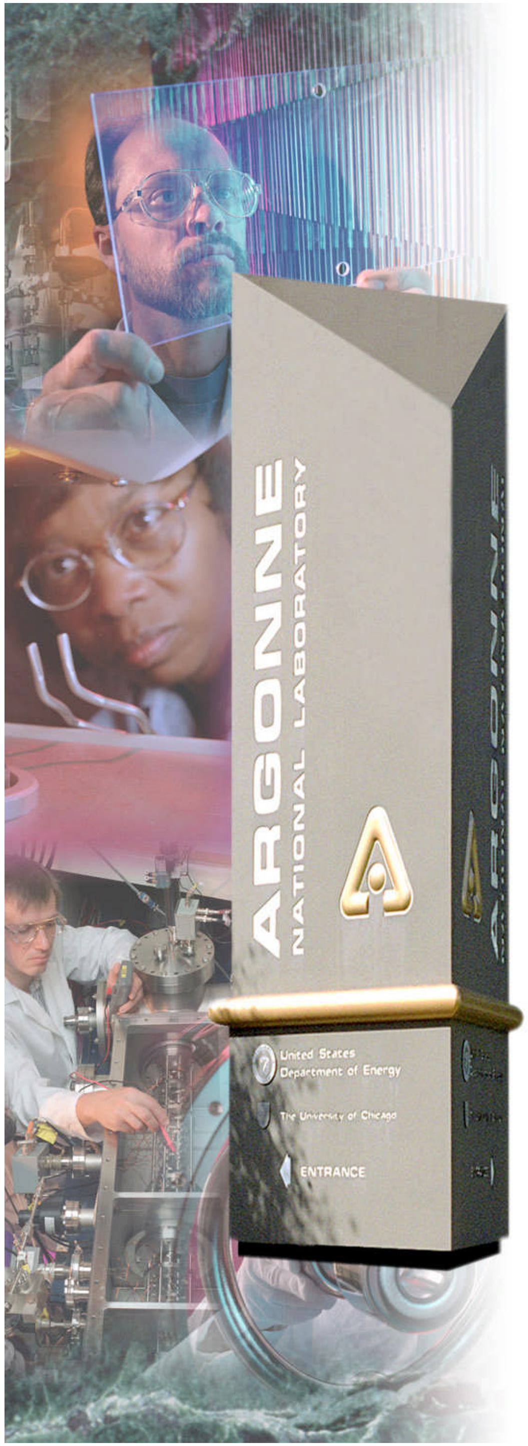

Radiation Shielding Design and Practices at the Synchrotron Radiation Sources

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Argonne National Laboratory

Office of Science
U.S. Department of Energy

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Advanced Photon Source

Radiation Shielding and Practices at the Synchrotron Radiation Sources

- **Radiation Sources at the SR Facilities**
- **Calculational Tools and Procedures**
- **Storage Ring Shielding Design**
- **Bremsstrahlung Source**
- **Beamstops and Collimators**
- **FOE Shielding Requirements**

Radiation Sources at SR Facilities

- **Bremsstrahlung (High Energy Photons)**
  (Gas and Non-Gas)
- **Bremsstrahlung produced Neutrons**

- **Synchrotron Radiation (Low Energy xrays)**

Calculational Tools and Procedures

- **Semi-empirical Methods**

- **Analytical Methods**

- **Monte Carlo Methods**

Calculational Tools and Procedures

- **PHOTON for Synchrotron Radiation (xrays)**
- **STAC8 for Synchrotron Radiation (xrays)**
- **Electron Gamma Shower Program (EGS4)**
- **MCNPX for Photons and Photoneutrons**

Calculational Tools and Procedures

PHOTON Program for Synchrotron Radiation

- Generate Bending Magnet Radiation Spectrum
- Simulate Photon Transport by Compton Scattering (isotropic) and photo-absorption through different materials
- Calculate Scattered Photon Flux as a function of Energy and Angle
- Convert the Resulting Photon Flux into Dose Rate

Calculational Tools and Procedures

STAC8 Program for Synchrotron Radiation

- **Generate Bending Magnet and Undulator Radiation Spectrum**
- **Generate Monochromatic Undulator Beams with a fixed Bandwidth**
- **Simulate Photon Transport by Compton Scattering (anisotropic), Rayleigh Scattering and Photo-absorption**
- **Calculate scattered photon flux as a function of energy and angle**
- **Convert the flux into dose rate.**

Calculational Tools and Procedures

Electron Gamma Shower Program (EGS4)

Simulates Electron-Gamma Coupled Monte Carlo Transport through diffferent materials and geometry by the following interactions;

- **Photoelectric Effect**
- **Compton and Rayleigh Scattering**
- **Pair Production (electron and nuclear field)**
- **Multiple Elastic Scattering**
- **Bremsstrahlung Production**
- **Moller and Bhabha Scattering**
- **Annihilation of Electron-Positron Pairs**
- **Continuous Slowing Down (Bethe-Bloch)**

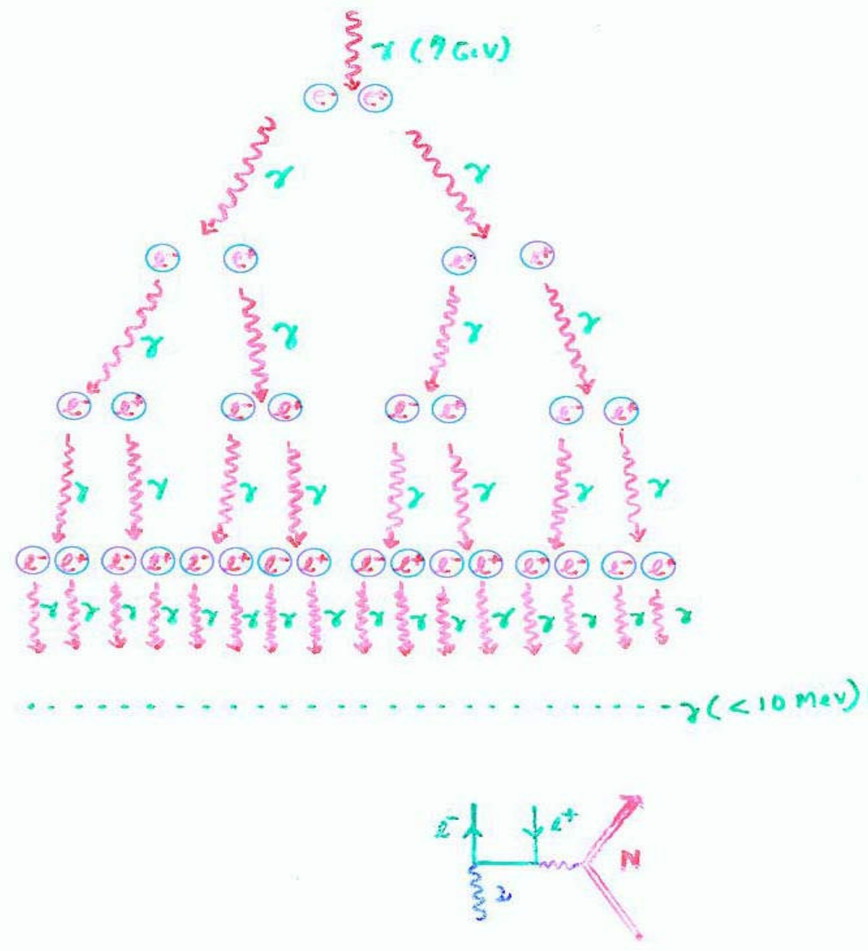
Calculational Tools and Procedures

MCNPX Monte Carlo Program for Photons and Neutrons

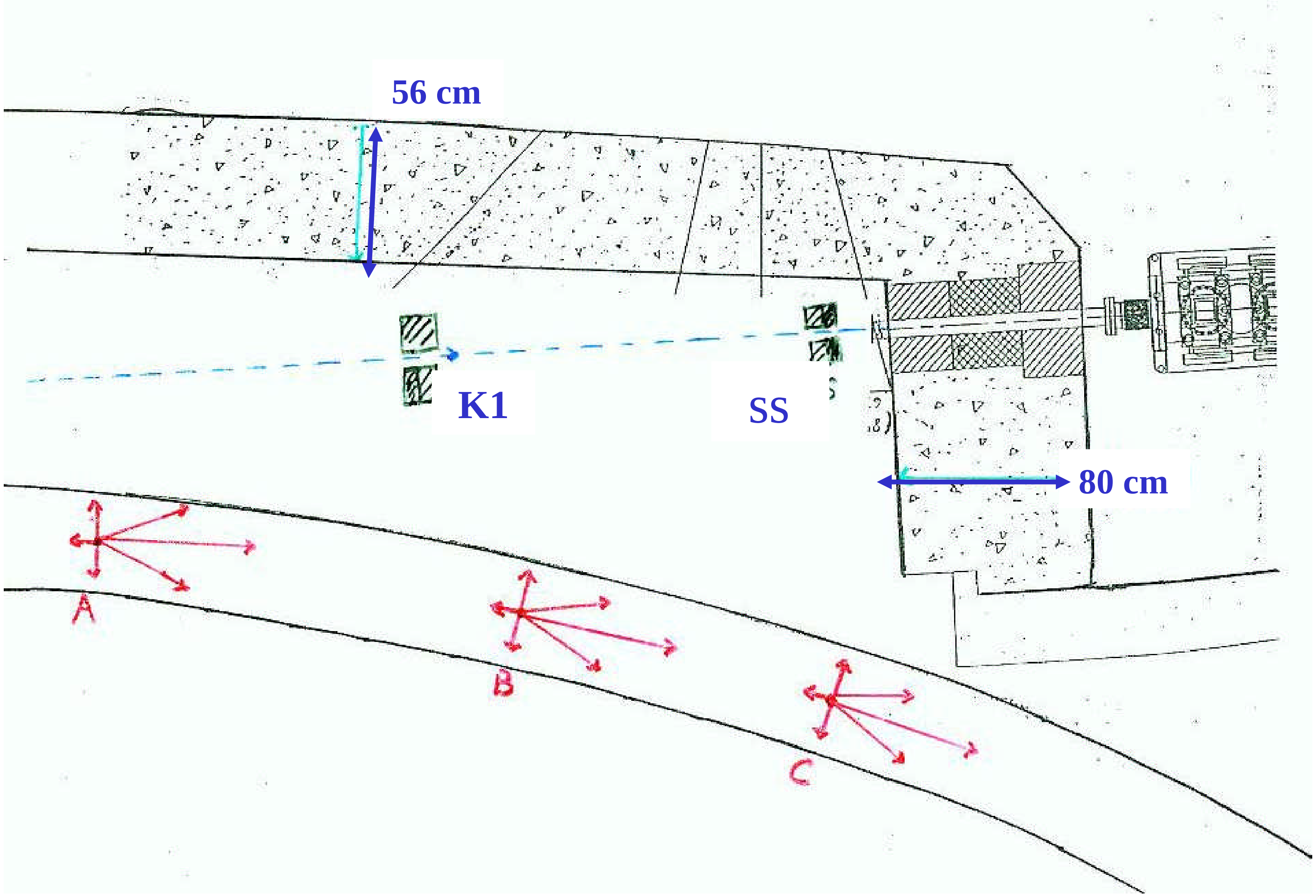
- Models the interactions of radiation/matter for 34 particles
  - **Heavy ions are being added under NASA funding**
- Uses both table and model physics
  - **All standard and 150-MeV neutron, proton, photonuclear libraries**
  - **Photon, Electron physics (upto 1 GeV)**
  - **Bertini, ISABEL, CEM, INCL, and FLUKA**
- 3-Dimensional, continuous energy, fully time-dependent
- Supported on all UNIX, PC Windows, Mac G5
  - **Auto configuration, build system**
  - **FORTRAN90/95, dynamic allocation**
  - **Distributed memory parallel processing, PVM, MPI**

Storage Ring Shielding Design

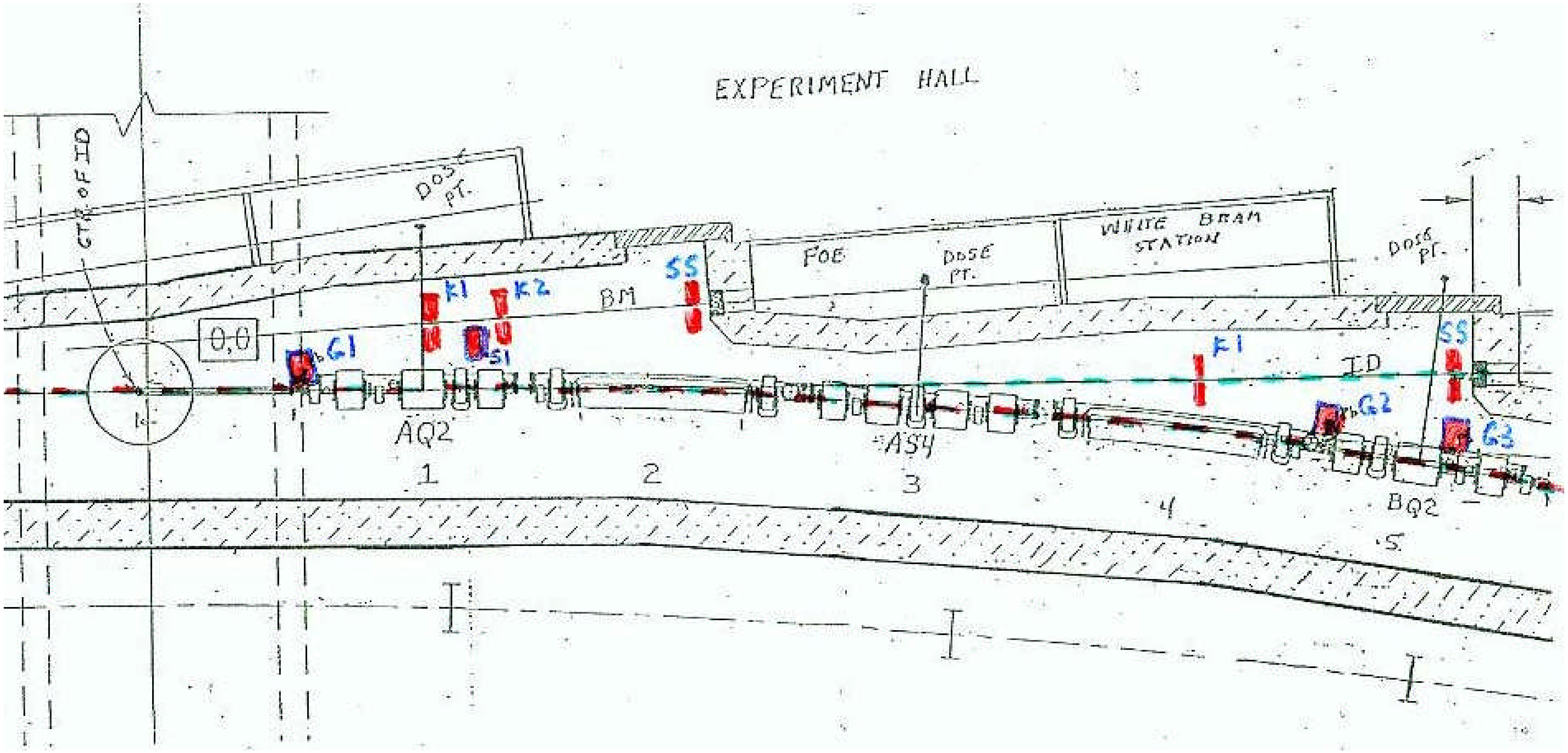
Electromagnetic Shower



Storage Ring Shielding Design



Storage Ring Shielding Design



Storage Ring Shielding Design (Shadow Shield)

Storage Ring Shielding Design

Dose Rates from 20% Beam Loss on the Injection Septum

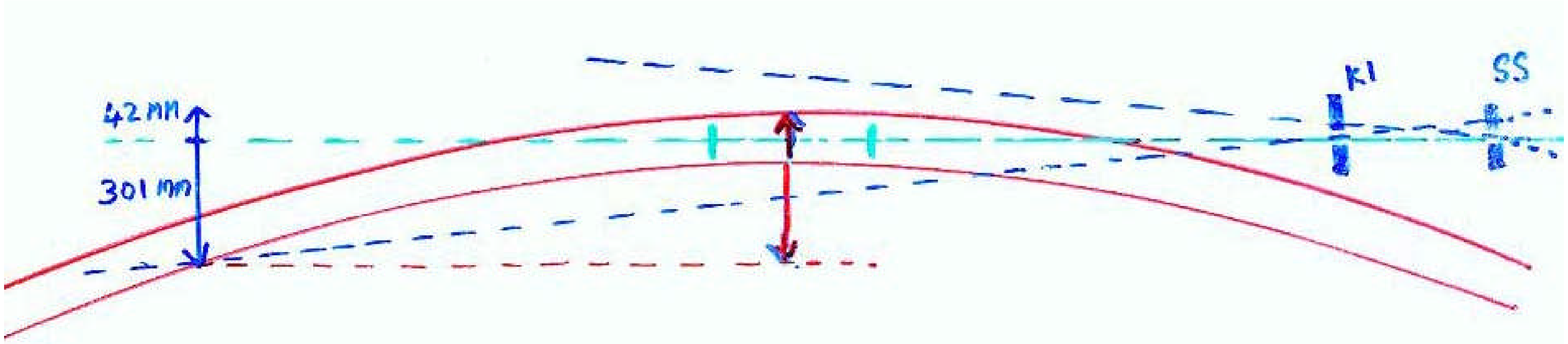
For 308 W Injection

(Operating Envelop is 154 W, 7.7 GeV, 10 nC, 2Hz)

(Shield wall 1 m HD Concrete, 3.4 g/cm^3)

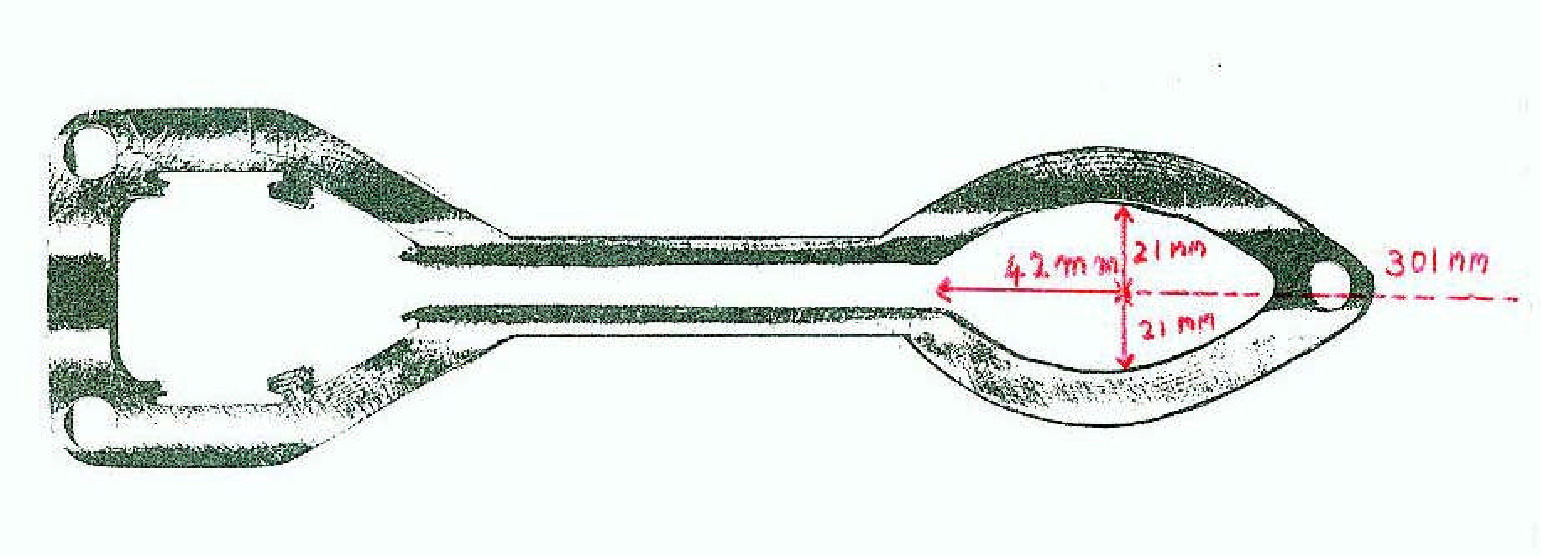
Location (Degrees)	Total Dose Rate (mrem/h)
0.0	0.08
20.0	0.32
32.0	0.90
70.0	0.82
90.0	0.87
120.0	0.20
152.0	0.27

Storage Ring Shielding Design (Brem. Source)

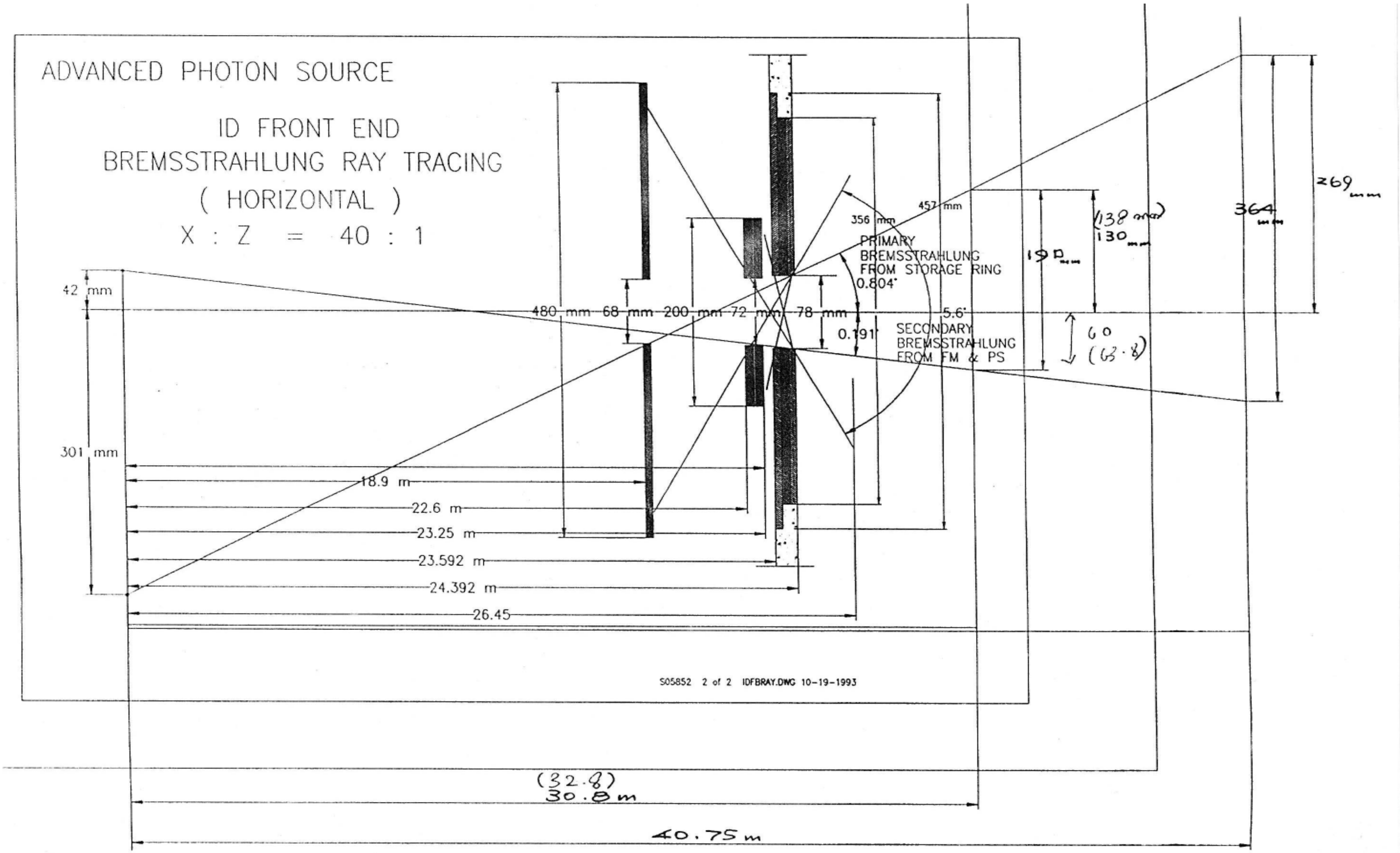


Front End Aperature
26 x 68 mm
26 x 72 mm
26 x 36 mm
14 x 16 mm

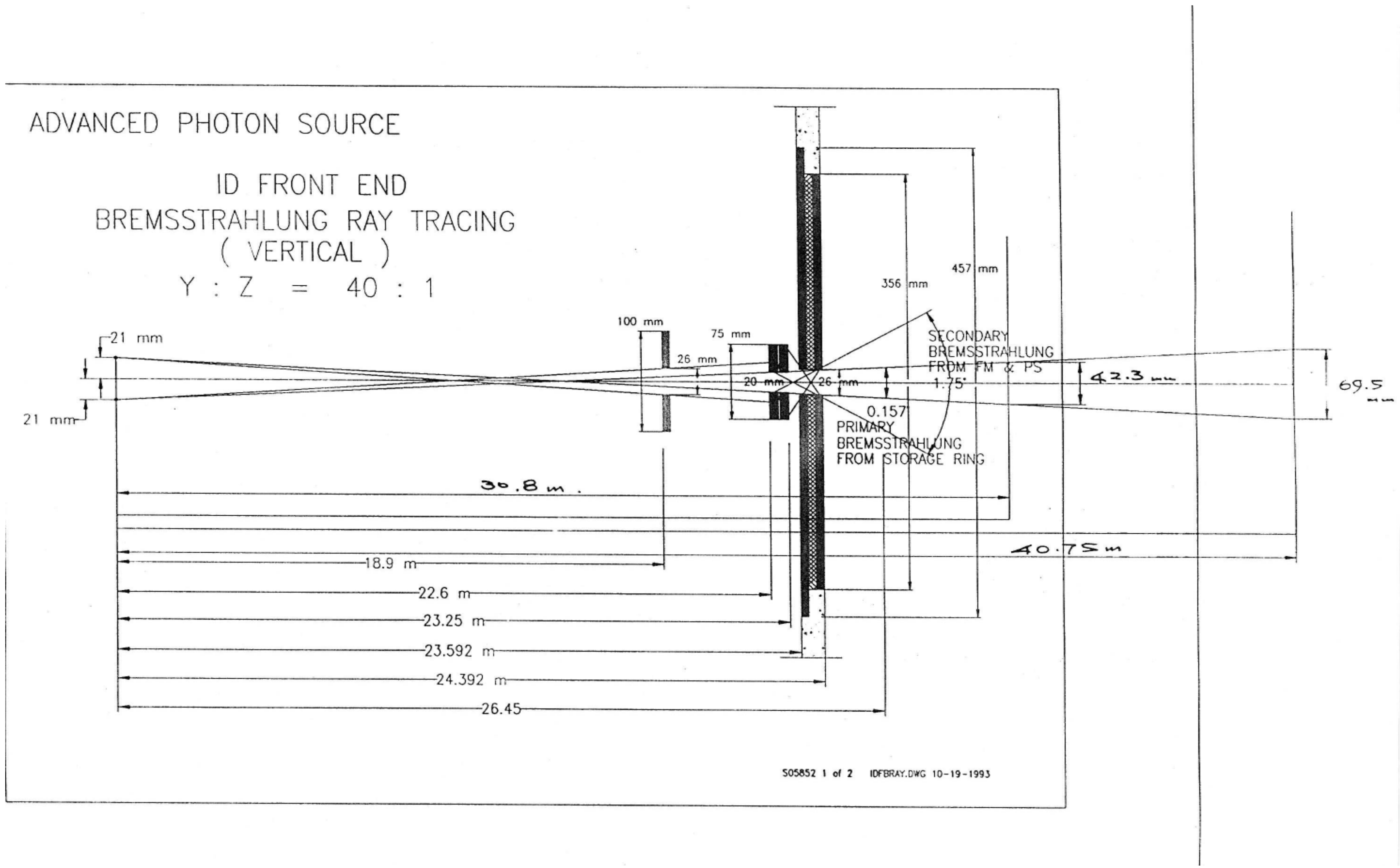
Storage Ring Shielding Design (Brem. Source)



Storage Ring Shielding Design (Ray Diagram)



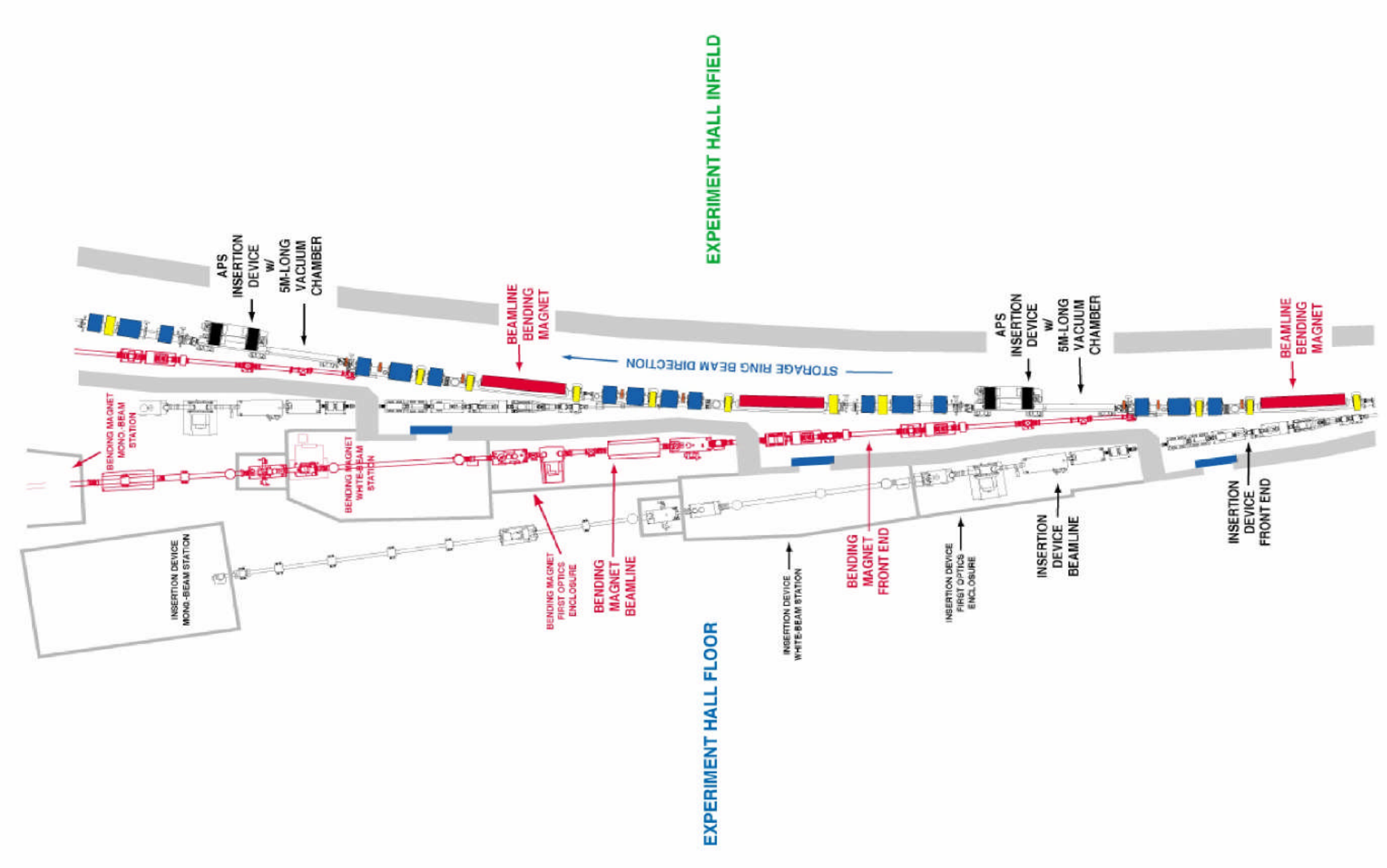
Storage Ring Shielding Design (Ray Diagram)



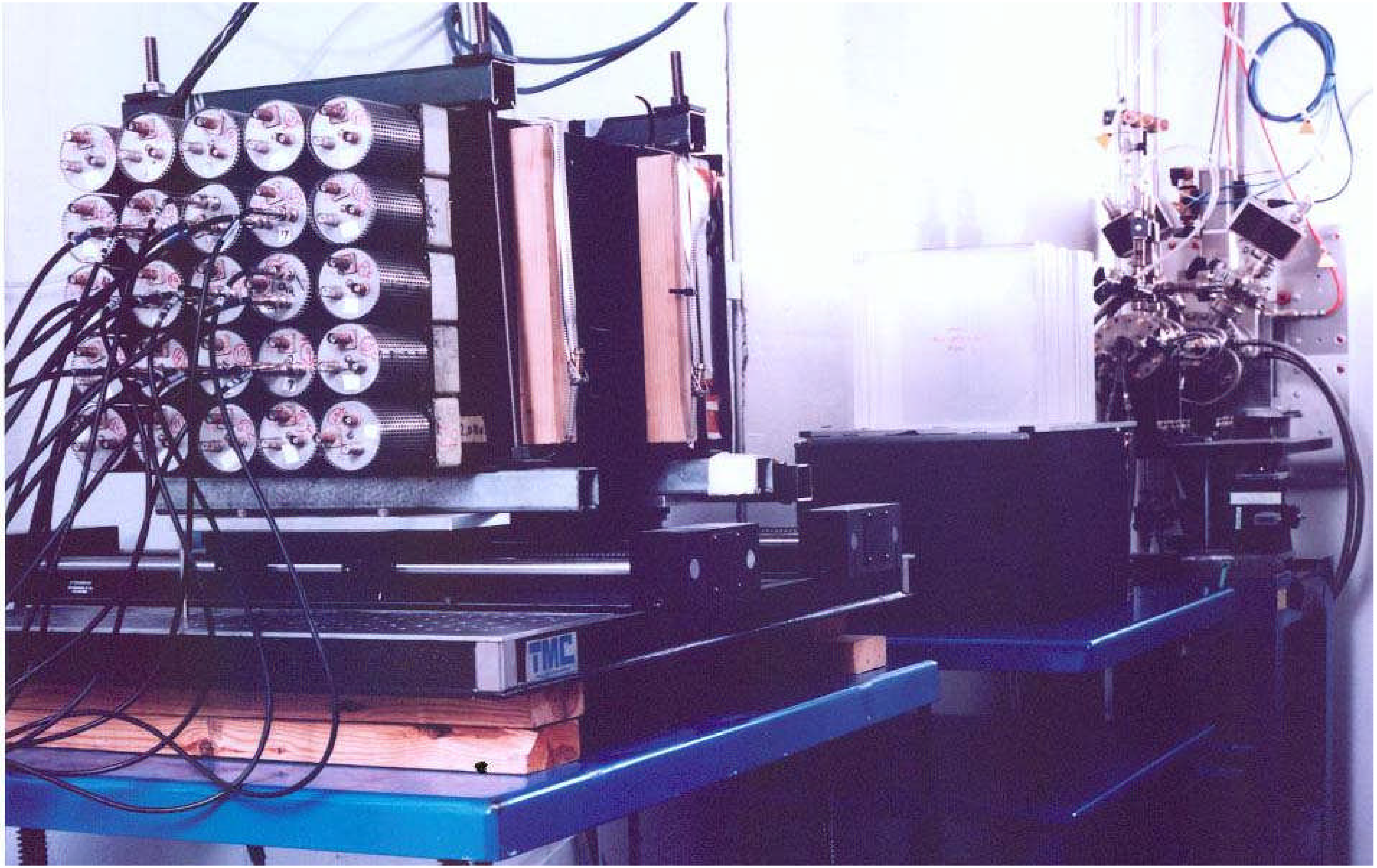
Storage Ring Shielding Design (Summary)

- **Ratchet wall shielding can be estimated by EGS4**
- **Shielding at the injection region need special attention**
- **Vacuum chamber constrictions increase beamloss**
- **Tangential shields inside the storage ring required**
- **Bremsstrahlung Source Dimensions can be estimated for ray diagrams**

Bremsstrahlung Source for Beamlines



Bremsstrahlung Measurements in ID Beamlines



Bremsstrahlung Measurements - APS & ESRF Beamlines

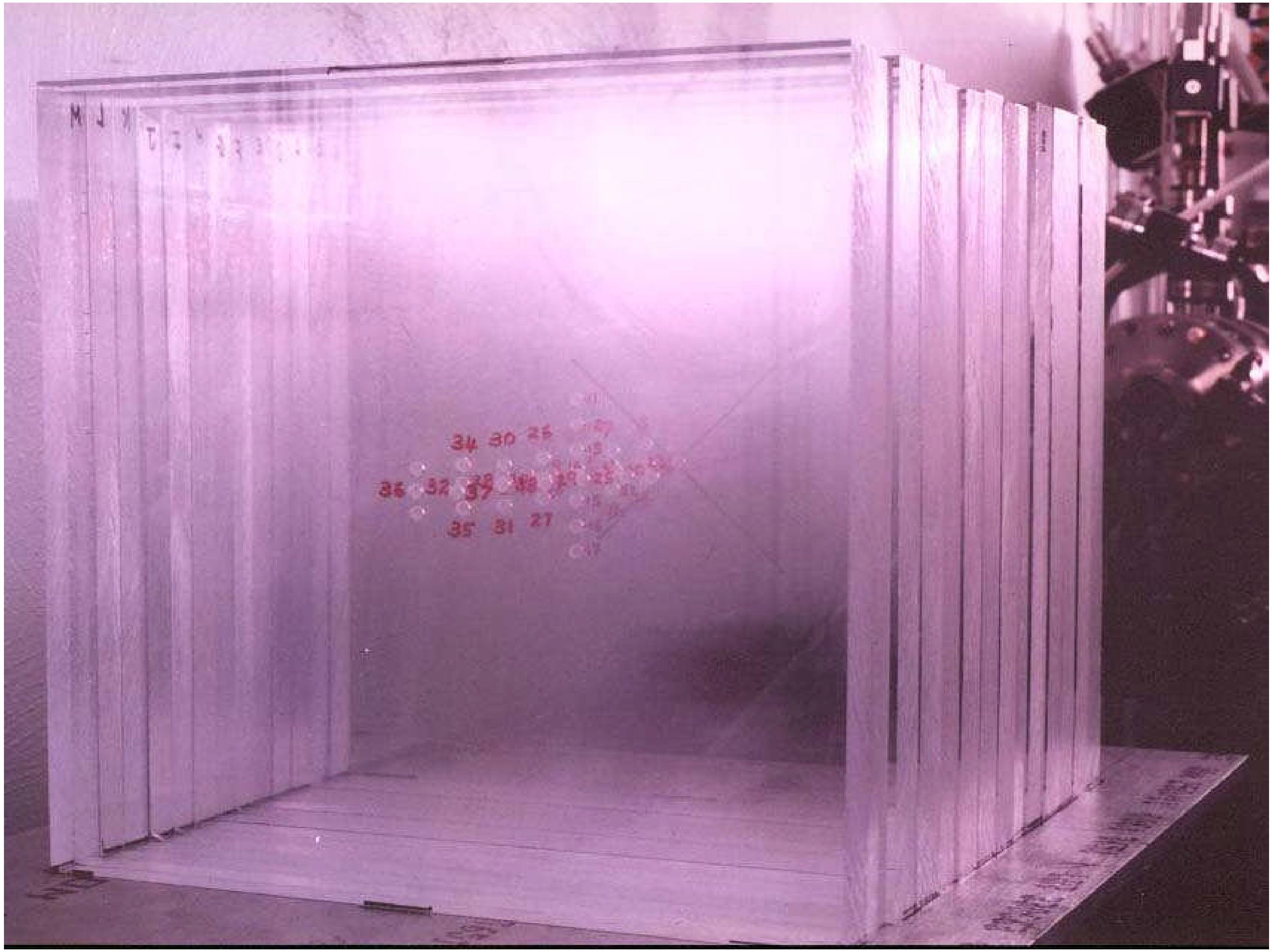
Beamline	Stored Beam Energy (GeV)	Stored Beam Current (mA)	Average Straight Section Pressure (nT)	Measured Bremsstrahlung Power (W)	Normalized Bremsstrahlung Power ($W\ mA^{-1}\ nT^{-1}$)
ESRF-ID31	4.0	100.9	1.8	1.3×10^{-6}	7.1×10^{-9}
ESRF-ID31	6.0	198.2	5.3	2.2×10^{-5}	2.1×10^{-8}
ESRF-ID29	6.0	50.4	1.1	2.2×10^{-5}	3.9×10^{-7}
APS - 6 ID	7.0	79.8	7.3	3.8×10^{-6}	6.5×10^{-9}
APS - 10 ID	7.0	78.3	7.4	5.6×10^{-6}	9.7×10^{-9}
APS - 11 ID	7.0	84.0	5.7	1.4×10^{-5}	2.9×10^{-8}
APS - 12 ID	7.0	80.8	7.4	1.2×10^{-5}	2.0×10^{-8}
APS - 13 ID	7.0	90.1	10.4	4.5×10^{-5}	4.8×10^{-8}
APS - 15 ID	7.0	90.8	5.3	3.4×10^{-6}	7.0×10^{-9}

Bremsstrahlung Measurements vs. Bunch Fill

ESRF Beamline	Fill Pattern	Storage Ring Vacuum Chamber	Beam Current (mA)	Absorbed DoseRate (mGy/h)	Normalized Dose rate (mGy/h/mA)
ID31	2/3 Fill [(a)]	Stainless steel	170.0	1390	8.2
ID31	16Bunches[b]	Stainless steel	84.2	1424	16.9
ID29	2/3 Fill	Aluminum	174.3	72.2	0.4
ID29	16 Bunches	Aluminum	76.6	33.6	1.4

(a) 2/3 of the 1000 buckets are filled continuously
(b) 16 equally spaced buckets are filled

Absorbed Dose Measurements in PMMA Phantom



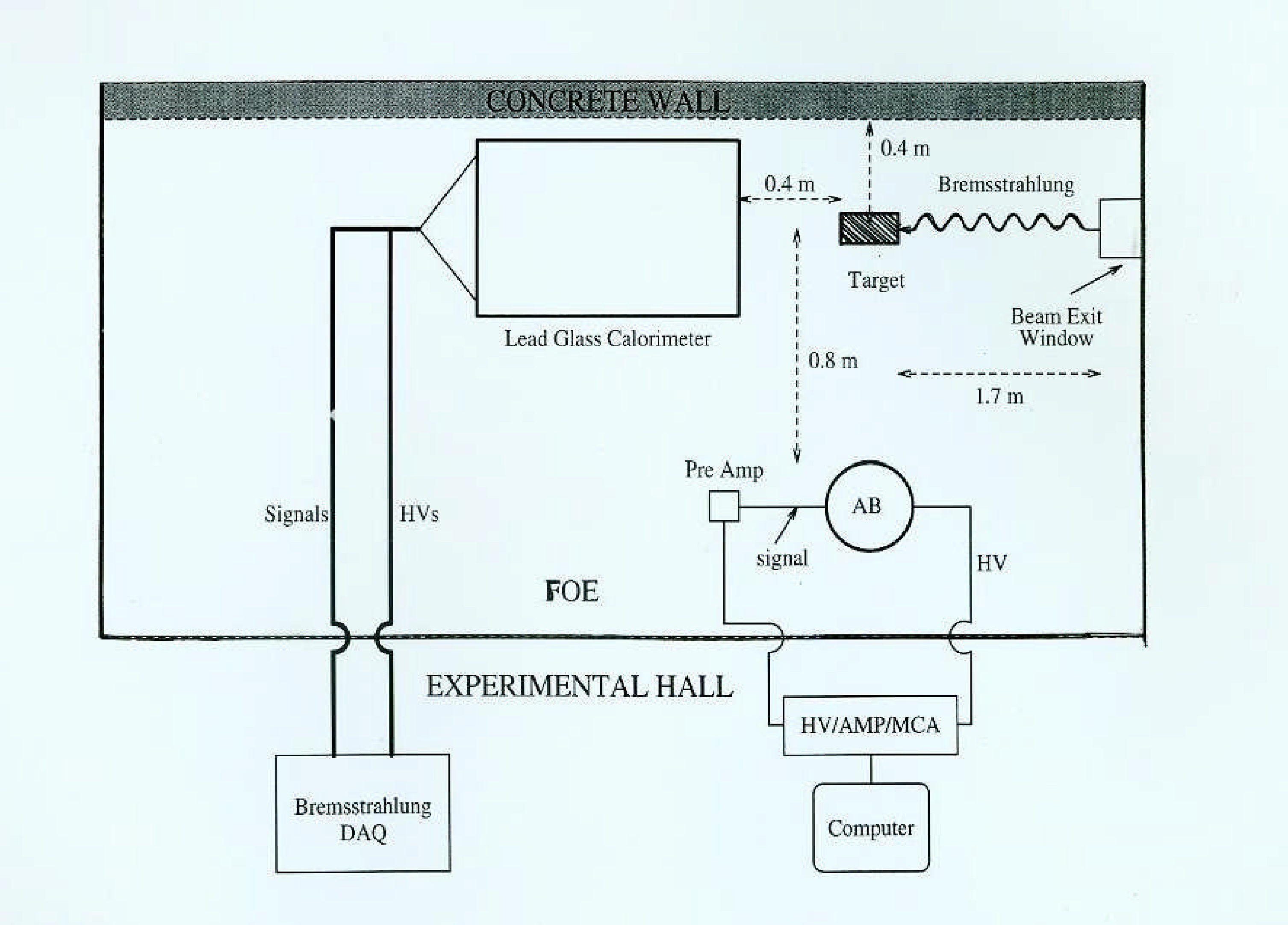
Bremsstrahlung Dose Results

Beamline	Stored Beam Energy (GeV)	Stored Beam Current (mA)	Measured Bremsstrahlung Power (W)	Absorbed Dose Rate in PMMA Phantom (mGy h^{-1})	Normalized Dose in PMMA Phantom (mGy h^{-1} W^{-1})
ESRF - ID31	4.0	98.0	1.2×10^{-6}	7.7×10^{0}	6.1×10^{6}
ESRF - ID31	6.0	186.7	2.1×10^{-5}	8.8×10^{1}	4.2×10^{6}
ESRF - ID31	6.0	197.0	2.2×10^{-5}	7.6×10^{1}	3.4×10^{6}
ESRF - ID29	6.0	200.0	2.2×10^{-4}	7.9×10^{2}	3.6×10^{6}
APS - 15 ID	7.0	90.8	3.4×10^{-6}	1.1×10^{1}	3.3×10^{6}

Bremsstrahlung Source

- Stored Beam Current
- Storage Ring Vacuum
- Vacuum Profile in the Straight Section
- Variation in Residual Gas Composition
- Non-Gas Bremsstrahlung
  - Vacuum Chamber Apertures
  - Vertical Emittance
  - Local Beam Steering
  - Bunch Density and Fill Pattern
  - Injection Mode (TopUp)

Bremsstrahlung Produced Neutron Dose (Measurements inside FOE)



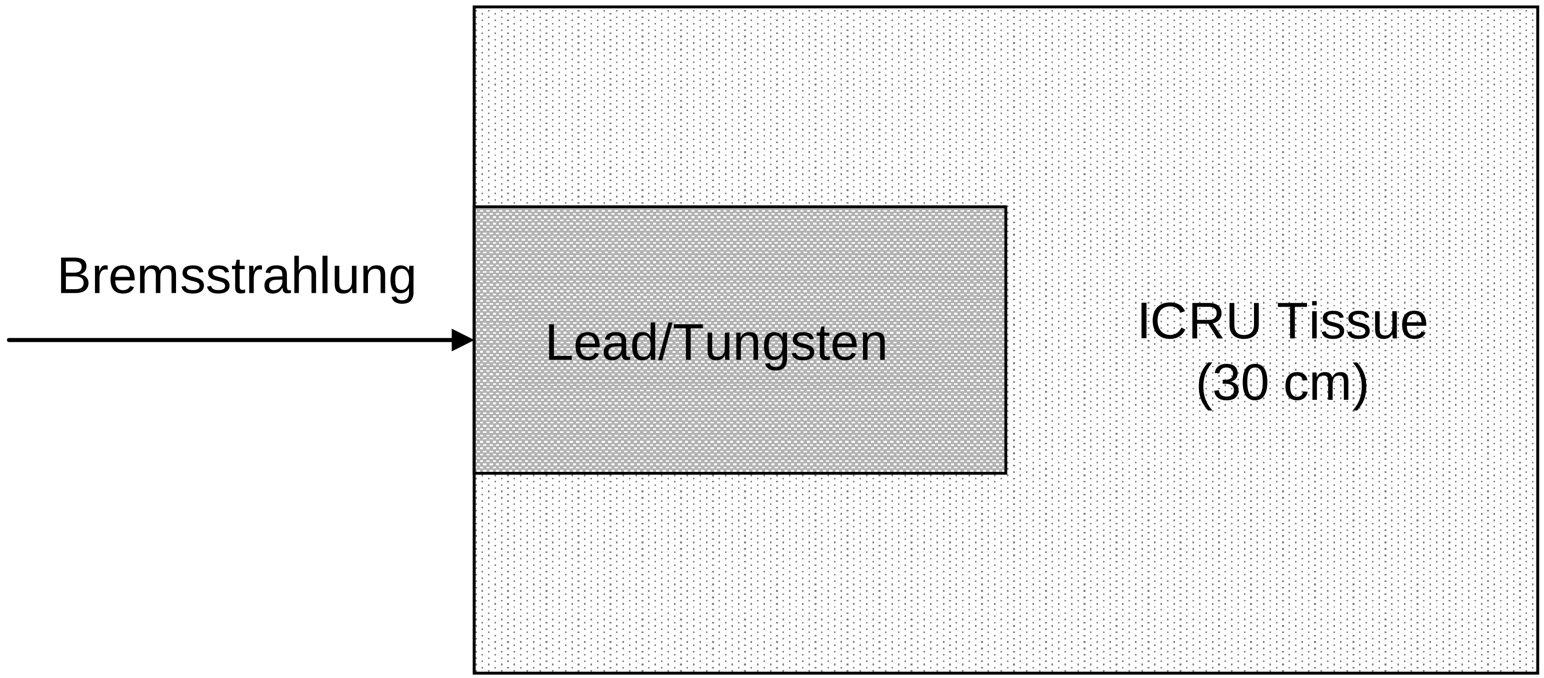
Bremsstrahlung Produced Neutron Dose (Measurements inside FOE)

Target Material	Beam Current (mA)	Neutron Dose Rate (μrem/h)
Iron	96.6	37.5 ± 3.2
Copper	96.0	53.6 ± 7.6
Tungsten	88.3	56.4 ± 7.8
Lead	90.9	59.5 ± 8.0

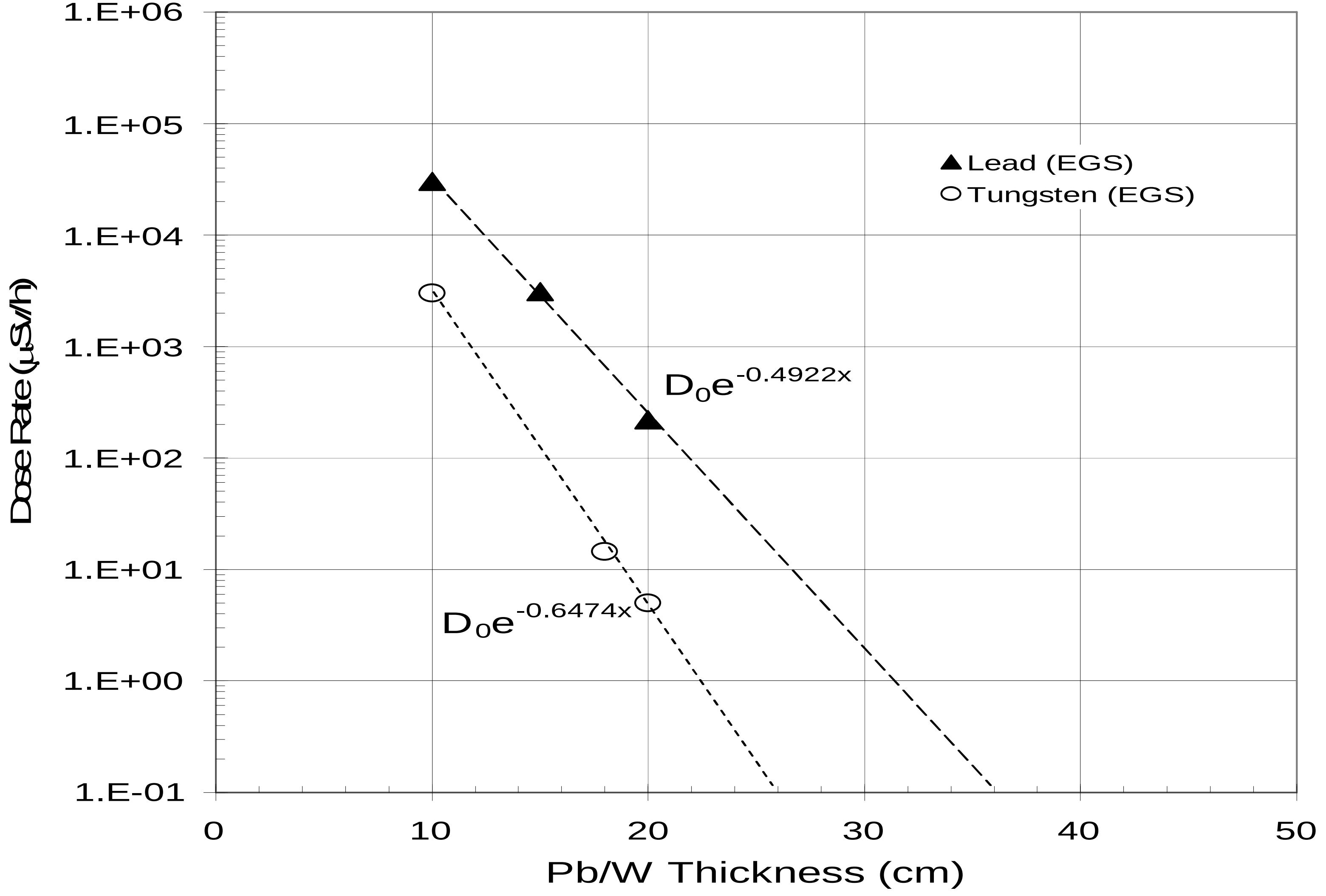
Bremsstrahlung Dose Measurements

- Lead glass calorimeter setup could measure the bremsstrahlung dose from a beamline accurately
- Several factors other than beam current and vacuum affects the bremsstrahlung dose from a beamline
- Bremsstrahlung dose can vary as much as a factor of 10 from beamline to beamline
- This makes comparison with calculations and other measurements difficut
- Bremsstrahlung produced neutron dose inside FOE is not significant

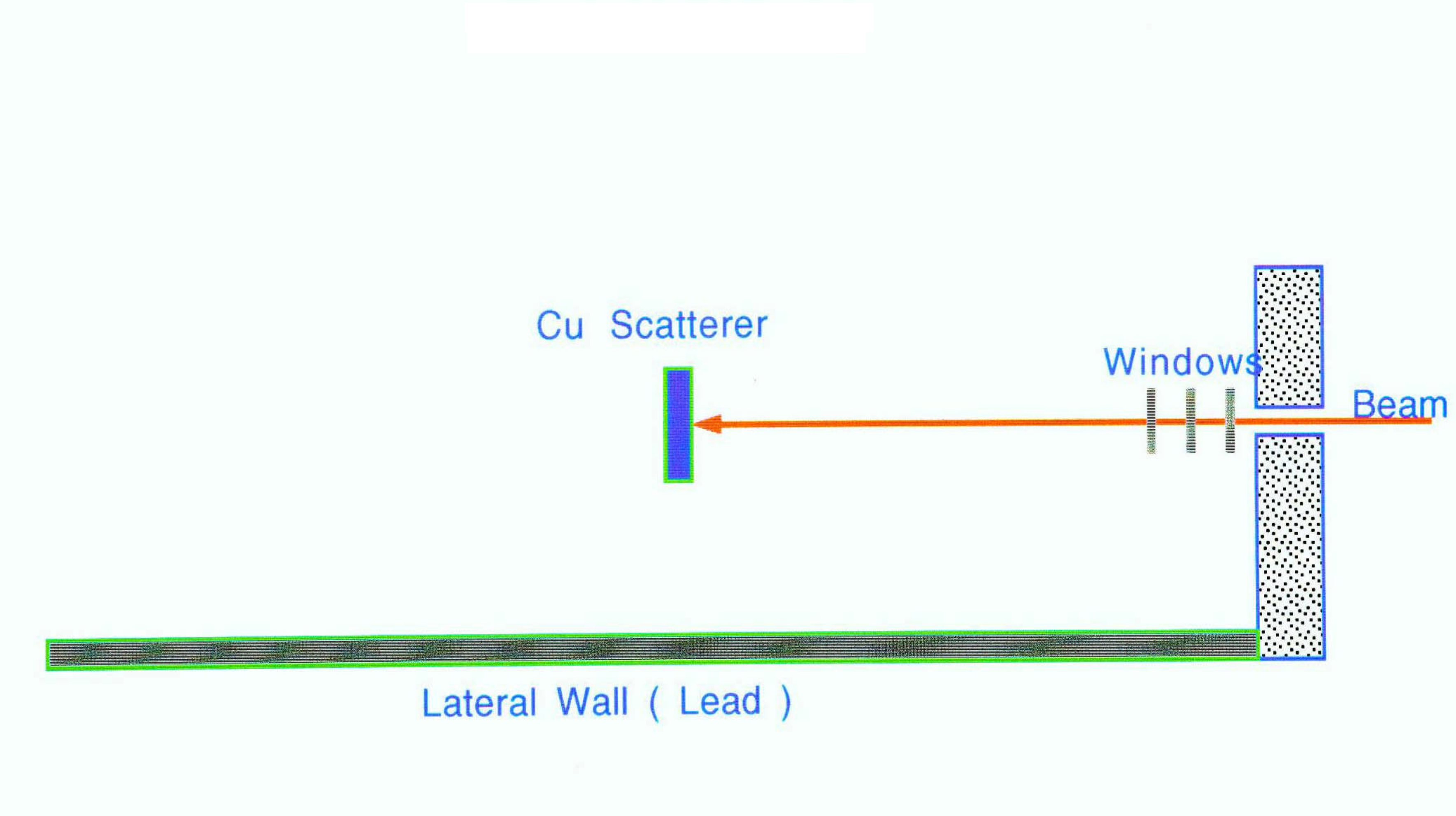
Beam Stops and Collimators



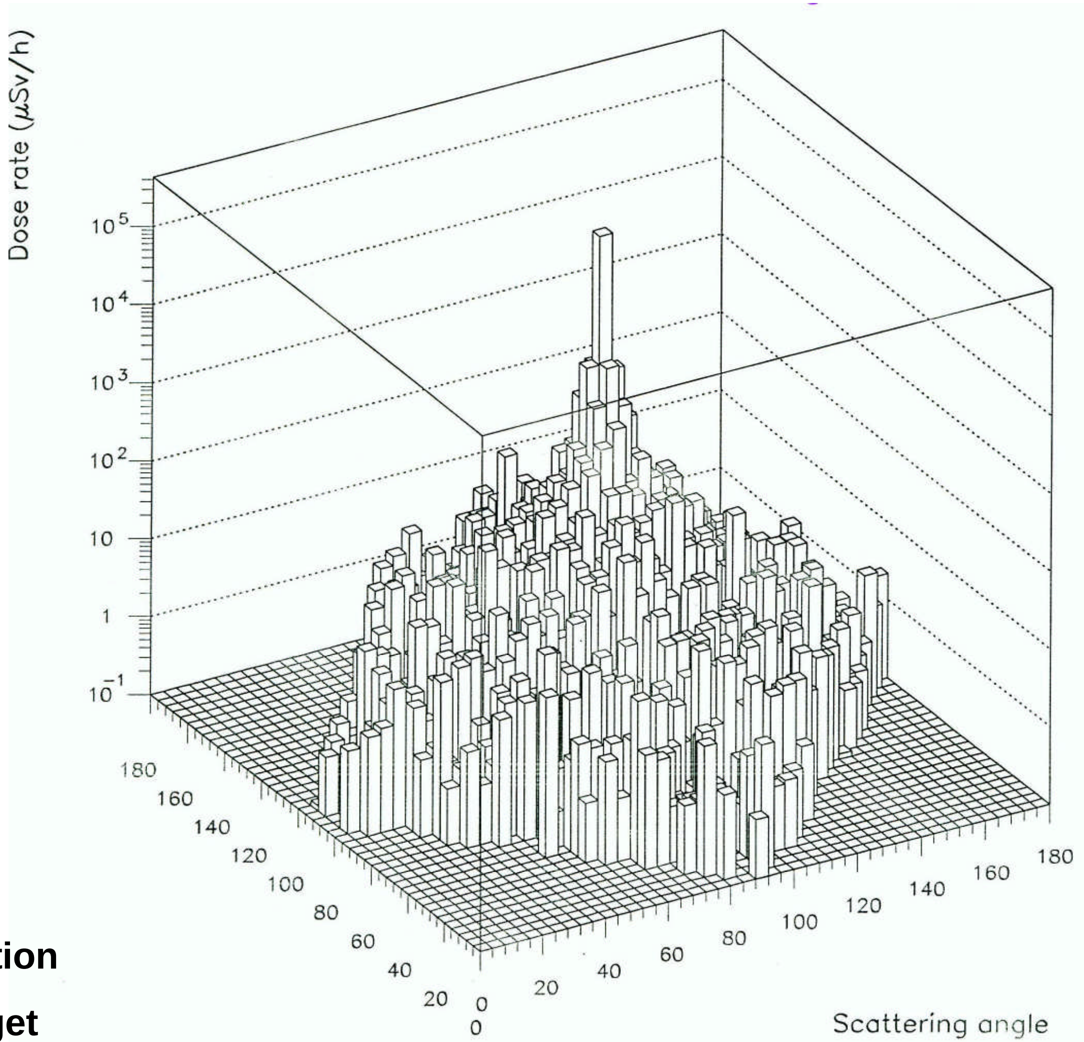
Beamstops and Collimators (EGS4 Results)



FOE Shielding Requirements
Calculational Geometry for PHOTON and EGS4



FOE Shielding Requirement – Dose Projections on the Downstream wall (EGS4 Calculations)



EGS4 Calculation

3 cm Cu Target

FOE Shielding Requirement – Dose Projections on the Downstream wall (EGS4 Calculations)

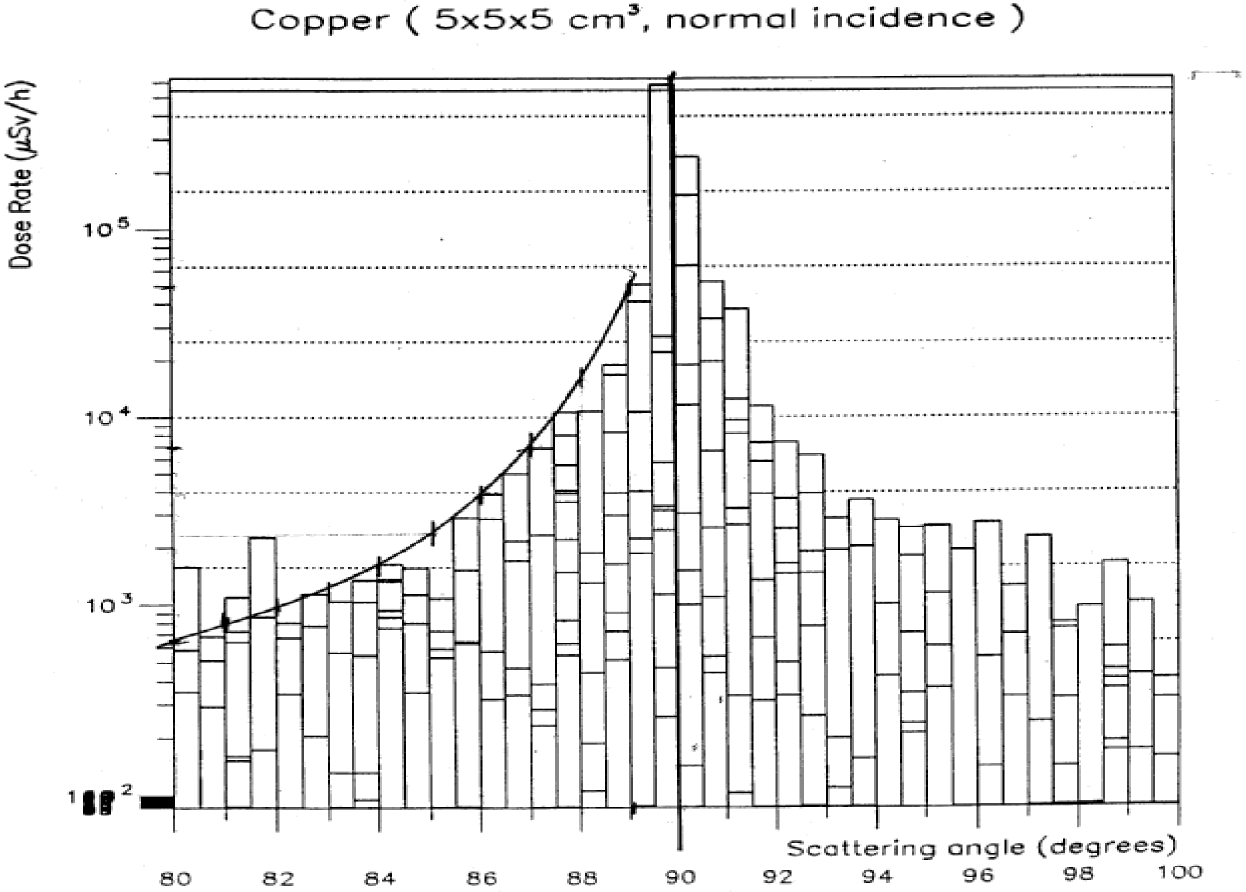
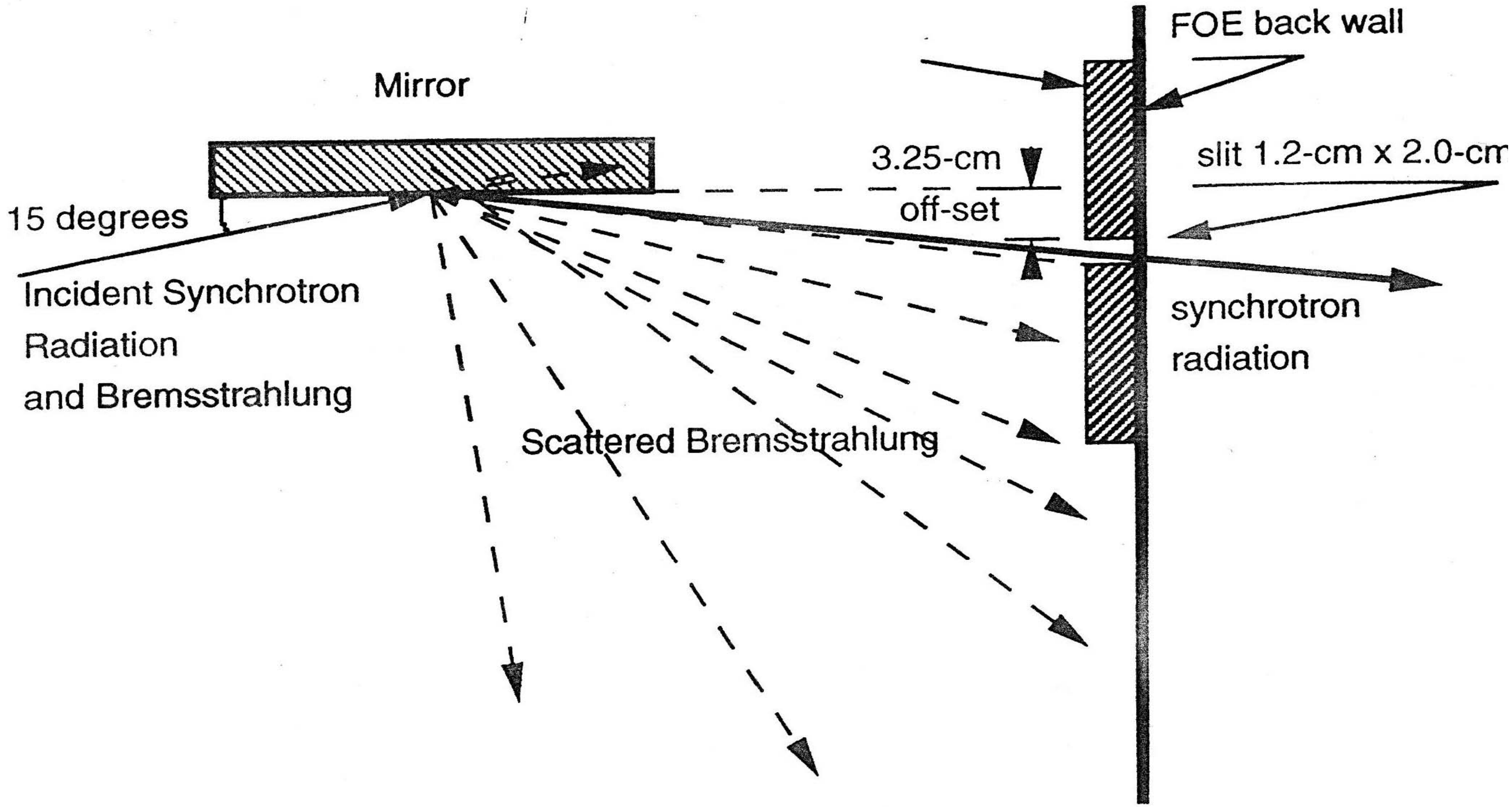
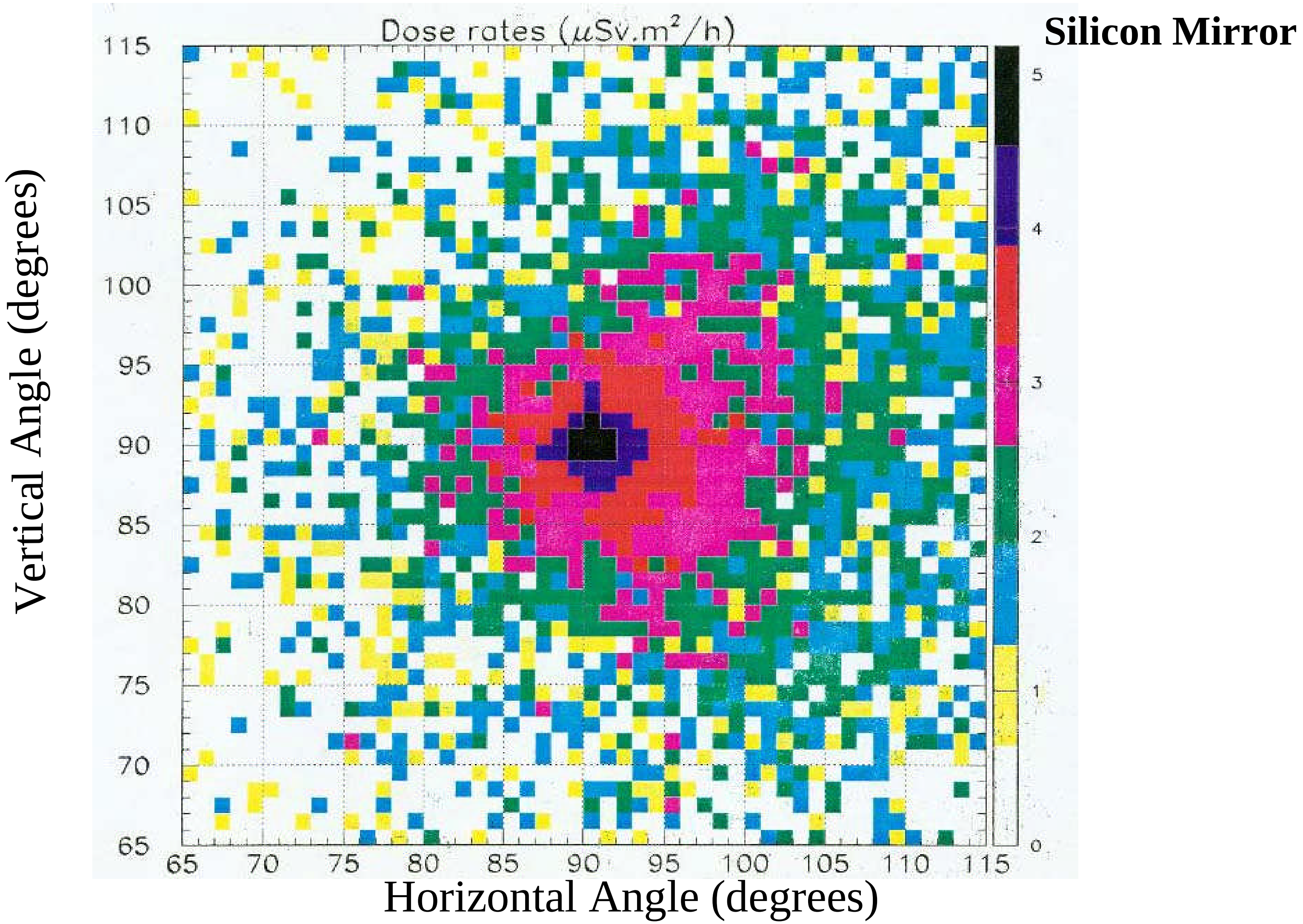


Figure 1. The EGS4 results for the scattering of the bremsstrahlung from a copper target (3 cm thick) of small transverse dimensions. The tissue is in contact with the target. (Figure 14 of TB 20).

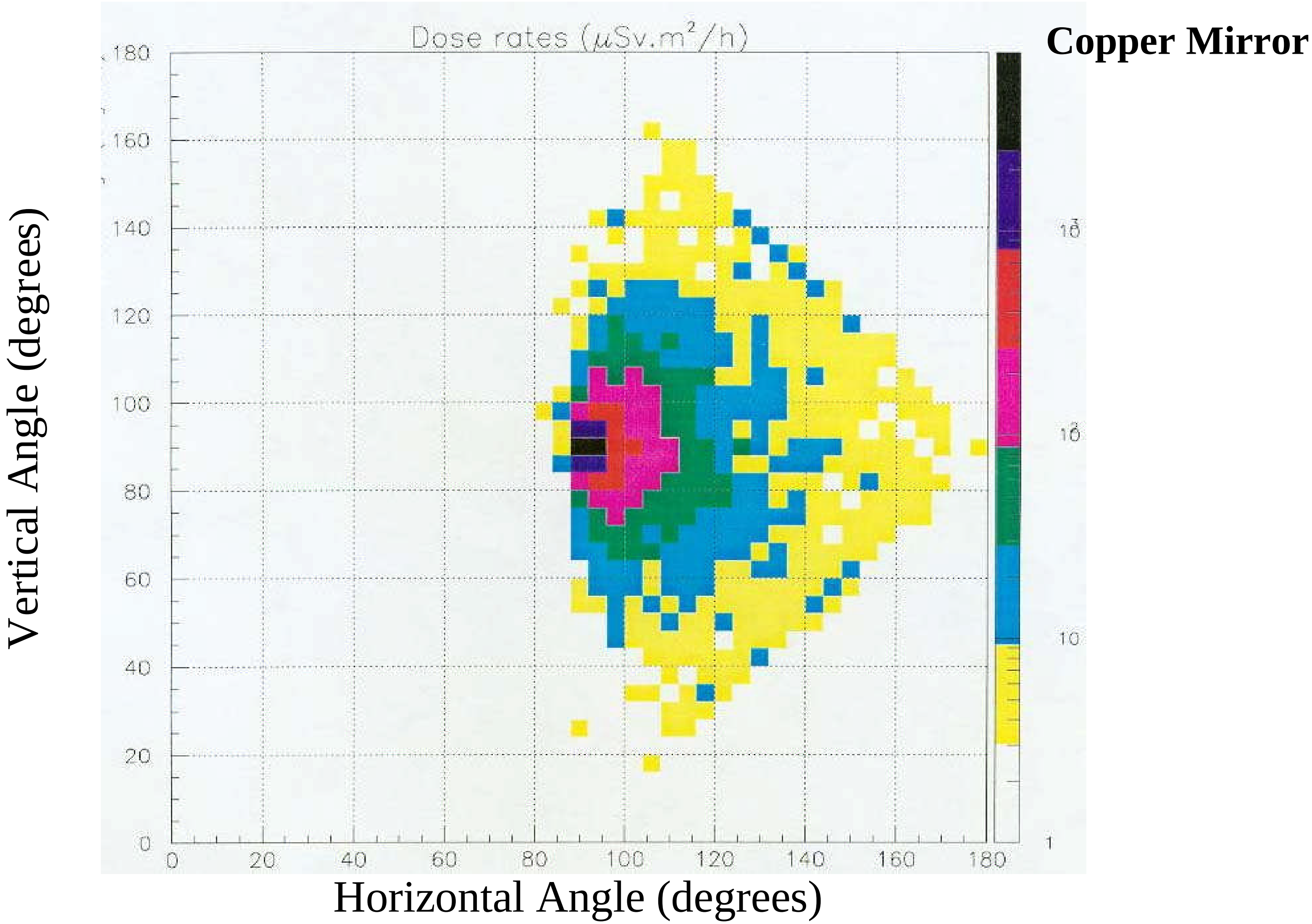
FOE Shielding Requirement - Scattering from Mirrors EGS4 Calculations



FOE Shielding Requirements – Dose Projections on the Downstream Wall (EGS4 Calculations)



FOE Shielding Requirement – Dose Projections on the Downstream Wall (EGS4 Calculations)



Summary

- Tools for shielding design simulation are readily available for SR facilities
- It is important to choose the right tool for a given radiation environment
- Realistic and reasonable assumptions should be made for each simulation based on the design features
- Close interaction between the designers and end users help to achieve high standards in radiation safety

For Further Reference

Accelerator Shileding	LS141
Beamline Shielding	TB 7
Beamline Shielding	TB 44
Bremsstrahlung Scattering Calculations	TB 20
Bremsstrahlung Scattering Calculations	TB 21
Bremsstrahlung Measurements at APS	NIMA 401 (1997)
Bremsstrahlung Measurements at ESRF	Rad.Phys. 59(2000)
Bremsstrahlung Dose Measurements	NIMA 438 (1999)
Photoneutron Dose Measurements	NIMA 430 (1999)