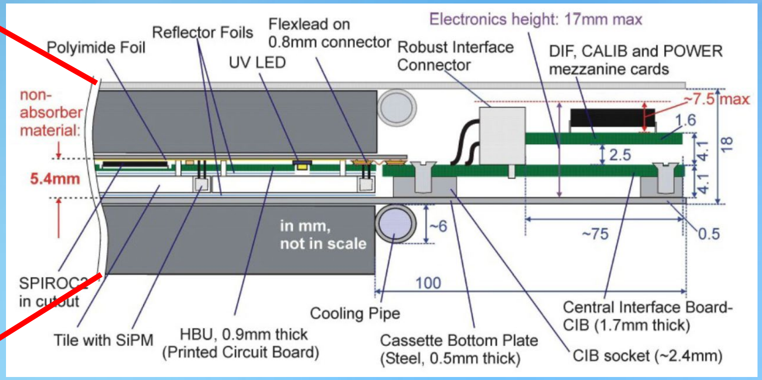
Marco Uriunno (SLAC)

SiD Hadron Calorimeter



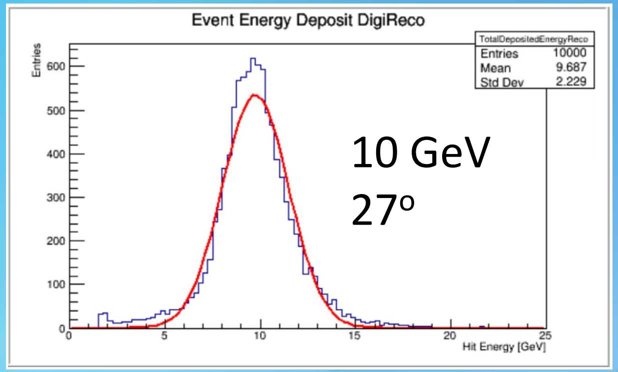
Active layer thickness = 7.383 mm

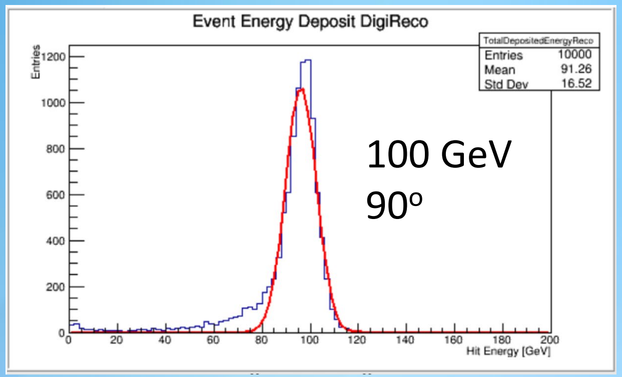
CALICE design

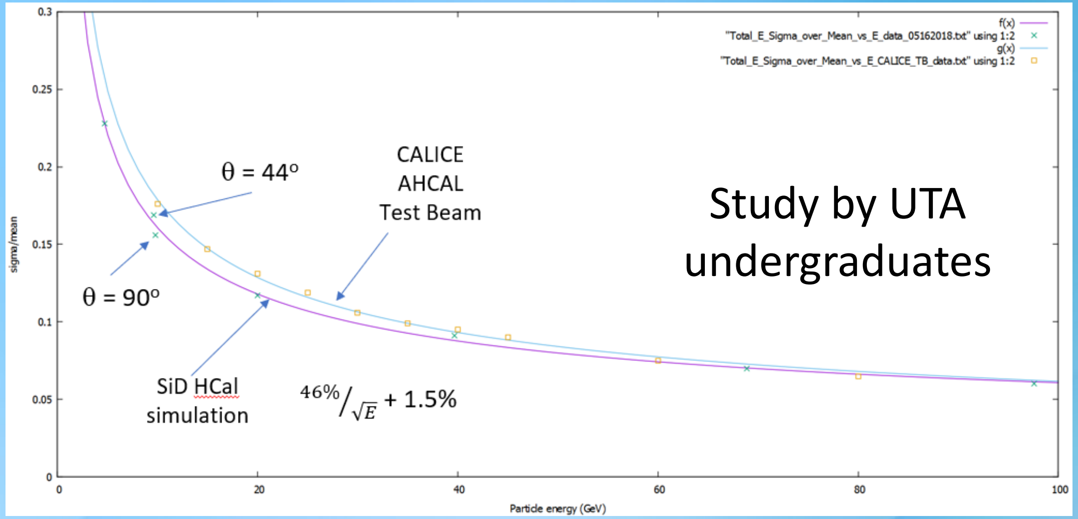


SiD simulation:
compare simulated single particle energy resolution with actual CALICE test beam results

Single particle studies.

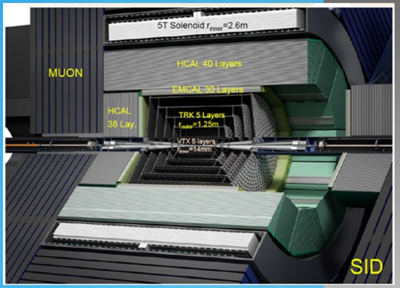


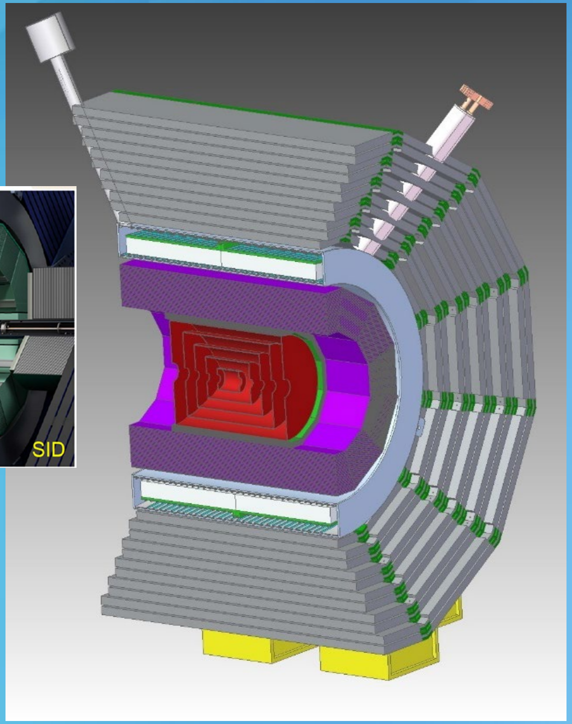




UTA, SLAC

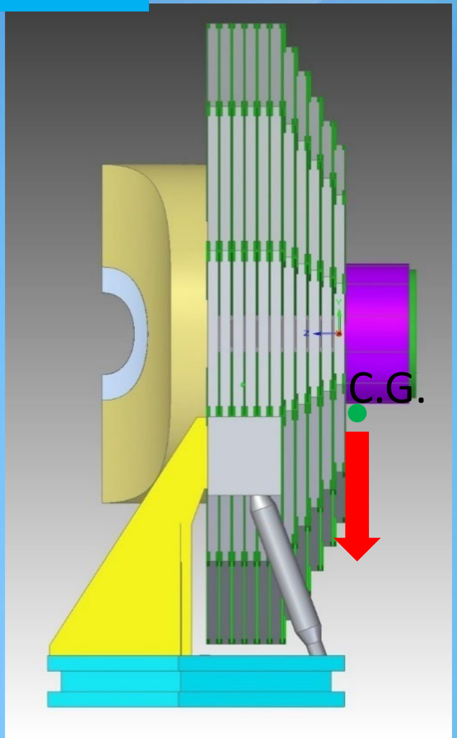
Muon identifier/Calorimeter Tail Catcher

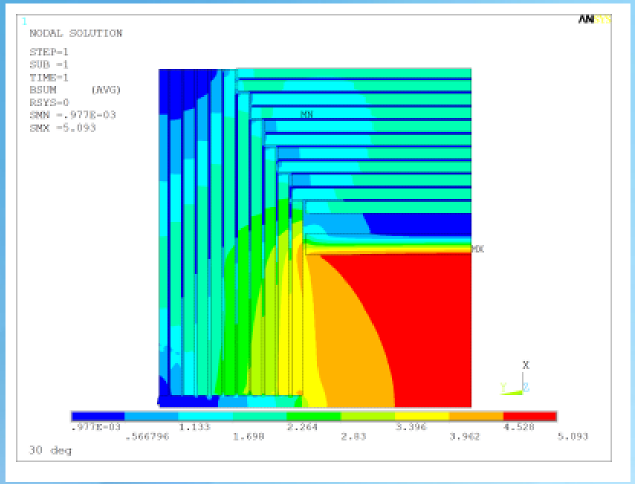


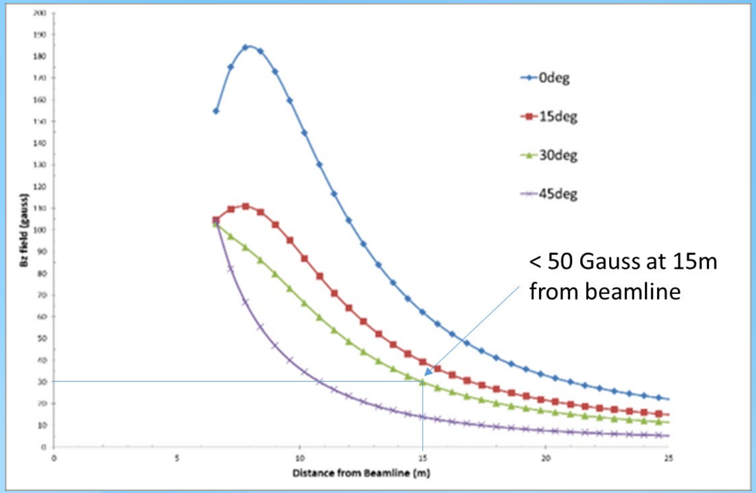


Redesign of barrel/door junction
More efficient flux return
Easier transport/handling

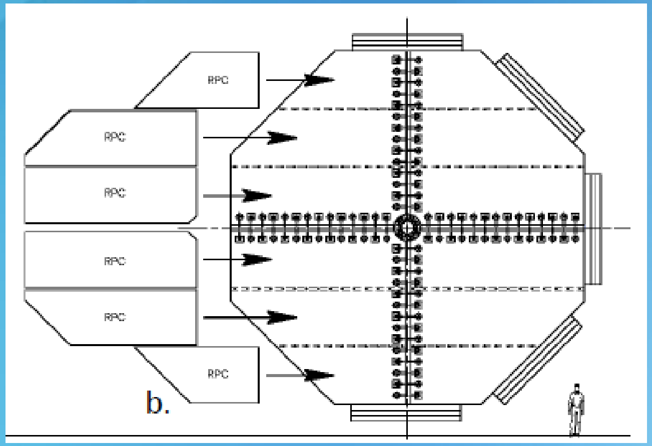
Marco Oriunno
(SLAC)

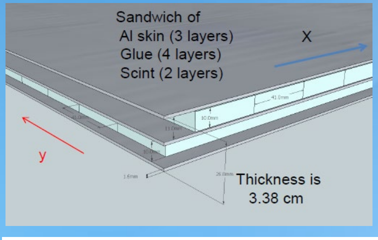


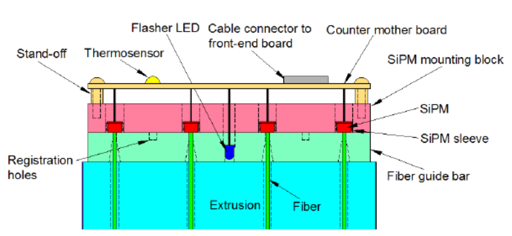




Muon identifier/Calorimeter Tail Catcher



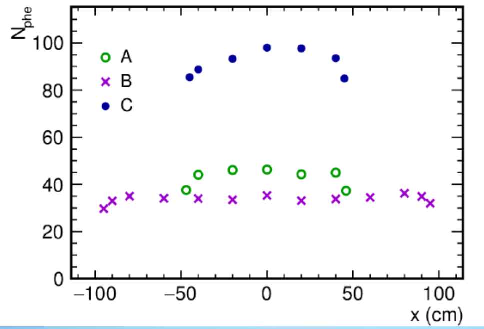




SiD Baseline – long scintillator strips with WLS fiber and SiPM readout

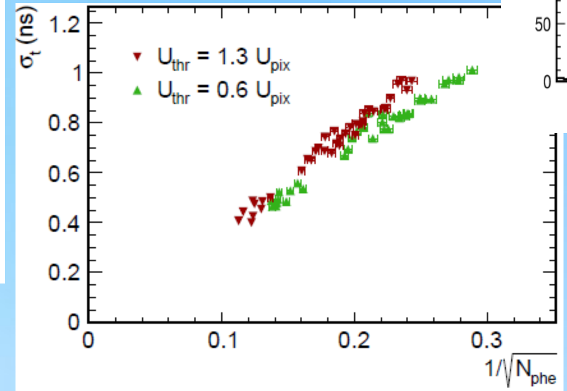
- Consistent extension of the baseline HCal scintillator technology
- Need to optimize number of layers, strip dimensions.

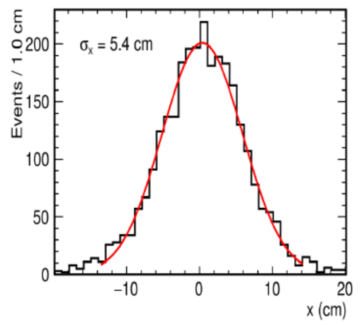
Development work at Fermilab:



Paper published:
NIMA, **848**, 54-59, 2017

Time resolution





Position resolution

R&D topics:

- Active layer design (single tiles/megatiles)
  review results from CALICE prototypes, latest megatiles
  ease of manufacture – number of megatile sizes vs. using small tiles
  megatile option for endcap HCal? Participate in DRD6 R&D/test beam(s).

- Module size (barrel/length, endcap/phi sectors)
  number of barrel modules in z, connecting modules in z
  endcap modules – lessons from CMS HGCAL?

- Signal, power, control lines distribution
  routing to/from adjacent modules

- HCal optimization in combination with digital/MAPS ECal.
  precision tracking layers in HCal to match ECal fine granularity?

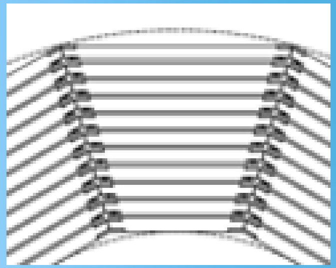
R&D topics:

HCal Optimization

- Cost saving by making some of the HCal outer layers thicker if there is no significant degradation in energy resolution.

- Optimization of the boundary region between the ECAL and the HCAL and optimization of the first layers of the HCAL to best assist with the measurement of e.m. shower leakage into the HCAL.

- Reconsideration of the effects of projective cracks between modules.



R&D topics:

Other possible updates/inclusions

- Inclusion of precision tracking layers to assist PFA? #layers, spacing?

- Explore benefit of timing layers - Δt (1ns, 100ps)? , #layers

- Could we use onboard intelligence?
  - Simple – zero suppression
  - Complex – cluster building, interlayer communication,…

Calorimetry and AI/ML

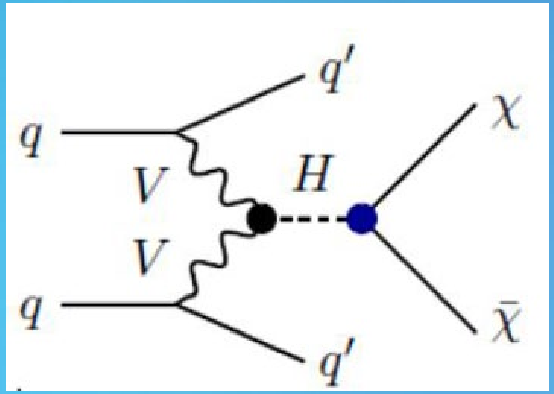
There are (at least) two approaches related to detector design and AI/ML:

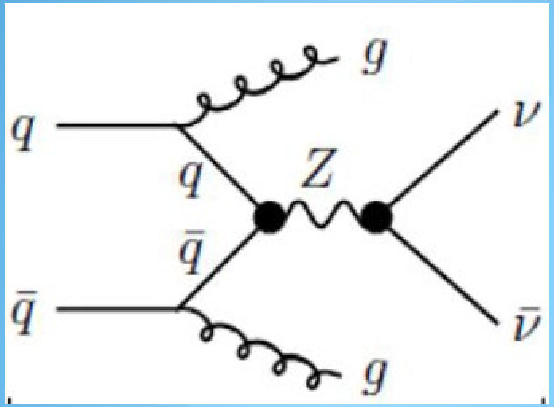
1) Using AI/ML to achieve an optimal design for e.g. best calorimeter energy resolution, shower position resolution.

2) Asking whether a detector design is optimal for the application of AI/ML in the analysis of the data output.

It is not *a priori* clear that 1) would lead directly to the desired outcome in 2), but perhaps studies using 1) could have a second stage leading to 2)?

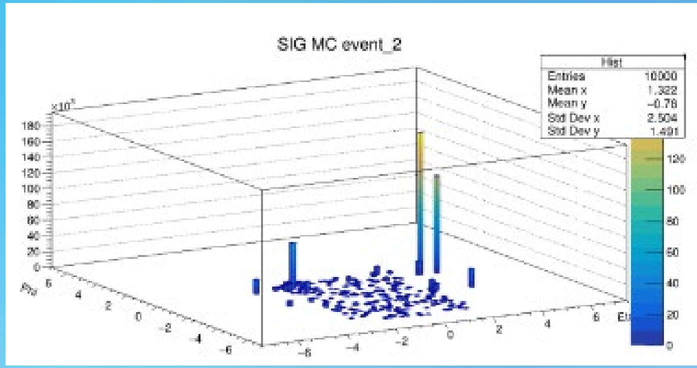
An example of an analysis using an ML approach to improving a search for new physics.



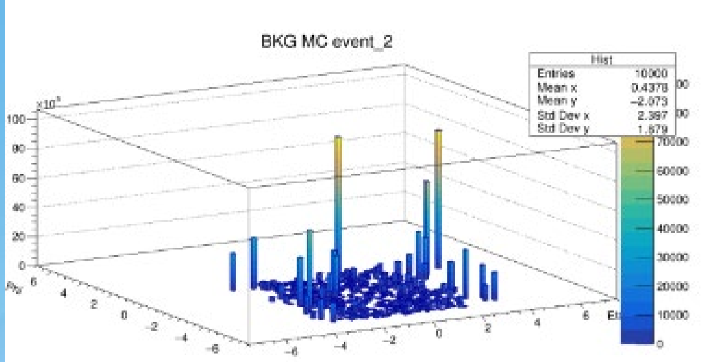


VBF Higgs to Invisible Analysis
Using ML on Calorimeter energy deposition patterns

Identified as Signal

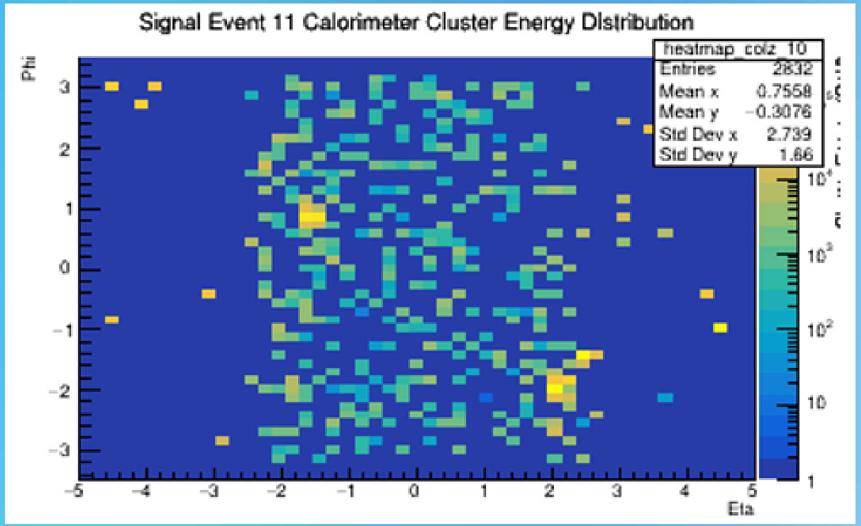


Identified as Background

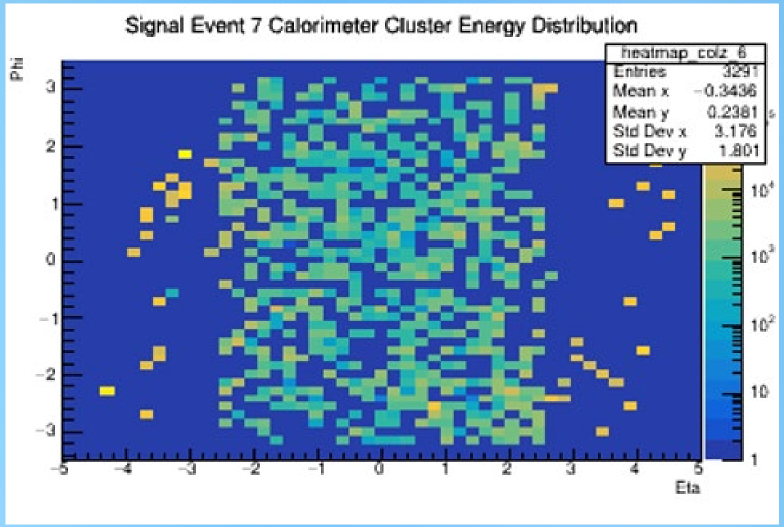


Calorimeter signal readout thresholds?

Some calorimeter energy deposition patterns allowing clear recognition of features



Some events have much noise/pile up etc.



- Need to test e.g. CNN efficiency vs. threshold(s): balance time vs. correct identification success
- Implications of ability of ML algorithms to “see through” noise etc. for electronics design/noise specification criteria?

Calorimeter design parameters/features that could influence the performance of a data AI/ML analysis

- Granularities: ECal, HCal
- Signal thresholds
- Timing – special layers?
- Tracking – special layers – to assist PFA?
- ECal/HCal separation, integrated design
- On-detector logic?
- Inter-layer communication?
- AI/ML in trigger – configuration, topological?
- DAQ - sequence

Electromagnetic/Hadronic Calorimetry Division?

- Many hadron showers start in the ECal (typically 1λ)

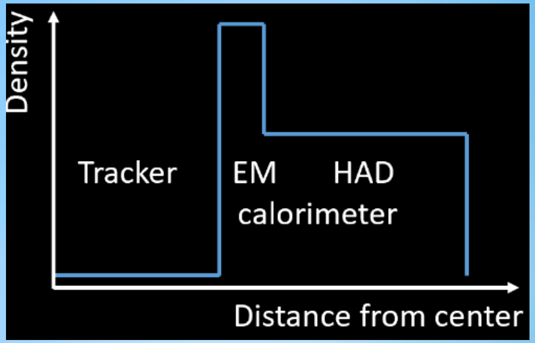
- If a MAPS ECal(*) is used with very fine structure (50 μm x 50 μm pixels?) how would say a CNN handle the abrupt change to e.g. a 3 cm x 3cm tile size HCal?

- Would some precision tracking layers in the HCal help?
 (not just for PFA, but for cluster building)

- Maybe some layers of e.g. smaller tiles at the front of the HCal?

(3) Is there a better density profile than the dichotomic one we have used in collider experiments for six decades?

T. Dorigo, DRD6 Meeting Nov 1 2024

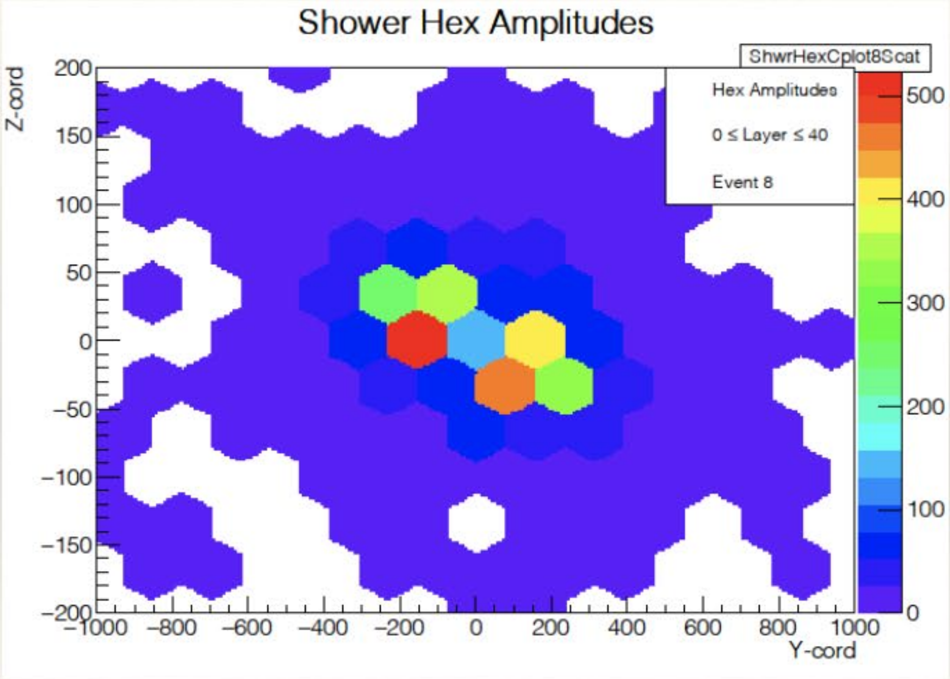


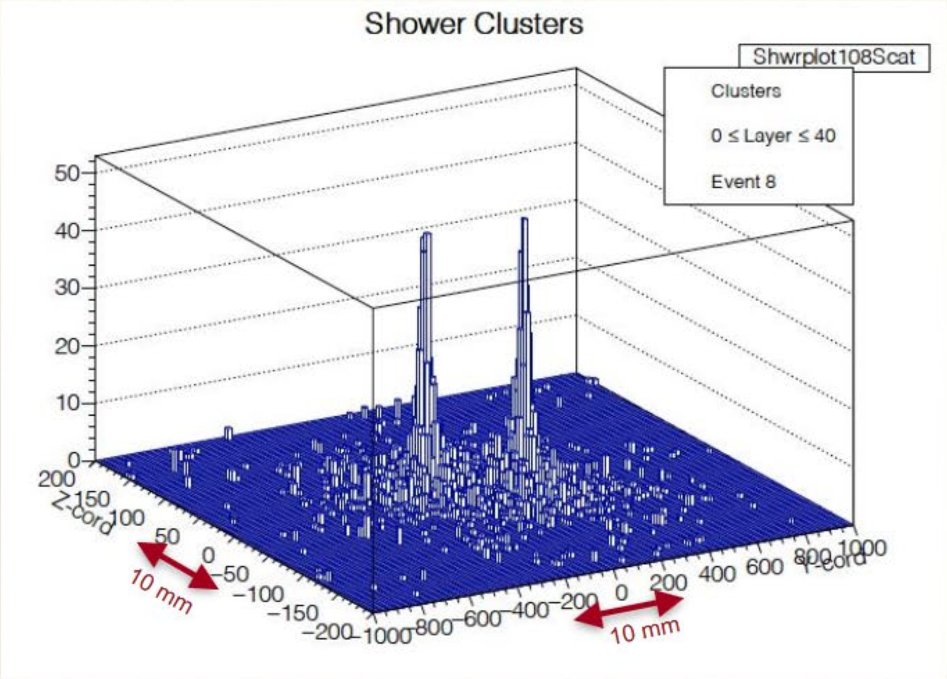
(*) See e.g. Jim Brau's talk on a digital ECal at this meeting.

Multi-shower of SiD MAPS compared to SiD TDR

40 GeV $\pi^0 \rightarrow$ two 20 GeV γ's

SiD Digital ECal based on Silicon MAPS J. Brau - 19 November 2024





SiD TDR hexagonal sensors
13 mm² pixels

Illustrates PFA Potential

New SiD fine pixel sensors
25 μm x 100 μm pixels

10

From talk by Jim Brau at CPAD 2024 Workshop, Knoxville, TN

"The SiD Digital ECal Based on Monolithic Active Pixel Sensors", 10.3390/instruments6040051, Instruments, 6, 51 (2022)

Calorimetry and AI/ML

Fundamental question – is a detector design and the data it produces optimal for analysis using AI/ML techniques?

Related question – if we use AI/ML to design a detector does this produce a good design for AI/ML analysis?

Maybe we need to think in reverse:

Define an analysis -> define optimal data -> let the data inform the design.

(while preserving the beneficial performance features from AI/ML detector design)

SiD Hadron Calorimeter – schedule, collaboration

As submitted to US Higgs Factory Consortium (Linear + Circular) 2024

– FY24-26, Simulation and optimization of design, including timing
– FY26-29, Specification of prototype layers, readout, services; beam tests of pro-totype
– FY29-31, Mechanical and electrical design of barrel and endcap modules

R&D Milestones:

– FY26 - Completion of simulation studies, active layer specification
– FY28 - Prototype assembled
– FY29 - Prototype tested
– FY31 - Barrel and end-cap module designs complete

USA			
University of Texas Arlington		Andy White	awhite@uta.edu
University of Minnesota		Jeremiah Mans	jmmans@umn.edu
Northern Illinois University		Vishnu Zutshi	vzutshi@niu.edu

Plus maybe… SLAC, other groups from CMS HGCAL,…

R&D topics:

- Active layer design (single tiles/megatiles)
- Module size (barrel/length, endcap/phi sectors)
- Endcap tiling (lessons from HGCAL?)
- Signal, power, control line distribution
- HCal optimization in combination with digital/MAPS ECal.
- Cost saving by making some of the outer layers thicker if there is no significant degradation in energy resolution.
- Optimization of the boundary region between the ECAL and the HCAL and optimization of the first layers of the HCAL to best assist with the measurement of e.m. shower leakage into the HCAL.
- Reconsideration of the effects of projective cracks between modules.
- Inclusion of precision tracking layers – PFA?
- Timing layers (number, Δt)
- On board intelligence?
- Optimizing calorimeter design for data analysis using AI/ML

Thank you