Novosibirsk State University

Fermi National Accelerator Laboratory

PROTON SOURCE DEPARTMENT

Negative Hydrogen Ion Source Research and Beam Parameters for Accelerators.

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Purpose

1. Show operation and analysis of H- ion source
2. Understand the processes which happens in emittance probe when we collect data
3. Be sure that this data is correct (find optimal parameters of probe)
4. Understand the beam emittance (quality estimate of emittance)

Ion source

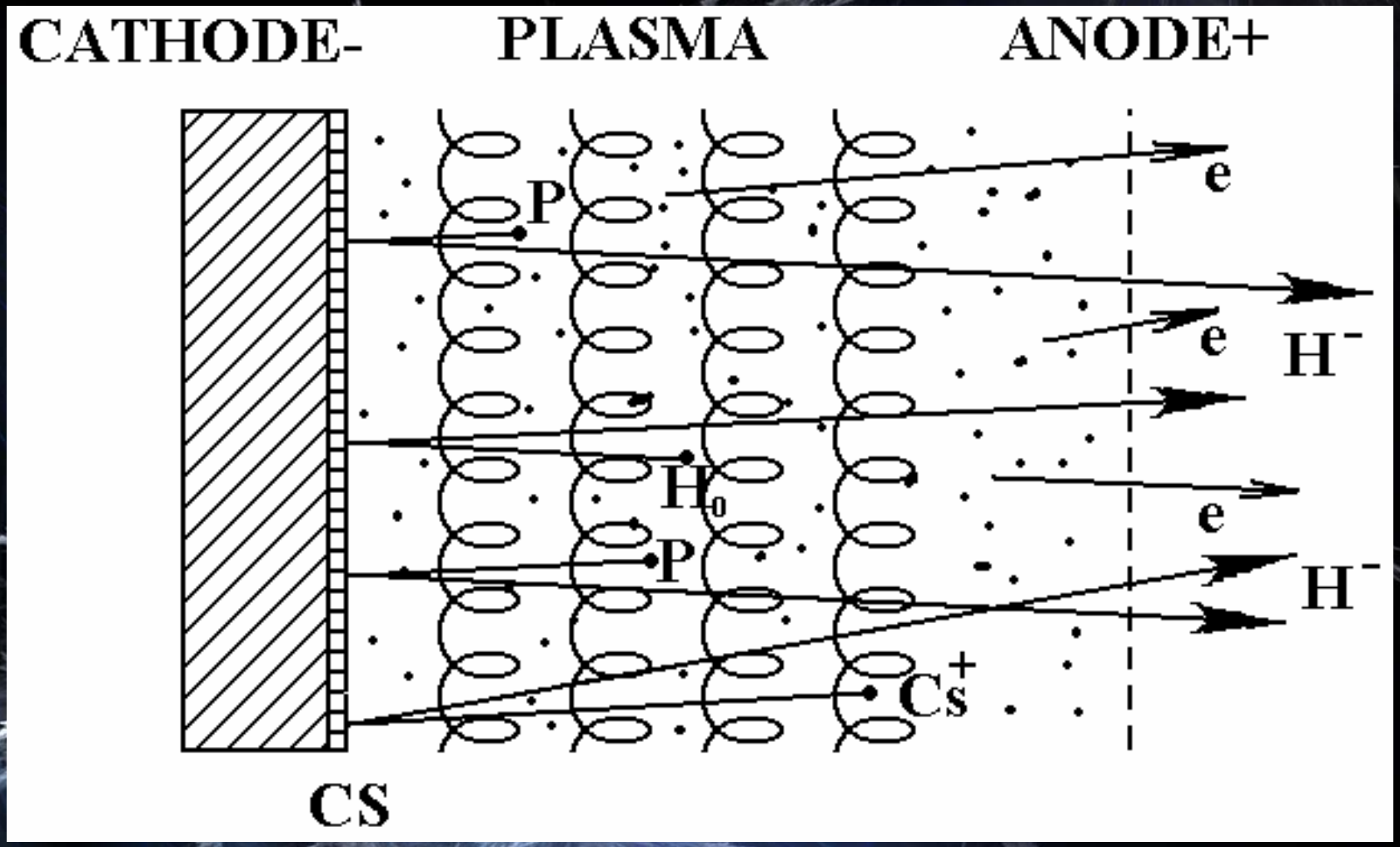


Figure 4: Plasma processes.

Ion source

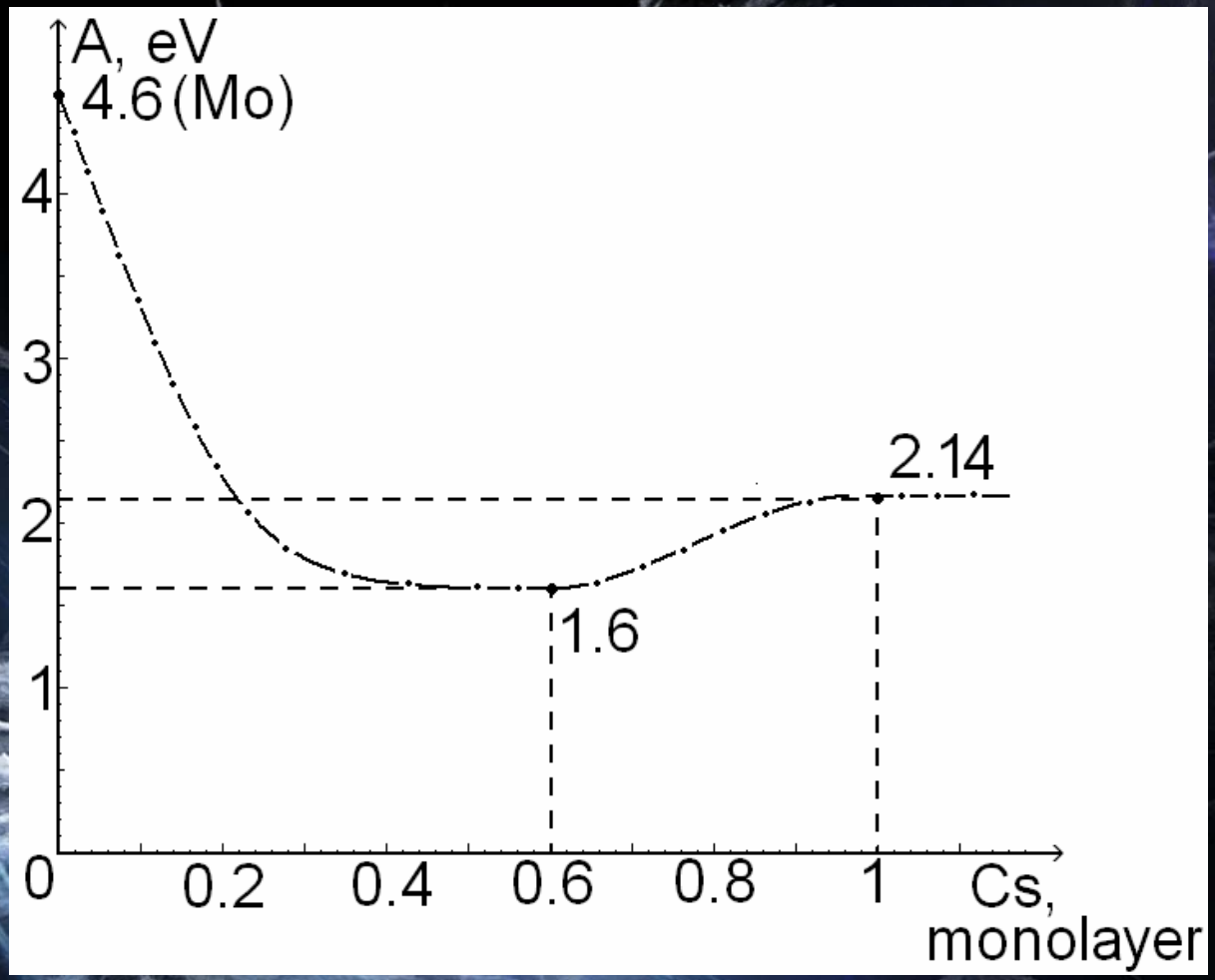


Figure 5: Work function of Mo as a function of Cs monolayer on Mo surface.

Ion source

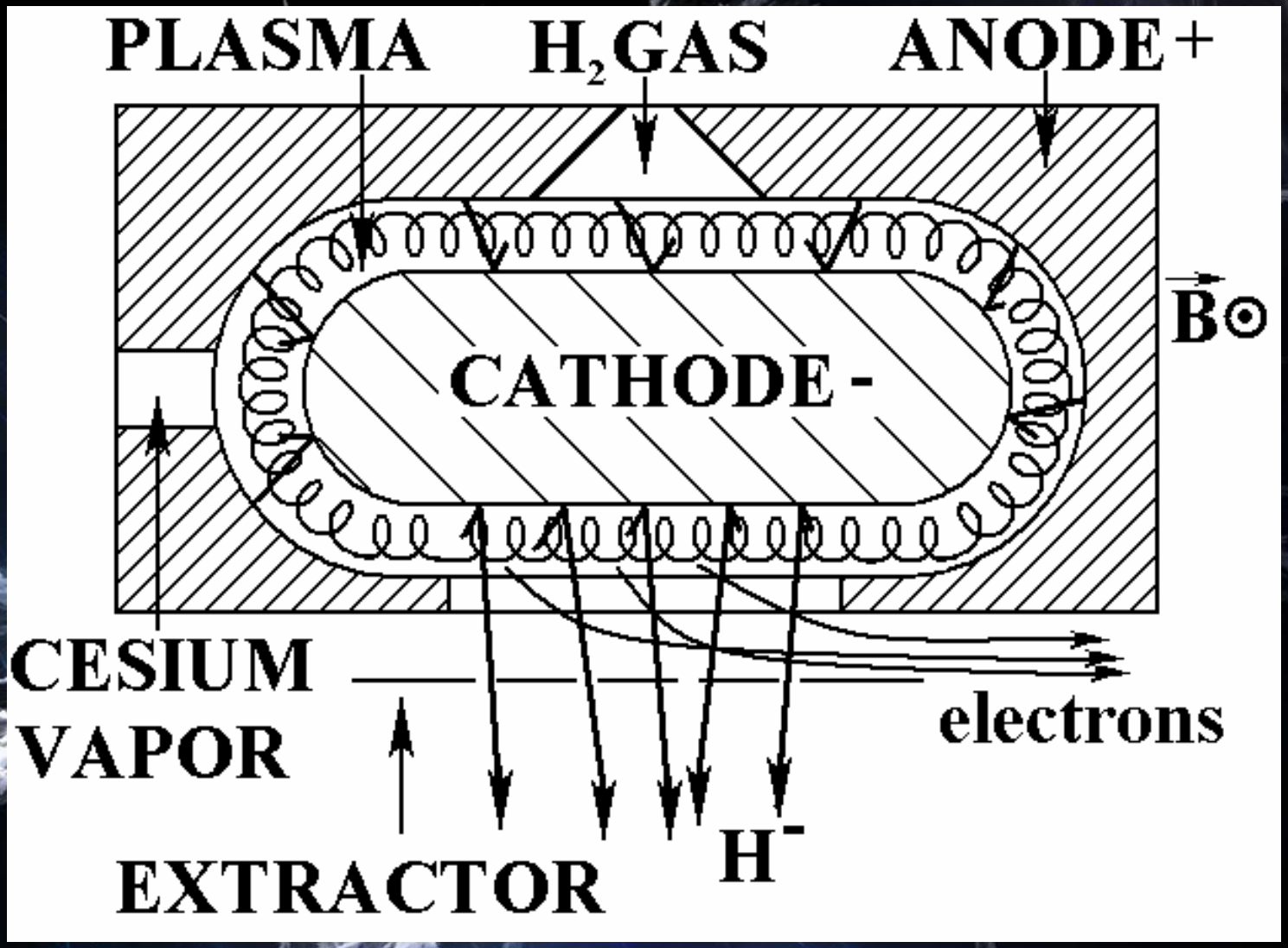


Figure 6: Magnétron type source.

Ion source

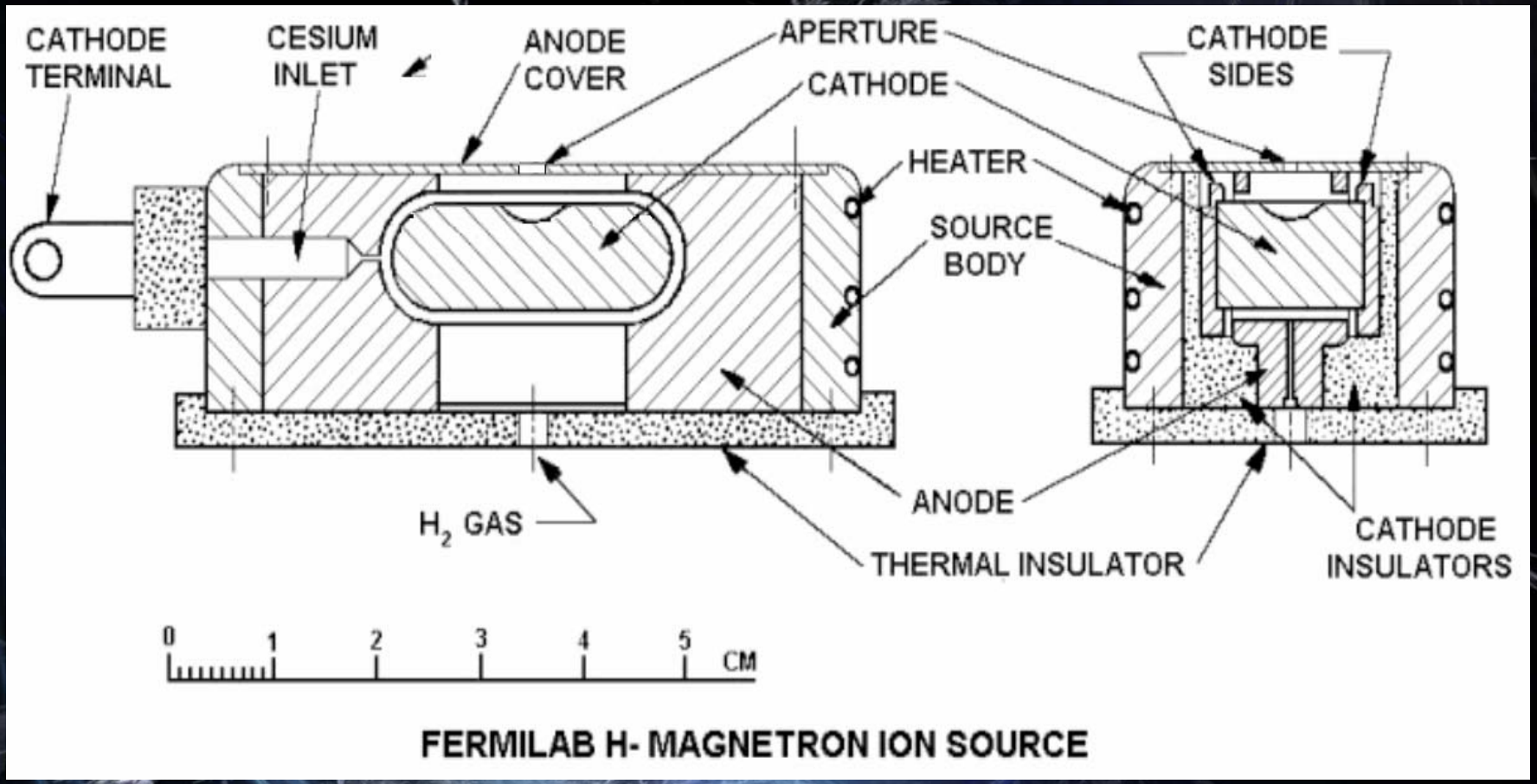


Figure 7: FERMILAB H- magnétron source.

Setup

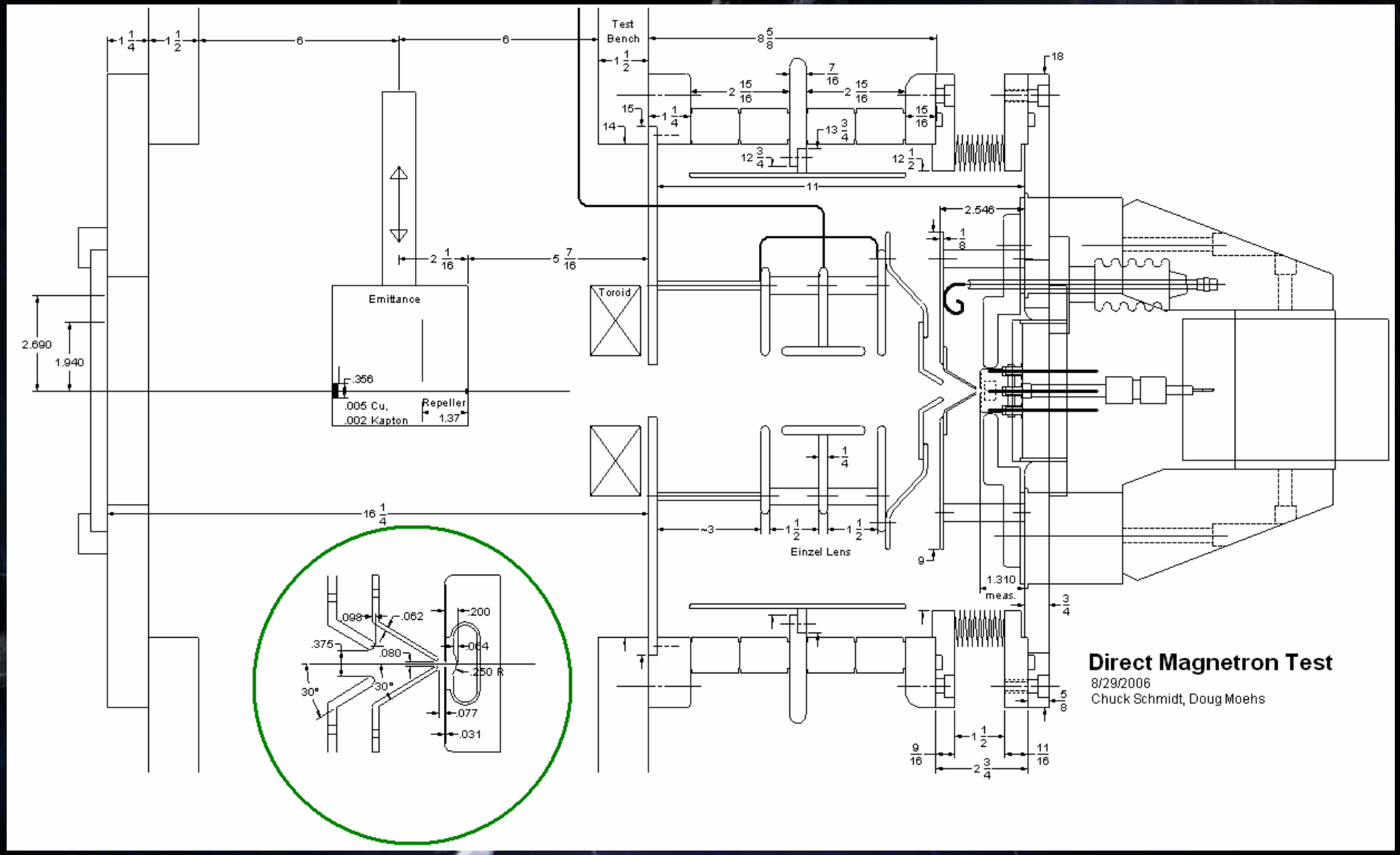
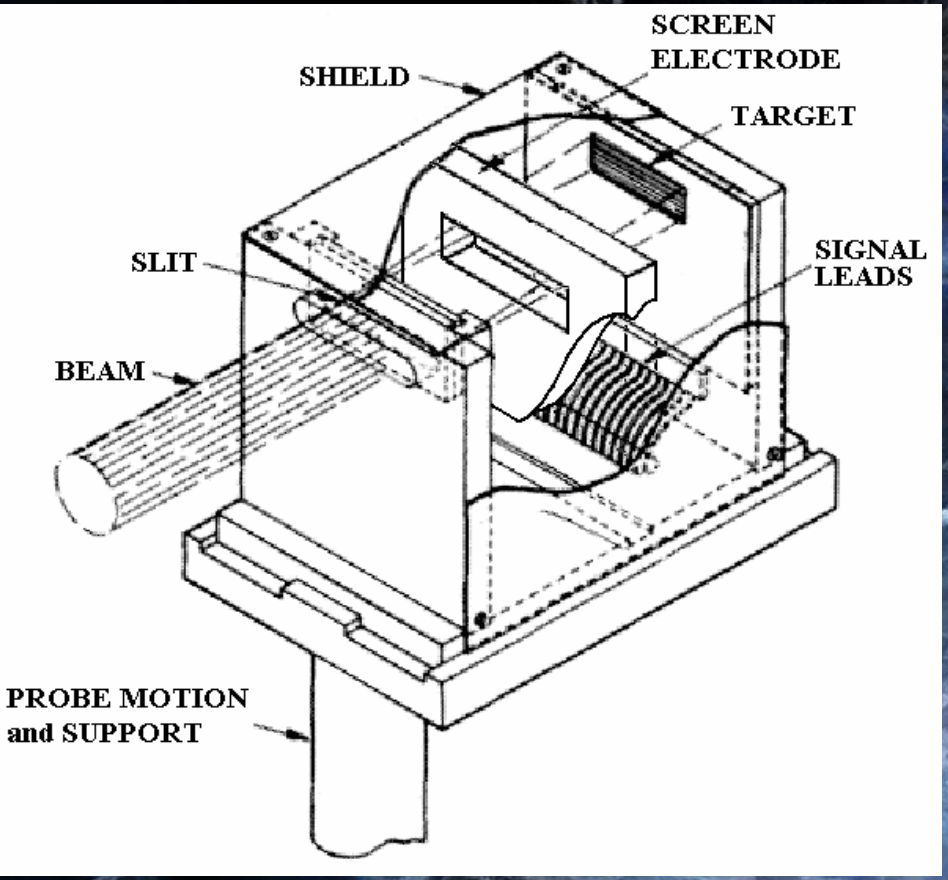


Figure 8: Direct extraction magnetron test.

Probe



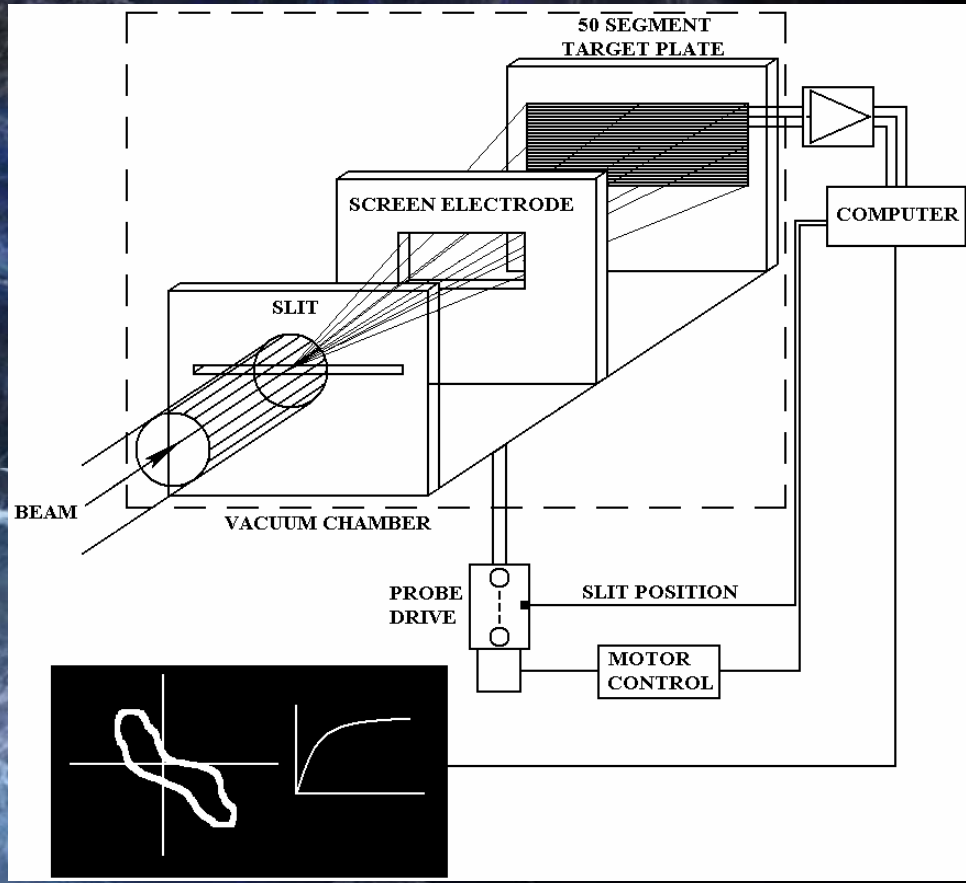


Figure 9: Emittance probe design.

Figure 10: Detail of emittance probe.

Beam Emittance

The basic equation of emittance is

$$A_6 = \iiint p_x p_y p_z dxdydz = \text{const}$$

The definition of 2-dimension emittance is:

$$\frac{A_2}{\pi mc} = \frac{1}{\pi mc}\int p_x dx = \frac{1}{\pi}\int \beta_x \gamma dx = \varepsilon_n$$ -normalized emittance, were

$$\beta_x = \frac{v_x}{c} \quad \text{and} \quad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

Sometimes emittance is given in terms of "laboratory" emittance

$$\varepsilon = \frac{\varepsilon_n}{\beta\gamma} = \frac{\int \beta_x \gamma dx}{\pi\beta\gamma} = \frac{1}{\pi}\int x' dx$$

Beam Emittance

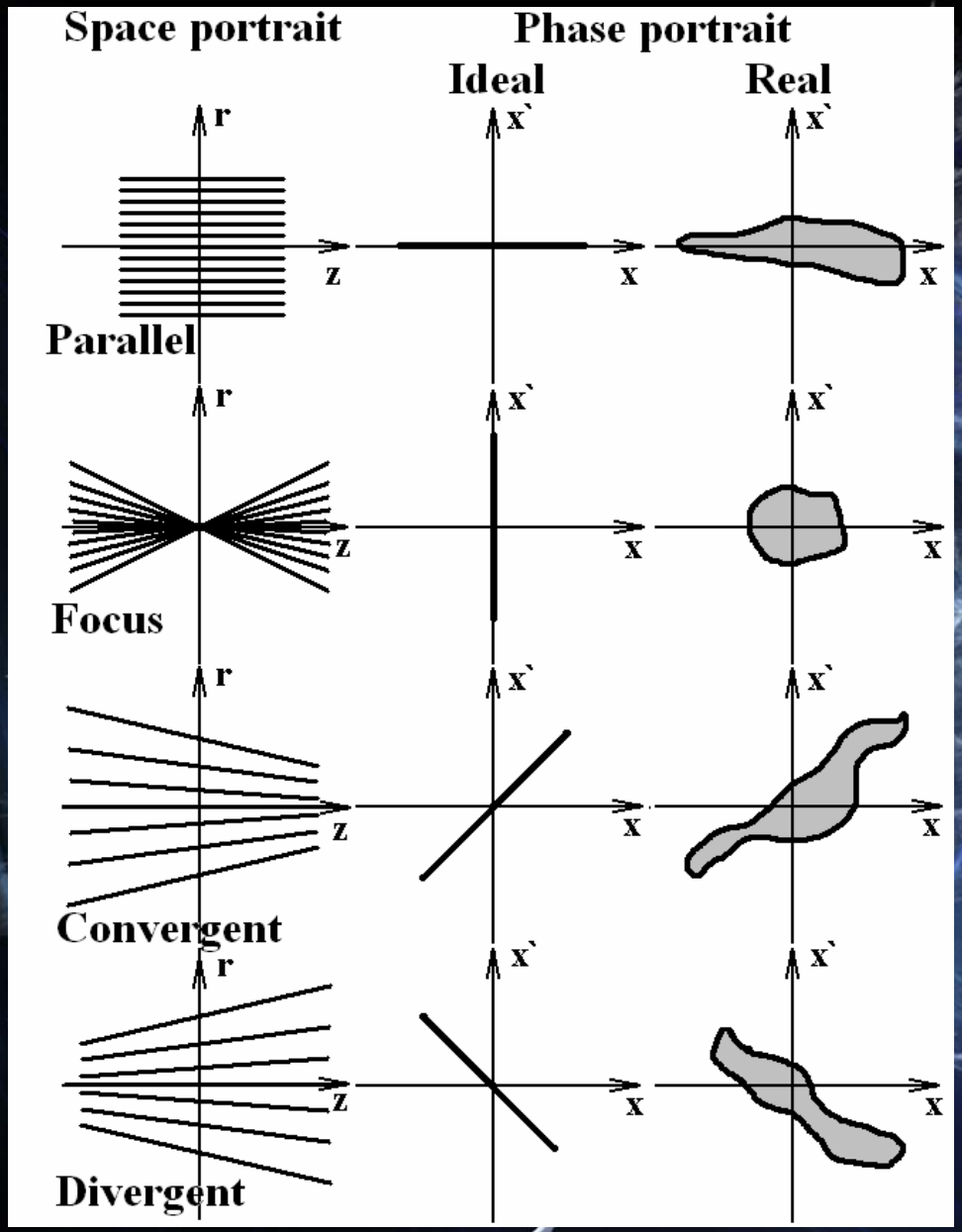


Figure 1: Ideal and real emittance in different cases

Beam Emittance

1.Analytical parameters:

$$x' = \pm\frac{b}{a}\sqrt{a^2 - x^2} + cx \Rightarrow \varepsilon = a \cdot b$$

$$a = x_{max}; b = x'_0$$

(only for centered ellipse)

2.Twiss parameters

$$\gamma x^2 + 2\alpha x x' + \beta x'^2 = \varepsilon$$

with

$$\beta\gamma - \alpha^2 = 1; \beta, \gamma > 0$$

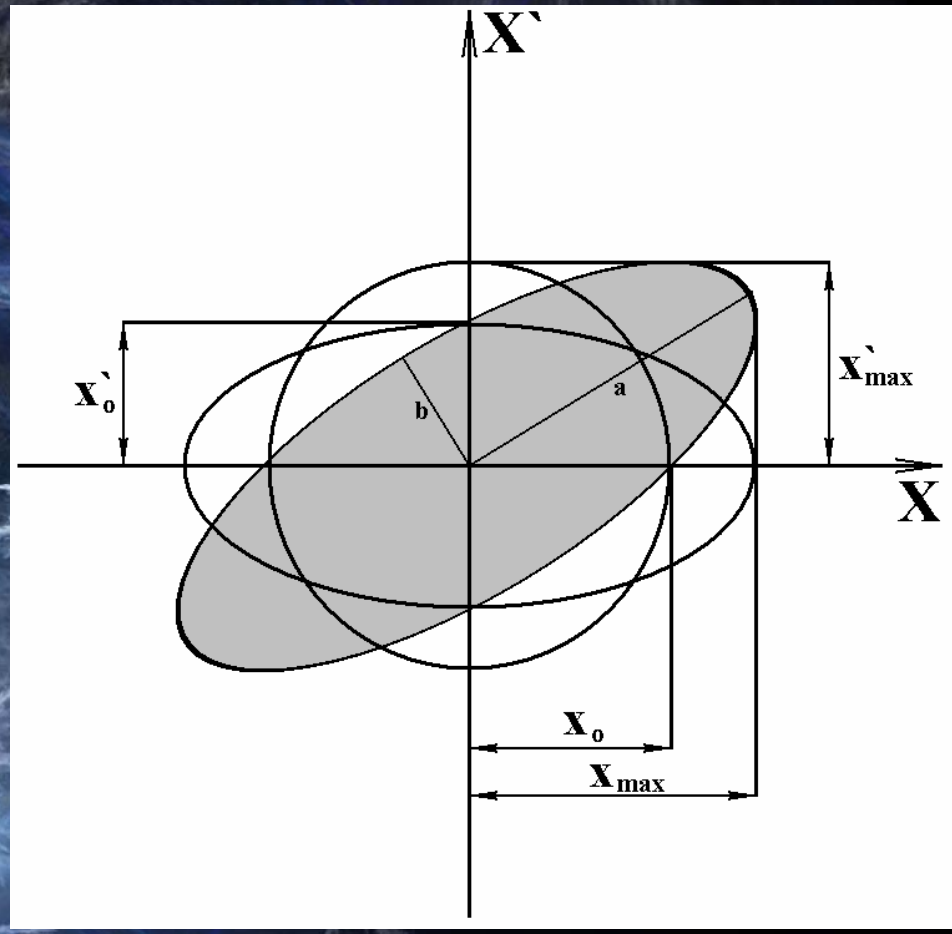


Figure 2: Representation of emittance as an ellipse.

Beam Emittance

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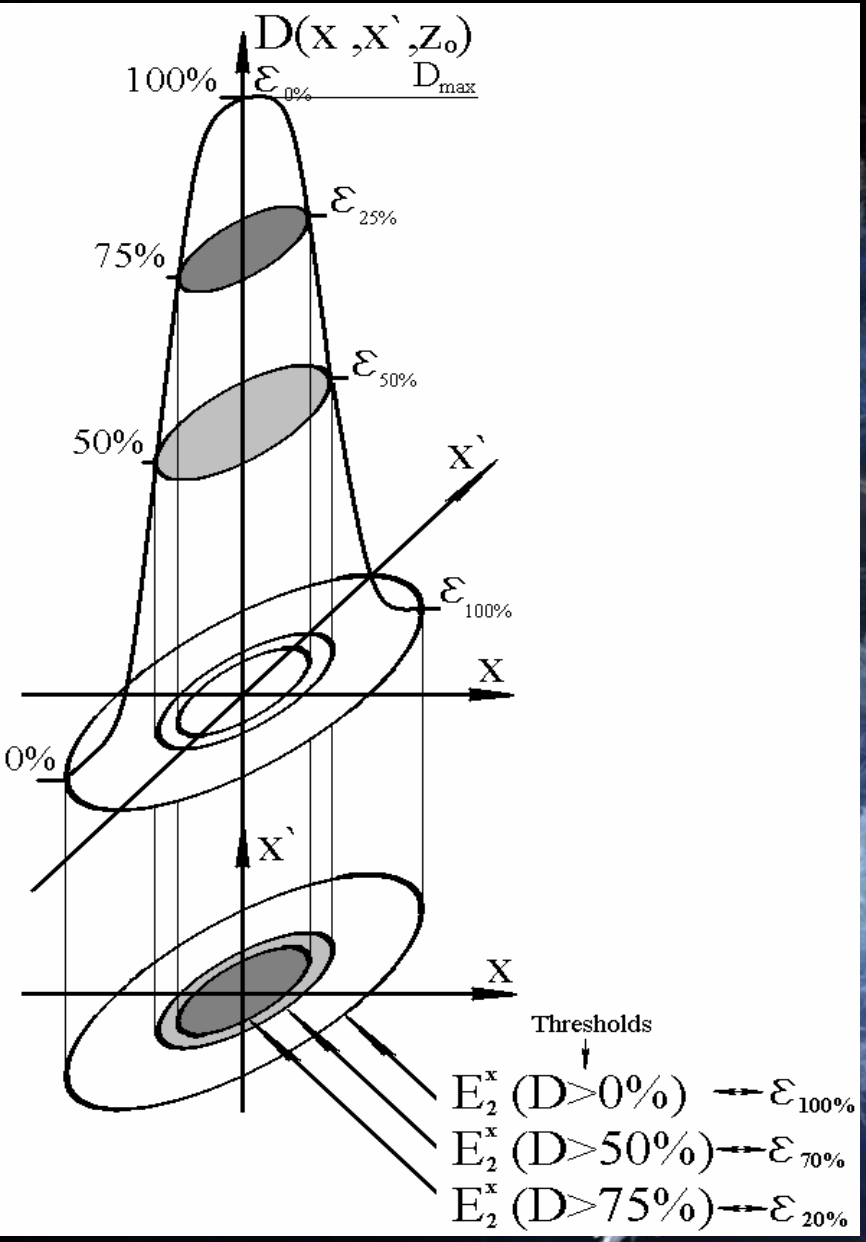

$$\varepsilon_{RMS} = \sqrt{\langle x`^2 \rangle \langle x^2 \rangle - \langle xx` \rangle^2}$$

with

$$\langle x^2 \rangle = \frac{\sum_{all} x^2 c(x,x`)}{\sum_{all} c(x,x`)}, \langle x`^2 \rangle = \frac{\sum_{all} x`^2 c(x,x`)}{\sum_{all} c(x,x`)},$$

$$\langle xx` \rangle = \frac{\sum_{all} xx` c(x,x`)}{\sum_{all} c(x,x`)}$$

$$\langle x \rangle = \frac{\sum_{all} x c(x,x`)}{\sum_{all} c(x,x`)} = 0, \langle x` \rangle = \frac{\sum_{all} x` c(x,x`)}{\sum_{all} c(x,x`)} = 0$$

$$\alpha = -\frac{\langle xx` \rangle}{\varepsilon}, \beta = -\frac{\langle x^2 \rangle}{\varepsilon}, \gamma = -\frac{\langle x`^2 \rangle}{\varepsilon}$$

Figure 4: The beam fraction.

Experimental Part

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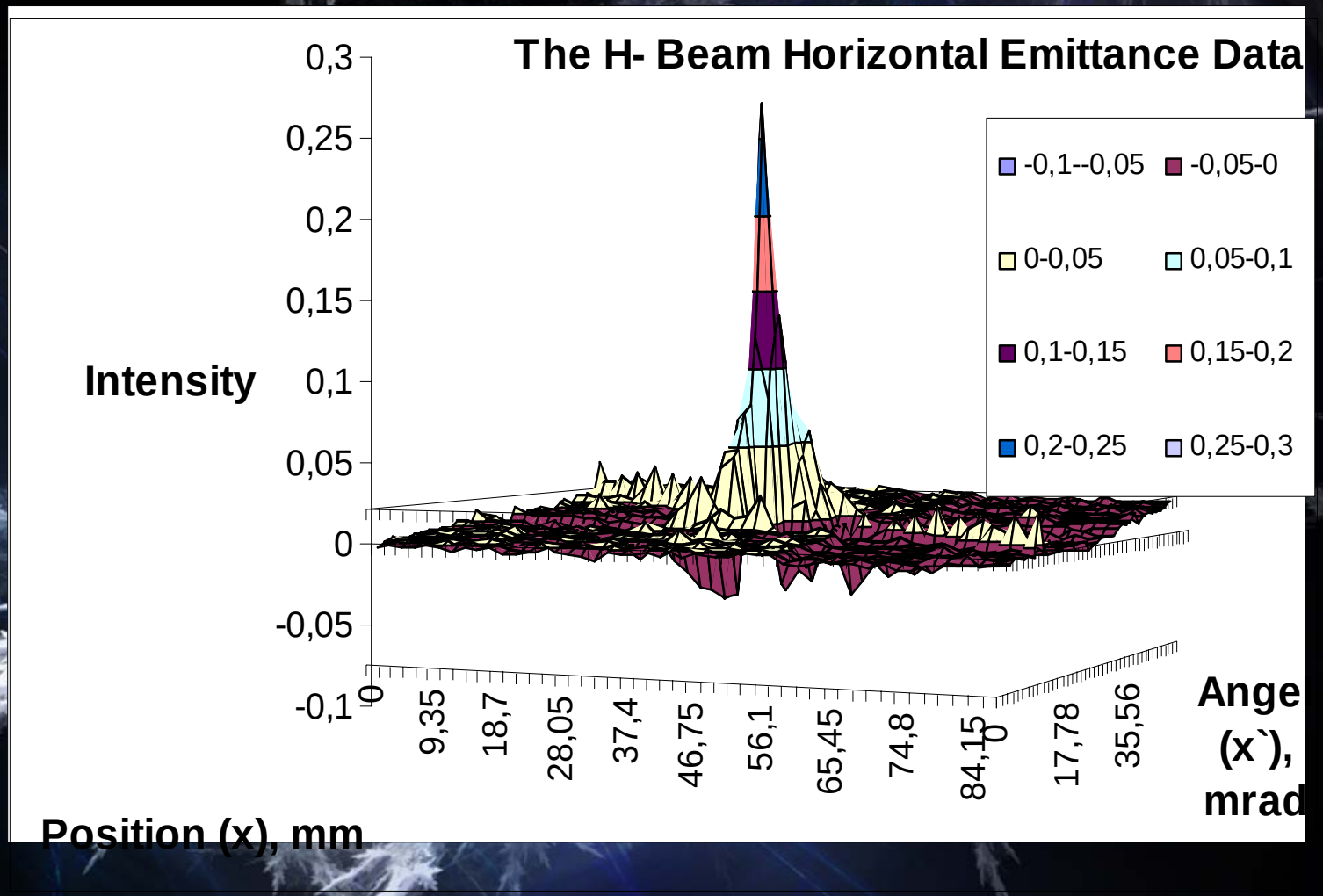

Figure 11: Illustration of typical data collected from probe.

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Experimental Part

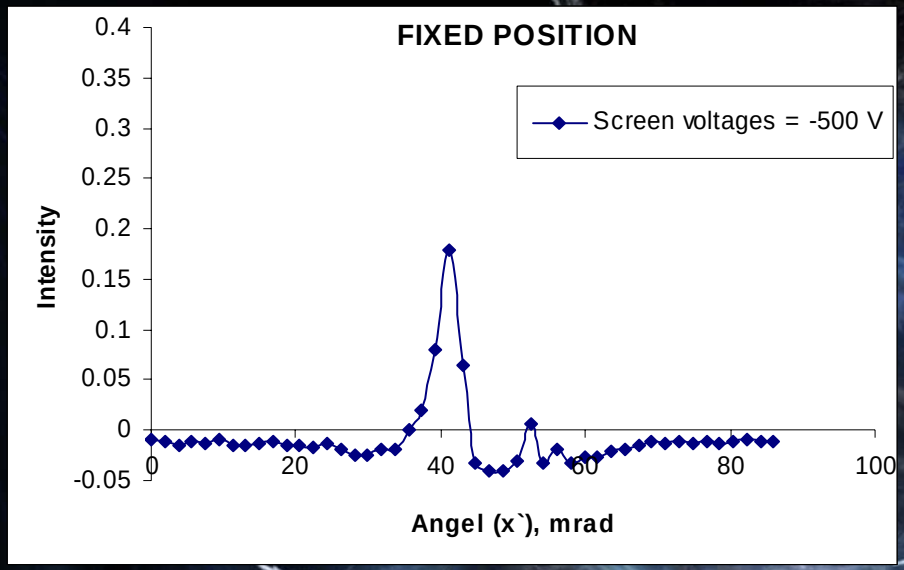

Figure 12: Slice of 3-D plot of H- beam X emittance data with negative screen voltage (-500 V).

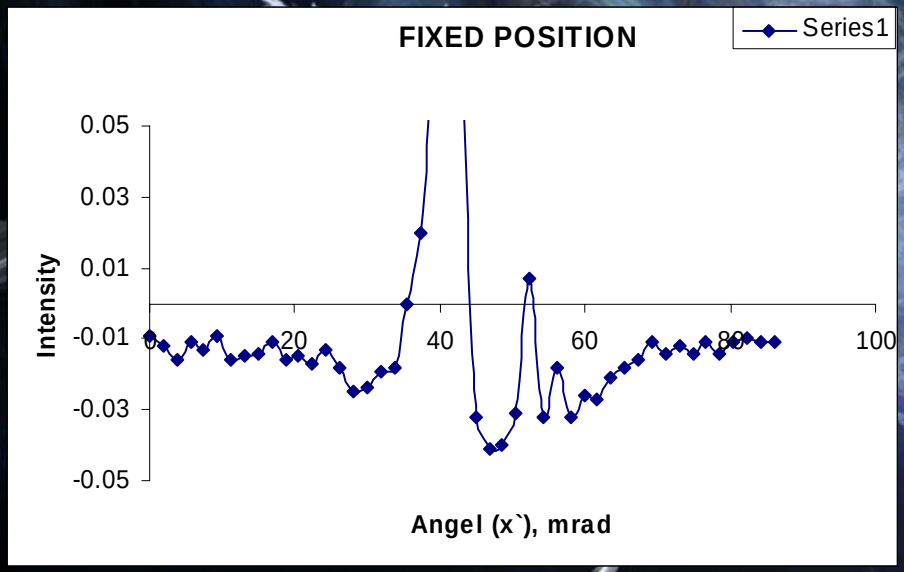

Figure 13: Slice of 3-D plot of H- beam X emittance data with negative screen voltage (-500 V).

Experimental Part

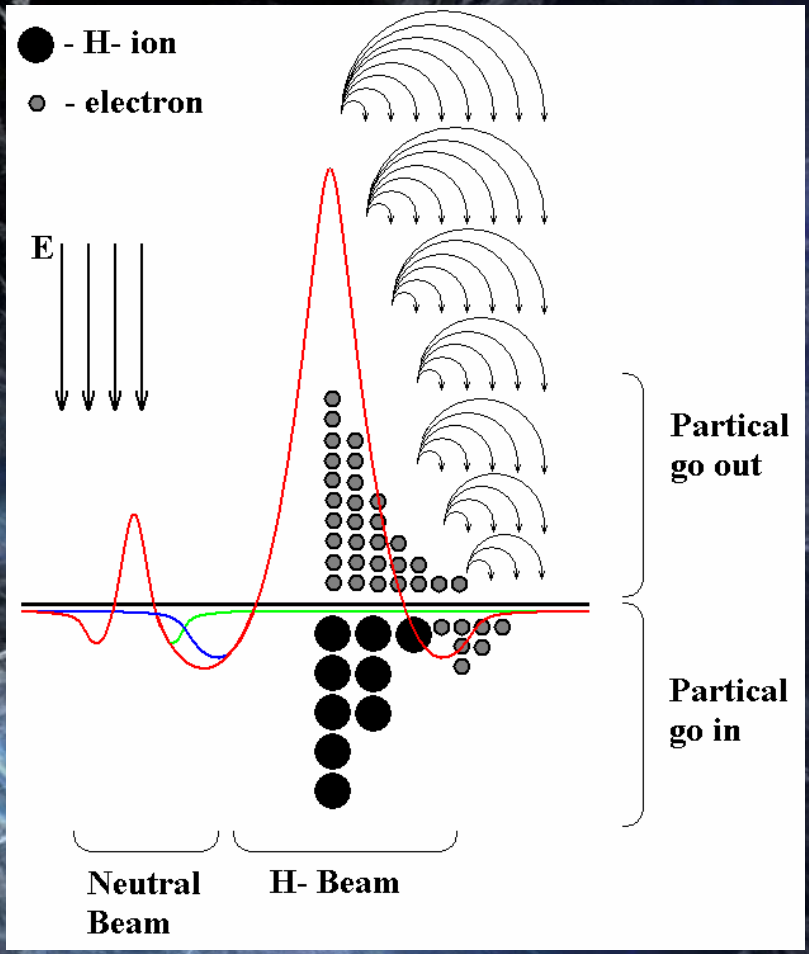

Figure 14: Model of process into the probe with negative screen voltages.

Experimental Part

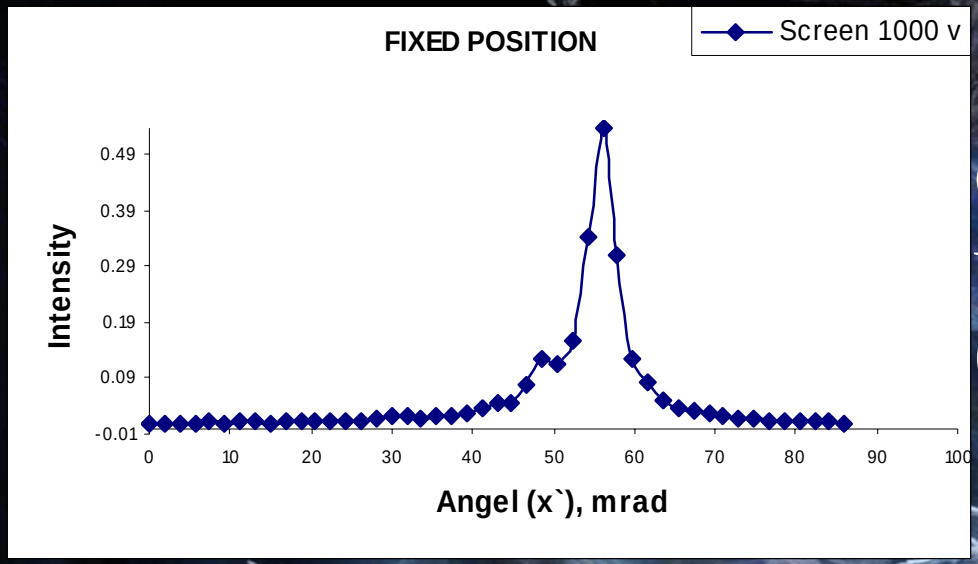

Figure 15: Slice of 3-D plot of H- beam X emittance data with positive screen voltage (1000 V).

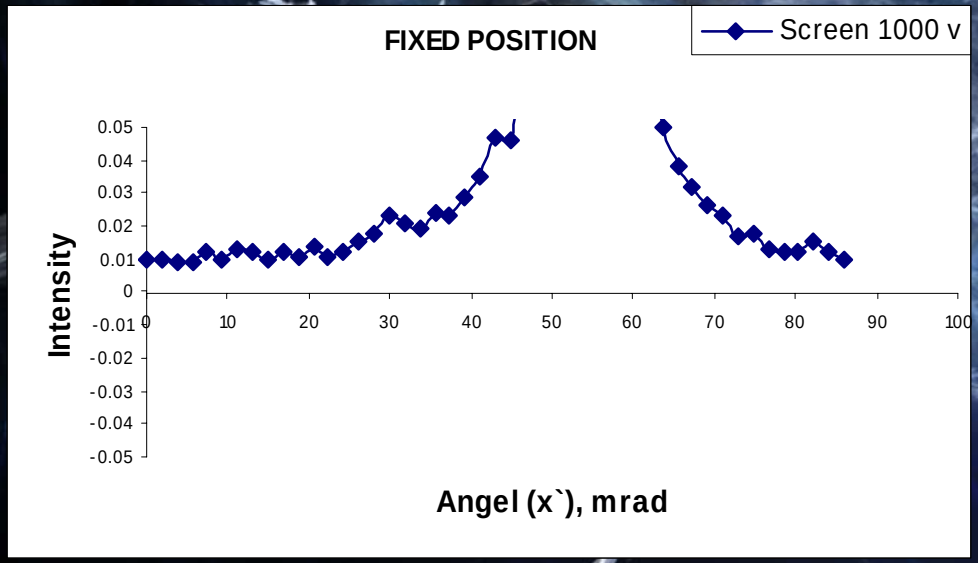

Figure 16: Slice of 3-D plot of H- beam X emittance data with positive screen voltage (1000 V).

Experimental Part

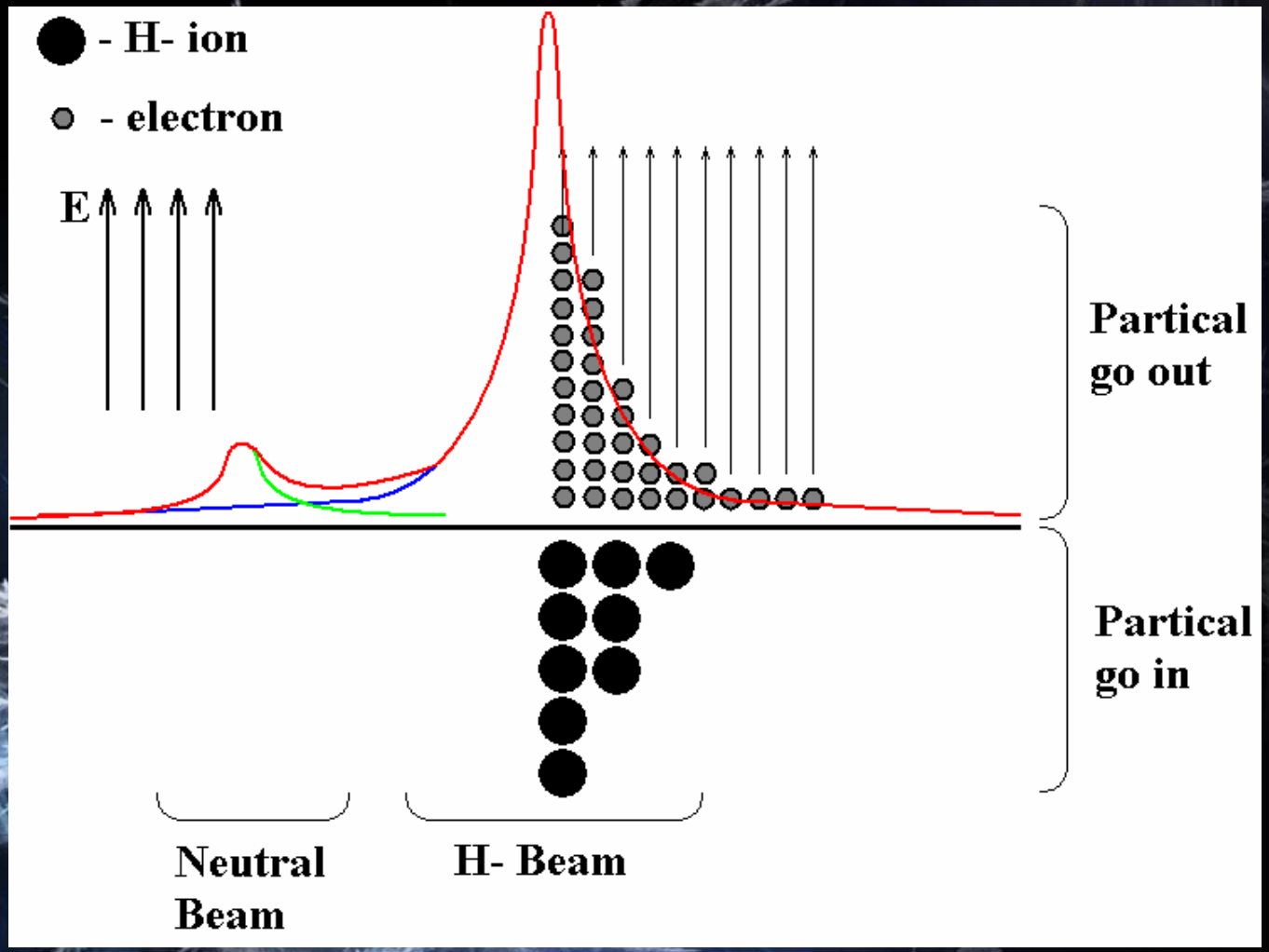

Figure 17: The model of process into the probe with positive screen voltages.

Experimental Part

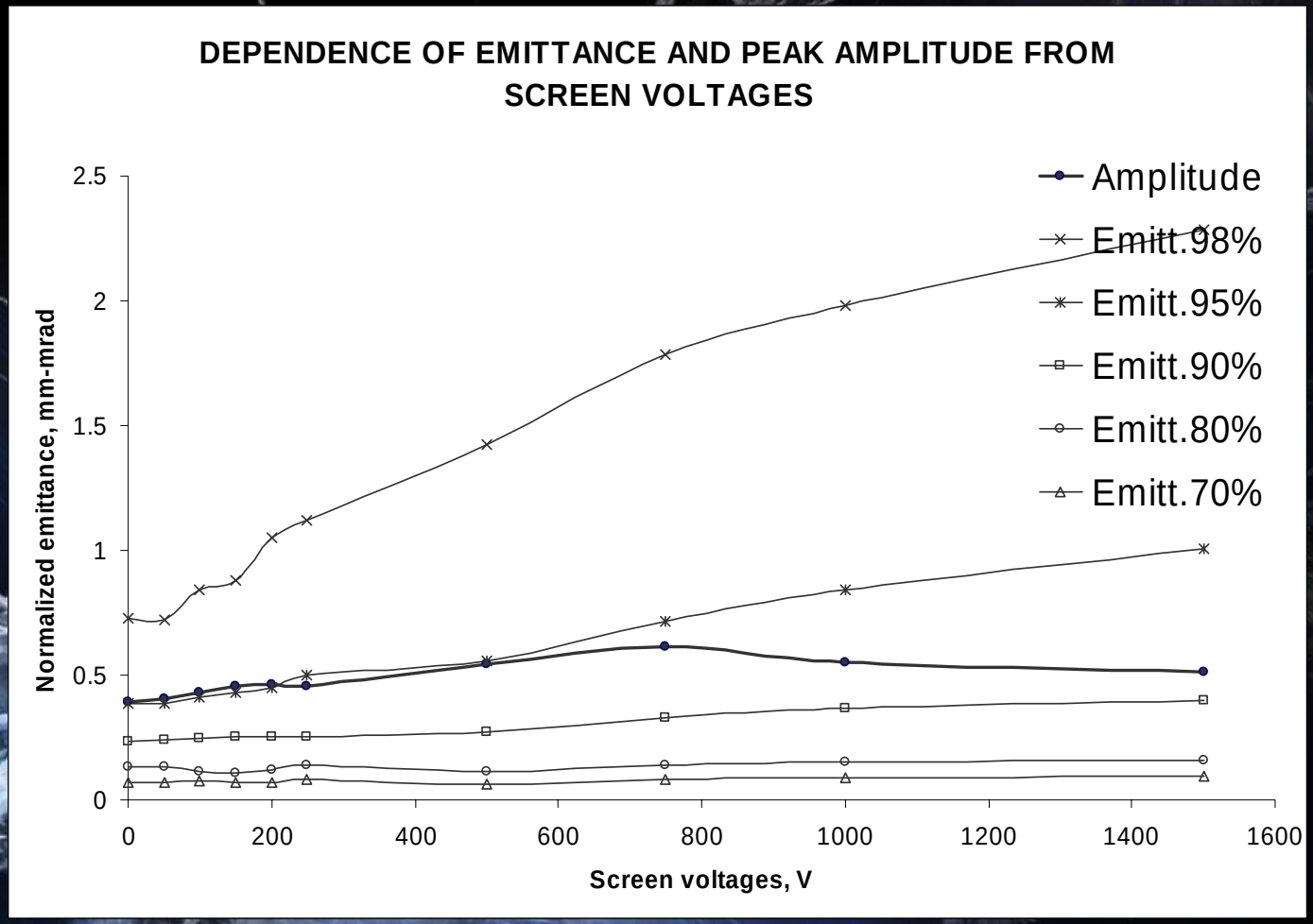

Figure 18: Dependence of emittance and peak amplitude as function of screen voltages (5 mil step).

Experimental Part

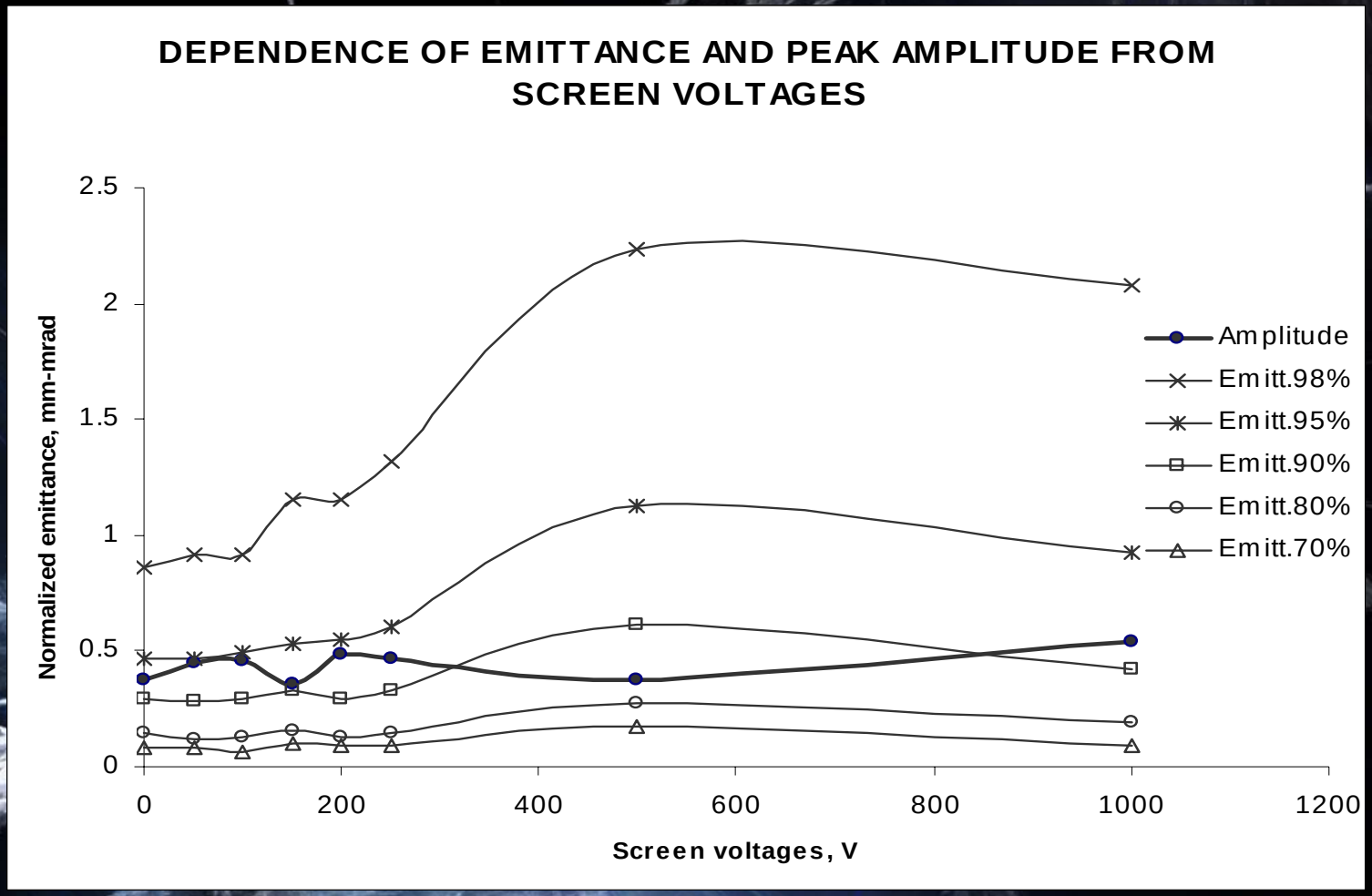

Figure 19: Dependence of emittance and peak amplitude as function of screen voltages (25 mil step).

Emittance estimate

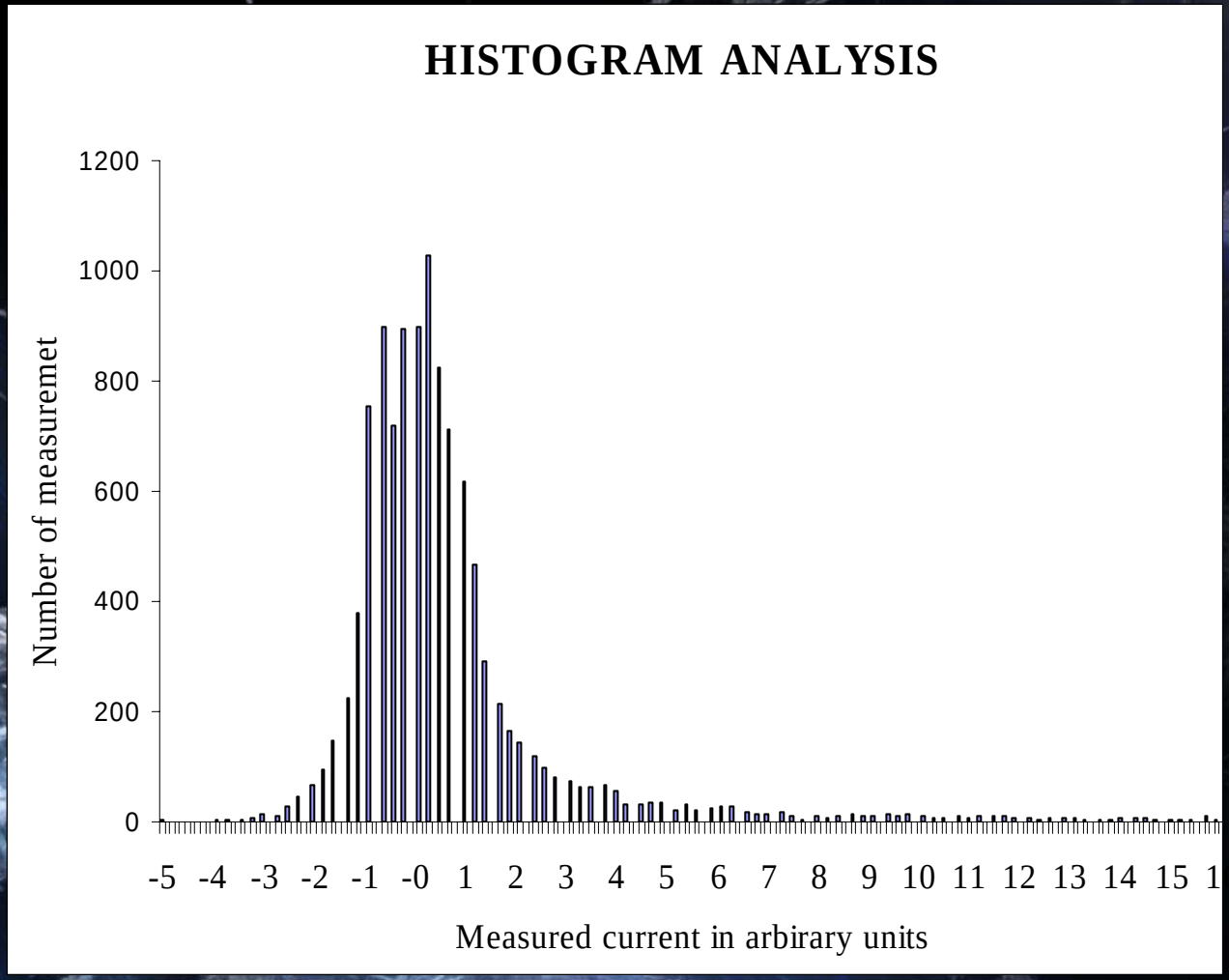

Figure 20: Histogram analysis of raw data for quality emittance estimate

Emittance estimate

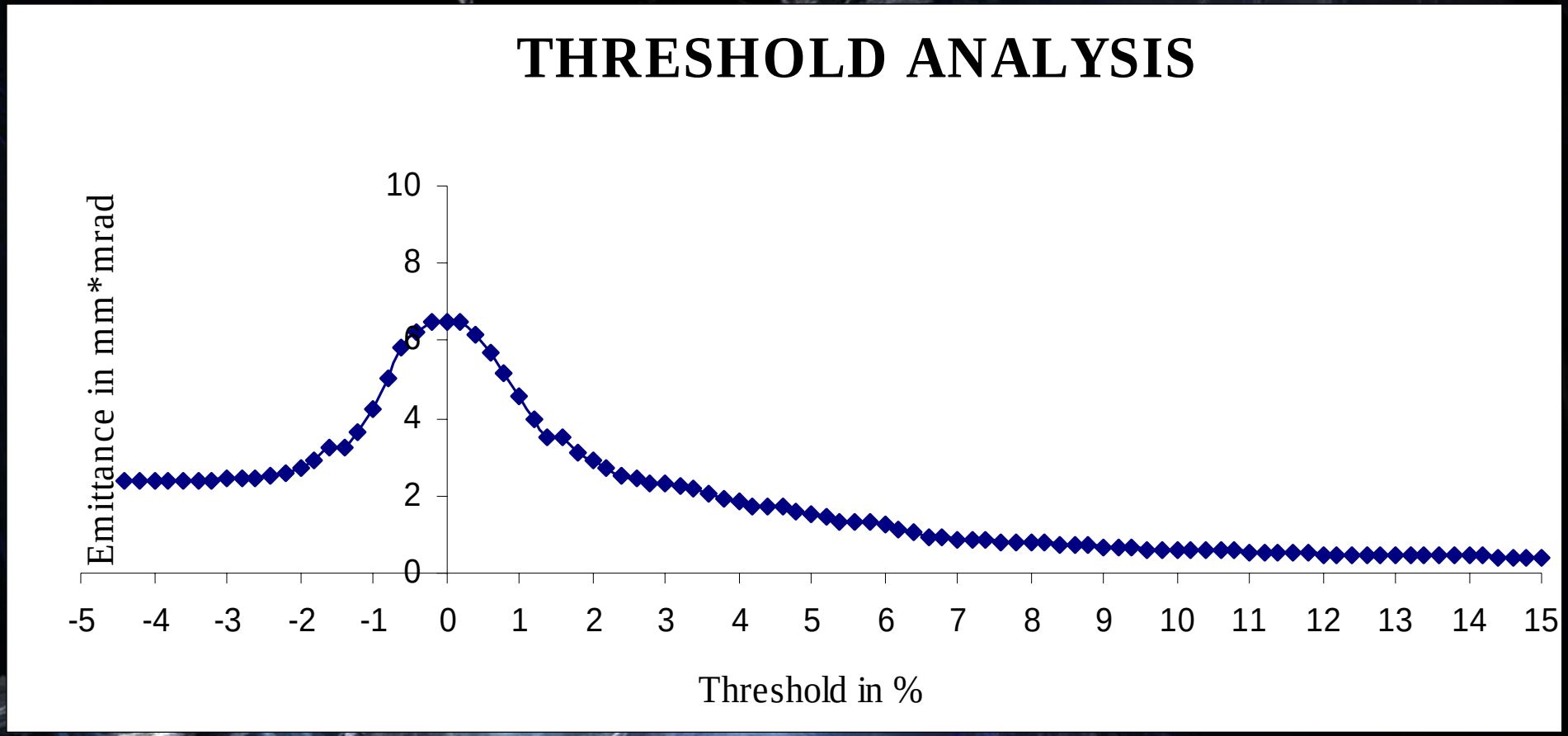

Figure 21: Threshold analysis of raw data for quality emittance estimate

Emittance estimate

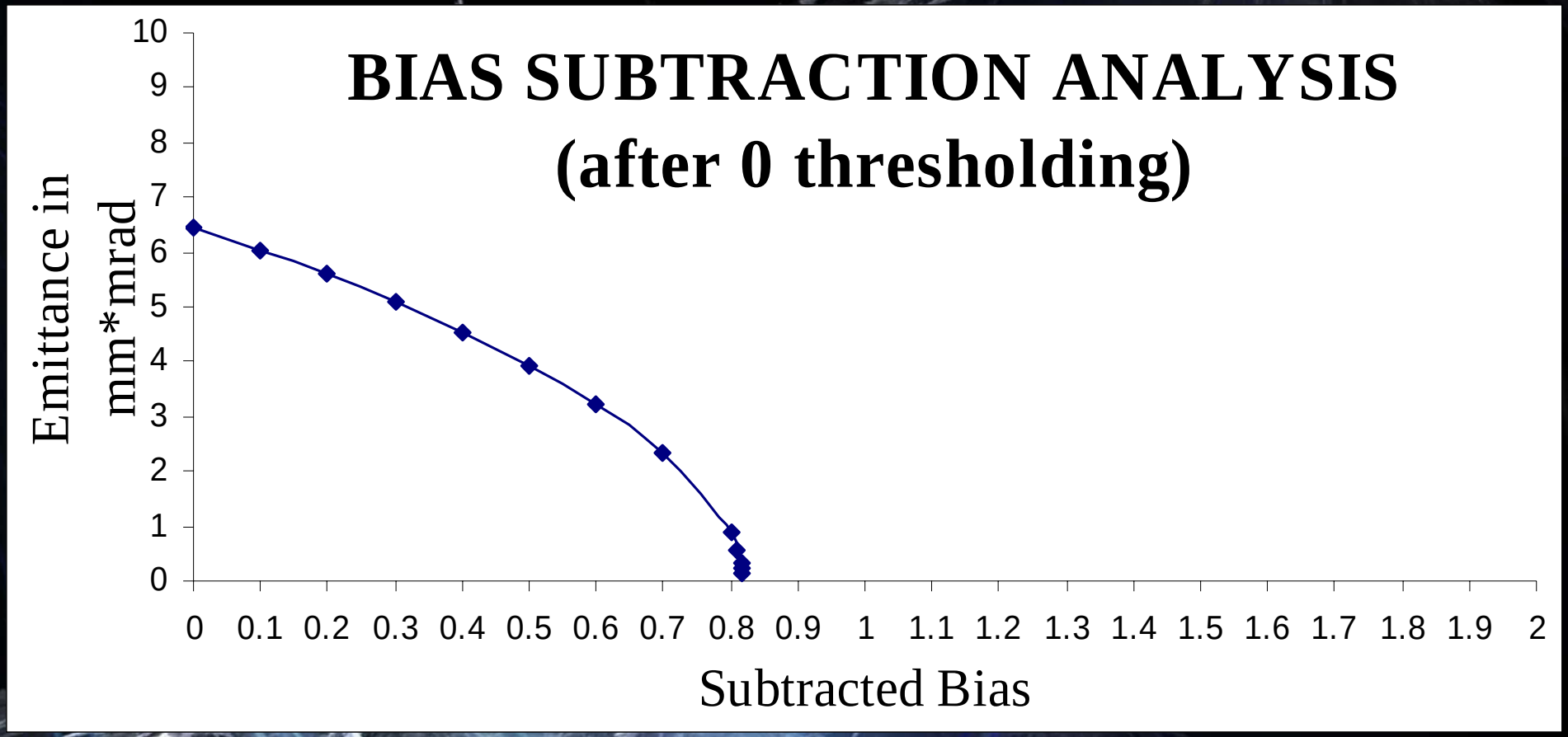

Figure 22: Bias subtraction analysis following 0% threshold of raw data

Emittance estimate

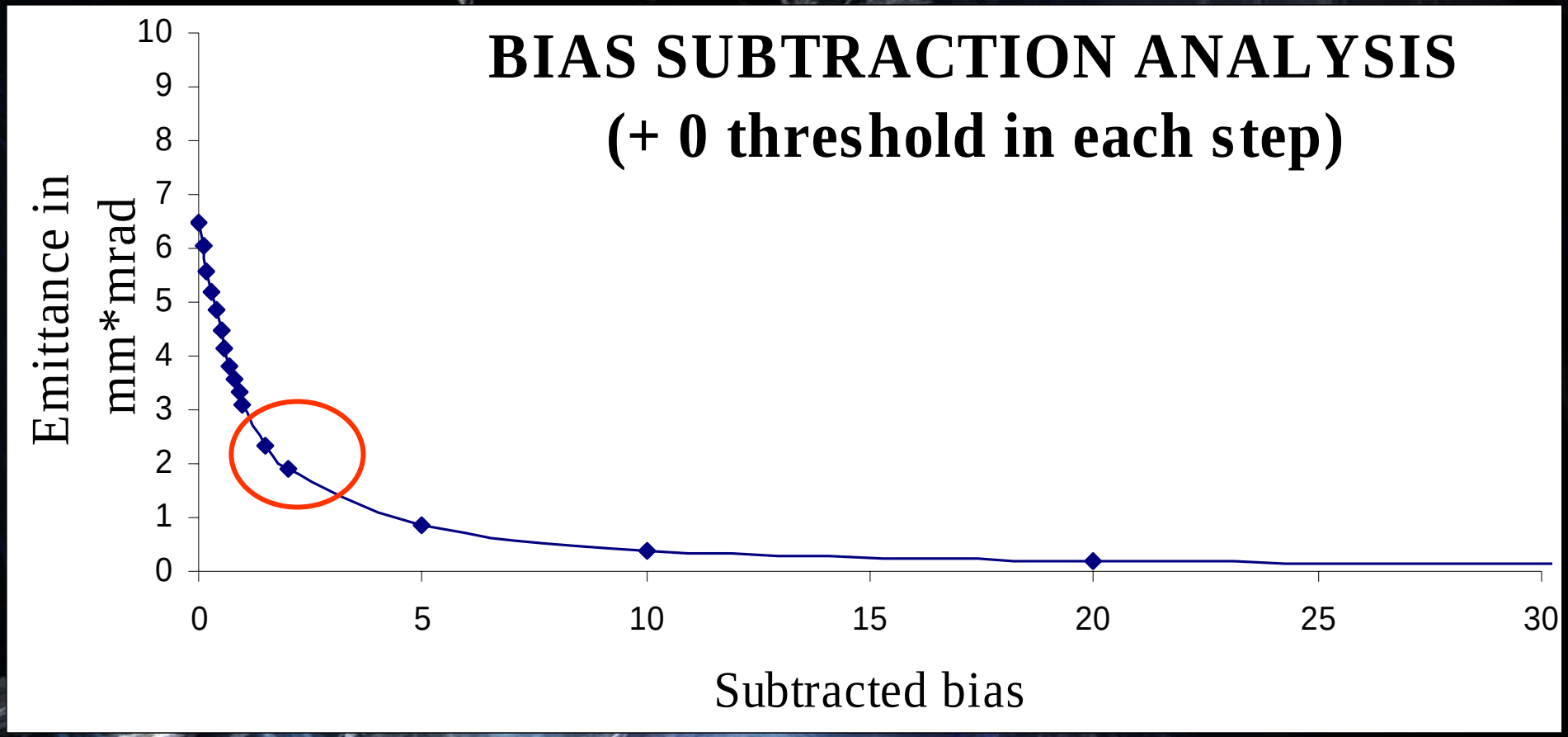

Figure 23: Bias subtraction analysis following after 0% threshold in each step

Conclusions

1. The emittance grows with screen voltages, but there is a flat around 100 V
2. The optimal screen voltage with which we collect the "good" data is about 100 V.
3. We have a model of ion electron emission in our probe
4. When we use a big step size in different measurement the emittance antiproportional of the peak amplitude
5. The optimal step with which we don't lose peak is about 5 mil (1.27 mm).
6. Conducting quality estimate of the emittance and understand approaches to eliminate a bias from a real signal
7. The best emittance which we obtained is 0.216 pi mm.mr (emittance 90% normalized, with acceleration voltages 30 KV and extraction voltages 18 KV, beam current 11 mA).

References

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[3] S. Ohnuma “The beam emittance: what we said we would have, what we think we have, and what we hope we could have”, FermiLab, EXP-111, November 28, 1983

[4] K. Prelec and Th. Sluyters “Formation of Negative Hydrogen Ions in Direct Extraction Sources”, Rev. Sci. Instrum., Vol 44, No10, October 1973.

[5] D. Moehs, J. Peters, and J. Sherman “Negative Hydrogen Ion Sources for Accelerators”, IEEE transaction on plasma science, vol. 33,no. 6, December 2005.

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[7]M. Stockli, R.Welton, R. Keller, A. Letchford, R.Thomae, and J. Thomason “Self-consistent, unbiased RMS-emittance estimates for data measured with a single current amplifier”

[8] M. Stockli, R.Welton, R. Keller, A. Letchford, R.Thomae, and J. Thomason “Accurate estimation of the RMS emittance from single current amplifier data”

Thank you, for your attention

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