dRICH photosensors and electronics

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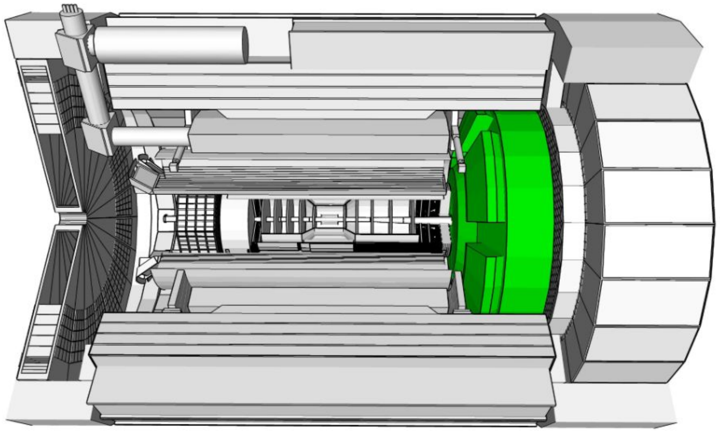
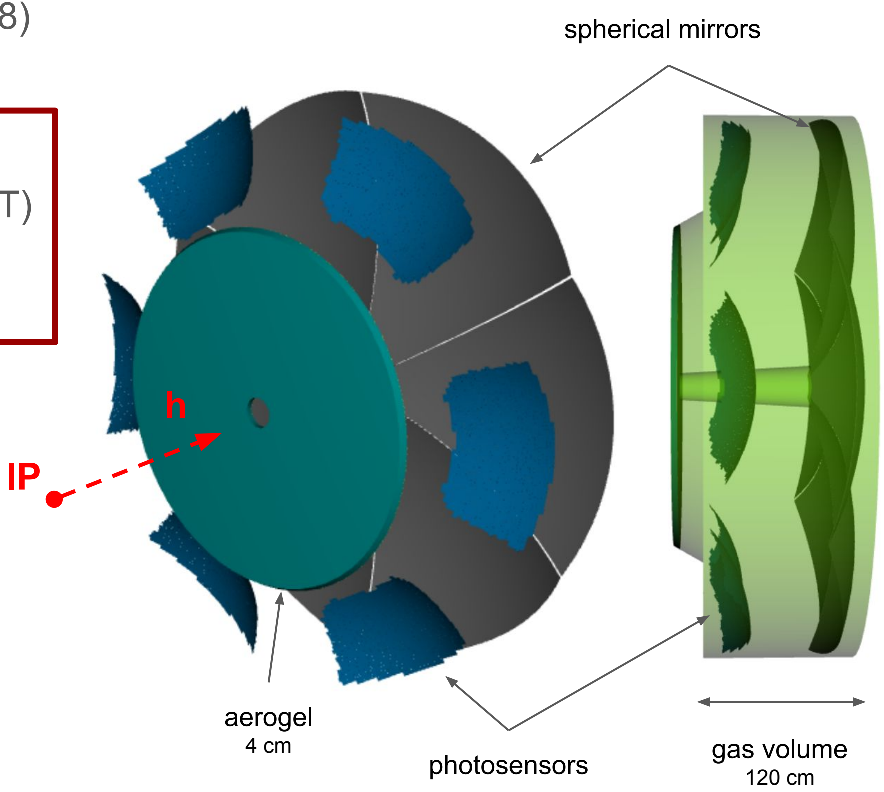
The dual-radiator (dRICH) for forward PID at EIC

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





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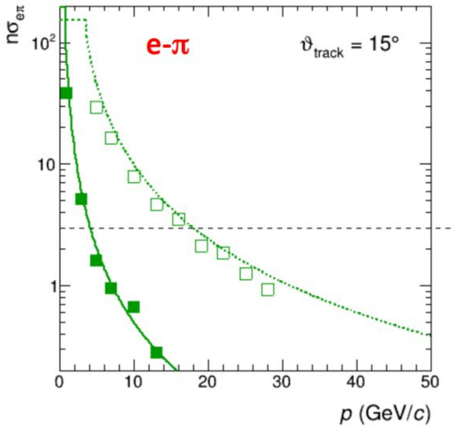
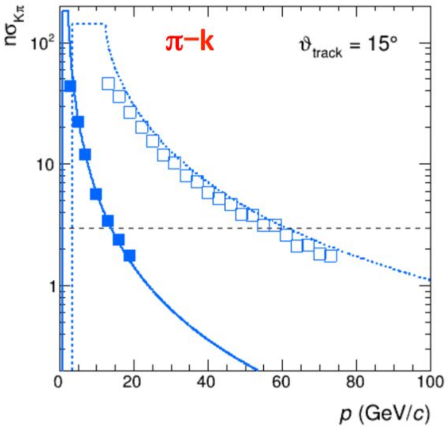
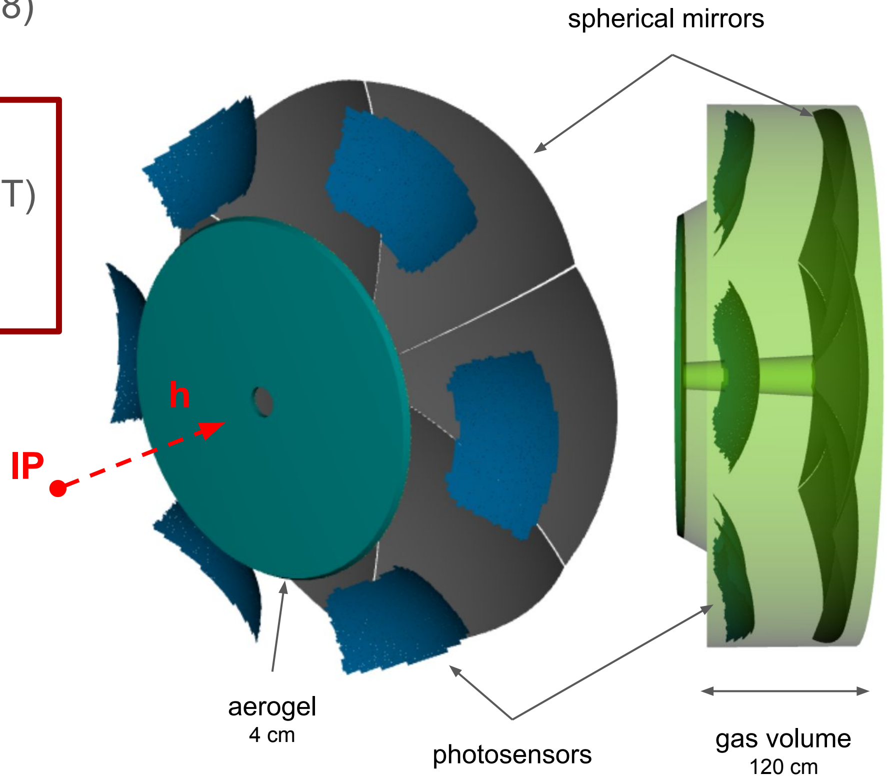




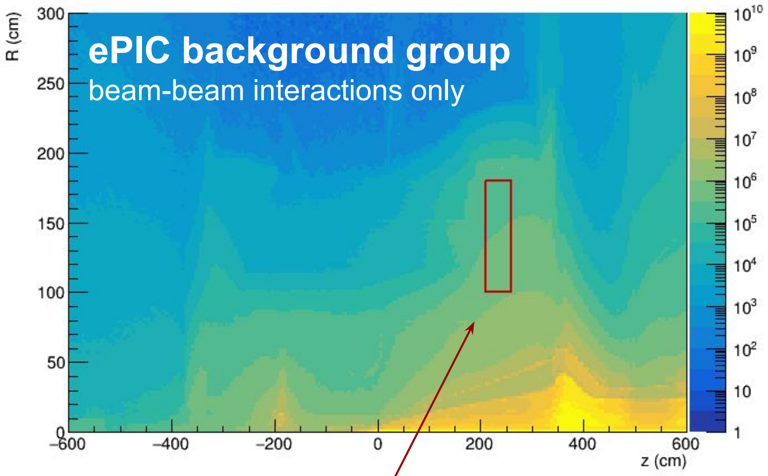


GEANT4 simulations: dRICH meets performance requirements

Environment

radiation damage estimates

1-MeV neutron equivalent fluence (1 fb^{-1} ep running)



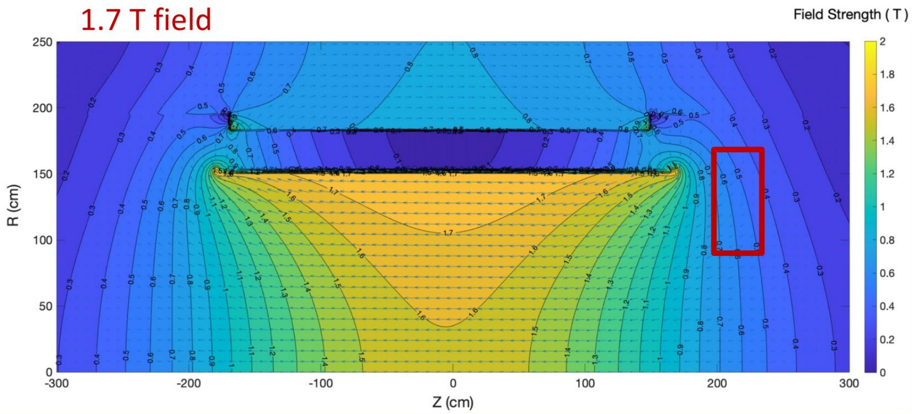
location of dRICH photosensors

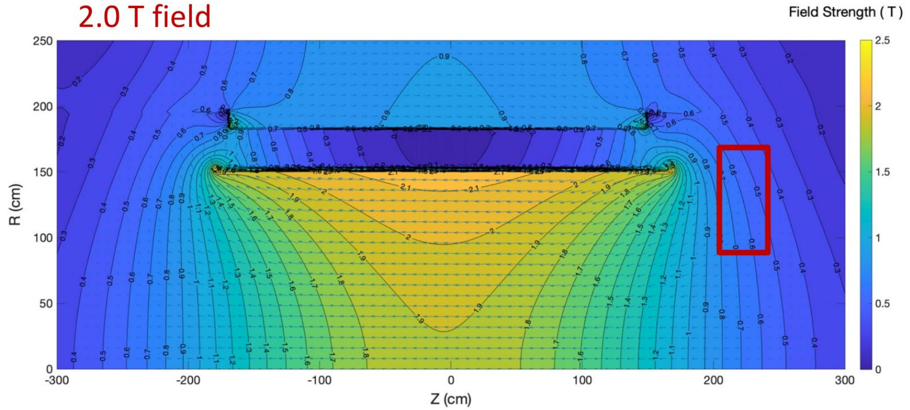
assume fluence: ~ 10^7neq / cm^2 / fb^{-1}

conservatively assume max fluence and 10x safety factor

moderate radiation, 1000 fb^{-1} integrated $\mathcal{L}$ corresponds to ~ 10^{10} n_{eq}/cm^2

MARCO magnetic field maps





non-uniform, strong magnetic field ~ 0.7 T

field lines ~ parallel to photodetector surface

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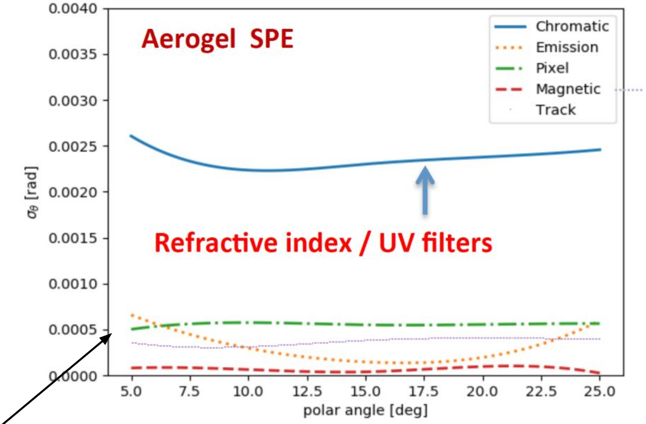
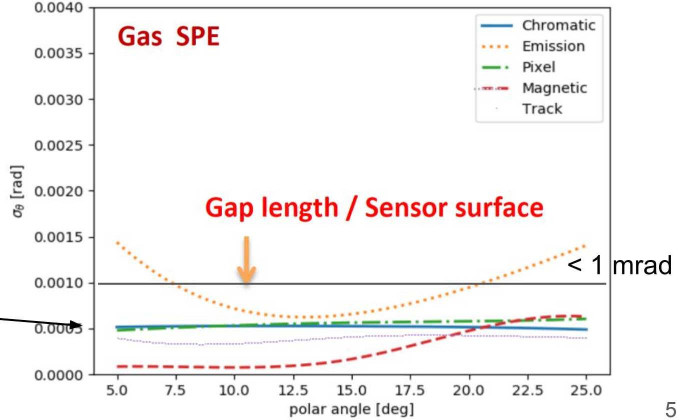
3x3 mm² pixel size optimises performance and number of SiPM / electronics readout channels

not the dominant contribution to the resolution
→ will <u>not benefit from smaller size pixels</u>
→ performance requirements already met
<u>bigger pixel size will have impact on gas</u>
→ will start becoming dominant contribution





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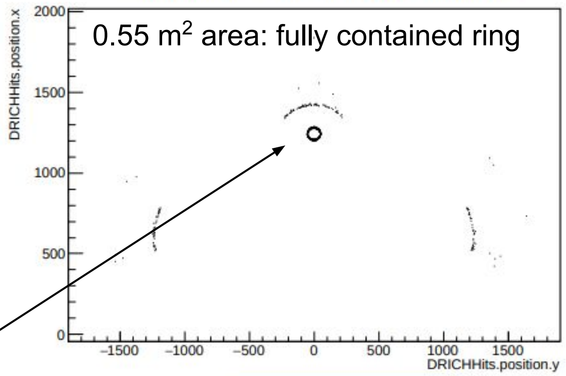
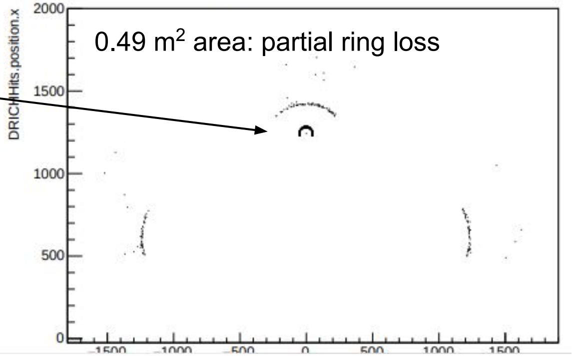
readout surface area of ~ 0.55 m^2 / sector required to fully contain rings at extreme pseudorapidities

high eta = most demanding for PID
→ large number of photons
→ no acceptance losses

0.55 m^2 / sector x 6 sectors (3x3 mm^2 pixels)
→ 3.3 m^2 of instrumented area (~ 317 k SiPM channels)

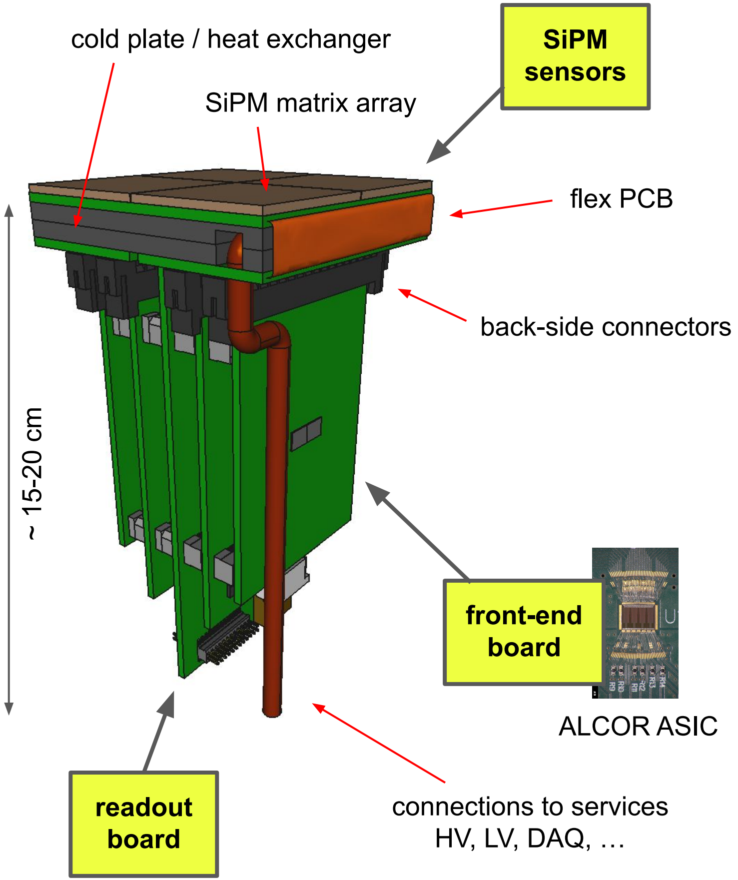




ePIC GEANT4 simulation

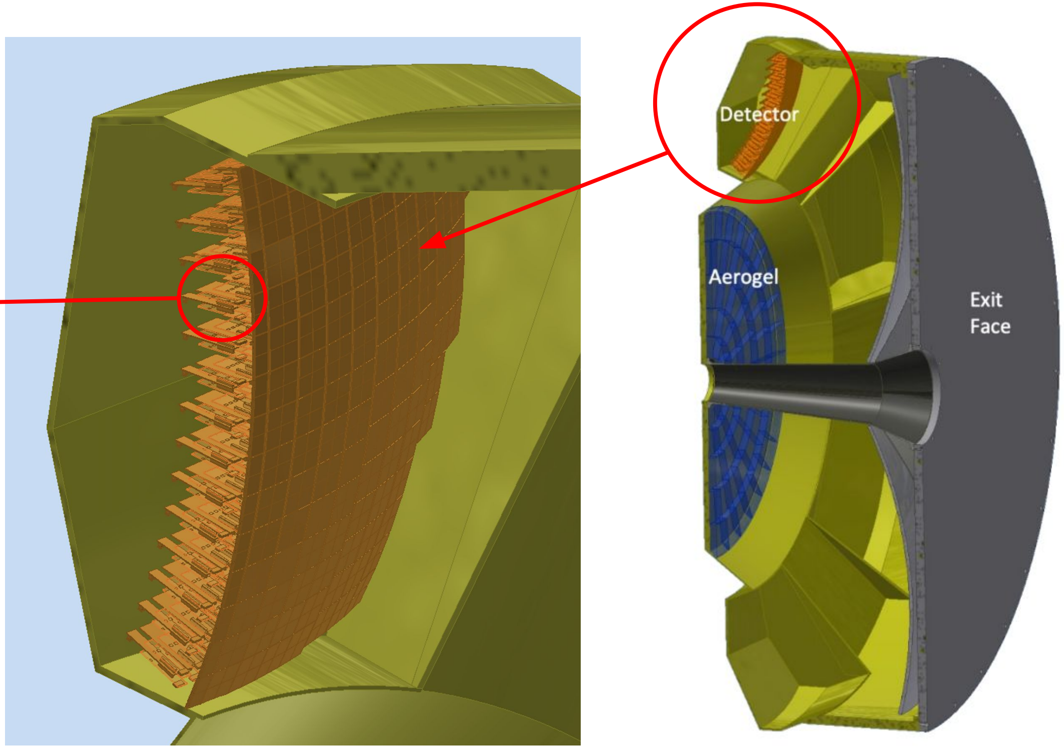
Photodetector unit

conceptual design of final layout



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 technical specs

baseline sensor device
64 (8x8) channel SiPM array
3x3 mm^2 / channel

Parameters	Value	Notes (all parameters at the recommended operating voltage and T = 25 C, unless specified)
Device type	SiPM array	
Number of channels	64	8 x 8 matrix
Active Area	3 x 3 mm^2	active area of one channel, total active area is 64 x 3 x 3 mm^2
Device Area	< 28 x 28 mm^2	device area should be small such as to have > 75% fraction of active area over device total area
Pixel Size	40 - 80 um	pitch of the microcell SPAD
Package Type	surface mount	
Operating voltage	< 64 V	
Peak Sensitivity	400 - 450 nm	
PDE	> 35%	at peak sensitivity wavelength
Gain	> 1.5 10^6	
DCR	< 1.5 MHz	
Temperature coefficient of Vop	< 60 mV / C	
Direct crosstalk probability	< 10%	
Terminal capacity	< 600 pF	
Packing granularity		
Vop variation within a tray	< 300 mV	Vop variation between channels in one device
Recharge Time	< 100 ns	ctau recharge time constant
Fill Factor	> 70%	
Protective Layer	silicone resin (n = 1.5 - 1.6)	radiation resistant, heat resistant (up to T = 180 C)
DCR at low temperature	< 10 kHz	at T = -30 C
DCR increase with radiation damage	< 1 MHz / 10^9 neq	at T = -30 C, after a radiation damage corresponding to 10^9 1-MeV neutron equivalent / cm^2 (neq)
Residual DCR after annealing	< 25 kHz / 10^9 neq	at T = -30 C, after a radiation damage of 10^9 neq and a 150 hours annealing cycle at T = 150 C
Single photon time resolution	< 200 ps FWHM	corresponding to < 85 ps RMS

very important parameters to ensure detector performance over the years

we will evaluate as part of QA, testing sensor samples in received batches

Ageing model

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

to keep dRICH performance throughout the years the sensors must fulfill requirements on

- effects of radiation damage
- capability of annealing recovery
- excellent time resolution

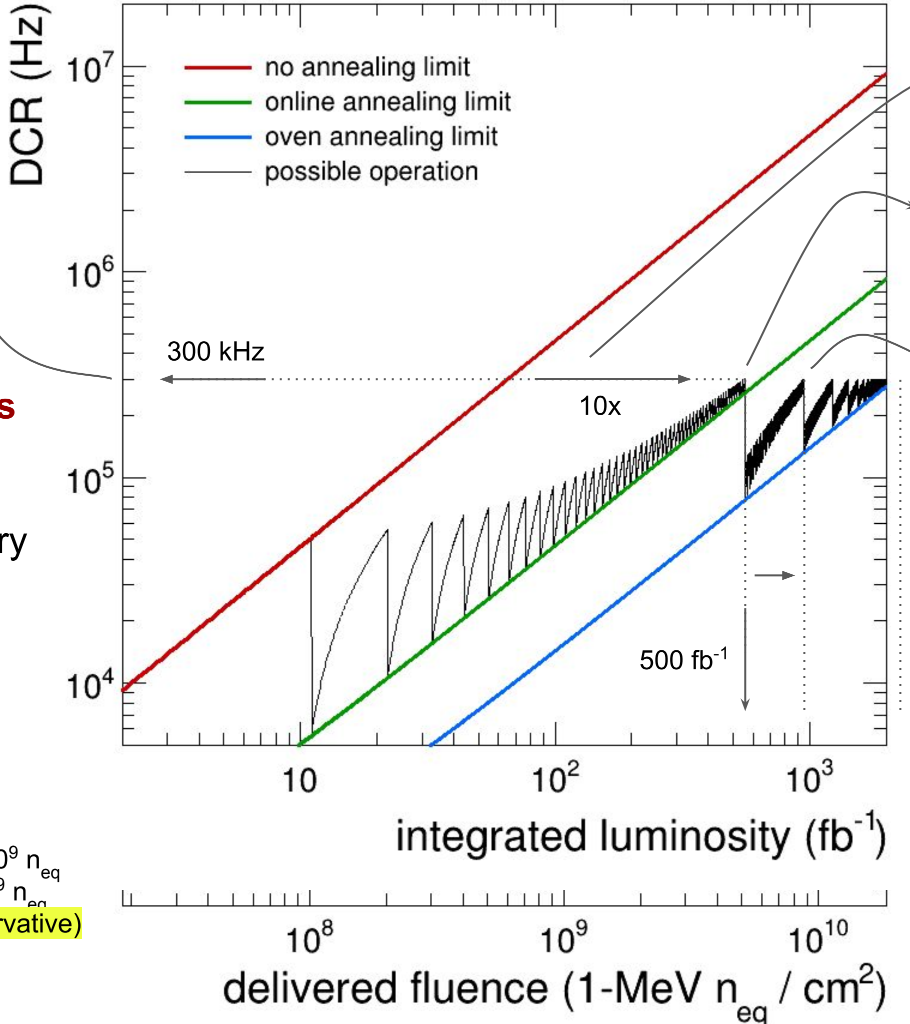
model input from R&D measurements

- 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

Hamamatsu S13360-3050 @ Vover = 4 V, T = -30 C



online annealing
extends SiPM
lifetime by ~ 10x

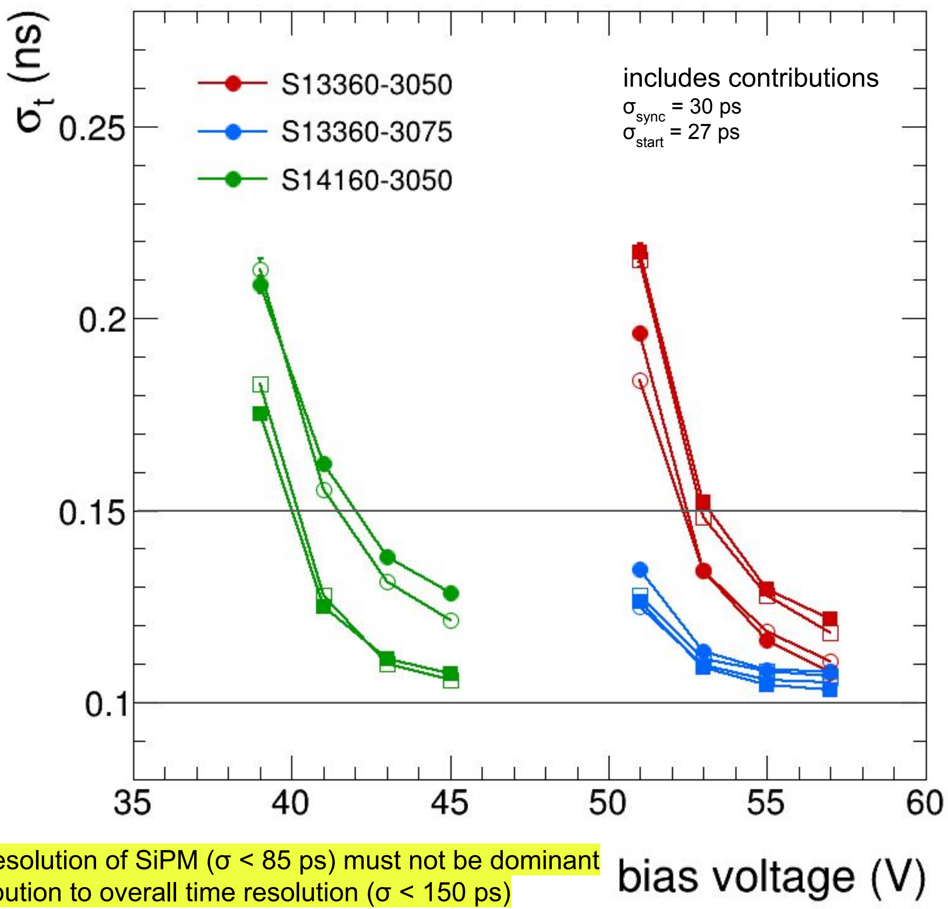
more aggressive
annealing needed here
might need to unmount SiPM (oven)

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

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

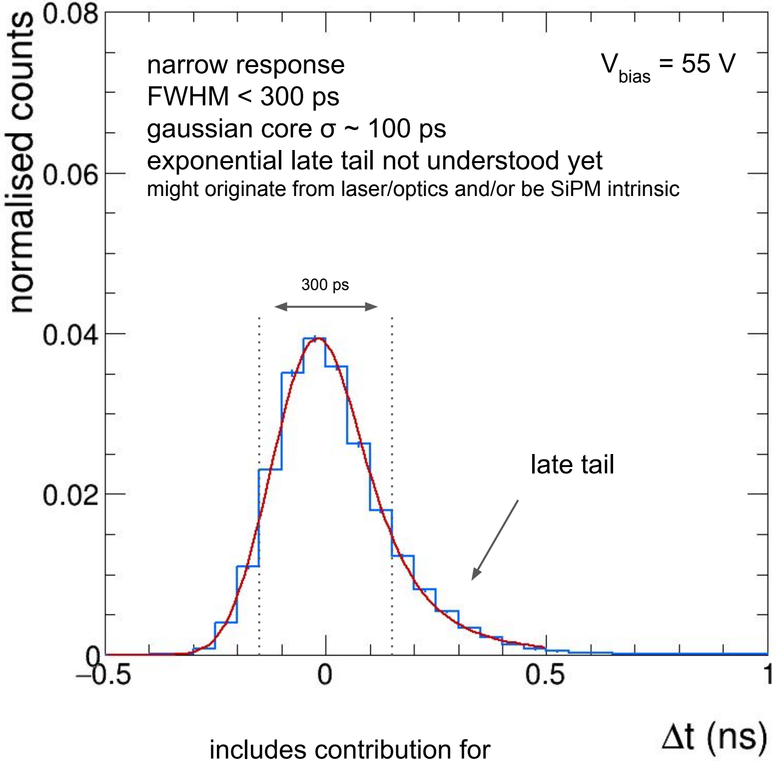
Timing performance measurements with ALCOR

standard ALCOR front-end bias configuration



time resolution of SiPM (σ < 85 ps) must not be dominant contribution to overall time resolution (σ < 150 ps)

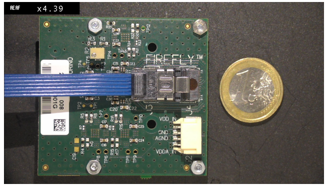
laser-SiPM correlations (time-walk corrected)

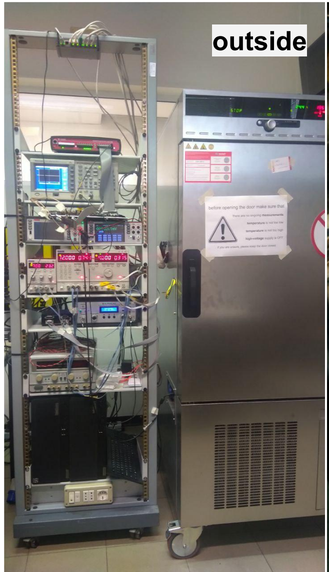


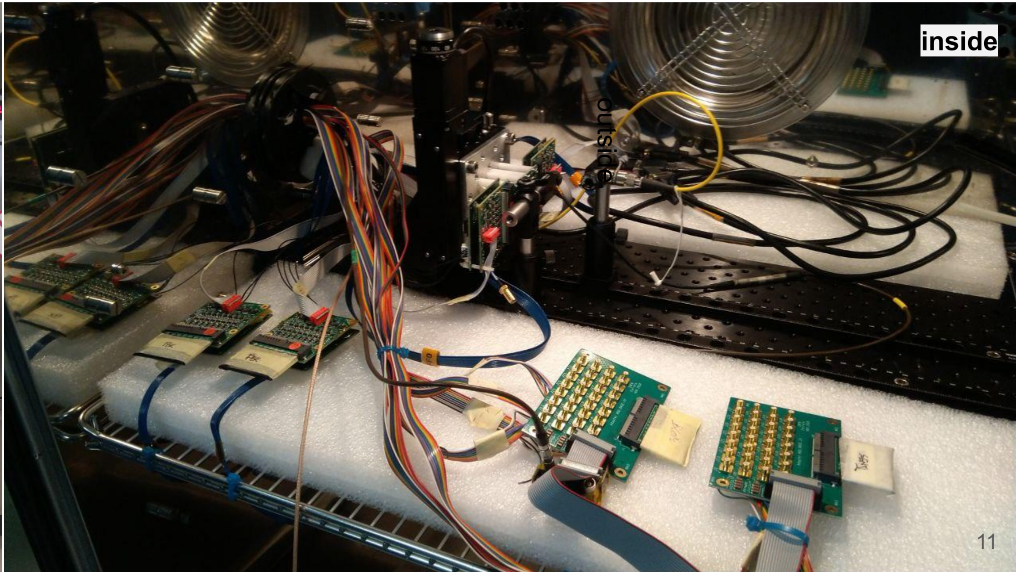
includes contribution for laser-ALCOR synchronization
measured to be σ_{sync} = 30 ps
and reference time resolution
measured to be σ_{start} = 27 ps

Characterisation setup

- **climatic chamber**
  large volume low-temperature operation
- **source meter & multiplexers**
  automatic IV characterisation of 80 SiPM channels
- **picosecond pulsed laser**
- **complete readout chain**
  automatic DCR and full readout of 128 channels

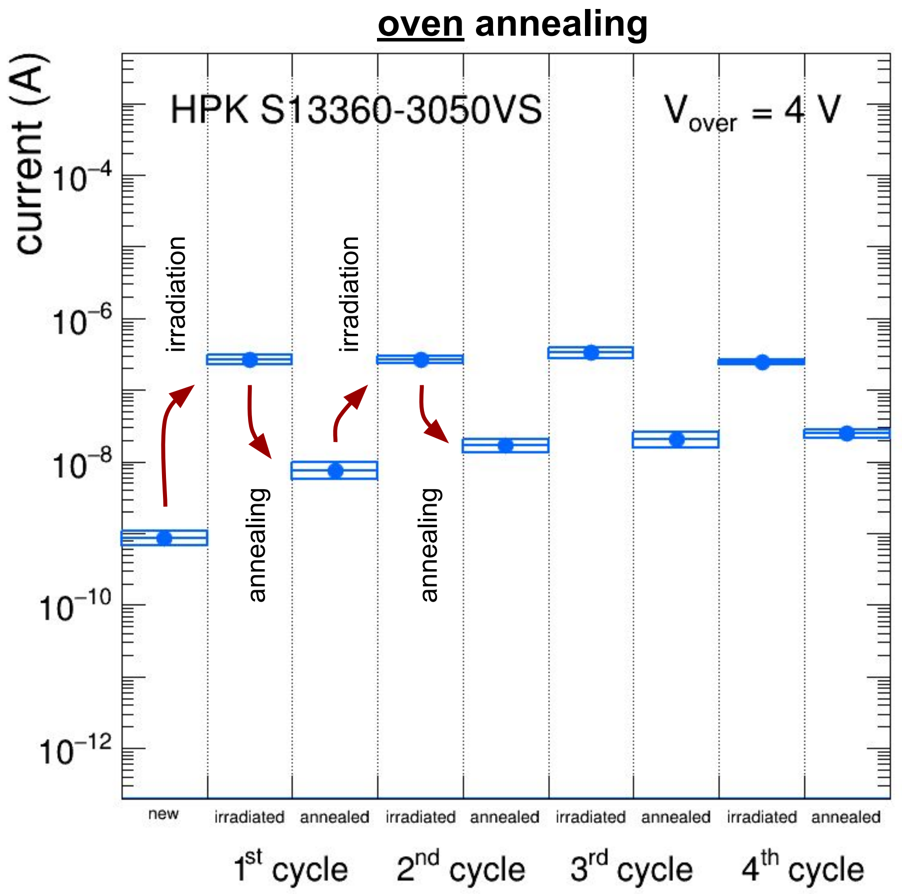






characterisation setup to be expanded for QA testing ~ 300 SiPM / day (25% of production over 2 years)
more setups (2-3) to be deployed (reach ~ 100%)

Repeated irradiation-annealing cycles



test reproducibility of repeated irradiation-annealing cycles

simulate a realistic experimental situation

- consistent irradiation damage
  - DCR increases by ~ 500 kHz (@ Vover = 4)
  - after each shot of 10^9 n_{eq}
- consistent residual damage
  - ~ 15 kHz (@ Vover = 4) of residual DCR
  - builds up after each irradiation-annealing

annealing cures same fraction of newly-produced damage

~ 97% for HPK S13360-3050 sensors

Summary

- **dRICH SiPM option fulfills dRICH requirements**
  - magnetic field limitations
  - excellent timing and efficiency
  - despite high DCR and not radiation tolerant
- **technical solutions to mitigate radiation damage**
  - low temperature operation
  - online “in-situ” self-annealing
  - extend lifetime of good detector performance for Physics
- **technical specs for the device are identified**
  - 8x8 matrix array of 3x3 mm SiPM channels (~ 317 kchannels)
  - large SPADs, high PDE, high gain, good time resolution
  - low DCR is a very important asset that will be closely monitored by QA
    - tests on batch samples to evaluate radiation damage / recovery throughout production
- **clear path towards TDR**
  - mating prototype electronics already exists
  - ALCOR front-end ASIC chip developed by INFN