

Recent advances in the development of the MARQ RICH detector

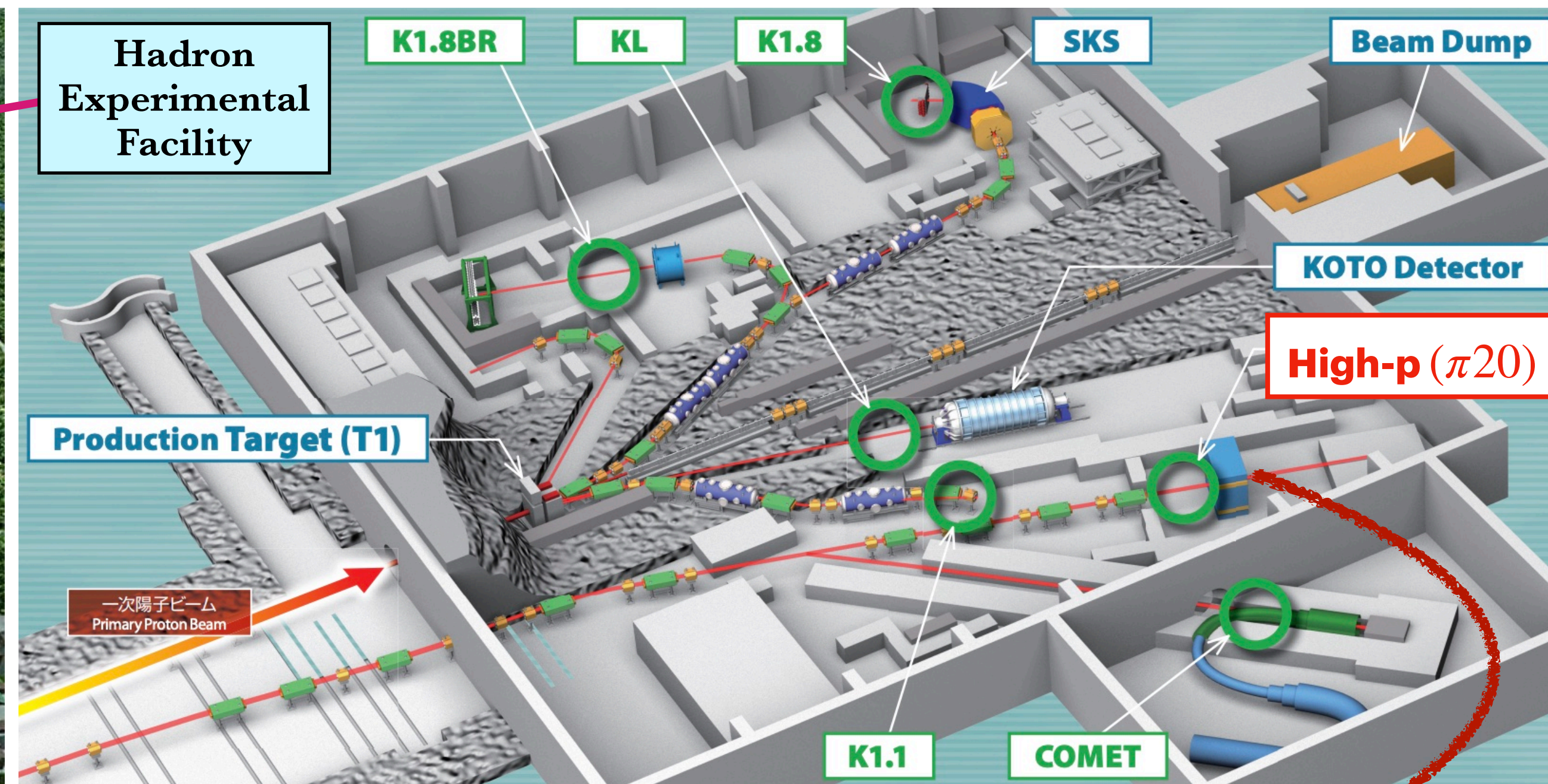
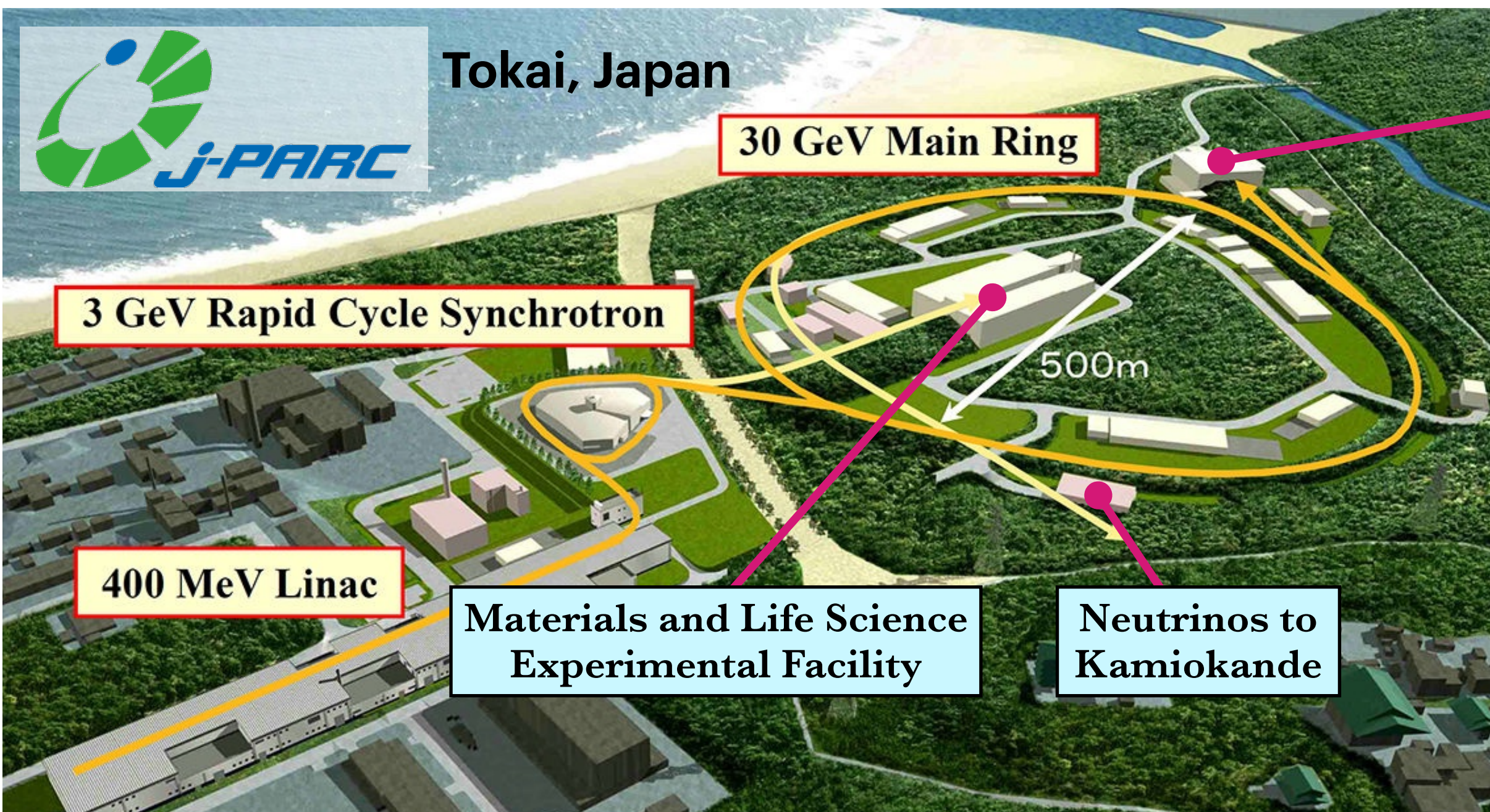
for hadron spectroscopy at the J-PARC High-p beamline

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Research Center for Nuclear Physics, The University of Osaka

INSTR2026 @ USTC, Hefei, China | 2026 October 13

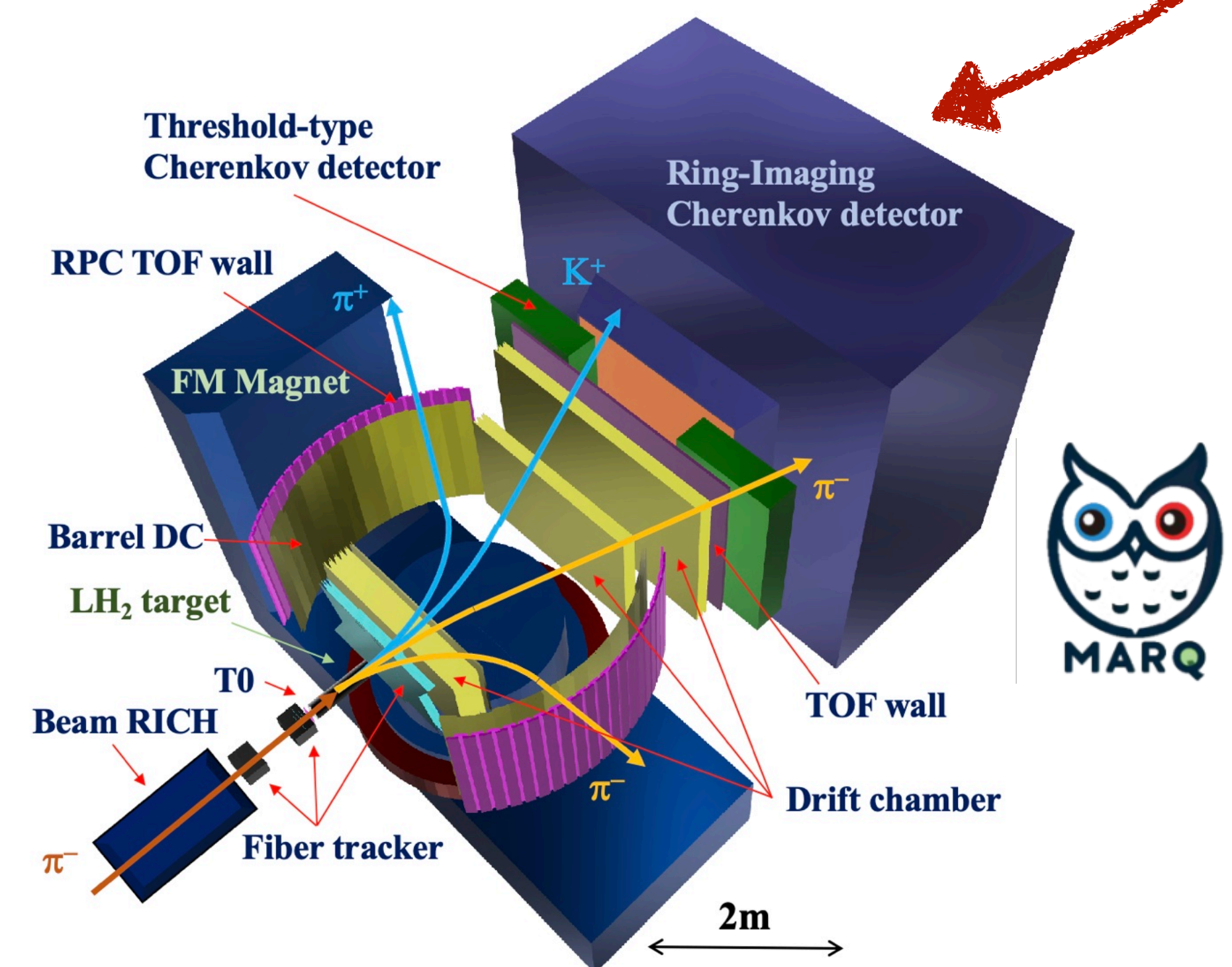


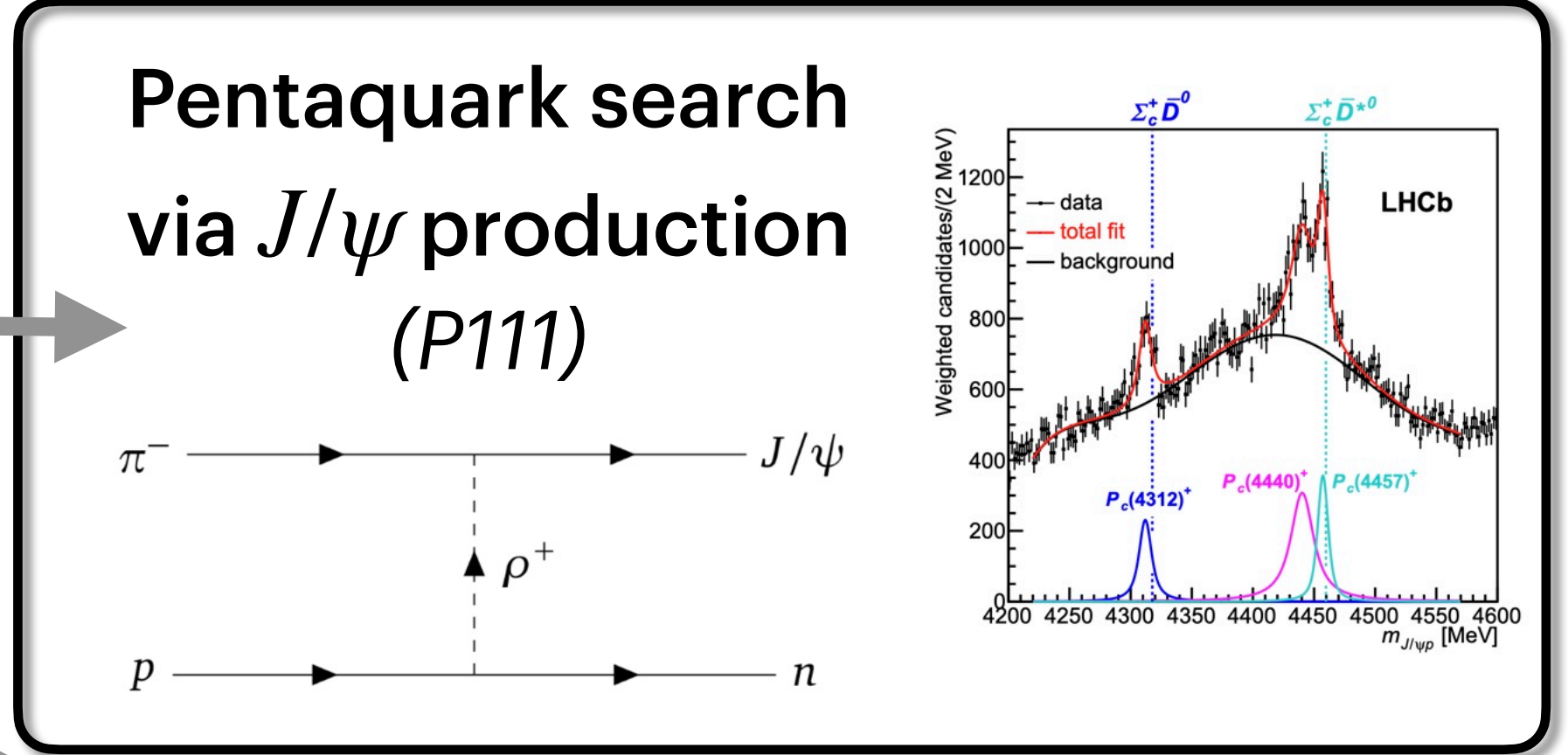
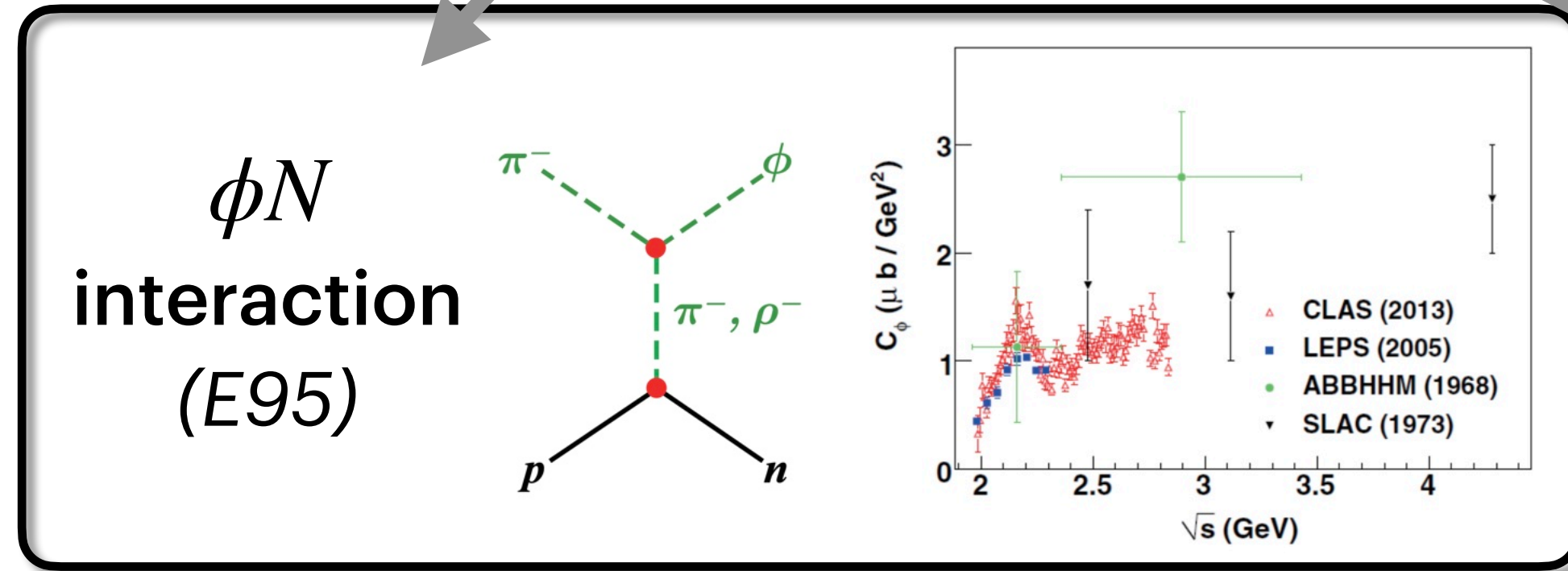
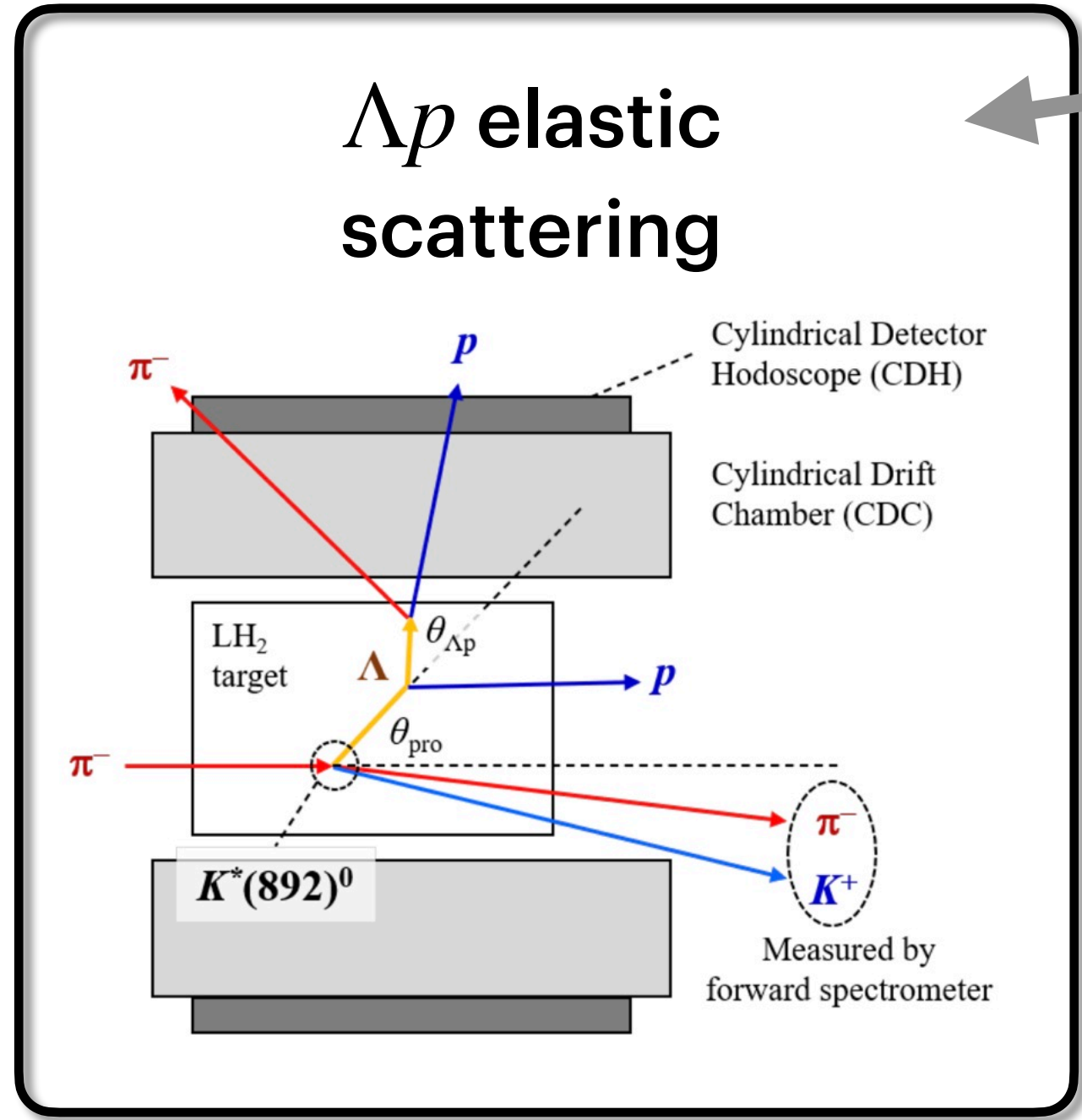
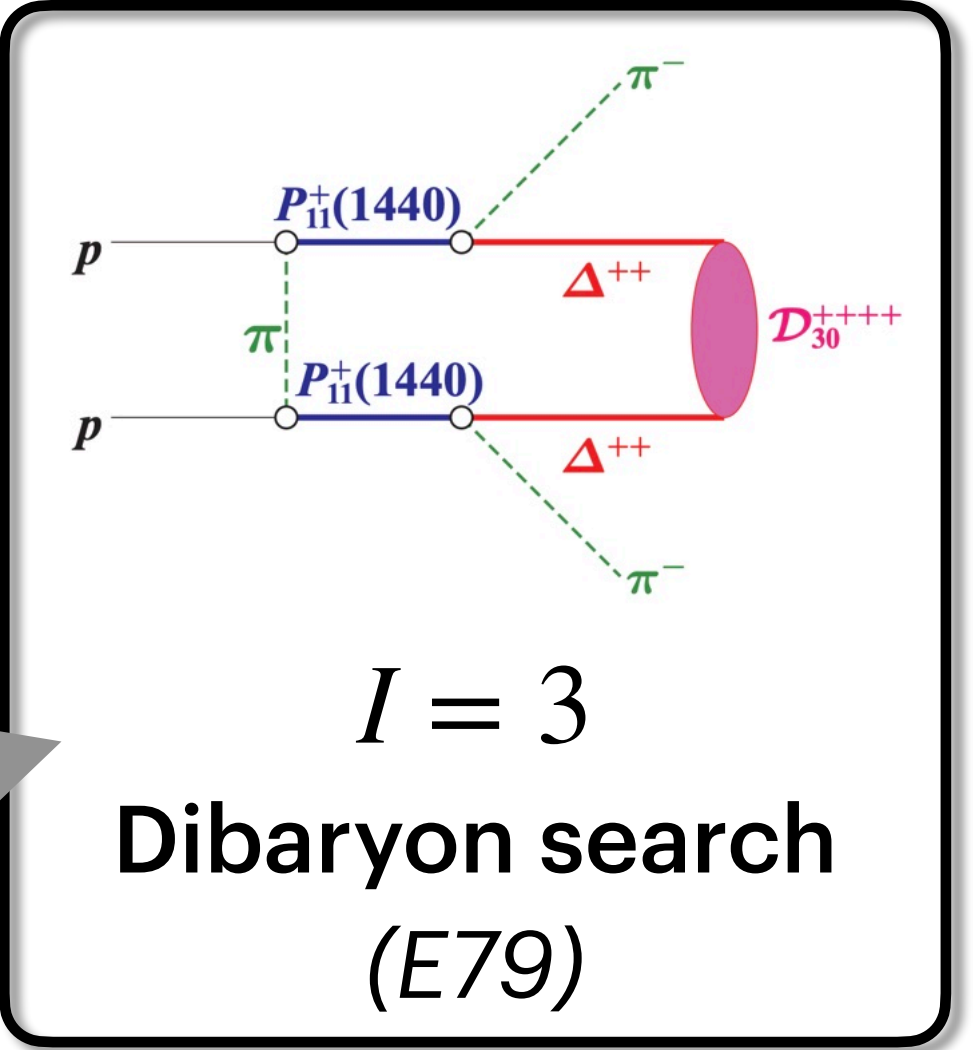
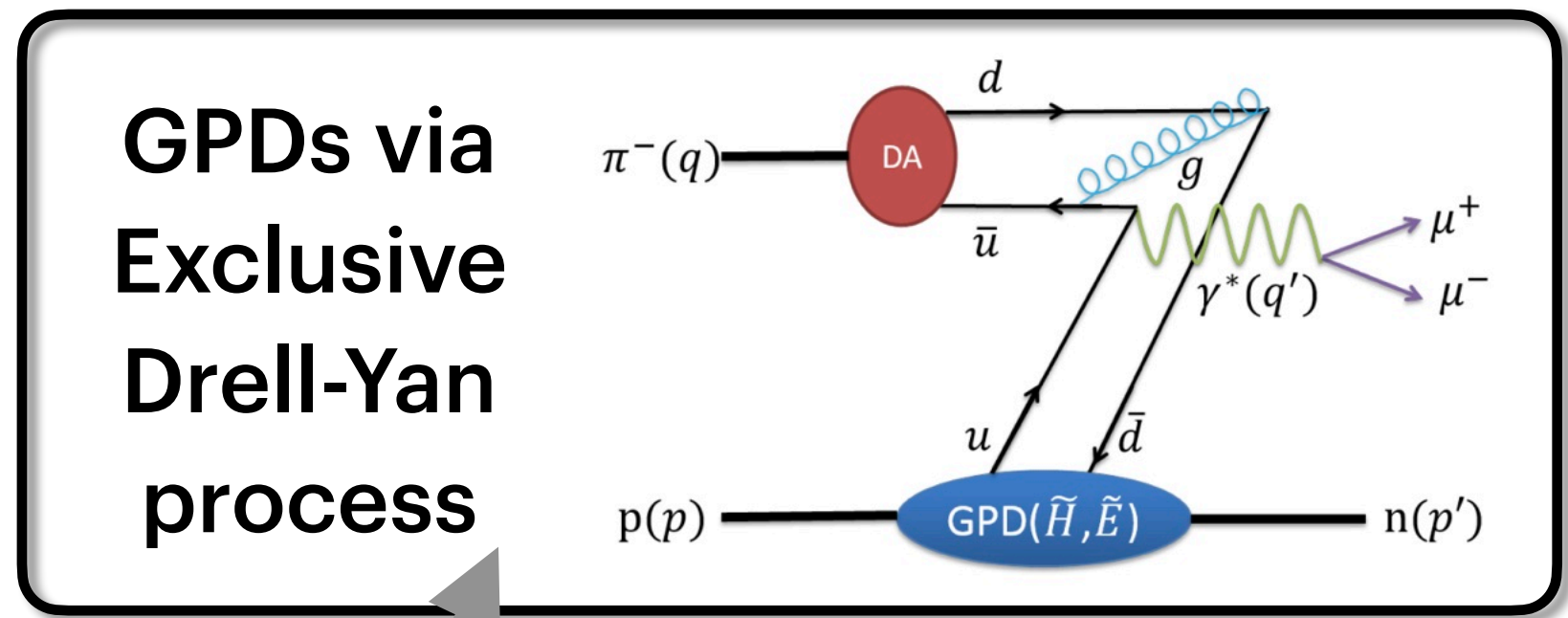
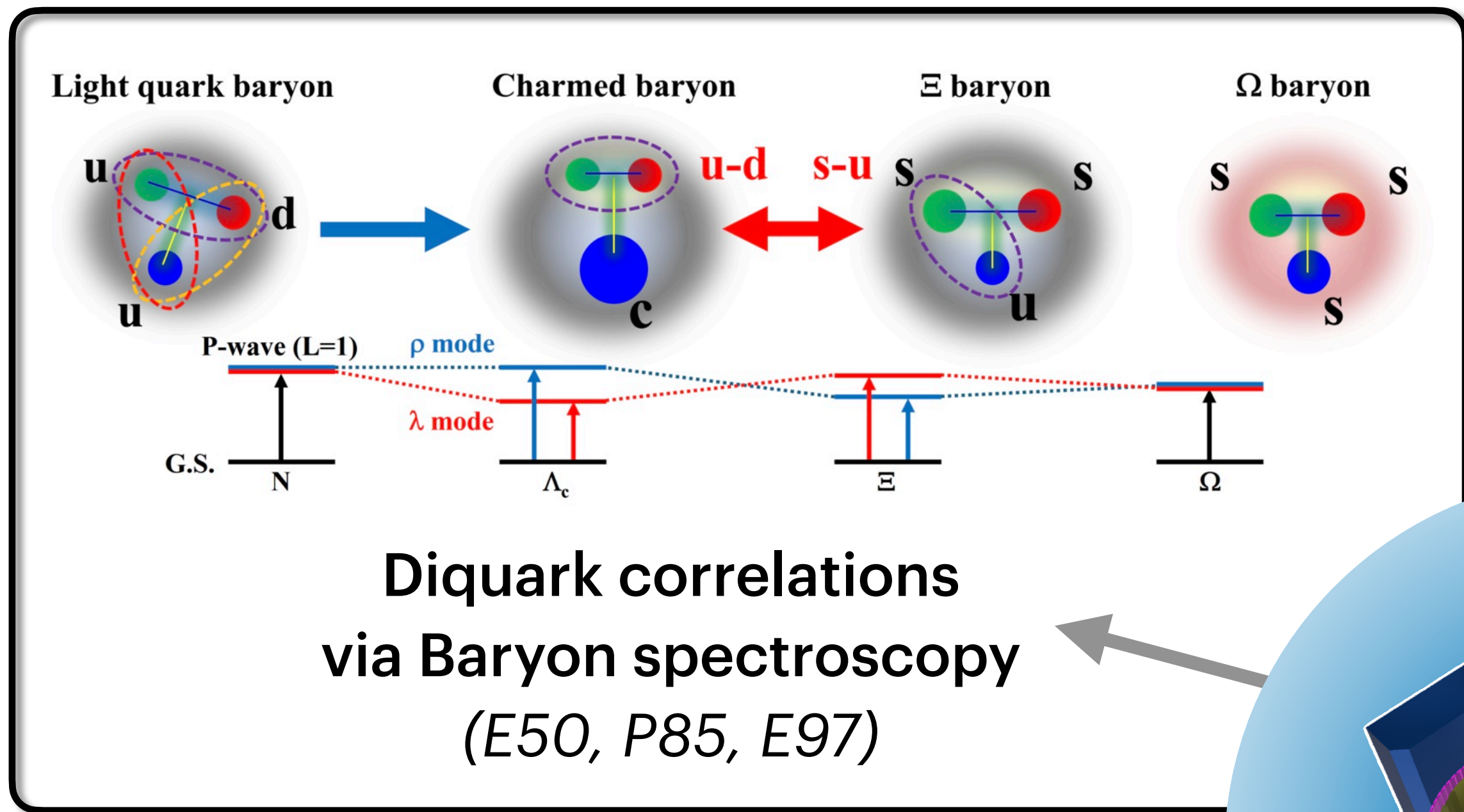


MARQ (*M*ultipurpose *A*nalyzer for *R*esonances and *Q*uark Dynamics) Spectrometer

- High-p delivering 2-20 GeV/c secondary particles $\pi^\pm/K^\pm/p^\pm/\mu^\pm$ up to 10^8 particles/spill
- First beam measurements done in 2025 Q1
- MARQ spectrometer for various fixed-target hadron physics experiments

[PoS\(HADRON2025\)142;](#)
[JPS Conf.Proc. 45, 011023 \(2026\);](#)
[arXiv:2608.25374](#)





And much more...
 $(p\bar{p} \rightarrow Y\bar{Y},$
Double Kaonic nuclei,
 $\eta' p$ interaction, etc.)

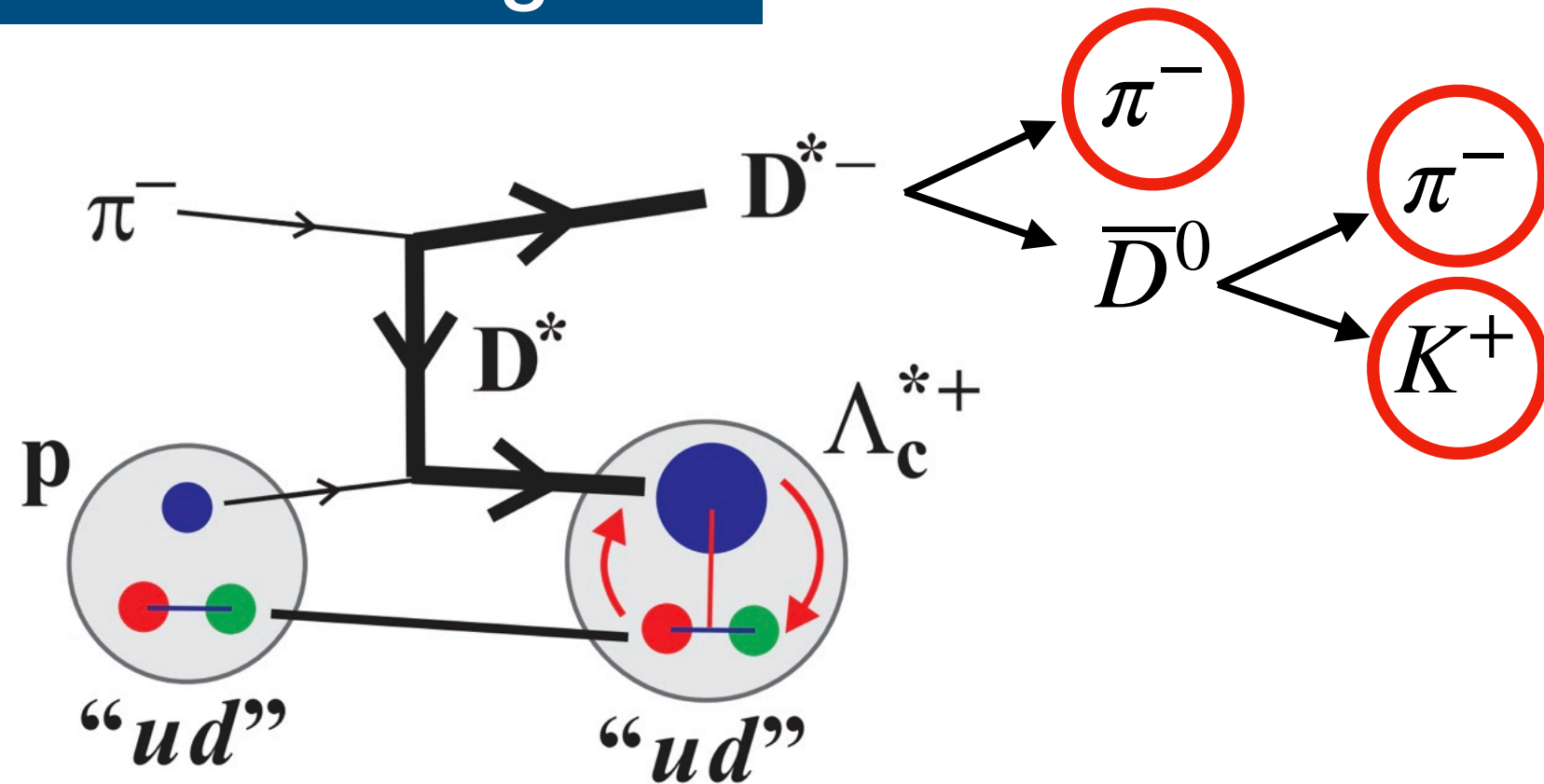
<https://www.rcnp.osaka-u.ac.jp/~jparchua/en/research.html>

Charmed Baryon Spectroscopy (E50)

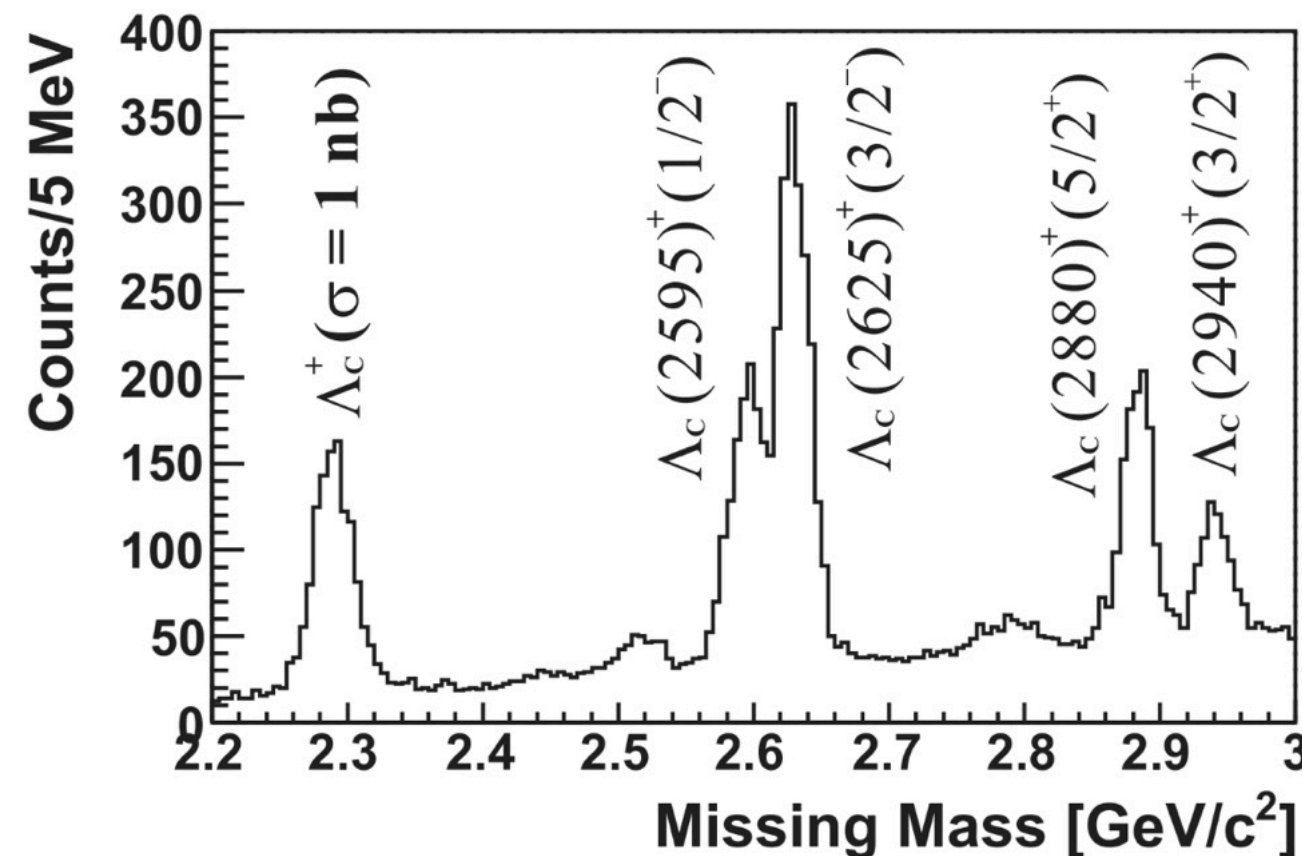
via Missing Mass Method

- How do quarks form inside hadrons?
- Investigate ‘diquark’ correlations from excitation spectrum of heavy baryons
- Missing mass method, measurement of decay products
- $\pi/K/p$ PID efficiency of 99% to keep background at only 5%

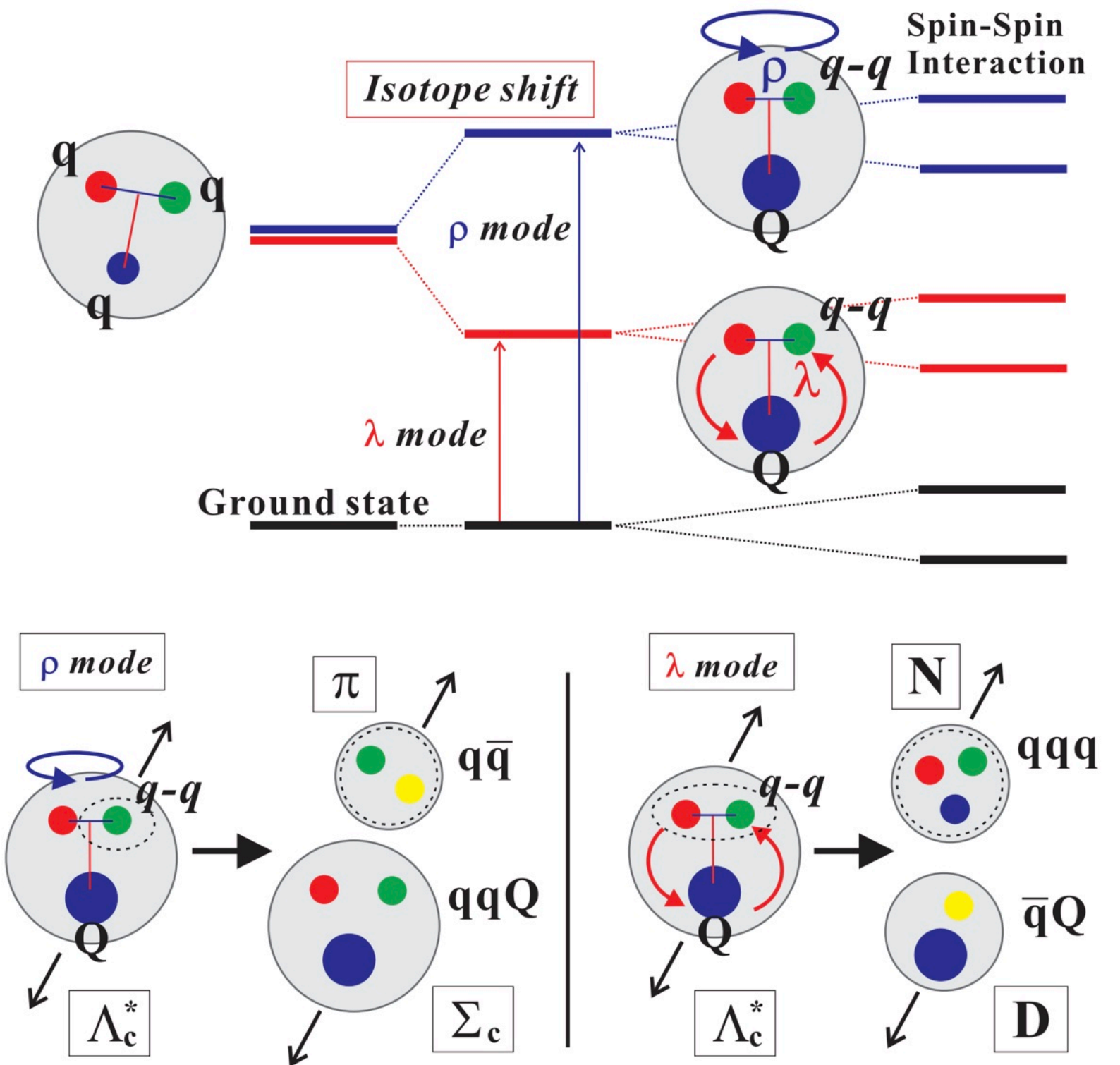
Reaction diagram:



Expected spectrum (simulation):



Diquark correlations:



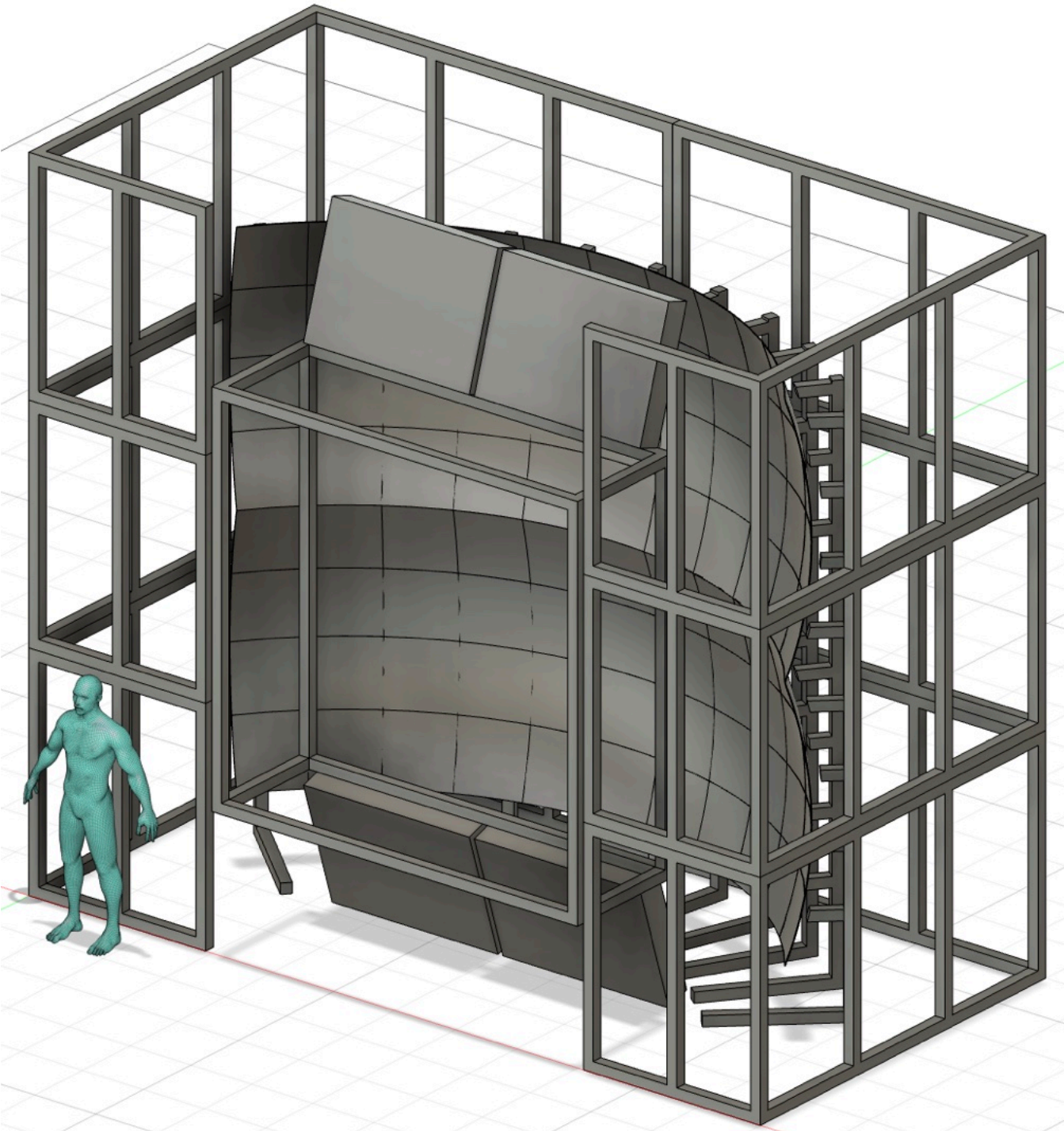
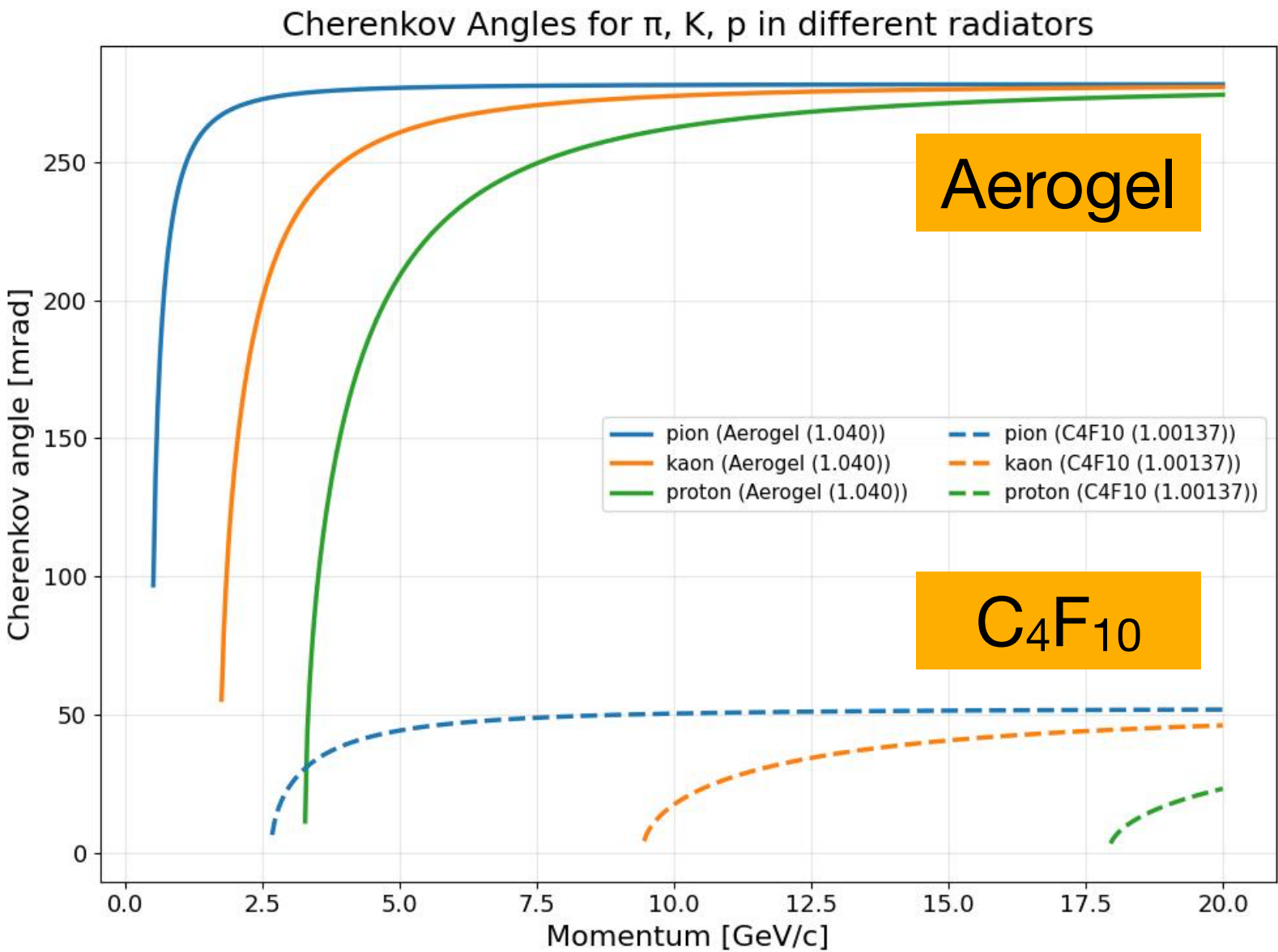
J-PARC Proposal E50;
JPS Conf.Proc. 45, 011113 (2026);
[Nuclear Physics A 954, 341–351 \(2016\)](#)

MARQ RICH Detector

for Hadron ID across wide momentum range

	COMPASS RICH-1	LHCb RICH-1	CBM RICH	ePIC dRICH	MARQ RICH
Purpose	Hadron ID $\pi/K/p$	Hadron ID $\pi/K/p$	Electron ID e/π	Hadron ID $\pi/K/p$	Hadron ID $\pi/K/p$
Momentum range	3–55 GeV/c	2-100 GeV/c	1–10 GeV/c	3-50 GeV/c	2–20 GeV/c
Angular acceptance	± 250 mrad	25-300 mrad	2.5° – 25°	3.5° – 25°	up to $\sim 20^{\circ}$
Radiator	C ₄ F ₁₀	C ₄ F ₁₀	CO ₂	Aerogel + C ₂ F ₆	Aerogel + C ₄ F ₁₀
Mirror area	21 m ²	2 m ²	12 m ²	10 m ²	17 m ²
Photon detectors	5.5 m ² (MAPMT + CsI-MWPC/THGEM)	3k MAPMT 196k ch	1k MAPMT 64k ch	~ 3 m ² 3x3 mm ² SiPM 300k ch	~ 4 m ² 6x6 mm ² SiPM 8k ch
Overall size	~ 120 m ³	~ 7 m ³	~ 80 m ³	~ 13 m ³	~ 72 m ³

*approximate values from available published sources, intended only for general comparison



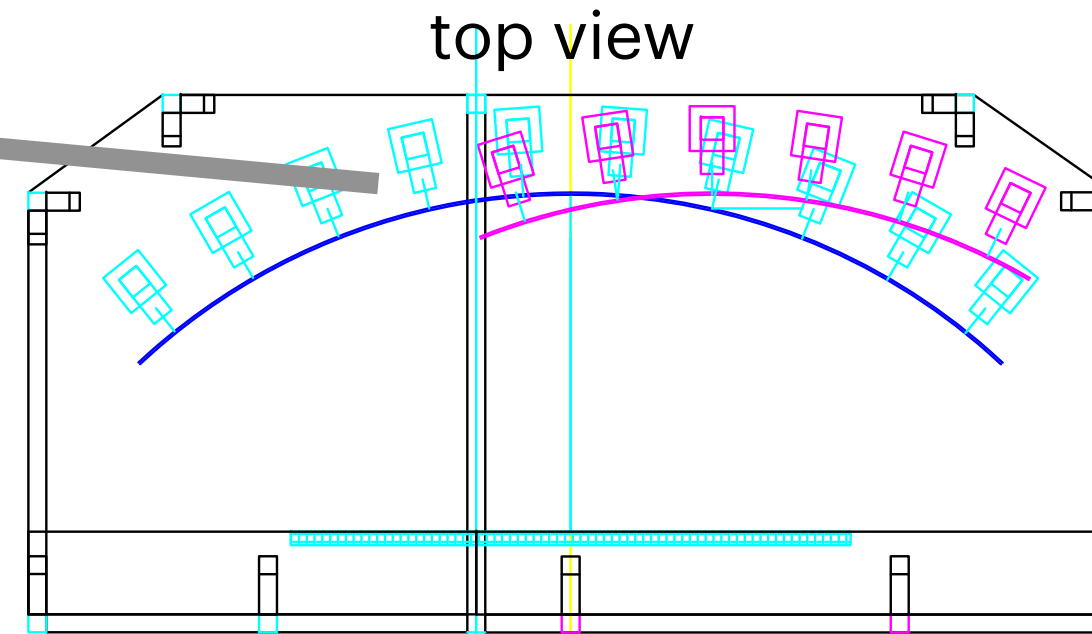
MARQ RICH Detector

Ongoing R&D for each subsystem

[NIMA 766, 36–38 \(2014\);](#)
[JINST 20, C06070 \(2025\)](#)

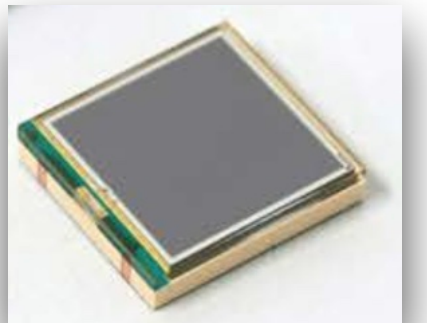
Spherical Mirror

- $r = 3\text{m}$, upper and lower
- 80 tiles of $\sim 40\text{cm} \times 50\text{cm}$
- Mounting and alignment still being studied



SiPM Detectors

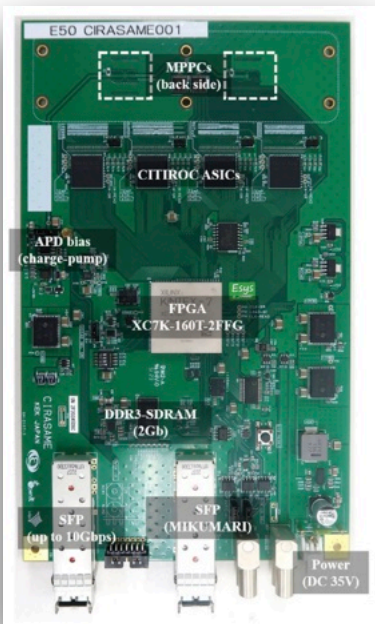
- 4 Photodetector modules of $\sim 1\text{m} \times 1\text{m}$
- Hamamatsu MPPC
- Pros: cost-effective, compact, robust
- Cons: small sensitive area, ^③ large dark count rate ^②



CIRASAME FEEs

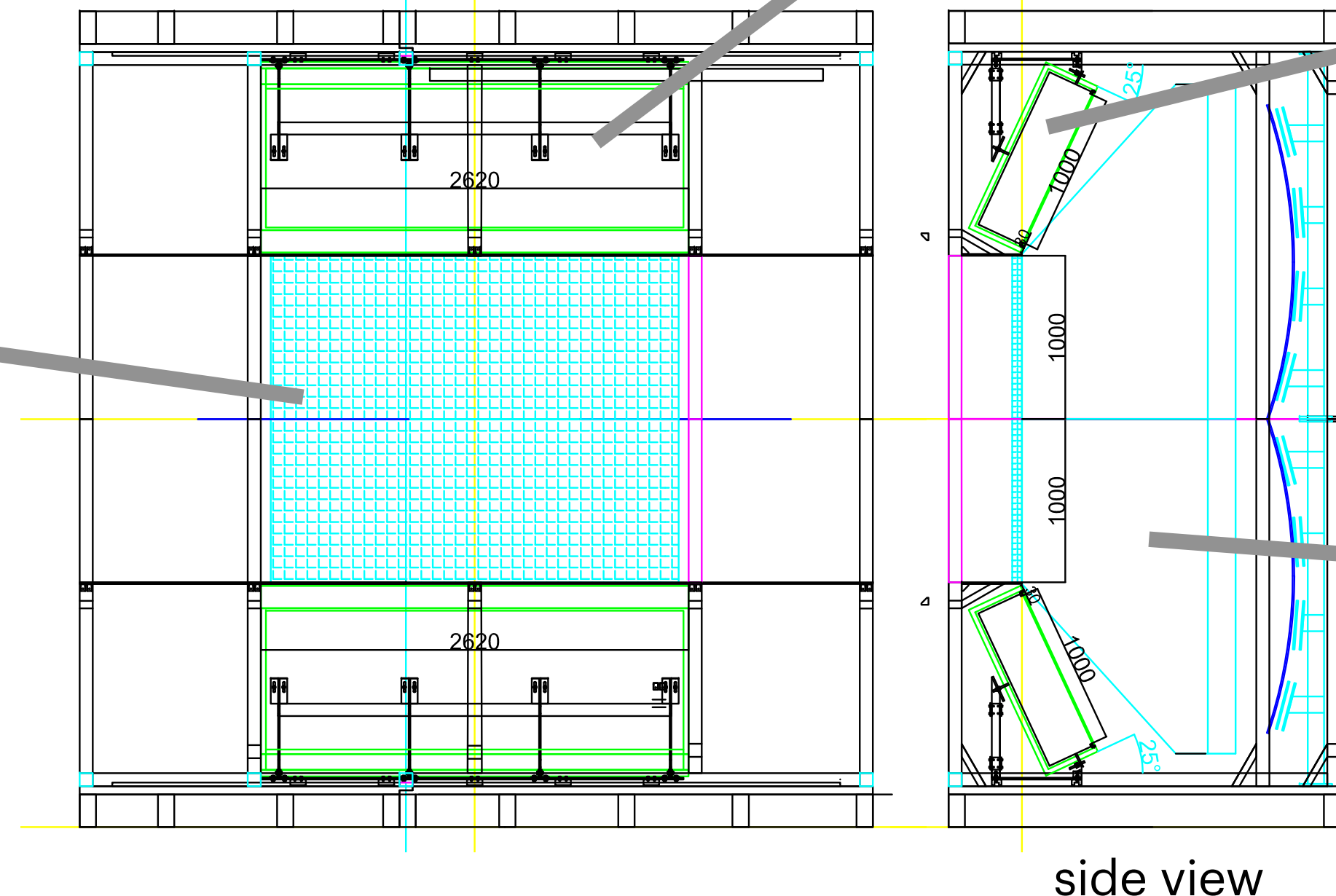
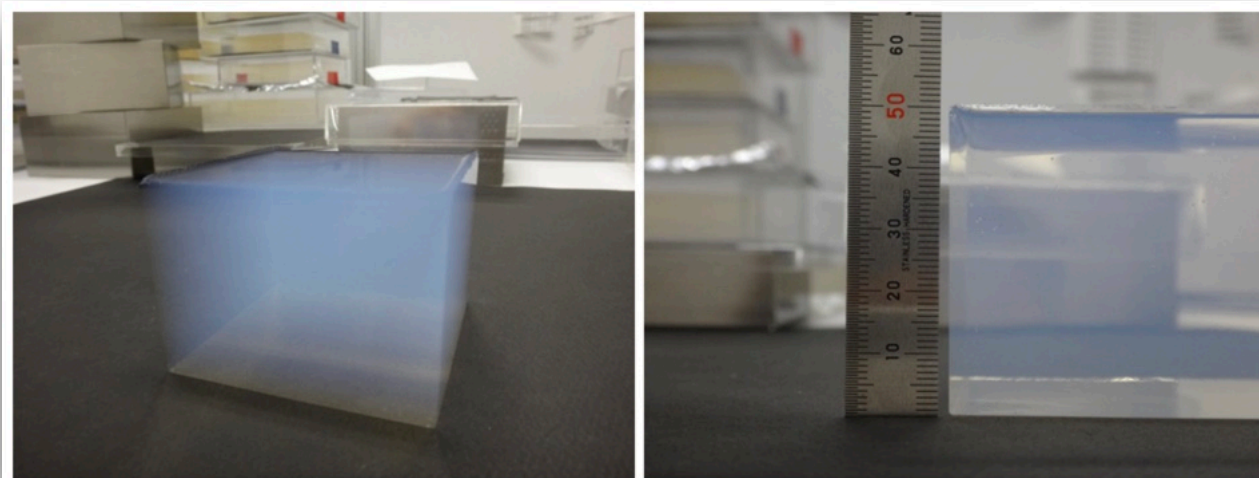
- for high-density SiPM readout with TDC, bias voltage supply, and CITIROC1A ASIC

[PTEP 2026, 083H01 \(2026\)](#)



Aerogel ($n = 1.04$)

- 5cm thickness, covering $\sim 2\text{m} \times 2\text{m}$ area
- Production c/o Aerogel Factory [NIMA 1090, 171665 \(2026\)](#)



C_4F_{10} Gas ($n = 1.00137$)

- 1.5cm thick gas chamber and recirculation system
- Issue: availability of gas ^①

R&D #1

Alternative Gases

Gas Radiator Issue

High GWP of RICH Gases

- Perfluorocarbons (C_nF_{2n+2}), standard RICH radiator gases, gradually disappearing in the market due to high Global Warming Potential (GWP)

- Still available in EU/USA, but production discontinued in Japan

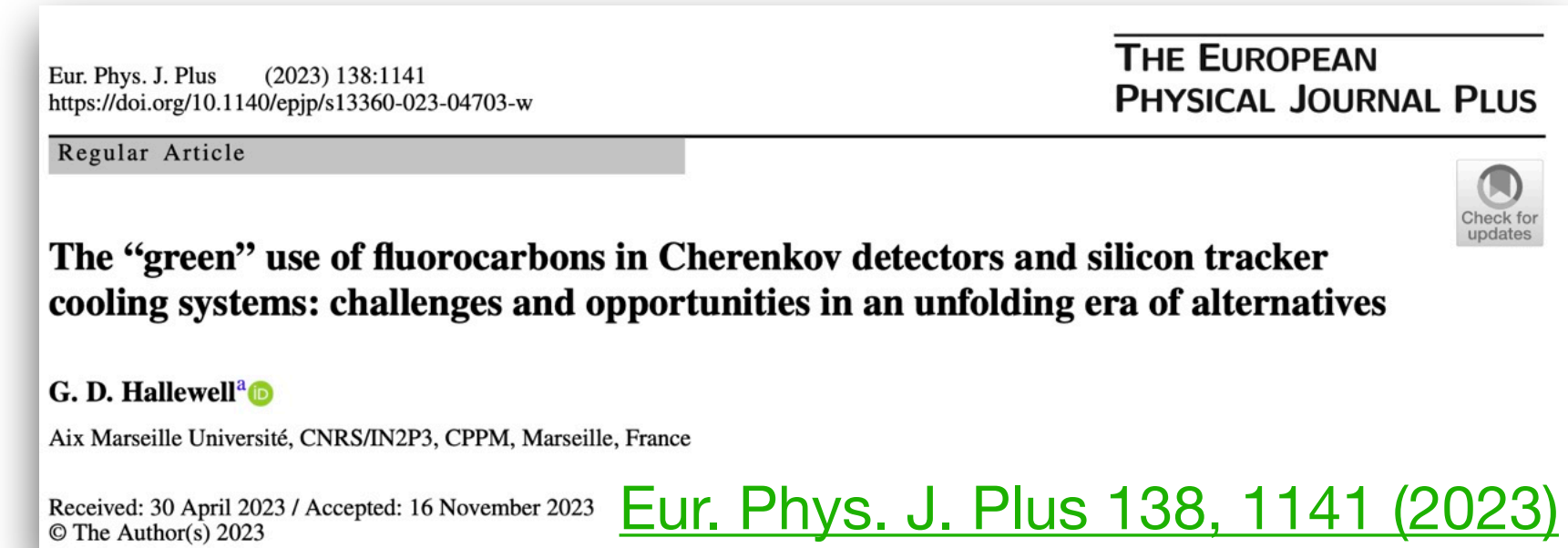
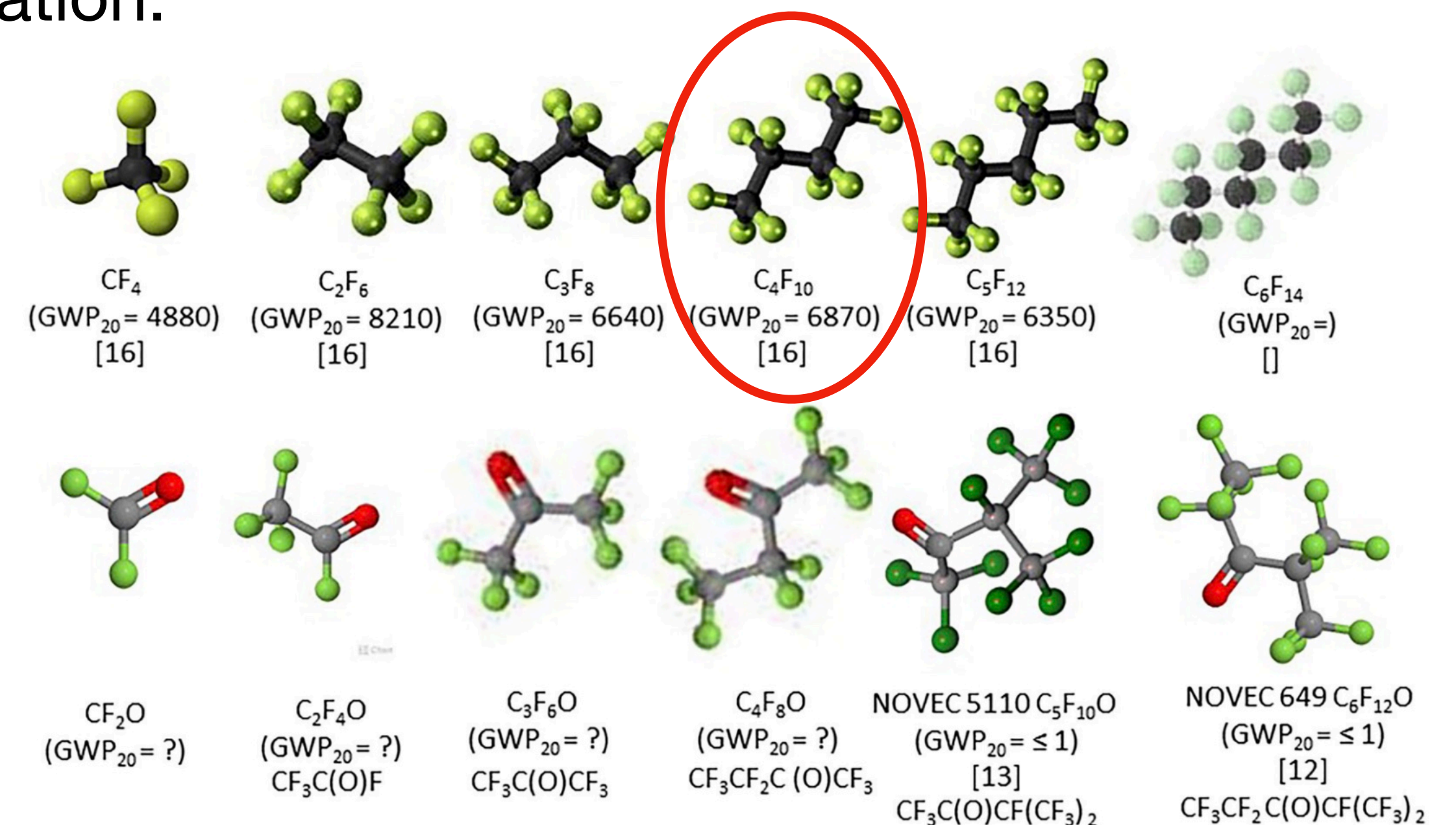
- Possible solutions being studied by DRD4 Collaboration:

- Closed circulation and leak monitoring

- Pressurized inert gases (ePIC dRICH)

https://indico.cern.ch/event/1609396/contributions/7037247/attachments/3256951/5813969/16_apr_pressurized_gas.pdf

- Alternative gases as substitution**



Search for Alternative Gases

New Generation of Fluorocarbons

- 4th Gen HFO/HCFO gases have low GWP
 - HFO gases are flammable
 - They are corrosive to some materials
- Requirements:
 - Optical quality (refractive index, chromatic dispersion, transparency)
 - Practicality (stability, dew point, low cost)

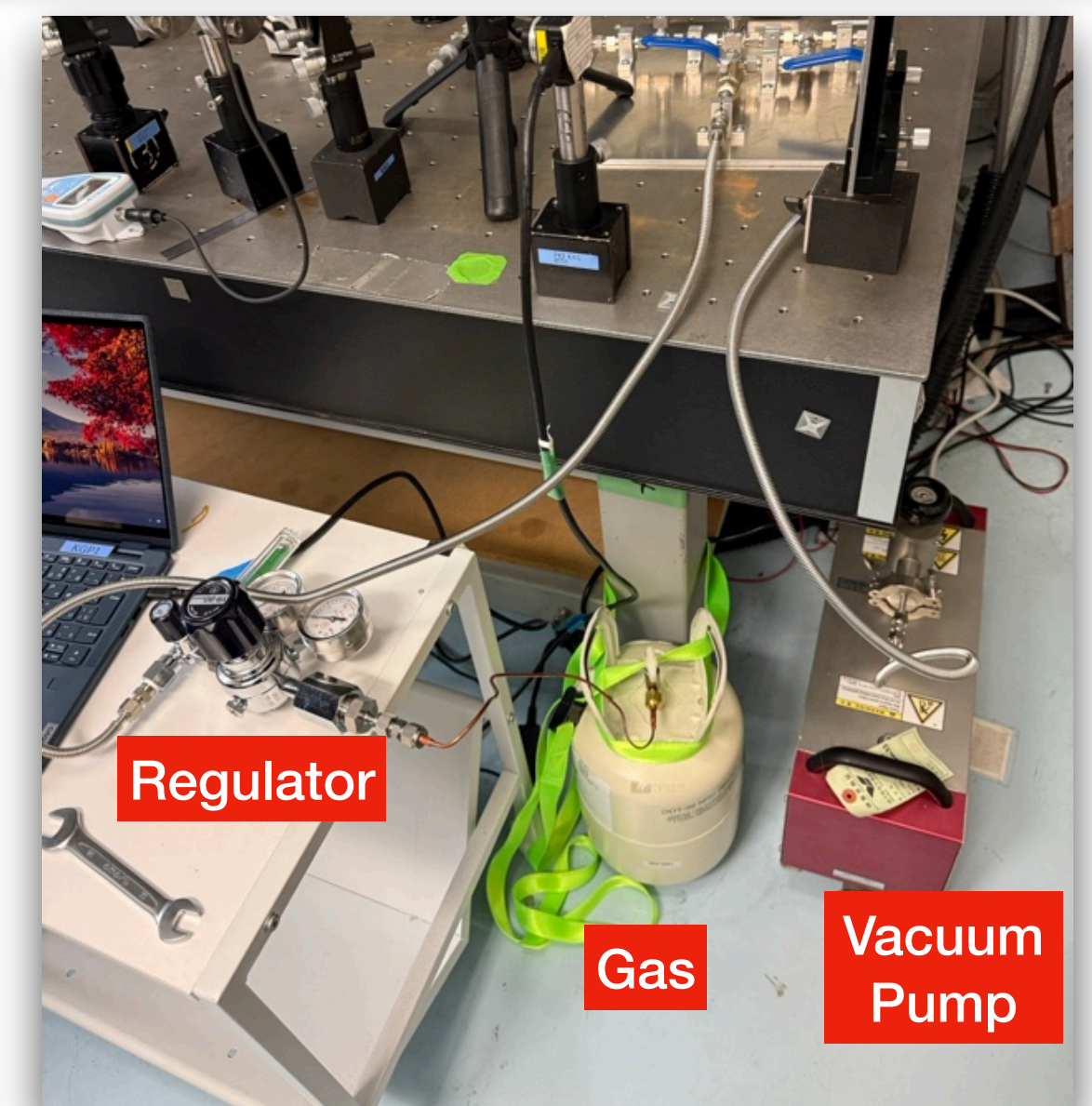
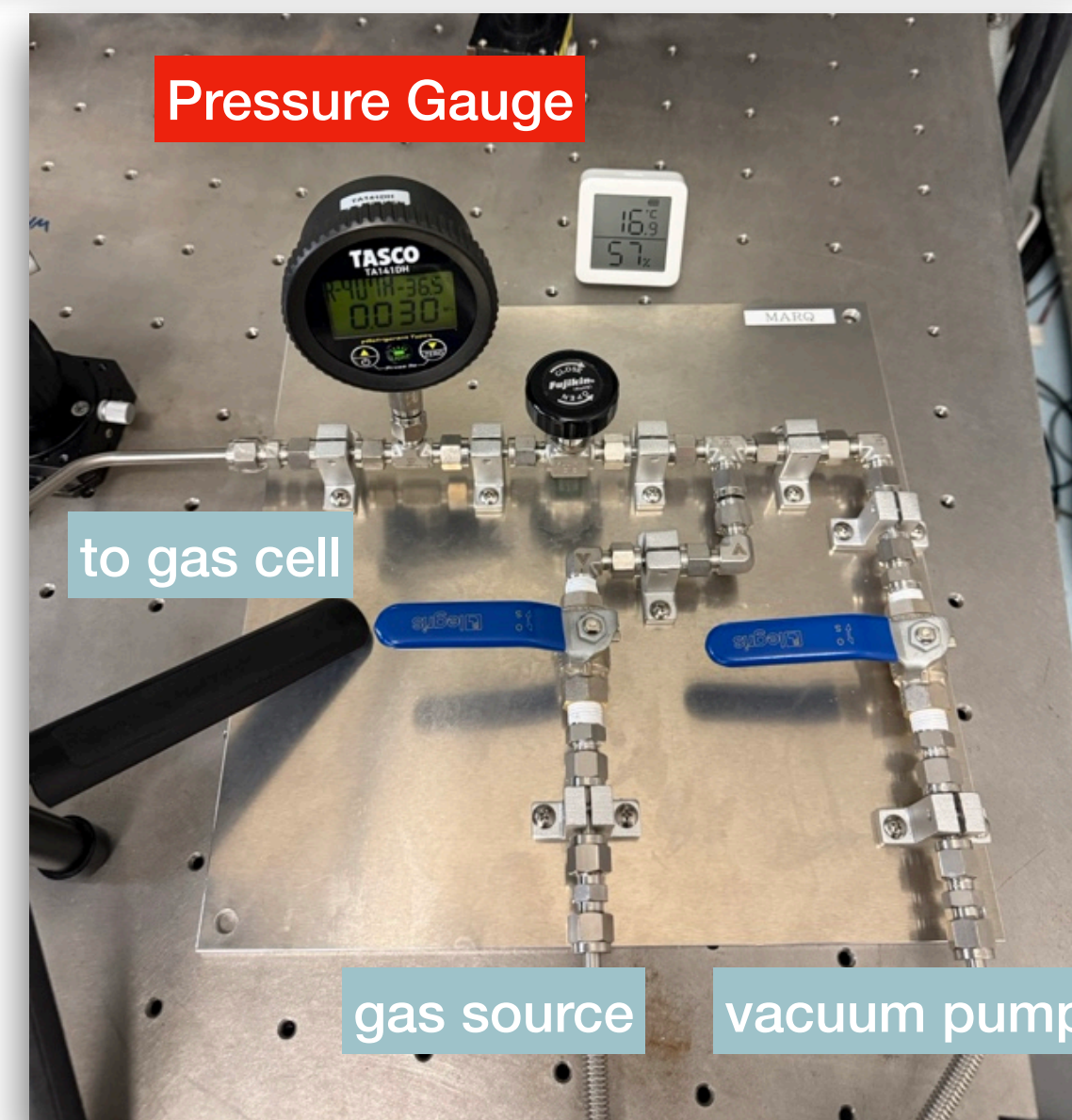
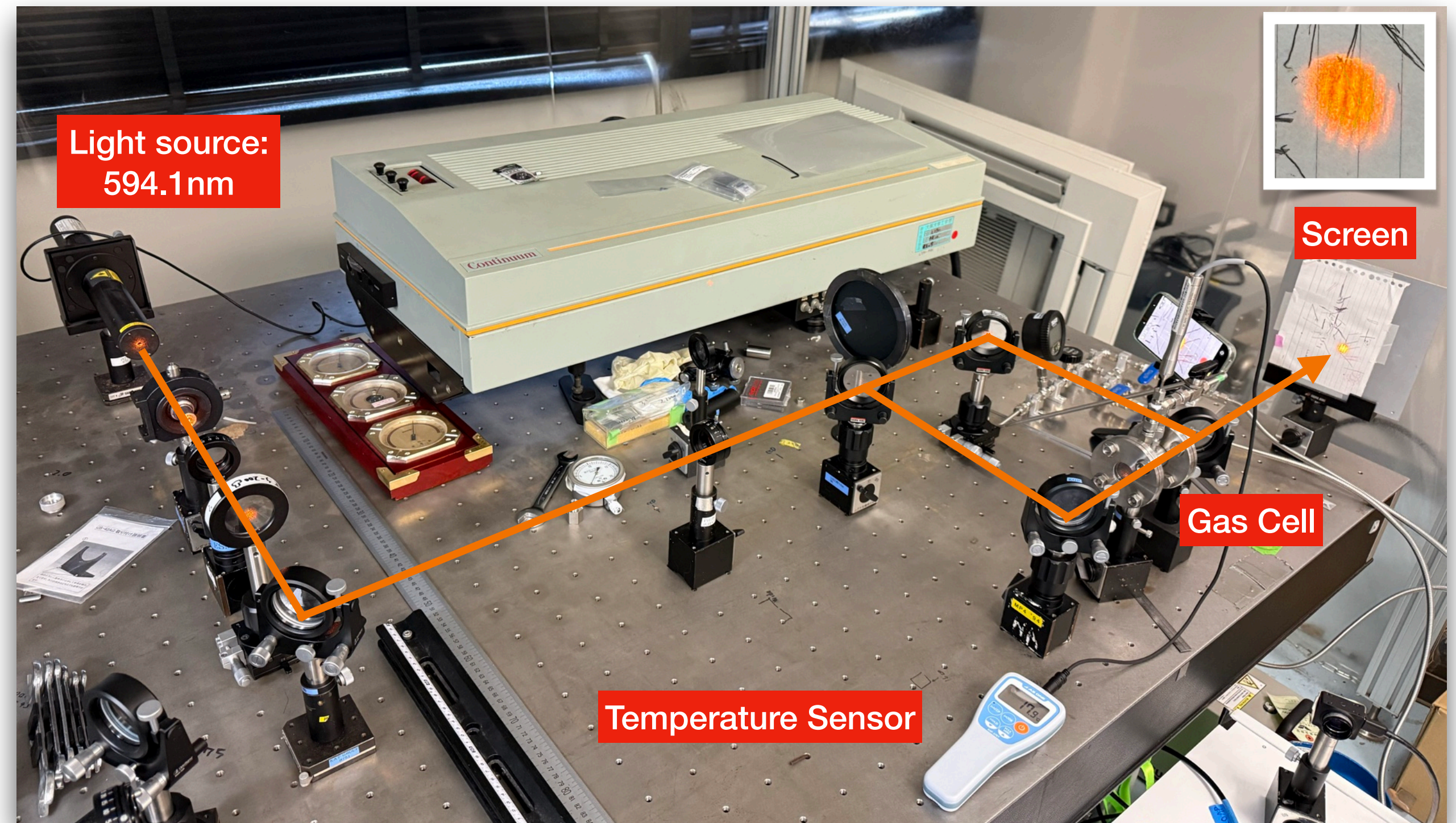
PFC: Perfluorocarbon	0th gen	GWP 7,00~10,000	PFC-14(CF ₄), PFC-116(C ₂ F ₆), PFC-218(C ₃ F ₈), PFC-3-1-10(C ₄ F ₁₀), ...	Stable, non-flammable, non-corrosive
CFC: Chlorofluorocarbon	1st gen	GWP 4,000~12,000	CFC-11, CFC-12, CFC-113, CFC-114, CFC-115, ...	Stable, non-flammable, non-corrosive
HCFC: Hydrochlorofluorocarbon	2nd gen	GWP 100~2,000	HCFC-22, HCFC-123, HCFC-142b, HCFC-225, ...	Moderately stable, Slightly reactive
HFC: Hydrofluorocarbon	3rd gen	GWP 200~12,000	HFC-32, HFC-125, HFC-134a , HFC-245fa, HFC-143a, ...	Stable, Non-corrosive, Slightly flammable
HFO: Hydrofluoroolefen	4th gen	GWP <1	R-1234yf , R-1234ze , R-1233mzz, ...	Less stable, Corrosive to resins, moderately flammable (A2L)
HCFO: Hydrochlorofluoroolefen	4th gen	GWP <1	R-1224yd , R-1233zd , ...	Less stable, Corrosive to resins, non-flammable

Index Measurement via Mach-Zehnder Interferometry

- Fill gas cell with select gas at positive pressure. Pump down from 0 MPa (~ 1 bar) to -0.1 MPa (vacuum).
- Record the interference image and count the movement of fringes.

$$n_{\text{gas}} = 1 + \frac{N\lambda}{L}$$

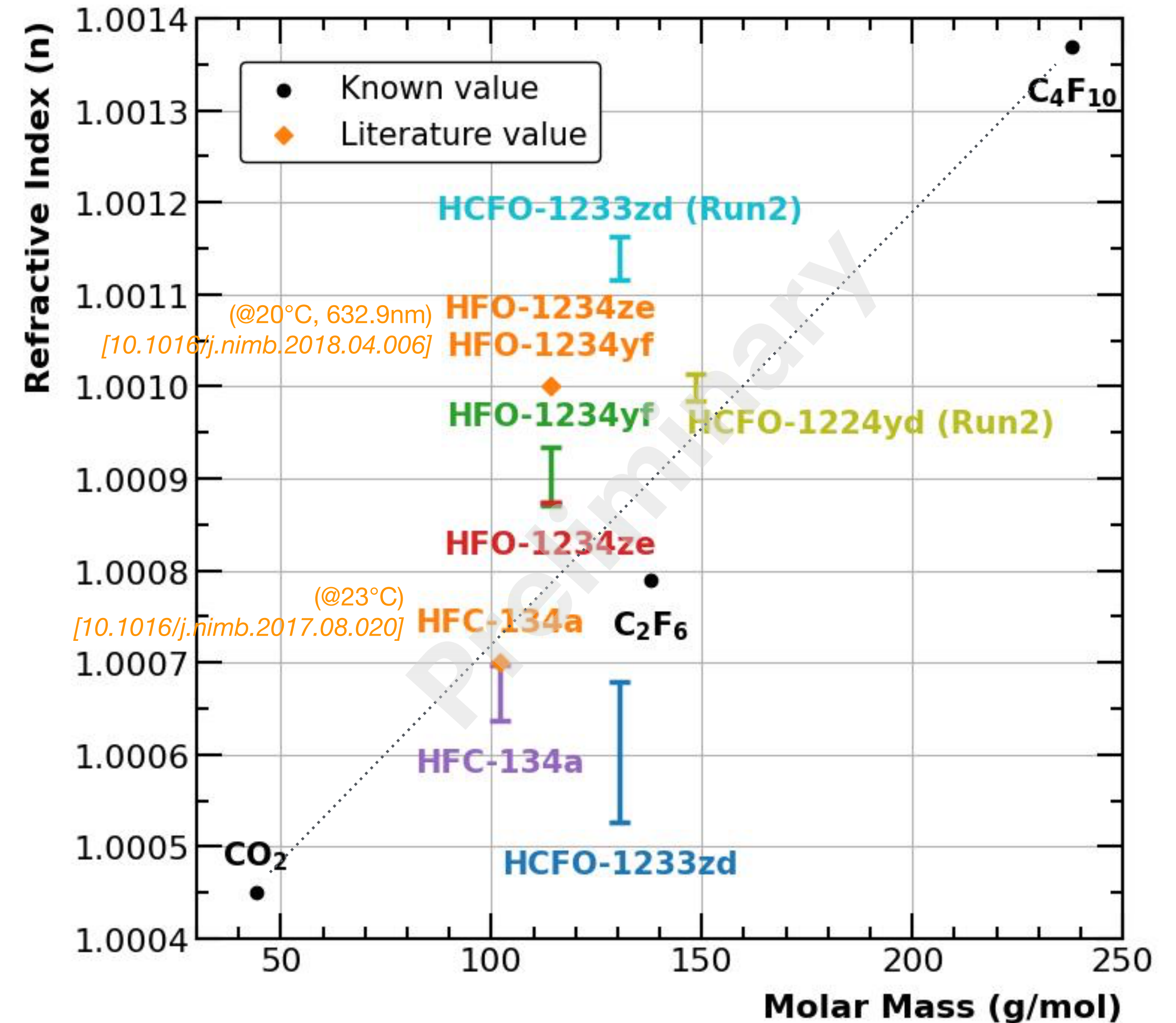
- L : cell length = 7cm, $\lambda = 594.1\text{nm}$
- N : fringe count, n_{gas} : index at 1 bar
- Temp: Monitored, at room temp w/ only ~0.1-0.2°C fluctuations



Index Measurement

Preliminary Results

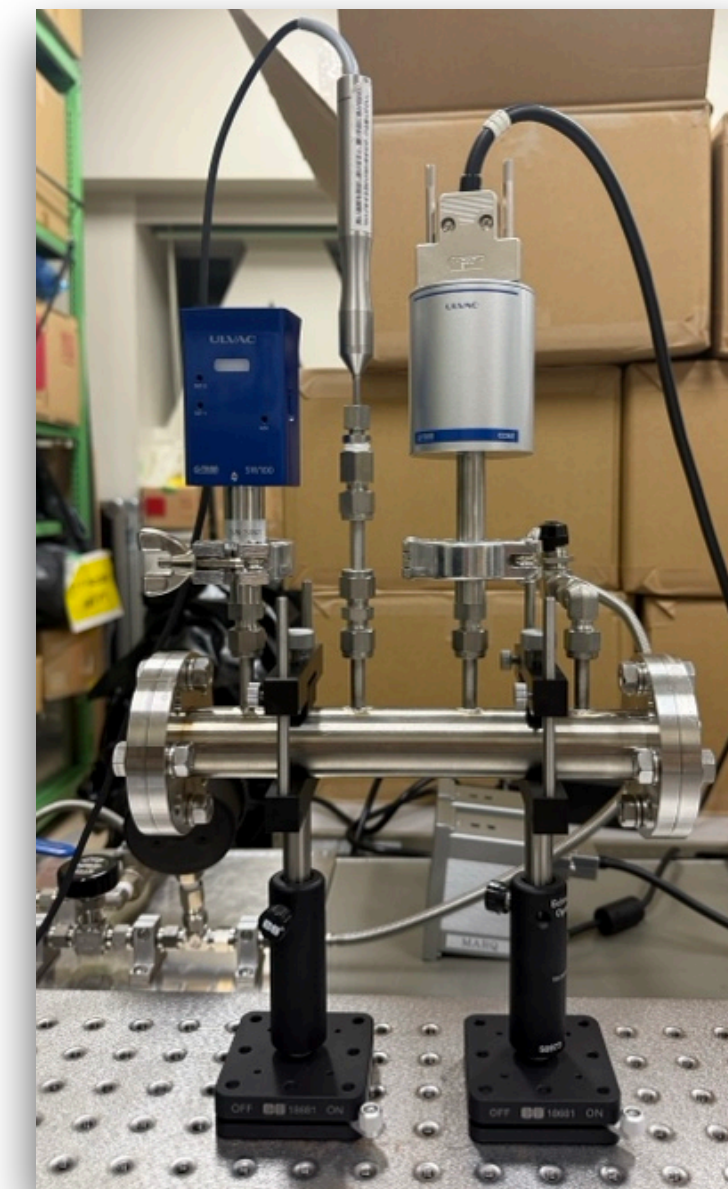
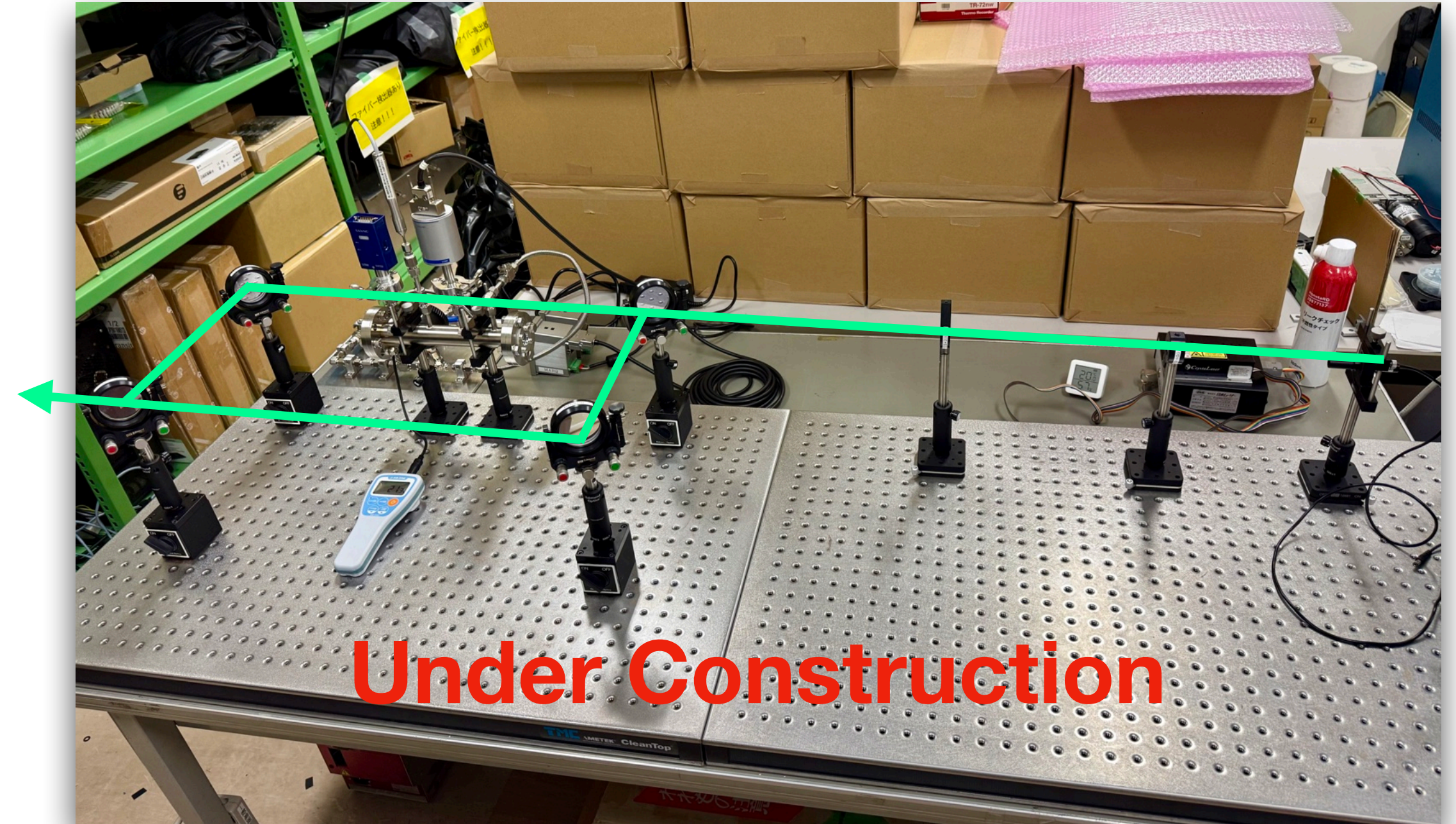
- Measured values at ~1 bar, 18°C, 594.1nm, after calibration/correction with N₂ gas
- Our results match other literature values to some extent, considering diff in temp and wavelength conditions
- Index values of HFO/HCFO gases comparable to C₂F₆
- Highest index we got so far ~1.0012 (c.f. C₄F₁₀ ~1.0014)
- Systematic errors and high uncertainties remain



Index Measurement

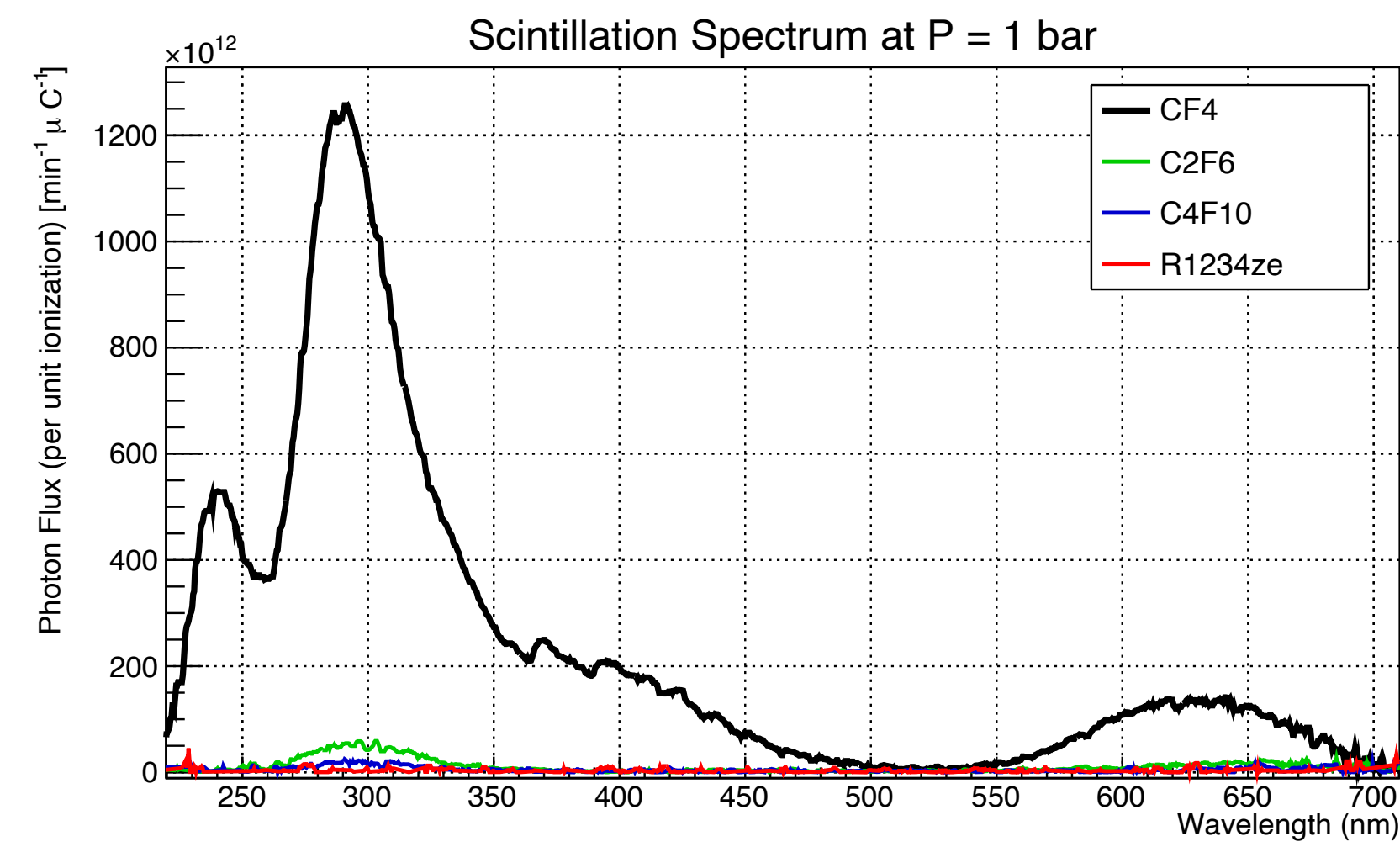
Next Steps

- New and improved Mach-Zehnder interferometer under construction
 - Better and more precise pressure gauges
 - Gas cell with longer path length (~20cm)
- Redo measurements and verify results
 - Plan to also investigate wavelength-dependence of index
- Results can be expected soon

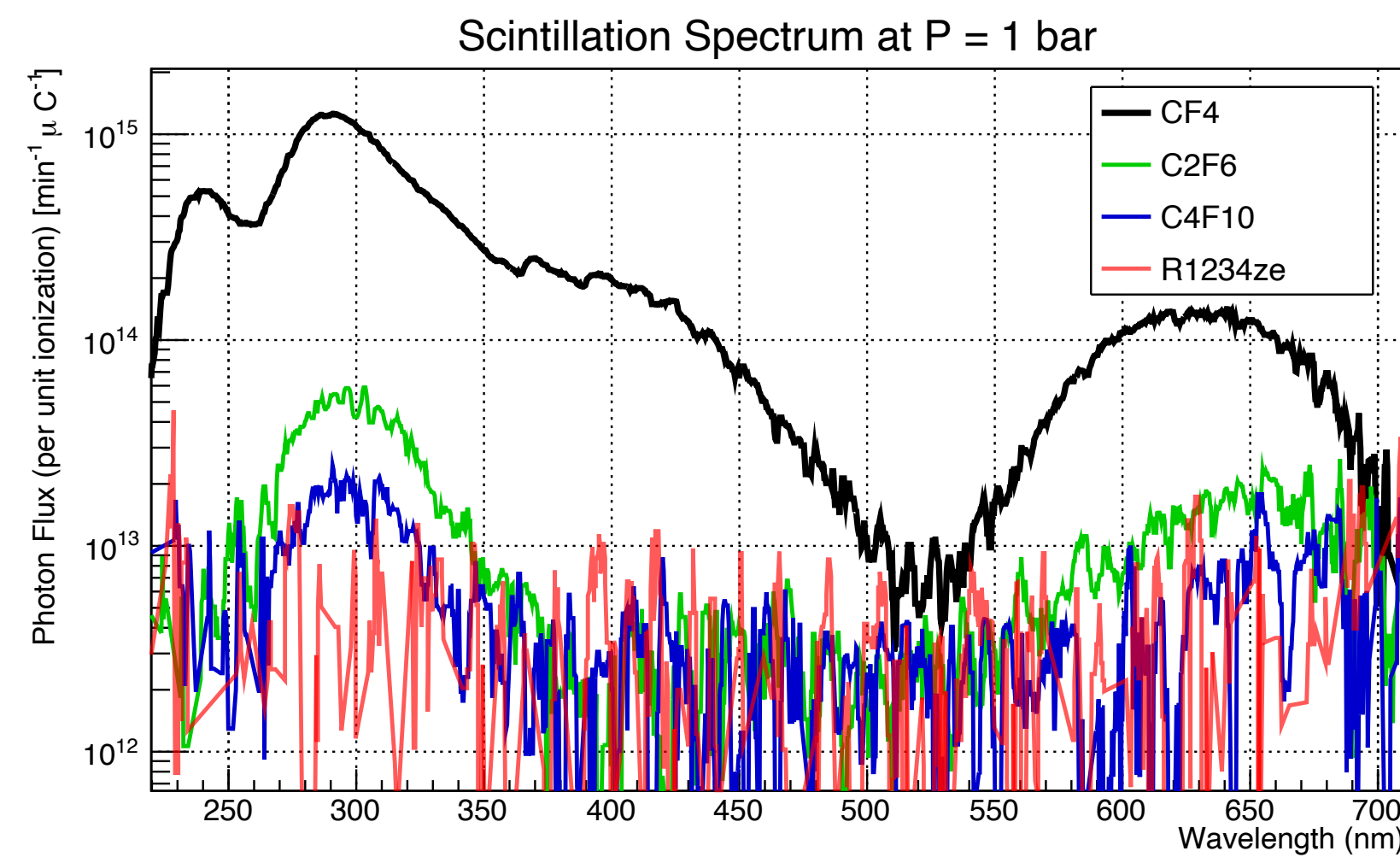


Other Measurements

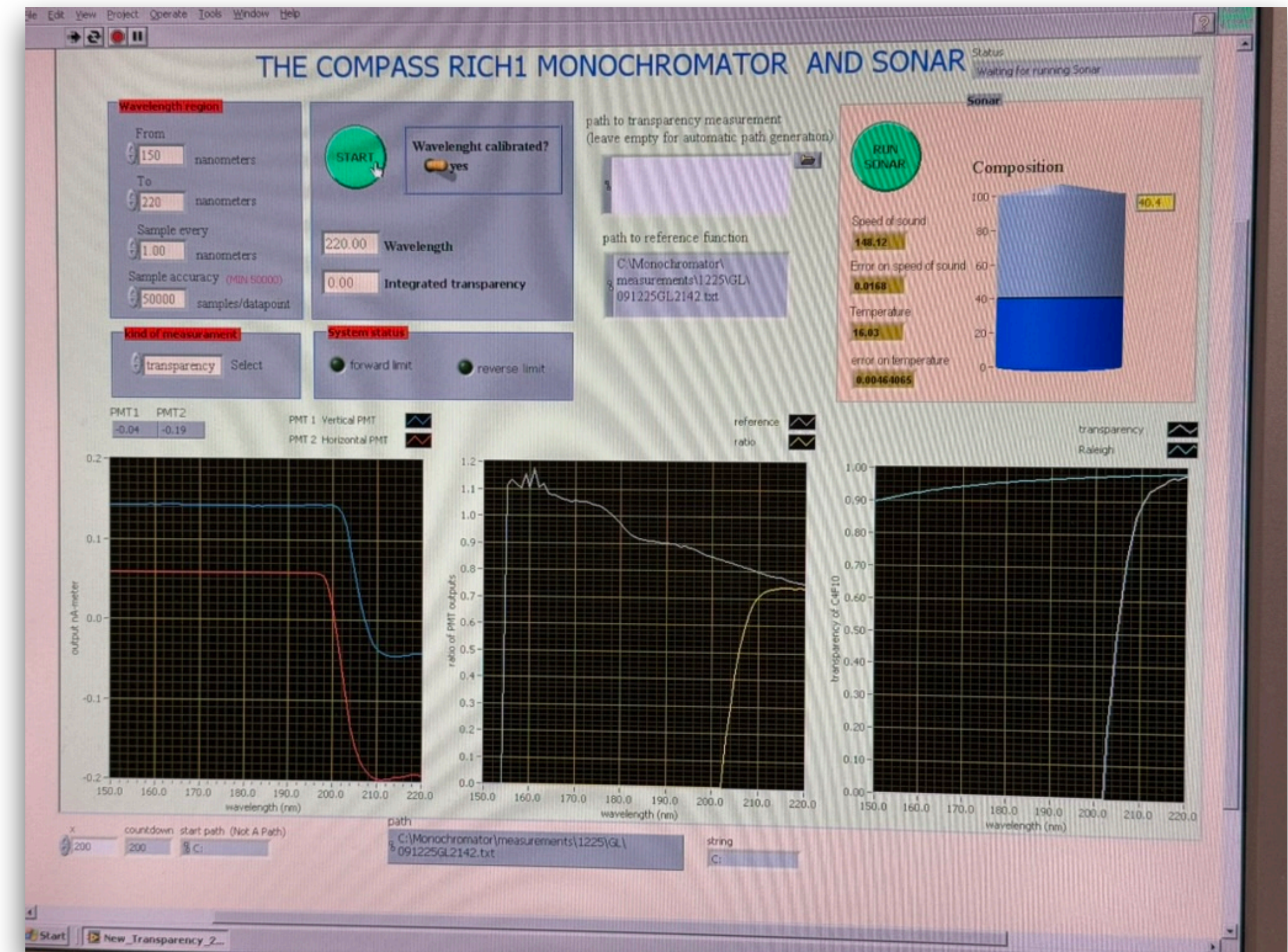
@CERN COMPASS and Gas Detector Lab (2025/12)



Scintillation



VUV Transparency



Special Thanks to Fulvio Tessarotto (CERN)

Corrosiveness Test

for HCFO-1224yd (AGC Chemical)

- HCFO gases have aggressive corrosiveness to acrylic
- Need a mitigation ⇒ Anticorrosion coating/film, Quartz window?
- Currently testing w/ acrylic sample, 22°C, >1week: no visible effects



Plastics					Elastomers						
Blowing agent	AMOLEA™ 1224yd		HFC-245fa		Blowing agent	AMOLEA™ 1224yd			HFC-245fa		
Material	Weight change, %	Volume change, %	Weight change, %	Volume change, %	Material	Weight change, %	Volume change, %	Elution %	Weight change, %	Volume change, %	Elution %
PVC (Rigid)	0	0	0	0	Natural rubber	2	-3	9	2	1	1
PVC (Soft)	-8	-12	N.D.	N.D.	Silicone rubber	93	103	3	12	10	1
LDPE	7	4	1	0	Urethane rubber	56	49	0	26	21	0
HDPE	4	3	N.D.	N.D.	Butyl rubber	2	-3	13	-4	-6	5
Polypropylene	9	5	2	0	Chlorosulfonated polyethylene rubber (Hypalon™)	11	9	5	-1	-3	2
Polystyrene	11	8	0	0	Chloroprene rubber	6	3	11	-3	-6	6
Acrylic resin	Dissolved	Dissolved	Dissolved	Dissolved	EPDM	6	1	9	1	0	1
Polycarbonate	1	1	0	0	Nitrile rubber	2	-4	10	6	4	7
Polyphenylene oxide	8	5	N.D.	N.D.	FKM	41	56	1	70	109	3
Phenolic resin	0	0	-1	0	HNBR	18	9	12	21	14	10
ABS resin	9	6	2	0							
Nylon 66	0	-2	-1	-1							
Epoxy resin	0	0	0	0							
PTFE	5	7	2	1							

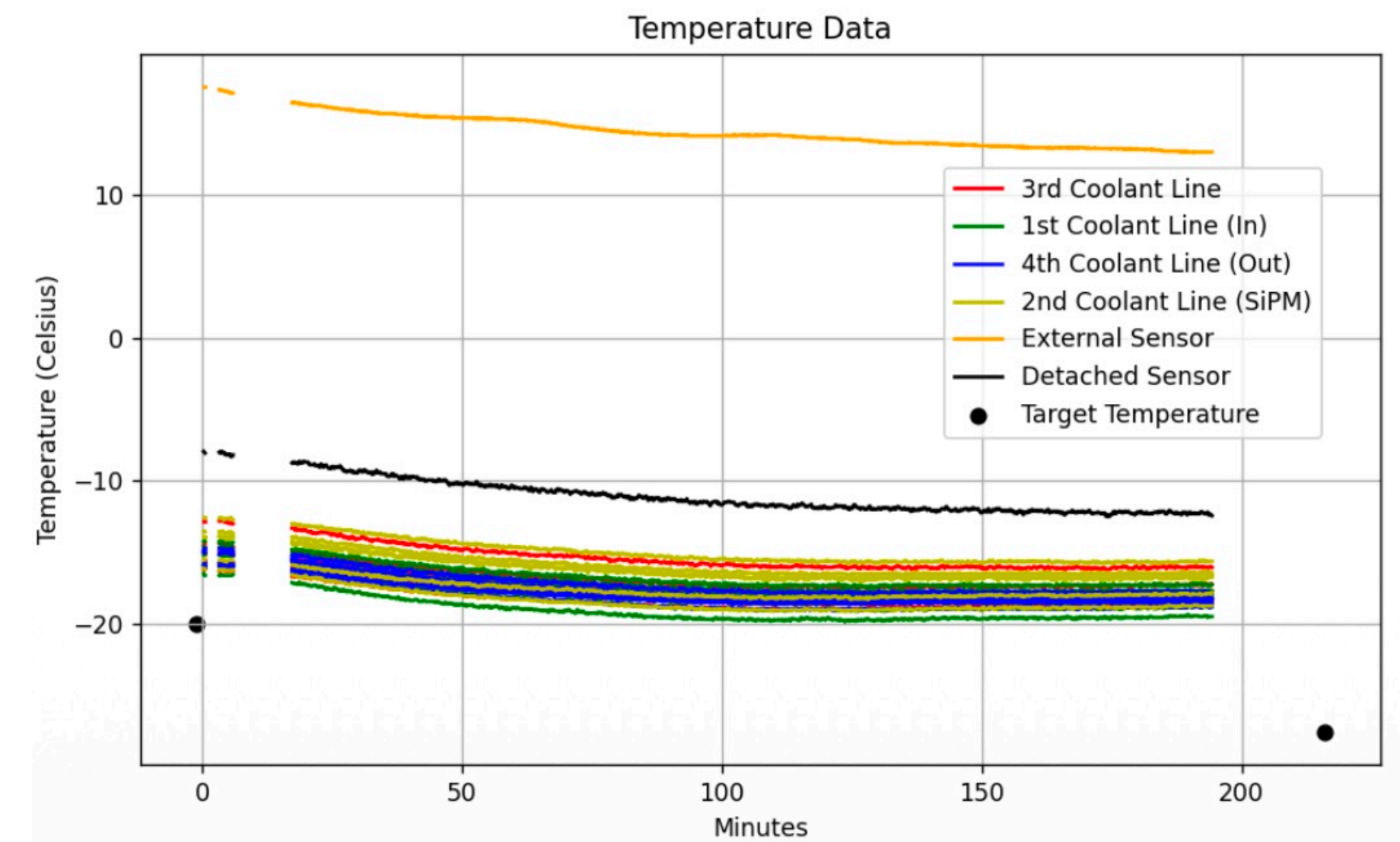
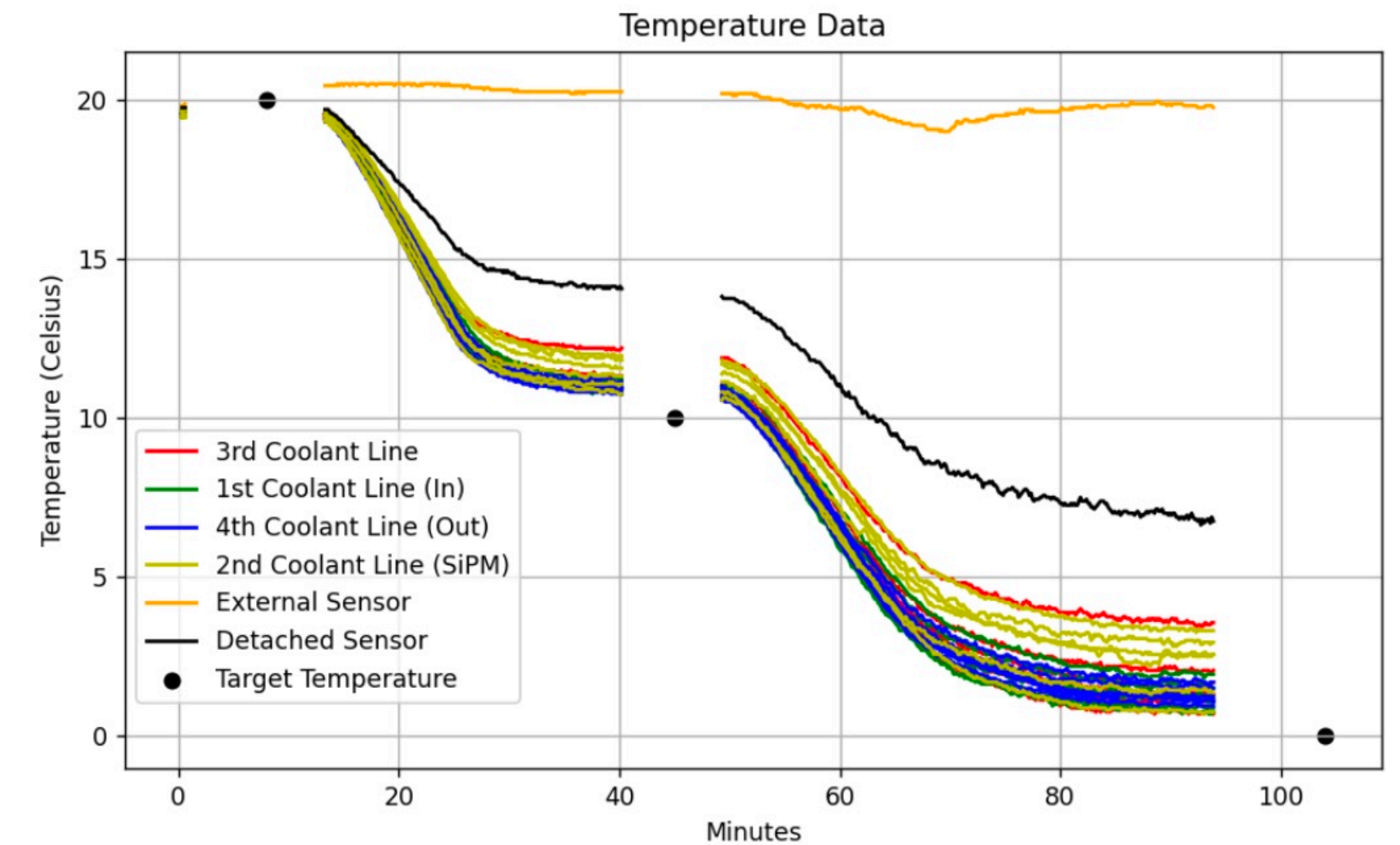
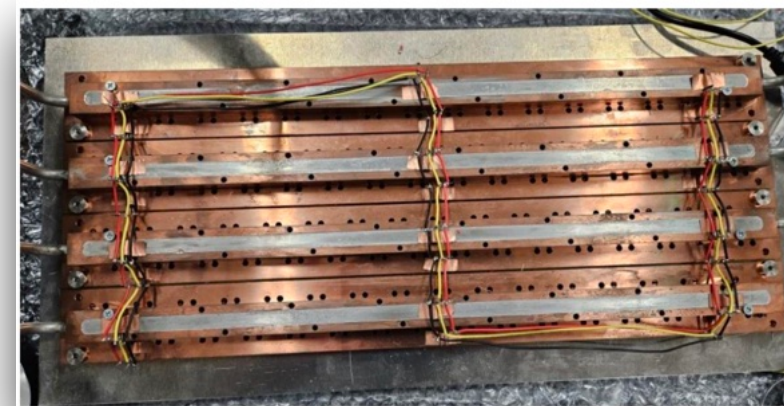
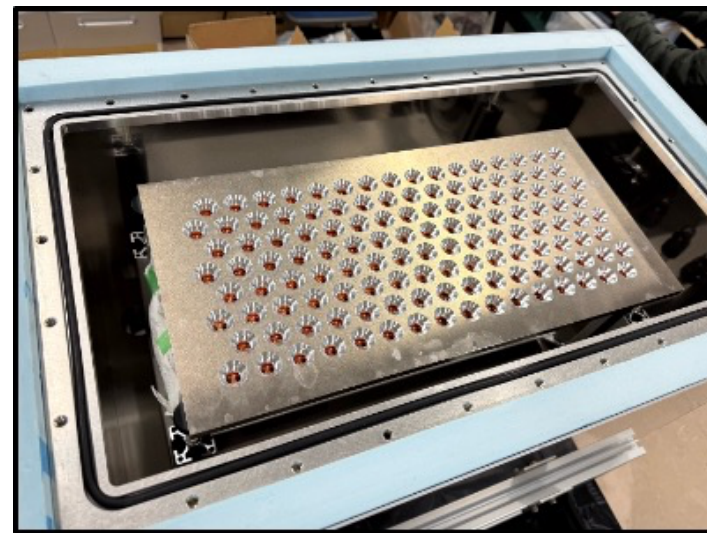
R&D #2

SiPM Cooling

Reduce Dark Count Rates

via Liquid Cooling of SiPM

- Dark count rate (DCR) dependence on operating temperature and bias voltage
- Characterization of Hamamatsu MPPC S13360-6075CS
- Simple SiPM liquid cooling test setup
 - Insulation box flushed with dry gas
 - Cooling pipes on copper plate with chiller-cooled glycol coolant
 - DS18B20U temp sensors

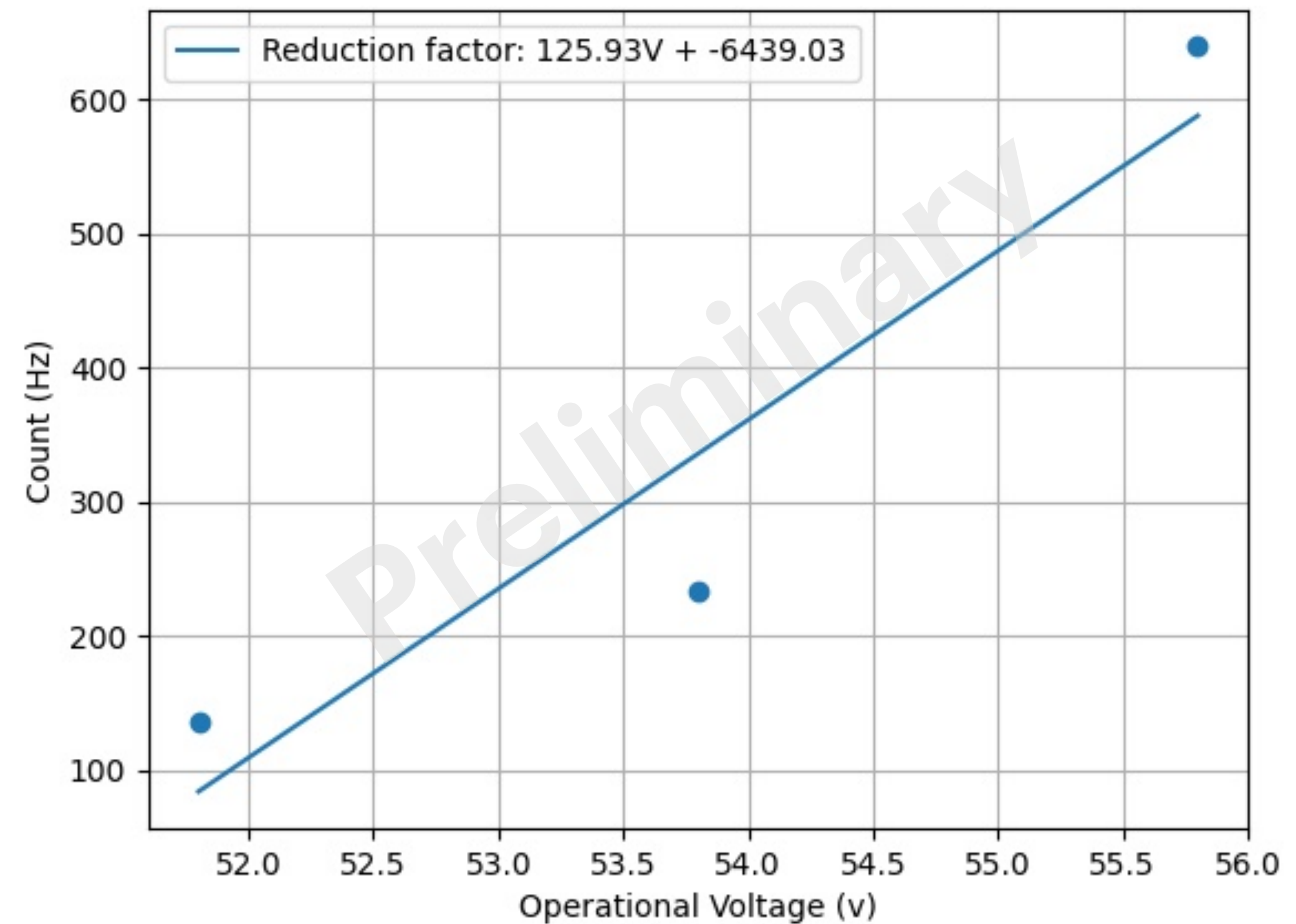
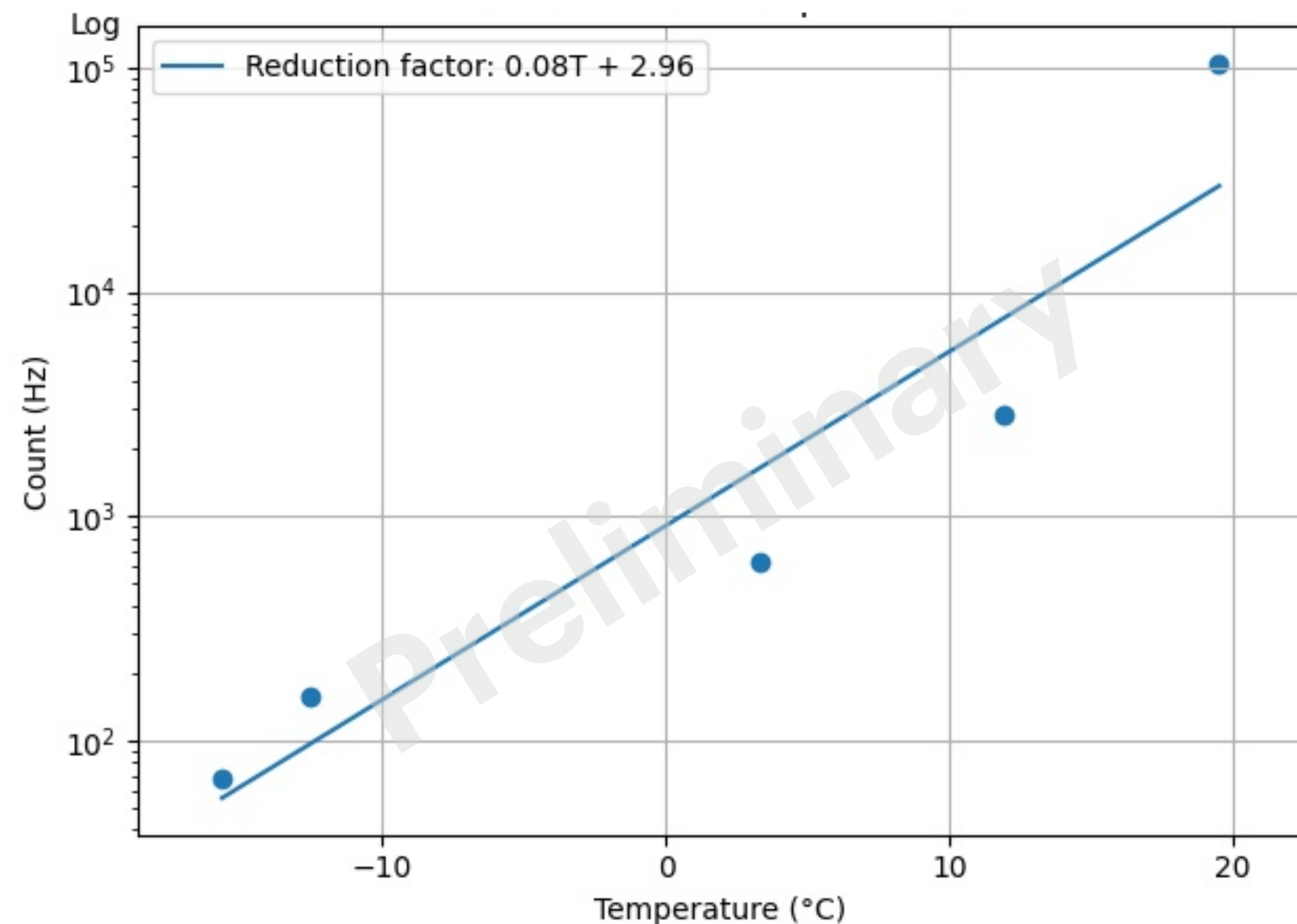


[Credits to T. Williams \(Duquesne U.\)](#)

SiPM Cooling

Preliminary Results for S13360-6075CS

- Every 10°C decrease in temperature reduces the DCR by approximately a factor of 6
- Overvoltage increases gain, but also increases DCR



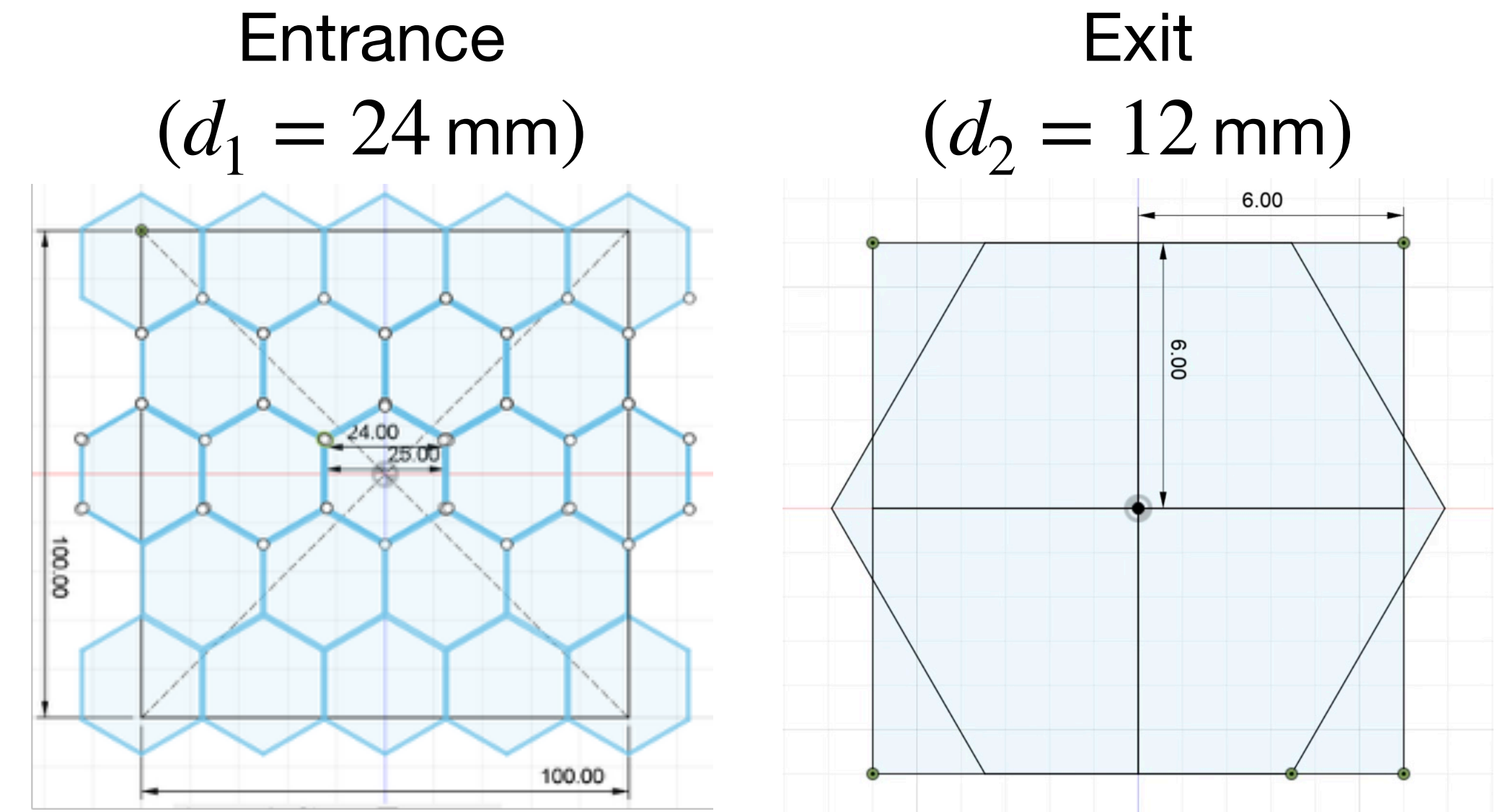
R&D #3

Light Concentrator

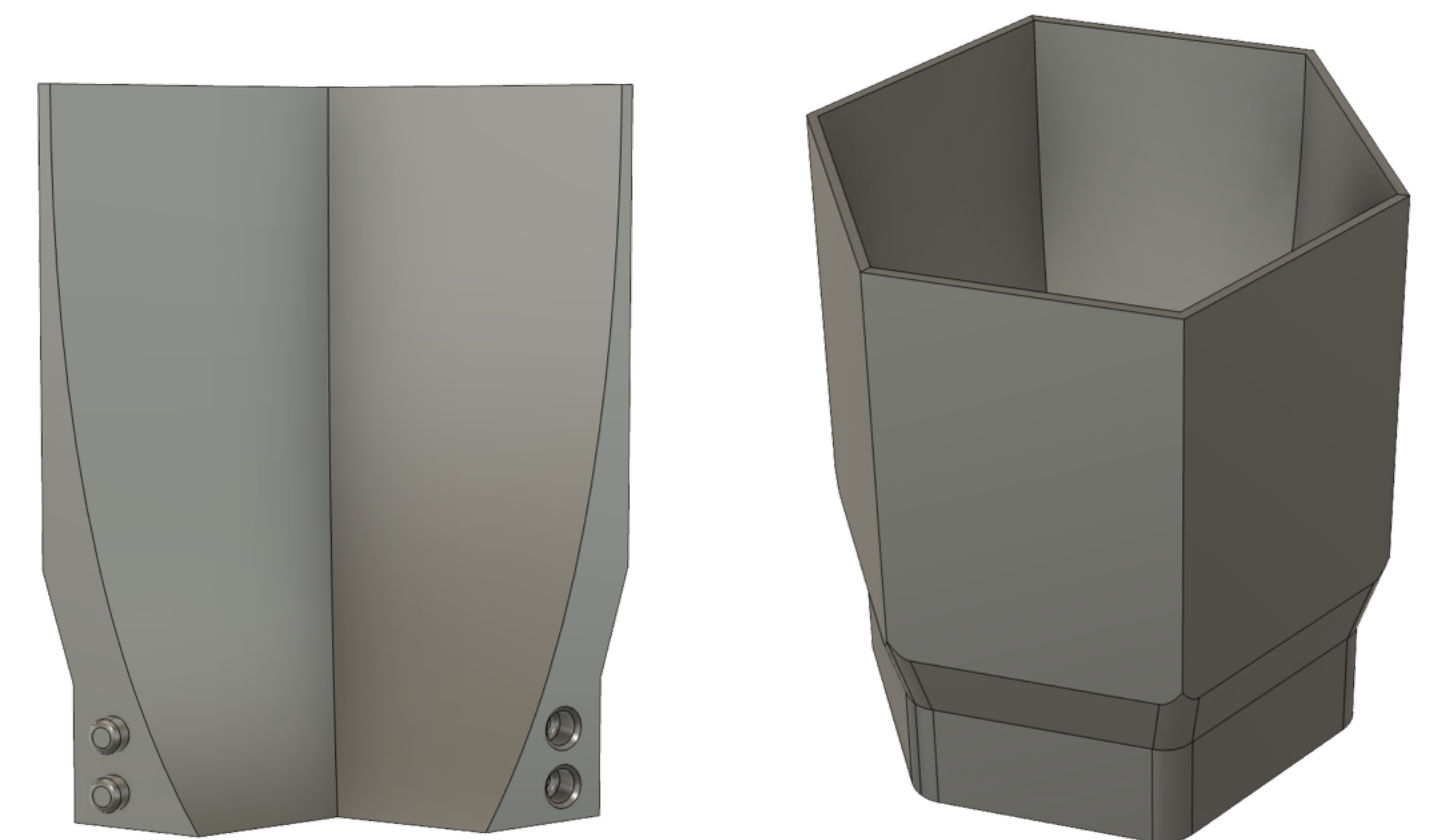
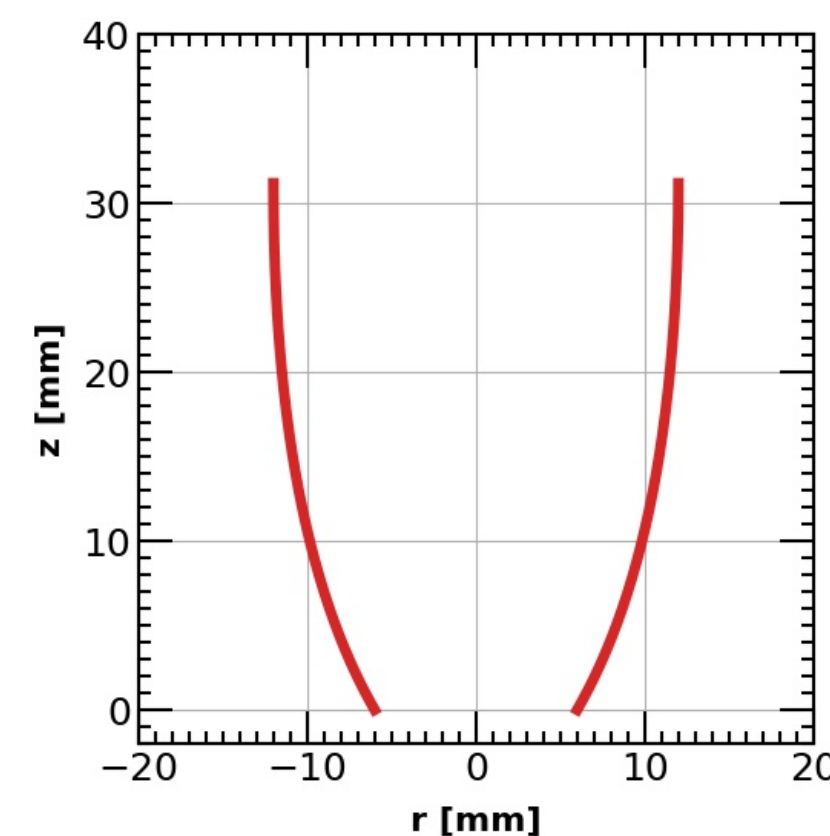
Maximize Photon Collection

using Light Concentrators

- Optimized hollow light concentrators to focus photons onto SiPM sensitive areas
- Hexagonal shaped for honeycomb-like packing layout to minimize loss
- 1/3 'open' pieces for vacuum evaporation coating (long-term stability)
- Entrance size determines granularity, exit size aligned to SiPMs
- Curved cones following 'Winston Cone' geometry for angular acceptance



Hex Light Concentrator



1/3 piece

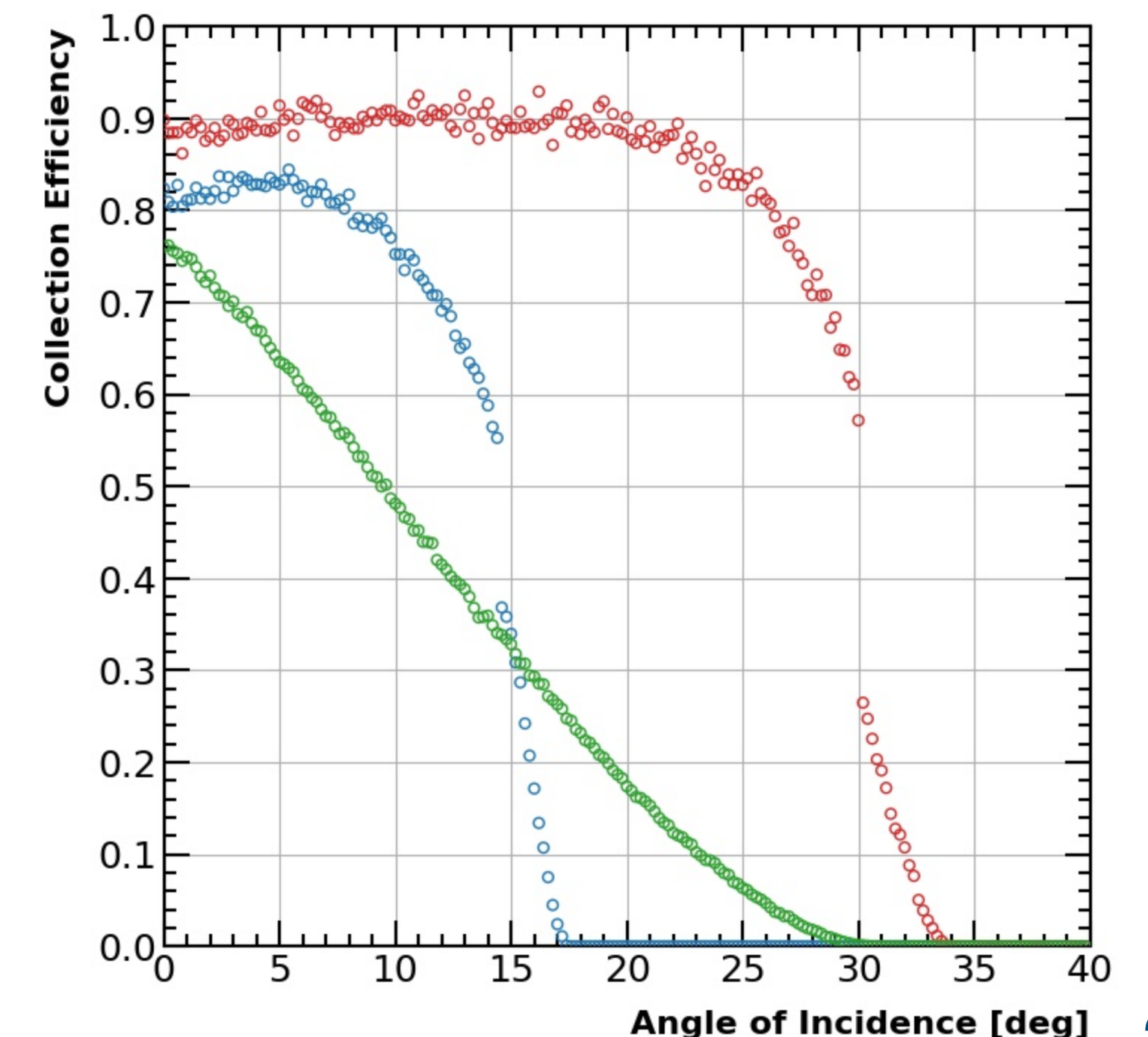
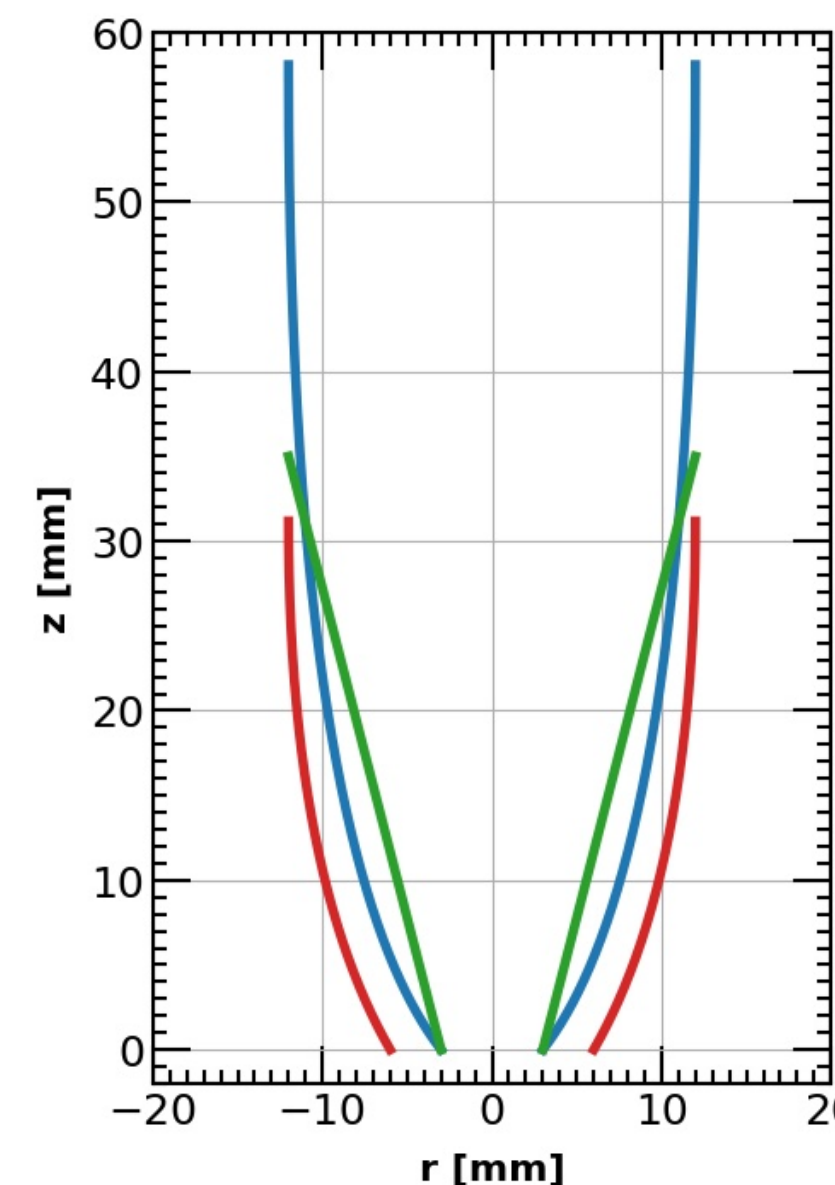
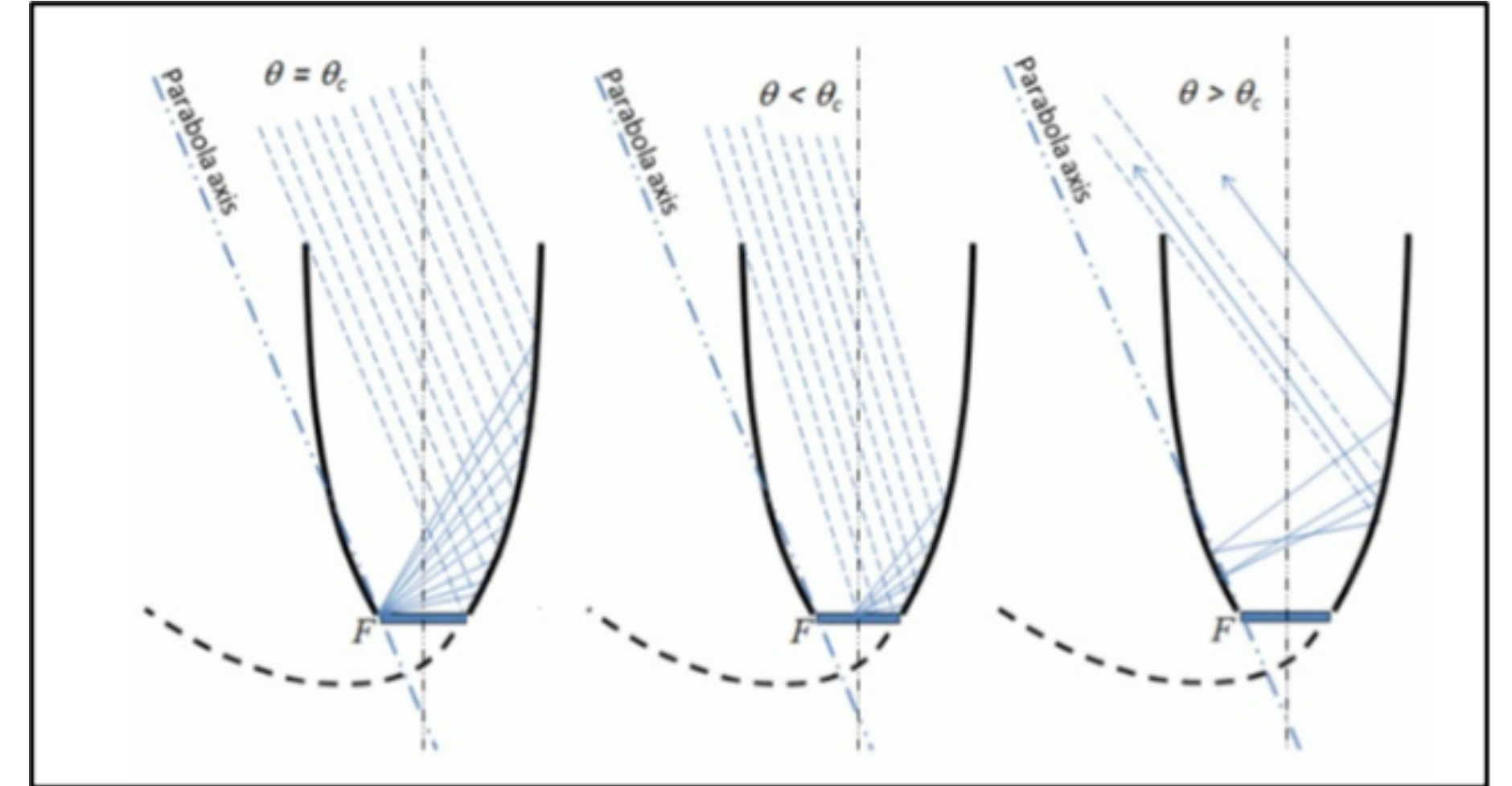
full assembly

Winston Cone Optimization

via Ray Tracing Simulations

[Astropart. Phys. 38, 18-24 \(2012\);](#)
[NIM-A 1087, 171395 \(2026\)](#)

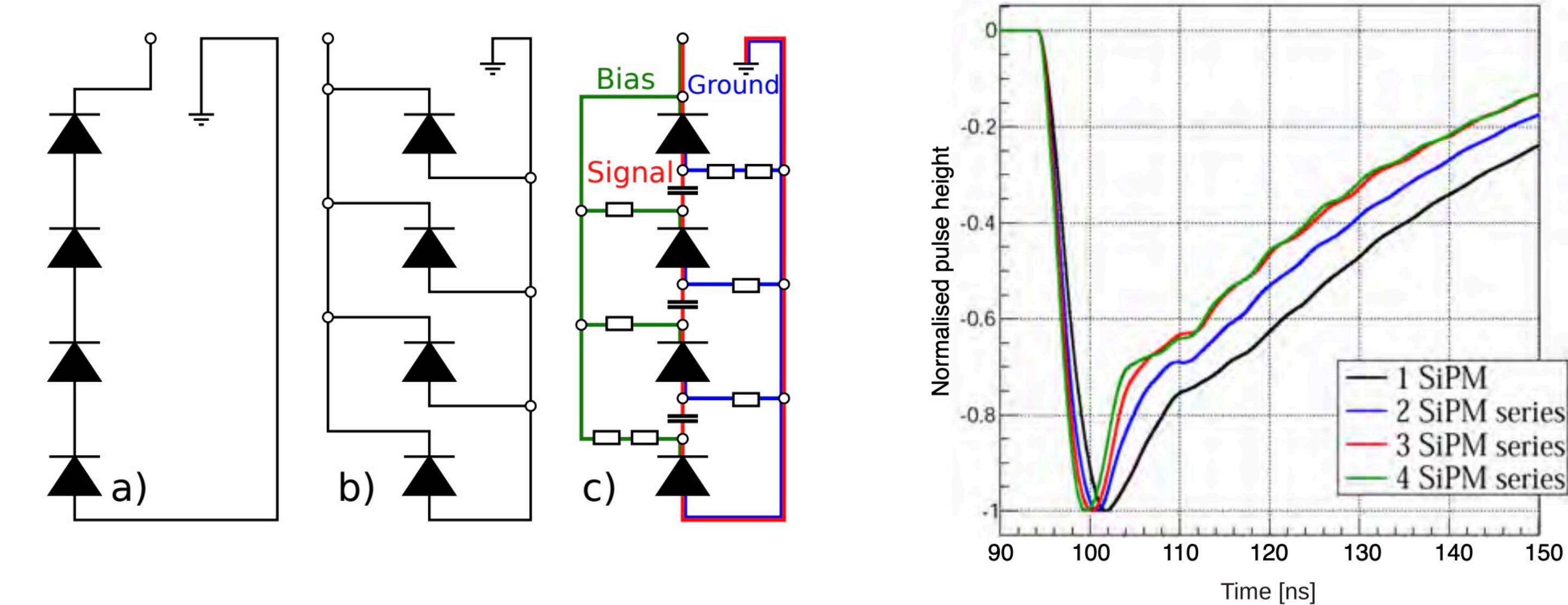
- Winston Cone geometries constrain angular acceptance
 - Photons entering at angles smaller than a critical value are collected with at most a single reflection, while those entering at larger angles are reflected out
 - Critical angle determined from 2 dof: d_1, d_2
- We fix entrance size, and investigate several options; We decide to go with the red design
 - This means exit is 12mm x 12mm, need to combine 2x2 array of 6mm x 6mm SiPMs



Combining Multiple SiPMs

Possible Connection Techniques

- Combining 4 SiPM as 1 sensor
- Options: (a) serial connection, (b) parallel connection, or (c) hybrid connection
- Pros and cons for each type of connection
- May go with parallel connection for common bias voltage and no loss in gain, but still an open choice

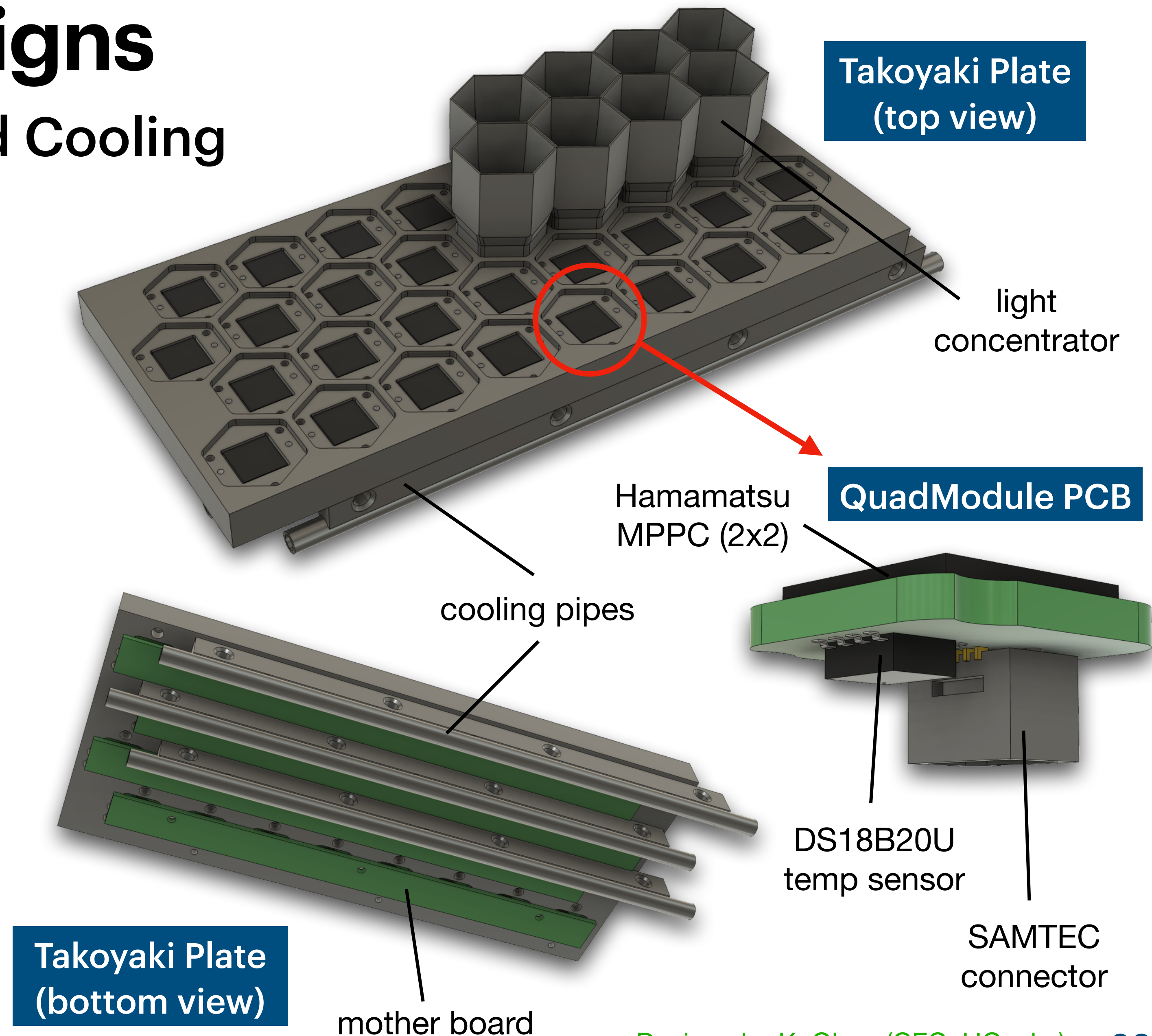


	Sensitive area	Bias Voltage	Signal shape	Gain	V_{BD} adjustment
Single	1	$V_{br} + OV$	-	1	-
Series	N	$N \times (V_{br} + OV)$	faster	$1/C$	Yes
Parallel	N	$V_{br} + OV$	slower	C	No
Hybrid	N	$V_{br} + OV$	faster	$1/C$	No

Latest Prototype Designs

Photodetector Module w/ LC and Cooling

- 2x2 array of MPPCs combined on a single QuadModule (QM) PCB
- Takoyaki plate for easy alignment and installation of light concentrators and QM PCBs
- Cooling pipes for coolant connected to Takoyaki plate via 'bridges'; QM PCBs with high thermal conductivity
- Other components still to be designed (insulation box w/ feedthroughs, mother board, connection to FEEs)



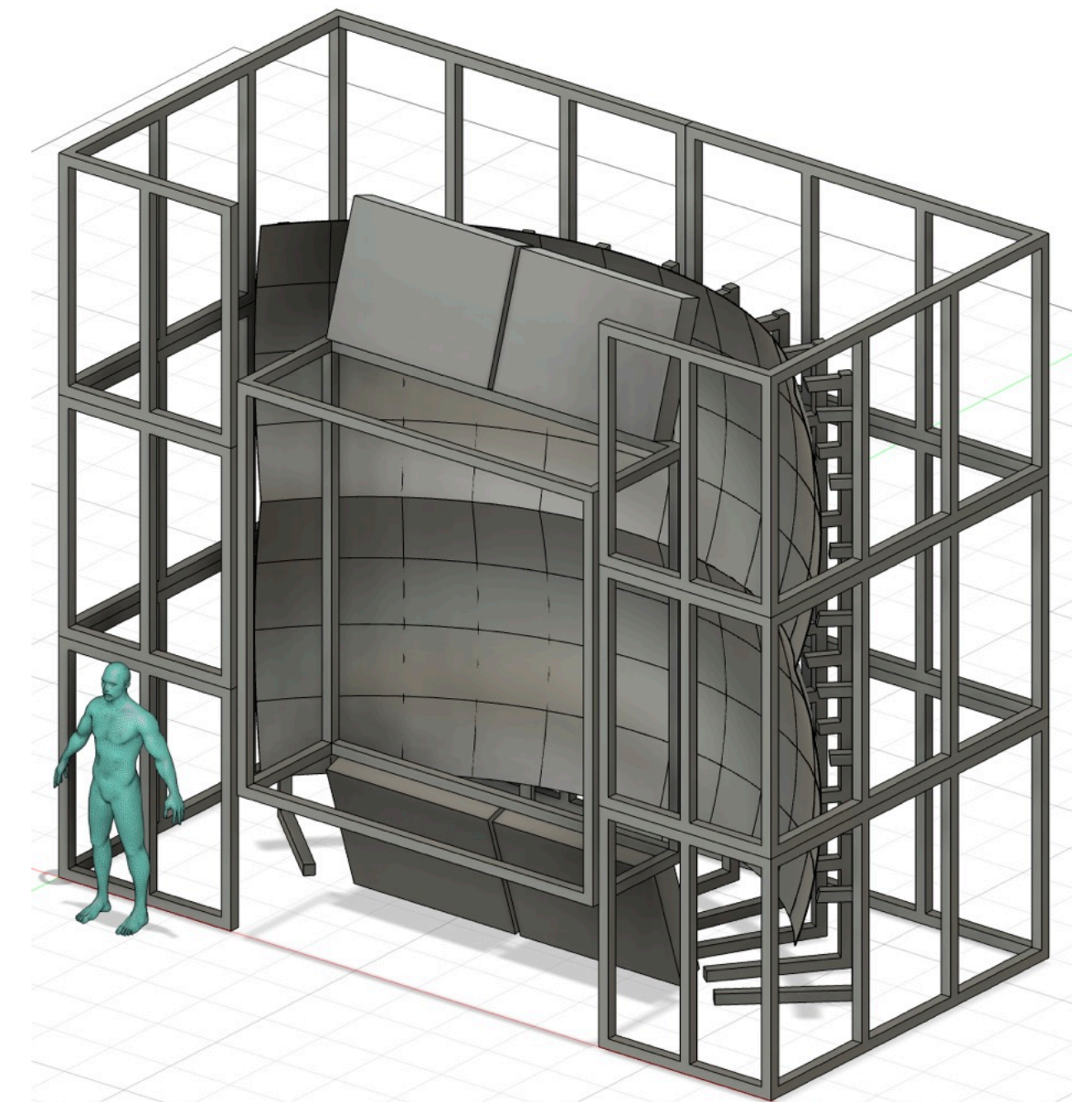
Conclusions

Summary and Outlook



- Next-generation RICH detector for hadron PID at J-PARC MARQ
- Ongoing R&D efforts on subsystems: (1) Optical quality measurements for alternative radiator gases; (2) SiPM cooling to reduce dark count rates; (3) photodetector module design with light concentrators
- **Towards a Mini-RICH (1/4 Module)**
 - 2026 Q4: Construction of components
 - 2027 Q1: Detector assembly and validation
 - 2027 Q2: Beam tests at J-PARC

Thank you for your attention!



Acknowledgements

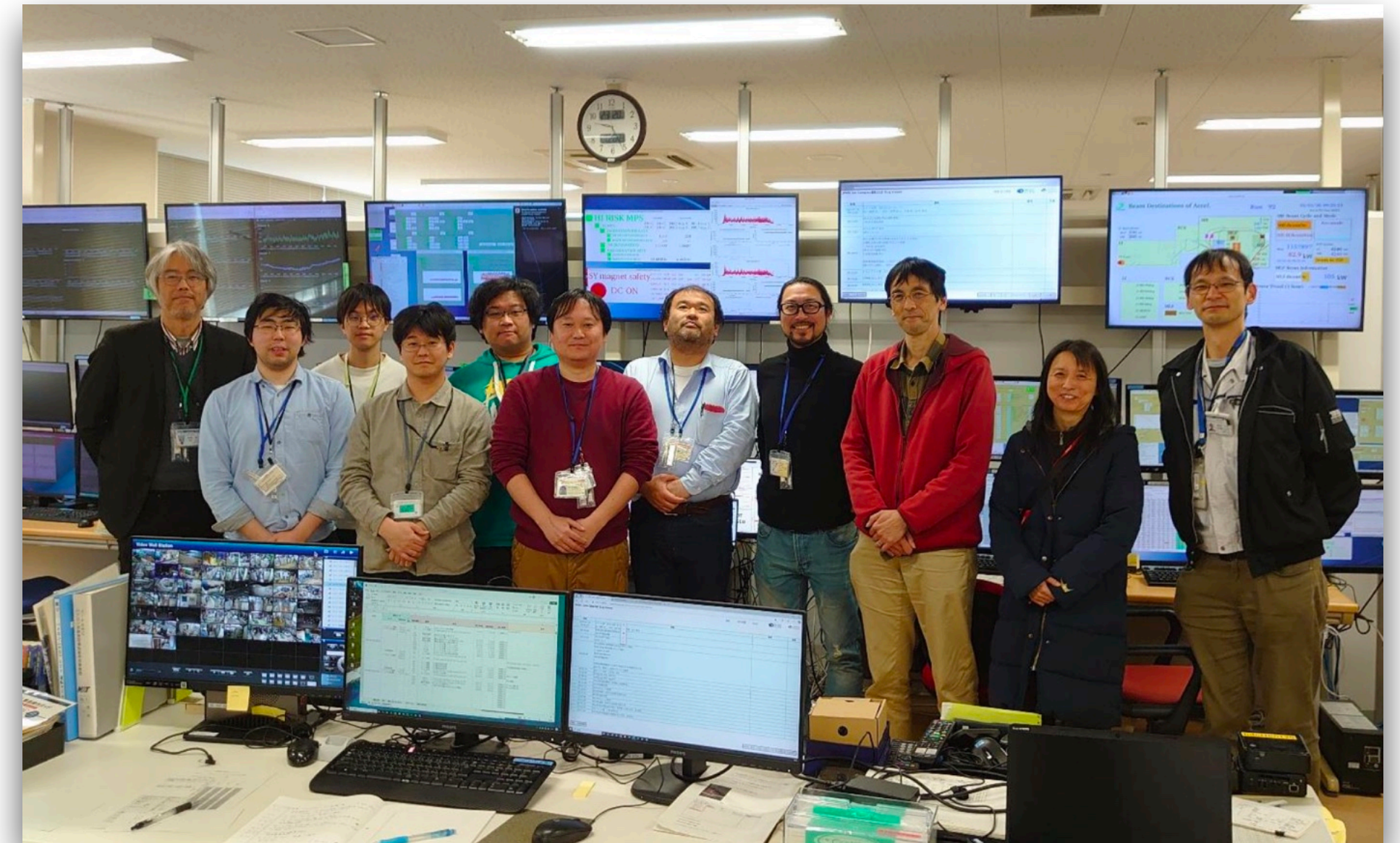
MARQ RICH Collaborators

Ken Suzuki, Kotaro Shirotori, Hiroyuki Noumi,
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*Department of Physics, Graduate School of Science,
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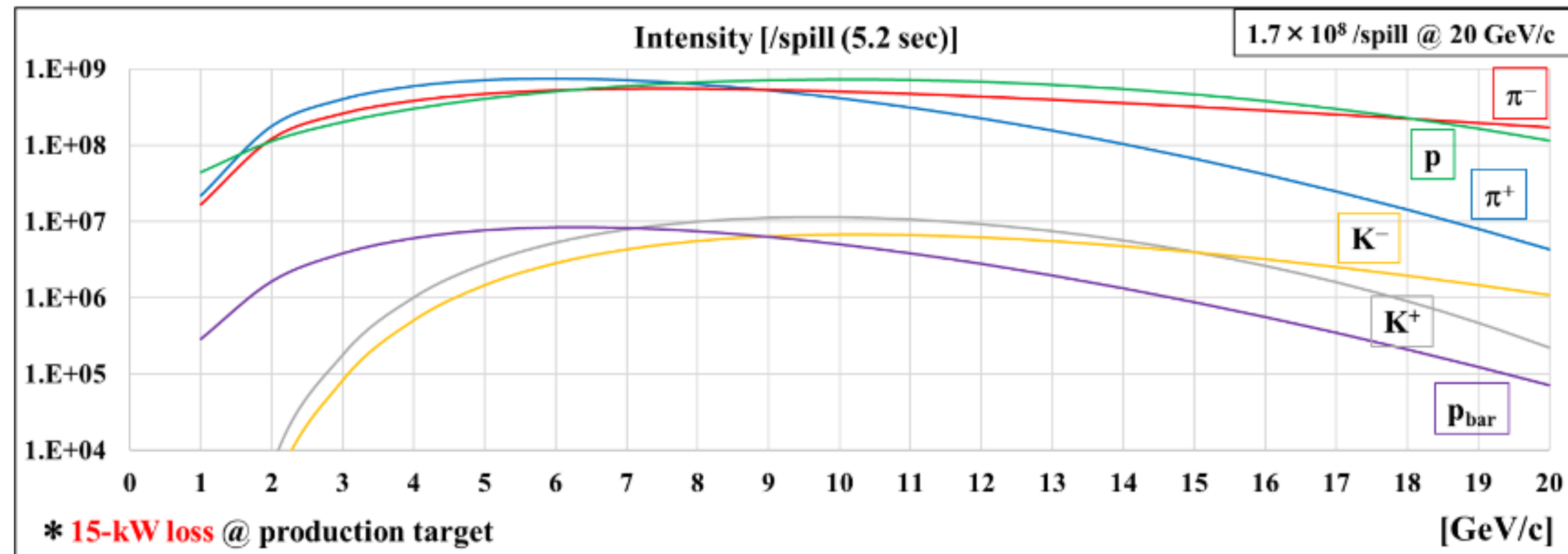
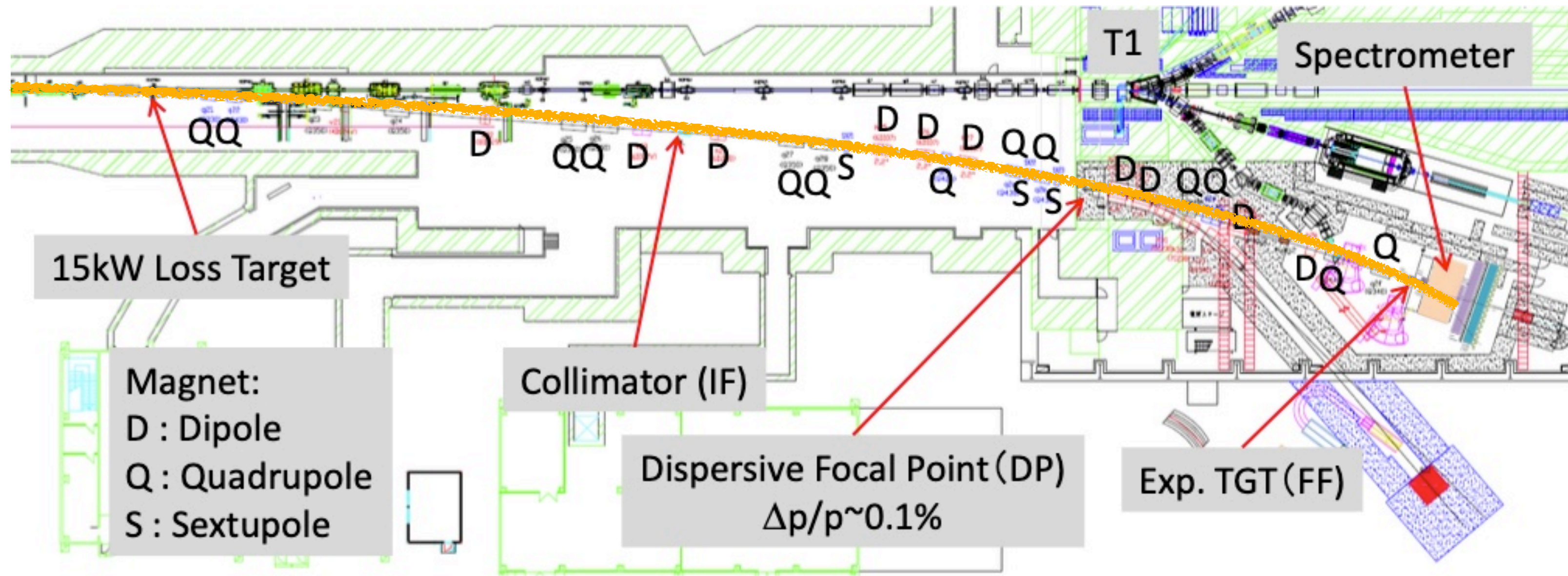
Makoto Tabata
Chiba University

Hiroshi Furutani, Kohji Ohno, Akira Sakaguchi, Kojiro Nagata
Core Facility Center, The University of Osaka



Backup

High-p ($\pi 20$) beamline @J-PARC

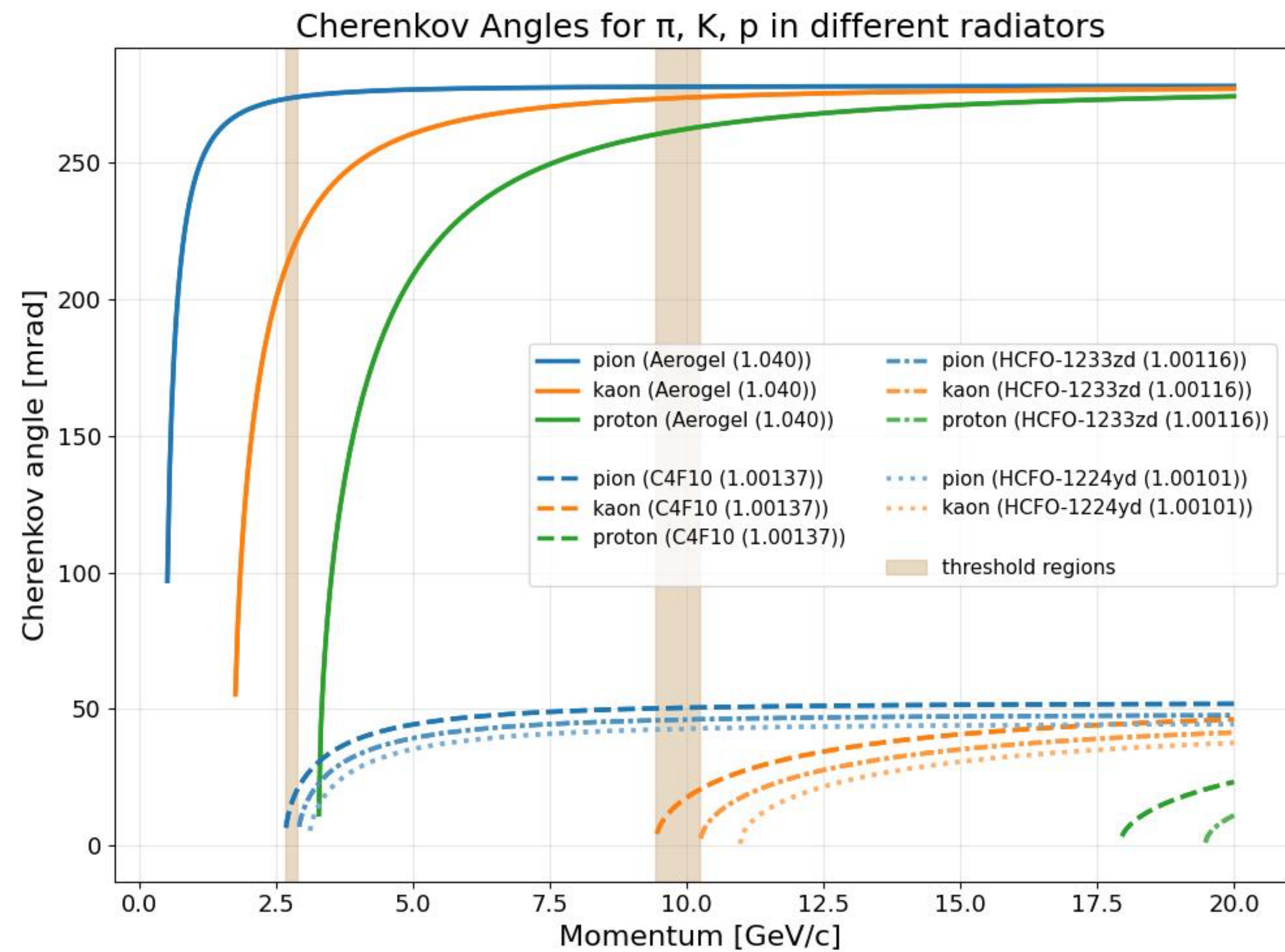


Gas Properties

Name	C ₄ F ₁₀	R-134a	HFO-1234yf	HFO-1234ze(E)	HCFO-1233zd	HCFO-1224yd
Manufacturer	various	various		Honeywell (US)	Honeywell (US)	AGC Chemical (JP)
Chemical Name	Perfluorobutane / Decafluorobutoane	1,1,1,2-Tetrafluoroethane	2,3,3,3-Tetrafluoroprop-1-ene	1,3,3,3-Tetrafluoropropene		(Z)-1-Chloro-2,3,3,3-Tetrafluoropropene
Chemical Formula	C ₄ F ₁₀	C ₂ H ₂ F ₄	C ₃ H ₂ F ₄		CF ₃ CH=CHCl	(Z)-CF ₃ CF=CHCl
CAS Number	355-25-9	811-97-2	754-12-1	29118-24-9	102687-65-0	111512-60-8
Typical Cost in Japan (JPY/kg)	-	3,800	30,000	13,000	12,000	13,000
Molecular Weight	238	102	114	114	130.5	148.5
Boiling Point (°C)	−2	-26.1	-29	-19	19	15
Freezing Point (°C)	−128	−103.3				−115
Critical Temp. (°C)		100.9	95			156
Vapour Pressure	330.3 kPa		0.677MPa @25°C, 2.44MPa @80°C	3.2bar @21°C, 9.7bar @54°C	106.3kPa @20°C	
Flammability Range (Vol% in Air)	non-flammable	non-flammable	6.2～12.3	7.0～9.5	non-flammable	non-flammable
Ozone Destruction Potential (ODP)		0	0	0	0	0.00023
Global Warming Potential (GWP)	6870	1,430	<1	<1	1	0.88

Impact on RICH PID

Considering lower refractive index



RICH Angular Acceptance

Estimation via Ray Tracing Simulations

