Radiation hardness study of optical glasses for the DIRC technology

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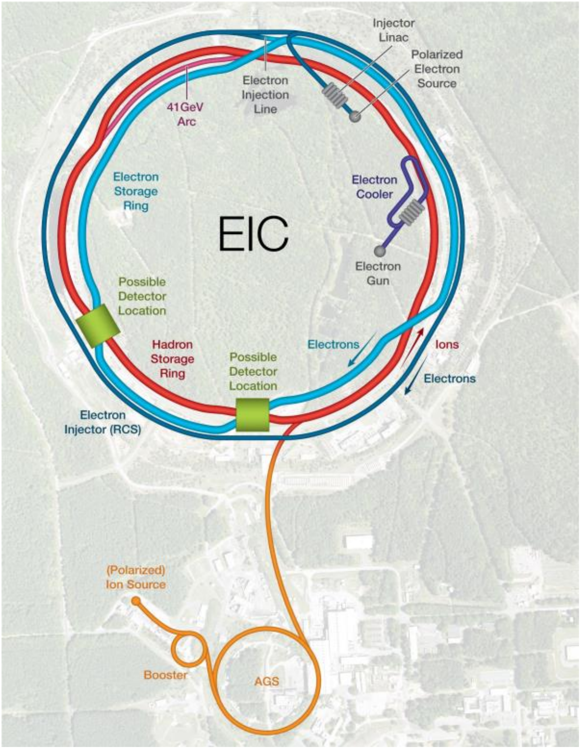
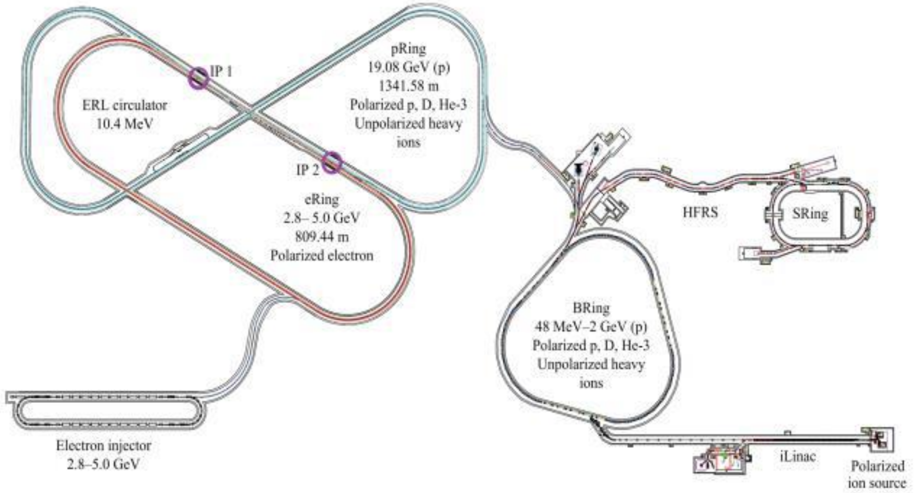
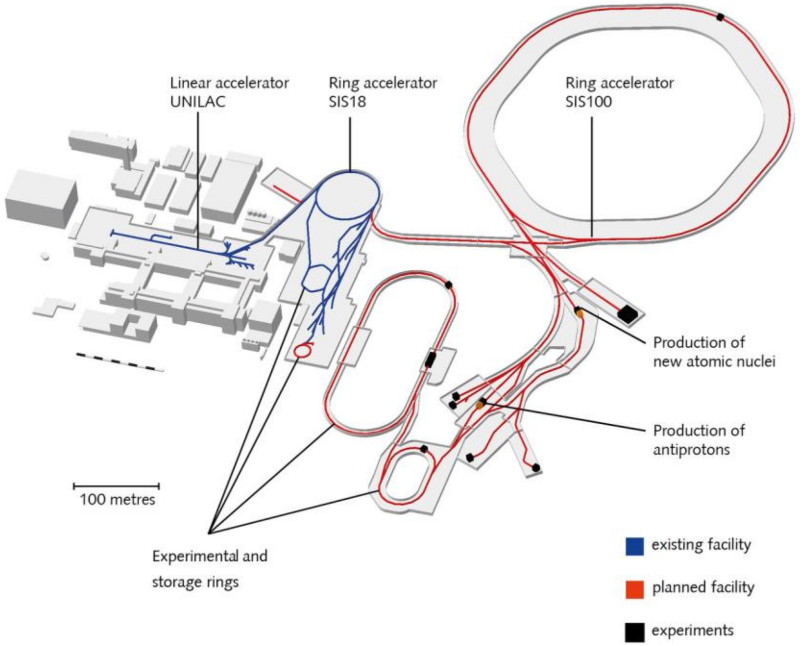
Future high-energy collider facilities



EIC (USA)



HIAF + EICC (China)



FAIR (Germany)

A high luminosity (10^{33} – 10^{34} $cm^{-2}s^{-1}$) polarized electron proton / ion collider with $\sqrt{s_{ep}}$ = 28 – 140 GeV

Luminosity of EicC is up to 2.0 x 10^{33} $cm^{-2}s^{-1}$ (for proton),
$\sqrt{s}$ = 15 - 20 GeV

Species: anti-protons, p to U
Design beams:
- U^{28+} 4 x 10^{11}, 1.5 GeV/u
- protons 2 x 10^{13}, 29 GeV

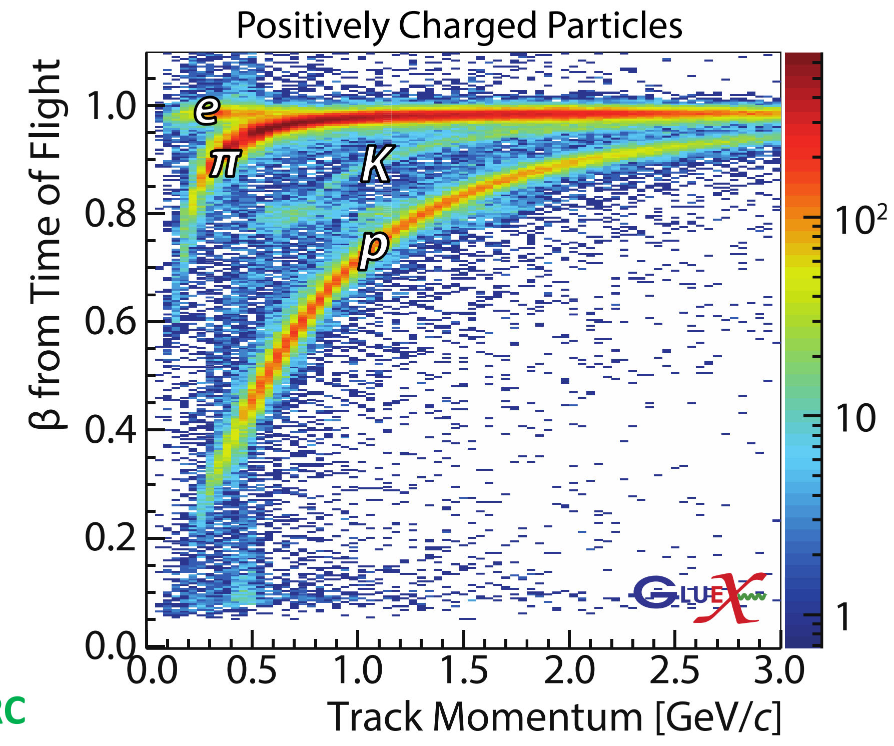
Charged particle identification

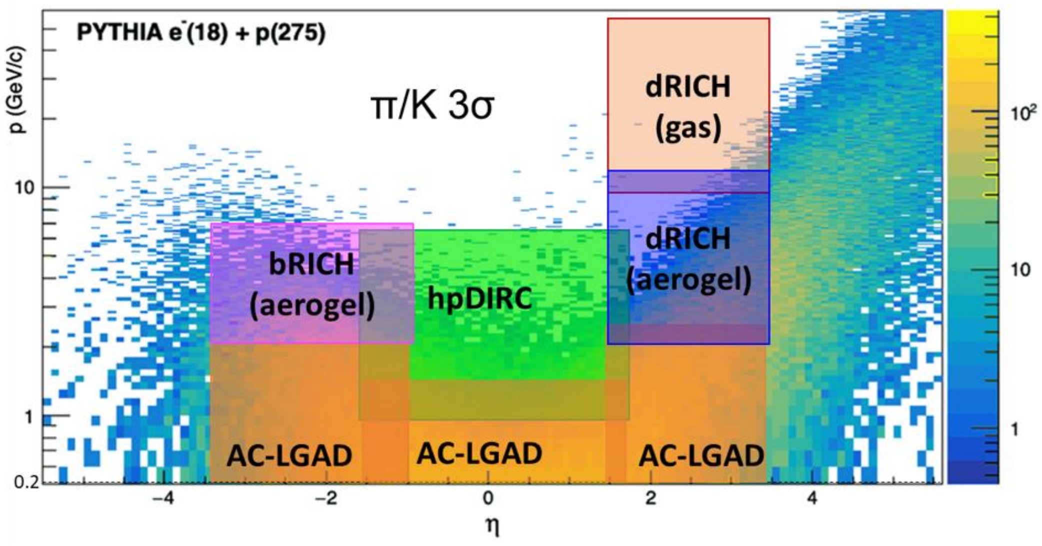
Momentum range up to several GeV/c (π/K up to 6 GeV/c at EIC)

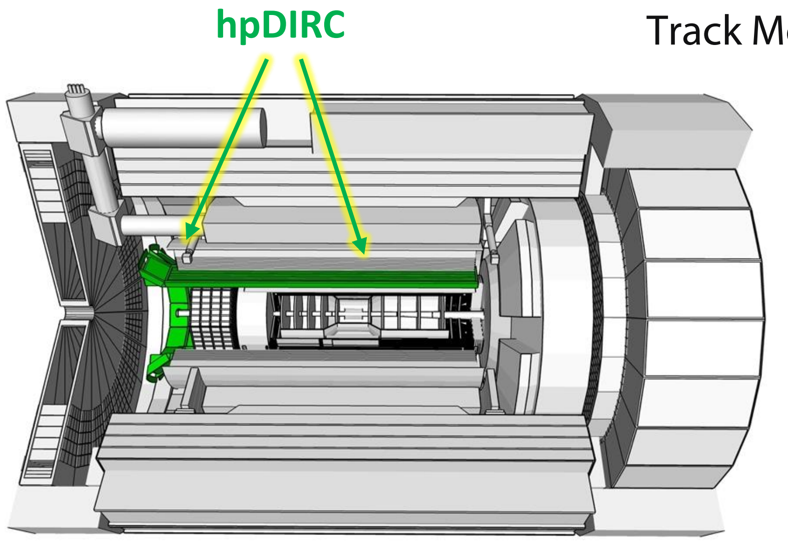
Large phase space

Need K-π and e-π separation

Cherenkov detectors: RICH and **DIRC**

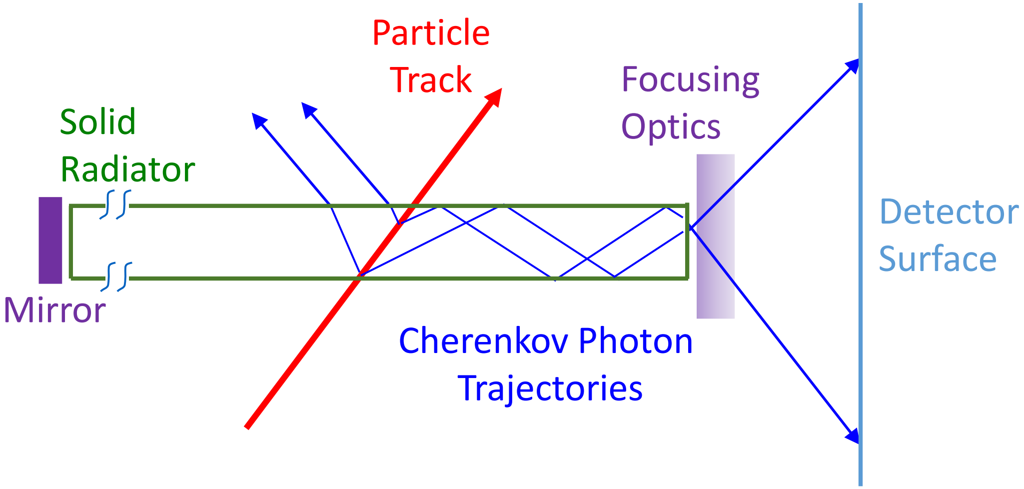


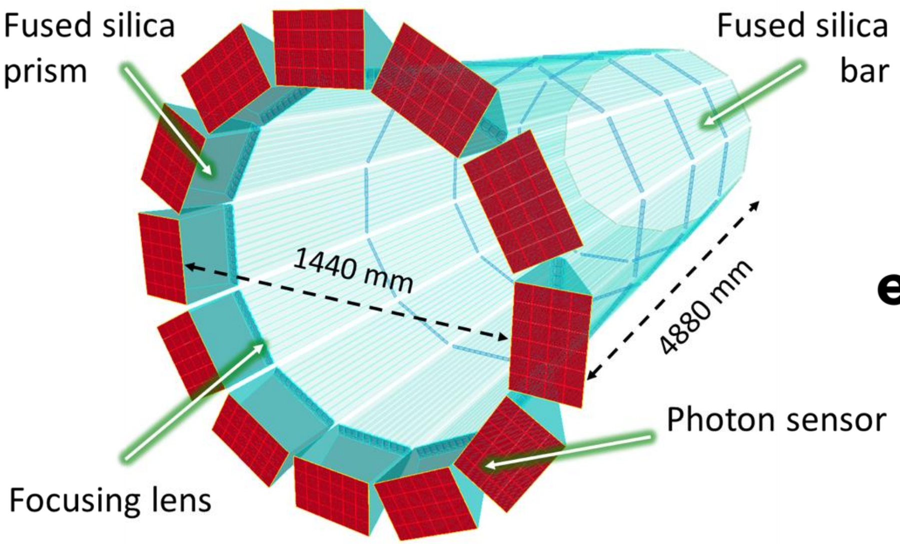




3D model of ePIC central detector

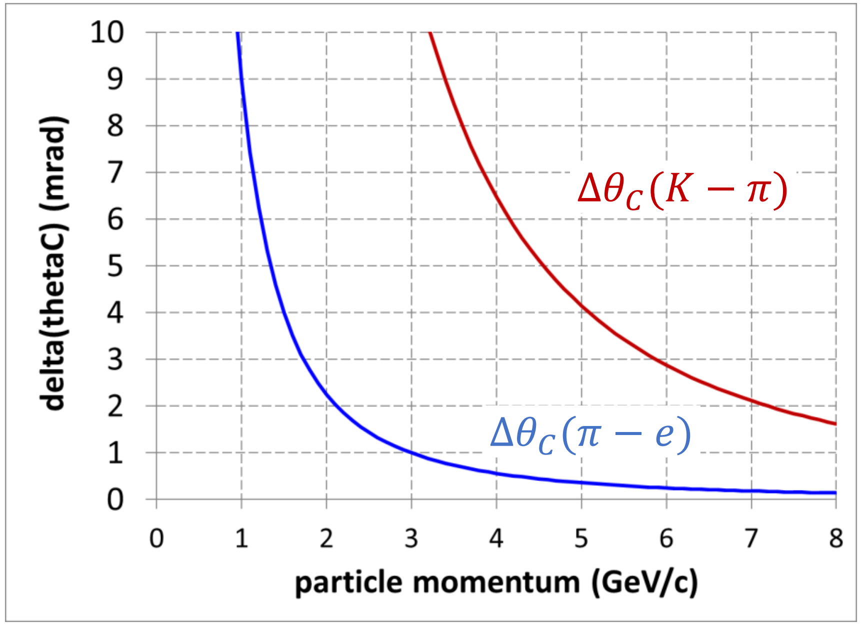
DIRC principles





- Fused silica radiator is used also as light guide
- Cherenkov angle is conserved during internal reflections
- **Cherenkov angle** at origin can be reconstructed from measured x, y, and time of photons that exit radiator.

DIRC performance



PID performance largely driven by track Cherenkov angle (θ_C) resolution.

Required resolution defined by refractive index of radiator.

Example: π/K separation in synthetic fused silica <n>≈1.473

→ 2.9 mrad π/K difference in θ_C at 6 GeV/c;

→ need ~1 mrad resolution per particle for 3 s.d. separation.

How to improve DIRC performance:

Smaller track angular error (better tracking detector)

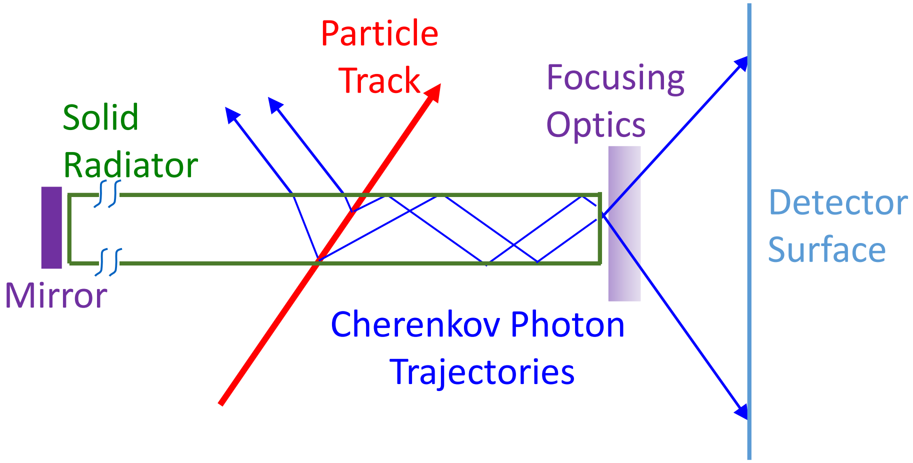
Higher photon yield (modern sensors with better PDE)

Improve Cherenkov angle resolution per photon

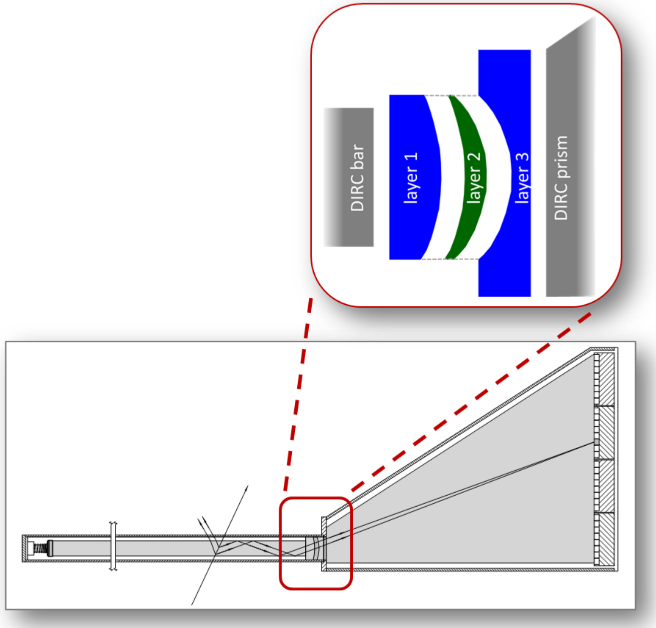
size of bar image -> focusing optics

size of PMT pixel -> smaller pixel size

chromaticity (n=n(λ)) -> e.g. achromatic focusing



Focusing is one of the current DIRC challenges

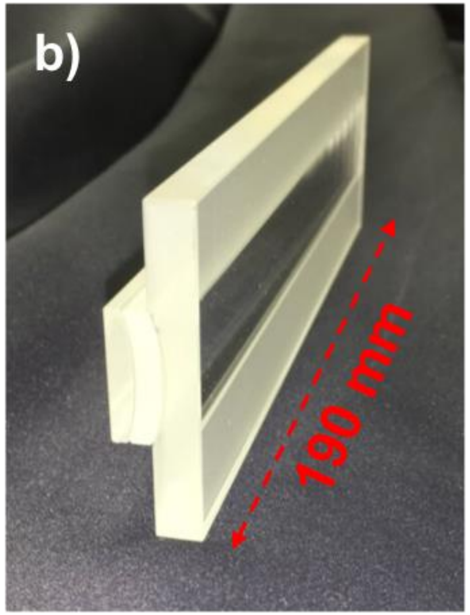


layer of high-refractive index material

(focusing/defocusing)

sandwiched between two layers of

fused silica



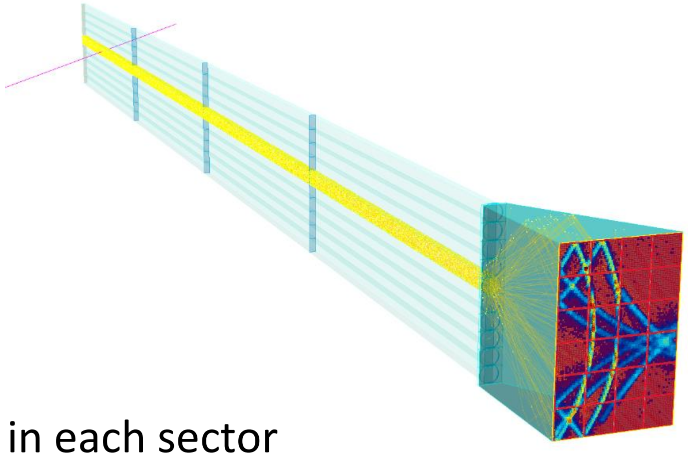
- 3-layer compound lens (without air gap):
- Creates flat focal plane – matched to fused silica prism shape
- Avoids photon loss and barrel PID gap
- Detailed radiation-hardness studies performed with ^{60}Co source, neutron irradiation next
- Lanthanum crown glass (LaK33B) for PANDA, rad-hard sapphire or PbF_2 for EIC
- Industrial fabrication of lenses demonstrated
- Performance of spherical 3-layer lenses validated with PANDA Barrel DIRC prototype

Need to study radiation-hard materials with high refractive index

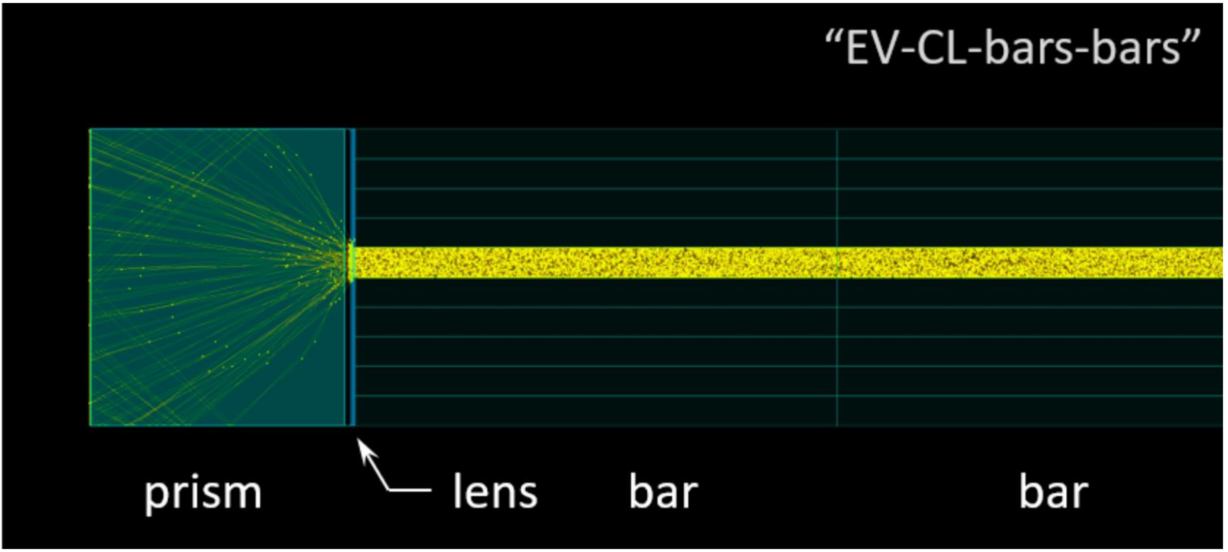
Industrial fabrication of compound achromatic multilayer lenses needs to be investigated

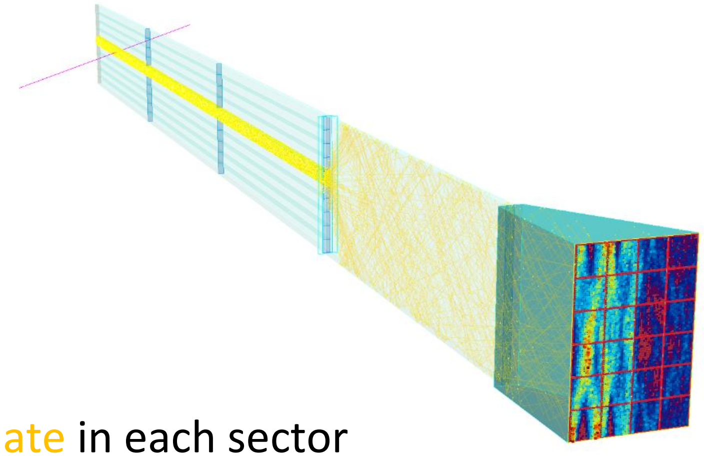
Alternative DIRC design

- ePIC detector barrel length requires additional “light guide” section to connect BaBar DIRC bars to prism
- Alternative to baseline (narrow bars) is one single short wide plate

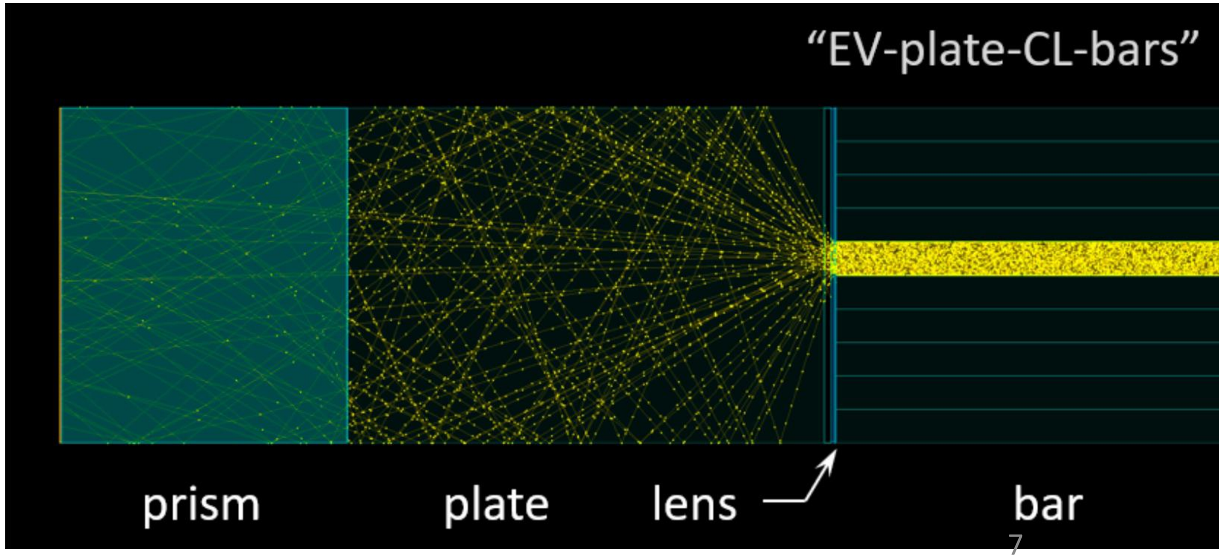


Only narrow bars in each sector

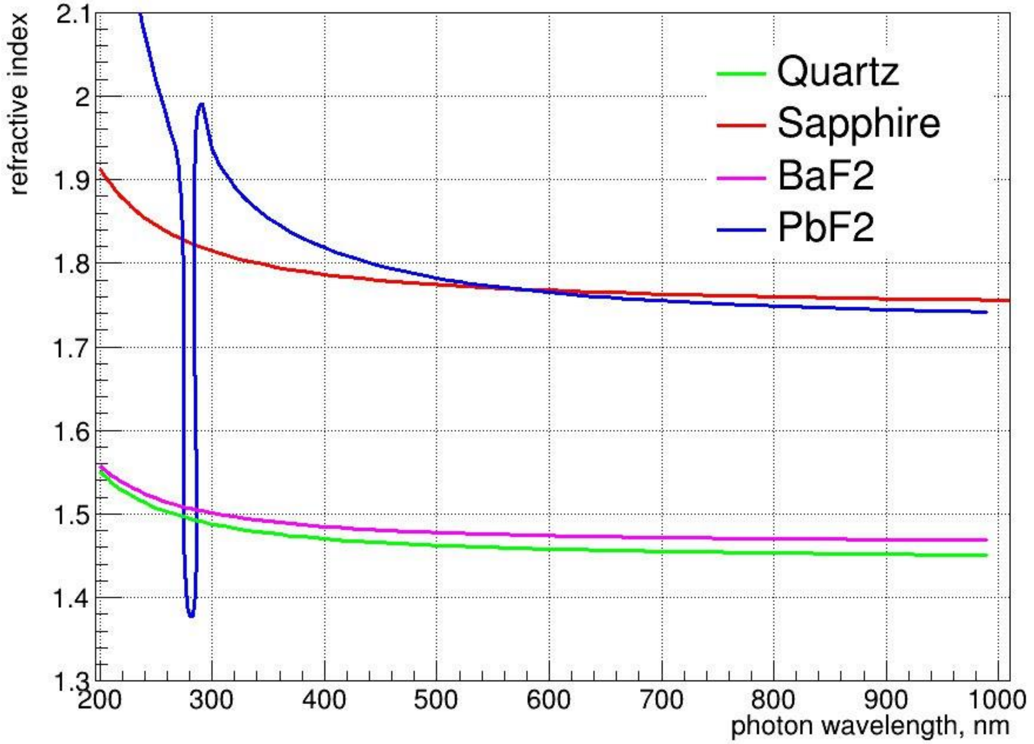




Hybrid of bars and plate in each sector



Potentially interesting optical materials



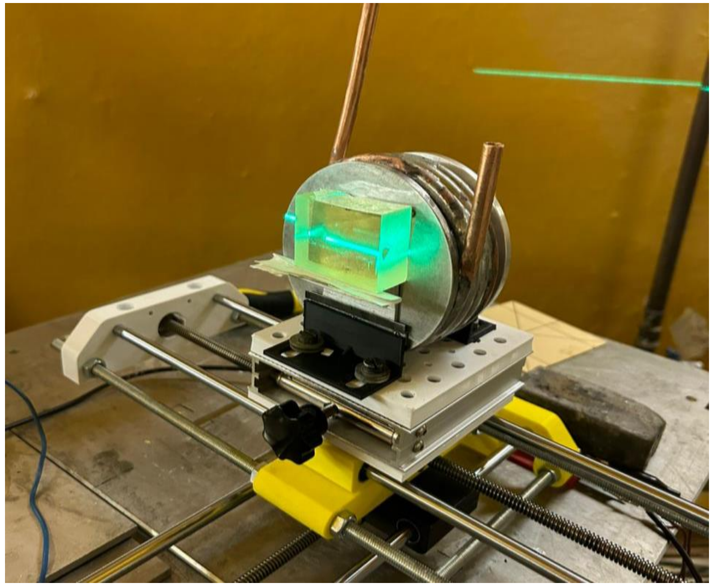
- High refractive index
- Reasonably radiation hard
- Transparent for the wavelength range where the photosensor is sensitive (e.g. 300-700 nm)

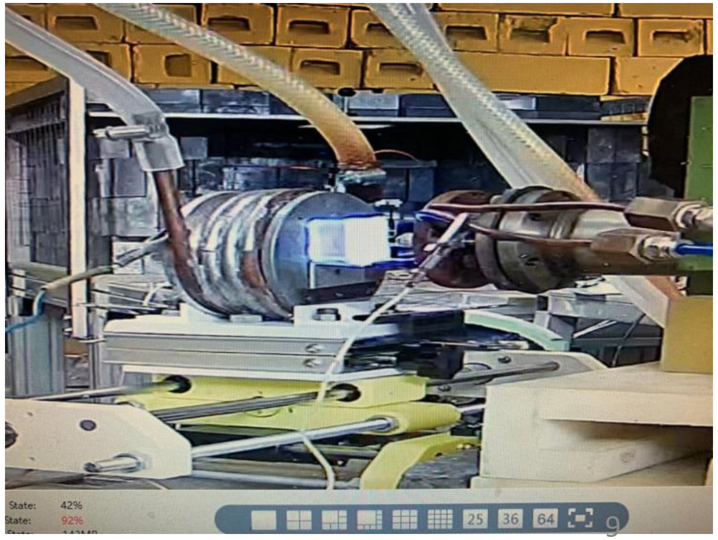
Irradiation setup

Irradiation tests were done at JINR Flerov laboratory on the Microtron MT-25 cyclotrone with **electron beams**

Samples of fused silica, optical sapphire, BaF2 and special optical glass TF-10 were irradiated by electron beam

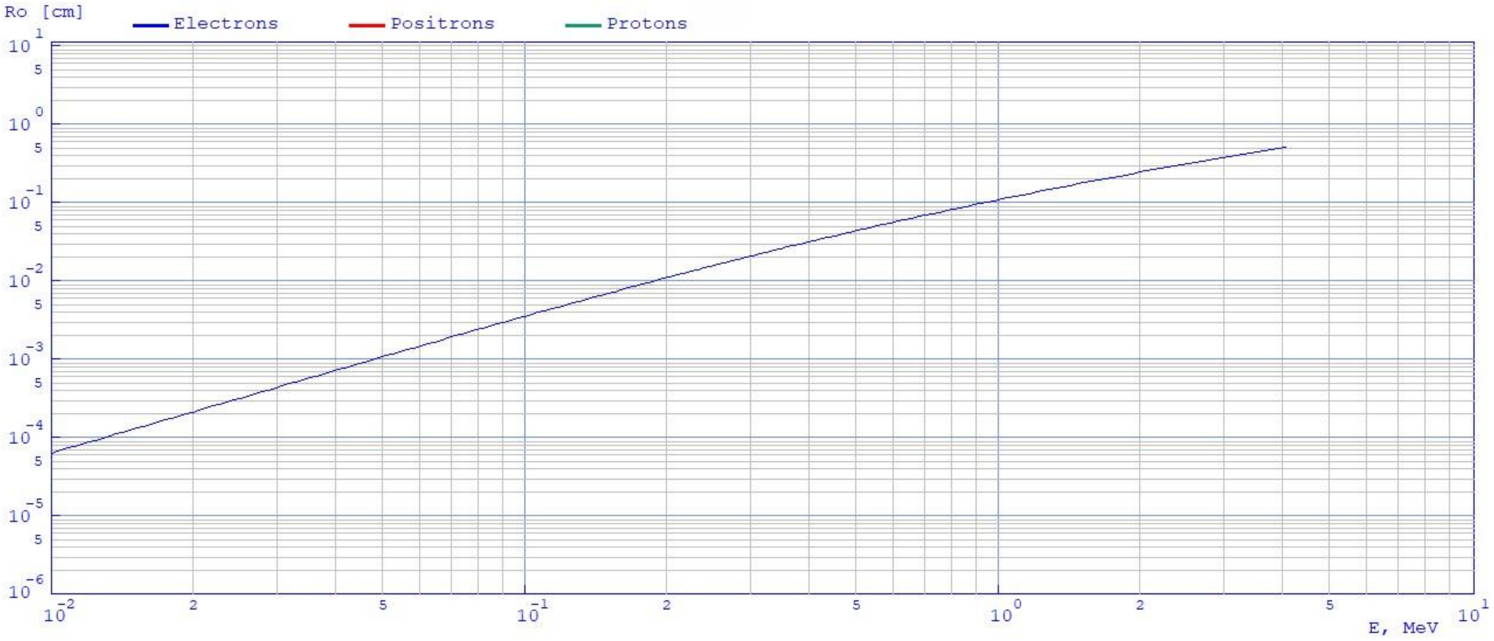
Beam energy for the samples were 5 MeV for TF-10
10 MeV for Sapphire and BaF2



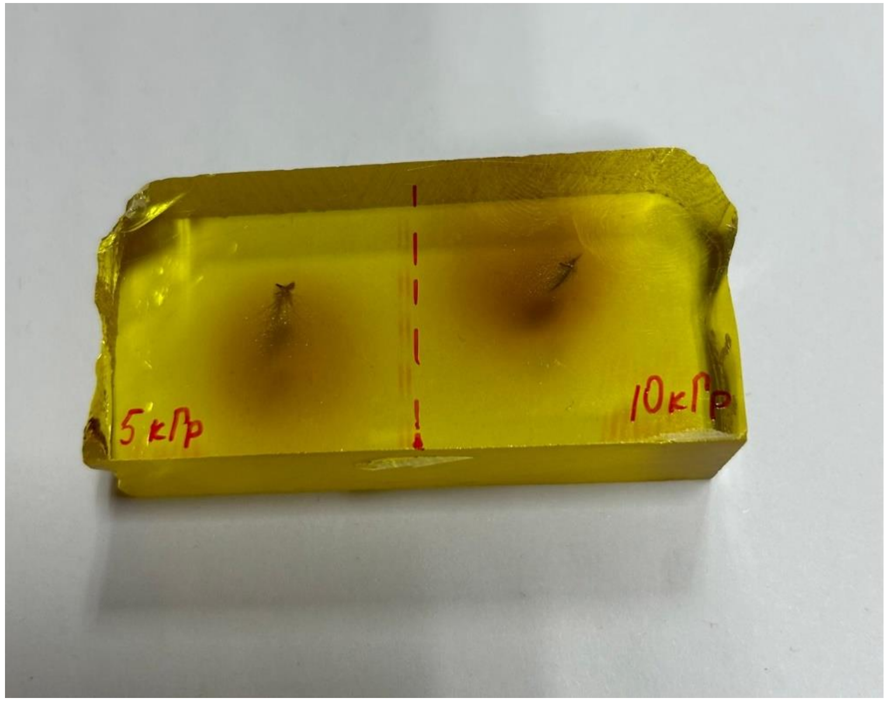


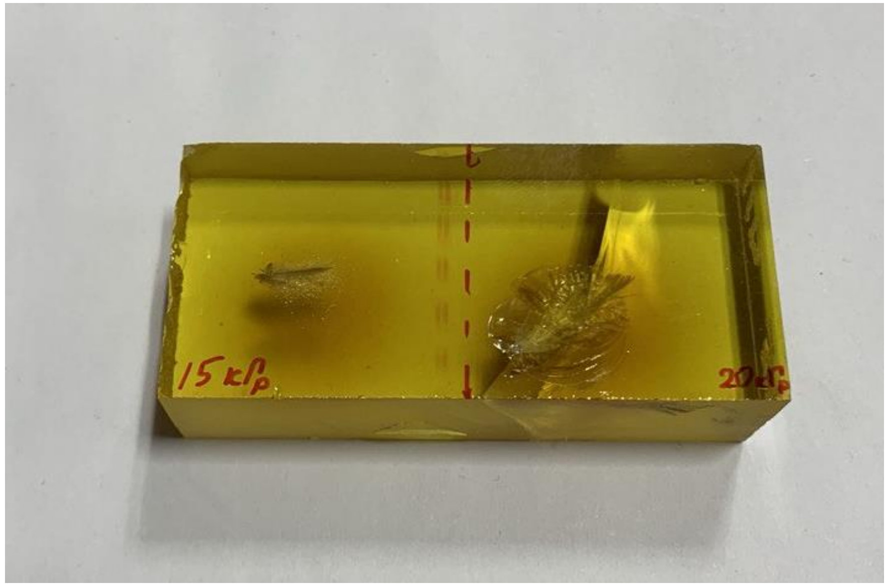
TF-10 glass damaged

Optical glass **TF-10** was damaged by the consumed electron dose
Attenuation length for 5 MeV electrons is ~ 5 mm



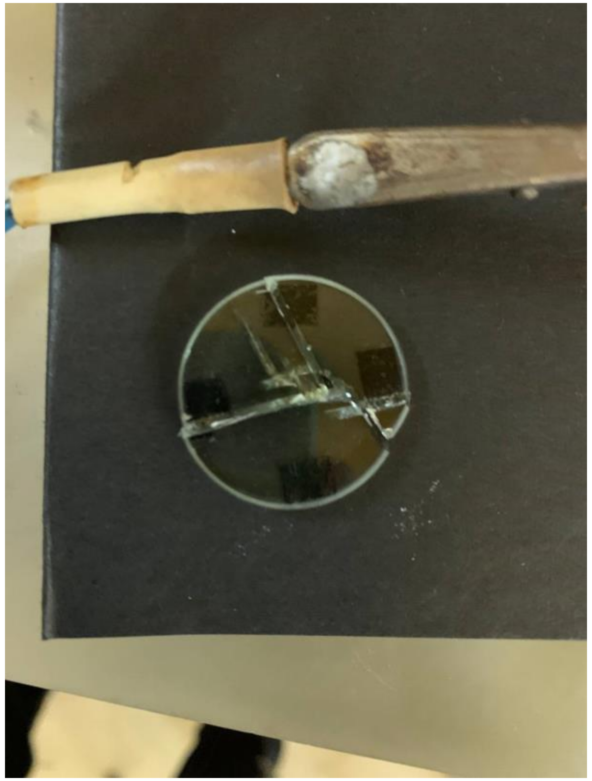
Depth of absorption for electron beam in TF-10 as a function of energy





BaF2 sample broke under <10 kGr dose

Cooling and fixation system



BaF2 10 kGr broke during irradiation

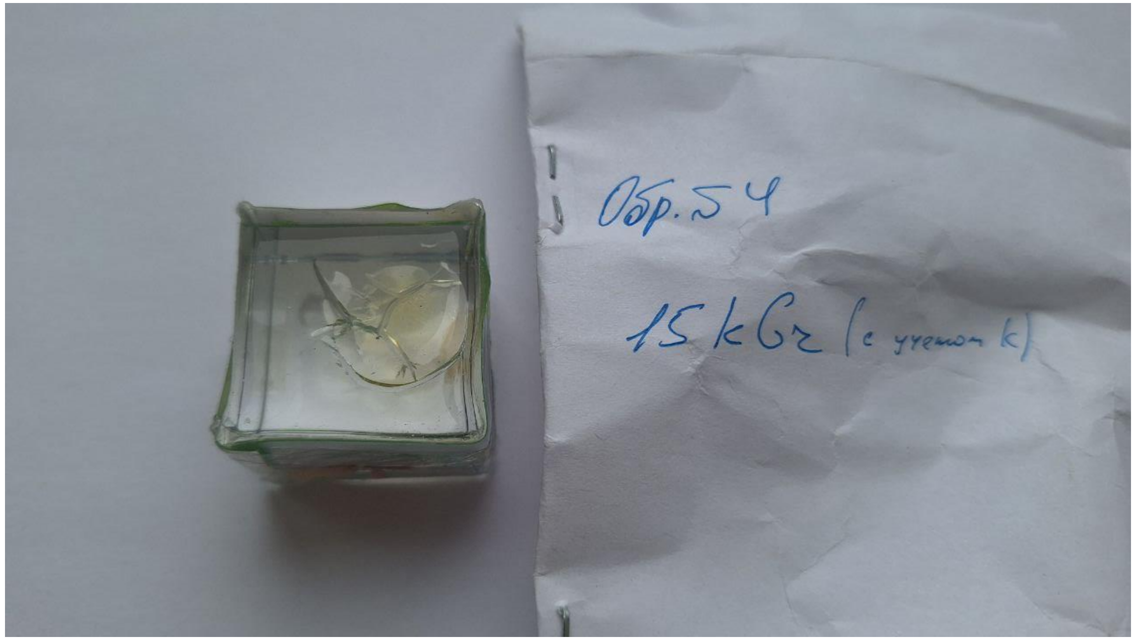
Local thermal effect can be harmful for some materials

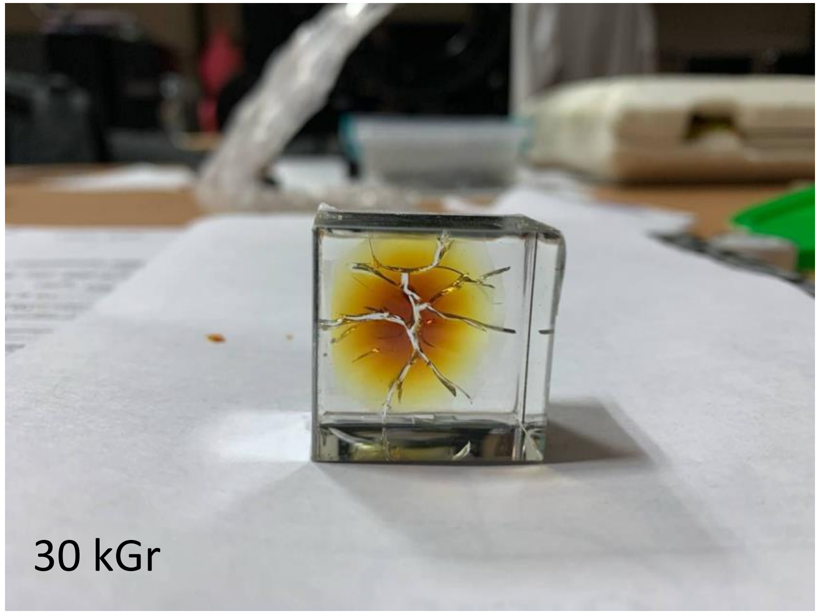
It can be a limiting factor for a multilayer lens made from those materials

Thermal effect also affects optical glue which is used to glue the radiator bars together

Irradiated Fused silica + RTV615

The epoxy layer got destroyed

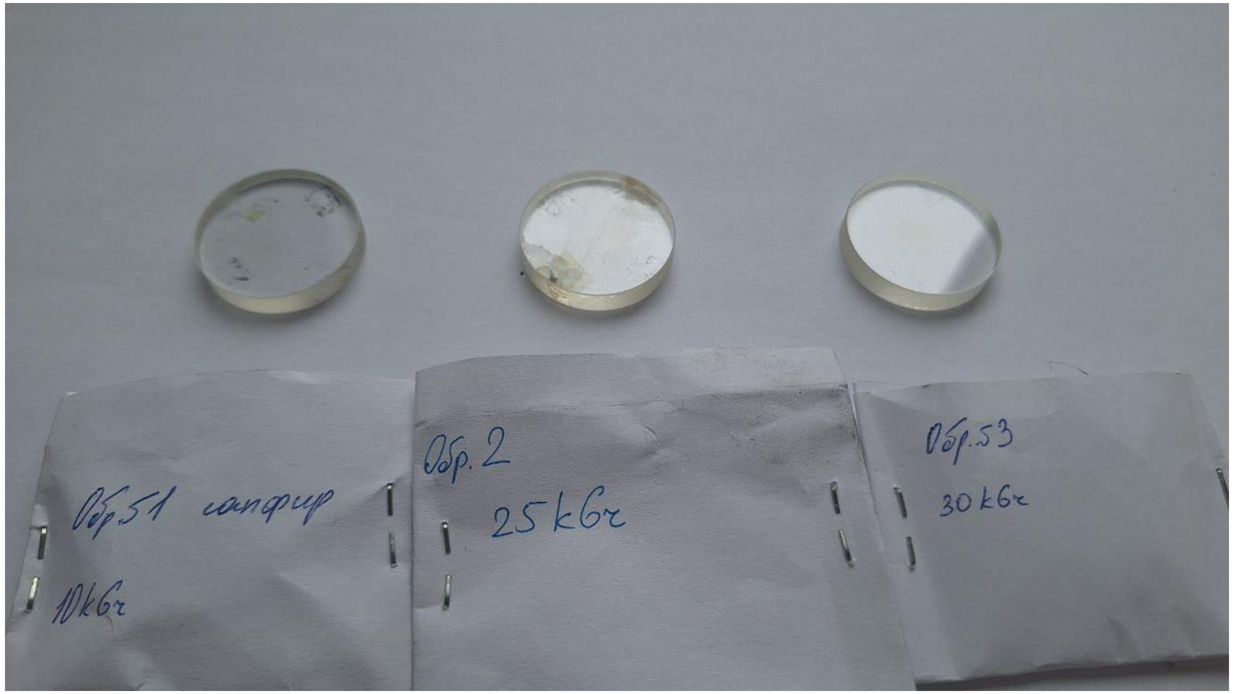




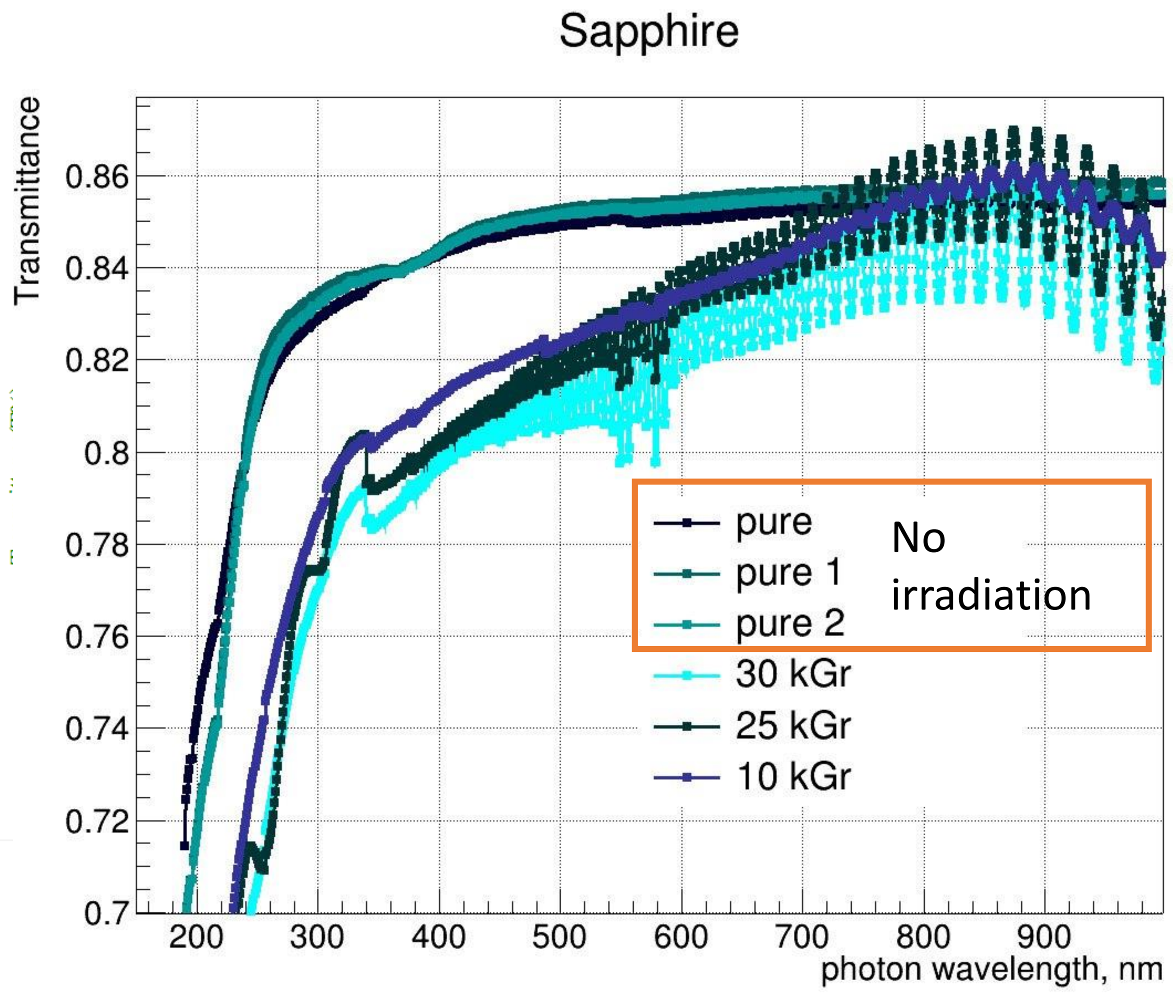
30 kGr

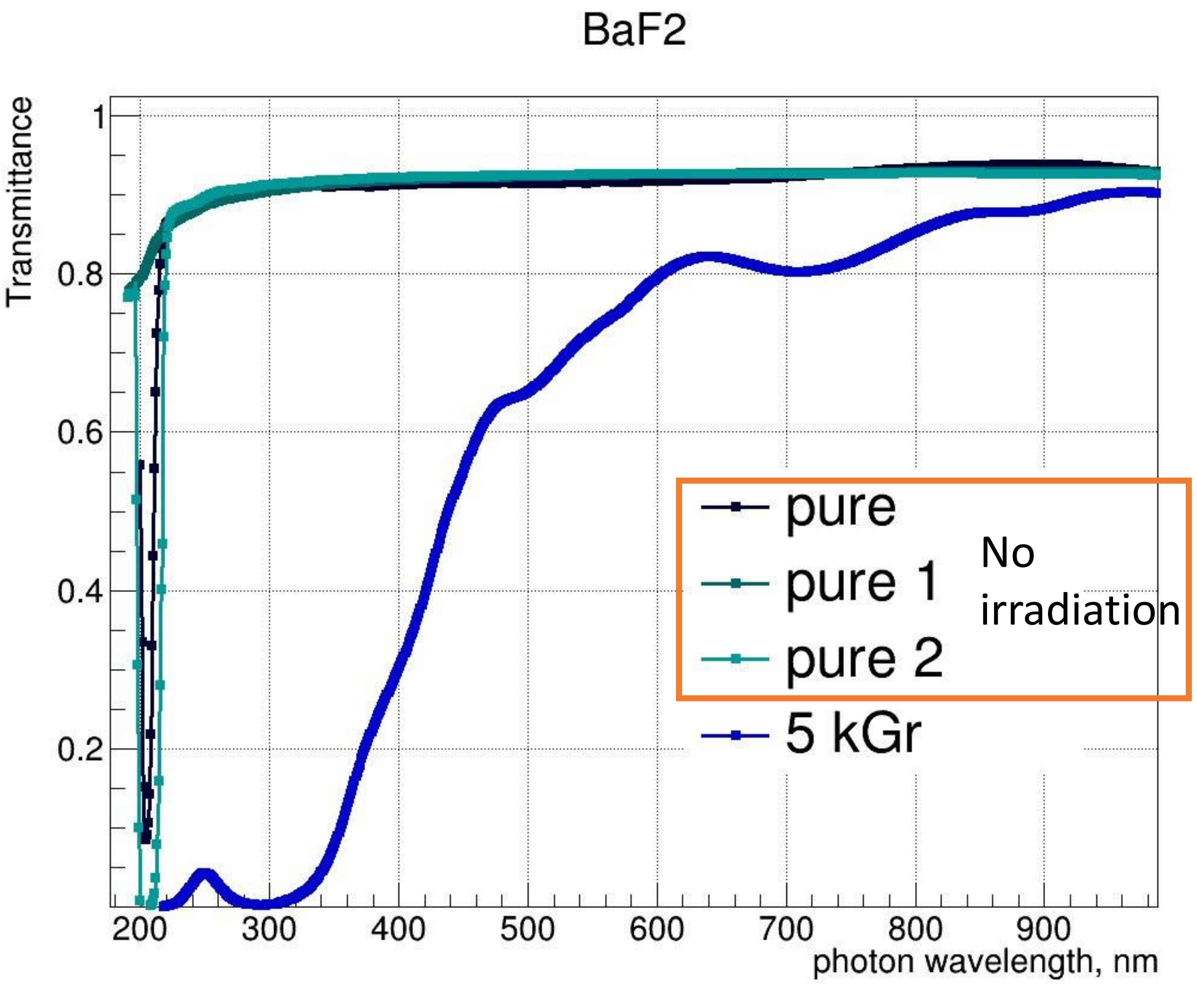
30 kGr

Irradiated Sapphire glass



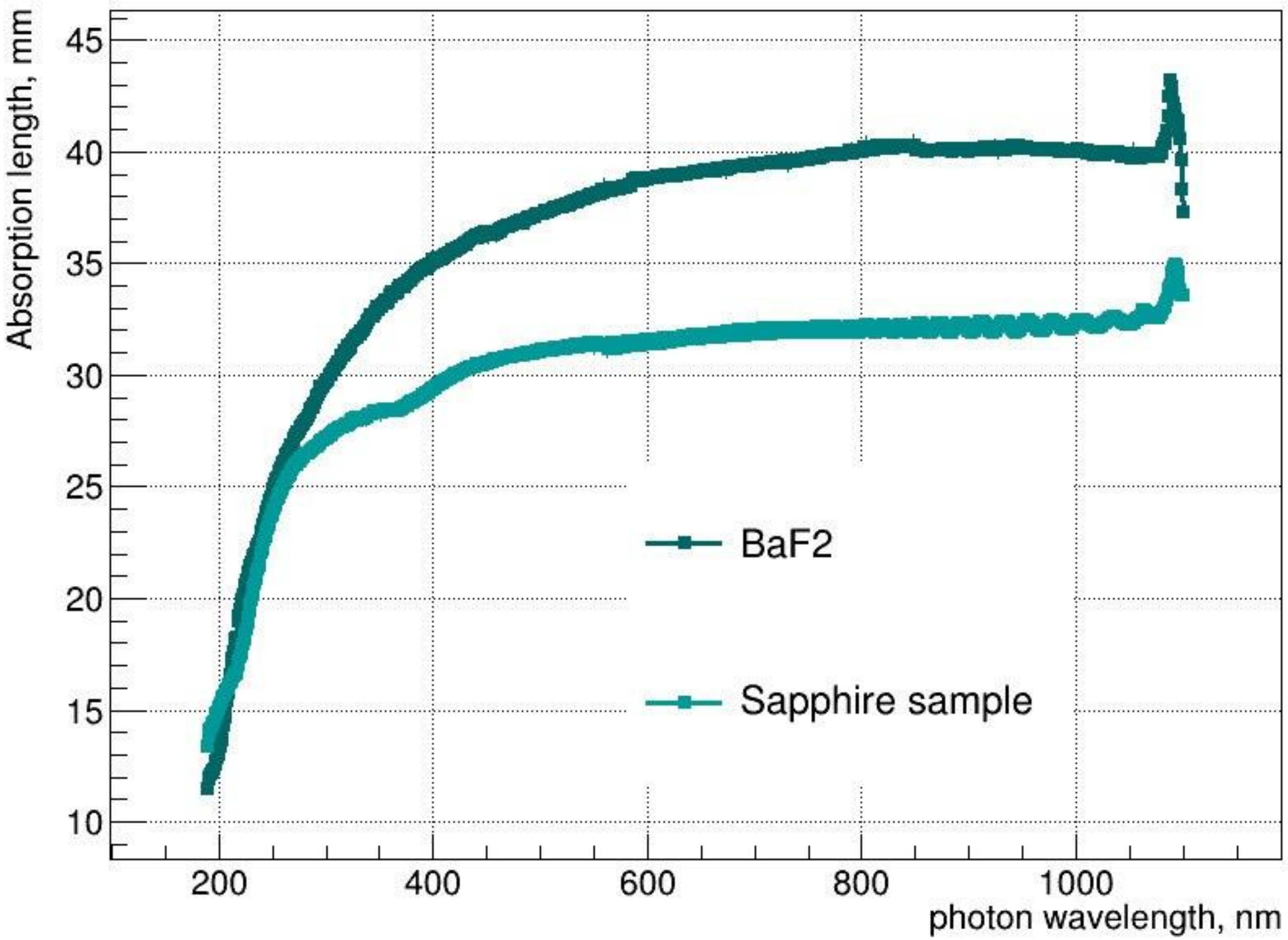
Transmittance of Sapphire and BaF_2





Both samples degrade after the irradiation

Absorption length of Sapphire and BaF_2



Not irradiated samples

Summary and outlook

- ✓ DIRC-based PID detectors are essential for the next generation collider experiments
- ✓ Focusing is one of the state-of-the-art DIRC challenges, which defines the detector performance
- ✓ Need to test potentially interesting optical materials at high radiation load
- ✓ More tests are needed with samples and particle beams of tens and hundreds MeV

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Thank you for the attention!

Спасибо за внимание!