Allison Scanner Emittance Diagnostic Development at TRIUMF

LINAC14

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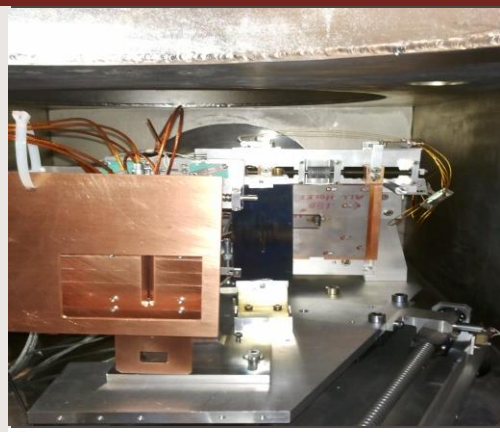
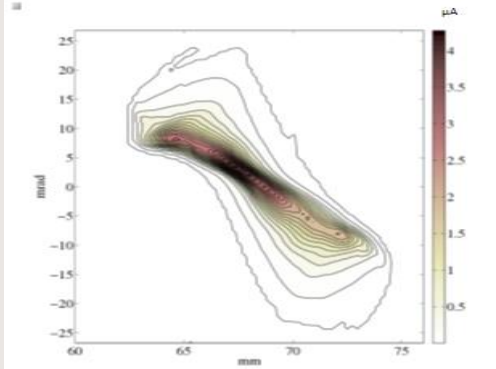
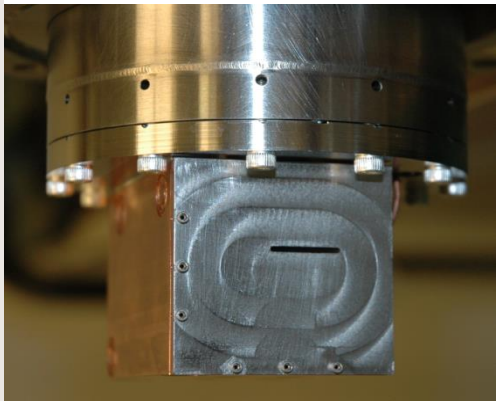
TRIUMF







Outline

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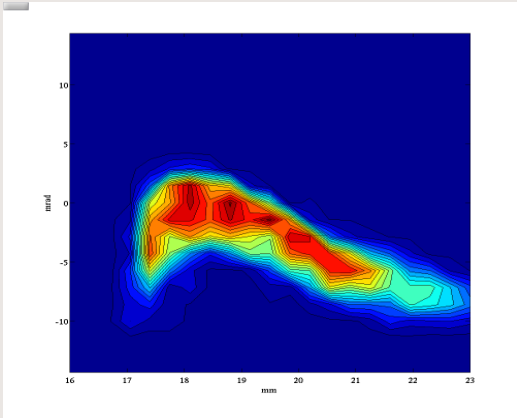
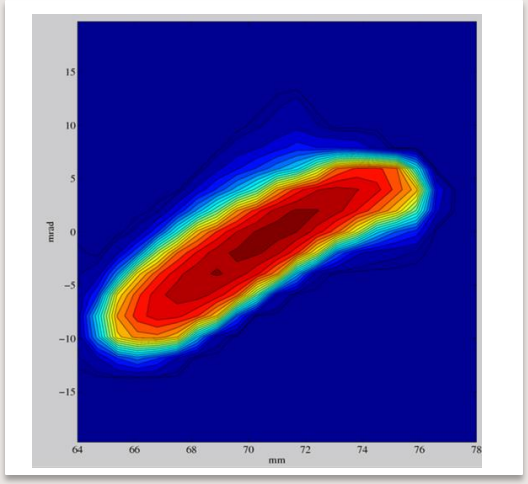
  - Principle and motivation
- Part 1: Low intensity emittance scanner
  - Conceptual design
  - Detail Design and hardware
  - Results
- Part 2: High power emittance scanner
  - Specification
  - Detail design, engineering and hardware
  - Results
  - Inspection
- Conclusions





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:

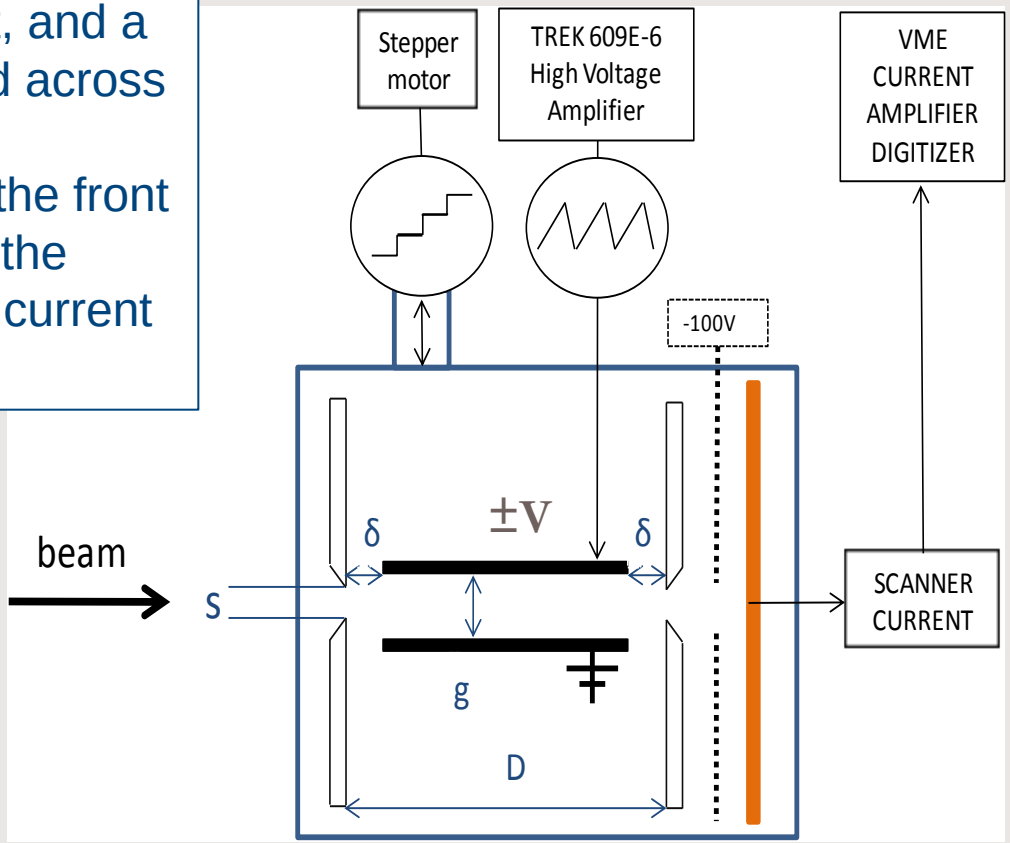
$$s^2 / D = 0.03\,\mathrm{mm-mrad}$$

- The maximum divergence

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

- The maximum voltage for the maximum analyzable divergence

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



* 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

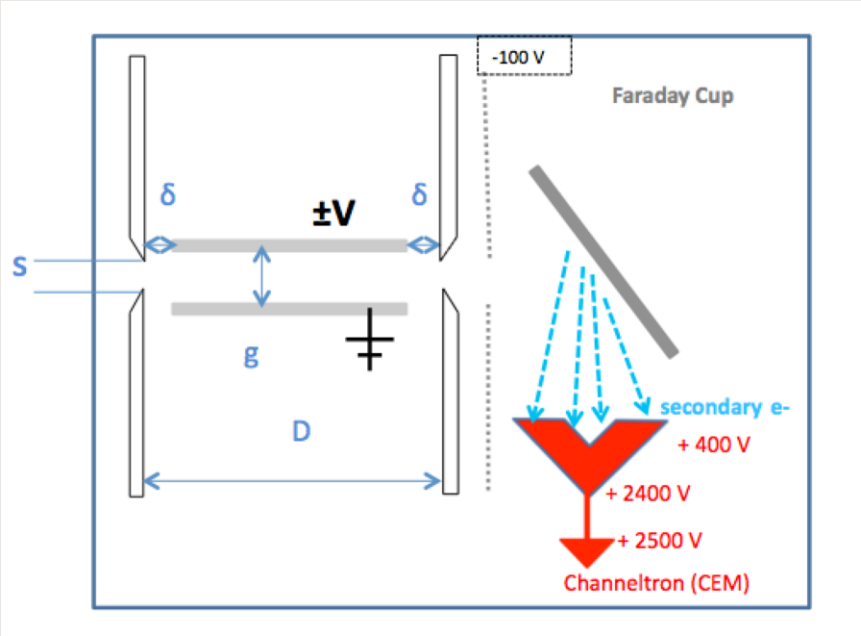
PART I

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

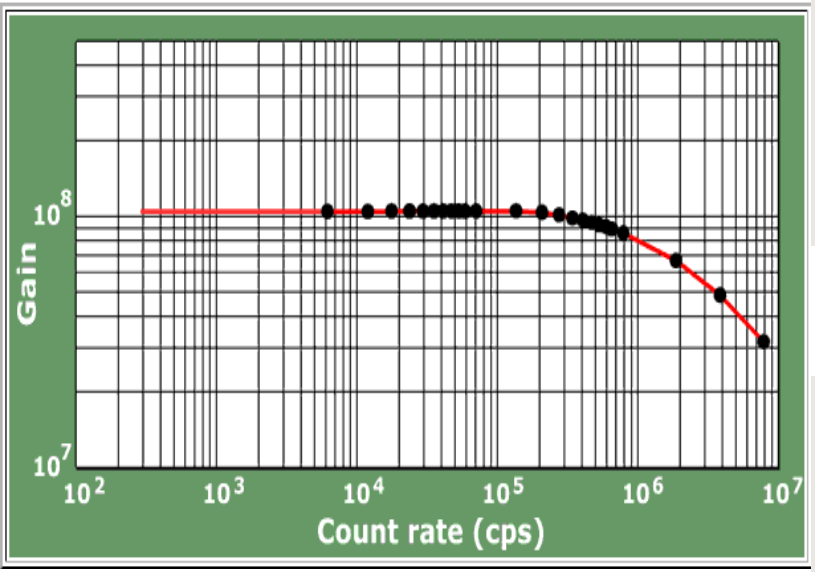
- In the new design – two modes can be used:
  - the Faraday cup at the end of the emittance scanner is tilted
  - a channeltron (Channel Electron Multiplier) is incorporated as an additional feature
  - the secondary electrons are captured, multiplied and measured at the anode
  - the emittance is indirectly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



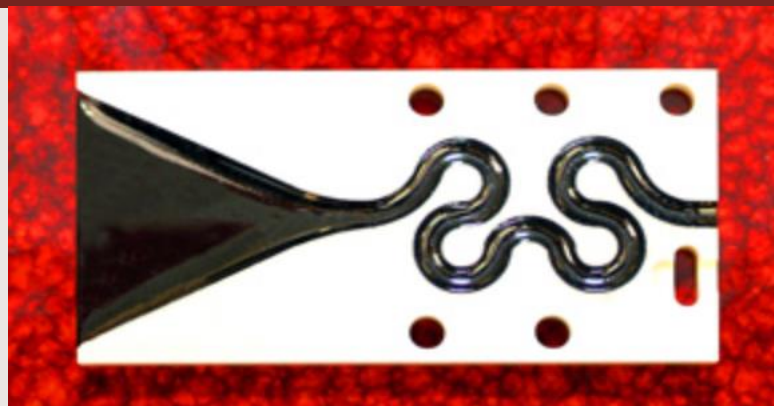
L [mm]	50
d [mm]	1.5
D [mm]	53
g [mm]	2
s [mm]	0.038
E [keV]	60
x'_m [mrad]	±75.5
V_m [V]	±770.77
El_F [V/mm]	±385.39

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)

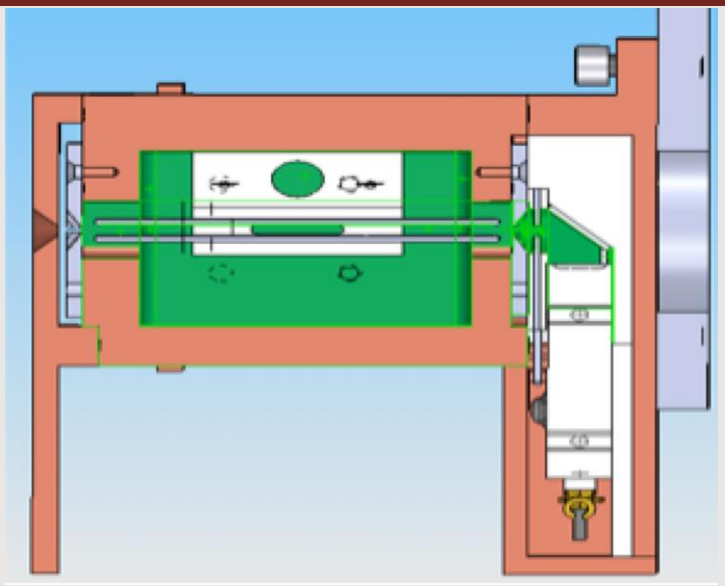
- The measured count rate represents the secondary electron intensity and is therefore proportional to the ion beam intensity.
- The system is capable of processing secondary electron intensities from tens to about 10^6 particles per second.

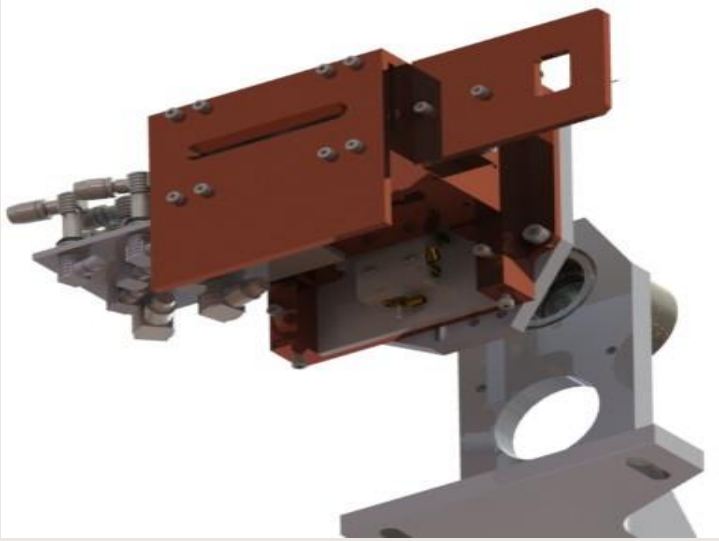
Mechanical Design

- 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.

Controls xx

- The emittance scanner software is a subroutine running under the control of EPICS.

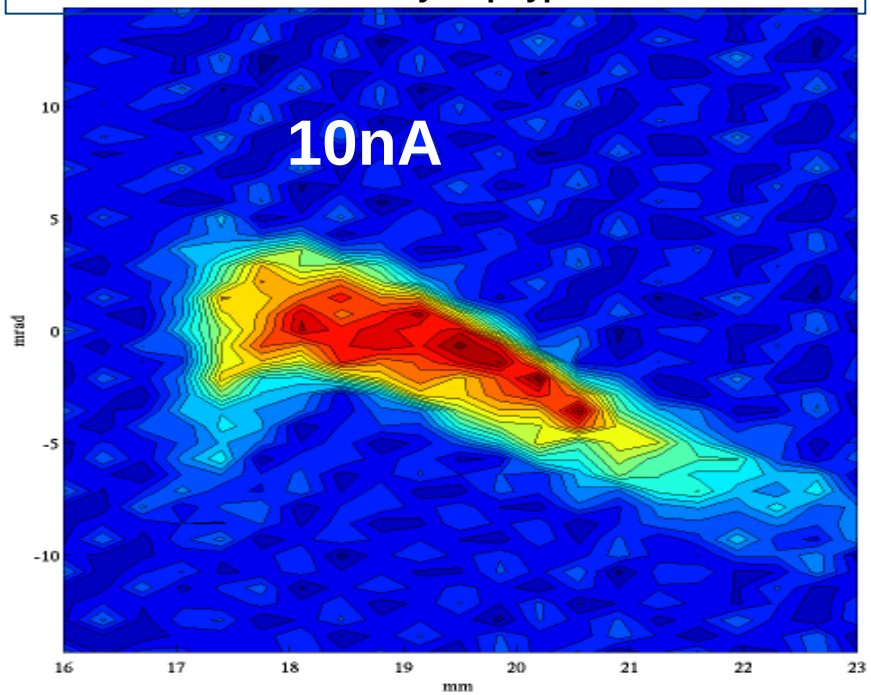
- There are two modes of operation:
  - Faraday cup using a VME current amplifier
  - channeltron using a VME scalar (model Joerger VSC16)

- 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

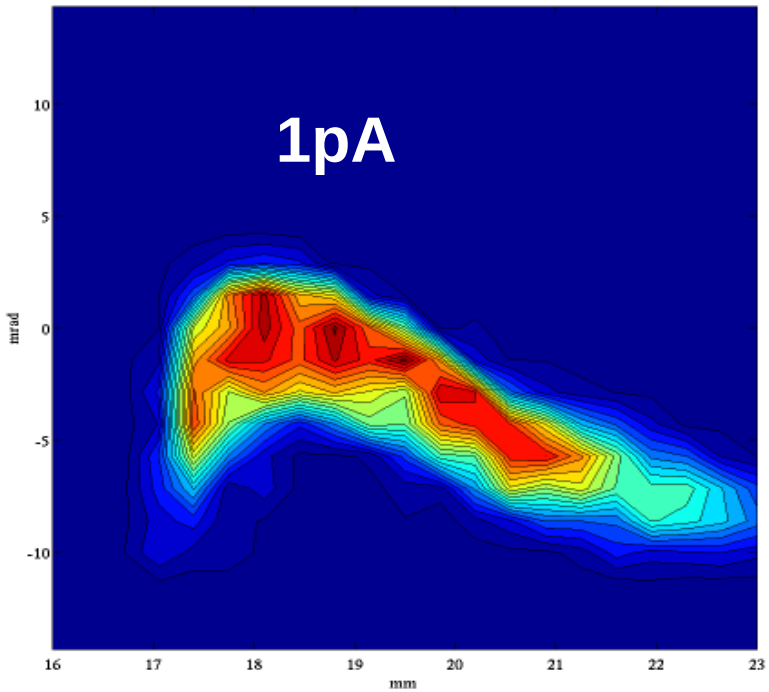


Above: 10nA 7Li at 20 keV

Notice the level of background noise.

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

Measurement with CEM type scanner



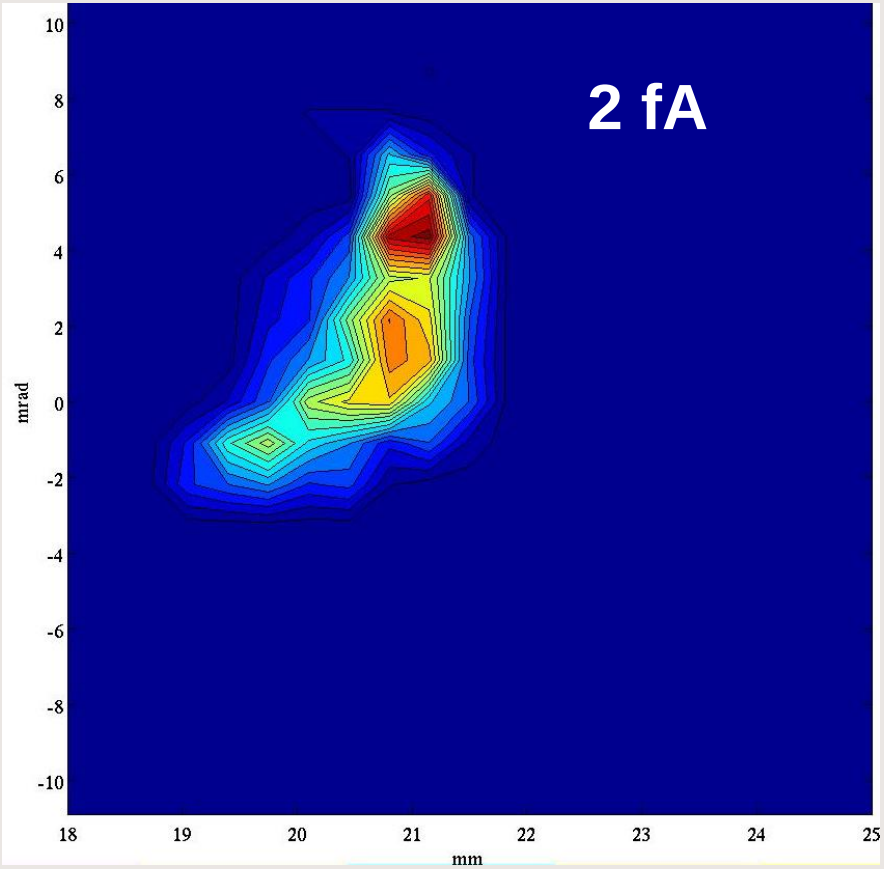
Above: 1pA, 27Al at 20 keV

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

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

Emittance scans with CEM

Emittances at very low intensities:



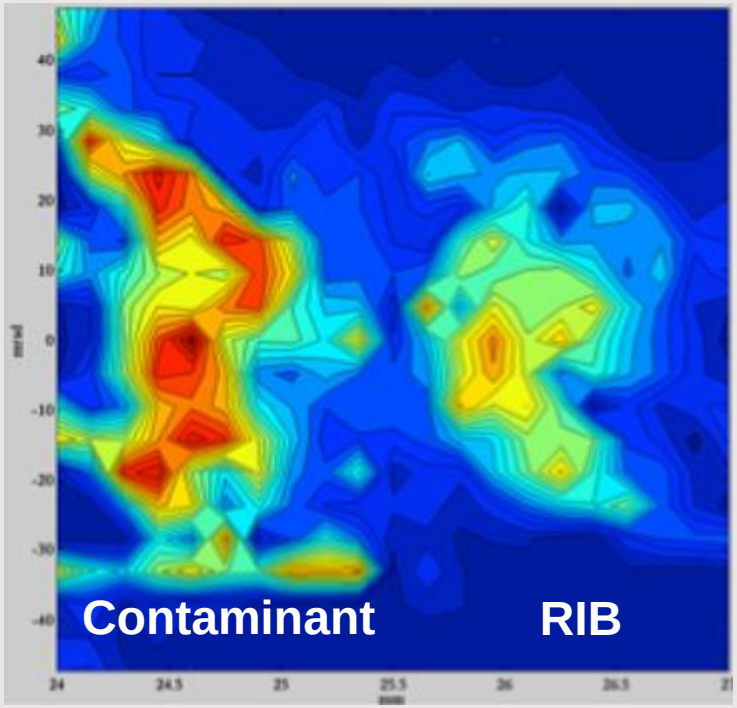
225Ra at 20 keV
Intensity=13,000 cps (2fA)
ε = 4.2 mm mrad

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

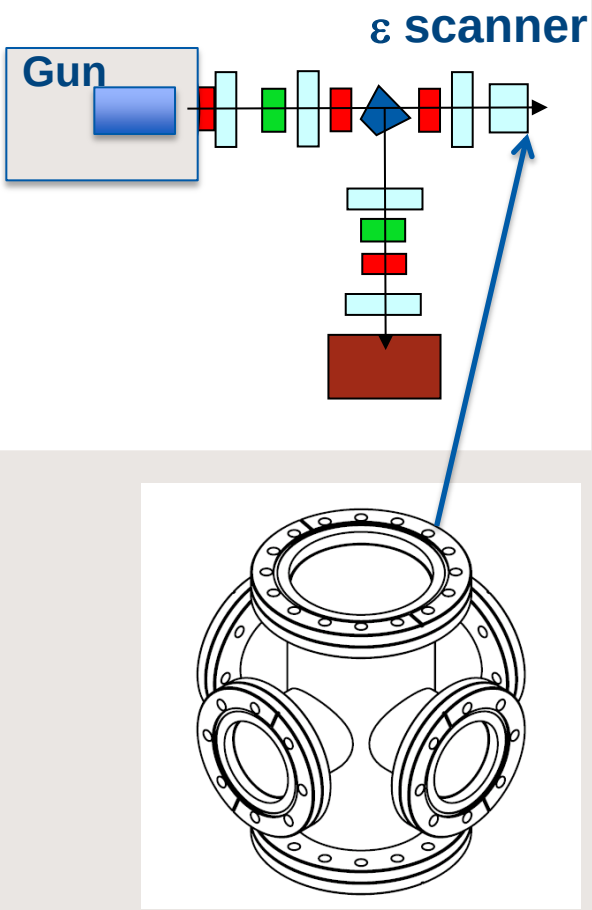
- Requirements for high power emittance meter for the e-linac project

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

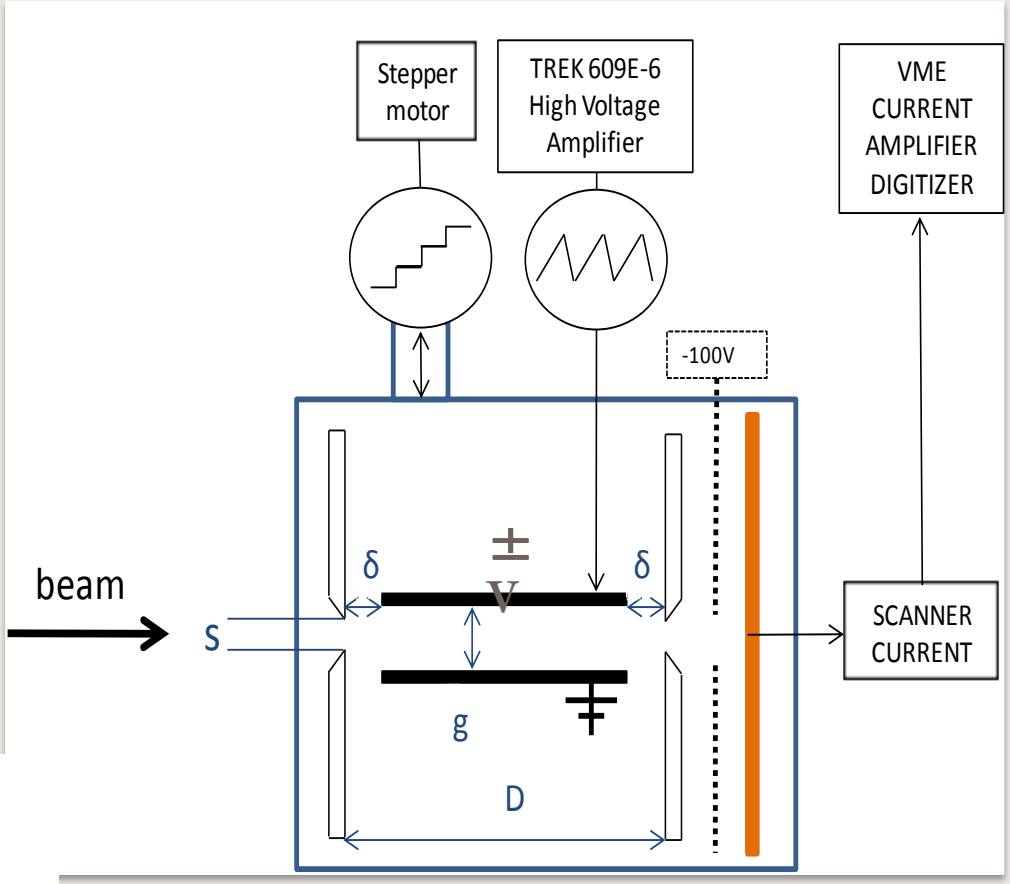
- Location of emittance meter
  - e-Linac LEBT beamline for e-Gun beam characterization
  - In a small diagnostic box
    - CF 6-way SS reducer cross (2x) 6” OD (4” ID) CF x (4x) 4.5” OD (2.5” ID) CF

E-Linac LEBT Beamline



Overview of Parameters

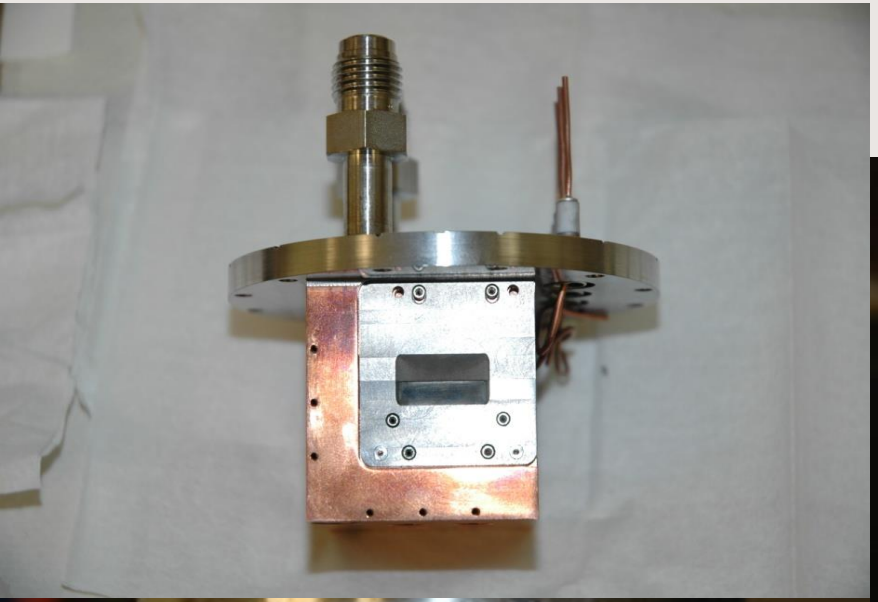
BEAM ENERGY	60 keV	300 keV
D (mm)	49	49
δ (mm)	2	2
g (mm)	3.5	3.5
s (mm)	0.038	0.038
K	1.06	1.23
$V_{m\text{-}rel}$ (V)	±2,337	±10,046
x'_m(mrad)	±132	±132
Electric field (V/mm)	668	2,870

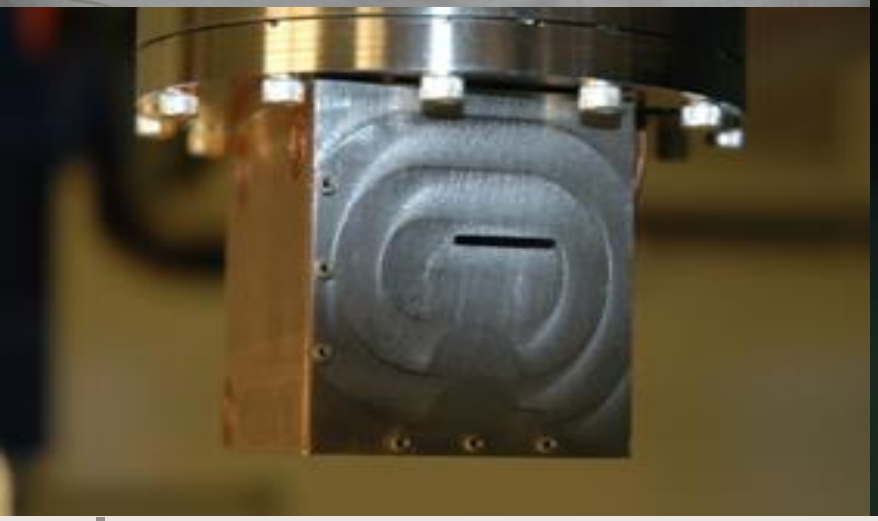


- For relativistic particles the voltage is smaller by a factor *k*

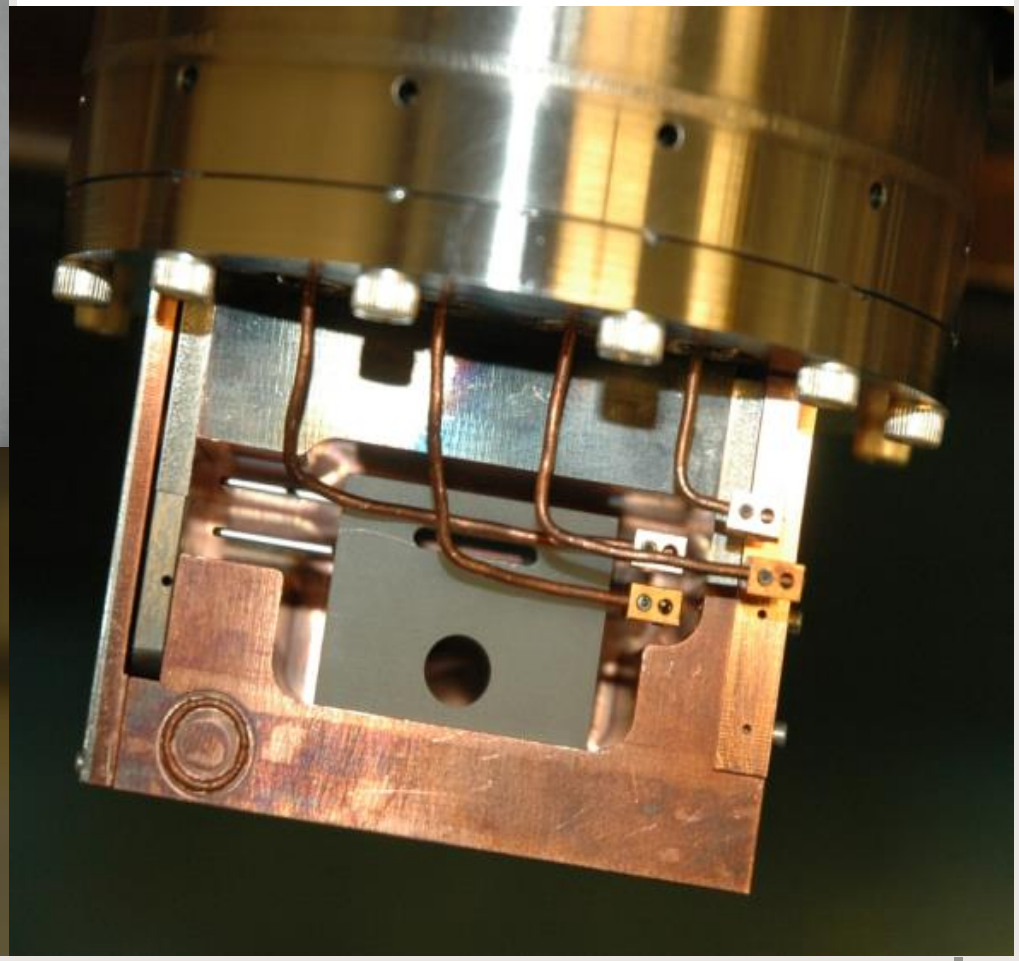
$$V_{m-rel} = \pm V_m / k \text{ and } k = 2/(1+1/\gamma)$$

Assembly



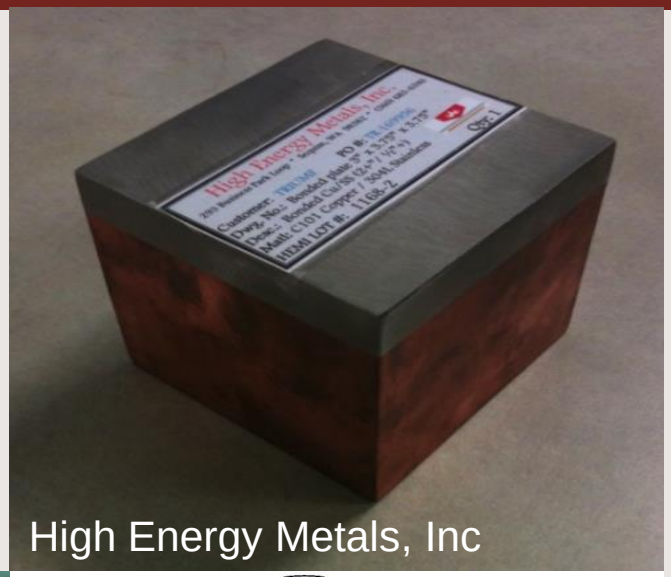


Dimensions:
l x w x h = 60 mm x 44 mm x 45

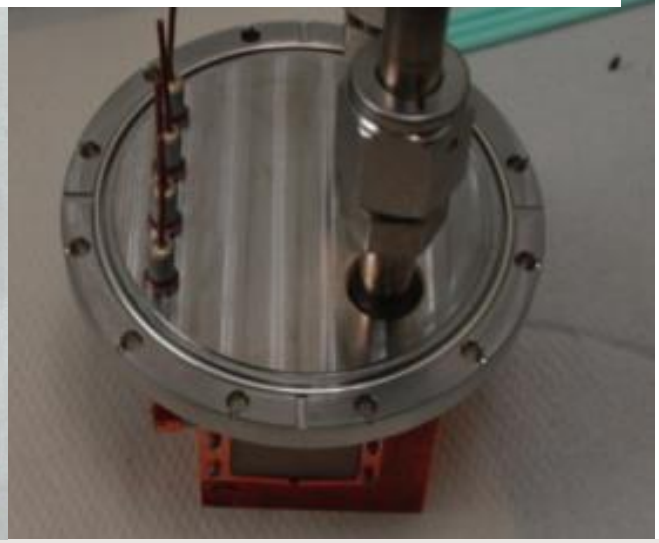


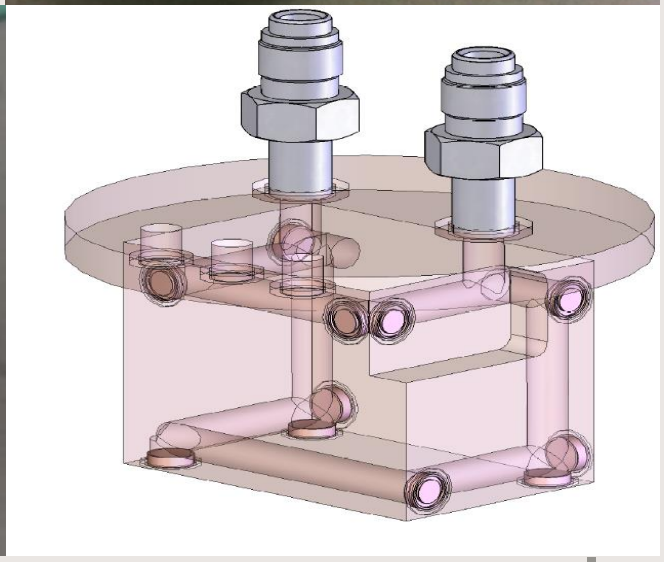
Design considerations - UHV compatible (1)

- 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





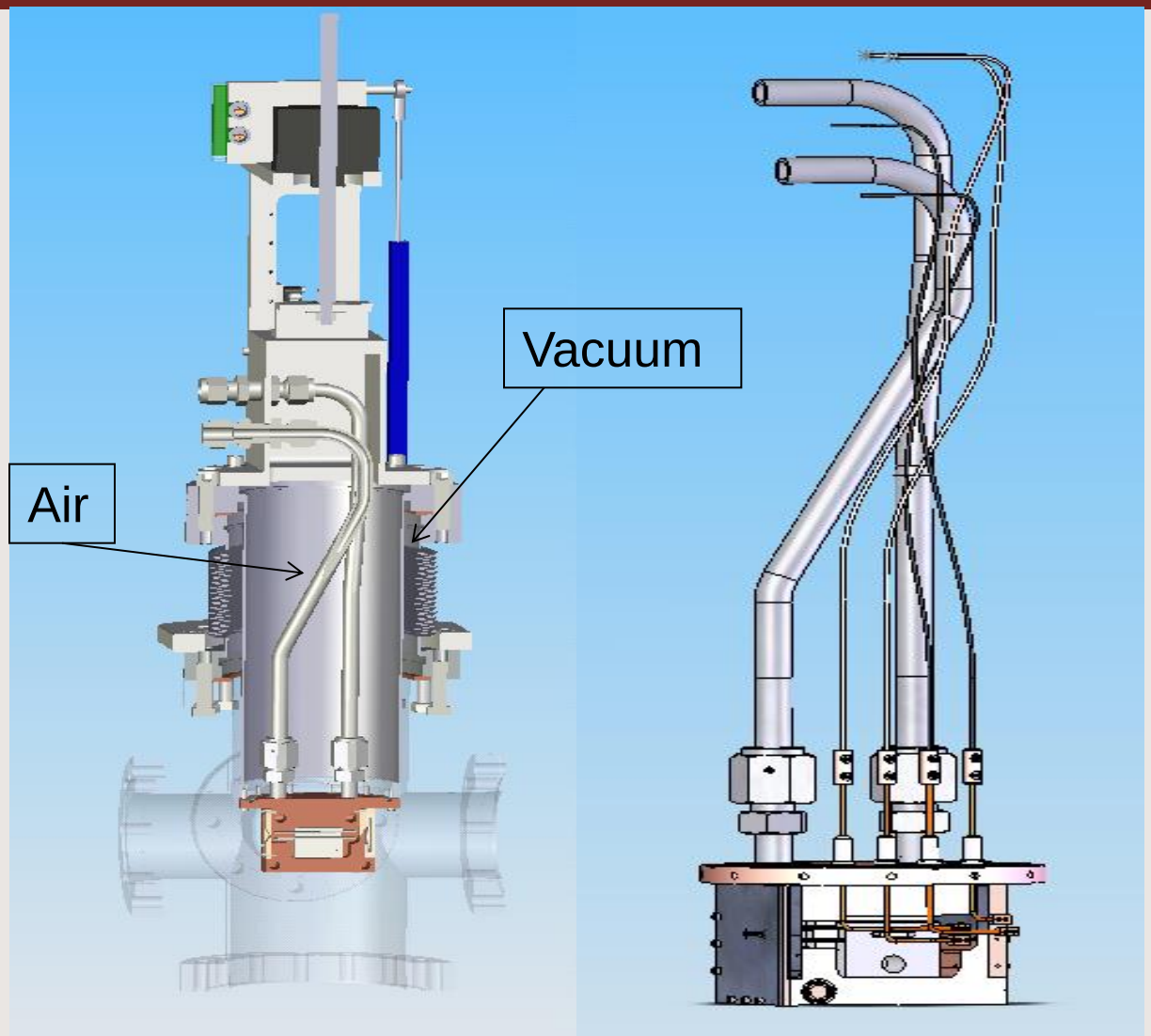
Design considerations - UHV compatible (2)

- 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

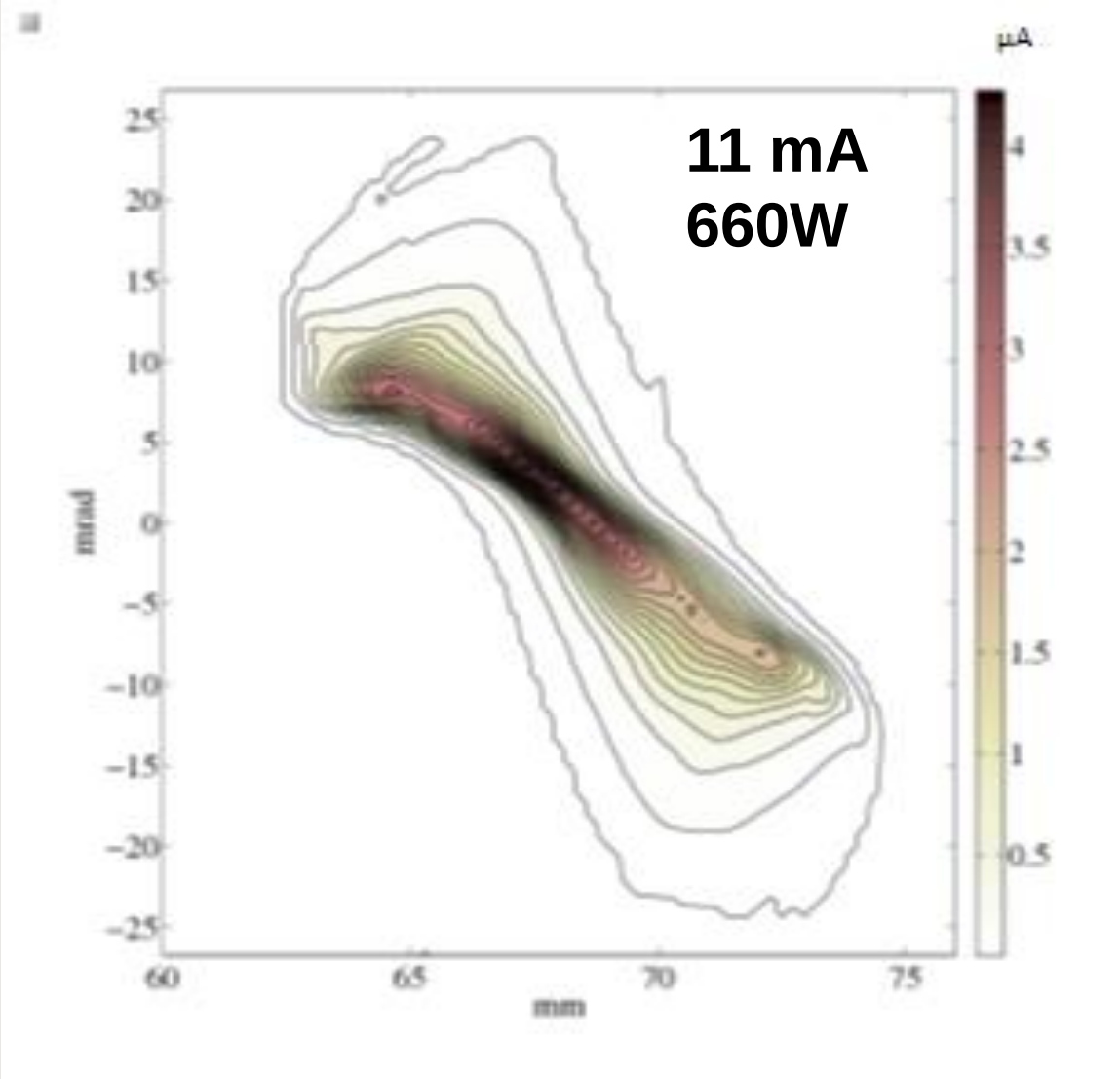
- Thermal calculations were done for the water-copper thermal convection; calculated the heat transfer coefficient.
- Results were used to do simplified 3D (ANSYS) models of the thermal conduction at different homogenous beam intensities and sizes
- The main constraint is introduced by the power density 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

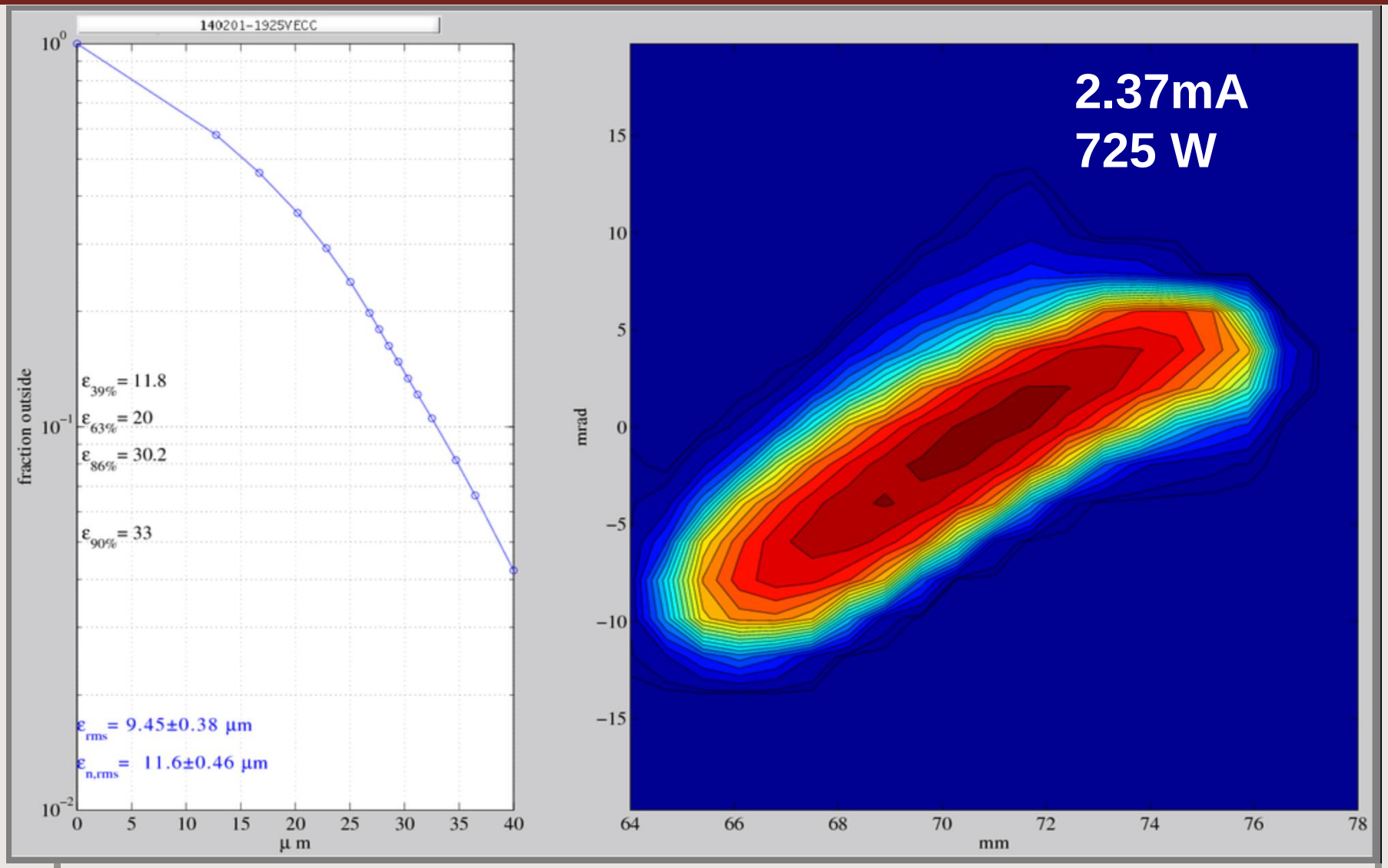
Results: 60keV and 660W

- 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.

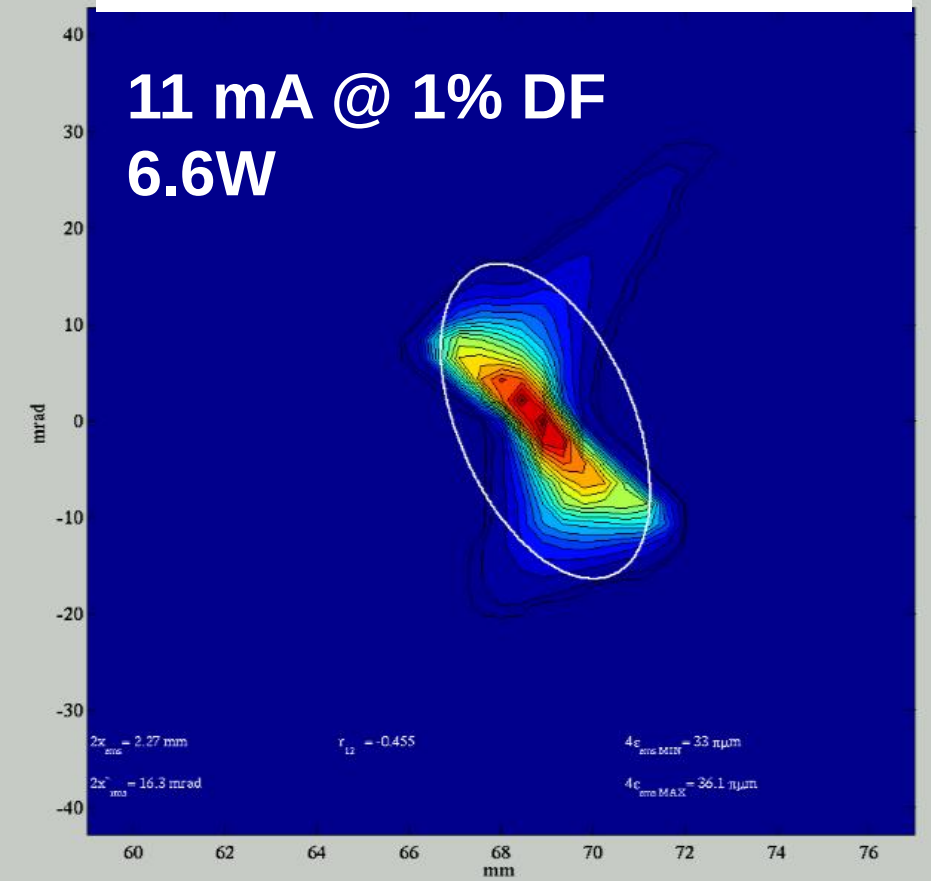


Emittance scan: 300keV, 725W

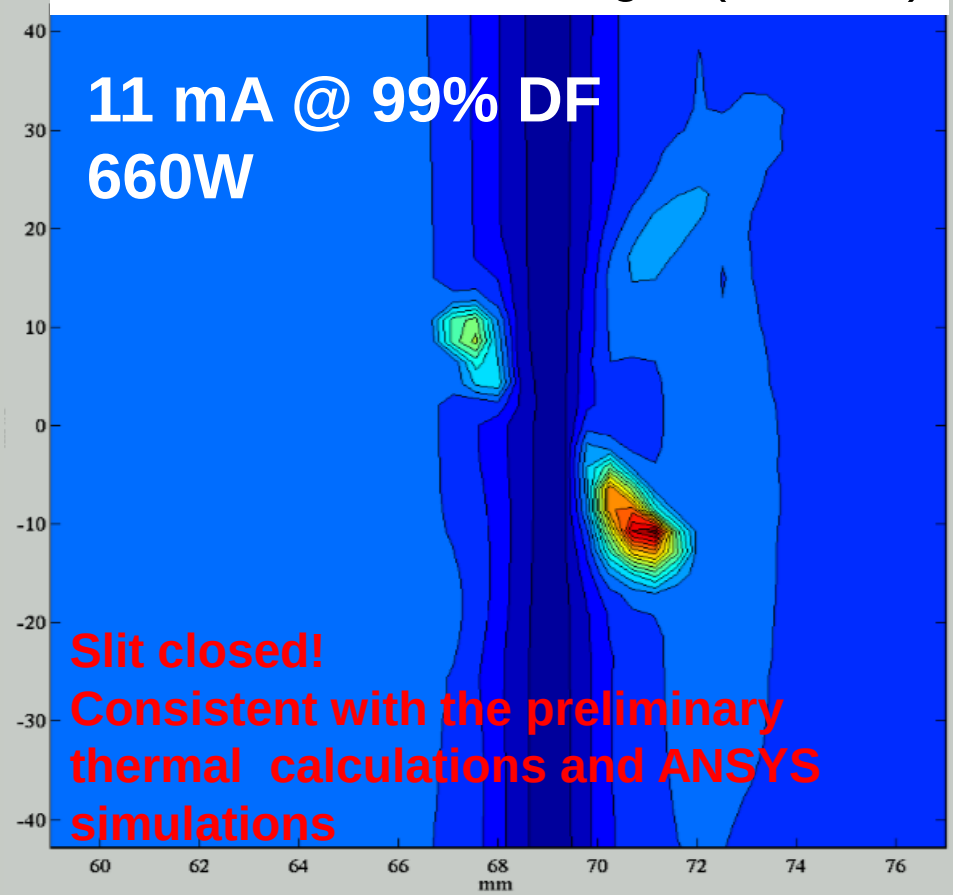


Emittance scans: 60keV, 11mA at WAIST

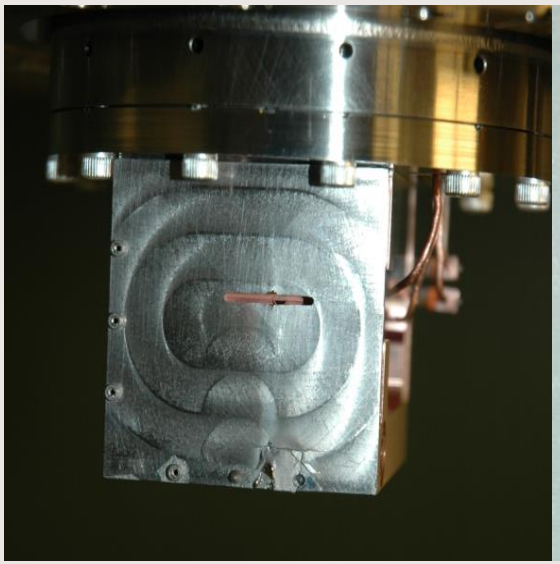
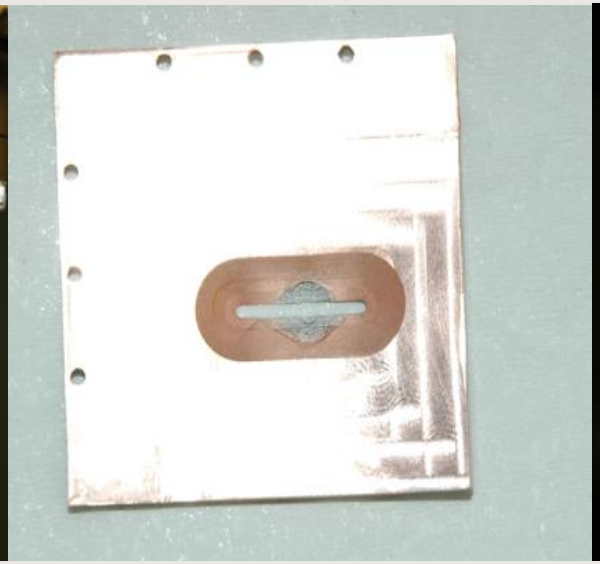
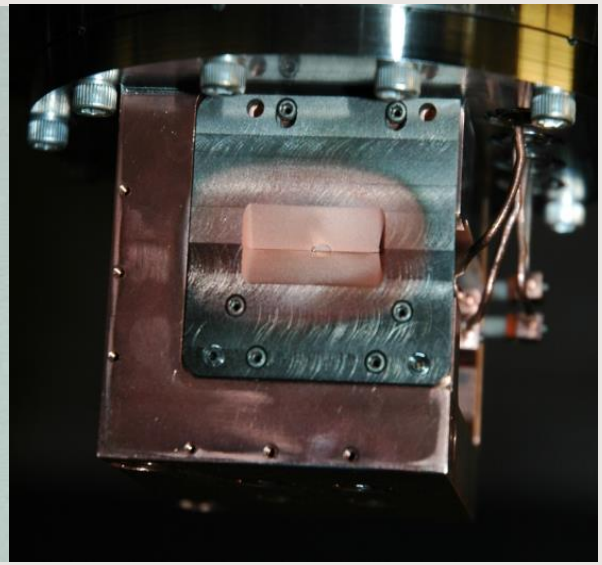
1% D.F.
rms beam size 1.14 mm
Power Density 1.6 W/mm^2



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.

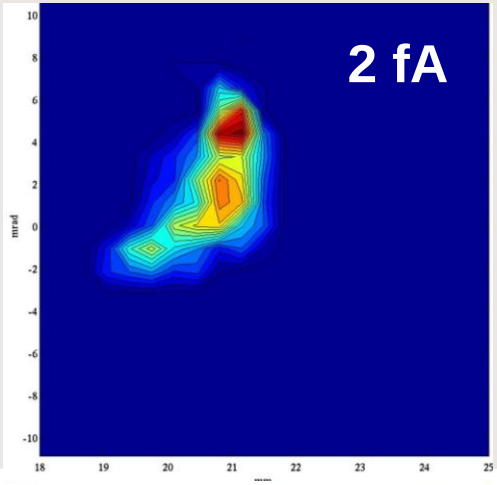
Conclusions

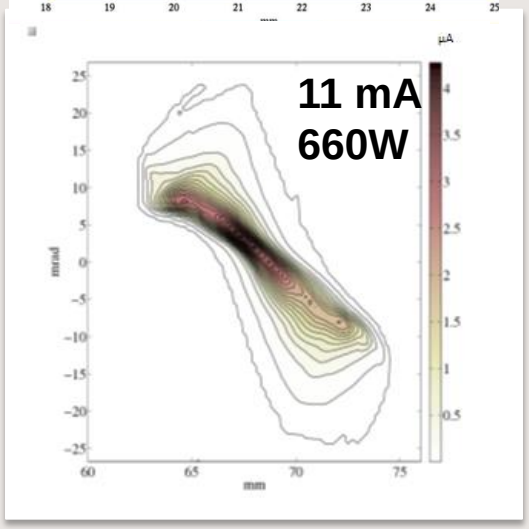
- We have extended the useful range of the TRIUMF Allison scanner down to 1 fA and up to 10 mA (1kW)
  - a range of 10^{13}

- 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

Collaborators:
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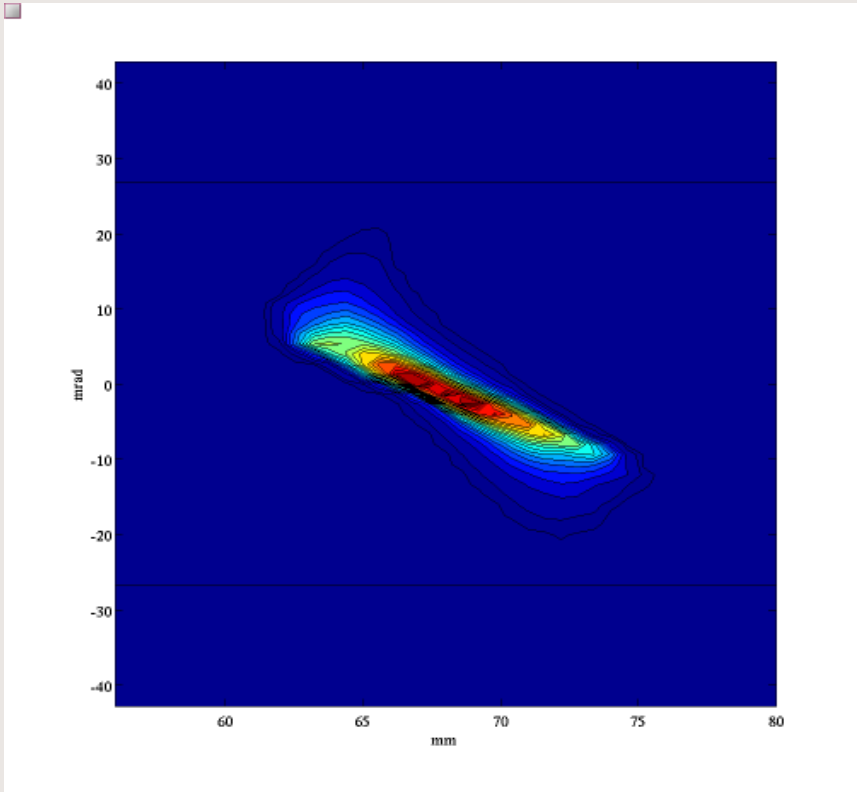
R. Hariwal - Inter-University Accelerator Centre
Students:
R.F. Paris – University of Ottawa
M. Kownacki - SFU

Machine shops & companies:
Dr. Sjuts Optotechnik GmbH - Germany
High Energy Metals, Inc. - USA
Omley Industries, Inc. – USA
Parker Hannifin Corporation - USA
Innovative Tool & Die, Inc. – Canada
TRIUMF Machine Shop



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

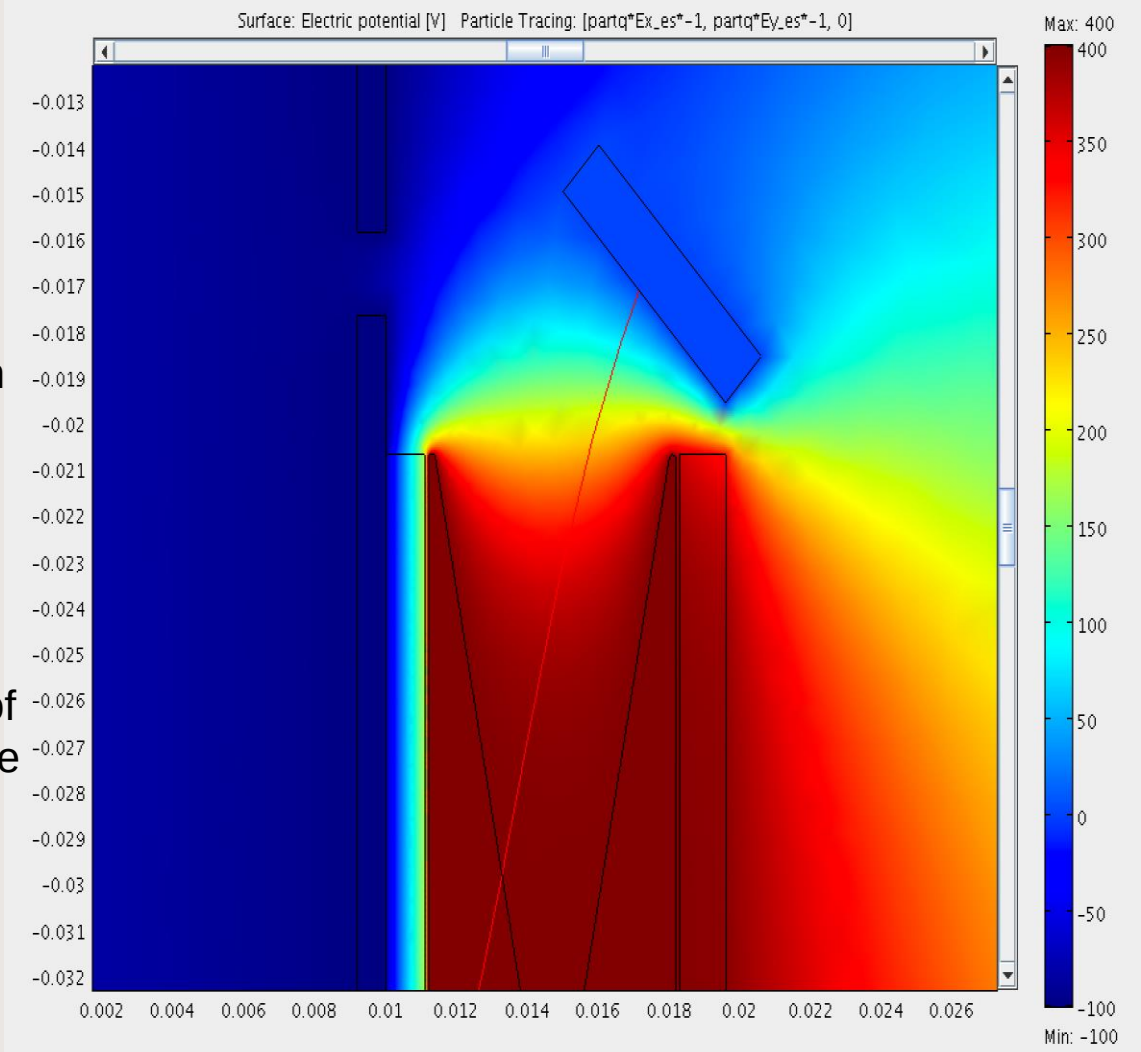
COMSOL Multiphysics simulations

Electrons are launched from the surface of the Faraday cup:

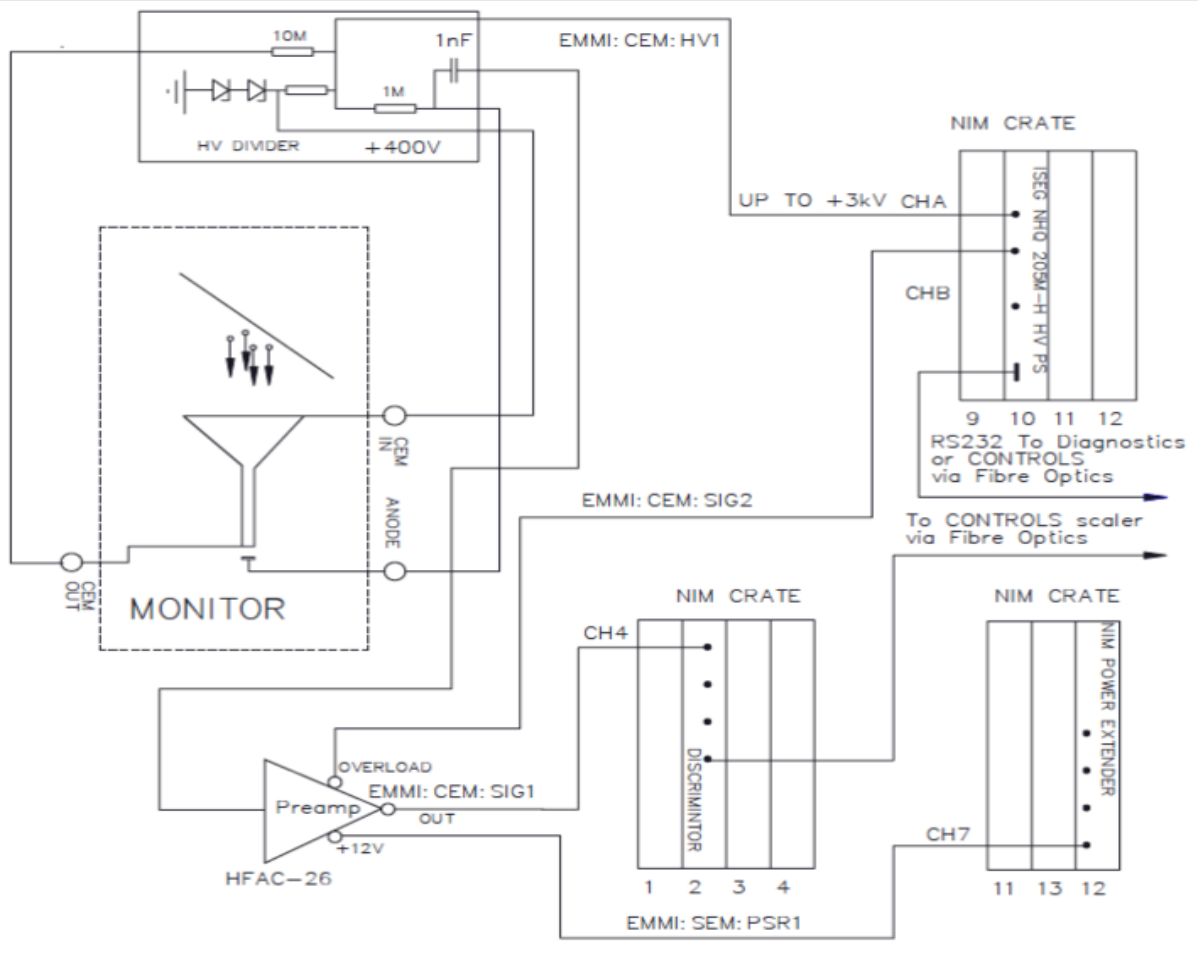
- at 10 eV kinetic energy,
- at different angles: between 90 deg and 135 deg,
- from different positions: +/- 40 mrad from the beam axis,
- with +400 V applied on the channeltron surface
- and -100 V on the bias ring

CEM captures all electrons launched when:

- the Faraday cup at 45 deg
- the on-axis distance between the exit of the second slit and the Faraday cup plate is 10.5 mm
- the distance between the center beam axis and the channeltron is 4 mm
- the channeltron is 7 mm wide and 21 long



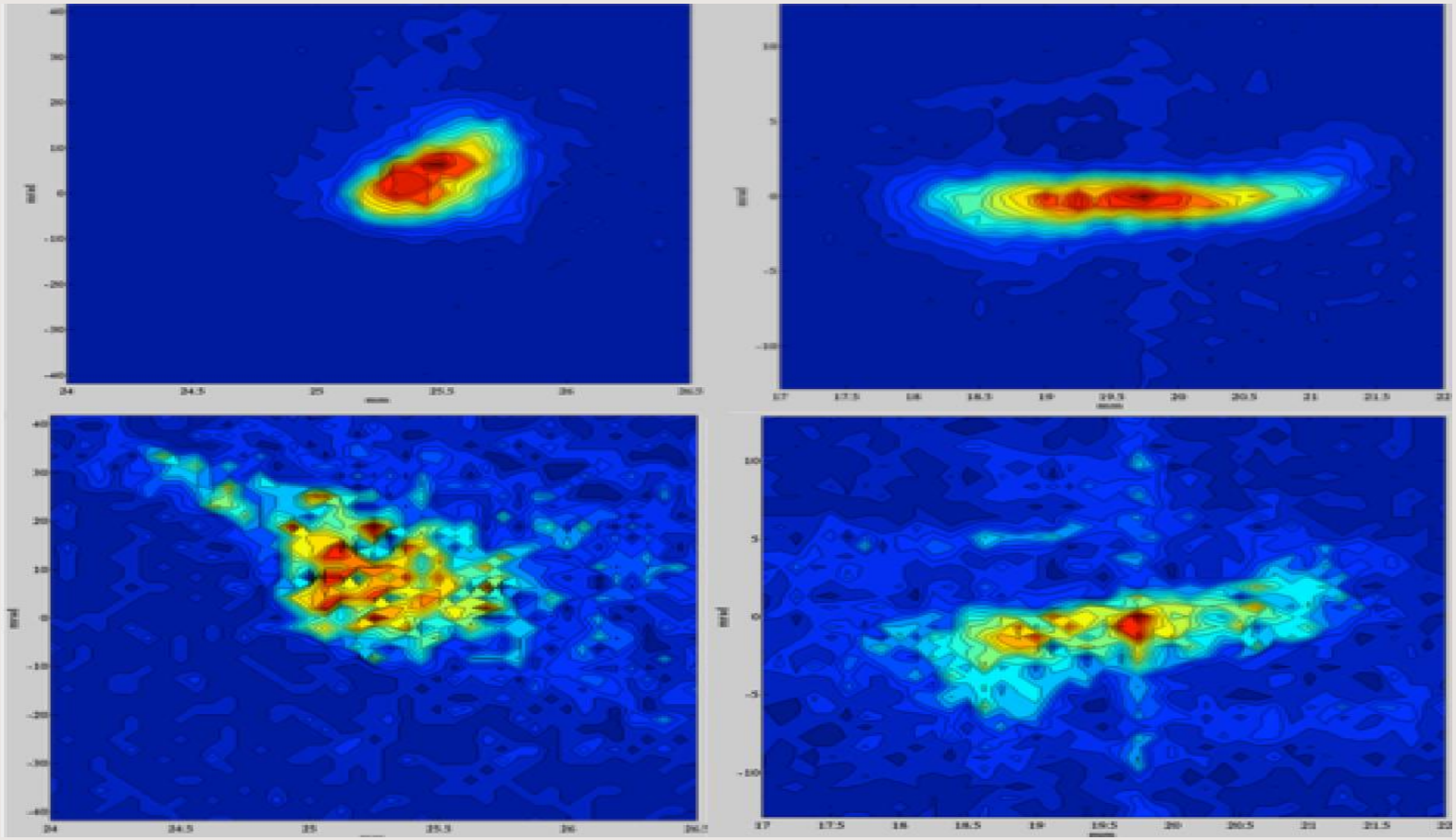
CEM Integration Schematics



- The High Voltage bias is applied to the channeltron via a voltage divider
- its entrance is kept under +400V
- The voltage applied across the device is varied in the range 2000-3000V depending on the required gain
- The signal from the anode through a decoupling capacitor is fed to a HFAC-26 preamplifier (Becker-Hickl) and to a discriminator.
- Logical signals from the discriminator are passed to a counter

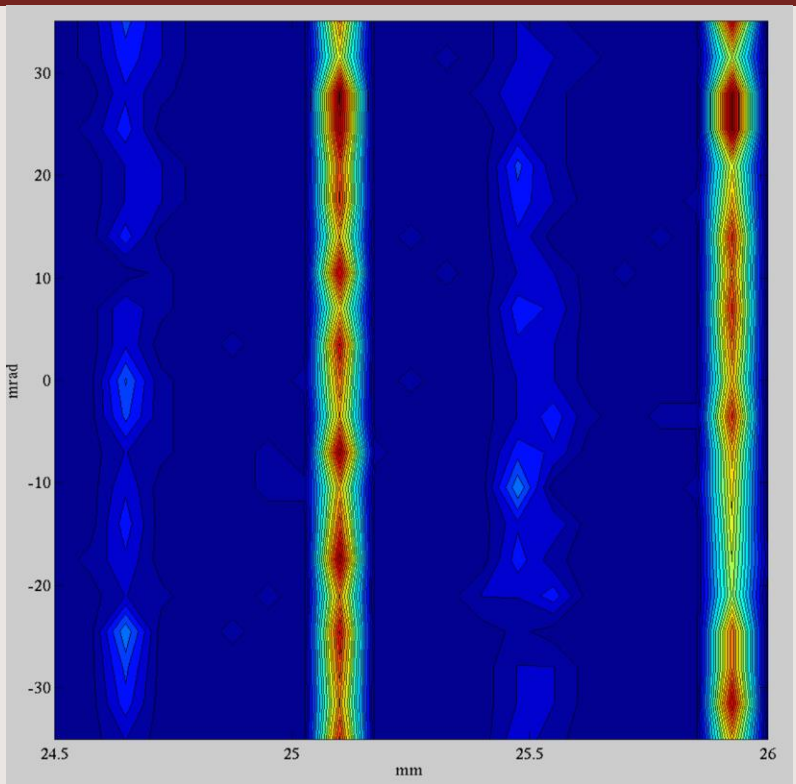
Beam Emittances from Laser Ion Source vs. Surface Ion Source

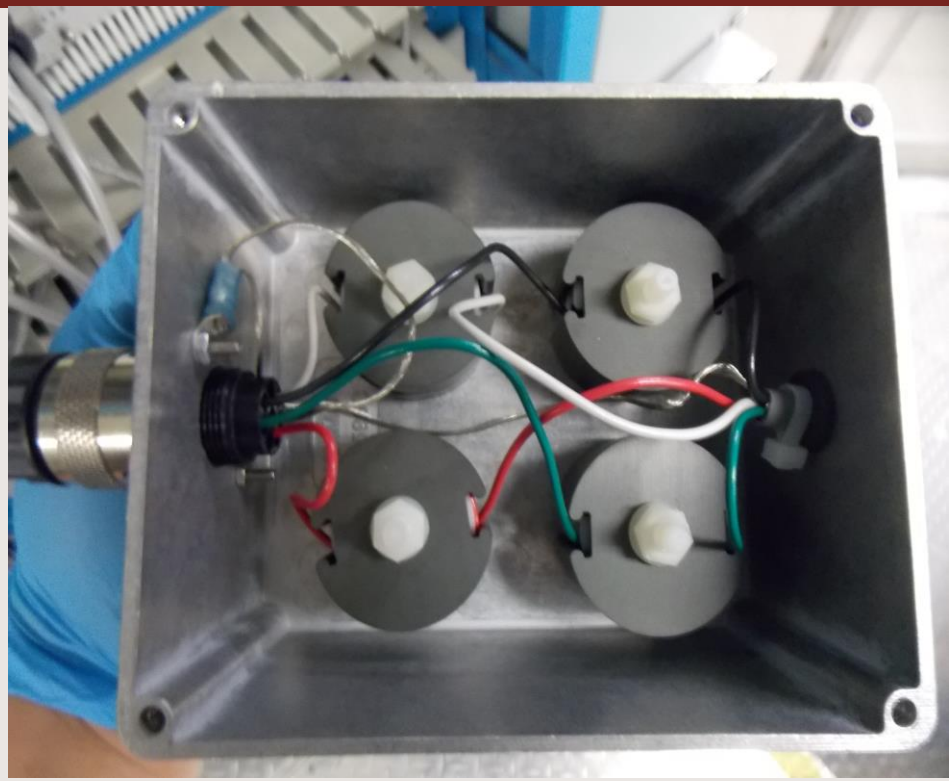
29Al at 20keV Intensity=4x10^{6}cps (0.64pA) Scalar time=0.25s Laser ON



29Al at 20keV Intensity=1.5x10^{6}cps (0.24pA) Scalar time=0.25s Surface Ionization

Emittance scans with CEM Noise detection





- During commissioning some noise was detected even when no-beam scans were taken.
- This noise was traced to the stepper motors.
- To cure it, ferrite boxes were mounted in series with the drivers of the stepper motors.