Abstract

Implementation of Reflectometry as a Standard Density Profile Diagnostic on DIII-D* L. Zeng, E.J. Doyle, W.A. Peebles and T.L. Rhodes, *UCLA*, T.C. Luce, General Atomics — The profile reflectometer system on DIII-D has been significantly upgraded in order to improve time coverage, data quality and profile availability. Building upon previous successful systems utilizing continuous frequency modulated radar techniques, system performance has been improved as follows: (1) A new PC based data acquisition system has been installed. The higher sampling rate allows to increase frequency sweep rates, thus improving profile accuracy by decreasing turbulence effects. The larger data record lets profiles be obtained throughout 5 s discharges. The data can also be obtained at variable sampling rates. (2) Availability of the data has been improved. Analyzed data is stored in the MDSplus database, and profiles are currently being made available within the 4-D profile fitting package. (3) The flexibility of the hardware system has been improved; the Q- (33-50 GHz) and V-band (50-75 GHz) reflectometer systems can be configured to use either O- or X-mode polarization. (4) The profile analysis code rewritten in IDL has been improved robustness. Routine analysis of profile data will be implemented soon.

*Work supported by US DOE Grant No. DE-FG03-86ER53225 and Contract No. DE-AC03-89ER51114

Goals

- **Improved Reflectometer Density Profile Coverage**
  - Time Resolution Improved
    Fast PC based data acquisition system --- 40MS/s sampling rate (2 chs)
  - Profile Measurement Through Whole Plasma Discharge
    PC based data acquisition system --- ~40MB data record
  - Reflectometer Polarization Flexibility : O- or X- mode
  - Improved Profile Quality: fast frequency sweep => reduce turbulence effect
- **Improved Reflectometer Density Profile Availability to Users**
  - Data Storage: MDSplus Database
  - Viewable by some DIII-D software packages (Reviewplus, Gaprofiles)
  - Profile Fit in Gaprofiles: (in progress)
- **Automated Data Analysis**
  - Rewritten program in IDL
  - Automatic analysis of phase or time delay from raw data
  - Automatic analysis of the edge density profiles
  - Routine analysis (in progress)

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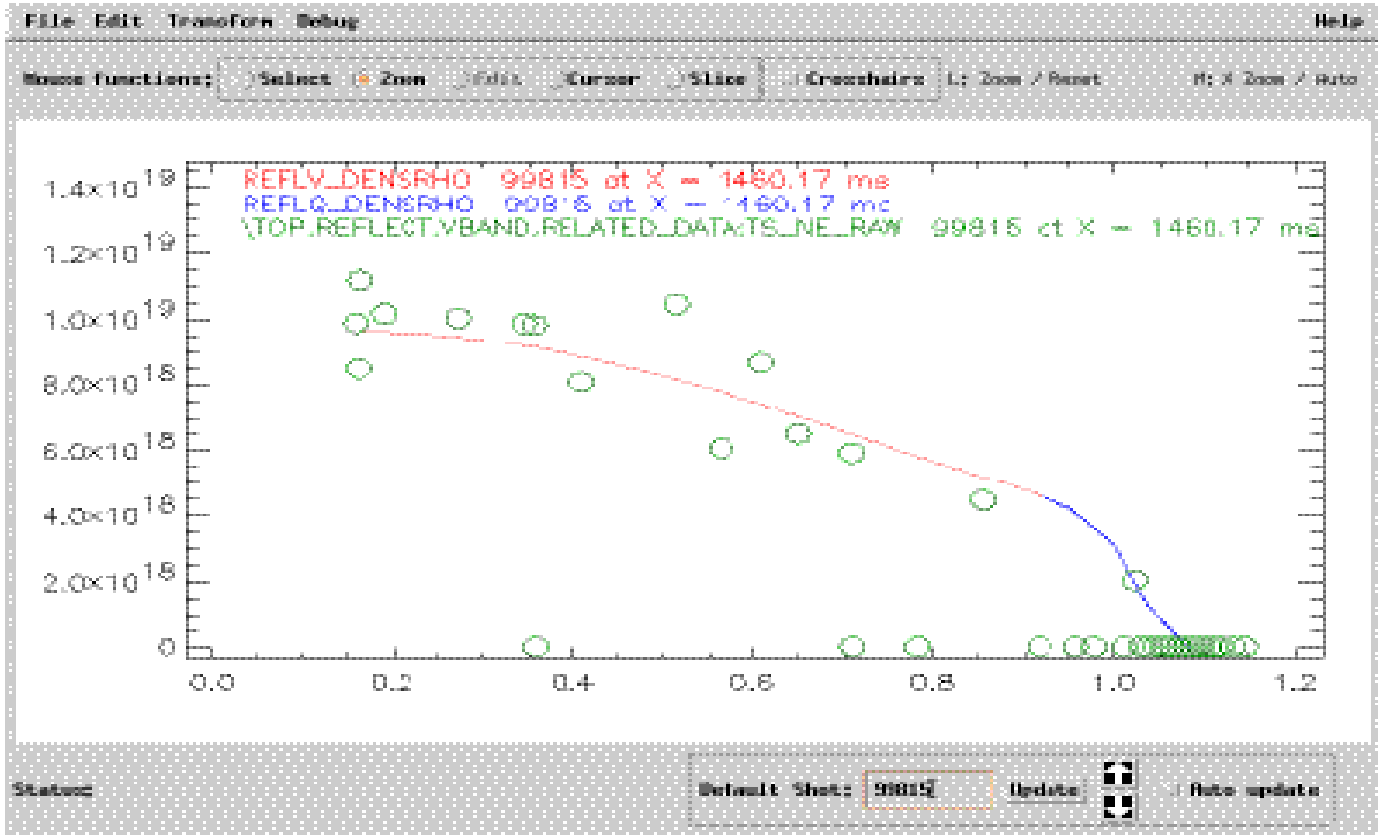
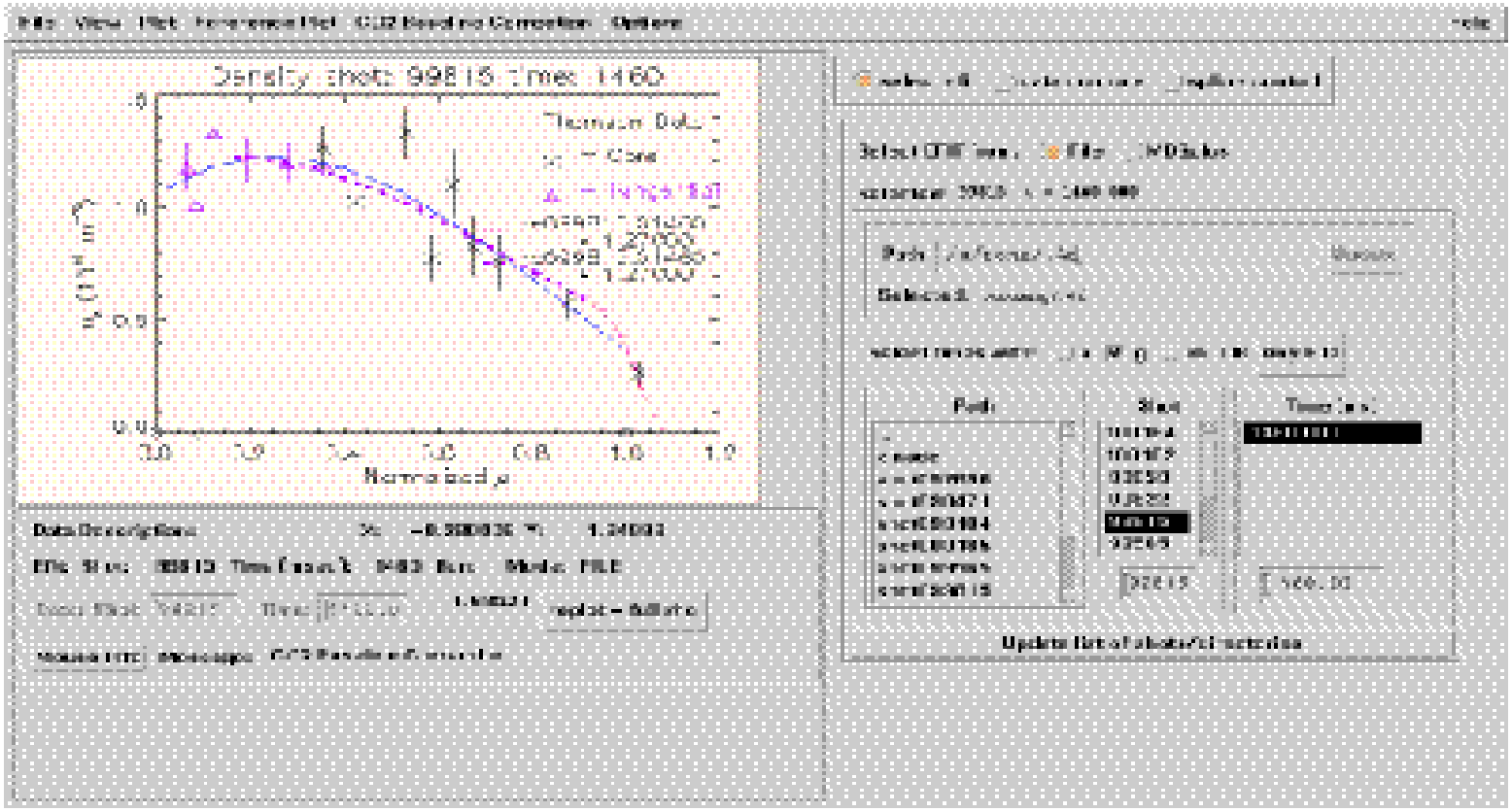
Reflectometer Density Profile Can Be Viewed in "Reviewplus"

- Reviewplus : Data View Software Package
- Reflectometer is viewable as function of ρ and time



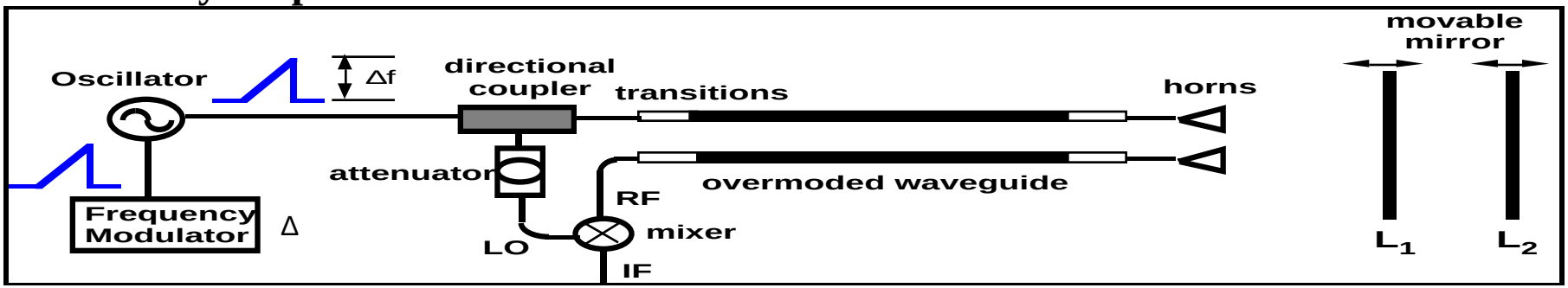
Reflectometer Density Profile Can be Viewed in "Gaprofiles"

- GAprofiles : Profiles Fitting Software Package
- Reflectometer data is viewable as reference, to be implemented to fit in

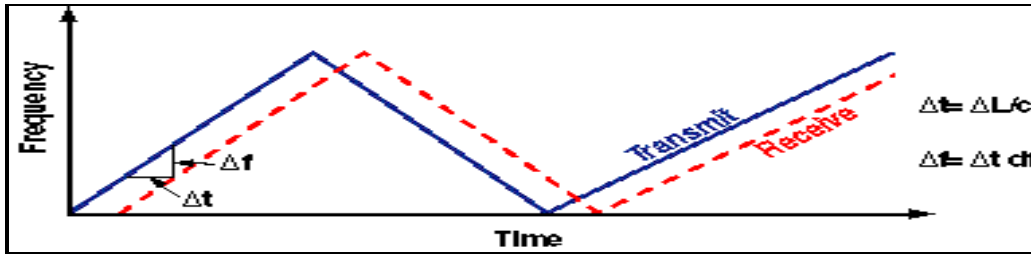


FMCW REFLECTOMETER PRINCIPLES

- **Reflectometers are specialized close range radar systems measuring distance to a cutoff layer in a plasma**
- **Example of frequency modulated, continuous sweep (FMCW) reflectometer system arrangement**
  - **Very simple microwave circuit**



- **Frequency sweep and path length difference between microwave paths leads to frequency difference**



  - **For mirror, $f_{if} = \frac{\Delta L}{c}\frac{df_0}{dt}$ where f_{if} is the detected signal frequency, ΔL the path length difference and f_0 the rf frequency**
  - **For plasma, spatial variation of refractive index means inversion is necessary to recover density profile**

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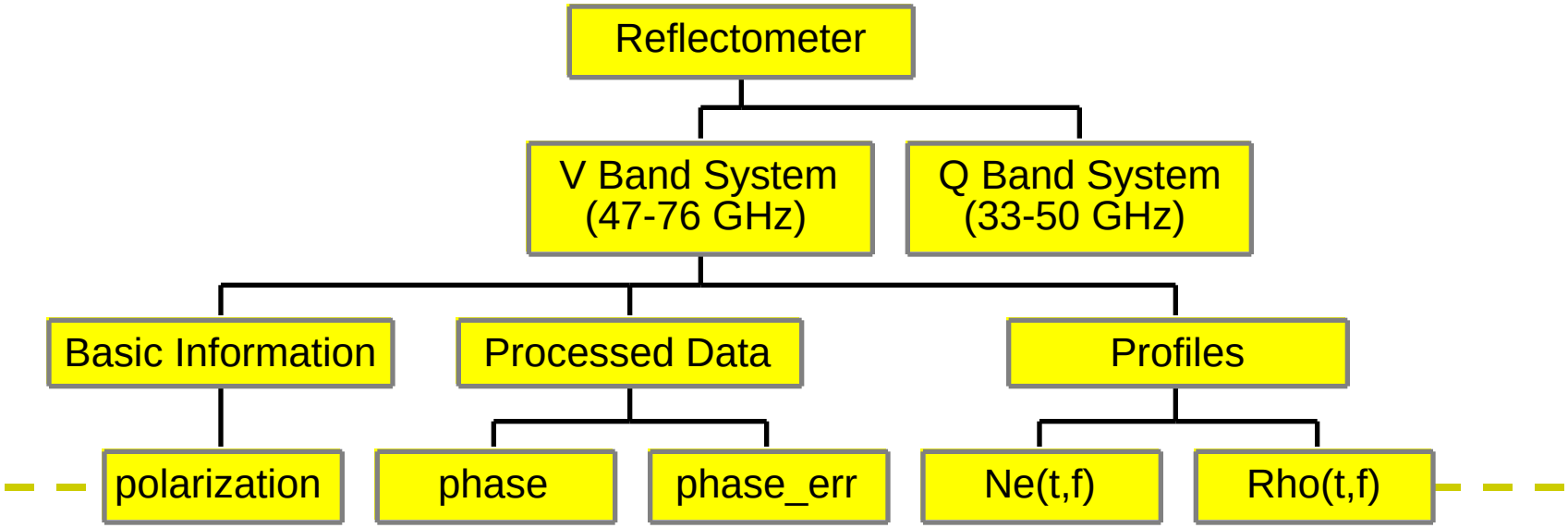
Analyzed Profile Reflectometer Data Stored in "MDSplus"

- MDSplus: DIII-D main analyzed data storage
- Structure of Reflectometer Tree in D3D main Tree



Hardware Description of Density Profile Reflectometer Systems on DIII-D

• Two FM density profile reflectometer systems on DIII-D, toroidal location: 255^0 R-0 port and 300^0 RF antenna

★ **Implemented to flexible polarization : X-mode or O-mode**

- Fast-sweep System (33-50 GHz) [Q Band]
  - Solid-sate source
  - Profile measured every 10 - 100 μs
  - Density range:
    - 0-4x10^{18} m^{-3} @ 2.1T, X-mode
    - 1.4 x10^{19} m^{-3} -3.1x10^{19} m^{-3} @ O-mode

- BWO-based System (47-76 GHz) [V Band]
  - Profile measured in 400-600 μs, but with dwell time of ~3 ms between sweeps
  - Density range:
    - 3.3 x10^{18} m^{-3} -3.x10^{19} m^{-3} @ 2.1T, X-mode
    - 2.7 x10^{19} m^{-3} -7.2x10^{19} m^{-3} @ O-mode

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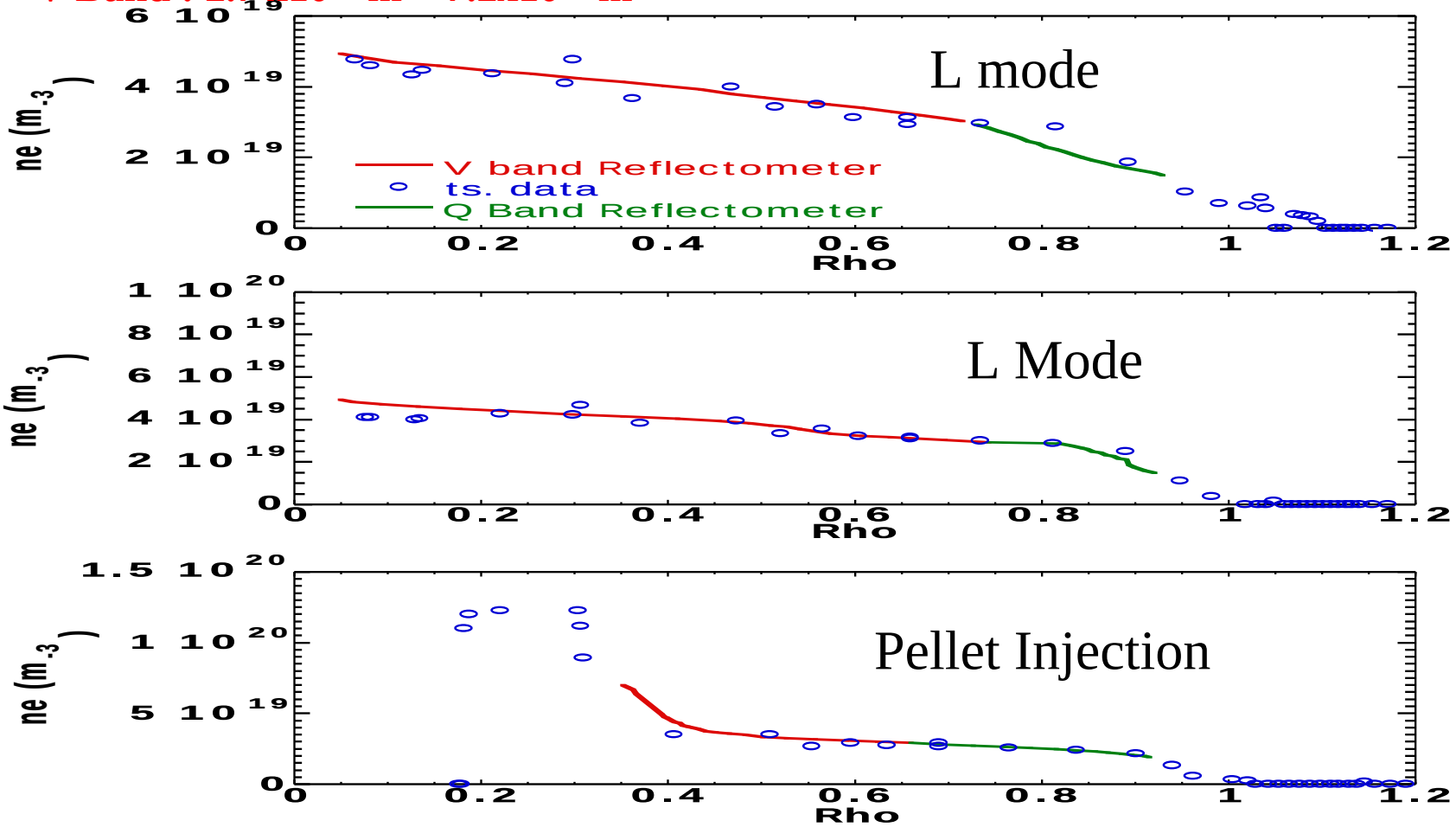
High Density Covered by Choosing the O-mode Polarization

Both Q and V band Reflectometer set in O mode

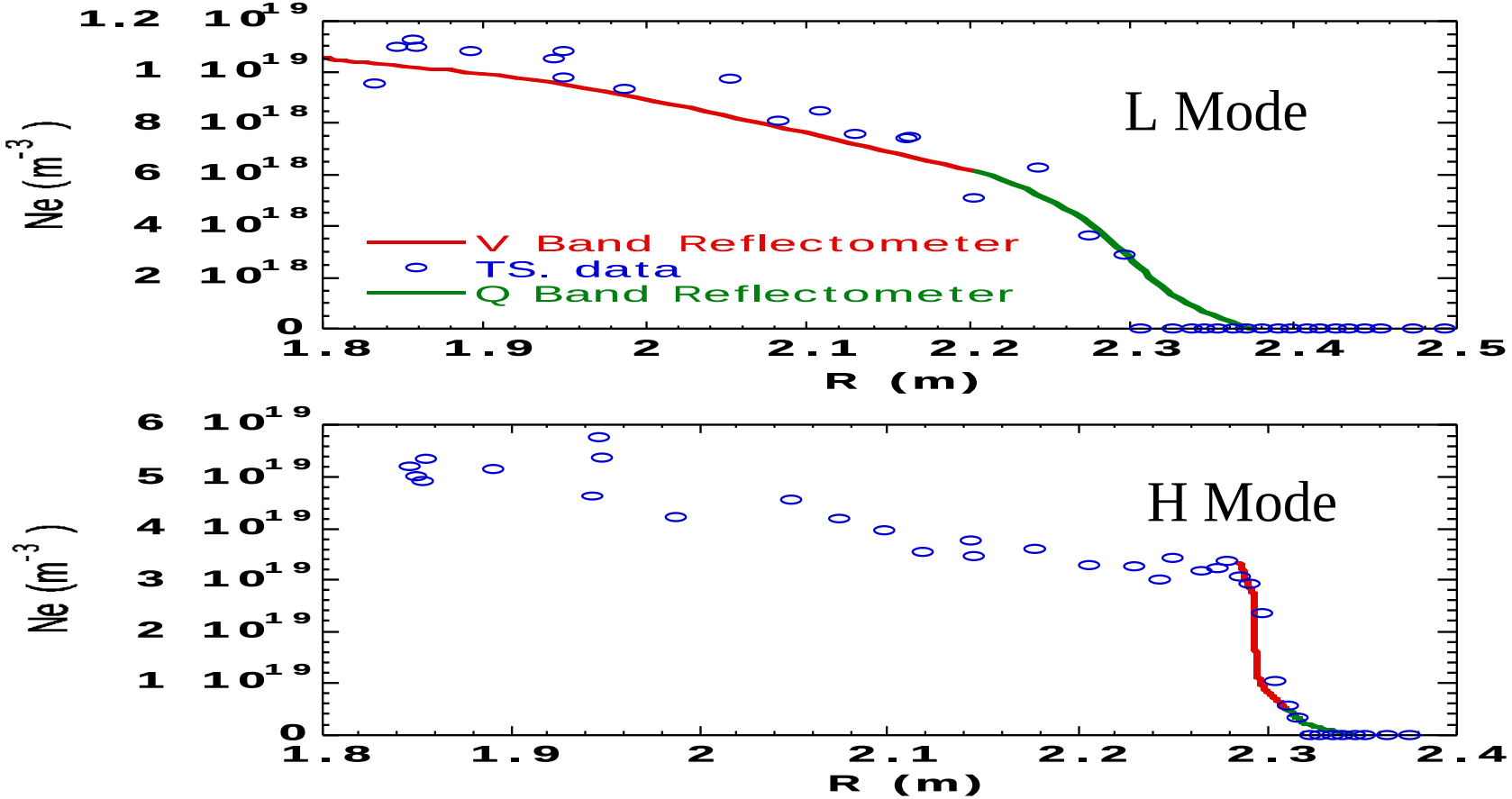
- **Q Band : 1.4 x10^{19} m^{-3} -3.1x10^{19} m^{-3}**
- **V Band : 2.7 x10^{19} m^{-3} -7.2x10^{19} m^{-3}**



Edge Low Density Covered by Choosing the X-mode Polarization

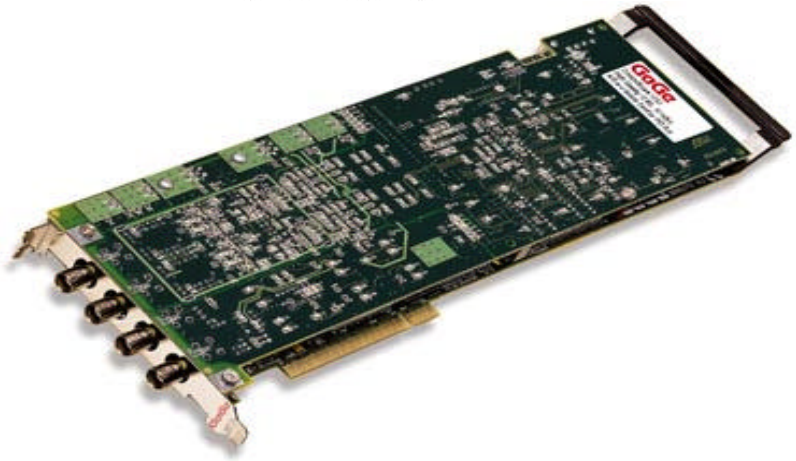
Both Q and V band Reflectometer set in X mode

- **Qband: 0- 6x10^{18} m^{-3} @ 1.9T**



New Reflectometer Data Acquisition System

- Acquisition uses **Gage 8012/PCI** Board
  - 12 bit Resolution
  - 80MS/s (single channel)
  - 40MS/s (dual channel)
  - 1MB on board Memory
  - Single Slot PCI Bus Card with Bus Mastering Capability
  - 100 MB/s Data Transfer Rate To PC memory
  - 60 dB Signal to Noise Rate
  - Software Development Kits for Dos , Win 95/NT

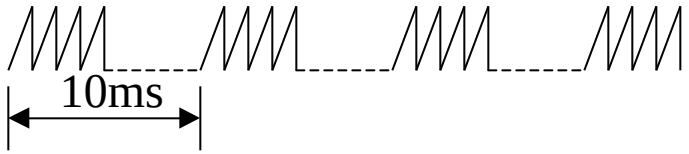


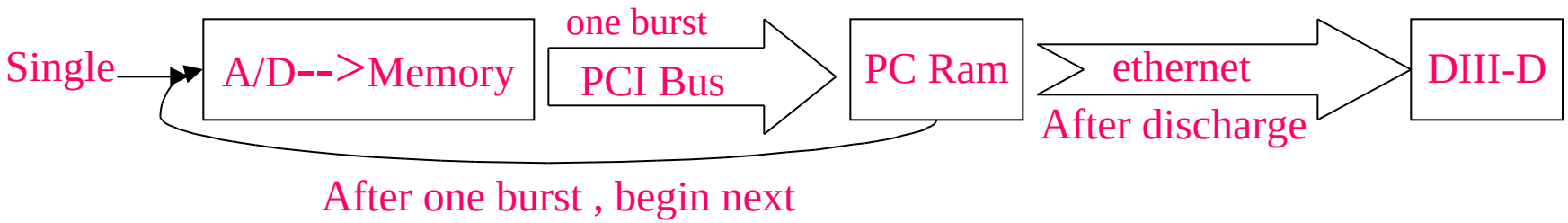
- PC Based: Pentium 200MHz, 128MB Ram, 10/100MB Ethernet Card
- Using VNC can remote control the system which is set up in Annex in DIII-D control room, from any X terminal.

Two Different Data Acquisition Mode: Continuous & Multi-Burst

- **Continuous Mode:**
  - Data directly flow in PC memory, continuously capture ~40MB data, sampling rate can up to 25MS/s for dual channel
  - Used to study L-H , ELMs , …, fast physics process

- **Multi-Burst Mode:**
  - Capture a burst of data , transfer into PC memory , then capture next burst,……
  - 40MS/s in dual channel. , ~40MB total
  - Usually setup: each burst 20kB, burst repeat rate ~100Hz
  - Used to cover the whole plasma duration measurement

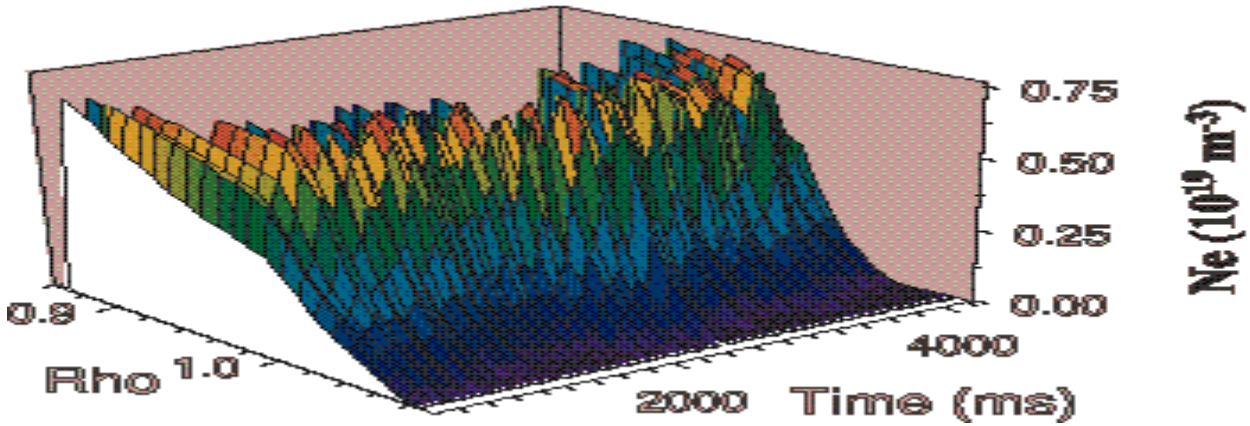




X-mode Multi-burst Measurement Example

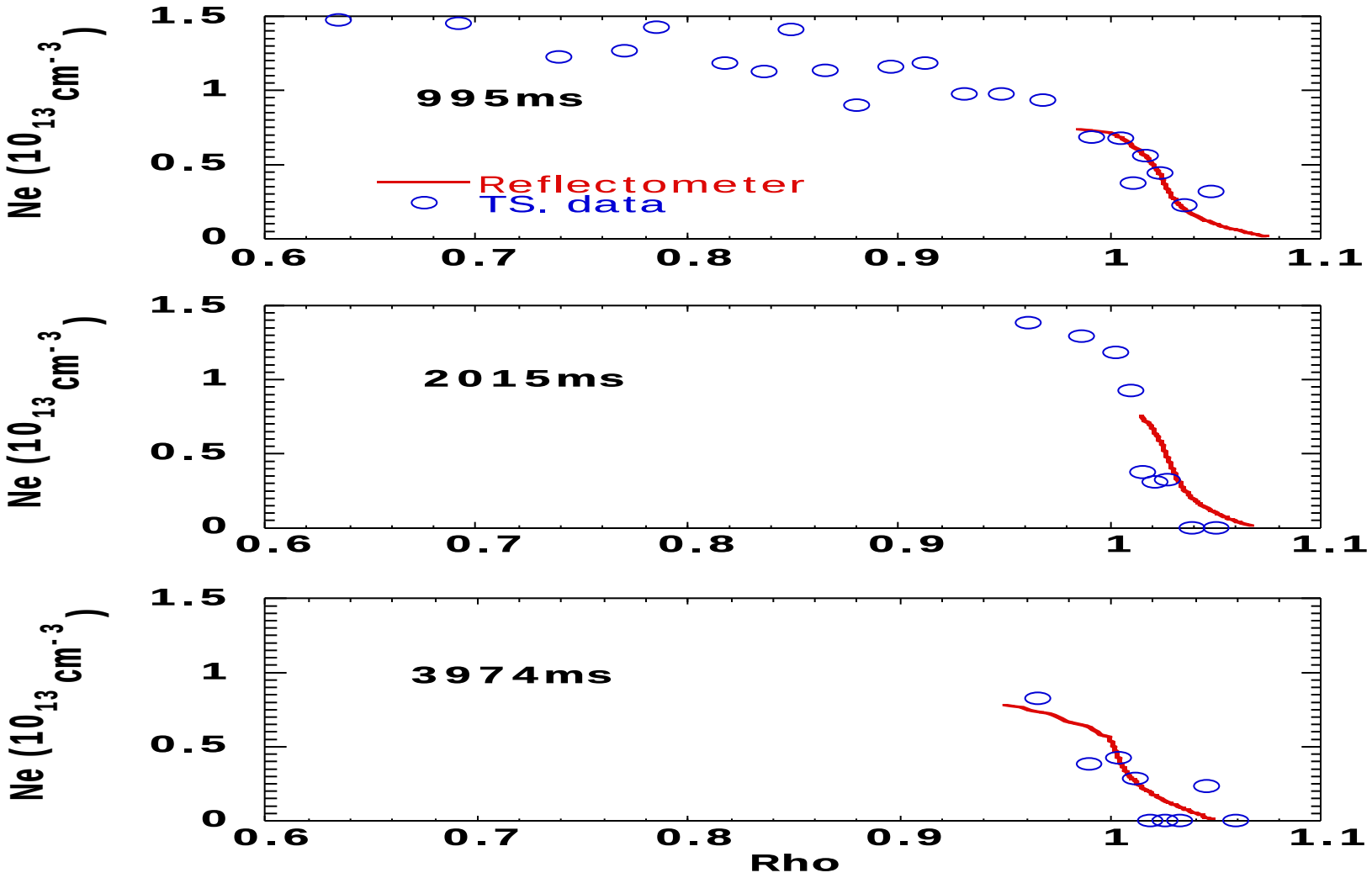
Q Band Reflectometer Edge Ne Profiles

- Use PC Acquisition System
- 10 ms per profile measurement
- Sampling through the whole discharge



- Ip=1.37MA, B_T =1.4T

X-mode Edge Profiles are Consistent with Thomson Scattering Ne Profiles

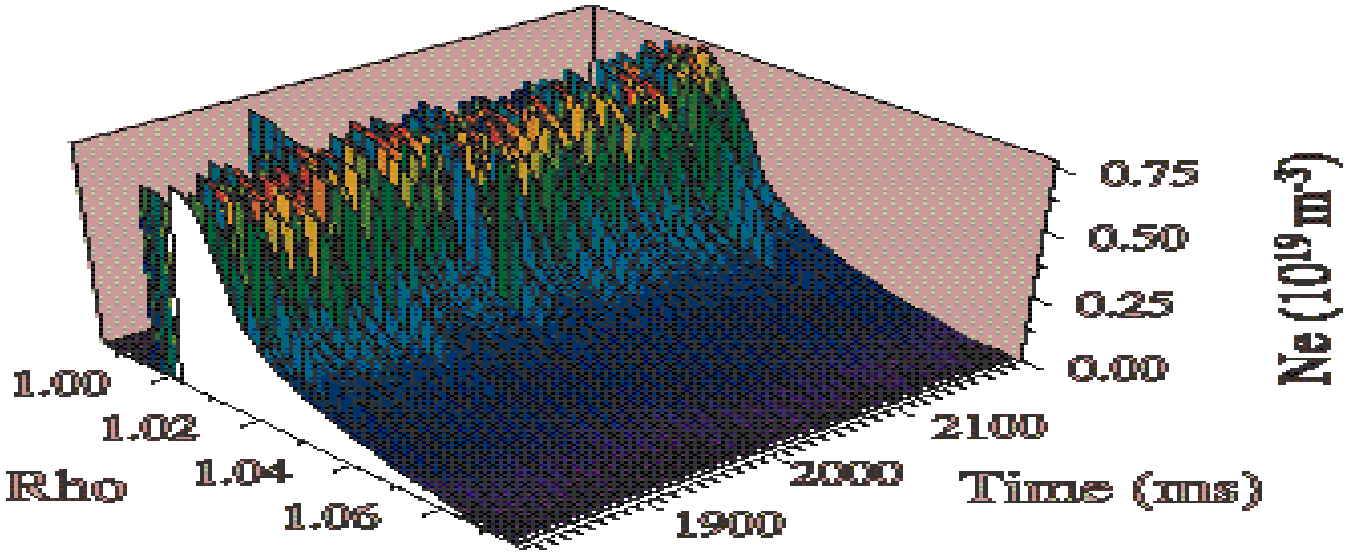


Reflectometer: Q Band X-Mode, Multi-Burst Sampling

High Time Resolution Continuous Measurements

Q Band X-Mode Reflectometer Edge N_e Profiles

- Use PC Acquisition System
- **50 μs** per profile measurement
  Sampling Rate 20MHz, total 400ms Data Record



Plasma Condition: Ip=1.2MA, B_T=1.4T

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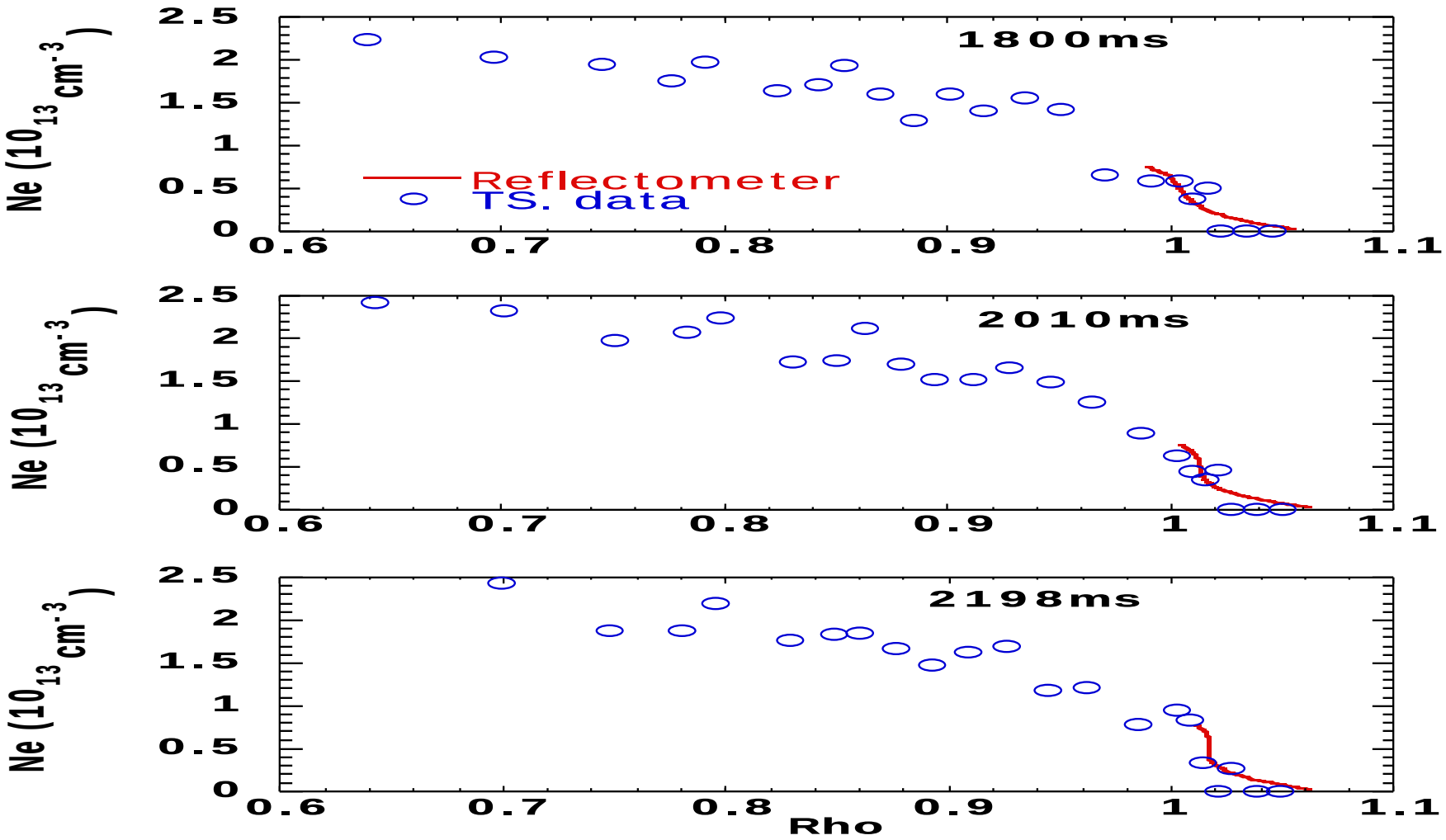
Reflectometer Edge Profiles are Consistent with Thomson Scattering Ne Profiles in Continuous Mode



Reflectometer: Q Band X-Mode, Continuous Sampling

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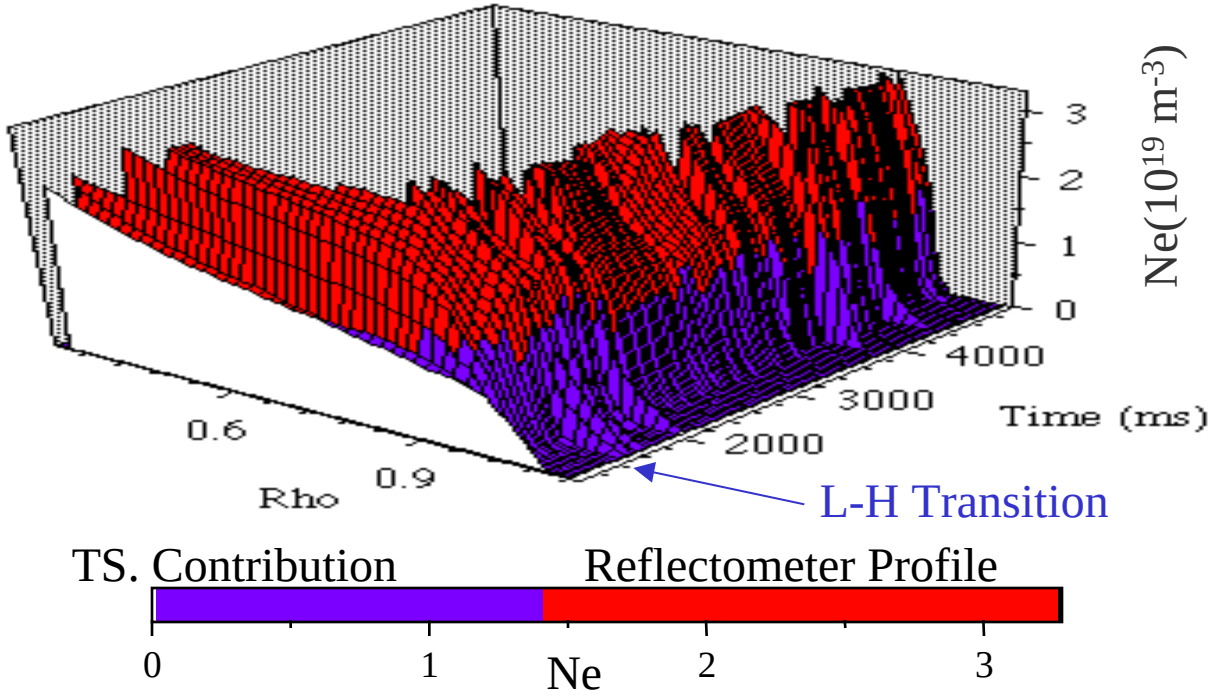
O-mode Multi-burst Measurement Example

Q Band Reflectometer Ne Profiles

- Use PC Acquisition System
- 10 ms per profile measurement
- Sampling through the whole shot



- Plasma Condition: Ip=1.2MA, B_T=1.6T

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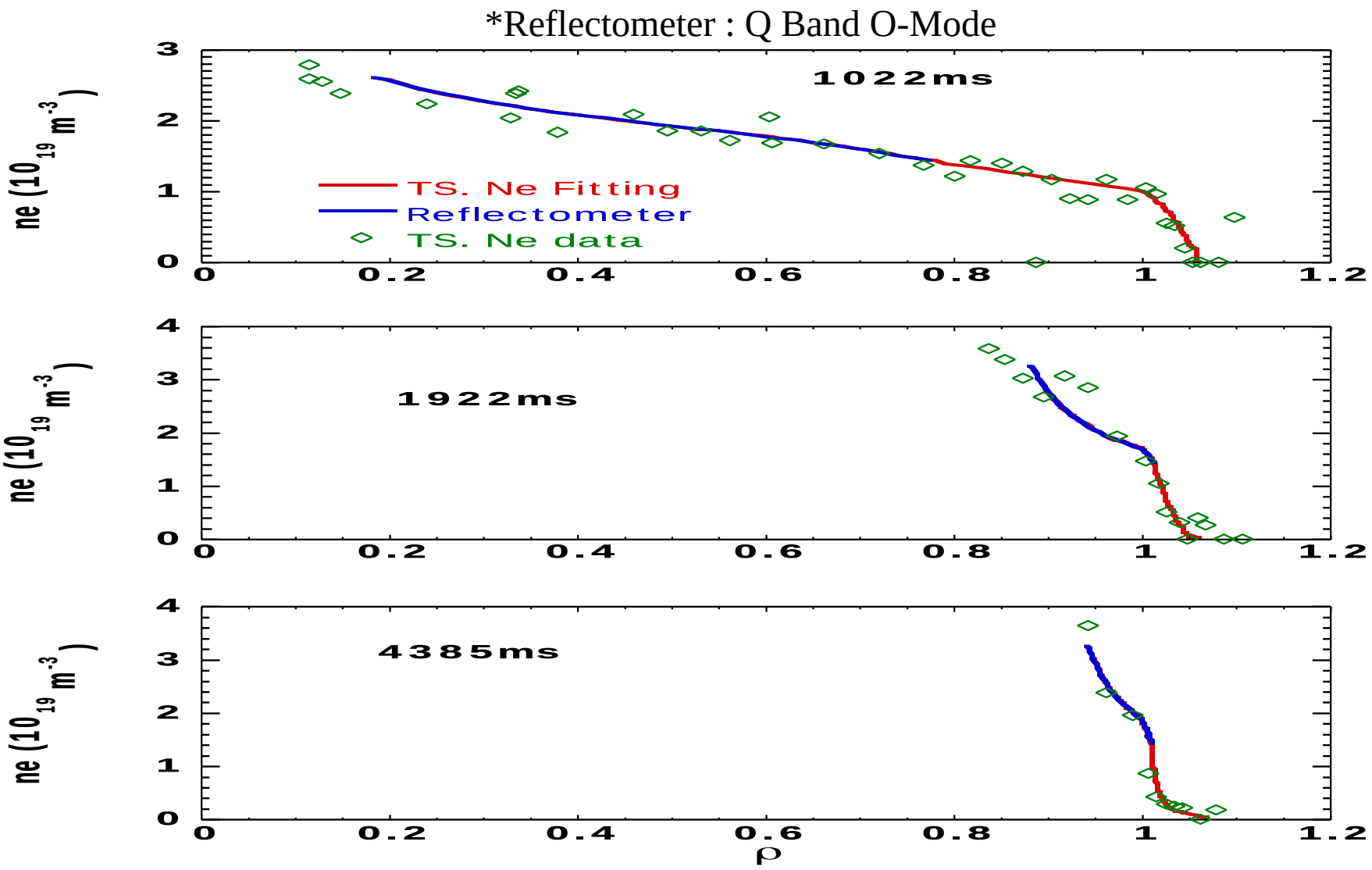
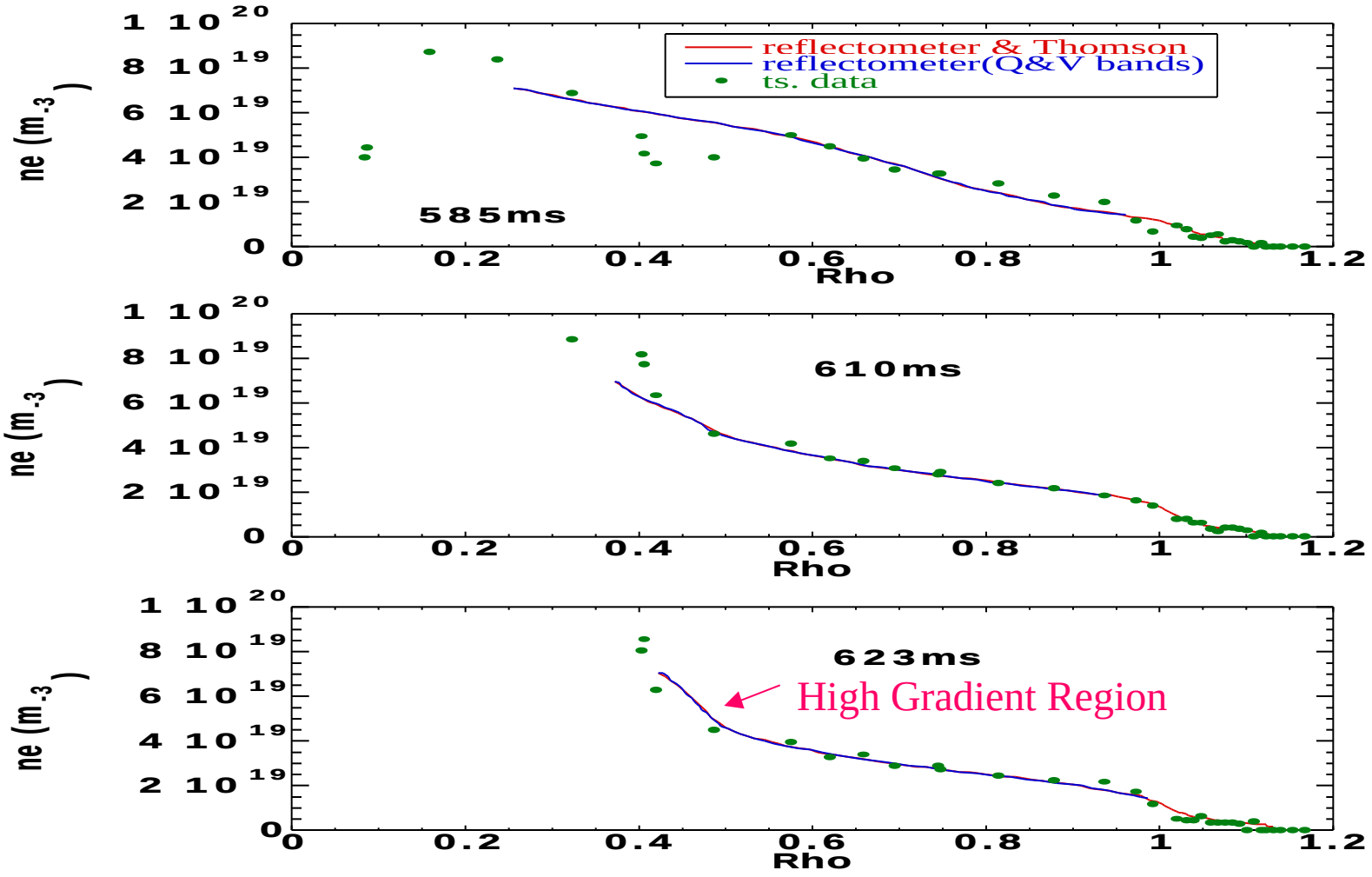
O-mode Reflectometer Profiles Are Consistent with TS Ne Profiles



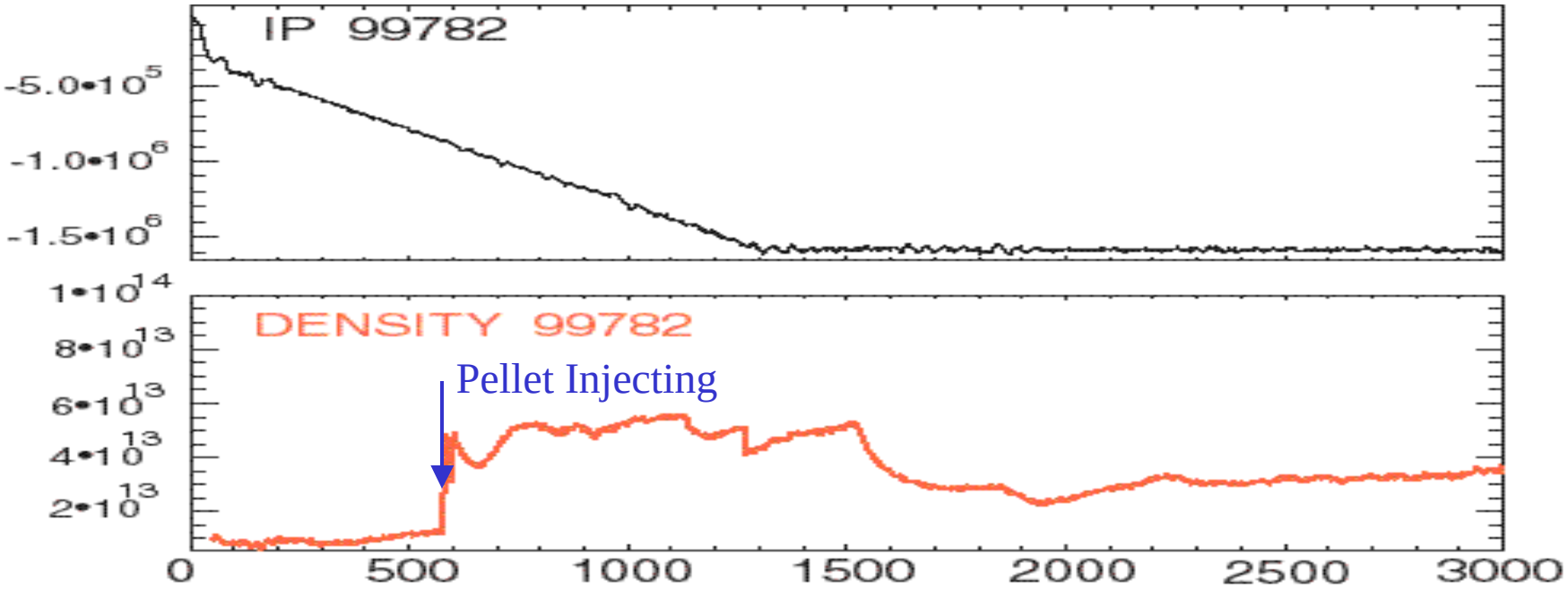
Reflectometer Defines Gradient in High Gradient Region

- Both Q and V Band Reflectometer setup in O Mode



Reflectometer Can Provide Core Density Profile with High Spatial Resolution

- High Spatial Resolution Profile is necessary to study the mechanism of the barrier forming.
- Pellet Injection is very successful technique to create core barrier in DIII-D



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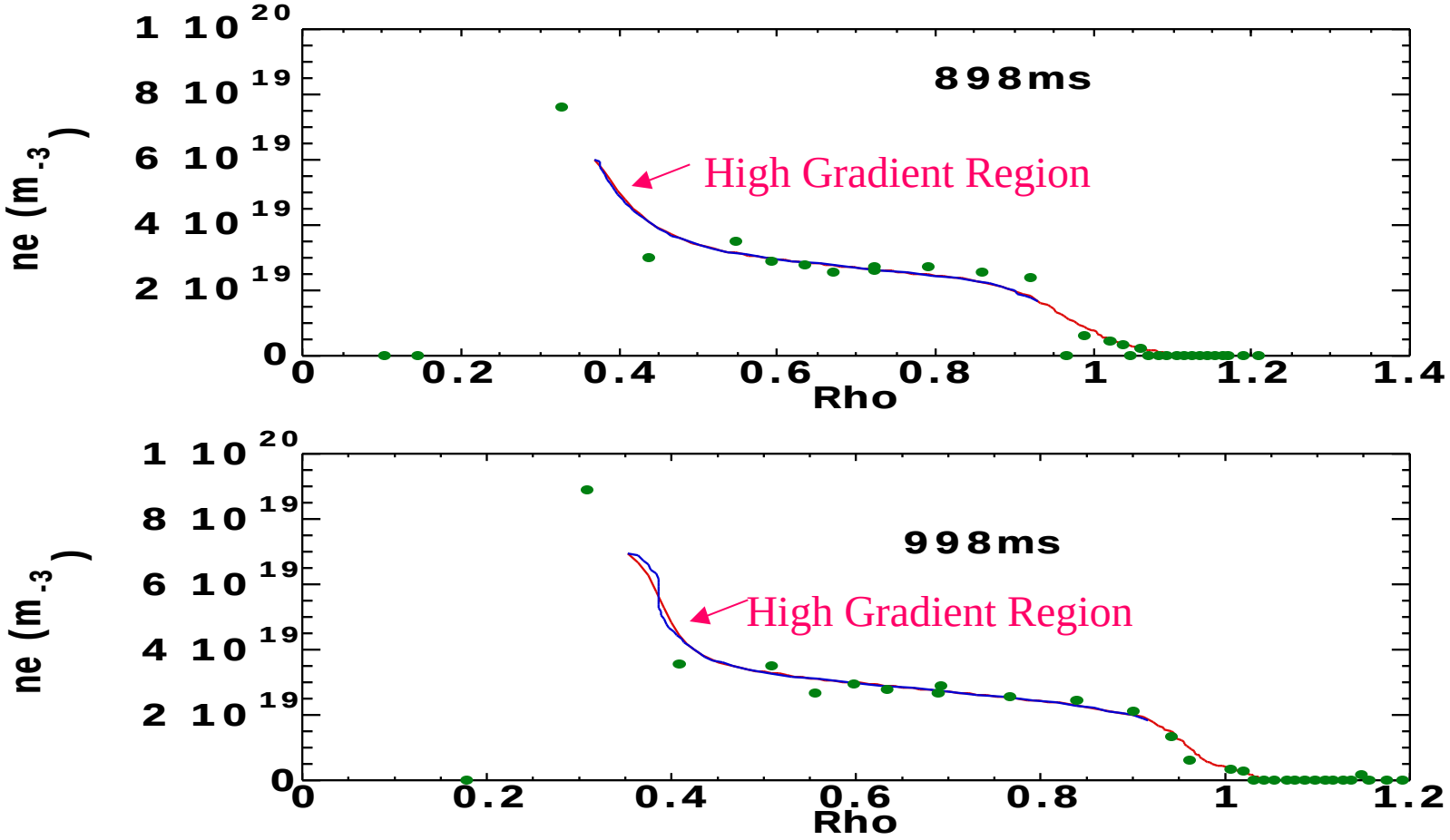
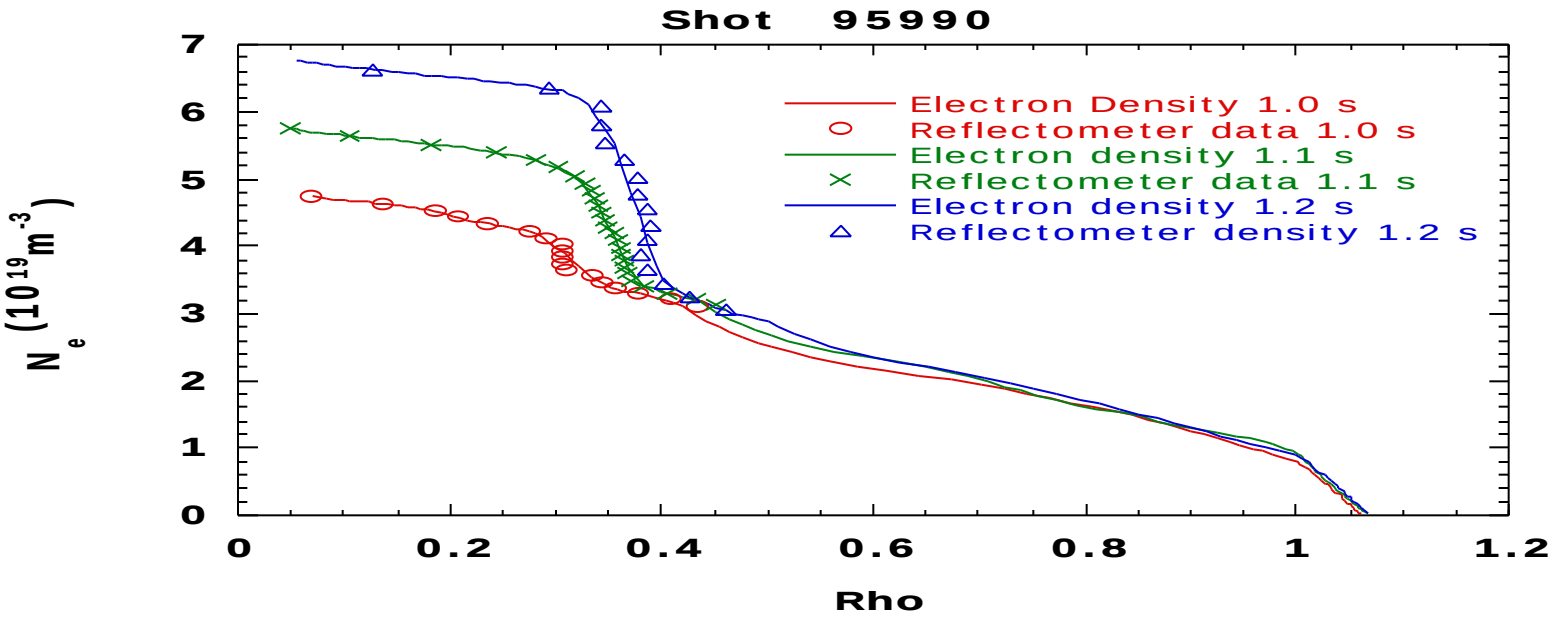

ne (m-3)
1 10 20
8 10 19
6 10 19
4 10 19
2 10 19
0
898ms
High Gradient Region
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Rho
ne (m-3)
1 10 20
8 10 19
6 10 19
4 10 19
2 10 19
0
998ms
High Gradient Region
0
0.2
0.4
0.6
0.8
1
1.2
Rho

Reflectometer Observes Steep, Localized Core Electron Density Barrier with Strong Negative Central Shear (NCS)

- Steep, sharply localized transport barriers (ITBs) have been observed in n_e in plasmas with strong NCS and $P_{NBI} > 8$ MW
- Very steep density gradients are observed in the plasma core, similar to those observed in the edge during H-mode operation



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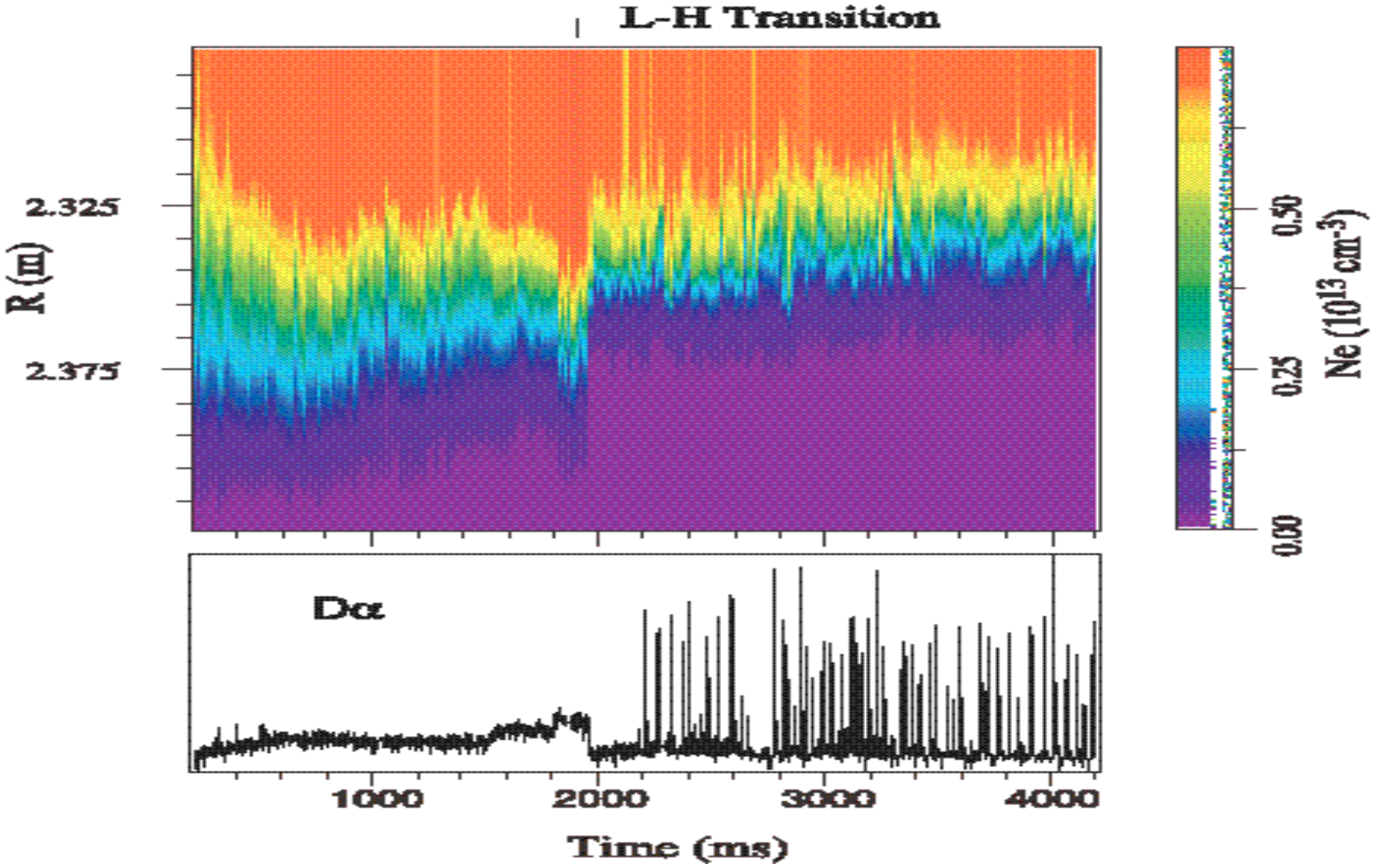
Provide High Spatial Resolution Suitable for Edge Modeling

- Reflectometer measurements cover the whole shot with 10 ms time resolution



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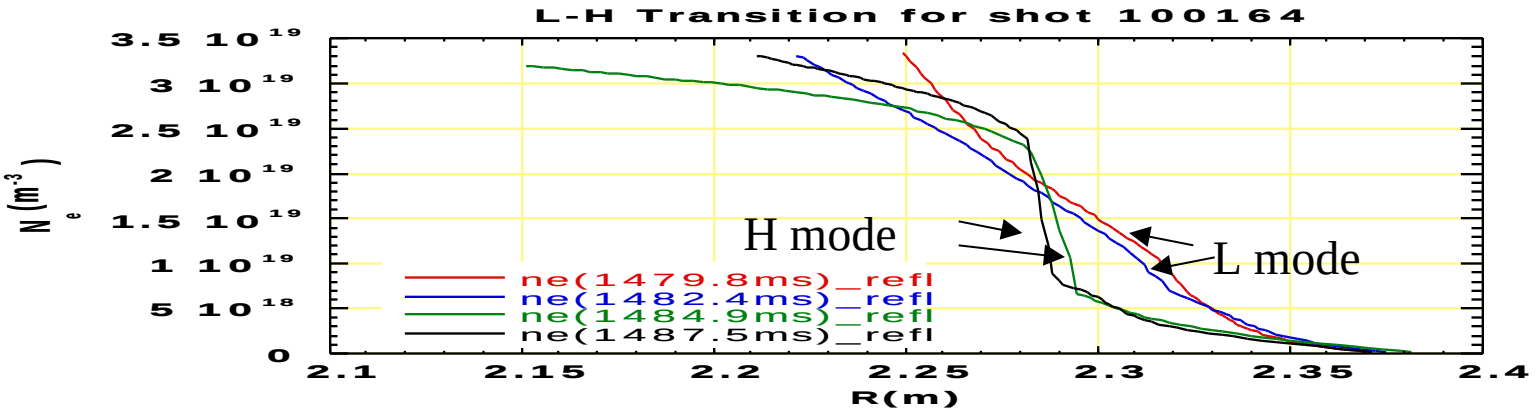
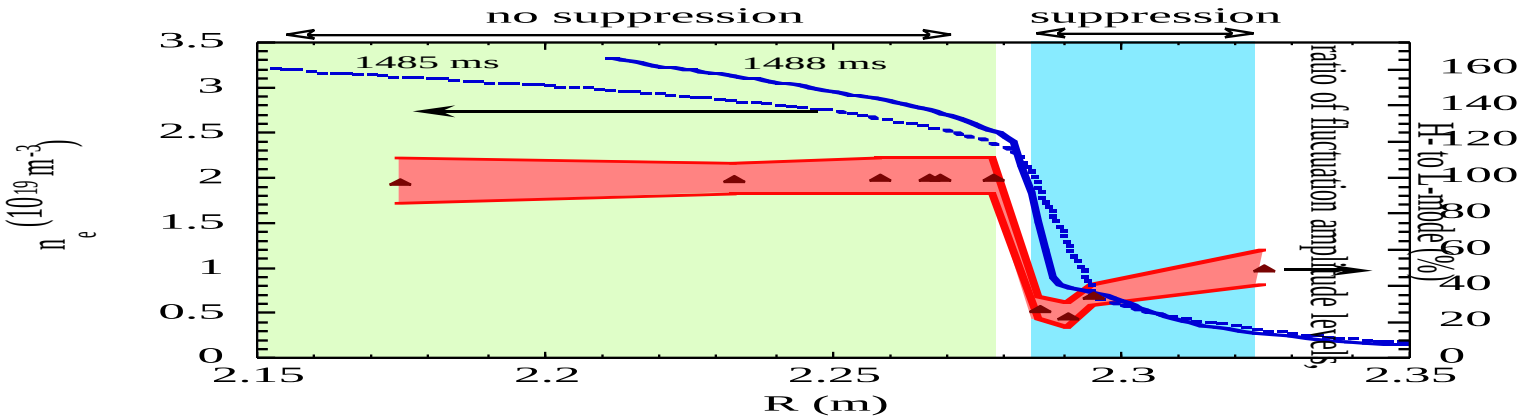
Reflectometer Can Provide High Spatial & Temporal Resolution Profiles Which Are Necessary for H Mode Physics Studies

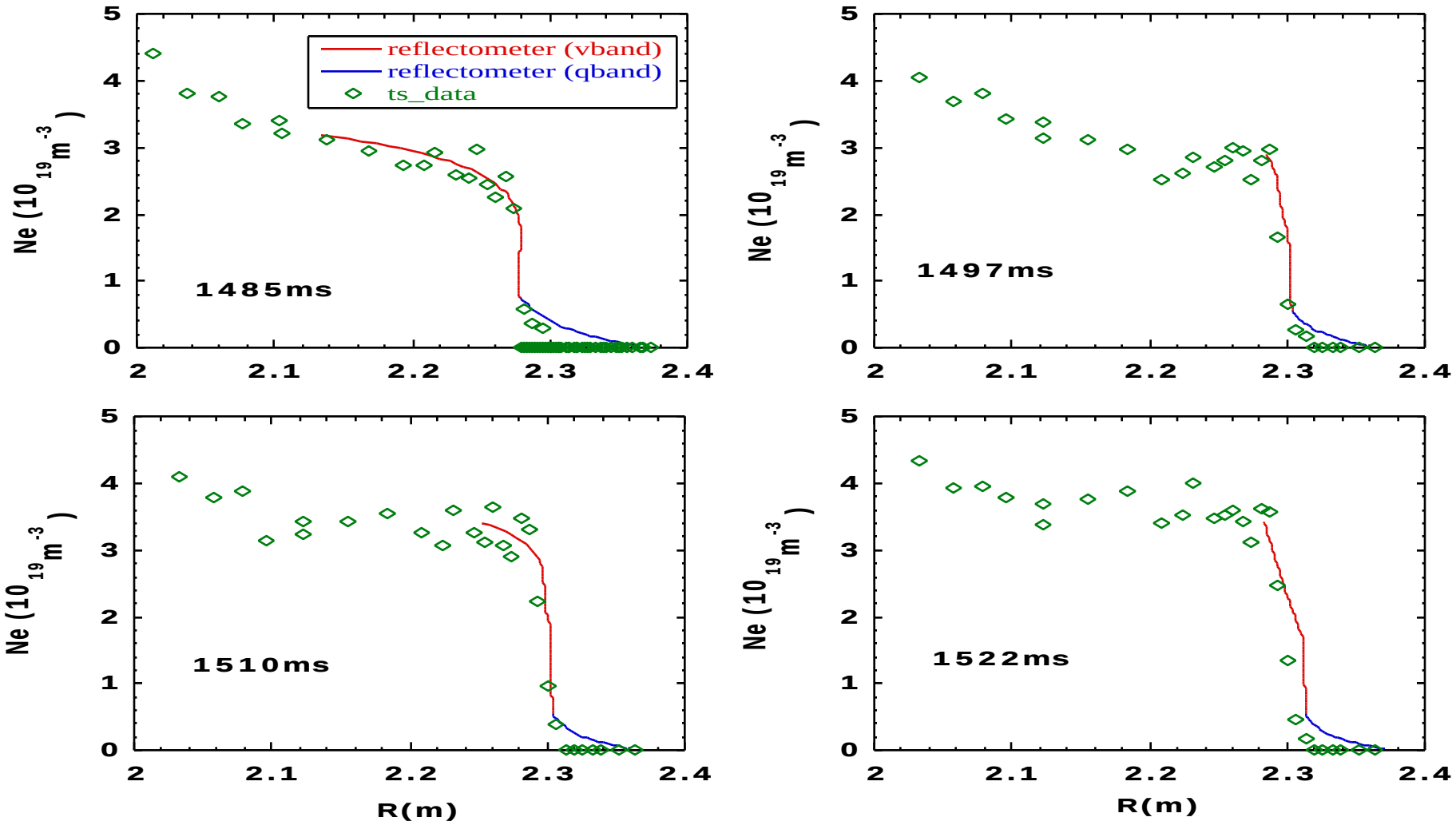
Turbulence measurement : fluctuation reflectometer

Time resolution of profile reflectometer: 100 μs



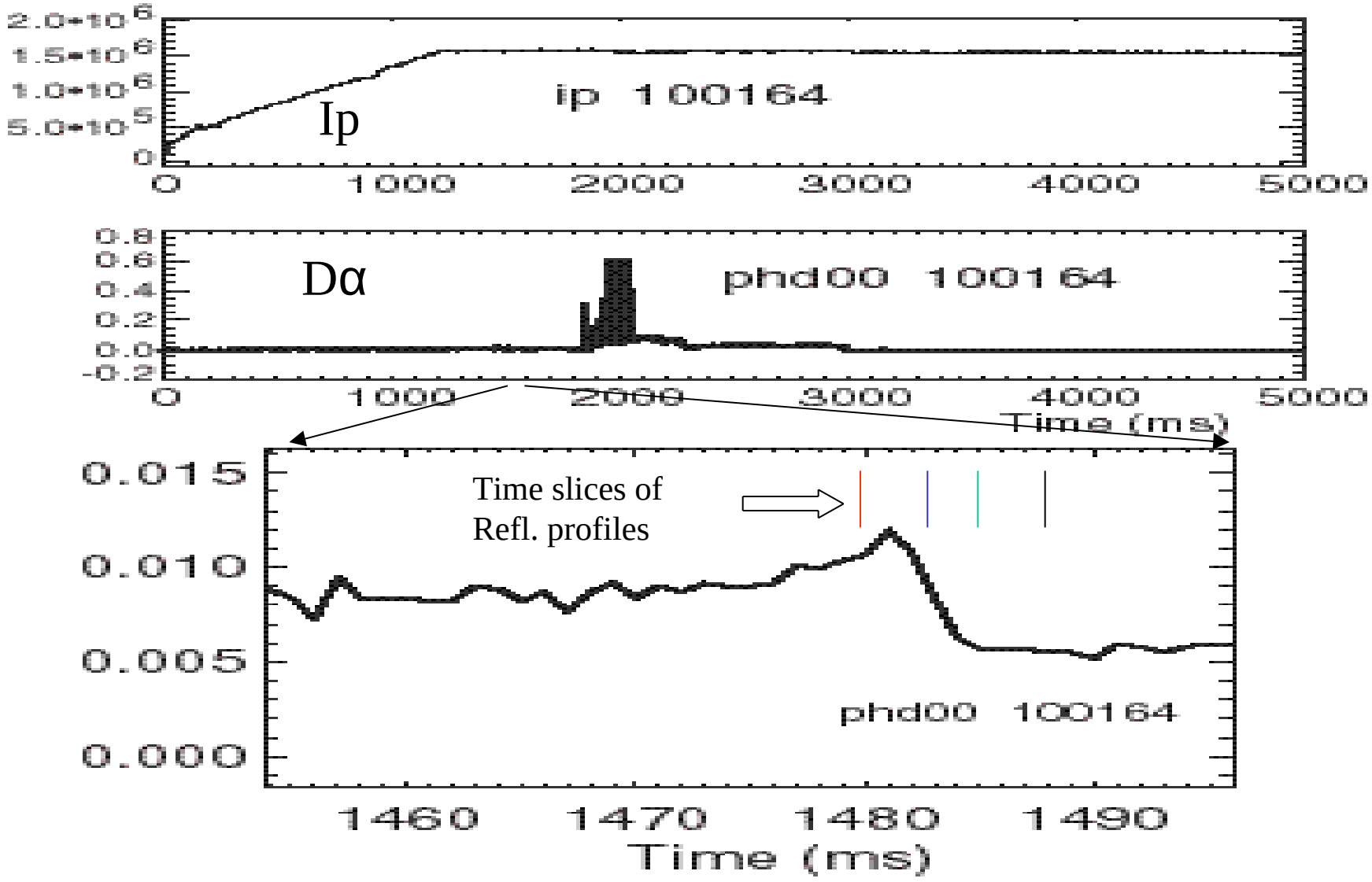


Reflectometer Ne profiles Compared to Thomson Scattering Ne profile



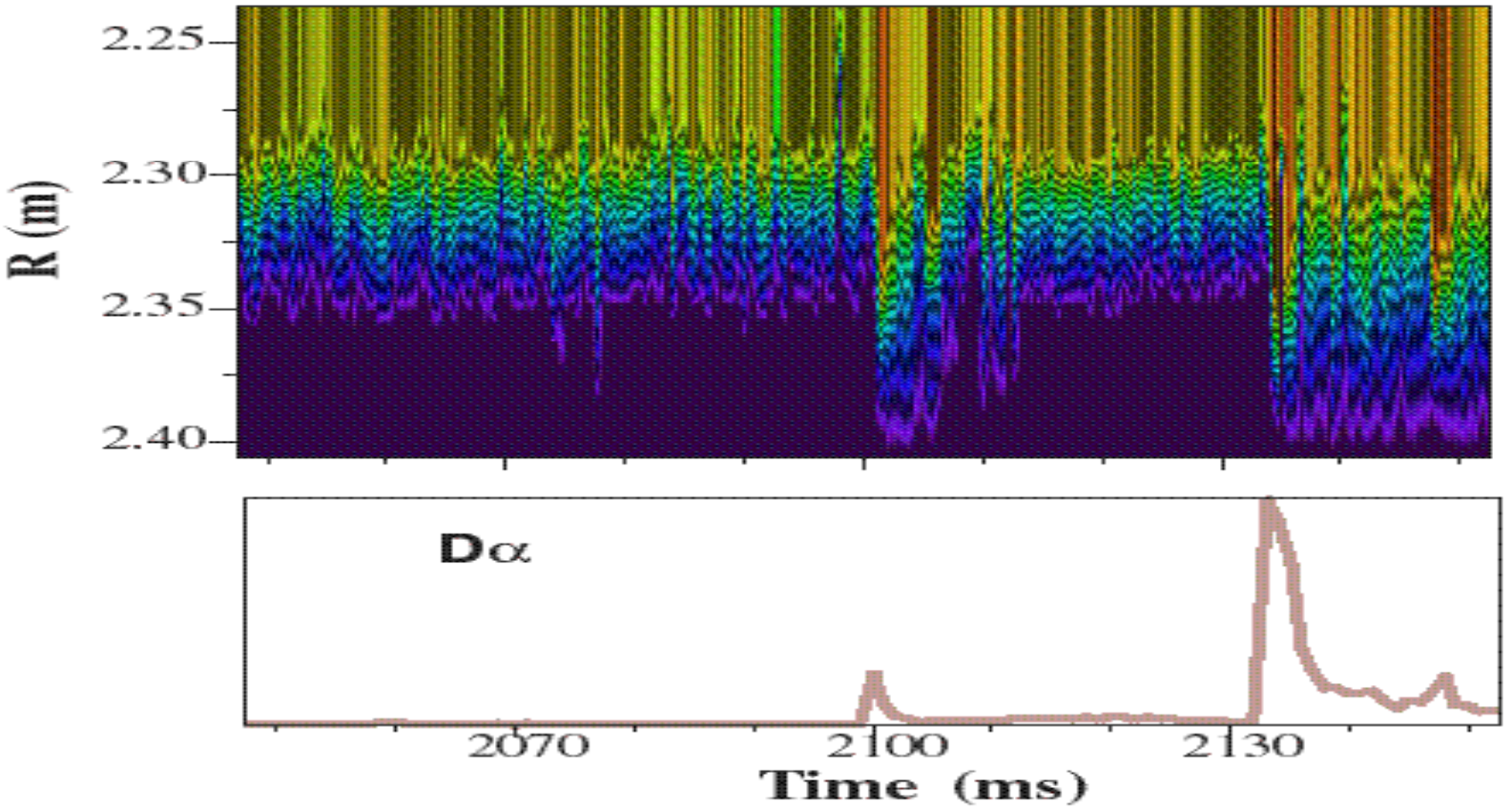
Reflectometer: Both Q and V bands set in X mode

Reflectometer Ne Profiles During L-H Transition



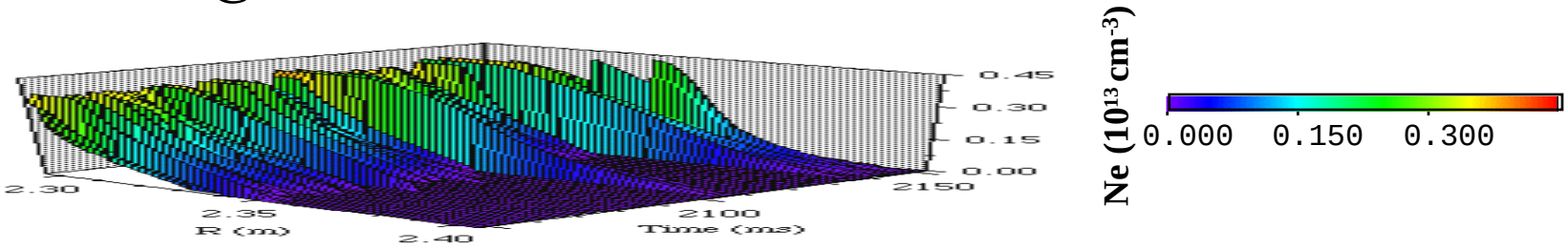
Edge Density Profile Image Through ELMs

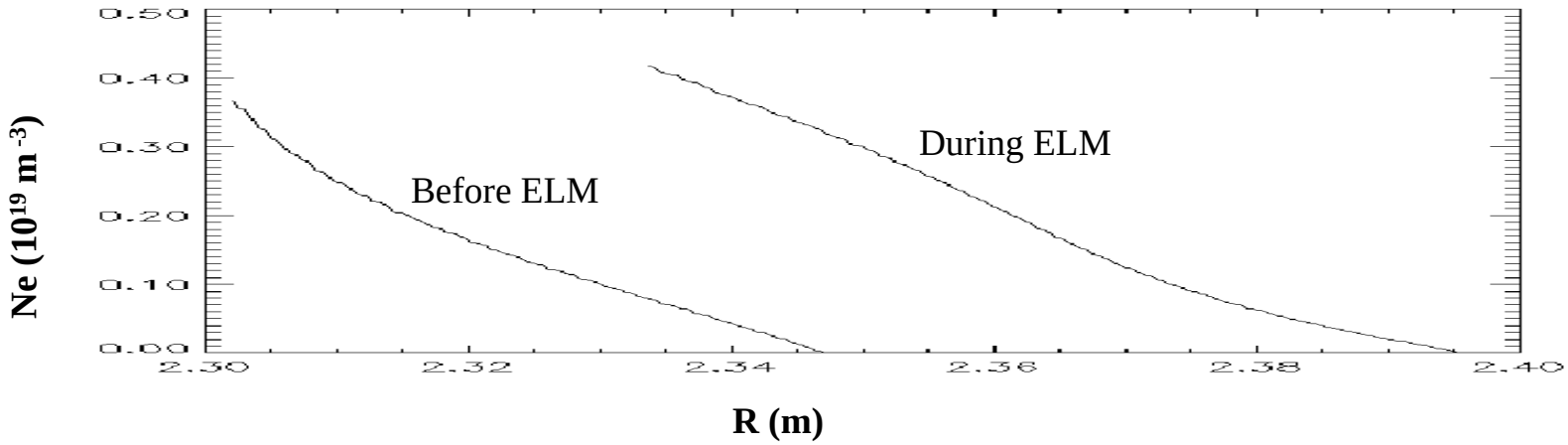
- **Reflectometer: 100 μs** per profile



Fast Reflectometer Can Track Edge Profile Evolution Through ELMs

- **Reflectometer Setting** : Q Band X Mode , and **100 μs** per profile measurement
- **Plasma Condition**: Ip=1.5MA, B_T=2.1T, Pellet ELMing H-mode @1800ms





Summary

- Reflectometer Profile quality is consistently good over wide range of plasma condition
  - Both Core and Edge
- Density profiles can be obtained throughout 5s covering the while plasma discharge with 100 Hz profile measurement rate.
- Very good time resolution (50 μs) edge density profile measurement is available in DIII-D now.
- Improved availability for users: the profile data is installed in MDSplus database now, and can be viewed by DIII-D data viewing software tools.

- The new PC based data acquisition system has been successfully installed.
  - Providing high sampling rate (80MS/s in 1-channel, 40MS/s in 2-channel)
  - Providing large memory
- Improved density measurement range: both Q and V band reflectometer systems can be configured as either O- or X-mode polarization.
- Can define the density gradient in the core barrier region
- The fast edge profile can resolve the L-H transition and track through ELMs.
- The Implementation makes the reflectometer systems become a standard density profile diagnostic on DIII-D, and play more important role for H-mode and core transport barrier studies

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