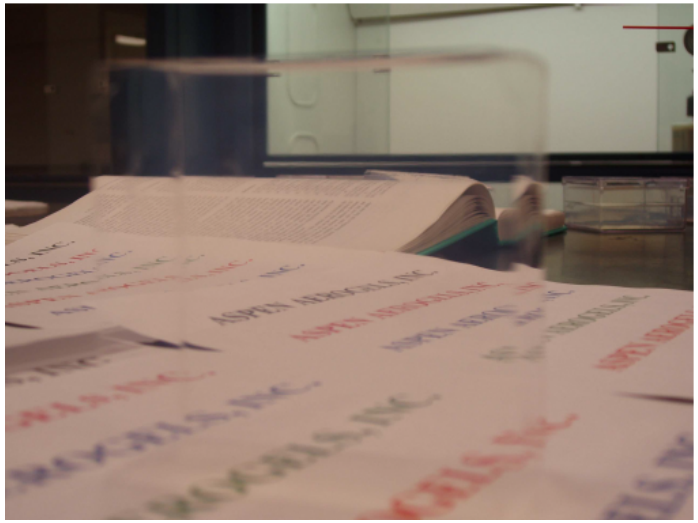
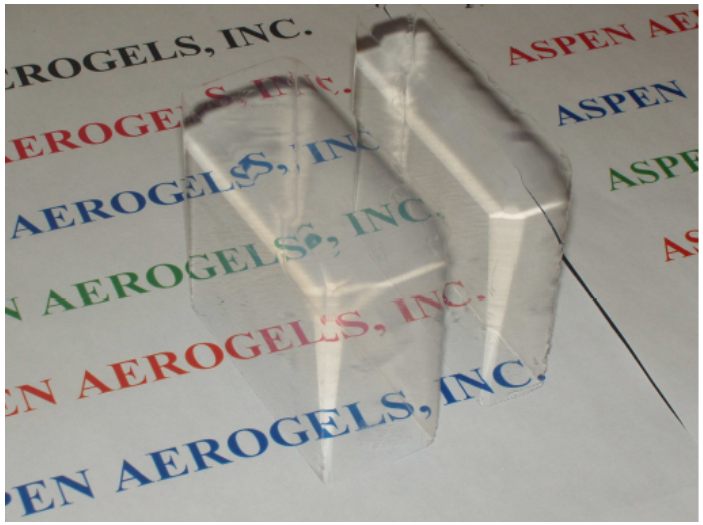
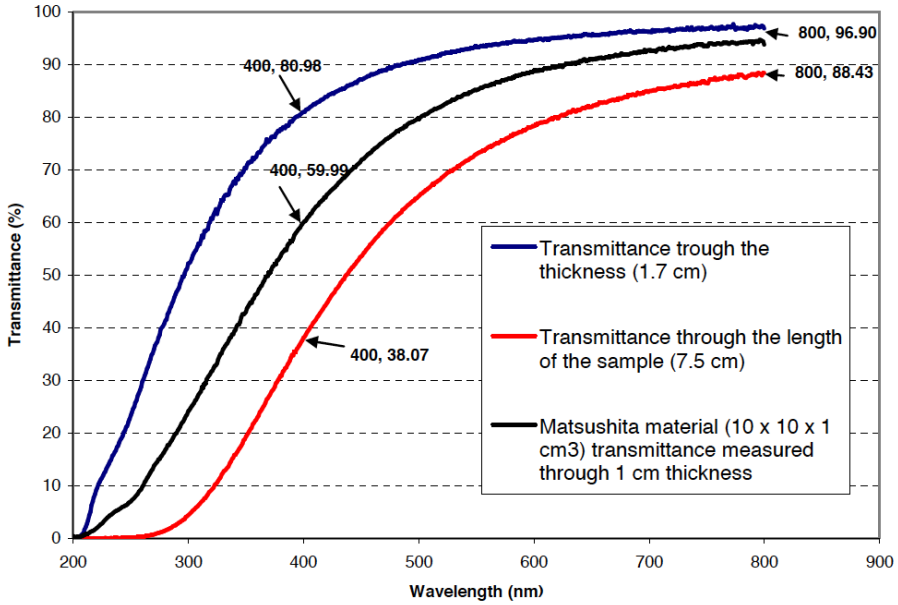
Aspen Aerogels & Arizona State University SBIR- NP DOE Project

Phase I	Design and Implementation of Aerogel Cherenkov Detector Testing System
Phase II	Design and Implementation of Aerogels for Nuclear and Particle Physics

Background

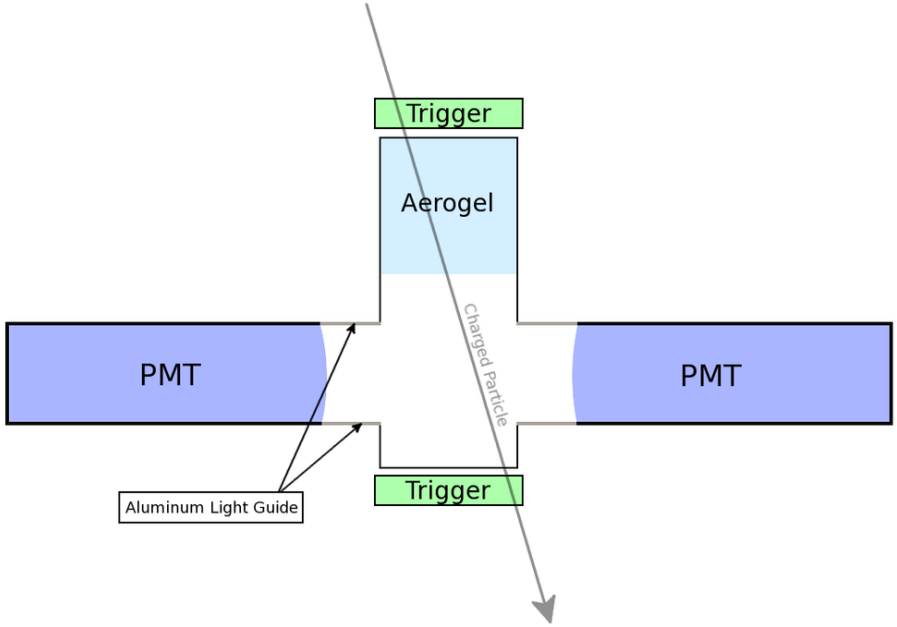



ASPEN AEROGELS, INC.

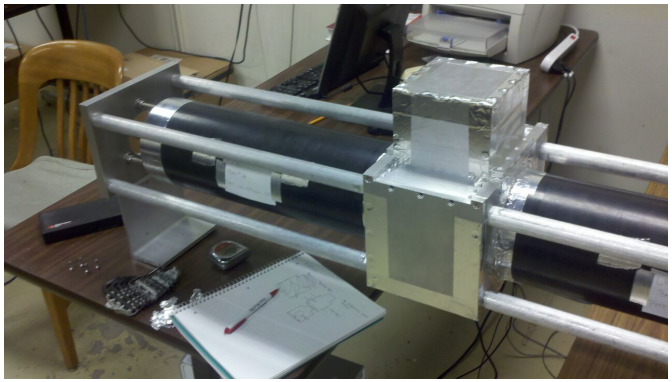

Transmittance (%)
Wavelength (nm)
0
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
400, 80.98
400, 59.99
400, 38.07
800, 96.90
800, 88.43
Transmittance trough the thickness (1.7 cm)
Transmittance through the length of the sample (7.5 cm)
Matsushita material (10 x 10 x 1 cm3) transmittance measured through 1 cm thickness

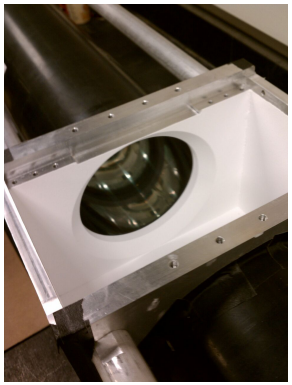
Phase I Goals

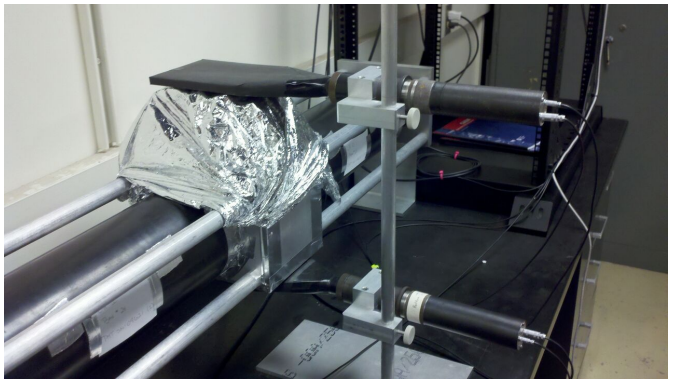
- Build a threshold Cerenkov counter to test new aerogels with cosmic rays
- Compare results with aerogels from Matsushita (Japan)



Phase I Instrumentation



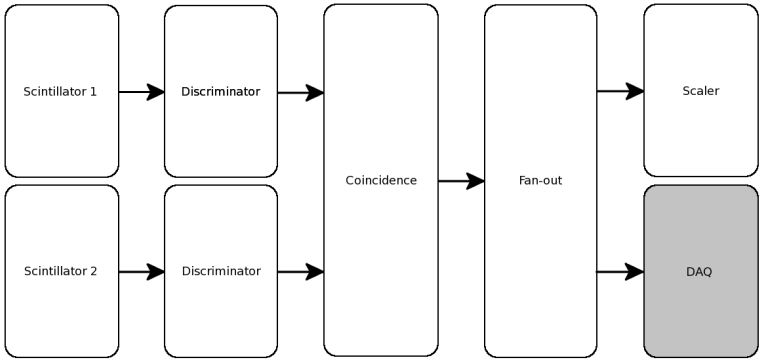




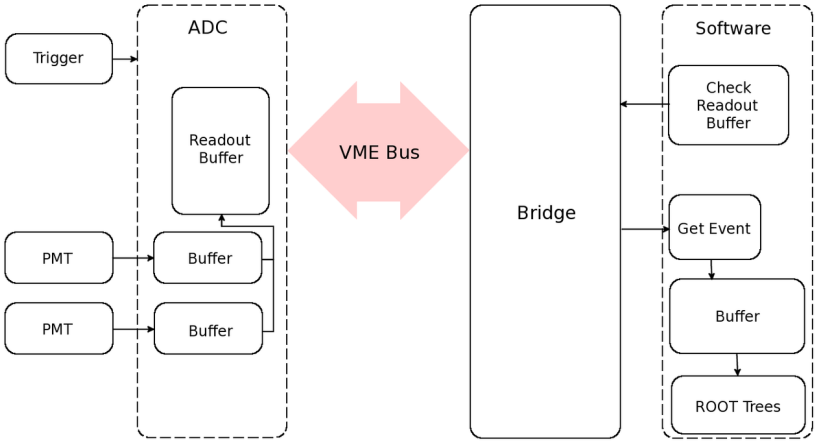
- Light box filled with air, containing a layer of aerogel, along with two large photomultiplier tubes on the sides.
- The inside of the main light box is coated with a white, diffusively-reflective coating of Spectraflect.
- The PMTs are 5” Photonis XP4500/B, VD105K voltage dividers/bases, coupled to the light box with highly specularly-reflective aluminum light guides, and reside in a 9.5 mm thick steel tube to minimize effects of ambient magnetic fields.
- On top sits a holding chamber for the aerogel. The aerogel is stacked in tiles to the desired height, and is suspended by the edges of the bottom tile. This chamber, too, is coated with Spectraflect.
- The signals from these tubes are fast, and since we are digitizing them, we are also passing them through a 35 MHz low-pass, in-line filter. This produces a smooth signal easily recorded by digitizing electronics.
- The main horizontal area of the scintillator paddles has the dimensions 12.7 cm by 15.2 cm.

Phase I Instrumentation

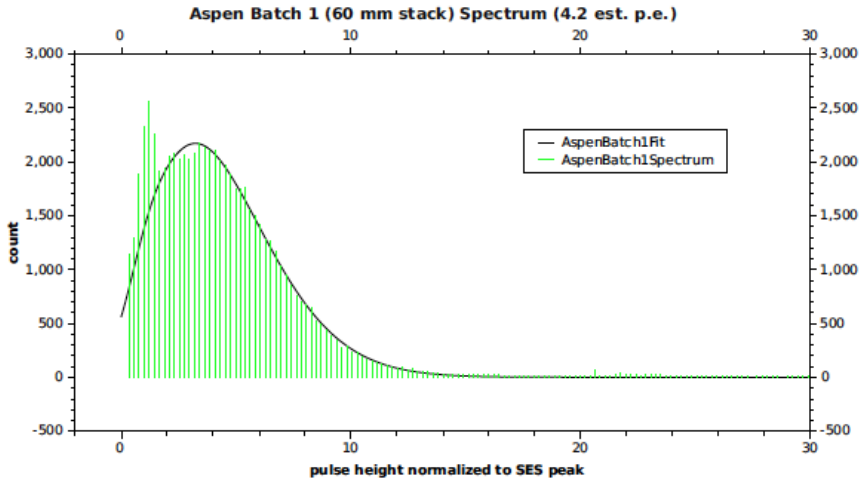
NIM Electronics



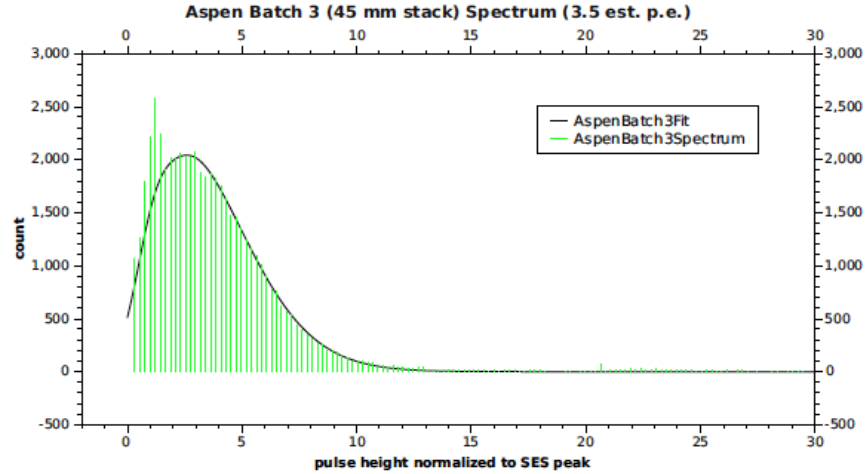
- A multi-channel 12-bit 250 MS/s (one sample every 4 ns) VMEbus digitizer,
- a VMEbus to usb 2.0 bridge,
- a VMEbus crate, and
- a computer with designed software for interacting with the bridge.



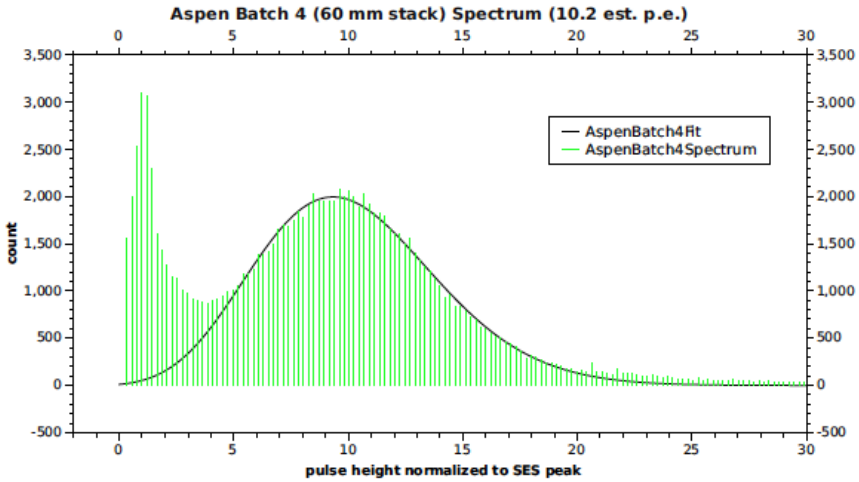
Phase I Results



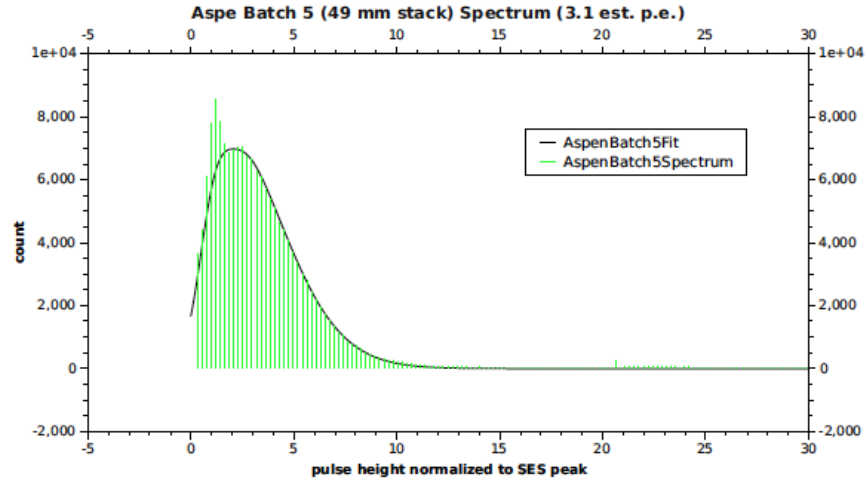
(a) Batch 1



(b) Batch 3

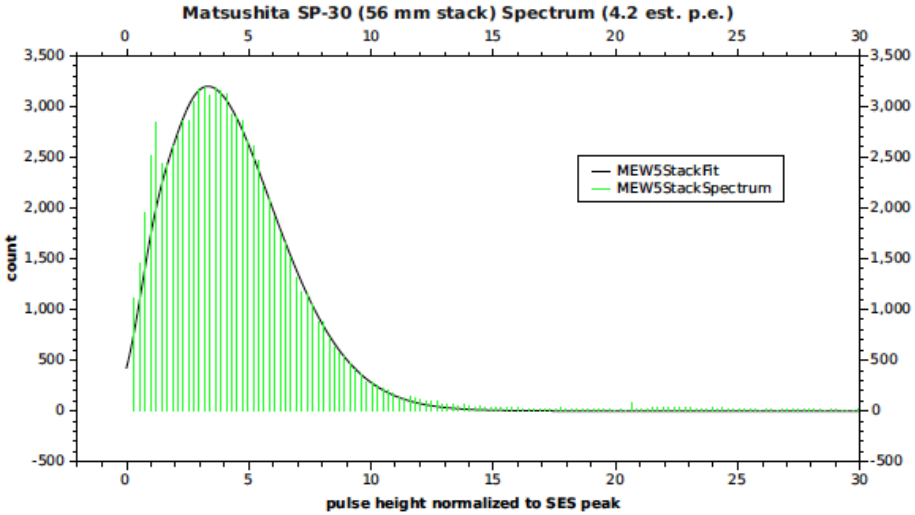


(c) Batch 4

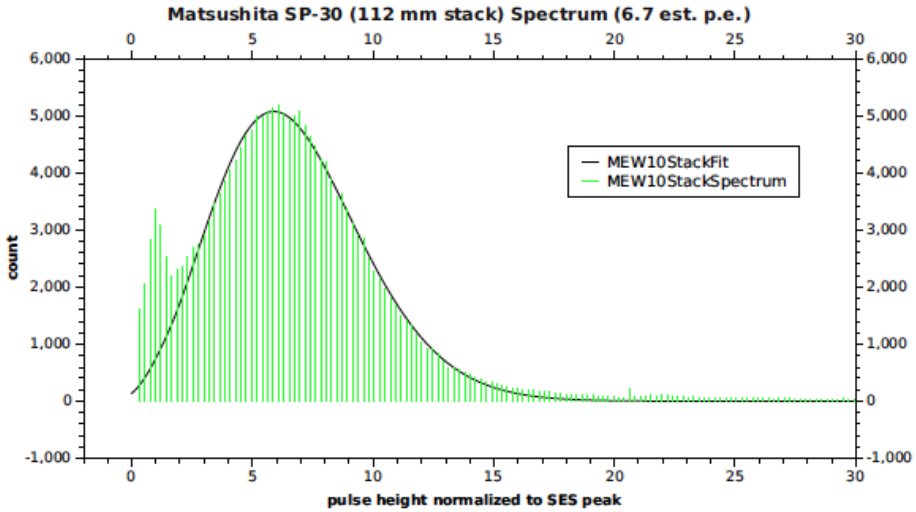


(d) Batch 5

Phase I Results

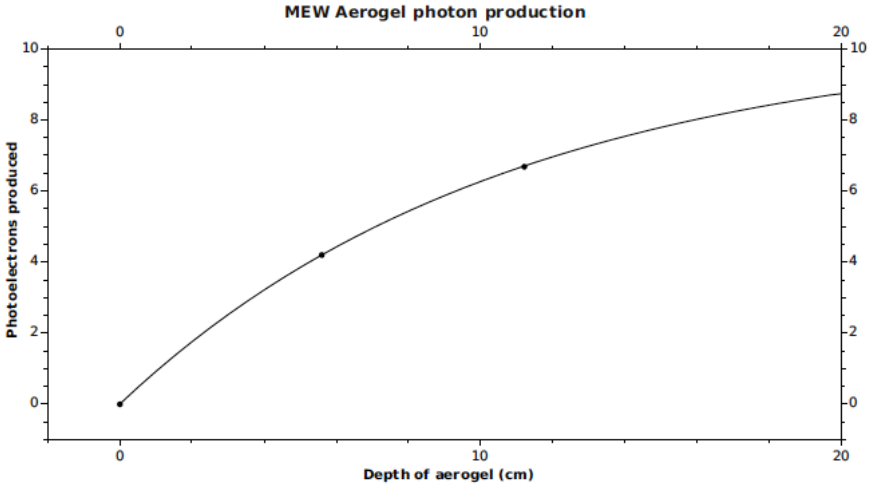


(a) 56 mm of SP-30



(b) 112 mm of SP-30

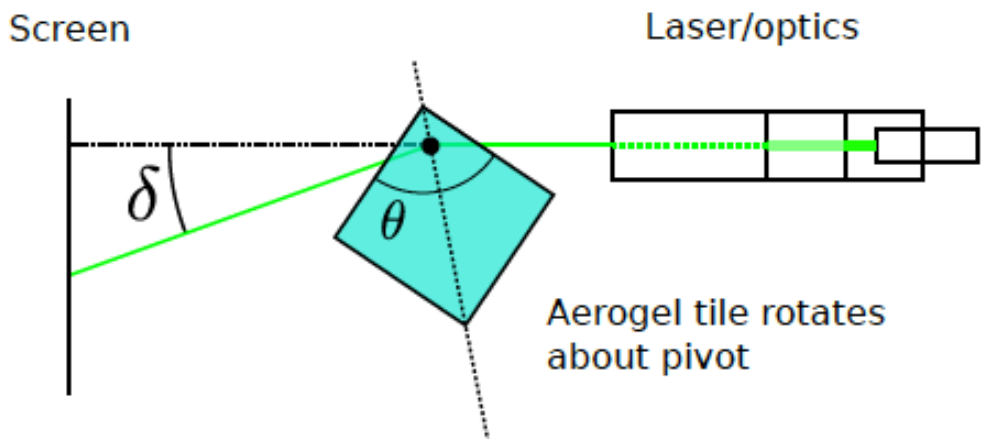
$$N_{pe} = a(1 - e^{\frac{t}{T}}),$$



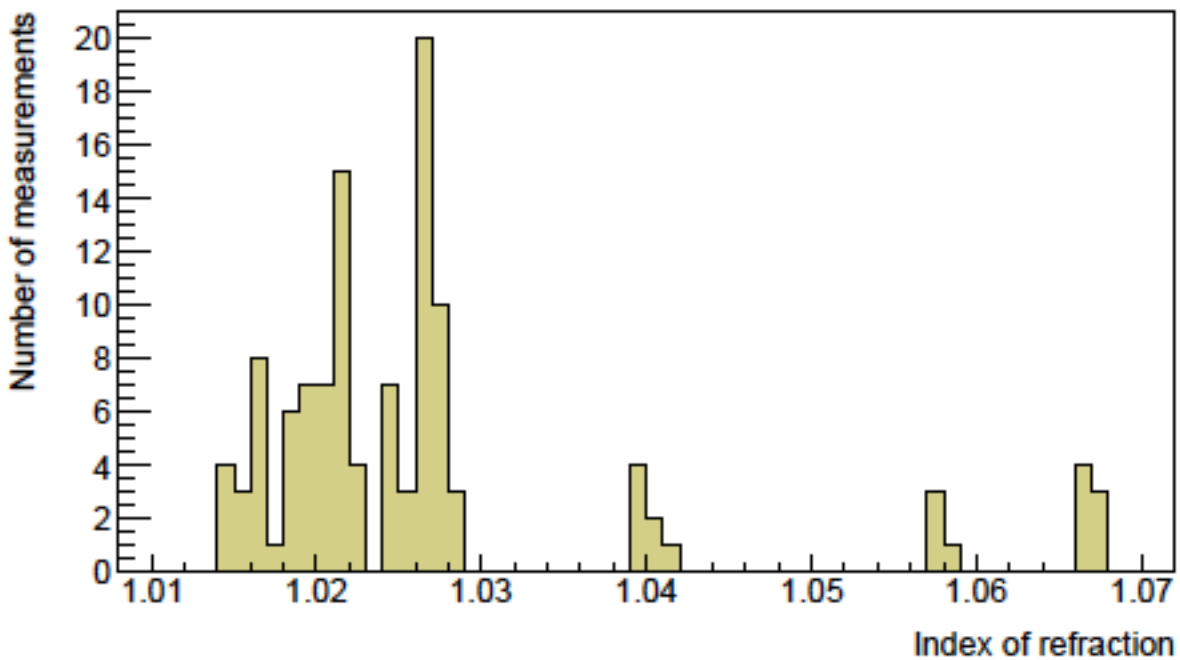
Phase II Goals

- Build a threshold Cerenkov counter to test new aerogels with a relativistic particle beam.
- Fabricate and test large tiles (20 cm by 20 cm).
- Build a RICH prototype

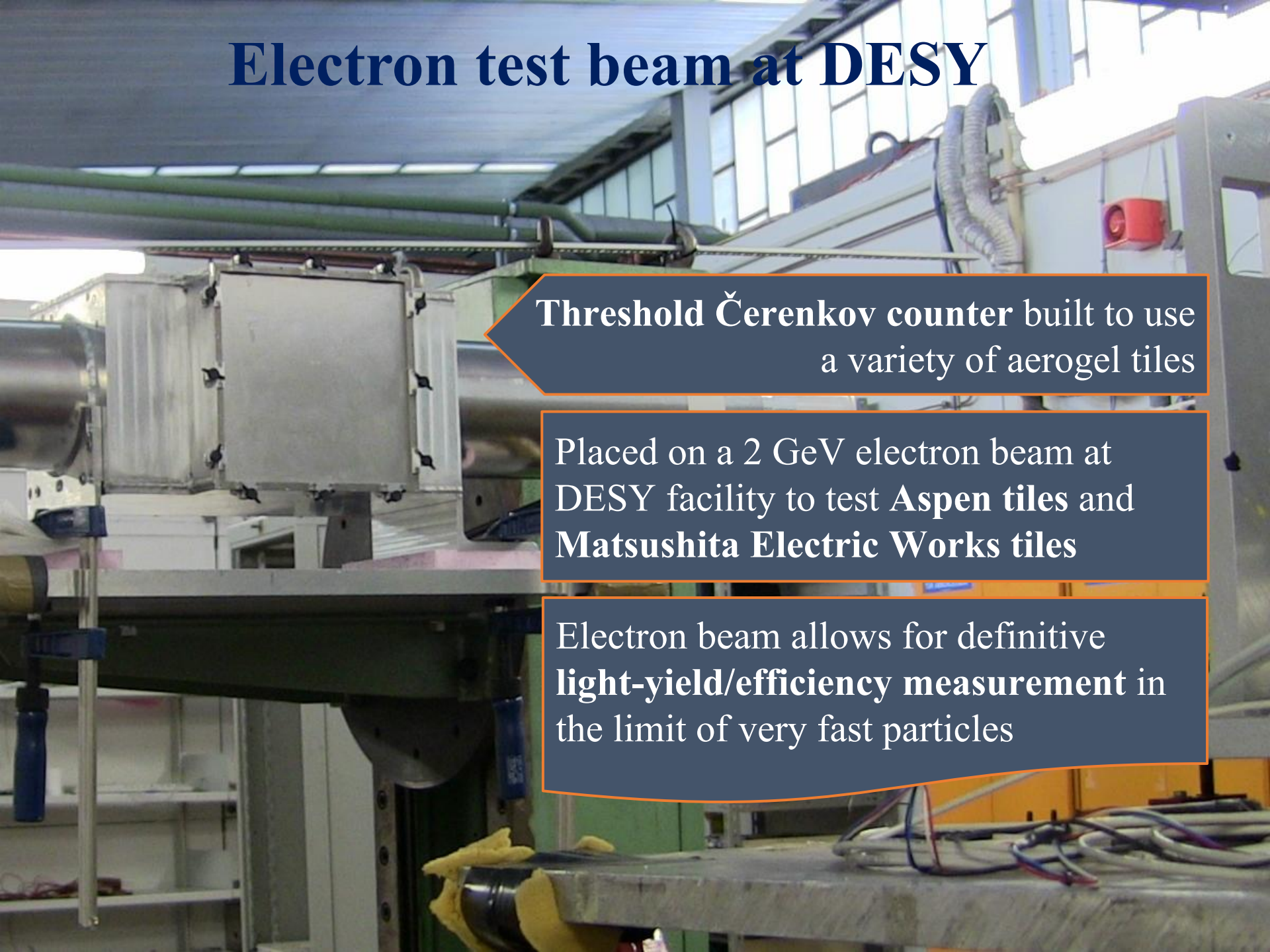
Refractive Index



$$n = \frac{\sin\frac{\theta+\delta}{2}}{\sin\frac{\theta}{2}},$$



Electron test beam at DESY

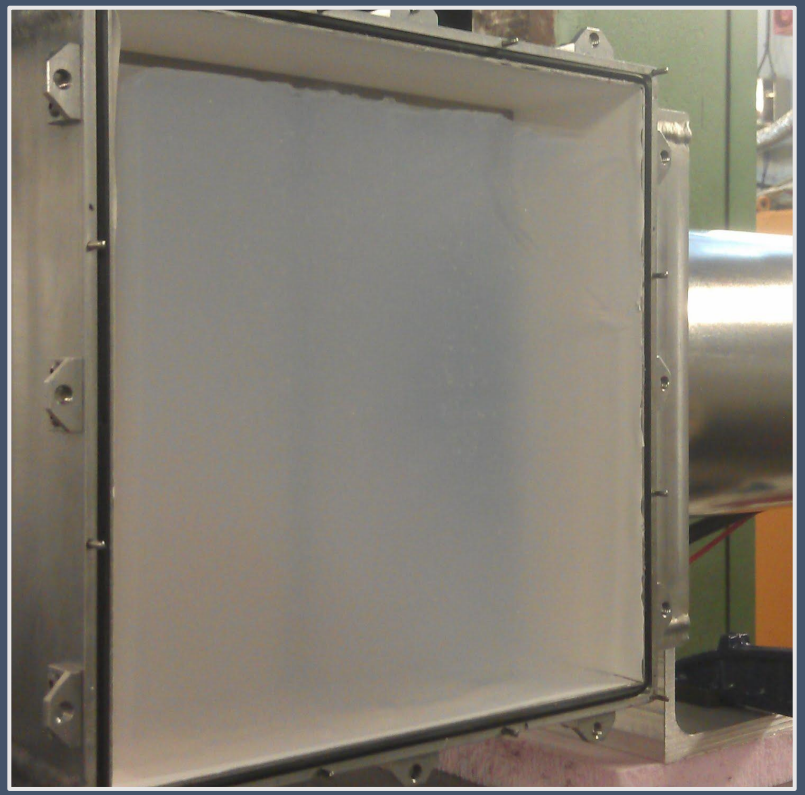


Threshold Čerenkov counter built to use a variety of aerogel tiles

Placed on a 2 GeV electron beam at DESY facility to test **Aspen tiles** and **Matsushita Electric Works tiles**

Electron beam allows for definitive **light-yield/efficiency measurement** in the limit of very fast particles

Čerenkov test counter



Designed to be **highly uniform**, with **diffusely reflective** internal surfaces

Uniformity helps to allow for **comparable results** between batches of aerogel

Two large (5") photomultiplier tubes used to produce a signal proportional to amount of Čerenkov light

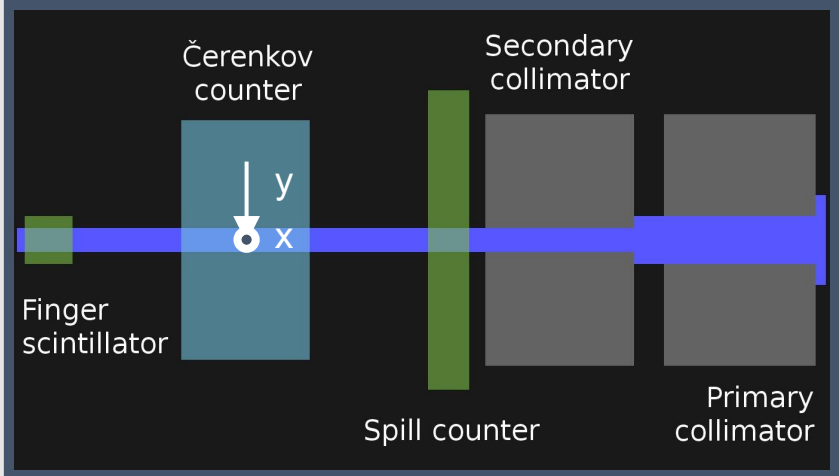
Experimental setup

Counter mounted to x-y table to precisely position beam through aerogel

Collimated beam (blue) ~1 cm wide

Two-scintillator trigger used (green), approx. 10 m apart, with counter in-between

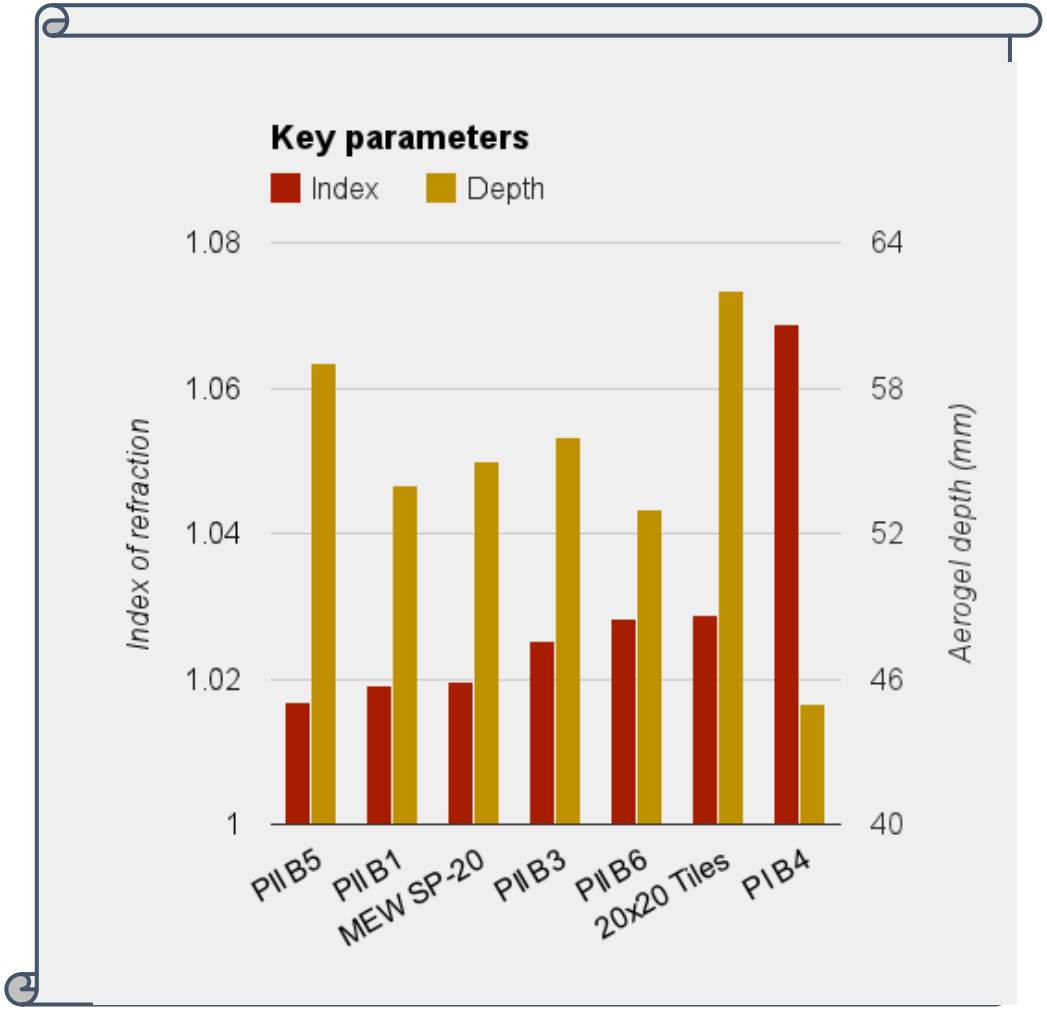
Downstream scintillator is ~2 cm wide, eliminating divergent paths



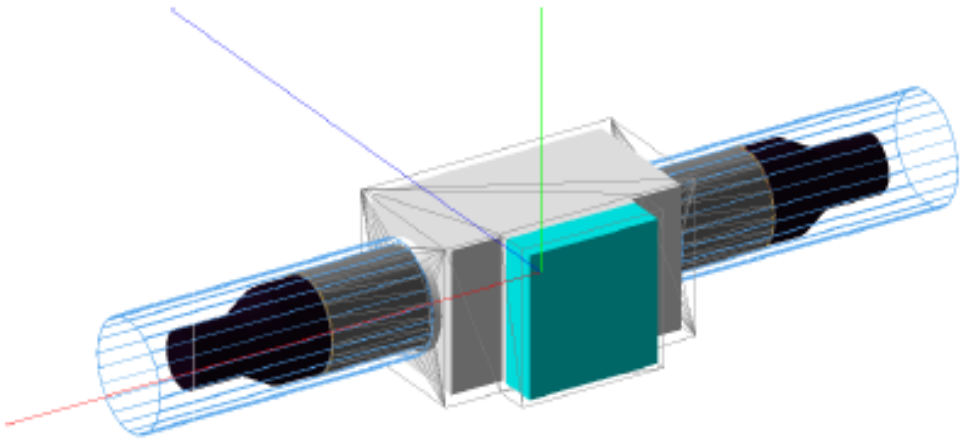
Aerogel key parameters

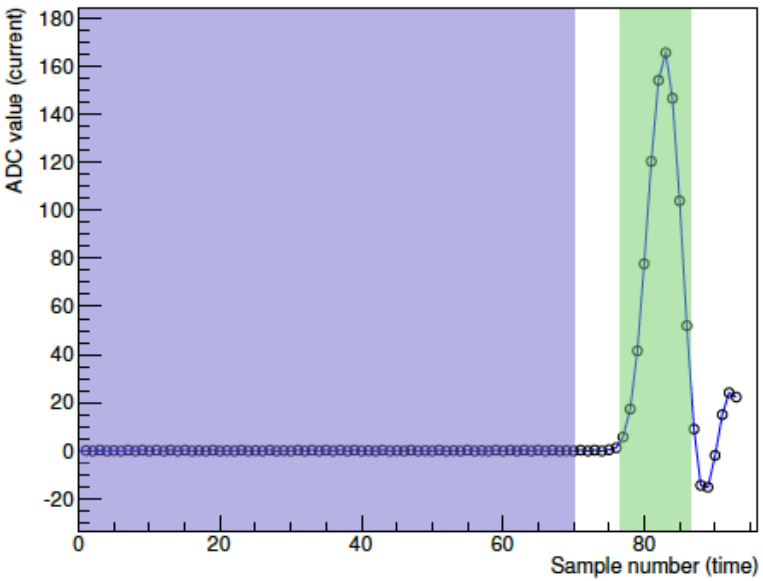
Batches ordered from lowest index of refraction to highest (1.017 - 1.069)

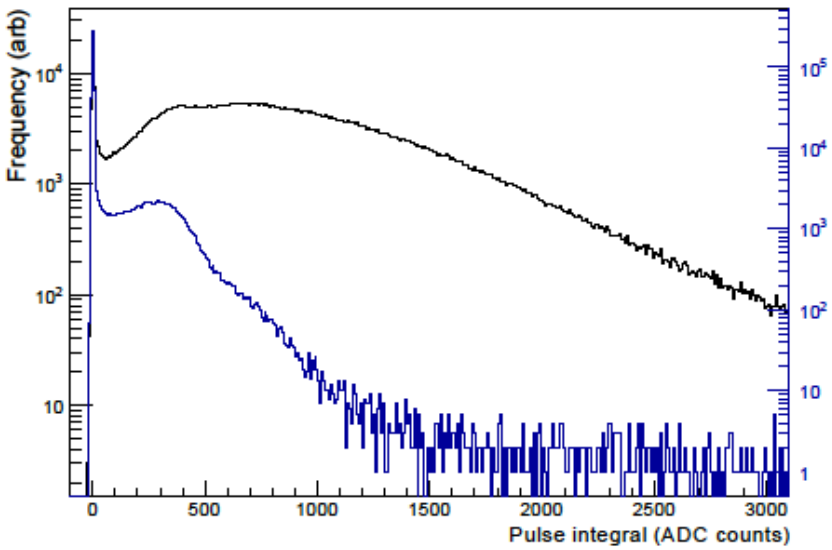
B1 and SP-20 are closely comparable with mean indices 1.0190 (5) and 1.0195 (6) respectively



Performance

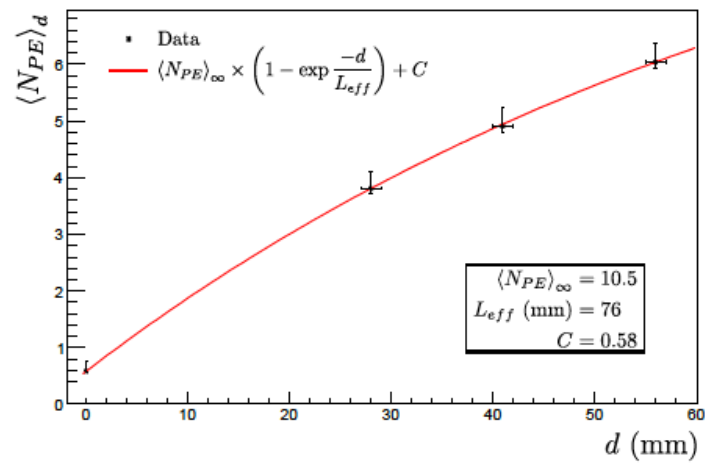


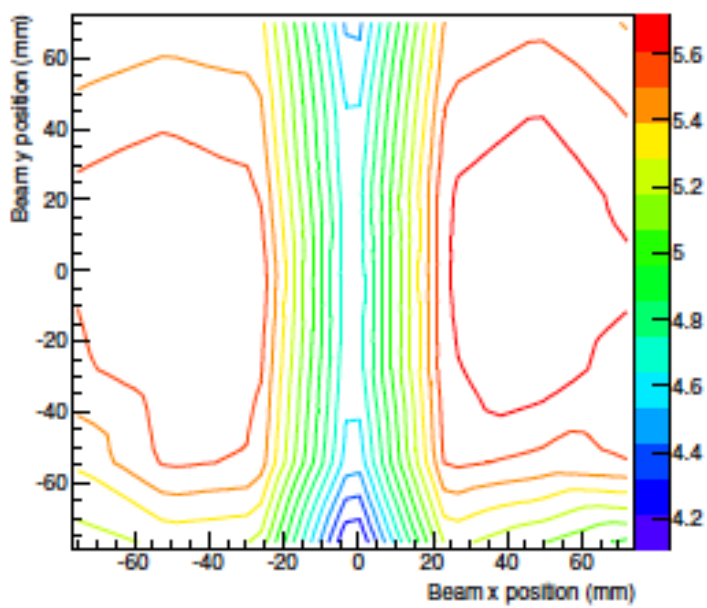


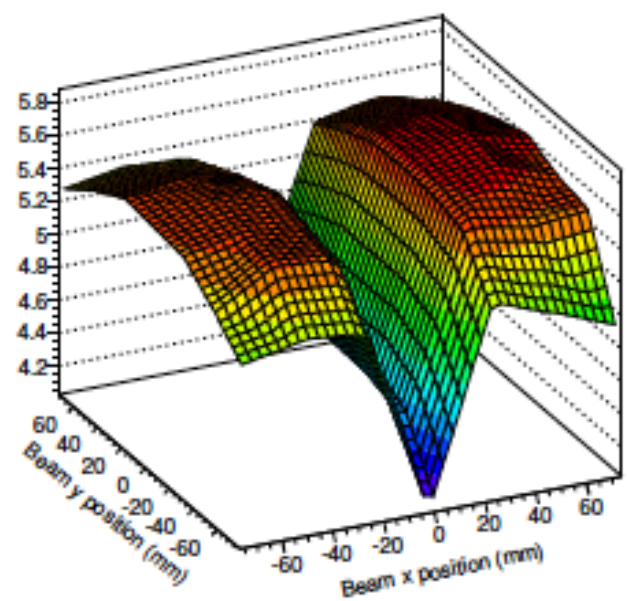


Results for Aspen Aerogels

Batch	Depth (mm)	$\langle N_{PE} \rangle$	$\langle n \rangle$	σ_n	H (cm^{-1})
Empty (air)	0	$0.58^{+0.19}_{-0.02}$	≈ 1.00028	N/A	N/A
1	28	$3.81^{+0.29}_{-0.08}$	1.026	0.0016	40
	41	$4.91^{+0.32}_{-0.10}$			36
	56	$6.04^{+0.34}_{-0.12}$			32
2	53	$6.36^{+0.34}_{-0.12}$	1.028	0.0007	34
3	62	$5.60^{+0.28}_{-0.09}$	1.028	0.0023	28







A direct comparison: Aspen vs Matsushita

Pulse height spectrum shows distribution of pulses from PMTs

Phase II Batch 1 yields more measurable light than MEW SP-20.

With this comes greater efficiency in the same application

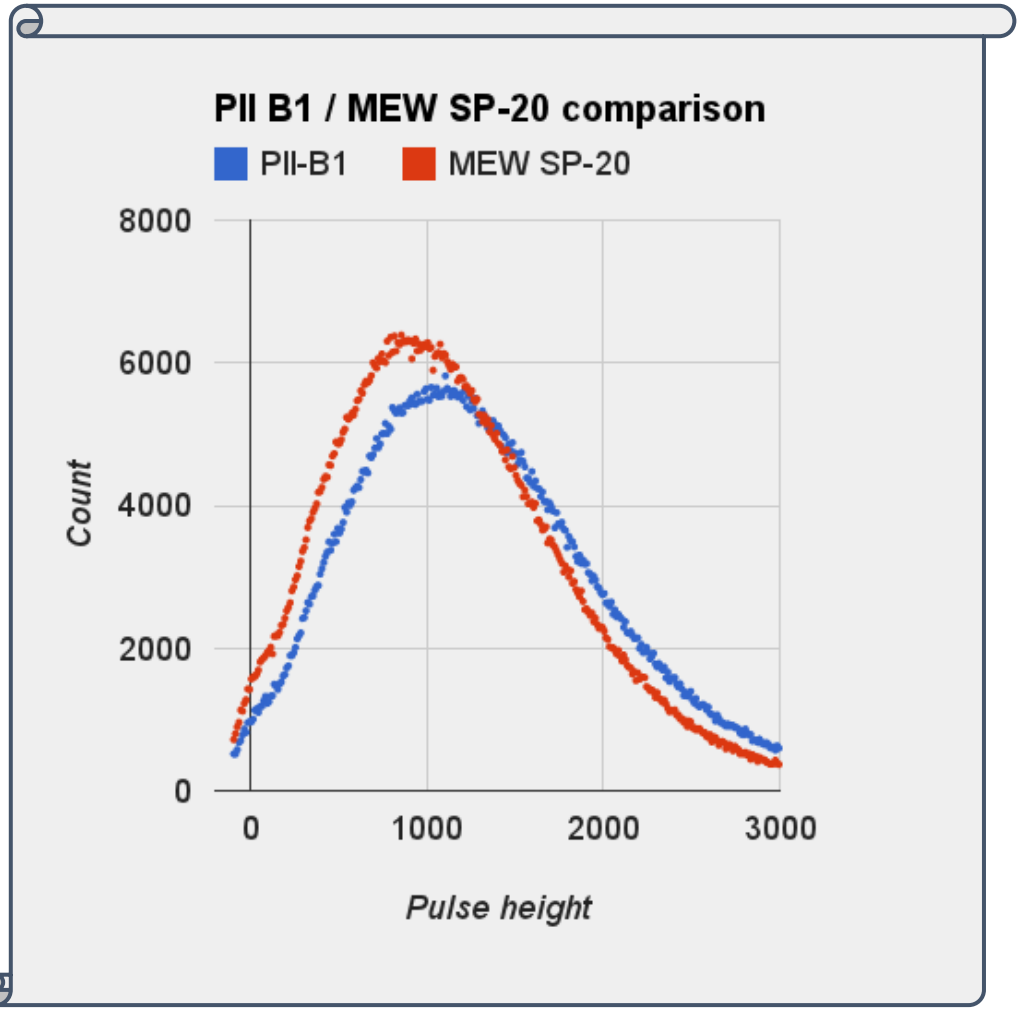


Figure of Merit

D. Higinbotham, *Diffusely reflective aerogel cherenkov detector simulation techniques*, *Nucl. Instrum. Methods Phys. Res. A* **414** (1998), no. 2-3 332 – 339.

$$H_{D.W.H.} \equiv \frac{\langle N_{PE} \rangle}{L\left(1 - \frac{1}{\beta^2 n^2}\right)} * \frac{1 - \eta\,(1 - \varepsilon)}{\varepsilon}$$

L : depth of the aerogel, ε : area fraction covered by PMTs,
η : average reflectivity

$$L\left(1 - \frac{1}{\beta^2 n^2}\right) \rightarrow L_g\left(1 - \frac{1}{\beta^2 n_g^2}\right) + L_a\left(1 - \frac{1}{\beta^2 n_a^2}\right)$$

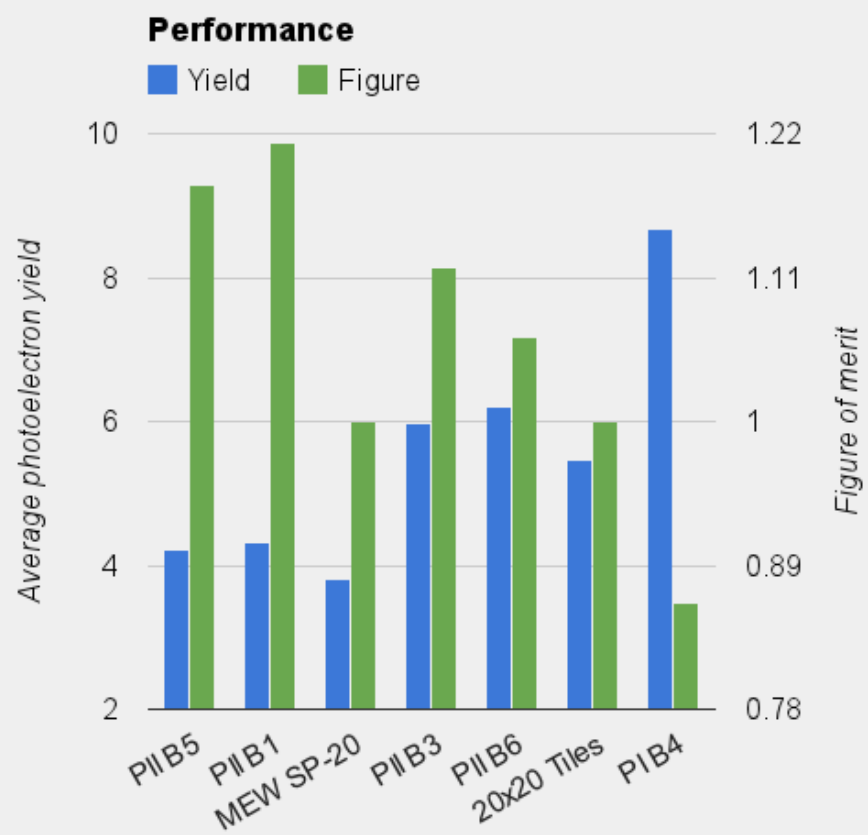
$$H \equiv \frac{\langle N_{PE} \rangle}{L_g\left(1 - \frac{1}{\beta^2 n_g^2}\right) + L_a\left(1 - \frac{1}{\beta^2 n_a^2}\right)} * \frac{1 - \eta\,(1 - \varepsilon)}{\varepsilon}$$

Test beam results: Summary

Raw photoelectron yields are somewhat comparable, but do not give a concrete comparison

Figure of merit uses MC to remove non-goodness related factors (geometry and refractive index)

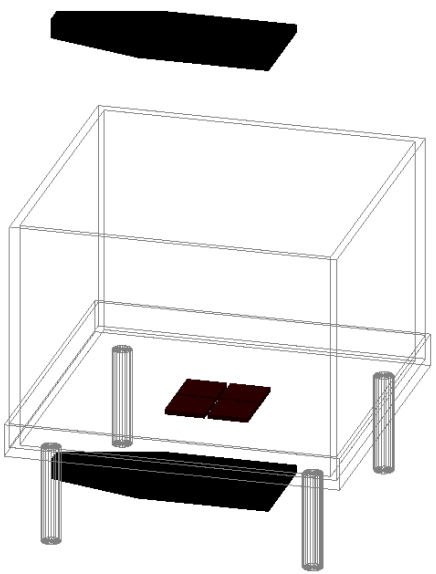
Higher figures of merit indicate more favorable optical properties of the aerogel

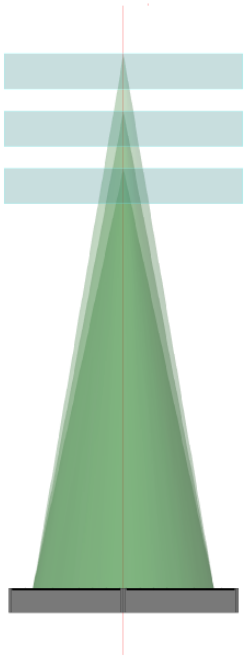


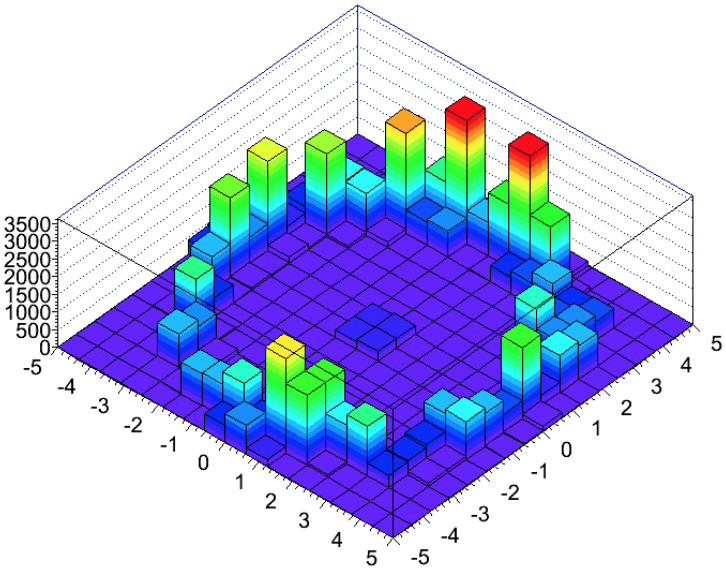
RICH Aerogel

$$\cos(\theta_{\check{C}}) = \frac{c}{nv} = \frac{1}{n\beta}.$$

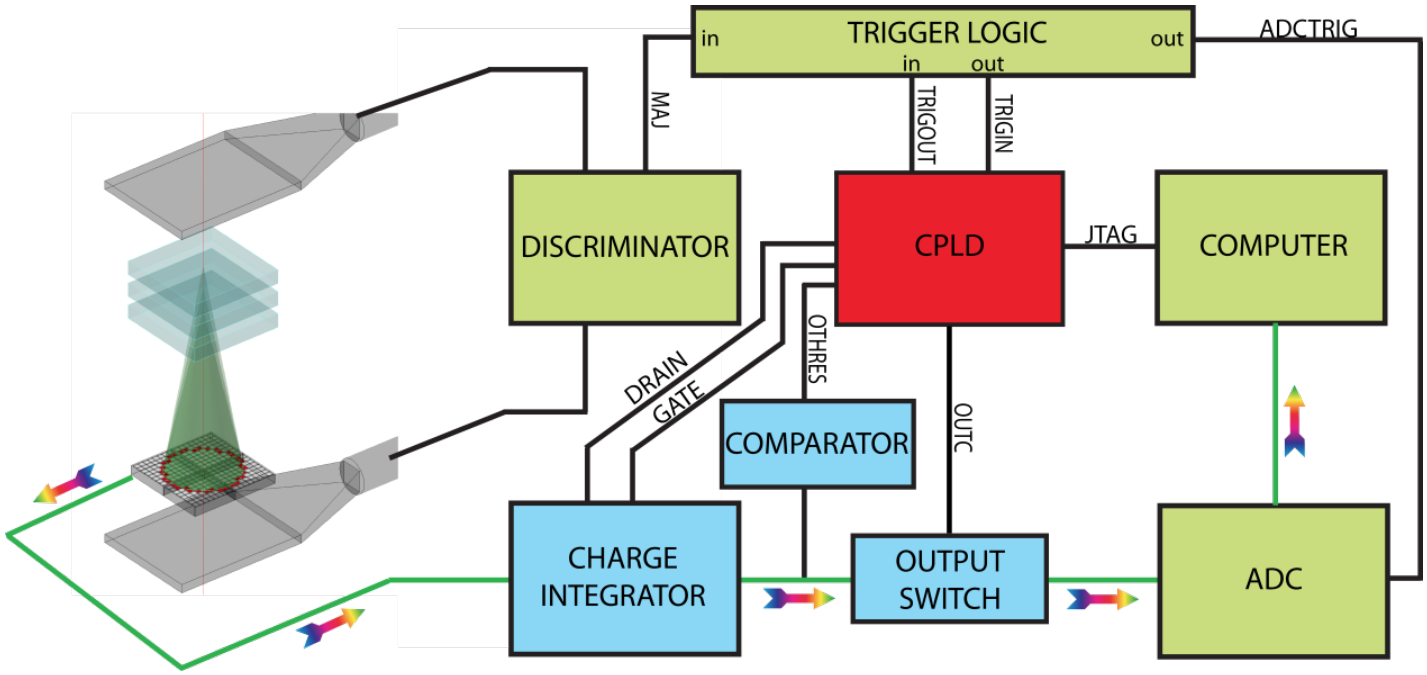
$$\lim_{v \to c} \theta_{\check{C}} = \cos^{-1}(1/n).$$





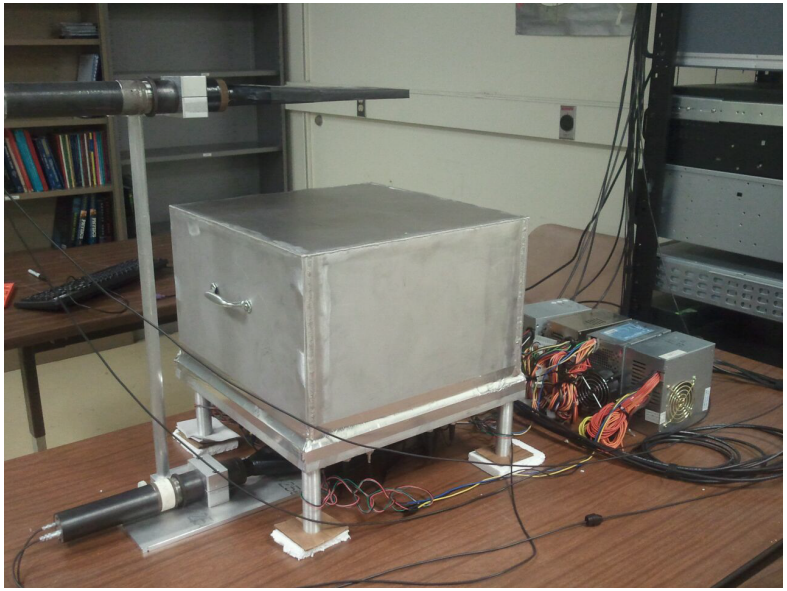


RICH Aerogel

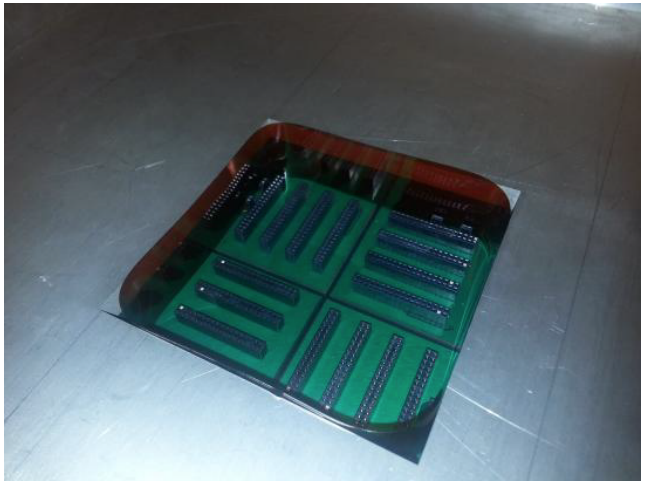


Position-sensitive photodetectors (Hamamatsu H8500D-03)

RICH Equipment



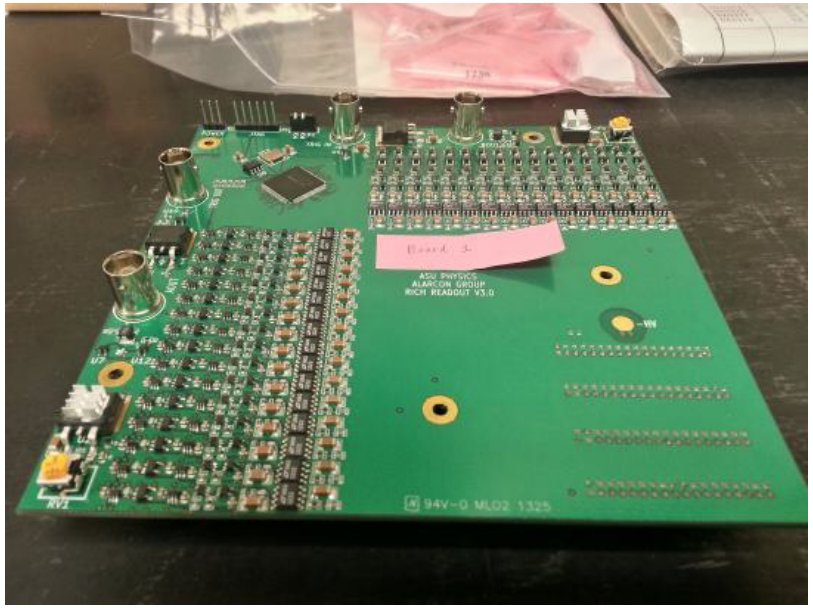
Aerogel Suspension

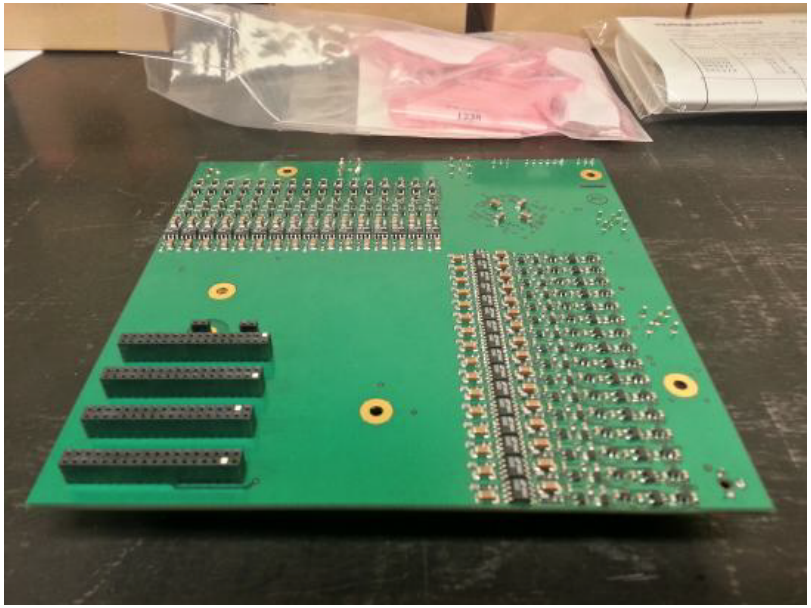


PCB Mounts for PMTs

4 PMTs: 256 channels

Read-Out PCBs





- Read-out system designed and built by ASU students
- One PCB per PMT

RICH Results: Aspen vs Matsushita

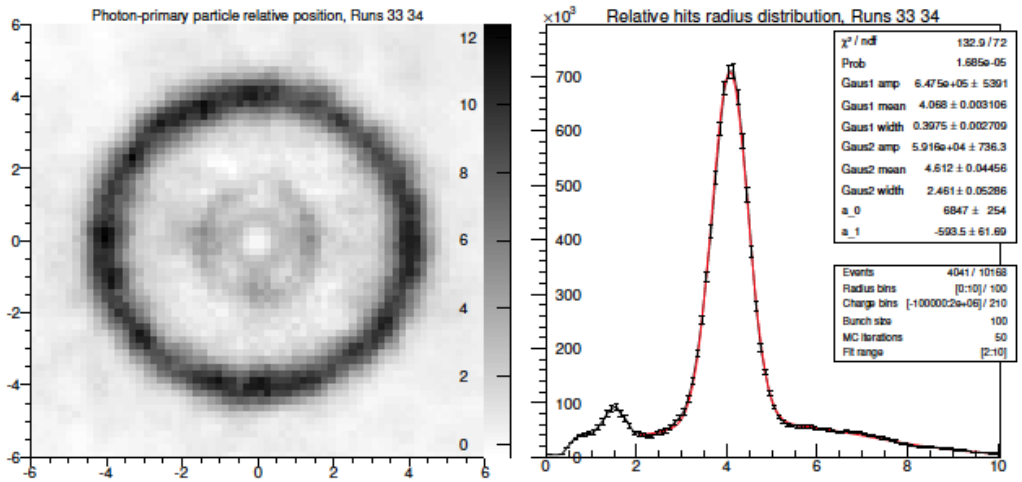


Figure 20: Single Matsushita tile ($n = 1.03$). $\beta = 1$ radius: 4.0 cm.

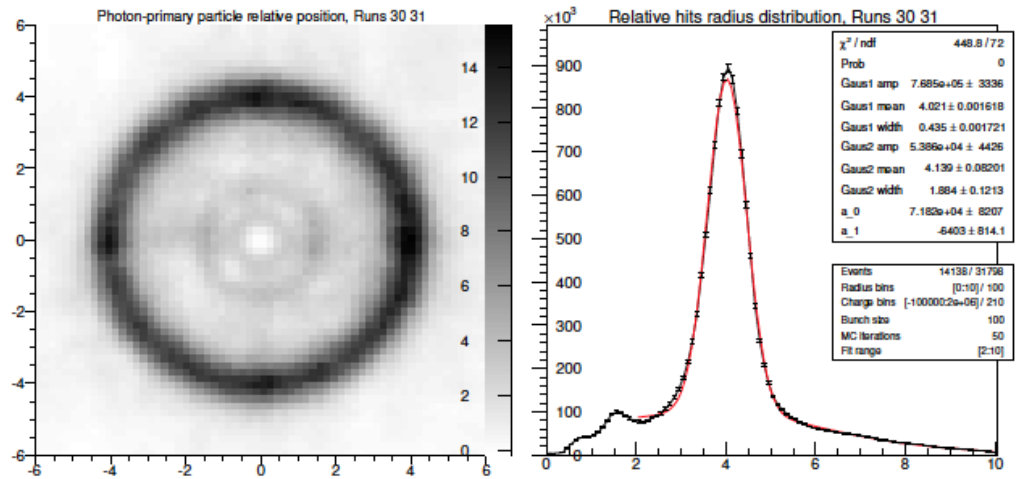


Figure 18: A particularly clear Aspen tile ($n = 1.0267$). $\beta = 1$ mean radius: 4.0 cm.

Focusing Aerogel RICH Results

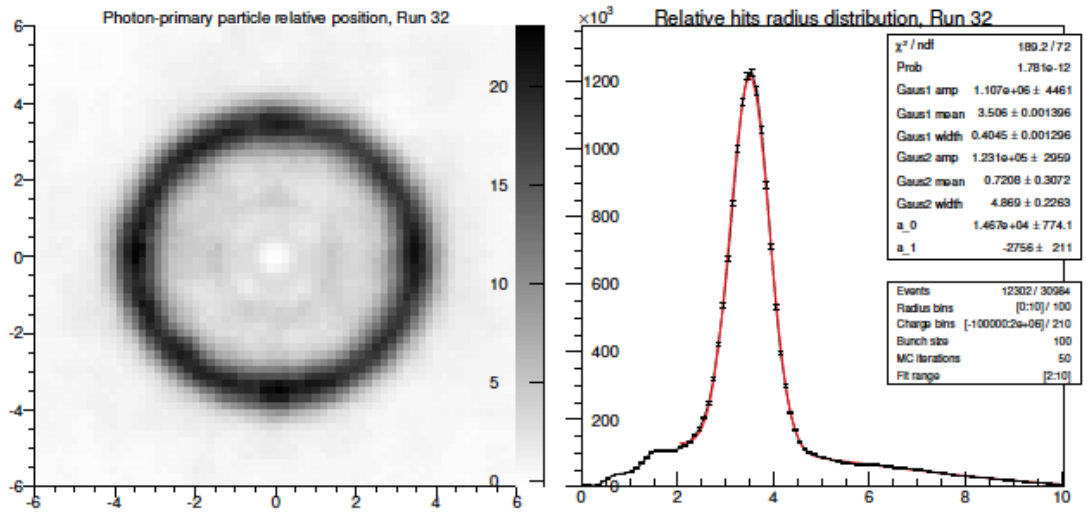


Figure 19: Two Aspen tiles arranged for FARICH. Focusing radius: 3.5 cm.

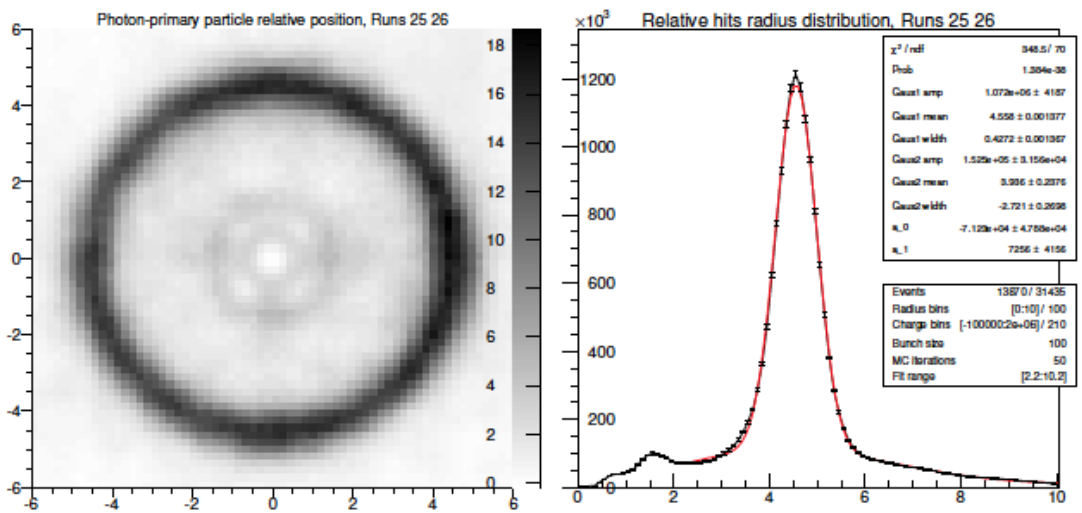


Figure 16: Three Aspen tiles arranged for FARICH at 4.5 cm.

RICH Aerogel Results

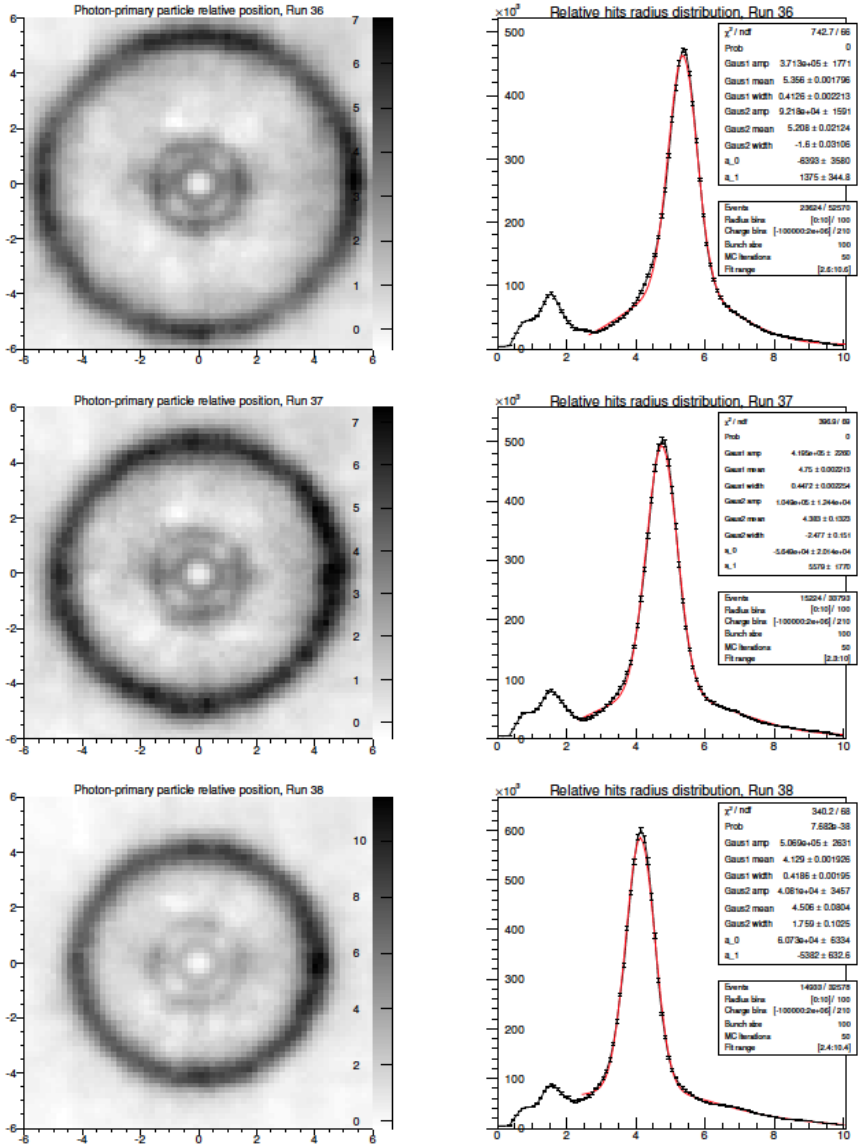


Figure 21: A single Aspen tile ($n = 1.024$) set at three decreasing heights so as to give $\beta = 1$ mean radii of 5.2, 4.6, and 4.0 cm, respectively.

RICH Summary Results

Table 2: Tabulation of elementary ring resolutions.

Run(s)	Short description	σ_{μ_1}/μ_1
25-26	Three Aspen tiles for FARICH at 4.5 cm	0.30×10^{-3}
30-31	Ultra-transparent Aspen tile for mean radius of 4.0 cm	0.40×10^{-3}
32	Two Aspen tiles for FARICH at 3.5 cm	0.40×10^{-3}
33-34	Single Matsushita tile for mean radius of 4.0 cm	0.76×10^{-3}
36	Single Aspen tile for mean radius of 5.2 cm	0.34×10^{-3}
37	Single Aspen tile for mean radius of 4.6 cm	0.47×10^{-3}
38	Single Aspen tile for mean radius of 4.0 cm	0.47×10^{-3}

Educational Impact

- ✓ David Blyth: ASU undergrad and graduate, Phases I and II, Ph.D. 2017, DNP Dissertation nominee (NPDGamma), ANL high energy postdoc.
- ✓ Matt Gibson: senior undergrad, Phase I, Ohio State Ph.D.
- ✓ Jason Holmes: ASU undergrad and graduate, Phase II, Ph.D. 2018
- ✓ Isaac Saldivar: ASU undergrad, senior honors thesis Phase I, graduate school at University of Columbia-Missouri
- ✓ Jesse Stryker: ASU undergrad, senior honors thesis Phase II, graduate school at University of Washington, NSF Graduate Fellowship