SAND2009-3986C

-6 MV Vacuum Voltmeter Development*

B. V. Weber[1], R. J. Allen[1], R. J. Commisso[1],
D. D. Hinshelwood[1], D. G. Phipps[1], S. B. Swanekamp[2]

[1]Plasma Physics Division, Naval Research Laboratory
Washington, DC, United States
[2]L-3 Communications, Reston, VA, United States

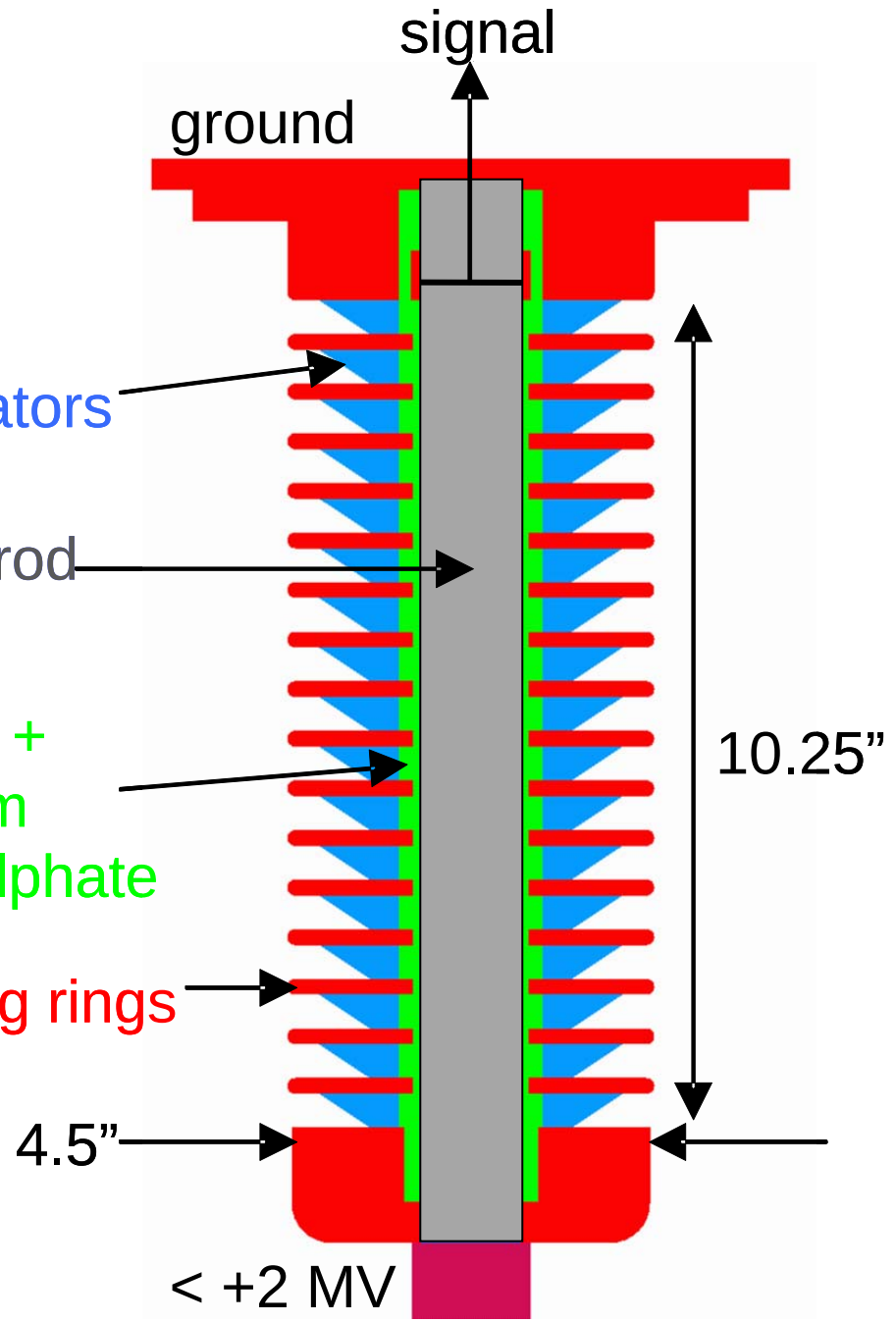
* Work supported by Sandia National Laboratories, Albuquerque, NM

Vacuum Voltmeter (VVM)

- Extend 2 MV divider for operation up to -6 MV
  - Wire array loads on Z predicted to have voltage at convolute in -4 to -6 MV range
- Design field shapers to control electron emission in negative polarity
- Test extended VVM on NRL Mercury generator
- Use circuit and PIC codes to evaluate VVM

2-MV Voltmeter

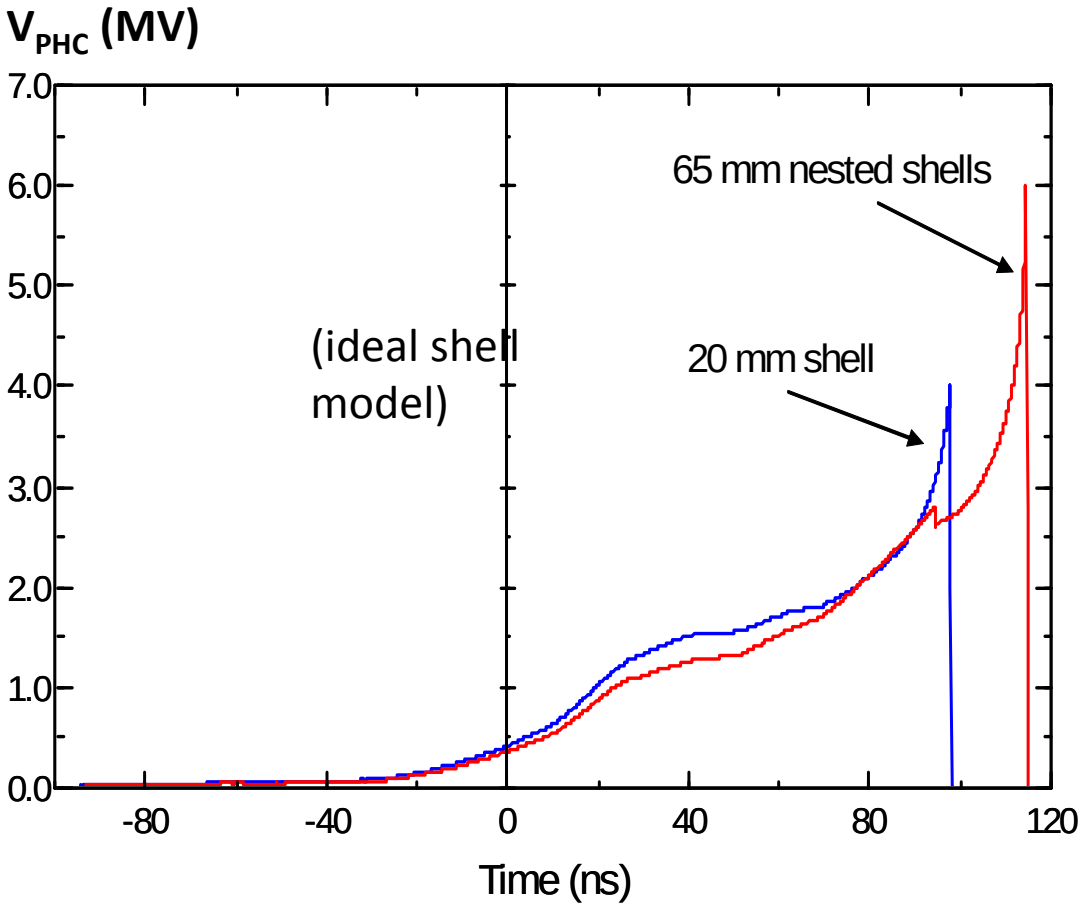
- PSI model VVM-2MV[1]
- Equal resistive, capacitive division factors
- Reverse insulators to change polarity
- Fielded successfully on Saturn z-pinch experiments[2]

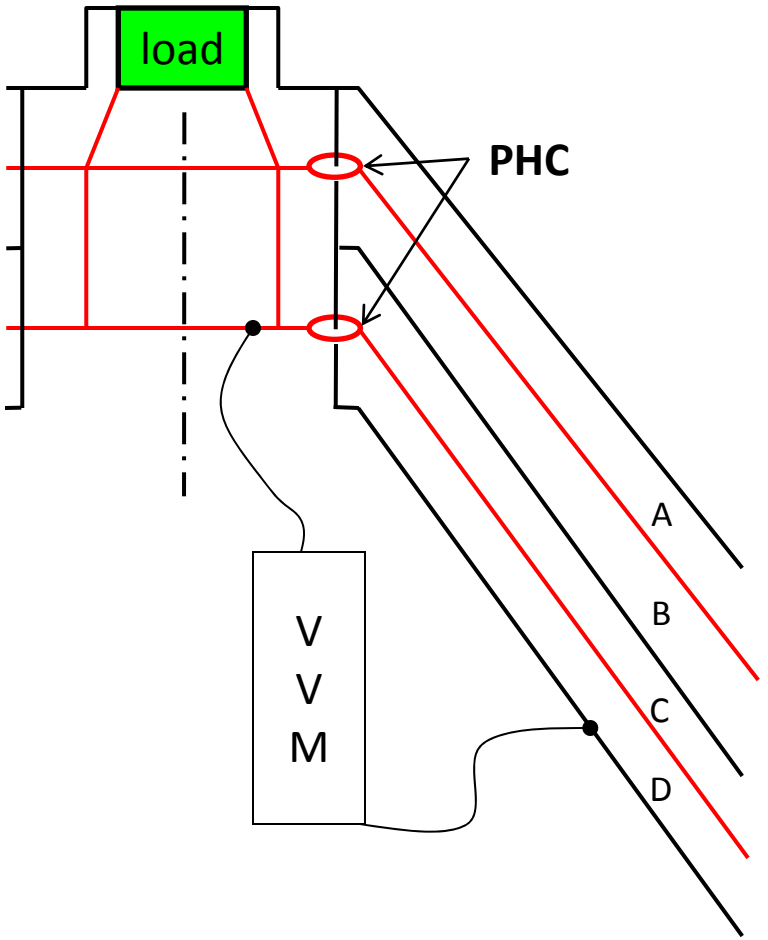


1. D.G. Pellinen and M. S. DiCapua, “Two-megavolt divider for pulsed high voltages in vacuum,” Rev. Sci. Instrum. 51 (1), 70 (1980).
2. D. P. Murphy, B. V. Weber, R. J. Commisso, J. P. Apruzese, D. G. Phipps, and D. Mosher, “Time-Resolved Voltage Measurements Of Z-Pinch Radiation Sources With A Vacuum Voltmeter,” Rev. Sci. Instrum. (2008).

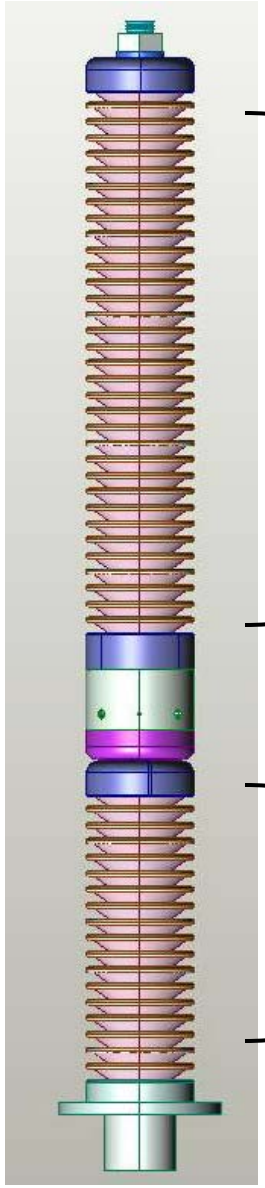
Calculated post-hole convolute voltages for wire array implosions on Z

(from B. Jones, Sandia)





Modified VVM for 6 MV



R ~ 700 Ω
so L/R ~ ns

4 MV extension
34 insulators

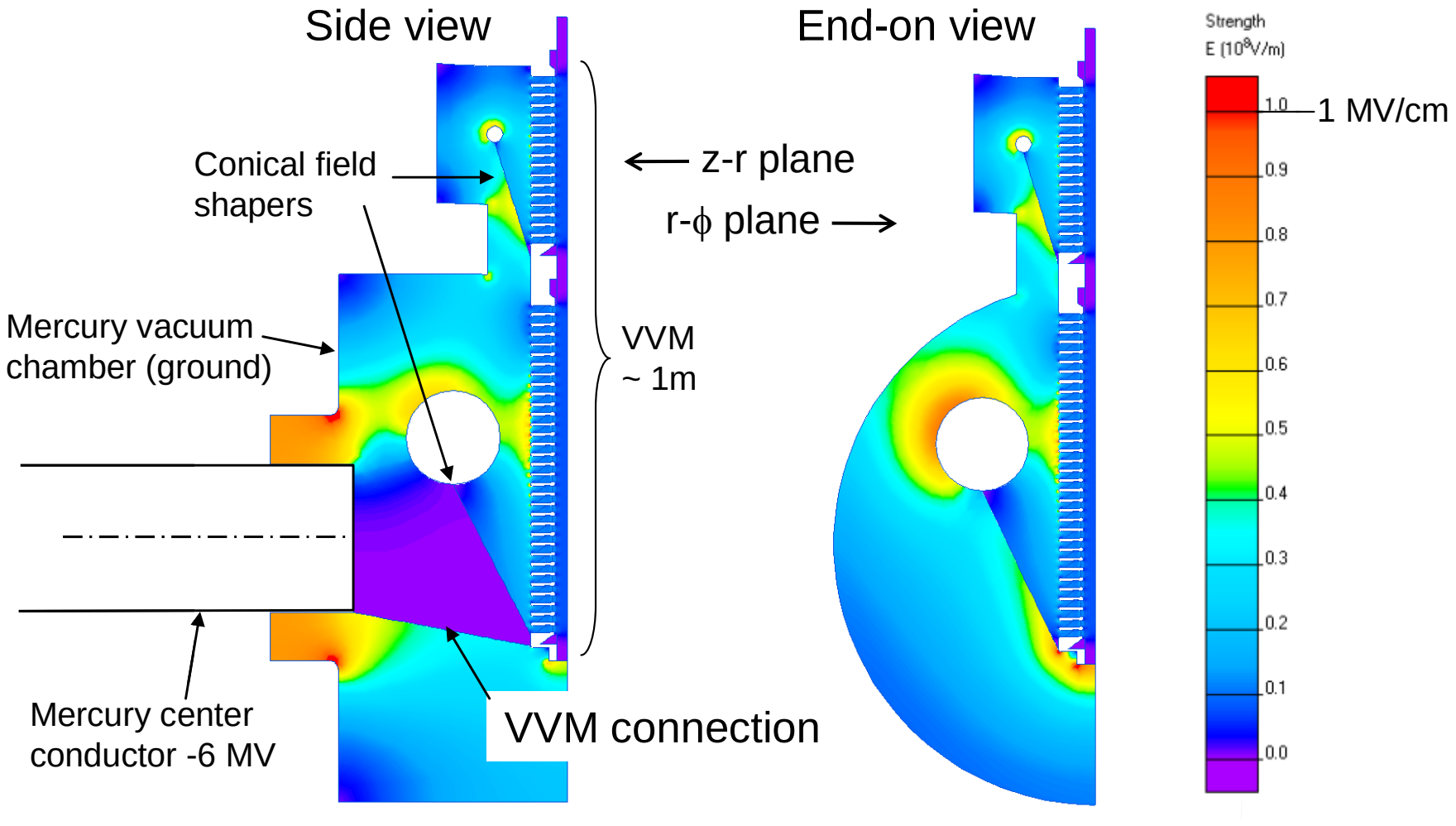
2 MV VVM
17 insulators

Extension design

Assembled VVM

Field shapers for Mercury VVM tests

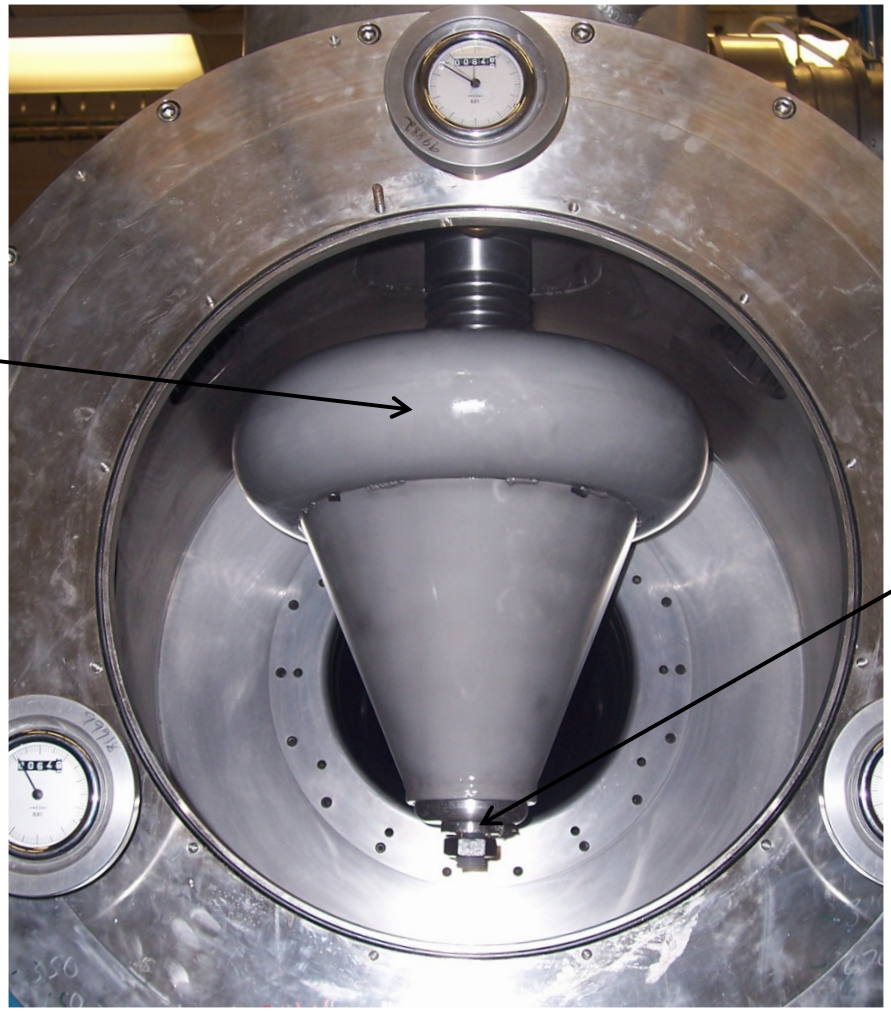
|E| plots for the VVM at -6 MV in the Mercury vacuum chamber



VVM installation in Mercury

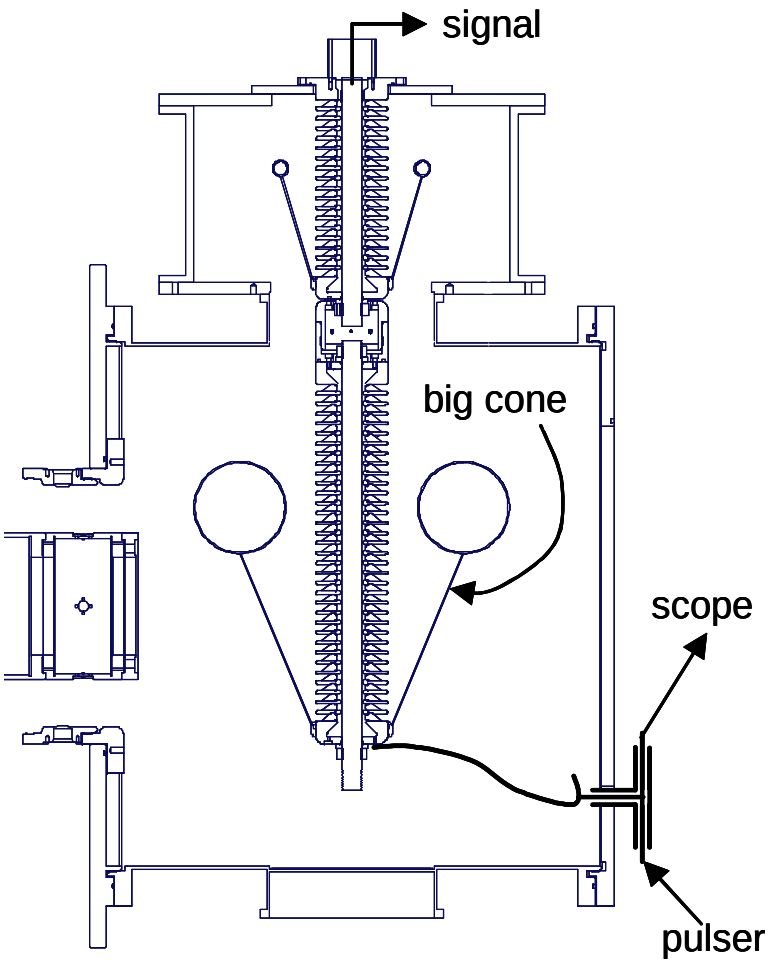
Conical field shapers treated to increase emission threshold to ~ 1 MV/cm

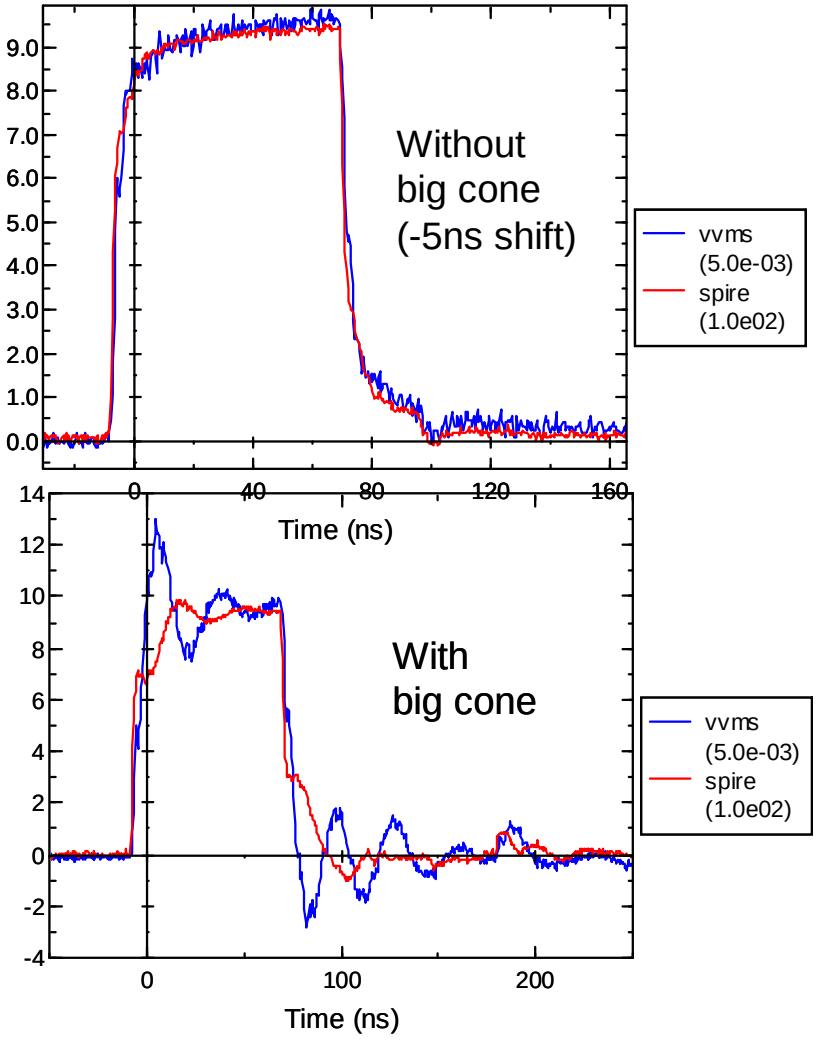
Aluminum surfaces bead blasted and coated with oil mixture



-HV electrode

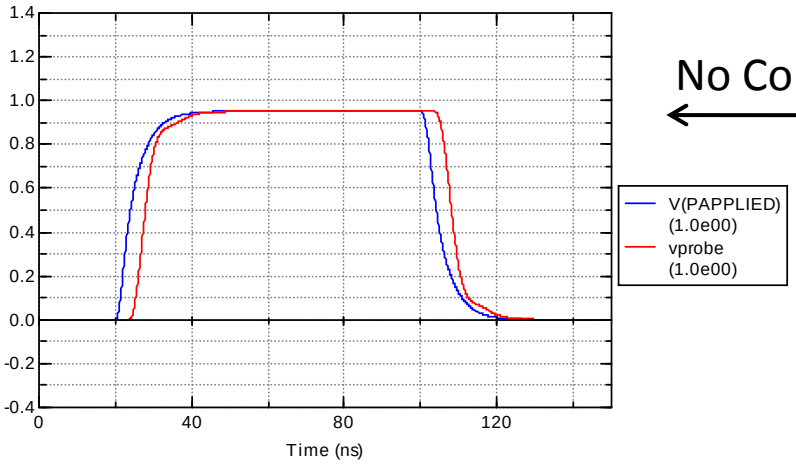
Calibration setup and data





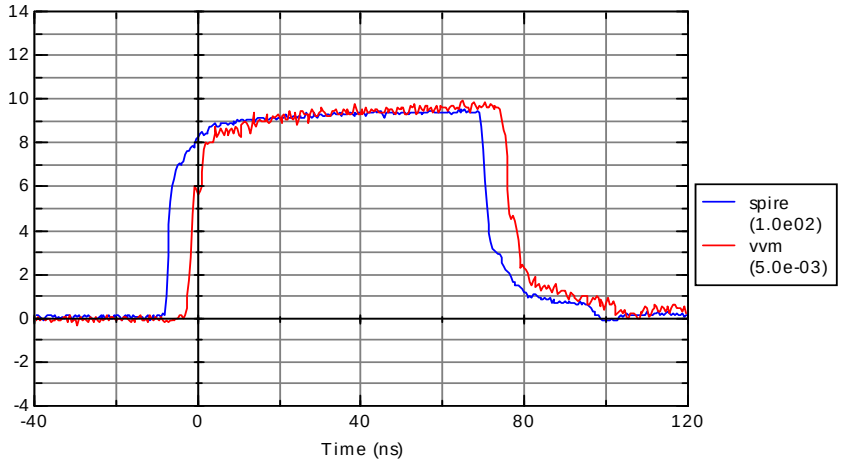
“Lossy transmission line” circuit model reproduces calibration data

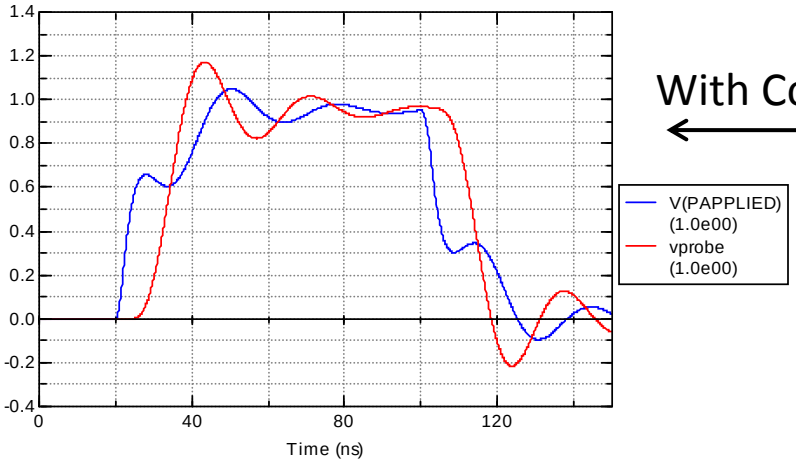
Circuit model



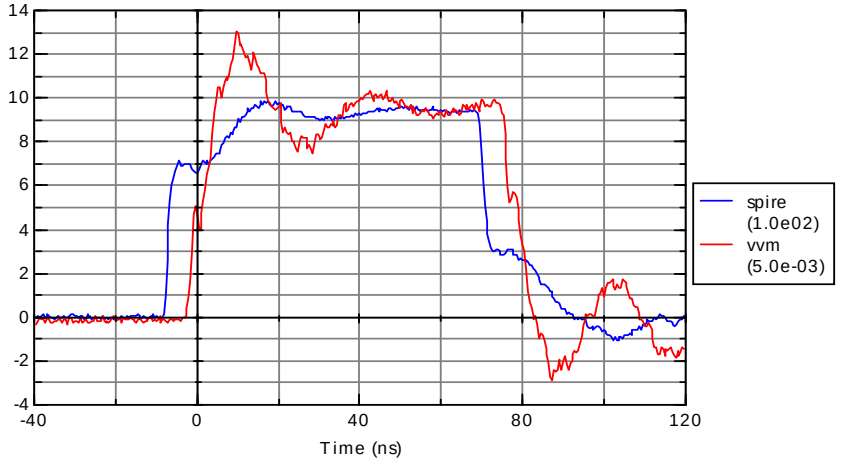
No Cones ⟷

Calibration data

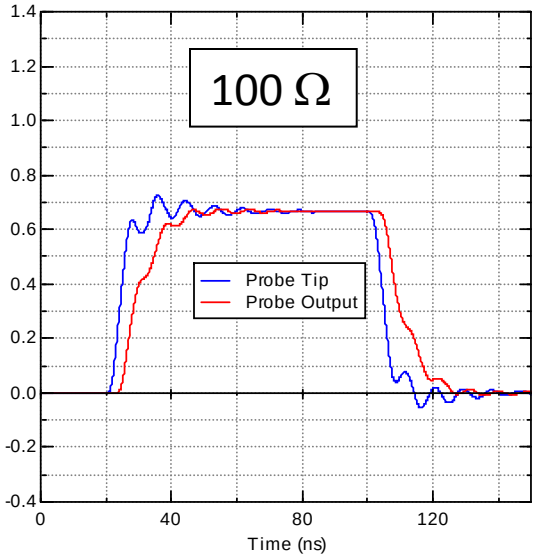


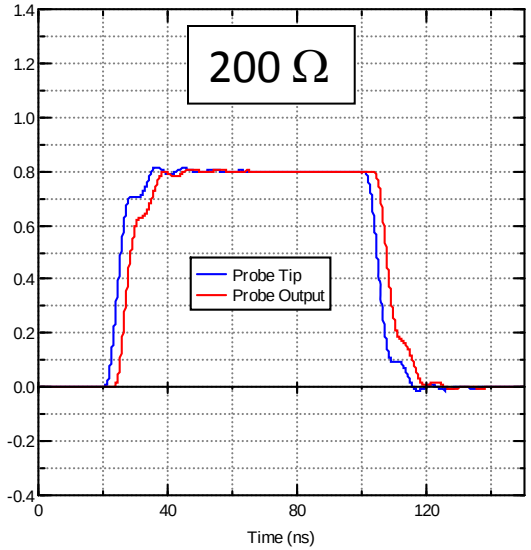


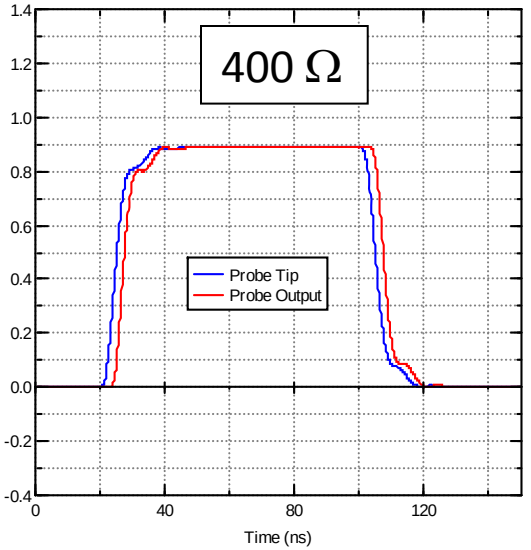
With Cones ⟷

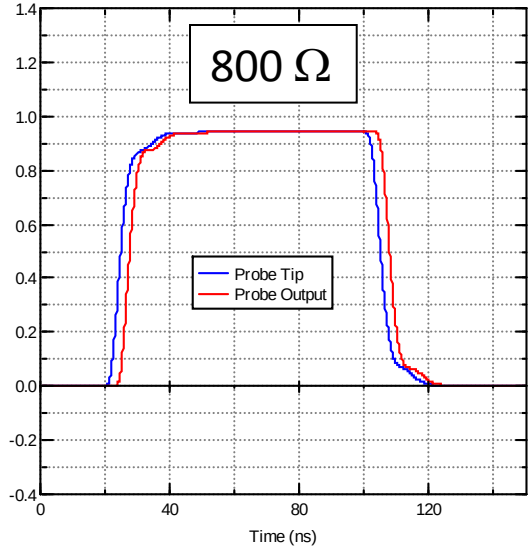


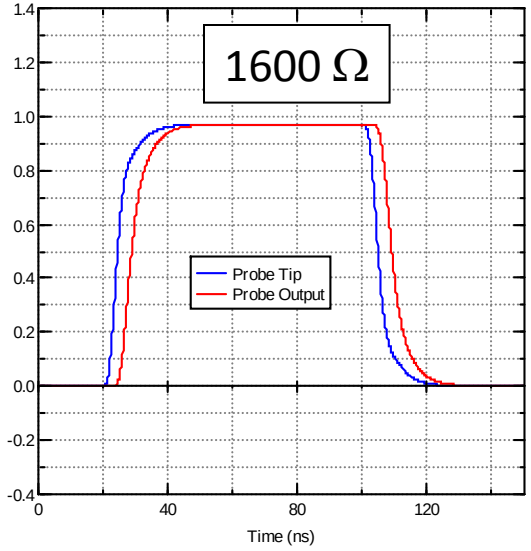
R = 700 Ω used in experiments, optimized for fast response

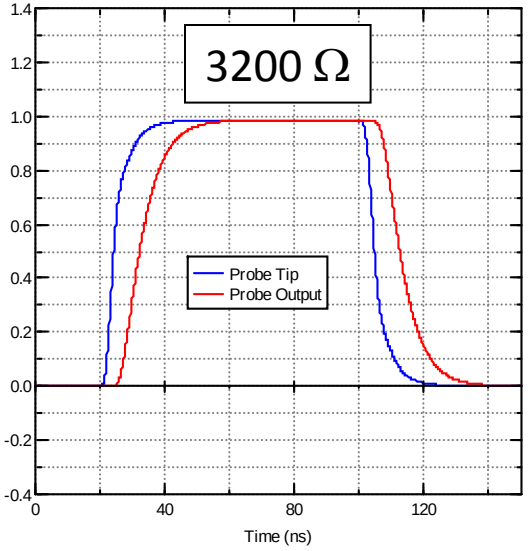




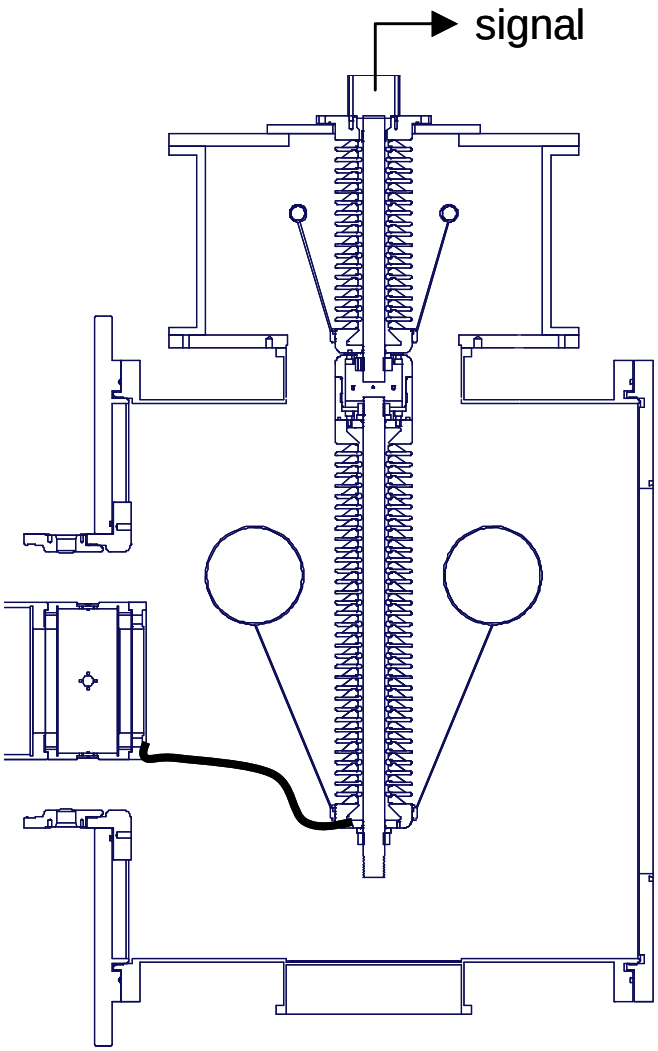


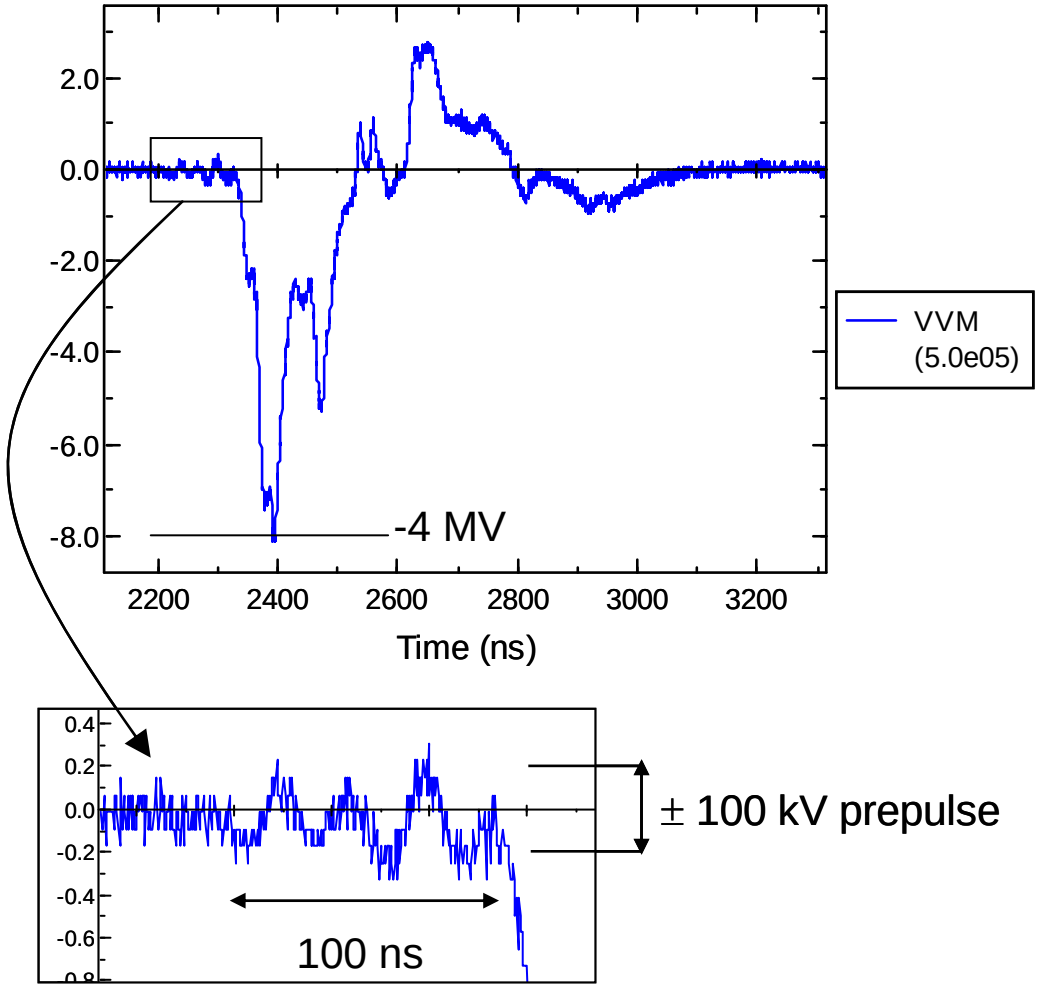




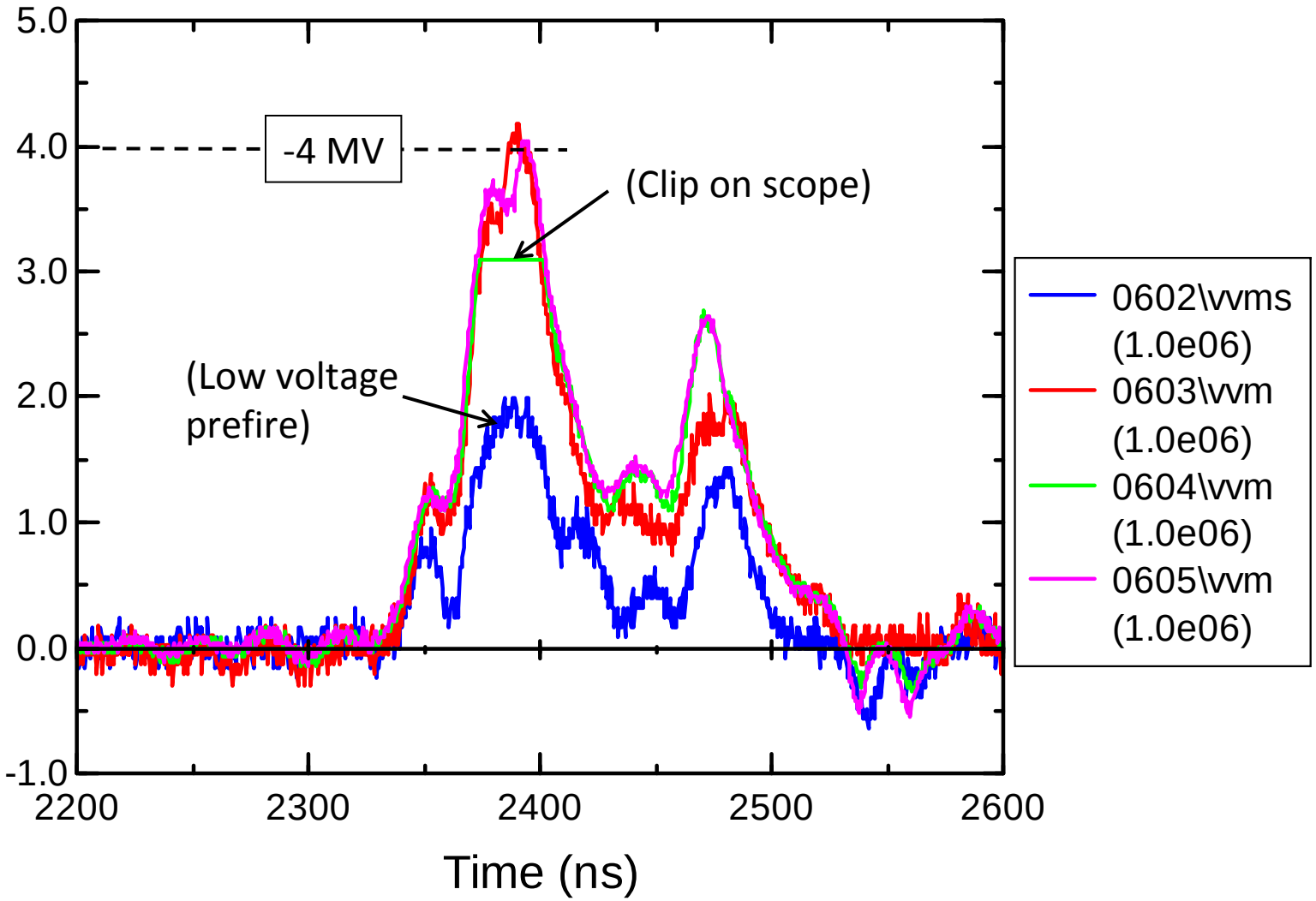


VVM on Mercury shot 605

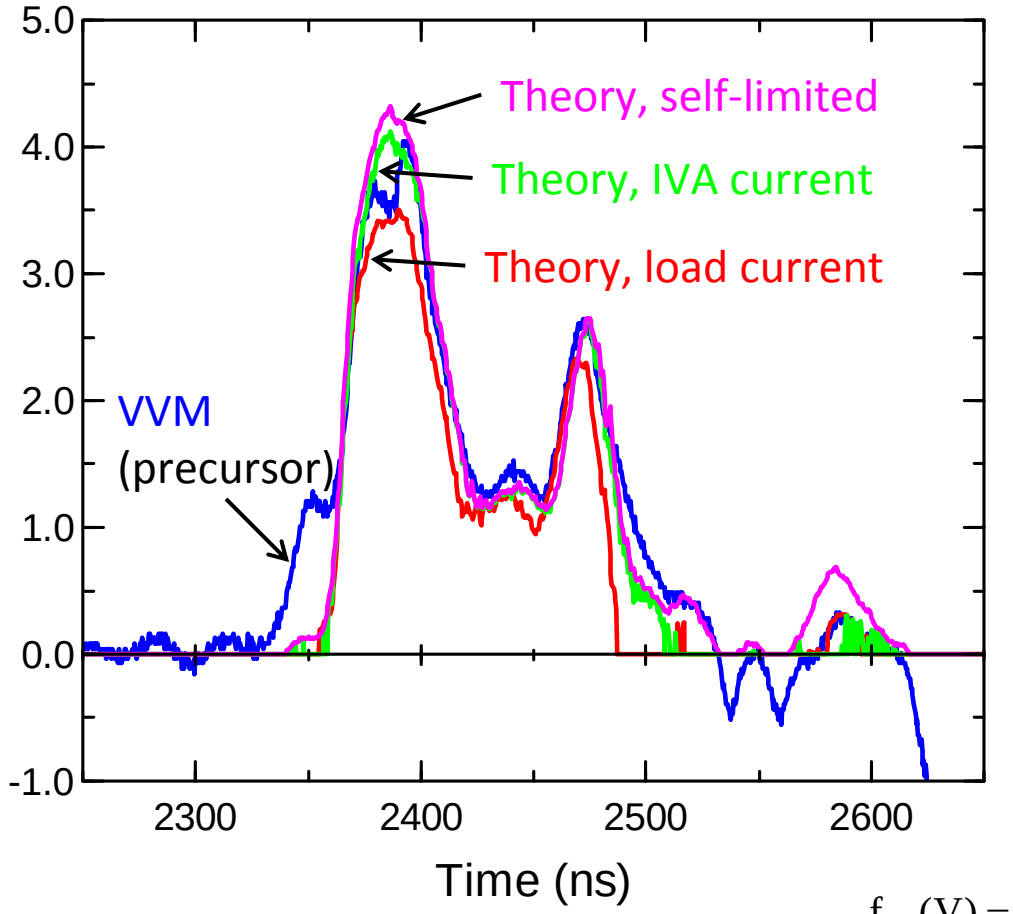




VVM data for -2 to -4 MV shots



VVM comparison with MITL theory[3]



$$V = Z_0\left(I_a^2 - I_c^2\right)^{1/2} - \frac{gmc^2}{2e}\frac{I_a^2 - I_c^2}{I_c^2}$$

$$g(V) = 0.99565 - 0.05332V + 0.0037V^2$$

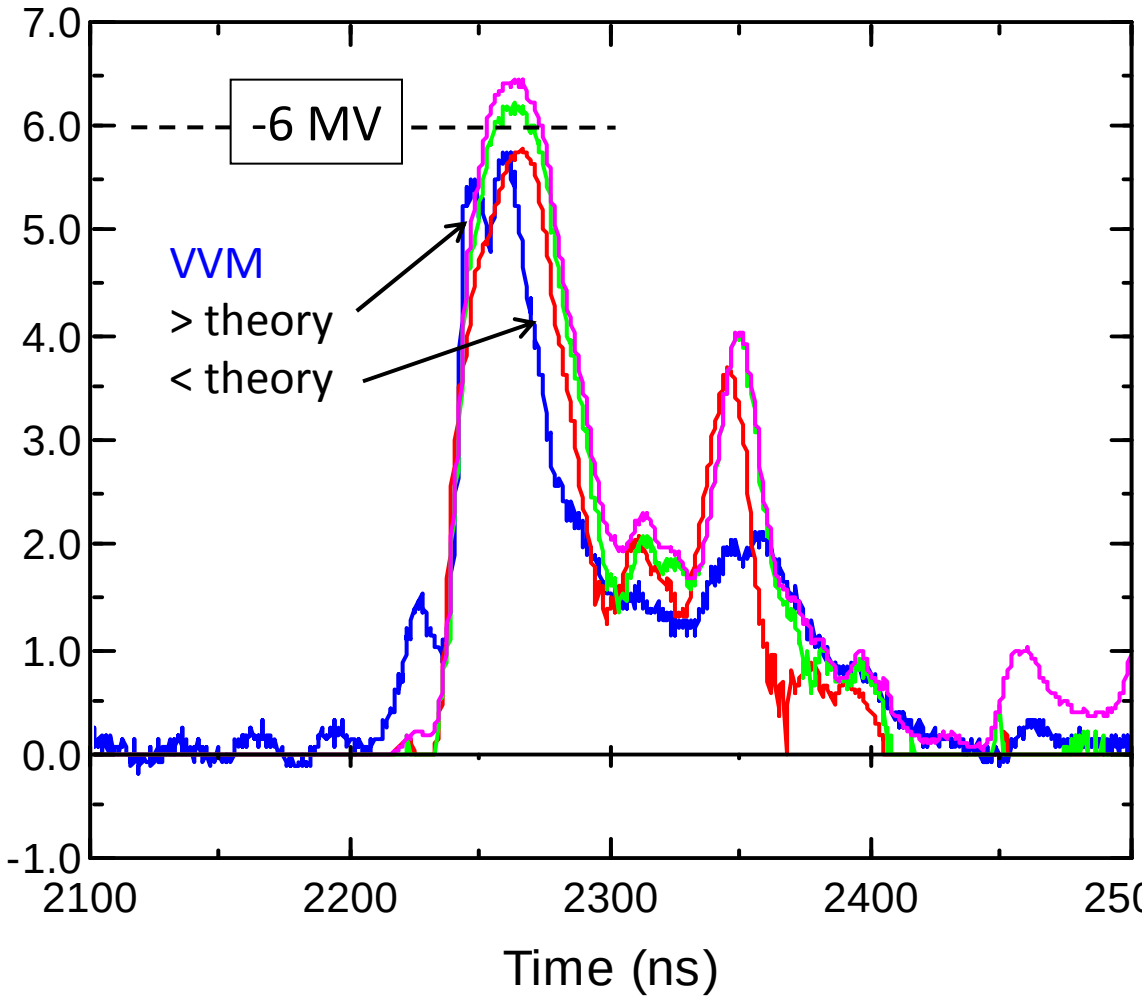
$$(= 0.84 \text{ for } V = 4\ MV)$$

$$I_a^{SL}(V) = \frac{V}{Z_0 f_{SL}(V)}\left[\frac{1+\left(\frac{g(V)mc^2}{2eV}-1\right)f_{SL}(V)}{1-f_{SL}(V)}\right]^{1/2}$$

$$f_{SL}(V) = \eta(V)\left\{\frac{\left(\frac{gmc^2}{8eV}-1\right)+\left[\left(\frac{gmc^2}{8eV}-1\right)^2+\left(\frac{gmc^2}{2eV}-1\right)\right]^{1/2}}{\left(\frac{gmc^2}{2eV}-1\right)}\right\}$$

3. P.F. Ottinger and J.W. Schumer, "Rescaling of Equilibrium Magnetically Insulated Flow Theory Based on Particle-in-Cell Simulations," Phys. Plasmas 13, 063109

At -6 MV, VVM signal less than expected from MITL theory



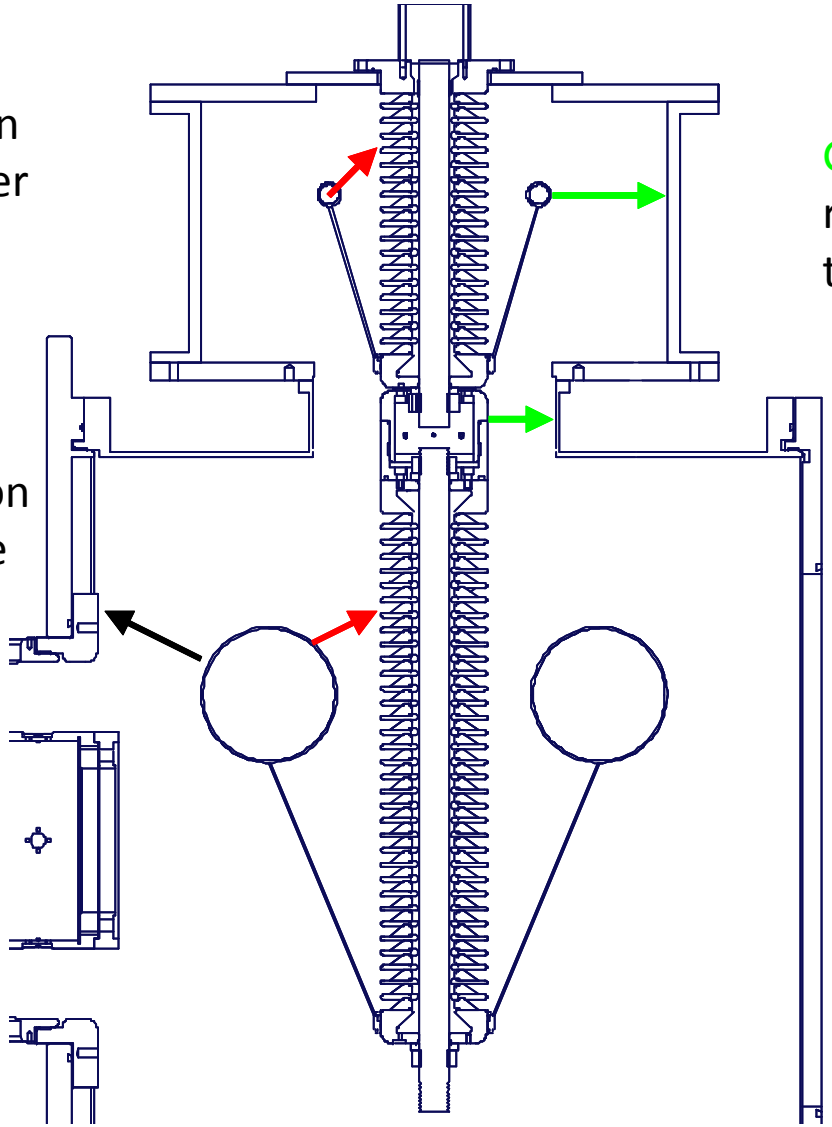
Electron emission from VVM can affect signal

Red: electron emission results in signal greater than actual voltage

Green: electron emission results in signal lower than actual voltage

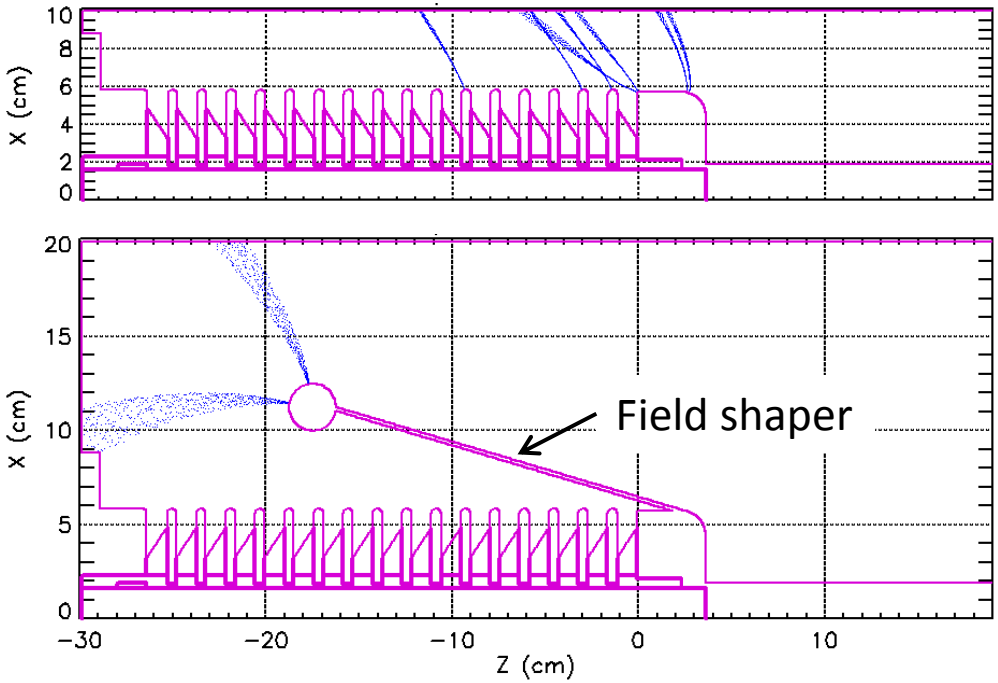
Black: electron emission does not affect voltage measurement

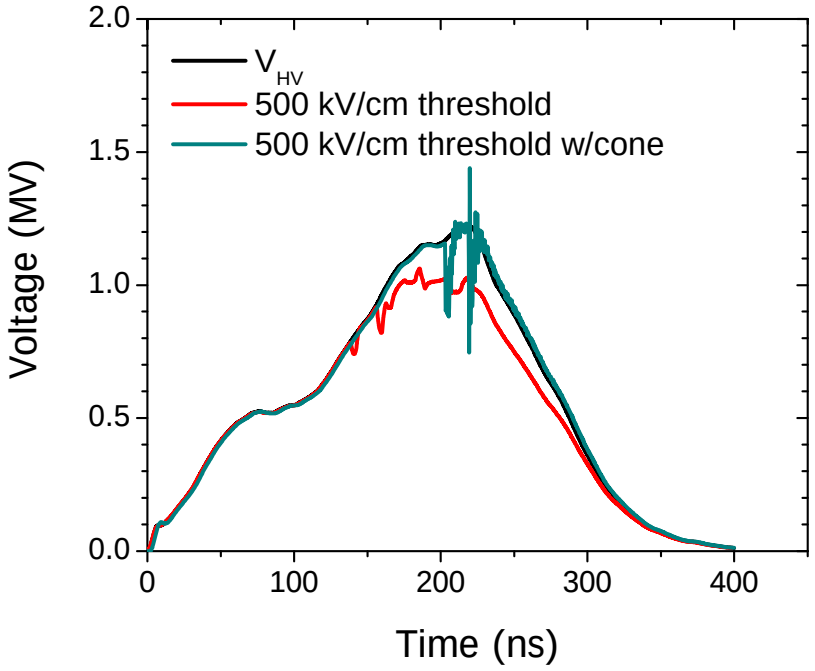
Insulator flashover: Signal greater than actual voltage



PIC calculations show effects of conical field shaper

t = 220 ns
Eth = 500 kV/cm





Summary

- Extended VVM works adequately for -4 MV on Mercury
  - Few ns time response, stray capacitance can cause ringing
  - Field shapers required to control electron emission
  - Suitable for -4 MV loads on Z
- Electron emission likely cause of incorrect signals at -6 MV on Mercury
  - Requires improved field shaping for -6 MV loads on Z