Design of Bolometer diagnostics for the KSTAR

Dongcheol Seo[1] and B.J. Peterson[2]

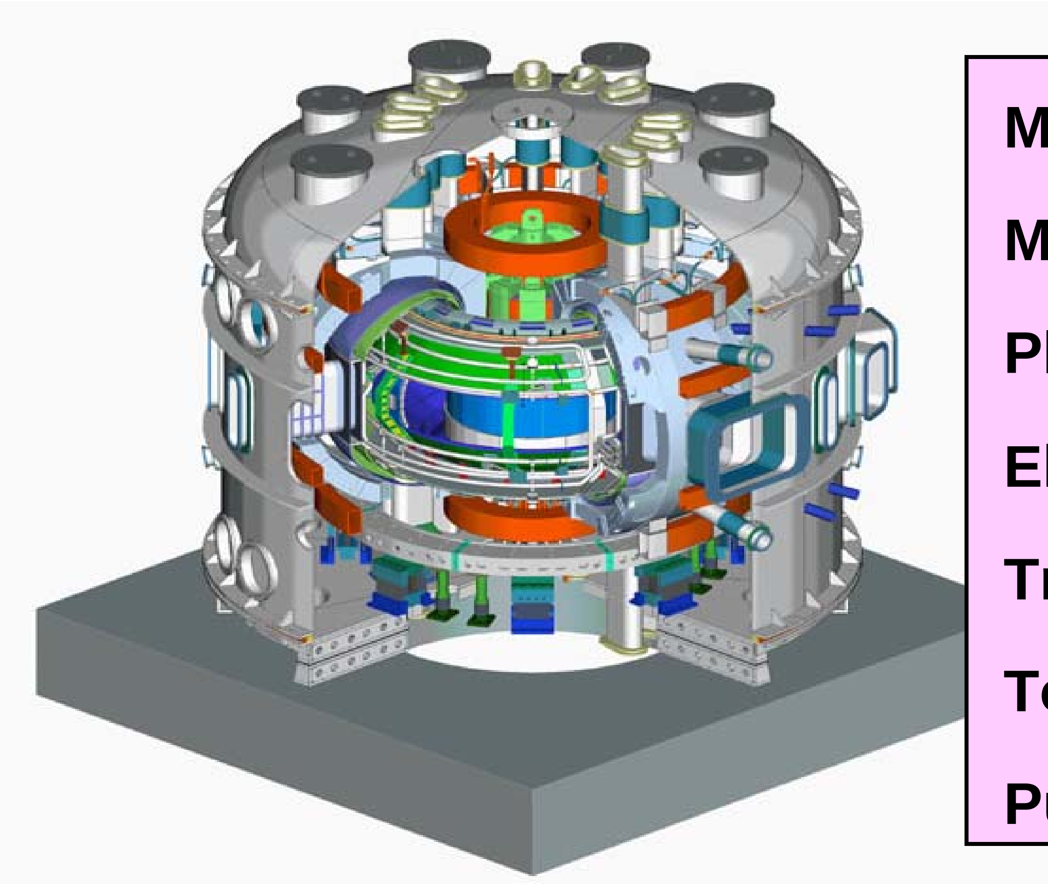
[1]National Fusion Research Center, Daejeon 305-806, Korea
[2]National Institute for Fusion Science , Toki-shi 509-5292, Japan

16th International Toki Conference
Advanced Imaging and Plasma Diagnostics
Ceratopia Toki, Gifu, JAPAN
December 5-8, 2006

Abstract

A 12 channel resistive bolometer array and an infrared imaging video bolometer (IRVB) have been designed for the Korean Superconducting Tokamak Advanced Research (KSTAR). In the 2nd campaign (2009), the 12 channel resistive bolometer array will be installed at the mid-plane tangential port, with the array viewing horizontally, and an Abel inversion will be carried out for a major radial profile of the radiation emissivity of the circular cross-section plasma. In the 3rd campaign (2010), an IRVB will be installed at the port of the resistive bolometers and the results of the resistive bolometer and the IRVB will be compared. In the 4th campaign (2011), the 12 channel resistive bolometer array will be moved to the divertor. The calibration constants of the 12 channel resistive bolometer such as the sensitivity, K, and the cooling time, τ_c, have been obtained by the In situ calibration.
This work is supported by the Korea Ministry of Science and Technology under the KSTAR Project and the Korea-Japan Fusion Collaboration Program.

KSTAR Machine Parameters



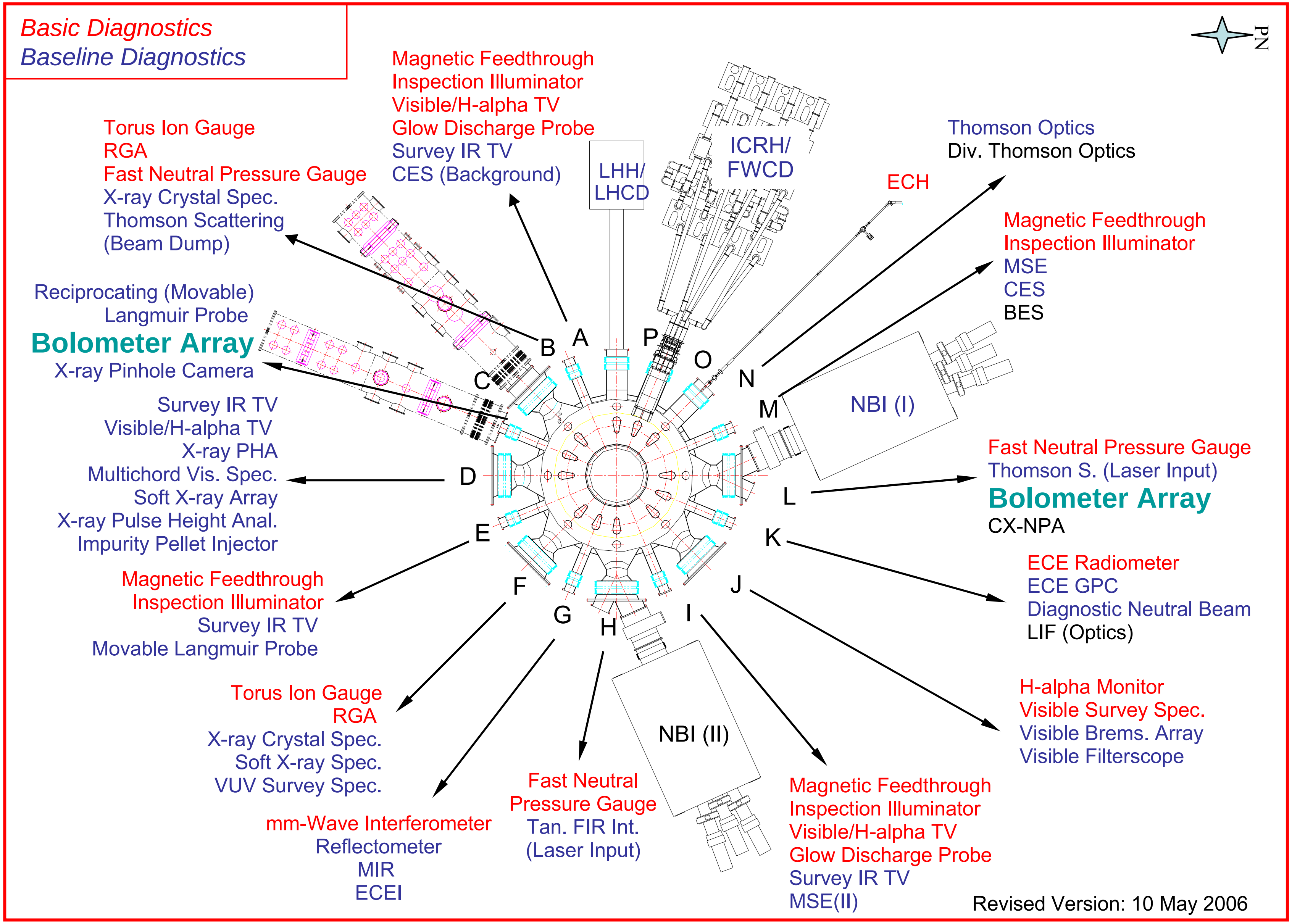
Major Radius,	R_0 = 1.8 m
Minor Radius,	a = 0.5 m
Plasma Current,	I_P = 2.0 MA
Elongation,	κ = 2.0
Triangularity,	δ = 0.8
Toroidal Field,	B_{T0} = 3.5 Tesla
Pulse Length	300 sec

List of KSTAR diagnostic systems

Revised : 03 March 2006

Diagnostic Set	Basic(2007)	Baseline I(2008)	Baseline II(2009)	Baseline III(2010)	Baseline IV(2011)
Control and Machine	**Rogowski Coil** **Flux/Voltage Loop** **Magnetic Field Probe** **Diamagnetic Loop** **mm-wave Interferometer (single-ch.)** **Survey Visible/H-alpha TV** **Inspection Illuminator** ***Torus Ion Gauge** ***Glow Discharge Probe**	Saddle/Locked-Mode Coil Vessel Structure Current Monitor Hard X-ray Detector Mirnov Coil (In-board) Survey Visible/H-alpha TV *Residual Gas Analyzer	Mirnov Coil (PFC) Vertical FIR Interferometer/Polarimeter Survey IR TV	Charge Exchange Recombination Spectroscopy (CER) Motional Stark Effect (MSE)	Modified MSE (Er, q)
Core Plasma	**Visible Survey Spectrometer** **H-alpha Monitor** **ECE Heterodyne Radiometer**	Soft X-ray Array X-ray Pulse Height Analyzer Visible Brems. Array X-ray Crystal Spectrometer Reflectometer	Thomson Scattering Bolometer Array X-ray Pinhole Camera Multi-chord Visible Spectrometer ECE Imaging (ECEI) System Epithermal Neutron Detector Microwave Imaging Reflectometer (MIR)	Poloidal Rotation CER BES Soft X-ray Spectrometer Visible Filterscope Escaping Fast-ion Detector ECE Grating Polychromator Tangential FIR Interferometer/Polarimeter	Multi-ch. Neutron Collimator Neutron Fluctuation Detector CX-NPA Diagnostic Neutral Beam
Divertor and Edge		Reciprocating (Movable) Langmuir Probe Fixed Langmuir Probe Array (Inboard Limiter)	Fixed Langmuir Probe Array (Divertor) Divertor IR TV Divertor Visible/H-alpha TV Bolometer Array VUV Survey Spectrometer *Fast Neutral Pressure Gauge *Divertor Thermocouple	Divertor Bolometer Array Divertor VUV Survey Spectrometer Divertor Microwave Interferometer Edge Thomson Scattering Edge Reflectometer	Electron Cyclotron Absorption (ECA) Reciprocating Langmuir Probe (Multi-head) Impurity Pellet Injector Divertor Thomson A

KSTAR Diagnostics layout



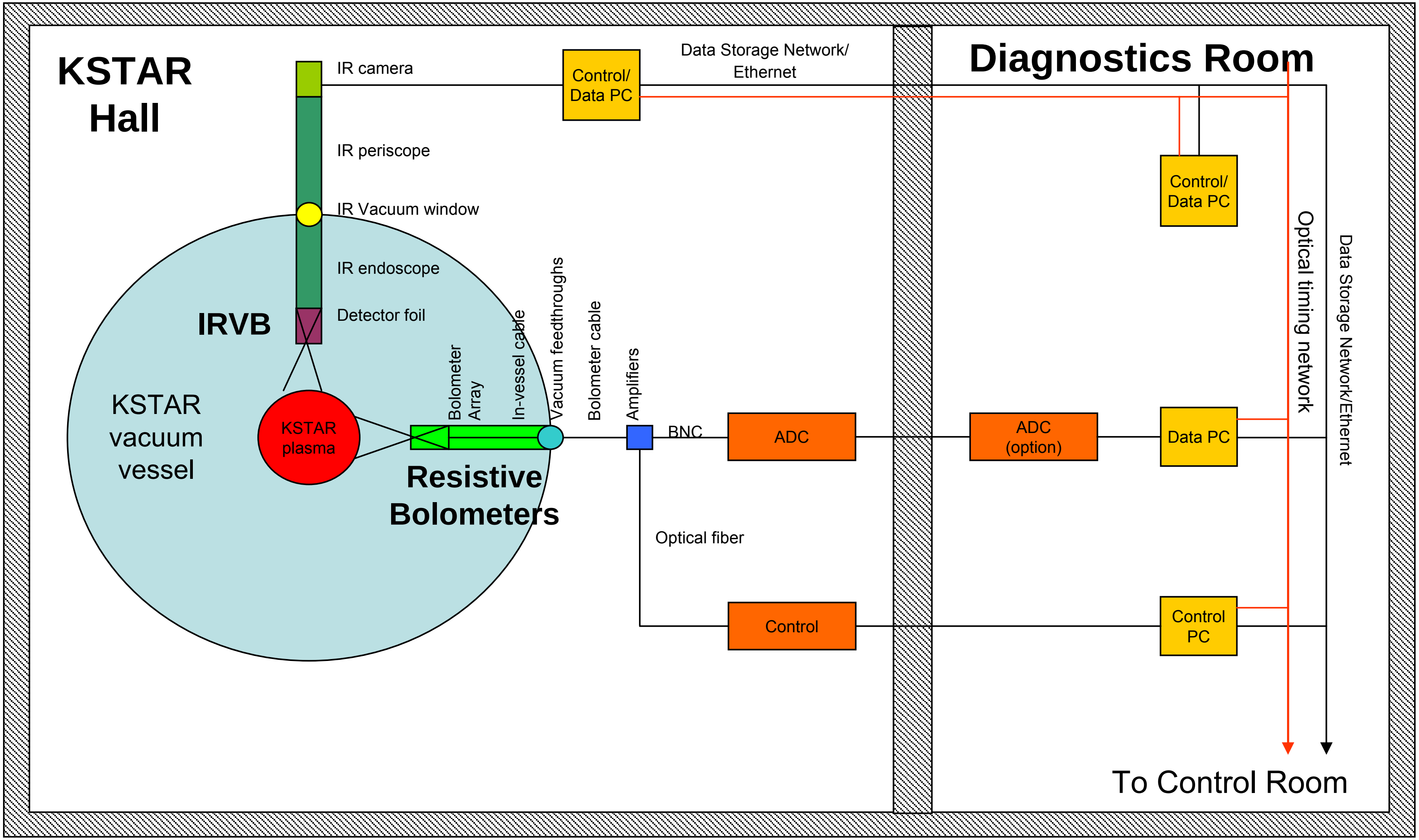
Current Plan for Bolometer System for KSTAR

Objective - To diagnose radiation from core and divertor regions by combining resistive and imaging bolometers

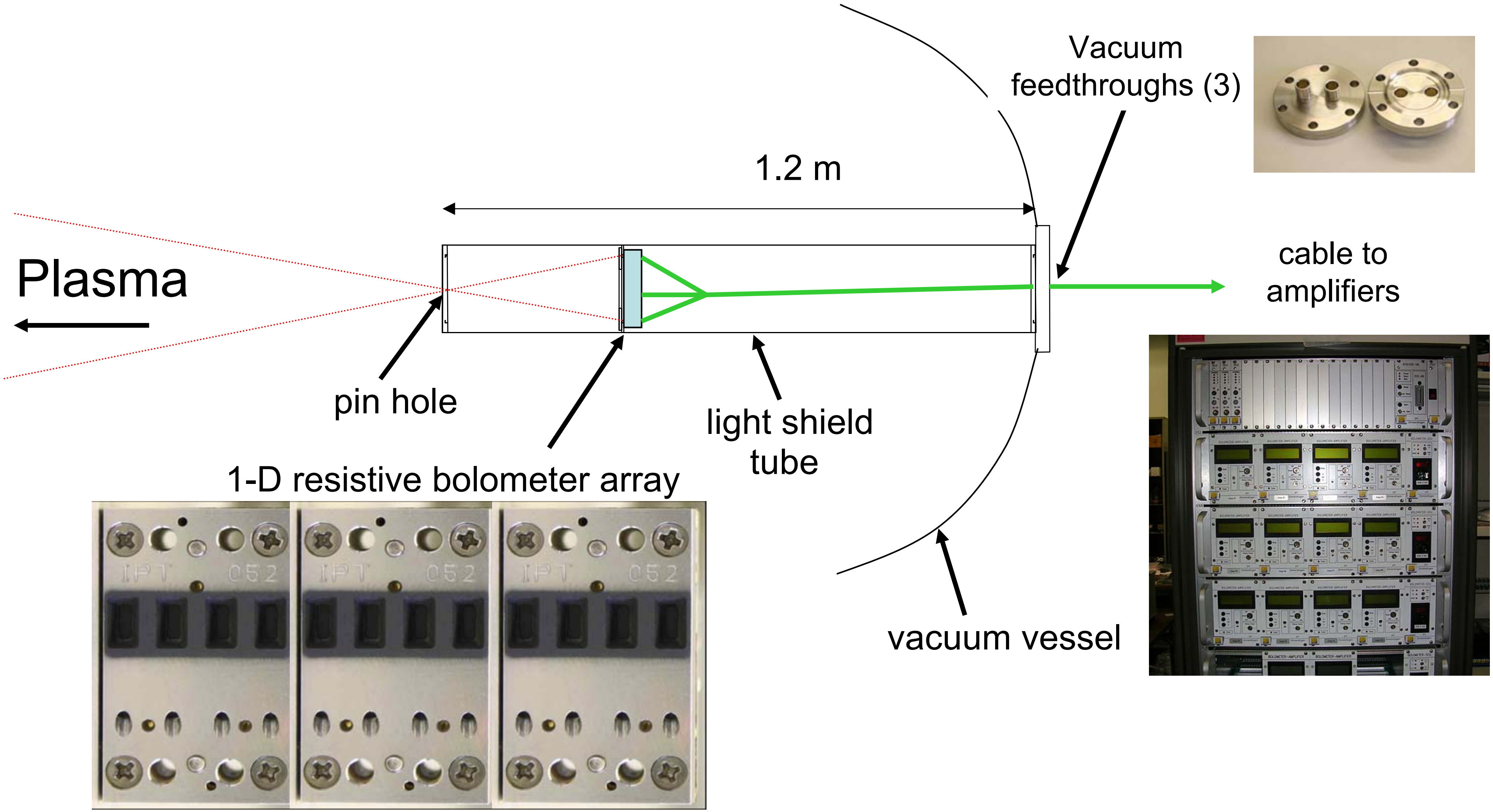
Current Proposal

- 1st camp. ('08) - no bolometer
- 2nd camp. ('09) - 12 ch resistive bolometer
  - Tangentially viewing array fanning out major radially
  - Assuming axisymmetry, Abel inversion for radial profile of circular cross-section main plasma (as in C-mod)
- 3rd camp. ('10) - Resistive and imaging bolometers
  - Add tangentially viewing imaging bolometer
  - Assuming axisymmetry, perform 2-D tomography of main plasma using ~140 imaging bolometer
  - the results of the resistive bolometer and the IRVB will be compared
- 4th camp. ('11) – Resistive bolometer for divertor
  - 12 channel resistive bolometer will be removed to the divertor.

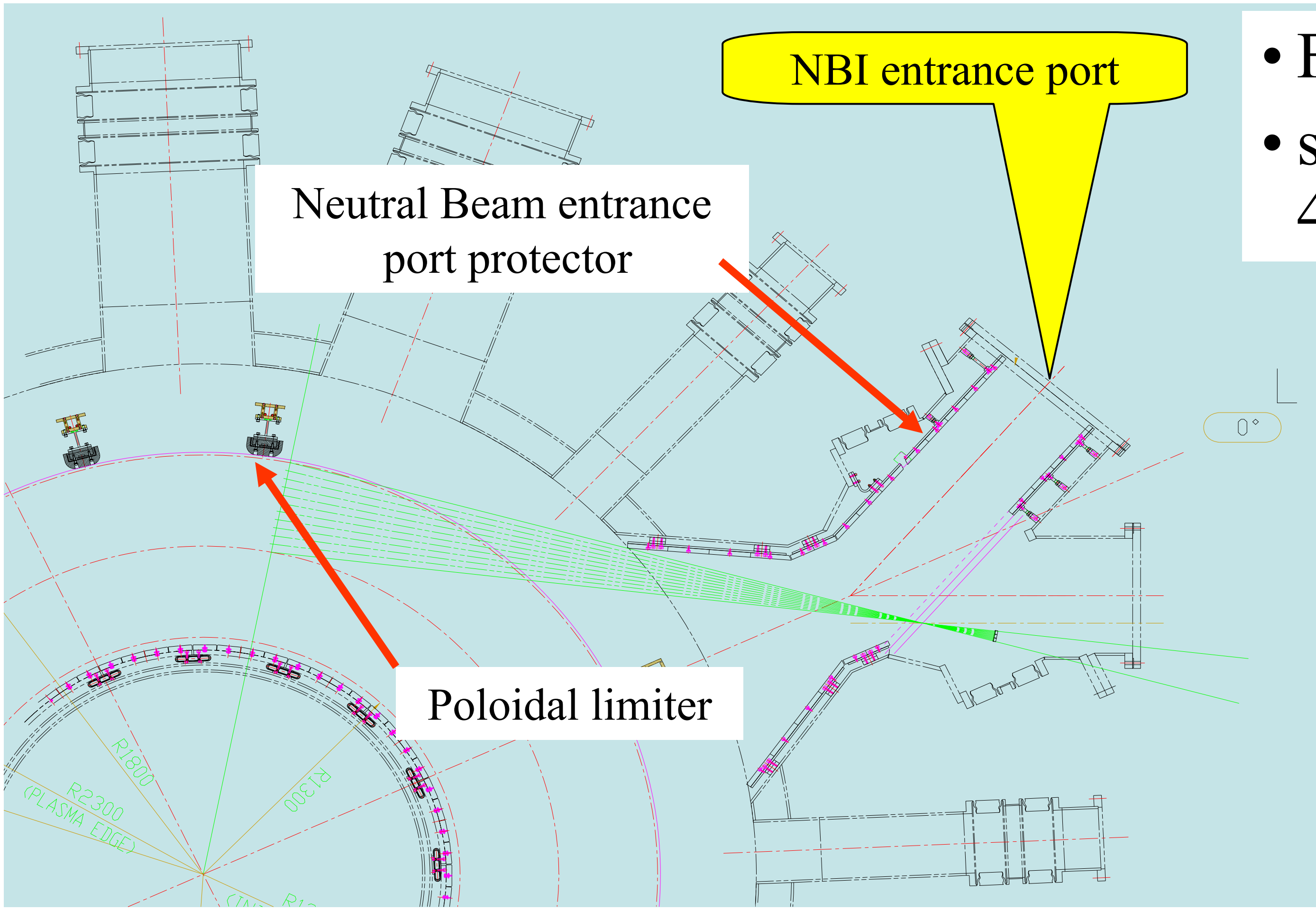
KSTAR Bolometer Systems



Resistive bolometer system-concept

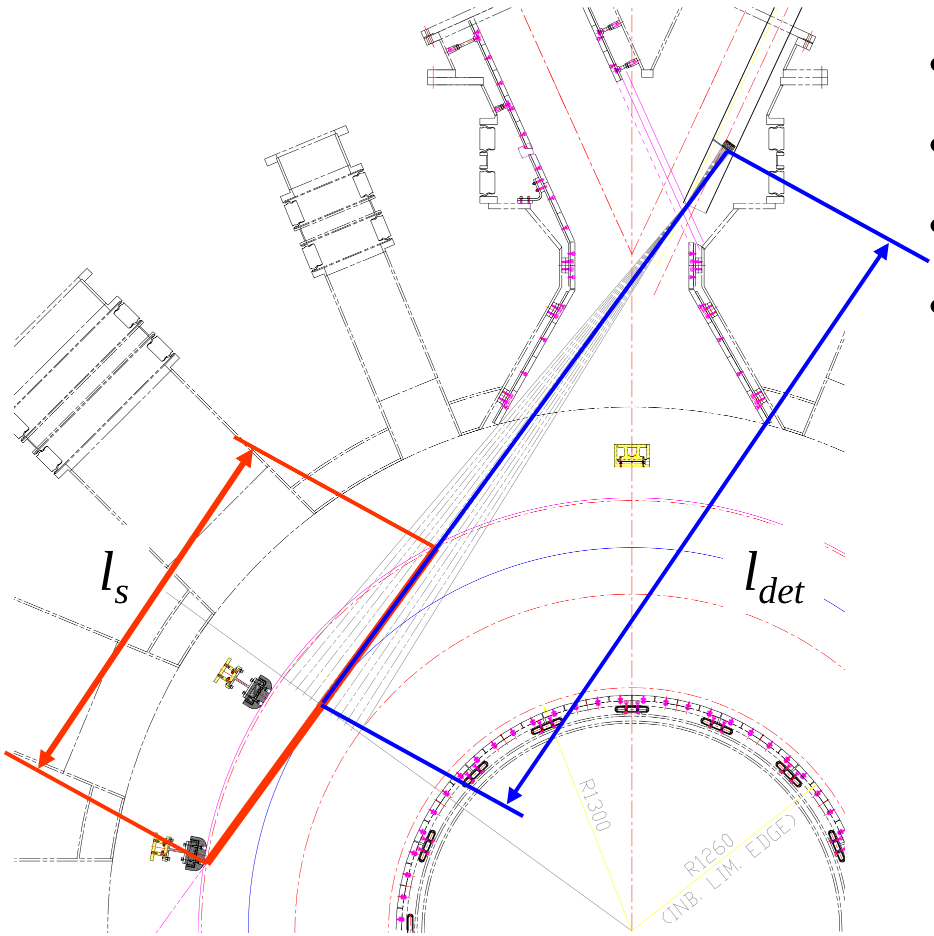


FOV for resistive bolometer on KSTAR



- FOV angle : 8.63˚
- spatial resolution : 4.5 cm

Estimation of S/N for resistive bolometer

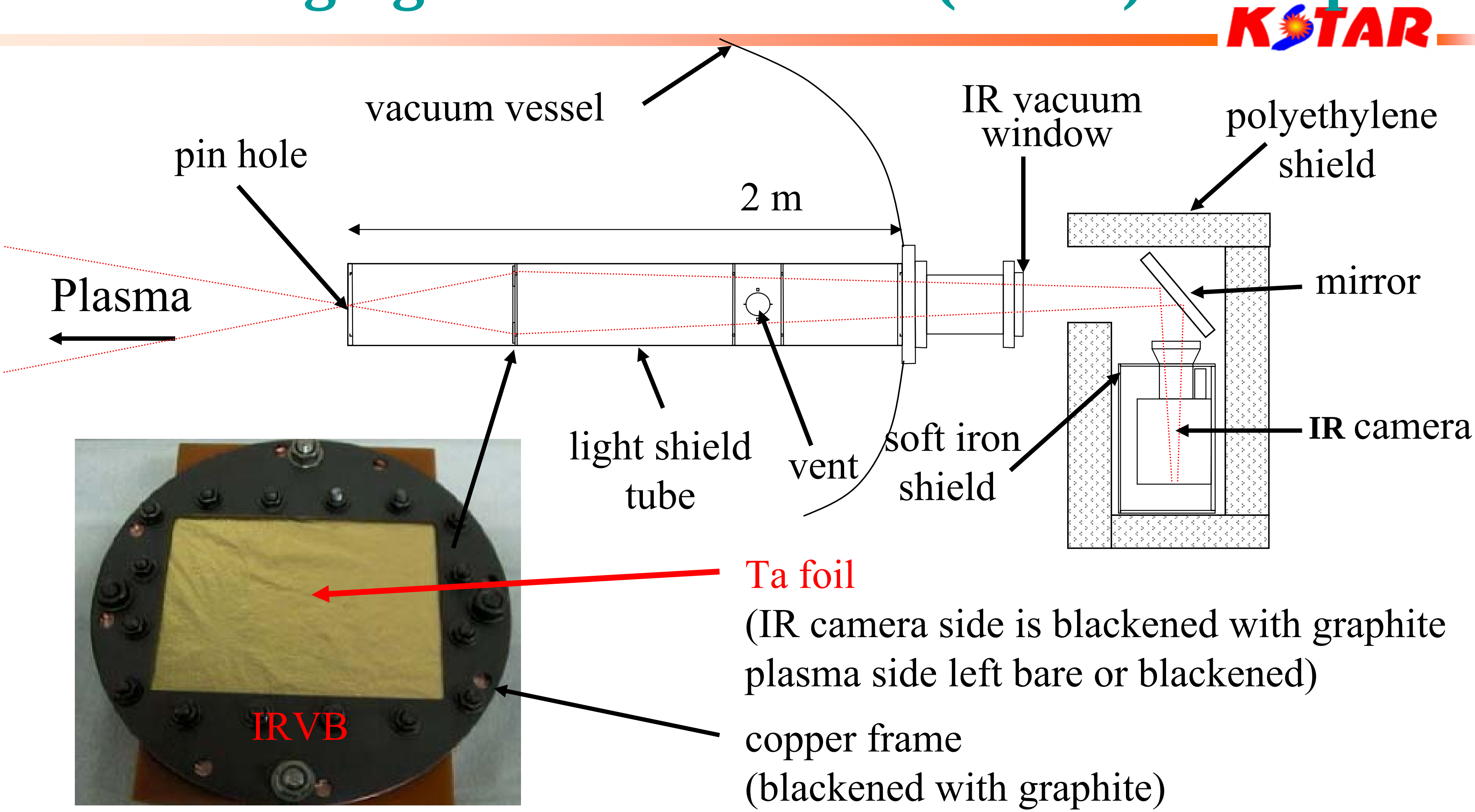


- P_{total} = 15MW, assume f_{rad} = 100%
- V_{plasma} = 8.9 m^3
- $V_s = A_s \cdot l_s$ = 836 cm^3
- l_{det} = 368 cm

$$S = \frac{P_{total}}{V_{plasma}} \frac{V_s}{A_{det}} \frac{A_{det}}{4\pi l_{det}^2}$$

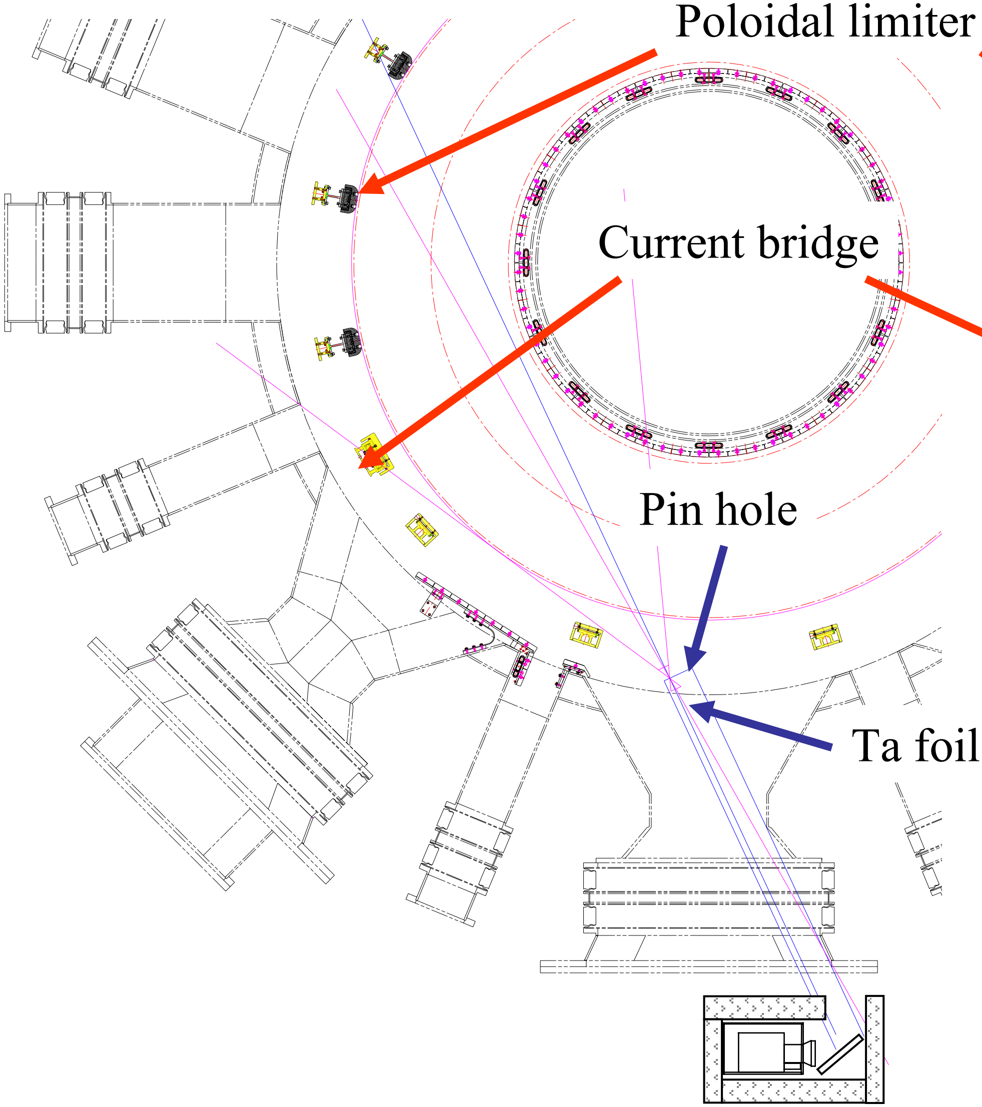
- S = 828 μW/cm^2
- Noise ≒ 20 μW/cm^2
- S/N ≒ 41.4

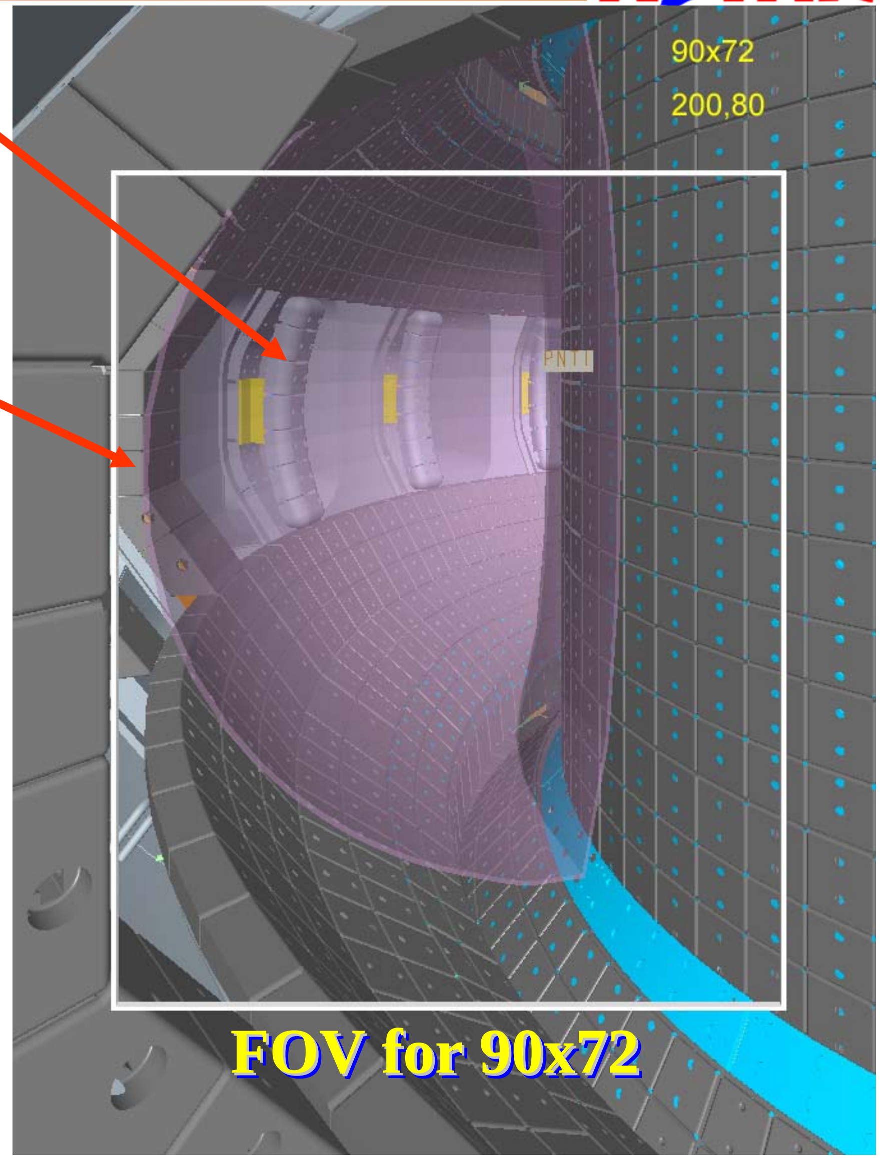
IR imaging Video Bolometer (IRVB)-concept



[1] B.J. Peterson, *Rev. Sci. Instrum.* **70** (2000) 3696. [2] B.J. Peterson *et al.*, *Rev. Sci. Instrum.* **72** (2001) 923.

FOV for IRVB on KSTAR





IR Camera Specifications

KSTAR

	Resolution	Full frame rate	NETD	Spectral range	Detector type	Size(LxWxH)
SC6000	640x512	125 Hz	<25 mK	3 - 5 μm	Indium Antimonide (InSb)	206x143x159 mm
SC4000	320x256	420 Hz	<25 mK	3 - 5 μm	Indium Antimonide (InSb)	206x143x159 mm
A40	320x240	60 Hz	<80 mK	7.5 - 13 μm	Focal Plane Array(FPA), uncooled microbolometer	207x92x109 mm
SC500	320x240	60 Hz	<70 mK	7.5 - 13 μm	Focal Plane Array(FPA), uncooled microbolometer	212x121x127mm
Omega	160x120	30 Hz	<85 mK	7.5 - 13.5 μm	Uncooled microbolometer	49x35x37 mm
Phoenix	320x256	345 Hz	<25 mK	1.5 - 5 μm	Indium Antimonide (InSb)	176x113x133 mm


SC6000


SC4000


A40


SC500


Omega


Phoenix

Foil Material Properties

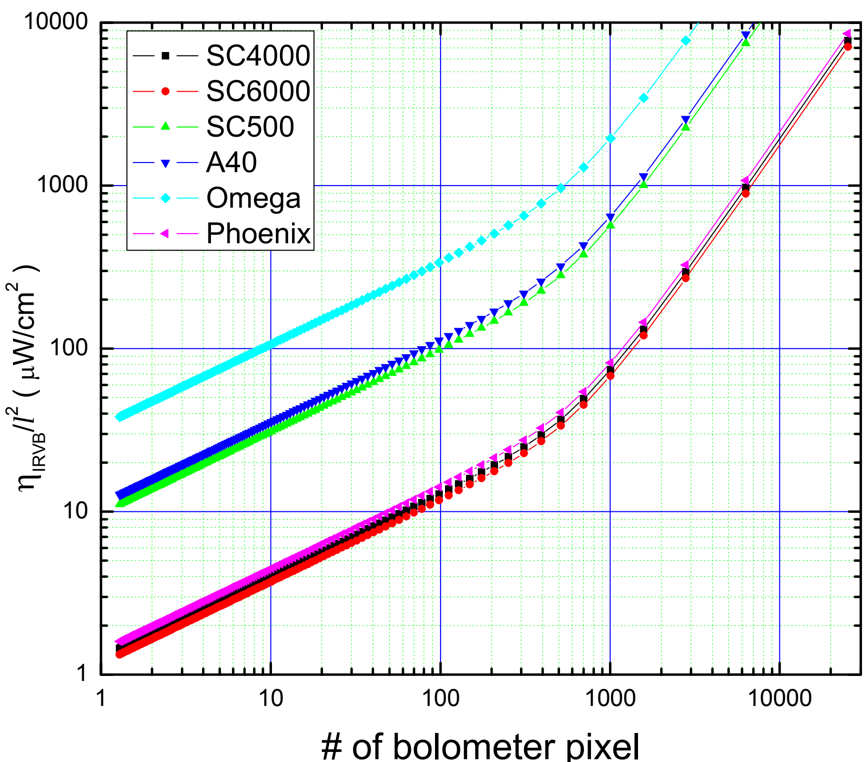
	Tensile strength (MPa)		$\sigma_{neutron}$ (Barns)	ρ (g/cm^3) @20C	C_p (J/K Kg) @25C	k (W/m K) @0-100C	κ (cm^2/S)	κ/k (cm^3 K/J)	Tm (C)	Wf (eV)	L_{atten} (μm) @9KeV	t_{min} (μm)
	soft	Hard										
Hf	445	745	103	13.1	146	23.0	0.12	0.52	2227	3.9	6.5	9
Ta	310-485 (397.5)	760	22	16.6	140	57.5	0.25	0.43	2996	4.1	5.1	2
Au	130	220	98.8	19.30	129	318	1.28	0.40	1064	4.8	3.4	2.5
W	550-620 (585)	1920	18.5	19.3	133	173	0.67	0.39	3410	4.55	4.2	10
Pt	125-150 (137.5)	200-300	9.0	21.45	133	71.6	0.25	0.35	1772	5.3	3.2	2

www.goodfellow.com

17th PSI, P1-60 B.J.Peterson, S.Konoshima, H.Parchamy, M. Kaneko, T. Omori, D.C. Seo, N.Ashikawa, A. Sukegawa

Noise Equivalent Power

$$\eta_{IRVB} = \frac{\sqrt{10}kt_f\sigma_{IR}}{\sqrt{mN}}\sqrt{1+\frac{l^4}{5\kappa^2m^2\Delta t_{IR}^2}+\frac{4l^4\varepsilon^2\sigma_{S-B}^2T^6}{5k^2t_f^2}}$$



k : thermal conductivity of foil

t_f : thickness of foil

σ_{IR} : sensitivity of IR camera

m : number of frames averaged ($\Delta t = m\Delta t_{IR}$)

N : number of IR pixels / bolo pixel

l^2 : bolometer pixel area

κ : thermal diffusivity of foil

Δt_{IR} : time resolution of the IR camera

Δt : time resolution for the diagnostic

ε : black body emissivity of the foil

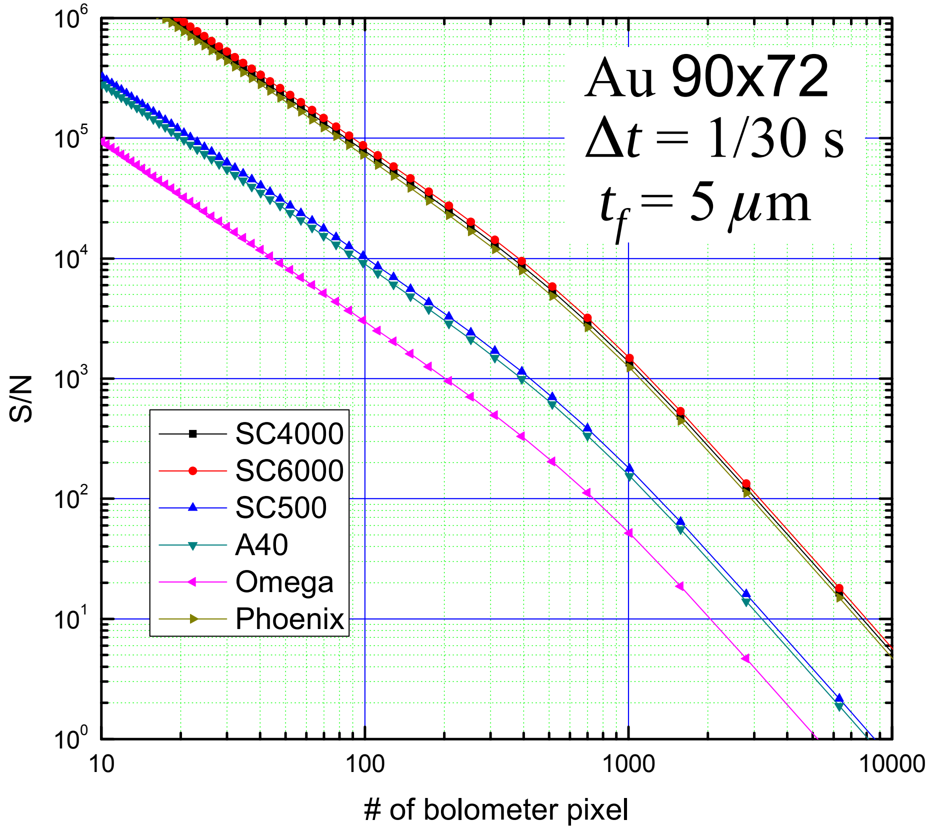
σ_{S-B} : Stefan-Boltzmann constant

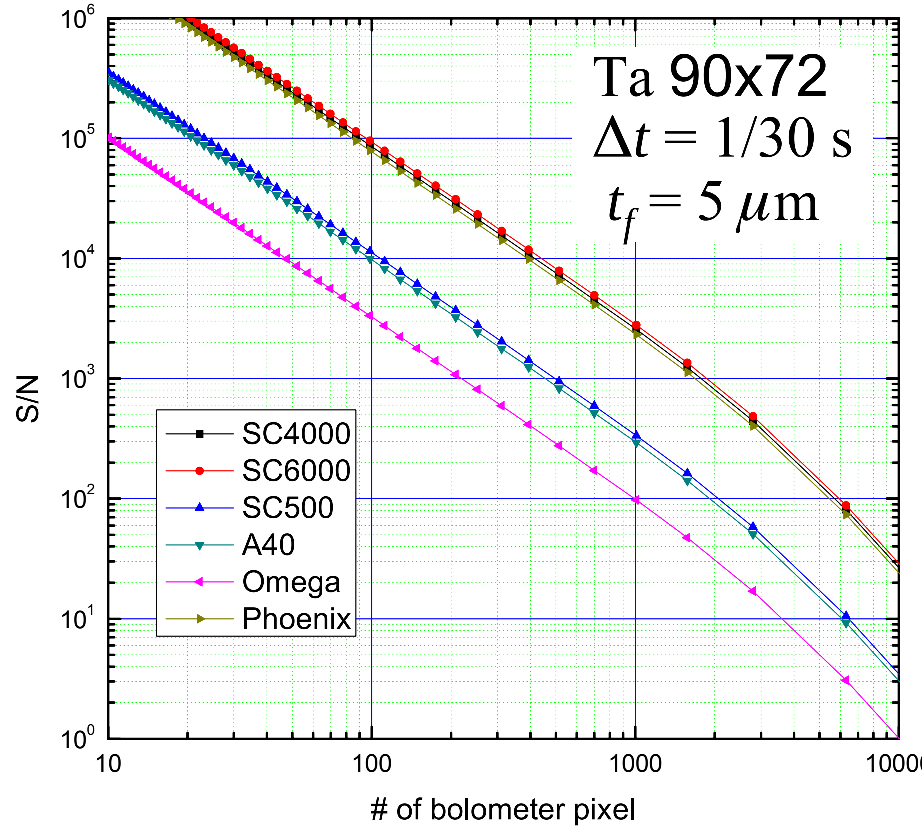
for Au foil(90x72), Δt = 1/30 s, t_f = 5μm

Estimation of S/N for IRVB

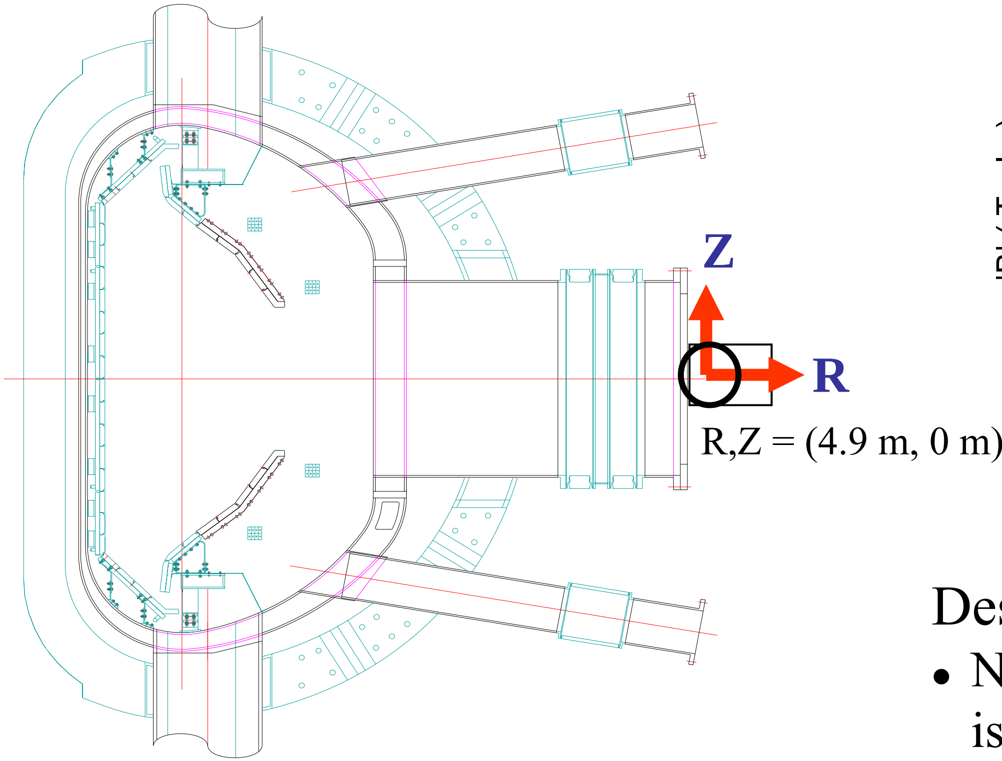
$$S = \frac{P_{total}}{V_{plasma}} \Omega V_s$$

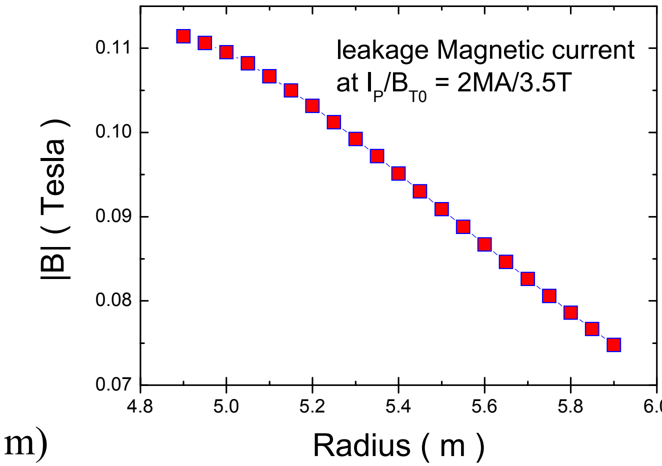
- P_{total} = 15MW, assume f_{rad} = 100%
- V_{plasma} = 15.8 m^3 (D-shaped plasma)
- Ω, V_s depend on l^2





Magnetic and neutron shielding boxes





Calculated by Dr. Lee DK

Design of magnetic shielding box

- Near the port surface, magnetic field is about 0.1 Tesla in KSTAR
- 2 times larger than results in LHD and JFT-2M(500-600G)

In JT-60U case

- Magnetic shielding (soft iron): thickness of 24 mm
- Neutron shielding (polyethylene): thickness of 90 mm @ 10^{16} n/s

*H.Parchamy et al, Rev.Sci.Instrum. **77**, 10E515(2006)

Neutron shielding box

KSTAR

- If we assume D-D operation with 2 MA of plasma current and 20 MW of heating power in KSTAR advanced operation mode, total Neutron Flux will be

  5×10^{15} #/sec (from JET Physicist, Dr. R Barnsley).

  (2~5) x 10^{15} #/sec (from RF Kurchatov Hard-Xray Report)

- Then, the optical components at ~300 cm from center,

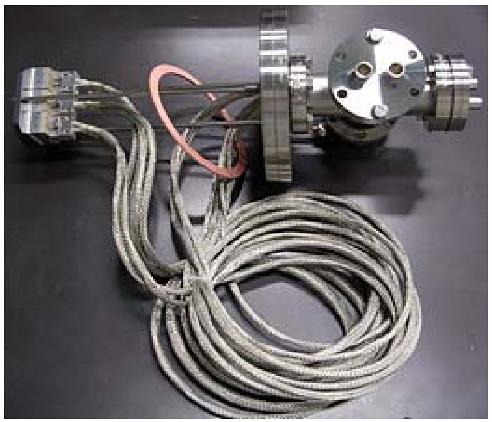
$$\text{Flux} = \frac{5\times10^{15}}{4\pi r^2} = \frac{5\times10^{15}}{4\times3.14\times300^2} = 4.4\times10^{9}\ \ \#/\text{cm}^2\ \text{sec}$$

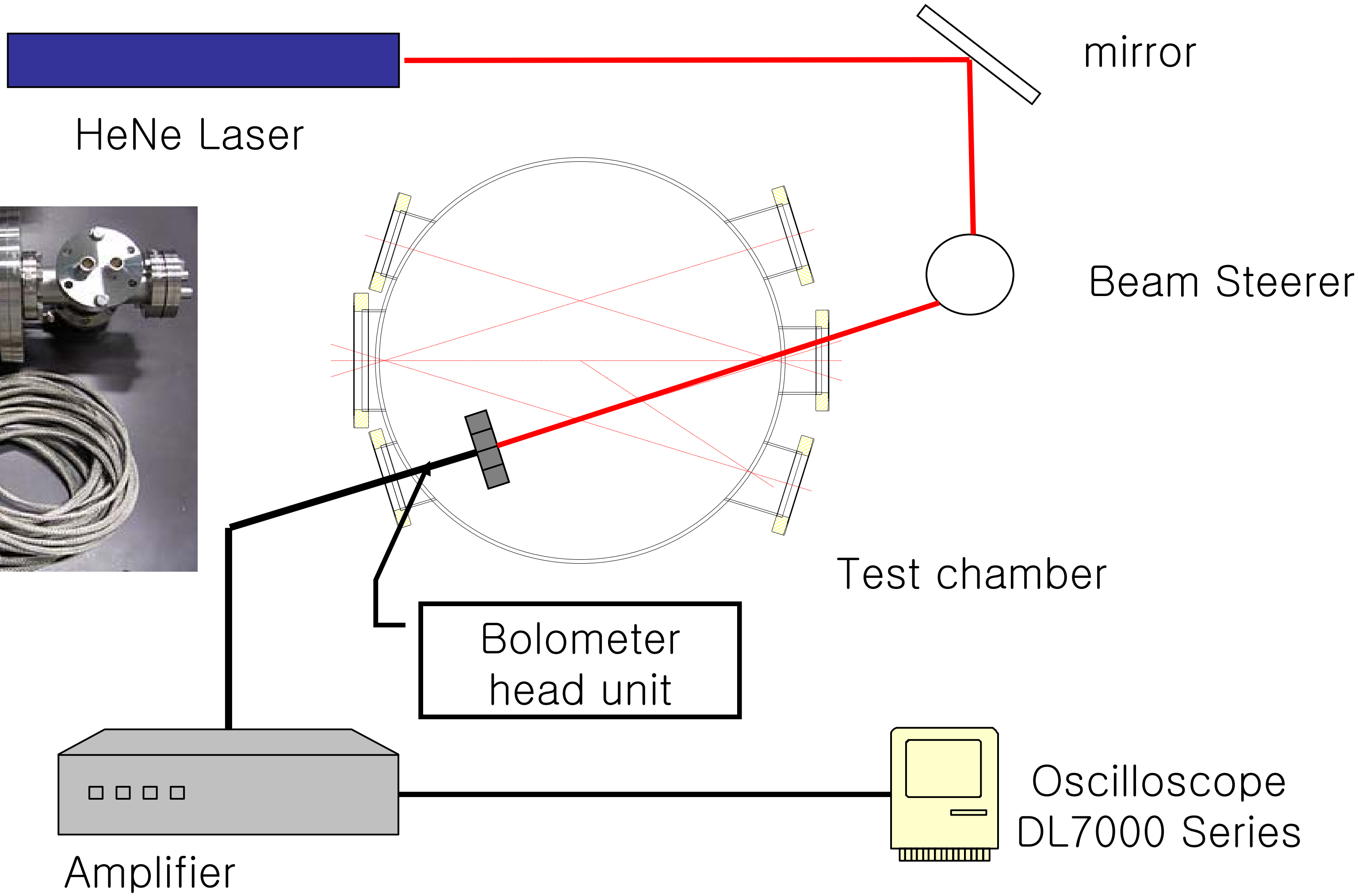
- If we assume that discharge pulse be ~ 300 s, day cycles be ~ 20 shots, operation days per one campaign be ~ 60 days, and campaigns for KSTAR Advanced Operation be ~5,
- Then, Total Neutron Flux / Unit Area

$$\sim 4.4\times10^{9}\ \ \#/\text{cm}^2\ \text{sec}\times300\ \text{sec}\times20\times60\times5$$

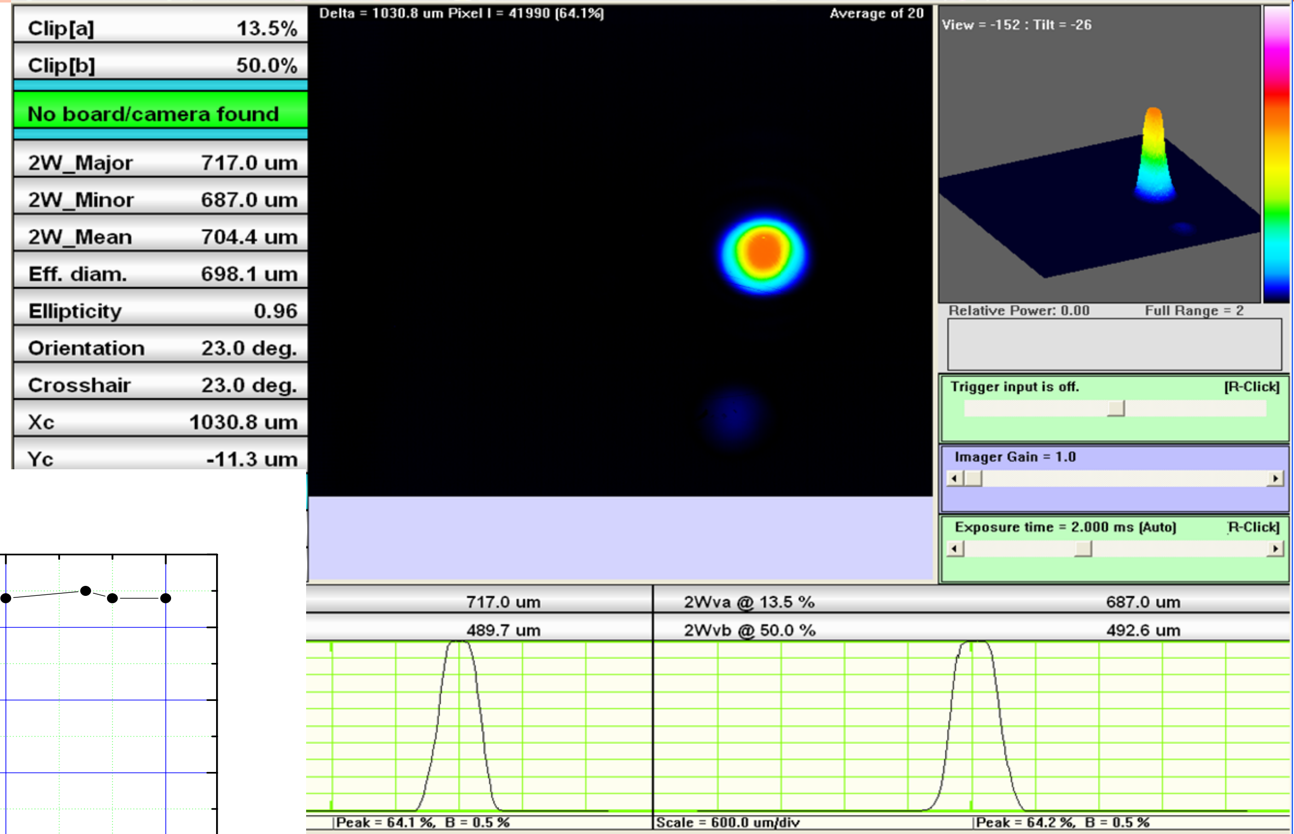
$$\sim 7.9\times10^{15}\ \ \#/\text{cm}^2\ \ \text{<== Total Neutron Influence}$$

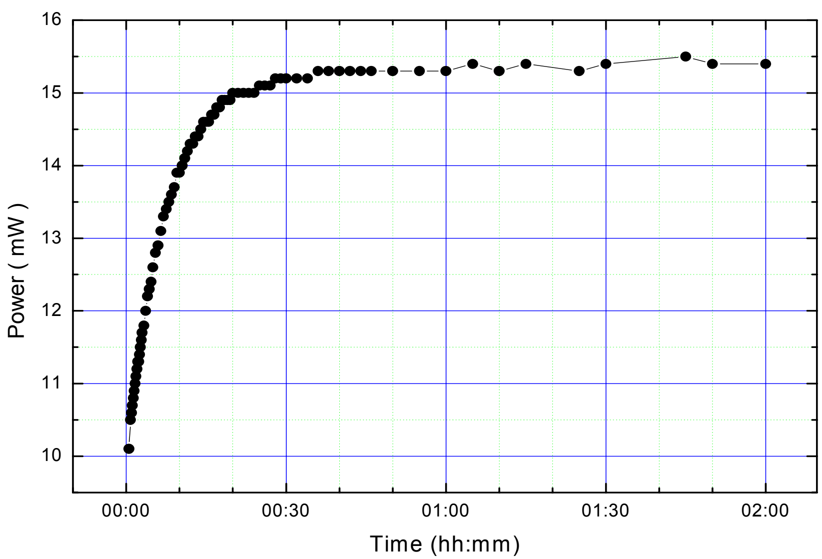
In-situ laser calibration setup of the bolometer





HeNe Laser beam profile



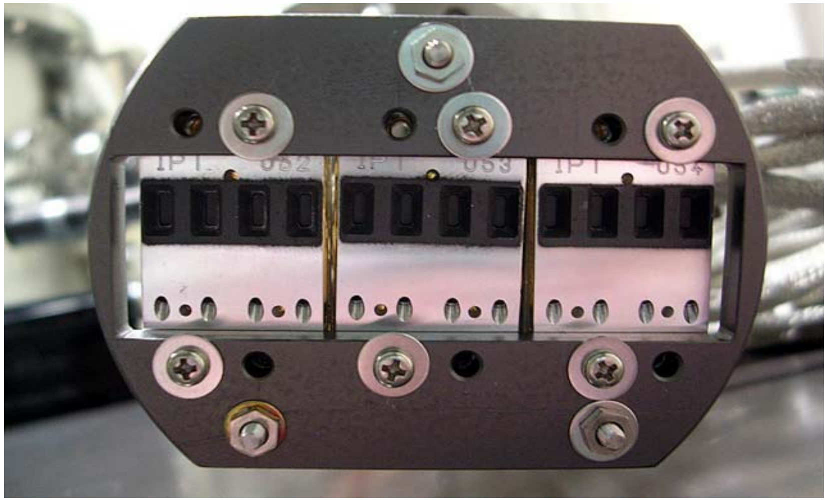


Measured by WinCamD

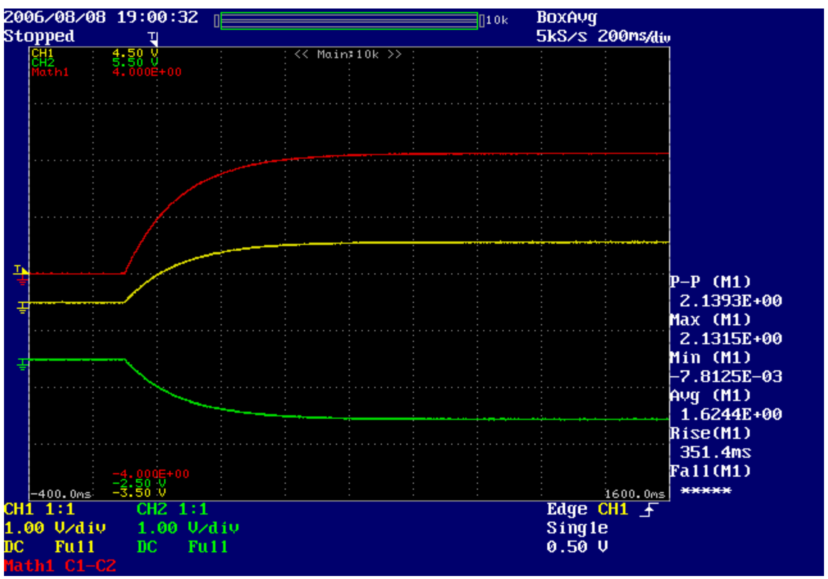
Beam diameter can be controlled by beam expender

Beam diameter : 0.7 mm

Calibration



12 channel resistive bolometer array



Detector

- Gold foil resistive bolometer
- Blackened with Graphite
- 12 channels will be installed in KSTAR
- Detection limit 10^{-6} W/cm^2
- Thermal drift dU/dT < 10^{-4} V/K

Calibration

Calibrated with chopped HeNe laser of power, P_{rad}, and bolometer signal voltage, V_b, to determine sensitivity, K, and cooling time, τ_c, from

$$P_{rad} = \frac{1}{K}\left(\tau_c \frac{\partial V_b}{\partial t} + V_b\right)$$

Results of calibration

IPT 52	ch1	ch2	ch3	ch4
τ [ms]	160.70	159.23	154.82	152.06
Senstivity [V/W]	9.76	10.33	10.28	9.93
IPT 53	ch1	ch2	ch3	ch4
τ [ms]	148.19	151.27	149.34	150.37
Senstivity [V/W]	10.01	9.64	9.64	9.55
IPT 54	ch1	ch2	ch3	ch4
τ [ms]	149.43	153.28	157.64	157.85
Senstivity [V/W]	10.05	10.20	10.44	10.36

Cooling time : 153.68 ms

Sensitivity : 10.02 V/W

Summary

- Design of Resistive Bolometer System
  - Located L-port, angular FOV is 8.63˚, spatial resolution is 4.5 cm, spot size is 12x34 mm^2
  - Estimated S/N is 41.4
- Delivered resistive bolometer system in 2006/02
  - amplifiers, control system electronics, sensor heads (3), in-vessel cables(2.5m), ex-vessel cables 40m, vacuum feedthroughs (3-ICF70mm)
- Design IR Imaging Video Bolometer
  - Foil material is Ta, size is 72x90 mm^2 (512x640)
  - Angular FOV is about 48º
  - If number of bolometer pixel is smaller than 2000, S/N get over 200.
  - Near the port surface, magnetic field is about 0.1 Tesla in KSTAR
  - D-D operation with 2 MA of plasma current and 20 MW of heating power in KSTAR advanced operation mode, total Neutron Flux will be 5 x 10^{15} #/sec
- Calibration of resistive bolometer
  - Cooling time is 153.68 ms
  - Sensitivity is 10.02 V/W

Future work

- Fabrication of resistive bolometer system.
- Detailed design for IRVB system.
- Conceptual design for divertor bolometer system.