NSTX-U

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The NSTX-U Thomson scattering diagnostic system

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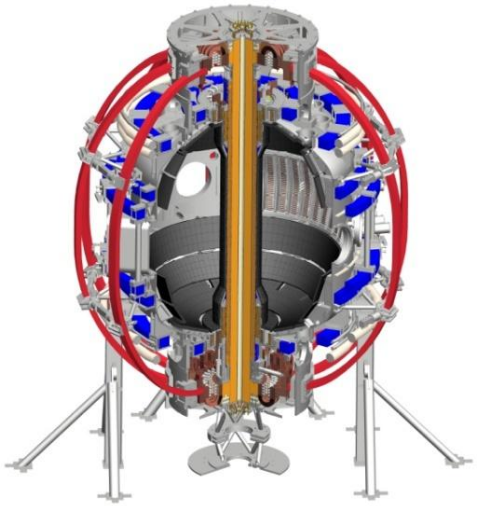
54th Annual Meeting of the APS Division of Plasma Physics
October 29 - November 2, 2012
Providence, Rhode Island



*** Work supported by USA DoE contract DE-AC02-09CH11466**

MPTS Mission and Challenges on NSTX-U

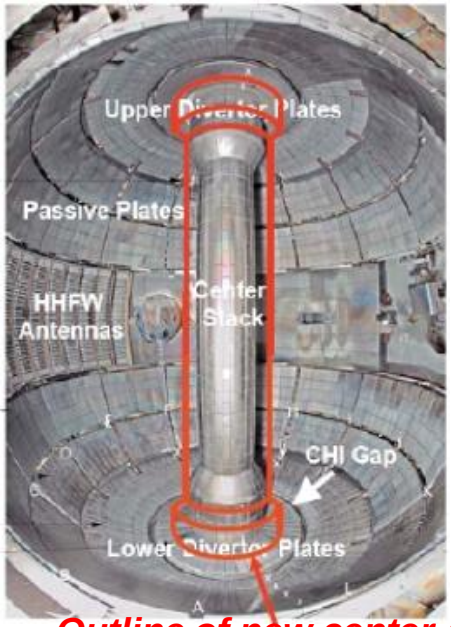
- Thomson scattering arrangement for NSTX-U
  - New laser beam path needed to avoid wider center stack
  - Complex laser exit route needed to avoid new NBI box
    - New beam dump
  - Use existing collection components in order to save time and money
  - Improved in-situ calibration system
  - Implement hardware changes for future third laser
  - Install remote mirror control in laser-beam delivery optics
  - Develop plan for operation with T_e up 10keV
- Plasma physics coverage
  - Continue full profile measurements at equatorial plane
    - Both sides of magnetic axis and SOL
  - Emphasis on outer edge pedestal and ITB regions
    - Recent radial resolution upgrade to 42 channels is installed
- Plasma operation support
  - Develop plan for TS real-time feedback for plasma control

Twofold I_p and B_T Increases and NBI Power

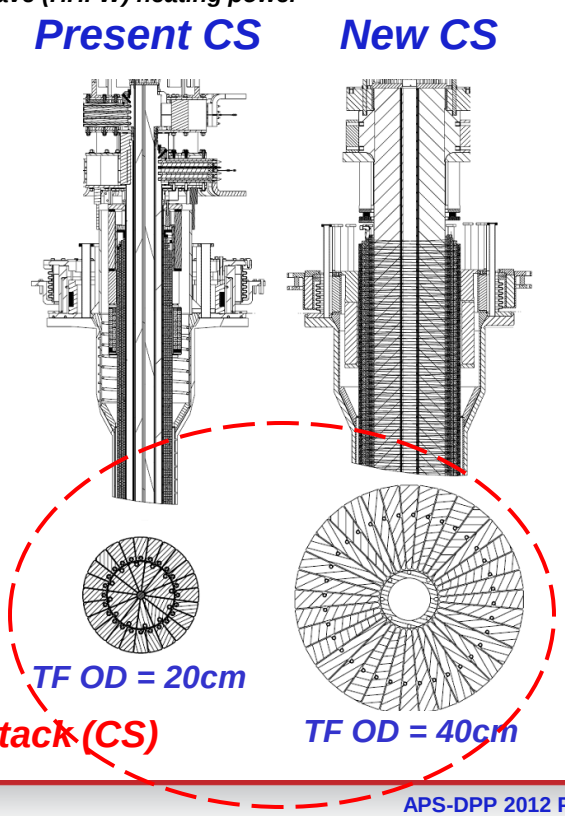
Wider center stack and second beam box

	NSTX	NSTX Upgrade	Plasma-Material Interface Facility	Fusion Nuclear Science Facility
Aspect Ratio = R_0 / a	ε 1.3	ε 1.5	ε 1.7	ε 1.5
Plasma Current (MA)	1	2	3.5	10
Toroidal Field (T)	0.5	1	2	2.5
P/R, P/S (MW/m,m^2)	10, 0.2*	20, 0.4*	40, 0.7	40-60, 0.8-1.2

** Includes 4MW of high-harmonic fast-wave (HHFW) heating power*

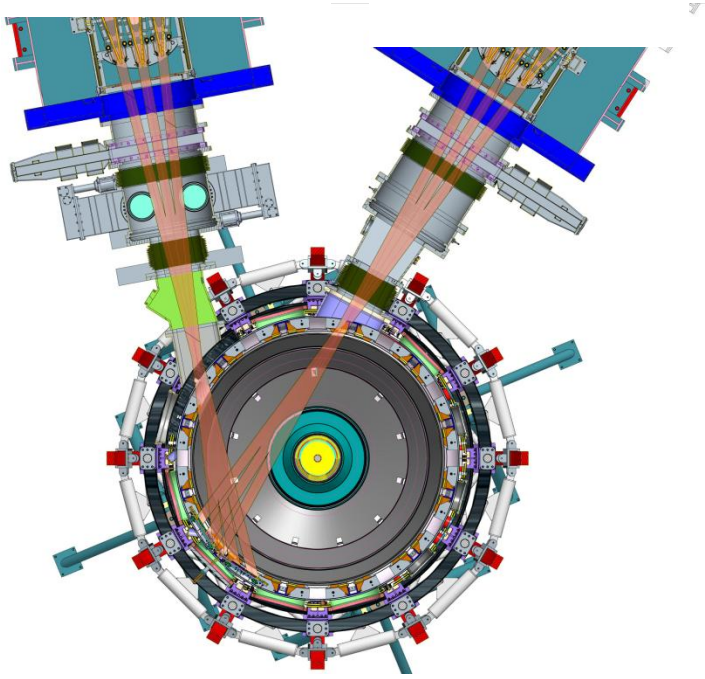


Outline of new center-stack (CS)



New 2nd NBI ***(R_{TAN}=110, 120, 130cm)***

Present NBI ***(R_{TAN}= 50, 60, 70cm)***



Base Parameters for NSTX and NSTX-U

Expect larger T_e up to 10keV

	Base NSTX	NSTX Upgrade
R_{geom} (m)	0.854	0.934
a (m)	0.669	0.619
A	1.27	1.50
I_p (MA)	1.0 (1.5)*	2.0
B_t (T)	0.55 (0.6)*	1.0
T_{pulse} (s)	0.5	5.0

	Base NSTX	NSTX Upgrade
NBI (MW)	6	12
HHFW (MW)	6	6
T_e (keV) HHFW	≤ 6.25	≤ 10*
T_e (keV) Beam-Heated H-Mode	≤ 1.5	≤ 4*

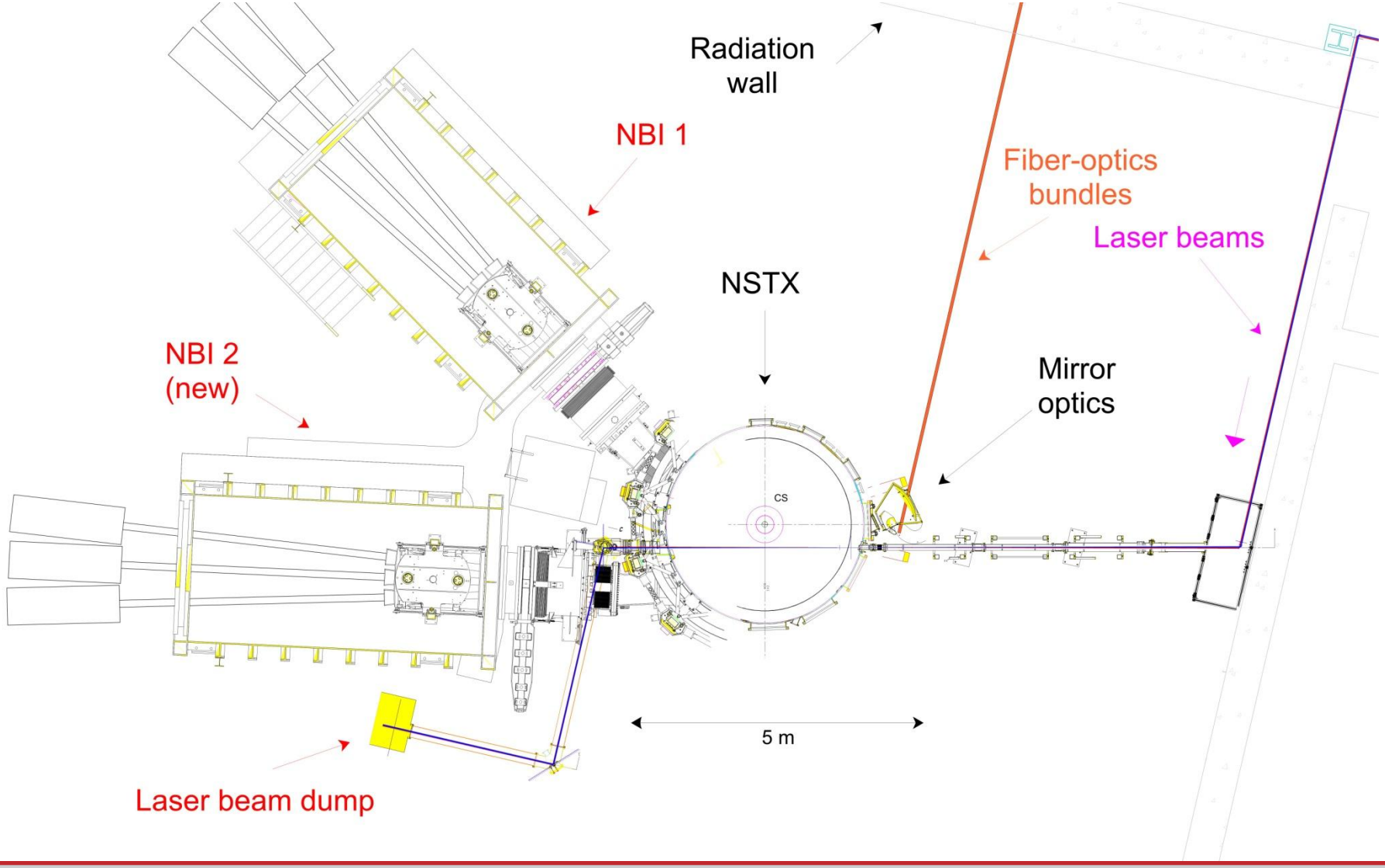
Estimates from J. Menard submitted to NF (2012)

Numbers on the left: C. Neumeyer, et al. Symposium on Fusion Energy (SOFE) -- June 1-5, 2009, *Achieved

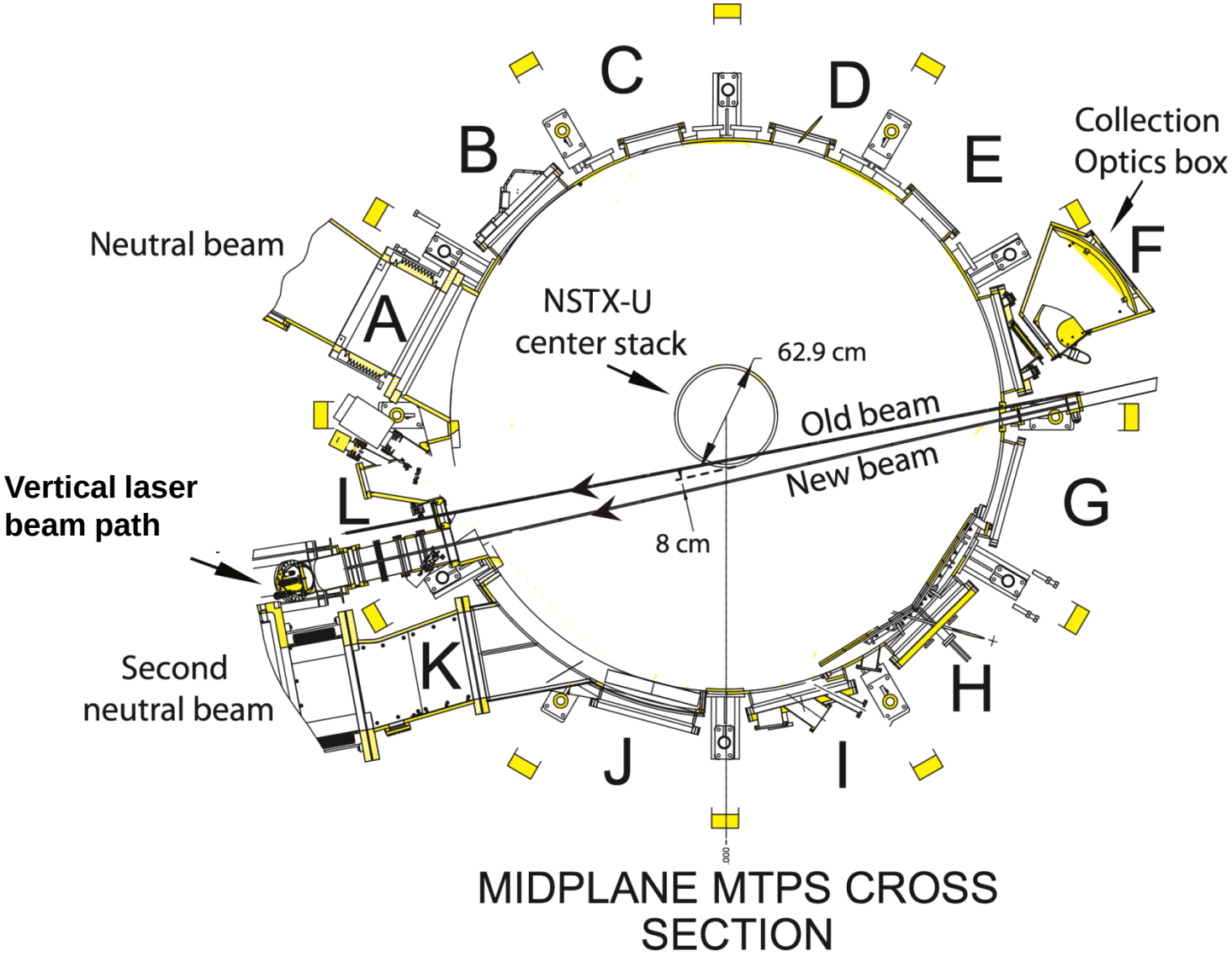
MPTS Configuration for NSTX-U

- Two Nd:YAG lasers, aligned side-by-side on the equatorial plane, with a combined nominal time resolution of 60 Hz
- Total of 42 radial channels
  - 32 polychromators with 6 spectral channels
    - 20 existing plus 12 new polychromators
  - 10 polychromators with 4 spectral channels
- Automation ready in-situ viewing window calibration apparatus
- More details can be found elsewhere:
  - A. Diallo, B.P. LeBlanc, G. Labik, and D. Stevens, Rev. Sci. Instrum. 83, 10D532 (2012)
  - B.P. LeBlanc, A. Diallo, G. Labik, and D.R. Stevens, Rev. Sci. Instrum. 83, 10D527 (2012)

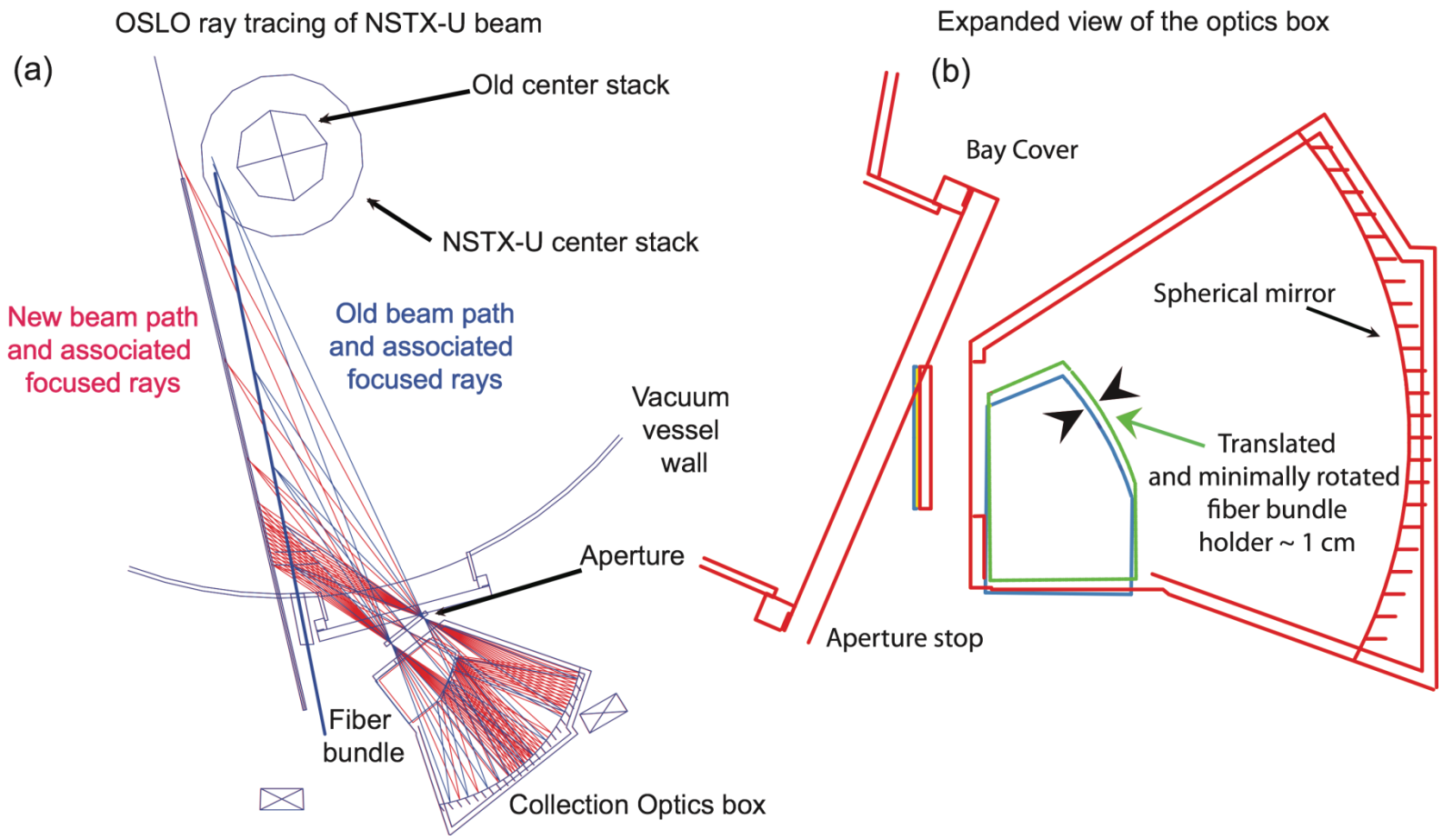
Laser-beam Path Circumvents New NBI Box



New Laser-beam Path Steered away from New Center Stack

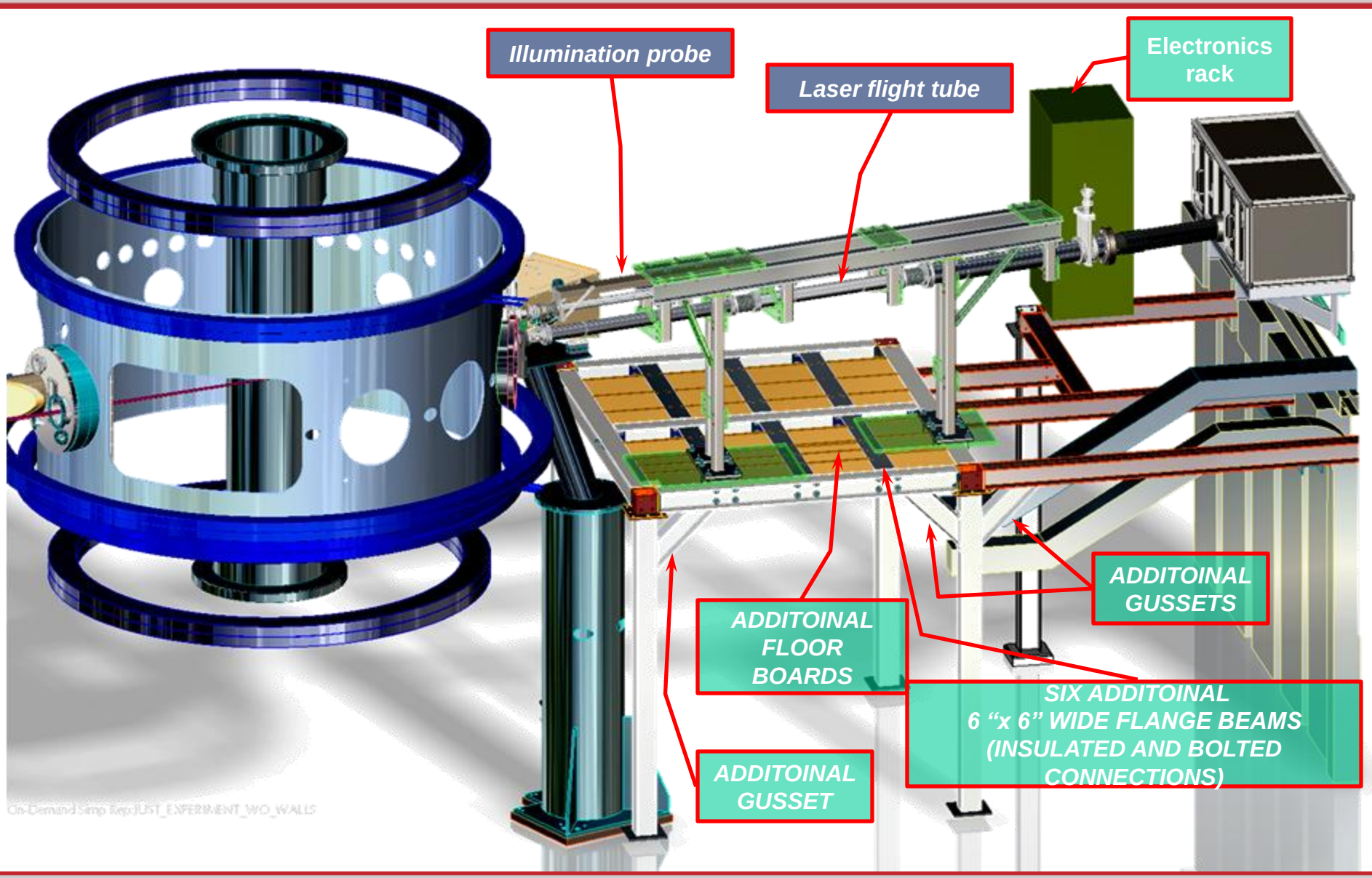


OSLO Ray Tracing shows that the fiber holder needs to be displaced by about 1 cm toward the mirror

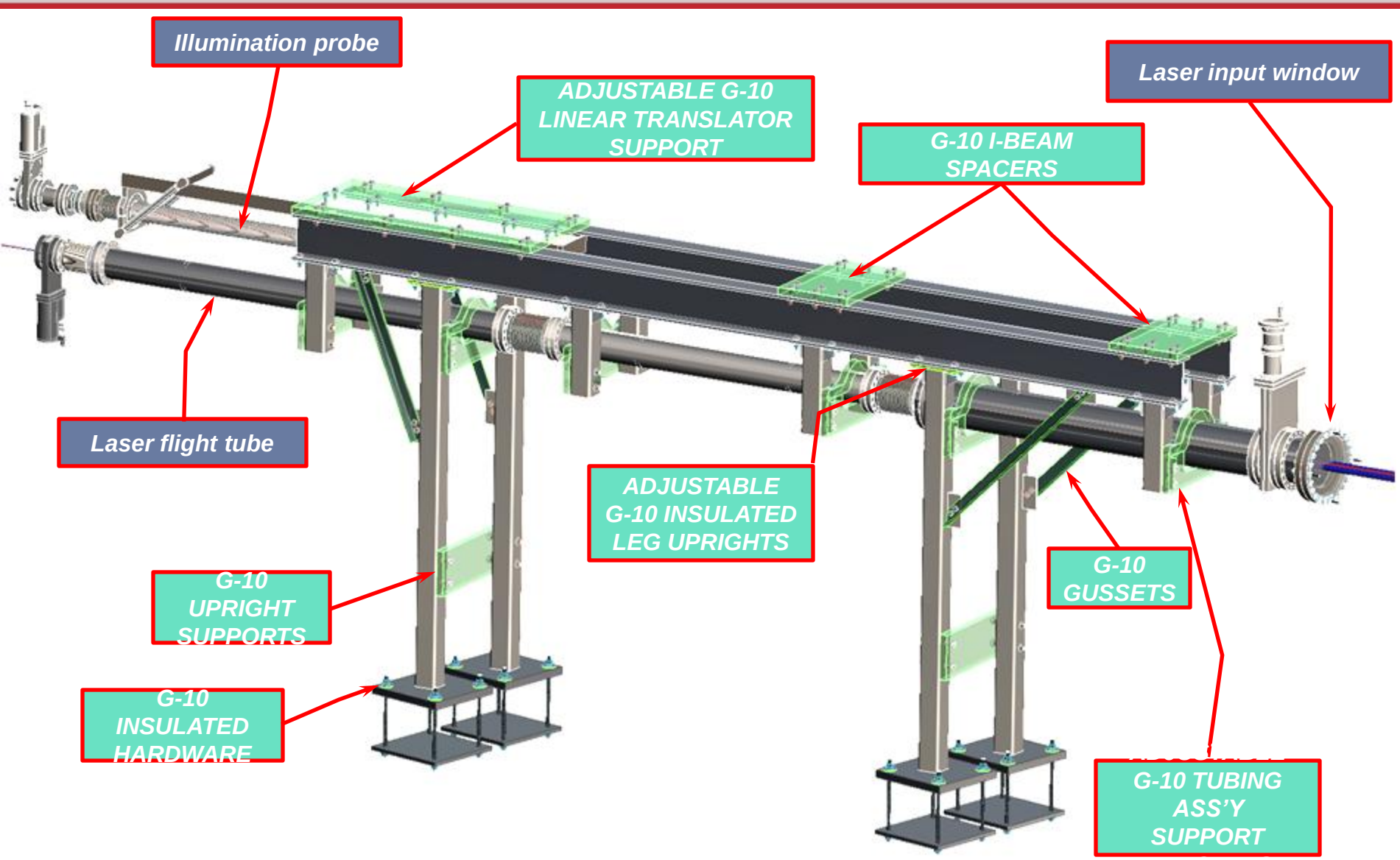


Laser Flight Tube and In-situ Illumination Probe

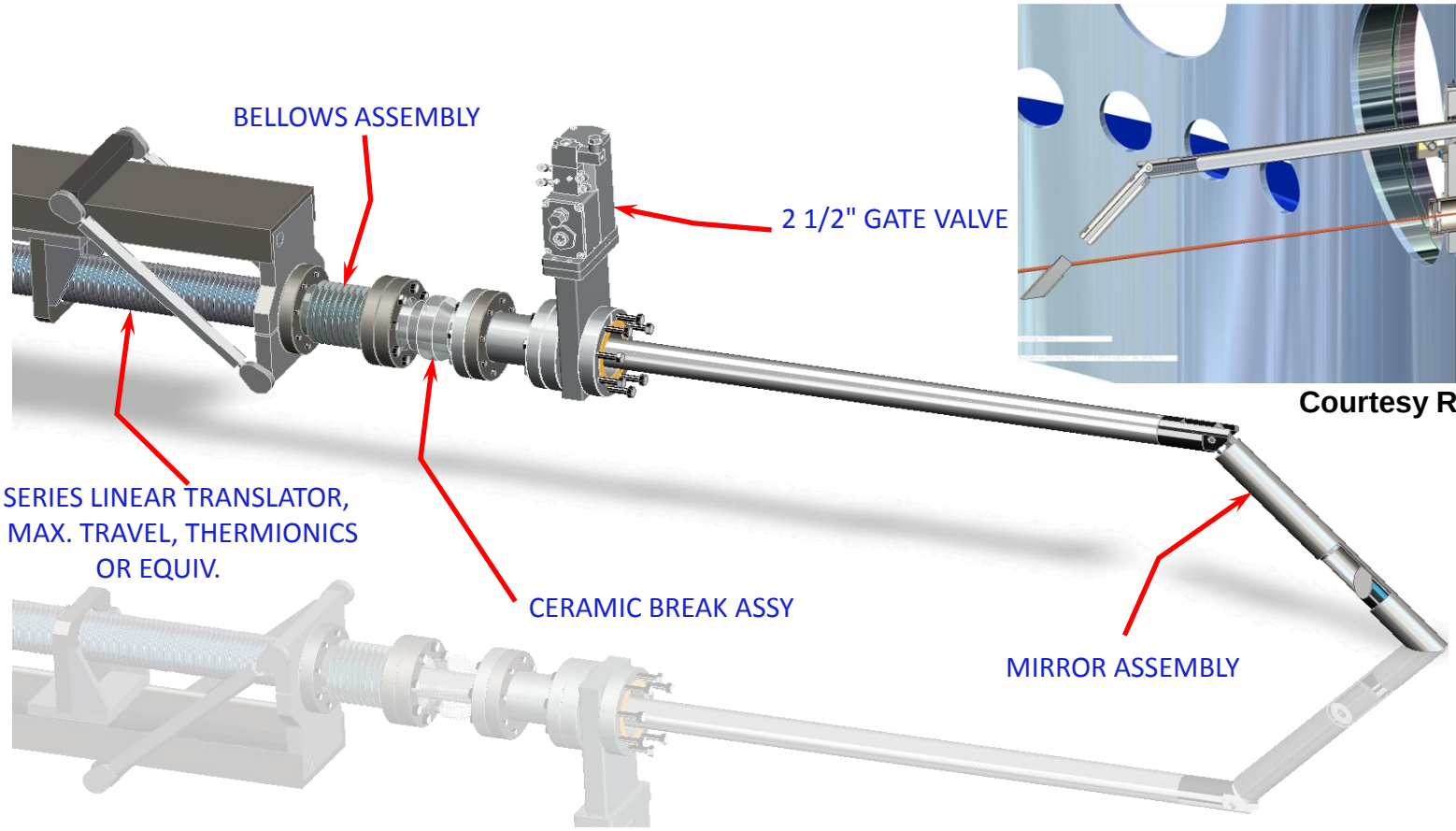
Reinforced support structure



Laser Input assembly and Illumination Probe



Redesign of the calibration probe assembly for MPTS with remote handling capability



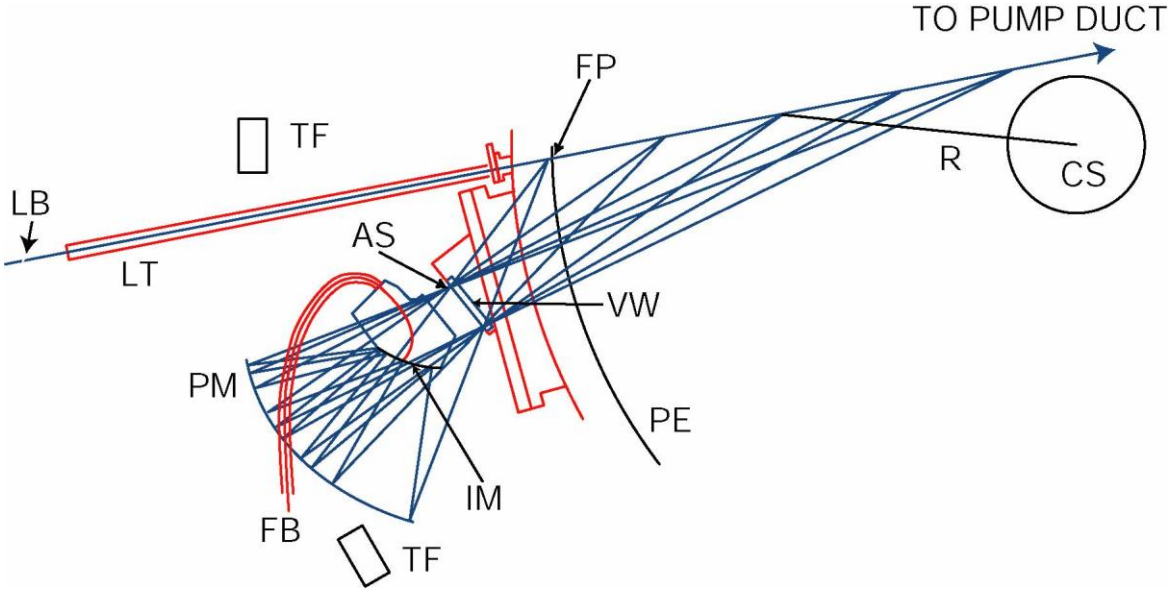
Courtesy Richard Upcavage

- The long discharges of NSTX-U will require routine window calibration

MPTS Collection Optics overview

Back Scattering Configuration

Mirror (PM) optics collect the light scattered along the laser beam (LB) path and focus it at the "image" IM onto 36 fiber bundles



LB: Laser beam; TF: Toroidal Field Coil; PM: Primary mirror; FB: fiber bundles; AS: aperture stop; VW: vacuum window; PE: nominal plasma edge; FP: laser beam focus; R: major radius; CS: Center stack; IM: image

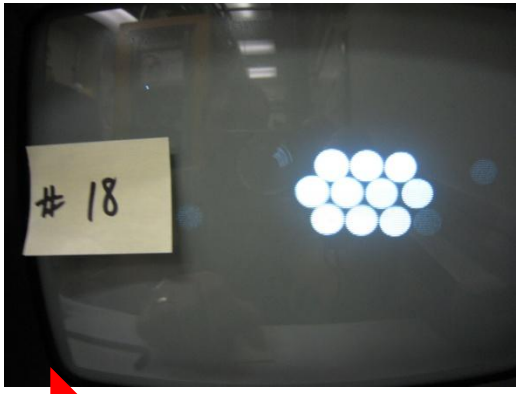
Splitting Fiber Bundle to Increase Spatial Resolution

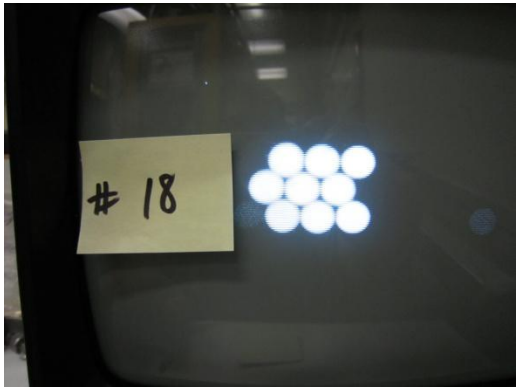
Separation made at output bundle output end

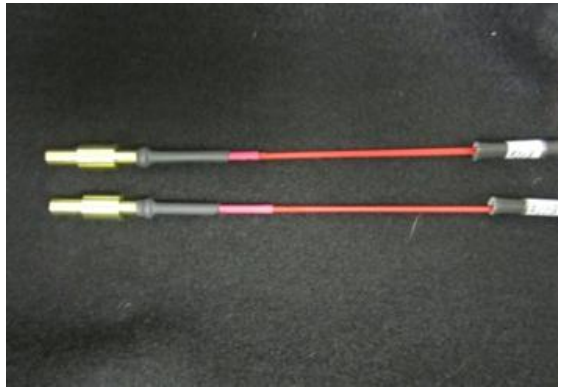
Whole bundle
Back illuminated input end

Light output end

Split bundles
Back illuminated input end





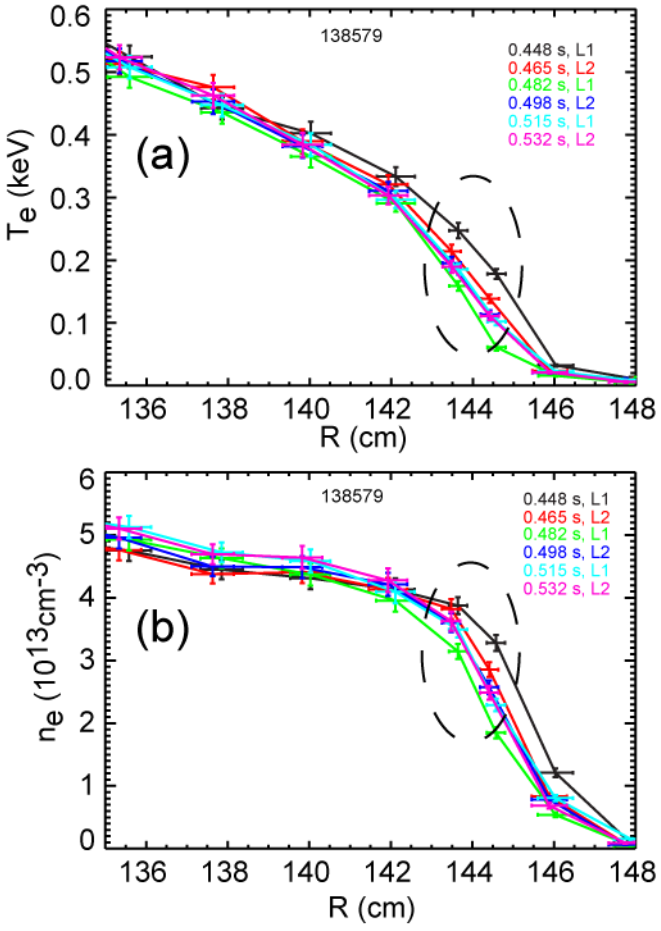


Light output end

Results from Previous Fiber-Bundle Division

R=143.6 and R=144.5 cm

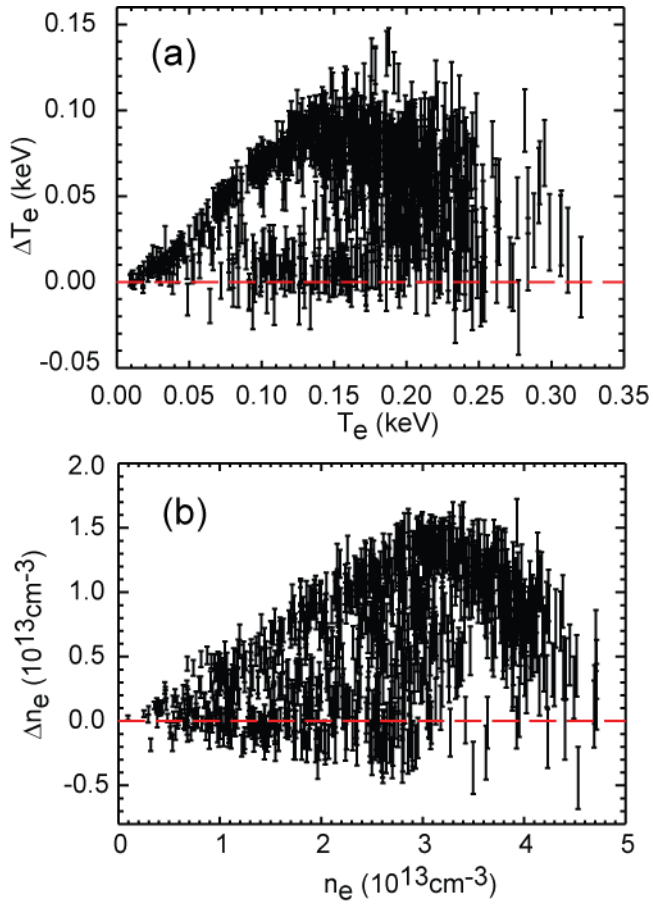
- *One divided fiber bundle used since 2005*
  - *Bundle at R=140cm divided in two: R=143.6 and R=144.5*
- *Conjoint channels provide high quality data*
- *Partial TS profiles in vicinity of conjoint radial locations: (a) T_e; (b) n_e.*
  - *Profiles shown at six consecutive times.*
  - *Conjoint channels circled with dashed line*



Experimental Data Confirm Low Major Radius Overlap

R=143.6 and R=144.5 cm

- 961 TS measurements during plasmas similar to shown in previous slide
- $\Delta T_e = T_e(\text{R=143.6cm}) - T_e(\text{R=144.5cm})$
- $\Delta n_e = n_e(\text{R=143.6cm}) - n_e(\text{R=144.5cm})$
- As expected ΔT_e and Δn_e are > 0.0

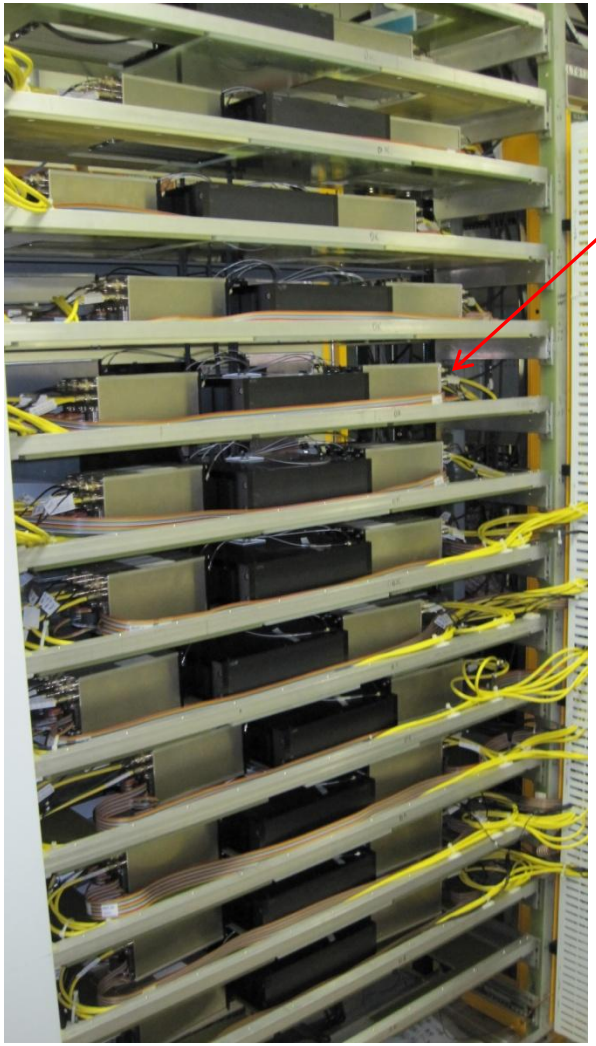


Allocation of the12 New Polychromators

- Inner edge: 1 new polychromator
  - 1 new bundle @31.8 cm (1) new poly(s)
- ITB region: 5 new polychromators
  - 2 new bundles @86.4 and 112.5 cm (2)
  - 3 split bundles [79.5,82.4] (1)
  - [121.5,123.0] (1)
  - [124.5,125.8] cm (1)
- Pedestal: 5 new polychromators
  - 6 split bundles [134.9,136.0] (1)
  - [137.2,138.3] (1)
  - [139.4,140.4] (1)
  - [141.6,142.5] (1)
  - [143.6,144.5] *existing split bundle*
  - [146.4,147.8] cm (1)
- SOL: 1 new polychromator
  - 1 new bundle @154.61cm (1)

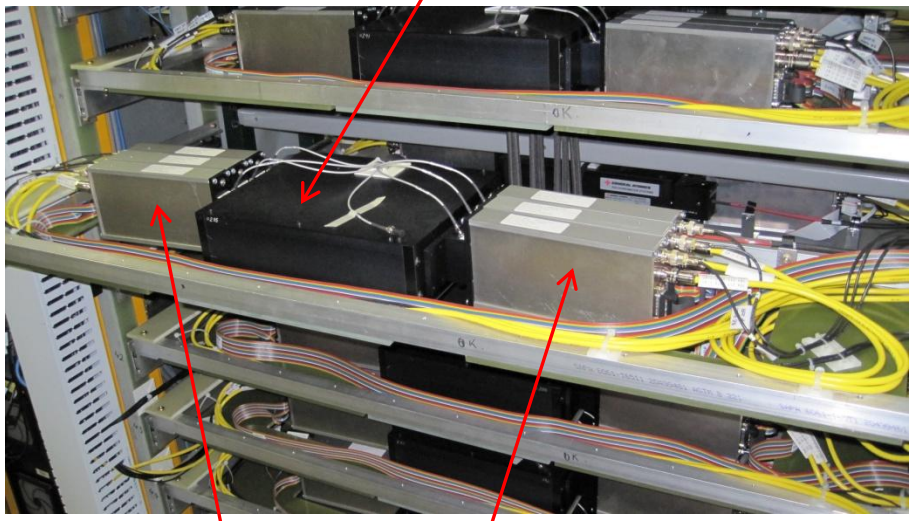
MPTS has a total of 42 radial channels

Implementation of 12 New Radial Channels Complete



New 12-high polychromator tower

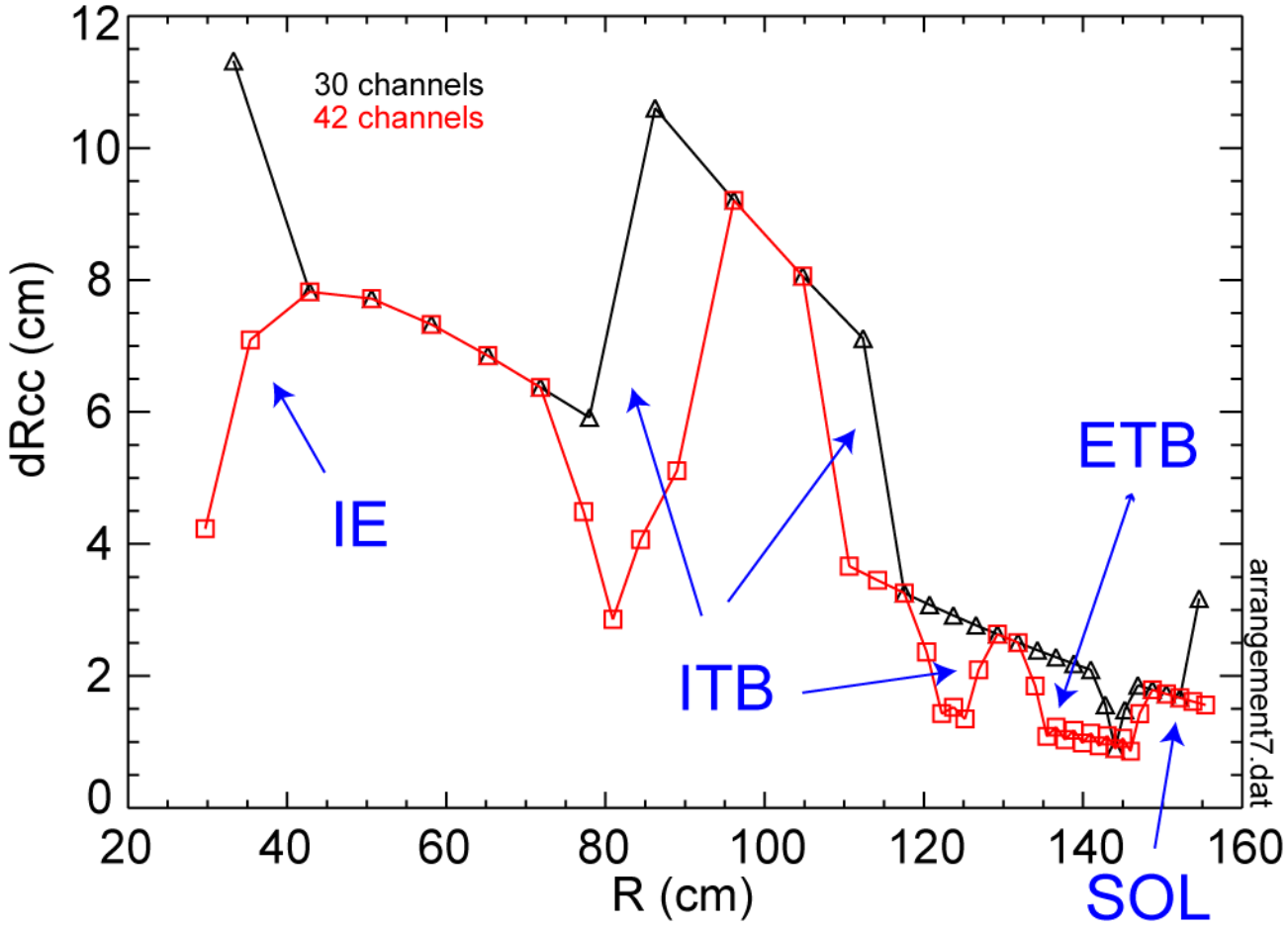
6-filter polychromator



PPPL "low readout noise" preamplifiers

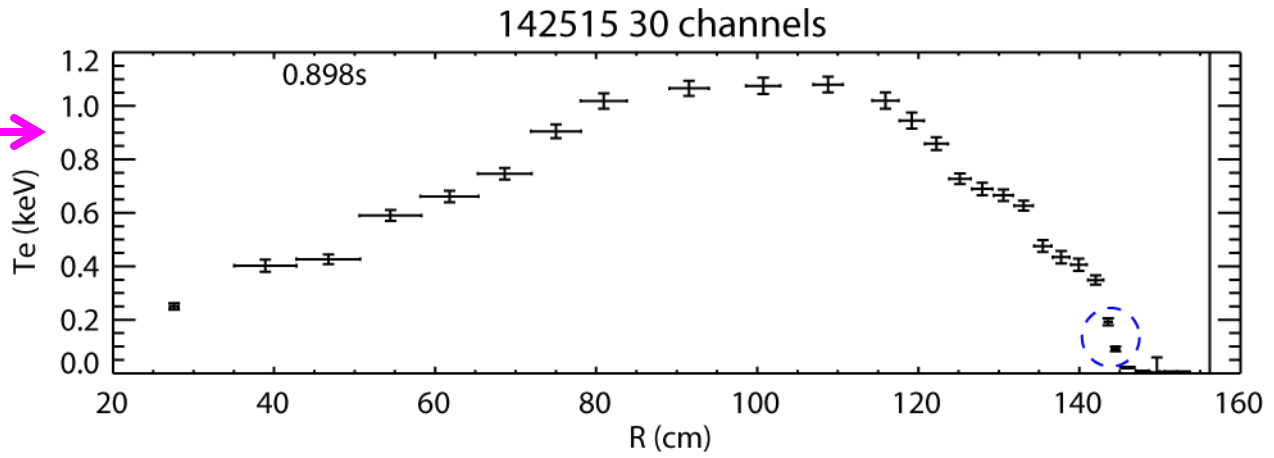
Improved Spatial Resolution with 42 Channels

Reduced center-to-center spacing (dRcc)

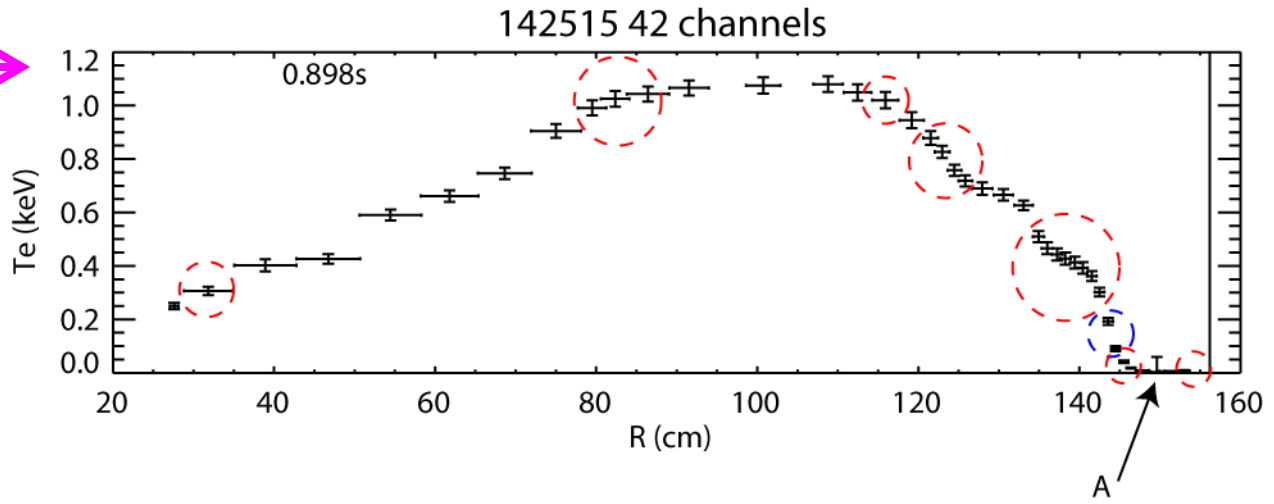


Comparison $T_e(R)$ 30 *vs.* 42 Channels

Experimental 30-channel data



Simulated 42-channel data



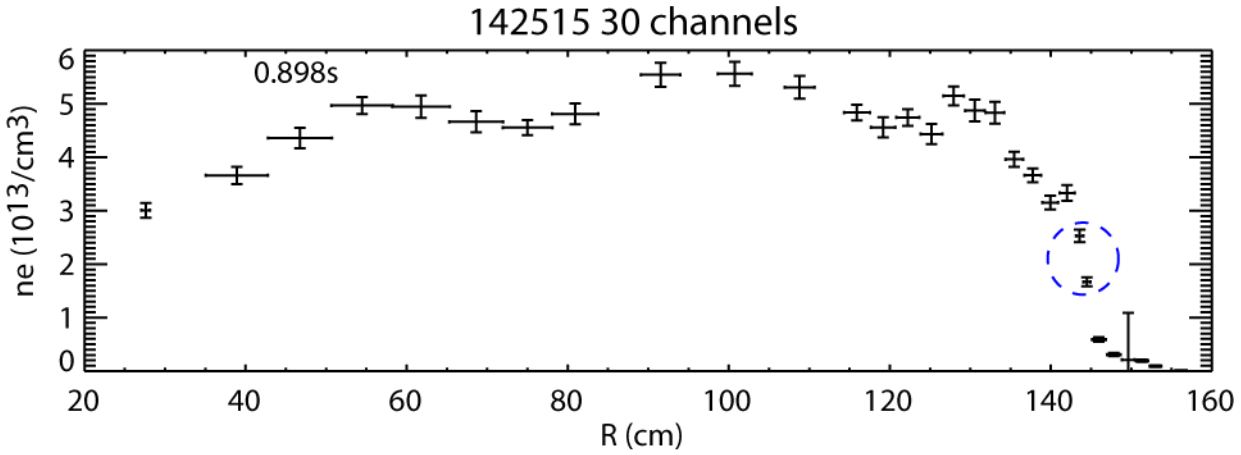
Blue dashed circles: previous split bundle

Red dashed circles: new installation

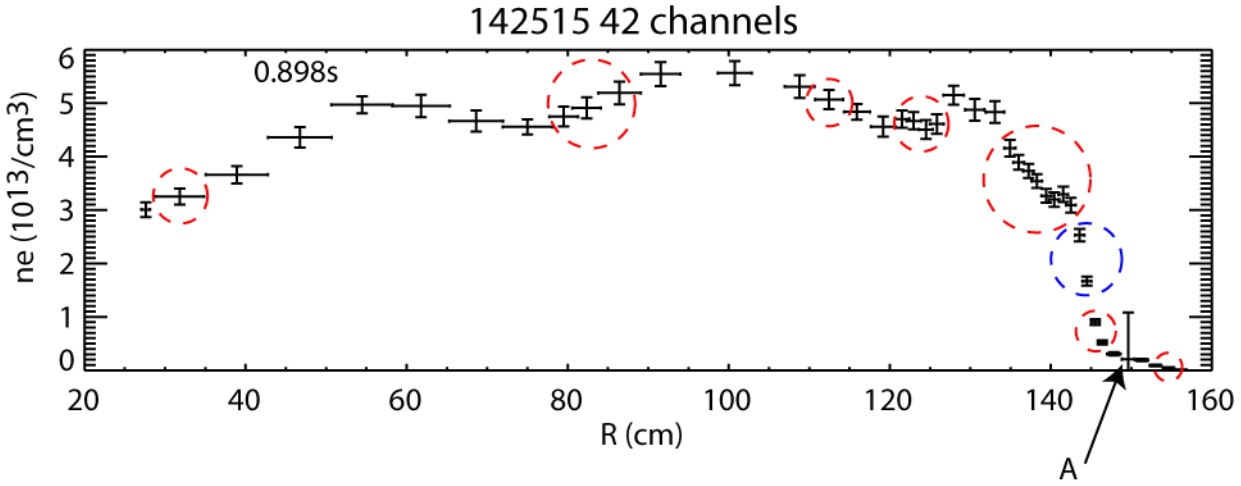
The existing 4-filter polychromator at position "A" has been replaced by one with 6 filters, and should produce smaller error bars – not presently reflected in the above figure.

Comparison $n_e(R)$ 30 *vs.* 42 Channels

Experimental 30-channel data



Simulated 42-channel data



Blue dashed circles: previous split bundle

Red dashed circles: new installation

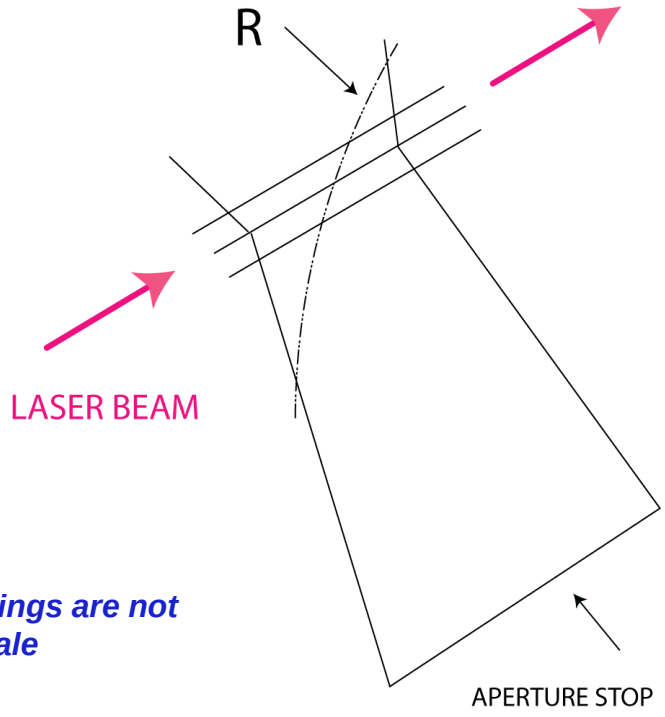
The existing 4-filter polychromator at position "A" has been replaced by one with 6 filters, and should produce smaller error bars – not presently reflected in the above figure.

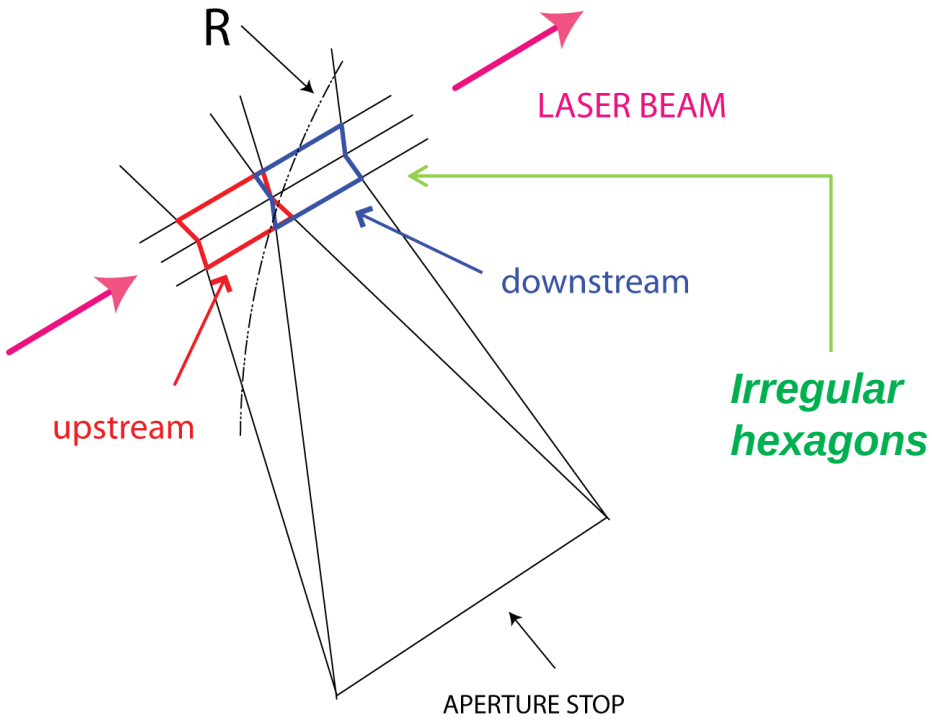
Schematic Illustration of Major Radius Overlap

- *Major radius overlap is caused by overlapping fields of view of the split fiber bundles – red and blue – with the laser beam.*
- *Same value of the major radius R being observed by both split bundles.*

Whole fiber bundle imaged along laser beam path

Split fiber bundles – red and blue – imaged along laser beam path



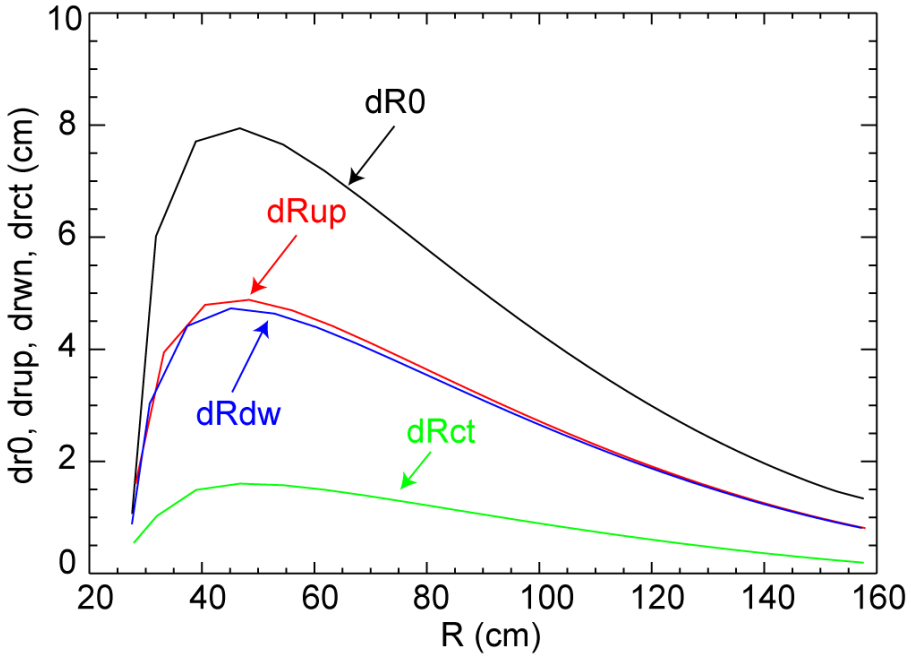


Drawings are not to scale

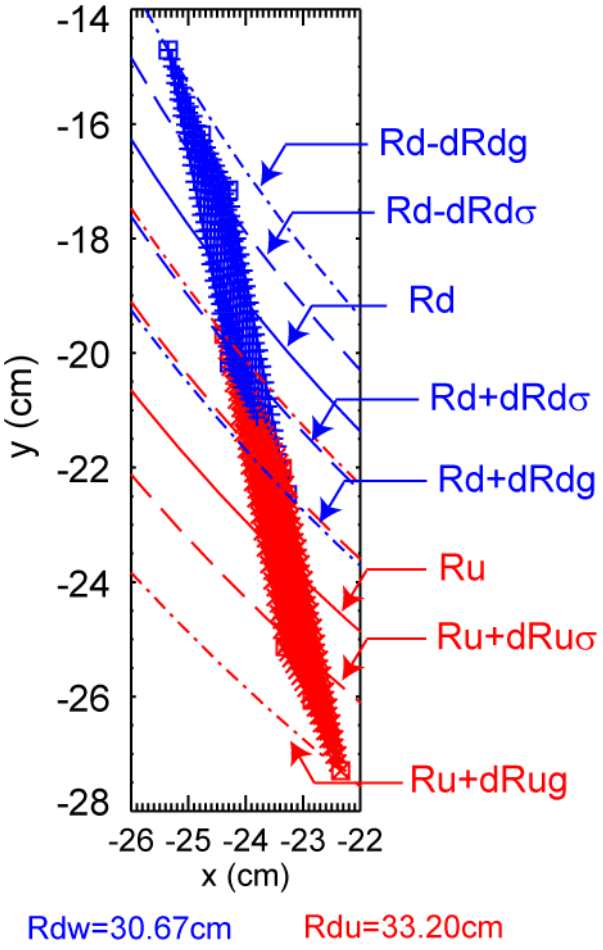
Geometric Major Radius Overlap Evaluation

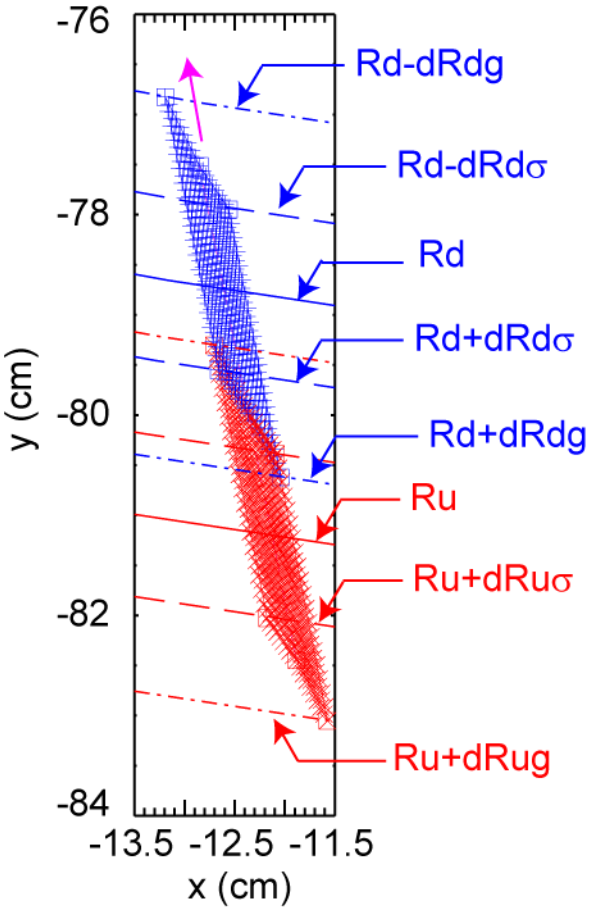
- dr0: major radius span for whole fiber bundles
- Evaluate major radius (R) at the hexagon vertices of upstream and downstream sub bundles and compute
  - dRup: upstream sub bundle R span
  - dRdw: downstream sub fiber bundle R span
  - dRct: geometric evaluation of R overlap

Overlap between 24 and 34% of R span of sub-bundle



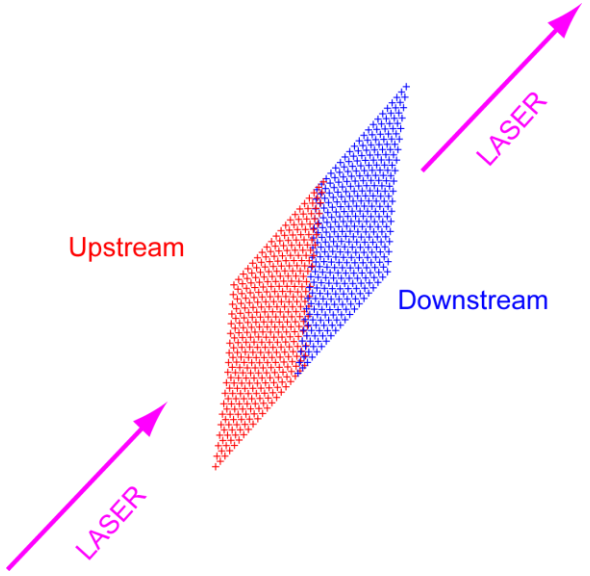
Scaled Drawings Split-bundle Field of View with distributed points



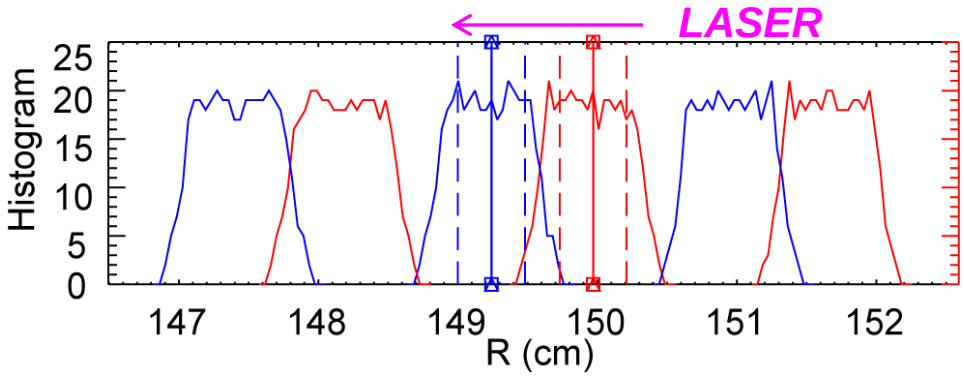


“Statistical” Crosstalk Evaluation

- Statistical analysis based on 400 points per split bundles



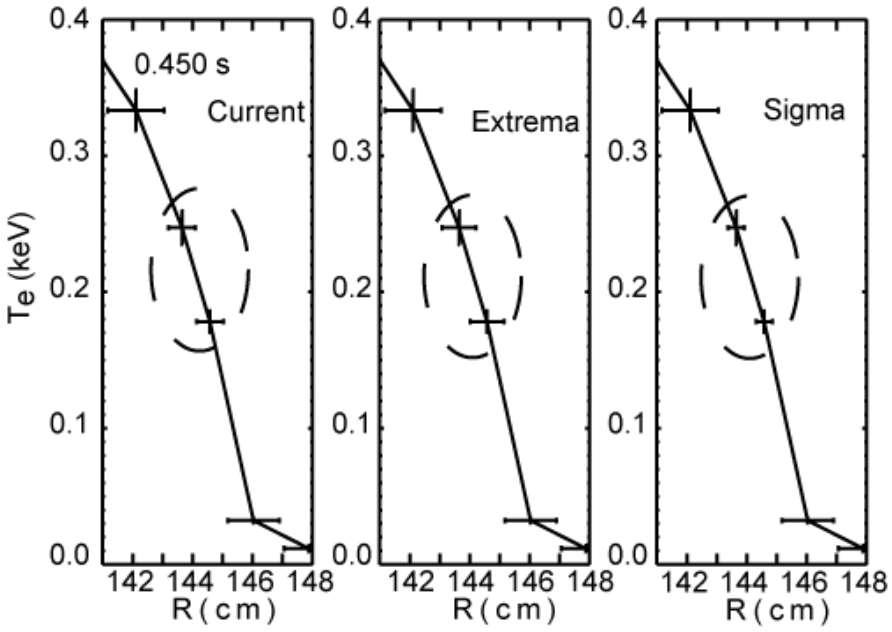
- ***Compute histograms of R corresponding to these points***
  - ±1 sigma indicated with vertical dashed lines
  - ***Crosstalk absent for ±1 sigma***



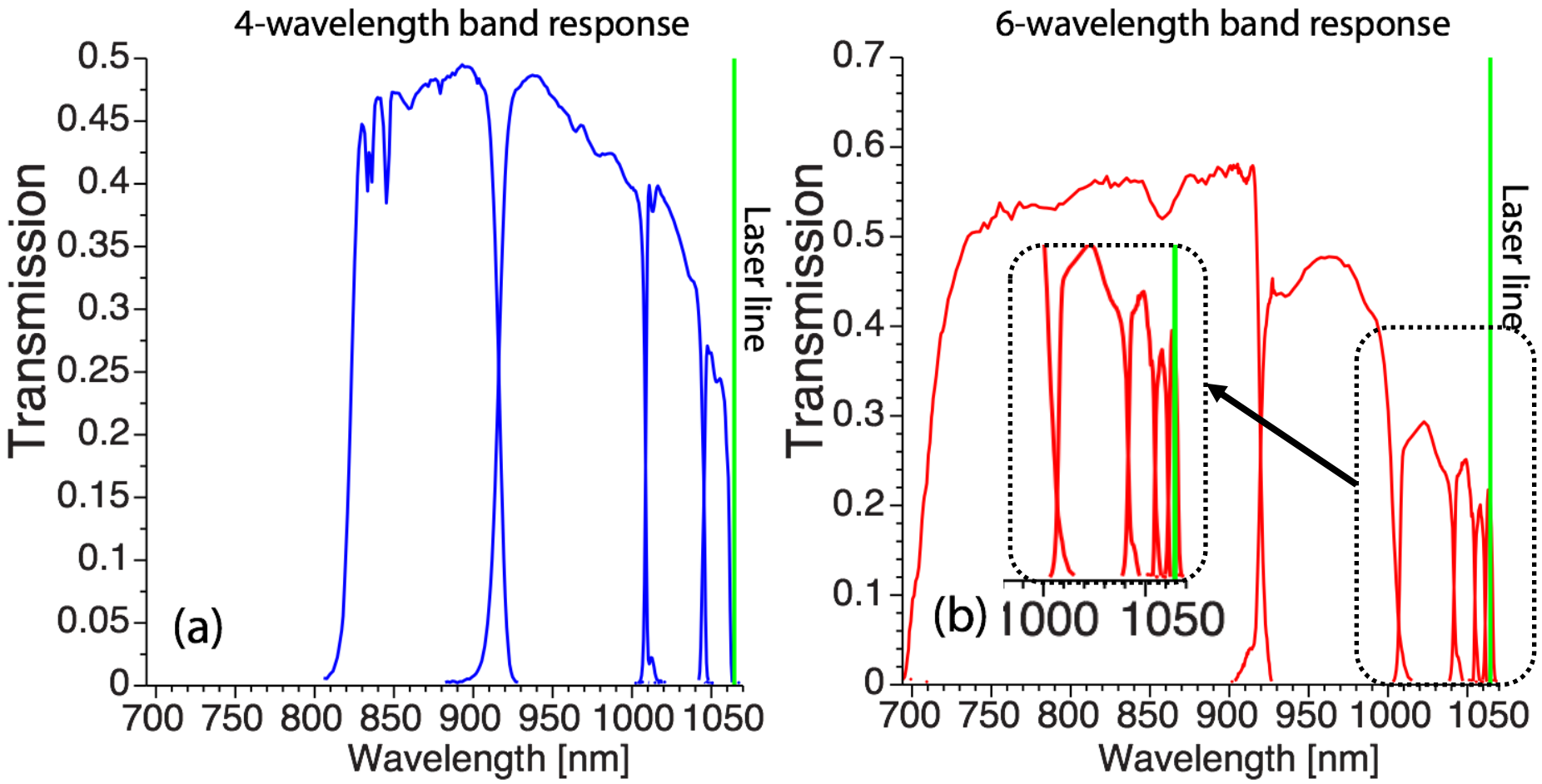
Histograms of R for three consecutive fiber bundles viewing near R=150cm.

Radial Span Overlap Estimates

- Major radius overlap between sub-bundles
  - Geometric estimate: 24-34% of R span of split bundle
  - Statistical estimate with 400 points per split bundle
    - ±1 sigma of R sampling shows no radial overlap
- Figure shows comparison of the three radial span calculations:
  - MPTS current estimates
  - Estimate based on hexagon extrema
  - Estimate based on even distribution (Sigma).
- The current calculation falls between the extrema and one-sigma evaluation.

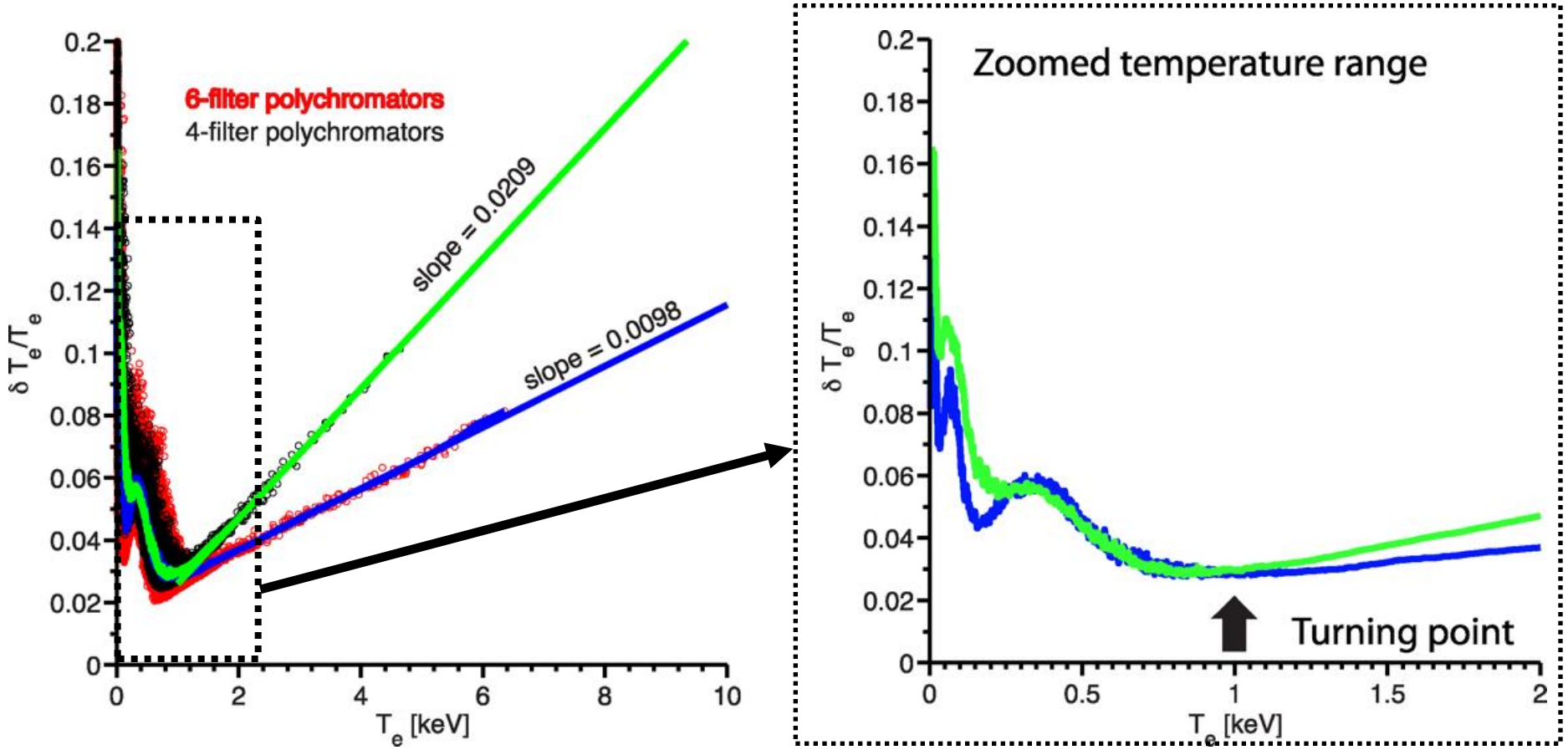


Example of the Polychromators Filter Response



Thomson scattering system on NSTX has two types of polychromator

Relative temperature error scaling projection for NSTX-U Using existing polychromator filter sets



- Extrapolation to 10 keV yields ±11% with 6-filter polychromator and ±20% with 4-filter polychromator
- Need to assign the 6-filter polychromator to plasma core measurements (now)
- Need to adjust filter array for more coverage on the “blue” side (in future)

Concluding Remarks - Future Work

- The hardware modification design is ongoing
- Installation will occur in fall of 2013
- Schedule MPTS ready date of March 2014
- The laser beam path has been re-aimed in order to avoid ablating the new center stack tiles
- The mirror collection optics will be refocused along new laser beam path
- We extrapolate to NSTX-U the error on the electron temperature in high performance discharges
  - Rearrange 4 filter polychromators to insure that they sample temperature less than 1 keV
  - Consider implementing a 7- or 8-filter polychromator?
- Ongoing work for ex-vessel in vacuum beam dump and calibration probe