MI-8 COLLIMATORS: FUNCTIONAL DETAILS AND MARS15 RADIATION MODELING

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OUTLINE

- MI-8 Beamline Collimation
- Radiation Limits and Design Constraints
- Max Palmer Collimators for 0.1% Scraping
- Booster-like Collimators for 1% Scraping
- Using Marble
- Proposed Compact Design for 1% Scraping

MI-8 BEAMLINE COLLIMATION

Tails of the 8-GeV proton beam need to be cut before injection to the Main Injector. The 5.2-m long section of MI-8 between 836B and 837A magnets is a natural choice (see Bruce Brown presentation). Horizontal collimation: β_x = 35 m downstream 836B and for a 20 π-mm-mrad emittance, the 3.72σ_x beam size (about 99.9% of beam) is 13 mm while the 3.03σ_x (about 99% of beam) is 10.65 mm. Vertical collimation: β_y = 35 m upstream 837A, the beam size discussion is the same, this location is 90 degrees of phase advance (plus many 2π) from the MP02 location.

The beam power at 8 GeV with 5×10^{12} ppp at 10 Hz is 64 kW. That corresponds to 5×10^{10} p/s or 64 W of the average scraping rate on the collimators for the 0.1% beam loss scenario, and 5×10^{11} p/s or 640 W for the 1% scenario.

Without shielding, corresponding prompt and residual radiation levels inside the tunnel, in ground/sump water and above shielding would exceed the regulatory limits.

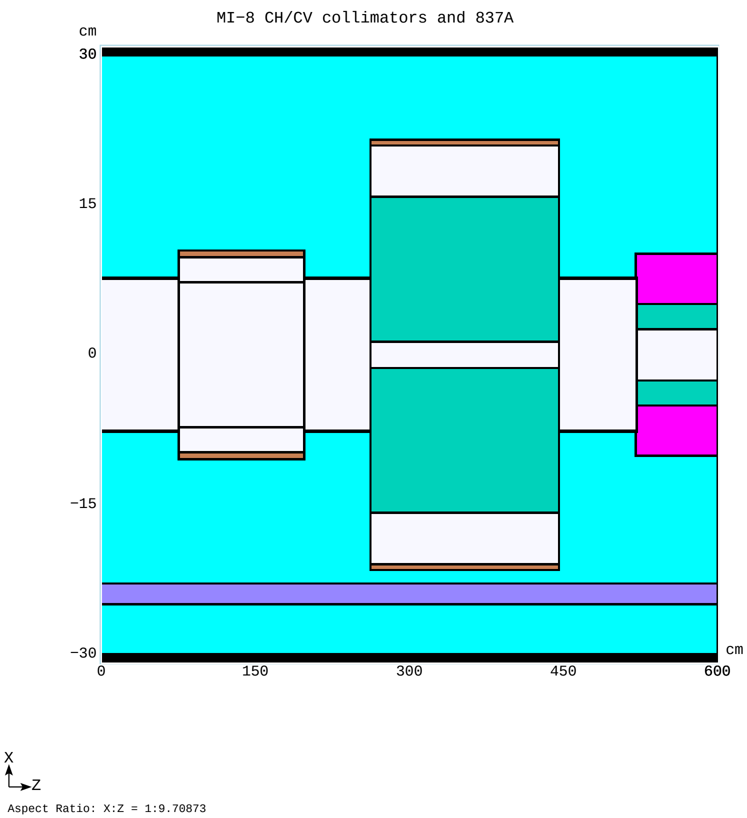
RADIATION LIMITS AND DESIGN CONSTRAINTS

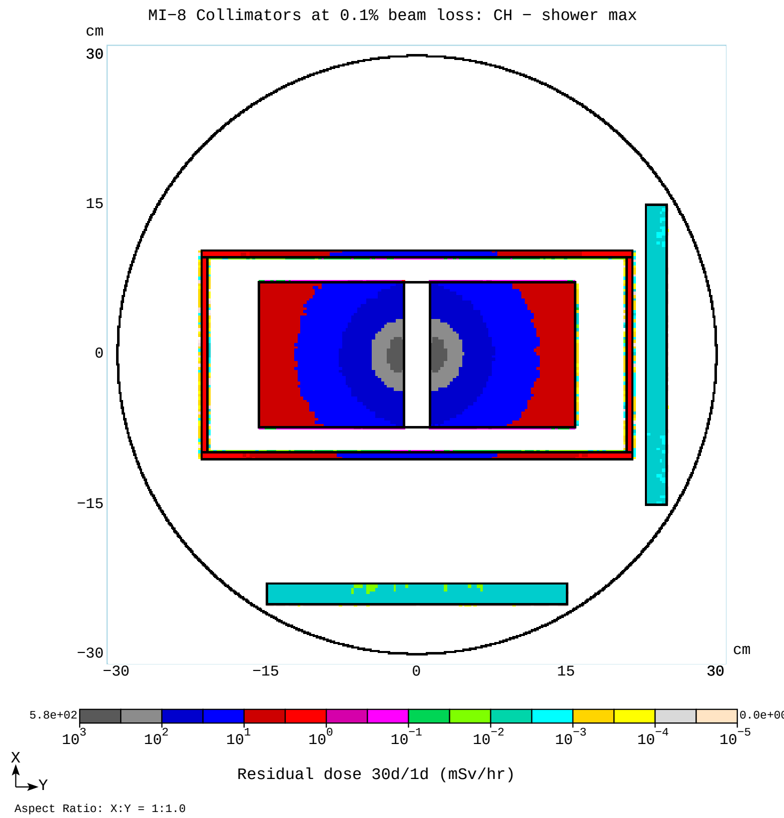
- Residual dose rate $P_\gamma < 100$ mrem/hr = 1 mSv/hr at 1 foot in tunnel (30 days / 1 day) – hands-on maintenance
- Prompt dose equivalent in non-controlled areas is $DE < 0.05$ mrem/hr at normal operation and < 1 mrem/hr for the worst case due to accidents; it is $DE < 5$ mrem/hr = 0.05 mSv/hr for limited access areas (needed 13.5 feet of dirt above the tunnel with Booster design)
- Sump water activation $< S >_{gravel} \; < 4000$ cm^{-3}s^{-1}
- Energy deposition in collimators
- Accumulated absorbed dose in cables, motors, instrumentation – lifetime
- Air activation

MAX PALMER COLLIMATORS FOR 0.1% SCRAPING

In MARS15 modeling, we look first at the 3.72σ case. A 8-GeV proton beam with the RMS spot size σ_x and σ_y of 3.5 mm at CH and CV, respectively, hits the collimators opened $\pm$13 mm horizontally (CH) and vertically (CH). A horizontal collimator (CH) consisting of a 4' Max Palmer Collimator is placed 0.75 m downstream of the magnet 836B. Setting this collimator to cut beam at 3.72σ_x will remove both edges of the beam at this size. A vertical collimator (CV) consisting of a 6' Max Palmer Collimator is placed 0.75 m upstream of the magnet 837A. A beam halo density distribution is assumed to be $1/r$ in the $3.72\sigma < r < 10\sigma$ region. The collimator steel jaws are 14.6$\times$14.6 cm encapsulated into a 0.6-cm thick steel vessel. A simple model for the 837A magnet is implemented. Components are connected with 6-inch OD, 1.5 mm thick beam pipes. Calculated are 3-D distributions of the contact residual dose rate (mSv/hr) after 30-day continuous irradiation at 5×10^{10} p/s and 1-day cooling, particle fluxes, energy deposition, and the yearly absorbed dose in Gy/yr at at 2×10^7 operational seconds per year. 1 mSv/hr = 100 mrem/hr, and 1 Gy = 100 rad. Cutoff E_{th} 0.1 MeV.

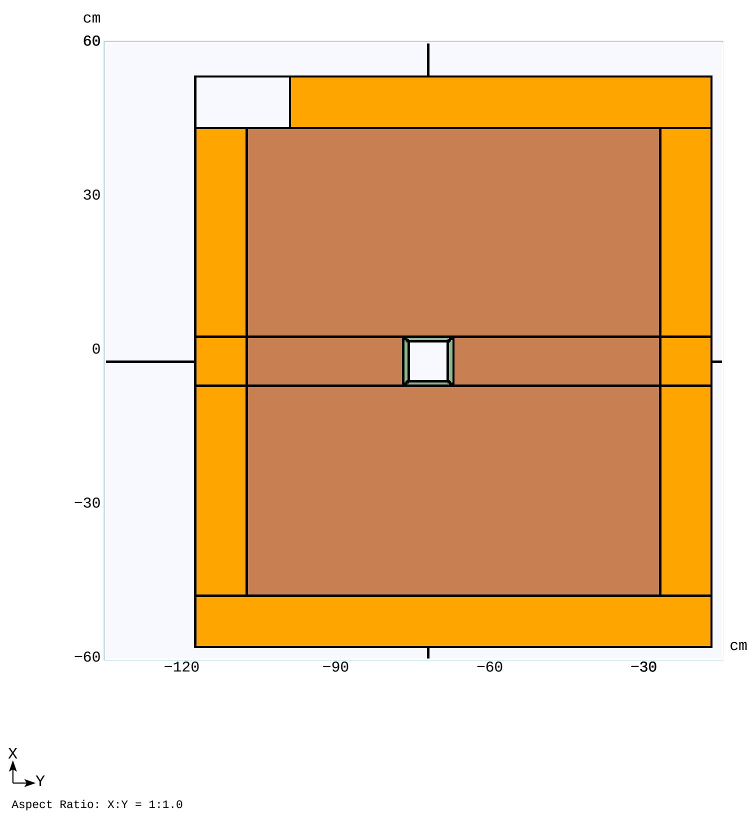
MAX PALMER COLLIMATORS

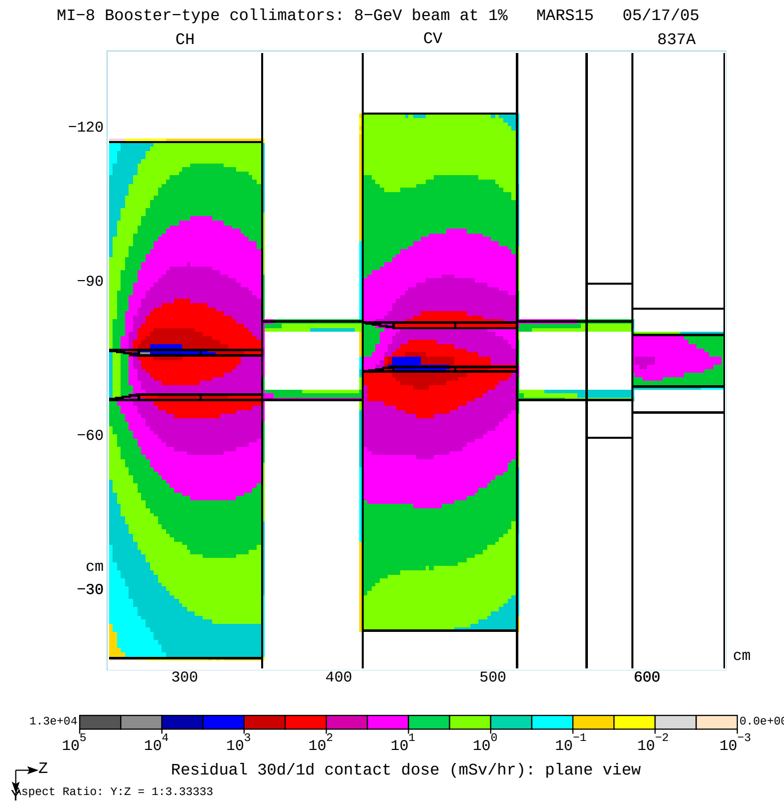




Can do a reasonable job for 0.1% scraping, but need a local shield to reduce residual dose by a factor of 10 and protect cables and motors.

BOOSTER-LIKE COLLIMATORS FOR 1% SCRAPING





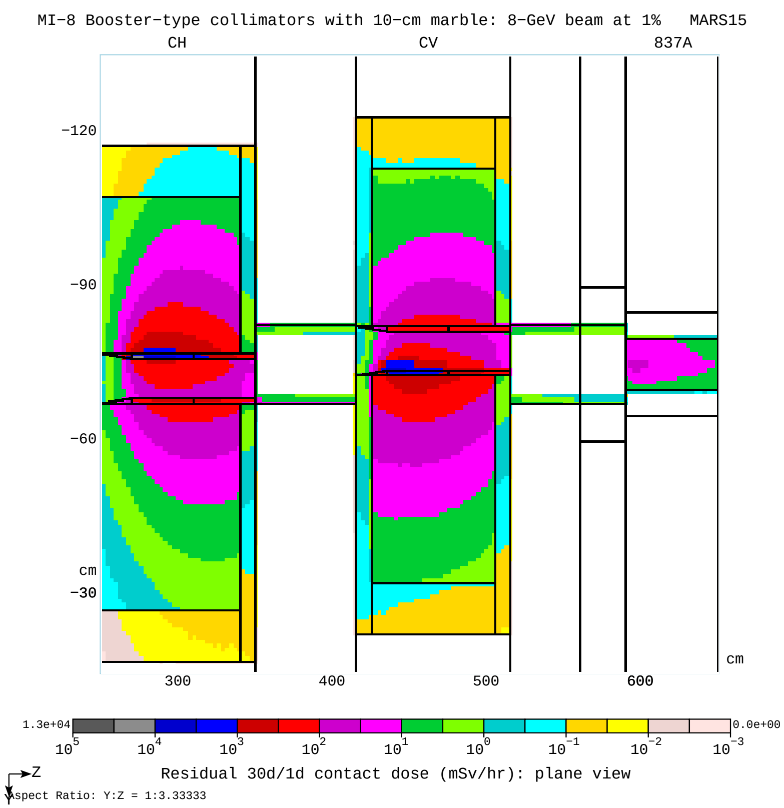
Setting collimator jaws to cut the beam at $3.03\sigma_x$ with $1/r$ halo in the $3.03\sigma < r < 10\sigma$ region (5×10^{11} p/s) require $44\times44\times44$ inch steel collimators (±55 cm). The residual dose is OK, but each collimator weigh 14 tons!

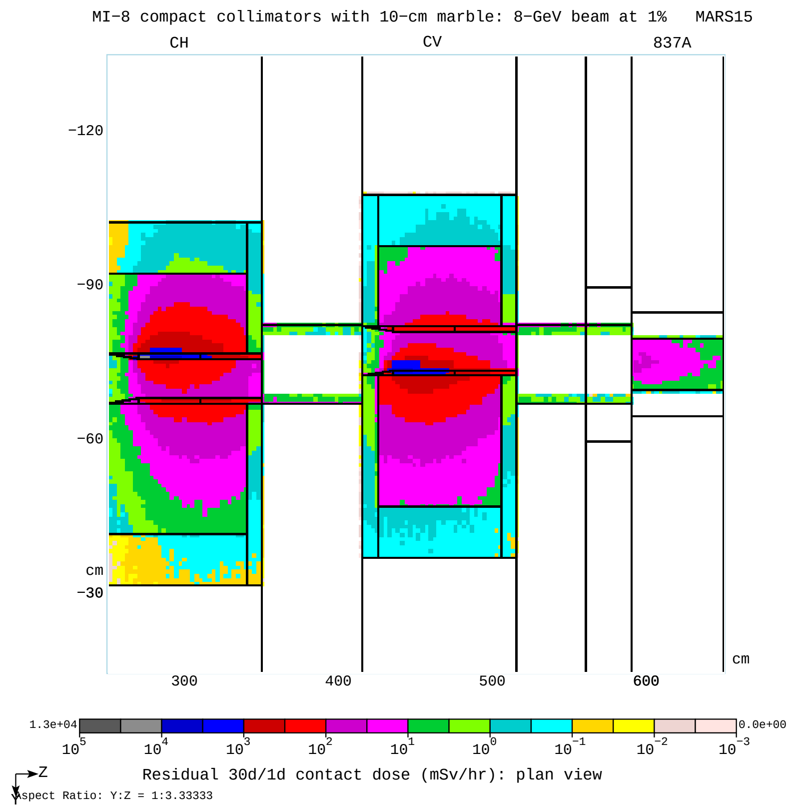
USING MARBLE TO REDUCE ACTIVATION

Dirt shielding above the MI-8 collimation region is 23 feet compared to 13 feet in the Booster case, therefore the prompt dose on the surface is not a driving issue. According to Dixon Bogert and Bruce Brown, the sump and groundwater activation in this region are also not an issue. Therefore, the driver is residual dose rate on the collimator shielding outer surface (keep it below 1 mSv/hr or 100 mrem/hr). Air activation should also be considered.

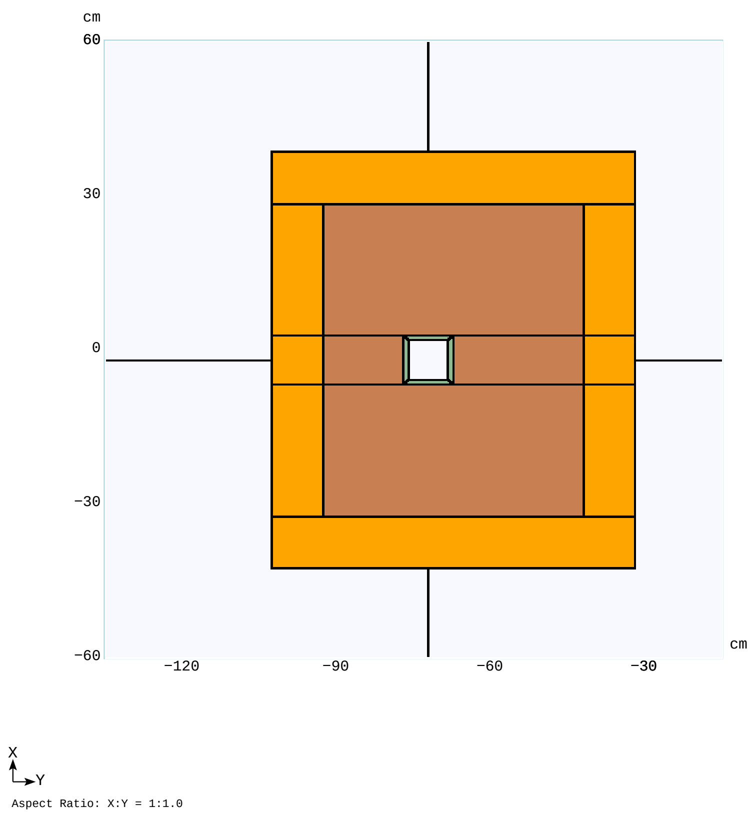
The lowest activation in materials used in similar cases found in marble ($CaCO_3$, ρ = 2.7 gcc. Was considered for SSC collimators and dumps. Will be used for LHC beam dumps. Was considered for Booster collimators but prompt dose, residual dose and groundwater activation criteria were equally important requiring massive steel shielding anyway. Replace outer layer of steel shielding with a marble shell. Its optimal thickness is about 5 inches: there is negligible activation and it provides 1/10 attenuation for 1-MeV photons leaking from the hot steel core. Two cases considered here: (1) outer 10 cm of iron replaced with marble ($\pm$45 cm iron + 10 cm marble); (2) iron reduced laterally by 15 cm on each side followed by 1 cm marble ($\pm$30 cm iron + 10 cm marble).

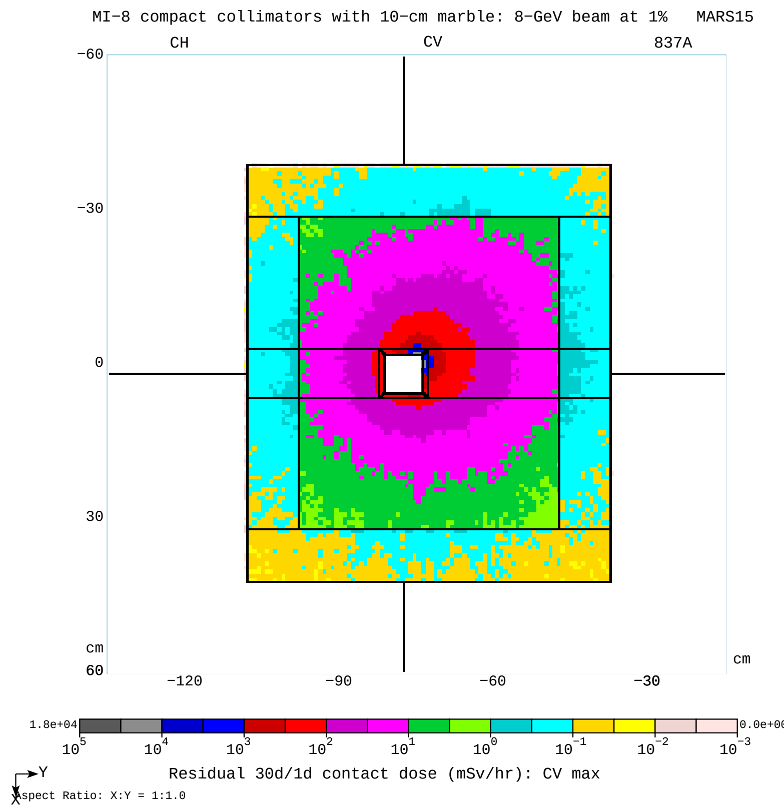
IRON-MARBLE COMBINATION IN MI-8 COLLIMATORS





DRASTIC IMPROVEMENT IN SHIELDING PERFORMANCE

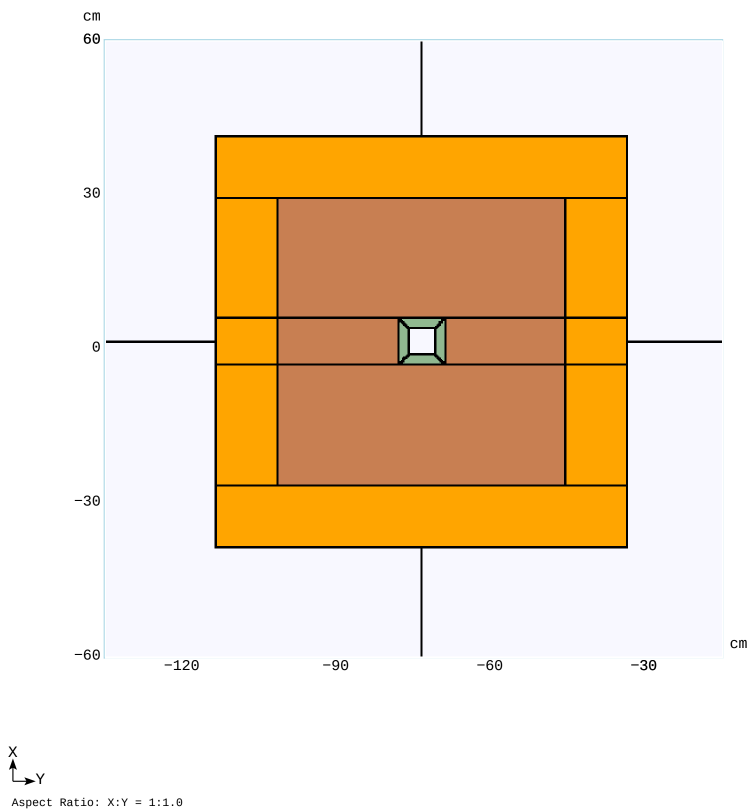


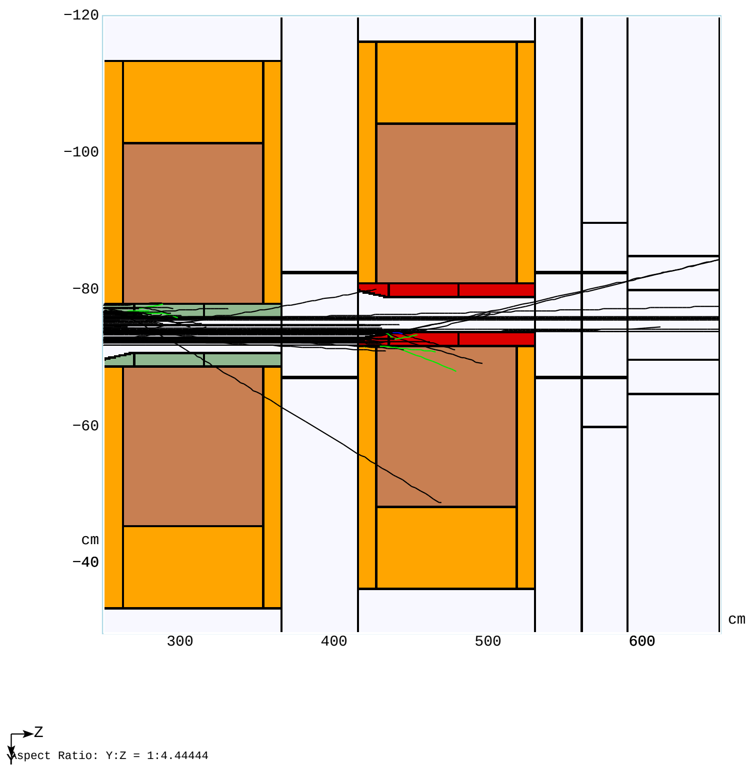


PROPOSED IRON-MARBLE COLLIMATORS (1)

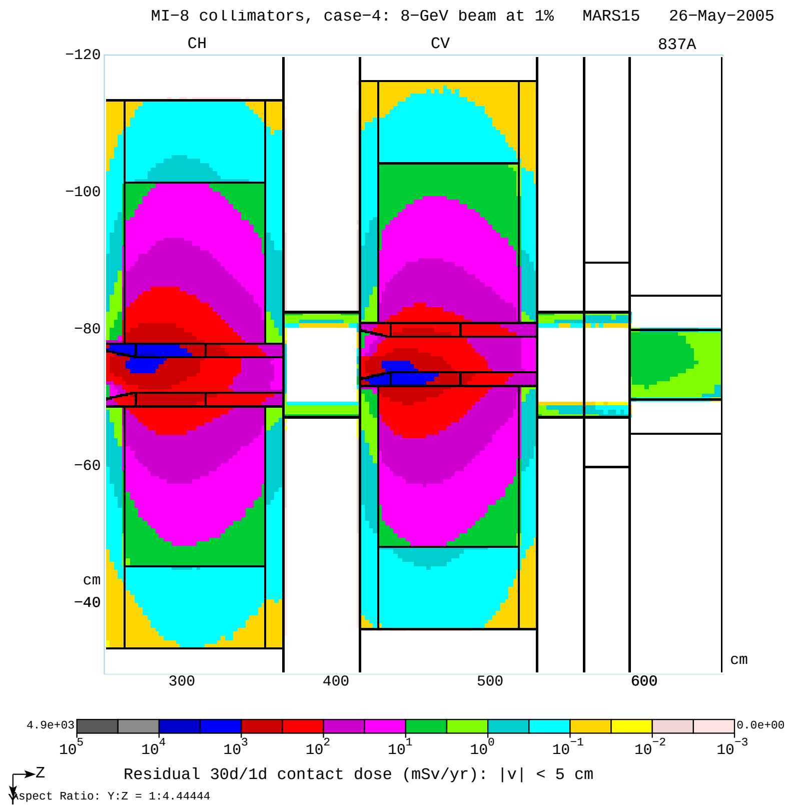
- To better protect downstream magnets reduce collimator aperture from Booster's 3×3 inches to 2×2 inches.
- Do X-Y scraping on both CH and CV: cut beam at 3.03σ horizontally and vertically by, e.g., bottom-left corner of the first collimator, and top-right corner of the second collimator.
- Increase stainless steel jaw thickness from 1 cm to 2 cm and length from 40 to 45 inches (including a 8-inch taper at the upstream ends).
- Make shielding symmetric.
- Shielding longitudinally: 5-inch marble + 35-inch iron + 5-inch marble.
- Shielding laterally (on each side): 10-inch iron + 5-inch marble.

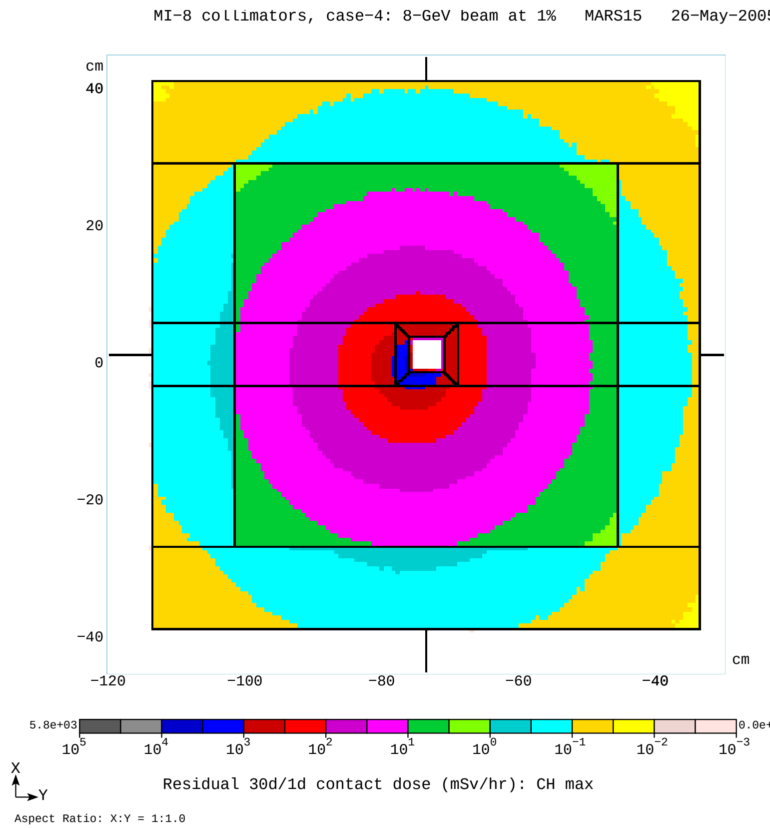
PROPOSED IRON-MARBLE COLLIMATORS (2)





RESIDUAL DOSE IN IRON-MARBLE COLLIMATORS





ABSORBED DOSE AT PEAK AND SPECTRA AT 837A MAGNET

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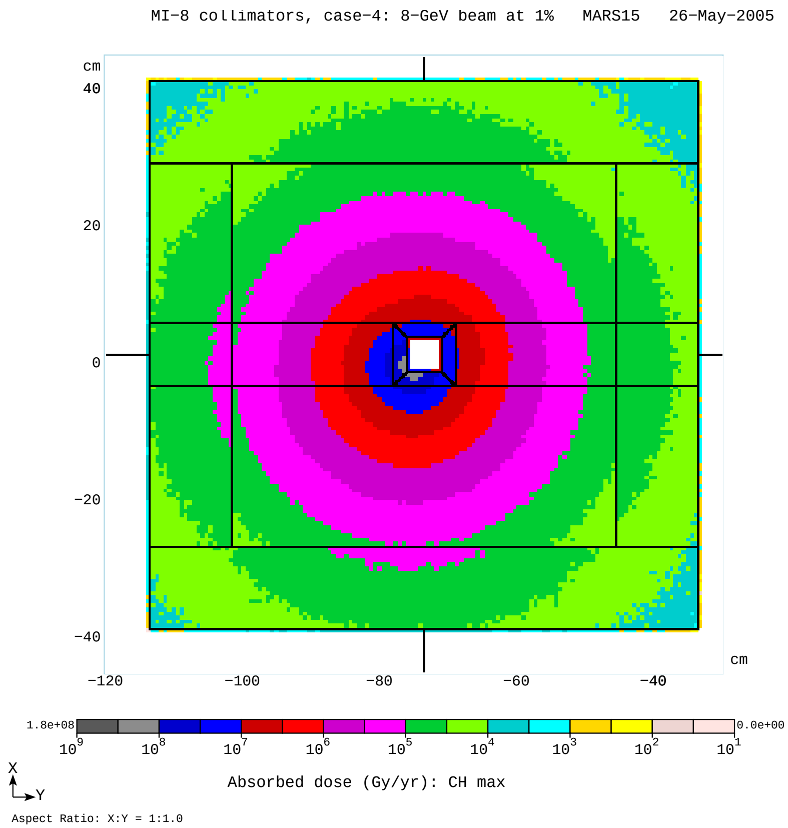
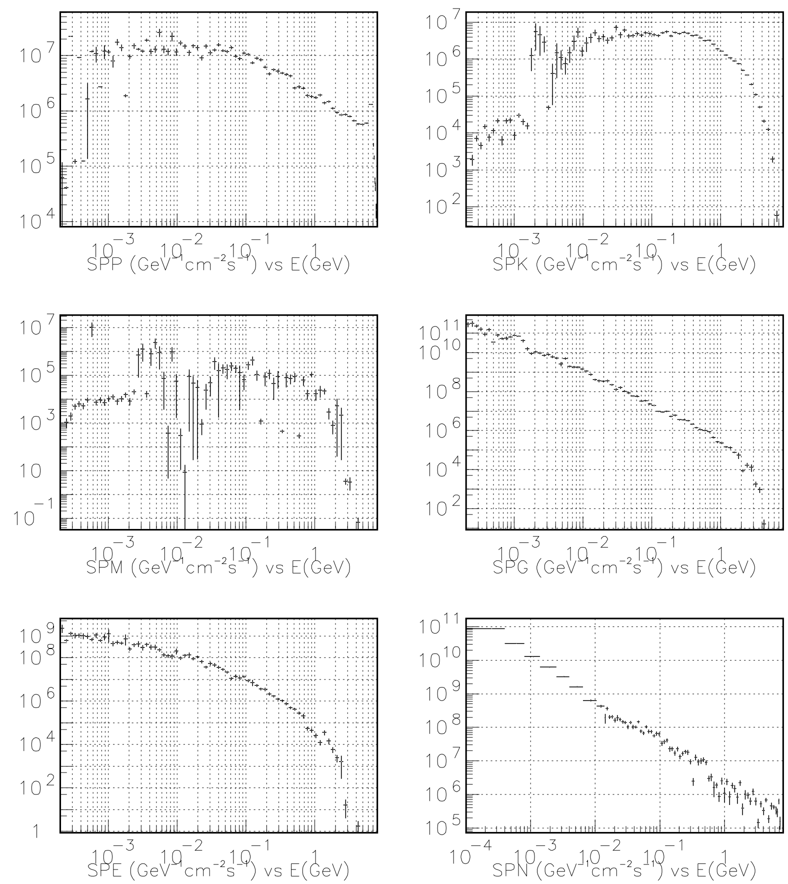
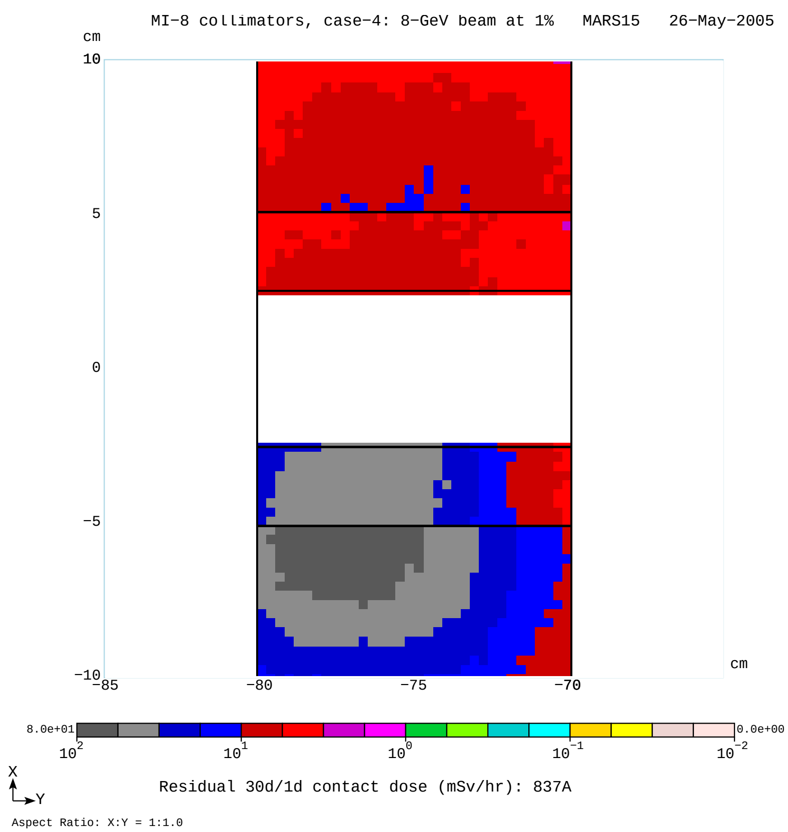
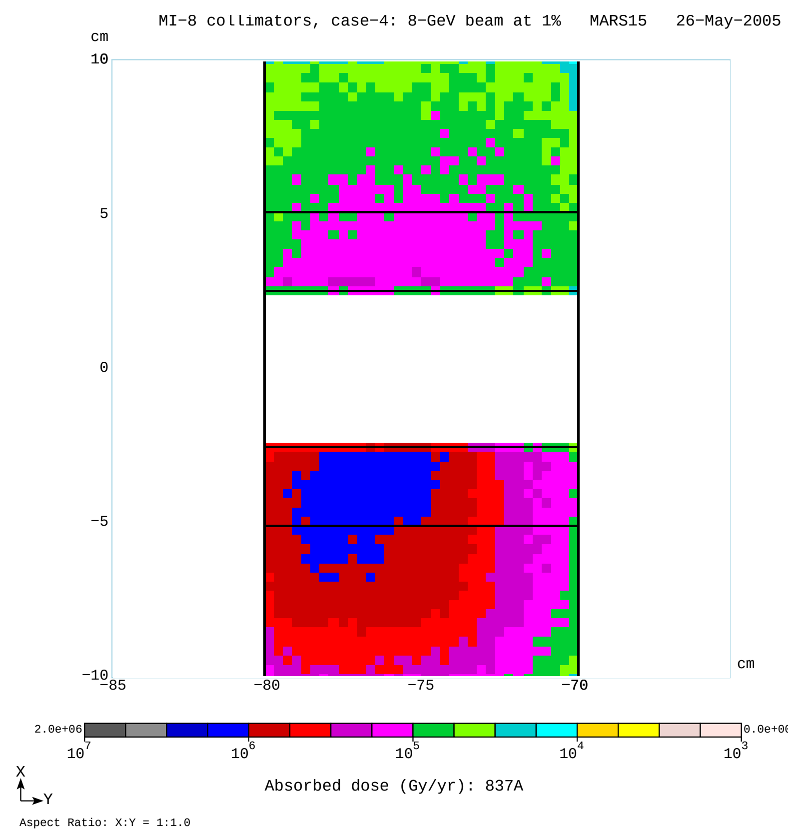




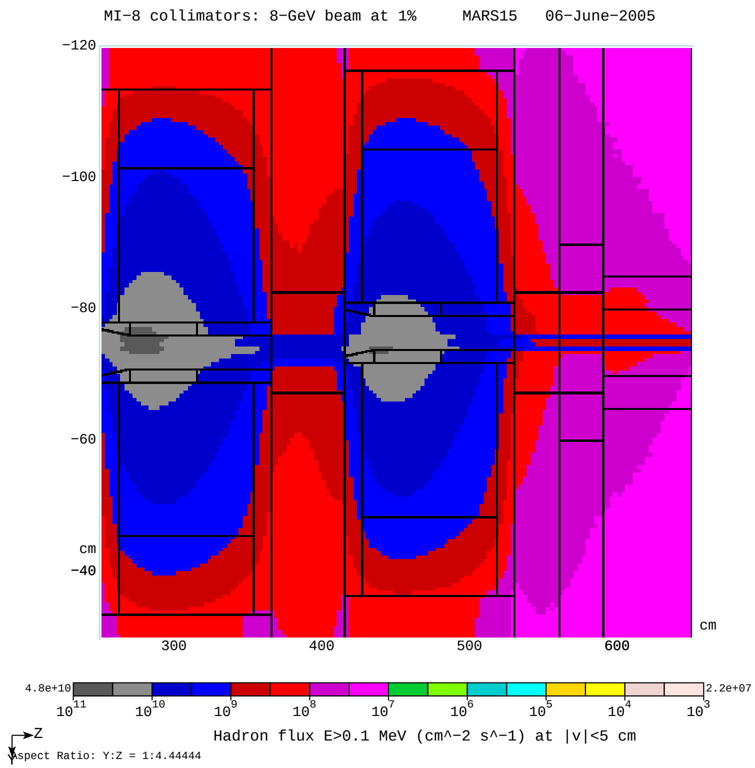
RADIATION LOADS TO 837A MAGNET

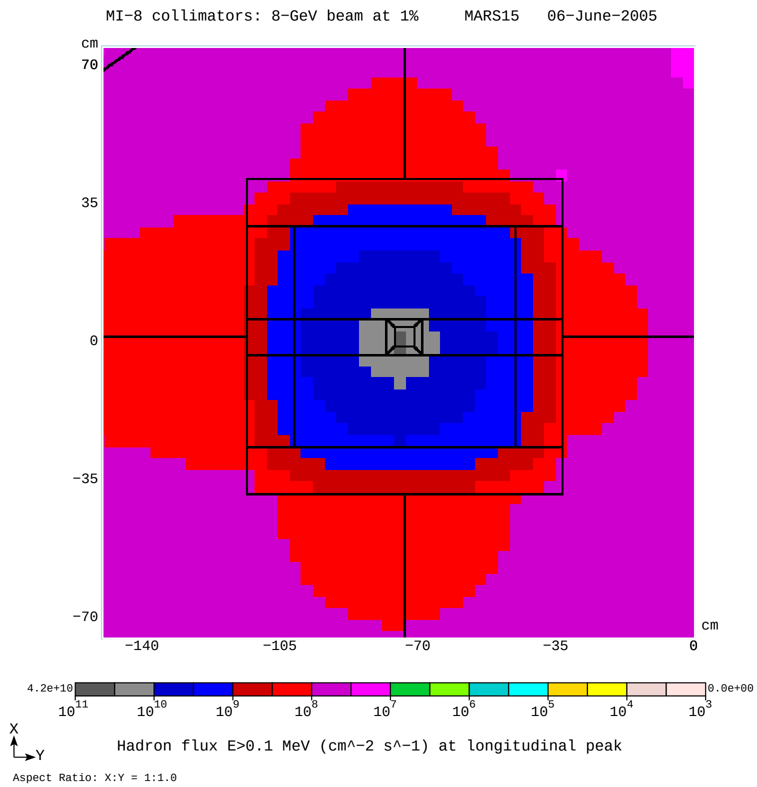




Put a 1-foot mask immediately upstream of 837A magnet!

HADRON FLUX FOR AIR ACTIVATION ANALYSIS





CONCLUSIONS

The collimation system developed for the Fermilab MI-8 beamline will localize majority of beam loss in a predetermined 836B-837A region followed – if necessary – by a second pair of collimators downstream.

The collimator/shielding units developed for a scraping rate of 1% (averaged over months of operation) and optimized via detailed MARS simulations, will provide adequate collimation, shielding and maintenance functionalities, assuring that prompt and residual radiation levels inside the tunnel, in groundwater and above dirt shielding are below the regulatory limits with a reasonable safety margin.

Distribution of hadron fluxes calculated in the collimation region can be used as a source for air activation analysis.