Implementation of the Motional Stark Effect with Laser-Induced Fluorescence (MSE-LIF) Diagnostic on NSTX

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Overview

- MSE-LIF Introduction
- MSE-LIF Capabilities
- State of MSE-LIF Development
- Projected MSE-LIF Performance on NSTX
- Timeline for Implementation on NSTX

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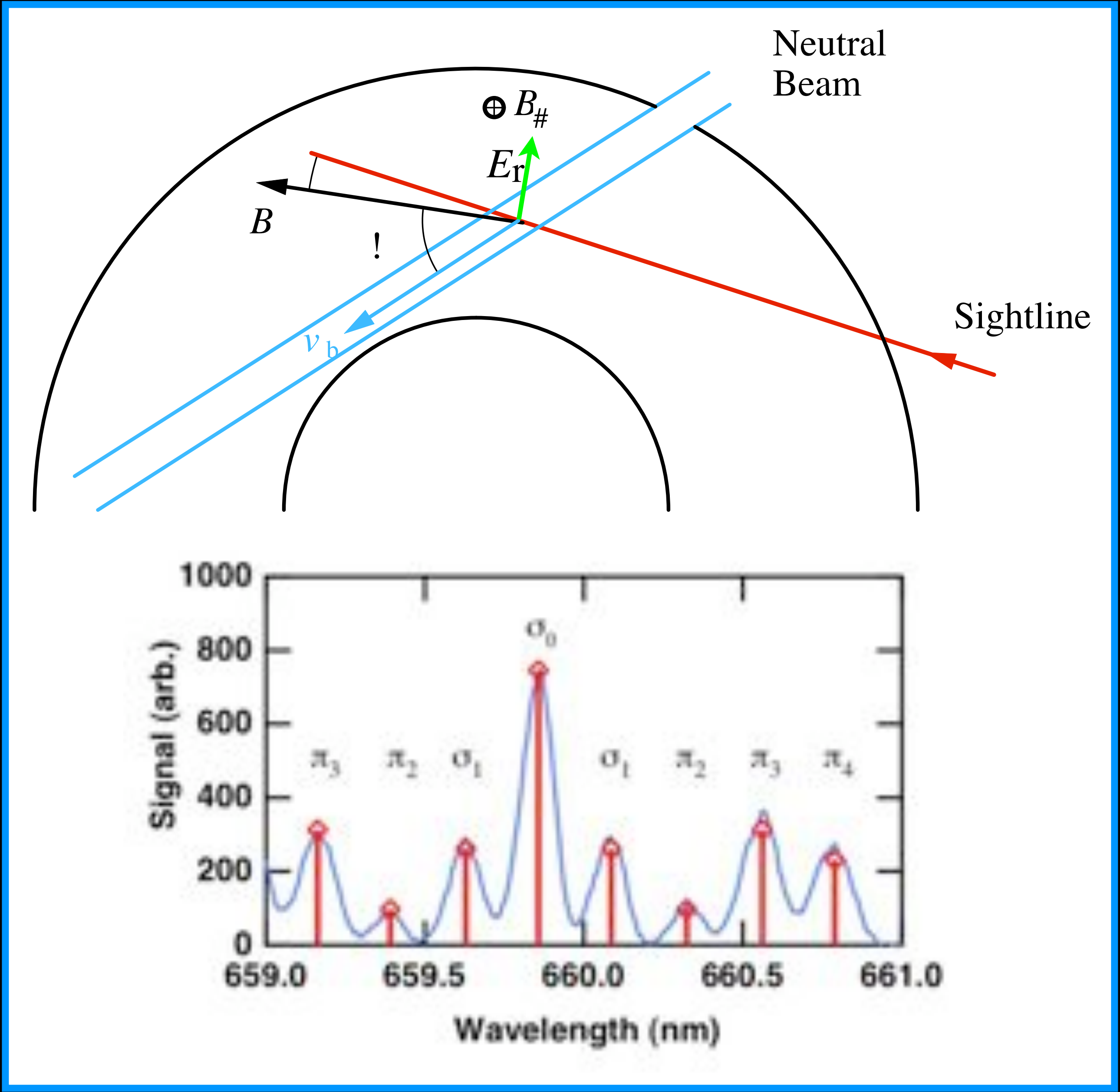
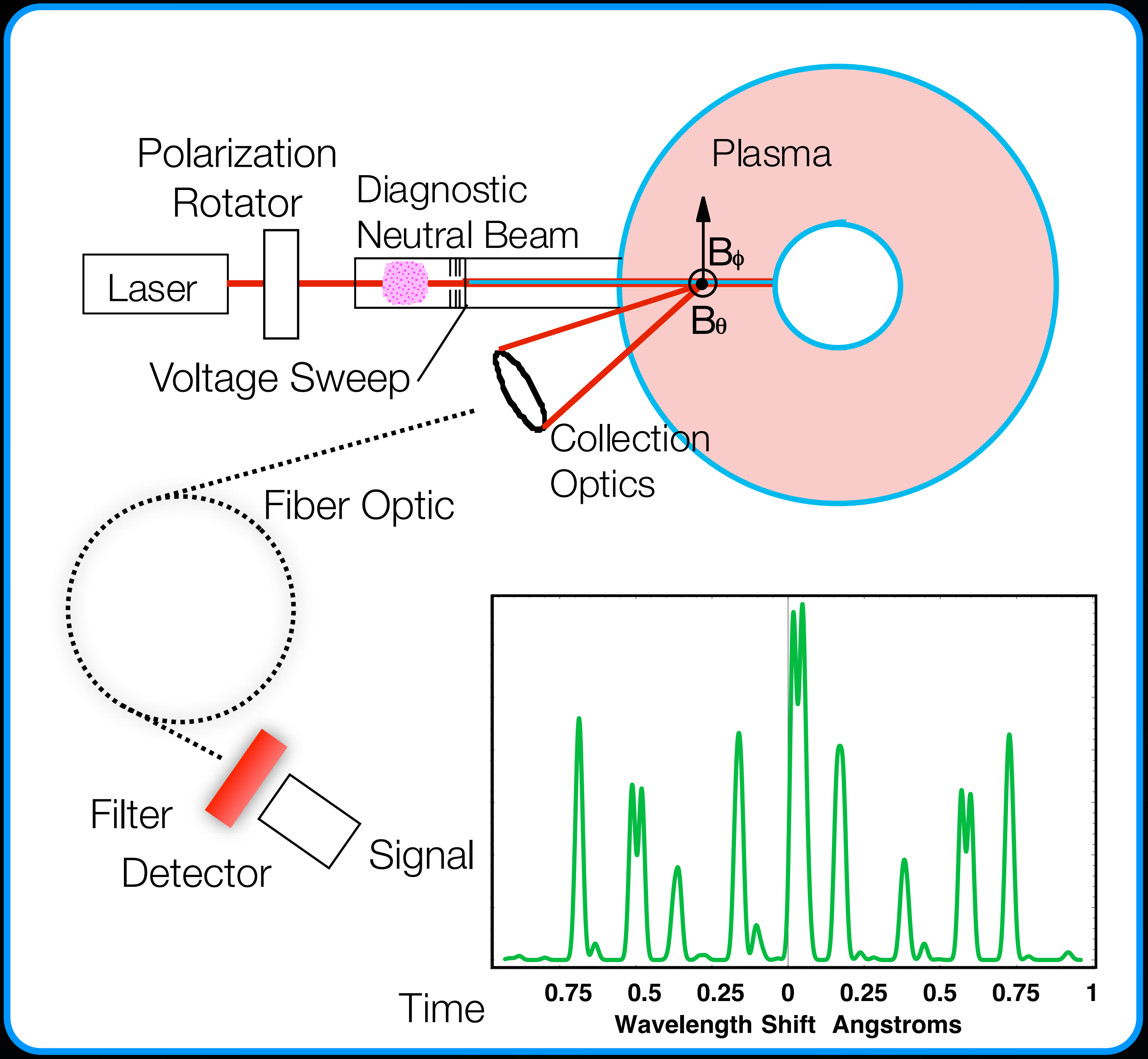
Introduction

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

Laser-Induced Fluorescence on Diagnostic Neutral Beam



- Dedicated diagnostic neutral beam. 30–40 kV, 40 mA, 4 cm FWHM in NSTX
- Rely on collisional excitation of beam atoms from ground to n=2 state, laser excitation from n=2 to n=3 (H-α transition) Observe fluorescence from spontaneous decay from n=3 to n=2
- 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

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MSE-LIF Capabilities

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Advantages of MSE-LIF System on NSTX

MSE without heating beams:

Enables studies of start-up, RF experiments, CHI. Can use pitch angle measurement in existing equilibrium codes

Measurement of |B|:

Measure |B|, use to constrain q, pressure, current. Spectroscopic |B| measurement has been proposed for ITER: MSE-LIF is unique opportunity to test concept

Sensitivity to Er:

Can use MSE-LIF in conjunction with existing MSE-CIF system to determine E_r

Ease of Calibration:

Insensitive to polarization effects in optics

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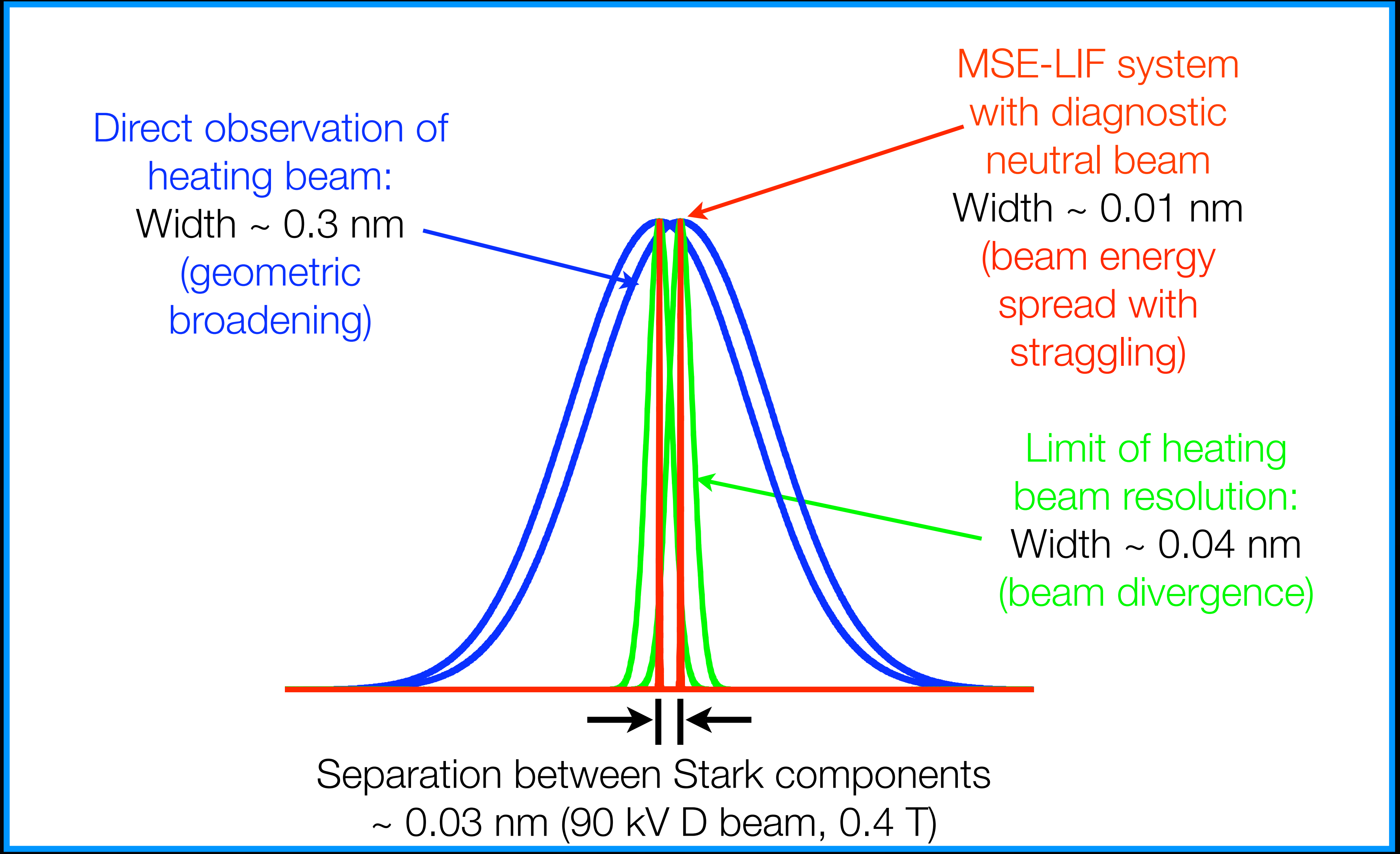
Unprecedented Spectral Resolution

Example: NSTX at ~ 0.4 T



- Precise line shift (MSE-LS) measurement of |B| with beam voltage sweep

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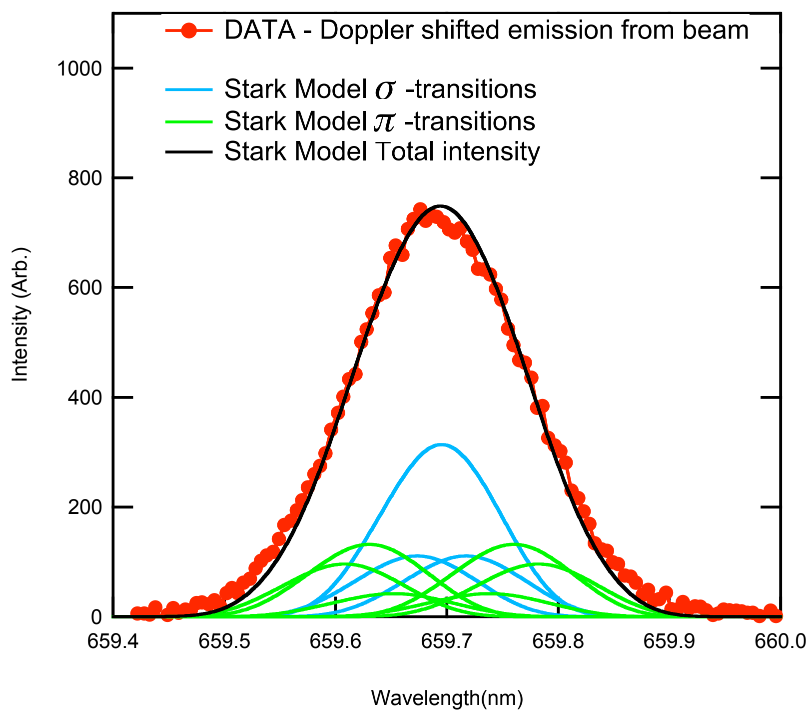
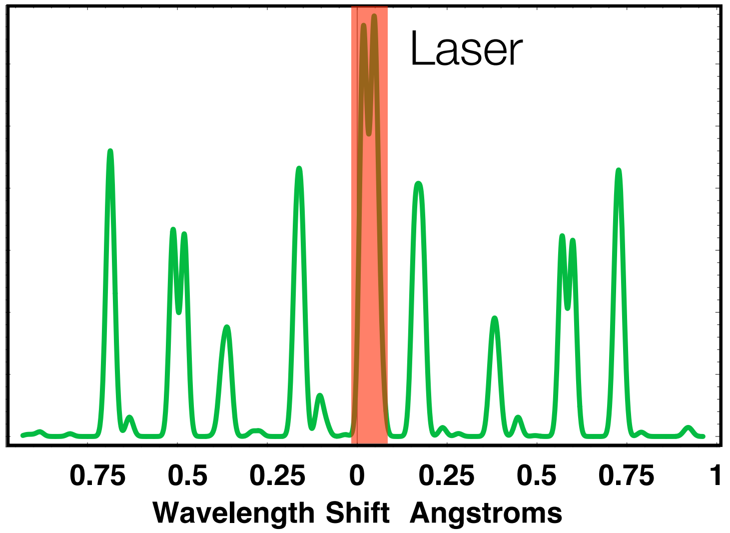
Unprecedented Spectral Resolution

Example: NSTX at ~ 0.4 T



NSTX data (spectrometer)

MSE-LIF Prediction



- Simultaneous pitch angle and |B| measurement possible with MSE-LIF

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Utility of MSE-LS for Equilibrium Reconstruction

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

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MSE-LIF Development

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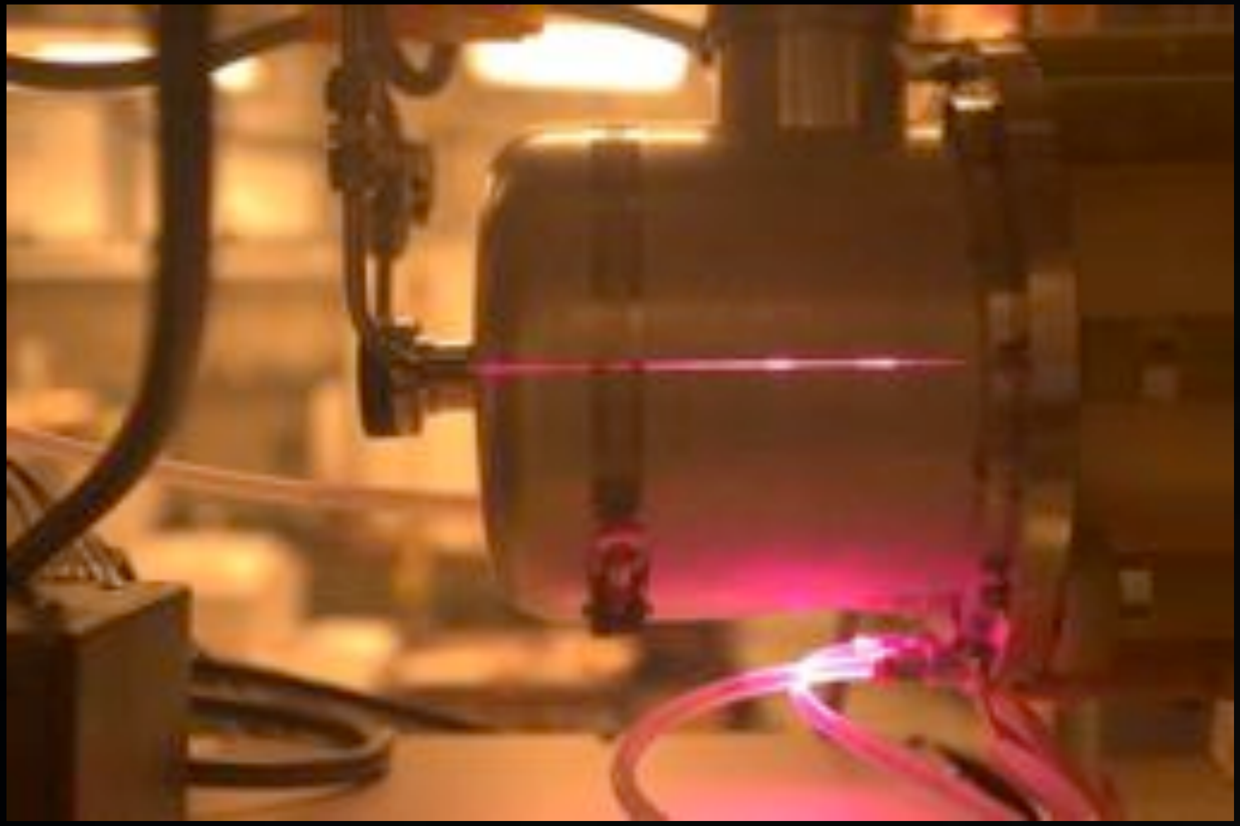
Funding: Diagnostic Development Grant

- 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
- NSTX schedule uncertainties necessitate earlier installation

Diagnostic Neutral Beam Fully Operational



- RF source built in collaboration with LBNL
- HV power supply and sweep capability built in collaboration with PPPL
- Routine operation in L112 lab: 30–40 kV, 40 mA (~1.5 kW)
- Presently implementing remote control capability
- Magnetic shielding required

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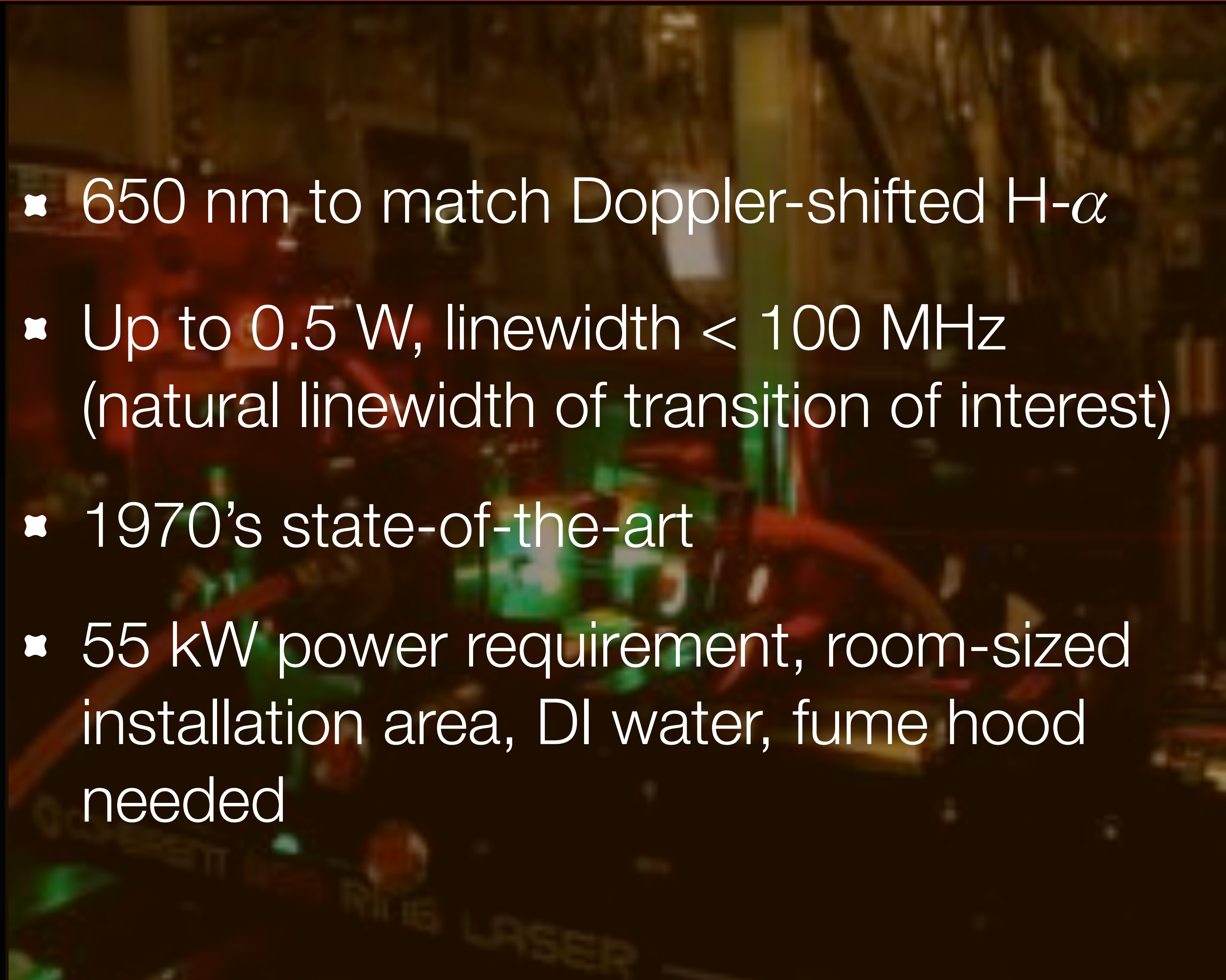
Ring Dye Laser

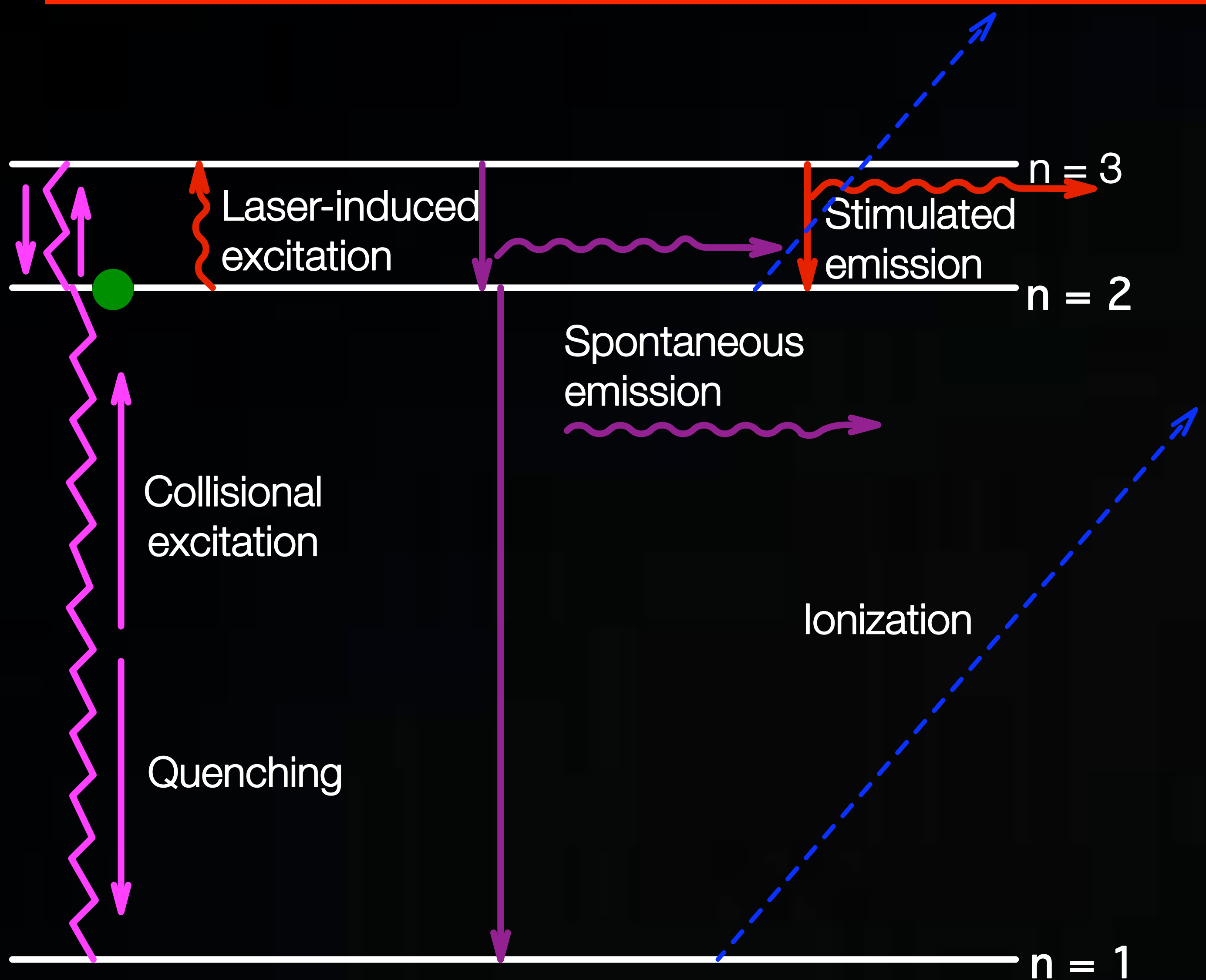


- 650 nm to match Doppler-shifted H-α
- Up to 0.5 W, linewidth < 100 MHz (natural linewidth of transition of interest)
- 1970's state-of-the-art
- 55 kW power requirement, room-sized installation area, DI water, fume hood needed

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

Collisional-Radiative Modeling



- Significant population enhancement in hydrogen plasma as compared to H_2 neutral gas
- Collisional-radiative model developed for H_2 gas as well as H plasma.

Extensive Laboratory Studies

- 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

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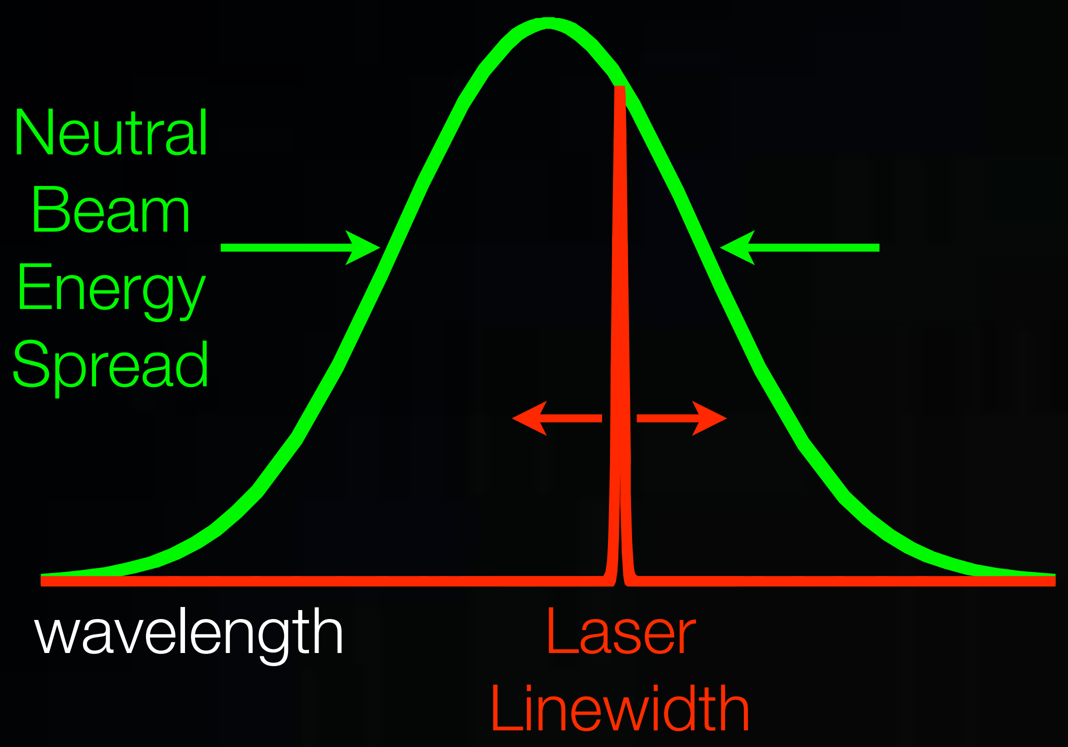
Beam Energy Variation: Effective Linewidth Increase



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 ~25 V (~1.5 GHz)
- Measured ~40 V (~2.5 GHz)
- Expect additional effect of same order in plasma: Final width ~5–7 GHz

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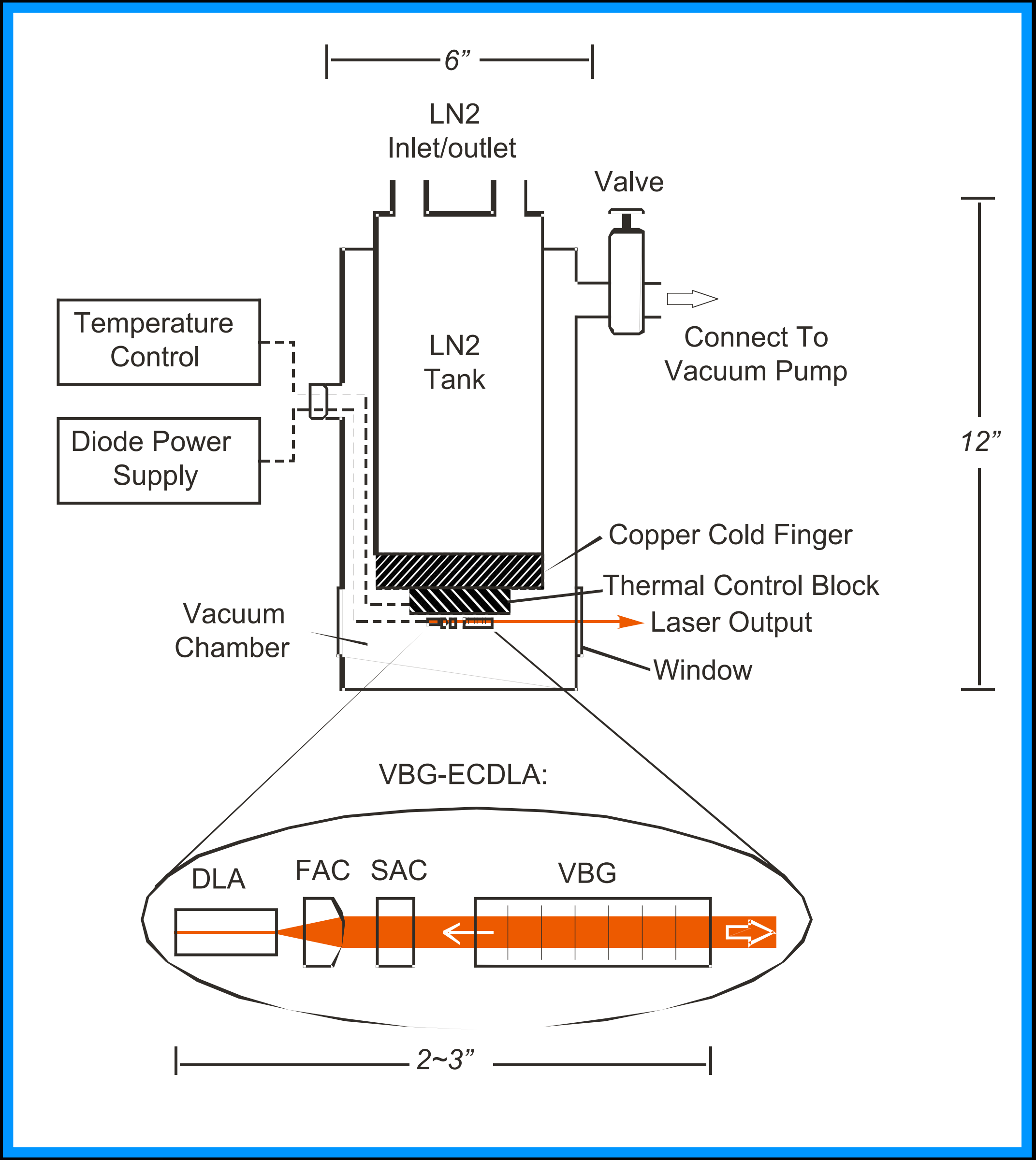
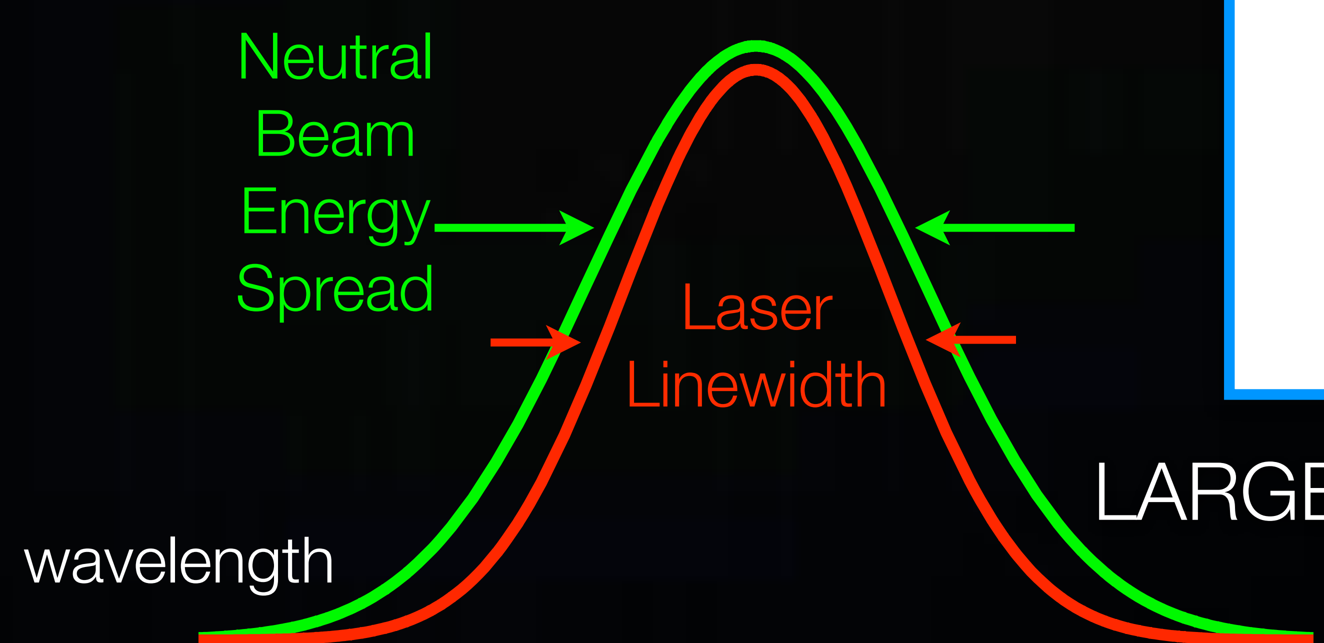
Solution: New Laser

- >10 W, 5–7 GHz linewidth (VBG narrowed), CW laser at 651 nm
- Diode laser array, 680 nm shifted to desired wavelength through cooling with LN2
- Order placed with Directed Energy Solutions. 7 to 9 month lead time





LARGE OVERLAP: LARGE SIGNAL

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Projected MSE-LIF Performance on NSTX

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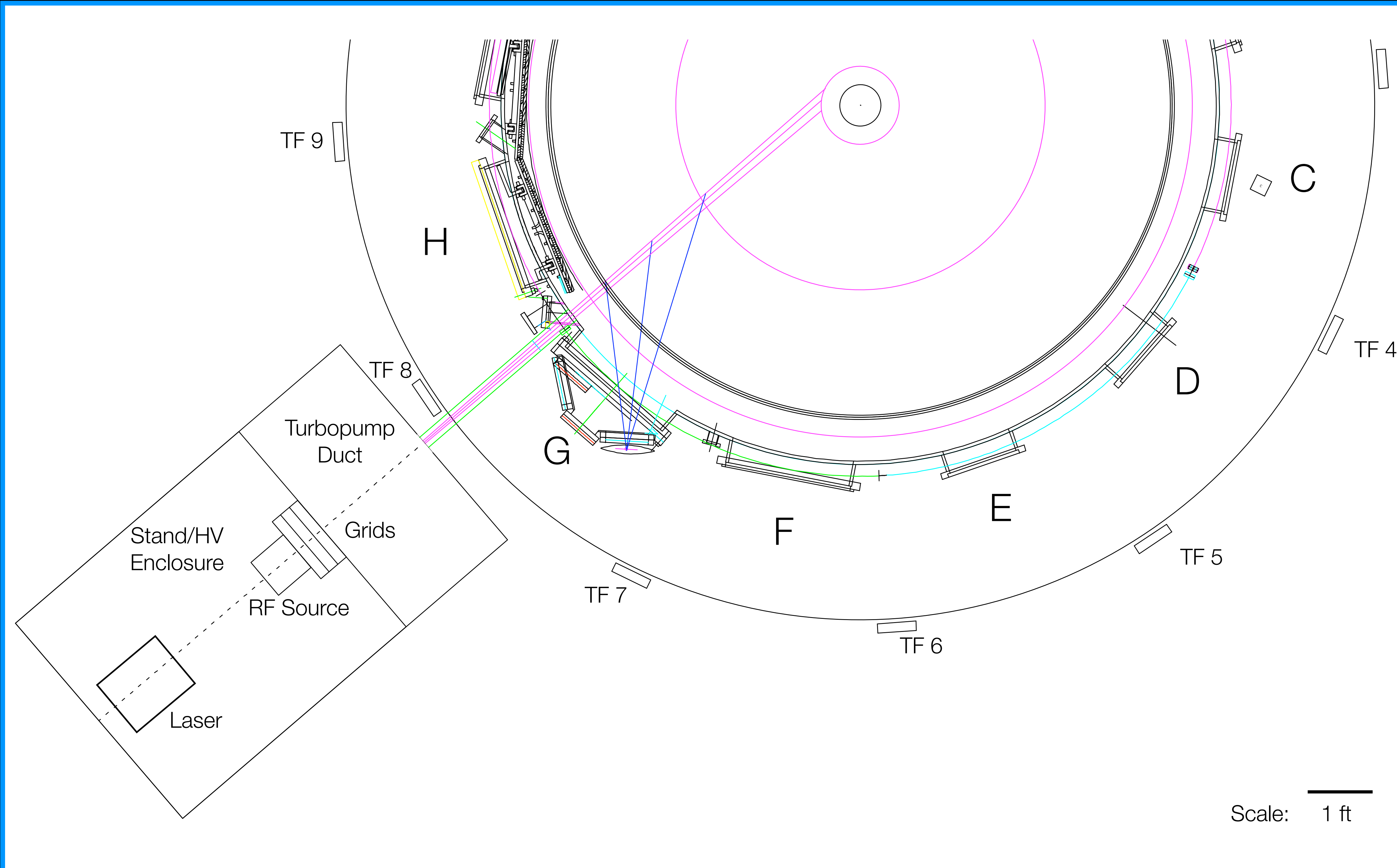
NSTX Layout



TF 9
H
C
TF 4
D
TF 8
Turbopump
Duct
G
Stand/HV
Enclosure
Grids
RF Source
Laser
TF 7
F
E
TF 5
TF 6
Scale:
1 ft

MSE-CIF Provides Reference Data for LIF

- CRM for H_2 gas and H plasma benchmarked using NSTX CIF data in gas, plasma
- Photon count rates used to predict MSE-LIF time resolution and measurement precision scaled from NSTX CIF system data
- Enables confidence in predictions of NSTX performance

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Signal Comparison

	LIF (DNB)	CIF (NSTX Beam)
Collection lens effective area (cm^2)	314	60
Etendue (cm^2/sr)	0.18	0.04
Filter transmission	90%	4%
Polarimeter efficiency	n/a	27%
Beam current density (mA/ cm^2)	5.7	150
Beam path length (cm)	3	15
% Total MSE emission	10	5
LIF/CIF ratio from CRM	0.25	n/a
Relative signal intensity	7.5	1.0
Measured photo-electron rate	n/a	1.56×10^9
Estimated photo-electron rate	1.1×10^{10}	n/a

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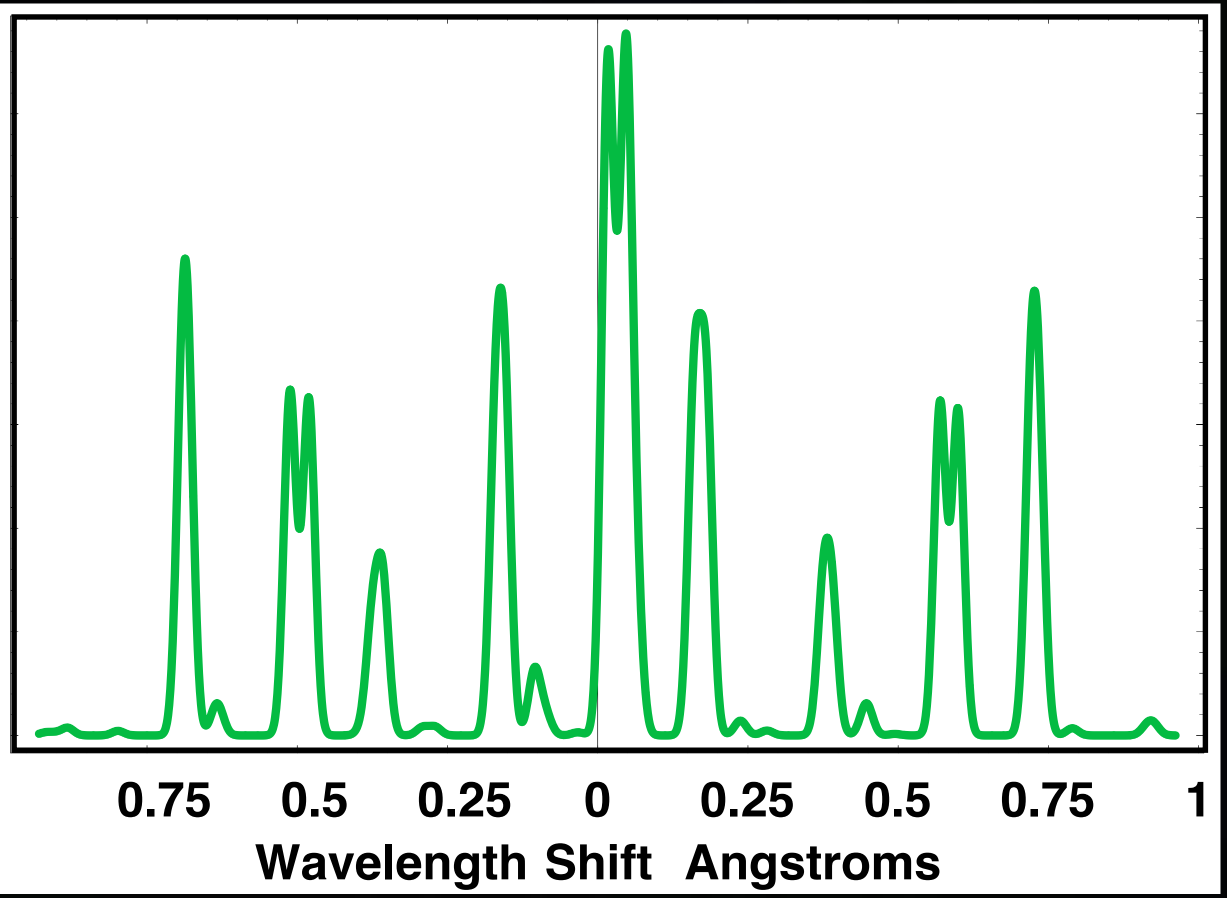
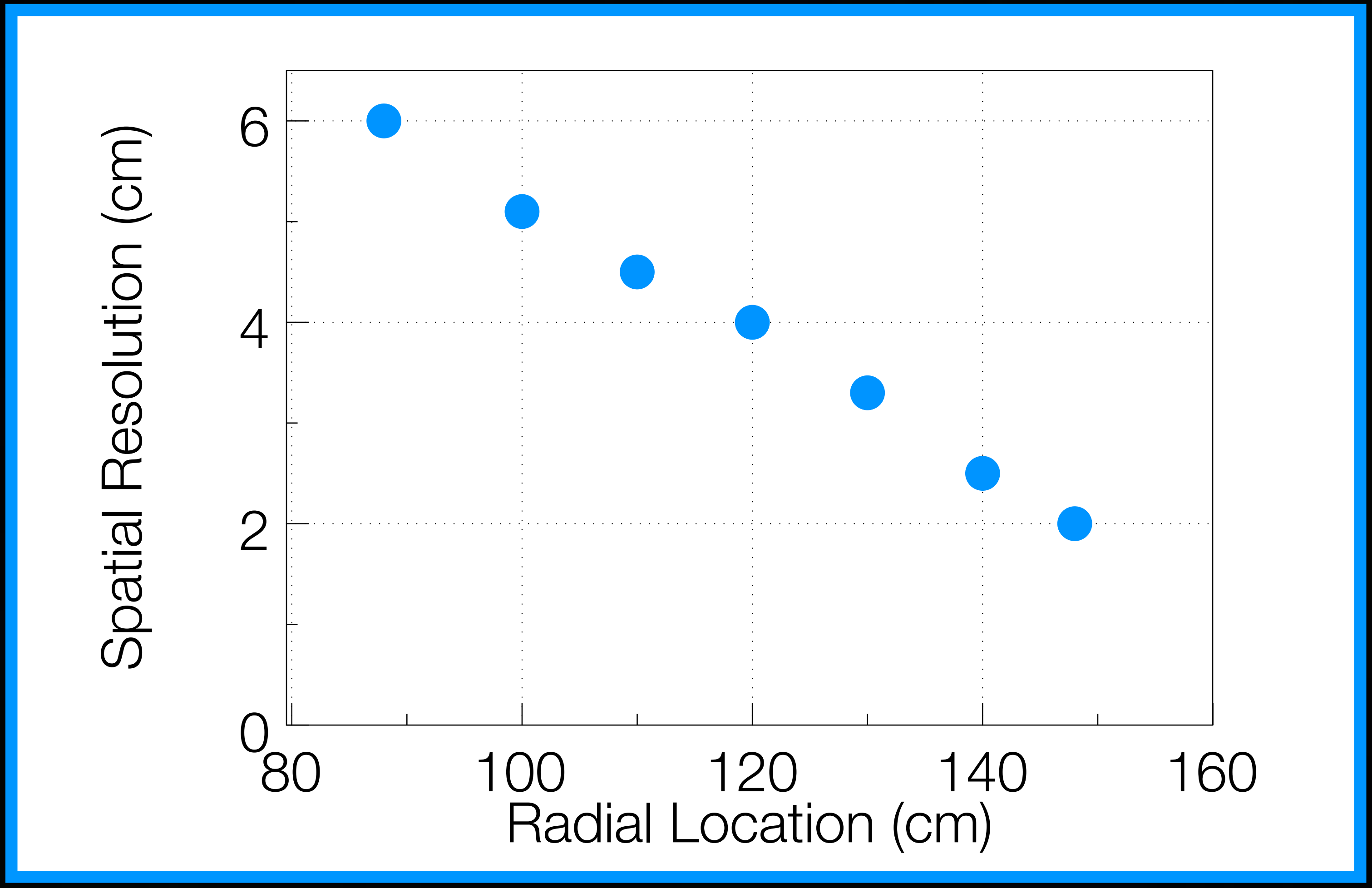
Time and |B| Resolution



- Spectral resolution expected to be sufficient to achieve measurement accuracy ~5 Gauss
- Time resolution at least as good as MSE-CIF 10 ms

Spatial Resolution



- Viewing geometry optimized for throughput

Timeline for Implementation of MSE-LIF on NSTX

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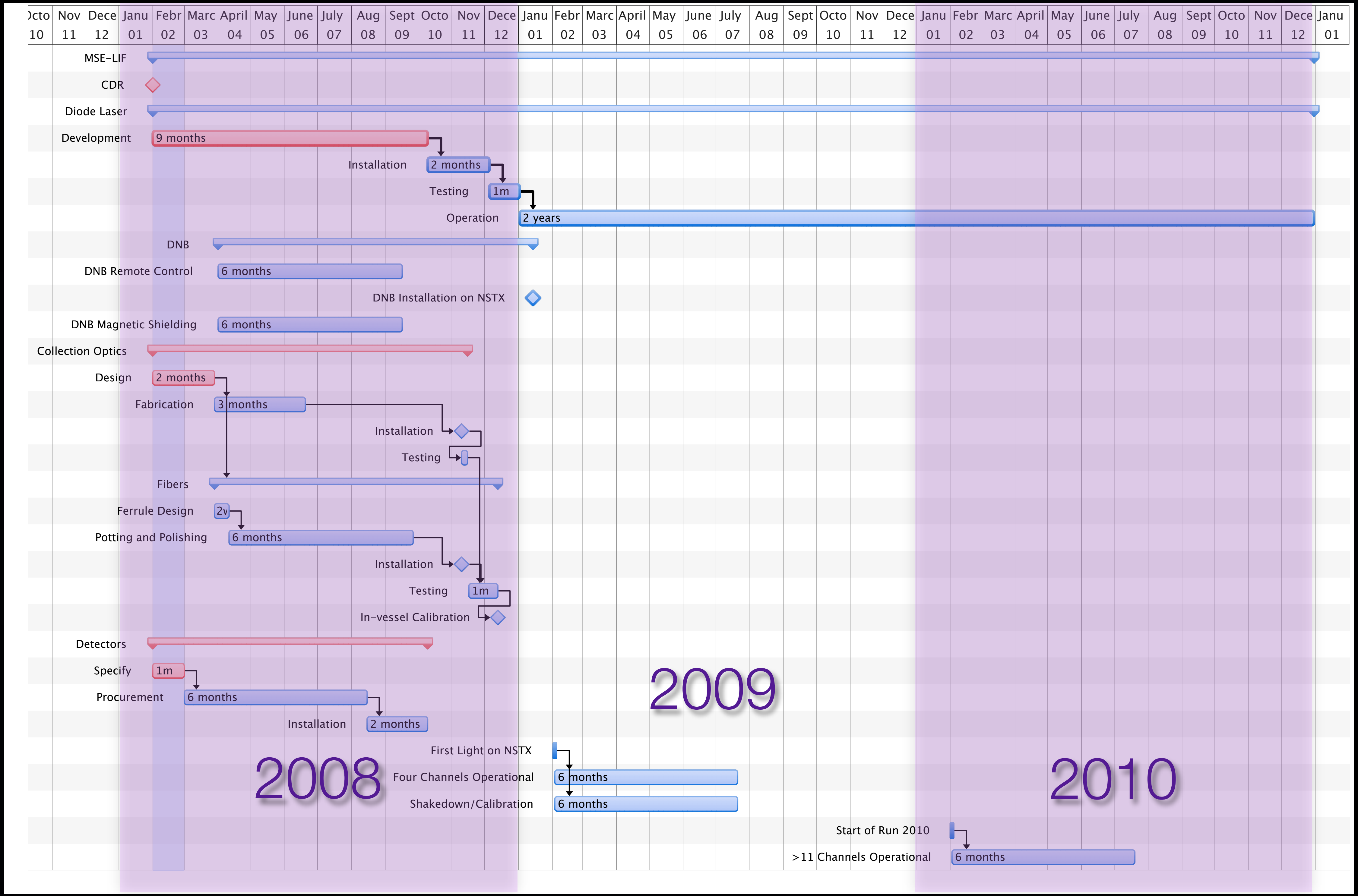
Timeline



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Conclusions

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Conclusions

- Opportunity for MSE data (both pitch angle and |B|) on NSTX in absence of heating beams
- First implementation of |B| measurement with precision appropriate for equilibrium reconstruction: Contribute to pressure, current profiles. Relevance for ITER MSE
- Complementary to MSE-CIF: Distinguish E_r, achieve excellent reconstruction accuracy with both systems
- Data and simulation predict good performance of MSE-LIF on NSTX
- Installation on NSTX during FY09 required for functional diagnostic in FY10

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