MASSACHUSETTS GENERAL HOSPITAL
CANCER CENTER℠

Aspects of optimizing the pencil beam performance in a universal nozzle

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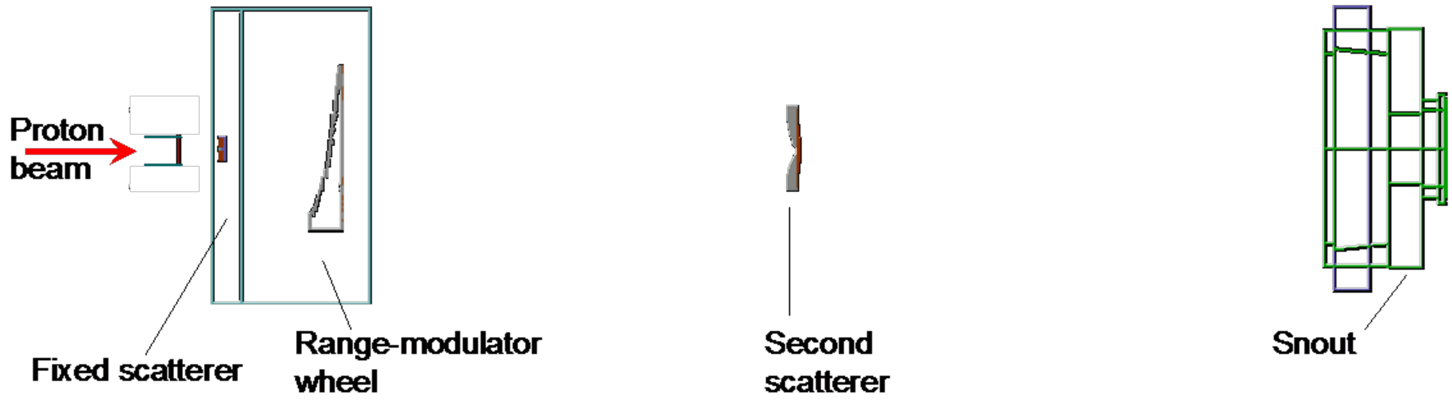
Outline

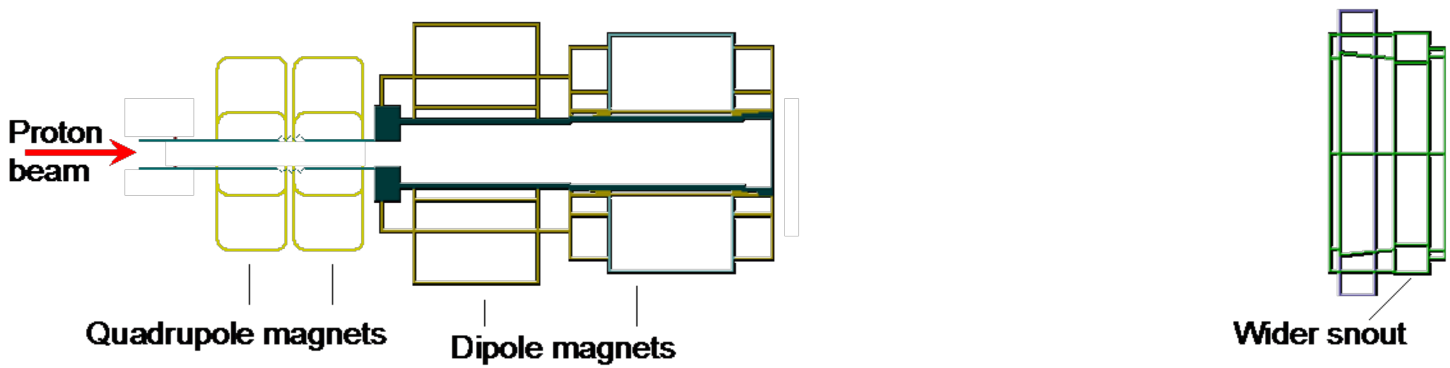
- Introduction to delivery equipment
  - Universal nozzle for DS, PBS, US, …
- Aim is to optimize the pencil beam width
- Original design for the dipole vacuum chamber
- New chamber solutions
  - Vacuum
  - Helium

Universal proton therapy nozzle

Double Scattering

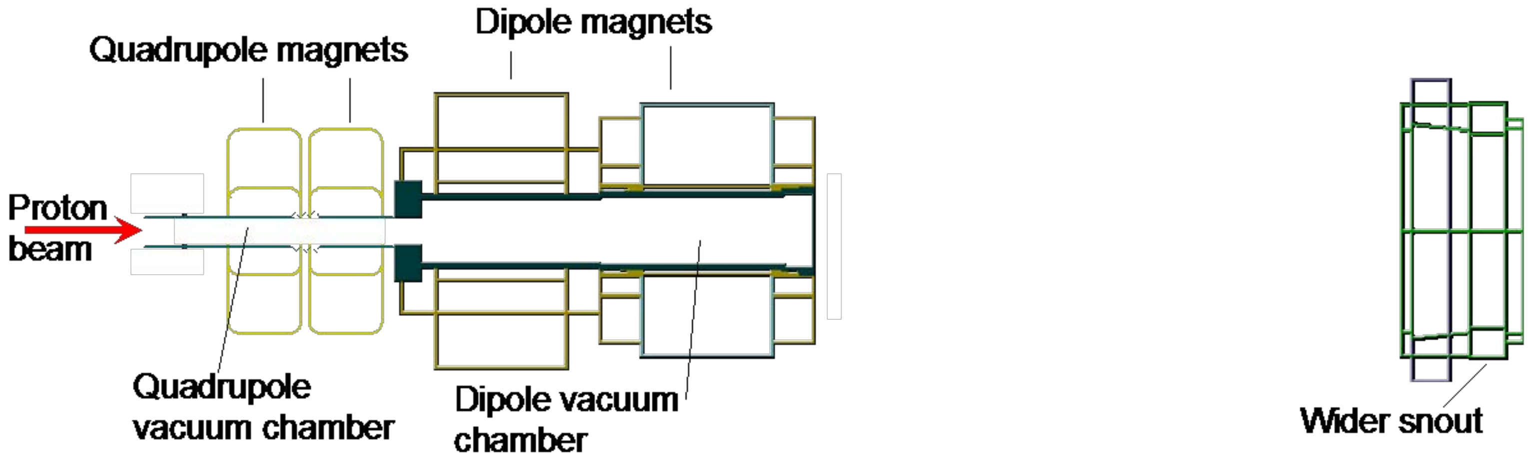


Pencil-Beam Scanning (PBS)

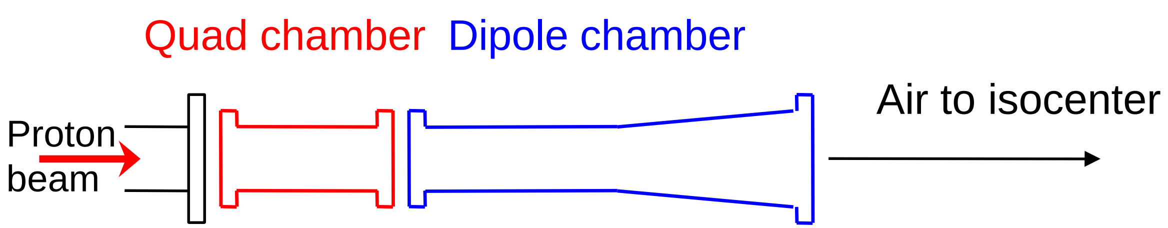


Universal proton therapy nozzle

- Vacuum chambers are employed when the nozzle is configured for PBS



- Schematic of the chamber positions



Optimizing the pencil beam width

$$\sigma^2 = (1 + 0.038\ln(\rho L/X_0))^2 \int_{(z_{up}-L)}^{z_{up}} \left(\frac{13.6\ \mathrm{MeV}}{cp}\right)^2 \frac{\rho}{X_0} z^2 dz$$

Highland approximation of the theory of Molière

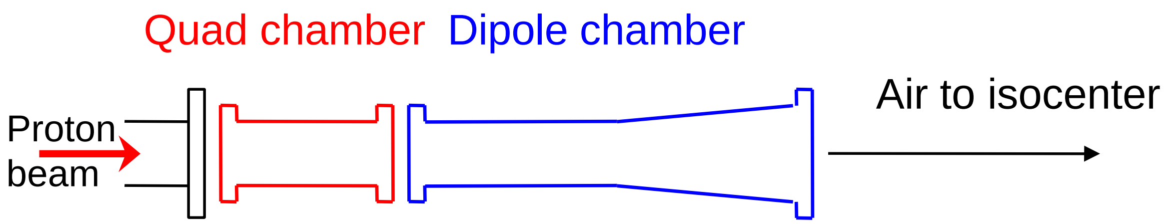
For E_{beam} = 180 MeV (R = 21.6 cm), zero emittance and no energy loss

Material	Upstream Position z_{up} (cm)	Thickness/ Rad. Length $\rho L / X_0$ (%)	Calculated σ (cm)	Monte Carlo comparison σ (cm)
Titanium window	290	0.07	0.23	0.22
Quad air chamber	290	0.13	0.30	0.30
Quad helium chamber	290	0.007	0.06	0.07
Kapton window	250.9	0.009	0.08	0.09
Dipole air chamber	250.9	0.25	0.34	0.34
Dipole helium chamber	250.9	0.014	0.07	0.07
Kapton window	176.1	0.009	0.05	0.06
Air volume to isocenter	176.1	0.58	0.26	0.24

Although- the calculated σ may have greater than 11% uncertainty for $\rho L / X_0 < 0.1\%$

Optimizing the pencil beam width

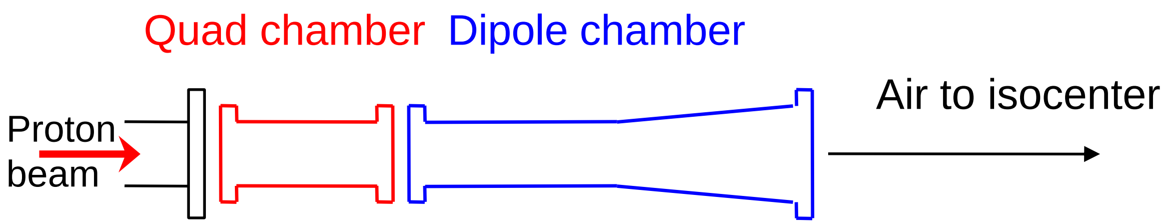
Combining the contribution from material in all chambers and windows



		P energy = 110 MeV		P energy = 180 MeV	
Quad chamber	Dipole chamber	Calculated σ (cm)	Monte Carlo σ (cm)	Calculated σ (cm)	Monte Carlo σ (cm)
Vac	Vac	0.420	0.427	0.264	0.271

Optimizing the pencil beam width

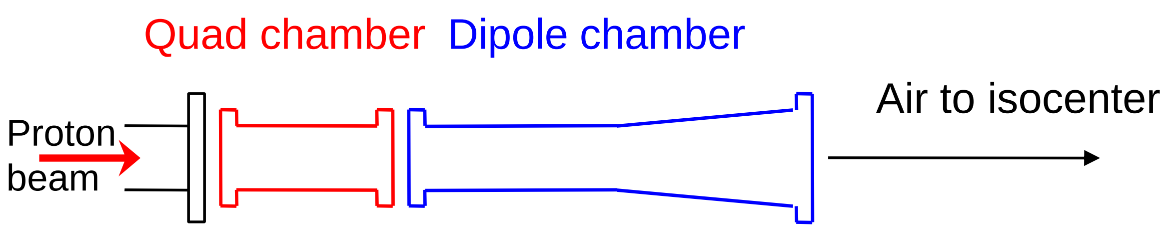
Combining the contribution from material in all chambers and windows



Quad chamber	Dipole chamber	P energy = 110 MeV Calculated σ (cm)	P energy = 110 MeV Monte Carlo σ (cm)	P energy = 180 MeV Calculated σ (cm)	P energy = 180 MeV Monte Carlo σ (cm)
Vac	Vac	0.420	0.427	0.264	0.271
Vac	He	0.488	0.491	0.308	0.310

Optimizing the pencil beam width

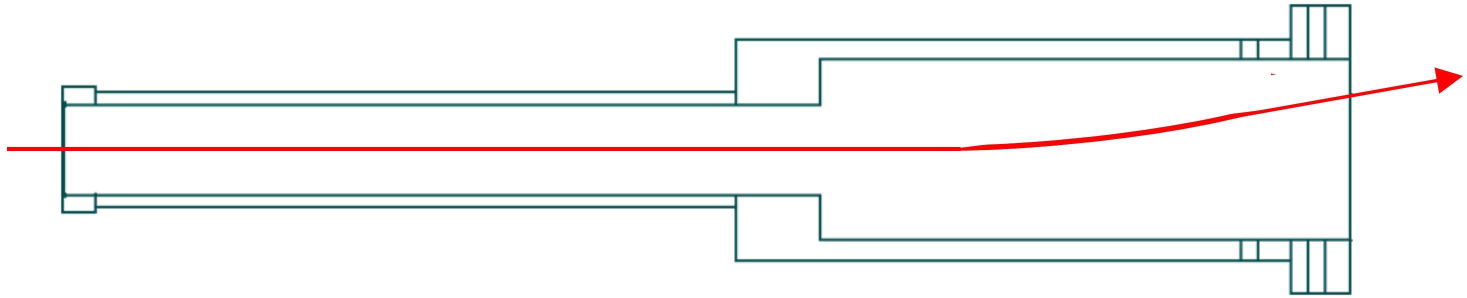
Combining the contribution from material in all chambers and windows



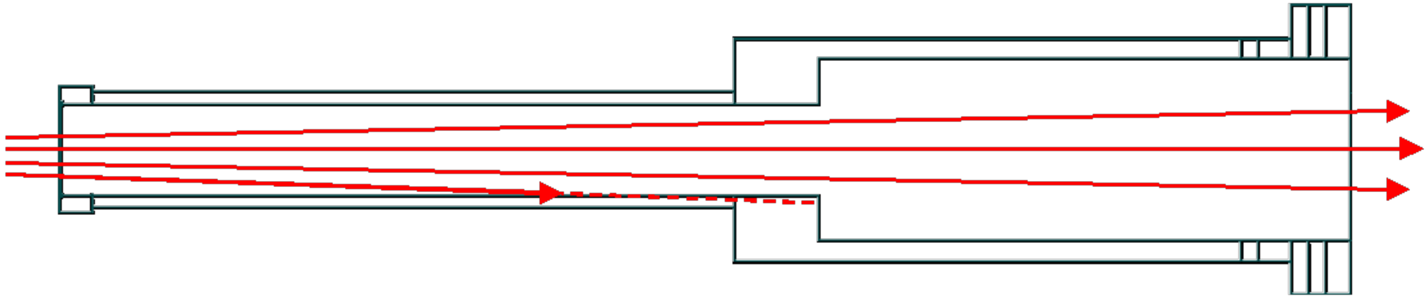
		P energy = 110 MeV		P energy = 180 MeV	
Quad chamber	Dipole chamber	Calculated σ (cm)	Monte Carlo σ (cm)	Calculated σ (cm)	Monte Carlo σ (cm)
Vac	Vac	0.420	0.427	0.264	0.271
Vac	He	0.488	0.491	0.308	0.310
Vac	Air	0.719	0.742	0.453	0.469

Dipole vacuum chamber

• The original design for the dipole vacuum chamber is acceptable for PBS

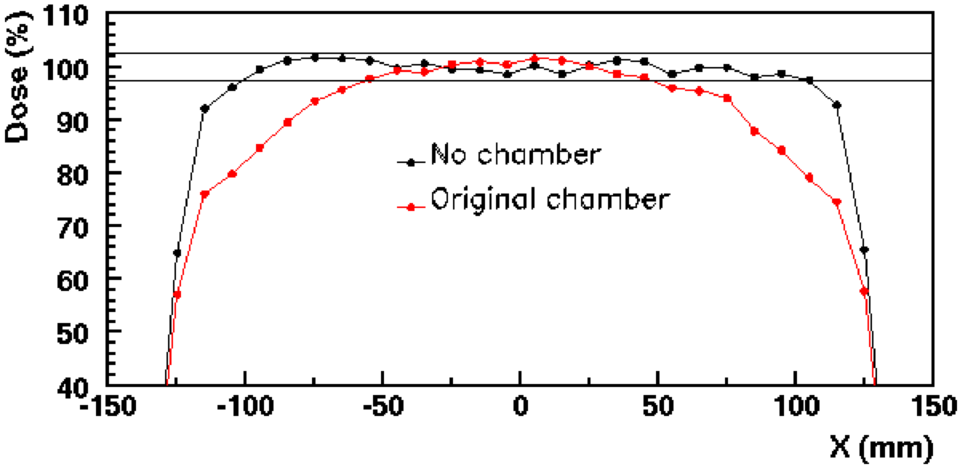


•The dipole vacuum chamber can not, however, be removed for DS treatments



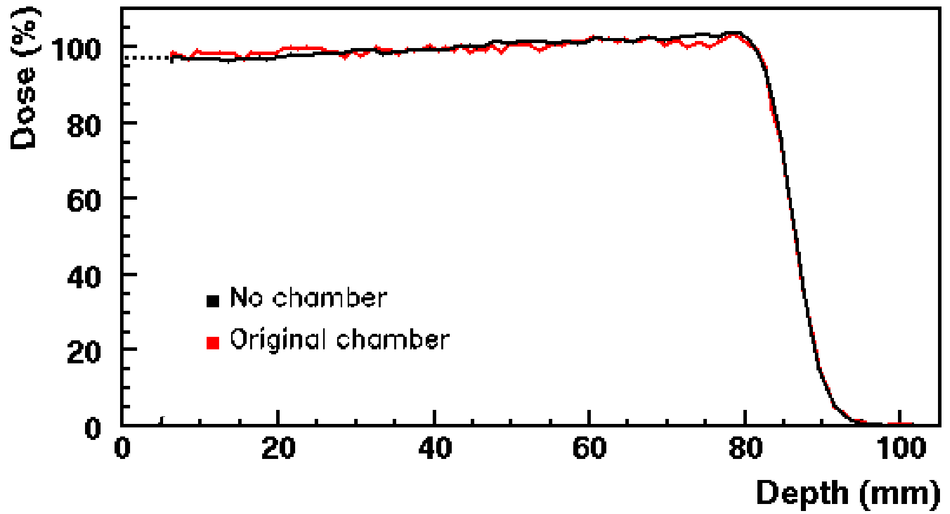
•Thus, perturbations for DS need to be assessed

Effect of the walls of the chamber on DS



Monte Carlo simulations

Field flatness is reduced in the X direction, which is the axis of rotation of the gantry

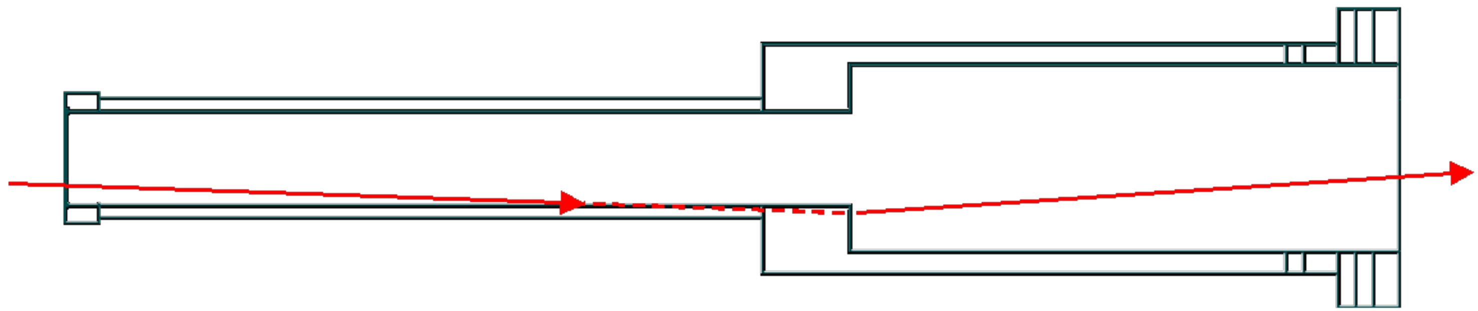


Slight change in slope

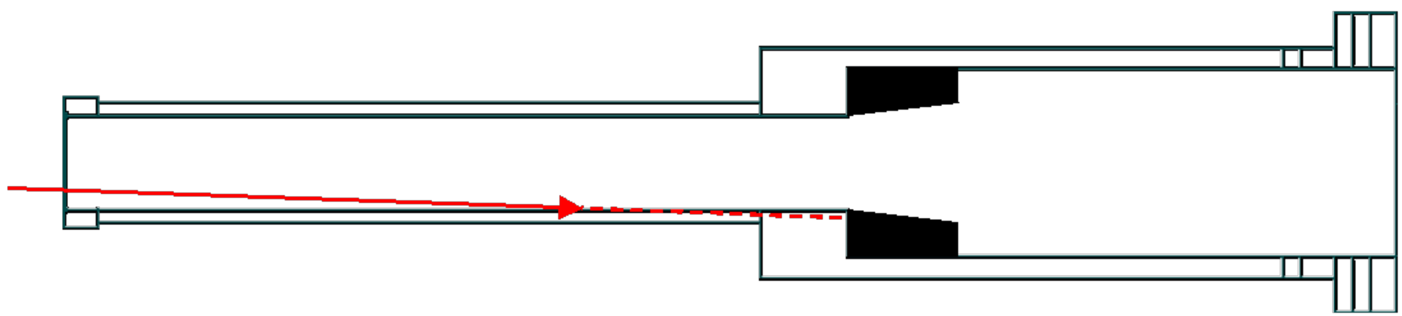
4% change in the output factor

Possible design improvement

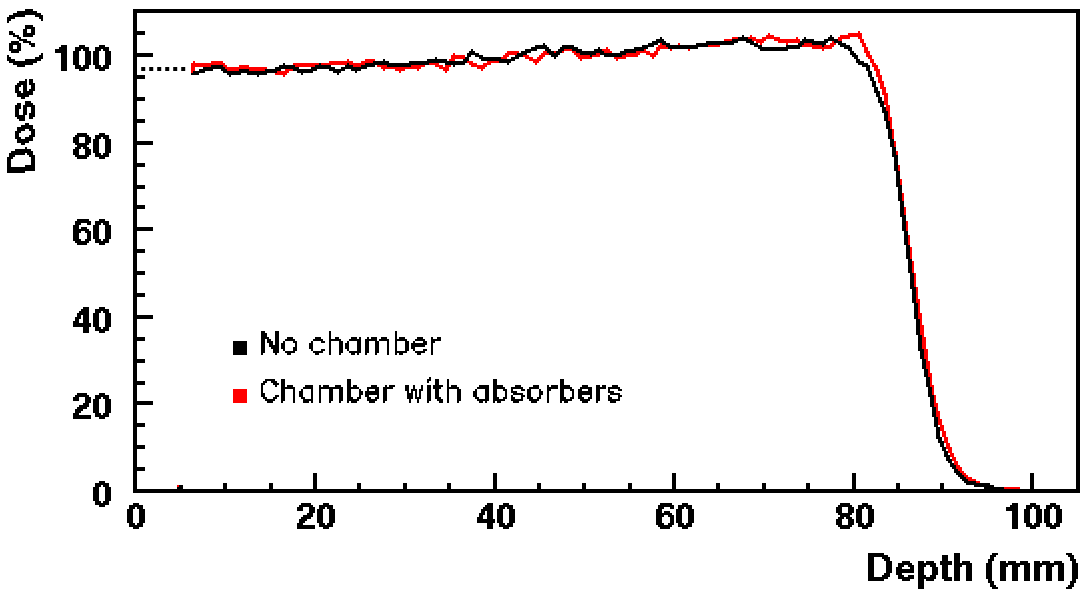
- Contamination comes from protons with reduced energy



- Smoothing edges and high-density absorbing material reduces this contamination



Possible design improvement

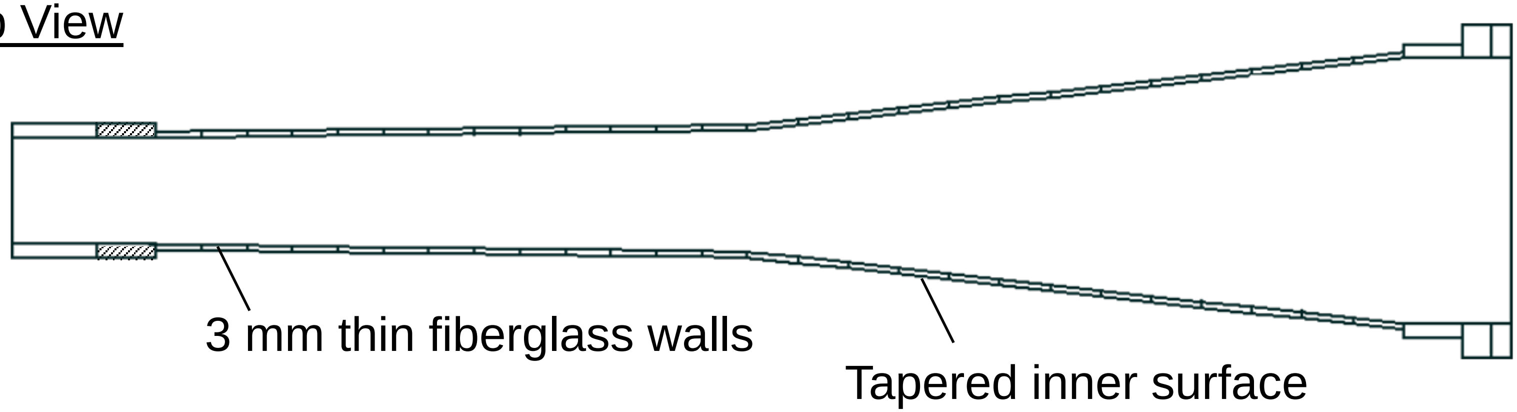


Better agreement in the slope
1.5% change in the output factor

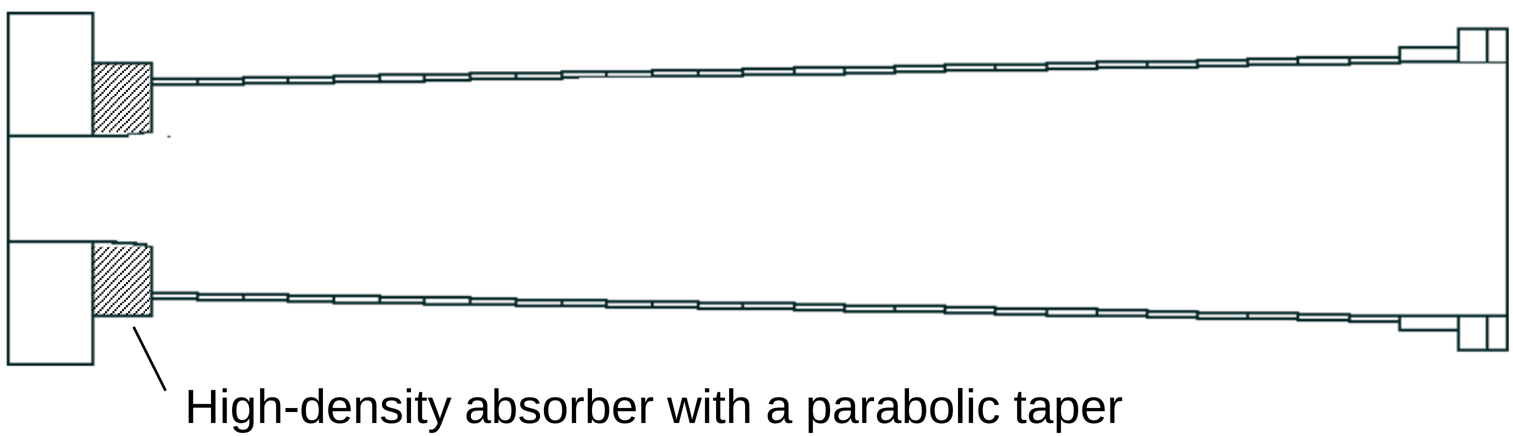
- However, the field flatness was not improved with this design
- An improved design is needed

New vacuum chamber solution

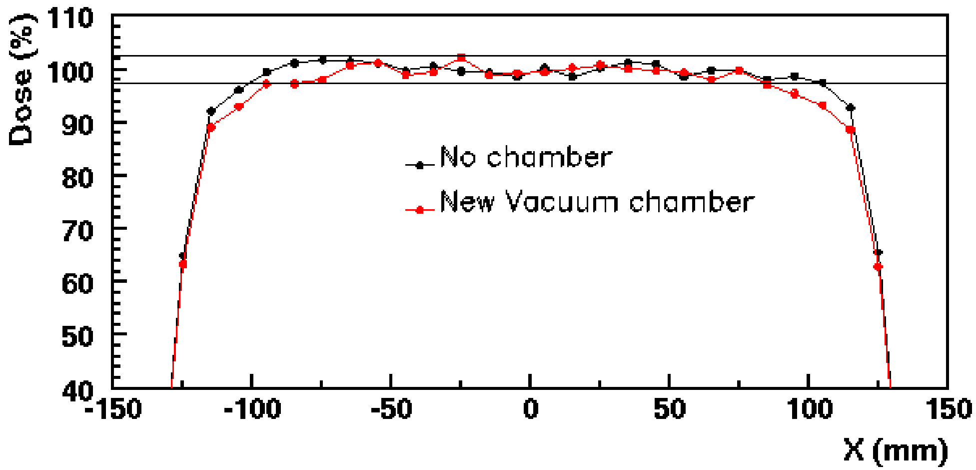
Top View



Side view

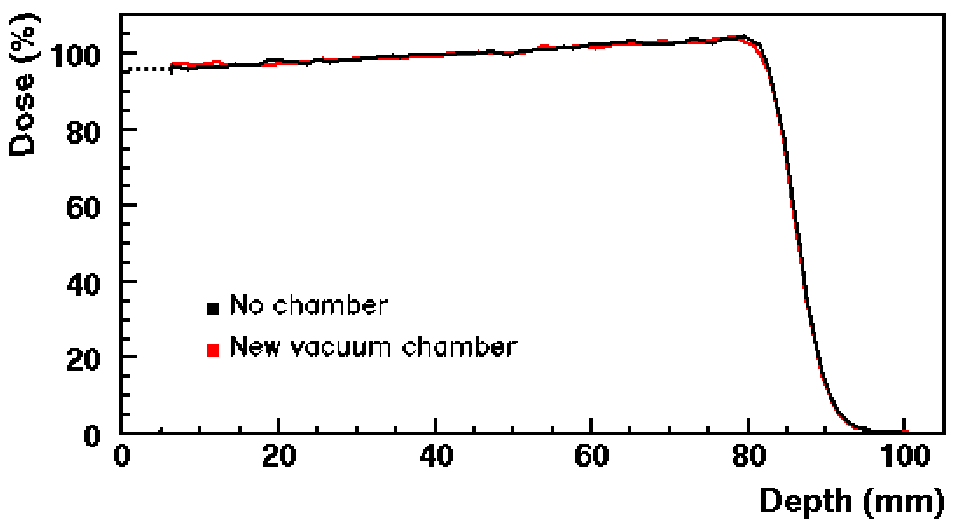


New vacuum chamber solution



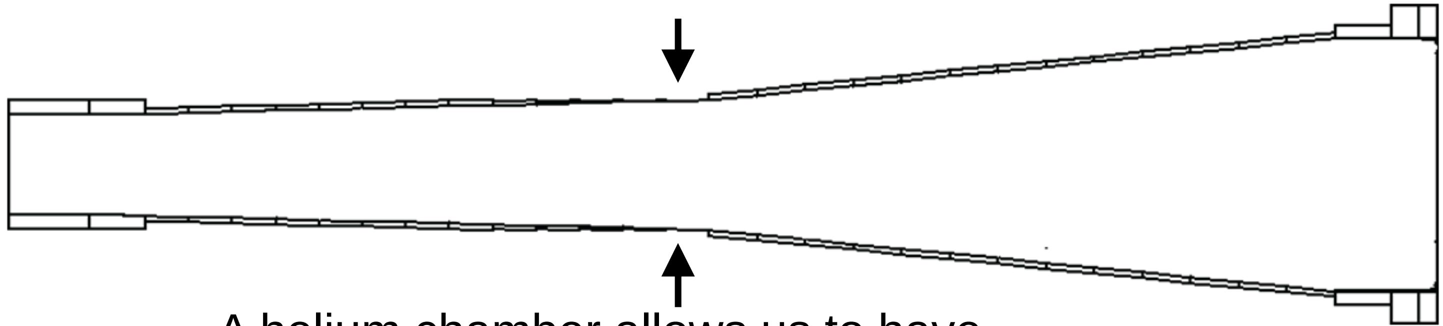
Monte Carlo simulations

Field flatness is greatly improved, but there is still a reduction in the field diameter

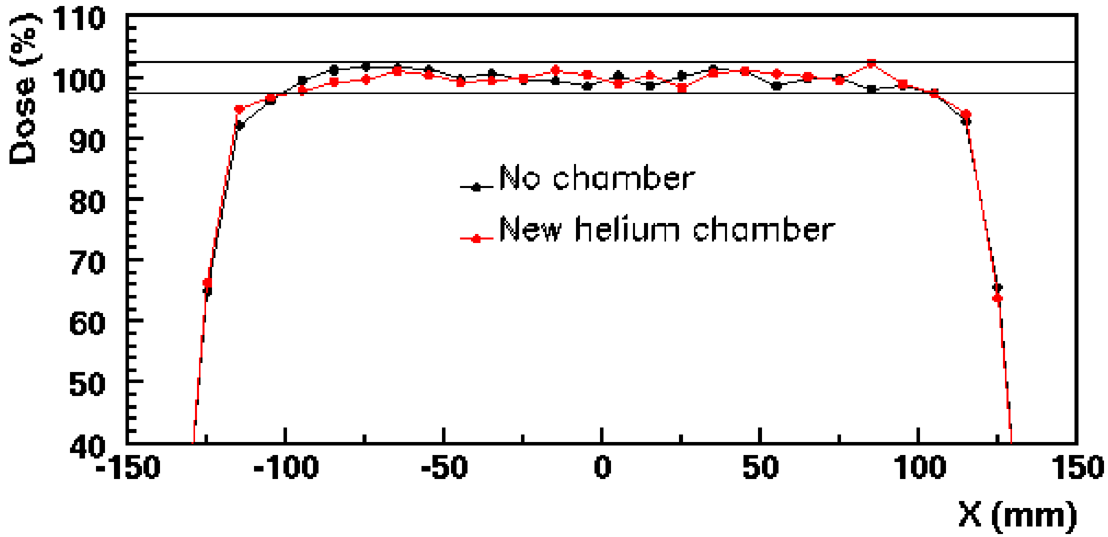


Slope has good agreement
0.3% change in the output factor

Helium chamber solution



A helium chamber allows us to have thin walls in strategic locations



Helium chamber has negligible effect on field flatness

Summary

- Acceptable PBS performance is achieved using either a helium or vacuum chamber inside the dipoles.
- A vacuum chamber reduces the beam width in PBS by 16% compared to a helium chamber
  - 0.264 cm vs. 0.308 cm at 180 MeV and 0.420 cm vs. 0.488 cm at 110 MeV
- However, a vacuum chamber reduces the usable DS field radius by 1.5 cm
  - Cannot be corrected by additional upstream scatterer
- Other factors for consideration
  - Construction of the chamber
  - Filling the helium chamber and maintaining purity
  - Patient safety
  - …

Thank you!

IBA - For support for my travel

Field flatness in Korea with the VC