Backward Hadronic Calorimeter DSC report

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The Ohio State University

ePIC Collaboration meeting, ANL 12.1.2024

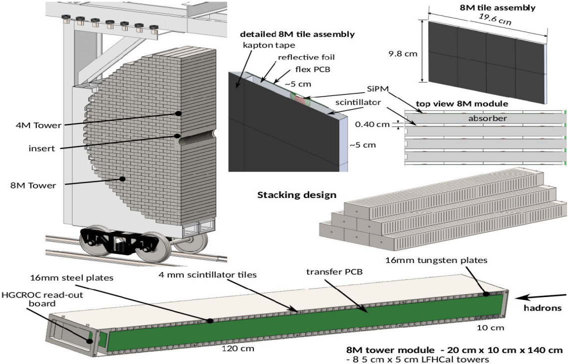
THE OHIO STATE UNIVERSITY

Outline

Introduction - backward HCal (nHCal)

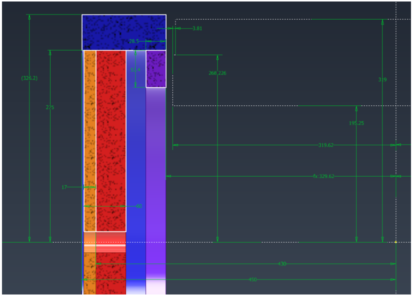
Requirements: https://eic.jlab.org/Requirements/

A future backward HCal shall provide functionality of a tail catcher for the high resolution e/m calorimeter in electron identification, as well as for jet kinematics measurement at small Bjorken x

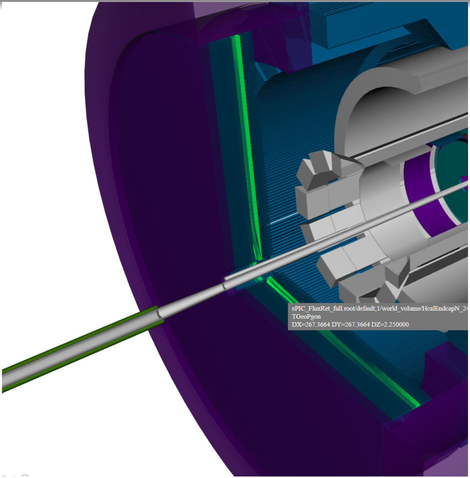


- Design considerations:
  - High efficiency for low energy neutron detection
  - Good spatial resolution to distinguish neutral/charged hadrons
- Follow similar solutions as Forward HCal instead of STAR EEMC megatiles
  - Due to required quick dissassembly of STAR - the EEMC megatiles are no longer an option
  - Can make adjustments to Forward HCal (LFHCAL) design, but no need to reinvent the wheel

- Sampling calorimeter with 10 alternating layers, $2.4\lambda^0$ (red), similar to Belle-II KLM:
  - non-magnetic steel 4 cm
  - plastic scintillator 4 mm - to be adjusted
- Light collection by SiPM:
  - Candidate (to verify): S14160-1315PS `https://www.hamamatsu.com/eu/en/product/optical-sensors/mppc/mppc_mppc-array/S14160-1315PS.html`
- Electronics to follow solutions of other calorimetry systems HGCROCv3
- FEEs placed in front of nHCal

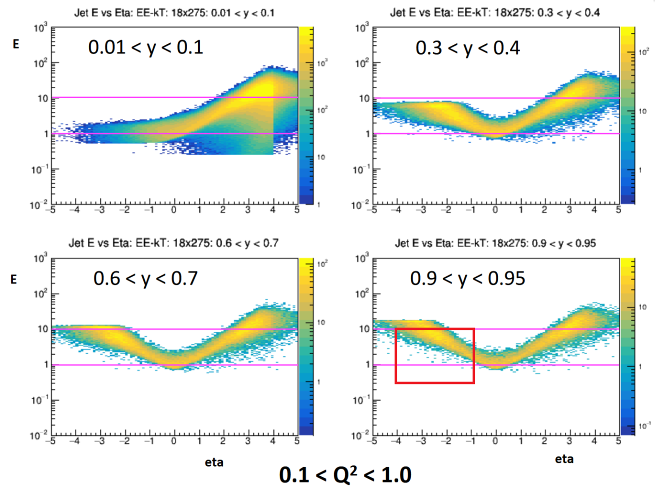


- nHCal decoupled from the magnetic steel ⇒ more flexibility
- Support structures design required for TDR



- A simplified version with STAR EEMC tiles already present in the main ePIC branch and included in the simulation campaigns up to November, stainless steel as an absorber
  - Good enough for basic checks
- Forward HCal-type geometry with $10\,\mathrm{cm} \times 10\,\mathrm{cm}$ tiles implemented for December campaign
- Flux return steel surrounding nHCal (purple) in private branch ready for commit into main

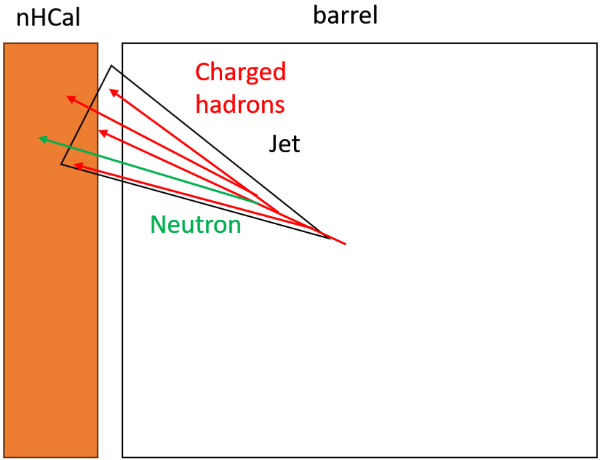
Low energy neutrons in jets



Brian Page, BNL

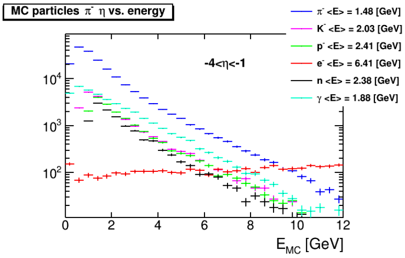
- Backward-going jets coming from low-x partons and high y events
  - Interesting physics!
- See more in presentation by Brian: `https://indico.bnl.gov/event/20679/`

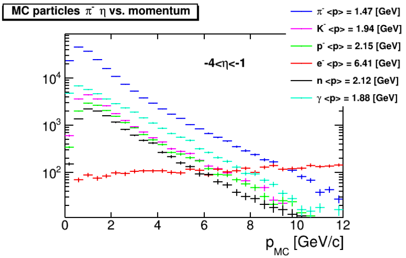
Neutral hadron reconstruction in a jet



- Jets reconstructed with charged hadron showers
- Missing a neutron will degrade the energy resolution of jets
- Need good low energy neutron:
  - detection efficiency
  - position resolution to distinguish from charged hadrons
- Need track-cluster matching to be able to see impact on neutrons vs. charged hadrons within jets - Required for TDR

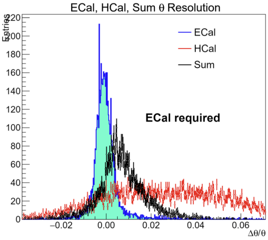
Particle distributions going into nHCal

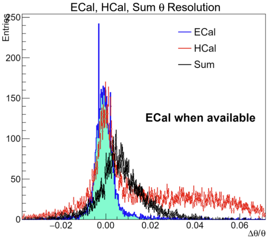


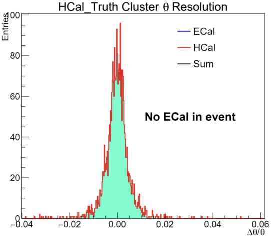


- All MC particles going into nHCal direction
- Mean energy (total) of neutrons $< E >= 2.38\,\mathrm{GeV}$, lowest $E = 1\,\mathrm{GeV}$
- Mean momentum of neutrons $< p >= 2.12\,\mathrm{GeV/c}$, lowest $p = 0\,\mathrm{GeV}$

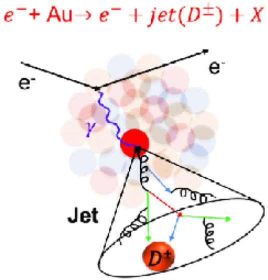
Alexandr Prozorov, CTU



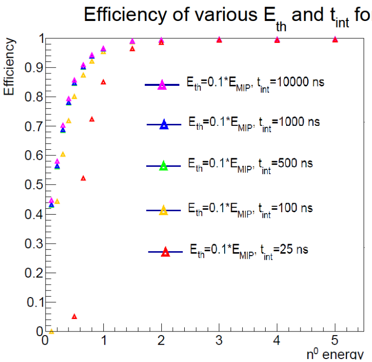




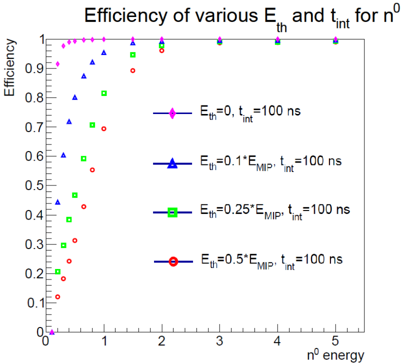
- 50% of neutrons scatter in backward EMCal
- Scattered neutron may fall out of a jet reconstruction cone
- We need to study this in coordination with Jet-HF PWG
- Work in progress on software compensation and neutron reconstruction with machine learning
- Following a study by LFHCAL group: `https://arxiv.org/abs/2310.04442`



Integration time dependence



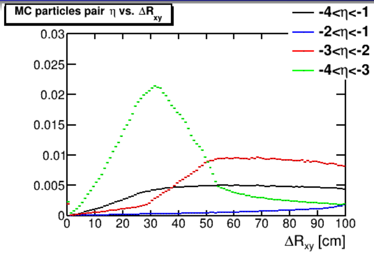
Threshold dependence

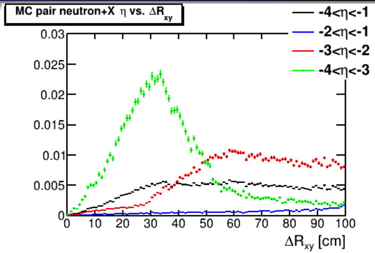


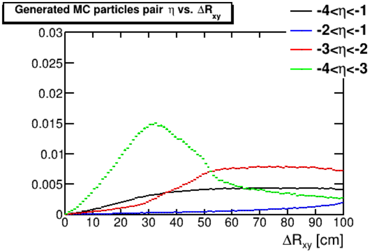
Sam Corey, OSU

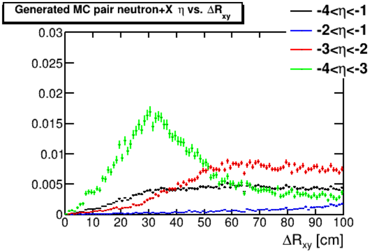
- Efficiency of requiring a hit with a sum of hit contributions energy integrated up to t_{int} and passing a threshold E_{th}, $t_0 = 0$
- Checked with simulation only - no digitization
- E_{MIP} is 0.75 MeV per layer
- E_{th} has the biggest impact
- 100 ns is good enough, but lower energy neutrons may need longer times
- 60% efficiency for $E = 300\,\mathrm{MeV}$ neutrons $E_{th} = 0.1 \times E_{MIP} = 75\,\mathrm{keV}$ and 100 ns

Distance between particle projections in nHCal



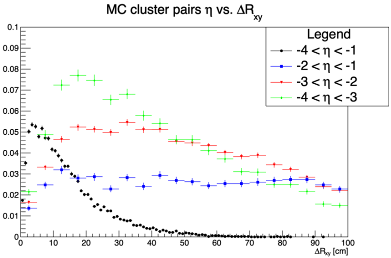


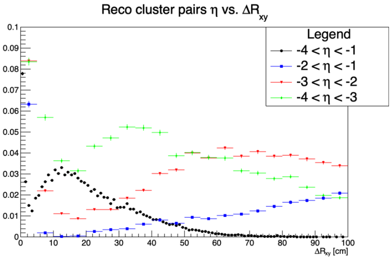




- Resolution of 20 cm at high η good enough to separate most particles
- Can be even larger at smaller η
- Generated particles = primaries only
- Distributions normalized over the entire range, but zoomed in $0 < \Delta R_{xy} < 100\ \mathrm{cm}$

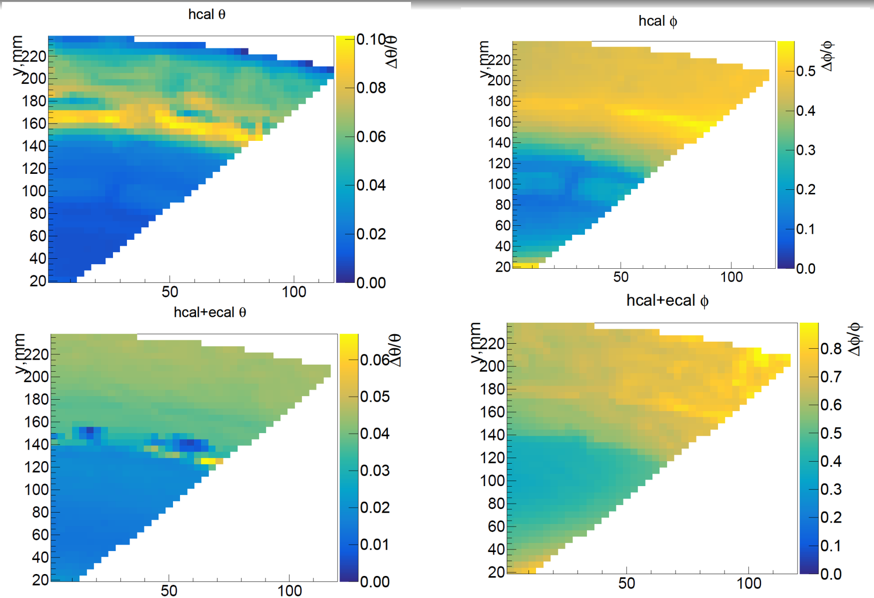
Distance between clusters - work in progress example





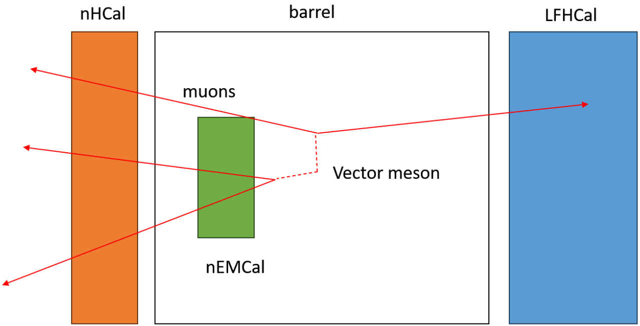
Nick Jindal, OSU

- Similar results for clusters, qualitatively consistent with MC particle straight line projections
- Resolution of 20 cm seems good enough, peak at 30 cm for reco clusters (20 cm for MC)
- Hit merging across layers was disabled here
  - Clusters from different layers overlap in XY, cause excess around 0

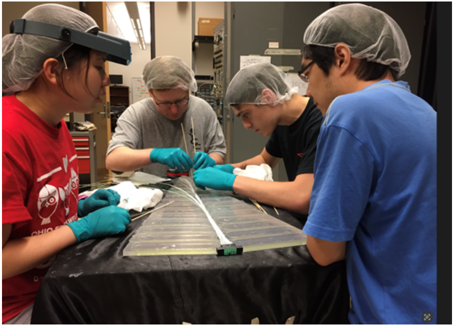


- Work in progress example
- Good resolution, but scattering makes it worse, especially in overlap region with barrel

Vector meson studies

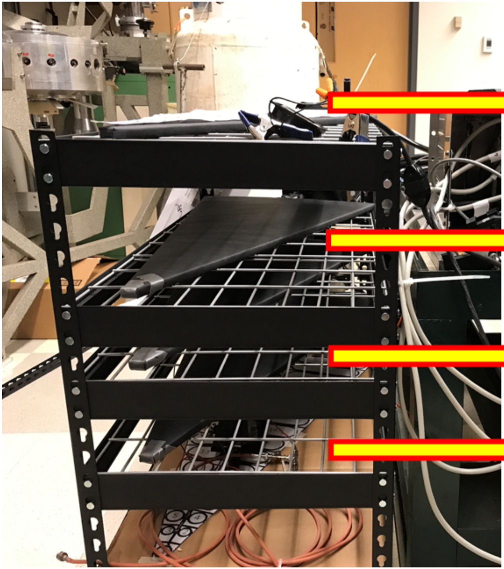


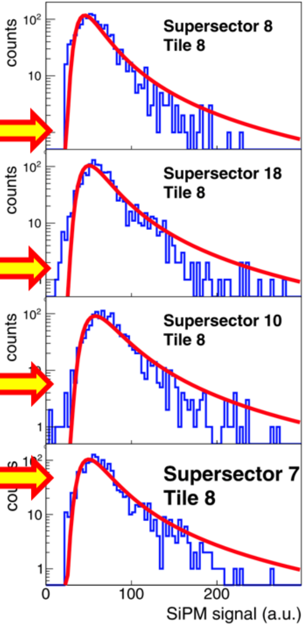
- Important for high y or low-p_T vector mesons - depends on type
- Increases acceptance
- Need projected MIP tracks and MIP signals in backward HCal and EMCal
  - μ/π distinction important, position resolution...
- Performance estimate required for TDR



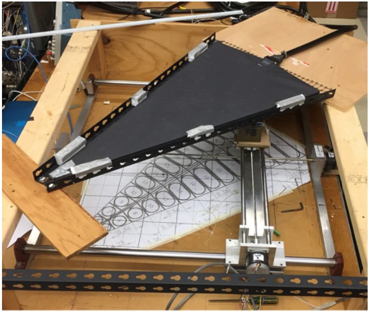
- Backward HCAL construction project well-matched for university group
  - subsidized shops with CNC, etc
  - characterization/testing with simple CAMAC systems etc
  - student-scale physical work

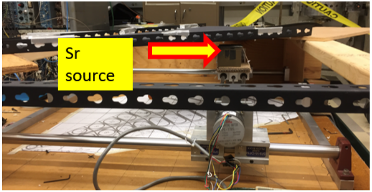
Tile characterization with cosmics

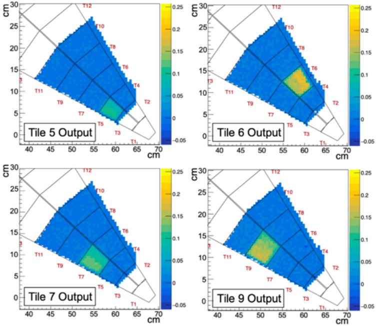




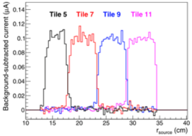
Uniformity, isolation characterization with source & translation table

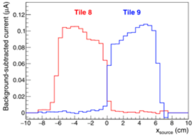






(a) Response of tiles 5,6,7 and 9 in one supersector, as a function of source position. Colors indicate background-subtracted current in μA.





Summary

Conclusions

- Presented basic concept for backward HCal for ePIC
- Simplified geometry already in simulation campaign:
  - for STAR EEMC geometry+extensions until November
  - for LFHCAL-style starting from November
- Work in progress on neutron detection with machine learning
- Estimated position resolution and distances between particles
  - $10\ \mathrm{cm} \times 10\ \mathrm{cm}$ is a good choice
- Testing and other work well suited to university groups
- Growing Detector Subsystem Collaboration: OSU, CTU, UNH, BNL

BACKUP

Dataset - simulation campaign

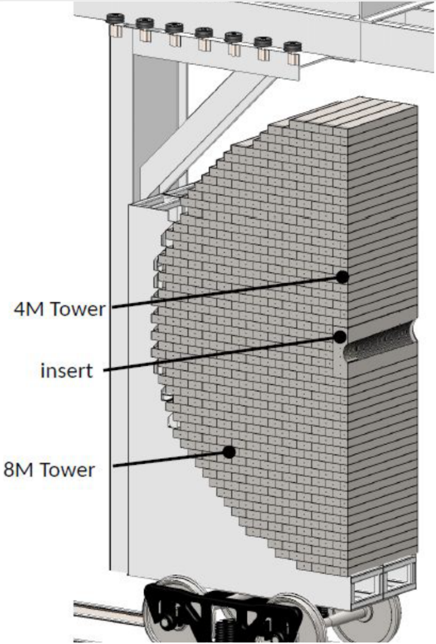
- Motivation:
  - Check distance between pairs of MC particles projected to nHCal surface
  - Check distance between neutrons and other particles
- Analysis of data from the simulation campaign:
  - $18 \times 275\,\mathrm{GeV}$ $e + p$ collisions, $0 < Q^2 < 1\,\mathrm{GeV}^2$
  - 1.3M SIDIS events simulated with PYTHIA
  - Brycecanyon geometry

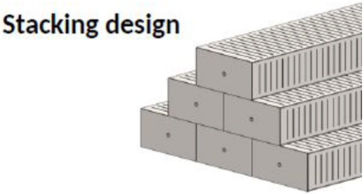
Listing: Files selection

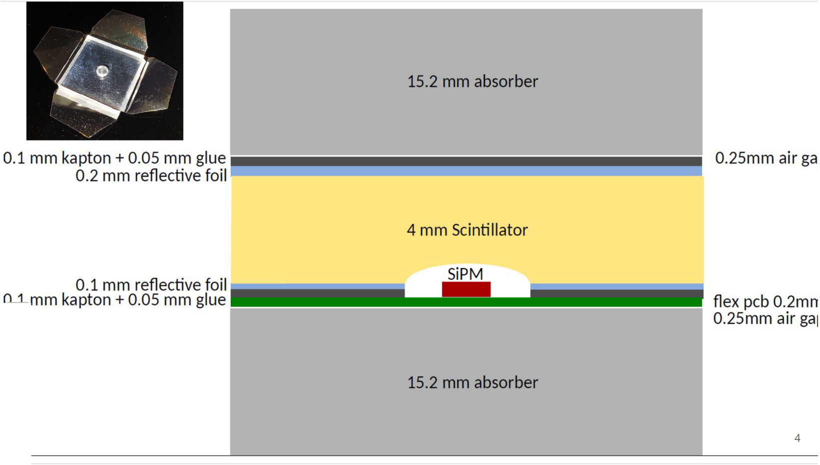
```
S3/eictest/EPIC/FULL/23.06.1/epic_brycecanyon/SIDIS/pythia6/ep_18x275/hepmc_ip6/noradcor/
ep_noradcor.18x275_q2_0_1*edm4hep.root
```

- Particle cuts:
  - primaries with start vertex $z > -395\,\mathrm{cm}$ (in front of HCal)
  - secondaries with start vertex $z > -300\,\mathrm{cm}$ (in front of HCal, after EMCal)
  - cut out e, γ, π^0, η
- Projected MC particles using straight line along their momentum direction to nHCal surface (simple check - neglects B field)

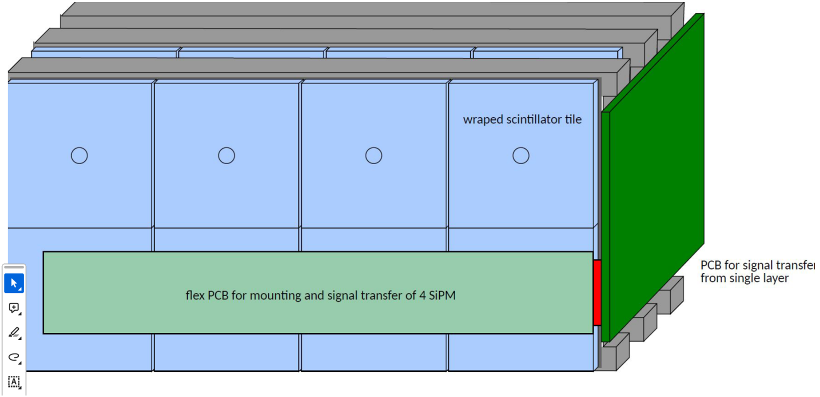
LFHCal design



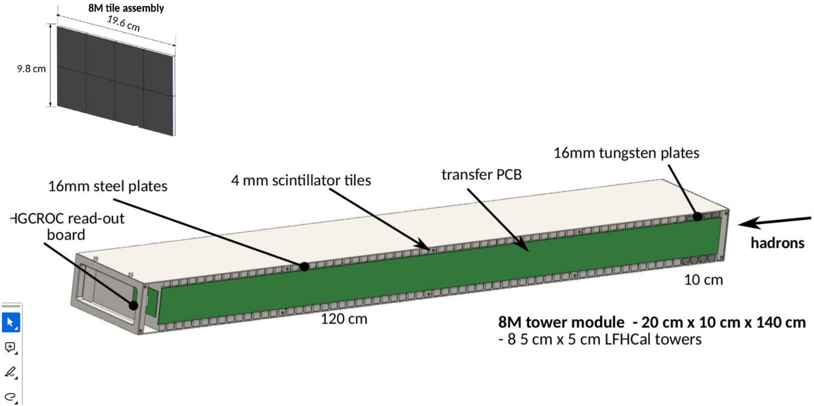



15.2 mm absorber
0.1 mm kapton + 0.05 mm glue
0.2 mm reflective foil
0.25mm air ga
4 mm Scintillator
SiPM
0.1 mm reflective foil
0.1 mm kapton + 0.05 mm glue
flex pcb 0.2m
0.25mm air ga
15.2 mm absorber
4

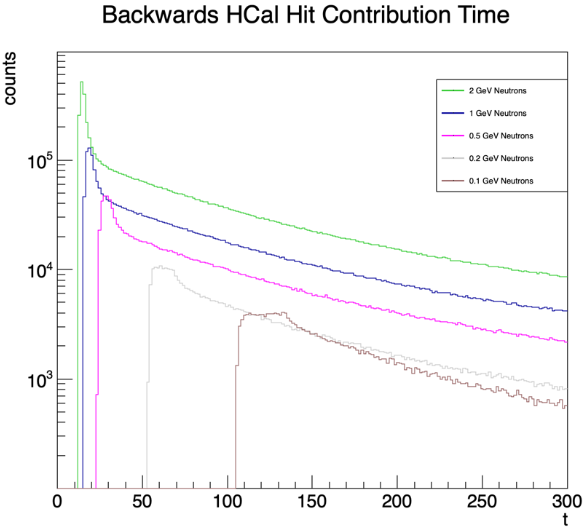
LFHCal PCBs


wraped scintillator tile
flex PCB for mounting and signal transfer of 4 SiPM
PCB for signal transfer
from single layer

LFHCal PCBs

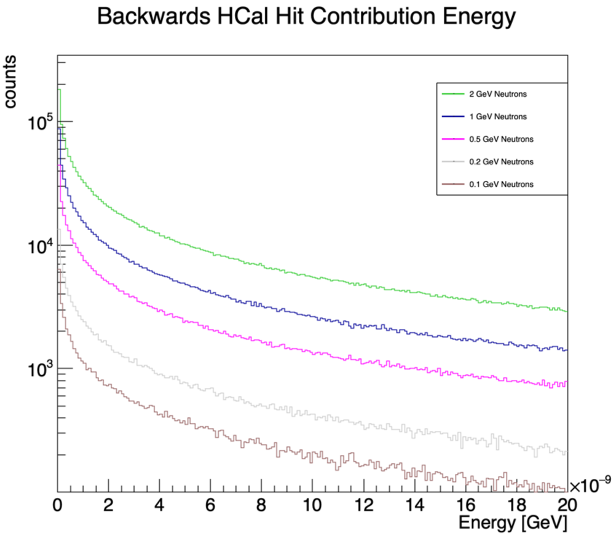

8M tile assembly
19.6 cm
9.8 cm
16mm tungsten plates
16mm steel plates
4 mm scintillator tiles
transfer PCB
HGCROC read-out
board
hadrons
10 cm
120 cm
8M tower module - 20 cm x 10 cm x 140 cm
- 8 5 cm x 5 cm LFHCal towers

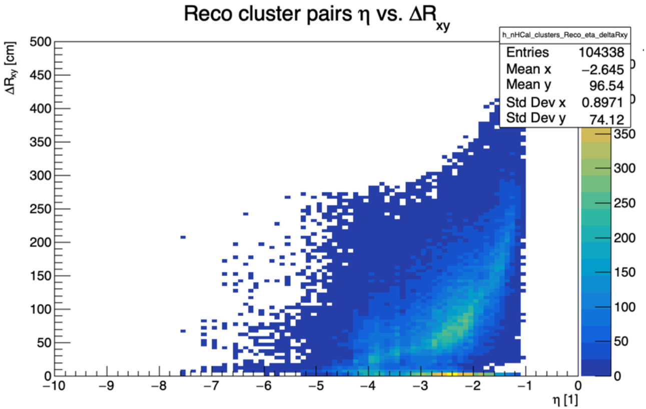
Hit contribution time



- Neutrons at lower energy are delayed

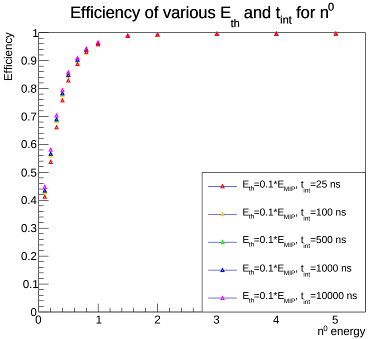
Hit contribution energy



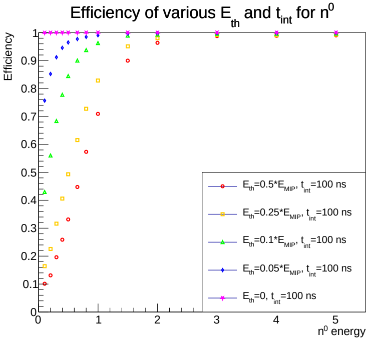

Reco cluster pairs η vs. ΔR_xy
h_nHCal_clusters_Reco_eta_deltaRxy
Entries 104338
Mean x −2.645
Mean y 96.54
Std Dev x 0.8971
Std Dev y 74.12
ΔR_xy [cm]
η [1]
500
450
400
350
300
250
200
150
100
50
0
−10
−9
−8
−7
−6
−5
−4
−3
−2
−1
0

Neutron detection efficiency

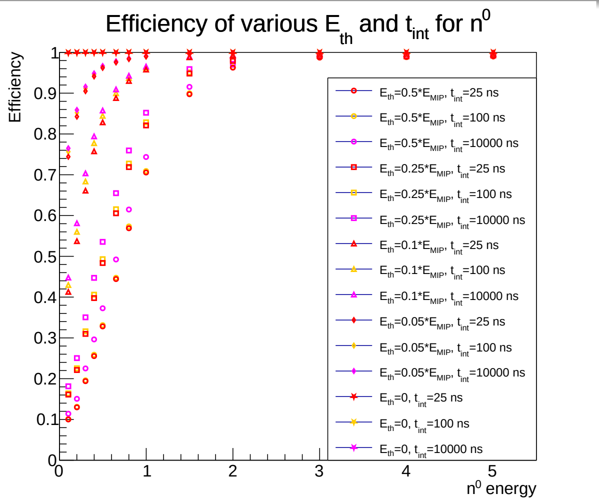
Integration time dependence



Threshold dependence

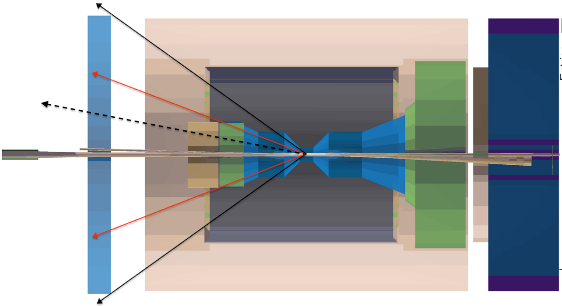


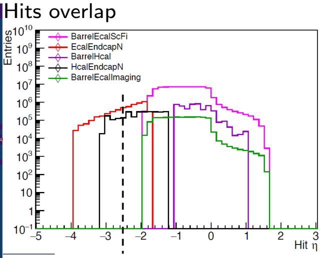
- Efficiency of requiring a hit with a sum of hit contributions energy integrated up to t_{int} and passing a threshold E_{th}
- Checked with simulation only - no digitization
- E_{MIP} is 0.75 MeV per layer
- E_{th} has the biggest impact
- 100 ns is good enough, but lower energy neutrons may need longer times
- t_0 starting from the first hit



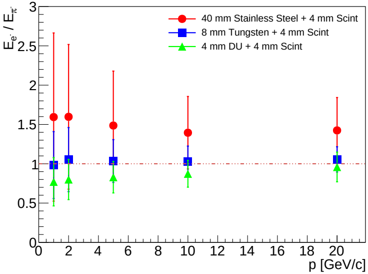
- Efficiency of requiring a hit with a sum of hit contributions energy integrated up to t_{int} and passing a threshold E_{th}
- E_{MIP} is 0.75 MeV per layer
- $E_{th} = 0.1 \times E_{MIP} = 75\,\mathrm{keV}$ and 100 ns provides good performance
- Need lower threshold and longer signal integration for better performance at low energy

Acceptance

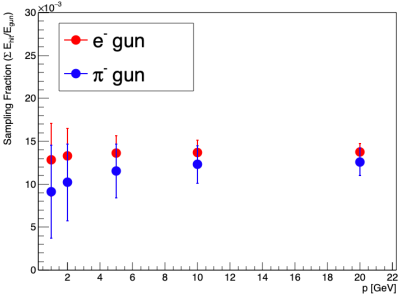




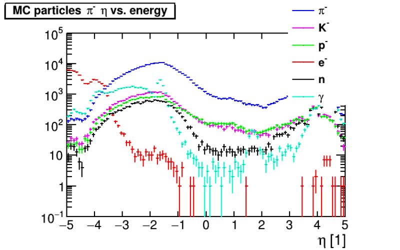
- Acceptance $-3.5 < \eta < -1.27$ - TO BE CHECKED
- Overlaps with backward and barrel EMcals
- Scattering may be important in these overlap regions

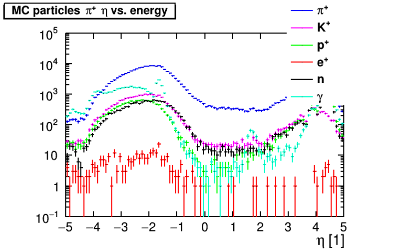


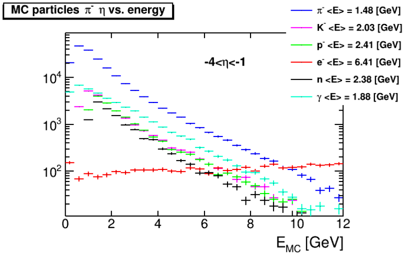
40 layers of 40 mm stainless steel+4 mm scintillator (for cross-check)

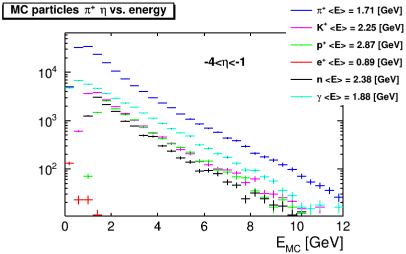


- Current design provides compensation
- Sampling fraction $\approx 1\%$
  - This means a 1 GeV hadron leaves similar signal to a $E_{MIP} = 7.5$ MeV across 10 layers
- Tungsten provides good performance
  - May add a few layers in front like for LFHCAL

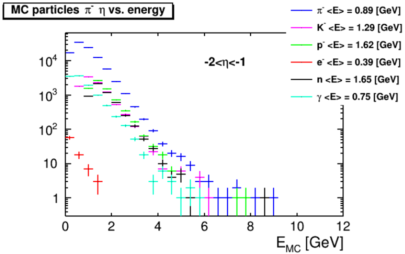


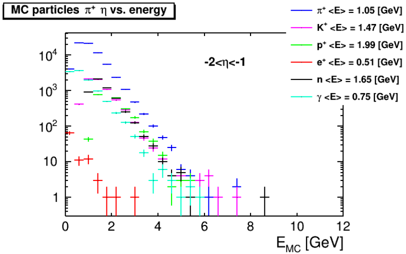


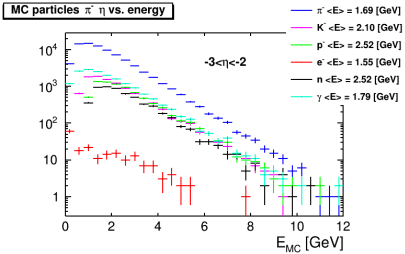


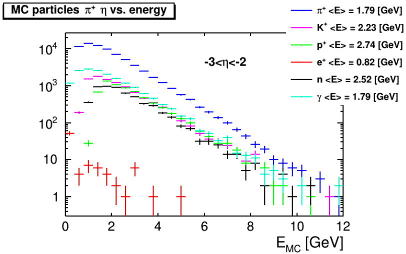


- All MC particles hitting nHCal
- Mean energy of neutrons $< E >= 2.38\ \mathrm{GeV}$
- Large number of high E e^- - from beam?

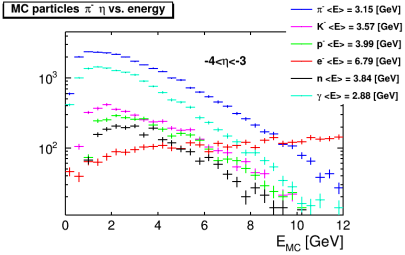


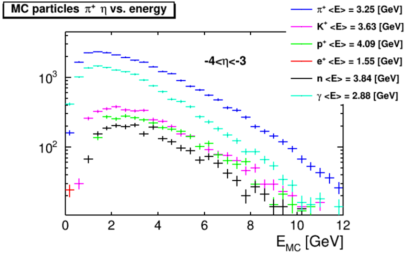




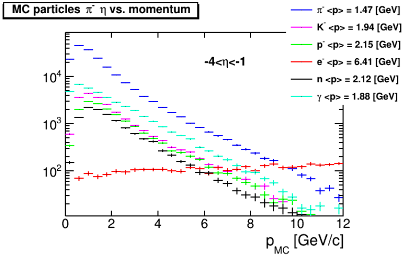


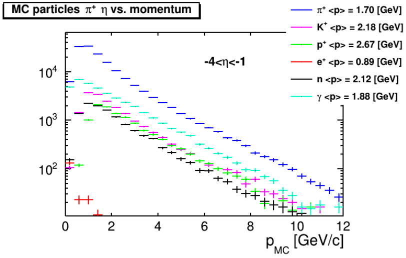
- All MC particles hitting nHCal
- Mean energy of neutrons $< E >_{-2<\eta<-1} = 1.65\ \mathrm{GeV}$ and $< E >_{-3<\eta<-2} = 2.52\ \mathrm{GeV}$





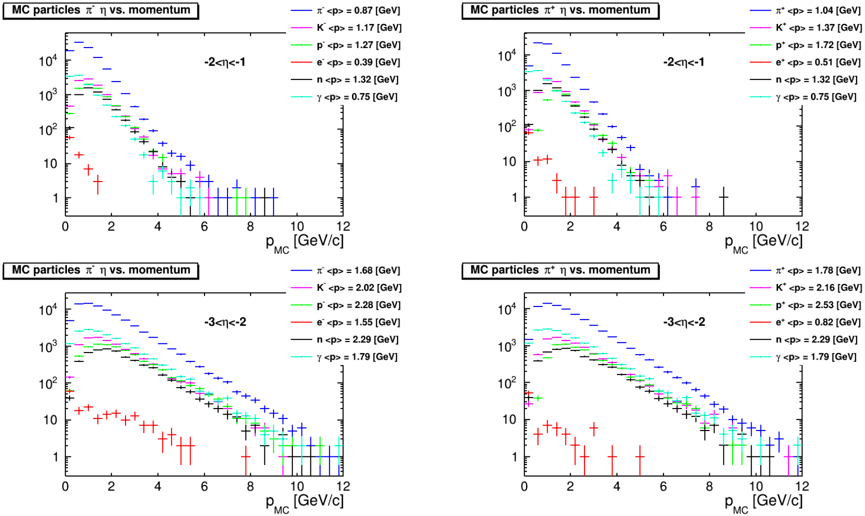
- All MC particles hitting nHCal
- Mean energy of neutrons $< E >_{-4<\eta<-3} = 3.84\ \mathrm{GeV}$



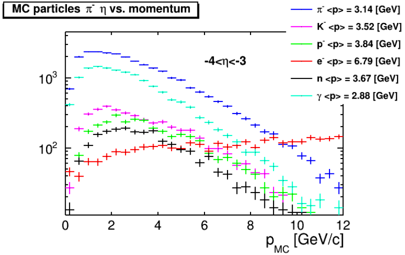


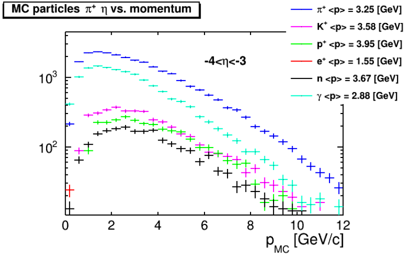
- All MC particles hitting nHCal
- Mean momentum of neutrons $< p >= 2.12\,\mathrm{GeV/c}$

Particle distributions - Momentum vs. eta



- All MC particles hitting nHCal
- Mean momentum of neutrons $< p >_{-2<\eta<-1} = 1.32\ \mathrm{GeV/c}$ and $< p >_{-3<\eta<-2} = 2.29\ \mathrm{GeV/c}$





- All MC particles hitting nHCal
- Mean momentum of neutrons $< p >_{-4<\eta<-3} = 3.67\ \mathrm{GeV/c}$

Summary table

Energy

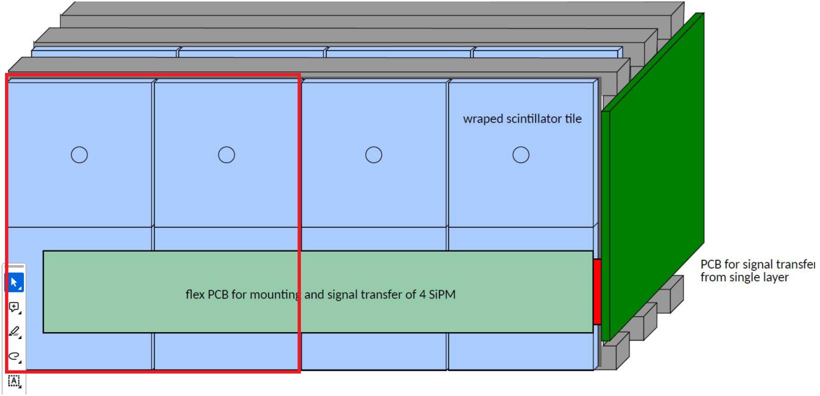
η	$< E >$ GeV inclusive n	$< E >$ GeV primary n
$-4 < \eta < -1$	2.38 GeV	2.38 GeV
$-2 < \eta < -1$	1.65 GeV	1.65 GeV
$-3 < \eta < -2$	2.52 GeV	2.52 GeV
$-4 < \eta < -3$	3.84 GeV	3.84 GeV

Momentum

η	$< p >$ GeV/c inclusive n	$< p >$ GeV/c primary n
$-4 < \eta < -1$	2.12 GeV/c	2.12 GeV/c
$-2 < \eta < -1$	1.32 GeV/c	1.32 GeV/c
$-3 < \eta < -2$	2.29 GeV/c	2.29 GeV/c
$-4 < \eta < -3$	3.67 GeV/c	3.68 GeV/c

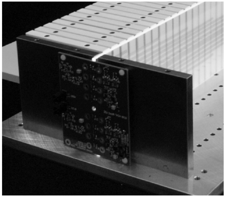
- Secondary neutrons have $< E >_{-4<\eta<-1} = 1.0$ GeV and $< p >_{-4<\eta<-1} = 0.27$ GeV - constant vs. η

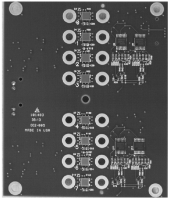
Design option 1 - LFHCAL style



- SiPM on tile with 5 cm $\times$ 5 cm tiles
- Use 2x2 5 cm $\times$ 5 cm tile modules similar to 4M module of LFHCAL
- Connect outputs of 2x2 tile module to integrate the signal and create an effective 10 cm $\times$ 10 cm segment
- Can readout each layer independently or integrate 5 forward and 5 backward layers to save costs
- No need to optically isolate tiles, only the whole module

Design option 2 - STAR FCS style



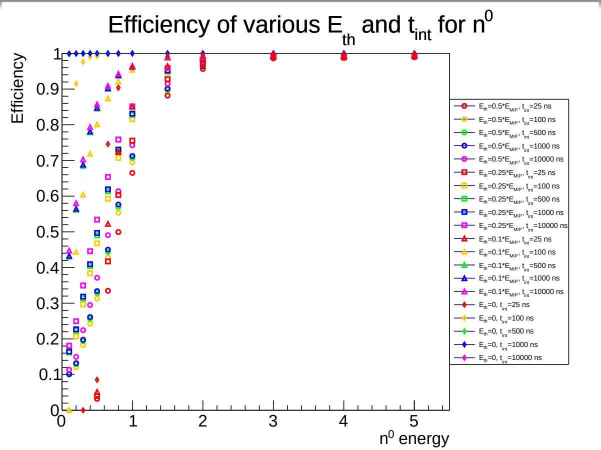


- $10\,\mathrm{cm} \times 10\,\mathrm{cm}$ tile modules similar to STAR FCS
- Light collection with SiPMs through WLS plate (middle)
    - Collects light from all 10 layers
    - Maybe can isolate WLS plate into 2 segments to collect light from 5 forward and 5 backward layers independently

Comparison of 2 options

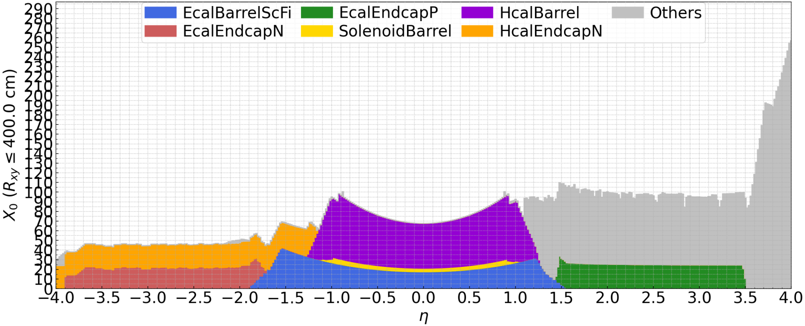
Design option	light collection	features	readout
1 SiPM on tile LFHCAL style	SiPM on tile	light collection closer to source	various configurations possible eg: each layer independently 2x2 tile signal adding
2 WLS plate to SiPM STAR FCS style	SiPM via WLS plate	collects light from all layers better light propagation	combined from 2x2 tile segment integrated cross layers 5+5 layer configuration possible

- Comparison in progress
- $\approx 21k$ channels with independent readout from each of 10 layers (cost $1.76M\$$)
  - Savings of factor of 5 on electronics ($\approx 4k$ channels) if integrated 5 front and 5 back layers (cost $1.53M\$$)
  - Savings of factor of 10 on electronics ($\approx 2.1k$ channels) with WLS plates (cost $1.5M\$$)



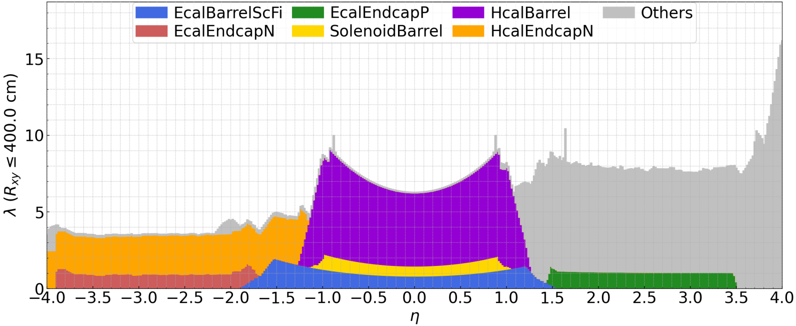
- Efficiency of requiring a hit with a sum of hit contributions energy integrated up to t_{int} and passing a threshold E_{th}
- E_{MIP} is 0.75 MeV per layer
- $E_{th} = 0.1 \times E_{MIP} = 75\,\mathrm{keV}$ and 100 ns provides good performance
- Need lower threshold and longer signal integration for better performance at low energy

Radiation length - brycecanyon geometry



- $\sim 24X_0$ for backward HCal
- Scintillator tiles do not cover the same volume as steel absorber yet

Interaction length - brycecanyon geometry



- $\sim 2.4\lambda_0$ for backward HCal
- Scintillator tiles do not cover the same volume as steel absorber yet