


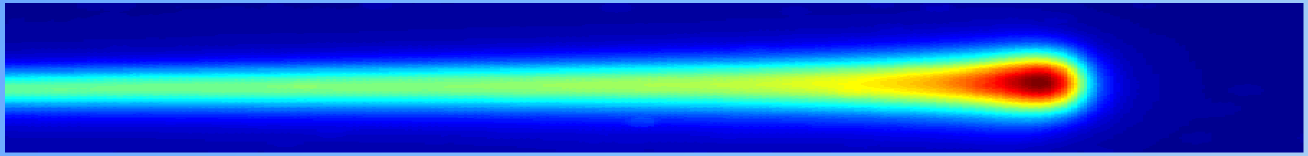

Gantry Optics & Some 'Challenges'

Gantry Workshop II

September 17, 2015

Thanks to those who provided information used in this presentation

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Harvard Medical School

Dependencies *(what creates the Gantry requirements ?)*

- Prescription/Treatment plan constraints
  - Healthy tissue vs. Target Dose Distribution – size and position
- Beam Delivery
  - Modality (Scanning; Scattering; Type of each) – size and position
  - Overall Tx time & Organ motion - Time
- Accelerator Beam Parameters
  - Raw Parameters (emitance value; equal or unequal; …)
  - Beam Shaping if necessary
  - Degrader
- Treatment planning ‘constraints’ (*limitations*)
  - Gantry angle dependence (on beam size)
  - Beam phase space representation
  - Beam symmetry
- Space & Cost

Beam Factors that (may) Contribute to Optics (1)

- Spatial Beam Dependence
  - Beam size/shape:
    - Is 'desired' to be independent of Gantry angle (due to treatment planning *limitations)*
    - Consistent with beam spreading modality & Treatment Rx
      - e.g. Provide of required edge "sharpness"
  - Beam position:
    - Consistent with spreading modality tolerances
    - Gantry angle 'dependence' (~≠ Mechanical Isocentricity)
    - Beam steering correction vs. dead reckoning (e.g. self correcting)
- Angular Beam Dependence
  - Account for skin to target dose difference (SAD)
  - Provide for Matching capability if field size is insufficient
  - Provide divergence consistent with positioning tolerances
    - Same conditions at distal end of target as at proximal end

Beam Factors that (may) Contribute to Optics (2)

- Energy Dependence
  - Range in patient should not depend upon position in patient
  - Spread of ranges should be consistent with spreading modality
    - "Stacking" of Bragg peaks
  - Ability to change range in a time frame consistent with 'reasonable' treatment time
    - Patient comfort
      - Overall Tx time
    - Target Motion
      - Repainting
- Accelerator Beam "Shaping" may be needed
  - e.g. ESS Capability
  - E.g. mismatch with accelerator extracted phase space
- Cost $ € ¥

Assumptions? ⇒ Challenges?

- Particle Therapy needs a Gantry
- Infinite SAD is advantageous
- Need a small Gaussian beam
- Gantry should be Achromatic
- Mechanical Gantry “Isocentricity” is important
- Beam parameters should be Gantry angle “independent”
- Particle facilities are too big to fit in an existing Hospital

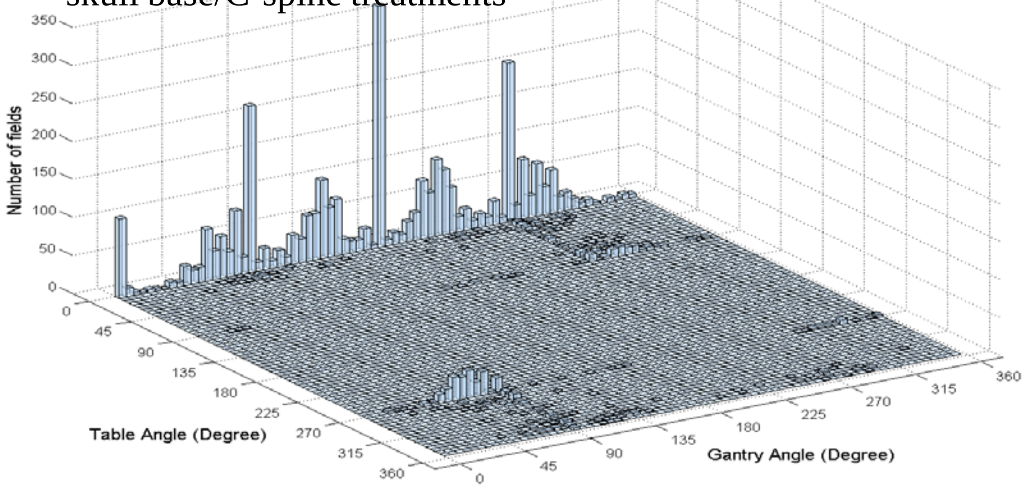
MGH 1811

VE RI TAS

Challenge 1: Need for a Gantry? What Assumptions?

Relook at 10 years 4332 patients – MGH - **Geometry**

Figure 1: 3D histogram of gantry and table angles used for skull base/C-spine treatments



A Slightly different definition of "Fixed" = Non-Gantry (Small bend + Robot Moves + Head move)

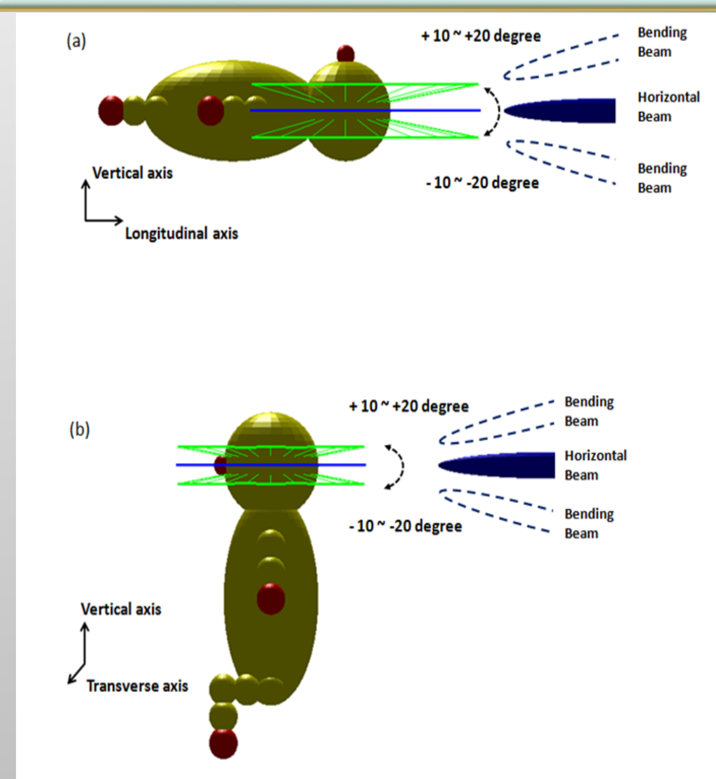
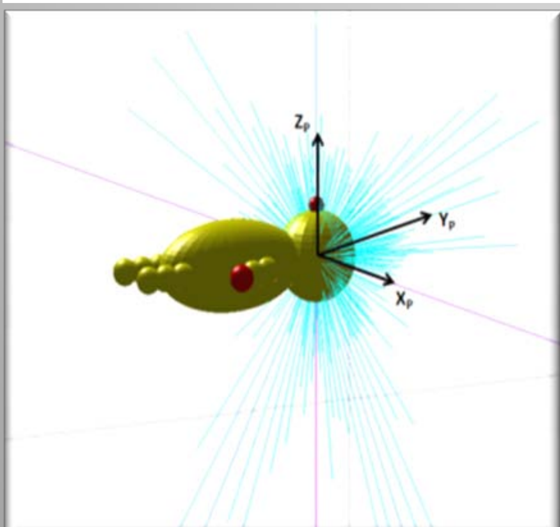


Figure 2: Gantry-less beam set-up for (a) patient in lying position and (b) sitting position. The achievable treatment beam angles for the FIXED are the angles in the coronal plane for lying position and the angles in the axial plane for sitting position, shown as the blue line. For BEND, the achievable angles range from +10 degree to -10 degree, +15 degree to -15 degree, or +20 degree to -20 degree. In the MOVE, head rotation is around longitudinal axis in lying position (a), and head nod is around transverse axis in sitting position (b).

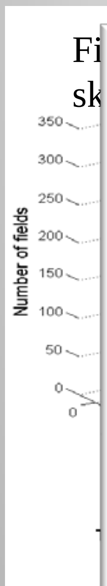


Old Assumptions:

- Scattering
- No MFO
- No Robots
- Limited Imaging

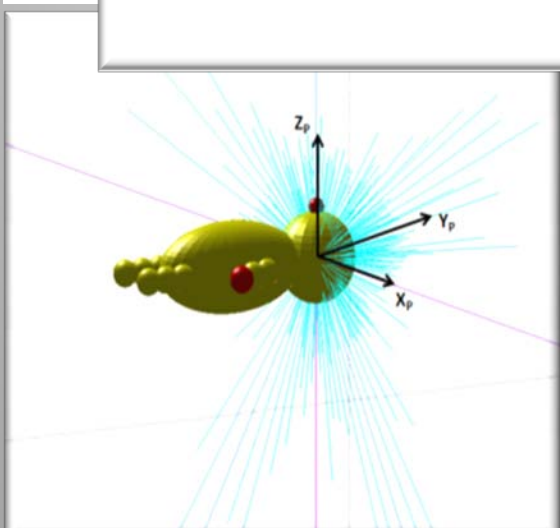
Challenge 1: Need for a Gantry? What Assumptions?

Relook at 10 years 4332 patients – MGH - **Geometry**



Key Conclusions:

- Percentage of patients with head-and-neck tumors which could be treated without a gantry using double scattering was 44% in the FIXED, 70% in 20-degrees BEND, and 100% in 90-degrees MOVE.
- For torso regions, 99% of patients could be treated in the 20-degree BEND.
- Of 104 PBS treatments, all but one could be reproduced with FIXED geometry. The only exception would require a 10-degree BEND capability. Note here that the PBS treatments were applied to select anatomical sites, including only two patients with skull-base tumors. (So far)



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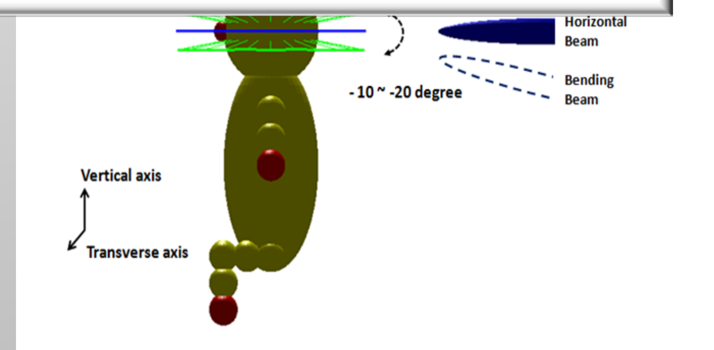

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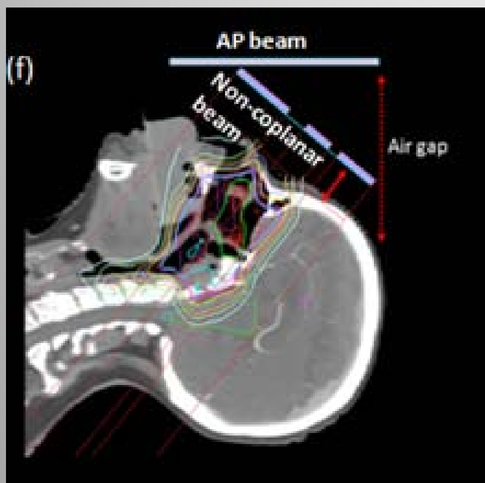
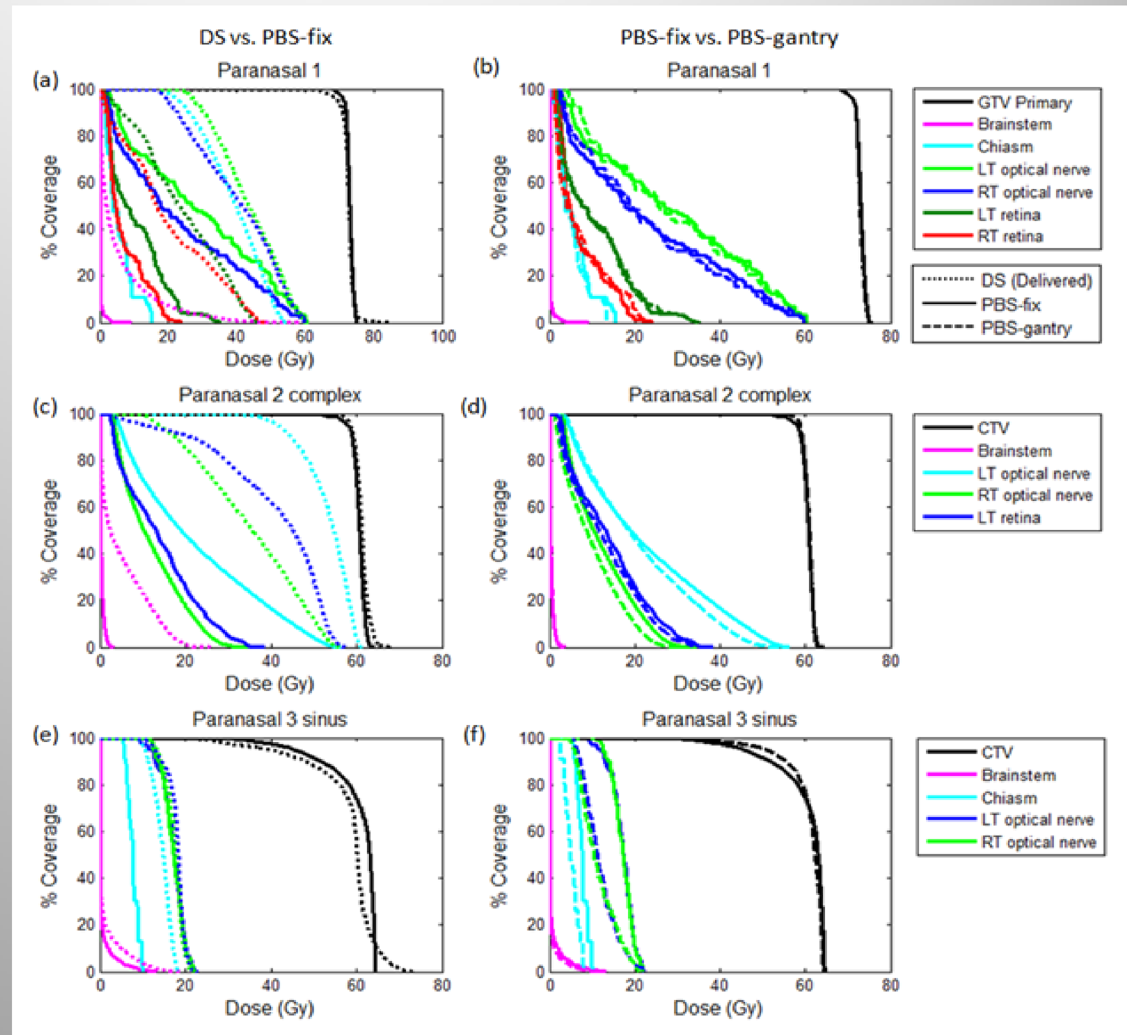
Challenge 1: Need for a Gantry? What Assumptions?

Relook at 10 years 4332 patients – MGH – **Tx Planning**



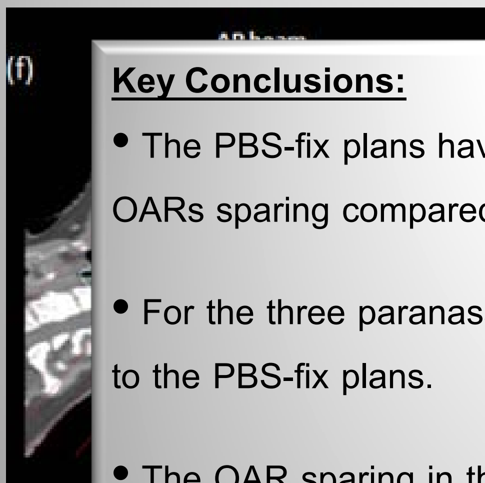
(f) Non-coplanar beam is chosen instead of AP beam to minimize the air gap between the aperture and the skull for uniform dose

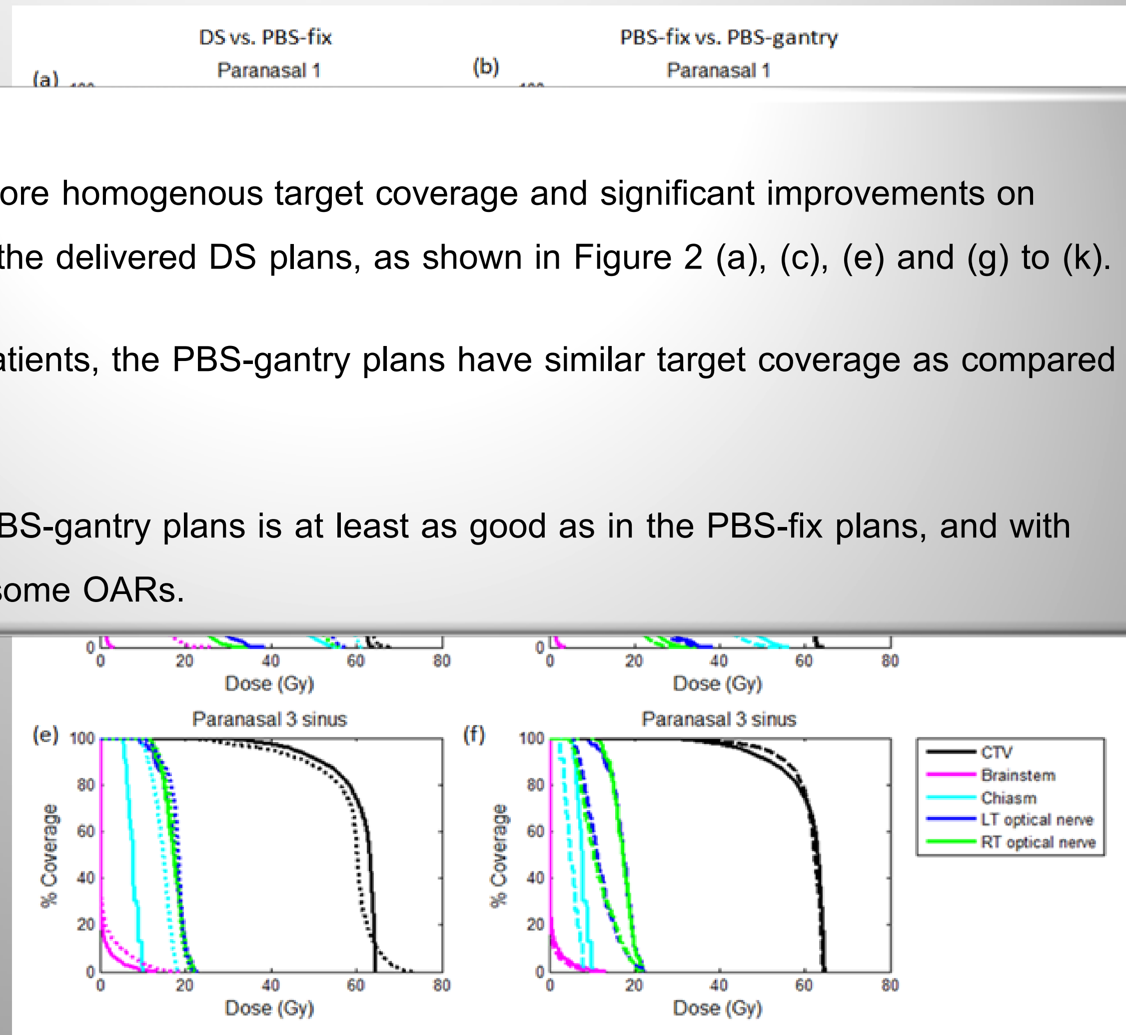


Not everything learned from Scattering is helpful– Fully utilize the flexibility/conformity of PBS

Challenge 1: Need for a Gantry? What Assumptions?

Relook at 10 years 4332 patients – MGH – **Tx Planning**





Key Conclusions:

- The PBS-fix plans have more homogenous target coverage and significant improvements on OARs sparing compared to the delivered DS plans, as shown in Figure 2 (a), (c), (e) and (g) to (k).
- For the three paranasal patients, the PBS-gantry plans have similar target coverage as compared to the PBS-fix plans.
- The OAR sparing in the PBS-gantry plans is at least as good as in the PBS-fix plans, and with marginal improvements for some OARs.

(f) N chosen instead of AP beam to minimize the air gap between the aperture and the skull for uniform dose

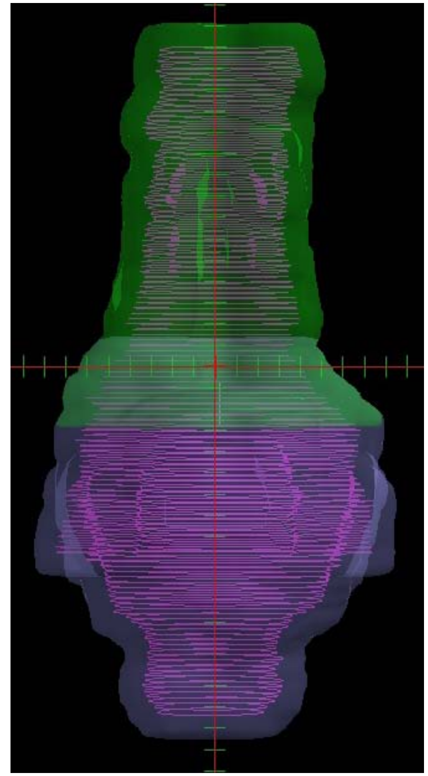
Not everything learned from Scattering is helpful– Fully utilize the flexibility/conformity of PBS

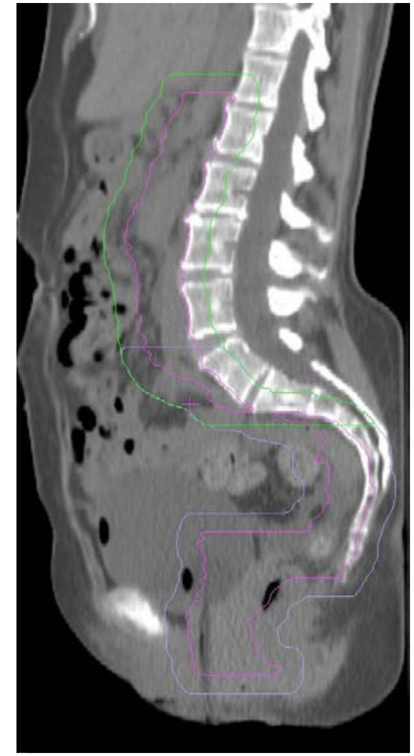
Some "Optics-related" Trade-offs

- Upstream vs. Downstream Scanning
  - Gantry Dipole Size
  - Scanning SAD
- Normal Temp vs. Superconducting
  - Speed of magnetic field change
  - Aperture/Field Quality
  - Cryogenics 'complexity'
  - Size of bending Radius (NOT necessarily Gantry)
- Trajectory corrections vs. Fixed Collimators
- Beam size vs. Sharp Edges

Field Matching
Para Aortic Lymph Nodes

Overlap region

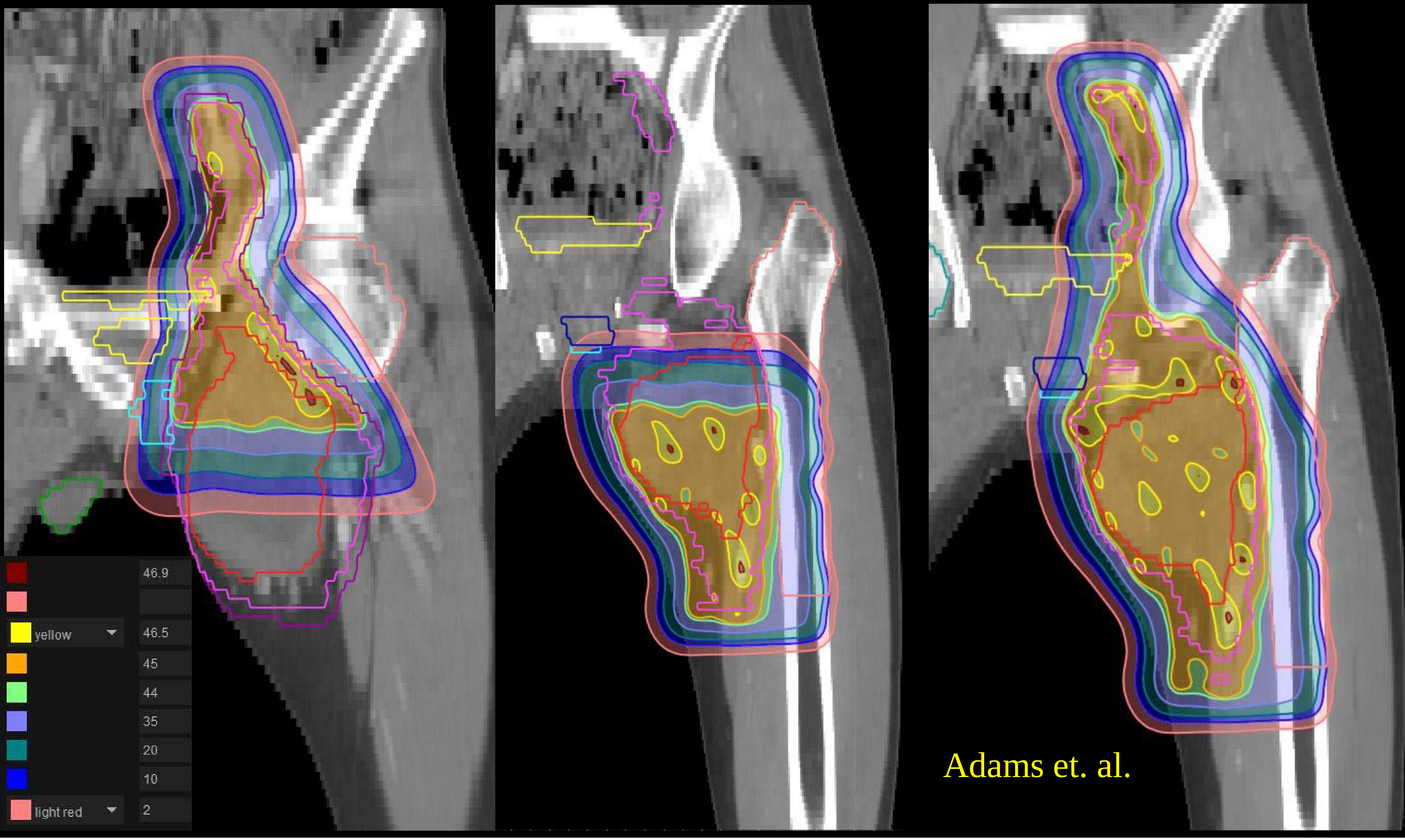




CHALLENGE 2: SAD REQUIREMENTS
Example: 2.3m SAD with PBS

Benign Chondromyxoid Fibroma

PBS with overlapping STVs and apertures



Adams et. al.

BEAM OPTICS/QUICK REVIEW

Beam and Ray

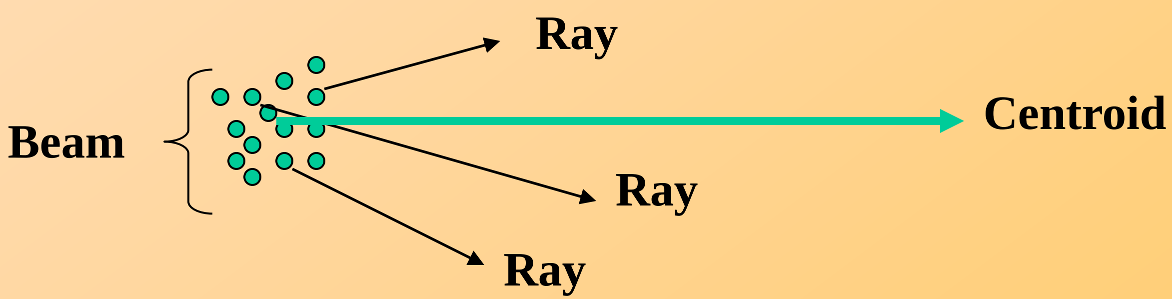
• **Beam** is a Collection of Particles generated by a source. A beam is a collection of many particles all of whose longitudinal and transverse momenta are relatively close enough to be transported through a beam transport system and remain more or less close to each other in all coordinates.

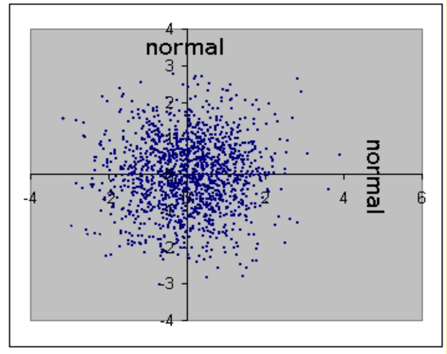
• Trajectory of an individual particle in that beam is sometimes called a **Ray**.

• The collection of motions of the rays in a beam produce a **beam** that has an overall beam envelope/size which can be modified by a beam transport system and follows some laws.

• However the **centroid** of the **beam** can be considered to behave like a **ray**.

• Louiville's Theorem - Conservation of *phase space area* in the absence of external forces.





Optics solutions can be applied to deal with the Ray trajectory, or the beam envelope

General Ray Coordinate Transform

- For small coordinate values the taylor series:

$$x_f = \left.{}^{\partial x_f}\!\big/_{\partial x_o}\right|_0 (x_o) + \left.{}^{\partial x_f}\!\big/_{\partial \vartheta_o}\right|_0 (\vartheta_o) + \bullet\bullet\bullet$$ can also be written as;

$x_f = (x/x)x_o + (x/\theta)\theta_o + \bullet\bullet\bullet$ (other coordinates)

$$\begin{pmatrix} x_f \\ \vartheta f \end{pmatrix} = \begin{pmatrix} (x/x) & (x/\vartheta) \\ (\vartheta/x) & (\vartheta/\vartheta) \end{pmatrix} \begin{pmatrix} x_o \\ \vartheta_o \end{pmatrix}$$

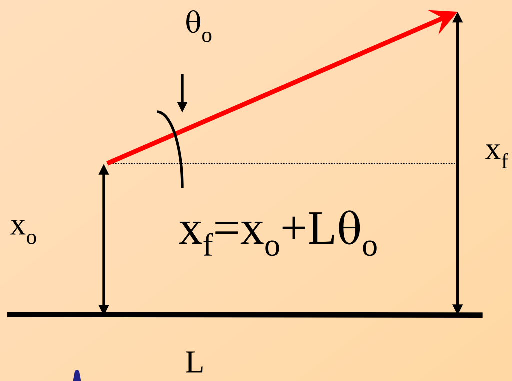
$$\begin{pmatrix} x_f \\ \vartheta f \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \begin{pmatrix} x_o \\ \vartheta_o \end{pmatrix}$$

$$\begin{pmatrix} x_f \\ \vartheta f \end{pmatrix} = \underline{\underline{R}} \begin{pmatrix} x_o \\ \vartheta_o \end{pmatrix}$$

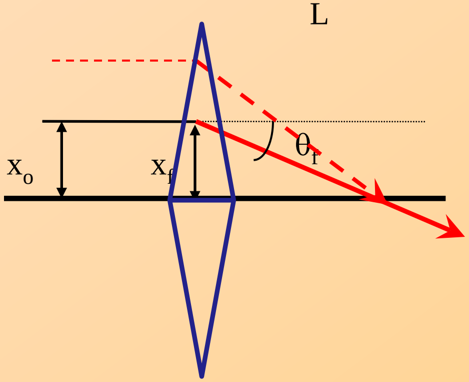
Note the **R** Matrix !!

The RAY “Transfer” Matrix

Physical Interpretations



$$\begin{pmatrix} x_f \\ \vartheta_f \end{pmatrix} = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix} \begin{pmatrix} x_o \\ \vartheta_o \end{pmatrix}$$

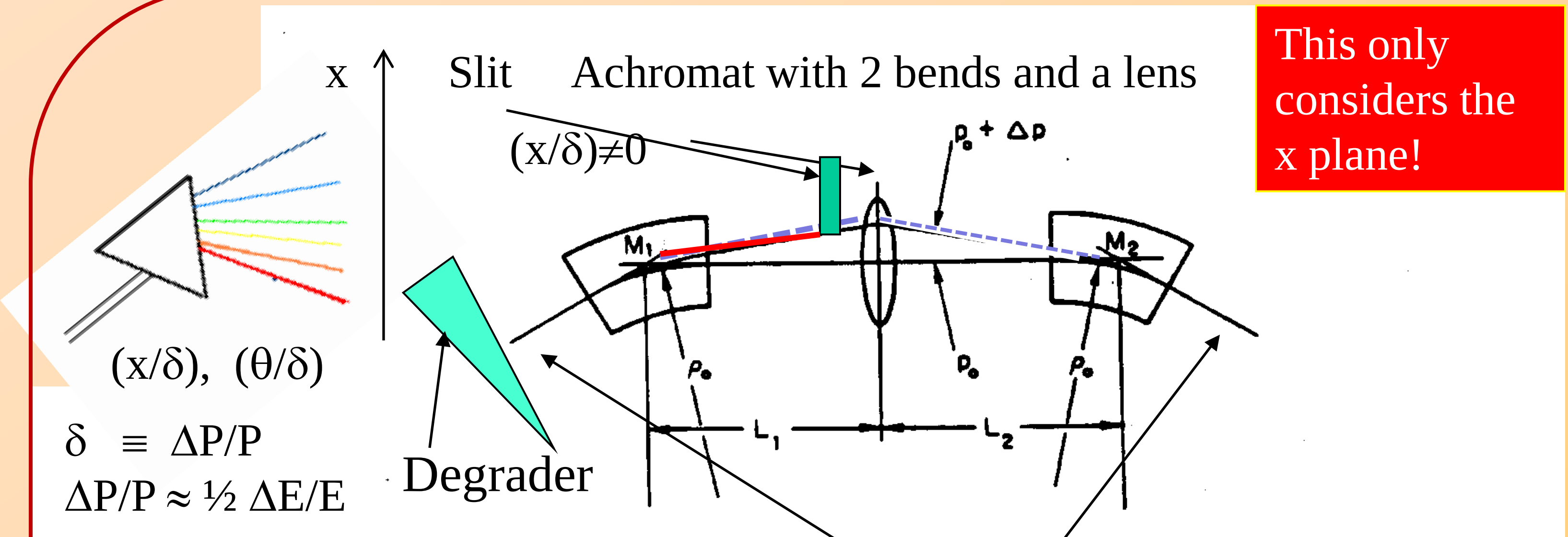


$$\begin{pmatrix} x_f \\ \vartheta_f \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -1/f & 1 \end{pmatrix} \begin{pmatrix} x_o \\ \vartheta_o \end{pmatrix}$$

$$\begin{pmatrix} (x/x) & (x/\vartheta) \\ (\vartheta/x) & (\vartheta/\vartheta) \end{pmatrix}$$

(x/x) = Transverse Magnification
(x/θ) = Effective Drift Distance
(θ/x) = -1/focal length
(θ/θ) = Angular Magnification

Achromaticity & Energy Selection



This only considers the x plane!

Achromaticity: BOTH the spatial and angular dispersion = 0

$(x/\delta) = (\theta/\delta) = 0$

Dispersion: Usually refers to the spatial dispersion = (x/δ)

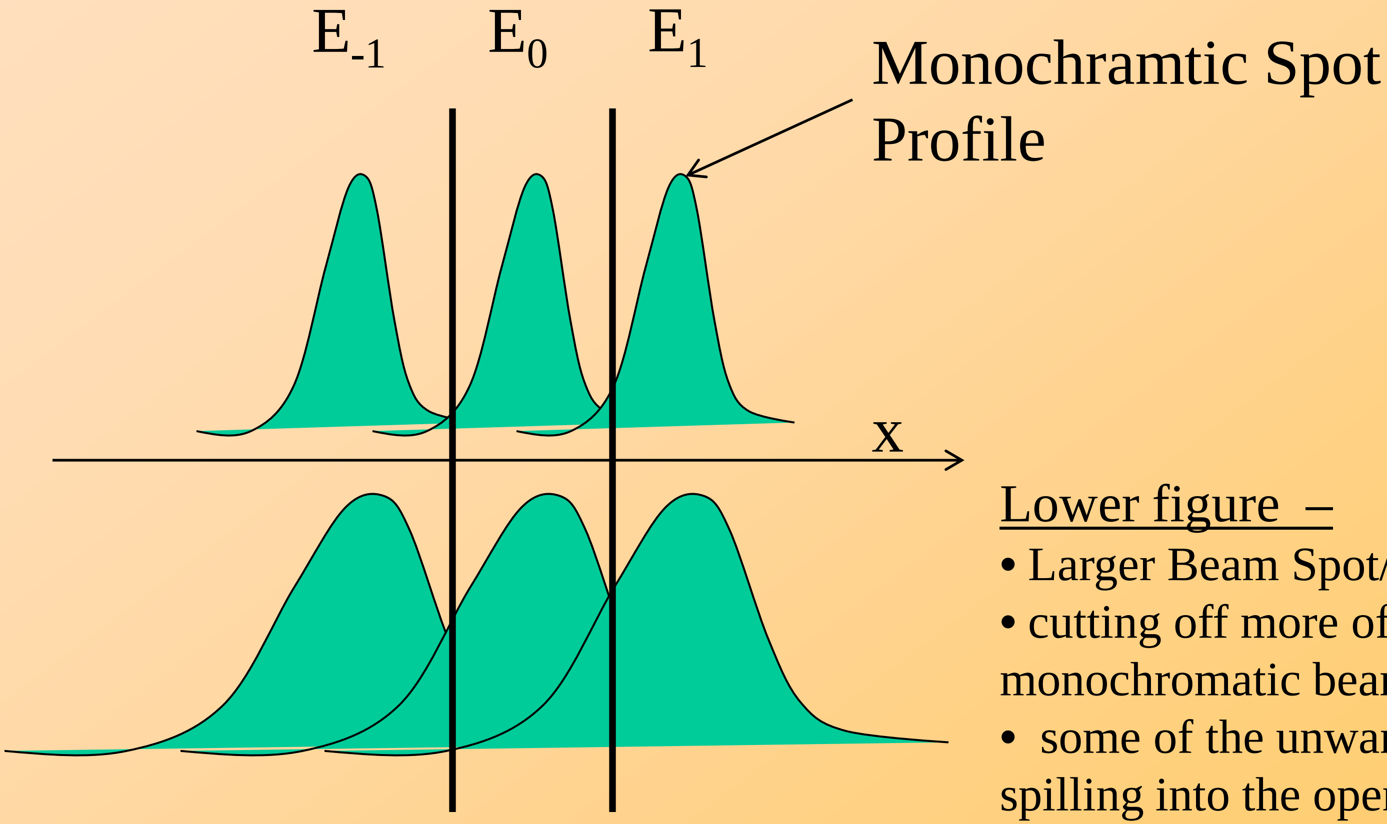
Energy Selection: Installing a slit at some distance from the axis will block particles of a certain momentum from being transported.

Beam Size in dispersive region: Fold "Monochromatic" beam size with growth from dispersion (x/δ)

$\sigma_x = SQRT(\sigma_{ox}^2 + (x/\delta)\delta_o)$

Optics Requirement: Do not cut off monochromatic beam – monochromatic beam size should be small compared to dispersion effect to block desired energies.

Energy Selection



<u>Lower figure –</u>

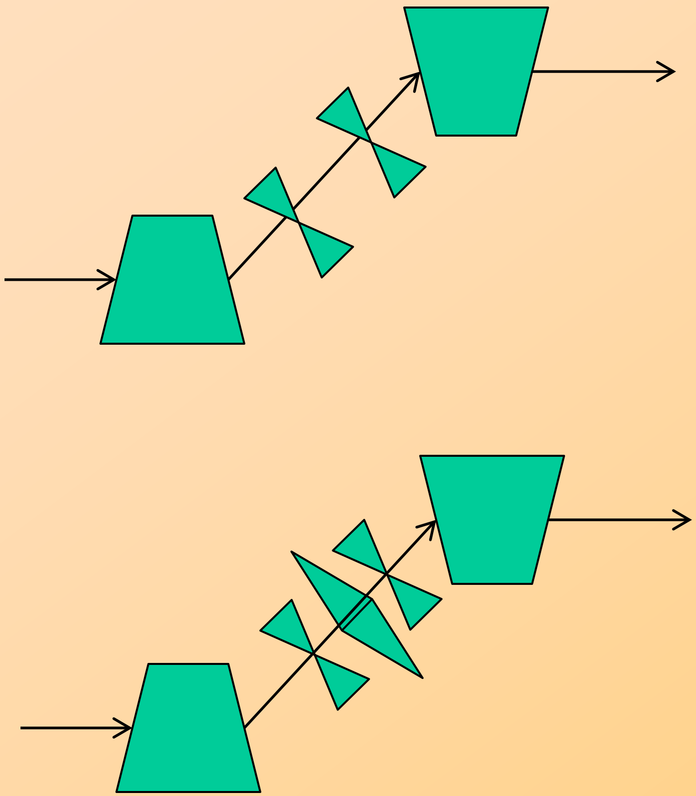
• Larger Beam Spot/Same Dispersion

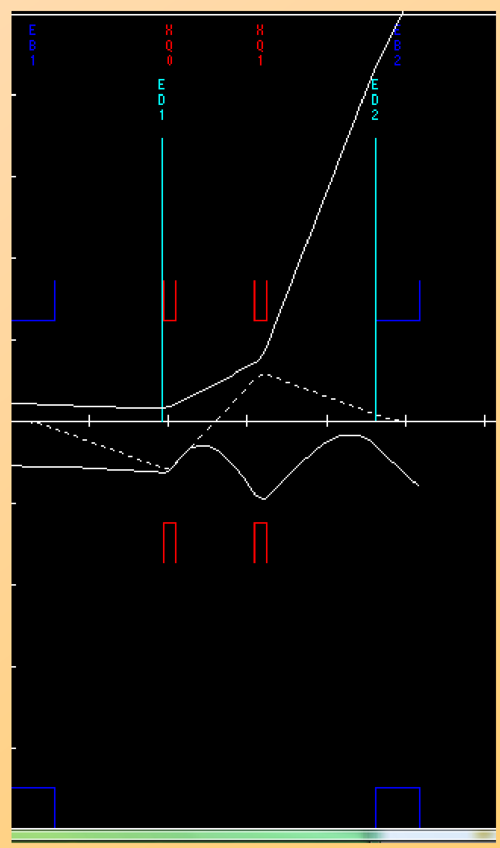
• cutting off more of the monochromatic beam AND

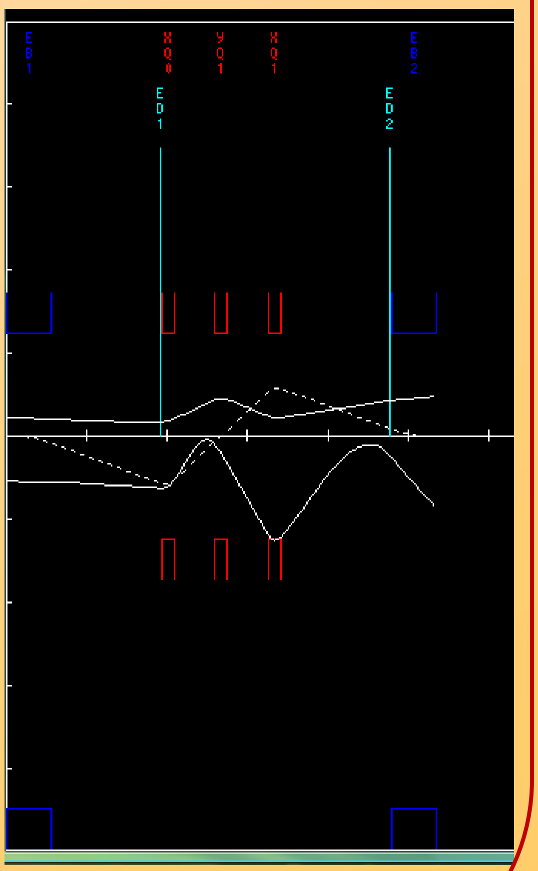
• some of the unwanted energy is spilling into the open (Non-cut) region

Achromat with Reverse bend

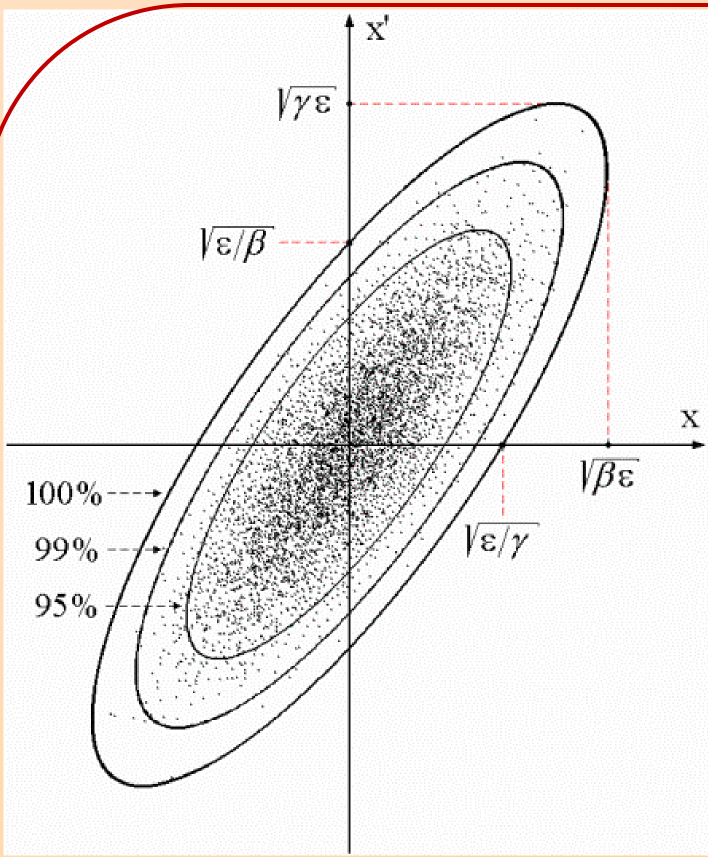
(Most Gantries)







Beam Phase Space Representation



- Particle distribution can be represented as a gaussian distribution (SOMETIMES). $e^{-(\gamma x^2)}\ e^{-(\beta\vartheta^2)}$
- Therefore, in two dimensions, the particle number density can be represented as:

$$\rho(x,\vartheta) = \rho_o e^{-(\gamma x^2 + \beta\theta^2)}$$

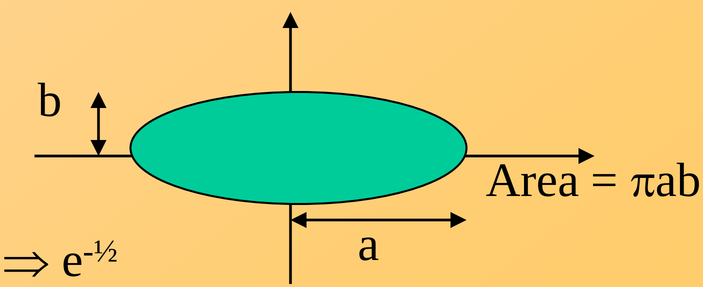
- Therefore the locus of constant particle distribution is
- $\boxed{\gamma x^2 + \beta\theta^2}$ = Constant. Note that this is the equation of an ellipse and is the outline of the phase space..
- The area of this ellipse is $\pi\alpha\beta$, otherwise written as $\pi\varepsilon$ where ε is the 'emittance' of the beam. Note that when an emittance is quoted, it is important to ask what fraction of particles are included within the ellipse, it is not always 1/e (e.g it could be 1σ). This is especially important when aperture restrictions are an issue.

$$\gamma_x x^2 + 2\alpha_x x x' + \beta_x x'^2 = \varepsilon_{x,full}$$

$$\varepsilon_{x,rms} = (\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2)^{1/2}$$

Phase space Area = $\pi\varepsilon$ (mm•mrad)

$1\,\sigma \Rightarrow e^{-1/2}$



•f(x) = $1 / [(2\pi)\sigma] * \exp(-\tfrac{1}{2}[(x-\mu)/\sigma]^2)$

BEAM PARAMETER DEPENDENCIES

Beam size Matrix Propagation

$$\underline{\underline{\sigma}}(1) = \underline{\underline{R}}\,\underline{\underline{\sigma}}(0)\underline{\underline{R}}^T$$

($\sigma_{11} = \beta\varepsilon$ = beam size^2)

$$\begin{pmatrix} [R_{11}{}^2\sigma_{11}(0) + 2R_{11}R_{12}\sigma_{21}(0) + R_{12}{}^2\sigma_{22}(0)] & [R_{11}R_{21}\sigma_{11}(0) + (R_{11}R_{21} + R_{12}R_{21})\sigma_{21}(0) + R_{11}R_{22}\sigma_{22}(0)] \\ [R_{11}R_{21}\sigma_{11}(0) + (R_{11}R_{21} + R_{12}R_{21})\sigma_{21}(0) + R_{11}R_{22}\sigma_{22}(0)] & [R_{21}{}^2\sigma_{11}(0) + 2R_{21}R_{12}\sigma_{21}(0) + R_{22}{}^2\sigma_{22}(0)] \end{pmatrix}$$

- **Beam Size Related**
- R_{12}=0
  - σ11(1) = $R_{11}{}^2\ \sigma_{11}(0)$:
  - Final beam size depends only on initial beam size.
- R_{11}=0
  - σ11(1) = $R_{12}{}^2\ \sigma_{22}(0)$:
  - Final beam size depends only on initial divergence

- **Beam Trajectory Related**
- R_{12}=0
  - $x(1) = R_{11}\ x(0)$
  - final beam position INDEPENDENT of angle.
- R_{11}=0
  - $x(1) = R_{12}\ \theta(0)$
  - final beam position INDEPENDENT of position.

Propagation of a beam in a drift length

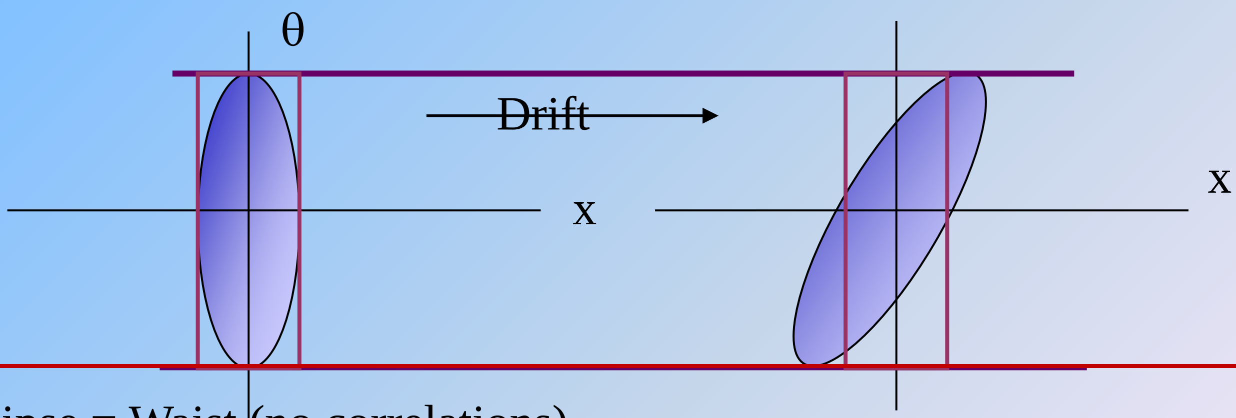
Consider a drift length (of length L) which can be described by the transfer matrix:

$$\underline{\underline{R}} = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix}$$

The sigma matrix at the end of the drift length can be related to the sigma matrix at the beginning of the drift length as shown below:

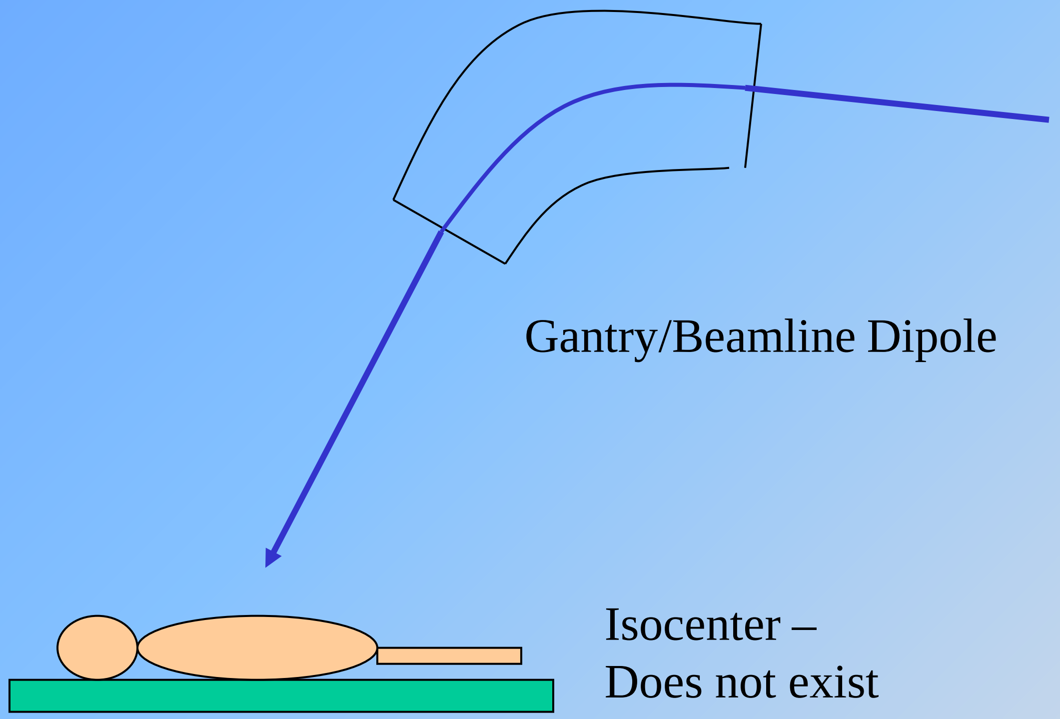
$$\begin{pmatrix} [\sigma_{11}(0) + 2L\sigma_{21}(0) + L^2\sigma_{22}(0)] & [\sigma_{21}(0) + L\sigma_{22}(0)] \\ [\sigma_{21}(0) + L\sigma_{22}(0)] & [\sigma_{22}(0)] \end{pmatrix}$$

The most directly measurable quantity is the beam size, which is related to σ_{11}. It is seen that σ_{11} is a parabolic function in length L, and depends on σ_{22} related to the angular divergence of the beam. This beam size growth is modified by the σ_{12} correlation.

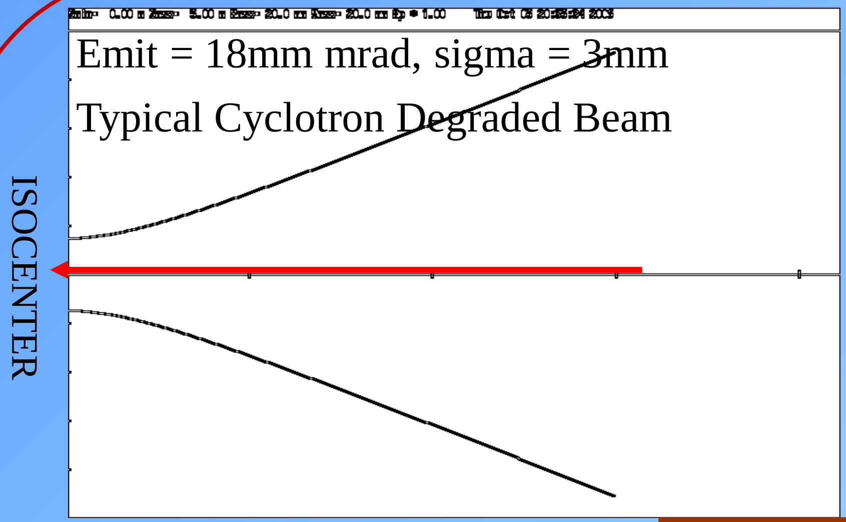


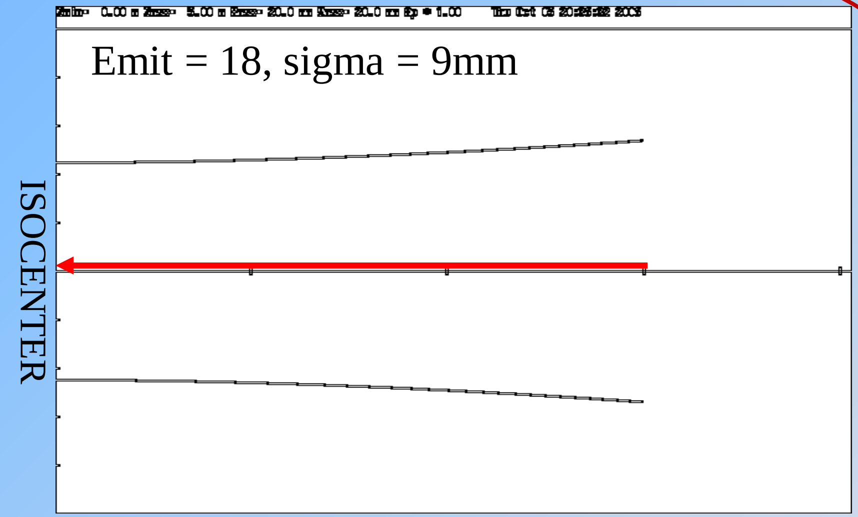
Upright Ellipse = Waist (no correlations)

What happens to the beam from the last magnet to the target?

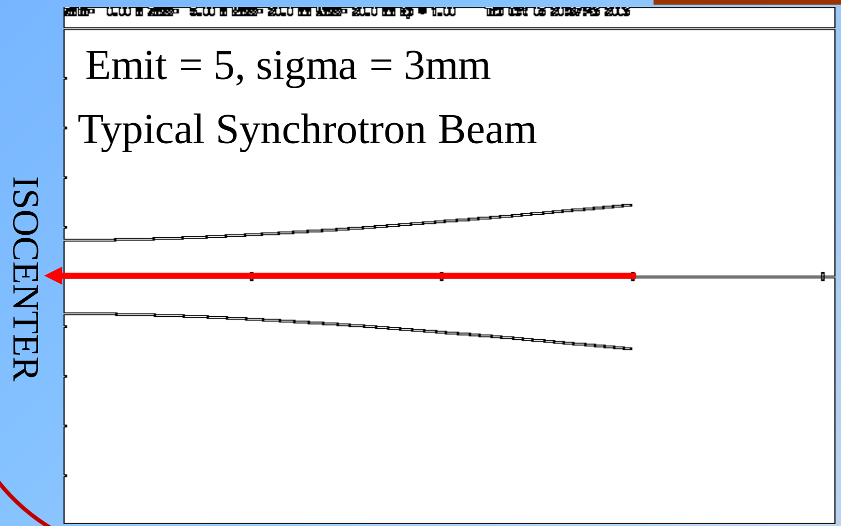


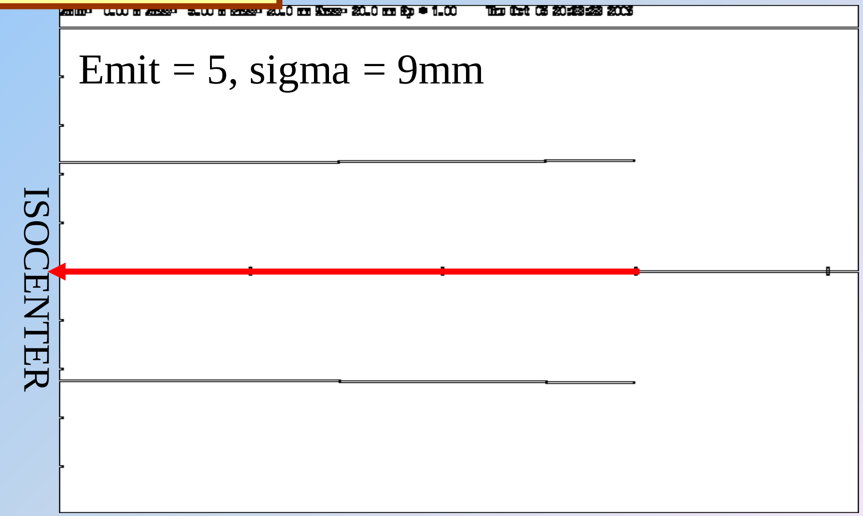
Effect of beam emittance on the Gantry Design





$$X^2_{DIP} \sim X^2_{ISO} + L^2 * \theta^2_{ISO}$$





Effect of emittance on the Gantry design

PS Current ~ Gap

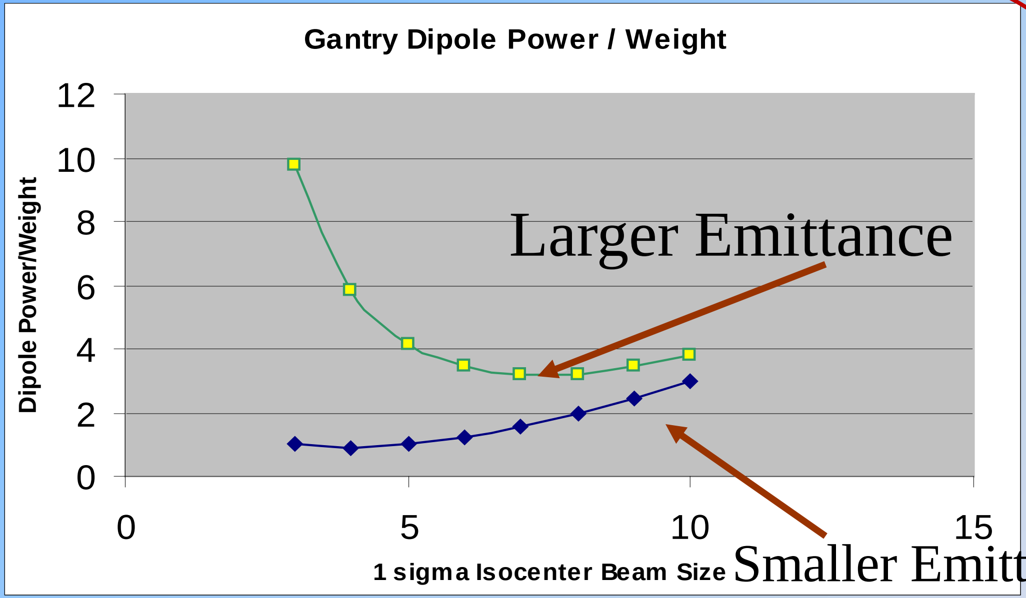
Magnet weight ~ Gap ^{2}

Power ~ Current ^{2} ~ Gap ^{2}

Gap ~ 1/final beam size $^?$

$$v(t) = L\frac{di(t)}{dt}$$

Fast Energy Changes ⇒ POWER (or Huge Bandwidth) !

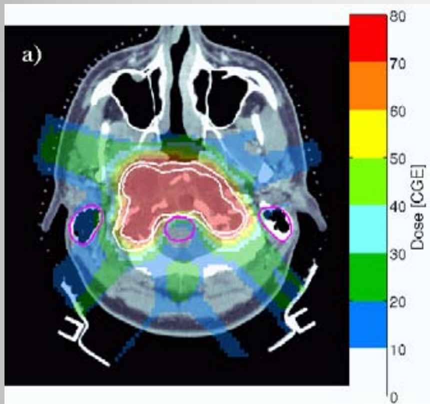


For Larger Emittance Beams, the power and weight requirements increase a factor of 3 when reducing the beam size from 6mm to 3mm

!!Even smaller optical beam size is necessary when considering scatter from MATERIAL IN THE BEAM PATH (Instruments, Windows (Acoustic Accident?), Gas, Range shifter/Ridge filter.

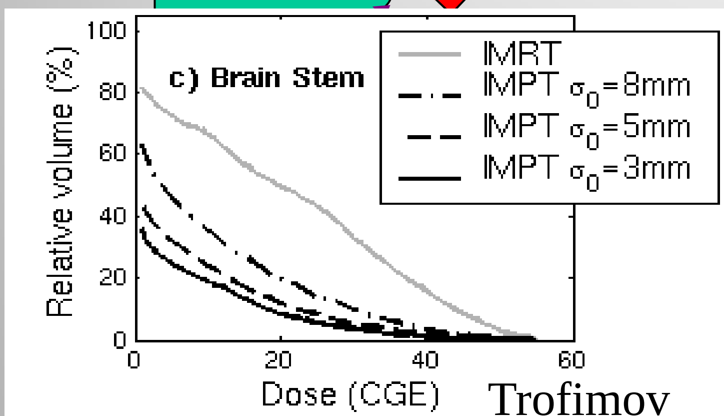
Small Beam at Isocenter --> Larger magnet aperture --> bigger magnet --> More power --> bigger gantry --> Higher cost

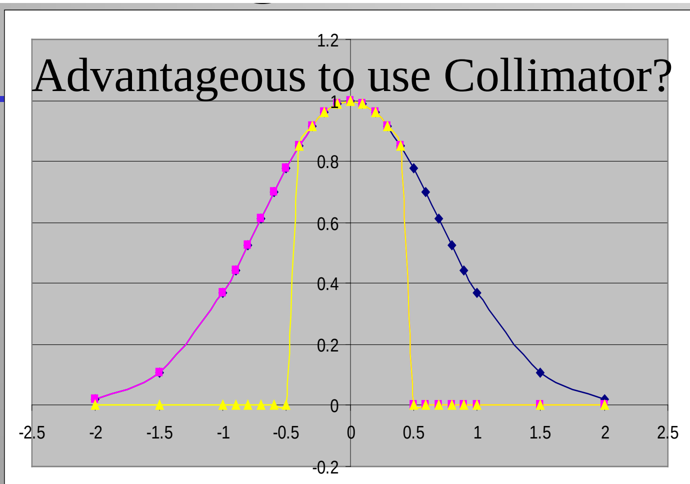
Challenge 3: What beam size is needed?

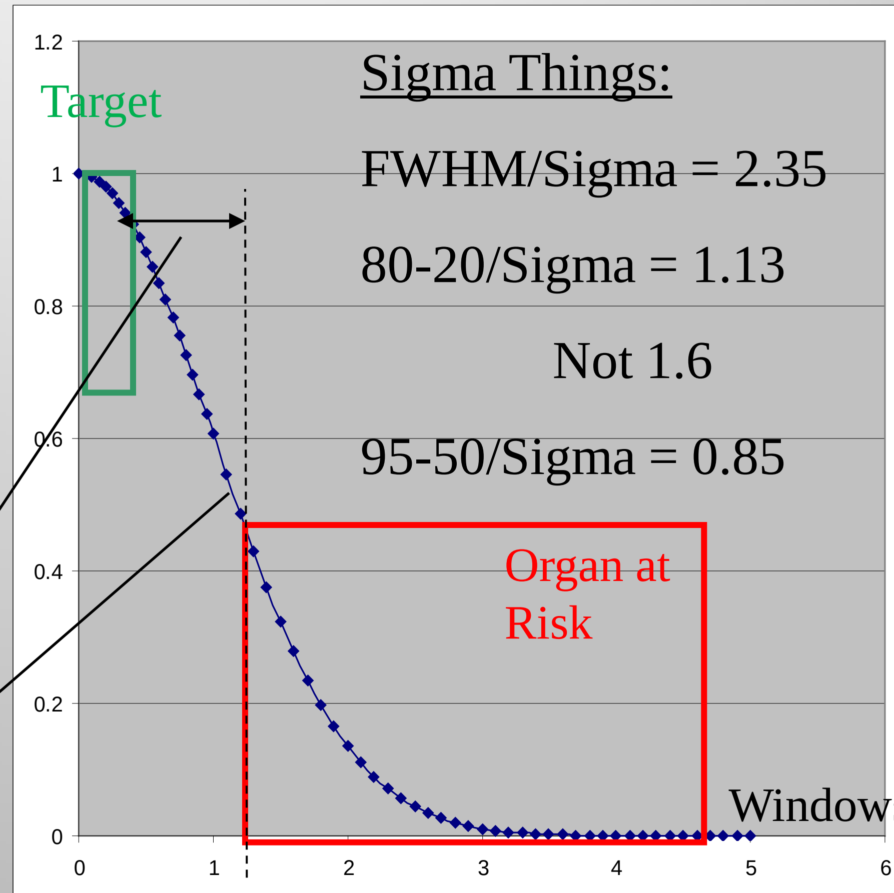


$$y = e^{-\frac{1}{2}\left(\frac{x}{\sigma}\right)^2}$$

Assume: Dose to Target within +/- 2.5% and Organ at Risk < 50%

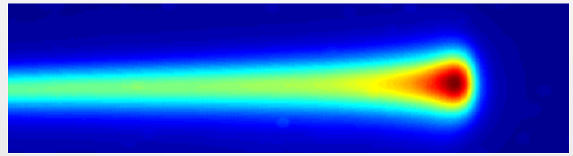






Not efficient to always use small beam !

Real beam size at target !



$$\theta_f = \sqrt{\theta_i^2 + \theta_{MS}^2}$$

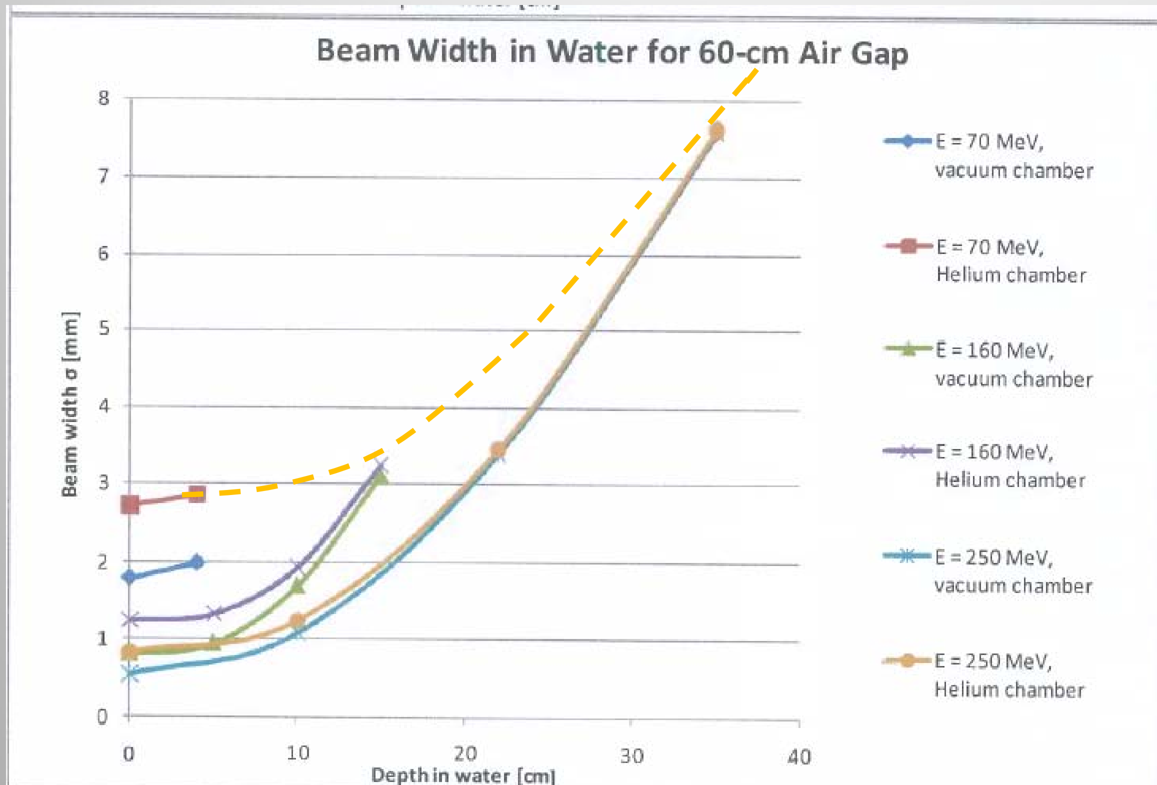
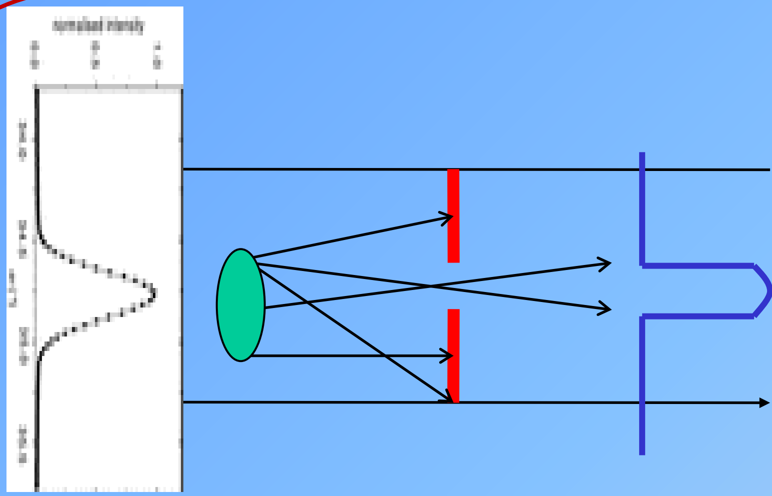
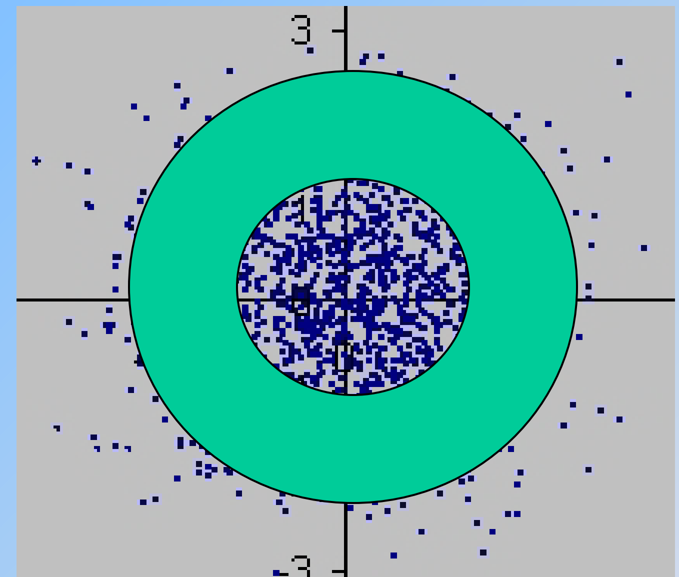


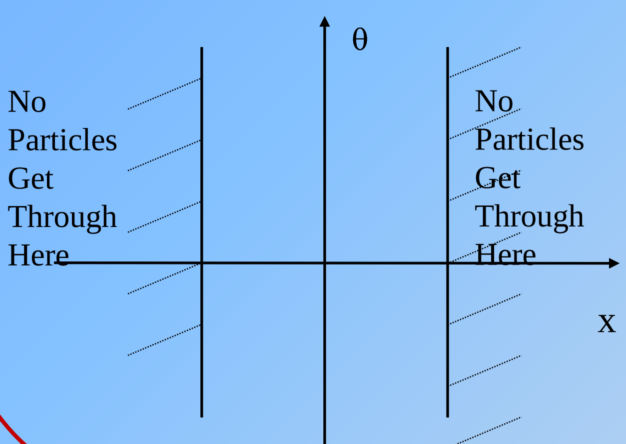
Figure 7: Beam width in water for 80 and 60-cm air gap

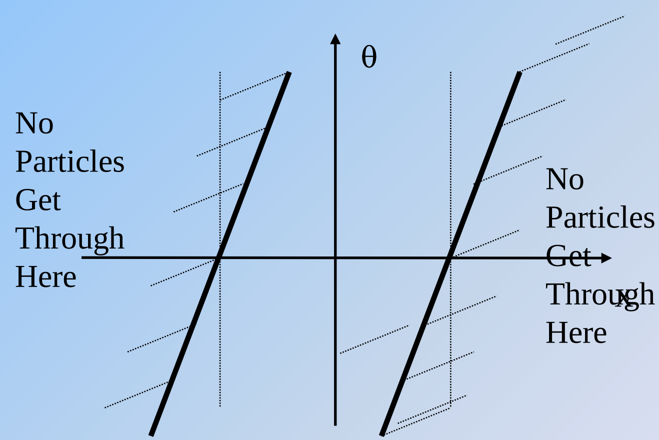
Phase space representation of an Aperture



One way to make a beam edge sharper is by use of an aperture.



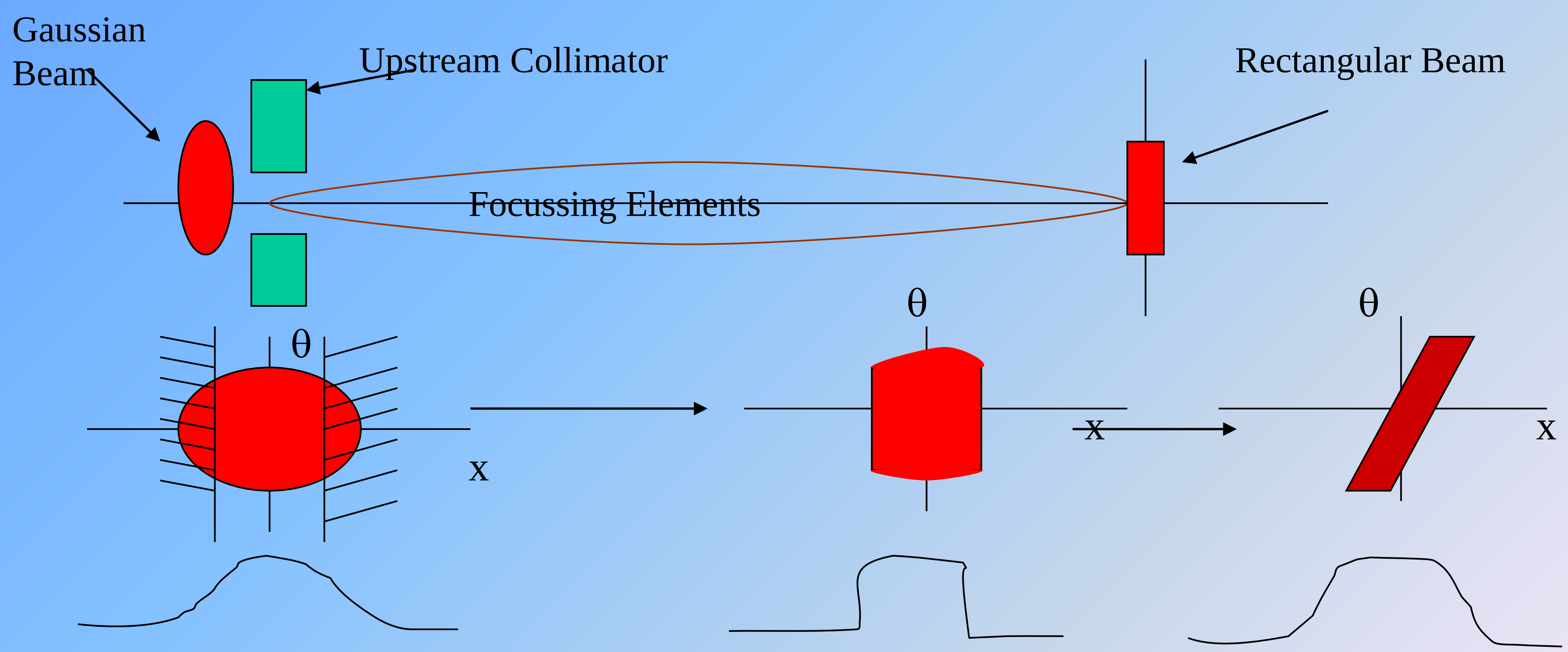




PTCOG 36, Catania J. Flanz What Questions should we be asking about Scanning Systems.

How can one achieve a sharp edge beam

Without a collimator right at the patient?



- With a selectable effective drift one can also control the 'penumbra' which could be useful in matching.

Use of a Collimator

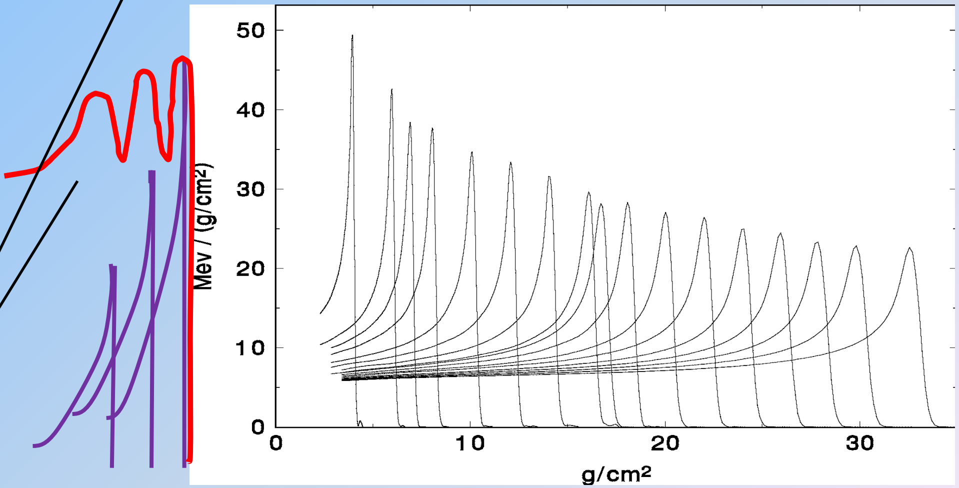
- If $R_{12}=0$, then final position does not depend upon angle at Collimator
- If position at collimator changes, so does position at Isocenter (but if the beam is within the collimator aperture, then it's within(?) tolerance at isocenter OR if the beam is LARGER than the collimator opening, then beam size/position does not change because only the part through the collimator gets through – (which part?))
- The beam size at Isocenter will depend on the collimator aperture and the optics R_{11}**:** $\sigma_{11}(1) = R_{11}\ \sigma_{11}(0)$:
- What about angular variations? This will cause position shifts at isocenter. What is more likely position or angle shifts at collimator (or both)? See also the $R_{11}=0$ story
- What if x and y beam sizes are unequal?
  - If focus to make equal $\Rightarrow$ larger divergence $\Rightarrow$ bigger beam in gantry; so just make divergence equal (and gentle) and $R_{11}=0$
  - Or use a collimator to get rid of part of the larger beam.

Momentum, Energy, Dispersion

- $dP/P \sim \frac{1}{2}\, dE_k/E_k$
- Beam size due to dispersion
  - $\sigma_x = SQRT(\sigma_{ox}^2 + (x/\delta)\delta_o)$
- Beam Position Shift due to dispersion
- How to Change Energy?
  - V= L dI/dt; OR BandWidth

- Lowest Energy Range of Gantry?
  - Where to degrade?
  - How to deal with increased divergence?
- Degrading for Bragg peak spacing

		delta range in mm		
Energy Spread		1%	0.10%	
Momentum Spread		0.50%	0.05%	
	50	0.402	0.0402	
	100	1.37	0.137	
	150	2.75	0.275	
	200	4.45	0.445	
	230	5.59	0.559	
	250	6.39	0.639	
	Spread range before magnets ==> dispersion			
	Spread range after magnets ==> NO Dispersion			

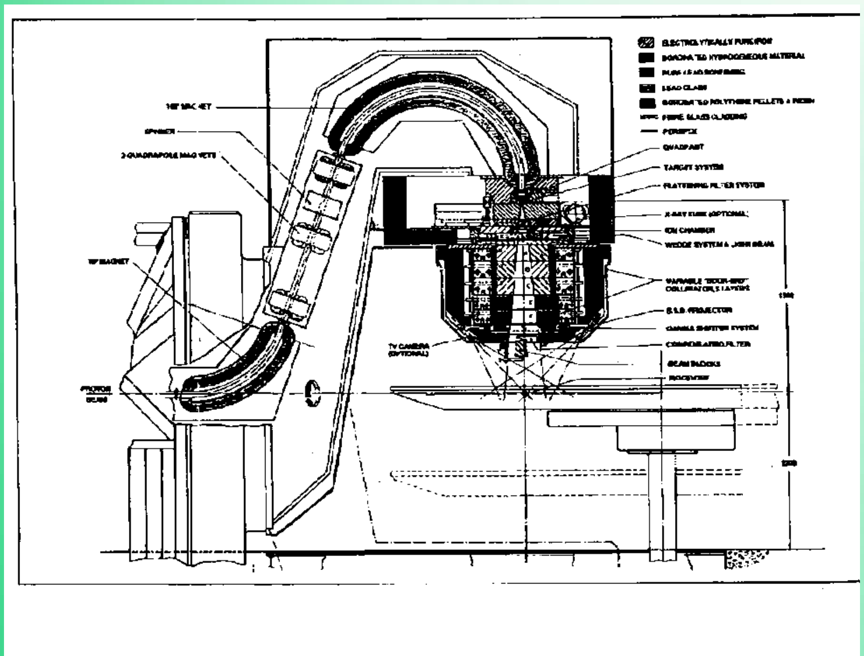


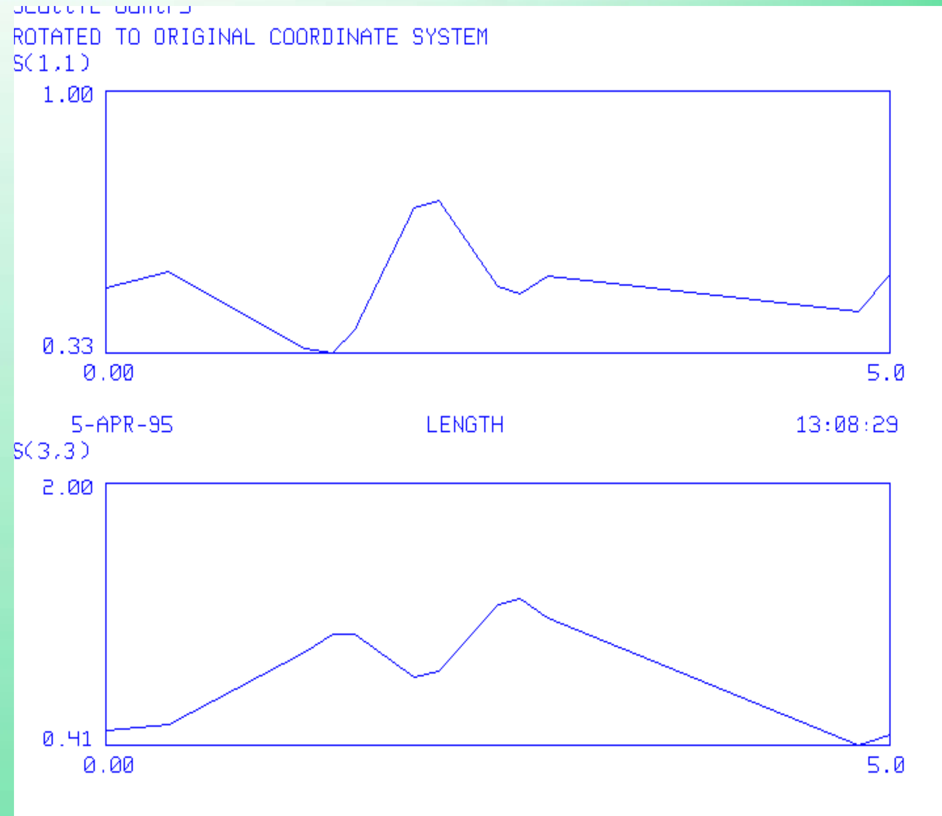
6% momentum spread = 8cm @ 250 MeV
Need something at Lower energy anyway??

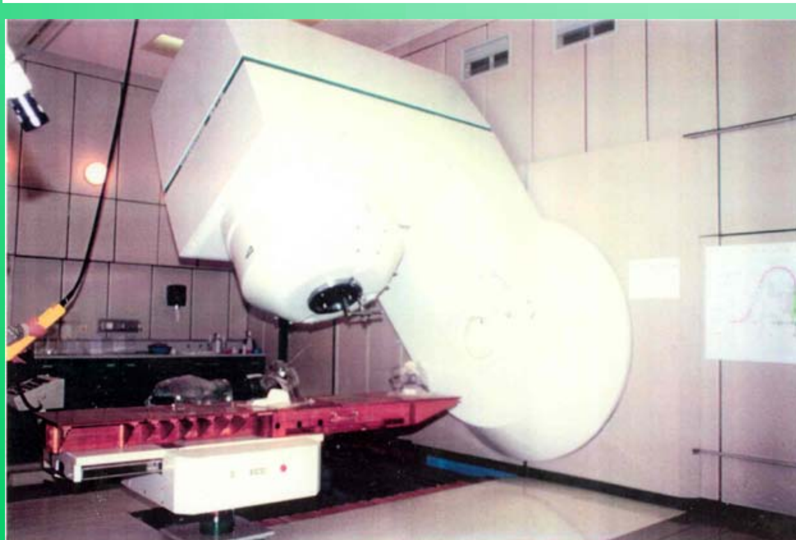
SURVEY OF GANTRIES:
NOT ALL SHOWN – JUST REPRESENTATIVE OPTICS

THE EARLY YEARS: GANTRIES

Scanditronix Neutron Therapy Gantry



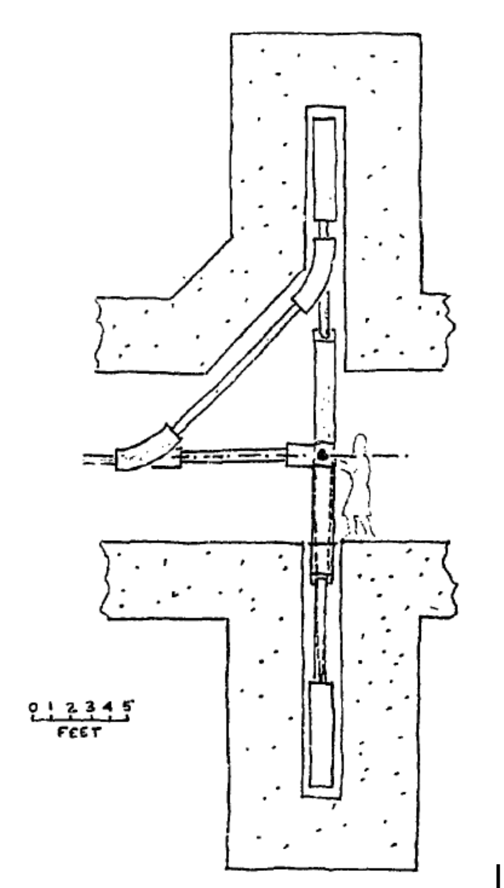


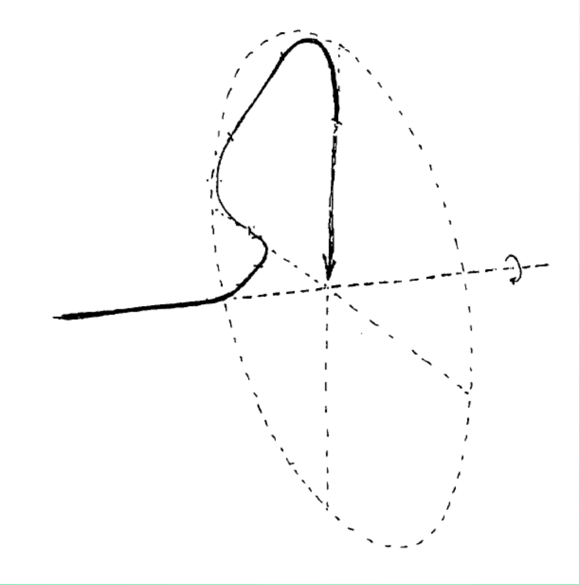


<u>Optics Conditions</u>

- Almost point to point (R_{12}=0)
- Achromatic (Reverse bend)
- Beam size adjusted for target heating
- Minimum (?) bend = 180°

Corkscrew Gantry





LBL--22962
DE87 009281

Proceedings of
The Fifth PTCOG Meeting
&
International Workshop on Biomedical Accelerators

December 1 and 2, 1986
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

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MASTER

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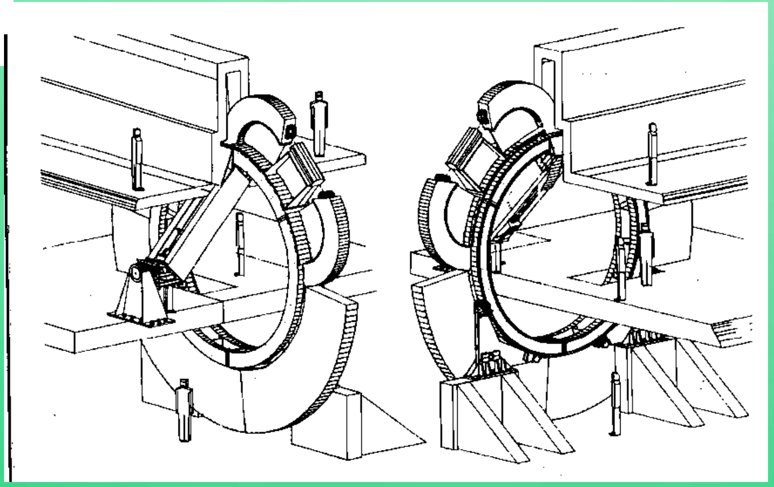
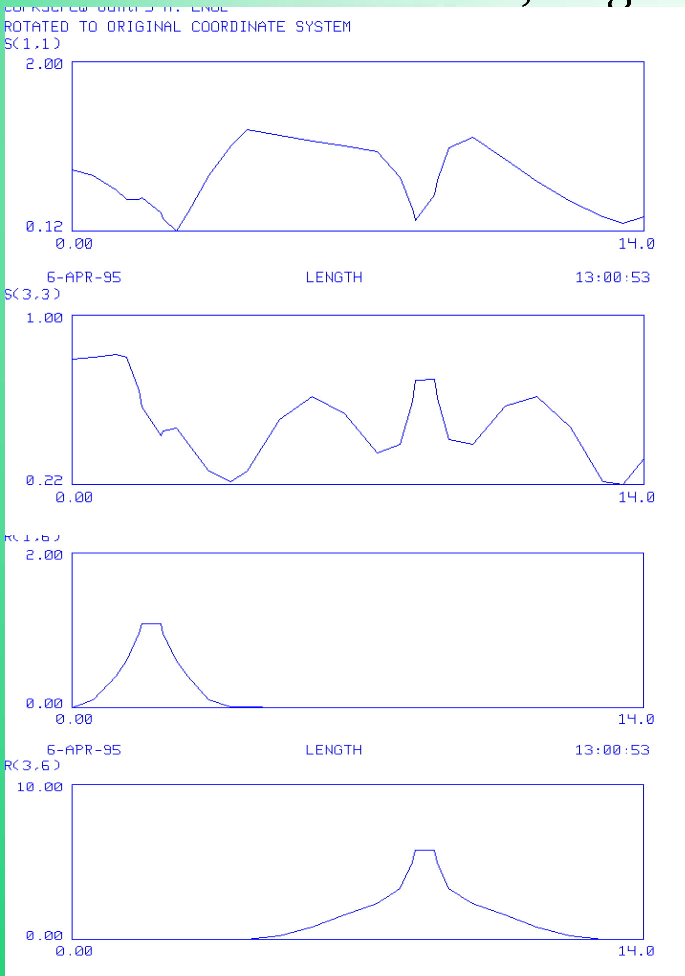


Corkscrew Gantry

Koehler, Enge …………………….. Sumitomo



Proprietary

<u>Optics Conditions</u>

- Stringent Focus
- Achromatic x2
- 360° of Bend

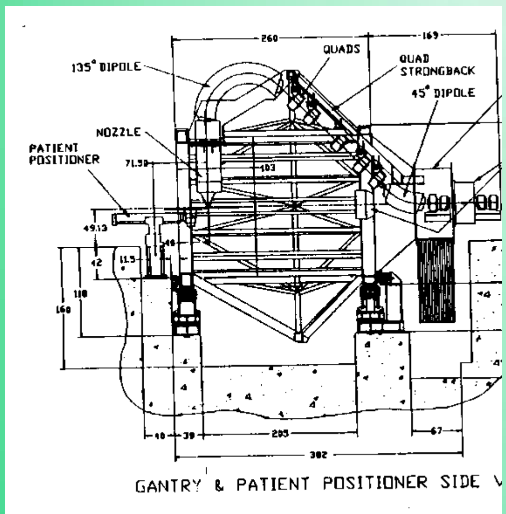
<u>Optics Conditions – Similar to Enge</u>

- Stringent Focus (long distance of small aperture)
- Achromatic x2
- 360° of Bend
- Beam size 2σ < 7mm at isocenter

DOWNSTREAM SCANNING PROTON GANTRIES

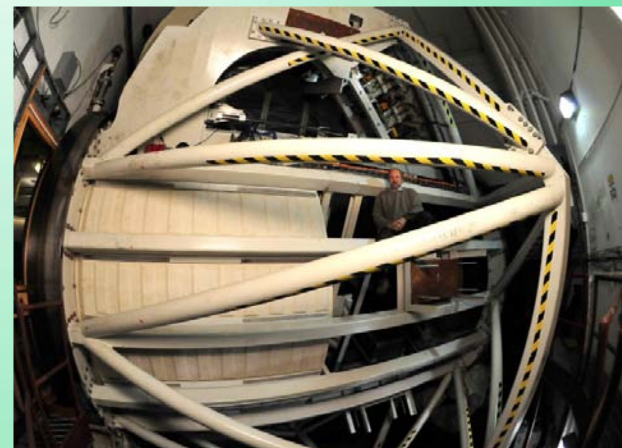
In-Plane Gantry (Conventional)

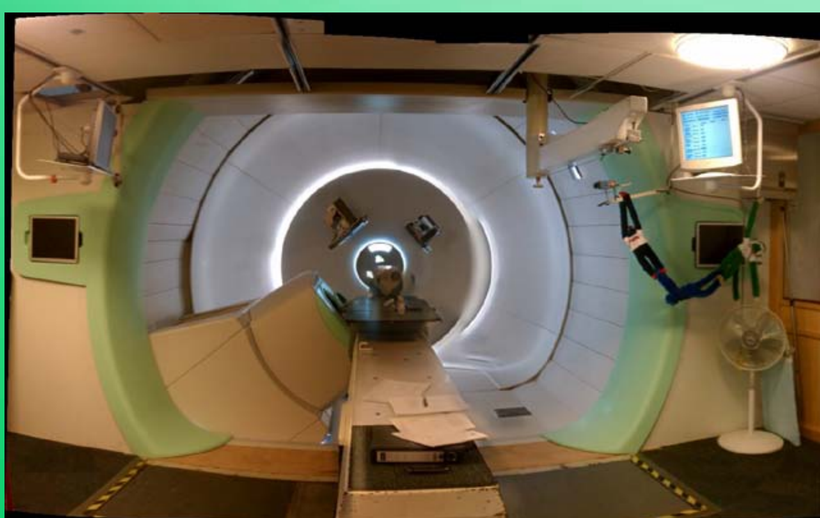
IBA/GA/MGH

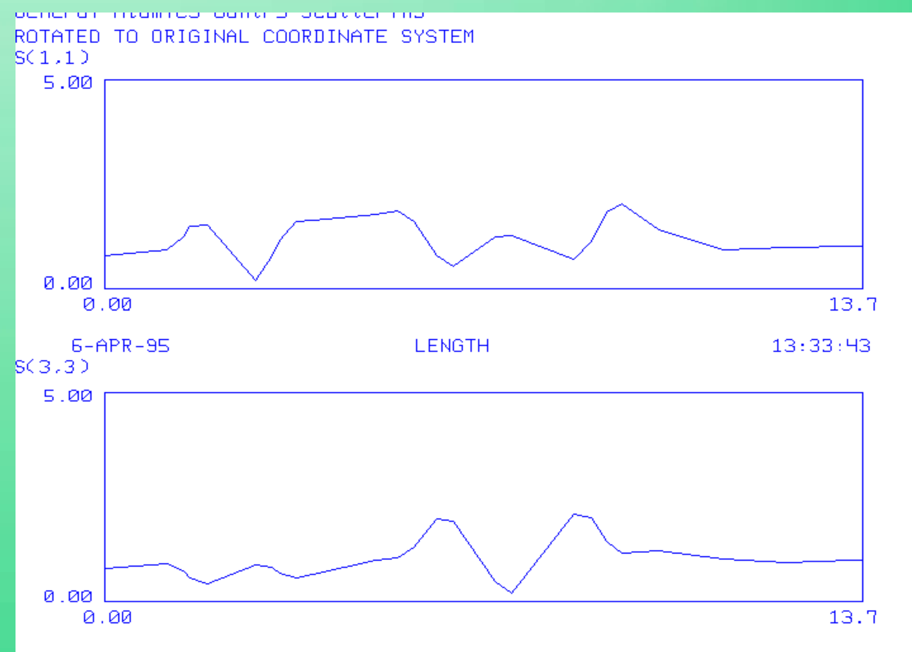


Optics Conditions

- Different focusing for Scattering and scanning
- Reverse bend Achromat
- Matching section at gantry start
- Steering corrections at optimum phases
- $R_{12} \sim 0$





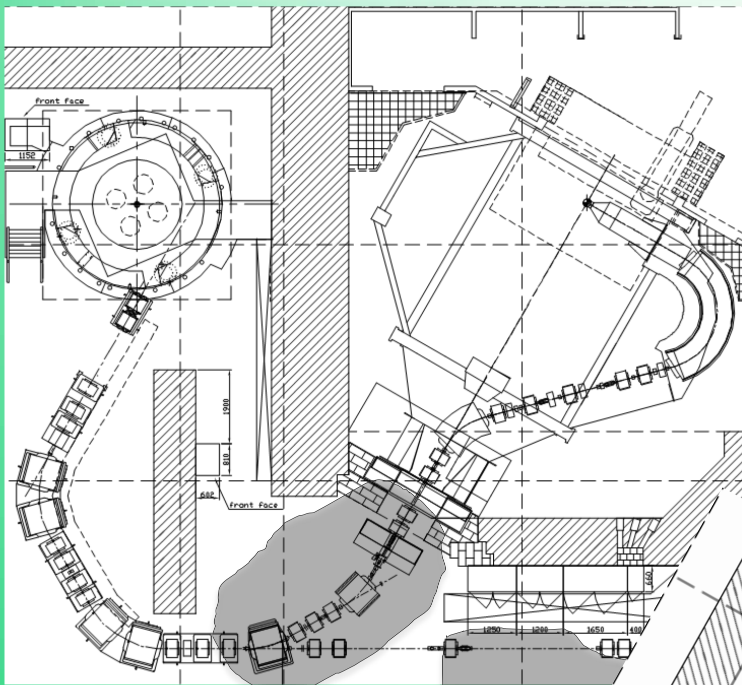


ProTom Gantry

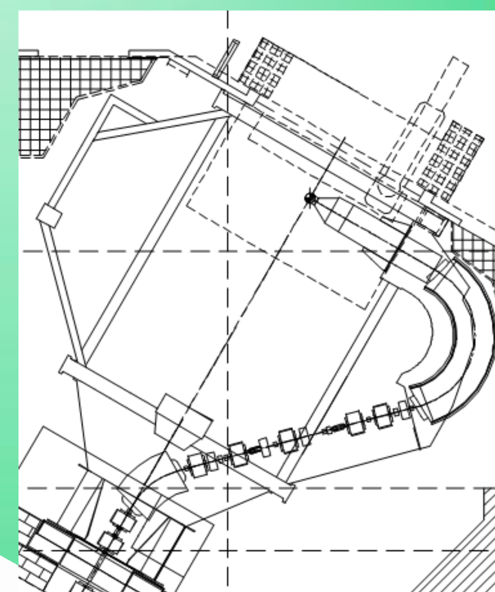
<u>Optics Conditions</u>

- Achromatic Overall (Taking advantage of reduced beam energy spread) (Larger Dispersion okay)
- Focusing for Scanning (taking advantage of small emittance)
- Point to Point (Gentle parallel beam entry)
- Smaller magnets/Smaller beam
- *(Gantry size dominated by field size and SAD spec)*
- *(Gantry weight dominated by mechanical isocentricity spec)*

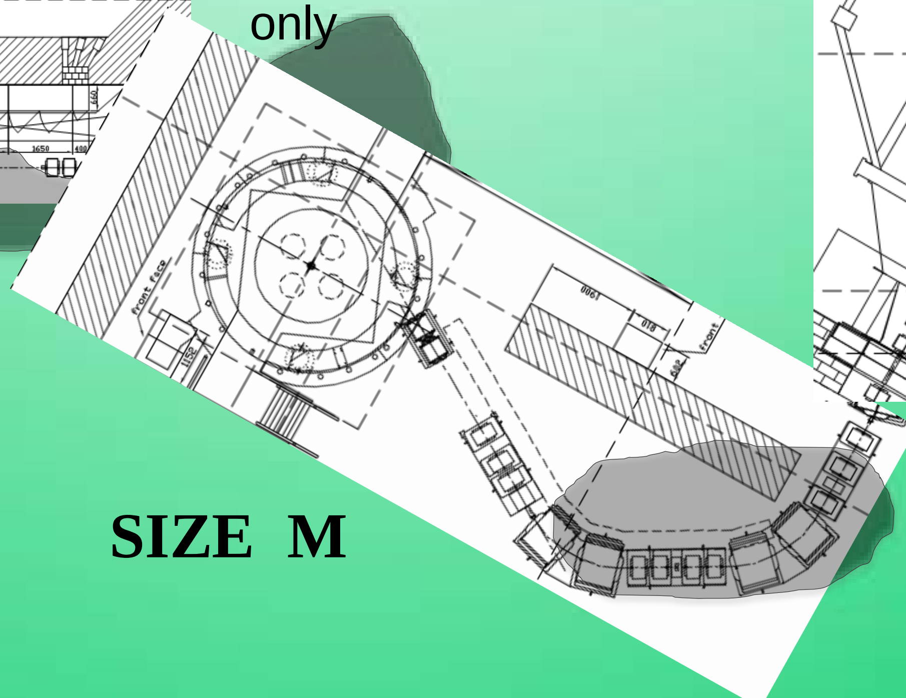
The IBA "Journey" to Small



Don't need switching section



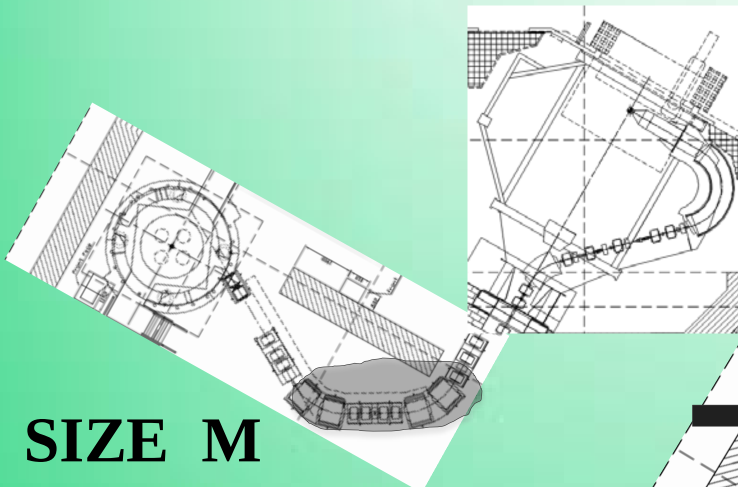
1 room only



SIZE L

SIZE M

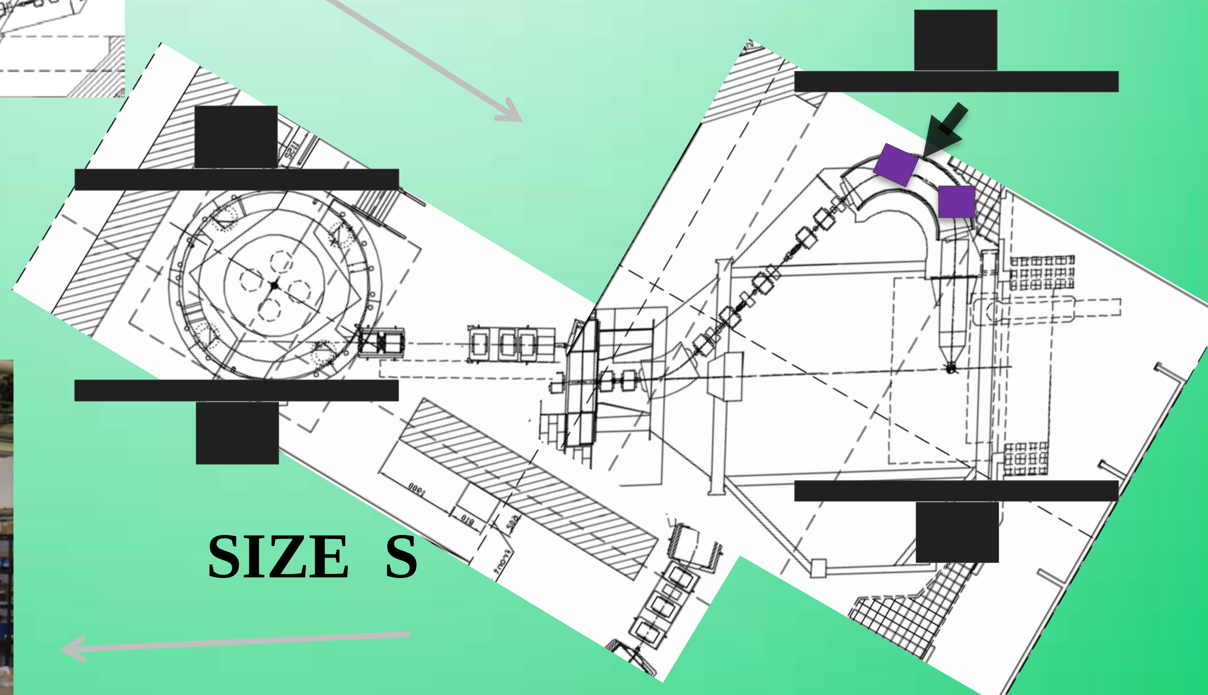
The IBA "Journey" to Extra Small



SIZE M

Integrate the ESS into the Gantry Optics

Downstream scanning becomes upstream scanning



SIZE S

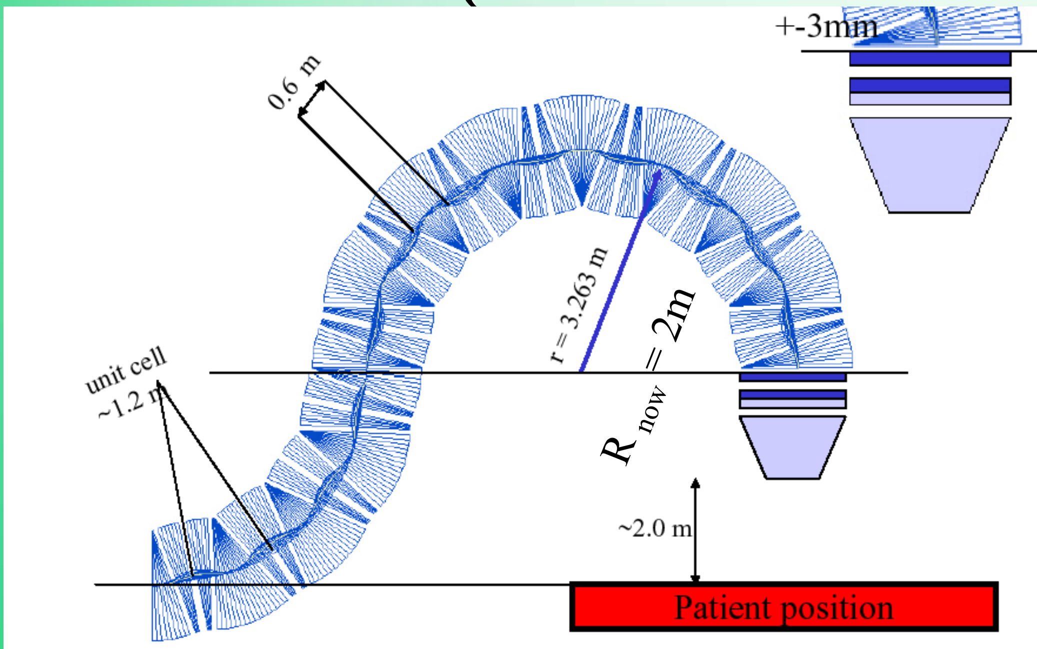
SIZE XS

Introduce the S2C2 cyclotron to reach Extra Small Status

In-plane Gantry - FFAG Optics

(Permanent or SC Magnets)

Patented !



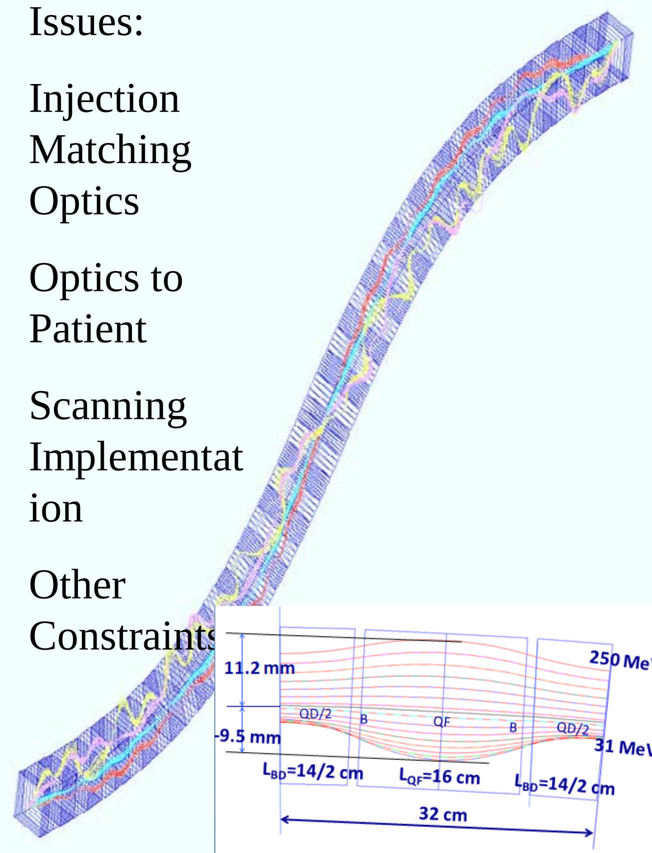
Issues:

Injection
Matching
Optics

Optics to
Patient

Scanning
Implementation

Other
Constraints



Energy Acceptance of Gantry
$\Delta\ \delta > 50\%$ (ΔE from 35 to 250 MeV)
Δ x (within Gantry acceptance) < 2cm?

$(x/\ \delta) = 2/50 = 0.04$cm/% maximum
Range of the energies: 35 MeV — 250 MeV for protons.

- RED color for 250 MeV and
- YELLOW for the 35 MeV.

A lot of magnets, but VERY lightweight !

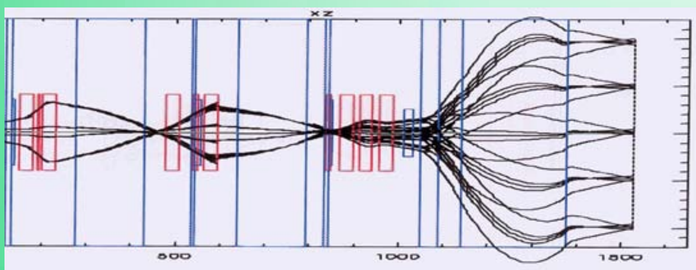
Trbojevic, BNL

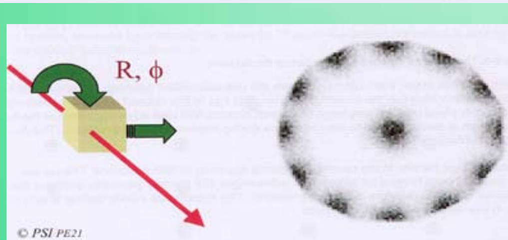
UPSTREAM SCANNING GANTRIES

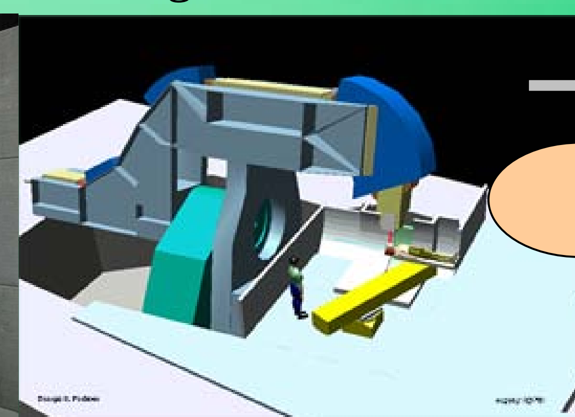
In-Plane Gantry - PSI Gantry 2

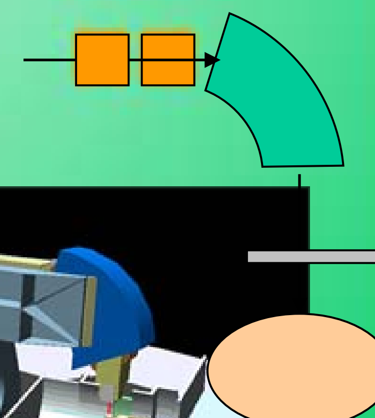
New Opportunities REALIZED? The Ultimate PBS Device?

- **Optics Conditions**
  - Infinite SAD (Point to Parallel from Scan Magnet to ISO) (Adjustable?)
  - EDGE CONTROL (Point to Point R_{12} from Start to ~ISO)
  - Collimator at Start – Beam position independence & 1:1 Imaging
  - Achromatic
  - 80msec Momentum Change









PSI Gantry 2 & MedAustron

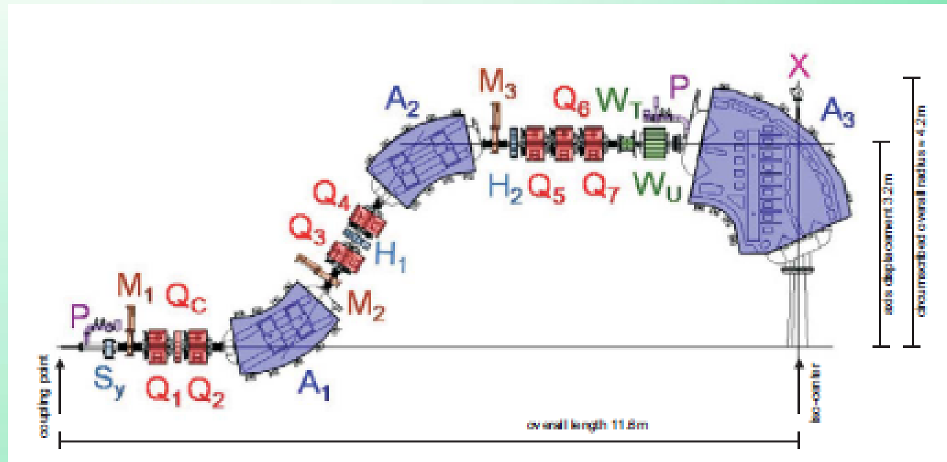
Optics Comparison:

PSI: (Cyclotron)

- In = Out; x = y

MedAustron: (Synchrotron)

- Unequal beam profiles at input
- Overall magnification NOT 1:1
- Utilize "Rotator" with Gantry
- Slower Momentum Change
- SAME layout as PSI 2



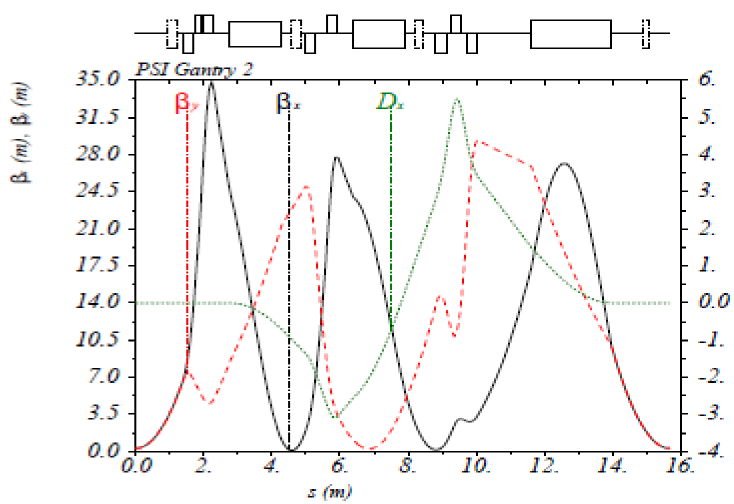


Figure 2: PSI Gantry 2 beam optics characteristics ($\beta_{x,\mathrm{in|out}} = \beta_{y,\mathrm{in|out}} = 0.3\,\mathrm{m}$).

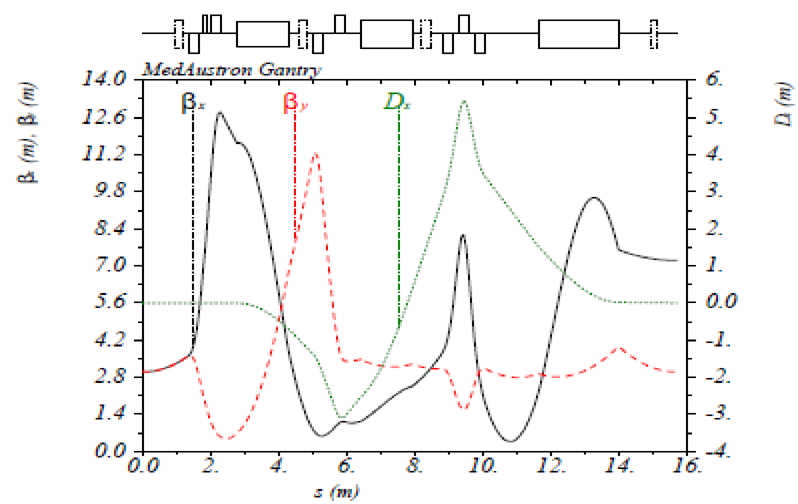
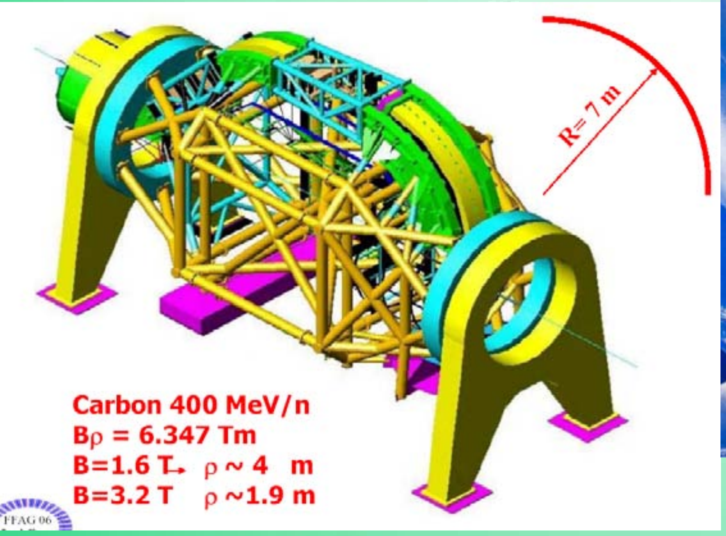


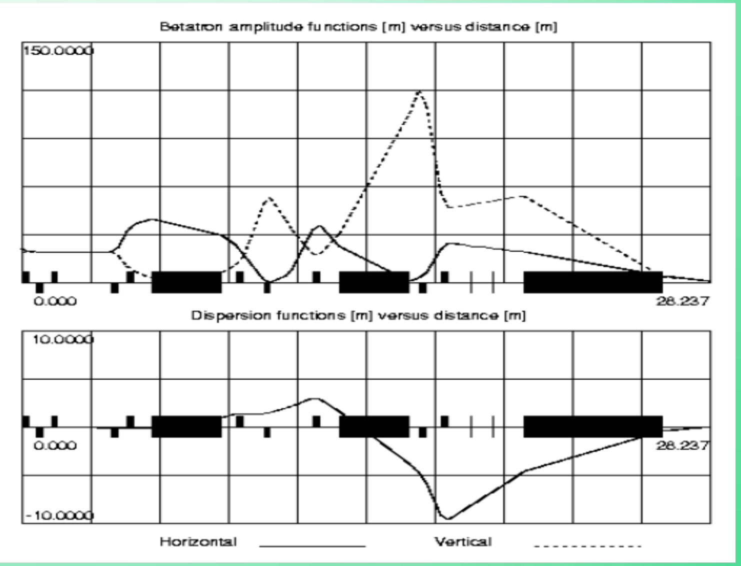
Figure 3: *MedAustron* Gantry nominal beam optics characteristics ($\beta_y = 3\,\mathrm{m}$).

Heidleberg Heavier Ion Gantries

HIT Implementation



630 Tons

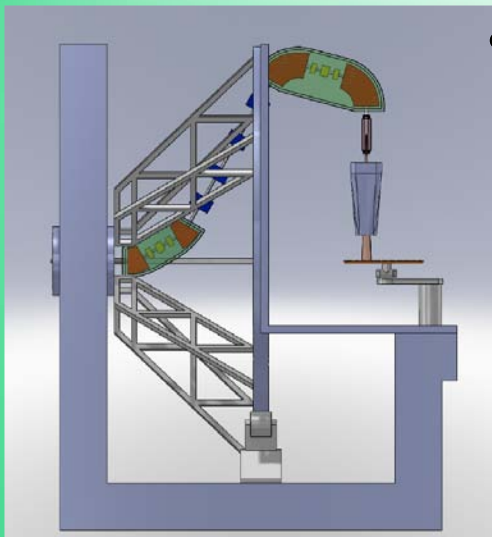


Optics Conditions

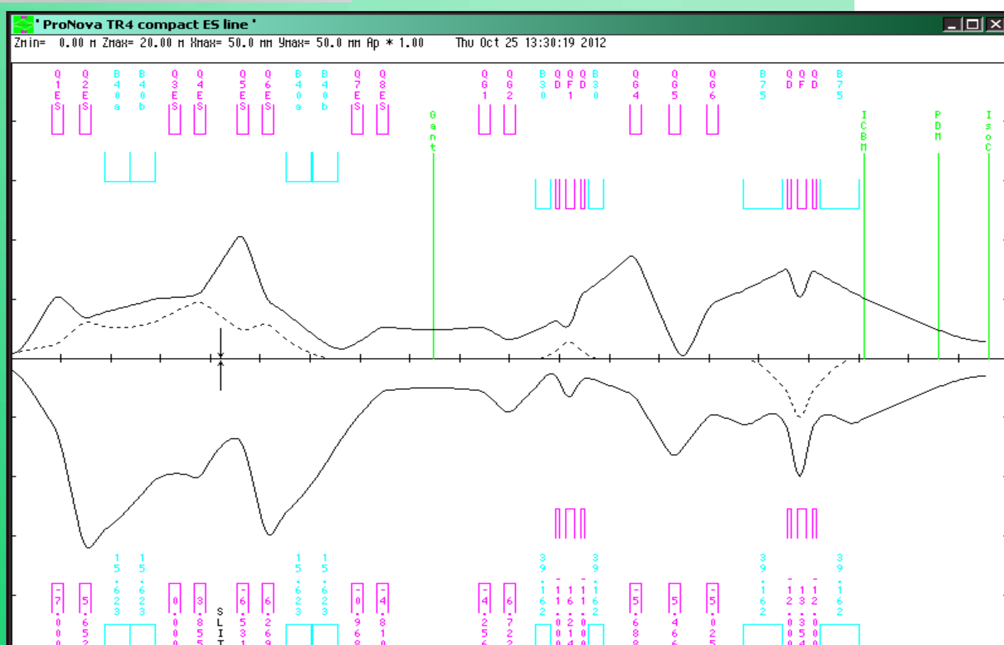
- Accommodate range of emittance and different emittance in x and y.
- Final result independent of Gantry angle
- Generate a spot radius between 2mm and 5mm at ISO
- $R_{11} = R_{22} = 0$ and adjust beam divergence at input for equal final size
- $R_{12} = R_{34}$
- Achromatic

SC GANTRIES

ProNova SC360 Gantry



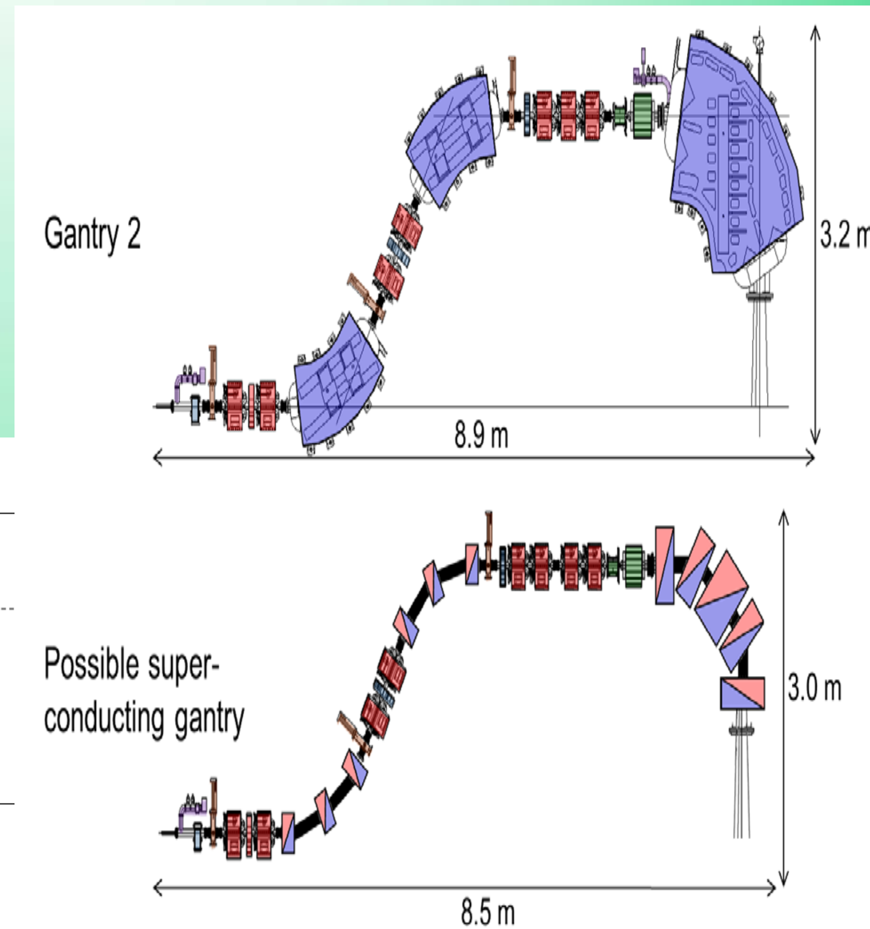
- ProNova Gantry Optics Conditions
  - Achromatic Bend pairs (2)
    - 3% energy bandwidth (SC magnets are slower)
  - Focusing for Scanning
  - SHORT !
    - 210° bend

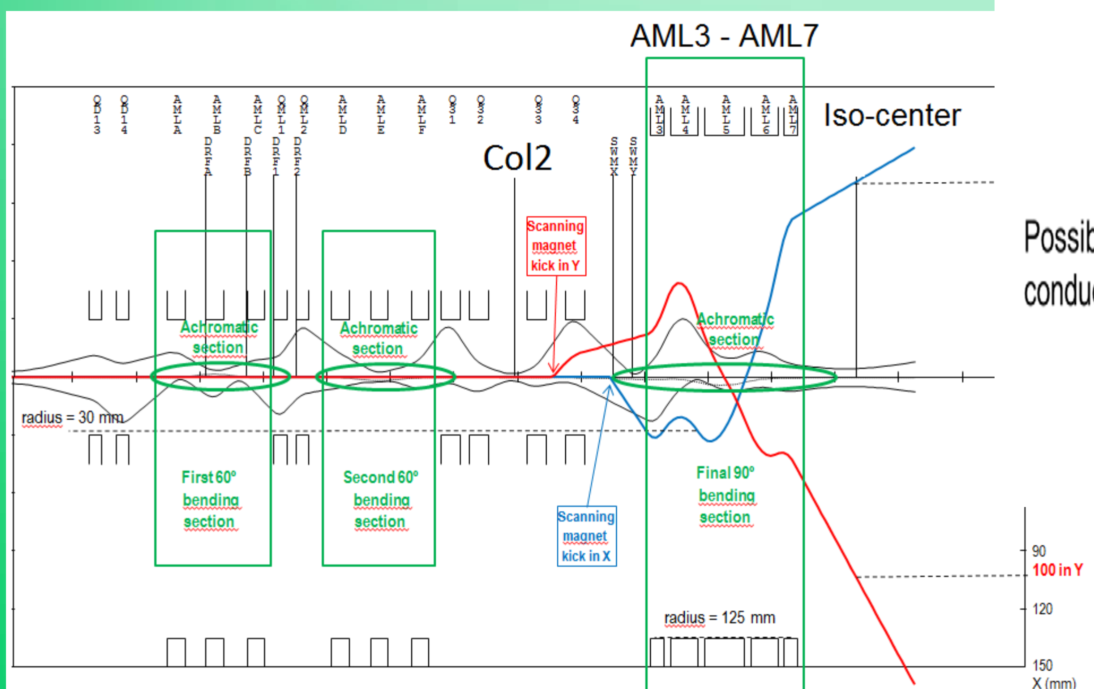


PSI SC Gantry Studies

Key Points:

- Start with PSI Gantry 2 Properties/Geometry
- Increase the Momentum bandwidth (compared to ProNova)





Gerbershagen et. al.

PSI SC Gantry

- PSI SC Gantry Optics Conditions
  - Achromatic Bend pairs
    - 10% energy bandwidth
  - Focusing for Scanning
  - Point to not quite parallel in l plane from Scan dipoles
  - Point to Point to Point (entrance collimator /on board collimator/isocenter)
  - Lowest Energy Range of Gantry – 70 MeV
    - Degrade before final Bend
    - CONTAIN degraded beam (bottom figure)
  - Bandwidth allows for Bragg peak spacing
  - Bandwidth may also allow for ‘quick’ energy changes (only needing to change the dipole fields a few times during the irradiation)

NIRS SC Ion Gantry

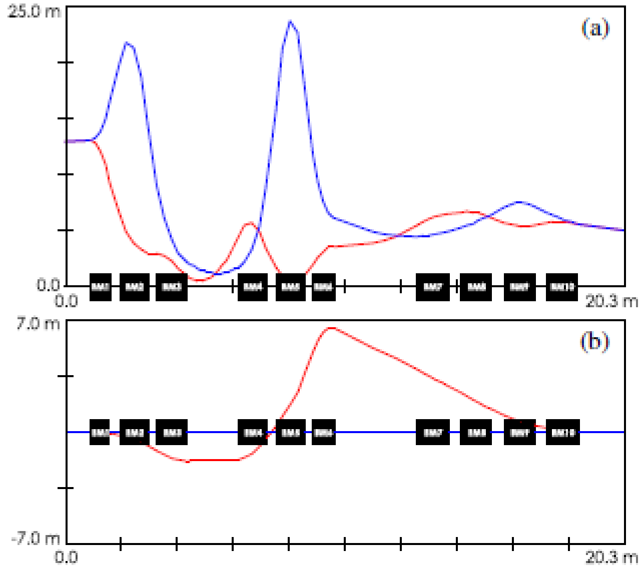
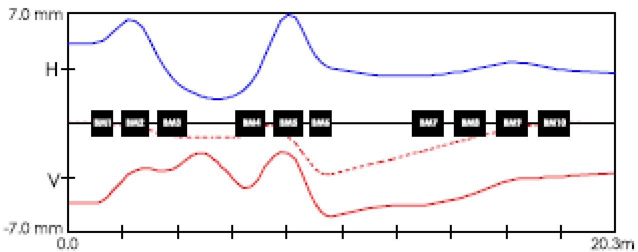
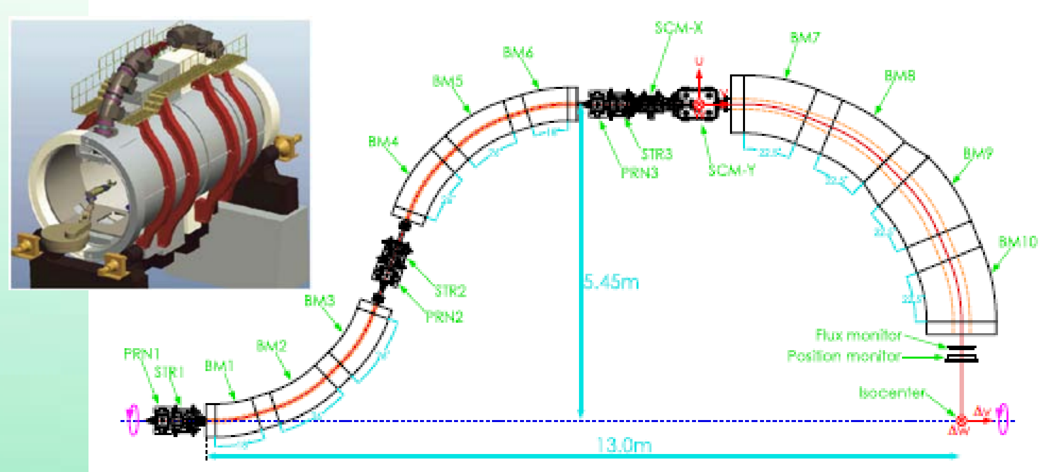


FIG. 3. (a) Beta and (b) dispersion functions of the beam line in the rotating gantry. The blue and red lines show those for the horizontal and vertical coordinates, respectively.





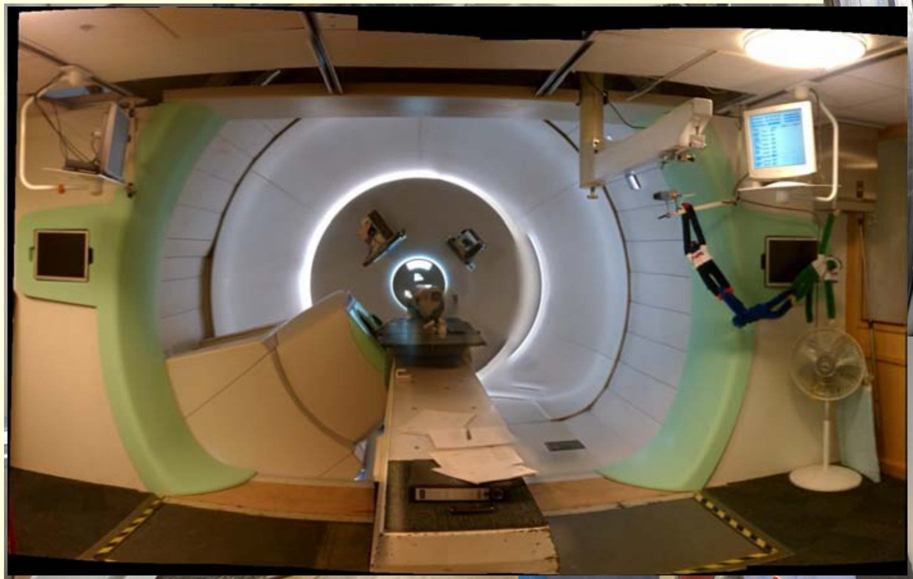
Optics Conditions

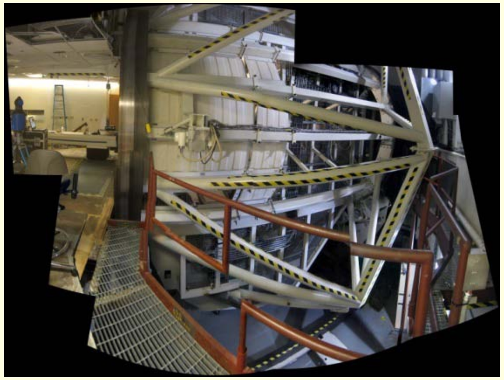
- Combined Function Dipoles (NO Quads)
- σ11=σ22 and waist condition
- Range of beam sizes at ISO
- *Use a thin Scatterer to equalize the emittances (different from Synchrotron)*
- Achromatic
- Parallel Scanned Beam
- Energy Changes within 1 sec (see red line) (Consistent with Accelerator)
- ~ size of a conventional proton gantry

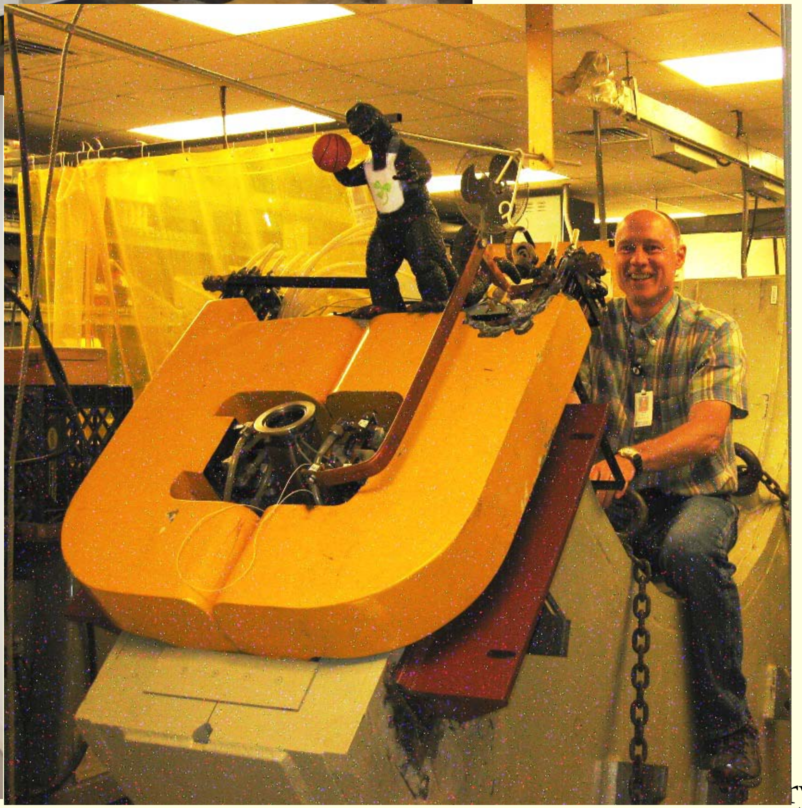
OTHER CONSIDERATIONS

Design for Maintenance *(It will be needed!)*

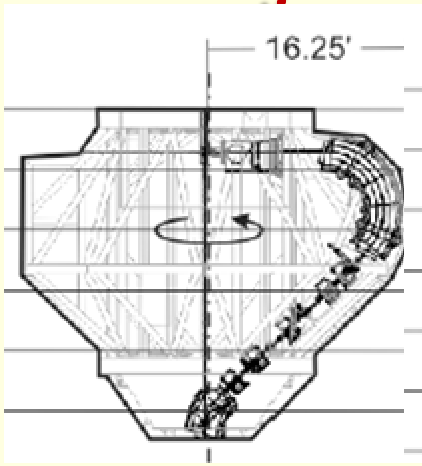
Gantry Dipole Replacement @ MGH



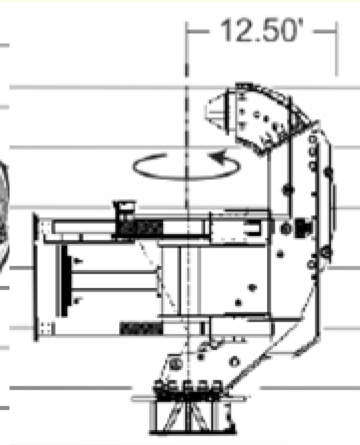





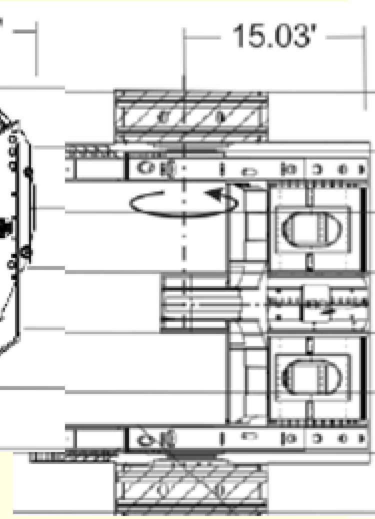
$ize of Gantries



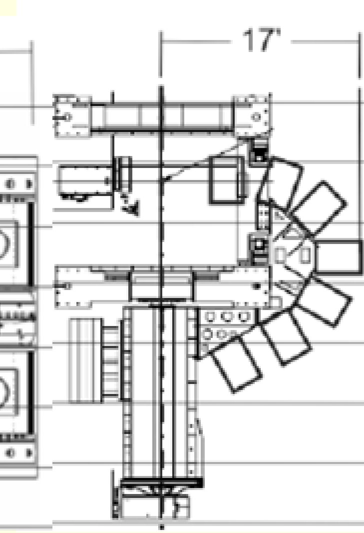
IBA/SHI/
Hitachi
In-Plane



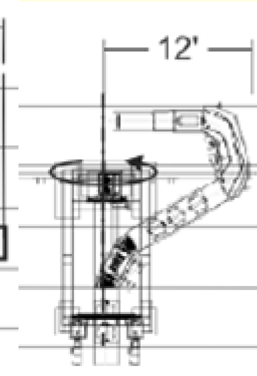
IBA
Proteus
One



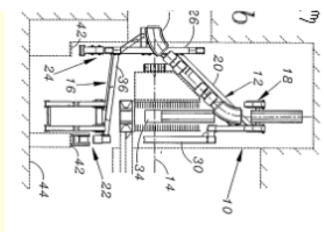
MeVIon



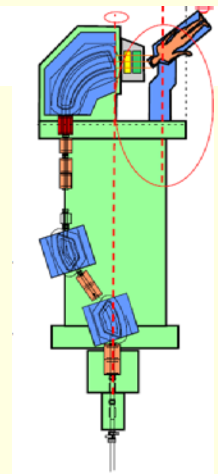
ProTom



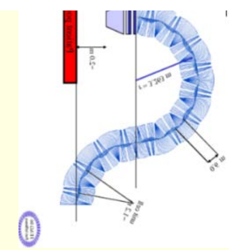
ProNova



SHI Corkscrew
Note – Corkscrew gantry is 'shortest' length.

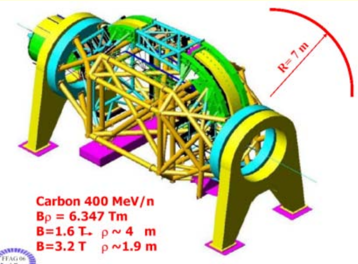


PSI 1 shortest radius



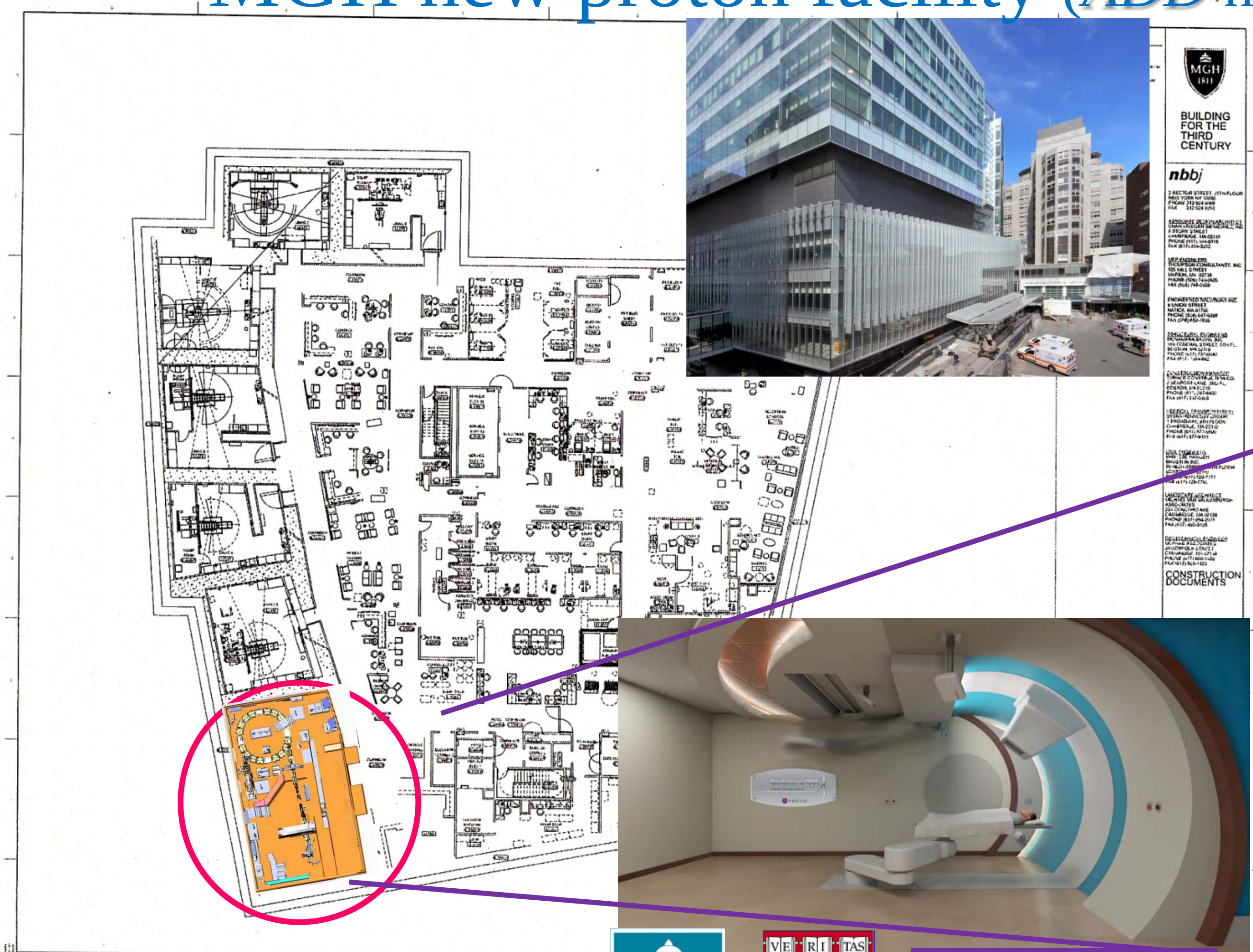
FFAG is the lightest

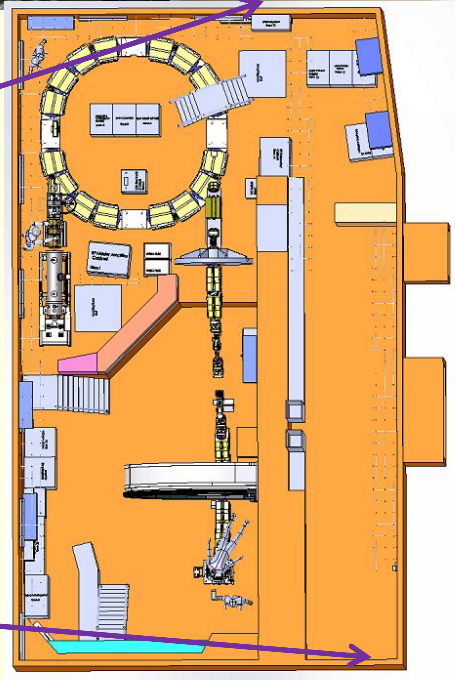
DOE Patents?



Challenge 4: Install within an existing Department

MGH new proton facility (*ADD* not Replace)





Okay – we added a pit

The Francis H. Burr Proton Therapy Center

Thank You !