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HIGH PRESSURIZING HYDROGEN GAS FILLED RF CAVITY TEST

Review last test and future plan

CHALLENGE
IN MUON ACCELERATION

- Study muon acceleration for muon collider and neutrino factory
- Muon has a short lifetime (2.2 μs in stationary state)
- Need compact ionization cooling to fit acceptance of SRF system
- High pressurizing hydrogen gas filled RF (HPRF) cavity is proposed to apply in ionization cooling channel
- HPRF cavity has two functions
  - HP hydrogen gas is used for Ionization cooling
  - RF field compensates energy loss
- In addition, dark current is suppressed by HP gas, hence it can operate under high magnetic field

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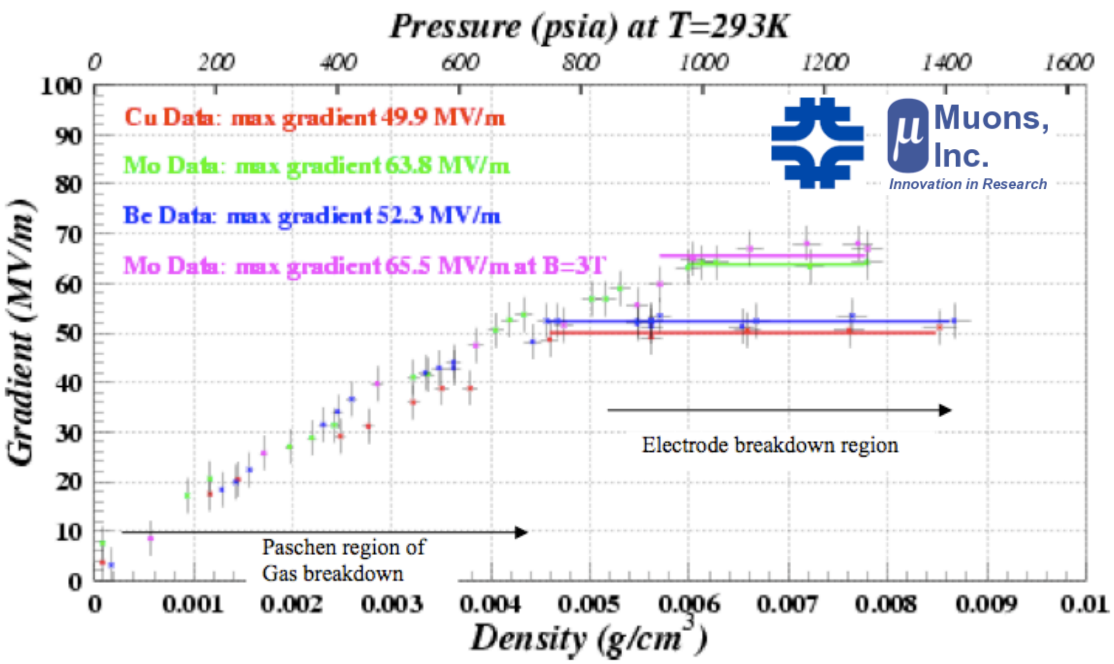
HPRF R&D HISTORY

- The HPRF project has been started in 2002 (Muons, Inc./IIT awarded DOE SBIR/STTR fund)
- Obtained first result in 2002 by using Mk-I test cavity
- Made a new test cavity (Mk-II) in 2003
- Discovered B-field insensitivity in the HPRF cell in 2006
- Proposed beam test in 2005
- Constructed MTA beam line in 2008
- Commissioned beam in 2009
- Beam will be ready in 2009



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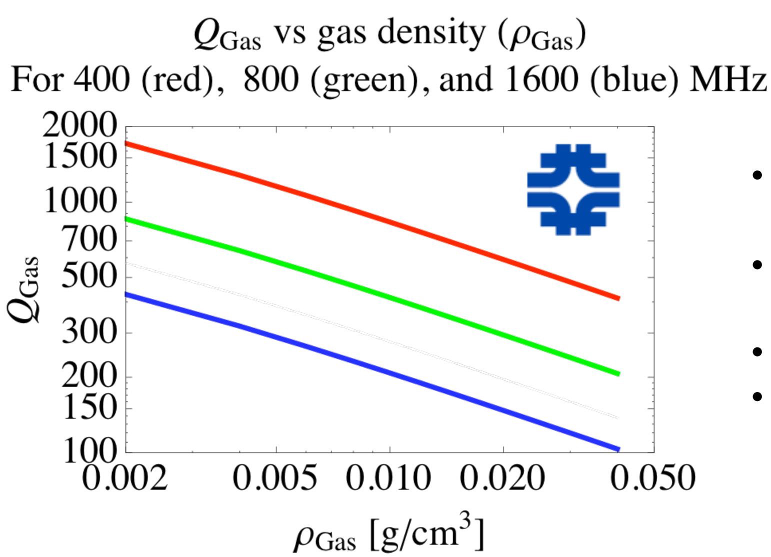
SCIENTIFIC GOAL

- Scientific goal of current project
  - Demonstration of HPRF cavity for muon collider and neutrino factory
  - Investigate dynamics of electrons in HPRF to improve the system
    - Huge RF power dissipation in electrons should be removed



- Q_{Gas} is an effective Q value based on an RF power dissipation in the HP GH2
- Assume 6 10^9 μ/bunch × 16 bunches = 10^{11} μ passing through the HPRF cell
- Higher Qgas means larger power dissipation
- No electron absorption process is included in this simulation

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CAN WE OPERATE HPRF WITH HIGH INTENSITY BEAM?

What's the challenge?

If there is no (or negligibly small) electron absorption process…

- 10^{11} to 10^{12} μ/bunch (total 10^{13} μ/sec) will pass through HPRF
- Generate secondary electron
- Electron will be accumulated by many RF cycles
- Form electron swarm (density will be > 10^{14} /cm^{3}!)
- RF power will be dissipated in electron swarm
- RF field quality factor will be degraded
- Insufficient RF power for later coming muon beam

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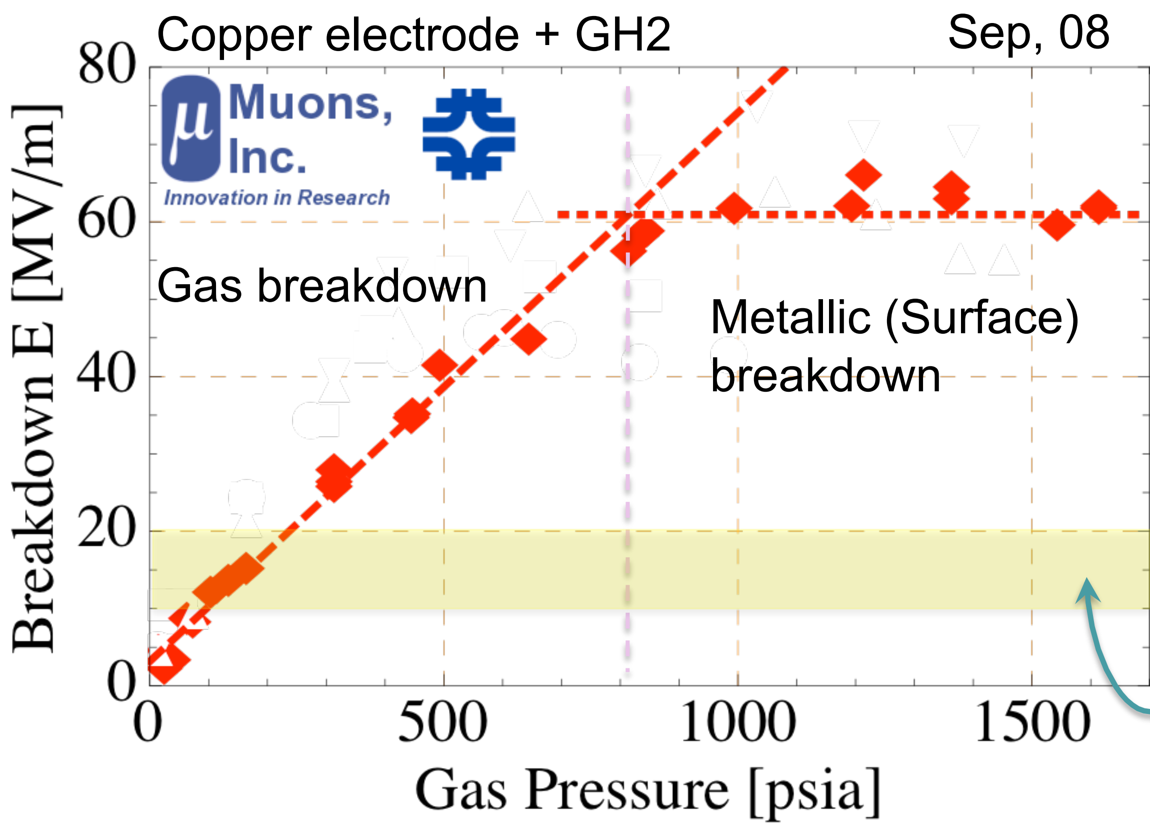
HOW TO SOLVE?

- More investigation is required
  - Recombination rate ($H^{+}_{(n)}$+e → $H^{0}_{(n)}$, n=1,2…)
  - Hydrogen has many branches, i.e. attachment of electrons (H_2+e → H^{-}+H)
  - Those are strongly dependent on electron temperature
- Electronegative gas will remove electron swarm

BREAKDOWN IN HPRF



Gas breakdown:

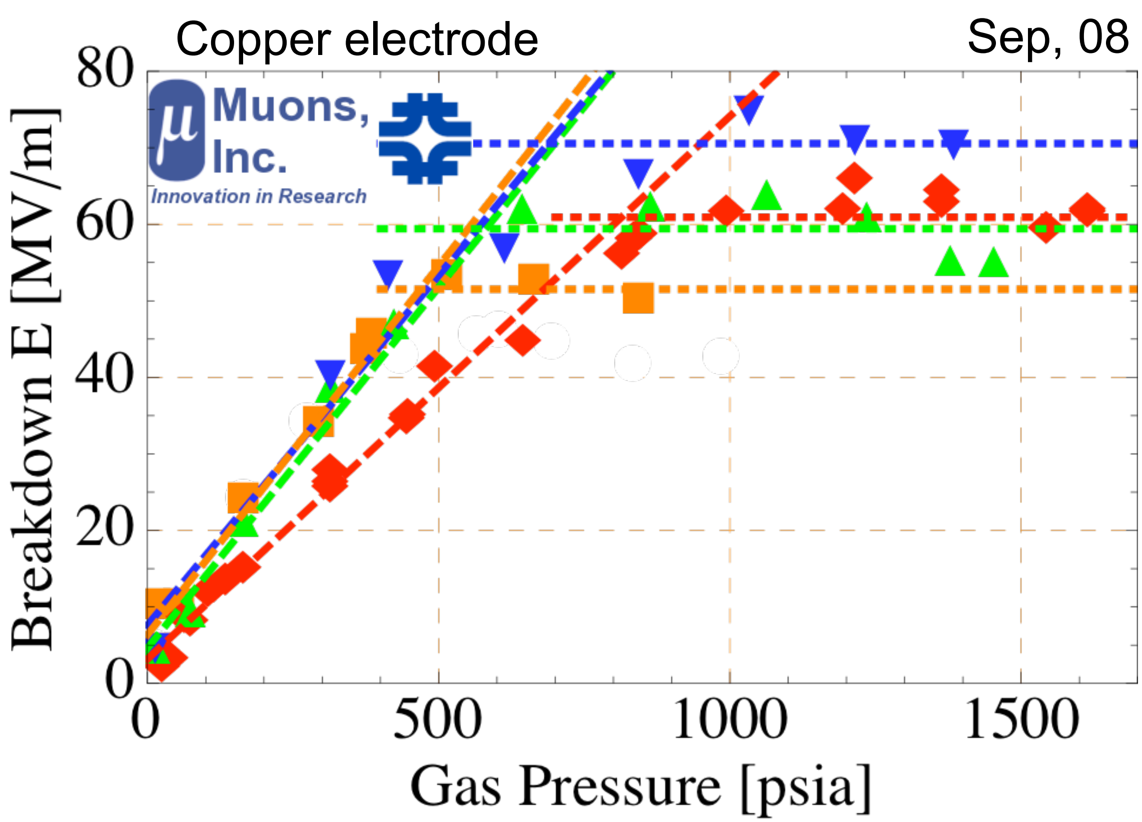
Electron is stopped by gas.
Hence, E/p is determined by gas species.

Metallic breakdown:

Breakdown E is constant.
Same breakdown E is observed in evacuated RF cell.
Plasma may be formed by molten elecrode.

Ex) Design E for helical cooling channel is 10~20 MV/m.

ELECTRONEGATIVE GAS MEASUREMENT



H2+SF6 (0.2 %)
H2
H2+SF6 (0.01 %)
N2

E/p [MV/m/psia]

0.096 N2
0.071 H2
0.094 H2+SF6 (0.01 %)
0.091 H2+SF6 (0.2 %)

Plateau [MV/m]

52 N2
61 H2
59 H2+SF6 (0.01 %)
71 H2+SF6 (0.2 %)

COMPARE WITH SIMULATION

- Numerical simulation has been done by D. Rose (Voss Scientific)
- The expected breakdown E value in H2+SF6 (0.01 %) is 38 MV/m @ Gas pressure = 325 psia
- Experimental result is 39 MV/m
- A reasonable agreement in both values

SF6 IN CAVITY

Preliminary inspection

- Scanning electron microscopy (SEM) has examined and elements attached on the electrode surface has been found
- Black discolorations are made of carbon compound and sulfur
- We do not know where these elements come from
- More chemical investigation is required

FAST SIGNAL

PMT

RF pickup

RF reflected

RF forward

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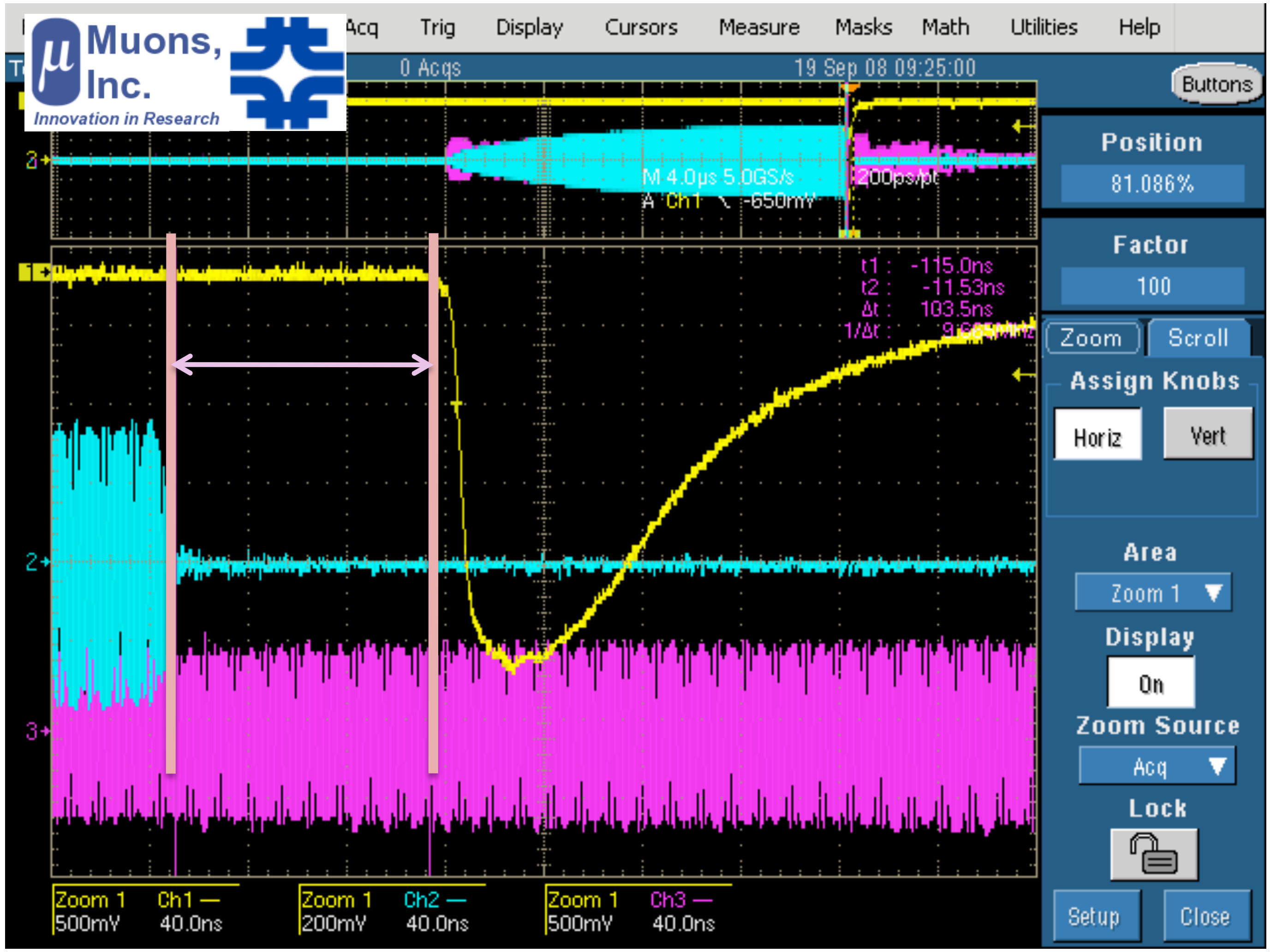
OPTICAL SIGNAL

- Very high intensity light is emitted at breakdown event
- PMT is saturated
- Rise time of light is 4~5 ns that is very close to the PMT rise time (3 ns)
- Timing delay is Measured
- Timing delay was calibrate within 10 ns
- Need fine timing resolution detector in the next test



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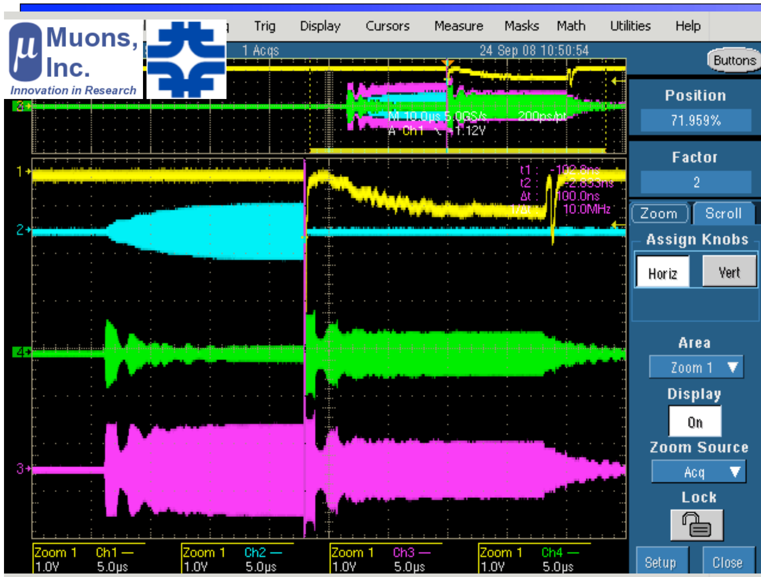
MORE THOUGHTS

Neutrino Factory

Muon Collider

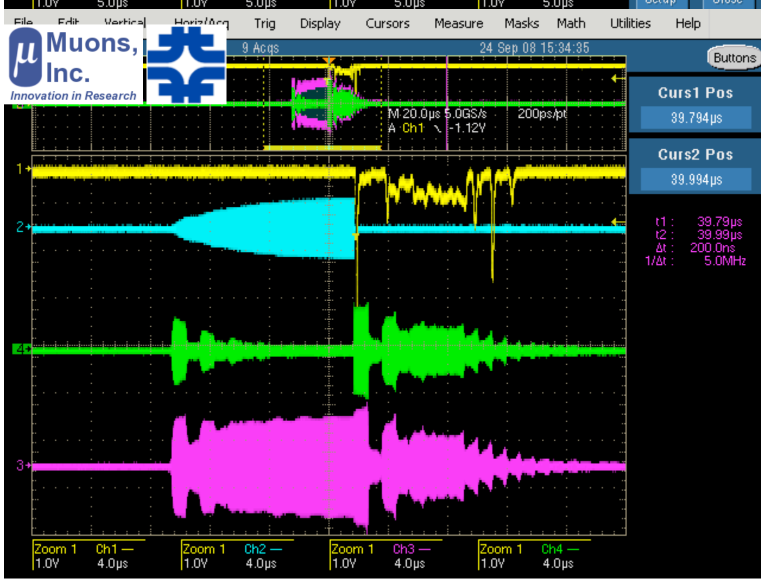


Optical signal in a pure H2:

We sometime observed continuous light emission after the big flashing.

It seems to be a glow discharge.

RF structure never be back to normal.



Optical signal in H2+SF6 (0.01 %):

Above condition happens even in a dopant gas.

SF6 cannot kill a conductance.

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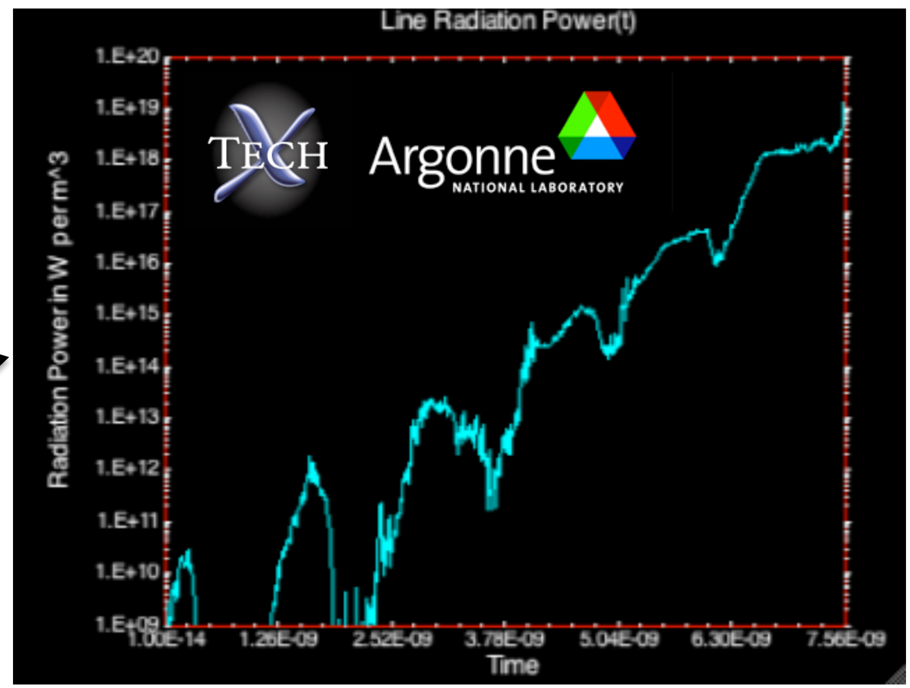
PHYSICS INTEREST

- Very high intensity current flow in big breakdown
  - Expected electron density is 10^{16}~10^{20} /cm^3
- Our interest is not such a breakdown!
- Our interests are:
  - Physics with electron density of the order 10^{14} /cm^3
  - Dynamics of electrons in HPRF
- Fine spectroscopic measurement is required

REQUIREMENTS FOR SPECTROMETER

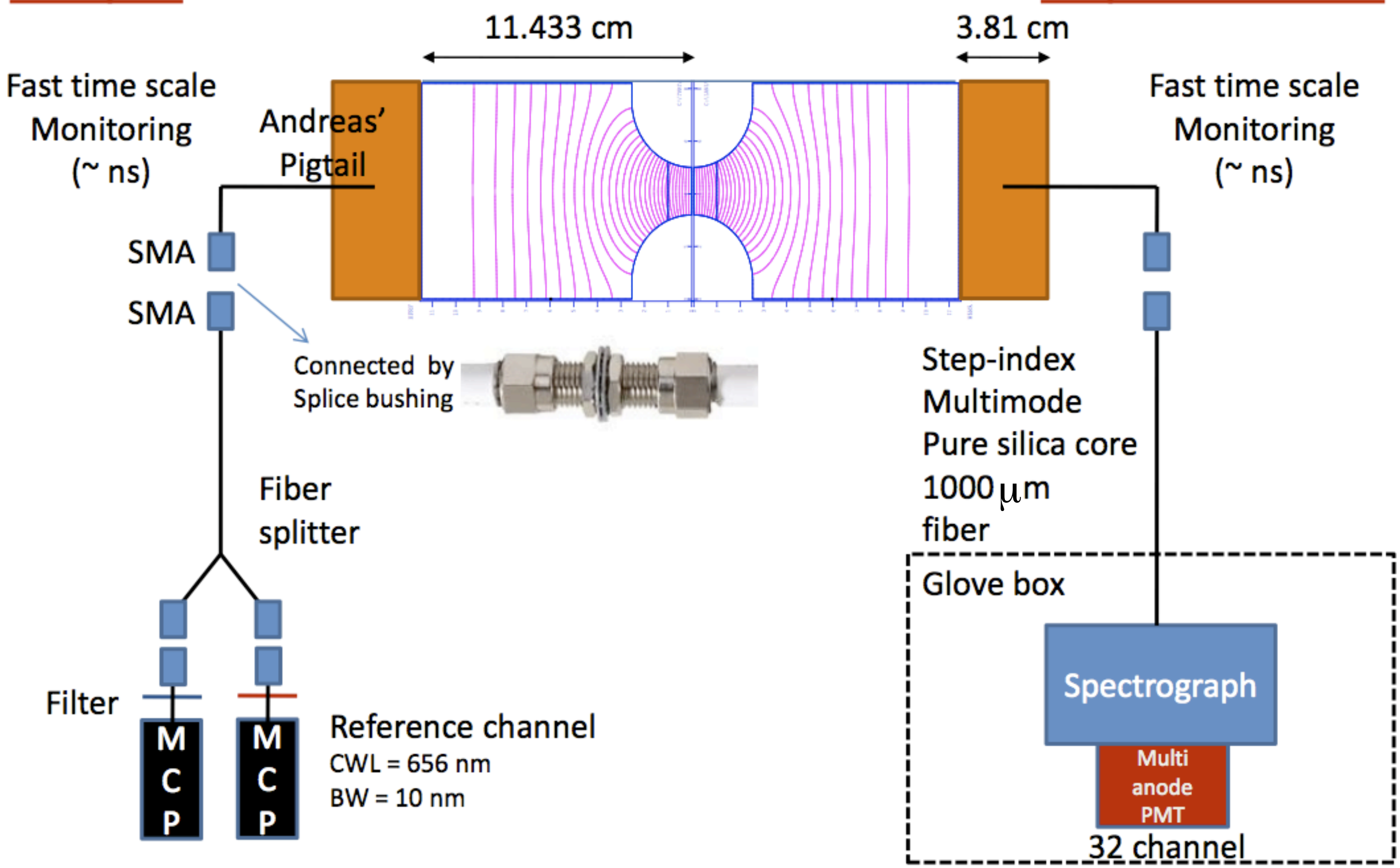
- Fast timing
  - Interesting physics process happens in ns
- Time evolution
  - Trace specific physics event

PIC simulation result;
Light emission from
molten (plasma) copper



SPECTROMETER

Simple — M. Chung — Sophisticated



CONCLUSION

- HPRF cavity will be a great tool to make a compact ionization cooling channel
- Propose demonstration of HPRF cavity with high intensity beam at MTA beam line (400 MeV proton)
- Considered physics processes those will take place with a high intensity beam passing through HPRF
- Electronegative gas (SF6) has successfully tested
- Experimental result is reasonably agreed with simulation
- We design a fast spectrometer to investigate dynamics of electrons in HPRF

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PUBLICATIONS

- K. Yonehara et al, “Hydrogen-Filled RF cavities for muon beam cooling”, PAC’09
- A. Tollestrup et al, “Handbook for gas filled rf cavity aficionados’”, to be submitted to PRSTAB
- M. Chung et al, “Mitigation of Plasma Effects in High Pressure RF Cavity for Ionization Cooling”, NFMCC-doc-#532
- M. BastaniNejad et al., “Studies of Breakdown in a Pressurized RF Cavity”, EPAC’08, MOPP080
- M. BastaniNejad et al., “Evidence for Fowler-Nordheim Behavior in RF breakdown”, PAC’07, WEPMS071
- P. Hanlet et al, “High Pressure RF Cavities in Magnetic Fields”, EPAC’06, TUPCH147
- R. Johnson et al, “A Short Overview of Muons, Inc. Projects and Proposals”, COOL05
- R. Johnson et al, “Technical Challenges of Muon Colliders”, NuFact05

More publications before 2005