

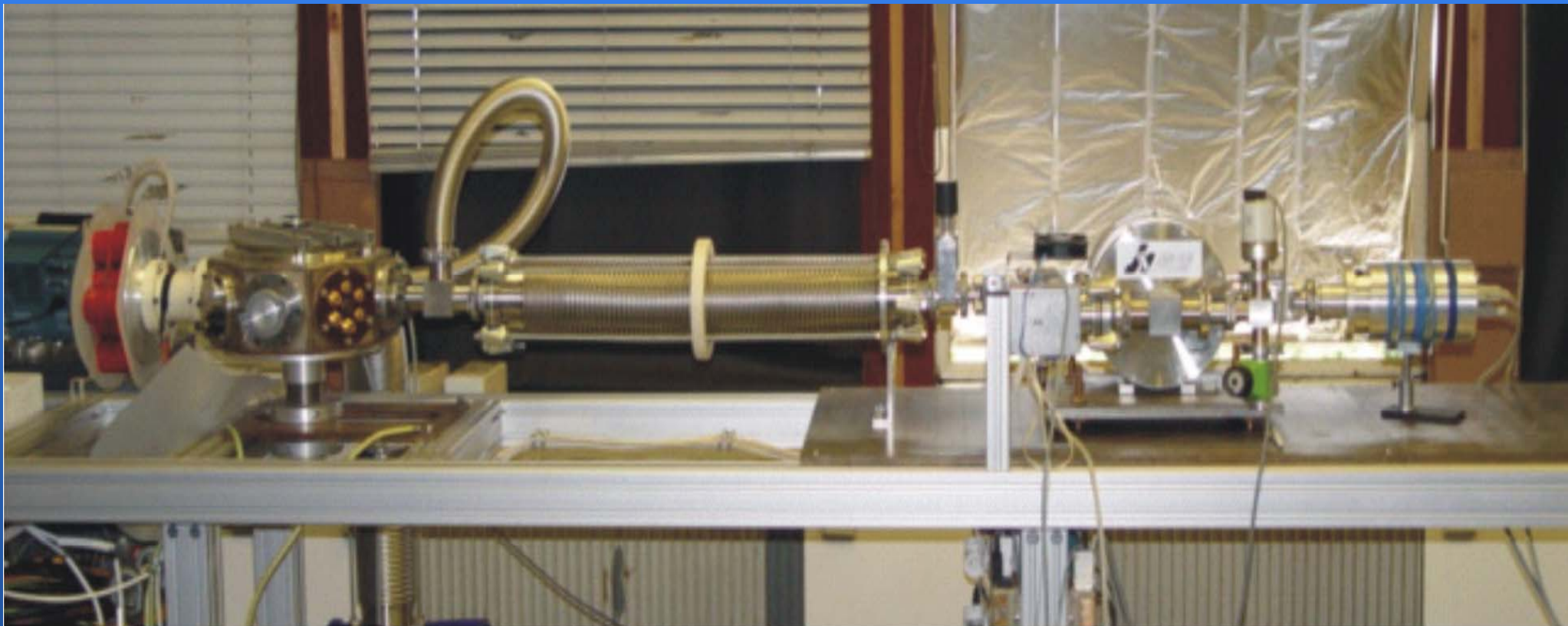


L. Pina, A. Fojtik, R. Havlikova, A. Jancarek, S.Palinek, M. Vrbova

Faculty of Nuclear Sciences, Czech Technical University, Brehova 7,
115 19 Prague, Czech Republic



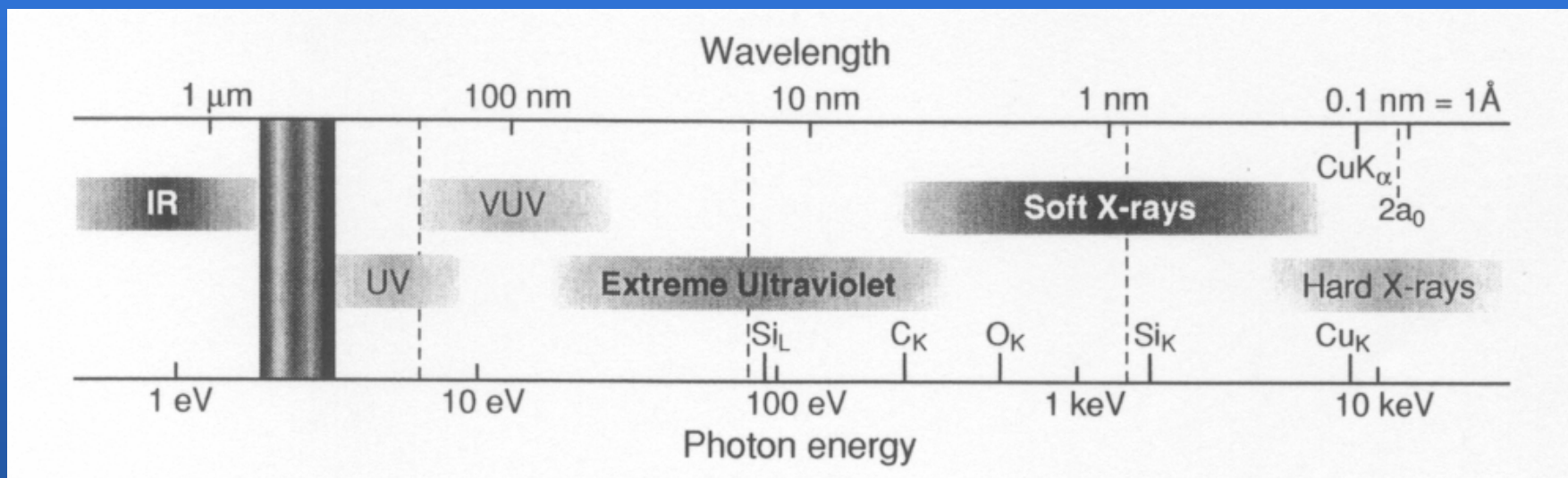
CD EXPERIMENTAL ARRANGEMENT





SPECTRAL CONSIDERATIONS

UV – EUV – XUV – SXR - XR





IDEAL DIAGNOSTIC

UV and XUV radiation from CD - spatial, spectral, angular and temporal studies

$$I(x, y, \lambda, t)$$

REALIZED DIAGNOSTICS

UV Monochromator with detachable PMT
(Time resolved UV spectroscopy)

$$I_{\lambda}(t)$$

| | |
|---------------------|--------------|
| Spectral range | 200 – 500 nm |
| Spectral resolution | 0.3 nm |
| Temporal resolution | 3 ns |

UV Polychromator with integrated CCD
(Broadband UV spectroscopy)

$$I(\lambda)$$

| | |
|---------------------|--------------|
| Spectral range | 200 – 500 nm |
| Spectral resolution | 0.3 nm |



XUV Monochromator + Scintillator + PMT **(Time resolved XUV spectroscopy)**

$I_{\lambda}(t)$

| | |
|---------------------|-------------------------|
| Spectral range | 40 – 300 eV (4 – 30 nm) |
| Spectral resolution | 0.3 nm |
| Temporal resolution | 2 ns |

XUV Transmission Grating + CCD, Image Intensifier $I(\lambda)$ **(Broadband XUV spectroscopy, XUV Polychromator)**

| | |
|--|------|
| Material: | Au |
| Bar width (horizontal): | 0,7 |
| Bar length (vertical): | 1714 |
| Gap width (horizontal): | 0,7 |
| Period (horizontal): | 1,4 |
| Aperture width (horizontal): | 70 |
| Dispersive resolution, 1st order (nm): | 0,27 |
| Aperture length (vertical): | 1714 |
| No of periods: | 50 |

(all dimensions in microns)



X-RAY DETECTORS (XUV, SXR, 50 – 500 eV)

(All dimensions in micrometers unless stated in other units)

DETECTOR 1 (X-ray Gated MCP)

| | | | |
|--------------------------|--------|---------------------|-----|
| Photocathode diameter | 25 000 | Quantum Efficiency: | 0.6 |
| Resolution: | 200 | | |
| Temporal resolution (ns) | 10 | | |

DETECTOR 2 (X-ray Streak Camera)

| | | | |
|---------------------------|------------|----------------------|------------|
| Spectral range (eV): | 50 – 2 000 | Quantum Efficiency : | 0.05 – 0.2 |
| Temporal resolution (ps): | 100 | | |

DETECTOR 3 (X-ray BI CCD, 16 A/D)

| | | | |
|-------------------------------|--------|----------------------|-----|
| Detector width (vertical): | 12 300 | Quantum Efficiency : | 0.7 |
| Detector length (horizontal): | 12 300 | | |
| Pixel width (vertical): | 24 | | |
| Pixel length (horizontal): | 24 | | |
| No of pixels (vertical): | 512 | | |
| No of pixels (horizontal): | 512 | | |

DETECTOR 4 (X-ray Si PIN)

| | | | |
|---------------------------|-----------------|----------------------|-----------|
| Detector size: | 1000 (diameter) | Quantum Efficiency : | 0.5 – 0.9 |
| Spectral range (eV): | 60 – 2000 | | |
| Temporal resolution (ns): | 1 | | |

DETECTOR 5 (X-ray scintillators + PM)

| | | | |
|---|-----------------|----------------------|------------------|
| Detector size: | 8000 (diameter) | Quantum Efficiency : | 0.05 – 0.2 (TBD) |
| Spectral range (scintillator, eV): | 50 – 2000 (TBD) | | |
| Temporal resolution (scintillator, ns): | 5 (TBD) | | |
| Temporal resolution (PM, ns): | 1 | | |



PLANNED DIAGNOSTICS

- XUV Optics
(Condensing, Imaging) $I(x, y)$
- TGS + Slit + BI CCD
(1D Imaging Broadband XUV spectroscopy, XUV Polychromator) $I(y, \lambda)$
- TGS + Slit + Streak Camera
(1D Imaging Broadband Time Resolved XUV spectroscopy) $I(y, \lambda, t)$
- TGS + Slit + Scintillator with Fast CCD Camera
(1D Imaging Broadband Time Resolved XUV spectroscopy with high dynamic range) $I(y, \lambda, t)$



TEMPORAL STRUCTURE OF CD XUV RADIATION

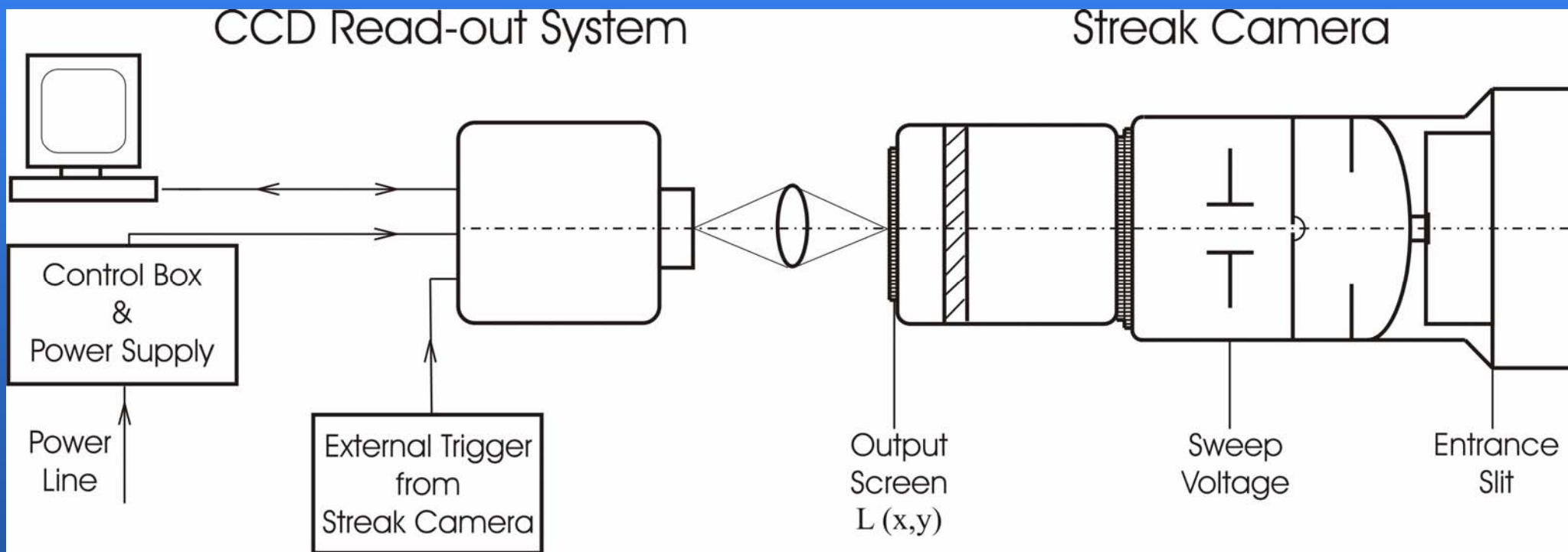
Streak Camera

Lens Relay

Scientific Grade Digital CCD Camera



Experimental setup to study time structure of CD XUV radiation





Streak Camera Reca 1M- Technical Parameters

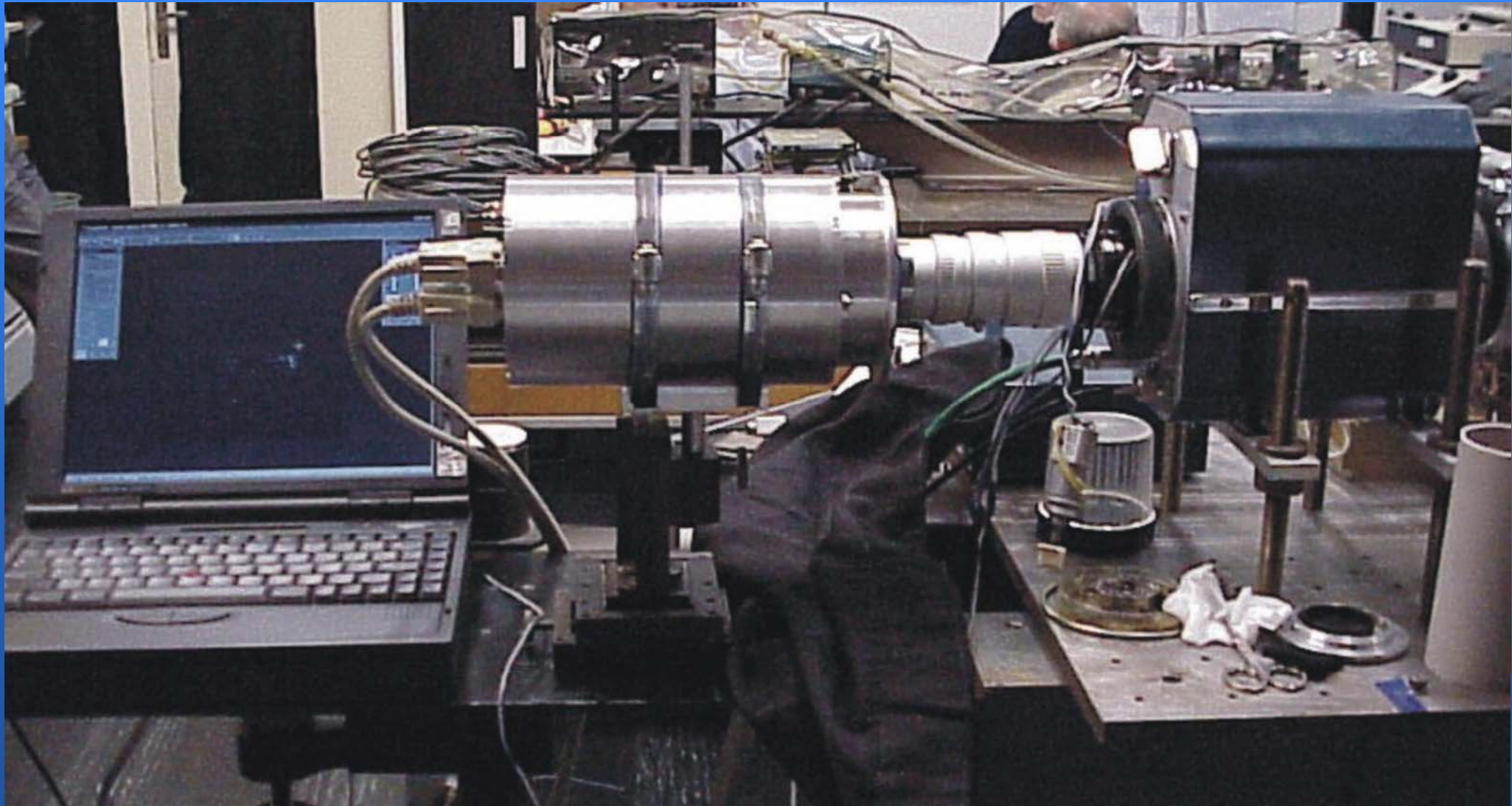
| | | |
|---|-----------|-------------------------------------|
| Measurable spectral region | | 2 nm ... 140 nm |
| Temporal resolution for the fastest sweep | appr. | 40 ps |
| Dynamic range | more than | 100 |
| Dynamic spatial resolution on screen center | appr. | 5 line pairs / mm |
| Streak time / full screen | | 3,5,10,20,50,100,200,400 ns / 25 mm |
| Sweep nonlinearity | less than | 10 % |
| Input trigger signal | positive | 5 ... 30 V / 50 Ω |
| Trigger delay time | less than | 20 ns |
| Trigger jitter | | less than 100 ps |

Streak tube SXR-M

| | |
|--------------------------|--|
| photocathode | electrostatic type with removable photocathode |
| photocathode substrate | Au (300 Å) or CsI (1 000 Å) |
| useful photocathode size | cellulose nitrate film 500 Å thick |
| image magnification | 8 mm x 0.1 mm slit M = 1x |

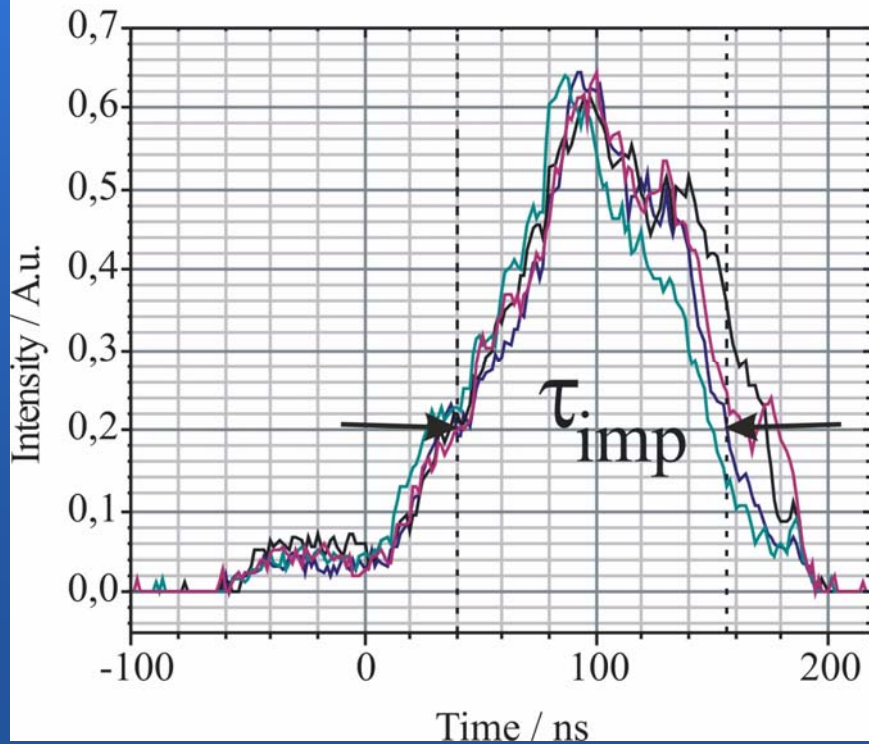
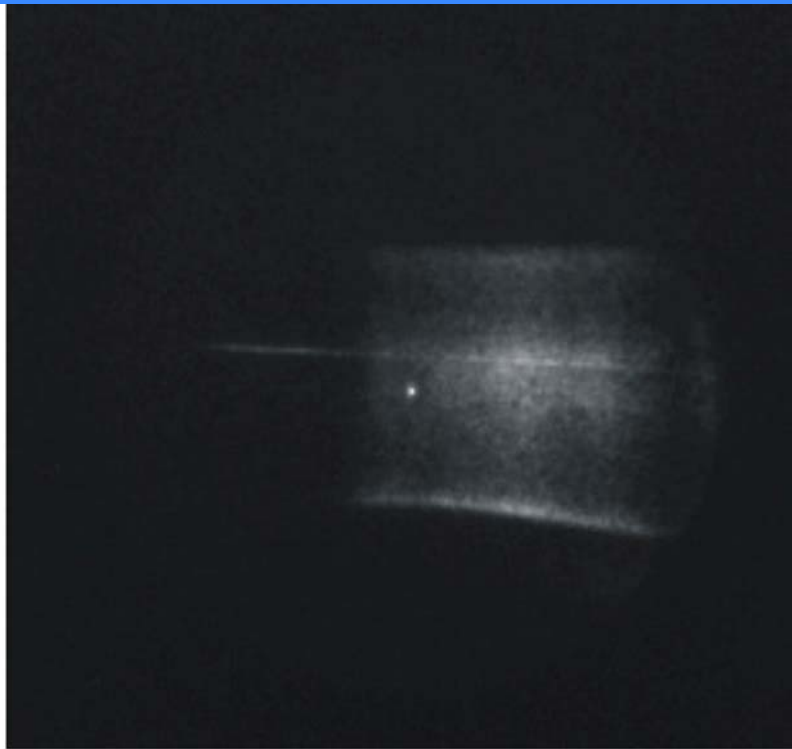
Image intensifier KANAL

| | |
|---------------------------------------|--|
| photocathode | 1" second generation type (with MCP) |
| screen phosphor | S-20 |
| useful photocathode and phosphor size | P-11 (green) |
| luminous gain | 25 mm diameter |
| image magnification | 5 000 typical |
| Synchronization "out" pulse | M = 1x + 4 V / 15 μ s / 50 Ω |





Time resolved CD XUV radiation
Streak camera output
No spatial resolution



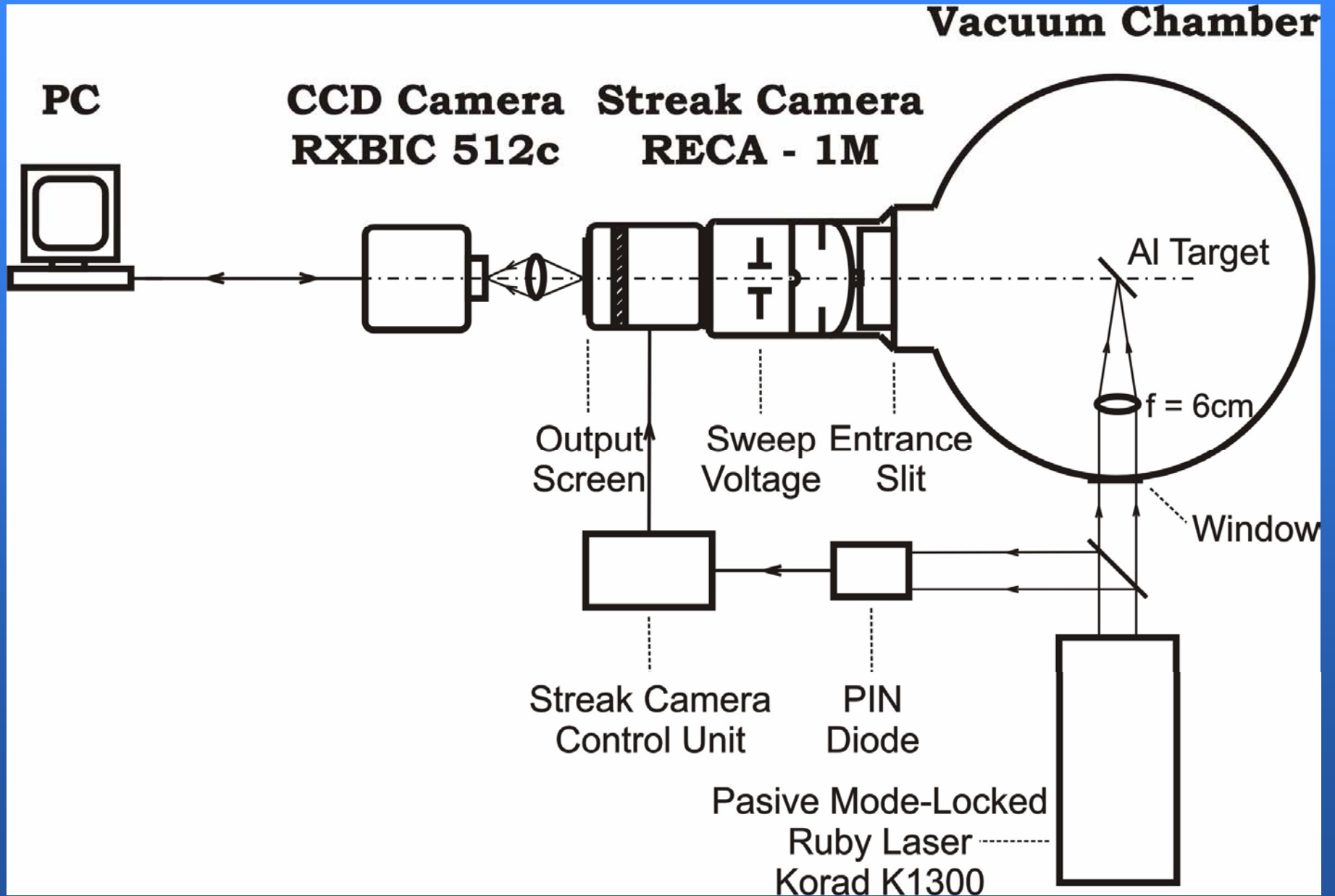


STREAK CAMERA TEMPORAL CALIBRATION

Laser Plasma X-ray Source

Al target

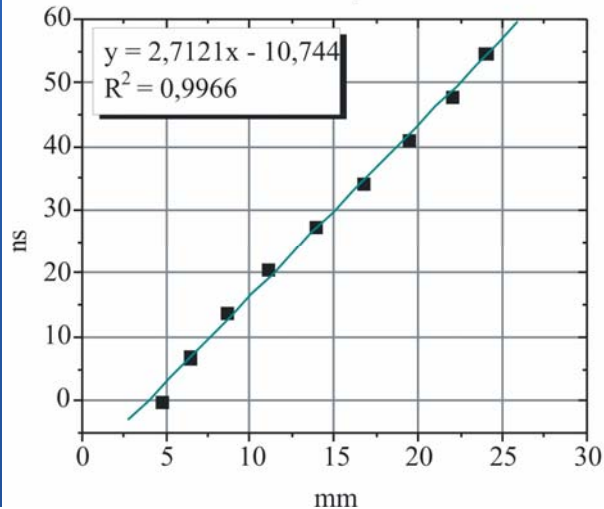
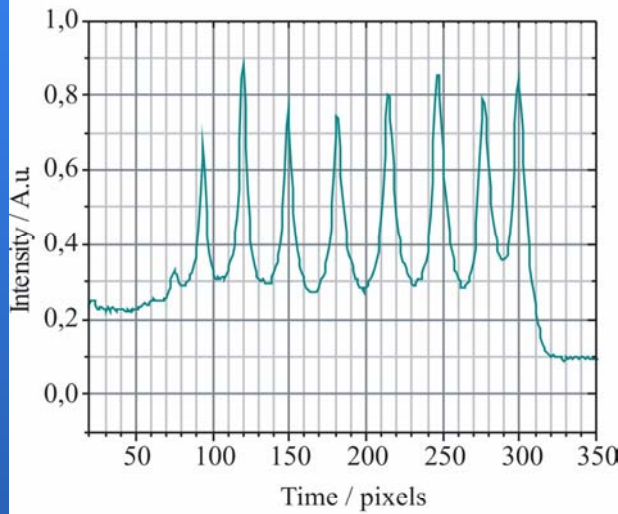
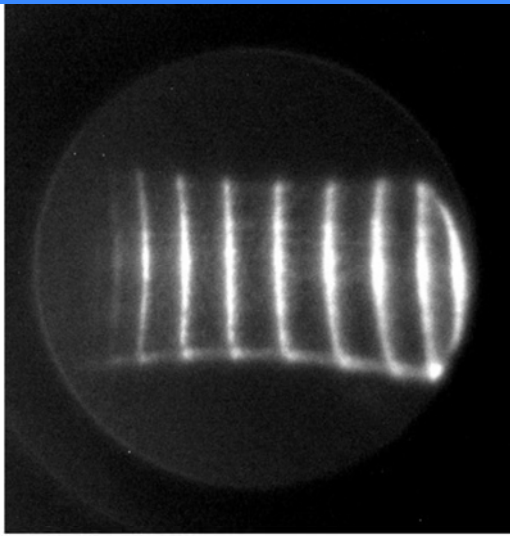
Mode locking





STREAK CAMERA TEMPORAL CALIBRATION

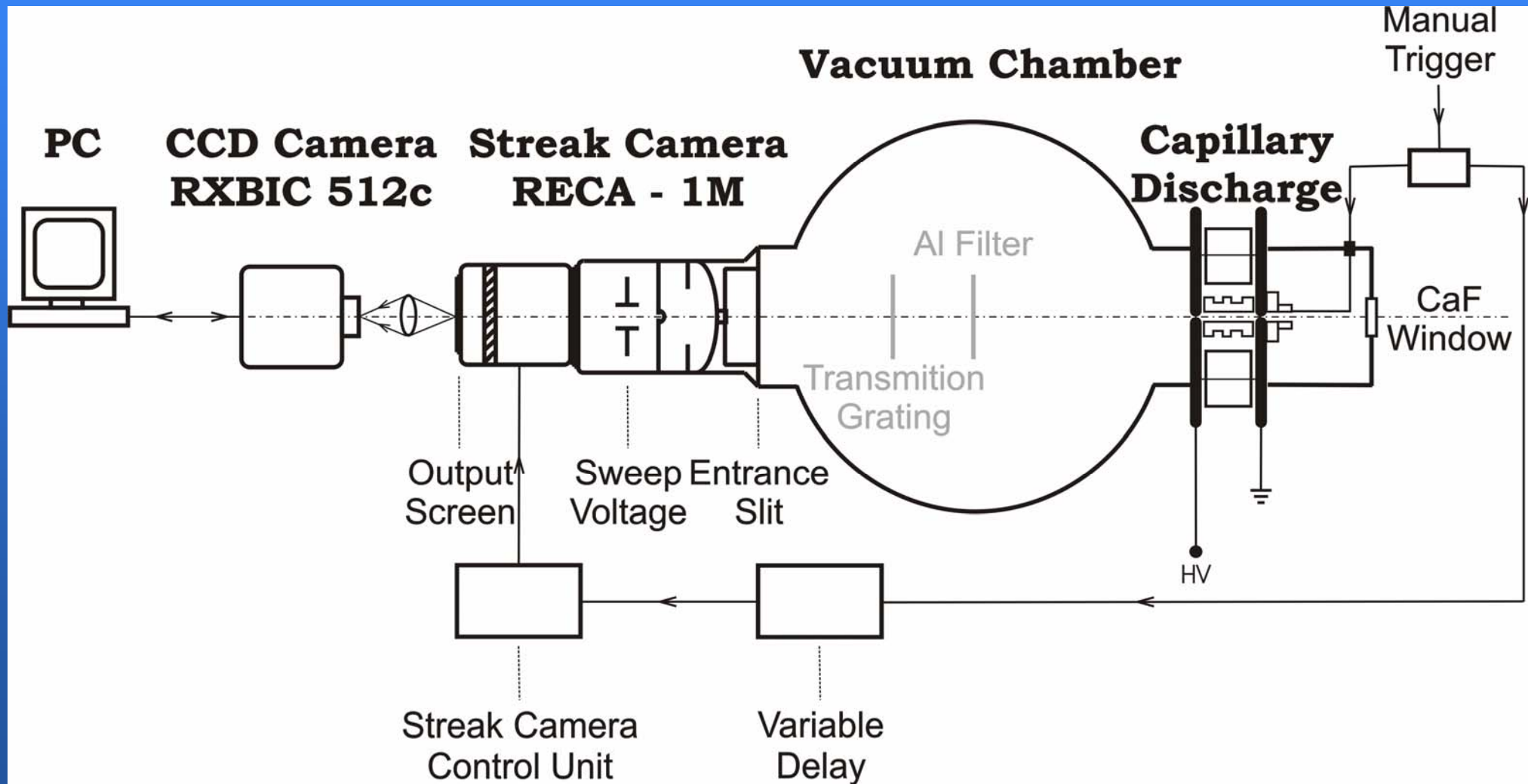
Laser Plasma X-ray Source
Al target
Mode locking





XUV SPECTROSCOPY OF CD PLASMA

Capillary Discharge (CD) X-ray Source
Transmission Grating Spectrometer (TGS)
Streak Camera / Image Intensifier





TRANSMISSION GRATING SPECTROMETER (TGS)

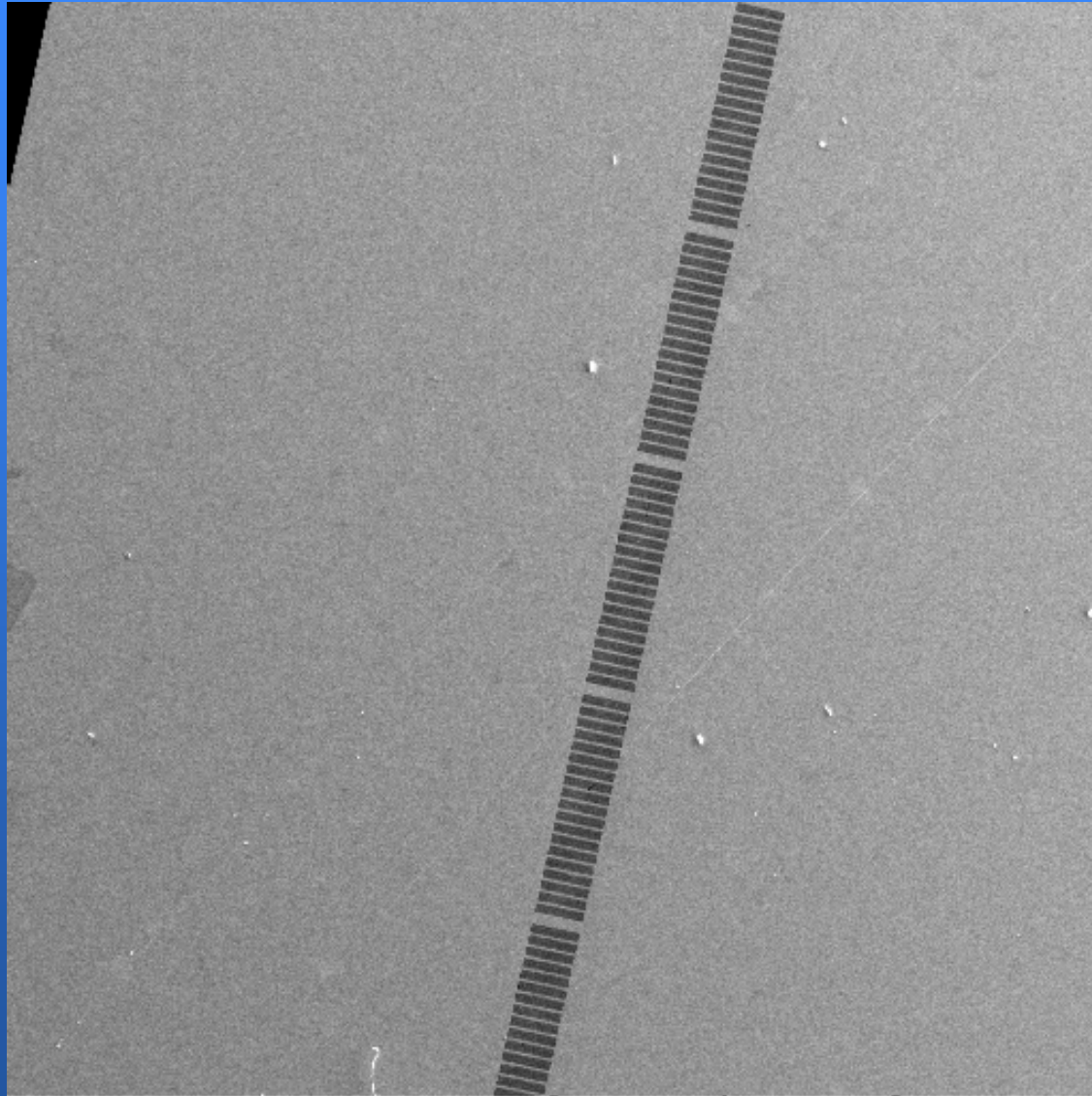
(All dimensions in micrometers unless stated in other units)

TRANSMISSION GRATING

| | |
|------------------------------|------|
| Material: | Au |
| Bar width (horizontal): | 0,7 |
| Bar length (vertical): | 1714 |
| Gap width (horizontal): | 0,7 |
| Period (horizontal): | 1,4 |
| Aperture width (horizontal): | 70 |
| Aperture length (vertical): | 1714 |
| No of periods: | 50 |

TGS GEOMETRY (x, y, z - optical axis, vertical, horizontal)

| | |
|---|-------------|
| Lambda (nm) | 13,5 |
| Source size: (0,Sy,Sz) | 100 |
| Source position: (0,0,0) | 0 |
| Grid position: (Gx,0,0) | 400000 |
| Detector position: (Dx,0,0) | 705000 |
| Dispersive resolution, 1st order (nm): | 0,27 |
| Geometrical resolution, 1st order (nm): | 0,916311475 |
| Dispersive resolution, 2nd order (nm): | 0,54 |
| Geometrical resolution, 2nd order (nm): | 0,458155738 |
| Overall resolution, 1st order (nm): | 0,955262644 |
| Optimum value of Gx: | 429435,7959 |

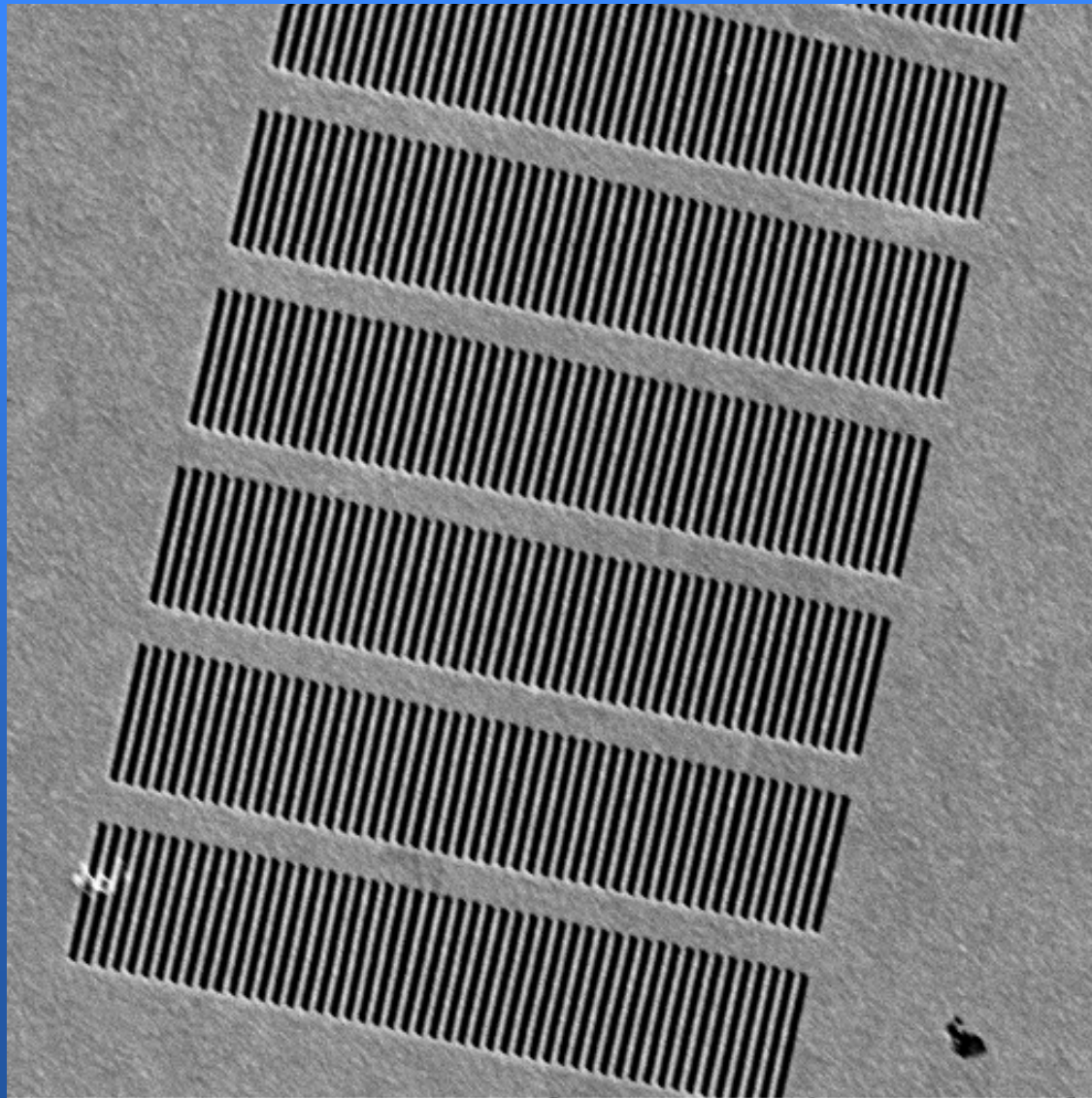


SEM MAG: 100 x
HV: 30.0 kV
VAC: HiVac

DET: SE Detector
DATE: 04/11/02

500 μ m

Vega ©Tescan
Digital Microscopy Imaging

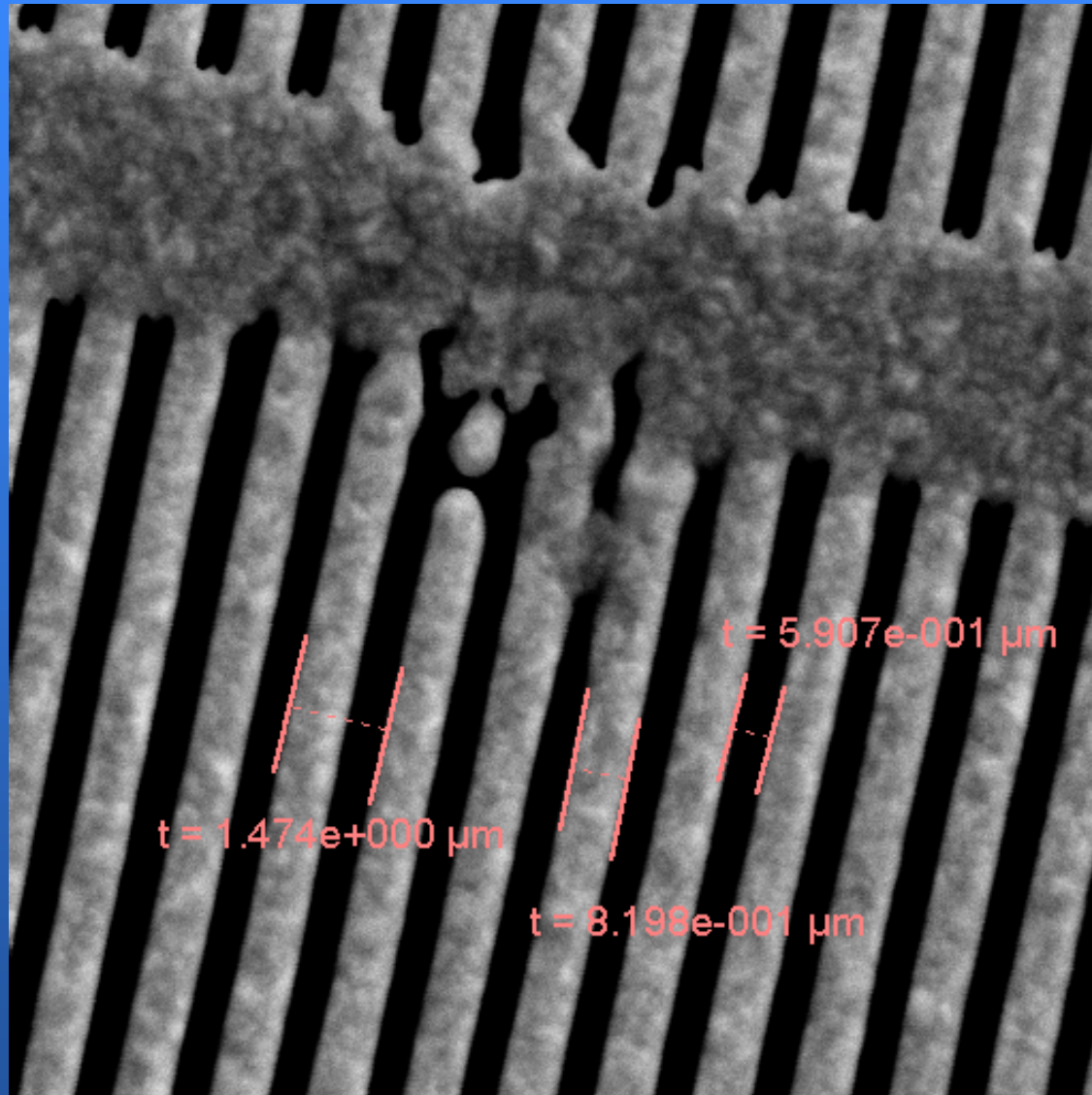


SEM MAG: 1.51 kx
HV: 30.0 kV
VAC: HiVac

DET: SE Detector
DATE: 04/11/02

50 μ m

Vega ©Tescan
Digital Microscopy Imaging



SEM MAG: 10.02 kx
HV: 30.0 kV
VAC: HiVac

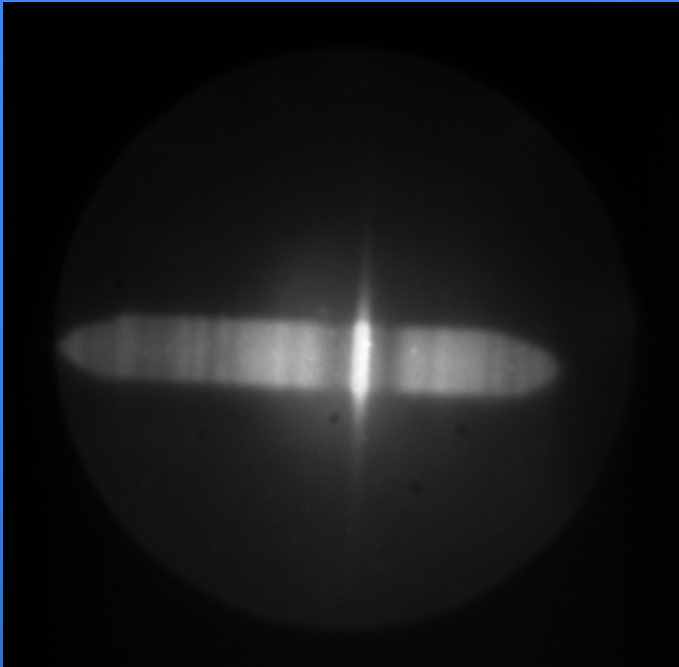
DET: SE Detector
DATE: 04/11/02



Vega ©Tescan
Digital Microscopy Imaging



XUV spectrum of CD radiation
Transmission Grating Spectrometer
MCP Image Intensifier KANAL
Digital CCD camera RXBIC 512c



TGS parameters:

| | |
|---------|--------------------------------|
| mezera | $0,7 \times 10^{-6} \text{ m}$ |
| perioda | $1,4 \times 10^{-6} \text{ m}$ |

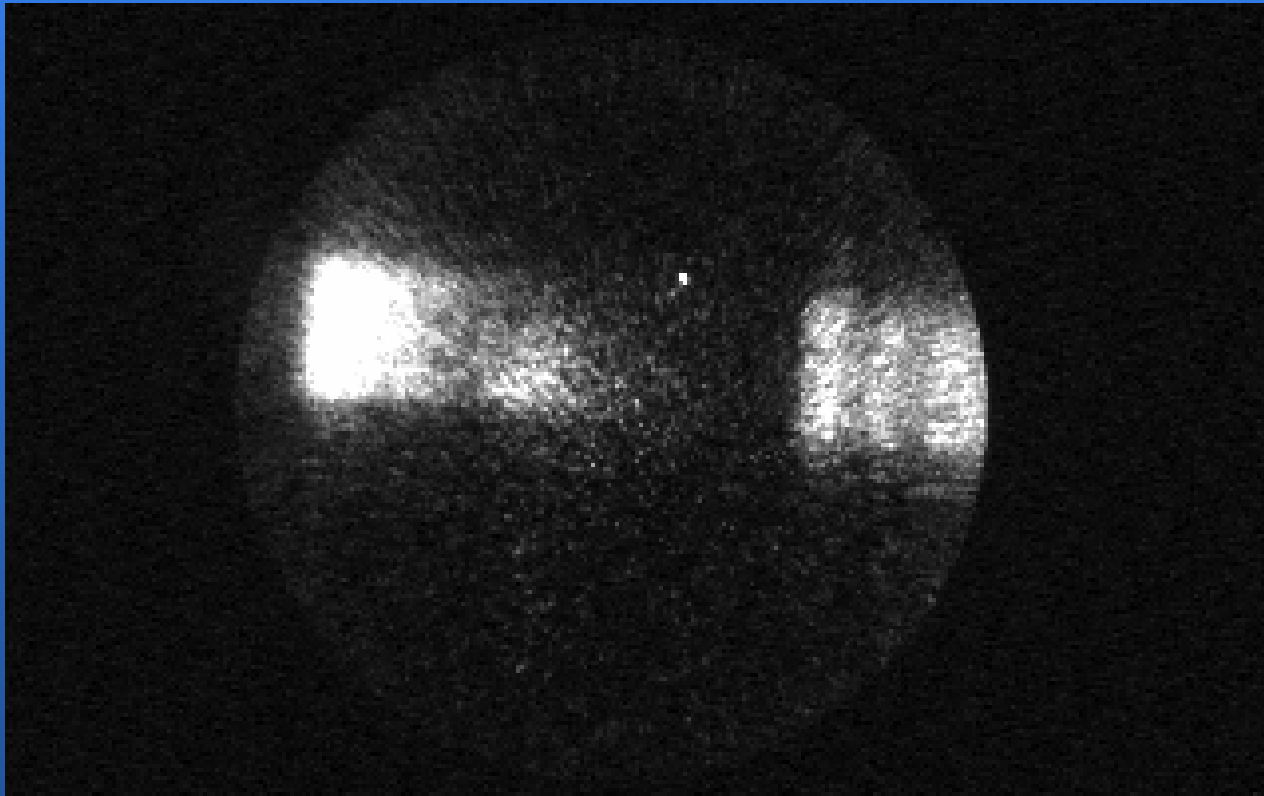
Image Intensifier Input Aperture: 25 mm

| | [mm] | [mm] |
|------------|---------|---------------|
| Geometry 1 | a = 749 | b = 418 |
| Geometry 2 | a = 400 | b = 418 |
| Geometry 3 | a = 400 | b = 320 |
| Geometry 4 | a = 400 | b = 305 (295) |



XUV spectrum of CD radiation

Transmission Grating Spectrometer
MCP Image Intensifier X-SHOT
Digital CCD camera RXBIC 512c





XUV SCIENTIFIC GRADE BACK ILLUMINATED XCCD SENSOR

BI XCCD

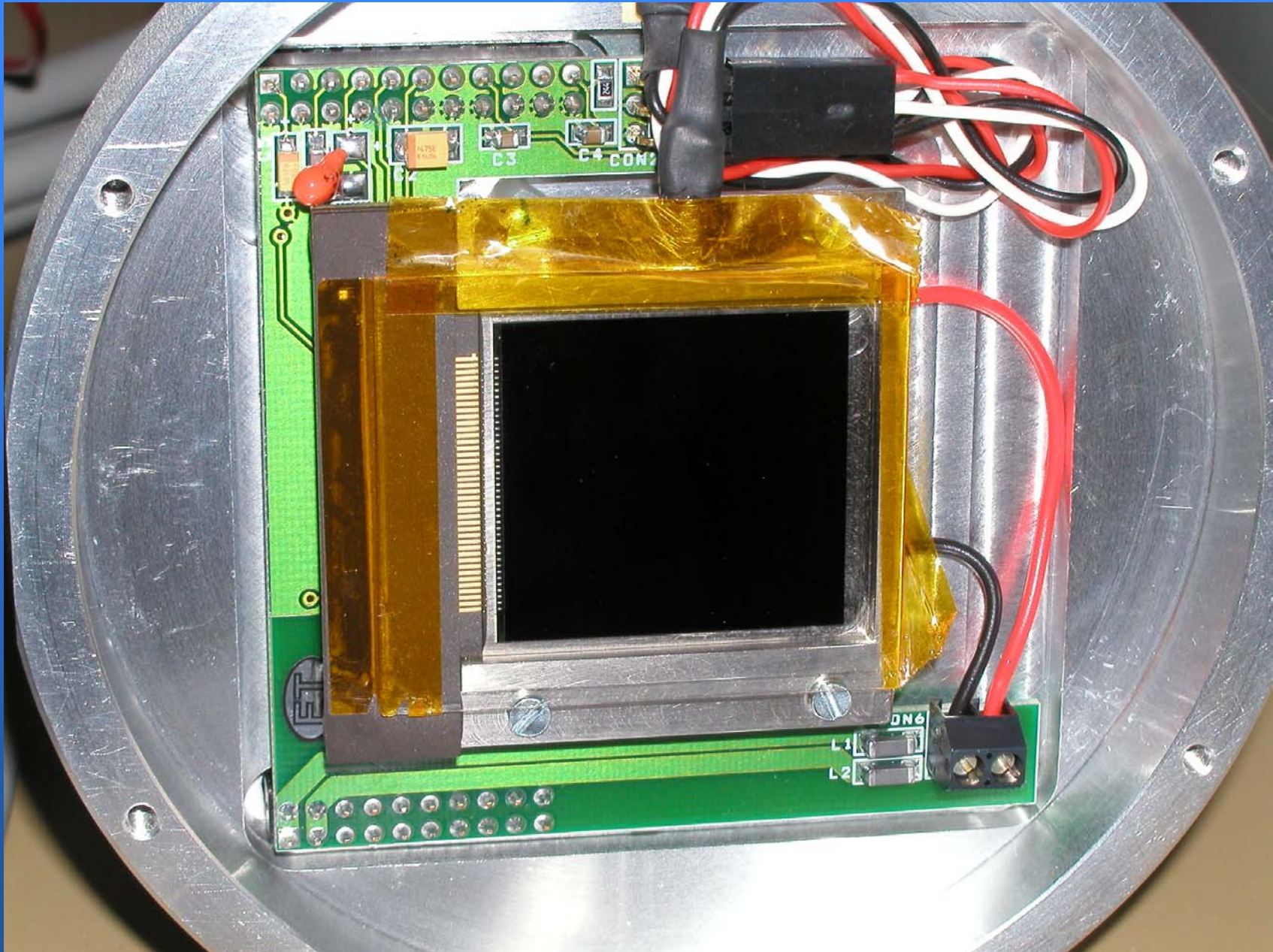
2k x 2k

1.5 e-/ADU

2-3 ADU

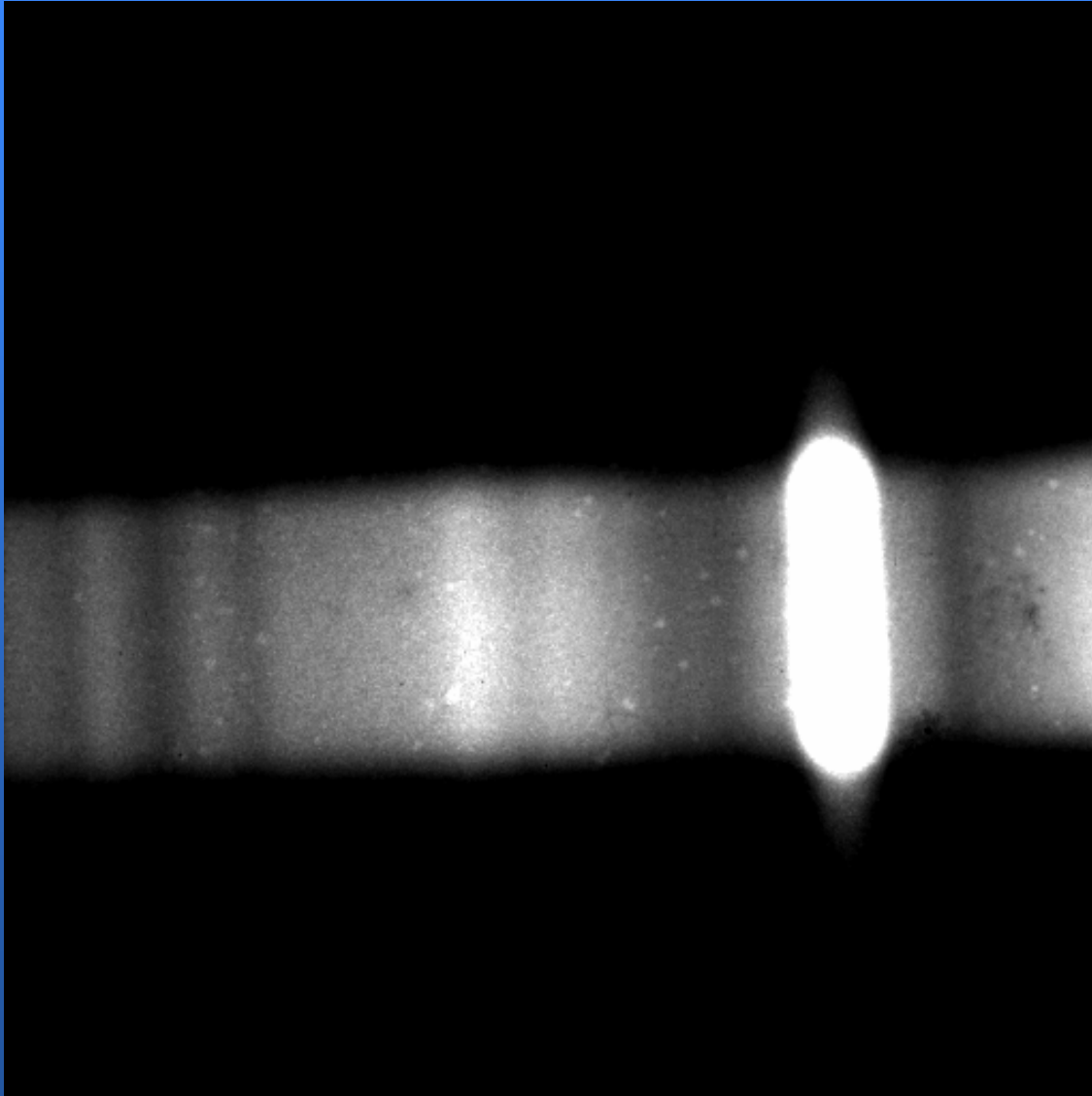
rms noise

DR > 20000





XUV SPECTRUM



Energy Range

30 eV to 120 eV

Capillary Discharge

TGS

Czech Tech. Univ. Prague

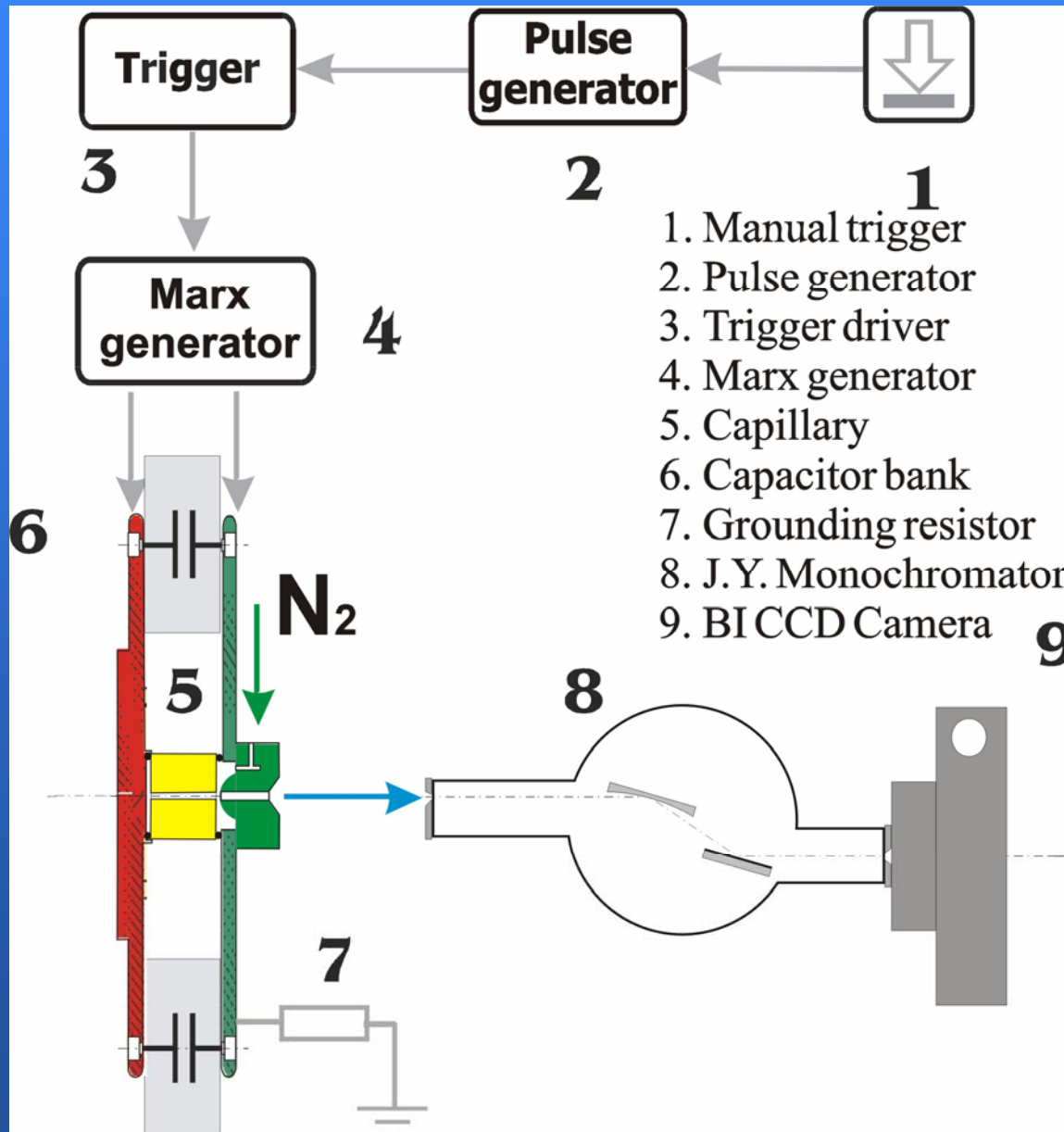


XUV SPECTROSCOPY OF CD PLASMA

Capillary Discharge (CD) X-ray Source
Reflection Grating Spectrometer (RGS)
BI CCD Camera



XUV SPECTROSCOPY OF CD PLASMA EXPERIMENTAL ARRANGEMENT



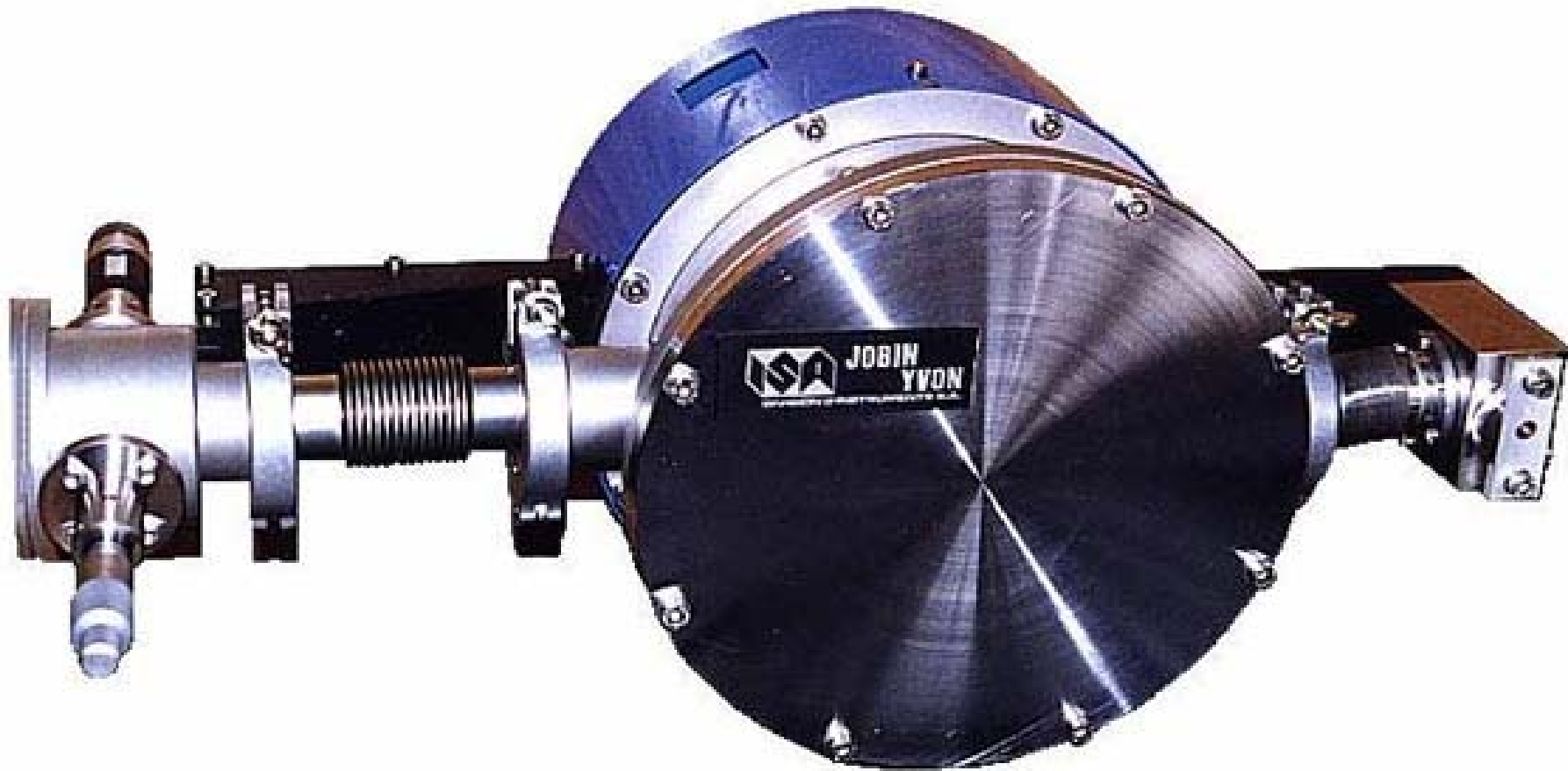
Capillary Discharge (CD)
X-ray Source

Reflection Grating
Spectrometer (RGS)

BI CCD Camera

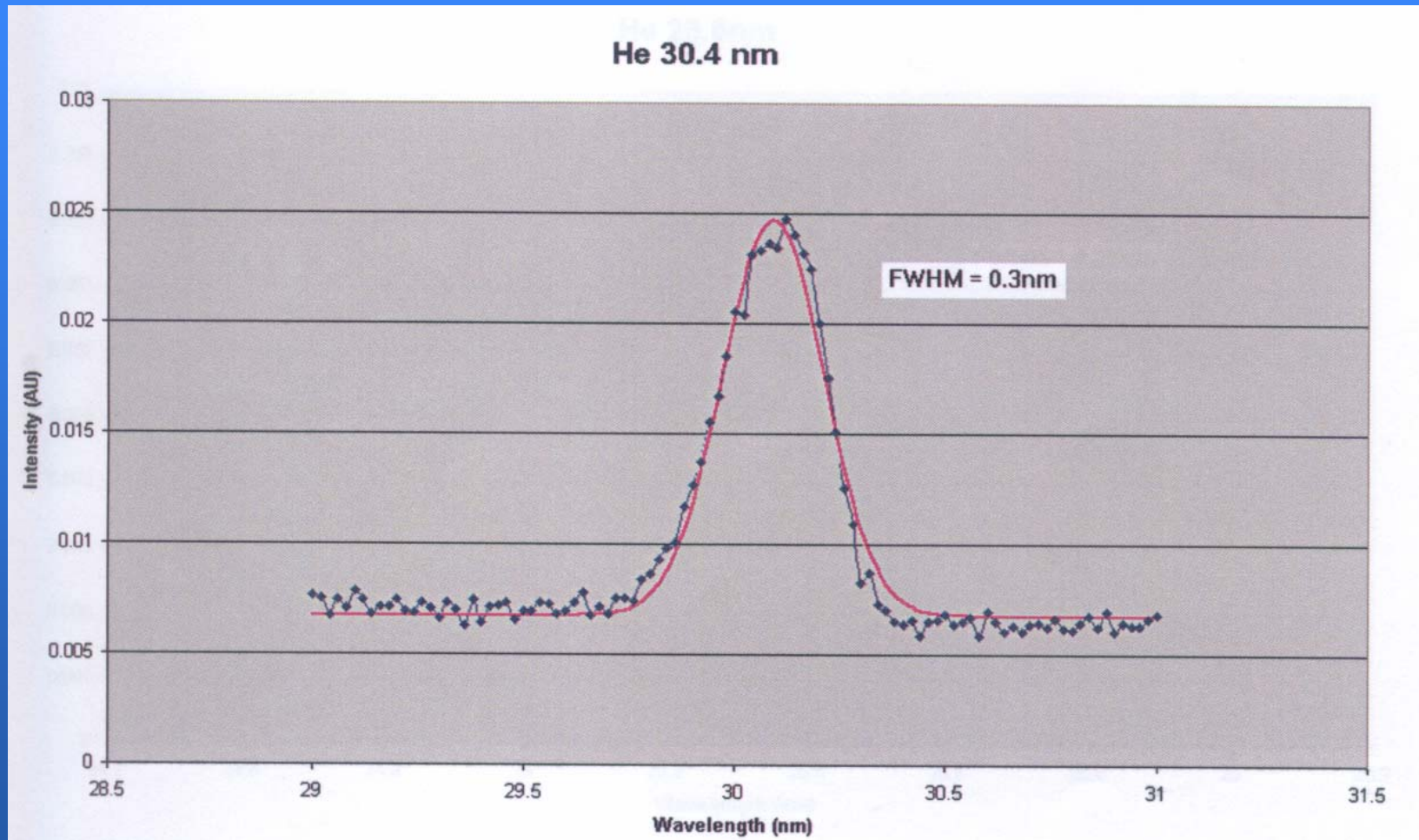


XUV Spectrometer Jobin Yvon PGM-PGS 200





Spectral Resolution of XUV Spectrometer Jobin Yvon PGM-PGS 200





Digital XCCD Camera Reflex RXBIC 512C



BI XCCD

512 x 512

1.5 e-/ADU

2-3 ADU

rms noise

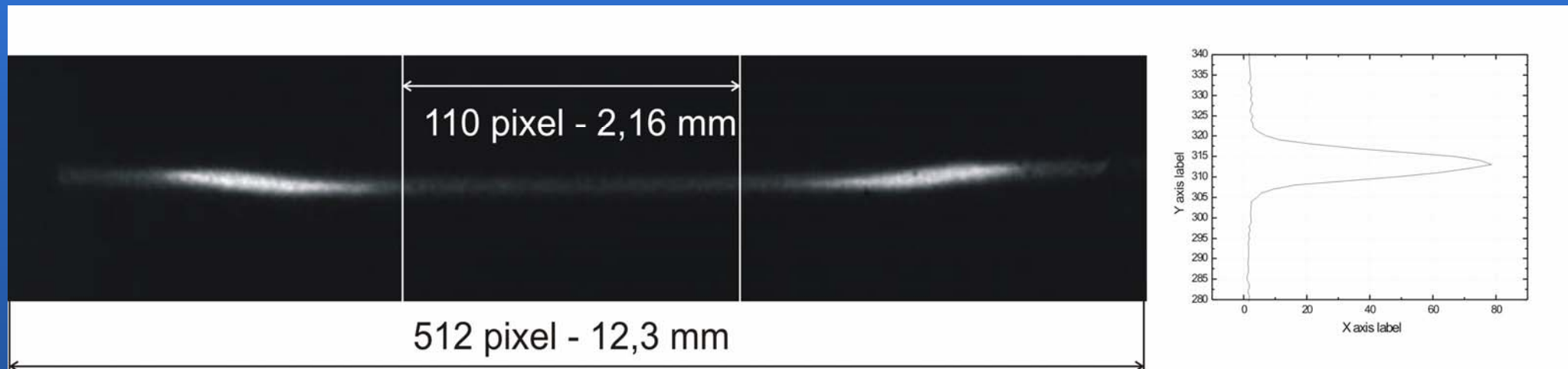
DR > 20000





Spectral Line Behind Output Slit of RGS

XUV Spectrometer Jobin Yvon PGM-PGS 200
Digital XCCD Camera Reflex RXBIC 512C





Time Resolved XUV spectroscopy

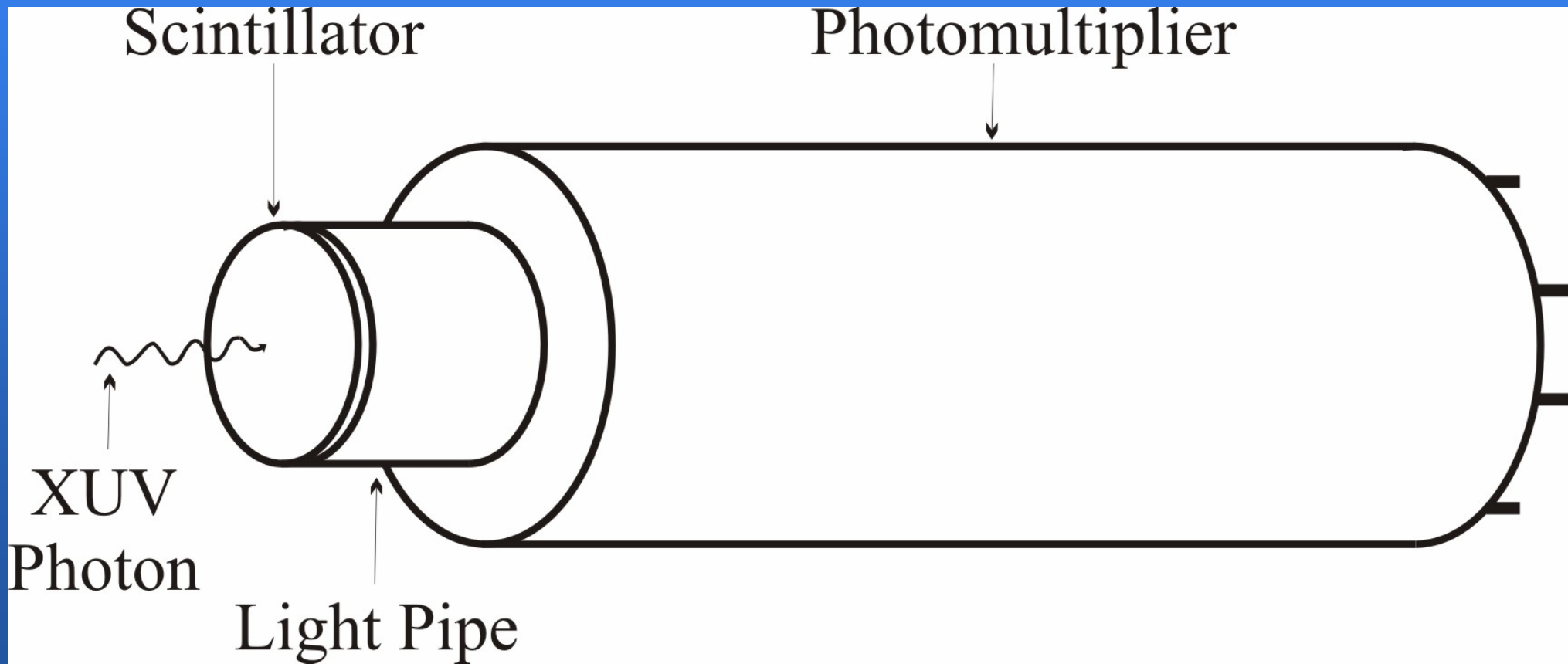
Scintillators

Photomultiplier



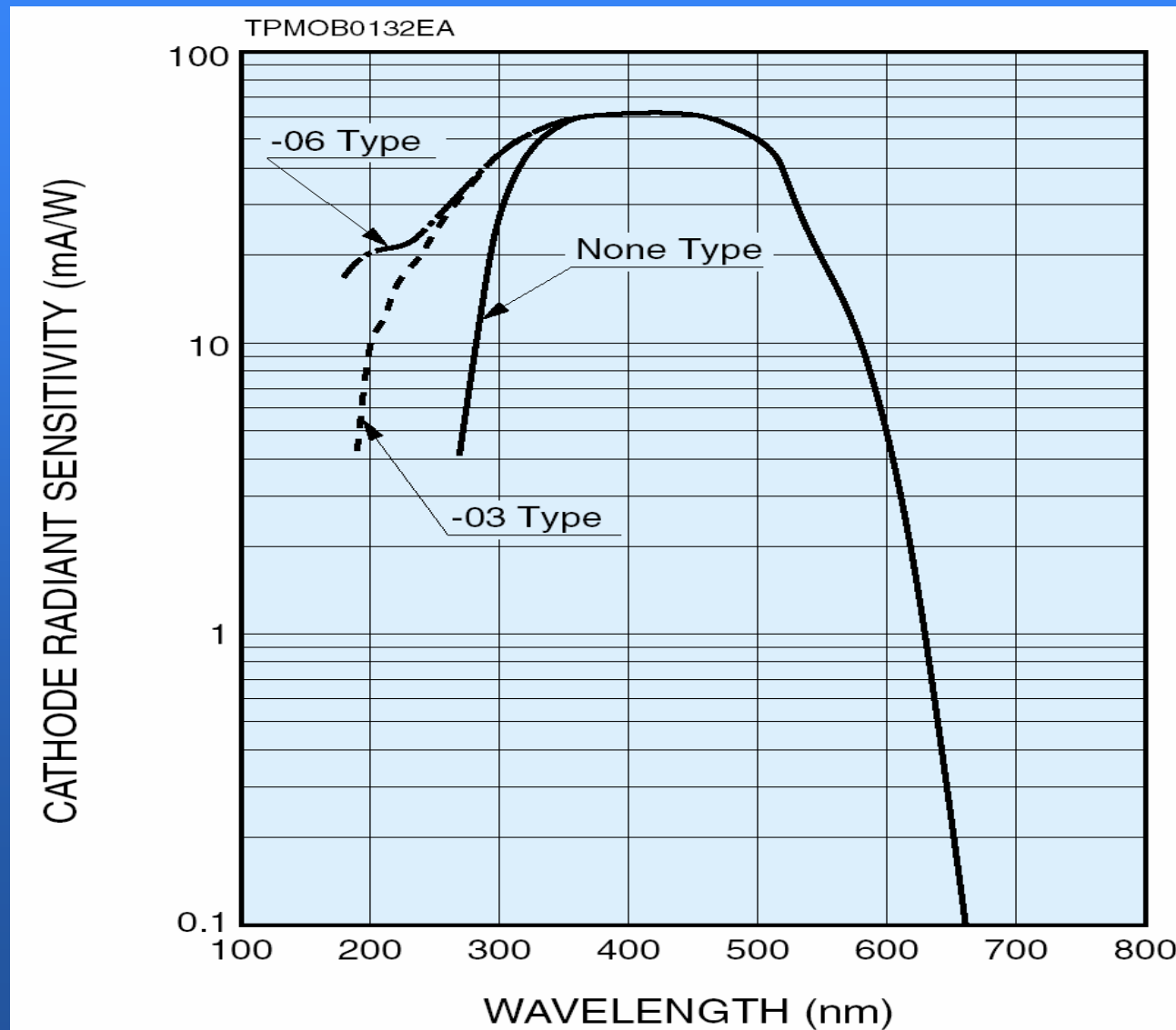
Time Resolved XUV spectroscopy

Scintillators: YAG:Ce
YAP:Ce
BaF₂
Plastic Scintillators





Spectral sensitivity of PM Hamamatsu H5773-06





TGS + Slit + Scintillator with Fast CCD Camera $I(y, \lambda, t)$

1D Imaging Broadband Time Resolved XUV spectroscopy with high dynamic range

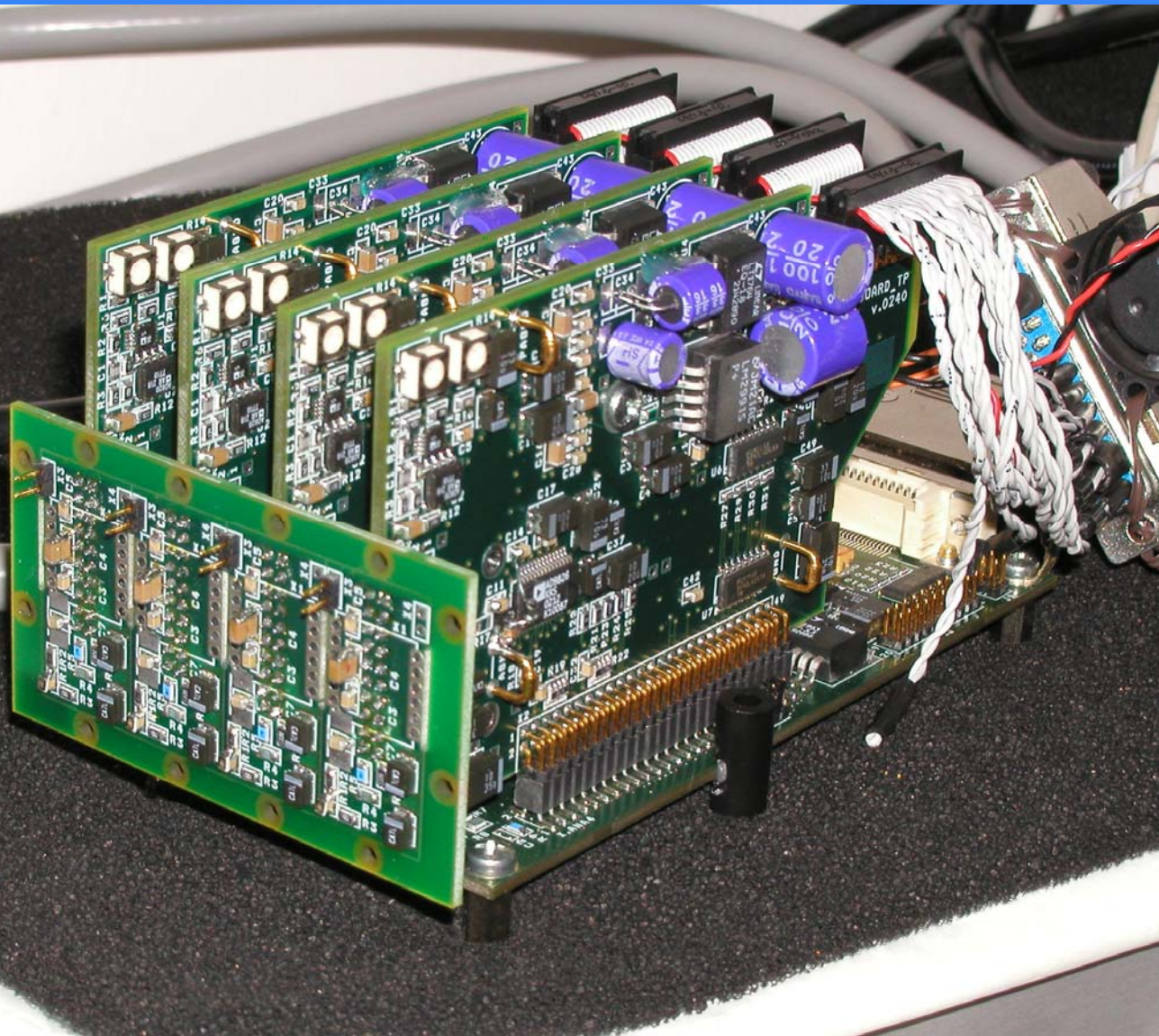


Fast X-ray CCD Camera

4 CCD fast readout
X-ray Camera
Electronics
(Reflex RX4)

2632 x 496 pixels
16 bit ADC
10 bit dynamics
40 Mpixel / sec

Camera Link

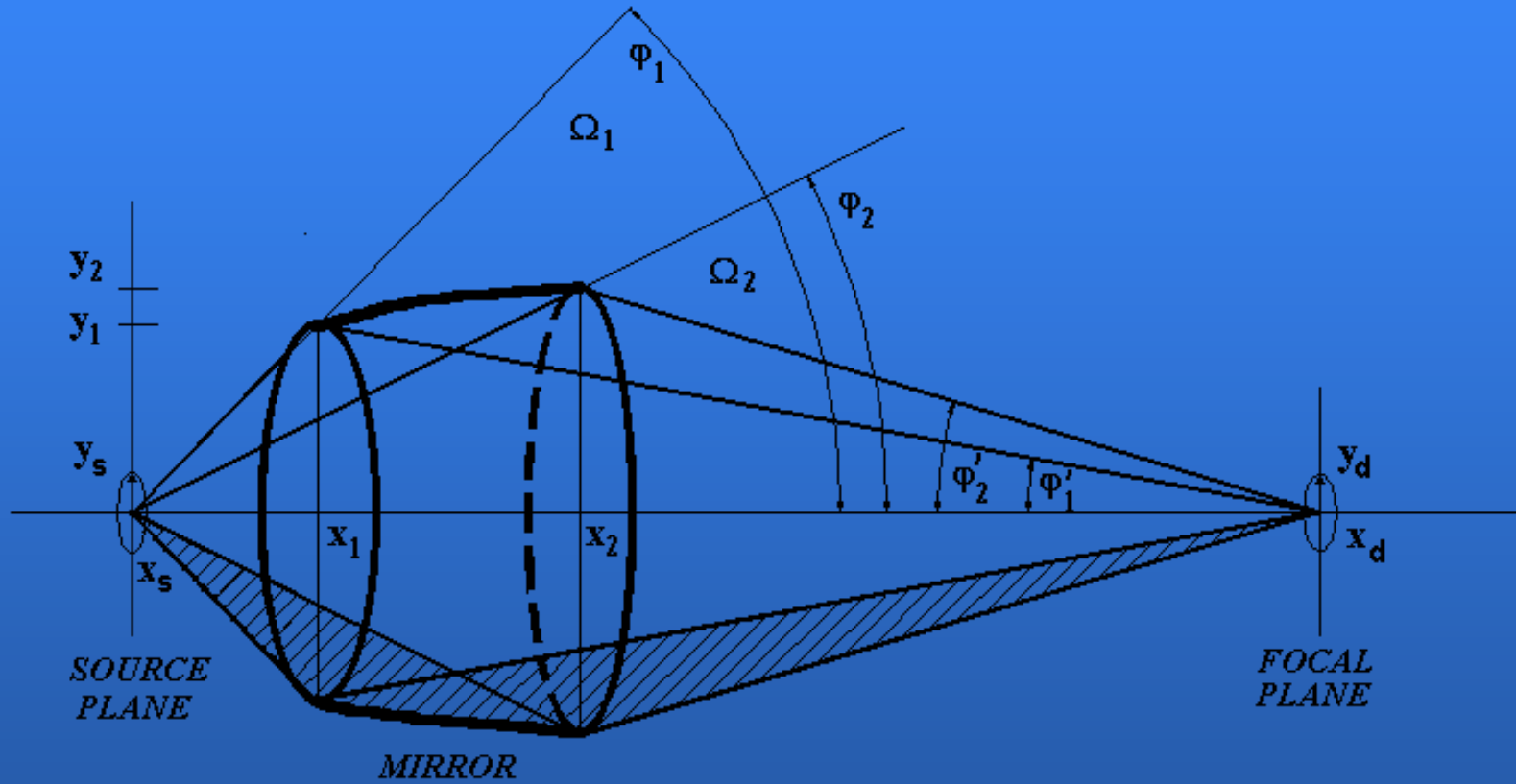




XUV - SXR Optics for Spectrometry and Imaging

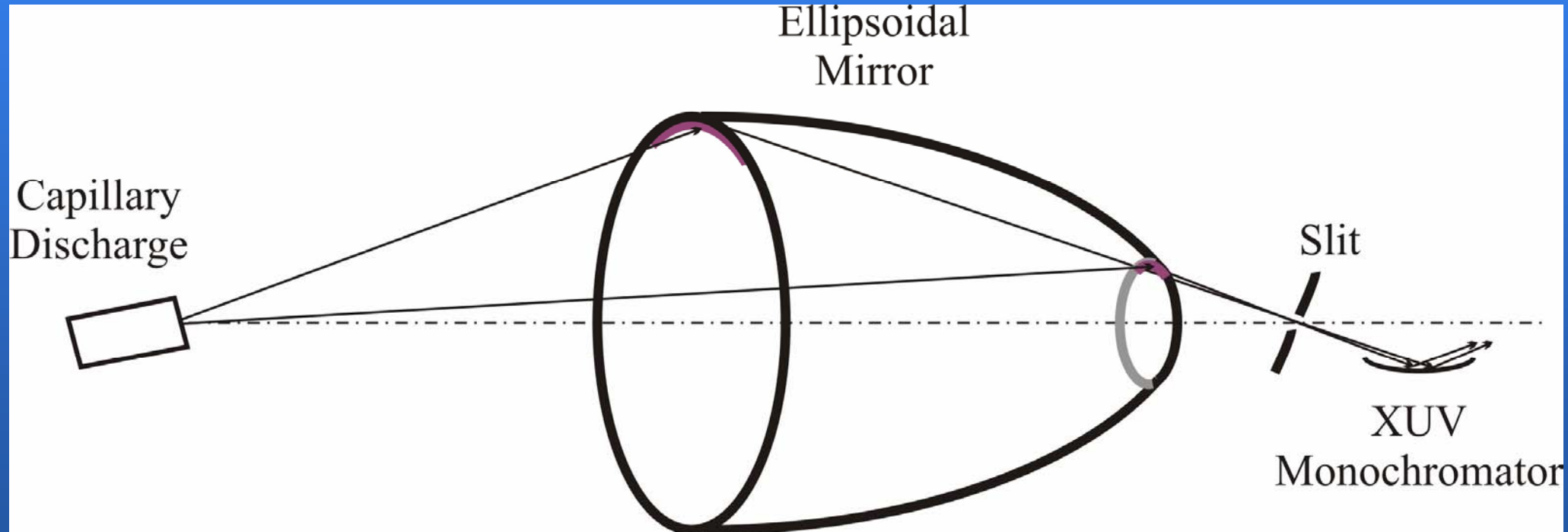


ELLIPSOIDAL MIRROR





Experimental Arrangement of XUV Spectrometer with XUV Optics





XUV ELLIPSOIDAL MIRROR for 50 to 120 eV range



Reflex