TRIUMF

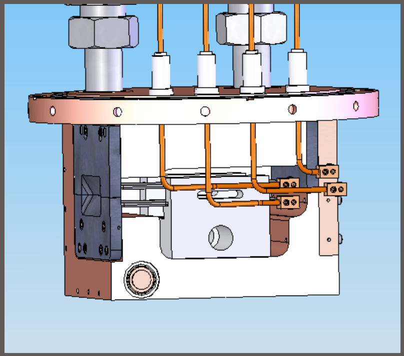
Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

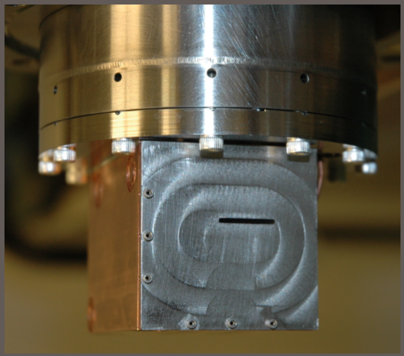
High Power Allison Scanner for Electrons

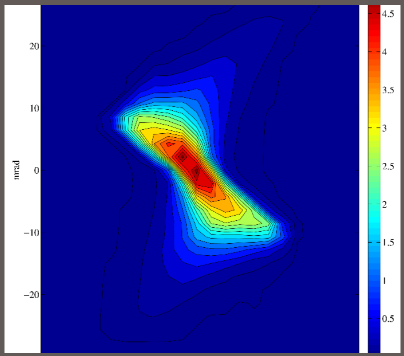
BIW12

April 17, 2012

Aurelia Laxdal TRIUMF







SUMMARY

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- Emittance scanner:
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  - Constrains
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  - Design considerations
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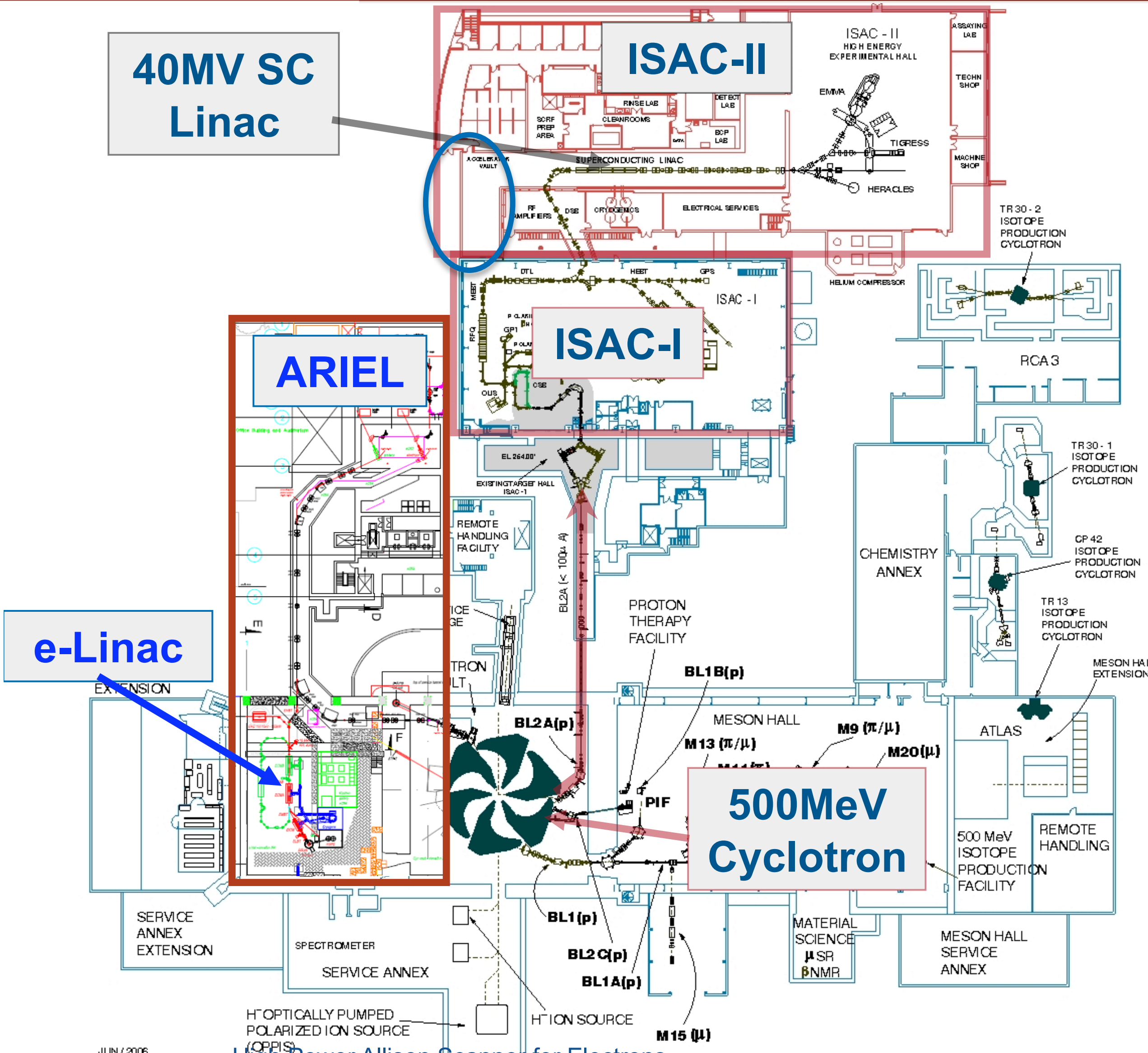
- Assembly, installation & baking
- Controls
- Results
- Inspection and conclusions

ARIEL at TRIUMF

- Now adding ARIEL to increase from one to three simultaneous beams
- Add e-Linac (50MeV 10mA cw - 1.3GHz SC linac)
- E-LINAC/VECC test area established in ISAC-II building



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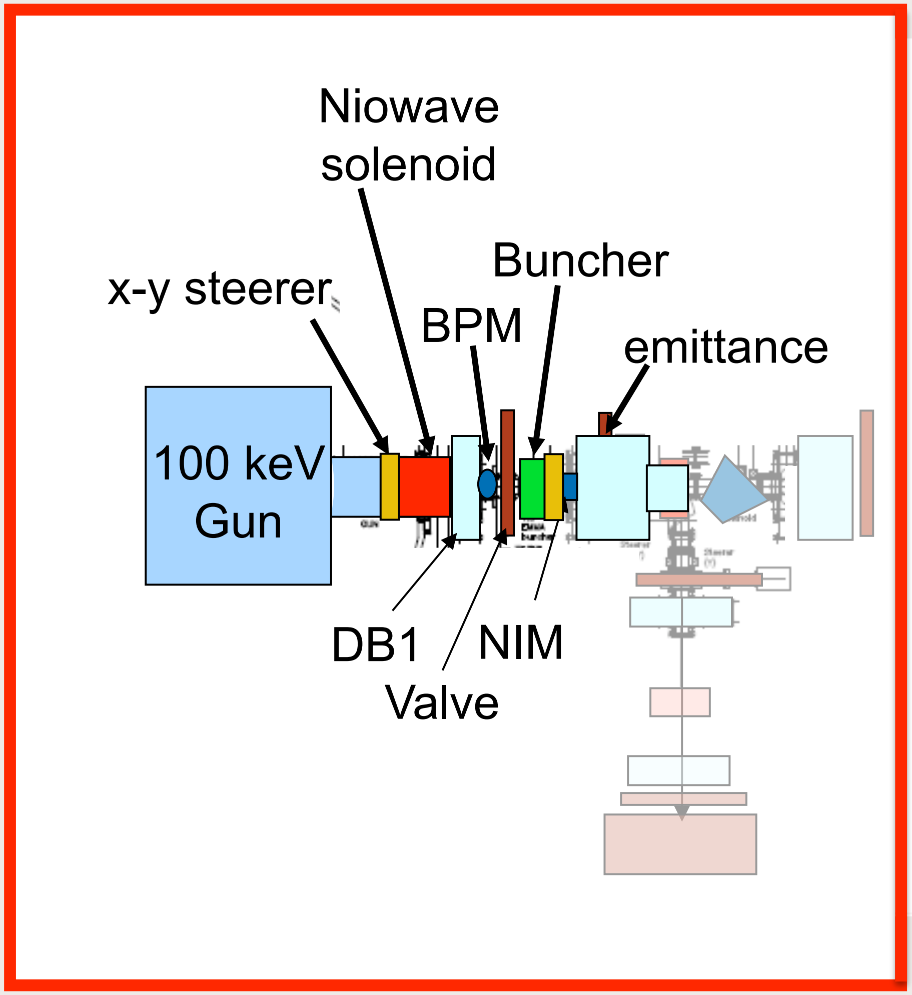
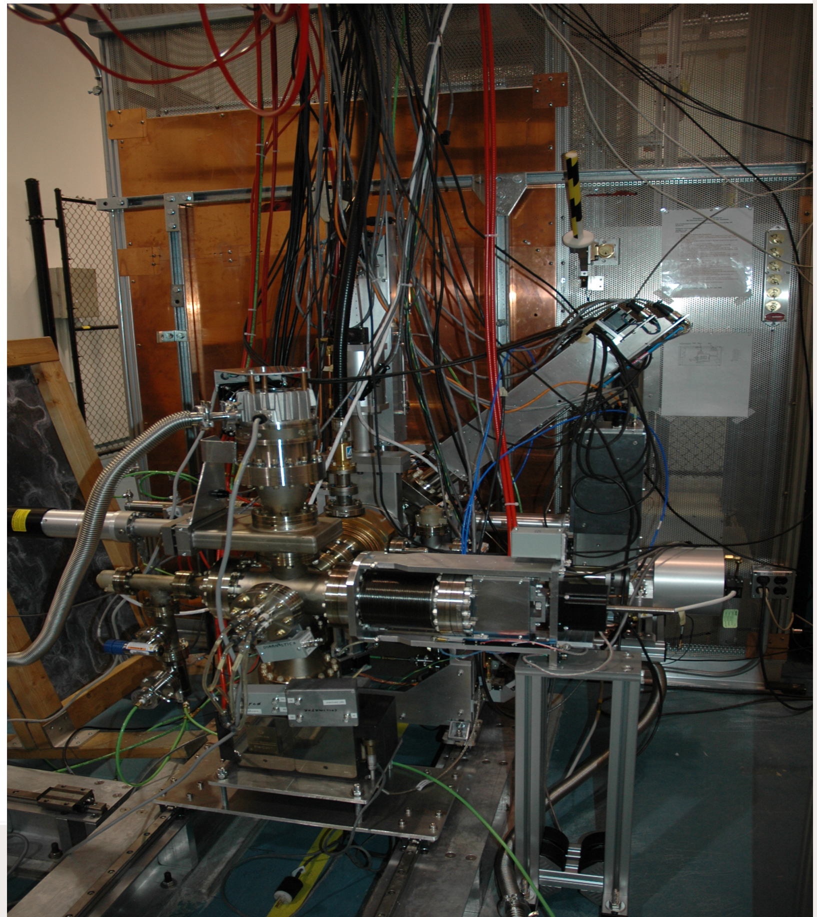
E-GUN Test Station



- 100 keV e-gun test area



Overview of the 100 keV E-Gun parameters

The specifications for the 100keV electron source derived from the requirements of the e-LINAC are:

beam energy	100 keV
average current	10 mA
modulation frequency	650 MHz
bunch length	≤ ± 20 deg. of 650 MHz (170 ps)
bunch charge	15.3 pC
energy spread	≤ ±1 keV
transversal emittance	≤ 30 μm normalized 2σ x 2σ
cylindrical beam	
UHV	10^{-9} Torr

Emittance scanner specifications

- **requirements for low energy emittance meter for the e-linac project**

beam particles	electrons
particle energy	100 – 300 keV
beam current	<10 mA
beam power	1 kW
beam size	~10 mm
vacuum	$< 10^{-9}$ T

- **location of emittance meter**

1. directly after the electron source for initial source commissioning in E-Gun Test Station area
2. in diagnostic line of LEBT for beam characterization during operation

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Overview of the Allison type emittance scanner

• At each step the beamlet selected by the front is slit swept across the rear slit with the deflecting plates and the transmitted current measured by the Faraday cup.

• The necessary voltage for an electron of energy E entering with an angle x' through the Entrance slit and exiting through the second slit is:

$$V = 4gx' E/(D - 2\delta)$$

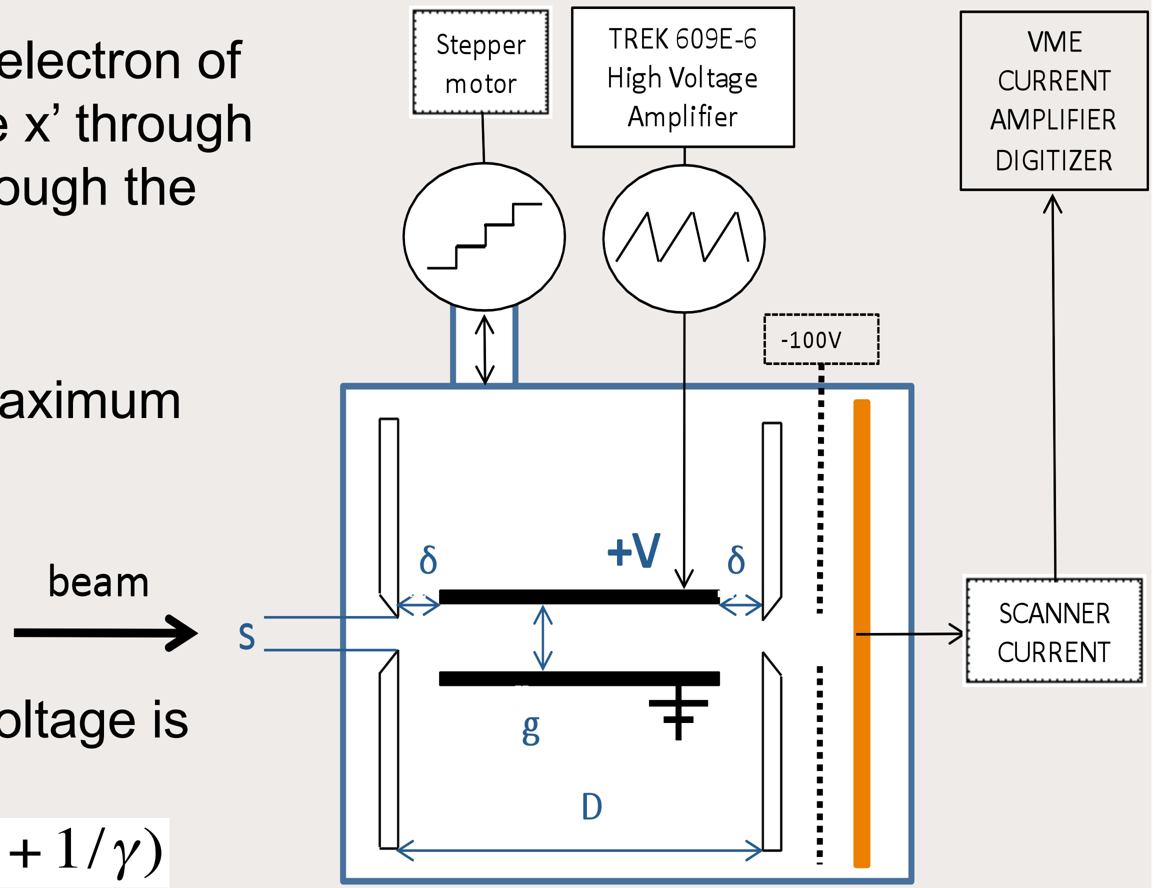
•The maximum voltage for a maximum analyzable x' angle is:

$$V_m = \pm 8Eg^2/(D^2 - 4\delta^2)$$

$$x' = \pm 2g/(D + 2\delta)$$

• For relativistic particles the voltage is smaller by a factor *k*

$V_{m-rel} = V_m / k$ and $k = 2/(1 + 1/\gamma)$



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Scanner Parameters

Summary of chosen design parameters

BEAM ENERGY	60 keV	100 keV	300 keV
D (mm)	49	49	49
δ (mm)	2	2	2
g (mm)	3.5	3.5	3.5
s (mm)	0.038	0.038	0.038
K	1.06	1.09	1.23
$V_{m\text{-}rel}$ (V)	±2,337	±3,773.2	±10,046
x'_m(mrad)	±132	±132	±132
Electric field (V/mm)	668	1,078	2,870

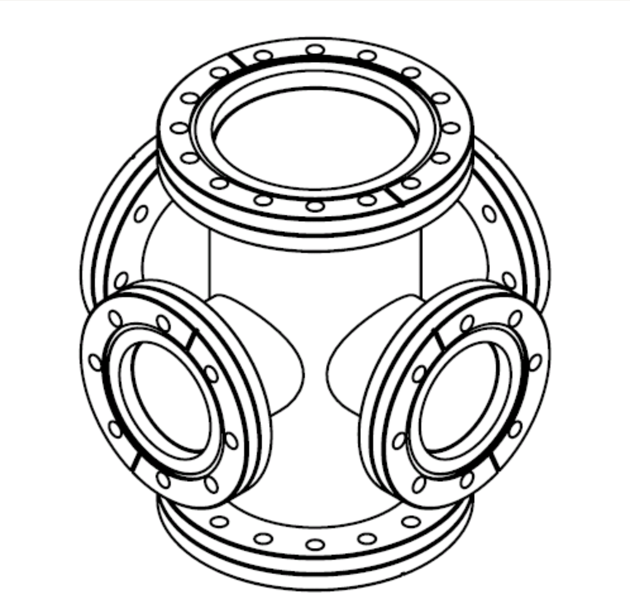
Conclusion: at these parameters the emittance scanner has **high resolution**.

Transverse phase space as large as 1600 πμm can be measured with a resolution of 0.03 μm

MECHANICAL DESIGN

Design constrains

UHV constrains:

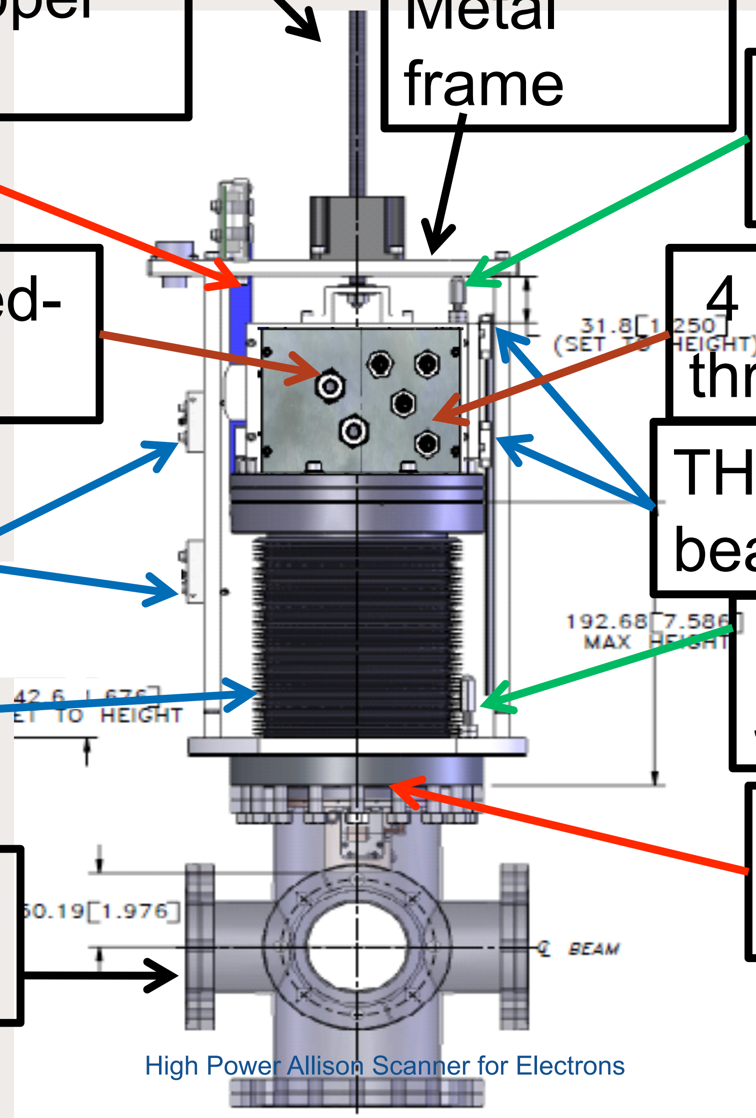


- **small volumes**
- **UHV competitive materials**

So, assembled in:

•The emittance meter is attached to a CF 6-way SS reducer cross **(2x) 6” OD (4” ID) CF x (4x) 4.5” OD (2.5” ID) CF** , clear holes rotatable.

Overview of the Emittance Scanner Assembly



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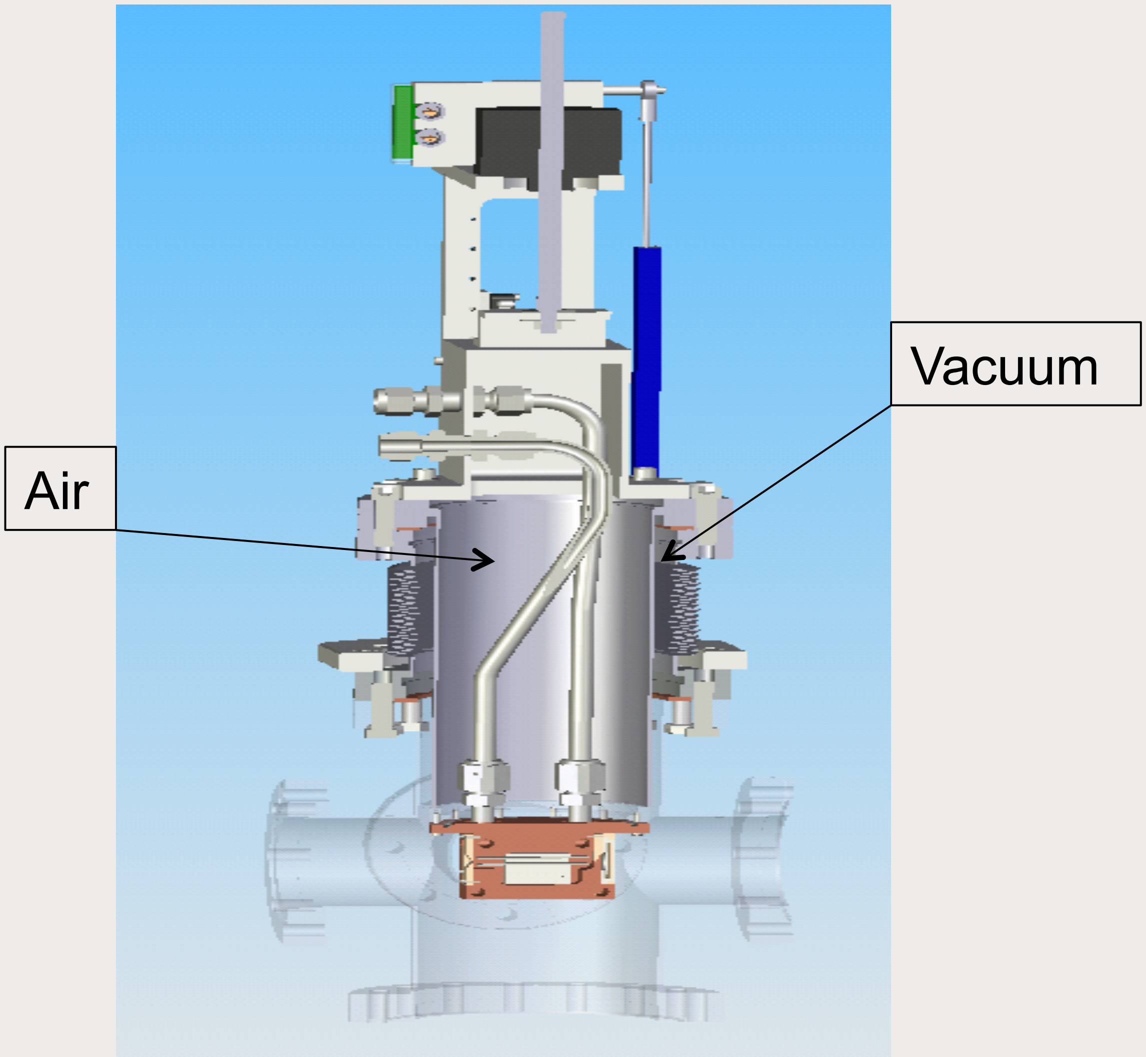
Design considerations (1)

In order to **preserve the UHV** and **limit the space:**

1. the cooling lines are placed into an inner tube, **at atmospheric pressure**.

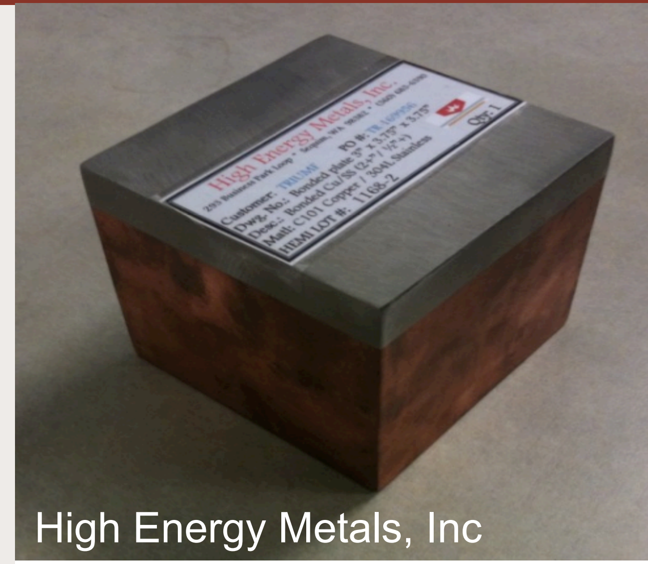


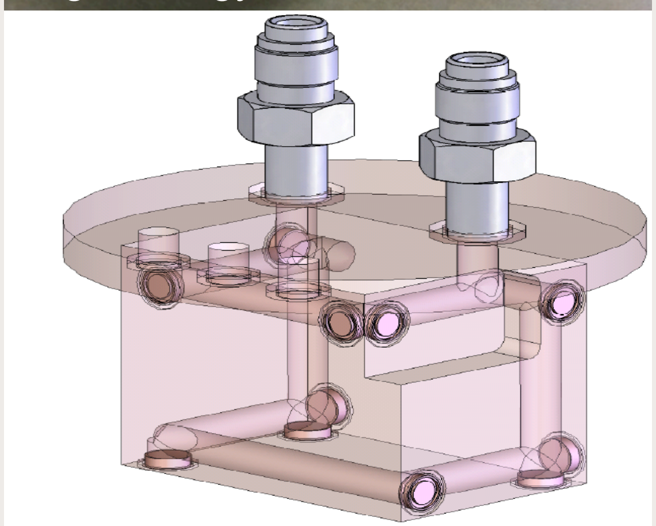
Design considerations (2)

2.
Flange and emittance scanner in one body
AND
to eliminate soldering/brazing in vacuum

Solution:
OFHC copper explosively bonded to SS to get:
• SS flange ➔ all feedthrough can be welded (EB welding)

• emittance scanner body OFHC copper ➔ asymmetric water cooling configuration: 2 parallel water lines, of ¼" ID to cool the emittance head (convection) and the entrance slit (conduction).


High Energy Metals, Inc

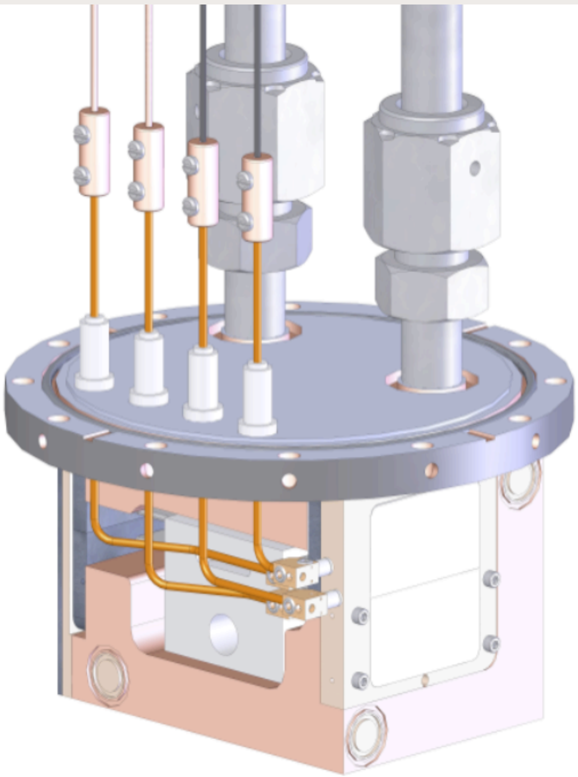


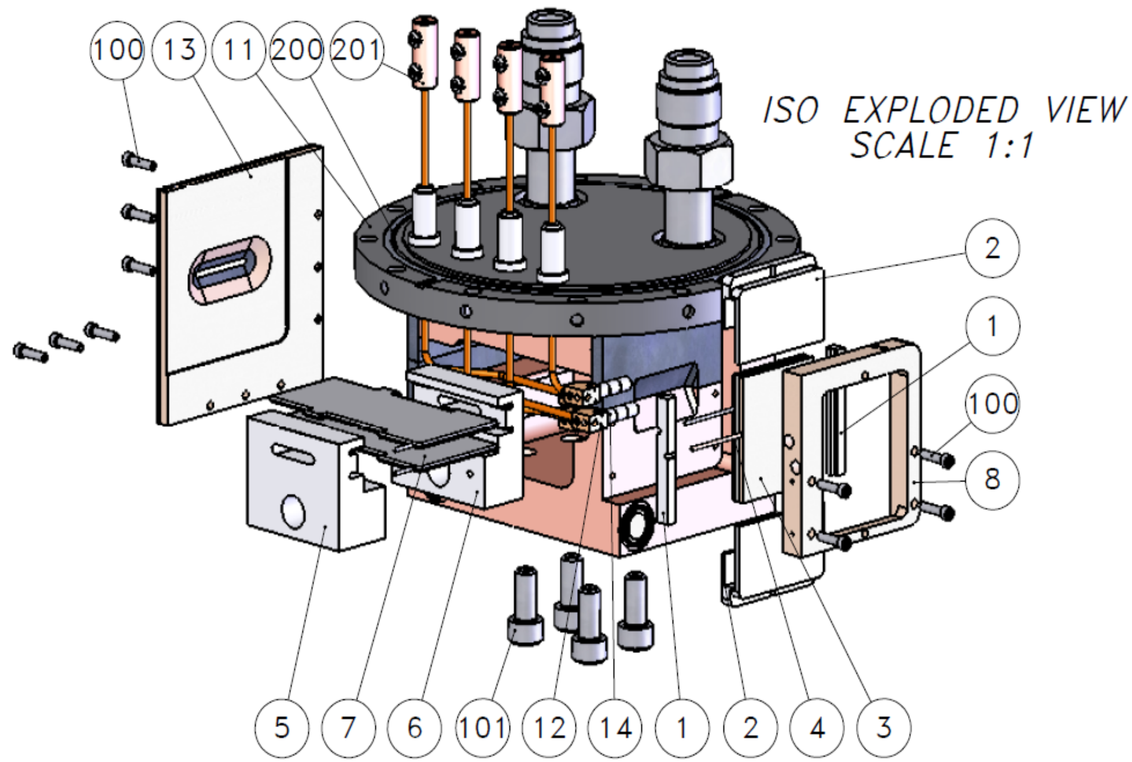
Overview of the Emittance Scanner Body design

- **Dimensions:** length x width x height = 60 mm x 44 mm x 45 mm

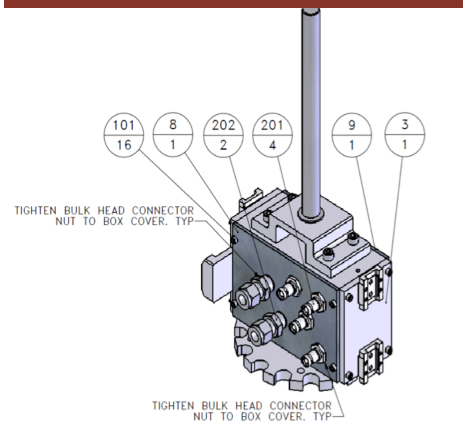
➔Very small emittance scanner.

- Open on one side (asymmetric) ➔ helps for vacuum pumping

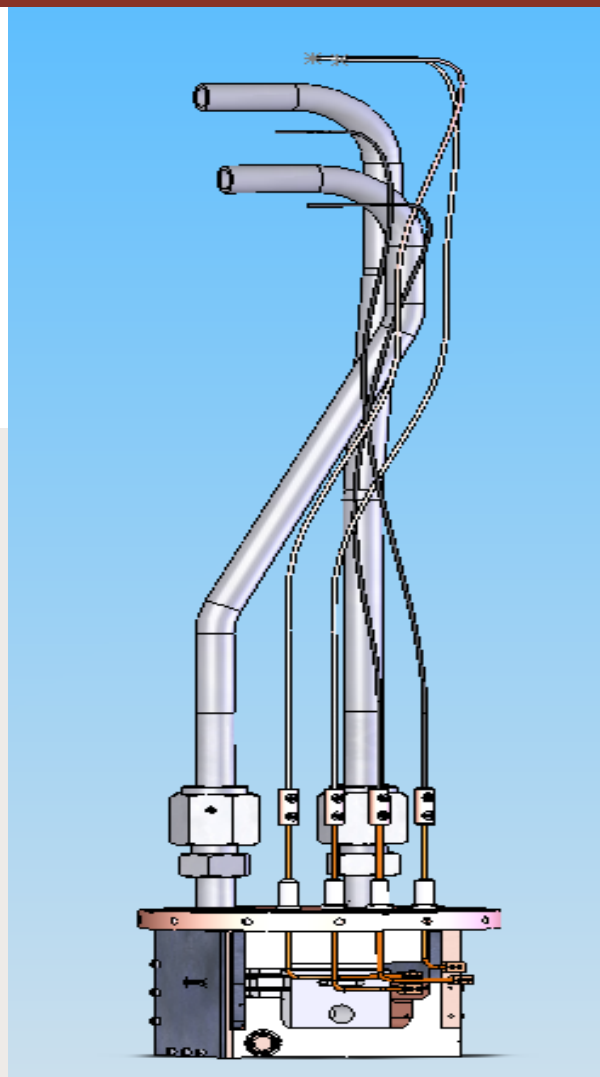




Electrical Feedthroughs & Wires



- All feedthroughs are rated at 5kV and they are UHV compatible, bakeable at 250deg.
- They are EB welded on the SS flange.

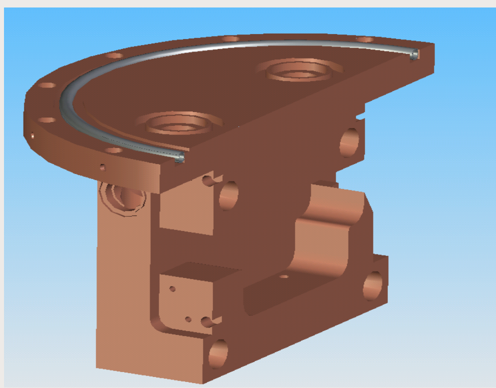


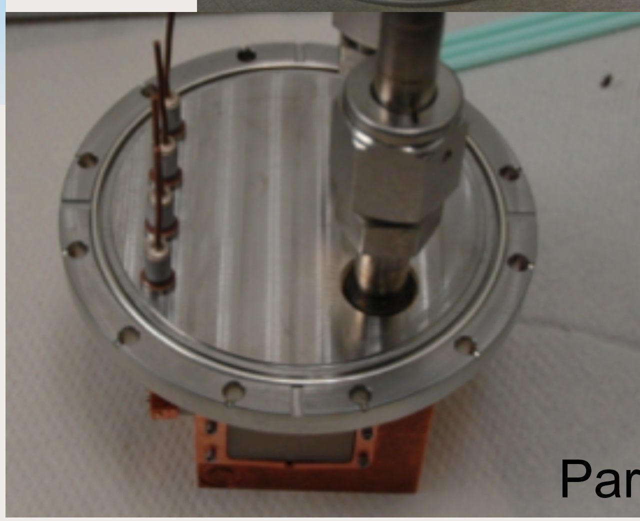
There are 4 weldable single pin feedthroughs:
- 2 for the steering plate;
-1 for the secondary electron suppressor;
- 1 for the Faraday cup.

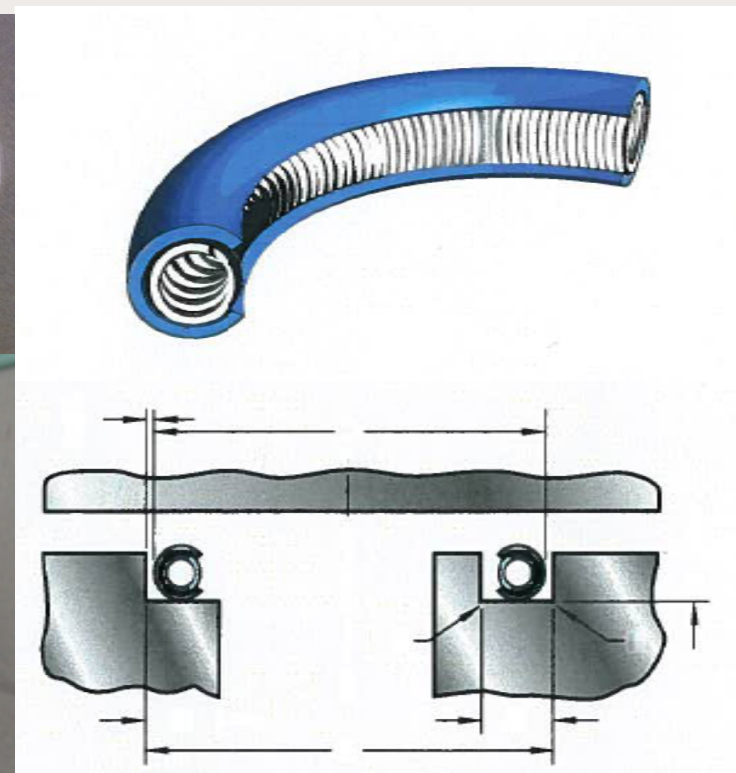
The 4 wires (signal and voltage) are Kapton insulated, except for the Faraday Cup signal which is also shielded (coaxial cable).
- X-Ray resistant

ESI Spring Energized Metal C-Ring

- The SS flange has an UHV compliant seal gland. The seal is a spring energized metal C-ring, made of Inconel/silver plated.
- This seal was chosen since it is UHV compatible and due to the geometry constraints.







Parker Hannifin Corporation USA

- It takes less than 5,000 pounds clamping force.

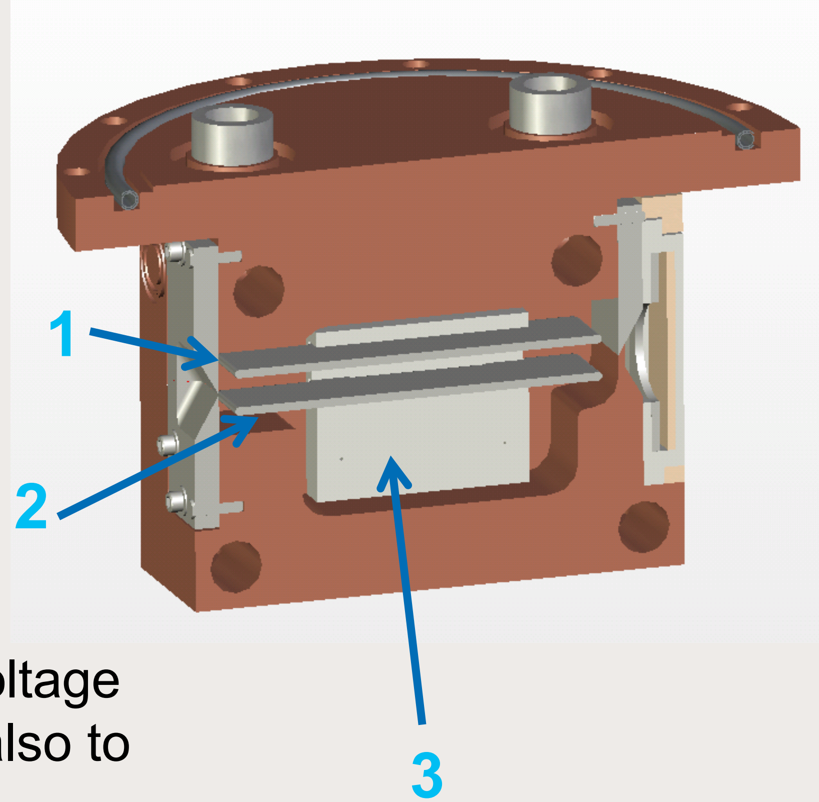
Internal Components Description.

1 SS Top Steering plate

Biased plate

2 SS Bottom Steering Plate

This steering plate is kept grounded with the option of biasing this plate too, when used for the 300 keV e-gun, to reduce the scanning voltage.



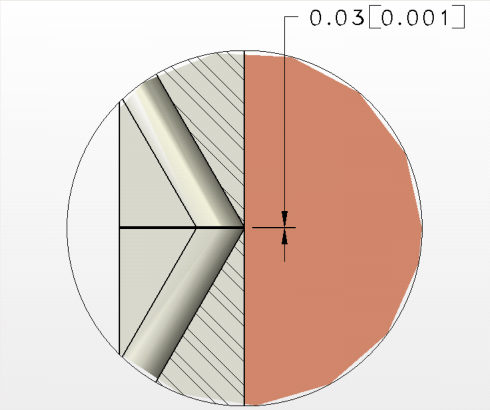
3 Aluminum Nitride Insulators

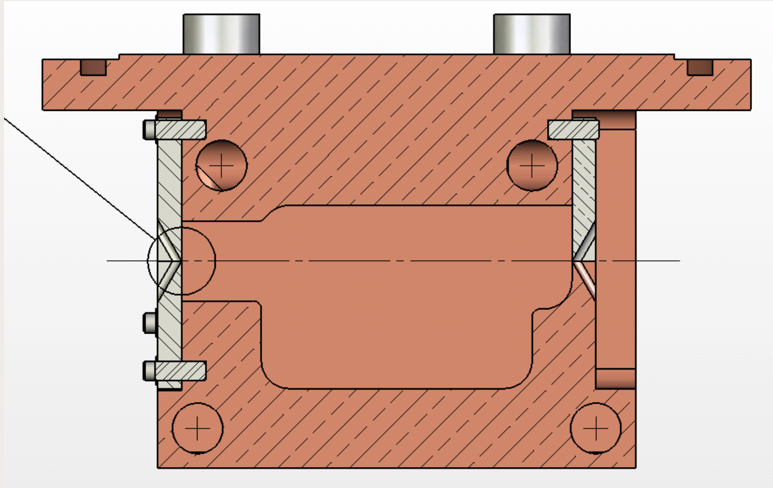
- AlN insulators are used to maintain the voltage difference across the steering plates and also to preserve the gap width between them.
- Low outgassing rate, low porosity.

Manufactured by Omley Industries Inc. - USA

Tungsten Slits Jaws

• The entrance slit jaws are made of tungsten. This is the part of the emittance head that sees ~10% of the beam and it gets to high temperatures.





• The top slit jaws are easily removable.

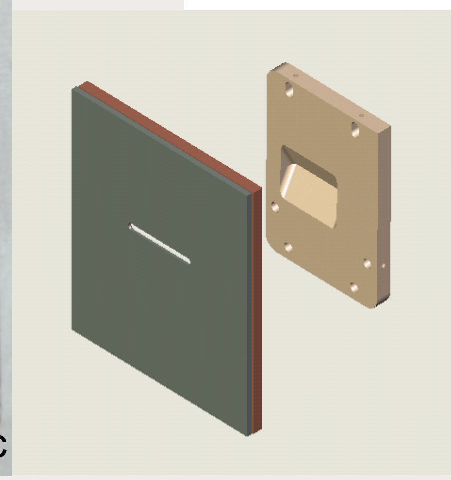
• Both slits apertures are 1.5 thou (0.038 mm)

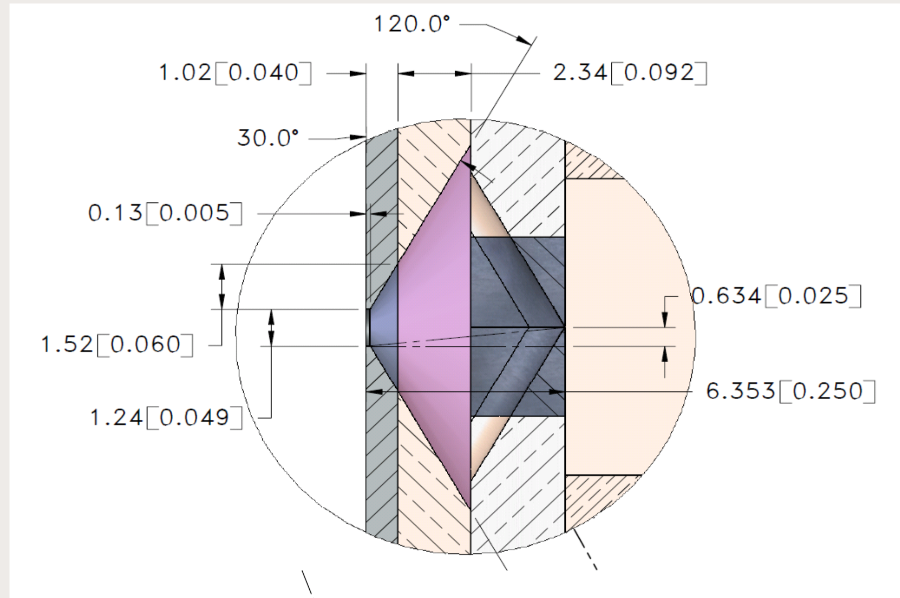
The bottom slits jaws are stationary: the end one is built in, the front one is dowel pinned. To achieve alignment the bottom slit jaws were wire EDM (Innovative Tool & Die Inc. – Canada)

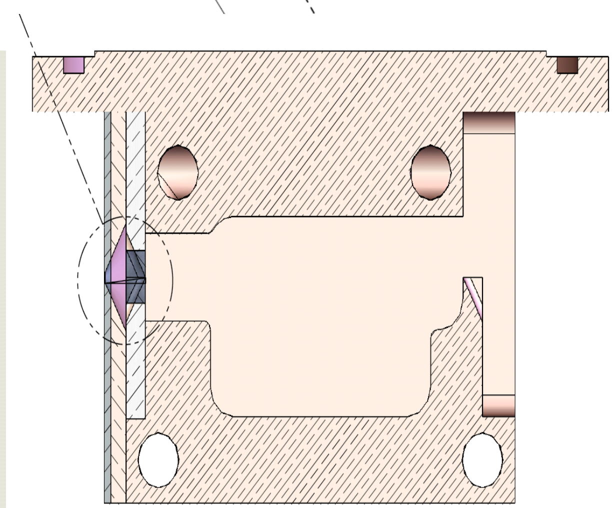
Tungsten-Copper Protection Plate

- For protecting the first pair of slits against the 1000 W beam power an external plate is attached in front of them. This introduces more flexibility in the design. The protective plate is made of tungsten explosively bonded to a OFHC plate for thermal conduction purposes.


High Energy Metals, Inc







Thermal considerations and ANSYS simulations

• Thermal calculations were done for the water-copper thermal convection; calculated heat transfer coefficient.

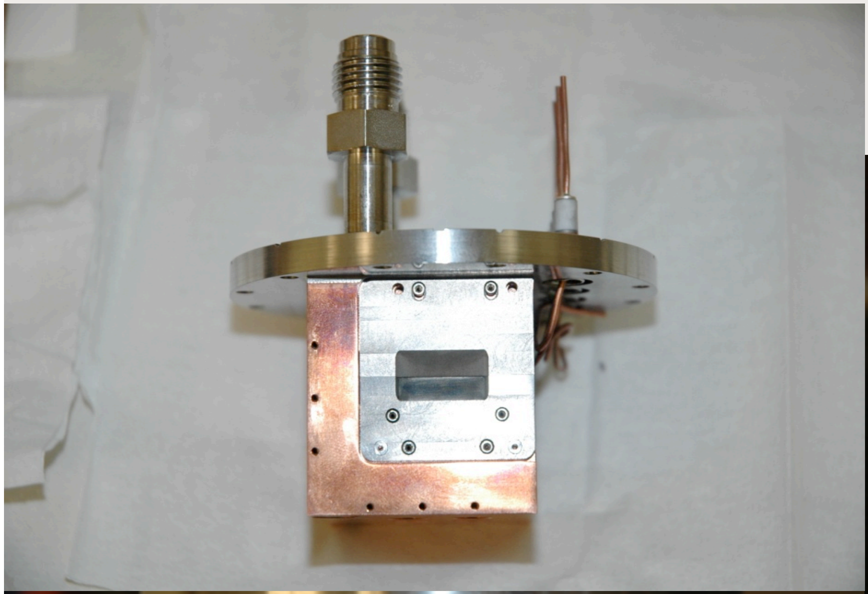
• Results were used to do thermal simplified 3D models at different homogenous beam intensities and sizes, with ANSYS, of the thermal conduction.

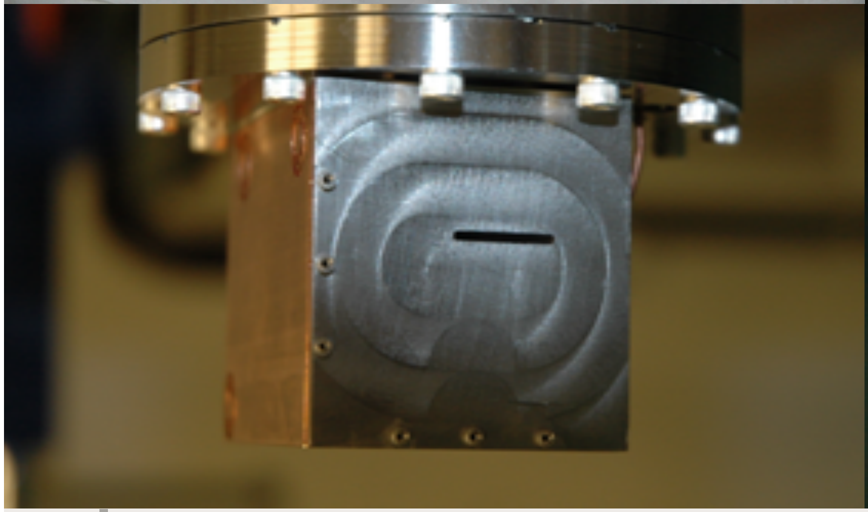
• The main constrain is introduced by the **power density** on the front slit: densities in excess of 115 W/mm^2 will close the slit (of 1.5 thou) through **thermal expansion**.

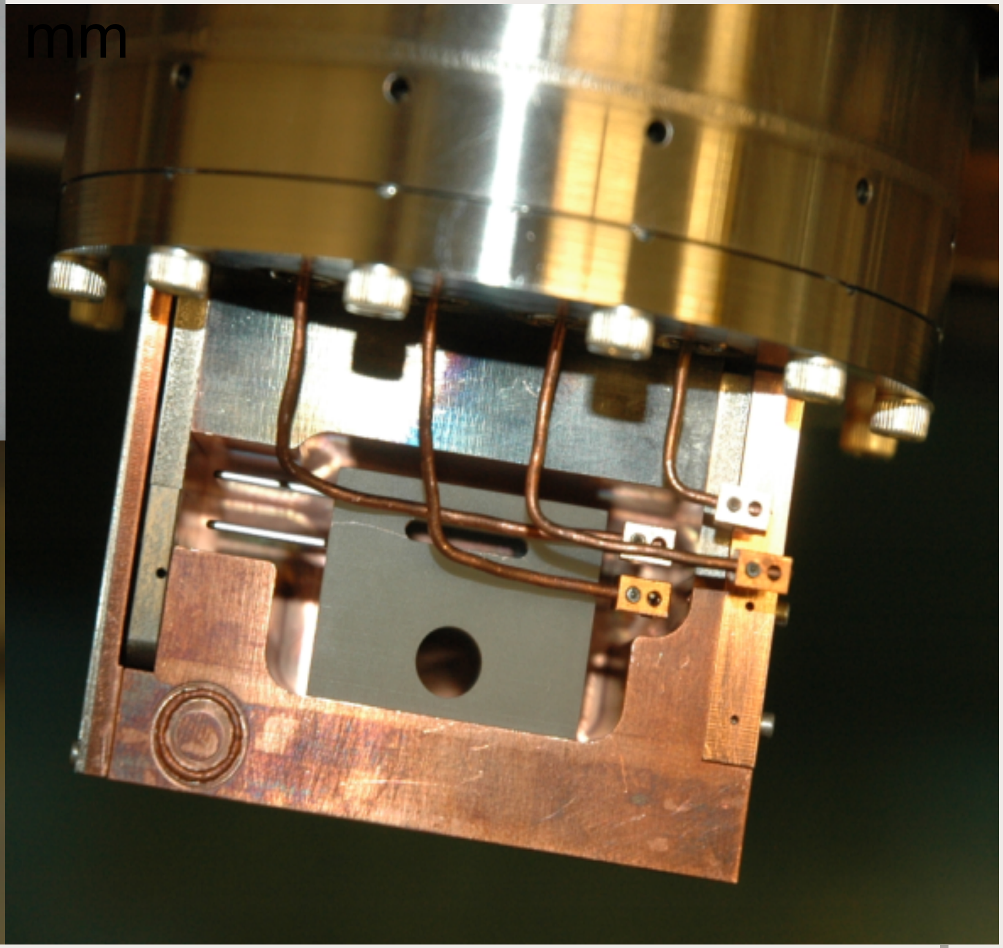
Beam energy [keV]	60	100
Beam diameter [mm]	2	10
Beam intensity [mA]	6	10
Power density [W/mm]	115	10
Slit Temp [deg C]	1650	300
Front plate Temp [deg C]	445	560
Thermal expansion [μm]	33	<< 10

Assembly

Dimensions:
l x w x h = 60 mm x 44 mm x 45 mm

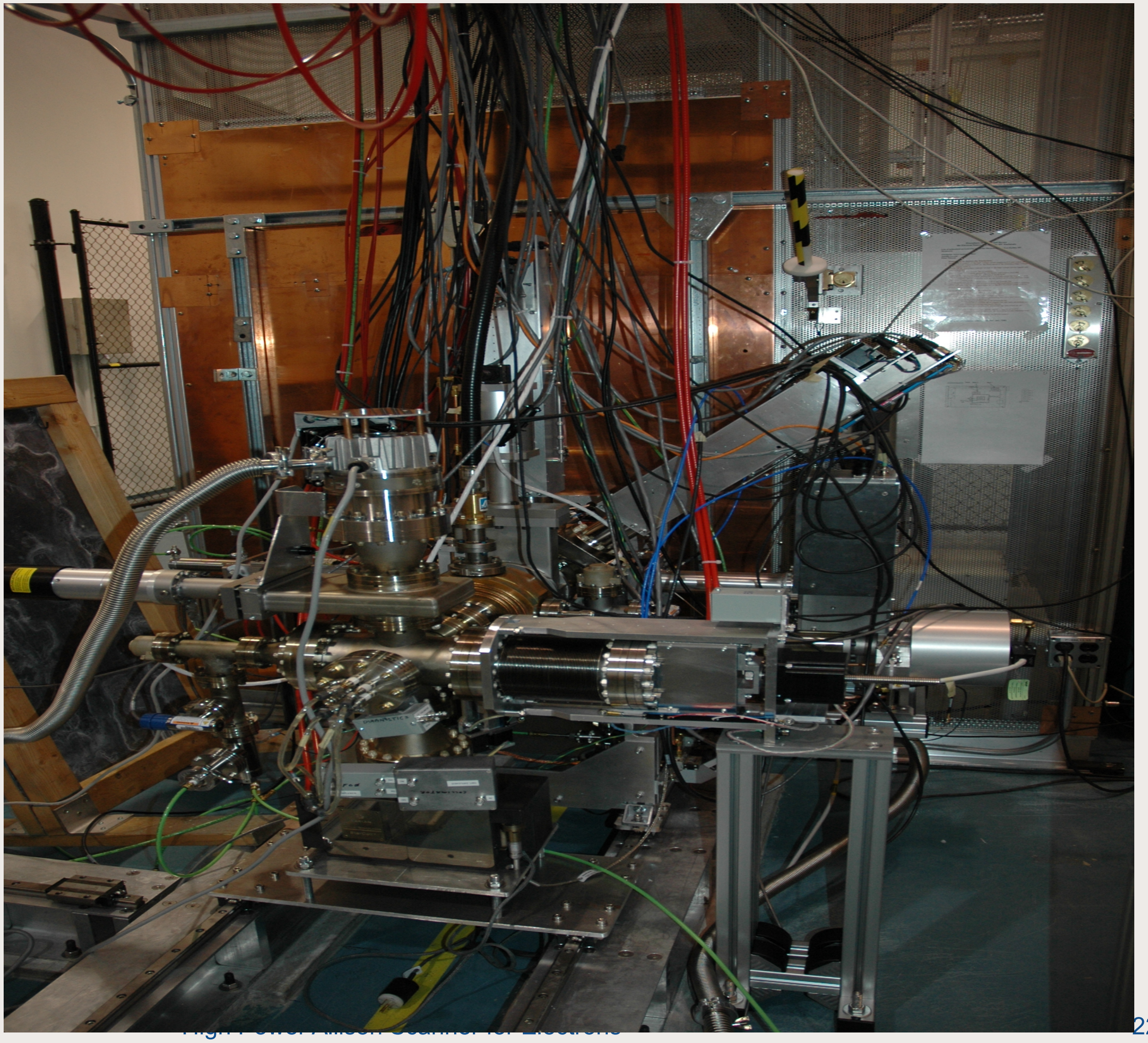






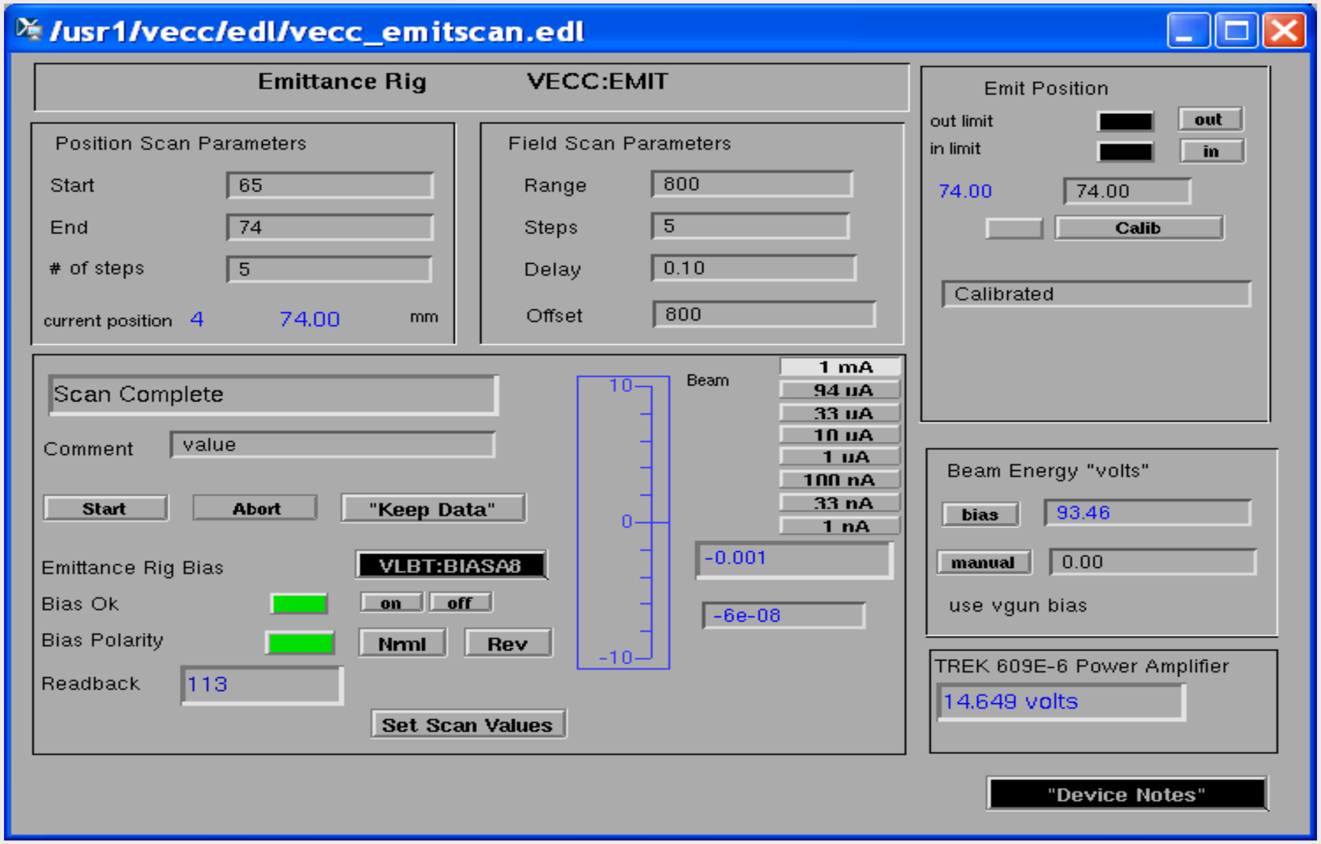
Installation & baking

- Used the cooling lines to flush hot air at 200 deg C to bake the emittance scanner head.



Controls (1)

- Scans are initiated from an EPICS GUI which communicates with the VME EPICS IOC running under Linux.



Controls (2)

- Types of VME modules:
  - stepping motor controller for positioning the slit;
  - DAC for controlling the voltage ramp;
  - variable gain current amplifier/digitizer for the current measurement.

- The present readback device has a 10 Hz update rate;
- Emittance scanner has a variable delay with a minimum value of 100 ms;
- Coarse scan of 21 positions x 21 angles takes 58 seconds;
- Medium scan of 41 positions x 41 angles tales 190 seconds;
- Detailed scan of 81 positions x 81 angles takes 700 seconds.

- Data file is processed and contour-plotted using a MATLAB script.

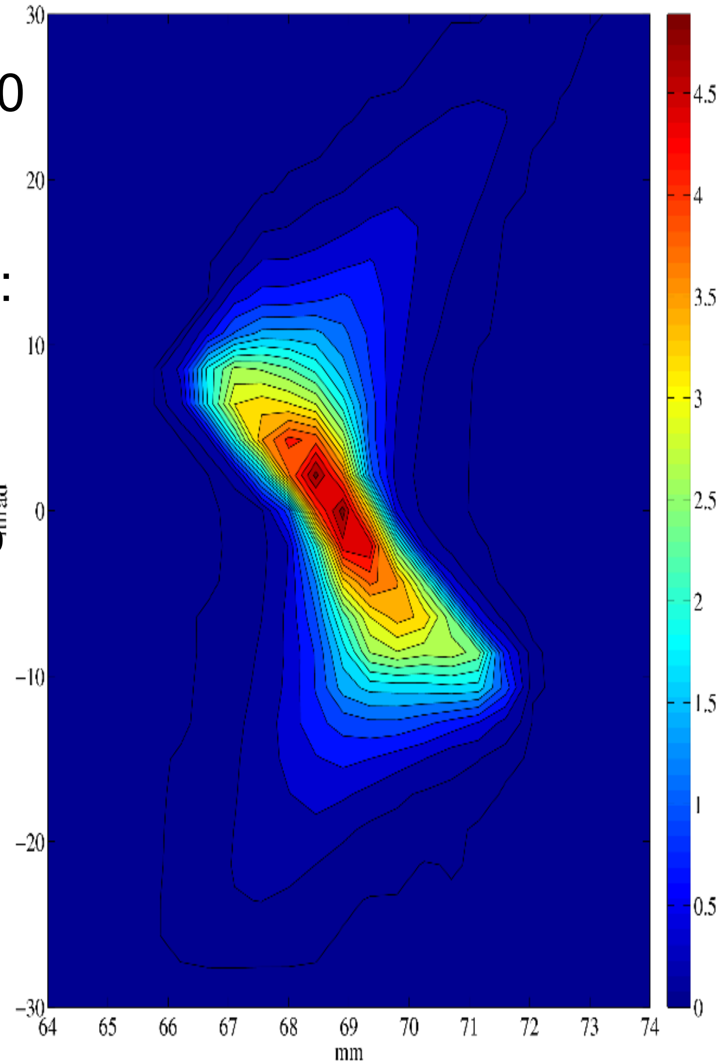
Emittance scan: 60keV 10mA 1% D.F.

- 41 x 41 readings
- Average current 100 μA
- In a 0.03 mm-mrad pixel of phase space: 50 nA at the peak of the figure;
- Noise: 10-20 pA

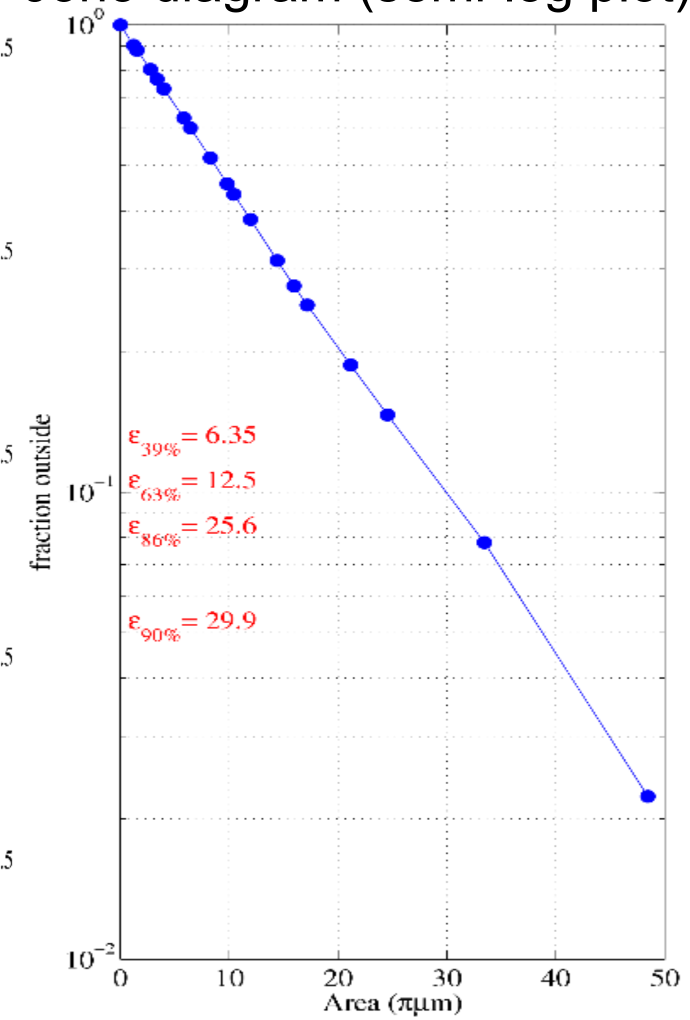
This allows details to the 98% contour;

- ε_{rms} = 9.2 μm

- Distortion may be due to space charge combined with non-optimal Pierce geometry angle.



Joho diagram (semi-log plot)

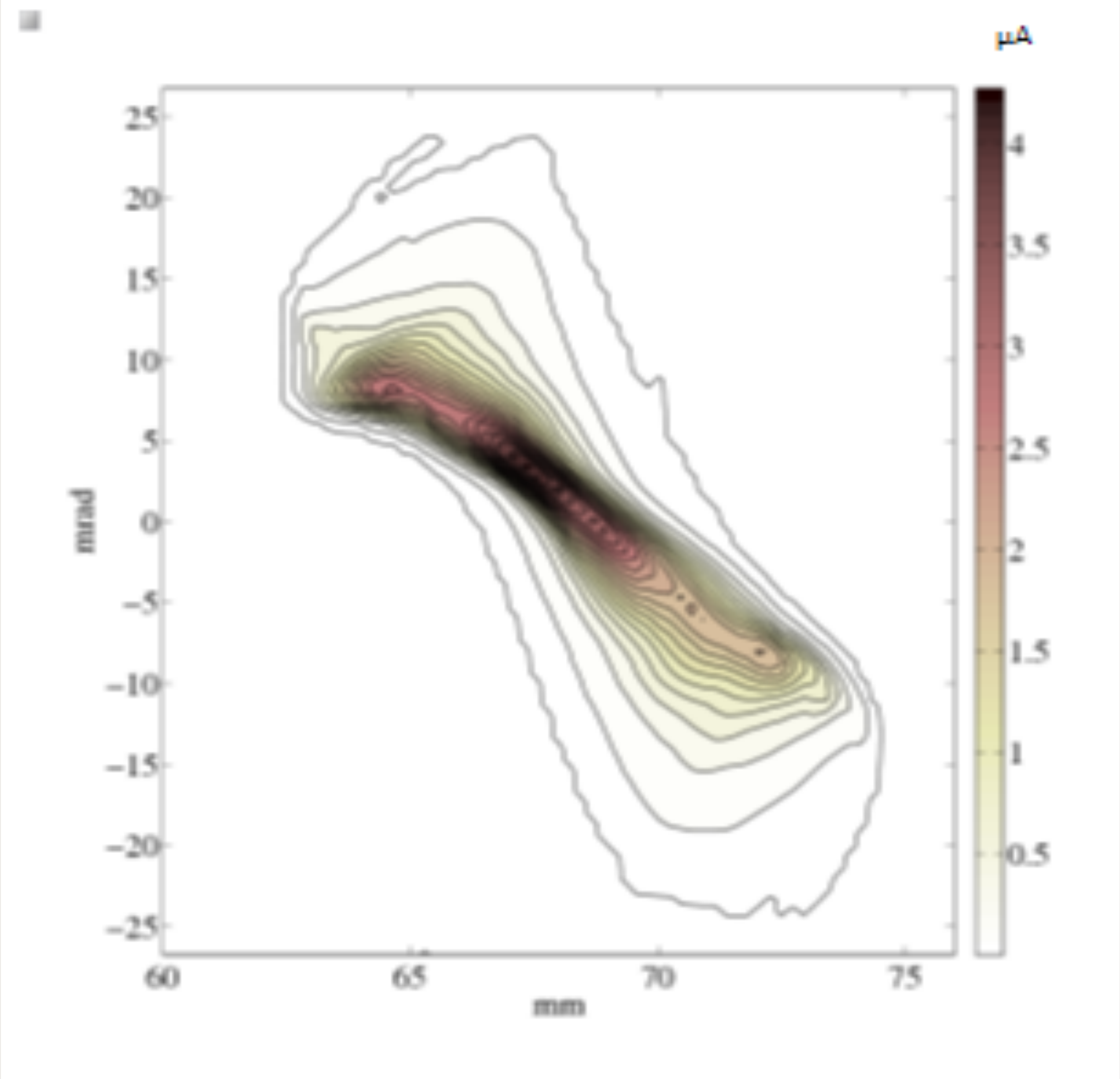


Emittance scan: 60keV 11mA 99% D.F. (1)

- 81 x 81 readings
- The *rms* beam is 2.69 mm with 30 W/mm^2
- Average current 100 μA
- In a 0.03 mm-mrad pixel of phase space:

4 μA at the peak of the figure;
- Noise: 1nA. This allows details to the 98% contour;
- ε_{rms} = 10.1 μm
- $\varepsilon_{39\%}$ = 7.1 μm

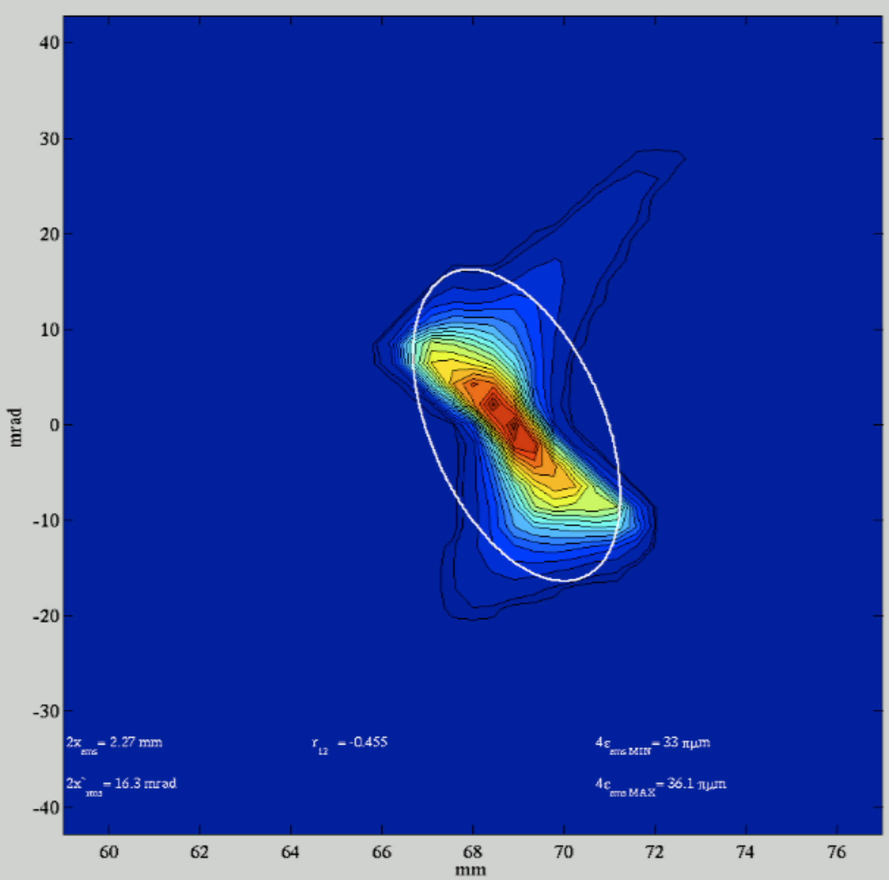
- Distortion ("bow-tie") may be due to space charge, non-optimal Pierce geometry angle and conduction angle.

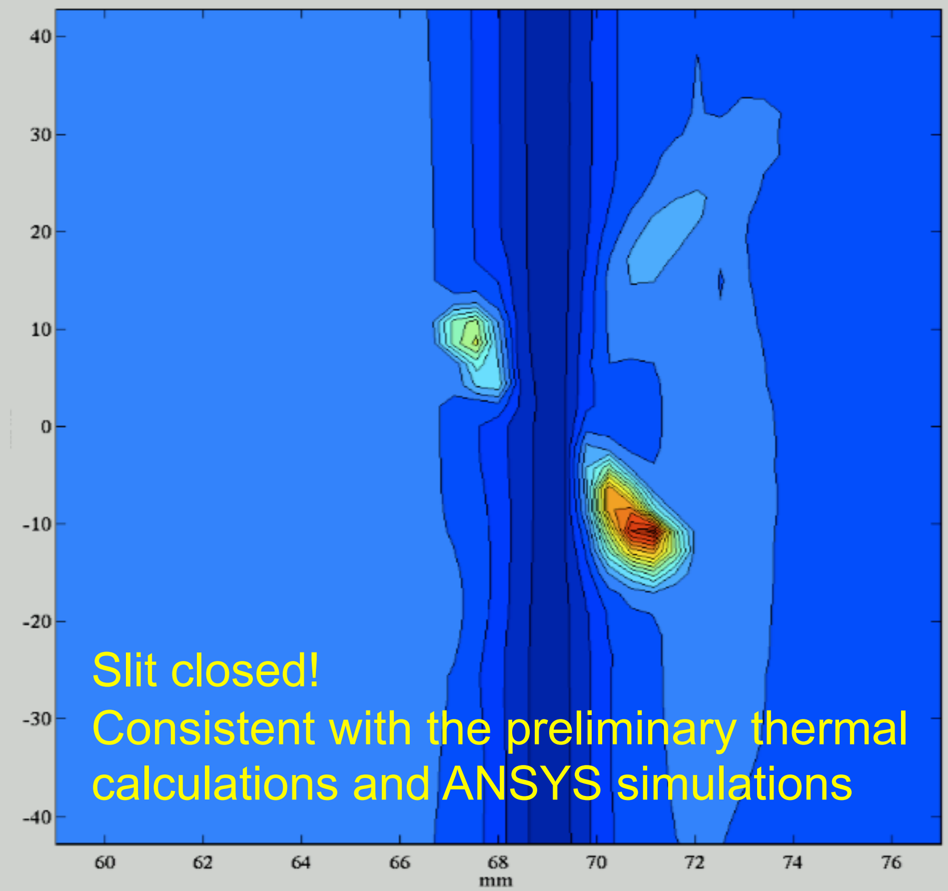


Emittance scans: 60keV 11mA at WAIST

1% D.F.
rms beam size 1.14 mm
Power Density 1.6 W/mm^2

99% D.F.
1.14 mm
160 W/mm^2 → 2,300 deg C (ANSYS)





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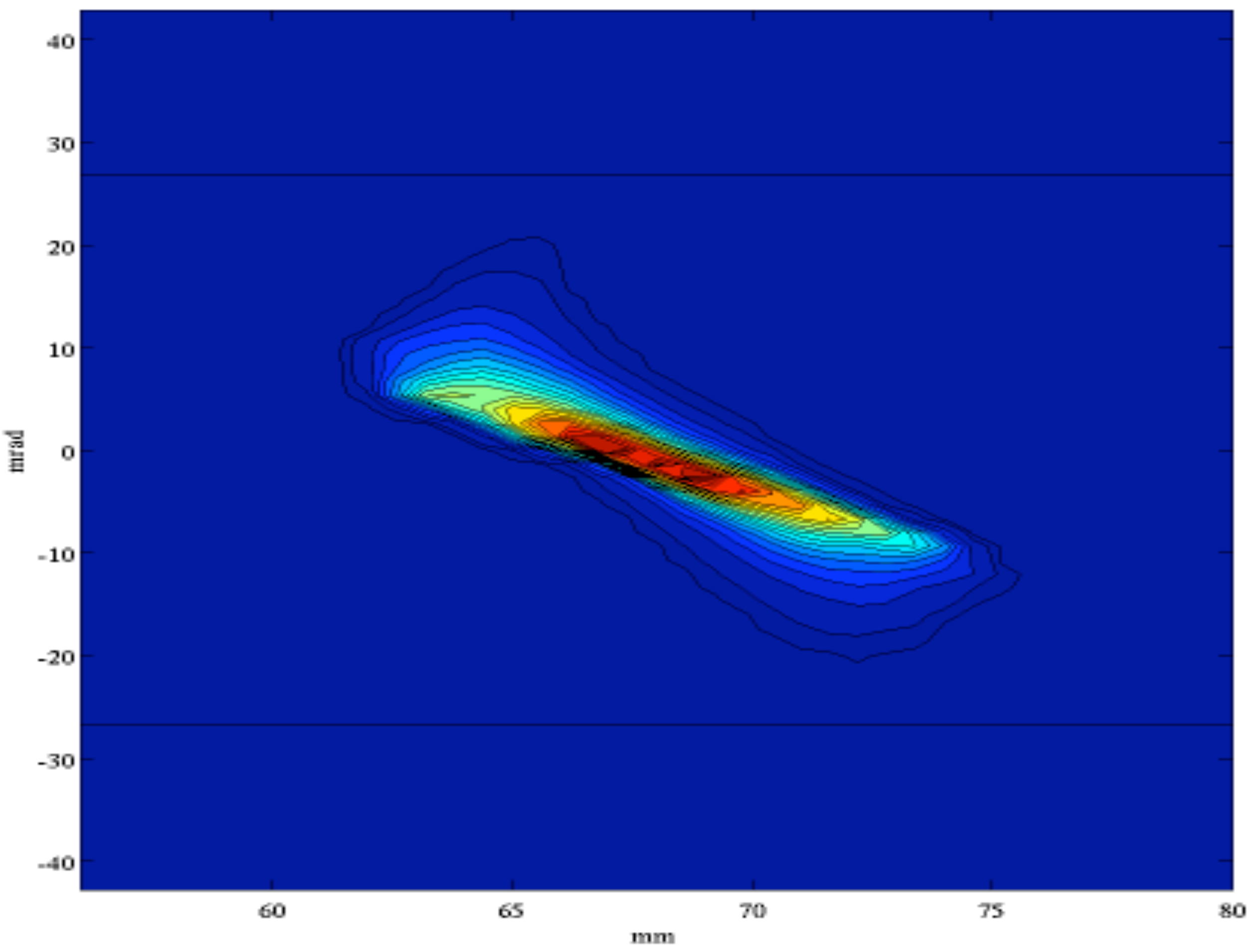
Emittance scans at different D.F.

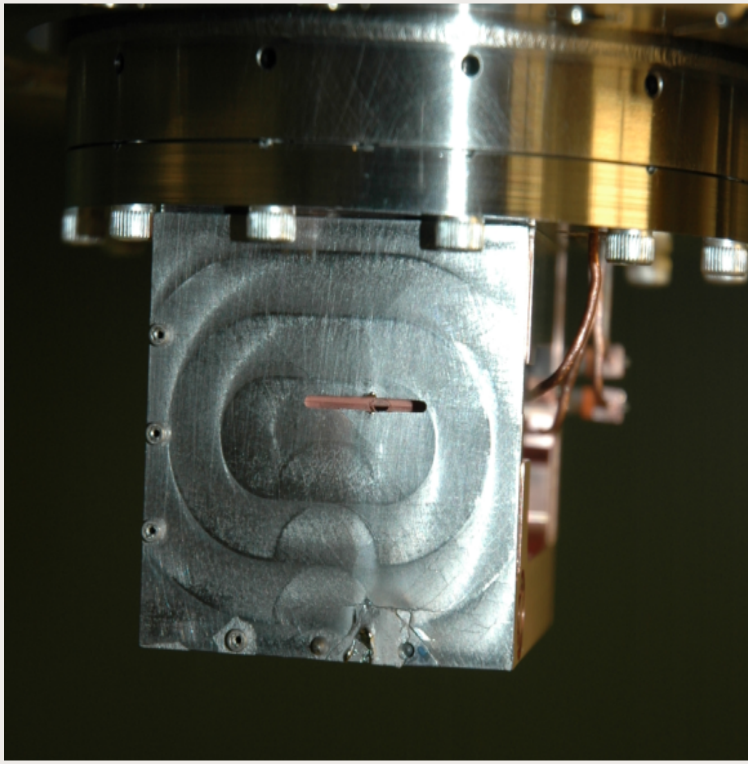
- Took scans at different D.F. 10%, 30%, 50%, 70% and 99% for the same source parameters:
    - same RF amplitude,
    - cathode bias and
    - solenoid currents

➔ the emittance values were consistent;

Solenoid scans



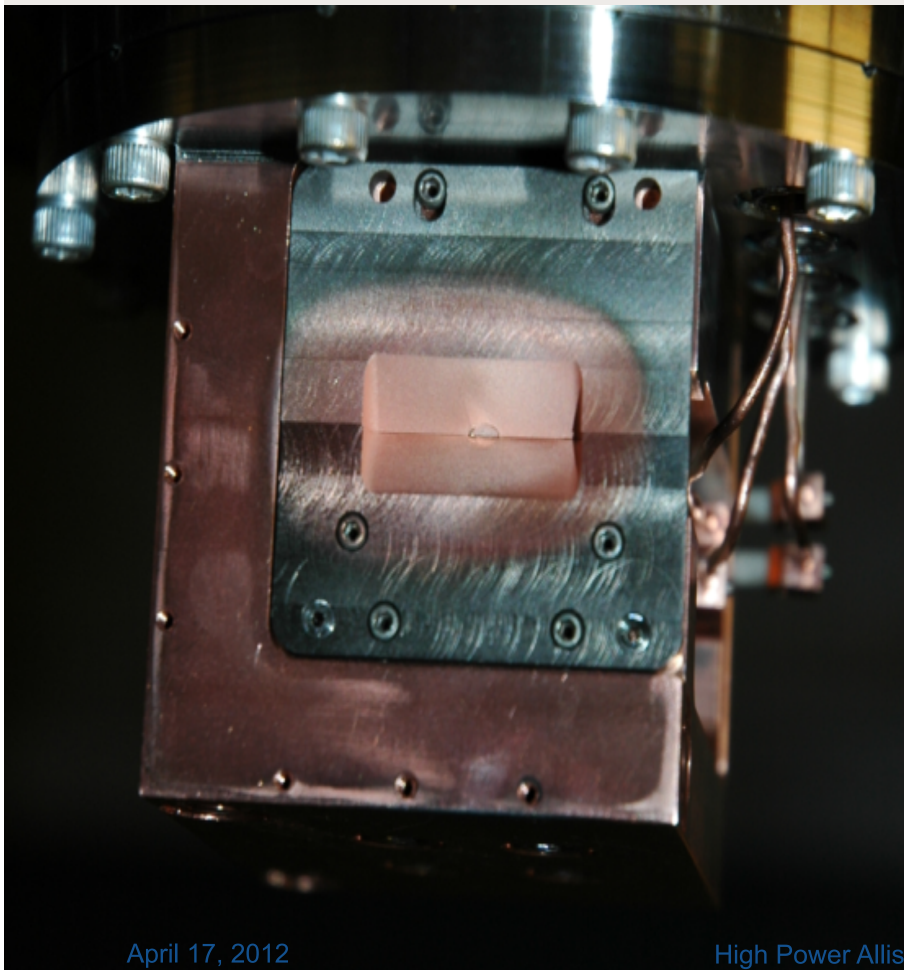
Inspection - Front plate



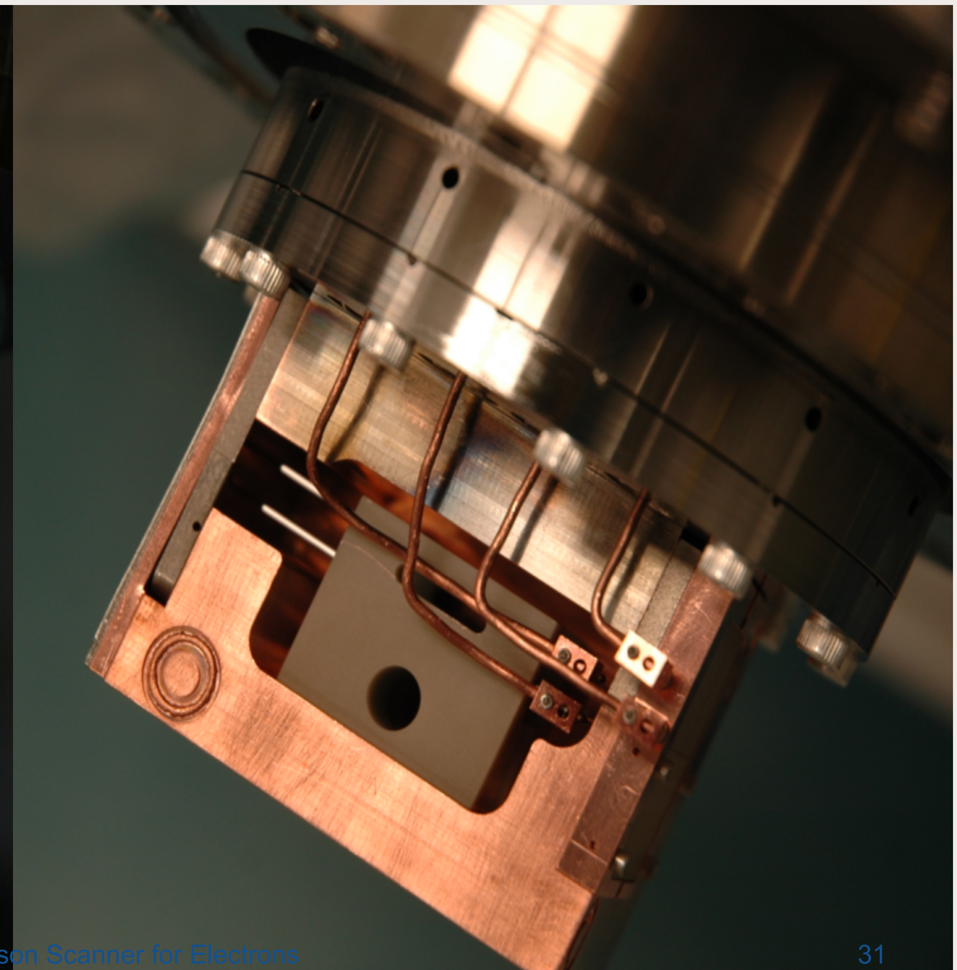
Copper vaporization from the back of the protection plate, that plated the entrance tungsten slit.

Inspection – Front slit & Emittance scanner body

- Tungsten entrance slit plated with copper.

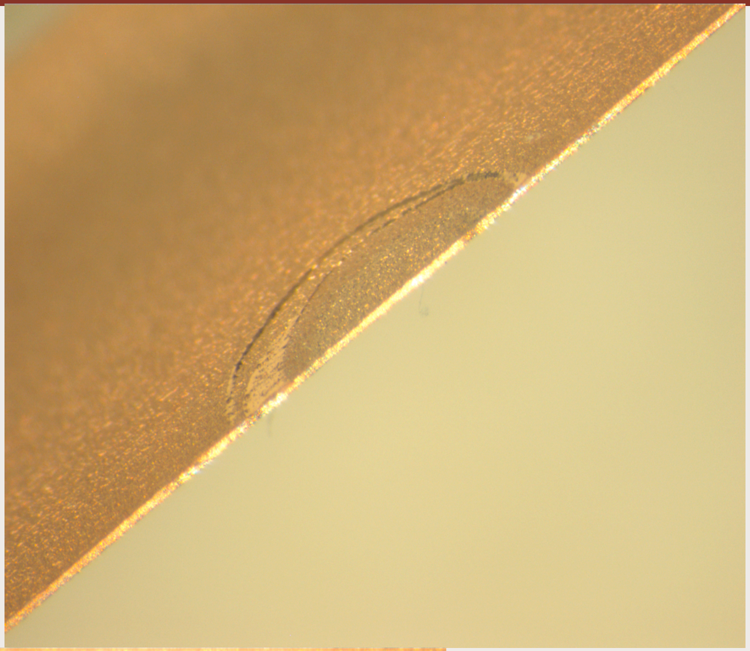


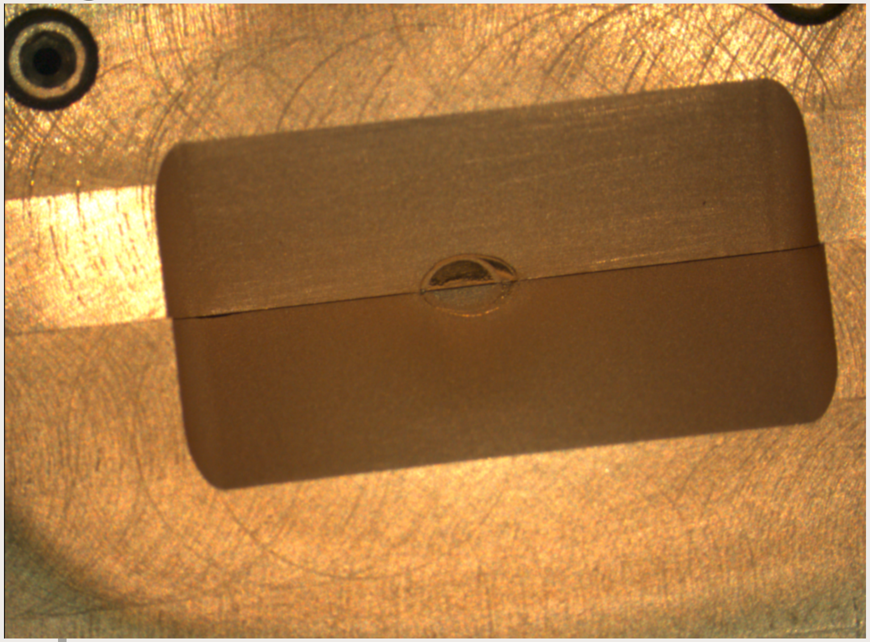
- The emittance scanner body was not not damaged.



Front slit inspection - Microscope

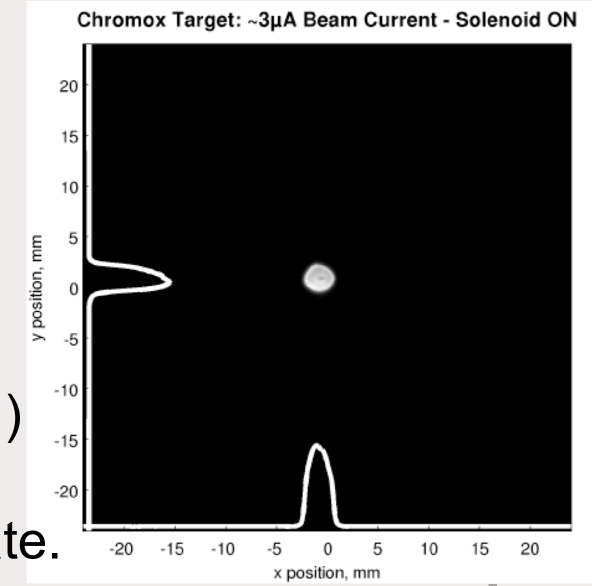
Height = 1.14 mm
Big Diameter = 2.69 mm
Small Diameter = 2.15 mm
Slit gap in the center = 1.5 thou (preserved)
Magnification: 1mm -> 365 pixels





Conclusions

1. The Allison type emittance scanner for electrons:
   - can measure a **large transverse phase space** (1600 πμm) at a **high resolution** of 0.03 μm, in **high vacuum** 10^{-9} Torr.
   - can take **high power beams**: so far measurements were done for 660W.
2. The emittance measurements are consistent with independent measurements using a scintillator-type profile monitor, and a simple analytical model for a thermionic gun.
3. It is used for **understanding the source parameters,** at high and low D.F., and **optimizing the source**:
   - Thermal effects in the source (RF heating up);
   - Conduction angle;
   - Pierce geometry angle;
   - Space charge neutralization (changes with D.F.)
5. It can be used for the 300 keV e-gun also.
6. It can be further improved: redesigning the front plate.



Acknowledgments

TRIUMF participants:
F. Ames, R. Baartman, D. Brennan, S. R. Koscielniak, D. Morris, W. Rawnsley, P. Vincent, G. Waters, D. Yosifov

Machine shops & companies in USA and Canada:
High Energy Metals, Inc. - USA
Omley Industries, Inc. – USA
Parker Hannifin Corporation - USA
Innovative Tool & Die, Inc. – Canada
TRIUMF Machine Shop

TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

Thank you!
Merci!

Questions?

TRIUMF: Alberta | British Columbia | Calgary Carleton | Guelph | Manitoba | McMaster Montréal | Northern British Columbia | Queen's Regina | Saint Mary's | Simon Fraser | Toronto Victoria | Winnipeg | York