Exploration of the Triplet Parameter Space

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on behalf of the

JAI FCC Team

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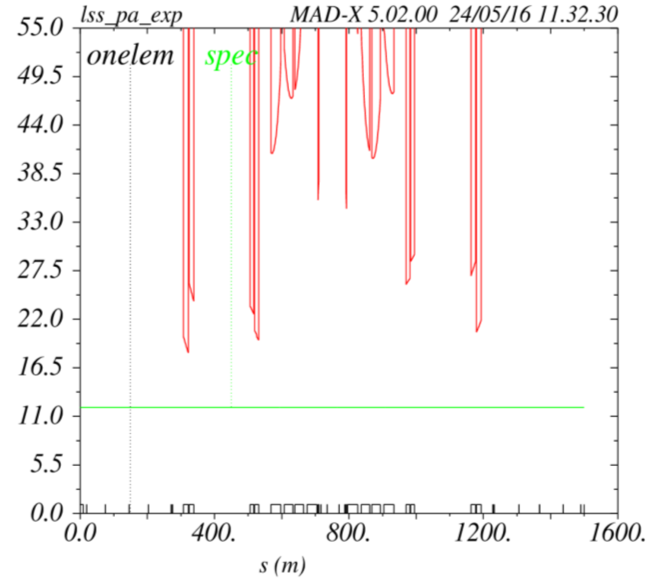
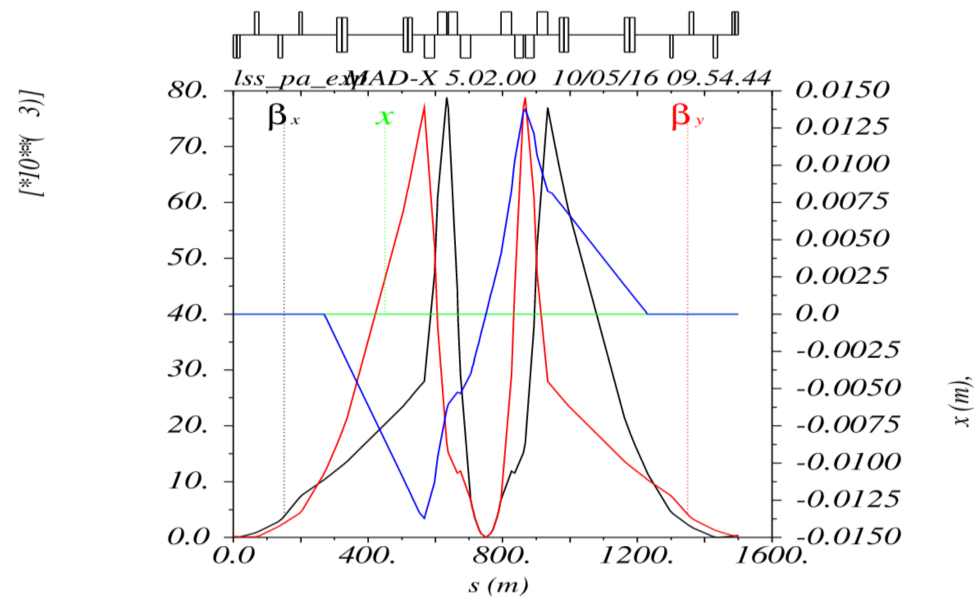
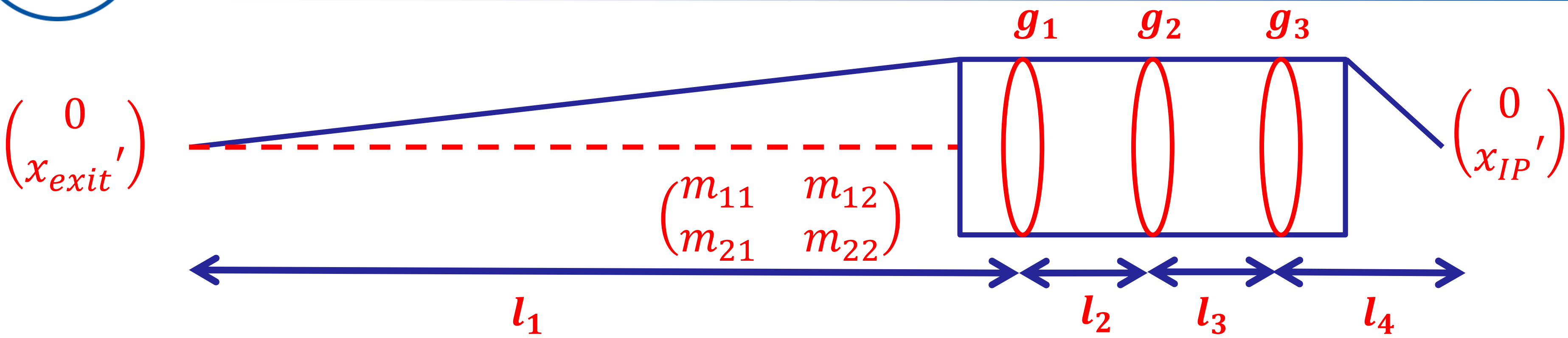
Shortening Inner Triplet

- **Minimise the size of the inner triplet**
  - Save space
  - Reduce chromaticity
  - Easier correction scheme
  - Cheaper
- **Keep sufficient beam stay clear**
- **Initial design (early 2016)**
  - ~ 40 σ beam stay clear
  - ~140 m long
  - 10 m gaps between magnets





Inner Triplet



- **Simplified approach:**
  - **Using thin lenses**
  - **Point-to-point focusing**
- $m_{x12} = m_{y12} = 0$
  - **Two constraints**
- **Analytical solution**
  - **Work out lens strength for fixed spatial layout**
  - **Iterate through many configurations quickly**

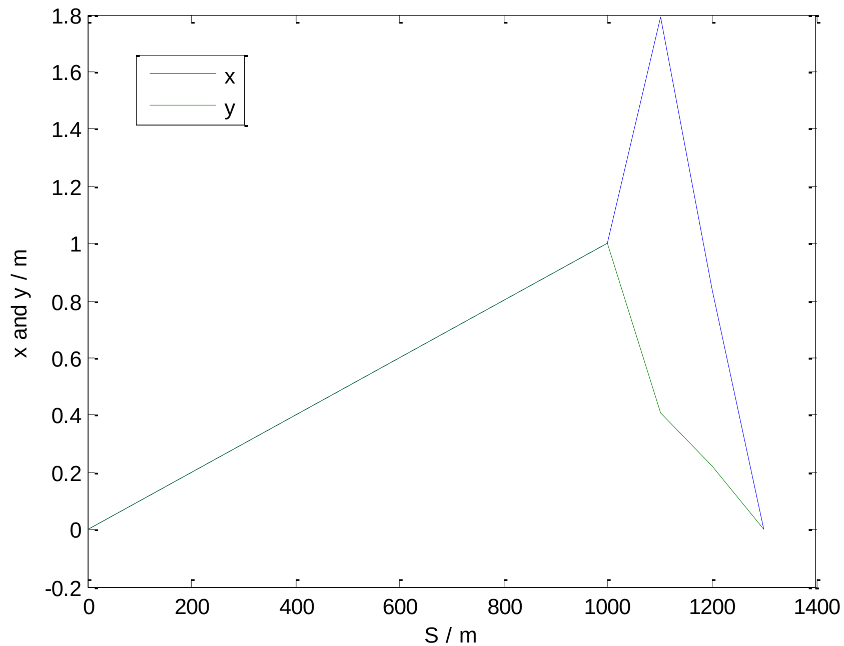
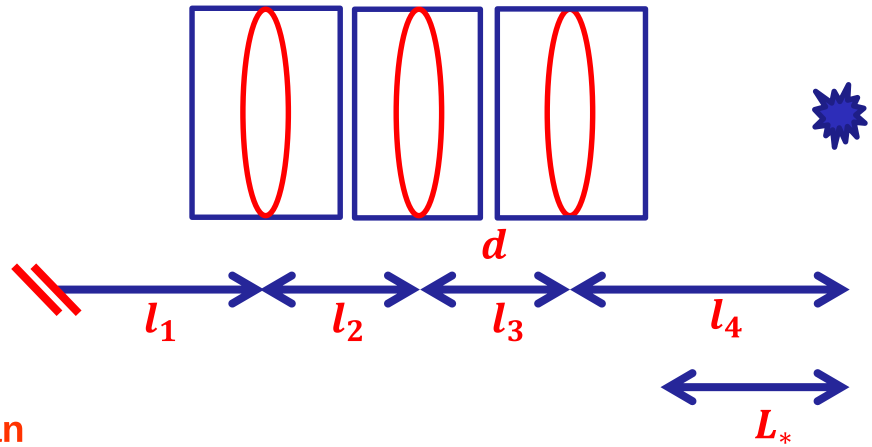
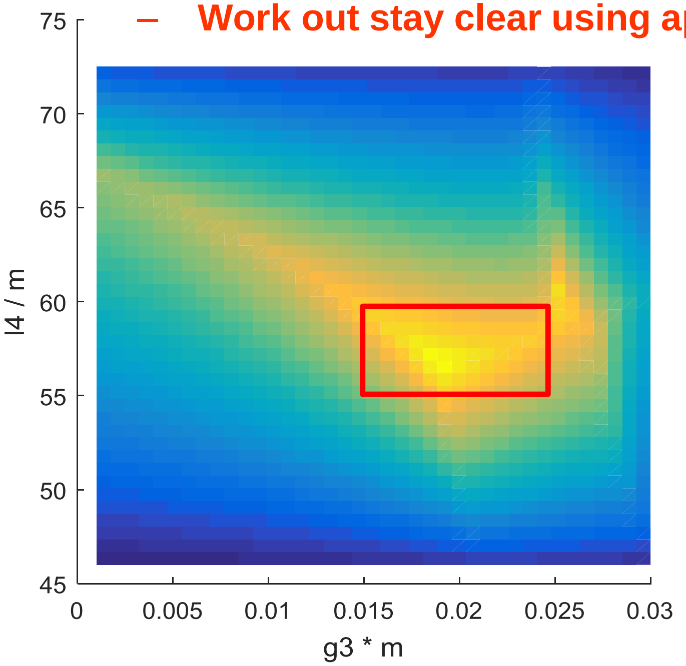
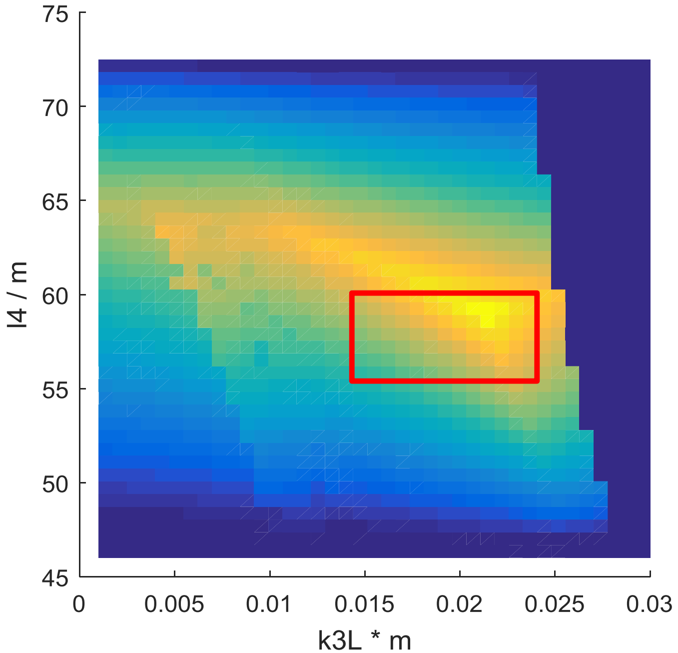


Figure of Merit

- **Figure of Merit (FOM):**
  - $\frac{x_i}{g_i} l_{Qi}$
- **Quadrupole Lengths**
  - $l_{Q1} = l_{Q3} = 2 \times (l_4 - L_*)$
  - $l_{Q2} = 2 \times \left(l_3 - \frac{l_{Q3}}{2} - d\right)$
- **Thick lens PyMadX**
  - Scan smaller area determined by fast scan
  - Match accurately using MadX
  - Work out stay clear using aperture module







Python Script

Set total length and fix required beam stay clear, β*, L*, gaps and shielding

Use fast FOM to scan large range in parameter space

Determine sensible range $g \pm 0.005$, $l_4 -2\% +8\%$

Use PyMadX for small scan of accurate beam stay clear using current shielding (12×25 resolution)

Find setup with largest beam stay clear

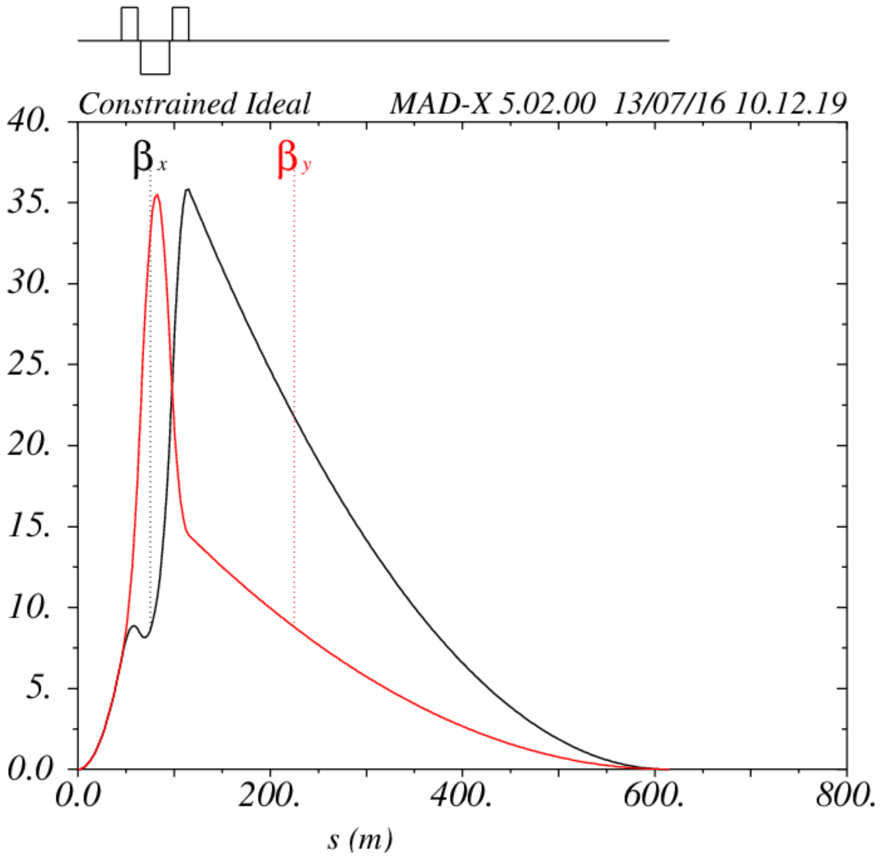
If beam stay clear larger than required

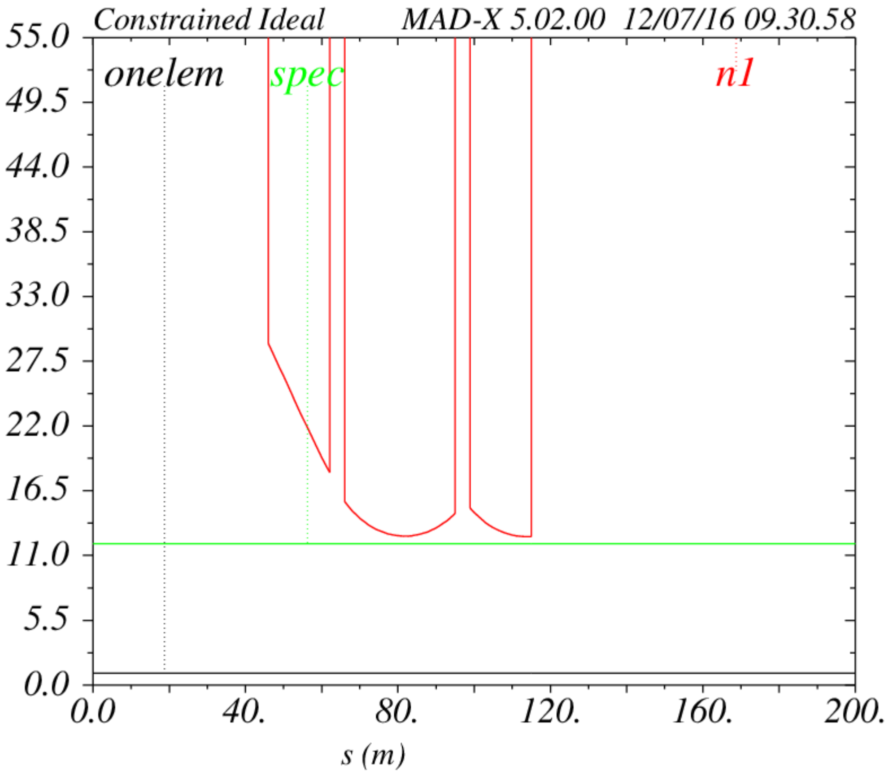
Plot ideal setup and output lengths + strengths

If beam stay clear smaller than required

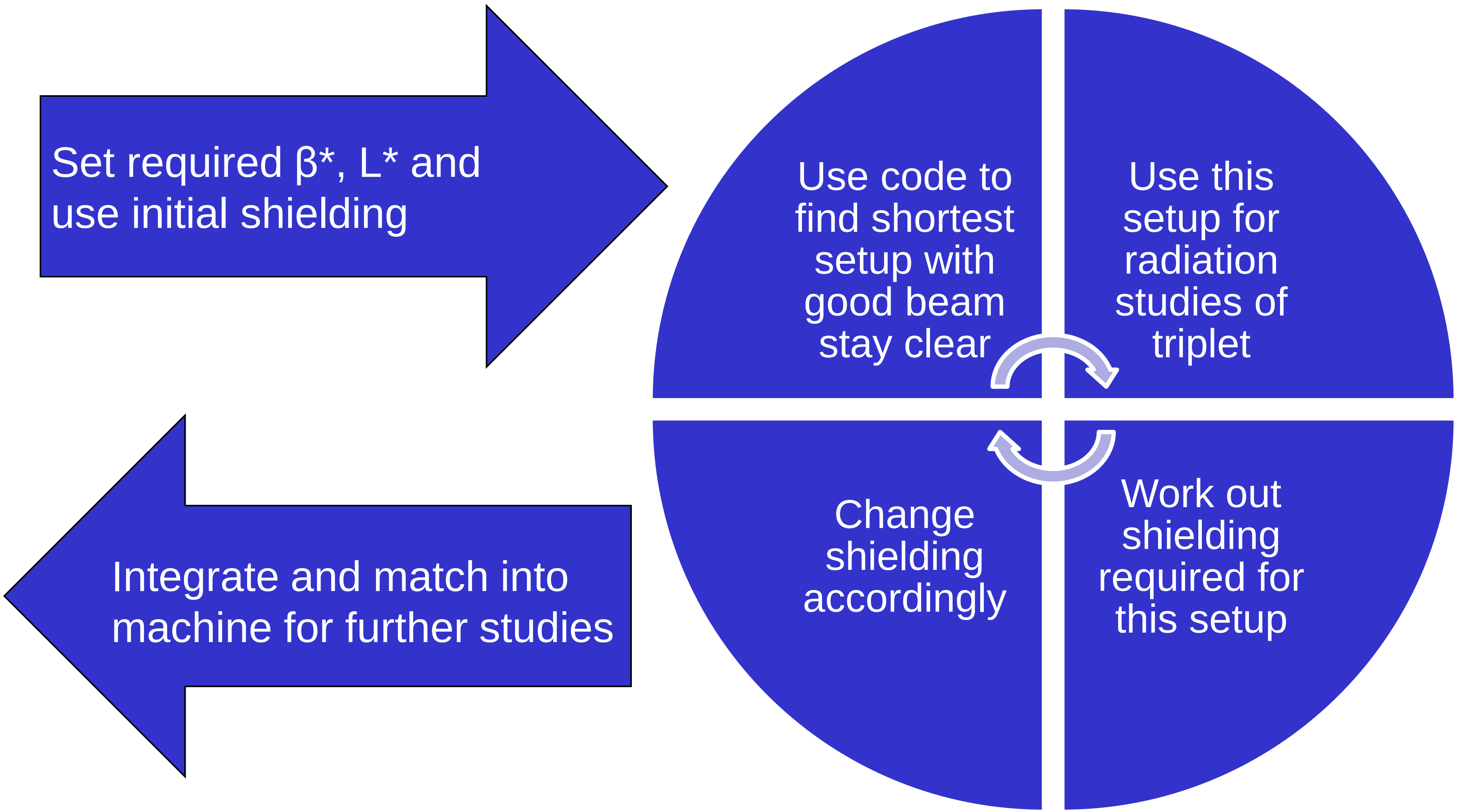
Increase total length

First attempt 70 m (12 σ, $\beta^* = 0.3$, 3 m gaps)

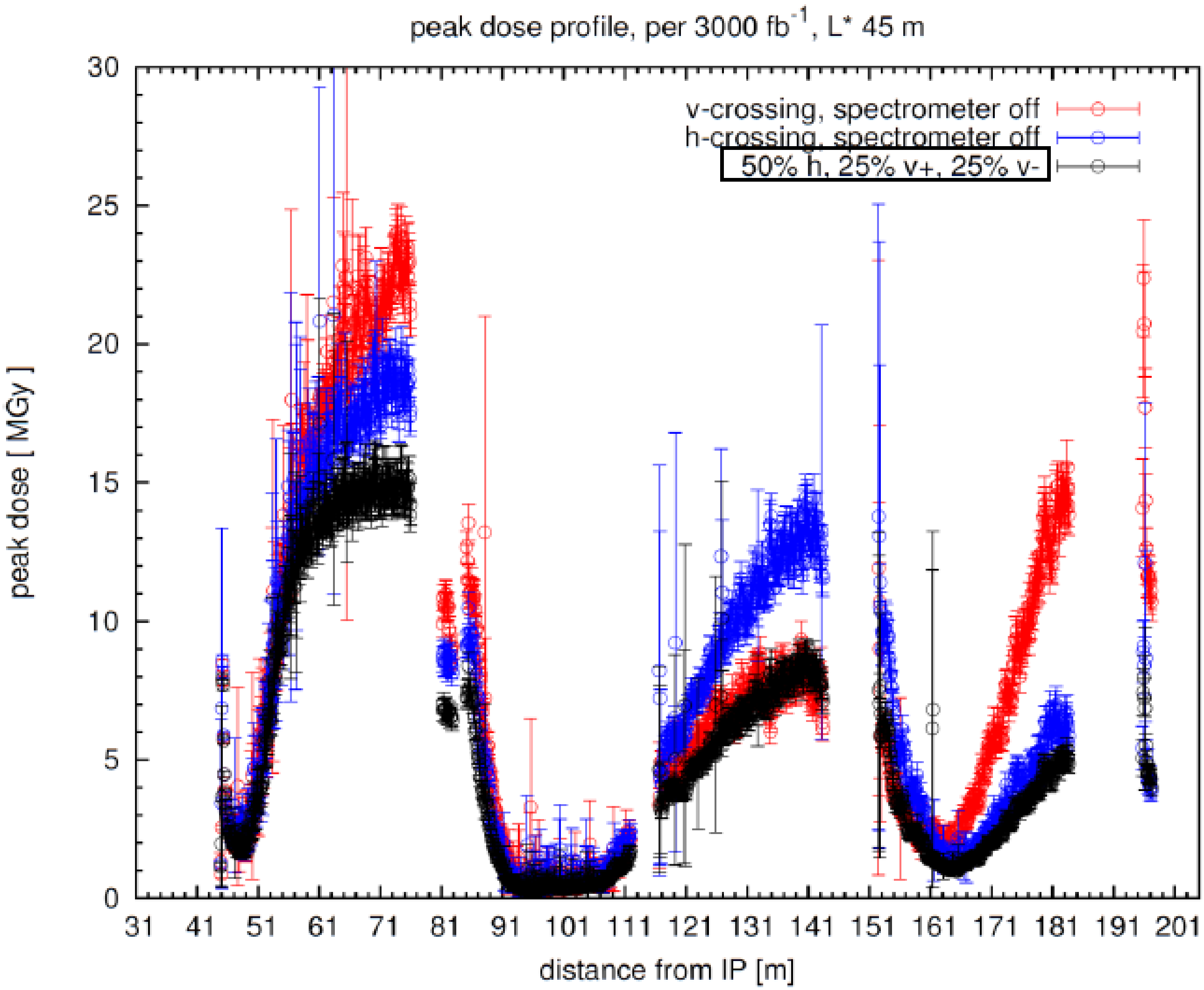




Optimising shielding



Comparison to baseline



Ilaria. Dose in nominal triplet (FCC week 2016)

Constraints

Parameter	Baseline	Final Design
Space Between Magnets	10 m	2 m
β^*	0.3 m	0.3 m
L^*	45 m	45 m
Peak dose profile, per 3000 fb-1	< 15 MGy	< 15 MGy
Beam Stay Clear	40 σ	15.5 σ

JAI Nov 2016 Triplet

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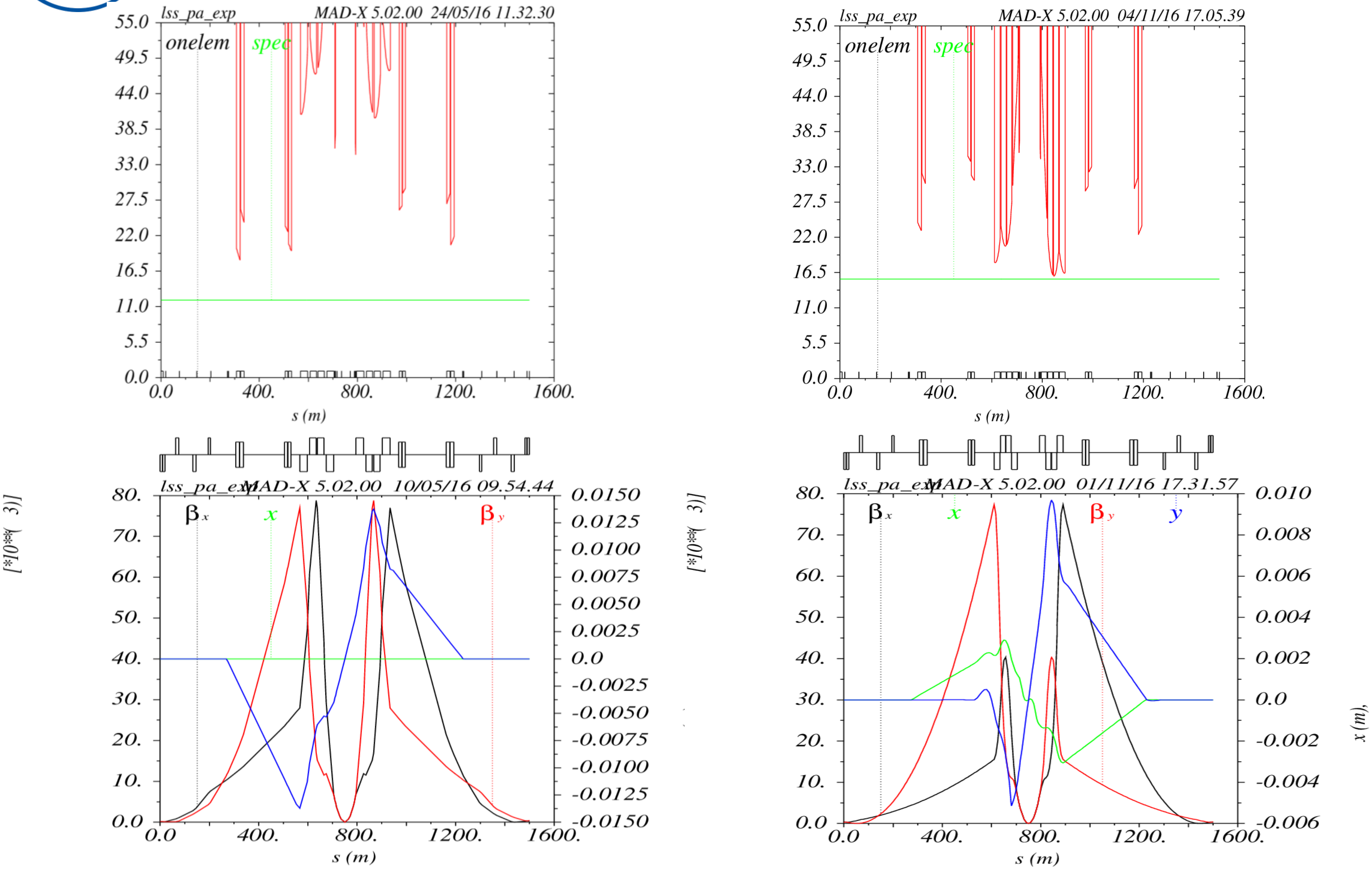
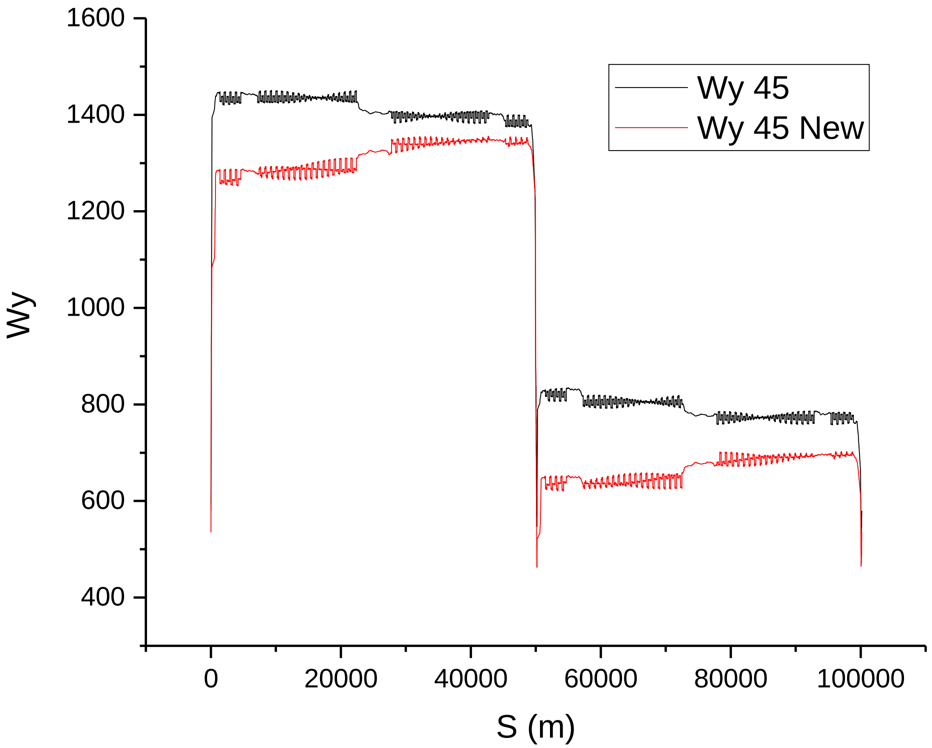
Beam Stay Clear	40 σ	15.5 σ
Shielding	15 mm	24.2 mm
Triplet Length	138.5 m	95 m
(of which is quadrupoles)	108.5 m	89 m

Comparison

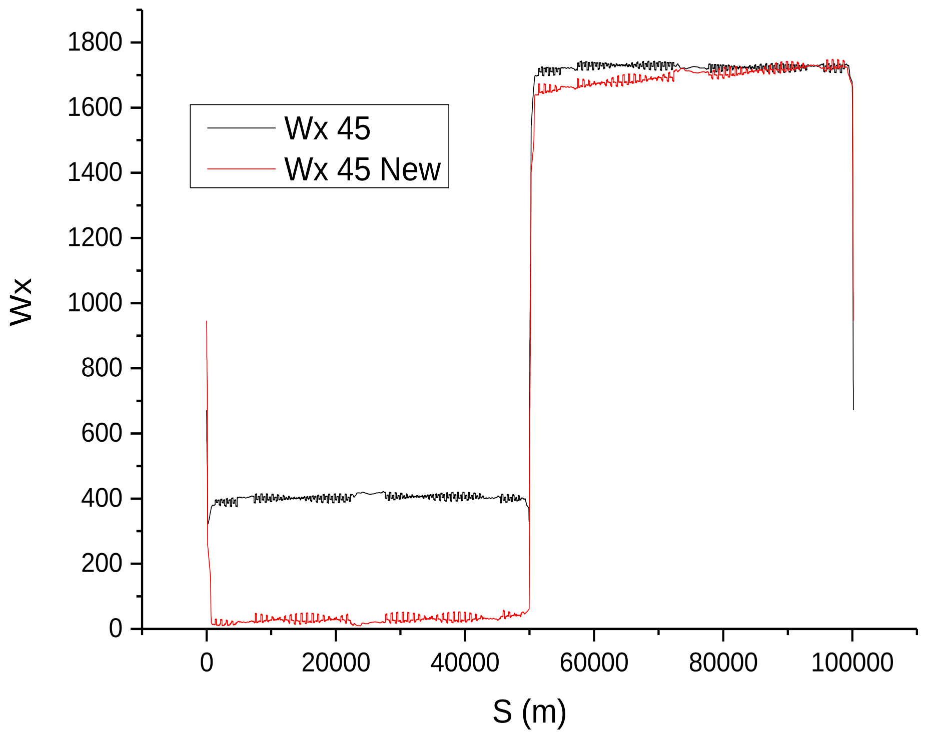


lss_pa_exp
MAD-X 5.02.00 24/05/16 11.32.30
onelem
spec
55.0
49.5
44.0
38.5
33.0
27.5
22.0
16.5
11.0
5.5
0.0
0.0
400.
800.
1200.
1600.
s (m)
lss_pa_exp
MAD-X 5.02.00 04/11/16 17.05.39
onelem
spec
s (m)
lss_pa_exp
MAD-X 5.02.00 10/05/16 09.54.44
βx
x
βy
80.
70.
60.
50.
40.
30.
20.
10.
0.0
0.0150
0.0125
0.0100
0.0075
0.0050
0.0025
0.0
-0.0025
-0.0050
-0.0075
-0.0100
-0.0125
-0.0150
[*10**(3)]
s (m)
lss_pa_exp
MAD-X 5.02.00 01/11/16 17.31.57
βx
x
βy
y
0.010
0.008
0.006
0.004
0.002
0.0
-0.002
-0.004
-0.006
x (m),
[*10**(3)]
s (m)

Comparison

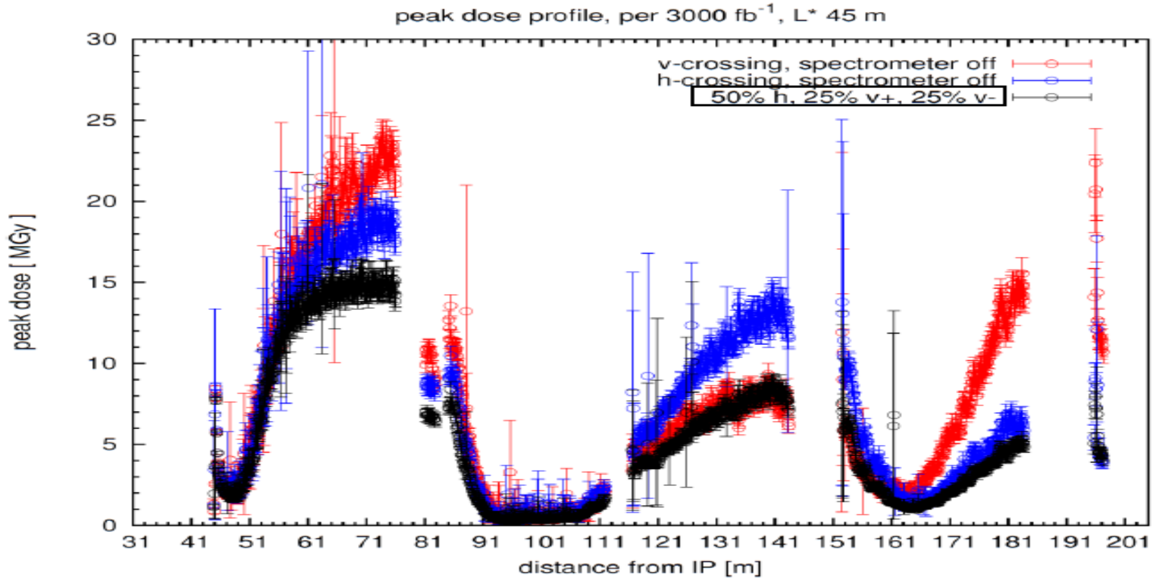


Wy 45
Wy 45 New
Wy
S (m)
1600
1400
1200
1000
800
600
400
0
20000
40000
60000
80000
100000

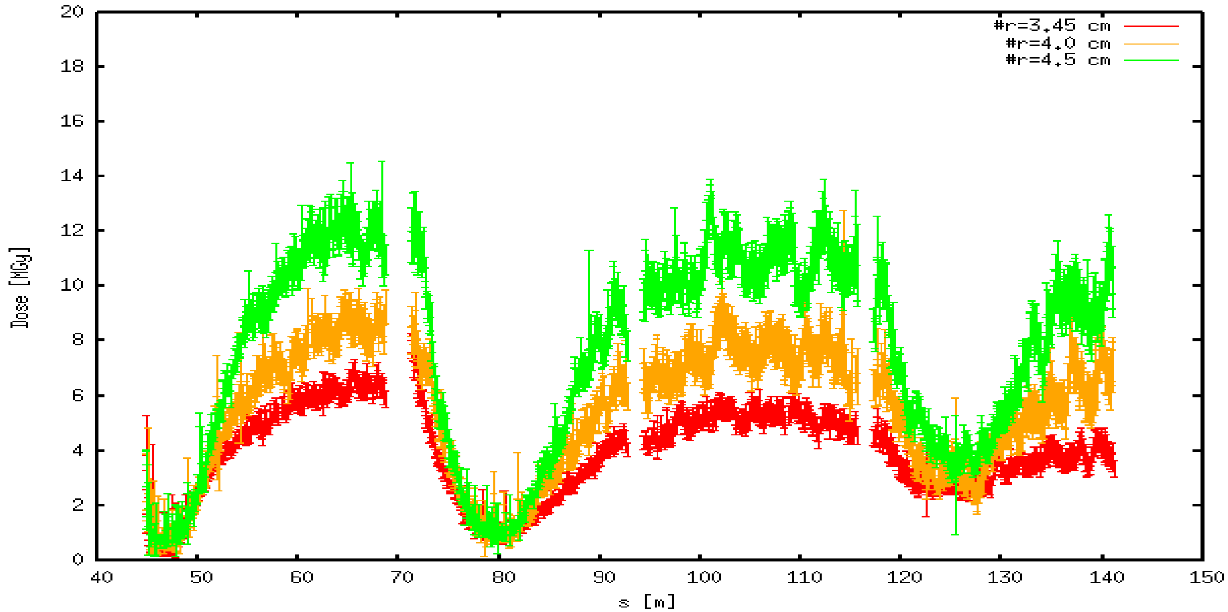


Wx 45
Wx 45 New
Wx
S (m)
1800
1600
1400
1200
1000
800
600
400
200
0
20000
40000
60000
80000
100000

Comparison



Ilaria. Dose in nominal triplet (FCC week 2016)



Conclusions

- **Wrote up an algorithm that helps find the optimum triplet layout for a set of constraints**
- **Designed optics in collaboration with radiation studies**
- **Used this to come up with an alternative design**
- **In future we can use this to quickly find new designs satisfying requirements**

John Adams Institute for Accelerator Science

Imperial College London

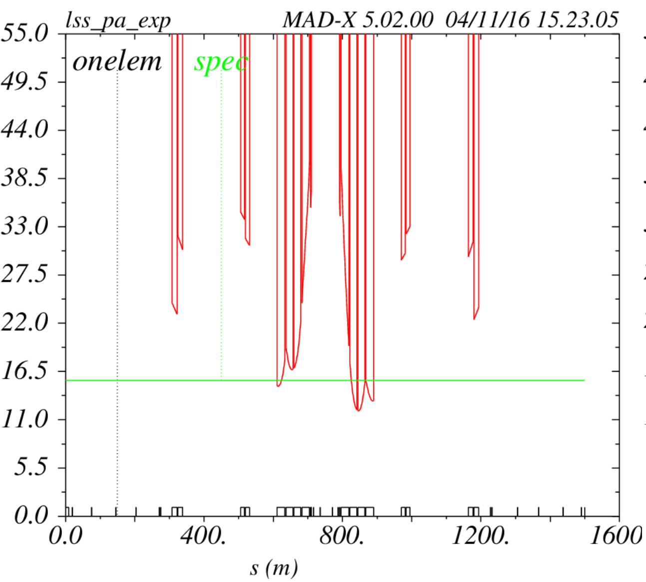
Royal Holloway University of London

University of Oxford

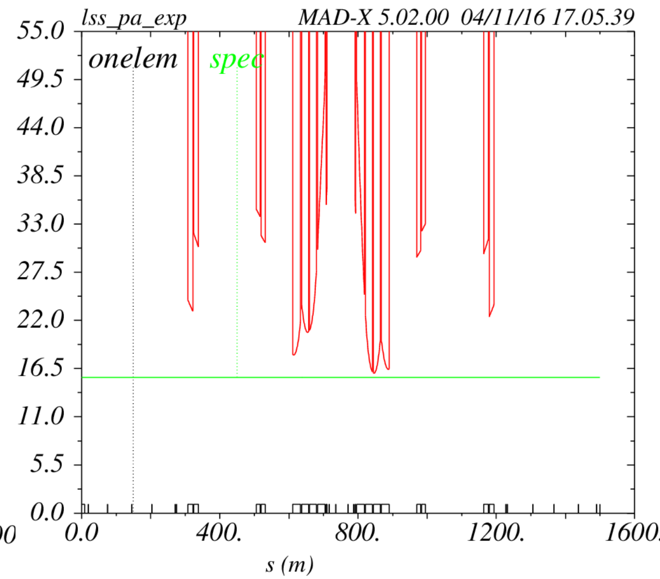
Thank you!

Different Shielding

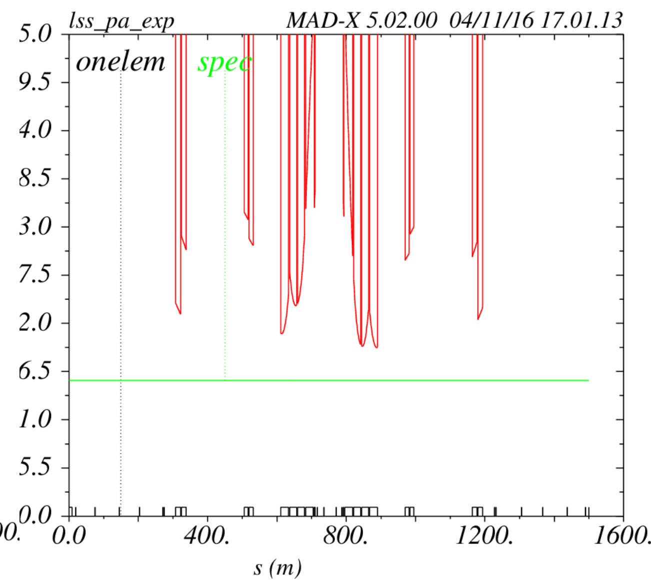
12 σ



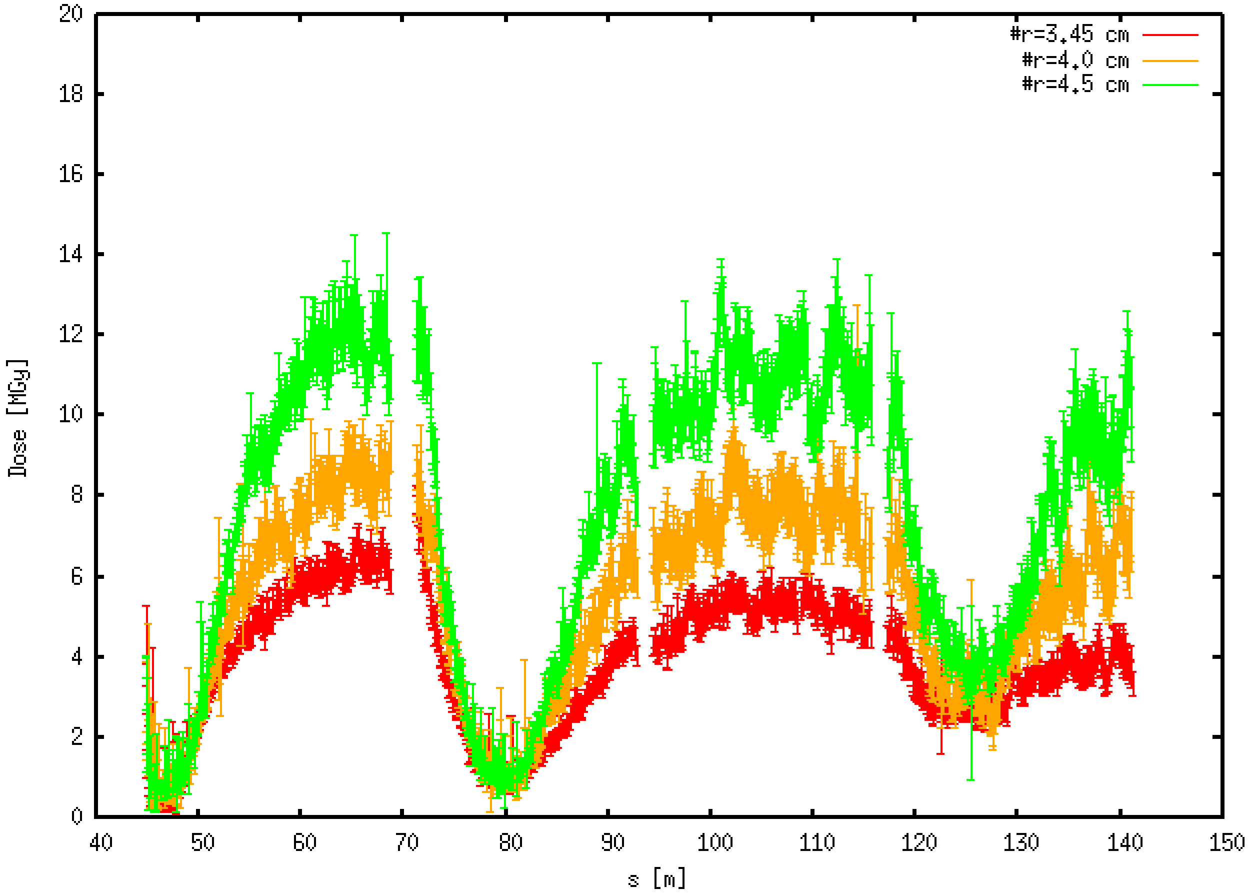
16 σ



19 σ



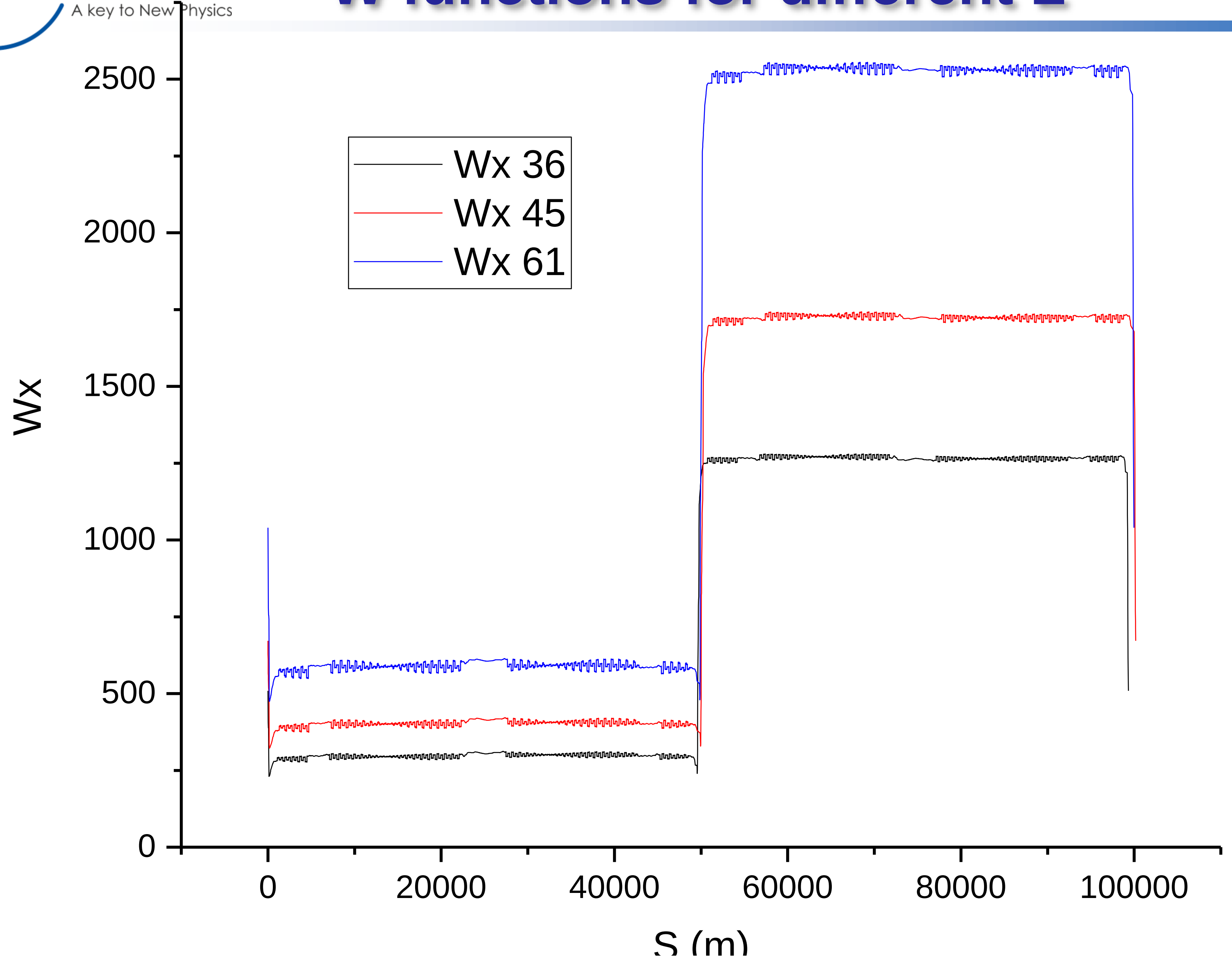
Different Shielding



Chromaticity

- $\frac{\partial Q}{\partial \delta} = \frac{1}{4\pi} \int \beta(s) k(s) ds$
  - Larger β and longer quads cause higher chromaticity
  - Larger L* forces β to be larger and needs stronger focusing
  - Higher chromaticity requires more correction and takes more space
  - Try and keep triplet as short as possible

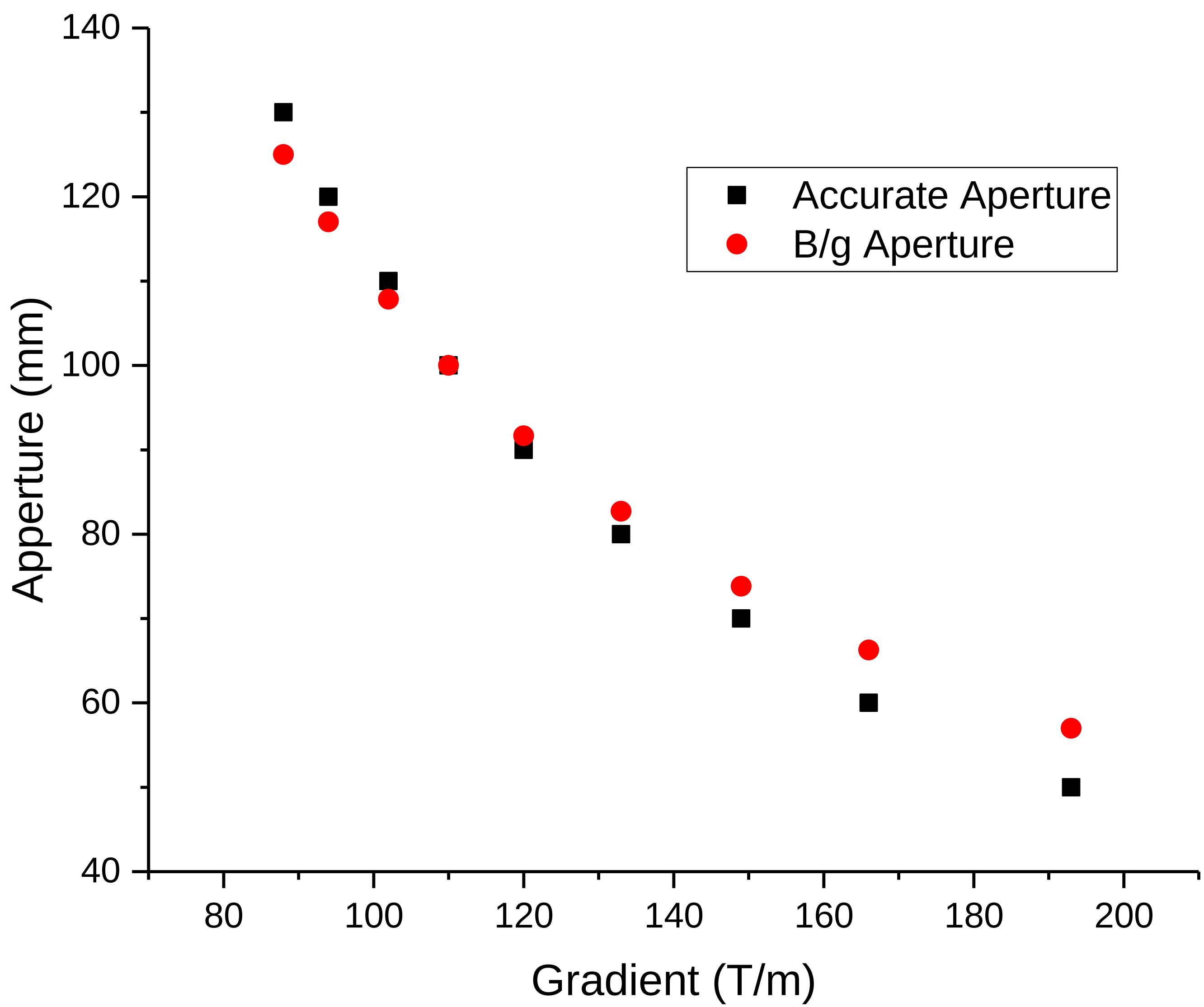
W functions for different L*



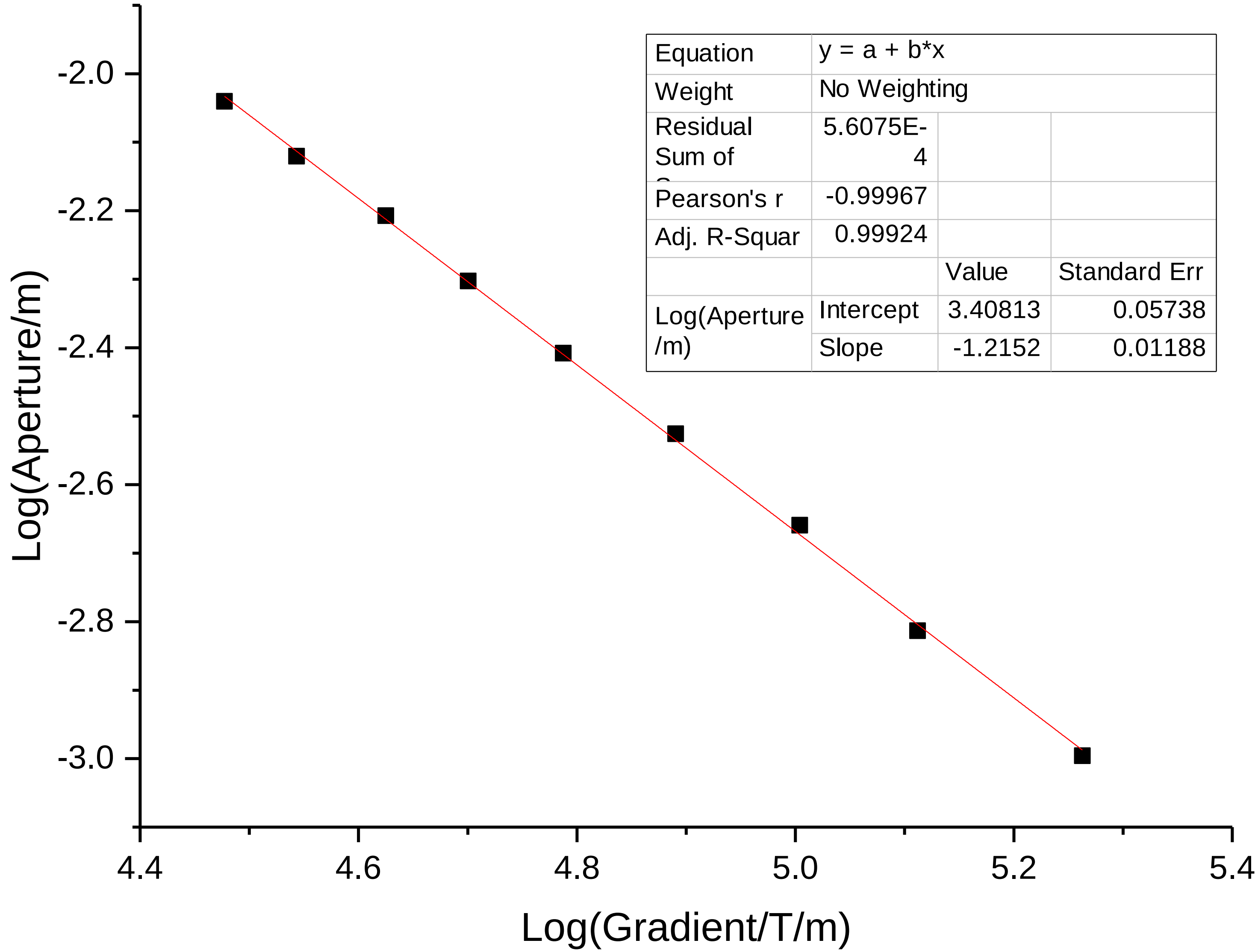
Aperture as a function of strength

- So far assumed constant maximum strength:
  - $r_{aperture} = \frac{B_{MAX}}{g} = \frac{11\ \mathrm{T}}{g}$
- Received an email by Daniel Schoerling about the cold bore

ap. R (mm)	w (mm)	G (T/m)
50	25	193
60	28	166
70	33	149
80	35	133
90	38	120
100	40	110
110	43	102
120	45	94
130	48	88


140
120
100
80
60
40
80
100
120
140
160
180
200
Apperture (mm)
Gradient (T/m)
Accurate Aperture
B/g Aperture

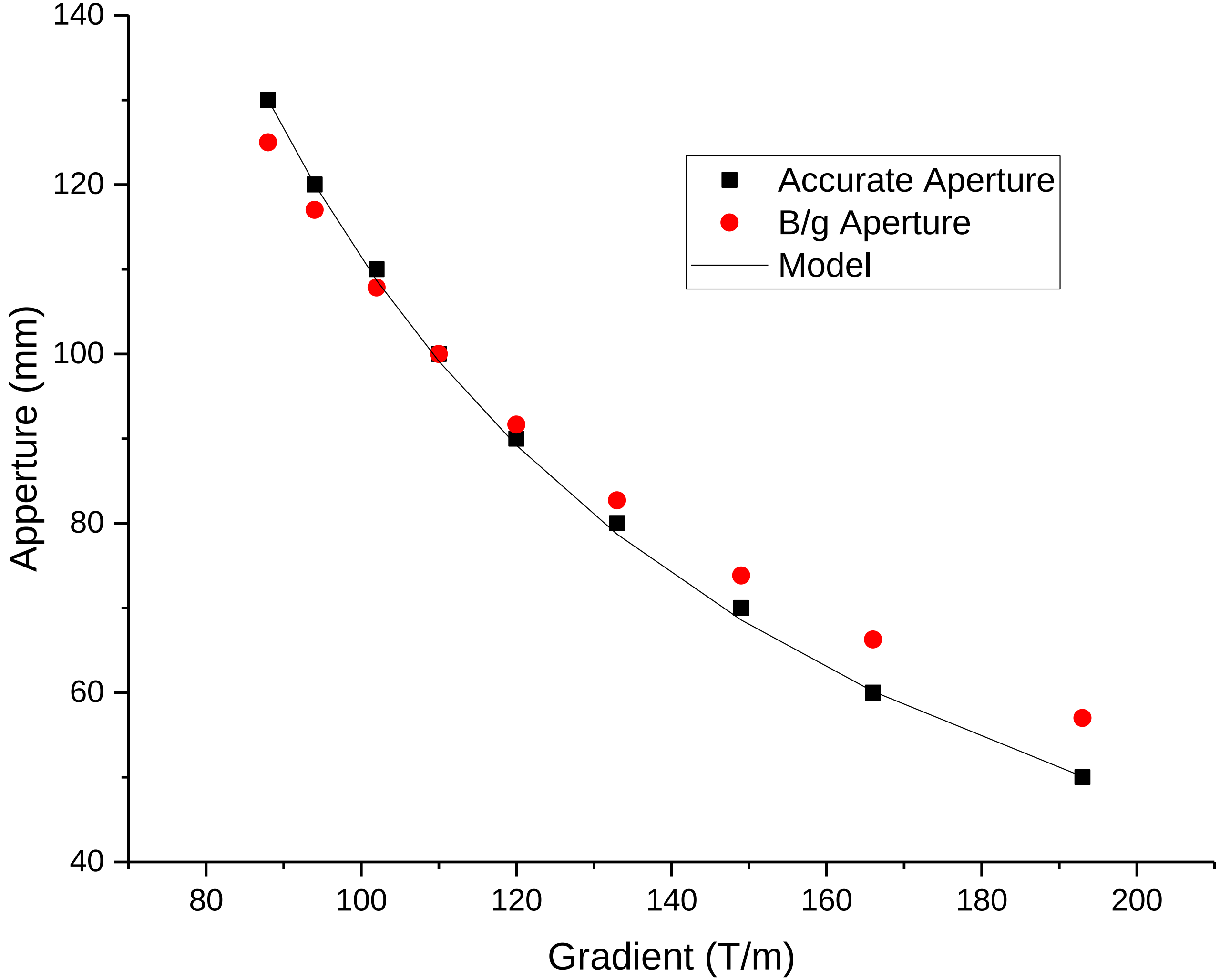
EuroCirCol
A key to New Physics



Equation	y = a + b*x		
Weight	No Weighting		
Residual Sum of	5.6075E-4		
Pearson's r	-0.99967		
Adj. R-Squar	0.99924		
		Value	Standard Err
Log(Aperture /m)	Intercept	3.40813	0.05738
	Slope	-1.2152	0.01188

Model

- **In future uses of my code I can update the aperture calculations**
- $A = e^{Intercept} g^{Gradient} = 29.96 g^{-1.215}\ \mathrm{m}$
- **Difference not significant to change previous designs**
- **Previous designs probably discarded when iterating with Jose**



Accurate Aperture
B/g Aperture
Model
Apperture (mm)
Gradient (T/m)
140
120
100
80
60
40
80
100
120
140
160
180
200