

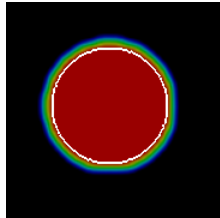
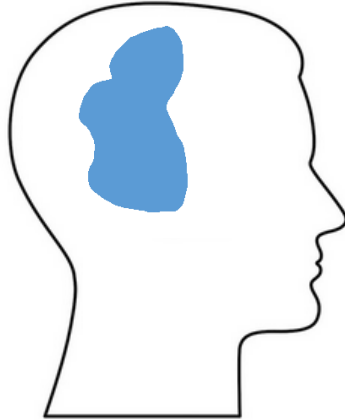


Vivek Maradia :: Center for Proton Therapy :: Paul Scherrer Institute

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

09.12.2022 CYC 2022, Beijing, China

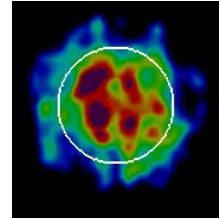
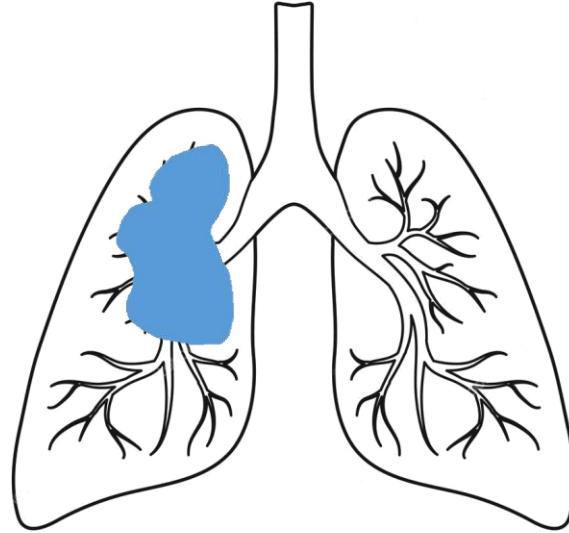
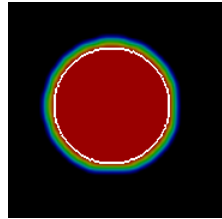
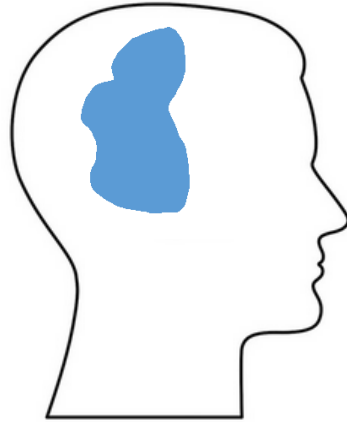
Pencil Beam Scanning proton therapy



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

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

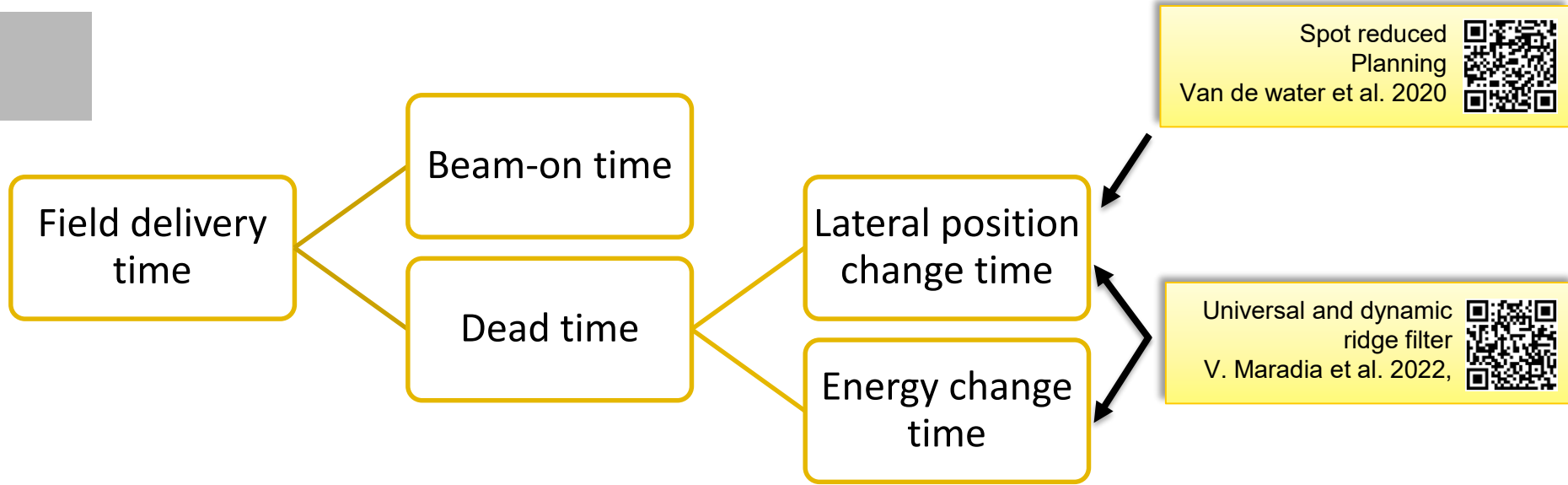
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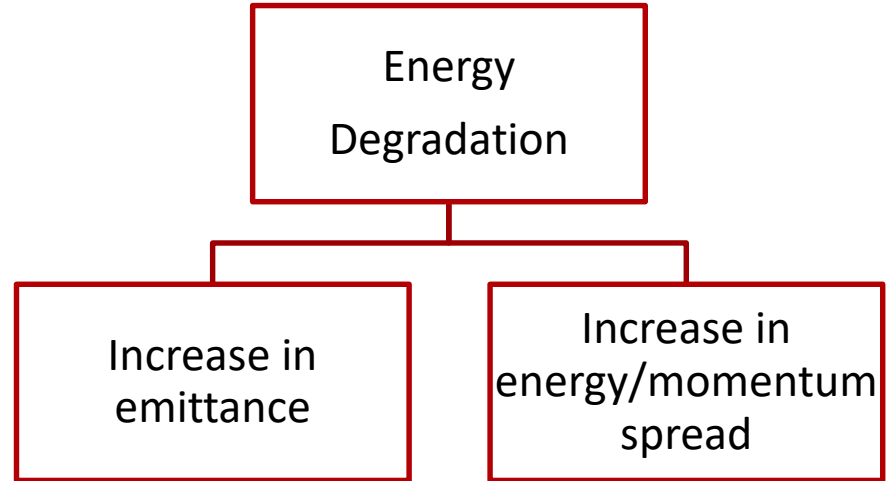
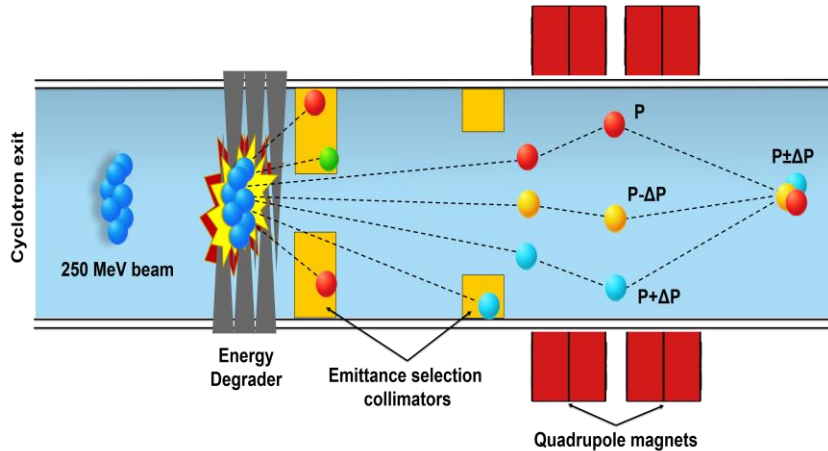
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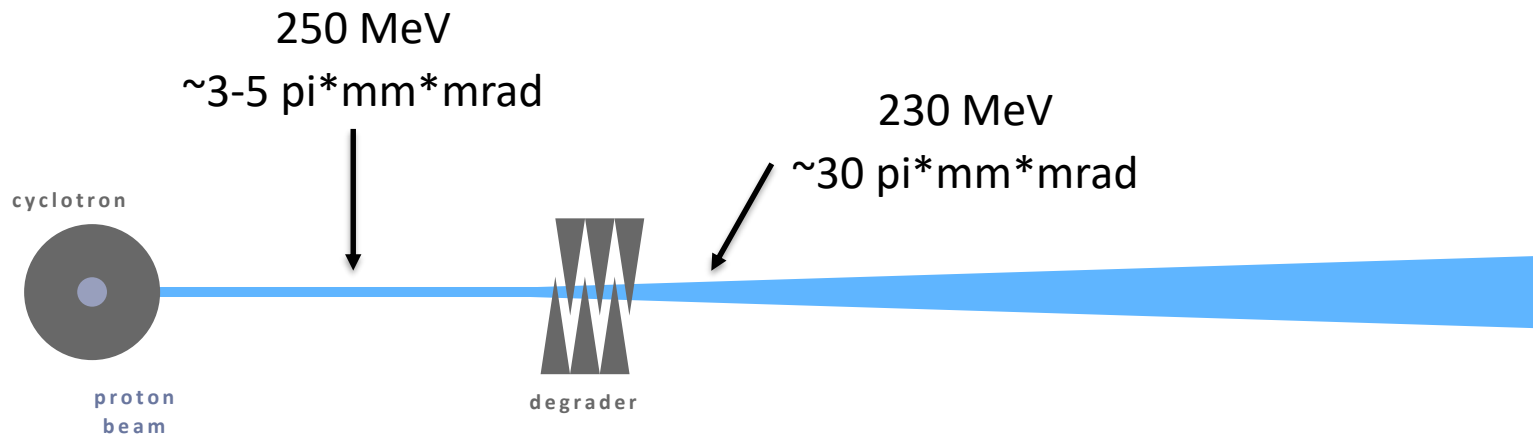
PBS field treatment delivery time



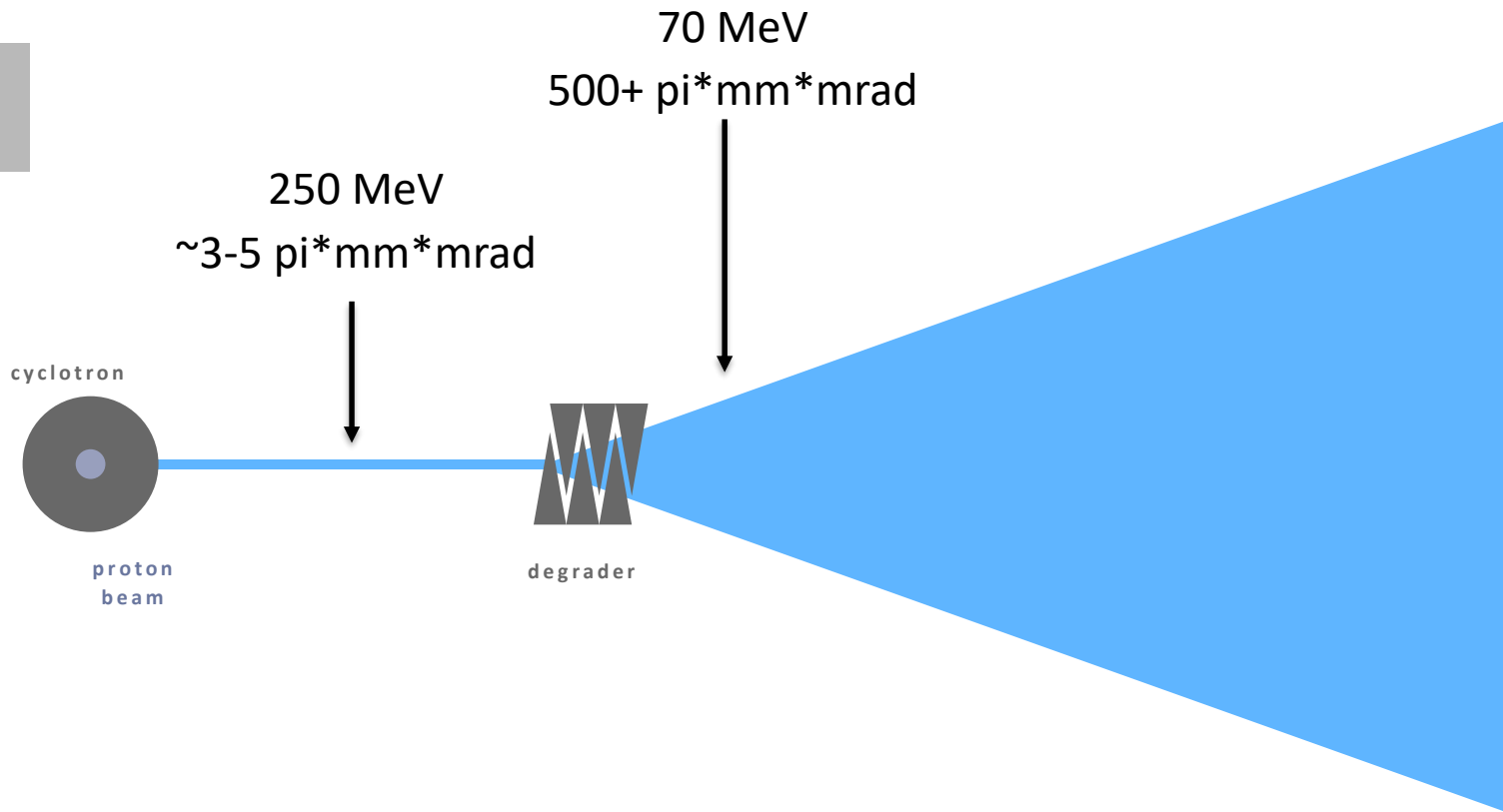
Shorter field delivery times are advantageous

Problem with Energy degradation

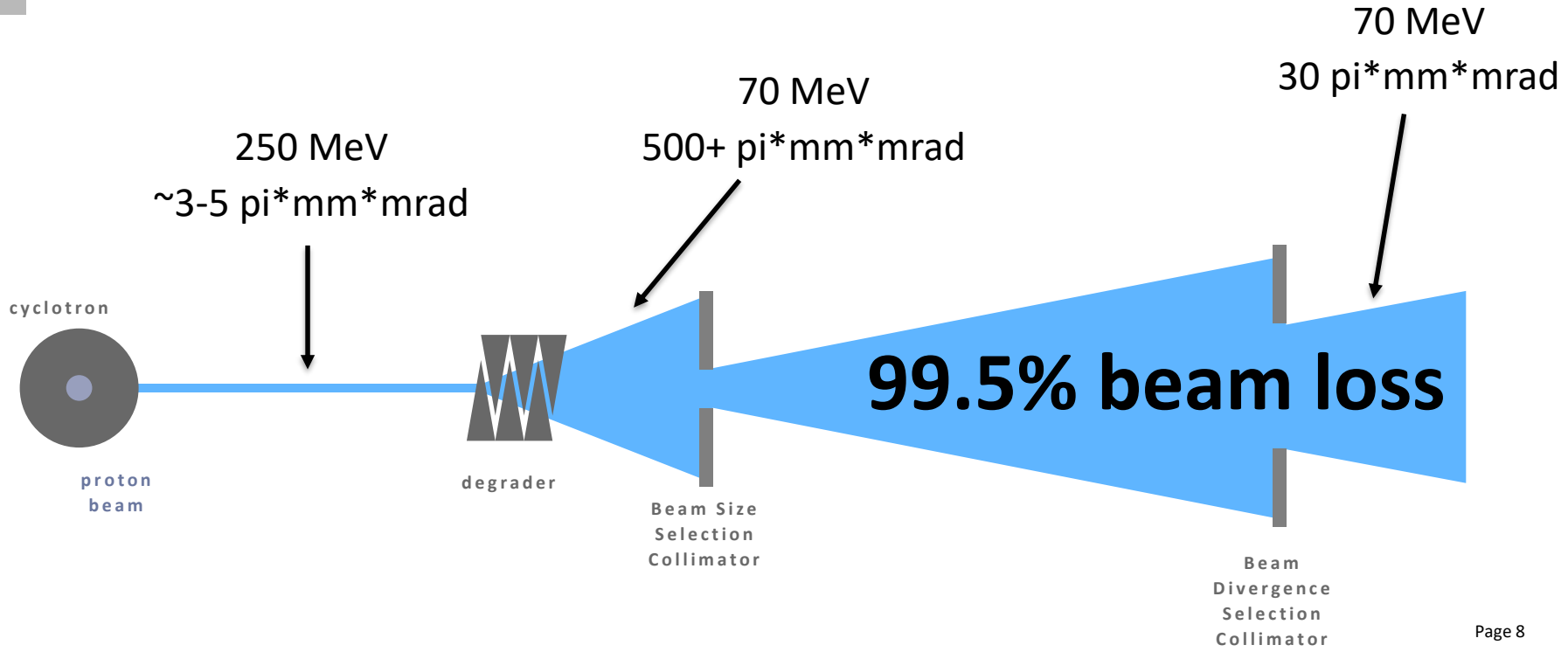




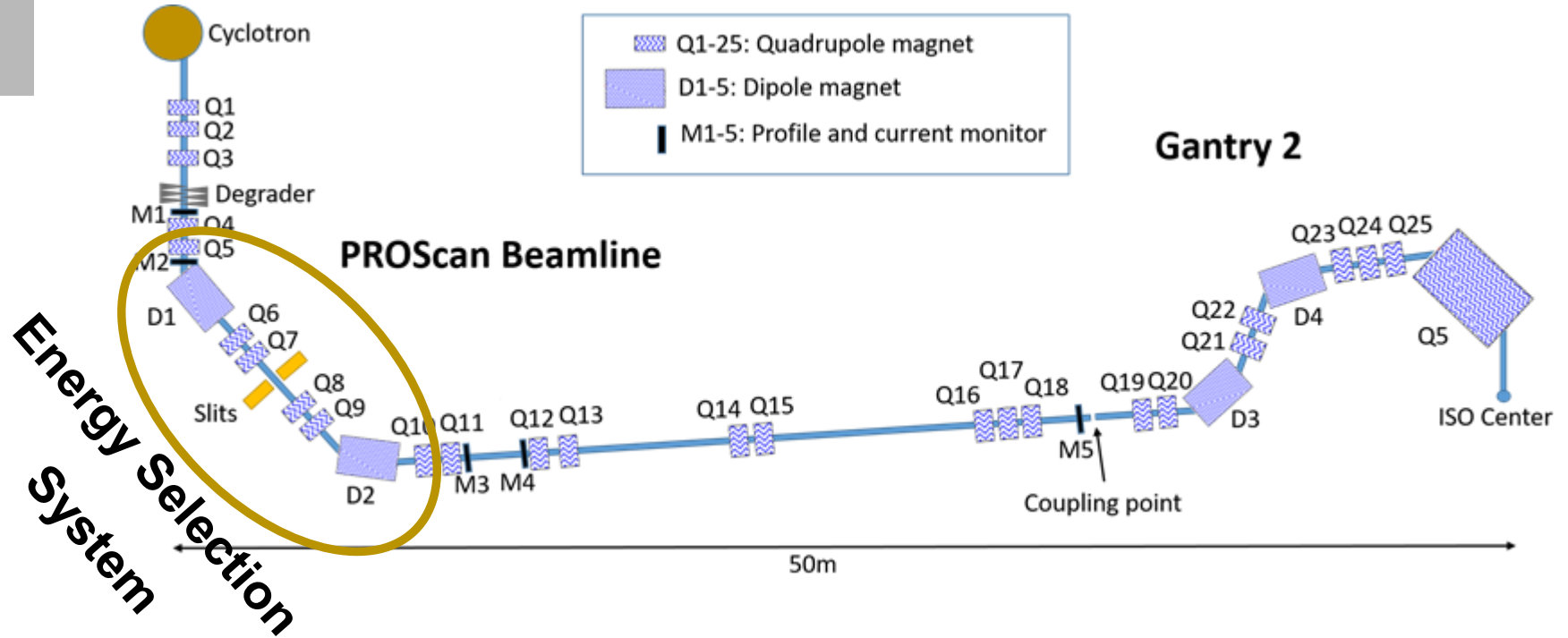
Emittance



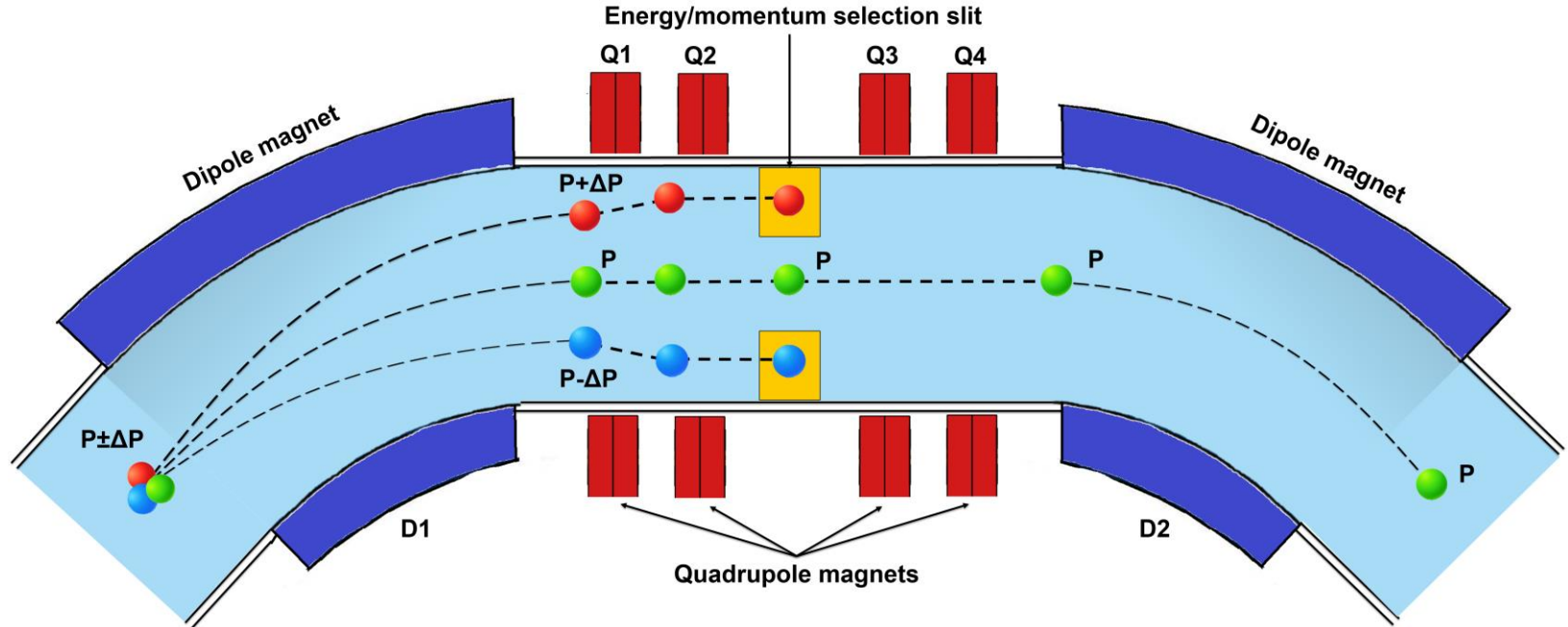
**Most of the facilities transports
30 $\pi \cdot \text{mm} \cdot \text{mrad}$ or less emittance**



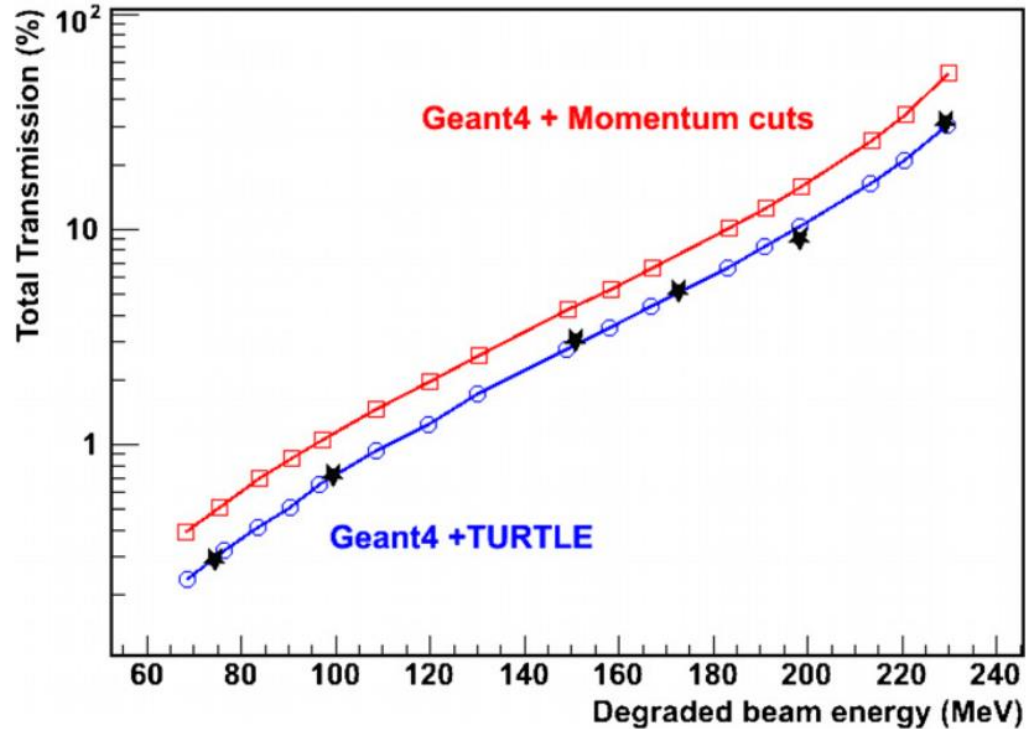
PROScan beamline



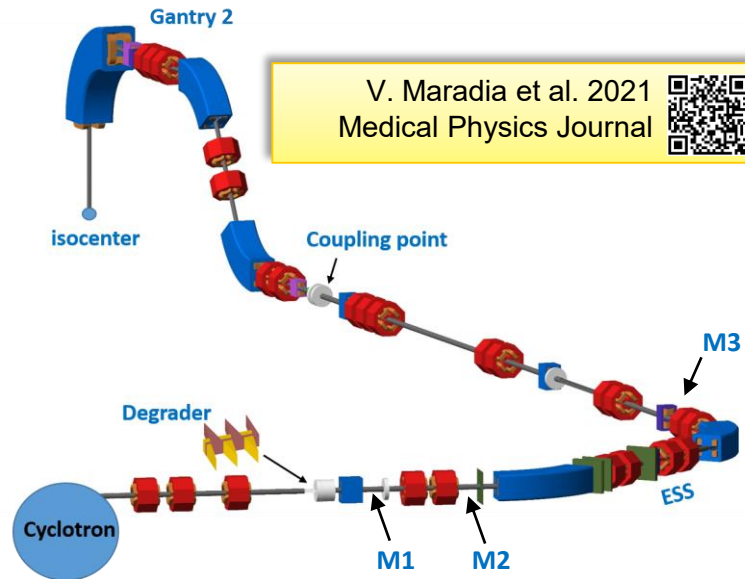
Energy selection system



Transmission through degrader and ESS

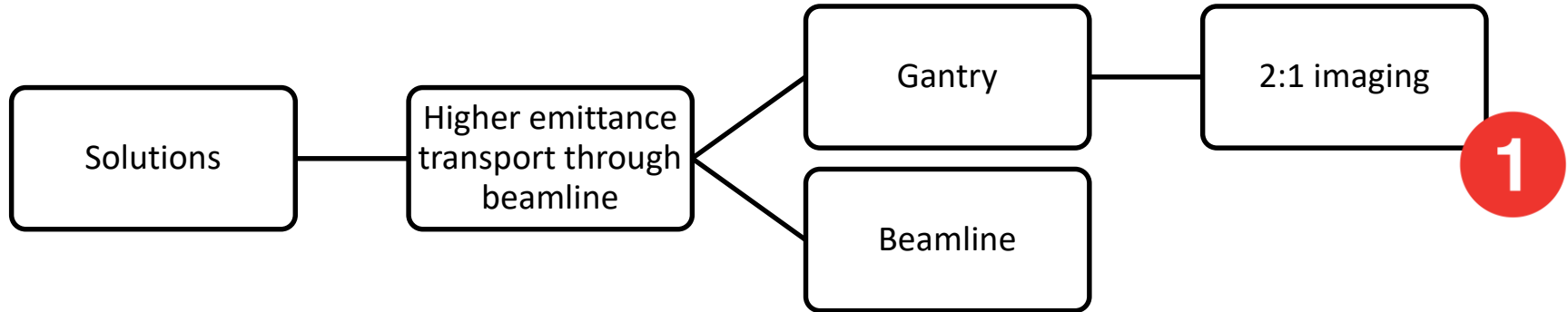


We have developed a simulation model in **BDSIM** and validated with our clinical tune.

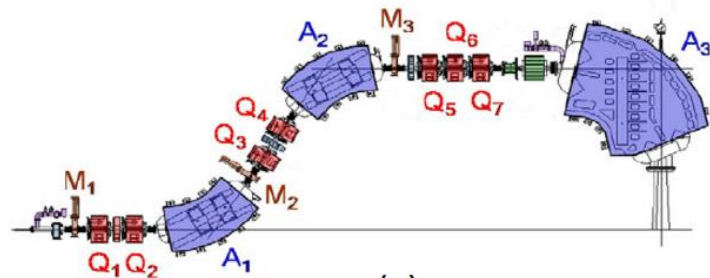


	M1	M2	M3	Coupling point	isocenter
BDSIM Simulation	$10 \pm 0.3\%$	$1.47 \pm 0.04\%$	$0.23 \pm 0.007\%$	$0.22 \pm 0.007\%$	$0.13 \pm 0.004\%$
Measurements	$10.1 \pm 0.7\%$	$1.46 \pm 0.1\%$	$0.21 \pm 0.015\%$	$0.21 \pm 0.015\%$	$0.13 \pm 0.002\%$

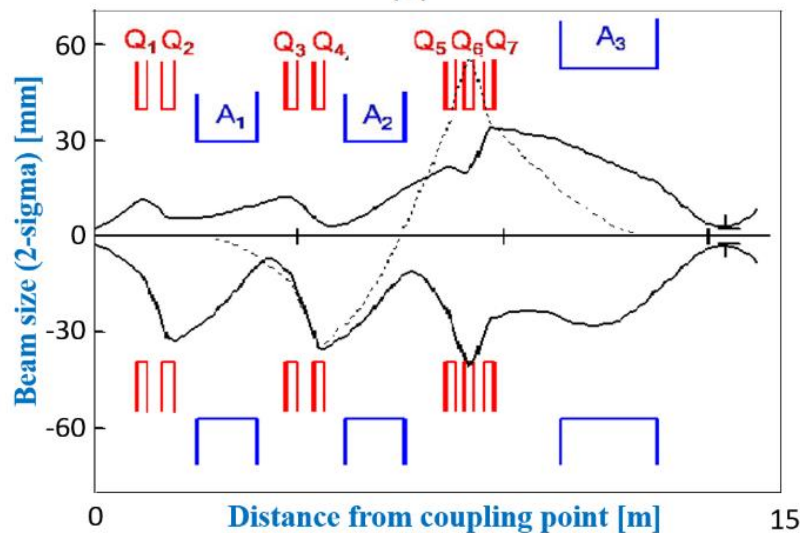
How to overcome all these challenges ?



Gantry beam optics



(a)



(b)

1:1 imaging

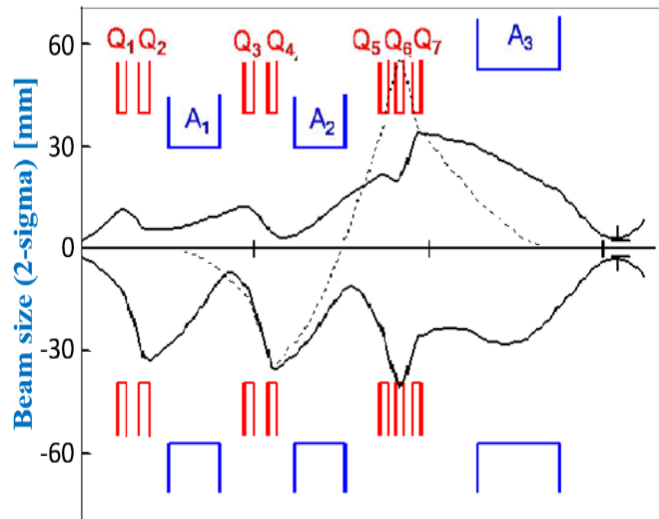
Emittance : $30 \pi \cdot \text{mm} \cdot \text{mrad}$

Beam size : 3 mm

Divergence : 10 mrad

Transmission : 57%

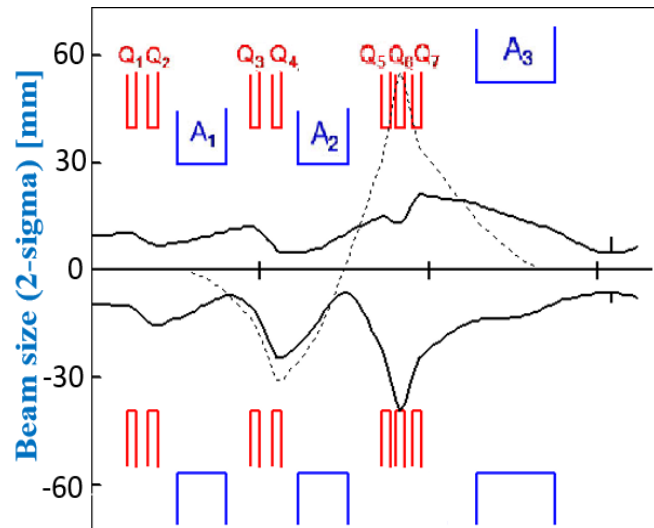
Gantry beam optics



1:1 imaging

Emittance : 30 π *mm*mrad

Transmission : 57%

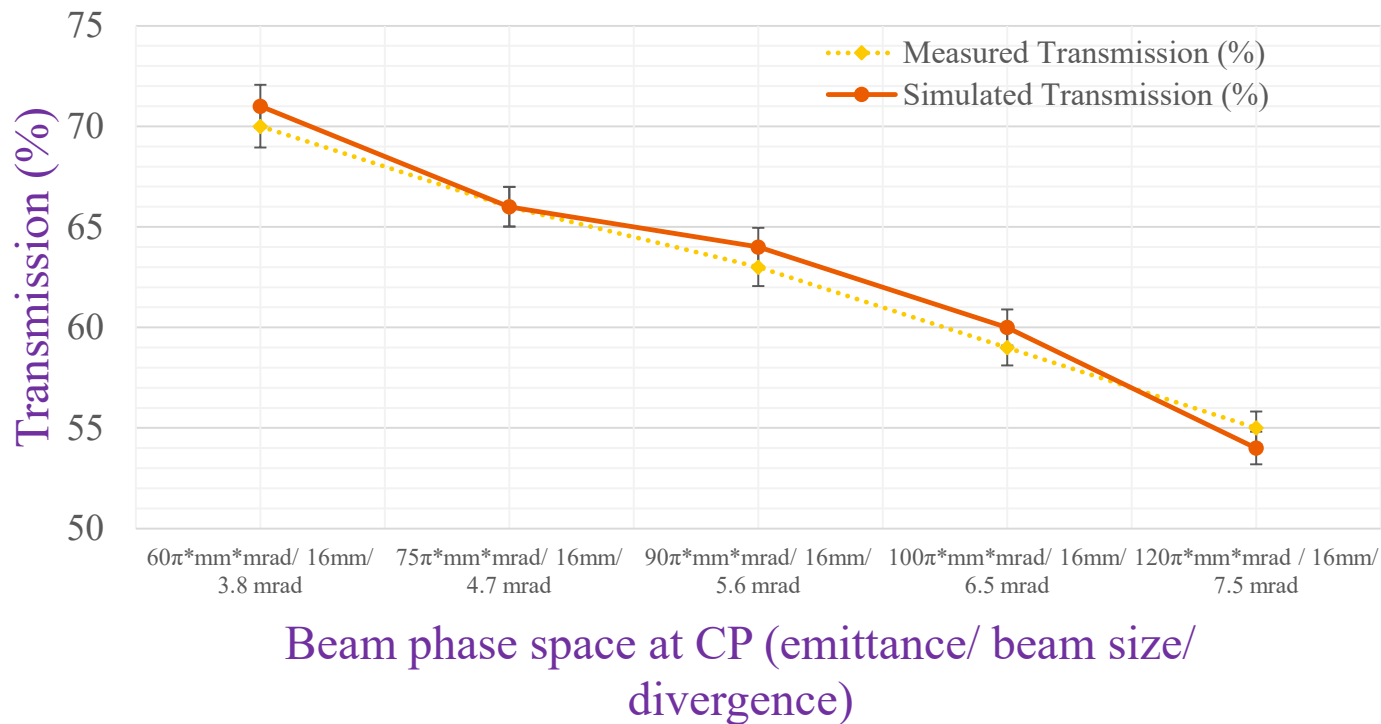


2:1 imaging

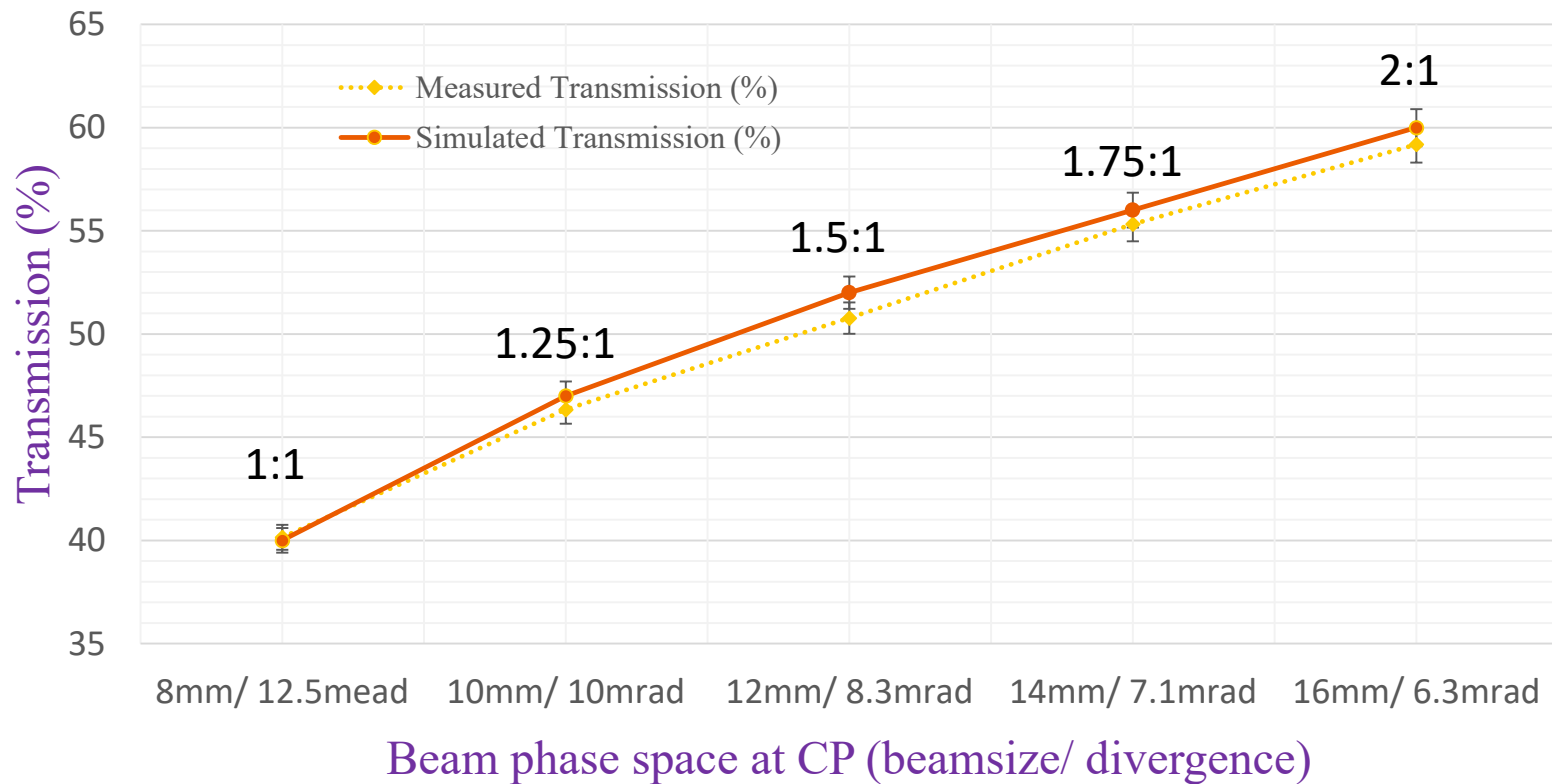
Emittance : 30 π *mm*mrad

Transmission : 84%

Gantry beam optics with 2:1 imaging

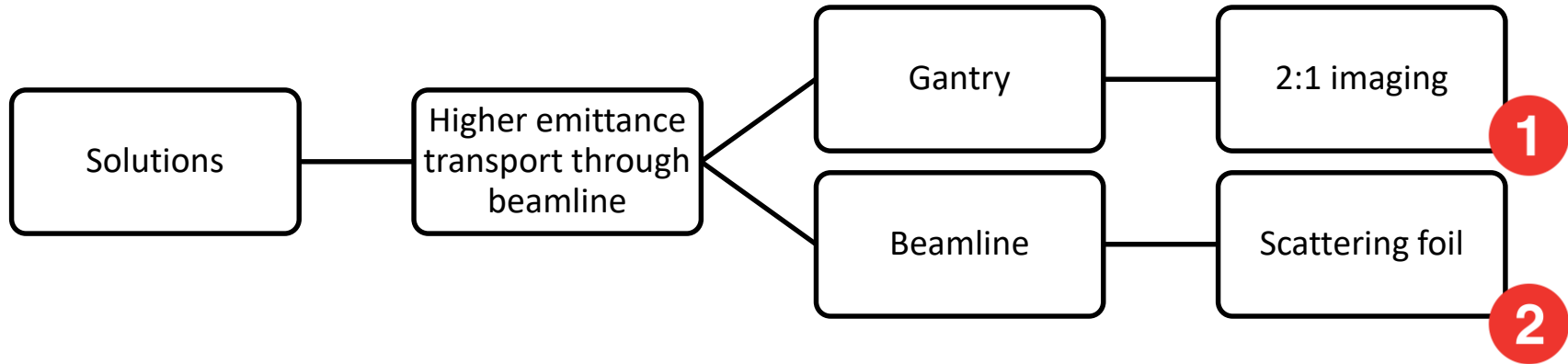


Gantry beam optics

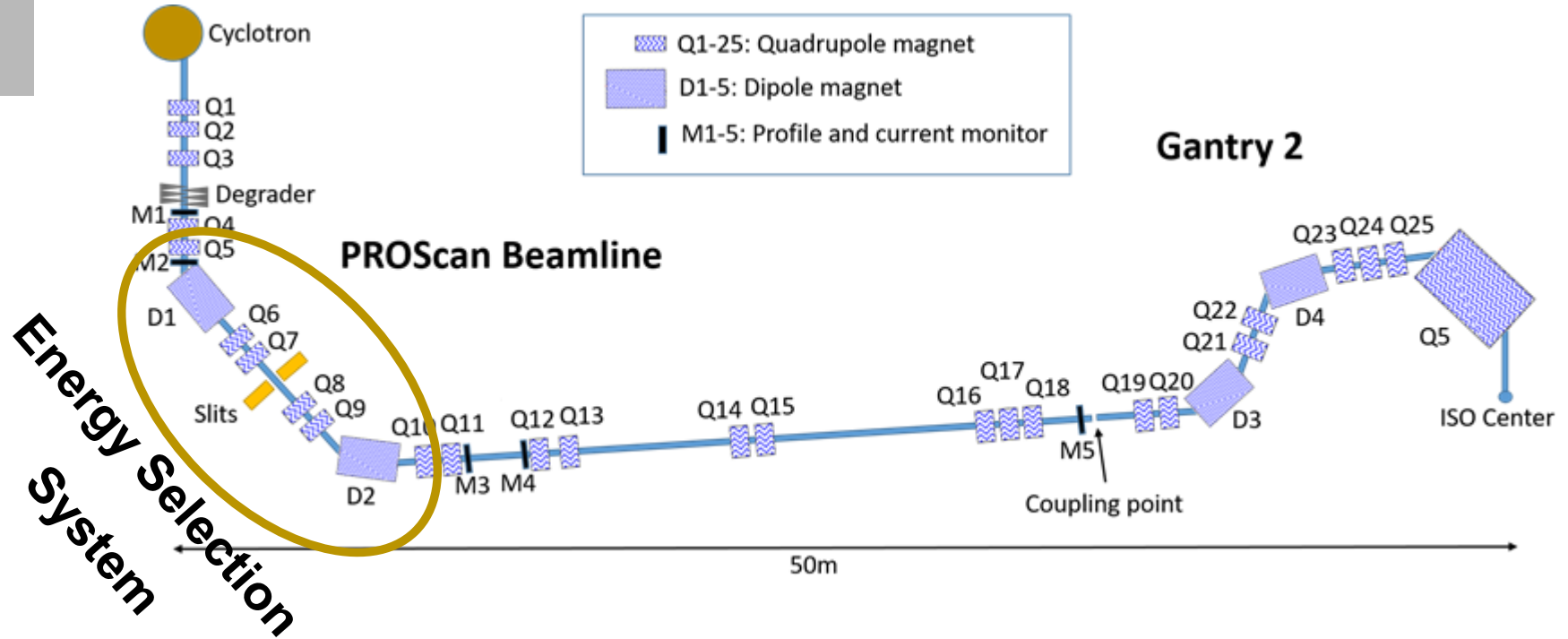


Use of *large beam size & small divergence*
at gantry entrance together with *2:1 imaging* beam
optics will allow to transport
 *$100 \pi * mm * mrad$* through gantry
while having *60%* transmission.

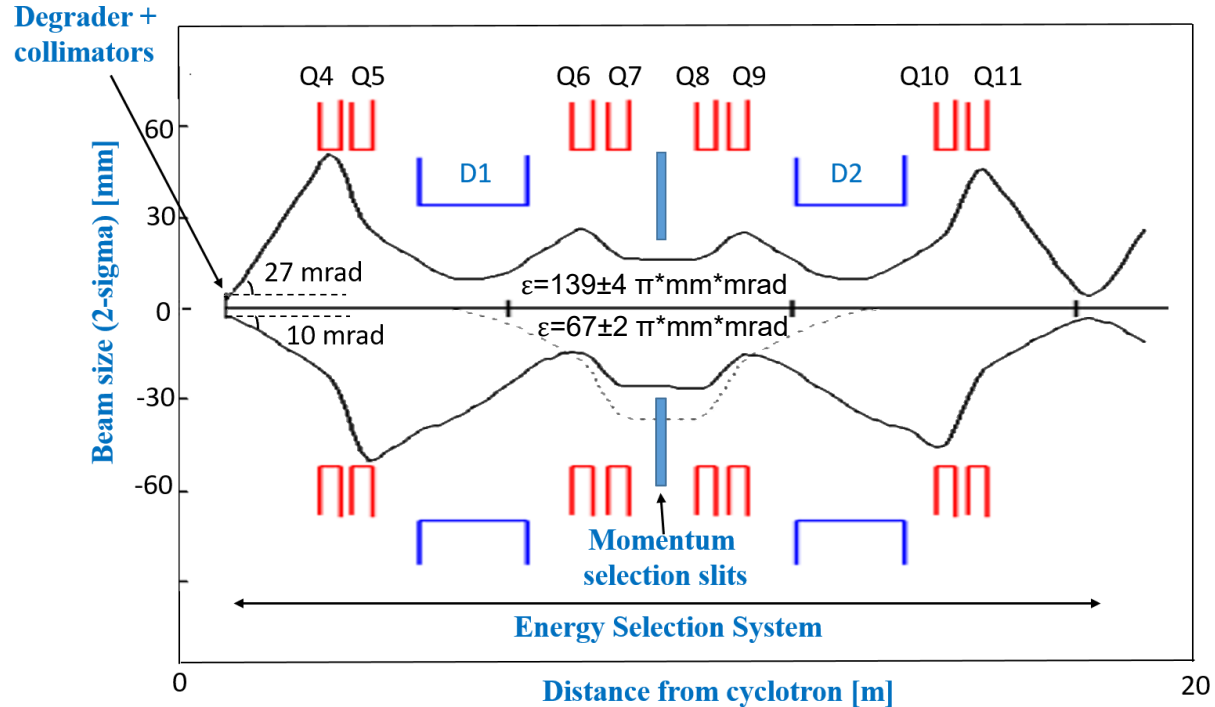
How to overcome these challenges ?



PROScan beamline



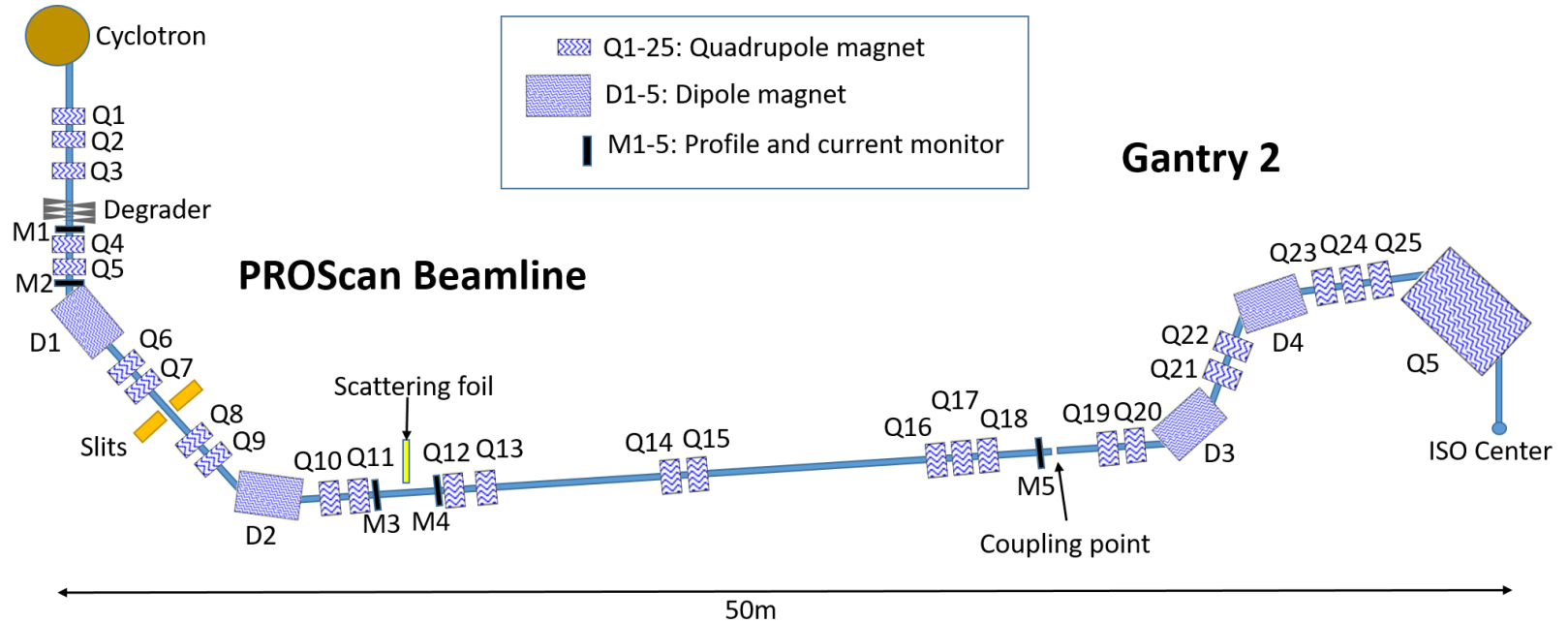
Energy selection system

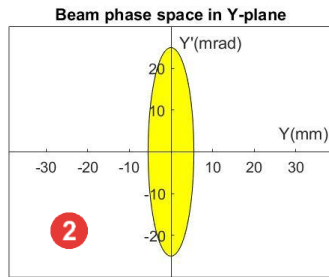


We can transport higher emittance
In y-plane compare to x-plane

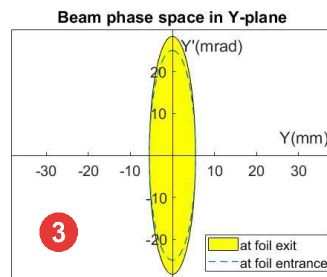
To achieve gantry angle independent beam at
isocenter, we need to have same emittance in
both planes at gantry entrance.

Scattering foil

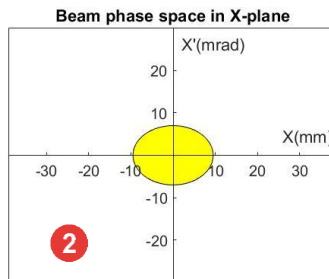
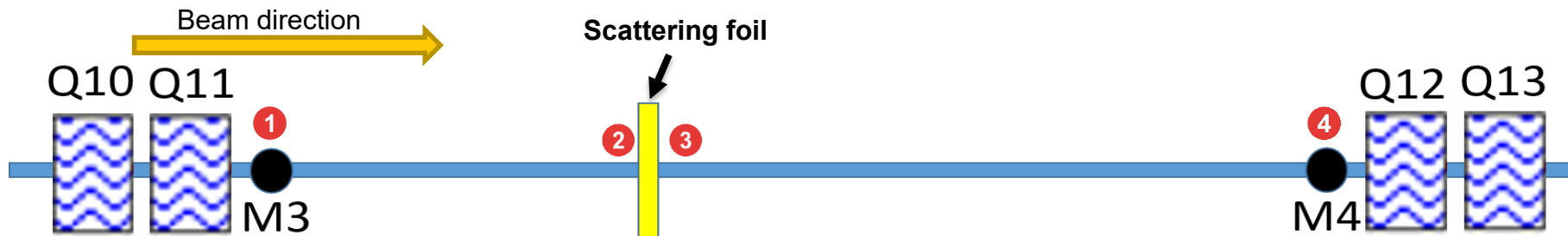




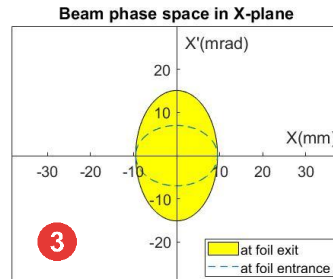
$$\varepsilon = 139 \pm 4 \pi \cdot \text{mm} \cdot \text{mrad}$$



$$\varepsilon = 148 \pm 5 \pi \cdot \text{mm} \cdot \text{mrad}$$

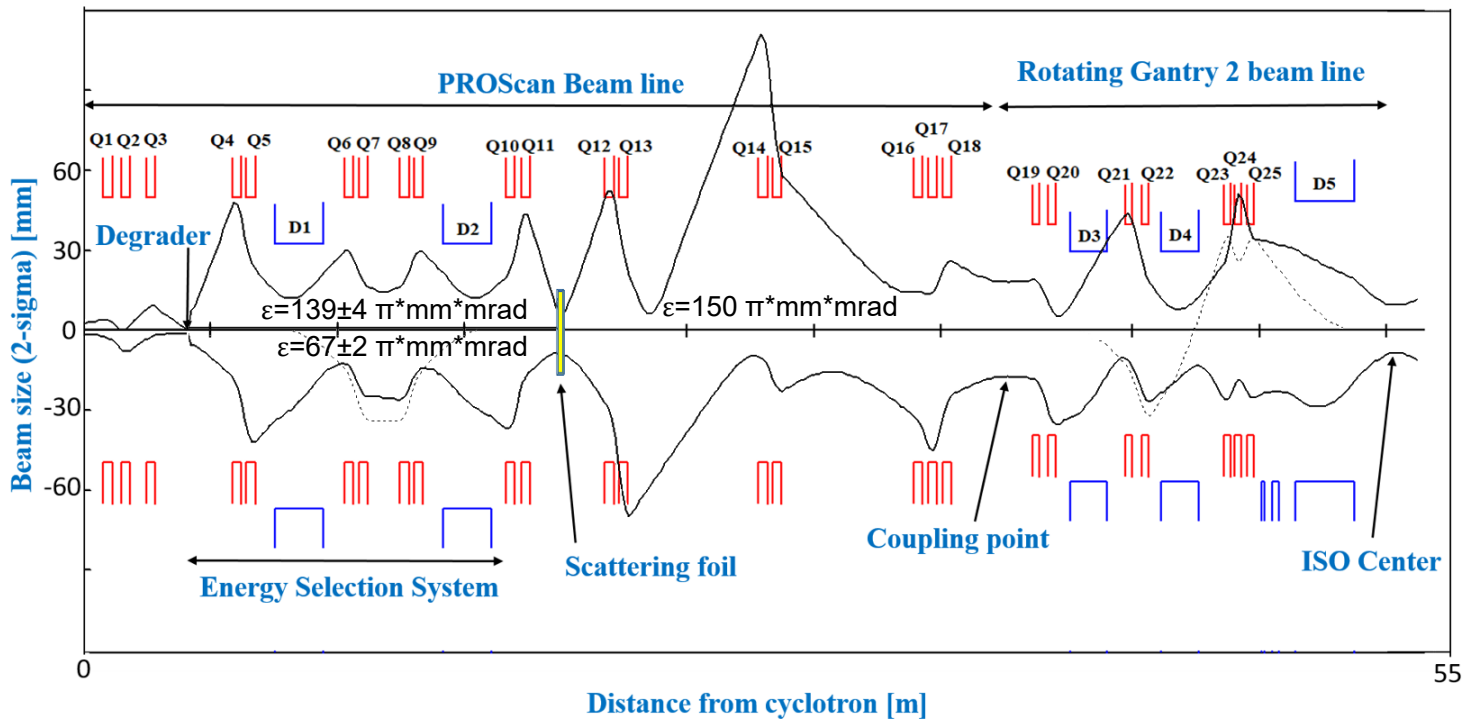


$$\varepsilon = 67 \pm 2 \pi \cdot \text{mm} \cdot \text{mrad}$$



$$\varepsilon = 145 \pm 6 \pi \cdot \text{mm} \cdot \text{mrad}$$

Scattering foil



Transmission gain

For 70 MeV beam

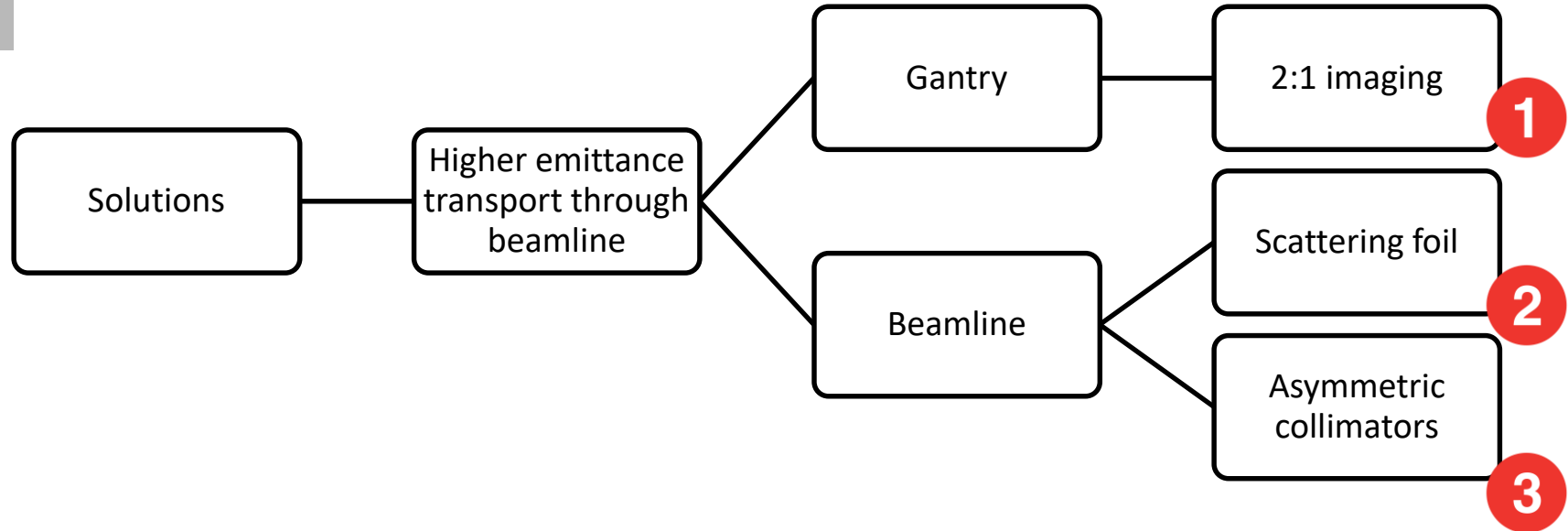
Clinical beam optics : **0.13%**

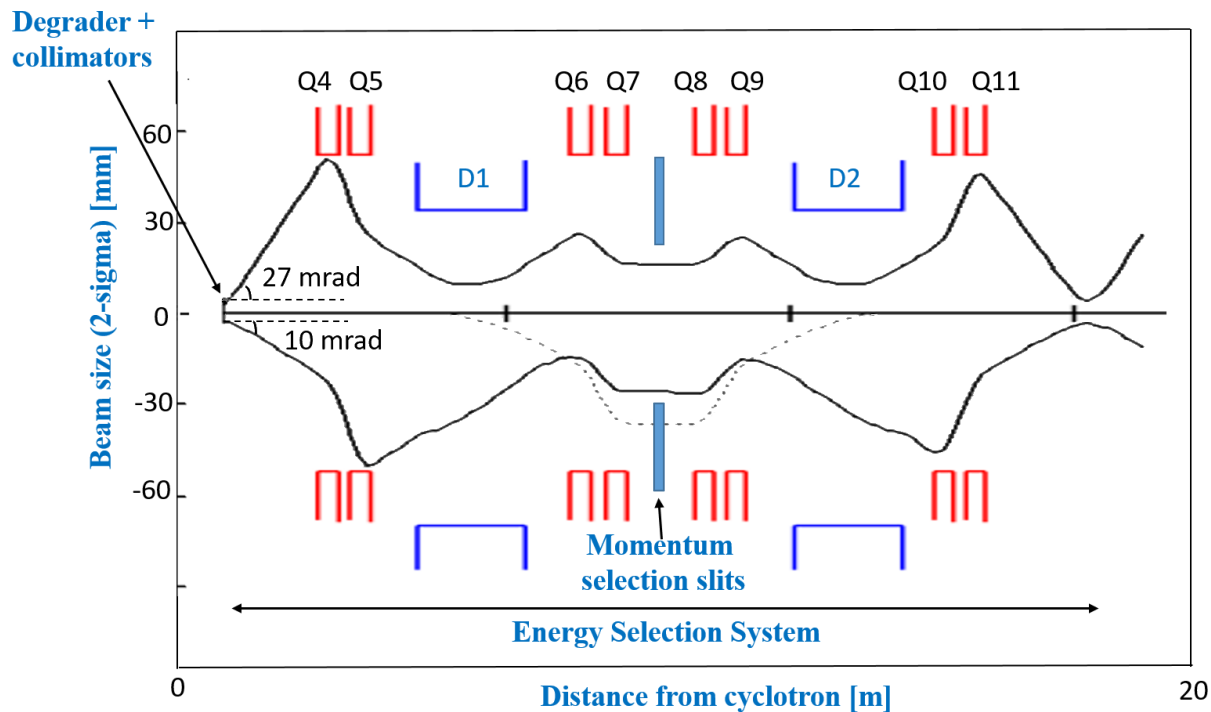
Scattering foil + 2:1 imaging : **0.4%**

(1.8 times larger beam size)

Gain : ~ factor 3 (Experimentally)

How to overcome all these challenges ?

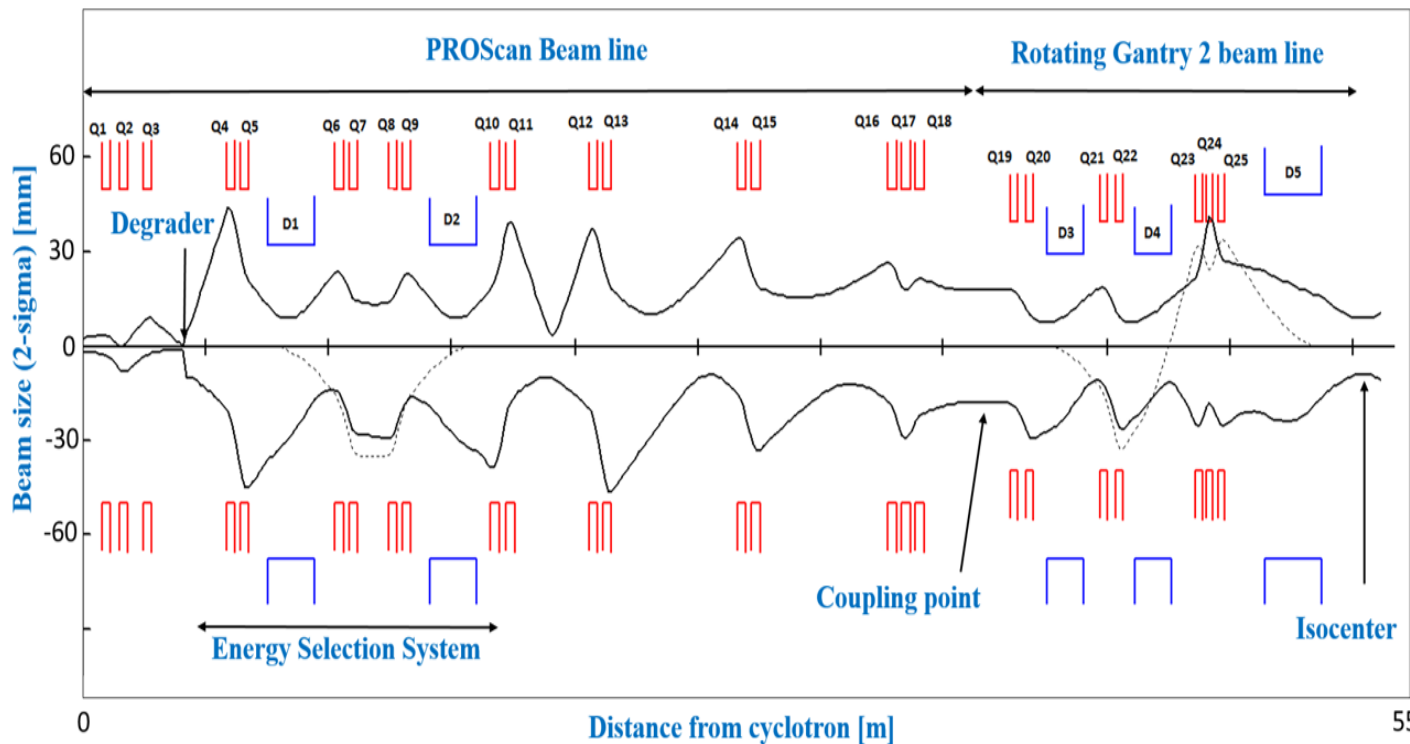




Asymmetric collimator

Y-axis:
Beam size: 4 mm
Divergence: 25 mrad

X-axis:
Beam size: 10 mm
Divergence: 10 mrad



Transmission gain with asymmetric collimator

For 70 MeV beam

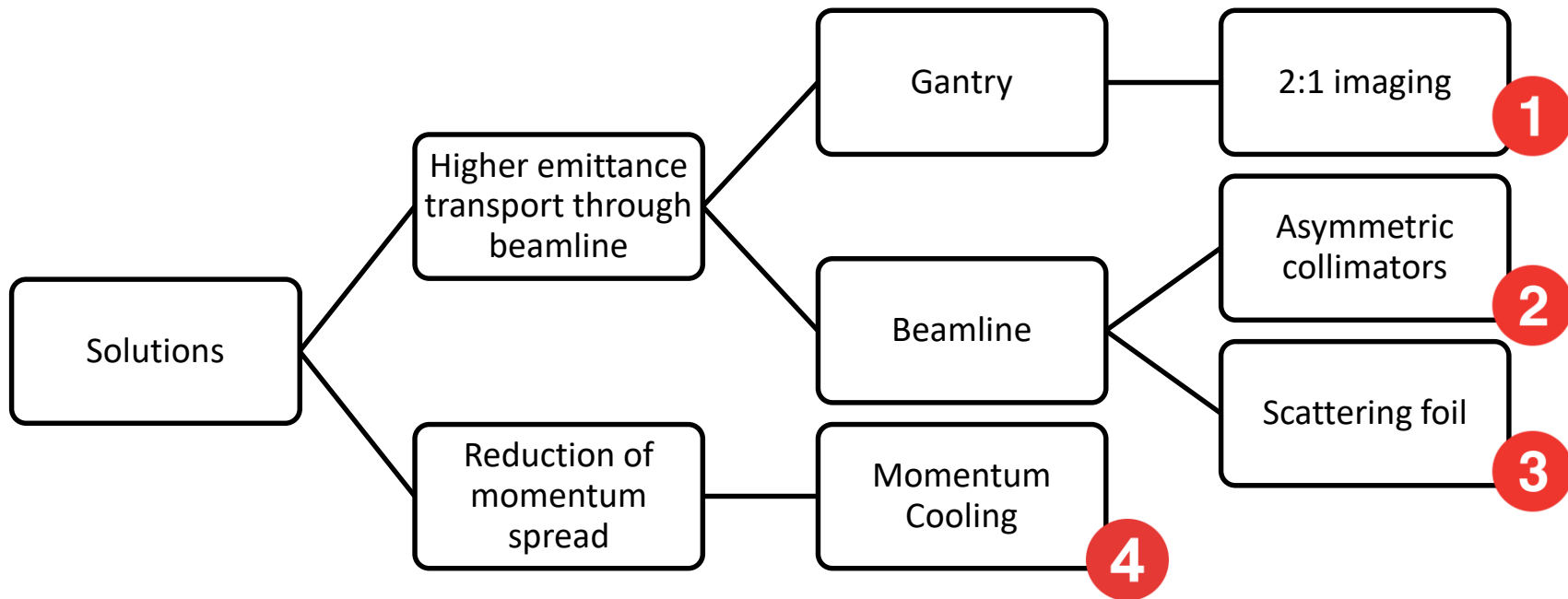
Clinical beam optics : **0.13%**

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

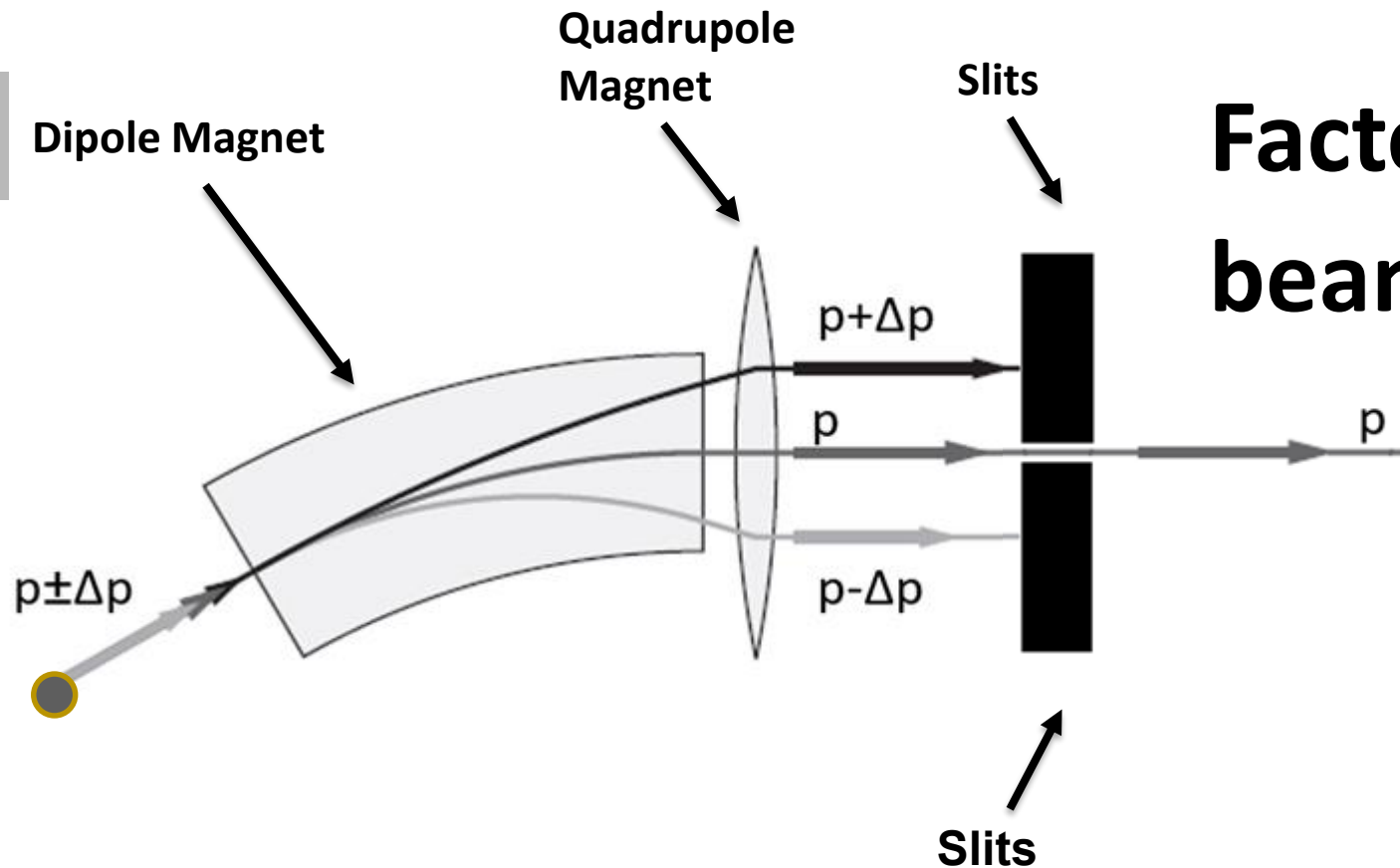
(1.5 times larger beam size)

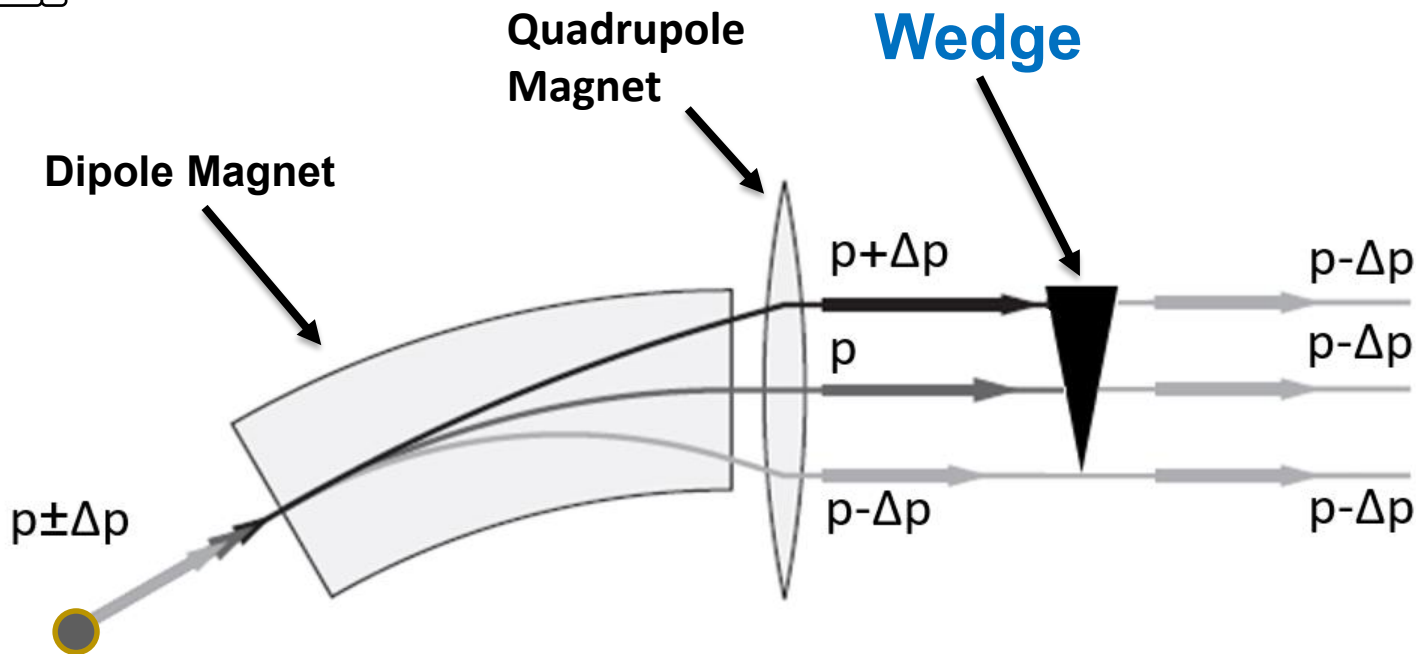
Gain : ~ factor 6 (Simulation)

How to overcome all these challenges ?



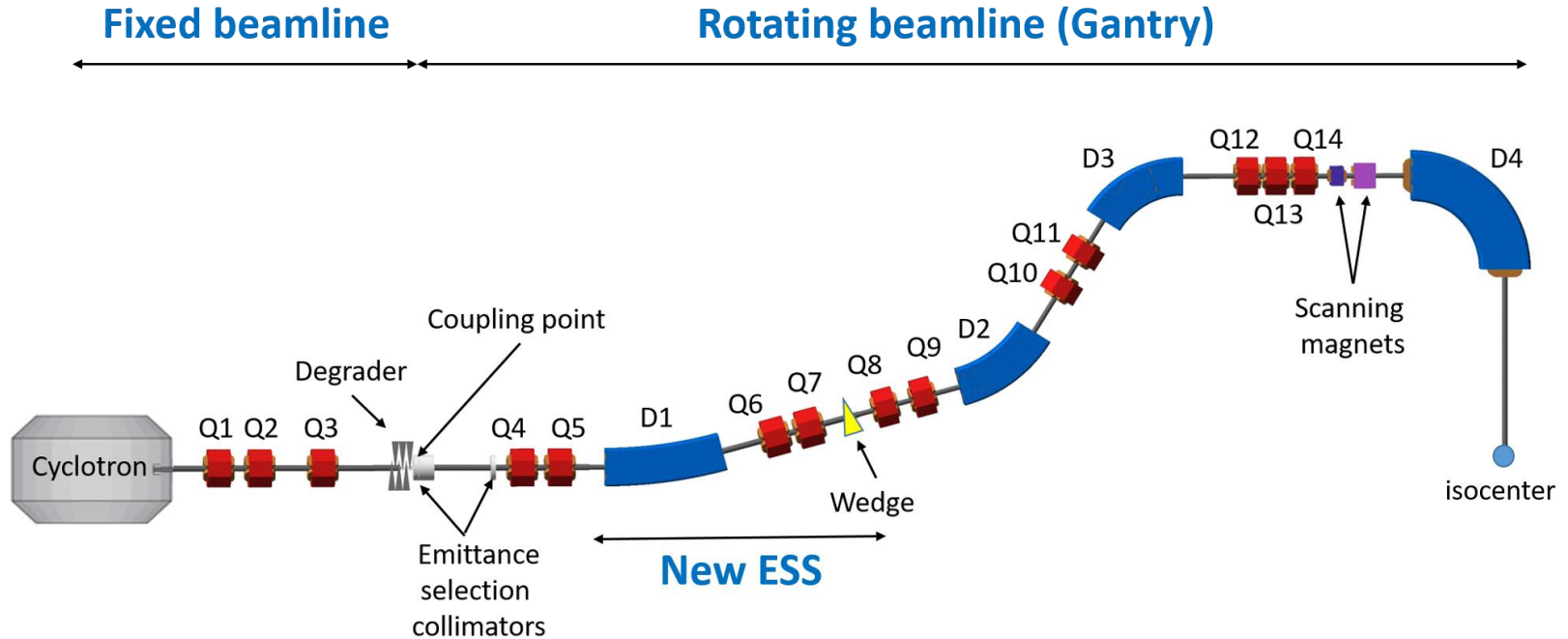
Energy/momentum spread



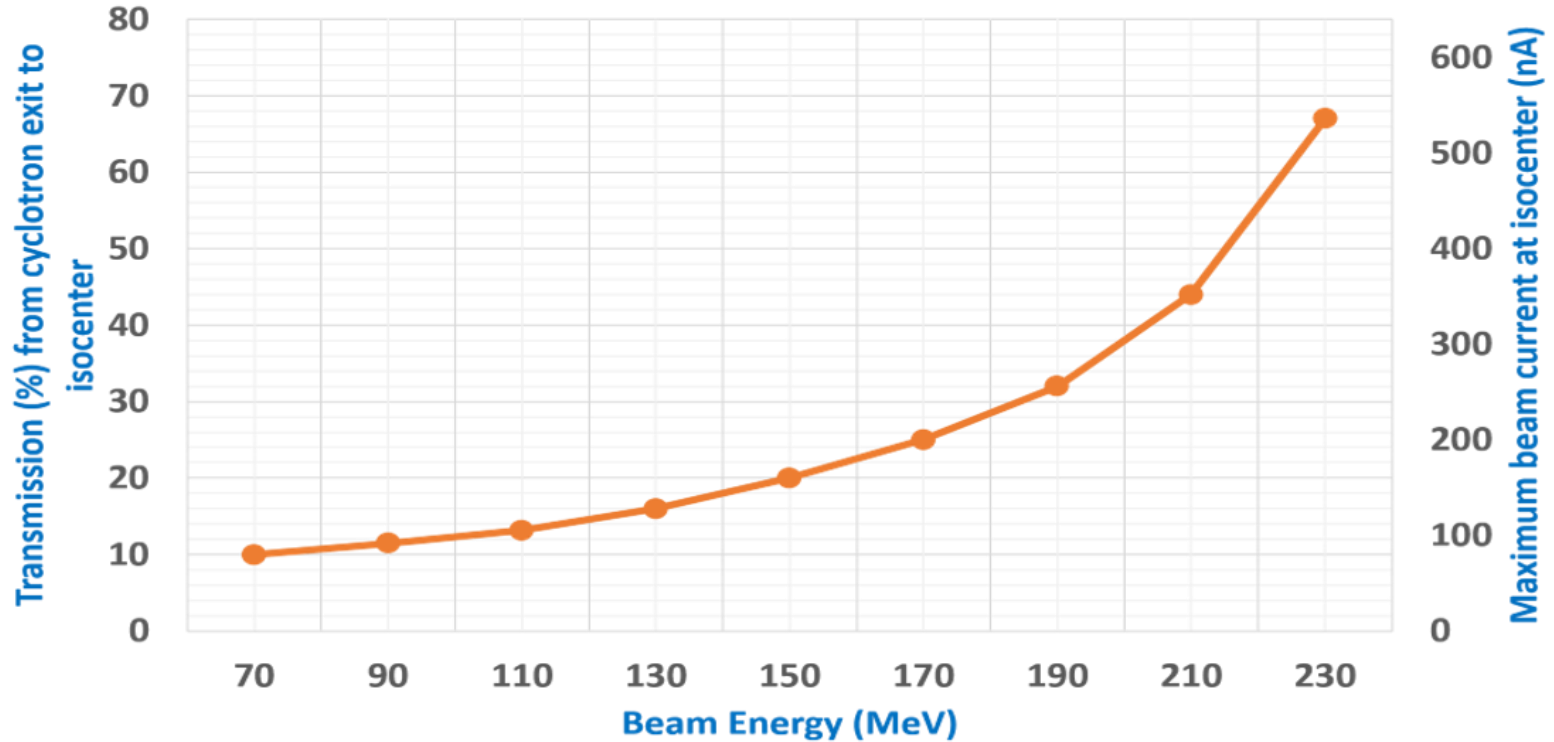


250 MeV -> 70 MeV -> $dp/p = 4.5\%$  $dp/p = 0.4\%$

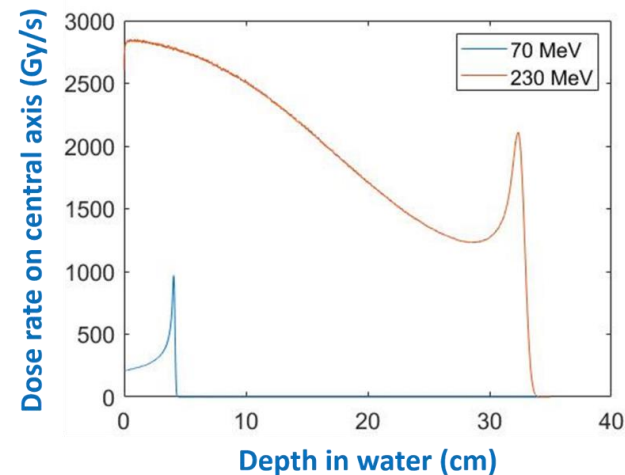
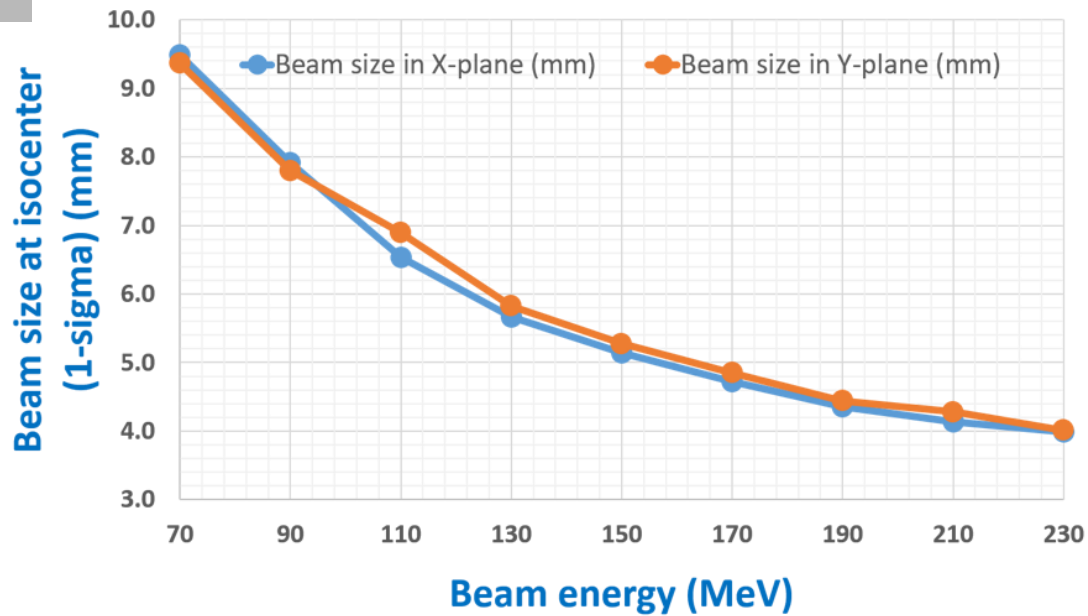
Gantry with momentum cooling capabilities



Transmission



Beam size and dose rate



Transmission gain

For 70 MeV beam

Clinical beam optics : **0.13%**

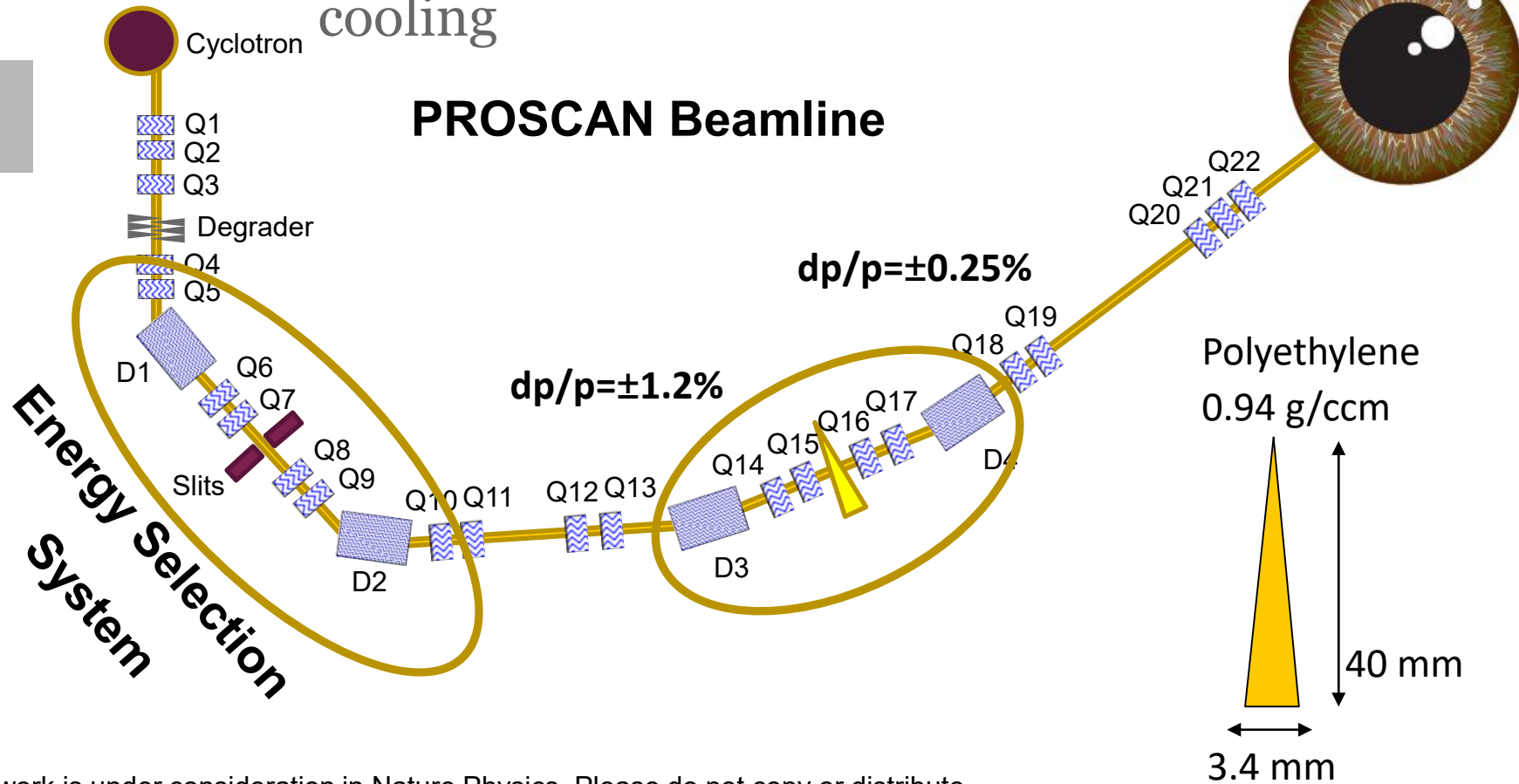
Momentum cooling + 2:1 imaging : **10%**

(1.7 times larger beam size)

Gain : ~ factor 80 (Simulation)

Experimental demonstration of momentum cooling

PROSCAN Beamline



For 70 MeV beam

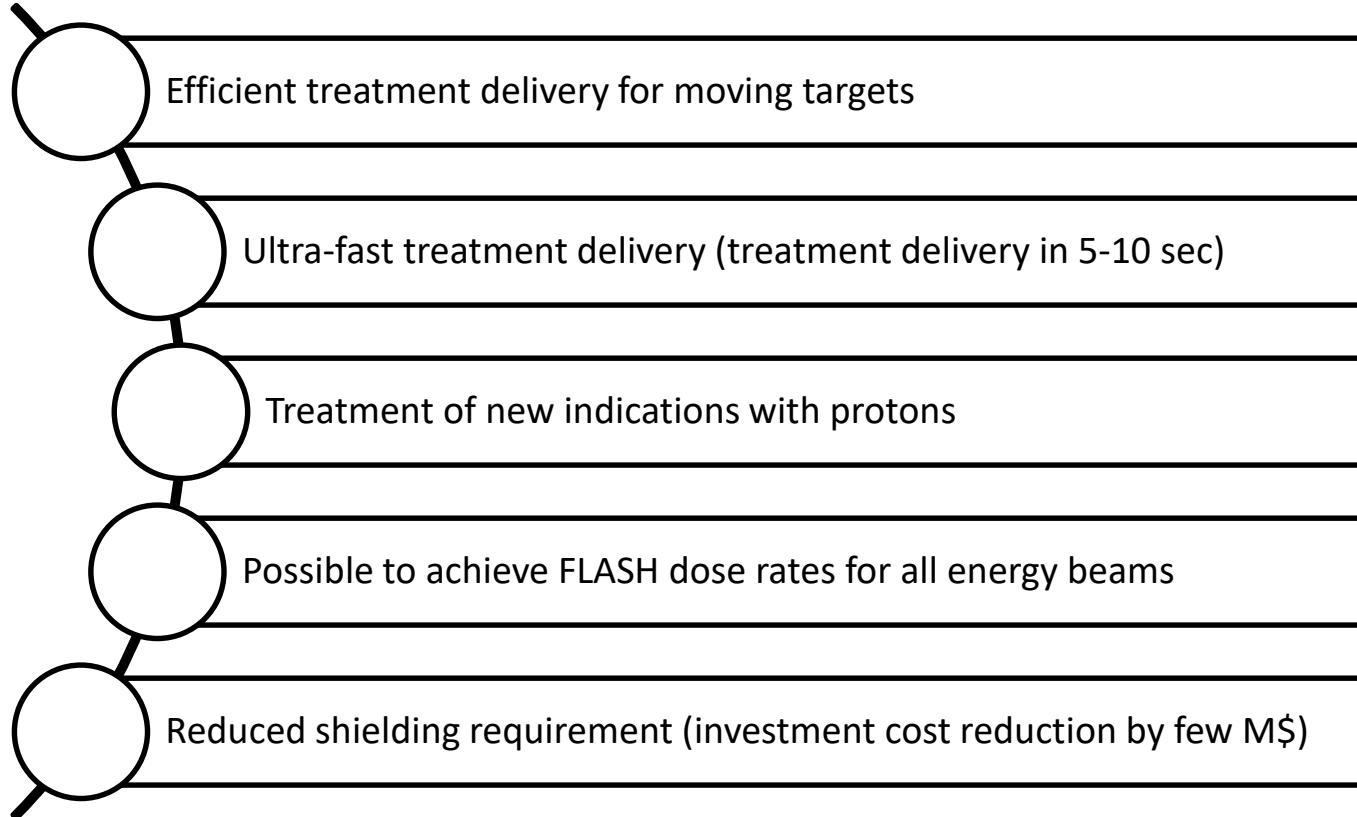
Clinical beam optics : **0.13%**

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



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

