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Assembly of a Silica Aerogel Radiator Module for the Belle II ARICH System

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On behalf of the Belle II ARICH Group

Outline

- **Introduction**
  - ARICH PID system in the Belle II detector
  - Requirements for silica aerogel radiator
- **Mass Production of Silica Aerogel Tiles**
  - Crack-free yield
  - Optical characterization
- **Assembly of an Aerogel Radiator Module**
  - Water jet machining
  - Aerogel installation

Introduction

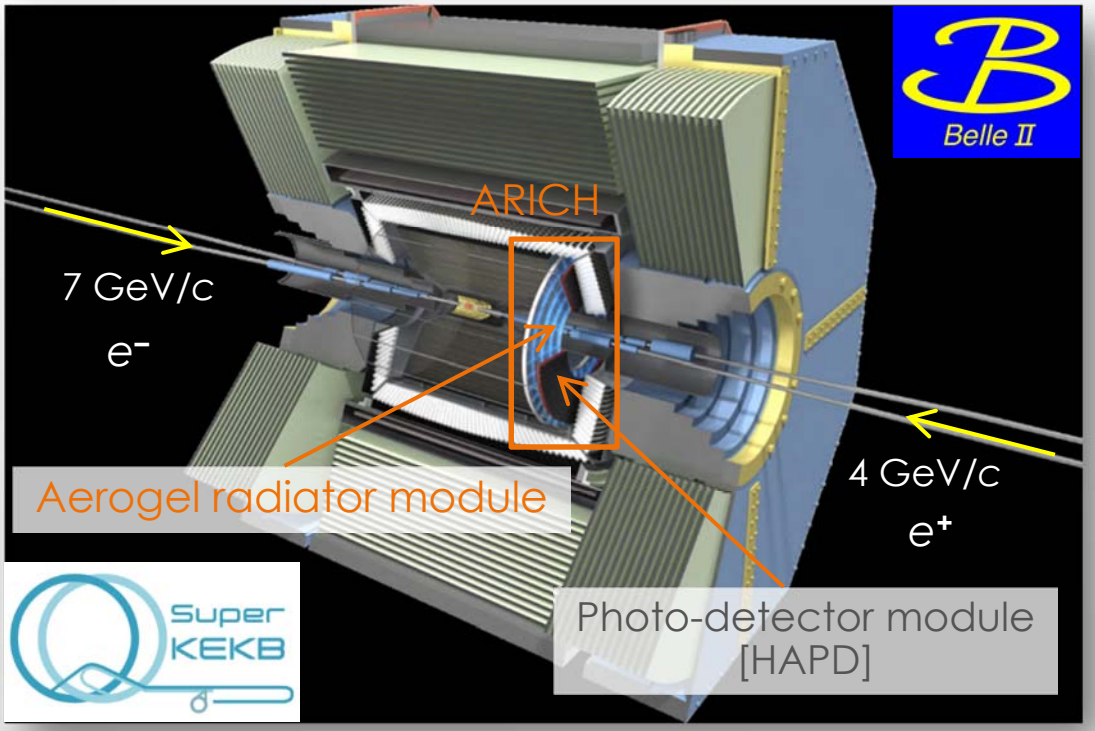
ARICH Counter in the Belle II Detector

- **Super-B factory experiment, Belle II at KEK, Japan**
  - Detector upgrade in progress [Physics run from 2018]
- **Forward endcap PID subsystem, ARICH**
  - **A**erogel-based proximity focusing **R**ing **I**maging **CH**erenkov counter [ARICH]

↑ Upgrade

Threshold-type aerogel Cherenkov counter [ACC] in the Belle

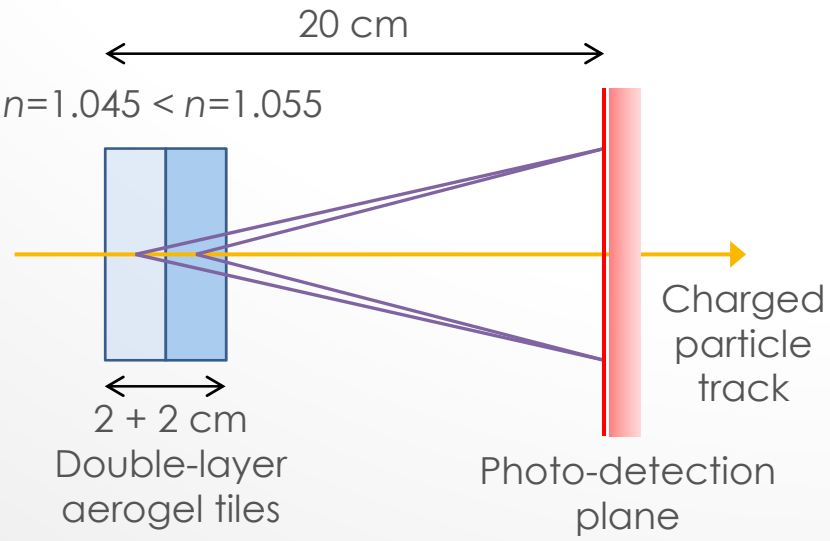
- **Design objective**
  - ***π/K* separation** capability exceeding **4σ at 4 GeV/*c***



Presentation refs. /
T. Konno *et al.* [ARICH general, oral];
K. Ogawa *et al.* [HAPD, poster];
M. Yonenaga *et al.* [Slow control, poster].

Requirements for Aerogel Radiator

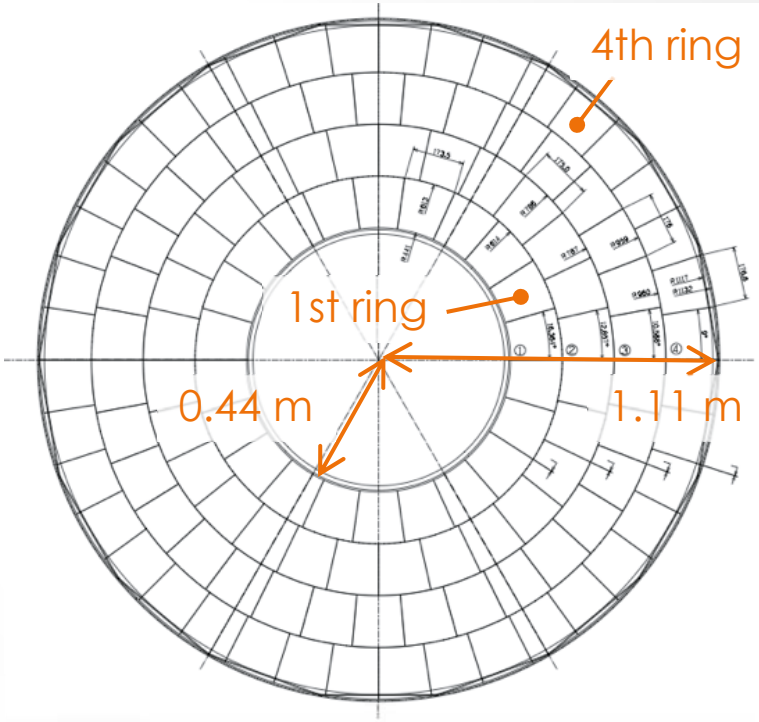
- **Double-layer focusing radiator scheme**
  - 20-cm expansion distance
  - High Cherenkov angle resolution and high photon yield
  - **$n_{upstream}$ = 1.045 [2 cm thick]** & **$n_{downstream}$ = 1.055 [2 cm thick]**
  - Transmission length **Λ_T ~ 40 mm** at 400-nm wavelength
- **Large radiator coverage: 3.3 m^2 [cylindrical]**
  - Minimum tile boundaries
  - 124-segments tiling scheme [**248 tiles**]
  - Fan-shaped tiles trimmed from **crack-free 18 X 18 cm^2 tiles**
- **Hydrophobic characteristics**
  - Water jet machining [**waterproof**]
  - Long-term stability

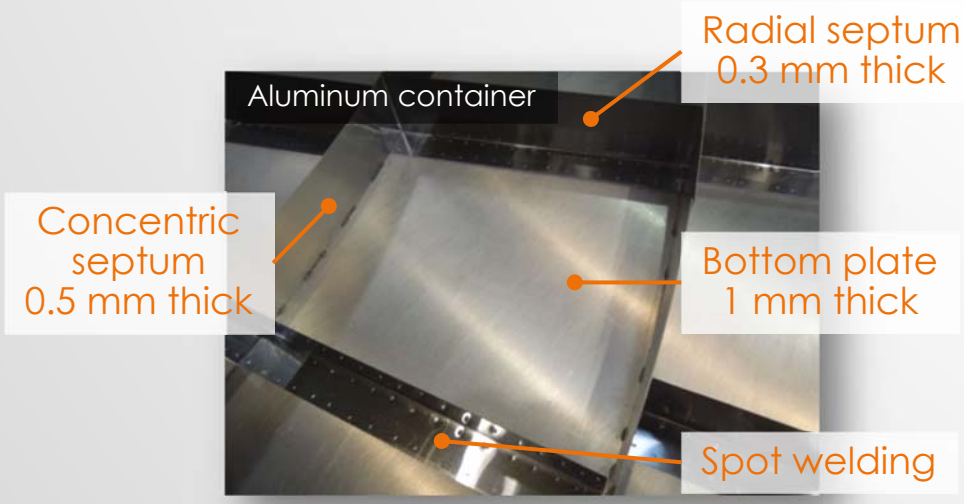


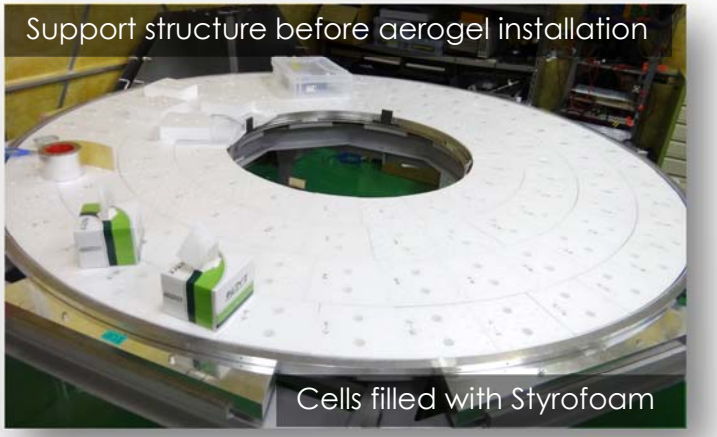
Journal ref. / M. Tabata *et al.*, Nucl. Instrum. Methods A 766 (2014) 212.

Aerogel Tiling Scheme

- **Aerogel support structure**
  - 2.2 m dia. cylindrical module
  - 3.3 m^2 [130 L]
  - 4 concentric rings
    → 4 types of aerogel shapes
  - 124 aluminum cells
  - 248 fan-shaped aerogel tiles

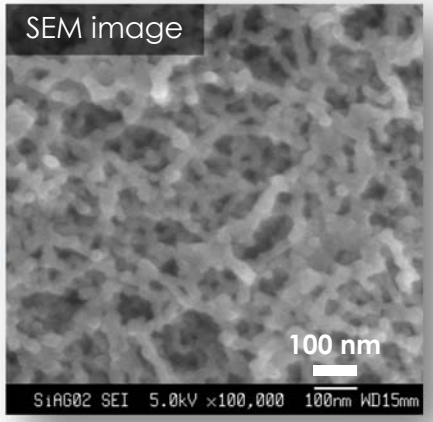






Silica Aerogel

- **Colloidal foam of nanoscale SiO_2 particles**
  - **Transparent**
  - **Tunable refractive index** [i.e., bulk density]
    n = 1.003–1.26 Journal ref. / M. Tabata et al., Nucl. Instrum. Methods A 623 (2010) 339.
    - Density determined by silica–air volume ratio



- **Basic production procedure**
  - Journal ref. / M. Tabata *et al.*, Nucl. Instrum. Methods A 668 (2012) 64.

1. Wet gel synthesis by the sol–gel method
2. Solvent exchange & Surface modification
3. Supercritical CO_2 drying

Mass Production of Silica Aerogel Tiles

Mass Production of Aerogel Tiles

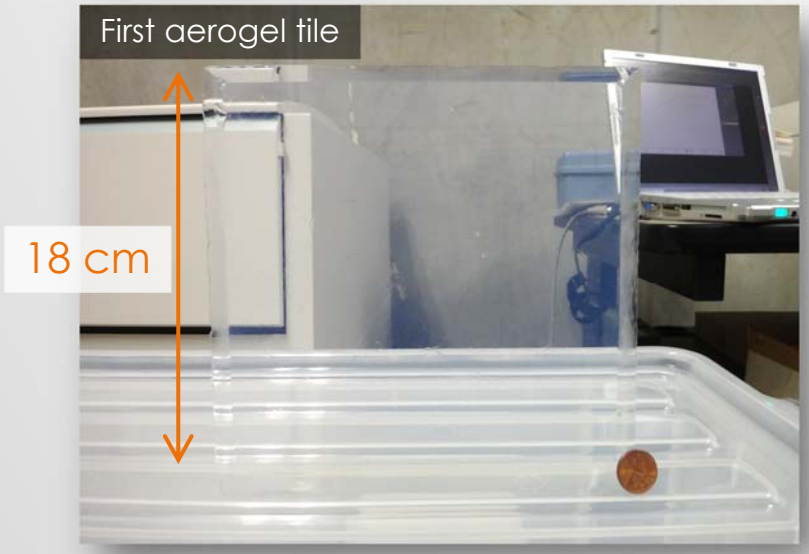
- **Prior to mass production, large-area [18 × 18 × 2 cm³] tiles were successfully developed in good crack-free yield [~80%].**
  - Collaboration among KEK, Chiba Univ., Japan Fine Ceramics Center [JFCC], and Panasonic Corporation

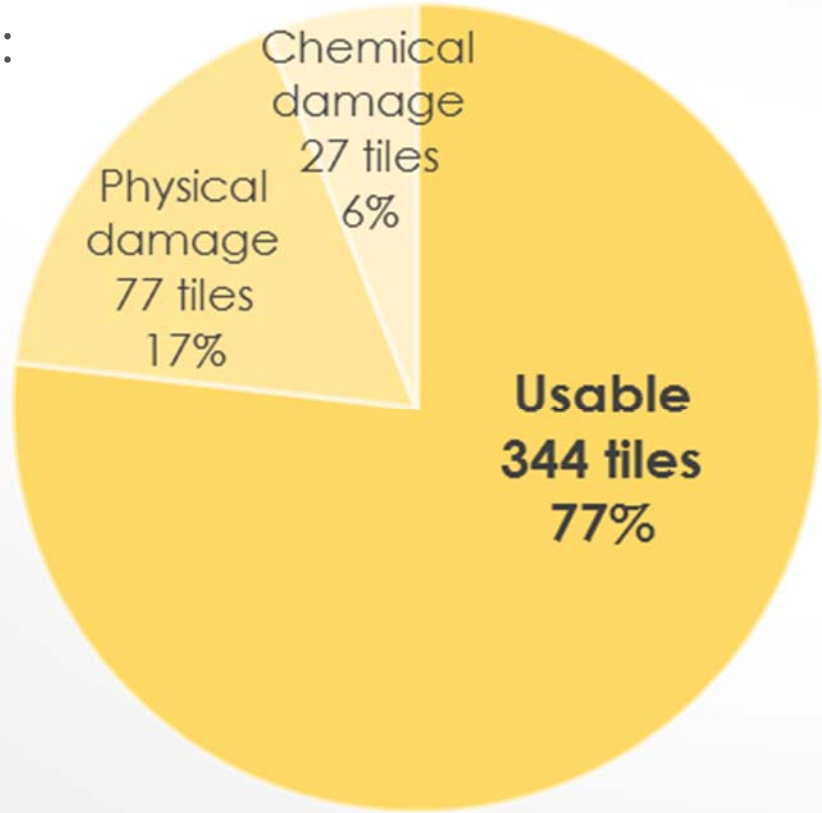
Panasonic

  - Technology transfer from Chiba U. and Panasonic to JFCC
  - Journal ref. / M. Tabata *et al.*, J. Supercrit. Fluids 110 (2016) 183.
- **Aerogel mass production was begun in Sep. 2013 and completed in May 2014 at JFCC.**
  - 16 lots / 448 tiles
  - Delivered to KEK for quality check as soon as production lots became available

Yield of Tiles without Damages

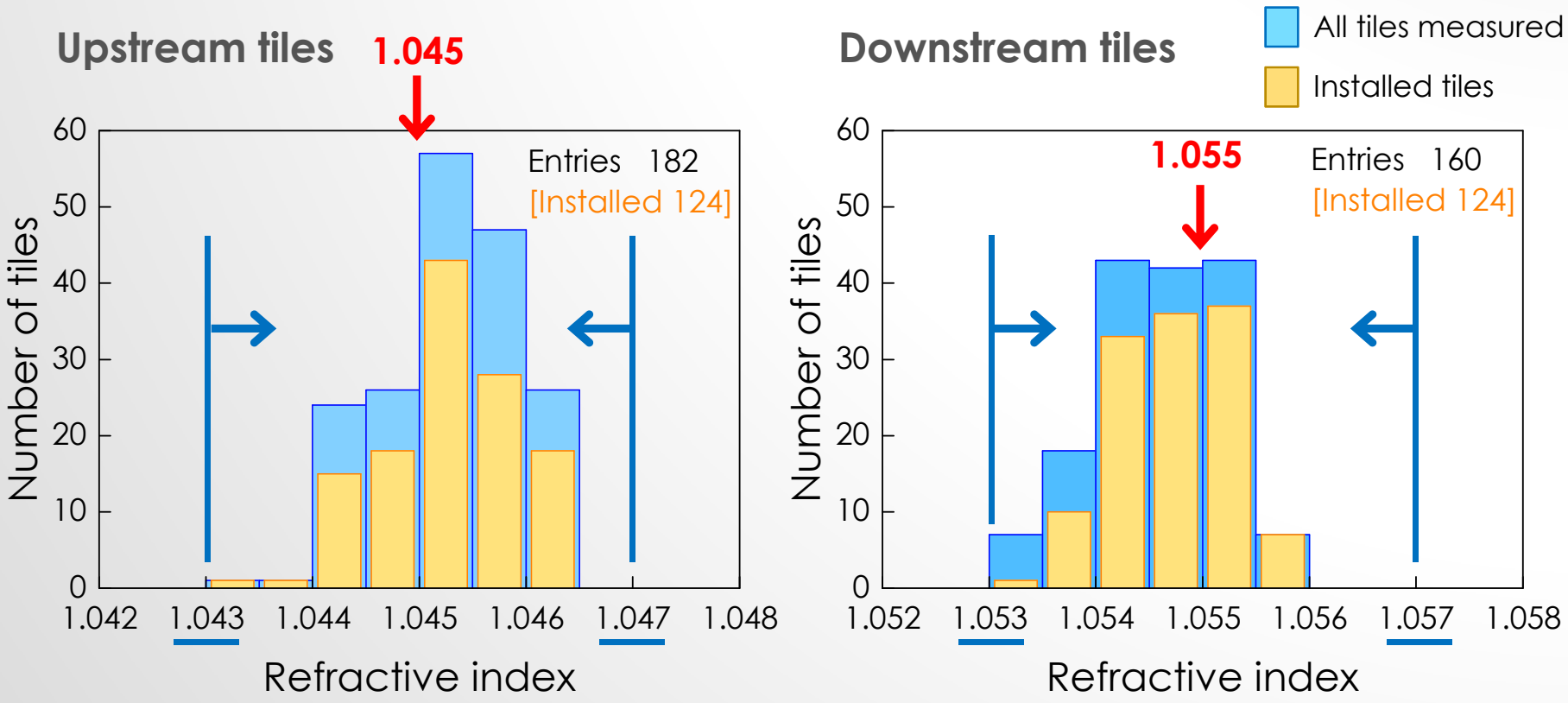
- **The tile yield was 77%, obtaining 344 usable tiles.**
  - 448 tiles manufactured
  - 248 mandatory and 96 [39%] spare tiles obtained
- **Tile damage classification**
  - Physical [mechanical] damages: Tile cracking, chipping, etc.
  - Chemical [optical] damages: Milky tile due to a sol–gel error





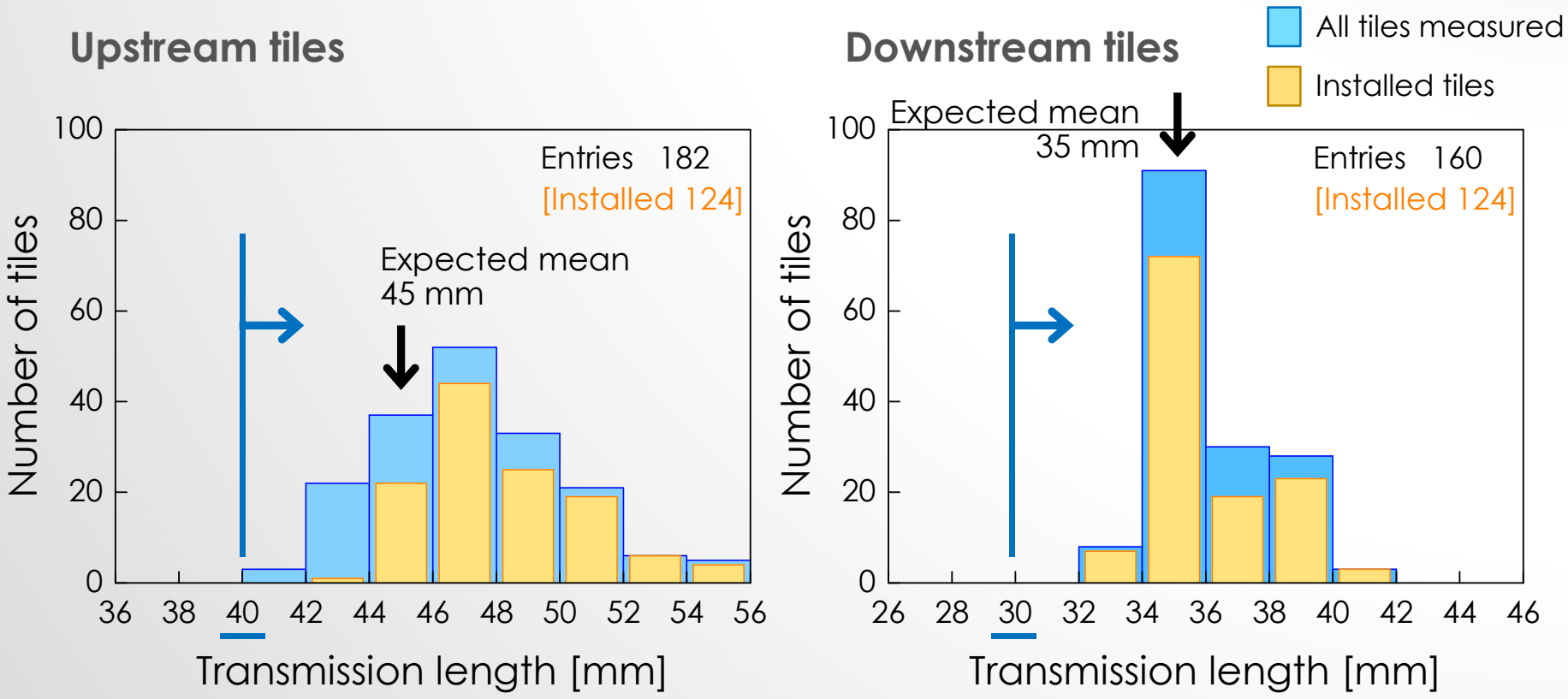
Refractive Index

- **The deviations from the target refractive indices were within our expectation.**
  - *n* [target] = 1.045 ± 0.002 [up] & 1.055 ± 0.002 [down]



Transmission Length

- **The transparency was enough to meet our requirements.**
  - Λ_T [target] > 40 mm [up] & 30 mm [down] at 400-nm wavelength

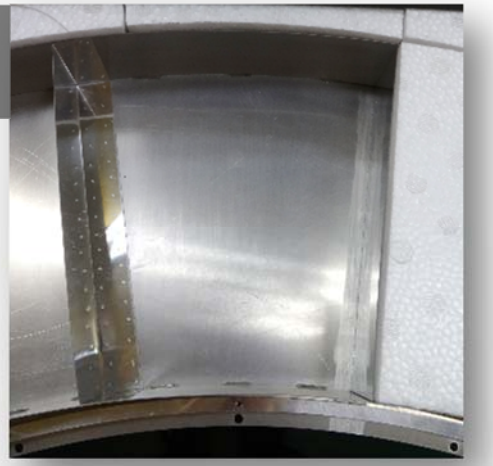


Assembly of an Aerogel Radiator Module

Water Jet Machining

- **Square tiles were cut into fan shapes using a water-jet cutting device at a company.**

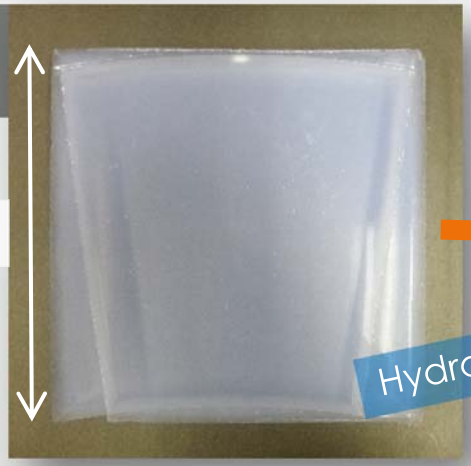
Fan-shaped container



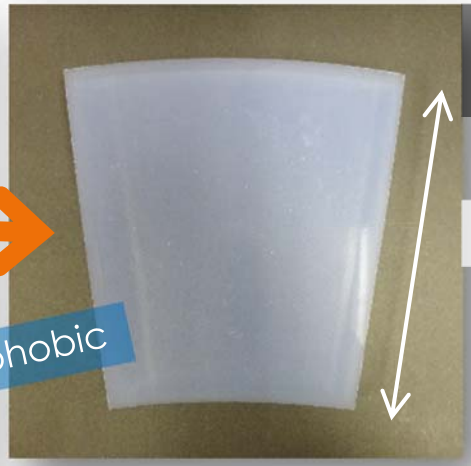
CAD drawing

Delivered tile after machining

18 cm



Hydrophobic

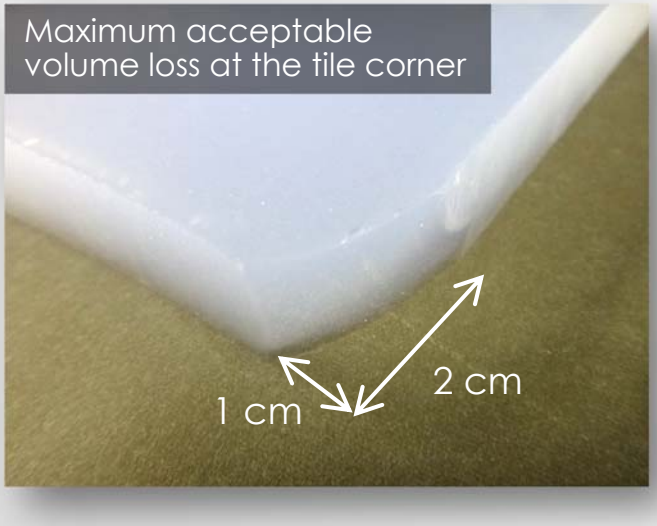


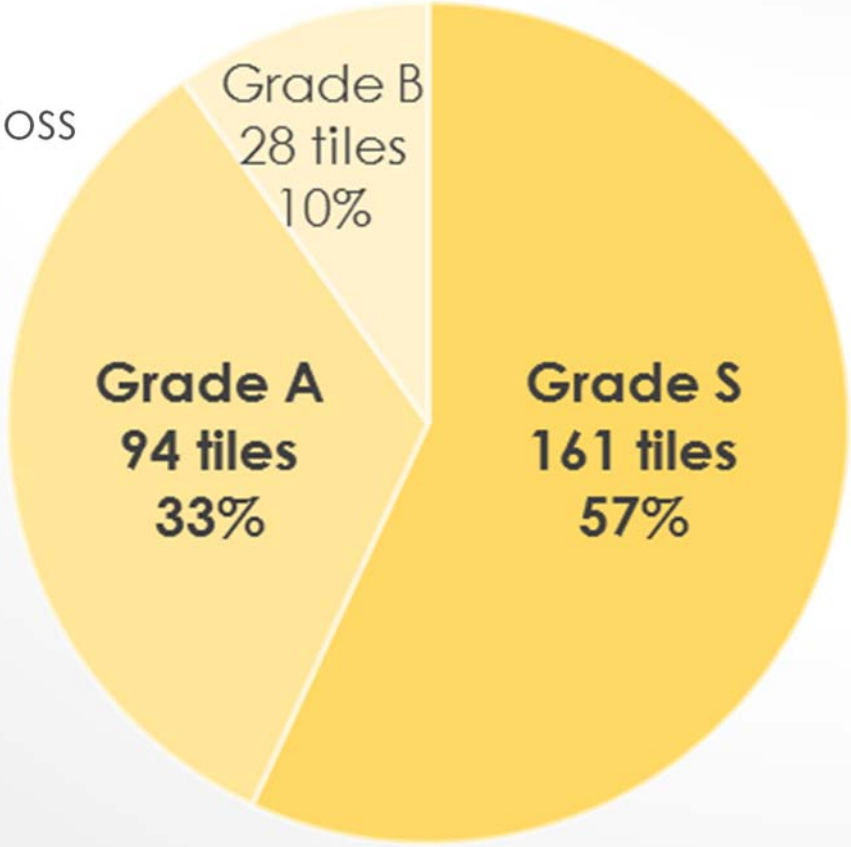
Trimmed part to be used

17 cm

Yield of Tiles without Volume Loss

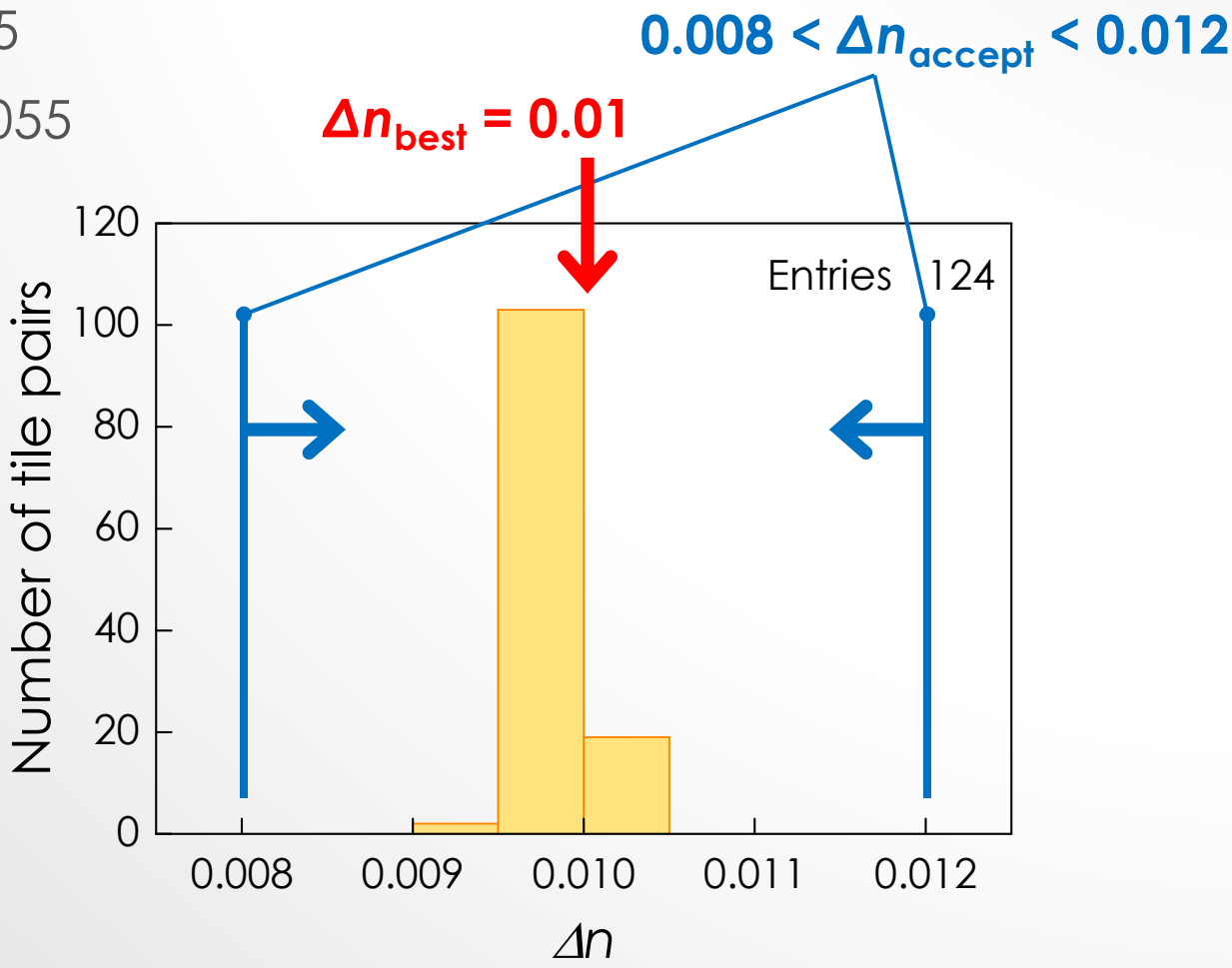
- **The success rate of water jet machining was 90% without volume loss, yielding 248+ tiles.**
  - 283 tiles water-jet machined
- **Classification**
  - Grade S / No volume loss
  - Grade A / Acceptable volume loss [≤ 1 cm^2, 0.4%]
  - Grade B / Unusable





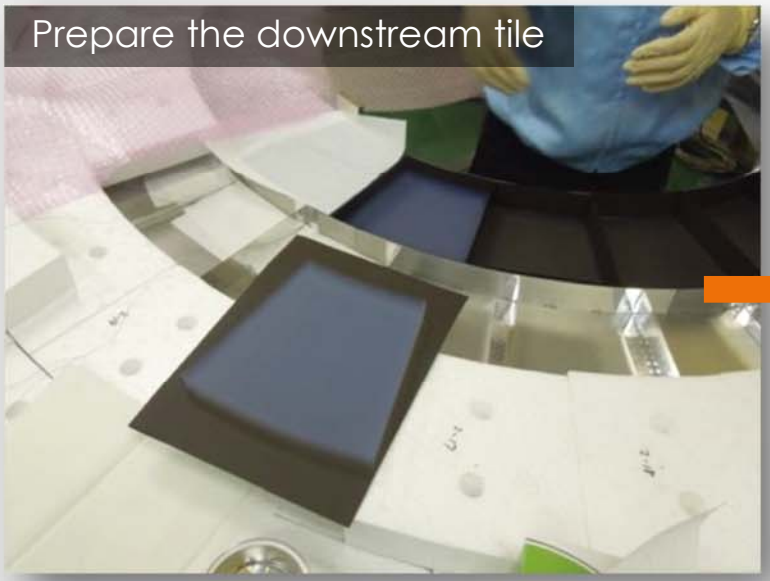
Combination of 2-layer Tiles

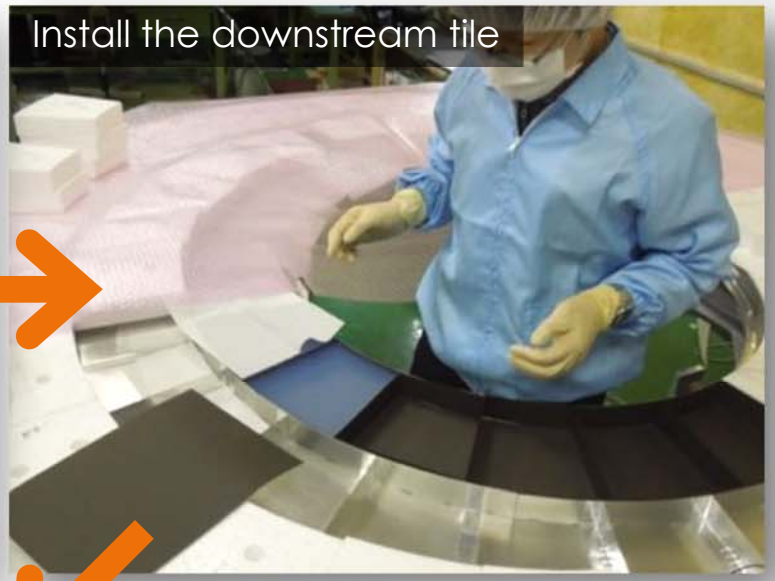
- **Pairs of upstream and downstream tiles were determined to build a good-focusing-radiator framework.**
  - n_{up} [target] = 1.045
  - n_{down} [target] = 1.055
  - $\Delta n \equiv n_{down} - n_{up}$



Aerogel Installation Procedure

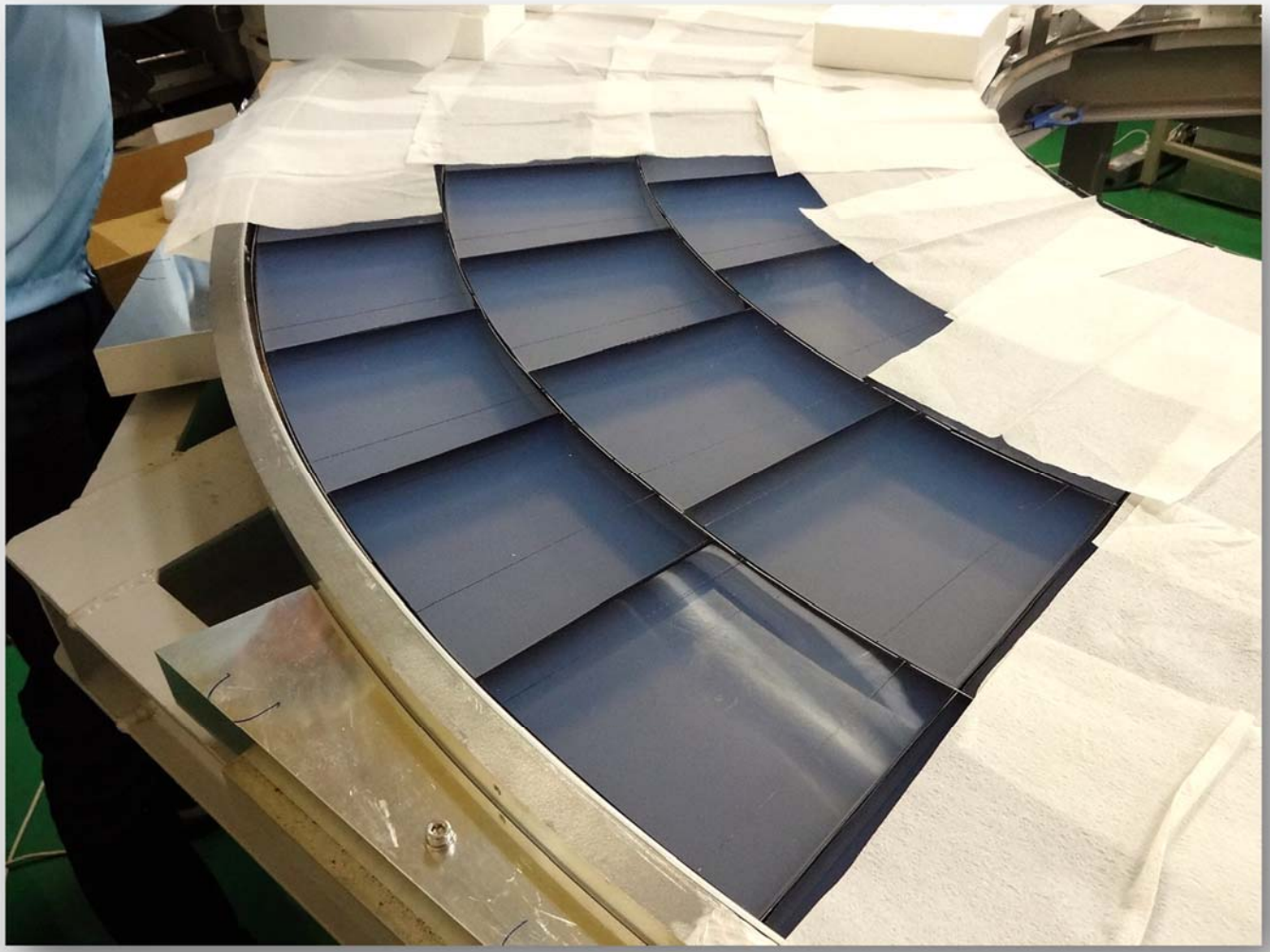
Aerogel Installation Procedure (cont'd)





Aerogel Installation Completed

- **Aerogel installation for 124 cells was completed in Dec. 2016.**



Summary

- **Large-area, hydrophobic silica aerogel tiles for use as Cherenkov radiators in the ARICH system were developed.**
  - The ARICH system will be used for identifying π and K mesons at the forward endcap of the Belle II spectrometer.
- **Mass production of highly transparent aerogel tiles with high refractive index was successful.**
  - The optical performance of mass-produced aerogel tiles was validated.
- **Assembly of the aerogel radiator module was completed.**
  - The aerogel module with the photo-detector module will be installed in the Belle II spectrometer in around Sep. 2017.