Spectrometers 101

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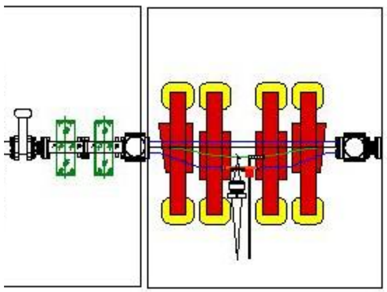
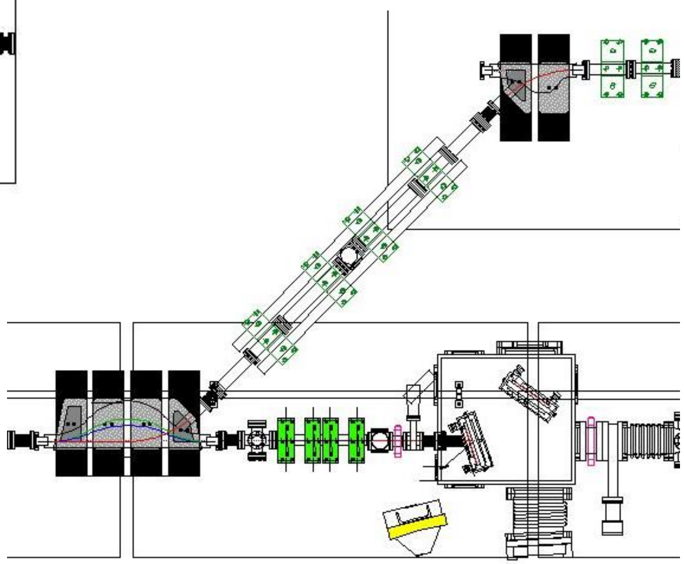
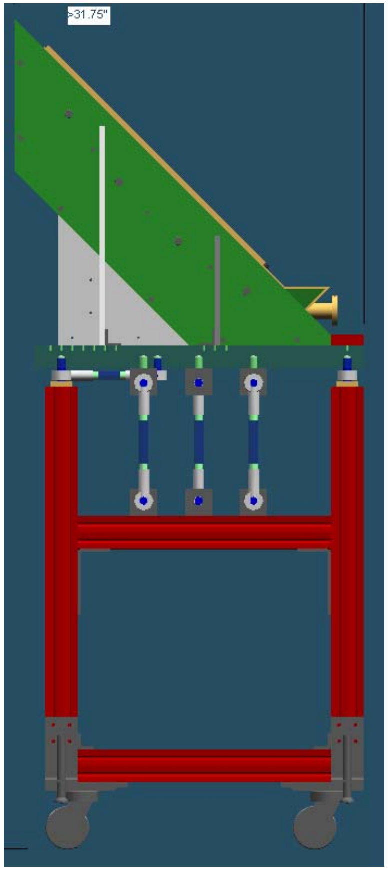
PBPL Group Talk

March 7, 2003

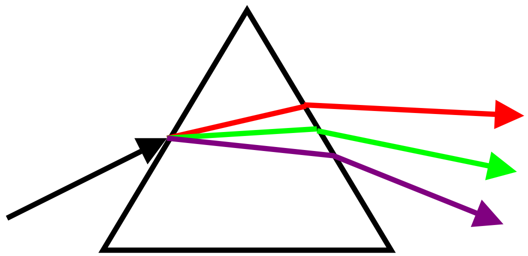




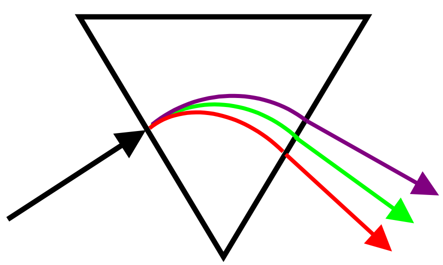


What is a Spectrometer?

A Spectrometer is a device that separates the components of a beam according to their energy. The function of spectrometers is the same for both photons and charged particles. The physics, however, is a little different.



$$n_\lambda = A + \frac{B}{\lambda^2} + \dots$$



$$R[m] = \frac{E[MeV]}{299.8B[T]}$$

What do we need spectrometers for?

Energy Measurement

Spectrometers are ubiquitous instruments that allow us to measure beam energy and energy spread.

This is critical for producing useful beams and for proving that our advanced accelerators actually work.

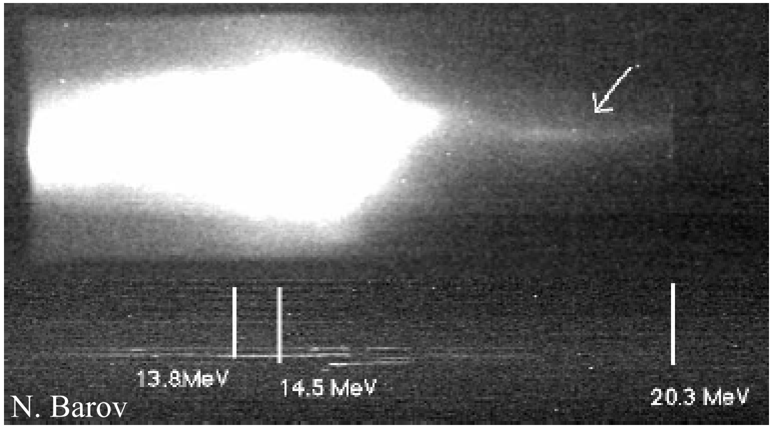


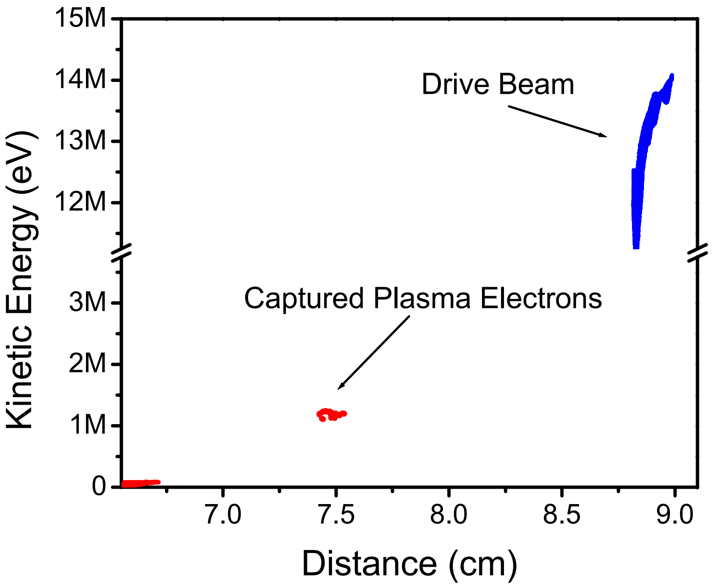
Figure 3. Spectrometer image with plasma on. The accelerated electrons are the whisker-like feature near the arrow.

Advanced Uses

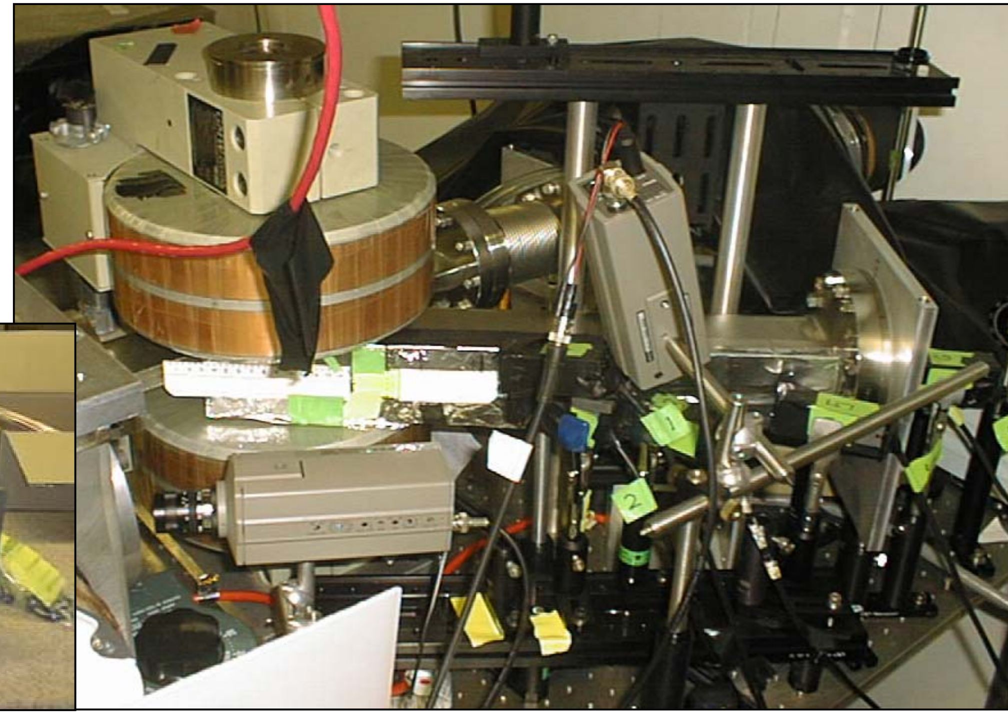
If beam energy can be correlated to other quantities, spectrometers can measure much more than just energy.

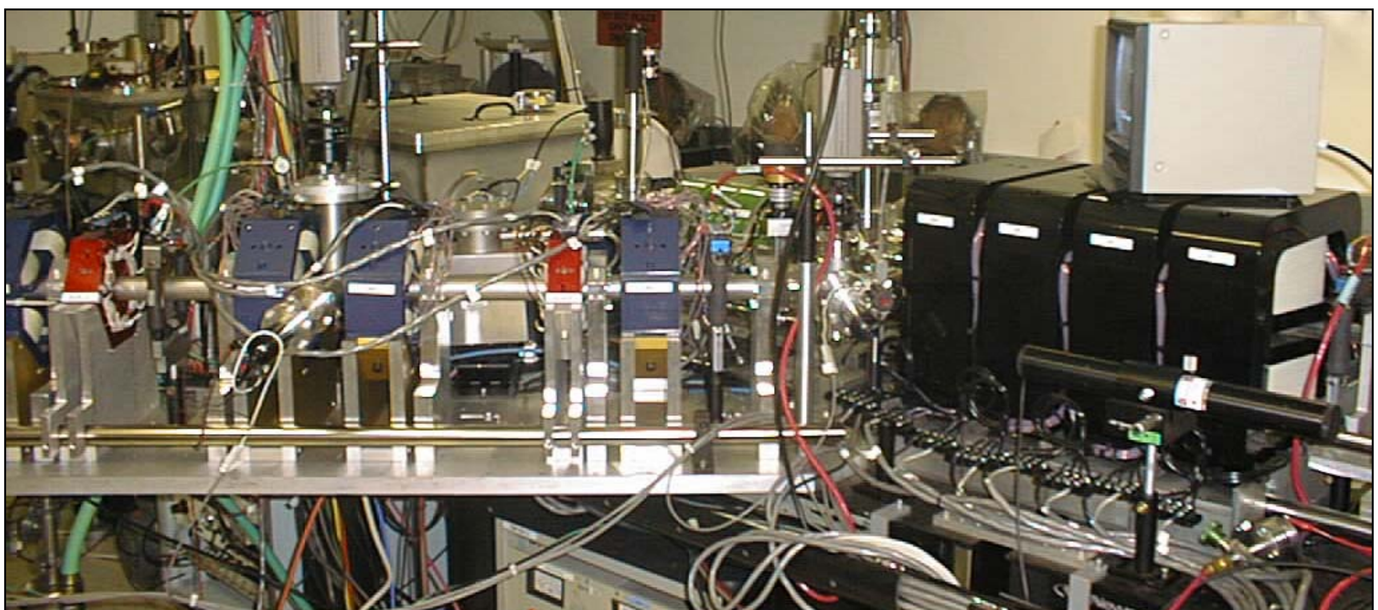
The Transition Trapping experiment will use energy to discriminate between the drive beam and captured beam

Deflecting cavities correlate energy with longitudinal position, allowing spectrometers to measure a beams temporal structure.



Spectrometers in Real Life

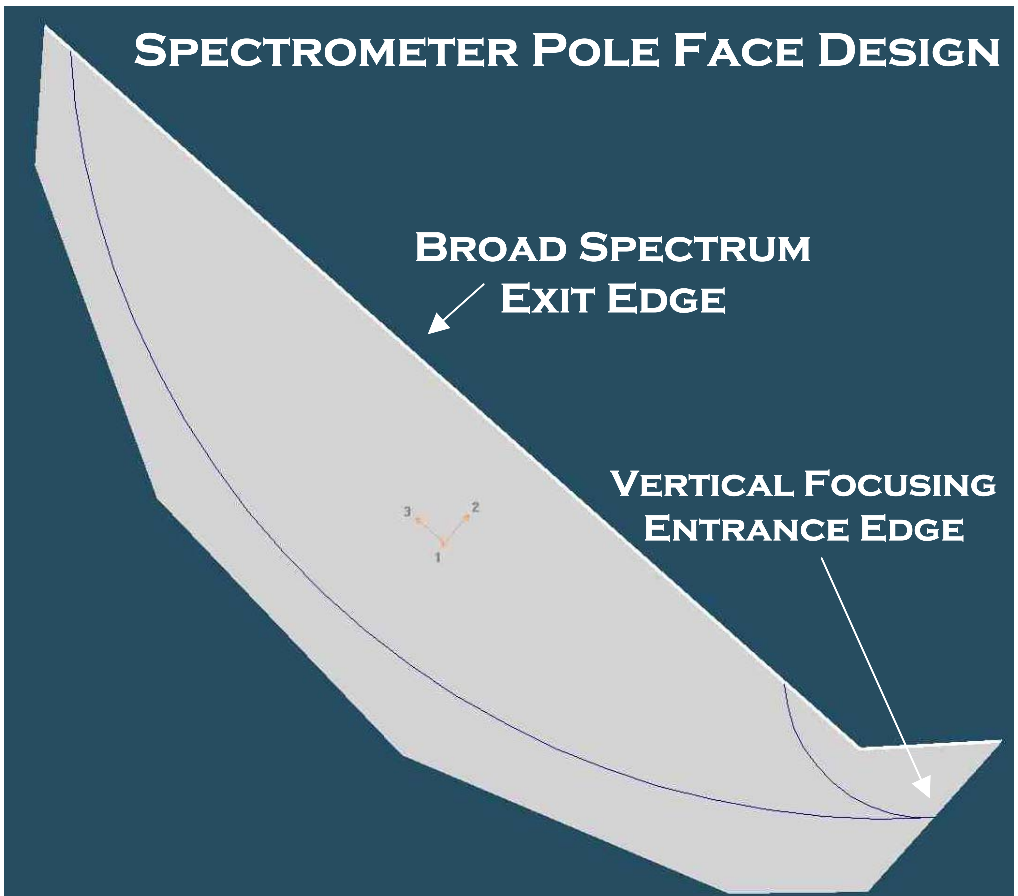




Spectrometer Design Factors:

Energy Range | Magnetics | Optics

Energy Resolution | Mechanics | Particle Detection



$$R[m] = \frac{E[MeV]}{299.8B[T]}$$

General Design Parameters:

Gap: 2 cm

Max Field: 1600 Gauss

Radii of Curvature: 10cm - 58cm

Energy Range of Spectrometer at Field =

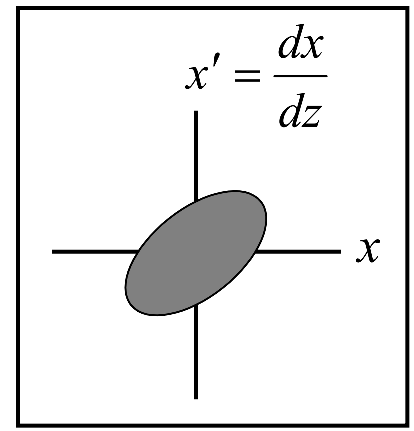
1550 Gauss: 4.7 – 27 MeV

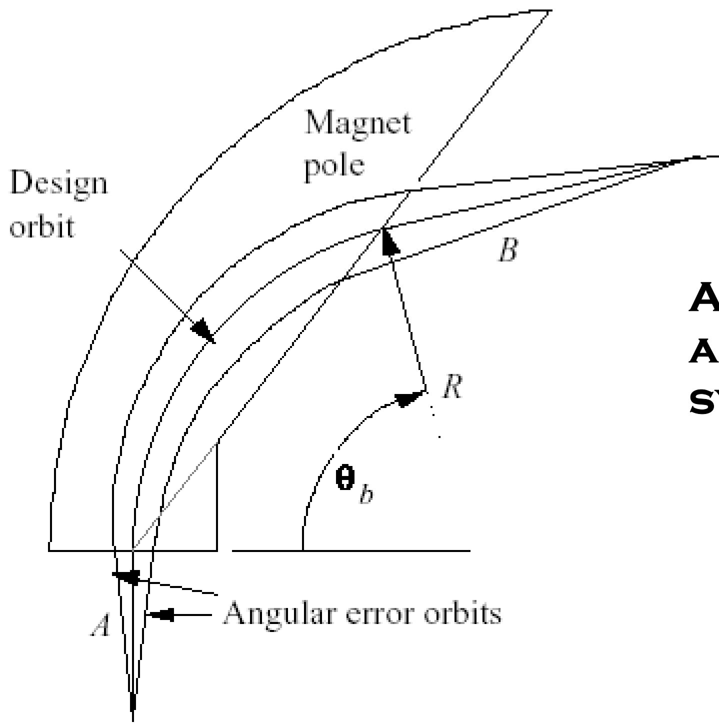
180 Gauss: 740 KeV – 3.17 MeV

Sorting momentum effects from optical ones

All real beams have a finite emittance or phase space area and therefore (in the absence of focusing) grow in size as they propagate.

Consequently, we want the observation point of the spectrometer to be an optical focus, so that the dispersion of the beam is due solely to momentum.



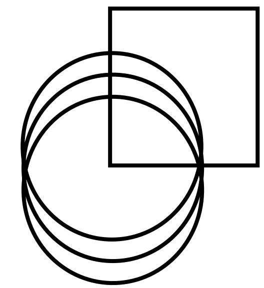


Achieving this will require a little linear algebra. The focusing properties of a system can be represented by a matrix:

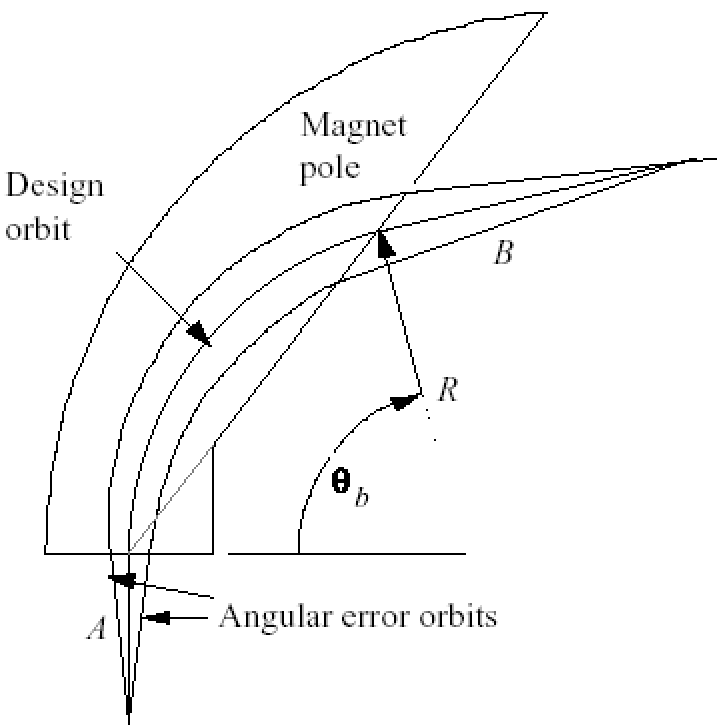
$$\begin{pmatrix} x_{final} \\ x'_{final} \end{pmatrix} = M_{Transport} \begin{pmatrix} x \\ x' \end{pmatrix}$$

For a Typical Spectrometer:

$$M_x = \underbrace{\begin{pmatrix} 1 & B \\ 0 & 1 \end{pmatrix}}_{\text{Drift 2}} \underbrace{\begin{pmatrix} 1 & 0 \\ -\dfrac{\tan\theta_E}{R} & 1 \end{pmatrix}}_{\text{Edge 2}} \underbrace{\begin{pmatrix} \cos\theta_B & R\sin\theta_B \\ -\dfrac{\sin\theta_B}{R} & \cos\theta_B \end{pmatrix}}_{\text{Bend}} \underbrace{\begin{pmatrix} 1 & 0 \\ \dfrac{\tan\theta_E}{R} & 1 \end{pmatrix}}_{\text{Edge 1}} \underbrace{\begin{pmatrix} 1 & A \\ 0 & 1 \end{pmatrix}}_{\text{Drift 1}}$$



Why bends focus



For the New Plasma Experiment Spectrometer we Choose:

$$\theta_B = \frac{\pi}{2} \qquad \theta_E = \frac{\pi}{4}$$

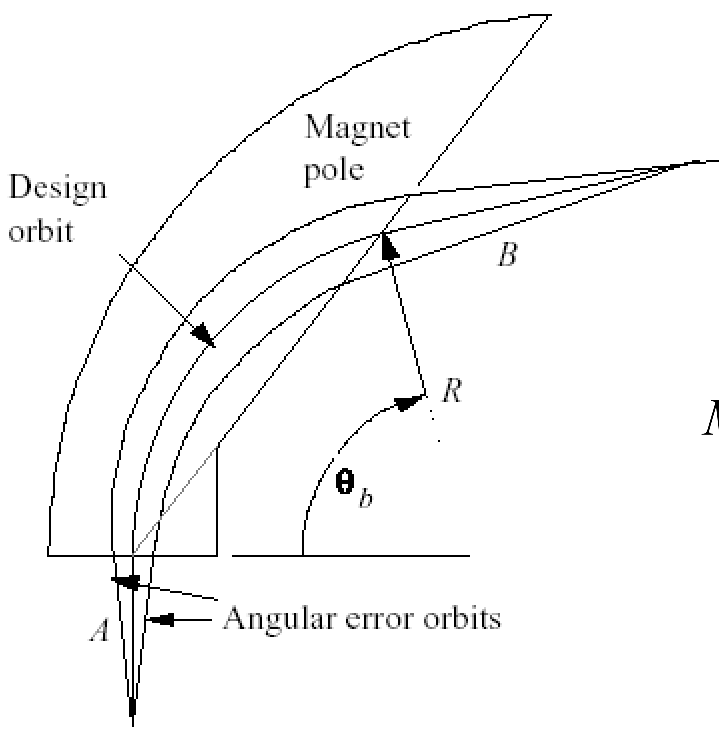
$$M_x = \begin{pmatrix} 1 - \dfrac{2B}{R} & A - B - \dfrac{2AB}{R} + R \\ -\dfrac{2}{R} & -\left(1 + \dfrac{2A}{R}\right) \end{pmatrix}$$

The Point-to-Point Condition:

Satisfying the point-to-point condition insures that angular spread of the beam will not impact the beam size at the spectrometer observation point. Mathematically this takes the form:

$$\begin{pmatrix} x_{final} \\ x'_{final} \end{pmatrix} = M_x \begin{pmatrix} x \\ x' \end{pmatrix} \longrightarrow x_{final} = M_{x11}x + M_{x12}x'$$

$$M_{x12} = 0$$



To Satisfy this our spectrometer must obey the relation:

$$M_{x12} = A - B - \frac{2AB}{R} + R = 0 \Rightarrow B = R\left(\frac{A+R}{2A+R}\right)$$

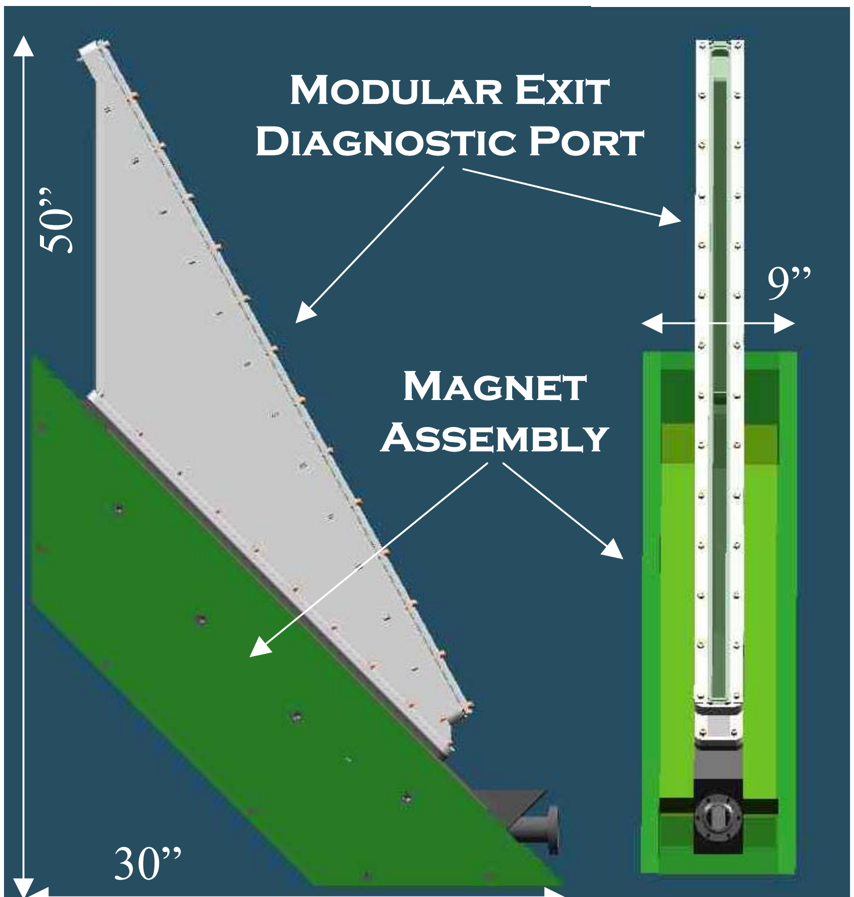
With

$$10cm < R < 58cm \qquad A = 30cm$$

PARTICLE DETECTION

WITH HIGH ENERGY BEAMS WE CAN JUST PUT A FOIL AT THE EXIT EDGE OF THE SPECTROMETER AND PLACE A PHOSPHOR OR OTHER DETECTOR WHERE EVER THE POINT-TO-POINT CONDITION DICTATES.

LOW ENERGY BEAMS, HOWEVER, WILL NOT MAKE IT THOUGH FOILS AND THE ATMOSPHERE SO DETECTION MUST BE DONE IN VACUUM.



PLEASE NOTE THAT THE EQUATION DESCRIBING THE POINT-TO-POINT CONDITION,

$$B = R\left(\frac{A+R}{2A+R}\right)$$

IS NOT LINEAR. MAKING A VACUUM VESSEL WITH THIS FIGURE IS NEXT TO IMPOSSIBLE, SO, LIKE ALL GOOD PHYSICISTS, WE LINEARIZE:

$$B \approx \frac{7}{9}R - \frac{10}{3}$$

Is Linearizing Good Enough?

To find out I computed the size of the expected beams at the spectrometer observation point due to both the momentum dispersion and the optical error and compared the two.

	σ_x	$\sigma_{x'}$	E_{ave}	ΔE_{rms}
Drive Head	759μm	−0.002	14 MeV	0.75%
Drive Middle	702μm	0.012	13 MeV	3.4%
Drive Tail	2 mm	0.025	12.5 MeV	2.3%
Trapped Beam Core	596μm	0.028	1.22 MeV	4.6%

The max error is less than 1% so this design should work, but will it hold vacuum . . .