Update of SciFi Studies
in Canada

Z. Papandreou, Wouter Deconinck on behalf of EIC Canada

BIC In-Person Workshop

May 14, 2024


Happy to be here in person!
Jan 2024 dinner

USA

Argonne National Laboratory

NASA Goddard Space Flight Center

Oklahoma State University

University of Connecticut

University of California Santa Cruz

Canada

University of Manitoba

University of Regina

Mount Allison University

NSERC

Canada Foundation for Innovation

Possibility for in-kind funding

Korea

Kyungpook National University

Yonsei University

University of Seoul

Pusan National University

Korea University

Sungkyunkwan University

Hanyang University

Gangneung-Wonju National University

Germany

Karlsruhe Institute of Technology

University of Giessen

ePIC BIC Detector Subsystem Collaboration

Canadian CFI IF Team and Expertise

Combination of experienced and up-and-coming researchers

- **Wouter Deconinck** (Manitoba, **lead**): EIC Canada spokesperson and PI, ePIC software & computing deputy coordinator, Compton calorimetry, EDI
- **Zisis Papandreou** (Regina, **co-lead**): deputy subsystem technical lead for lead/fiber, PI of GlueX barrel calorimeter project (lead/fiber technology)
- **Dave Hornidge** (Mt Allison): study of origin of mass and spin of the proton
- **Michael Gericke** (Manitoba): silicon pixel detectors and calorimeters
- **Savino Longo** (Manitoba): calorimeter detectors and photo-sensor testing
- **Juliette Mammei** (Manitoba): photo-sensitive subatomic detectors, EDI
- **Garth Huber** (Regina): subatomic detectors, origin of mass of the nucleon
- **Aram Teymurazyan** (Regina): nuclear imaging detectors, commercialization
- **Sylvester Joosten** (Argonne): BIC subsystem lead, EDI
- **Maria Żurek** (Argonne): deputy BIC subsystem lead, EDI

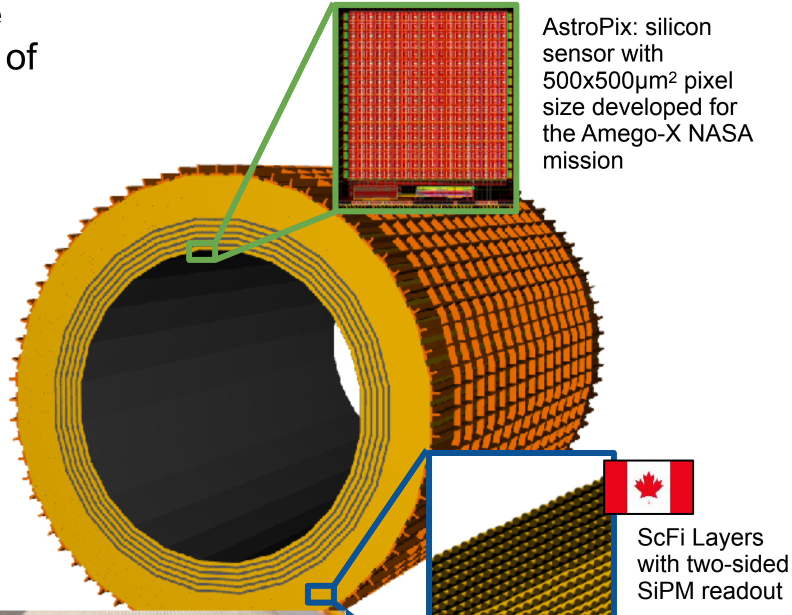
In conversations with other institutions (Red River, **TRIUMF**, and others)

Innovative Technology:
BARREL IMAGING CALORIMETER

Addressing the unique challenges for the barrel region in ePIC

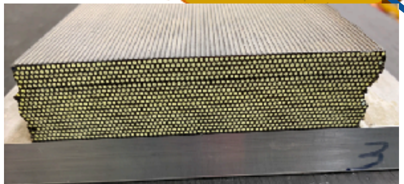
Hybrid concept: 4 (+2) layers of AstroPix interleaved with the first 5 Pb/ScFi layers, followed by a large volume with the rest of the Pb/ScFi layers

- ✓ Deep calorimeter (η = 0 ~17.1 X_0) while compact at ~ 40 cm thickness (fits inside solenoid magnet)
- ✓ Excellent energy resolution (5.2% $/\sqrt{E} \oplus$ 1.0%)
- ✓ Unrivaled position resolution due to the silicon layers
- ✓ High-granularity: a detector made for the data science era!



Canadian Scope for production and installation:

- **Lead/fiber sector construction**
  - Pressed assemblies of swaged Pb sheets, optical fibers, epoxy
- **End-of-sector readout boxes**
  - Lightguides, silicon photo-sensors, gain stabilization, signal digitization



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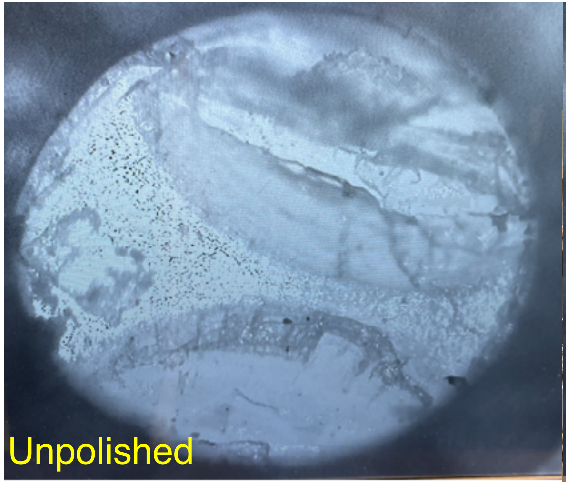
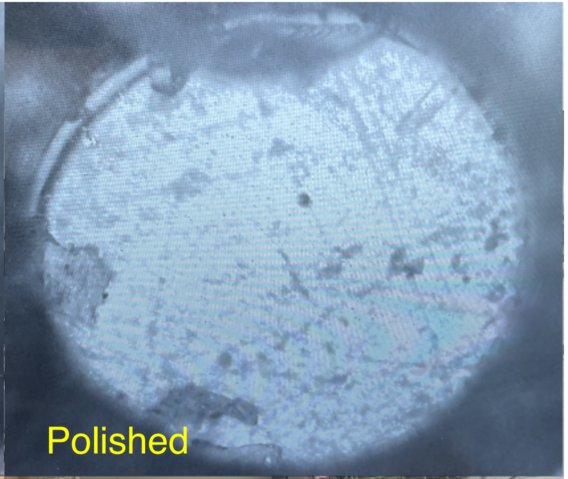
Fiber Polishing





- Kuraray fibers came unpolished
- RBTX-12B[1] machine used for fiber polishing; from plant imaging lab
- Fibers were polished for 45 min each using 30µ, 9µ, 1µ grinding sheets
  - new fibers were covered with double layer of UV-absorbing film[2] for protection
- Inspected with RBTX-400GM[1] fiber microscope; quick cleaning needed

[1]Shenzhen Rongbang Optical Fiber Equipment Manufacturing Co., Shenzhen, Guangdong Province, China (www.rbtx.cn/EN/)
[2]Window Film Systems, London, ON, Canada (www.windowfilmsystems.com)

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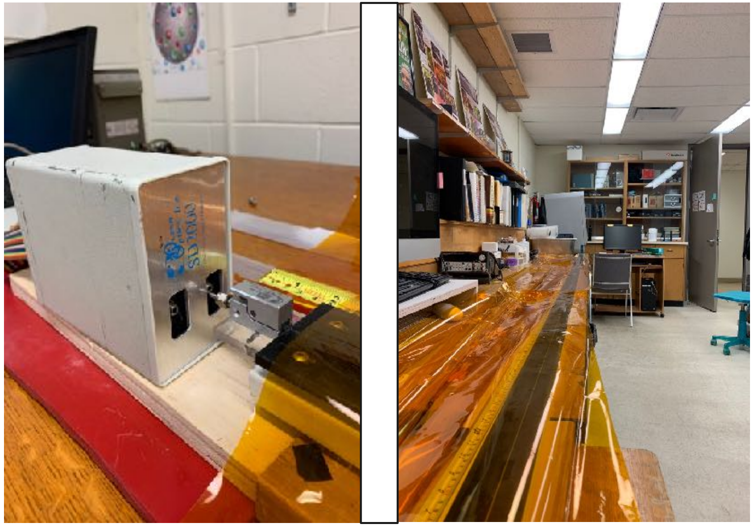
Spectrophotometer Set-up

- Single fiber laid in groove of polyethene tray
- Fed into channel 0 of Ocean Optics SD2000[1] spectrophotometer
- SD2000 connected to ADC (Ocean Optics ADC1000-USB Serial[1]), then connected to DAQ laptop via USB plug in
- Measurements predominantly carried out in darkness, otherwise double layer of same UV-absorbing film covered fibers was placed over fibers on the tray



Spectrophotometer with fiber inserted (left); view down the tray holding the fibers (right)

[1]Ocean Insights, Orlando, FL, USA (www.oceaninsight.com)

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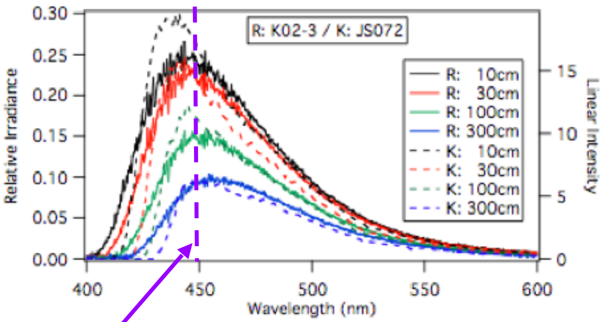
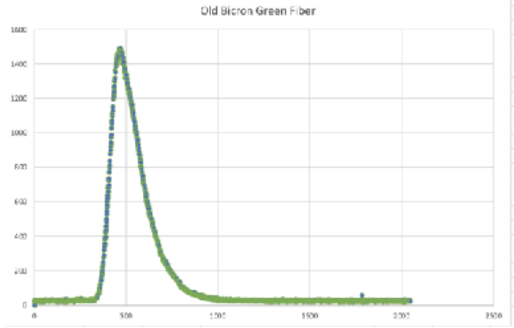
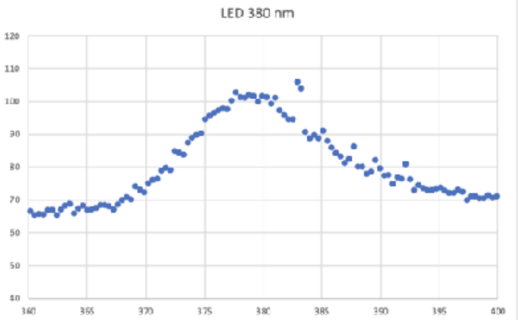
GlueX BCAL Fiber Spectra (ca 2009)

- Kuraray (GlueX):
  - Peak near 450 nm
  - Evolves to 460 nm
  - Single “hump”
- Kuraray (EIC)
  - Peak near 490 nm
  - Double hump
- Bicron Green remeasured
  - Looks right
- LED 380 nm in right spot
- Needs to be resolved

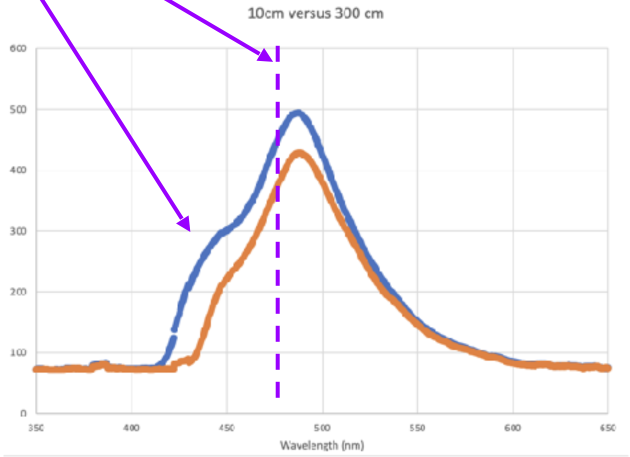
Spectrophotometer calibration: summer 2024







huh?



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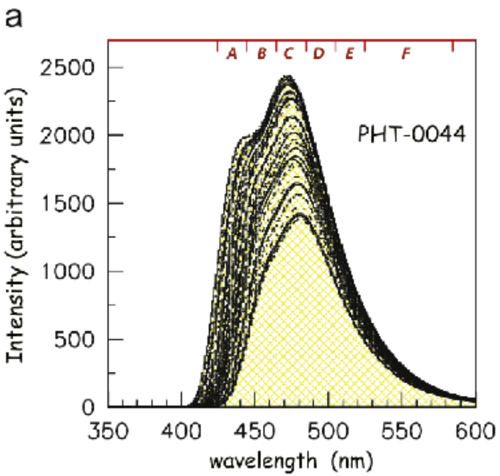
Procedure to Extract Attenuation Length

Once measurements are taken:

1. Fit each spectra with double Moyal function
2. Use fit to extract integral over accepted wavelengths
3. Plot LN scale of integrals as a function of wavelength
4. Fit linear equation, attenuation length is inverse of slope

Attempt similar analysis: summer 2024

$$f(\lambda, a_1, \mu_1, \sigma_1, a_2, \mu_2, \sigma_2, b) = a_1 \cdot \exp\left(-\frac{1}{2}\left(\frac{(\lambda-\mu_1)}{\sigma_1}\right) + e^{-(\lambda-\mu_1)/\sigma_1}\right) + a_2 \cdot \exp\left(-\frac{1}{2}\left(\frac{(\lambda-\mu_2)}{\sigma_2}\right) + e^{-(\lambda-\mu_2)/\sigma_2}\right) + b$$



λ - wavelength
a_1, a_2 - scaling terms
μ_1, μ_2 - characteristic wavelength terms
σ_1,σ_1 - width terms
b - background term

Examples of double Moyal functions - Z. Papandreou, B.D. Leverington, G.J. Lolos, Nuclear Instruments and Methods in Physics Research A 596 (2008) 338–346.

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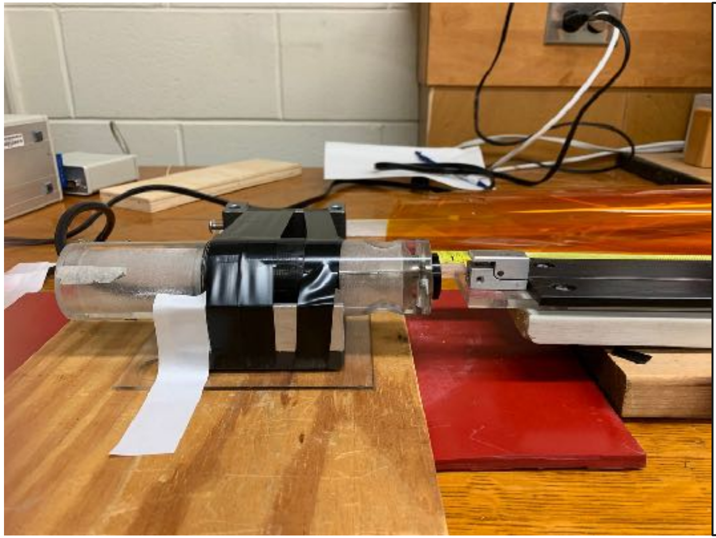
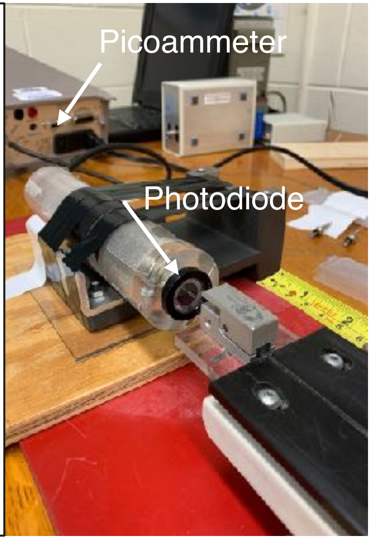
Photodiode Set-up for Attenuation Length Extraction

- New set-up for attenuation length extraction
- Fiber still in groove of tray, but now placed against Hamamtsu S2281 photodiode[1] connected to Keithley 6485 picoammeter[2]

[1]Hamamatsu Photonics, Shizuoka, Japan (www.hamamatsu.com/jp/en.html)
[2]Keithley Instruments, Cleveland, OH, USA (www.tek.com/en/products/keithley)





Repeat and new measurements: summer 2024

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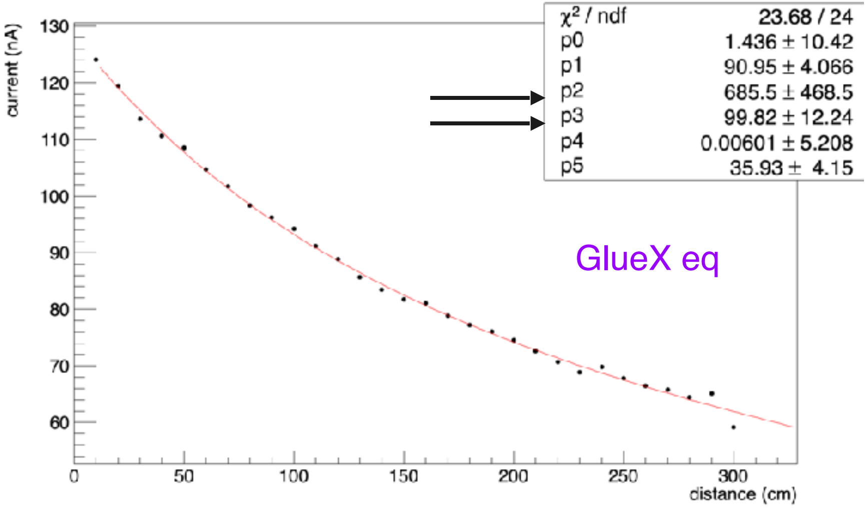
Re-analysis: summer 2024

GlueX

Photodiode Station: two-exp fit function

Table 1
Short and long attenuation length components for the PHT-0044 and BCF-20 fibers, as extracted from a double-exponential fit

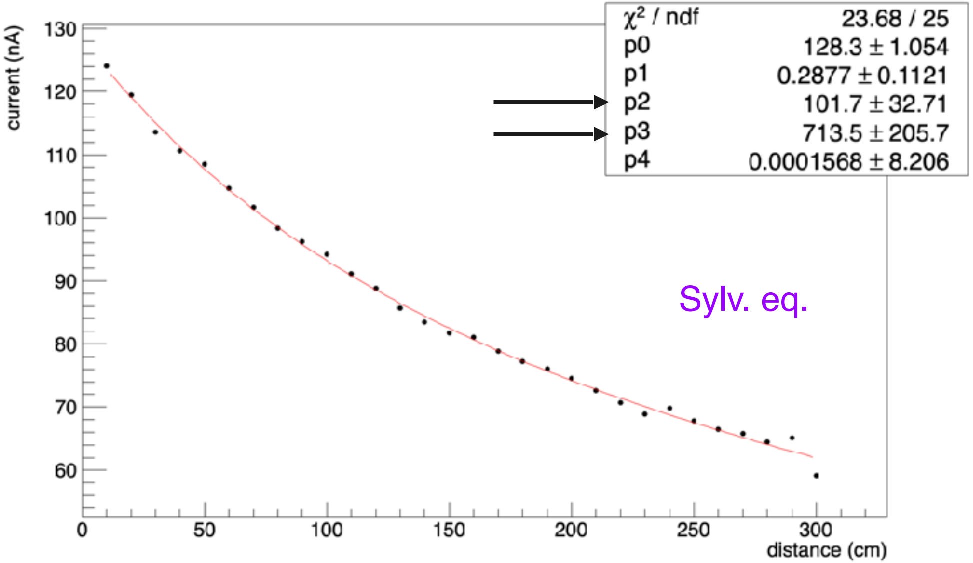
	Without photosensor		With photosensor	
Component	PHT-0044	BCF-20	PHT-0044	BCF-20
Short (cm)	50 ± 14	48 ± 8	43 ± 8	50 ± 9
Long (cm)	478 ± 21	481 ± 21	414 ± 14	491 ± 21
Weighted (cm)	428 ± 23	400 ± 23	353 ± 18	408 ± 25



GlueX eq

$$I(d) = I_0 + \alpha_1 \cdot e^{-(d-d_0)/\lambda_1} + \alpha_2 \cdot e^{-(d-d_0)/\lambda_2}$$

Double Exponential Fit for Photodiode Attenuation Measurement (NKD4G_towa)



Sylv. eq.

$$I(\Delta) = I_0(\alpha e^{\Delta/\lambda_1} + (1-\alpha)e^{\Delta/\lambda_2})$$

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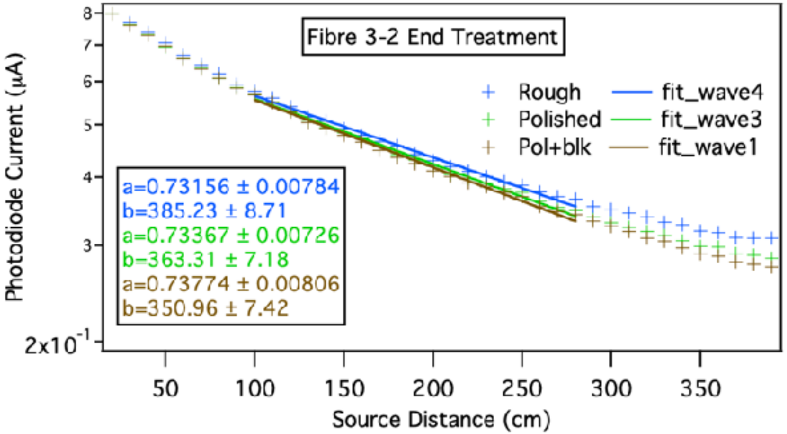
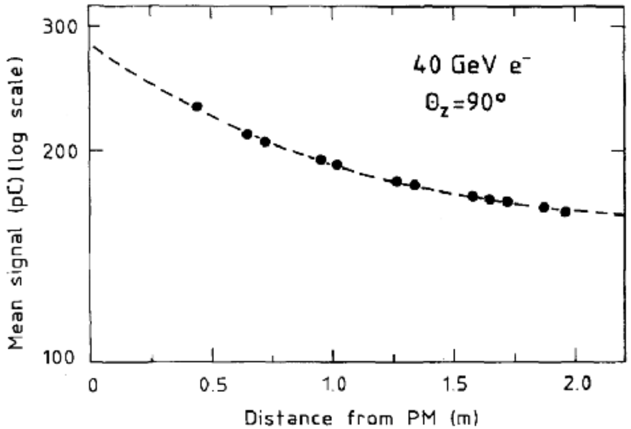
Fiber End Treatment

GlueX BCAL



SPACAL Calorimeter



$$I(z)\,[\mathrm{pC}] = 102\,[e^{-z/11.0} + 0.85\,e^{(z-4.4)/11.0}] + 124\,e^{-z/0.77}$$

long reflection short

New analysis: summer 2024

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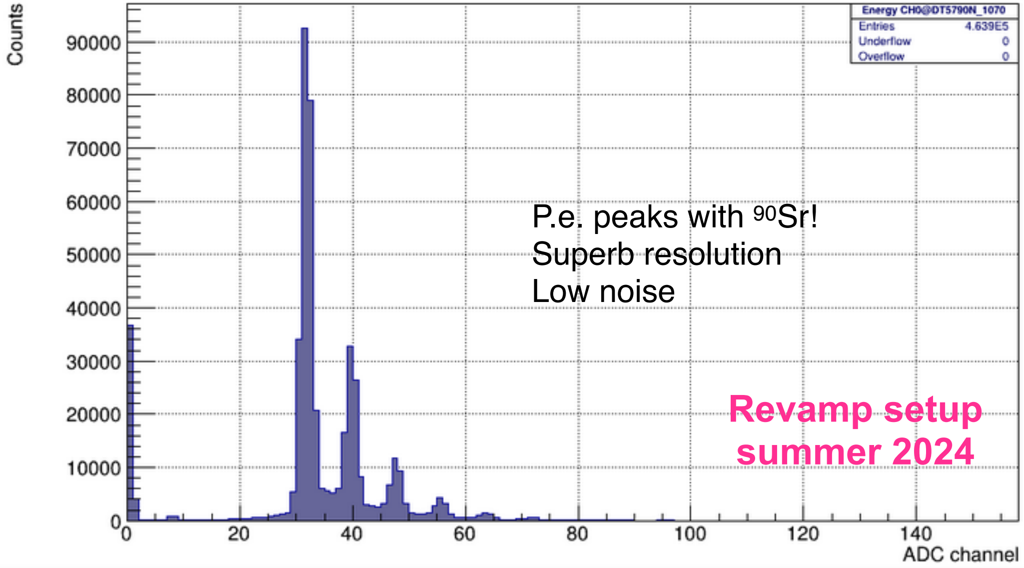
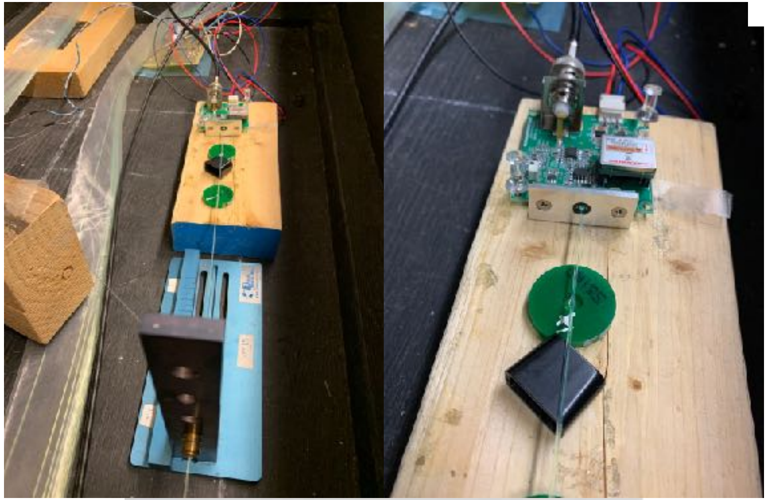
[1]Hamamatsu Photonics, Shizuoka, Japan
(www.hamamatsu.com/jp/en.html)

Hamamatsu Module

- MPPC: S12571-050C/Module: C11205[1]

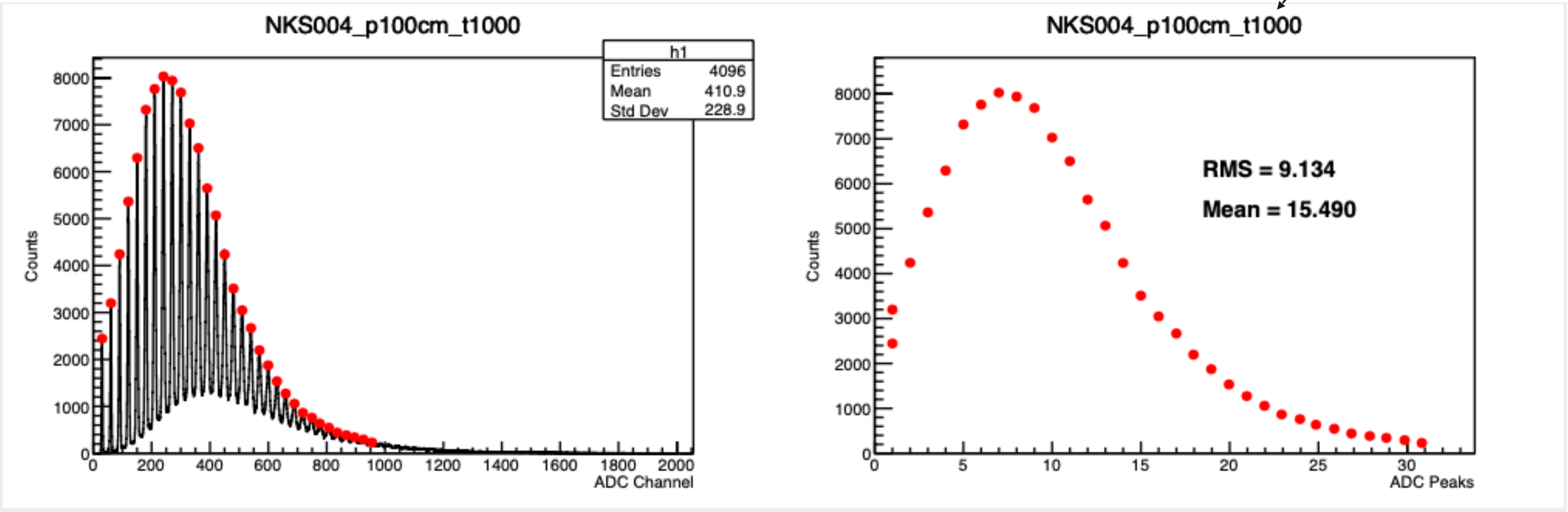




Improve analysis summer 2024

Npe - Peak finding & calibration

10 min running



ADC units → p.e. units

Shipment to ANL and Manitoba
BARREL IMAGING CALORIMETER

Shipment very soon: waiting for BNL Broker

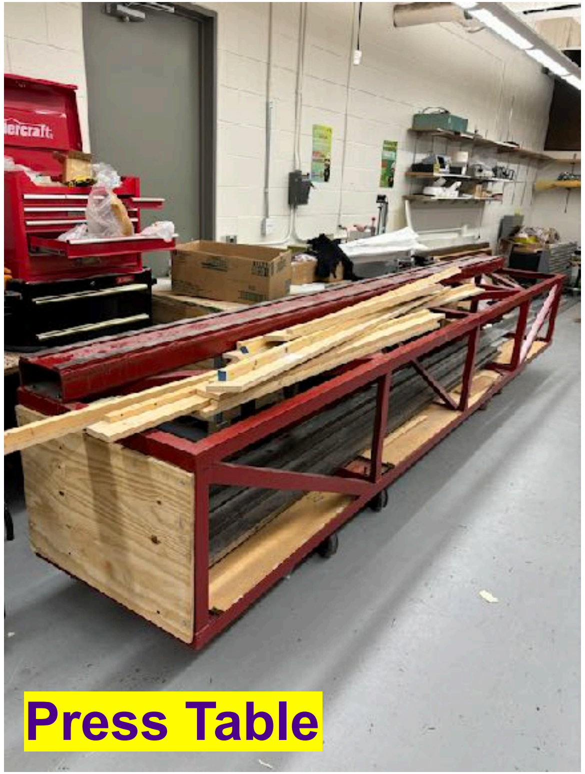
ANL:

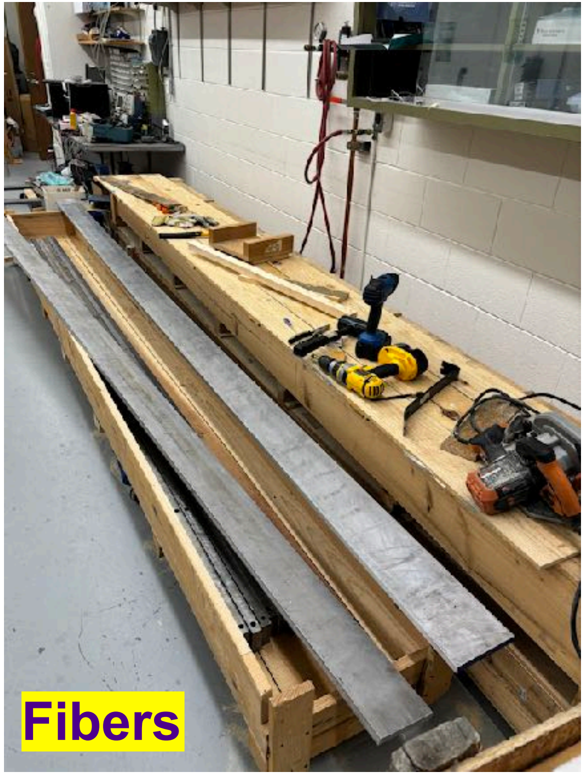
- ✓ Fibers: ~30,000 Kuraray SCSF78-MJ (double-clad) 410-cm-long
- ✓ Lead: 24 405-cm-long 13-cm-wide coils
- ✓ Press Table: 450-cm-long
- ✓ Press Controls: Electropneumatic manifold controls and parts
- ✓ Swager: 1-mm-pitch rollers
- ✓ SiPM Boards for SFILs

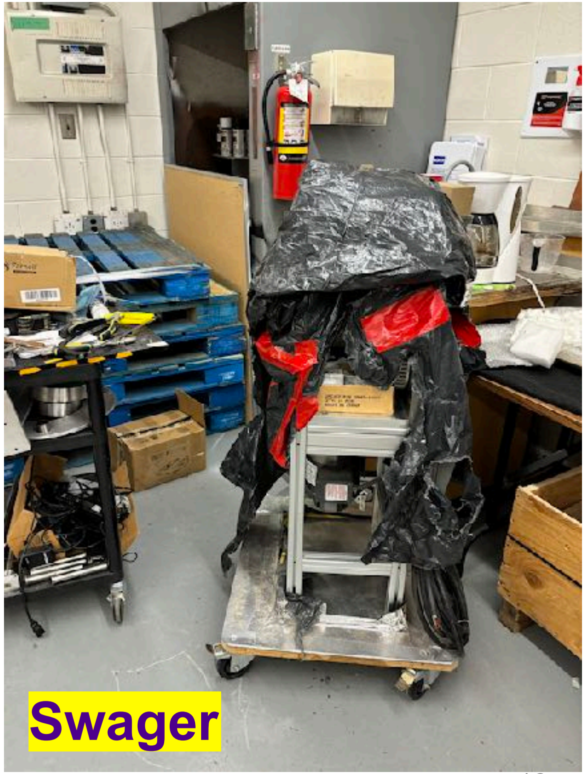
Manitoba:

- ✓ Fibers: a few hundred Kuraray SCSF78-MJ (double-clad); length not decided yet
- ✓ Lead: none
- ✓ SiPM Boards for SFILs
- ✓ Mechanical support at Manitoba for ESB construction

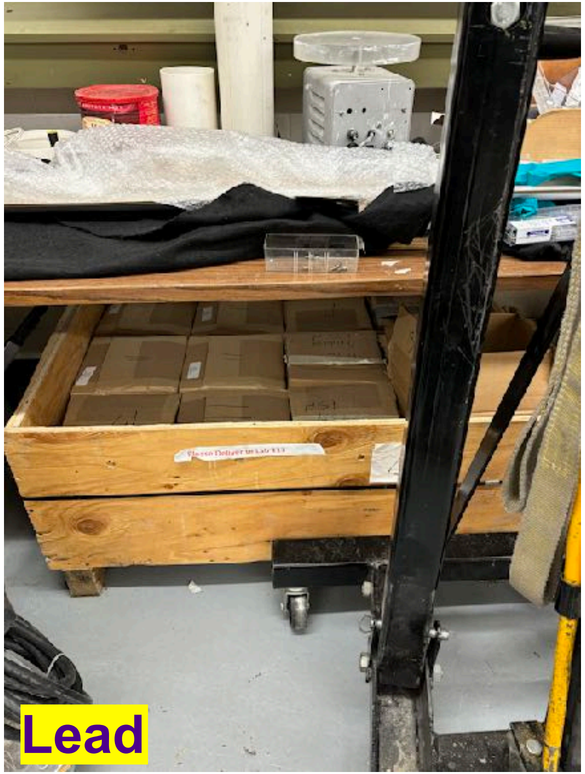
Lead-Sci-Fi Construction: Tooling shipment to ANL
BARREL IMAGING CALORIMETER

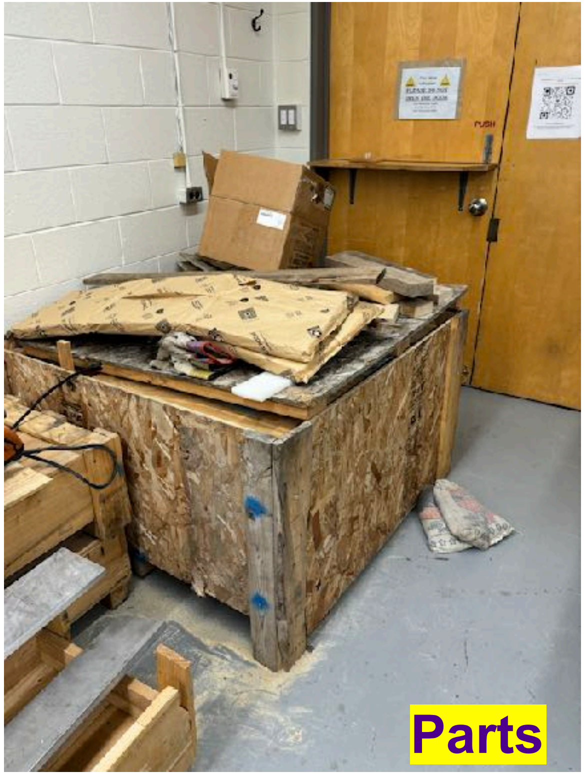






Lead-Sci-Fi Construction: Tooling shipment to ANL
BARREL IMAGING CALORIMETER



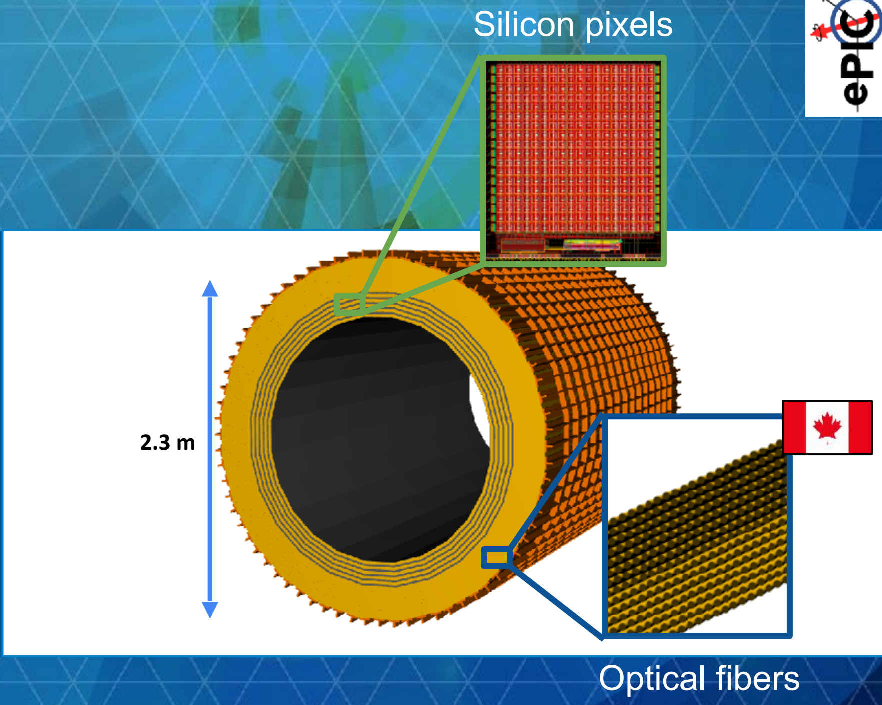


Barrel Imaging Calorimeter (BIC) for the Electron-Ion Collider (EIC)

CFI IF: Production and installation of lead/ fiber & end-of-sector boxes

CFI IF: TPC ~C$3.5M ($700k each from **Manitoba**, **Regina** envelopes)

Visibility of key contribution to large international collaboration



Wouter Deconinck & Zisis Papandreou & Team
U. Manitoba, U. Regina, Mt. Allison U.
with Argonne National Lab, et al.

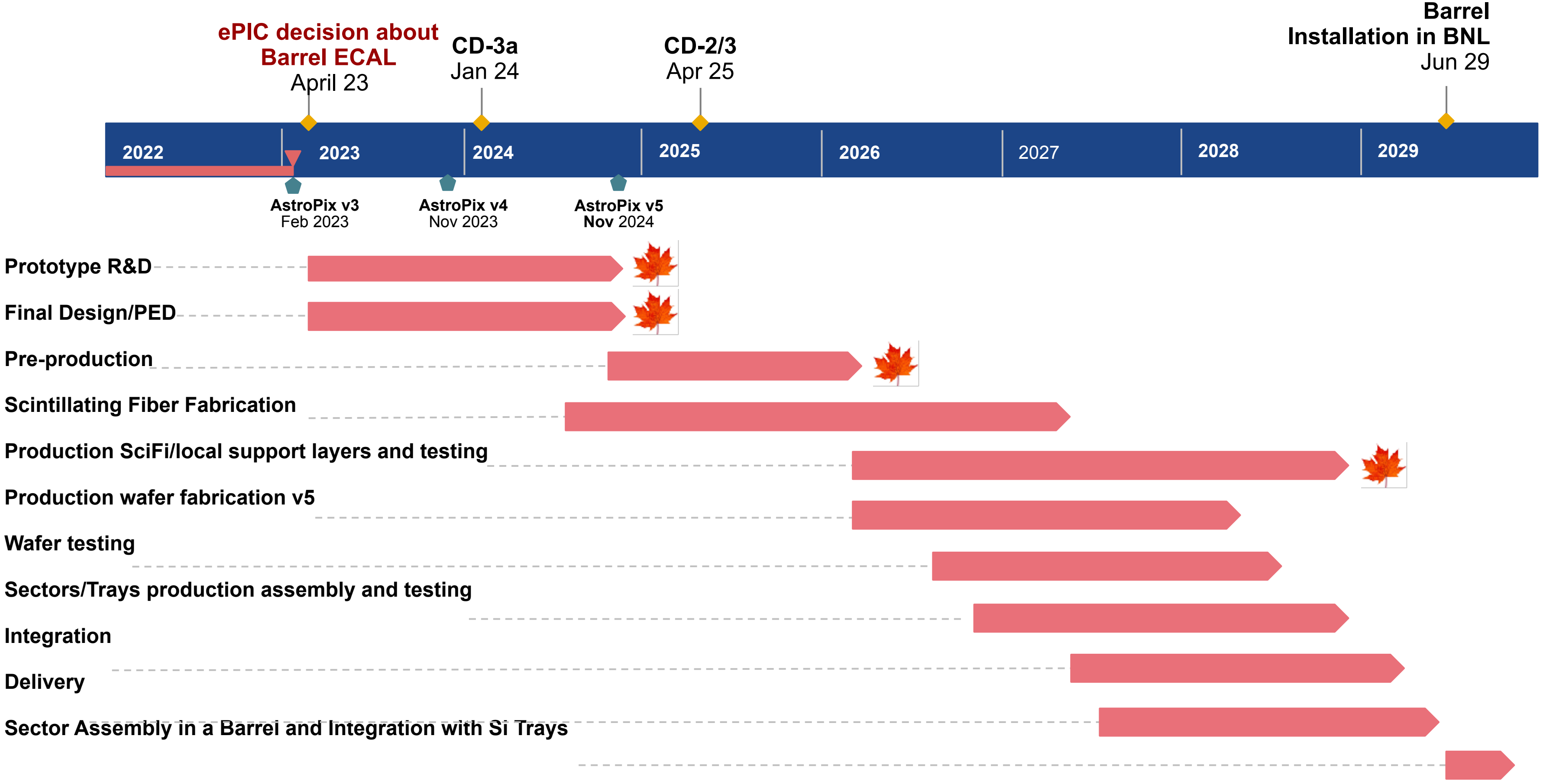
Benefits to Canada

A Canadian flag on the flagship EIC detector for the next decades

- Canadian **international scientific competitiveness** depends on significant and visible participation in international collaborative science efforts.
  - **CFI** has already been delegating Mark Lagacé, Directory of Programs, to the twice-yearly EIC Resource Review Board meetings
- Silicon photo-multiplier sensors (**SiPMs**) and silicon pixel detectors are **key nuclear imaging methodologies**, with medical and industrial applications.
  - E.g. Dr. Teymurazyan’s work using **nuclear imaging** to study nutrient uptake and water use of commercial crops in the Canadian Prairies.
- Participation in data-rich high-granularity detectors gives Canadian researchers opportunities to develop **novel data science techniques**.
  - The EIC is the first particle collider co-designed with artificial intelligence/**machine learning**: detector placements and parameters to optimize physics objectives

Backup slides

BIC HIGH-LEVEL SCHEDULE



Physical Construction at U. Manitoba

Renovations of 218/218B Allen to accommodate lead/fiber presses

Class D estimate in preparation:

- door 218/218B
- renovation 218

Major equipment to accommodate:

- pneumatic press
- cutting table
- swager with table feed-in/out

Budgeting

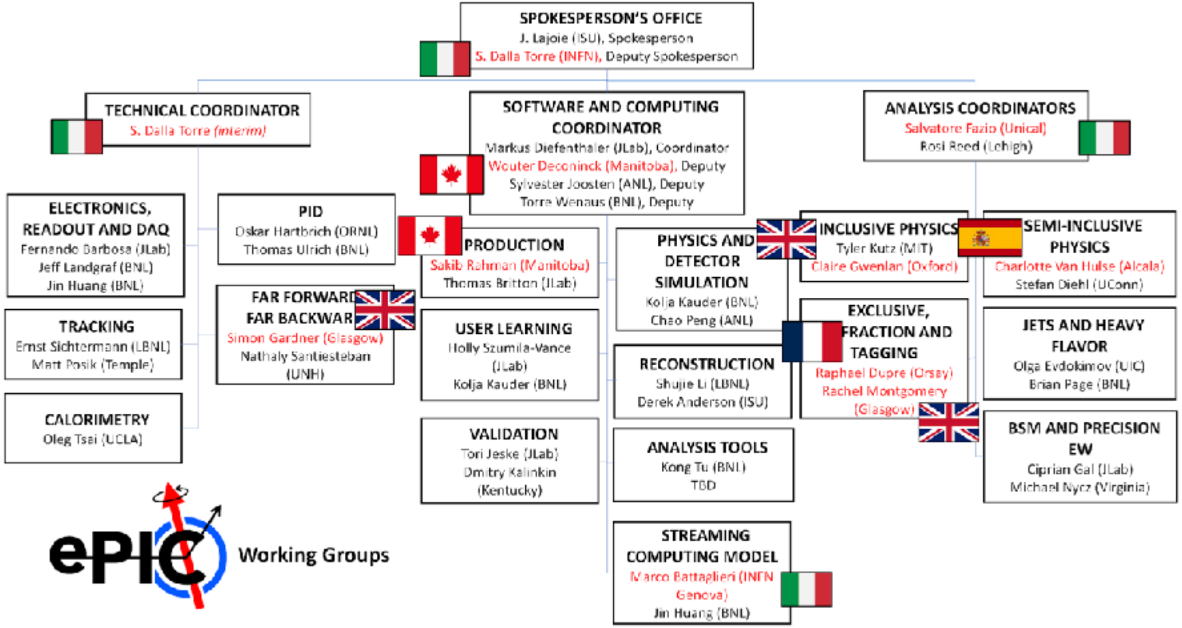
Total project cost (US$) per US DOE EIC Project with CFI IF treated as in-kind contribution

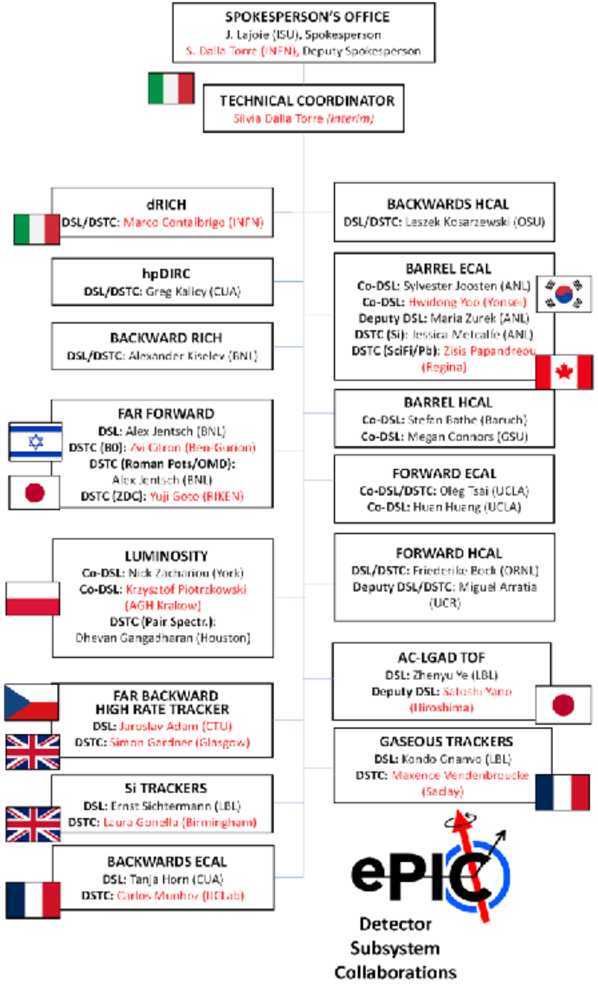
Barrel EMCal Summary					
Phase	**Subdetector**	**Scope**	**Labor**	**M&S**	**TOTAL**
Project Engineering & Design (PED)	Pb/ScFi		$793,240.86	$100,000.00	
	Imaging		$1,410,411.34	$100,000.00	
Pre-production	Pb/ScFi		$324,910.97	$261,376.97	
	Imaging		$581,035.41	$1,623,260.17	
Production	Pb/ScFi	Sectors	$1,204,461.97	$6,363,616.26	
		EOS Boxes	$300,945.10	$199,190.00	
		TOTAL	**$1,505,407.06**	**$6,562,806.26**	
	Imaging		$1,162,070.83	$6,954,278.00	
Installation	Pb/ScFi		$405,150.13		
	Imaging		$183,157.16		
TOTAL	Pb/ScFi		$3,028,709.02	$6,924,183.23	$9,952,892.25
	Imaging		$3,336,674.73	$8,677,538.17	$12,014,212.90
	TOTAL		**$6,365,383.76**	**$15,601,721.40**	**$21,967,105.16**

CFI IF phase

CFI IF + IOF + NSERC SAP ≈ 50% or CA$350k

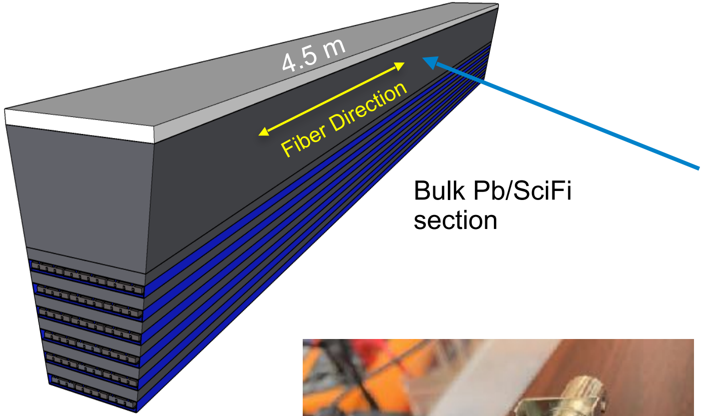
ePIC Collaboration Structure

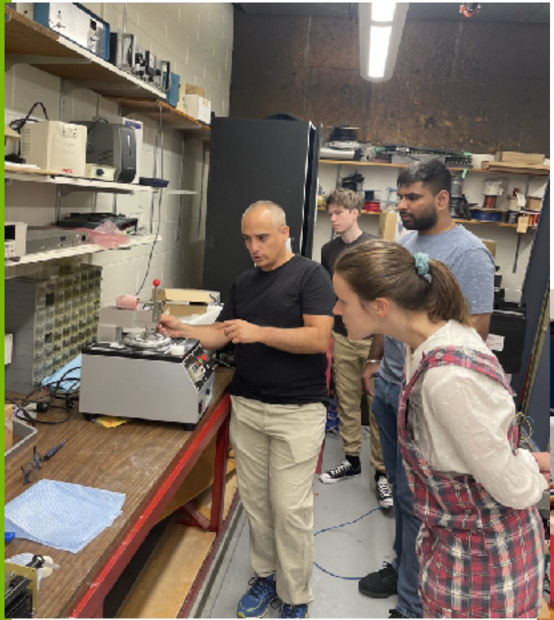


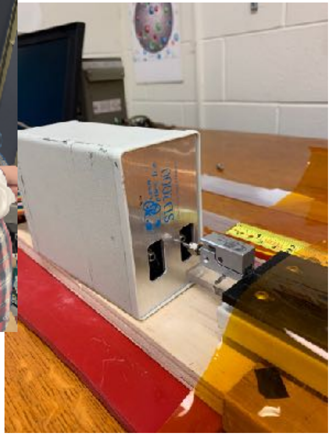


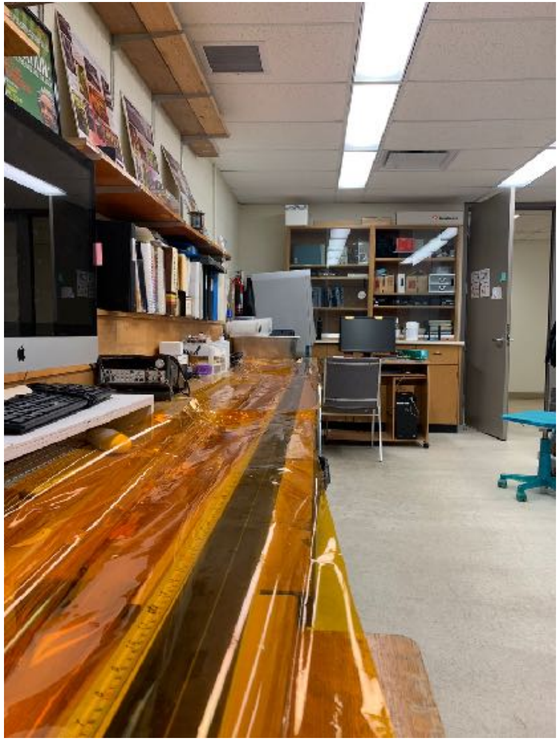
Canadian Impact on Research & Design: 90% Engineering Readiness by January 2025

Quantity of fibers needed makes this a long-lead procurement item; DOE review passed in November 2023





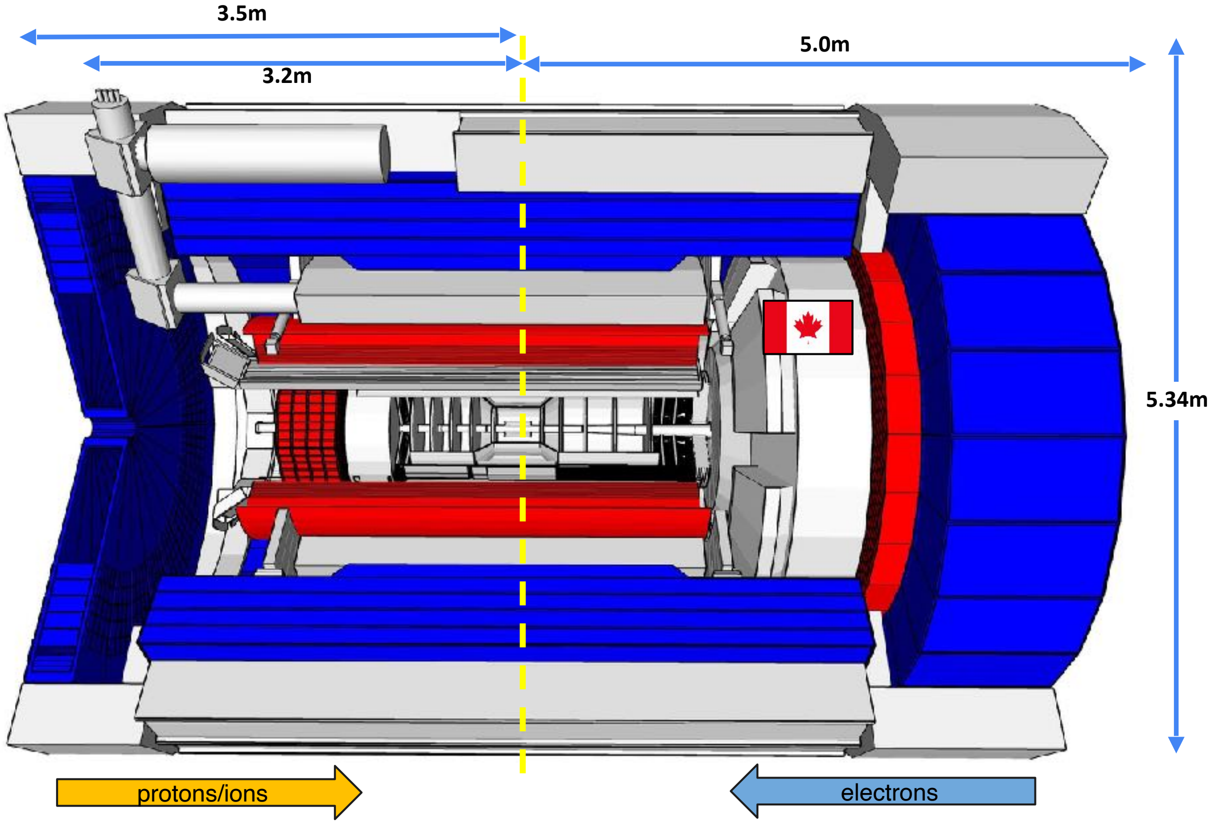




↑ Fiber splicing and polishing
Spectrophotometer →

↑ Fiber attenuation measurements
← SiPM readout of scint. fiber

The electron-Proton/Ion Collider Detector (ePIC)

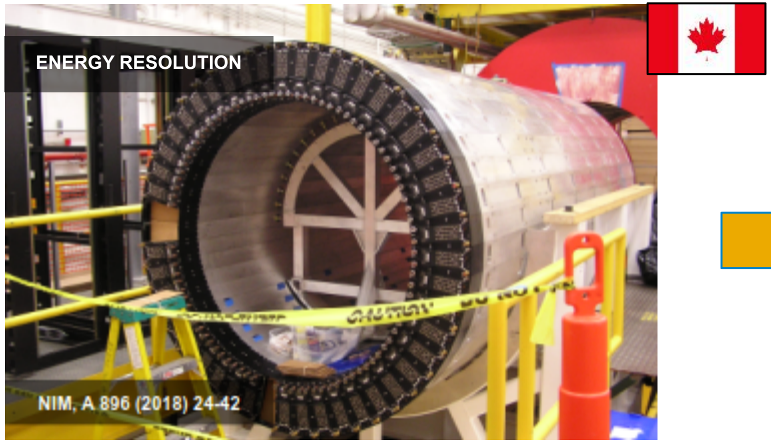


Calorimetry: energy measurements

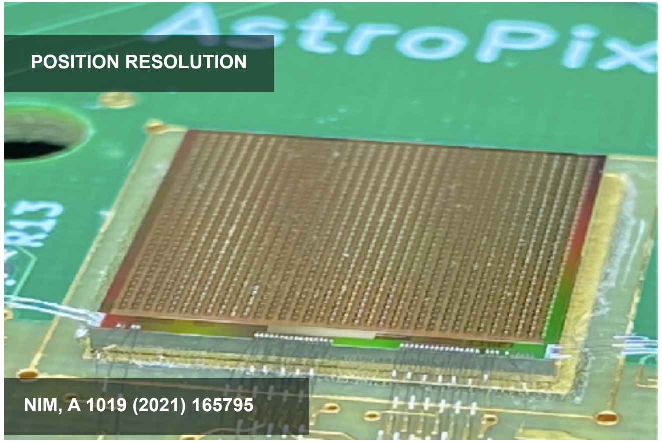
- Imaging Barrel ECal
- $PbWO_4$ ECal in backward direction
- Finely segmented ECal +HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

Innovative Technology:
BARREL IMAGING CALORIMETER

high-performance sampling calorimeter + low-power silicon sensors for shower profiling



Start from **mature layered lead/fiber technology** with **two-sided readout** (like U. Regina's GlueX calorimeter) for state-of-the-art high-resolution sampling calorimeter performance

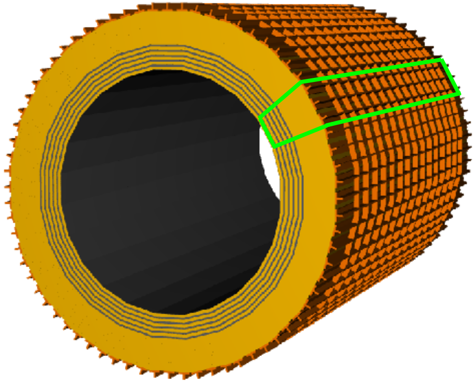


Insert layers of monolithic AstroPix imaging sensors (inexpensive ultra-low-power silicon sensor developed for NASA) in the first half of the calorimeter to capture a 3-D image of the developing particle shower

Energy resolution - Primarily from lead/fiber layers (+ imaging pixels energy information)
Position resolution - Primarily from imaging Layers (+ 2-sided lead/fiber readout)

Canadian CFI IF Scope Components

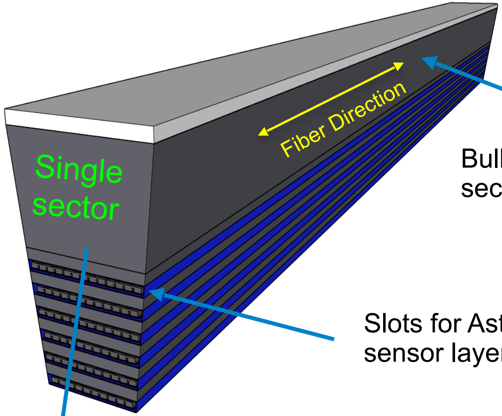
BARREL IMAGING CALORIMETER (BIC)



Length: 432.5 cm

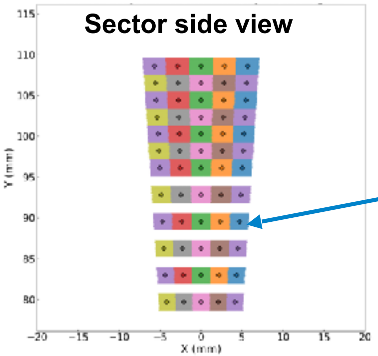
Radius: ~ 80 cm radius,

Structure: 48 sectors



Bulk Pb/SciFi section

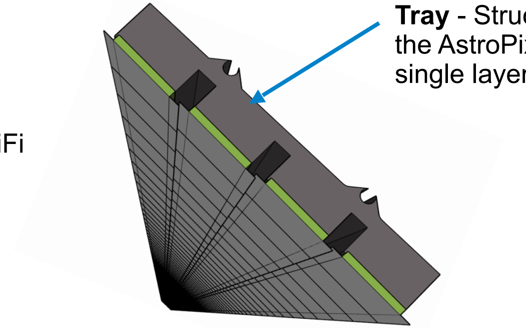
Slots for AstroPix sensor layers



Pb/SciFi **Layer** - 12 layers per sector

Structure: 5 readout cells (one light-guide per readout cell)

Construction: 17 rows of fiber



Tray - Structure holding the AstroPix staves for a single layer

Length: ~ 200 cm (half length)

Structure: 6-7 “turbofanned” staves per tray

Stave Structure: ~ 13 **Modules** per stave

Module - Several AstroPix chips daisy-chained together on Flex PCB

Length: ~ 16 cm

Width: ~ 2 cm

Gaps: < 200 μm

Structure: ~ 8 chips/ module

Why Electromagnetic Calorimetry at EIC is Hard

From the EIC design requirements: stringent barrel ECal requirements

EIC is an **electron scattering** machine and identifying scattered electrons mainly depends on the electromagnetic calorimetry.

The electromagnetic calorimeter is the main detector for **electron-pion separation**. The inclusive physics program requires up to 10^4 pion suppression at low momenta in the barrel.

The exclusive program requires **decent energy resolution** ($< 7\%/\sqrt{E} \oplus$ 1-3%) **for photon energy reconstruction, and also the fine granularity for good** π^0-γ separation up to 10 GeV.

The bECal should be capable of measuring **low energy photons** down to 100 MeV, while having the range to measure energies well above 10 GeV

The system is space-constrained to very **limited space** inside the solenoid.