Electron Temperature Diagnostics on the Pegasus Toroidal Experiment

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Abstract

A soft X-ray (SXR) Pulse Height Analysis (PHA) system has been implemented to measure the electron temperature on the Pegasus Toroidal Experiment. The detector is a silicon drift diode (SDD) mounted on a bellows. The SDD detector is well suited for high resolution (139 eV at 5.9 keV), high count rate (10^6 cps) X-ray spectroscopy and therefore is able to obtain time-resolved temperature measurements on the order of a millisecond. The detector is radially scannable which permits profile measurements on a shot-to-shot basis with a spatial resolution as low as a few centimeters. Temperatures in the range of 300eV - 1keV should be measurable with the PHA system. Temperatures below 300 eV can be measured using oxygen and carbon line ratios with SXR Ross filter spectroscopy. A Thomson-Scattering system is also being designed for future implementation. The first generation of the diagnostic will include a 10 J, 40 ns Q-switched ruby laser ($\lambda = 694.3$ nm) and a single-spatial-channel avalanche photodiode detector/spectrometer system.

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Motivation

- T_e is a figure of merit for plasma performance and confinement properties
- T_e measurements support equilibrium reconstruction and stability analysis
  - Important for q-profile and current drive modeling
- Deployment strategy must match available resources

T_e Measurements on Pegasus

First generation T_e diagnostics

- SXR Ross Filter spectroscopy (70 eV - 300 eV)
  - Spectral line intensity ratio of impurities provides crude measurement of T_e
  - Temporally resolved measurements
- SXR Pulse Height Analysis (200 eV - 1 keV)
  - SXR continuum spectrum depends strongly on T_e
  - Temporally and spatially resolved measurements
  - SXR emission code developed to model Pegasus system

Second generation T_e diagnostic

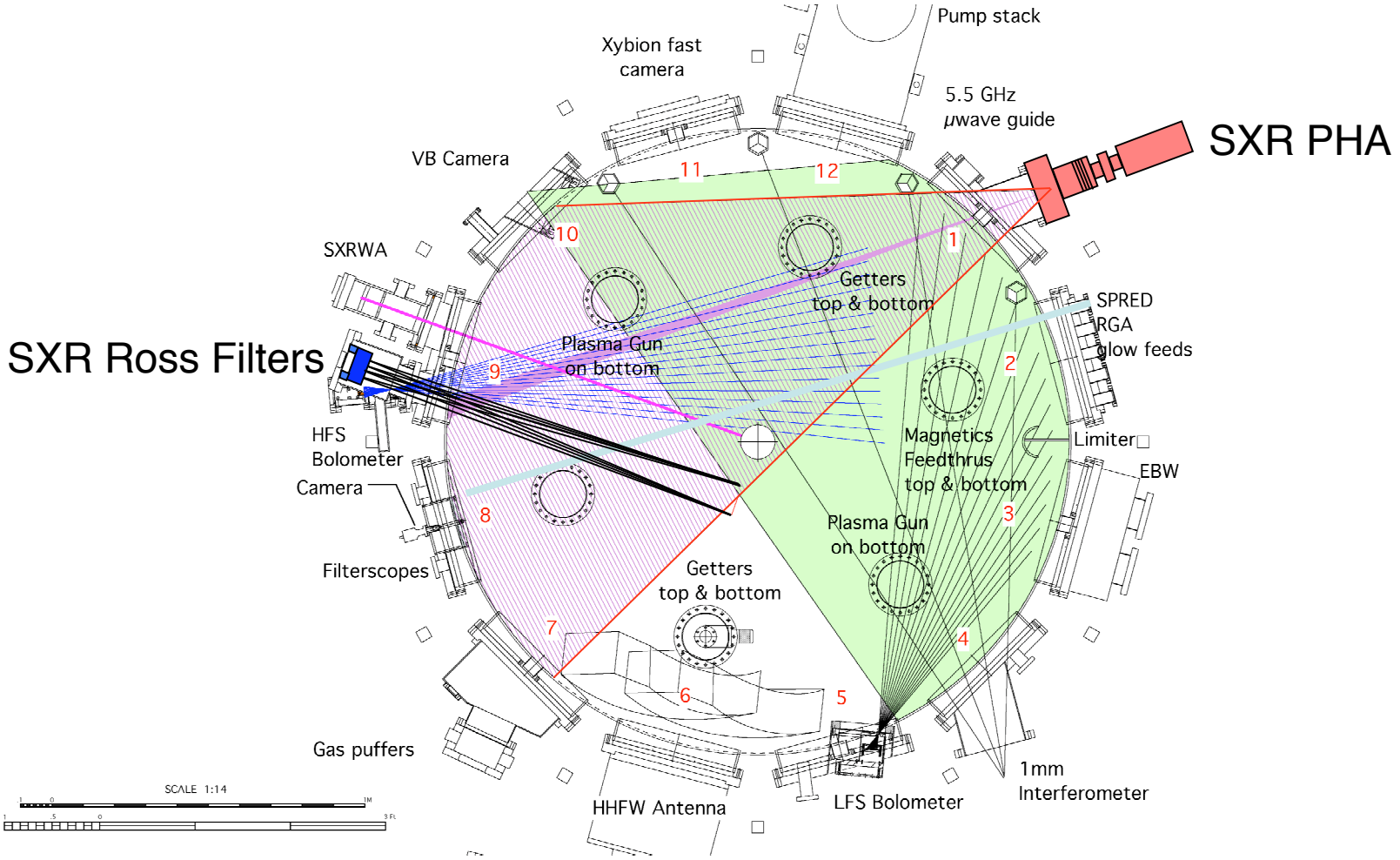
- Thomson Scattering (20 eV - 1 keV)
  - Ruby laser TS system from MST
  - Collection optics from MST and Phaedrus-T

Pegasus Diagnostic Suite

Diagnostic	Capability	Measures	Status
Core Flux Loops	6	V_L, Y_{pol}	Operational
Wall Flux loops	6	Vessel currents	Operational
Int. Flux loops	20	Y_{pol}	Operational
Rogowski Coils	2	I_p	Operational
Diamagnetic Loop	2	F_{tor} / b_p	Operational
Bp, Mirnov Coils	56	B_r , B_z / MHD activity	Operational
VUV (SPRED)	Central Chord	Relative impurity monitor	Operational
Interferometer	Single Chord	N_{el}	Operational
High Res. Camera	1000 fps	Plasma shape / position	Operational
Poloidal SXR Diode Array	19 chords	MHD Activity	Testing
Filterscopes	Central Chord	Oxygen, Carbon, VB, Da	Testing
Tangential SXR PHA	Single Chord	$T_e(t)$	Testing
Tangential Bolometer Array	32 Chords	P_{rad}	Testing
SXR Ross Filters	4 Chords	$T_e(t)$	Testing
Tangential VB Array	20 Chords	$Z_{eff}(R,t)$, $n_e(R,t)$	Testing
2-D SXR Camera		Internal Shape / q(R)	Planned
EBW Radiometer		$T_e(t)$	Planned

Pegasus Diagnostic Layout

First generation T_e diagnostics



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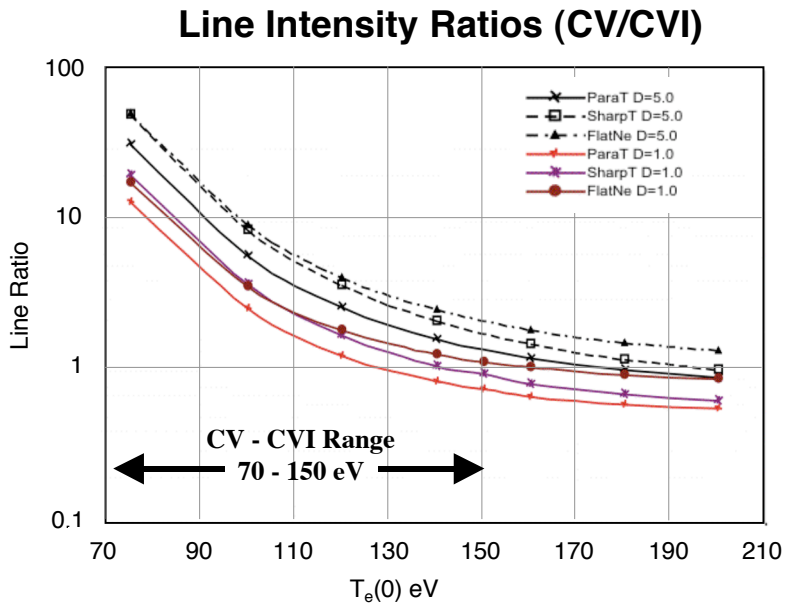
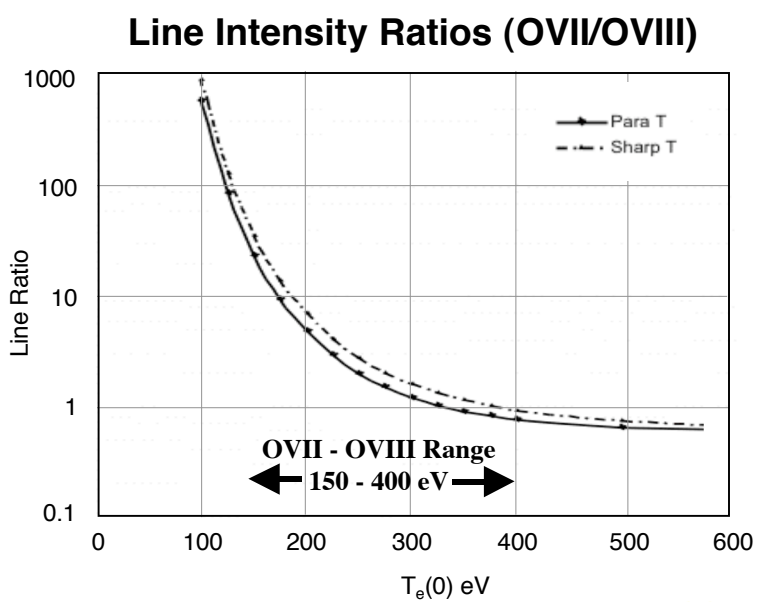
SXR Ross Filters

Central chord temperature measurement based on H-like and He-like impurity line intensity ratios for carbon and oxygen

MIST calculations of line ratios for both species considering different temperature profiles and diffusion coefficients (D)

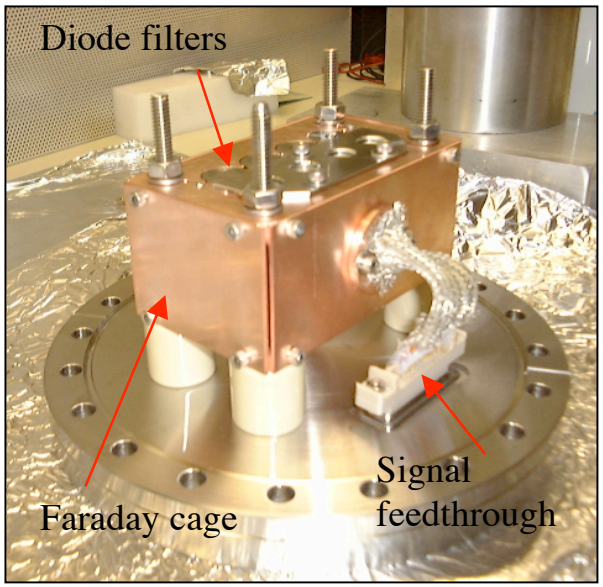




Ross filter system can provide a crude estimate of temperature since line ratios depend on temperature profile and electron diffusion rate.

SXR Ross Filter Diode Array

- Four diode pairs (8 total channels)
  - 10 x 10 mm diode size
  - AXUV-10 International Radiation Detectors Inc.
- Filters:
  - C_V (4.0268 nm)
  - C_{VI} (3.3736 nm)
  - O_{VII} (2.1602 nm)
  - O_{VIII} (1.897 nm)
- Temporal resolution ~0.1 ms
- The Ross Filter diode array has been implemented on the machine and noise suppression work is in progress

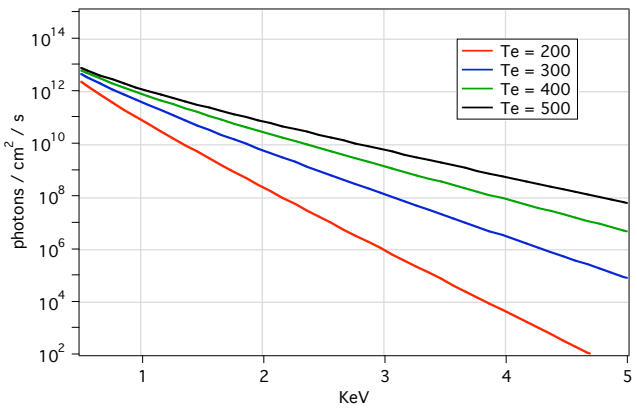


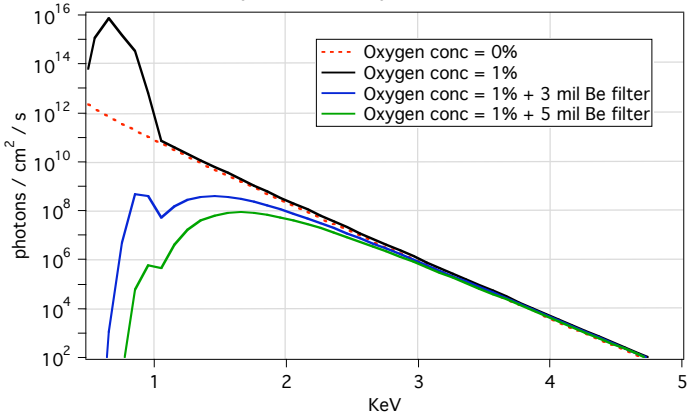
SXR Pulse Height Analysis (PHA)

Scannable midplane temperature measurement based on SXR continuum spectrum

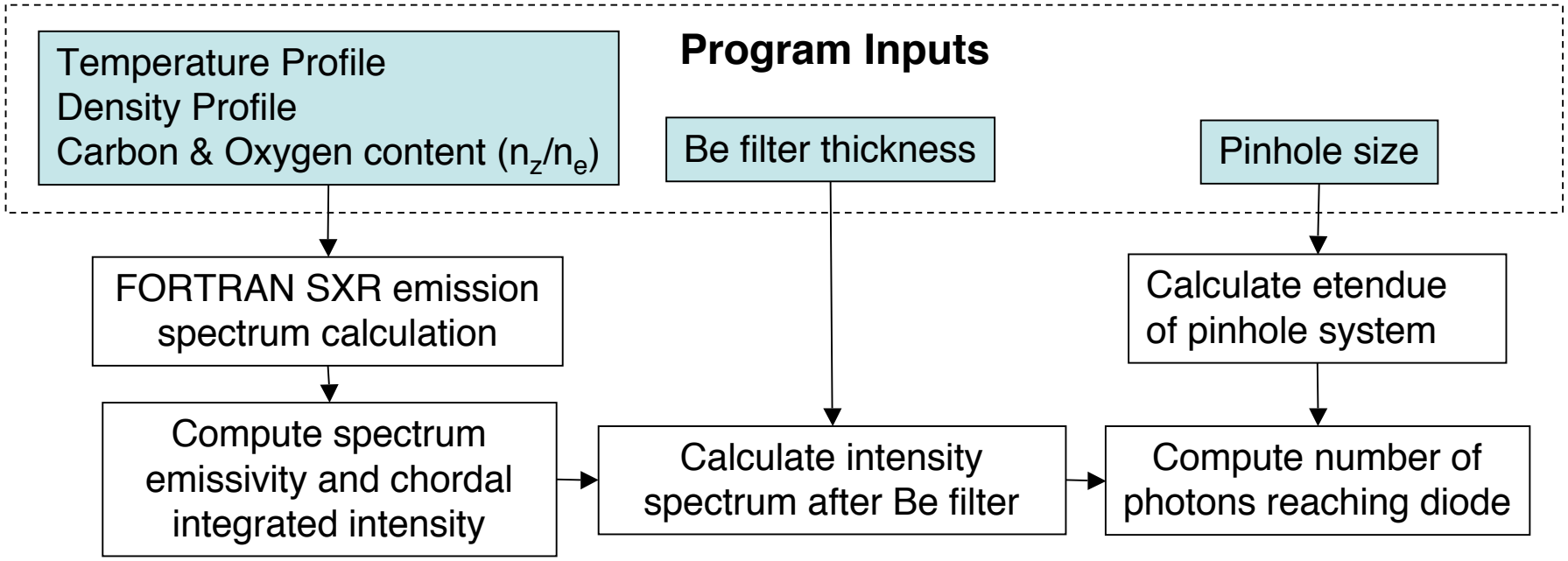
- For $h\nu \geq T_e$, the emission spectrum has an exponential dependence on T_e
- Oxygen recombination line radiation can dominate SXR spectrum
- Be filter is added to the system to attenuate emission below 1 keV

Model results for Pegasus-like plasma and current PHA design





SXR Emission Model for Pegasus



Based on code written by Ryan Schoof

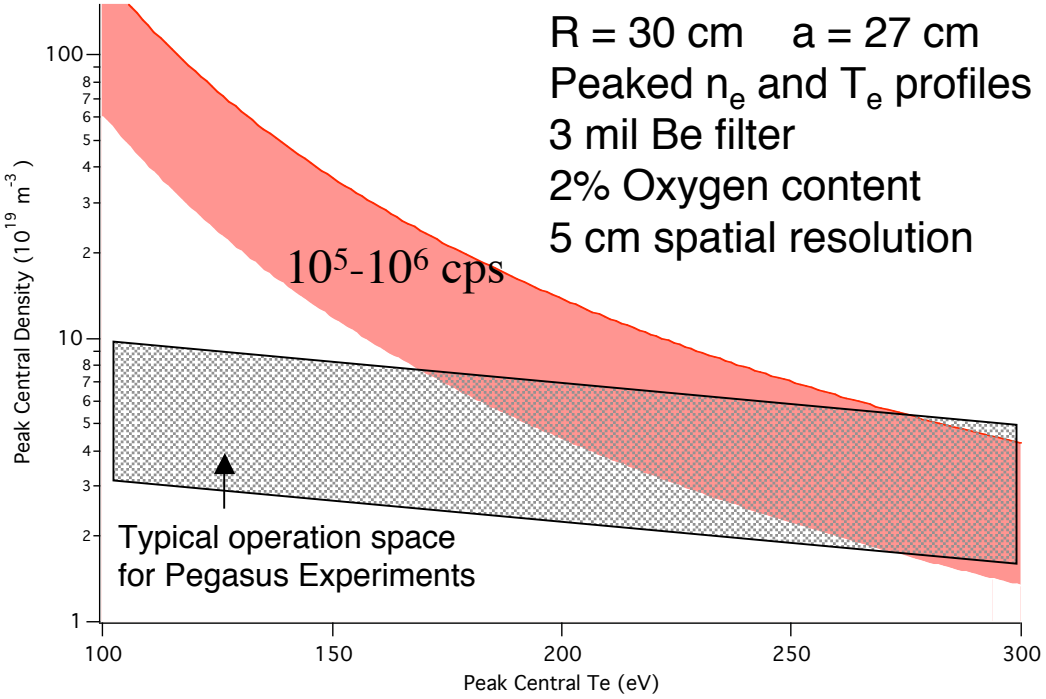
Design parameters influenced by SXR emission model

- Pinhole aperture: chosen so expected operating regime yields detector count rate of 10^5 - 10^6 cps

- Be filter: chosen so oxygen line radiation about equal to level of non-recombination radiation

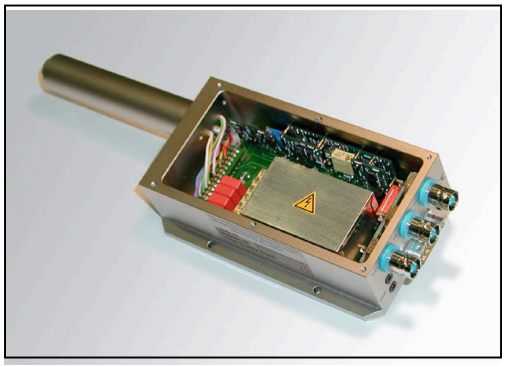
PHA Well Suited for T_e > 200 eV in Pegasus

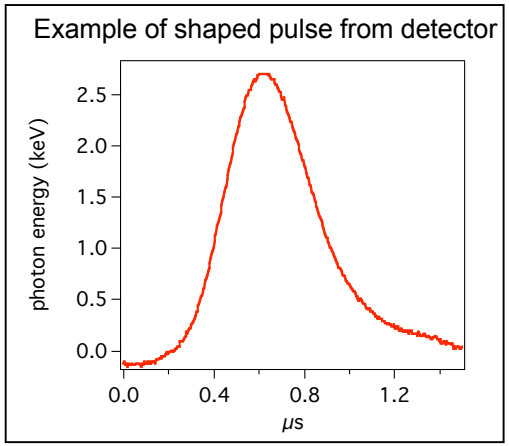
SXR emission code is used to model PHA performance for different plasma parameters.



It is possible to optimize the system for other operating spaces by changing the spatial resolution of the pinhole system.

Silicon Drift Diode Detector for SXR PHA





KETEK AXAS (Analog X-ray Acquisition System)

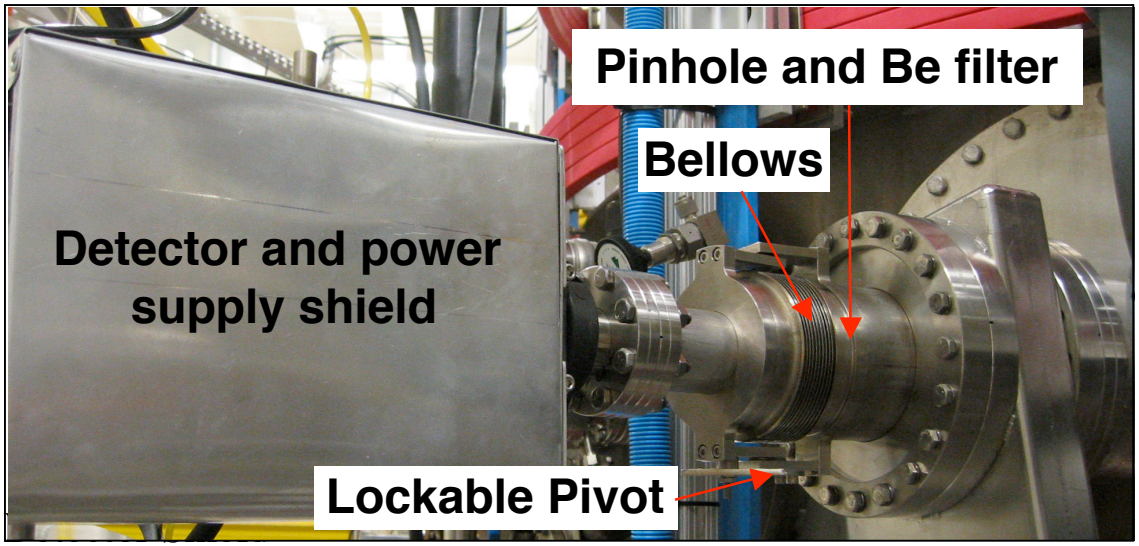
- Windowless
- Single channel
- Peltier cooling allows for room temperature operation with no external cooling
- 5 mm^2 silicon drift diode (SDD)
- Energy resolution ≤ 200 eV @ 5.9 keV
- Maximum count rates nearing 10^6 cps

Shaping electronics incorporated within detector

- Shaping time of 150 ns
- Allows operation at maximum count rate of detector with minimal pulse pile-up
- Aided by pulse pile-up correction software

Accurate temperature measurements require ~1000 pulses per spectrum. Thus, at 10^6 counts per second, the temporal resolution is ~1 ms.

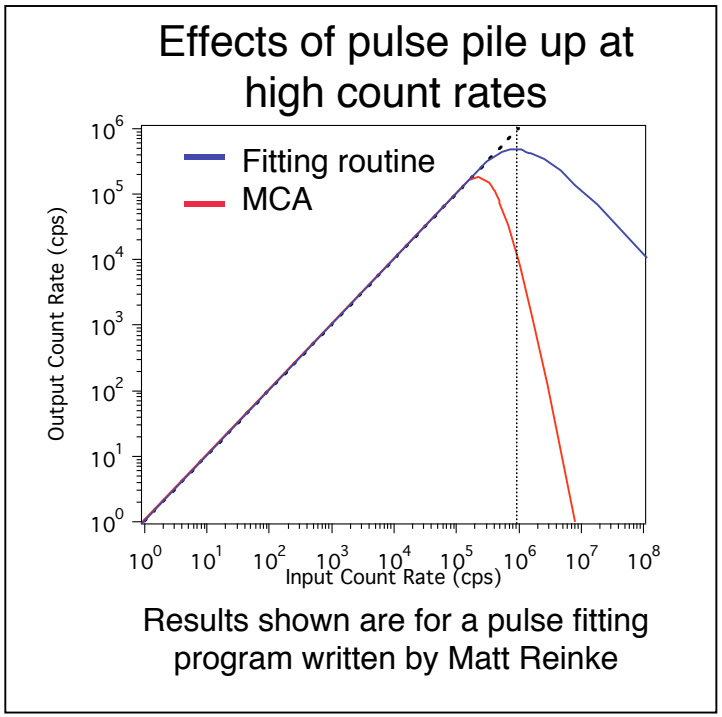
SXR PHA System

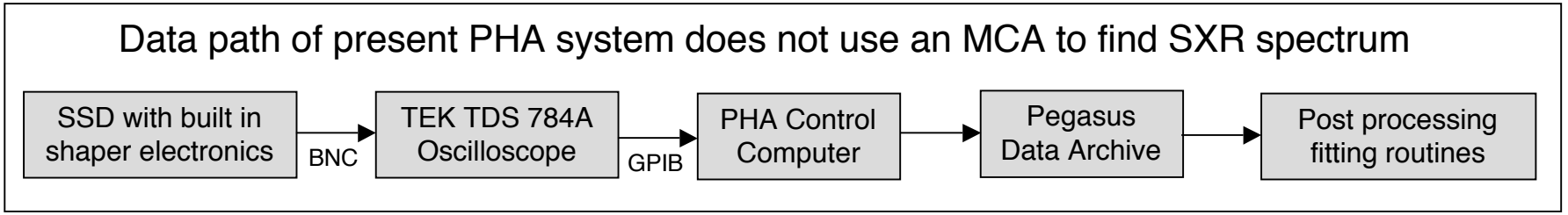


Tangency radii can be changed on a shot-to-shot basis

Pulse Fitting Reduces Pile-up Effects

- Pulse pile-up inevitable at high count rates
- PHA uses pulse fitting routines instead of an MCA
  - Pulse fitting routines are less sensitive to pile-up effects at high count rates than a traditional MCA
  - Increases useable count rate by about a factor of five





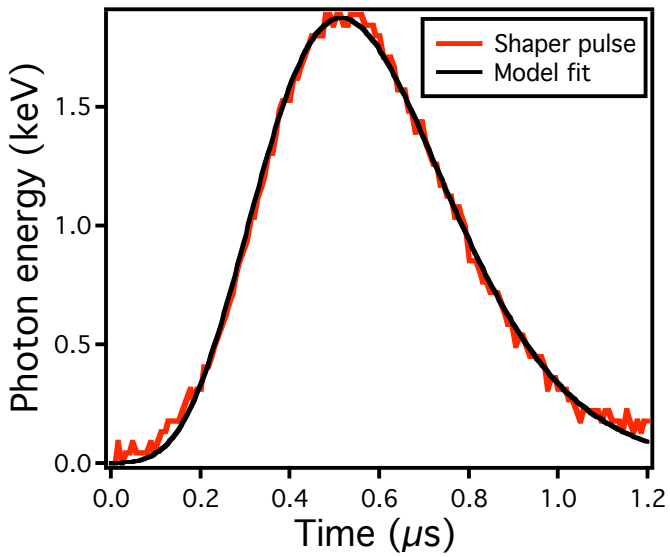
Fitting the Pulse Train

Functional form of pulse:

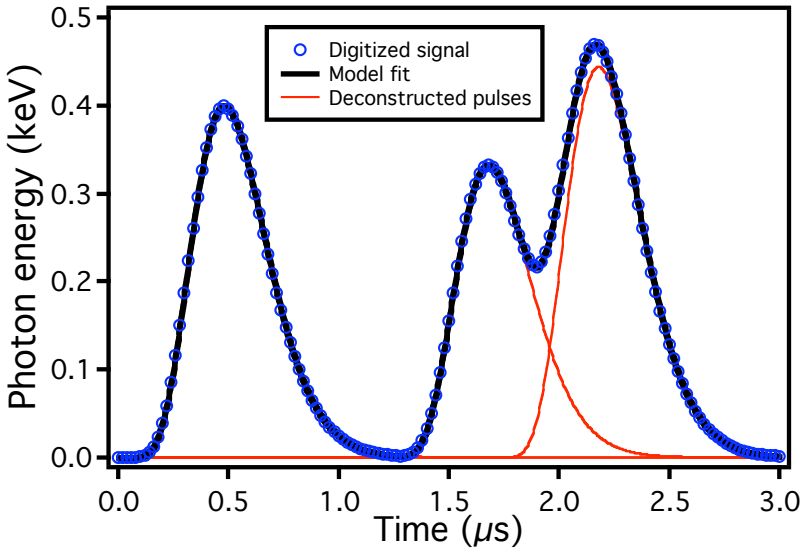
(n = 8 and τ = 150 μs)

$$E = \frac{E_0}{n^n \exp(-n)} \left(\frac{2(t - t_0)}{\tau} \right)^n \exp\left(\frac{-2(t - t_0)}{\tau} \right)$$

Example pulse from shot 27590 fit with pulse model



Simulated pulse train deconstructed by pulse train fitting routine



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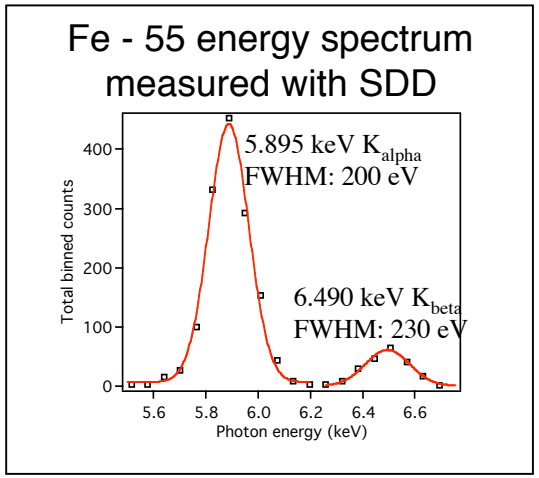
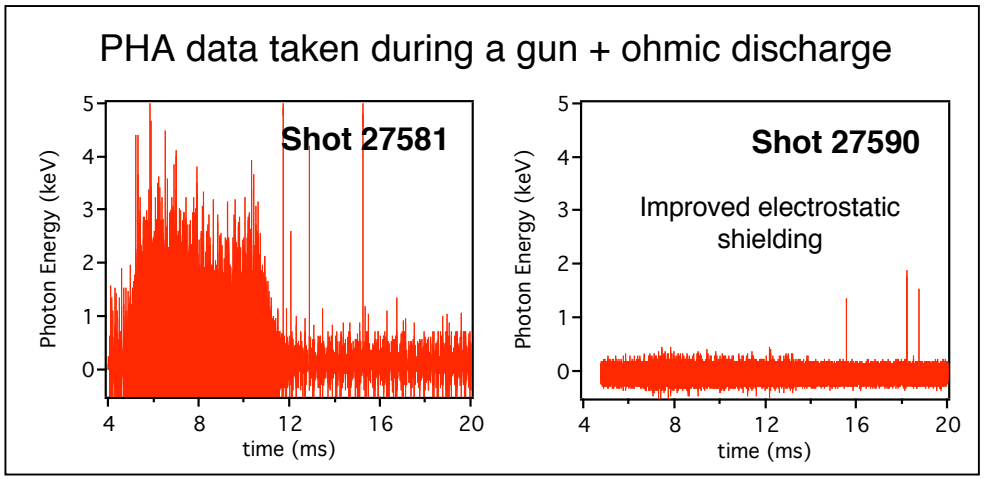
Status of the SXR PHA

- Energy resolution measured
- PHA system built and integrated into operations
- Electronic noise has an RMS of < 50 eV, well below the measured energy resolution of 200 eV.





Thomson Scattering System

Single and multi-point Thomson scattering system being developed with MST and Phaedrus-T hardware

Ruby laser from MST

- Wavelength: 694.3 nm
- Q-switched (Pockels cell)
- Linear flash-lamped pumped
- Multimode (not spatially filtered)
- Maximum output energy: 10 J
- Output beam diameter: 16 mm
- Pulse duration (FWHM): 40 ns
- Polarization: Horizontal
- Beam divergence: 90% within 1.2 mrad

Spectrometers and detectors

First generation

- Single spatial point, multi-spectral point APD system from MST

Second generation

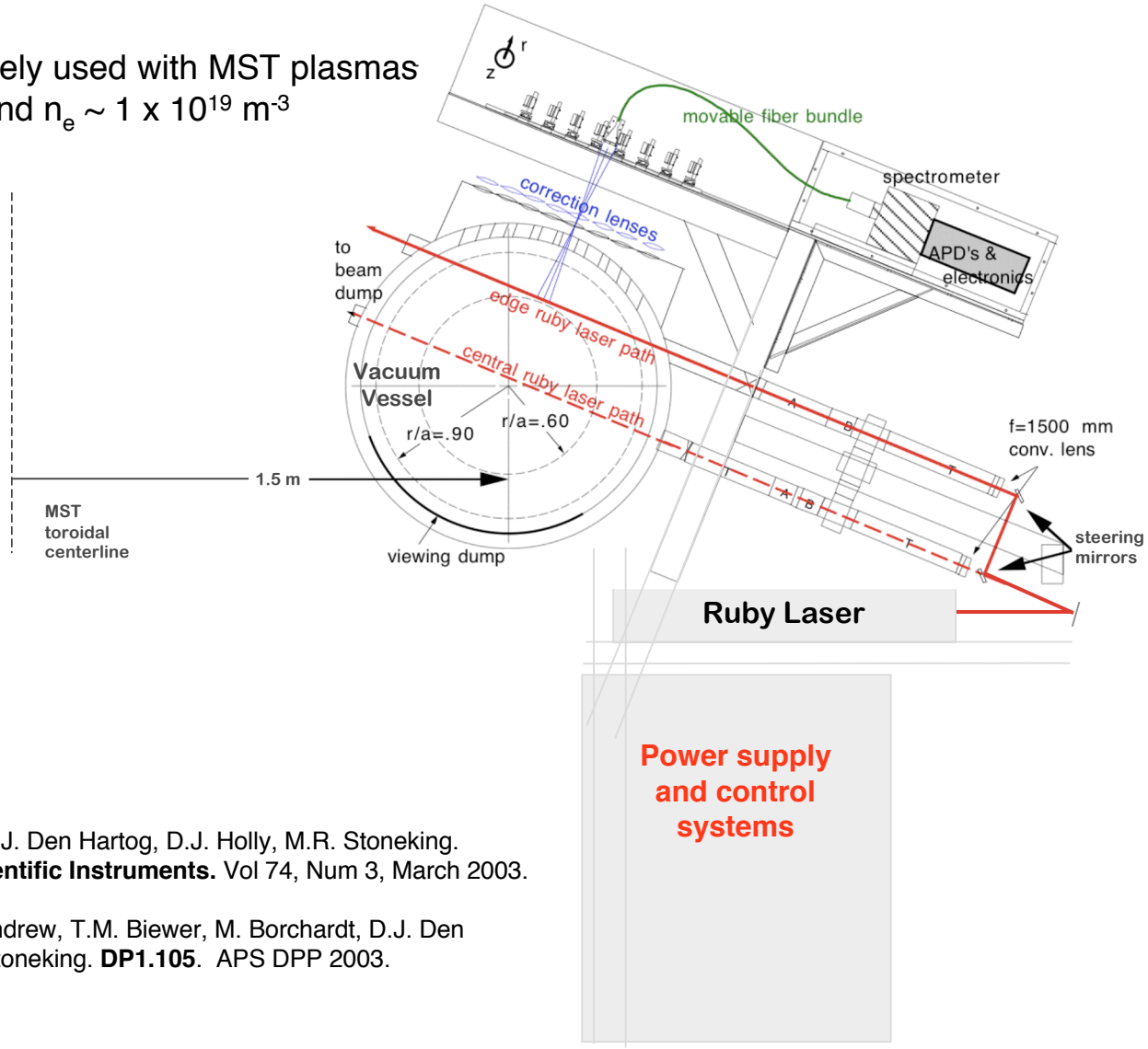
- Multi-spatial point (ten radial points), multi-spectral point MCP system from Phaedrus-T and S1

Optics

- Holographic edge filter from MST
- 8” collection lens from Phaedrus

Thomson Scattering System on MST

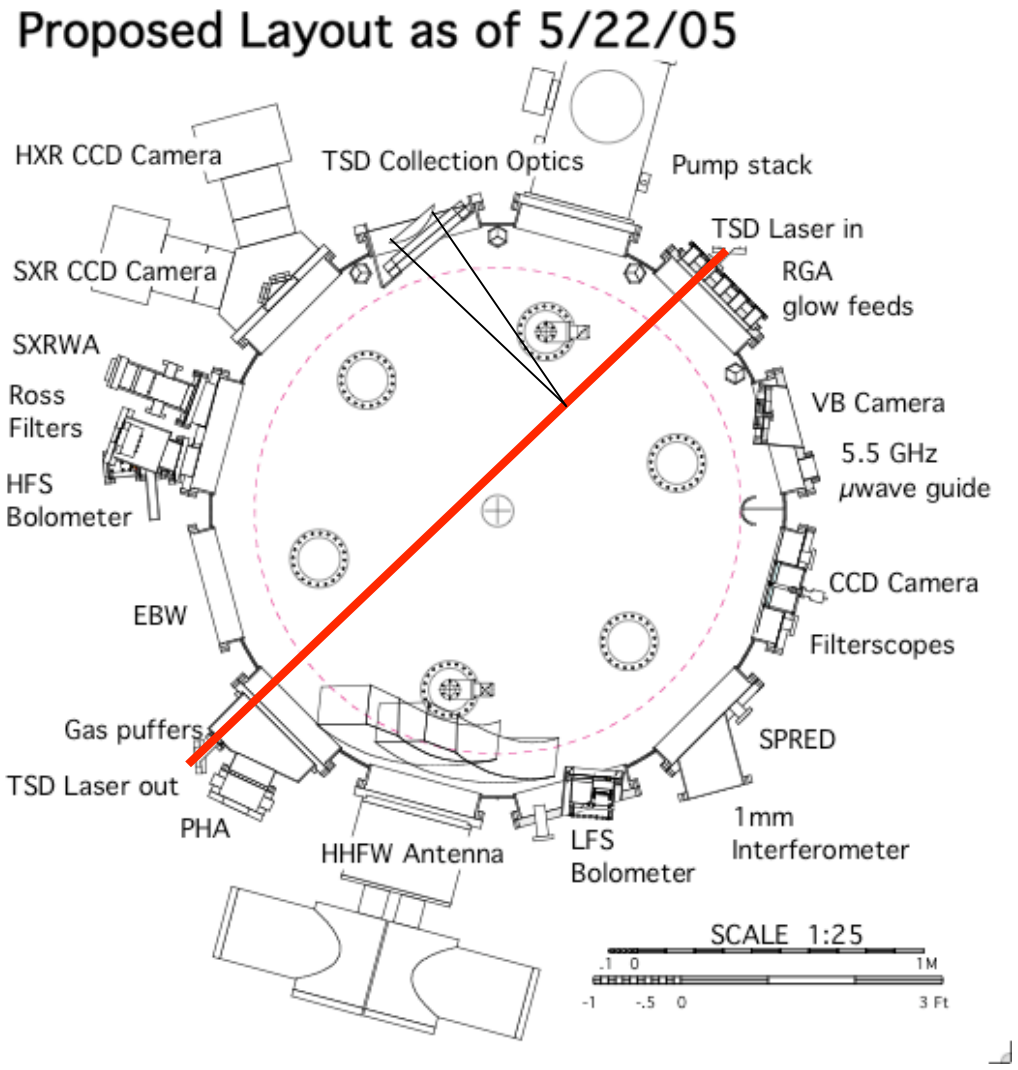
System routinely used with MST plasmas
$T_e \sim 200$ eV and $n_e \sim 1 \times 10^{19}$ m^{-3}



T.M. Biewer, D.J. Den Hartog, D.J. Holly, M.R. Stoneking. **Review of Scientific Instruments.** Vol 74, Num 3, March 2003.

D.J. Holly, P.Andrew, T.M. Biewer, M. Borchardt, D.J. Den Hartog, M.R. Stoneking. **DP1.105**. APS DPP 2003.

Proposed Pegasus Beamline



TS Future Plans

- The ruby laser and collection optics are now in house
- The system will be constructed and calibrated off-line
- A small laser room will be built to minimize dust and control the ambient temperature of the optics environment
- The TS system will be integrated into Pegasus operations in approximately two years

Summary

- Accurate and reliable T_e measurements are important to Pegasus experiments

- T_e diagnostics deployed for present experiments
  - SXR Ross Filters: Compares impurity line ratios for crude measurements at low Te
  - SXR PHA: Spatially and temporally resolved SXR spectrum measurements at higher Te

- Thomson Scattering system will be integrated into Pegasus operations in the future

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