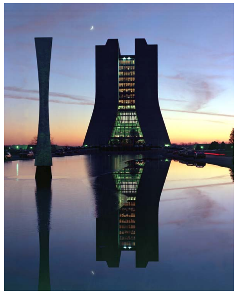
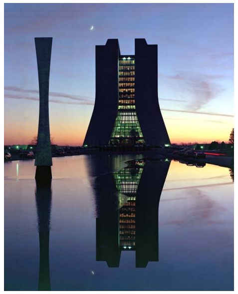


HPRF physics & technology

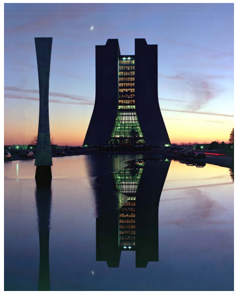
K. Yonehara

APC, Fermilab



Contents

- Verify HPRF physics to apply for ionization cooling channels
  - Plasma chemistry
  - Beam-plasma interaction
- R&D for Dielectric Loaded HPRF cavity
- Advanced technology based on HPRF towards to GARD

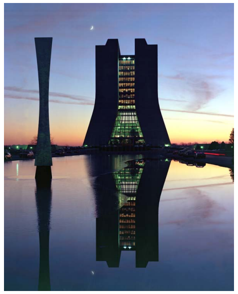


Electronegative gas doped hydrogen in RF cavities for muon ionization cooling

- Act as an ionization cooling material and suppress dark current flows
- Quickly thermalize and remove high energy free electrons in the cavity
- Work as a coolant of the cavity
  – Permit usage of a thin RF window

Remaining physics challenges:

- Investigate HPRF physics with intense muon beams
  – RF power loading due to gas plasma for a hybrid channel
  – Beam-plasma interaction



Primary Plasma Process

Ionization process (Produce beam-induced plasma)

$$p + H_2 \rightarrow p + H_2^+ + e^-$$
$$\Updownarrow$$
$$\mu^{+/-} + H_2 \rightarrow \mu^{+/-} + H_2^+ + e^-$$

- Same plasma production process with different incident charged particles

Amount of electron-ion pair production

$$\dot{N}_e = \frac{\left\langle {dE}/{dx} \right\rangle_{p=p_0}}{W_i} \rho_{H_2} \cdot I_{incident}$$

- Known ionization energy loss
- Known ion pair production energy (W_i)
- Easy to estimate total number of electron-ion pairs

RF energy dissipation (Generate plasma loading)

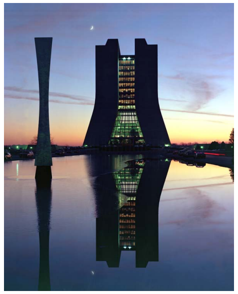
$$dw = \int_T q\bar{v}E(t)\,dt$$

- RF energy dissipation is modeled as a resistive motion of plasma in a matter by an RF field
- Drift velocity of electron & ion ($\bar{v}$) are known from other experiments
- Model predicts
  Electron dw >> Ion dw

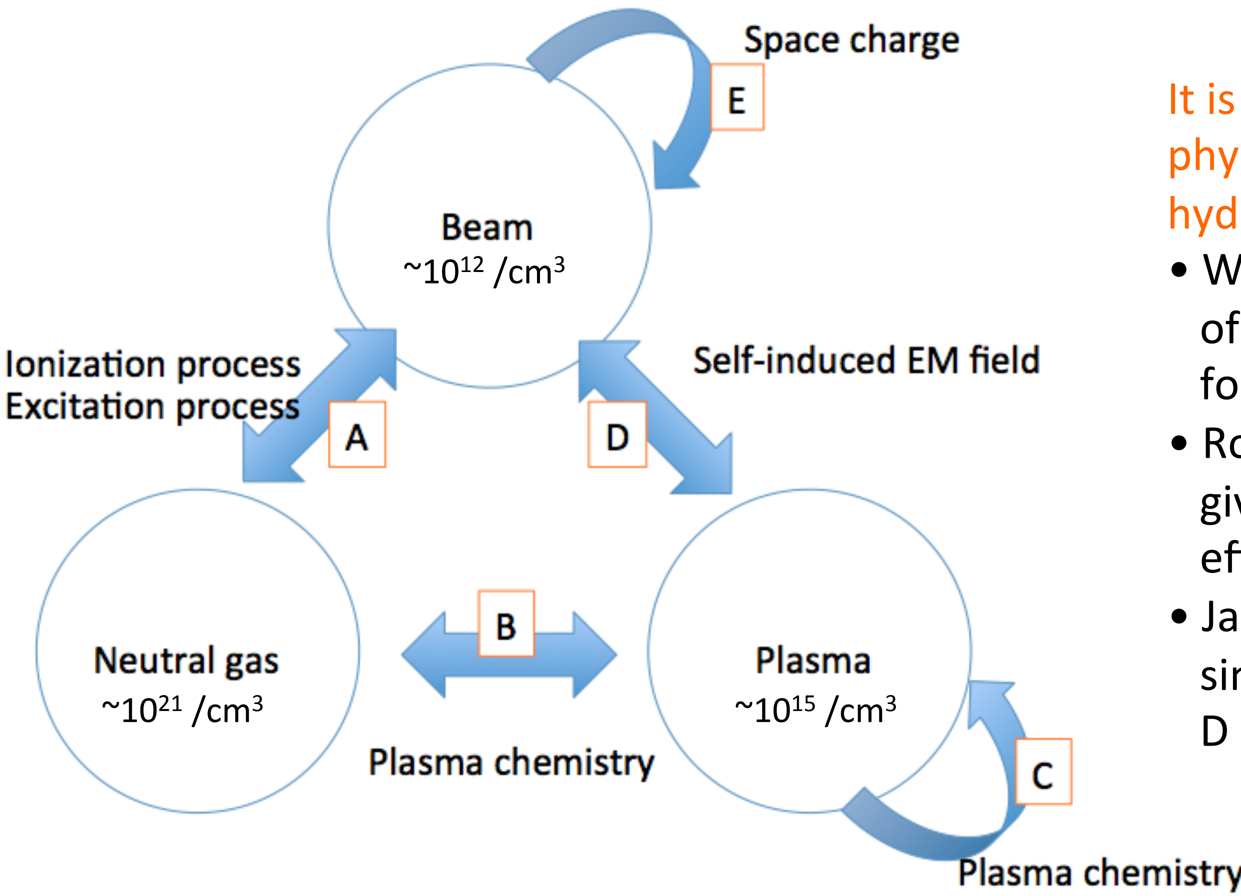
No model dependence

Linear Theory

Model is validated by recent beam tests

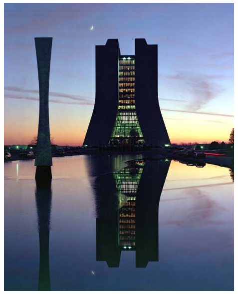


Interaction among three states



It is a new explore of plasma physics because of such a dense hydrogen gas!

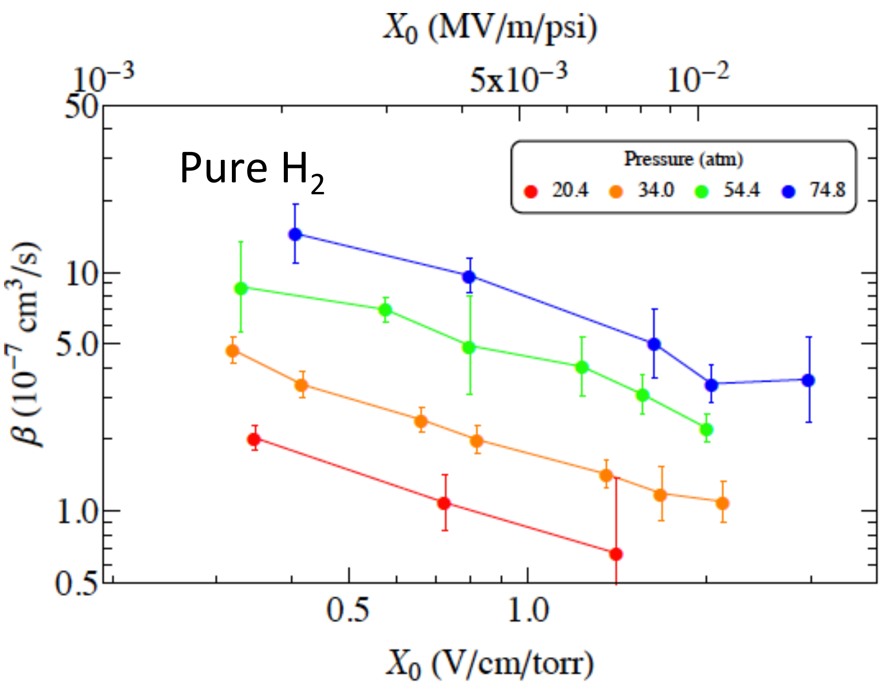
- We will publish a full paper of the experimental results for processes B & C
- Roman and Kwangmin will give a talk about the simulation efforts for processes B & C
- James will give a talk about the simulation efforts for processes D & E



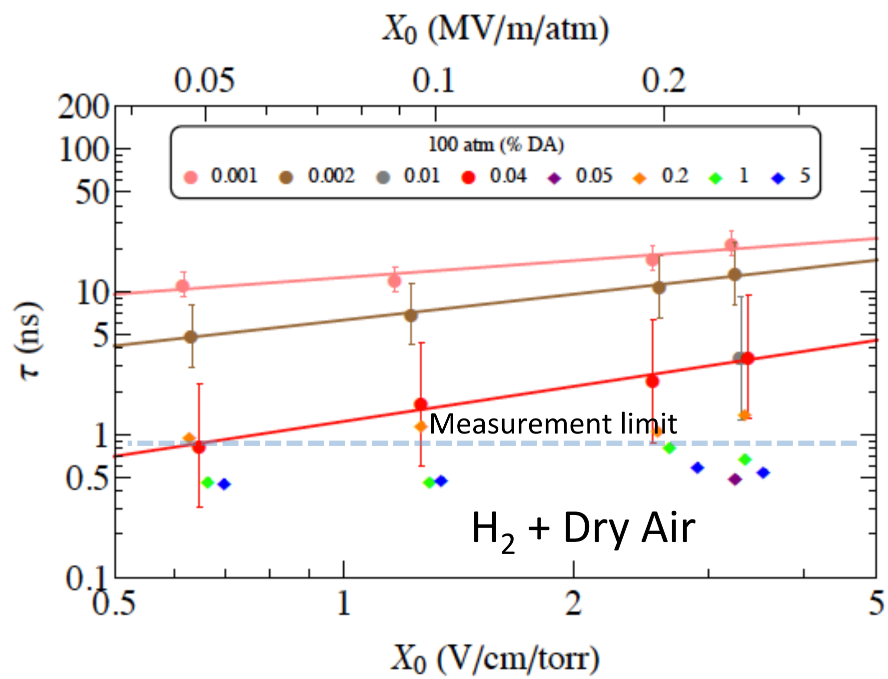
Electron capture process

$$\frac{dn_e}{dt} = \dot{n}_e - \beta n_e n_{H_n^+} - \frac{n_e}{\tau}$$

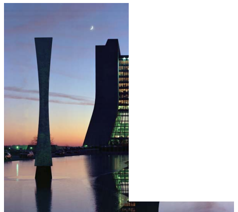
Draft PRSTAB, B. Freemire



Obtained β shows that a positive hydrogen cluster is formed



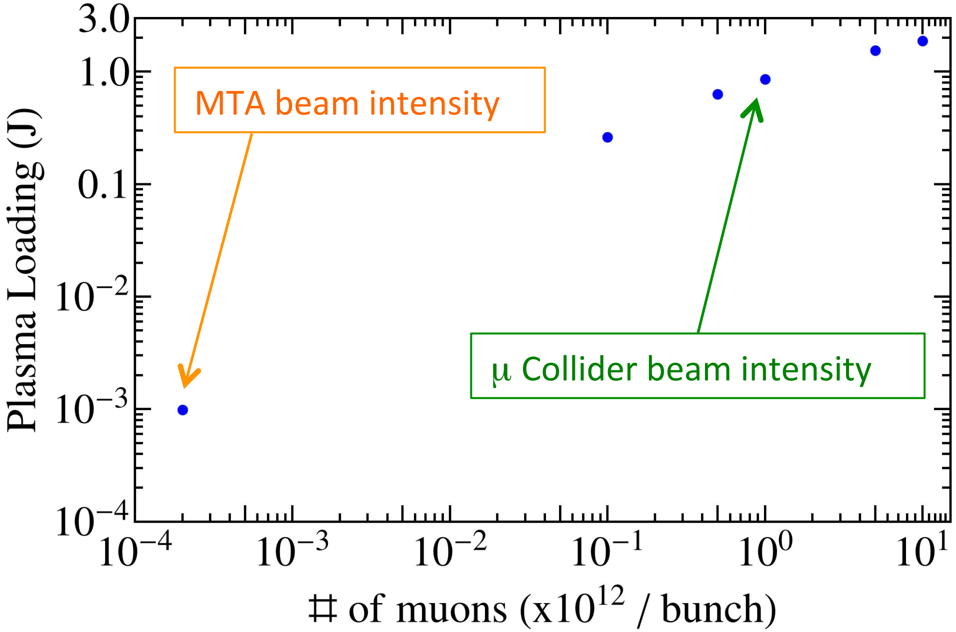
Obtained τ shows that a three-body reaction with H_2 is dominant



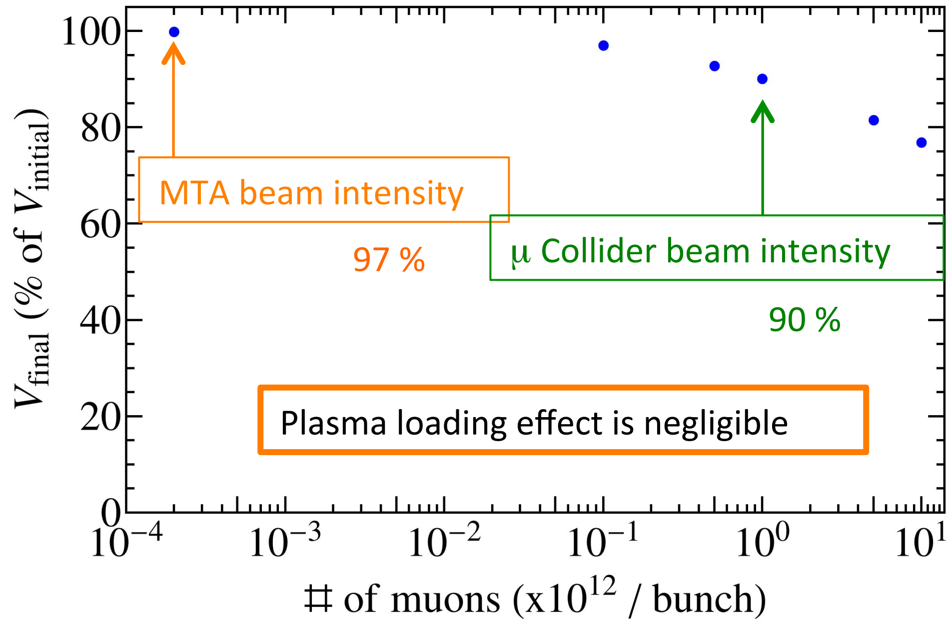
Estimated Plasma Loading in 650 MHz HPRF cell in Helical Cooling Channel as a function of Beam Intensity

B. Freemire

Estimated Plasma Loading (single charge)



Estimated RF gradient seen by the last bunched beam



Conditions:

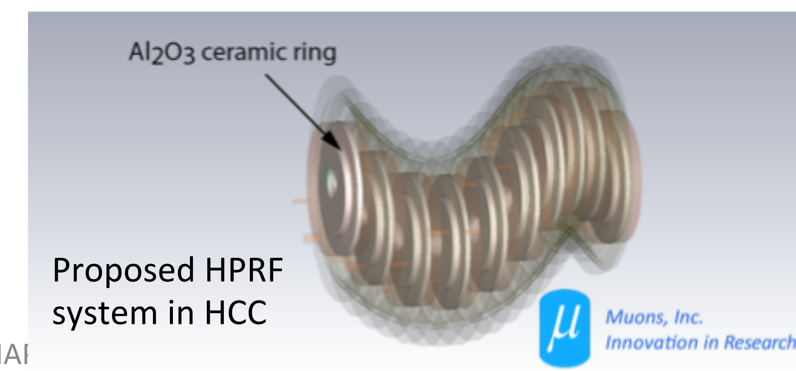
RF frequency = 650 MHz

Cavity length = 5 cm

RF gradient = 20 MV/m

Gas Pressure = 160 atm at room temperature

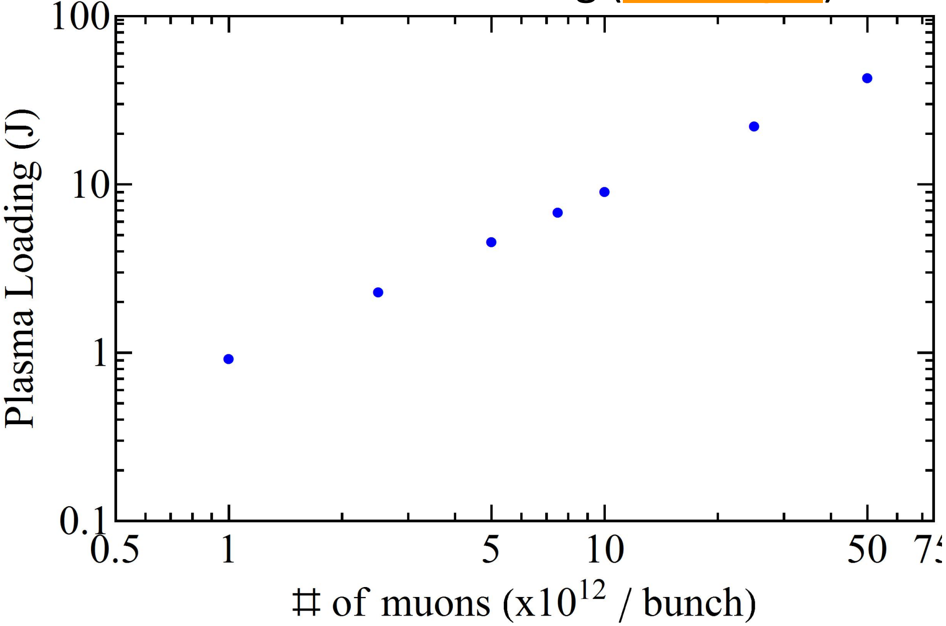
Concentration of O2 = 0.2 %



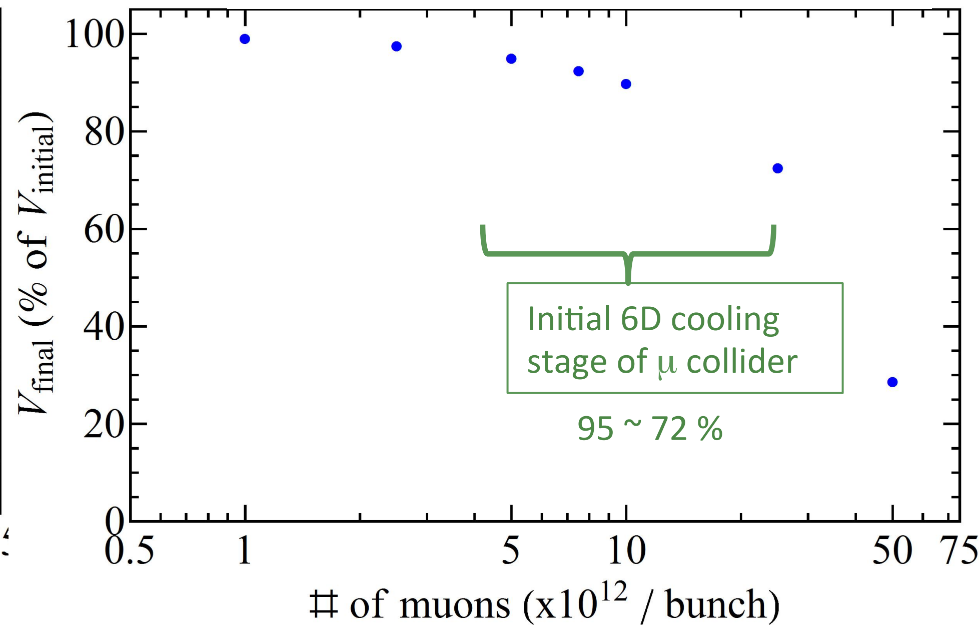
Plasma loading in Helical FOFO Snake

B. Freemire

Estimated Plasma Loading (both signs)



Estimated RF gradient seen by the last bunched beam



Conditions:

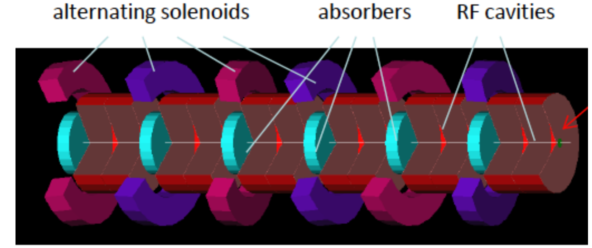
RF frequency = 325 MHz

Cavity length = 25 cm

RF gradient = 25 MV/m

Gas Pressure = 171 atm at room temperature

Concentration of O2 = 0.2 %

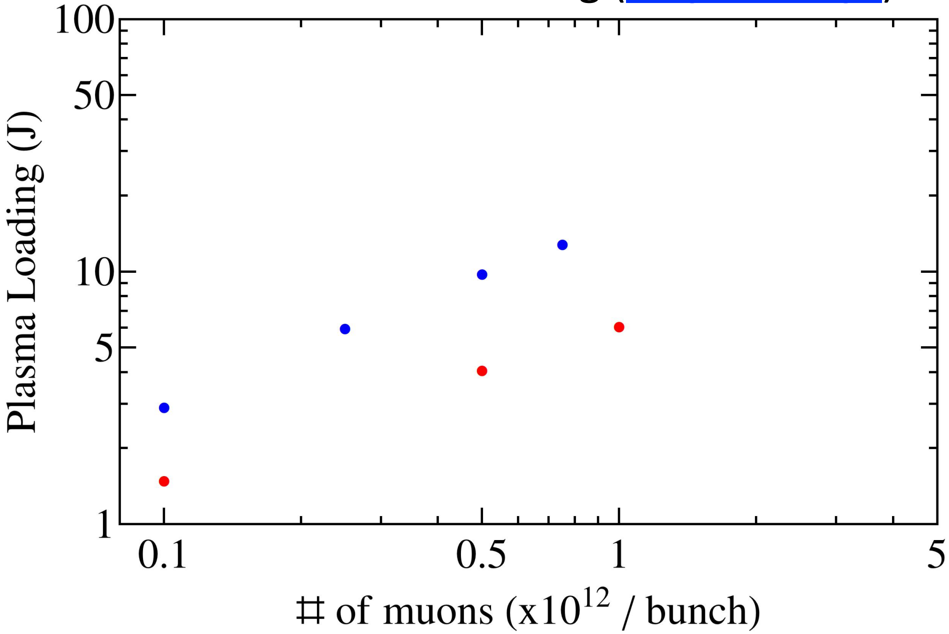


Proposed H2 gas-filled Helical FOFO Snake, Y. Alexahin, MAP-doc-4377

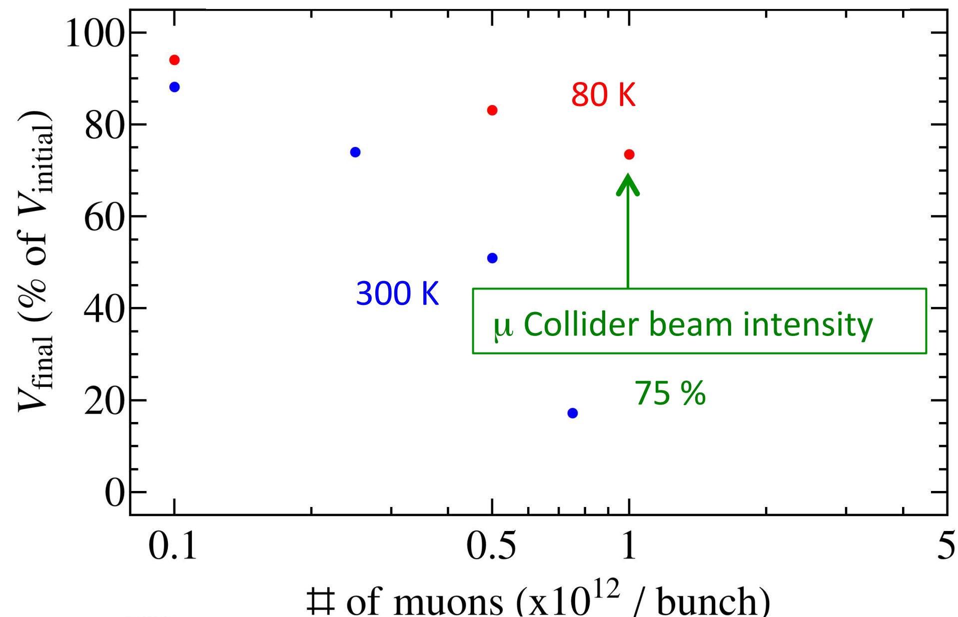
Plasma loading in hybrid Rectilinear Channel

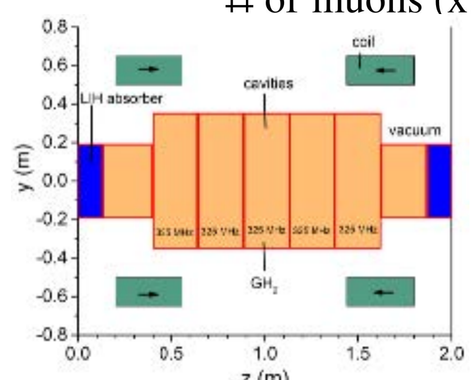
B. Freemire

Estimated Plasma Loading ([single charge])



Estimated RF gradient seen by the last bunched beam





Proposed HPRF system in rectilinear FOFO

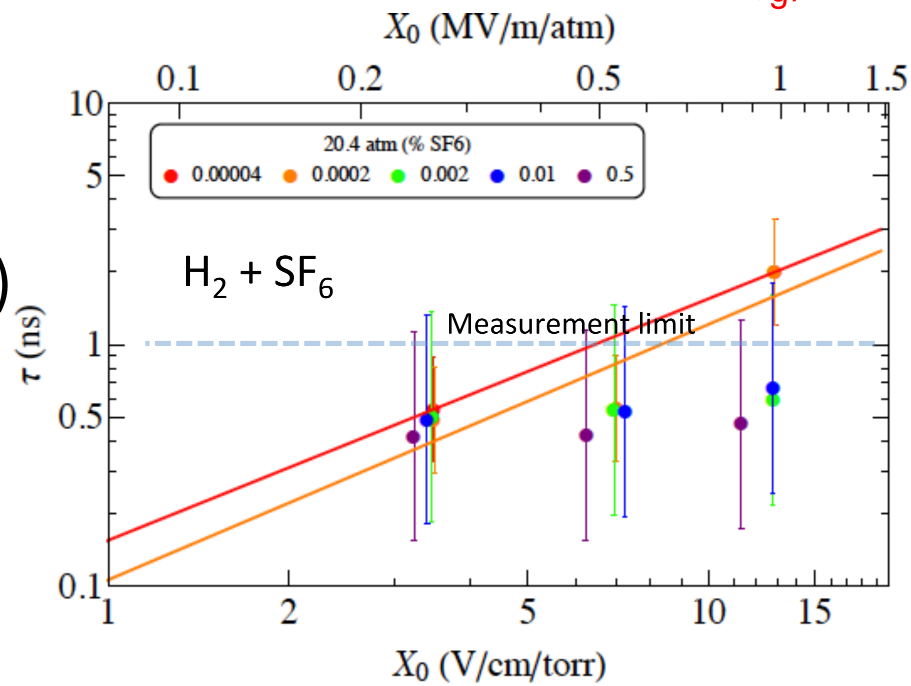
D. Stratakis, IPAC'14, TUPME024

Conditions:
RF frequency = 650 MHz
Cavity length = 12 cm
RF gradient = 29 MV/m
Gas Pressure = 34 atm at room temperature
Concentration of O2 = 0.2 %

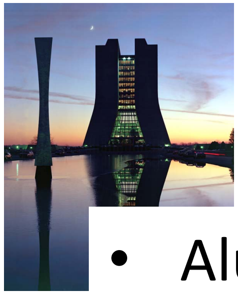
Enhance electron capture process

- More chemical reactions
  - SF6 is very effective although it reduces the cooling performance (short radiation L)
- Cold cavity operation
  - Drift velocity of electrons in H2 gas becomes slow
  - Hydrogen recombination becomes faster
  - e + H_2 + O_2 reacts faster
  - No data for β and τ

Draft PRSTAB, B. Freemire



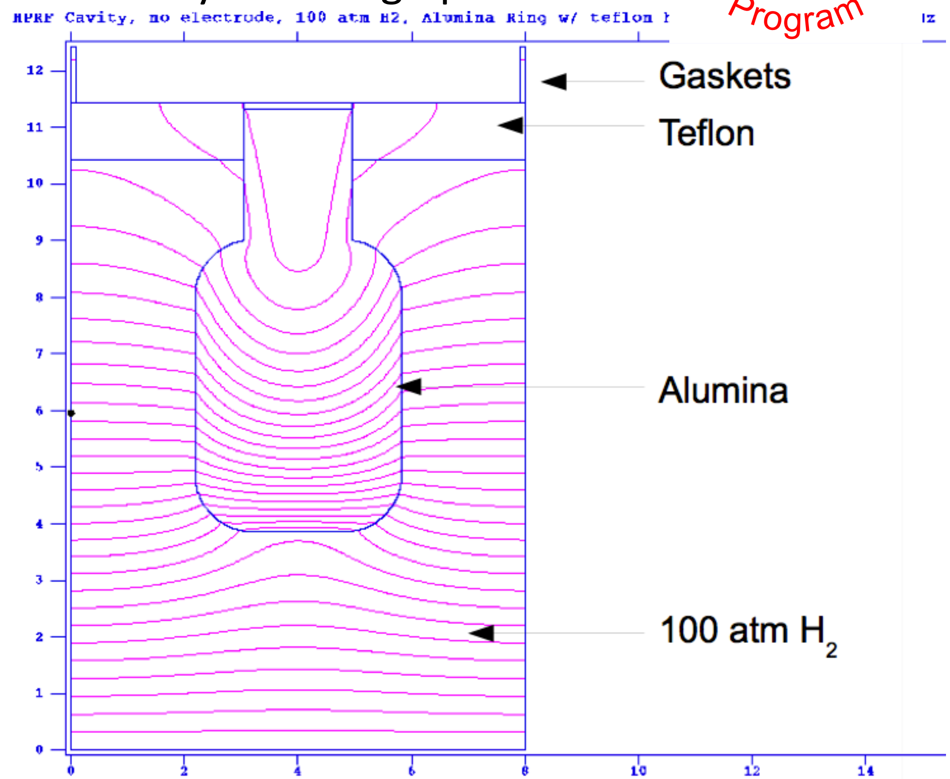
Cold cavity test should be demonstrated if the low pressure hybrid channel is our choice



Dielectric loaded RF test

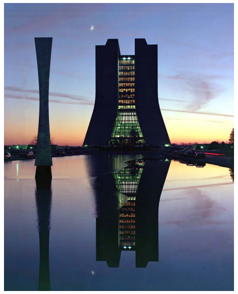
- Alumina 99.5 % shows the best material (B. Freemire)
  - Loss tan δ ~ 0.4e-4 at room temperature
  - Dielectric strength can be >30 MV/m (past measurement)
  - Peak power is 2.5 times higher than the pillbox cavity
- Stored RF energy is twice higher than the pillbox one
  - Dielectric material is a good energy storage material like a battery

Layout of high power test



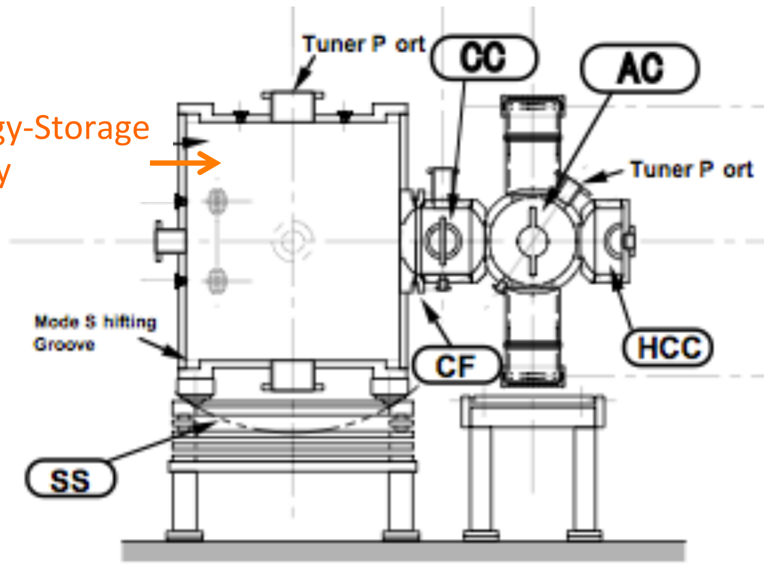
Additional plan for high power test

- Change geometry of ceramics
- Cold test

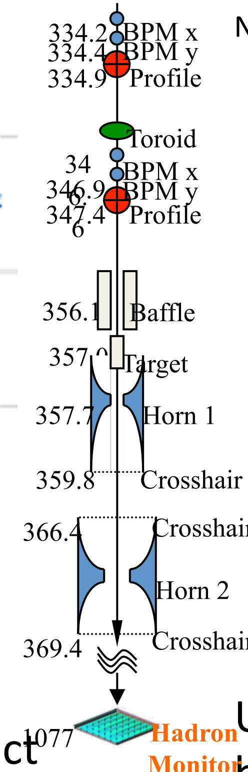


Advanced technology based on HPRF resonator

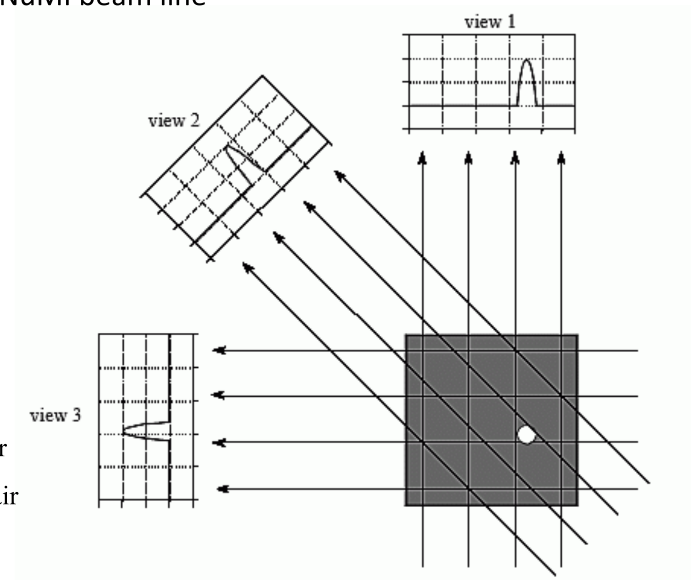
Energy-Storage Cavity



KEK-B accelerator



NuMI beam line

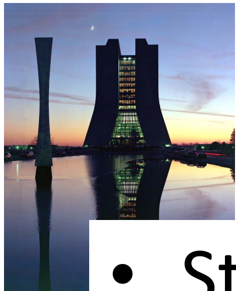


Apply a DL HPRF resonator for a compact RF energy-storage cavity

- RF energy can be stored in a loaded ceramics
- It is proportional to the permittivity of ceramics
- Lower loss tangent & higher dielectric strength is better for this application

Use a HPRF resonator to measure hadron flux

- Gas-plasma is formed in the resonator by beam
- It changes $\varepsilon = \varepsilon' + j\varepsilon''$
- ε is proportional to the intensity of incident charged beam and gas pressure
- RF frequency is shifted by the beam intensity



Summary

- Still provides unique & New physics
  - Gas plasma in a dense gas and high electric fields
    - Observed huge density effects
    - Considered cold cavity test for low pressure hybrid channel
  - Beam-plasma interactions
    - Additional charge neutralization process during ionization cooling → Induce a new beam dynamics
- Proposed dielectric loaded RF test
- Extend the HPRF technology for other applications
  - Hadron monitor for extremely high radiation beam line
  - RF energy storage cell
- Do we need to investigate the hydrogen safety?