Plasma Loading Estimation in the Helical and Hybrid Cooling Channels

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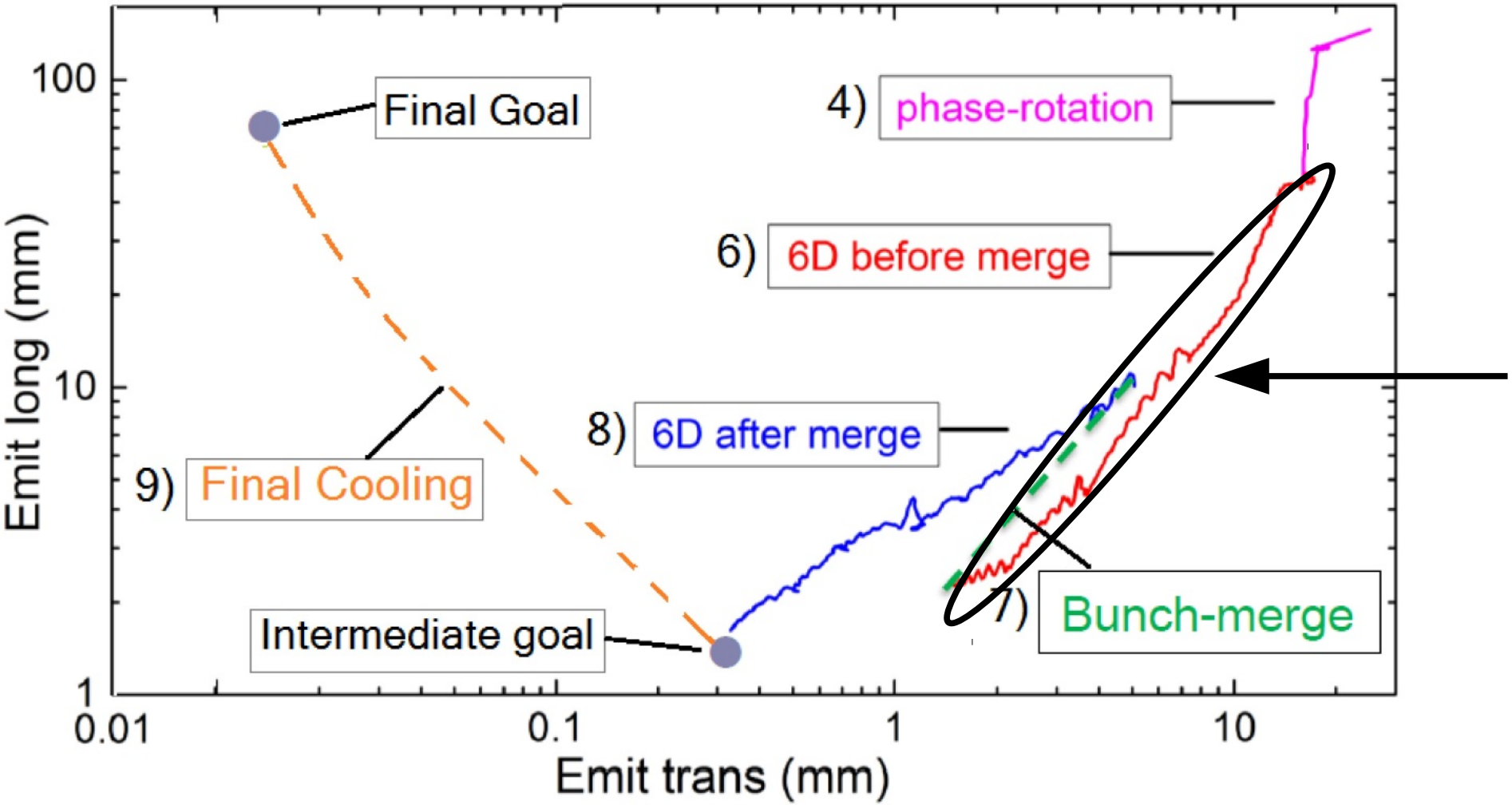
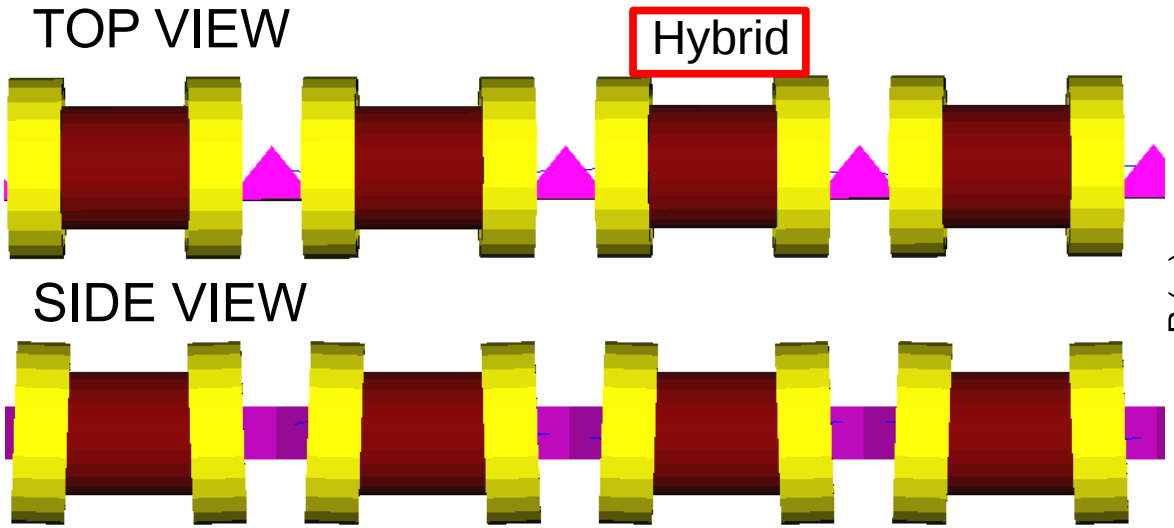
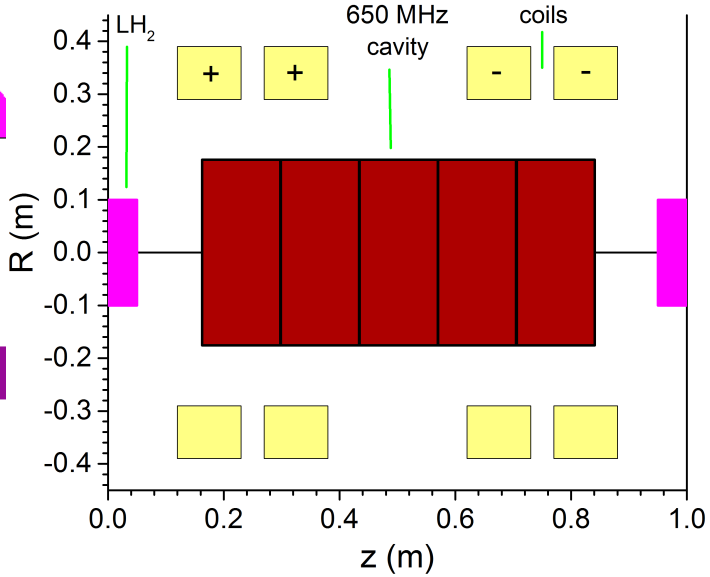
6D Cooling

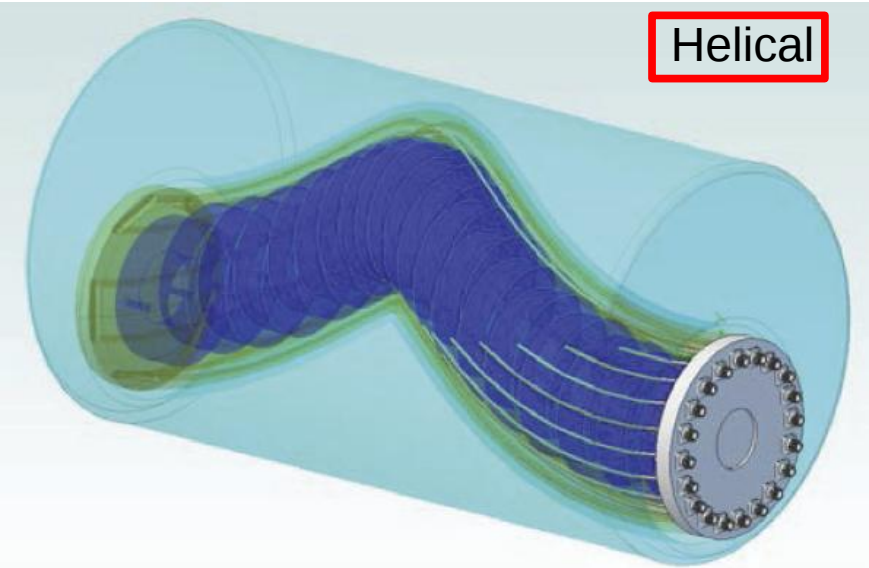
- Before bunch merge – 21 bunches

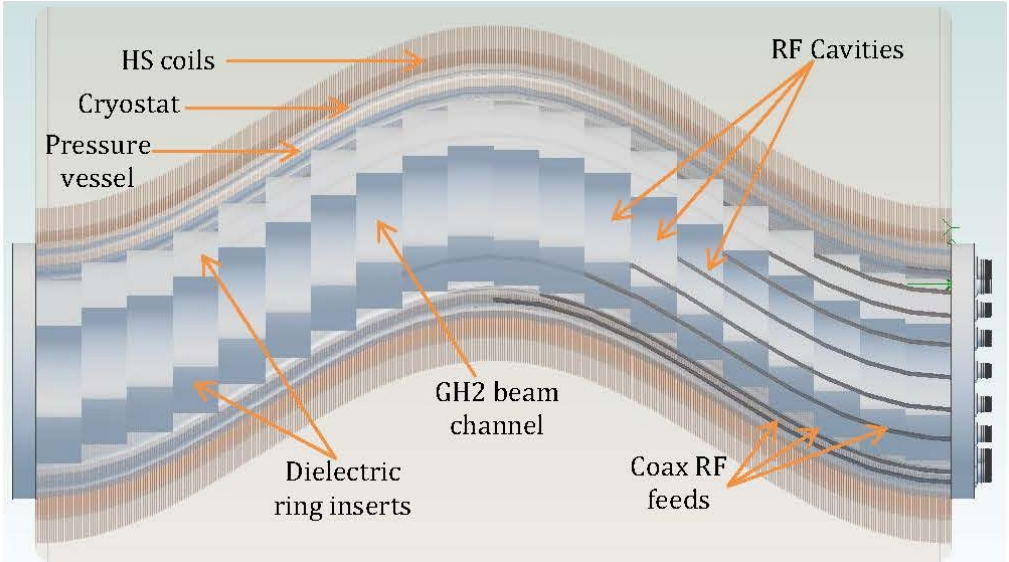


A Tale of Two HCCs









HCC vs HCC Concepts

- Both channels utilize gas filled cavities at 325 & 650 MHz doped with 0.2% O_2

- Helical:
  - Helix
  - 160 atm H_2
  - Continuous H_2
  - Helical solenoids

- Hybrid:
  - Rectilinear
  - 34 or 100 atm H_2
  - Wedge LH_2 absorbers
  - Tilted solenoids

RF & Beam Parameters

- 34 & 100 atm Hybrid channel, 160 atm Helical channel
- Hydrogen gas doped with 0.2% oxygen
  - Change in radiation length affects cooling performance
- Beam is bunched at 325 MHz, 21 bunches
  - Delta functions in time

f (MHz)	325			650		
P (atm)	34	100	160	34	100	160
E (MV/m)	28.33	28.88	20	28.53	28.73	20
Phase (deg.)	13.505	13.466	-17.922	20.558	21.036	-17.922
Length (cm)	25.5	25.5	10	13.5	13.5	5
Stored Energy (J)	95.6	95.6	18.7	13.0	13.0	2.34
Avg. Mom. (MeV/c)	271	271	230	221.6	225.6	230
Trans. 1 σ (cm)	8.4	8.4	-	2.5	2.5	-
Trans. 5 σ (cm)	-	-	8.0	-	-	3.0

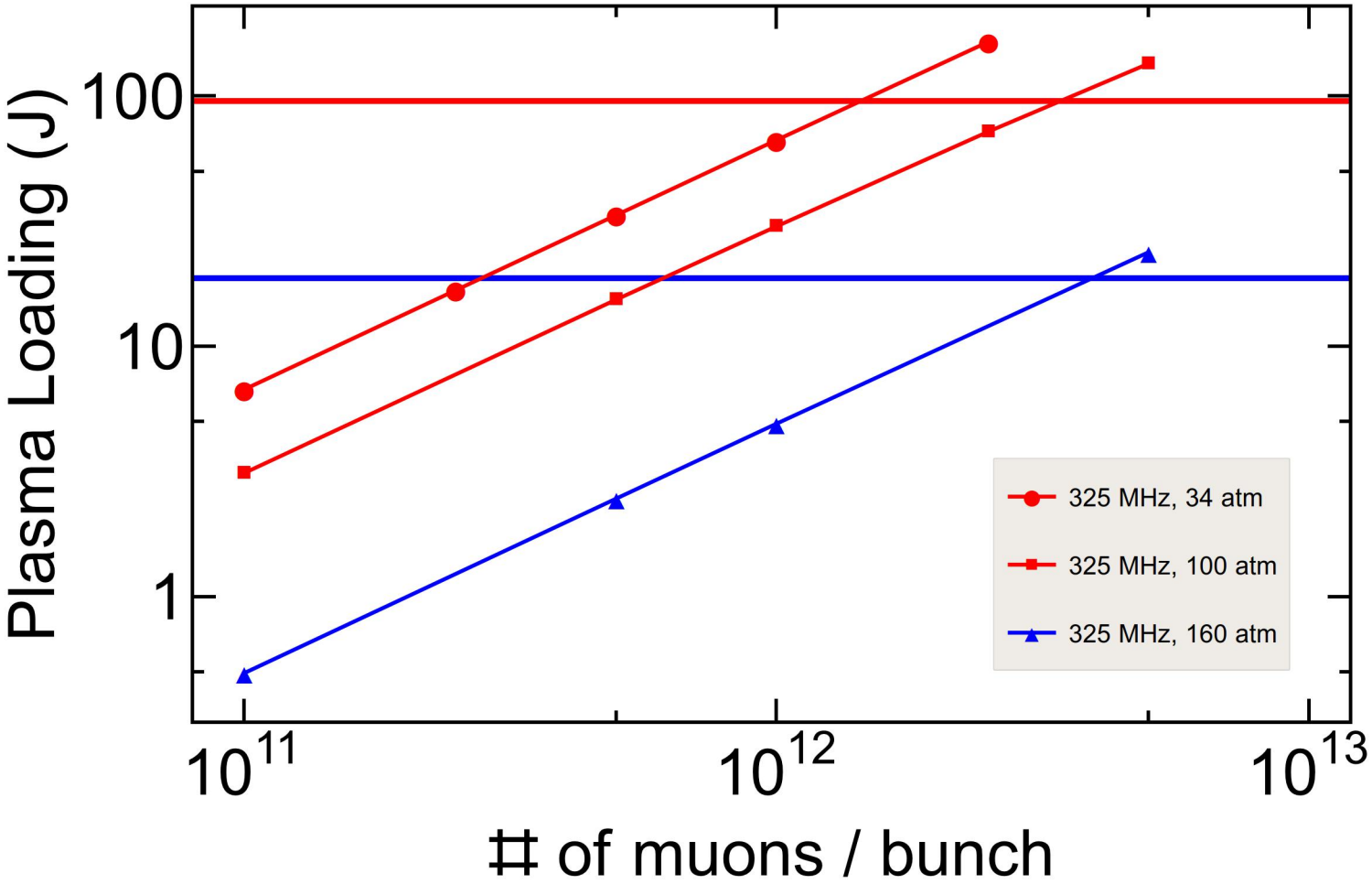
Plasma Processes

- Results of HPRF beam test used to extrapolate values for:
  - Electron and ion loading
  - Electron-ion and ion-ion recombination rates
  - Electron-oxygen attachment time
- Positive effects:
  - Higher gas density & dopant concentration
  - Lower electric field
  - Higher plasma density

Assumptions

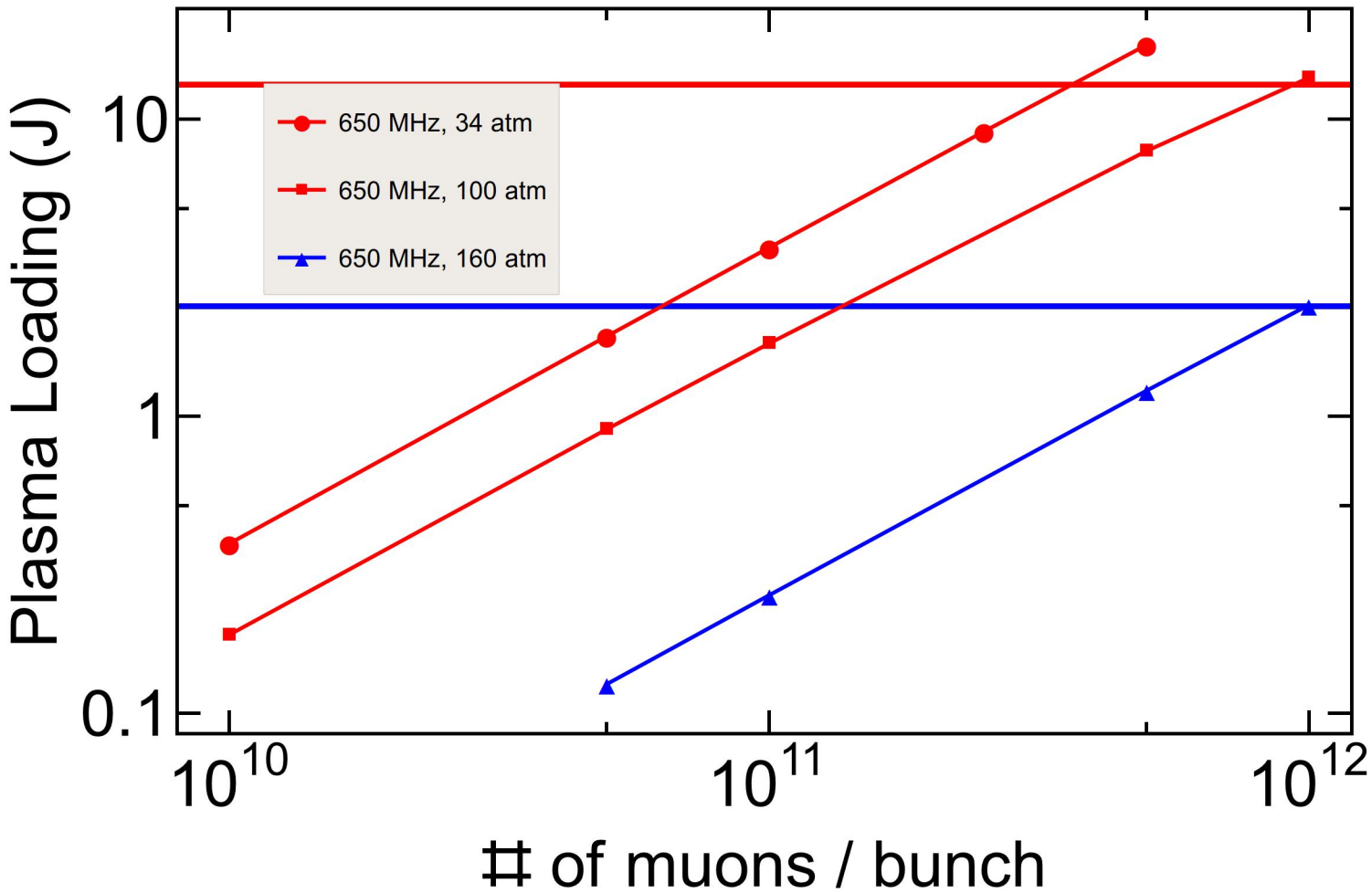
- Electron-ion recombination rate:
  - 2×10^{-7} cm^3/s @ 34 atm
  - 10^{-6} cm^3/s @ 100 atm
  - 10^{-6} cm^3/s @ 160 atm
- Electron-oxygen attachment time:
  - 6.81 ns @ 34 atm, E_0, varies with E
  - 0.769 ns @ 100 atm, E_0, varies with E
  - 0.160 ns @ 160 atm, E_0, varies with E
  - Minimum: 0.100 ns
- Ion-ion recombination rate:
  - 2×10^{-8} cm^3/s @ 34 atm
  - 2×10^{-8} cm^3/s @ 100 atm
  - 10^{-9} cm^3/s @ 160 atm
- Electron and ion loading:
  - Electron loading based on MTA extrapolated values for 100 & 160 atm
  - Electron loading based on measured values for 34 atm
  - Ion loading based on measured values for all
- Cavities at room temperature

Results – 325 MHz



- Horizontal lines = stored energy of cavities
- Ions dominate plasma loading for 100 & 160 atm

Results – 650 MHz



- Horizontal lines = stored energy of cavities
- Ions dominate plasma loading for 100 & 160 atm

Conclusions

- Entire stored energy of cavities are dissipated by plasma at:

	325 MHz			650 MHz		
P (atm)	34	100	160	34	100	160
10^{11} / bunch	14	34	39	3.6	9.3	9.9

- Acceptable intensities are on the order of:
  - 325 MHz: 10^{12} muons per bunch (10^{13} total)
  - 650 MHz: 10^{11} muons per bunch (10^{12} total)
- Further optimization of RF and gas parameters could be done

Ways To Improve Performance

- There are two ways in decrease plasma loading:
  - Decrease amount of plasma created
  - Improve effect of plasma
- Decrease amount of plasma created:
  - Decrease beam intensity
  - Decrease gas density
  - Increase muon momentum
  - Decrease length of cavities

$$N = N_b \times \frac{dE/dx \times \rho}{W_i} \times L$$

- Improve effect of plasma:
  - Operate cavities at colder temperatures
  - Decrease RF gradient
  - Increase gas pressure
  - Increase oxygen concentration (0.2% assumed here)
  - Change RF phase
  - Decrease beam radius

$$\frac{dn_e}{dt} = \dot{N} - \beta n_e n_{H_5^+} - \frac{n_e}{\tau}$$