Scintillator Fiber Trackers for the ZDC and off-momentum detectors

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EIC-Related Generic Detector R&D Proposal Review Meeting

30 October 2023

Reviewer Questions

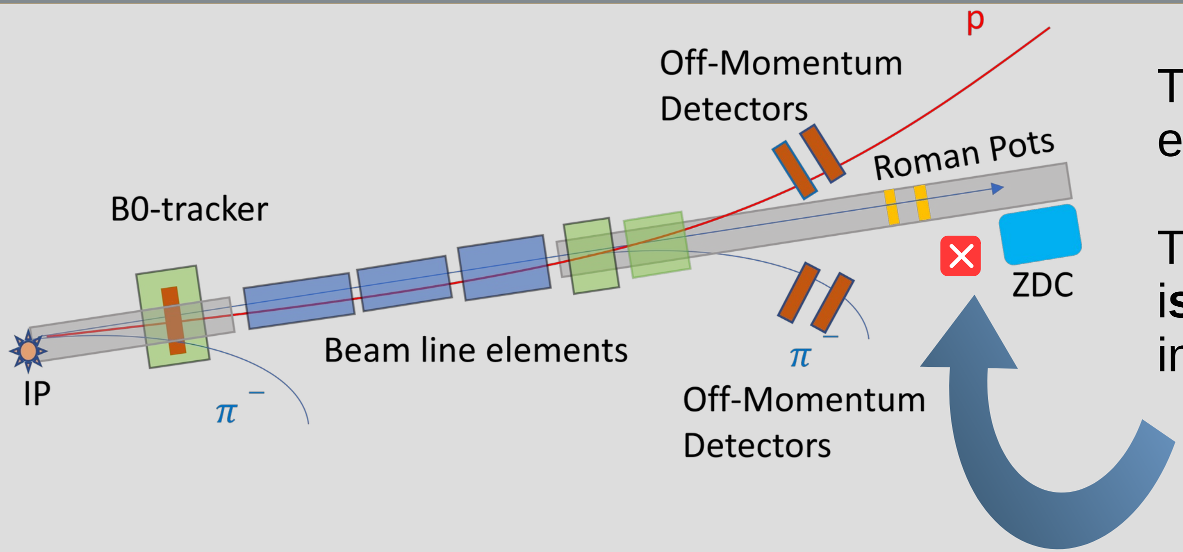
1. **Can you briefly summarize what the ZDC will be used for at the EIC?**
2. **Please comment on the advantages of using scintillator fiber trackers as the ZDC charged particle vetoing device, compared with other technologies.**
3. **Can you explain the aspects of the fibers and their coupling that need to be optimized for the EIC needs? What are the new aspects?**
4. **Please highlight the potential knowledge gained by performing the proposed prototyping work on top of the previously published work on the scintillator fiber detectors.**
5. **Without Geant4 simulation, please use a back-of-envelope calculation to estimate the physics performance of the proposed design: what is the charged particle rejection factor, what is the expected boost in signal/background ratio in the physics observable, such as $\Lambda \rightarrow n \pi^0$**

Question 1

Can you briefly summarize what the ZDC will be used for at the EIC?

The Zero Degree Calorimeter (ZDC) will be critical for a number of important physics topics at EIC. For example: distinguishing between coherent diffractive scattering, in which the nucleus remains intact, deeply virtual meson production of neutral mesons, and incoherent scattering in which the nucleus breaks up; measuring the geometry of e + A collisions, spectator tagging in e + d/^{3}He, asymmetries of leading baryons, and spectroscopy. These physics goals require the ZDC to have high efficiency for neutrons and low-energy photons, excellent energy, p_T and position resolutions, large acceptance and sufficient radiation hardness.

Why this kind of detector?



The Far-forward region is quite established about its instrumentation.

The proposed charged-particle tracker **is NOT part** of the basic instrumentation of the FF region.

Scintillating fiber detector is a **non-expensive** option, with excellent position and timing resolution, for a detector not scheduled in the standard instrumentation. Scintillating fiber+maPMTs is **a robust**, well known, **radiation hard** technology comparable to Silicon detector, GEM technologies, more expensive alternatives.(**REVIEWER QUESTION 2**)

This detector would be a powerful veto for charged particle in neutral channels which rely on the ZDC.

Λ Charged Decay Channel vs Neutral Decay Channel

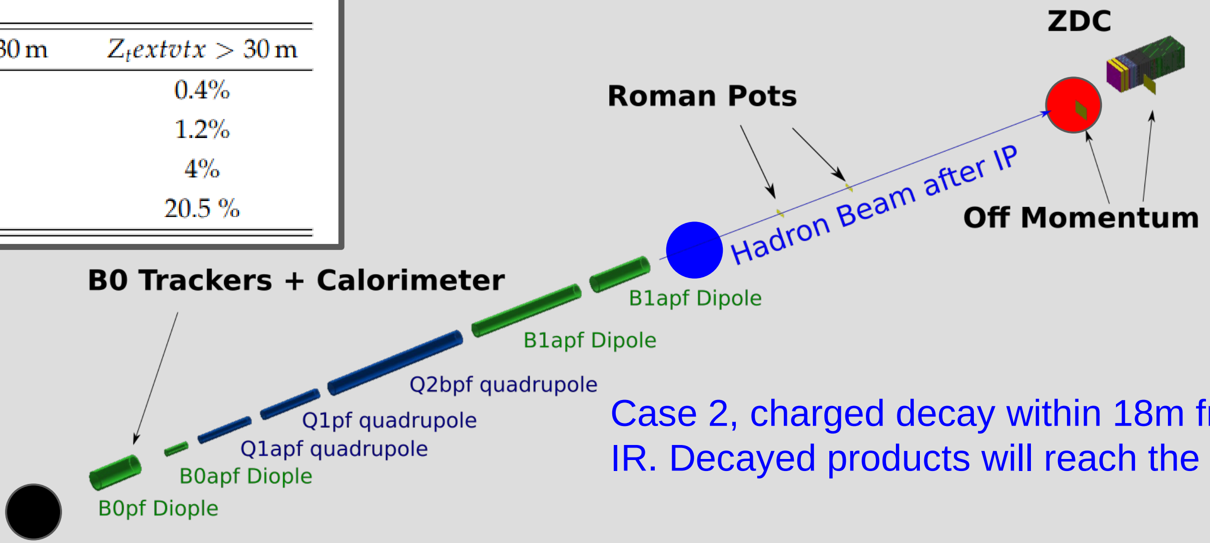
- **Question 5: Without Geant4 simulation, please use a back-of-envelope calculation to estimate the physics performance of the proposed design: what is the charged particle rejection factor, what is the expected boost in signal/background ratio in the physics observable, such as $\Lambda \rightarrow n\,\pi^0$**

Case 3, charged decay within 30m from the IR. Decayed products will reach the ZDC

Table 8.18: $e + p \rightarrow e' + X + \Lambda$: Percentage of decayed Λ's in different detection ranges.

E_{beams}	$Z_{\text{vtx}} < 5\,\text{m}$	$5\,\text{m} < Z_{\text{vtx}} < 30\,\text{m}$	$Z_{t}extvtx > 30\,\text{m}$
5 GeV on 41 GeV	83.0%	16.6%	0.4%
10 GeV on 100 GeV	52.1%	46.7%	1.2%
10 GeV on 130 GeV	41.8%	54.2%	4%
18 GeV on 275 GeV	23.3%	56.2%	20.5 %

Assuming SIDIS Λ production decay vertex distribution (Yellow report)



Case 2, charged decay within 18m from the IR. Decayed products will reach the ZDC

Case 1, charged decay within 5m from the IR. Decayed products will not reach the ZDC

IP6 beamline

Λ Charged Decay Channel vs Neutral Decay Channel

Branching Ratio:

- Charged decay: $\Lambda \rightarrow p\pi^-$, BR= 64.1%
- Neutral decay: $\Lambda \rightarrow n\pi^0$, BR= 35.9%

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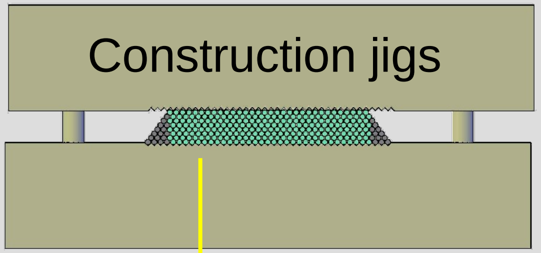
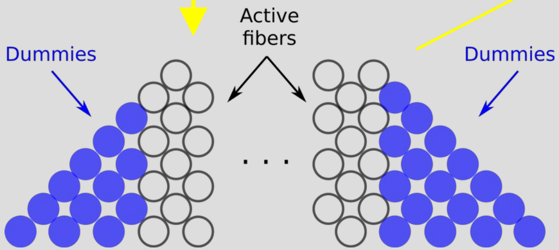
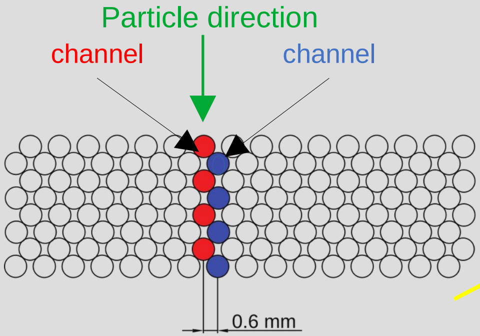
Setting	Charged decay / Neutral decay at ZDC	Charged decay contamination without proposed tracker	Charged decay contamination with proposed tracker
5x41	0.13	15.50%	<1%
10x100	0.35	26.20%	<1%
18x275	0.77	44.30%	<1%

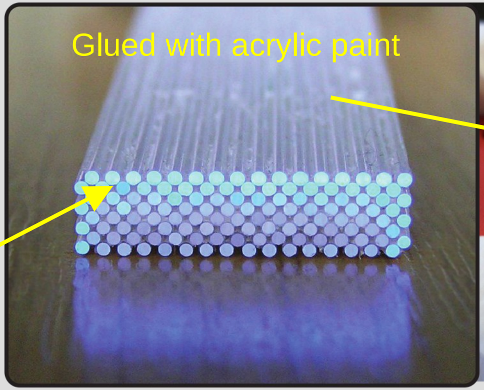
SciFi tracker detector concept (Mainz)

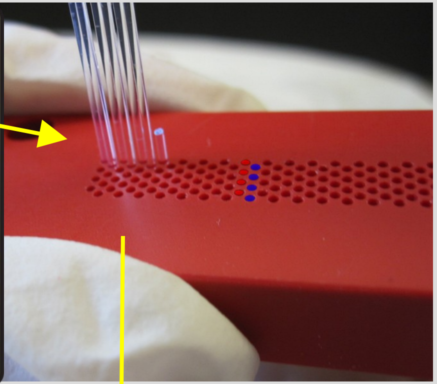


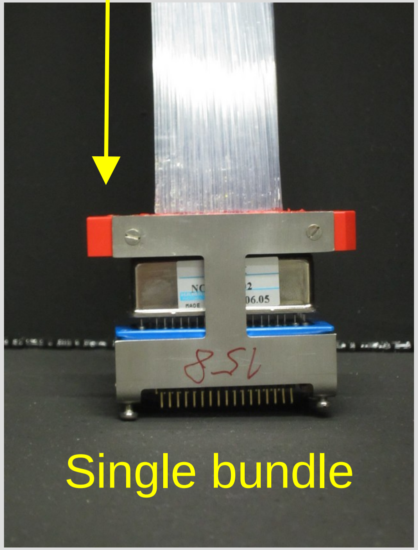


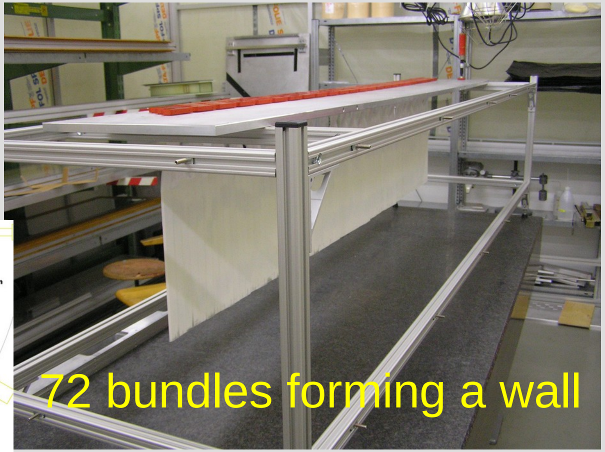


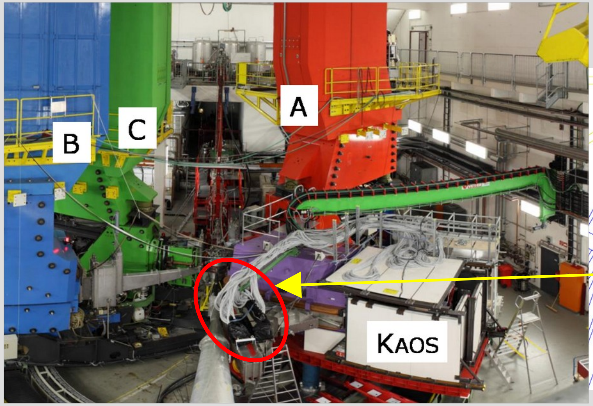
32 channels (4 fibers/channel)

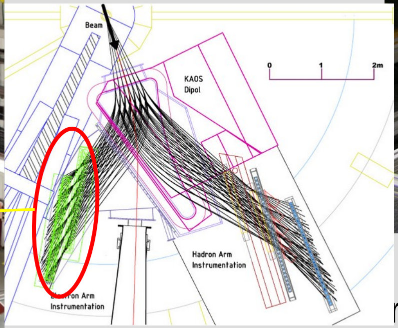




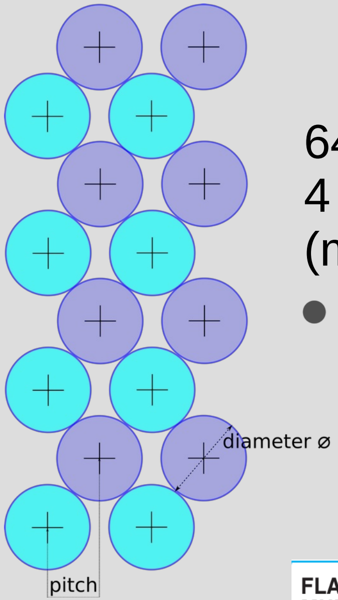








Layout of a plane



Kuraray SCSF78M ∅ = 1mm

64 channels.
4 fibers per channel
(maybe 3?)

● ● ●

Pitch (p) = 0.6 mm

Theoretical spatial resolution (binary distribution)

σ ≈ 100 μm

Width of the bundle

$$L = \varnothing + p \times (ch - 1)$$

→ L = 38.8 mm

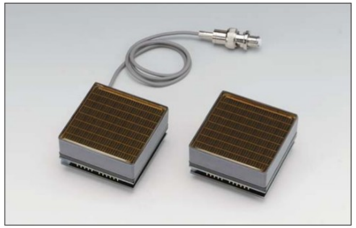
Erratum in the proposal, pag 6

To overlap the SciFi acceptance with that of the ZDC, the ZDC has a cross section area of 60x60 cm^2 → 999.33 channels /64 ch → 15.64 modules => (round up) **16 modules** → **1024 channels** → 614.8 mm

Minimum 2 planes → 2048 ch

FLAT PANEL TYPE
MULTIANODE PMT ASSEMBLY
H12700 SERIES / H14220 SERIES

FEATURES
- Large effective area: 48.5 mm × 48.5 mm
- Packing density: 87 %
- 8 × 8 multianode, Pixel size: 6 mm × 6 mm / anode
- High quantum efficiency: 33 % Typ.
- Small dead space
- Fast time response
- Two types for HV input
  H12700A series / H14220A: Cable input type
  H12700B series / H14220B: Connector input type
- With tapered divider (-10 type)
- High sensitivity in green region: H14220 series



Left: HV cable input type, Right: HV connector input type

Prototype proposed

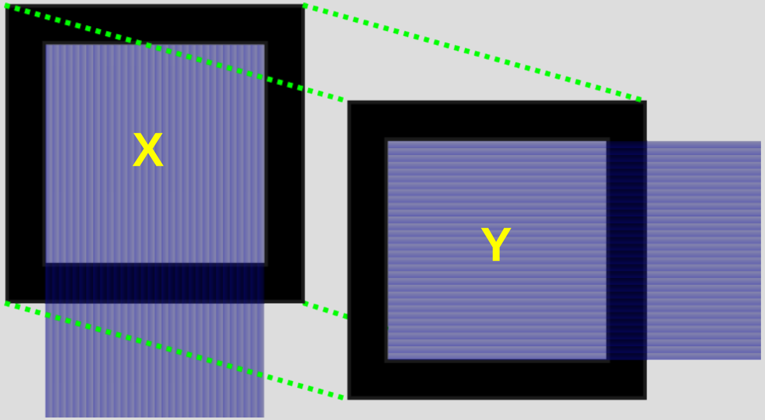
Two planes of 64 channels each → 38,8 mm width (1/16 of final size).

Length is variable up to the maPMT/extension fibers, but ‘active’ length will be similar to the width.

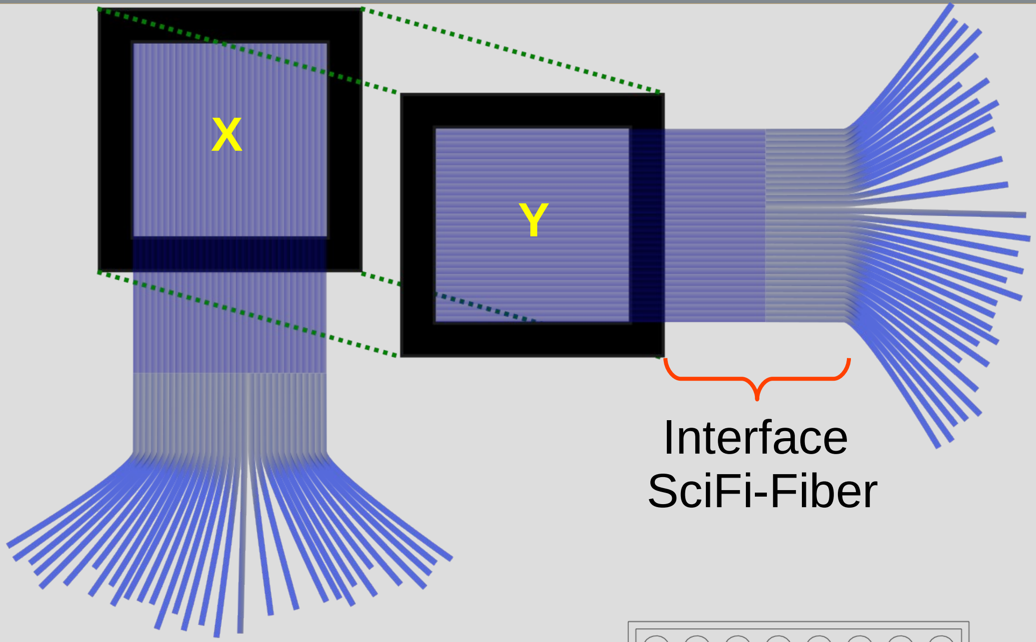
Each plane will be 90deg rotated to each other for a X-Y configuration.

Each plane connected to a **Hamamatsu H14220B**.

Power and **Read out loaned** by JLab GlueX DIRC



Veto charged particle tracker concept

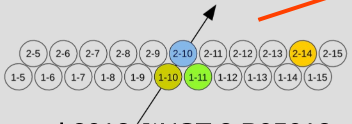


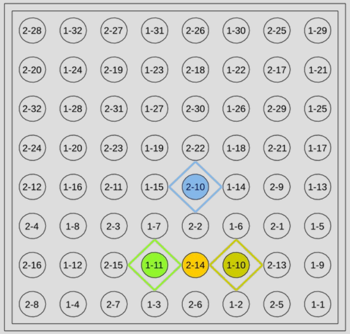
SciFi are generally connected directly to the readout device.

We would like to disentangle the SciFi area (‘active’) to the readout boards, through the use of WLS or optic fibers, which need to be determined and studied.
(**REVIEWER QUESTION 3**)

This will allow for better upkeep of the detector, since the fiber could be easily replaced and the readout device is kept out of radiation damage.
(**REVIEWER QUESTION 4**)

Disentangling it will also, easily, allow an arrangement HERMES-style of the channels to reduce cross-talk





A Airapetian et al 2013 JINST 8 P05012

Deliverables FY2024

	Production of assembly jig
	Development of fiber assembly and maPMT interface
Q1	Acquisition of fiber and support material
	Purchase of H12700B
	Development of Geant4 simulation
	Fiber bundle assembly. Glueing and polishing.
	Aluminization of fiber far end (opposite side to the maPMT)
Q2	Assembly of detector
	Transportation to JLab
	Completion of Simulation
	Cosmic test in dark box
Q3	Assembly on Hall D stand
	Test beam with beam (if possible)
	Test beam (continuation)
Q4	Data analysis
	Validation of the simulation

Prototype Budget

	Quantity	Cost/unit [$]	Total [$]
Hamamatsu mPMT H14220B	3	5000	15,000
Scintillating Fibers Kuraray SCSF78M	1x300	NA	2,000
Read-out/power board	2	-	LOAN
Optic fiber/WLS	2	NA	500
Frame support material (3D printing and Metal)	NA	NA	4,000
SBU Machineshop Cost	60 hours	50$/hour	3,000
Expendables (epoxy and coating paint)	NA	NA	1,000
Aluminum Evaporation	NA	NA	NA
Pulsed LED System	1	3,000	3,000
Transportation costs of detector	NA	NA	1,000
Travel budget	NA	NA	10,000
Total budget			39,500

Prototype Budget and Reduced Funding Scenarios

- Budget doesn’t include HV and DAQ
  - Those components will be loaned from the laboratories where the prototype will be tested.

- A reduction of 20%:
  - Reduction of personal during the test beam, causing delay in the installation.
- A reduction of 40%
  - The prototype will be reduced to a single plane (one dimension)

FULL ANSWER TO THE REVIEWER QUESTIONS

Question 1

Can you briefly summarize what the ZDC will be used for at the EIC?

The Zero Degree Calorimeter (ZDC) will be critical for a number of important physics topics at EIC. For example: distinguishing between coherent diffractive scattering, in which the nucleus remains intact, deeply virtual meson production of neutral mesons, and incoherent scattering in which the nucleus breaks up; measuring the geometry of e + A collisions, spectator tagging in e + d/^{3}He, asymmetries of leading baryons, and spectroscopy. These physics goals require the ZDC to have high efficiency for neutrons and low-energy photons, excellent energy, p_T and position resolutions, large acceptance and sufficient radiation hardness.

Question 2

Please comment on the advantages of using scintillator fiber trackers as the ZDC charged particle vetoing device, compared with other technologies.

The SciFi detector is not part of the of the standard package for the EIC Far Forward region, making it a supplemental detector system compared to the current proposed design of the EIC. The SciFi detector would help charged particle vetoing for any measurement at the EIC which requires the detection of neutral particles in the ZDC. One example of a specific channel where it would have a particularly large impact is lambda detection in the far forward region. Alternative options to a SciFi detector include drift chambers, GEM technologies, silicon trackers, among many others. All of those technologies, would demand a large investment in development, more services – as gas flow, and more sensitive to environment fluctuations, for a detector which is not included in the existing EIC proposal. SciFi technologies, however, are very affordable and have outstanding performance in position and timing resolution, comparable with the aforementioned alternative technologies, with the performances lying within the requirements of the physics involved.

Question 3

Can you explain the aspects of the fibers and their coupling that need to be optimized for the EIC needs? What are the new aspects?

The planned SciFi detector will have a large number of channels (>4000). Therefore, it requires the use of dense readout devices (e.g. multianode photomultipliers, maPMTs) in order to keep the costs low. The scintillating fiber array is designed such that 3 or 4 of the 1mm wide fibers will be connected to one read out channel.

However, it is challenging to combine the fibers together to a single readout pixel of a maPMT and depending of the location/distance of the maPMT to the fiber, the direct coupling of the fibers to the maPMT could be impracticable. The position of the maPMTs depend on the conditions of the far-forward region of the EIC and need to be optimized.

An alternative approach to couple the scintillating fibers to the maPMTs is the use of simple optic or wave-length shifting (WLS) fibers as an intermediary which also combines multiple SciFi to one fiber. This is a new aspect of fiber coupling which was not well studied in the past. We plan to use that method for the planes which will be build as part of the proposal.

Question 4

Please highlight the potential knowledge gained by performing the proposed prototyping work on top of the previously published work on the scintillator fiber detectors.

Scintillation detectors (scintillator plus photon sensor) are one of the most well known and established detection technologies, however there are several aspects still to be understood in the use of scintillating fibres and in their application to different bespoke situations/experiments. One aspect, for example, is how radiation damage affects their resolution or even their physical structure. Tests of the prototype under extreme beam conditions are planned, but only after a full understanding/analysis of the prototype after its original construction and testing. We are interested to disentangle the detector in two, the SciFi, active area, and the read out elements, far from the active area, connected by WLS or clear fibers.

Question 5

LONG ANSWER IN SLIDES 5 AND 6

Time line Motivation

- EIC Meson WG Yellow Report:
  - Λ tagging, in particular $\Lambda \rightarrow p + \pi^-$
    - Charged-particle tracker on the path of the ZDC (to veto all charged particles from p or A breakup)

      J. Arrington *et al* 2021 *J. Phys. G: Nucl. Part. Phys.* **48** 075106

- 2021 EIC UG Meeting Early Career Workshop:
  - Presentation of Scintillating Fiber detector for the EIC. Question: Can be used for the off-momentum detectors?
    - The answer is YES, it is possible (not discussed here).

- **REVIEWER QUESTION 5 (NEXT)**