Preliminary beamline designs for electron FLASH radiation therapy at PITZ

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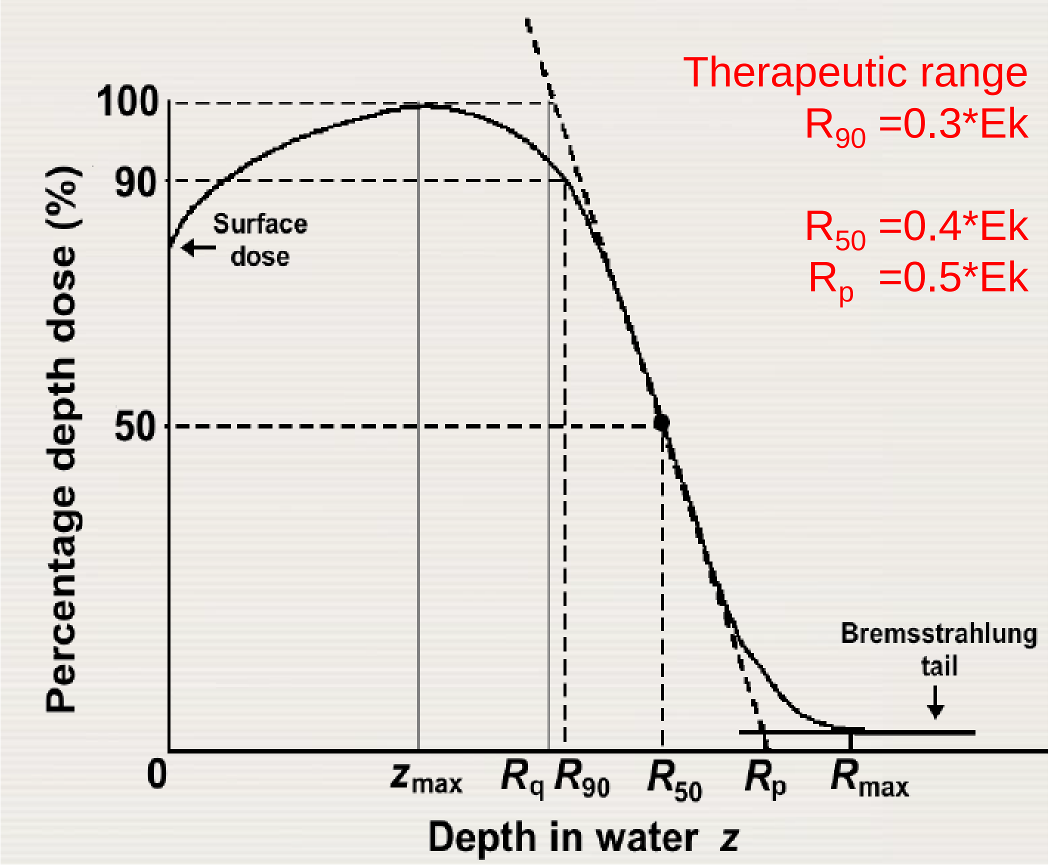
12.08.2021

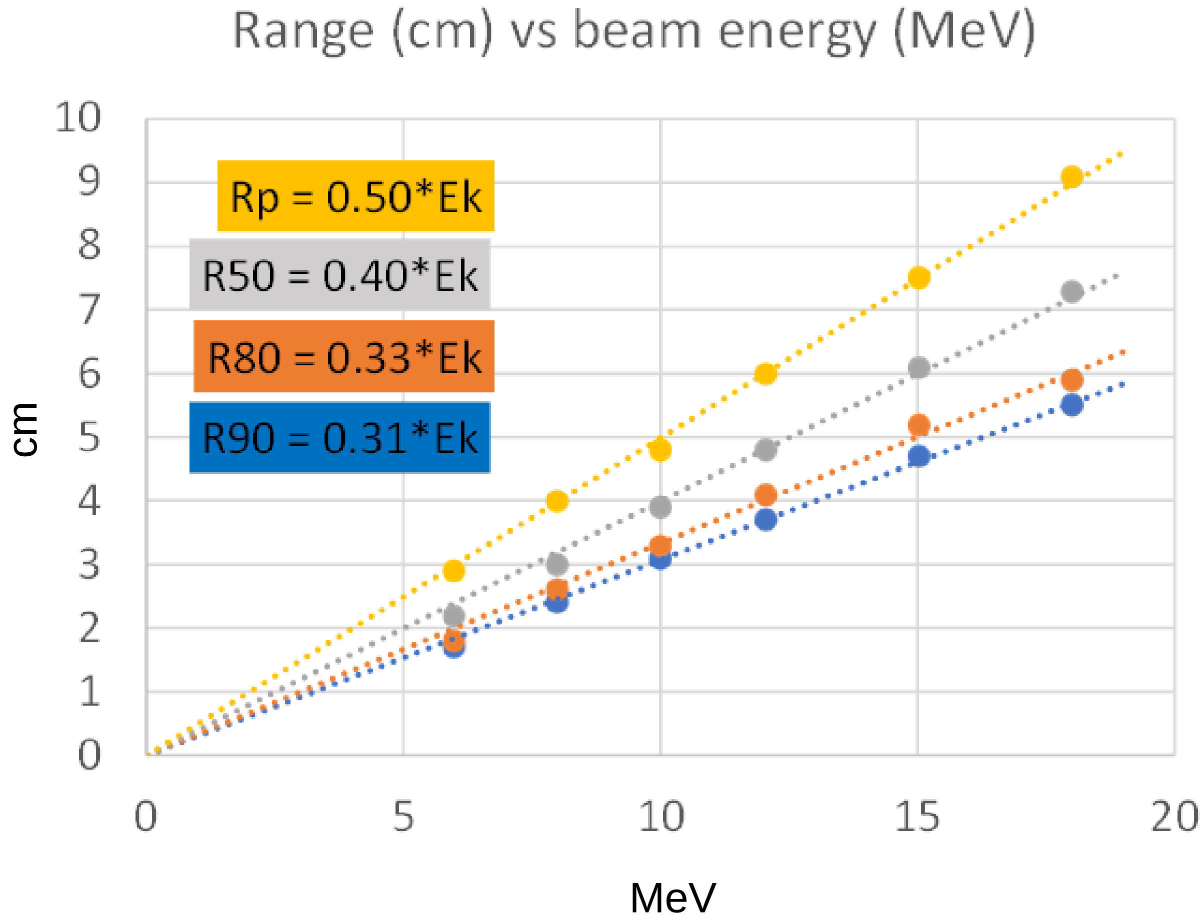
Outline

- Introduction
- Implications of beam focusing from Zakaria’s simulations
- Preliminary dogleg design

Central axis depth does distributions

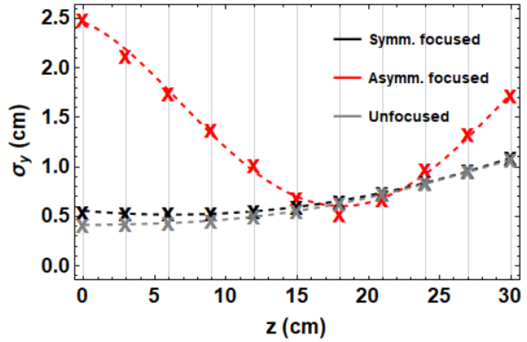
Single electron effect

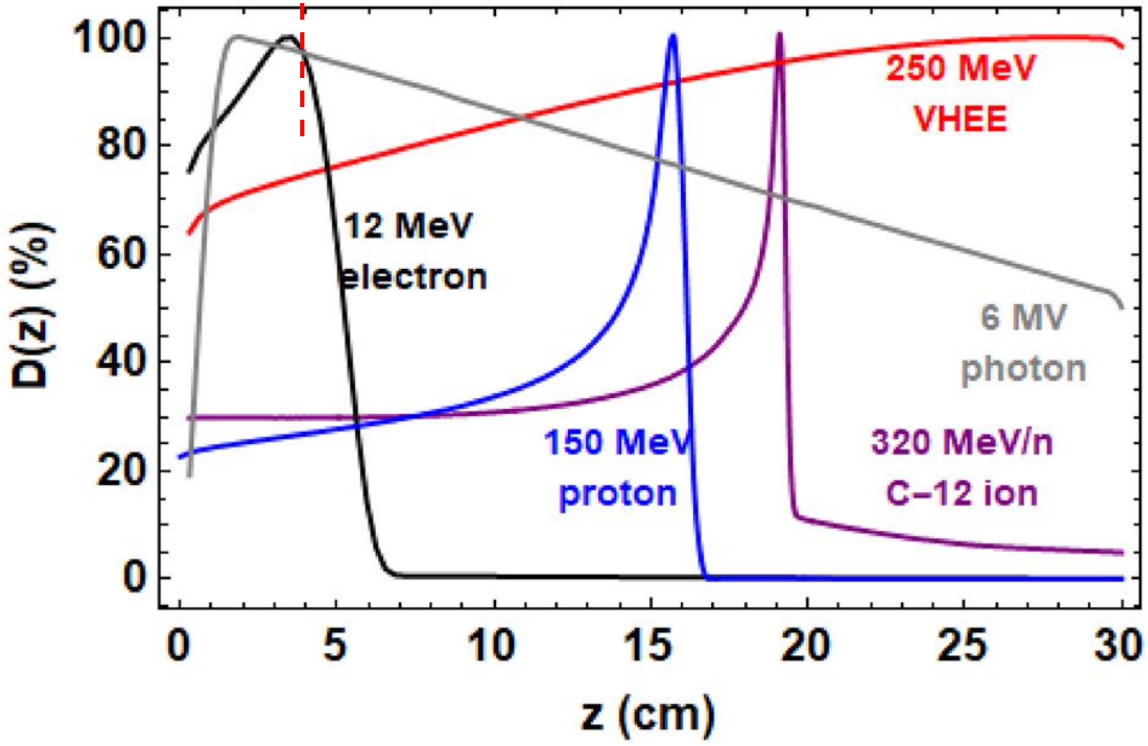


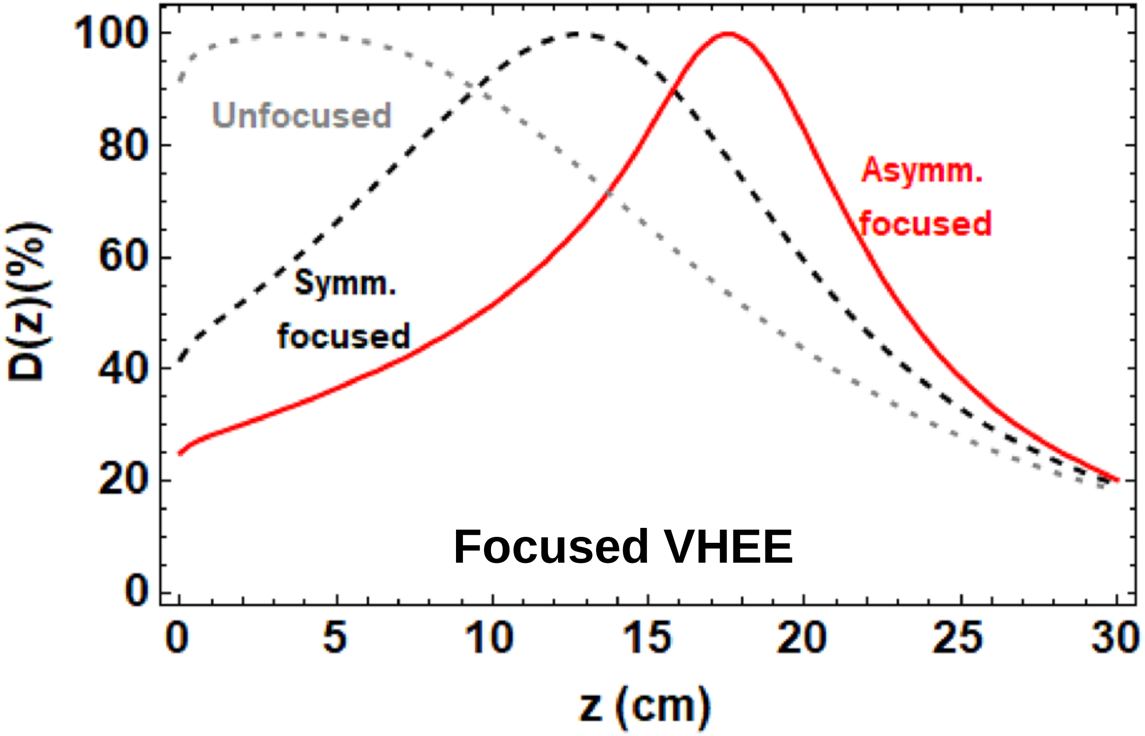


VHEE and focused VHEE

Electron therapy Vs other therapies





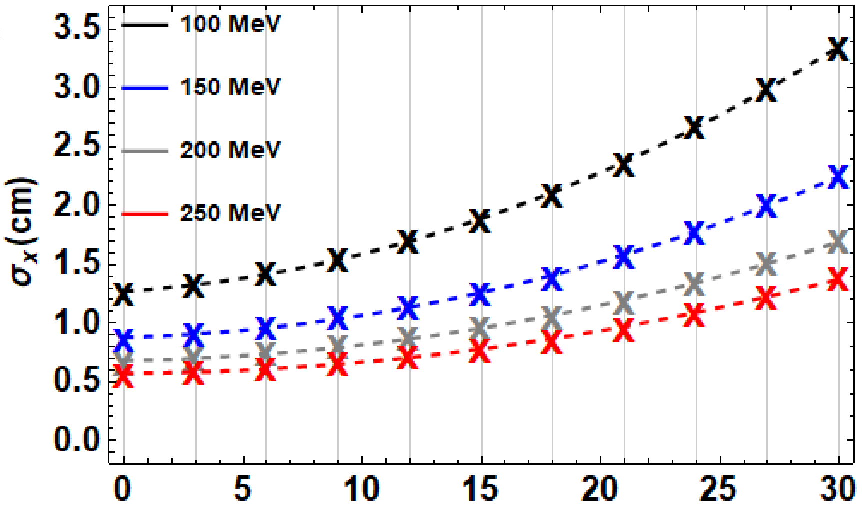


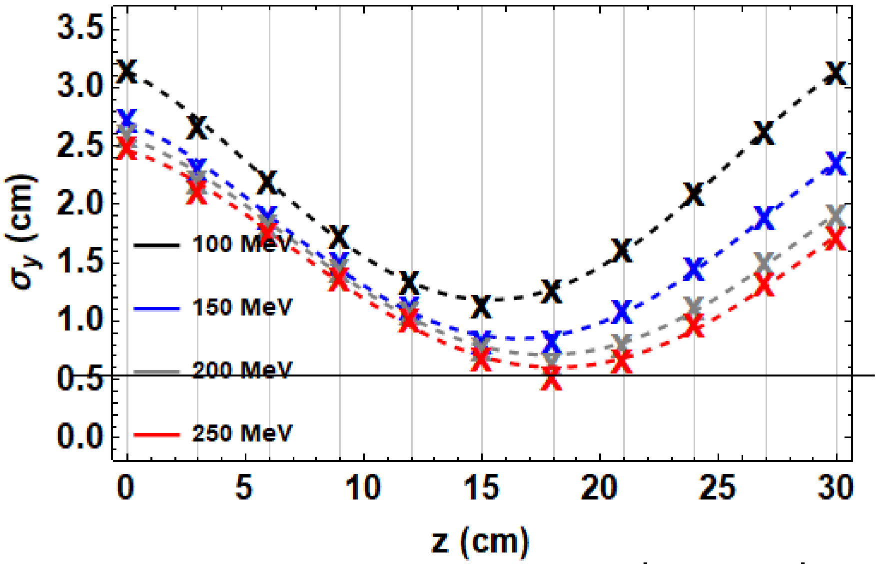
Current low energy electron therapy Vs photon and proton therapy:

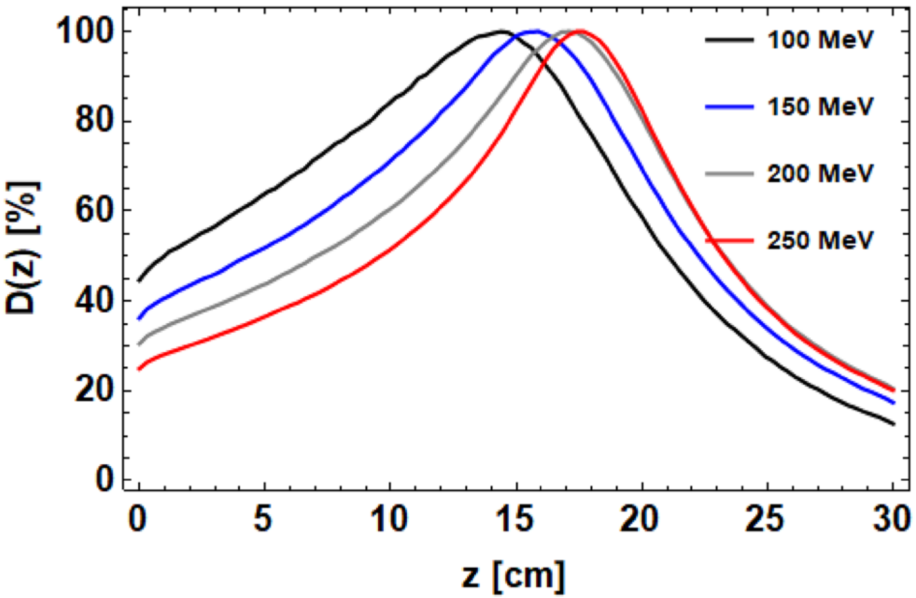
1) Short therapeutic range (~**5 cm**) → very high-energy (**50-250 MeV**) electron (**VHEE**), **15-30** cm
2) High entrance does → **Focus beam size at tumor location,** peak axis does near beam waist (bunch effect)

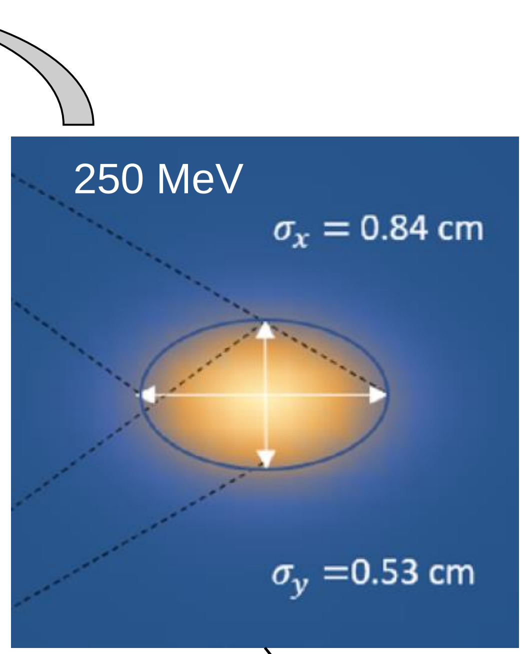
VHEE and focused VHEE

An simulation example



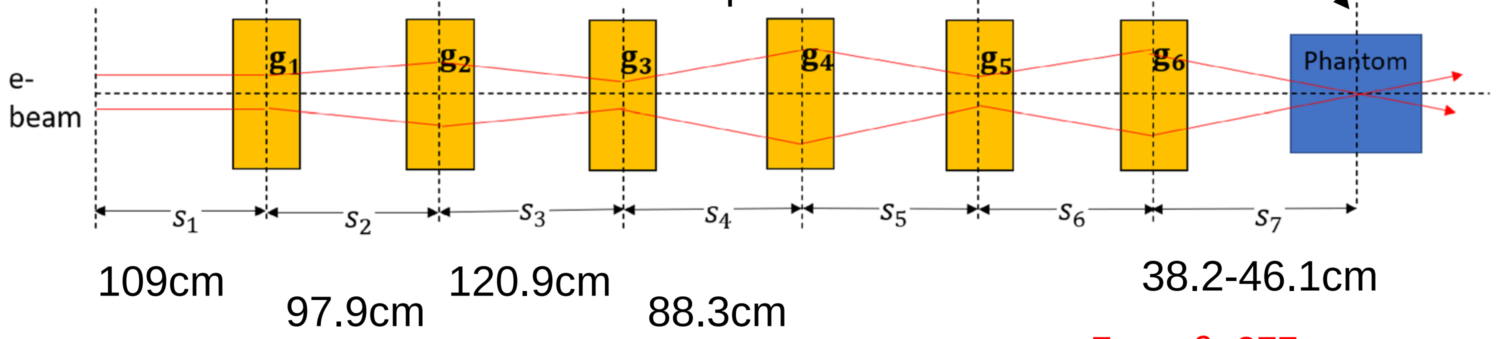






$\sigma_x = 4\ mm, \sigma_{x'} = 3.2\ mrad, \epsilon = 13\ mm.mrad, \epsilon_n = 6400\ mm.mrad$

Beam and quads in air

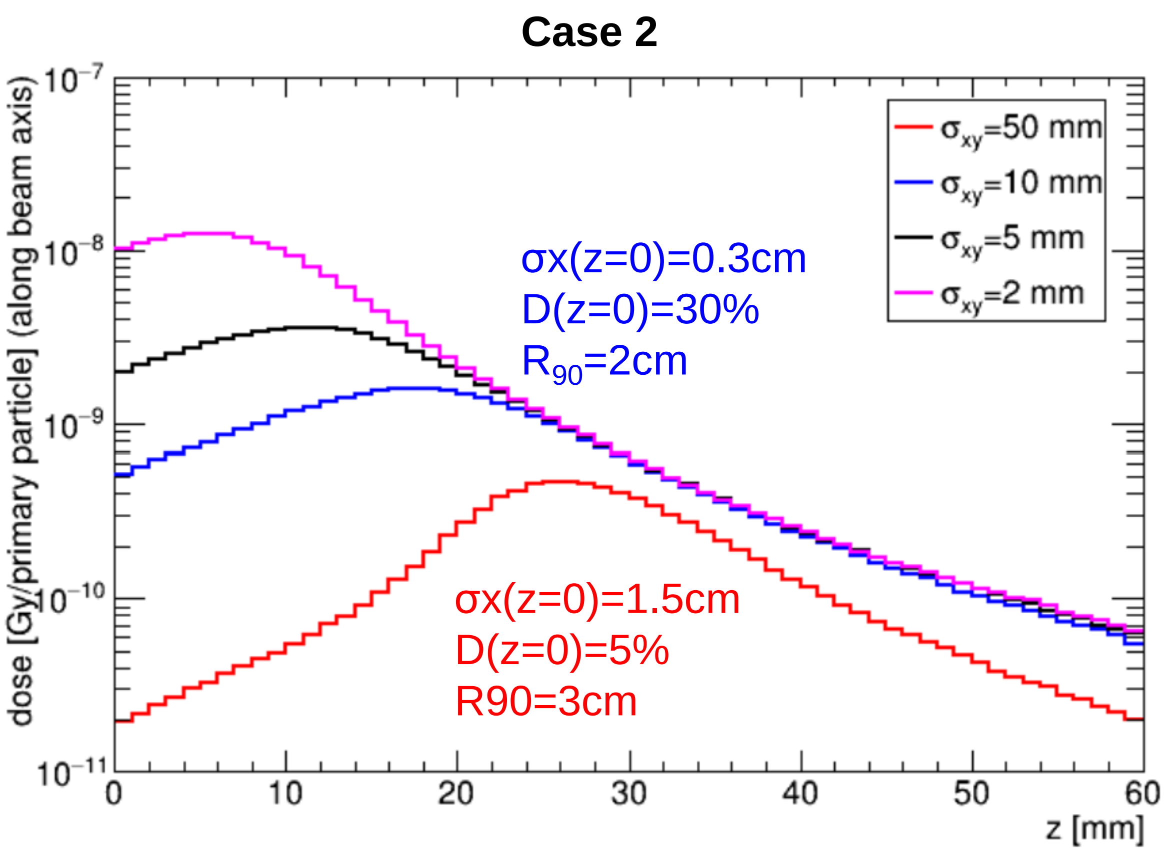


σ_y ~7 cm, β=377m @Q6

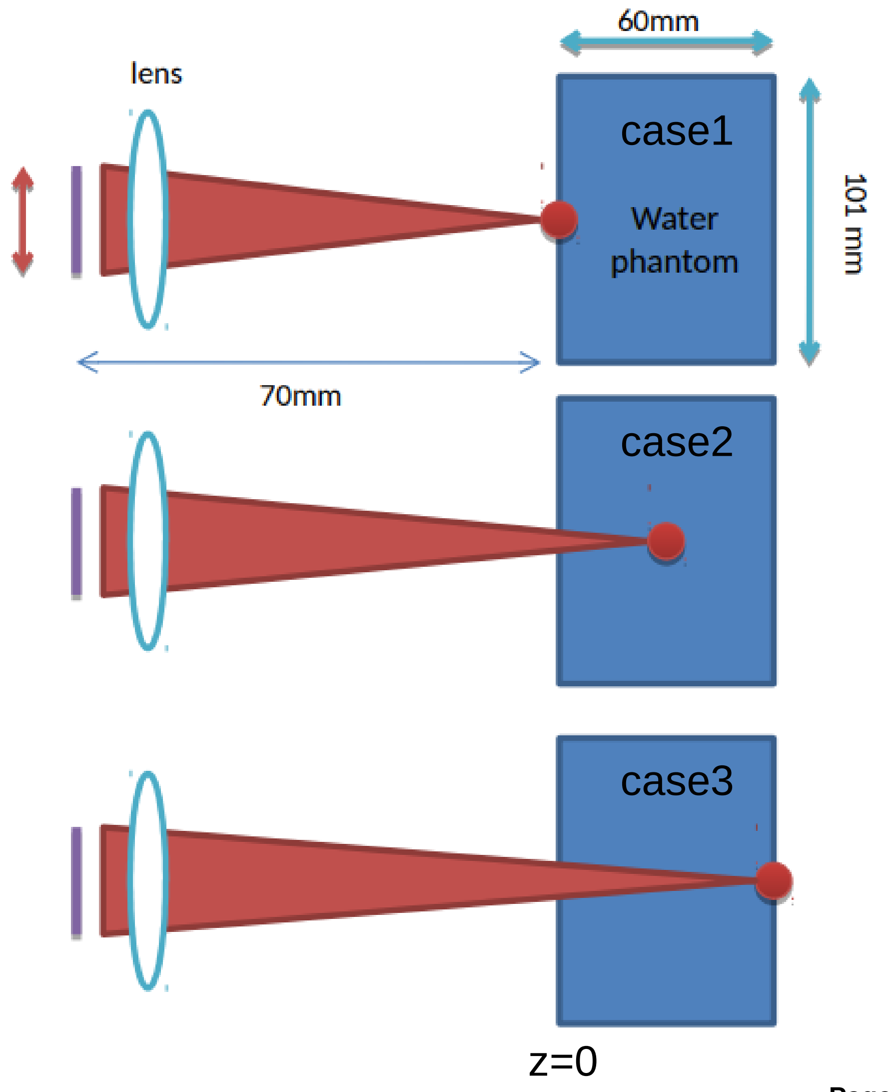
https://doi.org/10.1038/s41598-021-93276-8

PITZ simulations of focused beam

By Zakaria, using 22 MeV zero emittance beam



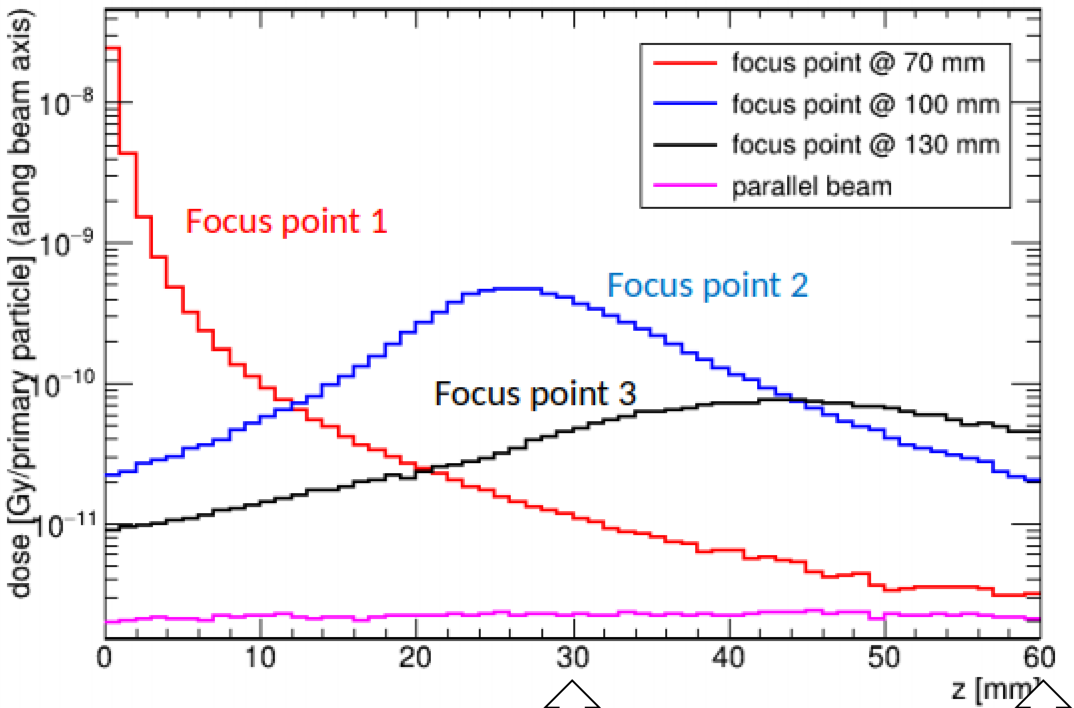
Parallel beam:
$D(z=0)=96\%$
$R_{90}=7cm$



PITZ simulations of focused beam

By Zakaria, using 22 MeV zero emittance beam

σ_x=50mm



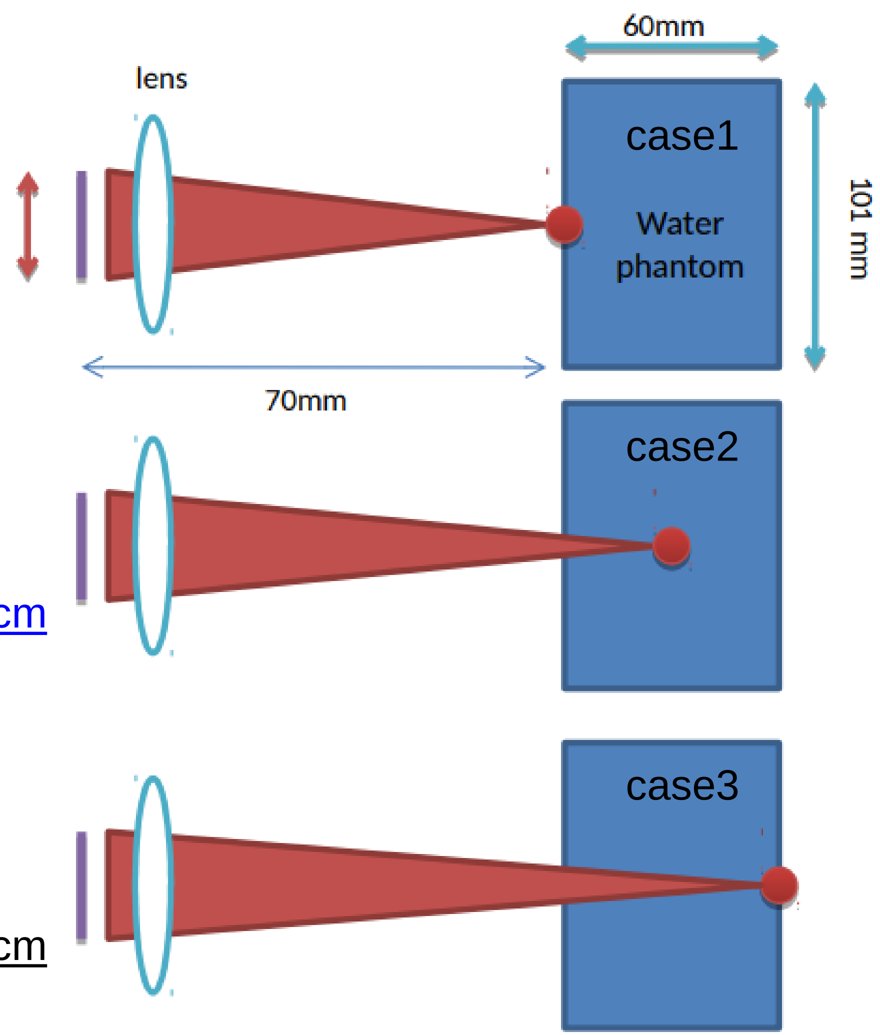
case2

case3

Parallel beam:
D(z=0)=96%
R90=7cm

D(z=0)=5%
R90=3cm
σx(z=0)=1.5cm

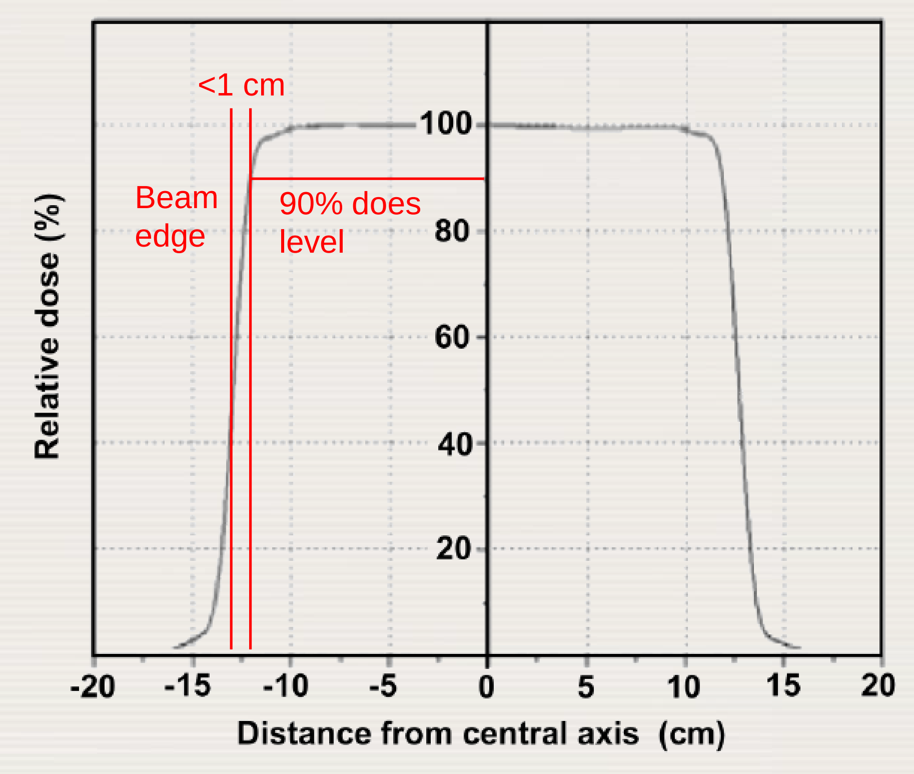
D(z=0)=12%
R90=5cm
σx(z=0)=2.3cm



z=0

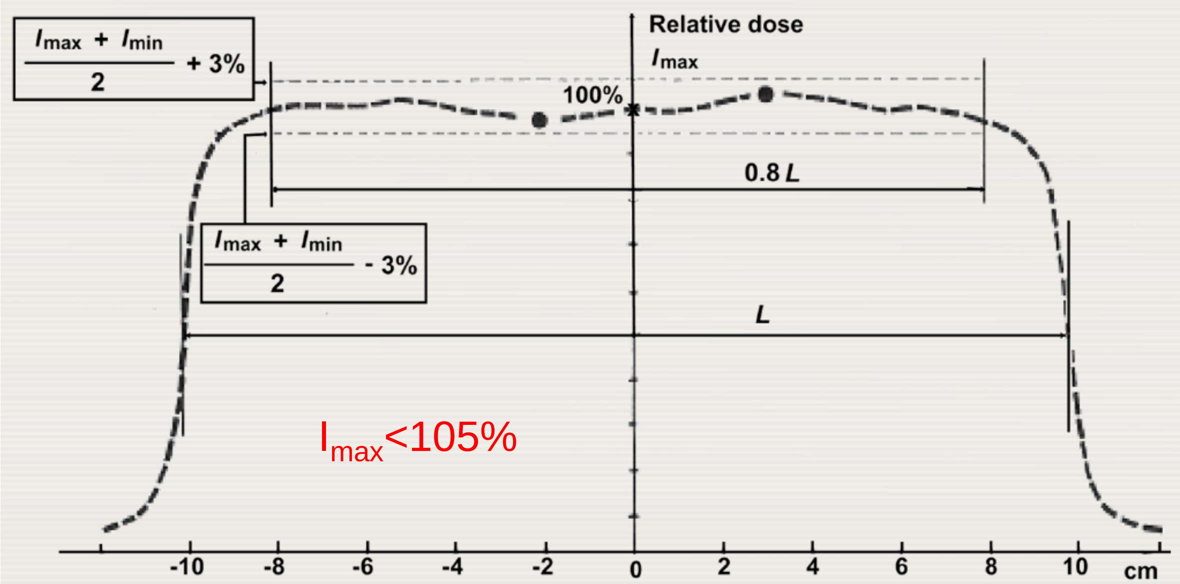
Does profile flatness and symmetry (IEC specs)

At max does depth (Zmax)



Dose profile measured at a depth of dose maximum z_{max} in water for a 12 MeV electron beam and 25×25 cm^2 applicator cone.

Does difference <3% for any symmetry points w.r.t. central ray



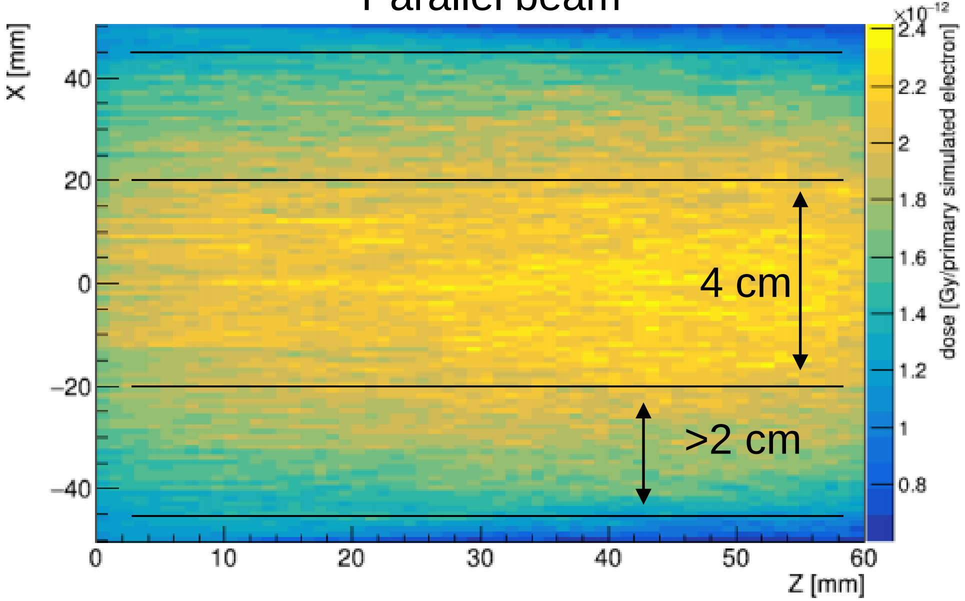
PITZ simulations of focused beam

By Zakaria, using 22 MeV zero emittance beam

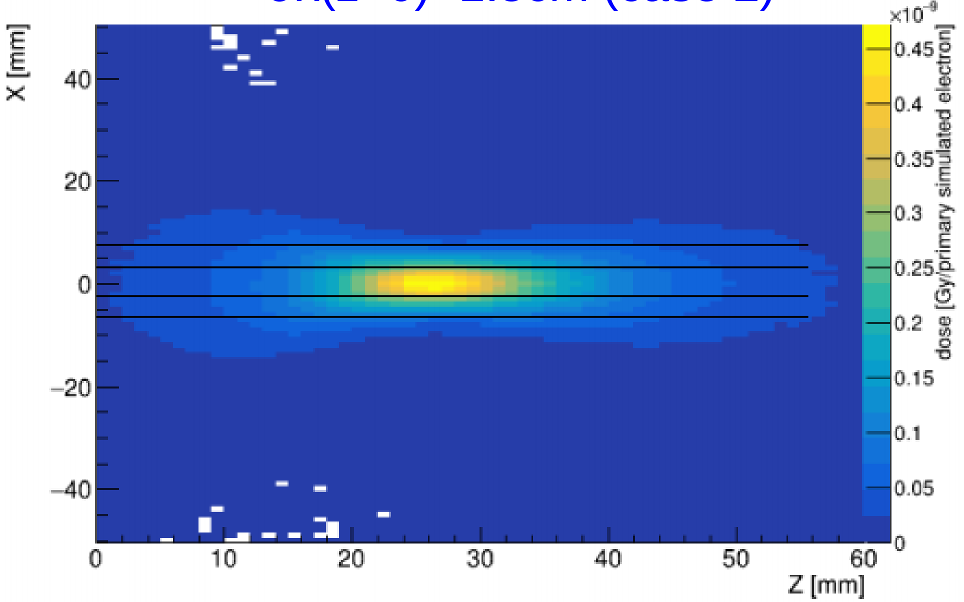
- Does profile flatness
  - Parallel beam
    - 90% does area, 4 cm
    - No sharp edge, >2cm (Gaussian beam)
      - Needs beam scattering and shaping
  - Focused beam (case2)
    - 90% does area, 0.5 cm, Distance to edge, ~0.5 cm
      - Needs bunch train scanning to cover tumor
      - e.g. 16 x 16 to cover 4x4 cm (parallel beam case)
      - e.g. 10 x 10 to cover 2.5x2.5 cm (current kicker goal)
      - Case 3, maybe 5 x 5 to cover 2.5x2.5 cm

σ=50 mm

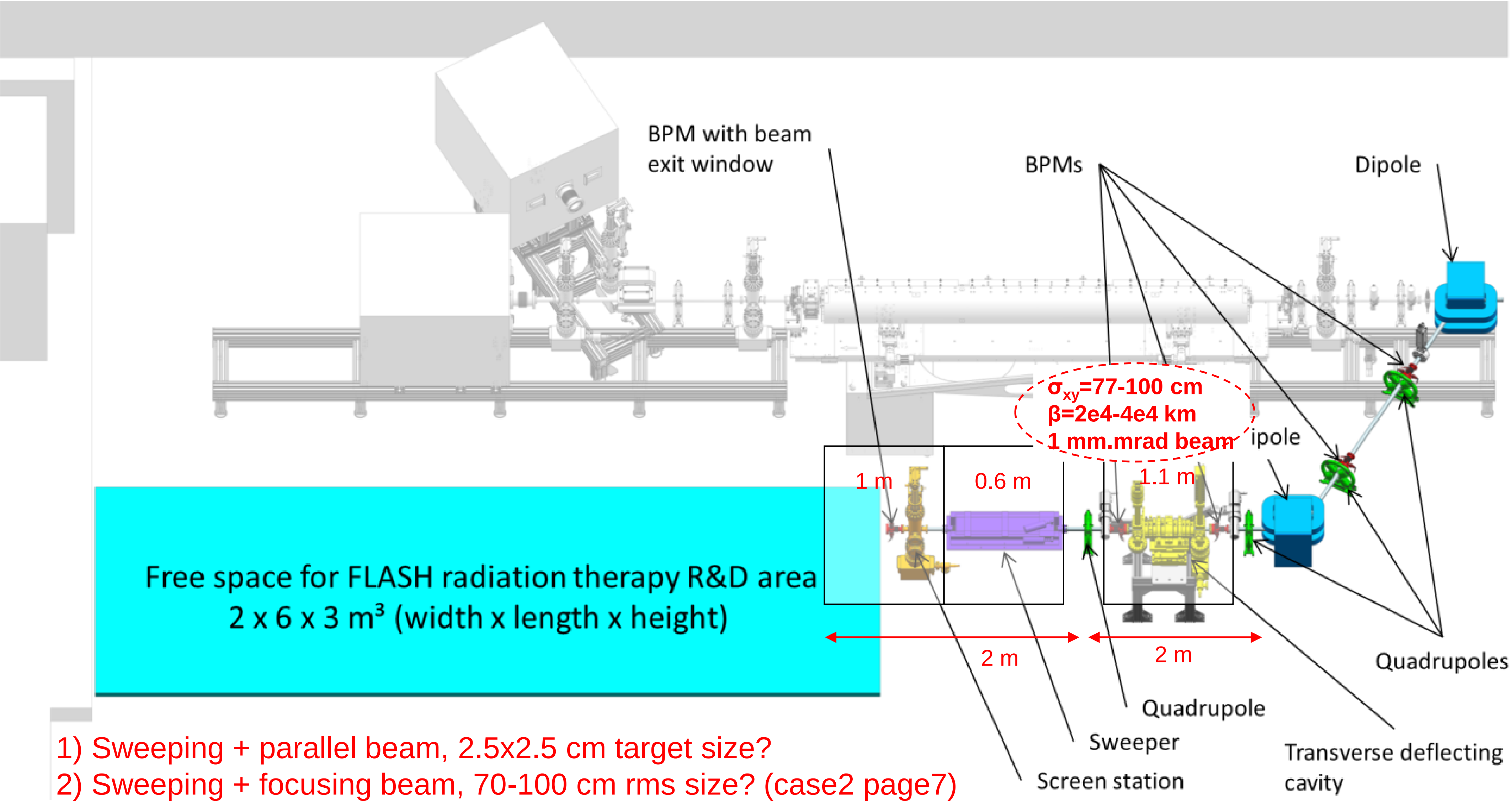
Parallel beam



σx(z=0)=1.5cm (case 2)



Schematic diagram



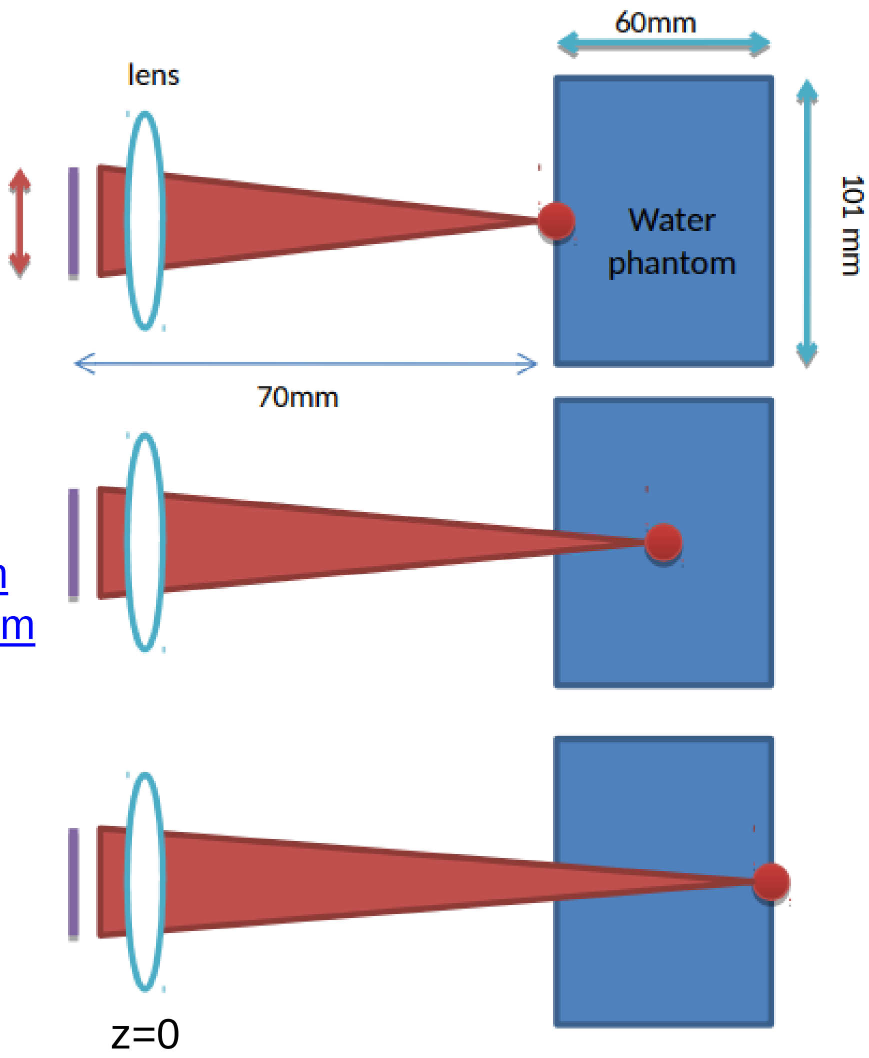
1) Sweeping + parallel beam, 2.5x2.5 cm target size?
2) Sweeping + focusing beam, 70-100 cm rms size? (case2 page7)

How to achieve a reasonable beam size at focusing magnets?

Add a quadrupole set after kicker for final strong focusing

- Based on the left case, let's further reduce beam rms size at lens to 2 cm to reduce lens bore size (1 cm beam is bit too small according to results on slide 6), which should still achieve a reasonable peak does effect.
  - In this case, 4 rms is about 8 cm beam at lens, requires a bore diameter about 10 cm.
  - Distance from lens to peak does depth about 10 cm.
    - If lens distance to waist gets longer, then beam size at lens and lens bore diameter increase proportionally, might not be a good idea to further increase lens bore size.
  - Quad strength (M21) ca 10 m^{-1} (1/10cm).
    - Consider a 5 cm effective quad length, this leads to a 15 T/m quad gradient (compared to 8.5 T/m at 12 A for PST quads)
    - PST Quads bore D=4 cm, here bore D=10 cm, leading to a B field of 1 T on pole surface, compared to 0.24 T for PST quads at 12 A.
    - With doublet or triplet to focus both x and y, then single quadrupole gradient is even stronger, close to pole field saturation.
    - Longer quads will help, but cannot be much longer due to beam distance requirement between quads center to sample, otherwise beam size increases at quads, leads to bigger bore radius and saturate B field again.

D(z=0)=5%
R90=3cm
σx(lens)=5cm
σx(z=0)=1.5cm



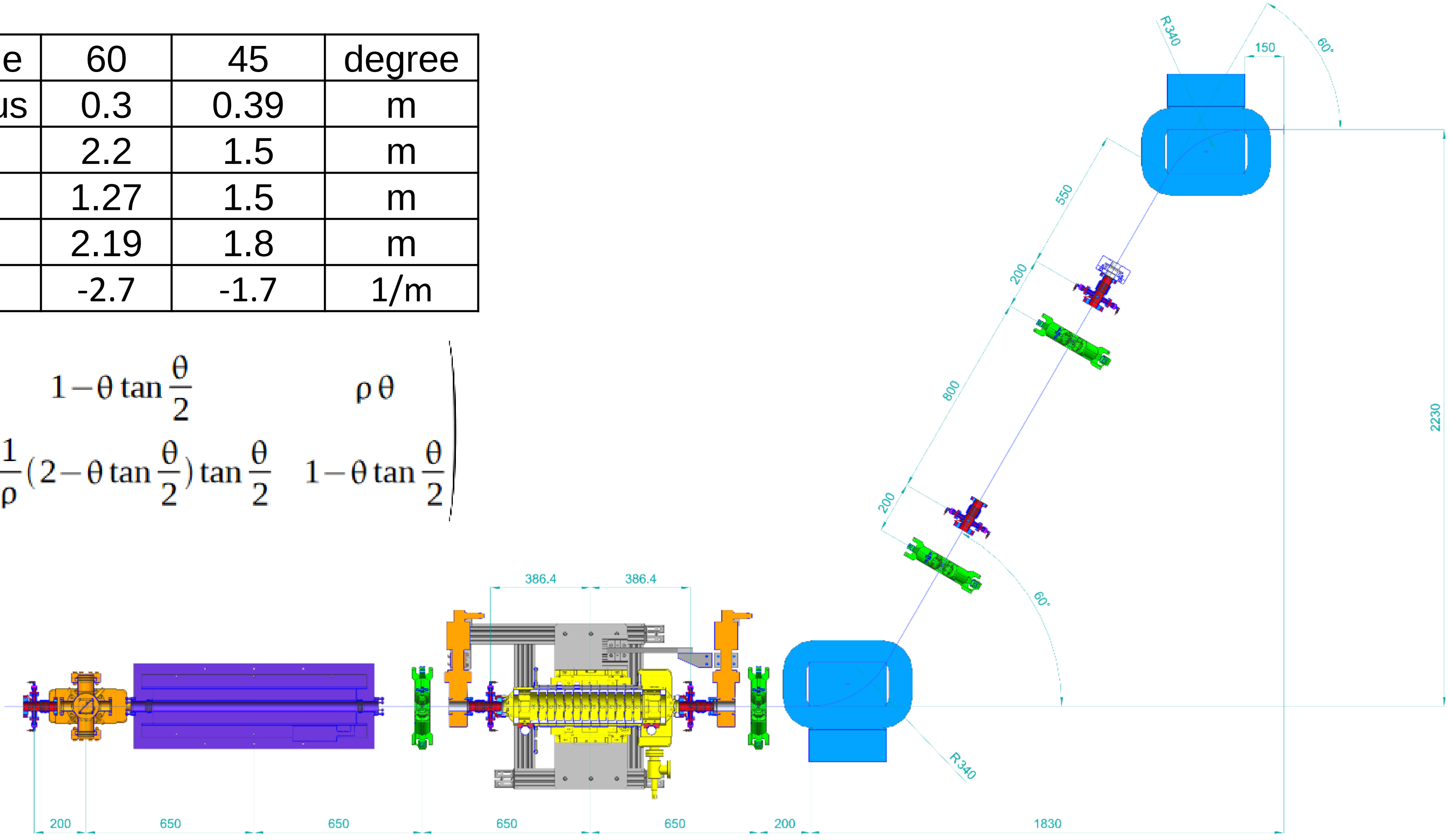
Some dimensions from Sebastian

Two cases considered

bend angle	60	45	degree
bend radius	0.3	0.39	m
dX	2.2	1.5	m
dZ	1.27	1.5	m
dL	2.19	1.8	m
M21	-2.7	-1.7	1/m

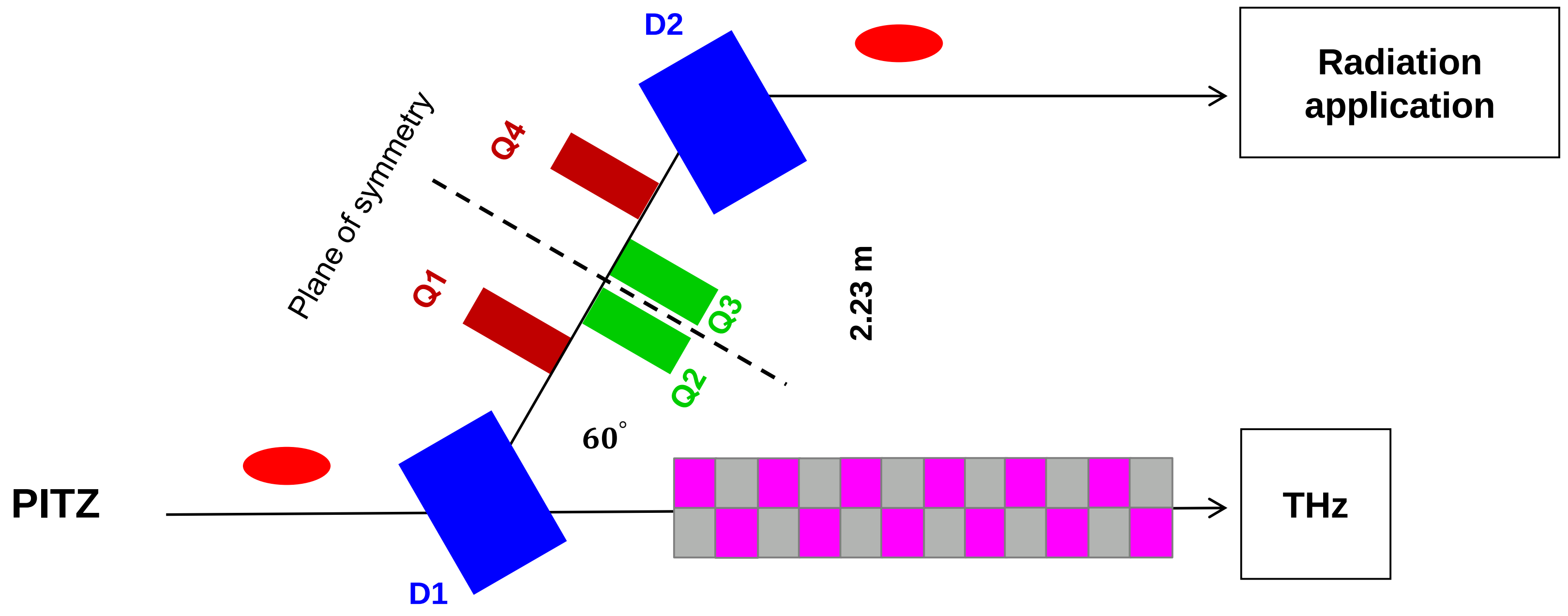
$$M_{y,rect} = \begin{pmatrix} 1-\theta\tan\frac{\theta}{2} & \rho\,\theta \\ -\frac{1}{\rho}\left(2-\theta\tan\frac{\theta}{2}\right)\tan\frac{\theta}{2} & 1-\theta\tan\frac{\theta}{2} \end{pmatrix}$$

Focusing

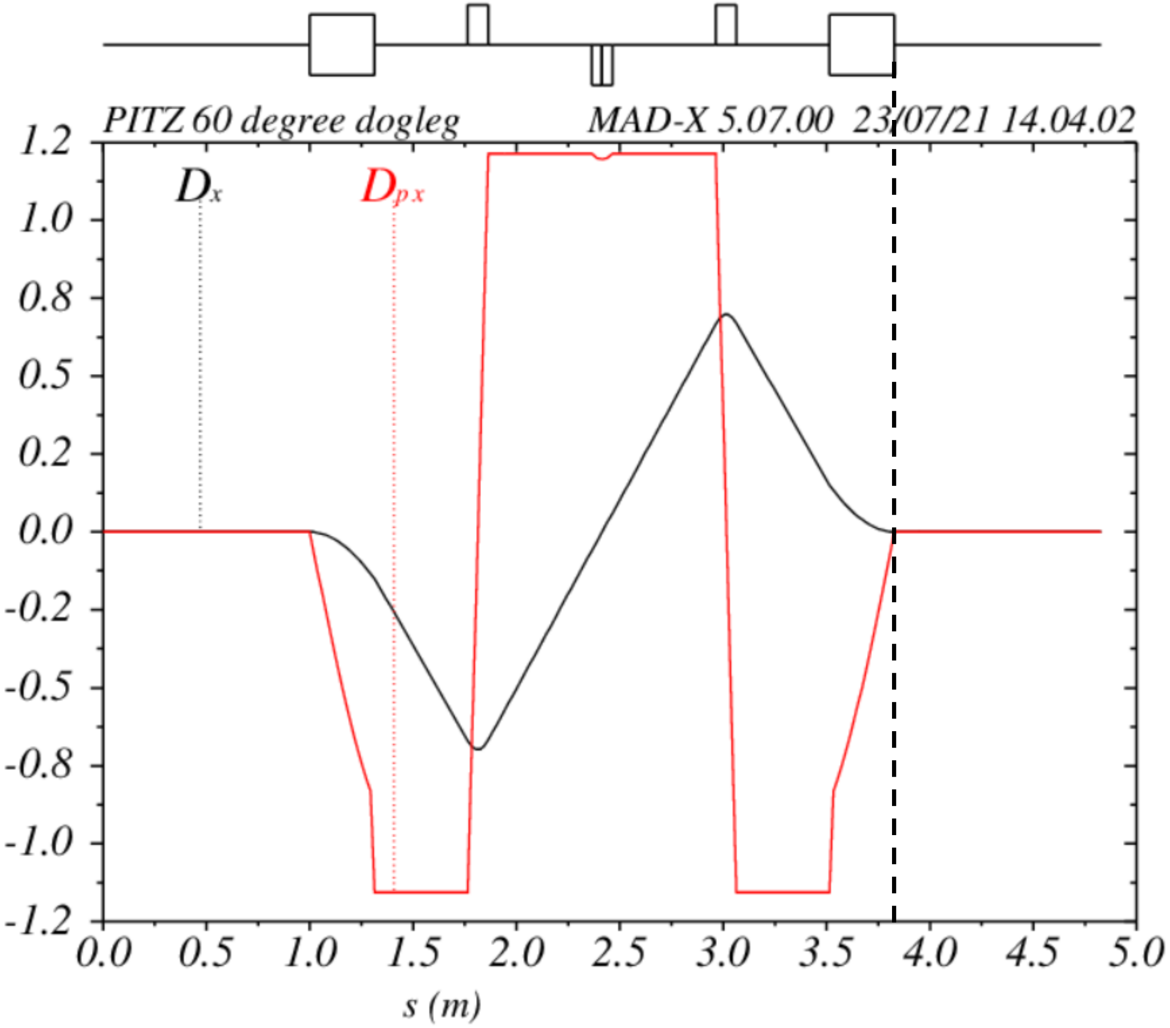


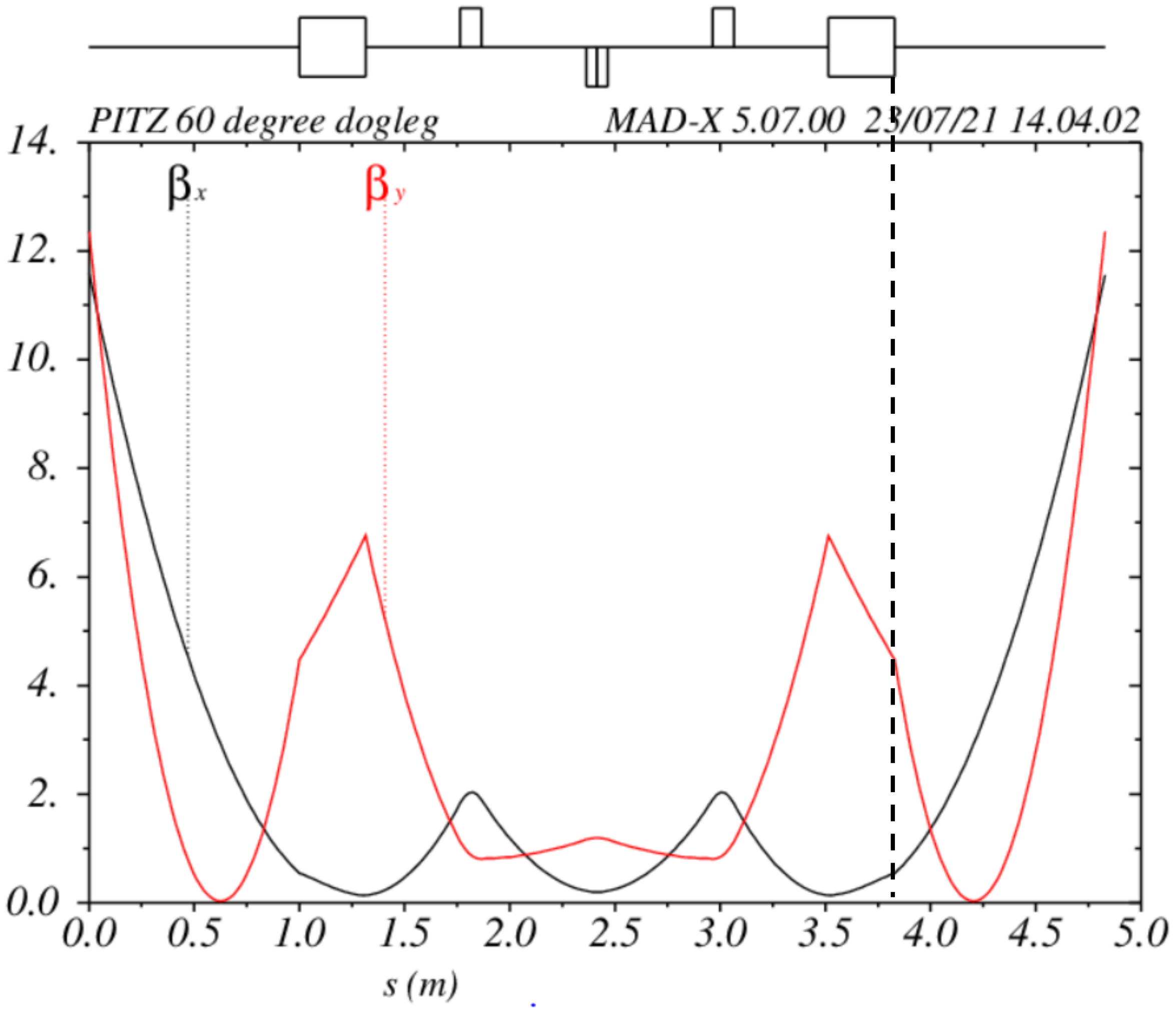
Dogleg optics

- Simple dogleg design to achieve achromat condition, i.e. Dx=0, Dx'=0
  - Consists of mirror optics w.r.t. the plane of symmetry
  - D1=-D2, Q1=Q4, Q2=Q3
  - To further simplify beam tuning, Q2/Q3 combined into a single quad located at the symmetry plane

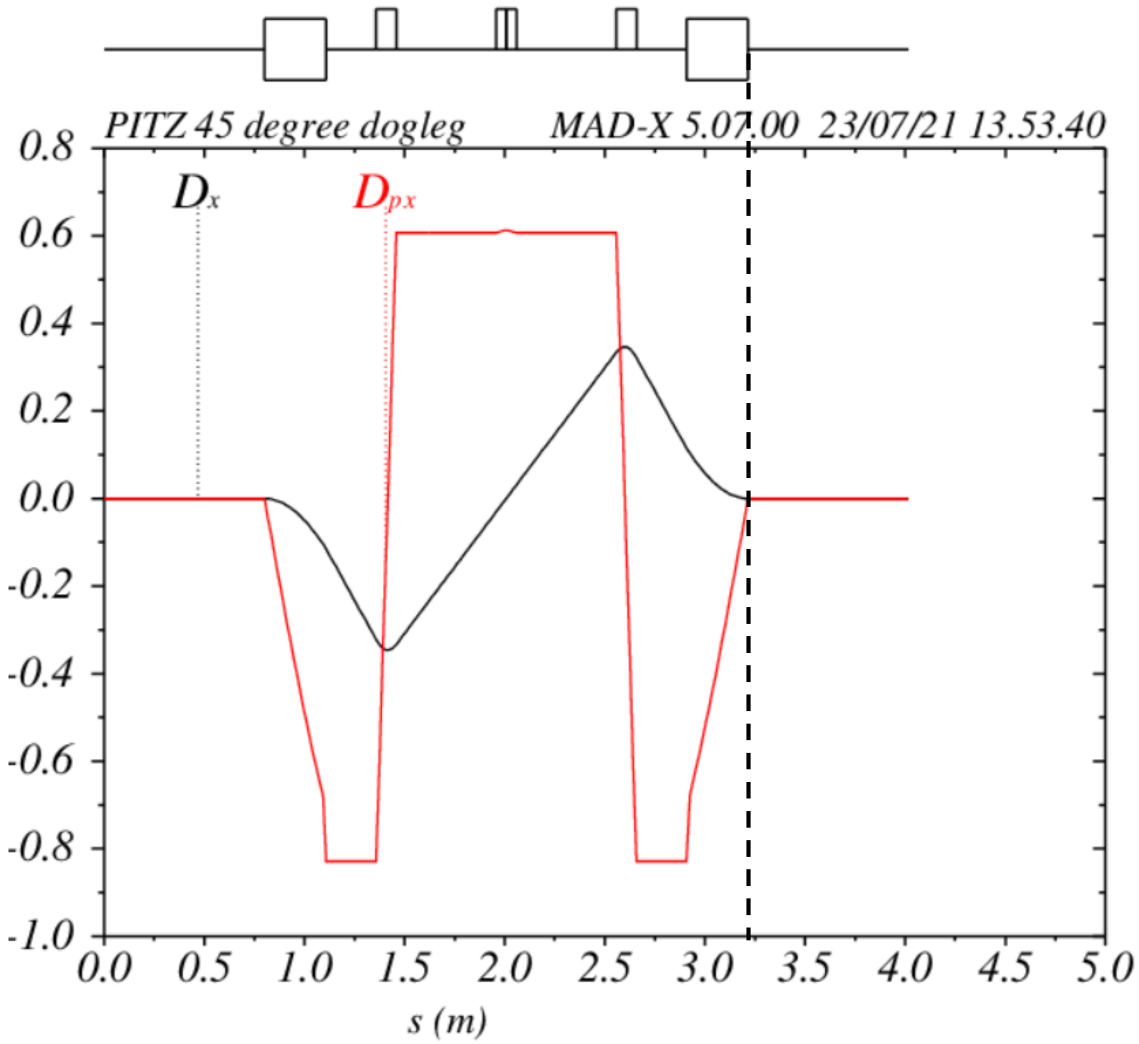


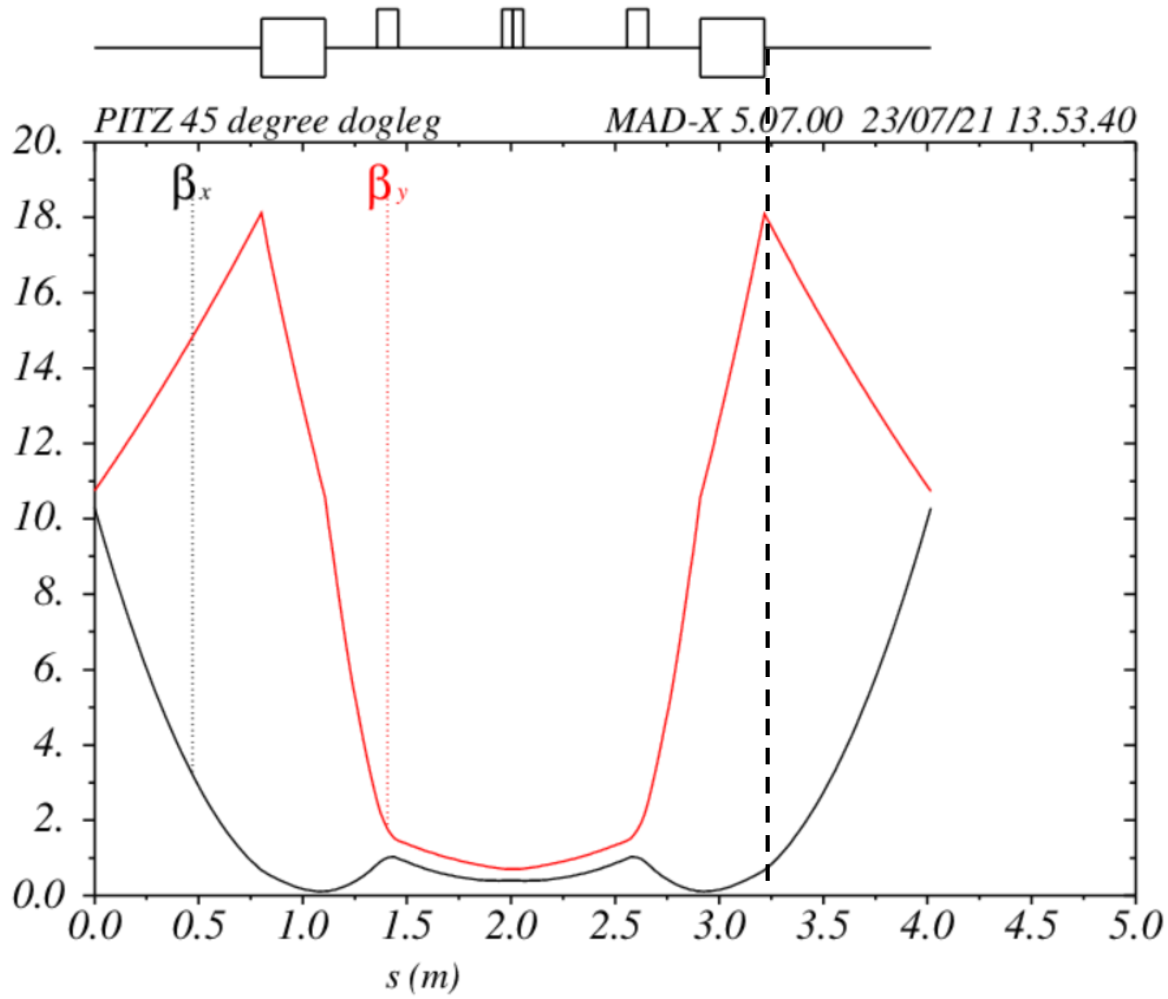
60 degree dogleg





45 degree dogleg





Focusing after dogleg

60 degree vs 45 degree