Fast radiation signal of MICE RF Cavity

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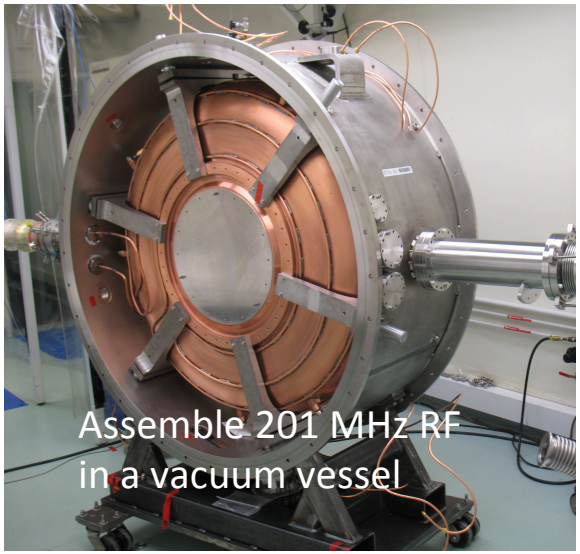
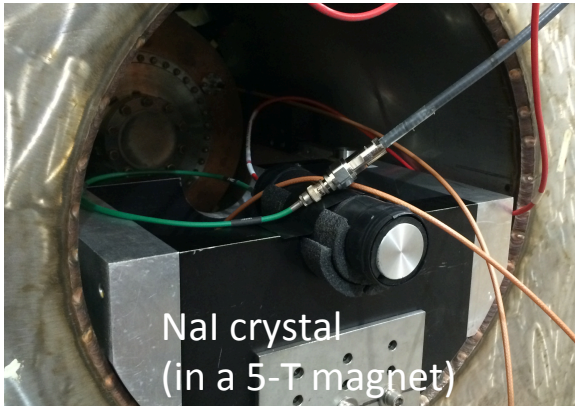
Mission

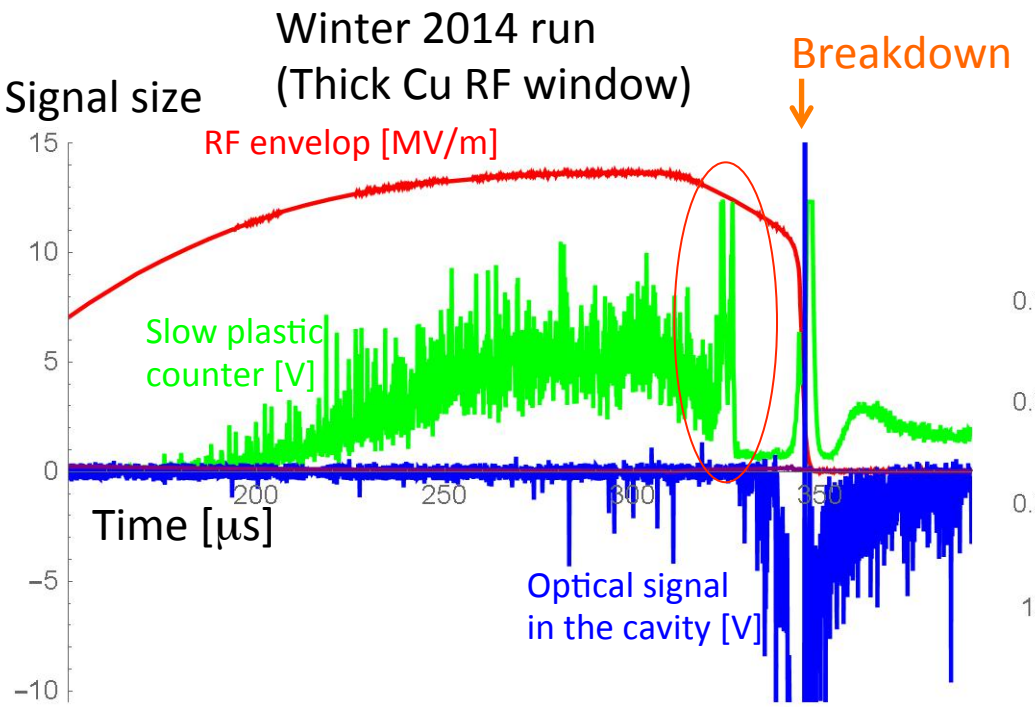
- Primary mission of the 200 MHz MICE cavity test at MTA is evaluating RF performance for MICE
  - Demonstrate stable RF operation in the MICE operation condition
- Measure radiation level generated by the cavity to estimate a background level for the MICE detector system
- We also realized that the cavity is an ideal device to study dynamics of dark current (field emission) and breakdown mechanism
  - RF period = 5 ns @ 200 MHz
    1.25 ns @ 800 MHz

MICE RF Cavity and radiation detector

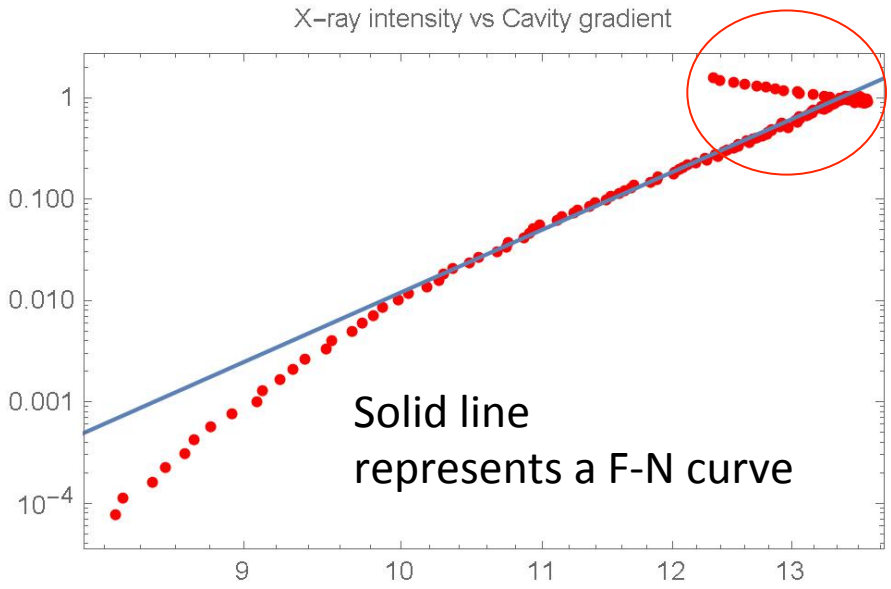




Mystery of slow counter measurement in Winter 2014 run



A. Tollestrup, 3/10/15 HPRF/RF BD meeting



- A slow counter sees field emission currents (F-N curve) in the cavity

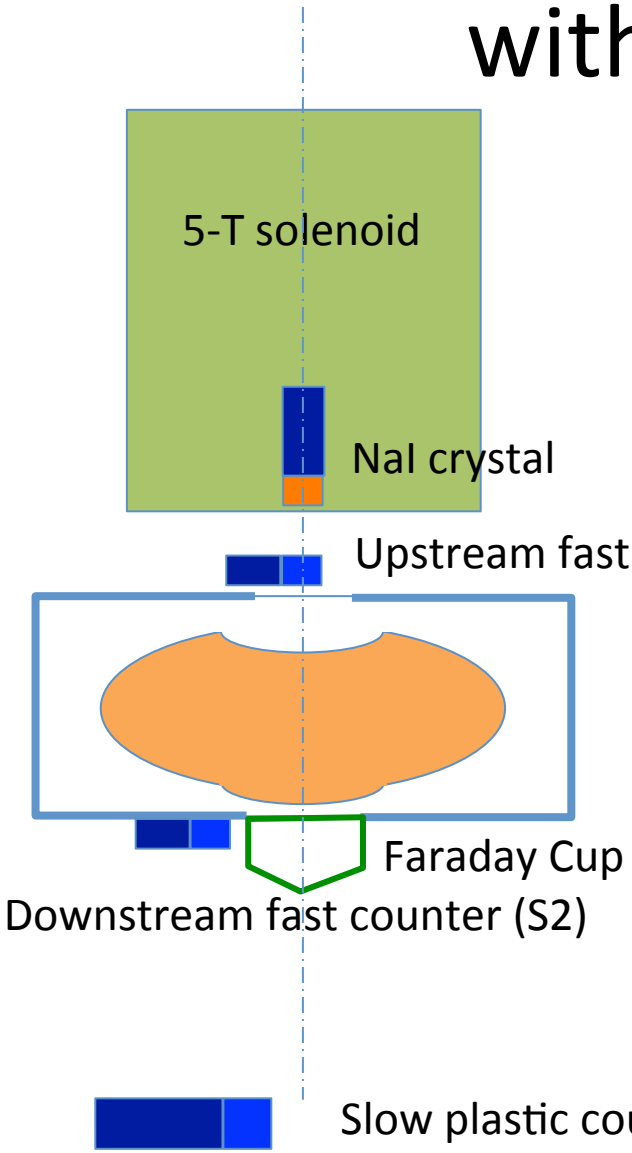
However…

- Radiation seems to be highly activated even the driving RF power was ramped down (A red oval in left plot)
- High activating radiation makes a big deviation from the normal Fowler-Nordheim curve (A red oval in right plot)

Motivation of utilize fast radiation detector in MICE RF test

- Investigate mysterious slow counter signal
- Observe time-domain field emission electrons
  - RF phase dependent FE electrons
- A pair of fast plastic scintillating counter w. fast Photomultiplier Tube (PMT)
  - $\tau < 5$ ns = RF peroid
  - Upstream and downstream of the cavity

Configuration of radiation detector with no B field

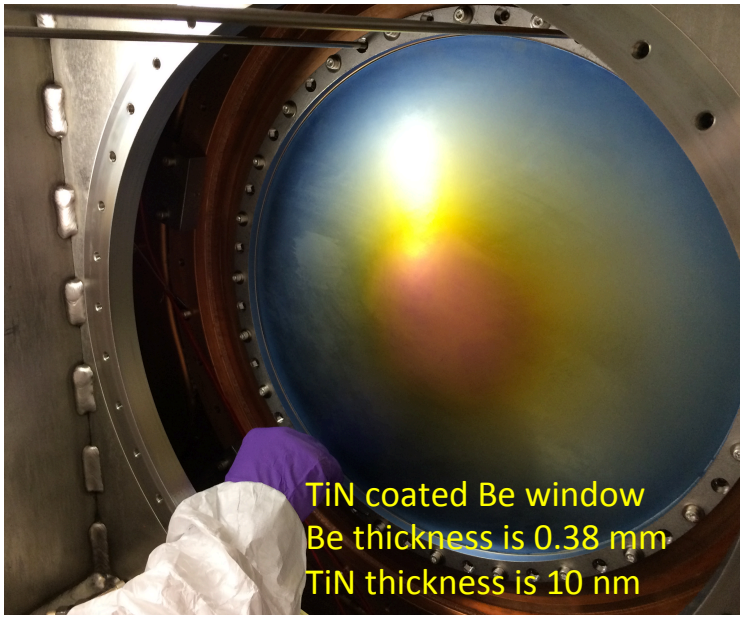


- Fast plastic scintillating counter (S1, S2)
- Slow plastic scintillating counter
- NaI crystal
- Faraday cup
- Ionization chamber (not shown)
- Optical signal (not shown)

- Ti Vacuum window: 0.2 mm
- Be RF window: 0.38 mm
- Cu Cavity wall thickness: 6.4 mm
- SS Vacuum Vessel wall thickness: 25.4 mm

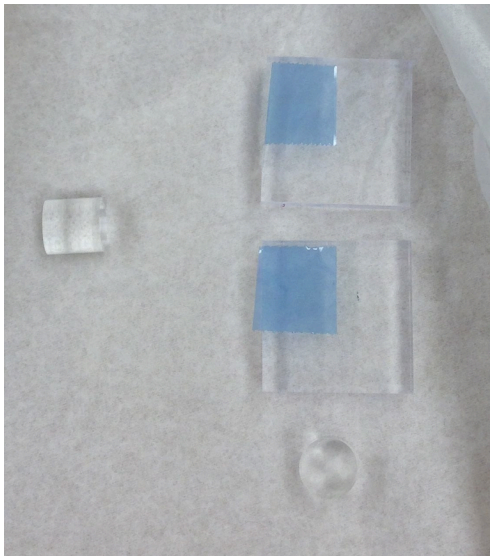
S1 sees small amount of material while S2 & slow plastic counters see a great amount of material

Be window and Faraday cup for Spring 2015 run



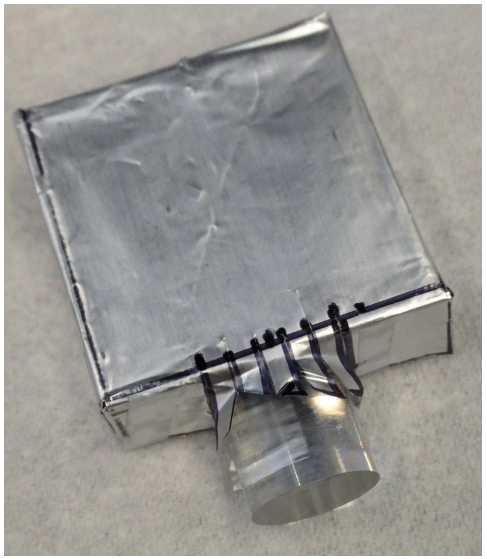
- Faraday cup is sensitive for a breakdown event but not for field emission events
- Breakdown analysis has not been done yet
- Show BD result next time

Fast plastic scintillating counter



BC408 and Acrylic rod

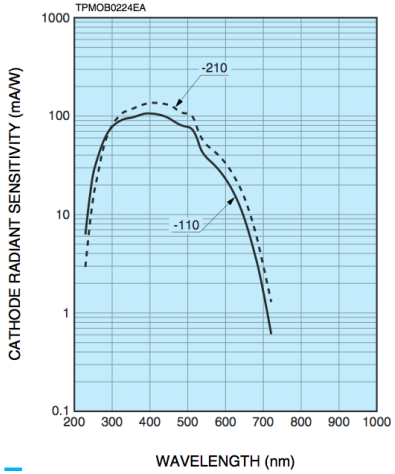
BC408, 2.5 cm x 2.5 cm x 1 cm
τ = 2.1 ns, w_{FWHM} = 2.5 ns
Acrylic rod, d1 cm x 1 cm
NO EXCLUDED type



Wrapped by Al foil

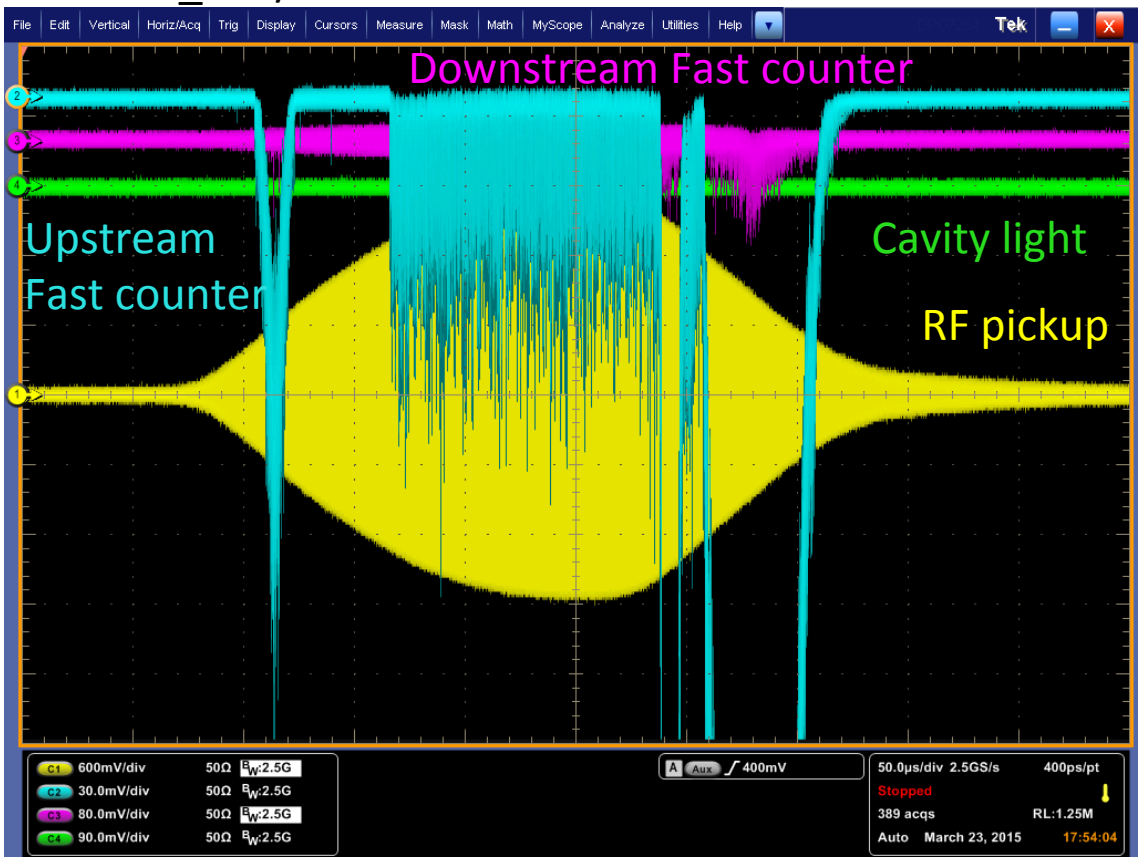
Assemble with PMT

Optical grease
BC630
Black foil + Black tape
PMT (H10721-10), τ = 0.5 ns



Snapshot of RF event

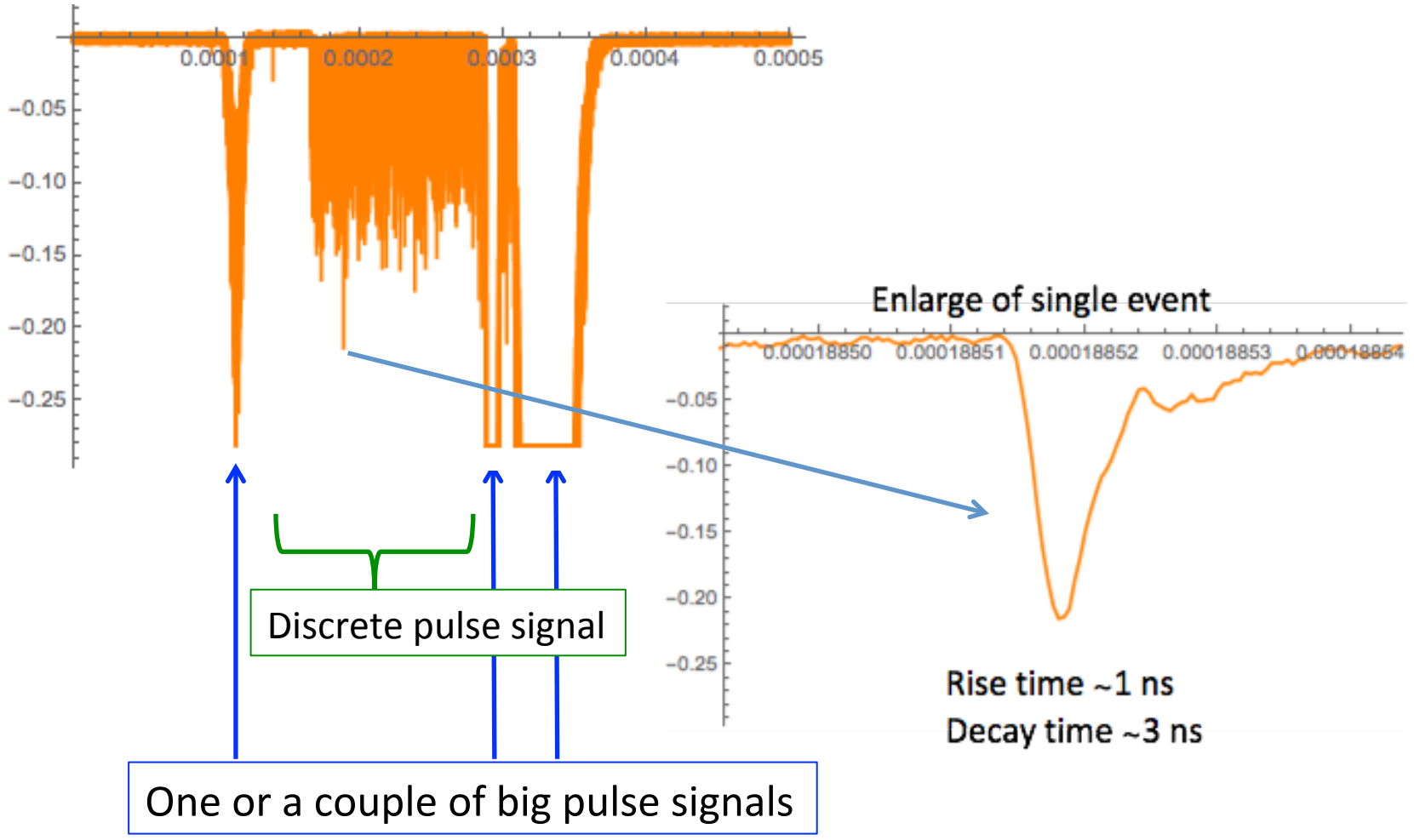
Run_130/evt#10057



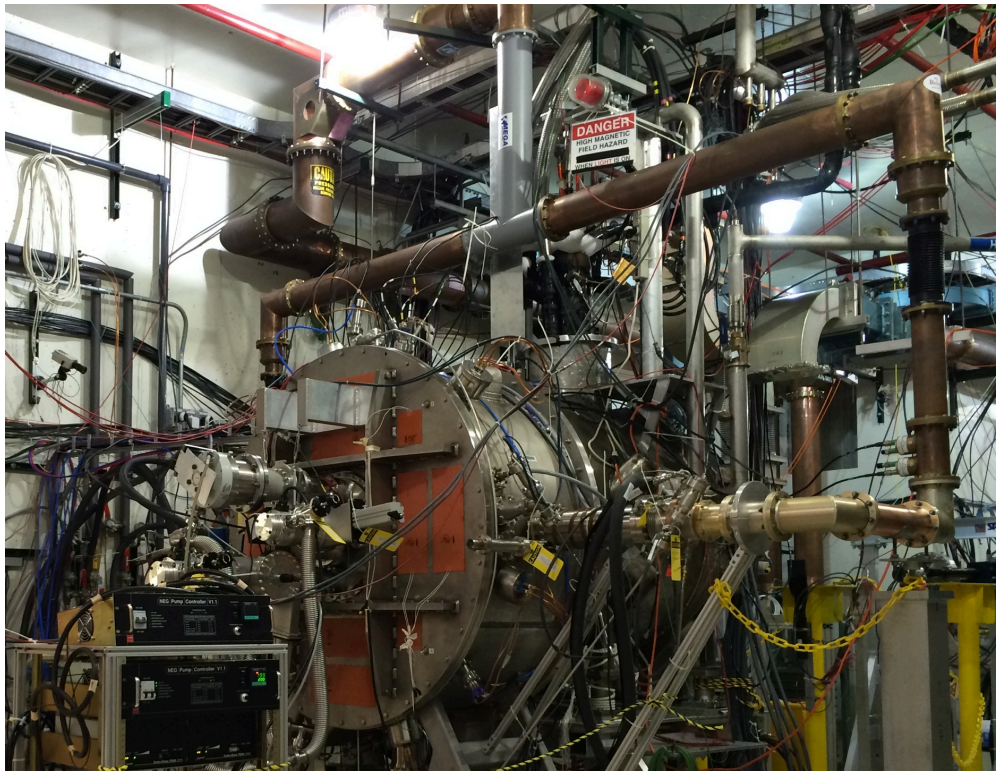
400 ps/S

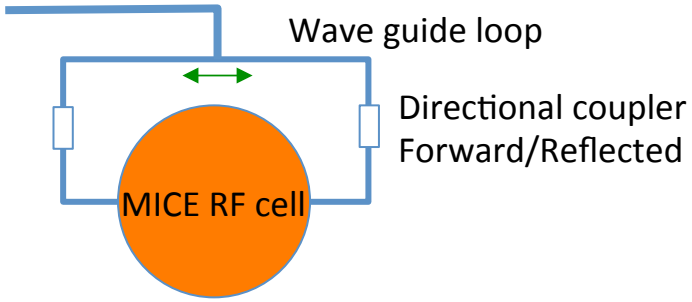
- Upstream counter (S1) shows a nice radiation signal
- Downstream counter (S2) is not much active
- S2 is shielded by various thick materials (see configuration figure, slide 6)
- It means that S2 can only see an X-ray

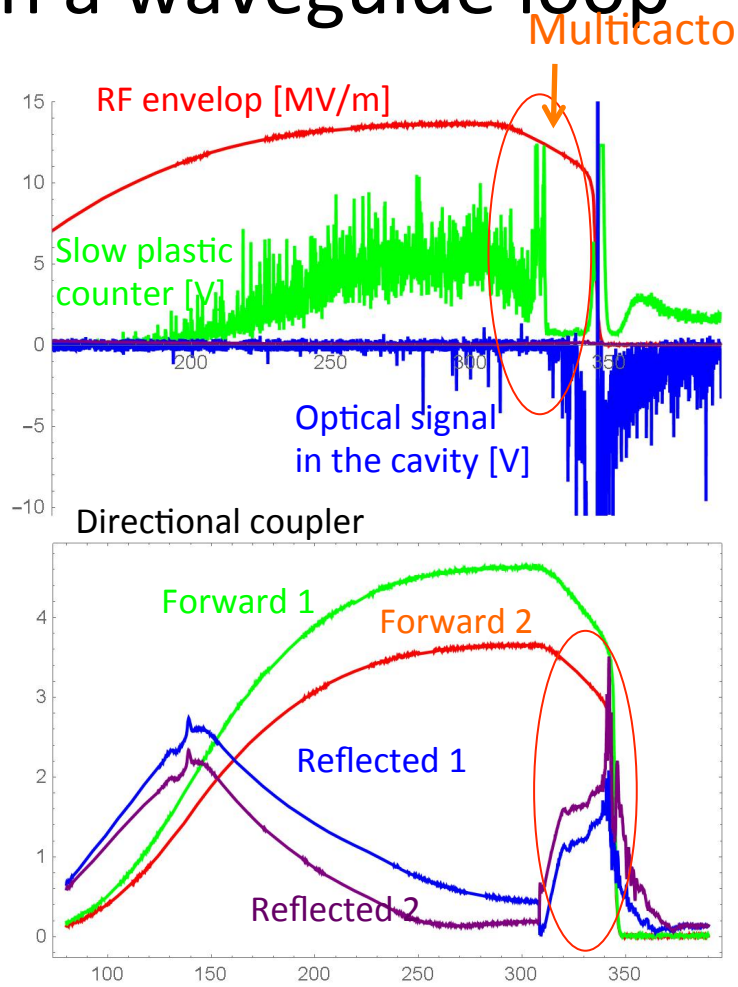
Time domain upstream fast counter signal



Possible multipactoring in a waveguide loop



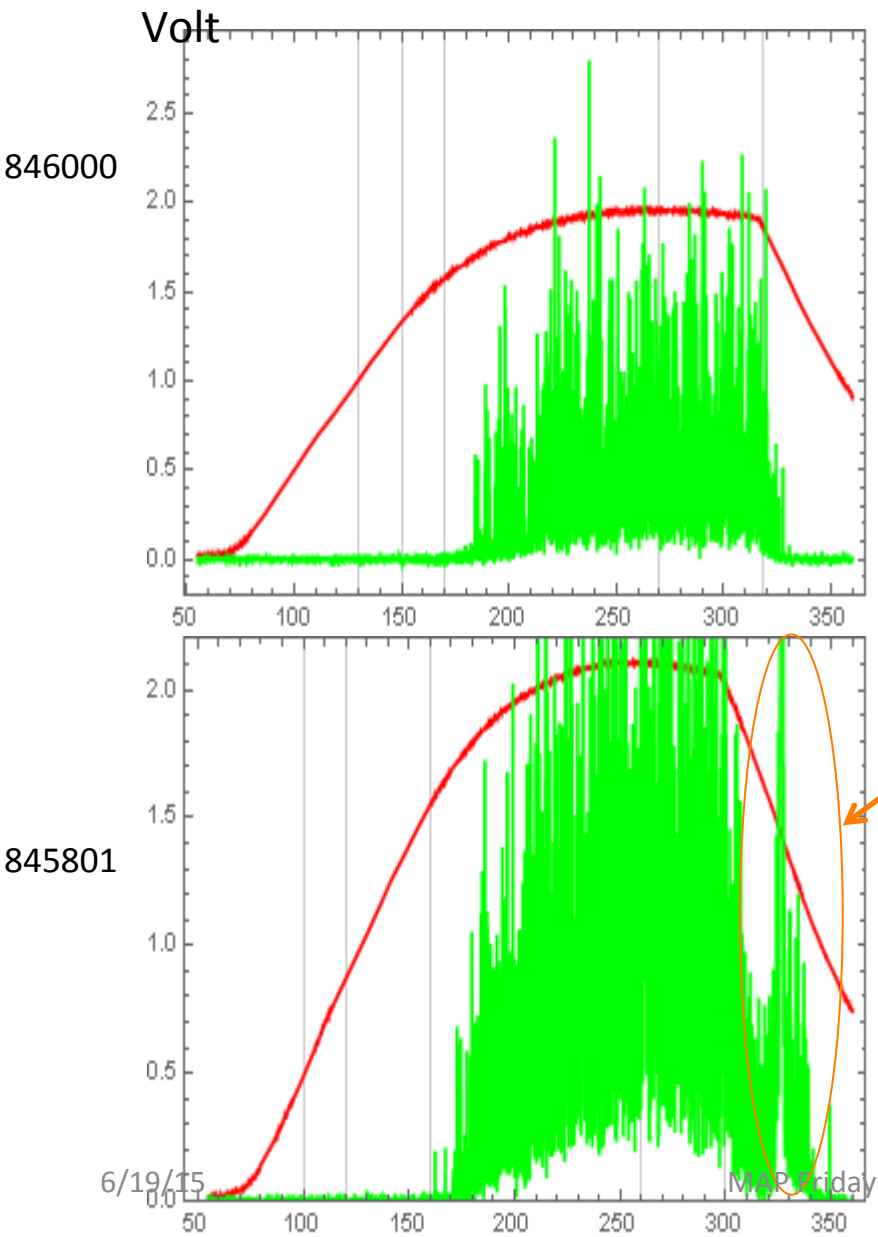


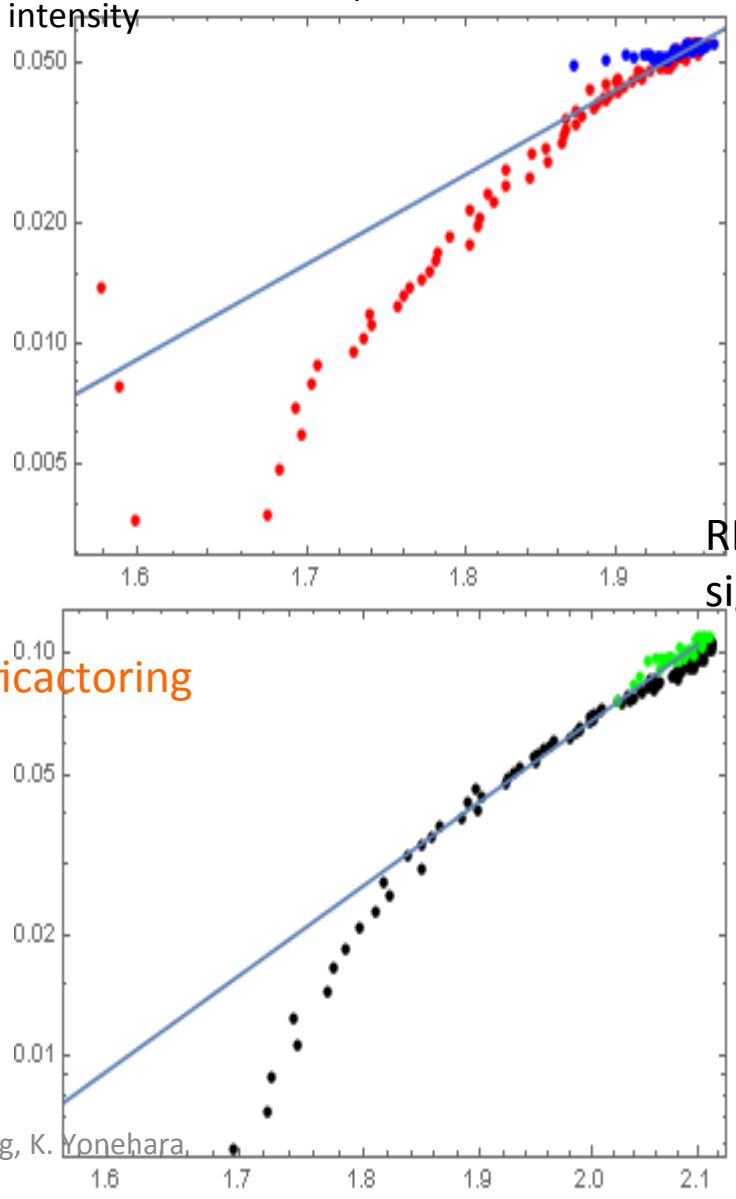


- When RF power source is turned off the stored RF power in the cavity is released to the loop
- The power is stored in the loop for a while
- Possibly a local hot spot which induces MP & BD

Fowler-Nordheim analysis for fast counter

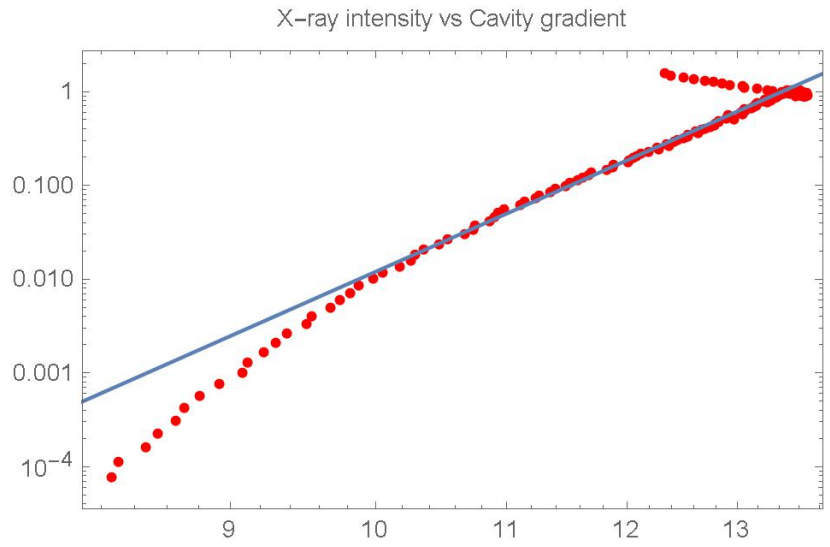
A. Tollestrup, 4/8/15 HPRF/RF BD meeting

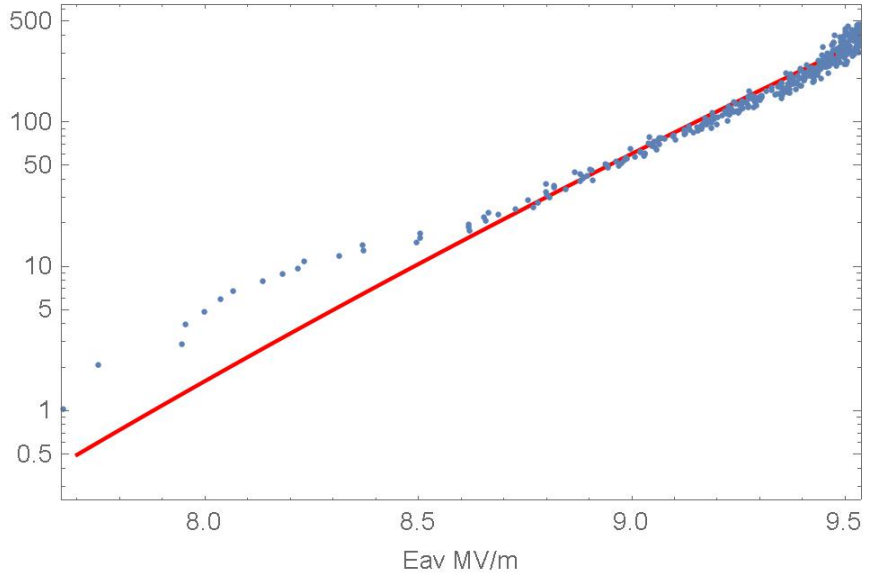


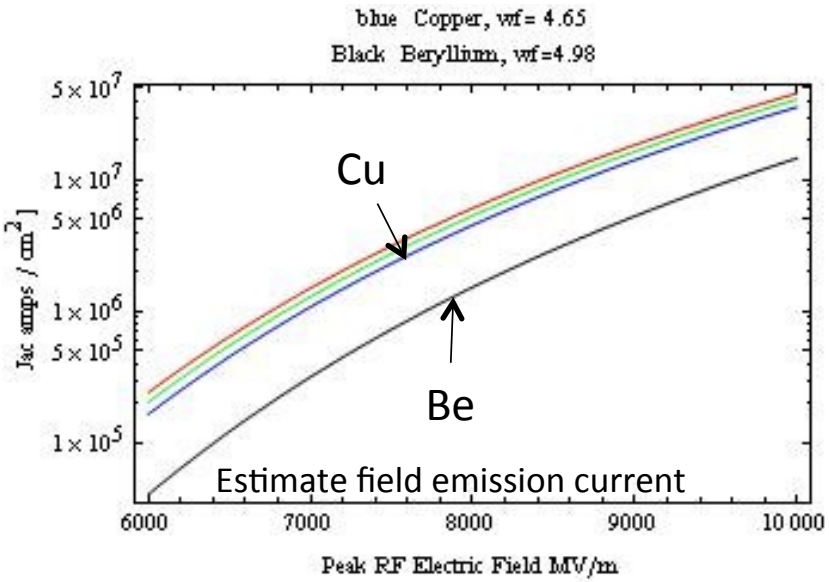


Cu vs Be

A. Tollestrup, 4/8/15 HPRF/RF BD meeting

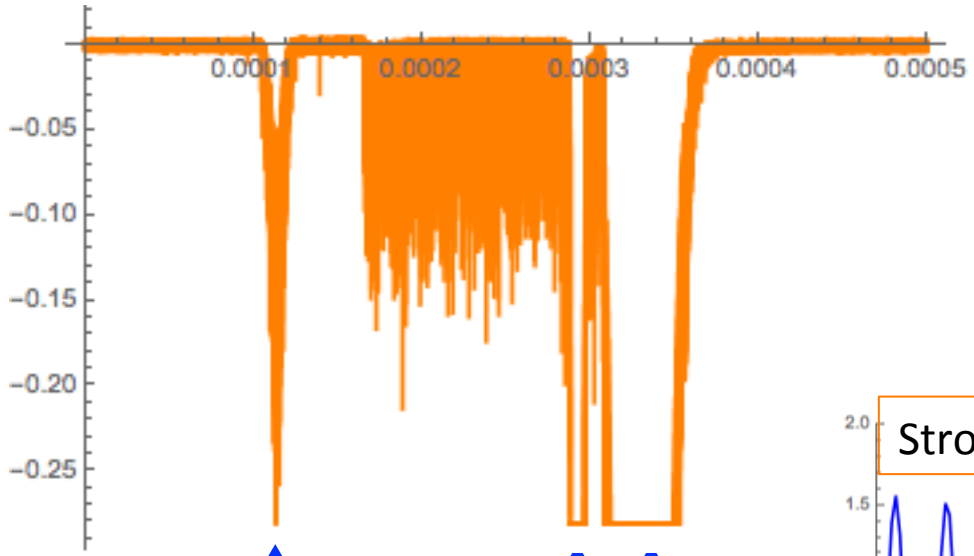


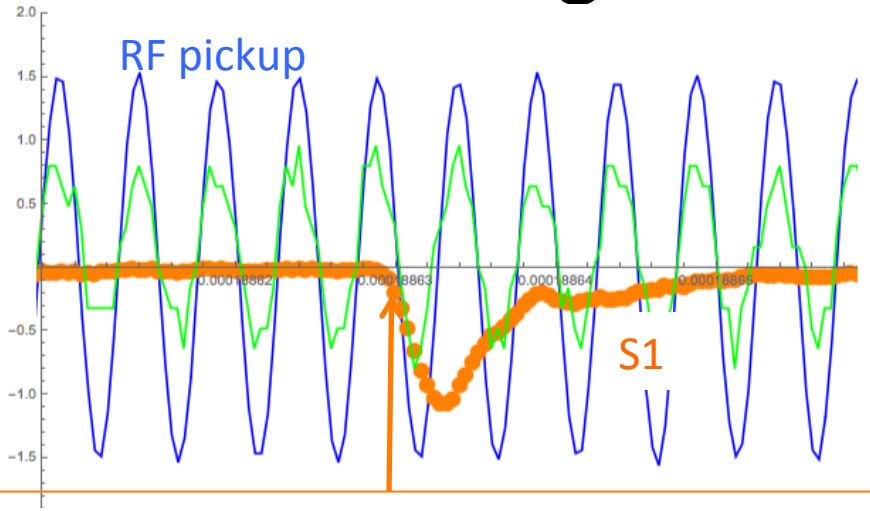




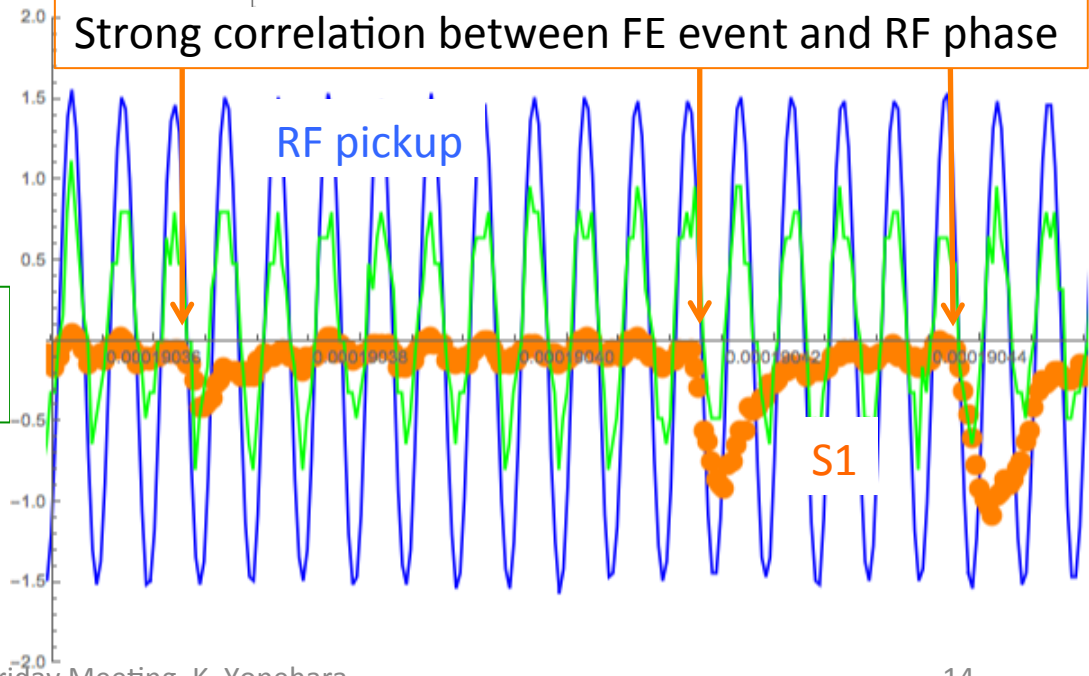
- Start E_{av} of Cu and Be are similar. But, this must be just accident.
- Surface gradient of the Cu cavity (flat) and the Be cavity (curvature) are quite different (factor 1.6).
- Be should emit less FE current wrt the FN theory (see left plot)

RF phase vs field emission electron signal





Strong correlation between FE event and RF phase



Field emission electrons
(Only see on S1)

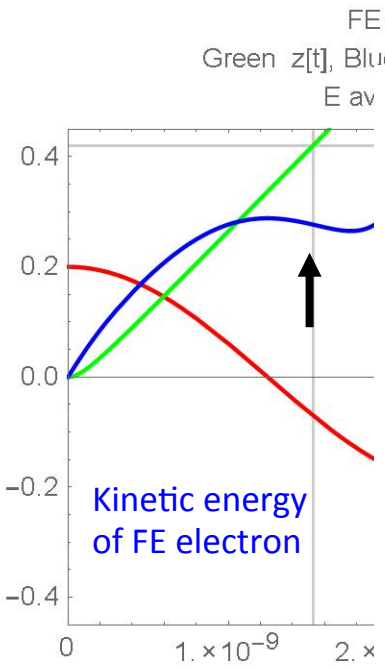
Multipactoring, soft X-ray
(X-ray emission is isotropic
thus, it appears on S1 & S2)

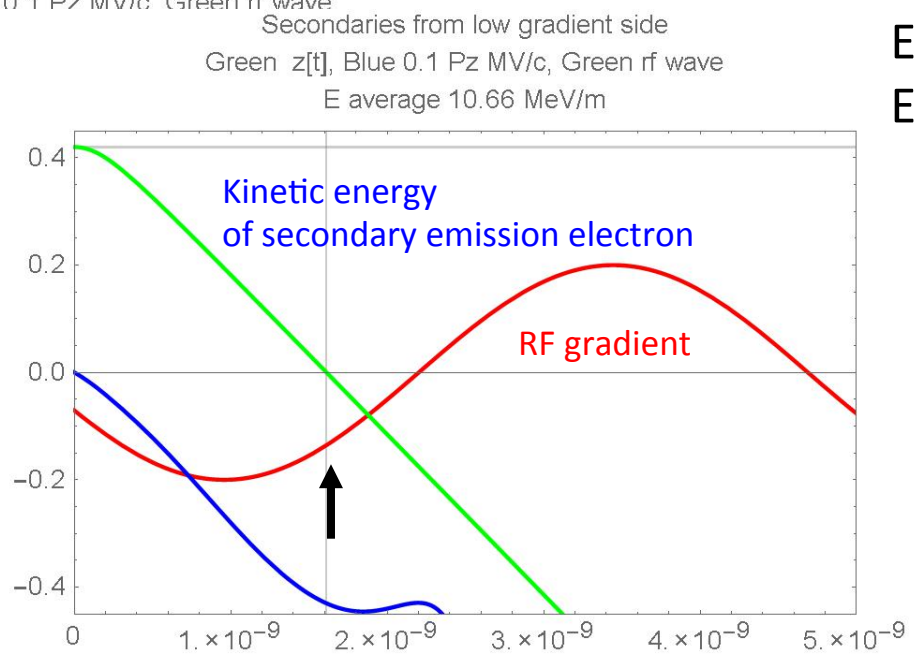
Electron motion in the cavity

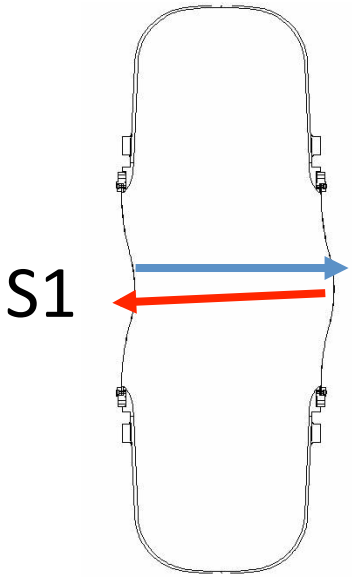
A. Tollestrup, MAP Spring 2015 meeting

Ez left side = 15.5 MV/m

Ez right side = 6.5 MV/m







Blue arrow FE 2.7 MeV @ 10.7 MV/m

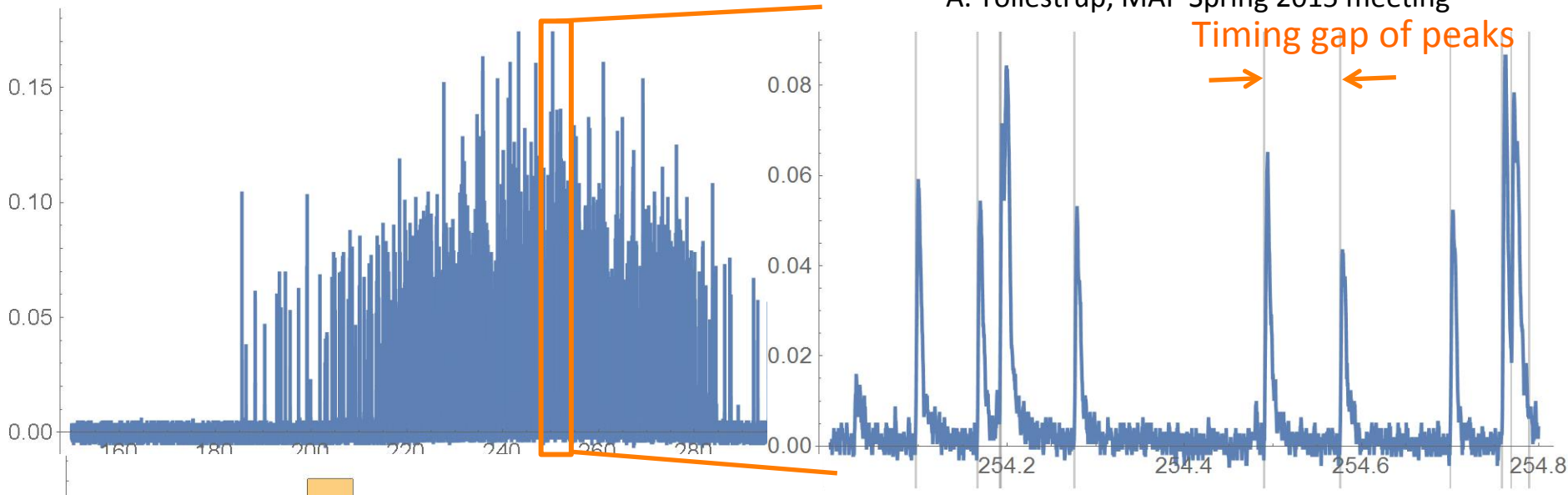
Red Arrow Secondary emission 4.4 MeV

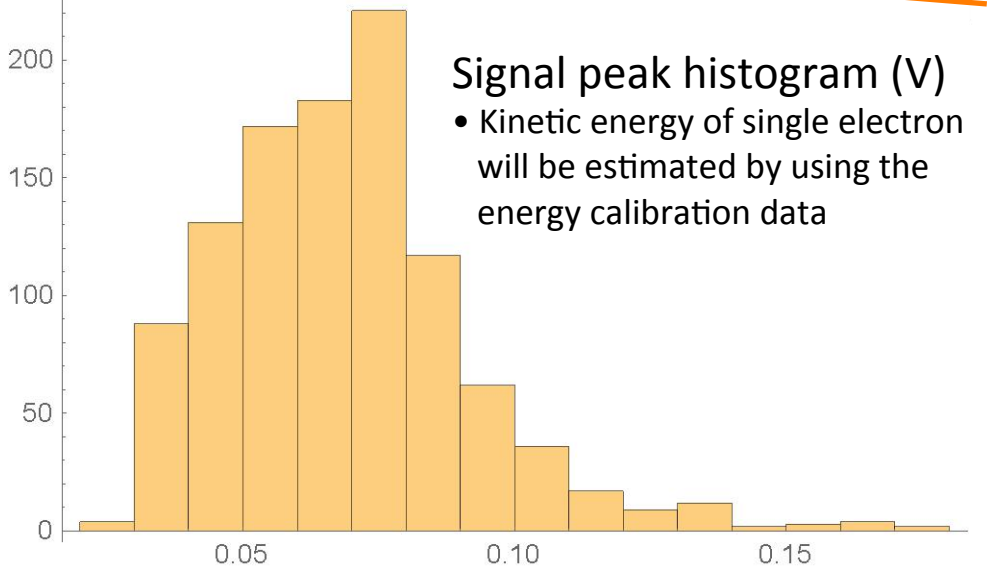
Forward and back trajectories only same on the z axis.

It suggests that the field emission signal should appear every 5 ns

Mystery of missing emitter

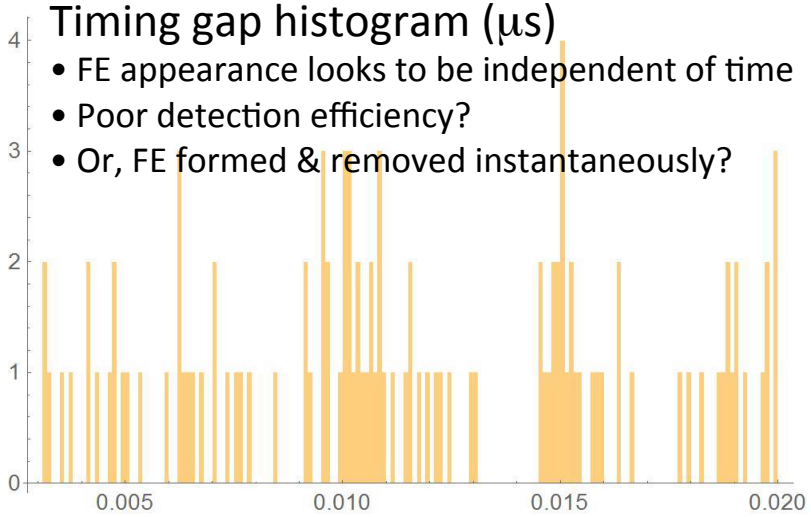
A. Tollestrup, MAP Spring 2015 meeting





Signal peak histogram (V)

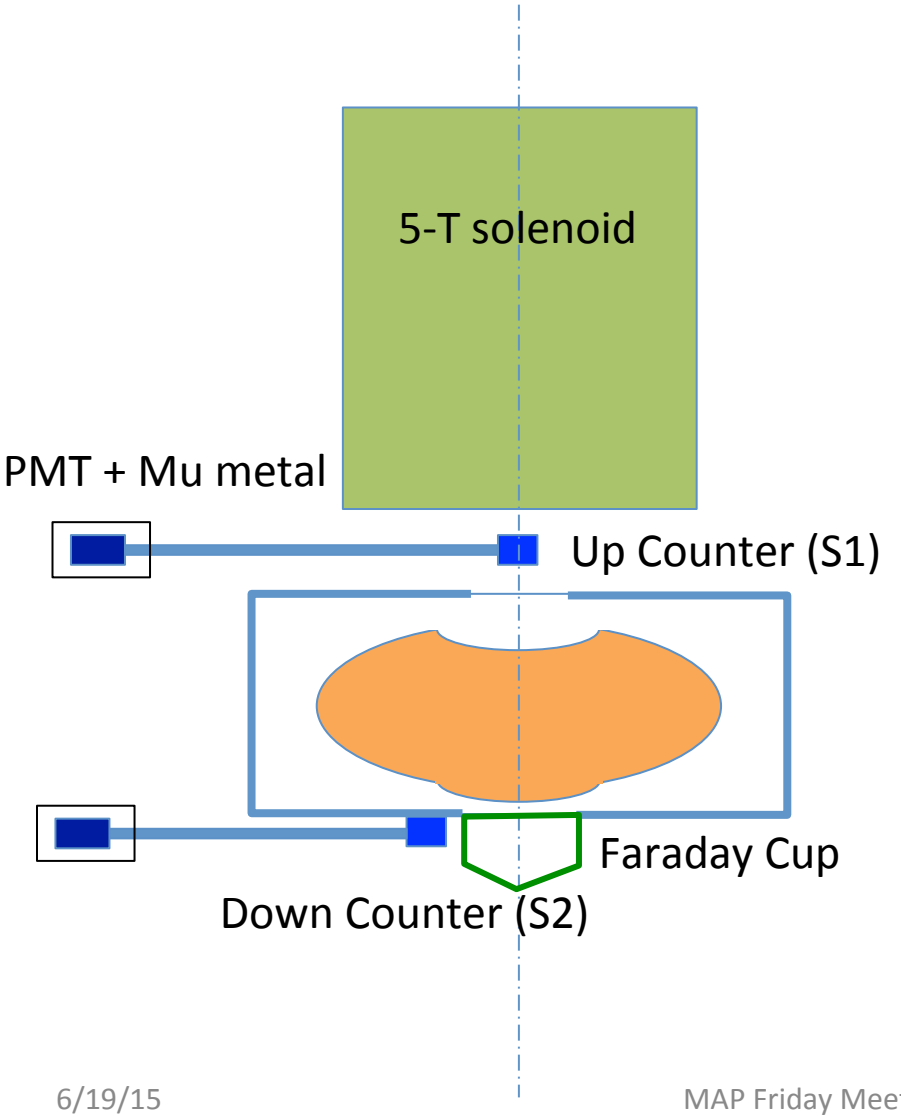
- Kinetic energy of single electron will be estimated by using the energy calibration data

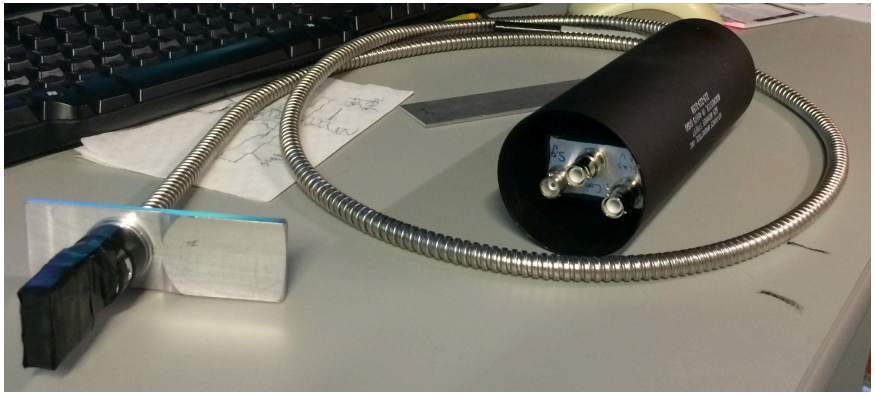


Timing gap histogram (μs)

- FE appearance looks to be independent of time
- Poor detection efficiency?
- Or, FE formed & removed instantaneously?

Radiation measurement with B



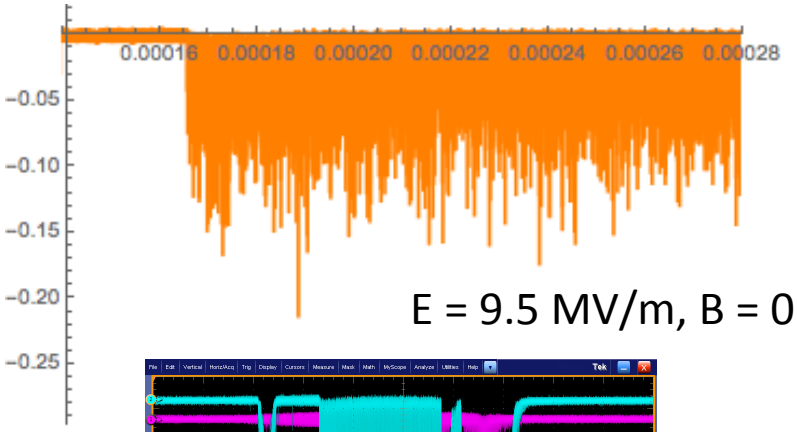


- Plastic counter (BC408, 2.5 cm x 2.5 cm x 1 cm)
- 6-ft optical fiber (8 φmm)
- PMT (H10721-10) inside Mu-metal

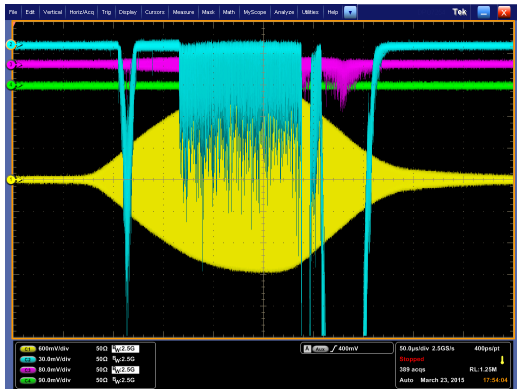
More complicated issue

- Radiation seems to be a big multipactoring when B is turned on

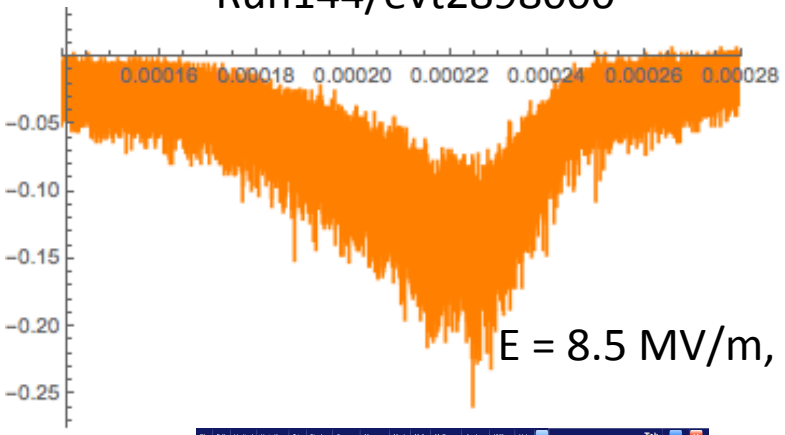
Run130/evt10057



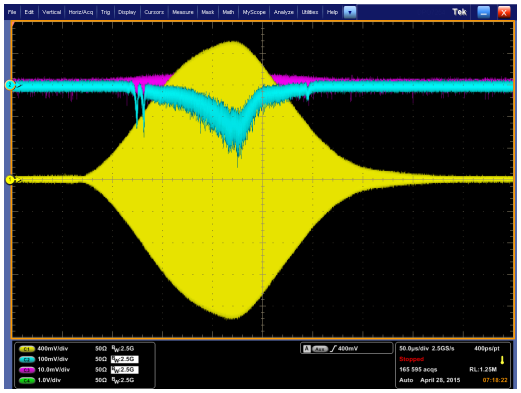
E = 9.5 MV/m, B = 0



Run144/evt2898000



E = 8.5 MV/m, B = 5 T



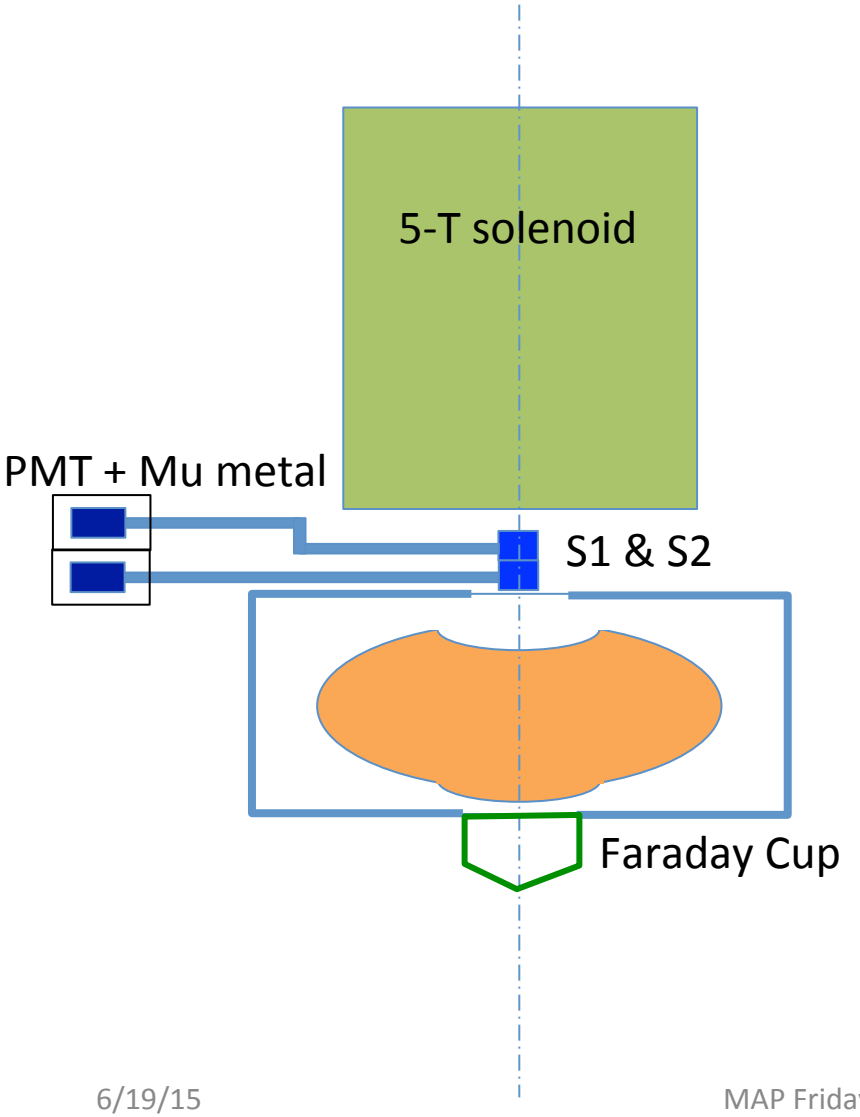
Summary

- Studied characteristic of multipactoring and field emission by using fast plastic counter
- Find strong timing correlation between FE event and RF phase
- FE event seems to be independent of time
- Multipactoring event seems to be dominant when B field is turned on

Planed fast counter measurement

- Find out whether the source of FE event at S1 is single electron or soft X-ray
- Finer time structure of FE event

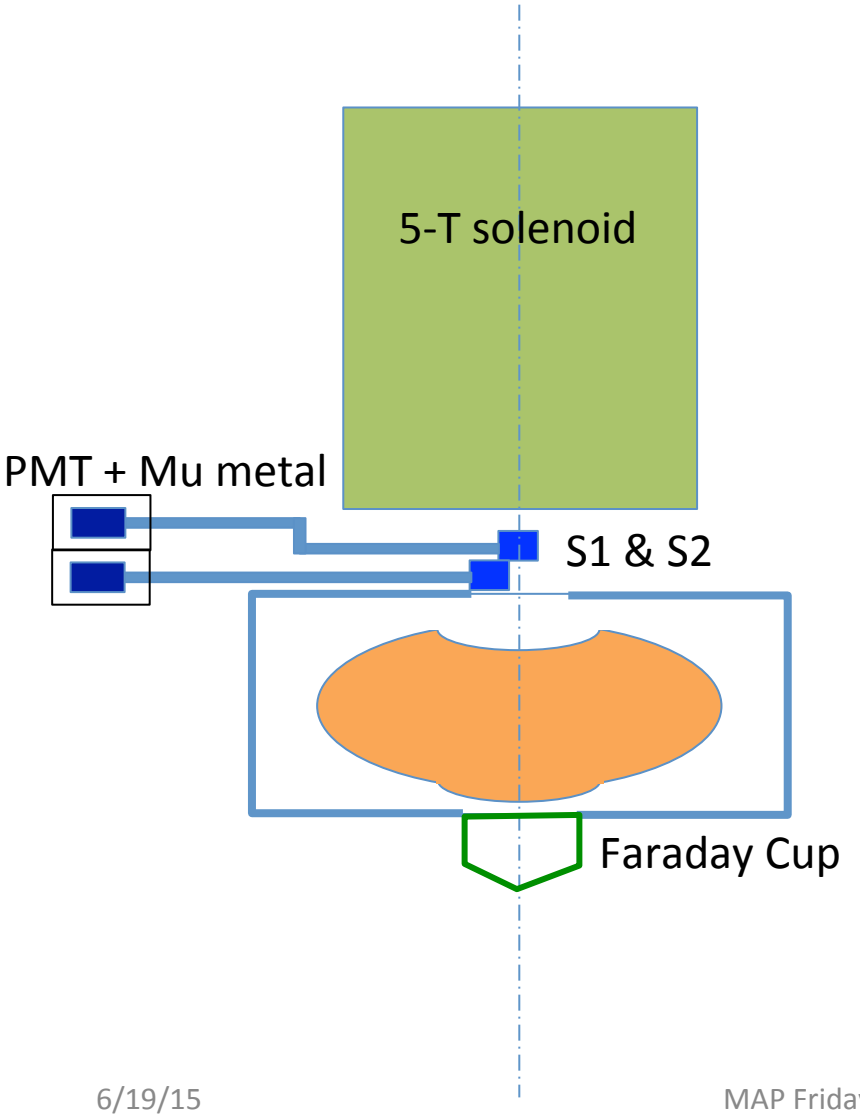
Two counter configurations



Plan 1:

- If the source of FE event is a high energy single electron we should see a coincidence in S1 & S2 in this configuration
- If the signal source is a soft X-ray or low energy electrons we only see a FE signal in the front side counter
- Take data with this configuration w & w/o B field

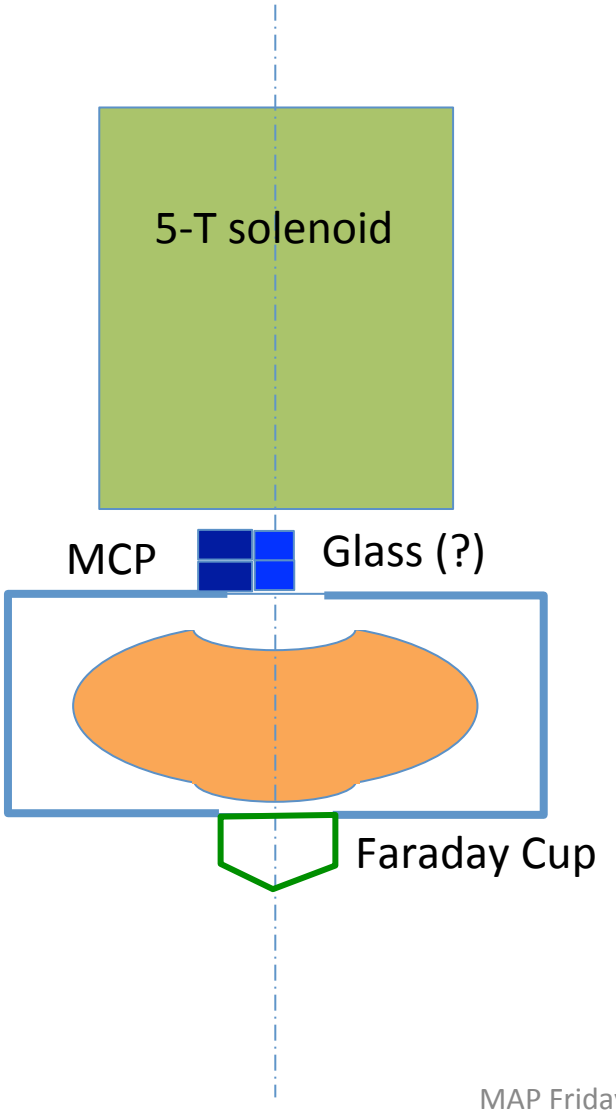
Two counter configurations



Plan 2:

- Measure an angular distribution of FE signal
- Take a coincidence event of S1 & S2
- Take data with this configuration w & w/o B field

Very fast counter



Plan 3:

- Use a Micro Channel Plate (MCP) and a Cherenkov emitter to realize the time resolution ~10 ps
- It requires high RF gradient to overcome energy threshold
- It can distinguish whether the source of FE event is an electron or a soft X-ray