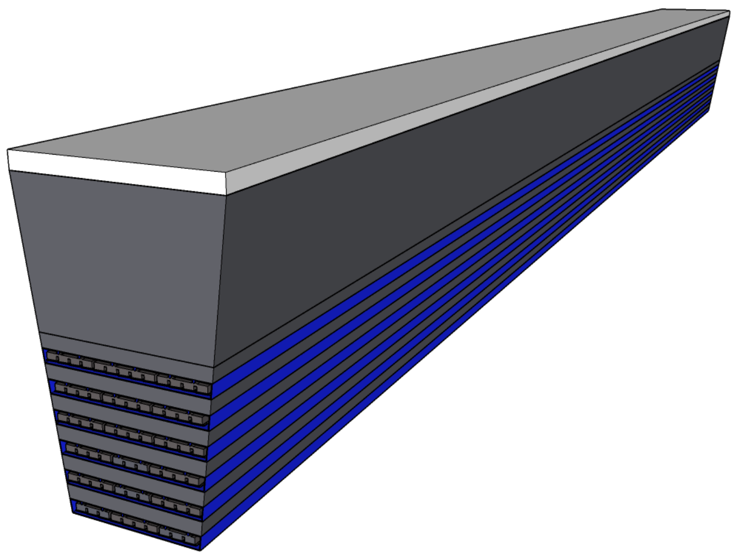
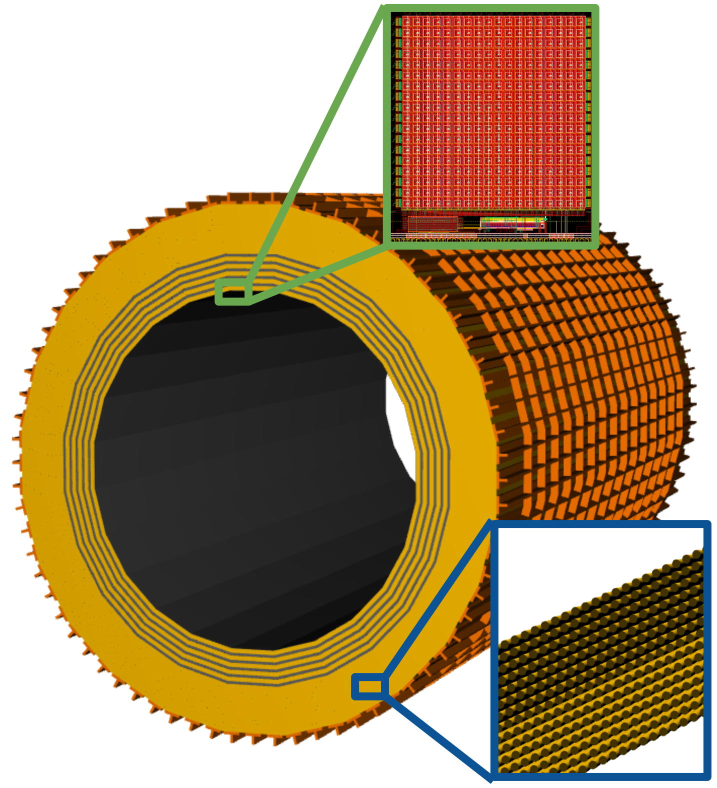




BIC Update - SciFi & SiPM

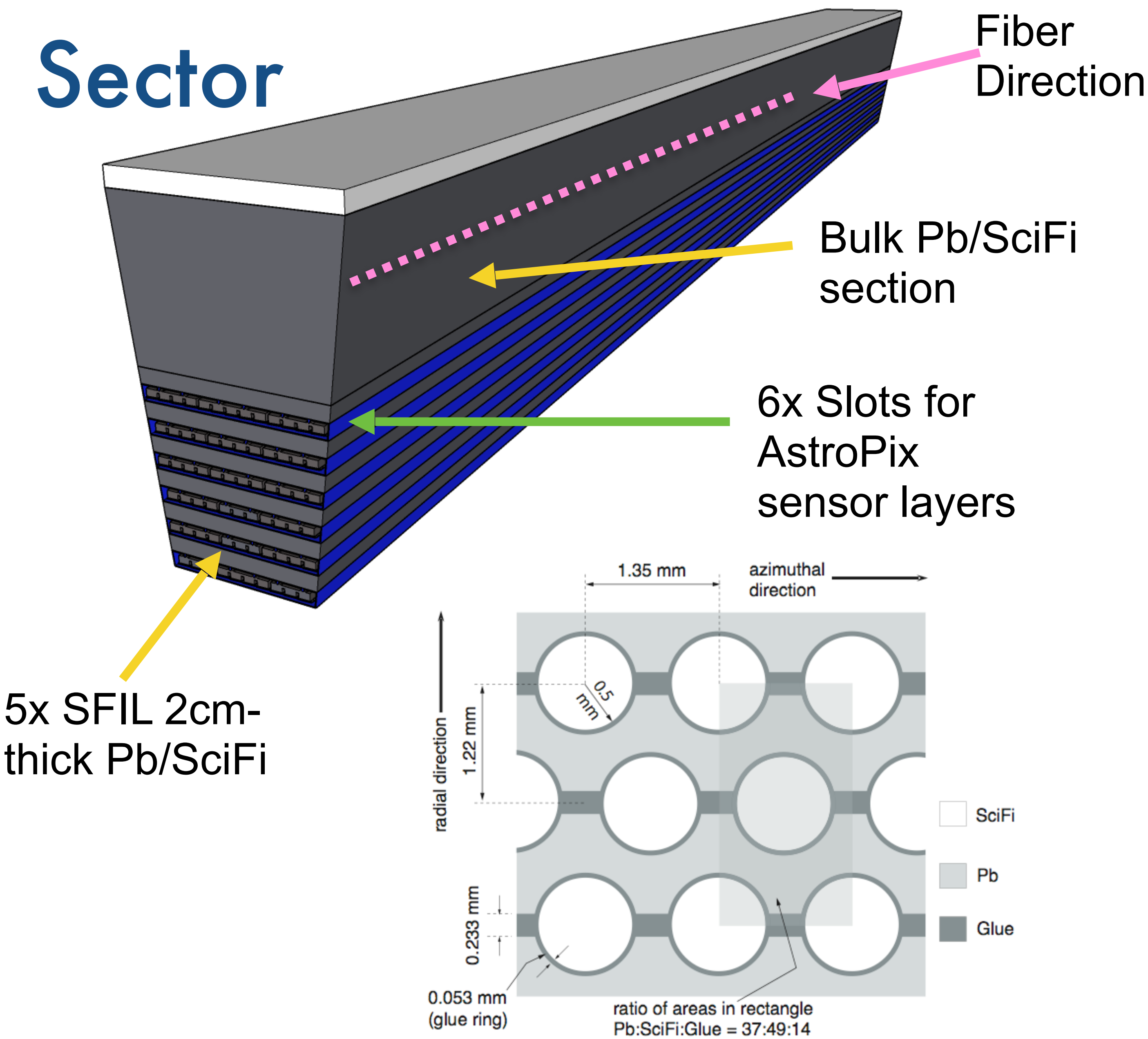
Z. Papandreou, M. Żurek, S. Joosten

TIC Meeting

October 2, 2023

ePIC-BIC v GlueX-BCAL

Calorimeter Sector



	ePIC	GlueX
Diameter (m)		
Inner	1.62	1.3
Outer	2.6	1.8
Length (m)	4.35	3.90
# Sectors	48	48
Mass/sector (T)	1.1	0.58
Weight	36 tons	23 tons

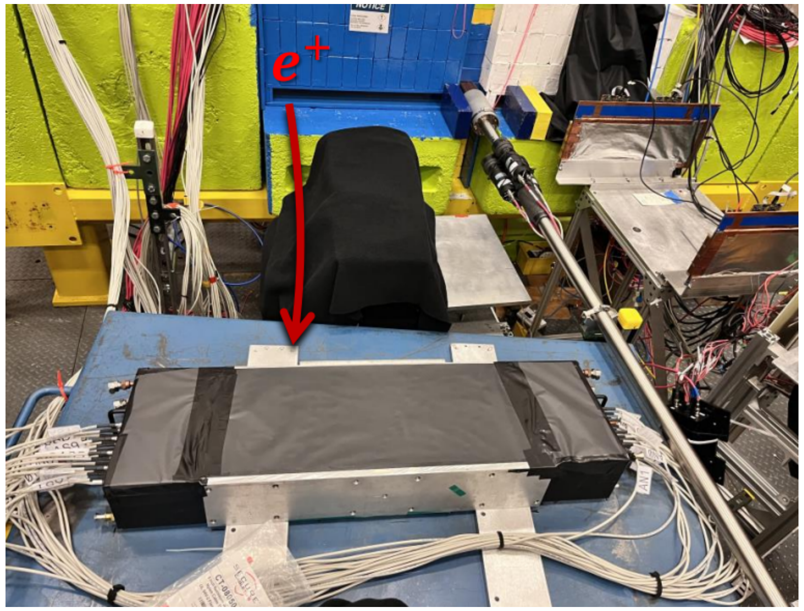
- Design hybrid vs monolithic
- 4,500 km vs 3,300 km
- Si cookies + Light guides
- Large area SiPMs

SciFi @ GlueX

- Mature Technology: **GlueX**, KLOE EMCals
- Tested extensively for electromagnetic response in energies $E_\gamma < 2.5$ GeV
- **Energy resolution: σ = 5.2% /**$\sqrt{E} \oplus 3.6\%$[1)]
  - New results from Baby BCAL prototype in Hall D extend coverage to **6 GeV** and show that **constant term is ~ 2%**

Hall D, March 2023
Baby BCAL Test

Extracted Resolution: ~ 2.5%
(analysis ongoing)



Baby BCAL 60 cm long, 15.5 X0, tested with e+, E ~ 3.6-6 GeV

GlueX BCAL parameters

SiPMs: S12045(X) 4×4 array of 3×3 mm², 50μm pixel
https://ieeexplore.ieee.org/document/7161418,
https://www.sciencedirect.com/science/article/pii/S0168900213009042,
https://www.sciencedirect.com/science/article/pii/S0168900213017233

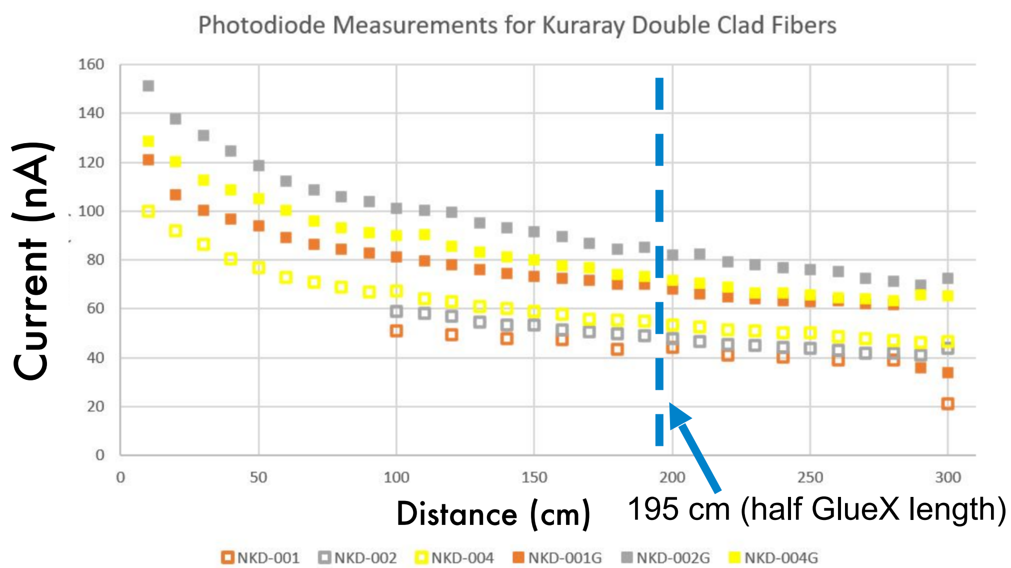
Lightguides: 8 cm long attached to the sector sides
https://halldweb.jlab.org/doc-public/DocDB/ShowDocument?docid=1784

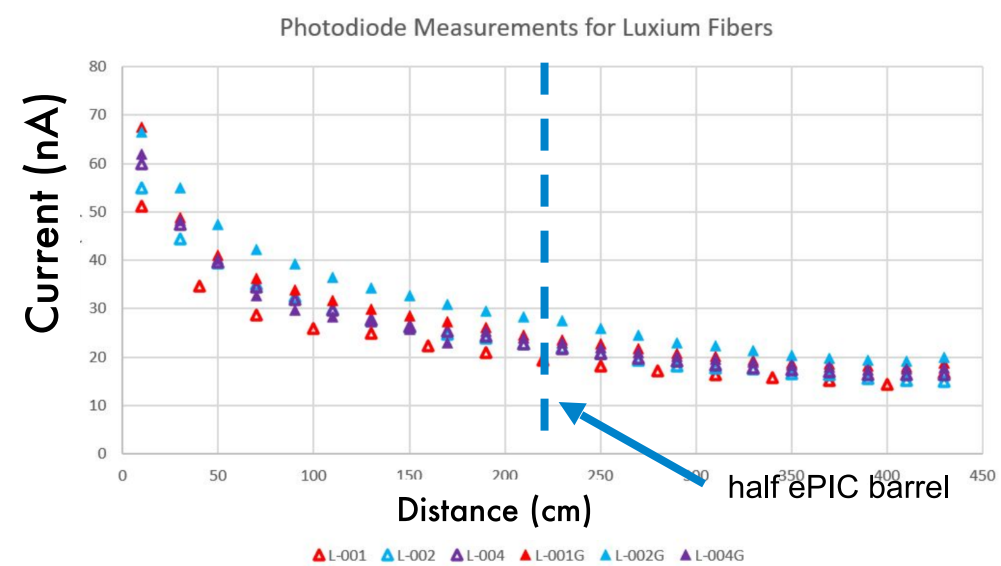
Fibers: **double-clad** Kuraray SCSF-78MJ

1) GlueX, Nucl. Instrum. Meth. A, vol. 896, pp. 24–42, 2018

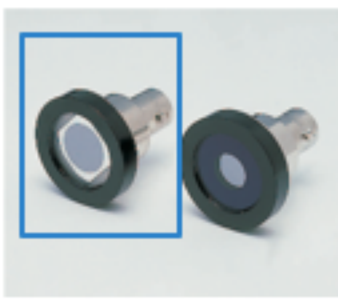
Atten Len & Light Output

Summer 2023 Measurements @Regina (Kuraray vs Luxium)

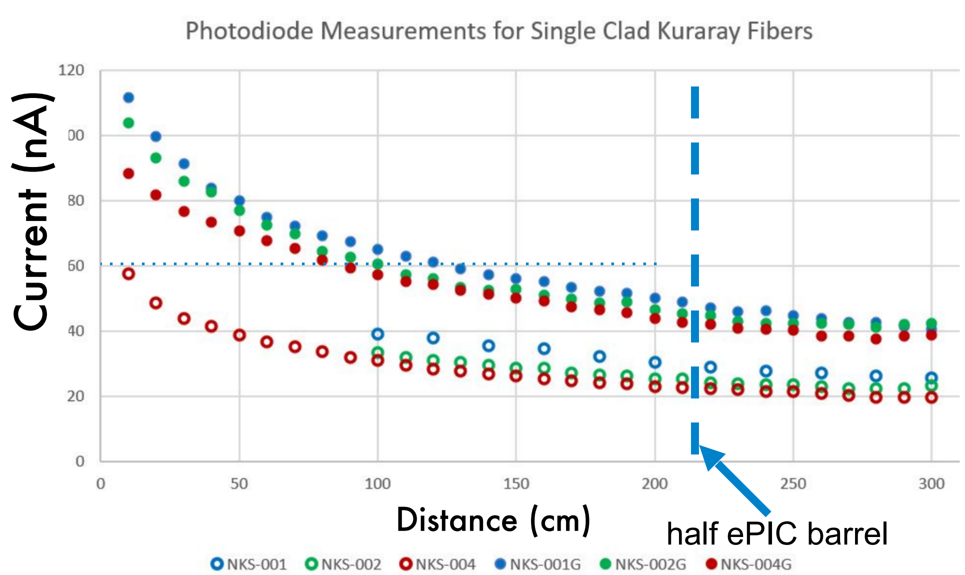




HAMAMATSU
PHOTON IS OUR BUSINESS



\+ UV LED,
+optical grease



* **Attenuation Lengths measured > 400 cm**

* **Light output: PRELIMINARY**

Kuraray double-clad/Kuraray single-clad

- at 10 cm: ~ 1.40
- at 200 cm: ~ 1.65

Kuraray double-clad/Luxium single-clad

- at 10 cm: ~ 2.01
- at 200 cm: ~ 2.80

Kuraray/Luxium single-clad

- ~ 1.4-1.7

Npe next

Fiber Timeline

L3 WBS	L4 WBS	Activity ID	EXPECTED AWARD DATE	DIRECT MATERIAL COST	Budgeted Labor Cost	Budgeted Nonlabor Cost	Total Cost (Burd&Esc)
		CD-3A Scope and Design					
		Scintillating Fibers		1,659,000	$16,800.26	$1,768,642.41	$1,785,442.67
6.10.05	6.10.05.03	Hadron Endcap EMCal Fibers	23-Jul-24	384,000	$7,768.29	$398,208.01	$405,976.30
6.10.05	6.10.05.02	Barrel EMCal Fibers	17-Oct-24	1,275,000	$9,031.97	$1,370,434.40	$1,379,466.37
		CD-3B Scope and Design					
		Scintillating Fibers		4,369,700	$2,323.61	$4,891,300.15	$4,893,623.76
6.10.05	6.10.05.03	Hadron Endcap EMCal Fibers	4-Feb-25	979,571	$1,146.50	$1,075,003.14	$1,076,149.64
6.10.05	6.10.05.02	Barrel EMCal Fibers	11-Jul-25	3,390,129	$1,177.11	$3,816,297.01	$3,817,474.12

- Cost estimates based on vendor quote from 2023 (Luxium for BIC).
- BIC, 4,500km, $1,275k + $3,390k, over 3-4 years after July 2024.

Long Lead Procurement

- July 2024: order fibers
- Summer 2024 - Summer 2028: receive fibers
- ~ Spring 2025 start block factories (after ramp-up curve of 6 months)
- December 2029 - barrel EMCal ready for installation
- June 2030 - barrel EMCal installed

FDR Closeout - Fibers

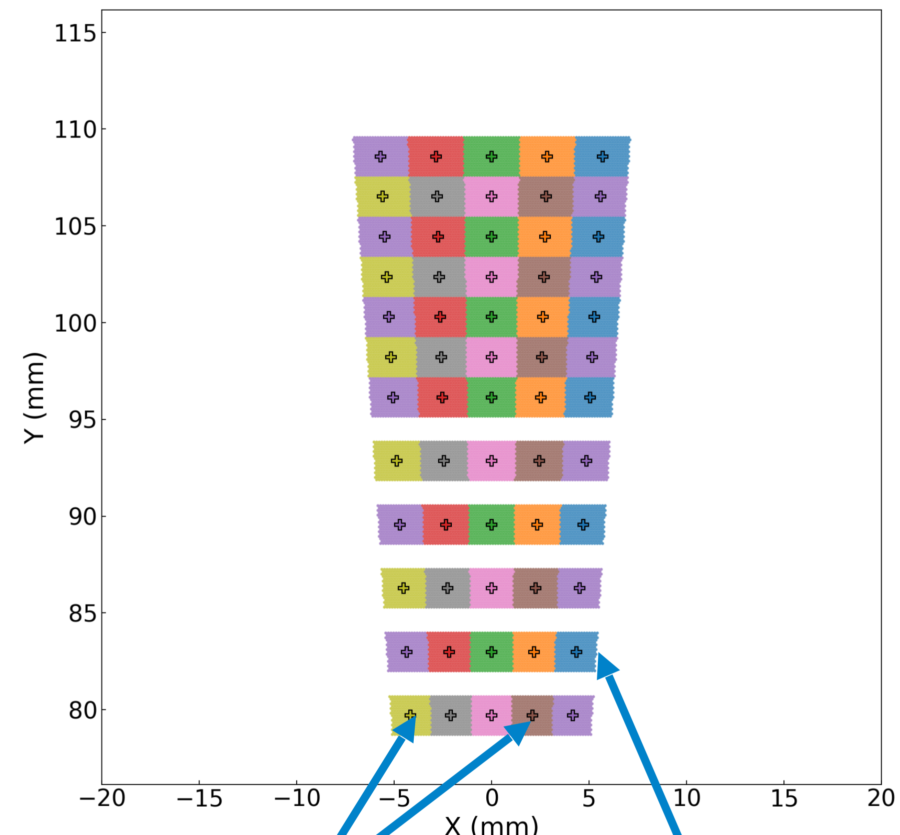
Technical performance met; no show stoppers.

- Q1: pay attention to redundancy (**single vs. double-clad** fibers to ensure good performance even in harsh conditions, like beam background or noise in the SiPMs).
- Q2: We strongly recommend exposing one minimal slice / element of the EPIC barrel EMCal into a **test beam** to study its performance and test as a slice of the full system latest before the second purchase order of the scintillating fibers.
- Q7: We recommend parallelizing the QA efforts, for example, make use of ways to measure attenuation length developed at one lab also at the other site.
- Q7: We recommend making a clear evaluation of the needed margin in fiber length to compensate for bad fibers and production training / losses / accidents.
- Q7: We recommend **ordering fibers in canes** if possible, to avoid the issue of elastic memory.
- Q8: We recommend considering pre-production of a small amount from both companies to evaluate the different sets of parameters.

SiPM Readout

- **2-sided SiPM readout**
- **Lightguides** on sector sides
  - inner surface ~2×2 cm^2
  - output face 1.3×1.3 cm^2
- SiPMs that meet our requirements:
  - e.g., pre-assembled S14161-3050-04 array
  - same dimensions as GlueX but with better performance:
    - PDE = 50% (GlueX ~33%)
    - Lower noise
- 12 layers x 5 cells x 2 sides x 48 sectors = **5760 channels**

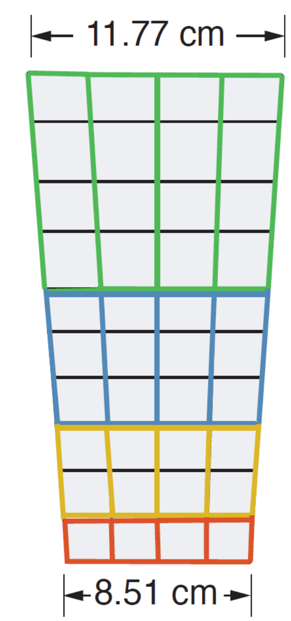
ePIC Sector End View (x-y plane view), 17.1 X0



Readout **Cell**
The area 1 light guide is attached to
Layer = 5 cells

Pb/SciFi **Layers**
1 sector = 12 layers
1 layer = 17 fiber rows

GlueX Sector End View, 15.5 X0



Hamamatsu S12045(X)
4×4 array of 3×3 mm^2
50×50μm^2 pixels

16 FADC per side
12 TDC per side

SiPM Dynamic Range

Energy measurement ranges in BIC:

- *Shall provide photon measurements up to 10 GeV* (F-DET-ECAL-BAR.2:)
- *Shall provide electron ID up to 50 GeV and down to 1 GeV and below* (F-DET-ECAL-BAR.1)
  - Electron energy measurement needed for e/π separation only (straightforward at high energies)
- Reasonable performance for MIPs needed for calibration and for muon ID

Largest energy deposit occurs for particles at large η (steep angle) where the path length in a cell is maximal and the attenuation is minimal.

From our 2023 Hall D tests using GlueX SiPMs and double-clad Kuraray fibers: **1077 phe/GeV** per side for showers at the center of the Baby BCAL prototype; (corrected for attenuation)
Scaling for **ePIC BIC** gave ~ **1239 phe/GeV** per side (corrected for attenuation)

- **10 GeV ɣ at η ~ -1.7 → 9.8 % max SiPM occupancy**
- **19 GeV e^- at η ~ -1.7 → 16.1 % max SiPM occupancy**
- **50 GeV e^- at η ~ 1.4 (most extreme case) → 30.1% max SiPM occupancy**

We are below the region where large nonlinearities in the SiPM response are expected in almost all cases. Small non-linear effects possible for some ultra-high energy electrons, which is acceptable (e-π separation straightforward).

SiPM Specs

TABLE 1: Barrel Imaging Calorimeter SiPM Specs

Parameter	Specification	Notes
Active Area	3 mm x 3 mm (4 x 4 array)	Preassembled array covering 1.2cm x 1.2cm
Pixel Size	50 µm	
Package Type	Surface Mount	
Peak Sensitivity	450 nm	
PDE	~ 50%	
Gain	> ~ 2 x 10^6	
DCR	Typ.: ~ 500kHz / SiPM Max: < 1.5 MHz / SiPM	DCR applies to each SiPM in the 4 x 4 array
Temperature coefficient of Vop	< 40mV/C	
Direct crosstalk probability	< ~ 7%	
Terminal capacity	~ 500pF / SiPM	Applies to each SiPM in the 4 x 4 array
Packing granularity		
Vop variation within a tray	< 200 mV	
Recharge Time	< 100 ns	
Fill Factor	> 70%	
Protective Layer	Silicone (n ~ 1.5-1.6)	

FDR Closeout - SiPMs

Technical performance met; no show stoppers.

- More than 1,000,000 SiPMs of various types are needed (**5760+spares for BIC**). The vendor pool capable of meeting the required specifications is limited, and the construction of some detectors necessitates a substantial amount of time.
- We emphasize three general considerations related to the selection of SiPMs:
  - The insensitivity of modern SiPMs to magnetic fields and their compact size makes them an excellent choice for many of the ePIC detectors.
  - The **specifications of individual SiPMs are well-matched** to the detector requirements presented at this review.
  - The choice of specific SiPMs is not strongly affected by final design of infrastructure and electronics, and therefore is compatible with early procurement.

Long Lead Procurement

- Based on the above observations, we strongly recommend **commencing the procurement process** for the SiPM light sensors as soon as possible, considering funding and other constraints.

Summary

- Pb/SciFi design of the ePIC-BIC derived from GlueX-BCAL.
- At ePIC we reach higher energies, larger average particle multiplicities, and need to measure full energy profile of the developing shower.
- SiPM requirements determined through a combination of full simulation studies, prototype measurements, and experience with GlueX BCAL.
  - Major departures from GlueX:
    - 432.5 vs 390 cm, fibers may come in a spool - elastic memory, tooling?
    - Fibers single-clad with double-clad at imaging layers before shower max?
    - Higher SiPM PDE, optical cookies instead of air gap
    - Readout scheme without summing (impacts thresholds)

Fiber choice: e.g., single clad Kuraray SCSF-78.

SiPM Choice: e.g., 4x4 pre-assembled arrays of 3×3 mm^2, 50 μm pixel SiPMs (S14161-6050-04 array) per channel is a good match for the physics performance requirements of the ePIC BIC.