GRAN SASSO
SCIENCE INSTITUTE

Updates on Electron Gun @ LNGS

Presentation for PTOLEMY National Meeting - Rome, 19 February 2025

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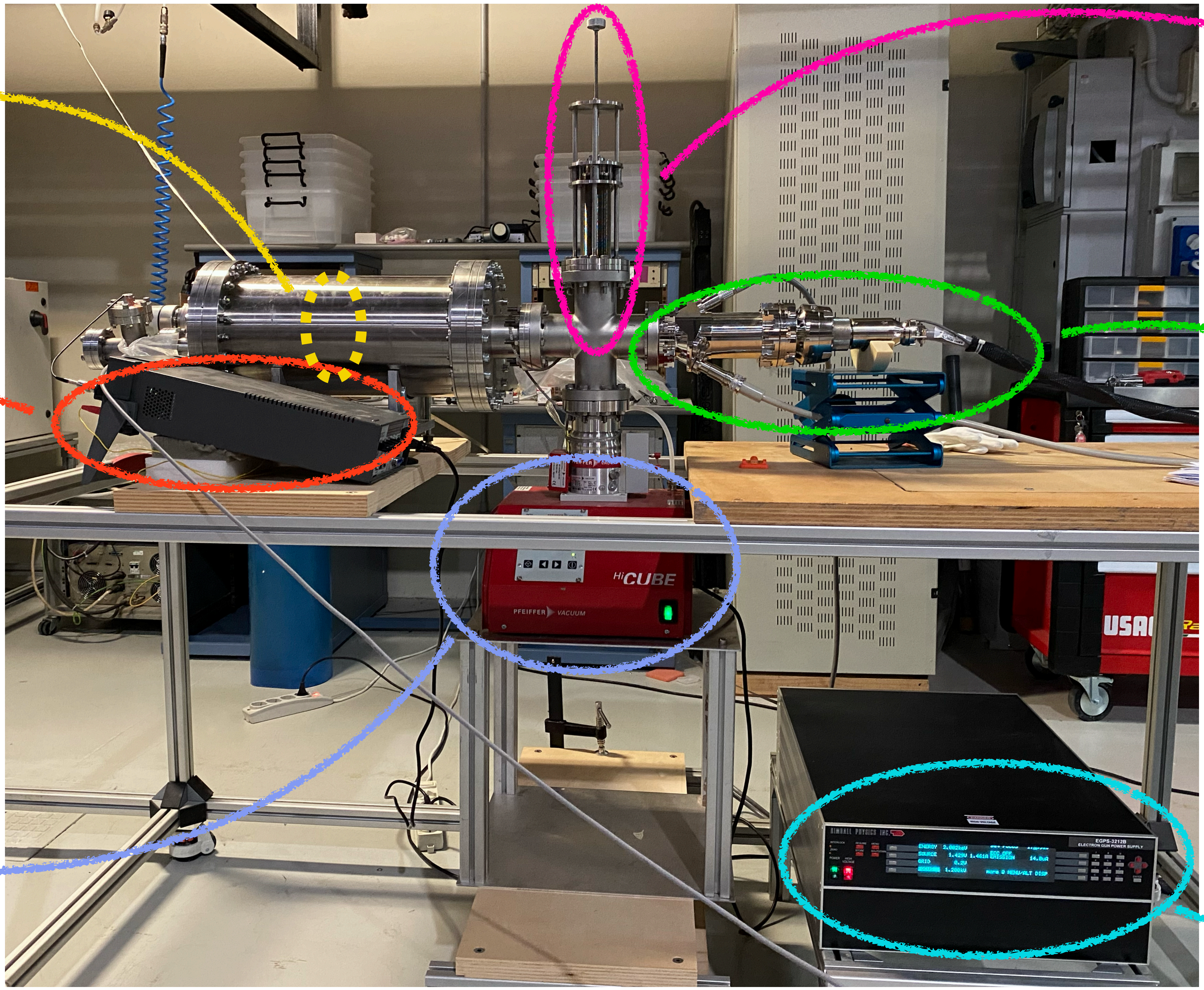
How the Full Setup Looks Like



MICRO CHANNEL PLATE

(INSIDE)

PICOAMMETER

VACUUM PUMP

FEEDTROUGH

+ (INSIDE)

FARADAY CUP (FC)

&/or

PHOSPHOROUS

SCREEN

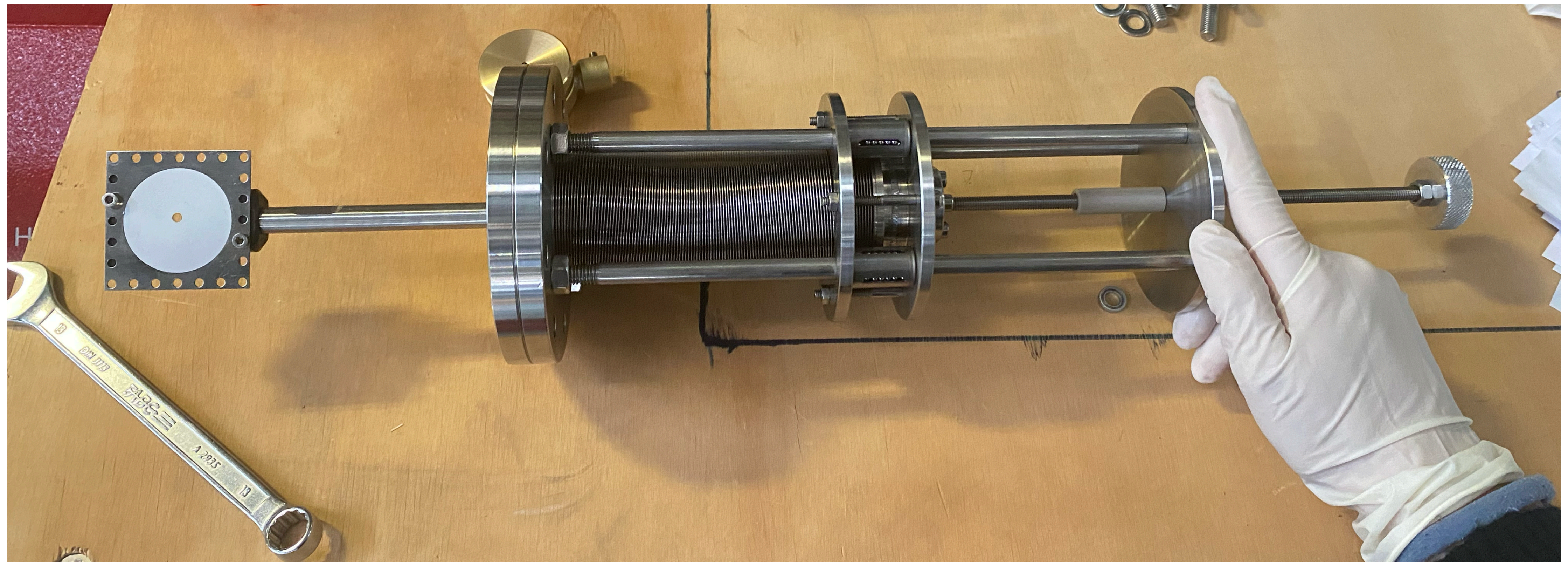
ELECTRON GUN

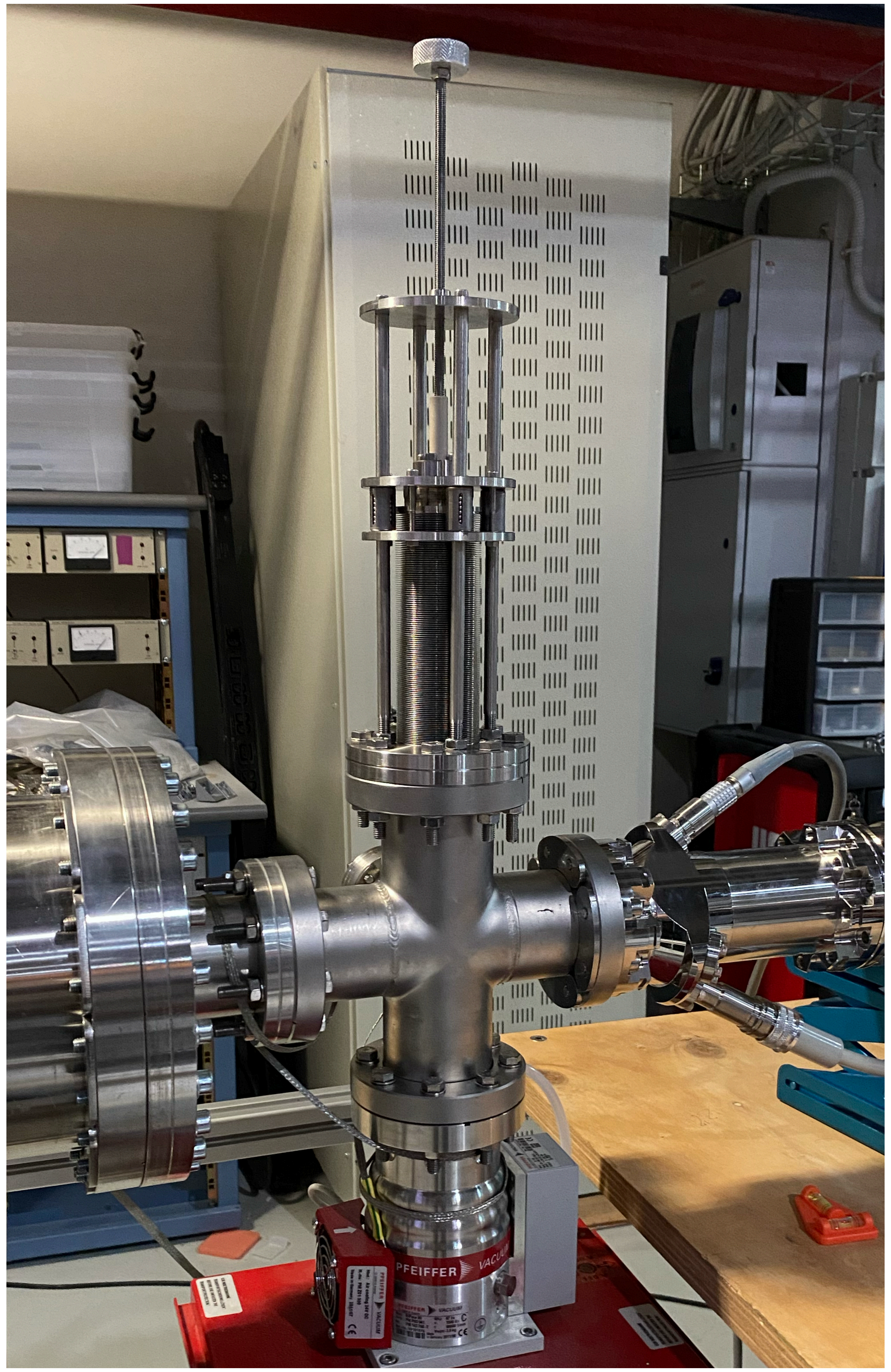
(E-GUN)

POWER SUPPLY

A Versatile Setup

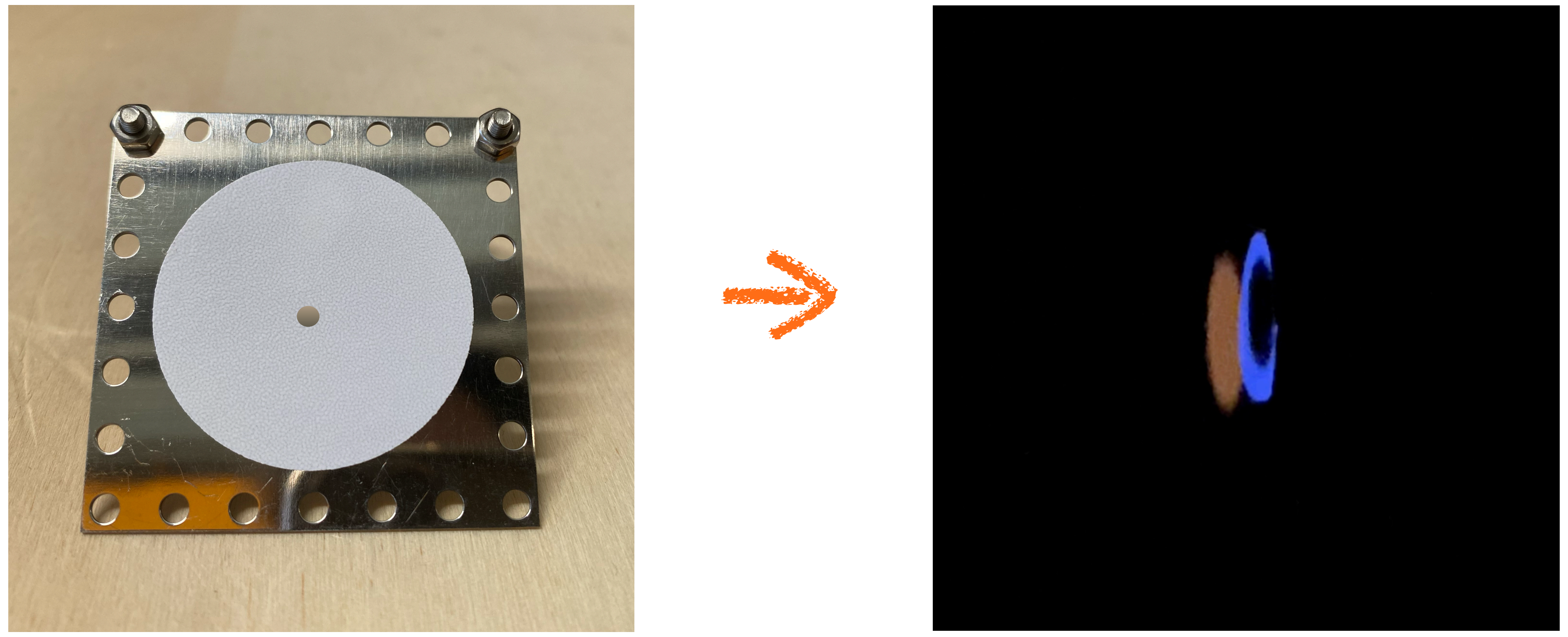
- Faraday cup &/or phosphor screen mounted on a feedthrough
  - ✓ Custom-made, in collaboration with LNGS Mechanics Workshop
  - ✓ Allows shifts on y-axis with sub-mm precision
  - ✓ Allows to completely remove beam monitoring unit from beam path



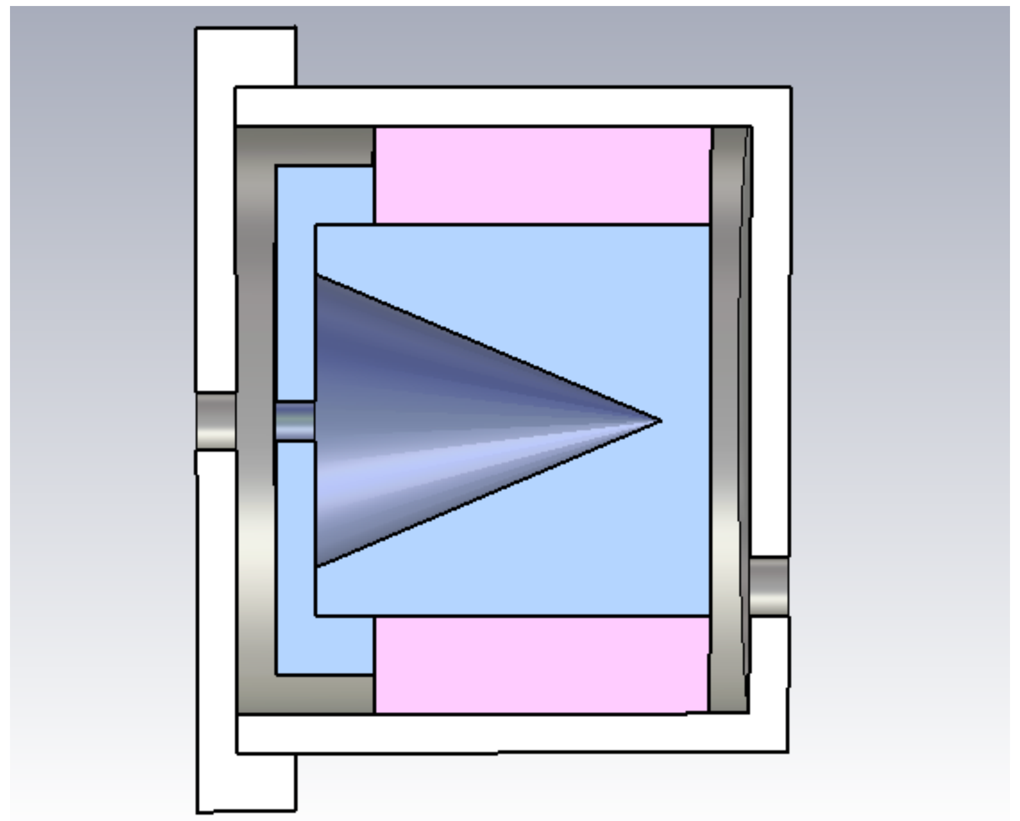


Output Monitoring: Ingredients

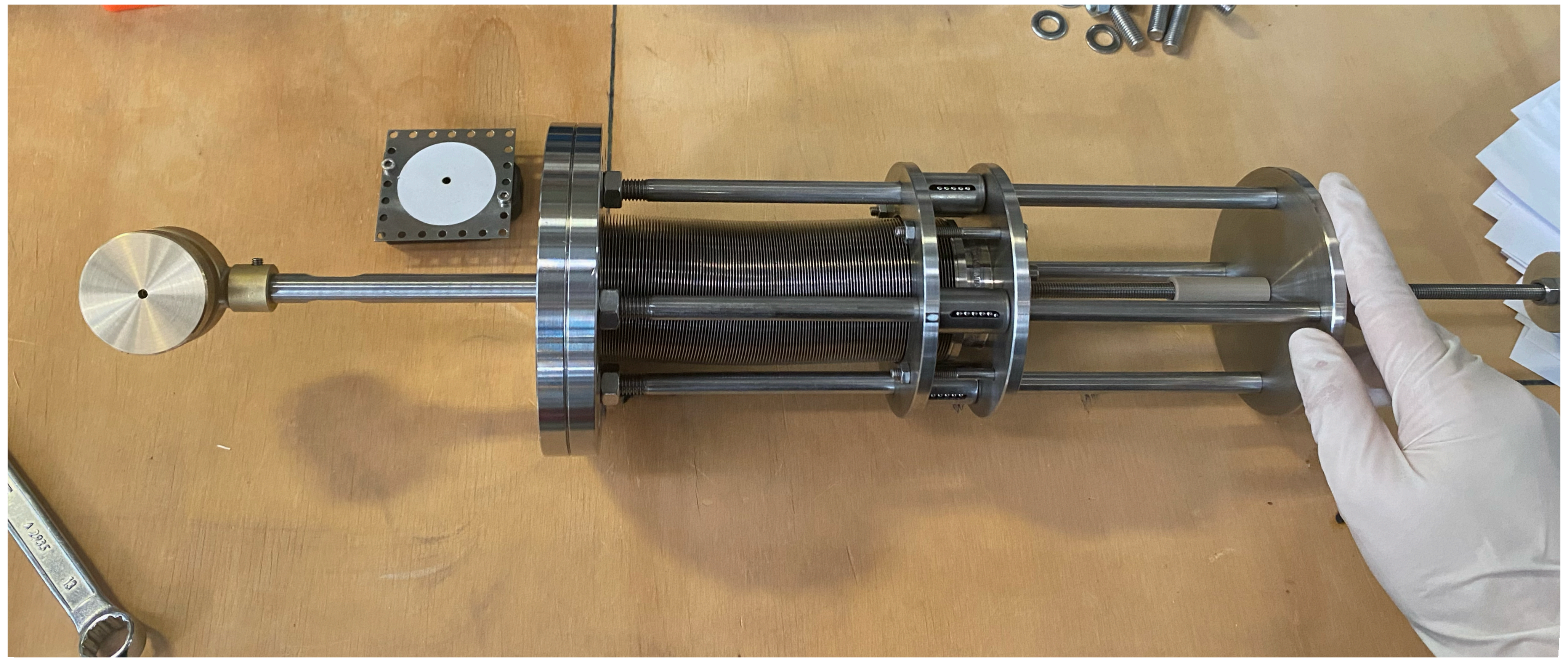
- Phosphorous screen:
  High luminosity blue phosphor disk, 4 cm diameter & 75 µm thickness on stainless steel
  - for preliminary gun focusing & centering



- Brass double Faraday cup



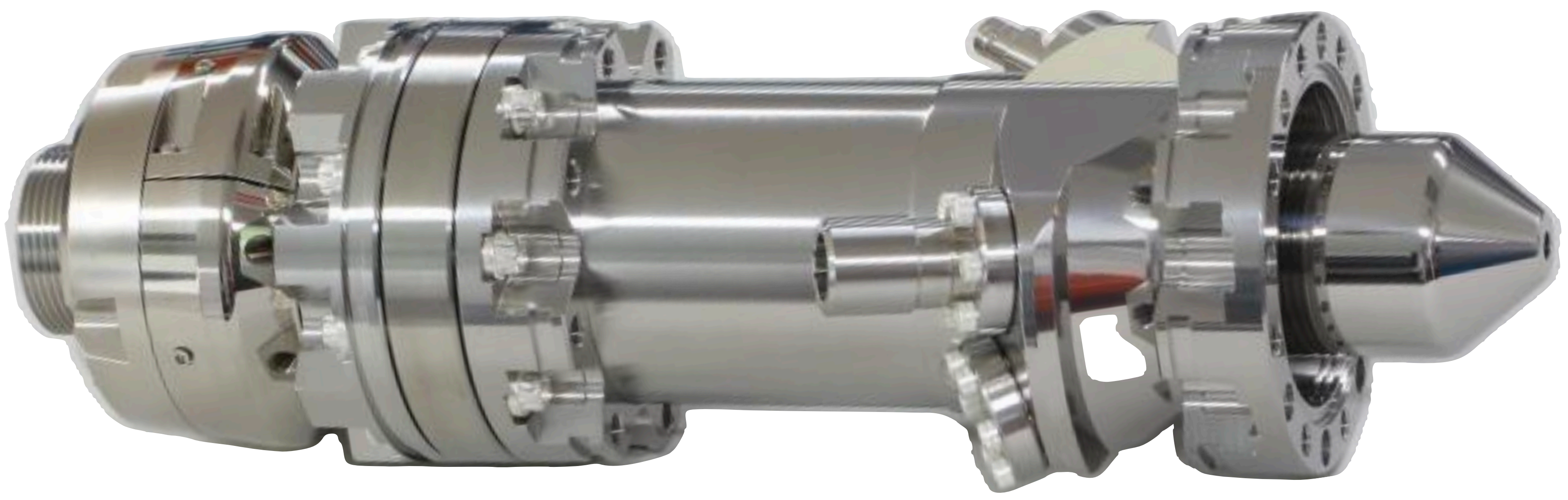
  - Outer grounded to shield, 3 mm hole diameter
  - Inner to read current, 3.5 mm hole diameter

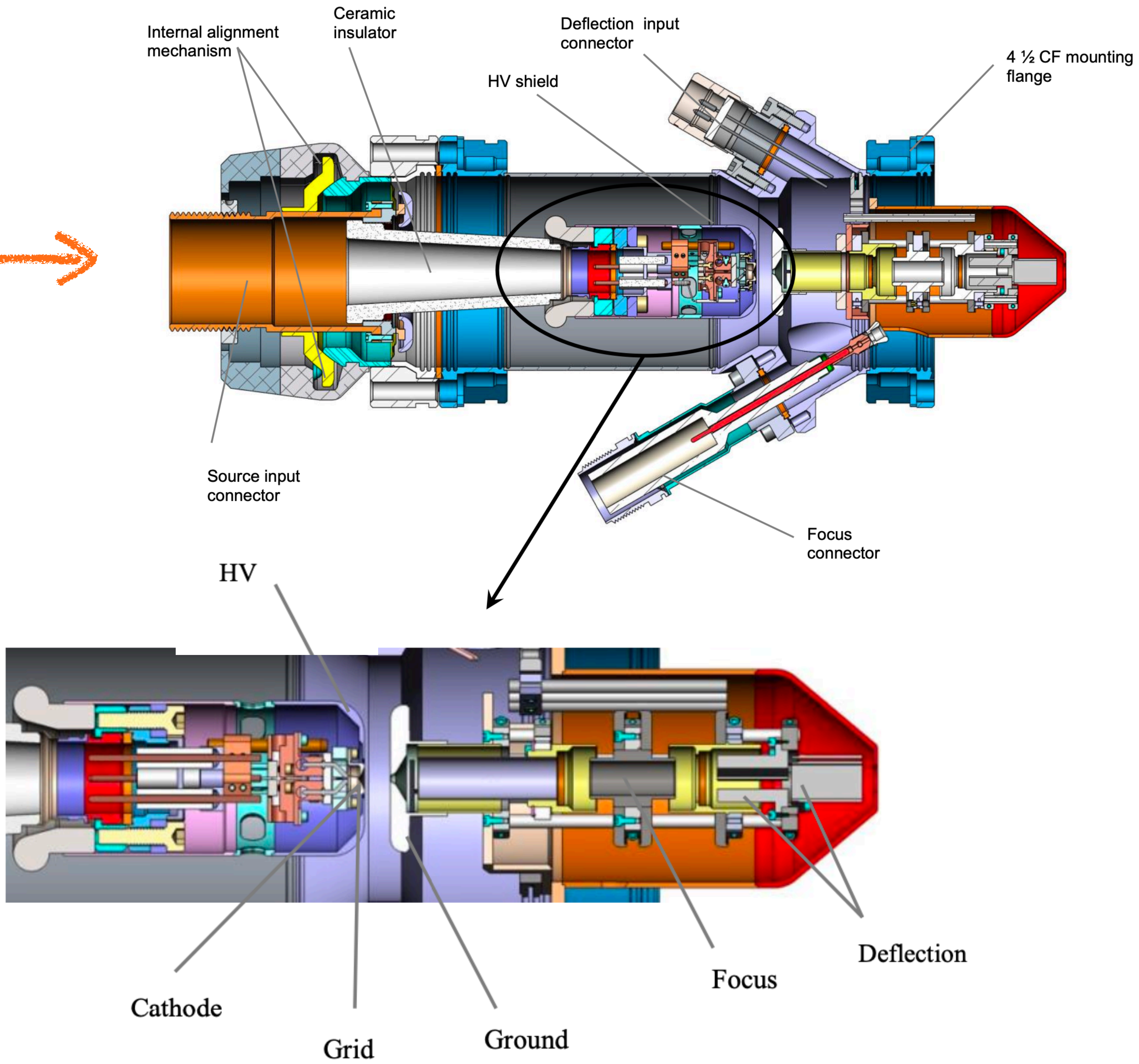


What’s Inside?

KIMBALL PHYSICS
Excellence in Electron and Ion Optics

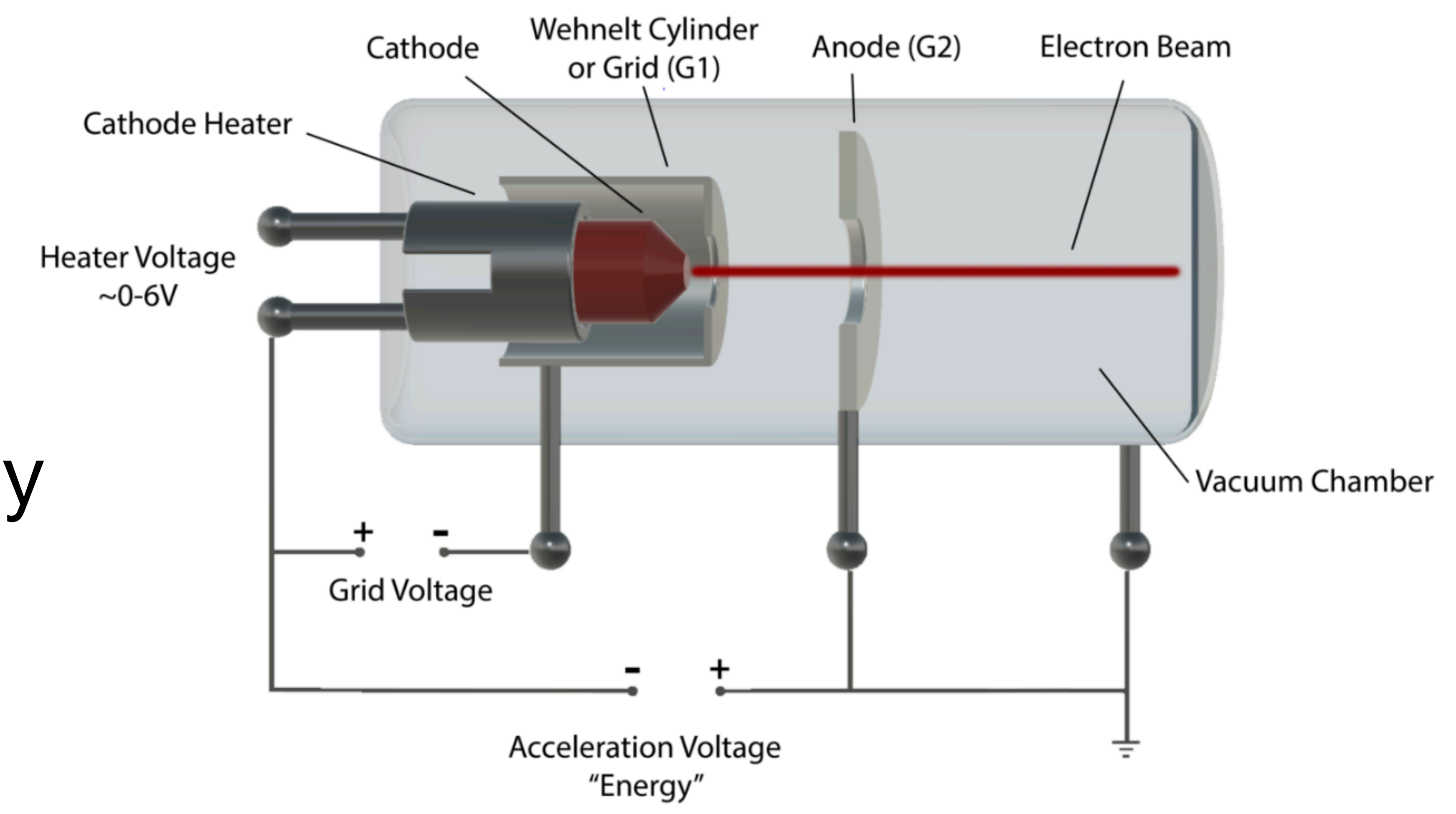
EMG-4212 / EGPS-3212
ELECTRON SOURCE / POWER SUPPLY





- Grounded Anode
- HV to accelerate electrons (up to -20 kV)
- Wehnelt (or grid, up to -500 V)
- Focus system (Einzel lens, up to -20 kV)
- X/Y deflection plates (up to ± 300 V)

Wehnelt as a Beam Intensity Filter



- What is?
  - Tubular housing for cathode with fixed aperture
  - Negative bias → secondary electric field in cathode proximity

- How can be employed?
  - Mid-range voltage → adjust beam divergence & uniformity → beam characterization (spot size, I-V curve etc.)
  - High voltage → reduce electron emission from cathode edges till complete beam suppression

→ **Beam Intensity Filter**

possible needing for future usage as *electron trap calibration source*

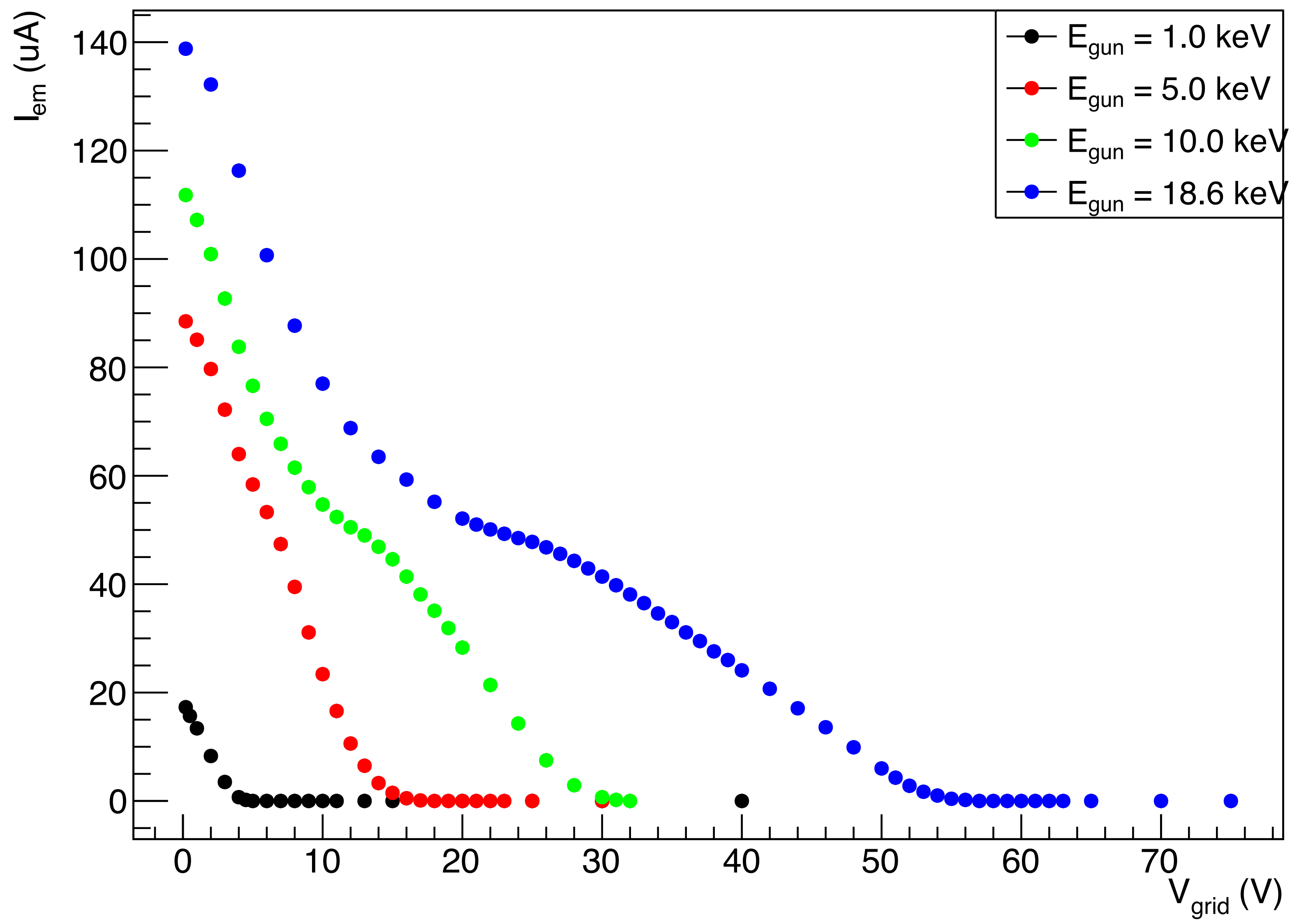
Beam Current Optimized by Wehnelt

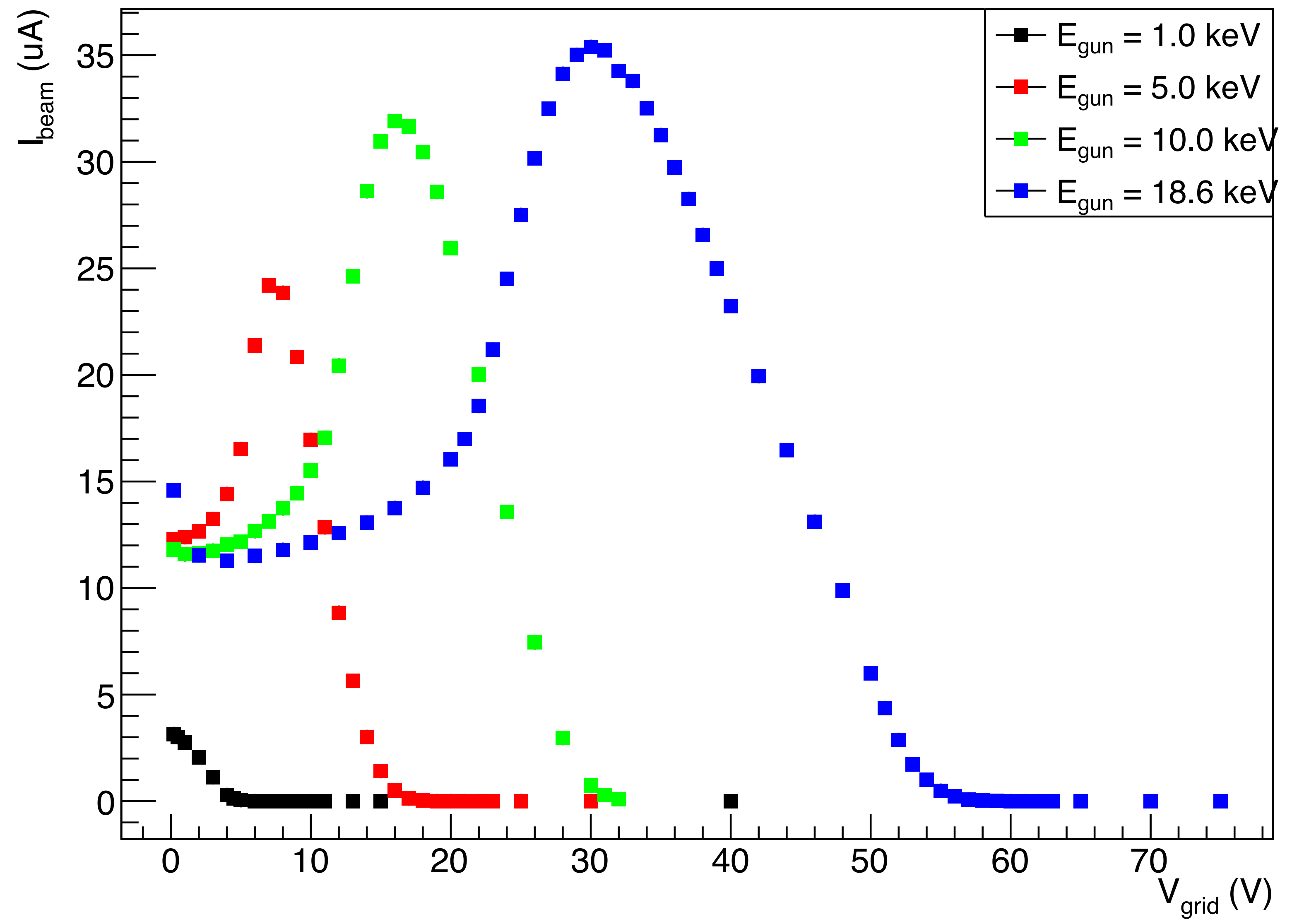
Setup:

- Keithley 2450 SourceMeter + double Faraday cup
- Beam electron energy: 1 keV, 5 keV, 10 keV, 18.6 keV
- Source voltage (V_{source}) set to 1.521 V
- Focusing & deflection voltages optimized through Phosphor screen for each energy
- Base pressure: 10^{-7} mbar

Results:

- Similar behaviors, different V_{grid} optimizing beam current
- Better I_{beam}/I_{em} ratio for lower electron energies



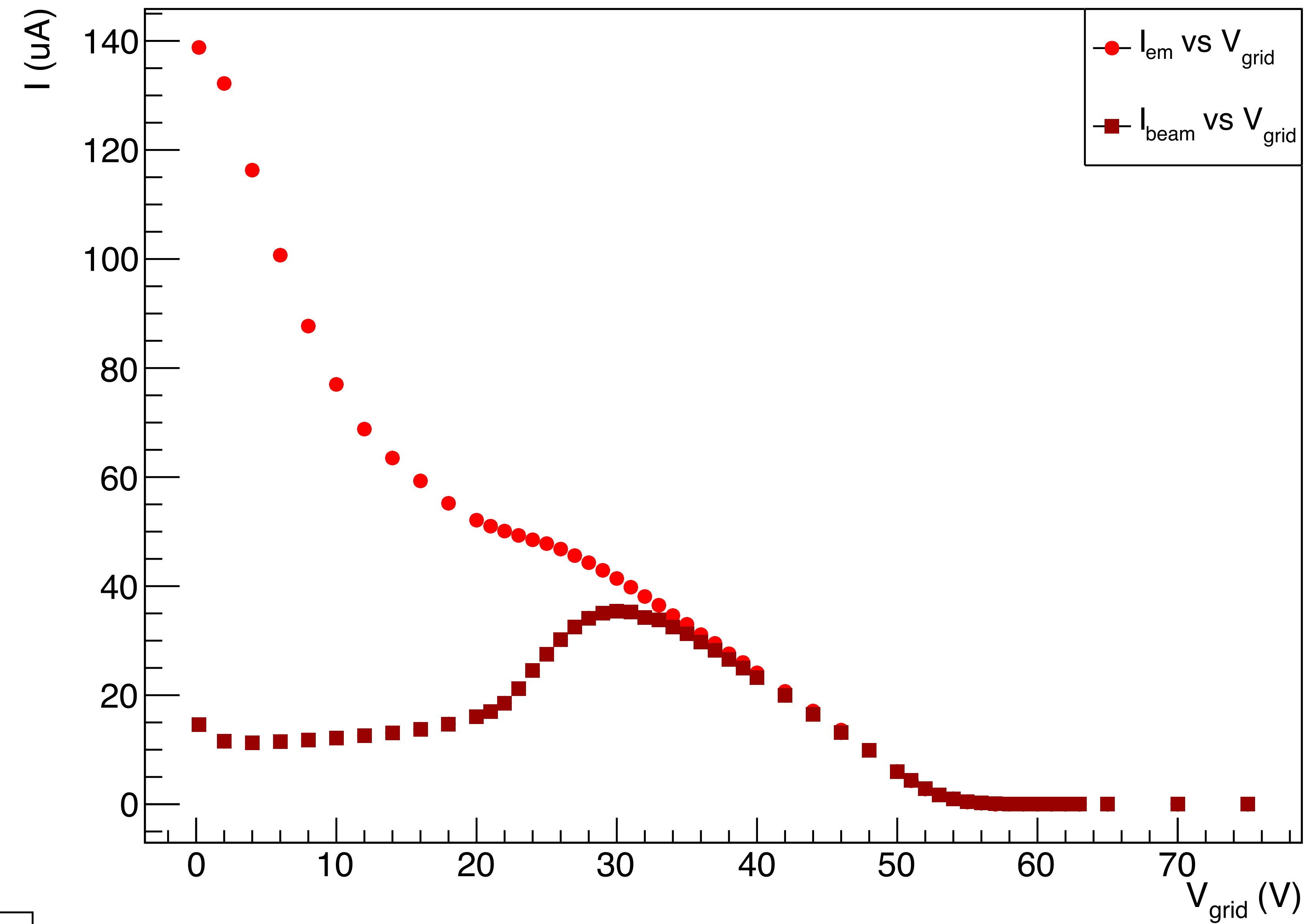


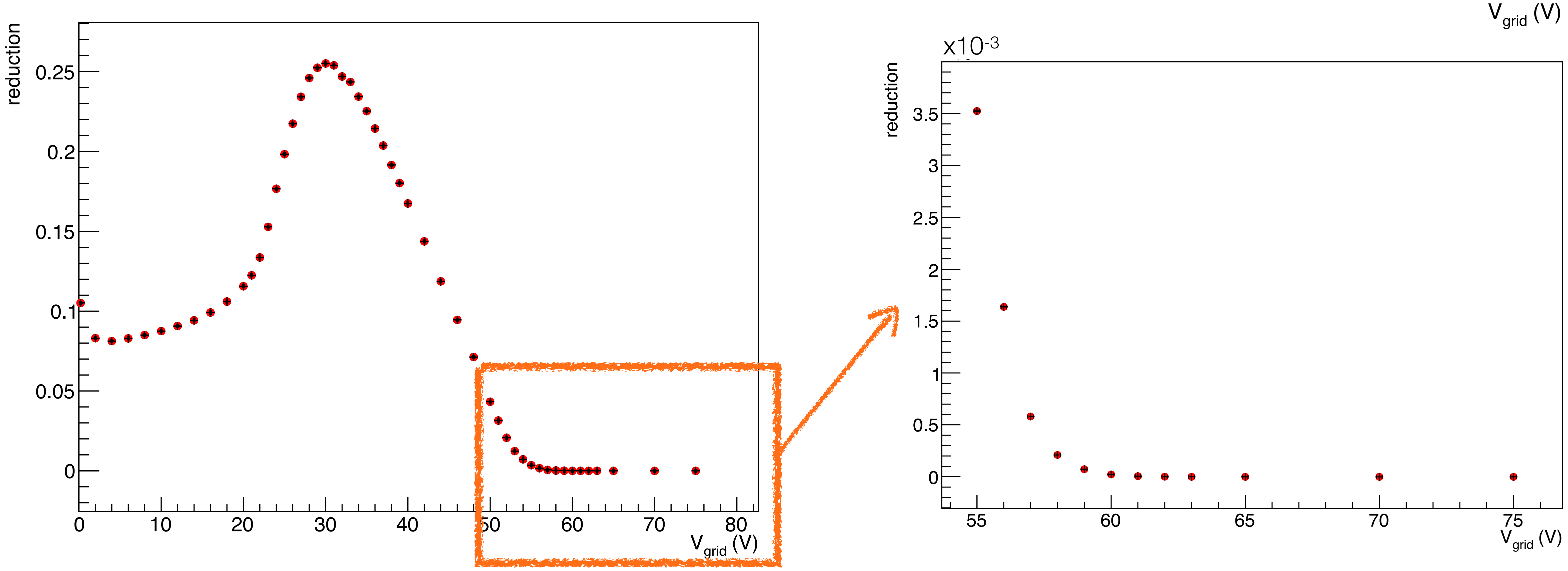
Up to 10^{-4} Reduction Factor

- Let’s define: - “collection” efficiency $\epsilon = I_{beam}/I_{em}$
  - reduction factor $r = I_{beam}/I_{em}(V_{grid} = 0V)$

- Focusing on run @ 18.6 keV:
  - beam current I_{beam} maximized for V_{grid} = 30 kV
  - ϵ from 11% to ~100% for V_{grid} > 45 kV
  - r > 10^{-4} for V_{grid} > 57 kV

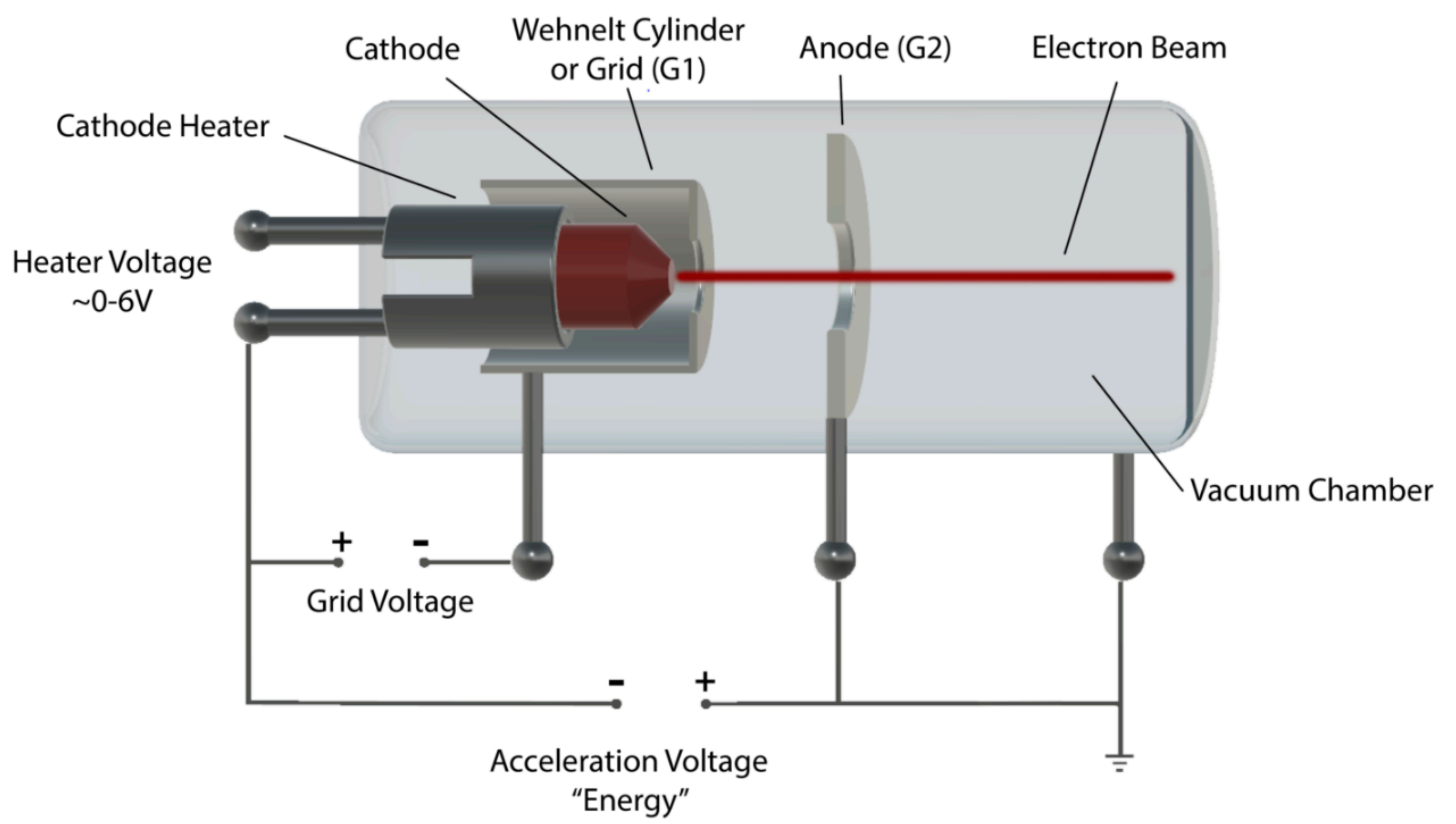
from 140 μA to 700 pA!
not able to read
higher reduction
for instrumental limit





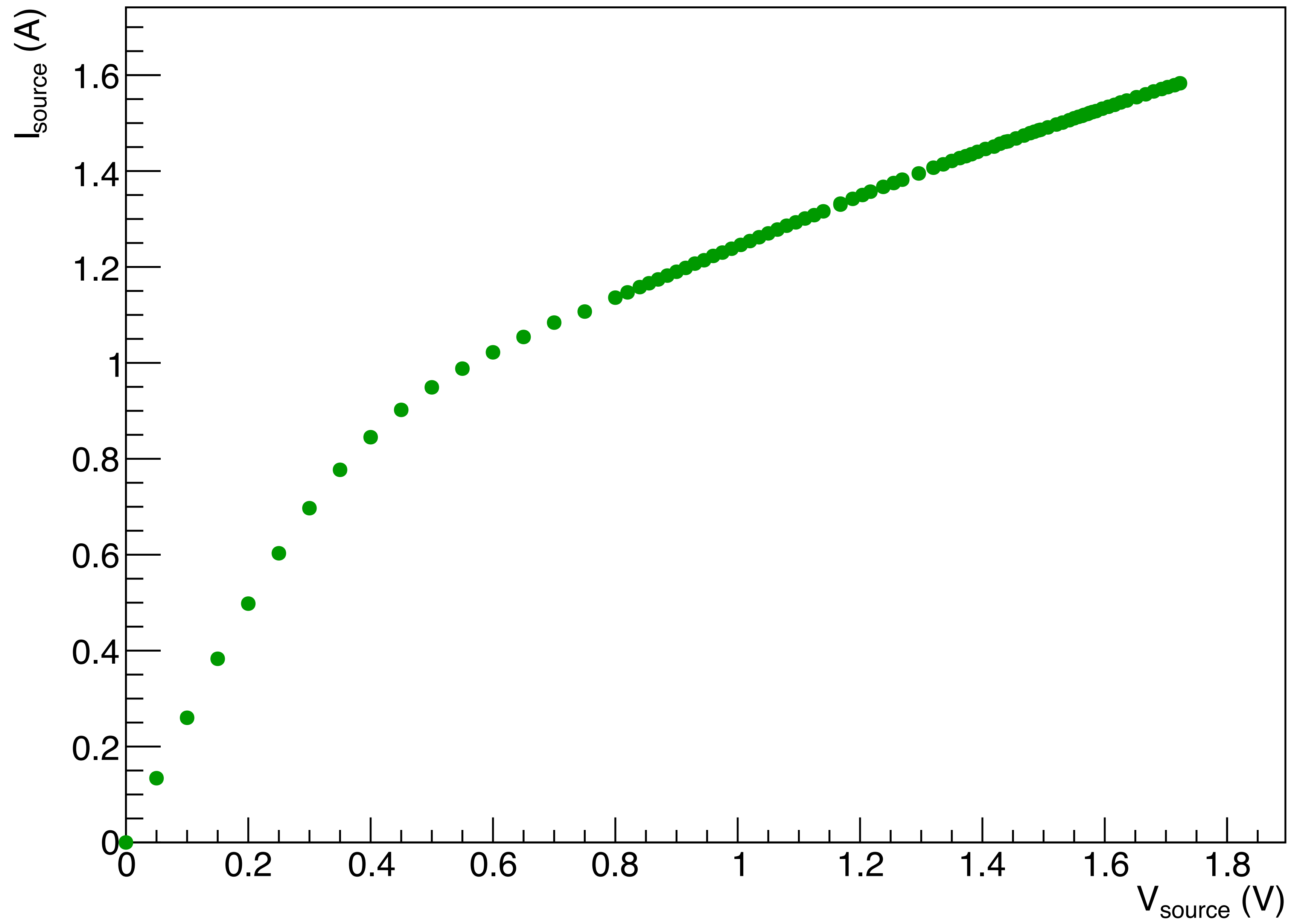
I-V Source Curve Linear in Emission Region

- Source = Refractory metal thermionic emitter
  - Tantalum disc, diameter 25 mm on tungsten hairpin filament
  - Circular, planar emission surface
  - Emitting electrons when filament heated by voltage source with energy spread 0.5 eV



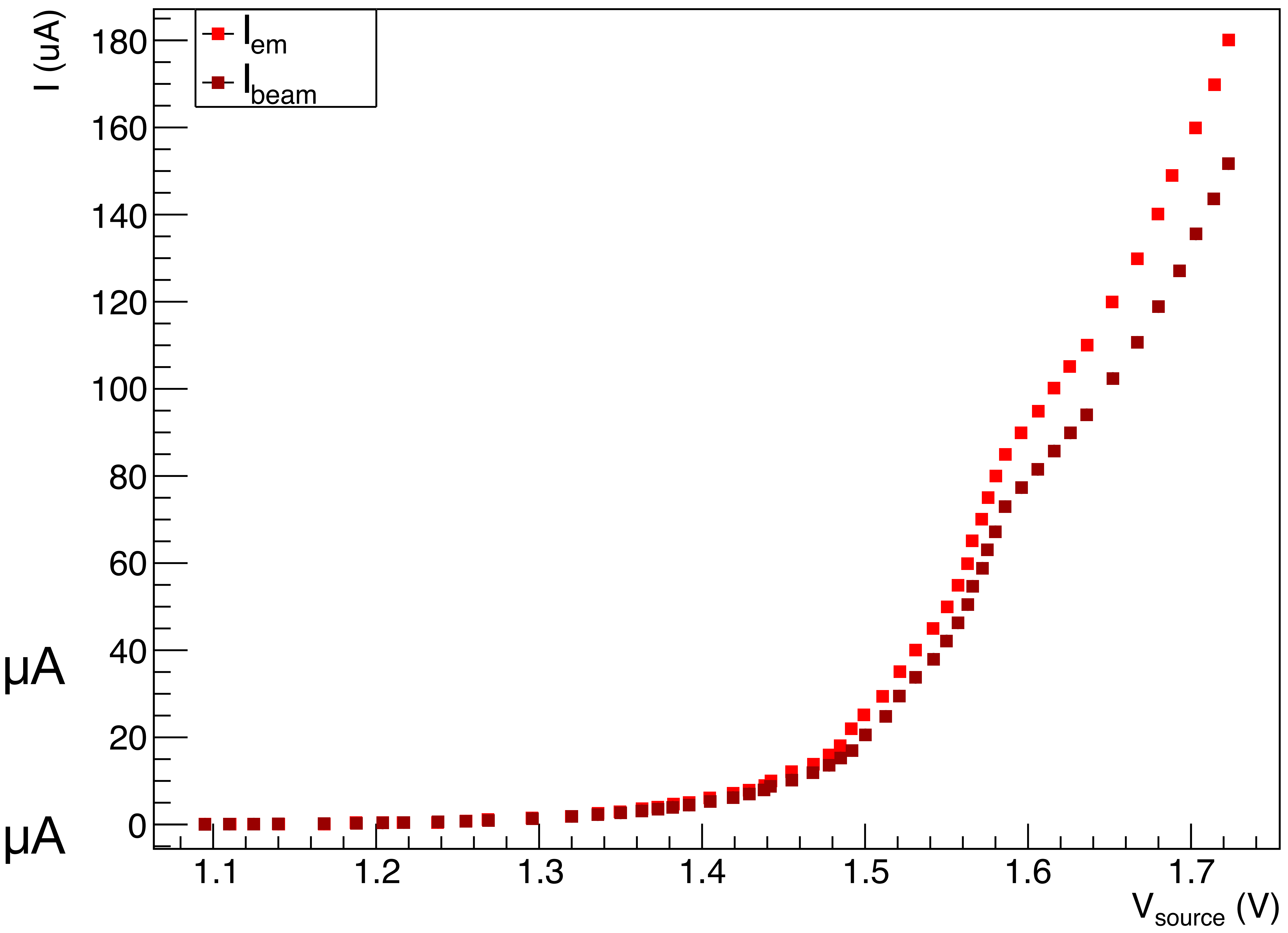
- Both voltage applied & current in filament displayed on power supply monitor

- I-V curve to characterize source
  - Linear behavior in the emission region ($V_{source} > 1$ V)
  - ~1 day stabilization



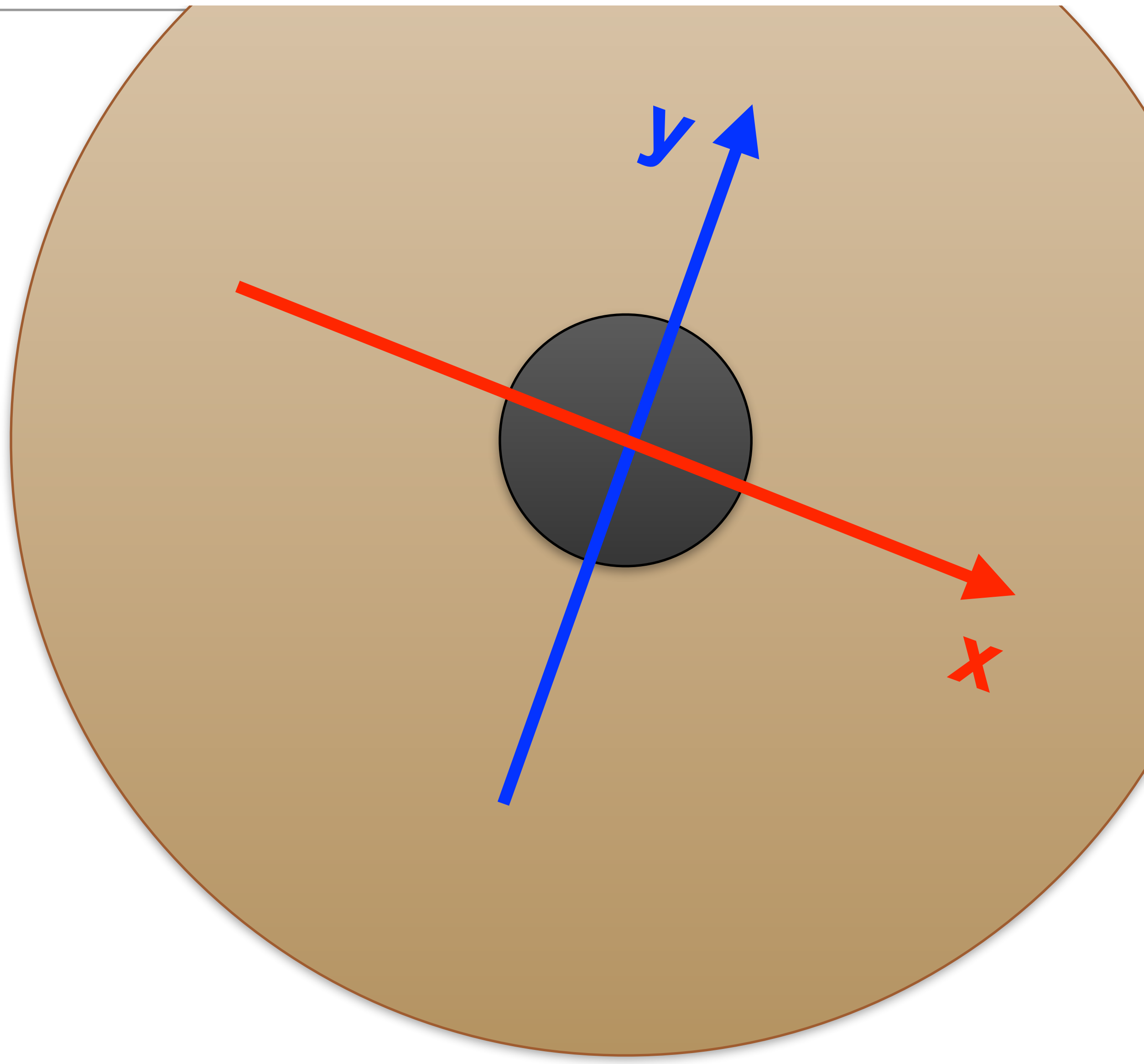
Agreement Between Measured & Emitted Current

- Setup:
  - Keithley 2450 SourceMeter + double FC
  - 18.6 keV electron energy
  - V_{grid}= 30 V (I_{beam} optimization value)
  - Focusing & deflection voltages optimized through Phosphor screen
  - Base pressure: 10^{-7} mbar
  - I_{em} in *controlled mode* from 0.1 μA to 180 μA



- Same behaviour, ~100% efficiency for I < 10 μA
- Discrepancy & stabilization time increase with V_{source} increasing

Preliminary Estimate of Beam Size



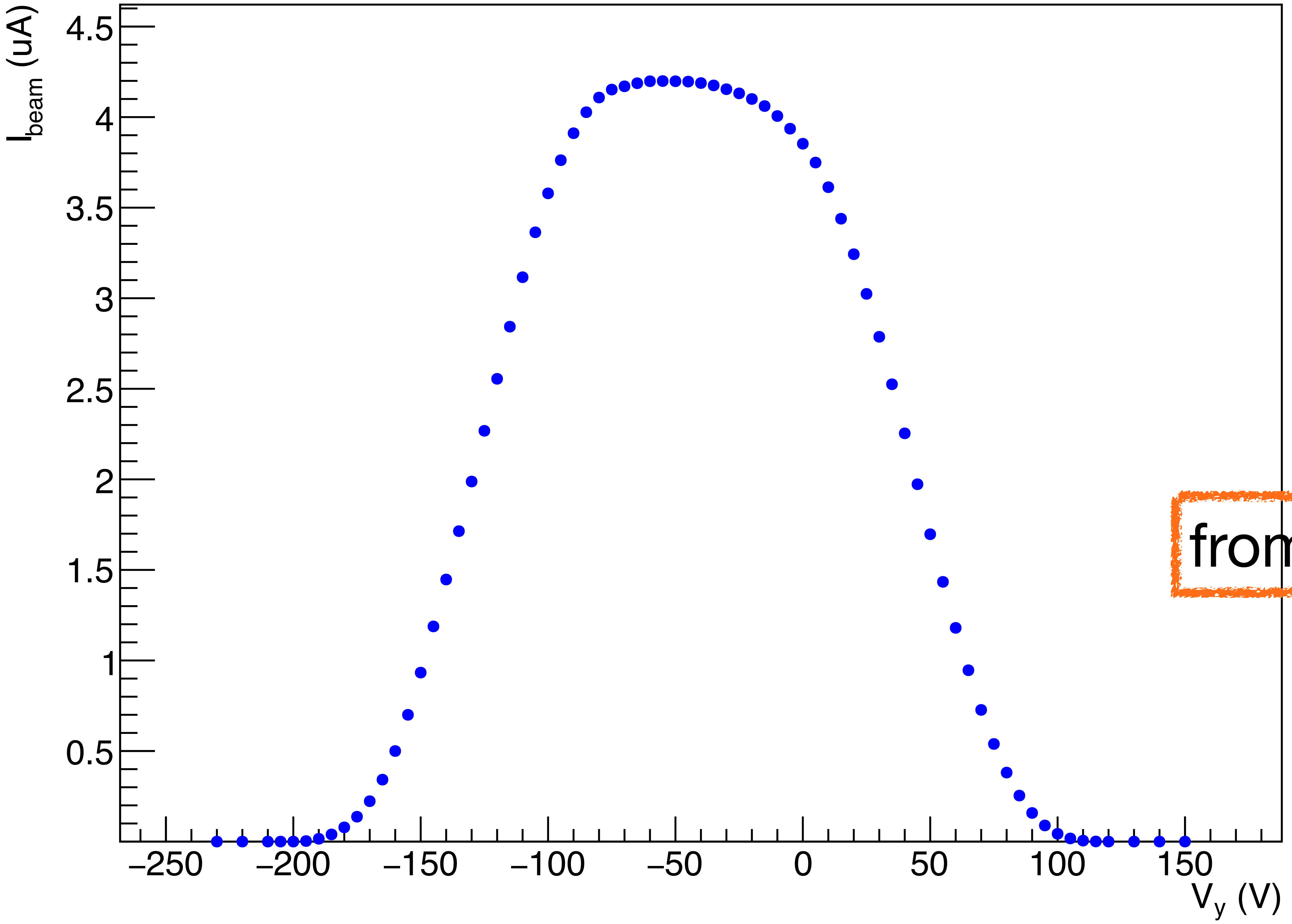
- Aims:
  estimate beam size + find correlation deflection voltage - position shift

- Scan of 3 mm Faraday cup hole moving beam with deflection voltages

  - I_{em} fixed to 5 uA

  - V_y from -240 V to 150 V with 5 V steps

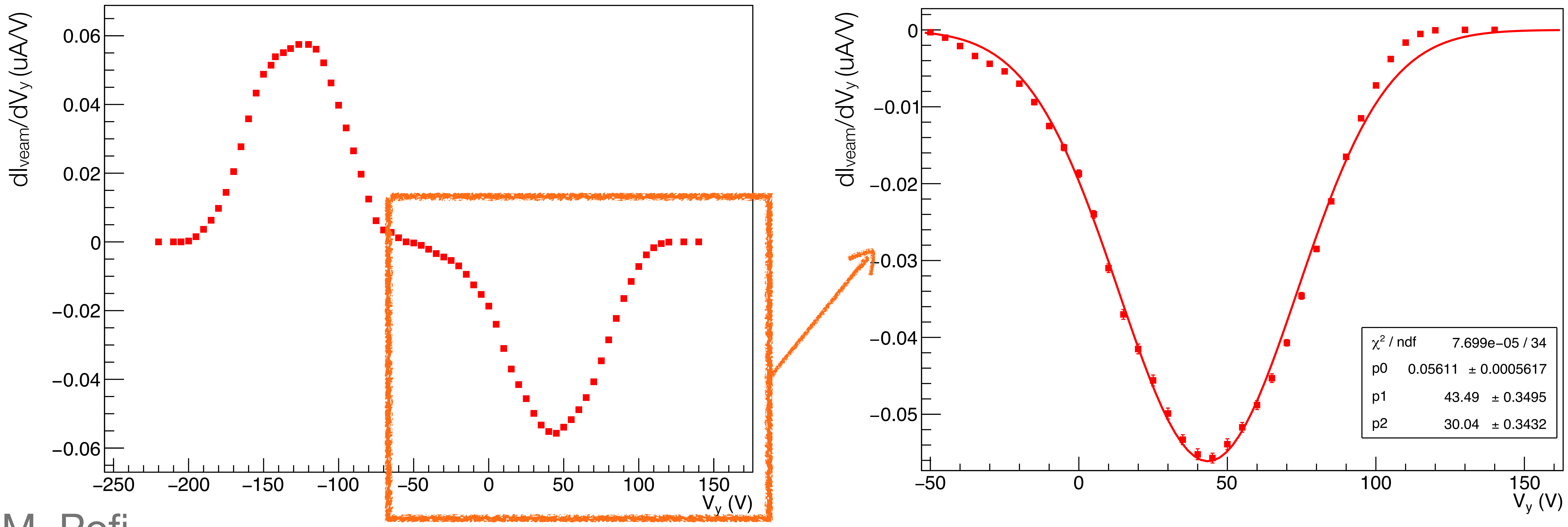
Result = convolution of
- gaussian
(e-gun spatial current distrib)
- step function (FC hole)



from rise & fall info

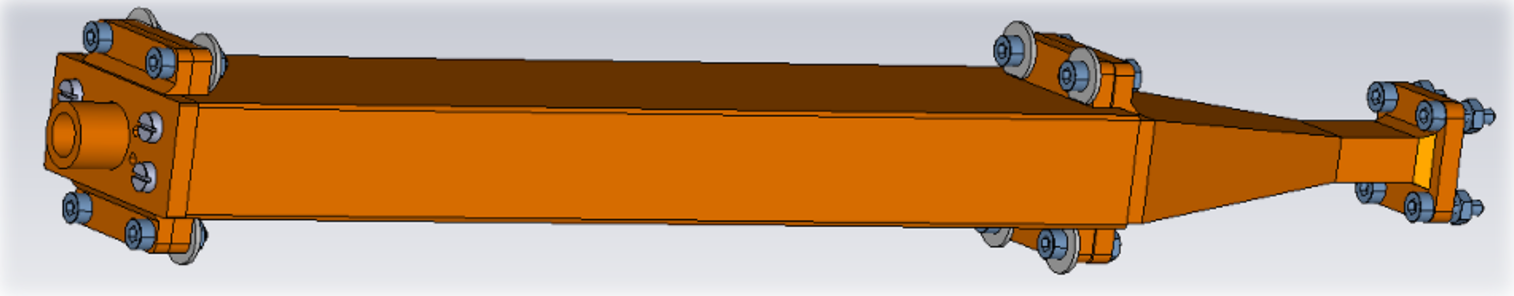
Sub-mm Spot Size

- From 1st derivative of I_{beam} vs V_y points (computed as $I_{beam}(V_y^i) - I_{beam}(V_y^{i-1}) / V_y^i - V_y^{i-1}$)
  - Gaussians reflecting beam spatial distribution with
    - Distance (peak to peak) $\simeq$ 170 V = FC hole diameter = 3 mm → 1 V = 0.0176 mm
    - $\sigma = 30 \pm 0.3$ V (fitted from 2nd gaussian) → $\sigma = 0.53$ mm

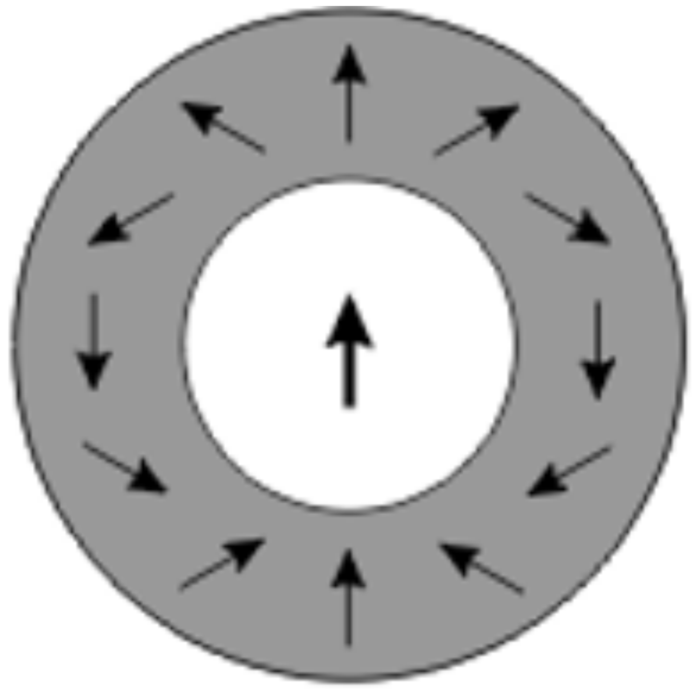


Electron Injection in the Trap: The Magnet

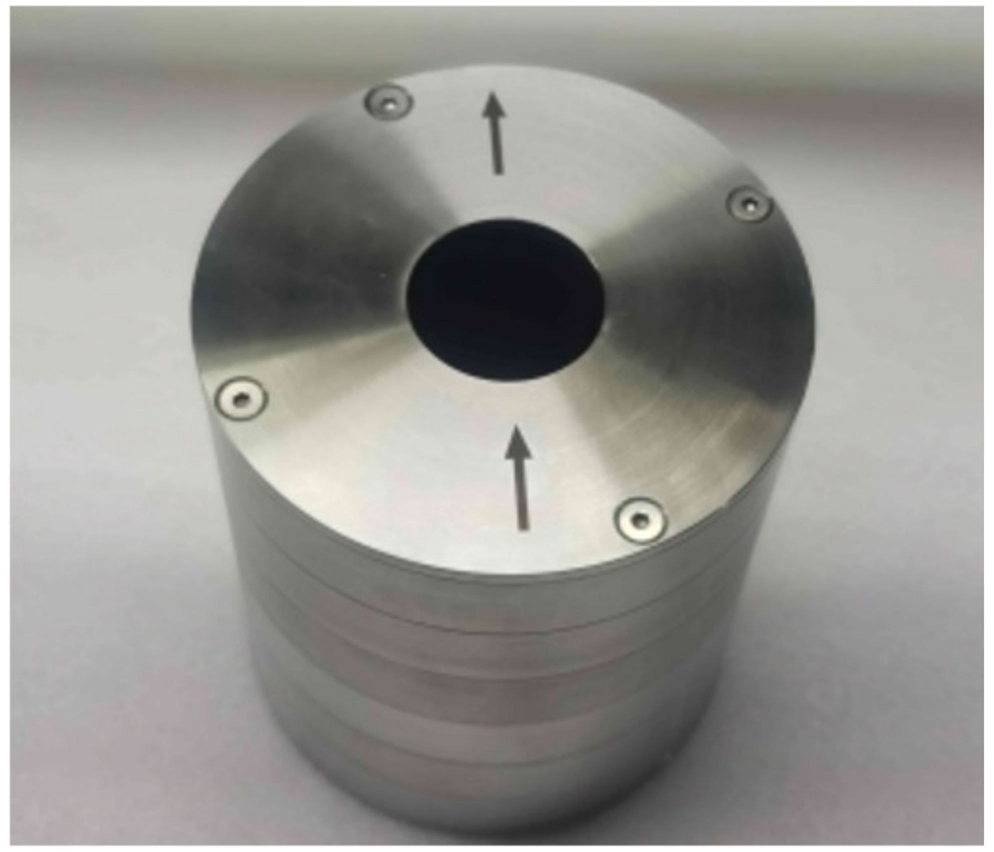
- Aim: simulate injection of beam electrons in actual RF region setup in LNGS (F. Virzi talk)
  - Now: ^{83m}Kr injection → 30.4 keV e^- (L line) produced in random point of trap
  - With e-gun: 18.6 keV e^- with more controlled initial info



- Magnet in LNGS:
  - Halbach cylinder permanent magnet
  - 1 T uniform magnetic field in limited region inside
  - Just z profile of B module given
  - Field lines difficult to simulate
    (field produced by array of magnets)



k=2



Exploiting Laplace Equation for Scalar Potential

- Aim: know magnetic field behavior **outside** magnet to simulate e$^-$ injection

- No sources in region of interest → governing laws:

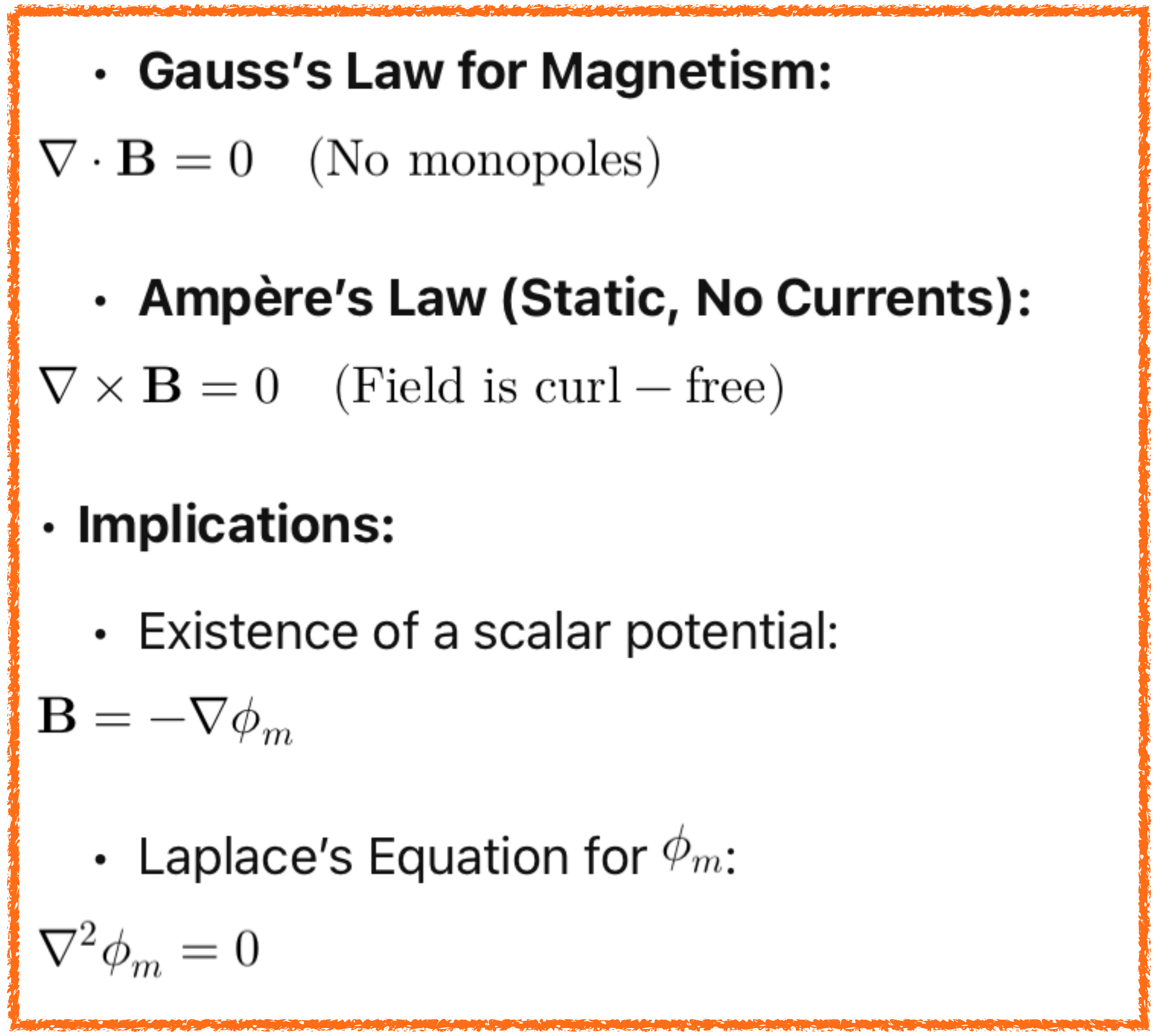
- Procedure:

  1. Solve Laplace equation with **Neumann boundary conditions** = $B_\perp$ on infinte plane

  2. Derive B from ϕ_m

  3. Outcome = magnetic field lines

- Only need to measure $B_\perp$ on “infinite” plane



- **Gauss’s Law for Magnetism:**

$$\nabla \cdot \mathbf{B} = 0 \quad \text{(No monopoles)}$$

- **Ampère’s Law (Static, No Currents):**

$$\nabla \times \mathbf{B} = 0 \quad \text{(Field is curl} - \text{free)}$$

- **Implications:**
  - Existence of a scalar potential:

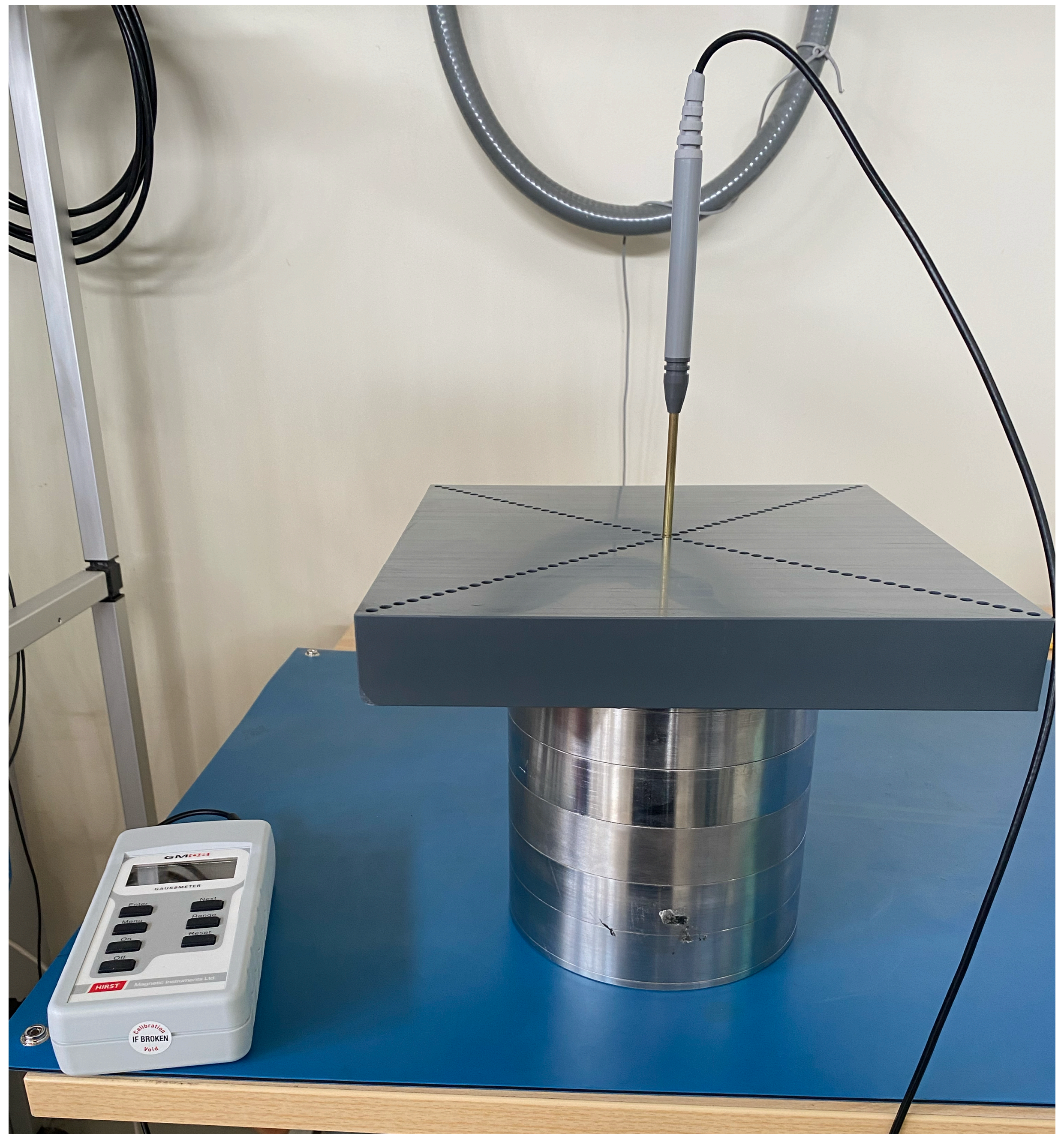
$$\mathbf{B} = -\nabla \phi_m$$

  - Laplace’s Equation for ϕ_m:

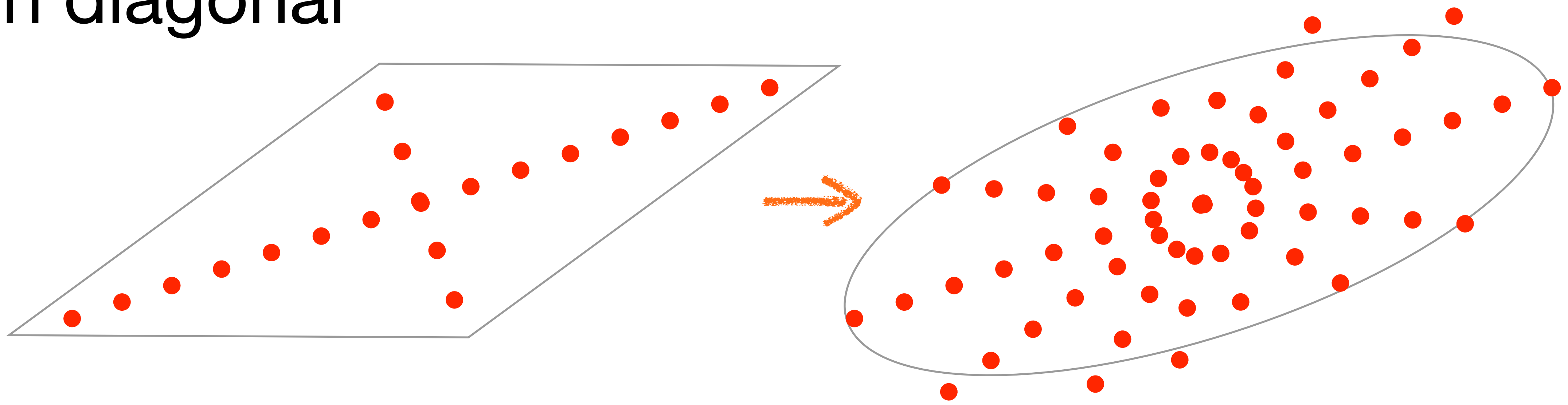
$$\nabla^2 \phi_m = 0$$

Measure of Boundary Conditions

- Aim:
  measure $B_\perp$ on infinite plane outside magnet
  - plane // to cylinder face, 3 mm from it



- Setup:
  - Halbach magnet dismounted from RF setup
  - Hirst GM08 Gaussmeter
  - cap by LNGS Mechanics Workshop with slots for inserting probe 7 mm apart on both diagonal



ONGOING!
measurement planned this week

From Measurements to Simulation Setup

- Given boundary conditions → solution of Laplace equation
  - using COMSOL simulation software based on advanced numerical methods (in collab with Dr. Carlo Rizza from UnivAq)
  - Result = Magnetic Field Map for the whole region of interest in txt (or other format) file

- Next steps:
  - Map Upload & Implementation of possible electrodes configurations in CST
  - Multiparticle Simulations with <u>measured</u> characteristics of electrons from E-gun
    - In CST
    - Using Lorentz4 ROOT code →

ONGOING!
new implementation with Dr. Nicola Rossi to read electric & magnetic fields from files

Recap & Next Steps

✓ Beam Current with reduction factor 10^{-4} exploiting Wehnelt grid

✓ 1st beam size estimate of ~0.5 mm
+ correlation deflection voltage - position shift

✓ I vs V from 0.1 μA to 180 μA

✓ Setup to measure $B_\perp$ on extended plane ready

→

TO DO

Beam Current with femtoammeter
to probe higher reduction

Estimate using manual shift via
feedthrough
+ optimize focusing voltage

Curve down to pA (or fA)

Measurement, COMSOL solution,
File Upload, Geometry implementation,
Multiparticle Simulation

Helmholtz coils cage