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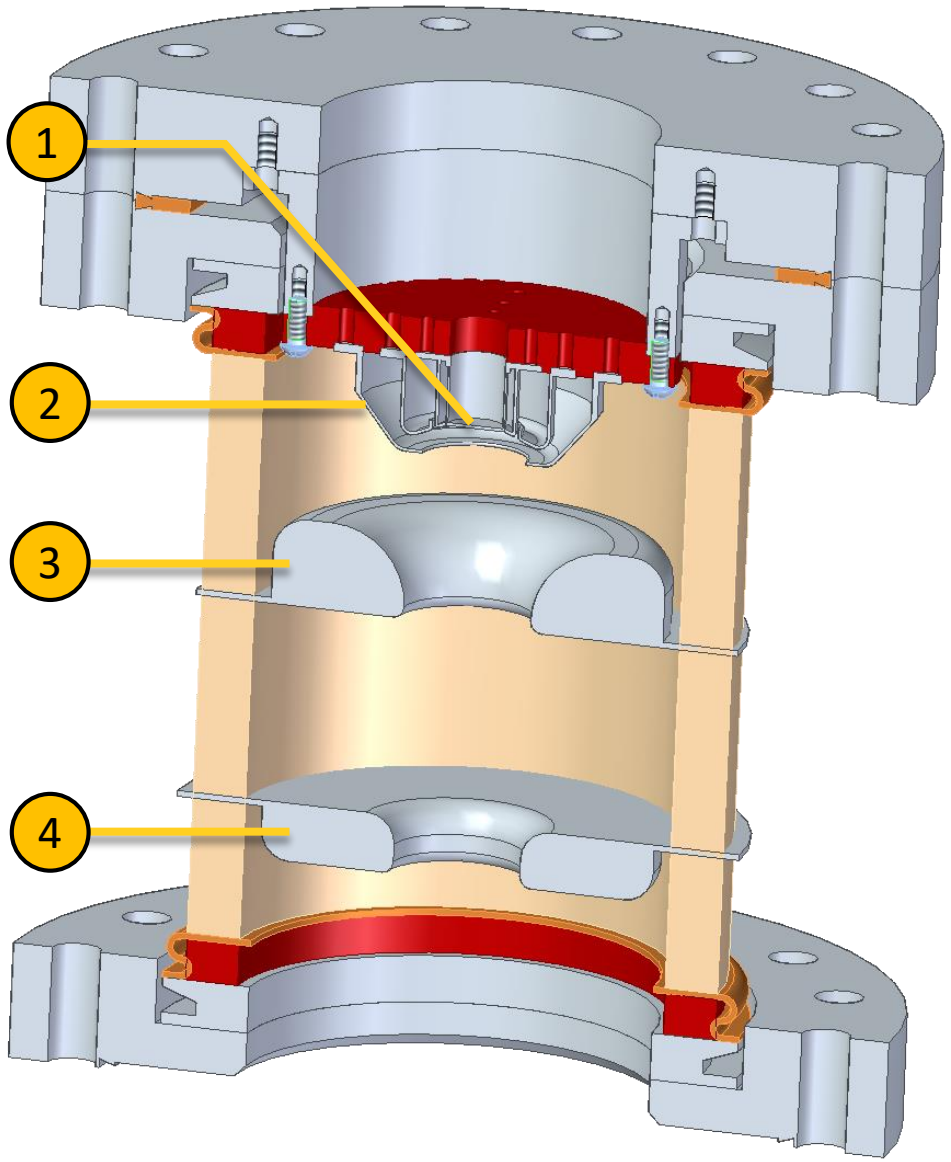
Tests of the Gun Prototype for the Electron Cooling System of the NICA Collider

Presenter:
Andrey P. Denisov
Russian Academy of Sciences The Budker Institute of Nuclear Physics

Authors:
A.P.Denisov, M.I.Bryzgunov, A.Bubley, V.Chekavinskiy, A.D.Goncharov, A.Ivanov, V.Parkhomchuk, A.Petrozhitskii, V.B.Reva, E.R.Urazov

Abstract:
The efficiency of the electron cooling depends on the electron beam quality produced be the electron gun. The characteristics of the electron gun were tested on the test bench with the linear transport channel. For the beam diagnostics, we used beam position monitors alongside with the W-Re wire sensor for 1-D quantitative profile measurements. We also used a high-definition CCD camera with high sensitivity for qualitative 2-D measurements of the electron density distribution via the wire thermal radiation.

ELECTRON GUN



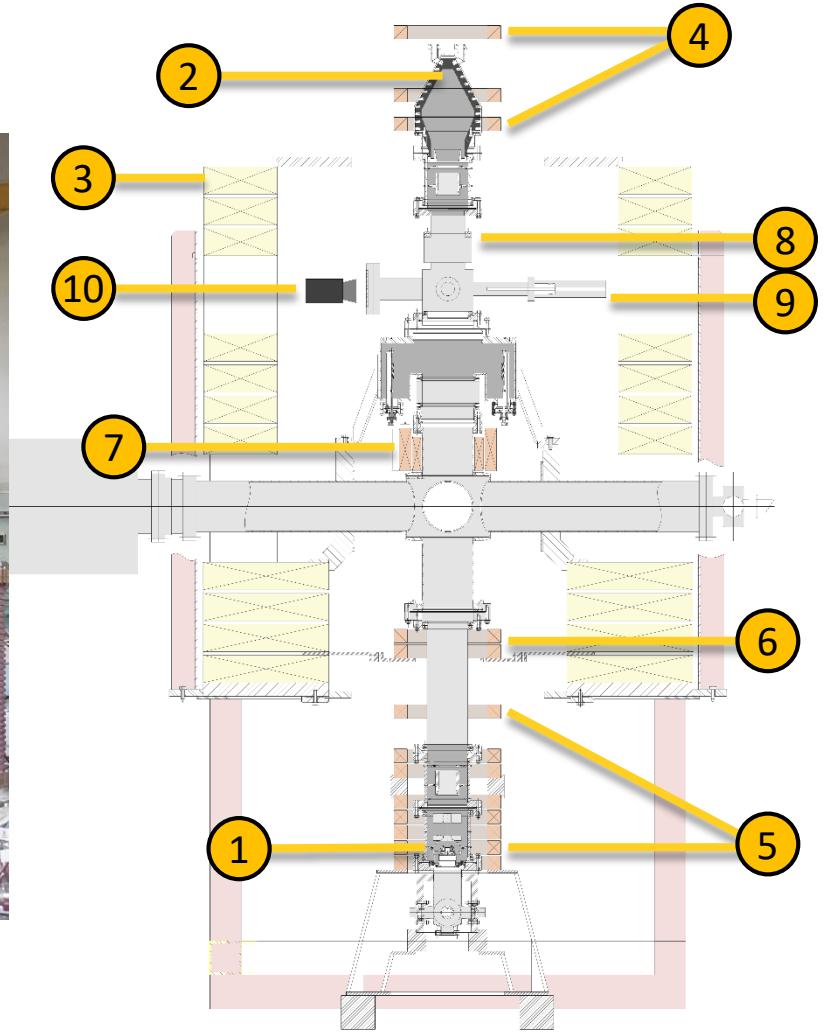
The electron gun we tested has the flat BaO cathode of 1 cm diameter. The cathode has the shielding electrodes similar to the Pierce electron gun.

For controlling the emission from the cathode, the anode and the control electrode are used. The anode controls the overall emission, whereas the control electrode controls the emission from the edges of the cathode. This allows us to change the electron current density distribution of the beam. Also an auxiliary electrode is introduced, which controls the output energy of the electron beam.

The gun is emerged into the longitudinal magnetic field. Positions of all electrodes is calculated in order to minimize the amplitude of Larmour oscillations.

1. Cathode
2. Control electrode
3. Anode
4. Auxiliary electrode (setting the beam output energy)

TEST BENCH

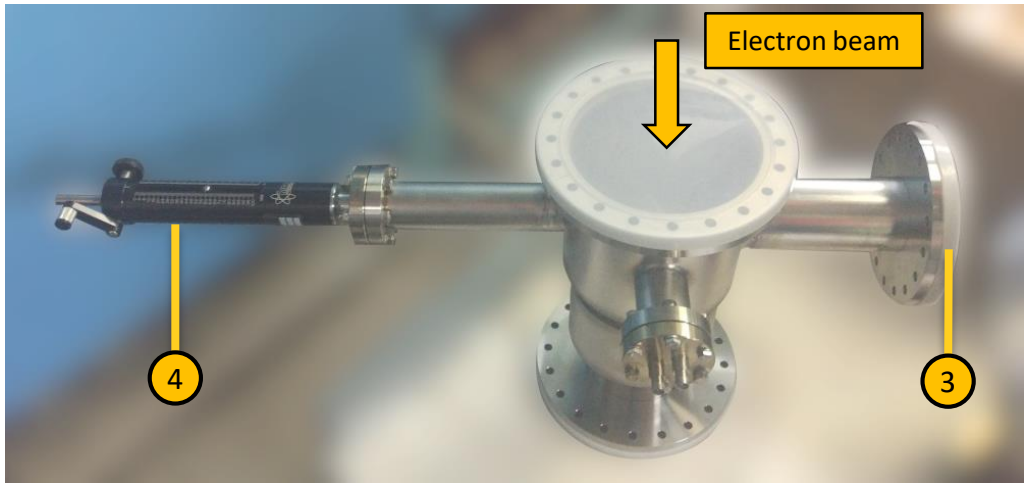


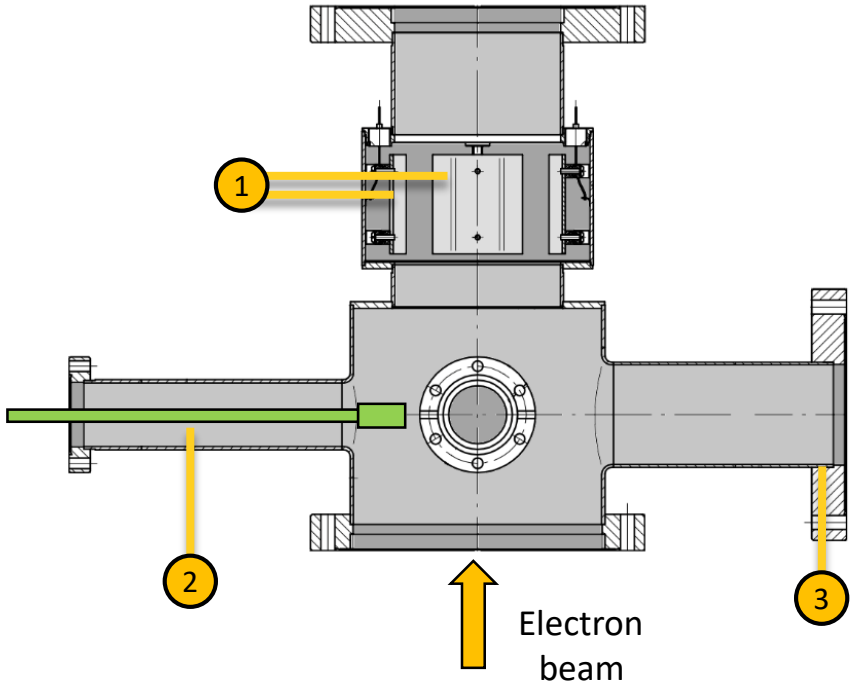
For testing the electron gun and developing the beam diagnostics techniques the test bench with a linear structure was assembled. It includes the magnetic coils for providing a longitudinal magnetic field about 900-1000 Gauss along the beam transport channel. The electron energy is up to 30 keV.

The profile scanning is performed by shifting the beam in the transverse direction so the electron beam crosses the beam profile sensor. We use two pairs of magnetic coils for producing the transverse magnetic field.

1. Electron gun
2. Collector
3. Coils for creating the magnetic field in the transport channel.
4. Coils for adjusting the magnetic field around the collector.
5. Coils for adjusting the magnetic field around the electron gun.
6. Coils for adjusting the Larmour oscillation phase
7. Coils for shifting the beam in the transverse direction (by shifting the magnetic force lines).
8. Diagnostics chamber (BPM + wire-based profile sensor)
9. Movable holder for changing the position of the wire sensor in the diagnostics chamber.
10. CCD camera for analyzing the thermal radiation from the wire profile sensor.

BEAM PROFILE MEASUREMENTS CHAMBER





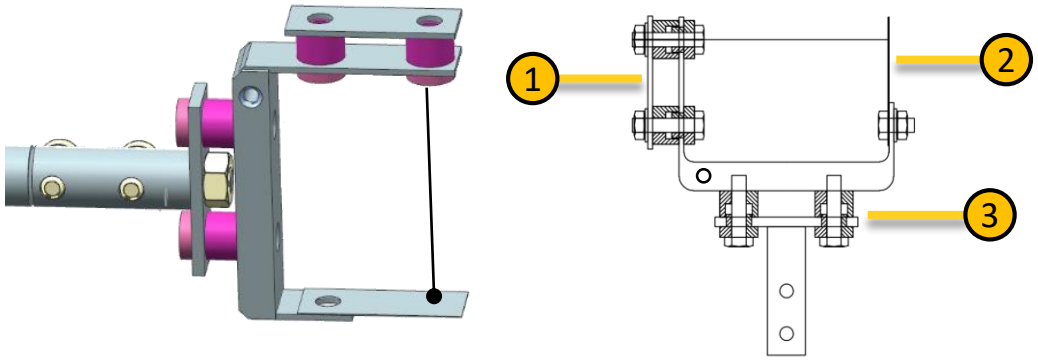
The diagnostics chamber includes the Beam Position Monitor (BPM), a channel for the wire-based beam profile sensor placed on a movable holder and a channel with a vacuum feedthrough.

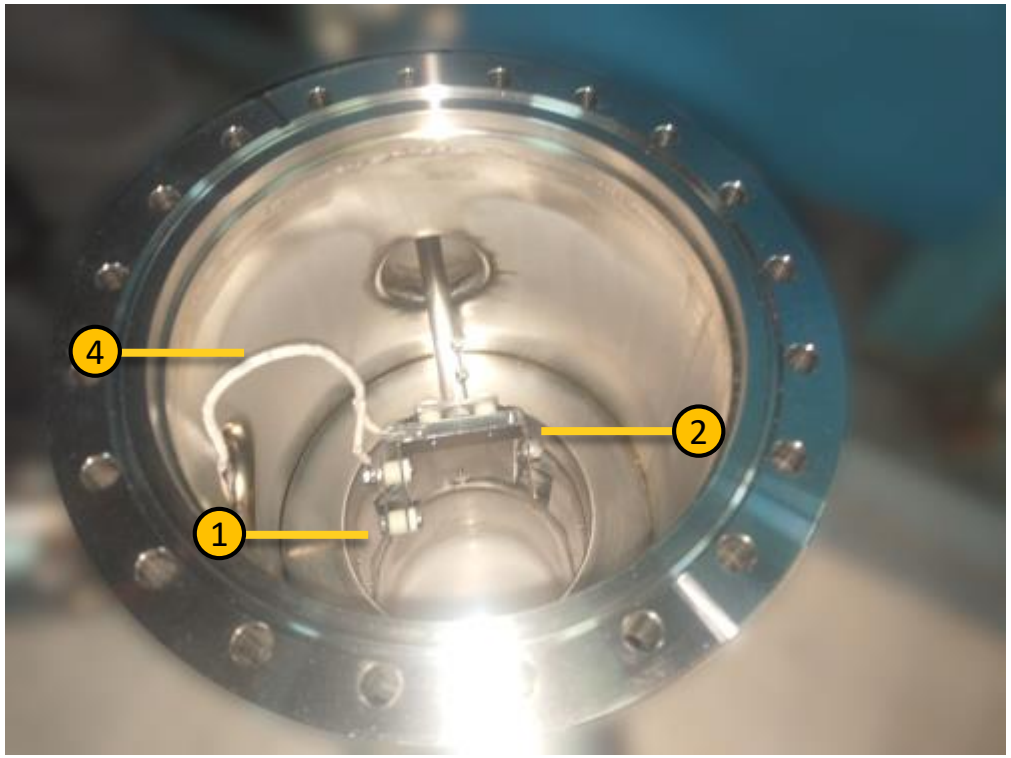
The BPM is used to control the position of the beam, necessary for performing the profile scanning. It also is used to measure the shape of the beam.

The window is necessary for the measurements of the thermal radiation of the wire. Such measurements can be used to restore the 2D profile, while the current measurements alone can provide only 1D profiles.

1. Plates of the BPM
2. The wire sensor attached to the movable holder.
3. Viewport for analyzing the wire thermal radiation.
4. Vacuum feedthrough

WIRE SENSOR FOR THE BEAM PROFILE MEASUREMENTS





For measuring the electron beam profile we use a wire-based profile sensor. The wire is 25 μm in diameter and made of W-Re alloy (85%/15%). The beam profile scanning is performed by changing the relative position of the beam and the wire.

When wire is heated, its length increases. To prevent the wire from sagging the flexible plate is used, which pulls the wire.

The current is measured through the shunt connected through wires to the rigid plate and the U-shaped part of the holder.

This design also allow us to let the current from the external power supply through the wire in order to heat it (for cleaning the wire and for thermal radiation measurements).

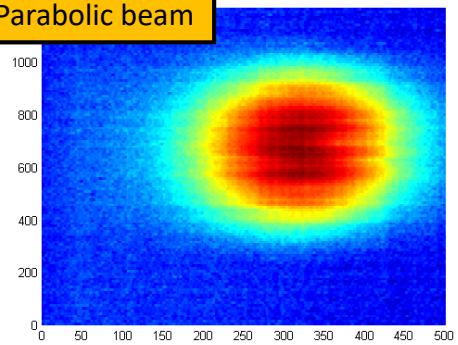
1. Rigid plate for attaching the wire
2. Flexible plate for attaching the wire
3. Insulators, for preventing the electrical current flow through the holder.
4. Wires for measuring the electrical current and letting the current to the wire sensor from the external power supply.

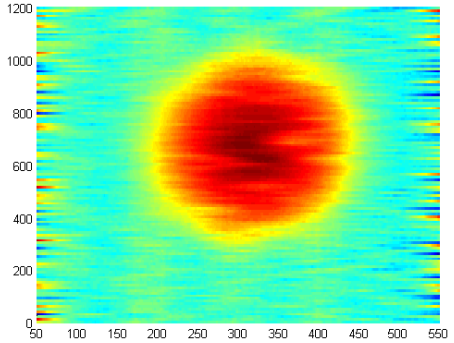
BEAM PROFILE MEASUREMENT RESULTS

Raw camera measurements (temperature)

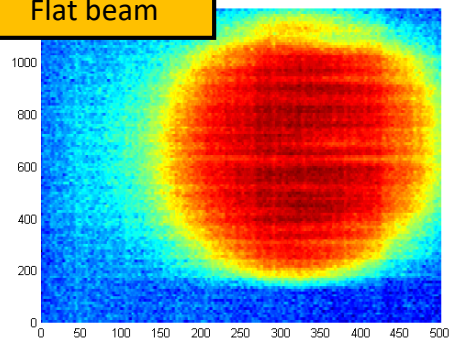
Taking thermal conductivity of the wire into account (current density)

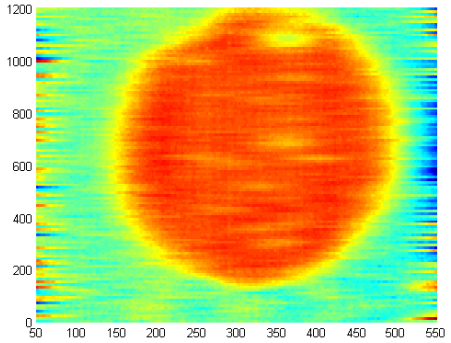
Parabolic beam



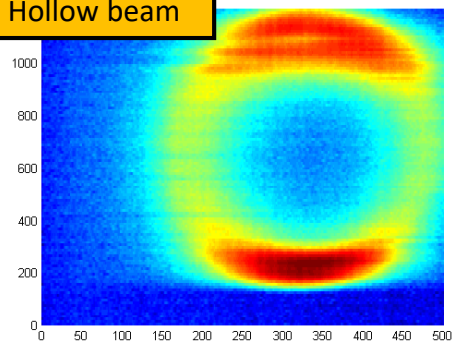


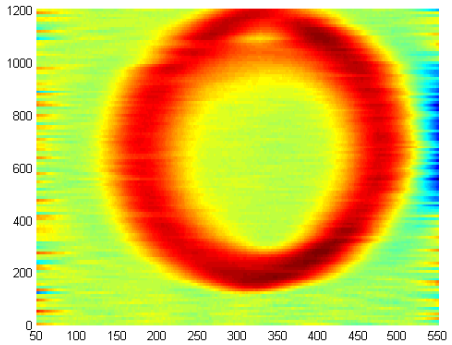
Flat beam





Hollow beam





The wire sensor was calibrated by analyzing the camera signal while the wire was connected to the external power supply with controllable current.

Due to the thermal conductivity an electron beam heats up not only the part of the wire where it is absorbed, but also its adjacent parts. Therefore, the signal from the camera doesn't match the actual distribution of the current density (images on the left side).

We can associate the current distribution with the measured temperature using the steady-state form of the heat equation (images on the right side).

$$T''(x) = A \cdot j(x) + B \cdot T^4(x) + C$$