Physics in high pressure hydrogen gas filled RF cell

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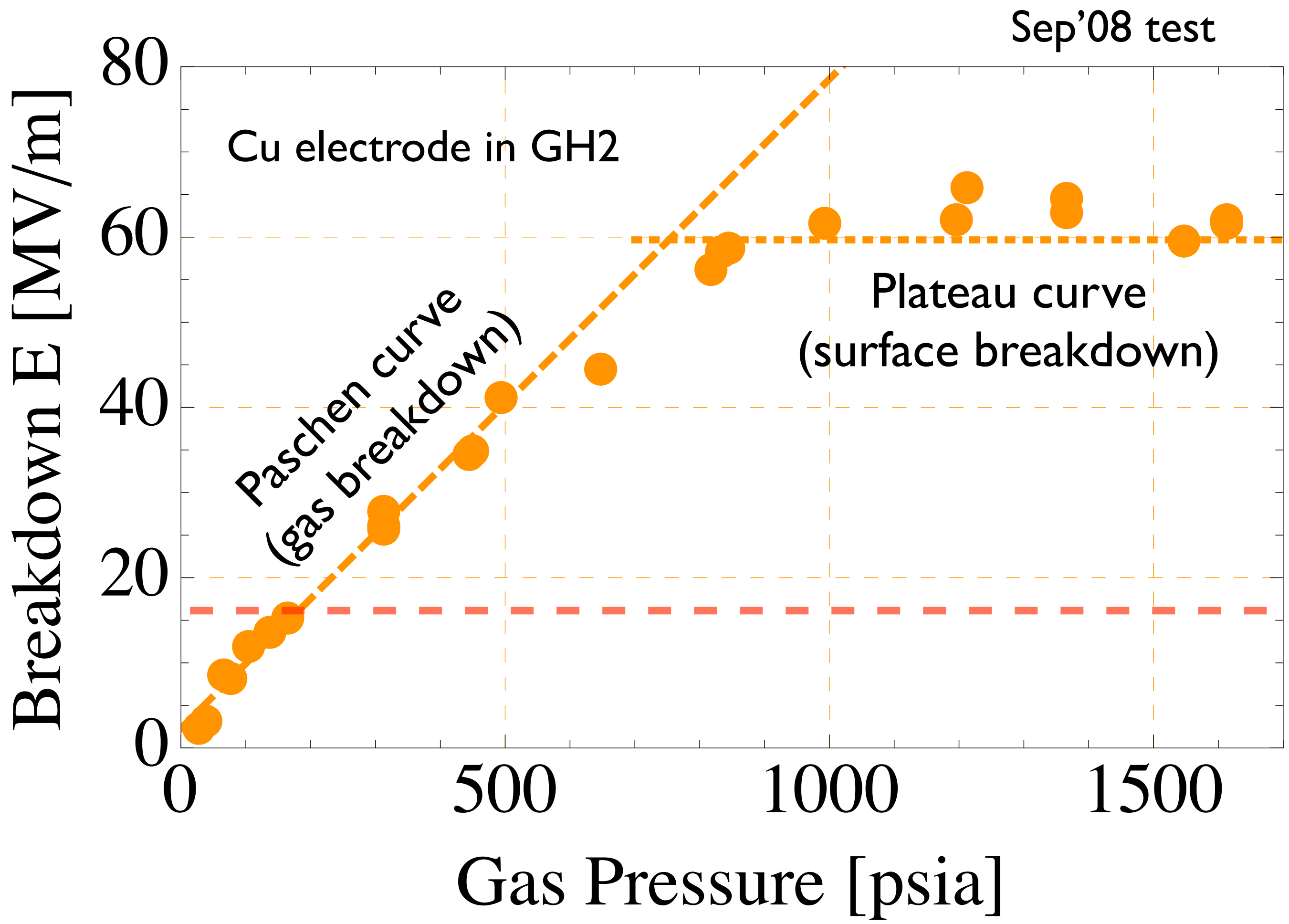
Introduction: Overview from past tests

Goal:

Investigate high pressurized GH2 filled RF (HPRF) cavity for muon collider



Design field in HCC

(Note!!
Design pressure = 200 atm
Maximum pressure in this plot
~ 100 atm)

Facts:

- Observed maximum E field in Cu was three times higher than the current design field in helical cooling channel (HCC)
- HPRF was successfully operated in high magnetic field
- We found that there are two RF breakdown phases

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Introduction: Questions

Questions:

- Can HPRF work under high radiative environment?
- What is two breakdown phases?
- What is breakdown?
- Study capability of the HPRF for various applications

⇩ To obtain these answers...

- Run with beam
- Run with new diagnostics

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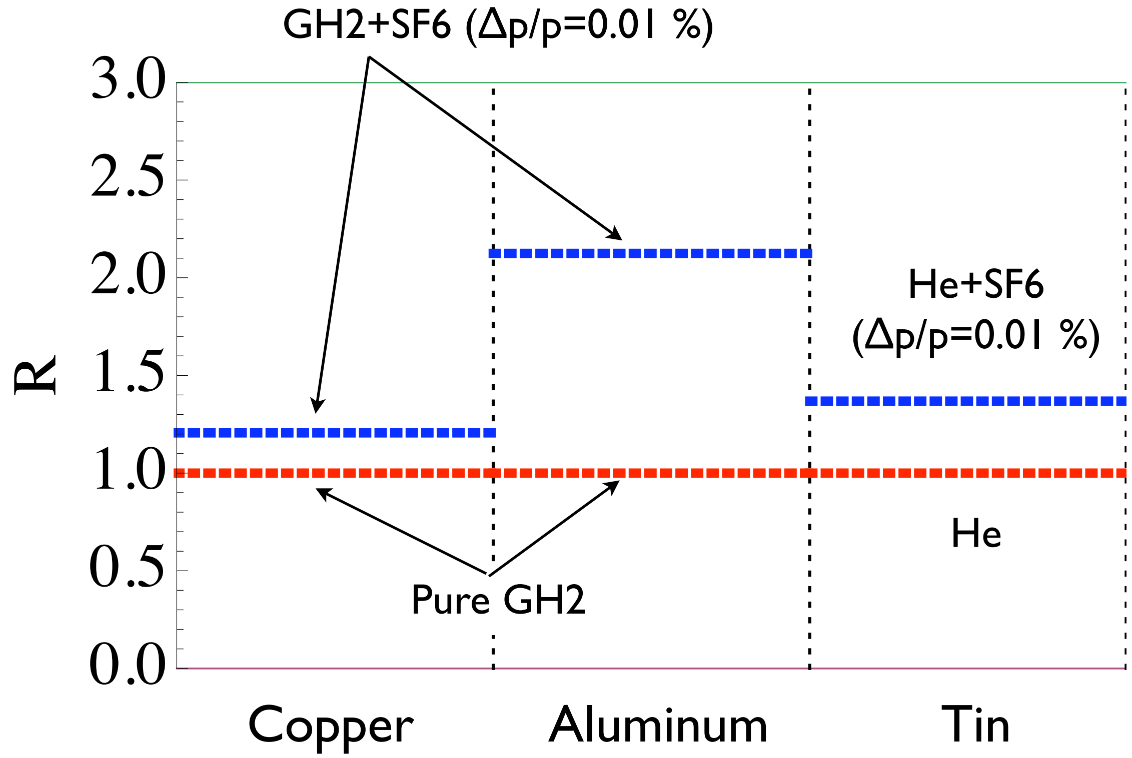
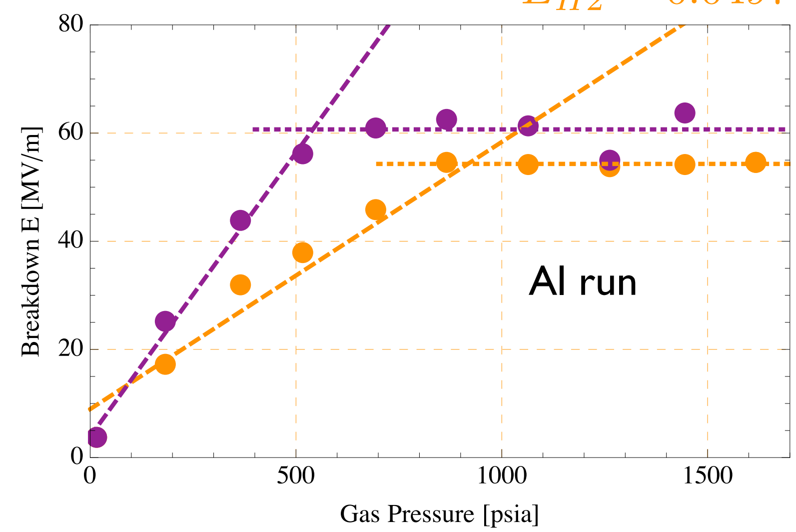
Dopant gas effect

$$R = \frac{\text{Paschen slope in } SF_6 \text{ dopant}}{\text{Paschen slope in pure } GH_2}$$

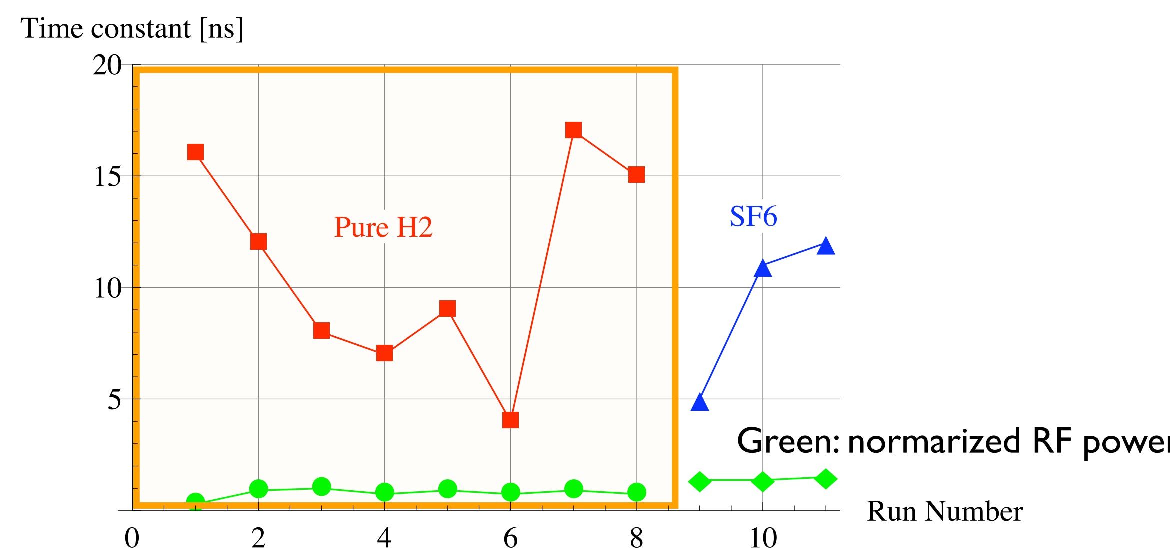


$E_{SF6} = 0.1076 \times Pressure + 4.378$

$E_{H2} = 0.0497 \times Pressure + 9.406$



- There will be an electron swarm generated by beams
- Remove the swarm is important to keep a good Q-value in the HPRF cavity
- SF6 was tested as a dopant gas
- It makes steeper Paschen slope
  - But no time constant difference with a dopant gas (see right plot)
  - "R" values are varied with different materials → Large measurement error? or R depends on material??



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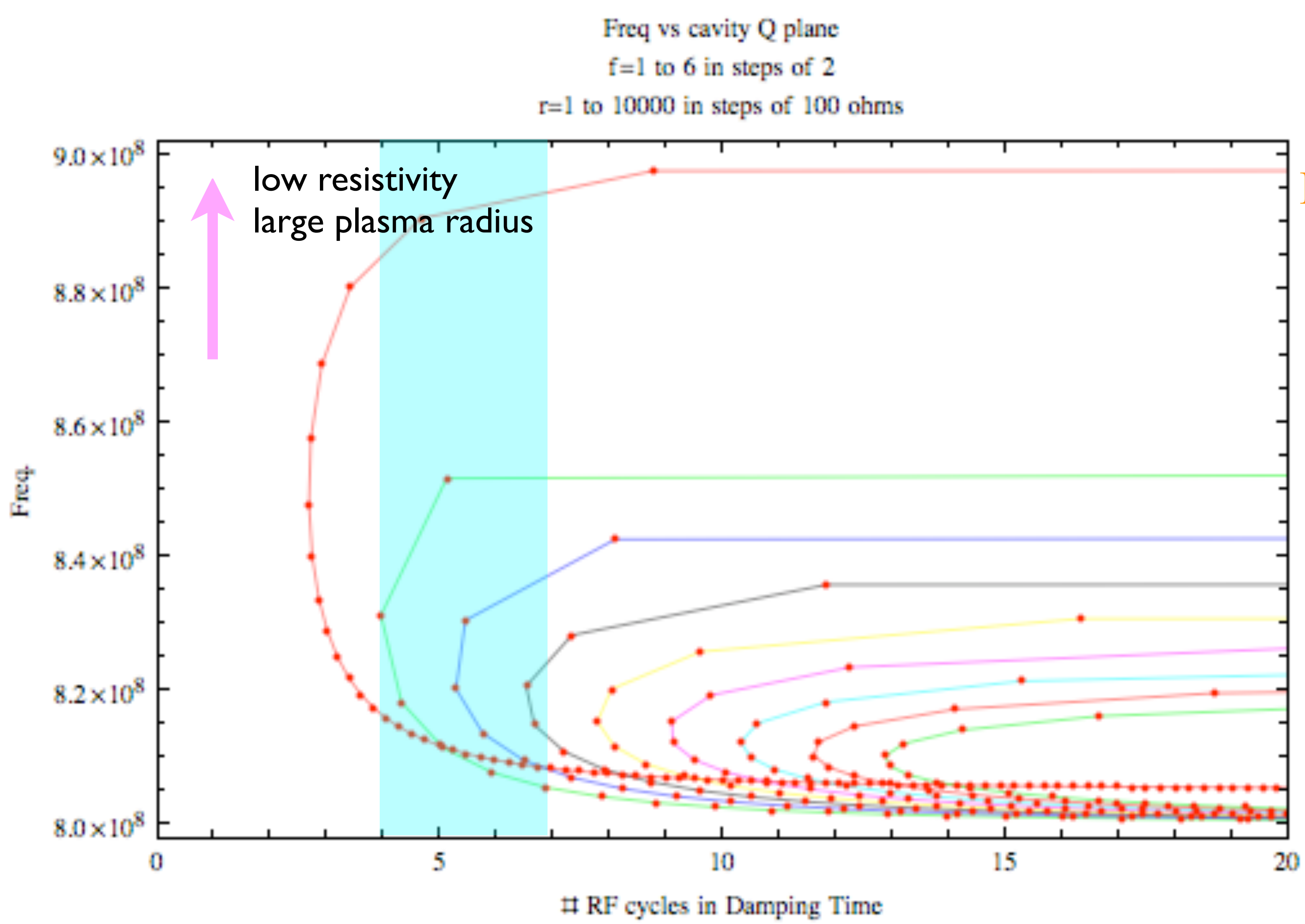
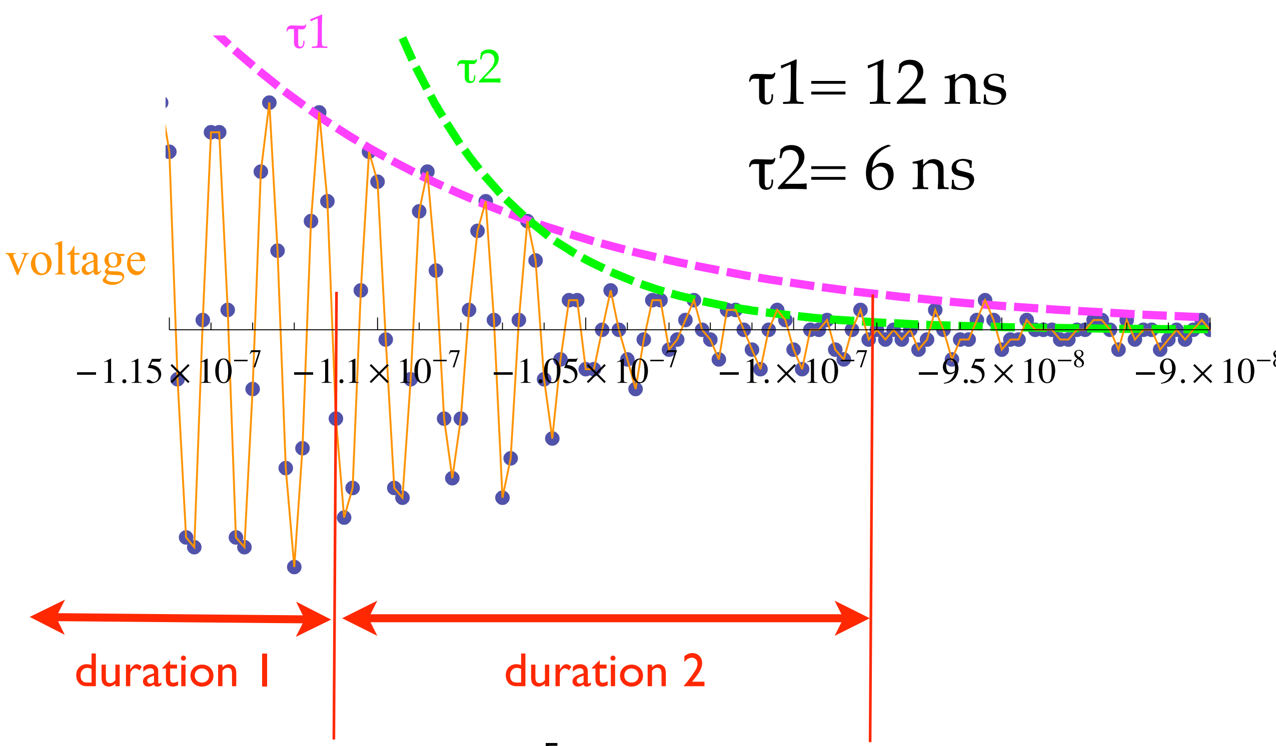
Plasma condition in breakdown

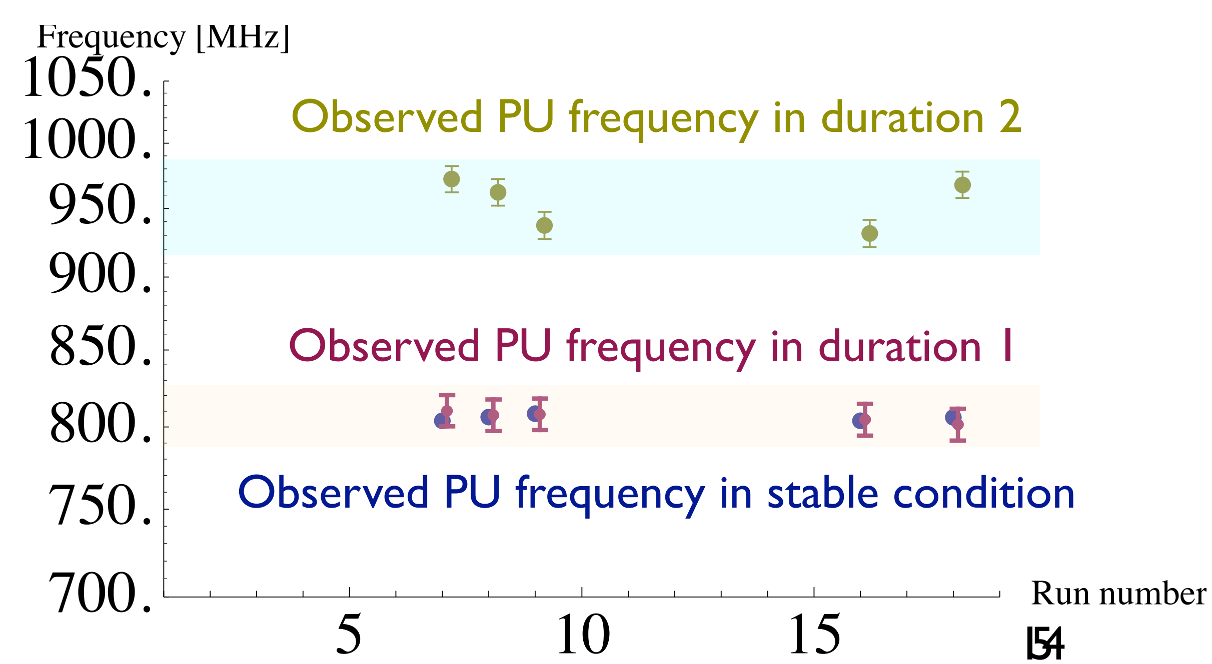
Alvin





run#	Frequency in stable	Fitting error		Frequency in duration1	Error		Frequency in duration2	Error	
7.	803.818	-0.224	0.224	810.257	-10.	10.	972.057	-10.	10.
8.	806.235	-0.346	0.346	807.45	-10.	10.	962.012	-10.	10.
9.	808.347	-0.36	0.361	808.081	-10.	10.	937.373	-10.	10.
16.	803.906	-0.412	0.413	804.593	-10.	10.	931.372	-10.	10.

- Resonant condition can be changed by a plasma formation in the cavity
- The plasma shape can be estimated from observed frequency and decay time
- Observed resonant frequency after breakdown is always higher than the frequency in stable condition
- This model predicts well this tendency
- We are waiting for the numerical simulation



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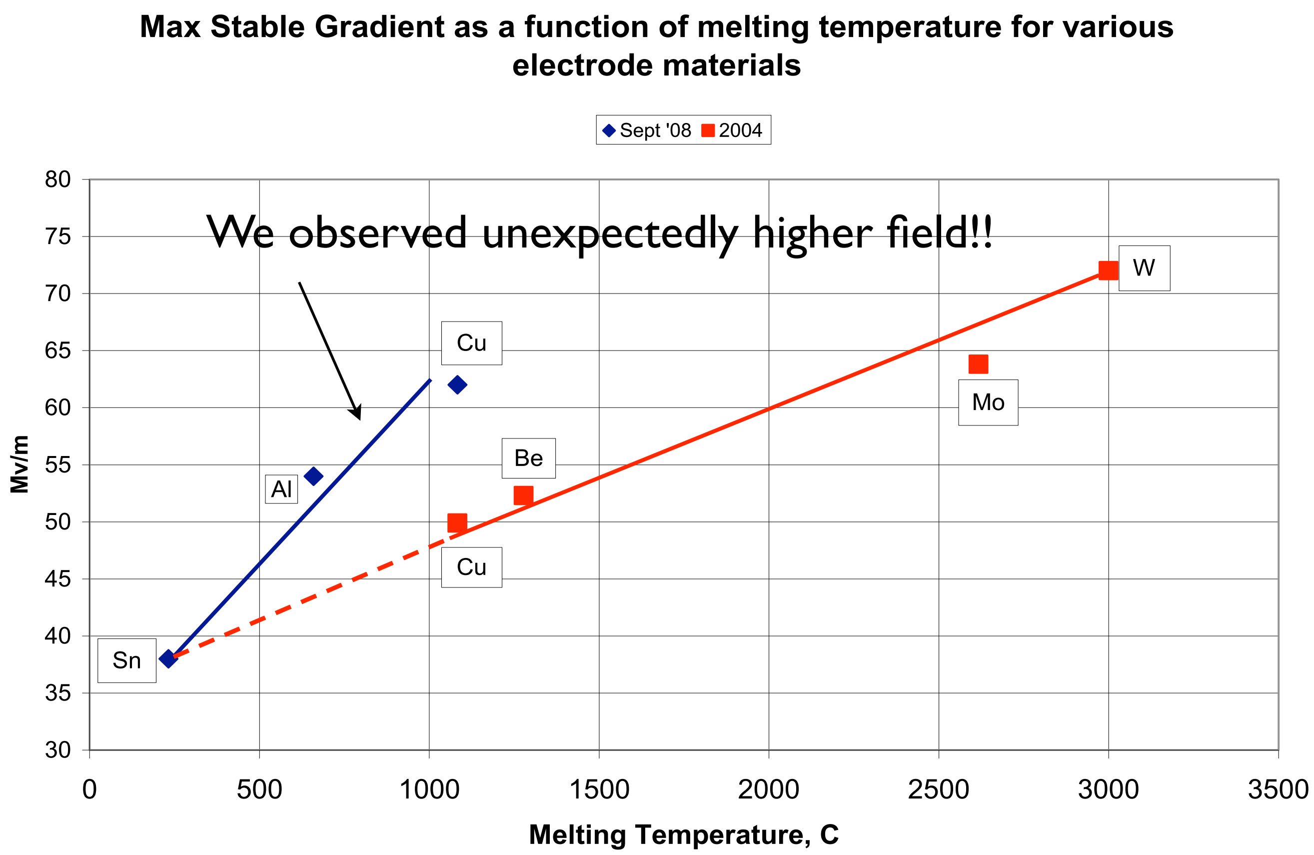
Melting point vs Breakdown field

Some people consider that the surface breakdown is determined on the melting point of the electrode

M. Neubauer



From SEM study

With regards to the copper electrode, copper sulfate was found, carbon, and some oxide. These compositions most likely increased the work function over pure copper and contributed to higher breakdown gradients.

With regards to the aluminum electrode, there appears to be ample evidence of Al2O3, with a thickness TBD that may have contributed to a higher work function and higher breakdown gradients than pure aluminum.

Some people suspect "Melting point" model

- Required (RF) power to reach the melting temperature by resistivity seems to be much higher than the current operation power → Need simulation
- Impossible to quantize the contamination → Impossible to reproduce the field grad in last measurement
- Take a pure Cu run again and add new materials to test this model

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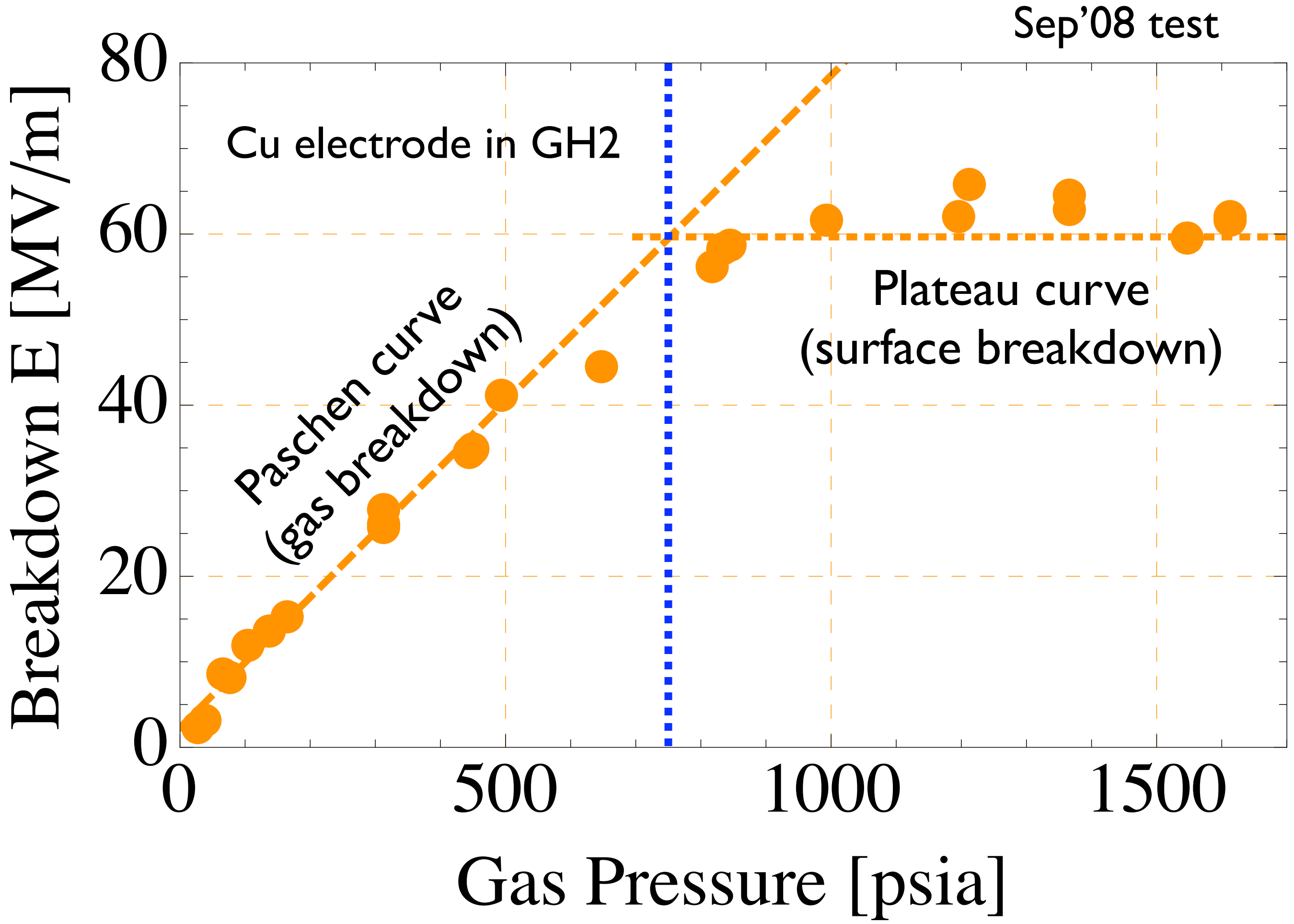
Optical spectroscopic measurement



- If the breakdown process in Paschen region is dominated by the gas dynamics a strong hydrogen spectra will be observed in the spectroscopic measurement.
- On the other hand, the breakdown process in Plateau region is dominated by the electrode surface condition a strong metallic spectra will be observed in the spectroscopic measurement.

- Other ambitious: We saw a precursory light in last optical measurement, which is generated before and after the breakdown. The spectra before and after the breakdown would be different because the electron dynamics are different during the transit time.

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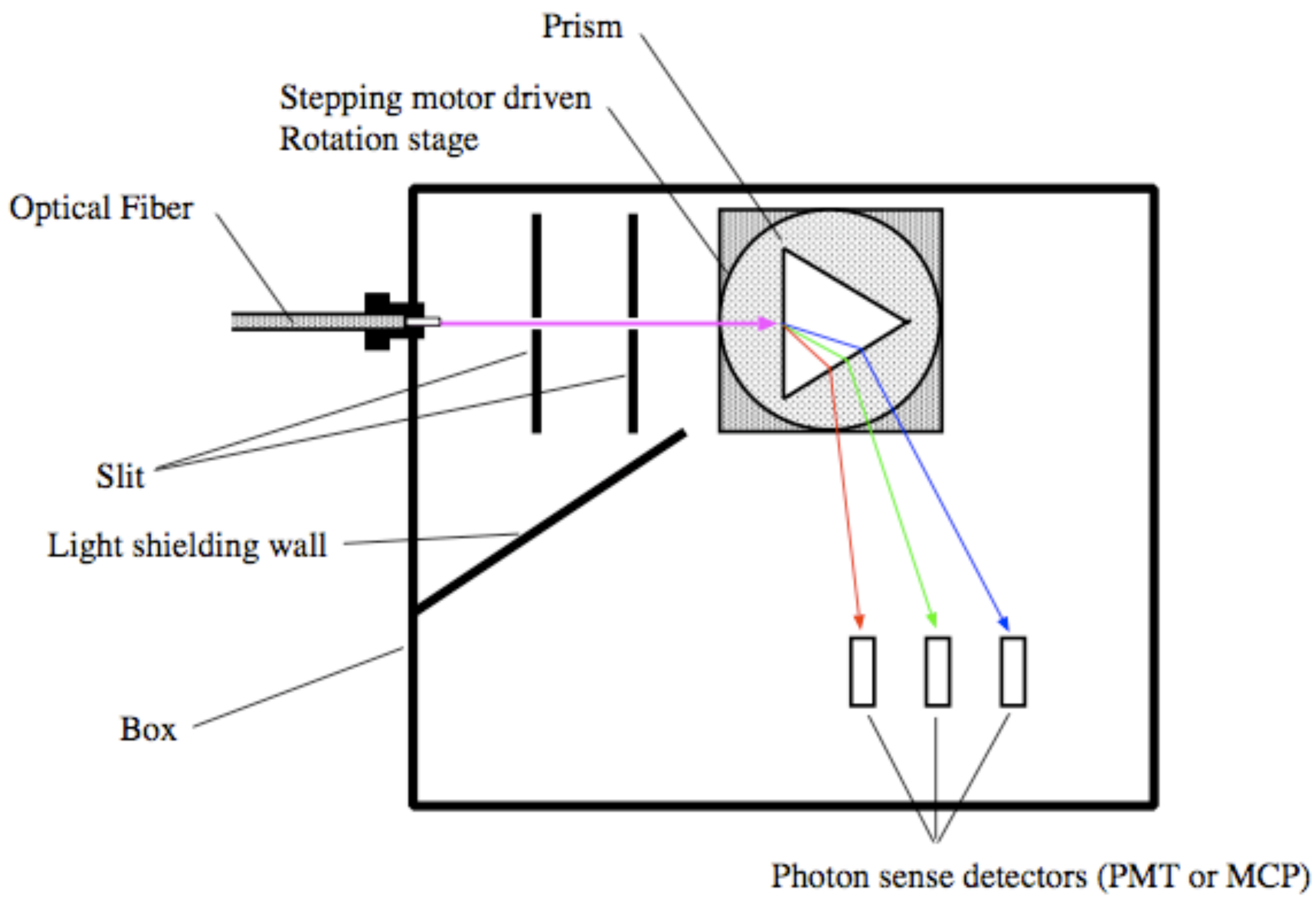
Design fast spectroscopy

- Wide range of spectra (UV to IR) is desirable
- Required wavelength resolution is less than 1 nm
- Fast data acquisition is required (a couple of ns)



Spectroscopic measurement device

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Beam test

- Very important to demonstrate the HPRF under high radiation environment
  - 400 MeV proton beam will be ready at MTA
  - There is a limitation of beam intensity due to the radiation safety issue
  - Probably, we can inject one beam per minute and operate one hour
  - Number of bunches in stable operation can be changed from 5 to 2000 bunches
  - Number of protons per bunch is $\sim 10^8$, hence beam intensity can be varied $10^8 \sim 10^{11}$ (Duration time is 5 ns = 1/200 MHz)
- How comparable is this test with a muon collider beam?
- Run plan: Observe beam intensity dependence, (various) gas pressure dependence, and dopant gas dependence

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To-Do List

- Need to satisfy the hydrogen safety requirements for new configuration
- Design and setup a new spectroscopic measurement device
  - Fast signal : Use PMT, MCP, or SiPM
  - SiPM would be preferable because its low bias voltage would relax the limitation of hydrogen safety issue
  - Need to modify current (Ajit's) data acquisition system
- Prepare beam test
  - Need radiation safety hazard report to DOE
  - Design and setup BPM system
  - Need to modify data acquisition system
- Simulation study
  - Collaborate with Tech-X and Voss Scientific for breakdown physics
  - Consider physics with beam (Moses et al. NFMCC-doc-532-v2)

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Collaborators

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Cary Yoshikawa,
Hydrogen safety team, Radiation safety team,
Main Control people

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Conclusion

- The goal of this project is a feasibility of the HPRF for muon collider
- We passed some tests: High field gradient, Operation under magnetic field
- We have studied breakdown physics: Plasma, Material, Interaction with beam, etc
- We plan to have a beam test in very near future!

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