MSE-LIF Installation on NSTX: Plans and Capabilities

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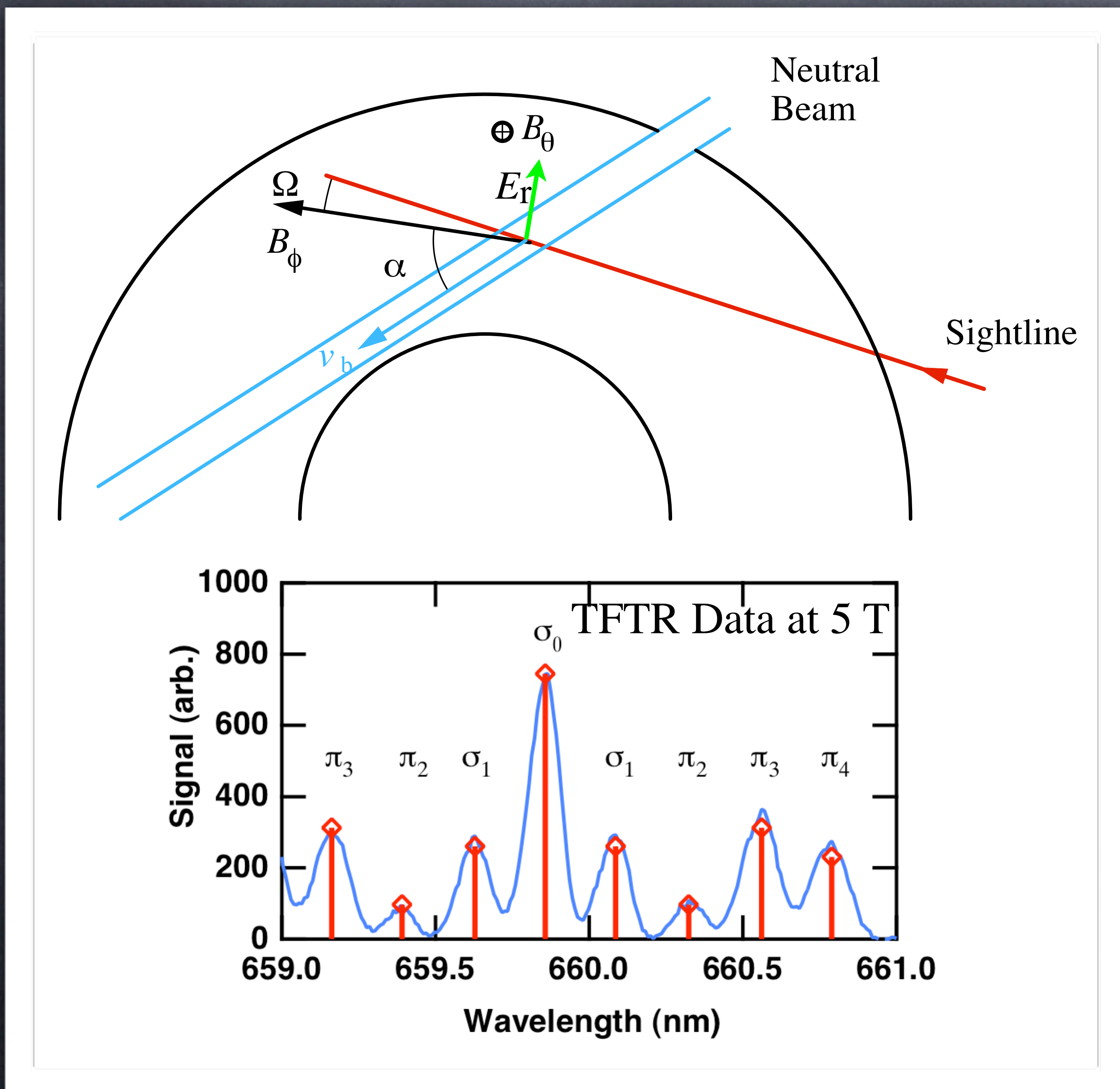
Presentation to NSTX Team 6/26/09

Overview

- Motional Stark Effect with Laser-Induced Fluorescence (MSE-LIF) Concept
- Physics topics accessible with MSE-LIF on NSTX
- Present Status of MSE-LIF Project
- MSE-LIF Installation Plans on NSTX
- Discussion

Motional Stark Effect with Laser-Induced Fluorescence (MSE-LIF) Concept

Motional Stark Effect Diagnostic



- Emission from hydrogen neutral beam is split and polarized due to Stark effect from $\vec{v} \times \vec{B}$ electric field. Split linearly proportional to |B|
- Emission generated from Collsionally-Induced Fluoresence (CIF)
- Pitch angle determined by polarimetry on single line of spectrum
- Radial profile of pitch angle used with external magnetics to reconstruct equilibrium
- Sensitive to radial electric fields

NSTX Low Fields Required New MSE Approach

Example: NSTX at ~0.4 T

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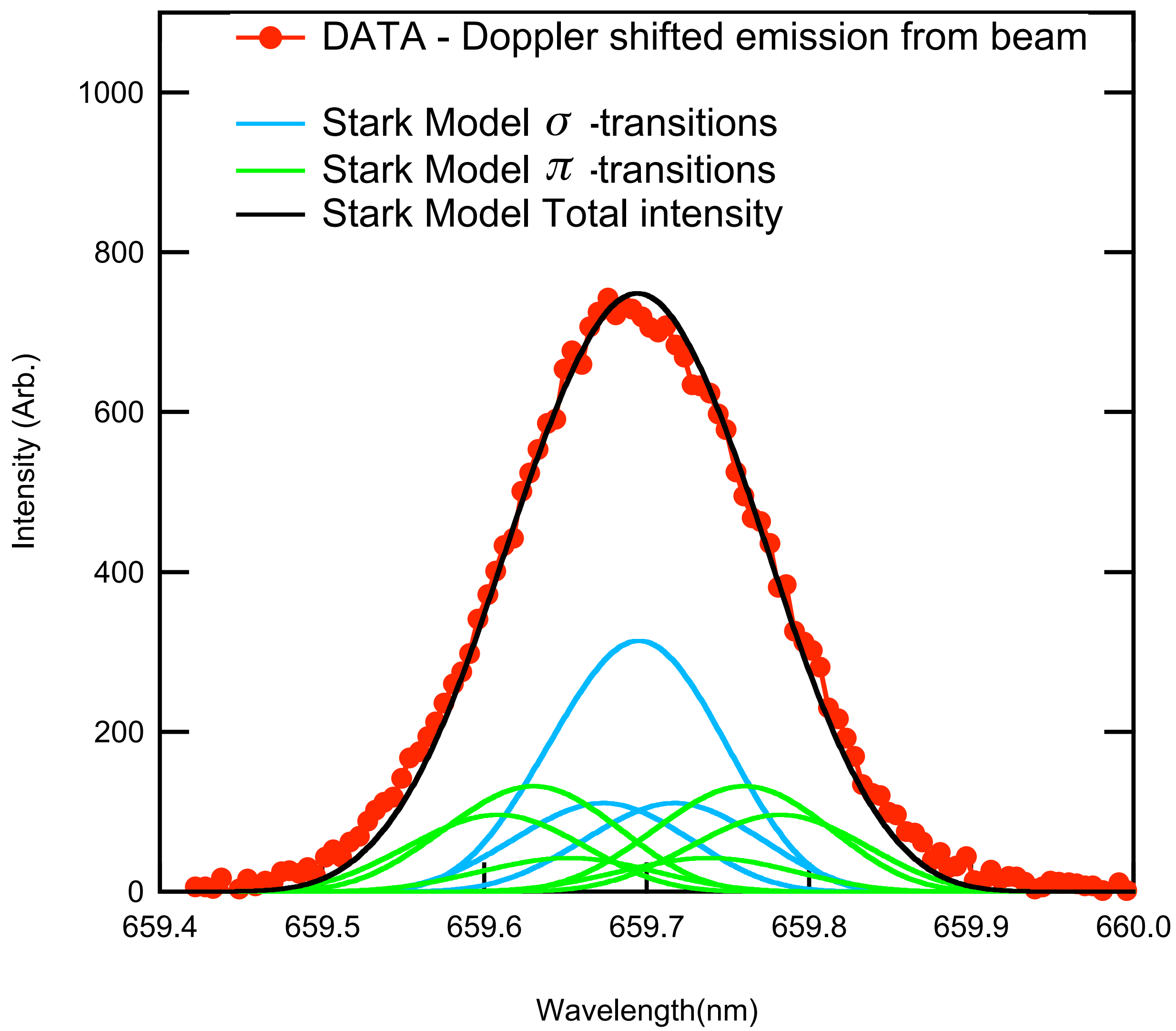
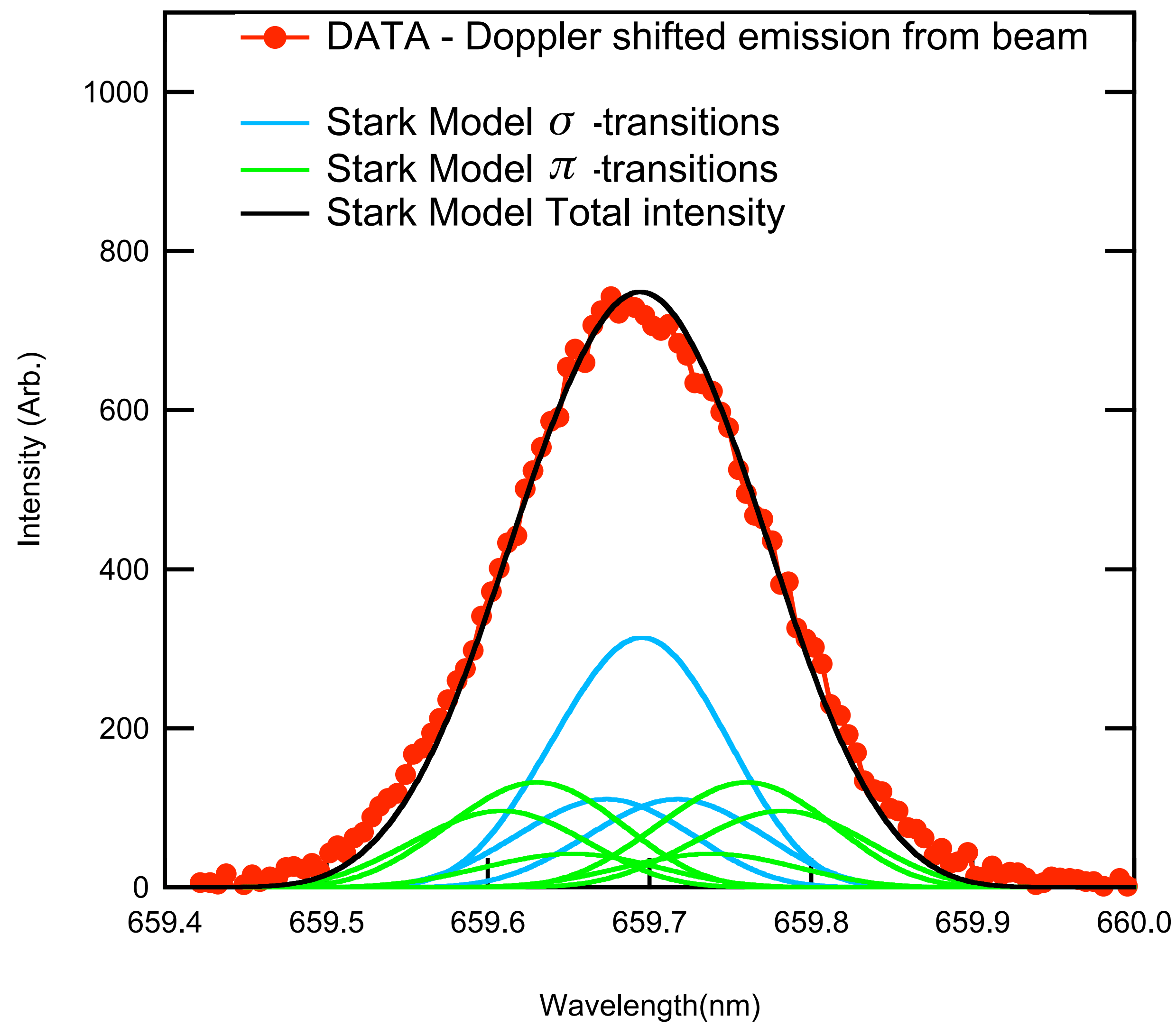


NSTX data
(spectrometer)

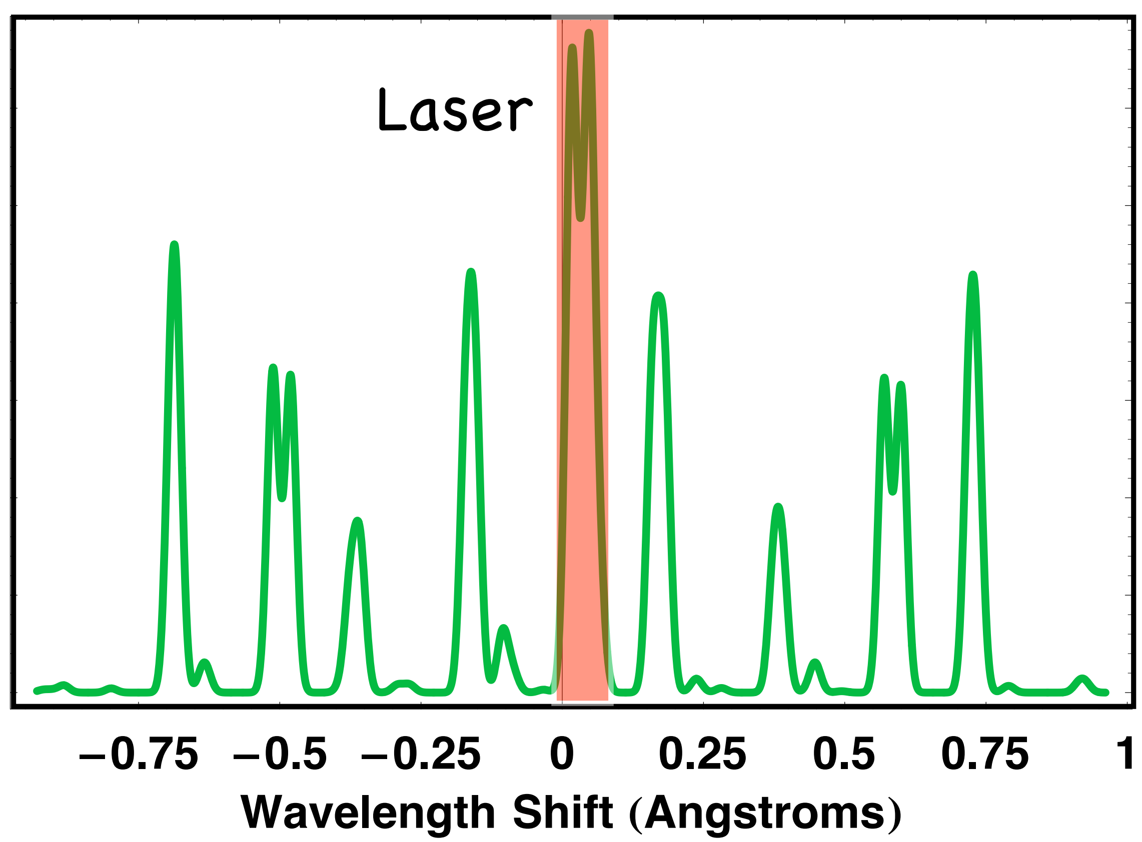
NSTX Low Fields Required New MSE Approach

Example: NSTX at ~0.4 T

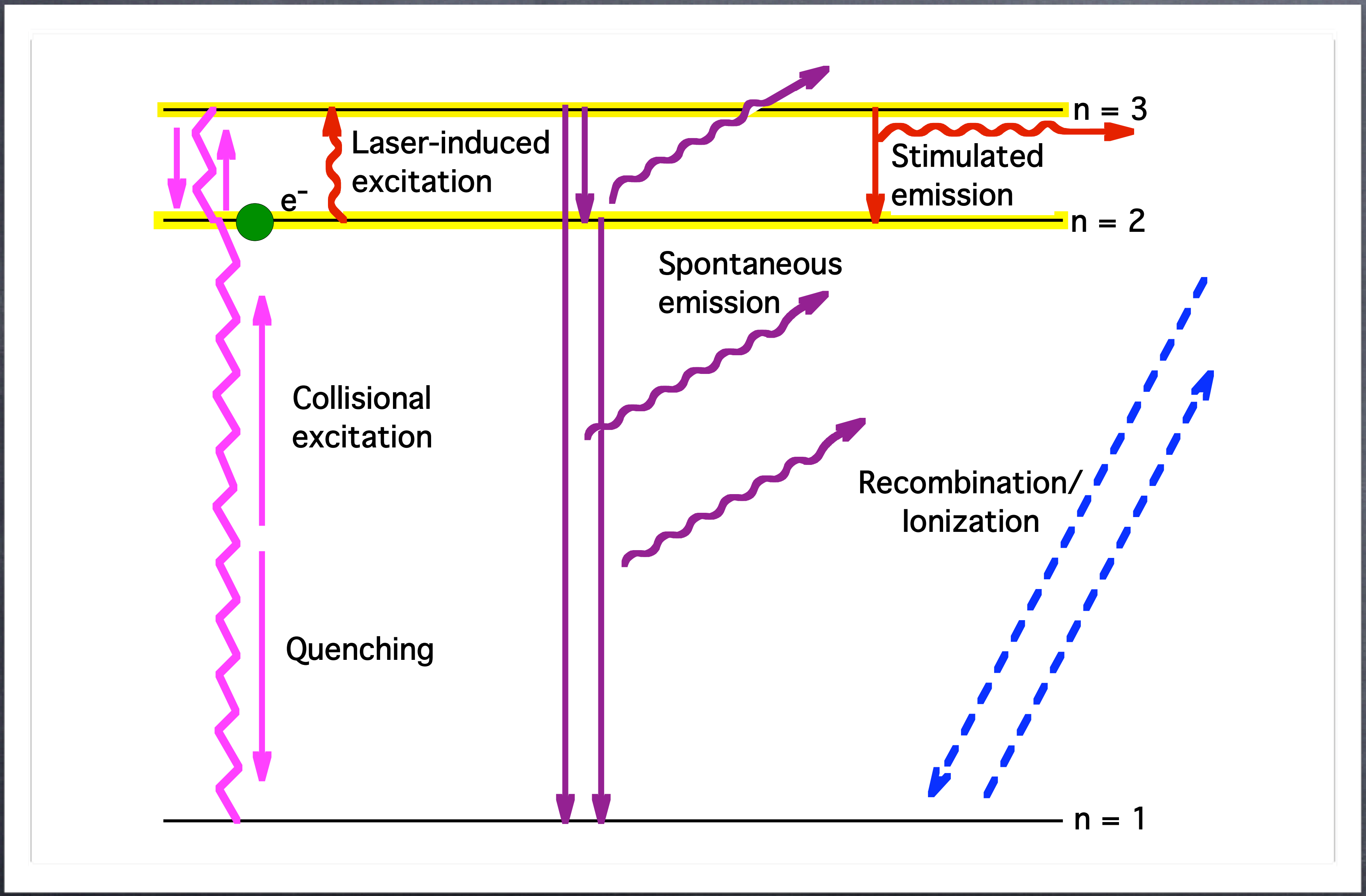


NSTX data
(spectrometer)

MSE-LIF
Prediction

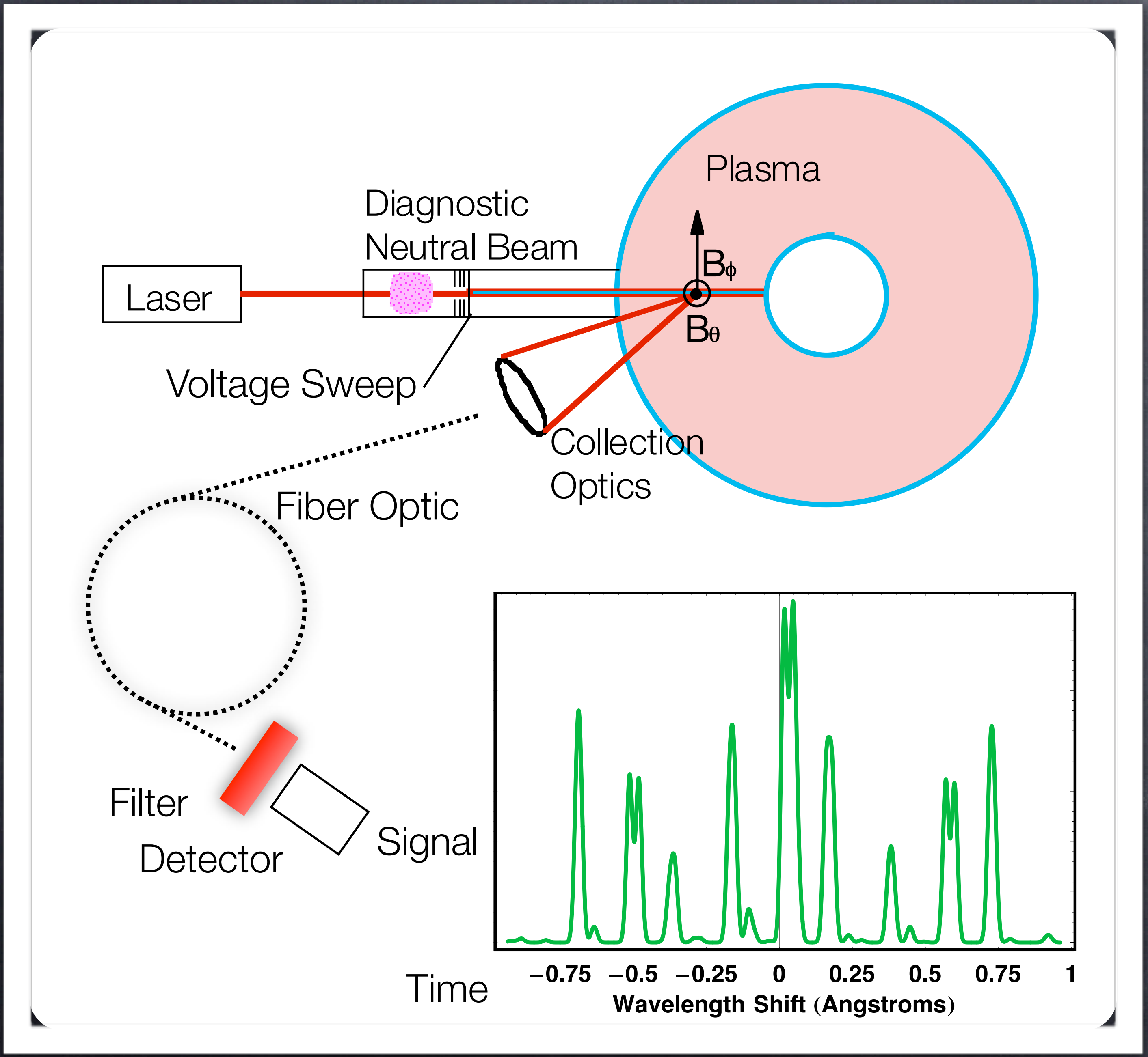


Laser-Induced Fluorescence



- Resonant laser absorbed - electron transitions to higher energy state
- Electron spontaneously decays from higher energy state, emission results.

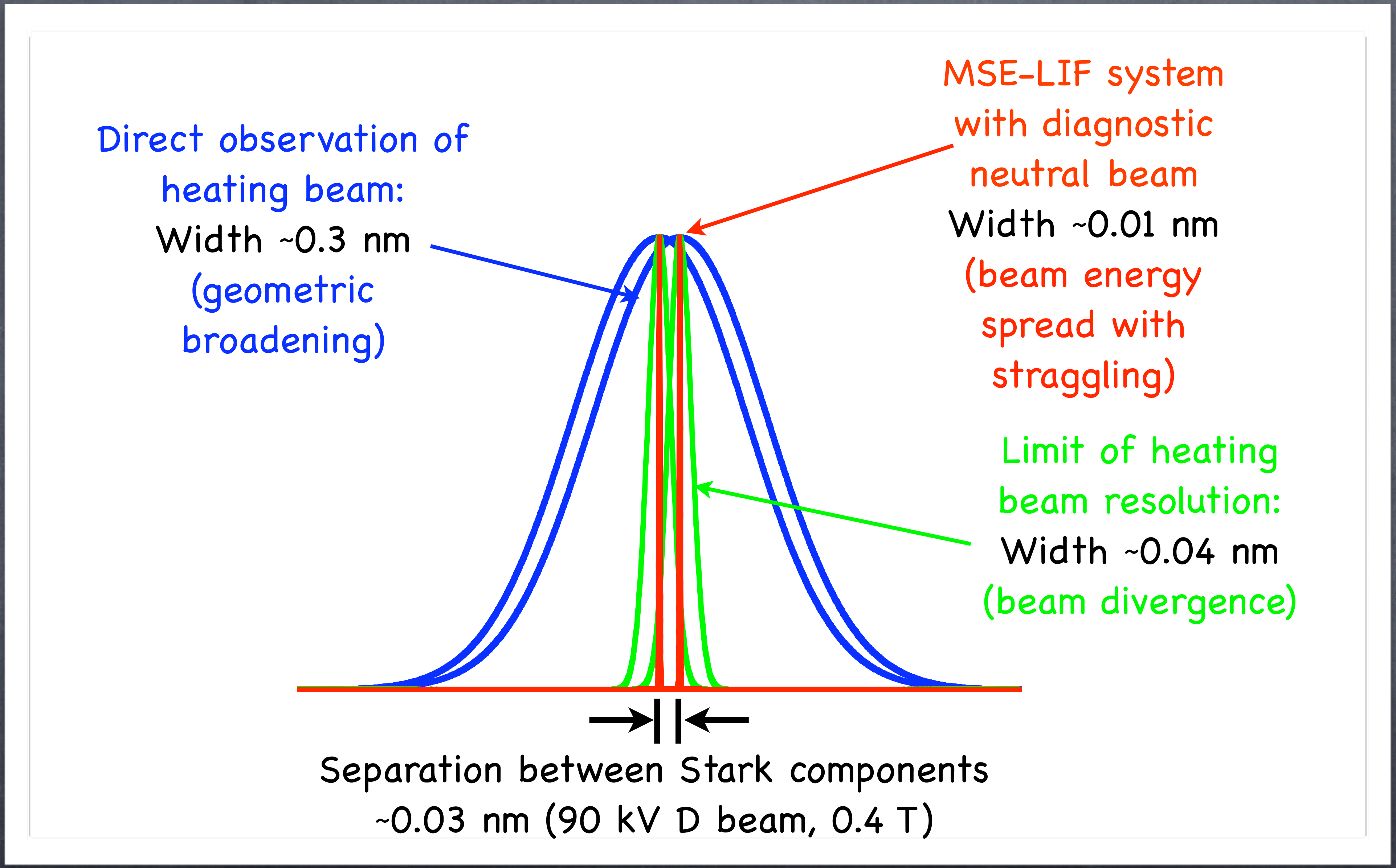
Laser-Induced Fluorescence on Diagnostic Neutral Beam



- Dedicated diagnostic neutral beam. 30-40 kV, 40 mA, 4 cm FWHM in NSTX
- Resonant nature of LIF enables measurement of LASER wavelength and LASER polarization to give knowledge of ATOMIC BEAM energy states
- Sweep beam voltage across spectrum, measure peak separation for |B|
- Use electro-optic polarization rotator, measure phase shift between input and signal for pitch angle - eliminates geometric broadening
- Measure only magnitude of collected light signal

Unprecedented Spectral Resolution

Example: NSTX at ~0.4 T



Enables NEW measurement capability - of magnetic field magnitude as well as pitch angle

Predicted Performance on NSTX

- MSE-CIF data from NSTX, MSE-LIF laboratory performance and collisional-radiative model used together to predict signal levels for NSTX - expect 10x higher photon count rates (at detectors) than CIF system. Time resolution of better than 10 ms expected.
- Magnitude of B resolved to few Gauss range, Pitch angle at least comparable to CIF system ~0.3 degrees.
- Spatial resolution few cm range - limited by view angle with respect to beam. Fundamental limit due to emission decay time close to 1 cm.

MSE-LIF Contribution to New Physics Studies

MSE Independent of Heating Beams

- MSE pitch angle measurements can be done in previously inaccessible conditions: Non-inductive start-up, CHI, HHFW heating/current drive.
- Pitch angle measurements can be used as MSE-CIF measurements are presently - for q-profile and current reconstruction.
- In conditions where heating beams are running and MSE-CIF system is operating, additional MSE-LIF data can help constrain equilibria, improving reconstructions, particularly current.

Radial Electric Field Measurement

- MSE intrinsically sensitive to radial electric fields - though MSE-LIF system injection angle minimizes this effect.
- MSE-CIF system and MSE-LIF system together can isolate radial electric fields.
- Radial electric fields at H-mode boundary, influence on turbulence, effects on transport, confinement.

Utility of |B| for Equilibrium Reconstruction

- Using ESC code extended with Equilibrium Reconstruction Variances (L. Zakharov)
- Initial studies for ITER, additional NSTX analysis performed
- NSTX result: Projected precision of ~5 Gauss comparable for reconstruction to ~0.3° pitch angle uncertainty in traditional MSE for q-profile reconstruction
- |B| constraint can be added to EFIT, ESC or LRDFit for q-profile, pressure, current reconstructions.

Pressure Profile Reconstruction

- Precise |B| measurement good constraint for total pressure in equilibrium reconstruction
- Existing measurements of thermal pressure can be used with MSE-LIF data to isolate non-thermal pressure
- Study fast ions, fast ion modes
- Pressure profiles derived from single measurement expected to give more accurate time and spatial derivatives
- Study pressure gradient driven MHD modes

Test of q-profile Reconstruction with |B| for ITER

- ITER first mirror coatings expected to make polarization-based MSE measurement extremely challenging to calibrate.

- Proposed solution to employ |B| measurement for q-profile reconstruction. Studies give favorable results

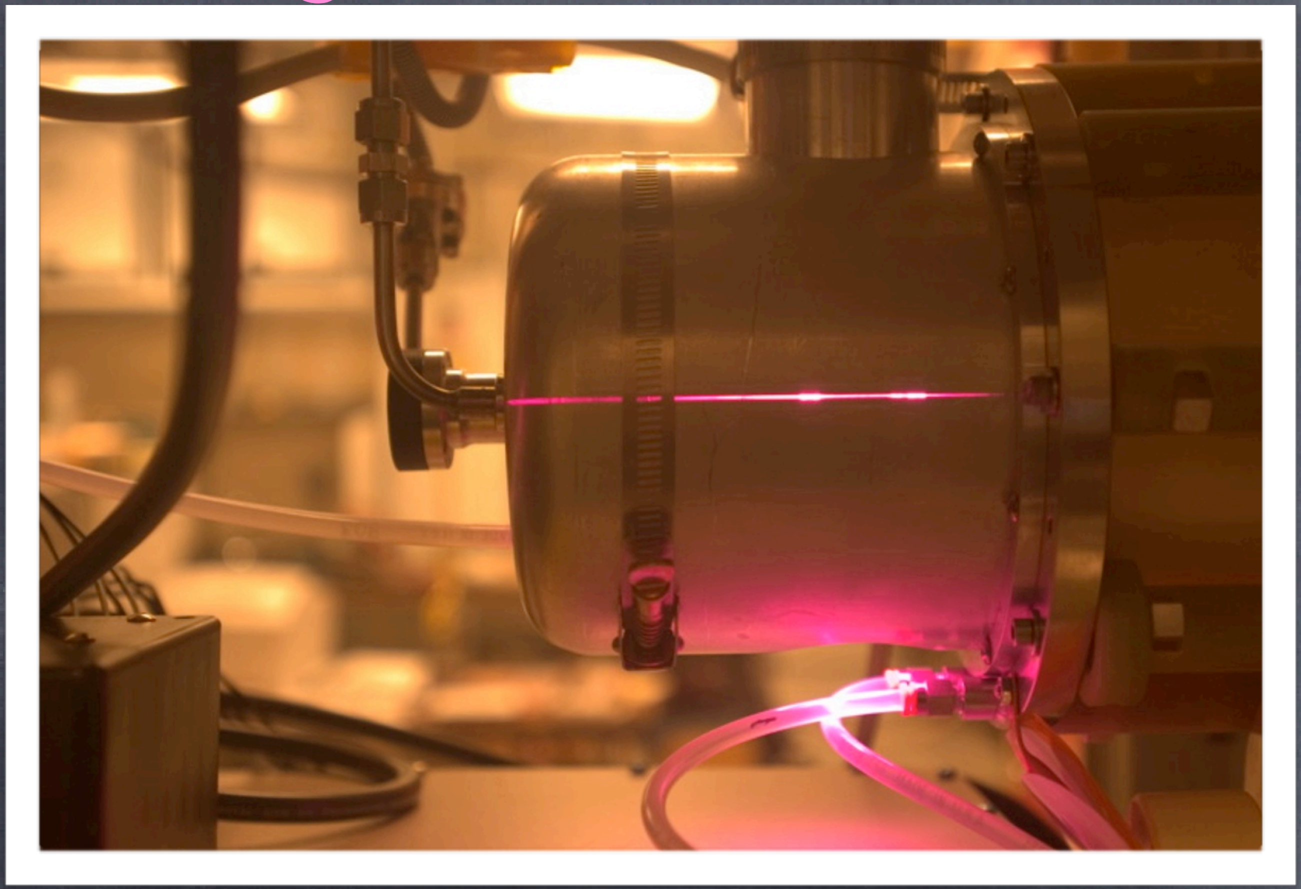
- MSE-LIF on NSTX provides unique opportunity to test concept - ITER spectral line spacing-to-width ratio large compared to existing tokamaks with traditional MSE systems. Can be achieved with MSE-LIF on NSTX.

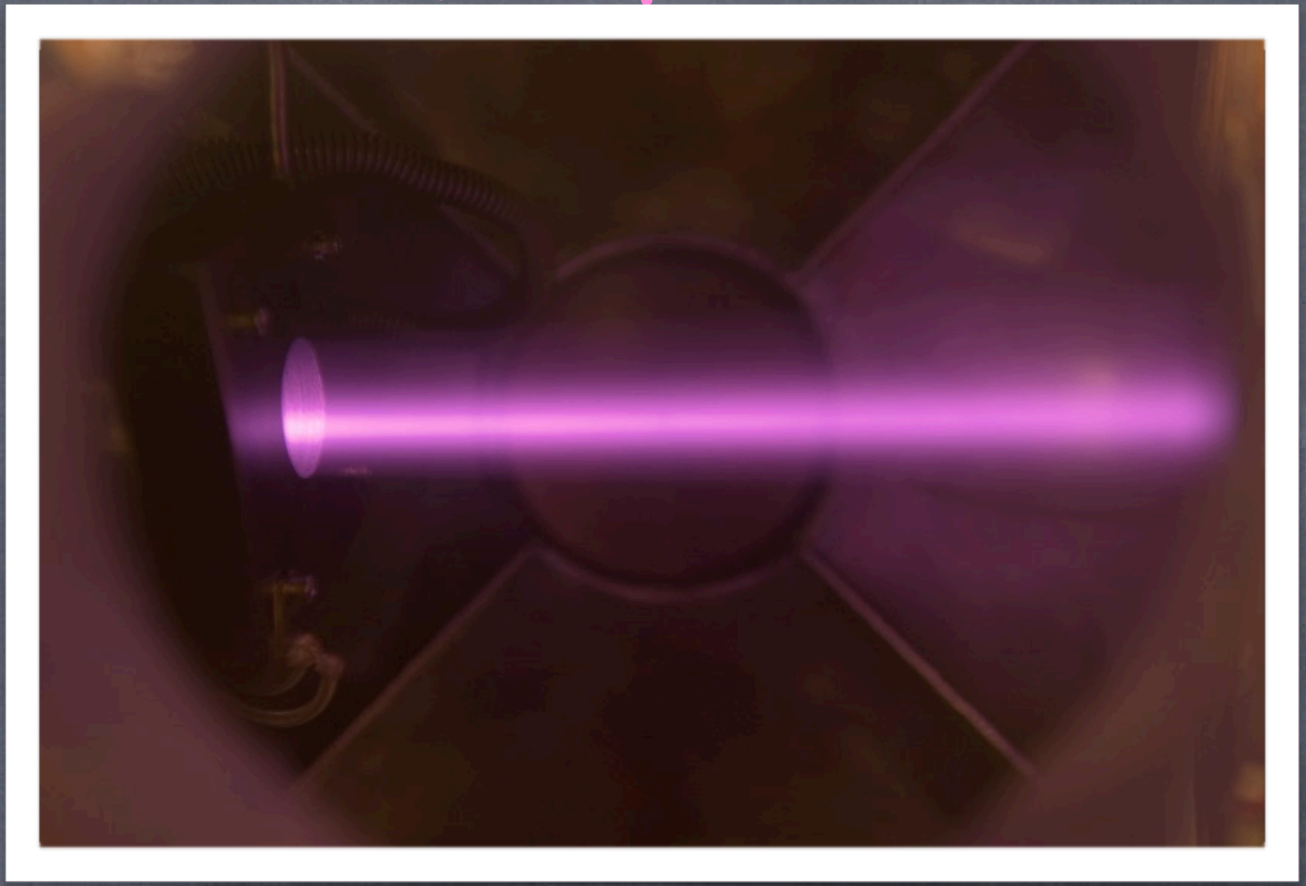
MSE-LIF Present Status

Funding: Diagnostic Development Grant

- Highly competitive open solicitation for OFES diagnostic development (DE-PS02-07ER07-10)
- Grant renewal beginning February 2008 for three-year period
- Proposed schedule had installation on NSTX for FY10
- Presently scheduled for installation and operation in FY11

Diagnostic Neutral Beam Fully Operational

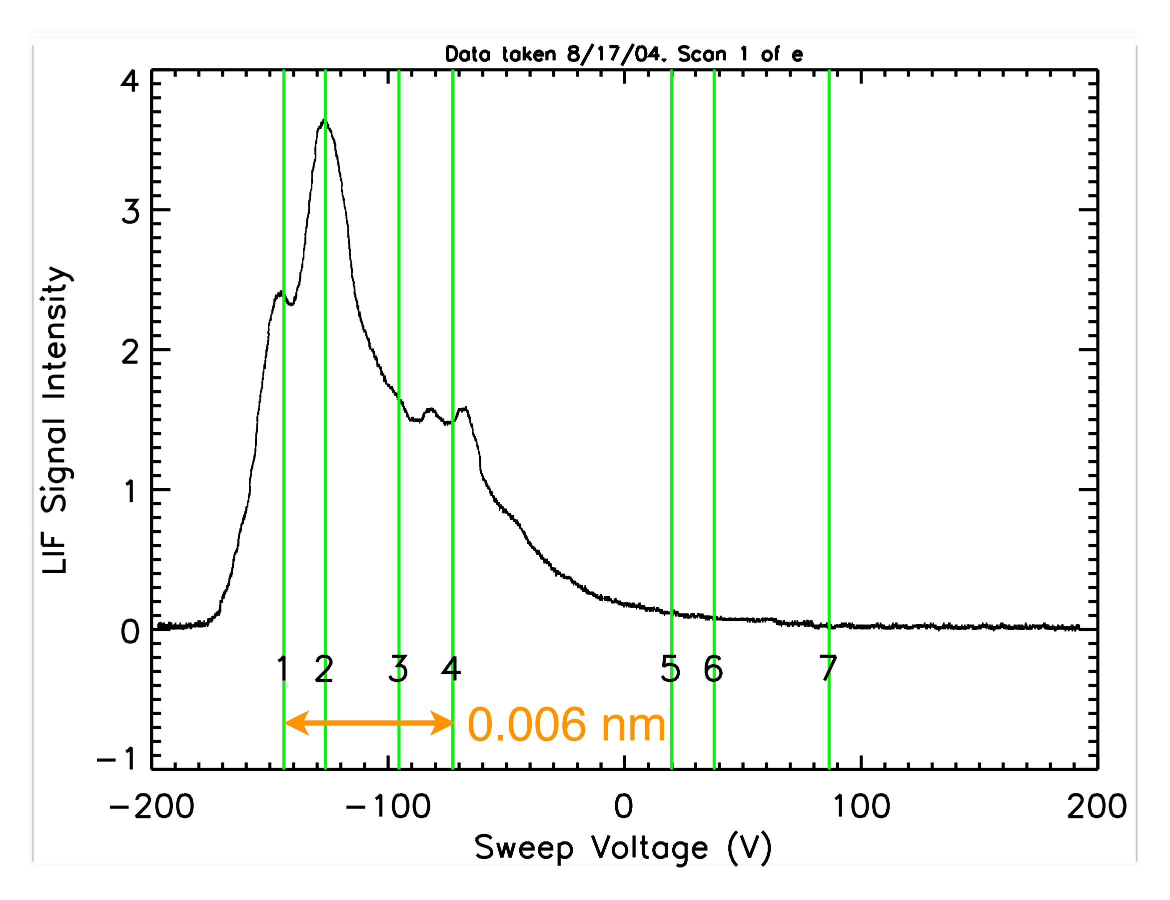




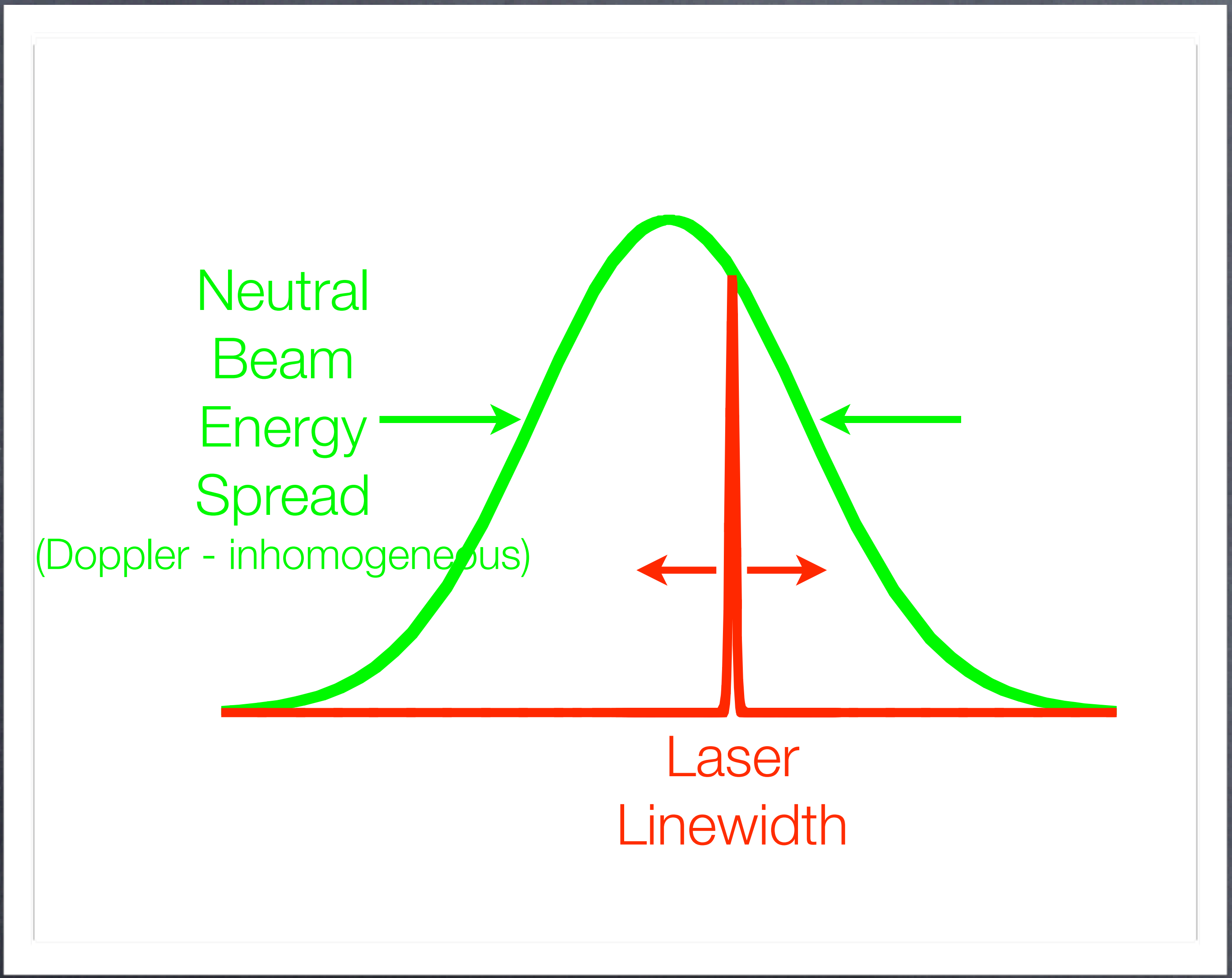
- RF source built in collaboration with LBNL
- Low noise HV power supply and sweep capability built in collaboration with PPPL
- Routine operation in L112 lab: 30-40kV, 40 mA (1.5 kW)
- Remote control partially implemented
- Magnetic shield design mature, procurement imminent, pending final vacuum tests and internal detail design review.
- Complete redesign of stand and pumping chamber undertaken for ease of installation on NSTX.

Extensive Laboratory Studies with Dye Laser

- LIF enhancement phenomena observed at low magnetic field (~40 Gauss) in neutral H_2 gas background
- Collisional-Radiative model developed including quantum mechanics effects
- Signal levels extensively studied and well-understood in neutral gas
- In development lab, LIF signal very low at 100's G field in argon plasma with high neutral fraction



Dye Laser/Beam Spectral Width Mismatch



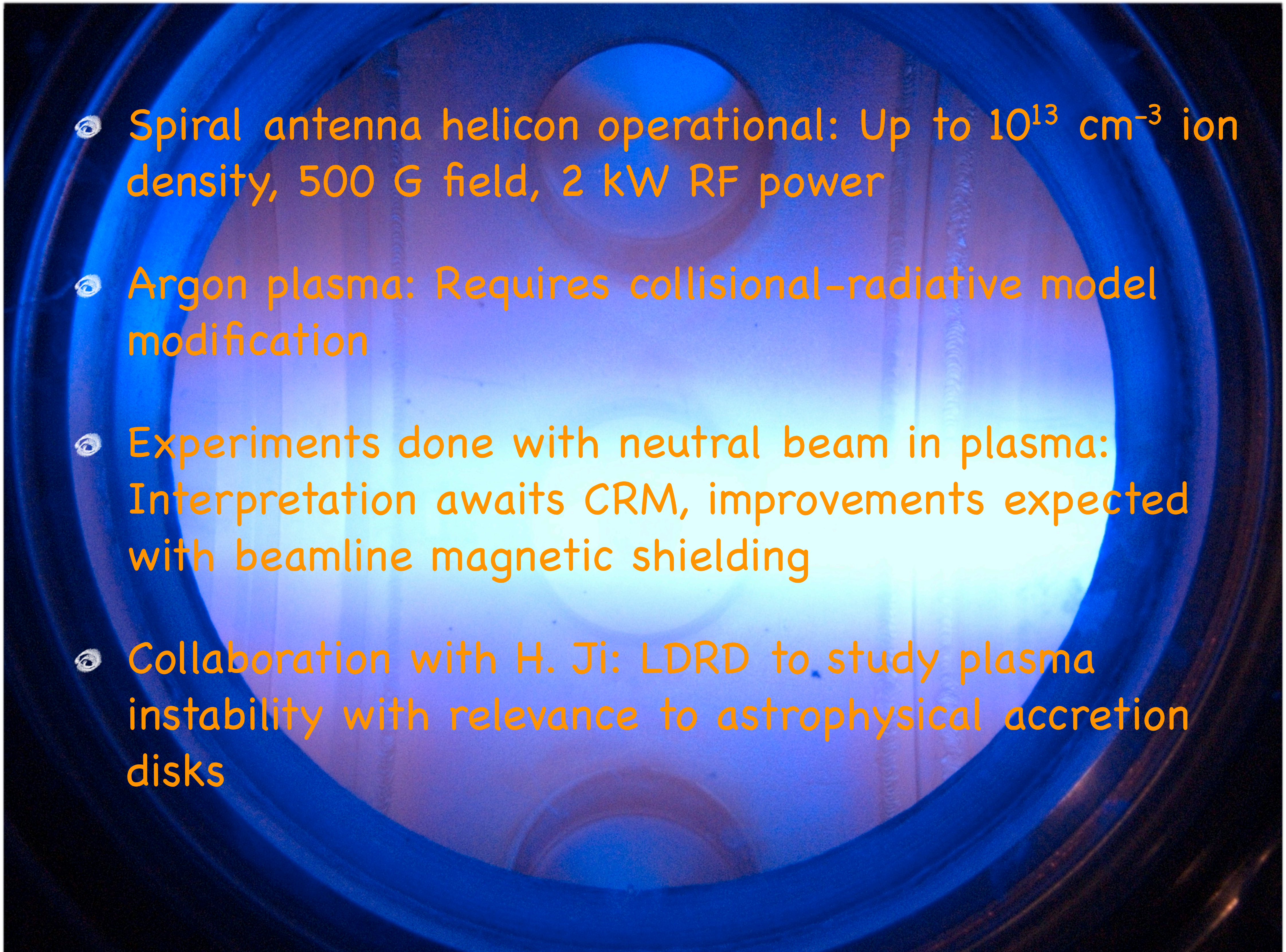
MAXIMIZE OVERLAP TO MAXIMIZE SIGNAL

- Beam energy spread reduced as much as possible (Acceleration voltage ripple, plasma potential variation in NB source, RF oscillations, etc)
- Fundamental limit of straggling during neutralization process
- Theoretical minimum ~0.002 nm (25 V, 1.5 GHz)
- Measured ~0.0036 nm (40 V, 2.5 GHz)
- Expect additional effect of same order in plasma: Final width ~0.009 nm (100 V, 5–7 GHz.)

10 W, 651 nm Laser Development

- Transitions of interest: Natural linewidth ~100 MHz, energy spread due to straggling ~ 5 GHz
- Keep laser power per unit linewidth same
- High power (10+ W), intermediate bandwidth (2–5 GHz) laser needed to maximize LIF signal FACTOR OF 30 - 50 INCREASE
- Pursuing approach using diode bar (2 nm bandwidth) narrowed with feedback from volume bragg grating to 0.009 nm (2–7 GHz)
- Laser system conceived and assembled by contractor using cryogenic temperature shift to achieve wavelength. Challenges of cryogenic operation led to procurement of custom diodes at correct wavelength. Expect delivery of sample bar 8/09

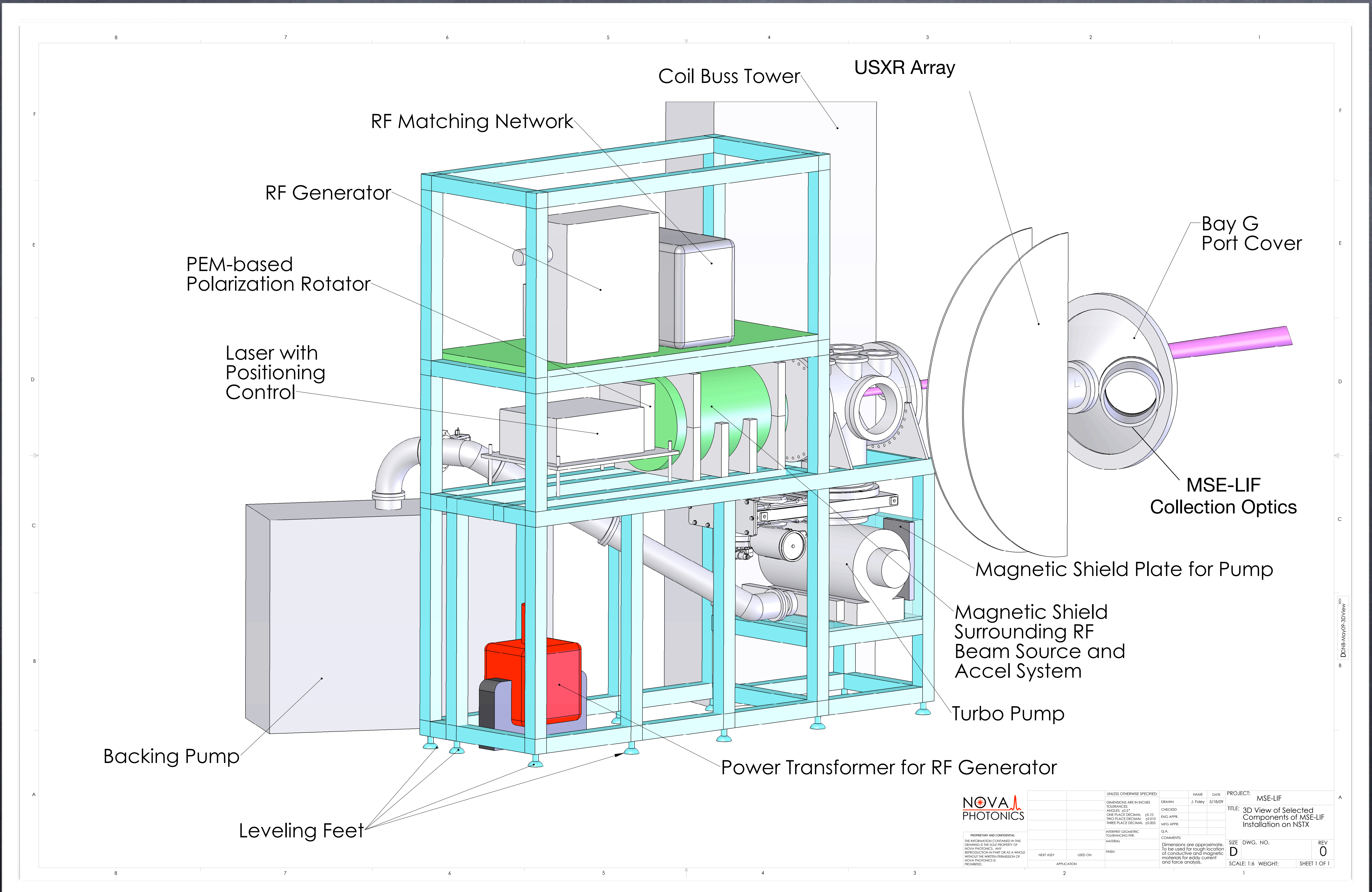
Helicon Plasma Testbed



- Spiral antenna helicon operational: Up to 10^{13} cm^{-3} ion density, 500 G field, 2 kW RF power
- Argon plasma: Requires collisional-radiative model modification
- Experiments done with neutral beam in plasma: Interpretation awaits CRM, improvements expected with beamline magnetic shielding
- Collaboration with H. Ji: LDRD to study plasma instability with relevance to astrophysical accretion disks

MSE-LIF Installation Plans on NSTX

Footprint on NSTX



Other Diagnostic Systems Affected

- Bolometer (S. Paul, PPPL) - electronics box in path of beamline - repackaging of electronics in progress (M. Hause, S. Raftopoulos)
- Interferometer (S. Kubota, UCLA) - support table interference with beam stand, view interference with MSE-LIF shutter - table to be redesigned as part of planned upgrade, shutter issue under present consideration. (G. Paluzzi, S. Raftopoulos)
- Poloidal Ultra Soft X-Ray Array (K. Tritz, Johns Hopkins) MSE-LIF should not interfere with installation, though some auxilliary components may need to be relocated.
- Multi-Energy Soft X-Ray Array (L. Delgado-Aparicio, Johns Hopkins) Presently at location of MSE-LIF viewport. Will relocate in 2011.

PPPL Accommodations

- Vacuum vessel modification needed between bays G and H to accommodate DNB.
- Bay G port cover modifications needed to install shutter for view, table for optics
- Interferences to be resolved - re-routing of helium piping, jog in RWM coil
- Services: power, water, air, interlock signals, etc
- Resolution of diagnostic interferences

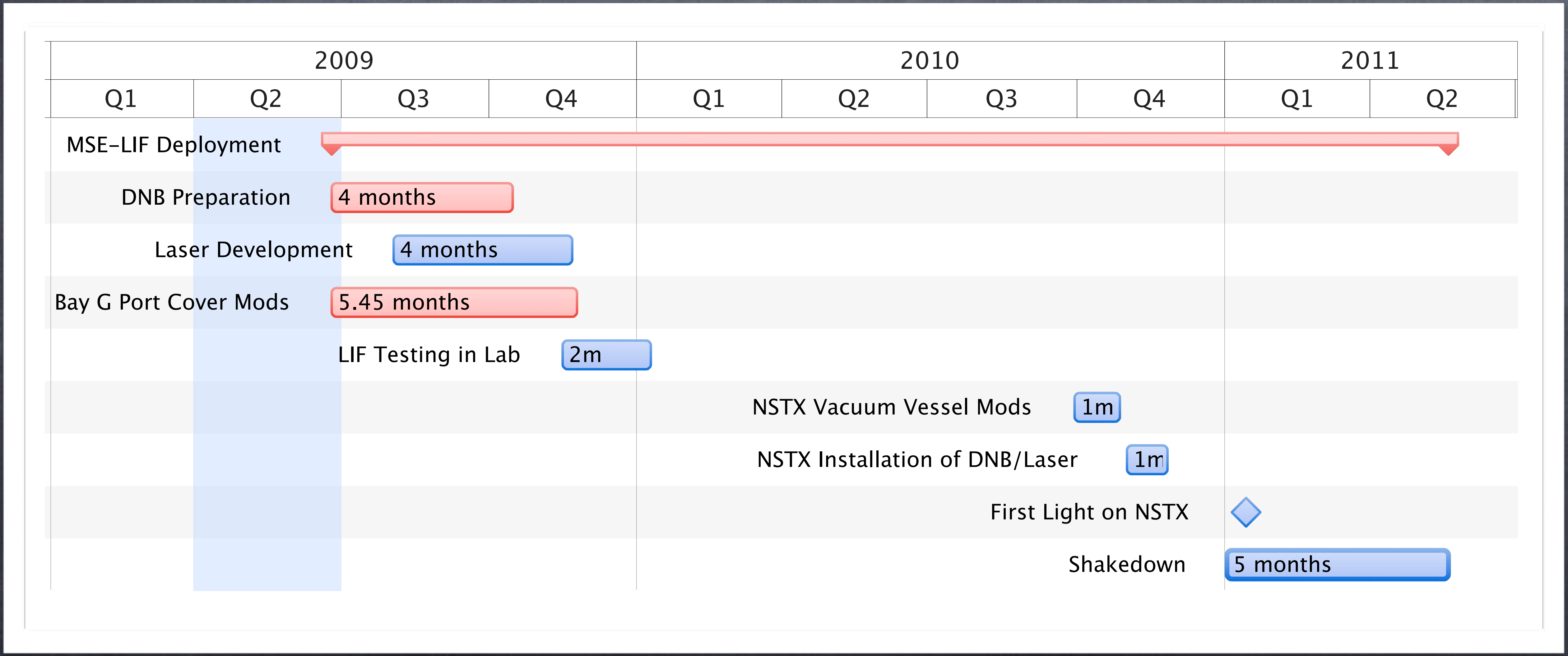
Nova Photonics Remaining Tasks

- Complete laser development
- Procure, install and test magnetic shielding on beamline
- Transfer beam system to completely redesigned stand for compact installation
- Test beam and laser LIF in L112 lab
- Complete remote operation
- Ongoing interfacing with PPPL

Installation Work in Progress

- ✓ 2/7/08 - Conceptual Design Review
- ✓ 1/9/09 - Preliminary Design Review (S. Raftopolous, PPPL)
- ✓ 5/22/09 - Final Design Review for Bay G Port Cover Modifications
- ✓ 5/22/09 - Peer Review for Diagnostic Neutral Beam packaging for installation on NSTX
- ✓ 6/23/09 - Peer Review for Beam Chamber

Timeline


2009
2010
2011
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
MSE-LIF Deployment
DNB Preparation
4 months
Laser Development
4 months
Bay G Port Cover Mods
5.45 months
LIF Testing in Lab
2m
NSTX Vacuum Vessel Mods
1m
NSTX Installation of DNB/Laser
1m
First Light on NSTX
Shakedown
5 months

Discussion