A MSE Polarimetry diagnostic for the measurement of radial electric fields on the HSX stellarator

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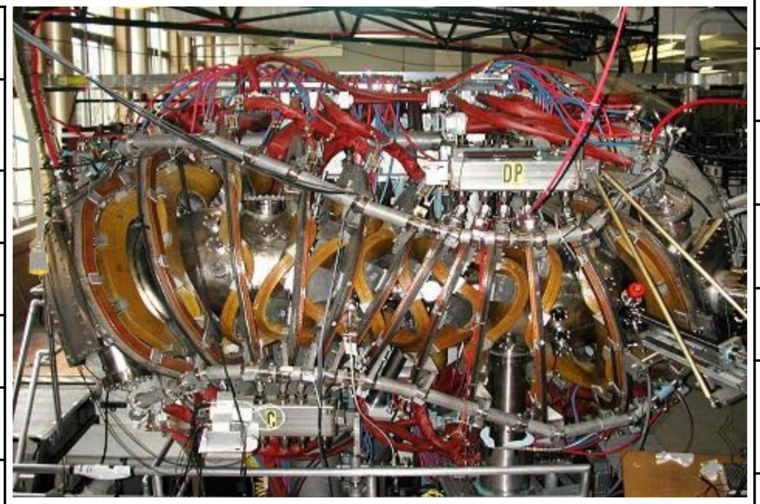
Overview

Abstract

- Neoclassical calculations estimate a large positive radial electric field (40-50 kV/m) near the core of HSX
- Previous impurity ion flow measurements did not measure this large electric field
- A MSE polarimetry diagnostic has been designed for the HSX stellarator to directly measure the radial electric field near the core of the plasma
- Initial results and diagnostic design are presented

HSX & Beam Parameters

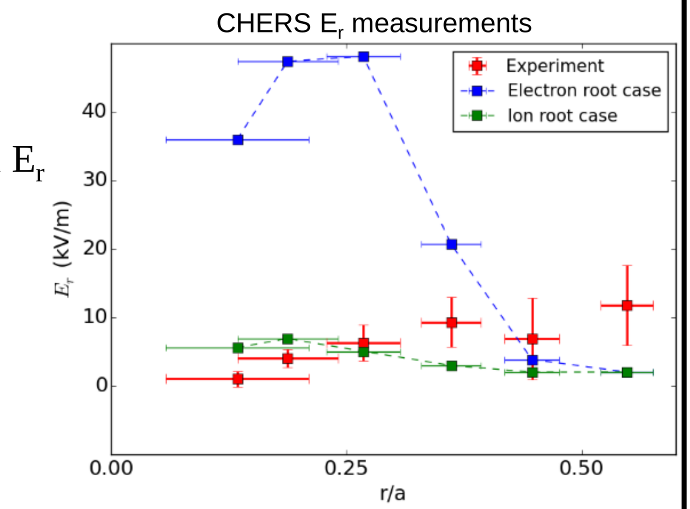
HSX	
<R>	1.2 m
<a>	.12 m
<n_e>	1-4*10^{18}/m^3
T_e	0.5-2.5 keV
T_i	30-60 eV
B_0	1 T
ι	1.05-1.12

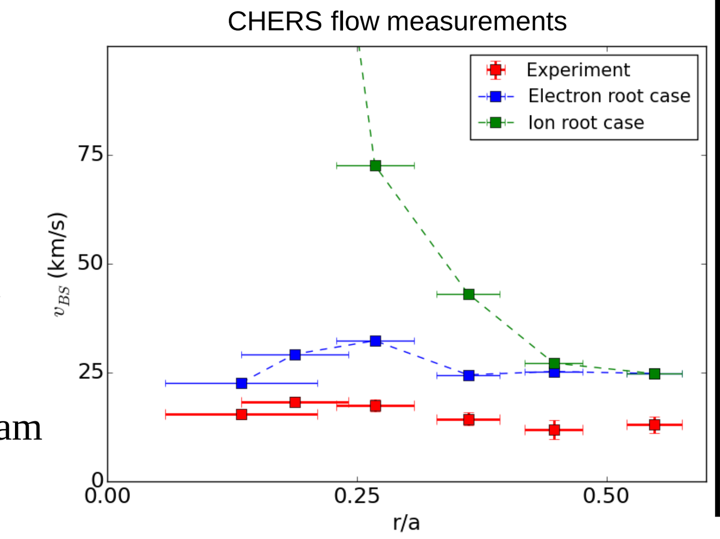


HSX Neutral Beam[1]	
E_b	30 keV
I_b	4 A
Time	3 ms
Species	Hydrogen
Full energy component	~80-90%
Beam radius	~1.5 cm

Motivation: Radial Electric Field on HSX

- Neoclassical modeling with the PENTA code[2,3] indicates a large positive radial electric field in the core
- A CHERS diagnostic has been used to measure flows and E_r
  - Compared to PENTA calculations
- Flows and E_r do not match PENTA calculations
  - Flows below, but comparable, to electron root solution
  - E_r nearer to the ion root solution
  - Work is in progress to resolve the discrepancy
- See S.T.A. Kumar poster for more details on CHERS measurements



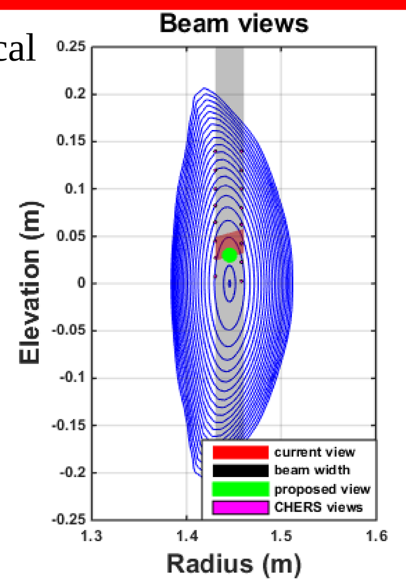


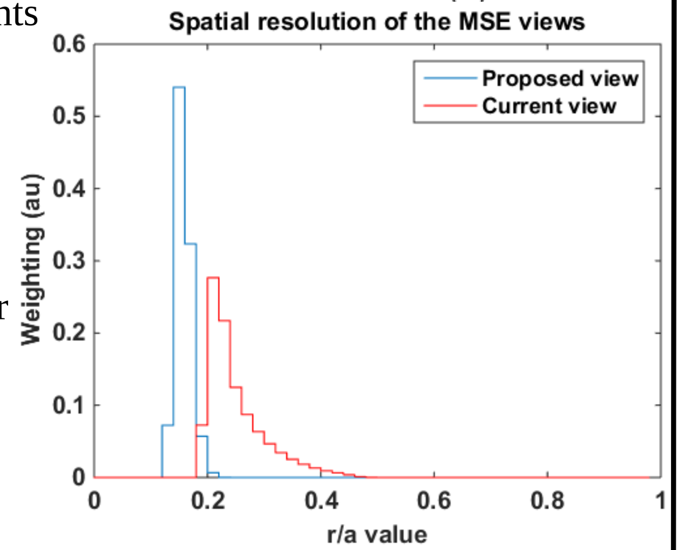
- The MSE system was built to help resolve this problem
  - Make measurements in H, He, CH_4 plasmas
- MSE measures the angle of the electric field felt by beam particles
  - $\vec{E}_{tot} = \vec{E}_{vxB} + \vec{E}_r$
  - The resulting polarization angle is $\tan\gamma = \frac{\vec{E}_{new}\cdot\hat{y}}{\vec{E}_{new}\cdot\hat{z}}$

MSE Synthetic Diagnostic

Beam Model

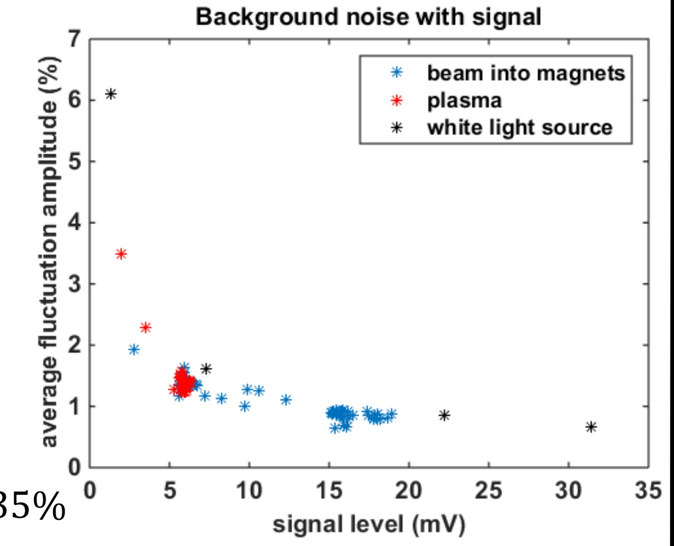
- There is up to 50% difference between the sightline averaged and focal point values of quantities of interest
  - Developed a synthetic diagnostic to compare experimental results with calculations[4]
- For a given view, the model provides what the measured change in polarization angle, γ, would be for a calculated $\vec{E}_r$ profile
  - Also calculates the spread in γ values with and without $\vec{E}_r$
  - Spatial resolution calculated
  - Expected signal level calculated
  - Used to optimize the view for MSE measurements
- Works by discretizing the beam along sightline
  - Each point is weighted by beam density profile, solid angle effects, plasma density, etc.
- The model is also applied to the CHERS Pfirsch-Schlüter measurements to calculate the sightline averaged PS factor, radial electric field, and parallel flows





MSE Measurement Uncertainty

- The uncertainty in E_r comes from the resolution and uncertainty in angle: $\sigma_{E_r} = \frac{\Delta E_r}{\Delta\gamma(°)}\sigma_{\gamma(°)}$
- $\sigma_{\gamma(°)} = \frac{1}{2}\frac{180°}{\pi}\frac{|A_{2f1}*A_{2f2}|}{A_{2f1}^2+A_{2f2}^2}\left[\left(\frac{\sigma_{2f1}}{A_{2f1}}\right)^2+\left(\frac{\sigma_{2f2}}{A_{2f2}}\right)^2\right]^{1/2}$
  - A_i are the modulation amplitudes of the harmonics
- The uncertainty comes mainly from background noise
  - Therefore $\sigma_{2f1} \approx \sigma_{2f2}$
- $\sigma_{\gamma(°)} = \frac{1}{2}\frac{180°}{\pi}\frac{\sigma_{amp}}{A_{tot}}$
  - $A_{tot} = [A_{2f1}^2 + A_{2f2}^2]^{1/2}$
  - Therefore for .1° uncertainty would need $\frac{\sigma_{amp}}{A_{tot}} = .35\%$
- Finally: $\sigma_{E_r} = \frac{\Delta E_r}{\Delta\gamma(°)}\frac{1}{2}\frac{180°}{\pi}\frac{\sigma_{amp}}{A_{tot}}$
- Factors leading to the uncertainty:
  - A_{tot}: depends on filter width and atomic physics, view dependent
  - $\frac{\Delta E_r}{\Delta\gamma(°)}$: depends on the viewing angle relative to the electric field direction
  - σ_{2fi}: Background noise scales like 1/signal$^{1/2}$
- All these factors are calculated by the model or are directly measured
  - This was used to find an optimal viewing location with the lowest σ_{E_r}



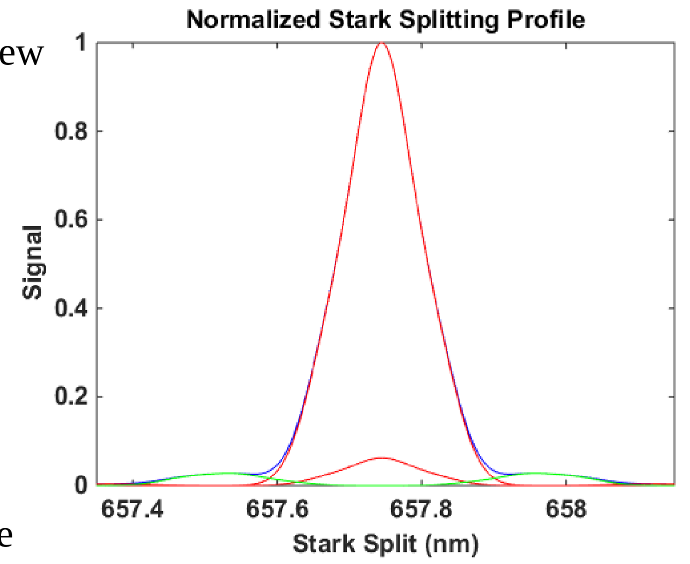
Experimental Results

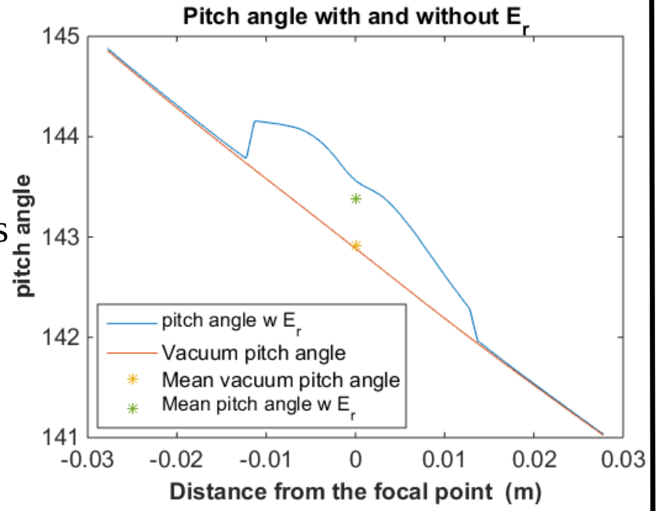
Current view

- Current view is a modified CHERS view
  - Not optimized for MSE measurements

Limitations of the view:

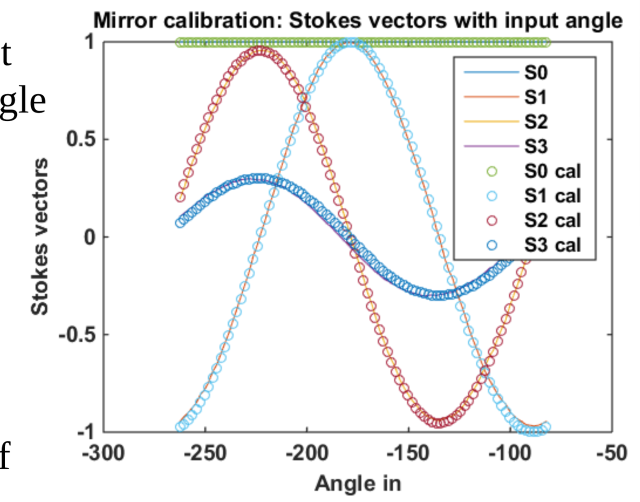
- Very small polarization fraction
  - Looks along $\vec{E}_{tot}$ direction
    - Most light is not polarized
  - Very small modulation amplitude A_{tot} ~2.5%
- Low signal level
  - SNR is poor
- Poloidal view and large beam width leads to poor core resolution
  - Large spread in polarization angle
  - Samples high and low electric field regions





MSE Results & Calibrations

- Measurements of angle have been made
  - Uncertainty too large for useful measurement of $\vec{E}_r$
- Beam into gas measurements of polarization angle is a few degrees from to modeled value
  - Offset angle from misalignment of the optics from the model and Faraday rotation in the optics
  - Accurate offset angle needed for measurements of E_r
- Calibrations of the system have been made
  - Linearly polarized light was input into the system and the output angle was calculated
  - The relative gains and polarizer angle have been measured
- Calibration of a mirror has also been completed
  - The reflectivity and phase shift of the mirror were calculated

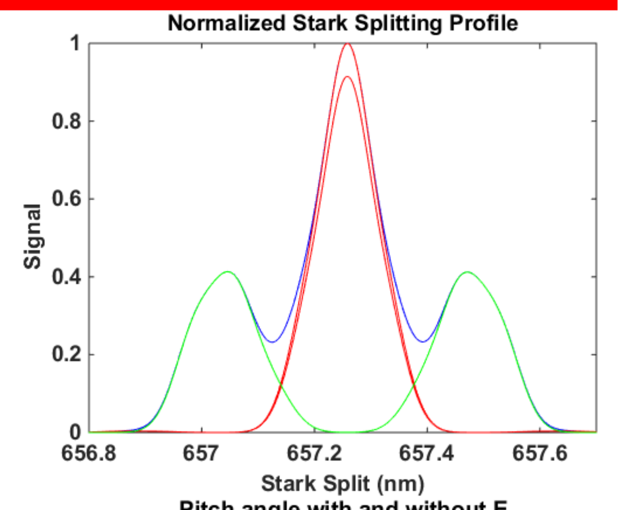


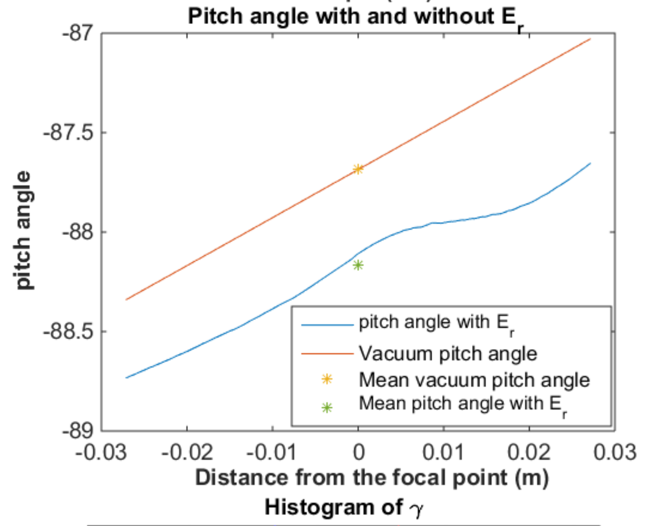
Proposed View

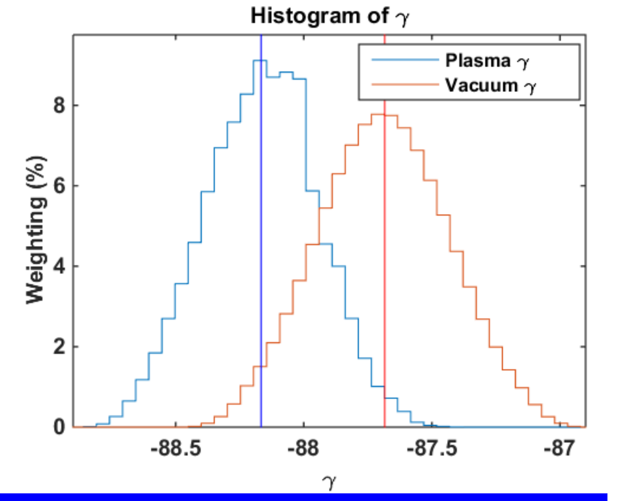
- A new optimized view has been selected
  - Optics design is in progress
- The new view requires a mirror
  - Mirror calibration has been completed on a test mirror

Advantages of the new view:

- Nearer to the beam
  - ~10 more signal expected= better SNR
- Looks ~perpendicular to $\vec{E}_{tot}$ direction
  - A_{tot} increases~10x (to ~25%)
  - Most light is linearly polarized
  - A_{tot} is limited by filter width
- Better special resolution
  - Toroidal view instead of poloidal view
  - Much less spread in polarization angle
    - Spread decreased by factor of 2
- Electric field magnitude and direction ~ constant in the viewing volume
  - Almost constant change in angle with E_r throughout the view







Summary

- An MSE system is being built to measure E_r on HSX
- The MSE system has been tested on an available view.
  - Initial results and calibration have been completed
- The optics for the dedicated MSE port is in development

References

[1] G. F. Abdrashitov, et al., Review of Scientific Instruments,72 (2001)

[2] D.A. Spong, *Phys. Plasmas* 12 (2005) 056114;

[3] J. Lore at al., *Phys. Plasmas* 17 (2010) 056101

[4] T. J. Dobbins, Review of Scientific Instruments, 87, (2016)

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