Low background optical system R&D for the SBC detector

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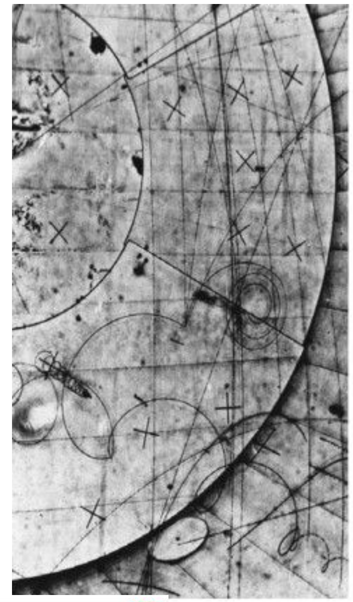
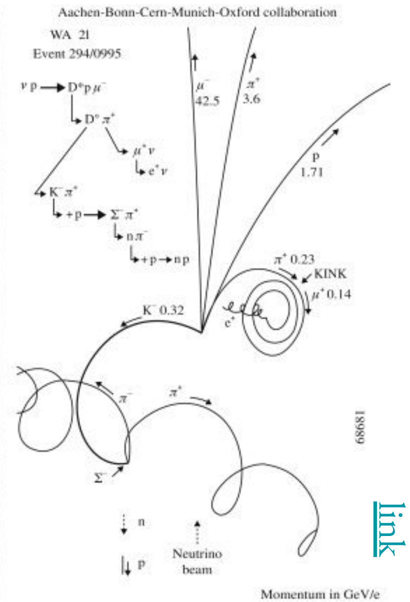
CAP2020, 9th June 2020

Bubble chamber : in past and now

- A bubble chamber is a vessel filled with a superheated liquid used to detect electrically charged particles leaving a track through it. [wikipedia]
- We are interested in a bubble chamber with an optimised design for the detection of WIMPs and/or neutrinos.





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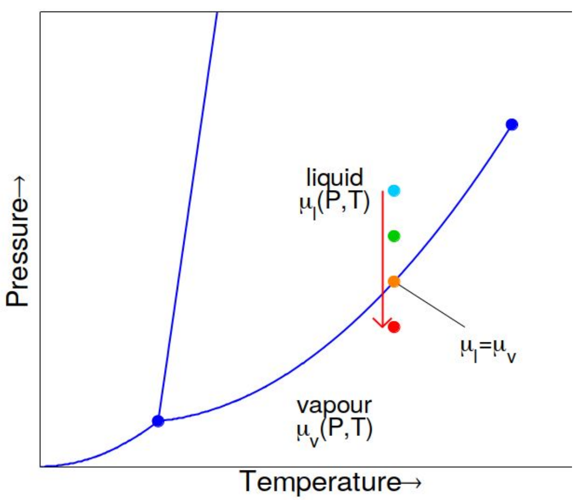
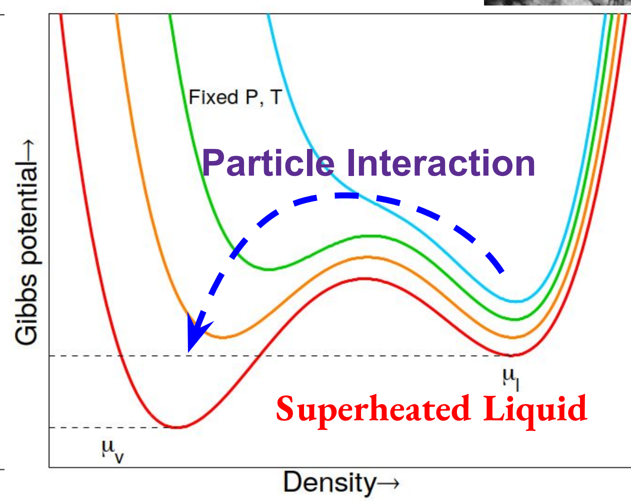
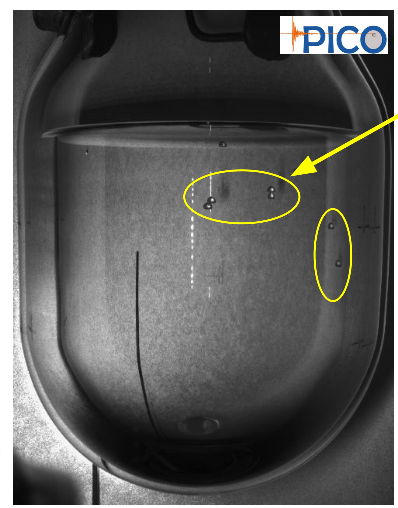
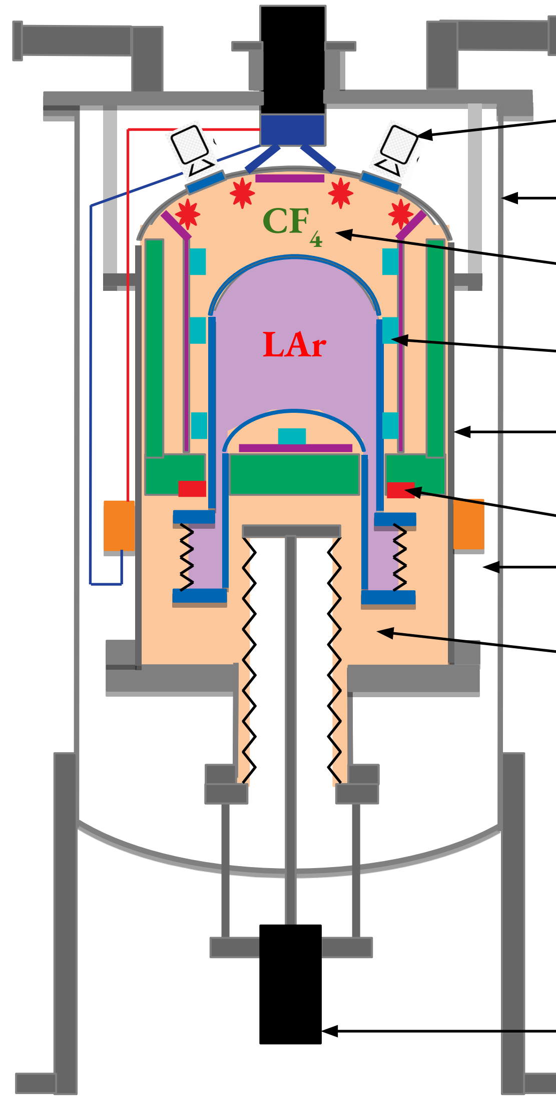






Scintillating Bubble Chamber (SBC) detector: a brief idea

- Active medium: Liquid Argon (doped with ~100 ppm of Xe)
- Buffer medium / thermal bath: Liquid CF4.
- Detection signal:
  - WIMP-like particles or neutrinos nucleate bubbles by direct heat deposition and scintillate VUV light.
  - Electromagnetic backgrounds are identified by VUV scintillation light.
- Target nuclear recoil sensitivity ~100 eV to detect ~1 GeV WIMPs.
- Signal detection mechanism:
  - Scintillation light from the LAr (spiked with Xe) is detected by 32 SiPMs (Hamamatsu VUV4) attached to the outer surface of the inner jar.
  - Bubble images are captured by a camera (Basler ace 200 fps 1.3 MP camera).
  - Bubble growth sound (acoustic signal) is recorded by a piezoelectric transducer.
- Each component used in the detector must be **ultra radiopure**.



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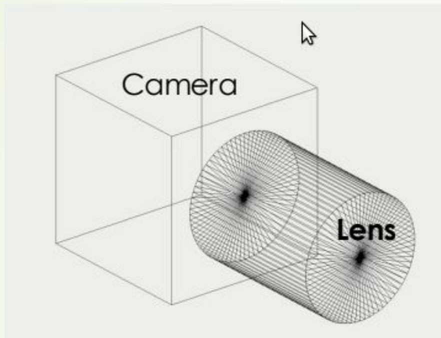
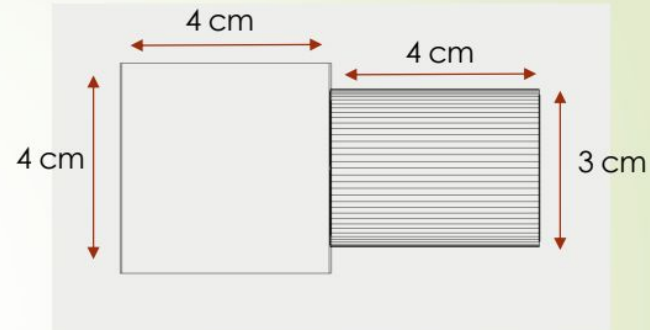
For more details look here: Prof. Ken Clark's talk 'Neutrino detection with scintillation bubble chamber' on 8th June.

Radioactive Backgrounds from Camera : Simulation results

Camera and Lens





- Cameras and lenses are considered 100% made of aluminum to estimate the neutron yield.
- Neutron Yield for (a,n) reactions in Al: $7.56 \bullet 10^{-5}$ neutron/decay.
- The mass of the camera is 74 g and the lens 56 g.

						^{238}U low	^{238}U up	^{235}U	^{232}Th
PICO 91 (Scintillating Bubble Chamber)	Camera: ID: 106752-16 SN: 2274565 and 22728402	147.8 g	4.917	Nov 30, 2018	(mBq/kg)	1908.00 +- 59.04	245.60 +- 496.50	156.10 +- 30.35	1337.00 +- 54.99
Basler Cameras		(73.9 g per camera)		Dec 5, 2018	(ppb or ppm)	154.55 ppb +- 4.78 ppb	19.89 ppb +- 40.22 ppb	274.74 ppb +- 53.42 ppb	328.9 ppb +- 13.53 ppb

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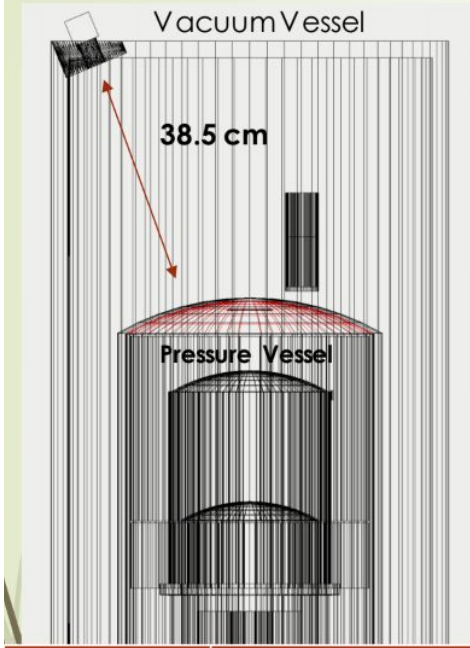
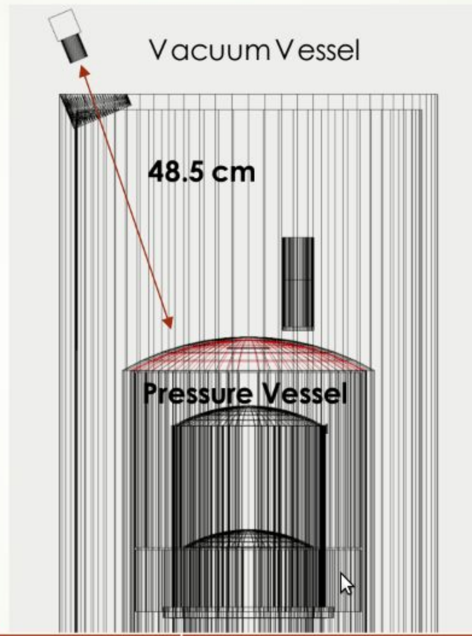
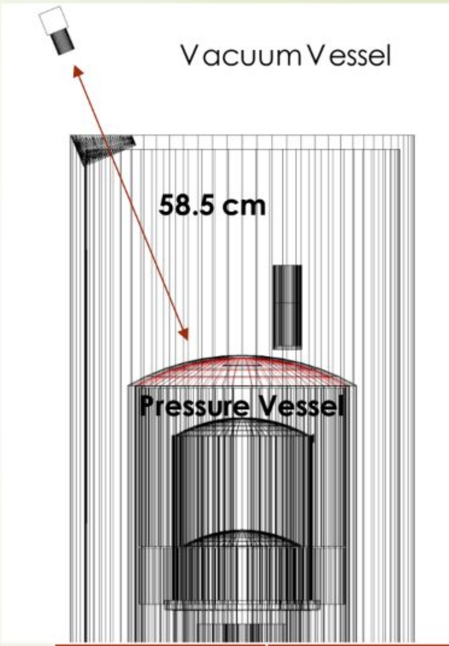
Camera + Relay Lens at different distance from the Pressure Vessel



	Count/year
Camera	0.66
Lens	0.82
Total	1.48



	Count/year
Camera	0.37
Lens	0.53
Total	0.90



	Count/year
Camera	0.27
Lens	0.30
Total	0.57

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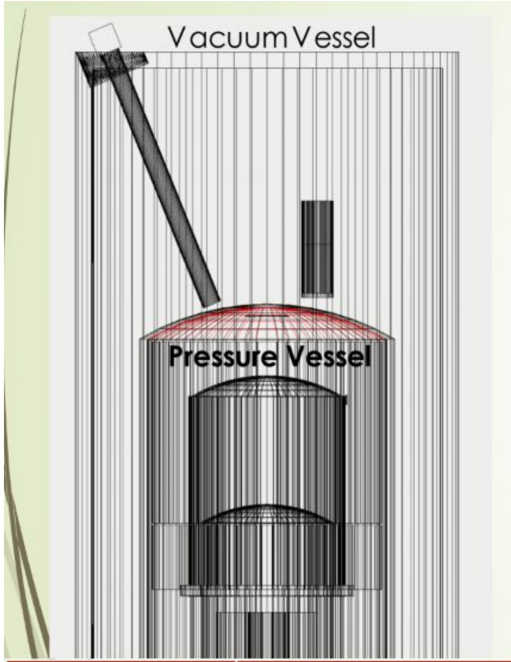
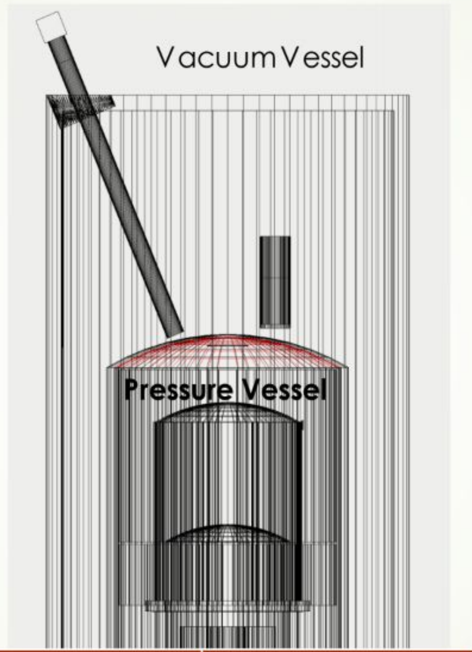
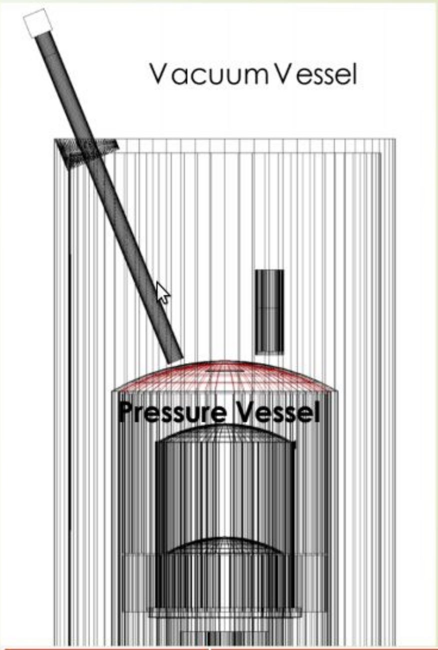
Camera + Lightguide at different distance from the Pressure Vessel



	Count/year
Camera	0.50
Lens	0.55
Total	1.05



+ 10 cm	Count/year
Camera	0.2945
Lens	0.2557
Total	0.5502



+ 20 cm	Count/year
Camera	0.24
Lens	0.13
Total	0.37

(Lightguide is assumed to be made of acrylic in simulation.)

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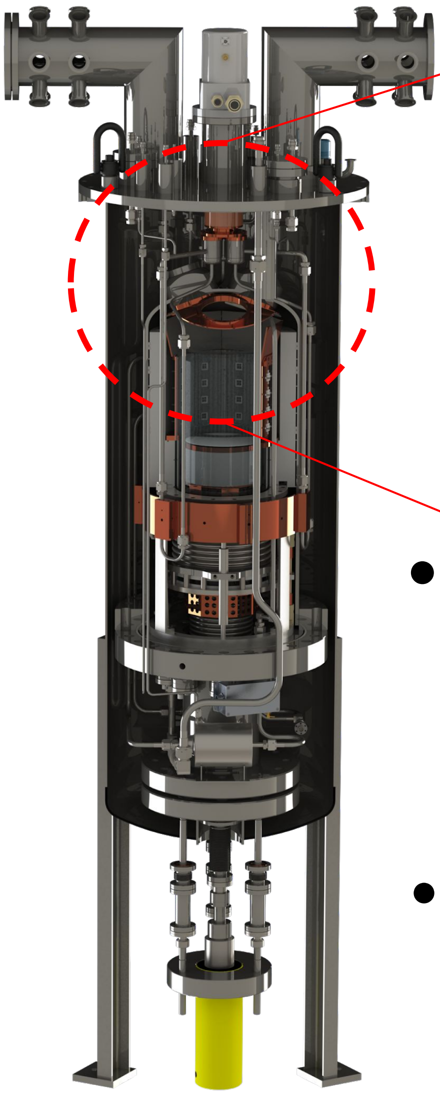
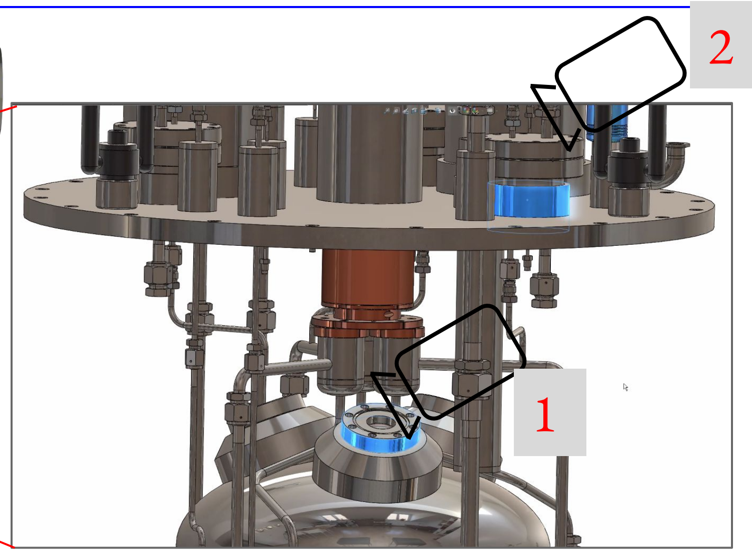
Camera location outside of the vacuum jacket : Challenges?





- Camera location '1',
  - then it is direct contact to the cold region (~130 K/-143°C) which is not suitable for the camera.
  - We would need to select a camera with lower radioactivity, to comply with the background budget requirements.
  - Optics is easier in this configuration.
- Camera location '2',
  - Camera at normal room temperature. Easy operation.
  - No issue from camera radioactive backgrounds.
  - But optics becomes a challenging job with other engineering constraints.

Requirement for images

-Resolution : 1280 x 1024 pixels

-Pixel size : 4.8 μm x 4.8μm

-Is the sensor able to resolve 1.0 mm bubble size?

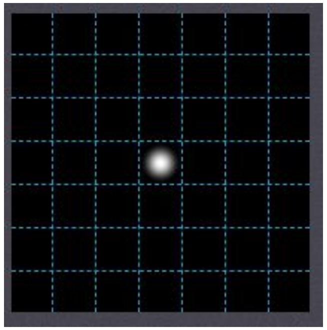
Sensor	Horizontal (6.1mm)	Vertical (4.9mm)
FOV	360 mm	360 mm
Minimum bubble size	0.28 mm	0.35 mm

- Maximum F/# at 640 nm: F/3 to create minimum spot size 4.8 μm

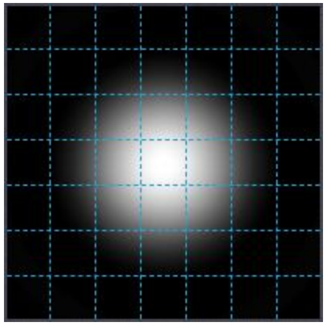
  (F/# < 3 : Full resolutions capacity, f-number = focal length/pupil diameter)

- 0% Contrast limit (mm) at 640nm : 0.056mm at F/3, impossible to resolve image.
  - 20% contrast limit is acceptable : Simulation will be carried out (zemax).

F/3
Min spot size 4.8 μm



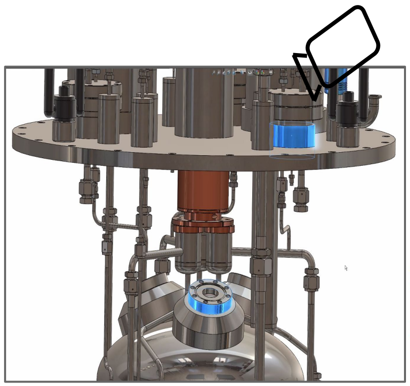
F/22
Min spot size 35 μm

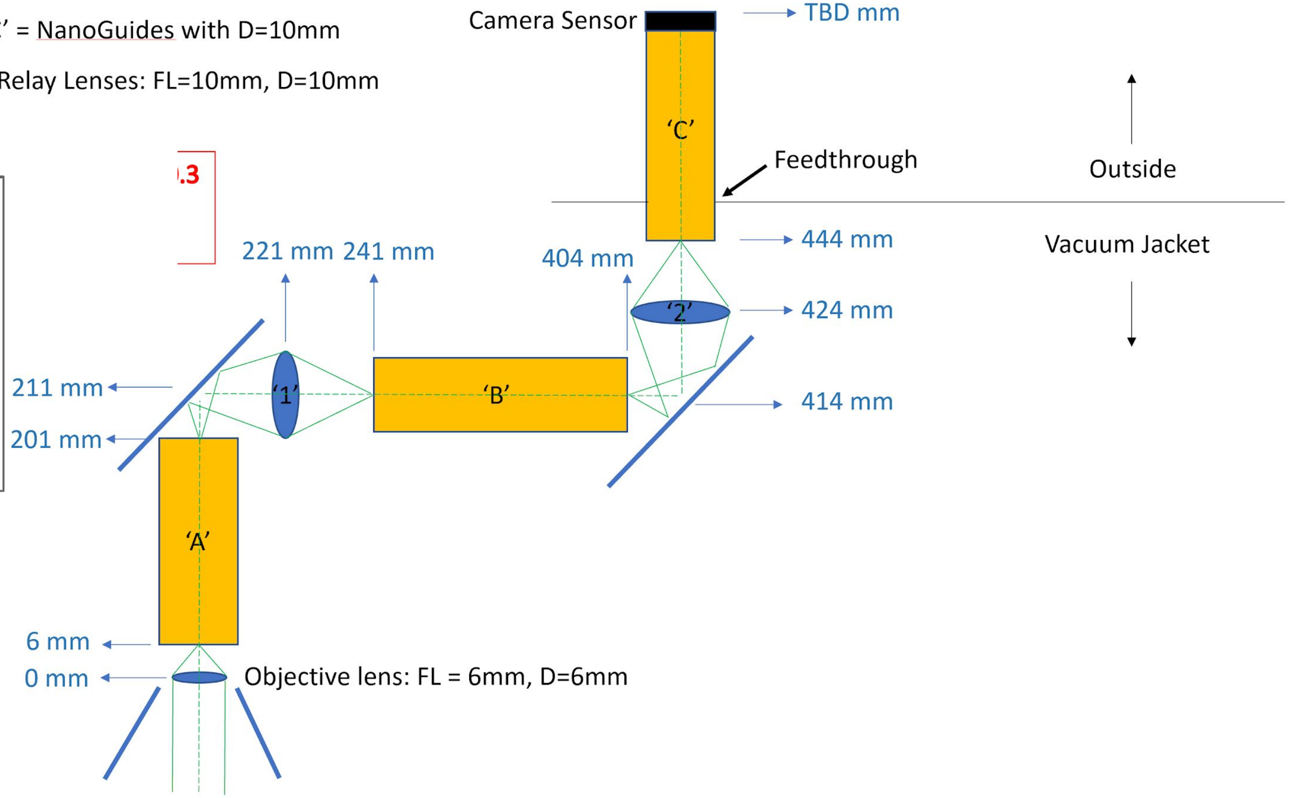


Possible optical arrangements

- Periscope :
  - Objective lens next to the PV viewport + Relay lens + Mirror.
  - Objective lens next to the PV viewport + nanoguide + Mirror.

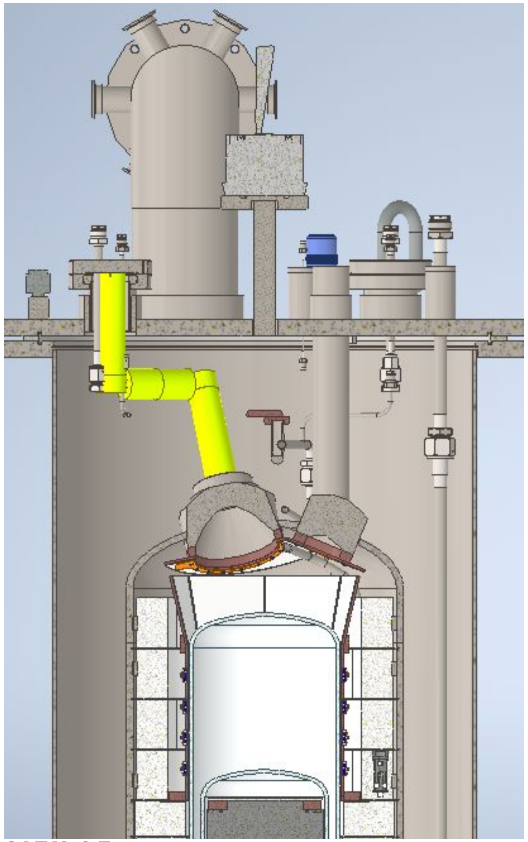
(nanoguide : low-weight polymer based imaging optic)

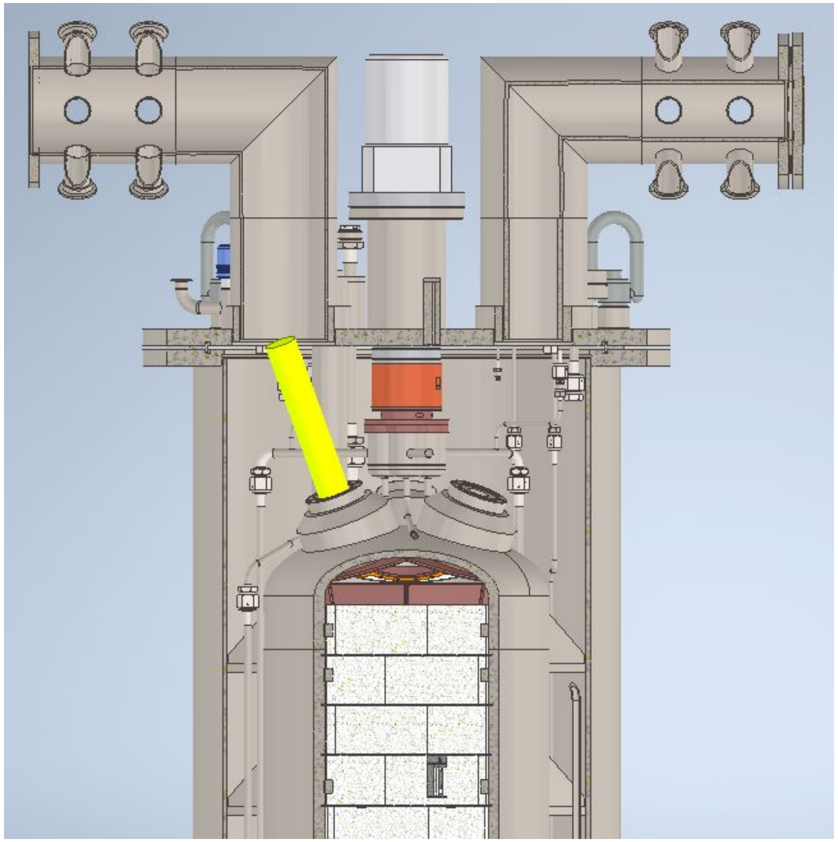




Possible optical arrangements

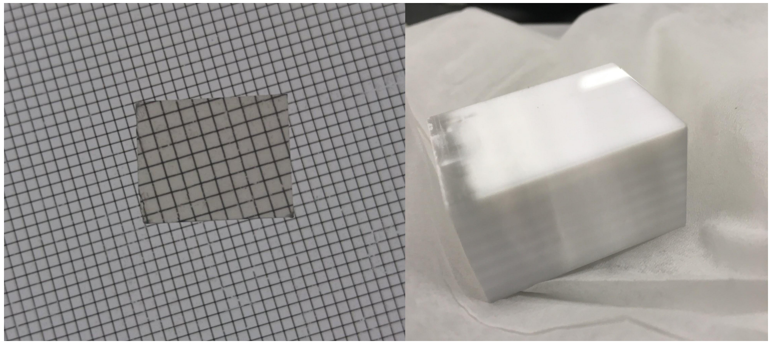
- Periscope (left):
  - Objective lens next to the PV viewport + Relay lens + Mirror.
  - Objective lens next to the PV viewport + nanoguide + Mirror.
- Camera sensor (*Cell phone cameras with Raspberry pi type control*) just below the vacuum jacket flange directly looking to the PV view port. (right)



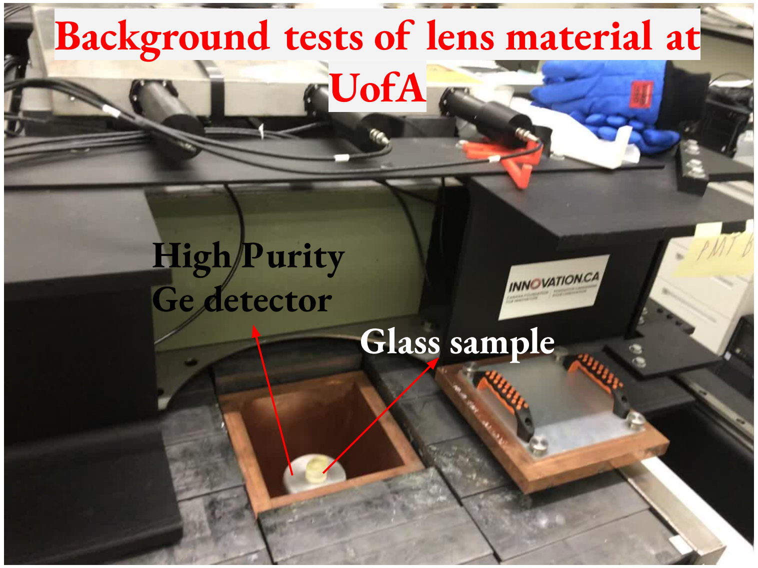


Background counting

- In order to ensure low activity of the lenses,
  - Assay testing of lens & other associated materials.
- High Purity Ge detector are used for counting at UofA.
- We have 5 different glass samples & nanoguide sample.
- We take background runs before and after the sample counting.
- Detector is calibrated using ^{54}Mn, ^{57}Co, ^{60}Co, ^{133}Ba, ^{137}Cs.
- Work is in progress;
  - Restricted access to the laboratory at the current situation.



1 inch Nanoguide sample



Conclusions

- New optics system for the SBC is needed and very challenging.
  - Cameras doesn't work in cold, radioactivity of lenses, etc.
- Few optic designs are under investigation:
  - Relay lens
  - Nanoguide
  - Cell phone cameras with Raspberry pi type control
- The optimisation will be verified by:
  - Optics simulation using professional software (Zemax).
  - Test bench setup at UofA with optical arrangements.
    - Test in vacuum and cold environment is an another challenge.
- Glass and nanoguide background counting are ongoing at UofA.
- Stay tuned!

Thank you

SBC Collaboration

Northwestern University

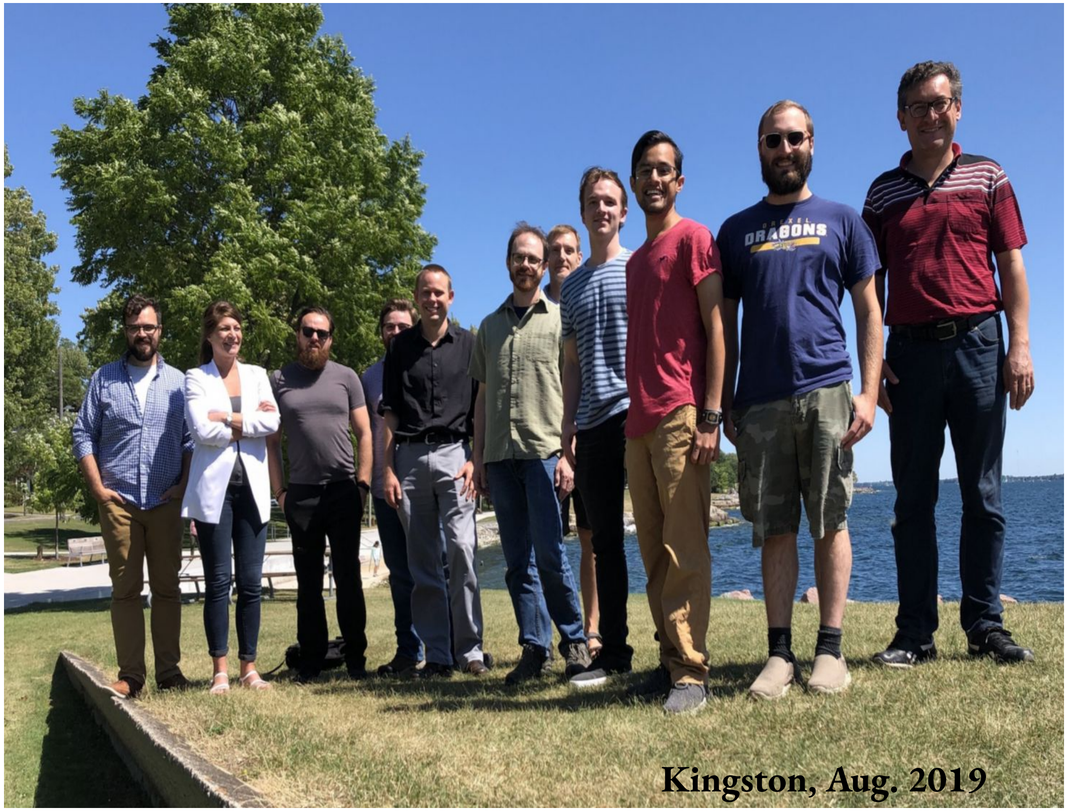
- **Eric Dahl**
- Rocco Coppejans
- Runze Zhang
- Jason Phelan
- Will Reinhardt
- Lawrence Luo
- Zhiheng Sheng
- Fangjun Zhu
- Aaron Brandon

Queen's University

- **Ken Clark**
- Hector Hawley

University of Alberta

- Marie-Cécile Piro
- Daniel Durnford
- Sumanta Pal
- Youngtak Ko
- Mitchel Baker



Kingston, Aug. 2019

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Fermilab

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