# Characterizing the RHEPP-1 oxygen beam and its effects on sold targets

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Workshop on Accelerator-Driven
Warm-Dense-Matter Physics

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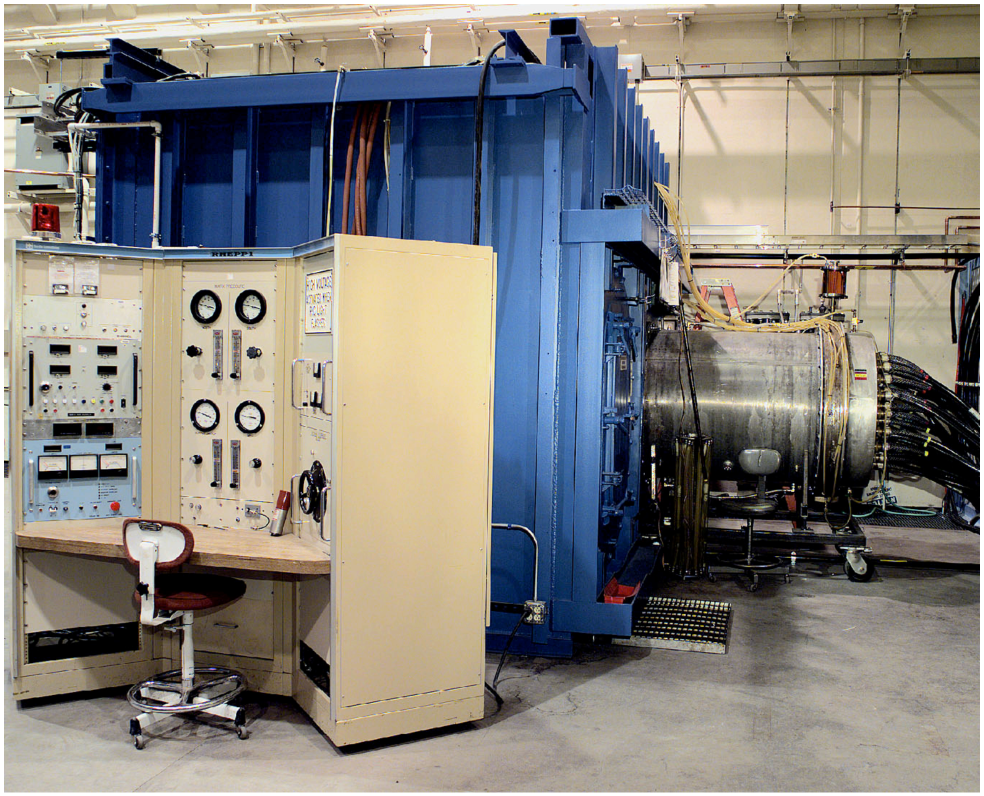
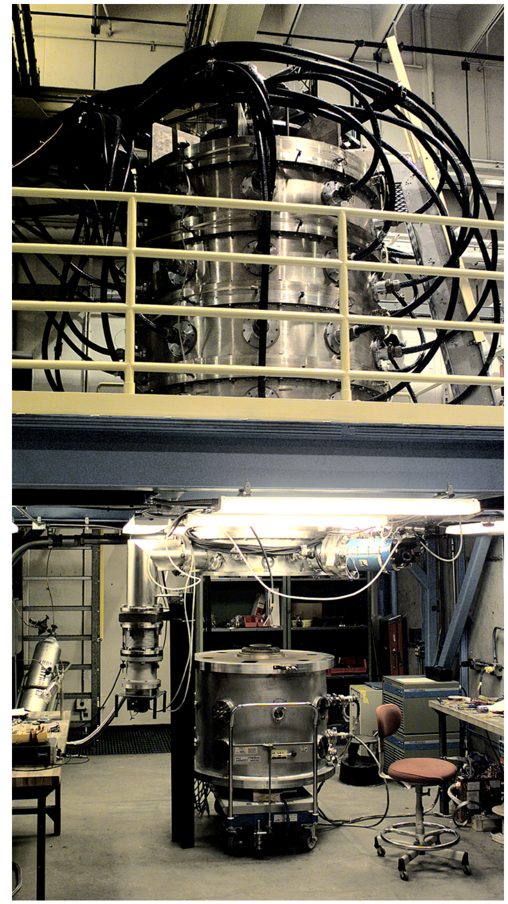
# Outline of Presentation

- RHEPP-1 and MAP diode background
- Prior beam optic studies on MAP by Dave Johnson
- Materials effect: single-pulse Oxygen on Al 2024-T6
- Beam optic study: 3-hole Ta aperture plate and Al target
- Ta 'HIF' Witness Plate exposure
- Summary

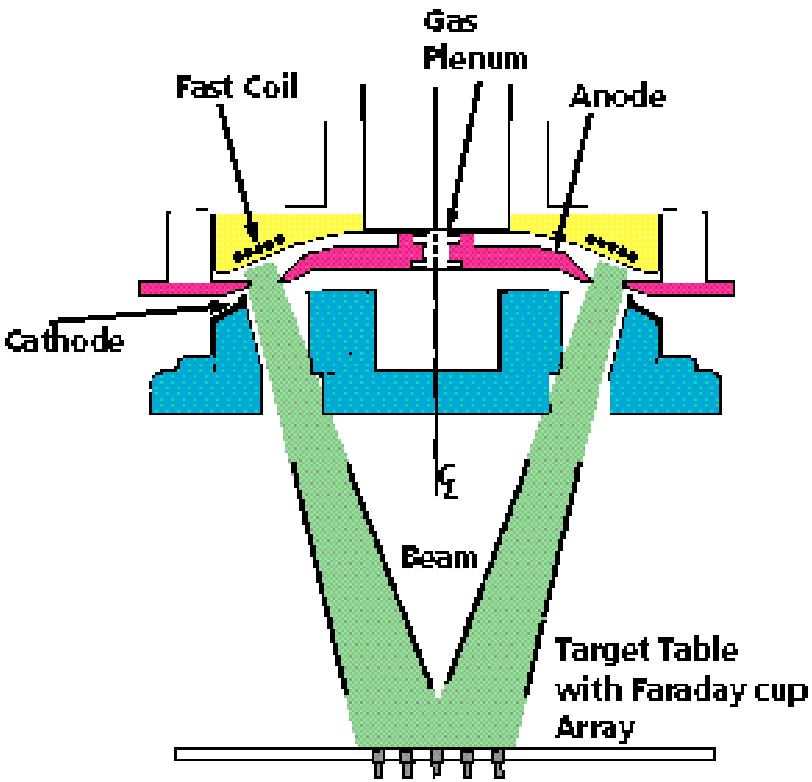
# The RHEPP-1 Facility: 5 kJ Marx feeding Extractor single-stage ion diode with active MAP source





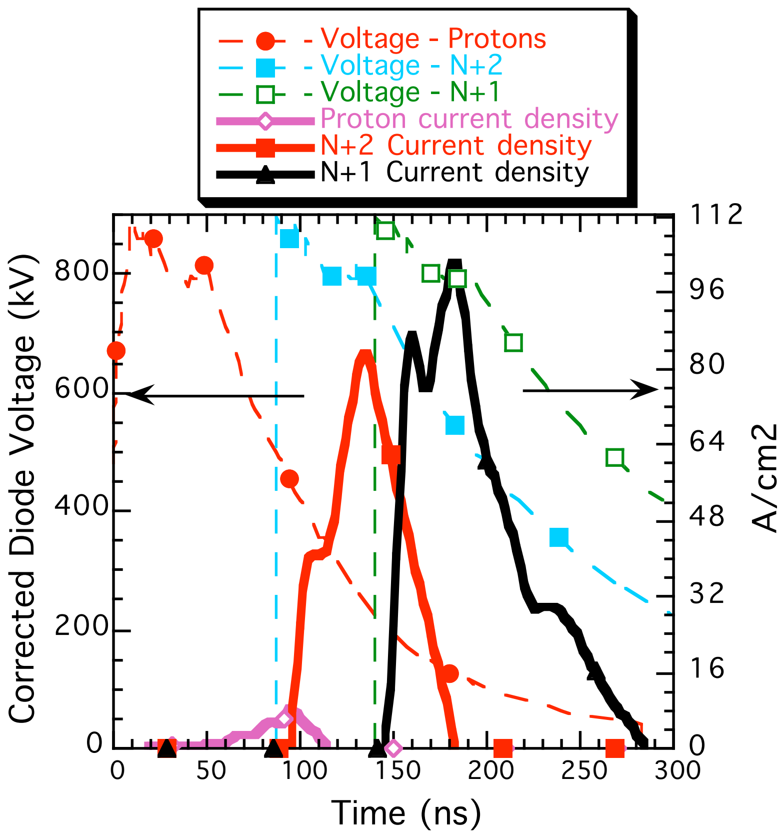
Left: Marx tank with pulse-forming line
Right: 4-Stage LIVA and treatment chamber

# The MAP (Magnetically Confined Anode Plasma) Ion Source is used for surface modification experiments on RHEPP-1




- 00-850 kV
- : 350 A/cm$^2$
- 3eams from H, He, I$_2$, O$_2$, Ne, Ar, Xe, Kr, CH$_4$
- Overall treatment rea ~ 100 cm$^2$
- Diode vacuum ~ 10$^{-5}$ Torr

# Nitrogen injection into MAP produces 3-component beam of mostly N++, N+




- Beam predominantly N++ and N+ after small proton pulse at front
- Peak voltage = 850 kV
  Peak current density (total) ~145 A/cm$^2$
- Total fluence = 7.9 J/cm$^2$ - will ablate almost all materials
- Total pulse width at target ~ 200 ns
- Ion range (TRIM):
  N+ 0.9 $\mu$m, N++ 1.2 $\mu$m
- Oxygen, Neon beams similar

Shot 31661

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# Side schematic view of MAP Diode

**A-K gap = ~ 1.3 cm**
**A-K voltage ~ 700 kV**

# Evolution of B-lines in MAP

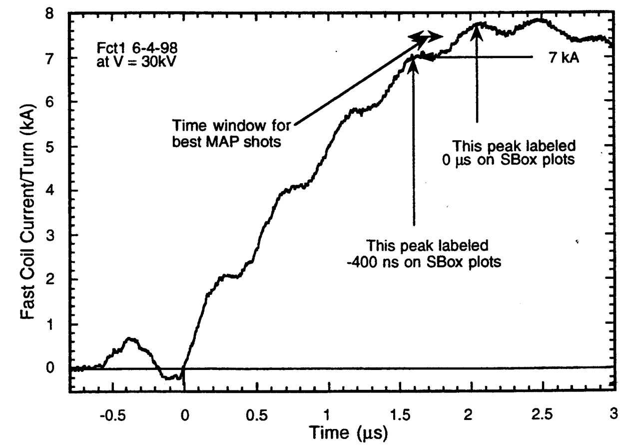


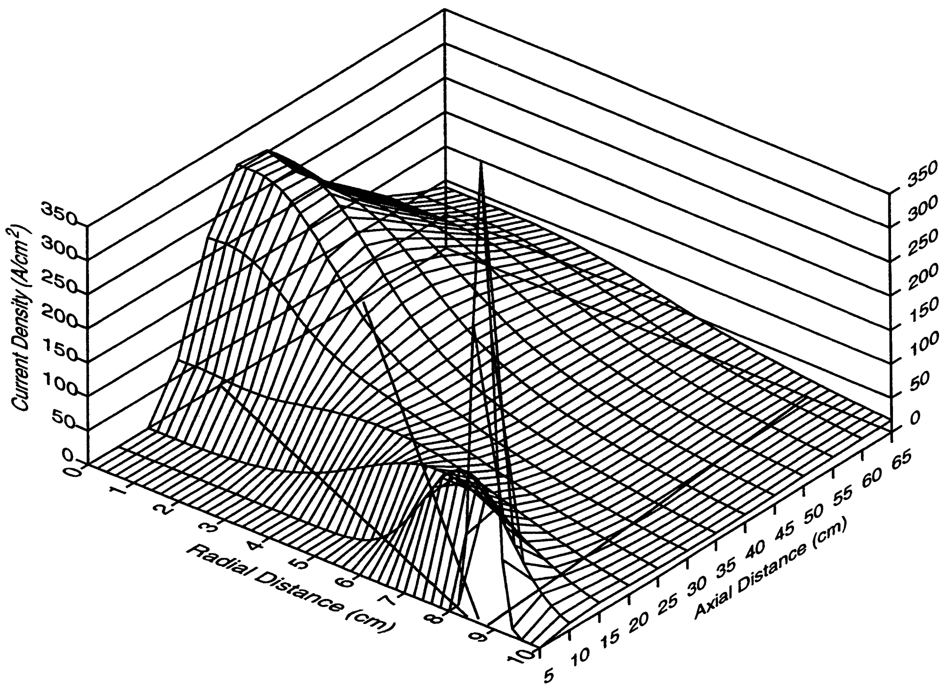

Figure 5. Fast coil current for 30 kV source voltage.

**A-K gap = ~ 1 cm**

**Bfield in gap ~ 3.5 T**

**C-L Enhancement (protons) ~ 20**

# A Beam Propagation Model has been developed



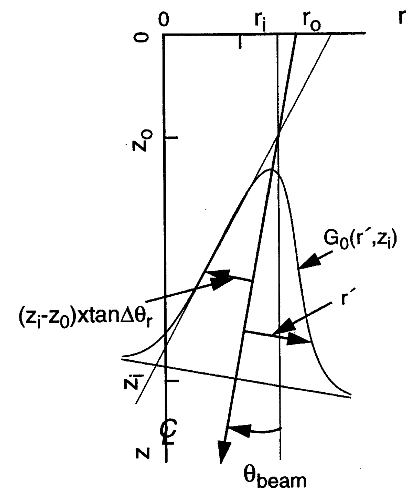
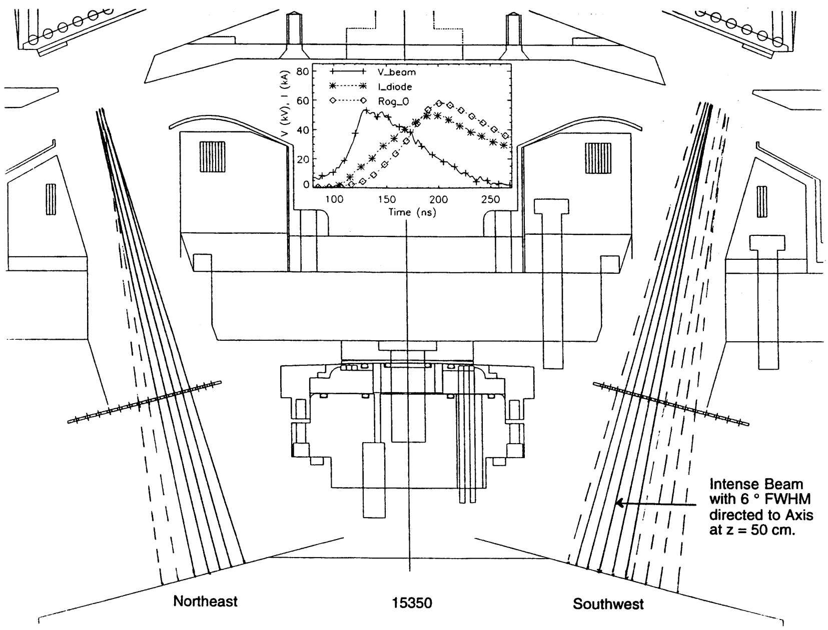
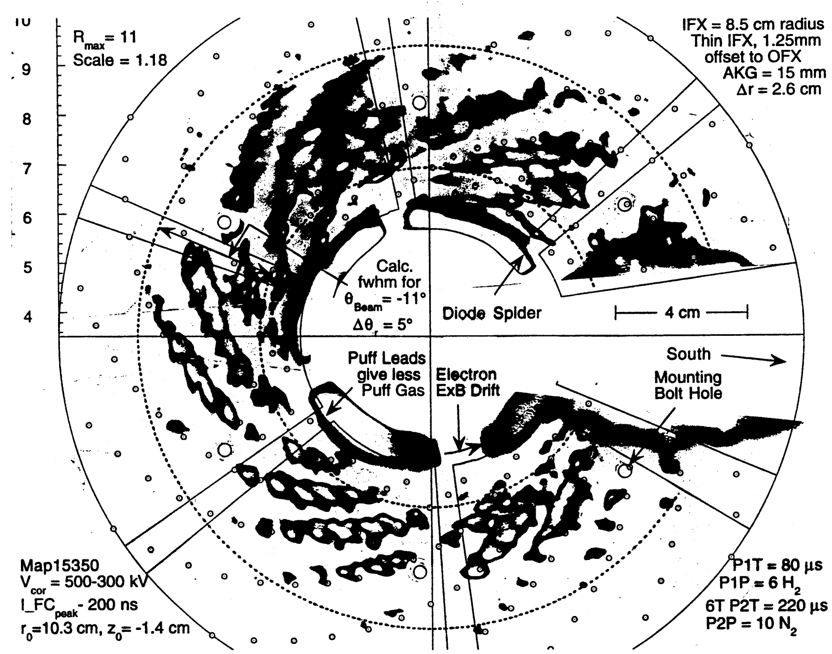




Figure 12. Schematic of the beam trajectory model used to account for the transported beam.

| z | $r_i$ | $R_{ca}$ | $fwhm_r$ | $fwhm_\delta$ | $fwhm_b$ | $I(r<5cm)$ |
|---|---|---|---|---|---|---|
| cm | cm | cm | cm | cm | cm | % |
| 9 | 8.03 | 0.28 | 1.76 | 1.24 | na | 0.00 |
| 18 | 6.28 | 0.45 | 4.94 | 1.26 | na | 27.4 |
| 25 | 4.92 | 0.62 | 7.40 | 3.50 | 6.6 | 49.5 |
| 35 | 2.97 | 0.69 | 10.9 | 4.90 | 6.2 | 58.9 |
| 45 | 1.03 | 0.87 | 14.5 | 6.29 | 8.0 | 51.8 |
| 50 | 0.06 | 1.27 | 16.4 | 6.99 | 8.8 | 46.3 |
| 63 | -2.46 | 1.62 | 20.8 | 8.80 | 11.8 | 32.0 |

# The MAP proton beam emits from a point focus in the A-K gap

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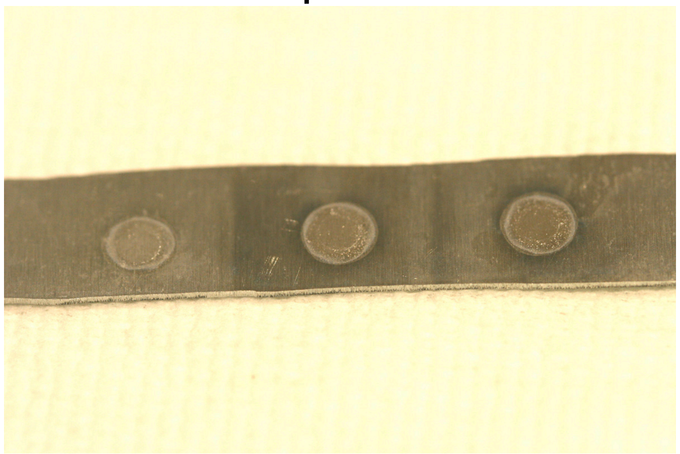
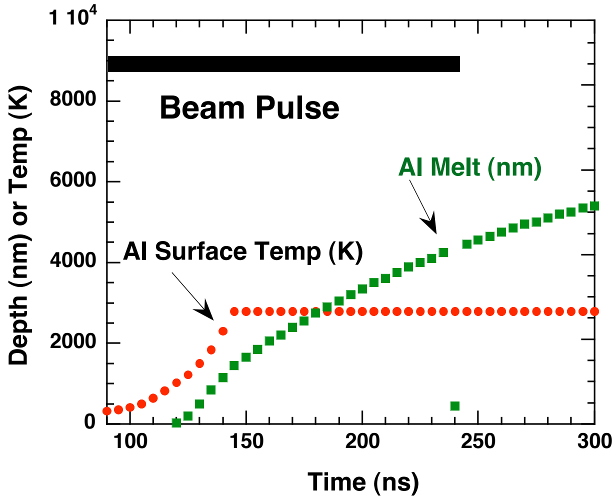
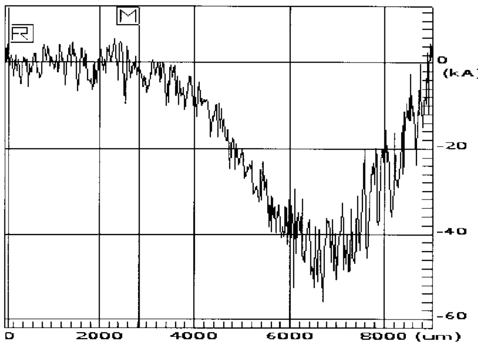
# Single Oxygen pulse makes 4 $\mu$m-deep crater in Al 2024-T6

Photo - 3 Al melt spots





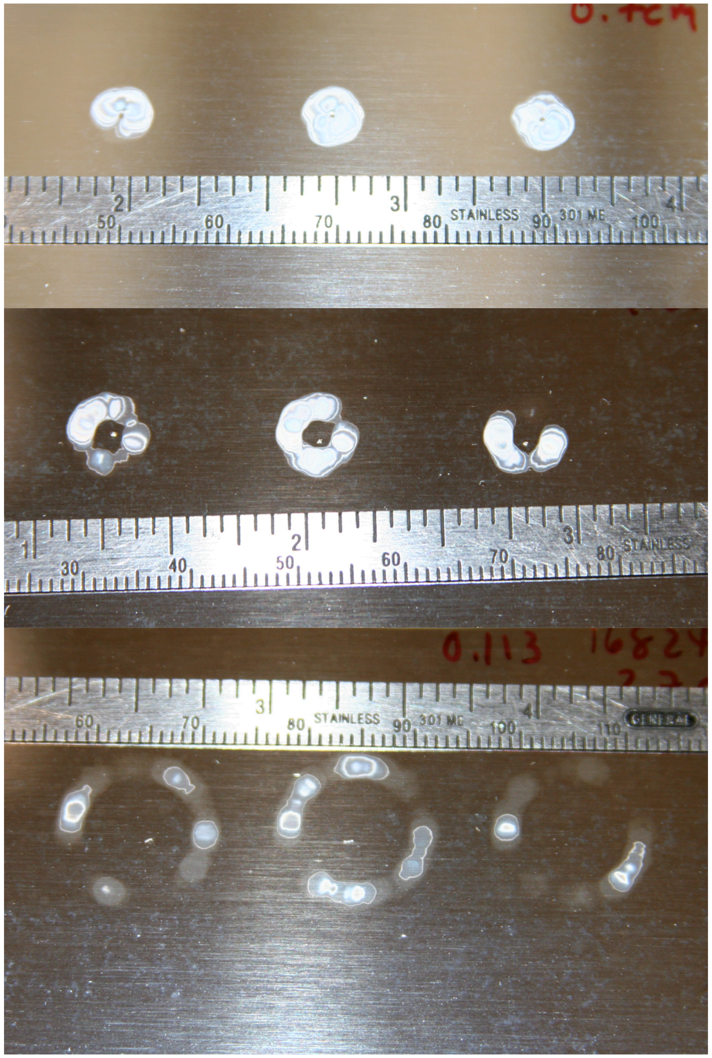




Center spot - Profilometer scan

- Material: Al 2024-T6
- Three 4mm countersunk holes 1.3 cm apart in Ta aperture plate aperture-target dist = 3.5 mm
- Profilometer: 4 $\mu$m-deep ablation pit
- SIM: I-d Heat Flow Code, energy input from TRIM, then bulk properties. Does NOT model ablation
- Beam pulse 0-250 ns, 6 $J/cm^2$
  - H - very small, 20K rise by 90ns
  - Oxy - ablation temp (2793K) by 140 ns
- Surface below 2793K by 660ns, Al melt depth reaches 10 $\mu$m by 1.5 $\mu$sec. Peak SIM Al temp = 9500K
- Ta: 6J/$cm^2$ simulation exceeds 12,000K (low Ta thermal conductivity)
- Al melt duration well beyond 10 $\mu$sec

| Al Melt Temp | Vapor Temp |
|---|---|
| 933K | 2793K |

# Oxygen Beam Focusing study



Aperture-target dist = 0.7 cm

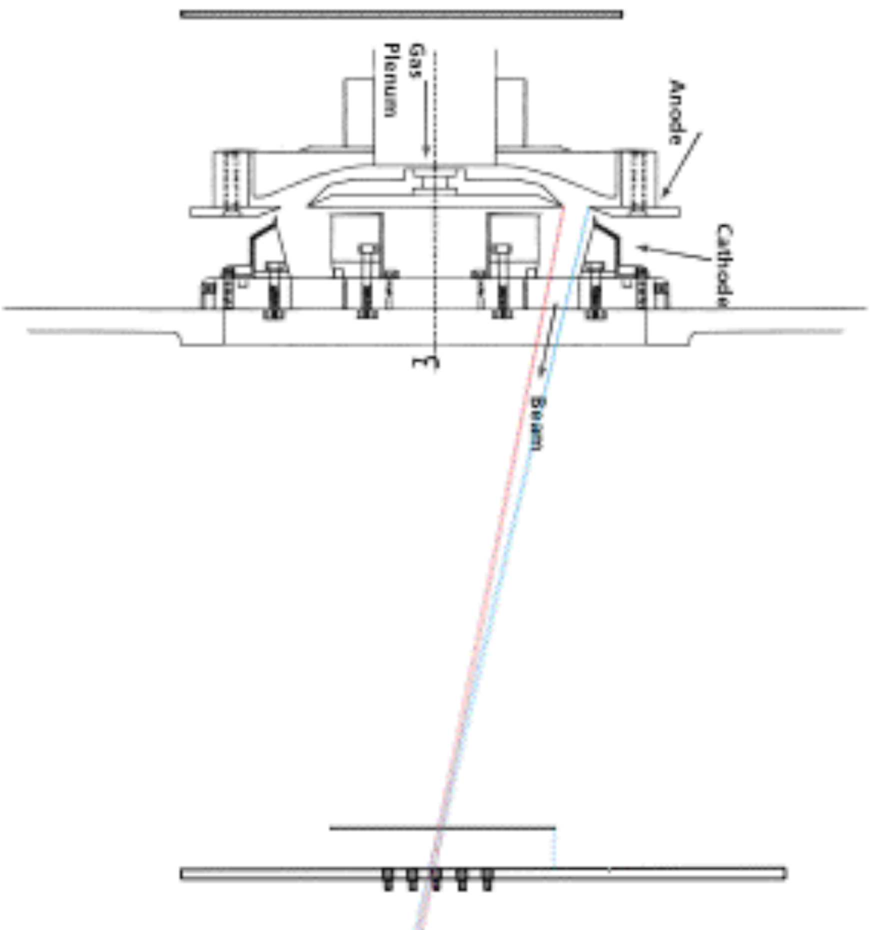
Aperture-target dist = 1.25 cm

Aperture-target dist = 2.7 cm

- Aperture Plate: 3 holes in Ta, 3/4 inch apart, countersunk, size 2.9 mm. Target: EVERBRITE (Al)
- (SinglePulse) Aperture-target dist =
  - 0.7 cm (TOP)
  - 1.25 cm (MIDDLE)
  - 2.7 cm (BOTTOM)
- SIM melt threshold - 0.55 J/cm$^2$
- Peak beam power ~ 6 J/cm$^2$
- Observations: source has discrete beam'sections', each has different $\mu$-divergence
- Damage to plate narrower than penumbra worst-case

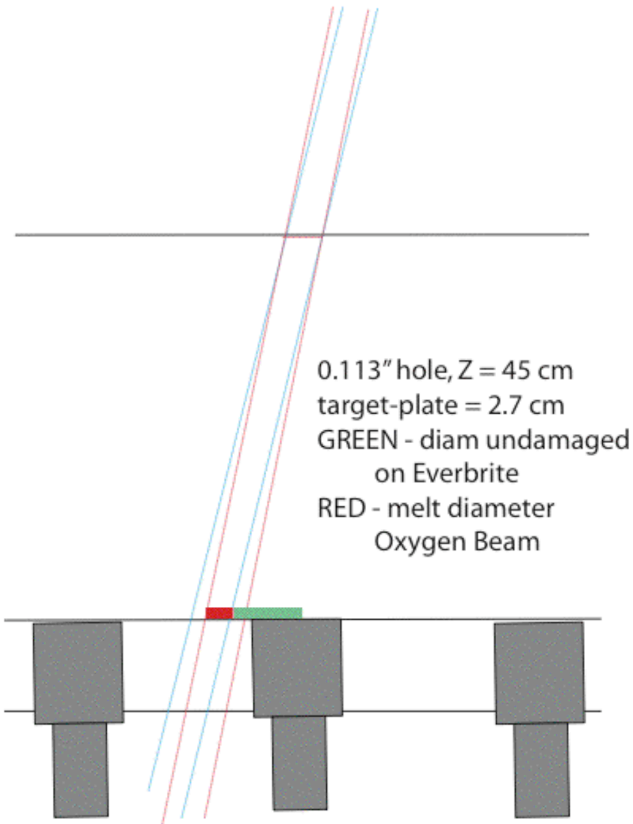
Al Melt Temp 933K    Vapor Temp 2793K

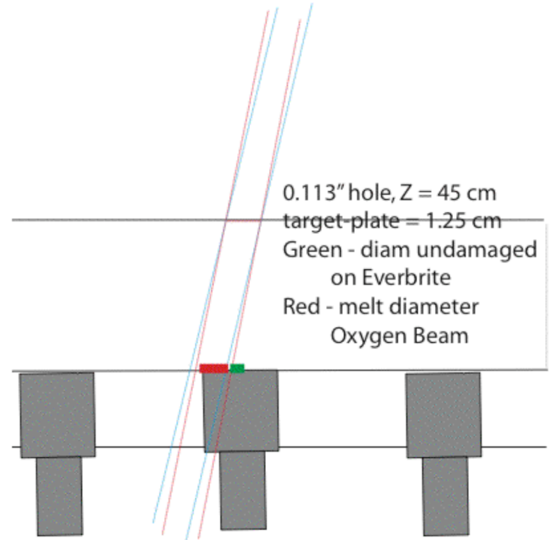
# Setup for Ray Tracing Study

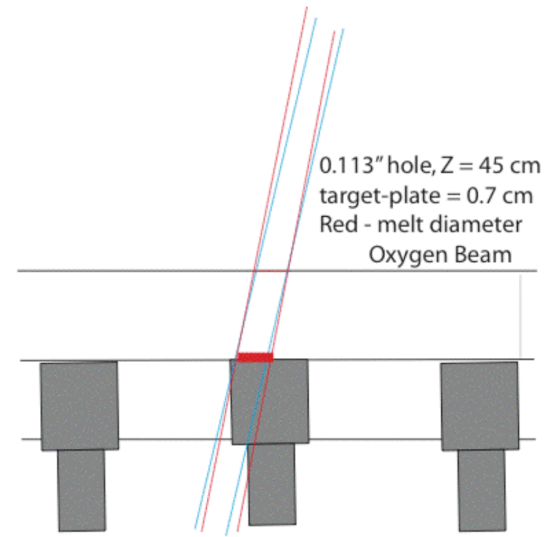



- Draw straight-lines from inner anode edge, to each side of aperture hole. Repeat for outer anode edge.
- Repeat for 3 aperture-target distances

# Ray-tracing results

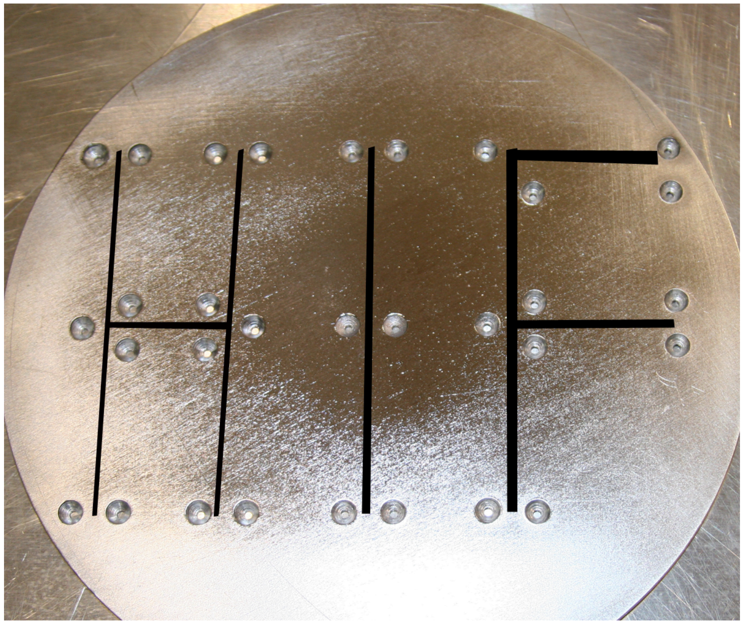


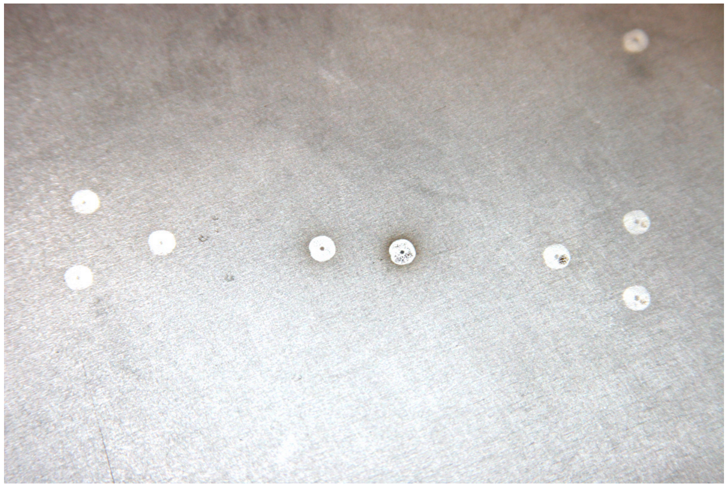




- **Red chords - inner edge. Blue chords - outer edge**
- **Red spot on Everbrite - actual damage. Green is damage-free**
  - **Gray objects are Faraday cup locations**
- **0.7 cm: No ‘Hole’, beam fills in, spot size matches**
- **1.25 cm: Damage less than penumbra**
- **2.7 cm: Spot size less than half worst-case. Could be we are below damage threshold**
- **But ‘persistence’ of image on HIG plate suggest 2 degree *μ*-divergence**

# Show-and-Tell Tantalum Witness Plate

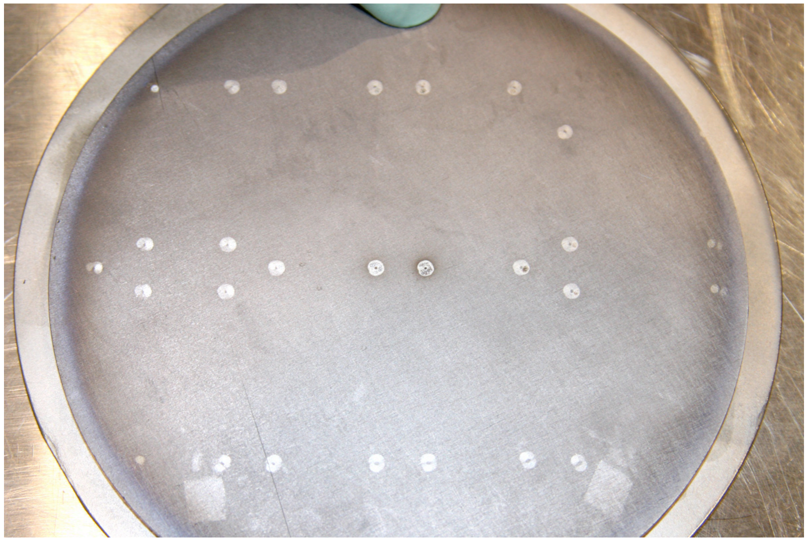


Ta Aperture Plate



Target plate center

- Ta Aperture plate at z = 45cm
- Ta Target plate offset = 0.5 cm. Target plate diameter = 13.5 cm
- 20 pulses oxygen beam
- Center holes ablated, other holes melted to ~ 3 cm radius
- Center of each damage pattern is undamaged (see above)



Ta Target Plate
Diam = 13.5 cm

# Summary

- **RHEPP-1 with active ion source can generate intense ion beams of total currents ~ 5 kA, peak currents ~ 250 A/cm$^2$, with variable dose over a ~150 cm$^2$ target area. Beam pulsewidth ~ 150 - 400 ns**
- **Present oxygen beam can ablate any metal, over a 50-500 ns timescale. Peak effective temperatures approach 10,000K (~1 eV).**
- **Beam optics studies indicate possible paths for improvement. One idea is to 'fill' the anode annular gap with a screen.**
- **RHEPP/MAP can be considered either for 1) preliminary effects experiments, or 2) as a test-bed for diagnostic development. Preference is for real-time diagnostics (not time-integrated)**