The Scintillating Fiber Tracking Detector, a qualitative approach

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Mississippi State University

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Motivation

- In the YR meson WG, a particular channel was discussed:

For $\Lambda \to p + \pi^-$ protons could be detected efficiently, but we need trackers in opposite direction (charge) => on the path to ZDC

Yulia Furletova, May 11th 2020

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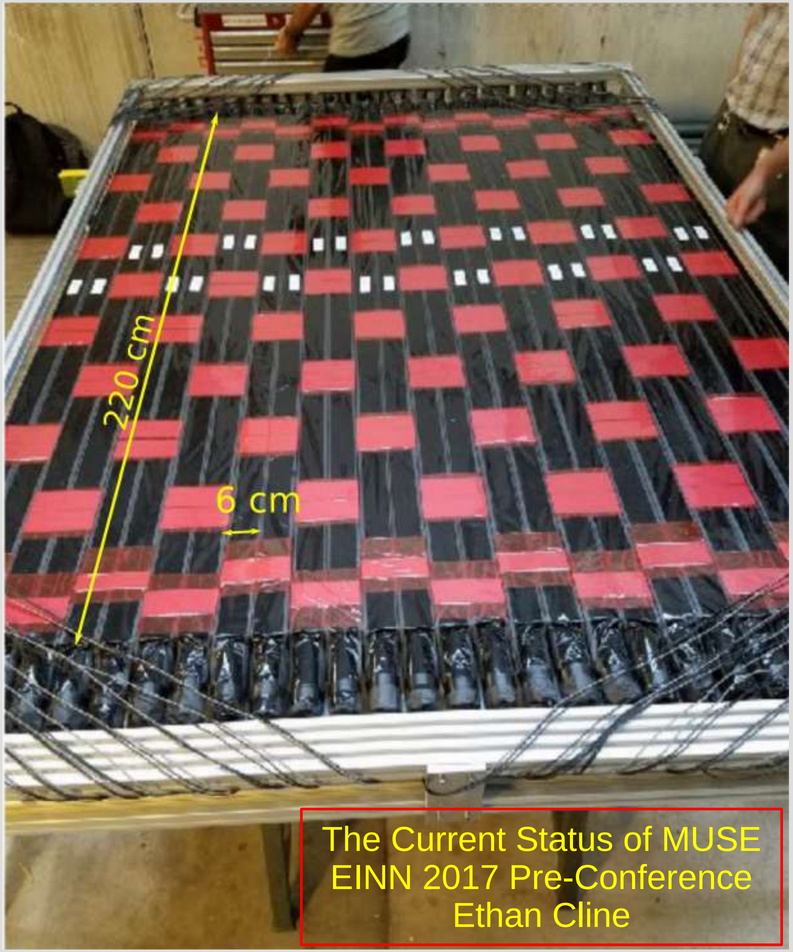
- But, they require expensive R&D and special facilities with relatively expensive hardware and electronics.

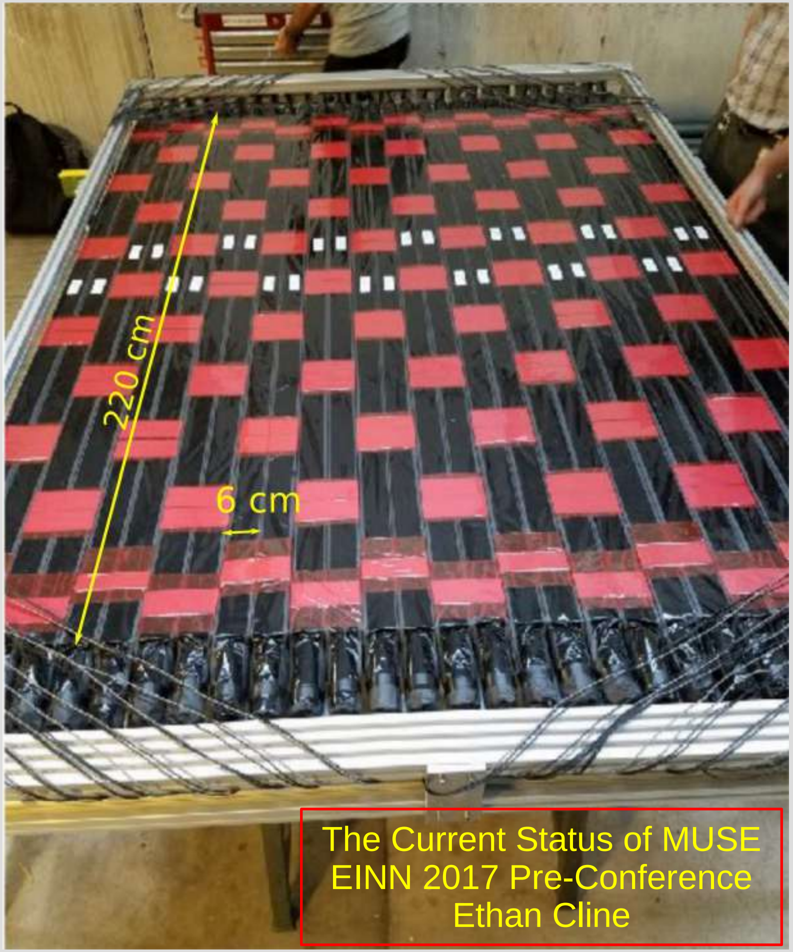
DISCLAIMER: this talk is not intended for trackers in the inner detector.

Scintillators + Photomultipliers



28 bars plastic scintillator
6x6 cm² x 220 cm
PMT ∅ 51 cm

Scintillators + Photomultipliers



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The resolution achieved by a detector like this one is:

Uniform distribution $$\sigma_x = \frac{b-a}{\sqrt{12}} = \frac{6\,cm}{\sqrt{12}} \approx 1.73\,cm$$

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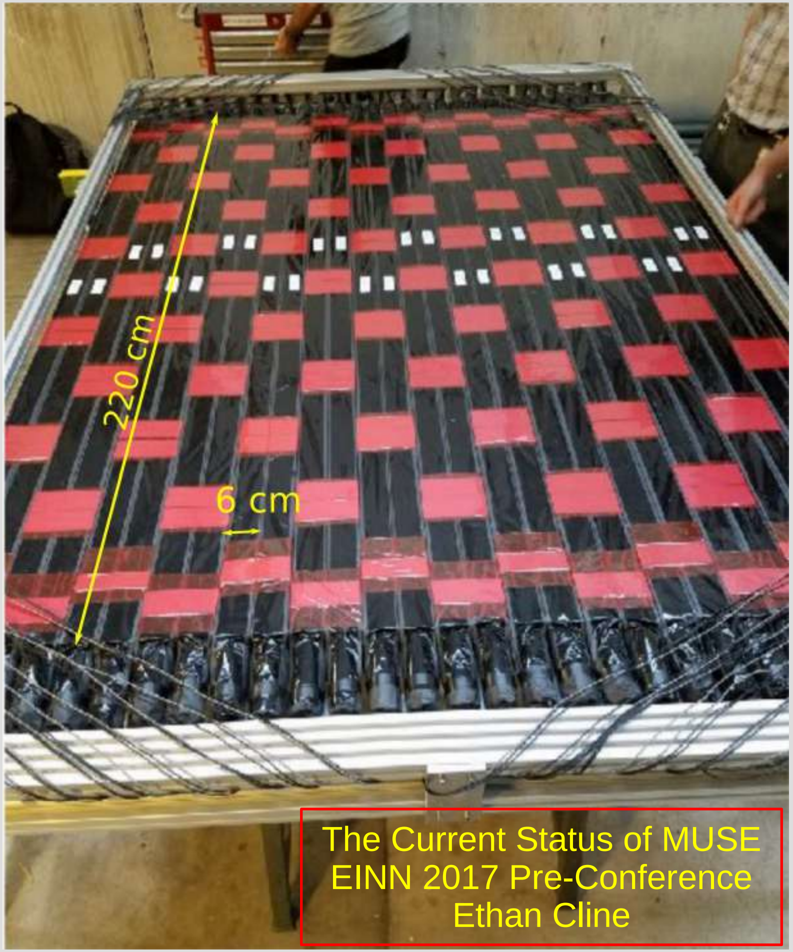

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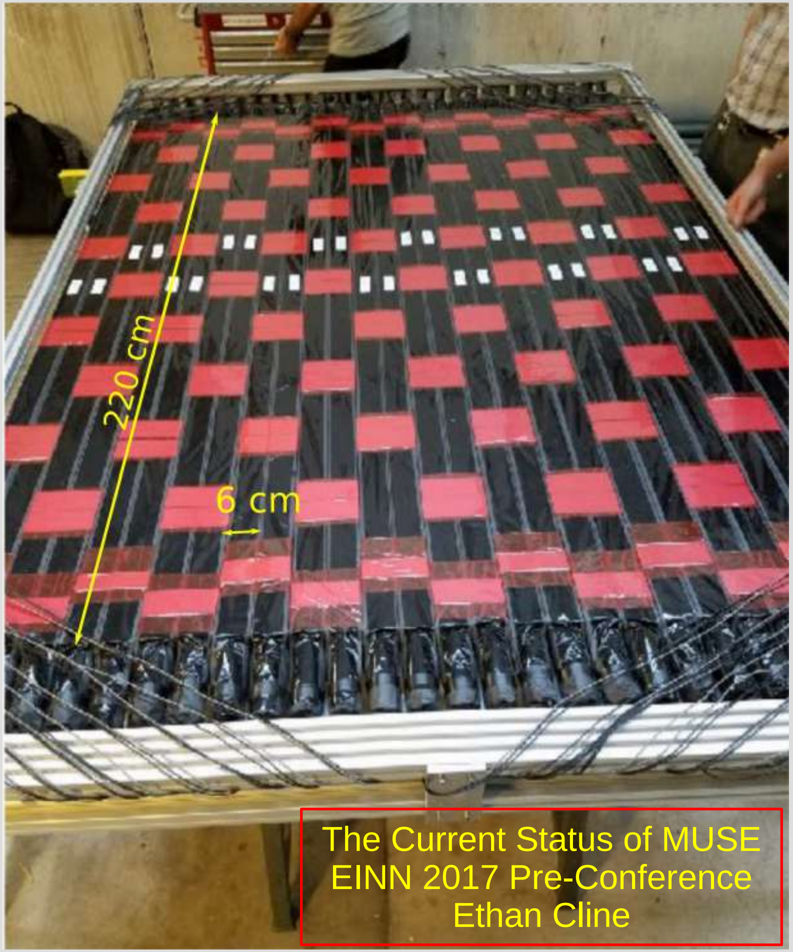

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In fact it is **NOT** design for this purpose but for event trigger and particle separation via TOF. $\sigma_t < 60\,ps$

Reducing size → fibers

The use of scintillating fibers has been in use for long time, initially with glass fiber material doped with Ce oxide, but low QE, slow component and significant optical self absorption discourage it use.

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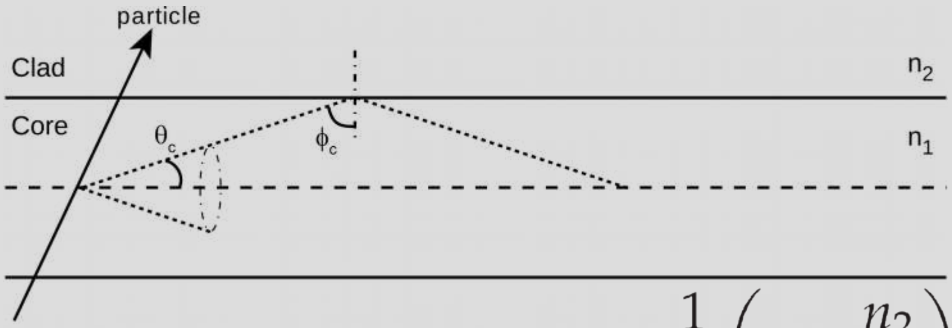
Multiclad fibers changed the paradigm of organic scintillator fibers, increasing the light yield and increasing the attenuation length

- Scintillating fibers are cover by PMMA layer for light confinament and protection of the core.
- Adding a Fluorinated polymer layer increases the light output.

Light yield

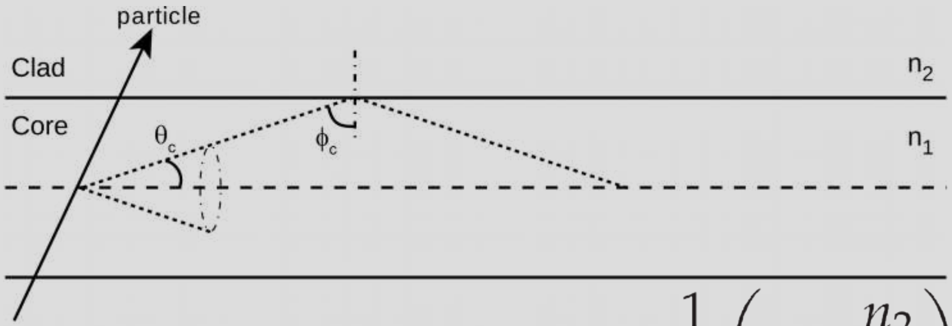


$$F_{core} = \frac{1}{2}\left(1 - \frac{n_2}{n_1}\right)$$

The fraction of a solid angle of light that is totally reflected as a function of the refractive index of the different layers.

The light collected in the outer clad-air is not considered.

Light yield



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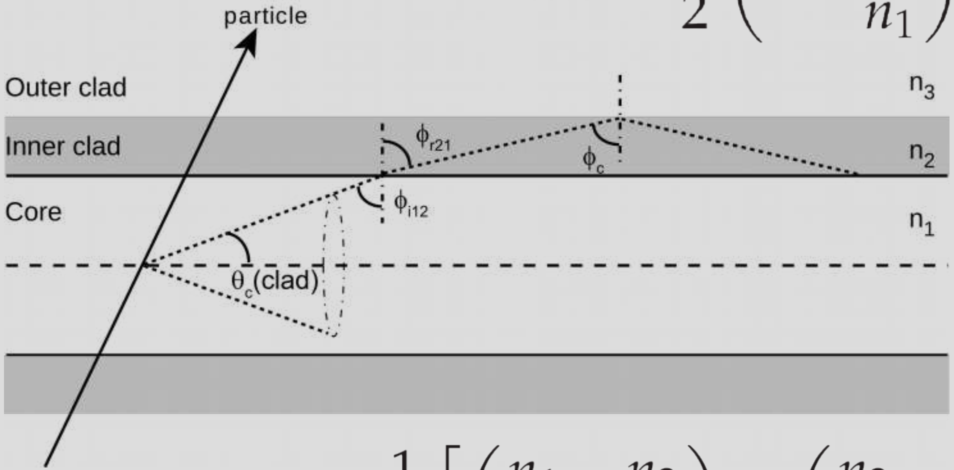

$$F_{core} + F_{clad} = \frac{1}{2}\left[\left(\frac{n_1 - n_2}{n_1}\right) + \left(\frac{n_2 - n_3}{n_1}\right)\right] = \frac{1}{2}\left(\frac{n_1 - n_3}{n_1}\right)$$

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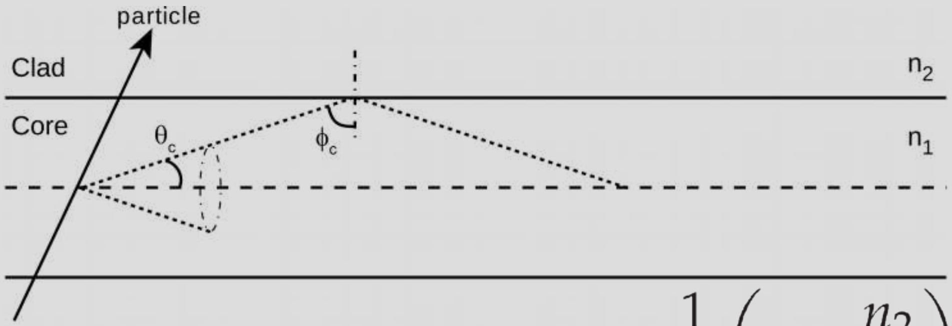

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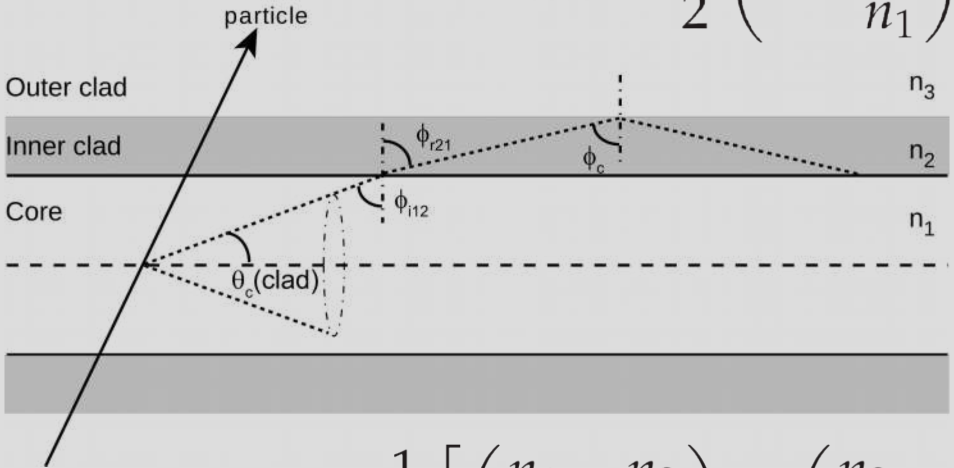

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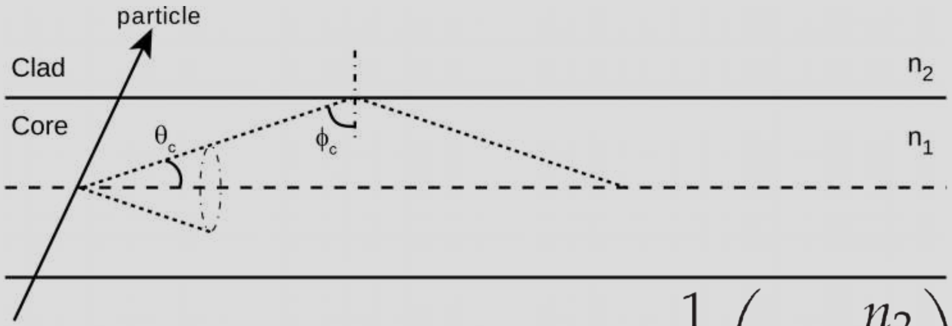
Some numbers:
Kuraray SCSF-78M

- $n_1 = 1.59$
- $n_2 = 1.49$
- $n_3 = 1.42$

$F_{core} = 3.1\%$
$F_{core} + F_{clad} = 5.3\%$

Light yield



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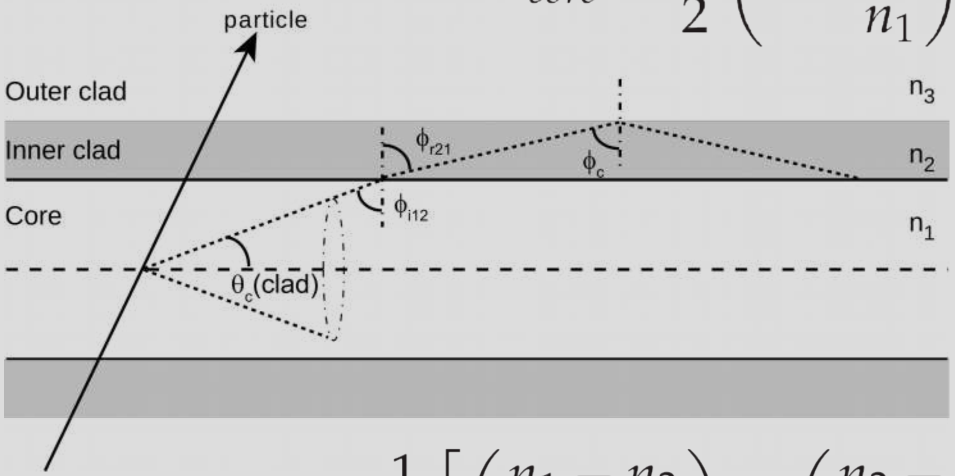

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Theoretically an increase of 70% of light yield!

Photodetectors

Low light light yield requires very sensitive detectors. In addition, the increase of the number of channels makes mandatory the use of compact devices.

32 ch (8x4)
19.5mm x 11.2mm

Each channel: 1.6mm x 1.6mm

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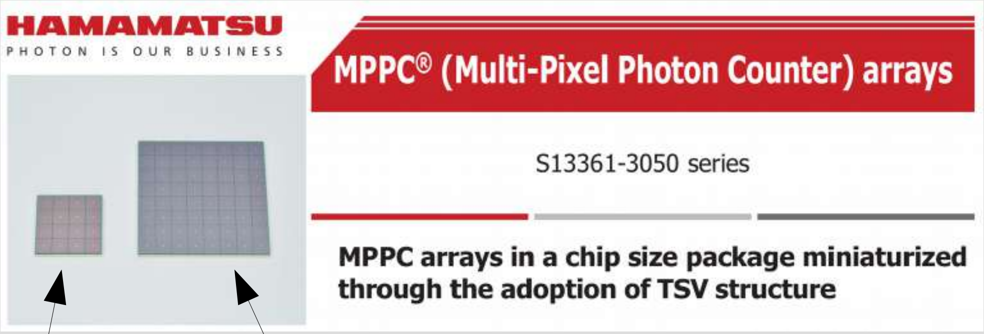

Each channel: 3mm x 3mm

16 ch (4x4)
13mm x 13mm

64 ch (8x8)
25.8mm x 25.8mm

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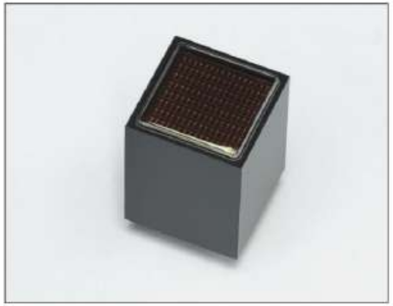
HAMAMATSU
PHOTON IS OUR BUSINESS

MULTIANODE PHOTOMULTIPLIER TUBE ASSEMBLY
H12428 SERIES

PATENT

8 × 8 Multianode, High Speed Response, High Collection Efficiency
30 mm Square, Super Bialkali and Ultra Bialkali Photocathode
12-stage, Head-on Type



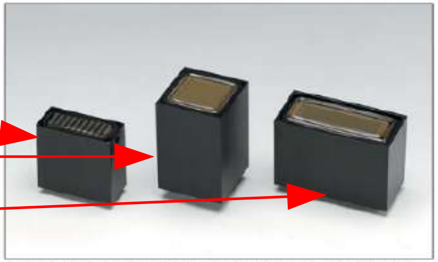
64 ch (8x8)
Each channel
2.88mm x 2.88mm

HAMAMATSU
PHOTON IS OUR BUSINESS

LINEAR MULTIANODE
PMT ASSEMBLIES AND MODULES

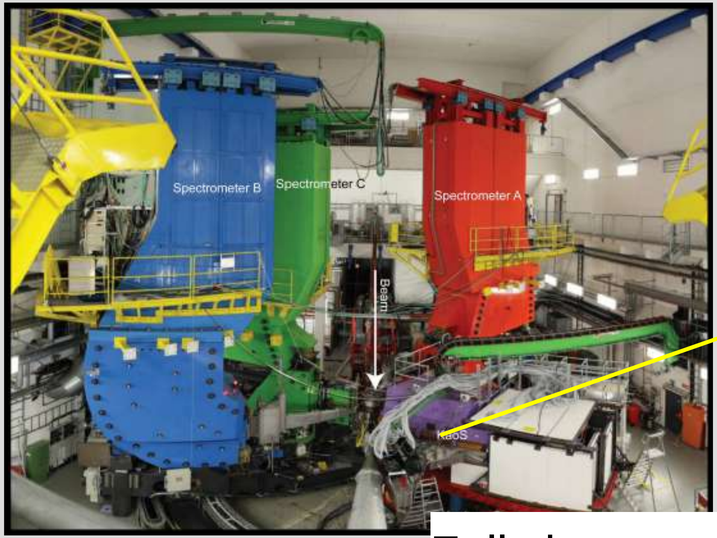
Photomultiplier tube with active divider circuit
Linear multianode PMT assembly, 8-channel (H9530 series) / 16-channel (H10515B series) / 32-channel (H7260 series)

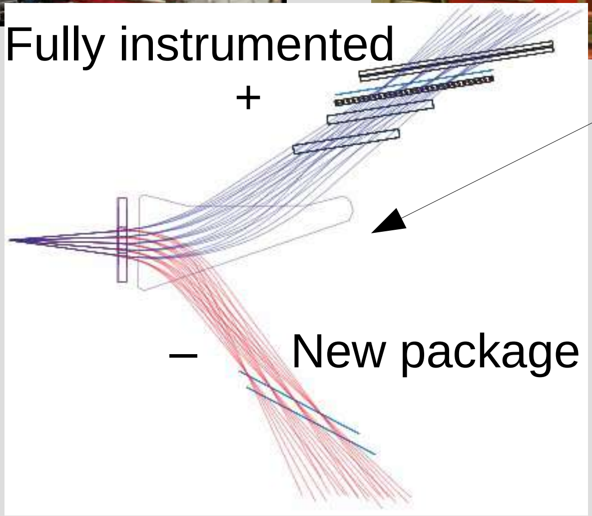
Each channel:
2mm x 2.5mm
0.8mm x 16mm
0.8mm x 7mm



Assembly types: H9530 series, H10515B series, H7260 series

Scintillator fiber detector at KaoS@MAMI

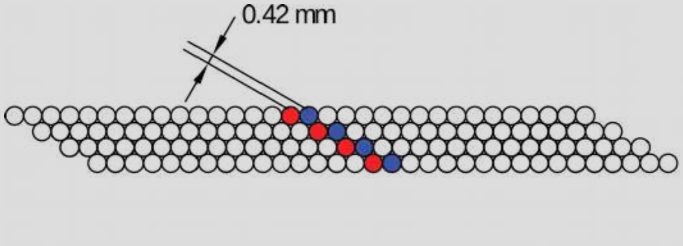


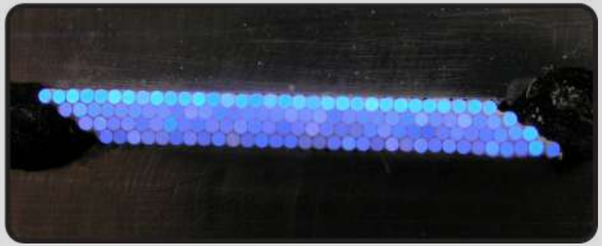


- KaoS is a magnetic spectrometer, used previously at GSI.
- In 2003 it was moved to the three spectrometers hall at the MAMI accelerator facility in Mainz.
- It was planned to be used as a double side spectrometer in the electroproduction of hypernuclei program.
- It was necessary the instrumentation of the electron side at very forward angles which must accomplish the following requirements:
  - High count capability
  - Good position resolution
  - Good timing information

Scintillator fiber detector at KaoS@MAMI

Kuraray SCSF-78M Double cladding, Ø0.83mm





One module consists of 128 fibers (4 fibers/PMT channel), glued with acrylic paint.

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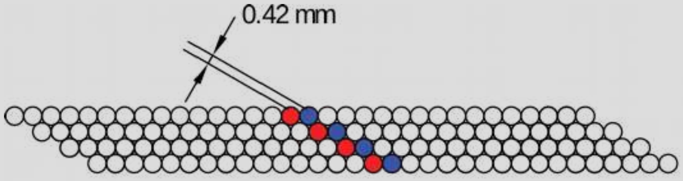

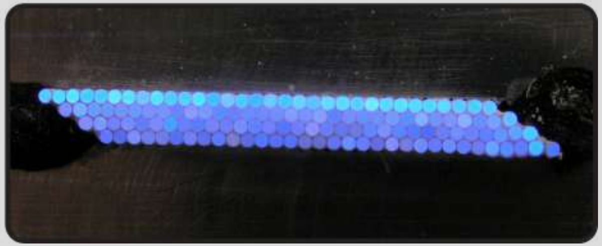

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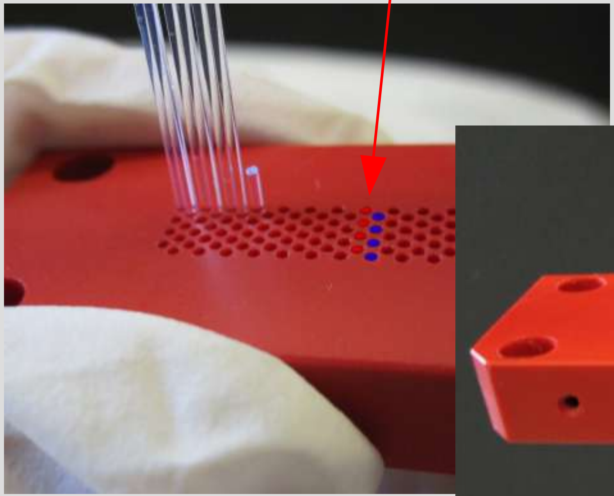

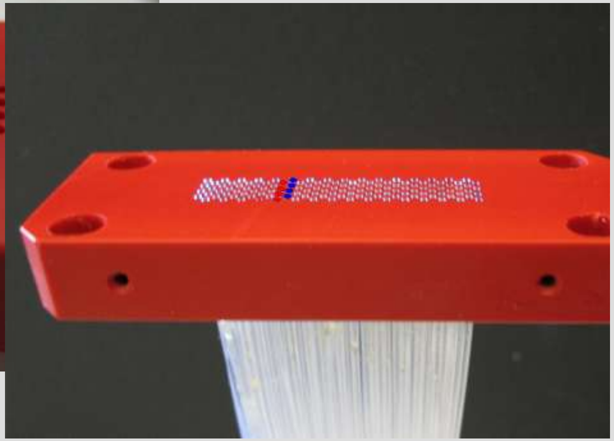

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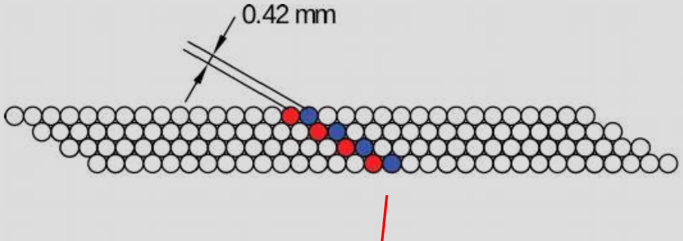
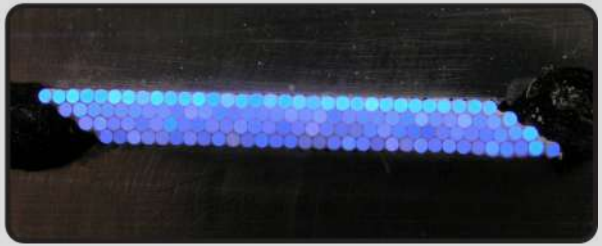
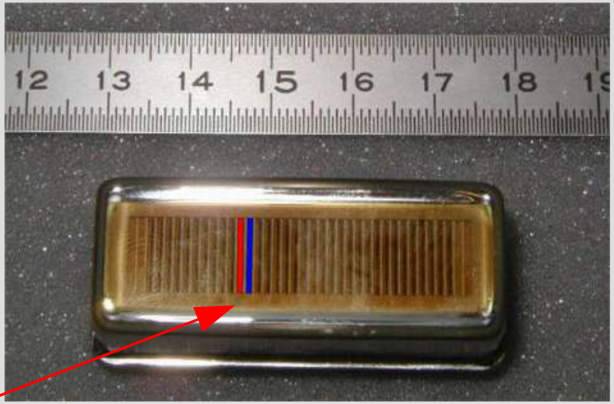




Hamamatsu H7259K

- 32 channels linear array



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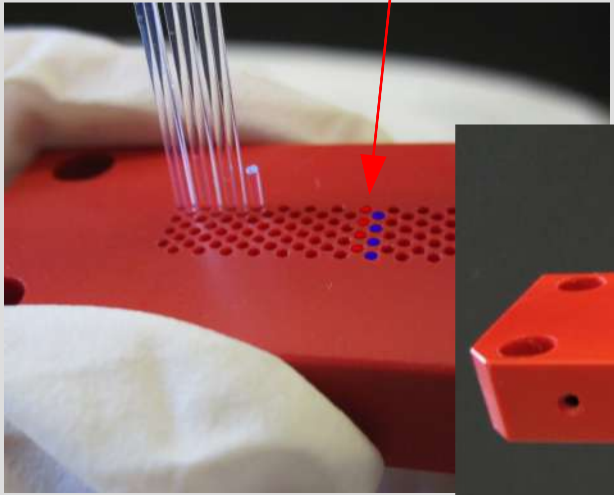
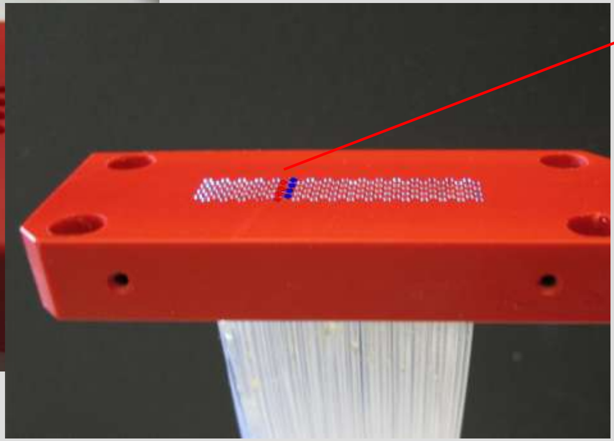
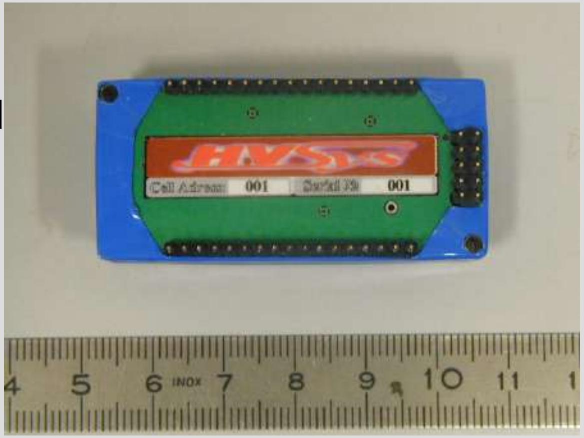
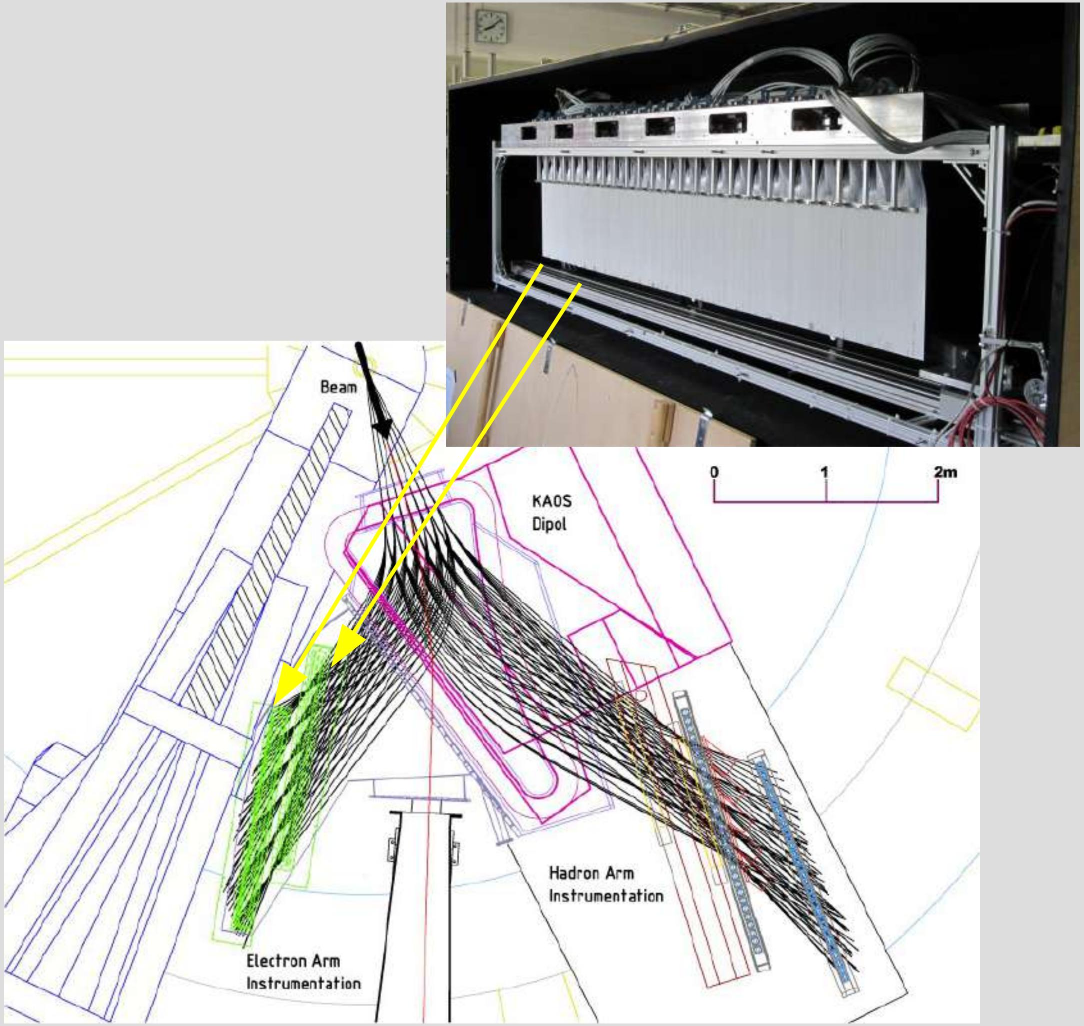




Each mPMT powered by a C-W voltage multiplier base.
Power is provided by flat cable (no need of stiff HV cables)



Scintillator fiber detector at KaoS@MAMI



<u>Scintillator fiber array with multianode photomultiplier readout</u>

The fiber detector summarizes:
- ✔Two scintillator fiber planes of 1.9 m length x 442 mm (297 mm “active”) height
- ✔72 modules per plane 2304 channels
- ✔18432 scintillating fibers assembled

Scintillator fiber detector at KaoS@MAMI

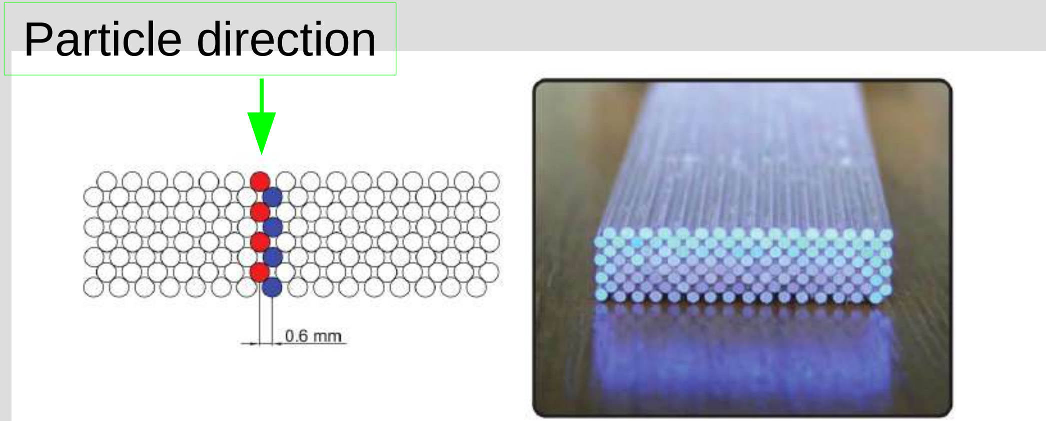


Figure 3.21: Left. Scheme of the fiber arrangement of 0°. Columns of the same color represent a single readout channel. The pitch between between each column is of 0.6 mm. Right. Photograph of the bundle arrangement.

First prototypes design used a 0deg layout, which was beam tested.

This slanted version was choose for the final version in order to reduce the multiplicity

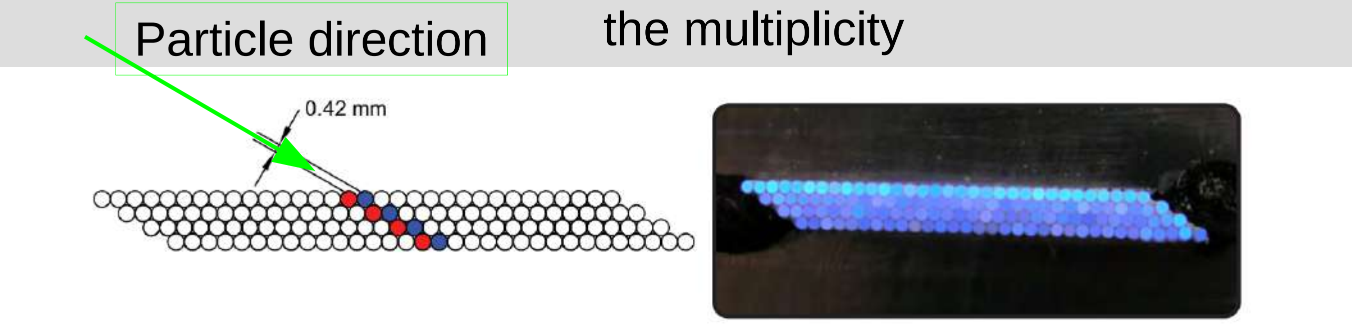
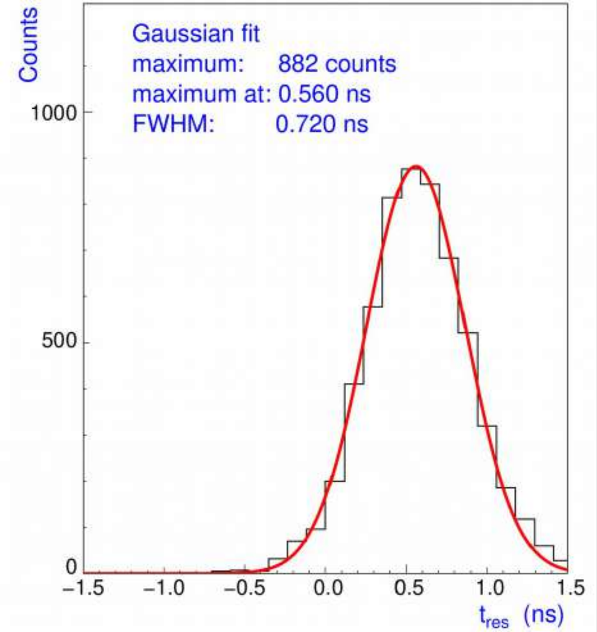
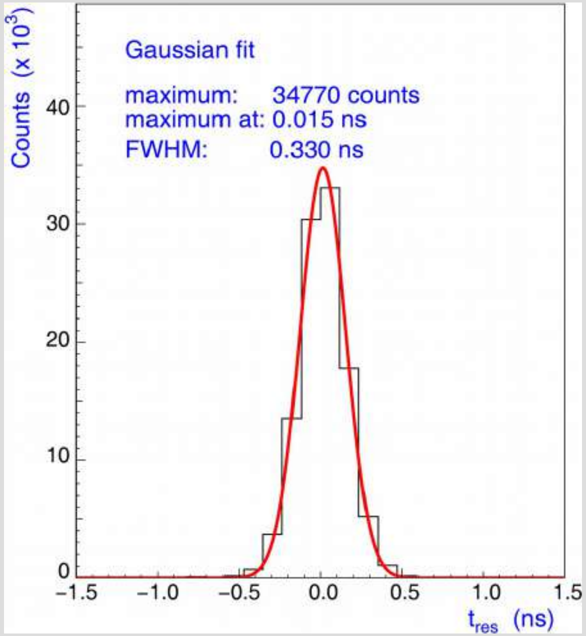


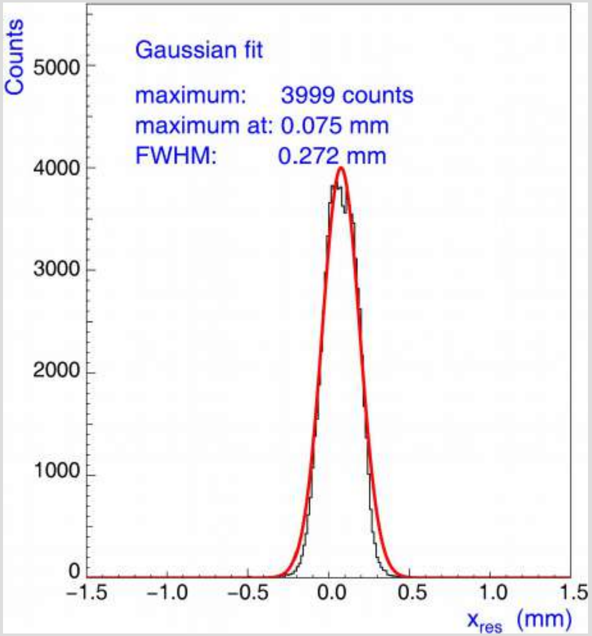
Figure 3.23: Left. Scheme of the fiber arrangement of $\phi = 60°$. Columns of the same color represent a single readout channel. Right. Photograph of the bundle arrangement.

CA – PhD thesis 2012

Test beam at GSI



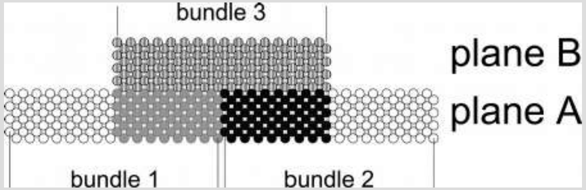




Some numbers from 2007 GSI beam test (cocktail beam π^+/p/d protons at 1GeV/c) and C beam of 2 AGeV energy:

- Residual of t_A-t_B FWHM = 720ps (cocktail) → 510ps single plane,
  330ps (carbon) → 220ps single plane

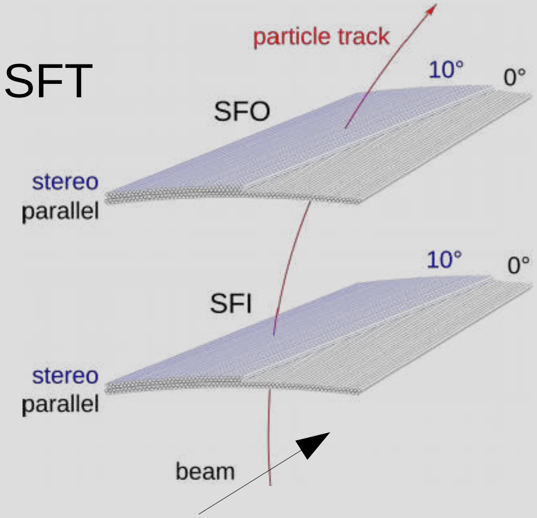
- Residual track position X_A-X_B FWHM ~0.27mm (carbon)

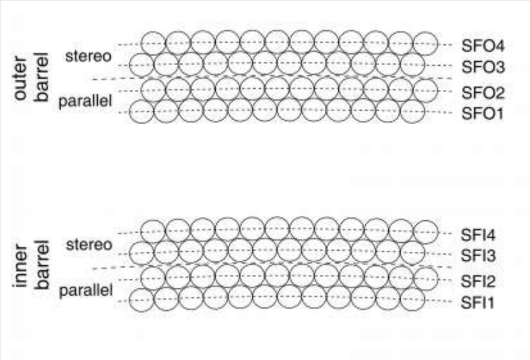


P. Achenbach, C. Ayerbe Gayoso, J. Bernauer, R. Bohm, M. Distler, et al., “In-beam tests of scintillating fibre detectors at MAMI and at GSI,” Nucl.Instrum.Meth.,vol. A593, pp. 353–360, 2008.

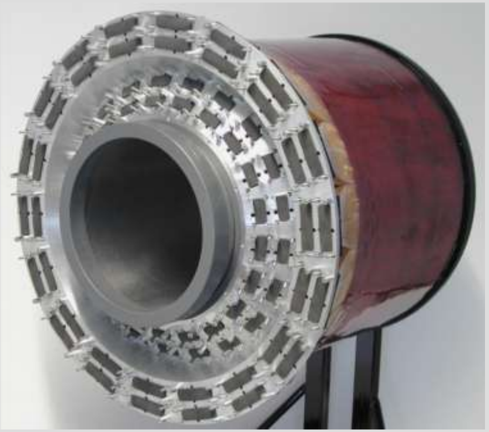
The HERMES recoil detector

Other examples





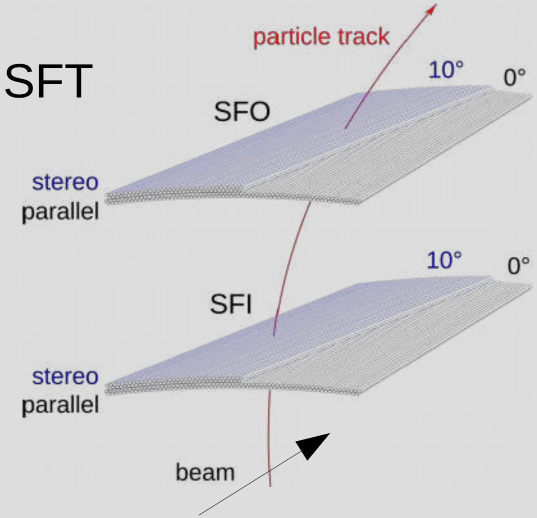
2 cylinders of 2 × 2 layers, 10° stereo angle
4992 channels

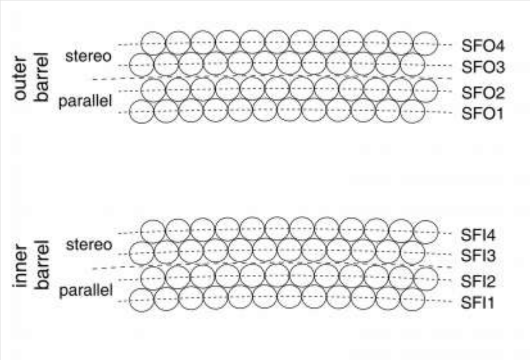


A. Airapetian, et al., “The HERMES Recoil Detector” JINST 8 (2013) P05012 2008.

Other examples

The HERMES recoil detector





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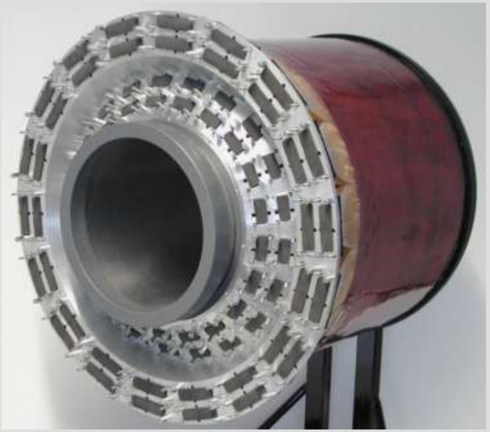

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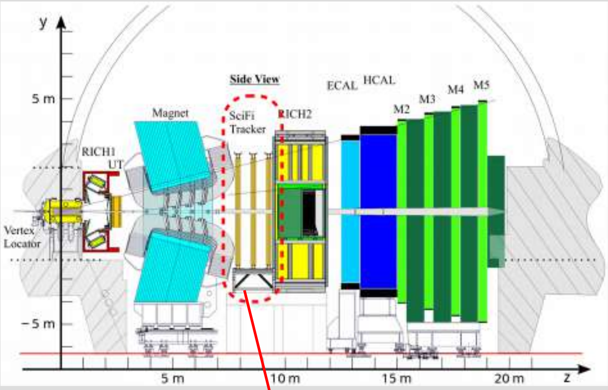
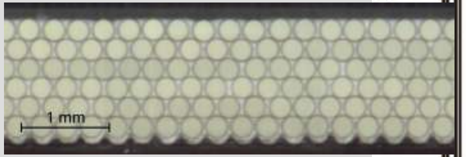
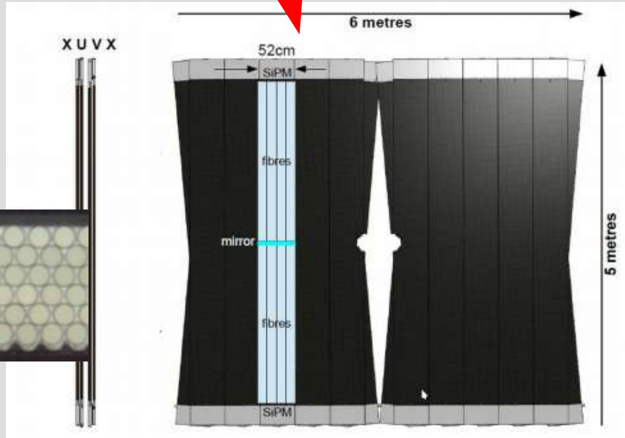
LHCb SciFi







Fibers of ø250 μm,
524k channels

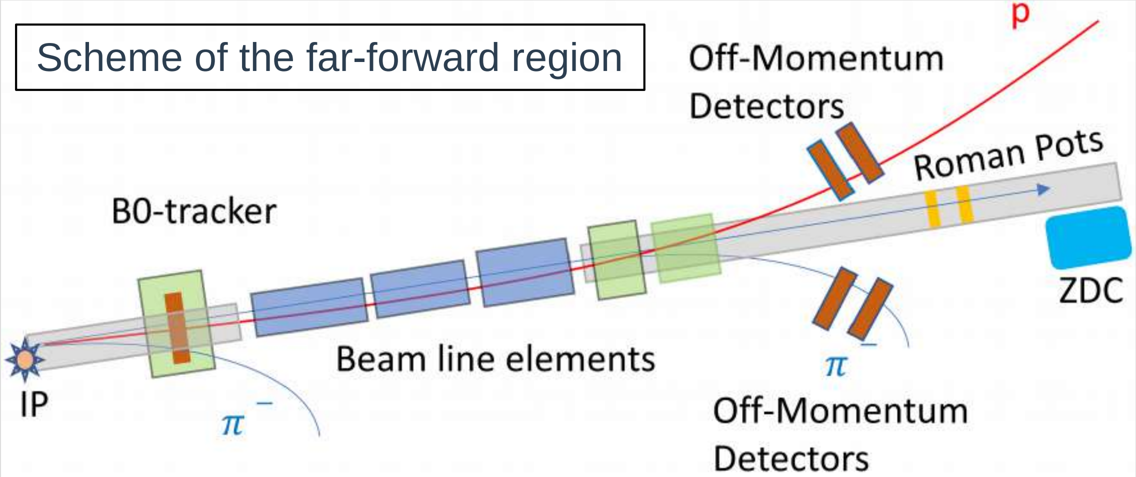
L. Gruber, LHCb SciFi, “Upgrading LHCb with a scintillating fibre tracker” NIM, A 958 (2020) 162025

Ok, but what happen with the EIC?

I will focus on the ZDC, as mentioned in the motivation

Ok, but what happen with the EIC?

The Zero Degree Calorimeter (ZDC) is part of the far forward instrumentation of EIC and play a critical role for different physics topics, in particular the meson structure.



From the EIC YR-Meson WG

Detection of the decay channel $\Lambda \rightarrow n + \pi^0$ is feasible (...).
Detection of the other decay channel, $\Lambda \rightarrow p + \pi^-$, poses a more challenging measurement owing to its requirement of additional **charged-particle trackers or a veto trigger** on the path to ZDC.

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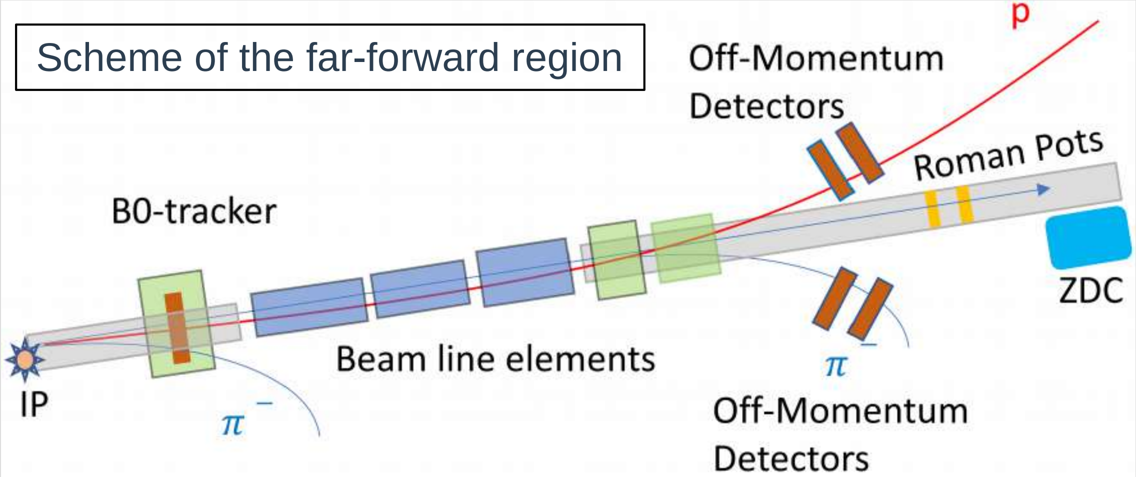

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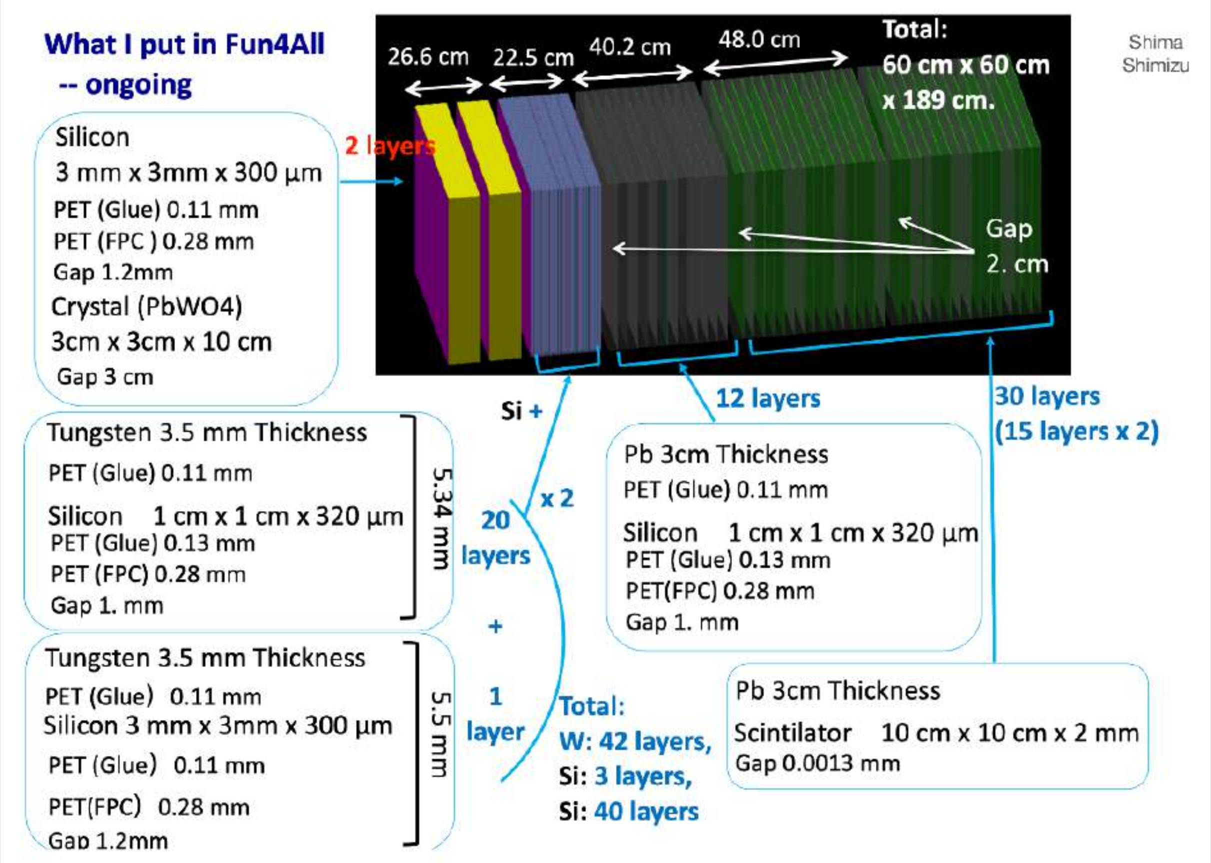
Here is where a scintillator fiber detector could enter.

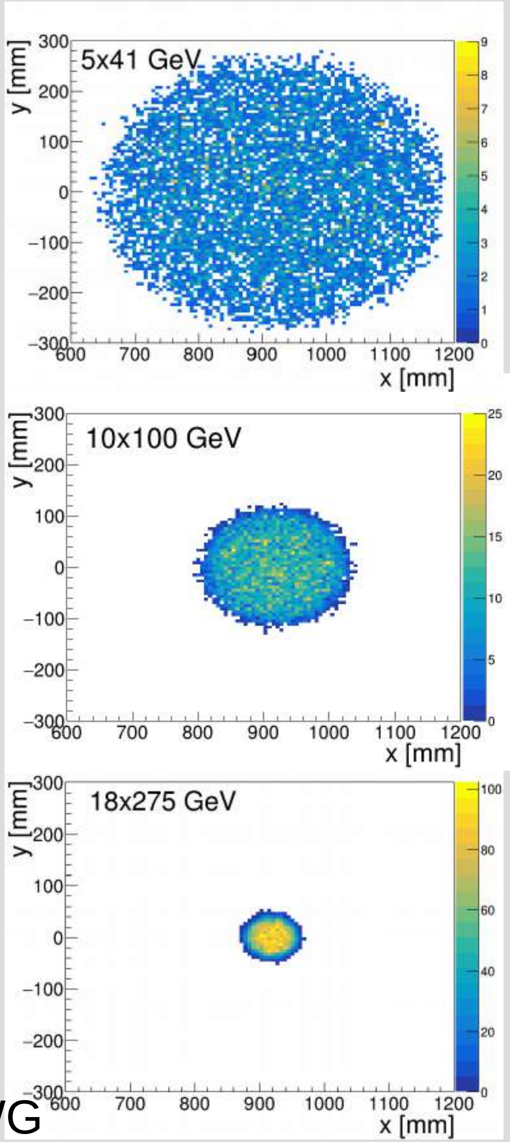
Some parameters of the ZDC*



Igor Korover- MIT, Yuji Goto Riken, Michael Murray Kansas U – for the ECCE consortium - Detector Integration Group. July 28th 2021

* except the cross-section area, dimensions under study

Neutron acceptance for a 60x60 cm² ZDC

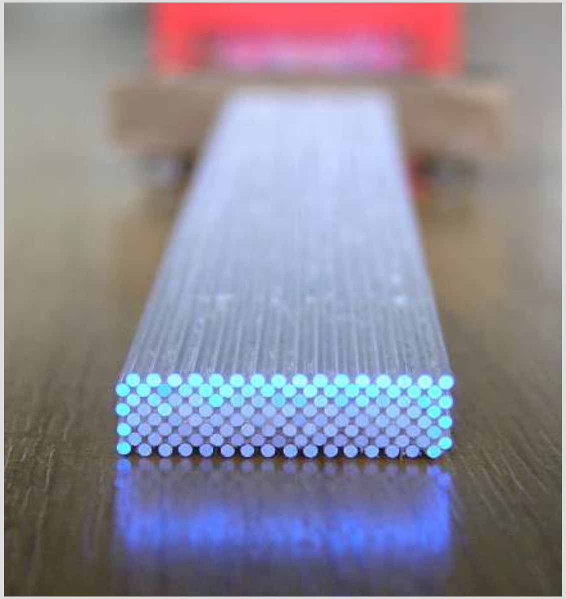


YR meson WG

Why a scintillator fiber detector?

- It is a fast detector
  - Useful for trigger purposes
- It is a well known technology
- It is easy to build
  - don’t need a special clean room to be build
  - It is mostly a craft work
- It is not expensive
  - With a good design, the fiber array is the less expensive part of the detector and easily to replace in case of accident or degradation of the fibers.
  - Electronics is always the expensive part and it is a matter of R&D&Simulation to choose the proper configuration of discriminators, ADC, TDC and/or logic modules.
- It doesn’t introduce excess of material in the path of particles

Some numbers



- Each 0deg bundle is ~1.9cm width and ~0.5 cm thick
  - $X/X_0 \approx 1.2\%$ (mostly polystyrene X_0=43.79 g/cm²)
- Kuraray (Japan) price 7.5km of fiber:
  - ~1.6M¥ (2009) → ~15k$ (rate 2020)
- For ZDC, cover 60x60 cm² (two planes X-Y)
  - Assuming similar layout (4 fiber/channel):
    - 60 cm/1.9cm/bundle = 32 bundles → 32x128 fibers = 4096 fibers
    - 4096 x (60 cm + 20 cm) ~3.3 km of fiber/plane
    - 1024 readout channels/plane
- Readout + associated electronics (discriminator+TDC)
  - Readout could be APDs, silicon photomultipliers, even multianode PMTs

Future

- I presented an idea as solution for a particular problem.
  - A scintillator fiber detector in front of the ZDC, for an efficient detection of the $\Lambda \rightarrow p + \pi^-$ decay channel.
- The immediate step is design a Geant4 simulation and test the best configuration.
- Find a consensus of the kind of detector to use.
  - As a postdoc I can’t compromise a full time research of the plausibility of this detector, but part of my time.