Characterization of CERN Scandia doped hollow electron gun (CHG-16-sc) at Fermilab electron-lens test stand

G. Gobbi, G. Stancari (FNAL), D. Perini, A. Rossi, A. Kolehmainen

With the collaboration of:

D. Crawford, J. Ruan, L. Valerio, A. Valishev (FNAL)

T. Coiffet, S. Redaelli, S. Sadovich (CERN)

Y. Yang, W. Liu, Z. Pan, J. Li, J. Wang, Y. Wang (BJUT)

8^{th} HL-LHC Collaboration Meeting

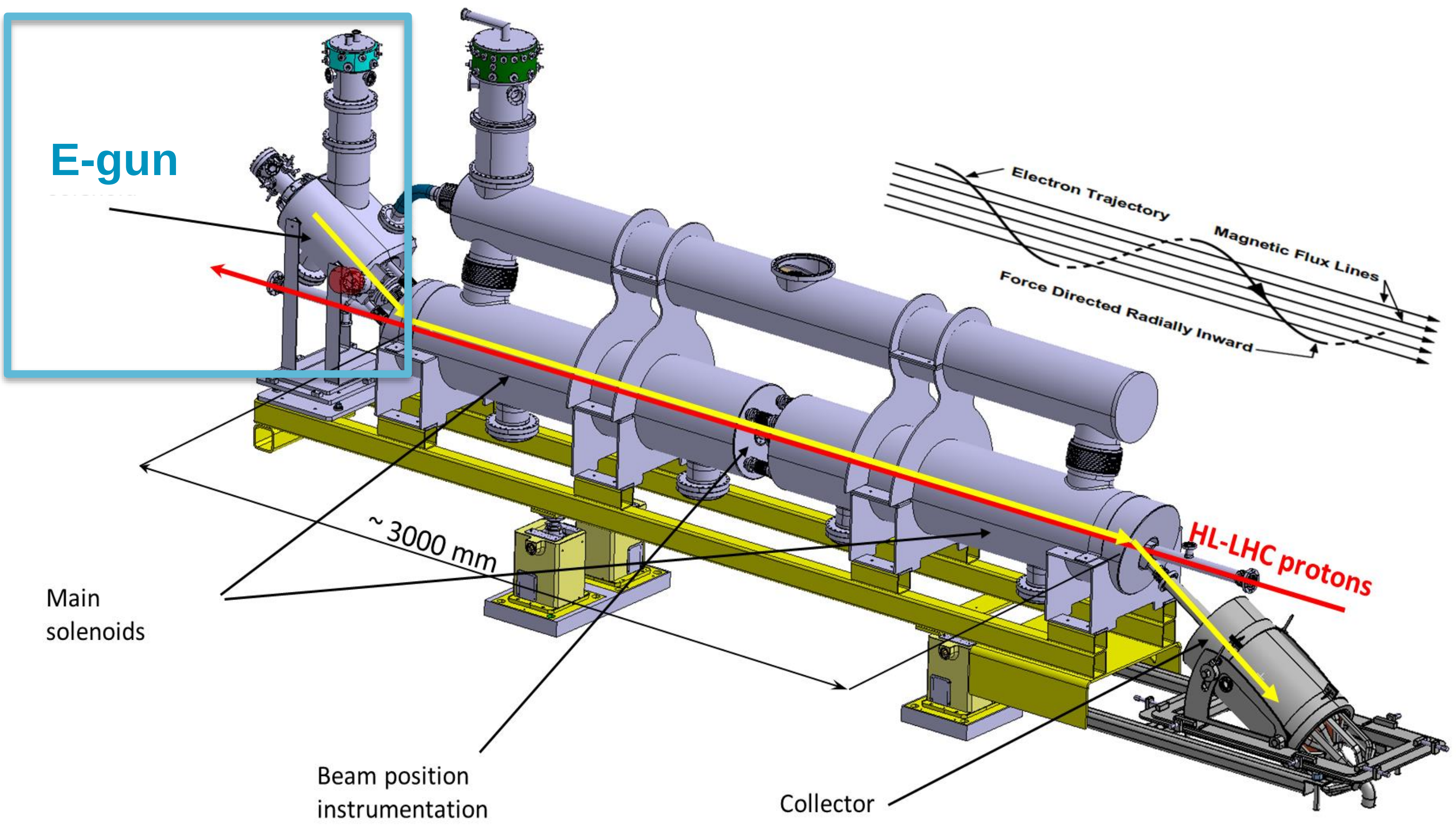
17/10/2018

Outline

- Introduction
    - Cathode
    - E-gun design development
- Installation of Scandia-doped cathode e-gun (CHG-16-sc) at FNAL
- Tests of Scandia-doped cathode e-gun (CHG-16-sc) at FNAL
- Next steps
- Conclusions

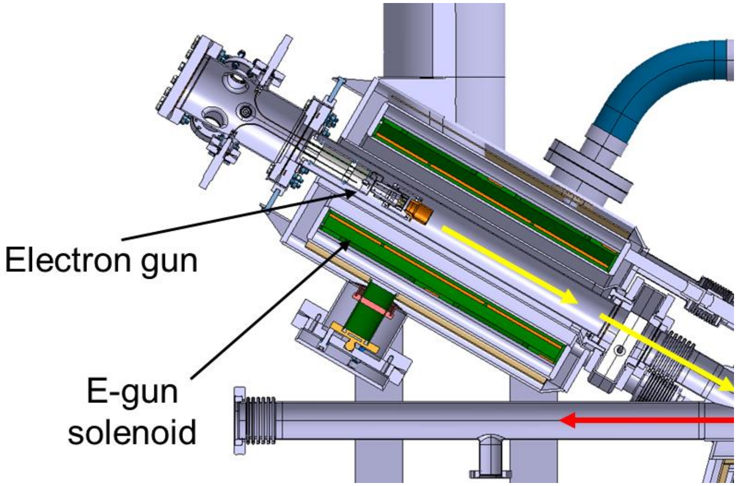
Introduction

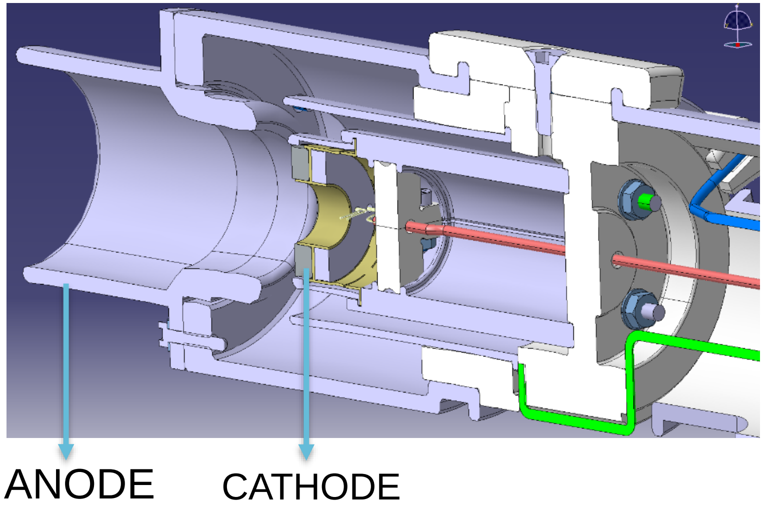
- Electrons are produced by a cathode installed in an e-gun
- A system of superconducting solenoids cooled at 4.5K generates the magnetic field to tune the size and steer the trajectory of the electron ring



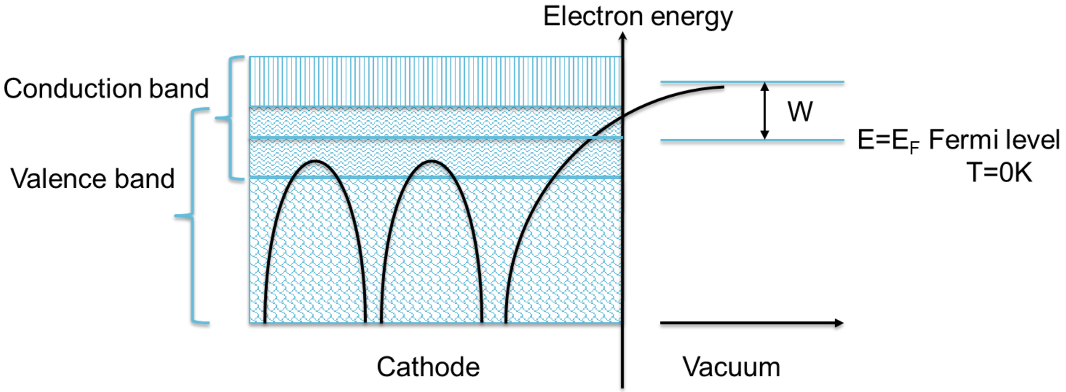
Cathode

- **Electron beam generated by hollow cathode**
- **Thermionic cathode→** electron emission T - activated





Porous tungsten matrix impregnated with oxides



HEL cathode

Target: minimize cathode dimensions fulfilling the HEL requirements

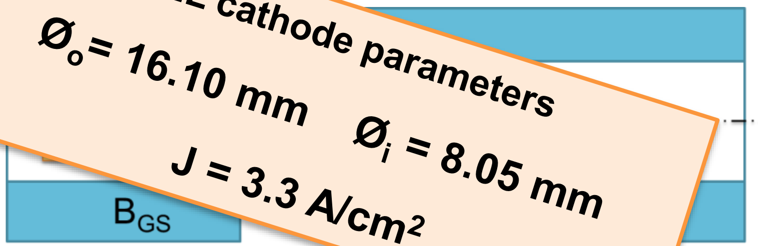
HEL parameter	
Magnetic field of the main solenoid $\mathbf{B_{MS}}$	5 T
Magnetic field in the e-gun $\mathbf{B_{GS}}$	0.25 T
Inner radius of hollow electron beam	0.9 mm
Outer radius of hollow electron beam	1.8 mm
Cathode - Anode voltage difference **V**	10 kV
Current at cathode **I**	5 A

Dimensions

A small cathode allows decreasing the field in main solenoid

$$\frac{R_{beam,cathode}}{R_{beam,MS}} = \sqrt{\frac{B_{MS}}{B_{GS}}}$$

mize field compression factor



HEL cathode parameters

$Ø_o$= 16.10 mm $Ø_i$ = 8.05 mm

J = 3.3 A/cm²

Performance

Small cathode means **high current density** → material play a key role

- Barium aluminate dispenser $Ø_o$= 25 mm
  J < 2 A/cm²
- Scandia doped dispenser $Ø_o$= 8 mm
  J > 20 A/cm²

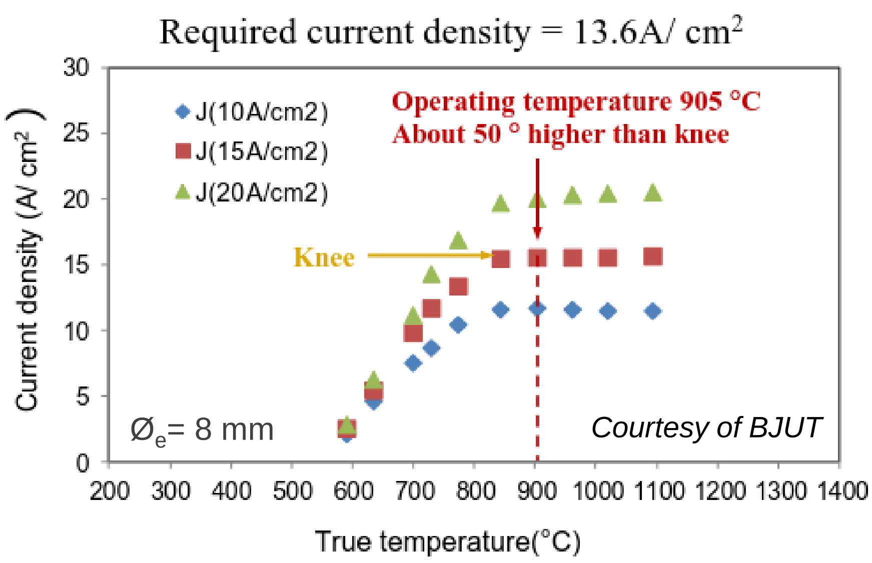
Scandia-doped cathode

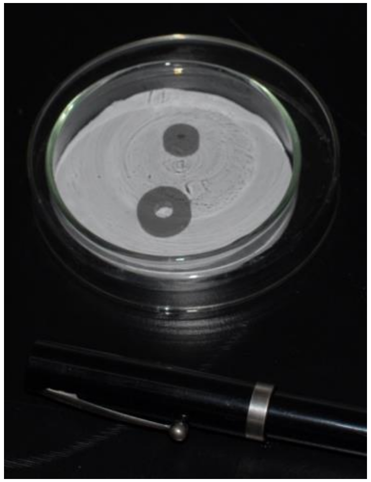
Scandia-doped W cathode

$Ø_o$= 16.10 mm $Ø_i$ = 8.05 mm

J = 3.3 A/cm²

BVERI (Beijing Vacuum Electronics Research Institute)
BJUT (Beijing University of Technology)





Courtesy of BJUT

FNAL e-gun design

Beginning 2017 — *Manufacturing and tests* — *June 2018*

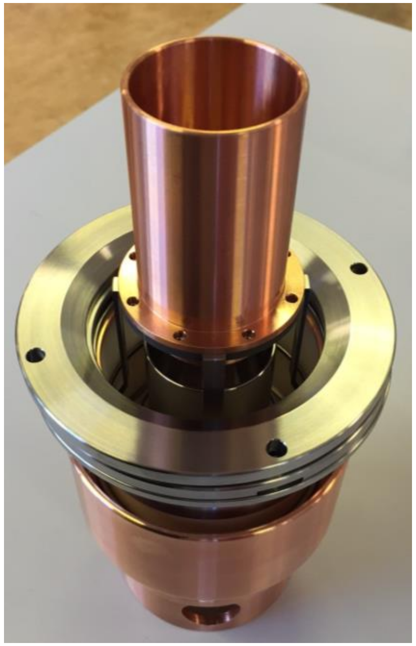
1

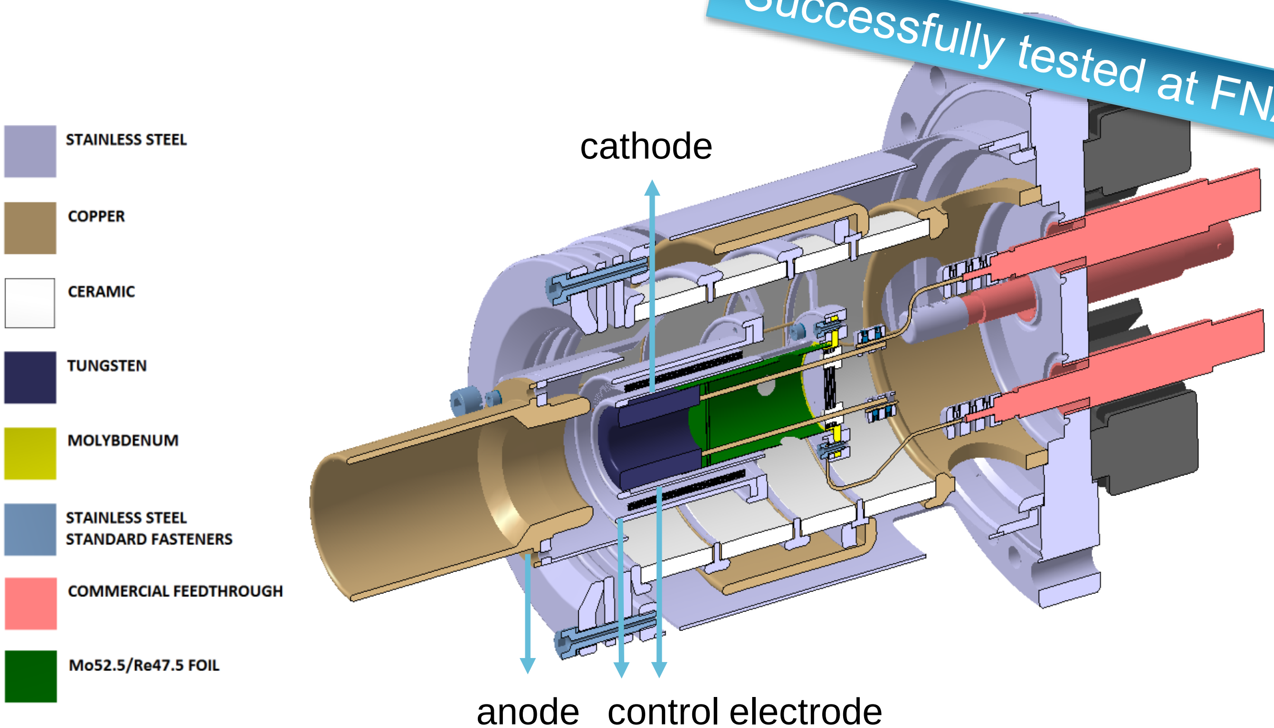
Know-how development

First e-gun manufactured at CERN (EN-MME workshop)

- E-gun design: FNAL → few modifications added (different standards)
- HeatWave Labs (US) dispenser cathode - $Ø_o$ = 25 mm $Ø_i$ = 12.5 mm
- P = 6.14 μperv → 5.5 A @ 10kV

Successfully tested at FNAL





Scandia-doped cathode in FNAL e-gun design

February 2018 *Manufacturing and first tests* *October 2018*

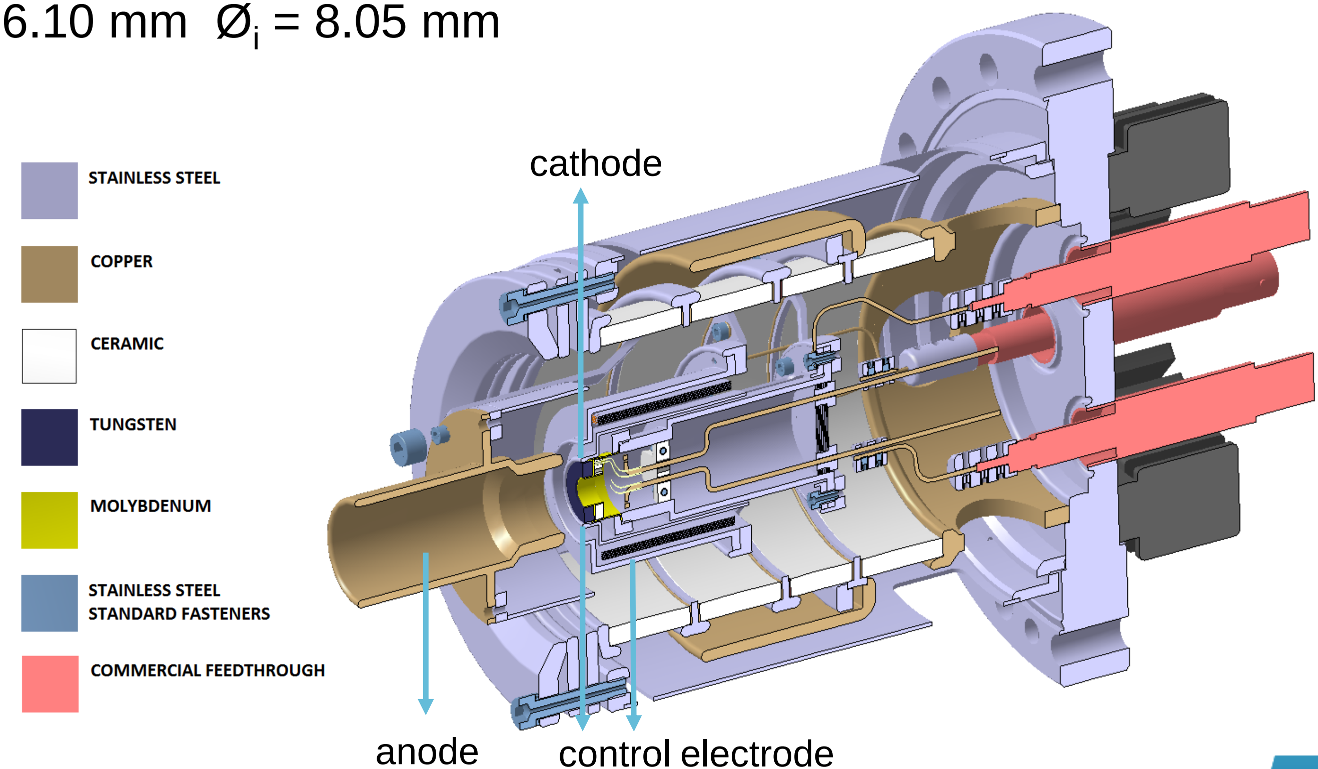
2

To test HEL size cathode

Second e-gun: design modifications minimized to allow to fit in the HEL nominal dimension cathode

- FNAL e-gun design with scaled electrode dimensions
- BJUT & BVERI Scandia-doped cathode

$Ø_o = 16.10$ mm $Ø_i = 8.05$ mm



E-gun installation at FNAL

- **June 5, 2018 →** Scandia-doped cathode installed in CHG1b electron gun body at FNAL electron-lens test stand (Coiffet, Gobbi, Stancari and Crawford)
  - CHG1 disassembling – insert HEL cathode with scaled electrodes – electrical connections – e-gun installation in the test stand – pump down
- New e-gun assembly → **CHG-16-sc** (CERN hollow gun, 16 mm diameter, Scandia-doped cathode)

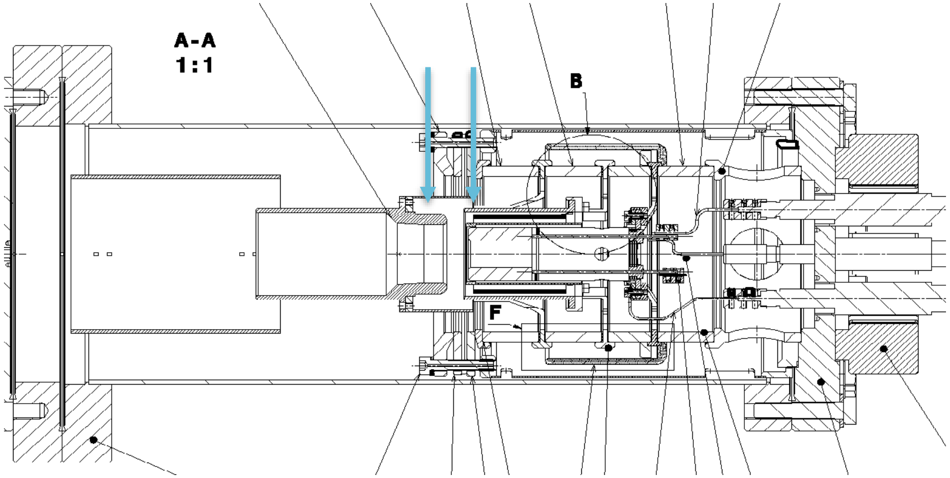


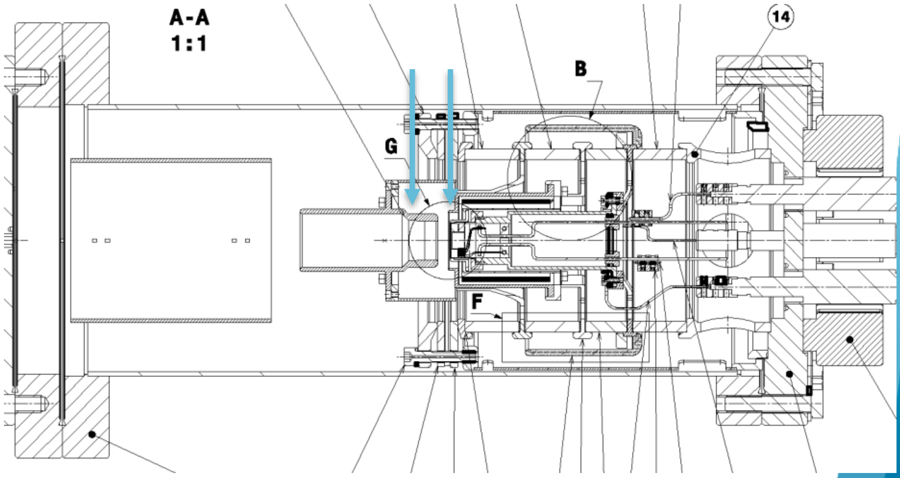
FNAL Test - first objectives

Scandia-doped cathodes first test objectives:

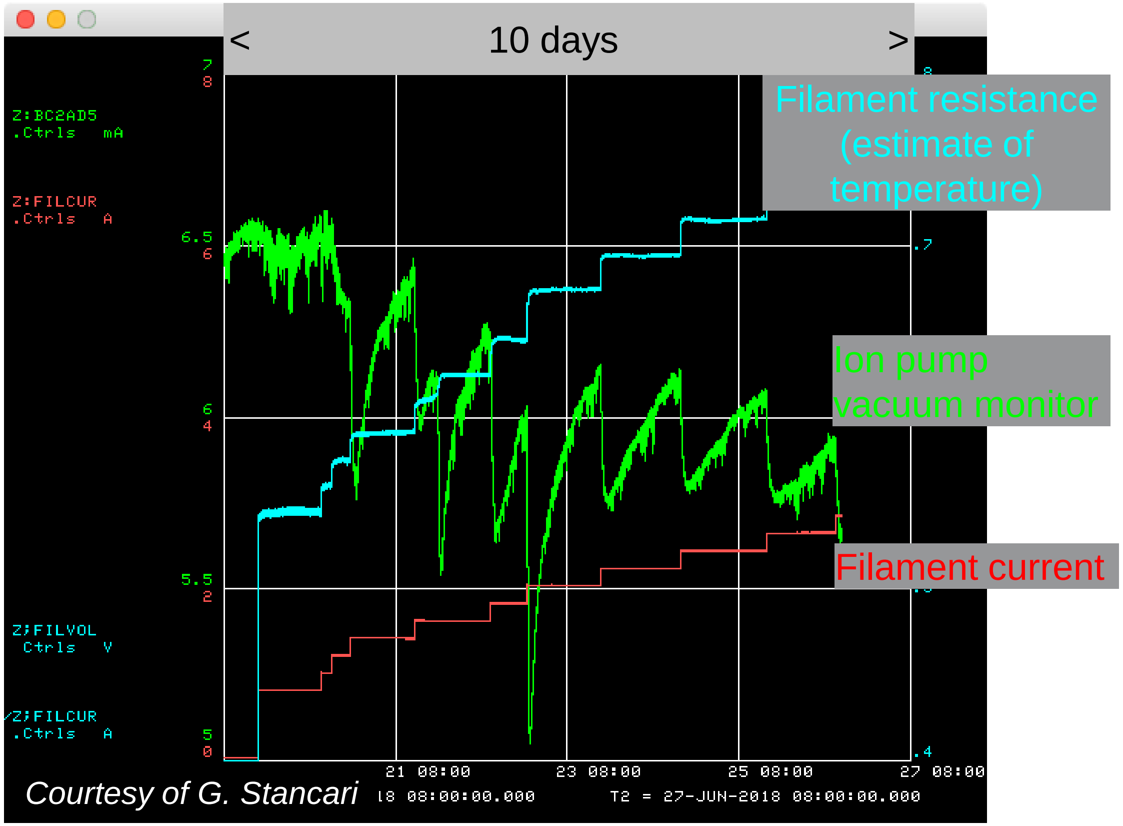
- Small cathode can deliver 5 A needed for HEL?

- Scaled electrode distance and dimensions match perveance of CHG1 e-gun?





Tests at FNAL – first cathode heating



Example of first heating procedure

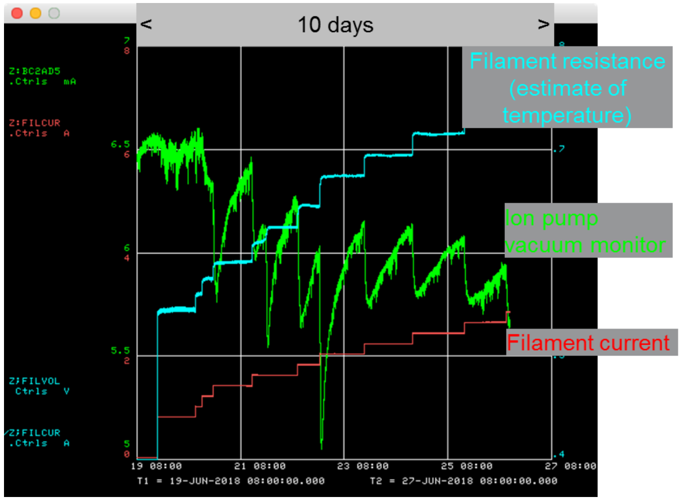
Possible factors:

- aging of one ion-getter pump → improved after high-voltage conditioning
- one faulty HV ion-pump controller → replaced
- outgassing of e-gun

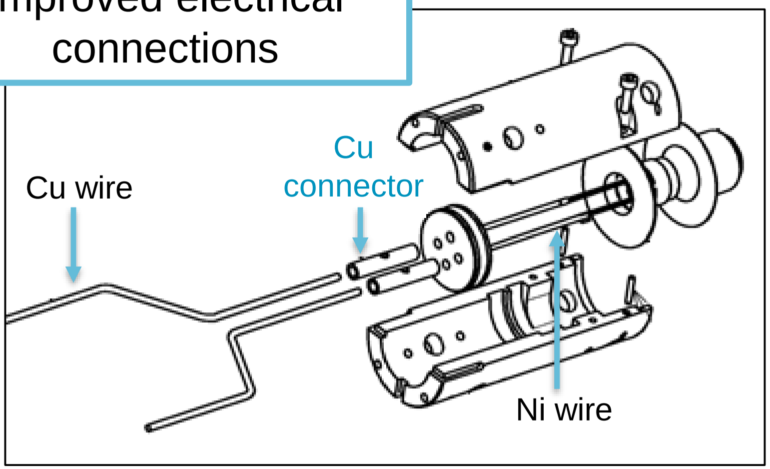
Tests at FNAL – first cathode heating

Possible factor:

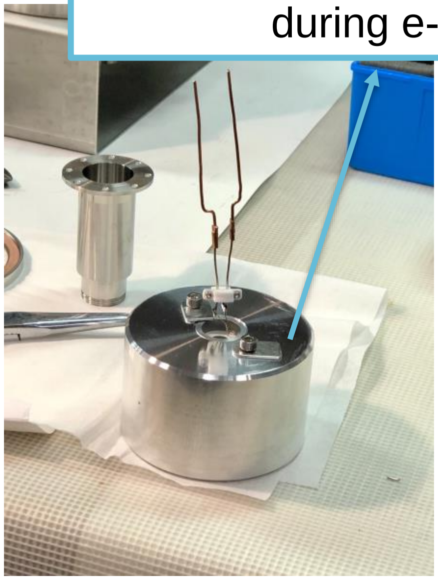
- Outgassing of the e-gun



Improved electrical connections



Tool to minimize cathode contamination during e-gun assembly



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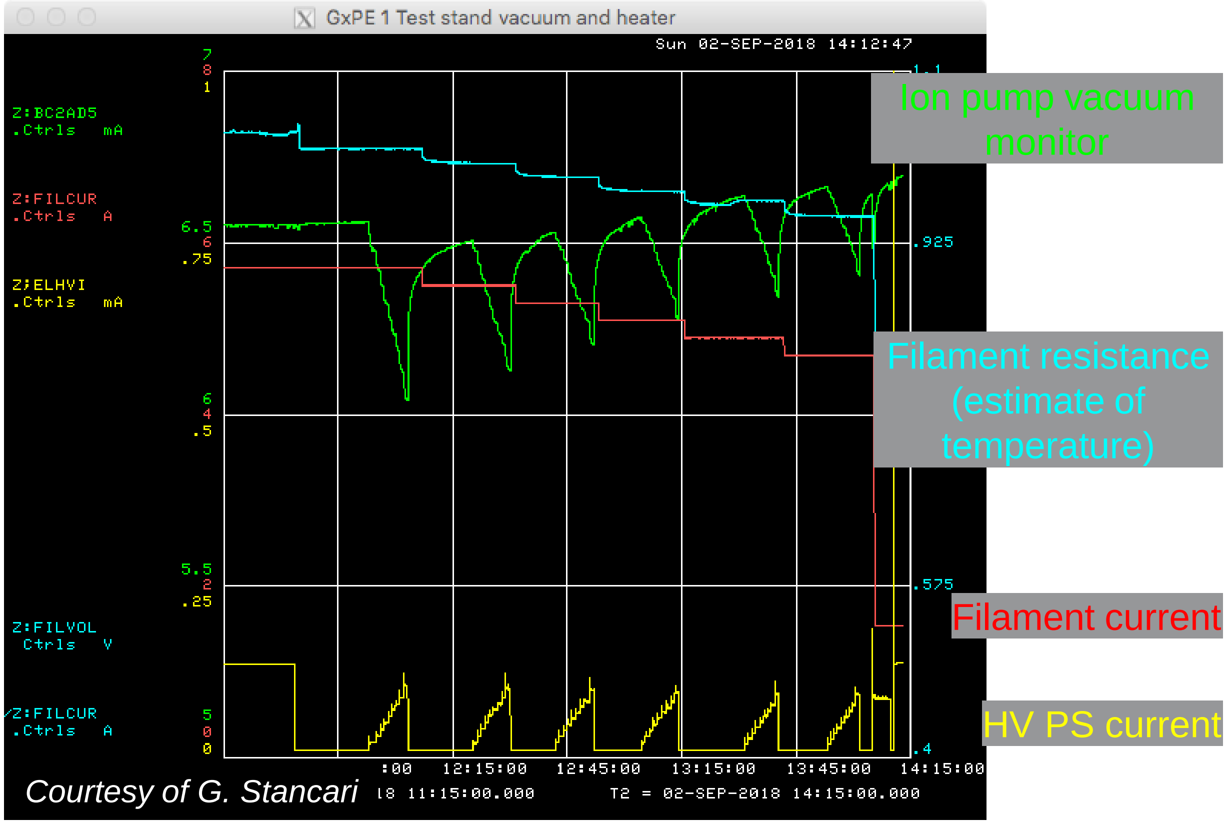
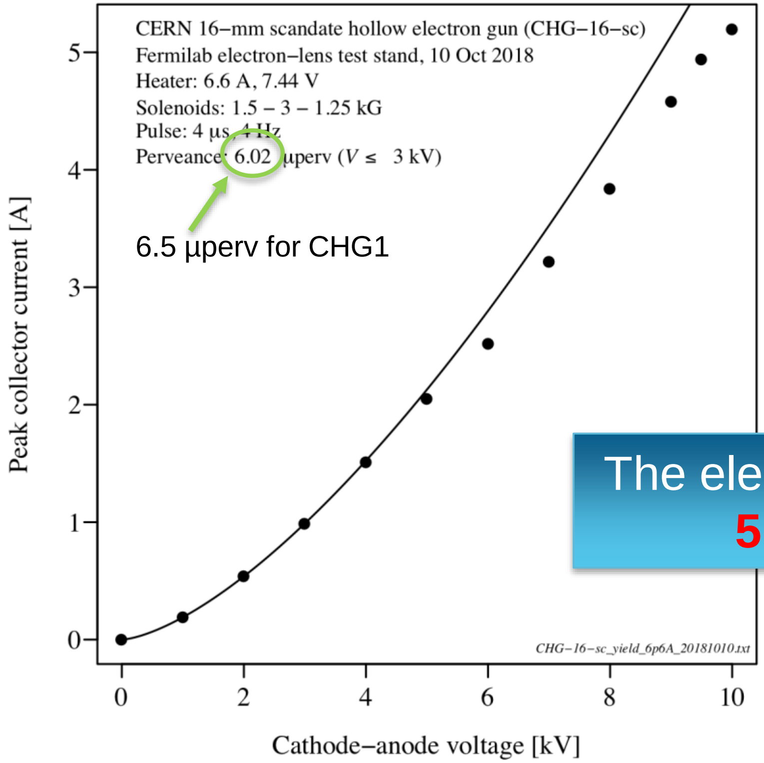


Courtesy of G. Stancari

Second and third heating ramps were faster and smoother

Tests at FNAL - Yield vs. voltage

Courtesy of G. Stancari



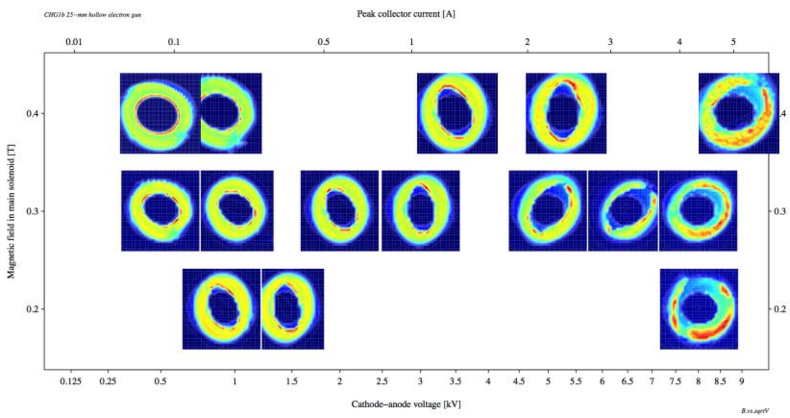
- Small cathode can ensure 5 A needed for HEL? **YES**
- Scaled electrode dimensions match perveance of CHG1 e-gun? **YES**

The electron gun delivered **5.2 A** at **10 kV**

At high voltage, cathode still temperature limited → Further conditioning is under way to extend space-charge-limited emission up to 10 kV

Next steps?

- Complete the tests on CHG-16-sc
  - Emission uniformity
  - Profile measurements
  - Long term reproducibility



Courtesy of G. Stancari – CHG1B 25 mm cathode

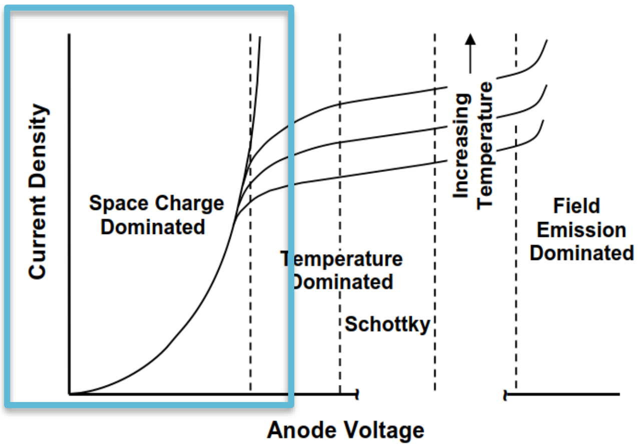
- E-gun design optimization

Conclusions

- Scandia doped cathode (BVERI & BJUT) for HL-LHC HEL was successfully tested at FNAL
- The first results, 5.2 A at 10 kV, prove that the cathode fulfills the HEL requirements!
- Next tests to measure the profile and to assess the long-term performance of the cathode foreseen for the next months at FNAL

Thank you for your attention

Perveance



Child-Langmuir law:

$$\boxed{\mathrm{I} = \mathrm{P}V^{3/2}}$$

$$I = JA \quad P = const \cdot \frac{A}{d^2}$$

A cathode area
d cathode-anode distance

Impregnated tungsten dispenser cathode

It is possible to combine the two favourable properties of tungsten and barium to obtain a cathode with low work function at high temperature.

Produce a Tungsten matrix containing Barium compound.

- Barium Calcium aluminate BaO : CaO : Al_2O_3
- Porous tungsten $\rho < 0.8\rho_{theor}$

During operation free Barium is 'dispensed'.

$$6\,BaO + W \qquad 3\,Ba + Ba_3WO_6$$

The released Barium diffuses to the surface and forms a low work function monolayer.

Courtesy of Diego Perini

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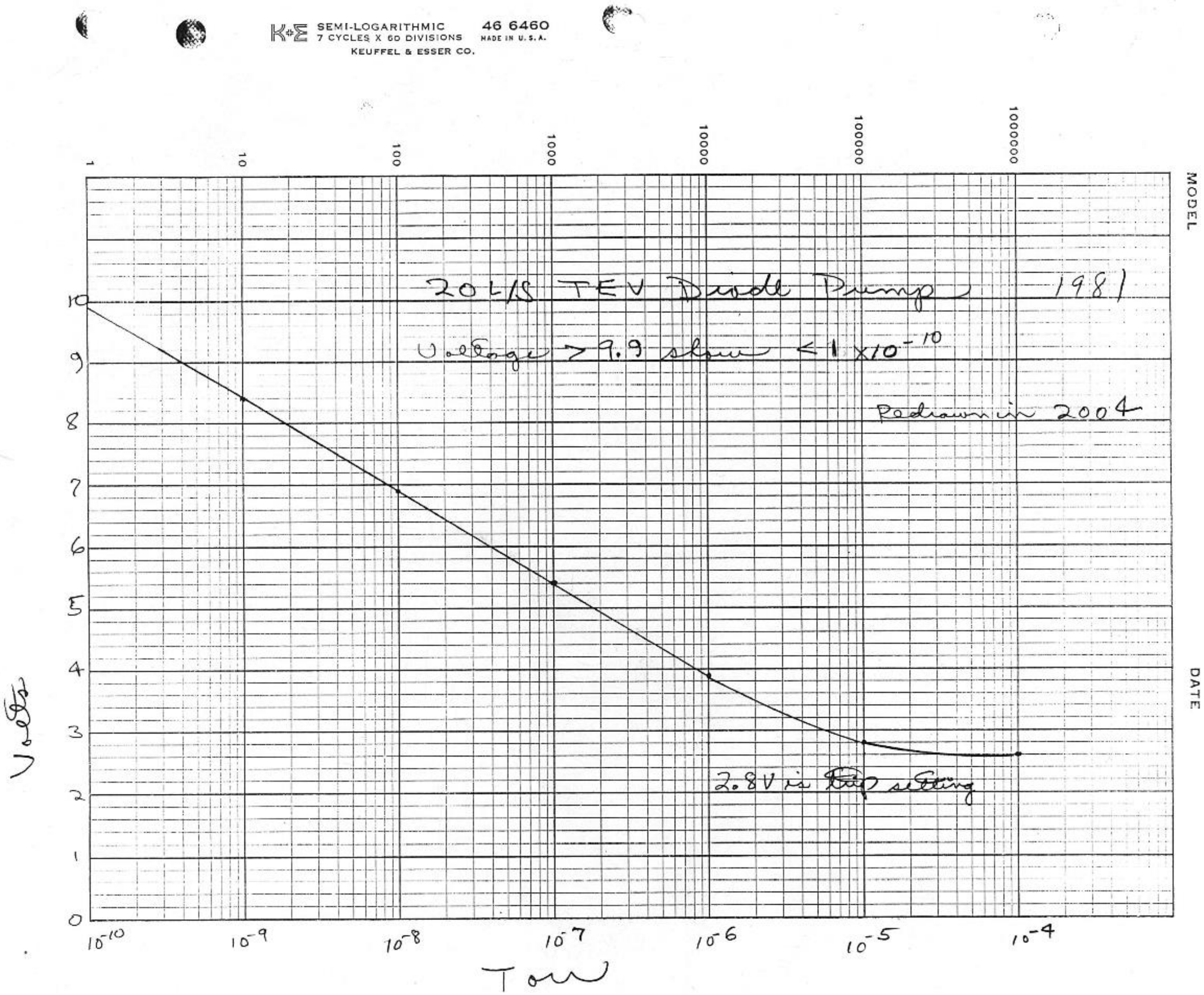
K+E SEMI-LOGARITHMIC 7 CYCLES X 60 DIVISIONS
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