Abstract

The central electron temperature, Te(0), of the Pegasus Toroidal Experiment is a key measurement for evaluating plasma quality, constraining equilibrium reconstructions, and monitoring RF heating. Te(0,t) is determined by two-color broadband spectroscopy of the soft x-ray continuum. Decreased sensitivity at lower plasma temperature limits this method to determining central Te. Analysis of impurity line intensities supplements this method by using the ratio of intensities at specific wavelengths. This ratio estimates concentrations of ionized states of an impurity, which infer Te(0). The Pegasus prototype system contains six photodiodes, four diodes for the impurity lines of CIV, CV, OVI, and OVII, while the other two use 2 and 3 mil thick Be filters. The expected range of Te(0) is 100 to 500 eV with a target frequency resolution of 2 kHz. The accuracy will be checked independently using a soft x-ray pulse height analysis method employing a CCD detector.

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Problem Statement

- Central electron temperature, T_e, required measurement in determining plasma characteristics.

- Thompson scattering most prominent T_e diagnostic, but system cost is too great for small experiments.

- Soft x-ray emission depends heavily on T_e and is easily detected using photodiodes.

- Focusing on line emission from impurities or continuum emission from free electrons are two independent means of determining T_e.

- Inexpensive, multi-layer filters enable selection of photon wavelength transmission to photodiodes.

T_e Determination Using Ratios of Impurity Line Intensities

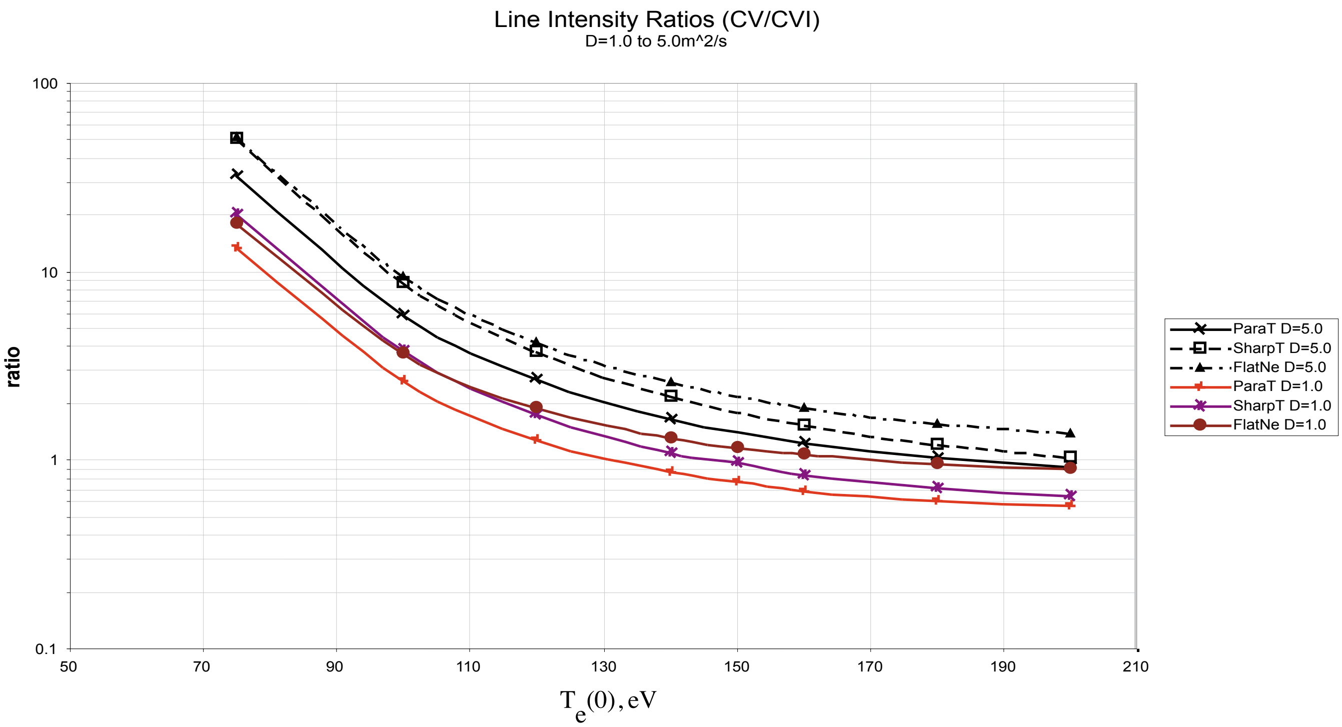
- Central electron temperature measured by comparing the intensities of line emission from different ionization states of impurities.
- Use standard, large area soft x-ray photodiodes.
- Photodiodes covered with multi-layer absorber films to limit absorbtion of photons to specified wavelengths.
- The Ross Filter system on Pegasus observes transitions: 4.0268 nm (C*V*), 3.3736 nm (C*VI*), 2.1602 nm (O*VII*), and 1.897 (O*VIII*) nm.
- Using two impurity species allows the system to obtain a range of $T_e(0,t)$ corresponding to 70 to 150 eV for the carbon ratio and 150 to 400 for the oxygen ratio.

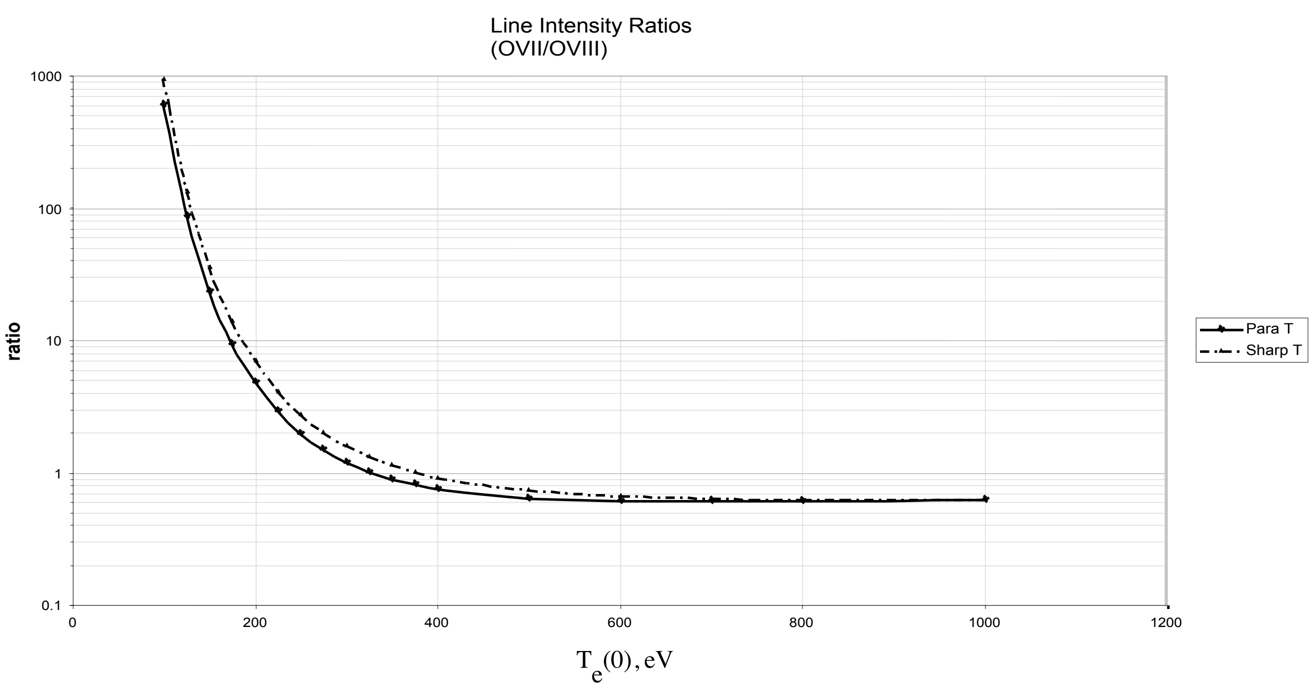
Strong Correlation of Line Intensity Ratio to T_e

- MIST results indicate applicable range of $T_e(0)$ for each species:

  C: 70 to 150 eV

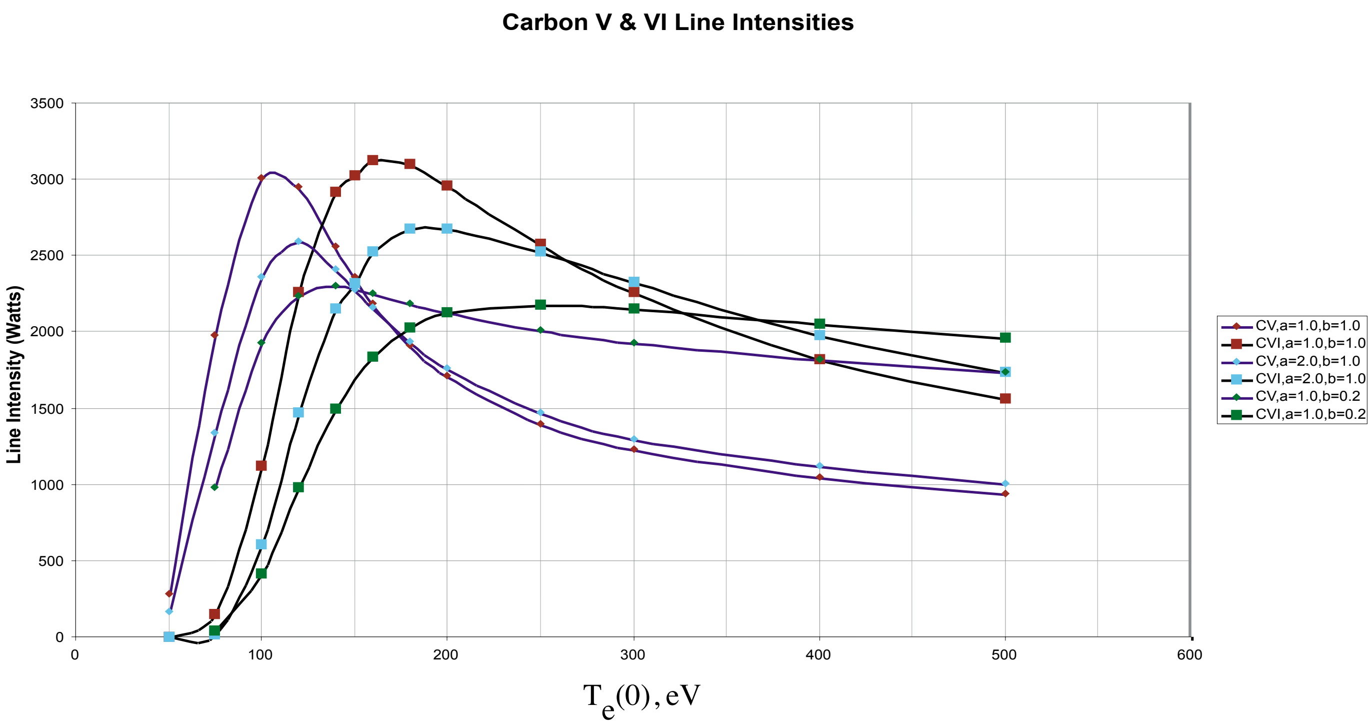
  O: 150 to 400 eV

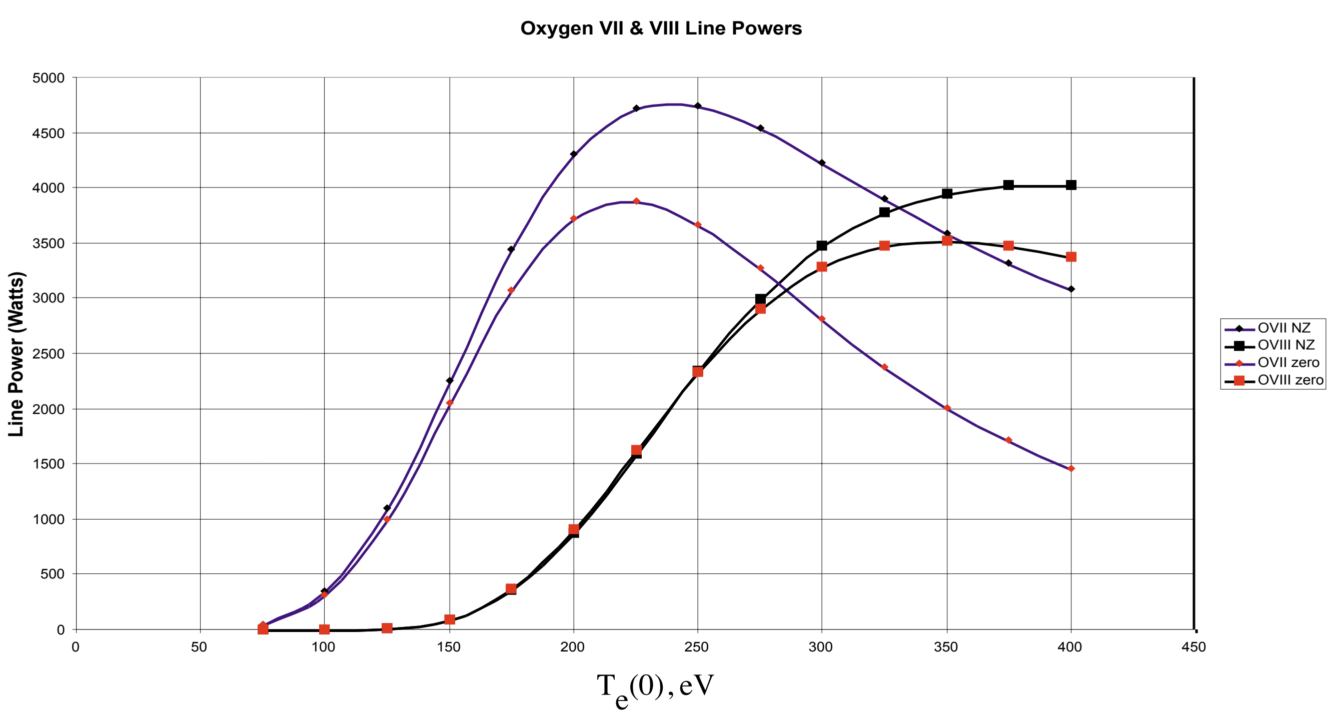




Modeling Ion Transport Effect on Local T_e

- Use Multiple Impurity Species Transport code to model line intensity
  - Cover wide range transport coefficients and plasma profiles
- Line power intensity plotted vs $T_e(0)$ for different profiles

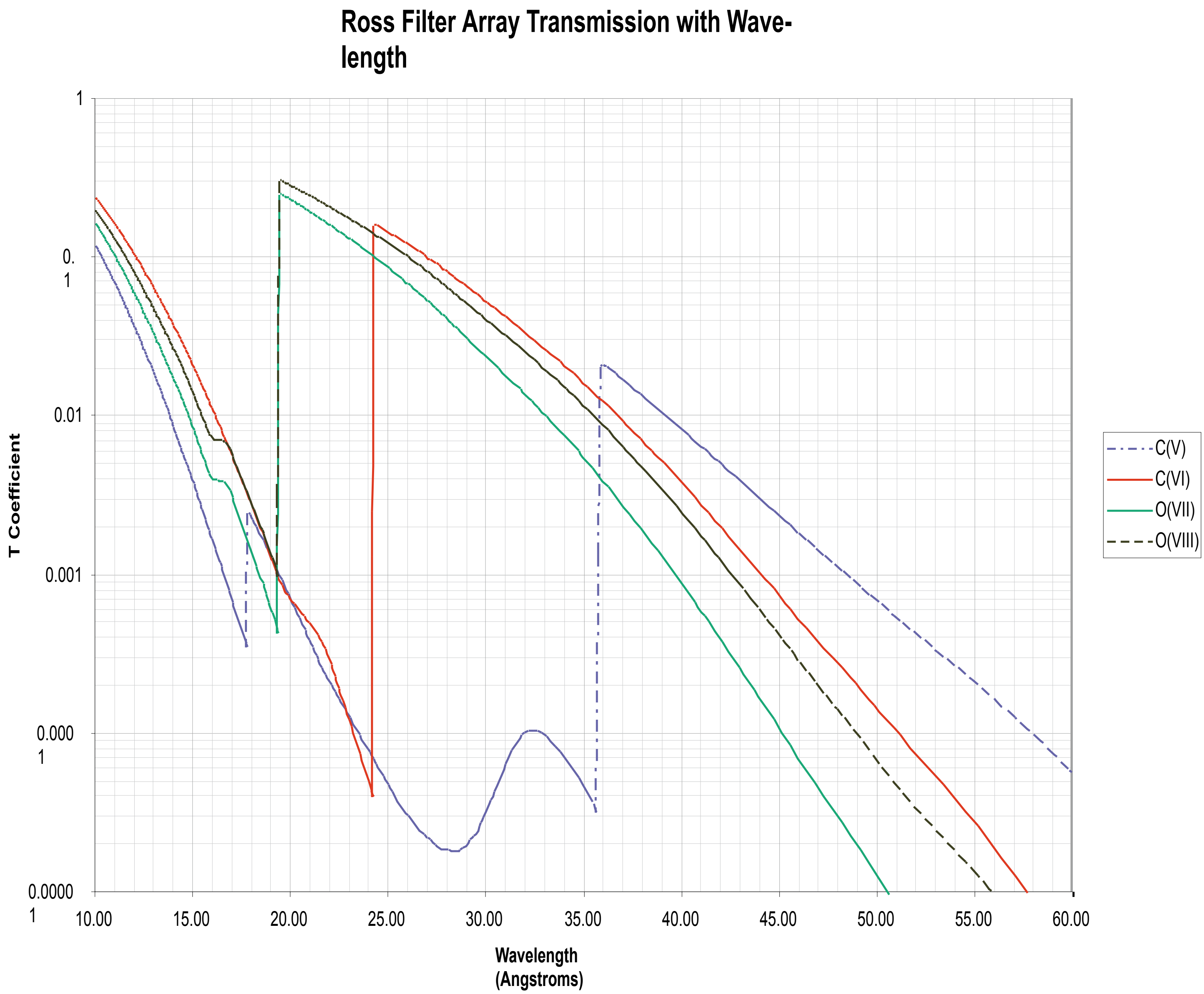




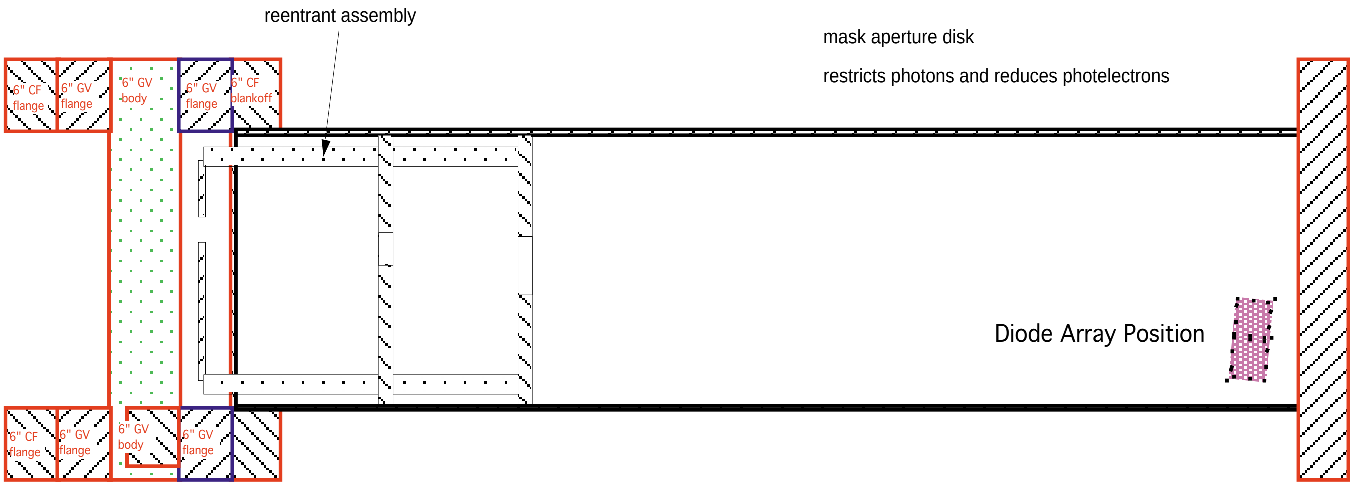
Ross Filter Transmission Curves

Material Composition of Filter:

C*V*	2000 Å Al, 2500 Å Ag, 1 µm CaF_2
C*VI*	4000 Å Al, 6000 Å V
O*VII*	5000 Å Al, 5000 Å Mn
O*VIII*	4000 Å Al, 4500 Å Fe



Prototype Soft X-ray Detector



- Simple set of six diodes installed on PEGASUS for T_e estimates.

- Diodes are the AXUV-100 from International Radiation Detectors Inc

  Active Area: 10 x 10 mm

  Set for central cord observation

- Multi-layer absorber foils directly deposited on diodes.

T_e Determination using SXR Multi-color Analysis

- $T_e(0,t)$ obtained from integrated SXR continuum measurement.

- Signals from photodiodes measure different portions of the spectrum determined by metal absorber foils.

- Electron temperature found from signal ratio using this equation:

$$I = F \cdot e^{-\left[\frac{h \cdot \omega}{k \cdot T_e}\right]}$$

where F is proportional to the inverse of the square root of T_e.

- Signal ratios can be predicted for various plasma conditions and a database can be formed to interpret data collected from experimental plasmas.

SXR Calculations to Set Foil Thickness

- X-ray code used to predict intensity of of photons emitted for a given plasma tangency radius.
- Specify plasma size, profile parameters, foil thickness, and impurity information

Parameters supplied for Analysis Illustration

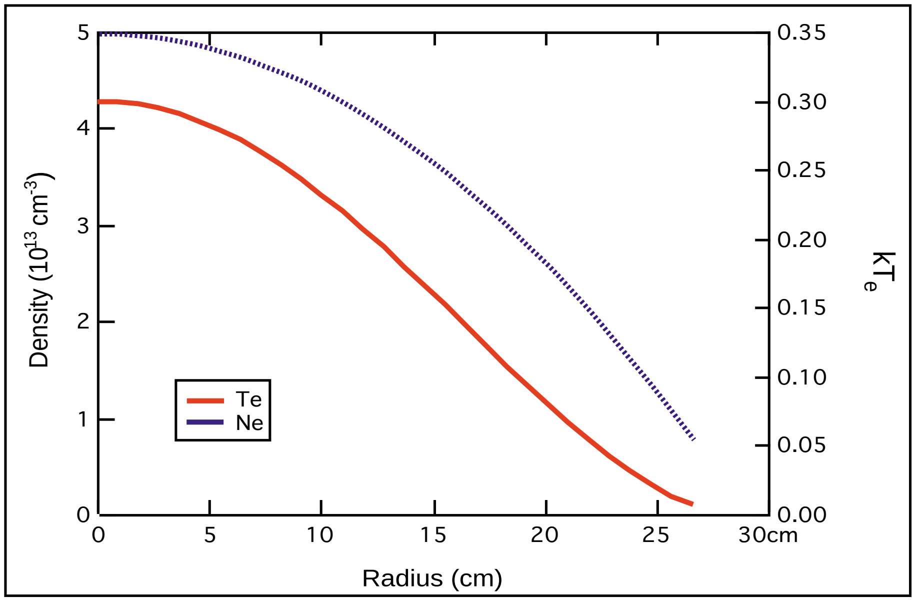
Major radius (cm): 35	Minor radius (cm): 29
Density profile r/a exponent: 2	Density profile total exponent: 1
Temperature profile r/a exponent: 2	Temperature profile total exponent: 2
Central Temperature (KeV): 0.3	Central density (10-13 cm-3): 5
Number of points in radial profile: 30	Max photon energy (KeV): 10
Foil 1 : Be thickness (mil): 3	Foil 2: Be thickness (mil):: 4
Foil 1 : Al thickness (mil):: 0.00394	Foil 2: Al thickness (mil): 0.00394
Foil 1 : ?? thickness (mil): 0	Foil 2: ?? thickness (mil): 0
Number of points in chordal integral: 5000	

Photon Central Spectrum Production

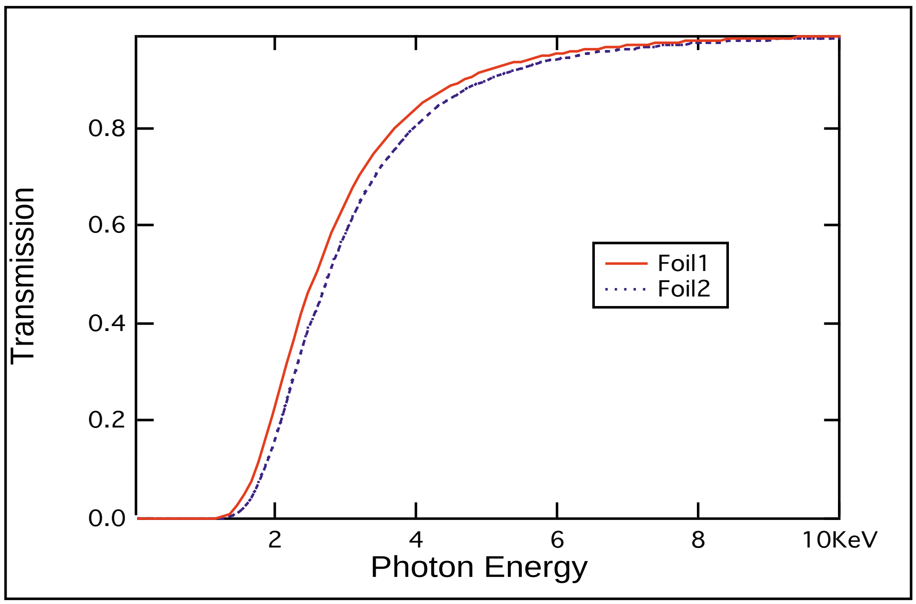
- Plasma profiles

$$N_e = N_0 \cdot \left[1 - \left(\frac{r}{a}\right)^{\alpha_N}\right]^{\beta_N}$$

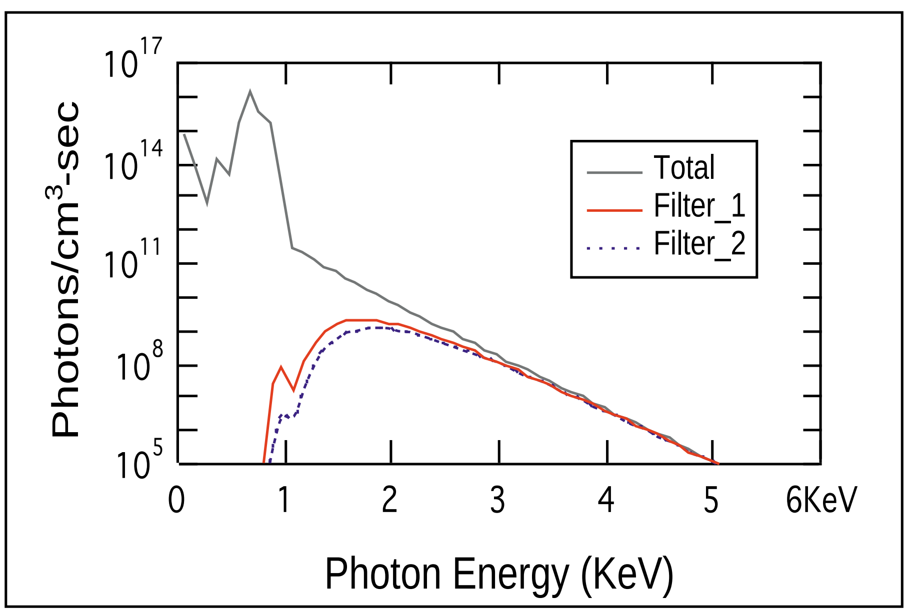
$$T_e = T_0 \cdot \left[1 - \left(\frac{r}{a}\right)^{\alpha_T}\right]^{\beta_T}$$



- Transmission curves
- Foils specified in mils of Be
- Mass attenuation coefficients obtained from www.cxro.lbl.gov/

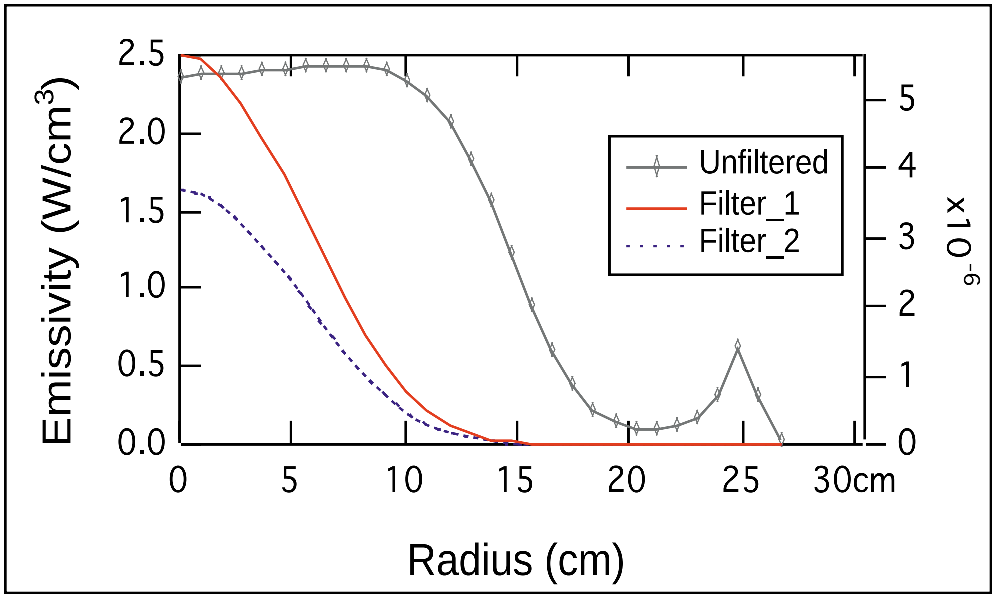


- Central photon spectrum

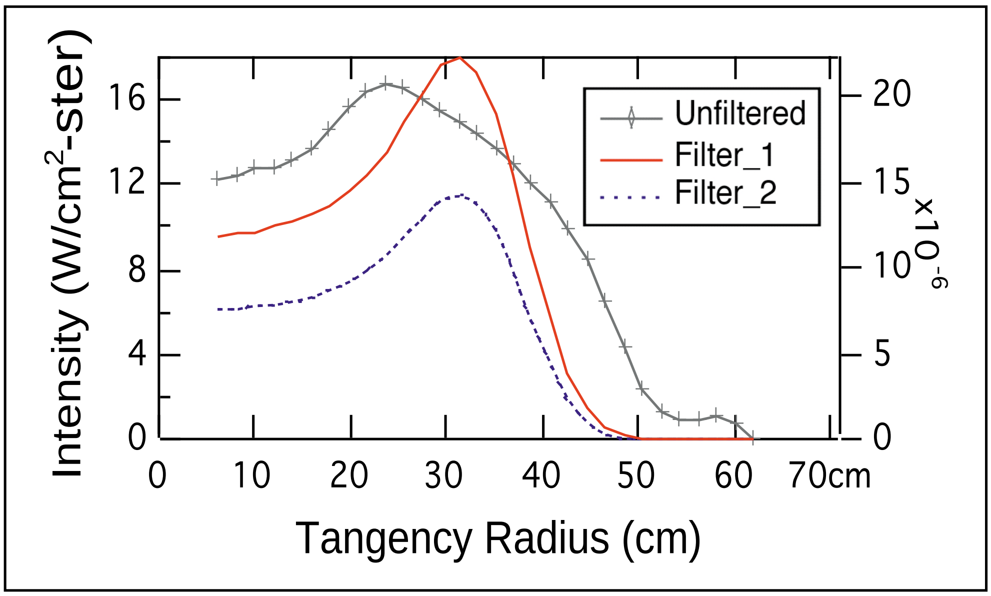


Obtaining Intensity for Foil Settings

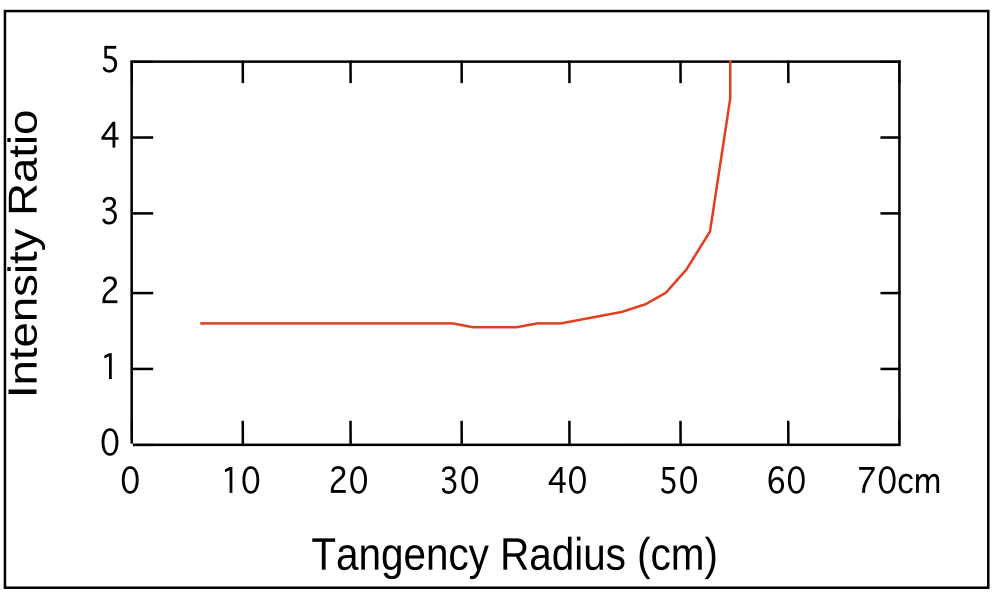
- Emissivity vs minor radius



- Intensity vs tangency radius

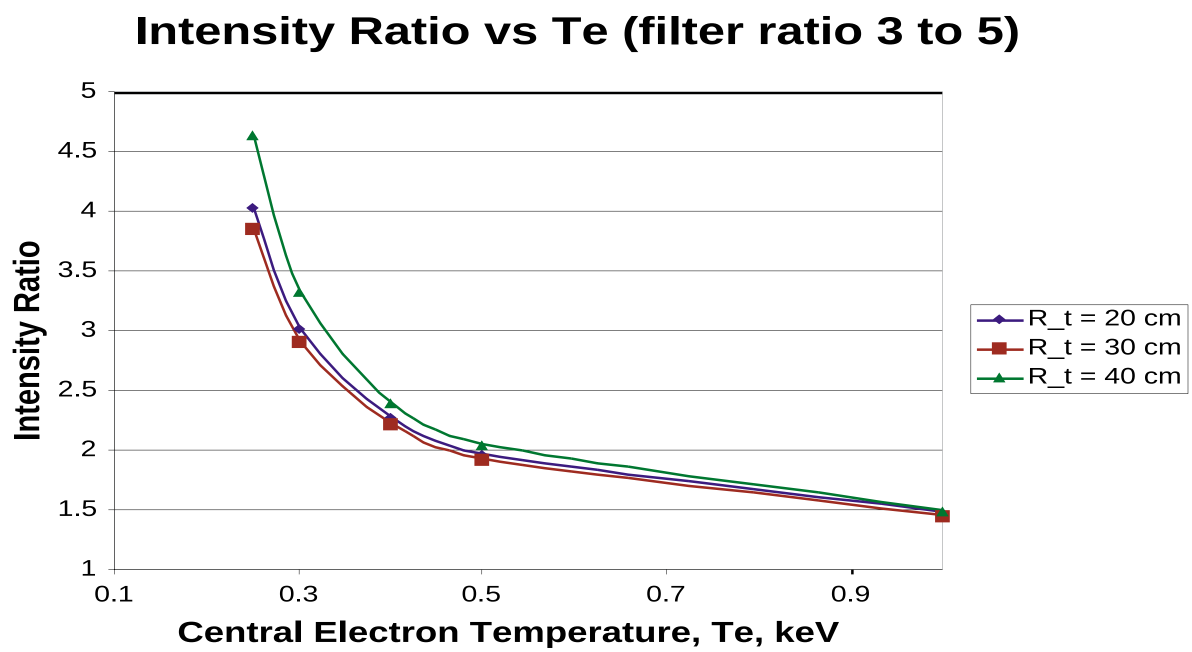


- Intensity ratio vs tangency radius

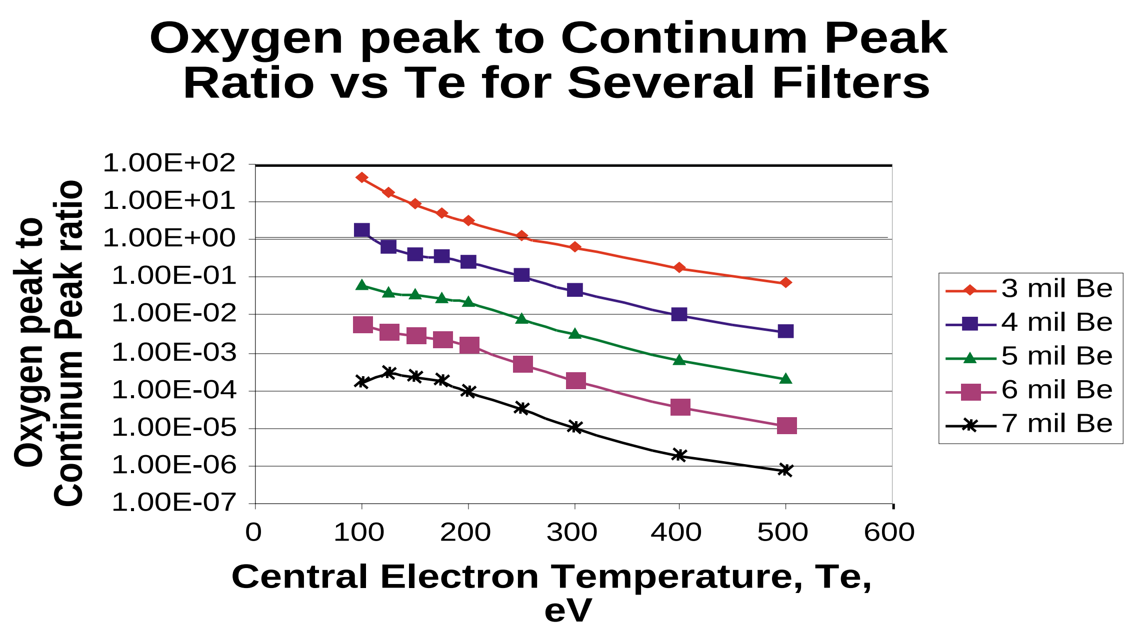


Further Signal Modeling

- Intensity ratio represents the signal ratio obtainable from the diodes.



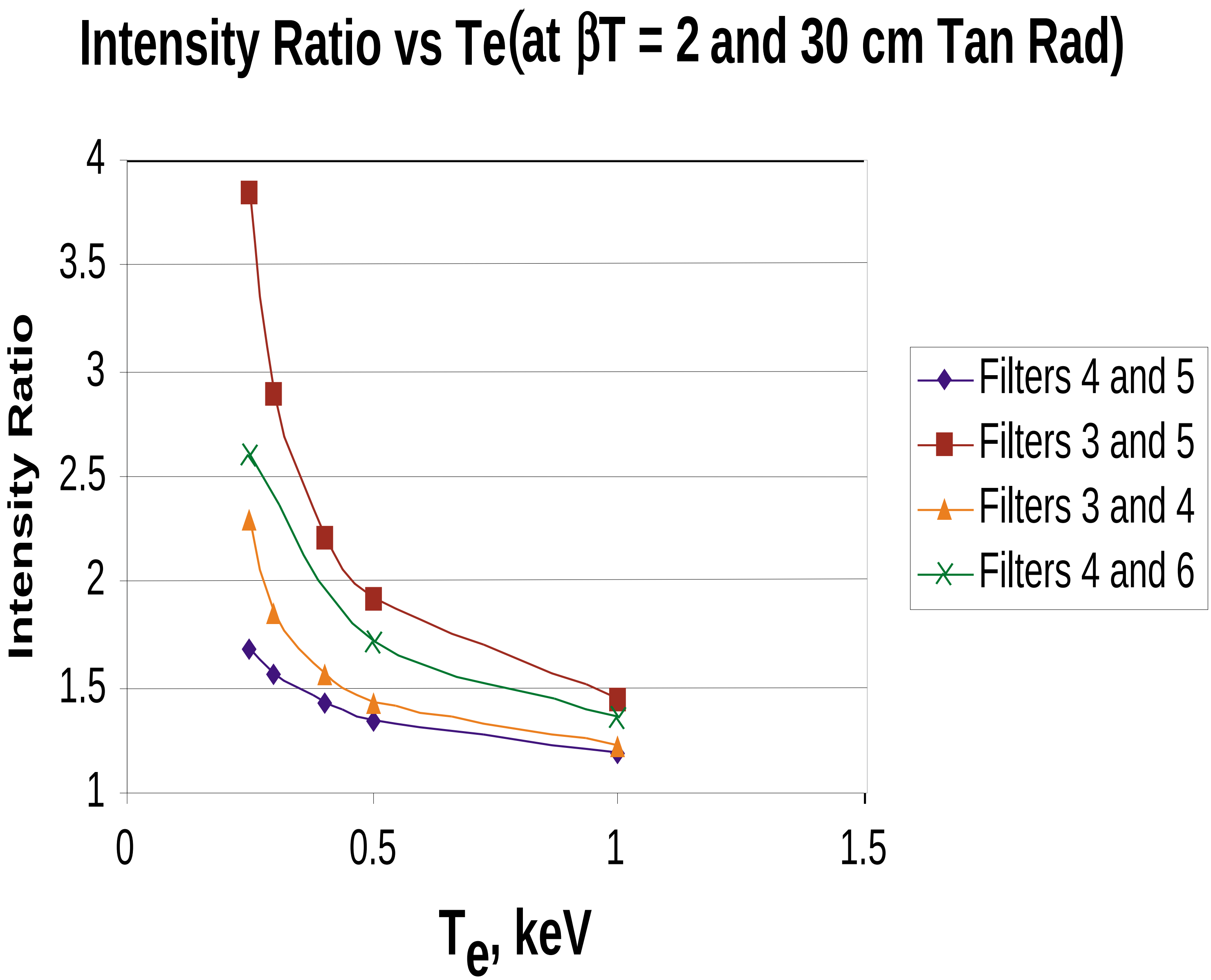
- Intensity ratio insensitive to tangency radius



- Larger foil thickness needed to surpress oxygen line contributions at lower T_e.

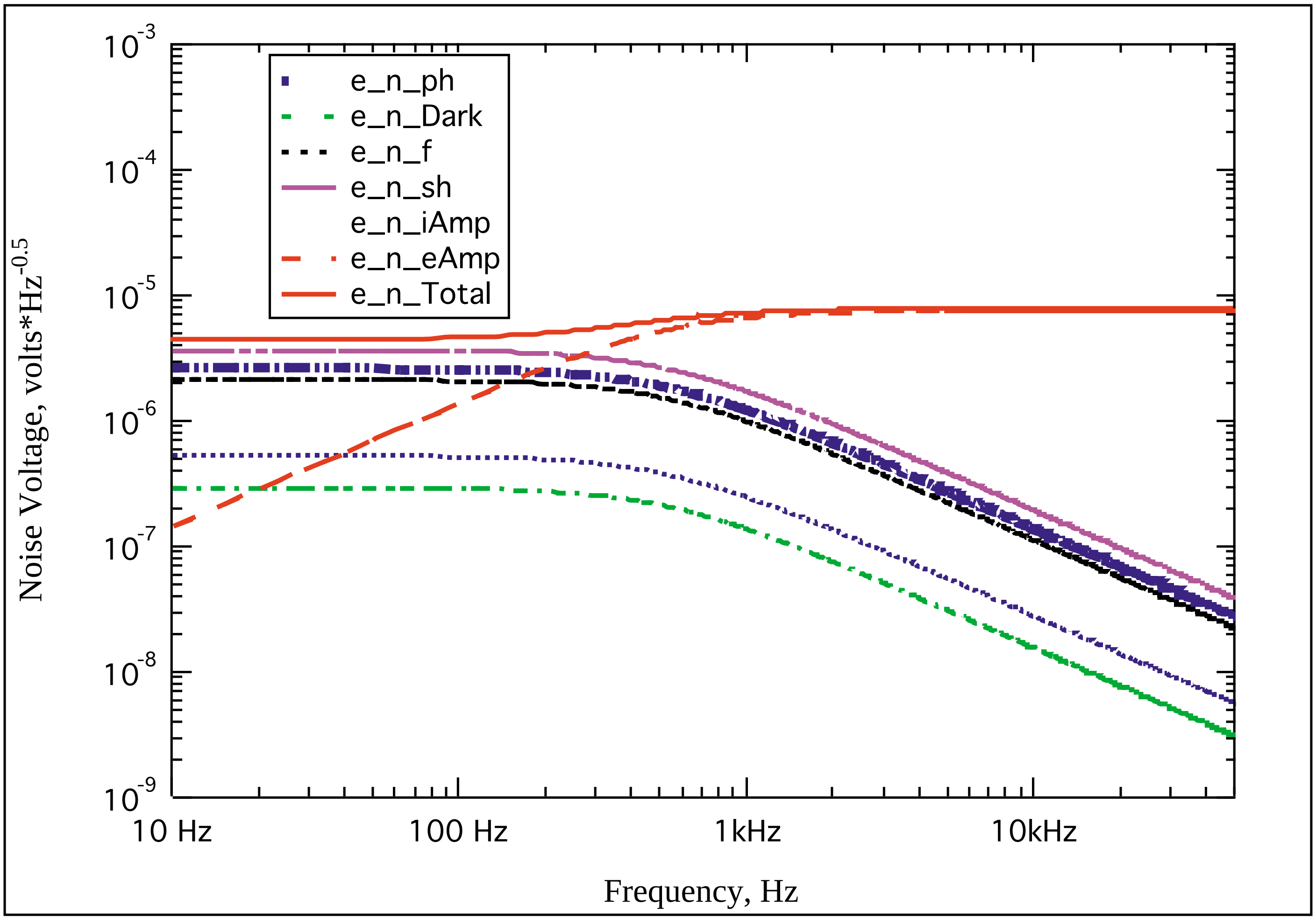
Foil Combinations Appropriate for PEGASUS

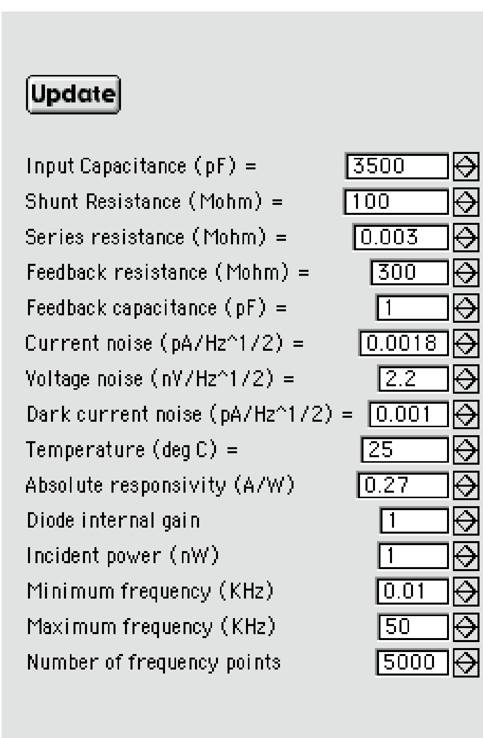
- Technique provides reasonable estimate of T_e for PEGASUS conditions.
  - Applicable for $T_e > 200$ eV
  - Compliments lower T_e sensitivity of Ross Filters



Filter numbers reflect filter thickness in mils

Noise Analysis





$$e_{nT}^2 = Z_f^2\left[\left(\frac{e_{nA}}{Z_S}\right)^2 + i_{nA}^2 + i_{nSh}^2 + i_{nf}^2 + i_{nD}^2\right]$$

$$Z_f = R_f / \left(1 + \omega^2 C_f^2 R_f^2\right)^{1/2}$$

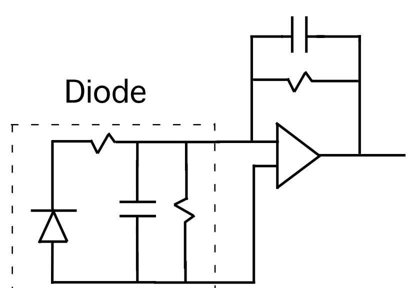
$$Z_S = R_{Sh} / \left(1 + \omega^2 C_j^2 R_{Sh}^2\right)^{1/2}$$

$$i_{nSh} = \left(\frac{4KT}{R_{Sh}}\right)^{1/2}$$

$$i_{nf} = \left(\frac{4KT}{R_f}\right)^{1/2}$$

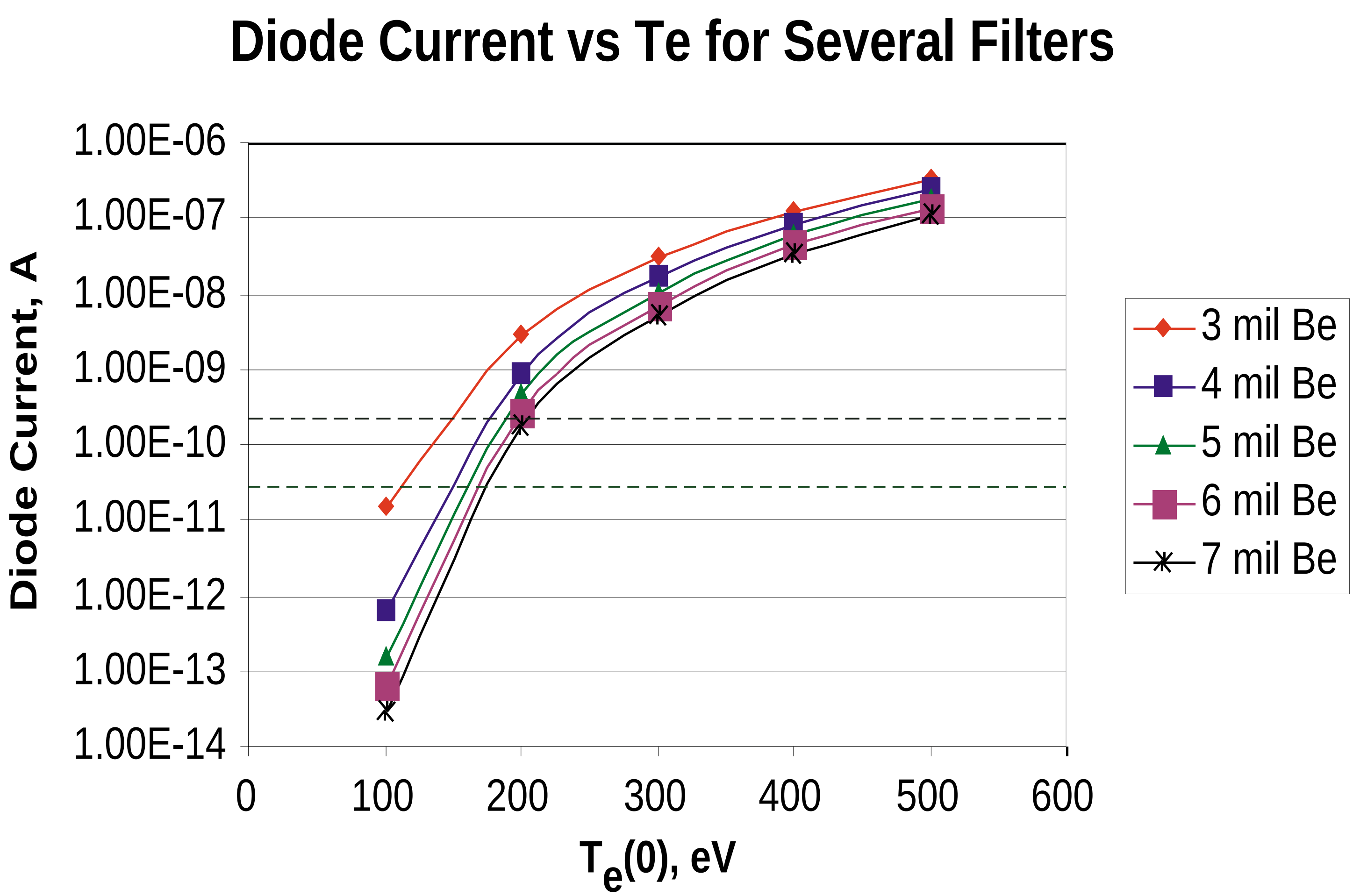
$$e_{Pc} = Z_f M \left[2qP_\gamma \xi F\right]^{1/2}$$

Feedback Capacitor and Resistor

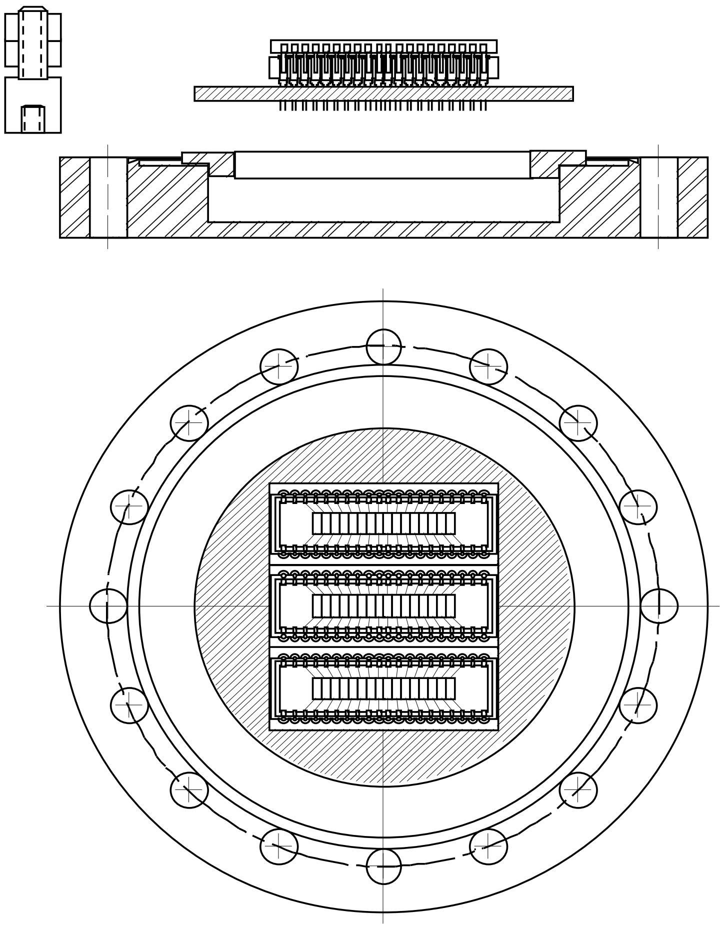


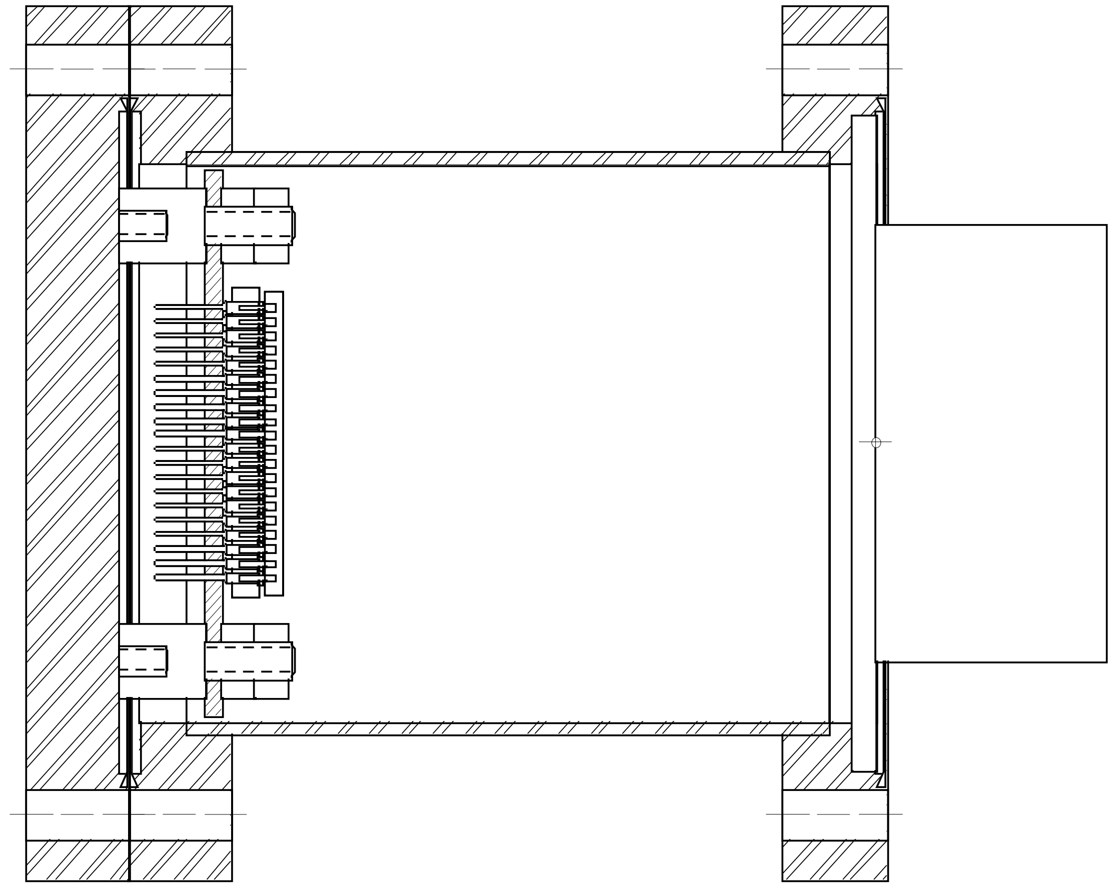
Expected Signal Levels

- Diode current found as the product of the incident power and diode efficiency.
- Incident power calculated from the intensity determined in x-ray code, adjusted by the optical throughput of the detector.
- Current noise on the order of 0.1 nA, represented by dashed green lines in the plot.
- Plot represents a central line of sight for diode.



Conceptual Design for Multi-color Array





- Conceptual design using integrated 16 diode array from IRD (AXUV-16EL).
  - Final design may discrete large area diodes.
- Filters mounted at vessel end of system housing.

Signal Processing of Photodiode Current

- Amplifier circuit used by BES system on DIII-D able to adequately amplify expected currents.

- Circuit easily modified to adjust gains and frequency response.

    Line intensity method:

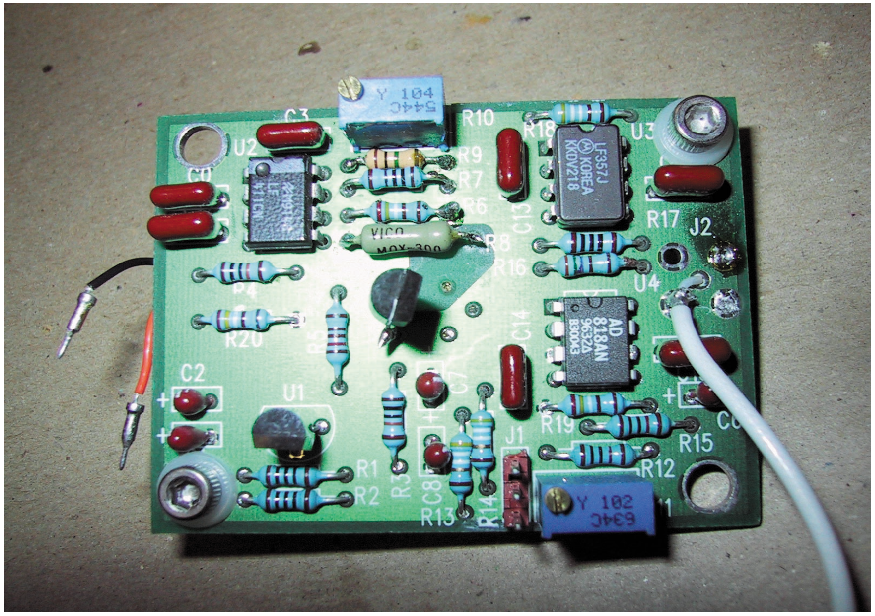
        Gain = 0.1 to 10 V/nA

        Bandwidth = 1 to 3000 Hz

    Multi-color method:

        Gain = 10 to 100 V/nA

        Bandwidth = 1 to 3000 Hz



- Adequate shielding and proper placement required to minimize vertical field pick-up and cable loss.

Summary of Investigation

- Line intensity system good for $T_e(0,t)$ less than 300 eV.

- Multi-color filter system optimal for $T_e(0,t)$ greater than 200 eV

- Combined system gives $T_e(0,t)$ for PEGASUS temperature range:

  0.1 to 1 keV

  - Four diodes and filters for line intensity method
  - Four diodes and filters for multi-color method

- Prototype Ross filter system on PEGASUS

- Complete eight diode system to be installed late 2001

Reprint Requests