Fermilab MTA 805 MHz RF Program

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MUTAC Review

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Collaborators

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- **JLab: Bob Rimmer**
- **Imperial College, UK: Ajit Kurup (working on 805 cavity automation RF control system)**

Outline

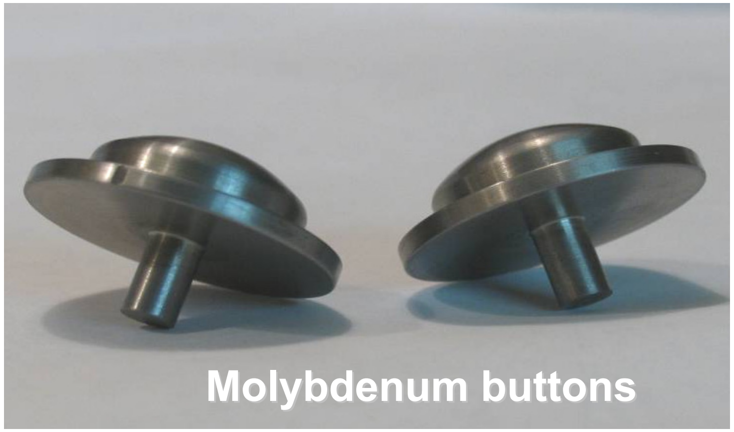
- **Introduction**
  - Goals & approaches
- **Button material test**
  - Motivation
  - Experiment setup
  - Procedures
  - Measurements and data analysis
- **E $\times$ B study**
  - Concept
  - Experiment schematic
- **Summary**

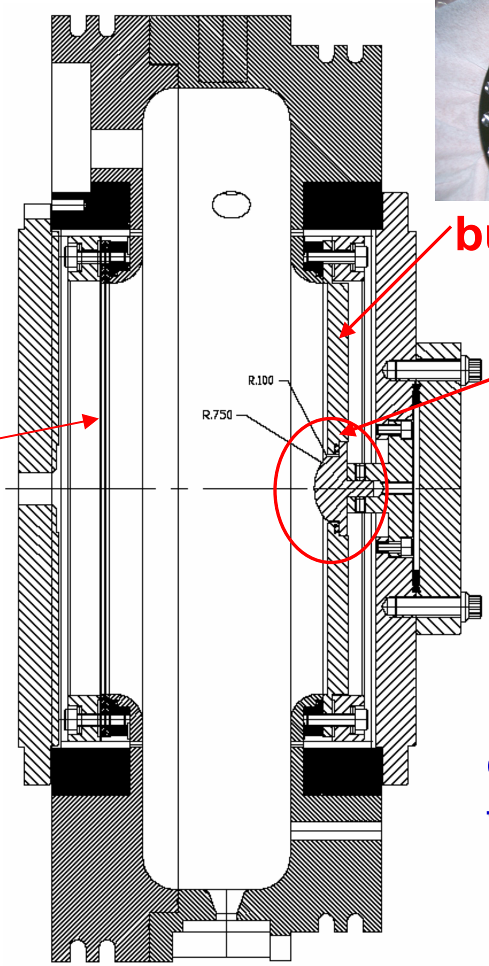
Introduction

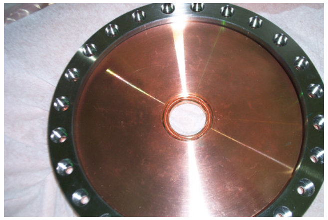
- **Cavity material test:**
  - *Goal*: find materials and coatings that can withstand high peak surface field in strong magnetic field
  - *Approach*: use 805 MHz cavity to test buttons made of various materials
- **$E \times B$ test:**
  - *Goal*: study RF breakdown limit when accelerating field $E \perp$ magnetic field B
    - **Will be extended to study arbitrary angles**
  - *Approach*: rotate 805 MHz cavity 90° in solenoid field

Cavity material ("Button") test

- "Button" system in pillbox cavity designed for easy replacement of test materials
- Tested so far: TiN-coated Cu & Mo, bare Mo and W
- To be tested: Cu (electro-polished & unpolished), Be
  - More to come

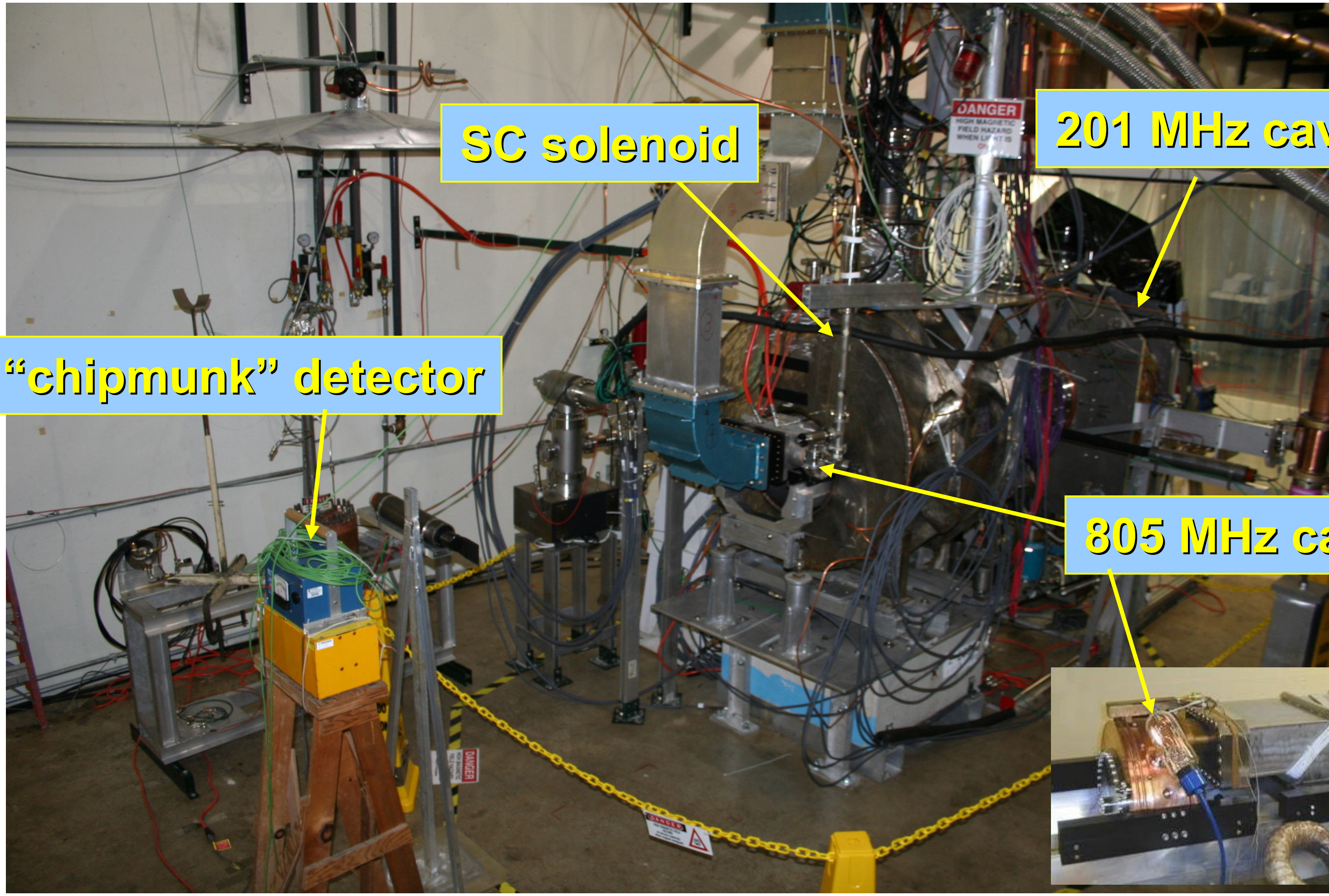






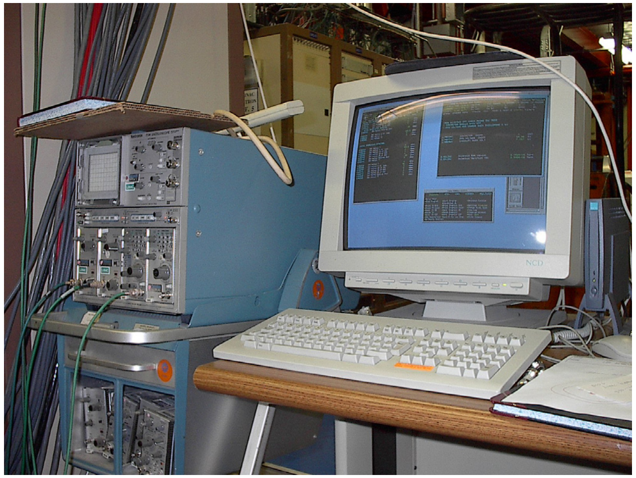
(*1.7x* field enhancement factor on button surface)

Button test: Experiment setup I



Button test: Experiment setup II

- Vacuum, radiation levels, LHe level, solenoid current & voltage monitored
- Accelerating gradient measured with pickup probe inside cavity
- Data recorded in computer for later analysis

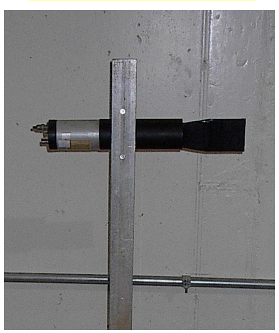


Button test: x-ray detectors

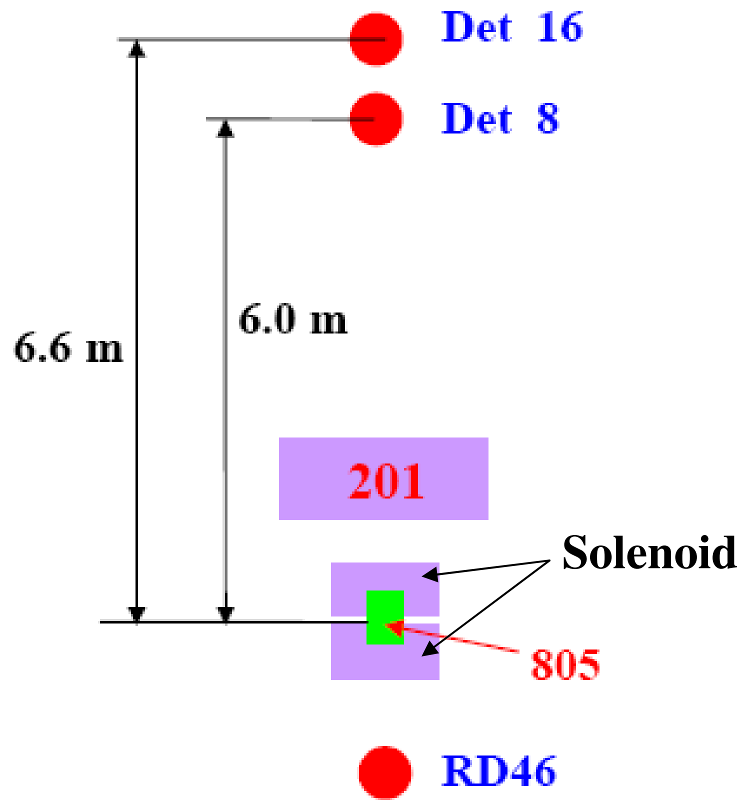
- 10 x-ray detectors in MTA hall
  - 9 fast scintillation counters, counting rate limit: ~ 10 MHz
  - 1 NaI-xtal energy measurement, counting rate limit: ~ 1 MHz

- Detectors frequently used in button tests:
  - #8 (small scint. paddle)
  - #16 (NaI crystal)
  - RD46 “chipmunk” (measuring integrated x-ray radiation dose in 20 sec.)

Det. 8



Det. 16

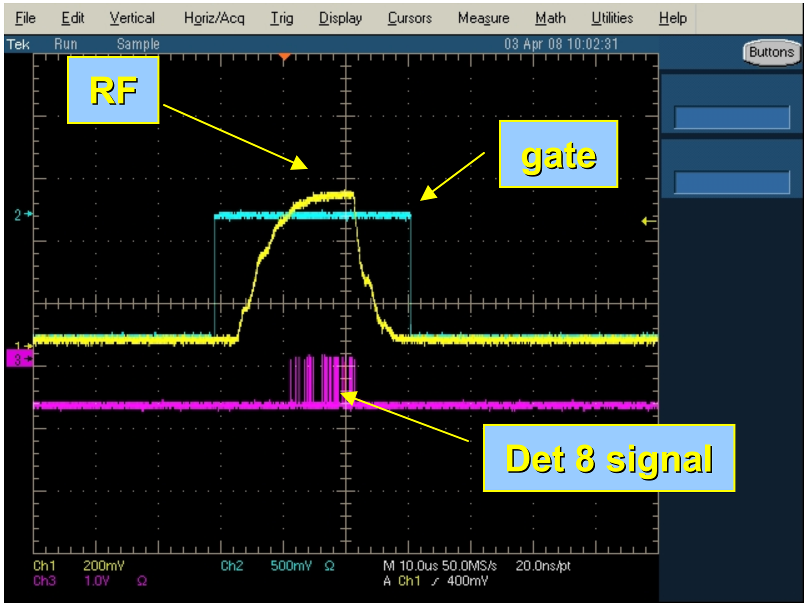


Button test: Procedures

- **Cavity conditioning procedure:**
  - Raise RF amplitude slowly
  - RF power automatically tripped by:
    - bad vacuum (>1e^{-8}Torr)
    - high radiation level (>200mrem/hr)
    - modulator error
  - On trip, reduce RF amplitude until stably below trip levels
  - After 5–10 min, gradually increase RF amplitude
  - Iterate to find maximal gradient without button surface damage

- **We measured the maximal accelerating gradient at *B* fields up to 3.5 T in 0.25 T increments.**

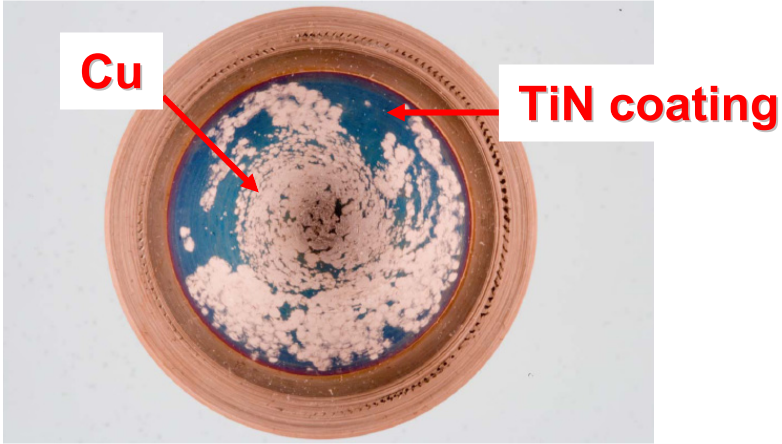
- **x-ray measurements:**
  - RF pulse length ≈ 20 μs
  - Use electronic gate covering RF pulse
  - Record x-ray events for 1000 RF pulses



Button test: coating issue

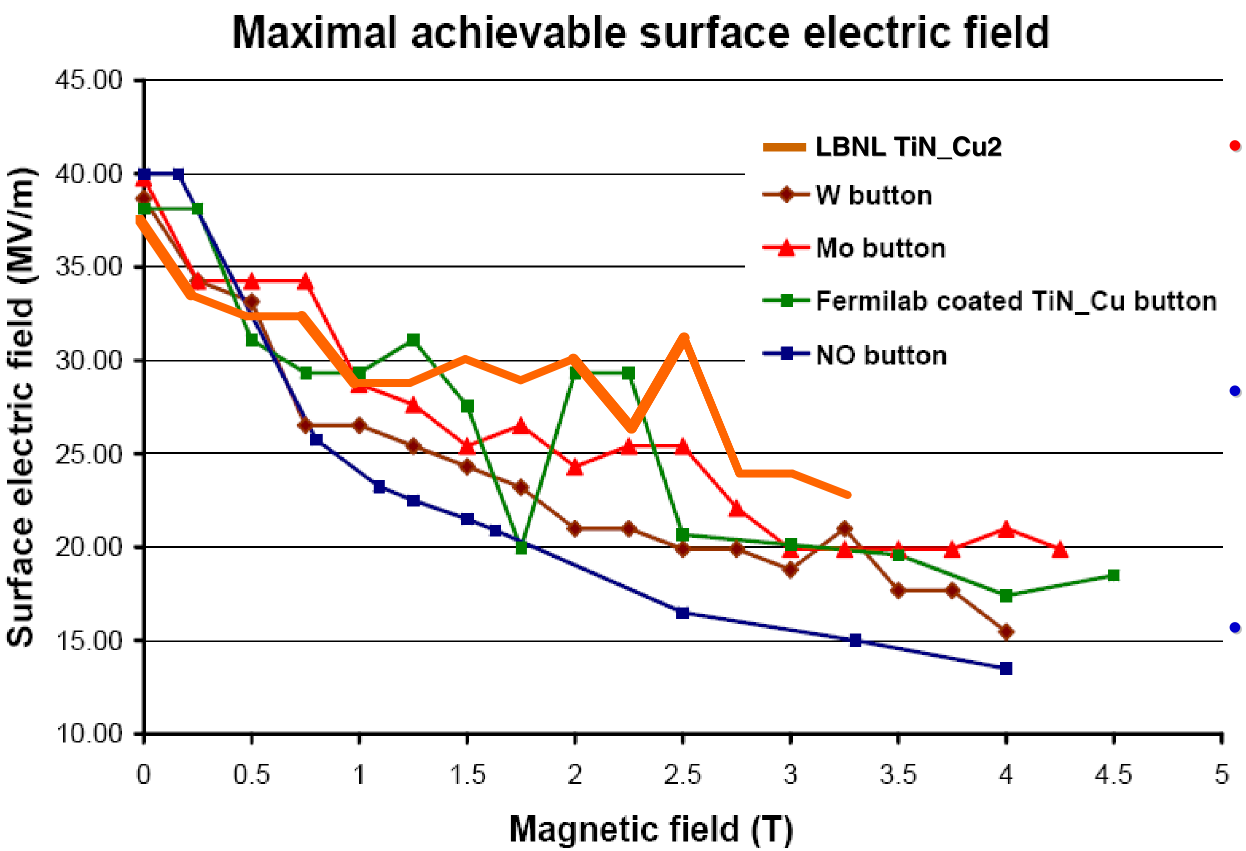
- After 1st (Fermilab-coated) TiN_Cu button test, observed ≈80% of TiN coating lost
- LBNL then coated 2 new TiN_Cu buttons via 2 different techniques
  - LBNL coating gold, unlike Fermilab's (color determined by thickness)
- After test of LBNL TiN_Cu button #2, observed smooth surface w/ no coating loss

Old (FNAL-coated) button



New LBNL button #2

Button test results: 2007 & 2008

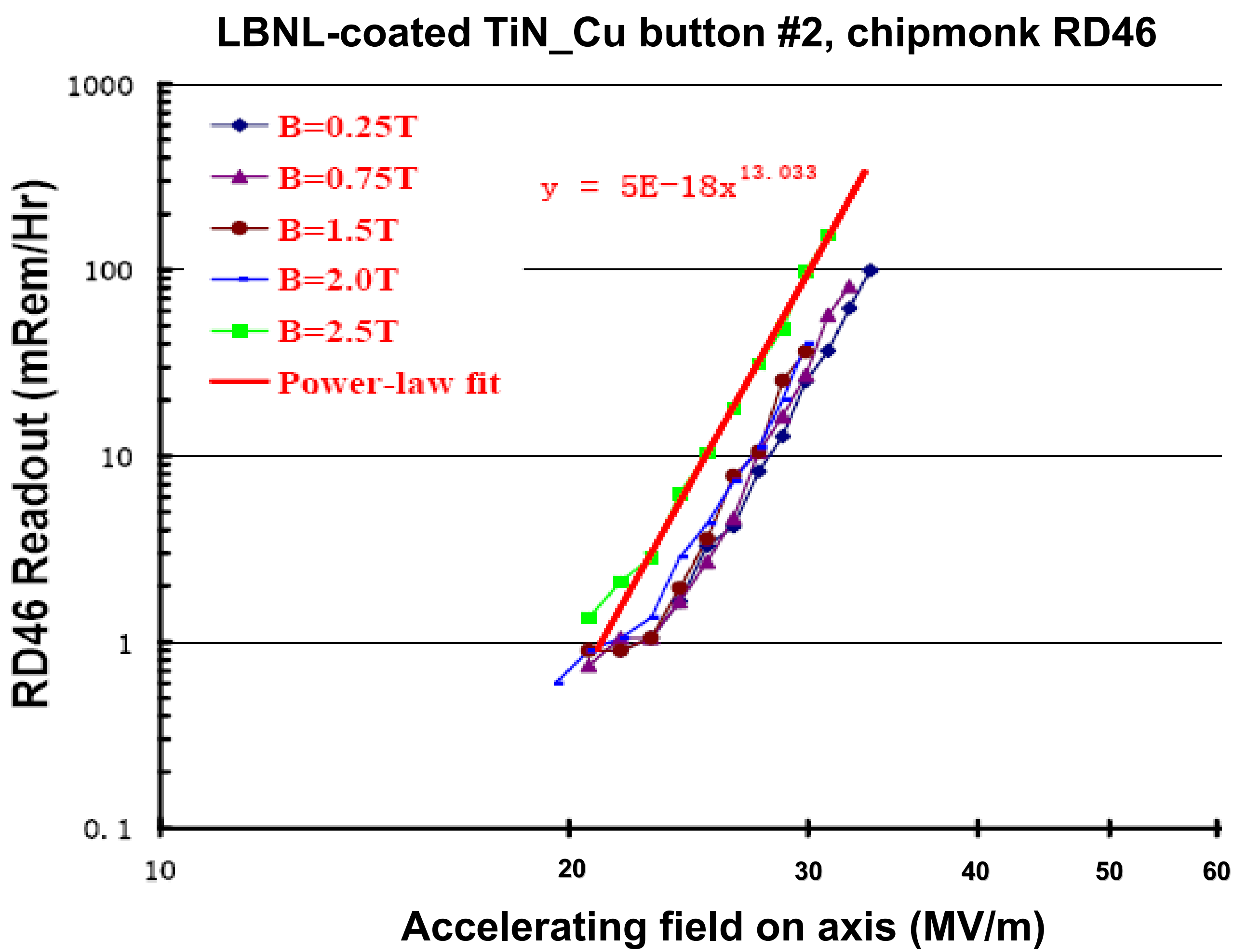


- **TiN_Cu** data:
  - less stable than rest, maybe due to loss of TiN coating
- **Mo** data:
  - generally above W data
  - Mo appears to withstand higher surface field than W
- **2008 tests:**
  - more systematic conditioning to avoid coating damage
- **New LBNL coated TiN_Cu button:**
  - data appear more stable than FNAL-coated **TiN_Cu**
  - better performance at high magnetic field

Where x-rays come from

- **RF fields in the cavity may induce**
  - multipactoring
  - field emission
  - sparking
  - …
- **As a result:**
  - electrons, ions, …, stripped from cavity walls, hit surfaces inside cavity → x-rays

Button test: x-ray radiation I

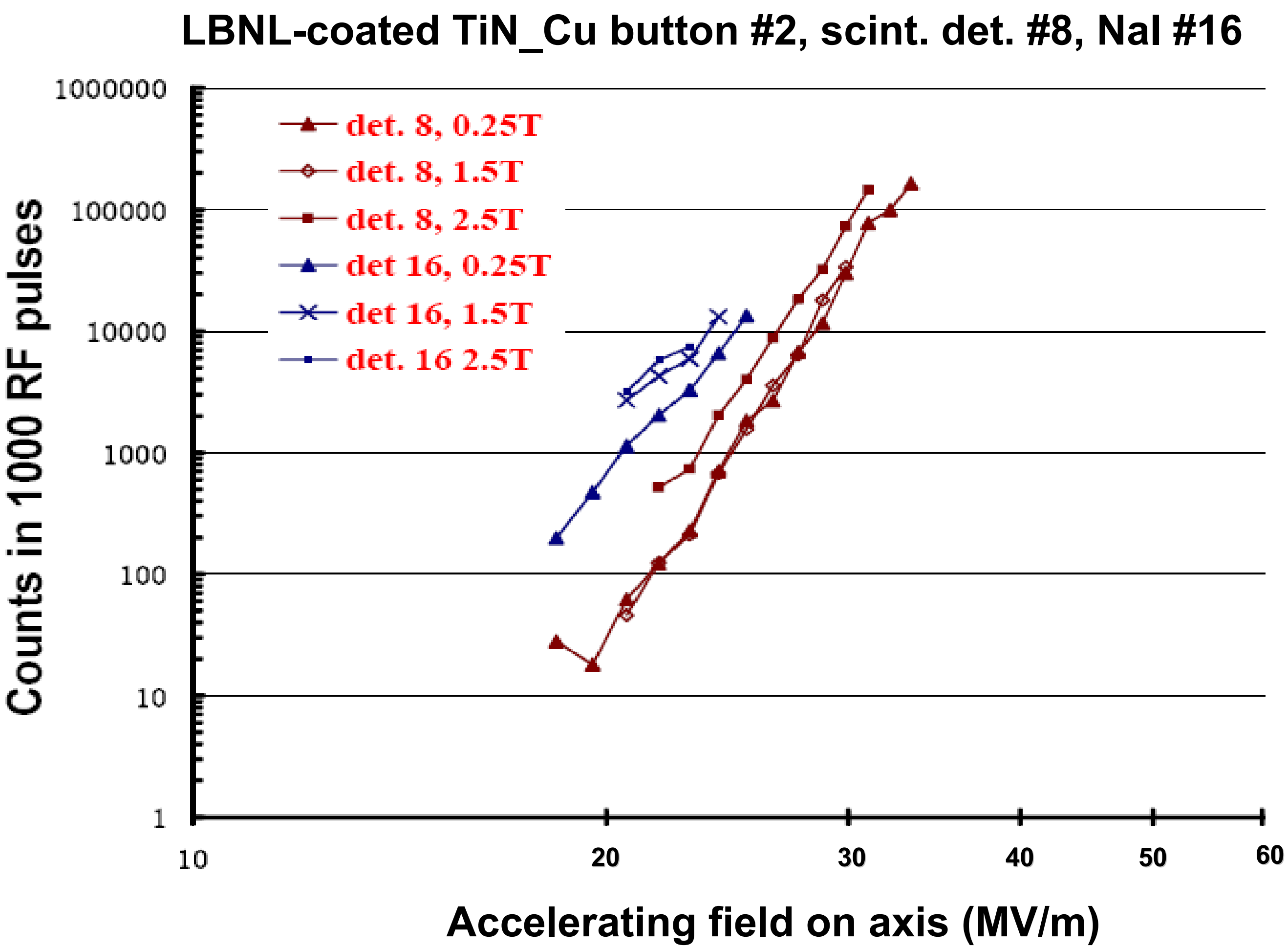


- **LOG-LOG** plot
- All curves display power-law growth, ~E^{13}, consistent w/ Fowler-Nordheim field-emission law which can be **approximated** by:

  $I \sim E^n$,

  where I is field-emission current, n depends on work function and local field

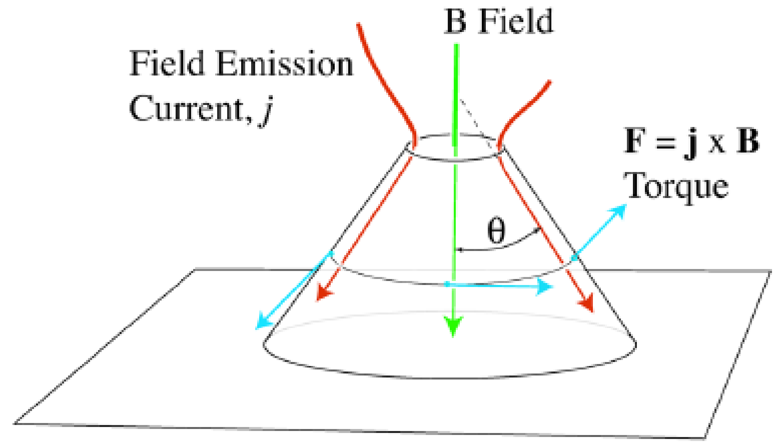
Button test: x-ray radiation II



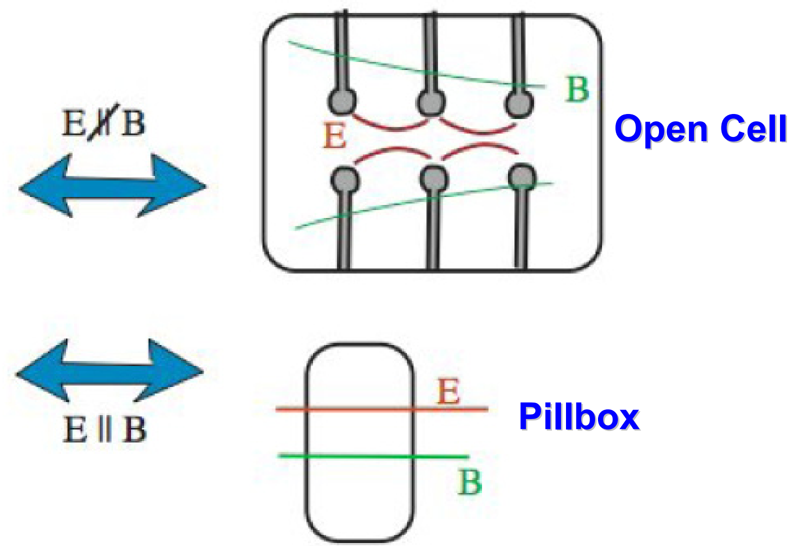
- **LOG-LOG** plot
- Det. 16 (NaI crystal) saturated at higher accelerating fields
- Again, very sensitive to accelerating gradient, display power-law growth

E × B study: Concept

- Stress on emitter $F \sim j \times B$
  - stress can be ~ 10 GPa, sufficient to trigger fracture
  - Data of Mo & W buttons consistent with this model

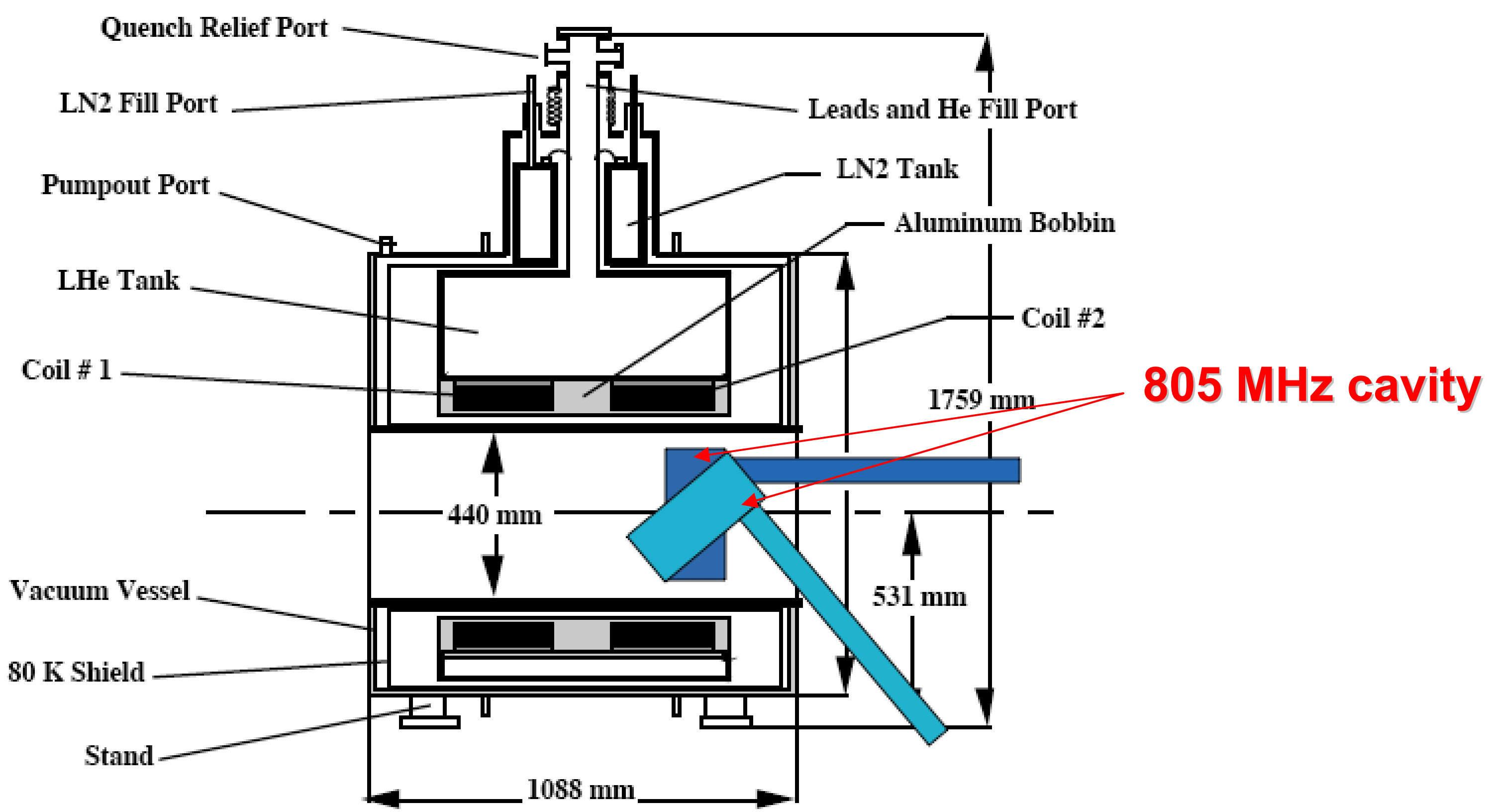


- In open-cell cavity (studied in ≈ 2000, lower-right), E generally not parallel to B, whereas in pillbox cavity, $E \parallel B$



- In order to reveal the relationship between field emission and orientations of E and B field, $E \times B$ study is planned.

E × B study: Experiment schematic



A Cross-section view of the RF Solenoid from the side

Summary

- **Experimental studies of various button materials in 805-MHz cavity have been carried out at MTA.**
  - Experiment setup and diagnostics worked well, ready for more extensive studies.
  - Coating loss on Fermilab-coated TiN_Cu button. LBNL-coated button #2 shows better behavior without visible loss
  - Mo seems to withstand higher accelerating field than W
  - More buttons to be tested: Another TiN_Cu coated by LBNL, electro-polished Cu, unpolished Cu & Be
  - X-ray radiation follows Fowler-Nordheim law
  - 805 cavity automatic control program is planned to be tested
    - **Improved uniformity of test procedures**
    - **Reproducibility improved**

- **Initial E $\times$ B experiment setup using existing 805 MHz cavity is going to be done soon**