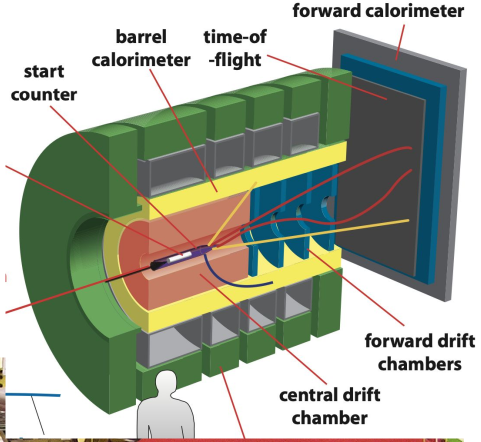
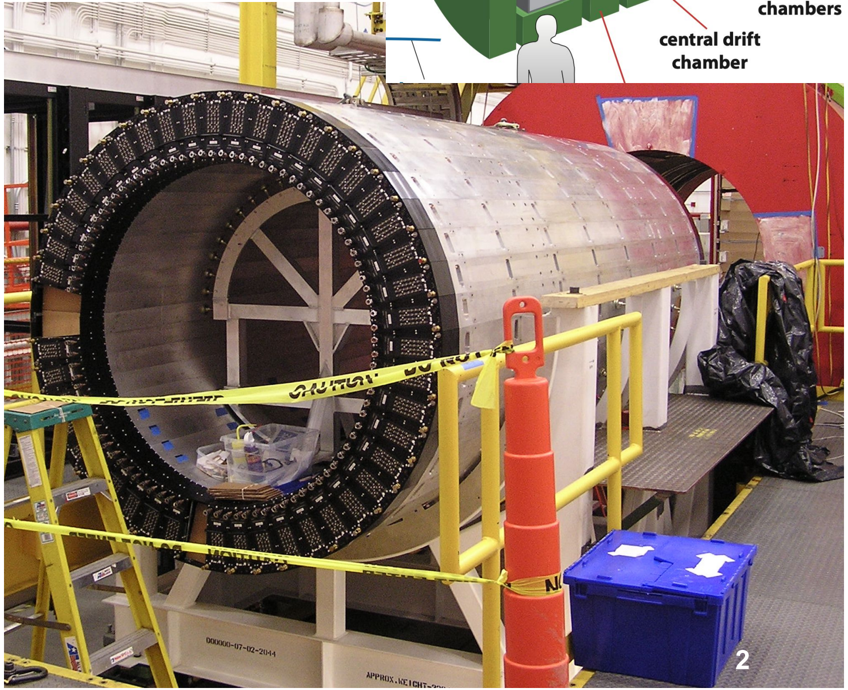
BIC ESB Cooling

EIC Project meets ePIC DSC: Barrel Ecal
May 2, 2025

GlueX/BCAL: inspiration for BIC

- **BCAL** operating since 2015 at Jefferson Lab
- **BCAL has similar scale (slightly smaller)**
- BIC Pb/ScFi matrix and end-of-sector box (ESB) design based on BCAL

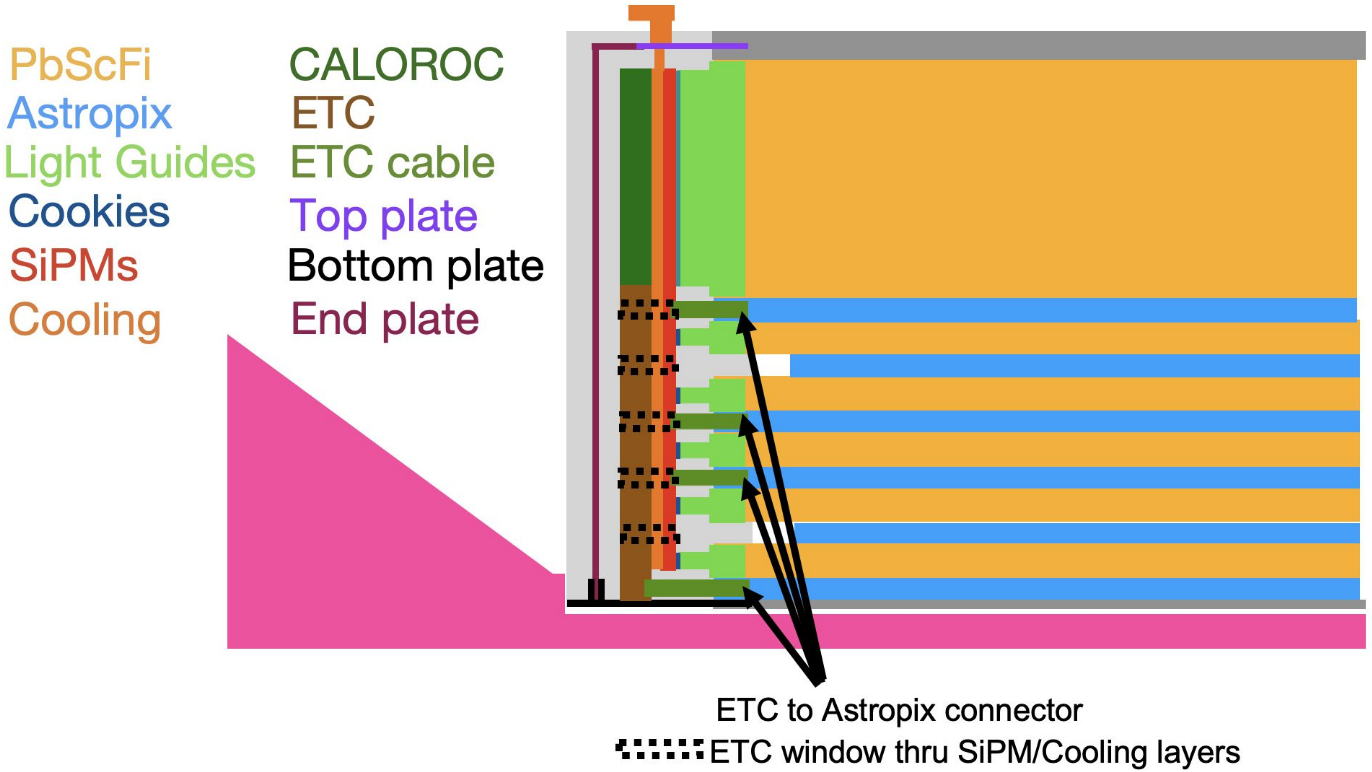




Approximate no's; do not use

		BIC	BCAL
Diameter (m)			
	Inner	~1.6	1.3
	Outer	~2.4	1.8
Length (m)		~4.4	3.9
Sectors (#)		48	48
Mass/sector (T)		~0.9	0.5
Weight (metric T)		~40	24

End of Sector Box (ESB) Napkin Sketch



***Q1:** What is the ambient temperature considered? This is required for dew point calculation.*

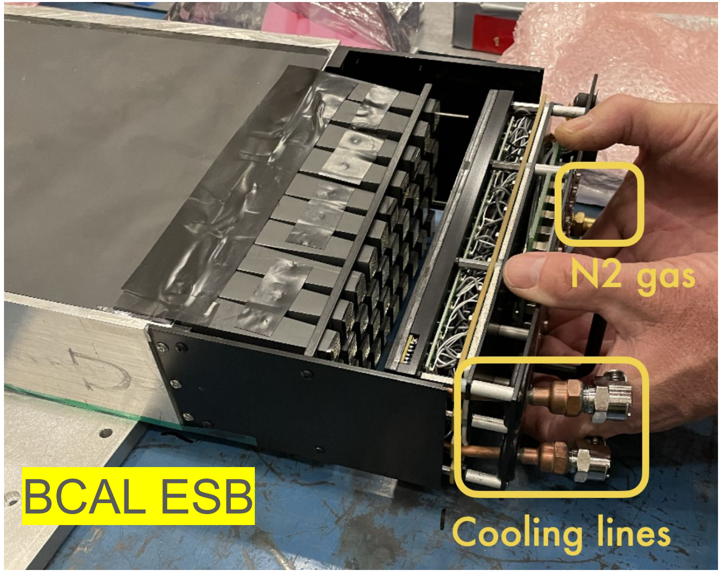
- BIC: We assume a relatively high dew point, and mitigate condensation risk in where needed with dry air/nitrogen
    - The end-of-sector box (ESB) will use 5C (41F) cooling water to cool the SiPMs and electronics excluding the AstroPix → We use dry air/nitrogen to prevent condensation in the ESB
    - We anticipate using standard “room temp” cooling water to temperature stabilize the aluminum back plate to the sectors, indirectly stabilizing the temperature of the AstroPix trays. This does not lead to condensation.
- To compare, for GlueX: The Jefferson lab Hall D ambient temperature is 73 F +/- 2 F, and GlueX uses a similar cooling and condensation prevention scheme in the ESB.

Q2: *What are the flow rates considered for this cooling requirements? Laminar, Transition, Turbulent regime.*

- BIC: We still have to estimate the flow rates. Power budget per ESB is about 20W including AstroPix end-of-tray cards, CALOROC board, and SiPM board. Can use the GlueX numbers as a guide for now (comparing 20W to 11W for GlueX).
- GlueX BCAL: Lower end of Turbulent; 48 wedges, 2 in series, BCAL 7 gallon/min / 24 = 0.28 gallons/min per module. 1/4” diameter pipes on the cooling plate. Cooling plate 9 mm thick copper -single U loop; plate shaped matched wedge. Calculated heat load is 11 W per module (1 at each end of calorimeter).

Q3: *What is the coolant chilled water inlet temperature 5 degree C or other value? To prevent condensation inlet temperature consideration important above dew point.*

- We use the same approach as GlueX (See picture):
  - We will use insulated water lines outside the ESB to prevent condensation on the outside
  - We will use dry air/N2 to prevent condensation inside the ESB



Q4: *Serpentine cooling tubes for SiPMs is good from heat transfer perspective, but is there any pressure drop constraint?*

Studies are just starting:

- Baseline design uses serpentine tubes
- Considering metal core PCBs for increased heat conductivity within the board, allowing to reduce the “serpentine-ness”.
- *(ESB heat load: < 20 W/ESB, < 10 kW / endcap)*

For comparison: GlueX pressure drop numbers (heat load of ~11 W/ESB):

- GlueX: BCAL 8 -10 psi drop through whole system, in manifold, supplied 15 psi, return is 7 psi through whole system. Pipe sizes: at manifold 2” (tbc), drops down to 1/4” lines and then 1/4” tubes.

Q5: *Is it an open loop or closed loop system?*

- Same as GlueX: Closed-loop chiller.
  - GlueX chillers support 1kW/chiller.
  - Lines will require (semi-)annual conditioning

Q6: *Cooling the SiPM's to 7C (±2C) similar to GlueX - BCAL. What is this GlueX interpretation with respect to Barrel Emcal?*

- Temperature requirement in BIC is driven by SiPM noise due to radiation exposure
  - Needed to minimize noise for required dynamic range of the detector (have to detect MIPs)
  - We chose to use the same solution as was used for the GlueX BCAL
  - 7C at SiPMs (using 5C cooling water + dry air/nitrogen) is relatively straightforward compared to colder temperatures,
  - 7C at SiPMs was demonstrated (Bologna irradiation measurements + simulations) to be sufficient to meet our SiPM noise requirements.
- Reason for cooled SiPMs at GlueX
  - Somewhat different, older (first) generation SiPM arrays much more noisy

Q7: *Forced convection consideration in ESB (End of Sector Box) to nullify heat generated by Astropix trays, Also for insufficient heat conduction in PbSciFi?*

AstroPIX heat load: ~1 W/stave (2 mW/cm^2), ~7 W/layer, 84 W/sector, ~4 kW/full system

Options for **conductive** heat removal: **longitudinally** or **radially outwards**

Autodesk CFD calculations of PbSciFi fiber matrix for anisotropic heat conduction coefficients:

k_φ=15.7, k_r=18.4, k_z=21.55 W/(m·K) (cf. k_{Pb}=35, k_{Ac}=0.19 W/m·K)

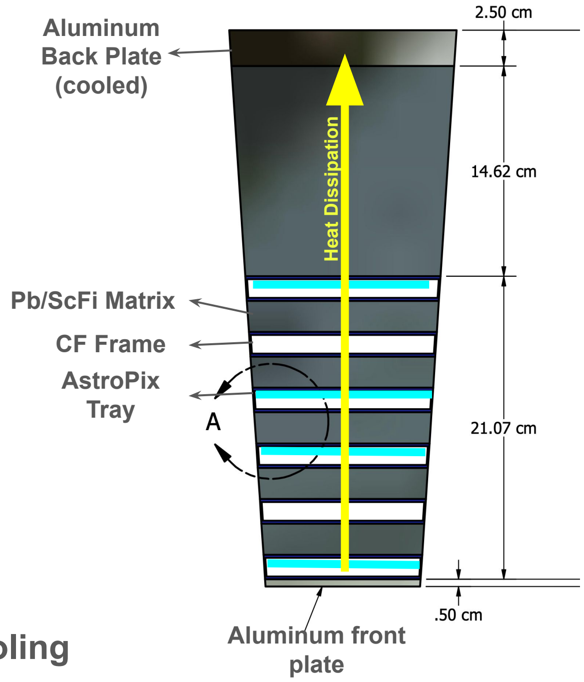
Longitudinally:

- Through 2-cm x 1-mm aluminum stave itself: not feasible, ΔT ~ 70 K over ESB at center
- Through 15-cm x 3-cm SFIL to ESB: not feasible, ΔT ~ 70 K over ESB at center

Radially outwards:

- SFIL: ΔT ~ 0.1 K for heat load of 1 layer
- No air gaps (tray makes thermal contact with next SFIL
- Carbon fiber tray (1-mm thickness; two sides): ΔT ~ 0.1 K for heat load of 1 layer

Strategy: Radially outwards conductive heat removal to water-cooled (room temp) sector aluminum support back plate. Do not anticipate convective cooling for the AstroPix trays. N2/dry air is for condensation mitigation in ESB only.



Q8: *HGCROC chip : 4W each operating at 40C without cooling, conduction or convection (from interface document)? Can you please elaborate about this.*

- These numbers were provided by the CALOROC board designer.
- We will cool the CALOROC board together with the SiPM board and the AstroPix readout electronics (ETC); this is included in our energy budget.

Q9: *Incorporating 1cm diameter Copper in ESB (End of Sector Box) verification done? Leads to Enhanced heat transfer.*

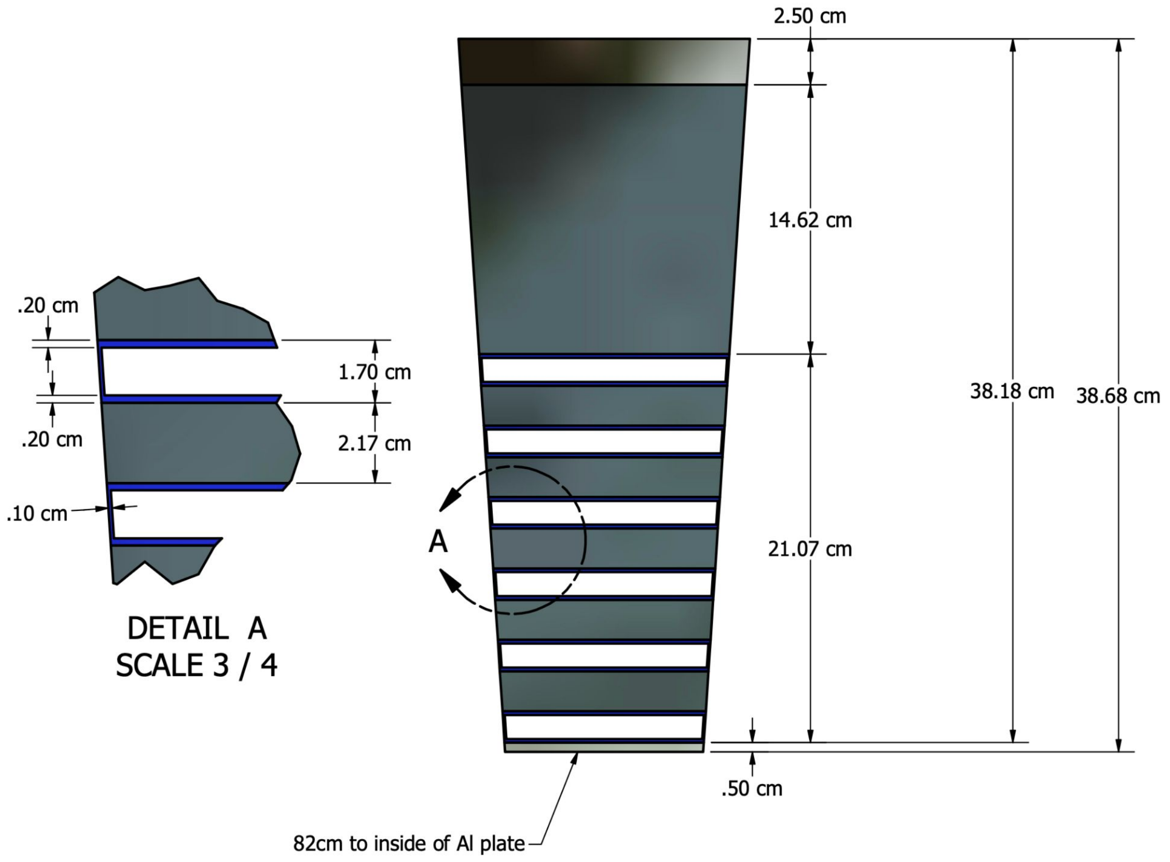
- 1cm copper was an early guess; GlueX 1/4” diameter pipes on the cooling plate should work (This needs to be verified). Cooling plate 9 mm thick copper -single U loop; plate shaped matched wedge.

Background Slides

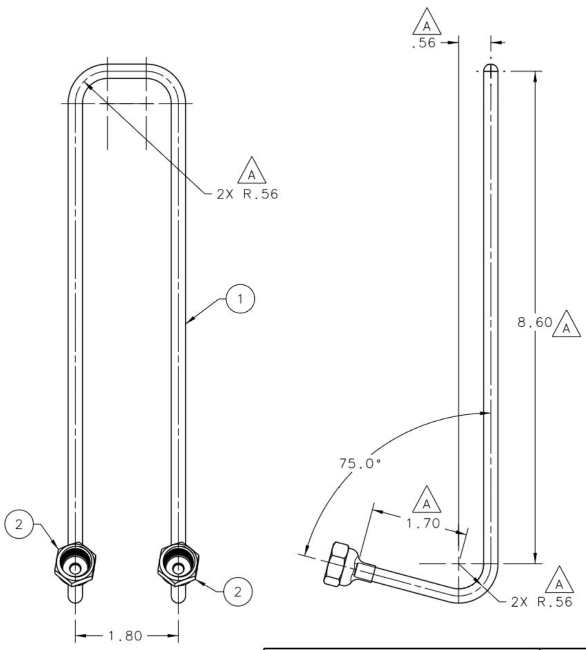
Review Questions

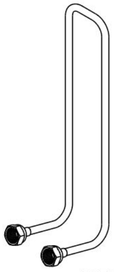
1. What is the ambient temperature considered? This is required for dew point calculation.
2. What are the flow rates considered for this cooling requirements? Laminar, Transition, Turbulent regime.
3. What is the coolant chilled water inlet temperature 5 degree C or other value? To prevent condensation inlet temperature consideration important above dew point.
4. Serpentine cooling tubes for SiPMs is good from heat transfer perspective, but is there any pressure drop constraint?
5. Is it an open loop or closed loop system?
6. Cooling the SiPM's to 7C (±2C) similar to GlueX - BCAL. What is this GlueX interpretation with respect to Barrel Emcal?
7. Forced convection consideration in ESB (End of Sector Box) to nullify heat generated by Astropix trays, Also for insufficient heat conduction in PbSciFi?
8. HGCROC chip : 4W each operating at 40C without cooling, conduction or convection (from interface document)? Can you please elaborate about this.
9. Incorporating 1cm diameter Copper in ESB (End of Sector Box) verification done? Leads to Enhanced heat transfer.

Single Sector, 82.5cm radius
Detector Length = 440cm
Total Length including EOS boxes = 470cm



BCAL-2





REVISION HISTORY				
ZONE	REV	DESCRIPTION	DATE	APPROVED
2-B 2-B,3-C 3-B 2-C 3-D	A	NOTE 1 WAS "SILVER-COPPER-CADMIUM FILLER, AWS SPEC BAG-1 (HANDY& HARMON EASY FLOW 45); INITIAL LENGTH WAS 23.3 QTY. 1 WAS 2, R.56 WAS R.50 1.70 WAS 1.86 8.60 WAS 8.20 .56 WAS .50 JPL07JUL13		
2B	B	ITEM PART# WAS 5520K173. ADDED NOTES 5 & 6. ADDED BRAZING BOX. CLH08JAN13		

NOTES:

1. SUGGESTED SOURCE OR JLAB APPROVED ALTERNATE:

   MCMASTER-CARR
   1-630-833-0300
   www.mcmaster-carr

A 2. BRAZE WITH SILVER-COPPER-ZINC FILLER, AWS SPEC BAg-5 (HANDY AND HARMON, BRAZE 450) OR ENGINEERING APPROVED EQUIVALENT PER MANUFACTURERS RECOMMENDATIONS ENSURING HERMETIC JOINTS.

3. THOROUGHLY CLEAN ALL FLUXES WITH APPROPRIATE METHODS TO ENSURE REMAINING FLUX IS COMPLETELY REMOVED OR RENDERED NON-CORROSIVE.

A 4. INITIAL LENGTH OF TUBE IS 24.0".

B 5. THIS ASSEMBLY IS PART OF JLAB PRESSURE SYSTEM PS-PHY-13-001.

B 6. PRESSURE TEST TO 110 PSI AND ENSURE JOINTS ARE LEAK FREE.

B

QTY REQD	ITEM NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	NOTES
2	2	MCMASTER-CARR 5520K174	FEMALE REDUCING ADAPTER 1/4 NPT	COPPER	1
1	1		TUBE .25 OD X .03 WALL	COPPER	4

PARTS LIST

FOR JLAB INTERNAL USE ONLY

ALL WELDS ON THIS DRAWING ARE AS DEFINED BY JLAB ES & H MANUAL, WELDING & BRAZING PROGRAM SUPPLEMENT

WELD CLASS: C

WELD SPECIFICATION: SEE NOTE 2

WELD ANALYSIS: N/A

DOCUMENT CONTROL STAMP

MATERIAL: SEE PARTS LIST

FINISH MACHINED SURFACES 125 UNLESS OTHERWISE NOTED
DEBURR & BREAK ALL SHARP EDGES

DO NOT SCALE DRAWING

DIM & TOL PER ASME Y14.5, UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS ± N/A; DECIMAL .X ±.1, .XX ±.01, .XXX ±.005; ANGLES ±.50°

THIRD ANGLE PROJECTION

TRACKING NO. N/A

APPROVALS	DATE
DRAWN C L HUTTON	02FEB12
CHECKED J.FOCHTMAN	03FEB12
APPROVED T.WHITLATCH	03FEB12
APPROVED J.FOCHTMAN	03FEB12

United States Department of Energy — Jefferson Lab, Thomas Jefferson National Accelerator Facility — Newport News Virginia

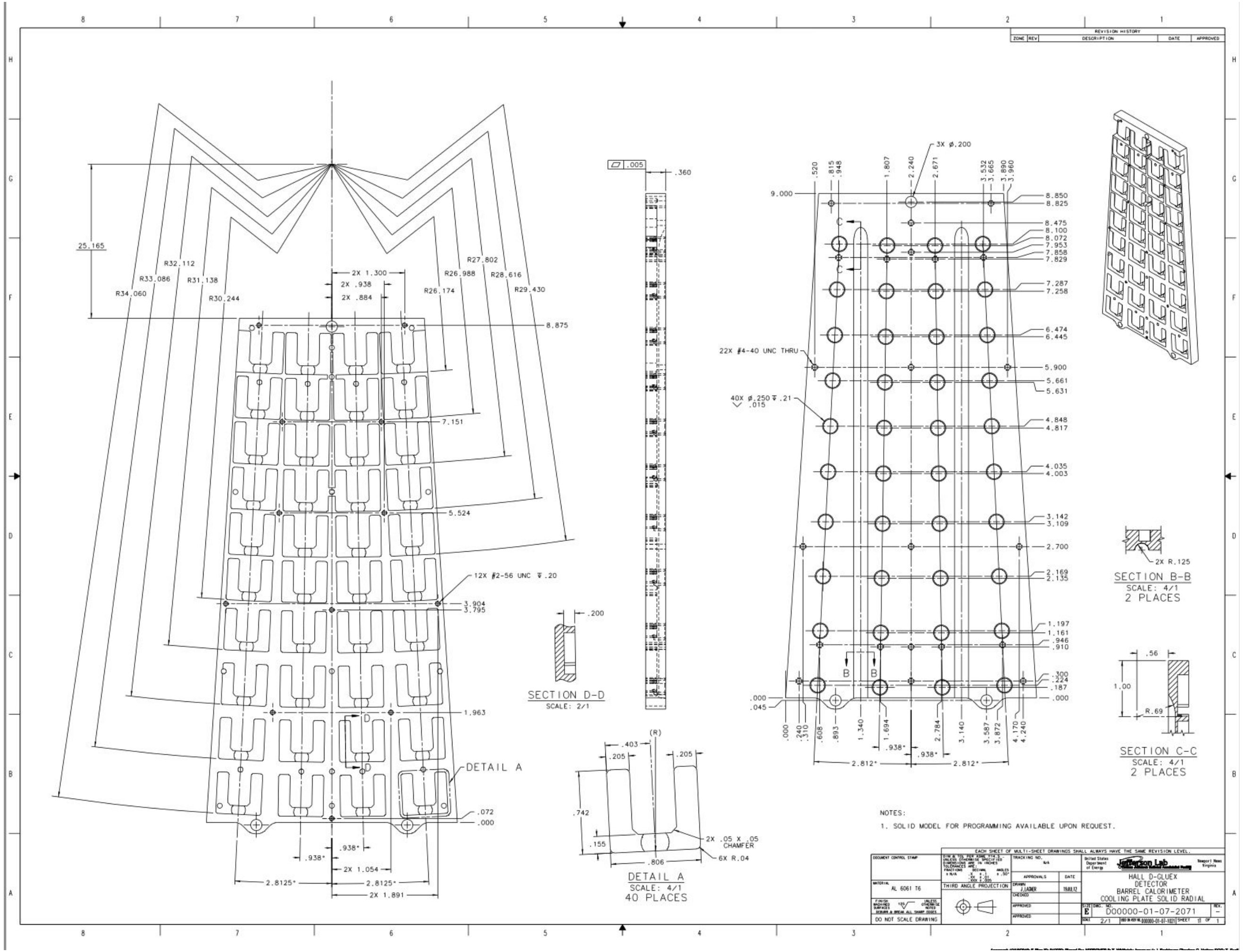
HALL D - GLUEX
DETECTOR
BARREL CALORIMETER
COOLING TUBE W/FITTINGS

SIZE C | DWG. NO. D00000-01-07-2079 | REV. B

SCALE 1:1 | USED ON ASSY NO. D00000-01-07-1021 | SHEET 1 OF 1

Approved: 01/23/2013: E-Sign ID: 224999: Signed By: Approver 1: T. Whitlatch: Checker: J. Fochtman: DCG: T. Fuell

BCAL-3



SECTION D-D
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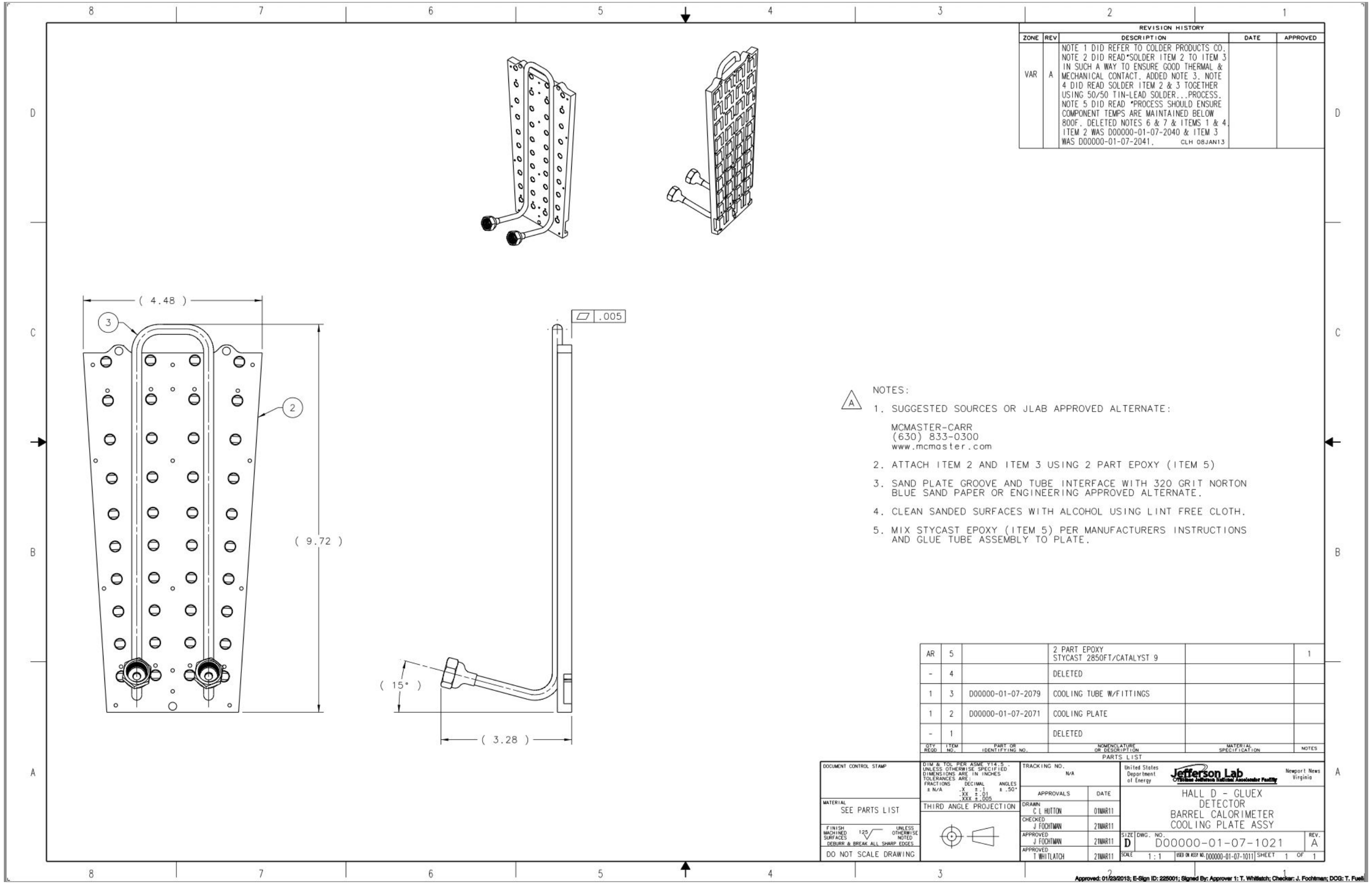
DETAIL A
SCALE: 4/1
40 PLACES
SECTION B-B
SCALE: 4/1
2 PLACES
SECTION C-C
SCALE: 4/1
2 PLACES
12X #2-56 UNC ⧁ .20
22X #4-40 UNC THRU
40X ⌀.250 ⧁ .21
3X ⌀.200
2X .05 X .05 CHAMFER
6X R.04
NOTES:
1. SOLID MODEL FOR PROGRAMMING AVAILABLE UPON REQUEST.
REVISION HISTORY
EACH SHEET OF MULTI-SHEET DRAWINGS SHALL ALWAYS HAVE THE SAME REVISION LEVEL.
Jefferson Lab
HALL D-GLUEX
DETECTOR
BARREL CALORIMETER
COOLING PLATE SOLID RADIAL
AL 6061 T6
THIRD ANGLE PROJECTION
DO NOT SCALE DRAWING
D00000-01-07-2071

BCAL-4


REVISION HISTORY
ZONE | REV | DESCRIPTION | DATE | APPROVED
VAR | A | NOTE 1 DID REFER TO COLDER PRODUCTS CO. NOTE 2 DID READ"SOLDER ITEM 2 TO ITEM 3 IN SUCH A WAY TO ENSURE GOOD THERMAL & MECHANICAL CONTACT. ADDED NOTE 3. NOTE 4 DID READ SOLDER ITEM 2 & 3 TOGETHER USING 50/50 TIN-LEAD SOLDER...PROCESS. NOTE 5 DID READ "PROCESS SHOULD ENSURE COMPONENT TEMPS ARE MAINTAINED BELOW 800F. DELETED NOTES 6 & 7 & ITEMS 1 & 4. ITEM 2 WAS D00000-01-07-2040 & ITEM 3 WAS D00000-01-07-2041. CLH 08JAN13
(4.48)
3
2
(9.72)
.005
(15°)
(3.28)
A NOTES:
1. SUGGESTED SOURCES OR JLAB APPROVED ALTERNATE:
MCMASTER-CARR
(630) 833-0300
www.mcmaster.com
2. ATTACH ITEM 2 AND ITEM 3 USING 2 PART EPOXY (ITEM 5)
3. SAND PLATE GROOVE AND TUBE INTERFACE WITH 320 GRIT NORTON BLUE SAND PAPER OR ENGINEERING APPROVED ALTERNATE.
4. CLEAN SANDED SURFACES WITH ALCOHOL USING LINT FREE CLOTH.
5. MIX STYCAST EPOXY (ITEM 5) PER MANUFACTURERS INSTRUCTIONS AND GLUE TUBE ASSEMBLY TO PLATE.
AR | 5 | | 2 PART EPOXY STYCAST 2850FT/CATALYST 9 | | 1
- | 4 | | DELETED
1 | 3 | D00000-01-07-2079 | COOLING TUBE W/FITTINGS
1 | 2 | D00000-01-07-2071 | COOLING PLATE
- | 1 | | DELETED
QTY REQD | ITEM NO. | PART OR IDENTIFYING NO. | NOMENCLATURE OR DESCRIPTION | MATERIAL SPECIFICATION | NOTES
PARTS LIST
DOCUMENT CONTROL STAMP
MATERIAL SEE PARTS LIST
FINISH MACHINED SURFACES 125 UNLESS OTHERWISE NOTED
DEBURR & BREAK ALL SHARP EDGES
DO NOT SCALE DRAWING
DIM & TOL PER ASME Y14.5. UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± N/A DECIMAL .X ±.1 .XX ±.01 .XXX ±.005 ANGLES ±.50°
THIRD ANGLE PROJECTION
TRACKING NO. N/A
APPROVALS | DATE
DRAWN C L HUTTON 01MAR11
CHECKED J FOCHTMAN 21MAR11
APPROVED J FOCHTMAN 21MAR11
APPROVED T WHITLATCH 21MAR11
United States Department of Energy
Jefferson Lab
Newport News Virginia
HALL D - GLUEX DETECTOR BARREL CALORIMETER COOLING PLATE ASSY
SIZE D DWG. NO. D00000-01-07-1021 REV. A
SCALE 1:1 USED ON ASSY NO. D00000-01-07-1011 SHEET 1 OF 1
Approved: 01/23/2013; E-Sign ID: 225001; Signed By: Approver 1: T. Whitlatch; Checker: J. Fochtman; DCG: T. Fuell

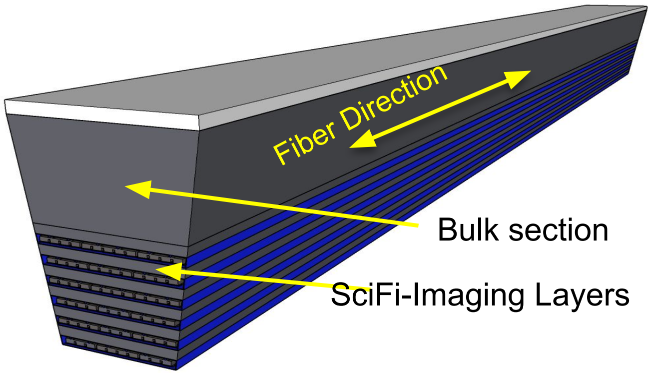
GlueX BCAL Background Info -1

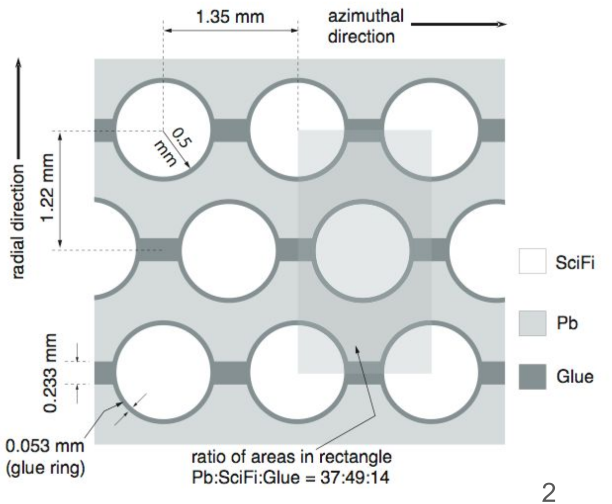
1. What is the ambient temperature considered? This is required for dew point calculation. **Hall D is 73 F +/- 2 F**
2. What are the flow rates considered for this cooling requirements? Laminar, Transition, Turbulent regime. **Lower end of** T**urbulent; 48 wedges, 2 in series, BCAL 7 gallon/min / 24 = 0.28 gallons/min per module. 1/4” diameter pipes on the cooling plate. Cooling plate 9 mm thick copper -single U loop; plate shaped matched wedge. Calculated heat load is 11 W per module (1 at each end of calorimeter).**
3. What is the coolant chilled water inlet temperature 5 degree C or other value? To prevent condensation inlet. temperature consideration important above dew point. **5 C chiller 7 C SiPMs; ??? Look ant CSS Screen Z(P will do). Condensation - flood with dry N2 off a dewar and leaks out. Each chiller is 1KW**
4. Serpentine cooling tubes for SiPMs is good from heat transfer perspective, but is there any pressure drop constraint? **Depends on chiller pressure drop; BCAL 8 -10 psi through whole system, in manifold, supplied 15 psi, return is 7 psi through whole system. Pipe sizes: at manifold 2” maybe, drops down to 1/4” lines and then 1/4” tubes**
5. Is it an open loop or closed loop system? **Closed loop chiller**
6. Cooling the SiPM's to 7C (±2C) similar to GlueX - BCAL. What is this GlueX interpretation with respect to Barrel Emcal? **Not sure what this means, but “as low as you can go” for SiPM noise reduction.**
7. Forced convection consideration in ESB (End of Sector Box) to nullify heat generated by Astropix trays, Also for insufficient heat conduction in PbSciFi? **Not sure who can answer this among the BIC people; BCAL does not have this. 3/4” gap between BCAL outer plate and magnet and touches at ; no sensors there.**
8. HGCROC chip : 4W each operating at 40C without cooling, conduction or convection (from interface document)? Can you please elaborate about this. **Cooled with chiller lines; BCAL Entrance to exit temp is about 0.25 C diff.**
9. Incorporating 1cm diameter Copper in ESB (End of Sector Box) verification done? Leads to Enhanced heat transfer. **See point 4 above.**

Pb/SciFi Matrix

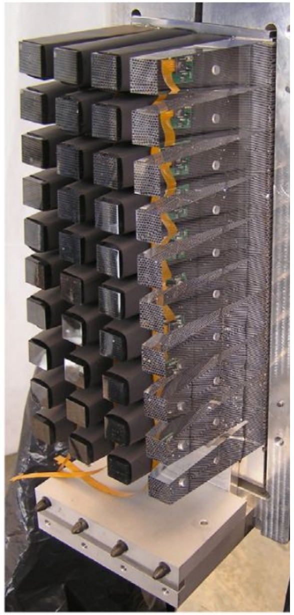
- Matrix geometry: fibers // to long axis
- BCAL "Ingredients"
  - 3,200 km Kuraray 1-mm SCSF-78MJ
    - Double-clad, provided in canes
  - 1-mm thick Pb sheets, cut to length
    - Pb sheets corrugated ("swaged")
  - BC-600 Optical Epoxy, manually
  - Industrial machining to dimensions

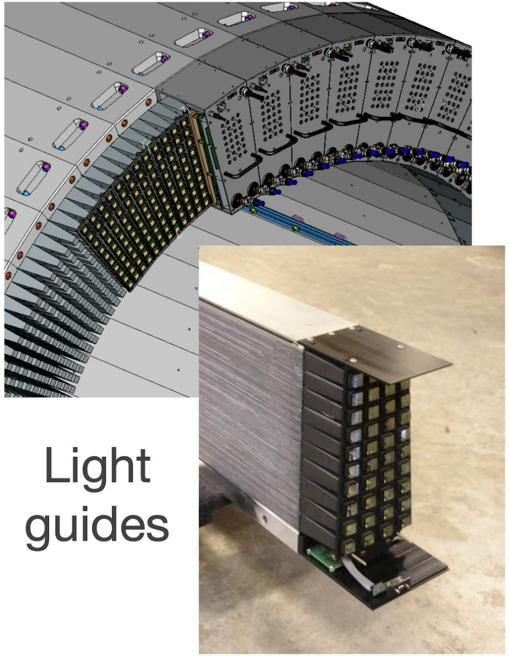
- BIC: composite geometry
  - SciFi+glue: 1.35mm/1.24mm pitch
  - bulk section + SFILs + Astro Trays



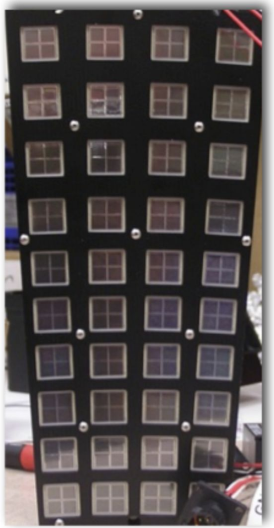


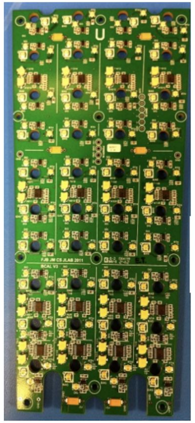
Light “chain”: in photos





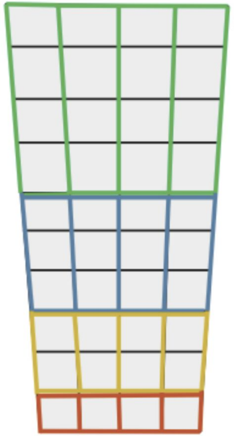
Light guides





Assembly

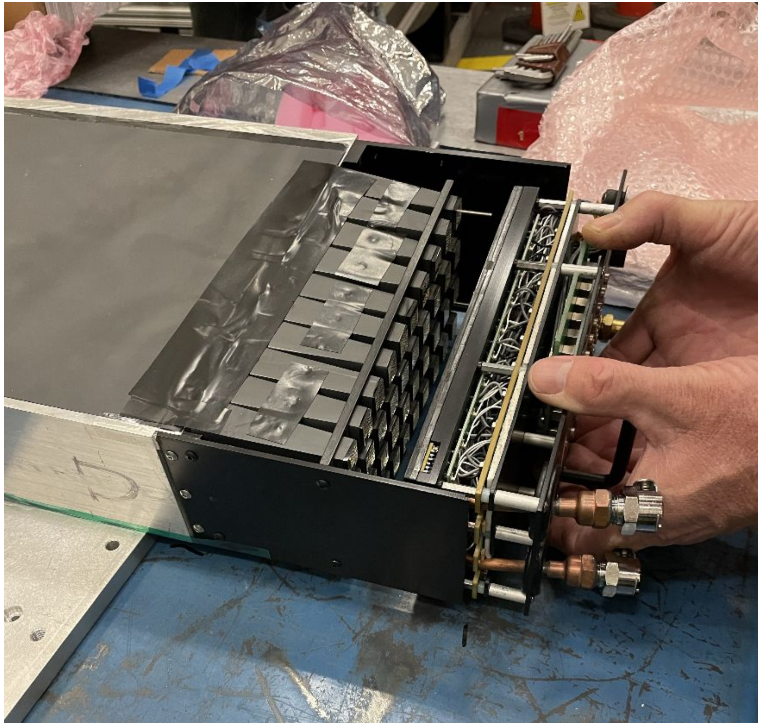
Electronics



Summing Scheme

BCAL: 0.5 mm air gap between LGs and SiPMs

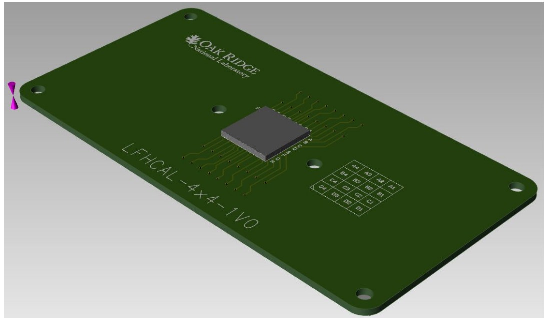
End-of-Sector Boxes (ESBs)



BCAL electronics “wedge”

End-of-Sector Boxes (ESBs)

Development at ORNL+partners



better photos???