Photon Radiometry

BESSY II OPERATED AS A PRIMARY SOURCE STANDARD

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Outline

- Introduction to PTB
- BESSY II as a source of calculable synchrotron radiation
  - calibration principle
  - measurement of the storage ring parameters
  - application examples
- Outlook

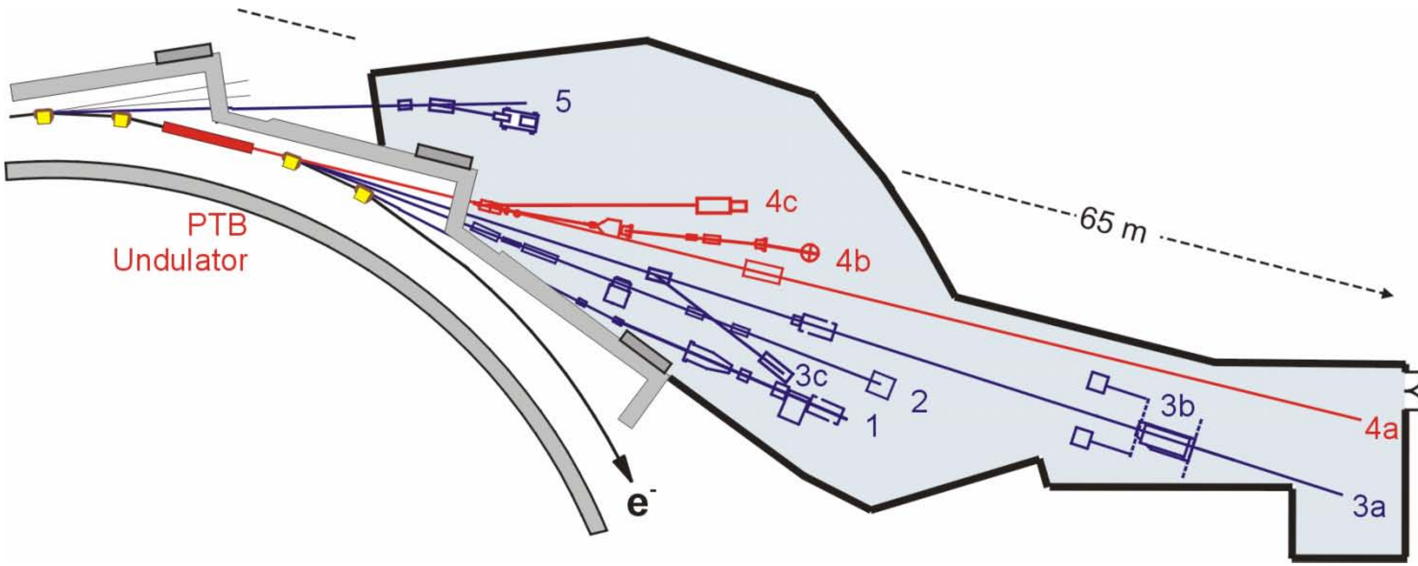
Physikalisch-Technische Bundesanstalt (PTB)

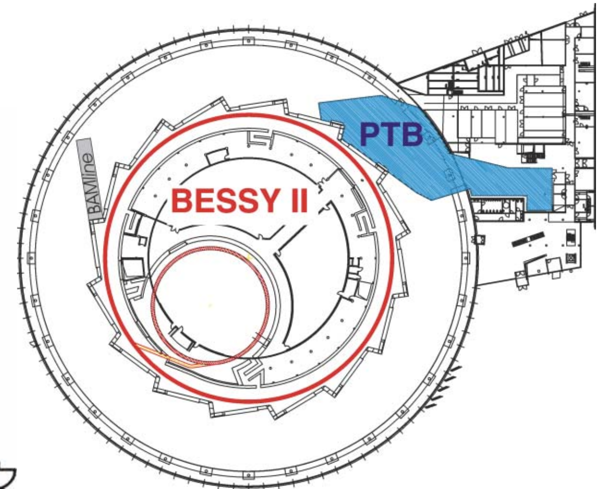
- PTB: German national metrology institute, located in Braunschweig and Berlin
- responsible for the realization and dissemination of the legal units in Germany
- department „Photon Radiometry“ located at BESSY II in Berlin-Adlershof
- **tasks**: - Realization and dissemination of radiometric units in the UV, VUV, X-ray spectral range by using
  - **BESSY II as primary source standard** („source-based radiometry“)
  - a primary detector standard („detector-based radiometry“)

  - Characterization of optical components, in particular for EUV lithography
  - Other applications of quantitative radiation measurements

PTB Radiometry Laboratory at BESSY II

Photon Radiometry





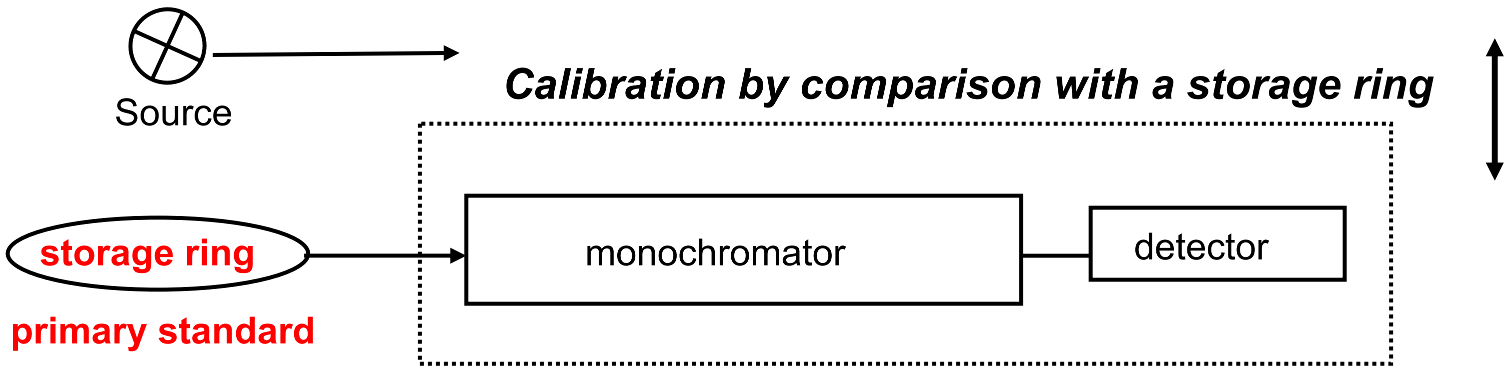
1	plane grating monochromator 30 eV to 1800 eV	4a	undispersed undulator radiation Compton backscattering
2	four crystal monochromator 1.75 keV to 10 keV	4b	plane grating monochromator at undulator 20 eV to 1900 eV
3a	undispersed bending magnet radiation	4c	deflected undispersed undulator radiation EUVL metrology test station
3b	normal incidence monochromator 3 eV to 35 eV	5	normal incidence monochromator 3 eV to 35 eV
3c	deflected undispersed bending magnet radiation, EUV irradiation test station		

Source-based radiometry

Photon Radiometry

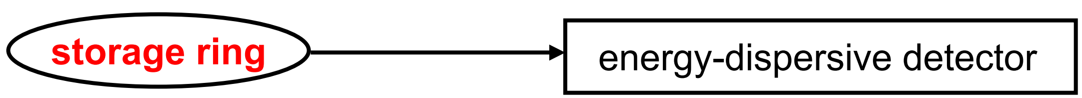
Basis: Primary source standard electron storage ring BESSY II

- Task 1: Calibration of sources



- Task 2: Calibration of - energy-dispersive detectors (e. g. Si(Li), HPGe, CCD)

- monochromator-detector systems

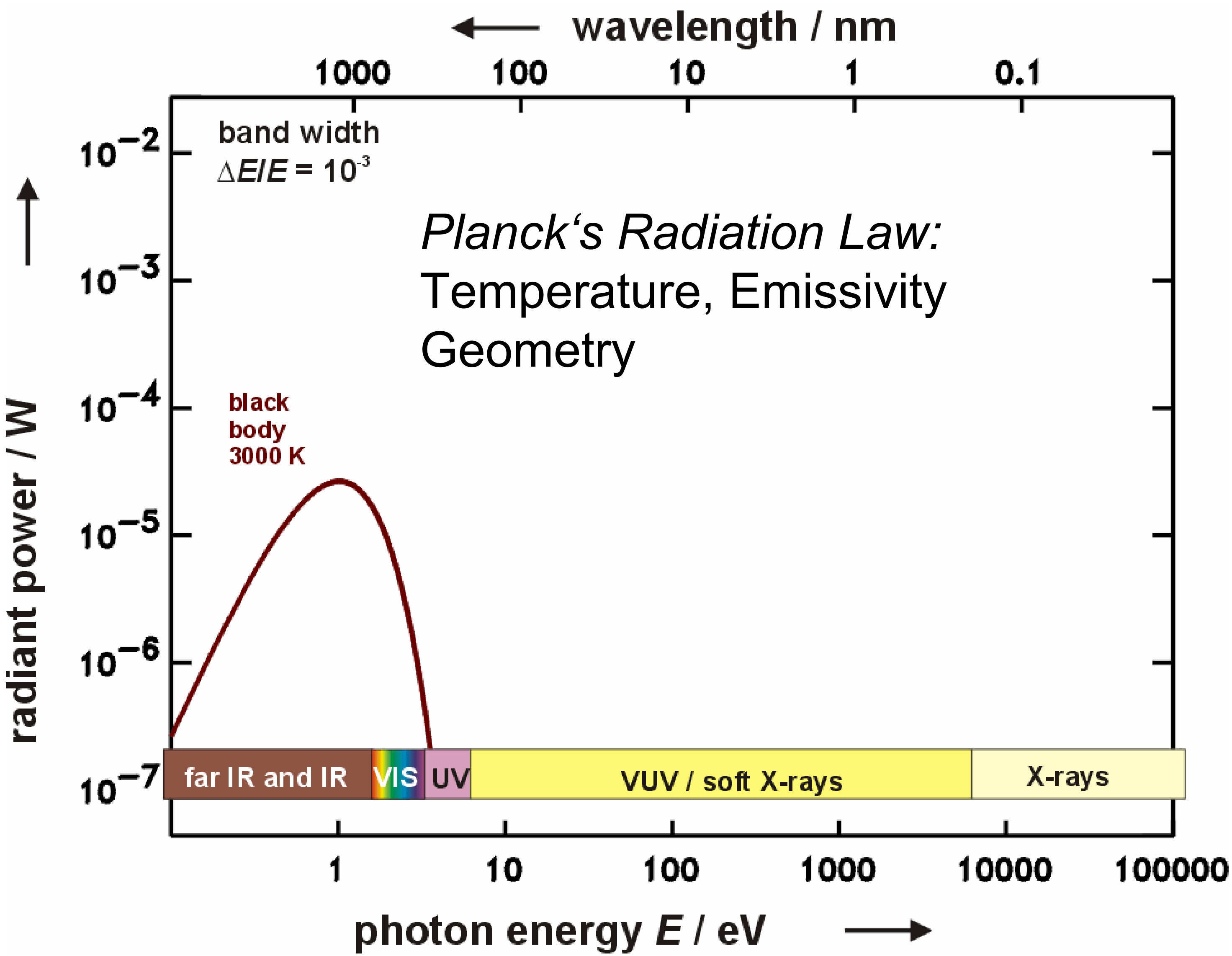


Important property: BESSY II has a dynamic range of 12 orders of magnitude in photon flux!

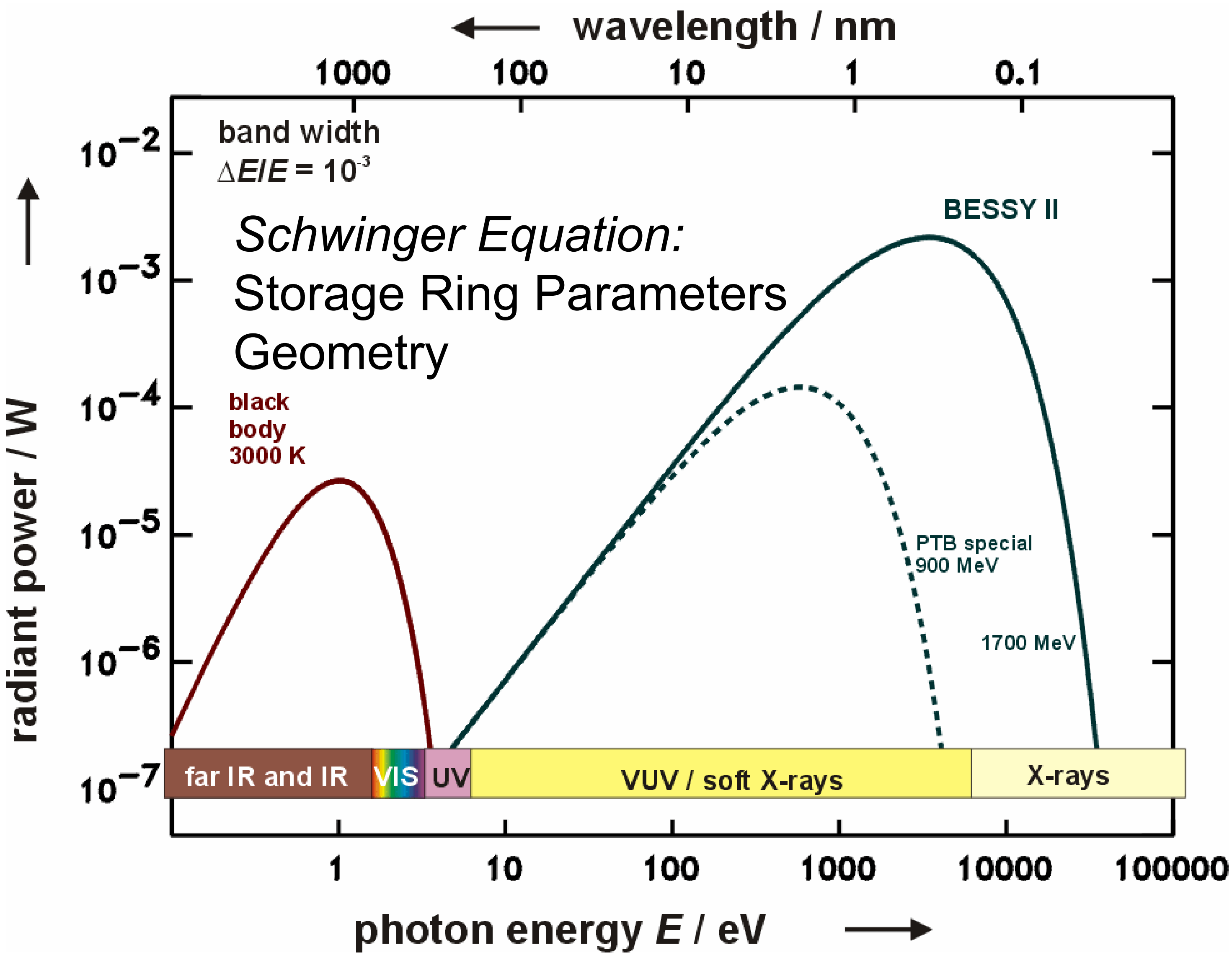
Requirement for calibration: Special operation parameters of the storage ring

Storage ring BESSY II as primary source standard

Photon Radiometry



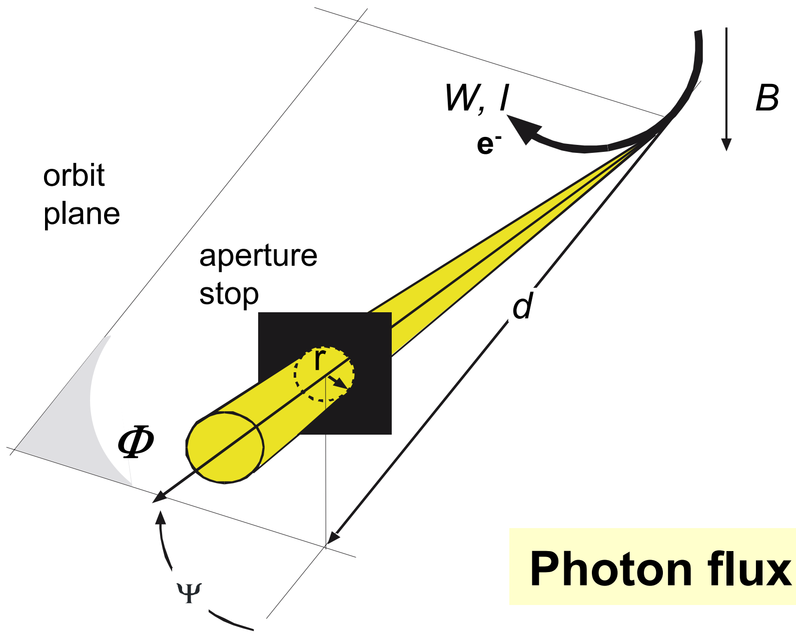
Storage ring BESSY II as primary source standard



Storage rings used for radiometry

Ring name (Inst.)	Location	Beam energy / GeV	E_c / keV
SURF III (NIST)	Gaithersburg, USA	0.4	0.17
TERAS (NMIJ)	Tsukuba, Japan	0.8	0.57
VEPP-2M (INP)	Novosibirsk, Russia	0.7	0.62
BESSY II (PTB)	Berlin, Germany	1.7	2.5
VEPP-3 (INP)	Novosibirsk, Russia	2.0	4.8

Calculable synchrotron radiation from bending magnets



Radiant power of synchrotron radiation is determined by (Schwinger 1949):

(a) storage ring parameters
(b) geometry parameters

Photon flux $\Phi = \Phi\ (W, B, I, \Sigma_y, \psi, d, r)$

- **electron beam and storage ring parameters**

  W electron energy

  B magnetic induction

  I electron beam current

  Σ_y vertical size and divergence of the electron beam

- **geometrical quantities**

  d distance

  r radius of aperture

  ψ emission angle

BESSY II as a Primary Source Standard

calculation of the radiant power of synchrotron radiation with a relative uncertainty of < 0.1 %

requires precise determination of the storage ring parameters

parameter	value	rel. uncertainty
electron energy W	1718.60(6) MeV	$3.5 \cdot 10^{-5}$
magnetic induction B	1.29932(12) T	$1 \cdot 10^{-4}$
electron beam current I (example)	10.000(2) mA	$2 \cdot 10^{-4}$
eff. vert. divergence Σ_y	3.5(7) μrad	0.2
vert. emission angle ψ	0(2) μrad	-
distance d	30 000(2) mm	$6.7 \cdot 10^{-5}$

Relative uncertainty of the spectral photon flux of BESSY II

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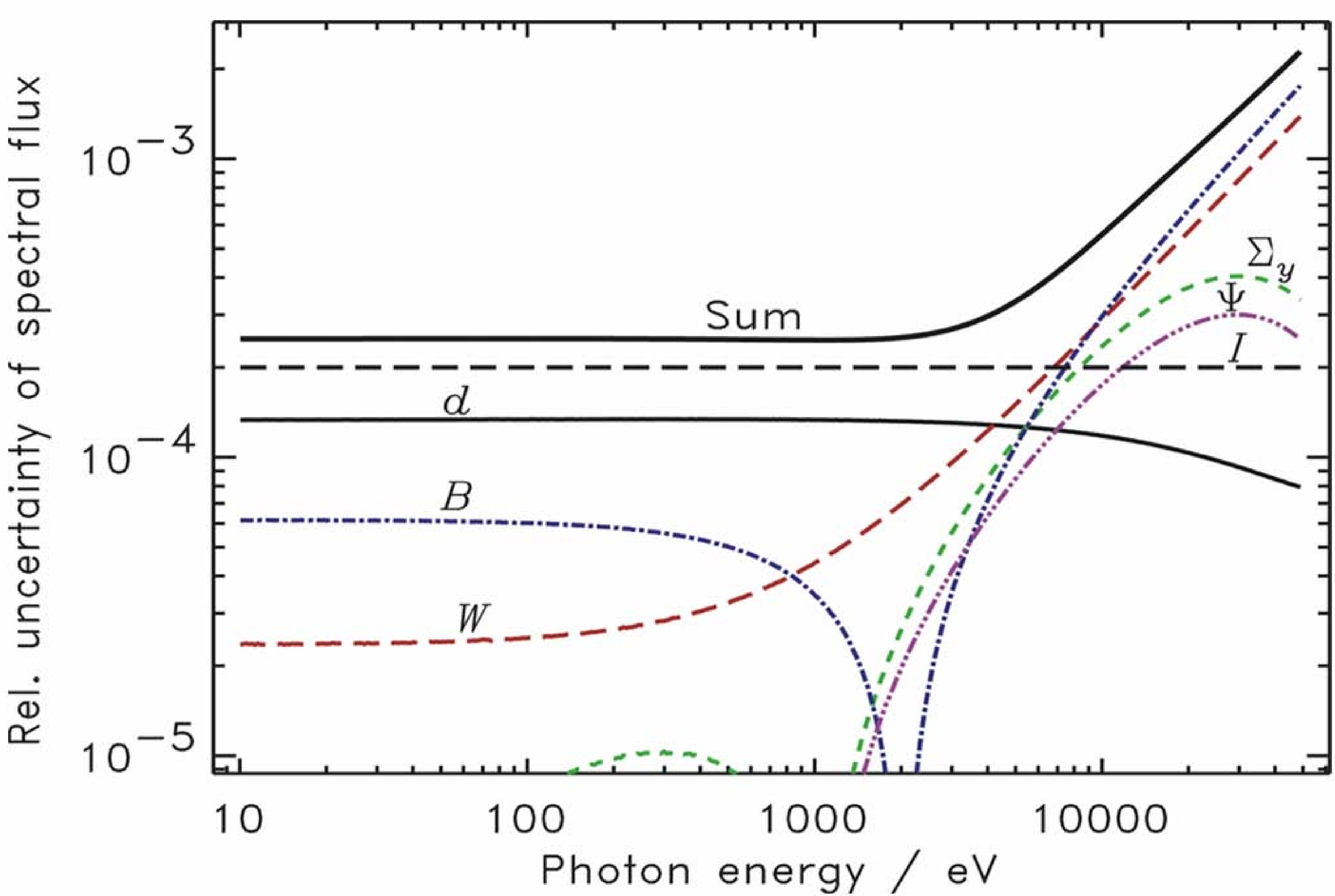


Storage ring BESSY II as primary source standard

Validation of the calculation of spectral power of BESSY:

- Comparison to black body in the IR/visible
- Comparison to radionuclides in the X-ray region
- Comparison of BESSY I and BESSY II
- Total power measured with a primary detector standard

Measurement of the storage ring parameters

electron energy	resonant spin depolarization and Compton Backscattering
beam current	two DC PCT, calibrated photodiodes
magnetic induction	NMR probe movable to source point (modified vacuum chamber)
source size	negligible influence at BESSY II
emission angle	during calibration by vertical adjustment
distance	projection of 5-fold slit to plane at known distance

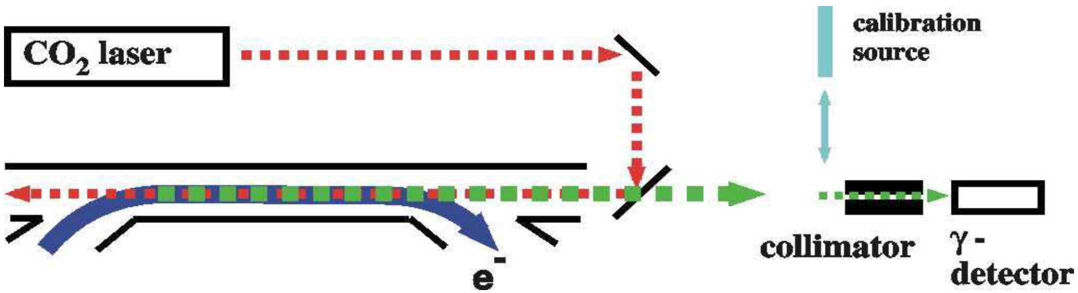
BESSY II: electron energy measurement

Methods/Equipment

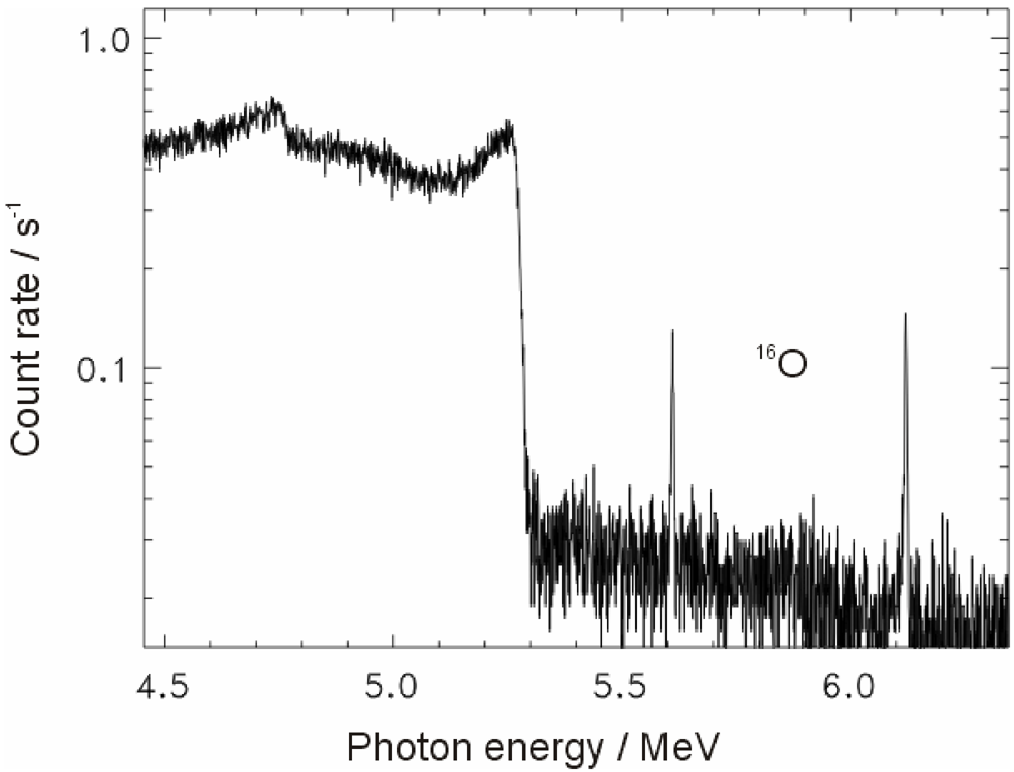
- Resonant spin depolarization for 1.7 GeV:
  strip-line for depolarization, rf-amplifier
  loss-detectors
  (see P. Kuske et al. Proc EPAC 2000, 1771)

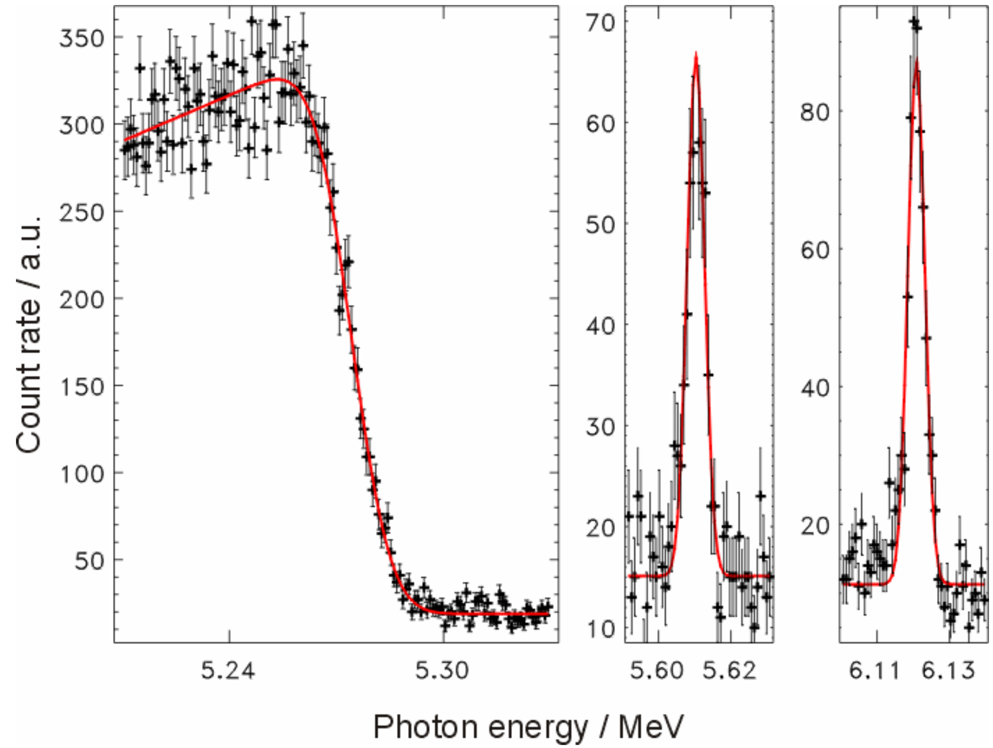
- Compton Backscattering of laser photons for 900 MeV and 1.7 GeV:
  CO_2-laser
  HPGe-detector

BESSY II: electron energy measurement



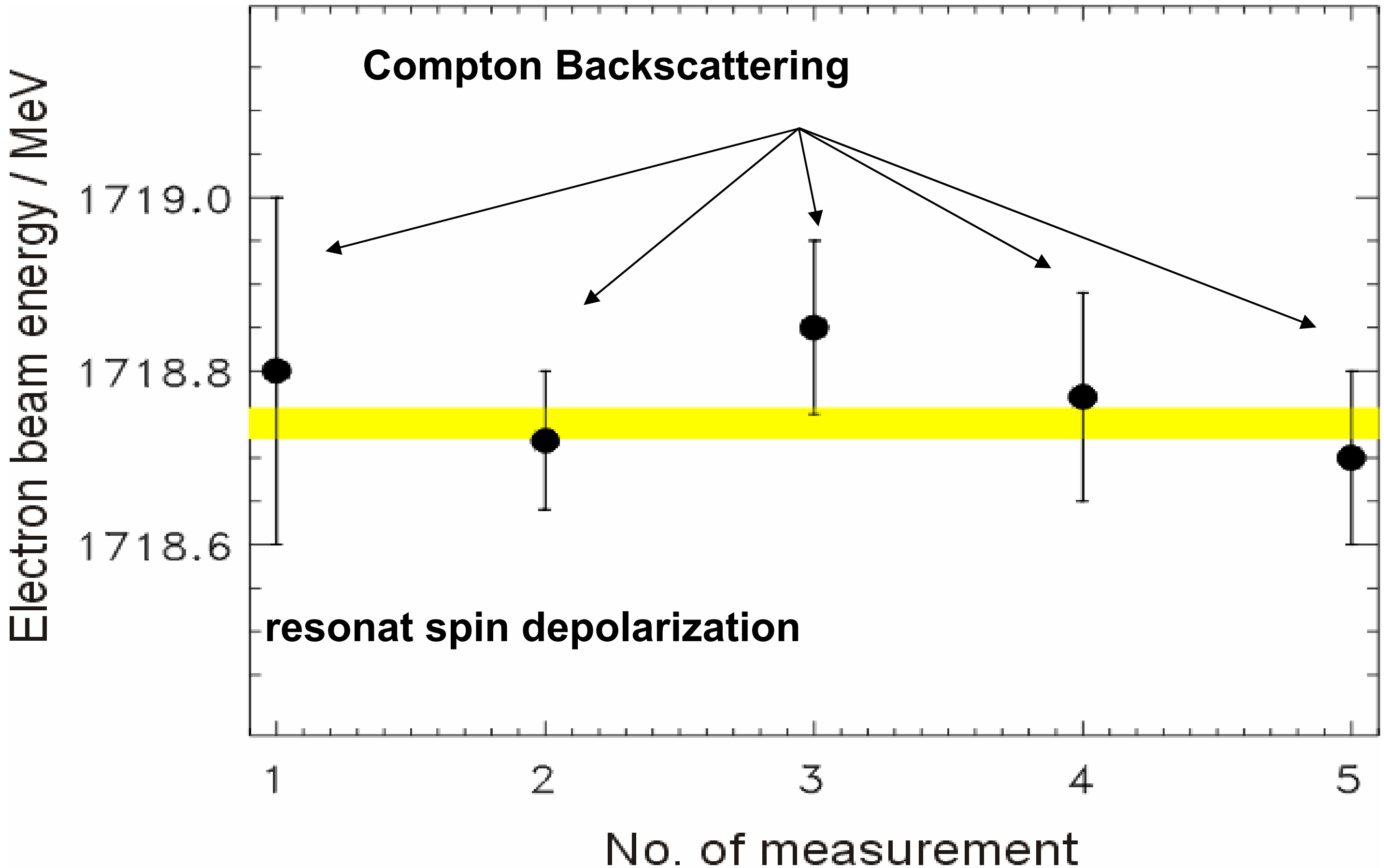
$$E_{max} \sim 4\,\gamma^2\,E_{laser}$$





BESSY II: electron energy measurement

Photon Radiometry



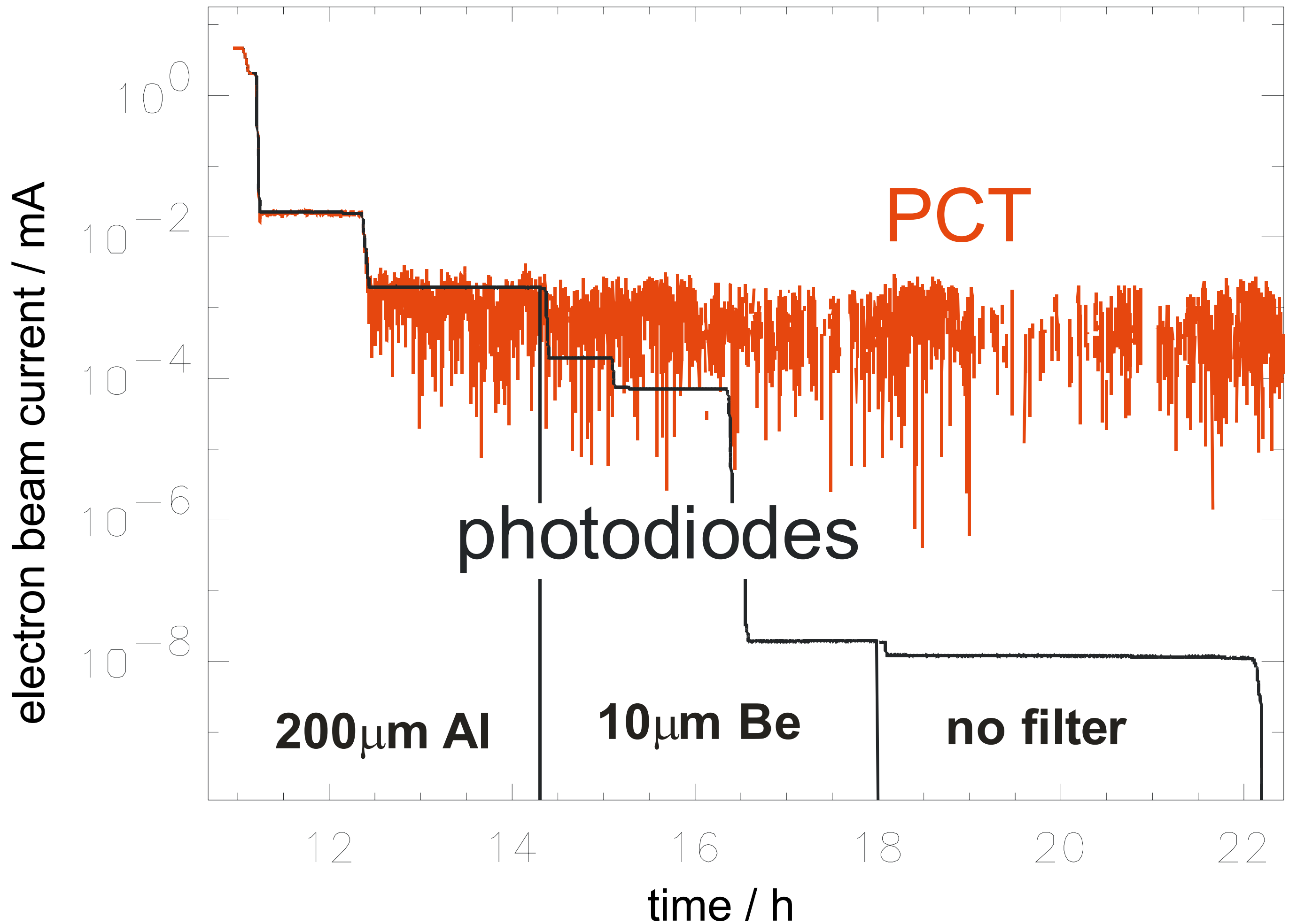
BESSY II: electron beam current measurement

Methods/Equipment

- currents above 2 mA:
  two DC Parametric current transformers
- currents below 2 mA:
  three sets of N_2-cooled photodiodes
  with different filters,
  illuminated by synchrotron radiation
- currents below 200 pA:
  single electron counting

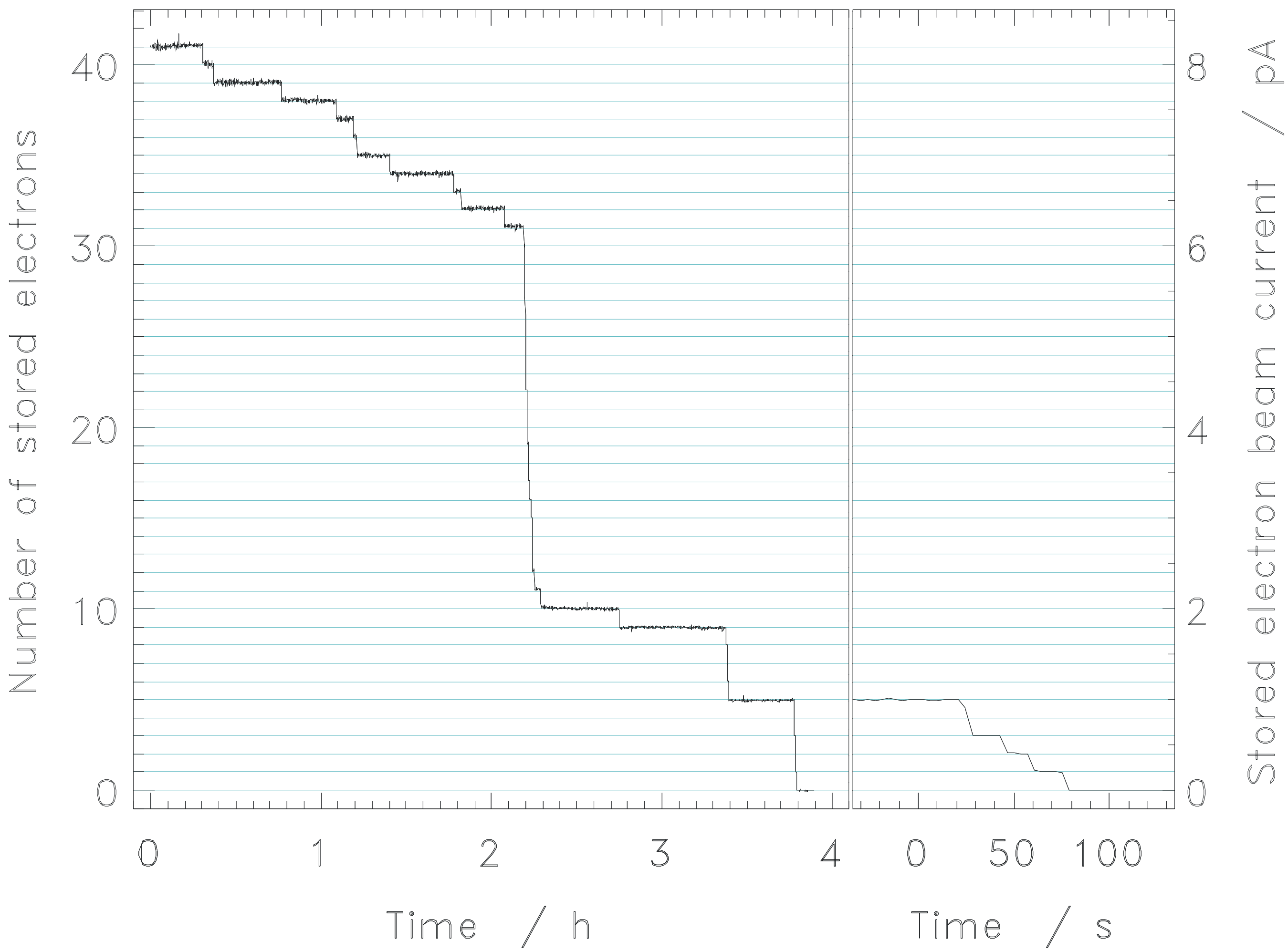
BESSY II: electron beam current measurement

Photon Radiometry



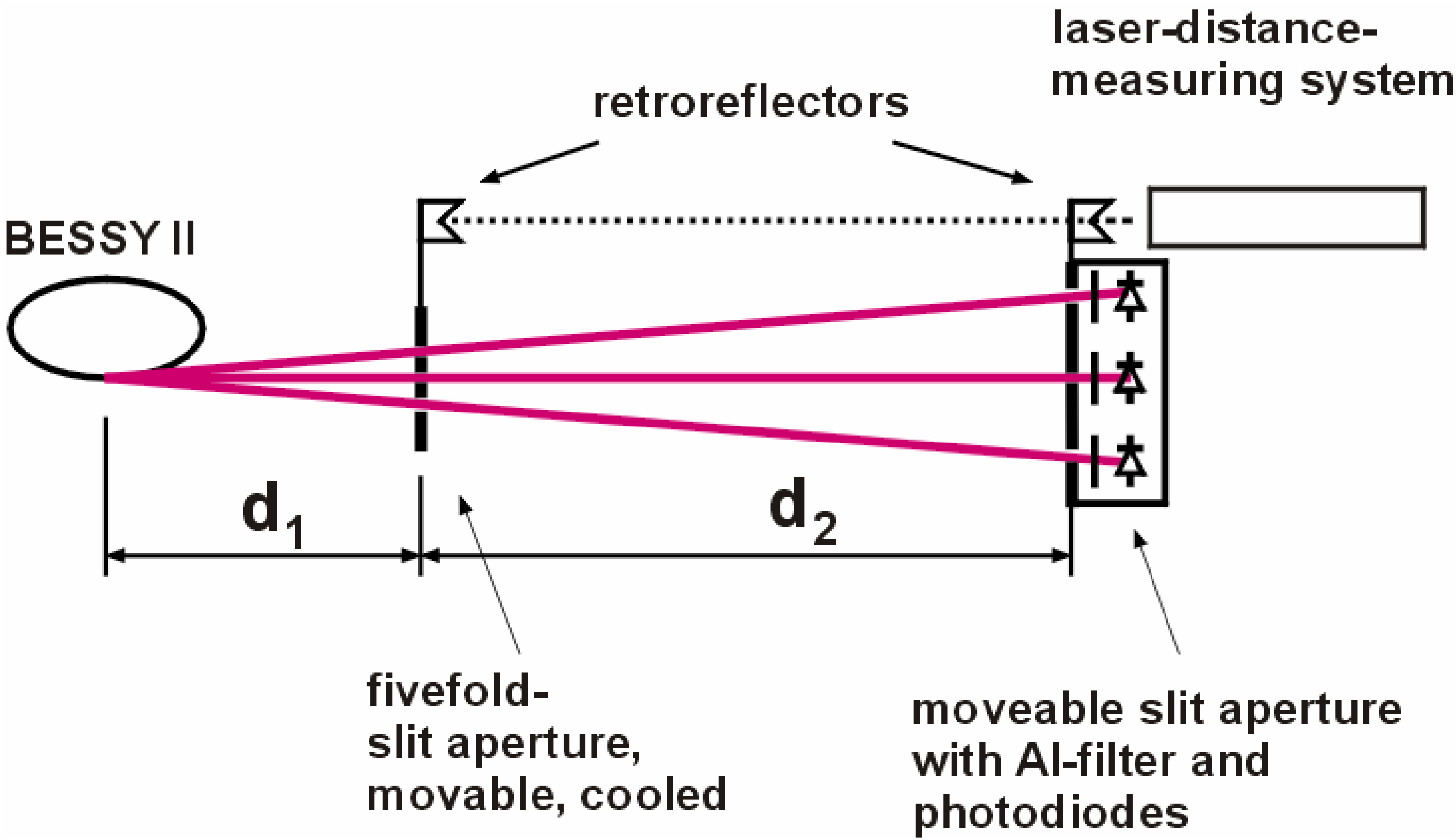
BESSY II is a radiation source with a dynamical range of 10^{12} in the photon flux

BESSY II: electron beam current measurement

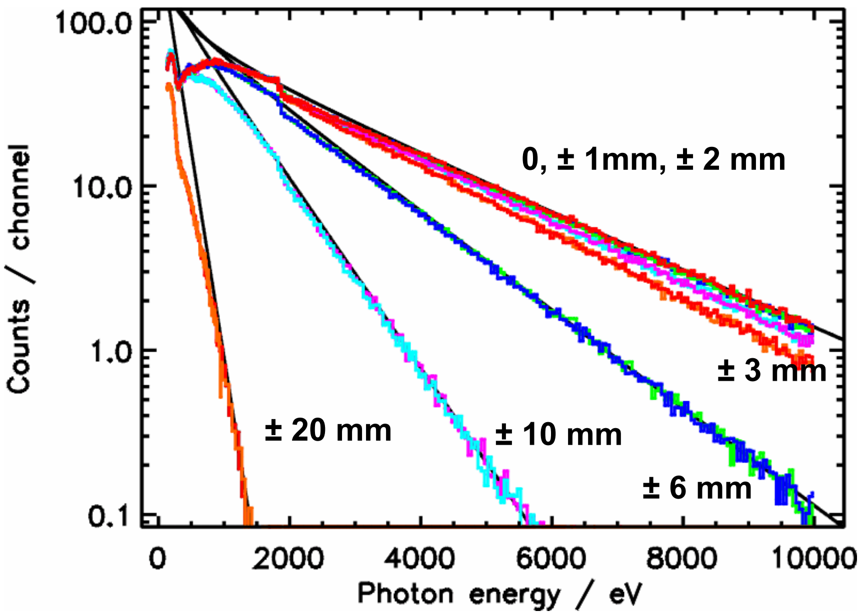


BESSY II is a radiation source with a dynamical range of 10^{12} in the photon flux

BESSY II: measuring the distance to the source point

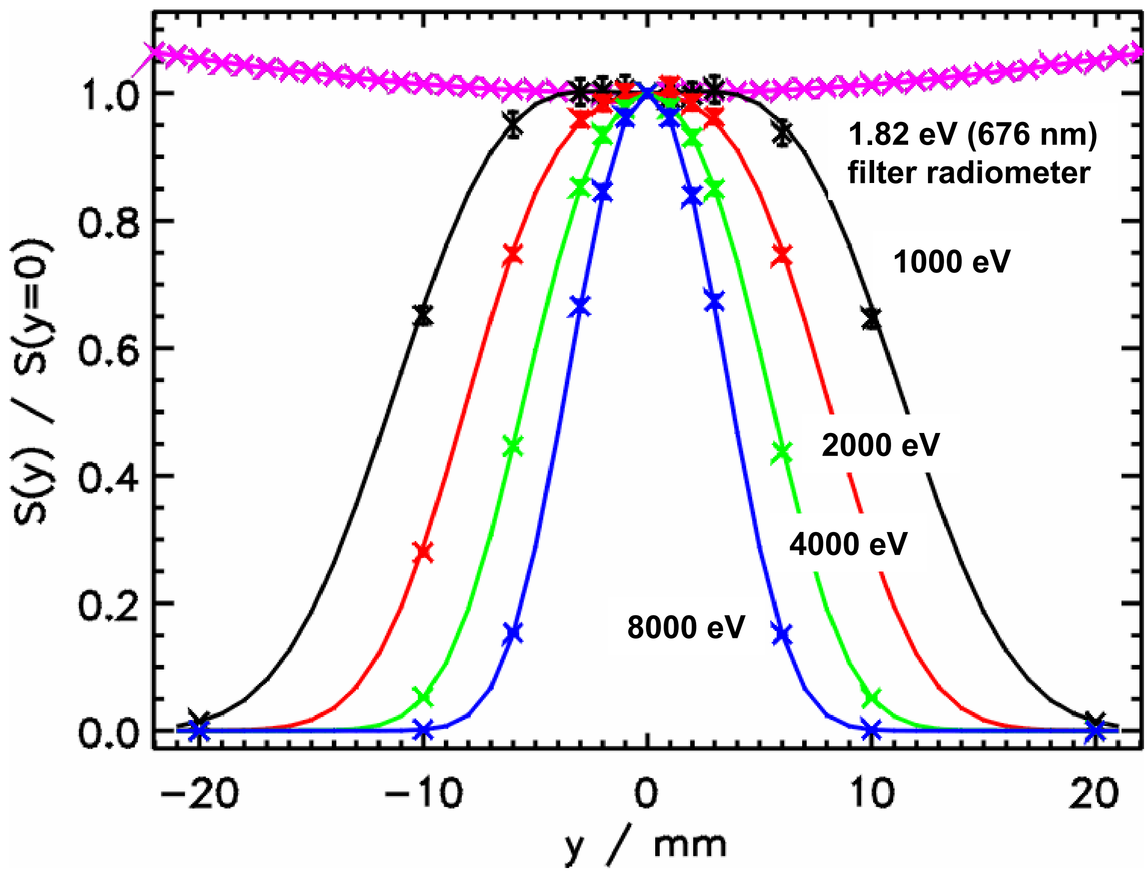


BESSY II: effective vertical divergence



Si(Li) detector spectra for different vertical offsets from the orbit plane

Vertical distribution for different photon energies

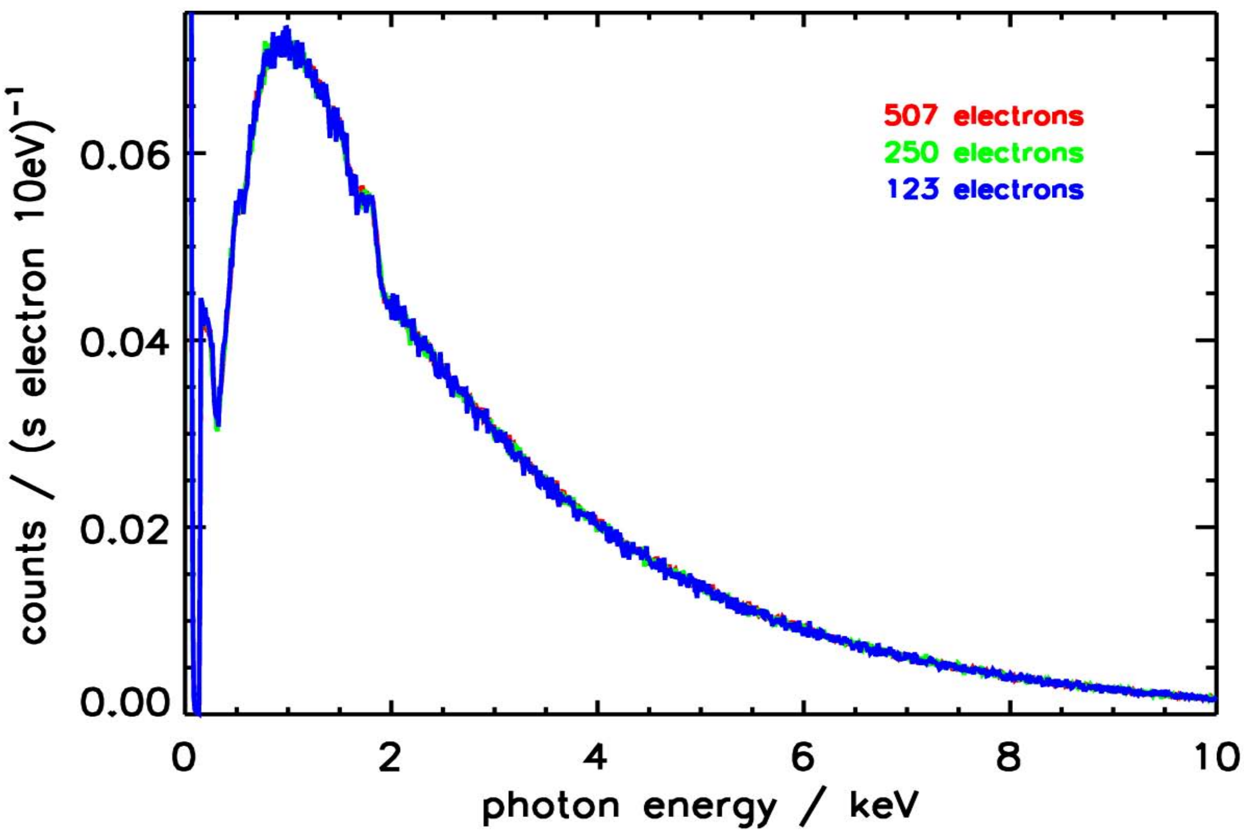


$\Sigma_y = (\sigma_{y'}^2 + \sigma_y^2/d^2)^{1/2}$

$= 3.5\ (7)\ \mu\text{rad}$ @ d= 30 m

σ_r (8000 eV) = 100 μrad

Calibration of energy-dispersive detectors

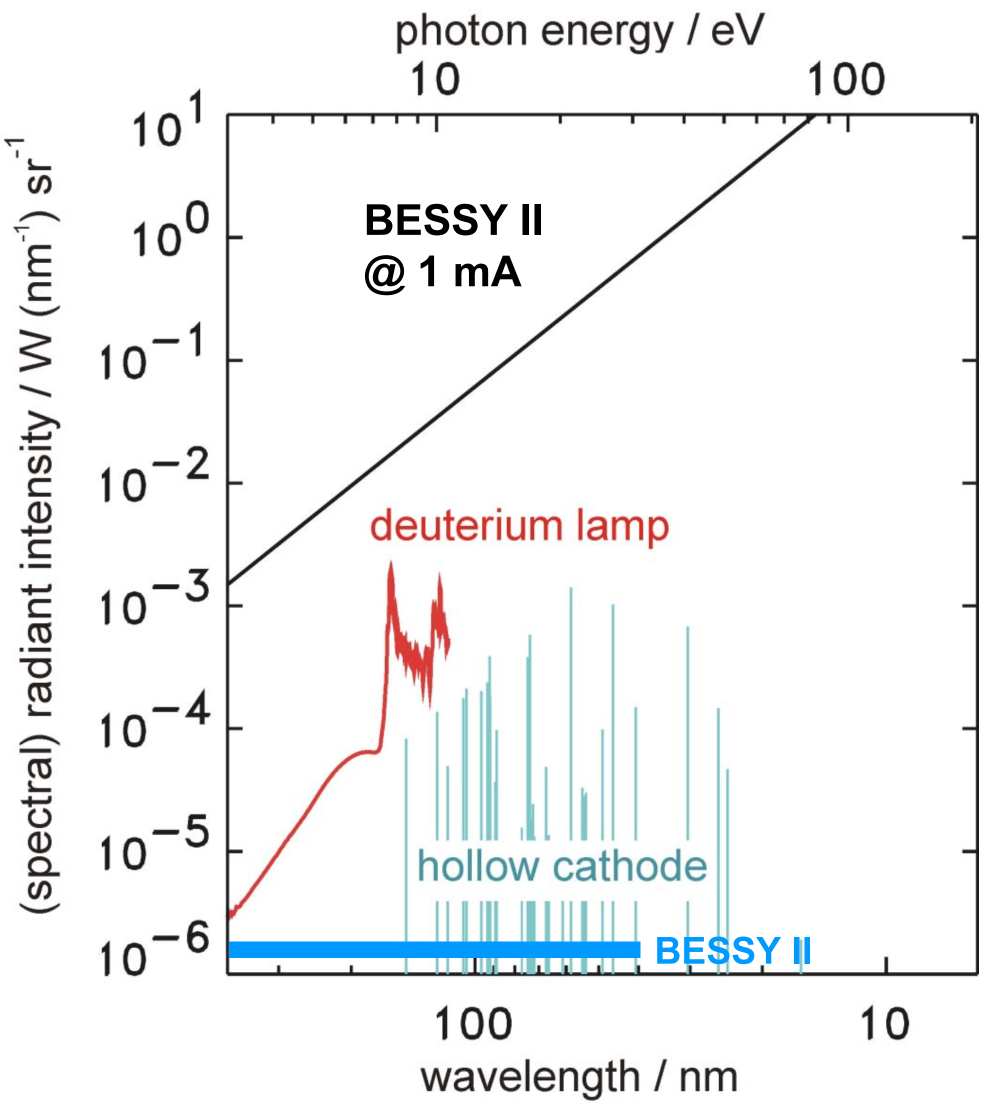


- Si(Li)- detectors
- HPGe-detectors
- CCD- detectors
- flow proportional counters

e.g.
for astronomy observatories

- CHANDRA (NASA)
- XMM-Newton (ESA)

Calibration of radiation sources in the UV and VUV



Calibration of deuterium lamps

'(V)UV Radiometric Scales'

NPL (UK): EUROMET 88/36
BNM (F): EUROMET 539
NIM (VR China)
NIST (USA)
PTB

Calibration of hollow cathode source

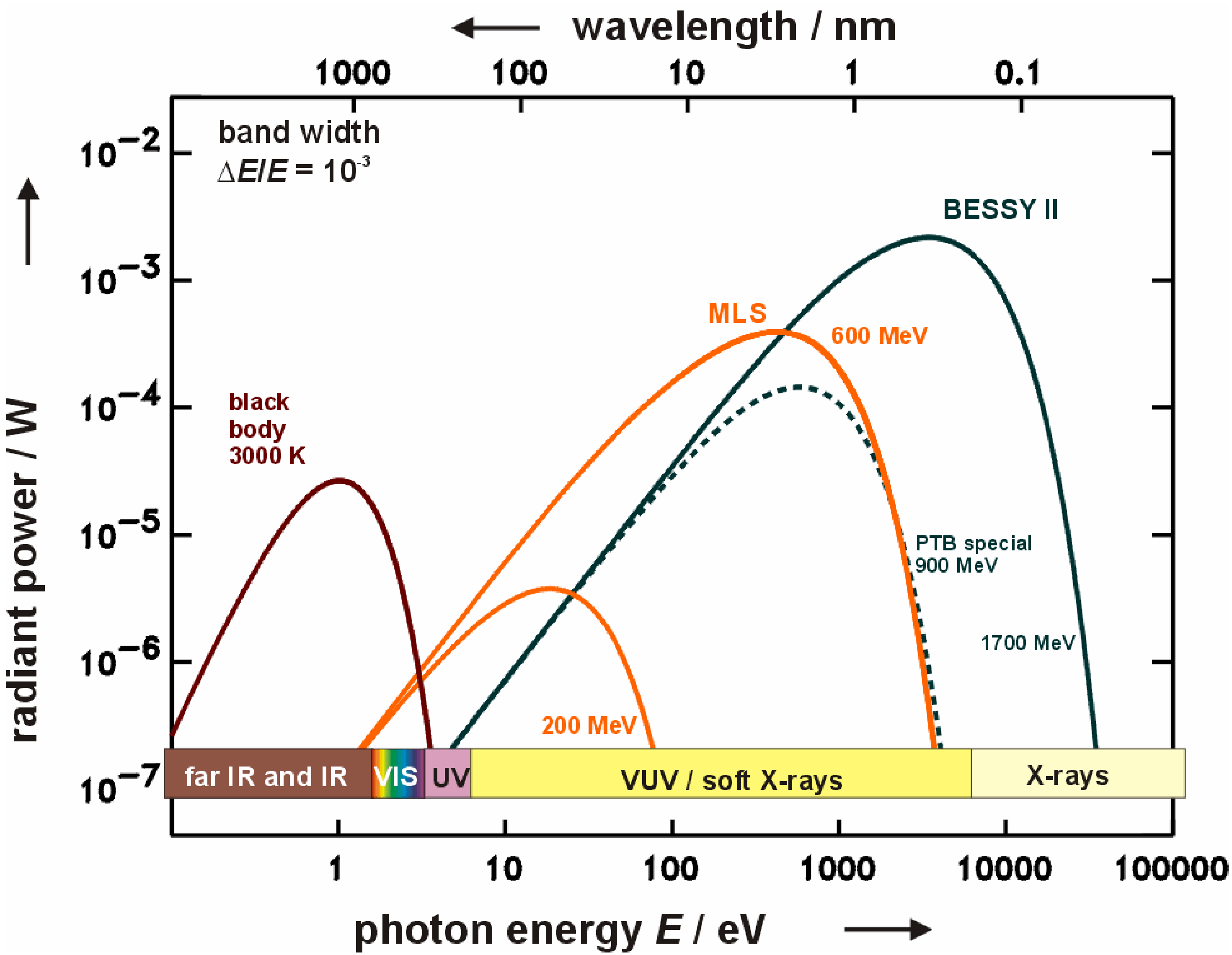
'Solar Observations'

MPAE (D), RAL (UK)

SOHO (ESA), SERTS (NASA)
Solar B (ISAS), EUNIS & SDO (NASA),
SOL-ACES & Solar Orbiter (ESA)

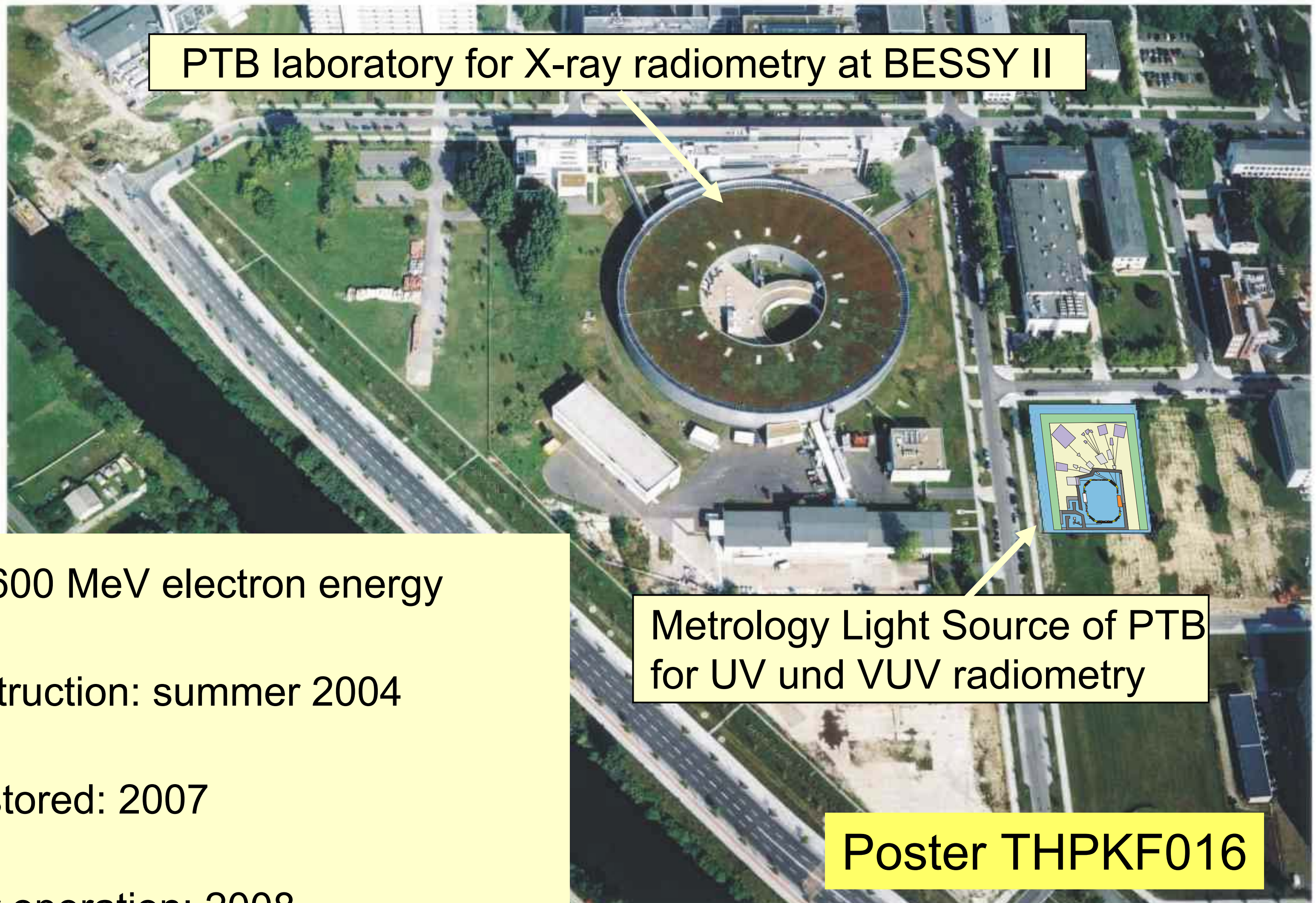
Storage ring BESSY II as primary source standard

Photon Radiometry



PTB in Berlin-Adlershof: Metrology with synchrotron radiation

Photon Radiometry



- 200 MeV to 600 MeV electron energy
- Start of construction: summer 2004
- First beam stored: 2007
- Start of user operation: 2008

Conclusions and outlook

- At BESSY II, PTB is operating a radiometry laboratory using synchrotron radiation from the UV to the X-ray range
- Radiometric units are realized and disseminated with high accuracy
- This is e.g. done by utilization of BESSY II as
  a Primary Source Standard;
  precise determination of storage ring parameters
- Future: PTB is constructing a 600 MeV electron storage ring, the **Metrology Light Source**, optimized for UV and EUV radiometry