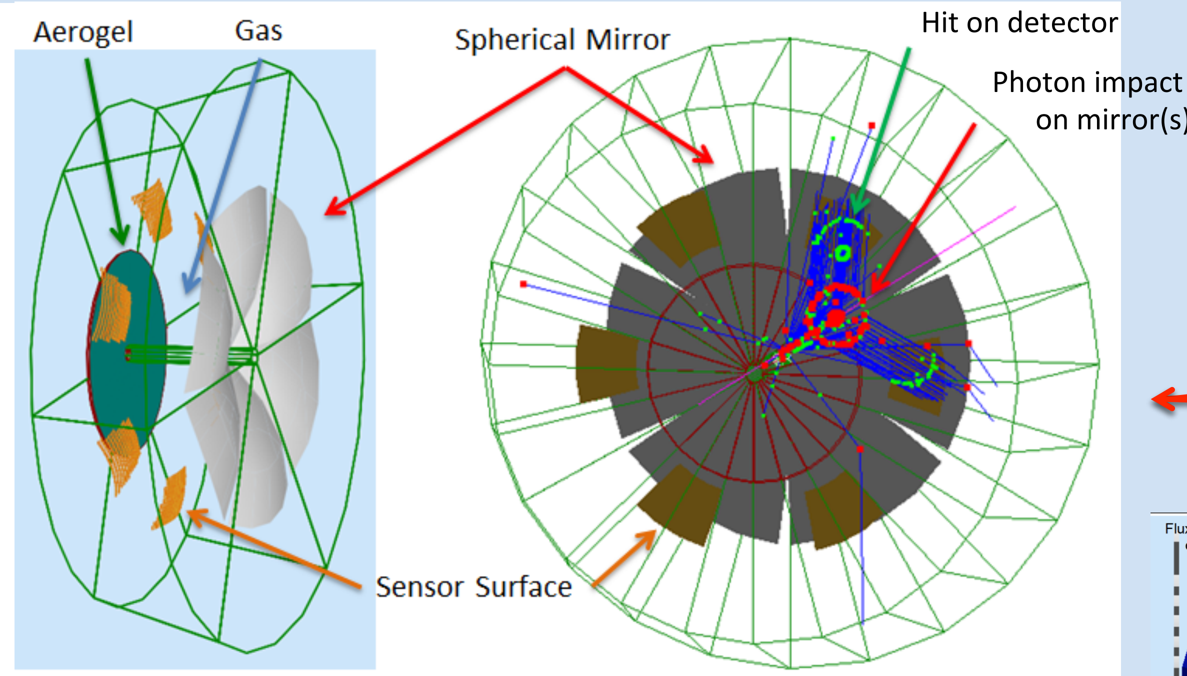
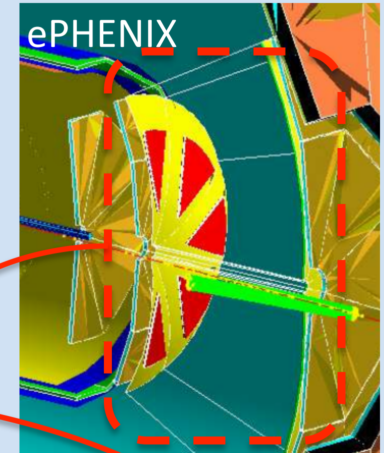
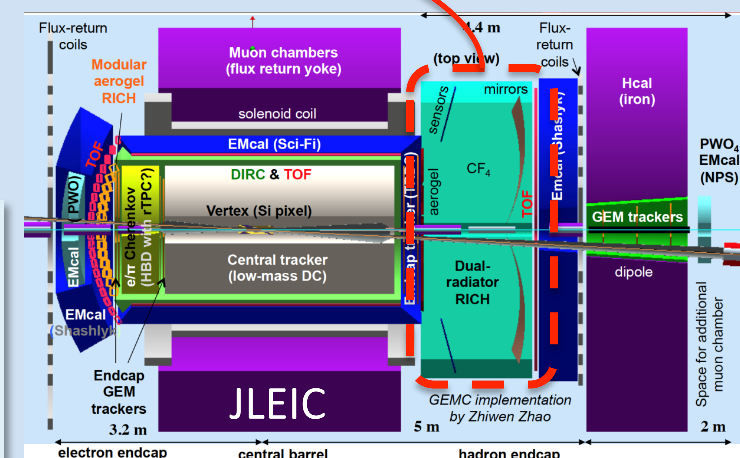
Dual Radiator RICH in EIC Hadron-endcap







dRICH: optimized for JLEIC, preliminary in ePHENIX

Radiators:

- Aerogel: 4 cm, $n_{(400nm)}$~1.02 + 3 mm acrylic filter
- Gas: 1.6m (1.1m ePHENIX), n_{C2F6}~1.0008

6 Identical Open Sectors (Petals):

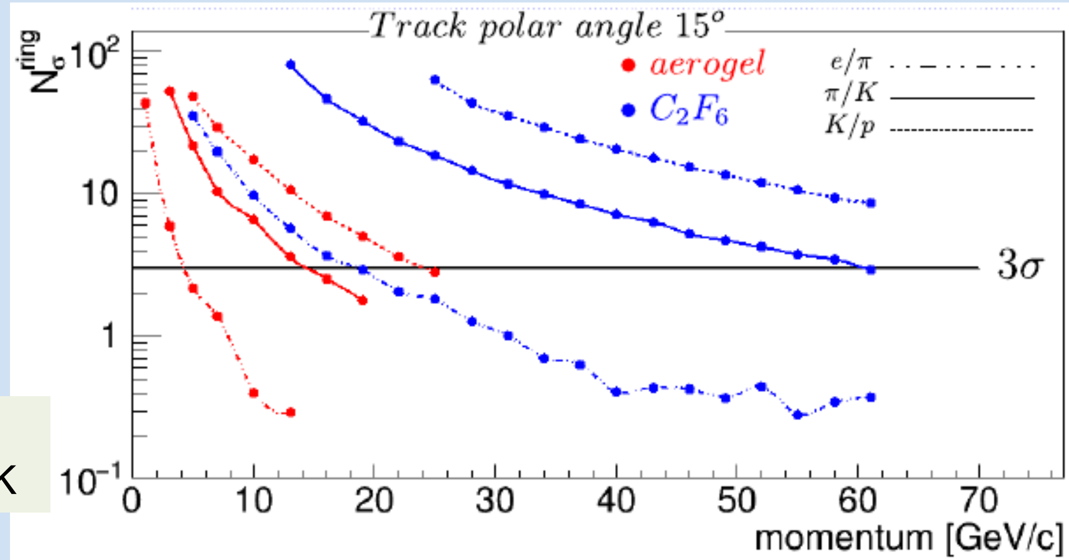
- Large Focusing Mirror with R ~2.9m (~2.0m ePHENIX)
- Optical sensor elements: ~4500 cm^2/sector, 3x3 mm^2 pixel, UV sensitive, out of charged particles acceptance

Phase Space:
- Polar angle: 5-25 deg
- Momentum: 3-50 GeV/c

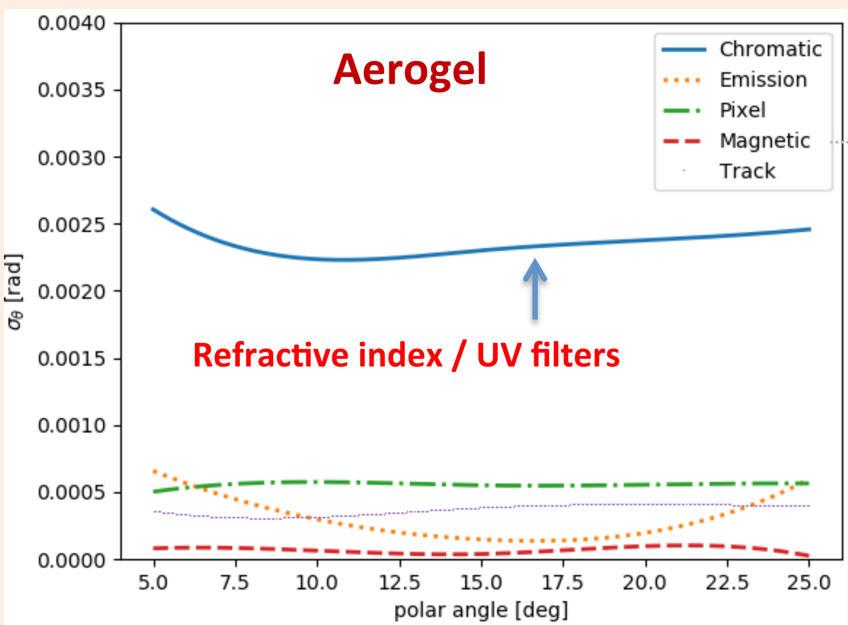
dRICH Expected Performance

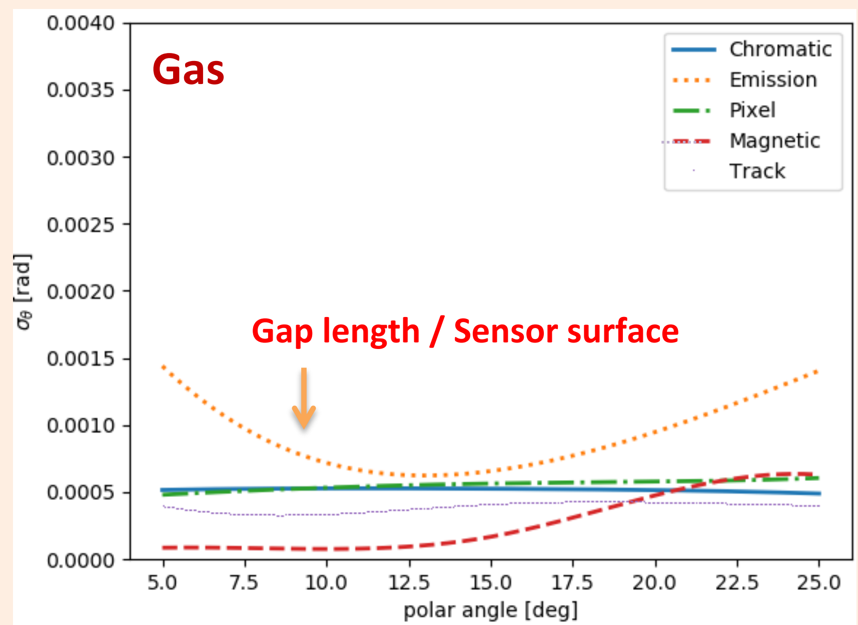
- **Montecarlo: GEMC (Geant4)**
- Realisti component quality from CLAS12
- PMT 3x3 mm pixel
- **Tracking accuracy 0.5 mrad**
- **Include 3T central magnetic field**

Hadron identification (π/K/p): provides better than 3 sigma from ~3 up to ~50 GeV/c for π/K



Single Photon Angular Resolution





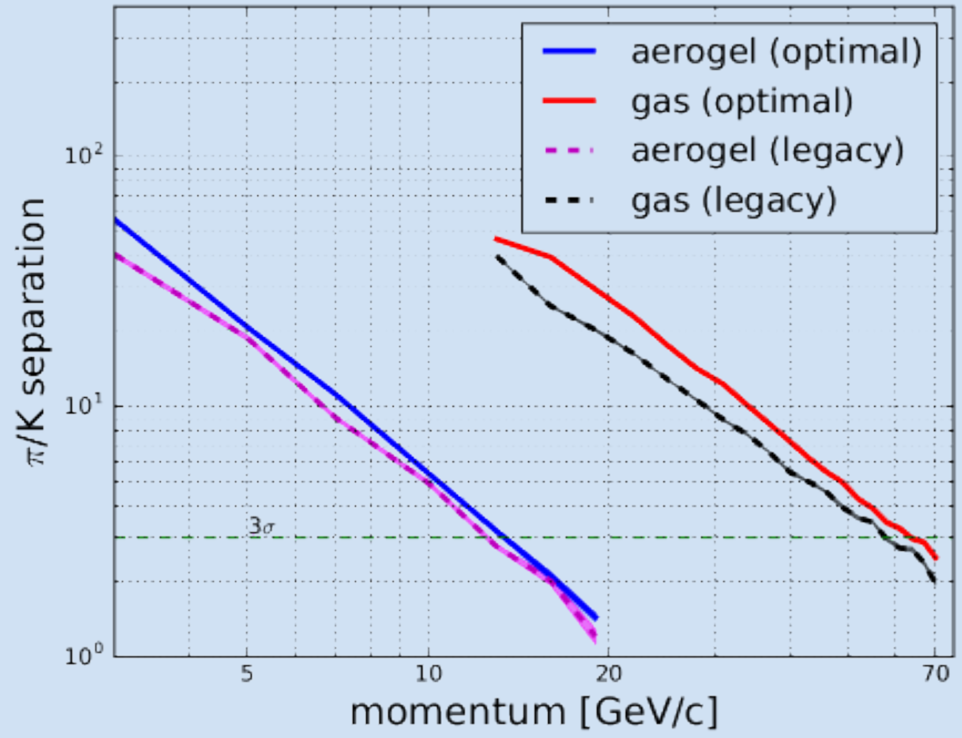
dRICH Model Integrated in Bayesian Optimizer

Use Bayesian Inference to efficiently maximize proper Figure of Merit

General optimization framework with parallelized computation associated to automated convergence criteria; implemented on python *sklearn* machine learning libraries

dRICH use case

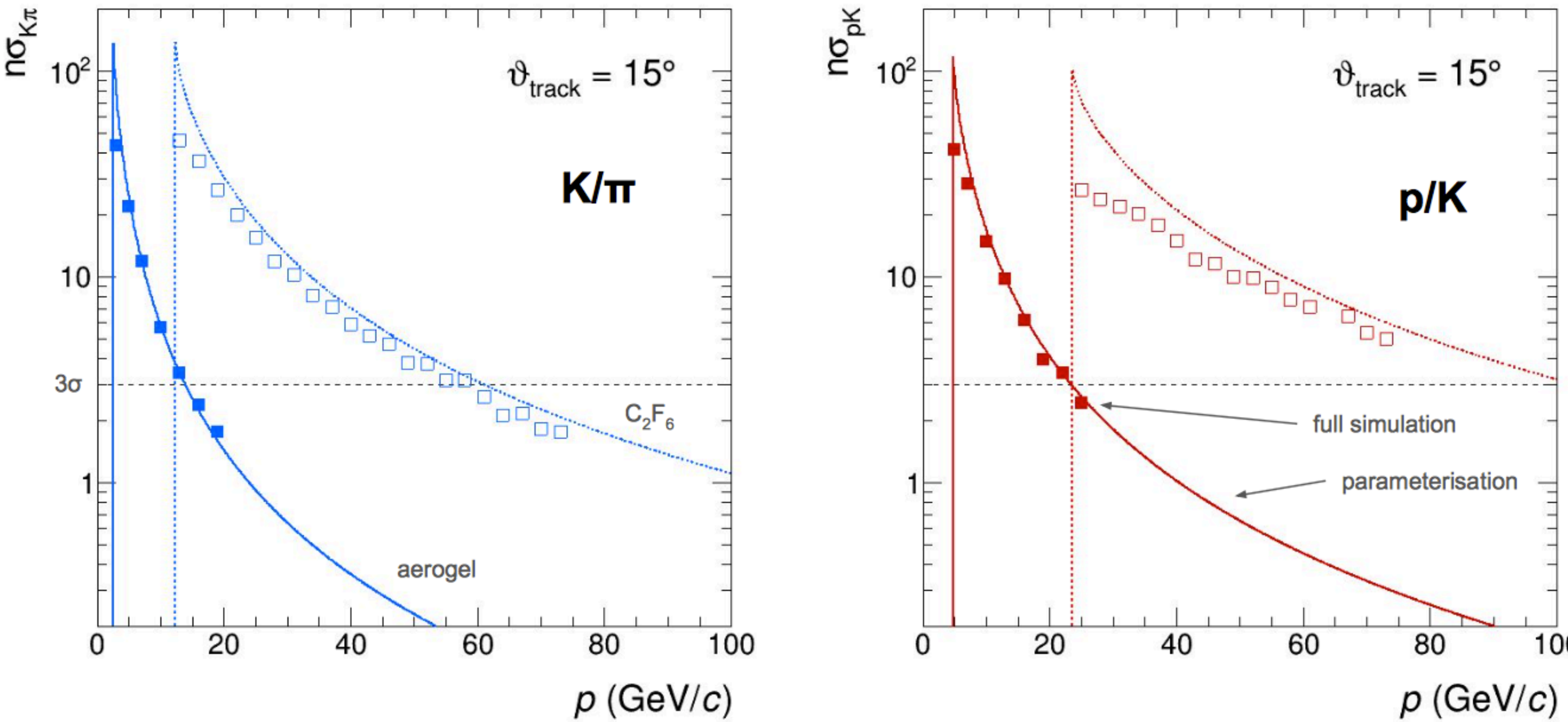
- **FoM: π-K Cherenkov angles separation in critical phase space regions (other criteria can be added);**
- **8 optimizable parameters selected (can be extended)**



An efficient way to re-optimize relevant parameters and consolidate the performances of the dRICH once we have prototype test results

Recently published: J. Inst., vol.15, May 2020 DOI: 10.1088/1748-0221/15/05/P05009

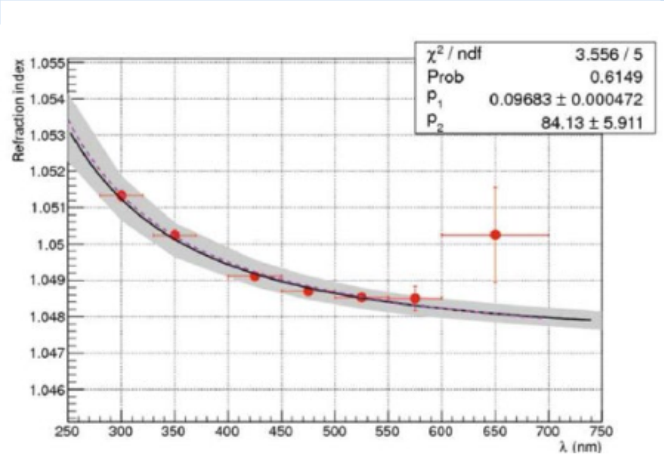
dRICH Performance Parameterization Post-MC



K/π and p/K separation as a function of momentum

dRICH Performance Parameterization Ab-initio

Chromatic term



Sellmeier parameterization

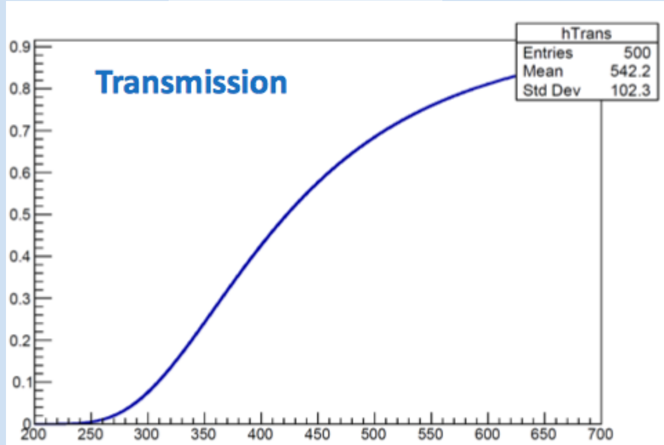
$$n^2(\lambda) = 1 + \frac{p_1 \lambda^2}{\lambda^2 - p_2^2}$$

Mixture of air and quartz

$$n(\lambda) = A n_{\rm air}(\lambda) + (1 - A) n_{\rm quartz}(\lambda)$$

$$A = \frac{n_{\rm quartz}(\lambda_0) - n(\lambda_0)}{n_{\rm quartz}(\lambda_0) - n_{\rm air}(\lambda_0)}$$

Light Transmission



Hunt parametrization

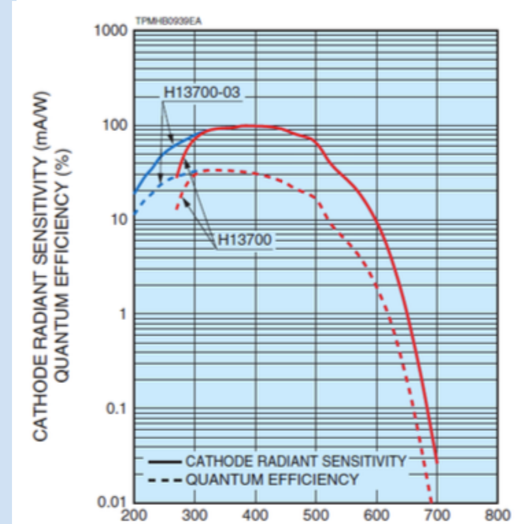
$$T = A e^{-Ct/\lambda^4}$$

Scattering length: $\Lambda_{sc} = \lambda^4 / C$

A=0.97

Λ_{sc}(400 nm) = 50 mm

Sensor QE



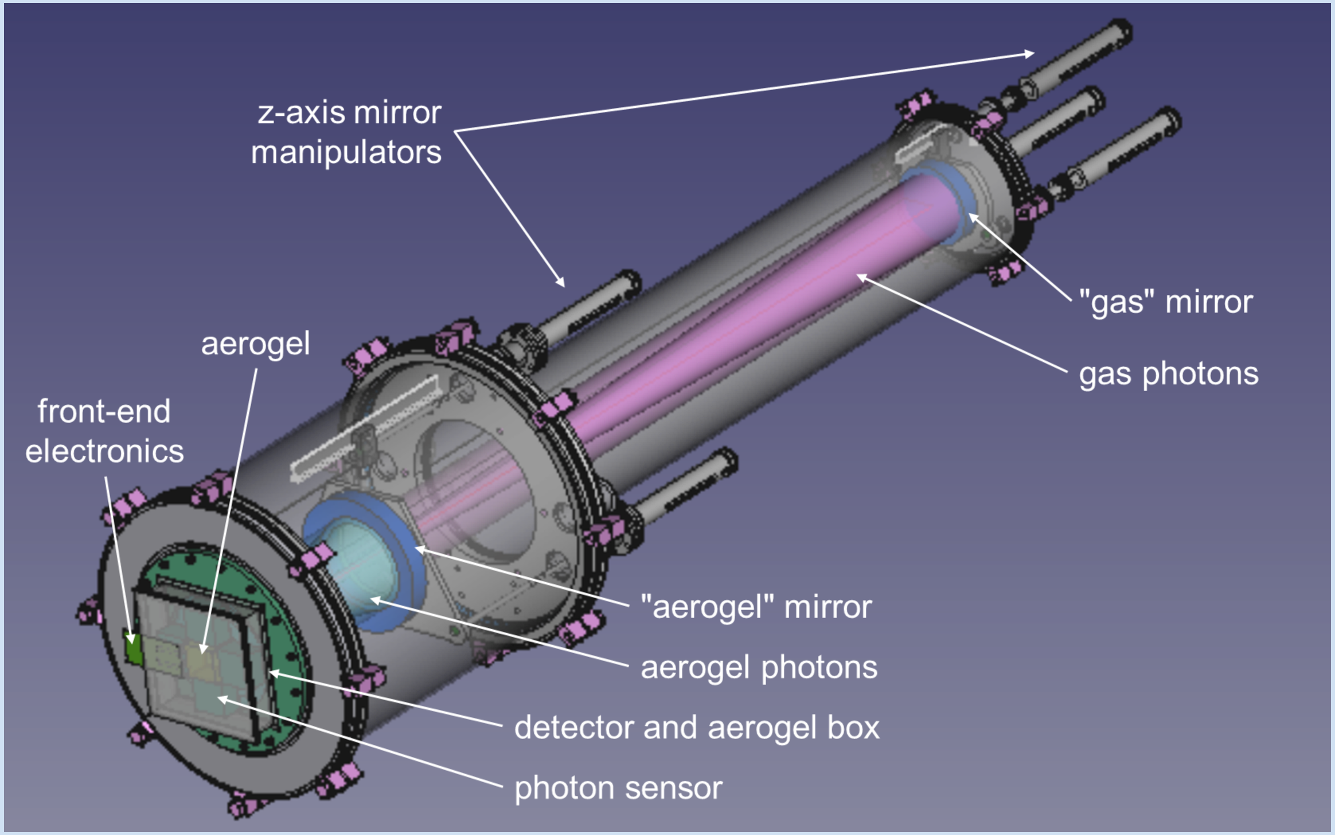
Data-Sheet

[Hamamatsu H13700]

Collection efficiency: 0.80
Packing fraction : 0.89
Discriminating eff. : 0.87

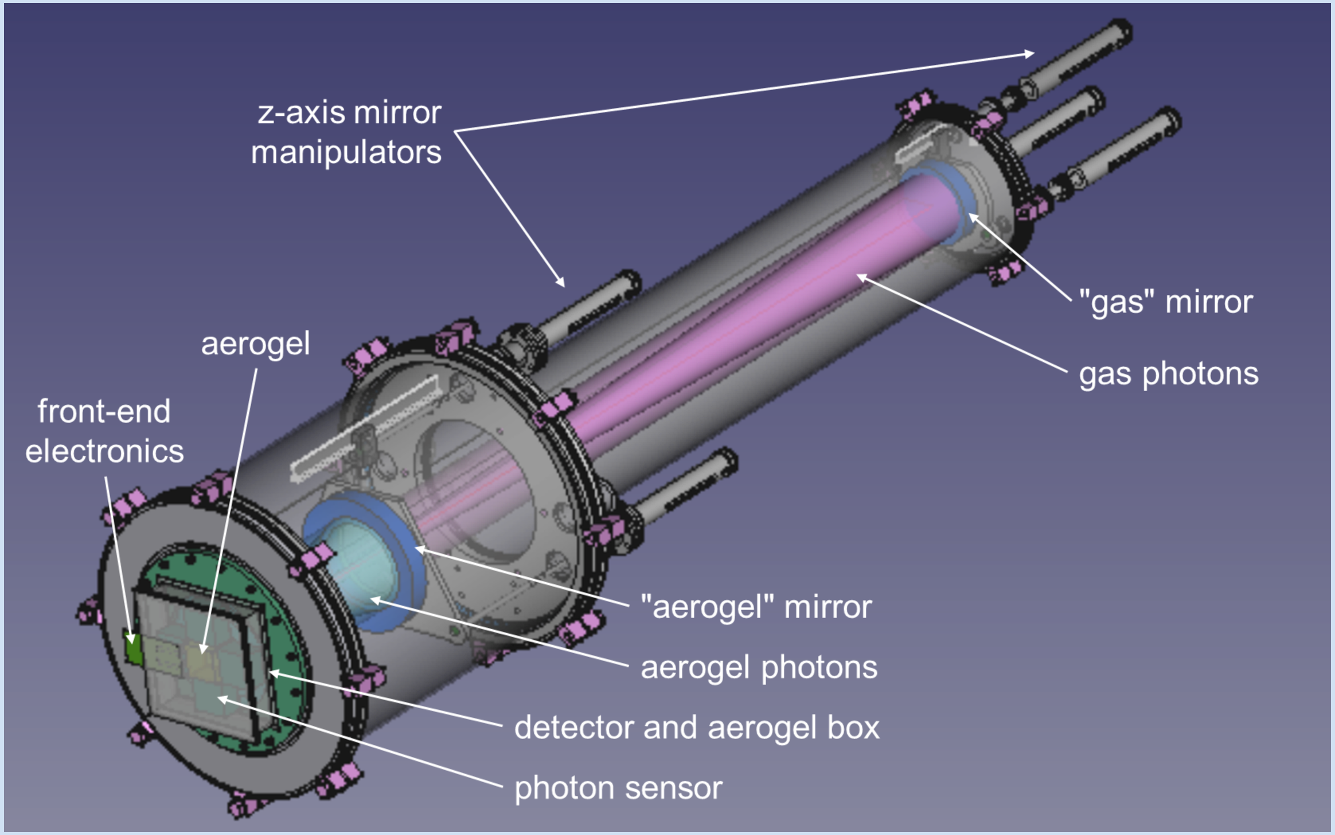
Instrumental to select & compare promising dRICH configurations prior to full MC simulation

dRICH Prototype Design



- Design in an advanced stage, mechanical details being finalized
- Standard Vacuum Technologies to optimize gas handling
- Two tuneable mirrors system for using the same detector
- Common (limited) sensitive surface for both aerogel and gas photons
- Detector and aerogel box isolated from the gas tank

dRICH Prototype Design



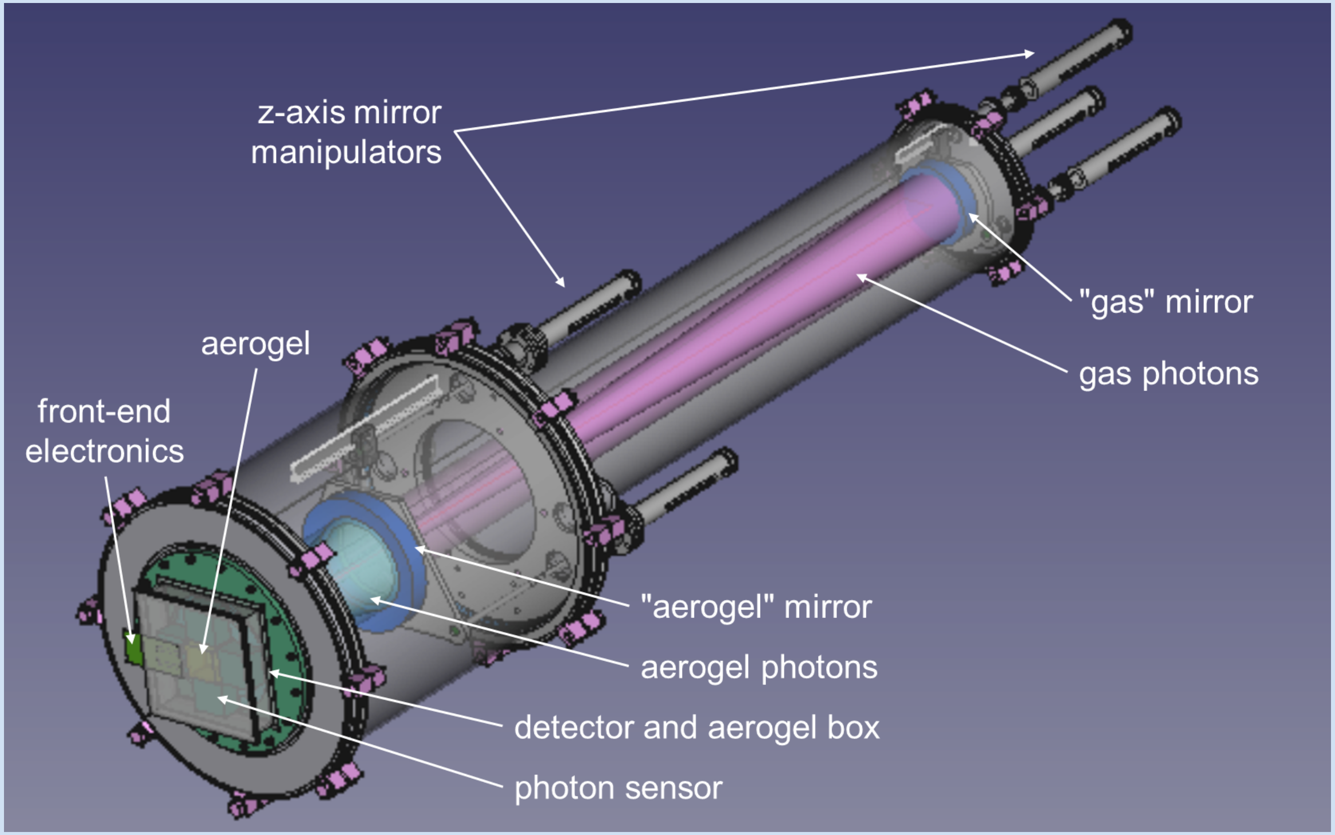
Procurement initiated (INFN in-kind):

* Aerogel (n=1.02, n=1.03) with dimensions compatible with mRICH
- Standard vacuum components (pipes, clamps, o-rings)
- Custom flanges

Survey ongoing:

- Gas / mirrors / mechanics

dRICH Prototype Design



Test-beam options under study or in preparation:

meson beams @ Fermilab:

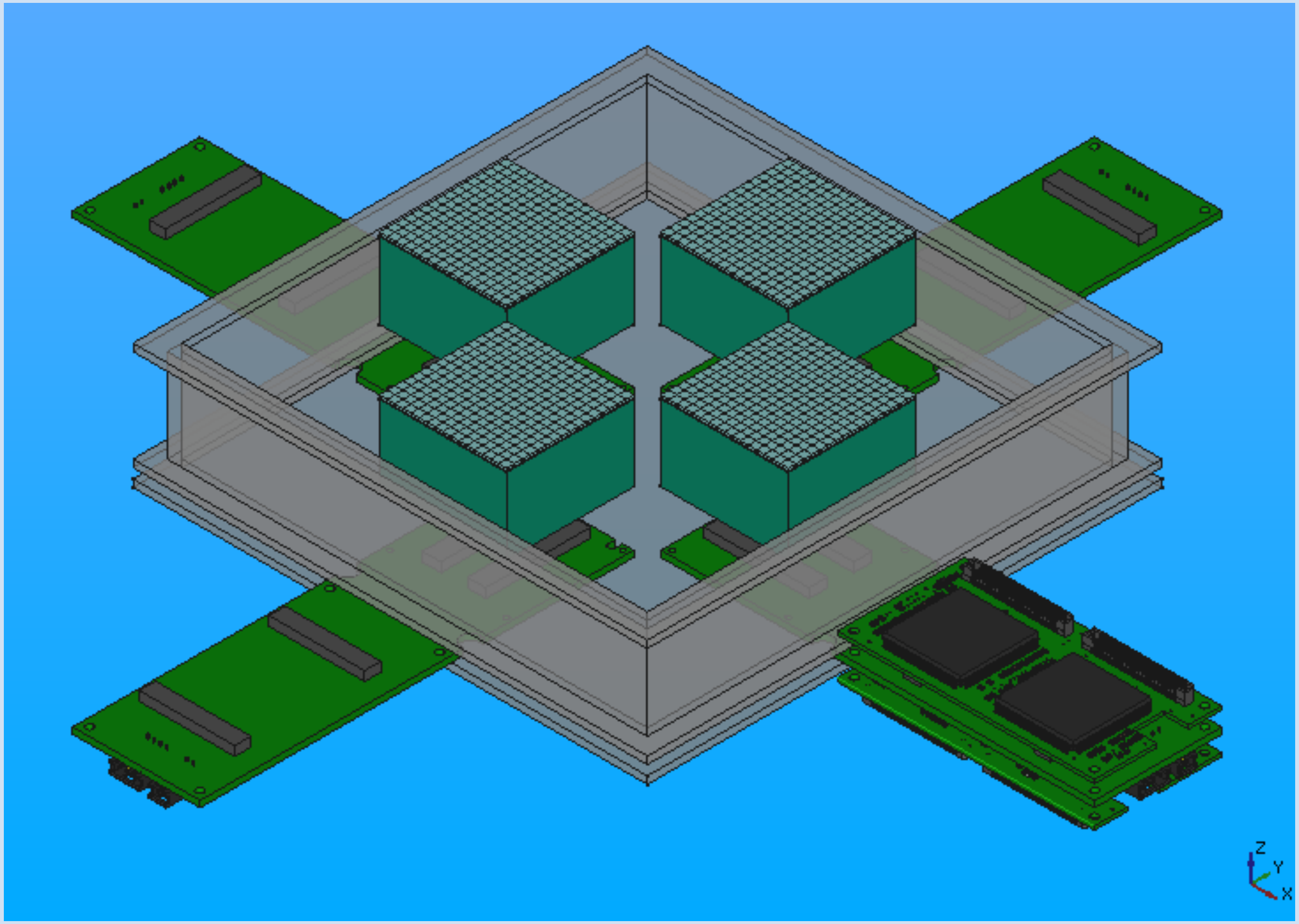
Preliminary agreem. with SBU (T. Hemmick) for gas purging system and GEM tracking

electron beams @ JLab: Generic setup with tracking capability (in conjunction with mRICH)

various beams in EU (CERN, DESY, Juelich): Instrumental for timely assessments

dRICH - H13700 Readout Box

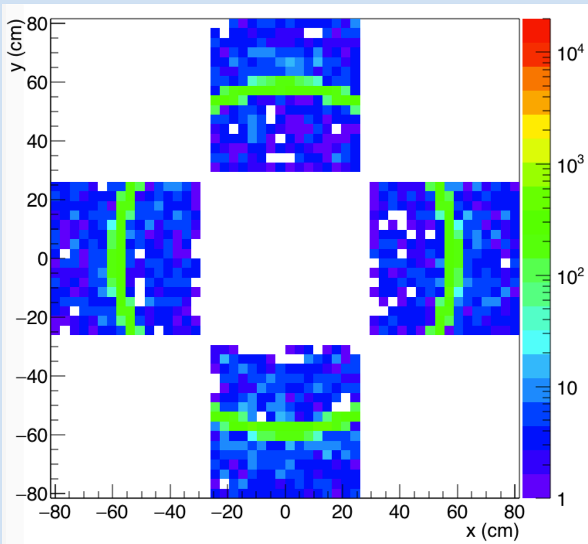
House the same principles and readout units used for mRICH test-beams
Compatible with H13700 + MAROC front-end
Allows to study the optical performance of the components

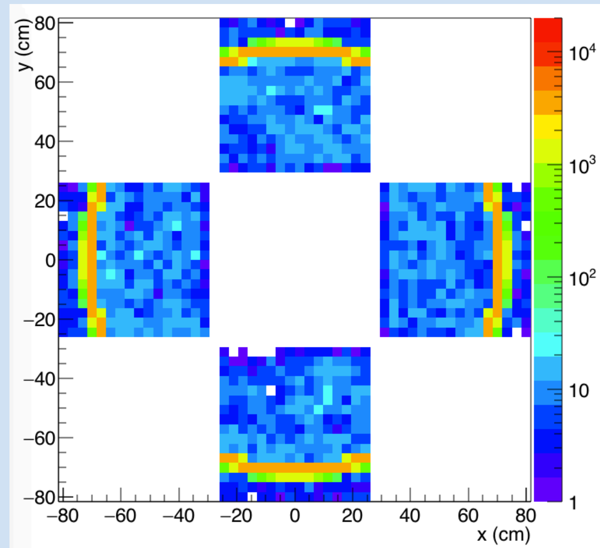


dRICH Imaging

House the same principles and readout units used for mRICH test-beams
Compatible with H13700 + MAROC front-end
Allows to study the optical performance of the components

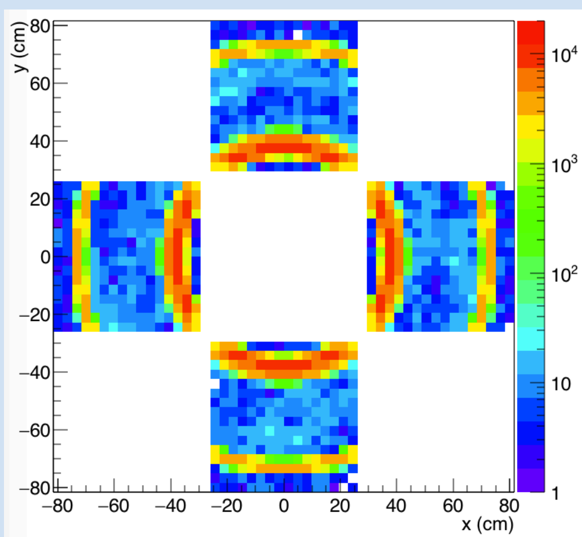
4 GeV kaon

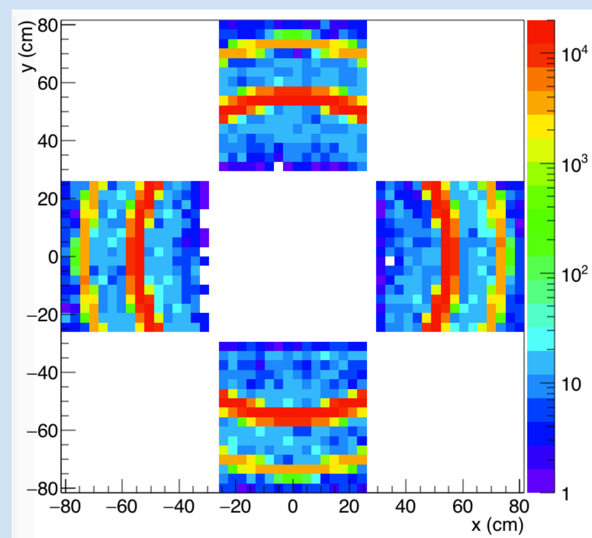




10 GeV kaon

15 GeV kaon

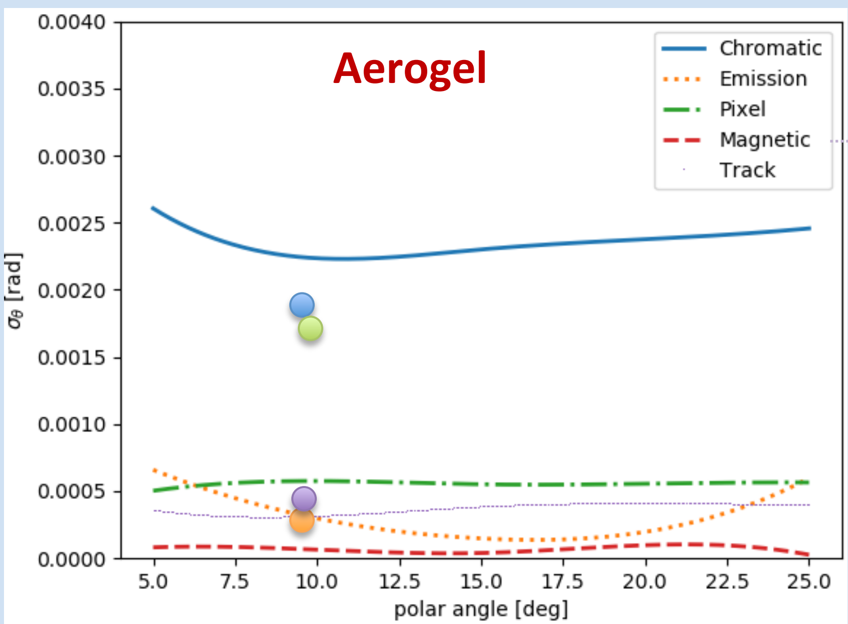


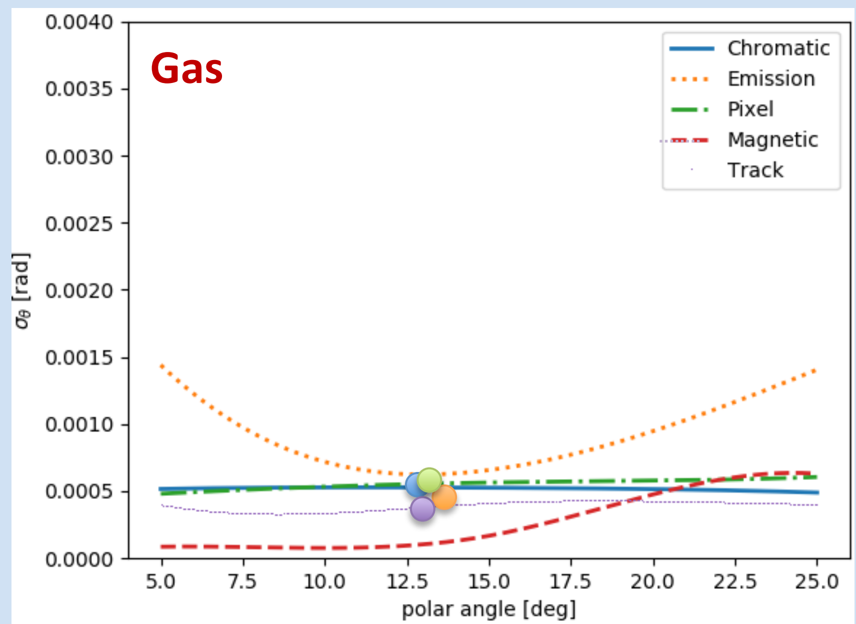


25 GeV kaon

dRICH Resolution

1 p.e. error (mrad)	Aerogel		Gas	
	Demo	dRICH	Demo	dRICH
Pixel (3mm pixel)	1.9	(0.6)	0.6	(0.5)
Chromatic (300 nm filter)	1.8	(2.2)	0.6	(0.5)
Emission (1 cm out of focus)	0.3	(0.3)	0.4	(0.6)
Beam spread (0.5 mrad)	0.4	(0.3)	0.4	(0.4)
Total	3.0	(2.3)	1.1	(1.0)

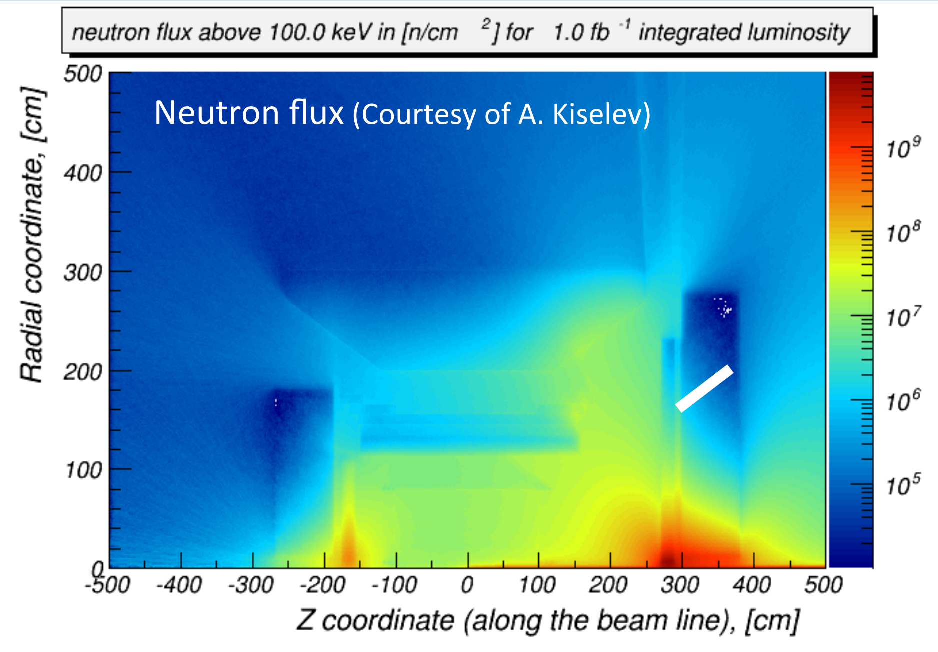


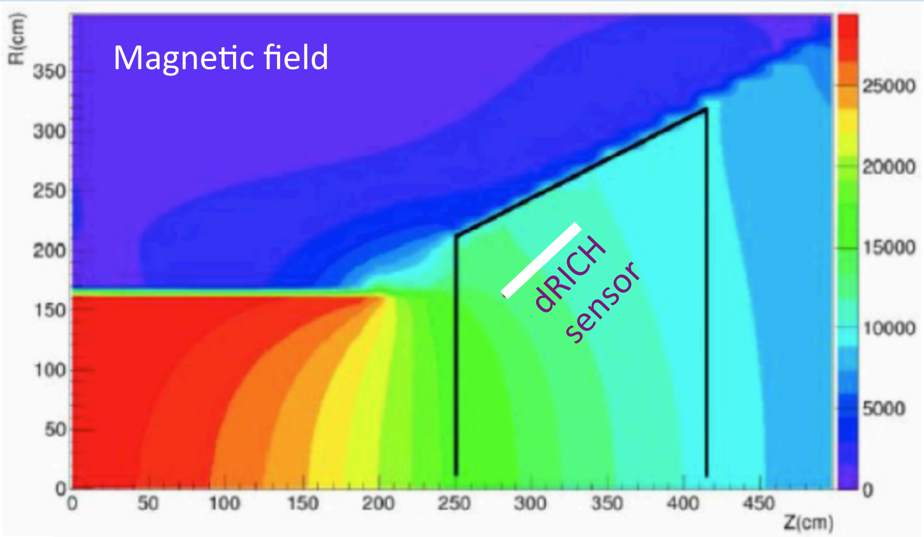


dRICH Key Hardware Components

Component	Function	Specs/Requirements	Critical Issues / Comments
Mechanics	Support all other components and services Keep in position and aligned	Large volume gas and light tightness; alignment of components	Technically demanding but feasible; no major challenges expected
Optics (Mirrors)	Focus (expecially for gas) and deflect photons out of particle acceptance and reduce sensor surface	sub-mrad precision reflectivity ≥ 90% low material budget	Spherical mirrors technology of CLAS12 suitable (optical fiber and/or glass skin); similar geometry; **Development for cost reduction**
Aerogel Radiator	Cover Low Mom. Range between TOF and Gas	≥3σ π-K separation up to Gas region (~13 GeV)	Procurement: currently 1 active provider (2 main producers + 1 potential) **Long term stability assessment in conjunction with gas**
Gas Radiator	Cover High Mom. Range above Aerogel	≥3σ π-K separation up to ~50 GeV and overlap to aerogel	Greenhouse gas: potential procurement issue **Search for alternatives**
Photon Detector	Single photon spatial detection	Magnetic field tolerant and radiation hardness; ~ few mm spatial resolution	MCP-PMT is likely doable, but expensive. LAPPD may represent an alternative. **R&D on SiPM:** a promising, quicky improving, wordwide pursued, and cheap technology.
Electronics	Amplify and shape single photon analog signal, convert to digital, transfer to DAQ nodes	Low noise Time res. ~ 0.5 ns μs signal latency	MAROC3 based readout available for prototyping; final choice will depend on sensor. **ASIC development for optimised streaming readout (discrimination vs sampling)**

dRICH Detector Environment





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

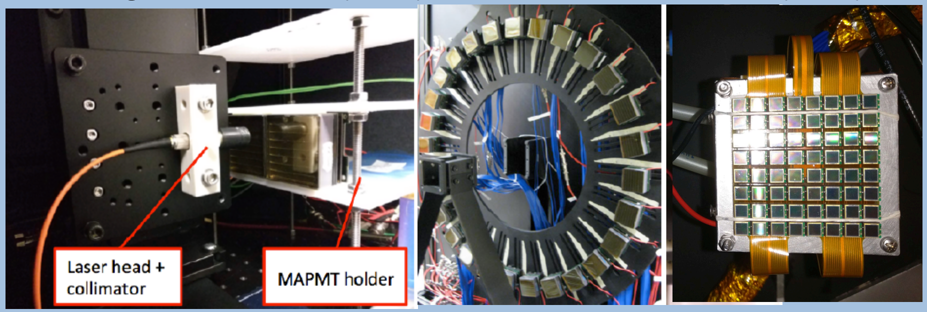
Magnetic Field

~ 1 T order of magnitude, varying orientation

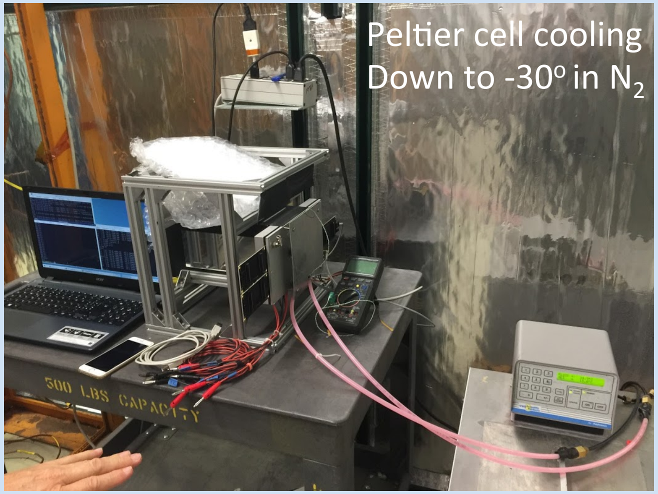
SiPM: PET study up to 7 T 10.1109/NSSMIC.2008.4774097

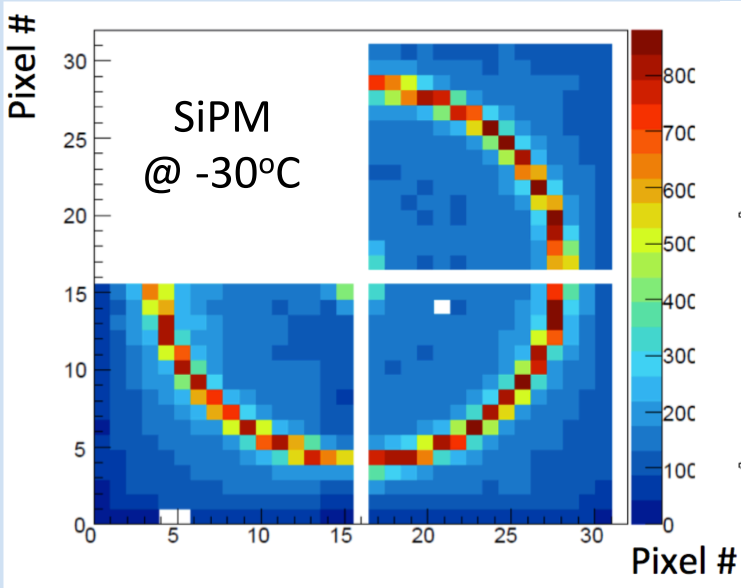
SiPM SPE capability under study since 2012 @ INFN

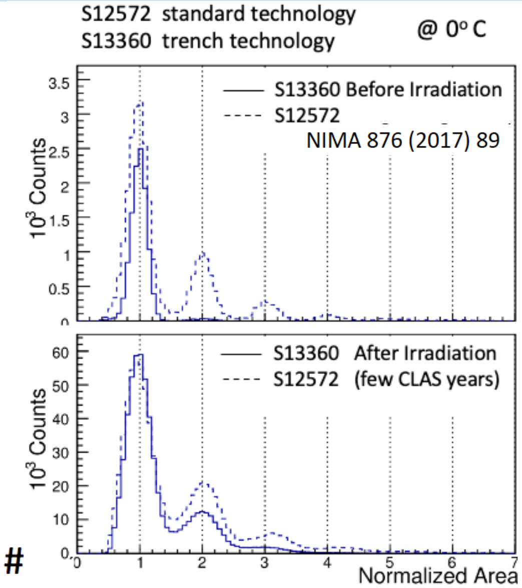
Contalbrigo++ NIMA 766 (2014) 22, Balossino ++ NIMA876 (2017) 89



SiPM and Electronics







EIC Detector Advisory Committee, Report on dRICH 11/25/2019

"An important remaining issue is the SiPM noise rate after irradiation which should be clarified. We expect that it will take 2-3 years to fully understand if SiPMs can be used in RICH detectors at EIC"

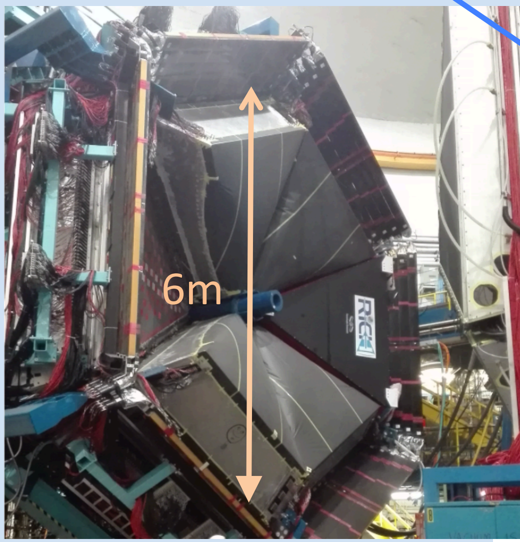
EIC Detector Advisory Committee, Report on Electronics 01/30/2020

"The committee again recommends the group to re-examine options that do not rely on waveform sampling […] which is radiation hard, has low power consumption and has achieved a very good resolution per single photon with SiPMs."

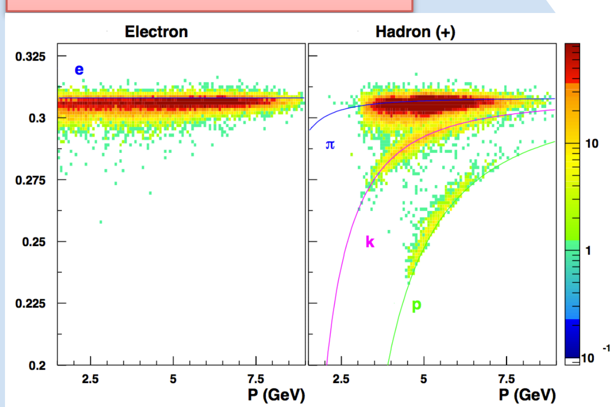
INFN Groups and eRD14

Several INFN groups interested to pursue dRICH and other activities within the eRD14 Consortium

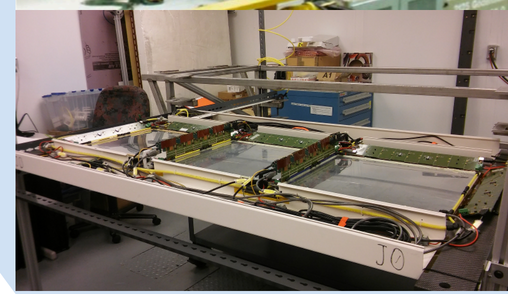
INFN-FE
CLAS12 RICH



INFN-LNF
CLAS12 RICH



INFN-RM1
HERMES RICH
Hall-A Tracking



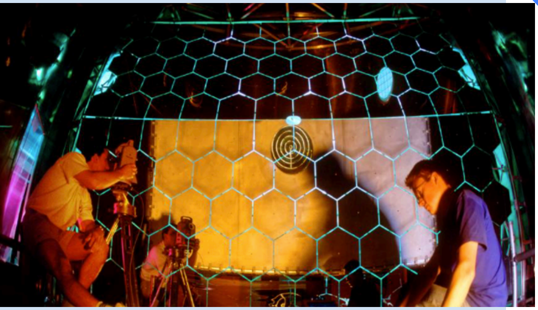
INFN-CT
Hall-A HCAL

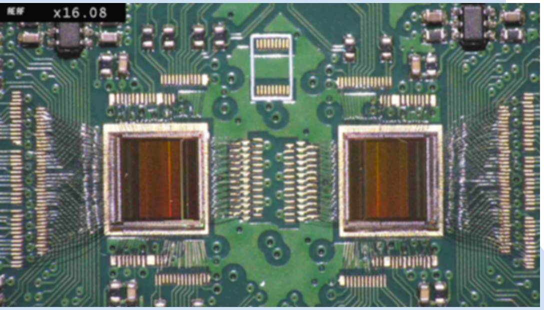
INFN Groups and eRD14

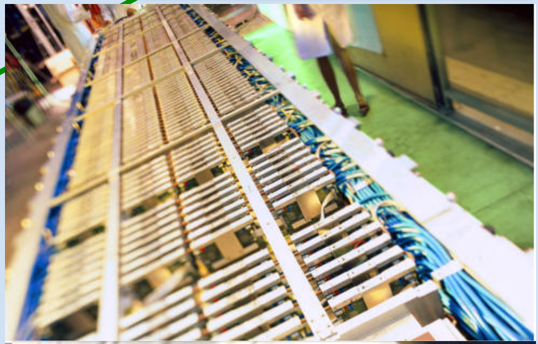
INFN-TO
COMPASS RICH F-E
DARKSIDE F-E

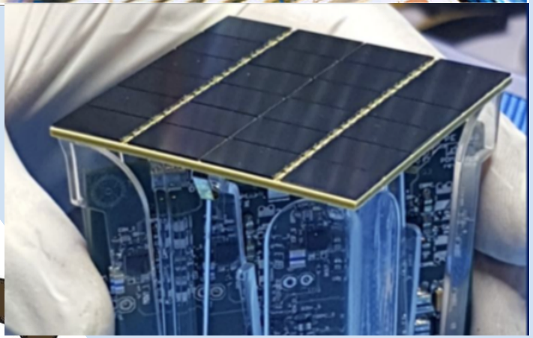
Several INFN groups interested to pursue dRICH and other activities within the eRD14 Consortium

INFN-BO
ALICE TOF
DARKSIDE SiPM









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 samples for the study of

- SiPM use for Cherenkov application prior of irradiation
- SiPM single photon counting as a function of radiation dose

Short term goal (~ 1 year):

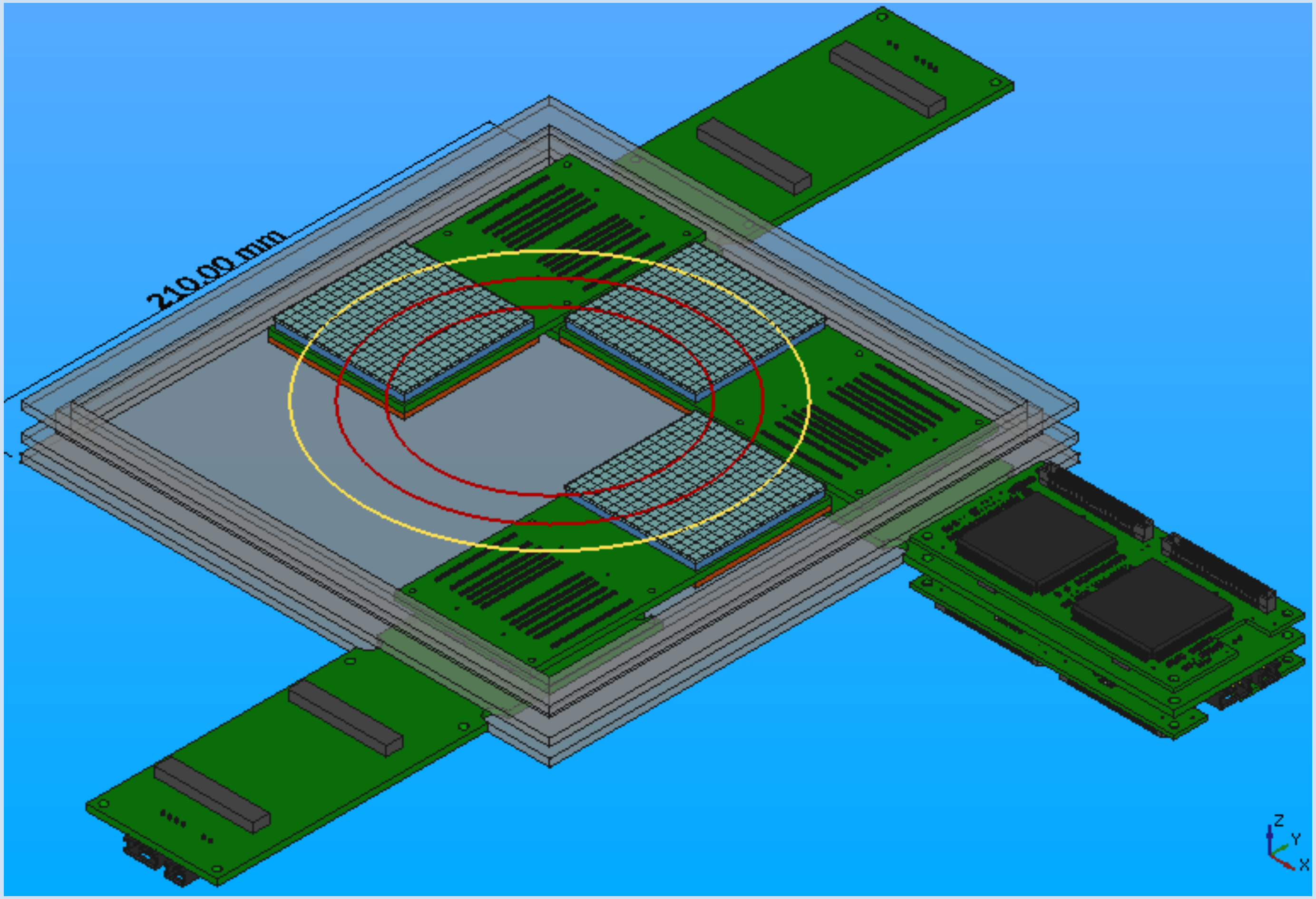
- Survey of SiPM available candidates
- Use in-house dedicated electronics (for cooled SiPM + annealing)
- SiPM use for Cherenkov application post (EIC-like) irradiation (proof-of-principle)

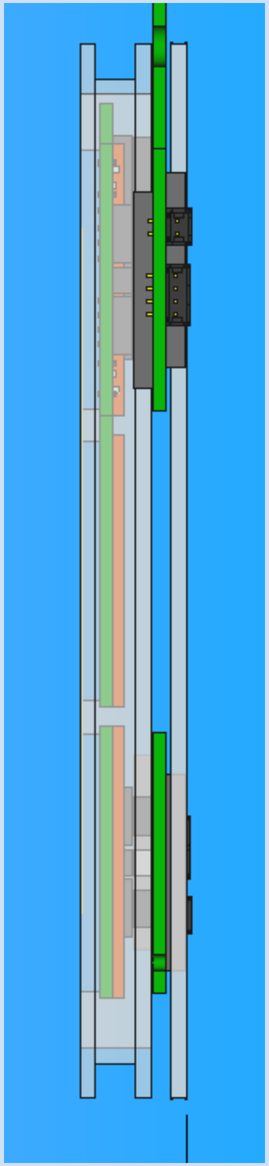
Long term plan (~2-3 years):

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

dRICH – MPPC Readout Box

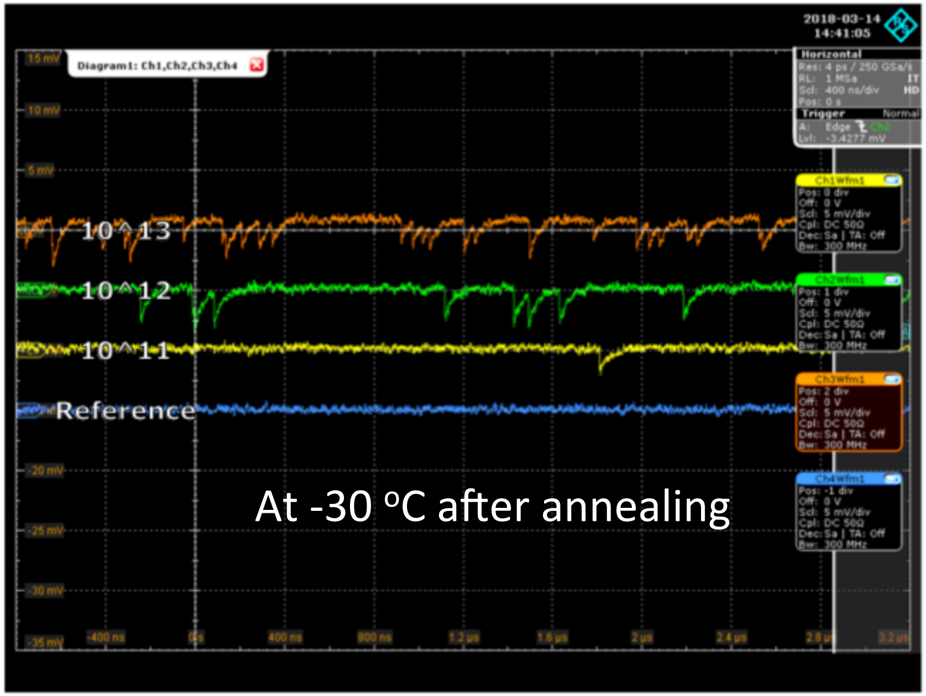
House the same principles and readout units used for mRICH test-beams
Compatible with 16x16 MPPC Hamamatsu matrices + MAROC front-end
Allows to study the SiPM performance (large area) vs temperature

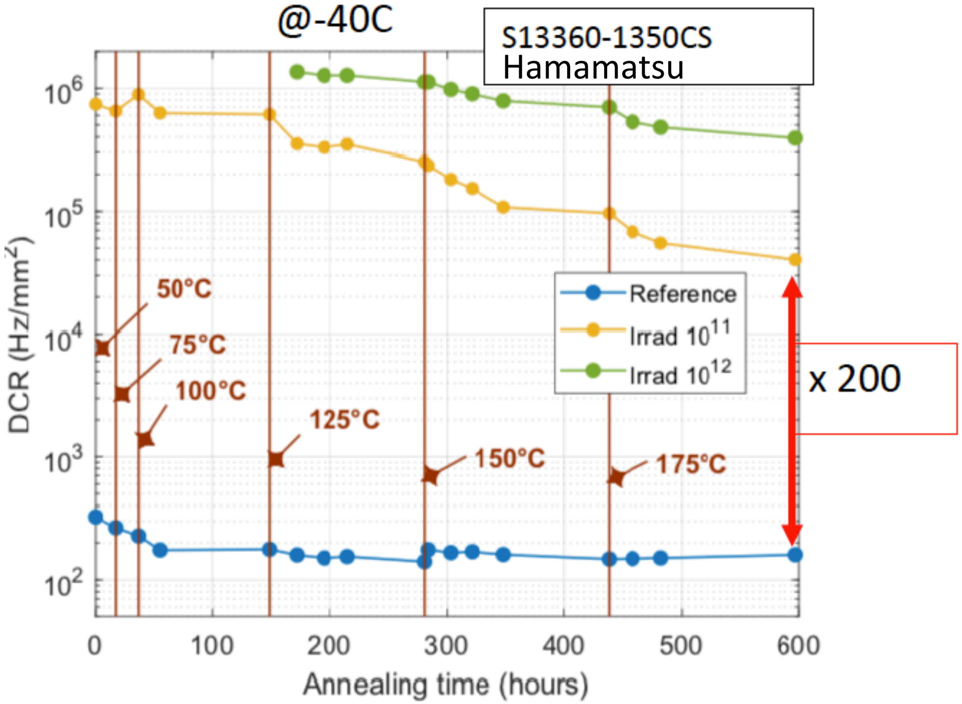




SiPM Radiation Damage

M. Calvi et al.
Nuclear Inst. and Methods in Physics Research, A 922 (2019) 243–249

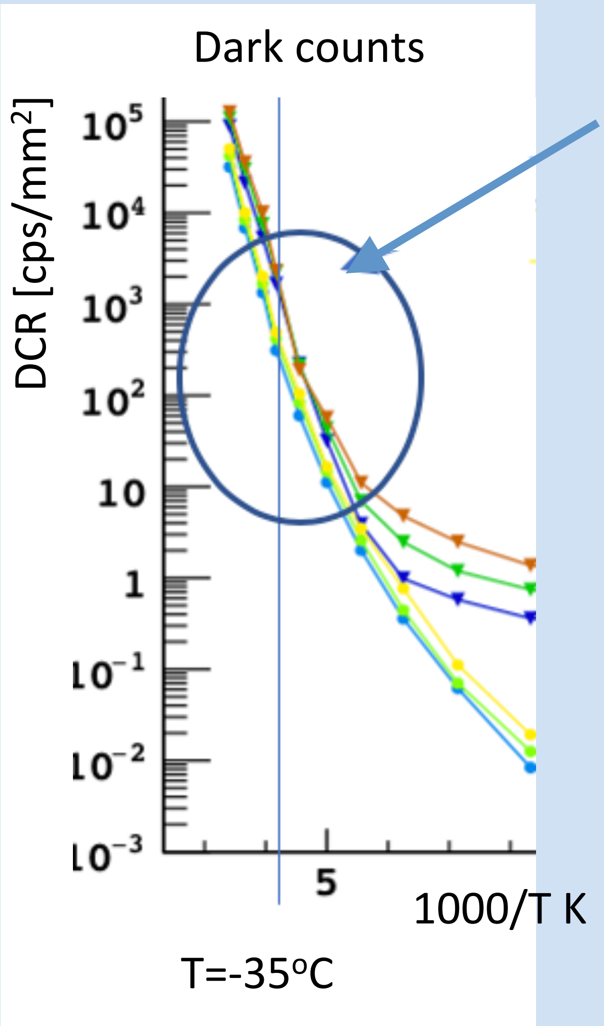




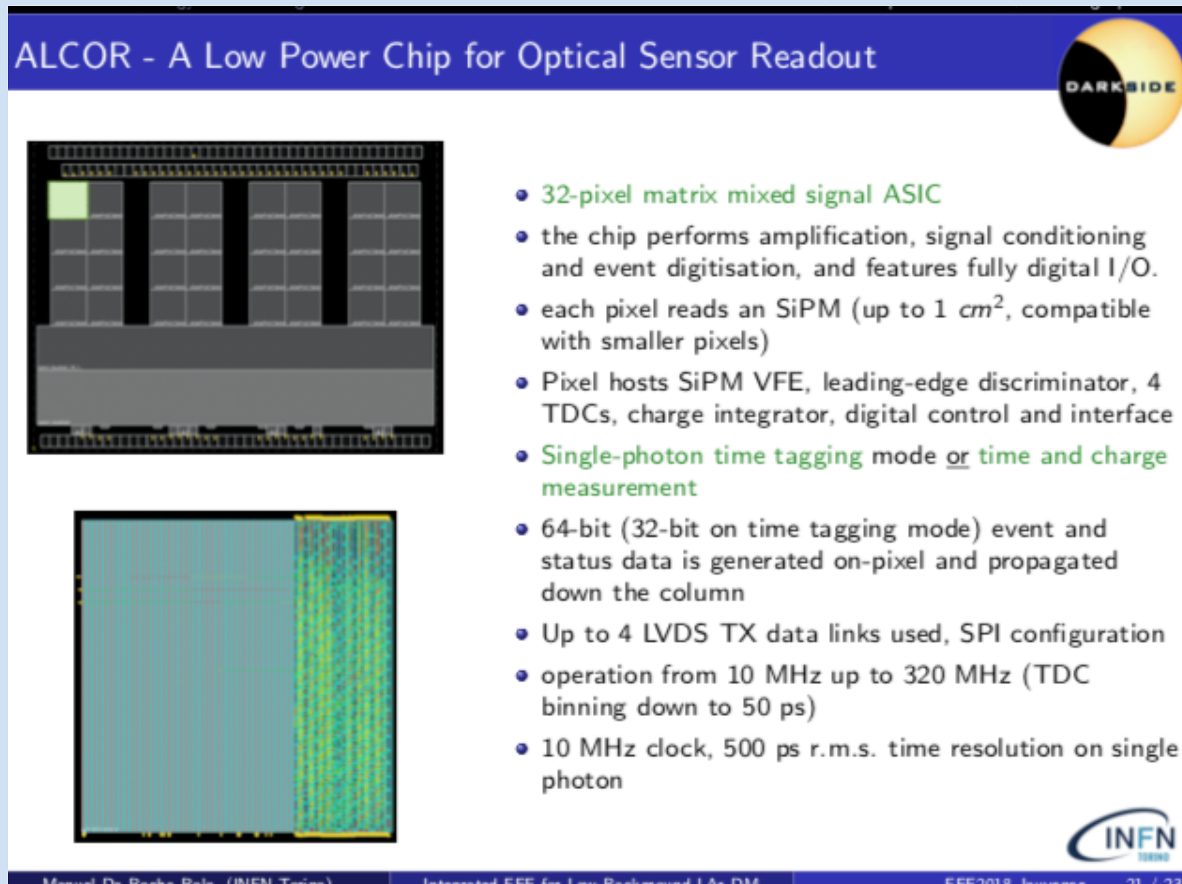
- SPD looks possible at -30°C/-40°C after annealing!
- 10^{11} seems a manageable fluence for annealing
- DCR penalty factor (pre-irradiation – post-annealing)@10^{11}: **200**
- Further lowering temperature is another option to explore
- Note, however, that with a 200 penalty factor we would have a $2 \cdot 10^5$ Gbit/sector throughput, still manageable... (and close to what "declared" @Temple)

SiPM Irradiation Program

Post-irradiation use: conjugate proper temperature conditioning and signal processing



Temperature control and dedicated electronics
Low-temperature discrimination + possible filtering



SiPM Candidates Survey

Hamamatsu (a sort of reference), Broadcom/FBK (a sort of 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					

Irradiation Tests

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

- various producers
- different n_{eq} integrated dose (cm^{-2})

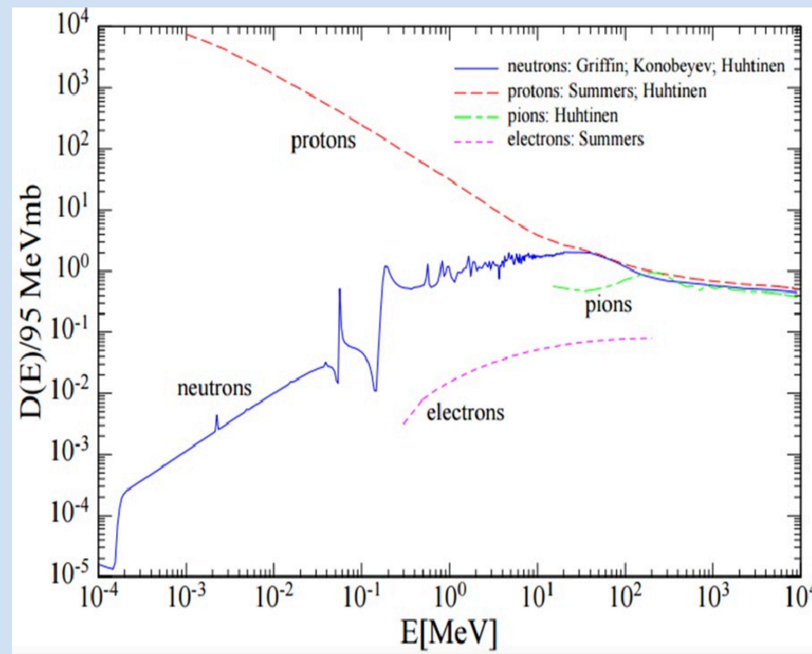
0	e9	e10	e11

- alternative designs (microcell size, quench resistor, wavelength range, …)

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

20	20	20	20
20	20	20	20
20	20	20	20
20	20	20	20
20	20	20	20
20	20	20	20
20	20	20	20
20	20	20	20

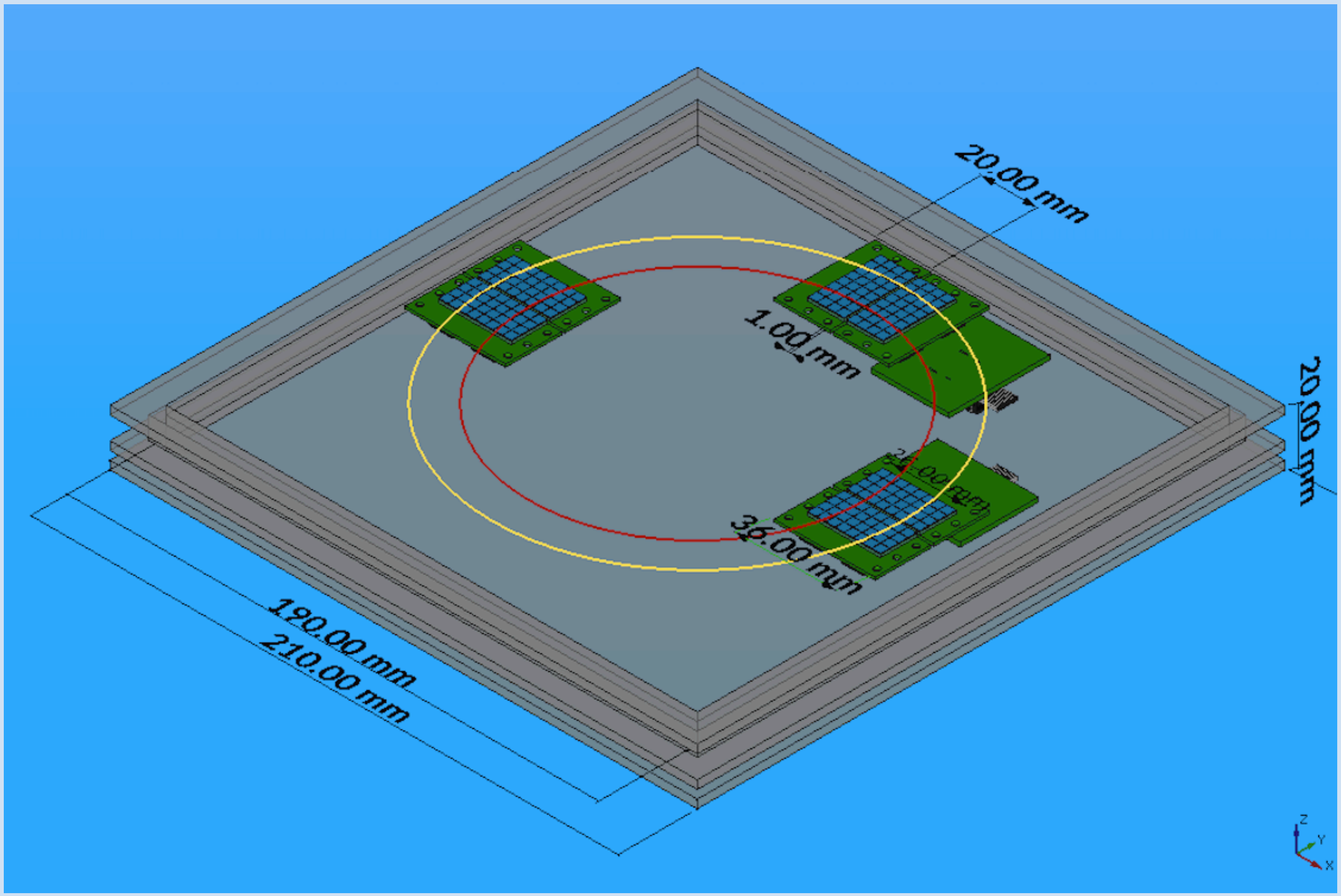
30	30	30	30
30	30	30	30
30	30	30	30
30	30	30	30
30	30	30	30
30	30	30	30
30	30	30	30
30	30	30	30

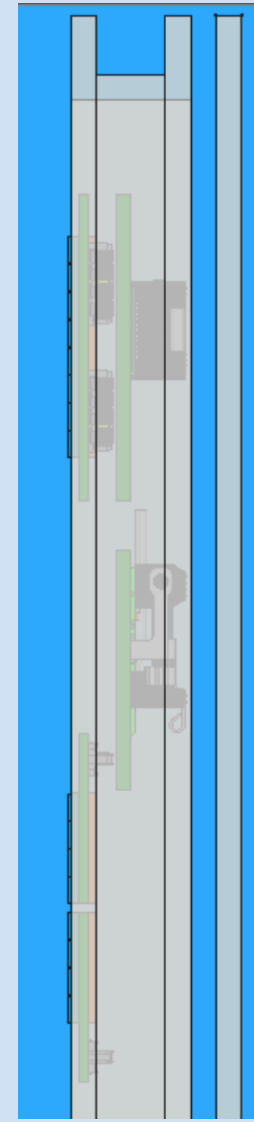


Designed to be used for irradiation tests and at test-beams after irradiation

dRICH – SiPM Readout Box

House the same principles and readout units used for mRICH test-beams
Compatible with 8x4 SiPM matrices + ALCOR front-end
Allows to study the SiPM performance after irradiation





Activity Plan & Deliverables

As discussed with the EIC R&D Committee in September 2019

✔ Ongoing

✔ In preparation

2020

✔ Prototype design, simulation and implementation

✔ Basic mechanics Electronics adaptation

✔ Component test and selection

✔ Start of INFN funds

2021

✔ **Basic prototype**

- basic tracking
- 1 radiator choice
- commercial mirror
- reference readout

✔ **Beam Test 1**

- MA-PMTs, SiPMs
- proton beam
- critical aspects

✔ **Optical components**

- test and selection

✔ **SiPM program**

- radiation tolerance
- and cooling program

Conclusions

INFN has developed a plan to address the EIC R&D Committee recommendations

To address crucial PID aspects at EIC:

cost-effective compact solution for
hadron PID in the forward region in a wide kinematic range

investigation of novel single-photon detector solution
to be operated in high magnetic field

Goal: have in one year a full-chain assessment (proof-of-principle) of the proposed approach and investigated technologies

A mandatory step for INFN and eRD14
given the YR, EoI and announced Call for Detectors in FY2021

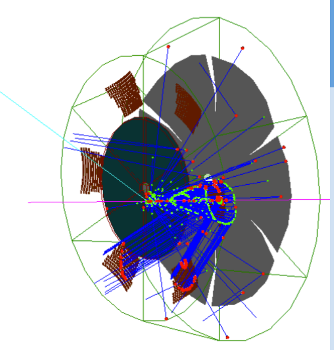
Backup

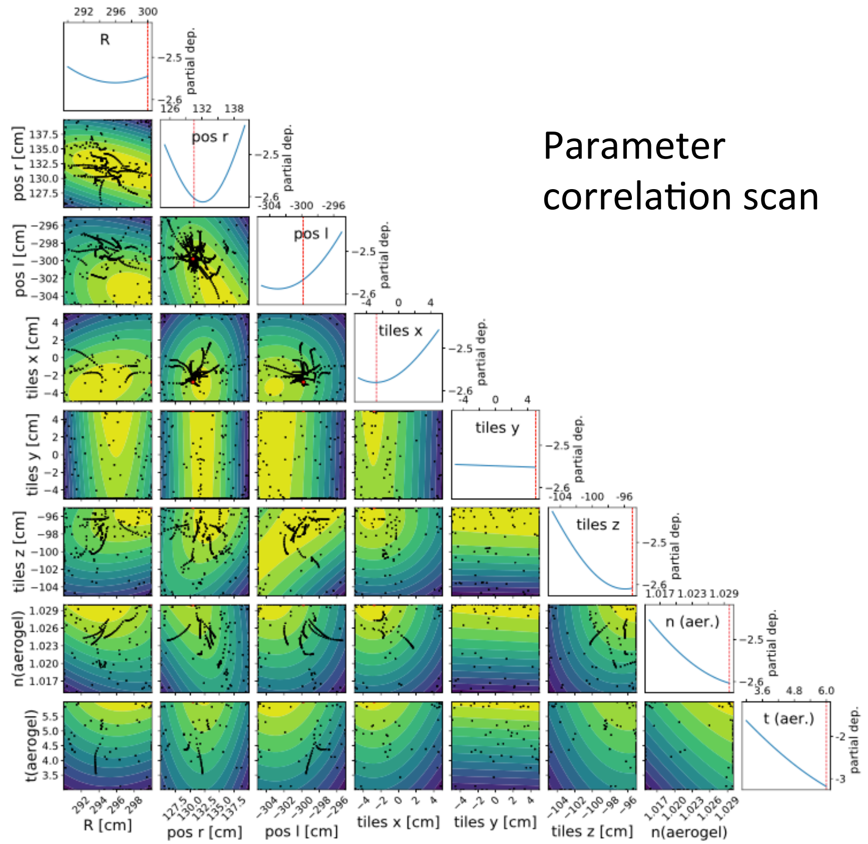
dRICH Performance Optimization

AI-optimized detector design for the future Electron-Ion Collider: the dual-radiator RICH case

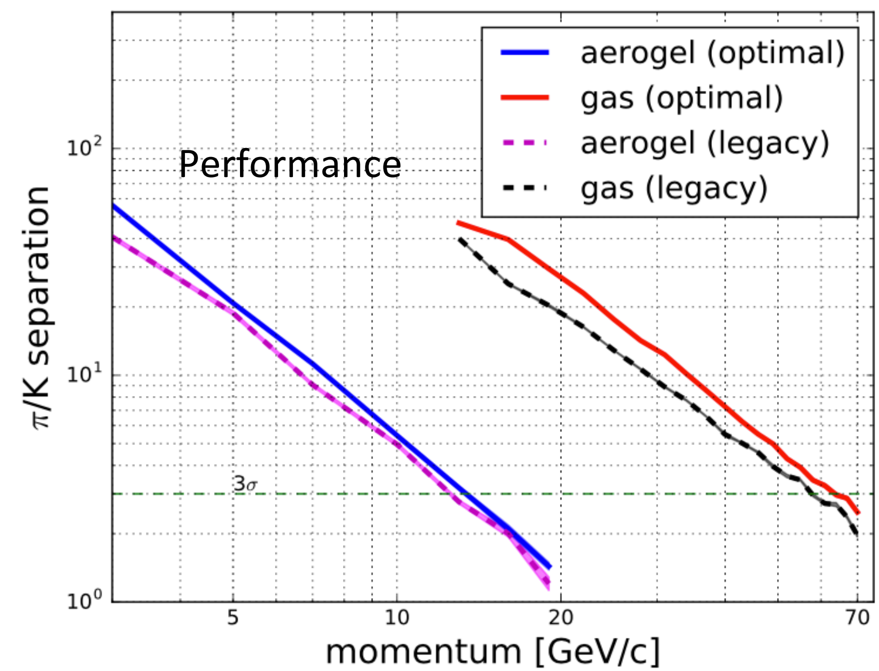
E. Cisbani[1,2] A. Del Dotto[3] C.Fanelli[4,5,*] …

JINST 15 (2020) 05, P05009





Parameter correlation scan



An efficient way to re-optimize relevant parameters and consolidate the performances of the dRICH once we have prototype test results