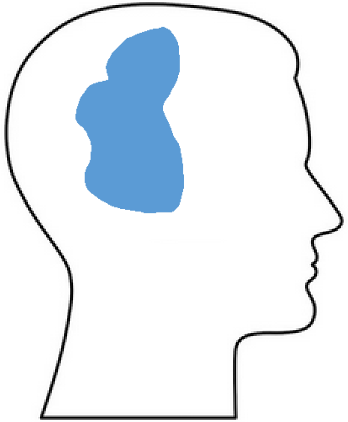
PAUL SCHERRER INSTITUT
PSI

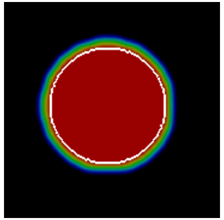
Vivek Maradia :: Center for Proton Therapy :: Paul Scherrer Institute

Different methods for increasing transmission in cyclotron-based proton therapy facilities

09.12.2022 CYC 2022, Beijing, China

Pencil Beam Scanning proton therapy

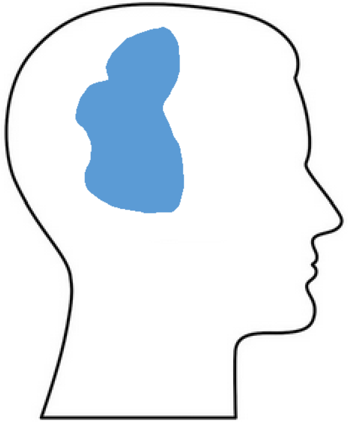


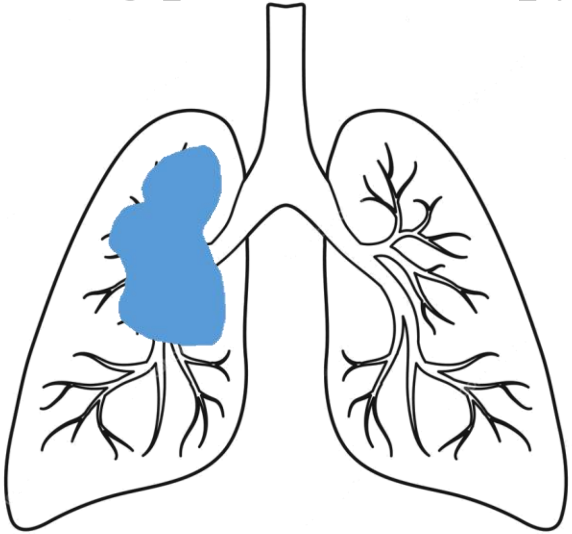


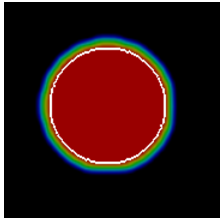
https://4570book.info/amazing-cliparts/kopf-mensch-clipart-fish.html

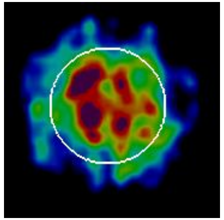
https://de.depositphotos.com/130440300/stock-illustration-lungs-icon-in-outline-style.html

Pencil Beam Scanning proton therapy







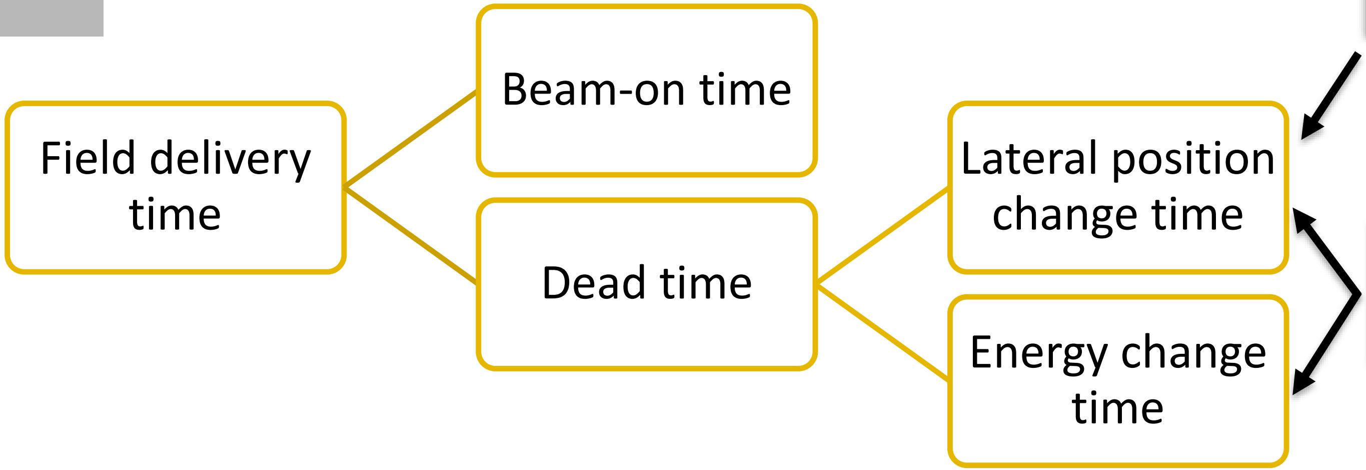


https://4570book.info/amazing-cliparts/kopf-mensch-clipart-fish.html

https://de.depositphotos.com/130440300/stock-illustration-lungs-icon-in-outline-style.html

PBS field treatment delivery time

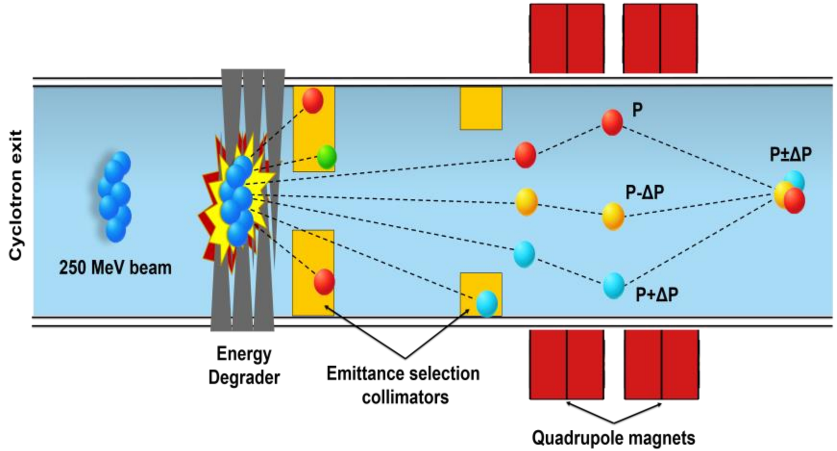
Spot reduced
Planning
Van de water et al. 2020



Universal and dynamic
ridge filter
V. Maradia et al. 2022,

Shorter field delivery times are advantageous

Problem with Energy degradation

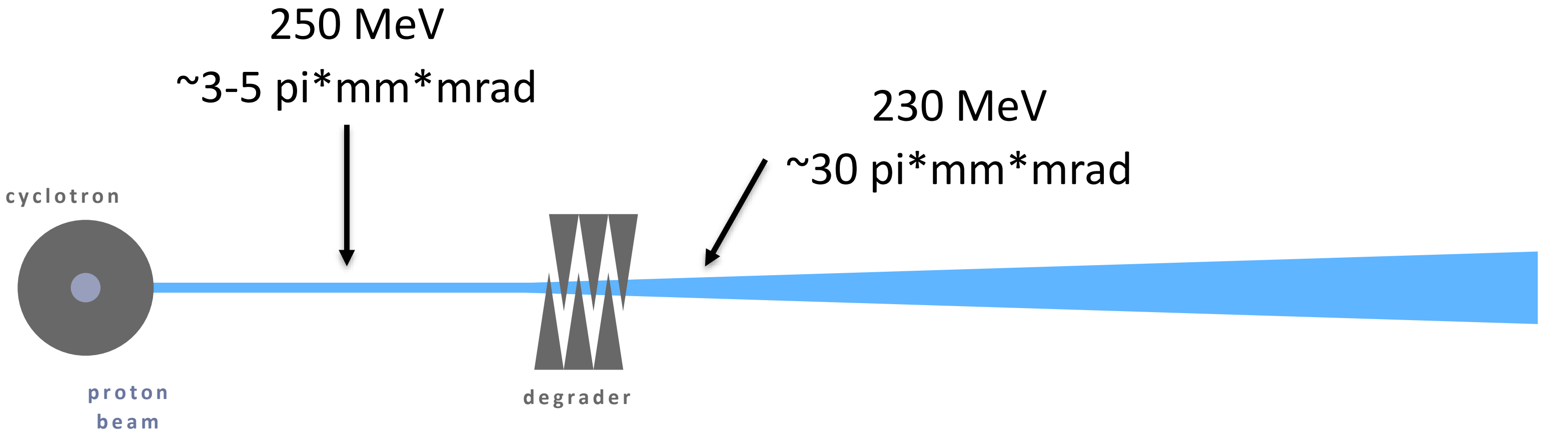


Energy Degradation

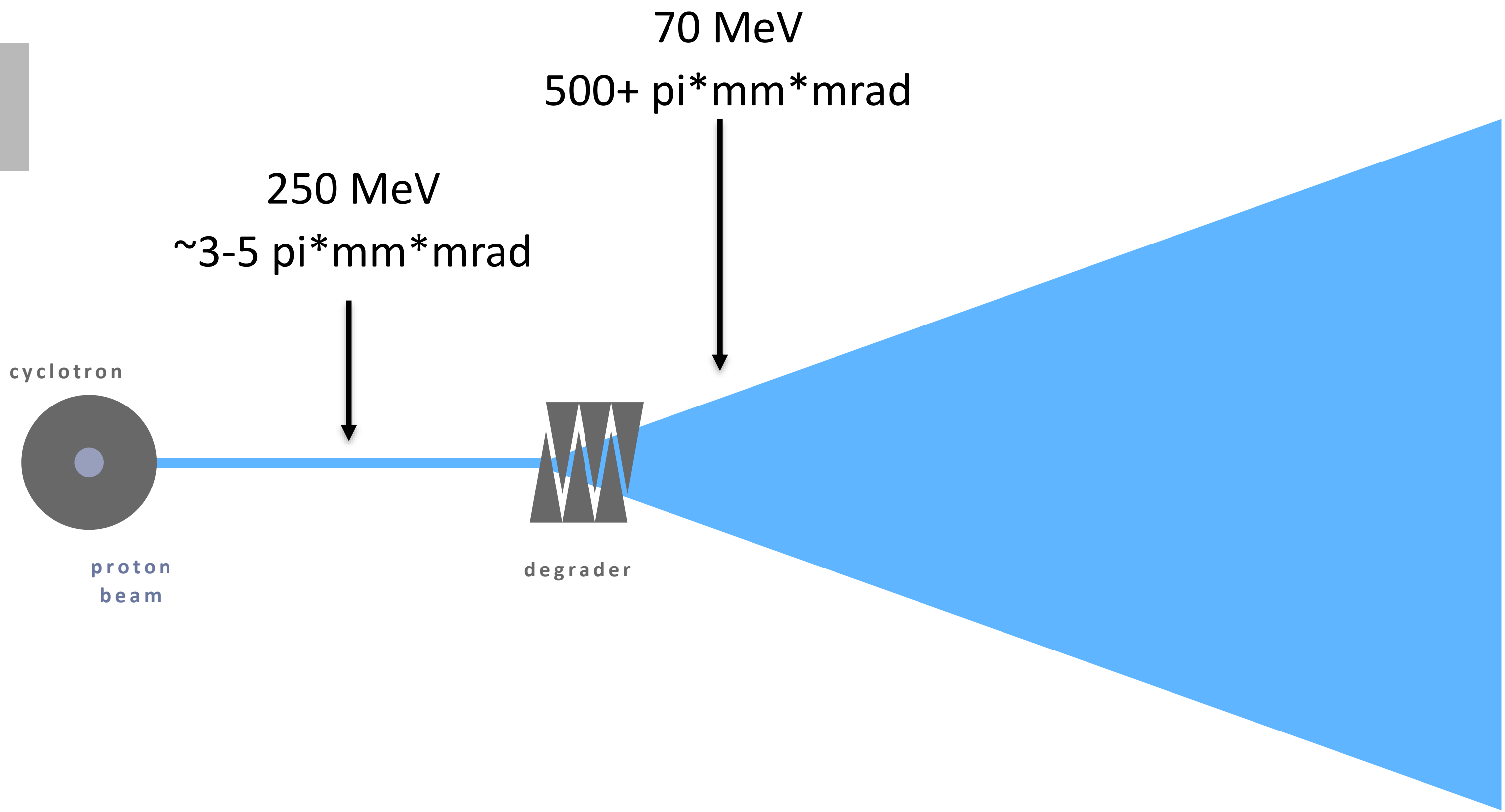
Increase in emittance

Increase in energy/momentum spread

Emittance

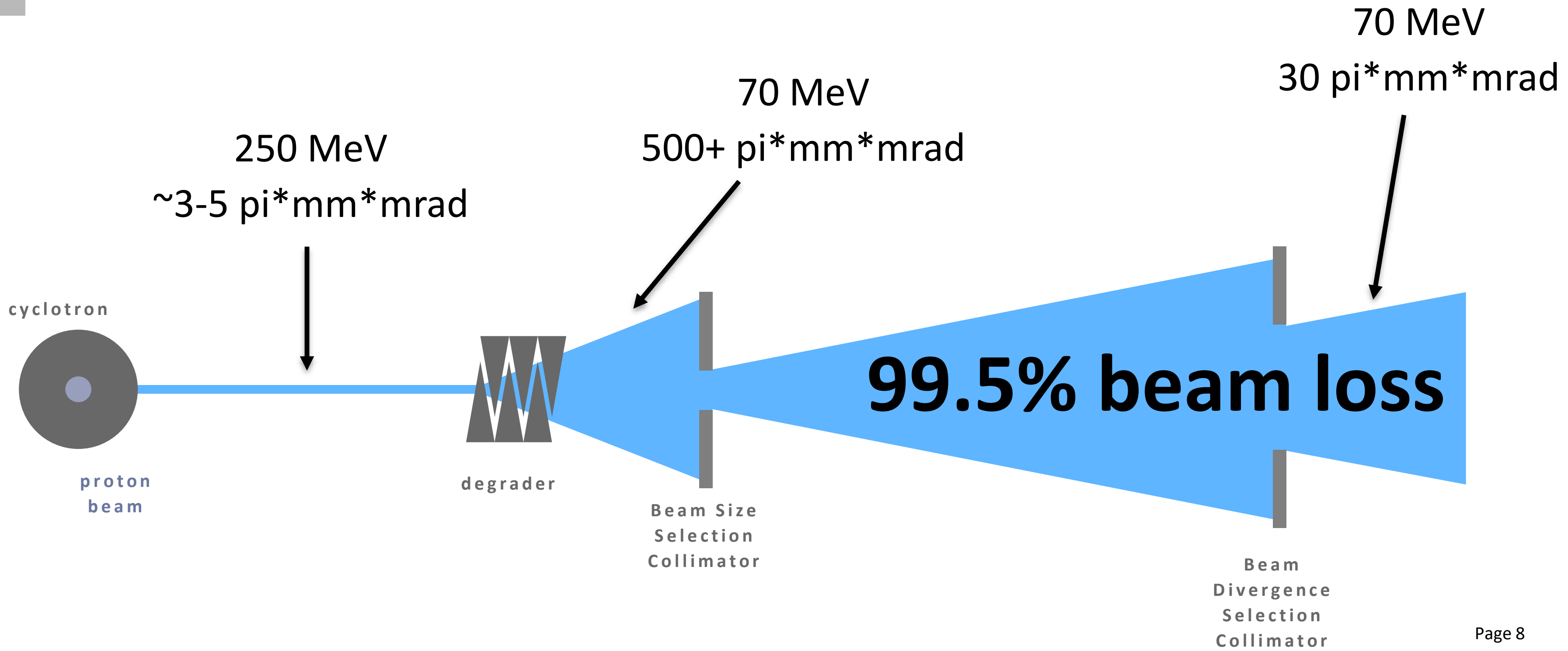

250 MeV
~3-5 pi*mm*mrad
230 MeV
~30 pi*mm*mrad
cyclotron
proton
beam
degrader

Emittance

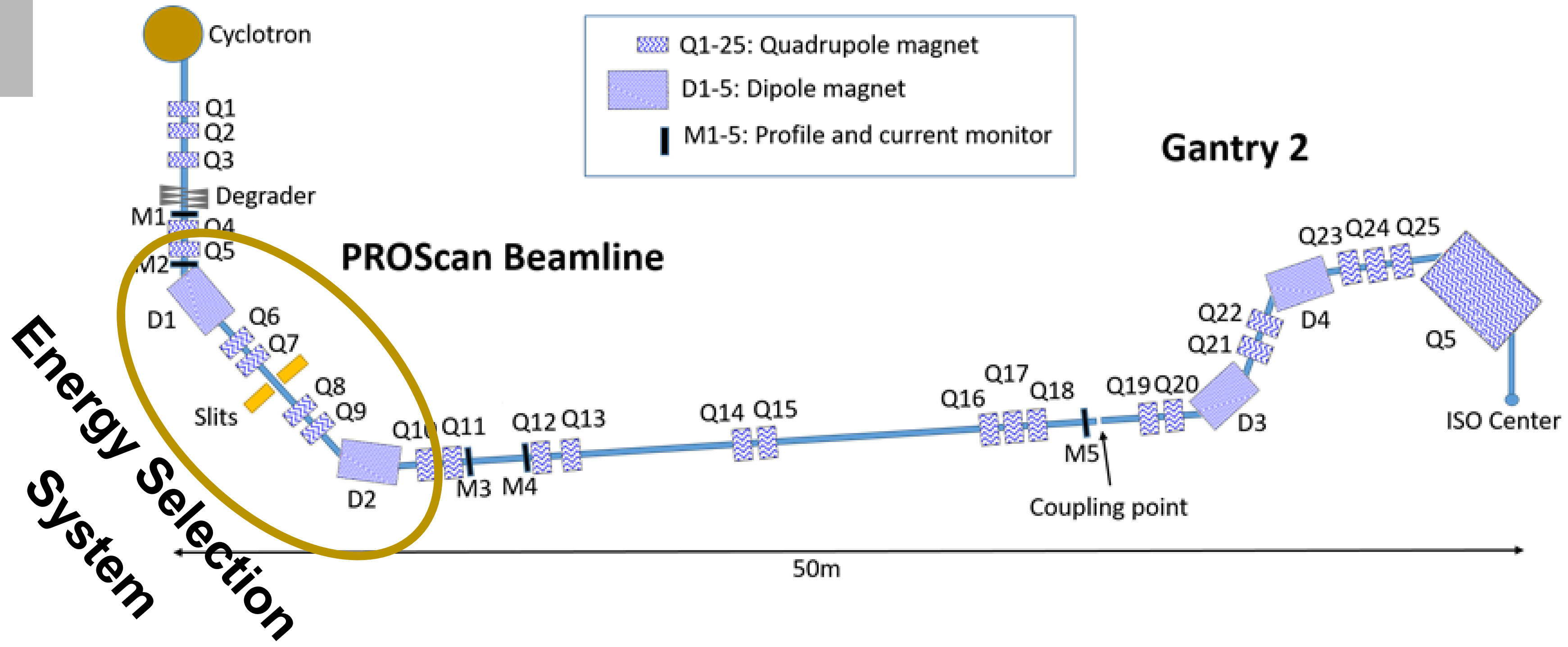

70 MeV
500+ pi*mm*mrad
250 MeV
~3-5 pi*mm*mrad
cyclotron
proton
beam
degrader

Emittance

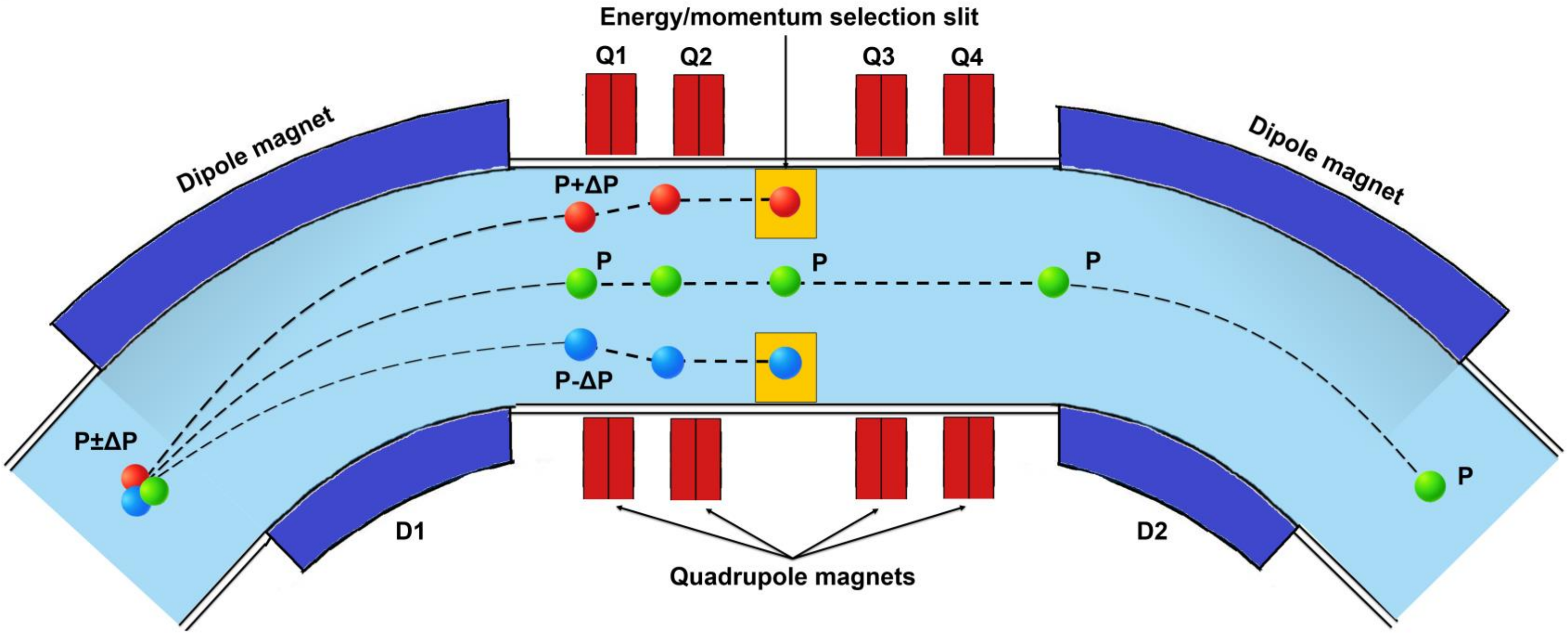
Most of the facilities transports 30 pi*mm*mrad or less emittance



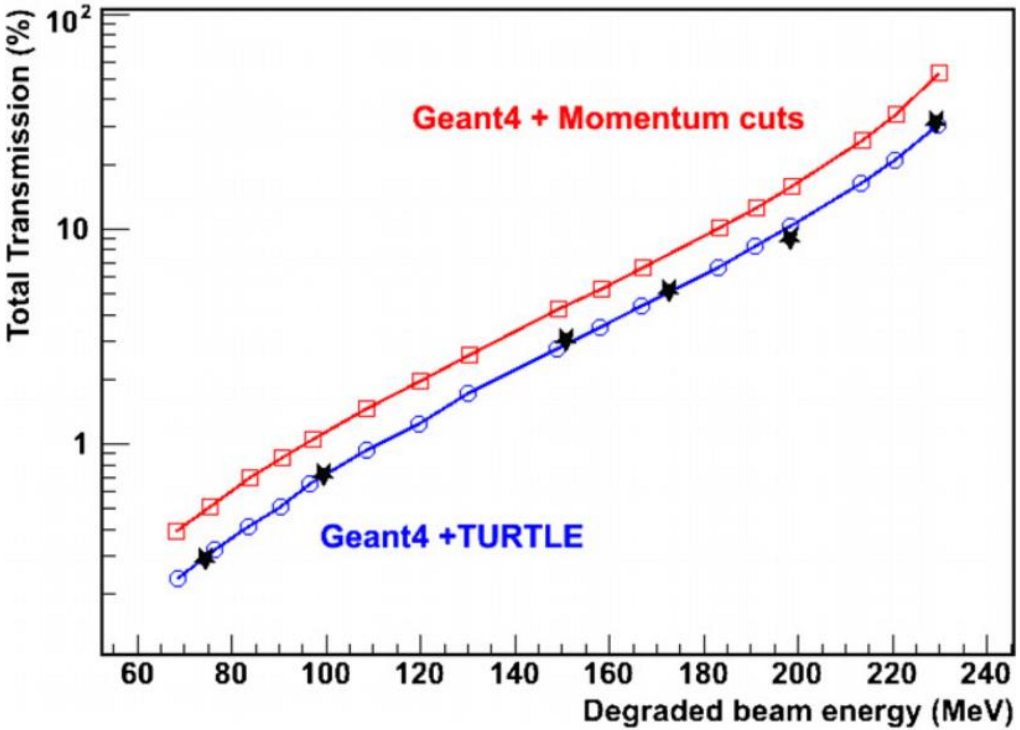
PROScan beamline



Energy selection system



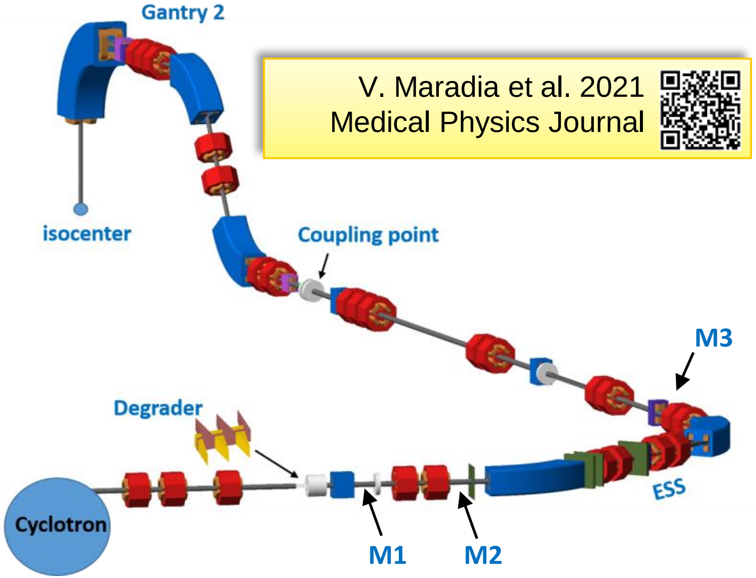
Transmission through degrader and ESS



M. J. van Goethem et al 2009, Phys. Med. Biol.

Simulation model

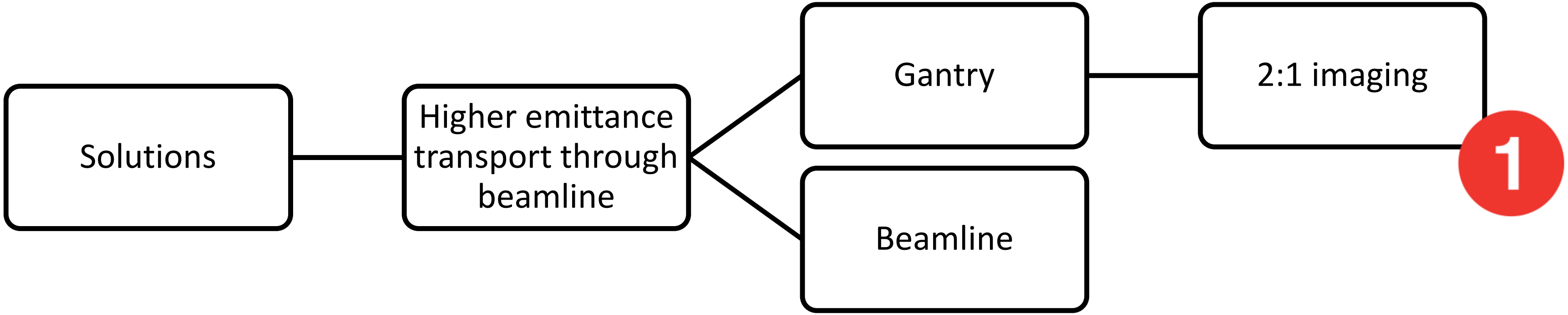
We have developed a simulation model in **BDSIM** and validated with our clinical tune.



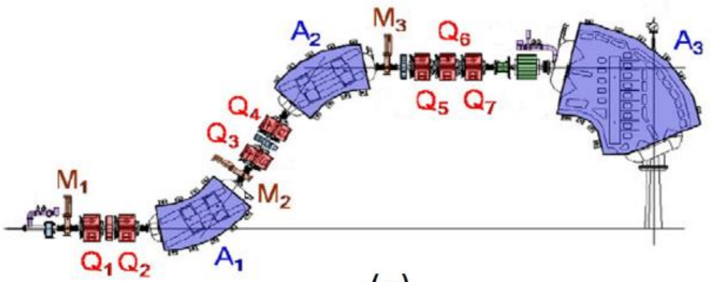
	M1	M2	M3	Coupling point	isocenter
BDSIM Simulation	10 ± 0.3%	1.47 ± 0.04%	0.23 ± 0.007%	0.22 ± 0.007%	0.13 ± 0.004%
Measurements	10.1 ± 0.7%	1.46 ± 0.1%	0.21 ± 0.015%	0.21 ± 0.015%	0.13 ± 0.002%

V. Maradia et al 2021, Medical Physics

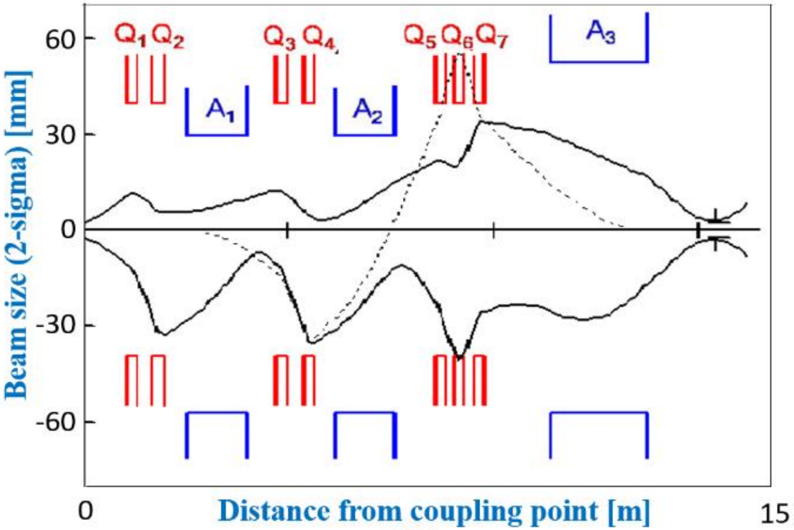
How to overcome all these challenges ?



Gantry beam optics



(a)



(b)

1:1 imaging

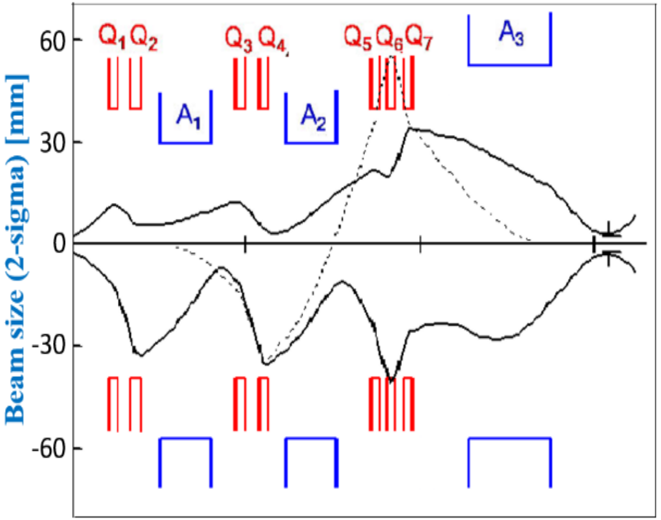
Emittance : 30 pi*mm*mrad

Beam size : 3 mm

Divergence : 10 mrad

Transmission : 57%

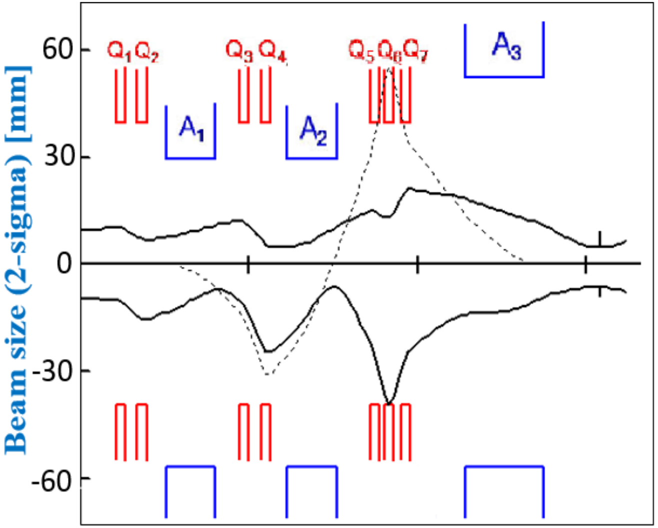
Gantry beam optics



1:1 imaging

Emittance : 30 pi*mm*mrad

Transmission : 57%



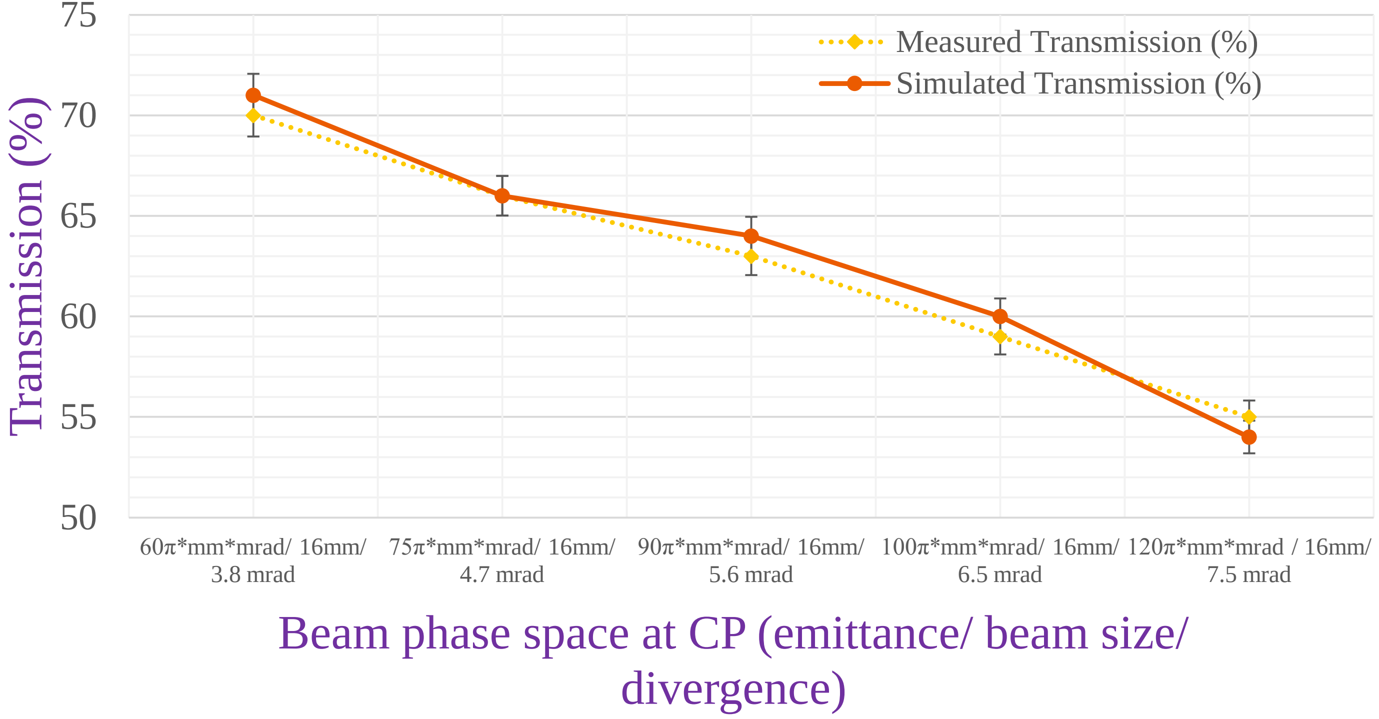
2:1 imaging

Emittance : 30 pi*mm*mrad

Transmission : 84%

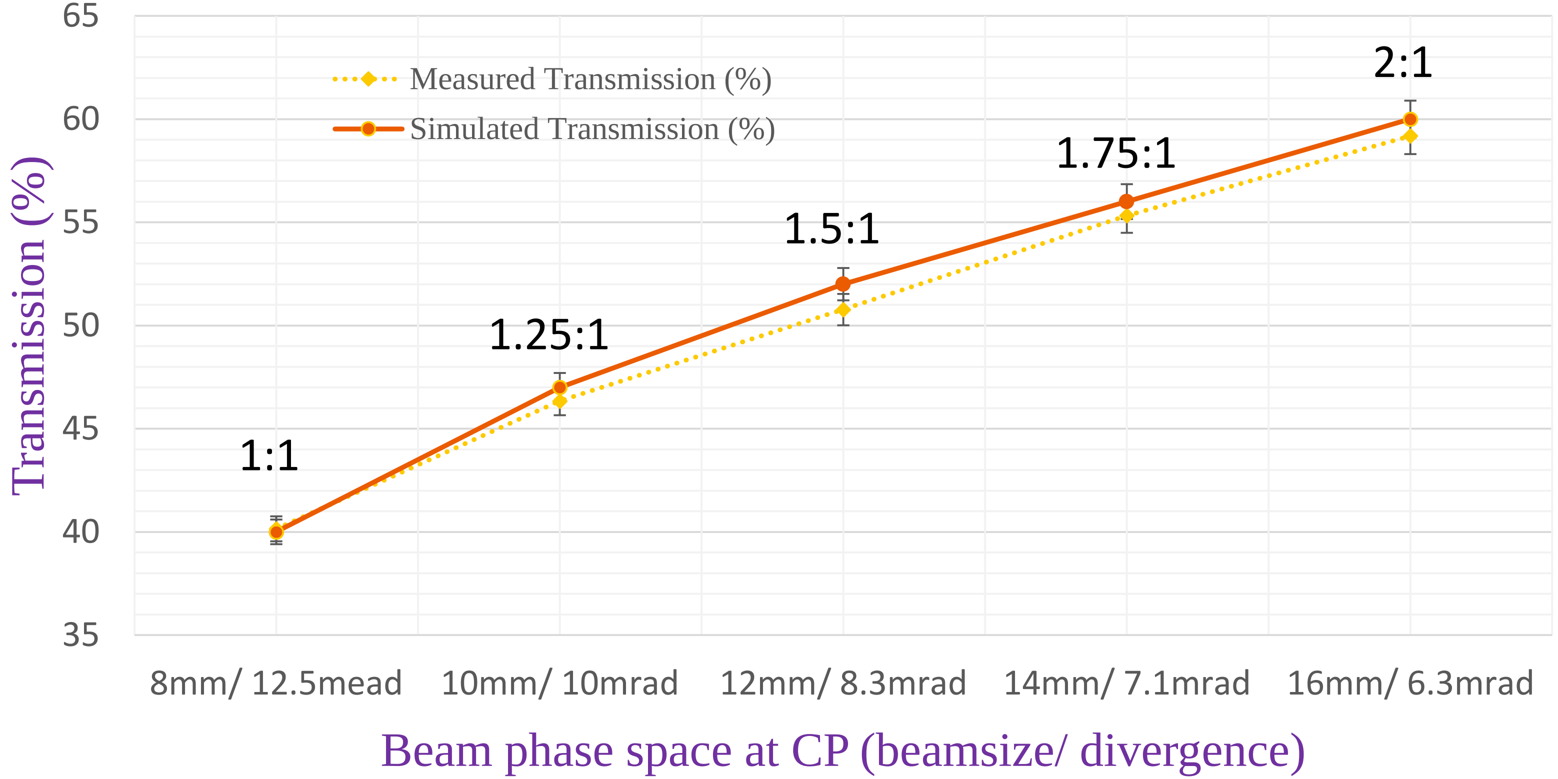
V. Maradia et al 2021, IPAC Proceedings

Gantry beam optics with 2:1 imaging



V. Maradia et al 2022, Medical Physics

Gantry beam optics

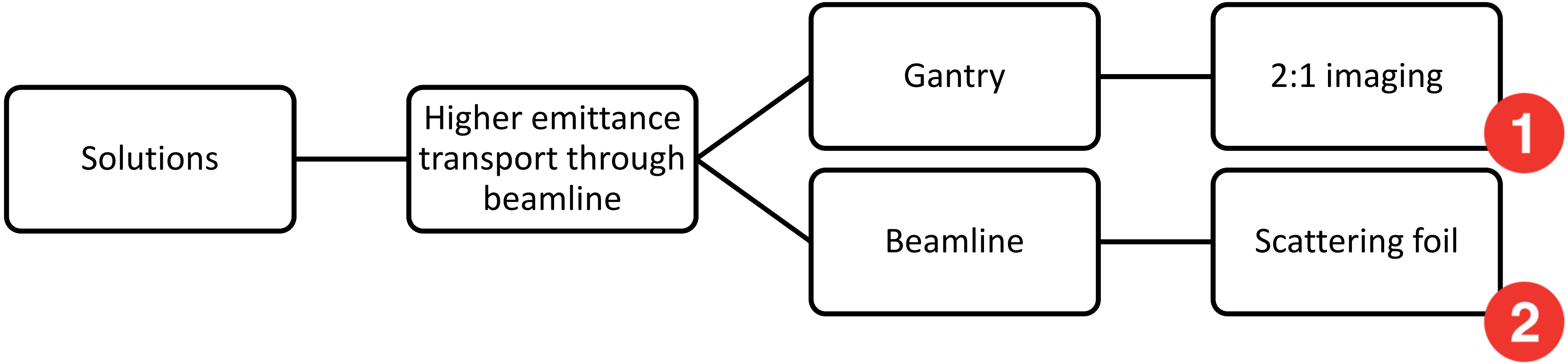


V. Maradia et al 2022, Medical Physics

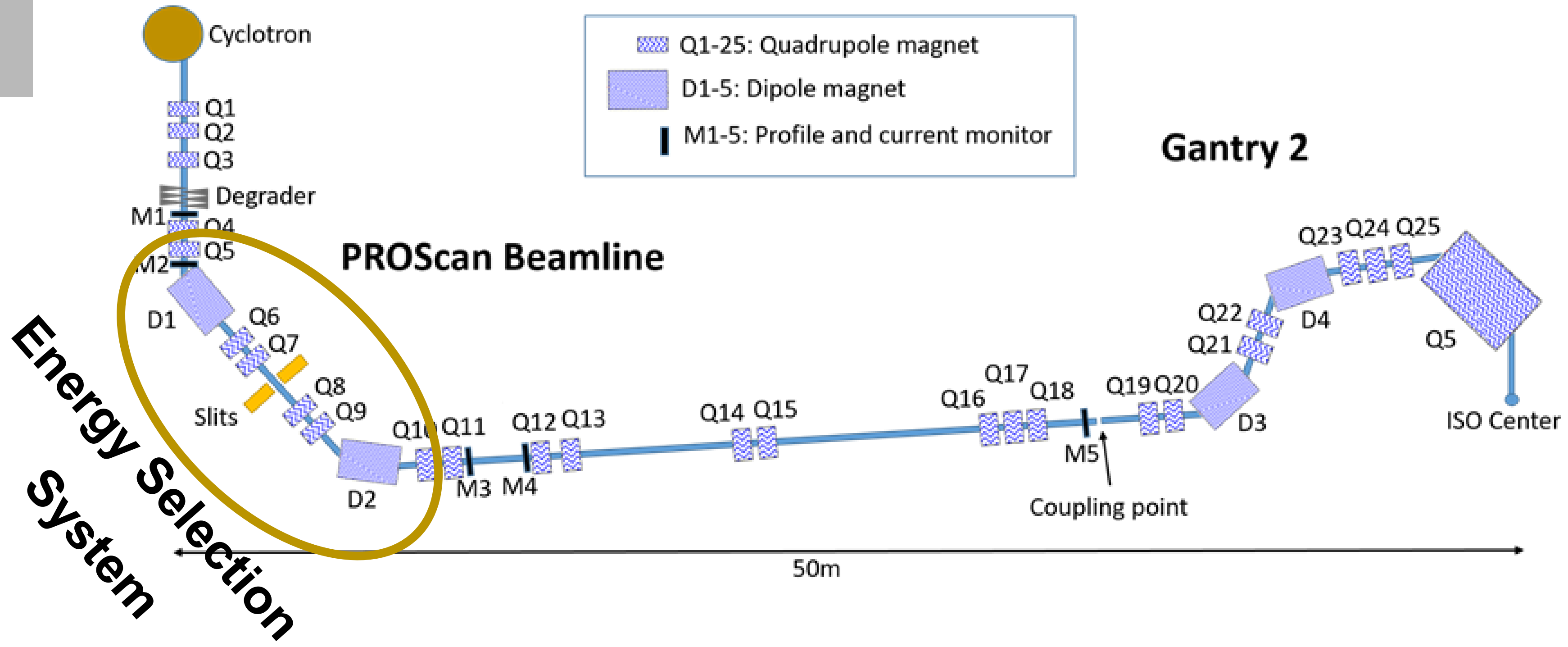
Use of ***large beam size*** & ***small divergence*** at gantry entrance together with ***2:1 imaging*** beam optics will allow to transport ***100 π*mm*mrad*** through gantry while having ***60%*** transmission.

V. Maradia et al 2022, Medical Physics

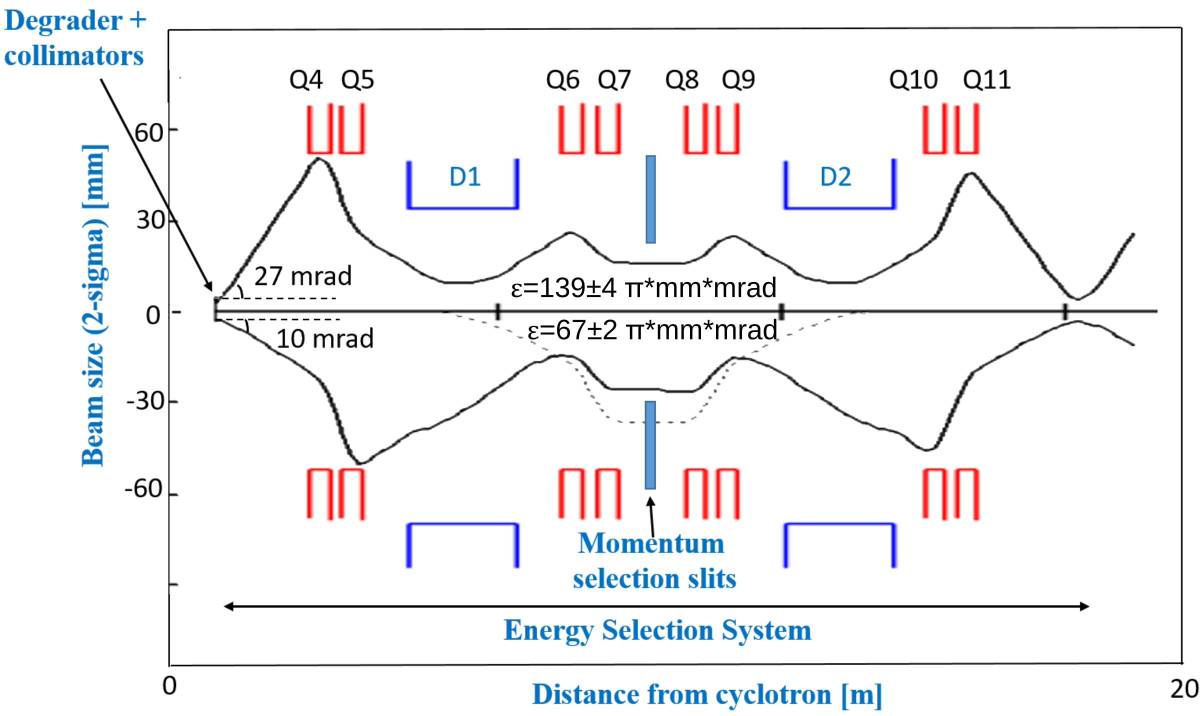
How to overcome these challenges ?



PROScan beamline



Energy selection system



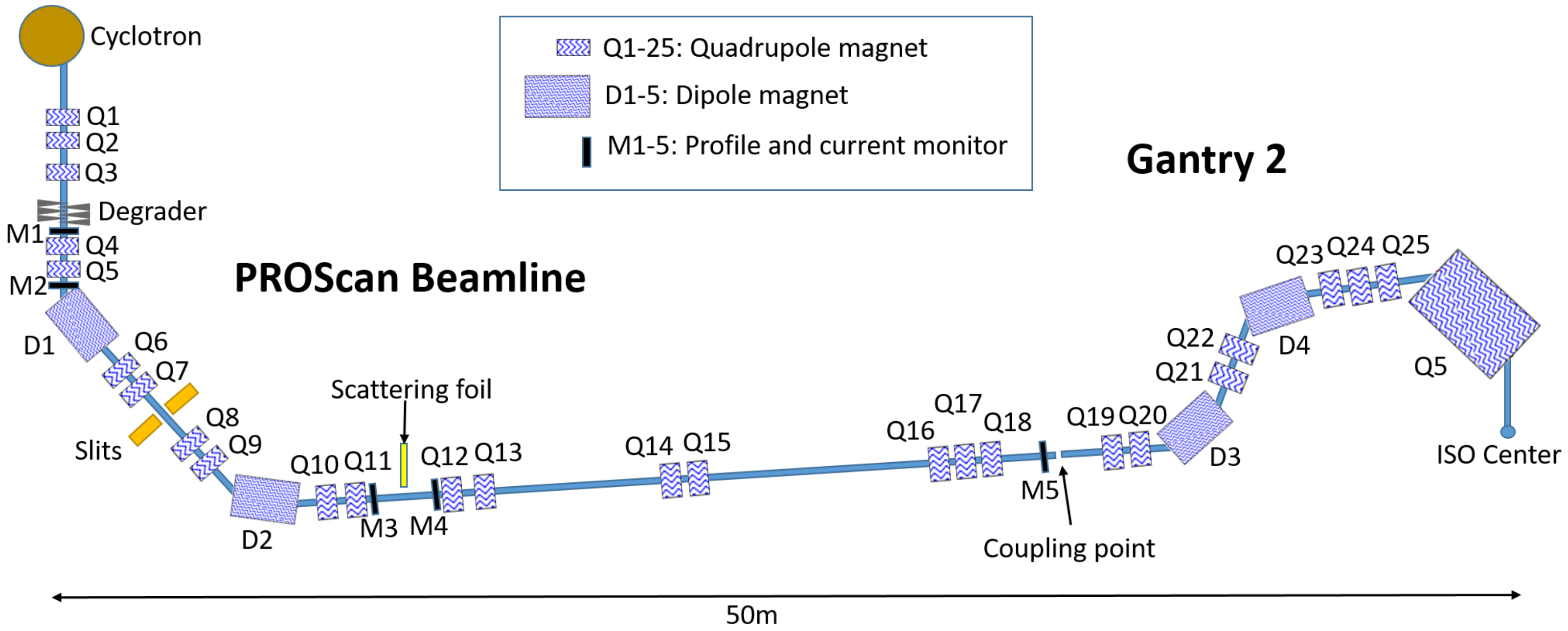
V. Maradia et al 2022, Frontiers in Physics

PAUL SCHERRER INSTITUT

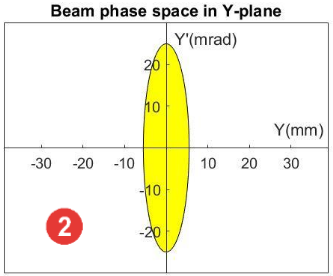
We can transport higher emittance
In y-plane compare to x-plane

To achieve gantry angle independent beam at isocenter, we need to have same emittance in both planes at gantry entrance.

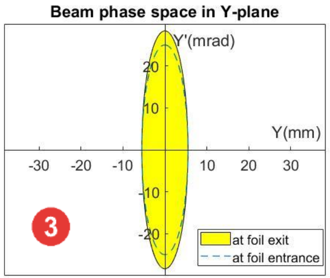
Scattering foil



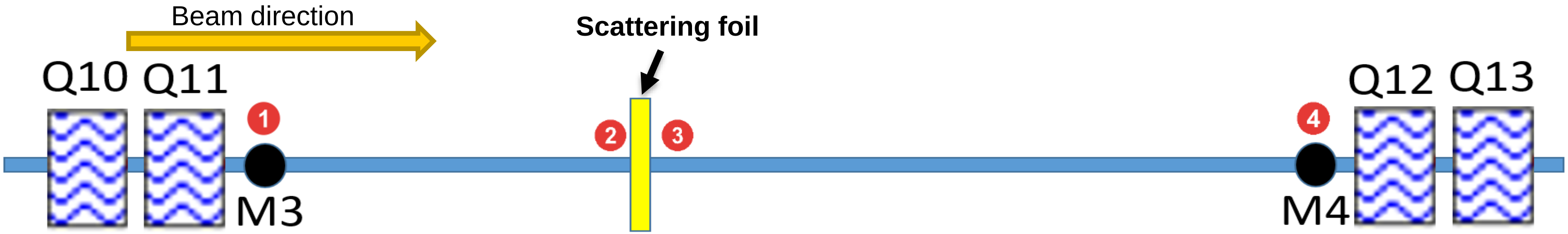
V. Maradia et al 2022, Frontiers in Physics

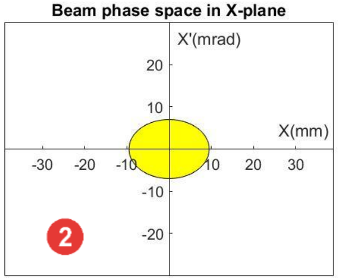


ε=139±4 π*mm*mrad

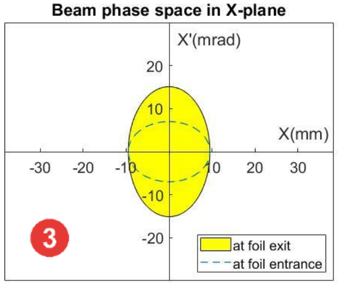


ε=148±5 π*mm*mrad





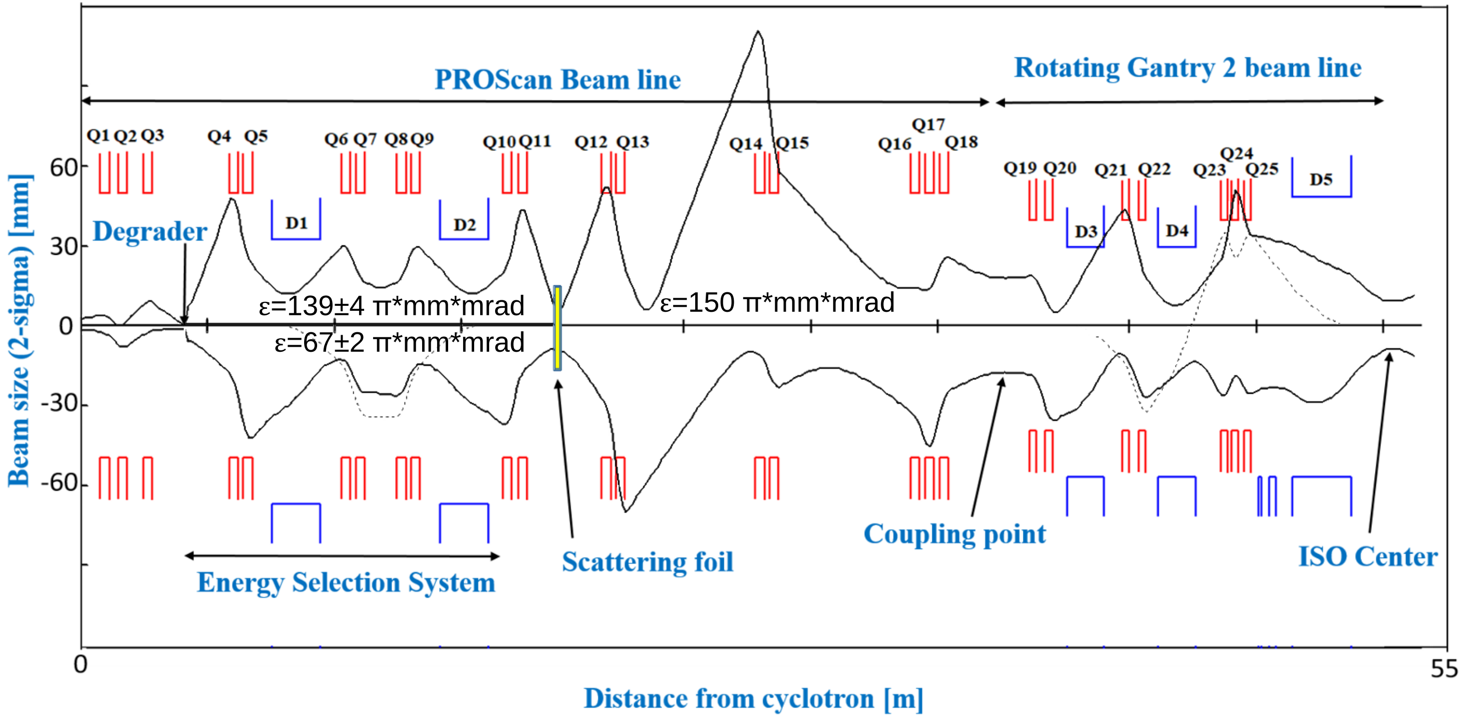
ε=67±2 π*mm*mrad



ε=145±6 π*mm*mrad

V. Maradia et al 2022, Frontiers in Physics

Scattering foil



V. Maradia et al 2022, Frontiers in Physics

Transmission gain

For 70 MeV beam

Clinical beam optics : **0.13%**

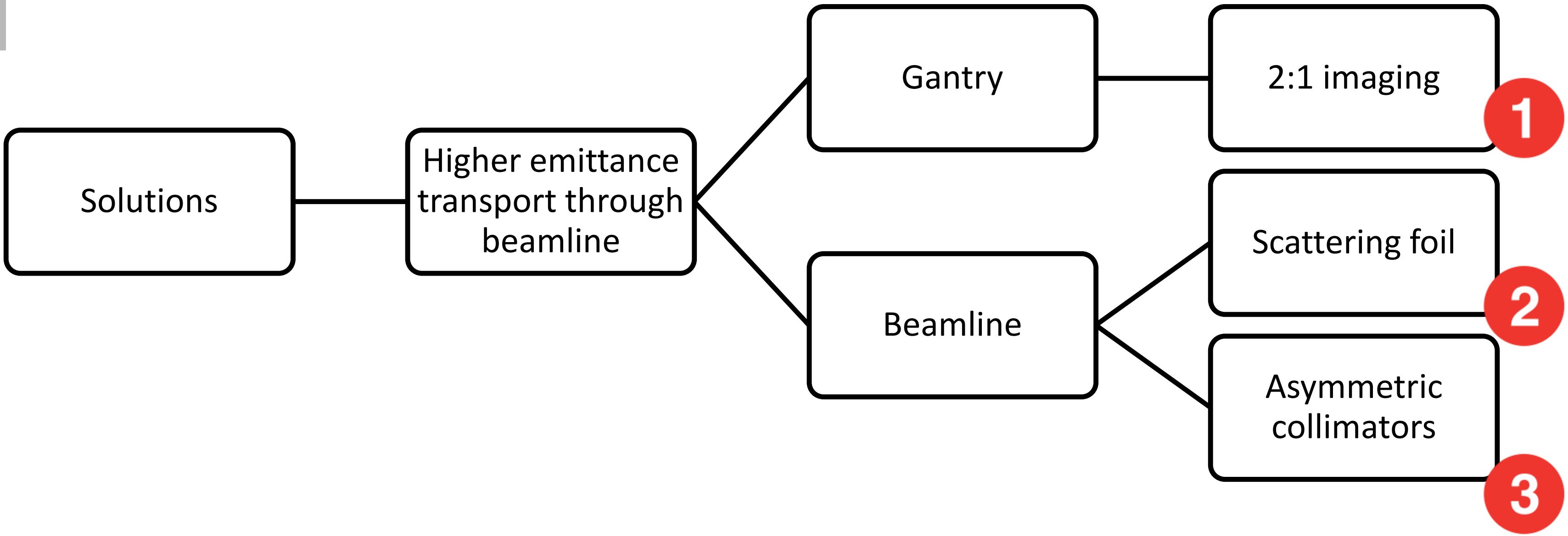
Scattering foil + 2:1 imaging : **0.4%**

(1.8 times larger beam size)

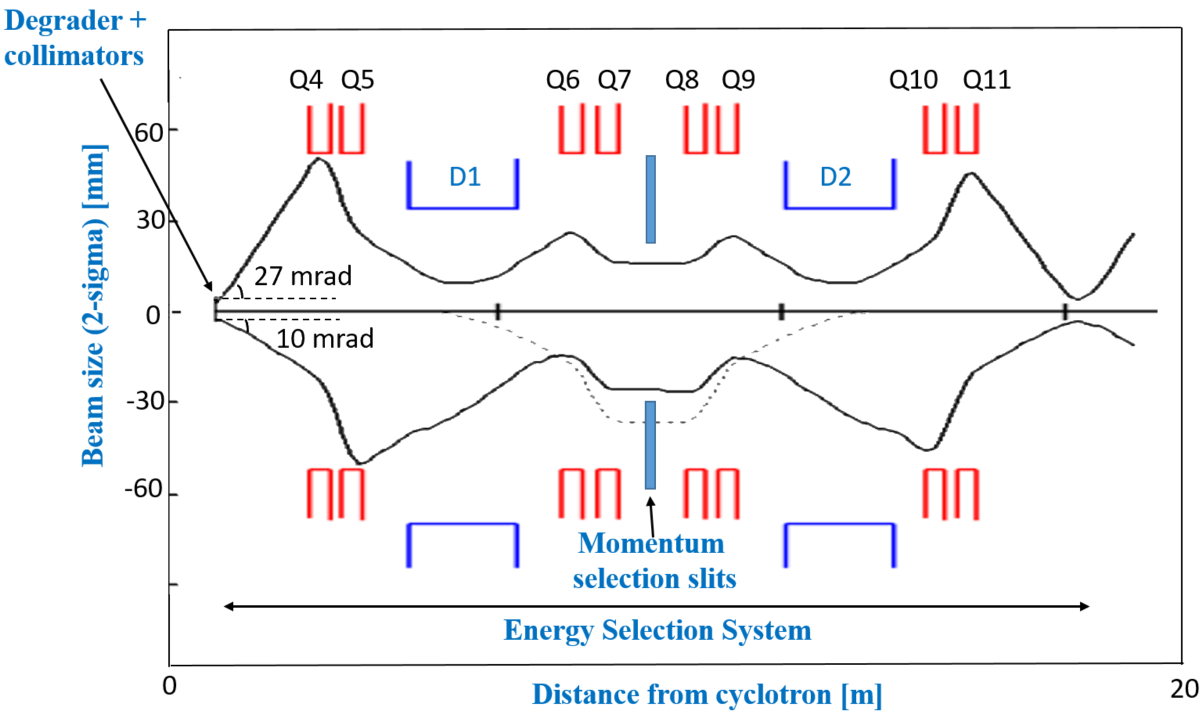
Gain : ~ factor 3 (Experimentally)

V. Maradia et al 2022, Frontiers in Physics

How to overcome all these challenges ?



Beamline


Degrader +
collimators
Q4
Q5
Q6
Q7
Q8
Q9
Q10
Q11
D1
D2
60
30
0
-30
-60
27 mrad
10 mrad
Beam size (2-sigma) [mm]
Momentum
selection slits
Energy Selection System
0
20
Distance from cyclotron [m]

PAUL SCHERRER INSTITUT

Asymmetric collimator

Y-axis:

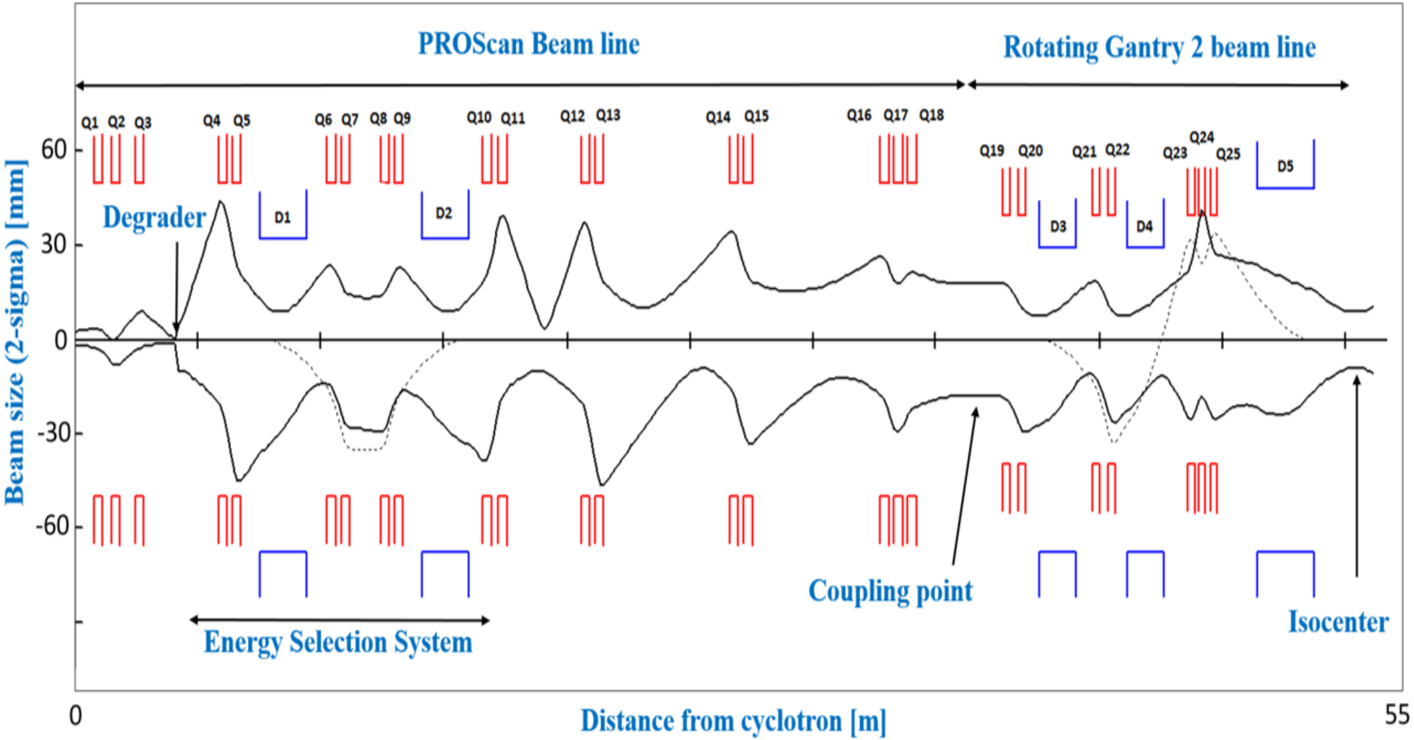
Beam size: 4 mm

Divergence: 25 mrad

X-axis:

Beam size: 10 mm

Divergence: 10 mrad



V. Maradia et al 2021, Medical Physics

Transmission gain with asymmetric collimator

For 70 MeV beam

Clinical beam optics : **0.13%**

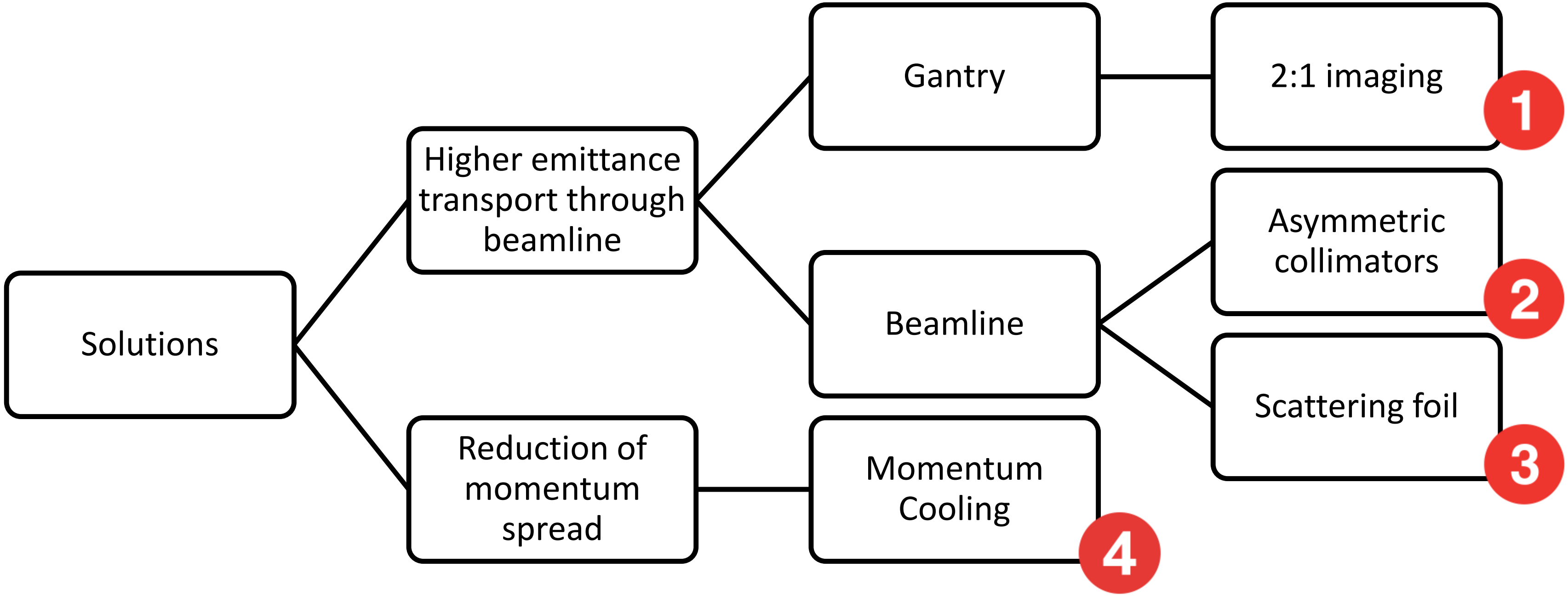
Asymmetric collimator + 2:1 imaging : **0.72%**

(1.5 times larger beam size)

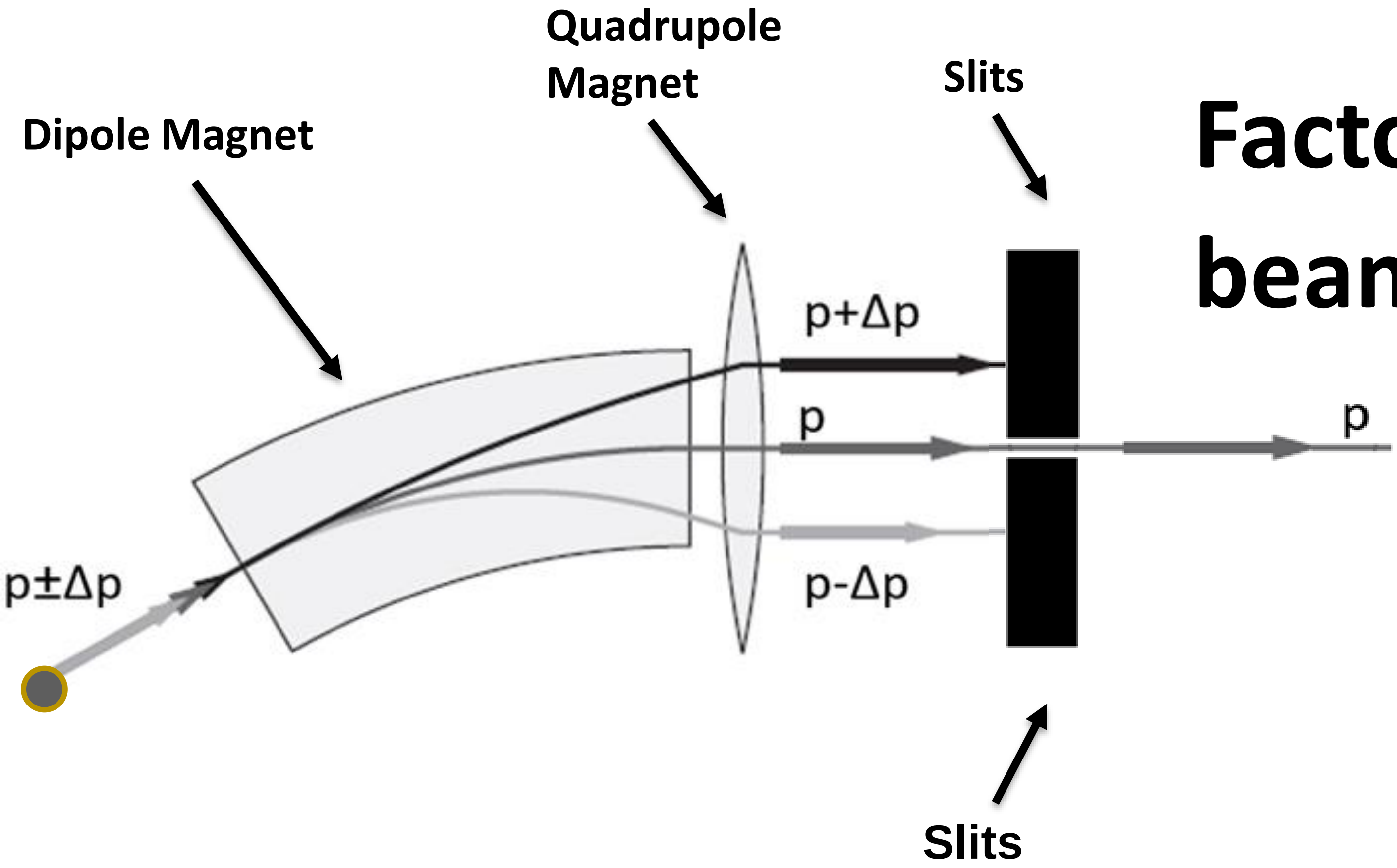
Gain : ~ factor 6 (Simulation)

V. Maradia et al 2021, Medical Physics

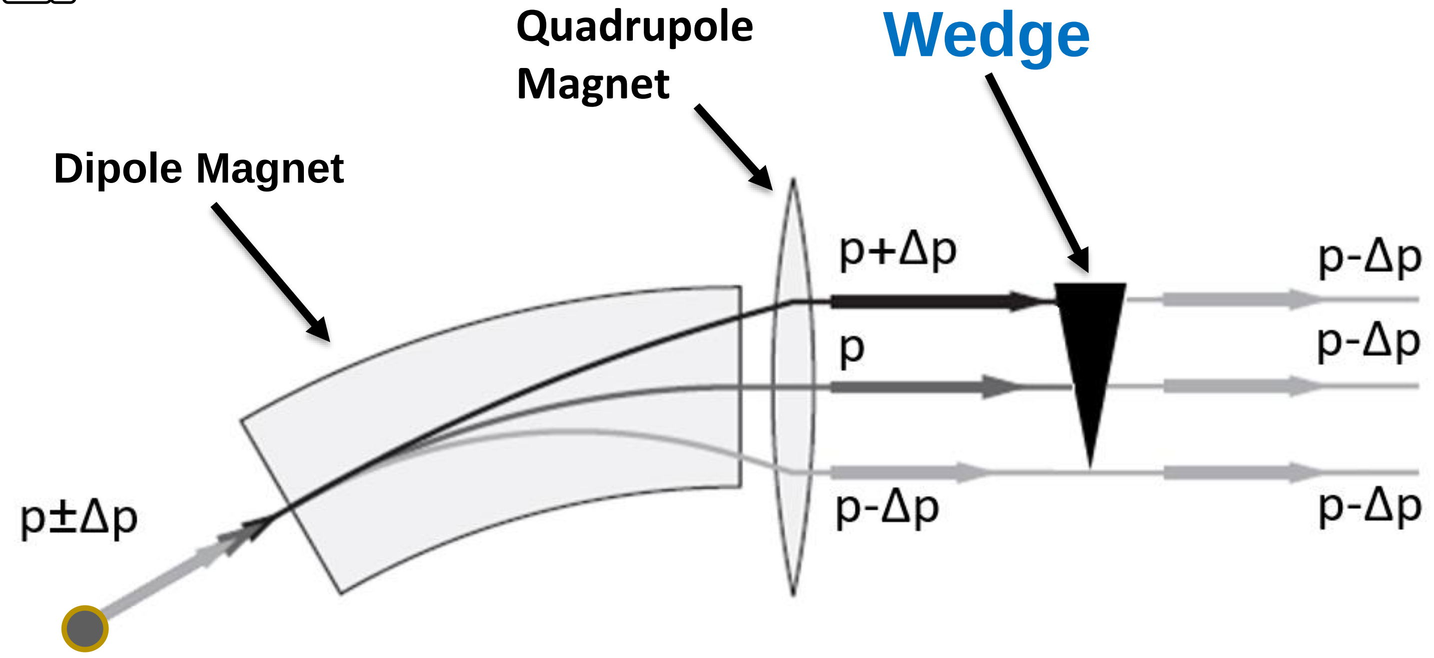
How to overcome all these challenges ?



Energy/momentum spread



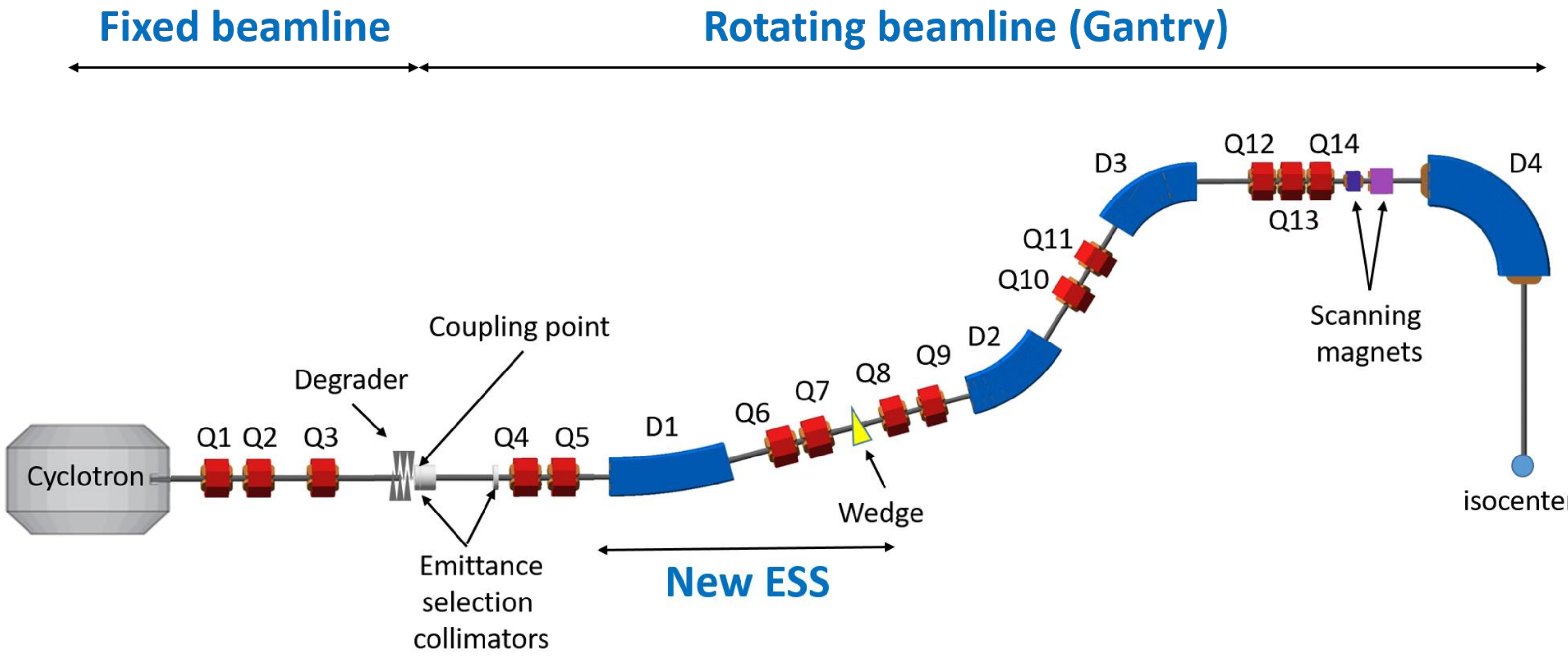
Factor 6-10 beam loss



250 MeV -> 70 MeV -> dp/p = 4.5% dp/p = 0.4%

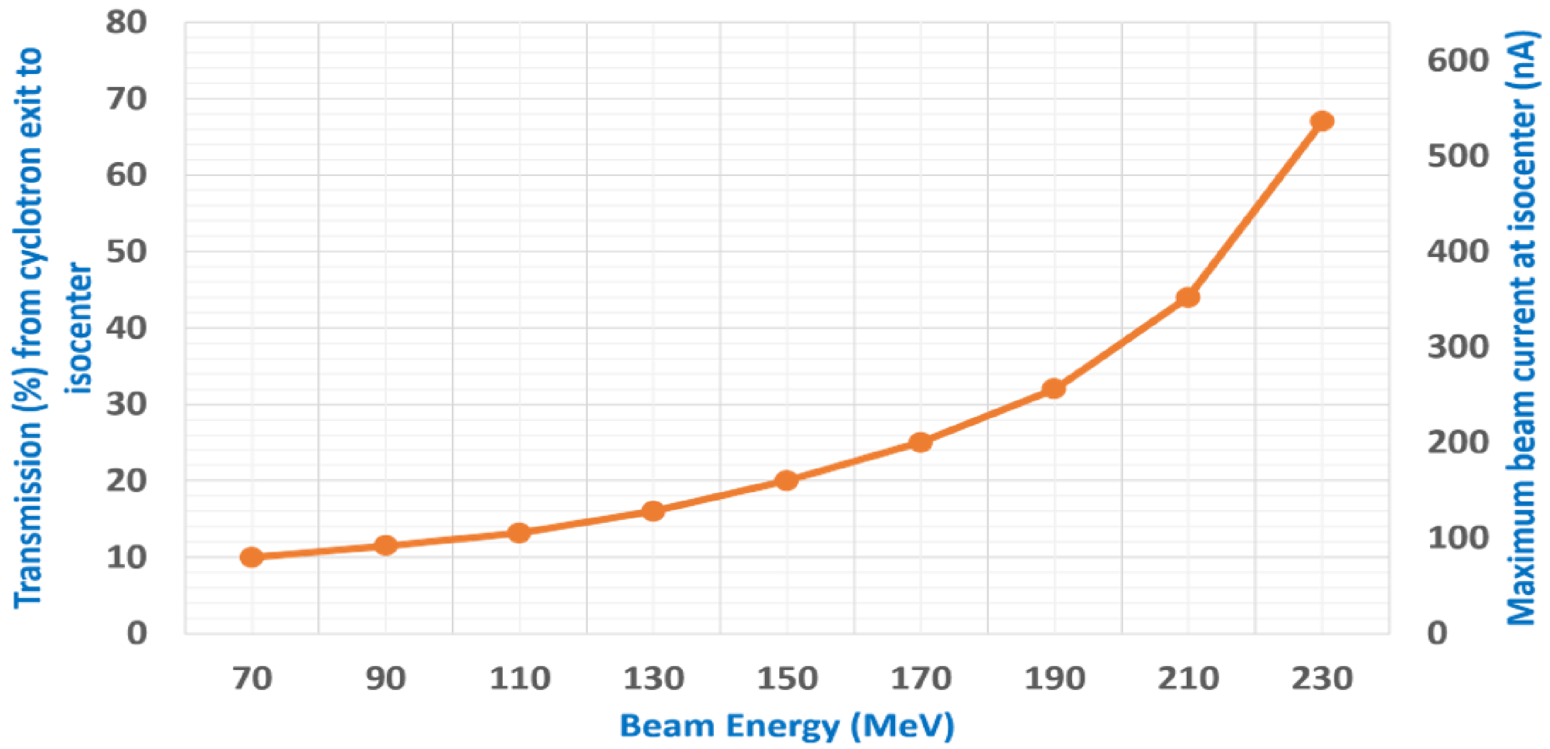
This work is under consideration in Nature Physics. Please do not copy or distribute.

Gantry with momentum cooling capabilities



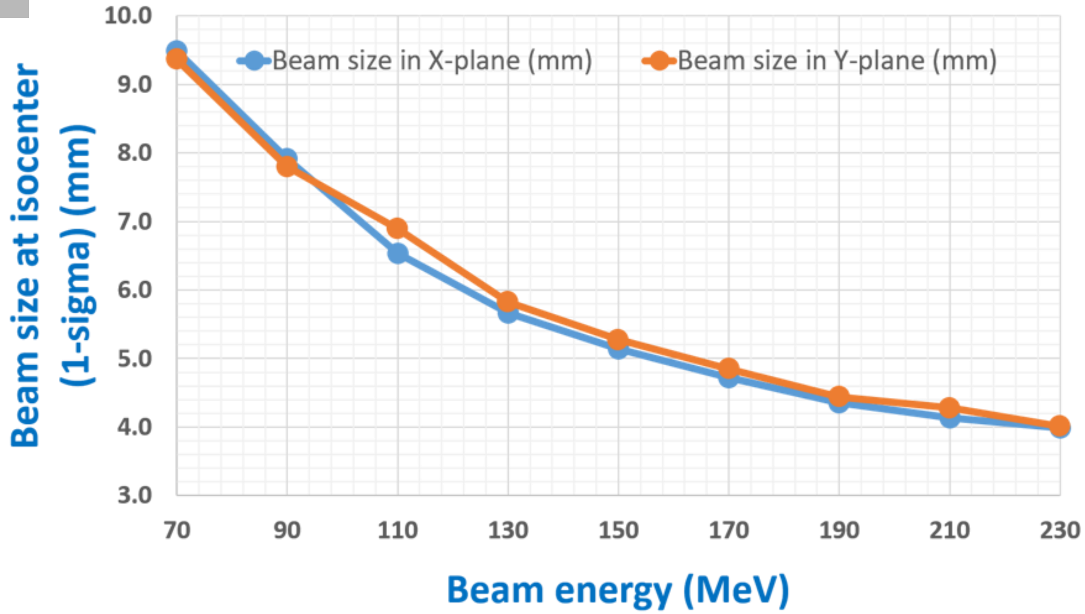
This work is under consideration in Nature Physics. Please do not copy or distribute.

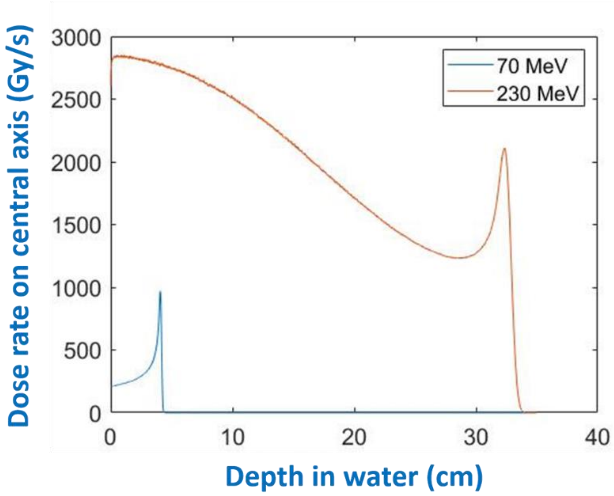
Transmission



This work is under consideration in Nature Physics. Please do not copy or distribute.

Beam size and dose rate





This work is under consideration in Nature Physics. Please do not copy or distribute.

Transmission gain

For 70 MeV beam

Clinical beam optics : **0.13%**

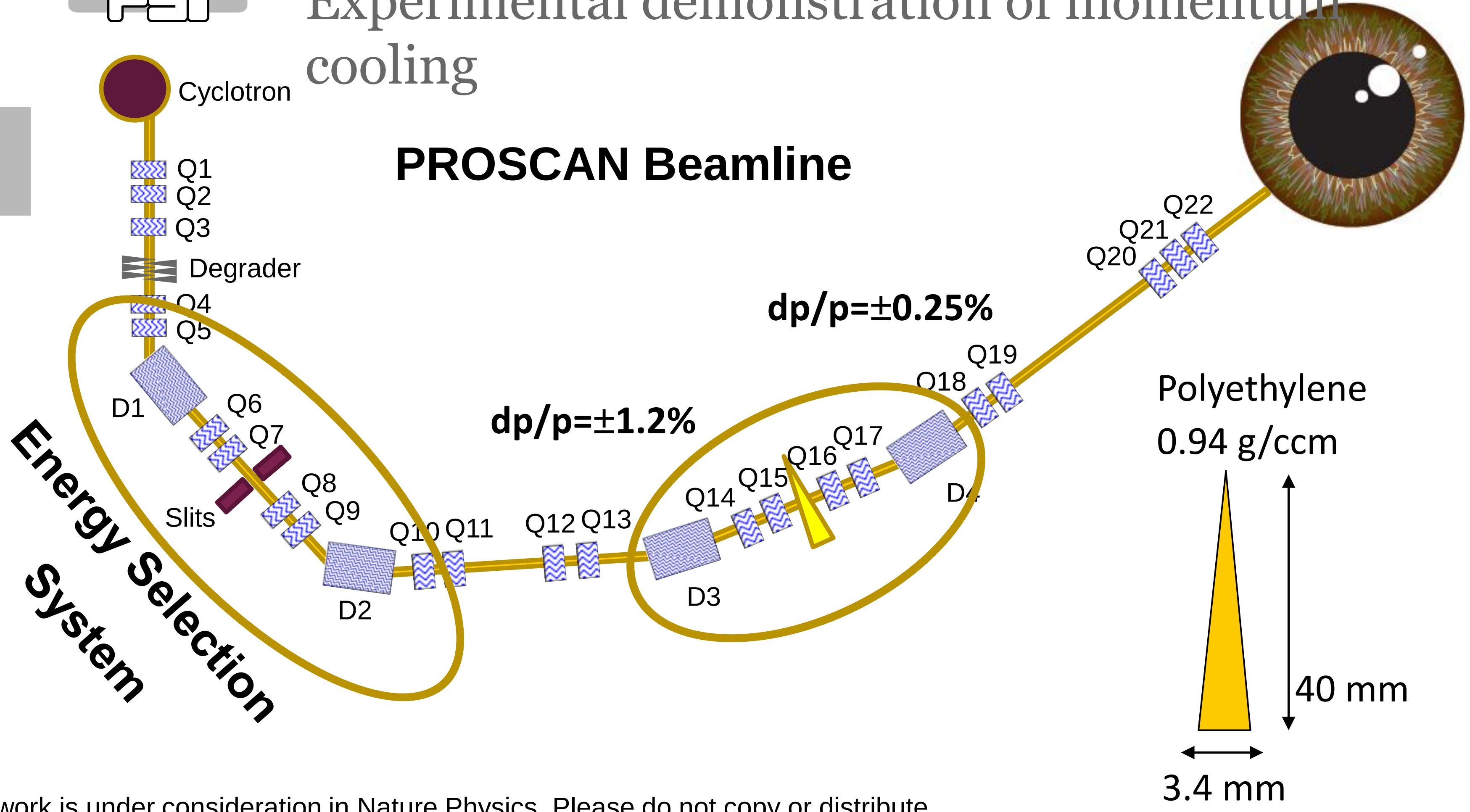
Momentum cooling + 2:1 imaging : **10%**

(1.7 times larger beam size)

Gain : ~ factor 80 (Simulation)

This work is under consideration in Nature Physics. Please do not copy or distribute.

Experimental demonstration of momentum cooling



This work is under consideration in Nature Physics. Please do not copy or distribute.

Overview of transmission improvement

For 70 MeV beam

Clinical beam optics : **0.13%**

Scattering foil + 2:1 imaging : **factor 3**

Asymmetric collimator + 2:1 imaging : **factor 6**

New gantry with momentum cooling : **factor 80**

Impact of the high transmission

- Efficient treatment delivery for moving targets
- Ultra-fast treatment delivery (treatment delivery in 5-10 sec)
- Treatment of new indications with protons
- Possible to achieve FLASH dose rates for all energy beams
- Reduced shielding requirement (investment cost reduction by few M$)

Wir schaffen Wissen – heute für morgen

My thanks go to

- Serena Psoroulas
- Marco Schippers
- Rudolf Doelling
- Christian Baumgarten
- David Meer
- Tony Lomax

- Cyclotron operation group
- Technical support group
- Radiation protection group