Progress of dielectric loaded gas-filled RF test at MTA

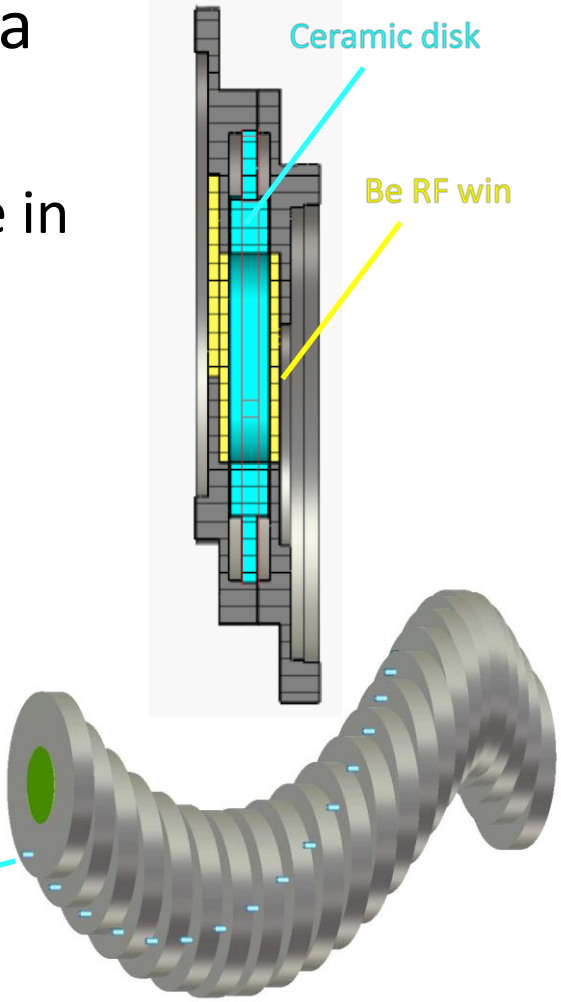
K. Yonehara

APC, Fermilab

Goal of the project

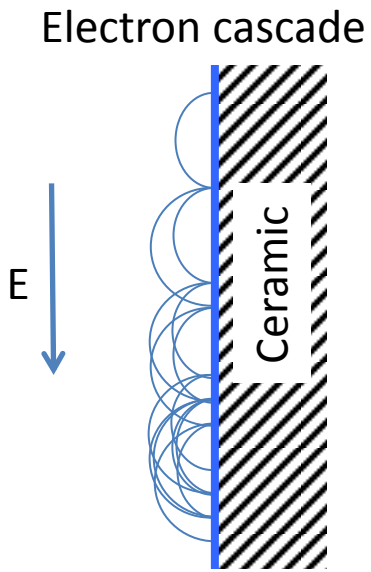
- Make a compact RF system by loading a dielectric material in a RF system
  - A compact accelerator system is attractive in general
  - Dielectric loaded RF system has been investigated for long time
- Especially, a helical cooling channel requires a small radius RF system
  - $\lambda_{HCC} \sim \lambda_{RF}$ (V. Balbekov & KY, EPAC'08 THPC110)

HCC RF cell
(F. Marhauser)



Goal of the first experiment (I)

- Critical issue is a Surface Breakdown
  - Ceramic has relatively large secondary electron emission (SEE) yield (SEE > 1)
  - Primary electron generates more than one electron
  - It induces a cascade process
  - Similar as a multipactor process
- Fill a buffer gas to eliminate the surface breakdown
  - Electrostatic accelerator, e.g. Van der Graaff
  - RF power window, e.g. High power Klystron
- No application for RF accelerator system
  - This concept works only for muon accelerator/cooler



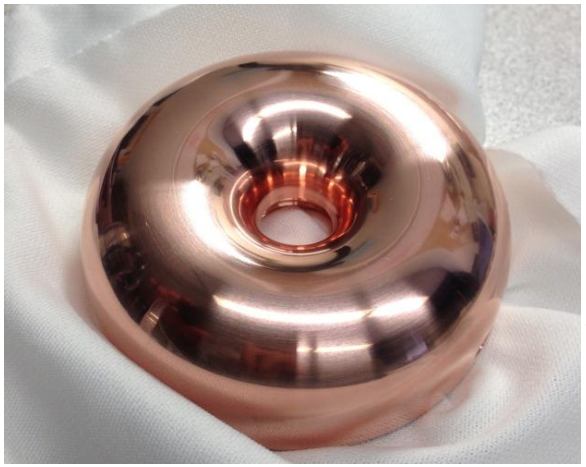
Van der Graaff tube

Goal of the first experiment (II)

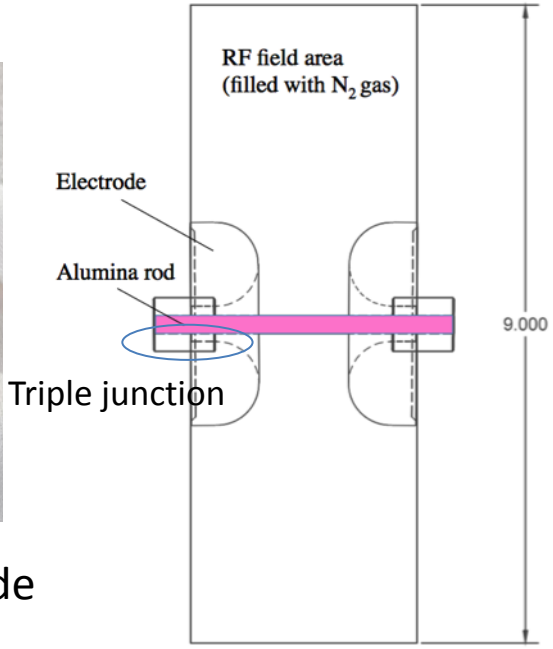
- Surface breakdown process can be terminated in a gas-filled RF cavity
- Verify this model
  - Since this is the first proof of principle test we do not care about a RF power dissipation in a loaded ceramic material
  - Material search will be the next step

Design test cell

- Minimize field gradient at triple junction
  - Metallic body, ceramic rod and GN_2



Donut shape copper electrode



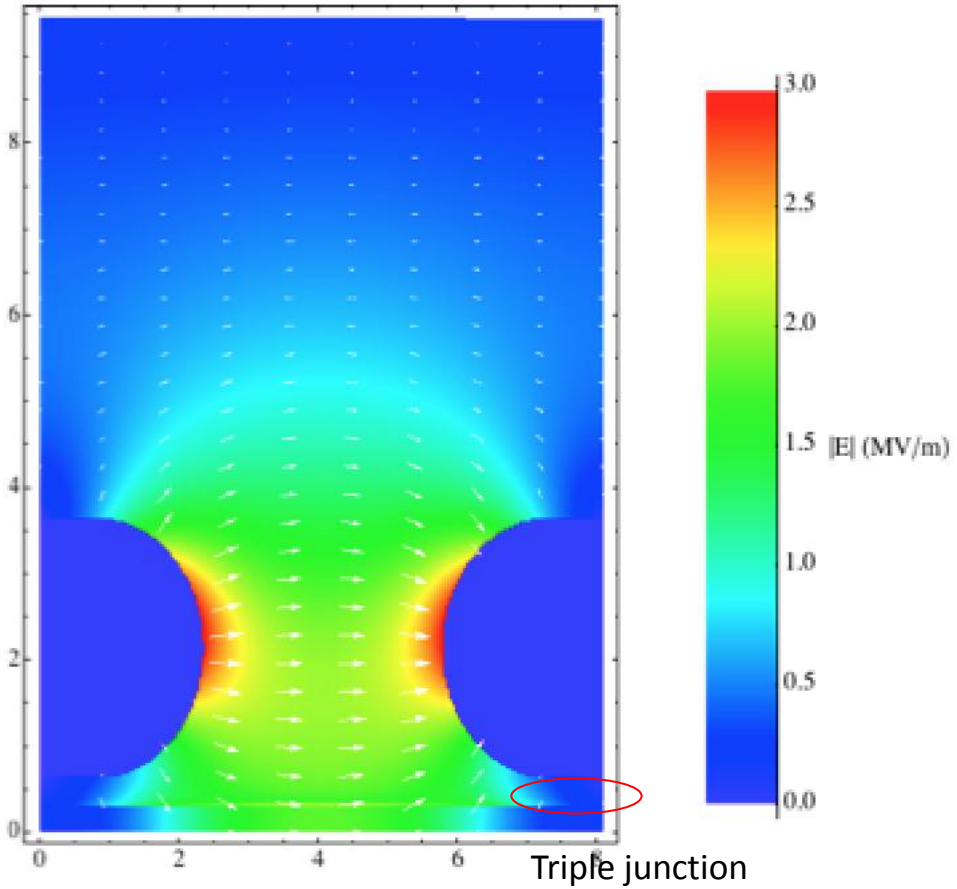
Frequency = 814.544 MHz @ 1 atm
Q_L = 4,250 from RF calibration

Simulated RF field distribution

- Simulated RF field
  - Parallel field on a ceramic rod
  - Field enhancement 1.5 @Electrode
  - Low field at triple junction

Table 1: Specification of tested alumina (Al_2O_3) rod.

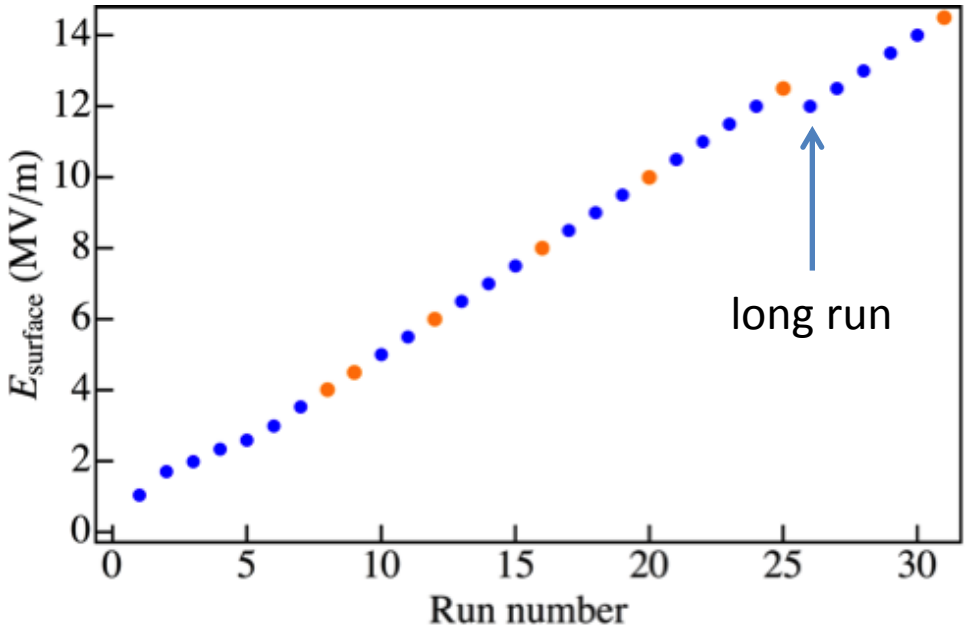
Property	Value	Unit
Length	4	inch
Width	0.25	inch
Purity	99.8	%
Relative dielectric constant	9.6	
Loss tangent	10^{-4}	
Dielectric strength	16.7	MV/m



RF field distribution in SF simulation

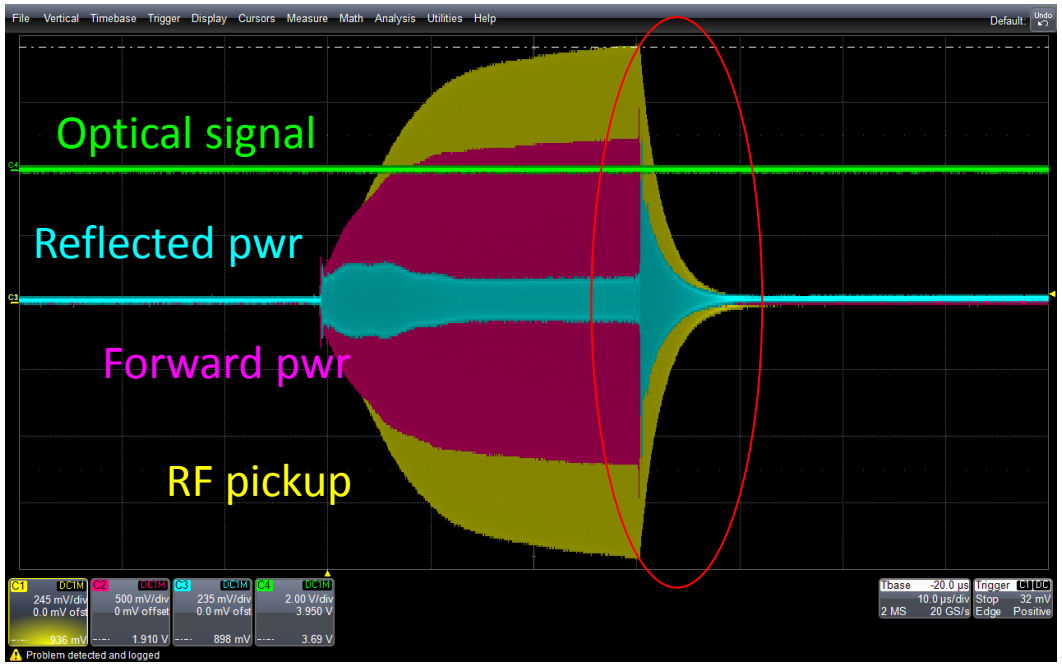
Maximum gradient search on surface of a ceramic rod

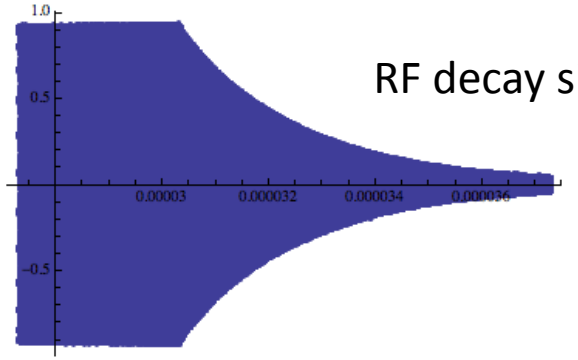
- In order to avoid permanent damage of ceramic rod, applied RF amplitude was gradually ramped up
  - 0.5 MV/m step
  - RF system was recovered even we had a breakdown

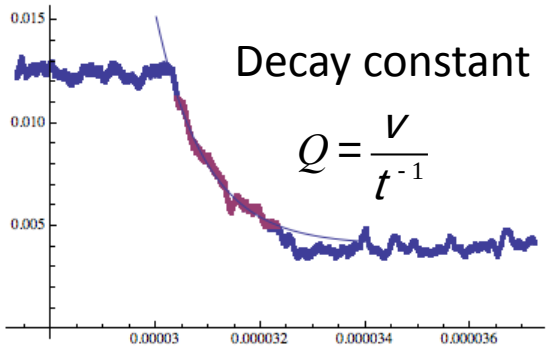


- N_2 gas pressure = 1,000 psi
- Observed unusual BD event at $E_{surface} < 10$ MV/m
- Observed usual BD event at $E_{surface} > 10$ MV/m
- Long run at $E_{surface} = 12$ MV/m
- No BD during 2 hrs long run (RF rep rate = 10 Hz)
- Multiple BD at 14.5 MV/m

Observed quality factor





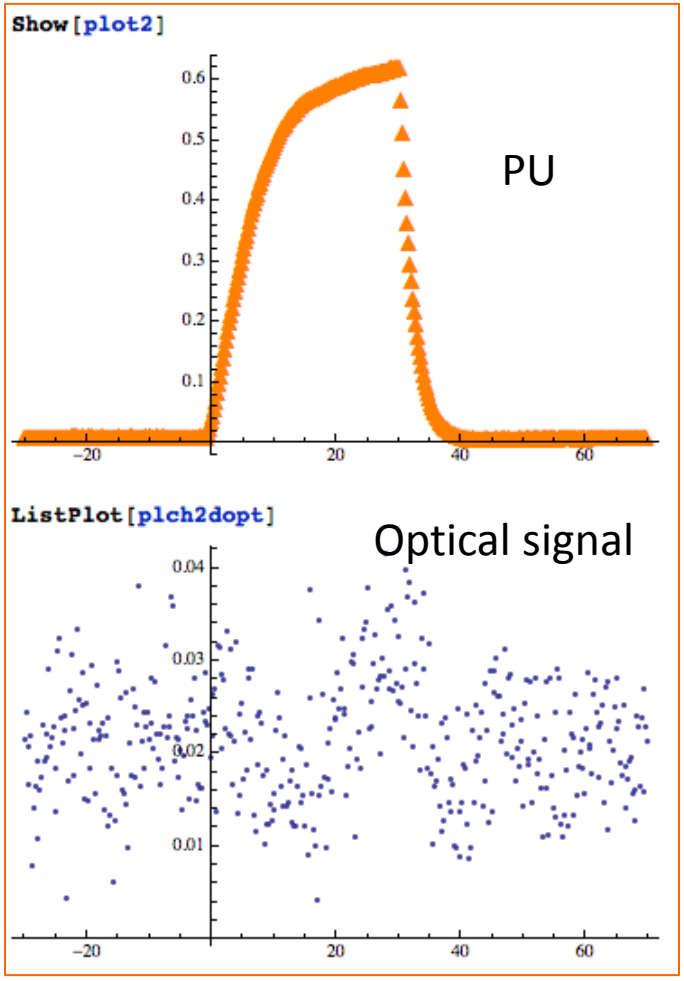


Observed Quality factor = 4554.02 ± 569.40

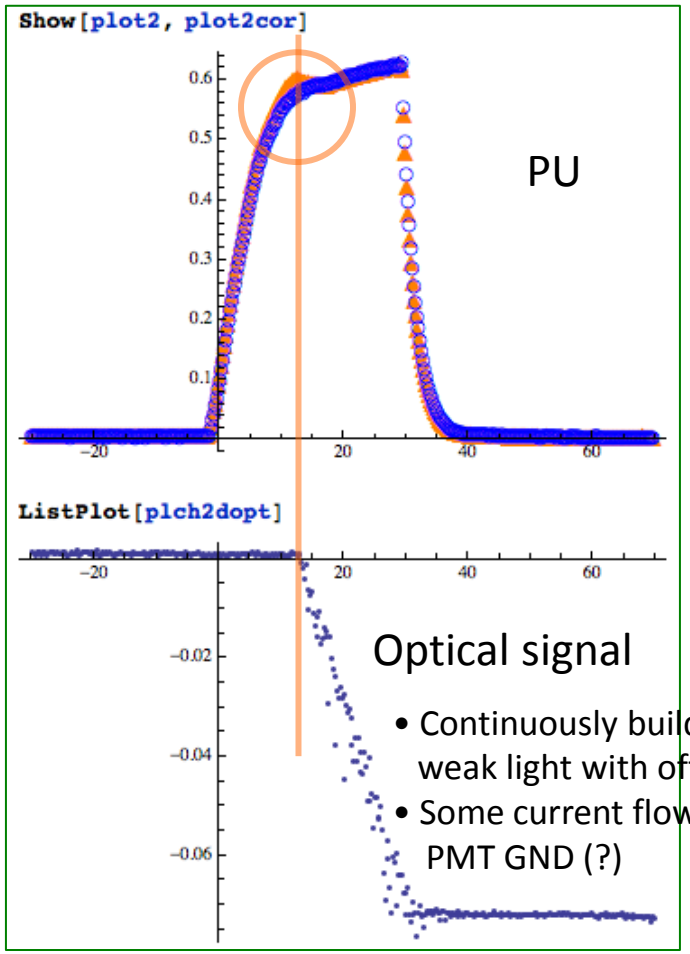
Observed frequency = 800.566 ± 0.004 MHz in 2 hrs

Weak breakdown at low RF gradient

No breakdown



Weak breakdown

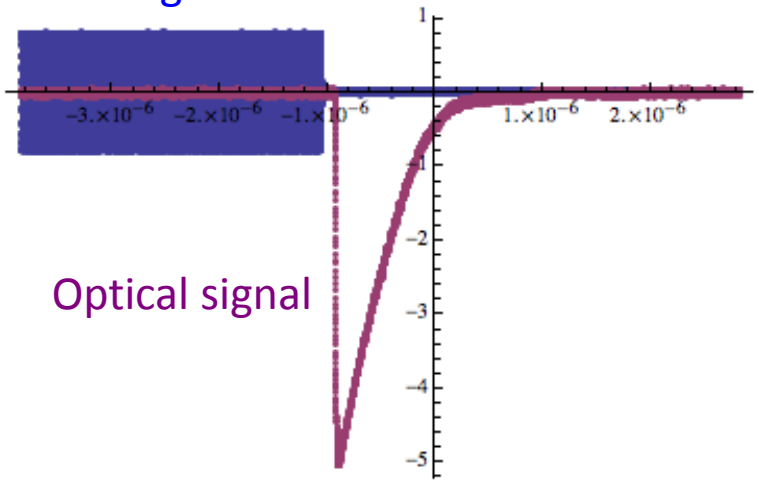


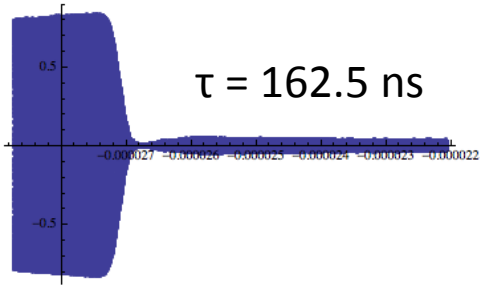
- Continuously build weak light with offset
- Some current flow on PMT GND (?)

Breakdown at high RF gradient

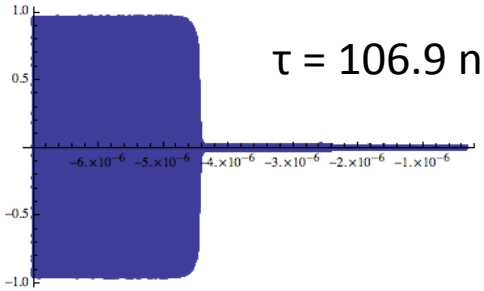
RF signal

Optical signal

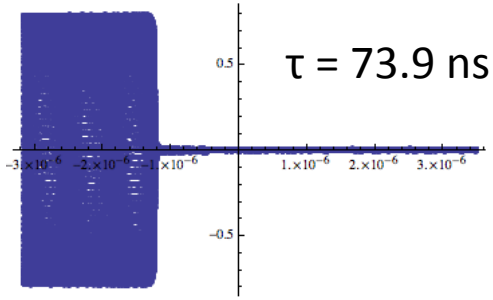




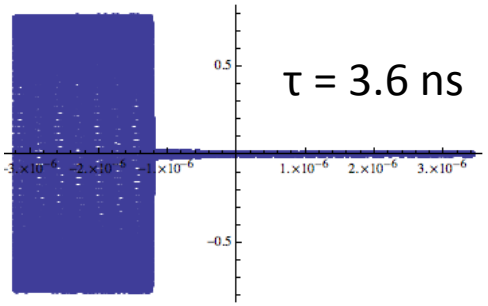
τ = 162.5 ns



τ = 106.9 ns



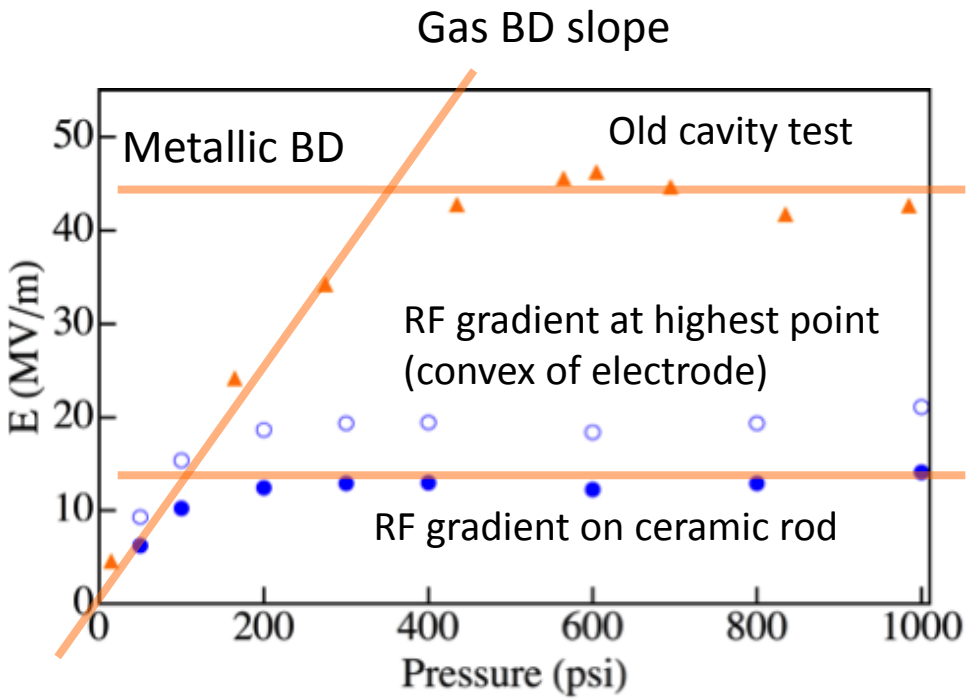
τ = 73.9 ns



τ = 3.6 ns

- Observed decay time constants, τ
- Various τ at various BD locations

Gas pressure dependence

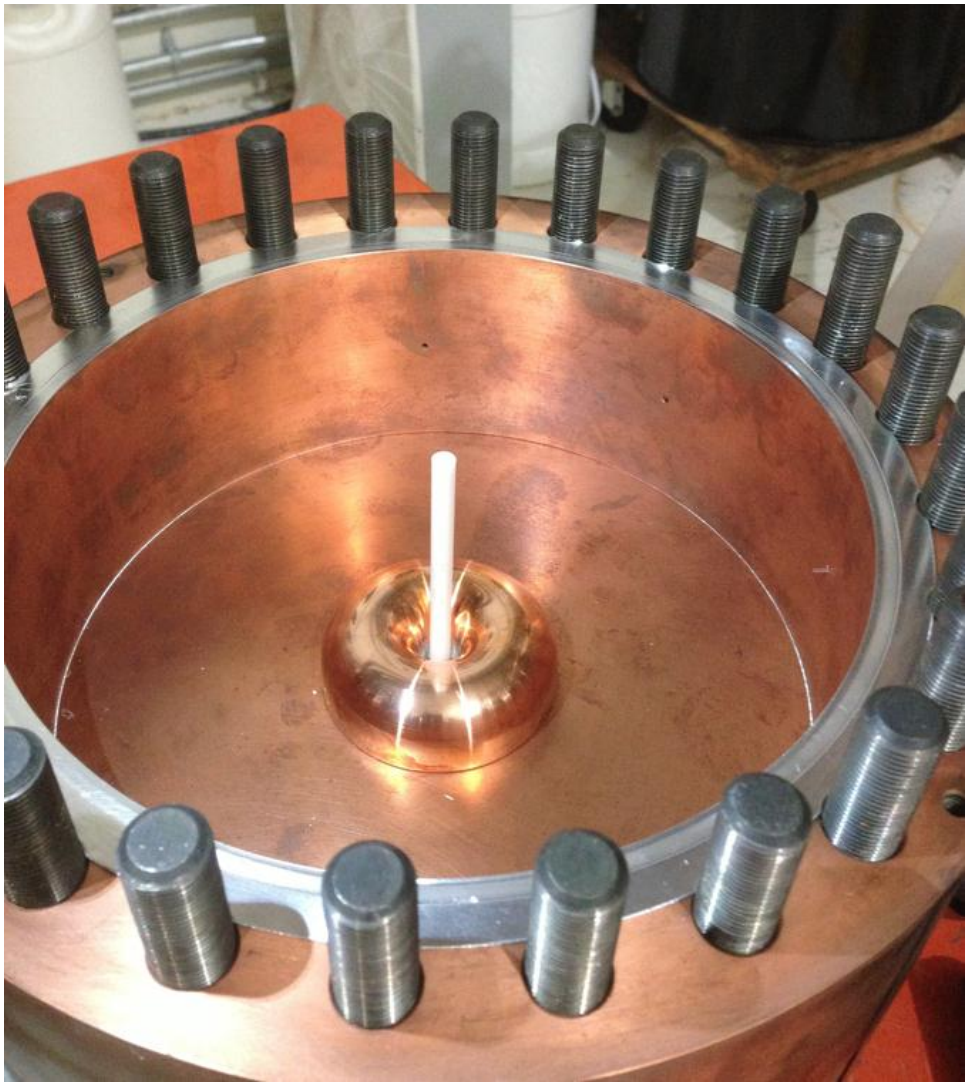


- Open blue circle: peak E at electrode
  Close blue circle: surface E
- Orange triangle:
  Compare old HPRF test with GN_2
- At p < 200 psi, observed peak E (open circle) shows gas BD
- At p > 200 psi, observed peak E shows a plateau
- The plateau seems to be determined by the dielectric strength of ceramic rod

Consider breakdown mechanism

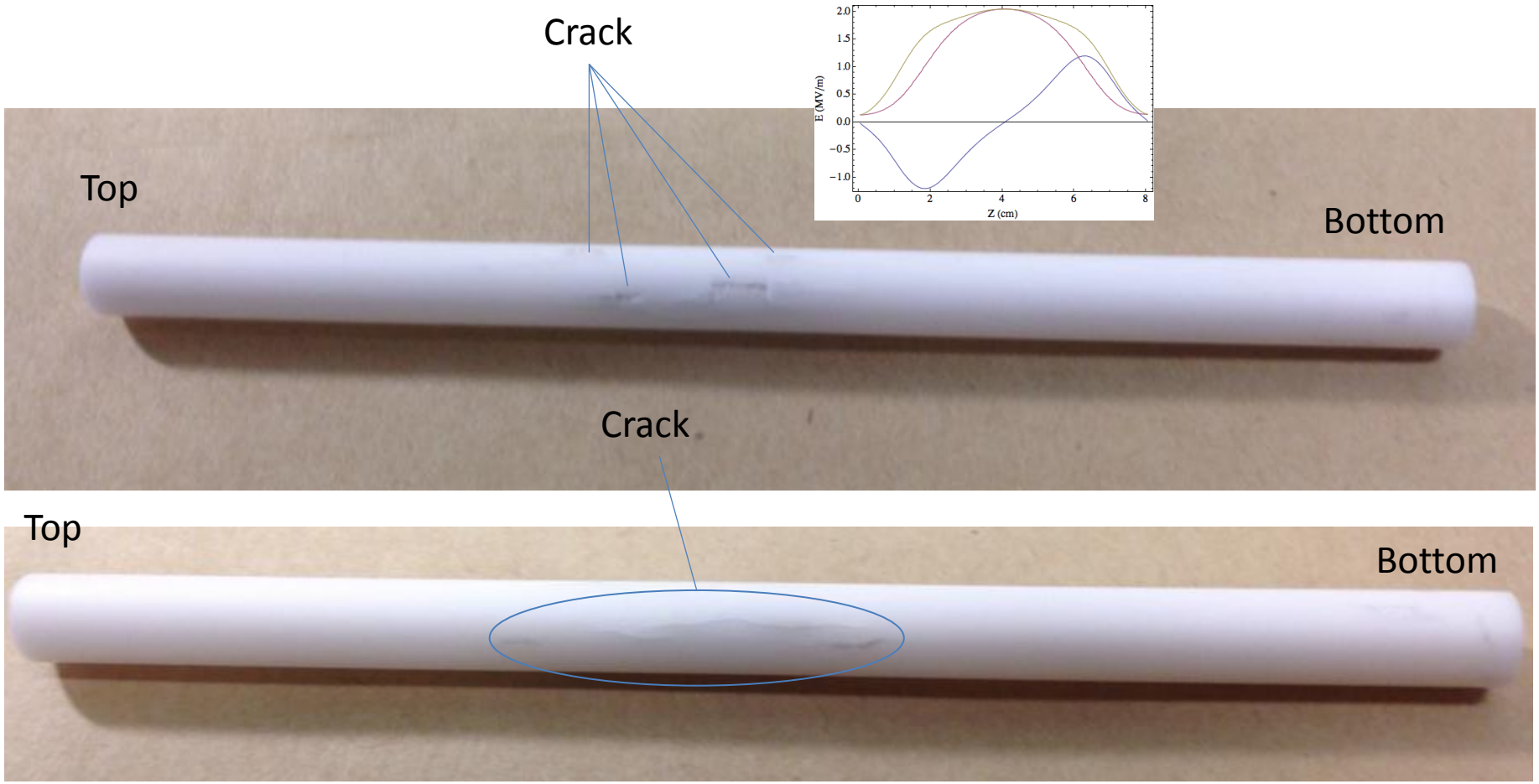
- Weak breakdown
  - Some amount of BD light came out from test cell
  - Never seen such a BD in past gas-filled RF test
  - It looks like a multipactor in a vacuum cavity
  - It disappeared in higher RF gradient
  - Is it a surface breakdown?
- Regular breakdown
  - Observed intense BD light at high RF gradient
  - Maximum RF gradient is close to the dielectric strength of alumina rod

Open cavity after first run



- Saw a small piece of broken ceramic
- Saw one breakdown spot on a Cu electrode

Inspect ceramic rod after test



- Since bottom part of rod is inserted to the rod holder deeper than top location of cracks is the middle of cavity that is the highest RF gradient

Summary

- Pressure measurement shows that there is a transition of BD mechanisms at p ~ 200 psi
  - Gas BD at p < 200 psi
  - New BD (plateau) at p > 200 psi
- Saw weak BD
  - Surface BD?
- The plateau can be the dielectric strength of ceramic rod (15 ~ 16 MV/m)
  - This can explain why ceramic rod is broken

Discussion and future plan

- These are just hypothesis although everything can be explained
- We do not know when the ceramic was broken
- Plan in near future (in 2013)
  - Measure maximum RF gradient w/o ceramic rod
  - Repeat the same test with a new ceramic rod (same material)
  - Repeat the same test with different materials
    - TiO
    - Teflon