PP9.00011: The design and status of a ChERS diagnostic for LTX

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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Abstract

There has been a long-standing collaboration between ORNL and PPPL in the area of edge and boundary layer plasma physics. As part of this collaboration, ORNL has a large role in the instrumentation and interpretation of the edge physics in the Lithium Tokamak Experiment (LTX). In particular, a charge-exchange recombination spectroscopy (ChERS) diagnostic is being designed and is undergoing a staged implementation on LTX. This year passive spectroscopy measurements have been made on LTX, in anticipation of active spectroscopy measurements, which will be enabled by the installation of a diagnostic neutral beam in 2012. The LTX ChERS diagnostic will consist of both toroidal and poloidal lines of sight, allowing for profile measurements of all the plasma parameters (T_i, n_{Li}, v_P, v_T) required for the calculation via force balance of the radial electric field profile (E_r), when combined with the magnetic field profile from equilibrium reconstructions. The effect of lithium on the E_r profile, as well as the fundamental plasma parameters, is a major topic of interest for LTX and the plasma physics community. Preliminary data will be presented.

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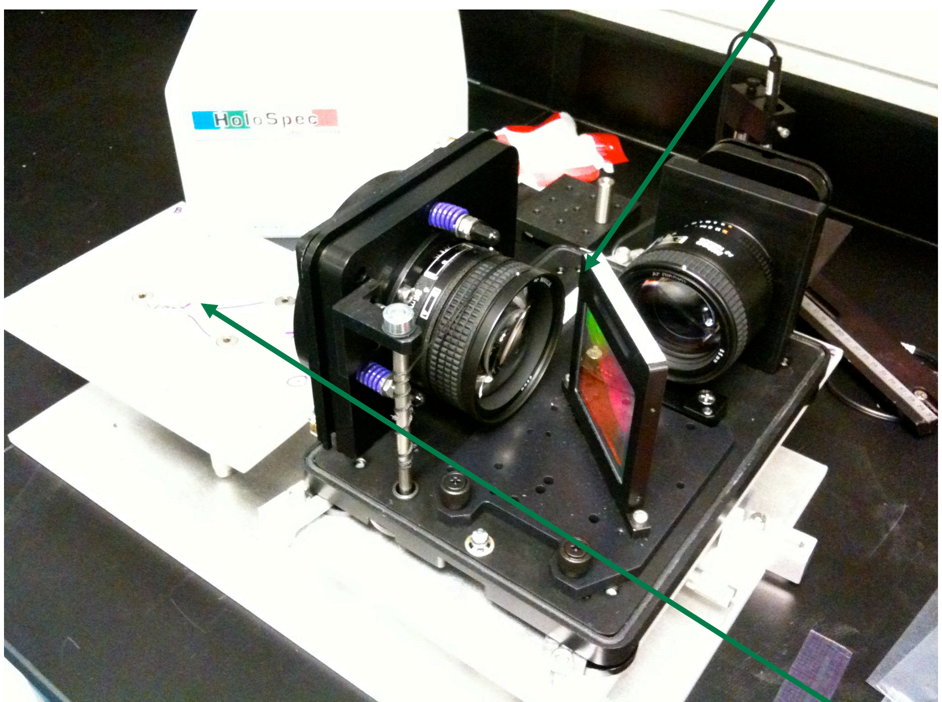
Staged Implementation Strategy

- Proposal awarded for 3 years of effort
- FY2011: Passive Spectroscopy
  - Install temporary optics and utilize available equipment to make preliminary measurements

Main subject of this Poster.

- FY2012: Active Spectroscopy
  - Design and install optics in conjunction with the installation of the neutral beam injection (NBI) system
- FY2013: Optimization and Physics Exploration
  - Purchase and install dedicated hardware for an LTX-optimized ChERS diagnostic

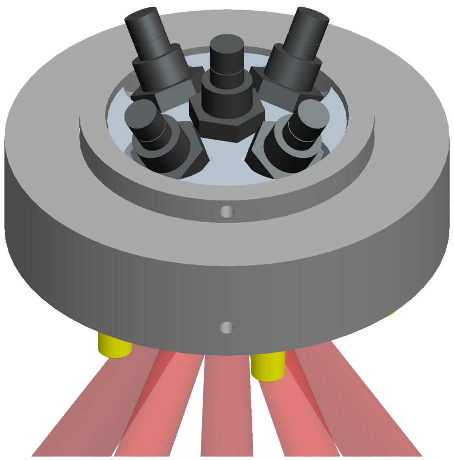
Short Focal Length Spectrometer

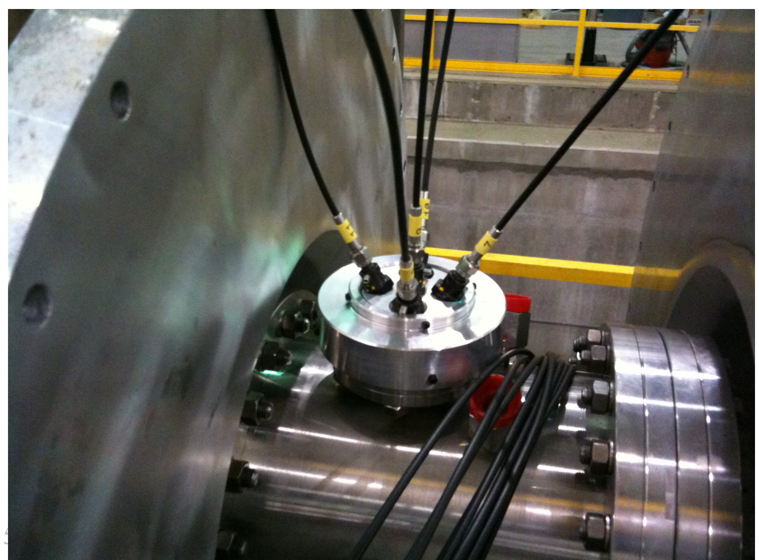


- Kaiser Optical Holospec f/1.8
  - Fixed “HD” grating
  - Curved entrance slits
- mounting plates
- Fiberbundle: 17 channel SMA bundle for HD
  - 600 μm PCS (100 °C), 7 m
- Configuration with above:
  - 10 views: 85 mm exit lens
  - 15 views: 58 mm exit lens
  - 17 views: 50 mm exit lens
  - More views = lower resolution
- BP filter and new bundle can 2x or 3x views (at ½ or 1/3 of the wavelength coverage)
- CCD camera
  - Buy: EMCCD ~$35k or sCMOS ~$20k?

Ref: R.E. Bell, Rev. Sci. Inst. **75**(10): 4 (2004).

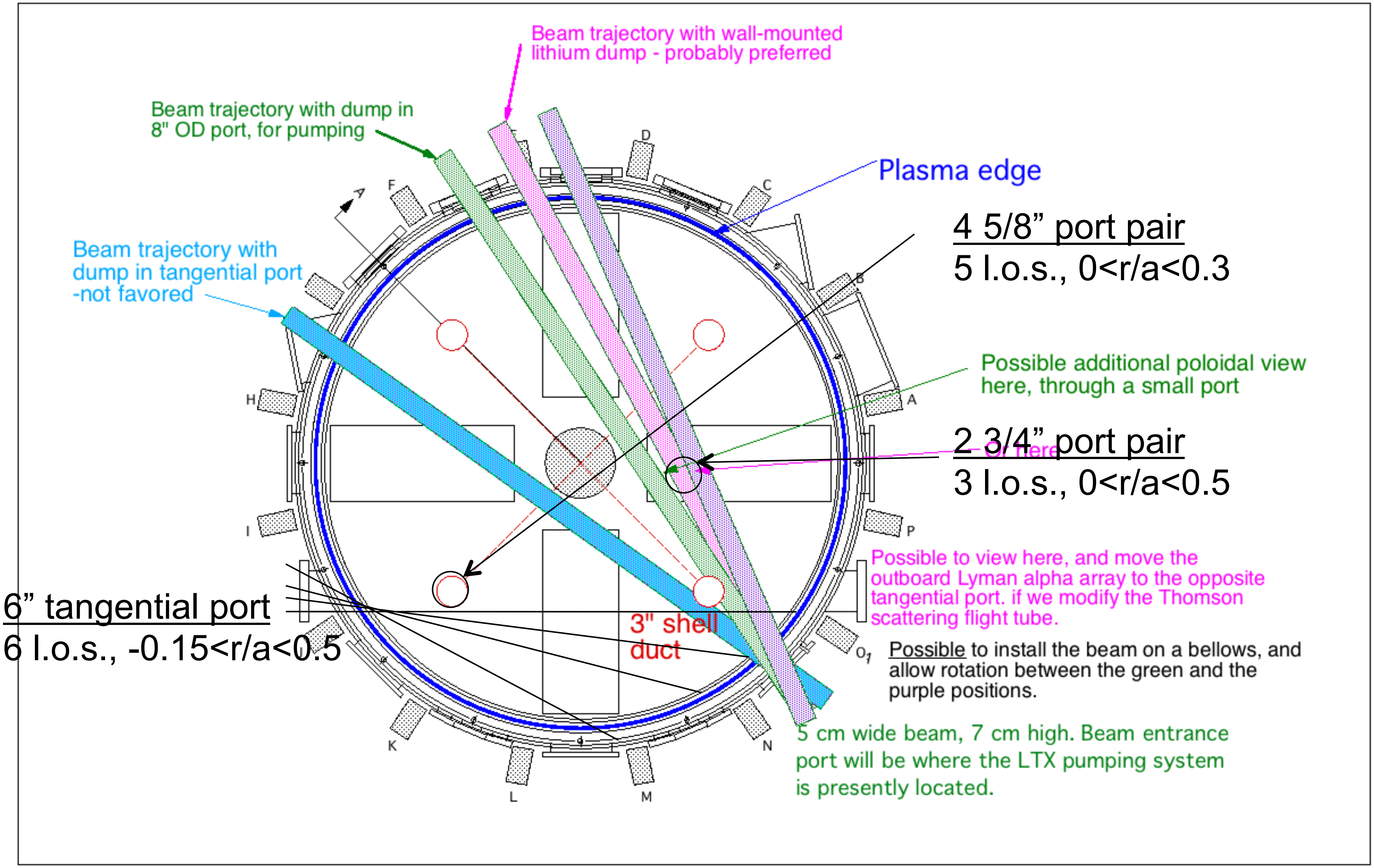
Example Multi-chord Viewing Optics



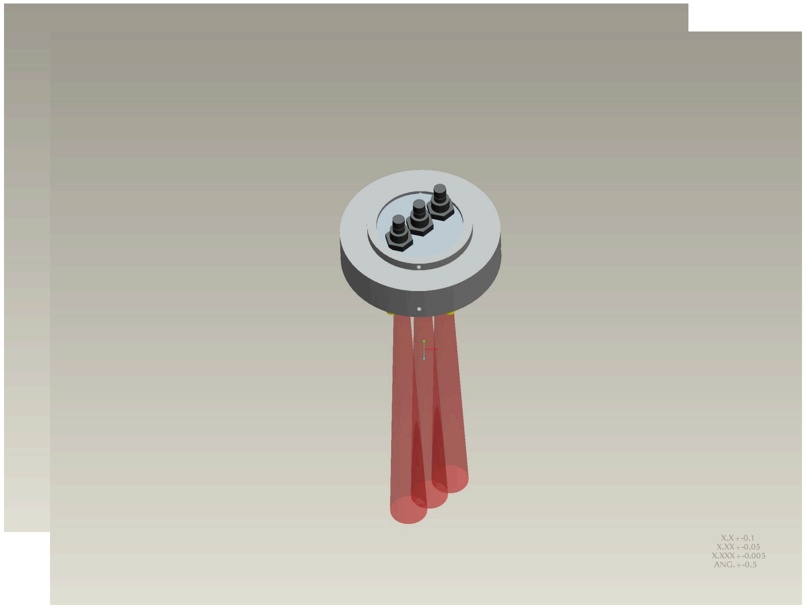


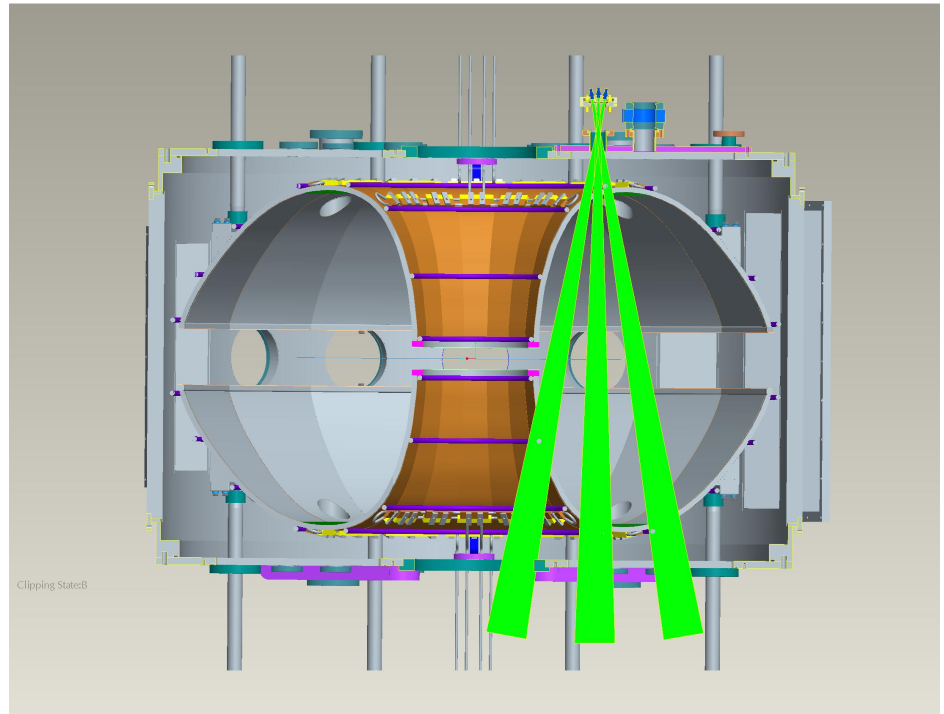
- Collimating (fused silica) lens attaches to fiber (SMA mount).
  - f=10 mm, d=5mm: f/2 acromat
  - Ocean Optics 74-ACR
- Pucks positioned at multiple locations with mounting collars.
- Designed to fit standard size vacuum windows: 2-3/4”, 4-5/8”, 6”, . . .
- Note: windows need to have cap head bolts, NOT hex-head.

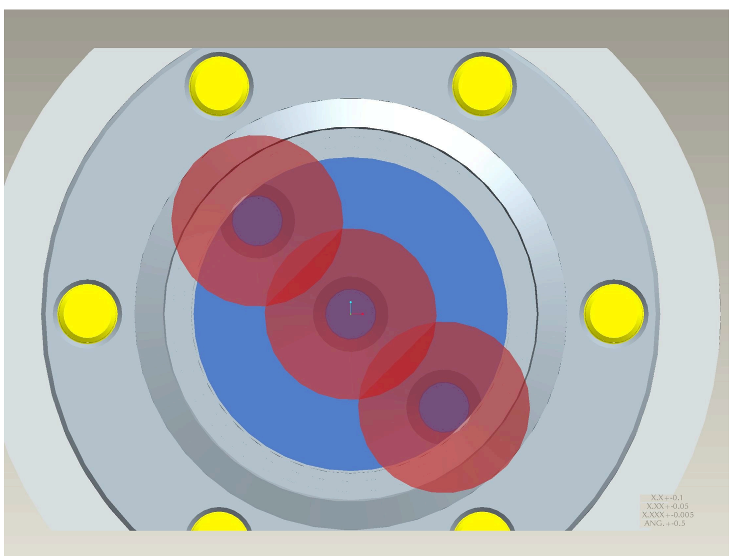
Sightline Layout for Passive Spectroscopy



2 ¾” Puck Detail for Poloidal L.o.S.

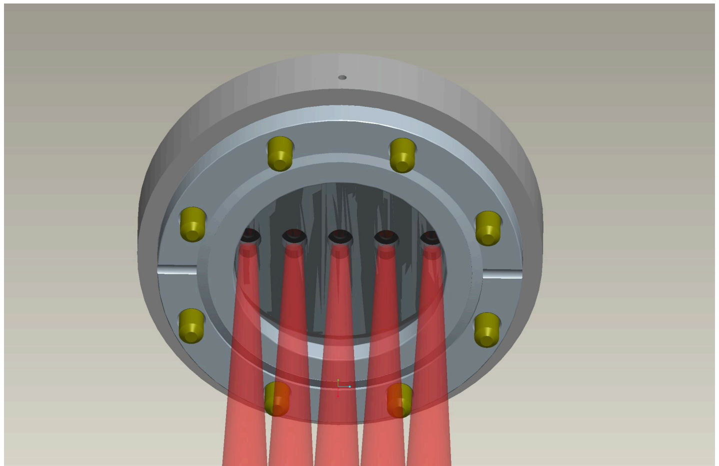


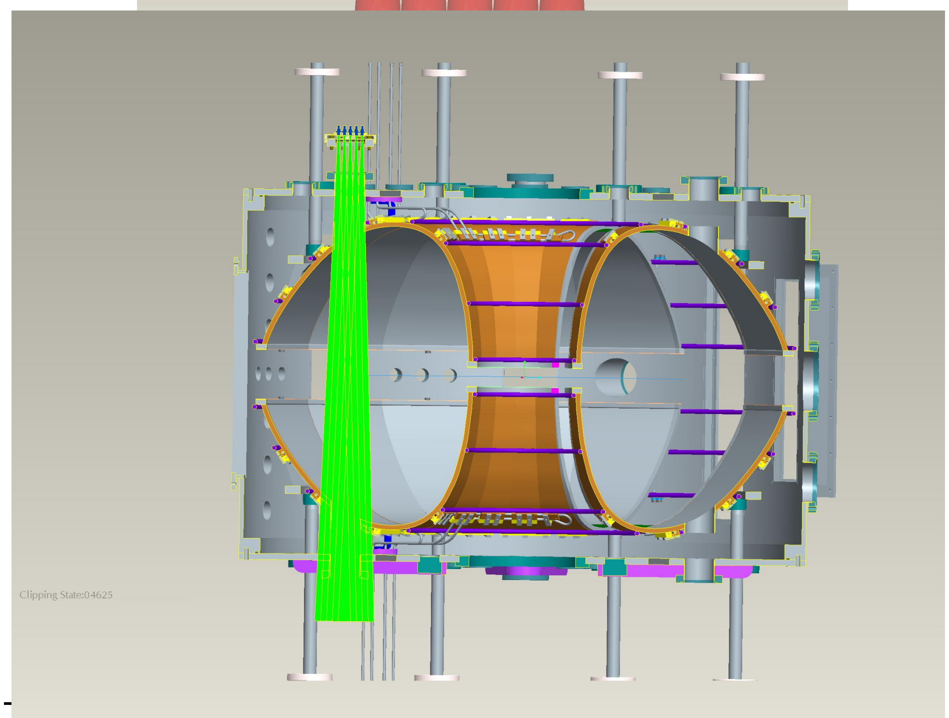




- Original “straight down” concept can be improved by angling outer views
  - Reduce vignetting
  - Expand radial range
  - “Straight” r/a: -0.16, -0.22, -0.28
  - “Angled” r/a: 0.02, -0.22, -0.46

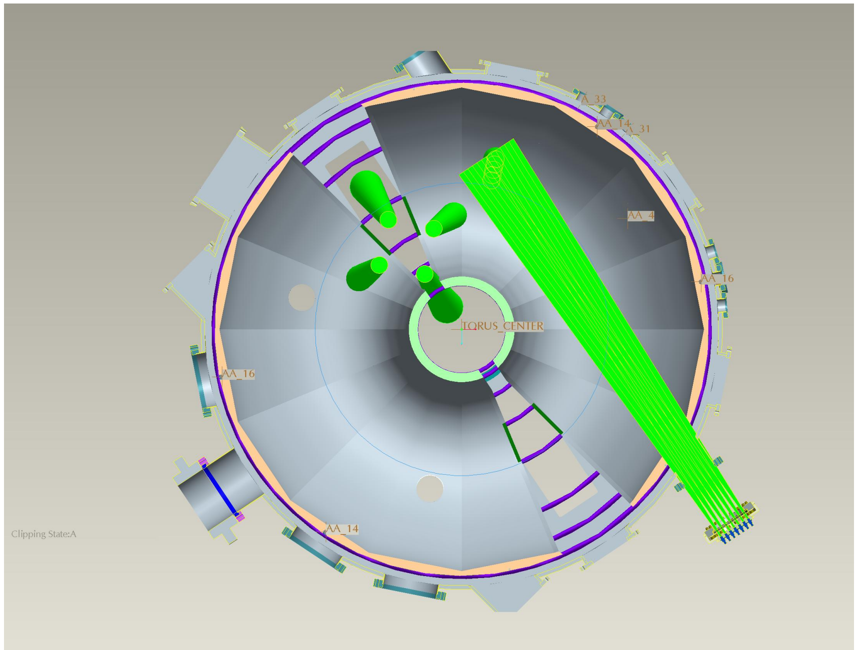
4 5/8" Puck Detail for Poloidal L.o.S.

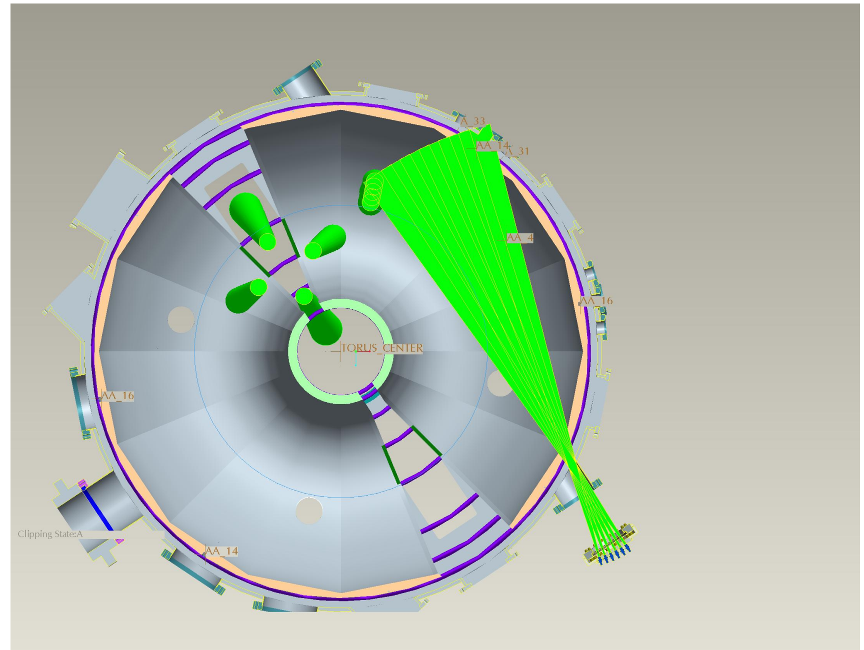




- This port is over a "chimney" in the shell.
- Large stand-off between window and chimney means little advantage to "angling" l-o-s.
- Vignetting of outer 2 l-o-s.
- r/a: 0.06, 0.12, 0.17, 0.23, 0.29

6” Puck Detail for Toroidal L.o.S.

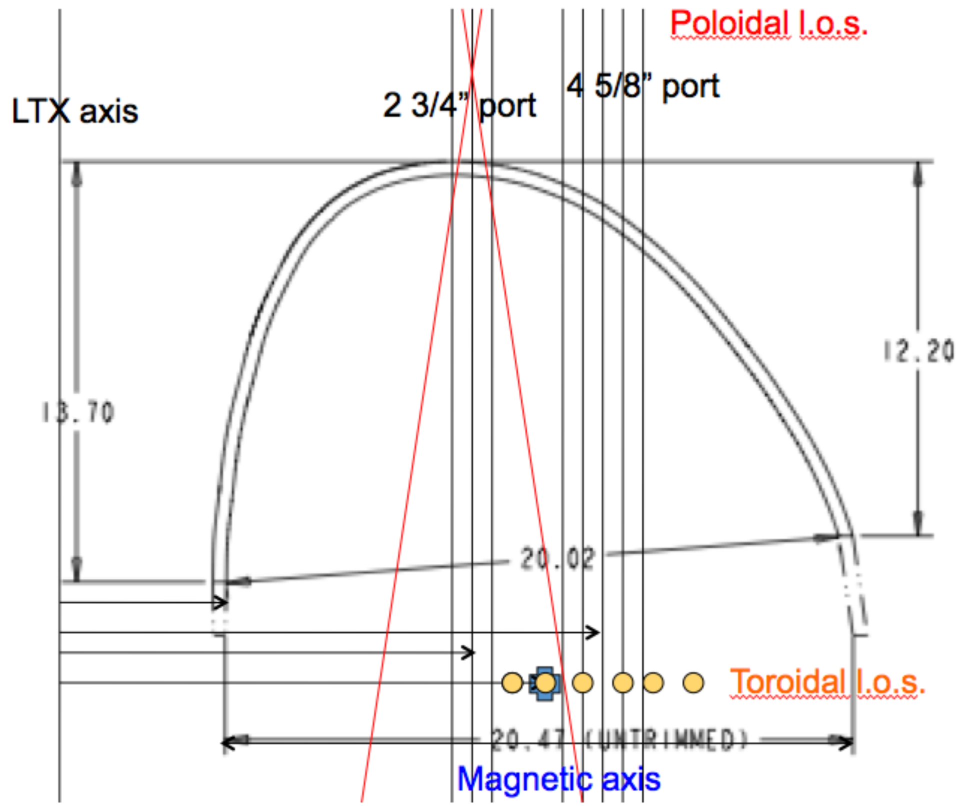




- Original “straight through” concept has sightlines inboard of magnetic axis; difficult to invert passive data
  - “Straight” r/a: -0.15, -0.20, -0.26,-0.32, -0.37, -0.43, -0.49
- Radial coverage shifted to outboard side by angling views
  - “Angled” r/a: -0.11, 0, 0.11, 0.27, 0.37, 0.48

Passive Spectroscopy Sightline Summary

- 2 ¾" port pair:
  - 3 poloidal sightline pairs
    - r/a: ~0, -0.22, ~-0.46
- 4 5/8" port pair:
  - 5 poloidal sightline pairs
    - r/a: 0.06, 0.12, 0.17, 0.23, 0.29
- 6" tangential port w/ gate valve:
  - 6 toroidal sightlines
    - r/a: -0.11, 0.0, 0.11, 0.27, 0.37, 0.48



- Toroidal and Poloidal coverage from 0<|r/a|<0.5
  - Sufficient to estimate light levels.
  - Can we also get some physics data?
    - Depends on $n_{Li\ 2+}$ profile (see following slides)

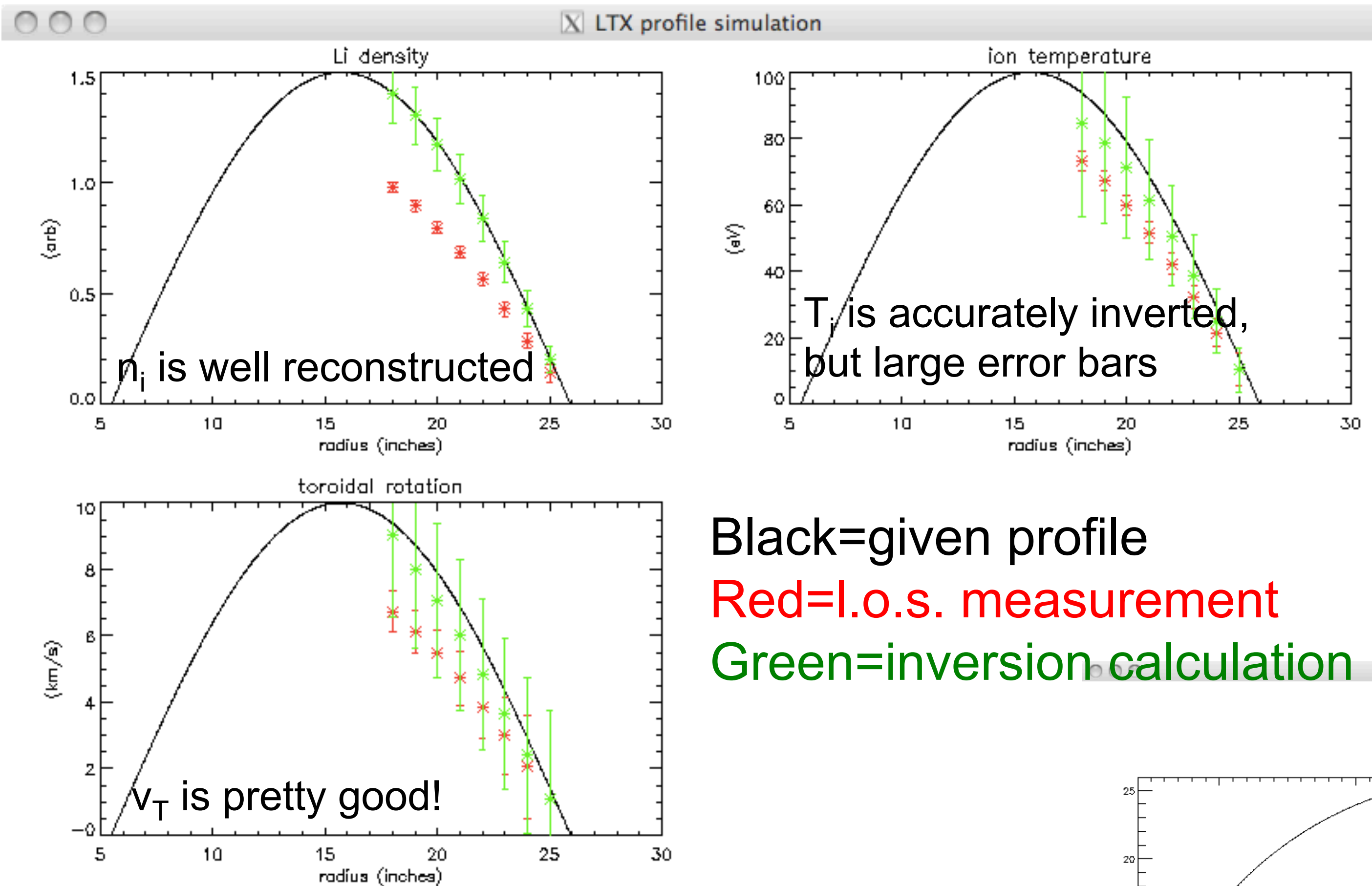
Equipment List and Cost Estimate

- Collection optics
  - Pucks & collars: ~$2k
  - Acromat lenses: ~$2.2k
- Fiberbundle: borrow from ORNL (~$4k)
- Spectrometer and detector
  - Slits (75, 150, 250 microns): borrow from ORNL (~$3k)
  - Spectrometer: borrow from ORNL (~$6.4k)
  - Gratings: borrow from ORNL, PPPL (NSTX) (~$5.7k ea.)
  - Output lens (85 mm= 10 channels): borrow from ORNL (<$500)
  - CCD camera (PI ProEM): borrow from ORNL (~$38k)
  - Plates & mounts: fabricate, ~$500
  - Chopper & electronics: probably not needed (spares at ORNL), ($2k)
- Data acquisition: PC $2k with WinSpec/Lightfield ($4k): borrow ORNL
- Total cost: spent ~$7k (borrowed equipment: ~$65k)

Passive Spectroscopy Simulations

- Code written to simulate (for a given set of Li^{2+} n_i, T_i, v_T profiles), what the measured passive spectra for this spectrometer/camera should look like.
- Additional code fits Gaussian distributions to this "data" to give l.o.s. estimations of the Li n_i, T_i, v_T profiles.
- These "measurements" are inverted to yield local values of Li n_i, T_i, v_T (which can be compared to the given profiles.)
  - R.E. Bell, Rev. Sci. Instrum. 68 (2) 1997, p. 1273.

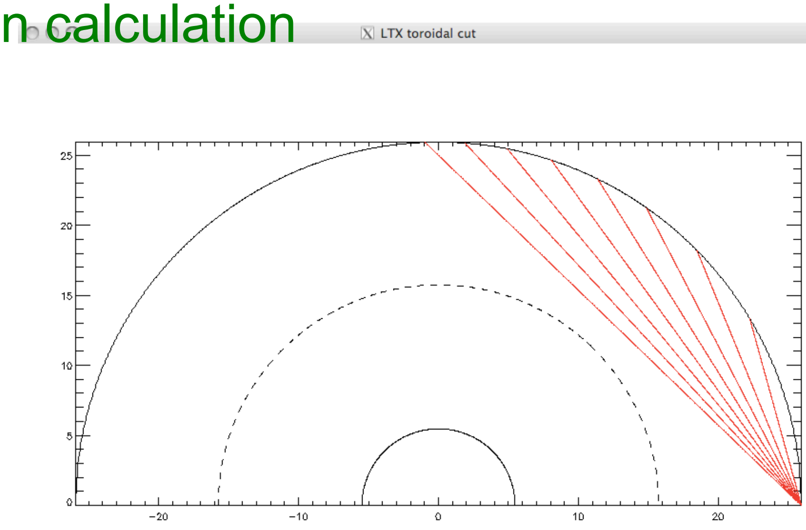
Example 1” Resolution Array, 8 L.o.S.



Black=given profile

Red=l.o.s. measurement

Green=inversion calculation



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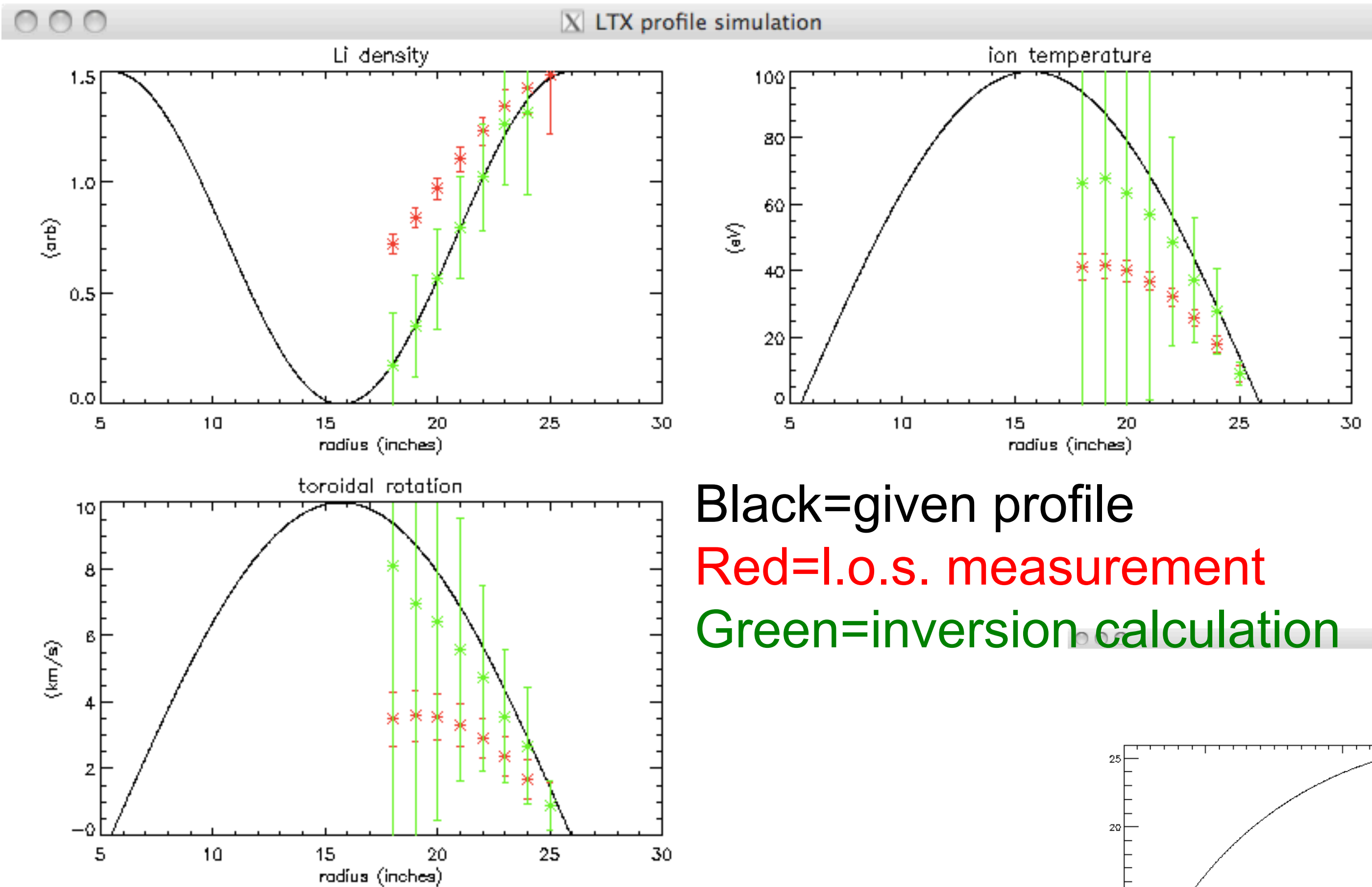
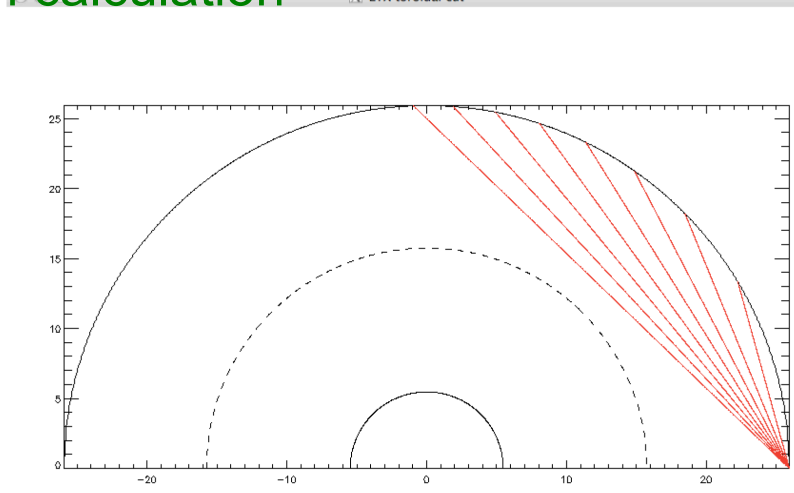
Example 1" Resolution Array is OK Even if n_{Li} is Hollow.



Black=given profile

Red=l.o.s. measurement

Green=inversion calculation



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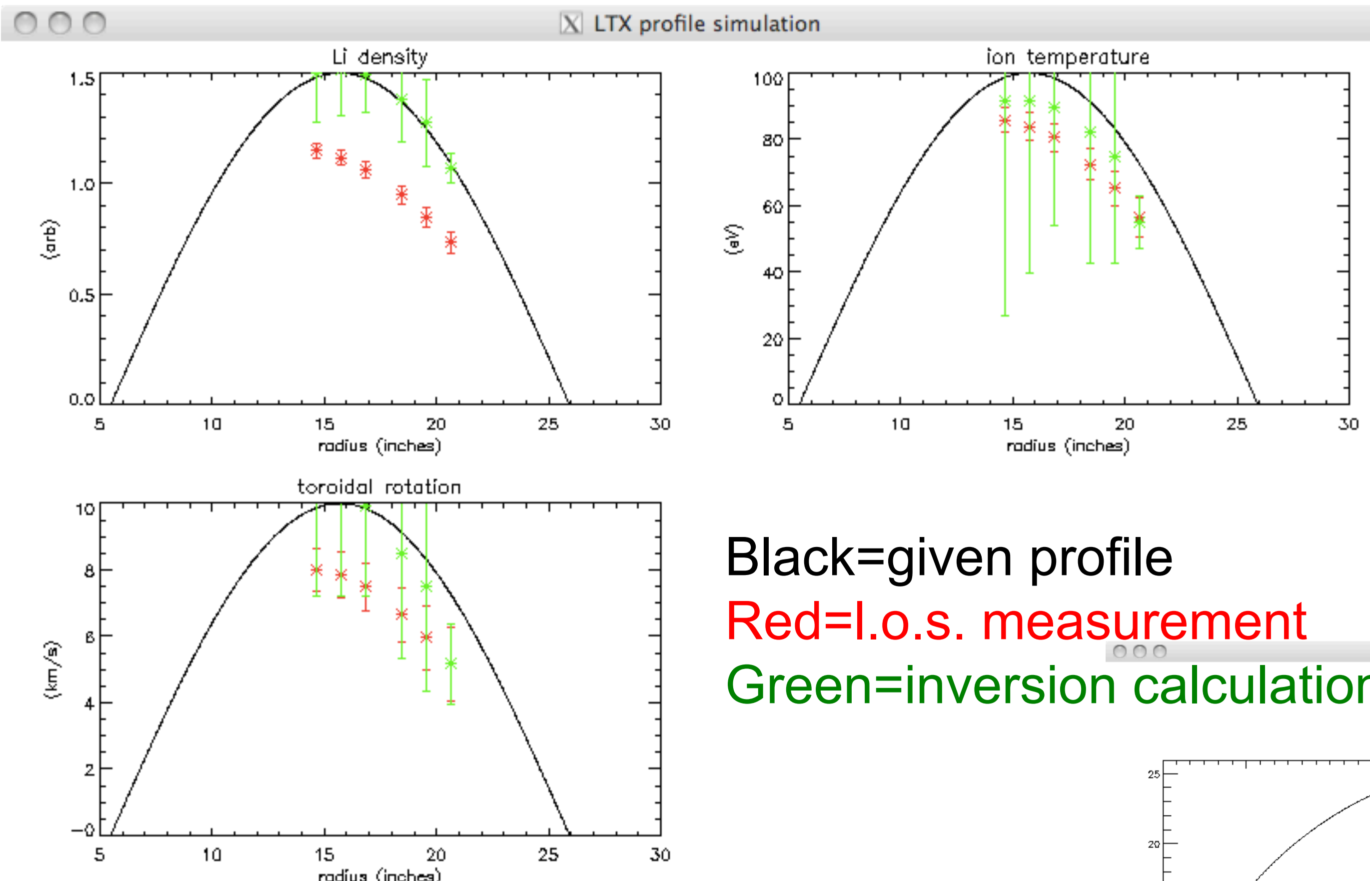
"As Built" Array with Peaked n_{Li} Profile



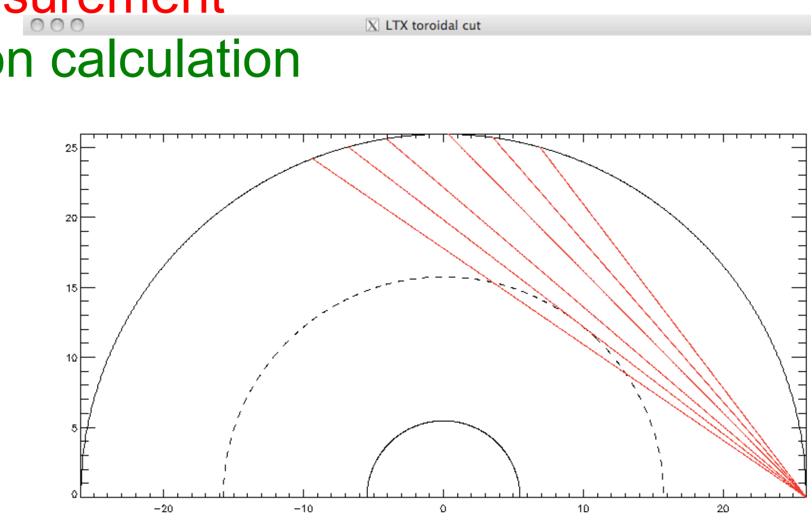
Lack of edge data leads to large error bar and inaccuracy on outer-most chord.

(75 micron instrument function)

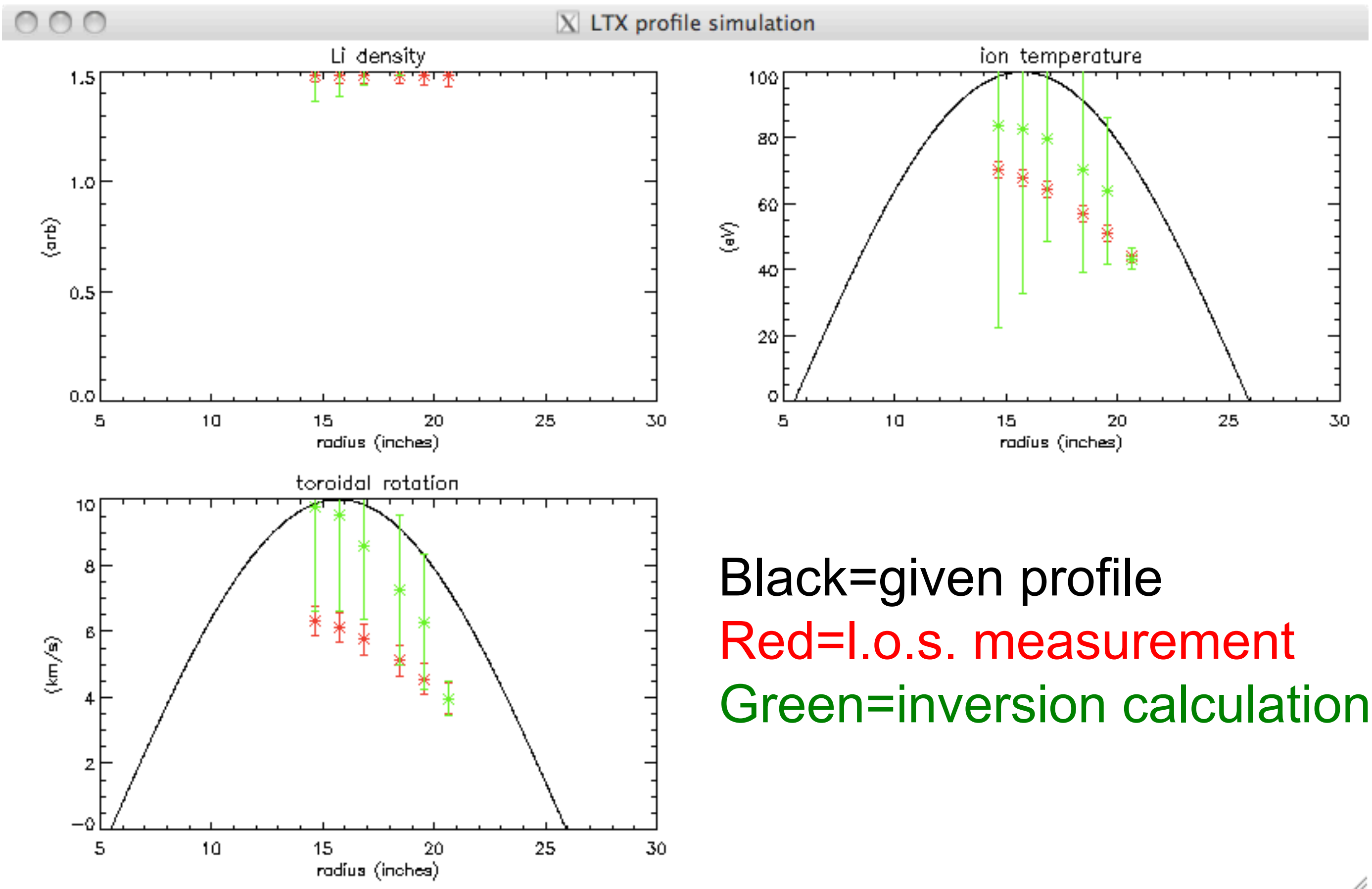
Black=given profile

Red=l.o.s. measurement

Green=inversion calculation



“As Built” Array with Flat n_{Li} Profile



Black=given profile
Red=l.o.s. measurement
Green=inversion calculation

Lack of edge data leads to large error bar and inaccuracy on outer-most chord.

Flat n_i profile causes difficulty for inversion routine.

(75 micron instrument function)

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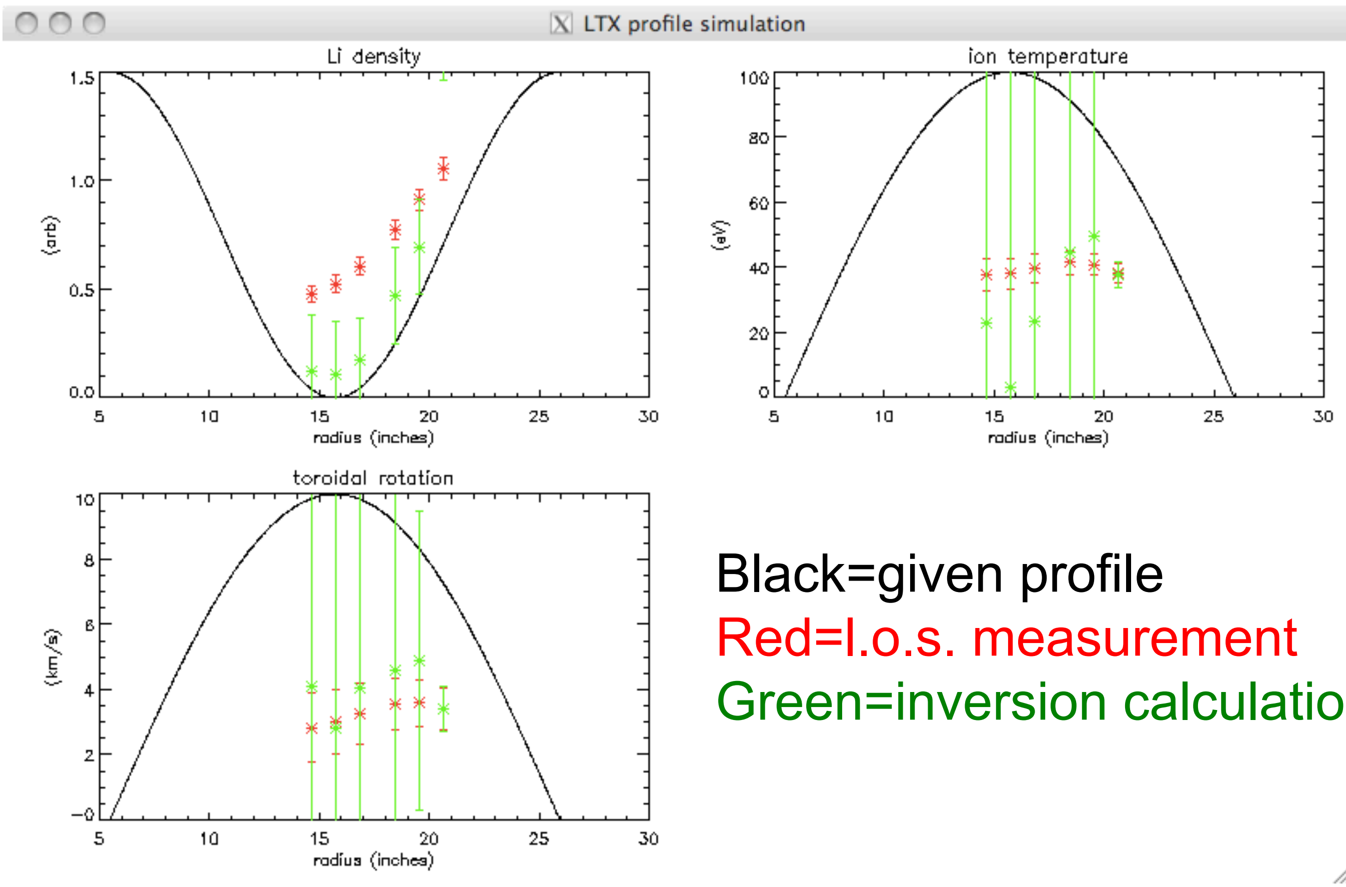
"As Built" Array with Hollow n_{Li} Profile



Black=given profile
Red=l.o.s. measurement
Green=inversion calculation

Lack of edge data leads to large error bar and inaccuracy on most chords.

Hollow n_i makes core T_i and v_T measurements problematic.

(75 micron instrument function)

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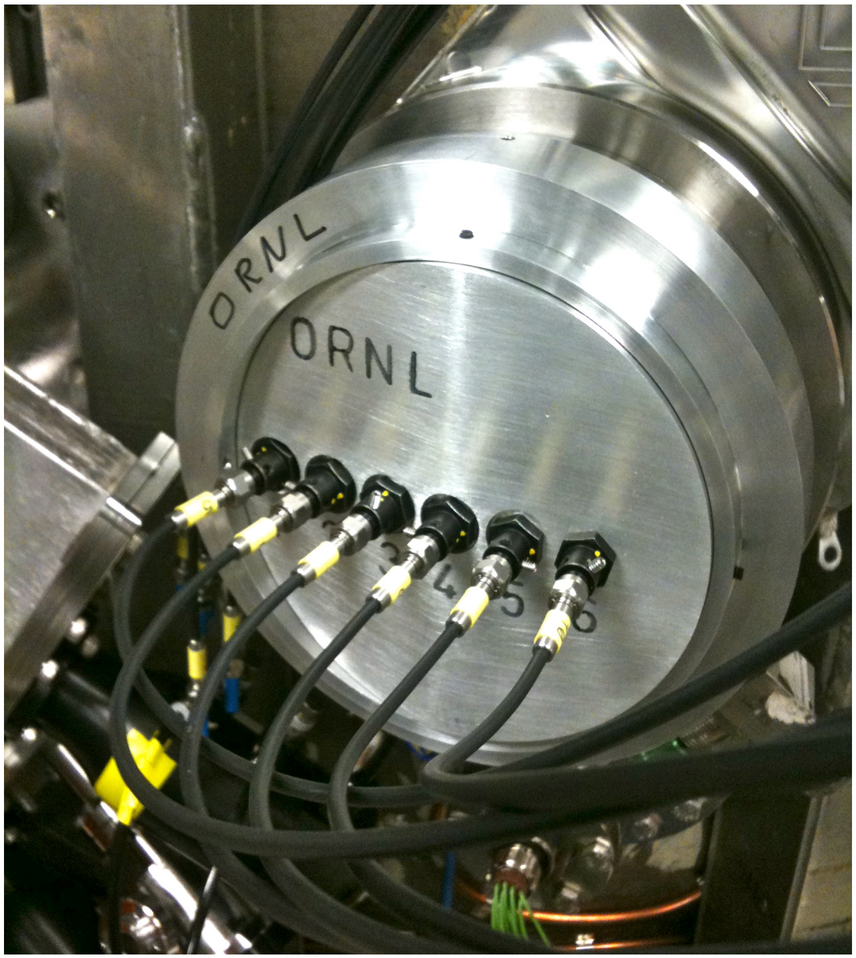
Passive Spectroscopy Simulation Summary

- Simulations of the "as built" toroidal array suggest that the inversion of line-of-sight passive spectroscopy data can be accomplished to yield local values of Li III emissivity, T_i, and v_T.
  - Greatest accuracy of the inversion is achieved when the brightness of Li III emission is centrally peaked.
  - Hollow Li III emission can not easily be inverted for the "as built" array.
  - Qualitative information about the Li III brightness profile shape can be inferred.
- Increasing the number of lines-of-sight improves the inversion accuracy, especially with the addition of edge chords.
- If the installation of the Neutral Beam Injector (NBI) is greatly delayed, then a more comprehensive passive spectroscopy array could be justified.

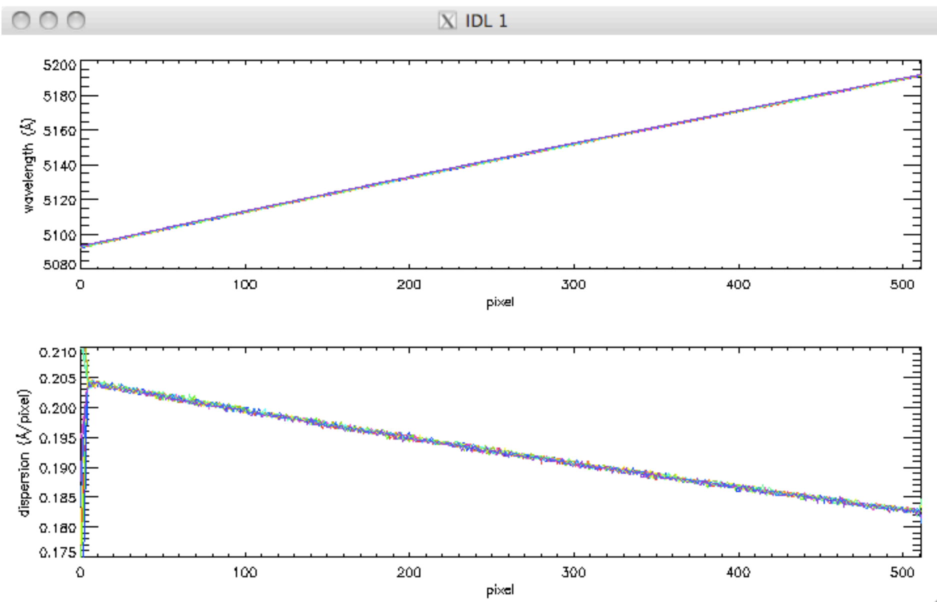
Passive Spectroscopy Measurements

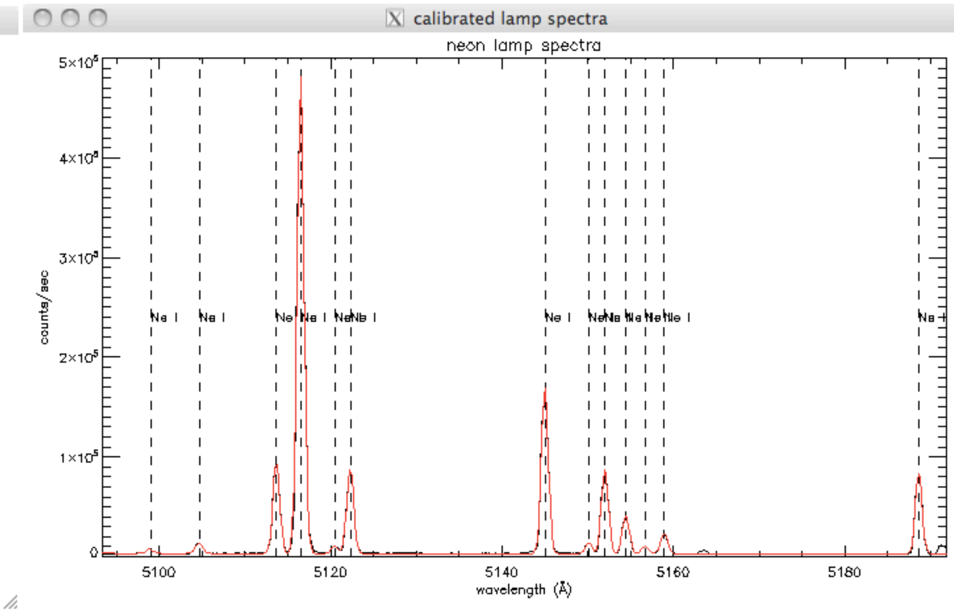
- Collection optics installed and back-illuminated: July 2011
  – Need to double-check optics pointing against engineering model
- Spectrometer/CCD installed: Sept. 2011
  – Wavelength calibrated ex-vessel with neon lamp and absolute-intensity light source
- LTX vessel-filling neon glow: Nov. 2011
  – Cross check of wavelength calibration
  – Instrument function for extant optical path
  – Vacuum window transmission estimation (with assumptions)
- LTX plasma discharge data collected (1 week ago)
  – Preliminary results shown below

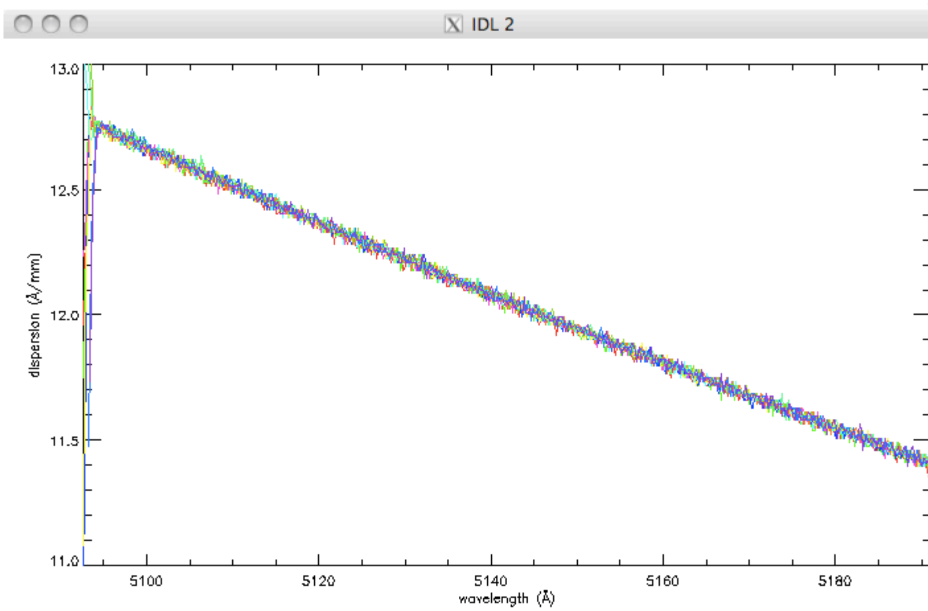
Hardware Installed on LTX (Sept. 2011)

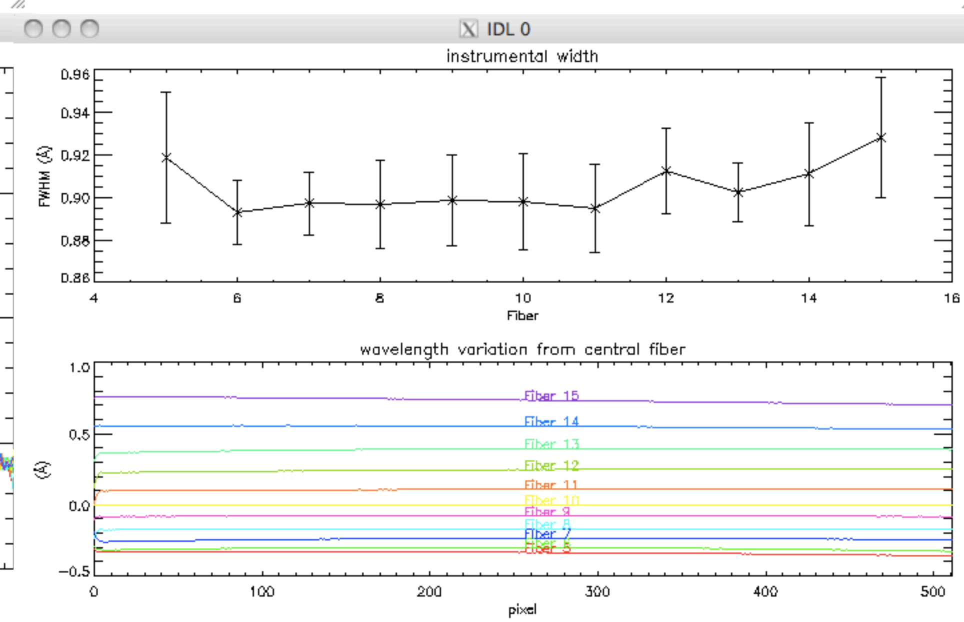


Calibration of Spectrometer/CCD









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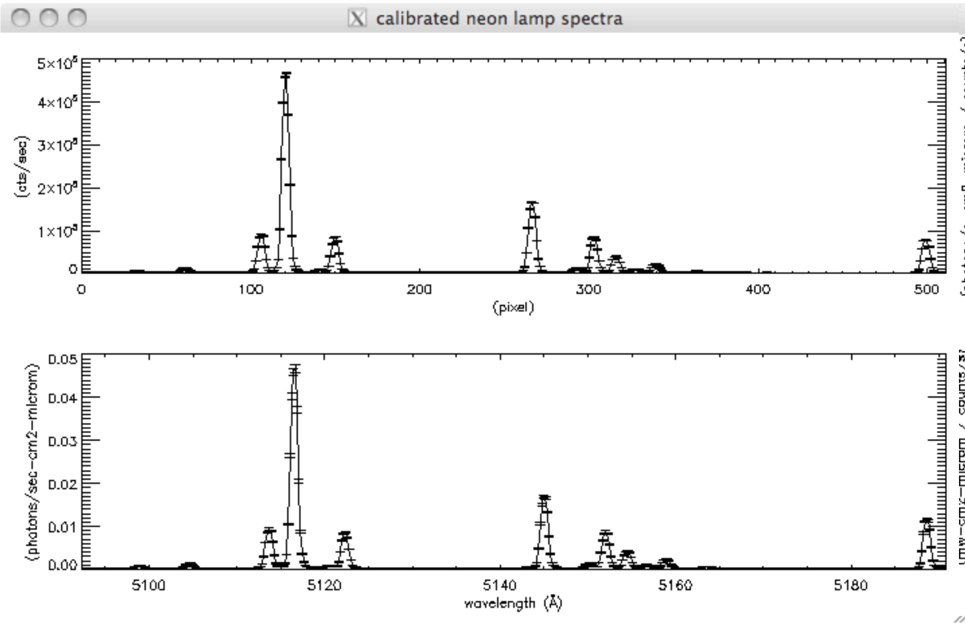
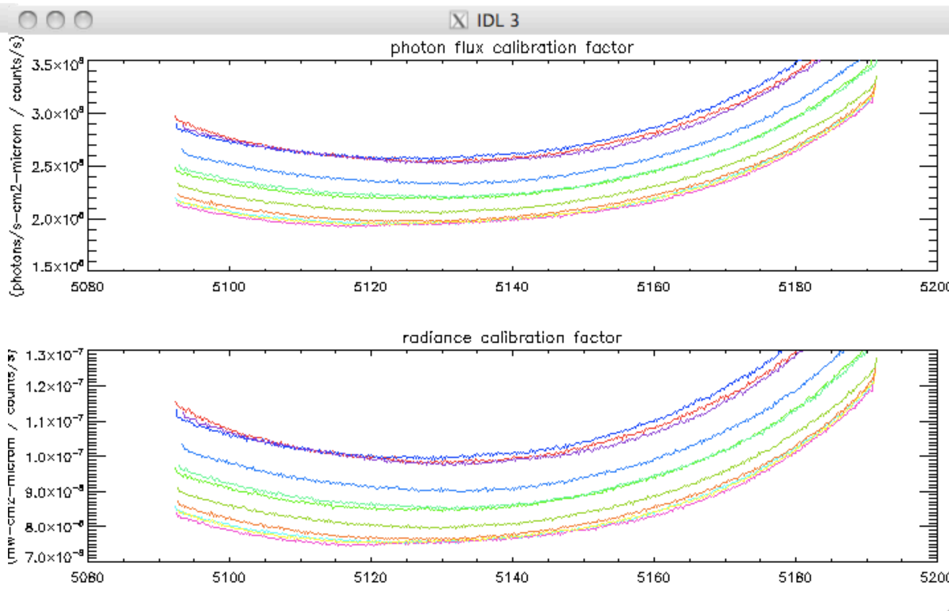
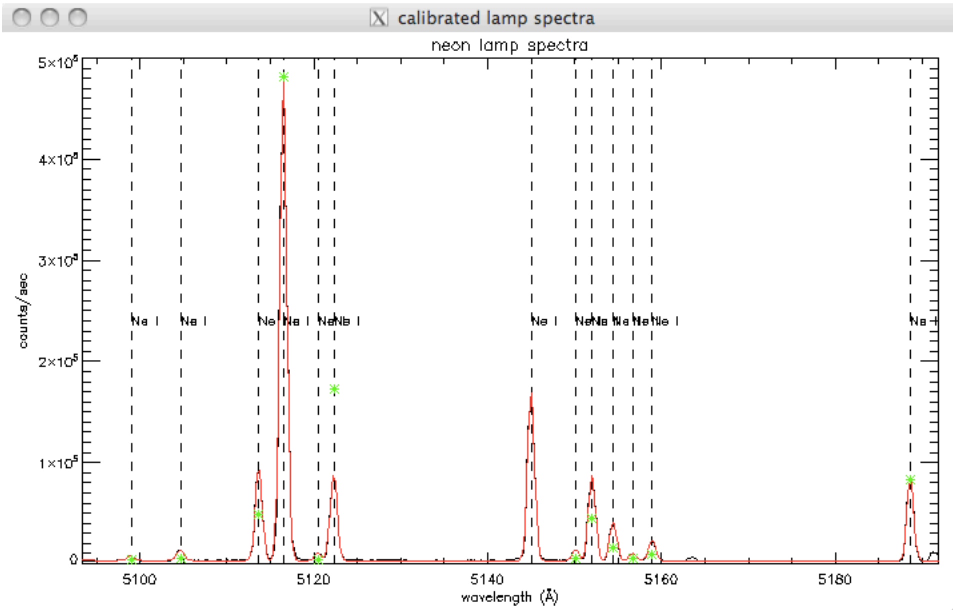
Calibrated Light Source

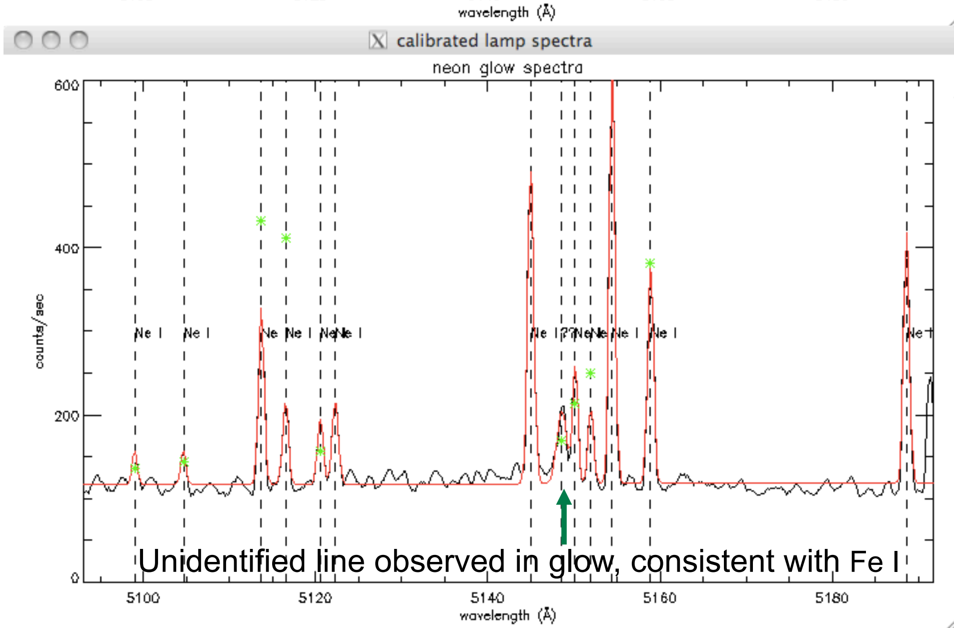




- **Ocean Optics HL-2000 calibration "white" light source used on each track**
- **Does not include transmission factors of vacuum window, lenses, and/or obstructions**

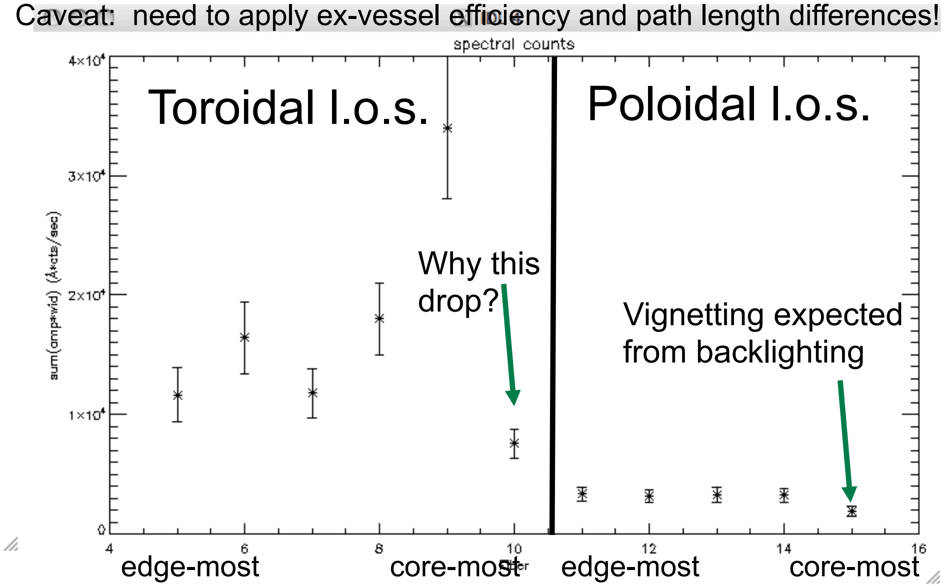
Vessel-Filling Neon Glow Calibration



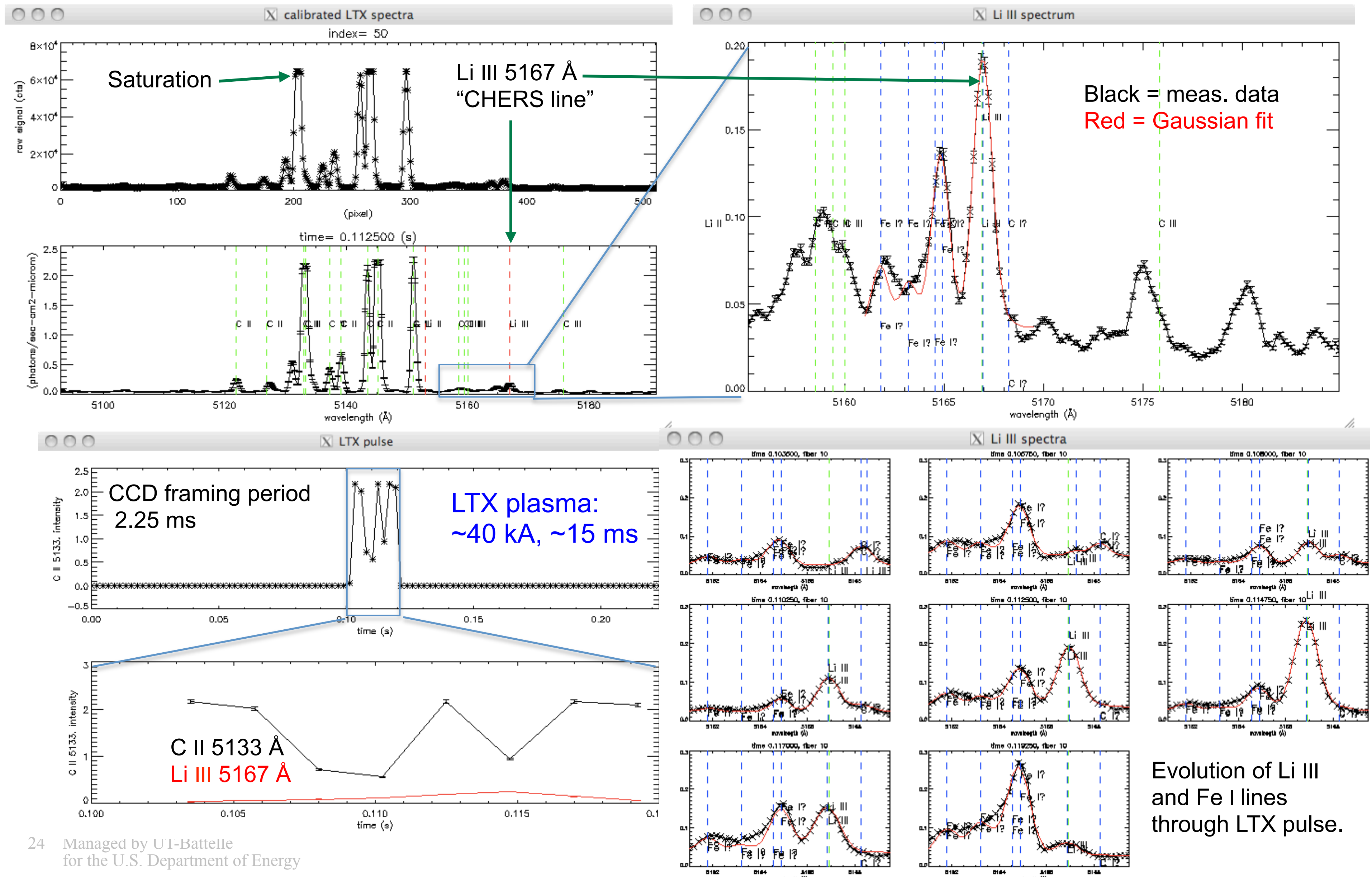


- **Wavelength calibration well preserved (2 months later)**
- **Relative intensities of Ne lines differ between lamp, glow, & NIST**
- **Transmission variation of vacuum window and/or obstructions (assuming uniform glow).**
  - **resolve prior to data inversions!**

Caveat: need to apply ex-vessel efficiency and path length differences!



Preliminary Data from LTX Pulses



Evolution of Li III and Fe I lines through LTX pulse.

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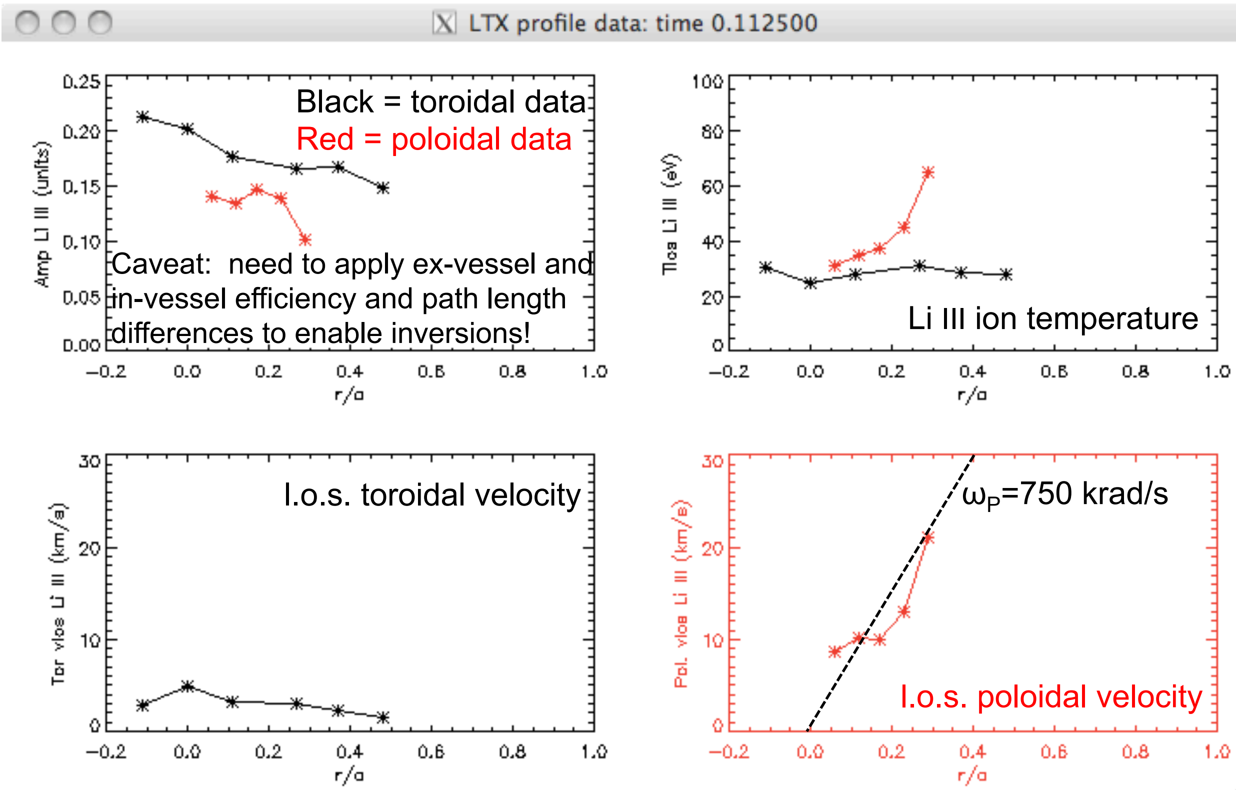
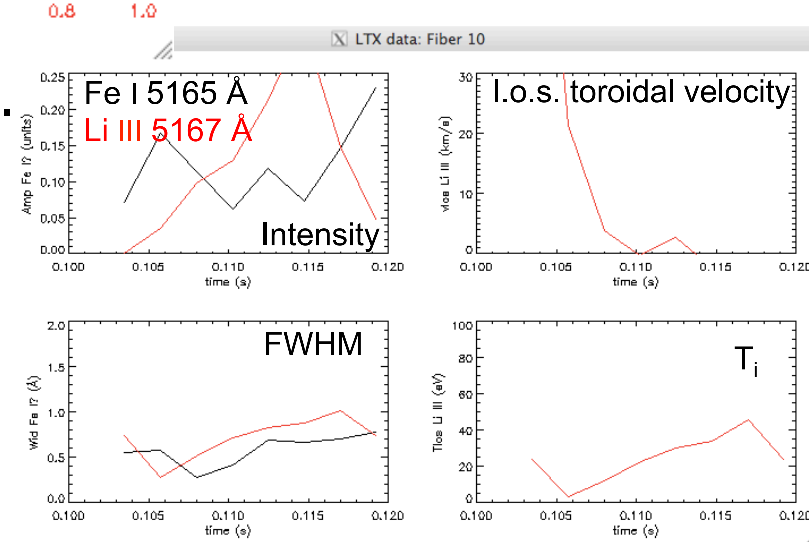
Line-Integrated LTX (Li III 5167) Profiles



- This data is ~1 week old: preliminary analysis!
  - Line-integrated, plotted against r/a of sightline tangency.
  - Must be inverted to get "local" values.

- Li III brightness qualitatively flat or central peaked.
- $T_i(r)$ ~ 30 eV, "flat"
- $v_T(r)$~ 0, "flat"
- v_P increasing linear with r/a: $\omega_P(r)$ ~ 750 krad/s



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Status of Active Spectroscopy Design

- ChERS design relies heavily on the amount of active emission of Li III in LTX, which depends on n_e, T_e, n_{Li}.
  - Have measured passive Li III emission in LTX
  - Need calculation to estimate active Li III emission at NBI ion energy (20 - 40 keV)
- Determine collection optics positions (toroidal and poloidal l.o.s.).
- Tailor CCD/spectrometer/fiberbundle combination.
- Critical item is the delivery of the NBI.
  - Estimate 2012

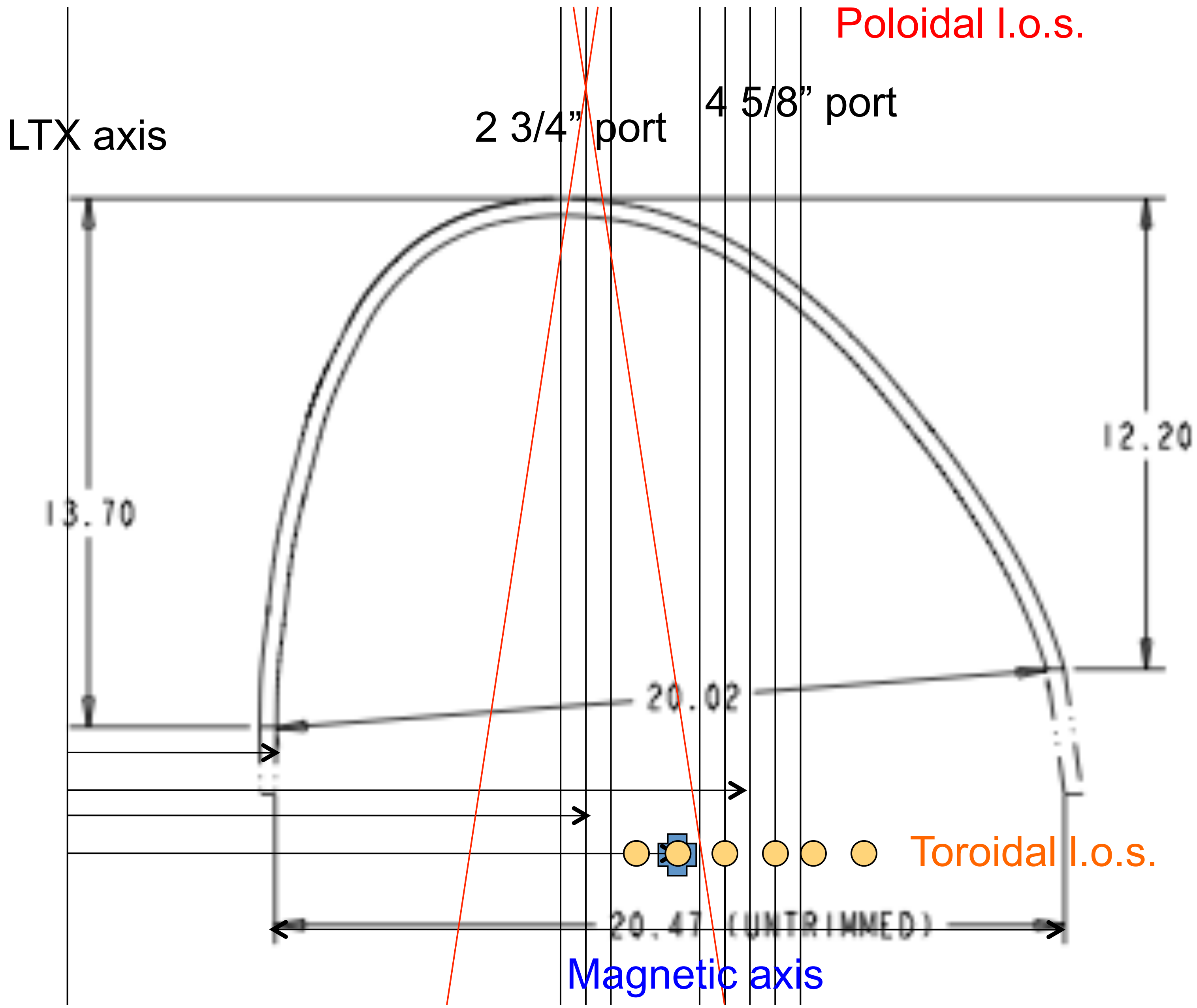
Summary and Conclusions

- Staged implementation of ChERS diagnostic on LTX: initial passive spectroscopy measurements presented here.
- Hardware installed on LTX in Sept. 2011.
  - Radial coverage from r/a < 0.5
  - 6 toroidal chords, 5-8 matched pair poloidal chords
  - Time resolution ~2 ms (LTX pulse length ~>20 ms)
- Spectral simulations suggest this configuration is sufficient to distinguish qualitative line-integrated profile effects.
  - May be possible to invert the data to achieve "local" values from passive emission.
- Preliminary data (from last week) suggests:
  - C II light dominates the measured spectra for this instrument
  - Fe I is observed in glow and discharge plasma (contamination from vessel liner?)
  - Li III (5167 Å) is measurable in LTX, increasing through the discharge
  - $T_i \sim 30$ eV, $v_T \sim 0$ km/s, $\omega_P \sim 750$ krad/s
- Active spectroscopy (ChERS) planned for 2012.

Reprints

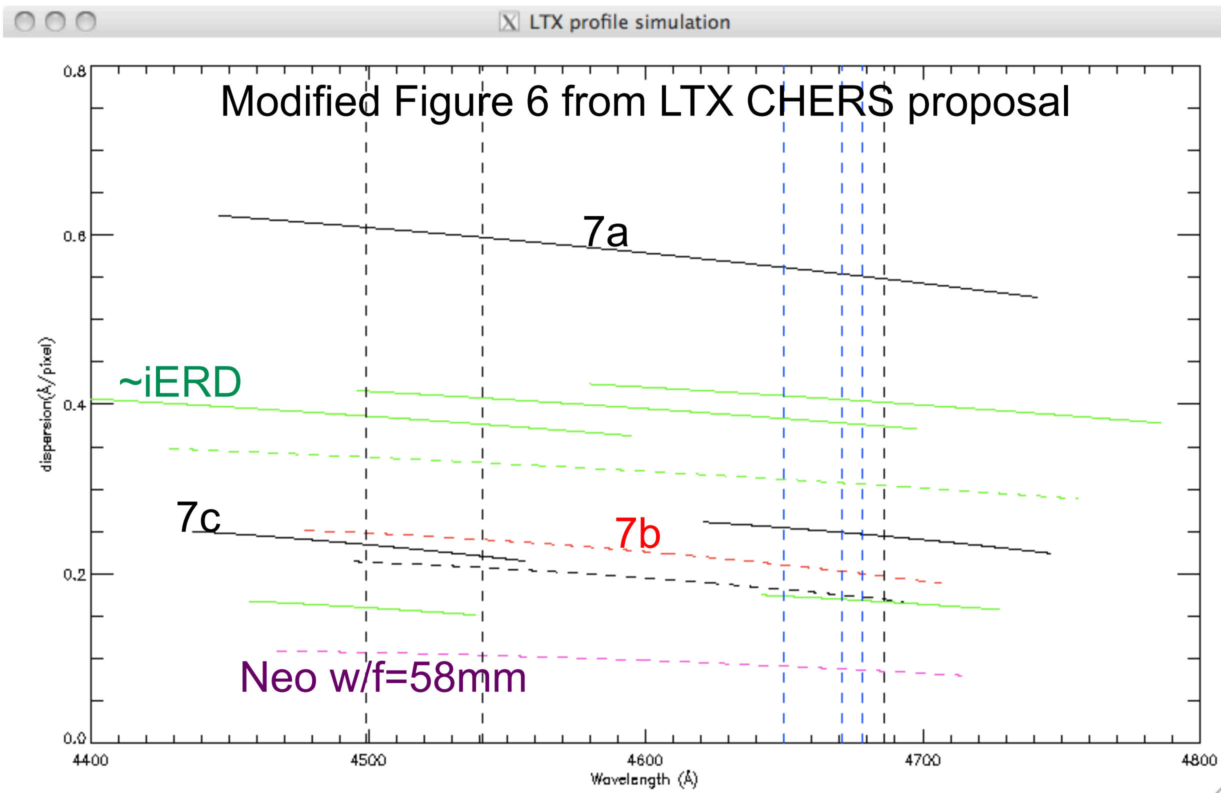
- Copies of this poster are available online:
  - http://sprott.physics.wisc.edu/biewer/APS2011poster.pdf
- Or, write your name and email address below:

Lines of Sight Projections



ProEM (EMCCD) v. Neo (sCMOS) Cameras

- Andor webinar on 1/20/11 detailing Neo sCMOS camera
  - A new technology that we should consider if we have the photons.
- Higher resolution
- Large FOV
  - ~30 channels/slit
- ~$15k cheaper
- Larger read noise
  - ~100x worse
- ~same speed



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