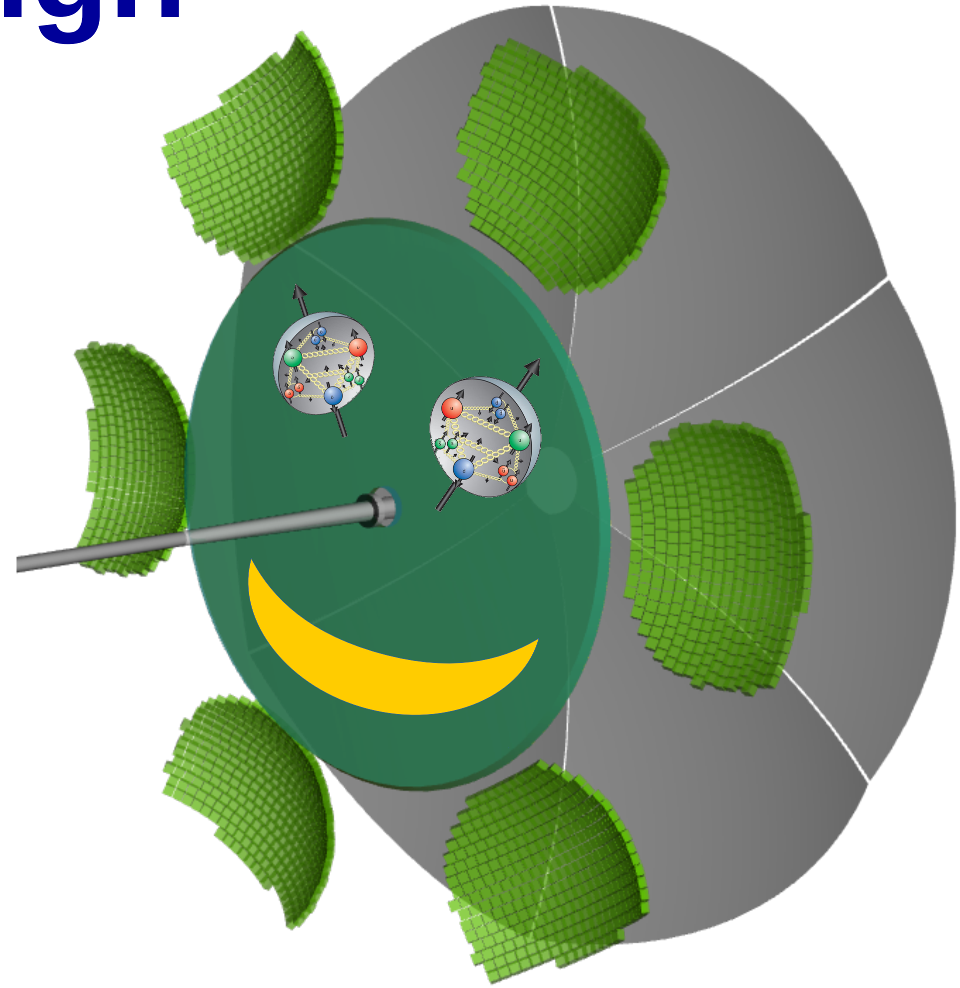
AI-inspired methods for experimental equipment design



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EIC-eR&D14 PID consortium

INFN/EIC-NET

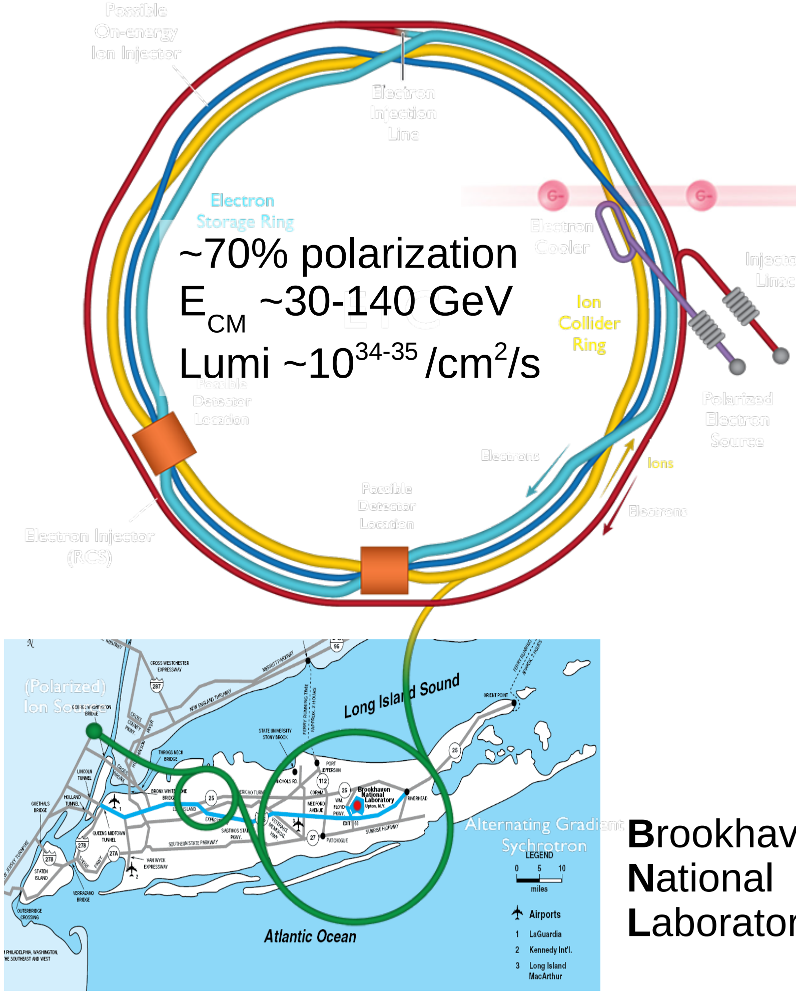
INFN-Roma, 06/Mar/2023

(Original) Physics Context

Activity triggered by the **Electron-Ion Collider** eR&D14

QCD

EIC : *“A Machine that will unlock the secret of the strongest force in Nature”*



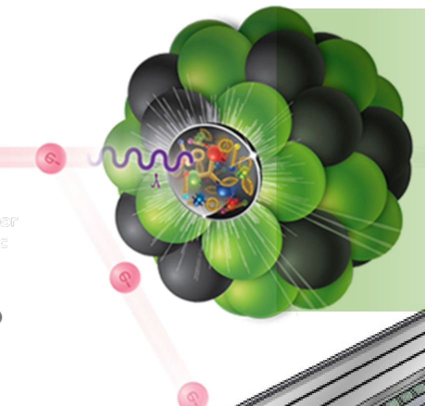
~70% polarization

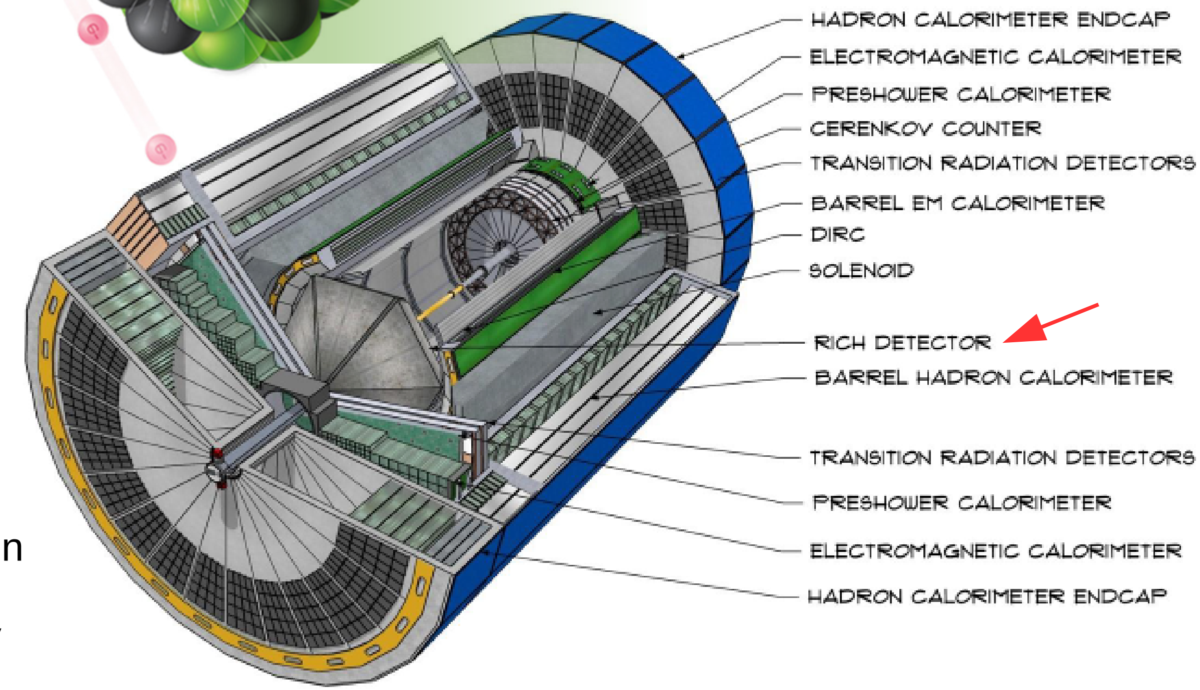
E_{CM} ~30-140 GeV

Lumi ~10^{34-35} /cm^2/s

Brookhaven **N**ational **L**aboratory

https://eicug.org/





… Conceptual Design	Design	Construction	Installation, Test and Commissioning

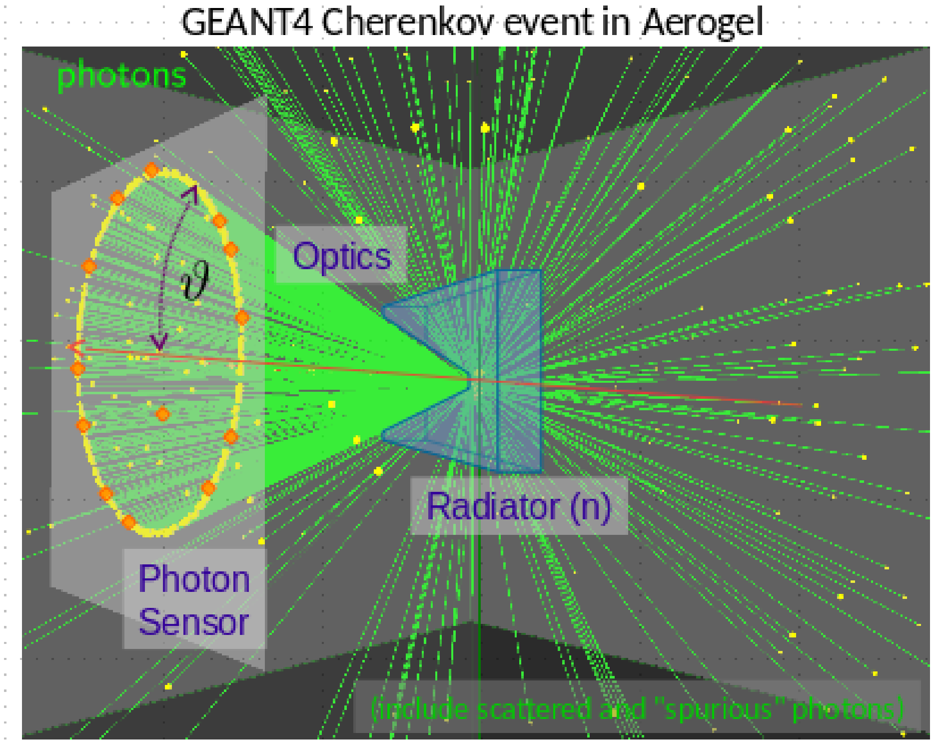
…	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034

Ring Imaging Cherenkov = Particle Identification detector

RICH principle

Charged particle traversing a material (with **n(λ)** refractive index) at speed **v>c/n** emits photons on a cone surface with specific angle **ϑ** depending on **v** and **n: cosϑ = c/[n(λ)v]**

Measuring **ϑ** → **v** → **mass** (particle type) when momentum is known from other detectors



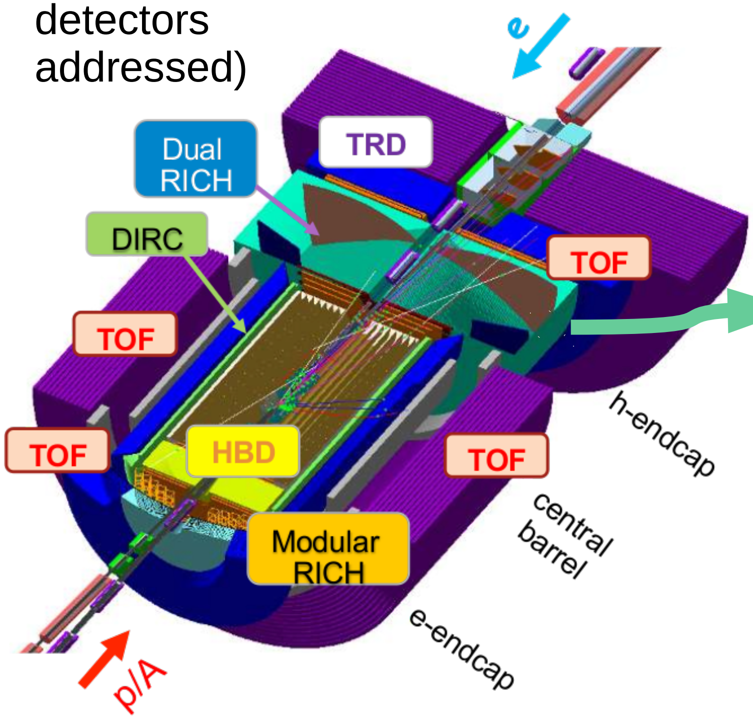
RICH design - rules of thumb:

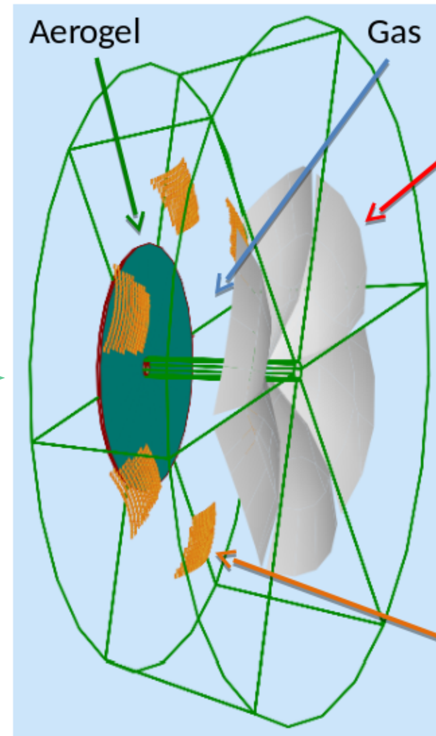
- Select **radiator**(s) to cover the desired particle range of momenta
- Choose and tune the proper **optics**: focus parallel photons, minimize wavelength dependence, ...
- Identify the **photon position detector**, e.g. high Quantum Efficiency matching the relevant Cherenkov spectrum

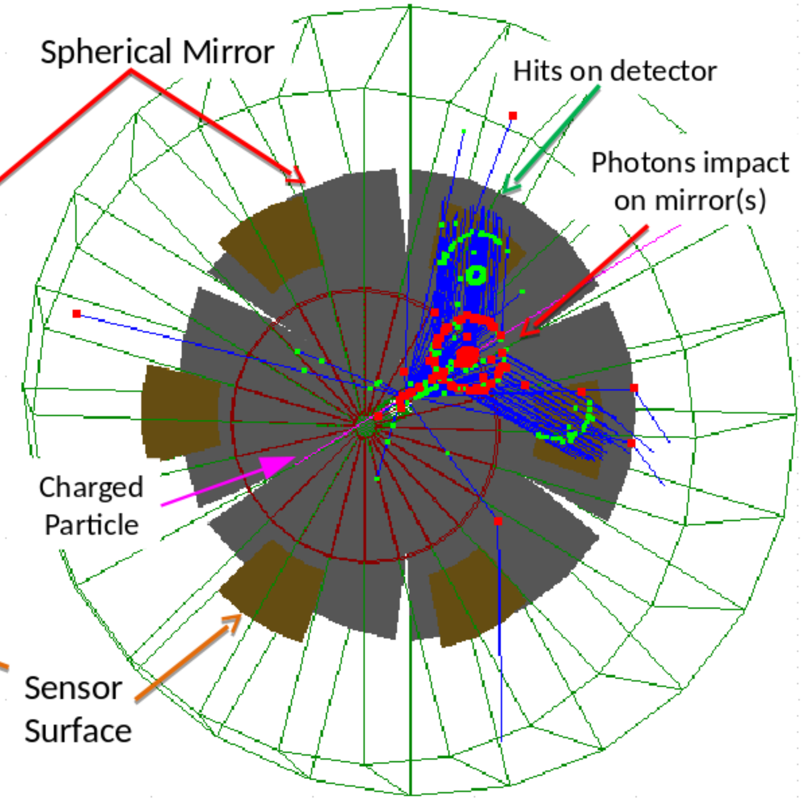
Require intensive simulation and prototyping, and many parameters involved

EIC-eRD14/PID **dual radiator RICH**

EIC spectrometer concept (only PID detectors addressed)







dRICH applicable momenta:

- **hadrons (π/K/p) from 3 to 50 GeV/c**
- (byprod.) electron up to ~15 GeV/c

Radiators: **Aerogel**: n~1.02 + **Gas**: n~1.0008

6 Identical Open Sectors (Petals):

- Large Focusing Mirrors with R ~2 m
- Optical sensors: ~3500 cm^2/sector, 3 mm pixel size

A. Del Dotto et al., "Design and R&D of RICH detectors for EIC experiment", NIM A876 (2017) 237-240

MO-Optimizer Framework

System (dRICH) defined by a set of (decision) variables **X**={x_i}, i=1,...,n (design space)

The set **X** may have bounds and constraints g_j(**X**)=b_j, with j=1,…,m

parameter	**description**	**range** [units]
R	mirror radius	[290.0,300.0] [cm]
pos r	radial position of mirror center	[125.,140.] [cm]
pos l	longitudinal position of mirror center	[-305.,-295.] [cm]
tiles y	shift along y of tiles center	[-5,5] [cm]
tiles z	shift along z of tiles center	[-105,-95] [cm]
tiles x	shift along x of tiles center	[-5,5] [cm]
$n_{aer.}$	refraction index of aerogel	[1.015,1.03]
$t_{aer.}$	aerogel thickness	[3.0,6.0] cm

optimal system
minimize (or maximize)
a set of objective functions
f_k(**X**), k=1,…,p

$$N\sigma = \frac{\| \langle\theta_K\rangle - \langle\theta_\pi\rangle \| \, N_{pe}}{\sigma_\theta}$$

Realistic model (e.g. Monte Carlo validated by literature and prototype tests) ***time consuming computation***

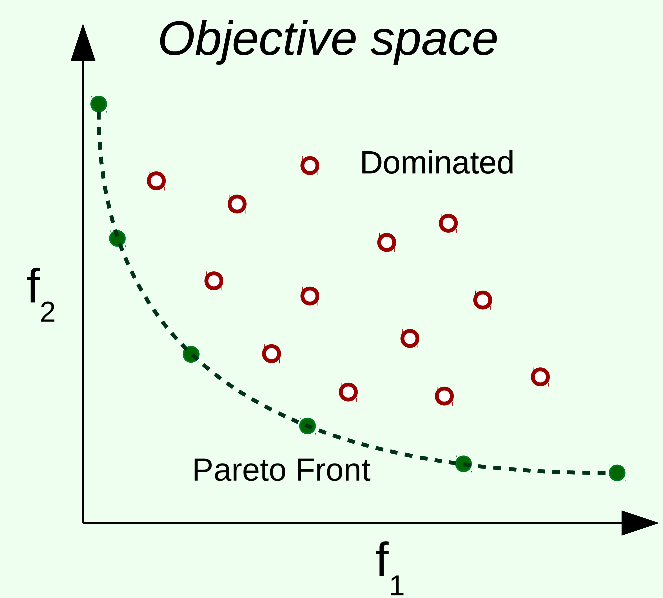
Multi-Objective Optimizer

Some optimization approaches:

- Bayesian Optimization
- Evolutionary Algorithms
- AI-driven model/Digital Twin + ML

→ **dRICH**
→ Tracker
→ Calorimeter

https://eic.ai/

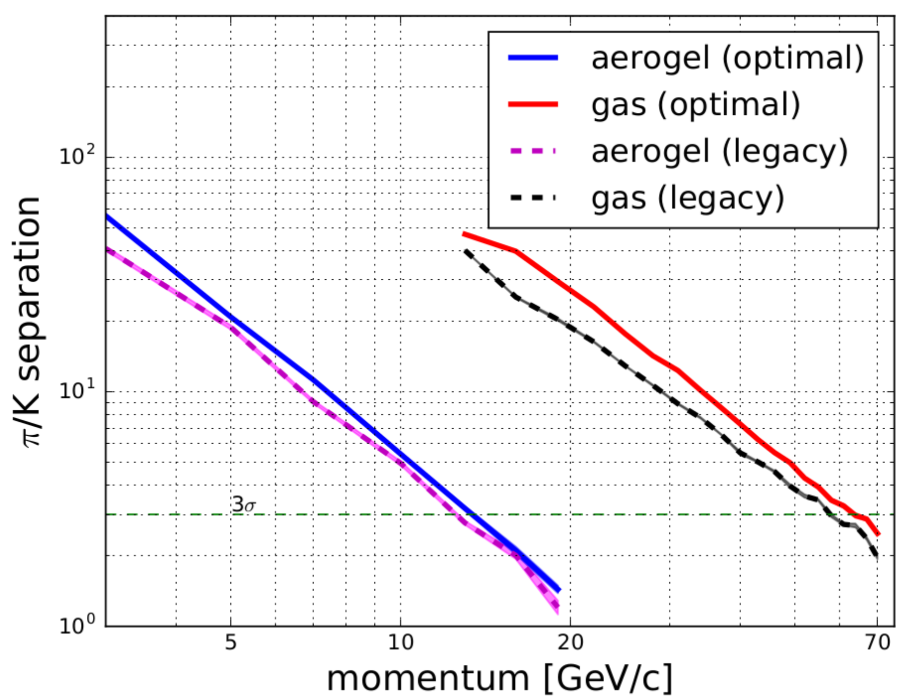


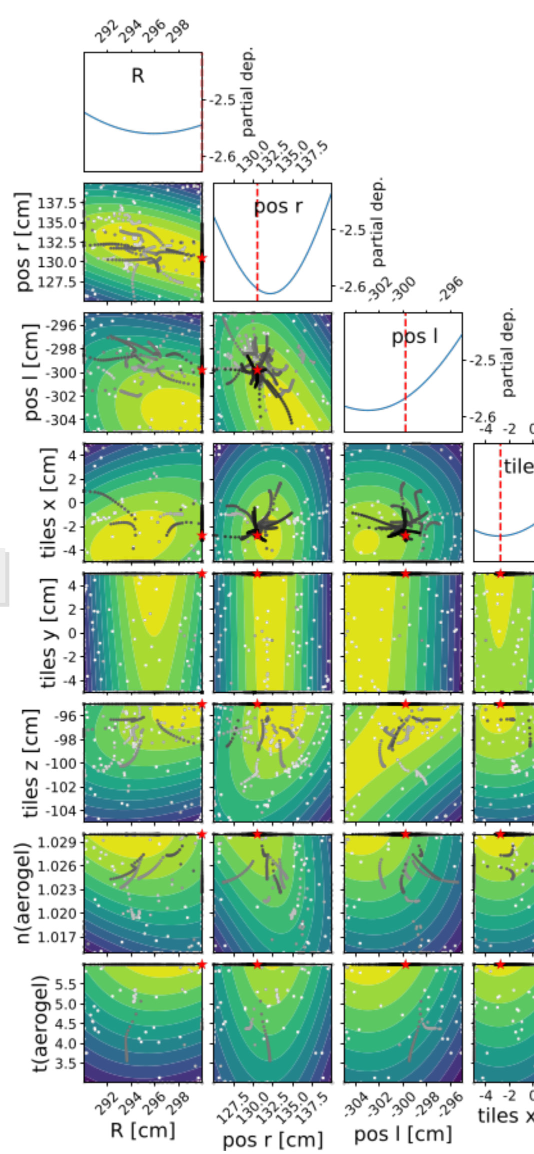
Trade-off solution
on the Pareto Front that corresponds to the design space where any objective function cannot be further improved without affecting the others

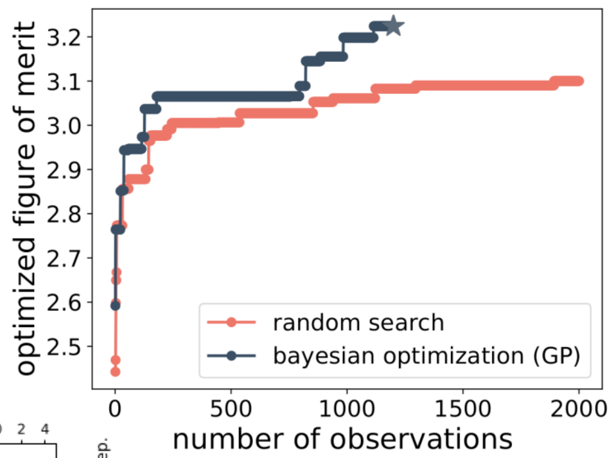
Bayesian Optimization - dRICH use case

1. Model the “black box” figure of merit (expensive to compute, derivative is unknown) as probability distribution → the prior (cheap to compute, surrogate model)
2. Apply Bayes inference to get the posterior which better approximate the “black box”
3. Use a strategy (acquisition function) to choice next design point to be evaluated
4. Iterate sequential evaluation of design points

http://krasserm.github.io/2018/03/21/bayesian-optimization/







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

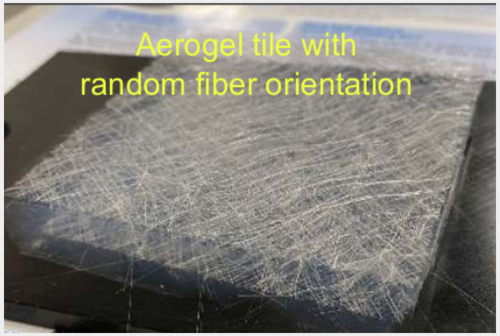
Next applications of MO-Optimization

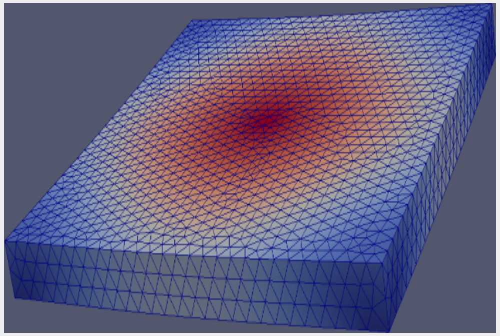
Development of composite aerogel Cherenkov radiator

- aerogel has exceptional properties (e.g. n~1.03, ρ~0.15 g/cm^3) but poor mechanical characteristics (e.g. brittleness), making it difficult to handle
- Mechanical strength can be improved by introducing fibers into the aerogel (composite aerogel) at the cost of worsening the optical properties

→ Find optimal trade off between number of fibers, size, distribution and optical aerogel performances

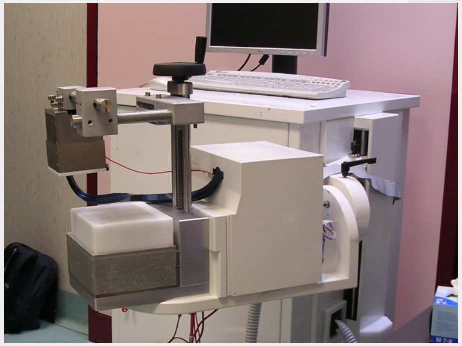
- combine FEM (Elmer), Cher. simulation (Geant4) and Bayesian Optimizer

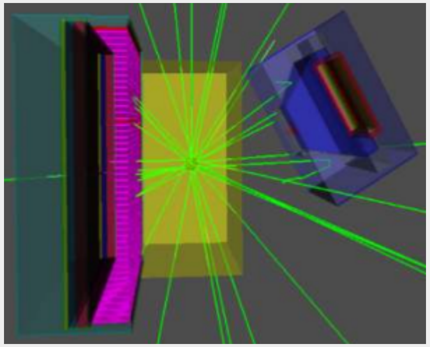




Scintimammography for early breast cancer diagnosis

- asymmetric dual head detectors with limited angle tomographic capability





→ Define and implement a prototype system driven by automated optimization which maximizes detectability and minimizes absorbed dose

Available PhD grant on “Ricerca e sviluppo di un dispositivo nell'ambito dell'imaging diagnostico con radionuclidi per diagnosi precoce del tumore alla mammella”, department of Basic and Applied Sciences for Engineering (deadline 20/Mar/2023)
https://www.uniroma1.it/it/pagina/dottorati-di-ricerca