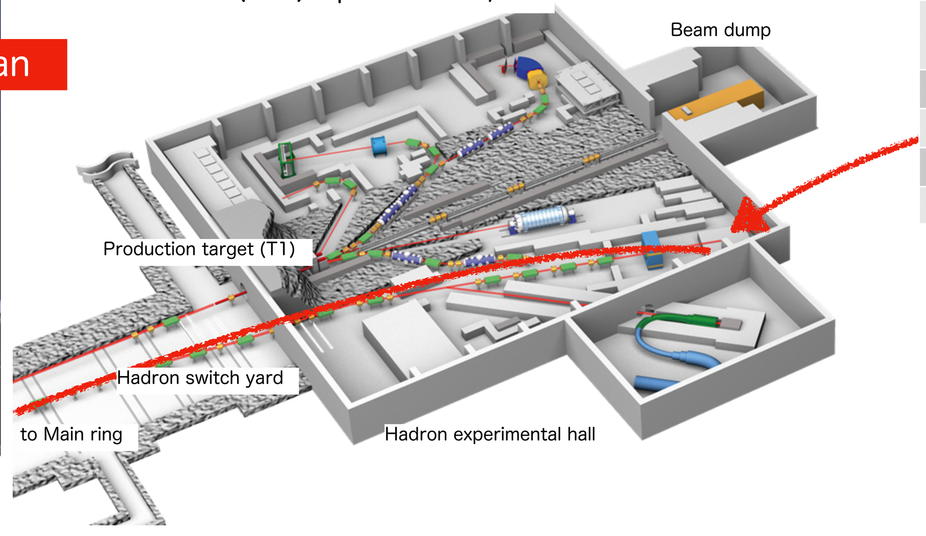
Development of a Gas/Aerogel Dual-Radiator RICH Detector for MARQ Spectrometer

K. Suzuki[1], H. Noumi[1], K. Shirotori[1], D. Co[1], T. Toda[2], K. Ohno[3], K. Nagata[3], A. Sakaguchi[3], T. Yokoyama[3], M. Takenaka[3], Y. Yabuta[3], H. Furutani[3], O. Finch[4], M. Frank[4], for the J-PARC MARQ collaboration
[1]RCNP, Osaka-U, [2]Physics Dpt., Osaka-U, [3]CFC, Osaka-U, [4]U-Connecticut

1. π20 Beam Line at J-PARC and MARQ Spectrometer

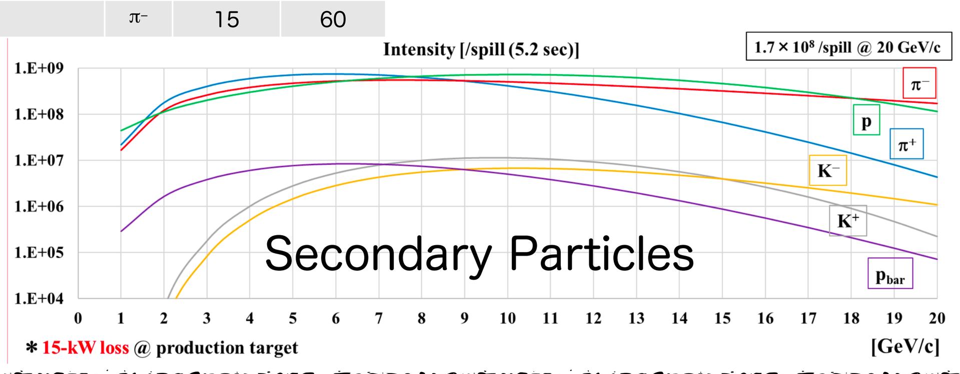
J-PARC Hadron Experimental Facility

K1.8, K1.8BR: up to ~2 GeV/c
π20 (new): up to 20 GeV/c

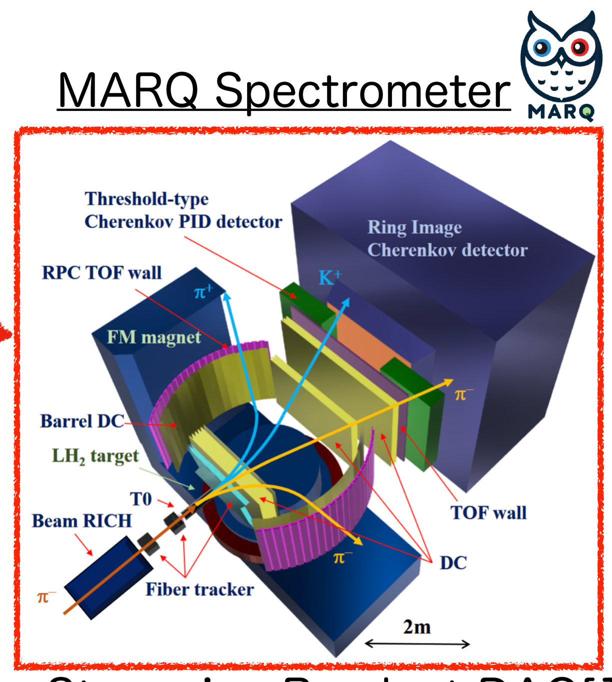


Experimental Plans at π20

No	Experiment	Beam	Mom. [GeV/c]	Intensity [M/spill]
E50	Charmed baryon	π^-	20	60
E79	Non-strange dibaryon search	p	2.85–4.50	2
E97	Ξ baryon	K-	8	0.6
P85	Ω baryon (pilot run)	K-	7,8,9,10	0.6
P95	ϕ meson production	π^-	1.6–2.4	~0.02
LOI	Drell-Yan experiment	π^-	15	60



MARQ Spectrometer

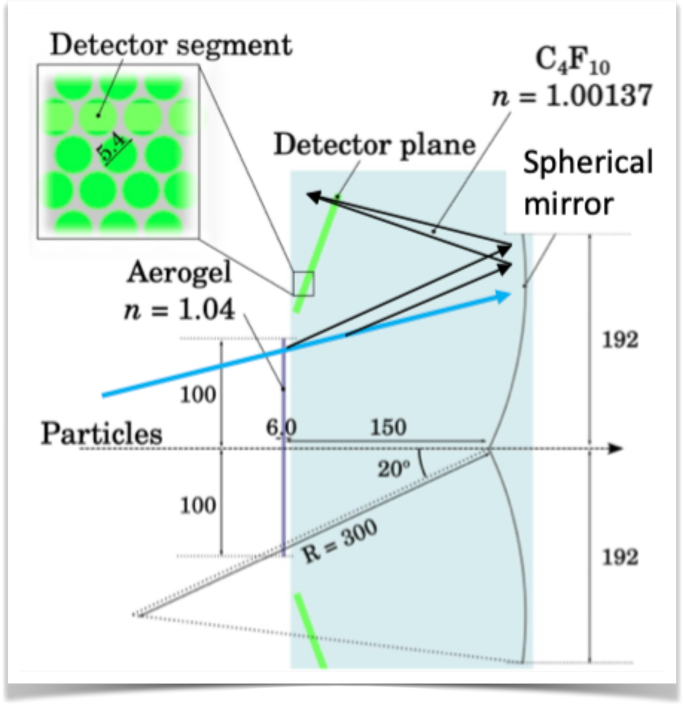


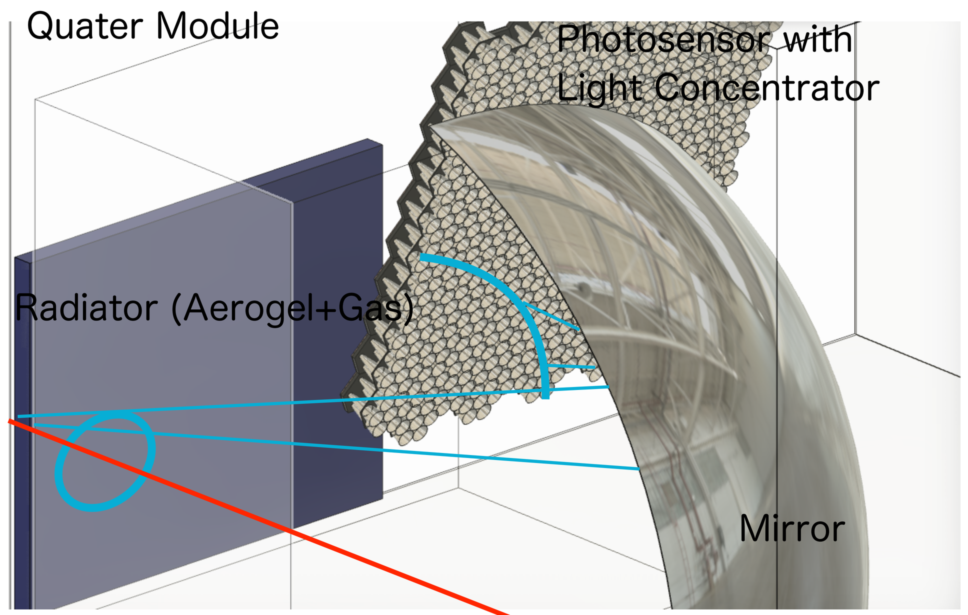
Streaming Readout DAQ[1]

2. RICH Requirements, Design, and Challenges

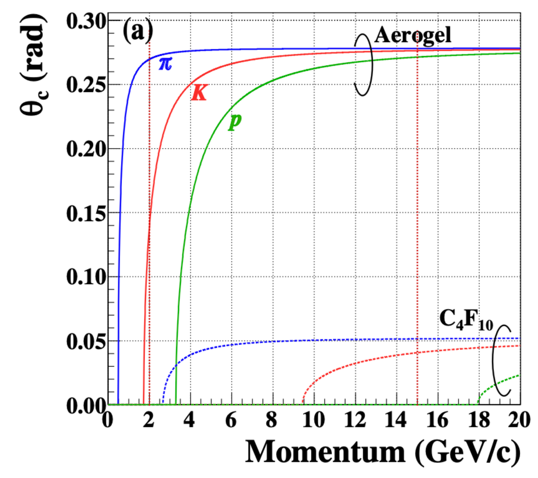
Momentum range: 1-16 GeV/c
PID efficiency: 99%

Angular resolution $\Delta\theta_c < 10$ mrad
Dual radiator: ~200×250 cm²
aerogel: n=1.04,
πK ID for 2~10 GeV/c, 6cm thick
C_4F_8O: n=1.00137
PID for 10-16 GeV/c, 150cm thick
2x2 Segments in x-y
Mirror focus: r=300cm, 541(W)x384(H) cm²
Use SiPM [1, 2]





p±/K±/π± 1~16 GeV/c

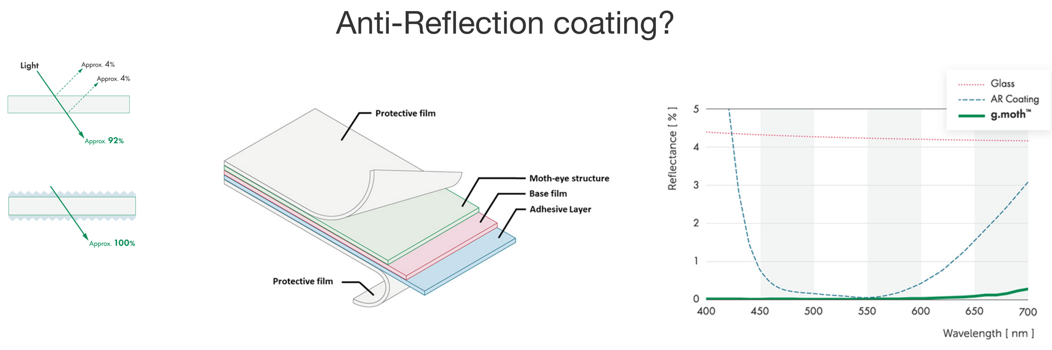


Silicon Photomultiplier: modern alternative to PMT
Pros: cost effective, compact, robust, longer future
Cons: small sensitive area, large dark count rate

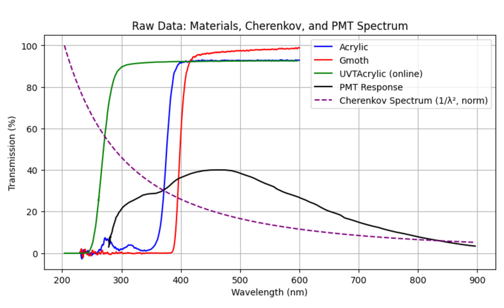
3. Reflection on acrylic surfaces

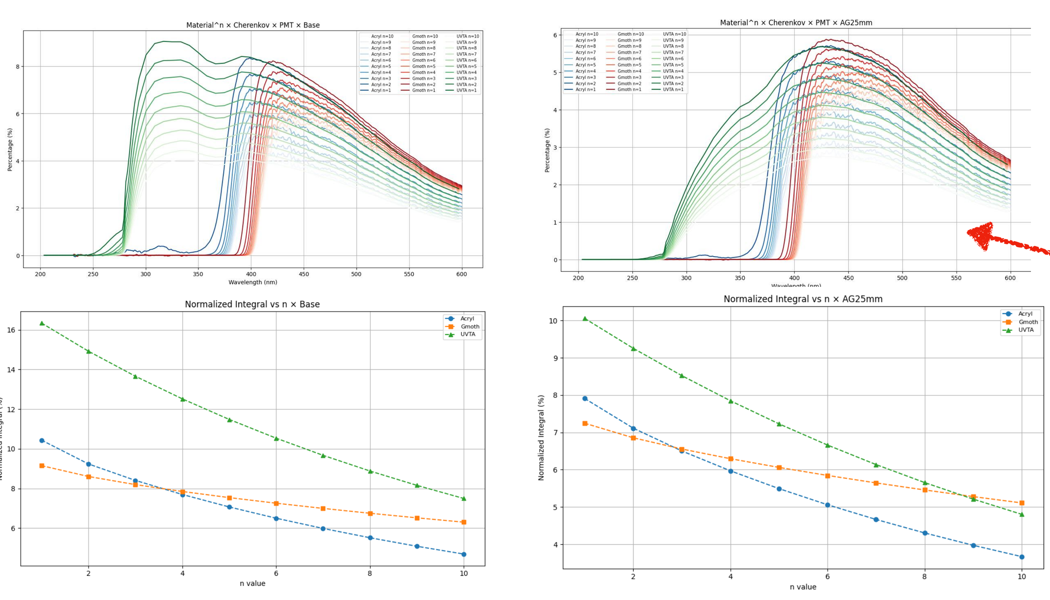
There are unavoidably layers of acrylic/glass surface on the light path. Gas radiator must be contained in a box. Photosensor is cooled down to -30℃ and therefore thermally isolated from surrounding. Most likely acrylic is the choice for our size. You lose ~10% of light at each layer.

Anti-Reflection coating?



g.moth™ film structure
Nano sized fine structure printed base film is sandwiched between the protective films. Base film: TAC or PET [x] [3]



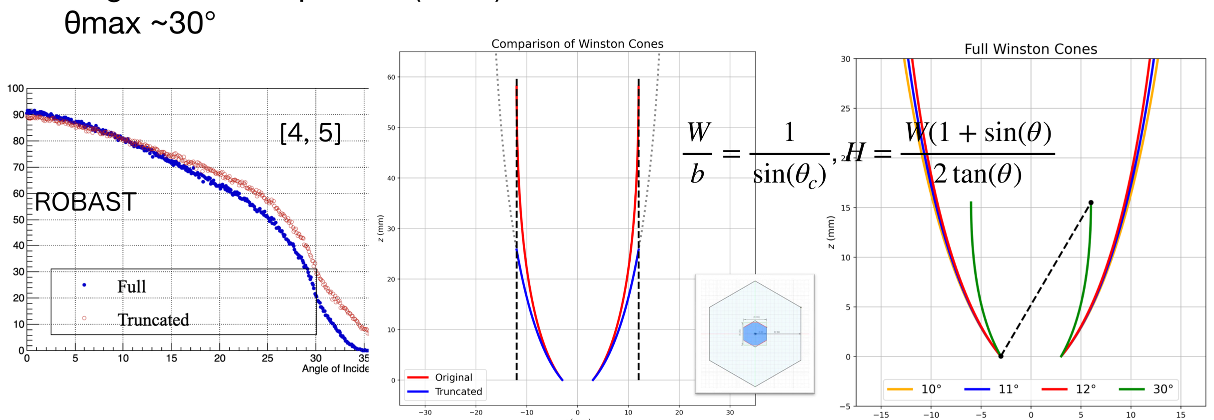


G-moth film lacks UV transparency, making it unsuitable for Cherenkov applications—except when several layers are used, where it can perform better.

4. Light Concentrator

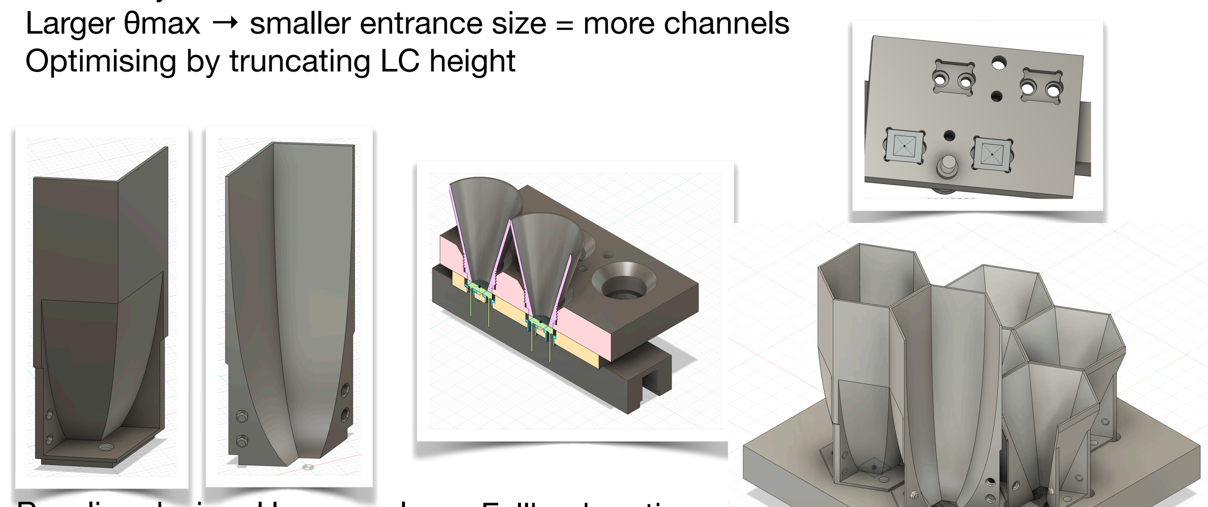
Light Concentrator, a hollow light guide to increase effective sensitive area, with effective coating inside, coupled with a 6x6mm² SiPM, Hamamatsu MPPC S13360-6075CS (DCR~2MHz)

Target entrance size: ϕ=25mm (granularity, angl. resolution, #channels)
Target exit size: ϕ=6mm (SiPM)
θmax ~30°



$$\frac{W}{b} = \frac{1}{\sin(\theta_c)}, \quad H = \frac{W(1+\sin(\theta))}{2\tan(\theta)}$$

Efficiency drops at large incident angle (non-ideal LC, e.g. hex-shape, <1 reflectance)
Practically: θc > θmax.
Larger θmax → smaller entrance size = more channels
Optimising by truncating LC height

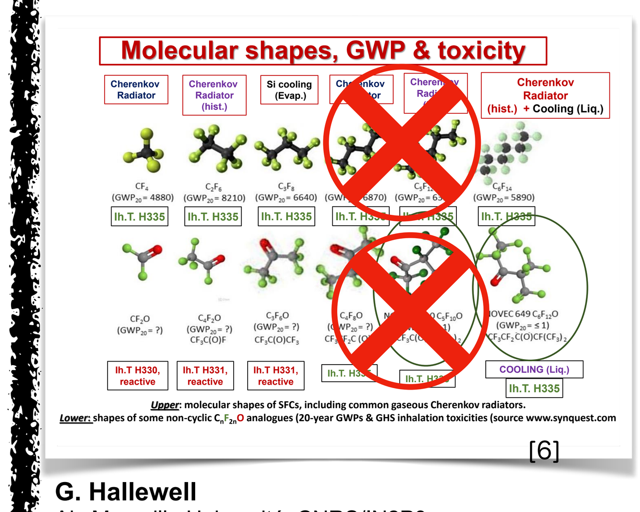


Baseline design: Hexagonal Winston cone

Fallback option: Conical shape, circular cross section

5. Gas Radiator

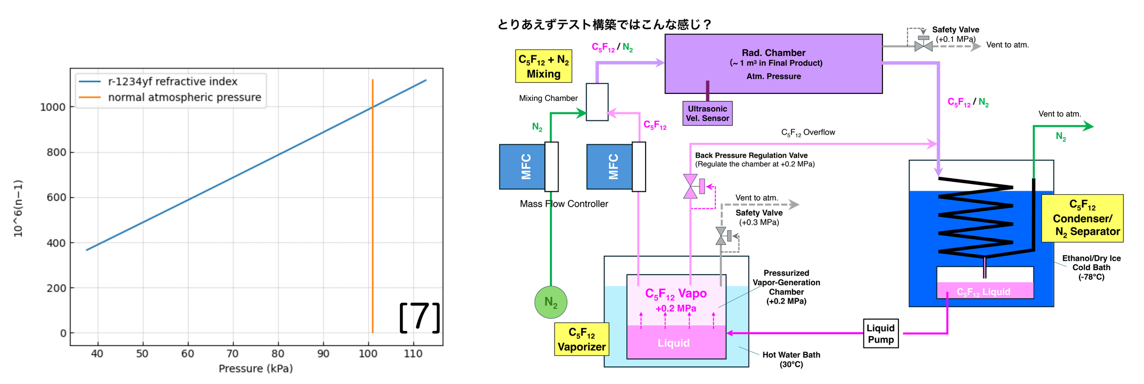
C_4F_{10} gas, a standard Cherenkov radiator for GeV-range particle ID, has been phased out due to environmental concerns. $C_nF_{2n}O$ series (3M), strong replacement candidate has been also discontinued.



G. Hallewell
Aix Marseille Université, CNRS/IN2P3, CPPM, Marseille, France
DRD4 Collaboration Meeting, WG-2: CERN Oct 21-25 2024

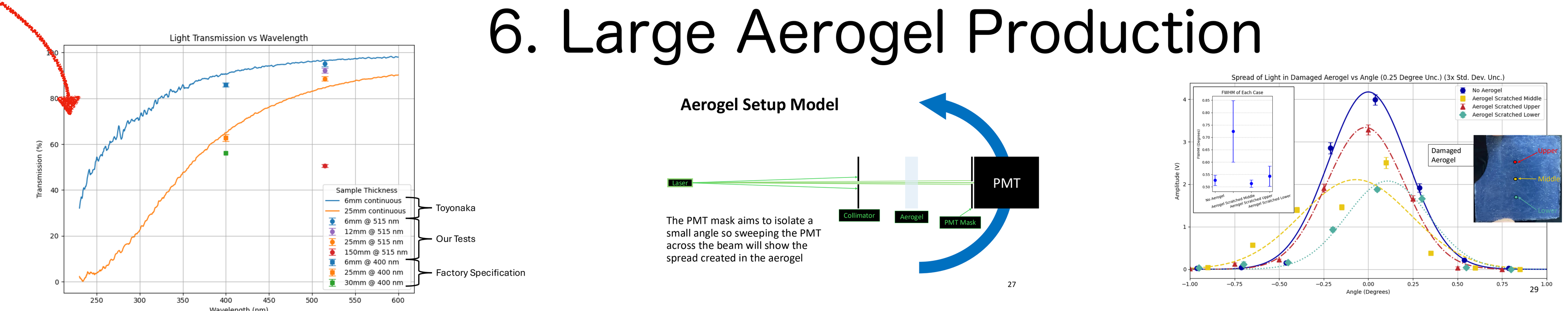
Composition (Wt%)	R-1234yf	R-1234ze	R-1233zd
Molecular Weight	114	114	130.5
Boiling Point (°C)	-29	-19	19
Critical Temp. (°C)	95		194kJ/kg
Vapour Pressure (25°C)	0.677MPa	3.2	-107°C
Vapour Pressure (80°C)	2.44MPa	9.7	106.3kPa
Liquid Density (20°C)	1.296g/ml		
Surface Tension (20°C)	13.3dyne/cm		
Viscosity (20°C)	0.489cP		
Frammability Range (Vol% in Air)	6.2～12.3	7.0～9.5	-
Solubility (25°C)			-
ODP	0	0	0
GWP	<1	<1	1

R-1234yf, R-1234ze, alternative gases for R-134a gas, appearing on horizon, despite their moderate flammability



A recirculation and purification circuit will be used for a stable and cost-effective operation.

6. Large Aerogel Production



A large auto-jar is being prepared to produce a 5x30x30 cm³ aerogel radiator. Work in Progress. [8]

→ 19.9 (Fr.) 11:20- "Developing hydrophobic silica aerogel for Cherenkov detectors", M. Tabata

[1] T. Yamaga, Master Thesis, 2014, Osaka University.
[2] M. Tokuda, Master Thesis, 2023, Osaka University.
[3] GEOMATEC https://www.geomatec.com/
[4] Okumura et al., Astroparticle Physics 38 (2012) 18.
[5] Okumura et al., Astroparticle Physics 76 (2016) 38.
[6] G. Hallewell, DRD4 collaboration.
[7] "Candidate to replace R-12 as a radiator gas in Cherenkov detectors", Harvey et al., NIMB425 (2018) 38-42
[8] M. Tabata et al., J. Supercrit. Fluids 110 (2016) 183-192.

Supported by JST [K program] Japan Grant Number JPMKP24J3 and MEXT Grant-in-Aid of Scientific Research S No. 22H04940

6. Summary and Outlook

The MARQ RICH is designed for PID of 2–16 GeV/c p/K/π at the J-PARC π20 beamline. It employs SiPMs as photosensors, that, once successfully built, will be an attractive cost effective option for this class of detectors. Our studies demonstrate that associated challenges can be successfully addressed, and desired angular resolution as well as PID performance can be achieved. A quarter-module prototype construction is planned for 2026.