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Storage Ring Shielding for the Advanced Photon Source - Upgrade

Bradley J. Micklich
Radiation Physicist
Argonne National Laboratory

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Outline of Presentation

- Description of the Advanced Photon Source - Upgrade
- Simulations of electron losses in the APS-U storage ring
- MCNP6 simulations of dose rates
- Future directions
- Summary

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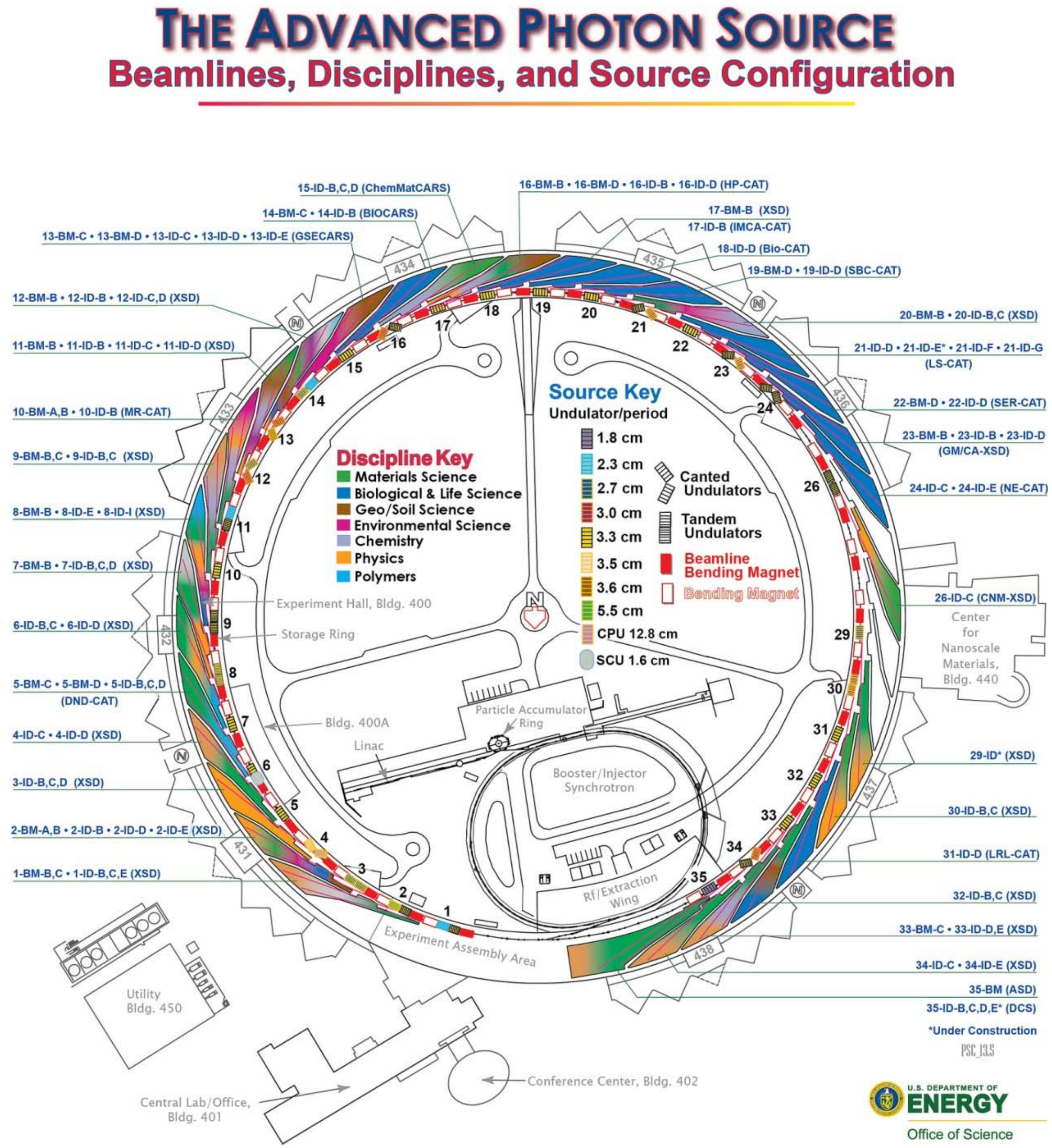
Advanced Photon Source

- Argonne's Advanced Photon Source provides high-brightness x-ray beams for experiments in a wide range of scientific disciplines
- The APS-Upgrade will increase photon brightness over the entire energy range by a factor of 100-1000

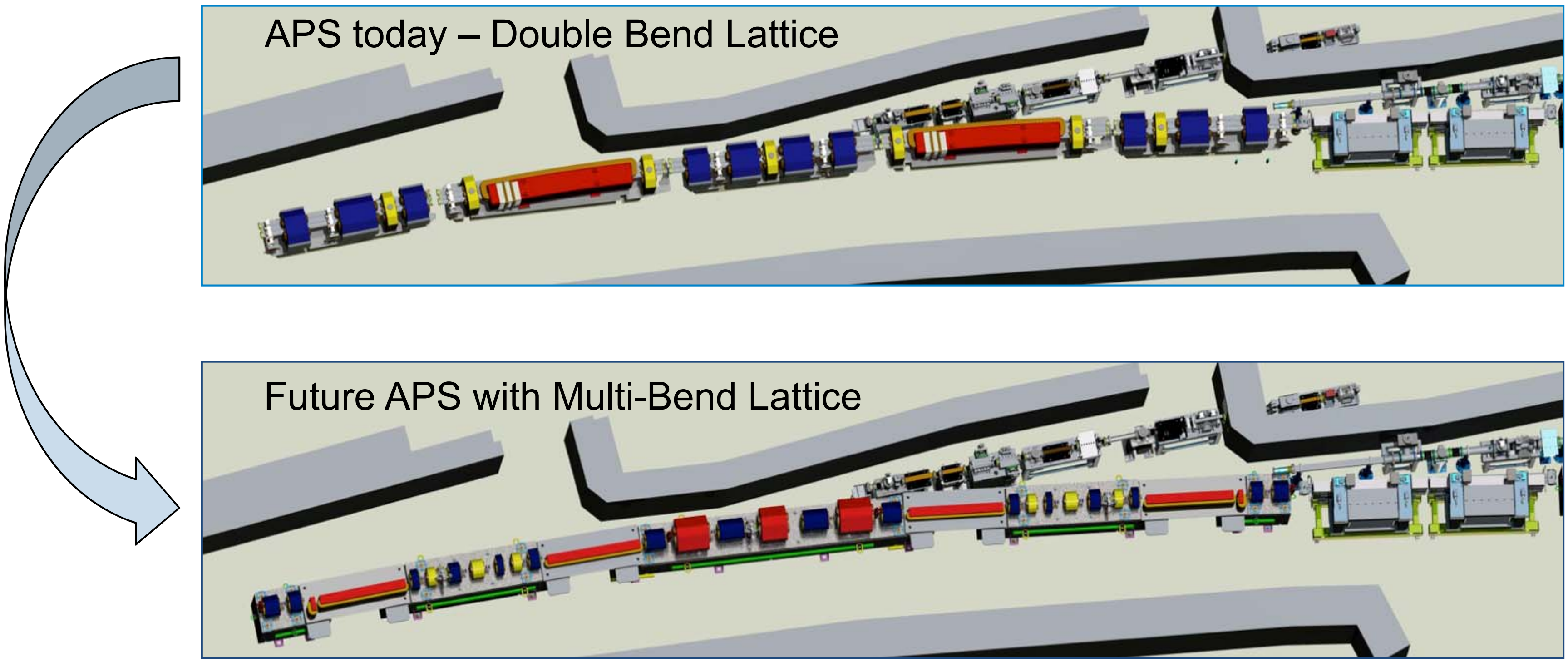
Advanced Photon Source

- The storage ring is divided into 40 sectors, each covering 9° of arc
- 35 sectors serve experiments, each containing one bending magnet (BM) and one insertion device (ID) beamline
- Four sectors contain RF stations to keep the beam energy constant
- One sector (#39) supports injection from the synchrotron
- Storage ring circumference 1104 m
- Orbit time 3.682 µs



Present vs. Upgrade Storage Ring

- The APS-Upgrade storage ring will enable x-ray beams of high brightness due to greatly reduced emittance – $\varepsilon_x/\varepsilon_y$ = 30/32 pm (round beams) or 45/4 pm (flat)
- This low emittance requires on-axis swap-out injection, in which entire stored bunches are replaced with new ones after falling to 90% of initial charge



$$\varepsilon_x = C_L \frac{E^2}{N_D^3}$$

E = Beam energy (E = 6 GeV for APS MBA)
N_D = Number of dipoles per sector (N_D = 7 for APS MBA)

APS Upgrade MBA Parameters

- Timing mode has 48 high-charge (15.3 nC) bunches (round beams)
- Brightness mode has 324 low-charge (2.3 nC) bunches (flat beams)

Quantity	Present APS	APS MBA Timing Mode	APS MBA Brightness Mode
electron energy (GeV)	7	6	6
beam current (mA)	100	200	200
number of bunches	24	48	324
stored energy (J)	2576	4420	4420
beam lifetime (h) †	8	2.91	5.96
injection mode	top-up	swap-out	swap-out
initial bunch charge (nC)		16.1	2.39
time for bunch to drop to 90% of initial charge (s)		1103	2260
bunch replacement time (s)		23	7
average injected power (W)	0.089	4.0	1.95

† 10th-percentile lifetime, includes Toushcek losses and gas scattering

Radiation Dose Limits and Shielding Criteria

- Annual dose limits for the APS-U will be the same as for the present APS

	annual	hourly
APS-U – radiation workers	5 mSv/y	2.5 µSv/h†
APS-U – non-rad workers and users	1 mSv/y	0.5 µSv/h†

†based on 2000 h/y

- The hourly dose rate should be considered as the dose in any one-hour period
- Readings from personnel dosimeters during APS operating history have demonstrated that the average dose to radiation workers is under 1 mSv/y
- Area dosimeters in the experimental hall register less than the detection threshold

- Facility shielding will be designed to 0.5 µSv/h for on-site personnel
- Dose for normal operations will be calculated at the design performance level (6 GeV, 200 mA)
- Normal operations for the storage ring includes losses of injected and stored beam plus some number of full beam dumps per year (usually initiated for machine protection)

APS-U Beam Loss Simulations

- Simulations have been completed for losses of injected beam and for intentional beam dumps (simulations conducted by M. Borland and A. Xiao of the APS)
- Simulations to determine spatial distribution of stored beam losses are ongoing
  - Touschek scattering (have completed calculations only for scattering in sector 1)
  - Electron scattering from residual gas – elastic and inelastic (bremsstrahlung)
- Contributions from both Touschek scattering and gas scattering were considered in calculations of stored beam lifetime

- The lattice model for these loss studies contains
  - Small-aperture IDs at sectors 4 and 33
  - Five horizontal collimators (actually whole beam dumps) in the upstream multiplets in sectors 37 to 1
  - Vertical collimators in the A:M1 dipoles in sectors 1 and 39 (swap-out dump)

- The results of injected and stored beam losses are combined to determine the total loss rate at each point around the storage ring

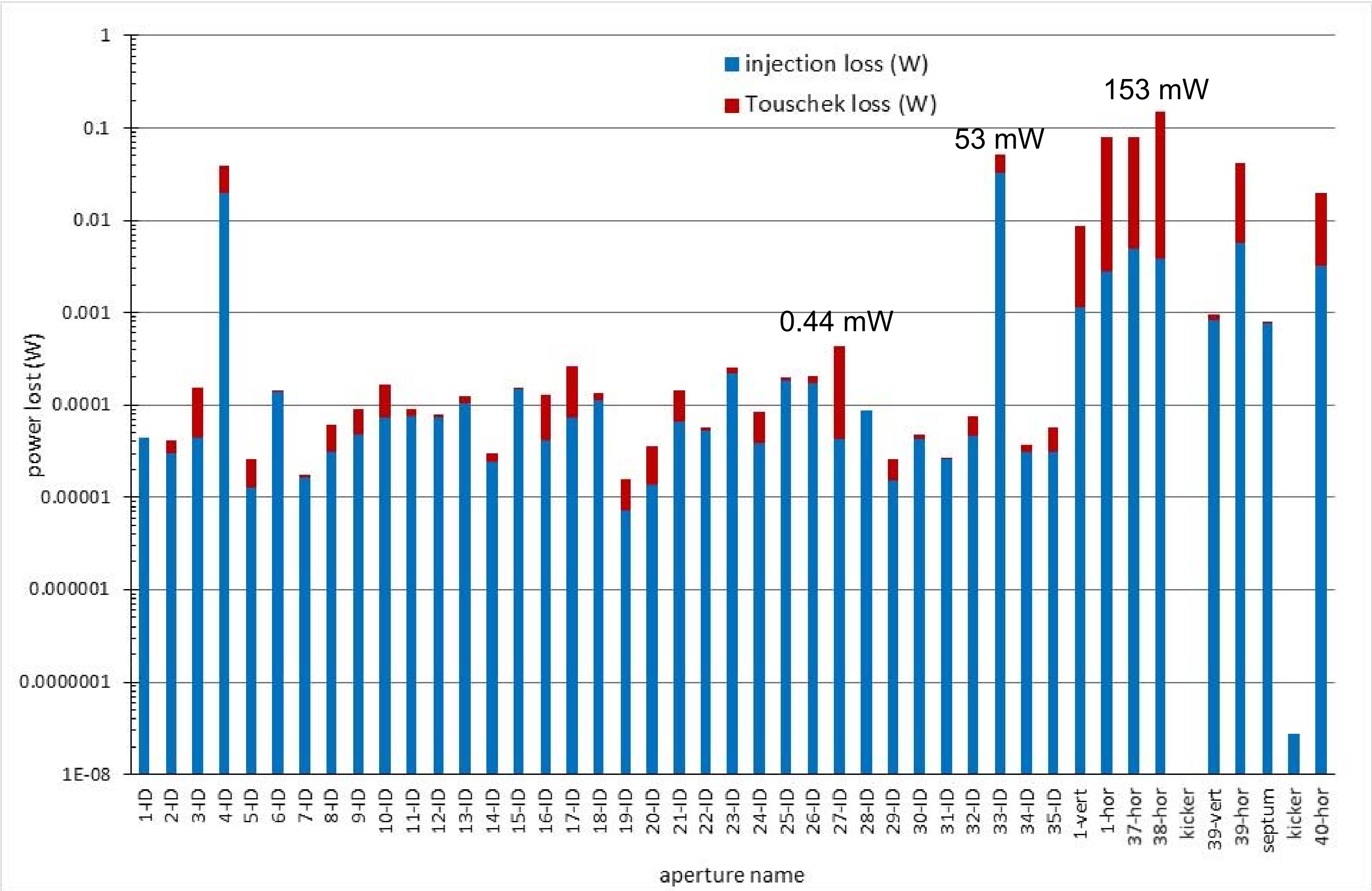
APS-U Beam Loss Calculations

- Stored beam losses
  - 48-bunch mode
  - Beam lifetime 2.91 h (10th-percentile lifetime)
  - Injected power of 4.0 W is needed to sustain this operating mode
  - Distribution of stored beam losses uses the Touschek losses at minimum lifetime
- Injected beam losses
  - 2% of the injected beam energy is lost (90th percentile)
  - For these parameters, stored beam losses are larger than for injected beam

- The injection and stored beam parameters were combined to determine the electron power lost at each aperture around the storage ring
- Results will be shown for
  - A 'normal' insertion device
  - A small-horizontal-aperture insertion device
  - A collimator in Zone F

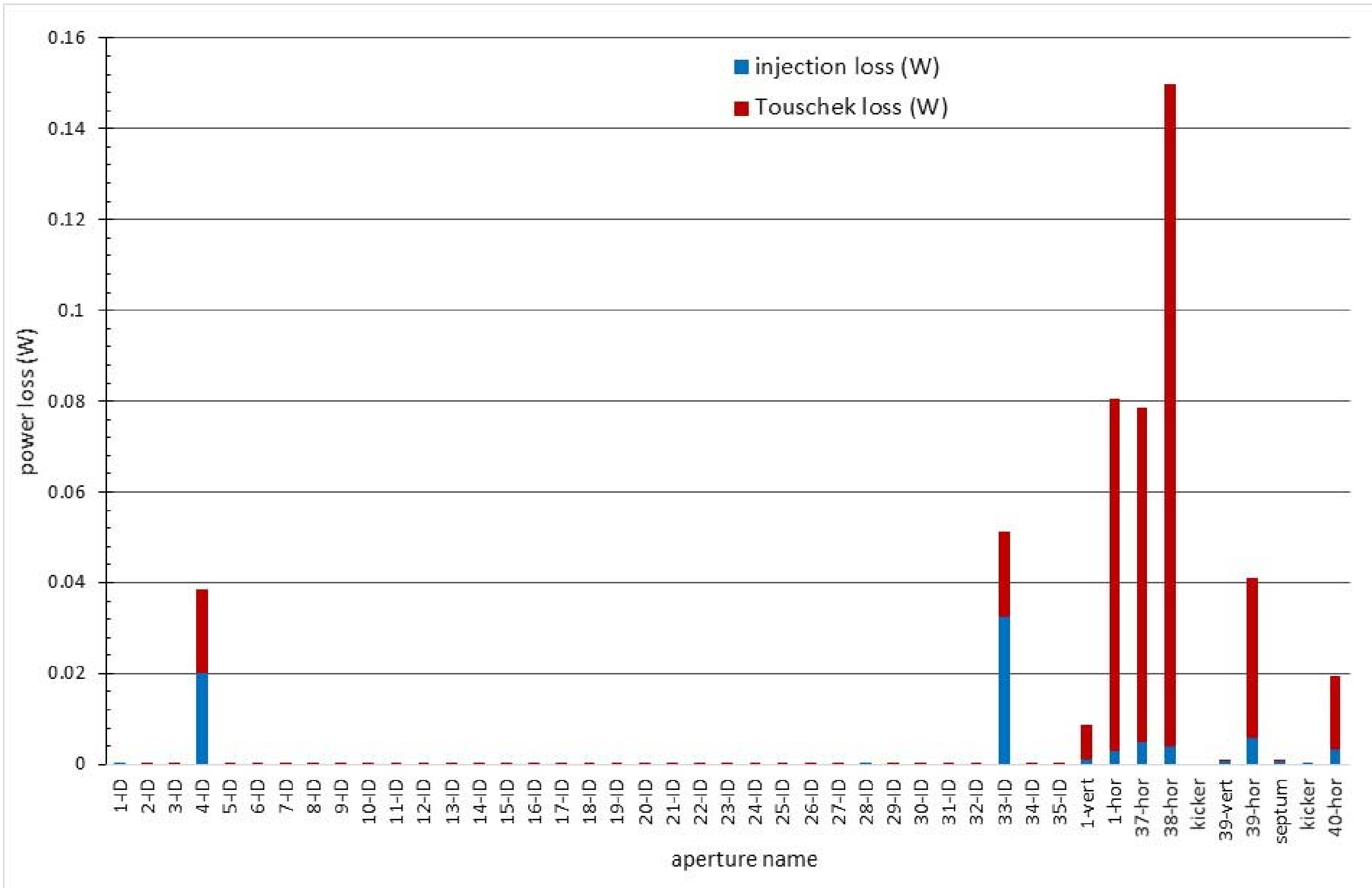
Injected and Scattered Beam Losses

- The maximum loss rate at a 'normal' ID is about 0.44 mW (sector 27)
- The loss rate at the small-horizontal-aperture IDs is much larger



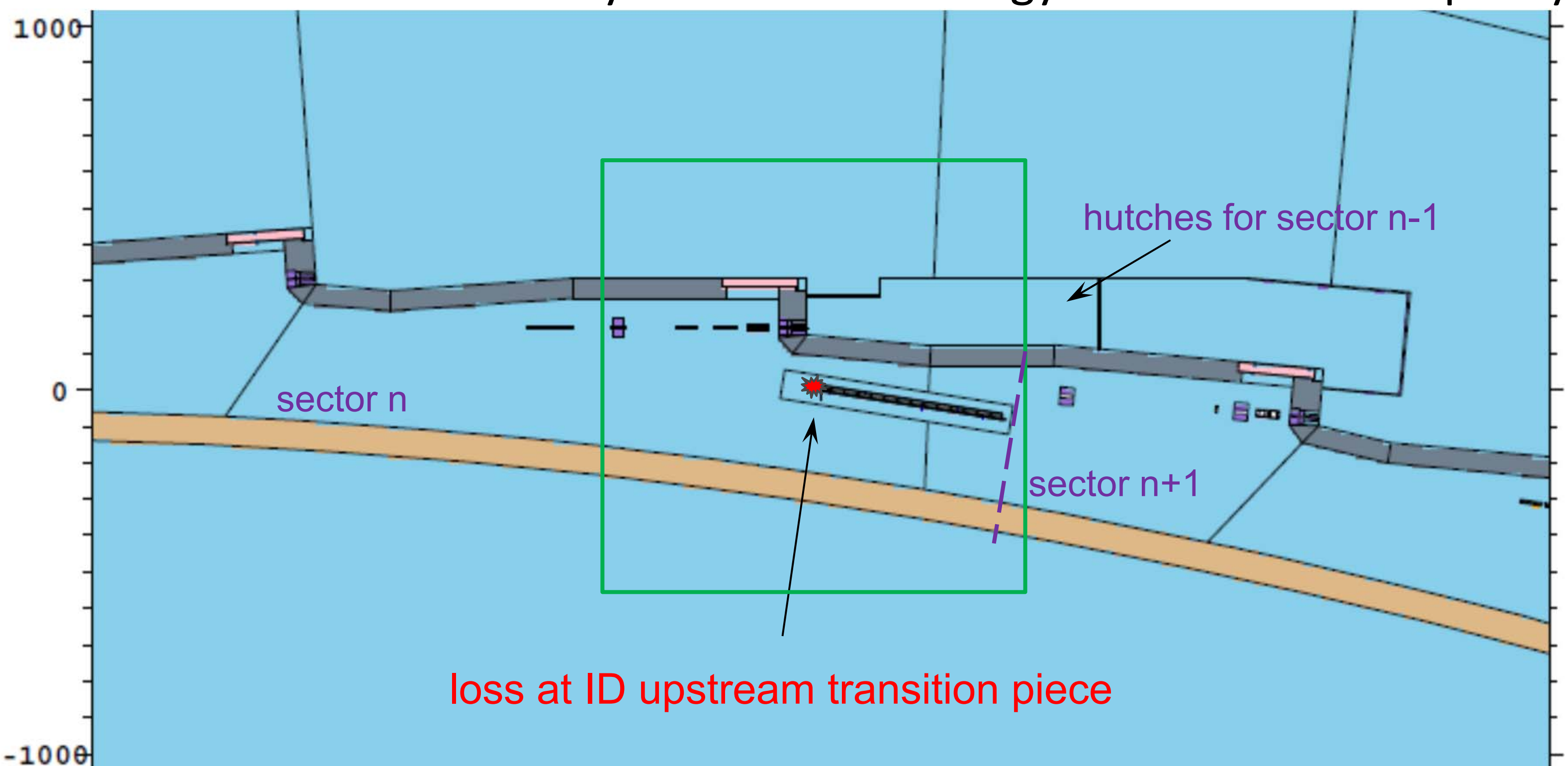
Injected and Scattered Beam Losses

- Injected beam lost primarily at the small-horizontal-aperture IDs
- Touschek scattering losses occur primarily collimators in Zone F (by design)
- We will try to improve collimation for injected beam losses, but want to avoid decreasing the beam lifetime



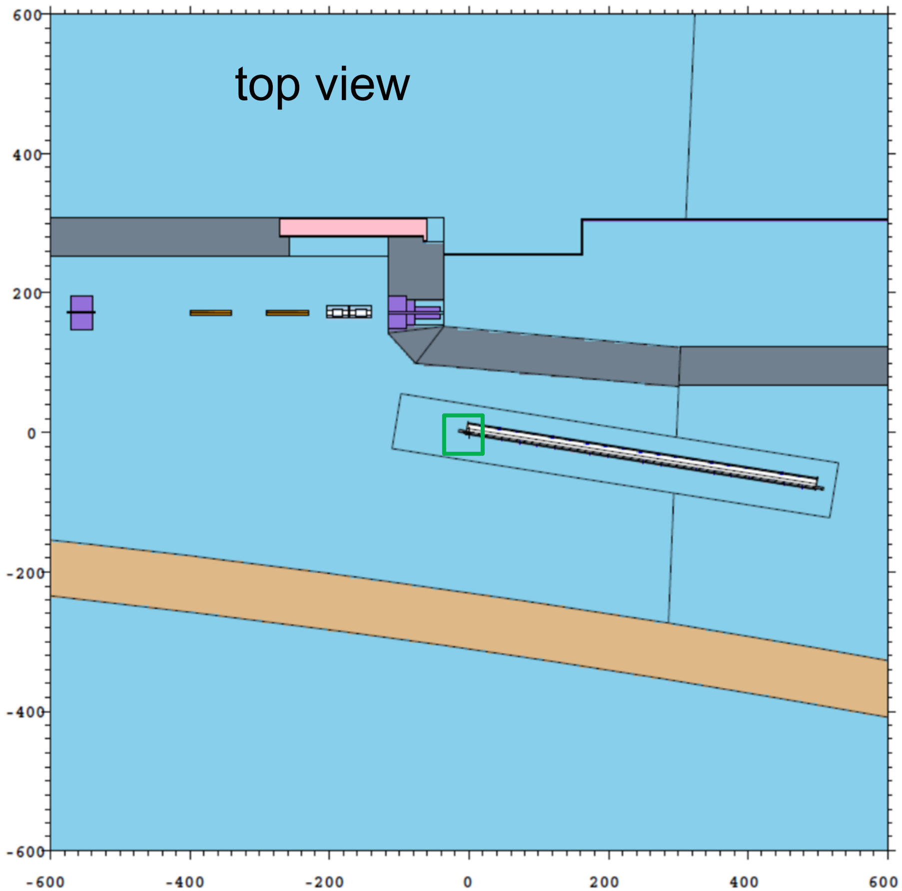
MCNP Model of APS Bulk Shielding

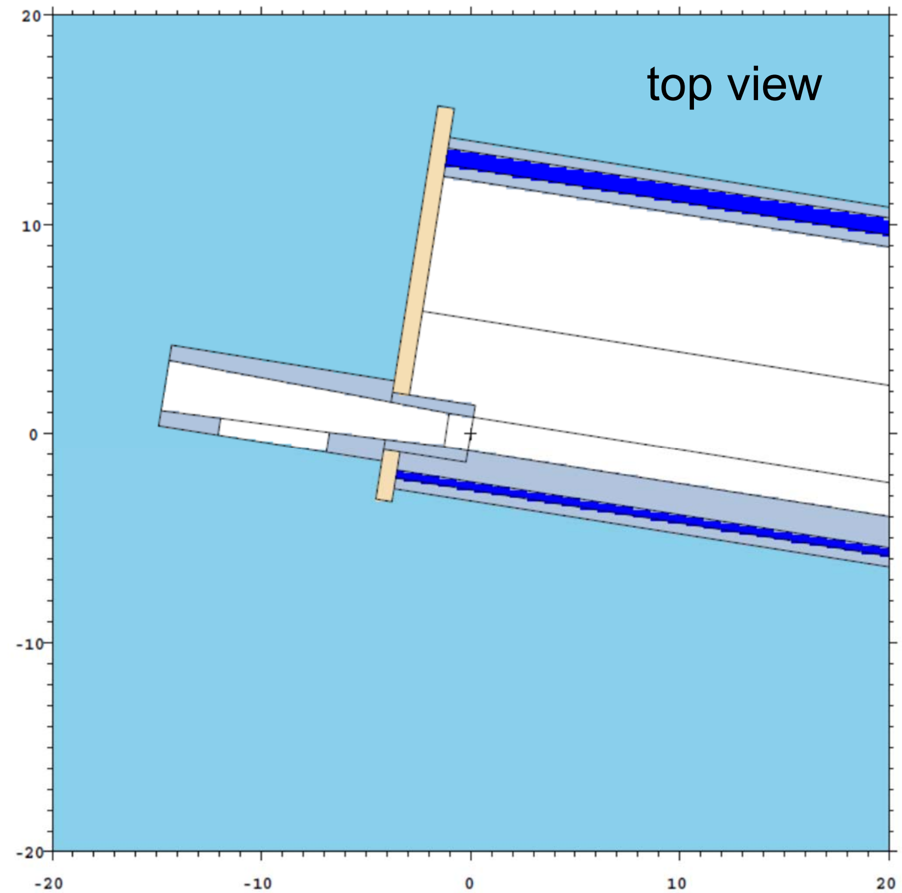
- A MCNP model was constructed covering two full sectors of the APS storage ring bulk shielding
- Bulk shielding will remain the same for the APS-Upgrade
- The dose outside the shielding for the APS-Upgrade can be calculated for beam lost at any given location (e.g. the entrance to an ID)
- The annual dose is determined by the electron energy loss and the occupancy



Dose due to Beam Loss at Insertion Device

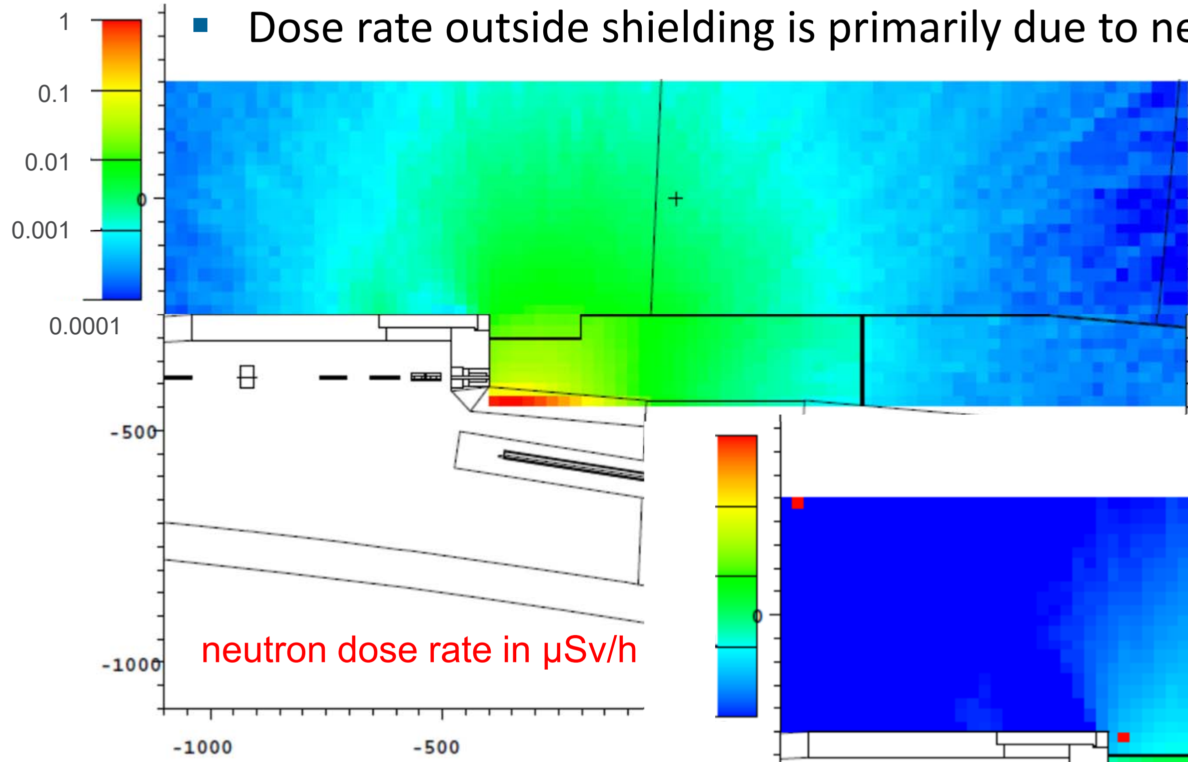
- An insertion device for APS-Upgrade was modeled in MCNP
- Dose rates outside the bulk shielding were calculated for an electron beam loss at the upstream transition piece

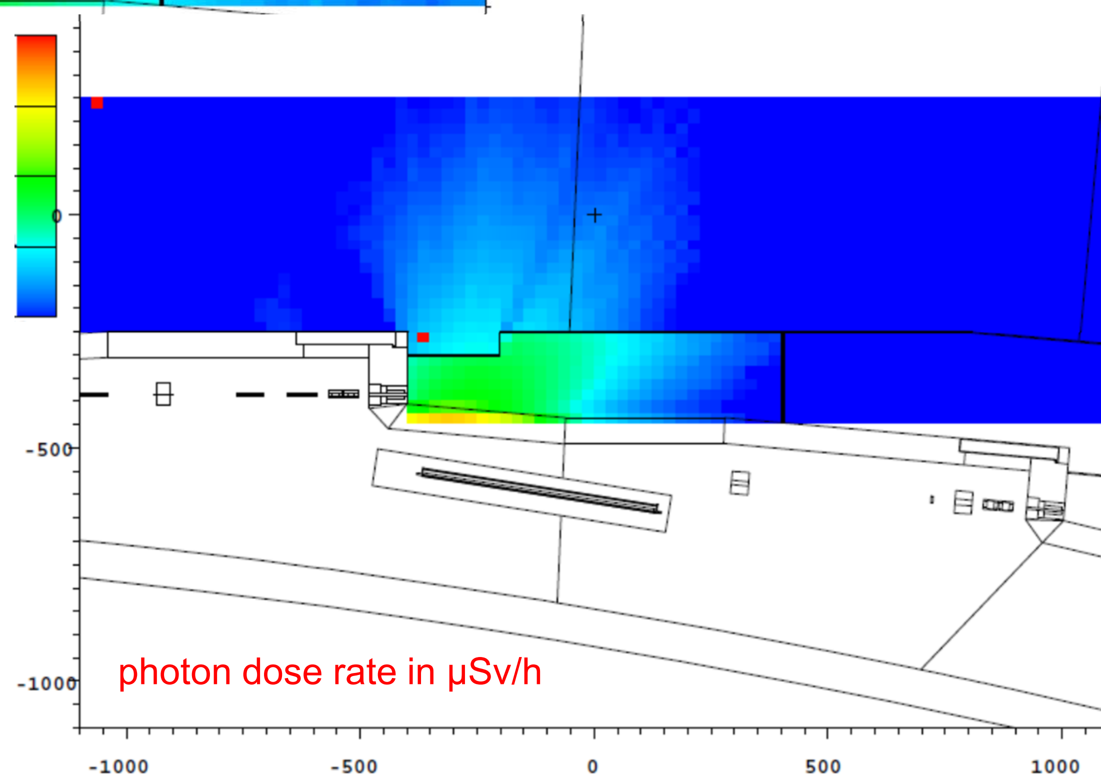




Dose Rate Calculation – Loss at 27-ID

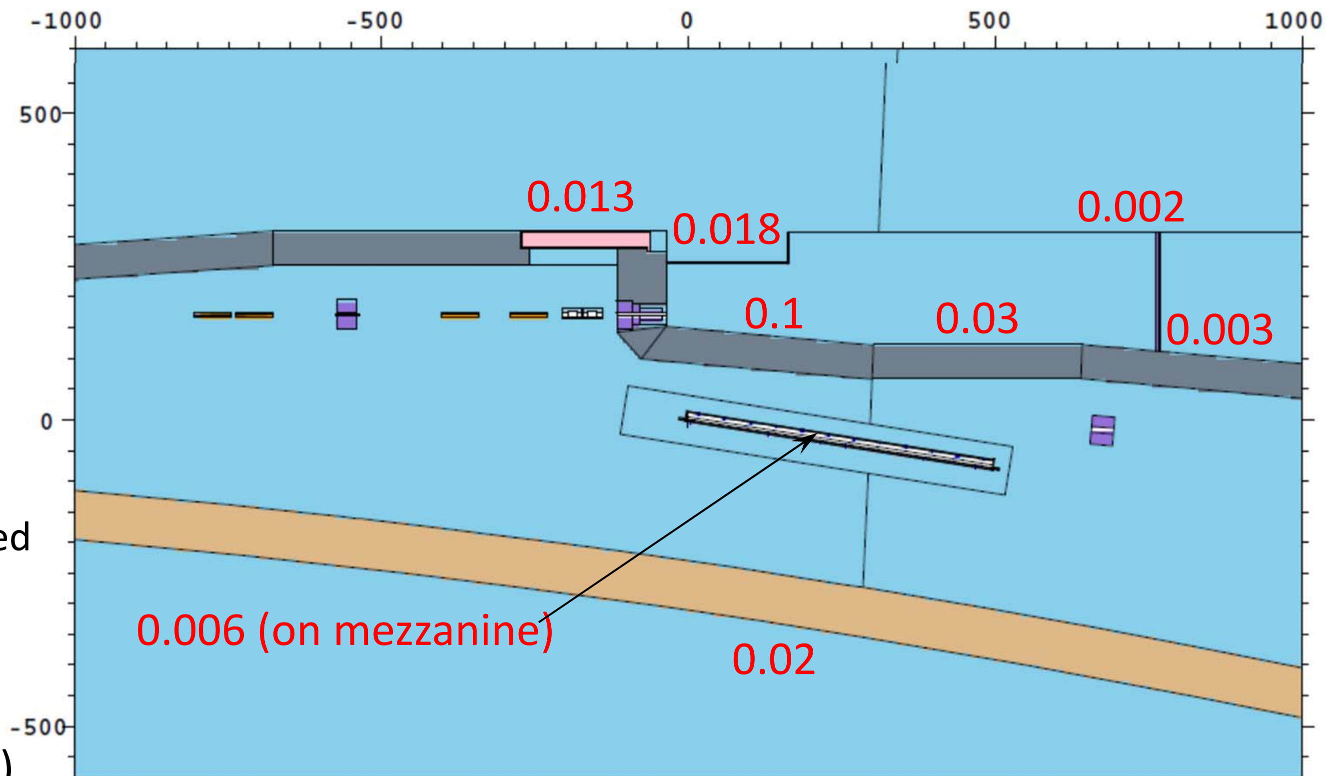
- Dose rate outside shielding is primarily due to neutrons





Annual Dose Calculation – Loss at 27-ID

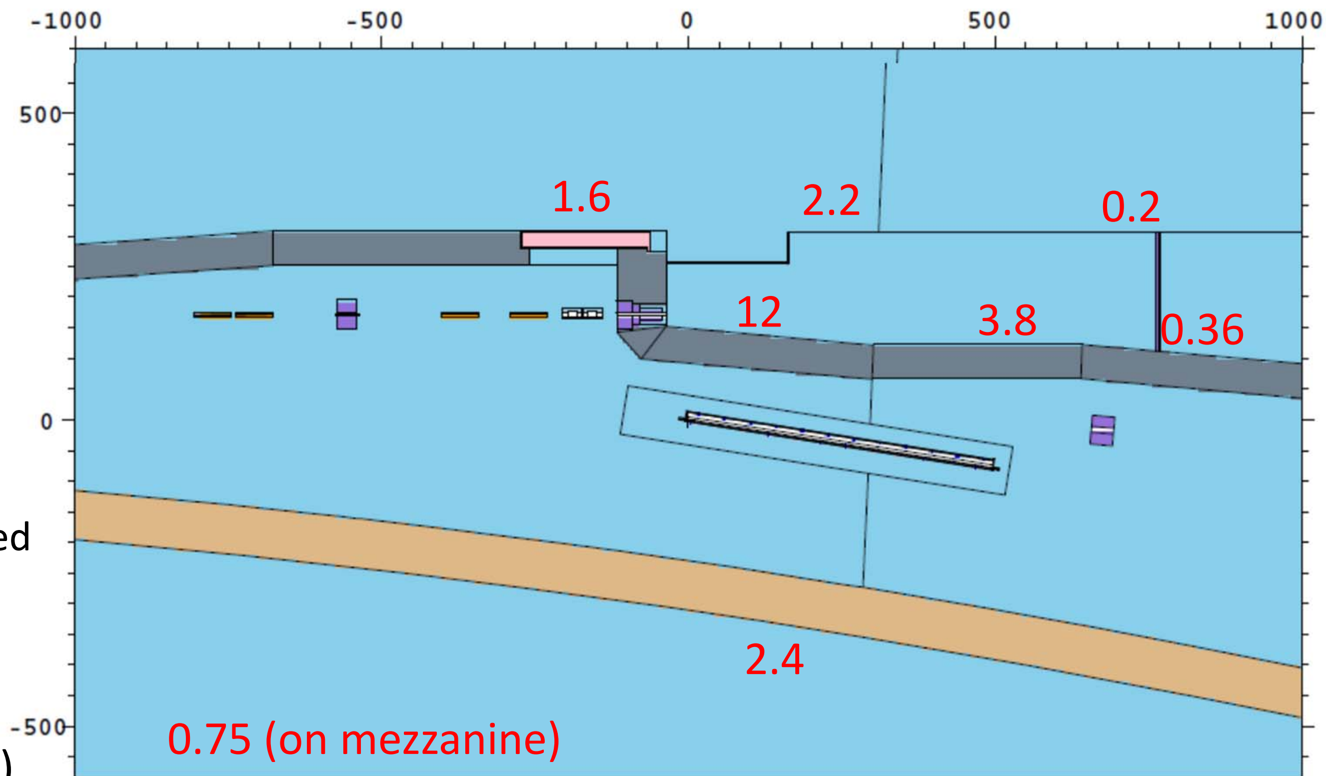
- Assumptions:
  - Stored energy 4420 J
  - 2.91 h lifetime
  - 0.09% of stored beam losses at 27-ID
  - Injected power 4.0 W
  - 2% injection losses
  - 0.054% of injection losses at 27-ID
  - No losses from dumped beam
  - 2000 h occupancy
- Annual dose in mSv (30 cm from boundary)



- Stored beam loss rate at 27-ID is (4420 J/2.91 h) x 0.0009 = 0.40 mW
- Injected beam loss rate would be 4.0 W x 0.02 x 0.00054 = 0.04 mW
- Shielding would be adequate for loss of 4 mW

Annual Dose Calculation – Loss at 33-ID

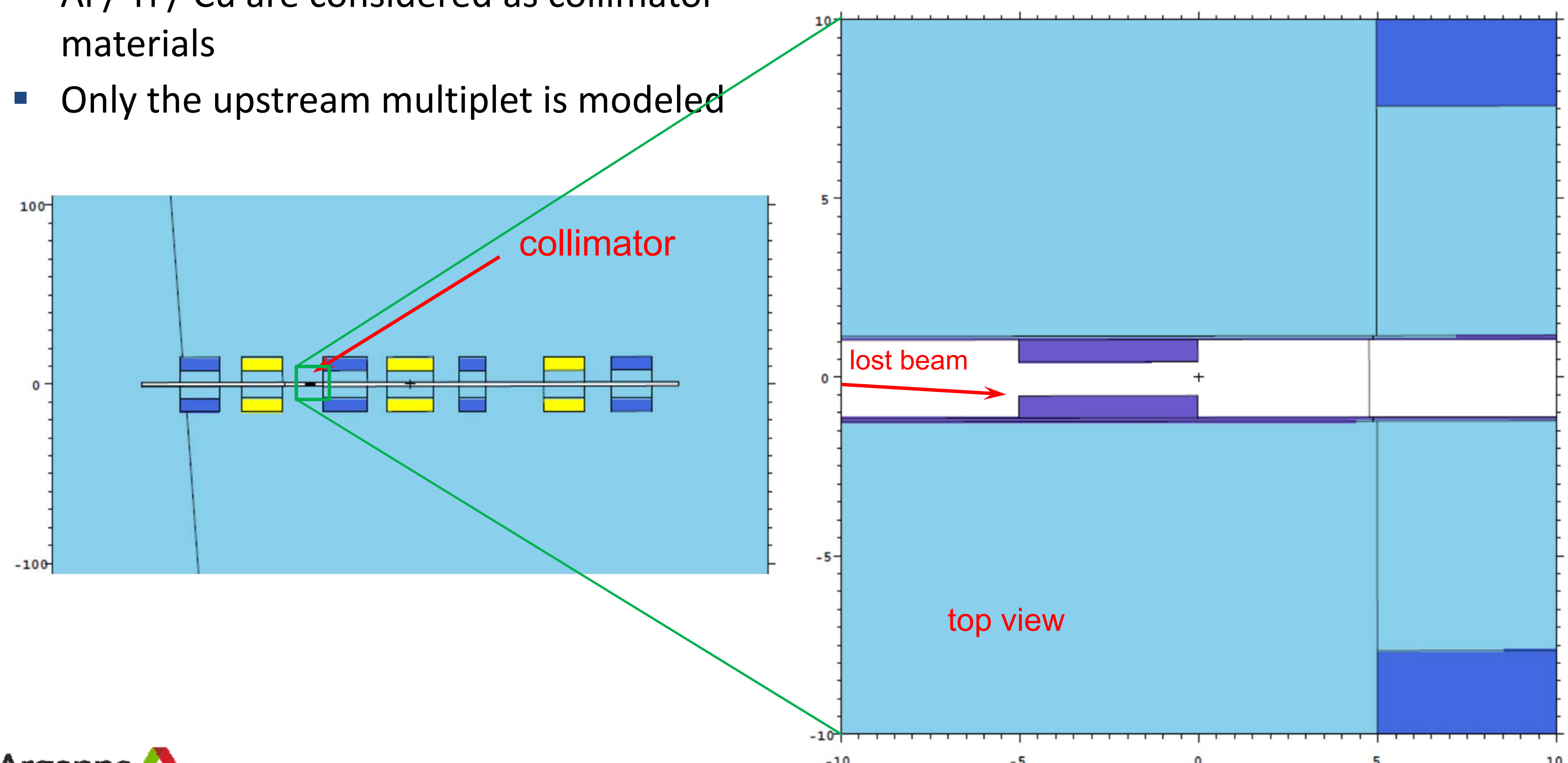
- Assumptions:
  - Stored energy 4420 J
  - 2.91 h lifetime
  - 4.57% of stored beam losses at 33-ID
  - Injected power 4.0 W
  - 2% injection losses
  - 41.6% of injection losses at 27-ID
  - No losses from dumped beam
  - 2000 h occupancy
- Annual dose in mSv (30 cm from boundary)



- Stored beam loss rate at 33-ID is (4420 J/2.91 h) x 0.0457 = 19.3 mW
- Injected beam loss rate would be 4.0 W x 0.02 x 0.416 = 33.3 mW
- Use of supplemental shielding can reduce the dose rate outside the FOE by a factor >2 (e.g. 30 cm of the material used inside the access doors)

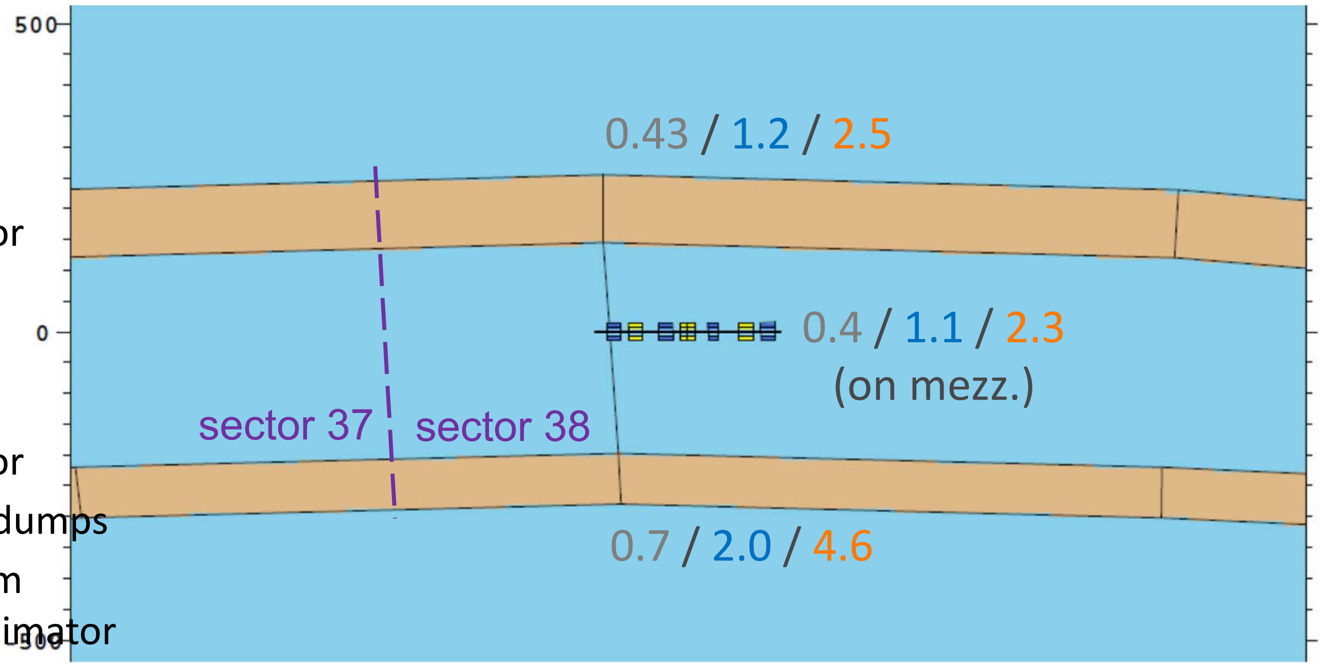
MCNP Model of Injection Region Shielding

- Stored beam is principally lost on the horizontal collimators in Zone F (sectors 37 to 01)
- Collimator is located in the upstream multiplet between the A:S1 and A:Q4 magnets
- Horizontal aperture ± 0.48 cm, length 5 cm (conceptual design)
- Assume beam lost at upstream end of collimator
- Al / Ti / Cu are considered as collimator materials
- Only the upstream multiplet is modeled



Annual Dose Calculation – Sector 38 Collimator

- Assumptions:
  - Stored energy 4420 J
  - 2.91 h lifetime
  - 35.4% of Touschek losses at this collimator
  - Injected power 4.0 W
  - 2% injection losses
  - 4.97% of injection losses at this collimator
  - 125 full-power beam dumps
  - 100% of dumped beam energy strikes this collimator
  - 2000 h occupancy
  - Annual dose in mSv shown for Al/Ti/Cu collimators (30 cm from boundary)



- Touschek loss rate at sector 38 collimator is (4420 J/2.91 h) x 0.354 = 149 mW
- Injected beam loss rate would be 4.0 W x 0.02 x 0.0497 = 4.0 mW
- 125 full-power beam dumps deposit 550 kJ at this location (equivalent to 76 mW over 2000 h)

Future Directions

- Develop detailed MCNP model with storage ring magnets located inside tunnel
- Fold in updated results for electron loss simulations when available
- Include magnetic fields in the MCNP simulations
- Consider dose / dose rate from x-ray beamlines in conjunction with dose due to losses in the storage ring

Summary

- Some radiation source terms at the APS-U will increase over present operations due to different operating parameters (increased stored charge, increased injected charge/bunch, more frequent injection, shorter beam lifetime)
- Simulations for beam losses at insertion devices and collimators indicate that the existing bulk shielding is sufficient to limit the dose outside the shielding
- The two small-horizontal-aperture IDs will require some supplemental shielding
- We are trying to refine the collimator number and locations to reduce the beam losses at the small-aperture insertion devices, without reducing beam lifetime