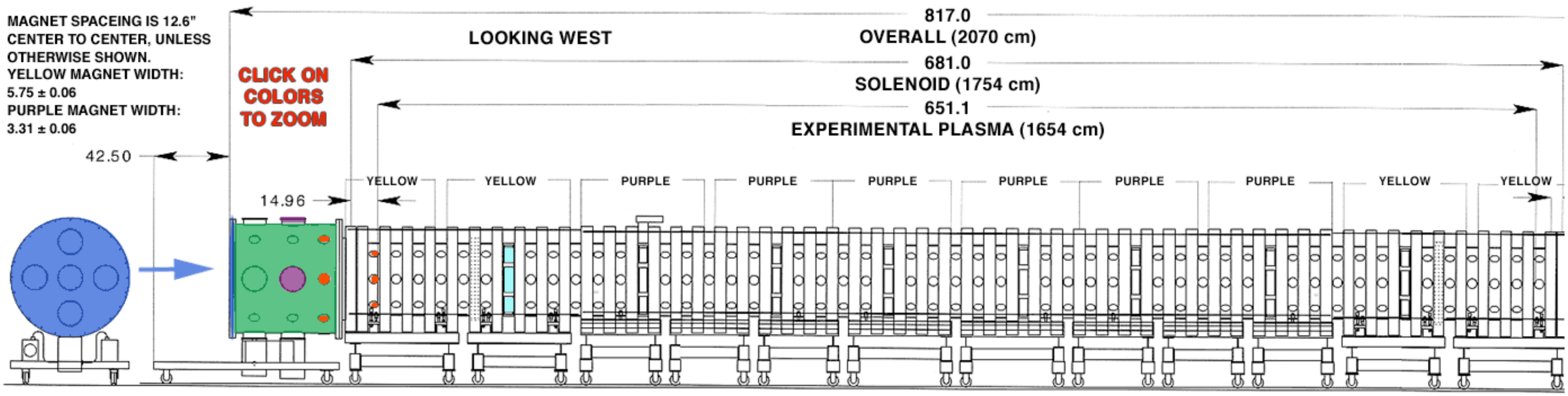
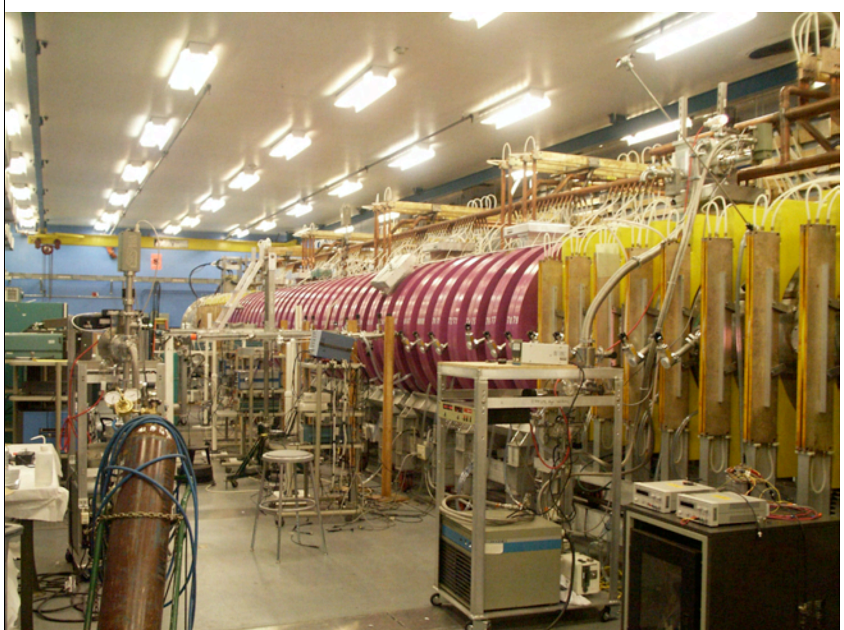
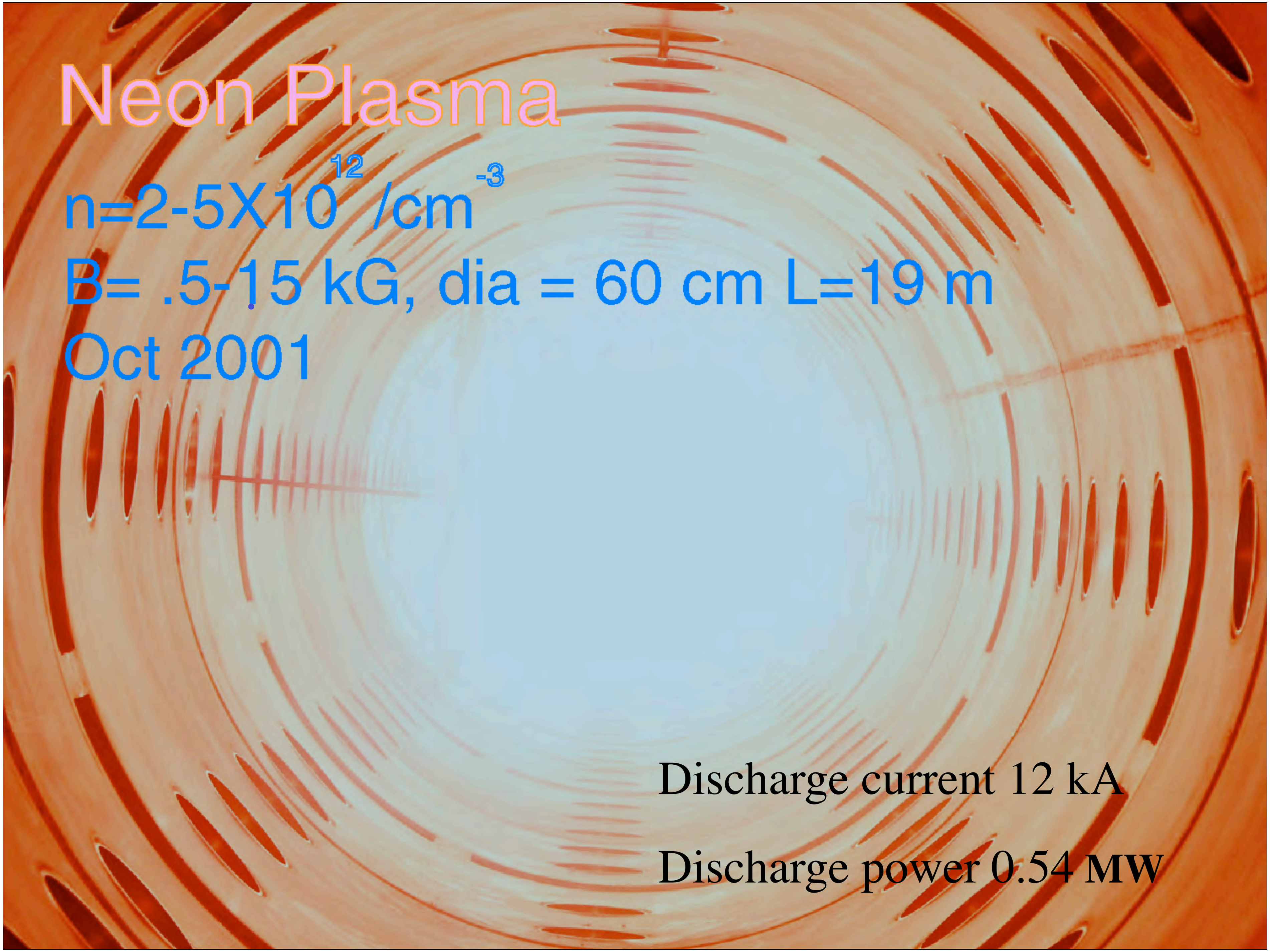
Large Plasma Device (LAPD)



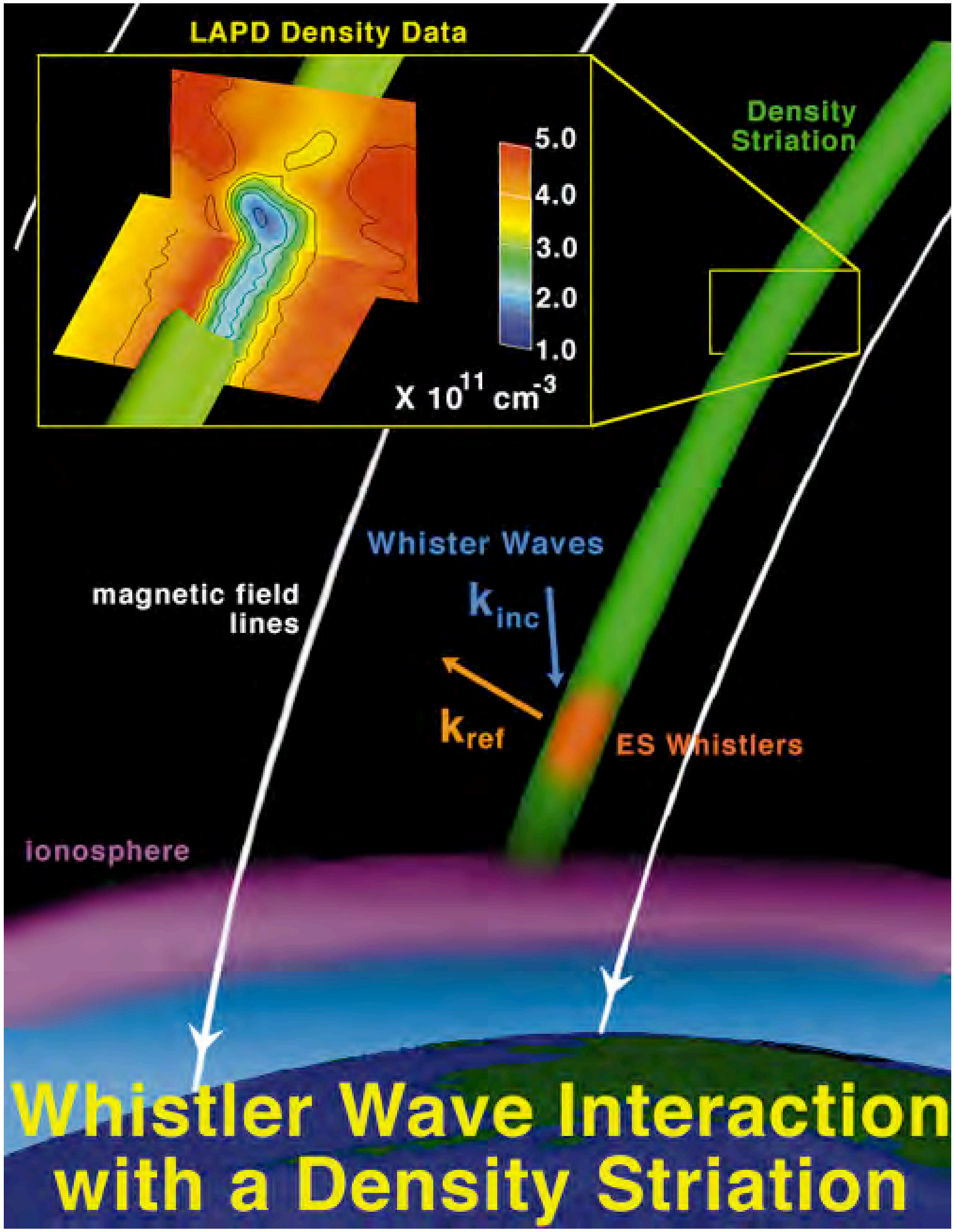


Over 450 Access ports
Computer Controlled Data Acquisition
Microwave Interferometers
Laser Induced Fluorescence
DC Magnetic Field: 0.05-4 kG , variable on axis
Highly Ionized plasmas n ≈ 5 X10^{12} cm^3
Plasma column up to 2000R_{ci} across diameter
Large variety of probes
Reproducable 1Hz operation
Now a user facility

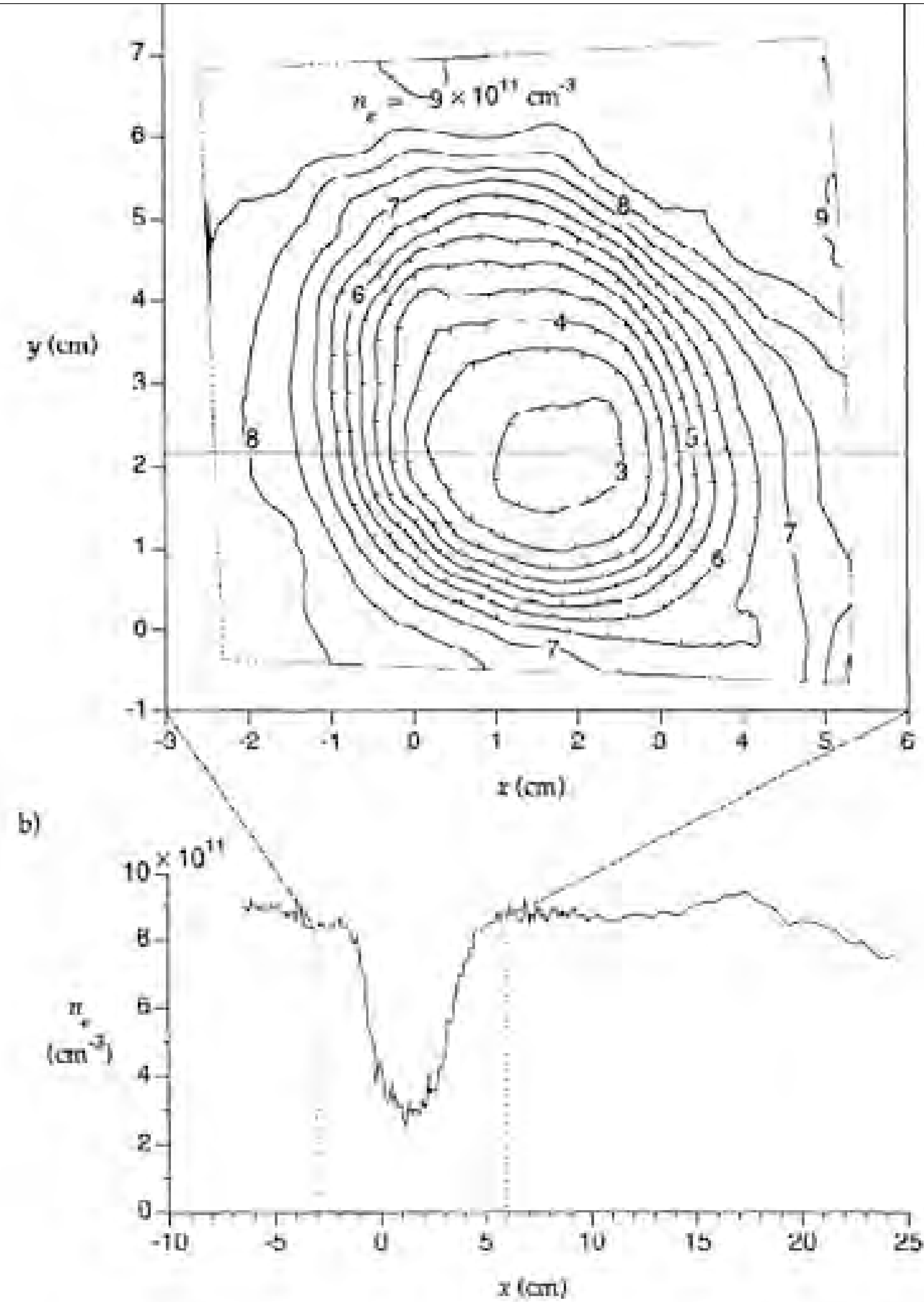

Neon Plasma
n=2-5X10^{12} /cm^{-3}
B= .5-15 kG, dia = 60 cm L=19 m
Oct 2001
Discharge current 12 kA
Discharge power 0.54 MW

Past-
Relevant Experiments

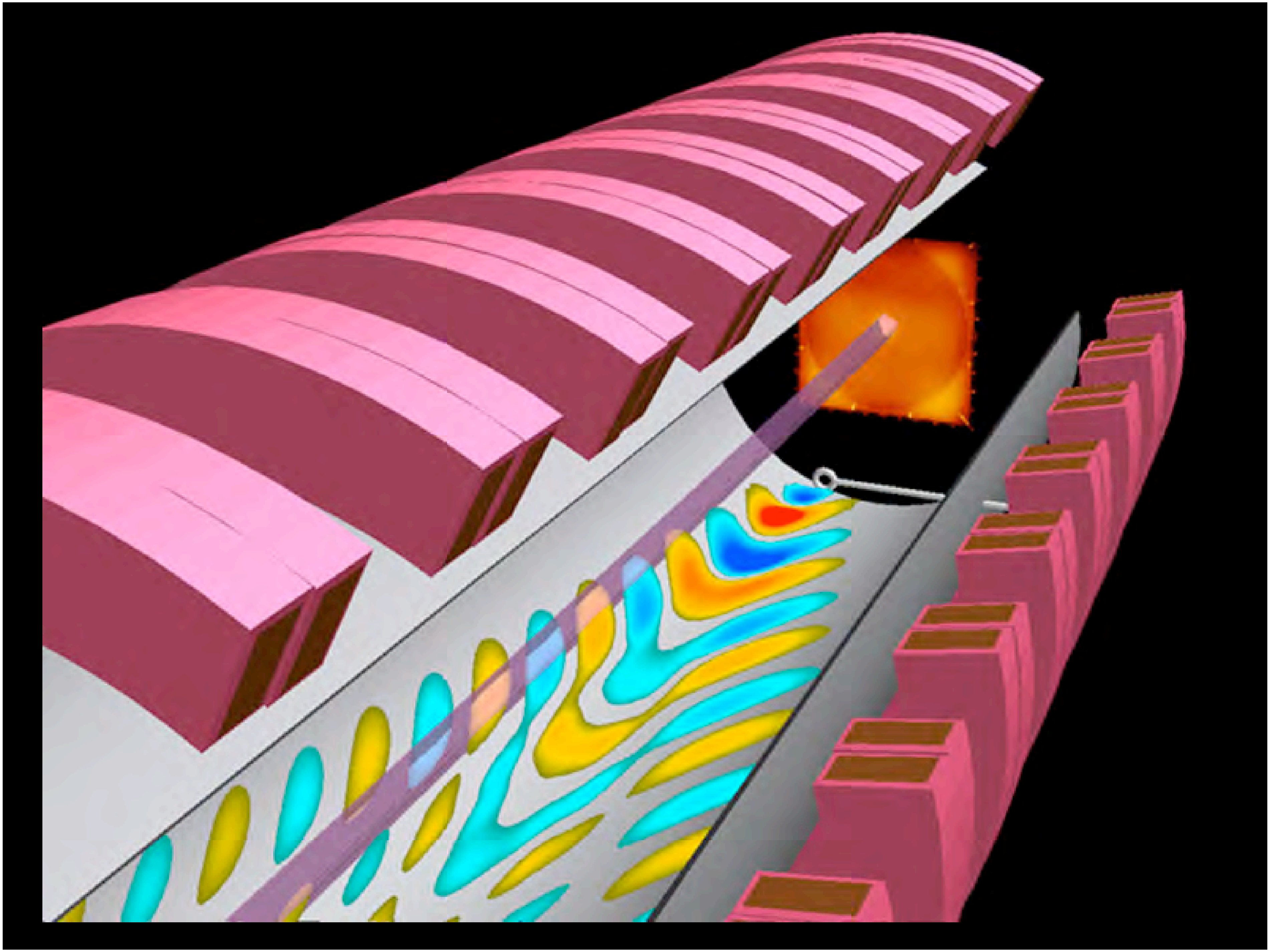
1) Whistler wave interaction with a density striation
2) Lower Hybrid wave interaction with a density striation
3) Alfvén wave MASER
4) Alfvénic Field Line Resonances
5) Interactions with a Dense Exploding Plasma
6) Alfvén Wave Generation by Resonant Absorption
7) Turbulence in Narrow Current Channels
8) Wave Propagation in Mirror Configurations

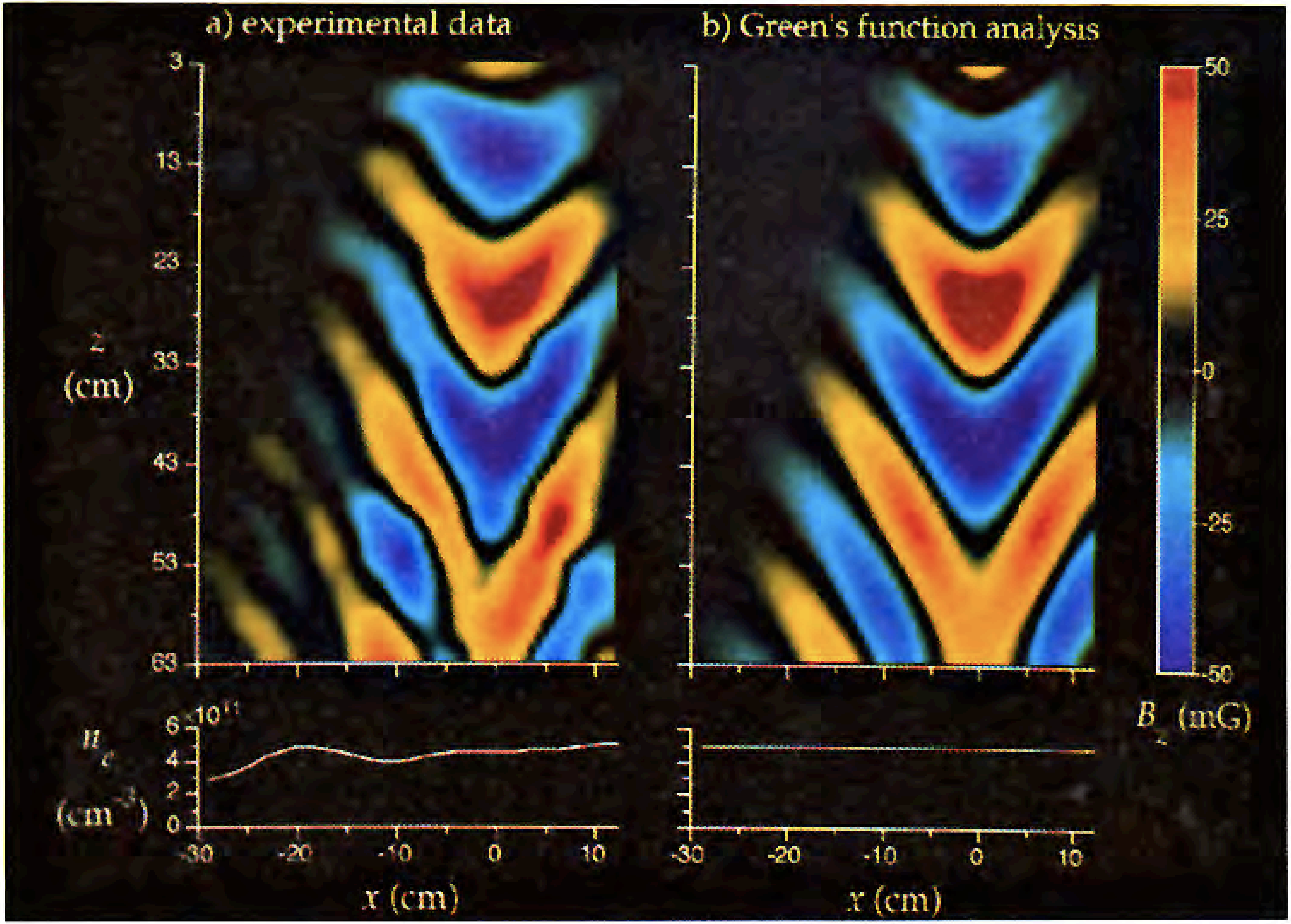


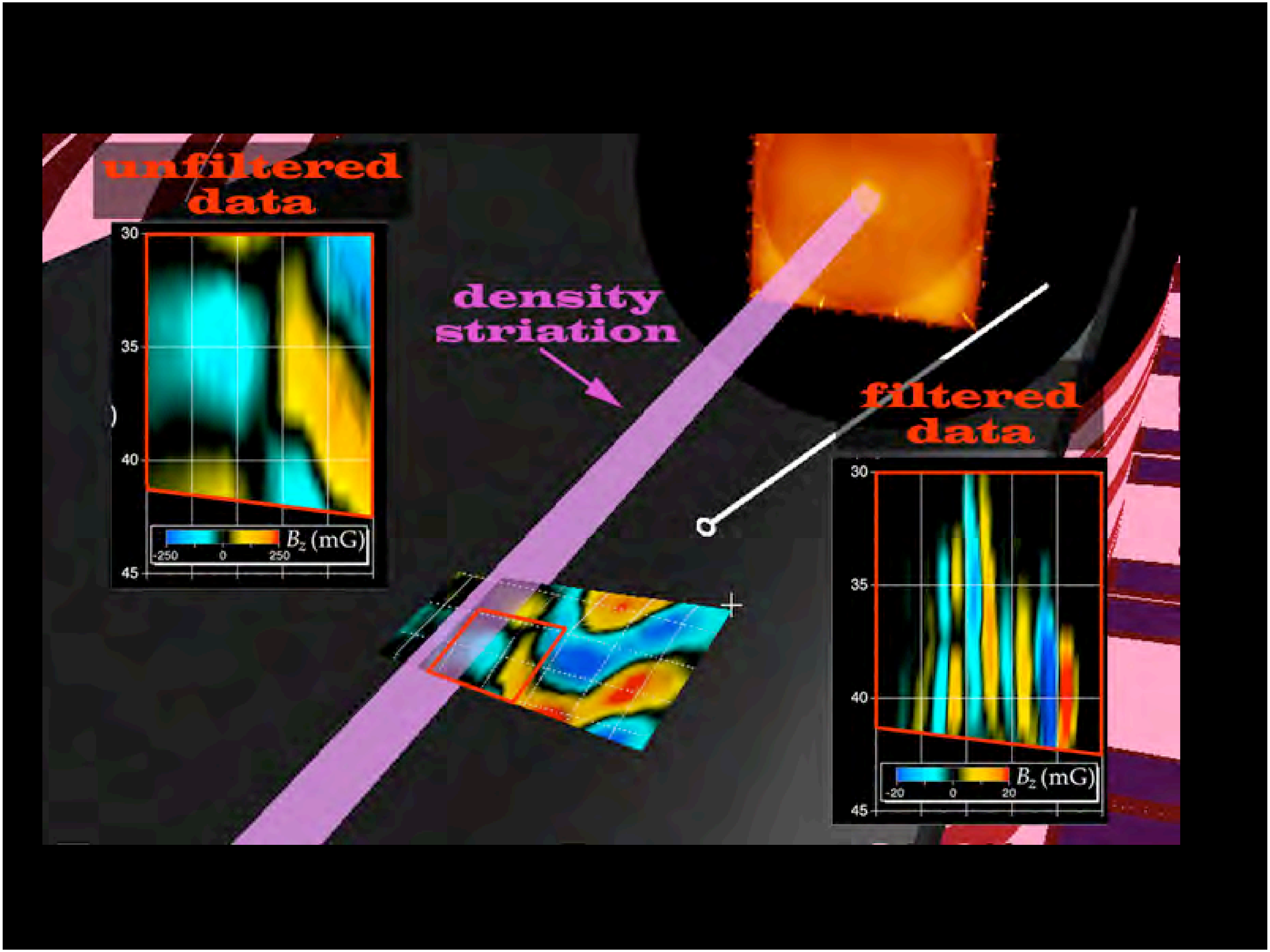
LAPD Density Data
5.0
4.0
3.0
2.0
1.0
X 10^11 cm^-3
Density Striation
Whister Waves
magnetic field lines
k_inc
k_ref
ES Whistlers
ionosphere
Whistler Wave Interaction with a Density Striation



n_e = 9 × 10^{11} cm^{-3}
y (cm)
x (cm)
b)
10 × 10^{11}
n_e
(cm^{-3})
x (cm)

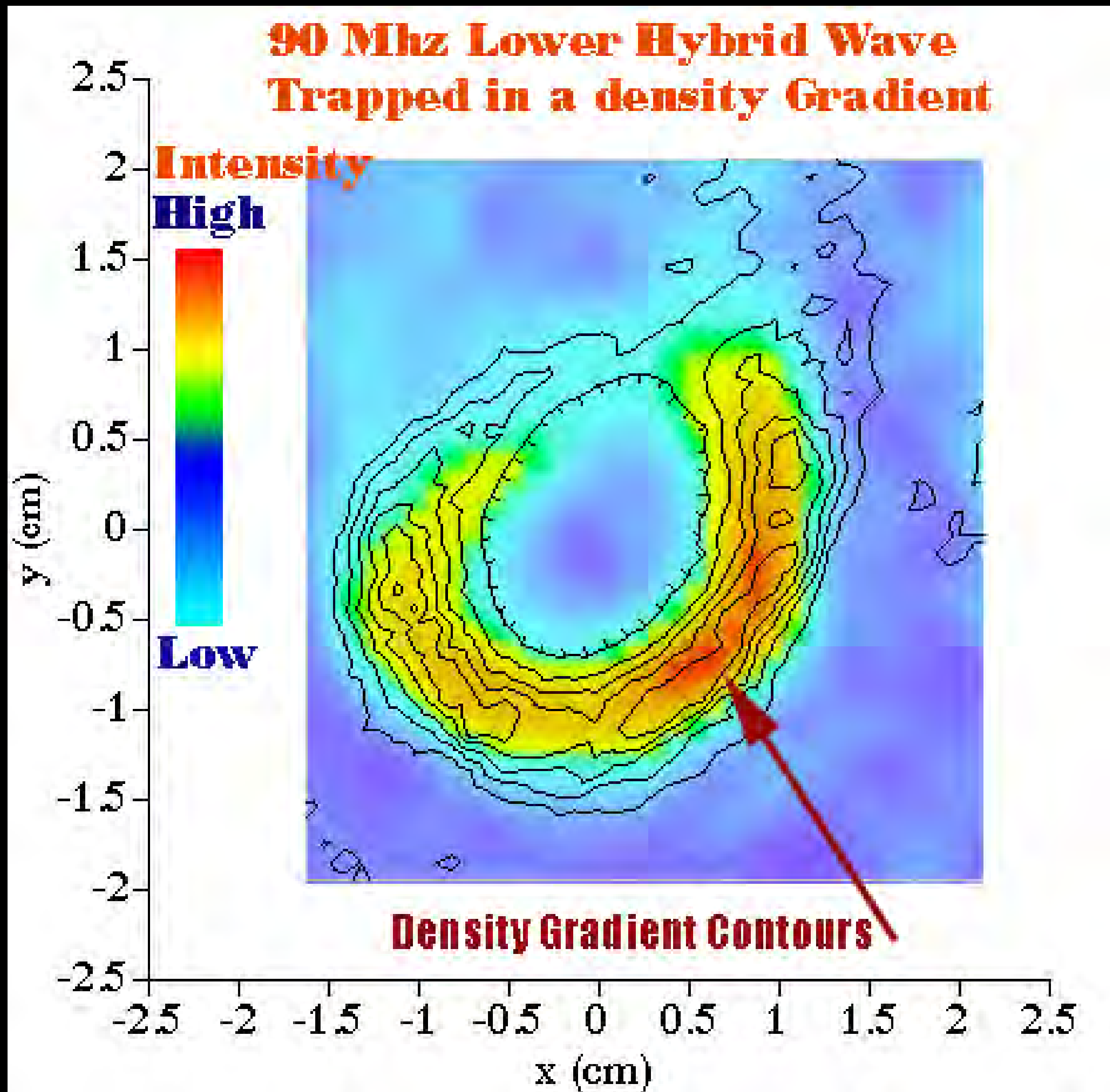



a) experimental data
b) Green's function analysis
z (cm)
3
13
23
33
43
53
63
n_e (cm^{-3})
6 ×10^11
4
2
0
-30
-20
-10
0
10
x (cm)
50
25
0
-25
-50
B_z (mG)

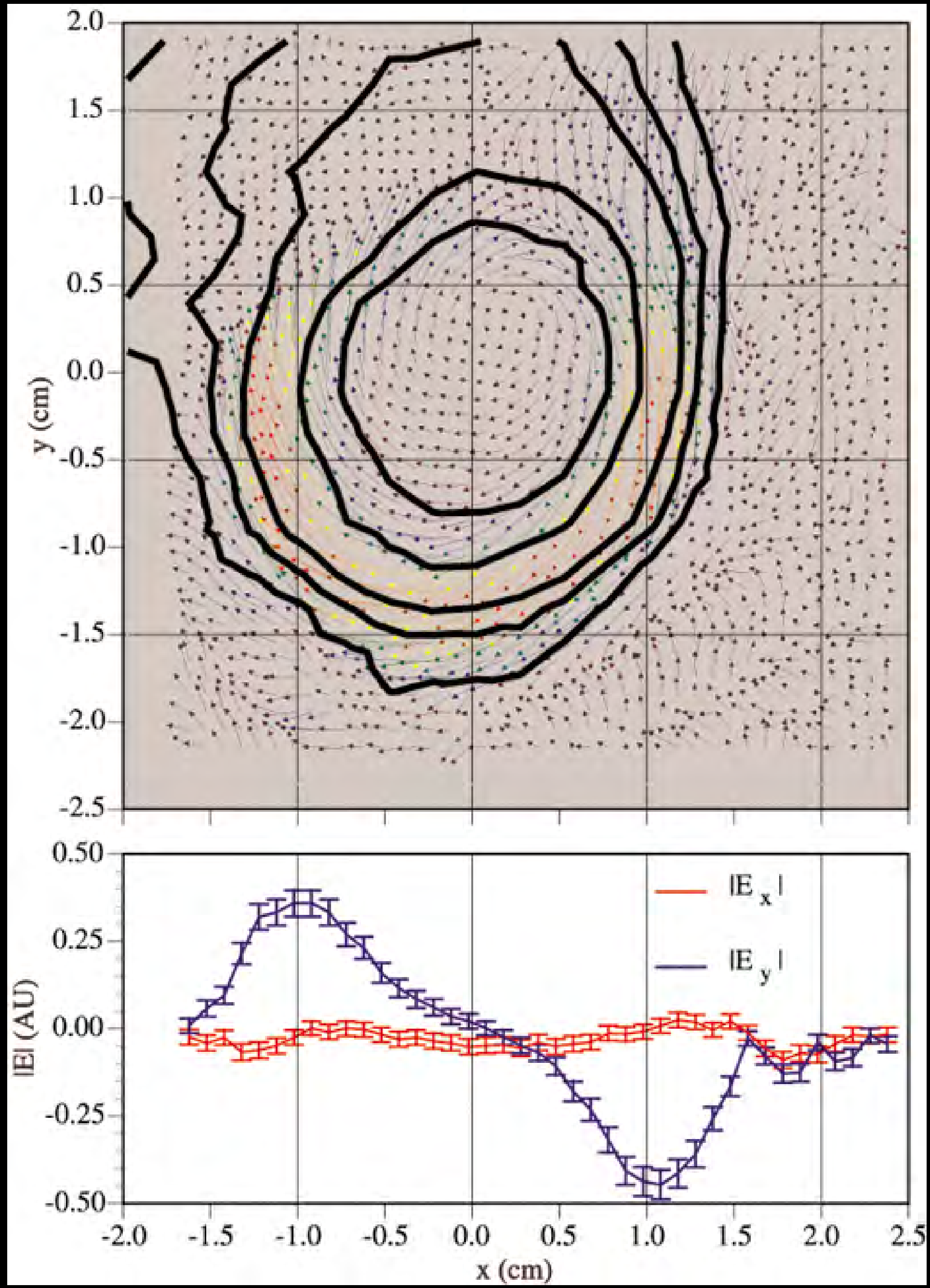


unfiltered data
density striation
filtered data
30
35
40
45
B_z (mG)
-250
0
250
-20
20

Lower Hybrid Waves incident on a density striation



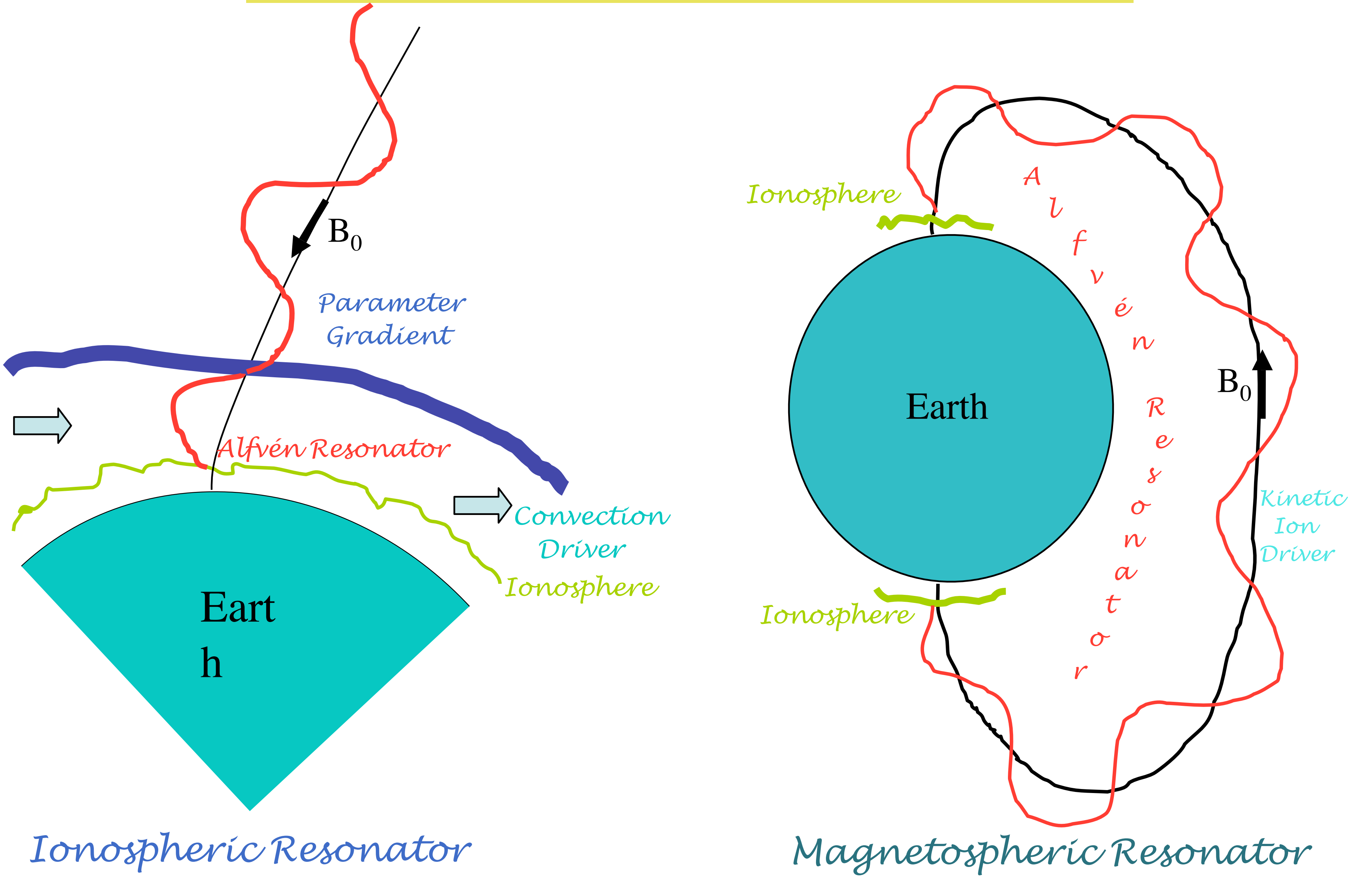
90 Mhz Lower Hybrid Wave
Trapped in a density Gradient
Intensity
High
Low
Density Gradient Contours
y (cm)
x (cm)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5



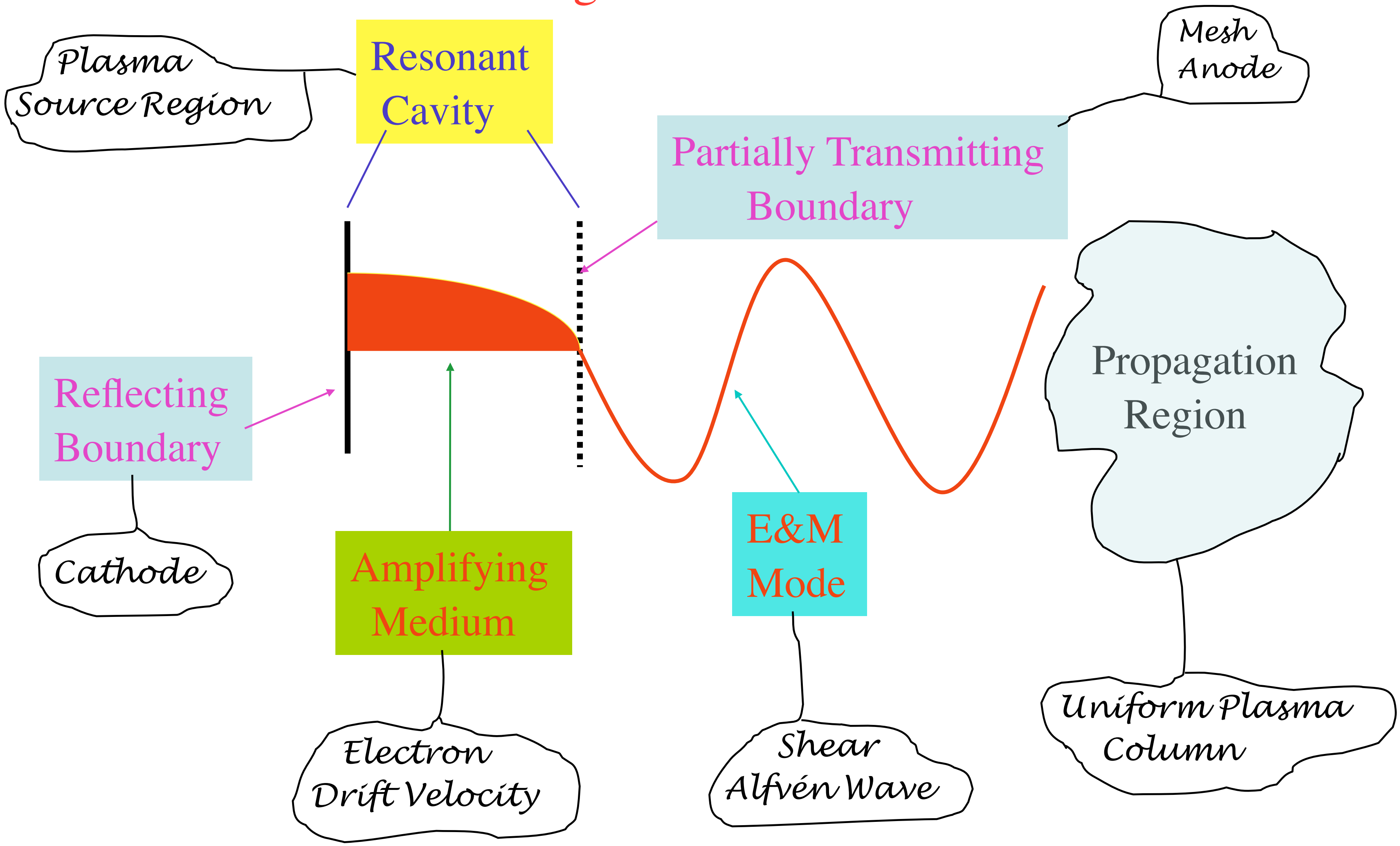
y (cm)
|E| (AU)
x (cm)
|E x|
|E y|

Alfvén Wave Maser

Examples of Geomagnetic Alfvén Wave Masers

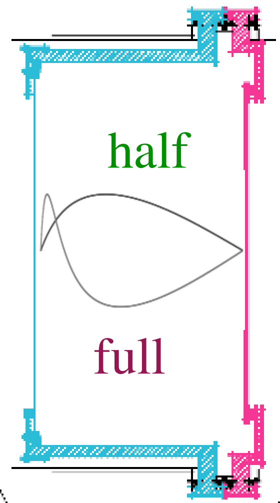


Essential Ingredients of a Maser



MASER SOURCE REGION

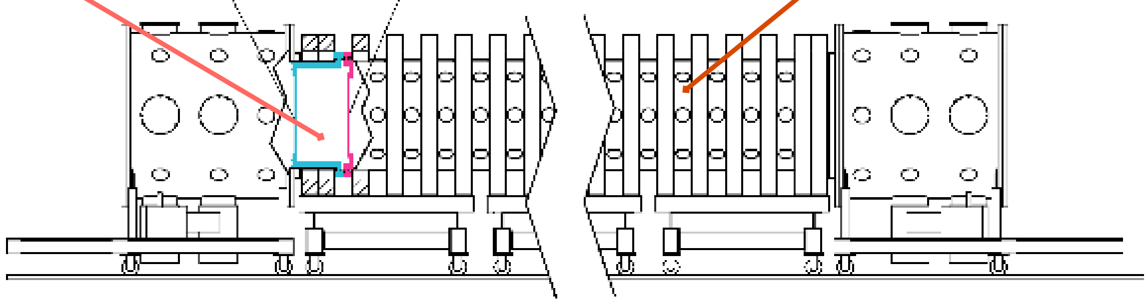
Region between anode and cathode acts as a resonant cavity



Half wave length and full wave length resonant modes illustrated

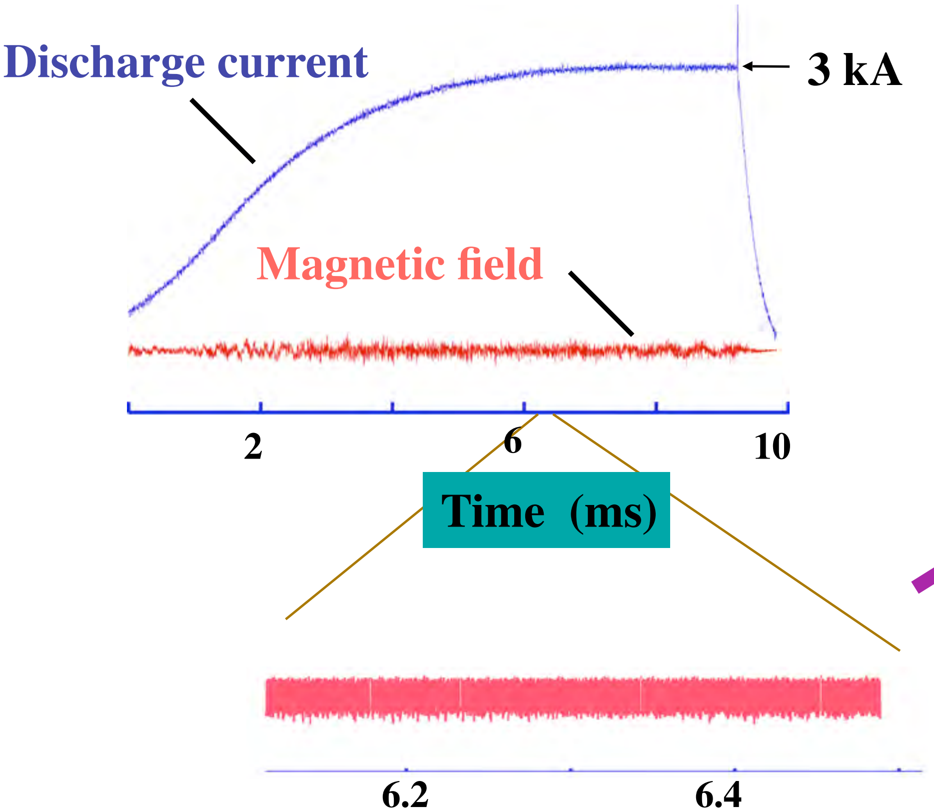
Alfvén wave is amplified here

Amplified Alfvén wave observed here

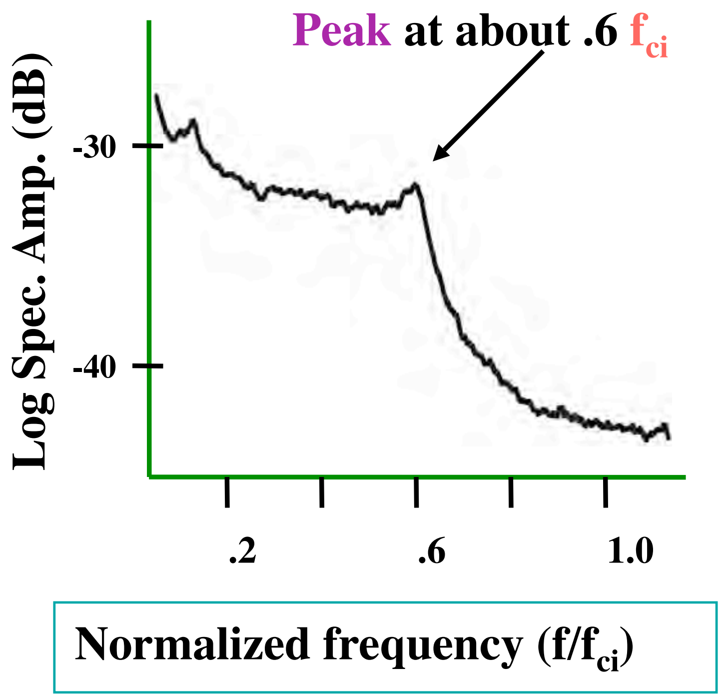


LAPDU Plasma Device

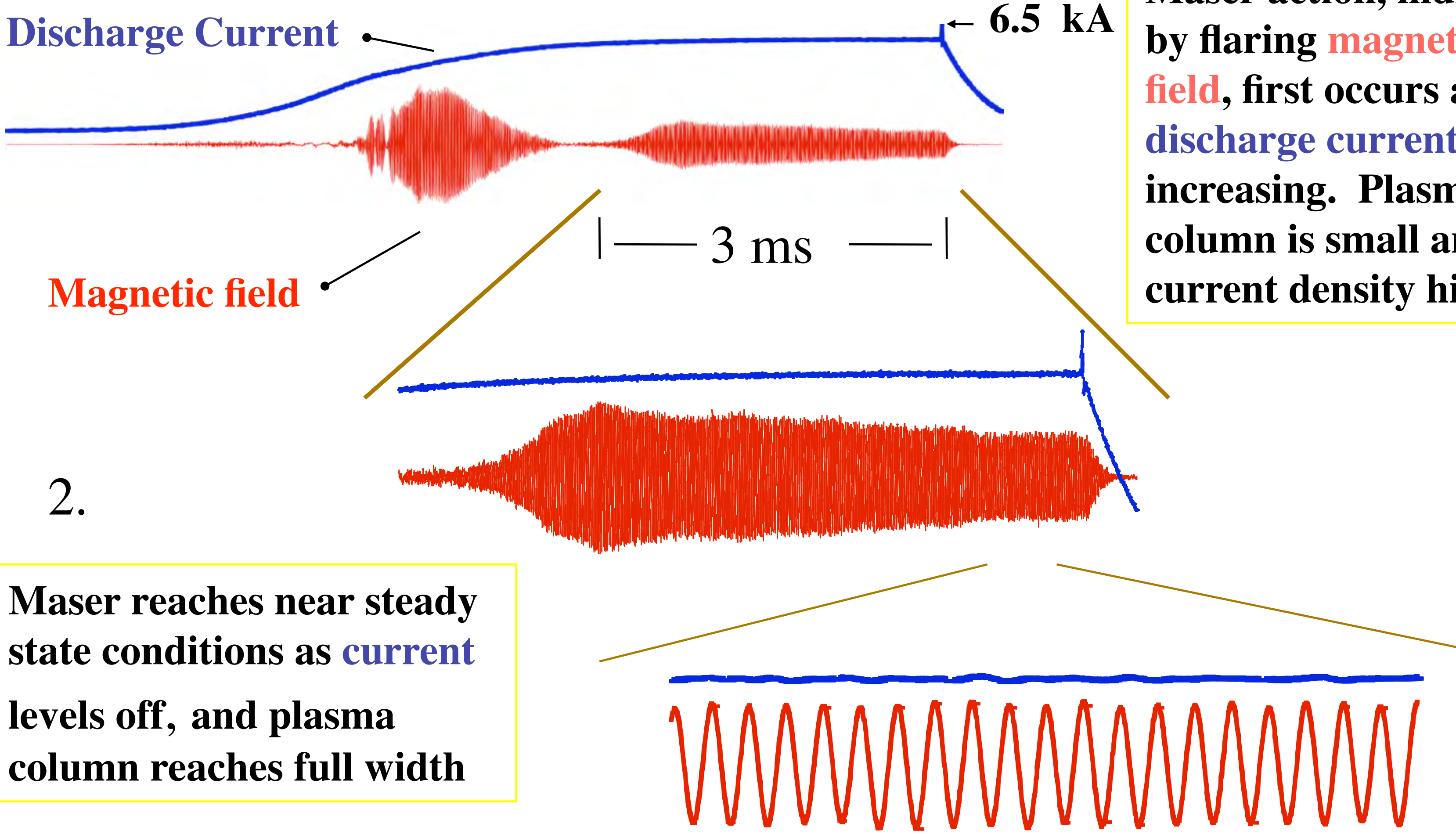
Plasma without Maser Present



Shear Alfvén wave frequency spectrum is broadband, with a peak at about .6 f_{ci}. This peak corresponds to the maser frequency



Maser Temporal development



1.

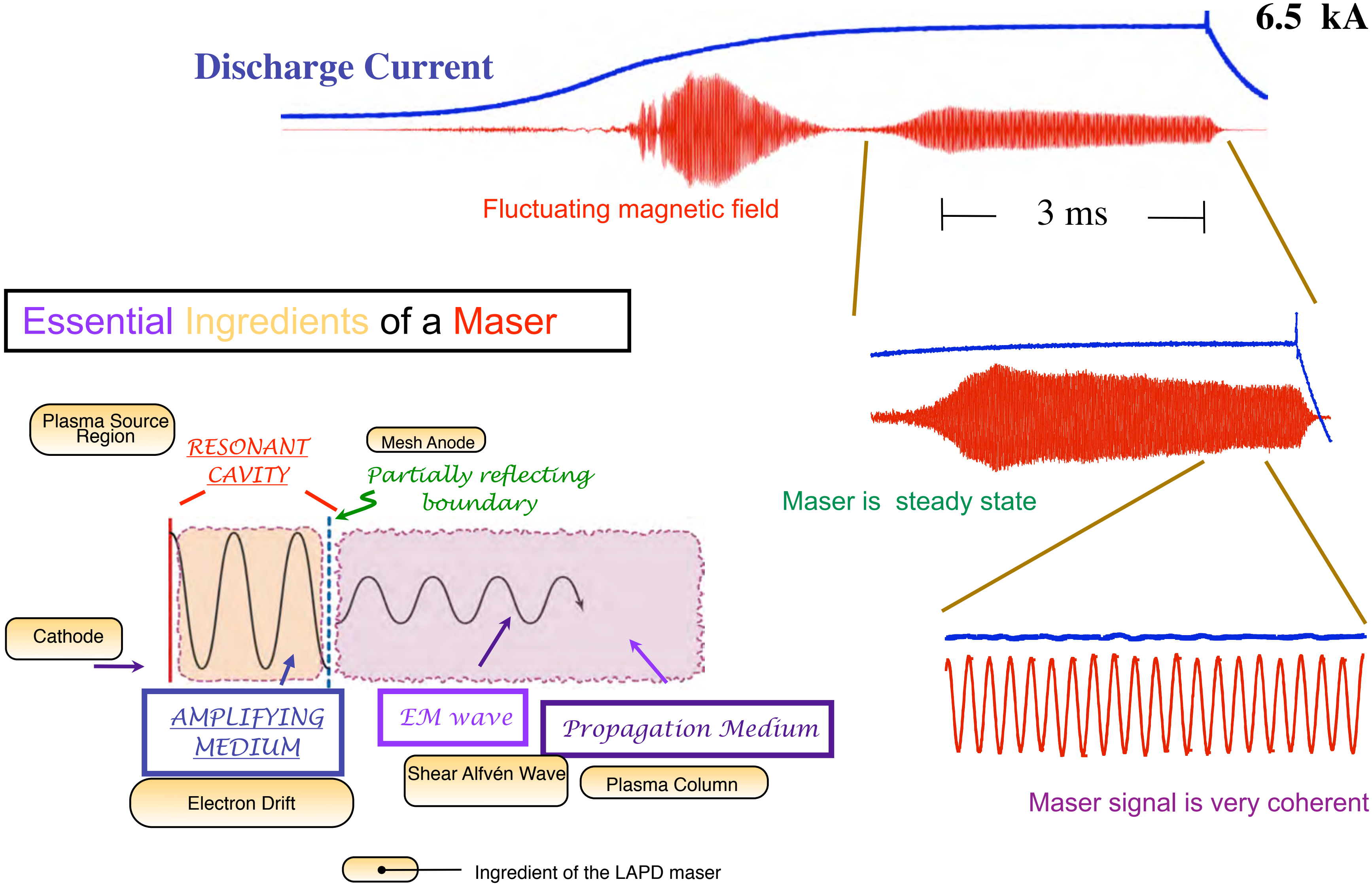
Maser action, indicated by flaring magnetic field, first occurs as discharge current is increasing. Plasma column is small and current density high

2.

Maser reaches near steady state conditions as current levels off, and plasma column reaches full width

3. **Final magnetic field signal is very coherent**

Alfvén wave maser well above threshold - steady state

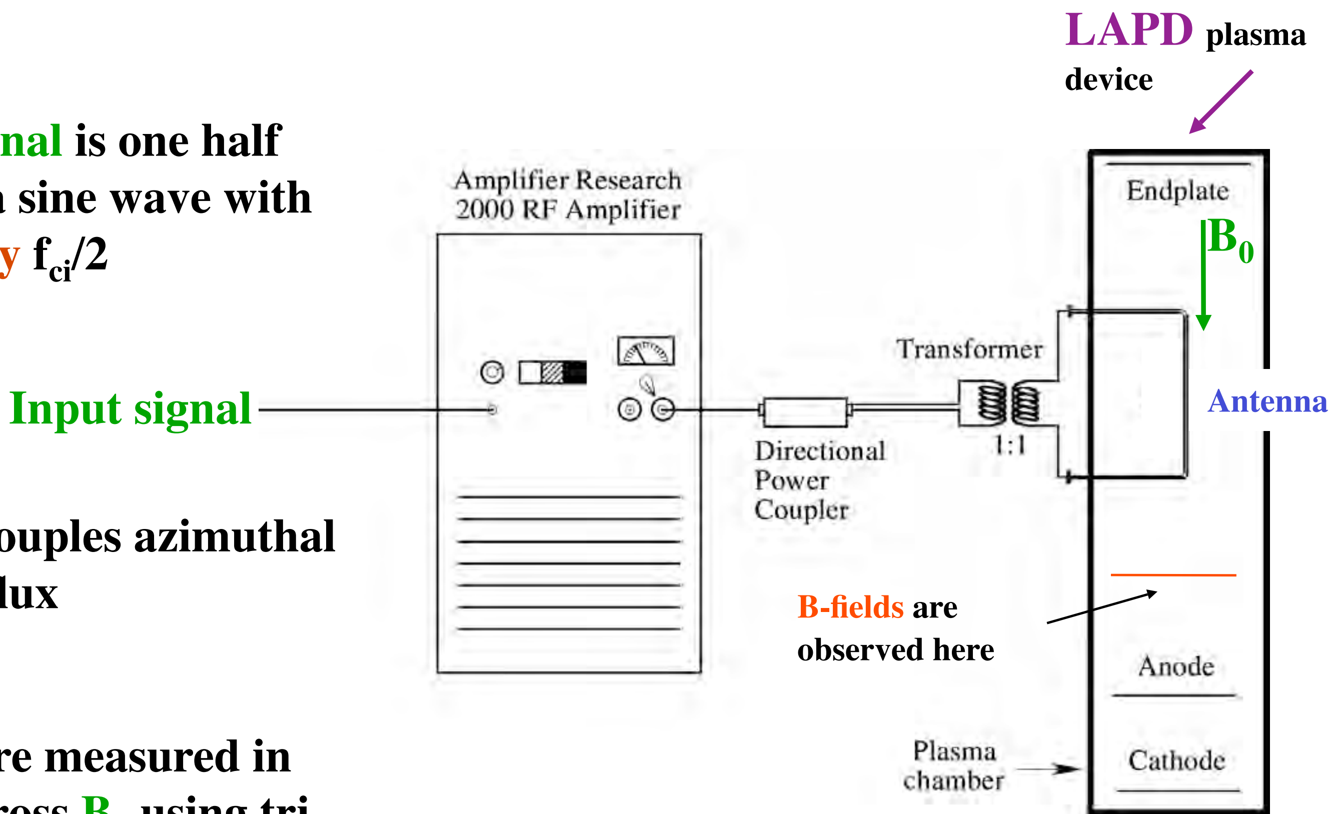


FLRs - Experimental Setup

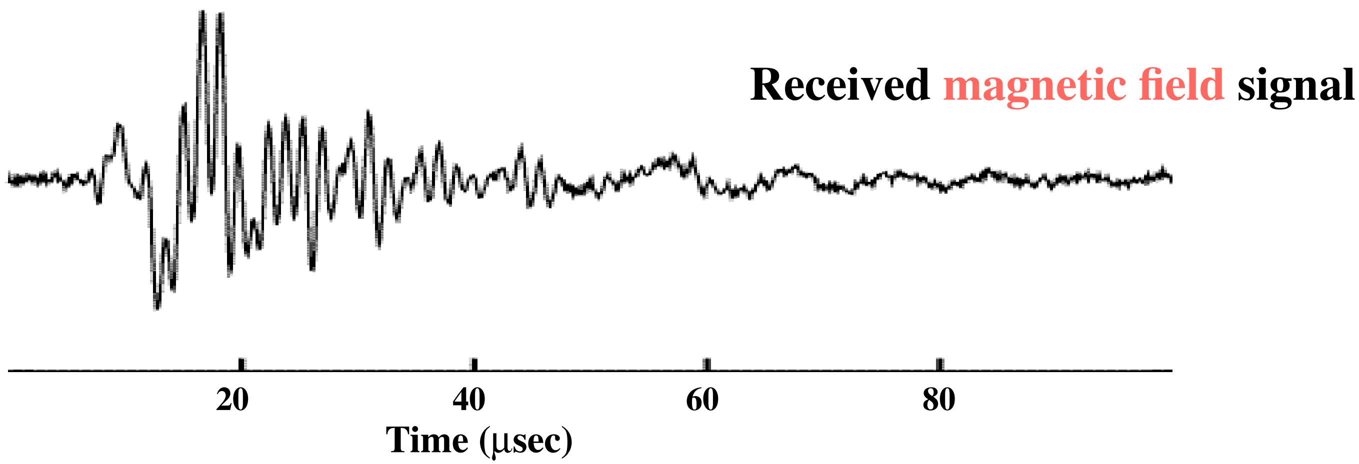
- **Input signal** is one half cycle of a sine wave with **frequency** $f_{ci}/2$

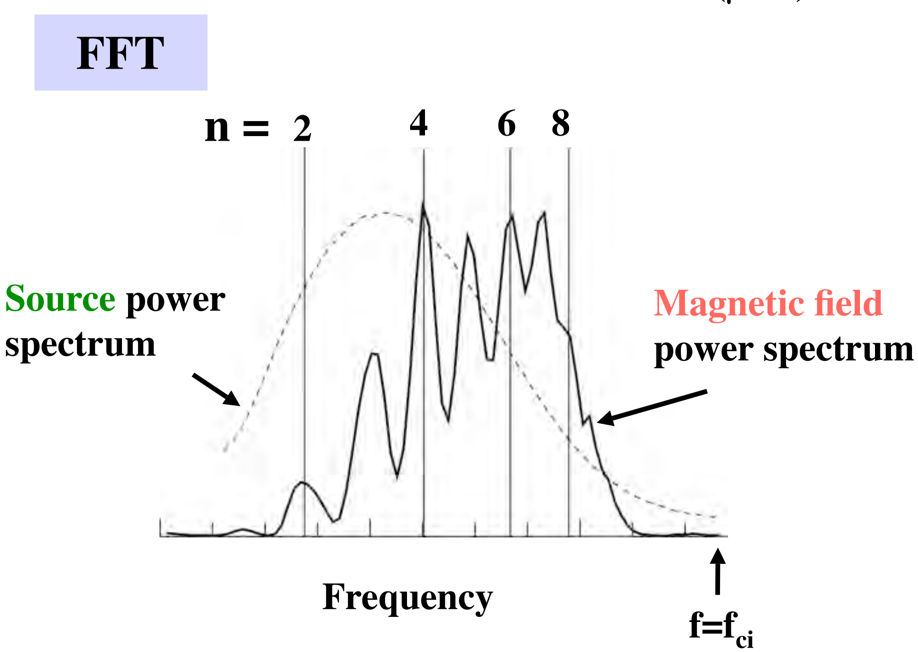
- **Antenna** couples azimuthal magnetic flux

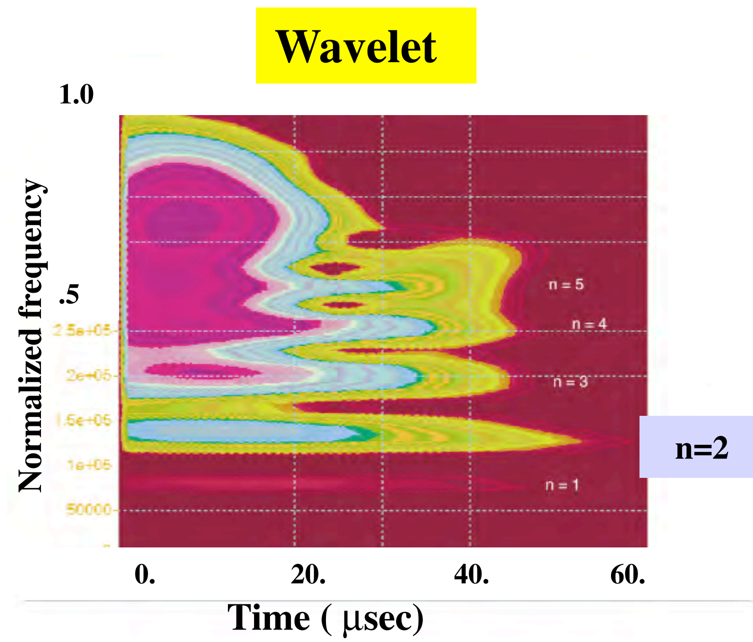
- **B-fields** are measured in planes across B_0 using tri-axial, differentially-wound, induction loop (B-dot) coils



Observed Field Line Resonances

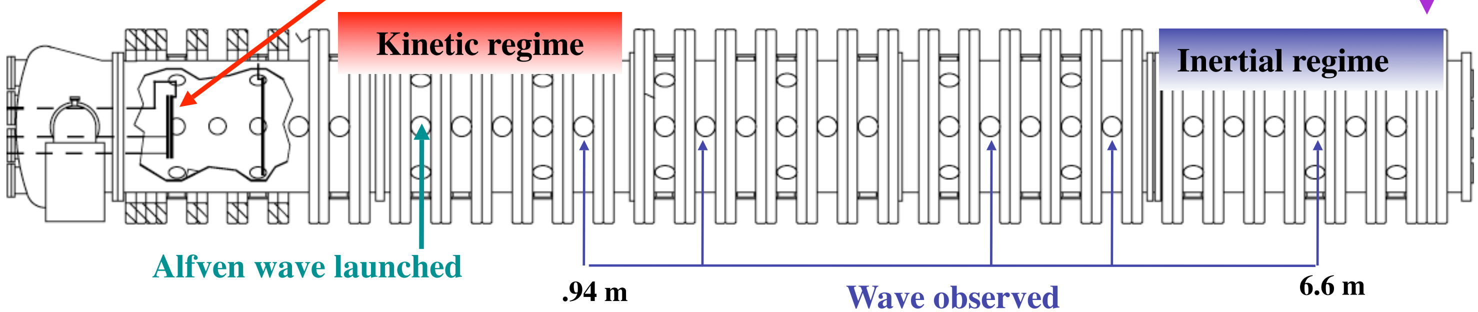


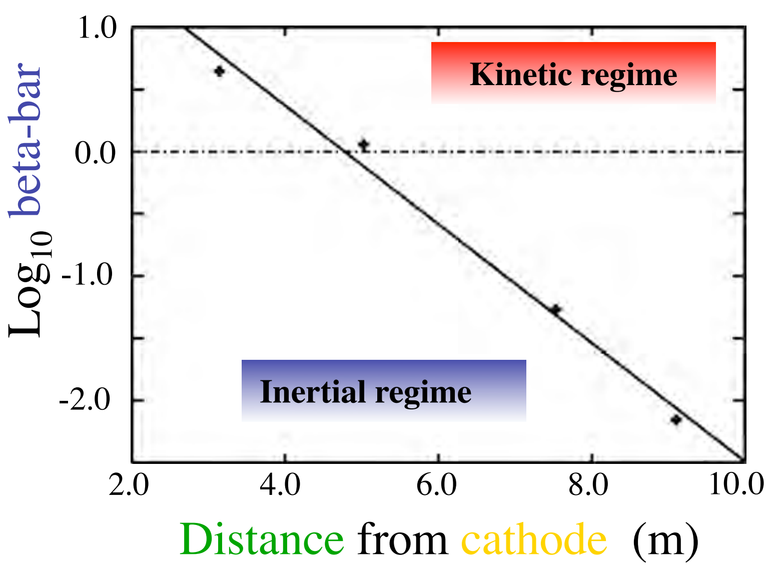




Shear Alfvén wave propagation in a parallel beta gradient

Axial magnetic field, B_0, increases from 500 G at cathode to 1500 G at end of plasma column.





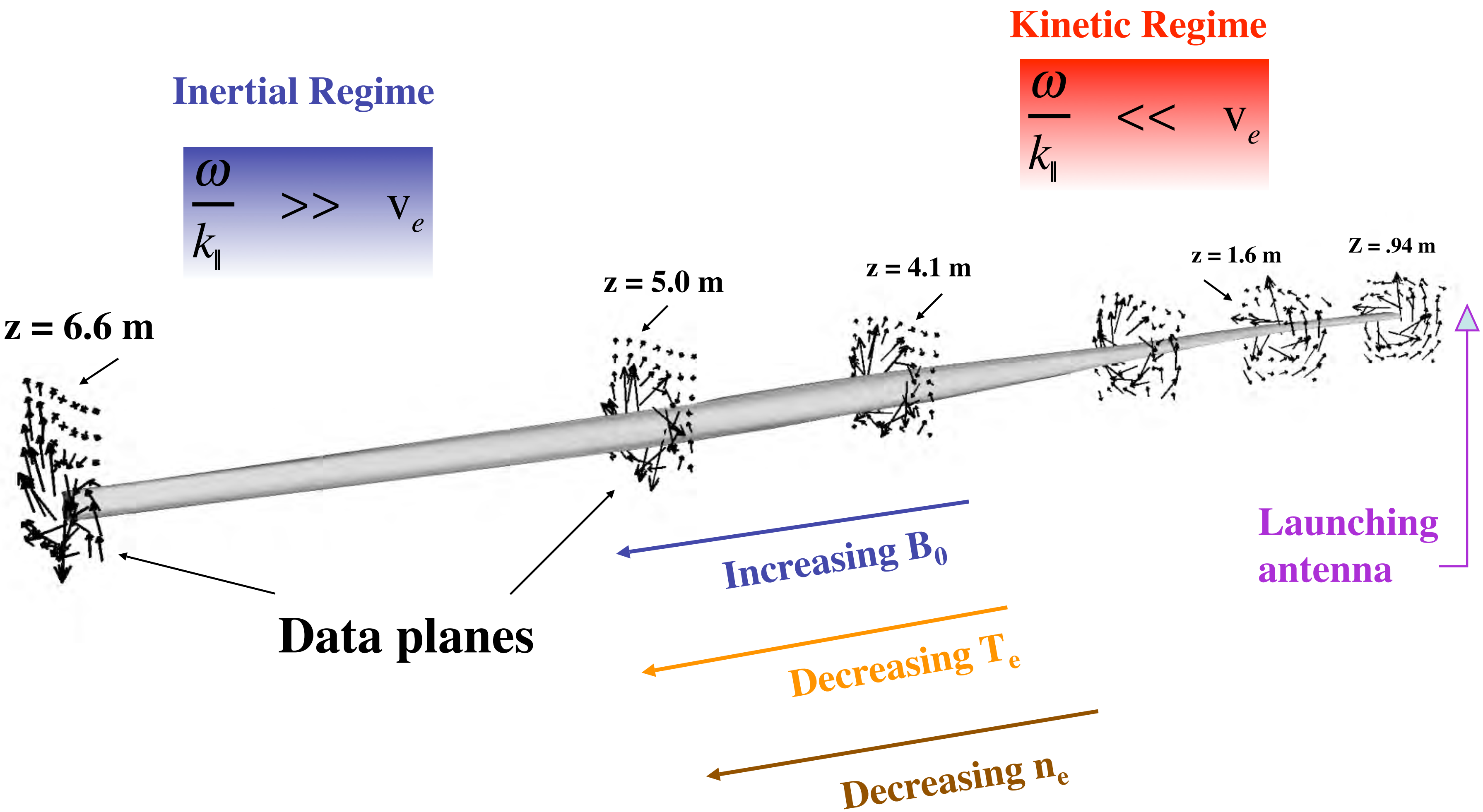
Plasma density decreases from 3.0×10^{12} cm^{-3} to 1.5×10^{11} cm^{-3}, and electron temperature decreases from 5 eV to .5 eV from the cathode to the end of the plasma column.

This combination of parameters leads to a three order of magnitude change in beta-bar

$$\frac{d\bar{\beta}}{dz} = 100\ m^{-1}$$

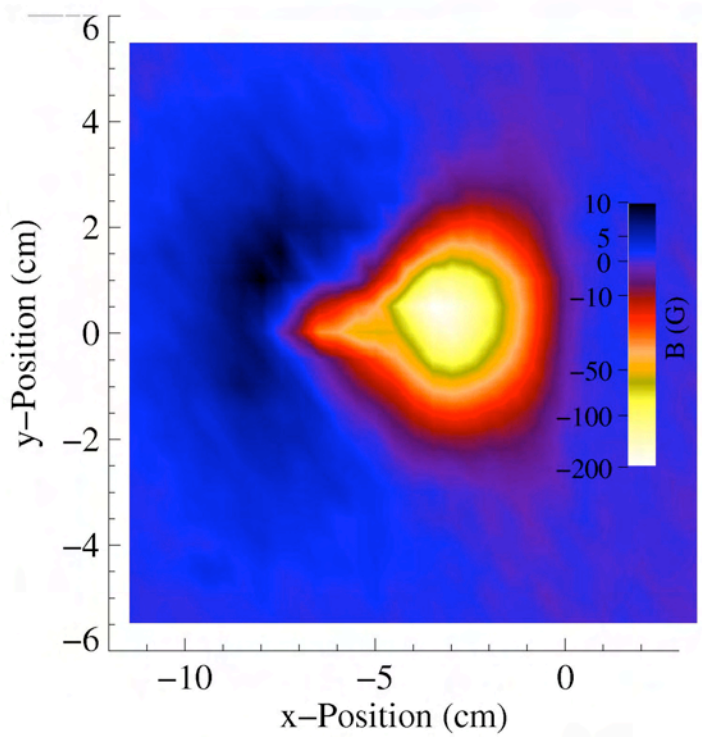
$$\bar{\beta} = \frac{M}{m}\beta = \frac{v_e^2}{V_A^2}$$

Iso-surface of B-perp



Generation of a Dense plasma (by laser irradiaition) in a background magnetoplasma

Excluded Magnetic Field



$\uparrow$ Target (x=0)

B_0 = 1.5 kG

δz = 2 cm

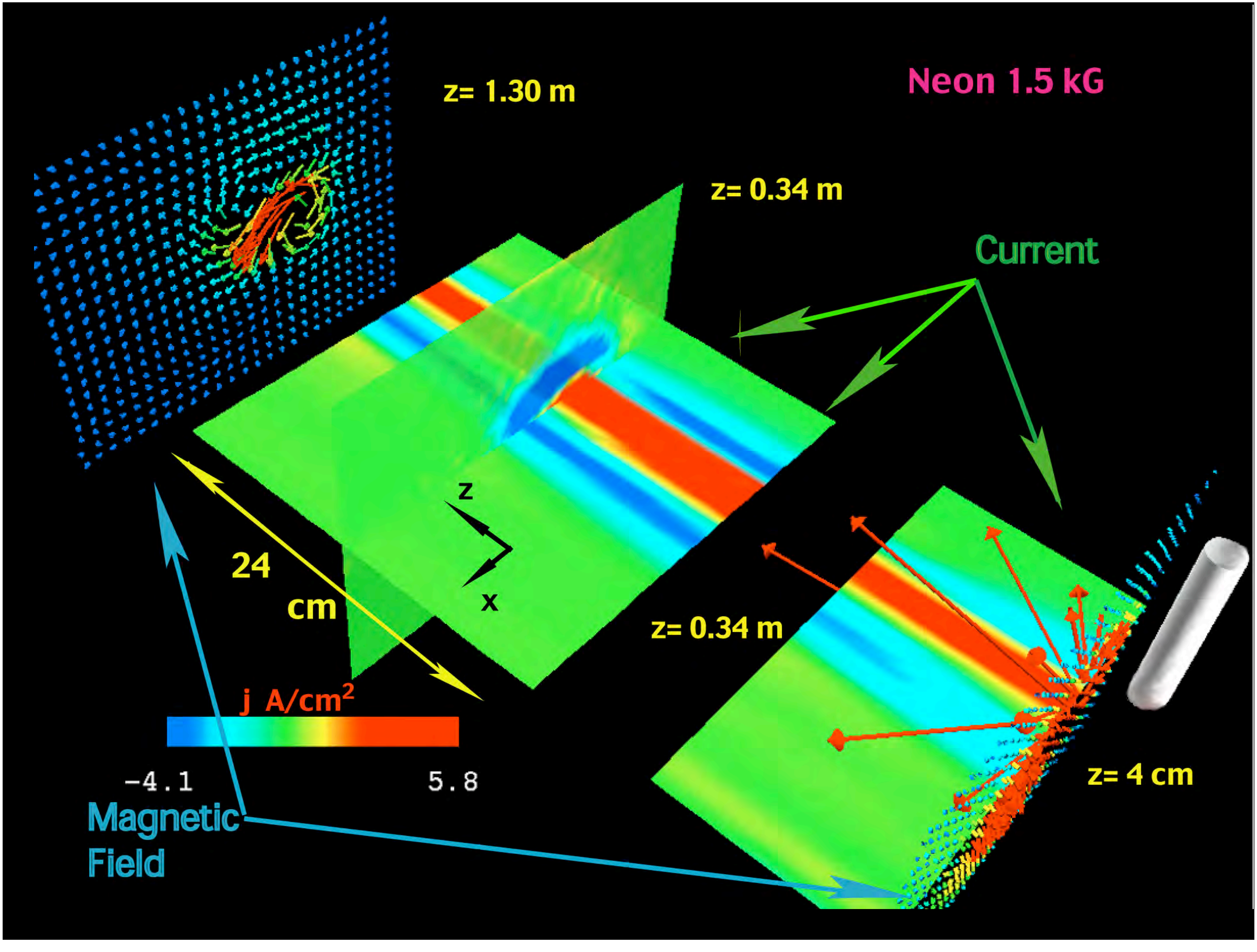
τ = 0.38 μs

Neon

$$R_{bubble} = \left(3\mu_0 \frac{E_{lpp}}{\pi B_0^2} \right)^{1/3} \approx \text{ 4 cm}$$

$$v_{\parallel} = 1.4 \times 10^7 \, cm/s \quad v_{\perp} = 1.1 \times 10^7 \, cm/s$$

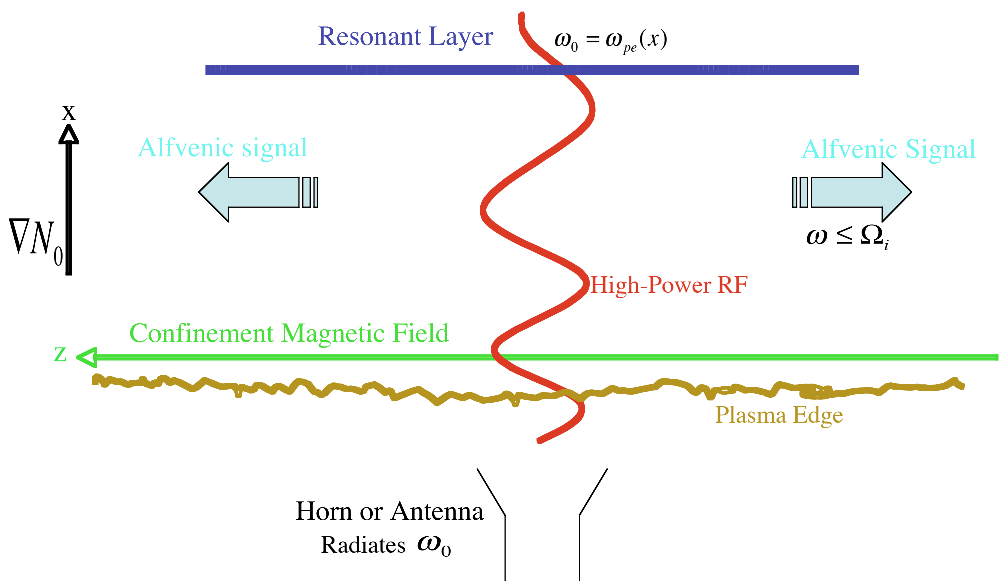
$$\tau_{bubble} \simeq \frac{2R_b}{v_{\perp}} = 0.7 \ \mu s$$


Neon 1.5 kG
z= 1.30 m
z= 0.34 m
Current
z
x
24
cm
z= 0.34 m
j A/cm^2
-4.1
5.8
z= 4 cm
Magnetic
Field

Intense Microwave interactions at plasma resonance locations

Fast electron generation by microwaves

Schematic Cartoon of Problem

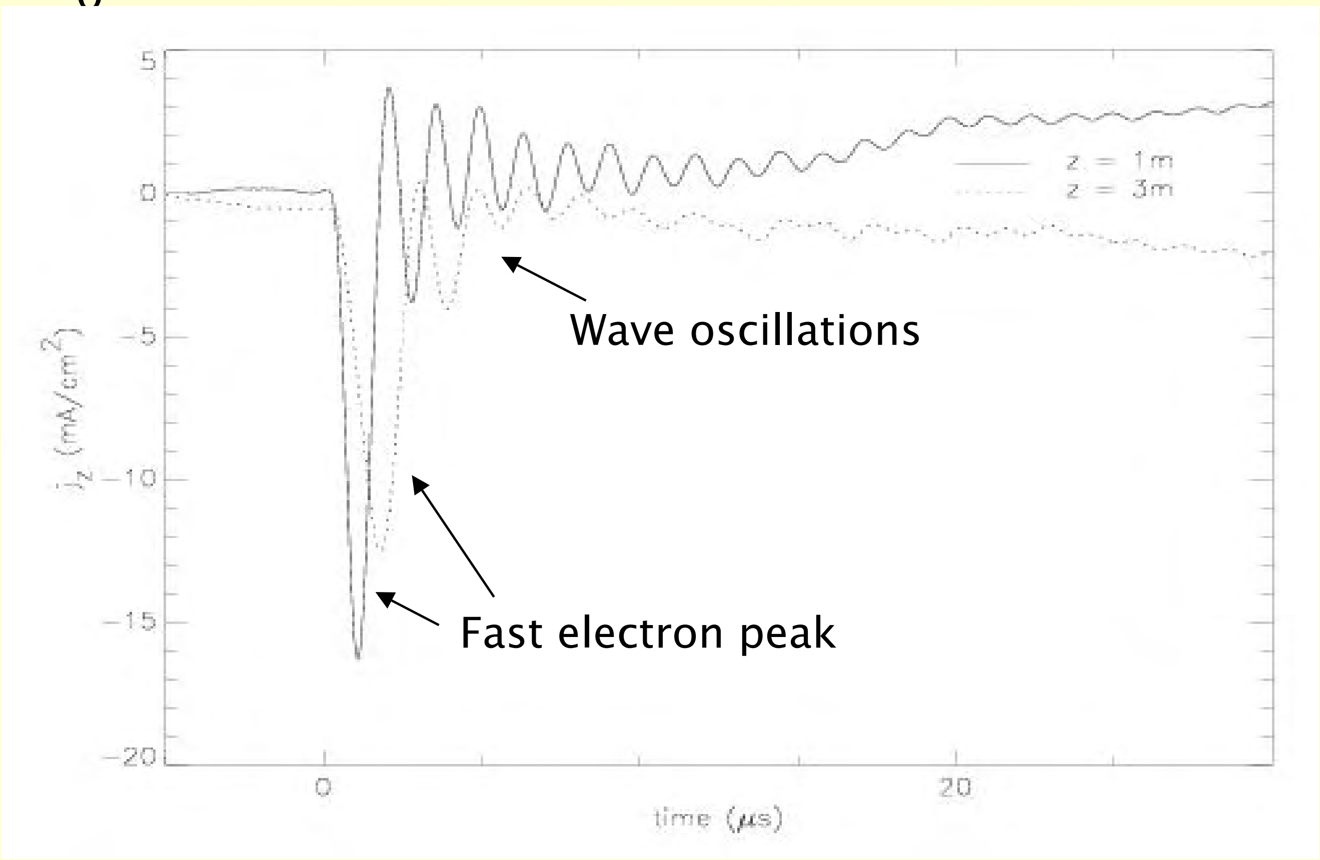


B. Van Compernolle Phd->Brussels
W. Gekelman
P. Pribyl
G. Morales

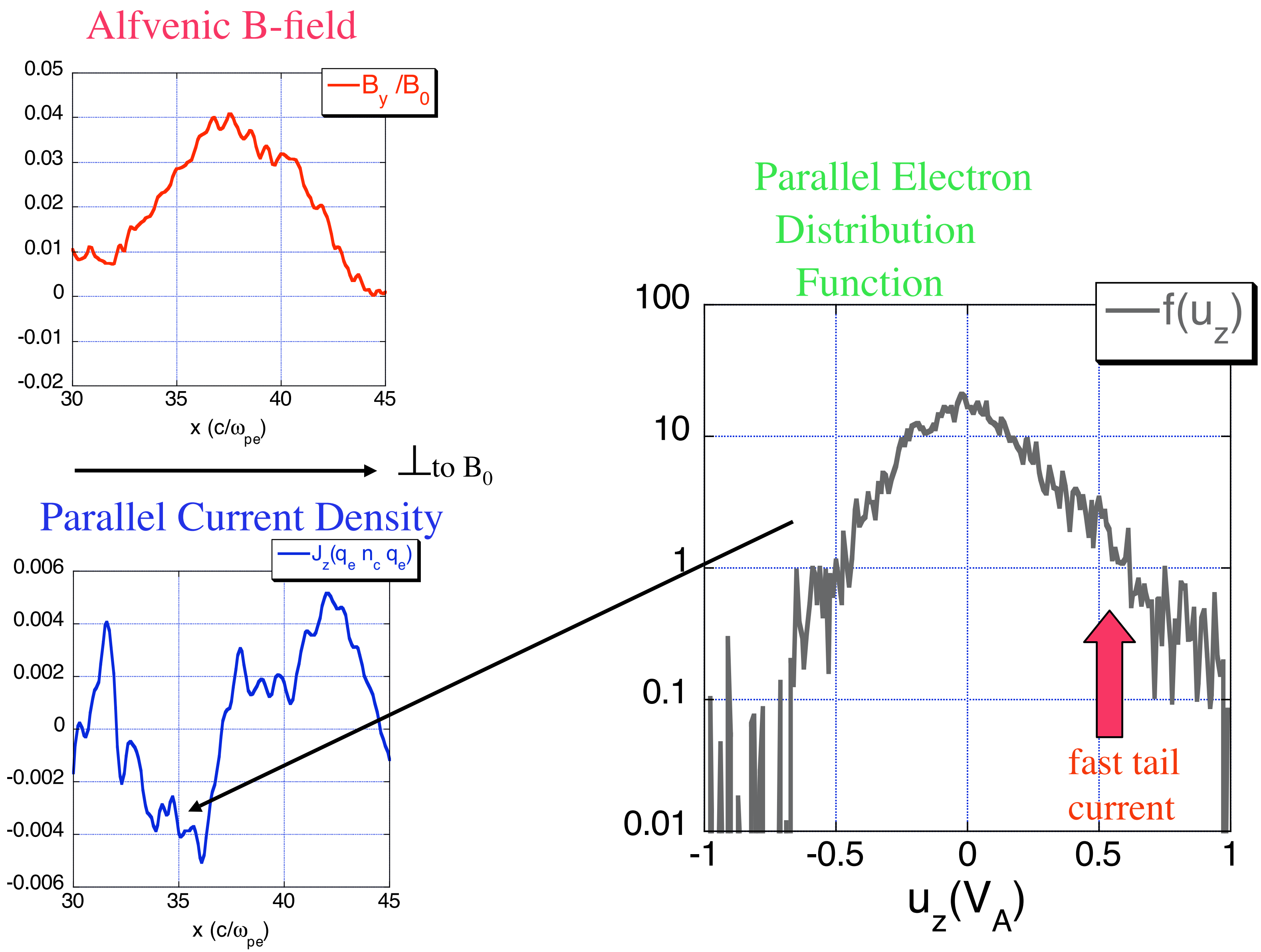
Related to Ionospheric Modification Experiments

Fast Electrons $j_z = \nabla \times B_t$

(x = –20 cm, y = 2 cm)
v_{de} = 3 x 10^8 cm/s
$dn_e/n_0 = 10^{-4}$

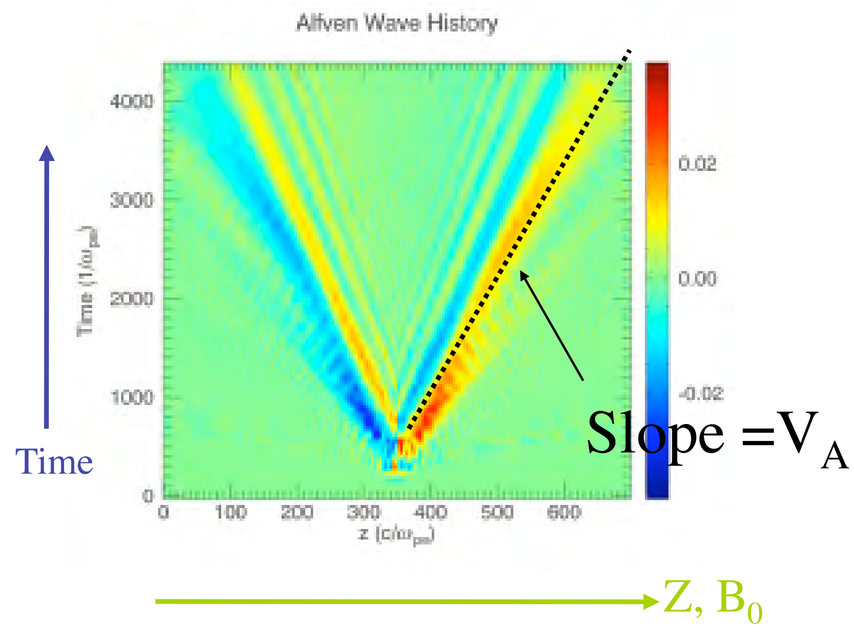


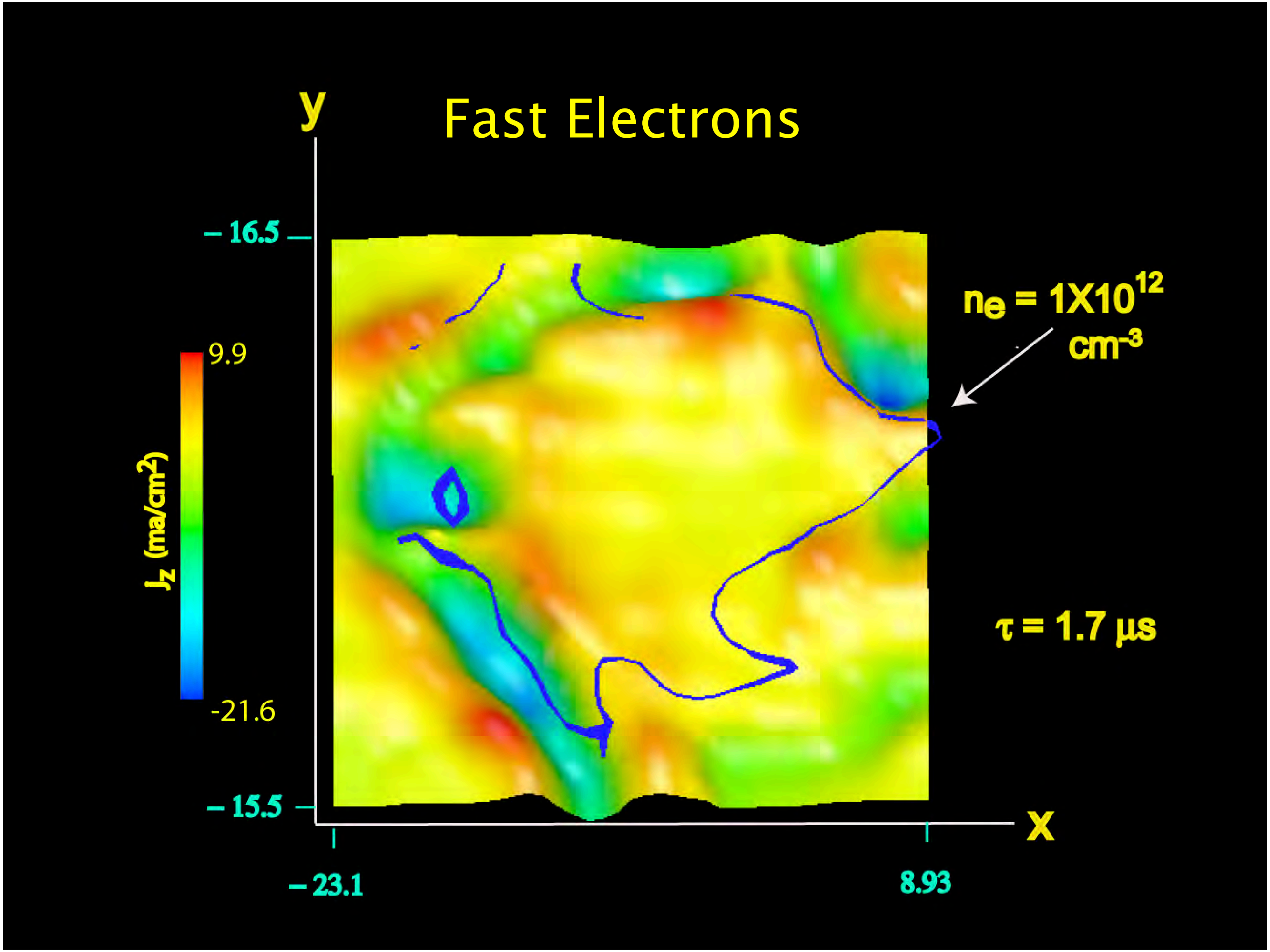
Self-consistent Low-Frequency Features Downstream from Exciter

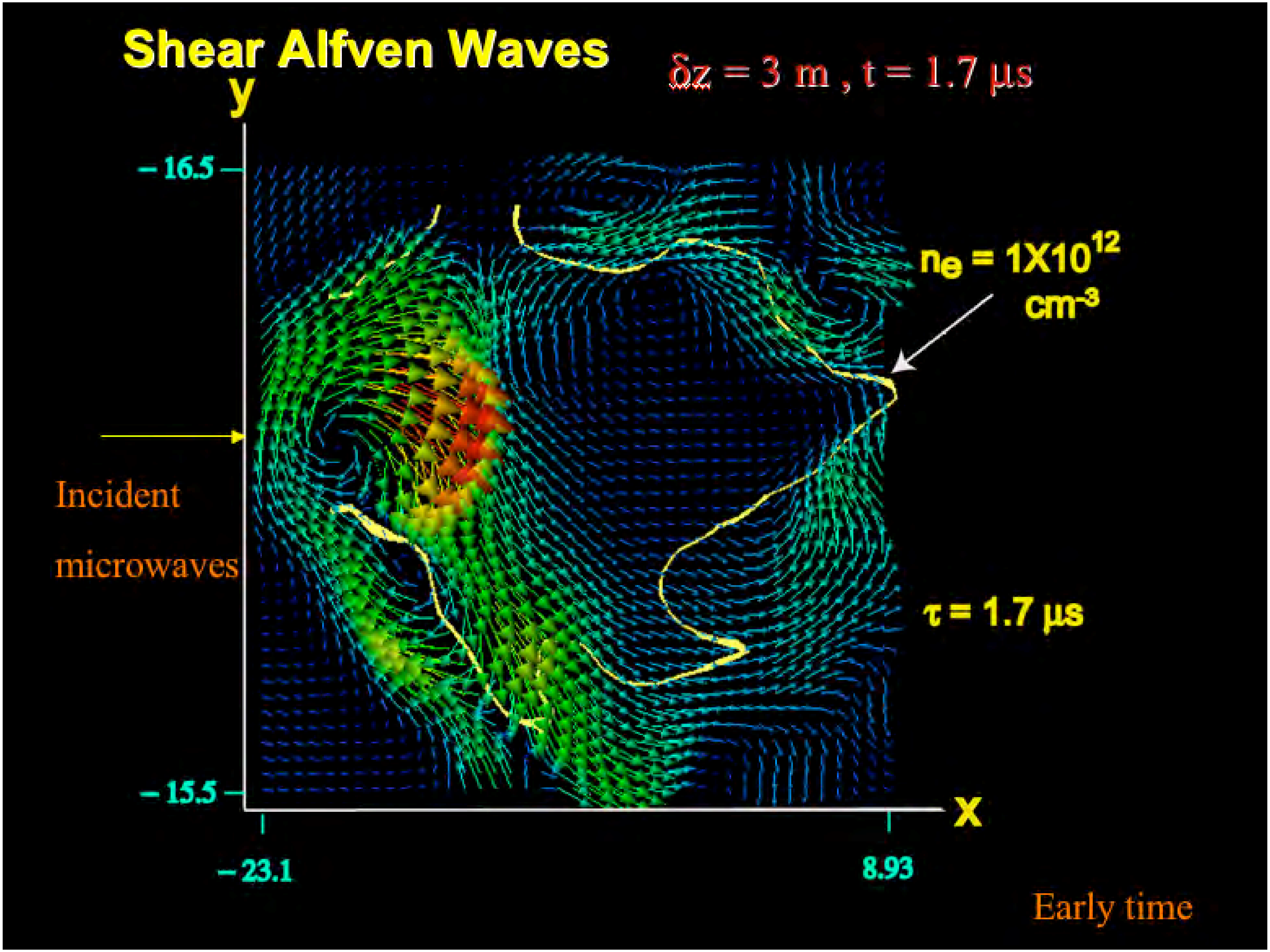


An Alfvén Wavepacket is Excited by the Nonlinear O-mode Pulse

Space-time (z,t) history of transverse magnetic field $B_y(x,t)$ at a fixed transverse position x shows a field-aligned structure that propagates with Alfvén speed, V_A, away from exciter



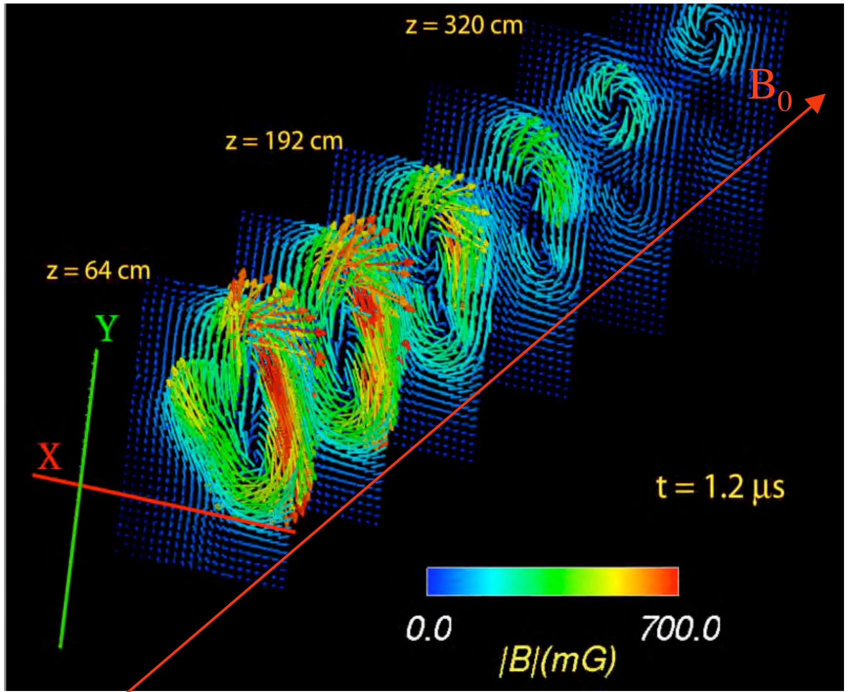

Fast Electrons
y
x
– 16.5
– 15.5
– 23.1
8.93
9.9
-21.6
j_z (ma/cm^2)
n_e = 1X10^{12} cm^{-3}
τ = 1.7 µs



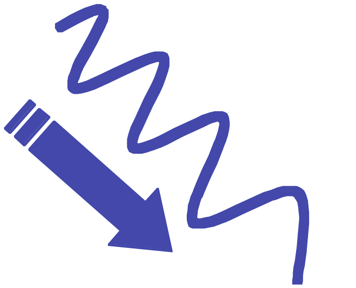
Shear Alfven Waves
δz = 3 m , t = 1.7 μs
y
− 16.5
− 15.5
x
− 23.1
8.93
Incident
microwaves
n_e = 1X10^12
cm^-3
τ = 1.7 μs
Early time

Alfven Wavepacket Excited in Experiment by O-Mode Pulse

Measured snapshot of
wave magnetic field →
at several axial positions away
from O-mode beam injection

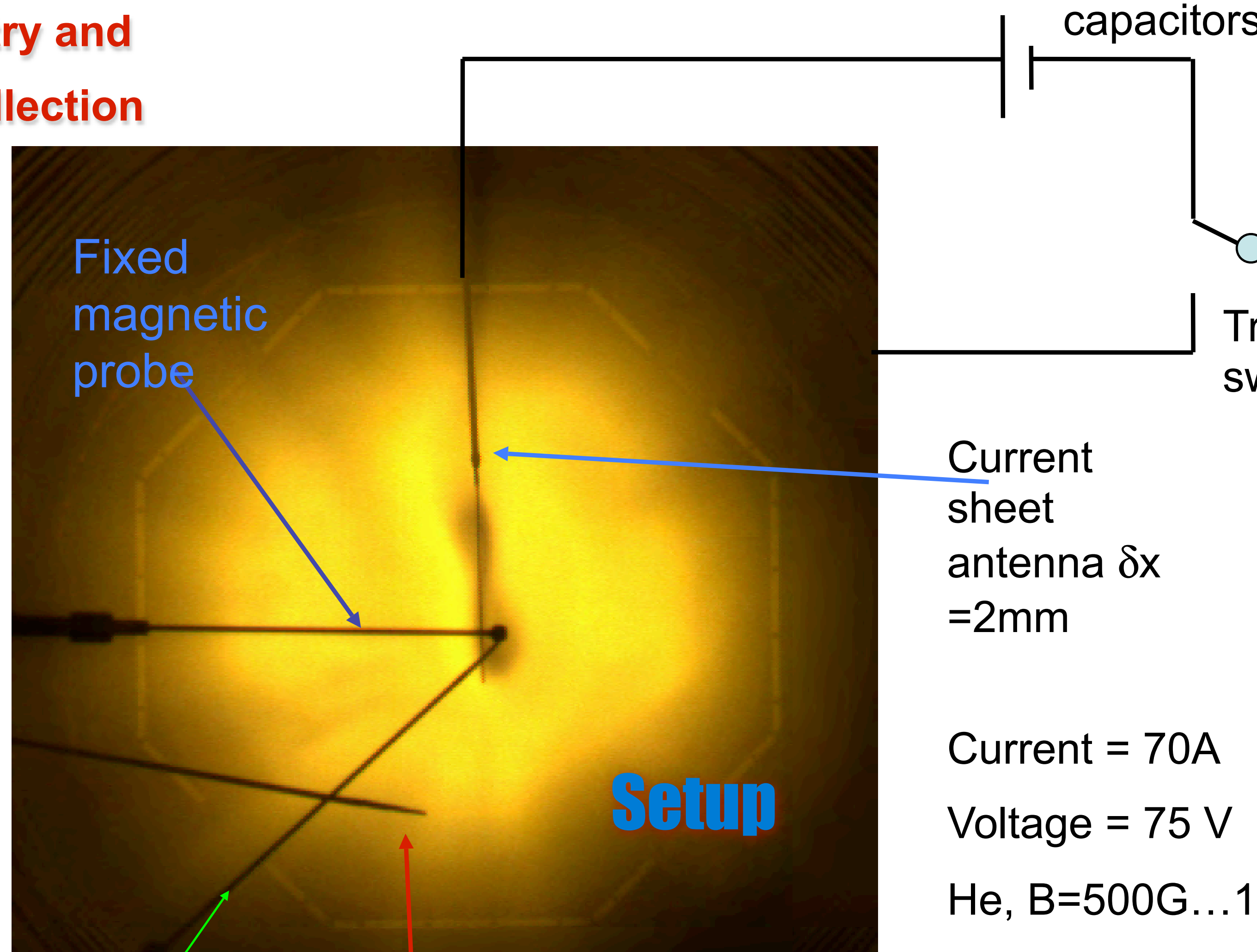


O-mode
injection
here



Turbulence in Narrow Current Channels

Geometry and data collection



Current = 70A

Voltage = 75 V

He, B=500G…1.5 kG

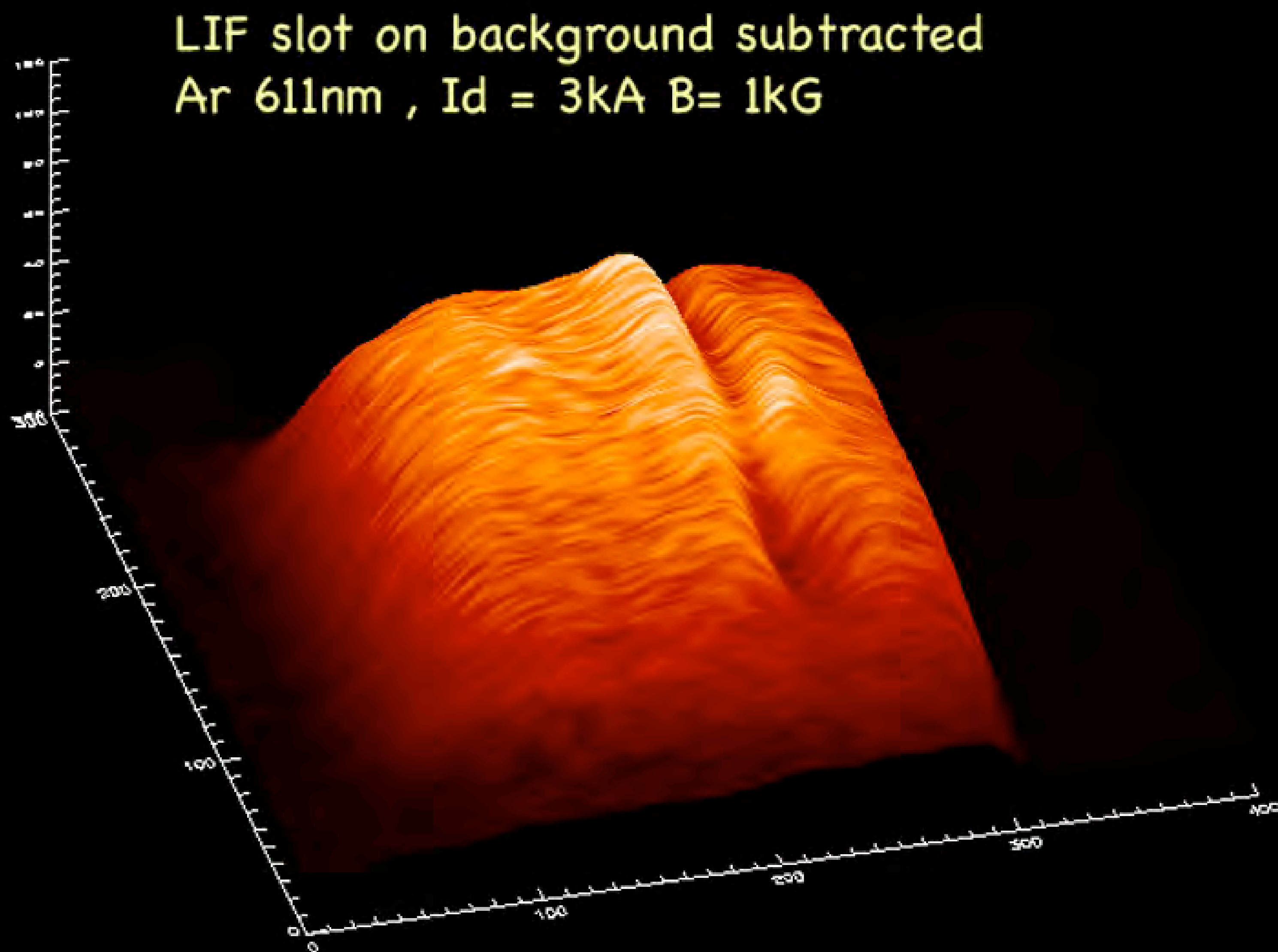
Photograph $T_{shutter}$ = 1 μs

View down axis of machine

LIF system

Dye Laser 12 MW
out 320nm-690 nm
YAG pump laser
50 MW 10ns
500 nm
Pulse stretcher
10ns-> 100ns

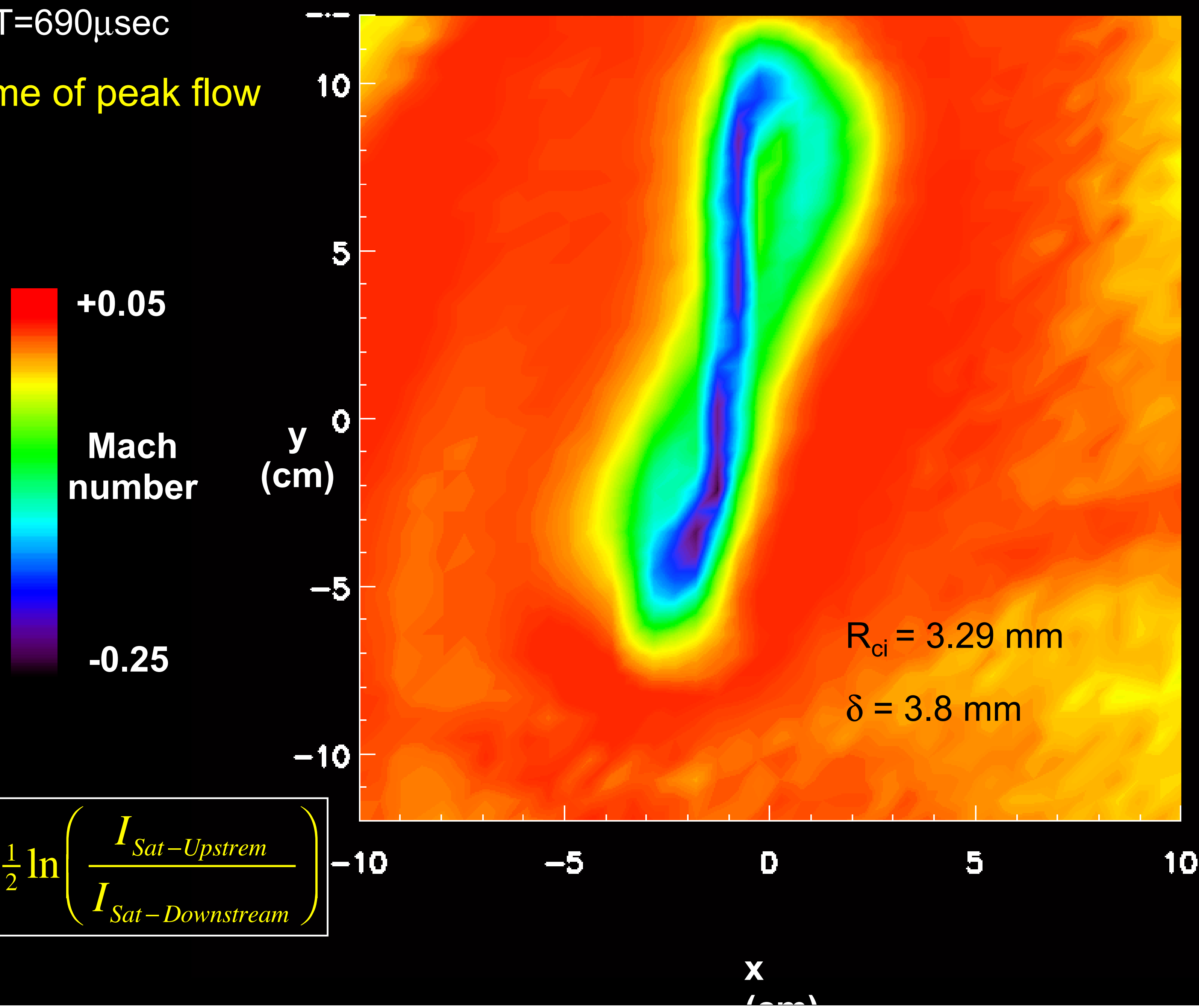
Density Perturbation as seen with Laser Induced Fluorescence



Parallel Ion Flow in a Perpendicular Plane

T=690μsec

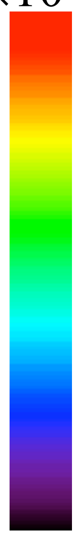
Time of peak flow



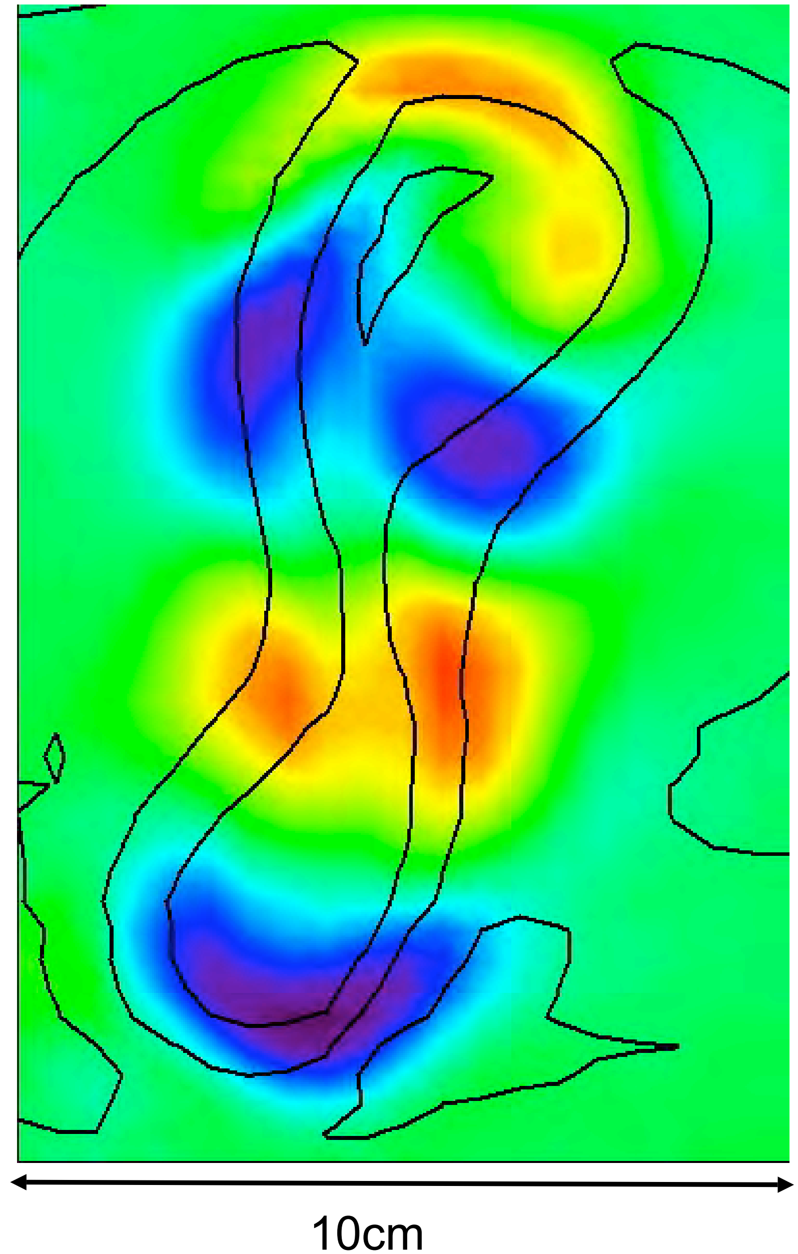
$$M_{\parallel} = \frac{1}{2}\ln\left(\frac{I_{Sat-Upstream}}{I_{Sat-Downstream}}\right)$$

Density plane as a function of time
Each location is an average over 20 plasma discharges

$> 2\times10^{12}\,/\,cm^{3}$



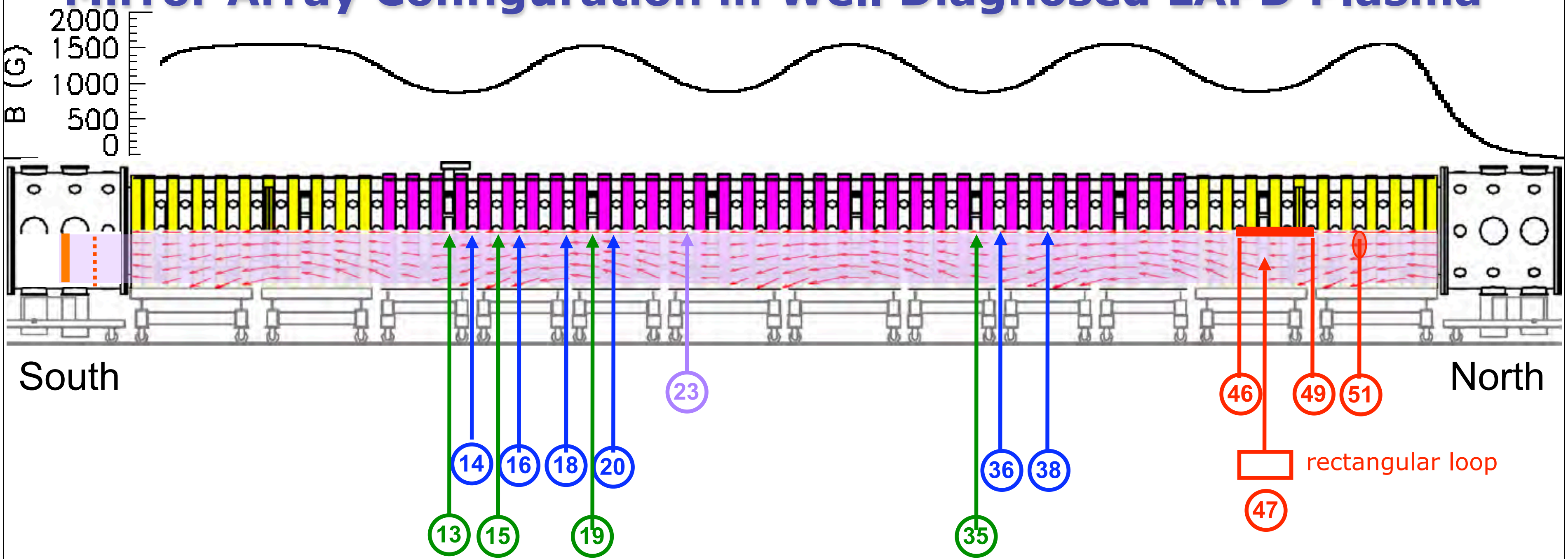
$< 2\times10^{11}\,/\,cm^{3}$



Watch for the repeated filling in of the density depression

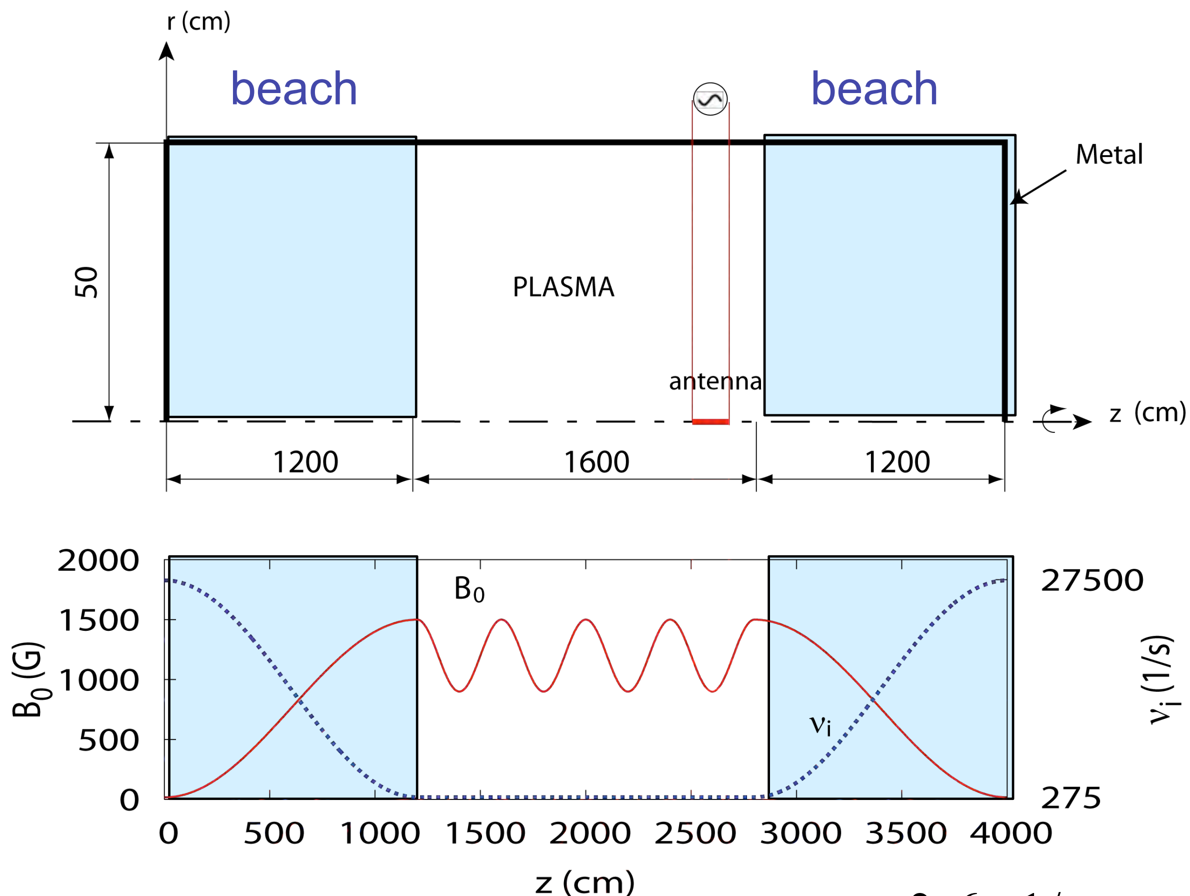
Alfvén wave propagation in multiple magnetic mirrors

Mirror Array Configuration in Well Diagnosed LAPD Plasma



- Various mirror array configurations are powered by 10 independent magnet power supplies; B_0~ 0.5 kG – 2.0 kG.
- Helium plasma column density FWHM ~0.60 m, 17 m length (1 shot per second cathode discharge)
- Microwave interferometers for column plasma density calibration (port 23) ($n_{peak} \approx 1 \times 10^{12}/cm^3$)
- Triple probes for local Te, n_i, V_f measurements (port 13, 15, 19, 35)
- SAW antennas: small disk (p51); copper rod (p46 to p49); rectangular loop (p47)
- B-dot probes for local B_{SAW} measurements (port 14, 16, 18, 20, 36, 38)

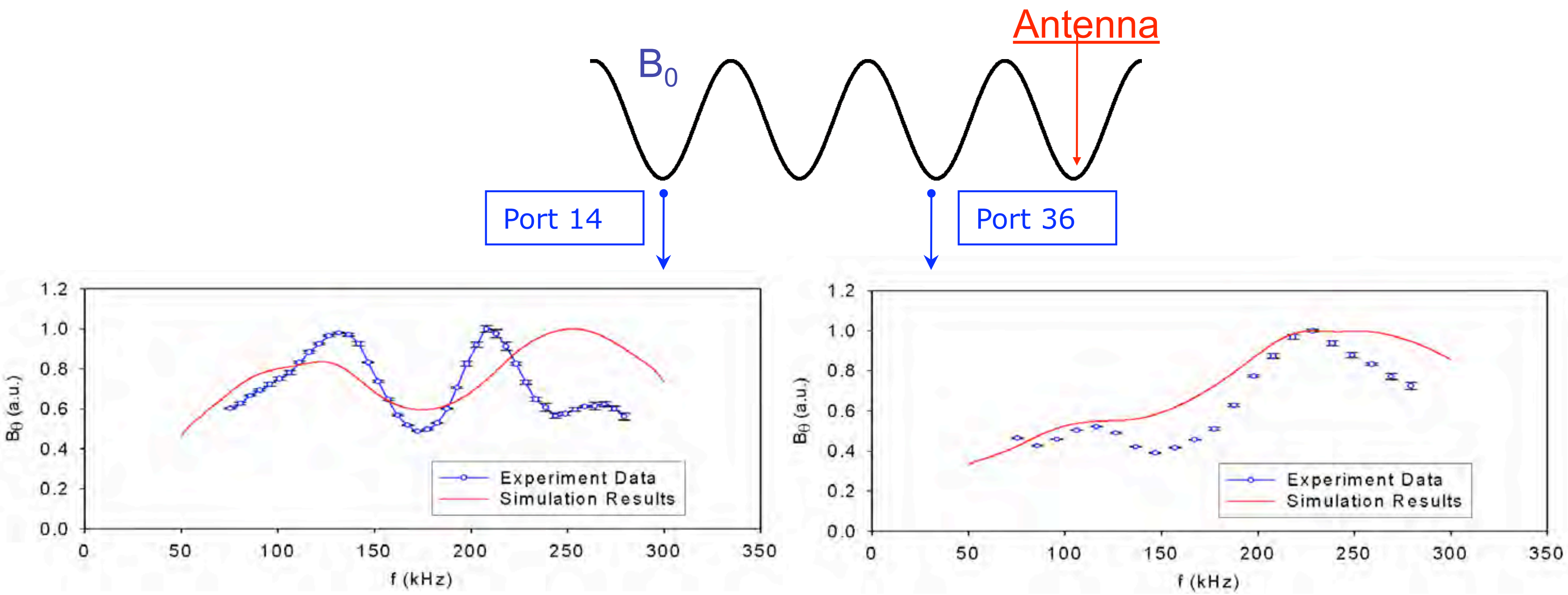
Computation Setup With



$$\nu_e = 2e6 \quad 1/s$$

- small Br approximation is used in the beach section.
- The beach section is set flatter than experiment.
- The effective ion collision frequency is introduced in the beach to resolved ion cyclotron resonance excitation.

Closer Look:
Simulation Results and Experiment Data

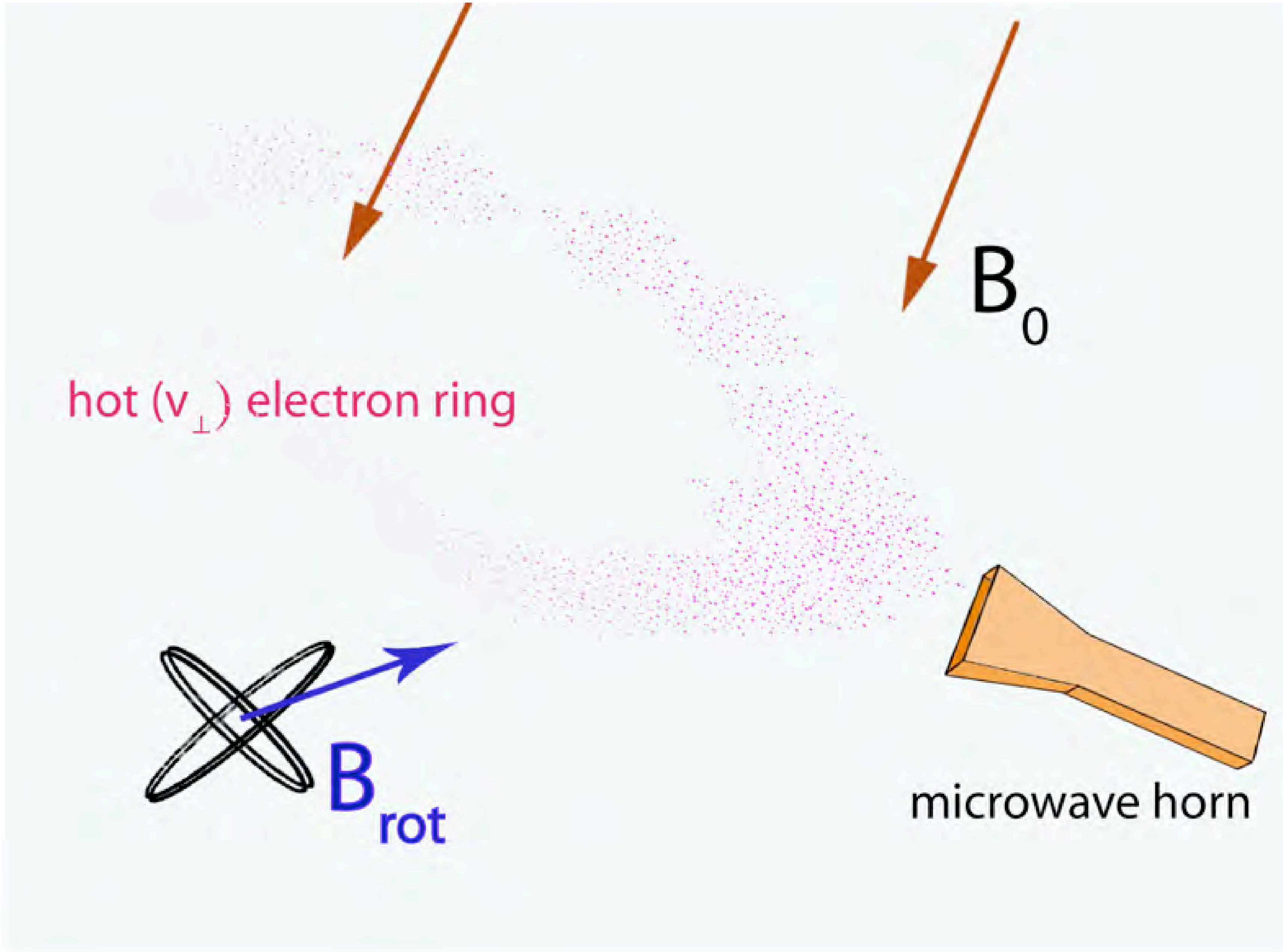


$$\nu_e = 2\times 10^6 \quad 1/s$$

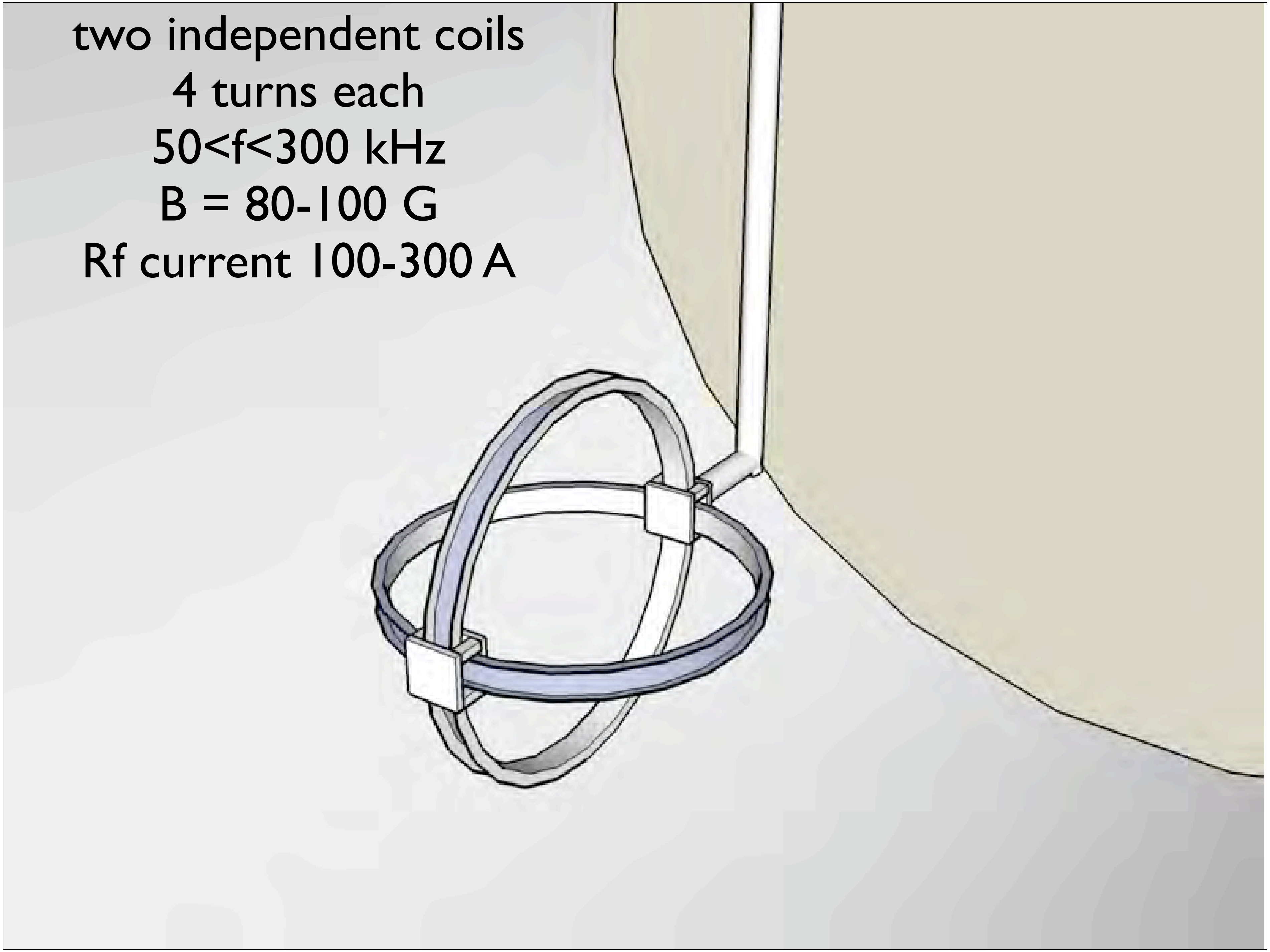
$$\nu_{LD} = 10\omega/\omega_{GAP}$$

Some Planned Experiments for the Muri project:

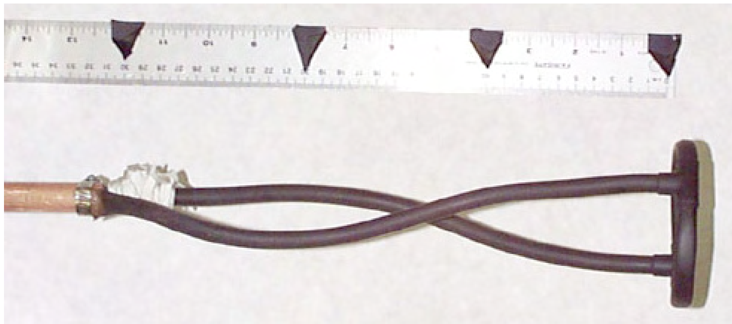
1) Creation of Mirror-Trapped Electron Populations
2) Interaction of Trapped Electrons with Rotating Magnetic Fields, Alfvén Waves, Whistler Waves, Lower Hybrid Waves
3) Measurement of Antenna Radiation Patterns
4) Wave particle Interactions in the Presence of Fast Ions



B0
hot (v⊥) electron ring
Brot
microwave horn


two independent coils
4 turns each
50<f<300 kHz
B = 80-100 G
Rf current 100-300 A

Antennas, Probes



Probes

Three 3-axis differentially-wound B-dot probes measure magnetic field.

- Calibrated up to 50MHz
- 5mm in size
- Attached to computer-controlled data-acquisition system
- At 1Hz rep rate, probe gradually sweeps out a 12cm x 11.5cm plane with position resolution of 5mm

2D LIF Probe

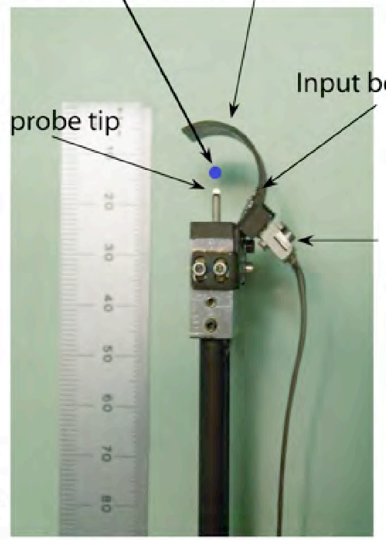
Axial View (along B_o)

Target detection spot

Extraneous light block

Input beam polarizer

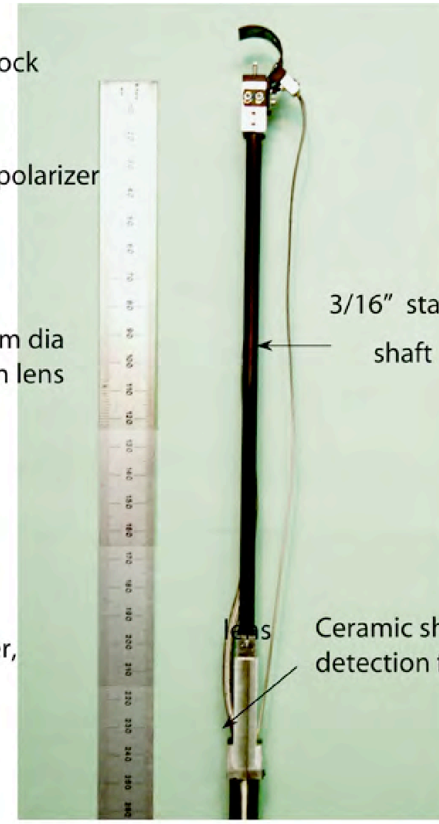
Langmuir probe tip



1mm dia
Grin lens

Scale in mm

Input beam fiber,
100μm core



3/16" stainle

shaft

lens

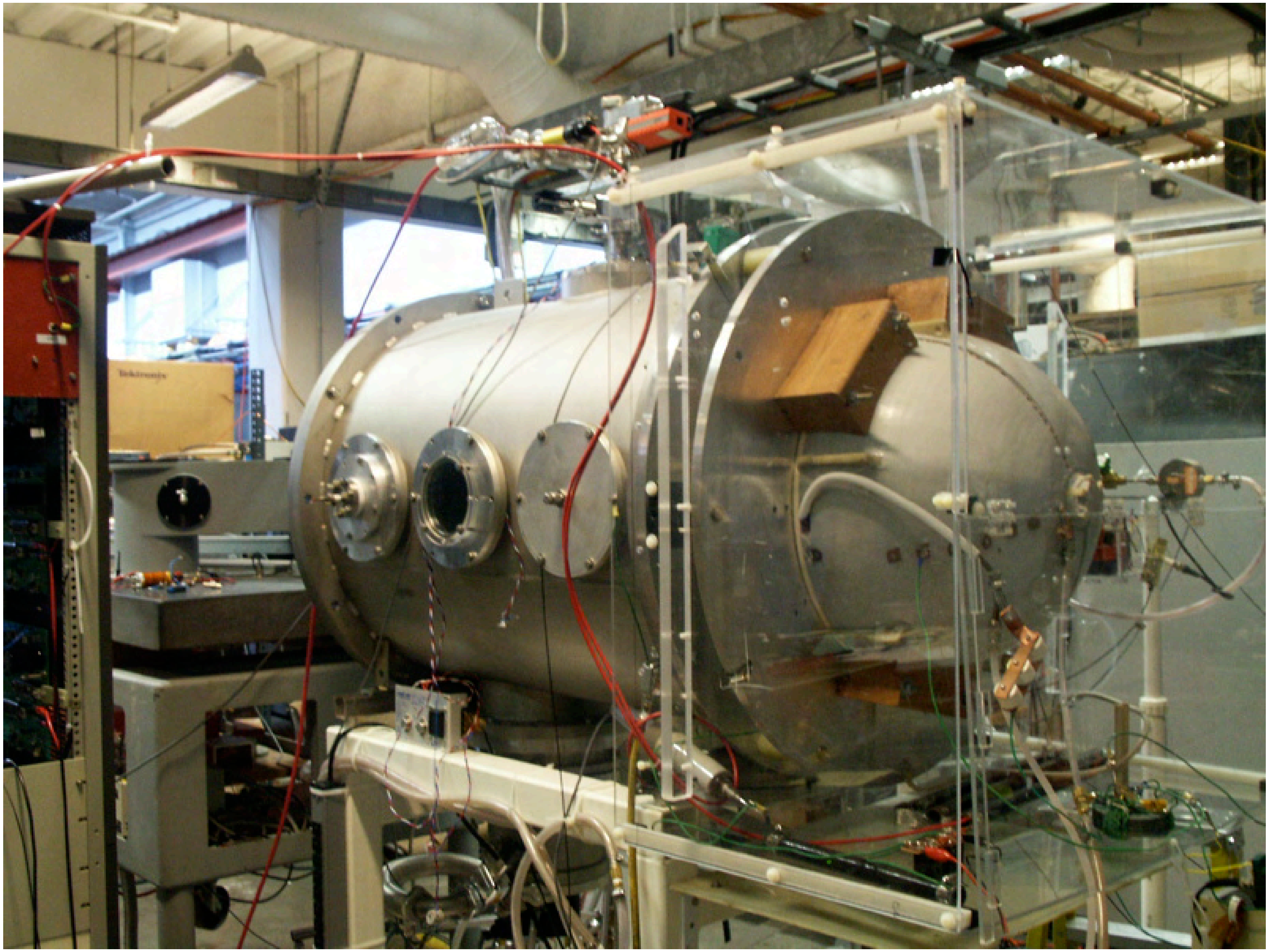
Ceramic shafts
detection fibe

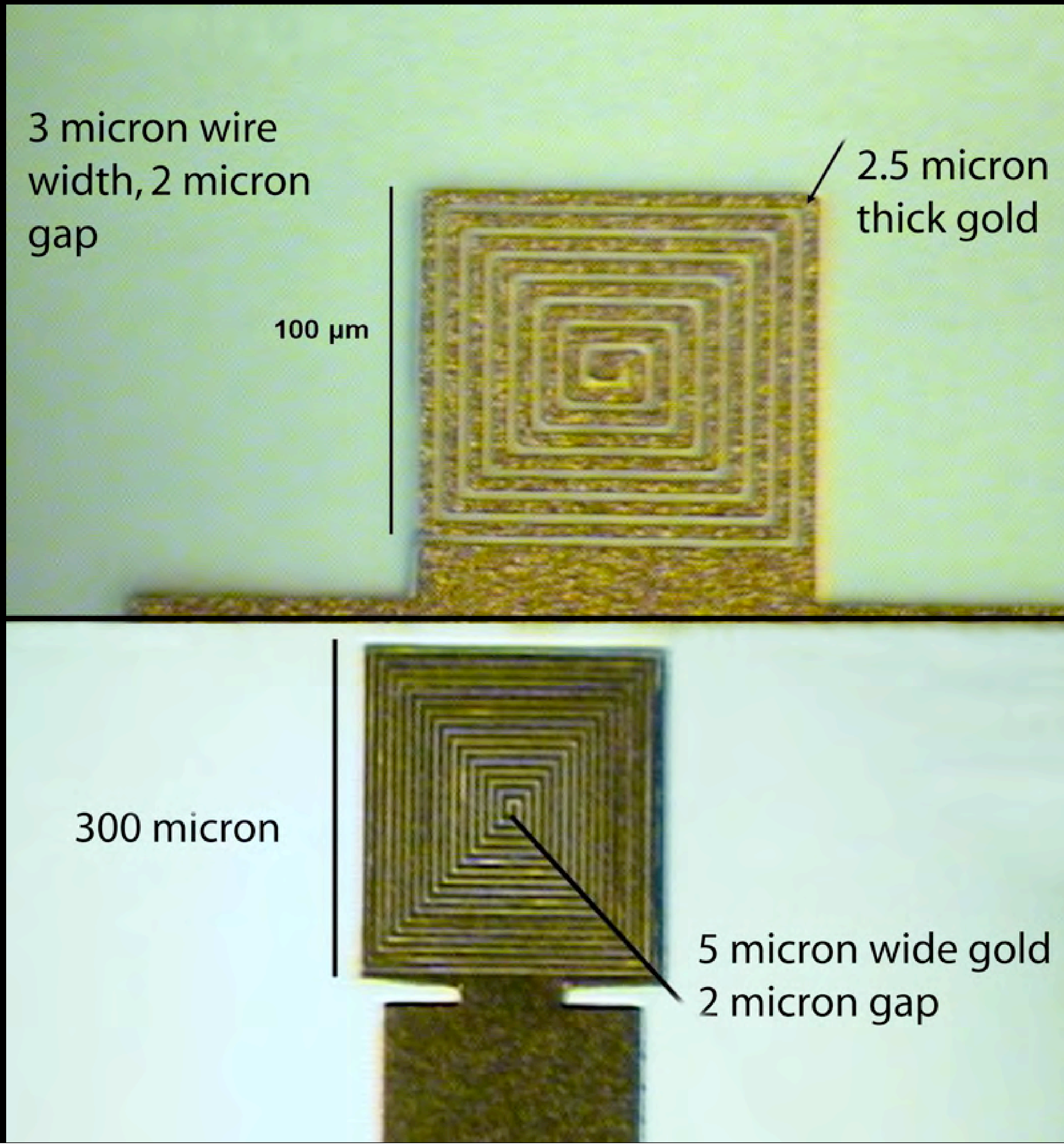
Detection optics coupled to 1500 μm cor

e fiber

s

Ion beam (under-development) 25 kV, 3 Amps , He



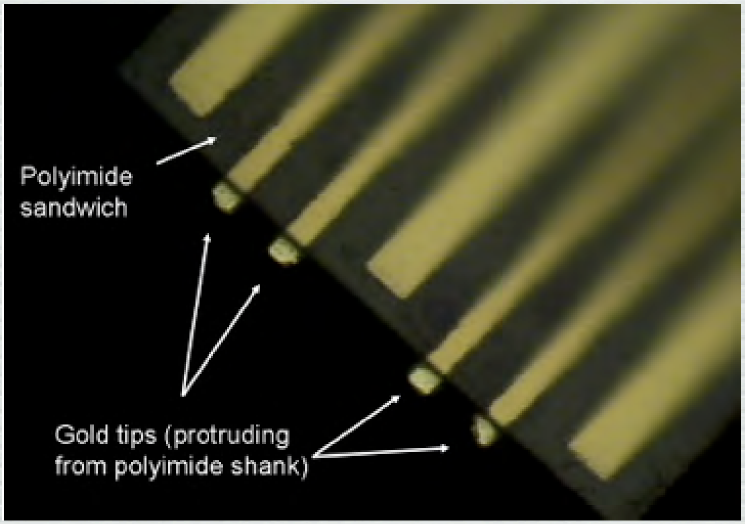


future magnetic probes

Development of Microprobes

collaboration with UCLA Engineering (Jack Judy), LANL

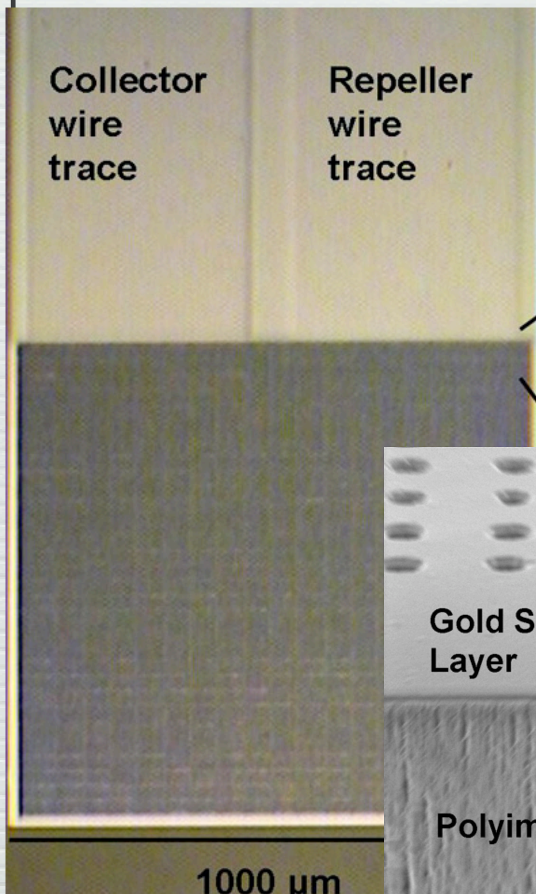
E field detectors smaller than $\lambda_D \sim 30\mu m$



10μm tips, 20μm spacing, 60 μm-gap

2 Publications RSI, JMEMS

Velocity Analyzer



2 grids, collector, can be made 100μ X 100μ