dRICH cooling

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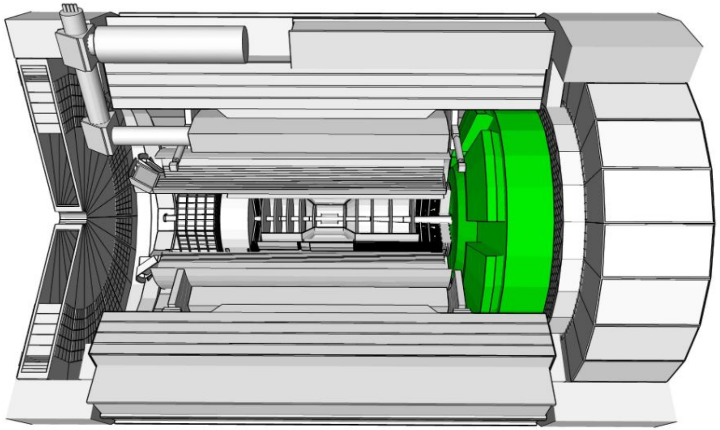
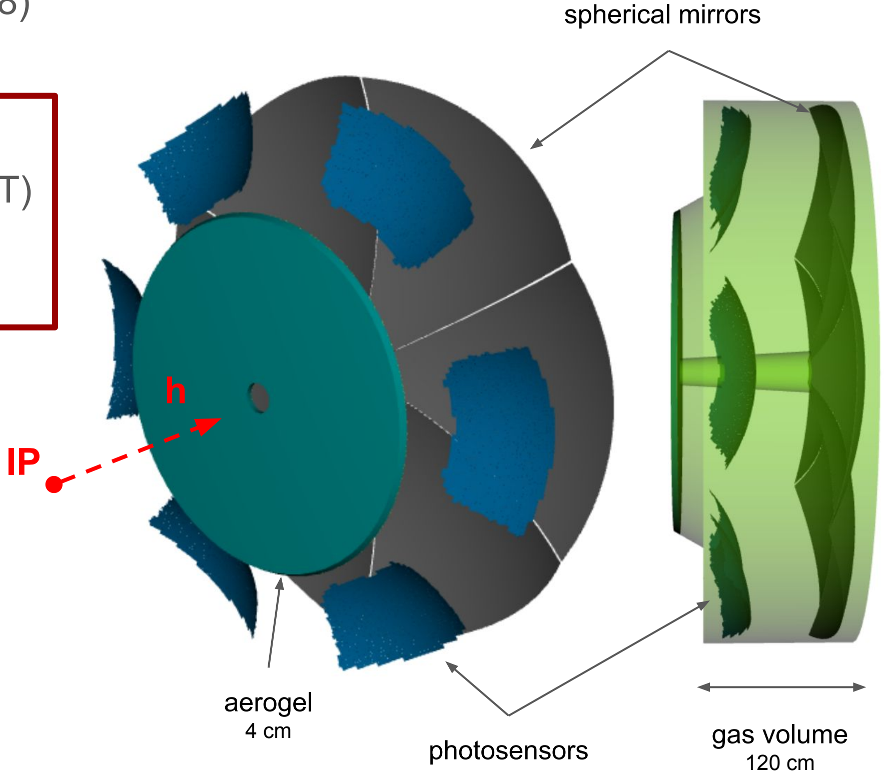
The dual-radiator (dRICH) for forward PID at EIC

compact and cost-effective solution for broad momentum coverage at forward rapidity

p = [3.0, 50] GeV/c
η = [1.5, 3.5]
e-ID up to 15 GeV/c

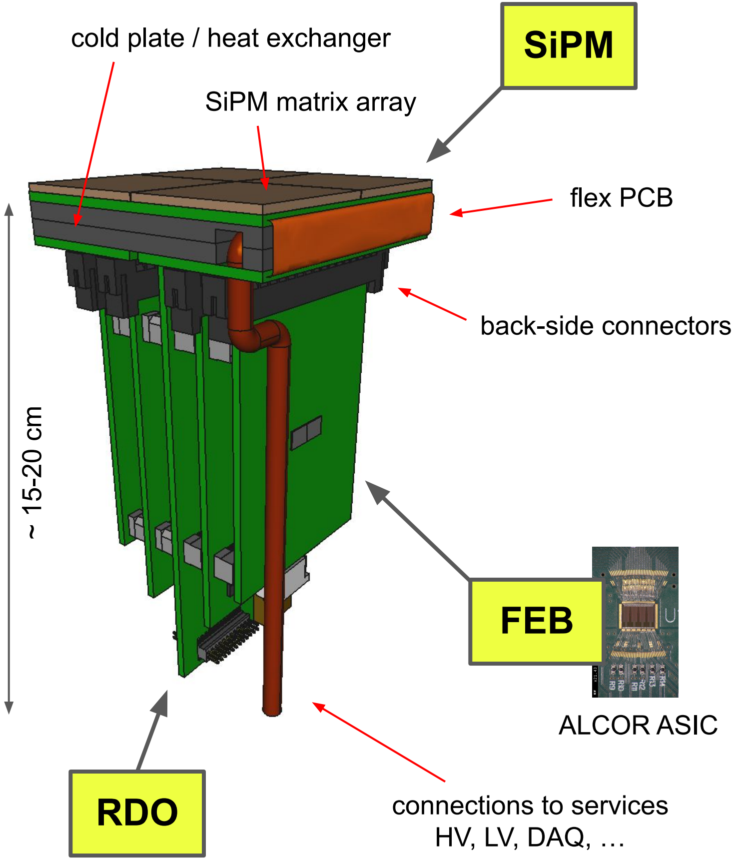
- **radiators:** aerogel (n ~ 1.02) and C_2F_6 (n ~ 1.0008)
- **mirrors:** large outward-reflecting, 6 open sectors
- **sensors:** 3x3 mm^2 pixel, 0.55 m^2 / sector
  - single-photon detection inside high B field (~ 1 T)
  - outside of acceptance, reduced constraints
  - SiPM optical readout





Photodetector unit

conceptual design of final layout



cold plate / heat exchanger

SiPM

SiPM matrix array

flex PCB

back-side connectors

~ 15-20 cm

FEB

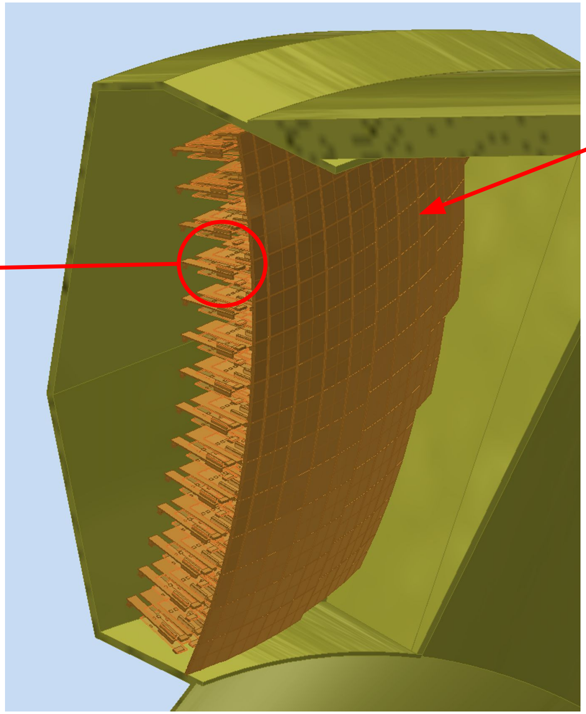
ALCOR ASIC

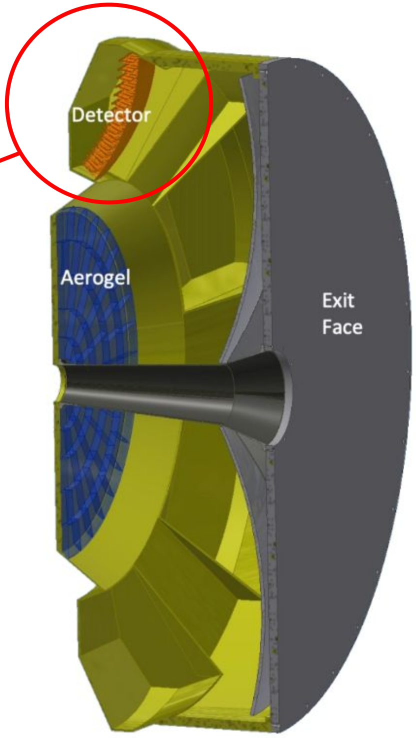
RDO

connections to services
HV, LV, DAQ, …

compact solution to minimise space

- cold plate and flex-PCB circuit
- uniform sensor cooling with no loss of active area
- all electronics and services on the back side





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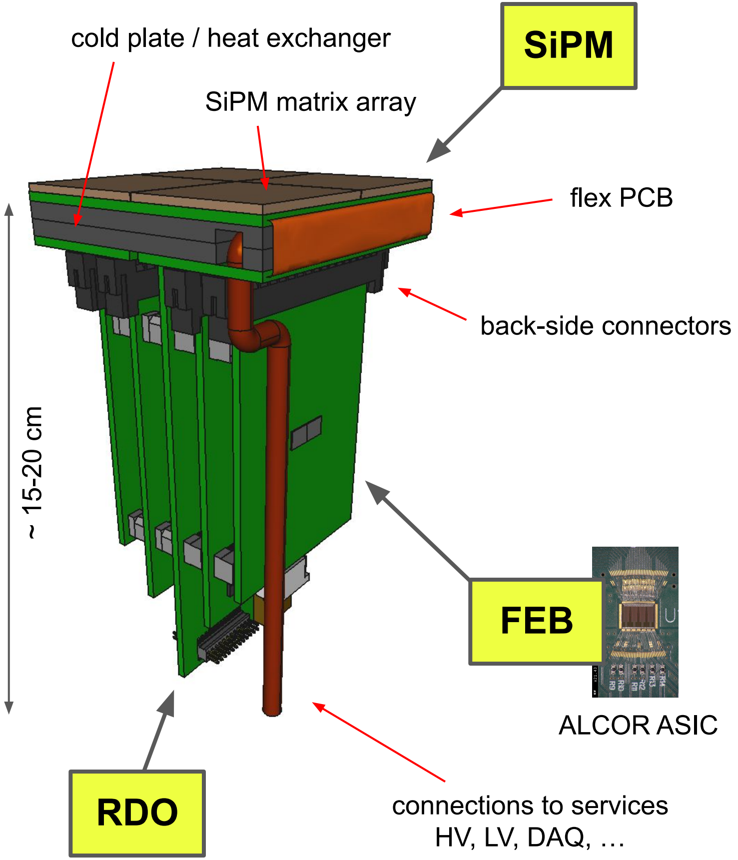
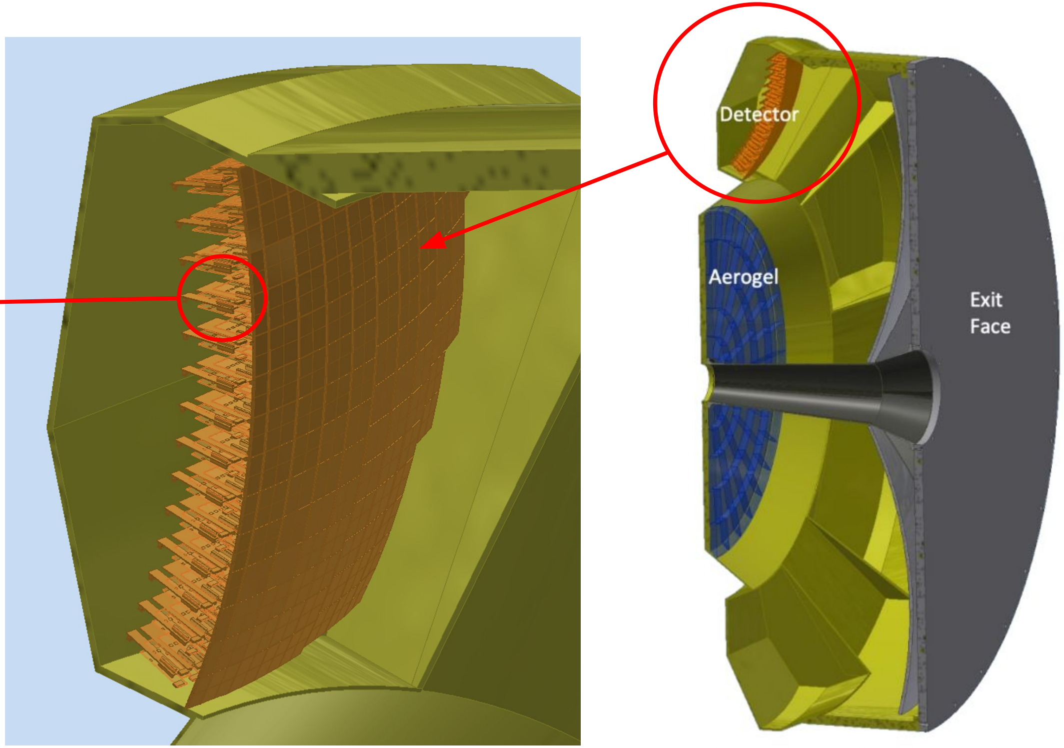


SiPM sensor matrices mounted on carrier PCB board

- 4x 64-channel SiPM array device (256 channels) for each unit
  - need modularity to realise curved readout surface
- 1240 photodetector units for full dRICH readout
  - 4960 SiPM matrix arrays (8x8)
  - 317440 readout channels



SiPM cooling for low-temperature operation (−40 °C or lower)

external chiller with fluid recirculation (ie. siliconic oil)

the chiller here one is just a commercial example

https://www.huber-online.com

cooling and heating capacity

could use heating capability for annealing? must be demonstrated to be feasible

cooling capacity at -40 C is large (1.5 kW)

General & Temperature Control	
Temperature range	-55...250 °C
Temperature stability	±0,01 K

Heating / cooling capacity	
Heating capacity	6 kW
Cooling capacity	

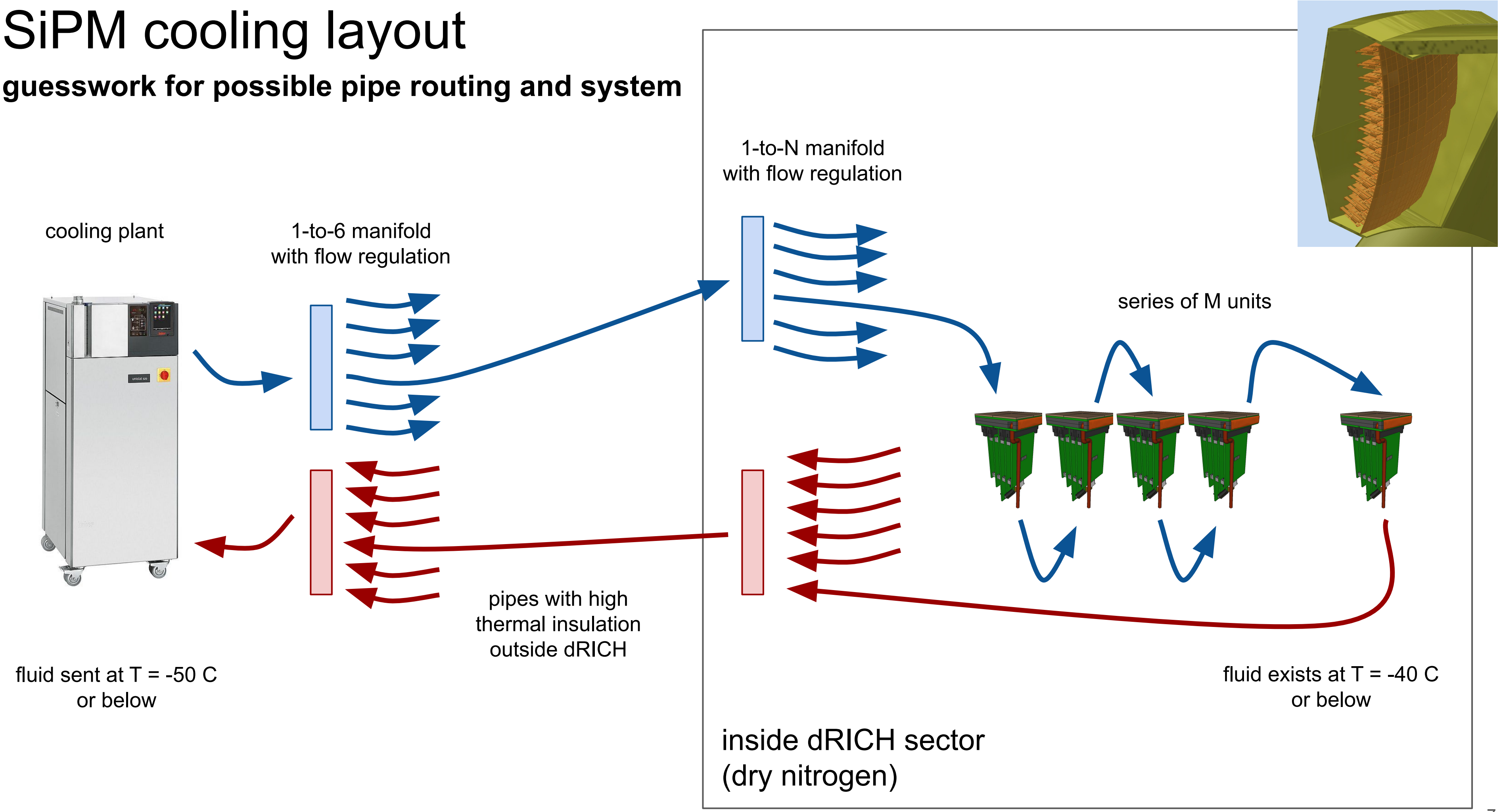
250	200	100	20	0	-20	-40	-50	°C
6	6	6	6	6	4,2	1,5	0,65	kW

SiPM cooling needs

- **goal is to be able to cool SiPM down to T = -40 C**
  - even lower if manageable
- **SiPMs do not heat up very much**
  - assuming maximum acceptable DCR: 300 kHz
  - assuming a SiPM sensor with large gain: 5 10^6
  - assuming a SiPM sensor with large bias voltage: 50 V (at low temperature)
  - current drawn by a single sensor: 250 nA
- **256 SiPM for each PDU → 60 uA / PDU**
- **200 PDU for each dRICH sector → 12.5 mA / sector**
- **6 sectors → 75 mA**
- **total power consumption when operated at 50 V is at most ~ 5 Watts**
  - even after irradiation
- **SiPM cooling looks basically like a thermostatic exercise, but**
  - of course it is not that simple because the environment around is not vacuum
  - and there are heat sources nearby (electronics)
- **a proper engineering calculation is needed to define all specs**
  - including flow of circulation fluid

SiPM cooling layout

guesswork for possible pipe routing and system



cooling plant

1-to-6 manifold
with flow regulation

1-to-N manifold
with flow regulation

series of M units

pipes with high
thermal insulation
outside dRICH

fluid sent at T = -50 C
or below

fluid exists at T = -40 C
or below

inside dRICH sector
(dry nitrogen)

Electronics cooling needs

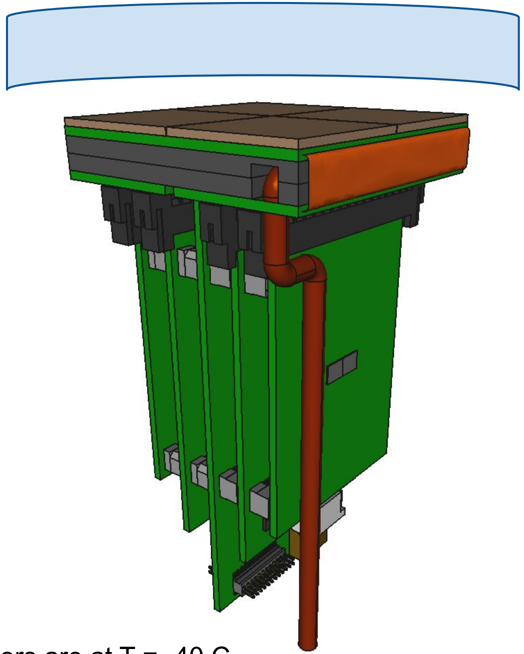
- **goal is to remove the heat generated by the electronics**
  - estimates below are based on current prototype electronics
  - there is no prototype RDO, so there is a bit of a guesswork here
- **1 PDU = 4 FEBs + 1 RDO**
  - current proto-FEB consumes ~ 1.5 W power
  - assume RDO consumes ~ the same (let’s put 2 W)
  - 1 PDU = 8 W
- **200 PDU for each dRICH sector → ~ 1.5 kW / sector**
- **6 sectors → 10 kW**
- **how to remove that heat?**
  - forced air circulation inside the readout box
    - this might bring heat towards SiPM
    - but also have beneficial effect of keeping quartz window “at room temperature”
  - water-cooling? needs piping and fingers on hot chips
    - perhaps possible, but very little space in the readout box
- **a proper engineering calculation is needed to define all specs**

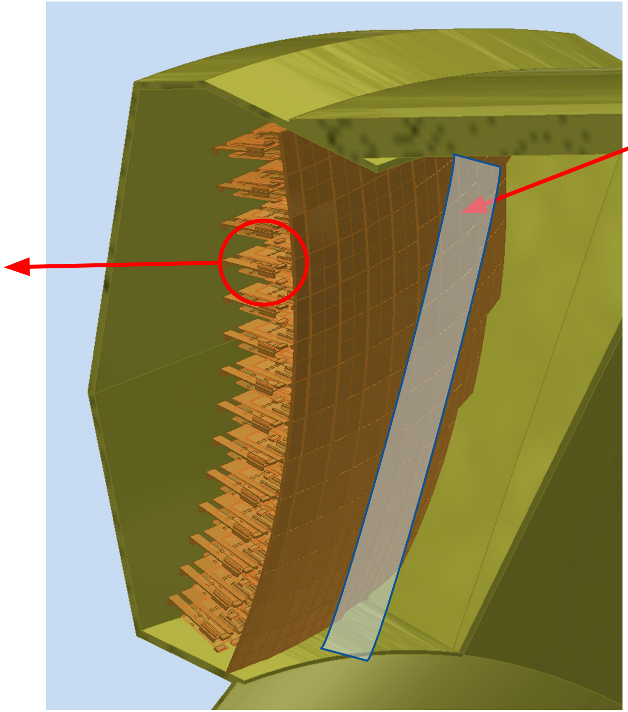
The quartz window

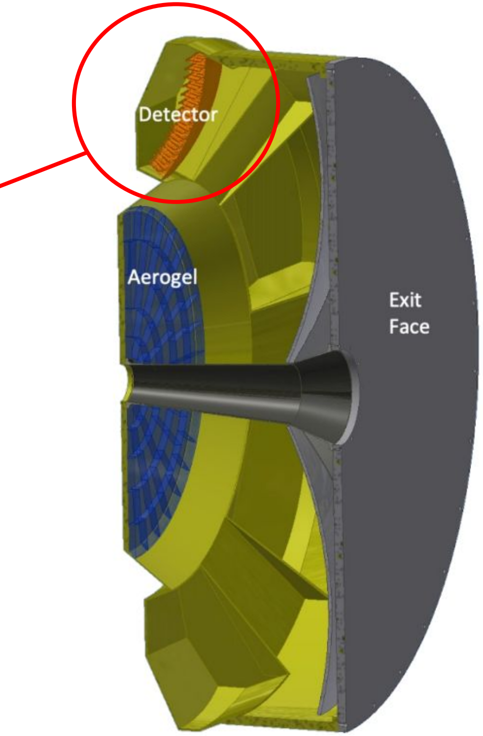
an area where there is need of Ansys

separate readout volume from gas-radiator volume

- gas types are different (N_2 vs. C_2F_6)
- limit temperature gradients in the gas radiator







sensors are at T = -40 C
how does the temperature look like behind the window?
how thik do we need it?
what if there is air circulation in the readout box?
and heat generation from the electronics?
we will prepare a test-bench in the lab to perform measurements
need engineering support from the project for engineering simulations to be compared to

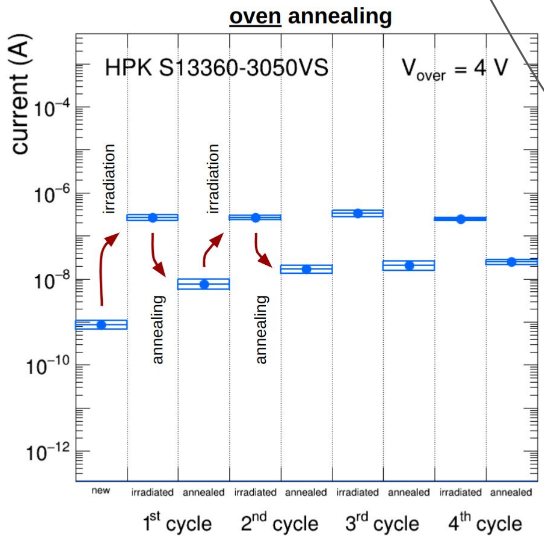
Summary

- **ideas on how to cool the SiPM are there**
  - target to cool down to T = -40 C
  - TEC Peltier-based cooling used in current prototype units works
  - very confident that a fully fluid-based cooling concept will work (want to avoid Peltier in experiment)
- **in principle a modest chiller should be sufficient for SiPM cooling**
  - if one only accounts for the SiPM heat generation
  - but we need to transport fluid (losses)
  - must take into account the environment inside the readout box
  - we need calculations
- **SiPM electronics generated ~ 10 kW across the whole dRICH**
  - ~ 1.5 kW from within each readout box
- **need support from project engineers for cooling calculations / simulations**
  - we will prepare test benches for measurements to be compared to Ansys
  - very important also to assess the impact on the gas radiator (see PID review)

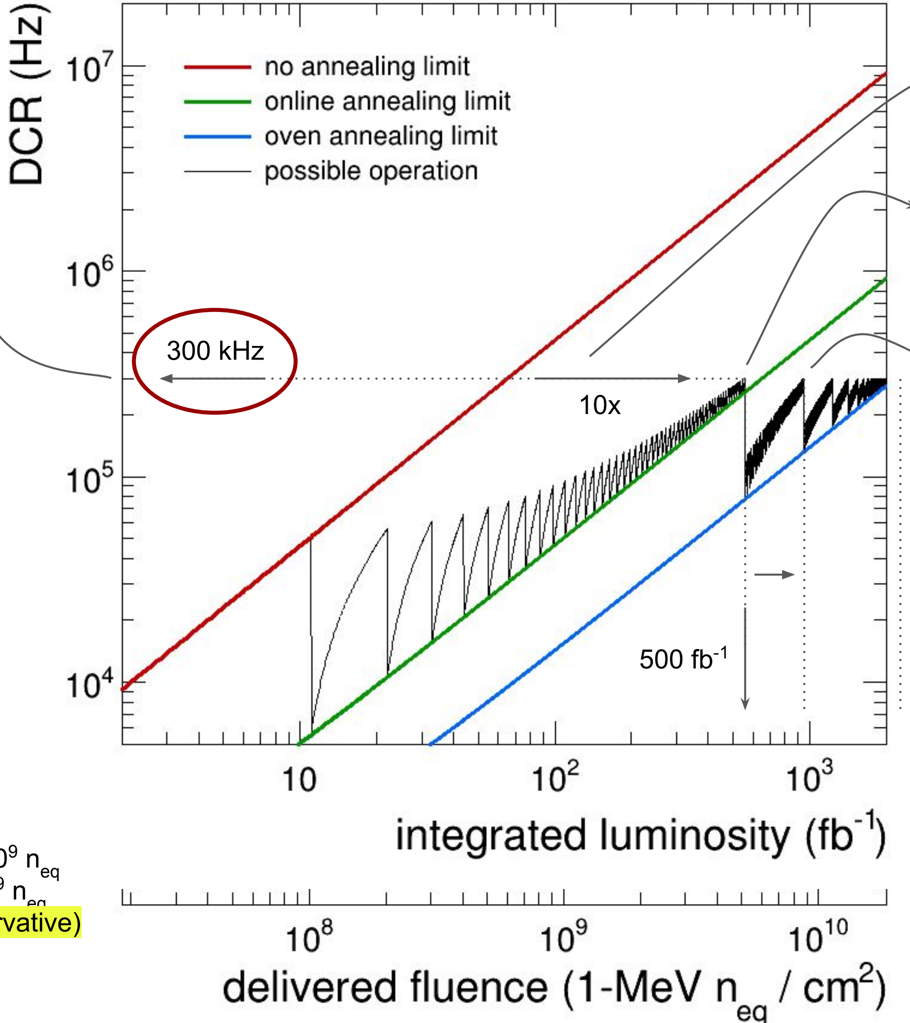
END

Ageing model

max acceptable DCR for Physics performance
~ 10 noise hits / sector within 500 ps



Hamamatsu S131360-3050 @ Vover = 4 V, T = -30 C



online annealing extends SiPM lifetime by ~ 10x

more aggressive annealing needed here
might need to unmount SiPM (oven)

up to 1000 fb^{-1} with only one oven annealing cycle
optimisation of online annealing protocol could reach beyond that

model input from R&D measurements (up to 2022)

- DCR increase: 500 kHz/10^9 n_{eq}
- residual DCR (online annealing): 50 kHz/10^9 n_{eq}
- residual DCR (oven annealing): 15 kHz/10^9 n_{eq}

1-MeV neq fluence from background group (conservative)

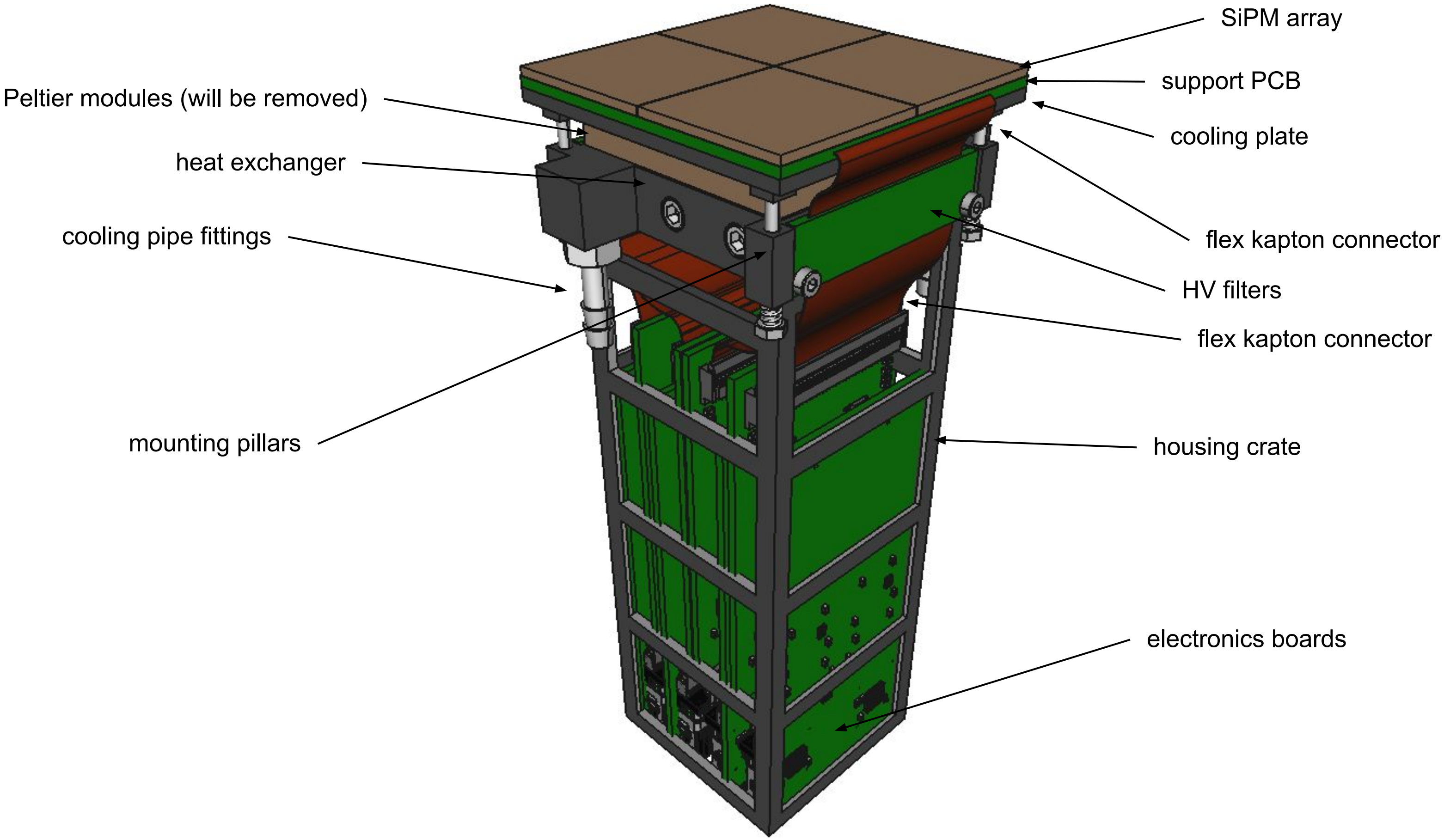
- 9 10^6 n_{eq} / fb^{-1}
- includes 10x safety factor

these predictions are according to present knowledge / tested solutions

there are more handles to further mitigate DCR

lower Vover, 3V
lover T operation -40 C or below

Prototype photodetector unit (PDU)



Prototype photodetector unit (PDU)