Wrocław University of Technology

Irradiation of insulators for EuCARD

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Workshop on Accelerator Magnet, Superconductor, Design and Optimization
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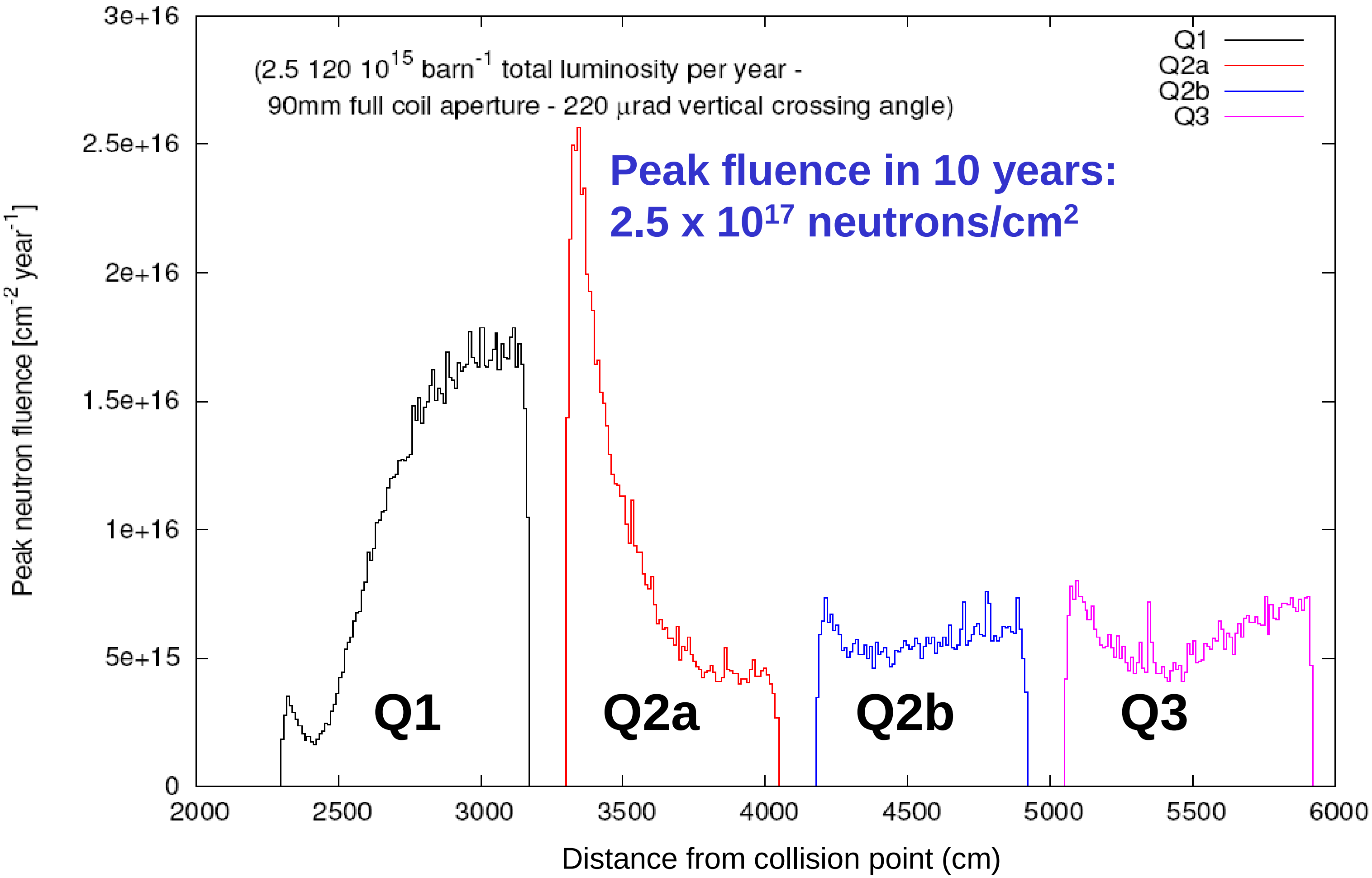
Outline

- Motivation of launching EUCARD irradiation task
- Irradiation methodology
- Post irradiation tests
  - Electrical
  - Thermal
  - Mechanical
- Irradiation cryostat
- Conclusions

Motivations

- Magnets in accelerators like the upgraded LHC and neutrino factories will be subjected to very high radiation doses.
- The electrical insulation employed on the coils must be resistant to this radiation
- A dedicated certification program for the radiation resistance of the insulation material has been launched within the EuCARD sub-task WP7.2.1, in parallel to the modeling of future magnets.

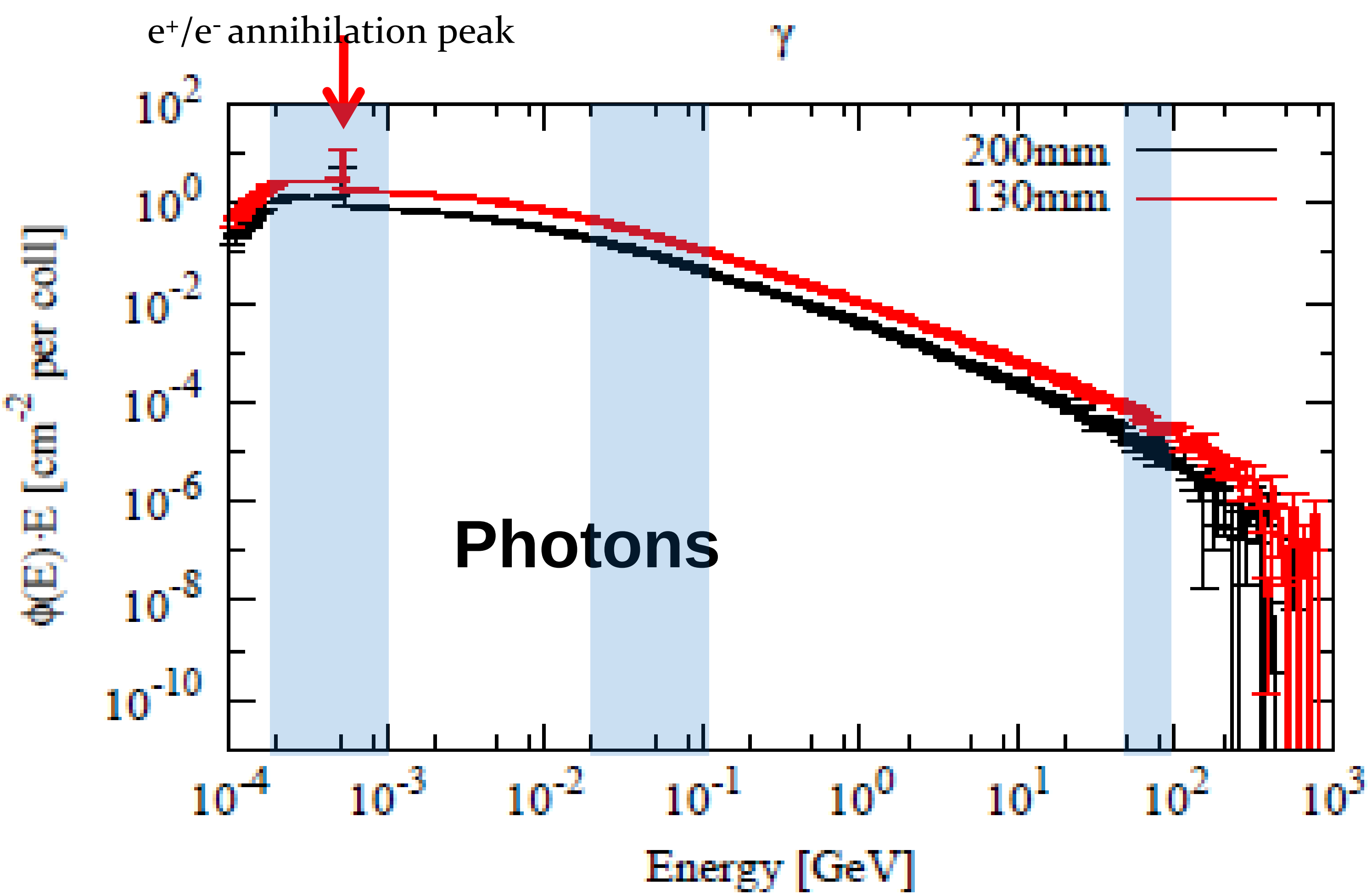
Radiation map for the Interaction Region Quadrupoles for LHC upgrade phase I [1]



Radiation spectrum at Q2a: 35m from Collision Point [1,2]

Radiation type	**Contents, %**	**Influence on magnet coil materials**
Neutrons	4.82	SC and Cu
Protons	0.14	SC and Cu
Photons (γ)	88.93	Insulation
Electrons	4.31	small effect
Positrons	2.23	small effect
Pions +	0.19	probably small effect
Pions -	0.26	probably small effect

Photon spectrum on the inner coil of Q2a at the peak location - FLUKA simulation [2]



Insulation candidates

- RAL mix 71 – DGEBA epoxy + D400 hardener
- RAL mix 237 – Epoxy TGPAP-DETD(2002)
- LARP insulation;   CTD1202 + filler ceramic
- Cyanate ester AroCy L10 40% + DGEBA epoxy 60%

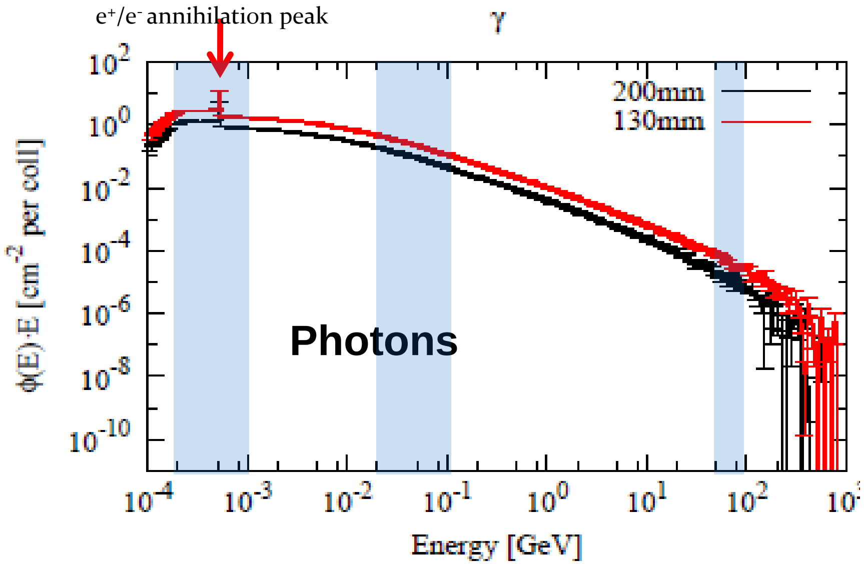
Radiation literature review

- The materials were irradiated mostly with fast neutrons.
- The other radiation sources were charcterized by the doses at least order of magnitude lower than predicted for new accelerators.
- Irradiations were mostly performed in non cryogenic conditions.
- Post-irradiation tests were mostly performed in non-cryogenic conditions
- Long delay time between irradiation and testing – material warm-up effects and aging not taken into account.
- Post irradiation tests – mostly mechanical.

EUCARD insulators certification conditions

- Radiation type: electron beam, E>1MeV
- Integrated radiation dose – 50 MGy
- Irradiation temperature – 77 K
- Warm-up between the irradiation and certification tests:
  - mechanical/electrical test – short time only
  - thermal – yes, contact with atmospheric air should be limited
- Certification tests temperature:
  - mechanical/electrical tests – 77K
  - thermal – 1.6 – 2.0 K

Photon spectrum on the inner coil of Q2a at the peak location – FLUKA simulation [2]



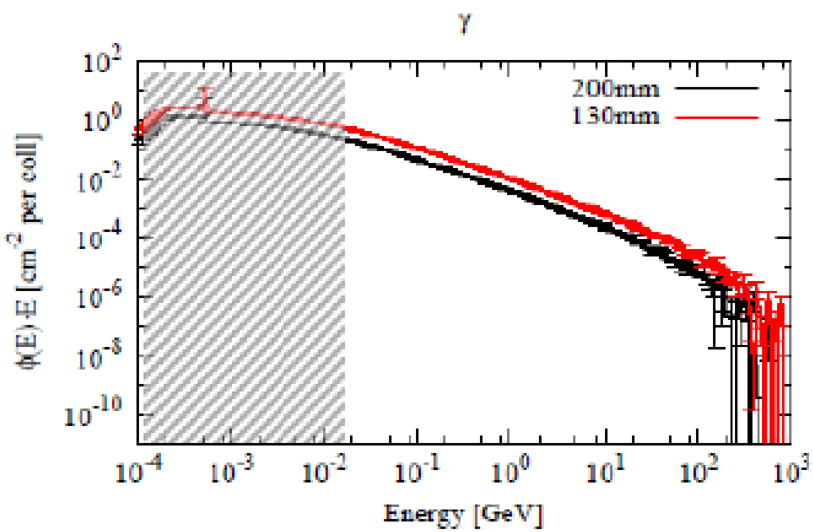


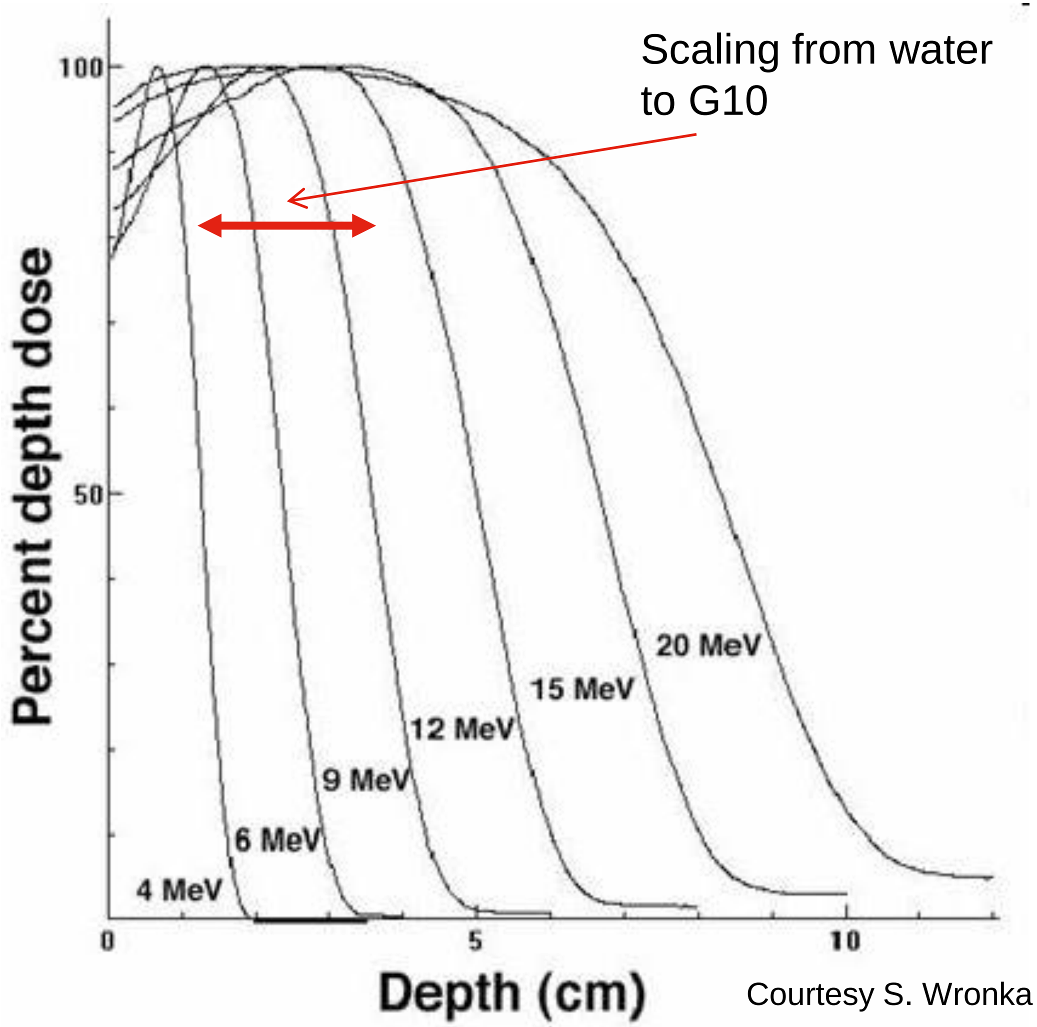
Fig. 3 Comparison of the required and available (shadowed) photon beam energies

Beam energy required for the sample irradiation

Depth of beam penetration in water for various beam energy value

ρ_{H20} = 1.0 g/cm^3
ρ_{PMMA} = 1.2 g/cm^3
ρ_{G10} = 1.8 g/cm^3

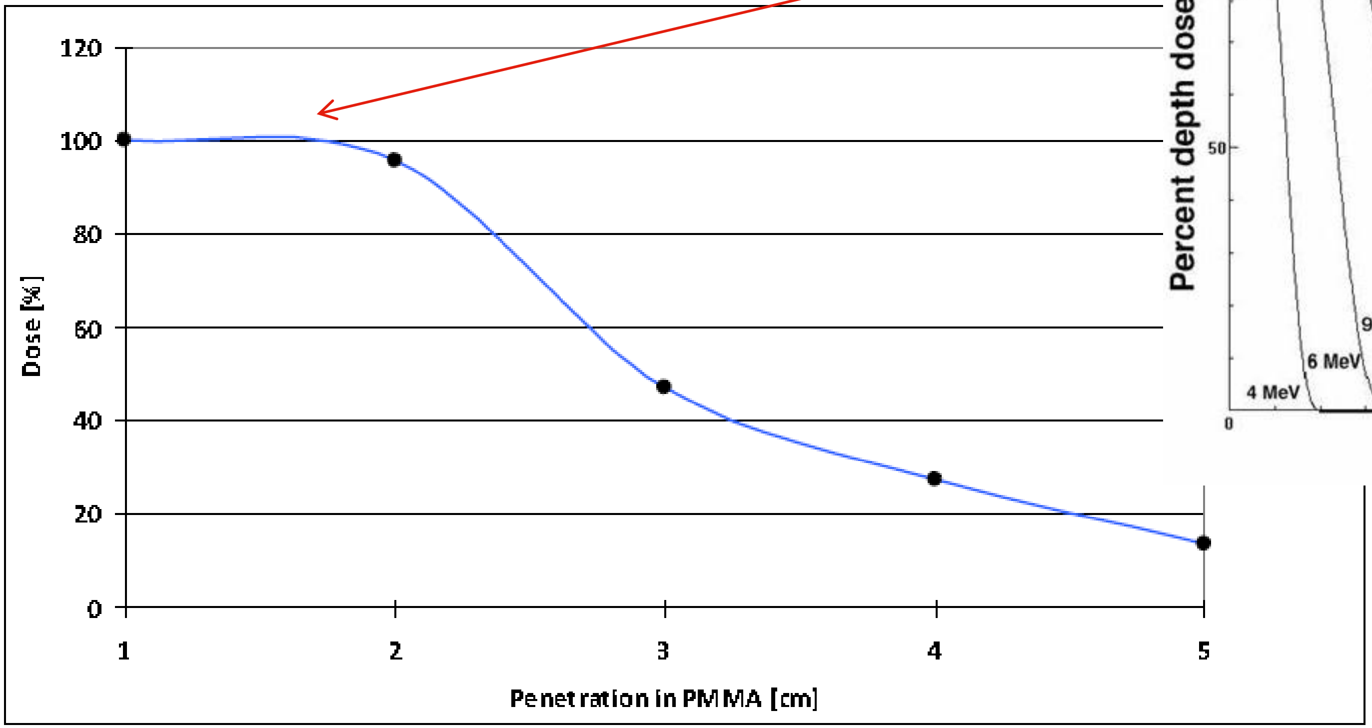
Scaling to G10 with density, For 2 cm long mechanical sample irradiation the beam energy as 10 – 11 MeV is necessary



Courtesy S. Wronka

Experimental confirmation of the beam energy for 12 MeV structure

„12 MeV" Accelerator Structure: PMMA irradiation



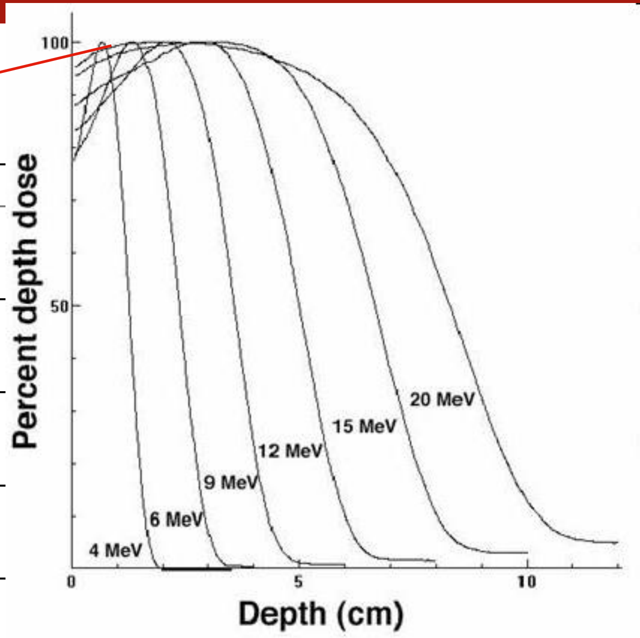


Fig. 3 Measured depth-dose curve of "12 MeV" structure.

Confirmed energy - 7÷8 MeV

CourtesyS. Wronka, Soltan Inst.

Technical limitations for higher doses

- The maximum dose rate limits come from existing in Soltan Institute accelerator technology – standing wave electron linac working at 3 GHz, gun current 300mA/pulse, transmission factor ~30%, i.e. beam current 100mA/pulse at the end of accelerating structure, pulse length typical 4.5-5us, PRF (Pulse Repetition Frequency) up to 300Hz.

- However in this application there is another limit. In all typical high power electron machines for industrial irradiations the beam on exit window is not point-like, but magnetically swept to avoid high current density (the window can be “burned”), this is called “scan horn window”.

- Therefore even the increasing of a linac current power will not decrease the irradiation time for each sample.

Electrical certification tests

- Test standard – EN 60243-1: “Methods of test for electric strength of solid insulating materials. Tests at power frequencies”
- Required electrical resistance of insulation > 5kV/mm

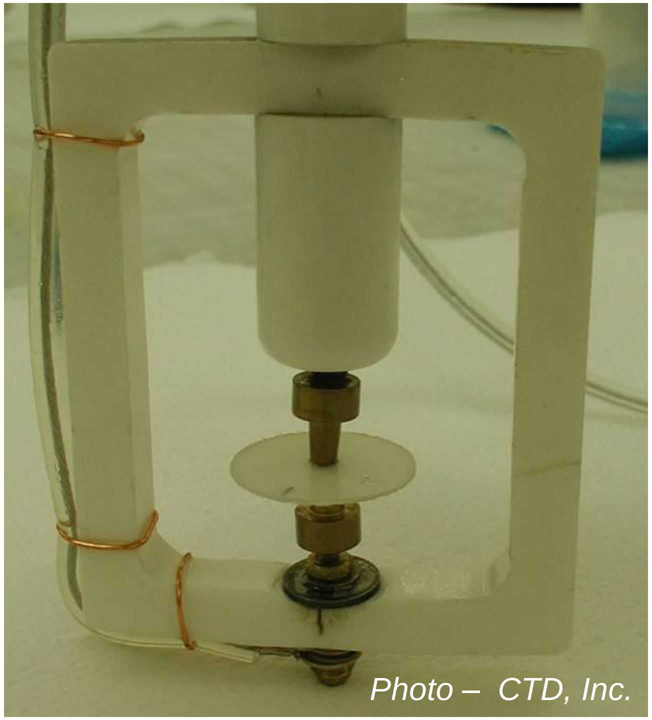
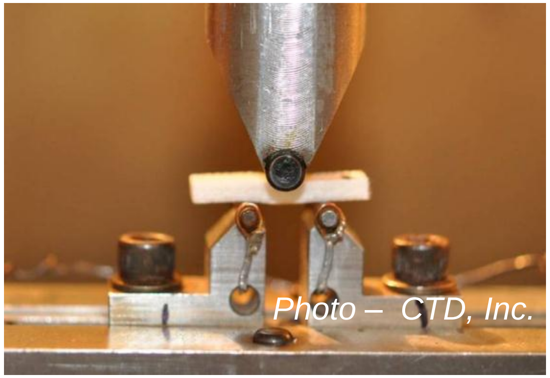


Photo – CTD, Inc.

Mechanical certification tests

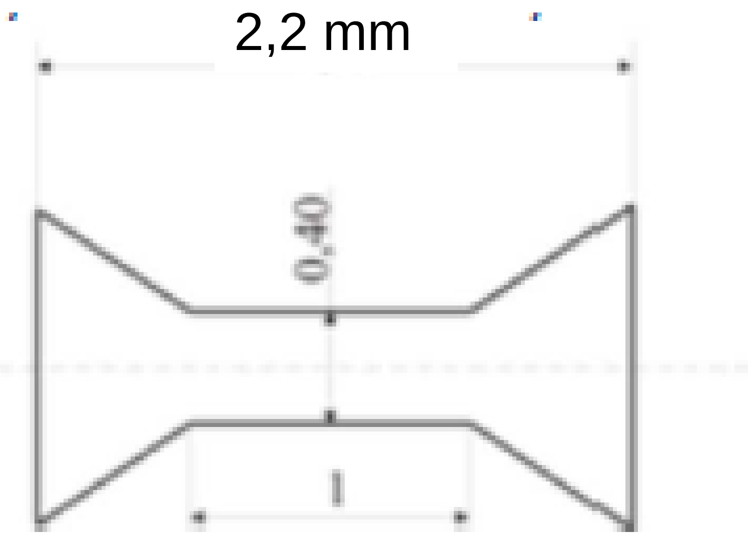
- Typical tests methods
  - *Determination of apparent interlaminar shear strength by short-beam method* - EN ISO 14130
  - *Determination of mode I interlaminar fracture toughness* - ISO EN 15024 standard
- Due to necessity of micro specimen applying of other mechanical test method is investigating



Interlaminar shear strength test

Interlaminar fracture toughness test

Mechanical tests - microsamples



- Tensile tests on microsamples with dimensions specified in the figure.

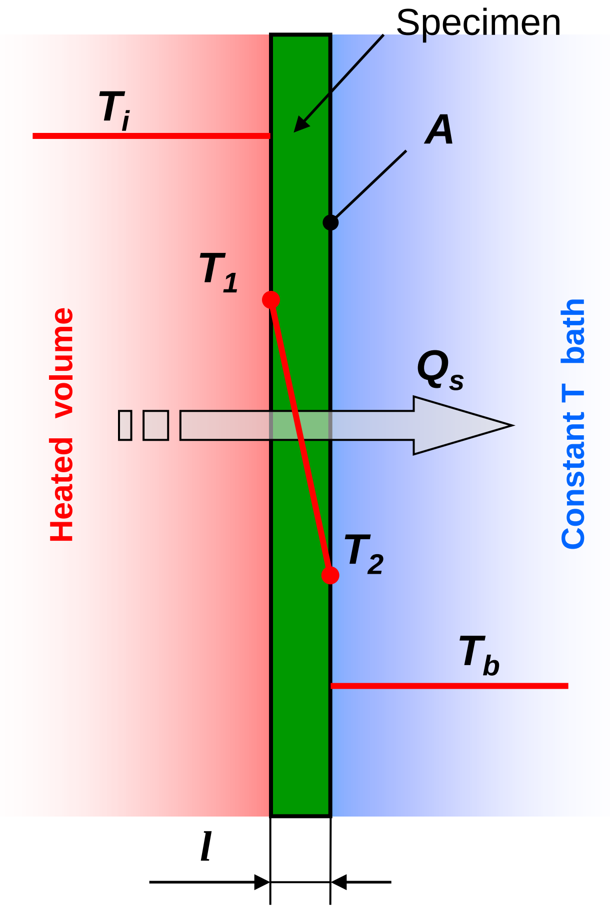
- Micro-bendig tests – sample's dimensions: 8 mm x 3-4 mm x thickness
- Microtomography
- Thermal analysis (DSC, TGA, DMA)

Thermal certification method

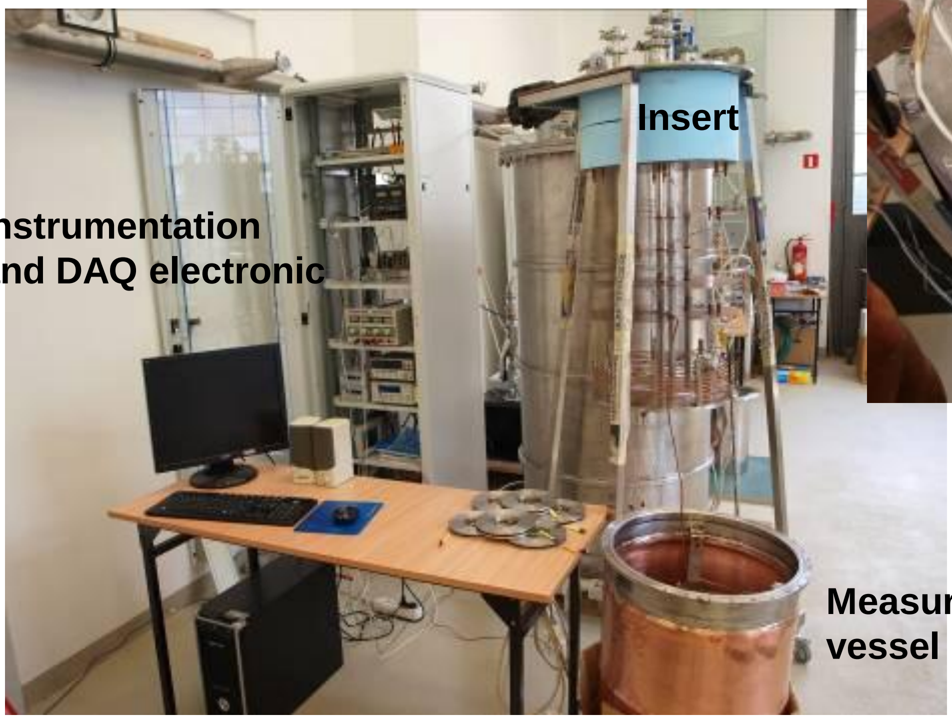
Drum method:

- allows determination of thermal conductivity and Kapitza resistance at superfluid helium conditions

- temperature range: 1.6 – 2.1 K

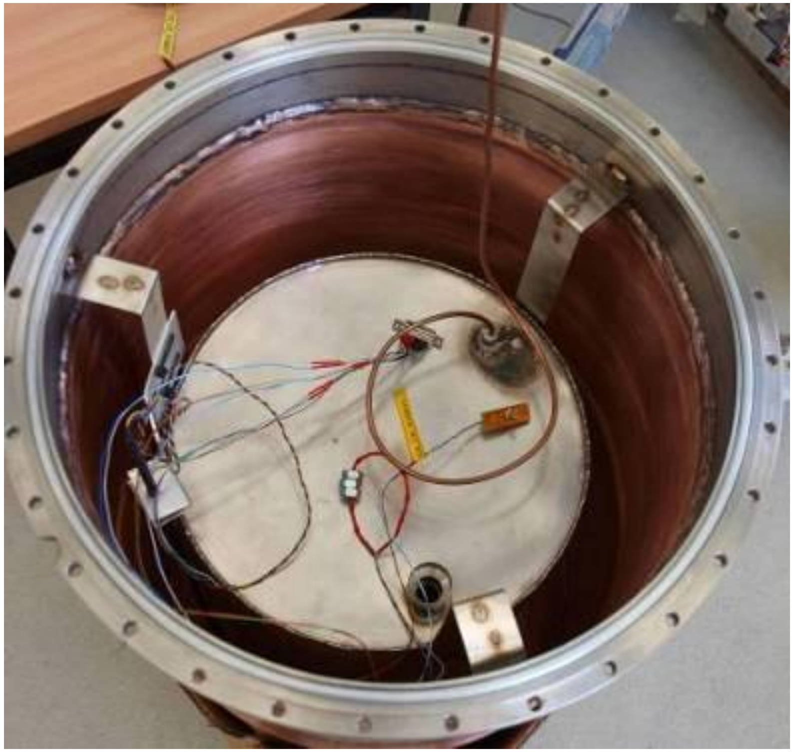


PWR Hell cryostat status

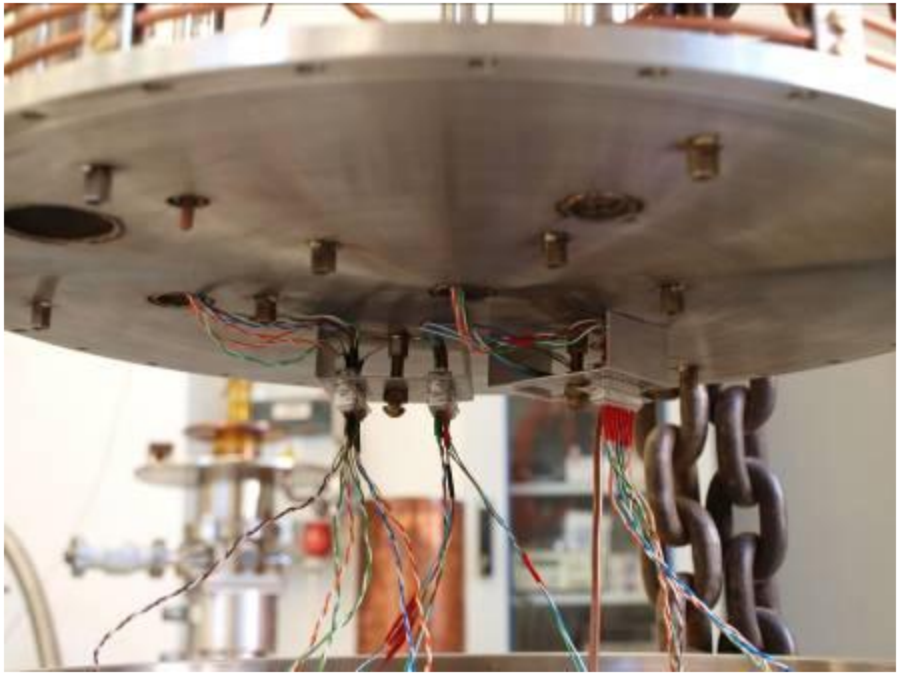


Top view of the cryostat with wiring

PWR Hell cryostat status

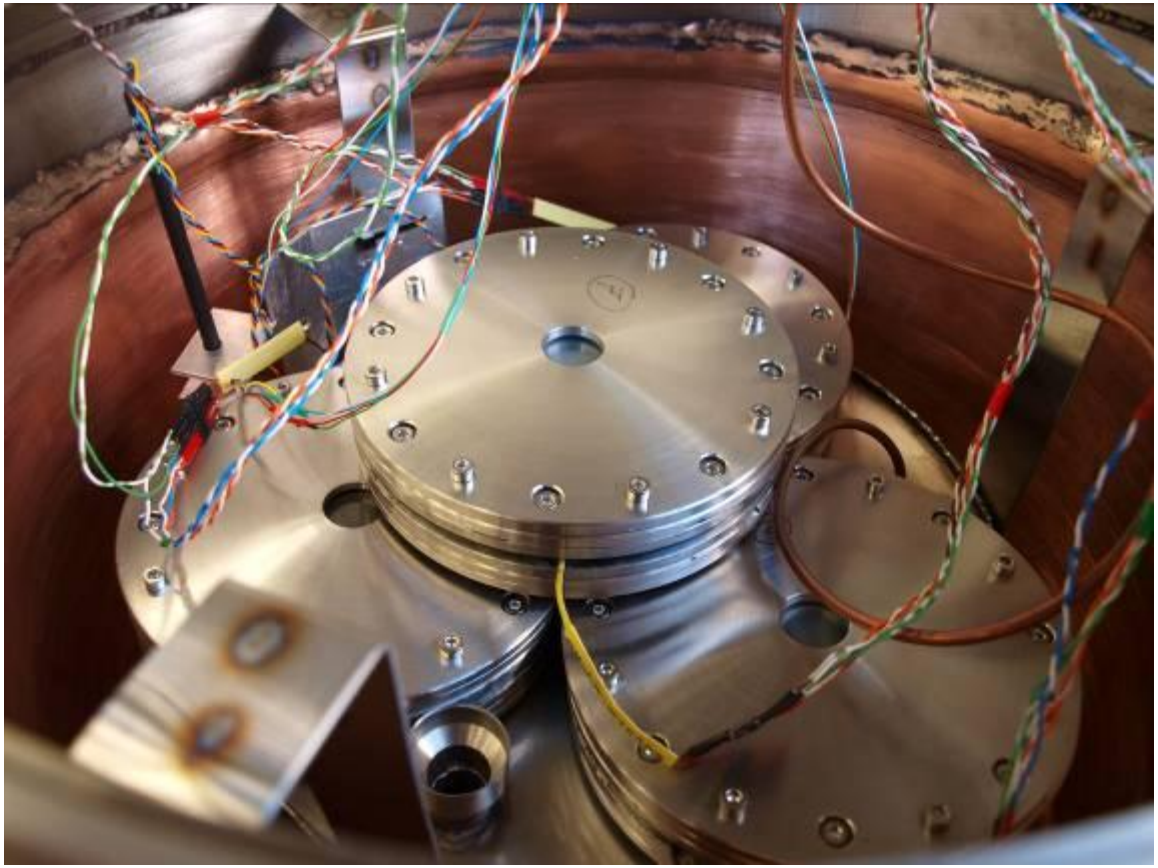


Measurement vessel



Top cover of measurement vessel

PWR Hell cryostat status



4 sample holders in the measurement vessel

PWR Hell cryostat status

- Instrumentation is installed
- Connection of instrumentation to DAQ system is done
- LabView program for cryostat operation is done
- 4 thickness of unirradiated 71 Mix samples are ready for thermal test
- During the first cool down with LHe some technical problems occurred
  - The manual shut-off valve need to be exchanged
  - Restart of measurement in expected till Dec. 2011

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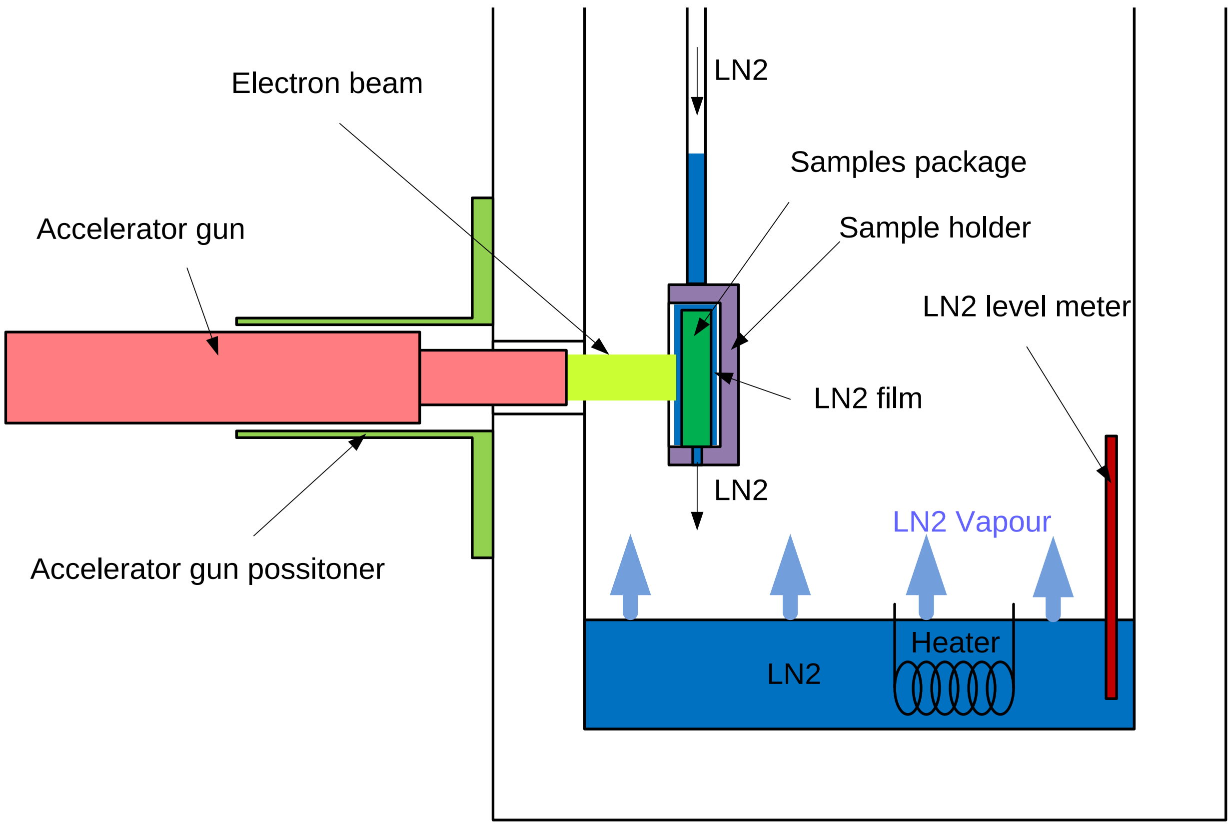
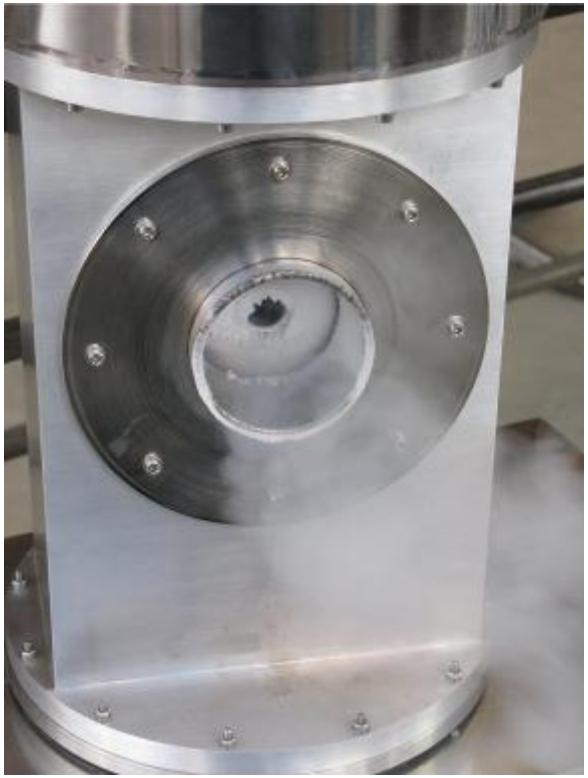
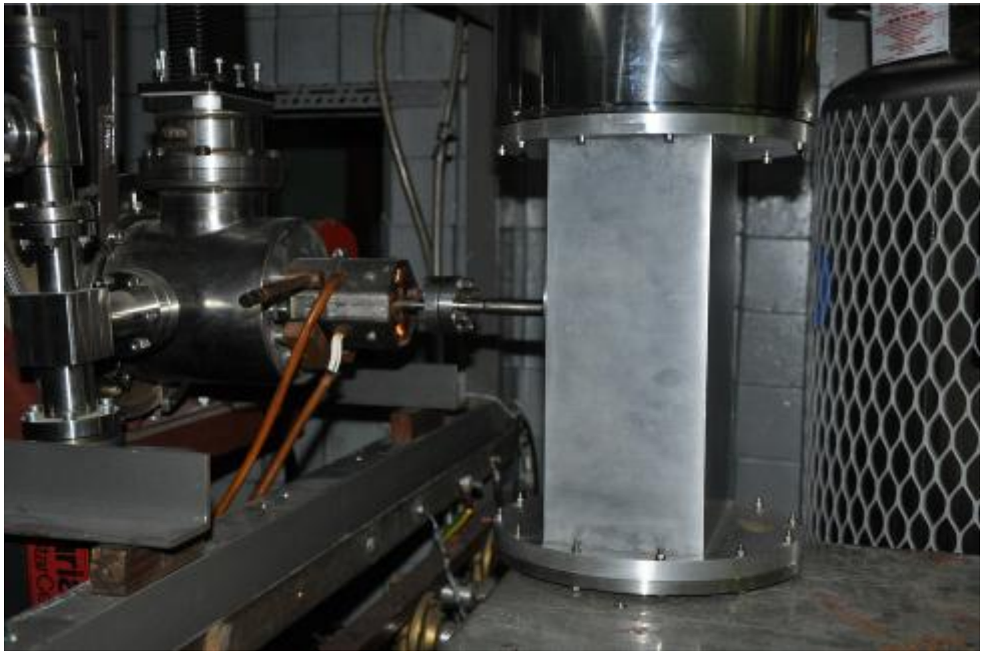
Irradiation cryostat - principle of irradiation process



Irradiation cryostat – commissioning test at manufacturer site



Irradiation cryostat installation at NCBJ



Conclusions

- The methodolology of the insulation has been specified and a dedicated test stand commissioned.
- Thermal tetst – cryostat under commissioning
- Electrical tests – cryostat under production
- Mechanical tests – will be based on microprobes