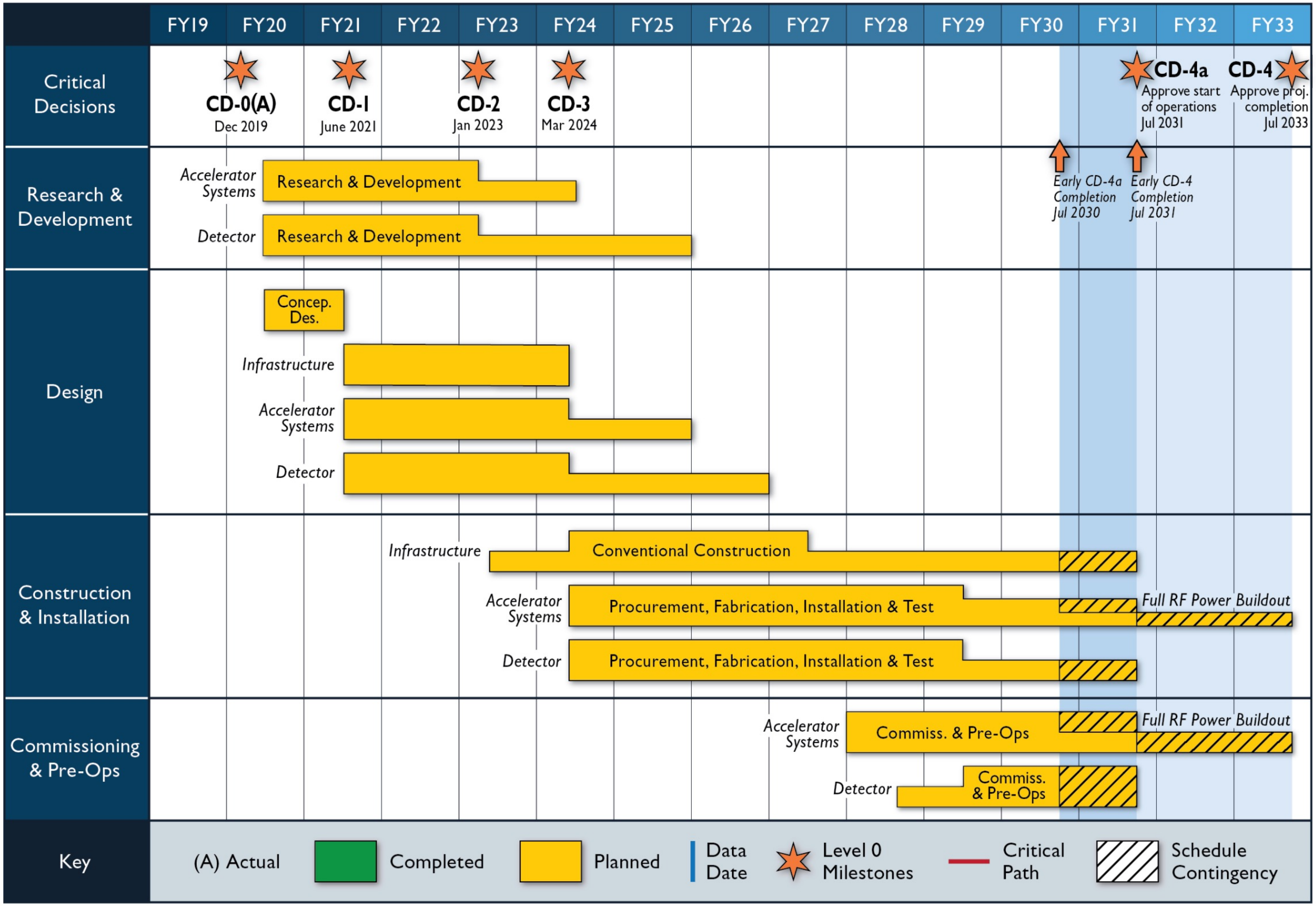
Electron-Ion Collider forward RICH R&D on SiPM and Aerogel

Marco Contalbrigo – INFN Ferrara

Incontro ALICE-EIC - 23th July 2021

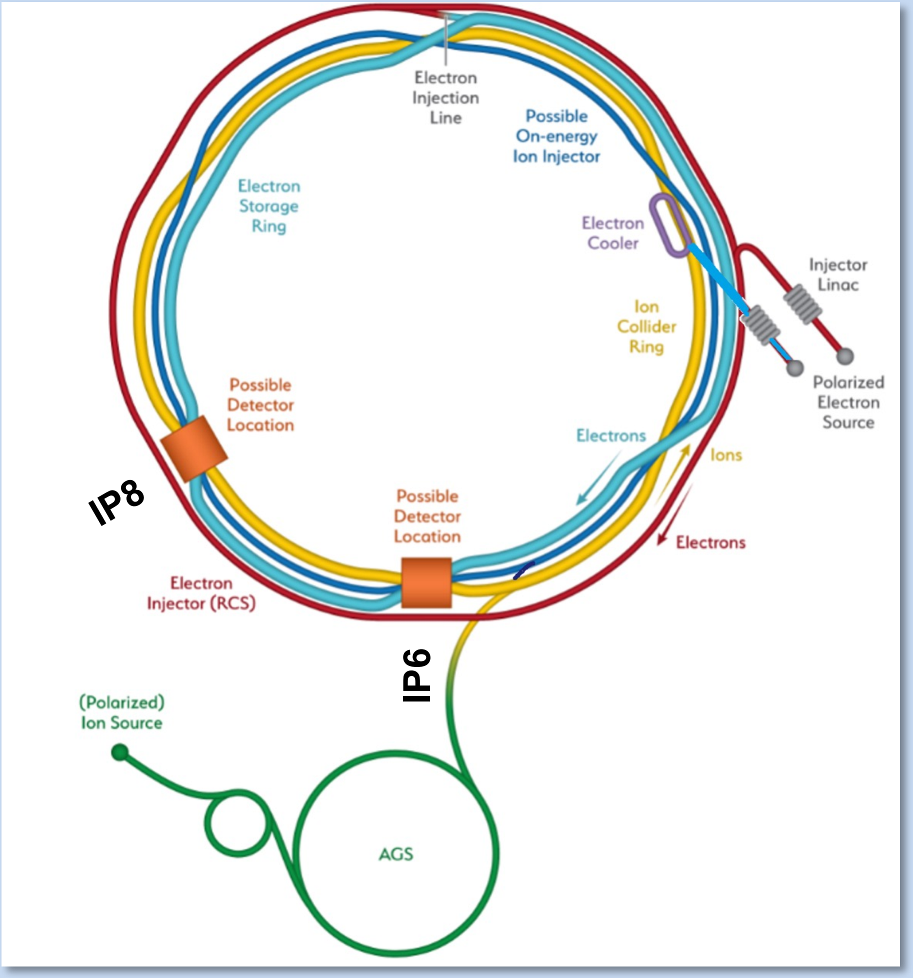
EIC Timeline



EIC Accelerator

Unprecedented Machine

Center of mass energy	20-140 GeV
Maximum luminosity	10^{34} cm^{-2} s^{-1}
Hadorn Beam Polarization	80%
Electron Beam Polairzation	80%
Ion Species Range.	P to Uranium
Number of IP	Up to two



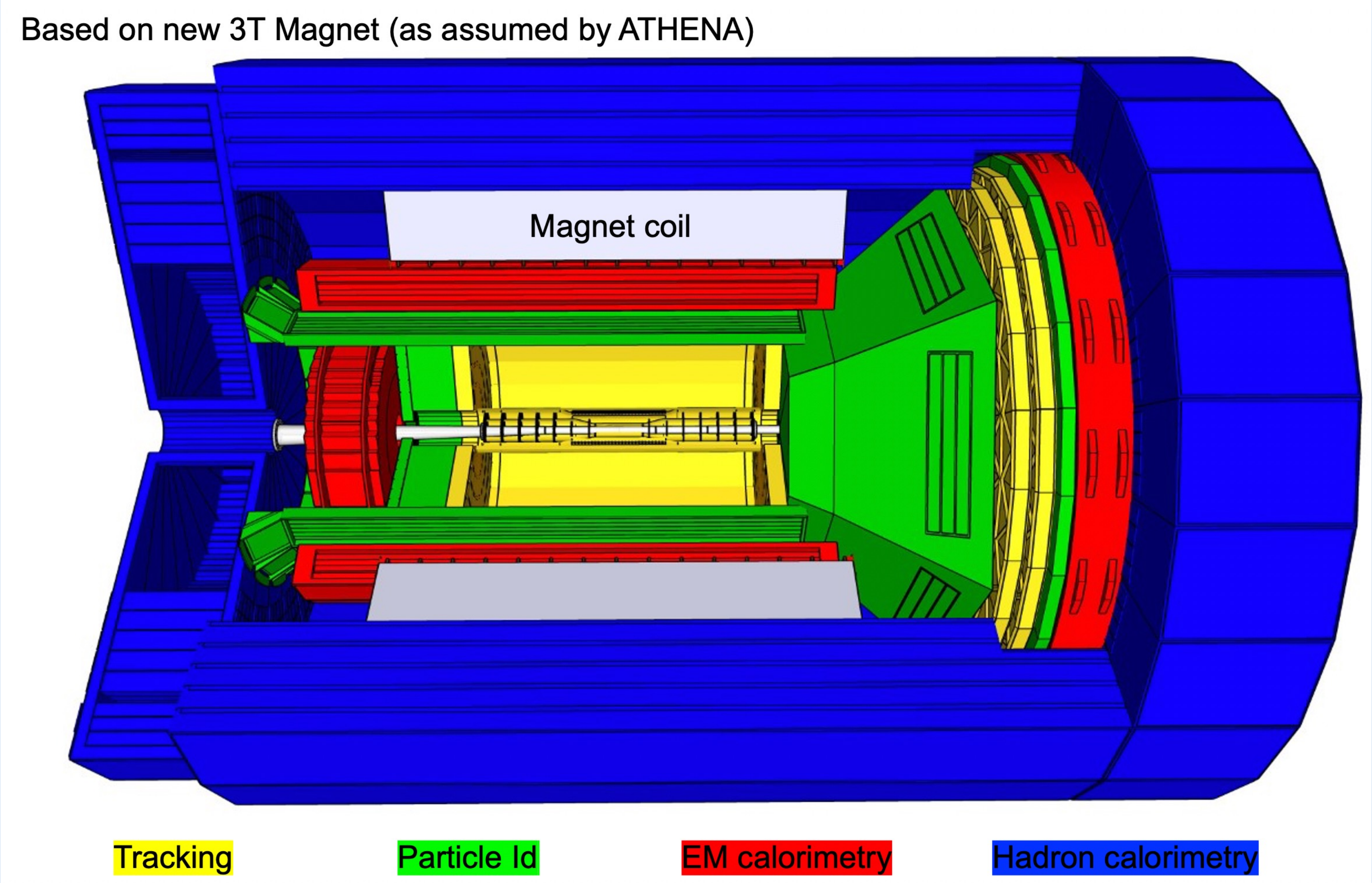
p/A beam

e beam

p: 41 GeV, 100 to 275 GeV

e: 5 GeV to 18 GeV

ATHENA Detector



INFN is concentrating on the forwad RICH PID of the EIC asymmetric detector

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R&D for photo-sensors: single-photon sensitivity in high-magnetic field

Silicon photomultipliers

LAPPD (cost-effective microchannel plate detectors) sensor

Windowless micro-pattern gaseous detector (MPGD)

R&D for aerogel section:

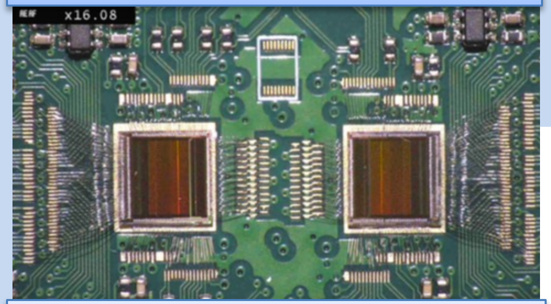
High transparency aerogel at low refractive index (n=1.02)

Also in collaboration with EIC mRICH (n=1.03) and INFN TRICK (n=1.045)

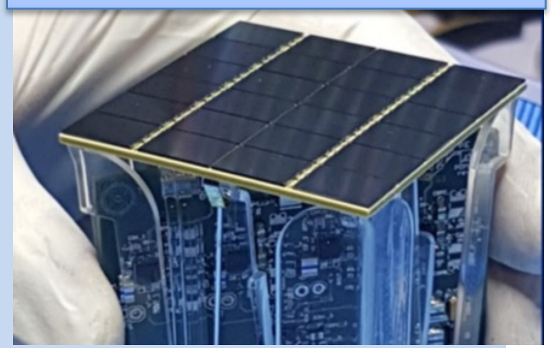
R&D for gaseous section:

High-pressure Argon as alternative to greenhouse gases

INFN TO COMPASS RICH F-E
DARKSIDE F-E

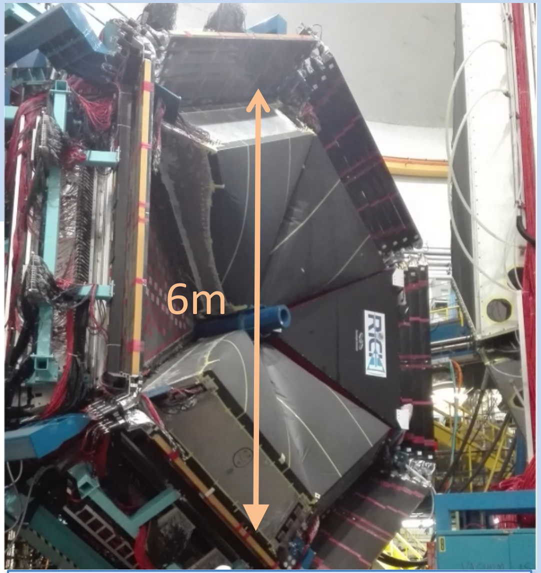


INFN BO ALICE TOF
DARKSIDE SiPM



INFN RM1 HERMES/Hall-A RICH
INFN CT/LNS Hall-A HCAL

Enriched INFN expertise and manpower to support dRICH & SiPM program

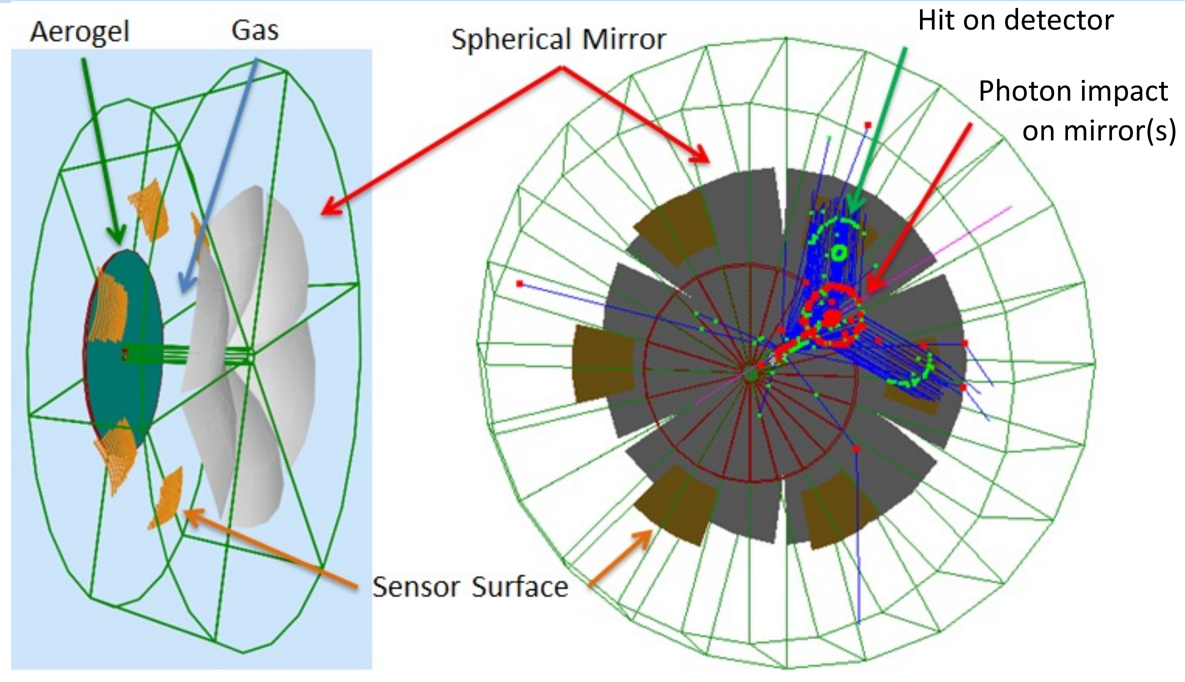


INFN FE CLAS12 RICH
INFN LNF

INFN TS COMPASS RICH
INFN BA Gaseous DET (eRD6)

EIC Detector Challenge I

Wide momentum coverage 3 - 60 GeV/c



dRICH: effective solution, part of reference detector

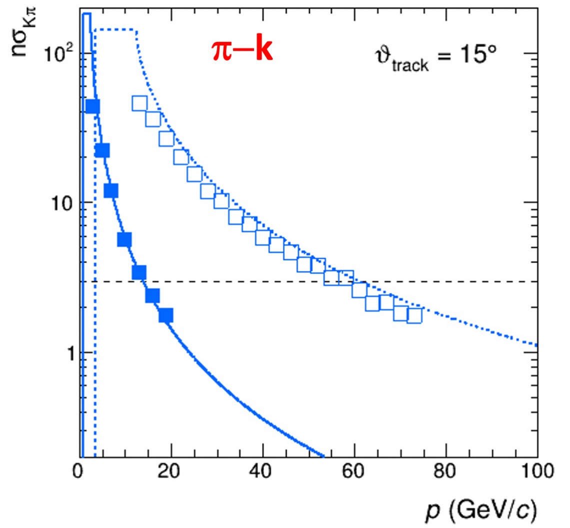
Radiators: Aerogel (n_{AERO}~1.02) + Gas (n_{C2F6} ~ 1.0008)

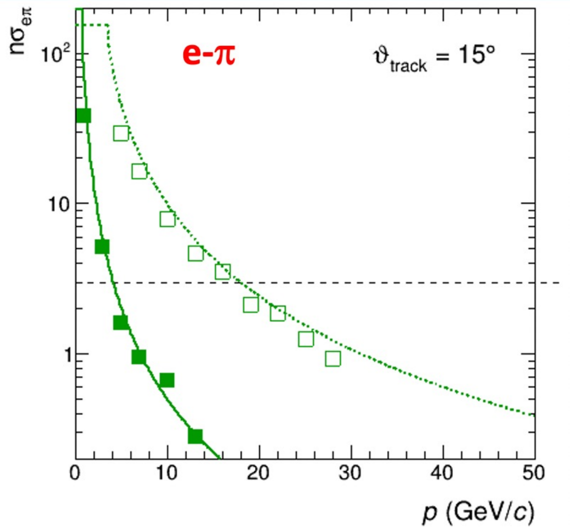
Detector: 0.5 m^2/sector , 3x3 mm^2 pixel

Single-photon detection in ~1T magnetic field

Outside acceptance, reduced constraints

→ best candidate for SiPM option





Phase Space:
- Polar angle: 5-25 deg
- Momentum: 3-60 GeV/c

Aerogel Radiator

Russia: Budker Institute of Novosibirsk (RAS Siberian branch)

pros: largest volume (bricks)
highest transparency at large refractive index (n=1.05)
wide experience from HERMES, AMS, CLAS12, LHCb
cons: hygroscopic
essentially handmade

Japan: Aerogel Factory Co. (spinoff from Chiba University)

pros: hydrophobic
with industrial partners
wide experience from BELLE-II
cons: to be validated for massive production

USA: ASPEN (collaborating with CUA)

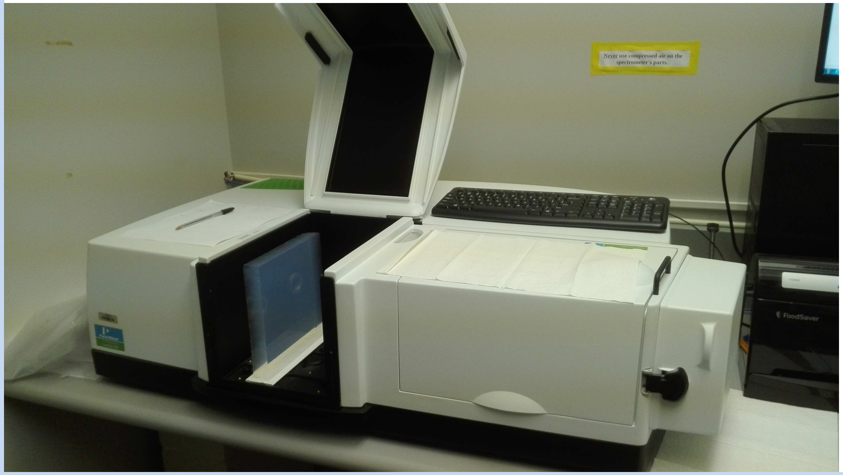
pros: industrial producer

cons: to be validated for transparency

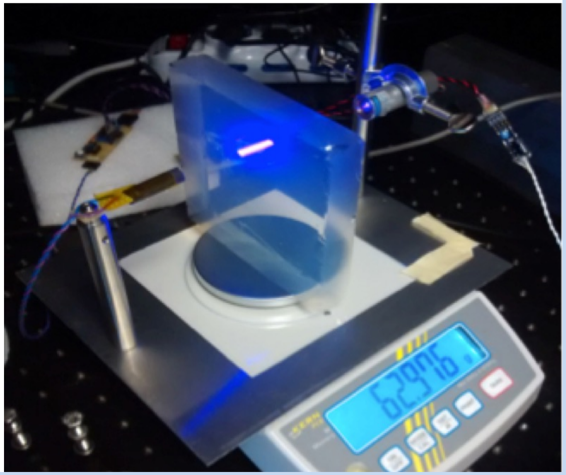
Aerogel Test Laboratory

Existing facility to study detailed aerogel optical properties
(refractive index, surface planarity, forward scattering)
safe handling and Interplay with gas radiator

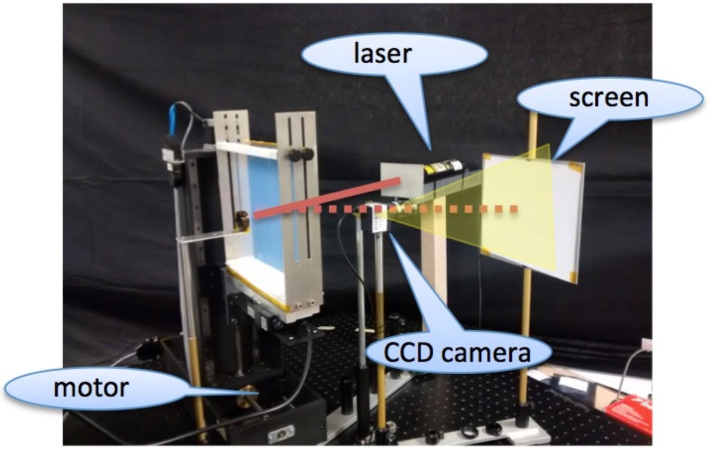
Spectrophotometer



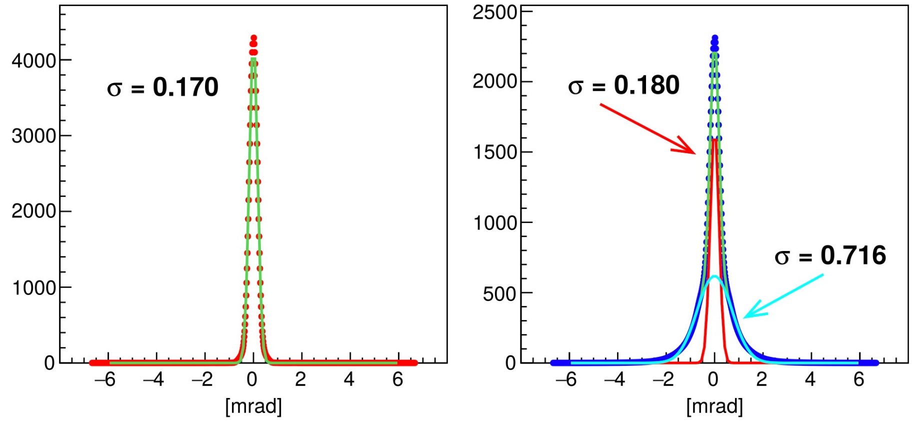
Characterization station



Controlled storage

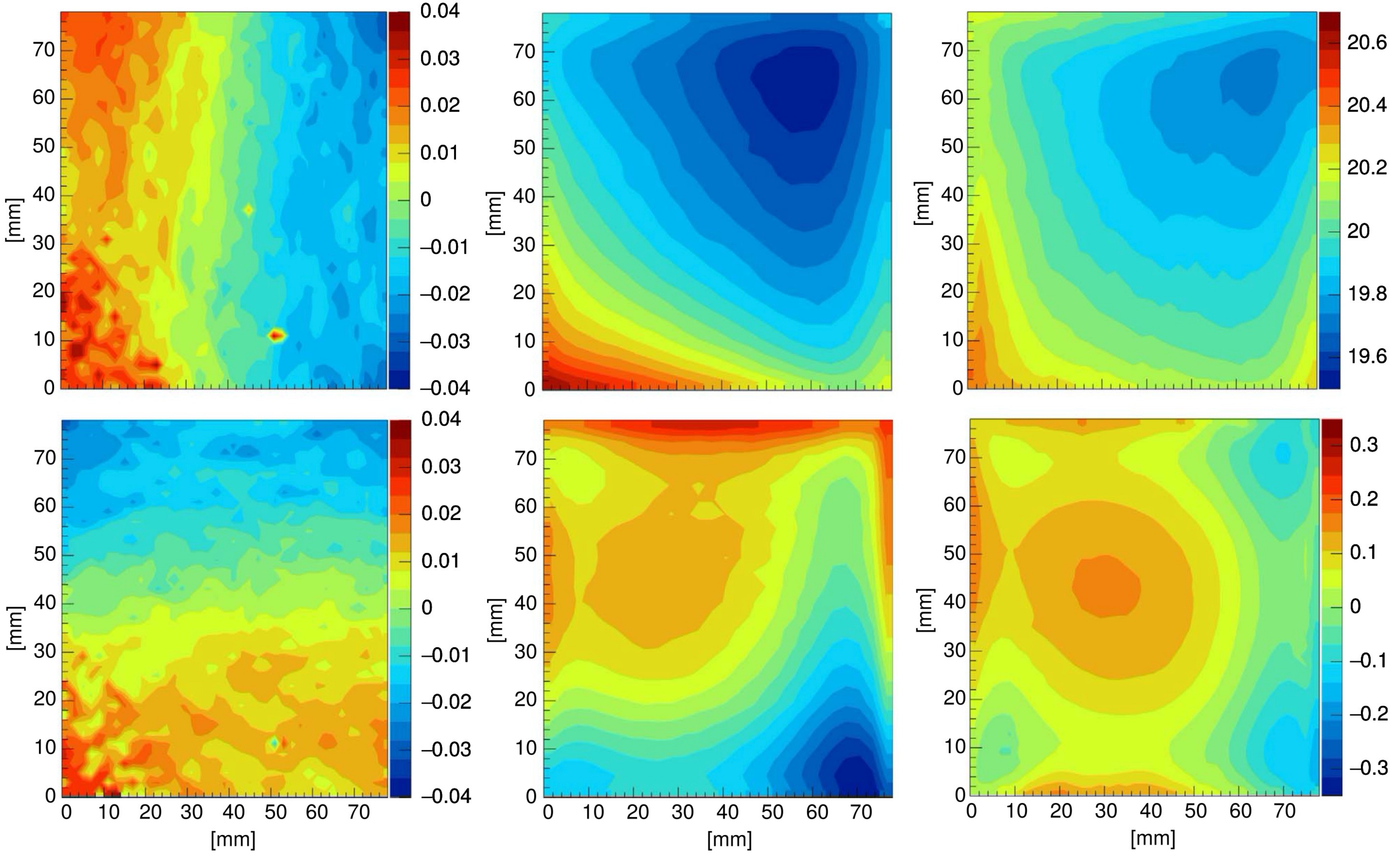


Forward scattering: bare after aerogel



Aerogel Surface Mapping

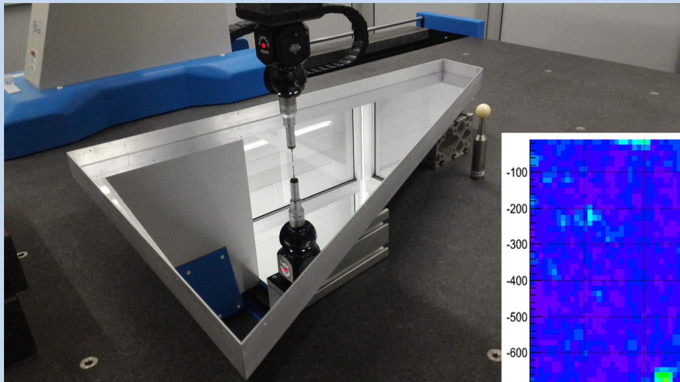
M. Contalbrigo et al, NIMA 876 (2017) 168

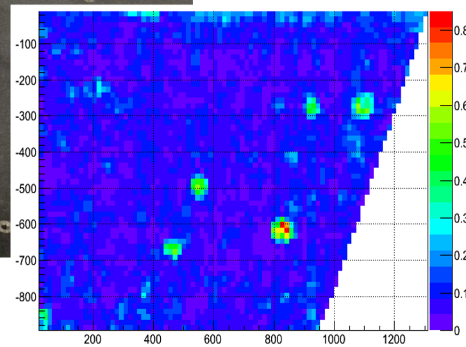


Mirror Test Laboratory

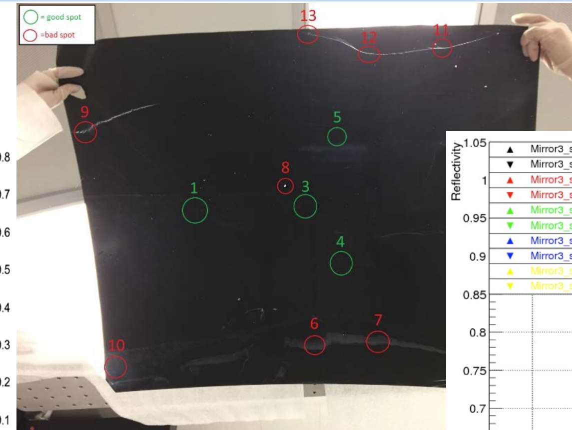
Existing facility to study detailed mirror optical properties (surface map, radius of curvature, reflectivity)

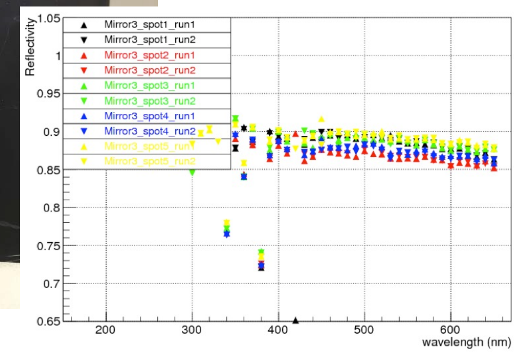
Planarity

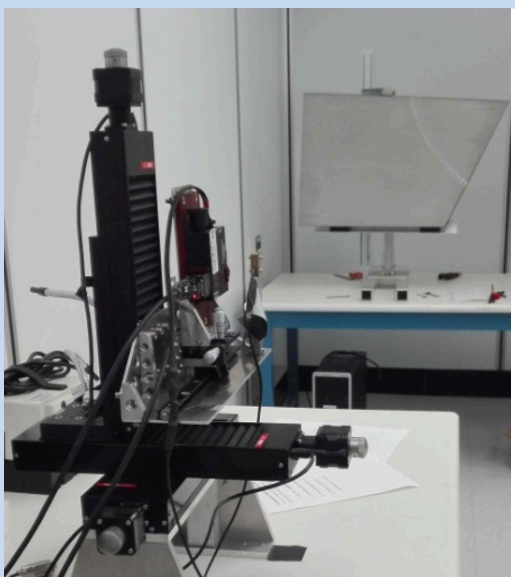




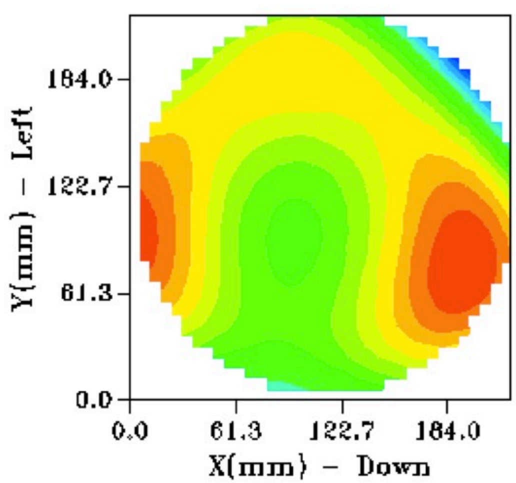
Reflectivity



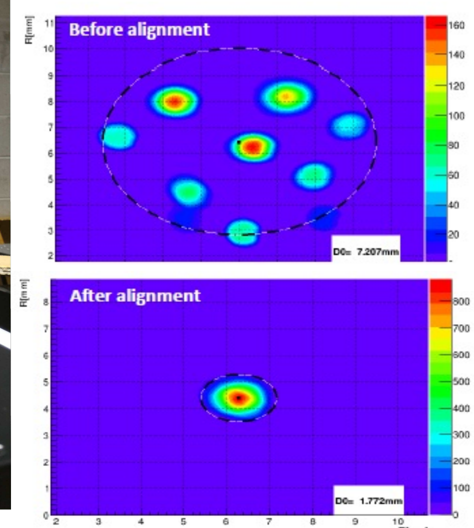




Shack-Hartmann: Aberrations

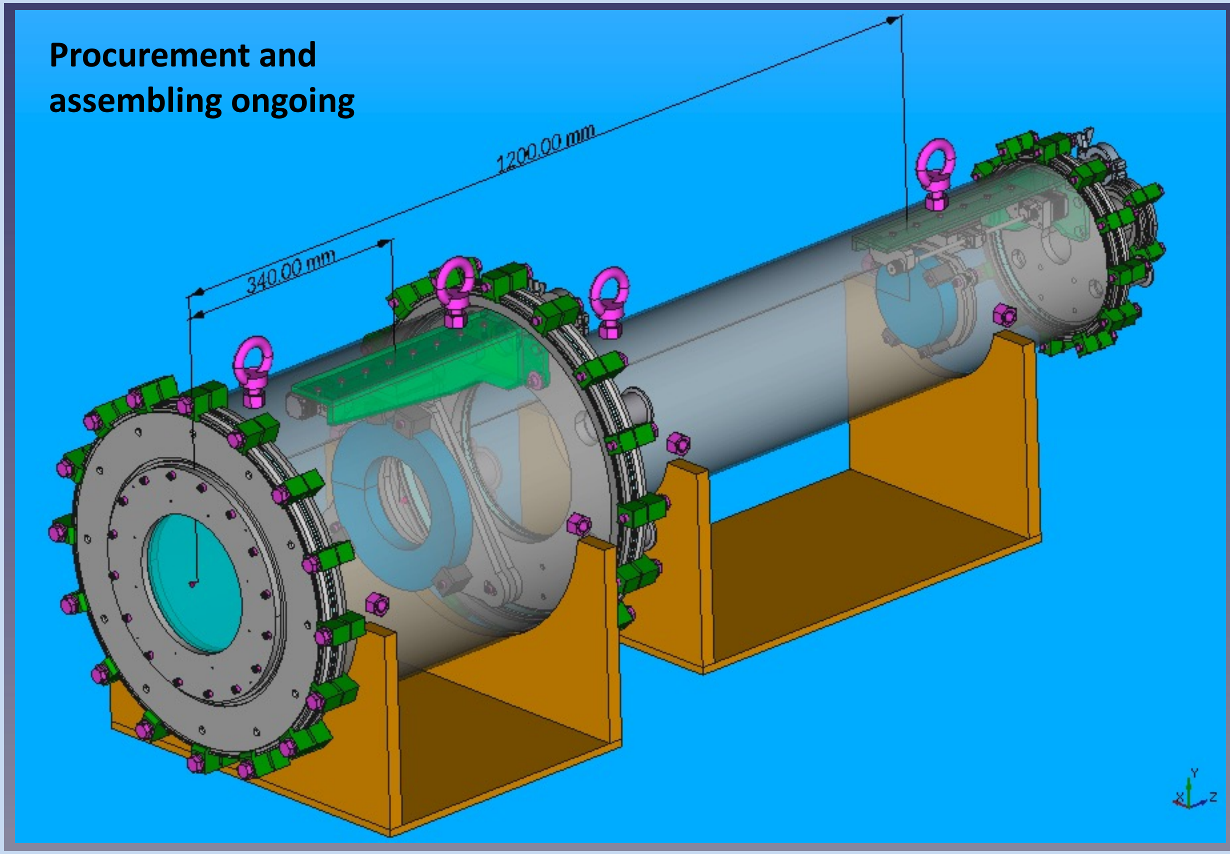


Point Image: Alignment



dRICH Prototype

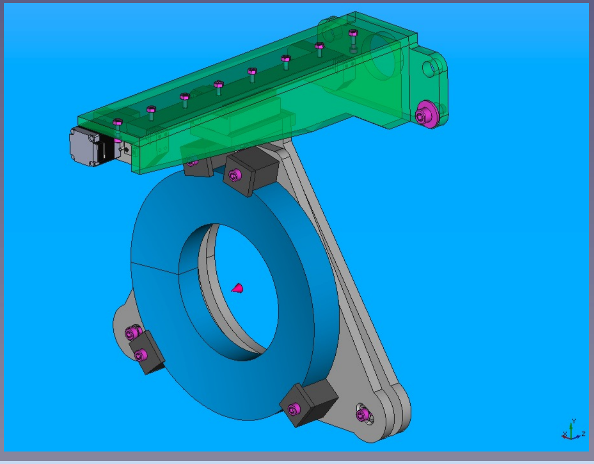
Procurement and assembling ongoing



Dual radiator imaging

Pressure vessel for gas & n tune

Sensor & readout friendly



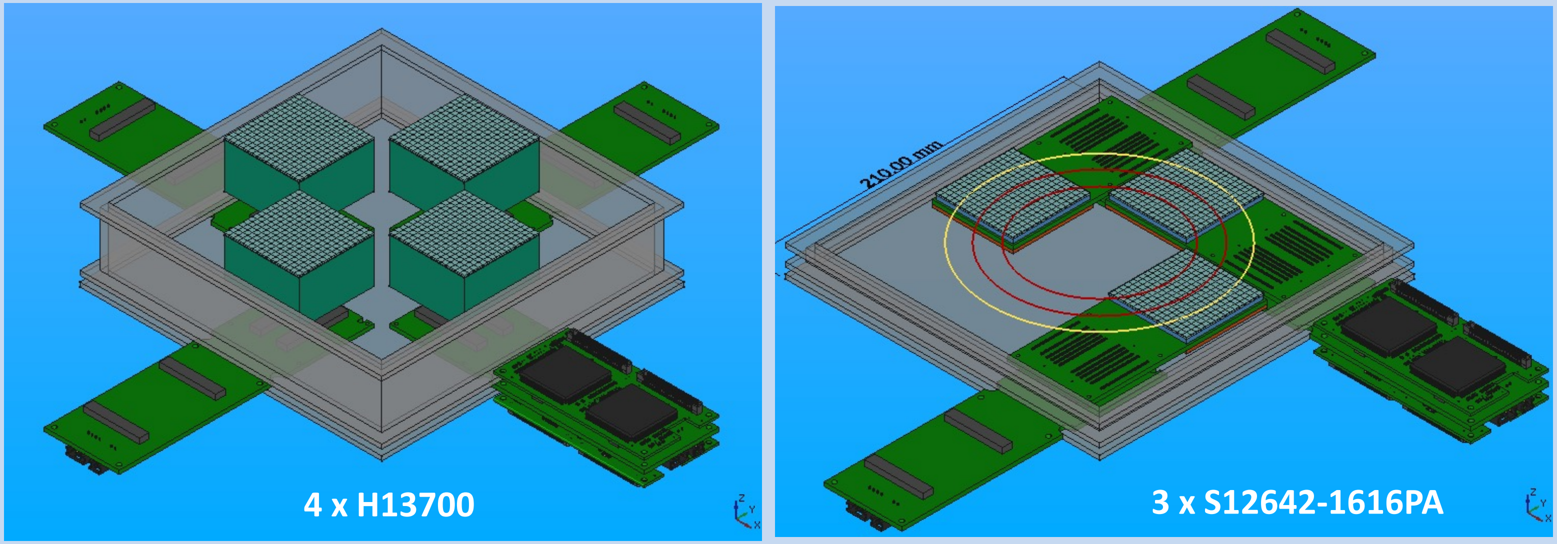
Goals:

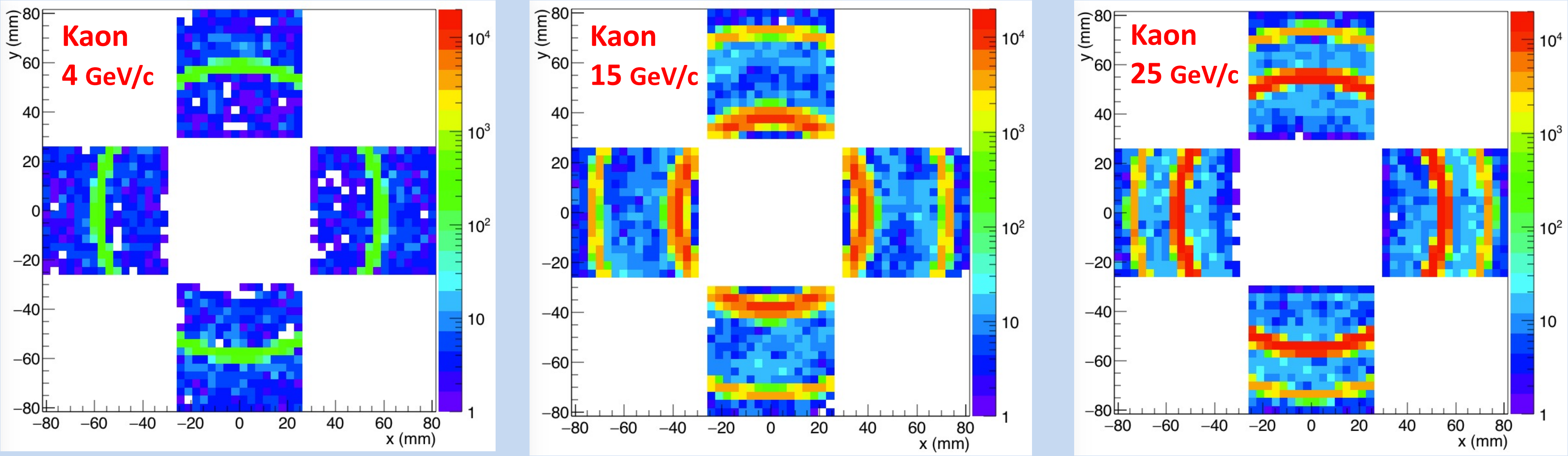
- Study dual radiator performance and interplay
- Study specifications and alternatives for optical components
- Test alternate single-photon detection systems

* First test-beams in September and October '21 at CERN (in synergy with ALICE at PS T10)

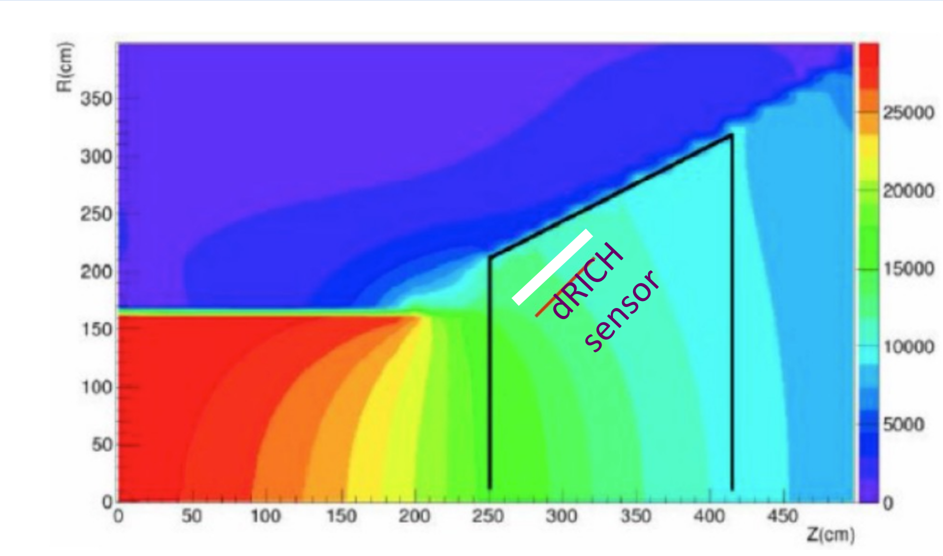
dRICH Imaging

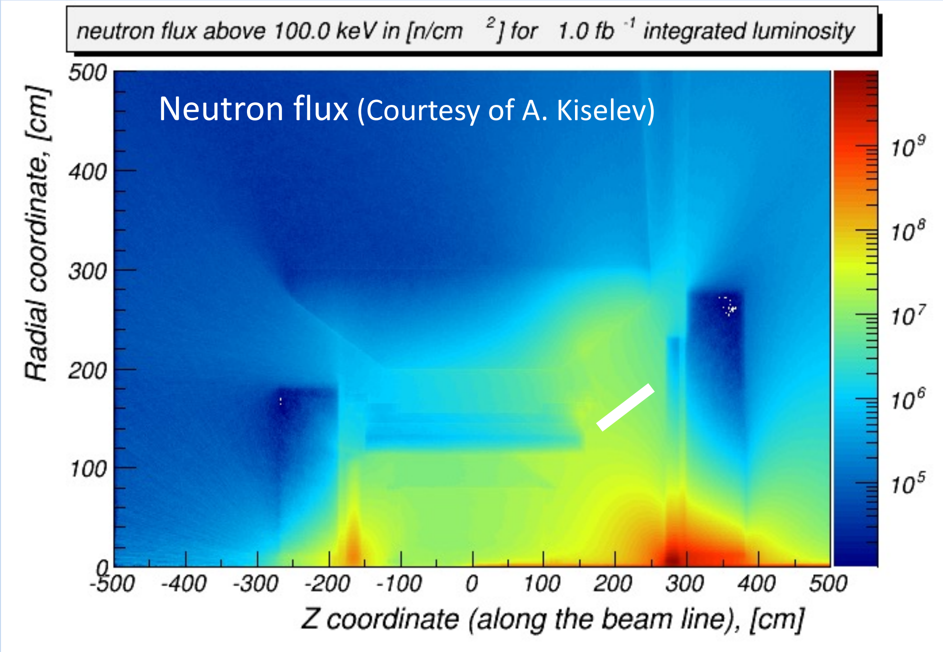
House the same principles and readout units used for EIC eRD14 test-beams
Compatible with H13700/S12642-1616PA + CLAS12 RICH MAROC front-end
Allows to study the working principles and optical performance of the components





EIC Detector Challenge II





High Magnetic Field

~ 1 T order of magnitude, varying orientation

SiPM: PET study up to 7 T 10.1109/NSSMIC.2008.4774097

dRICH sensor location relaxes requirements on neutron dose and material budget

Neutron Fluence

Moderate except for very forward regions

Reference value. ~ 10^{11} n_{eq}/cm^2 for several years at max lumi (10^{34})

SiPM: radiation mitigation for SPE actively studied till 10^{11} n_{eq}/cm^2 and above 10.1016/j.nima.2019.01.013
10.1016/j.nima.2018.10.191

SiPM Program

Enriched INFN manpower and expertise towards a comprehensive program of post-irradiation SiPM + electronics single photon detection assessment.

Done so far, use few SiPM samples for the study of

- Cherenkov application prior of irradiation
- Single photon counting vs dose and temperature

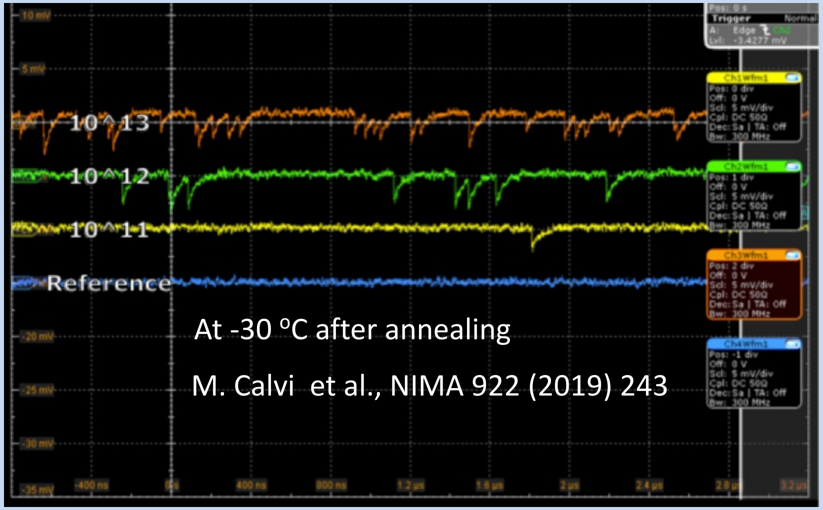
Short term goal (~ 1 year):

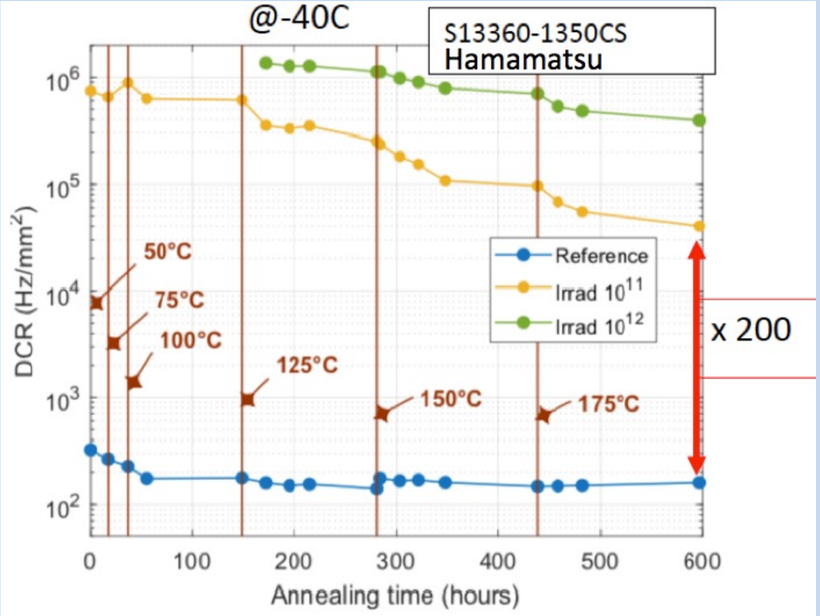
- Characterize irradiated status-of-the-art SiPM candidates
- Exploit in-house dedicated electronics (ToT based, for cooled SiPM + annealing)
- Cherenkov imaging after EIC-like irradiation (proof-of-principle)

Long term plan (~2-3 years):

- Systematic study towards performance optimization
- SiPM engineering with producers
- Temperature treatment protocols vs radiation
- Assess discriminating vs sampling readout performance
- Development of an optimized streaming readout

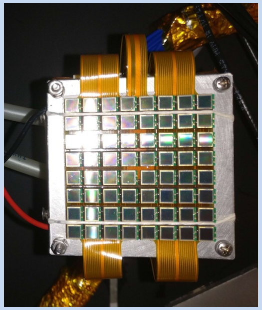
Key: Temperature treatment & dedicated readout



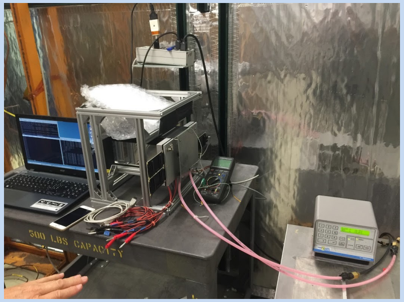


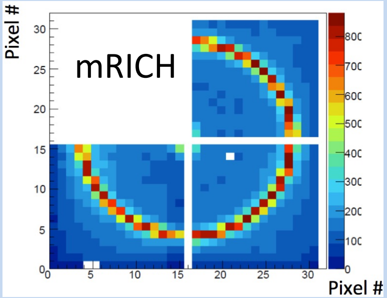
Previous Test-beam Campaigns

CERN 2012



Fermilab 2018





Survey of SiPM Candidates

Look for status-of-the-art 3x3 mm^2 SiPM
Hamamatsu (a sort of reference), Broadcom/FBK (INFN partner in Italy), ……

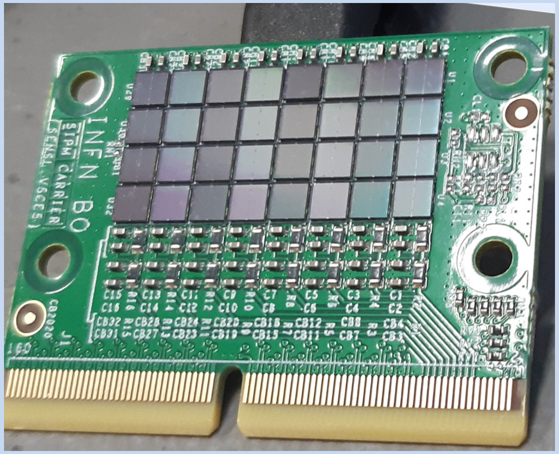
supplier	model	type	pixel (mm)	cell (um)	mount / connector	window	PDE (%) peak	DCR (kHz/mm2)	PDE / DCR	package fill factor (%)	x-talk (%)	after-pulse (%)	Vop (V)	CTR (ps)	rise time (ps)
Ketek	PM3325-WB-D0	single	3	25	smt	glass	45	125	0.36	82	26	5	30	70	110
Ketek	PM3315-WB-C0	single	3	15	smt	glass	31	125	0.25	82	18	5	30		630
Ketek	PA3325-WB-0404	4x4	3	25	Samtec	glass	45	125	0.36	80	26	5	30		110
Hamamatsu	S13360-3025CS	single	3	25	ceramic	silicone	25	45	0.56	23	1		60		
Hamamatsu	S13360-3025PE	single	3	25	smt	epoxy	25	45	0.56	54	1		60		
Hamamatsu	S13360-3050CS	single	3	50	ceramic	silicone	40	55	0.73	23	3		60		
Hamamatsu	S13360-3025PE	single	3	50	smt	epoxy	40	55	0.73	54	3		60		
Hamamatsu	S13360-3050VE	single	3	50	smt	epoxy	40	55	0.73	78	3		60		
Hamamatsu	S13361-3050NE-04	4x4	3	50	smt	epoxy	40	55	0.73	85	3		60		
Hamamatsu	S14160-3050HS	single	3	50	smt	silicone	50	165	0.30	78	7		40	60	
Hamamatsu	S14161-3050HS-04	4x4	3	50	smt	silicone	50	165	0.30	85	7		40	60	
Hamamatsu	S14160-3015PS	single	3	15	smt	silicone	32	78	0.41	54	< 1		45		
Hamamatsu	S13362-3050DG	single	3	50	metal	glass	40	25	1.60	4	3		55		
SensL	C-Series 30050	single	3	50	smt	compound	35	33	1.06	56	10	0.6	25		600
SensL	ARRAYC-30035-16P-PCB	4x4	3	35	Hirose	compound	31	33	0.94	56	7	0.2	25		600
SensL	J-Series 30035	single	3	35	smt	glass	38	50	0.76	94	8	0.75	25		90
SensL	J-Series 30020	single	3	20	smt	glass	30	50	0.60						
SensL	ARRAYJ−30035−16P−PCB	4x4	3	35	Hirose	glass	38	50	0.76	86	8	0.75	25		90
AdvanSid	ASD-NUV3S-P		3	40		epoxy	43	100	0.43	65		4	26		
Broadcom	AFBR-SGN33C013	single	3	30	smt	glass	54	255	0.21	91		1	10		
Broadcom	AFBR-S4N44P163	4x4	3	30	smt	glass	55	255	0.22	92		1	10		
Broadcom	AFBR-S4N44C013	single	3.72	30	smt	glass	55	270	0.20	92					

SiPM Selection

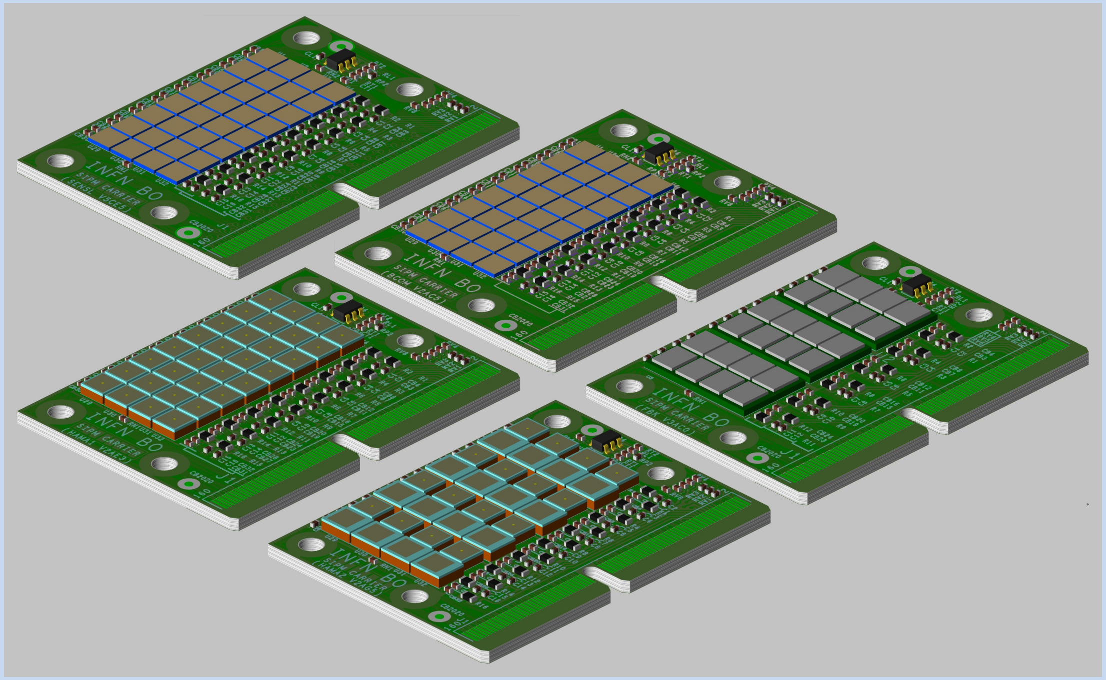
STAGE-I: Assess performance of 3x3 mm^2 SiPM status-of-the-art selection

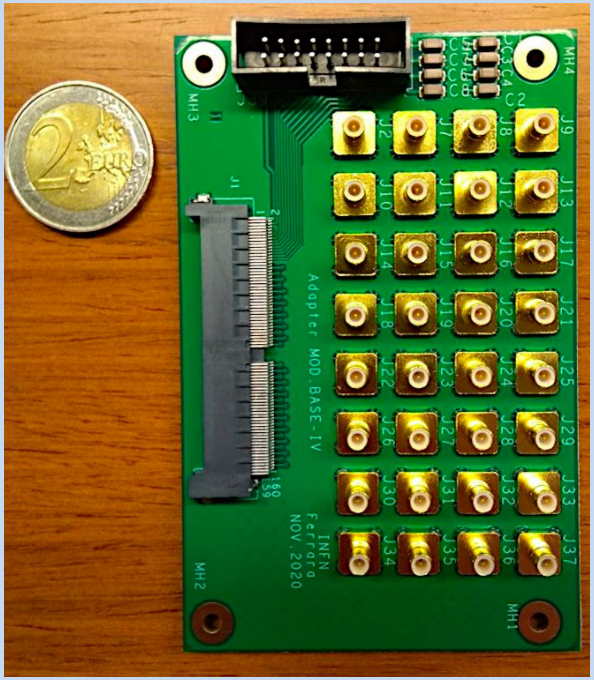
- (2x) OnSemiconductor microFJ-30020 and -30035
- (1x) Broadcom AFBR-S4N33C013
- (2x) Hamamatsu. S13360-3050VS and -3025VS
- (2x) Hamamatsu. S14160-3050HS and -3015PS
- (1x) FBK custom SIPM samples

Organized in matrices for irradiation and imaging tests



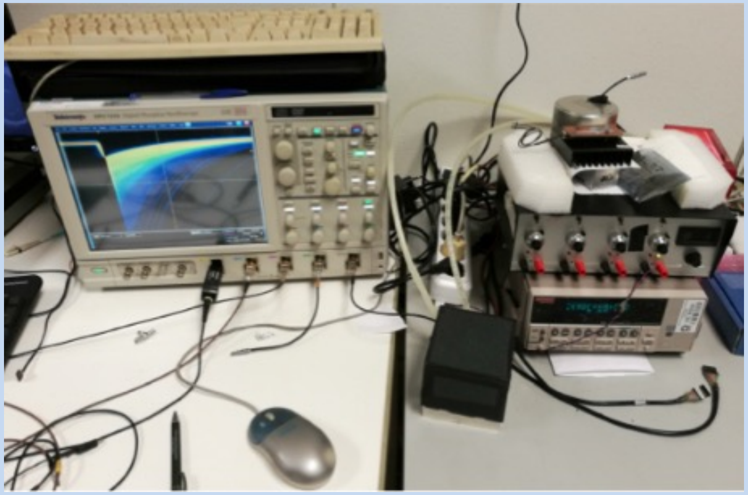
Test-board for lab characterization





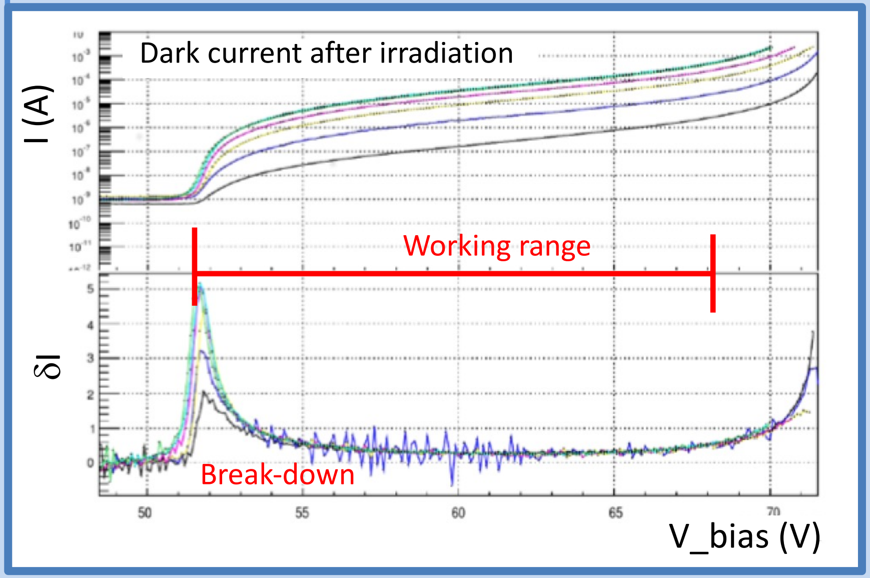
SiPM Characterization

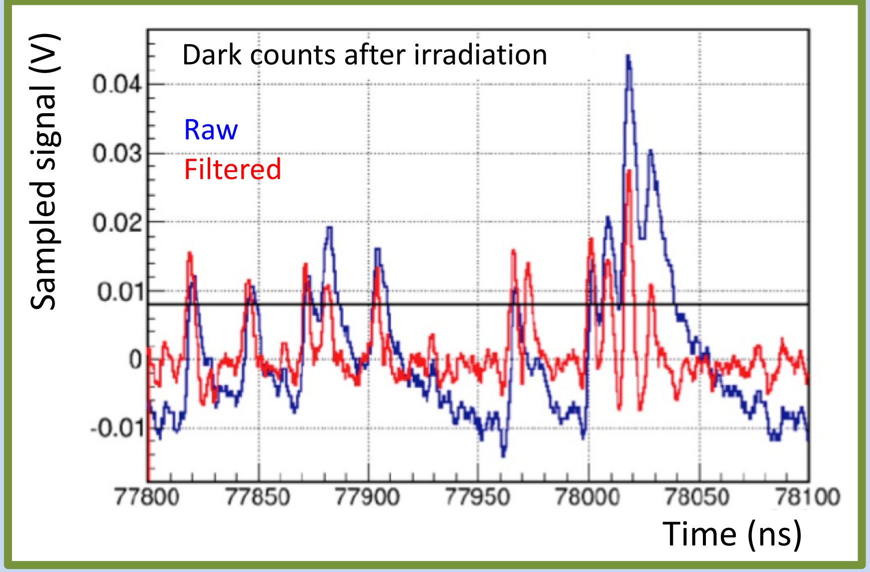
SiPM characterization vs temperature, pre- and post-irradiation



I-V characteristics & Signal sampling

Temperature control and treatments



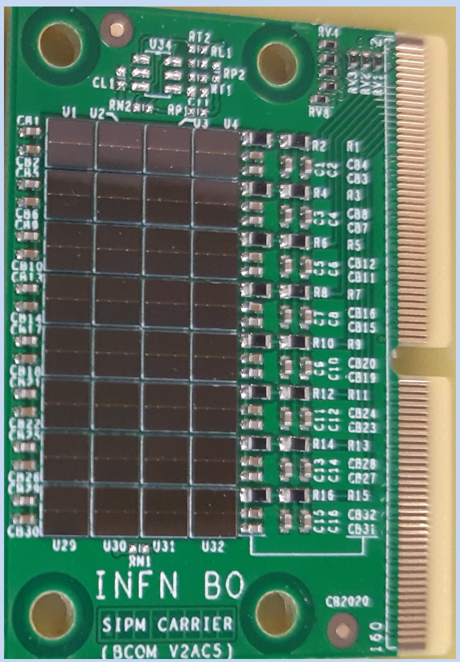


SiPM Carrier

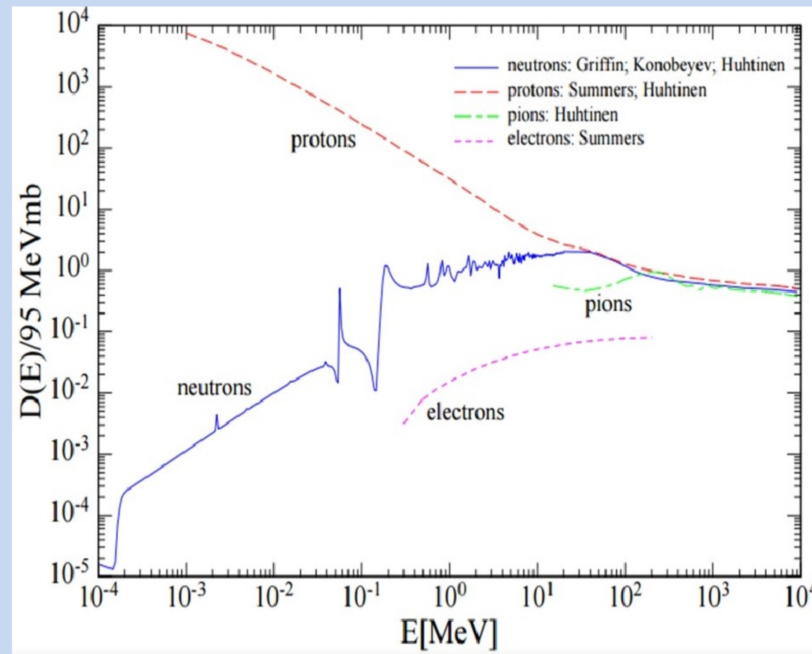
Organize groups of SiPM in 4x8 customized matrices, each group with

- alternate producers
- different n_{eq} integrated dose | e8 | e9 | e10 | e11 | (cm^{-2})
- alternative designs (microcell size, quench resistor, wavelength range, …)

Use available facilities in Italy (**protons: TIFPA**, LNS   neutrons: ENEA,)



50	50	50	50	μ–cell size
15	15	15	15	
50	50	50	50	
15	15	15	15	
50	50	50	50	
15	15	15	15	
50	50	50	50	
15	15	15	15	



Designed to be used for irradiation tests and at test-beams after irradiation

SiPM Irradition test

1st campaign
May '21 @ TIFPA (Italy)

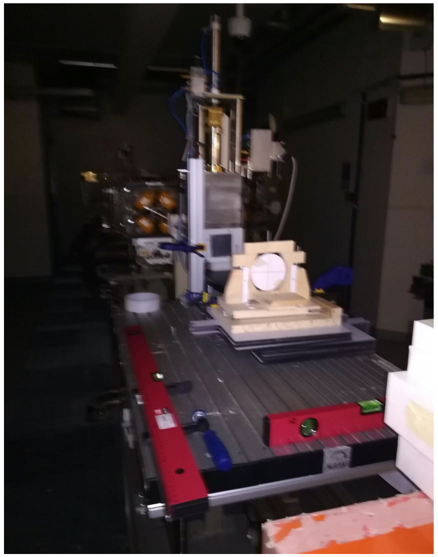
Collimated proton beam

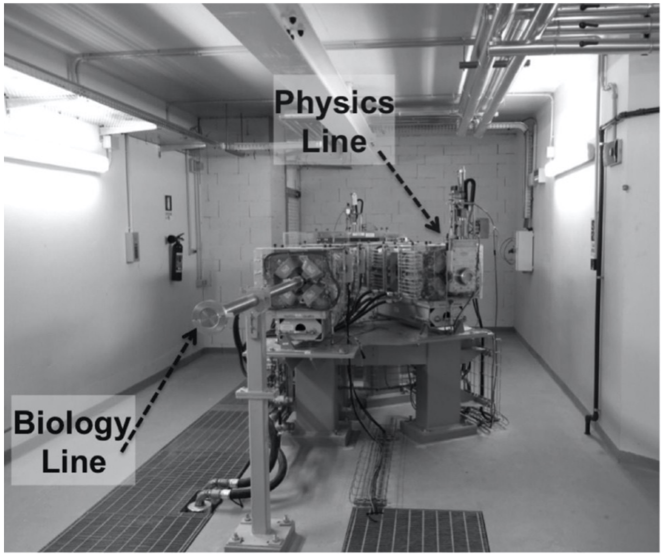
10^8 - 10^{11} n_{eq} fluence

Goal:

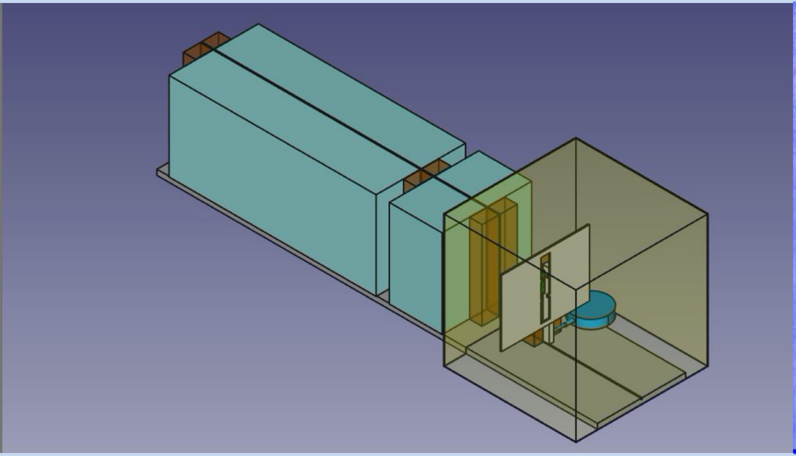
Study damage effects
with increasing dose

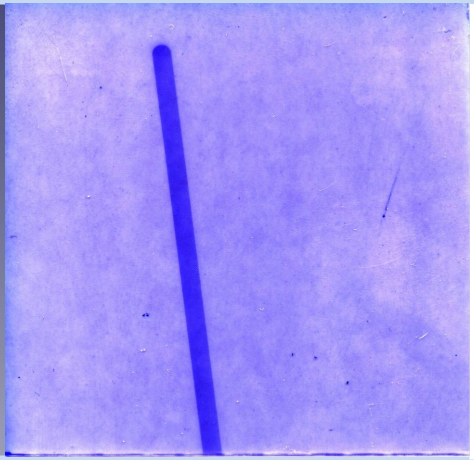
TIFPA Facility at Trento Hadron Therapy Center

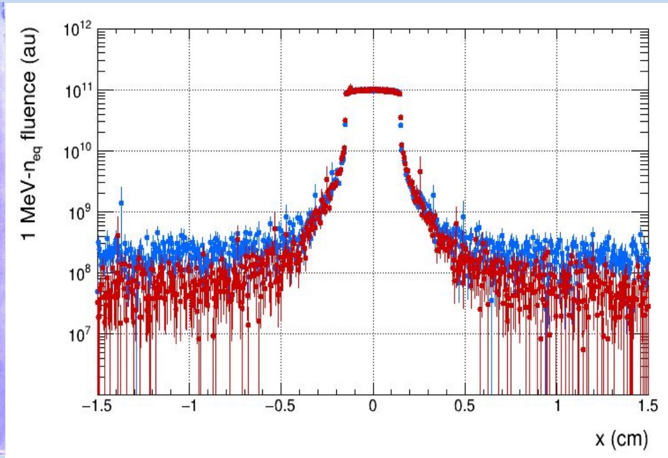




Assess post-irradiation and post-annealing single-photon detection capabilty

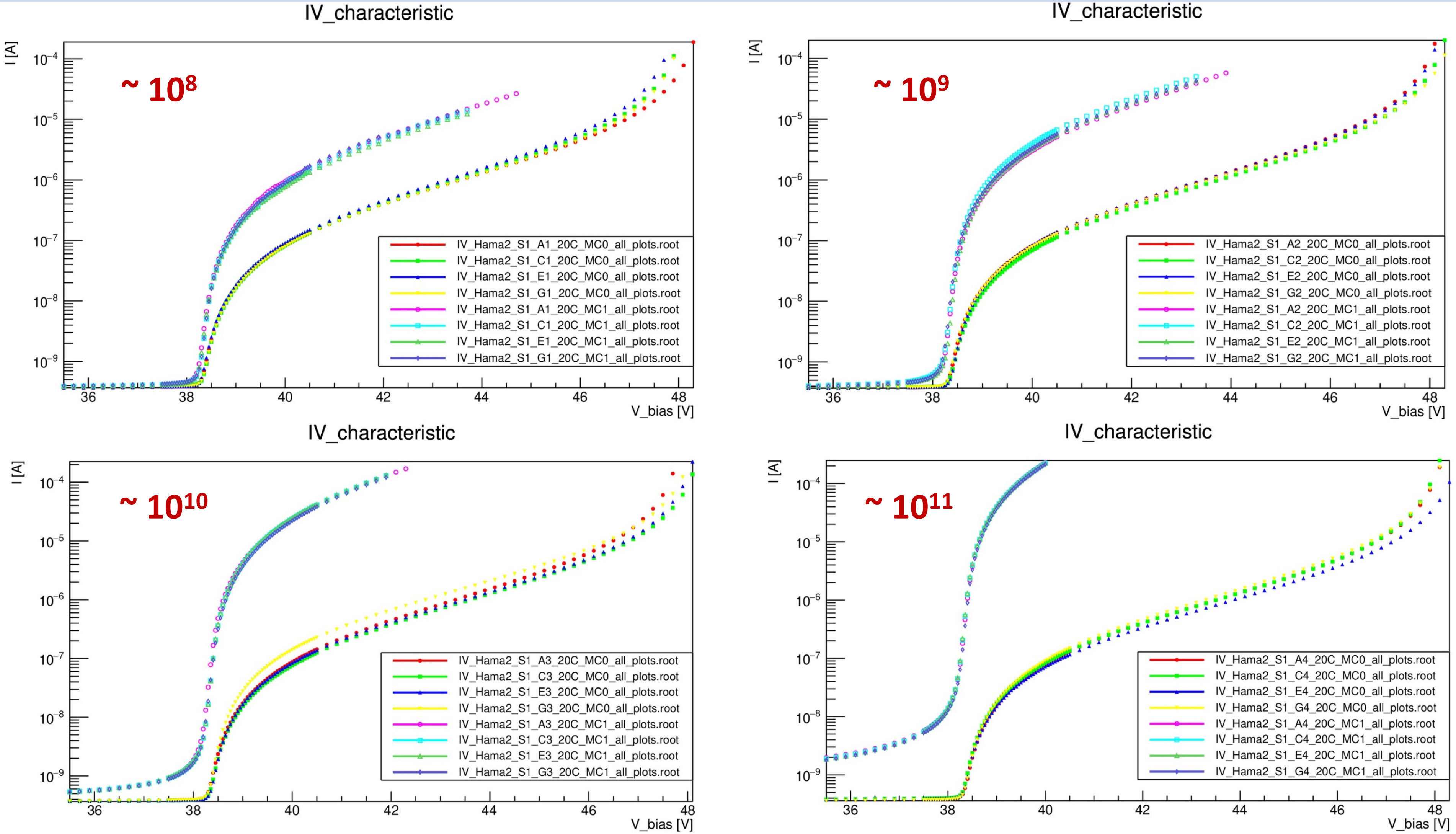


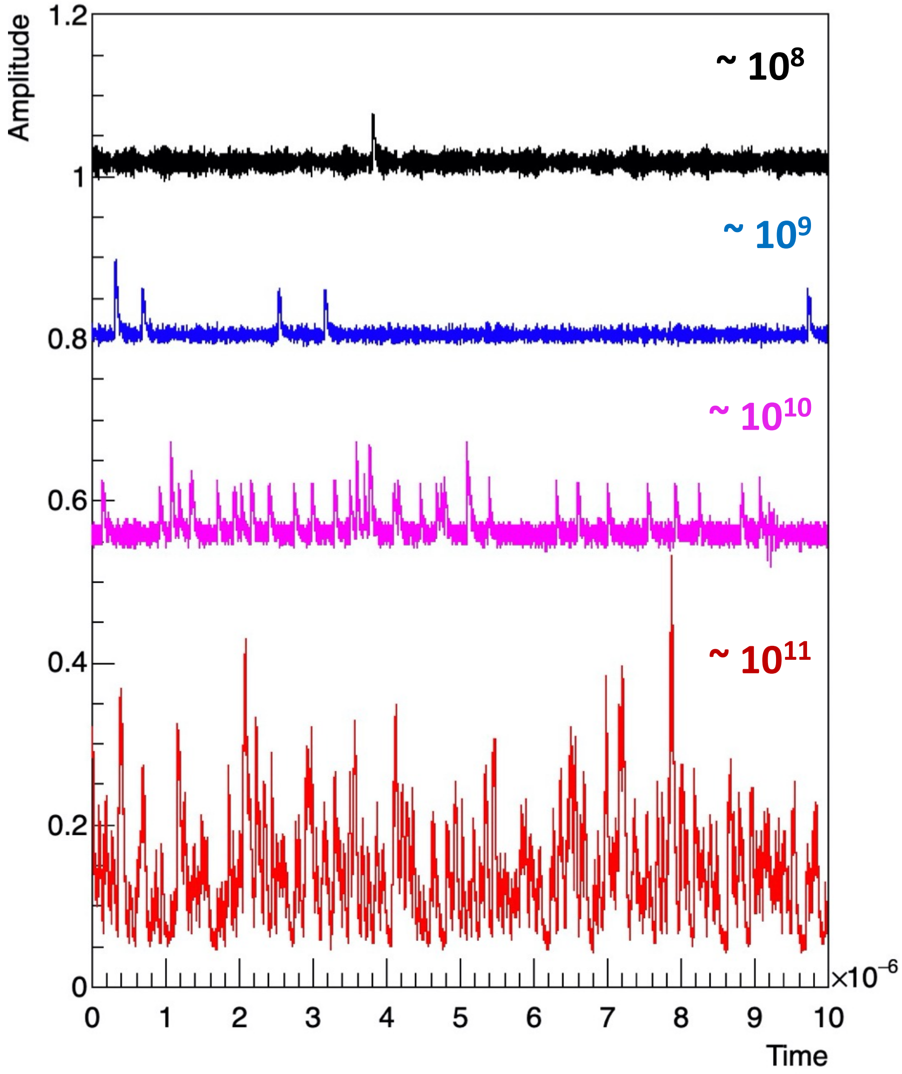


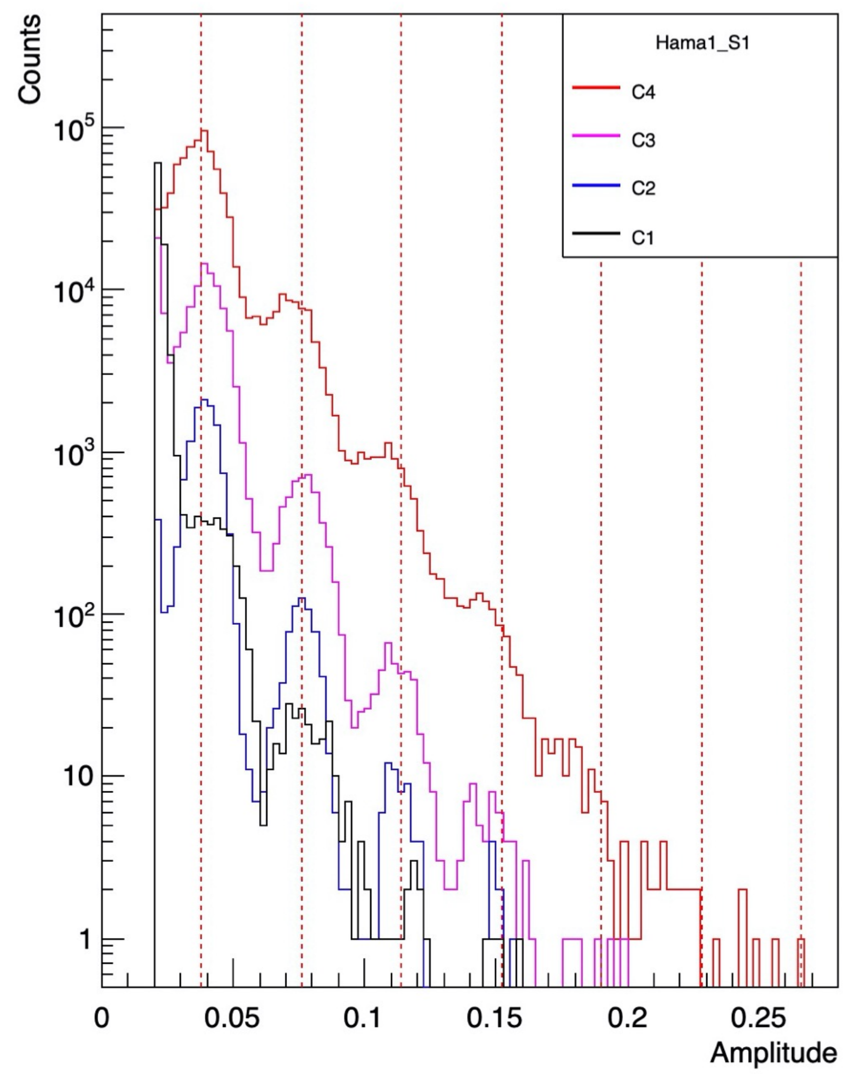


SiPM Radiation Damage

4x samples of S14160-3050 irradiation at various 1MeV neutron equivalent dose




Amplitude
1.2
1
0.8
0.6
0.4
0.2
0
~ 10^8
~ 10^9
~ 10^10
~ 10^11
0 1 2 3 4 5 6 7 8 9 10
×10^-6
Time


Counts
10^5
10^4
10^3
10^2
10
1
Hama1_S1
C4
C3
C2
C1
0 0.05 0.1 0.15 0.2 0.25
Amplitude

SiPM Annealing

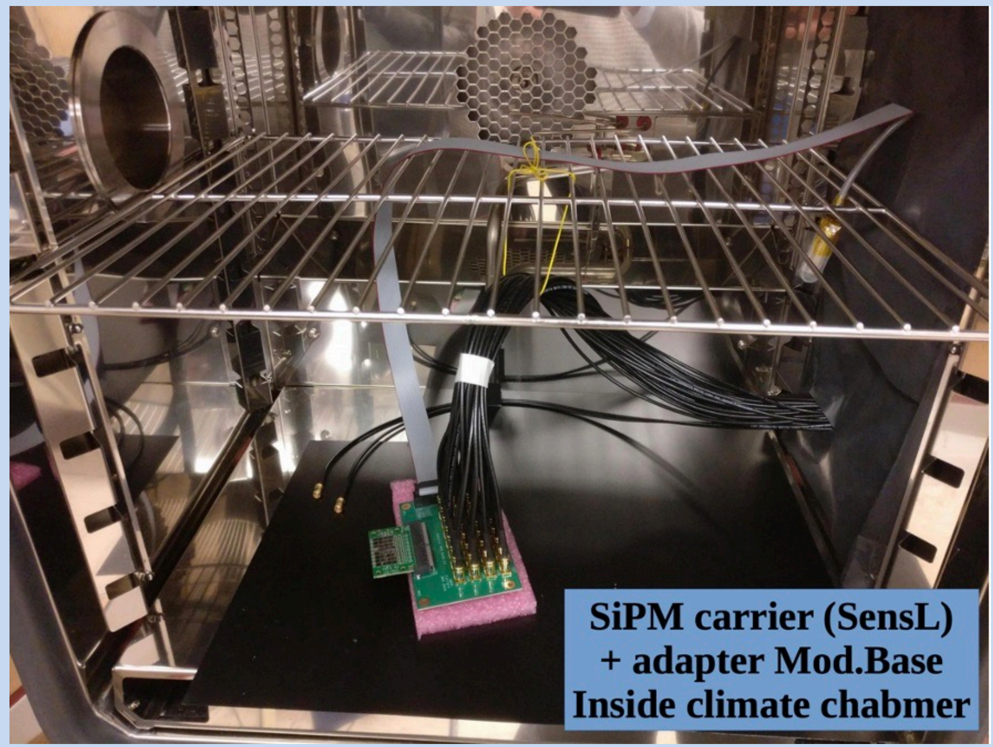
1 month annealing at ncresing temperarture from 50 to 170 C, check-up every few days

<=100 C | 125 C | 150 C | 170 C

Day	7	8	9	10	11	12	13	14	15	16	17	18	18	29	21	22	23	24	25
Temp	50	100	125	125	125	M	125	125	125	M	125	125	M	150	150	150	M	150	150
Hour	12	24	24	24	24	12	24	24	24	12	*24*	24	12	24	*24*	*24*	12	*24*	*24*
Time	12	36	24	48	72	84	108	132	156	168	192	216	12	36	60	84	96	120	144

Day	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13
Temp	150	M	175	175	M	175	175	M	175	175	M	175	175	175	M	175	175	175	M
Hour	*24*	12	24	24	12	24	24	12	24	24	12	24	24	24	12	24	24	24	0
Time	168	12	36	60	72	96	120	132	156	180	192	216	240	264	276	300	324	348	348

Oven 50 : 1100 C

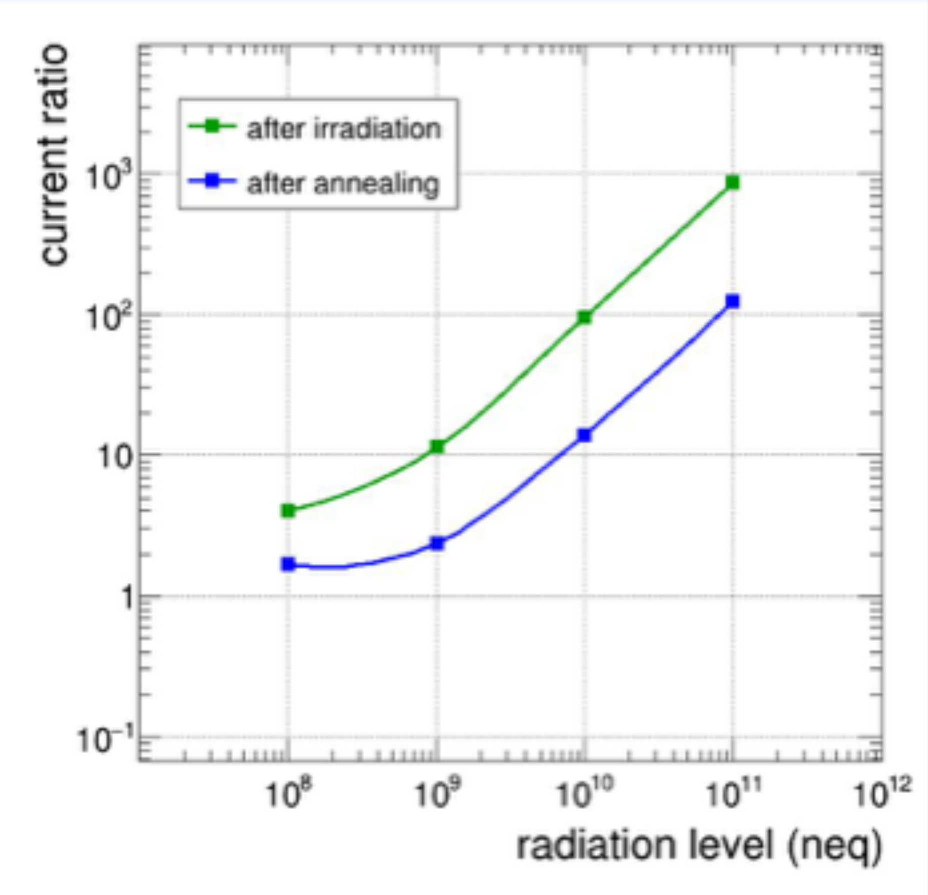


Climatic Chamber -40 : 80 C

SiPM Annealing

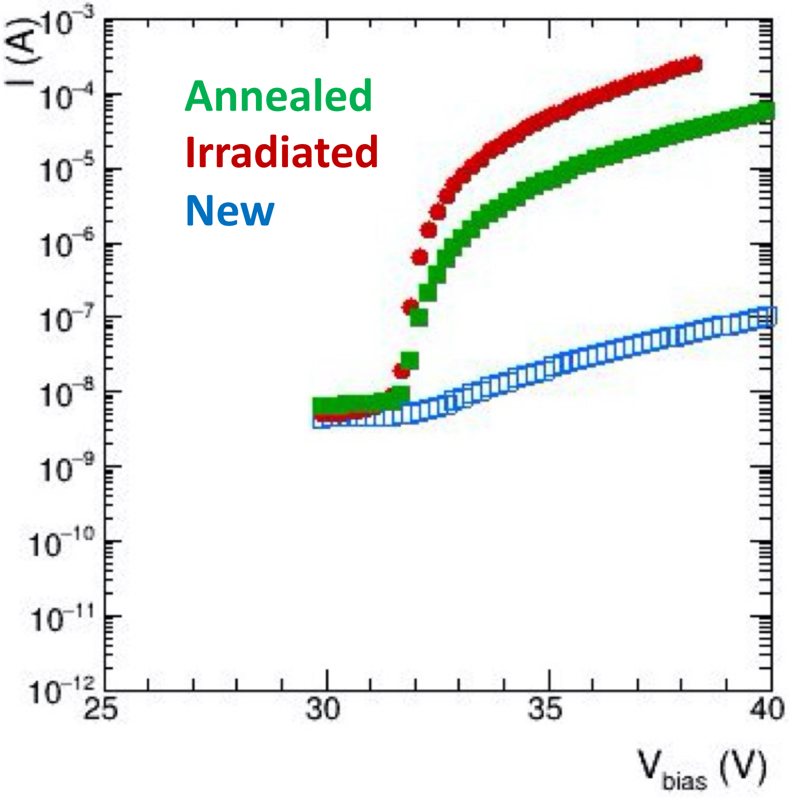
FBK SiPM [NUV-HD-RH

after 1 week of annealing at 125 C



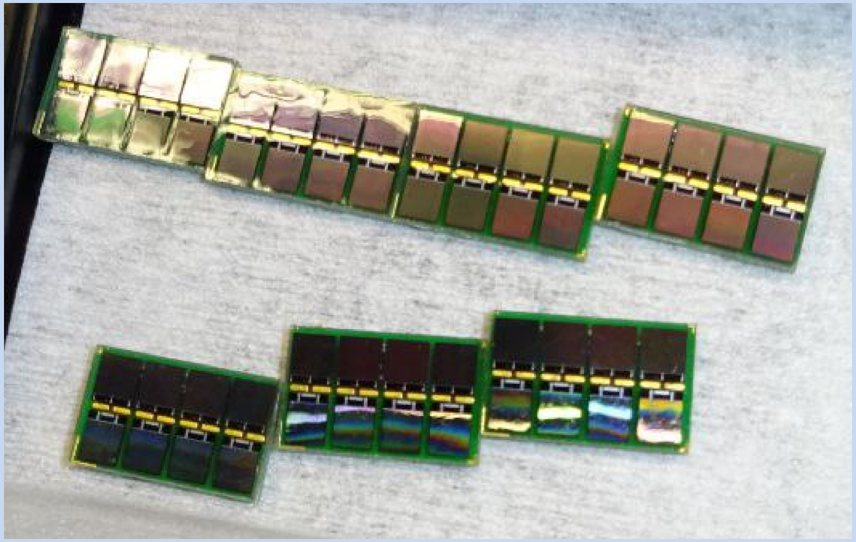
annealing reduced dark current by a factor of ~5-10, in line with expectations

SiPM irradiated up to 10^{11} now behave like if they were irradiated by 10^{10}



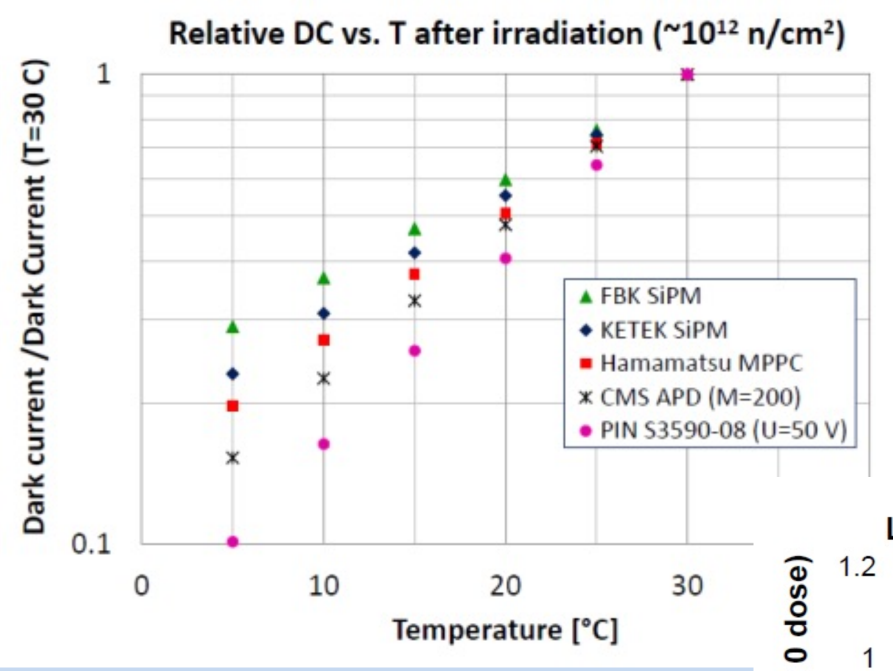
Custom SiPM solutions:
exploit INFN conventions with producers
e.g. FBK (development) and Lfundy (production)

FBK: 15 μm and 50 μm SPAD sample



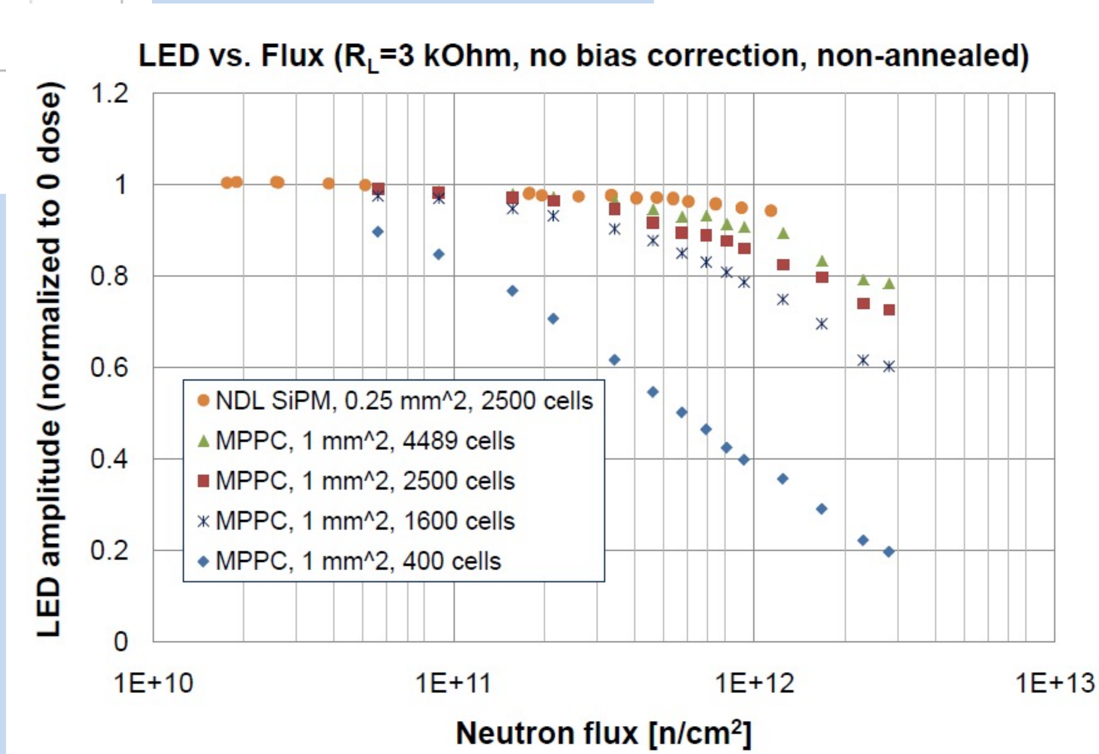
Questione finestre. Sinergia con LHCb

SiPM Radiation Tolerance



General trend is that SiPMs with high VB value have faster dark current reduction with the temperature

Yu. Musienko @ DIRC2019



SiPMs with high cell density and fast recovery time can operate up to $3*10^{12}$ neutrons/cm^2 (gain change is< 25%).

- + Low/uniform field
- + Entrance window (annealing)
- + Packaging (ΔT, cooling)
- + ……

Custom readout solutions:

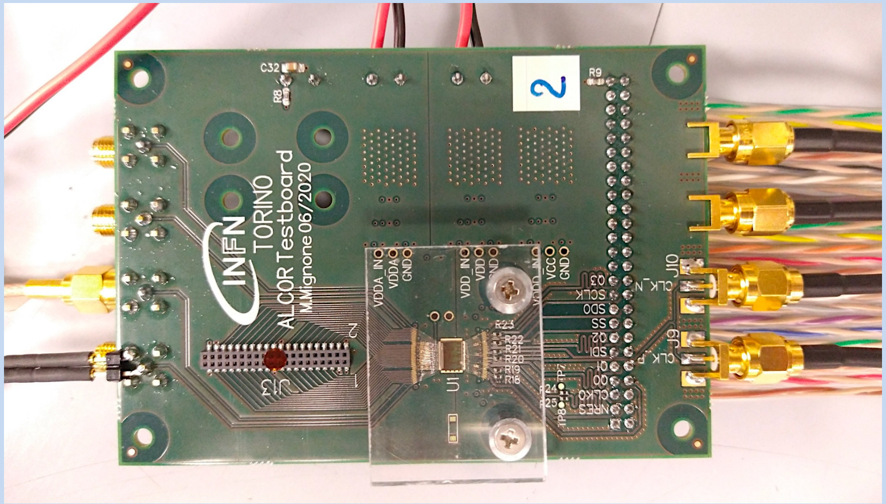
ToT readout bsed on

ALCOR (F/E) + ARCADIA (DAQ)

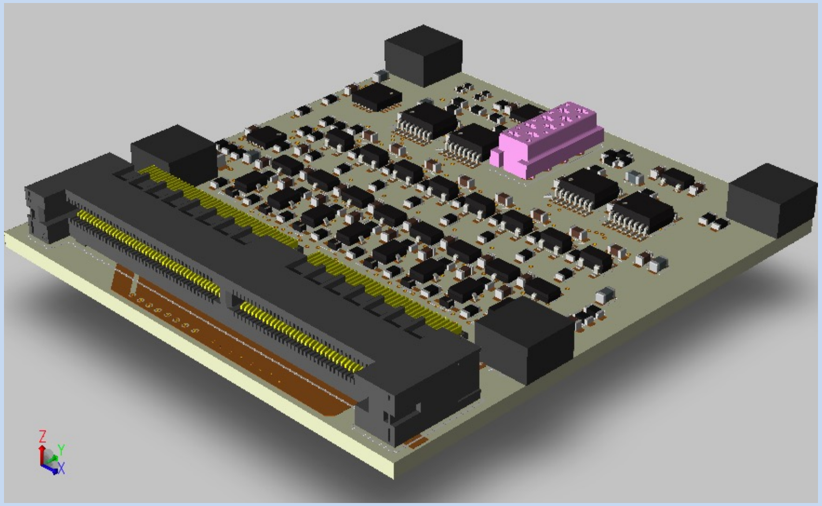
- 500 kHz per channel
- 50 ps time binning

FPGA!

ALCOR test board



SiPM carrier to ALCOR adapter board



SiPM and ALCOR Readout

Cherenkov imaging test with dRICH prototype. (starting in fall ’21)

Study signal over background ratio as a function of

irradiation + annealing, temperature, timing

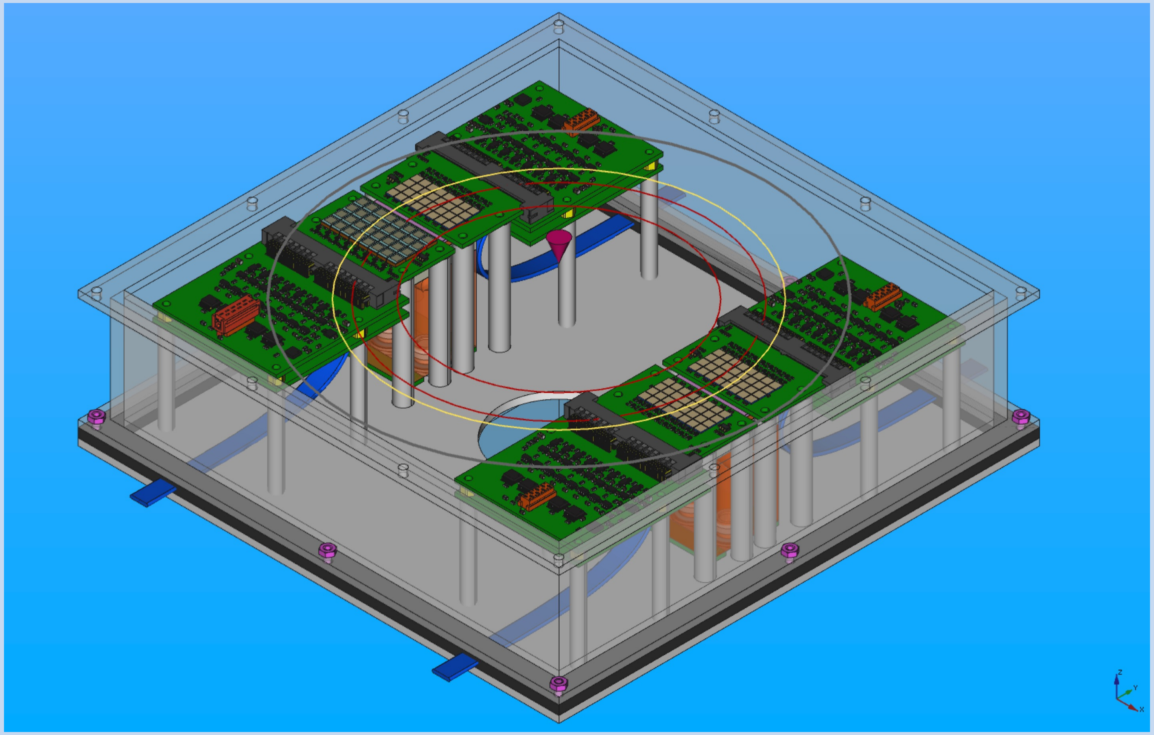
- SiPM carriers with

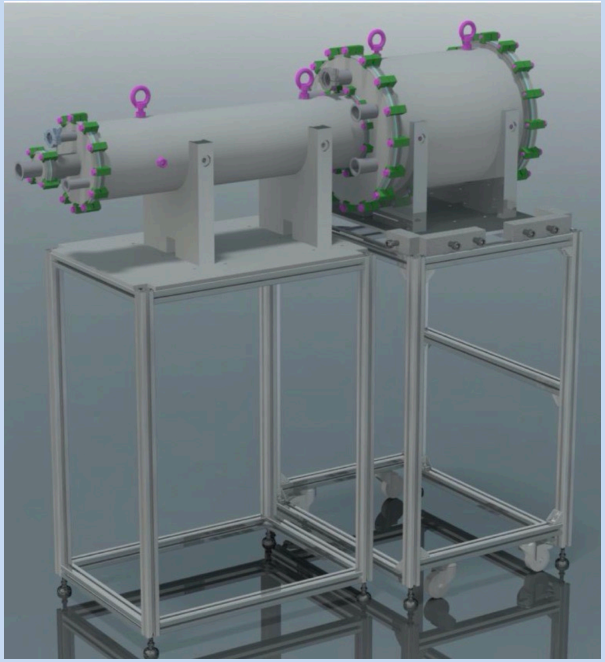
  pristine SiPM

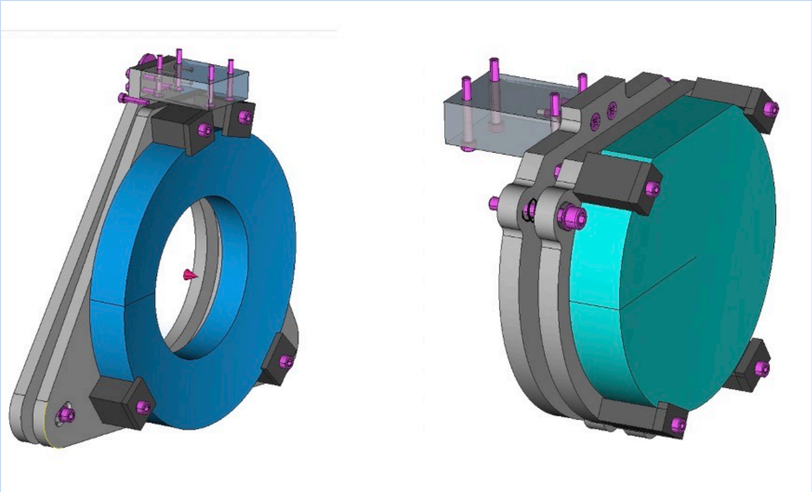
  irradiated and
  annealed SiPM

- dedicated readout:

  ALCOR front-end
  ARCADIA DAQ





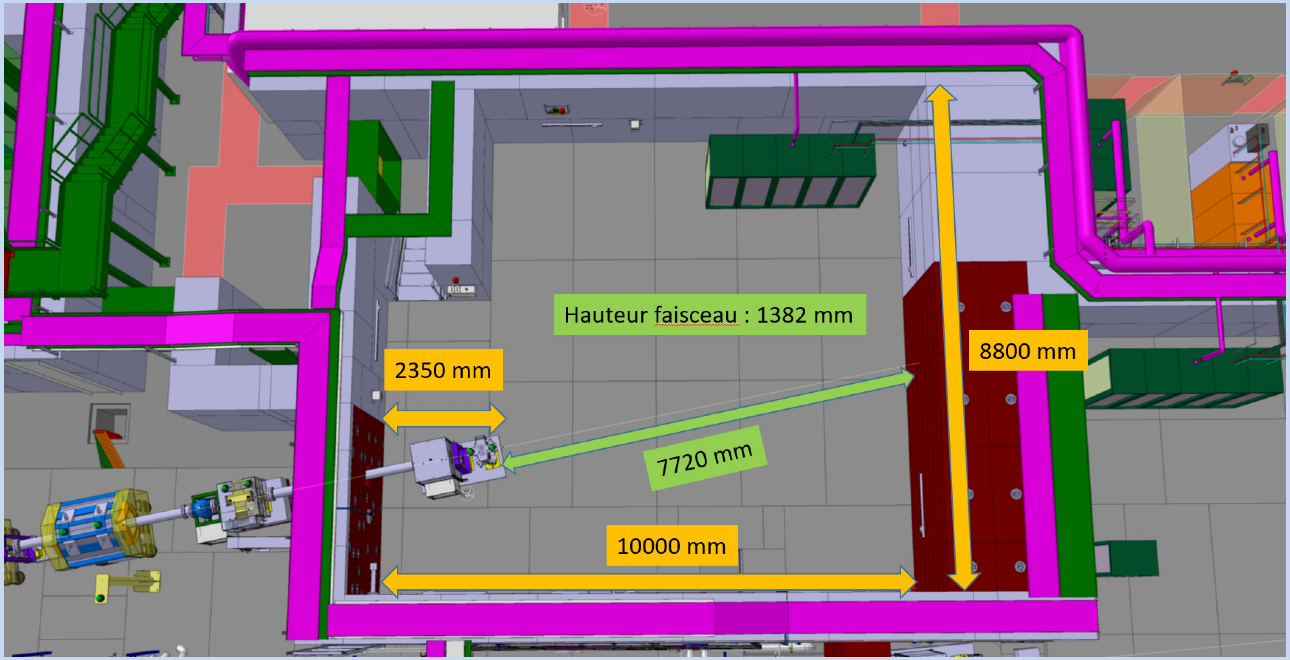


dRICH + SiPM beam test
October ‘21 @ CERN T10

Meson beam up to 15 GeV/c

Synergy with ALICE for
Japanese (Chiba U.) aerogel test

Goal: Validate dRICH Concept
Assess SiPM usage in realistic experimental conditions



Conclusions