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

Allison Scanner Emittance Diagnostic Development at TRIUMF

LINAC14

September 4, 2014

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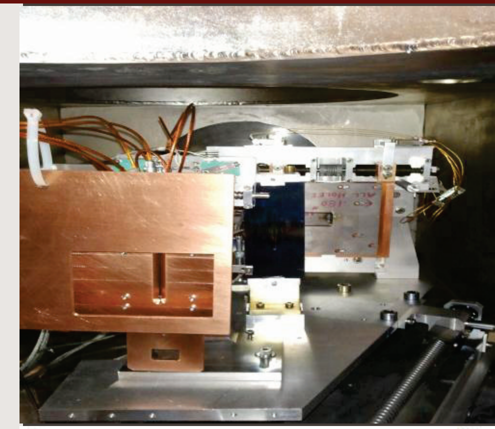

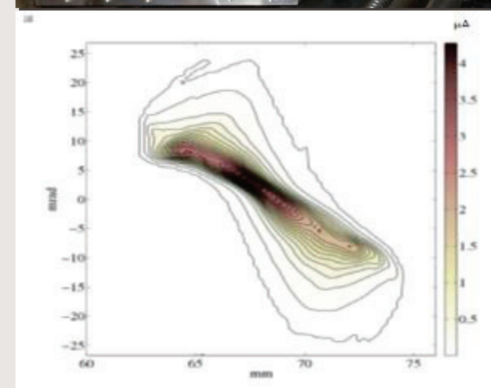

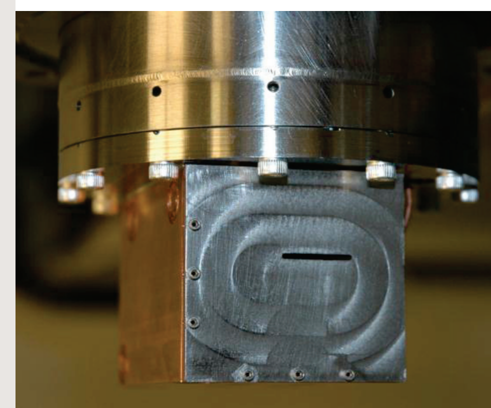

Outline

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  - Specification
  - Detail design, engineering and hardware
  - Results
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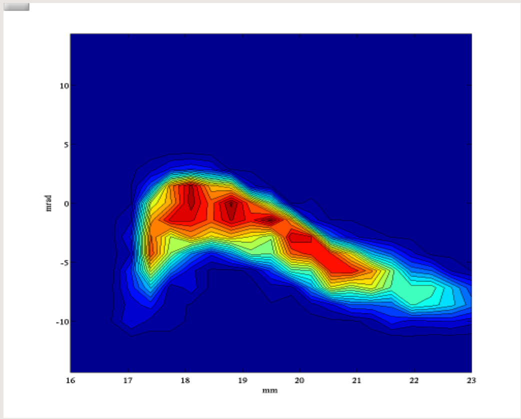
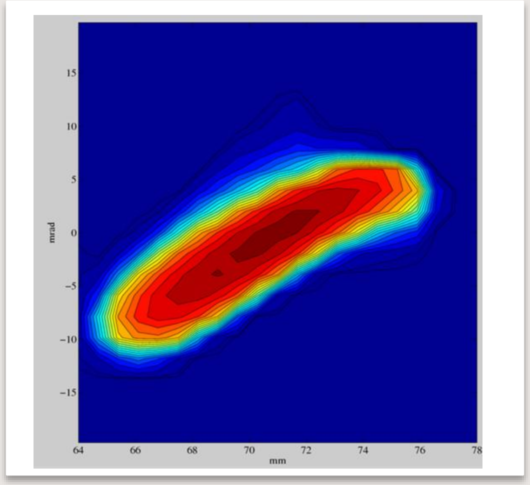




Principle

- Allison scanners are high-resolution compact emittance scanners *
- A front slit, deflecting plates, a rear slit, and a Faraday cup in a single unit is stepped across the beam with a stepper motor
- At each step the beamlet selected by the front slit is stepped across the rear slit with the deflecting plates and the transmitted current is measured by the Faraday cup.

- Scanner resolution:

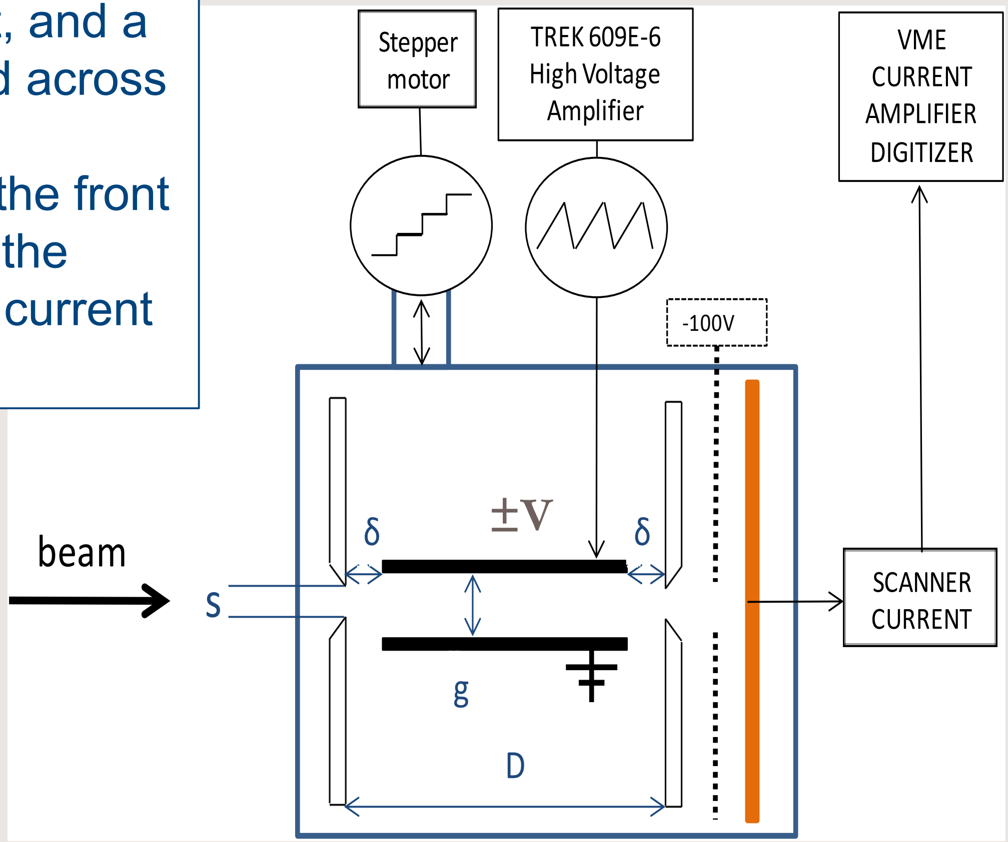
$$s^2 / D = 0.03\ \mathrm{mm-mrad}$$

- The maximum divergence

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

- The maximum voltage for the maximum analyzable divergence

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



* Allison et al – “An Emittance Scanner for Intense Low-Energy Ion Beams”

Motivation

- TRIUMF has several emittance scanners in operation ranging down to intensities of 1nA and beam powers up to 10W
  - Typical beam phase space is 30 mm mrad and the resolution is 0.03 mm mrad
  - the sampled beamlet selected through the back slit is ~200-1000 times less than the total beam intensity
  - so 1nA means sampling intensities of 1pA – limited by Faraday cup noise suppression

- Low intensity monitor
  - Radioactive beam intensities are typically in the range of fA to pA
  - a low intensity monitor was required for ion source development and on-line tuning

- High intensity monitor
  - The e-Linac operates with cw beam intensities up to 10mA
  - We wanted a monitor to diagnose the 300keV electron gun performance up to near cw conditions - 1kW average beam power

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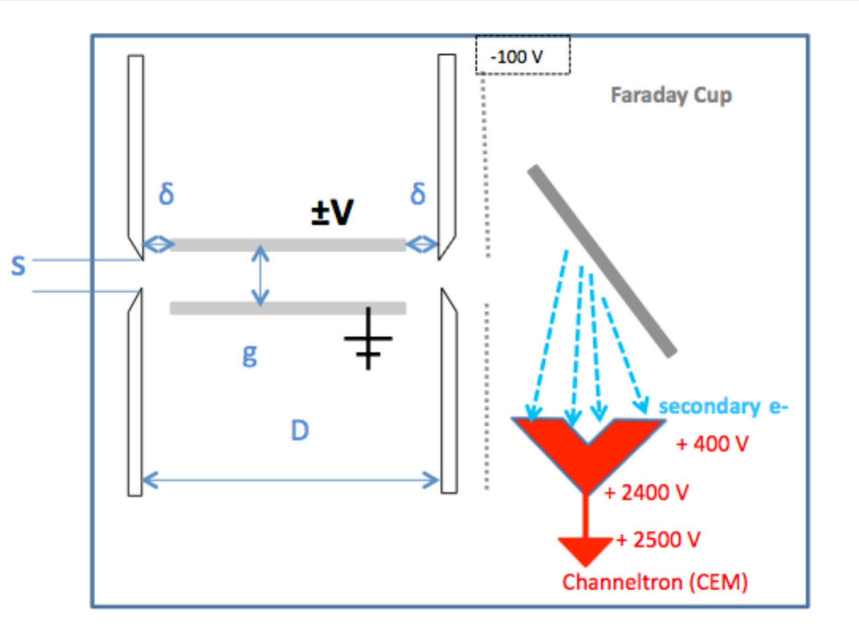
PART I

LOW INTENSITY EMITTANCE SCANNER

Low Intensity Emittance Scanner: FC mode, CEM Mode

- Goal: Low intensity emittance scanner to measure the beam emittance starting at very low beam currents: from 10^4 pps (1.6 fA) for diagnosing radioactive ion beams

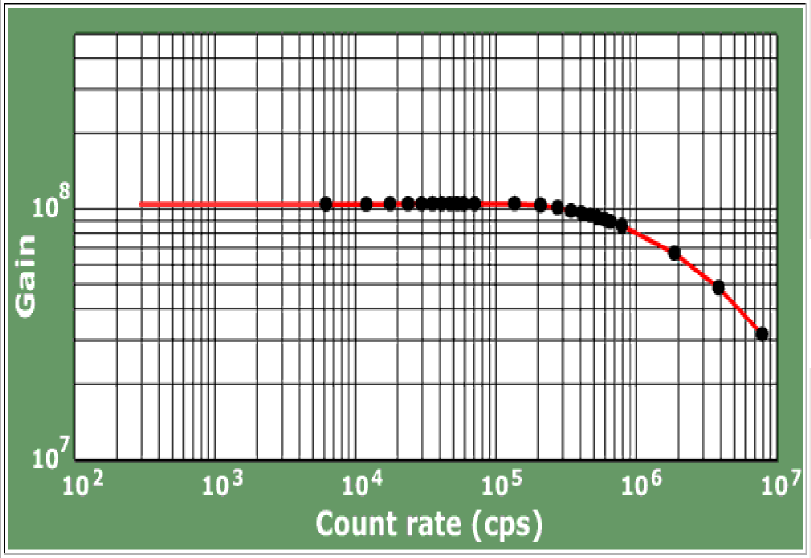
- In the new design – two modes can be used:
  - the Faraday cup at the end of the emittance scanner is tilted
  - a channeltron (Channel Electron Multiplier) is incorporated as an additional feature
  - the secondary electrons are captured, multiplied and measured at the anode
  - the emittance is indirectly determined from the secondary electrons



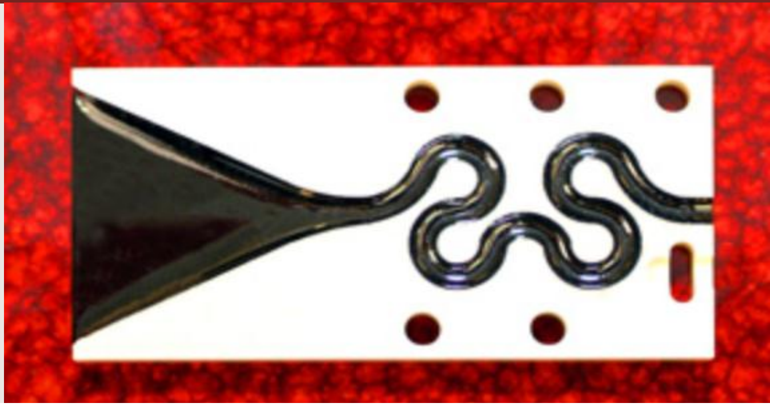
L [mm]	50
d [mm]	1.5
D [mm]	53
g [mm]	2
s [mm]	0.038
E [keV]	60
x'_m [mrad]	±75.5
V_m [V]	±770.77
El_F [V/mm]	±385.39

Channel Electron Multiplier (CEM)

Sourced from Dr. Sjuts Optotechnik GmbH
http://www.sjuts.com/



CEM Gain as a function of count rate



CEM model – KLB2107
Extended Dynamic Range CEMs (typically 70 MOhm)

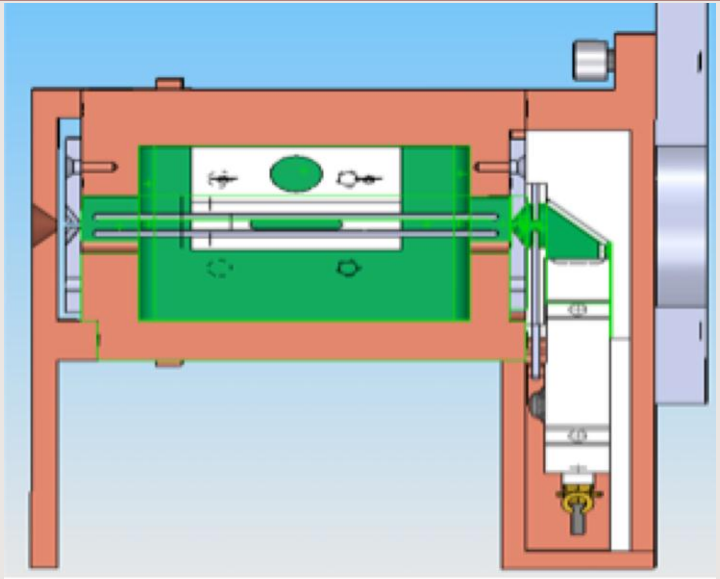
- The measured count rate represents the secondary electron intensity and is therefore proportional to the ion beam intensity.
- The system is capable of processing secondary electron intensities from tens to about 10^6 particles per second.

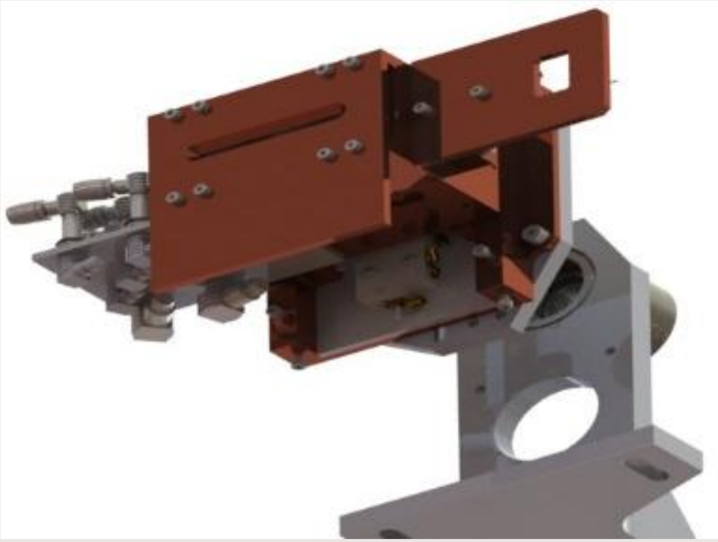
Mechanical Design

• The channeltron has a limited lifetime around $5x10^{12}$ accumulated counts.

•The end part of the scanner, housing the bias ring, the Faraday cup and the channeltron, can slide out and be replaced in situ.

• The slits and the electrostatic plates are not affected by the replacement of the channeltron.





- To allow replacement of the channeltron and Faraday cup in situ, LEMO connectors were mounted on a plate fixed to the side of the emittance scanner body.

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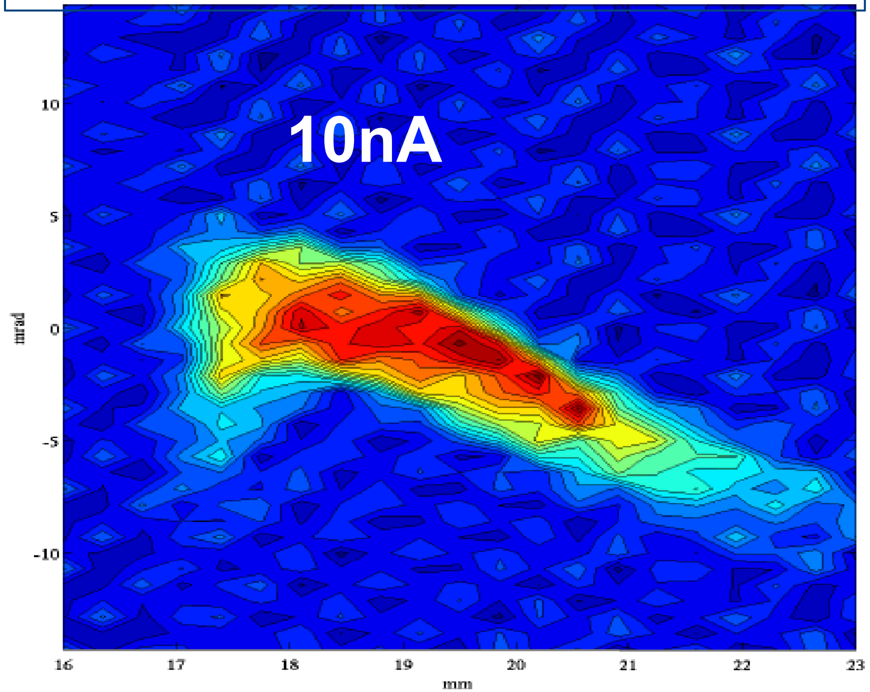
Controls xx

- The emittance scanner software is a subroutine running under the control of EPICS.
- There are two modes of operation:
  - Faraday cup using a VME current amplifier
  - channeltron using a VME scalar (model Joerger VSC16)
- Typical scan takes 1 minute to 15 minutes depending on resolution – 150ms/step
- Data file is processed and contour-plotted using a MATLAB script - automatic

Faraday Cup emittance measurement vs. CEM emittance measurement

Measurement with Faraday Cup type Scanner

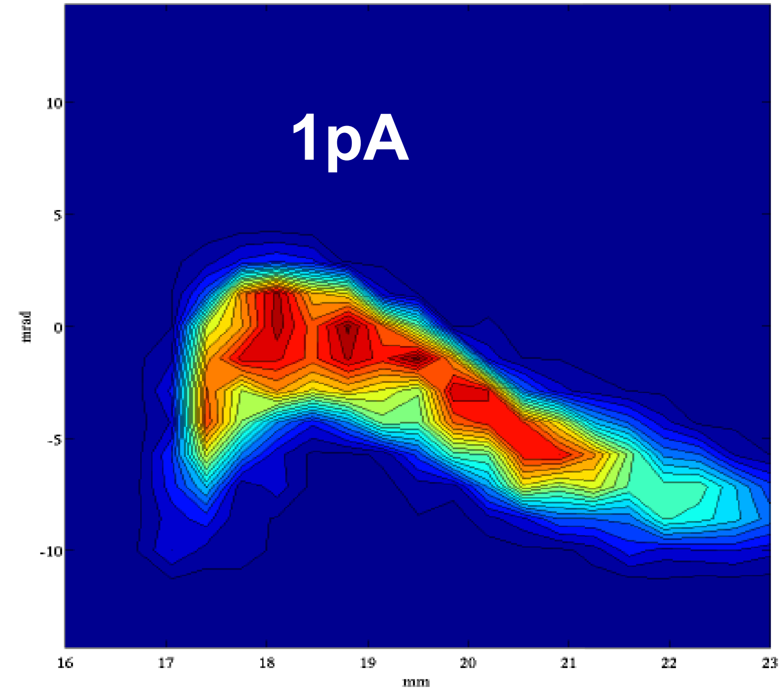


Above: 10nA 7Li at 20 keV

Notice the level of background noise.

This noise is about +/-1pA in one pixel.

Measurement with CEM type scanner



Above: 1pA, 27Al at 20 keV

10^4 times less current and yet the noise is far less.

Gain in sensitivity is roughly a factor of 10^6.

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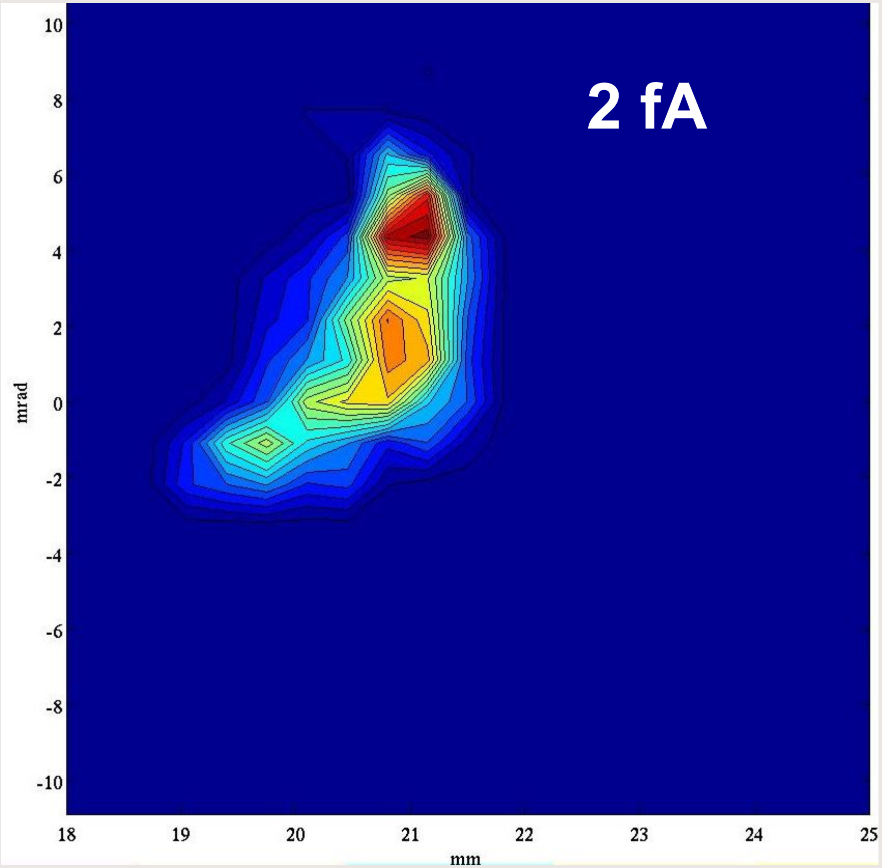
Emittance scans with CEM

Emittances at very low intensities:



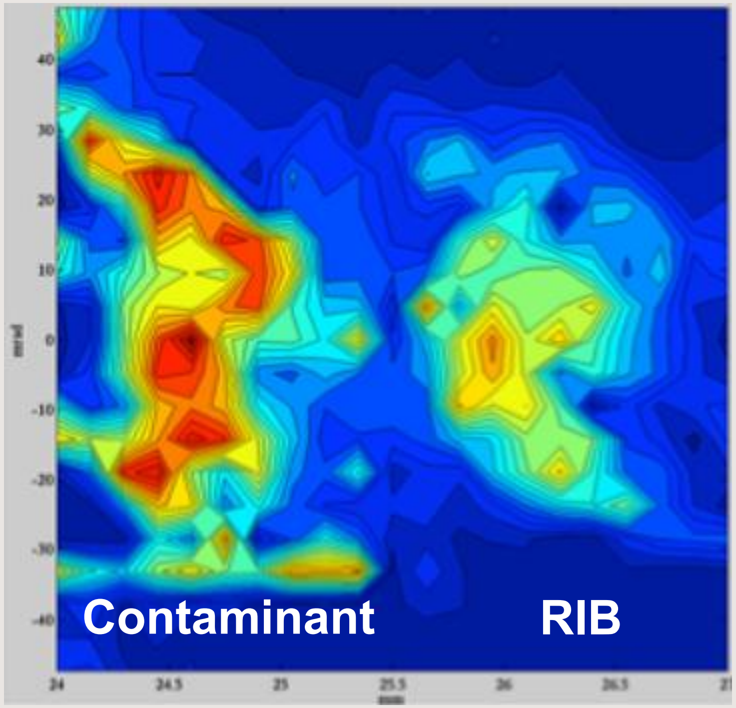
225Ra at 20 keV
Intensity=13,000 cps (2fA)
ε = 4.2 mm mrad

Detecting Isobaric Contamination

- Isobaric contaminant identification and separation
  - 1000pA before the mass separator – 5pA after the mass separator
  - Contaminant 26Na
  - RIB of interest 12C14O

- These scans show that the emittance meter is capable of detecting isobaric contamination

- helps us understand beam properties and transmission losses in the mass separator magnet, even at low intensities.



PART II

HIGH POWER EMITTANCE SCANNER

Specifications

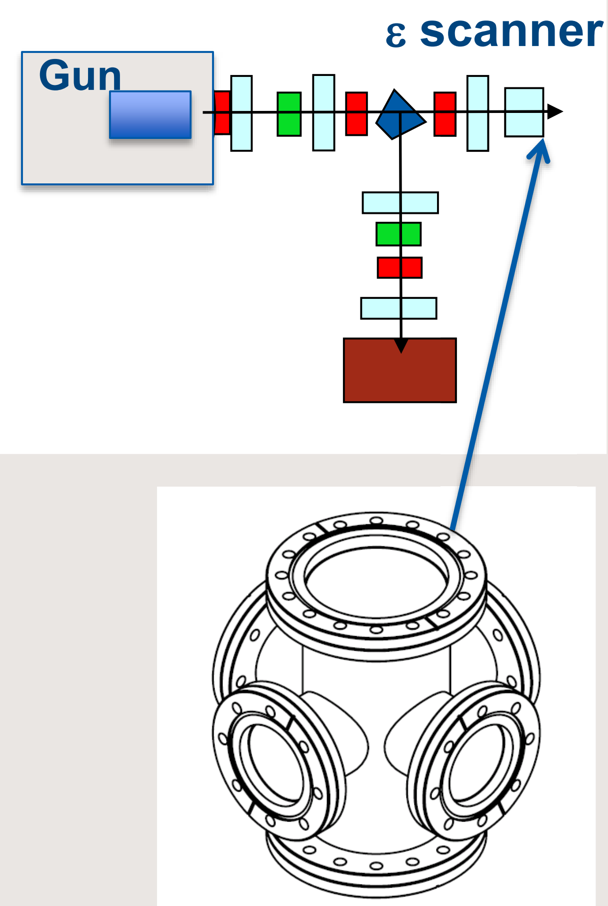
- Requirements for high power emittance meter for the e-linac project

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

small volumes
UHV competitive materials

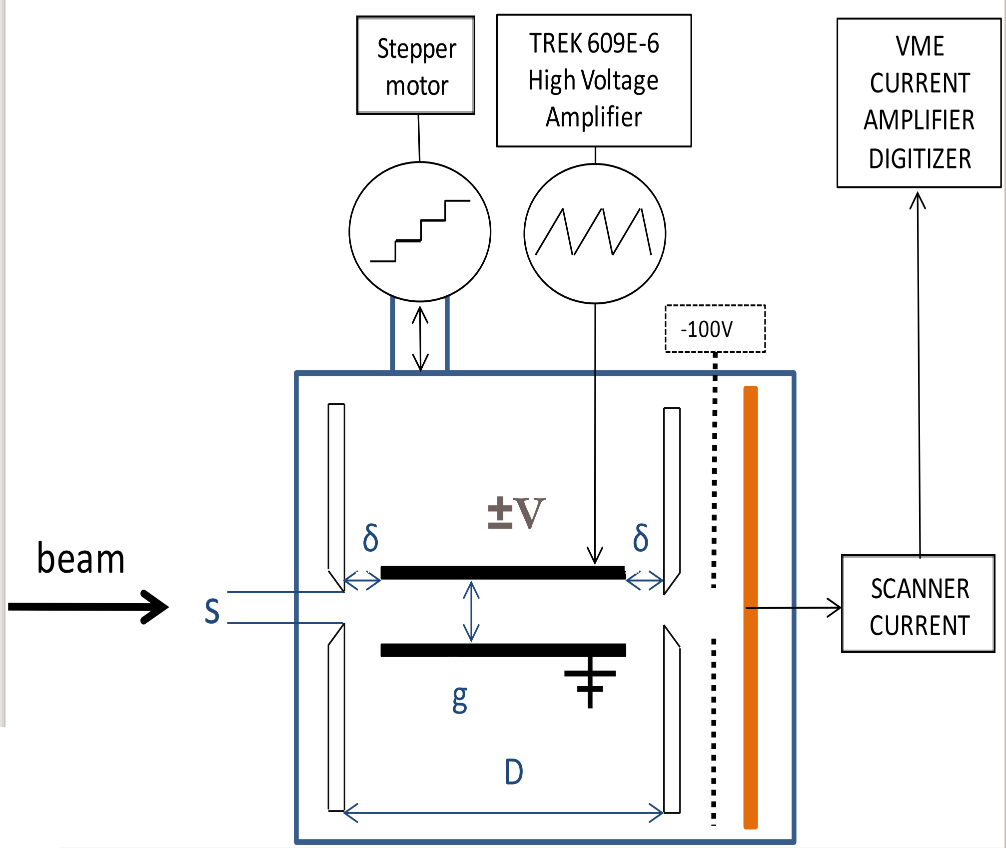
- Location of emittance meter
  - e-Linac LEBT beamline for e-Gun beam characterization
  - In a small diagnostic box
    - CF 6-way SS reducer cross (2x) 6” OD (4” ID) CF x (4x) 4.5” OD (2.5” ID) CF

E-Linac LEBT Beamline



Overview of Parameters

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

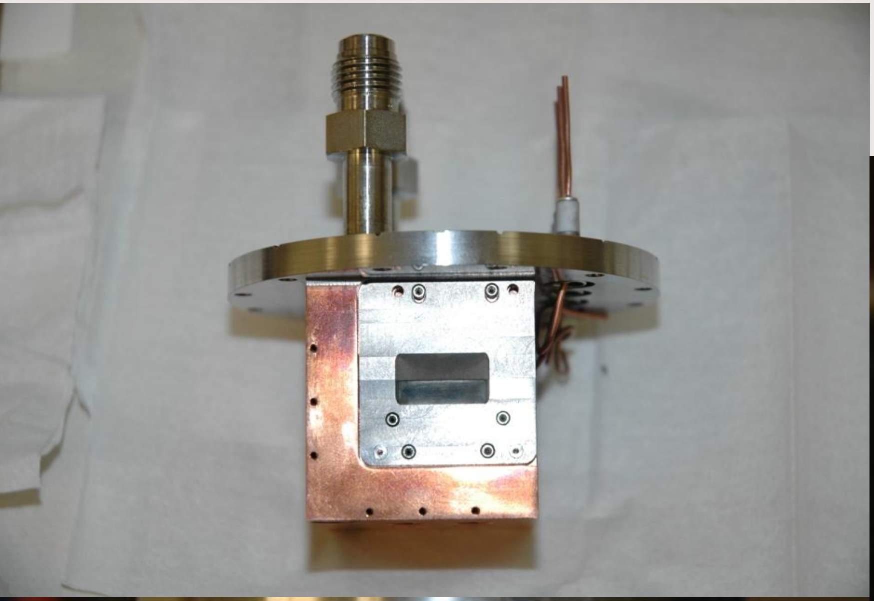


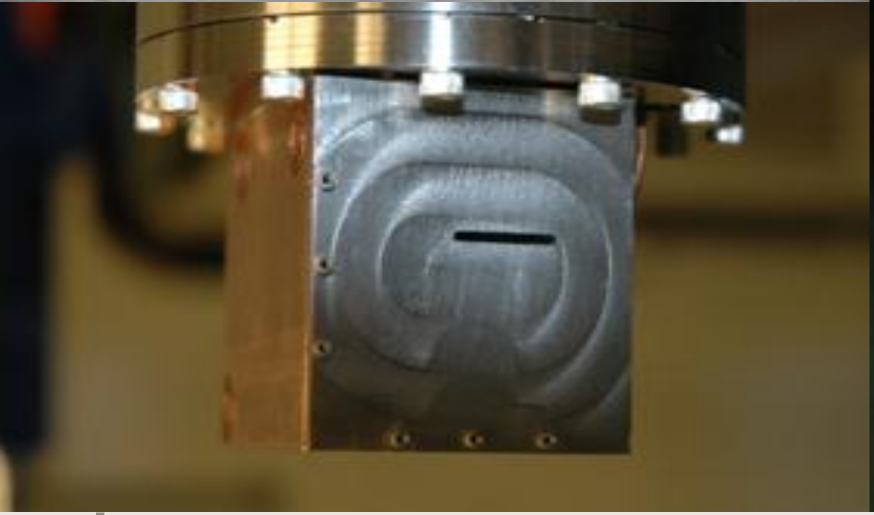
- For relativistic particles the voltage is smaller by a factor *k*

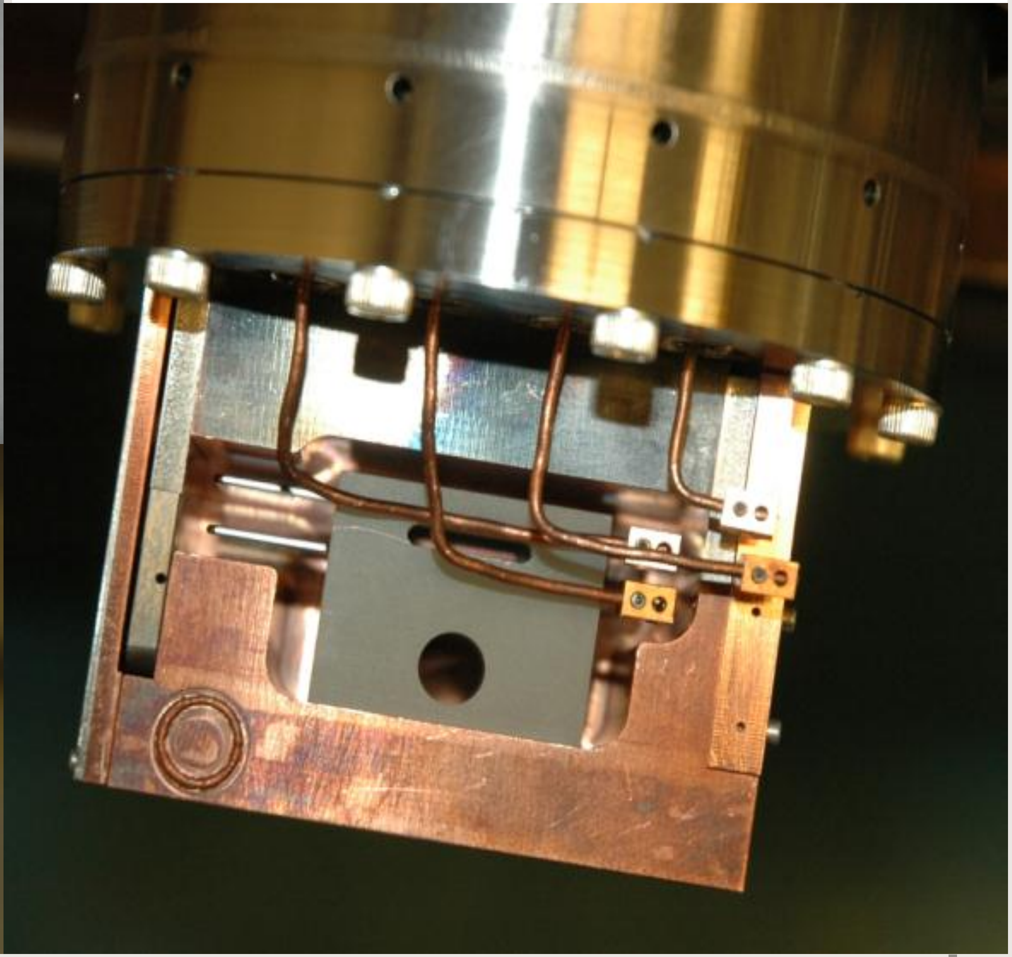
$$V_{m-rel} = \pm V_m / k \text{ and } k = 2/(1+1/\gamma)$$

Assembly

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

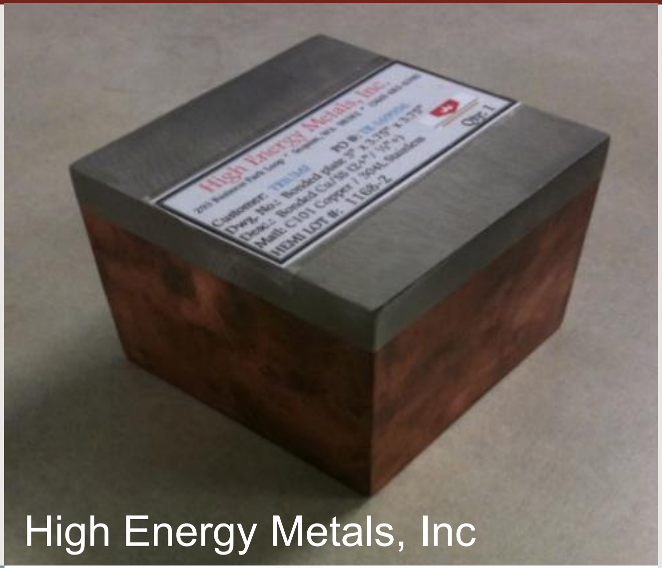




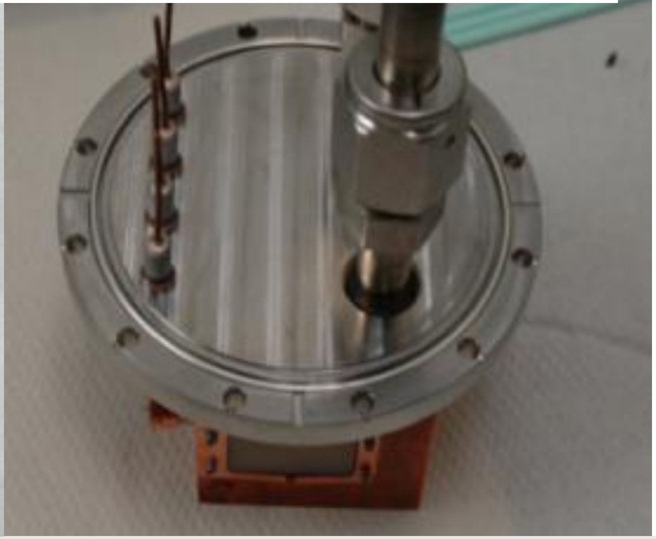


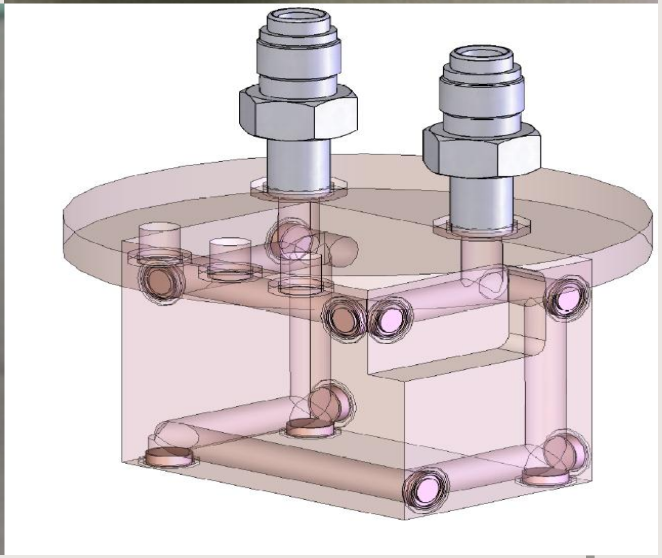
Design considerations - UHV compatible (1)

- Flange and emittance scanner in one body
  - OFHC copper explosively bonded to SS to eliminate soldering/brazing in vacuum
- SS flange → all feedthrough can be welded
- Very small UHV seal
  - spring energized metal C-ring, made of Inconel/silver plated
- The protective plate is made of tungsten explosively bonded to a OFHC plate for better thermal conduction.



High Energy Metals, Inc





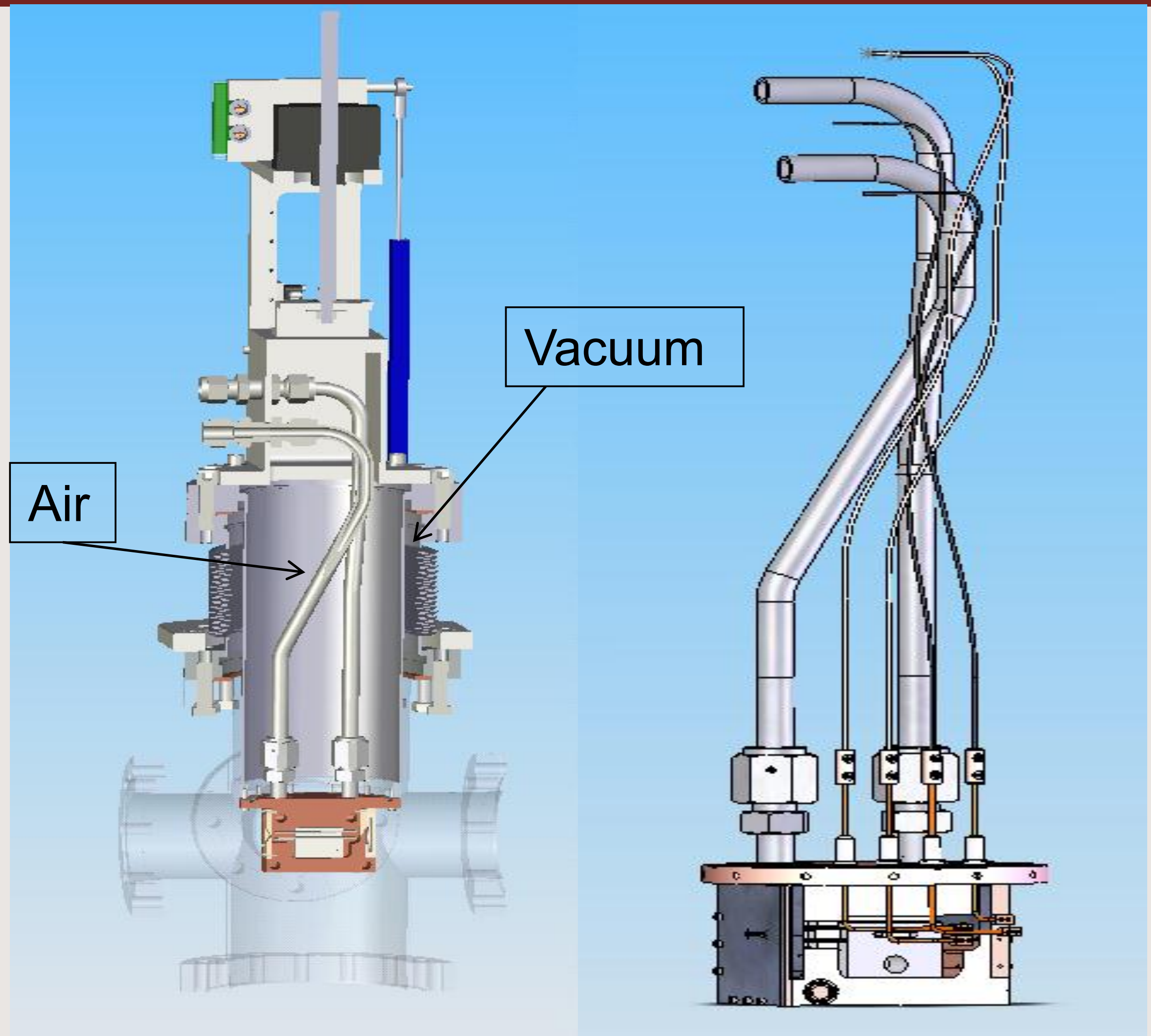
Design considerations - UHV compatible (2)

• The cooling lines are placed into an inner tube, at atmospheric pressure.

• All feedthroughs are rated at 5kV, bakeable at 250degC

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

• X-Ray resistant



Thermal considerations and ANSYS simulations

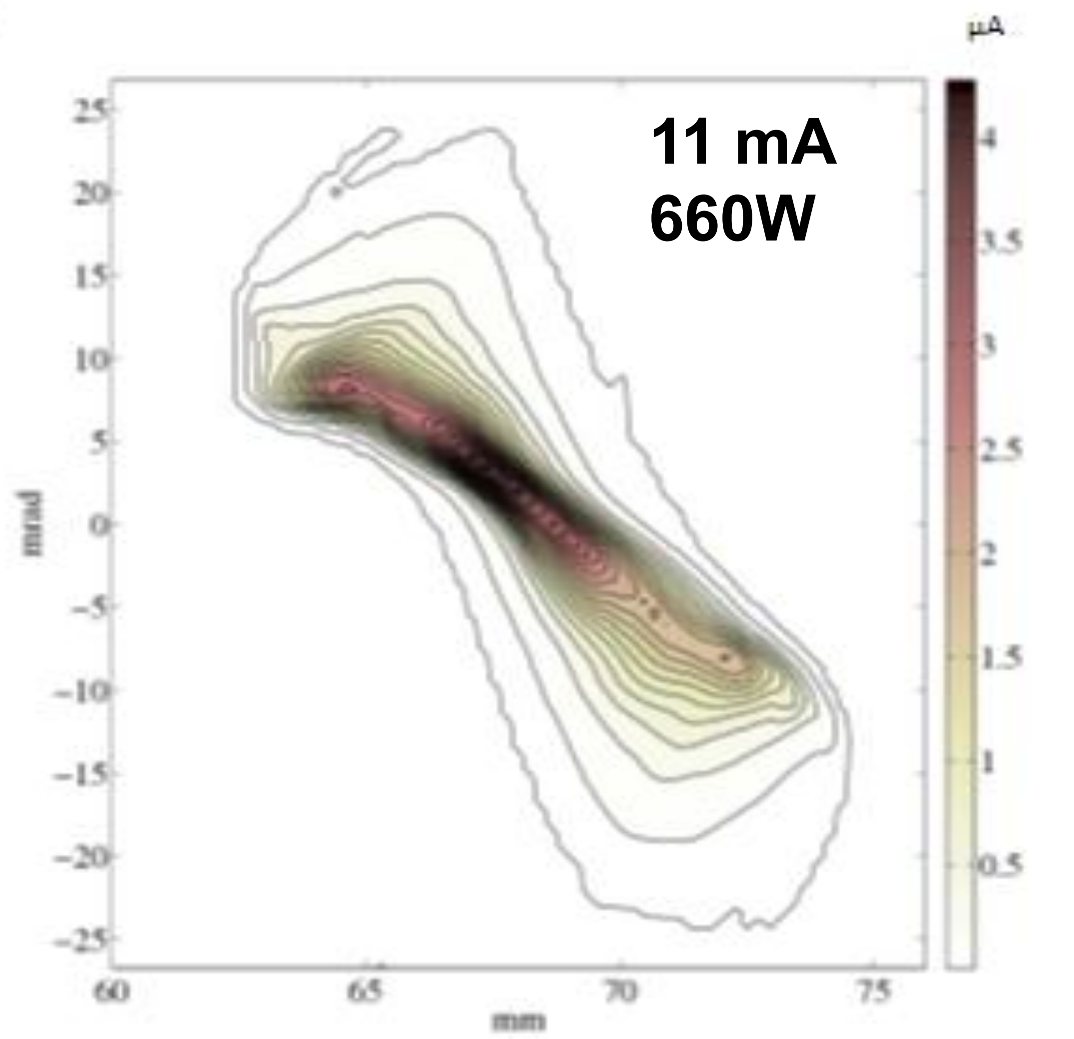
- Thermal calculations were done for the water-copper thermal convection; calculated the heat transfer coefficient.
- Results were used to do simplified 3D (ANSYS) models of the thermal conduction at different homogenous beam intensities and sizes
- The main constraint is introduced by the power density 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
Beam diameter [mm]	2
Beam intensity [mA]	6
Power density [W/mm^2]	**115**
Slit Temp [deg C]	1,650
Front plate Temp [deg C]	445
Thermal expansion [μm]	33

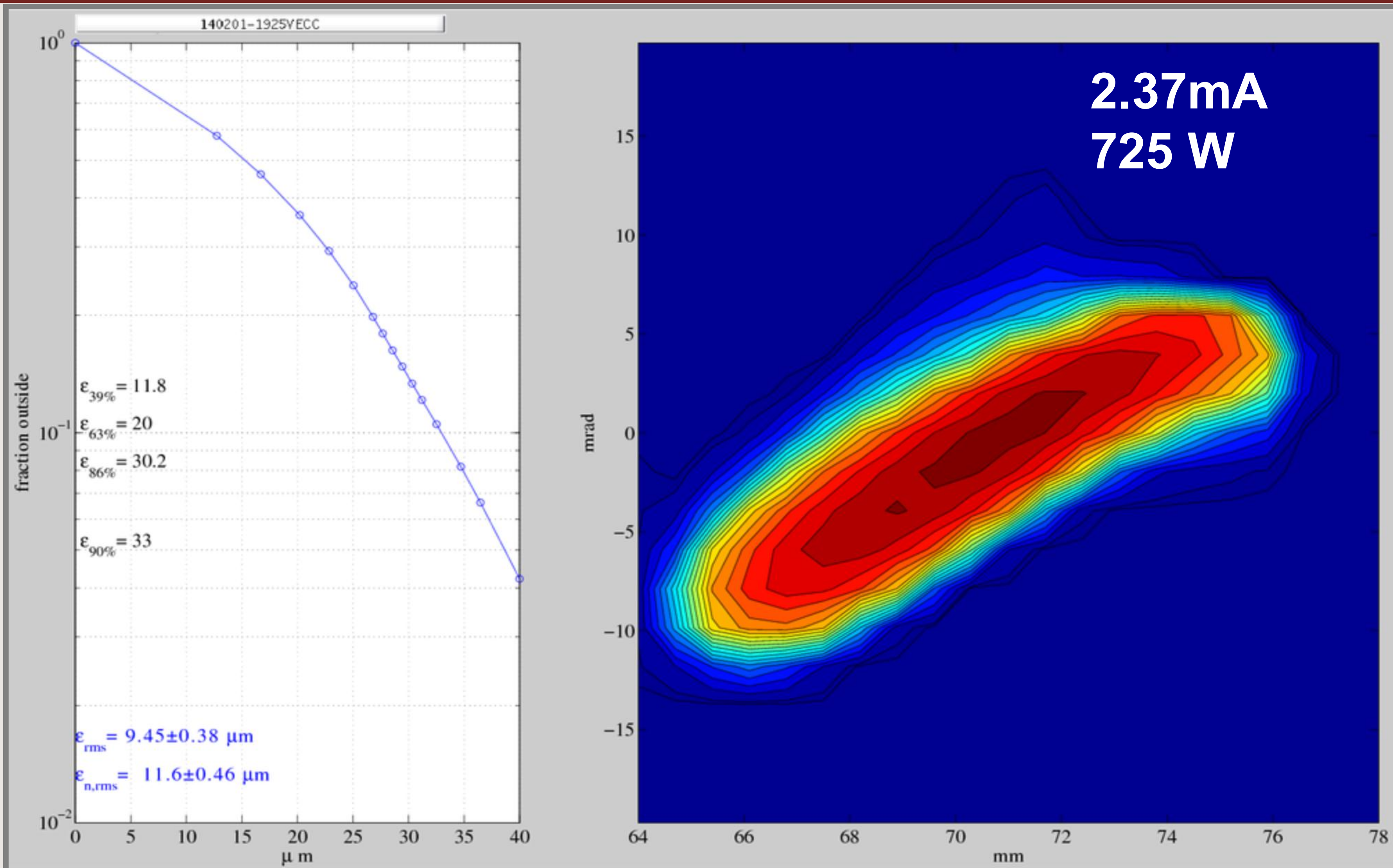
Results: 60keV and 660W

- I_{ave}=11mA , P=660W
- The *rms* beam is 2.69 mm with 30 W/mm^2
- Beamlet current
  - 100µA 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.

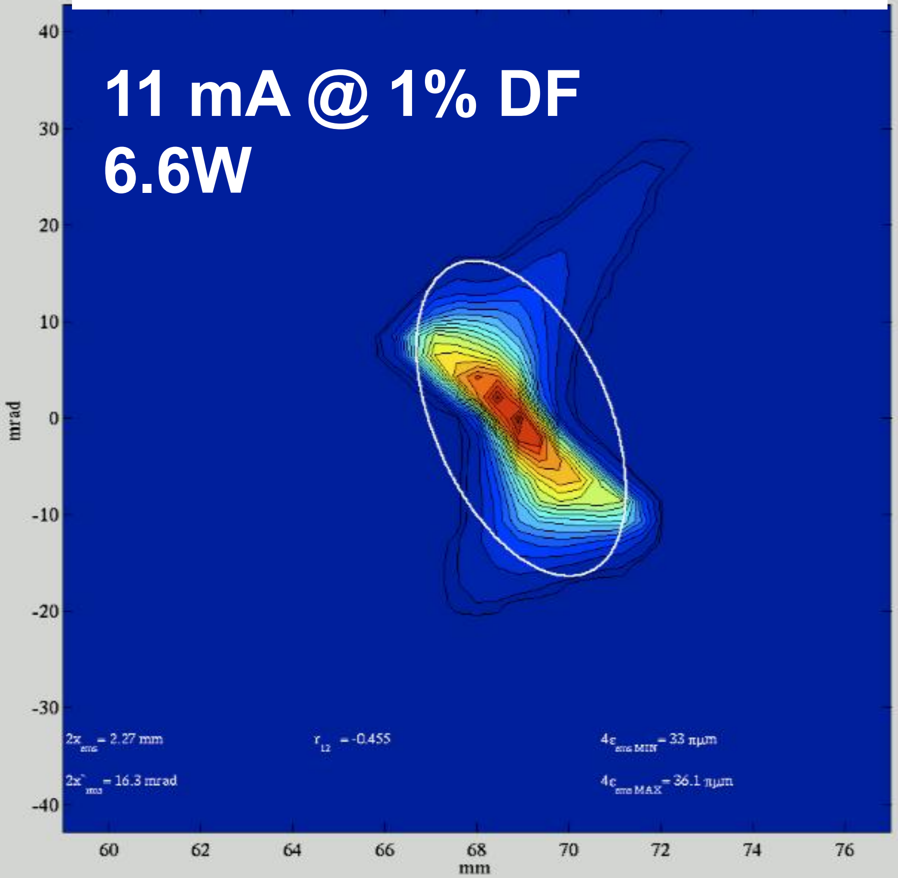


Emittance scan: 300keV, 725W

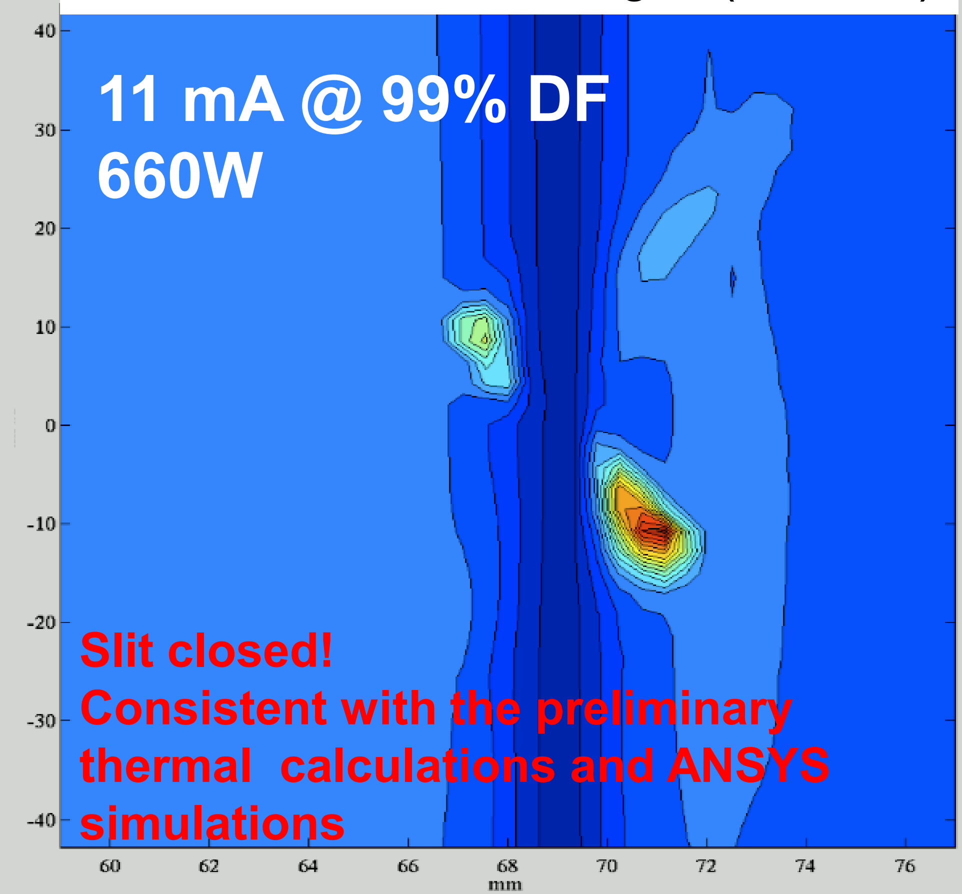


Emittance scans: 60keV, 11mA at WAIST

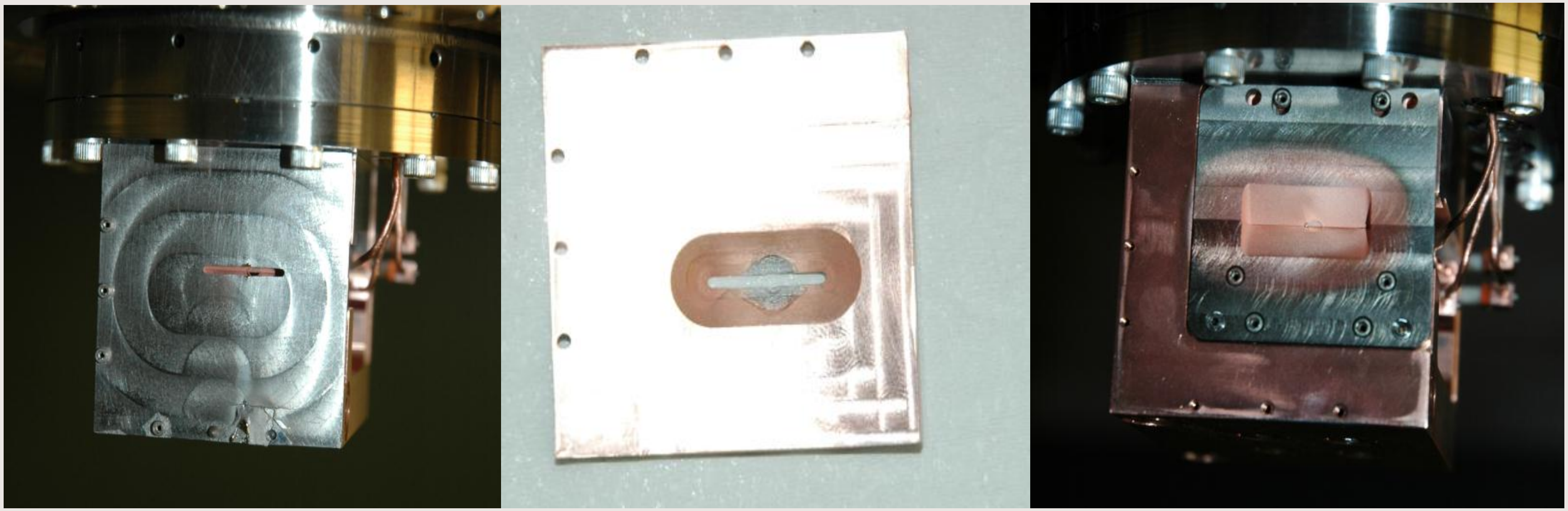
1% D.F.
rms beam size 1.14 mm
Power Density 1.6 W/mm^2



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



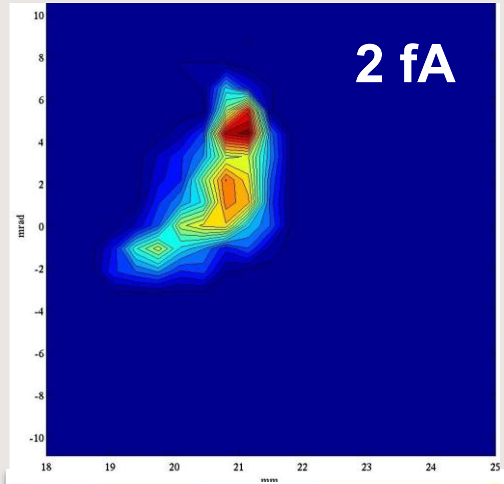
Inspection - Front plate

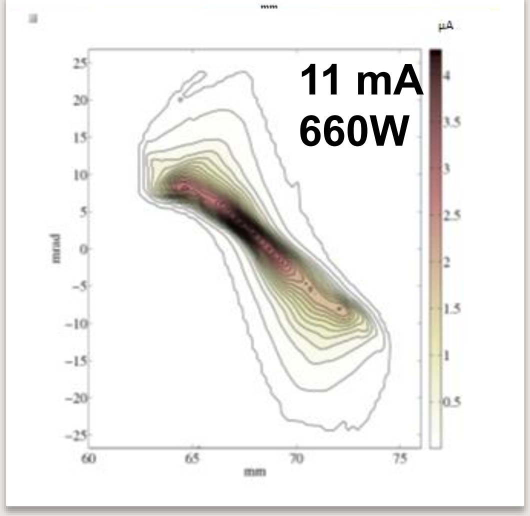


- Copper vaporization from the back of the protection plate
    - Tungsten entrance slit plated with copper
- The emittance scanner body and entrance slits were not damaged.

Conclusions

- We have extended the useful range of the TRIUMF Allison scanner down to 1 fA and up to 10 mA (1kW)
    - a range of 10^{13}
- Small/compact design
- A low intensity emittance meter is installed at ISAC and is routinely used to diagnose low intensity radioactive beams
    - 10^6 more sensitive than previous version
- A second scanner has been used at the e-linac injector to characterize c.w. beams up to a beam average power of 1kW.





Acknowledgments

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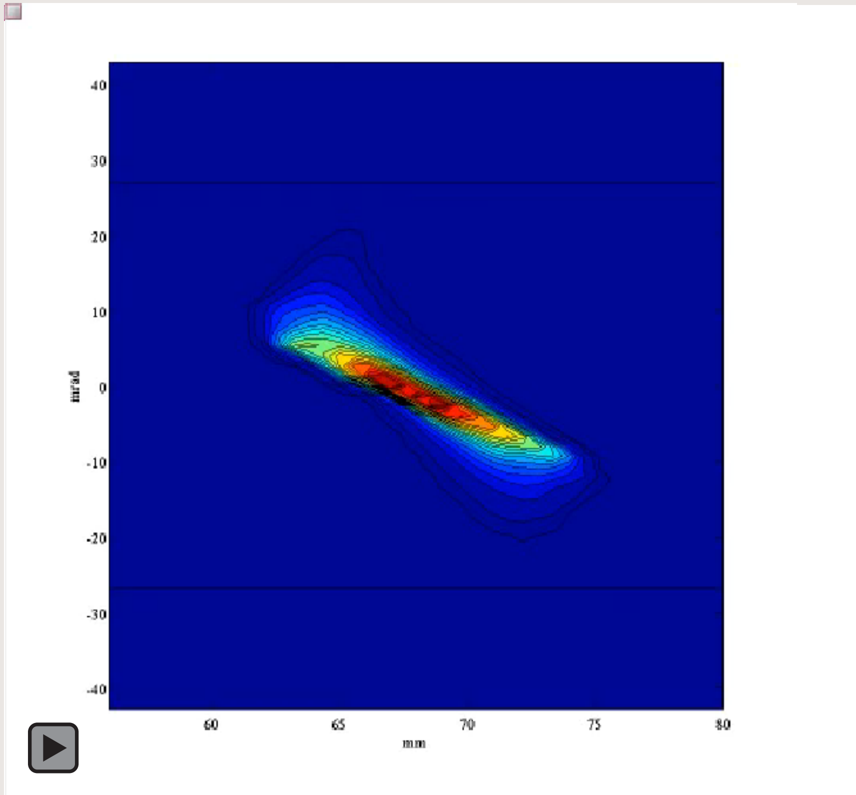
Omley Industries, Inc. – USA
Parker Hannifin Corporation - USA
Innovative Tool & Die, Inc. – Canada
TRIUMF Machine Shop



Thank you!

Merci!

Questions?

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