Uniform Irradiation of a Target Using a High-Power Beam*

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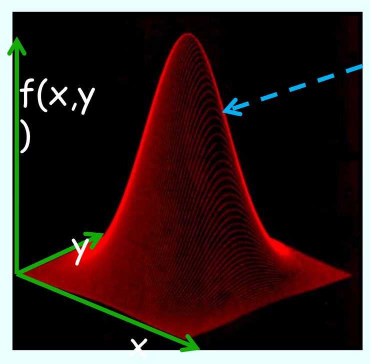
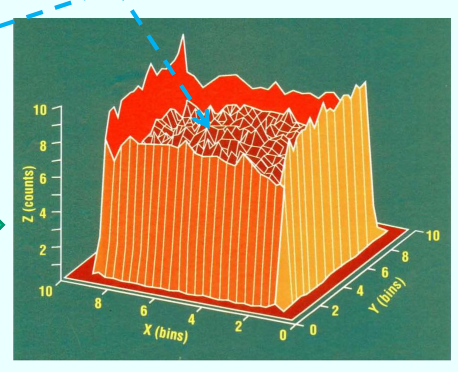
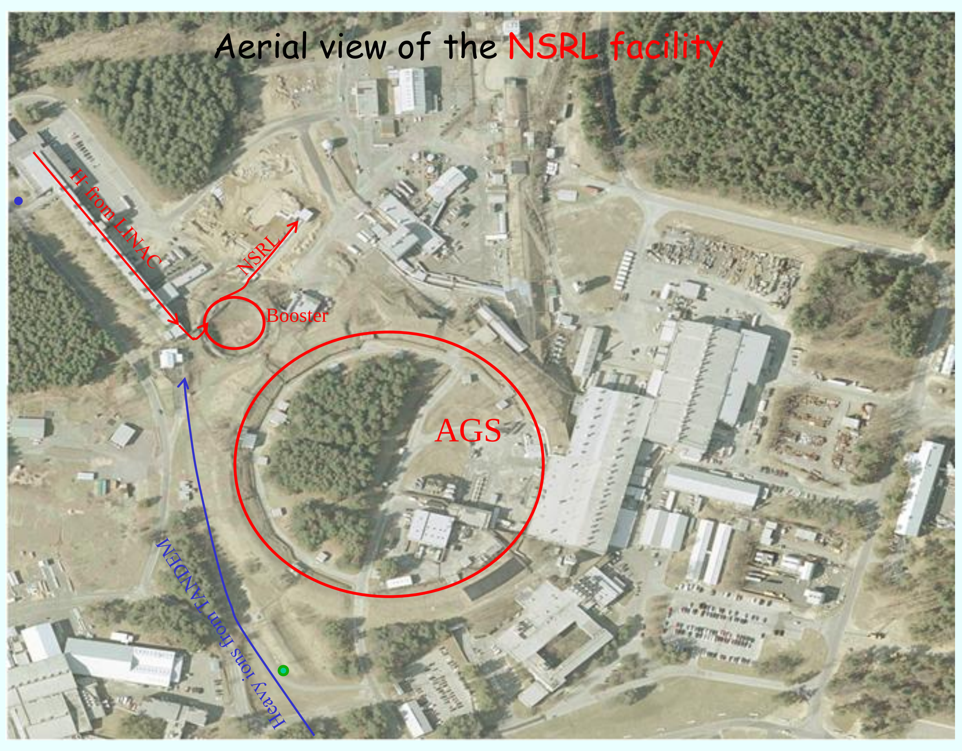
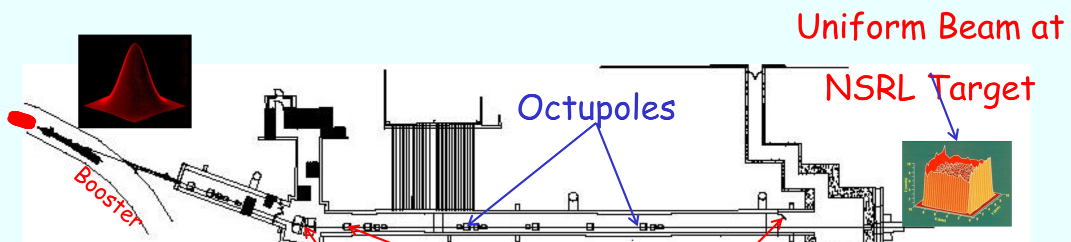
Abstract *The Accelerator Driven Systems (ADS) require high power beam (>10 MW) to irradiate the neutron production target. To mitigate the effect of the high power, and high intensity beam on the target we propose to reduce the intensity of the beam by uniformly irradiating the target. In this poster we present a well proven method which is being used at the NASA Space Radiation Laboratory (NSRL) facility at BNL for uniform irradiation of material and biological samples.*

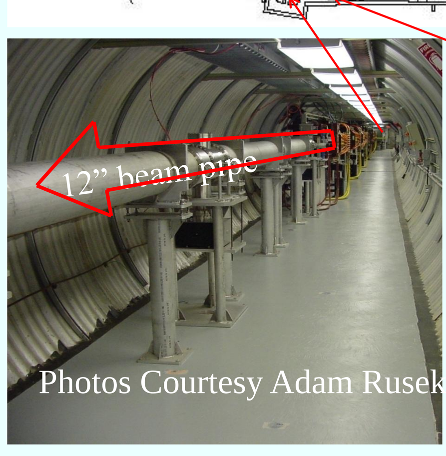
- Present a method to transform a beam with a Gaussian distribution into beam with a Uniform distribution.

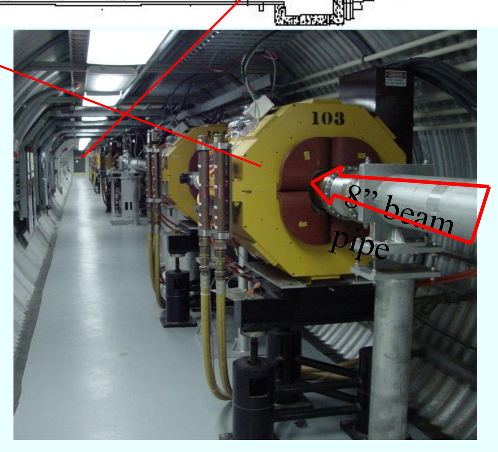




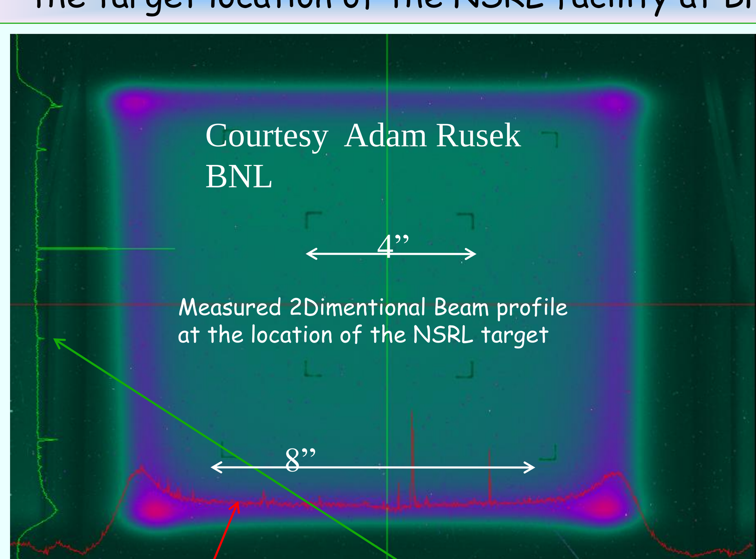




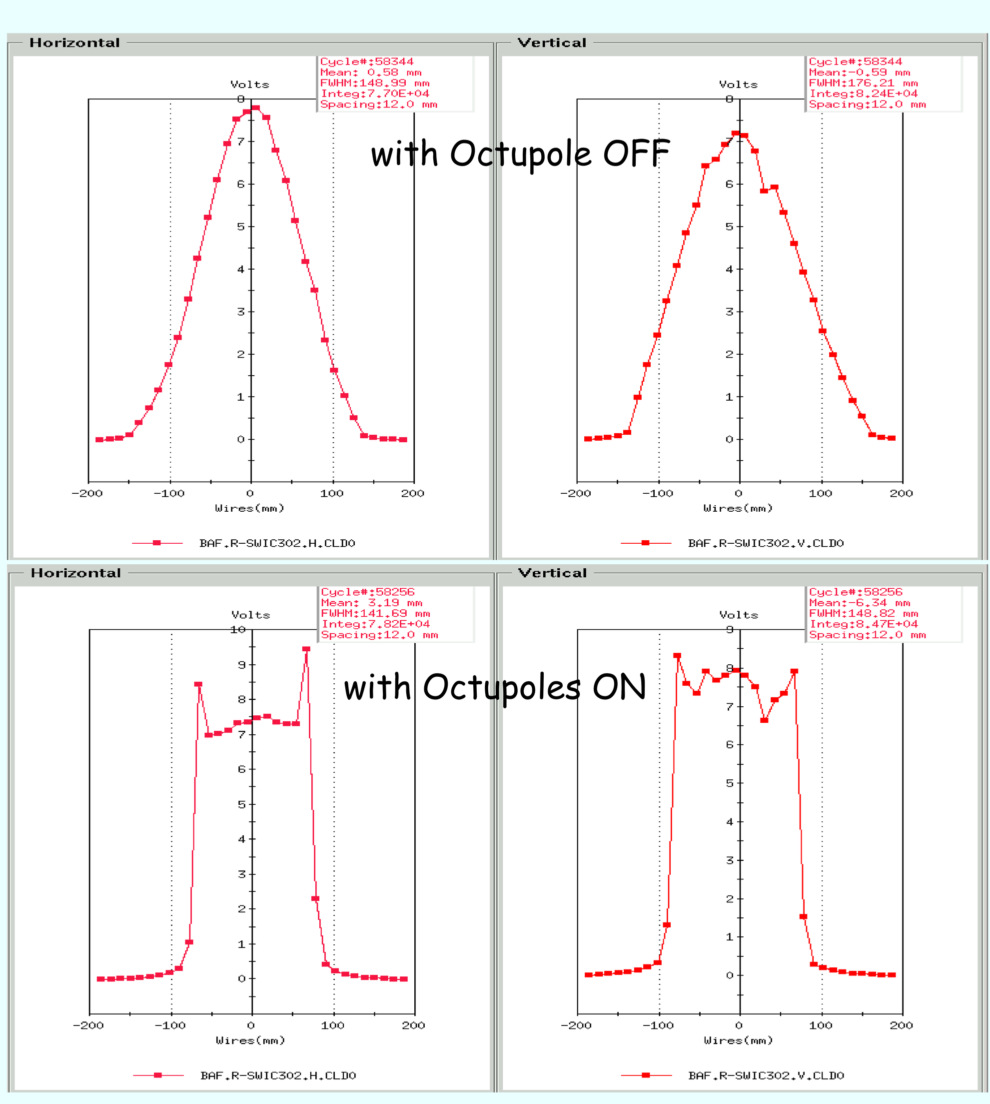




Experimental Results of Uniform beam Distributions at the target location of the NSRL facility at BNL



Measured beam profiles: Vertical (Green line) and Horizontal (Red Line) at the location of the NSRL target



Measured

Horizontal and Vertical Beam Profiles at the location of the NSRL target

NSRL Facility at BNL

Mathematical consideration of the method

A charge distribution in 6D can be expressed in terms of a 6-D σ-matrix

$$f(x, x', y, y', \delta l, \delta p) = \frac{1}{(2\pi)^{\frac{6}{2}} \sqrt{\det(\sigma)}} e^{-\frac{1}{2}(\tilde{X}\sigma^{-1}X)}$$

$$\tilde{X} = \{x \quad x' \quad y \quad y' \quad \delta l \quad \delta p\}$$

$$\sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} & \sigma_{14} & \sigma_{15} & \sigma_{16} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} & \sigma_{24} & \sigma_{25} & \sigma_{26} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} & \sigma_{34} & \sigma_{35} & \sigma_{36} \\ \sigma_{41} & \sigma_{42} & \sigma_{43} & \sigma_{44} & \sigma_{45} & \sigma_{46} \\ \sigma_{51} & \sigma_{52} & \sigma_{53} & \sigma_{54} & \sigma_{55} & \sigma_{56} \\ \sigma_{61} & \sigma_{62} & \sigma_{63} & \sigma_{64} & \sigma_{65} & \sigma_{66} \end{pmatrix} \qquad \sigma_{ij} = \sigma_{ji}$$

$$X^{(Out)} = RX^{(In)} \qquad X = \begin{pmatrix} x \\ x' \\ y \\ y' \\ \delta l \\ \delta p \end{pmatrix}$$

$$\sigma_{out} = R\,\sigma_{in}\,R^T$$

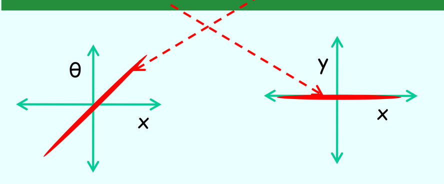
Under Linear Transformation R the beam distribution remains Gaussian

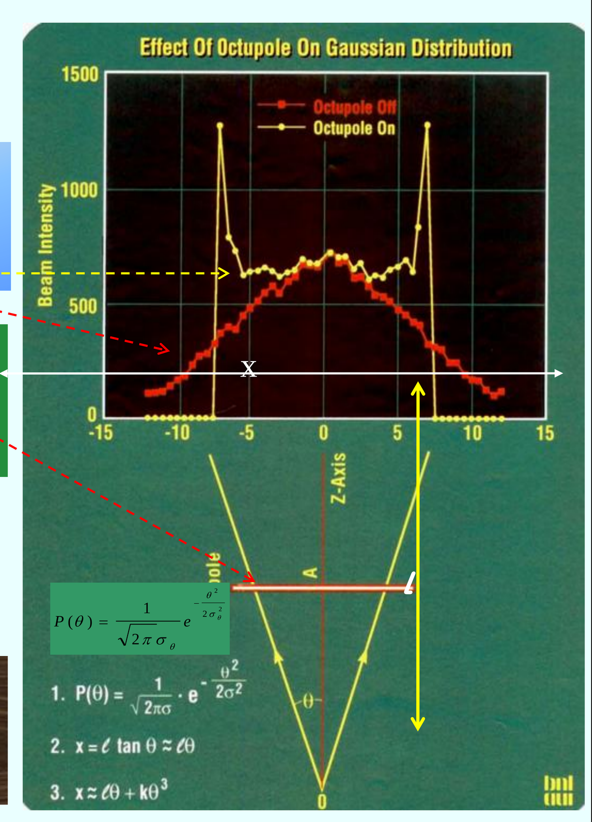
To modify the beam distribution we must use non-linear magnetic elements

Effect of an octupole on a Gaussian beam

An octupole can alter the distribution of a one dimensional Gaussian beam to a beam with more Uniform distribution.

Important constraints:
a) At the location of the Octupole there is perfect (x,θ) correlation.
b) Beam is "flat"





Can this simple example be modified and applied to a six dimensional realistic beam which has non-zero emittance?

The equations of motion of a charged particle moving in a quadrupole and octupole field

The x-component

$$(x'' - x'^2 x'' - x'y'y'') = -K_1(s)x - K_3(s)\left(\frac{x^3}{3!} - \frac{xy^2}{2!}\right) + \left(\frac{\partial K_1(s)}{\partial s}\right)xy\,y' + \left[\left(\frac{\partial^2 K_1(s)}{\partial s^2}\right)\frac{xy^2}{2!}\right]$$

Even if we drop the terms of the fringe field....

The y-component

$$y'' - x'y'x'' - y'y'y'' = K_1(s)y + \frac{1}{2}K_1(s)(yx'^2 + yy'^2) + K_3(s)\left(\frac{x^2 y}{2} - \frac{y^3}{3!}\right) + \left(\frac{\partial^2 K_1(s)}{\partial s^2}\right)\frac{y^3}{3!} - \left(\frac{\partial K_1(s)}{\partial s}\right)xy\,x'$$

Even if we drop the terms of the fringe field....

The s-component

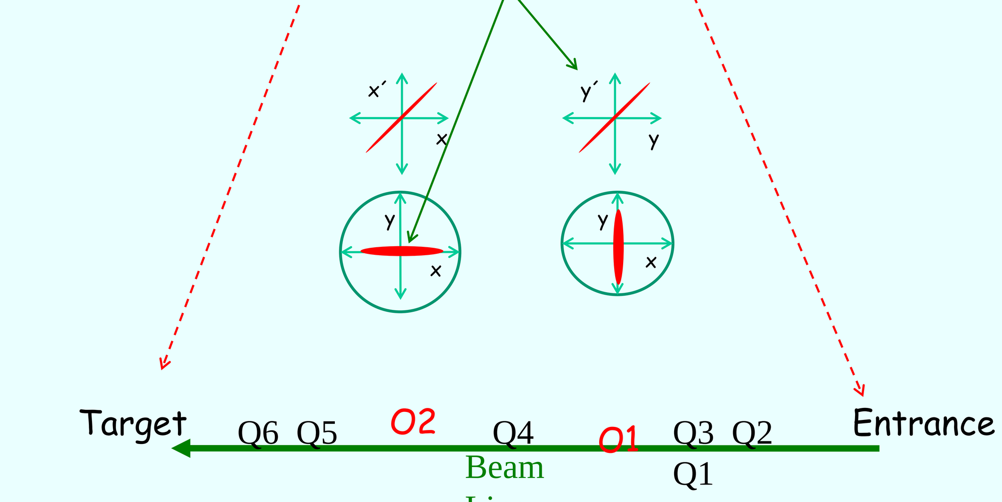
$$[x'x'' + y'y''] = K_1(s)(y'y - x'x)$$

Procedure to Generate uniform beam distribution at target.
1st Order Optics

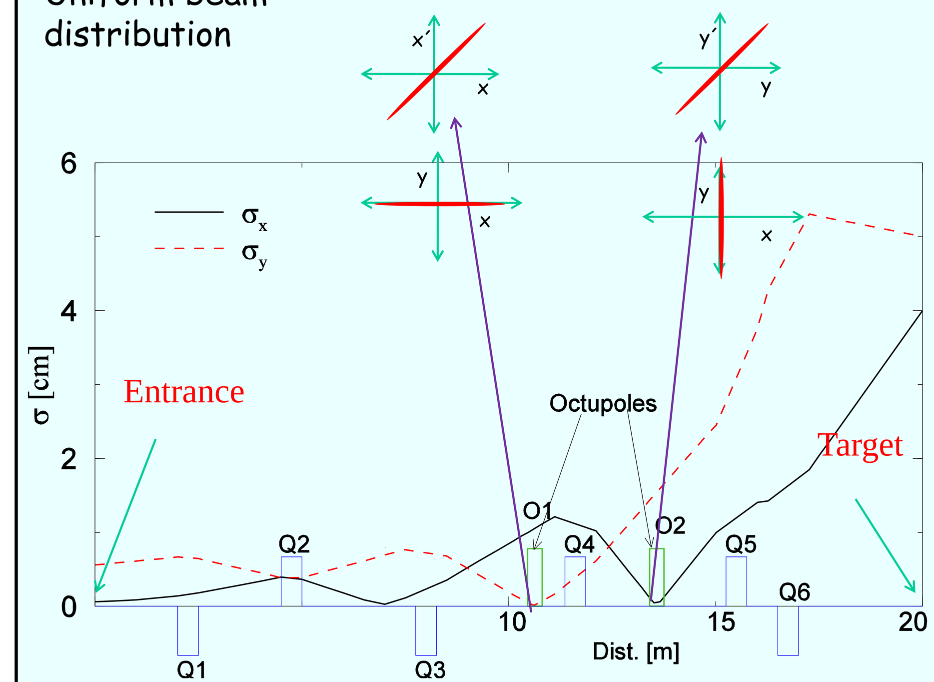
Beam distribution at the entrance of beam line is assumed to be Gaussian

First Order Optics:

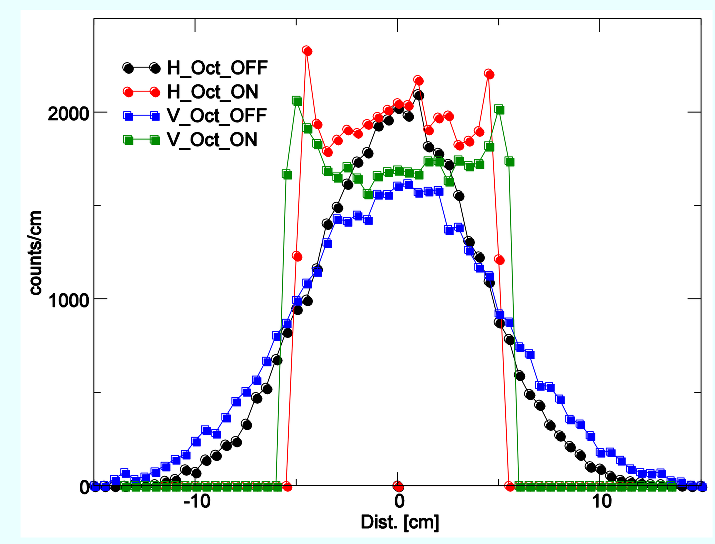
- Should satisfy the required beam constraints at the location of the Octupoles.
  - High correlation in (x,x') and "flat beam" in y-direction at the location of one Octupole
  - High correlation in (y,y') and "flat beam" in x-direction at the location of other Octupole
- Beam size at the target should be adjusted by the first order optics.



1st Order Beam Optics of an "Example Beam Line" to create Uniform beam distribution

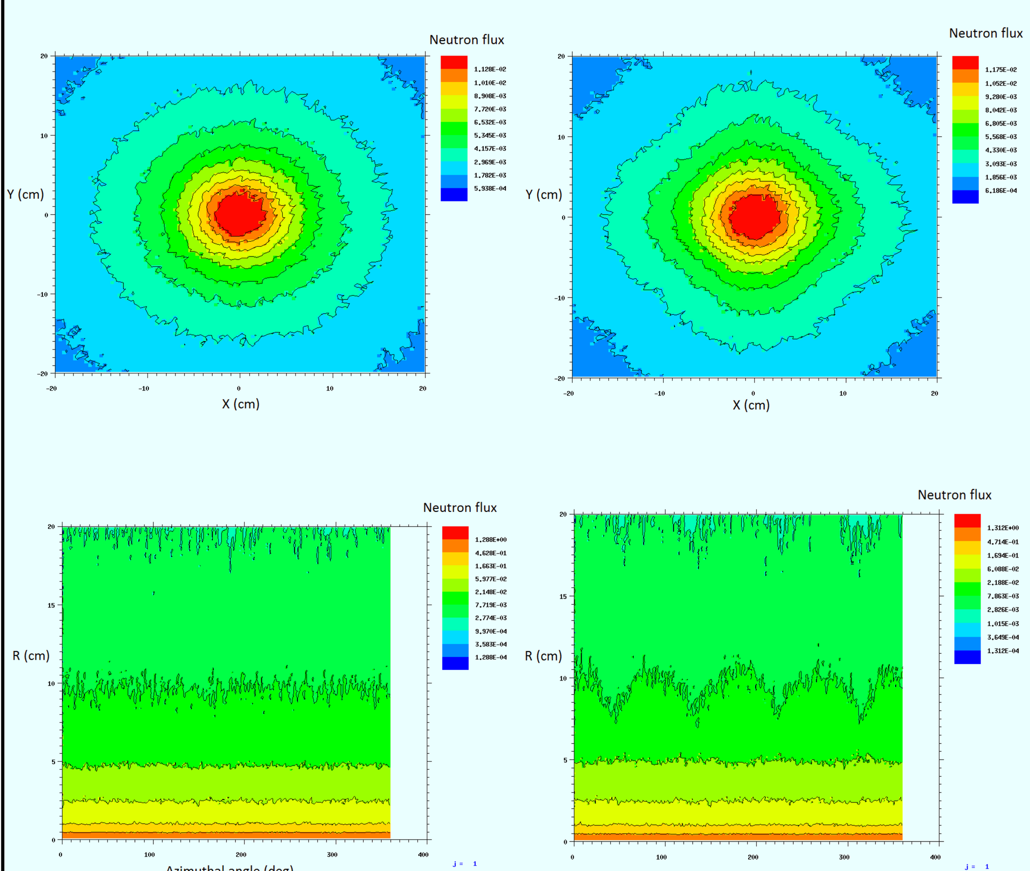


Horizontal (Black/Red circles) and Vertical (Blue/Green squares) Beam Profiles with Octupoles OFF(Black/Blue) and Octupoles ON (Red/Green) for the "Example Beam Line"



- Neutron flux distribution from a spallation target : comparison rectangular vs cylindrical target.

MCNP6 simulations of neutron flux distribution from a spalltion target.



The target on the left/right side of the picture is a circular/rectangular cylinder of lead which is 10 cm in diameter/side by 30 cm long. The beam has a 2 σ = 0.85 cm diameter spot size. (Gaussian beam)

Modifying the shape of the target does change the neutron flux distribution at the corners of the rectangular target. The same results were obtained with a uniform rectangular beam.

It seems that from the point of view of neutronics , a cylindrical target is preferrable to a rectangular one in order to ensure the symmetry of the neutron flux escaping to the blanket.

CONCLUSION

Non-linear elements are necessary to change the Gaussian beam distribution to a non-Gaussian one.

The experiment at NSRL proved that introducing two octupoles at specific locations of the beamline can transform a beam with a Gaussian distribution into a uniform one.. The beam size at the target should be adjusted by the first order optics.

This proves to be a major improvement to the target design since it will reduce the intensity of the beam and so increase the lifetime of the target.

Further studies could be pursued to determine whether the same method can be applied to generate a uniform circular beam.

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