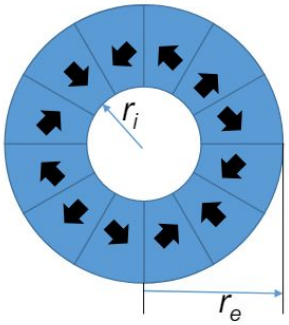
PoPLaR

16/05/2023 Meeting Updates from Josie

Quads proposed at last meeting:

Halbach, NIM 169, p. 1-10 (1980
Benabderrahmane, IPAC2017 THYB'

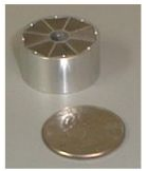
Permanent Magnet Quadrupoles



- **Halbach** array
- Typically small aperture
- Fixed (and quite high) gradient $G = 2B_r K\left(\frac{1}{r_i} - \frac{1}{r_e}\right)$

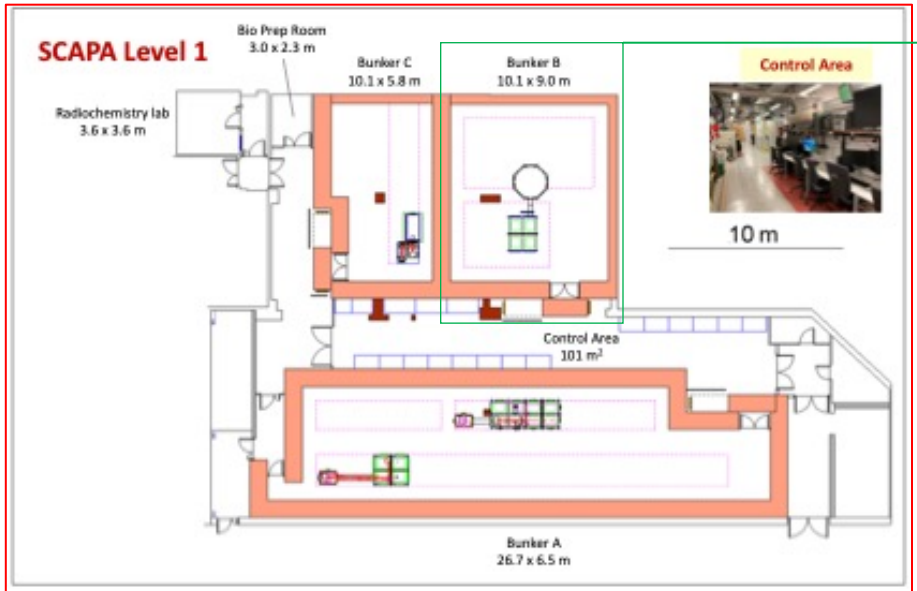
Number of segments *M*	4	8	12	16	20	24
Efficiency factor *K*	0.32	0.77	0.89	0.94	0.96	0.97

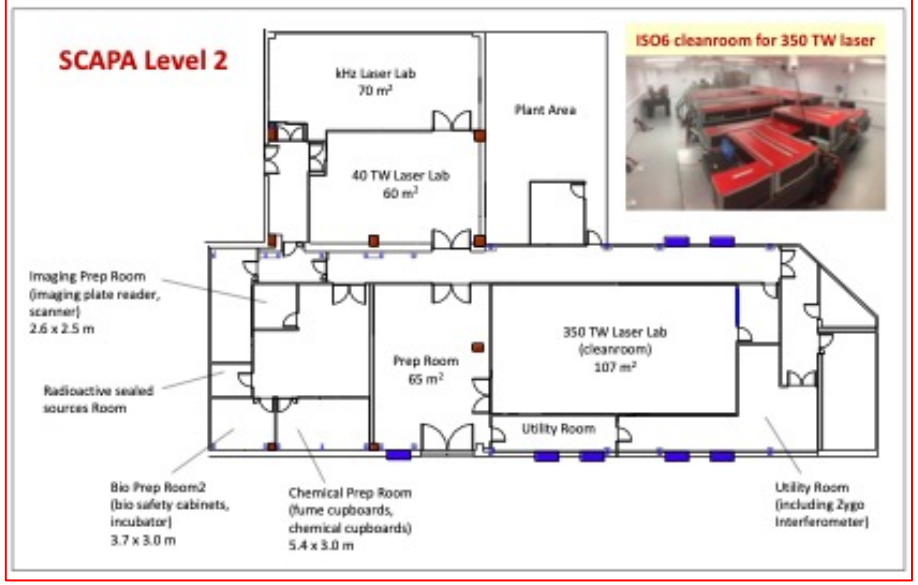
  - For r_i = 10 mm, r_e = 20 mm, B_r = 1.38 T, M = 16 ➔ G = 130 T/m
- Widely used
- Also dipoles, sextupoles…

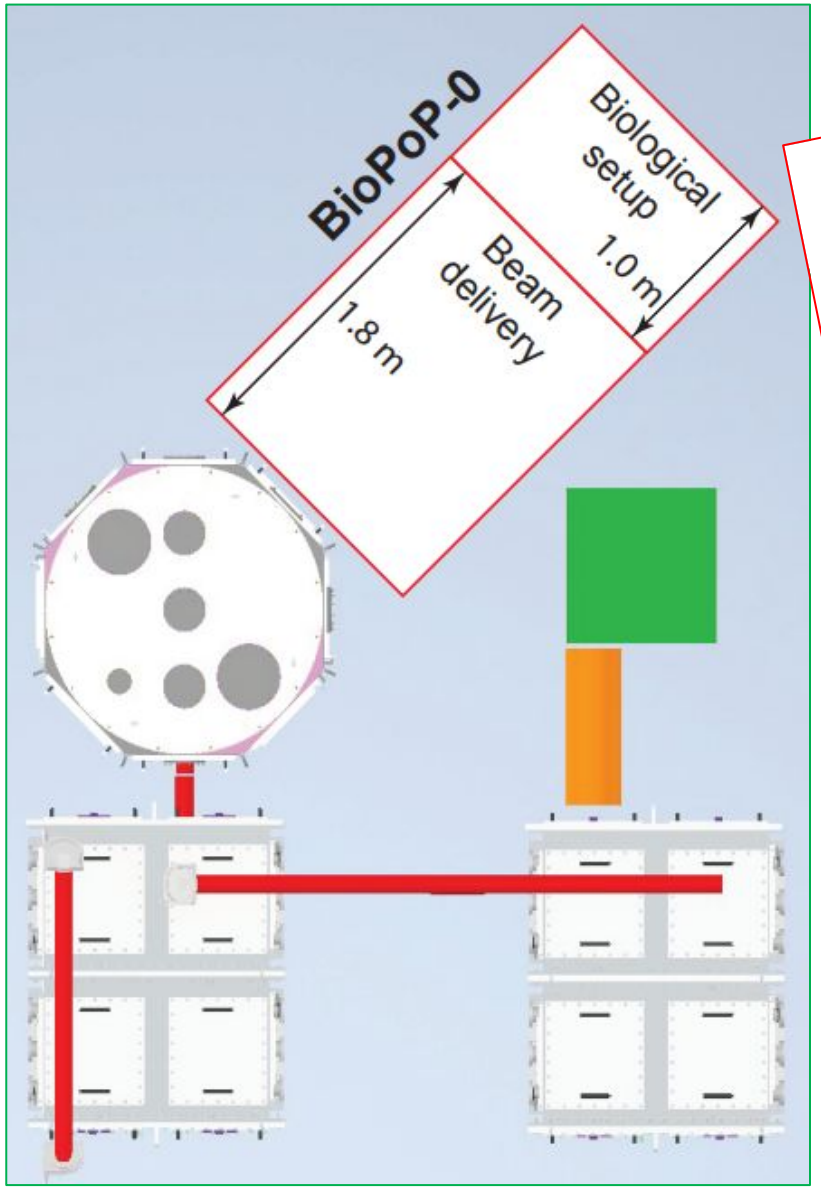


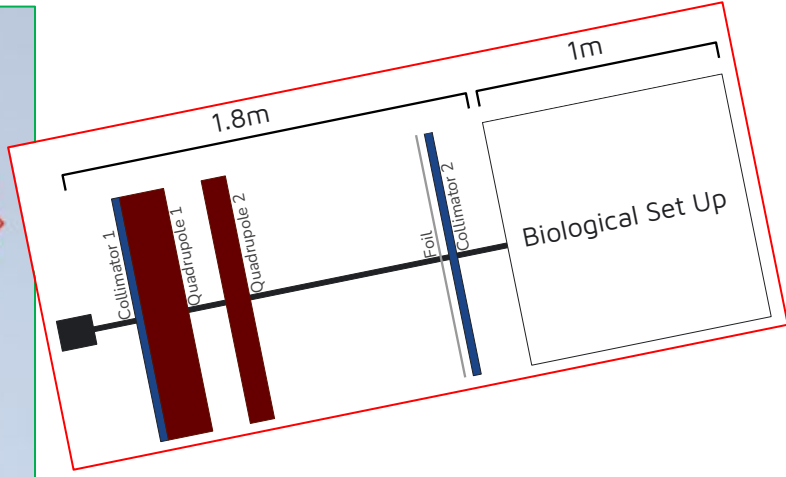
SABR Enterprises LLC

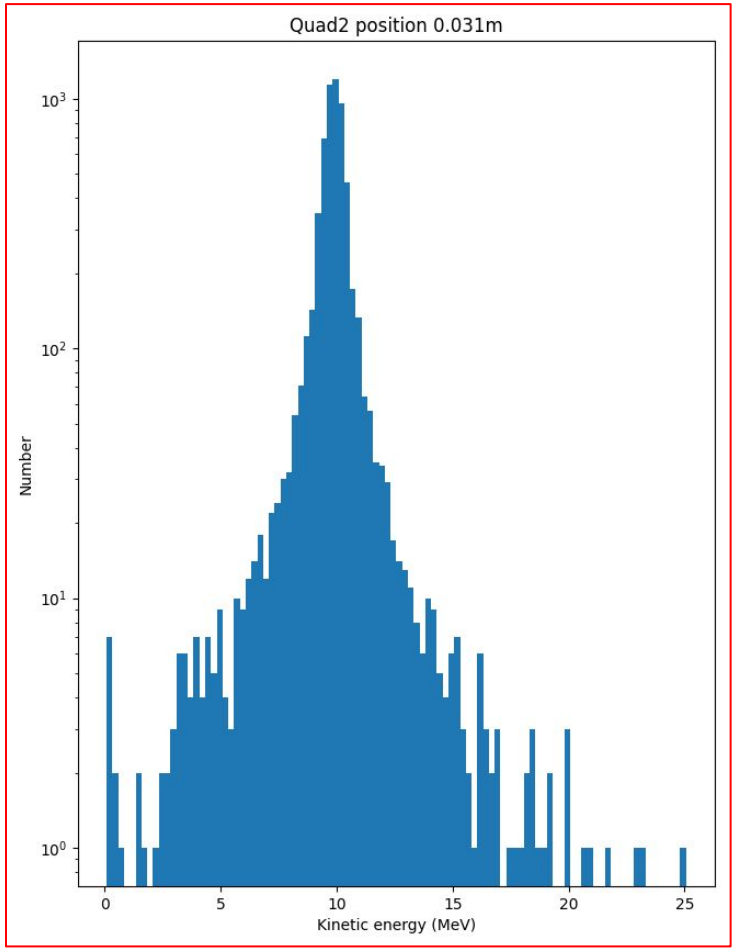
Biological measurement programme & proof-of-principle experiment











Quad sizes & rough prices:

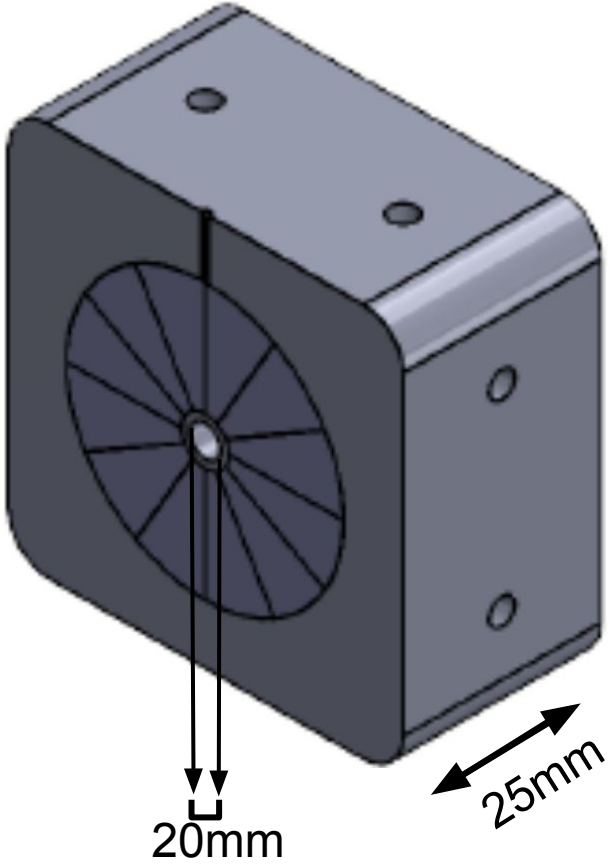
Quadrupole	Strength	Length	Aperture	Price estimate
Quad 1	130 T/m	25mm	20mm	£2000
Quad 2	130 T/m	18mm	20mm	£1820
Quad 3	130 T/m	13mm	20mm	£1775

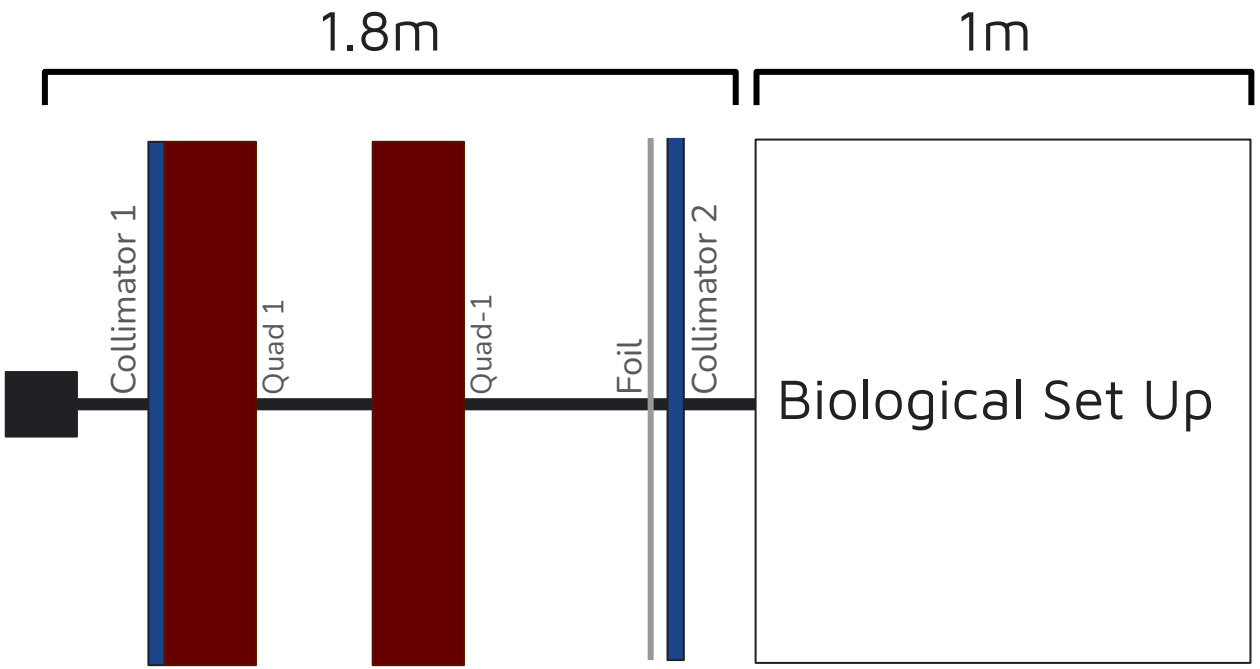
Summary

Quad configuration	Price estimate	Same design for both?	% particles at end station
25mm 25mm	£4000	Yes	0.23%
18mm 18mm	£3640	Yes	0.23%
13mm 13mm	£3550	Yes	0.065%
25mm 18mm	£3820	No	0.065%
18mm 13mm	£3595	No	0.4%
25mm 13mm	£3775	No	0.36%

Combination 1

2 x 25mm Quads at 130 T/m





Combination 1

2 x 25mm Quads at 130 T/m

Energy (MeV)	Focusing quad position (m)	Drift between quads (m)
5	0.06	0.05
7.5	0.07	0.07
10	0.07	0.08
12.5	0.07	0.11
15	0.08	0.11

Combination 1

2 x 25mm Quads at 130 T/m

Energy (MeV)	Horizontal beam size at end station (x)	Horizontal beam size at end station (y)	# particles at end station
5	0.001507m	0.0015377m	2316
7.5	0.001523m	0.001554m	2347
10	0.001505m	0.001543m	2265
12.5	0.001506m	0.001559m	2304
15	0.001505m	0.001544m	2345

Combination 1

2 x 25mm Quads at 130 T/m

PROs:

- Design for both quads the same

CONS:

- Price- Most expensive option (marginally)
- Only 0.23% of particles make it through at the optimal configuration

First attempt at optimising

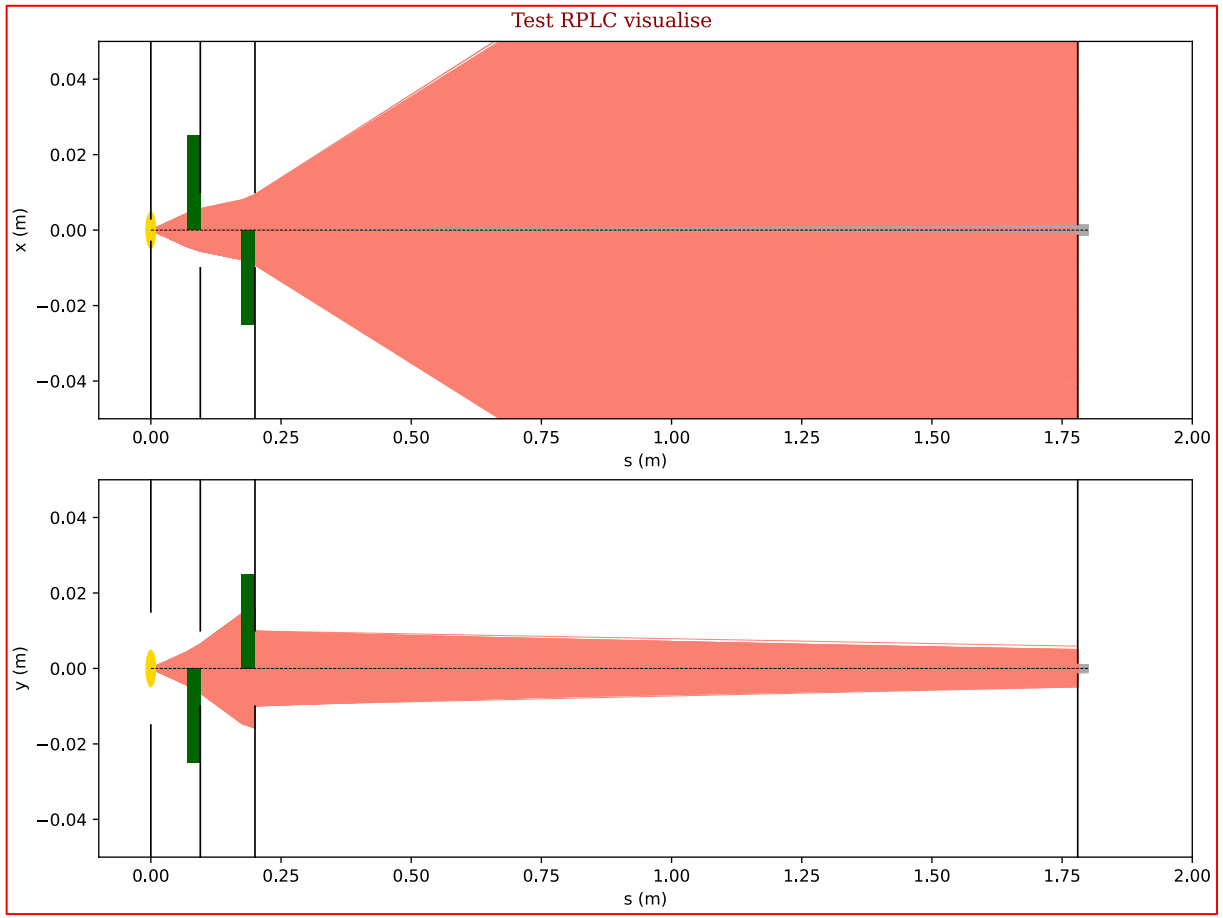
- Very simple approach:
  - Vary source-q1 drift and gap between quads keeping overall length fixed
  - Gaussian random number, RMS 2cm
  - Pass particles through beam line:
    - Calculate rms beam size
    - Record number of particles making it to the end
  - Accept the new configuration if transmission has increased
- Case considered:
  - 10 MeV:
    - Gaussian distribution, width 2%
    - “Forward-going” particles

Source	Gaussian	SourceMode	1		Gaussian kinetic energy
Source	Gaussian	SigmaX	0.000004	m	Gaussian width, x
Source	Gaussian	SigmaY	0.000004	m	Gaussian width, y
Source	Gaussian	MeanEnergy	10	MeV	Mean of guassian kinetic energy
Source	Gaussian	SigmaEnergy	0.3	MeV	Sigma of guassian kinetic energy
Source	Gaussian	MinCTheta	0.998		Minimum theta for flat cos theta

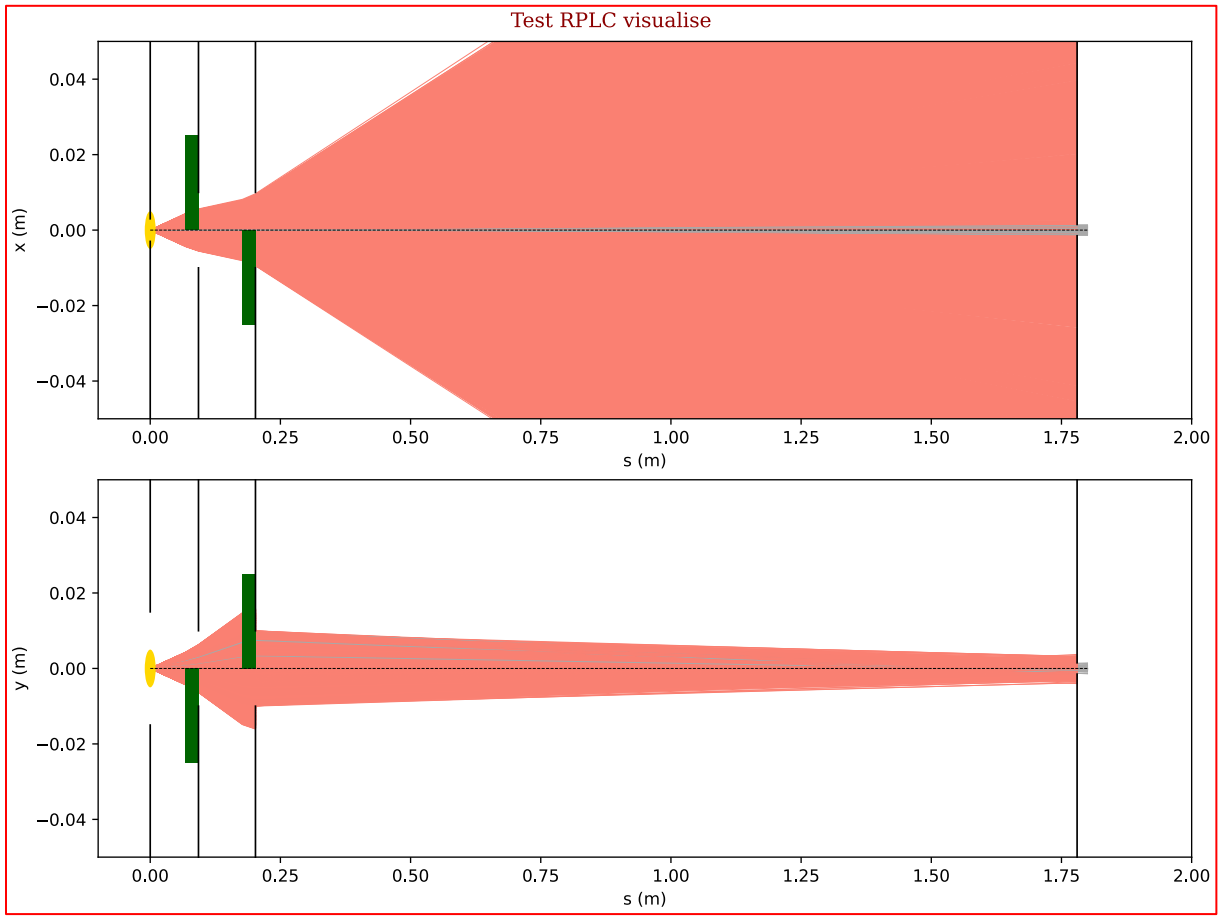
10 MeV; 130 T/m; lq1(F)=25 mm, lq2(D)=25 mm

- **Transmission: 0.69%**

Josie

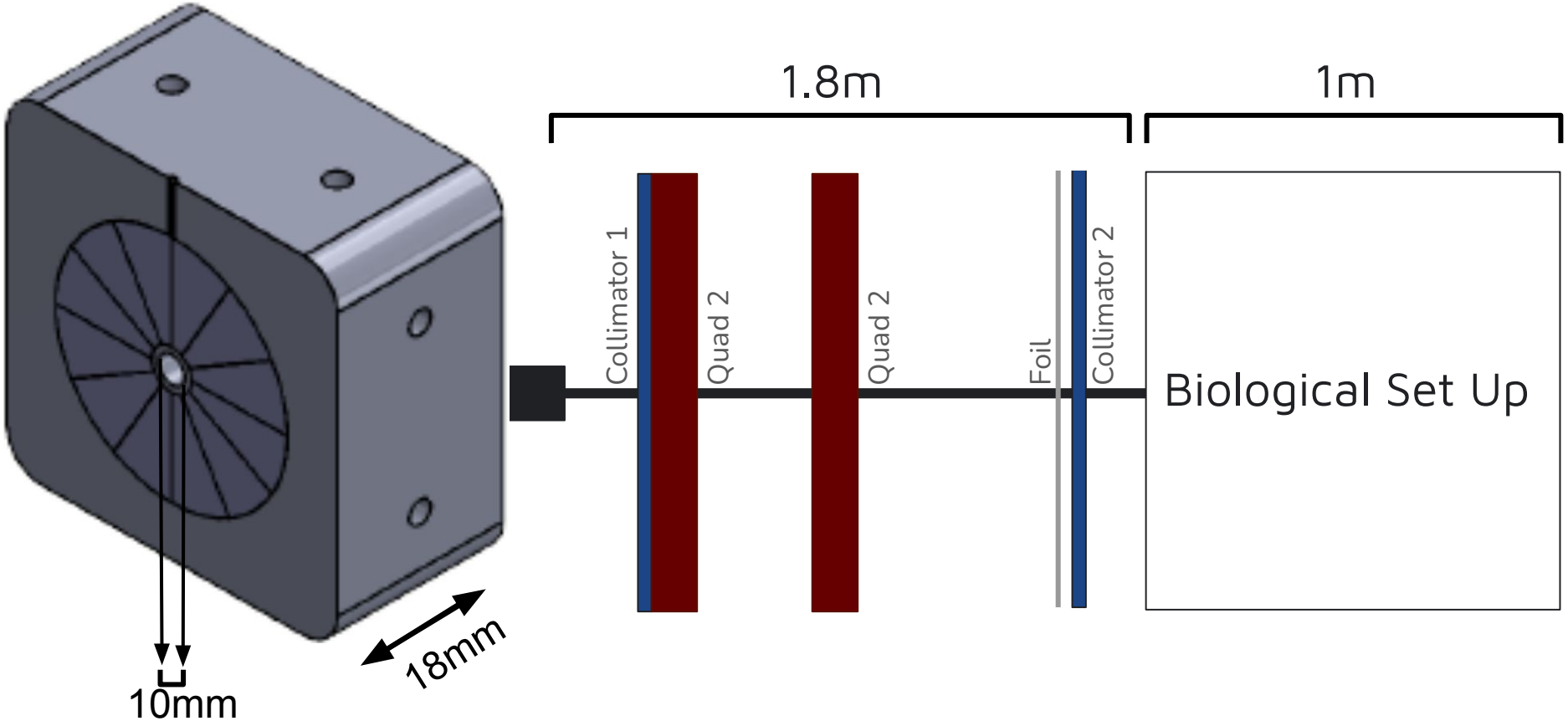


“Optimised”



Combination 2

2 x 18mm Quads at 130 T/m



Combination 2

2 x 18mm Quads at 130 T/m

Energy (MeV)	Focusing quad position (m)	Drift between quads (m)
5	0.03	0.1
7.5	0.07	0.13
10	0.08	0.15
12.5	0.08	0.18
15	0.08	0.2

Combination 2

2 x 18mm Quads at 130 T/m

Energy (MeV)	Horizontal beam size at end station (x)	Horizontal beam size at end station (y)	# particles at end station
5	0.001514m	0.00157m	2368
7.5	0.001512m	0.001542m	2336
10	0.001516m	0.001549m	2359
12.5	0.001501m	0.001546m	2284
15	0.001517m	0.001567m	2334

Combination 2

2 x 18mm Quads at 130 T/m

PROs:

- Design for both quads the same

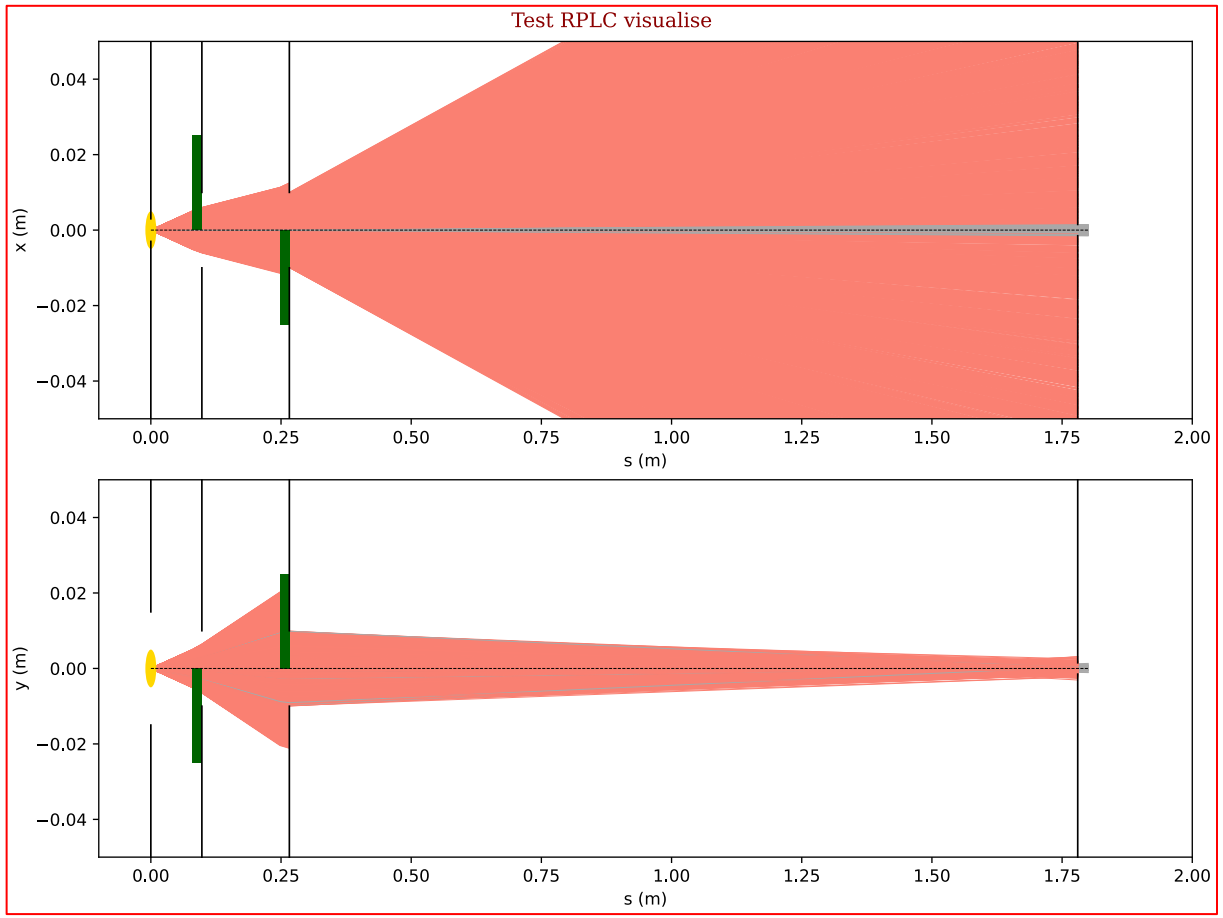
CONS:

- Only 3cm away from laser source for 5MeV focusing
- Only 0.23% of particles make it through at the optimal configuration

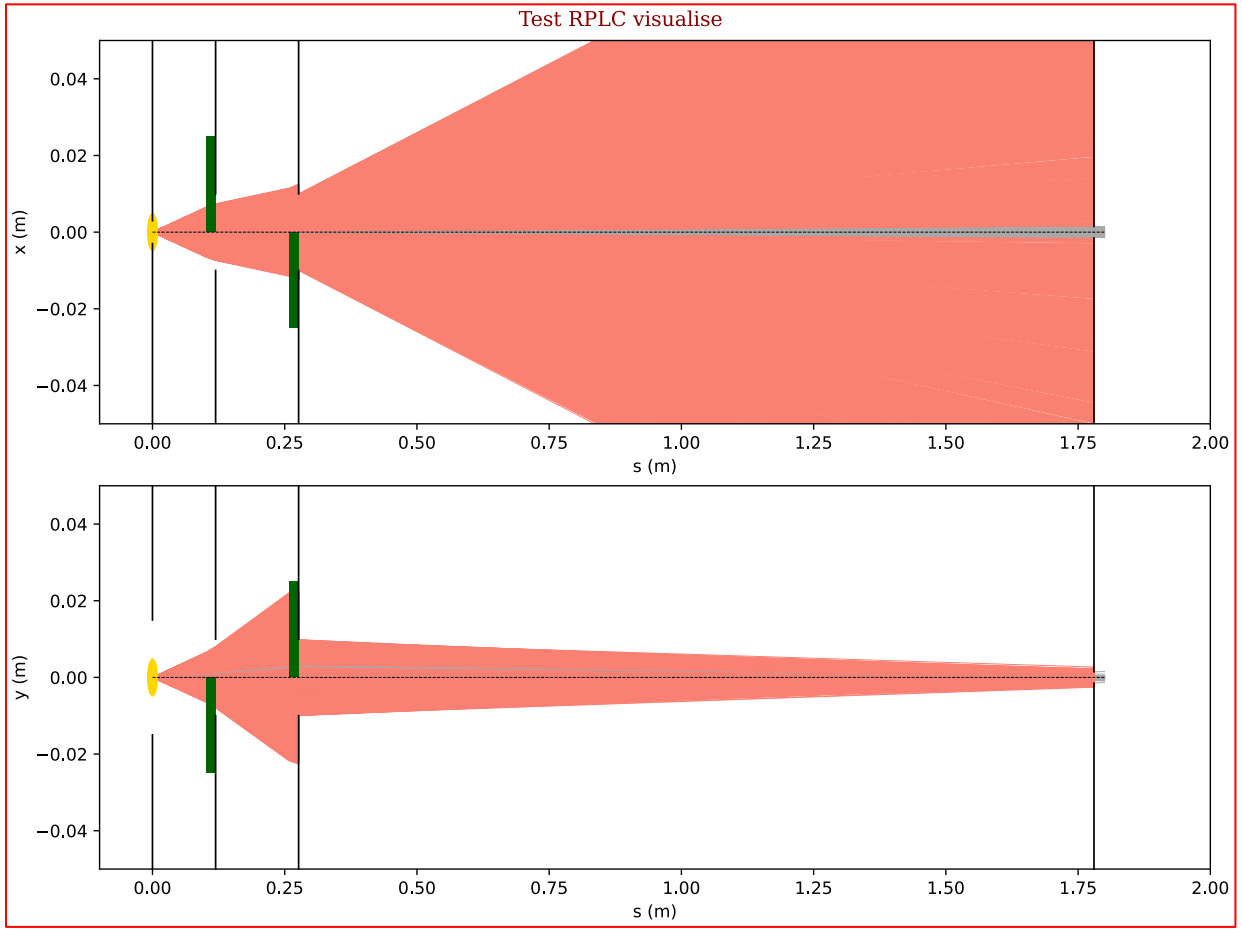
10 MeV; 130 T/m; lq1(F)=18 mm, lq2(D)=18 mm

- **Transmission: 0.65%**

Josie

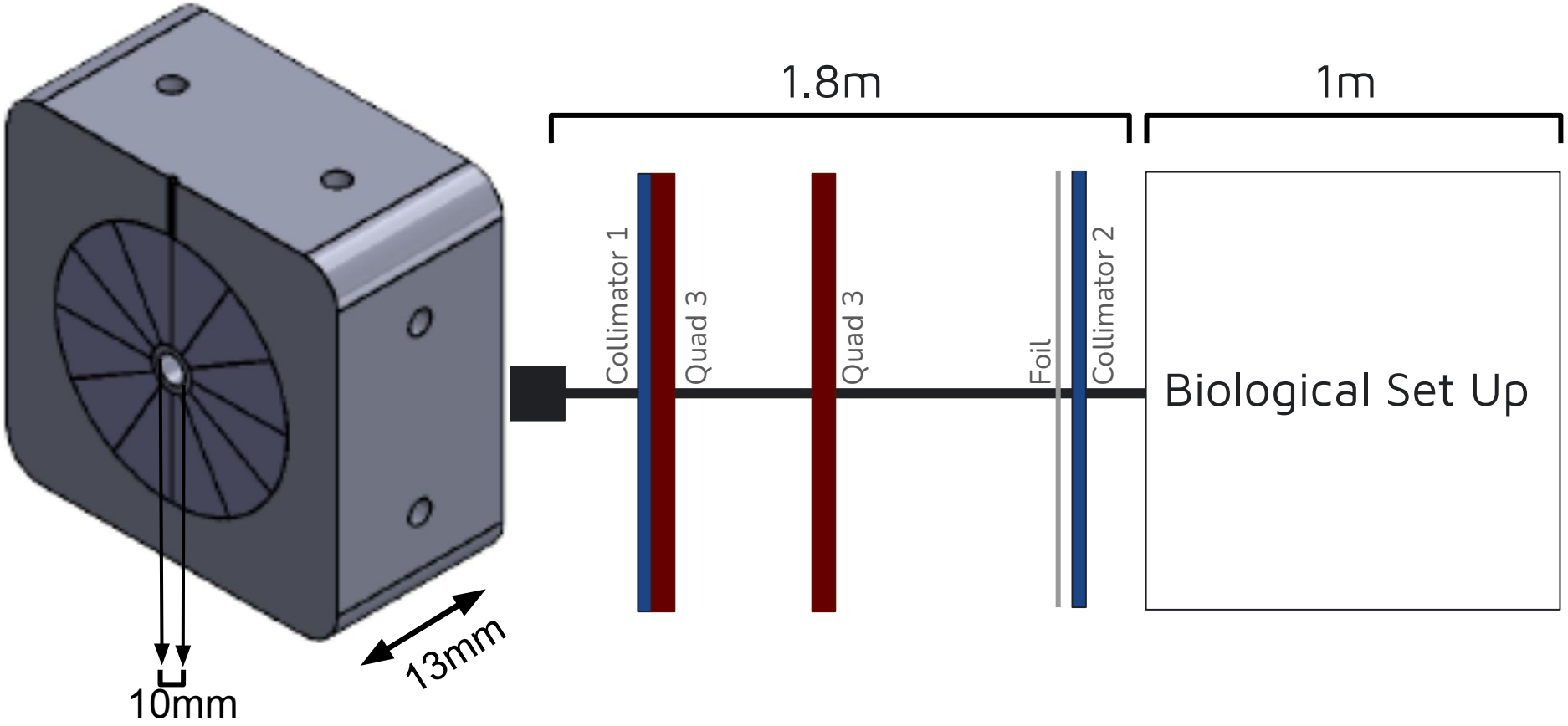


“Optimised”



Combination 3

2 x 13mm Quads at 130 T/m



Combination 3

2 x 13mm Quads at 130 T/m

Energy (MeV)	Focusing quad position (m)	Drift between quads (m)
5	0.04	0.18
7.5	0.05	0.22
10	0.06	0.27
12.5	0.07	0.33
15	0.11	0.38

Combination 3

2 x 13mm Quads at 130 T/m

Energy (MeV)	Horizontal beam size at end station (x)	Horizontal beam size at end station (y)	# particles at end station
5	0.00149m	0.001543m	639
7.5	0.001496m	0.001532m	667
10	0.001474m	0.001503m	616
12.5	0.00151m	0.001516m	674
15	0.001459m	0.00153 8m	678

Combination 3

2 x 13mm Quads at 130 T/m

PROs:

- Price- Cheapest option
- Design for both quads the same

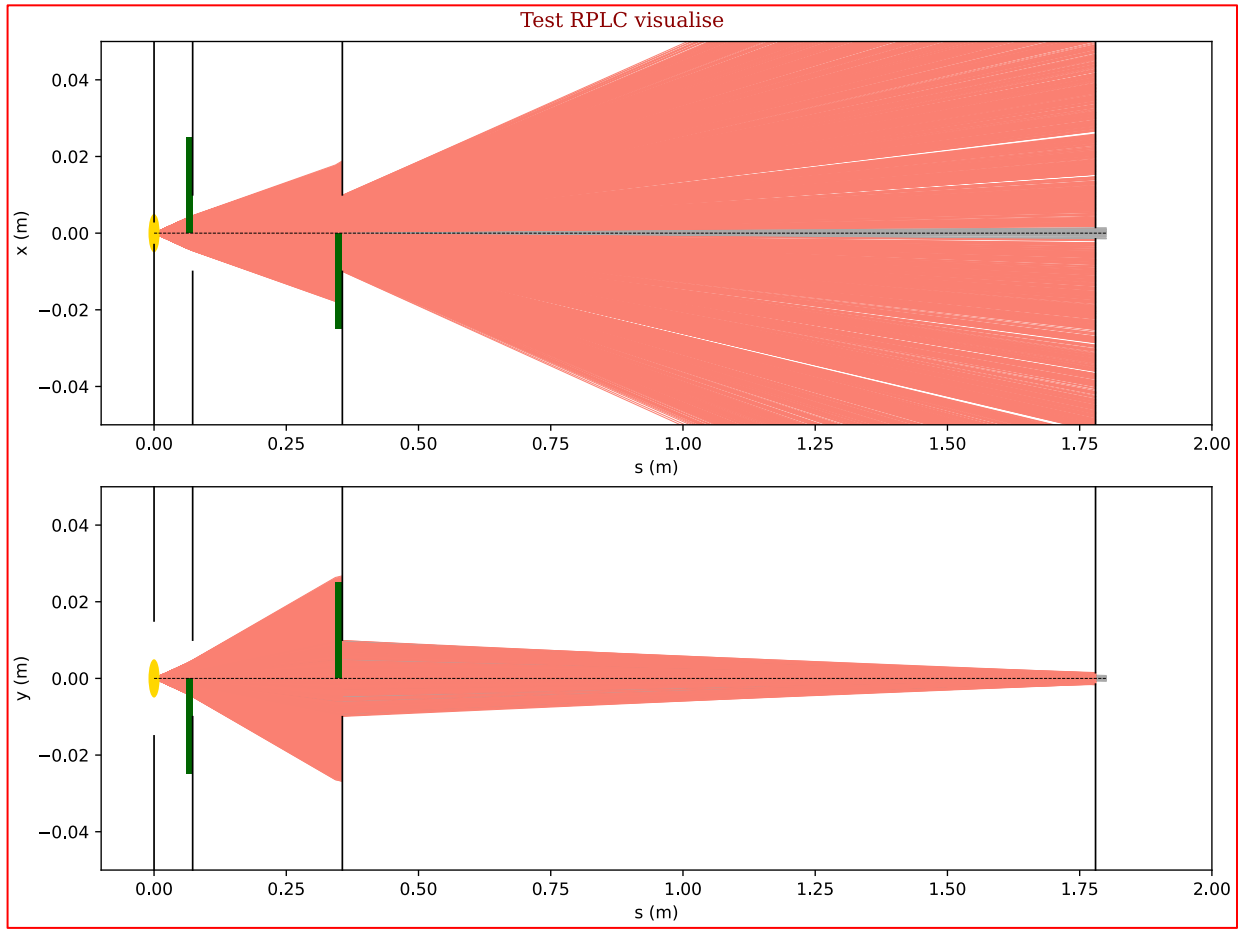
CONS:

- Very small amount of particles actually make it to the end- 0.065% of particles going in make it to the target

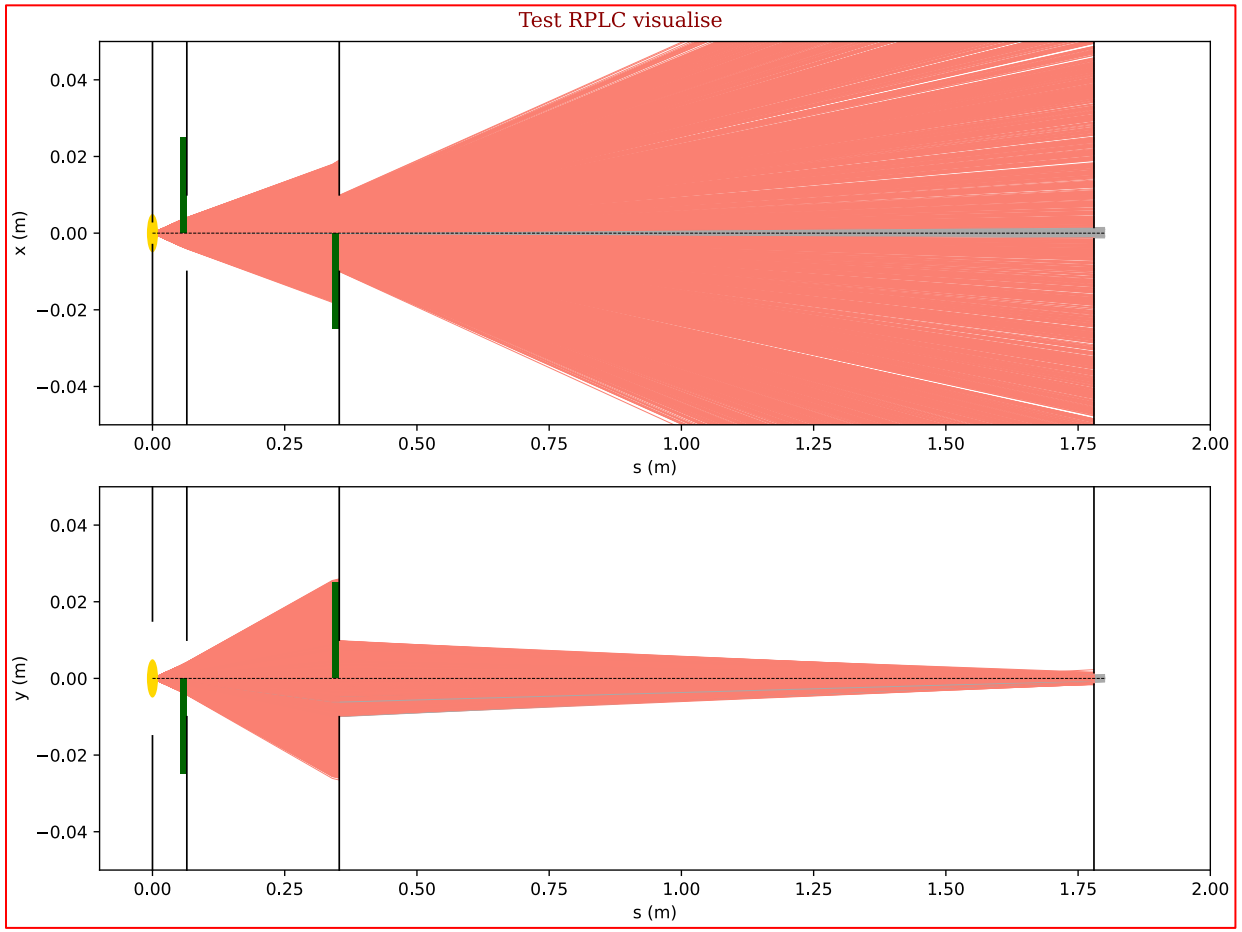
10 MeV; 130 T/m; lq1(F)=13 mm, lq2(D)=13 mm

- **Transmission: 0.38%**

Josie

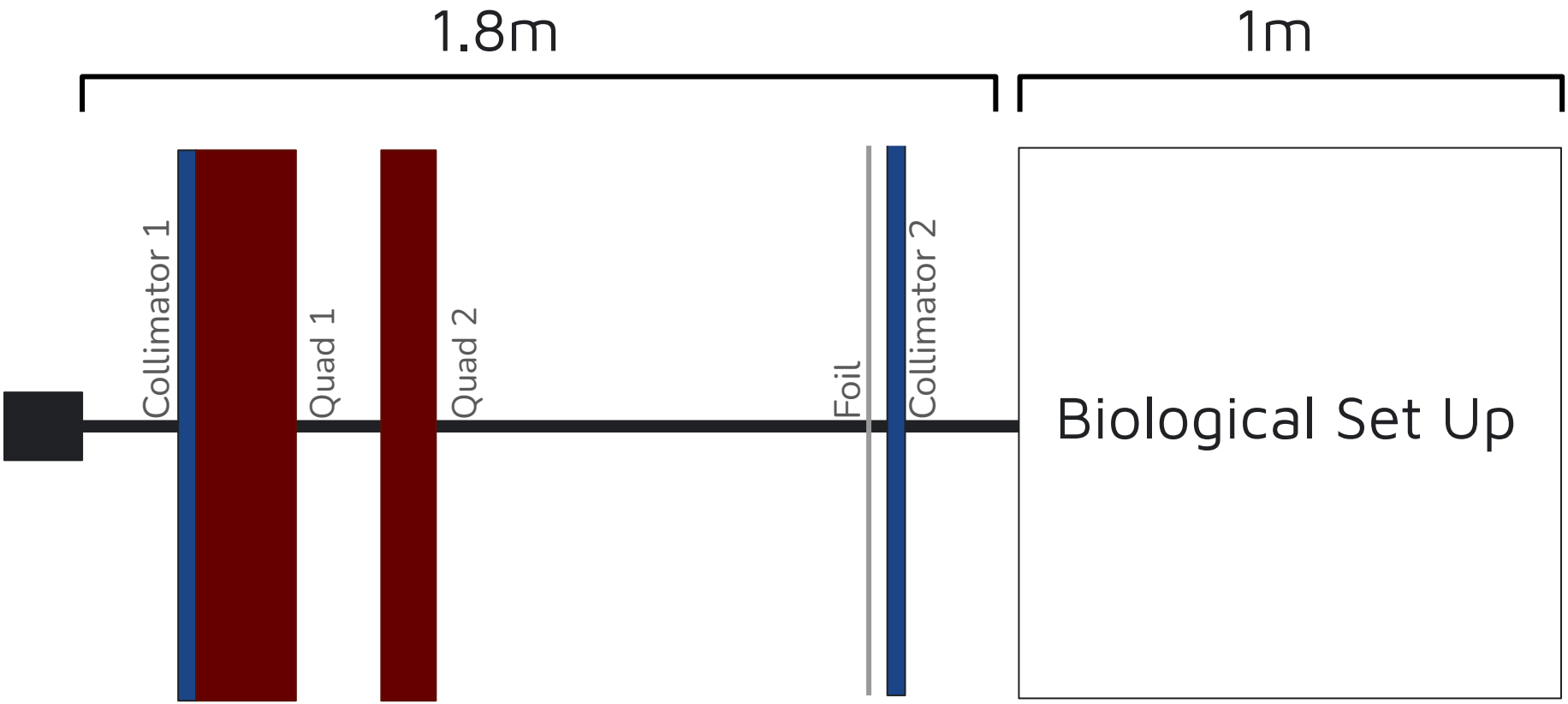


“Optimised”



Combination 4

25mm then 18mm Quad at 130 T/m



Combination 4

25mm then 18mm Quad at 130 T/m

Energy (MeV)	Focusing quad position (m)	Drift between quads (m)
5	0.05	0.11
7.5	0.06	0.13
10	0.09	0.16
12.5	0.1	0.16
15	0.1	0.17

Combination 4

25mm then 18mm Quad at 130 T/m

Energy (MeV)	Horizontal beam size at end station (x)	Horizontal beam size at end station (y)	# particles at end station
5	0.001506m	0.001527m	656
7.5	0.001469m	0.001505m	674
10	0.001495m	0.001529m	638
12.5	0.0015m	0.001533m	661
15	0.001508m	0.001526m	654

Combination 4

25mm then 18mm Quad at 130 T/m

PROs:

- I can’t think of one, not a good combination in my opinion

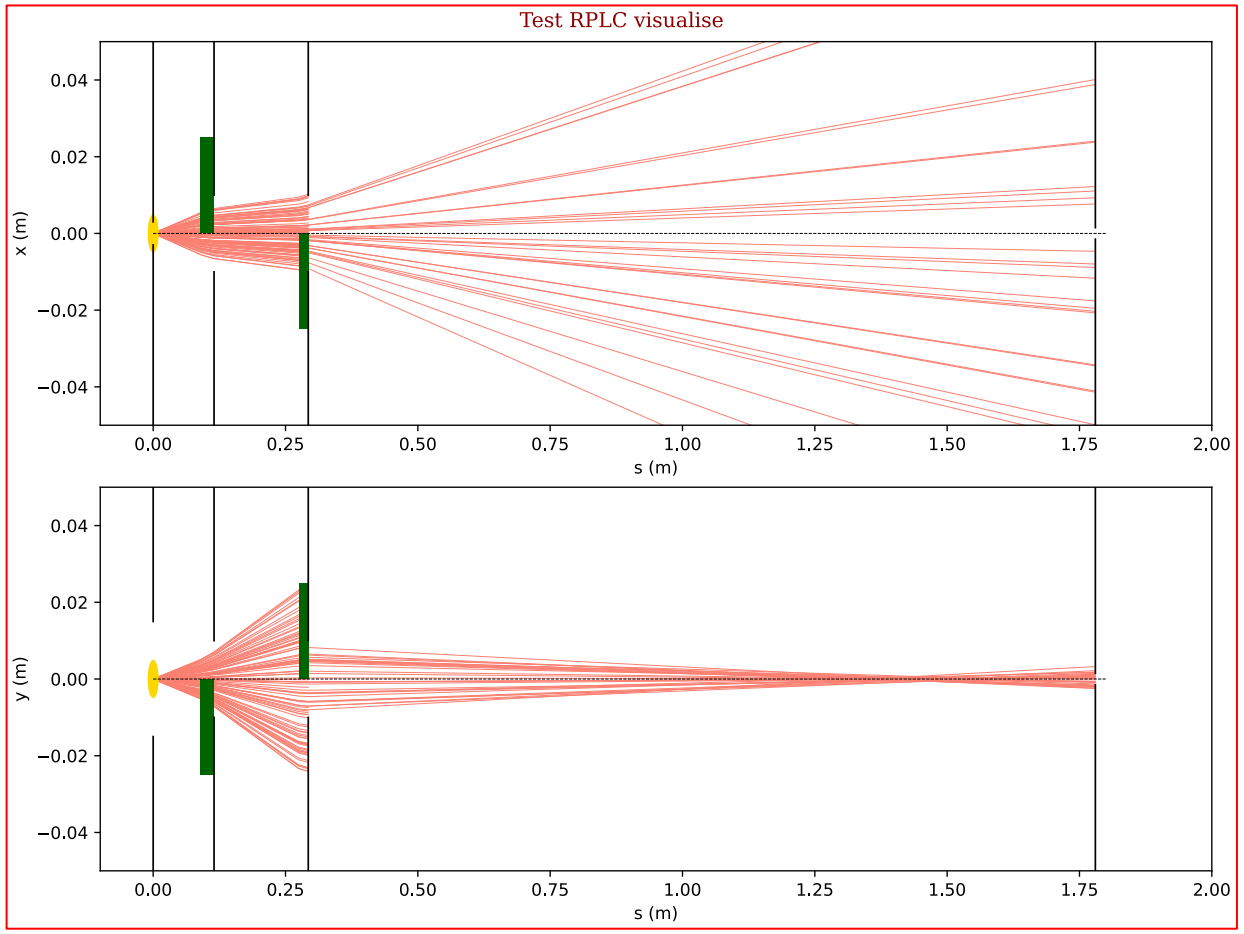
CONS:

- Price- 2nd most expensive
- Very small amount of particles actually make it to the end- 0.065% of particles going in make it to the target
- Different dimensions, two designs needed

10 MeV; 130 T/m; lq1(F)=25 mm, lq2(D)=18 mm

- **Transmission: 13%**

Josie



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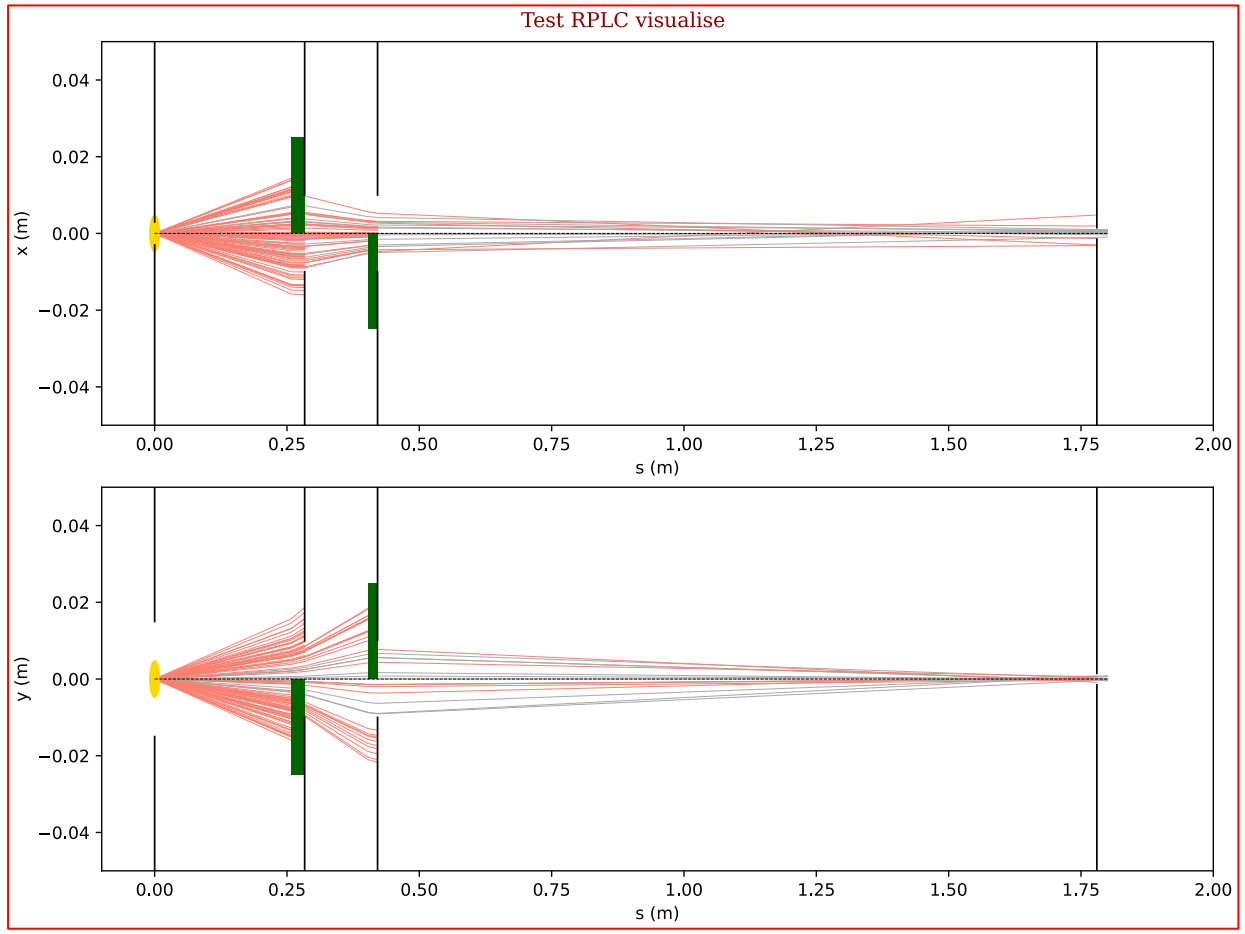
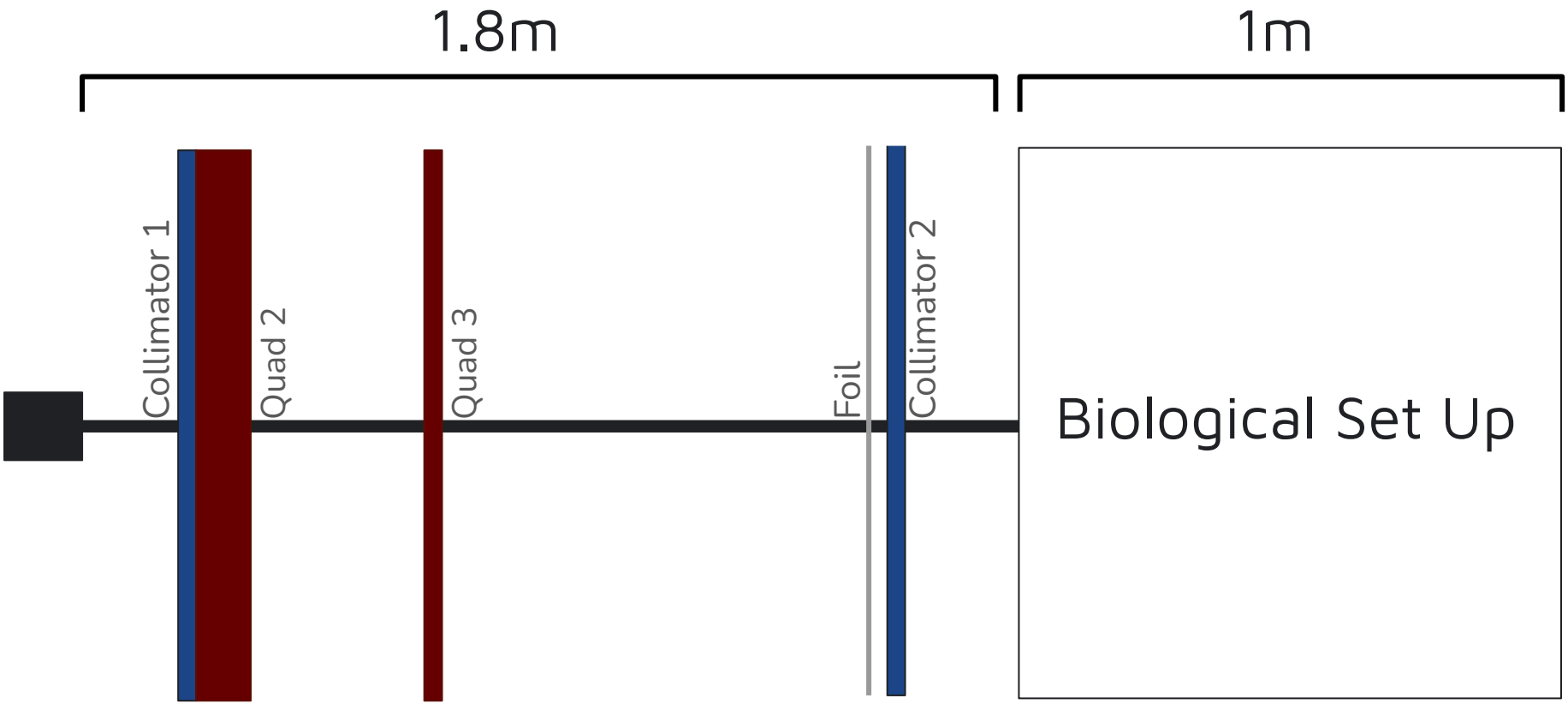


Combination 5

18mm then 13mm Quad at 130 T/m



Combination 5

18mm then 13mm Quad at 130 T/m

Energy (MeV)	Focusing quad position (m)	Drift between quads (m)
5	0.06	0.16
7.5	0.06	0.22
10	0.06	0.26
12.5	0.06	0.32
15	0.06	0.37

Combination 5

18mm then 13mm Quad at 130 T/m

Energy (MeV)	Horizontal beam size at end station (x)	Horizontal beam size at end station (y)	# particles at end station
5	0.001515m	0.001555m	4206
7.5	0.001515m	0.00155m	4231
10	0.001512m	0.001561m	4166
12.5	0.001512m	0.001593m	4091
15	0.001511m	0.001578m	4056

Combination 5

18mm then 13mm Quad at 130 T/m

PROs:

- Price- 2nd best
- 0.4% of particles make it through at the optimal configuration- the most of all combinations of quads
- Focus quadrupole seems to have a fixed optimal position, might only have to move one to focus 5,7.5,10,12.5 and 15MeV.=

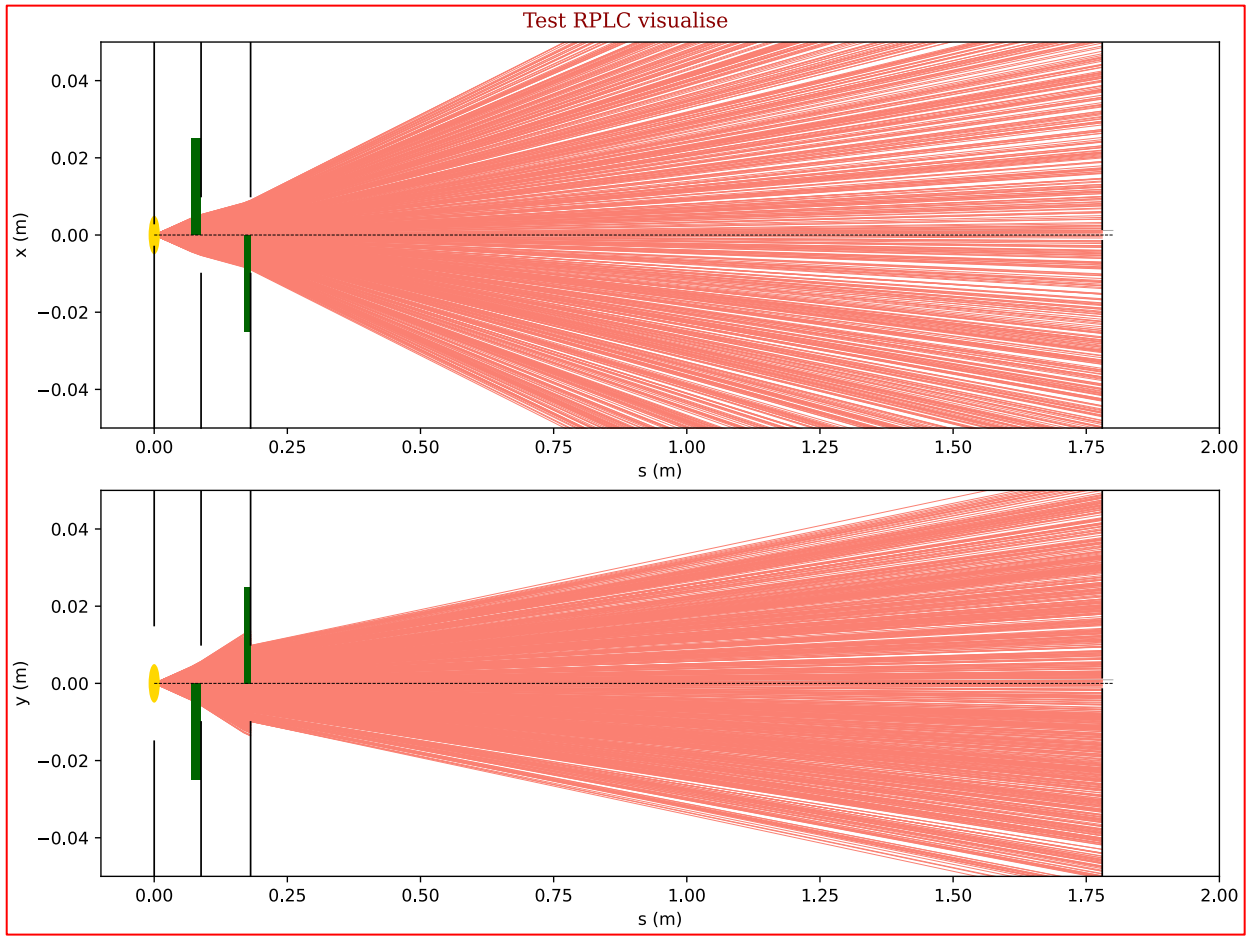
CONS:

- Different dimensions so 2 different designs needed

10 MeV; 130 T/m; lq1(F)=18 mm, lq2(D)=13 mm

- **Transmission: ~7.9%**

Josie



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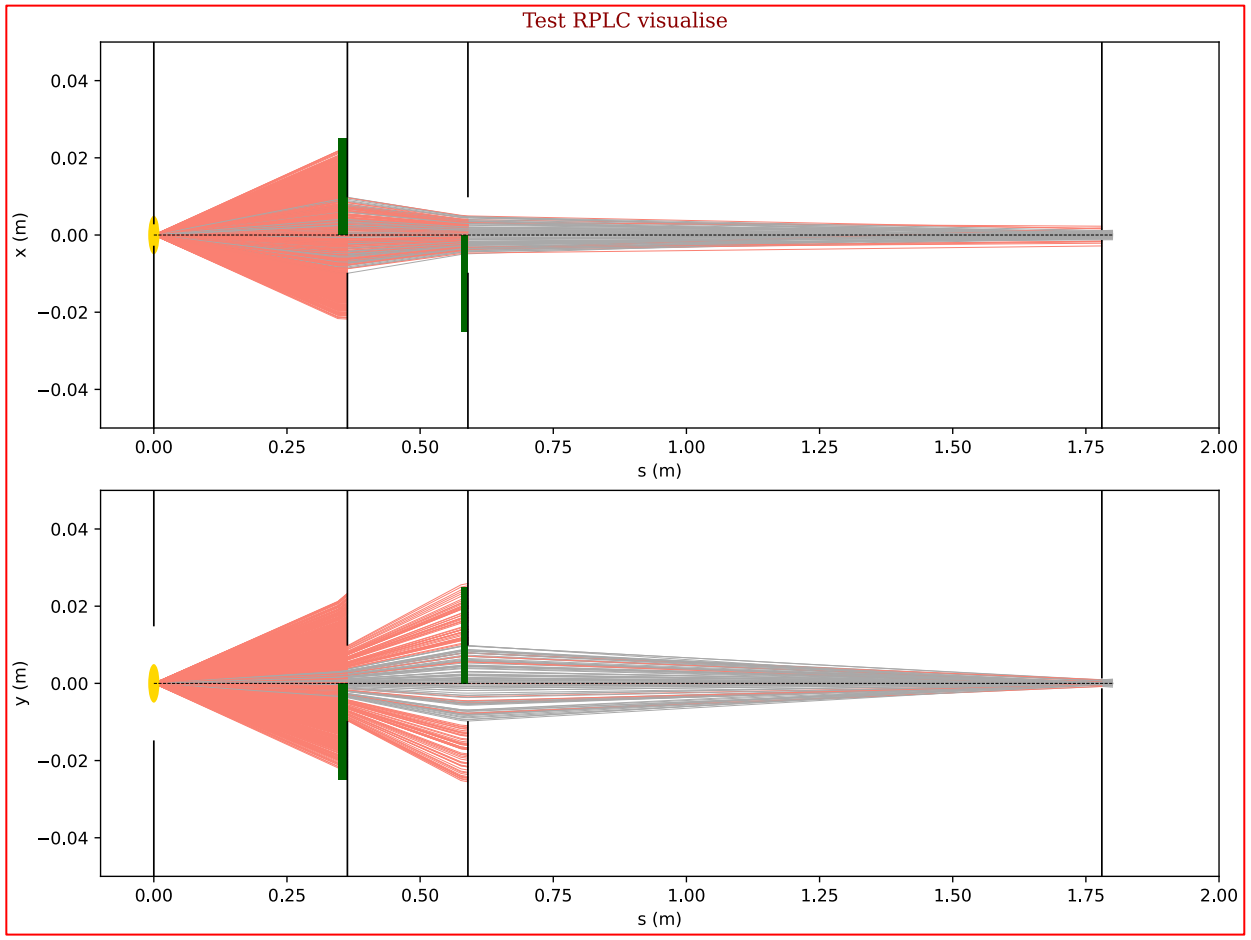
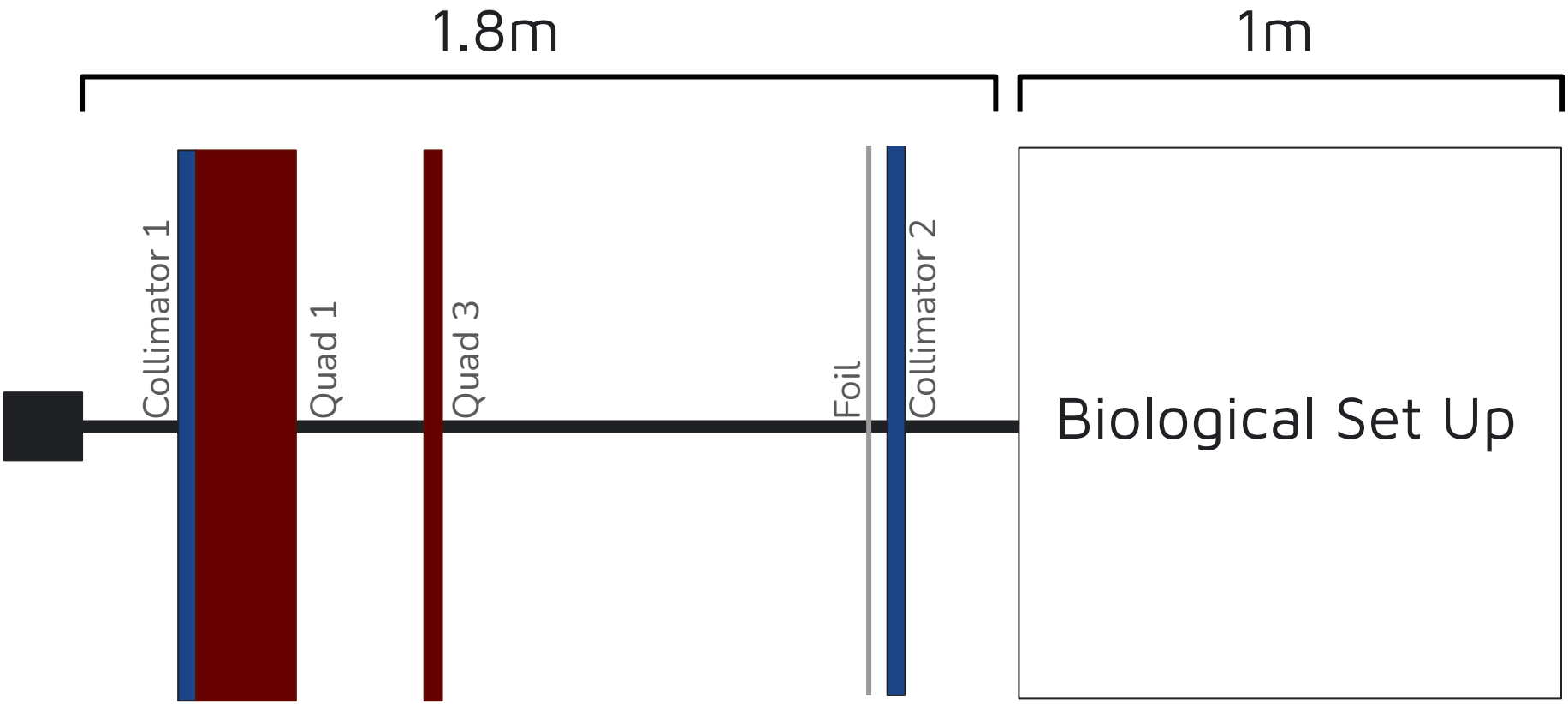


Combination 6

25mm then 13mm Quad at 130 T/m



Combination 6

25mm then 13mm Quad at 130 T/m

Energy (MeV)	Focusing quad position (m)	Drift between quads (m)
5	0.04	0.16
7.5	0.07	0.18
10	0.07	0.17
12.5	0.11	0.17
15	0.11	0.17

Combination 6

25mm then 13mm Quad at 130 T/m

Energy (MeV)	Horizontal beam size at end station (x)	Horizontal beam size at end station (y)	# particles at end station
5	0.001512m	0.00155m	3614
7.5	0.001504m	0.001556m	3642
10	0.001511m	0.001574m	3674
12.5	0.001511m	0.001568m	3592
15	0.001506m	0.00153lm	3596

Combination 6

PROs:

- Price average
- 0.36% of particles make it through at the optimal configuration- the 2nd most of all combinations of quads

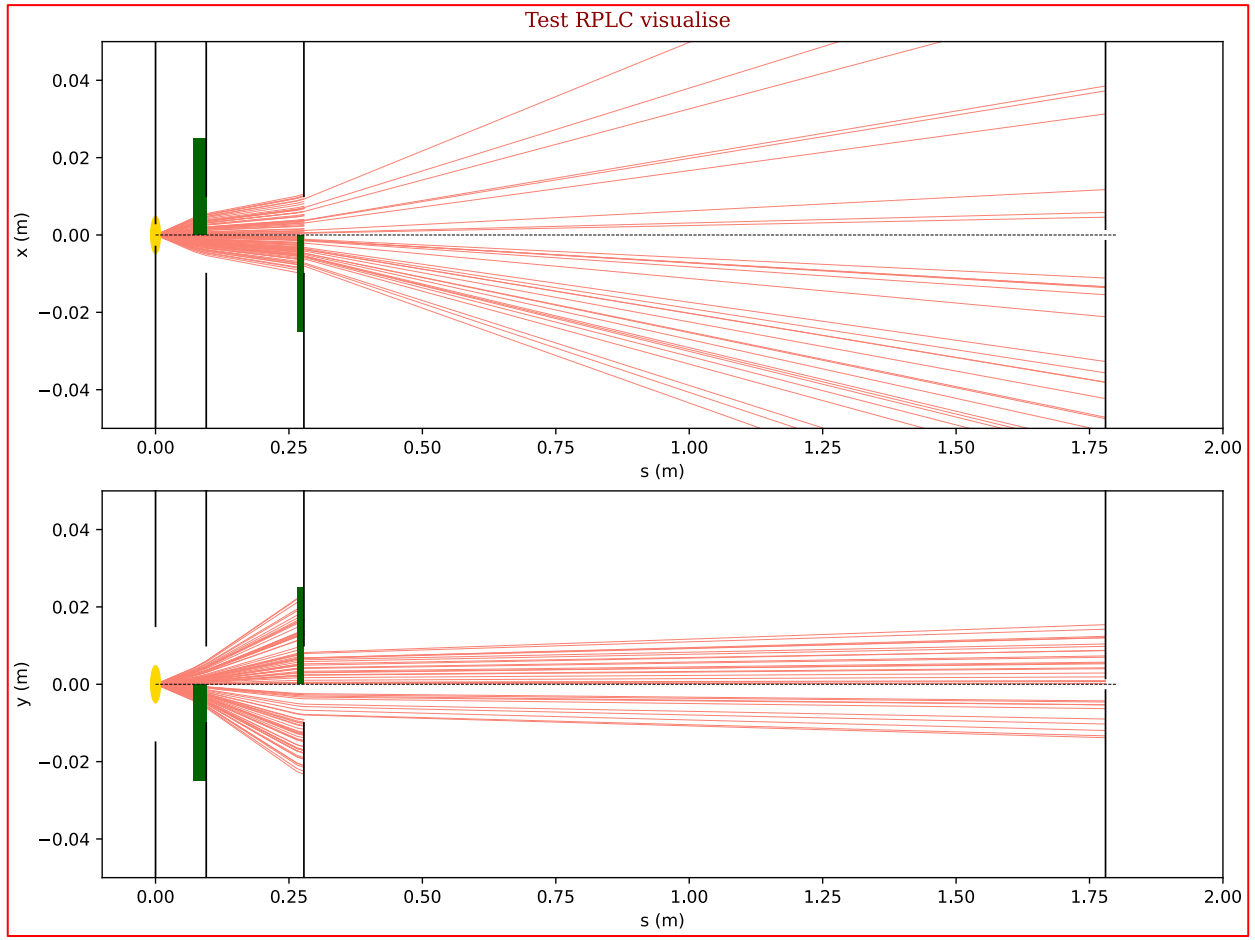
CONS:

- Different dimensions so 2 different designs needed

10 MeV; 130 T/m; lq1(F)=25 mm, lq2(D)=13 mm

- **Transmission: 14%**

Josie



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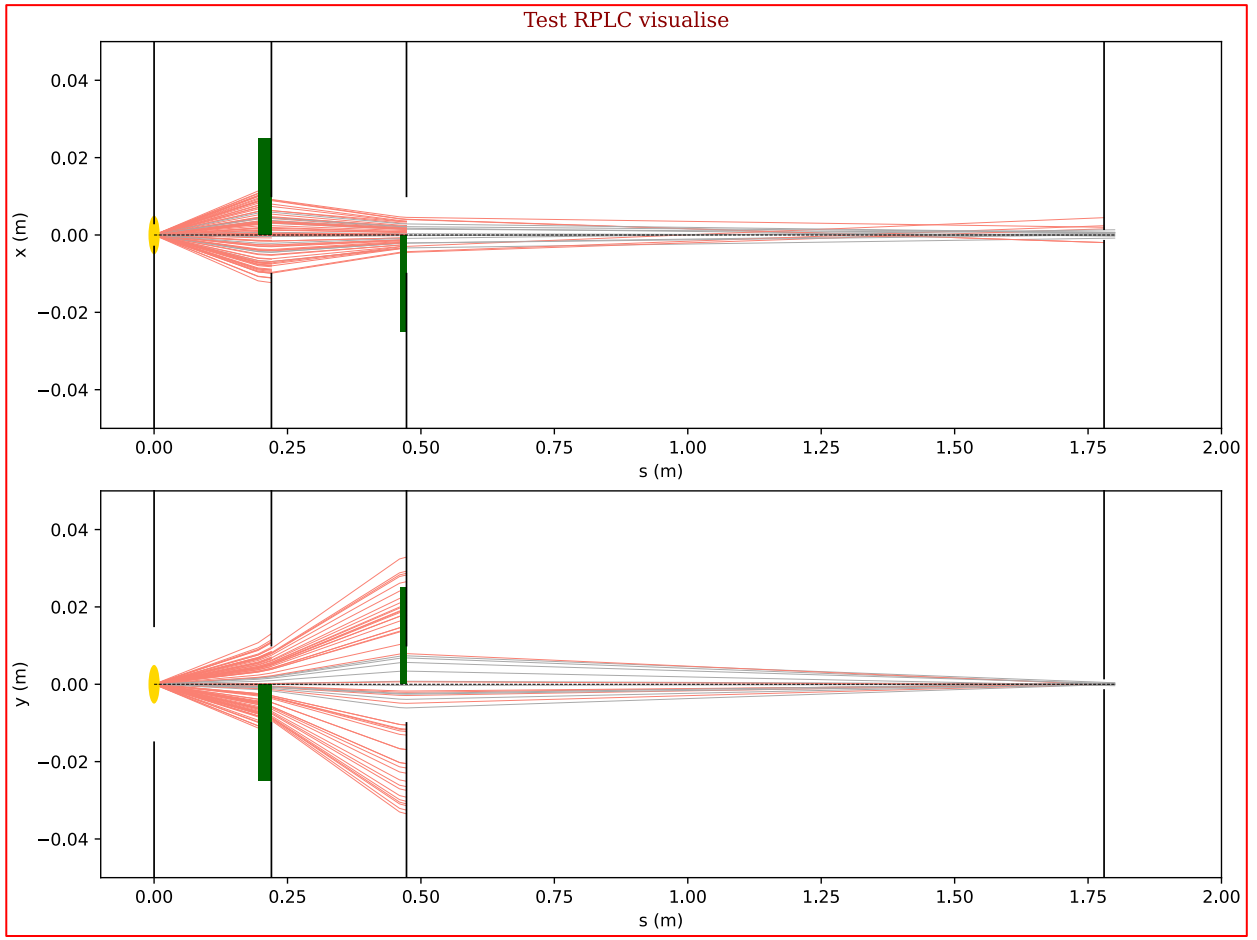

Summary

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13mm 13mm	£3550	Yes	0.065%
25mm 18mm	£3820	No	0.065%
18mm 13mm	£3595	No	0.4%
25mm 13mm	£3775	No	0.36%

Comments

- Good solutions also with longer, 130 T/m quads
- Good solutions with LMU-style (332 T/m) quads with smaller aperture

- Need to:
  - Check with, e.g., BDSIM
  - Upgrade optimiser (e.g. simulated annealing …)

- Practical:
  - Money and lead time