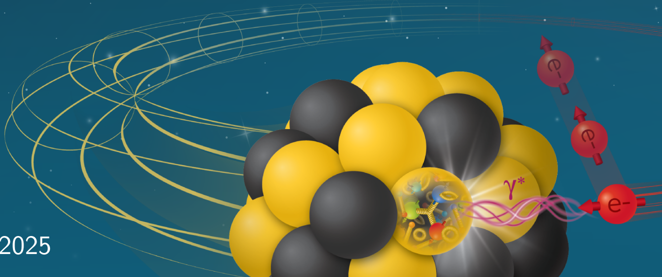
Forward Hadron Calorimeter

Longitudinally segmented Forward HCal (LFHCal)

Friederike Bock (ORNL)
Oct 31, 2025

Electron-Ion Collider
Preliminary Design Review, October 30-31, 2025



Outline & Charge

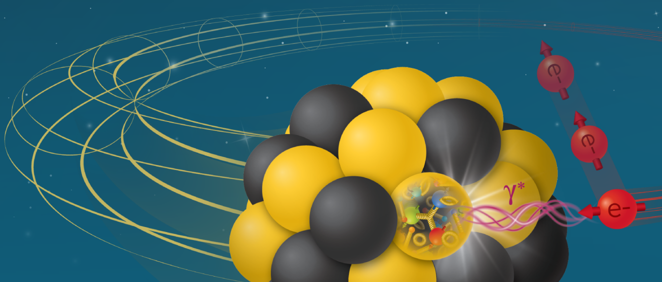
Outline

1. Concept & Motivation
2. Components & Technical updates - 8M/4M Modules
3. Components & Technical updates - Insert Modules
4. Construction & Assembly Plans

Charge Questions

1. Are the technical performance requirements appropriately defined and complete for this stage of the project?
2. Is the design of the various detector systems advanced enough and appropriately documented for this stage of the project? Are the current detector plans likely to achieve the performance requirements for the lifetime of the EIC physics program?
3. Are the assumptions for construction and fabrication of the various detector components sound and are assembly plans reasonable and consistent with the overall detector schedule?
4. Have ES&H and quality assurance considerations been adequately incorporated into the plans at the present stage?
5. Have recommendations from previous reviews been adequately addressed?

Concept and Motivation

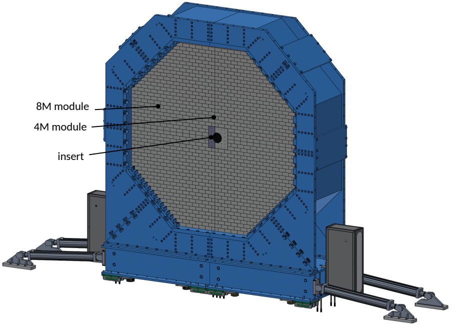


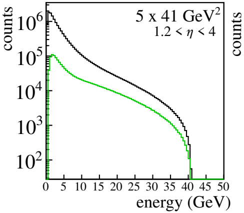
Electron-Ion Collider

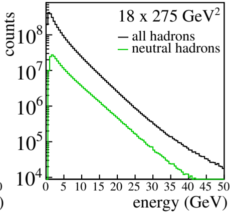
The General Idea

Concept:

- CALICE AHCal inspired Fe-Scintillator calorimeter with SiPM on-tile-readout
- SiPMs, absorber & support structures part of LLP
- Two main parts:
  - LFHCal built mostly out of 10x20x132 cm^3 8M modules
  - Insert built out of 2 halves surrounding the beam pipe
- **LFHCal:**
  - 60 layers of steel interleaved with scintillator material
  - Transverse tower size 5x5 cm^2
  - Multiple consecutive tiles summed to 7 longitudinal segments per tower
- **Insert:**
  - 60 layers of steel interleaved with scintillator
  - Hexagonal tiles of 14 cm^2 & 25 cm^2 each read-out individually







Charge Question 2

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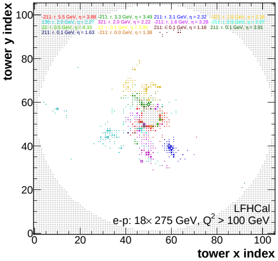
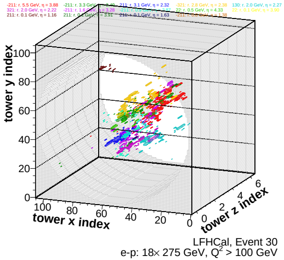
Motivation & Requirements

MC particle, classical readout



MC particle, LFHCal readout



Motivation:

- Maximum coverage for charged & neutral hadron reconstruction even in region, where tracking dies out
- Reconstruct jets at high rapidities
- Exploration of hadronization processes within jets using identified particles within jets and jet-substructure

Requirements:

- Excellent energy resolution for hadrons & jets $\sigma(E)/E \sim 50\%/\sqrt{E} \oplus 10\%$ combined with ECal
- Transverse granularity adequate to resolve deposits from different charged and neutral hadrons taking into account local particle abundance
  $\Rightarrow \sim$ 5x5 cm^2 for $\eta < 2.5$ & 3x3 cm^2 for $2.5 < \eta < 4$
- Longitudinal granularity adequate to identify showers starting at different depths and determine their shower maxima with increased segmentation for higher η due to higher particle density

Charge Question 1 & 2

LFHCal in Numbers

8M & 4M modules

- Acceptance: $1.2 < \eta < 3.5$
- Inner modules ($R < 1$m): machined scintillator tiles & 3mm SiPMs $\rightarrow \sim 11\% = 57800$ tile/ SiPMs
- Outer modules: injection molded tiles & 1.3mm SiPMs $\rightarrow \sim 89\% = 467320$ tile/ SiPMs

$\rightarrow$ 525,120 SiPMs, 61,264 read-out channels

Insert modules

- Acceptance: $3.5 < \eta < 4.4$
- ~ 120 hexagonal tiles/layer for first 16 layers (4.2 cm width) and ~ 80 for remaining (6.5 cm width), staggered positions in different layers

$\rightarrow \sim 7000$ SiPMs/tiles & read out channels

SiPMs part of CD-3A:

$\rightarrow$ 130K delivered since 06/2025, total CD-3A 320K
$\rightarrow$ Manual test stand available

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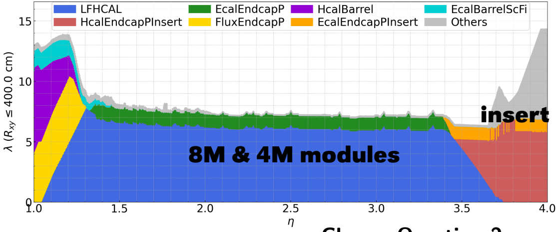
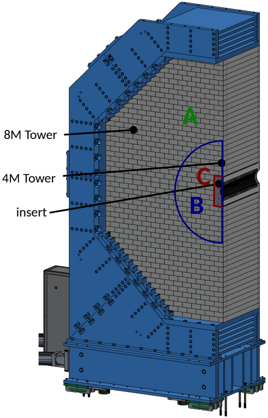
parameter	LFHCal 8M & 4M modules	insert modules
inner x,y (R)	-20 cm $> x > 40$ cm, -30 cm $> y > 30$ cm	$R > 17$ cm
outer R (x,y)	$R <$ 270 cm	-20 cm $> x > 40$ cm, -30 cm $> y > 30$ cm
η acceptance	$1.2 < \eta < 3.5$	$3.5 < \eta < 4.4$
tower information		
x, y	5 cm	$\approx$ 4.2 cm (layer 1-20) $\approx$ 6.5 cm (layer 21-60)
z (active depth)	120 cm	120 cm
z read-out	$\approx$ 8.4 cm	$\approx$ 8.4 cm
# scintillator plates	60 (0.4 cm each)	60 (0.3 cm)
# absorber plates	60 (1.52 cm)	60 (1.52 cm)
interaction lengths	5.8-6.5 λ/λ_0	5.8 λ/λ_0
# towers	8752	
# modules		2
8M	1058	
4M	72	
# read-out channels	7 x 8752 = 61264	$\approx$ 7000



Charge Question 2

Impact of Radiation Damage on Design



Radiation Regions

- **A:** $R > 1$ m: $< 5 \cdot 10^{9}$ neq/cm^2/year
- **B:** $R < 1$ m: $10^{9} - 10^{11}$ neq/cm^2/year
- **C:** $\sim 10^{11}$ neq/cm^2/year

Mitigation for different regions:

A: 8M & 4M modules with inaccessible SiPMs

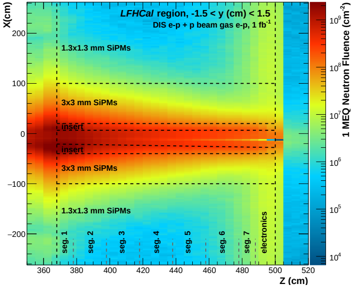
- 1.3×1.3 mm^2 SiPMs & injection molded scintillator

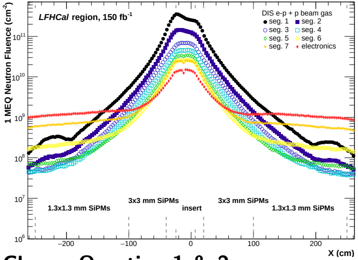
B: 8M & 4M modules with inaccessible SiPMs

- 3×3 mm^2 SiPMs & scint. mach. from cast material

C: Insert modules

- **Replacement or annealing of SiPMs & tiles possible**
- **Scintillator & SiPM assemblies accessible during longer shutdowns** (after removal of dust cover)





Charge Question 1 & 2

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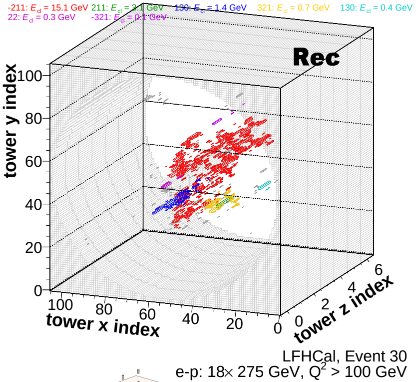
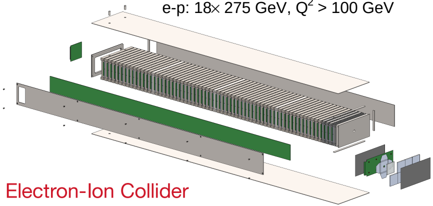
General Facts on the Read-out



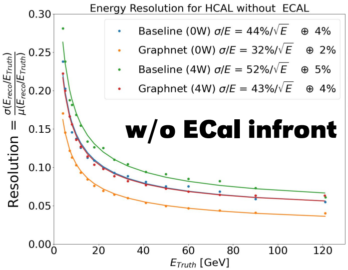


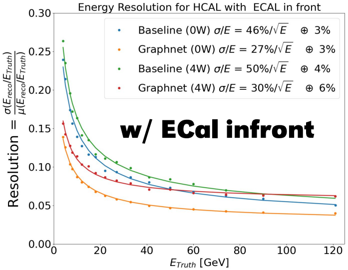
- High granularity needed to try to distinguish shower maxima (single particles/sub-jets) close to beam pipe
- **8M & 4M modules**:
  read out in 7 segments longitudinally (5 or 10 SiPMs summed in depth) desirable min measurable tower energy $<$ 0.5 MIP/segment, max. $\approx$ 1500 MIP/segment
- **insert modules**:
  read out every single tile desirable min measurable energy $<$ 0.5 MIP/tile , max. $\approx$ 500 MIP/tile
- SiPMs mounted to flexible PCBs, passive signal transfer to back side of calorimeter using long transfer PCB
- 2(1) CALOROC (up to 36 channels/chip) per 8M(4M) module in the back, 210 CALOROCs for insert readout

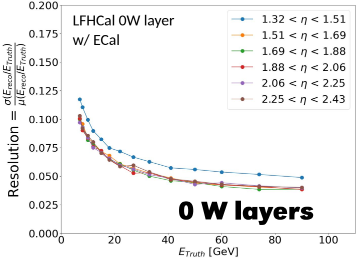
Electron-Ion Collider

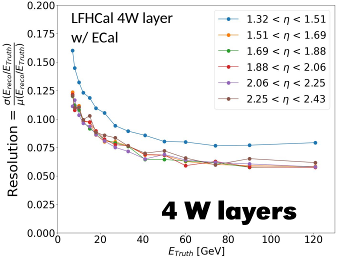
Charge Question 2

Performance in Simulations









- Implementation of realistic geometry in ePIC software stack
- First version of clusterization algorithm working well at high E
- Absorber optimization with ML assistance and full software compensation
  - Initial concept with 4 layers of tungsten
  - Software compensation with full detector system optimized with graphnet-algorithm
  - Improved E-resolution w/o tungsten layers
  - Little impact on spatial resolutions w/ or w/o tungsten layers

$\Rightarrow$ Tungsten layers removed & replaced with steel

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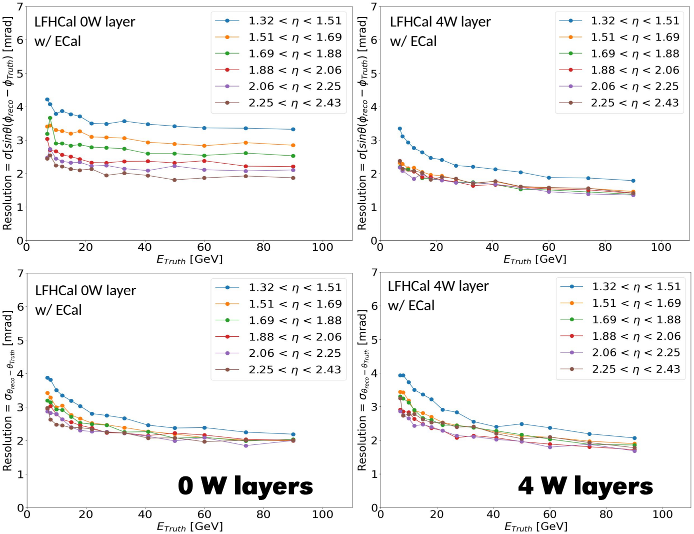
Charge Question 2 & 5

Performance in Simulations



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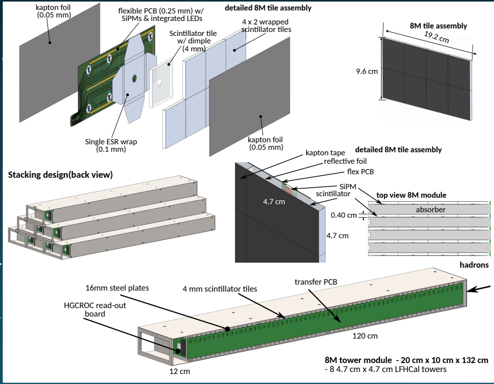
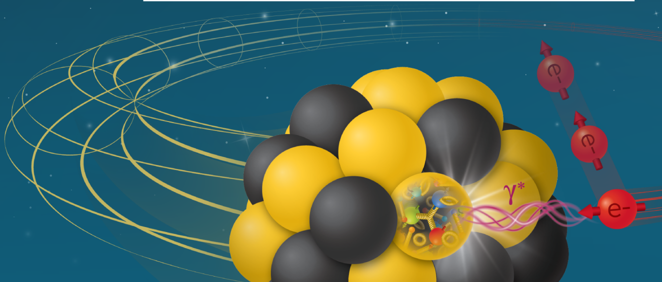
Electron-Ion Collider

Charge Question 2 & 5

Components & Technical updates

8M/4M Modules





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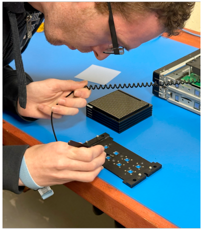
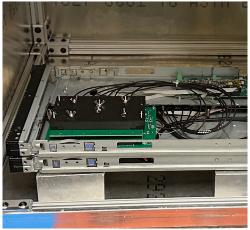
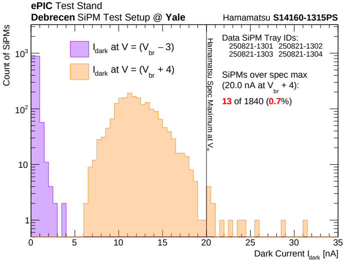
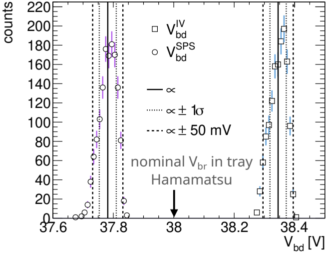
Components: SiPMs



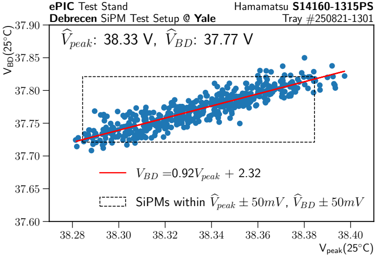






SiPM QA of CD-3A:

- Started receiving shipments from CD-3A procurement (33K/month since 06/2025) - final delivery 04/2026 (320K total)
- Establishing test procedure for 5% of trays for acceptance testing focussing on break down voltage measurements and visual inspection
  - Manual test stand available since September at Yale (32 SiPMs/h)
  - Automated test stand based on CMS Barrel timing layer under construction (up to 200-250 SiPMs/h) - delivery expected February



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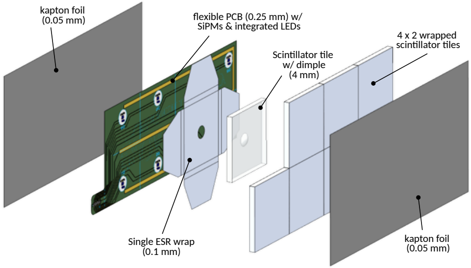
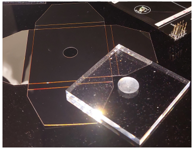
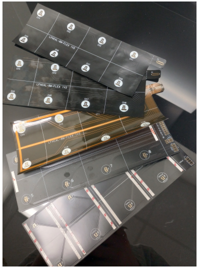
Charge Question 4

Components: Scintillator Tile Assemblies (1)







8M & 4M module layers:

- Square injection molded or machined tiles $\approx 0.4x5x5$ cm^3 with dimples individually wrapped in ESR foil assembled in a grid of 4(2)x2 tiles
- Backed by flexible PCB equipped with 8(4) SiPMs and LEDs sandwiched with Kapton foil
- Flexible PCB wrapped around side of absorber to connect with long PCB along the side of the module

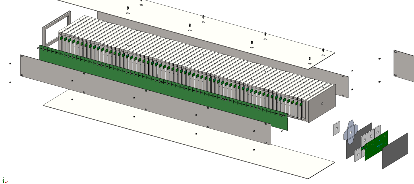
Progress:

- Tile production at FNAL via injection molding with established processes & chemical composition
- ESR wrap cut with commercial small scale laser cutter, exploring options to out-source process to local companies
- Finalizing Flexible PCB design, 3rd major iteration soon to be tested in test beam at CERN
- Manual tile wrapping & layer assembly process well established currently working on automatization for both

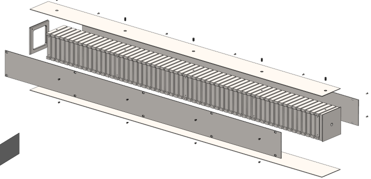
Charge Question 2 & 3

Components: Absorber Structures (1)

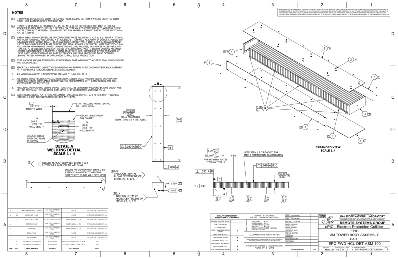
8M module x 1058



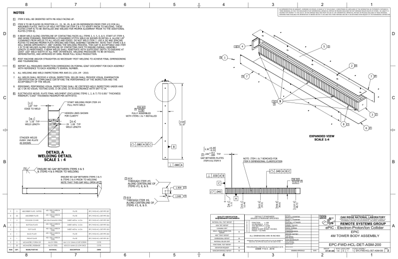
4M module x 72



8M drawing pack



4M drawing pack



- 2 different module types designed using the same construction process (4M scaled in width by 0.5)
- 60 single absorber plates, front and back plate electron beam welded to top & bottom sheet metal panel
- Side panels screwed to welded structure to cover slot with transfer PCB and remaining open side
- Absorber structure design concluded & full drawing pack available
- CD-3A procurement process started

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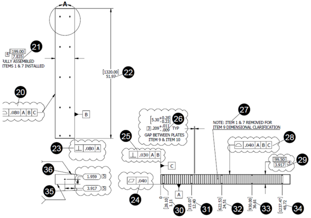
Charge Question 2

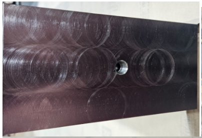
Components: Absorber Structures (2)

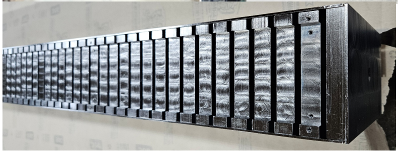


8M Tower Assembly (1320mm) Assembly Dimensions based on Rev 02 GD&T Values											
Dimension #	Description	Importance Category	DRW Tolerance (in)	Prototype 1	Prototype 2	Prototype 3	Prototype 4	Prototype 5	Prototype 6	Prototype 7	Prototype 8
20	Left Side Surface Tol	High	0.08	0.017	0.036	0.052	0.043	0.045	0.028	0.03	0.025
21	Width	Basic	7.795 - 7.875	7.828	7.845	7.831	7.837	7.832	7.842	7.835	7.835
22	Length	Low	±0.05	51.965	51.872	51.917	51.924	51.94	51.92	51.93	51.93
23	Right Side Perpendicularity Tol	High	0.08	0.018	0.03	0.09	0.018	0.035	0.03	0.028	0.01
24	Bottom Flatness Tol	High	0.04	0.015	0.027	0.02	0.025	0.015	0.025	0.015	0.015
25	Front Perpendicularity Tol	Medium	0.04	0.035	0.028	0.045	0.004	0.012	0.025	0.018	0.012
26	Plate Spacing	High	+.011 -.009	.207 / .213	.207 / .216	**.167 / .238**	.208 / .212	.208 / .212	.210 / .215	.210 / .216	.210 / .213
28	Top Surface Tol	High	0.04	0.018	0.037	0.03	**0.042**	0.035	0.028	0.032	0.022
29	Height	Basic	3.897 - 3.937	**3.96**	**3.949**	**3.945**	**3.946**	**3.94**	3.923	3.925	3.916
30	Location Tapped Plate #1	Low	±0.067	1.114	1.107	1.06	1.114	1.052	1.11	1.108	1.118
31	Location Tapped Plate #2	Low	±0.067	12.413	12.365	12.346	12.38	12.46	12.4	12.39	12.375
32	Location Tapped Plate #3	Low	±0.067	24.52	24.438	24.409	24.461	24.53	24.5	24.486	24.478
33	Location Tapped Plate #4	Low	±0.067	36.624	36.521	36.479	36.56	36.51	36.56	36.65	36.555
34	Location Tapped Plate #5	Low	±0.067	48.73	48.597	48.574	48.634	48.64	48.63	48.635	48.63
35	Horizontal location M12 Hole	Inspection		-	-	-	-	3.917	3.917	3.916	3.918
36	Vertical Location M12 Hole	Inspection		-	-	-	-	1.959	1.959	1.958	1.958

Engineering module production

- Established reproducible production procedures for the 8M module production over the past year
- 9 engineering test items produced so far
- Initial modules not fully within tolerances for some less important measures
- Corrosion prevention by using Nickel plating the whole module
- Engineering test items used for test beams as single module or 2x4 module stack





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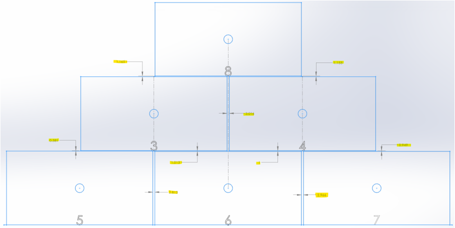
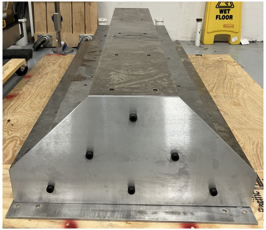
Charge Question 3 & 4

Components: Absorber stacking





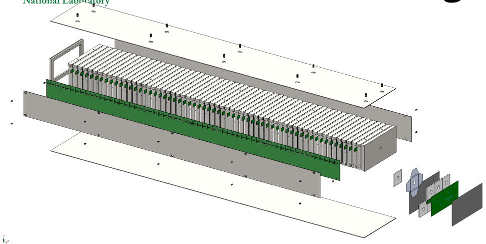
Stacking test

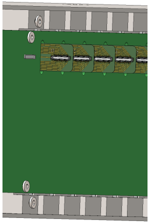
- Performed stacking test with 8 engineering test modules
- Used precomputed stainless-steel shims based on GD&T
  - Easy to assemble with predefined shim heights w/o modifications
- Basic GD&T requested for every (outer dimensions) for every module
- Sorting according to those prior to assembly in hall beneficial

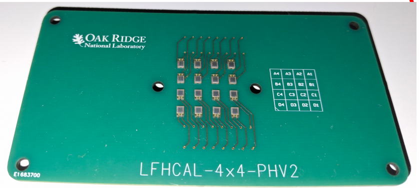
Electron-Ion Collider

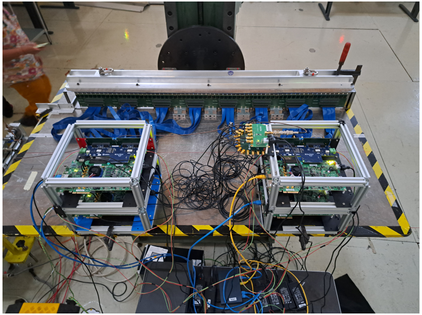
Charge Question 3 & 4

Overview: Signal-Transfer and Read-out









- For maintenance the read-out cards will be placed in the rear of the modules
- Passive signal transfer to the rear with long transfer boards

→ First prototype in production

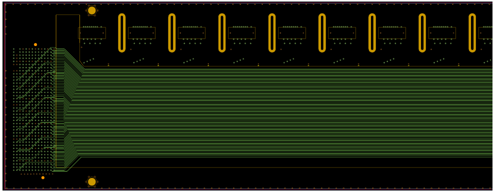
- To keep possibility of future upgrades signal summing done in rear as well

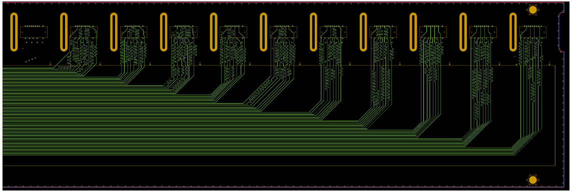
→ Test board employing passive summing produced & currently under test

- Read-out boards using CMS-H2GCROC (precursor to CALOROC) produced and have been operated in test beam since 2023

CALOROC details see N. Novitzky's talk

Components: Long Transfer board





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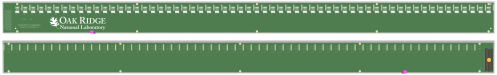
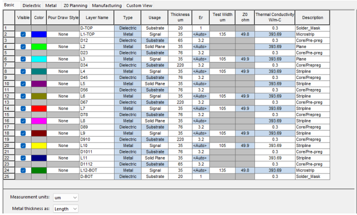
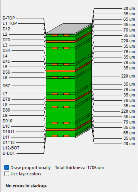
- Few vendors with capabilities to produce such boards (more common length up to 120 cm)
- Production ongoing, expect to receive 2 boards by end of October





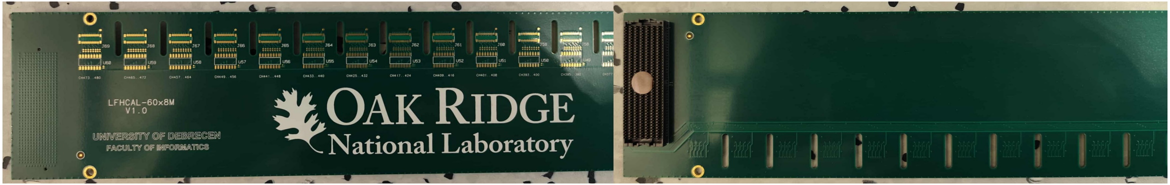
	Visible	Color	Pour Draw Style	Layer Name	Type	Usage	Thickness um	Er	Test Width um	Z0 ohm	Thermal Conductivity W/m-C	Description
1				D-TOP	Dielectric	Substrate	20	1			0.3	Solder_Mask
2	✓		None	L1-TOP	Metal	Signal	35	<Auto>	135	49.8	393.69	Microstrip
3				D12	Dielectric	Substrate	65	3.2			0.3	Core/Pre-preg
4	✓		None	L2	Metal	Solid Plane	35	<Auto>			393.69	Plane
5				D23	Dielectric	Substrate	76	3.2			0.3	Core/Pre-preg
6	✓		None	L3	Metal	Signal	35	<Auto>	105	49.9	393.69	Plane
7				D34	Dielectric	Substrate	220	3.2			0.3	Core/Prepreg
8	✓		None	L4	Metal	Signal	35	<Auto>	105	49.9	393.69	Stripline
9				D45	Dielectric	Substrate	76	3.2			0.3	Core/Prepreg
10	✓		None	L5	Metal	Solid Plane	35	<Auto>			393.69	Stripline
11				D56	Dielectric	Substrate	76	3.2			0.3	Core/Prepreg
12	✓		None	L6	Metal	Signal	35	<Auto>	105	49.9	393.69	Stripline
13				D67	Dielectric	Substrate	220	3.2			0.3	Core/Pre-preg
14	✓		None	L7	Metal	Signal	35	<Auto>	105	49.9	393.69	Stripline
15				D78	Dielectric	Substrate	76	3.2			0.3	Core/Prepreg
16	✓		None	L8	Metal	Solid Plane	35	<Auto>			393.69	Stripline
17				D89	Dielectric	Substrate	76	3.2			0.3	Core/Prepreg
18	✓		None	L9	Metal	Signal	35	<Auto>	105	49.9	393.69	Stripline
19				D910	Dielectric	Substrate	220	3.2			0.3	Core/Prepreg
20	✓		None	L10	Metal	Signal	35	<Auto>	105	49.9	393.69	Stripline
21				D1011	Dielectric	Substrate	76	3.2			0.3	Core/Pre-preg
22	✓		None	L11	Metal	Solid Plane	35	<Auto>			393.69	Stripline
23				D1112	Dielectric	Substrate	65	3.2			0.3	Core/Pre-preg
24	✓		None	L12-BOT	Metal	Signal	35	<Auto>	135	49.8	393.69	Microstrip
25				D-BOT	Dielectric	Substrate	20	1			0.3	Solder_Mask

Measurement units: um
Metal thickness as: Length



Charge Question 2 & 3

Components: Long Transfer board



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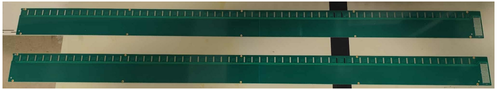

Basic | Dielectric | Metal | Z0 Planning | Manufacturing | Custom View

	Visible	Color	Pour Draw Style	Layer Name	Type	Usage	Thickness um	Er	Test Width um	Z0 ohm	Thermal Conductivity W/m-C	Description
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10	☑		None	L5	Metal	Solid Plane	35	<Auto>			393.69	Stripline
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15				D78	Dielectric	Substrate	76	3.2			0.3	Core/Prepreg
16	☑		None	L8	Metal	Solid Plane	35	<Auto>			393.69	Stripline
17				D89	Dielectric	Substrate	76	3.2			0.3	Core/Prepreg
18	☑		None	L9	Metal	Signal	35	<Auto>	105	49.9	393.69	Stripline
19				D910	Dielectric	Substrate	220	3.2			0.3	Core/Prepreg
20	☑		None	L10	Metal	Signal	35	<Auto>	105	49.9	393.69	Stripline
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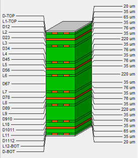
25				D-BOT	Dielectric	Substrate	20	1			0.3	Solder_Mask

Measurement units: um

Metal thickness as: Length



Draw proportionally Total thickness: 1706 um

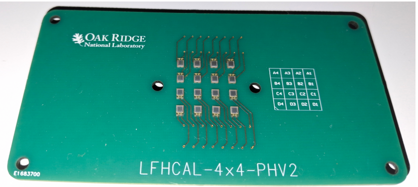
Use layer colors

No errors in stackup.

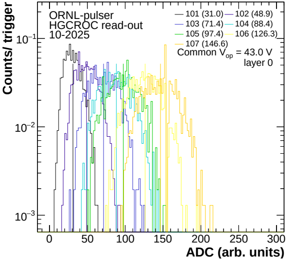
Electron-Ion Collider

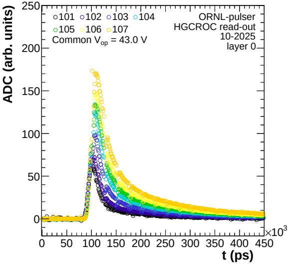
Charge Question 2 & 3

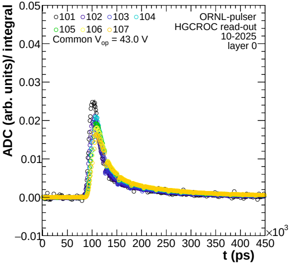
Components: Passive Summing Board



101 - 1 SiPM
102 - 2 SiPMs
103 - 3 SiPMs
104 - 4 SiPMs
105 - 5 SiPMs
106 - 6 SiPMs
107 - 7 SiPMs







- Small switchable 16 SiPM summing board produced and tested
- Signal increases linearly with summing of additional SiPMs
- Minimal signal broadening observed for 1.3mm x 1.3mm SiPMs

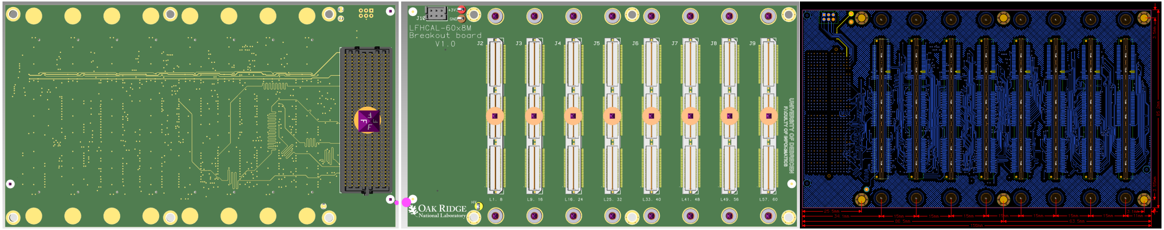
$\Rightarrow$ Passive summing viable solution for 8M/4M modules with smaller SiPMs

- Similar evaluation needed for 3 x 3mm SiPM region

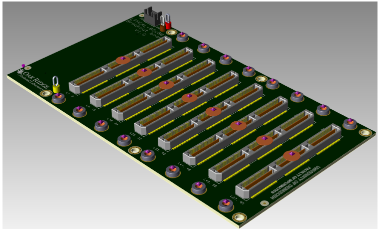
Electron-Ion Collider

Charge Question 2 & 3

Components: Single Channel Breakout Board



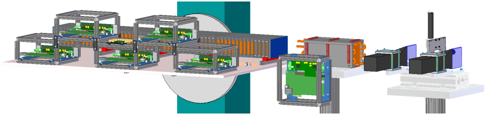
- For testing connectivity of SiPMs from flex board until the end of long transfer board as well as SiPM QA on detector
- Breaks out every single channel to 8 x 64 channel connectors currently used for H2GCROC test boards
- Currently in production and expected delivery by end of October



Electron-Ion Collider

Charge Question 4

Test beam - August 2024 (1)

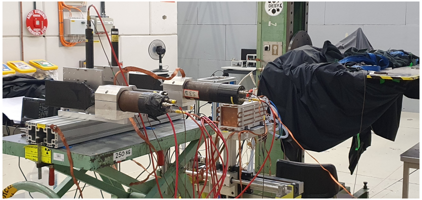


Dates: 28^{th} Aug-11^{th} Sept 2024 **Location:** PS - T09
Main purpose: First full module test & H2GCROC tests
Setup:

- Full 8M module testing 65 layers of absorber & scintillator per layer 8 channels (swapping scintillator geometry either 8M module or insert)
- Readout with multiple CAEN DT5202 64ch CITIROC SiPM readout units (2nd week) and H2GCROCs (1st week)

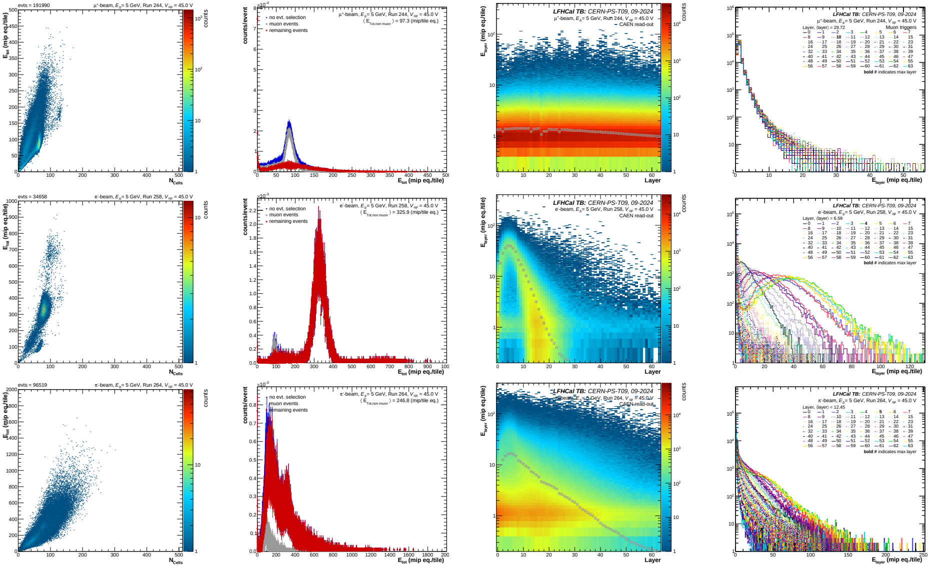
Main expected measurements:

- Energy resolution estimates for hadrons and electrons for full length module with both read-out versions
- Assessment of longitudinal leakage
- Longitudinal shower development
- Read-out validation
- Part of campaign with EEEMC in front



Electron-Ion Collider

Test beam 2024: First Highlights



μ **beam 5 GeV**

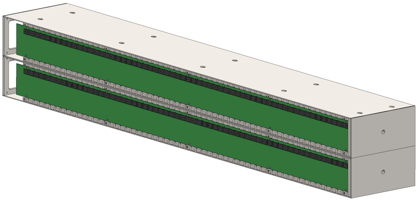
e- beam 5 GeV

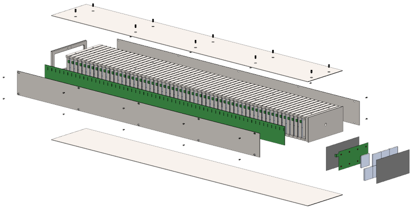
π^- **- beam 5 GeV**

Test Beam Plans 2025

Requested time: 1 week
Main purpose: Resolution studies & longitudinal shower development
Location: CERN PS (19th Nov.)
Setup:

- Very similar to 2024 setup, with more modules
- 2 full 8M modules (20x20x130cm)
- Readout with H2GCROCs



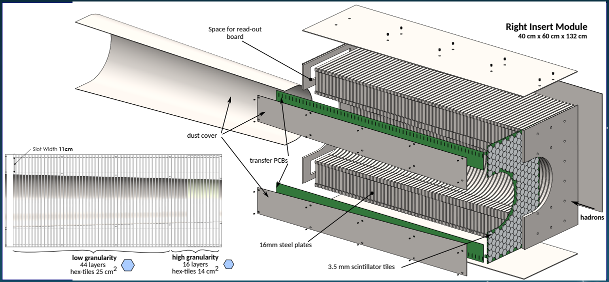


Main expected measurements:

- Energy resolution for electrons
- Longitudinal shower development
- Final-Flexible PCB validation & first test of long PCB

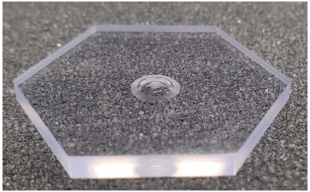
Components & Technical updates

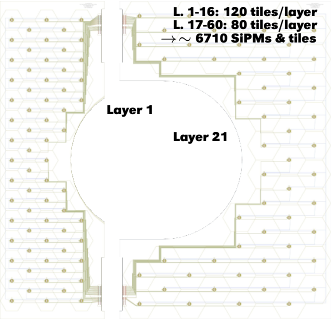
Insert Modules



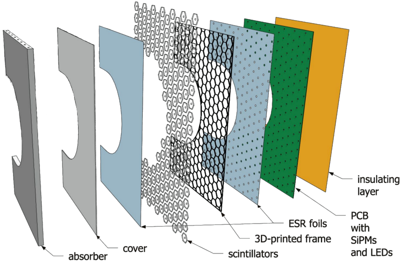
Electron-Ion Collider

Components: Scintillator Tile Assemblies





- 2 hexagonal sizes foreseen with staggered positions in different layers
- Tile production established with injection molding & machining
- ESR cutting with commercial small scale laser cutter
- Tile frame printed with commercial 3D printer
- First version of PCB layout for each layer available
  → space constraints largest challenge
- First larger scale prototype layers constructed for ZDC test beam with similar design approach

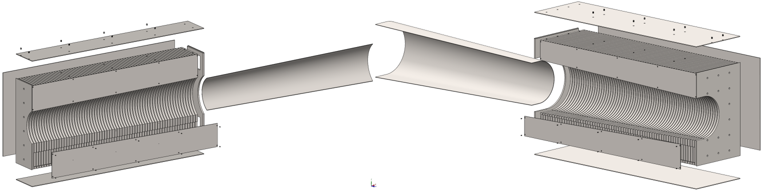


Electron-Ion Collider

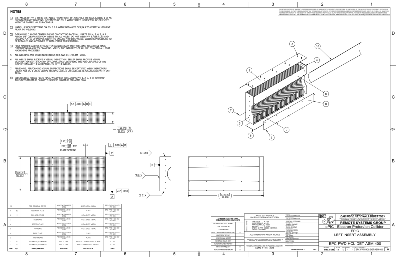
Charge Question 2 & 3

Components: Absorber Structures

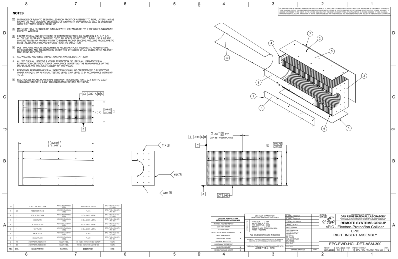
Insert Module Left **Insert Module Right**



Insert Left drawing pack



Insert Right drawing pack

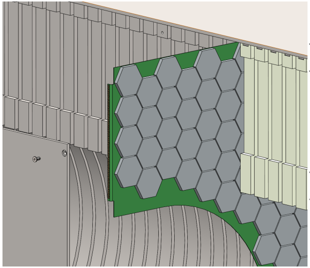


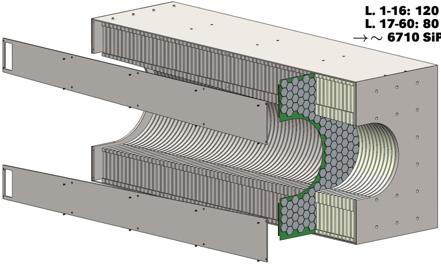
- 2 different module types designed using the same construction process as 8M modules with conical & slanted cut out for beam pipe
- 60 single absorber plates, front and back plate electron beam welded to top & bottom sheet metal panel
  → to be explored whether vertical full length plate to be welded or screwed
- Side panels on inside screwed to welded structure to cover slot with transfer PCB and beam pipe cut-out
- Initial absorber structure design concluded & full drawing pack available

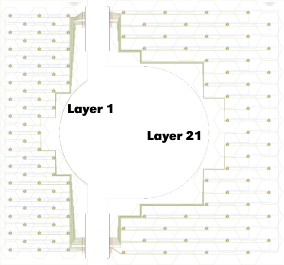
Electron-Ion Collider

Charge Question 2 & 3

Insert Challenges (1)



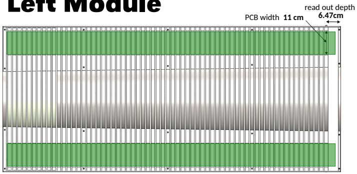




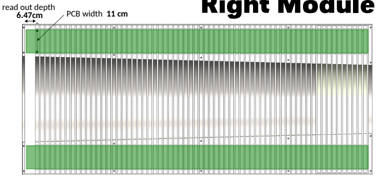
- Higher radiation load close to the beam pipe, needs possibility to replace layers
  ⇒ transfer PCBs situated between left and right module
- Limited space for connectors from each layer → worst case ∼ 80 SiPMs/layer
- Large PCB boards with complex layout and little repetition
- Single channel read-out requires
  ∼ 210 CALOROCs at the back of the module within tight spatial constraints
  ⇒ cooling might be needed

Insert Challenges (2)

Left Module



Right Module



Transfer board simulation & stackup

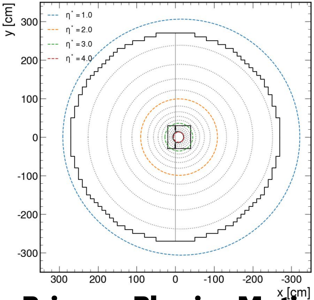
Cross Talk %					
		Trace Spacing (mil)			
		4	8	16	32
	4	8.650%	6.007%	1.250%	
	8		6.385%	4.321%	1.670%
Dielectric Height (mil)	12				
Estimated Required PCB Layers		30	38	56	
		Estimated Board Thickness (mm)			
	4	3.8	4.5	6.2	
	8	5.3	6.4	9.2	
Dielectric Height (mil)	12	6.8	8.3	12.1	

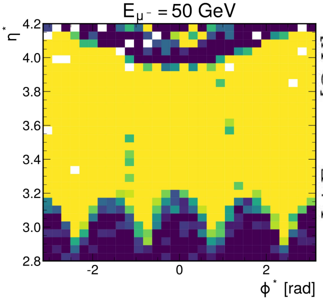
- Width of transfer PCB limited, channel desity for same cross section very high:
  - **Insert Left: 102 ch/cm** **Insert Right: 204 ch/cm** **8M module: 64 ch/cm**
  - Density of traces even higher, as LED lines need to be provided in addition + double of traces per read-out channel
  - Difficult to find vendor capable of producing such long and high density PCBs
  - Space constraints for connectors in the rear in addition
  - Initial cross talk simulations for single agressor lines on 56 layer PCB still 4.3%
- Joint efforts between mechanical & electrical engineers needed over coming month to realize concept

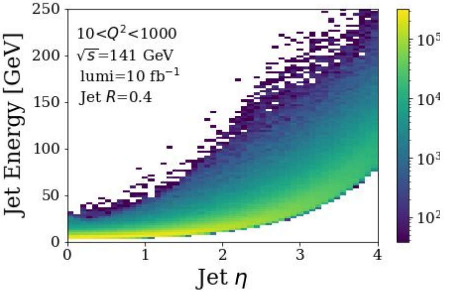
Electron-Ion Collider

Charge Question 3

Recap: Insert Motivation







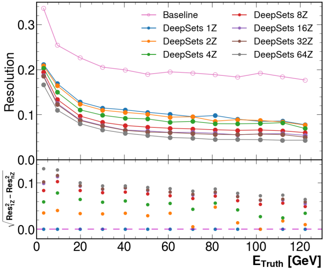
Primary Physics Motivations

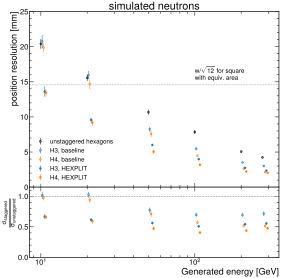
a) Increase coverage for highly energetic hadrons beyond $\eta = 3.0$ for (SI)DIS measurements
b) Improve spatial and energy resolution at high η for substructure measurements

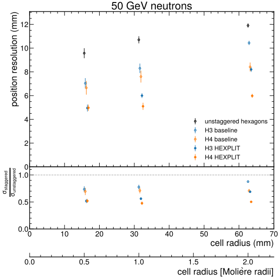
Practical Motivation

- Serves as support structure for the remaining LFHCal 8M & 4M modules atop the beam pipe $\Rightarrow$ similar steel distribution desirable
- Elegant solution for support with optimal usage of instrumented space around beam pipe

Original Insert Granularity Optimization

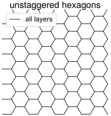


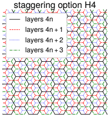


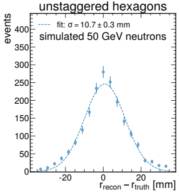


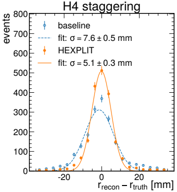
Charge Question 1 & 2

- Full jet reconstruction not possible at time of initial design & particle flow not yet implemented
- Optimized for highest single hadron energy & position resolution
- Single layer readout motivated primarily by improvements in energy resolution
- Transverse granularity and tile shape/positioning by spatial resolution







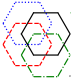


Electron-Ion Collider

Updated Granularity Comparison

High granularity

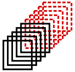
Insert default



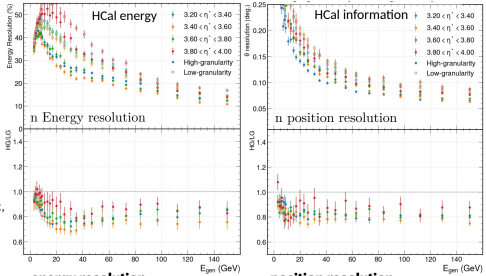
single layer readout, hex-tiles

Low granularity

8M default



summed layer readout, square tiles



energy resolution **position resolution**

HCal Insert only

- As expected energy and position resolution worsen by $\sim$ 20% for standalone performance
- Only 10 % worsening after inclusion of ECal response
- Assessment of impact on jets still not fully feasible with existing simulation framework
  $\rightarrow$ Use ρ^0 decay as proxy
- ρ energy resolution with little impact ($\ll$ 10%)
- ρ identification significantly better at high E with std. insert granularity

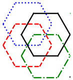
Electron-Ion Collider

Charge Question 2

Updated Granularity Comparison

High granularity

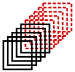
Insert default



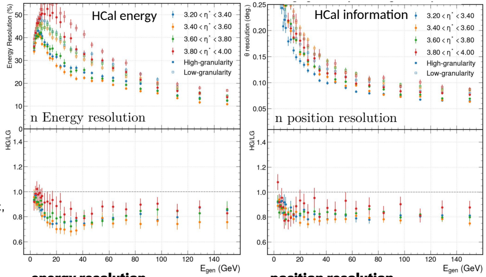
single layer readout, hex-tiles

Low granularity

8M default

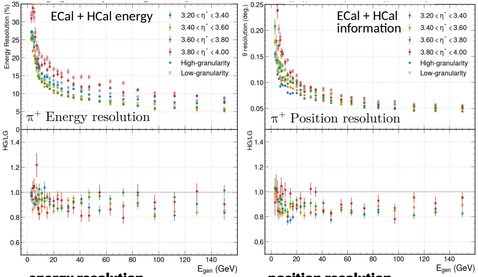


summed layer readout, square tiles



energy resolution **position resolution**

HCal Insert only



energy resolution **position resolution**

ECal & HCal

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Electron-Ion Collider

Charge Question 2

Updated Granularity Comparison

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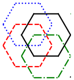
Insert default



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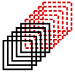
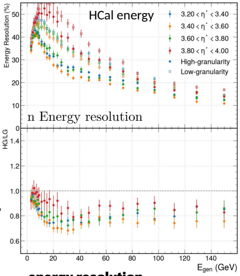
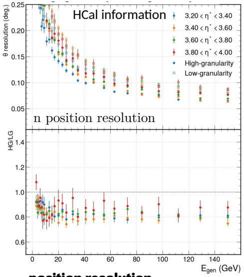


summed layer readout, square tiles

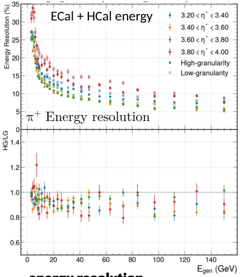


energy resolution

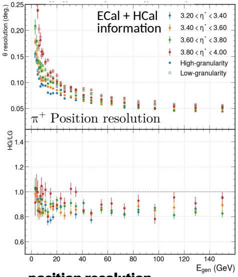


position resolution

HCal Insert only



energy resolution



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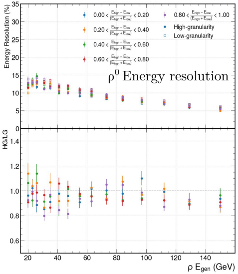
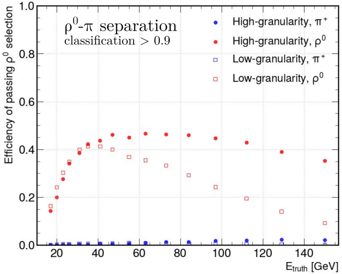




Electron-Ion Collider

Charge Question 2

Electro-Mechanical Solution (A)

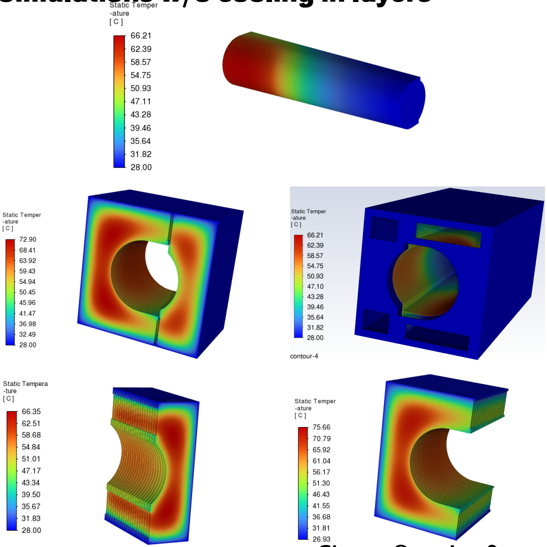
Proposal

- Embedd the CALOROC inside the layers on same board as SiPMs
- Only route digital signal to the rear with fibers or on much simpler transfer board

Implications

- Change of sampling fraction necessary, as PCB boards in layers need more space
- Heat load in layers requires active cooling within the insert
  → limited space for cooling lines (primarily insert outer corners) due to layer maintenance requirements
- Replacement layers would always include CALOROCs
- Simple annealing solution not as easy

Simulations w/o cooling in layers



Electron-Ion Collider

Charge Question 2

Electro-Mechanical Solution (B)

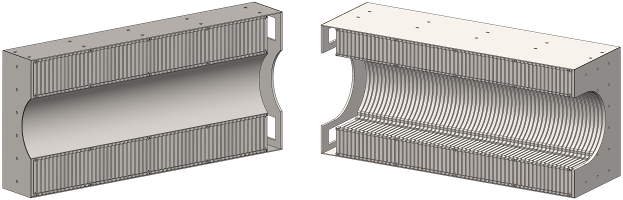
Proposal

- Increase area for long transfer boards by taking out conical structure and part of tilt
- Switch to square tiles to reduce channels/layer

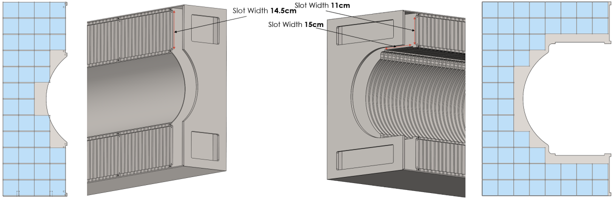
Implications

- Reduced acceptance in η (still needs to be simulated)
- **Insert Left: 2400 ch $\rightarrow$ 83 ch/cm**
  Insert Right: 3240 ch $\rightarrow$ 68 ch/cm
- Possible larger beam induced cross talk in PCBs closest to beam pipe - needs RF simulation & possible RF-shielding
- Reduction of number of CALOROCs: 75 (left) & 102 (right)
- Could employ summing in the back in addition
- Could mechanically fit readout in back

Insert Left



Tile layout & PCB slot arrangement



Electron-Ion Collider

Charge Question 2

Electro-Mechanical Solution (B)

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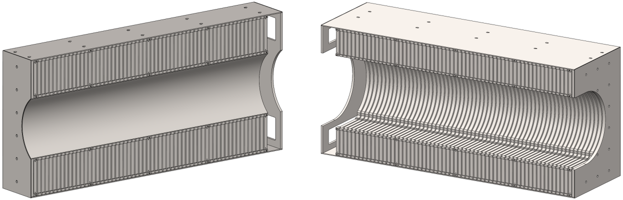
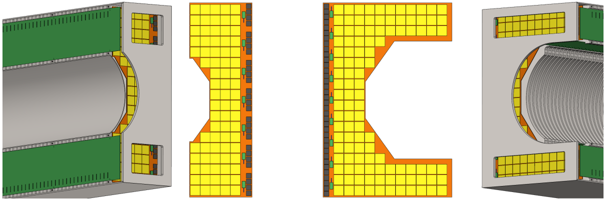


Read-out board layout



Charge Question 2

Insert: Next Steps

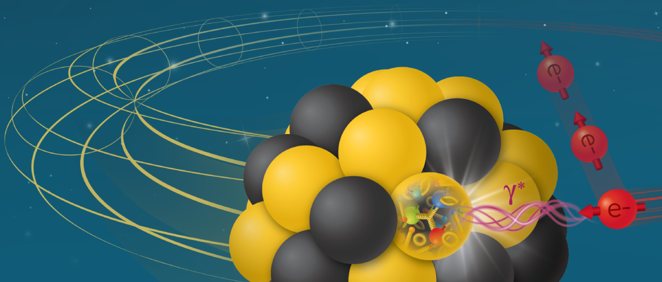
Physics Simulations

- Study impact of Electro-Mechanical Solution (A) & (B) on physics observables
- Evaluate advantages/disadvantages of solutions on clusterization in the transition region between 8M & insert modules
- Continue Implementation of particle flow in ePIC software framework for full jet physics impact evaluation

Engineering

- Fully evaluate Electro-Mechanical Solution (A) & (B) regarding:
  - mechanical stability
  - heat distribution
  - electrical implementation feasibility

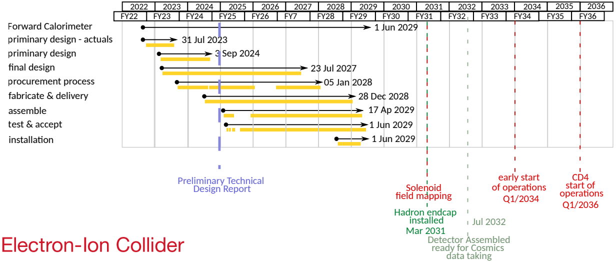
Construction & Assembly Plans

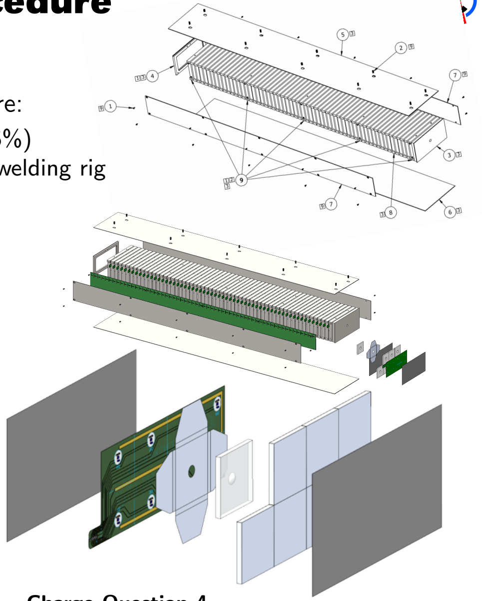


Electron-Ion Collider

Construction Procedure

- Construction done in units of modules
- Construction & QA steps per unit regarding absorber structure:
  1. Dim. tolerance and material composition measurements ($\approx 5\%$)
  2. E-beam welding of absorber structure w/o cover-plate using welding rig
  3. Stacking tests at vendor
  4. Assembly of tile-assemblies and installation
  5. Mounting of transfer PCB & cover plate
  6. Storing & Transport of modules to BNL
  7. Assembly in cradle at IP6

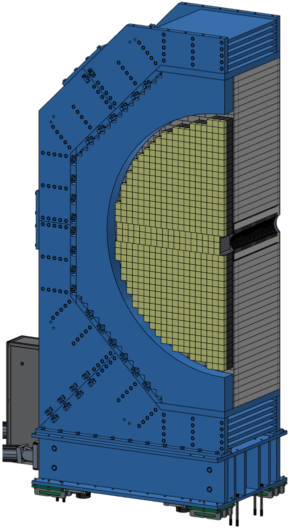




Charge Question 4

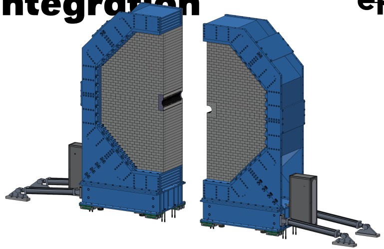
Electron-Ion Collider

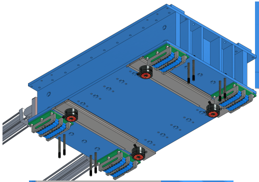
Support structure & ECal Integration

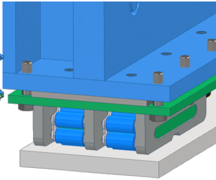


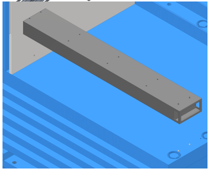
- Cradle build in multiple components
- Simultaneous construction of LFHCal stack and outer shell during installation at BNL
- 1-inch perforated steel plate mounted to front of LFHCAL serving as anchoring structure for both HCal & ECal modules
- Individual ECal blocks installed after completion of HCal construction
- Additional flux return steel mounted between Barrel HCal, forward ECal outer edge & LFHCal
- Purchase of support structures requested as part of CD3-B

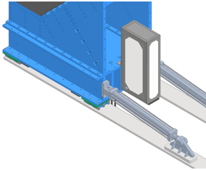
Details see R. Sharma's talk





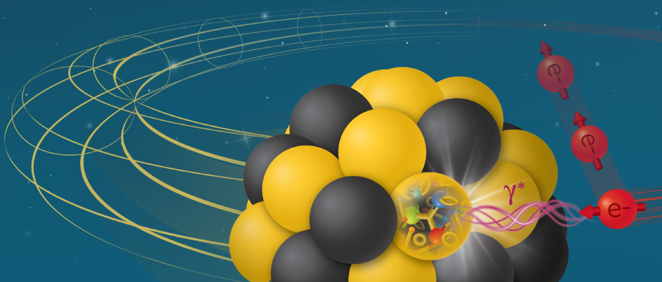






Charge Question 3
Electron-Ion Collider

Summary

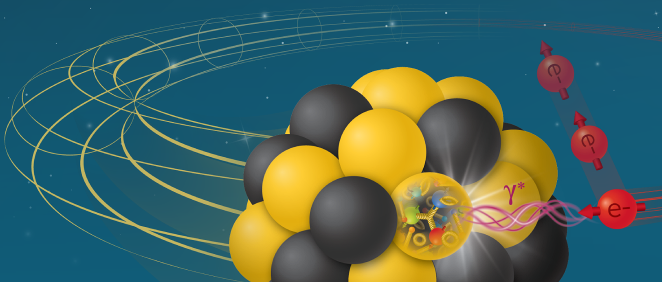


Electron-Ion Collider

Recap Charge Questions

1. Are the technical performance requirements appropriately defined and complete for this stage of the project?
   Yes, the technical performance requirements are derived from the YR and appropriately documented at this stage of the project.
2. Is the design of the various detector systems advanced enough and appropriately documented for this stage of the project? Are the current detector plans likely to achieve the performance requirements for the lifetime of the EIC physics program?
   Yes, the design of the LFHCal is far advanced and several components have received CD-3A approval. The current detector design meets the performance requirements and accommodates the replacement of potential components at risk for higher radiation damage. For the insert design two alternative paths forward have been presented and will be further evaluated regarding their realization potential.
3. Are the assumptions for construction and fabrication of the various detector components sound and are assembly plans reasonable and consistent with the overall detector schedule?
   Yes, for all major detector components first engineering test samples or fabrication plans have been presented and the construction plans are consistent with the overall detector schedule.
4. Have ES&H and quality assurance considerations been adequately incorporated into the plans at the present stage?
   Yes, initial quality assurance plans and ES&H procedures have been presented and are being executed for the items which are part of CD-3A.
5. Have recommendations from previous reviews been adequately addressed?
   Yes, after the previous recommendation to reevaluate the impact of the tungsten layers at the front of the LFHCal, they have been removed.

Backup



Facility Life Time

For EIC we define a 30-year lifetime; to define radiation doses one needs to have a rough split between the beam energies over this 30-year period. Here is the present assumption.

EIC is built to run the following beam energy combinations:
5 GeV x 41 GeV, 5 GeV x 100 GeV, 10 GeV x 100 GeV, 10 GeV x 275 GeV and 18 GeV x 275 GeV
For simplicity all hadrons are treated as protons, which should be okay for radiation purposes.
Based on this, one gets the following estimate for accelerator components:

Electron Energy			Hadron Energy		
5 GeV	10 GeV	18 GeV	41 GeV	100 GeV	275 GeV
10 years	10 years	10 years	5 years	12 years	13 years

For ePIC a 30-year lifetime for radiation will be too long for certain detector components so the present assumption is 15 years with 5 years at the EIC commissioning and ramp up luminosities ($\int L = 38\ fb^{-1}$) and 10 years at full EIC capabilities.

Electron Energy			Hadron Energy		
5 GeV	10 GeV	18 GeV	41 GeV	100 GeV	275 GeV
3 years	4 years	4 years	2 years	3 years	5 years

5 x 41 GeV --> 2 years
5 x 100 GeV --> 1 year
10 x 100 GeV --> 2 years
10 x 275 GeV --> 2 years
18 x 275 GeV --> 3 years

Electron-Ion Collider