Energy deposition in FCC-hh EIR

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on behalf of CERN EN-STI-BMI

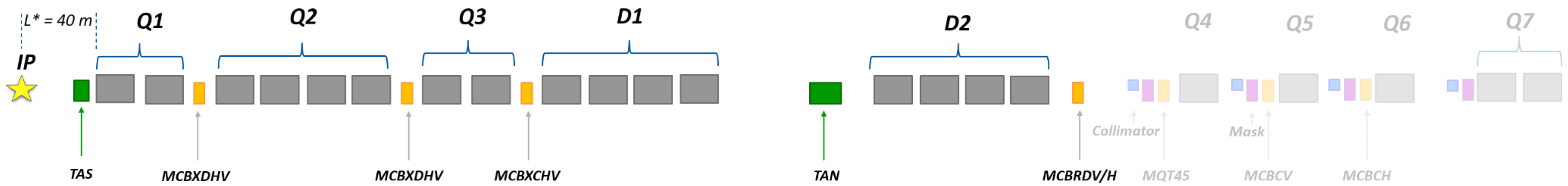
Special thanks to: C. Kotnig, R. Martin, D. Schörling

FCC-Week 2019, Brussels

Outline

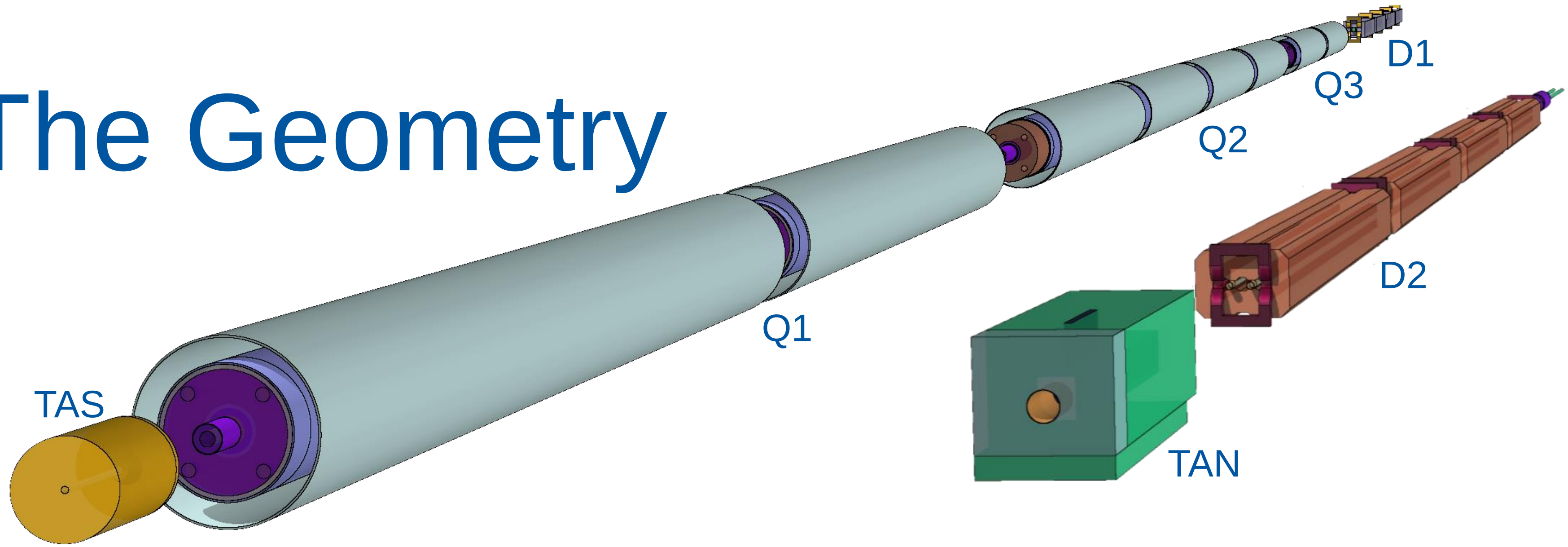
- Triplet
- Mitigation Strategies
- Matching Section
- Conclusion

TRIPLET



L* = 40 m
IP
Q1
Q2
Q3
D1
D2
Q4
Q5
Q6
Q7
TAS
MCBXDHV
MCBXDHV
MCBXCHV
TAN
MCBRDV/H
Collimator
Mask
MQT45
MCBCV
MCBCH

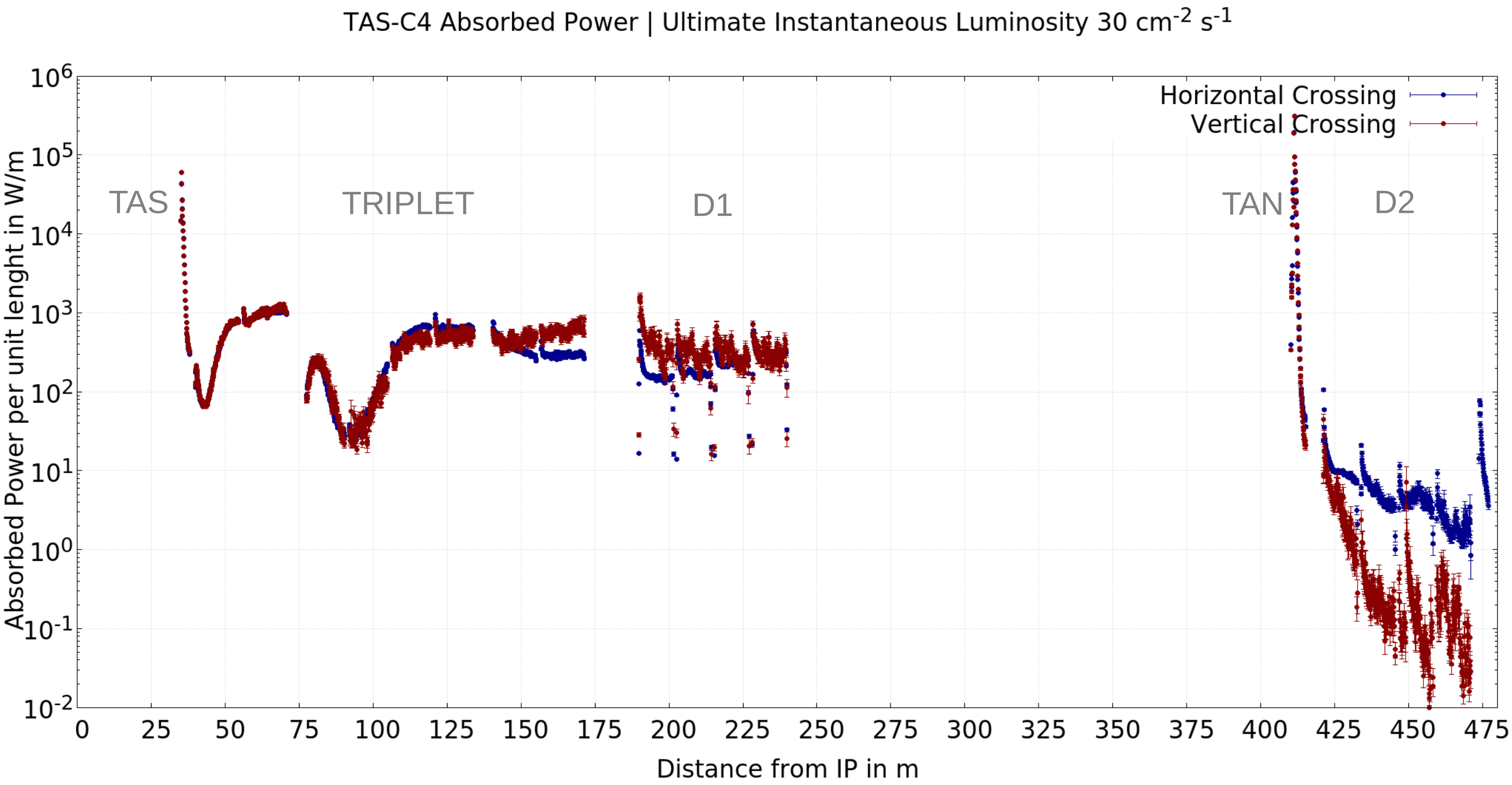
The Geometry



	(Magn.) Length in m	Aperture in mm	Gradient in T/m	Field in T
TAS	3.0	34	-	-
Q1a, Q1b	14.3	164	126	-
Q2a to Q2d	12.5	164	101	-
Q3a, Q3b	14.3	164	100	-
Correctors	1.3	210	-	0.5/1.9
D1a to D1d	11.3	170	-	2.0
TAN	5.0	52	-	-
D2a to D2d	11.3	85	-	2.0
MCBCRDV/H	3	70	-	2.5

- L^*= 40 m
- Crossing angle: 100 μrad
- Up to 490 m from IP
- 35mm Inermet shielding in the quadrupoles and correctors

Horizontal vs Vertical Crossing: Absorbed Power



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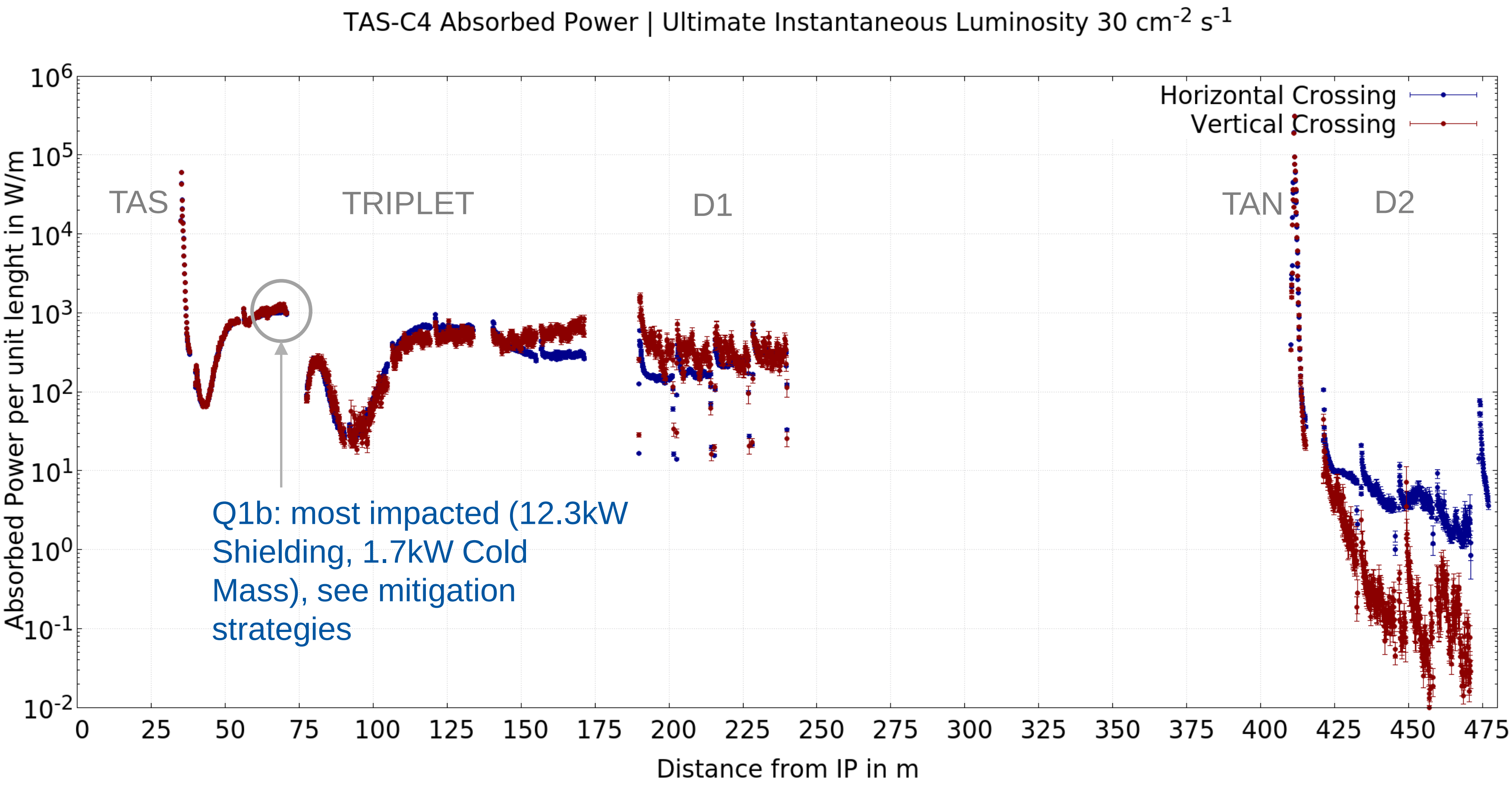

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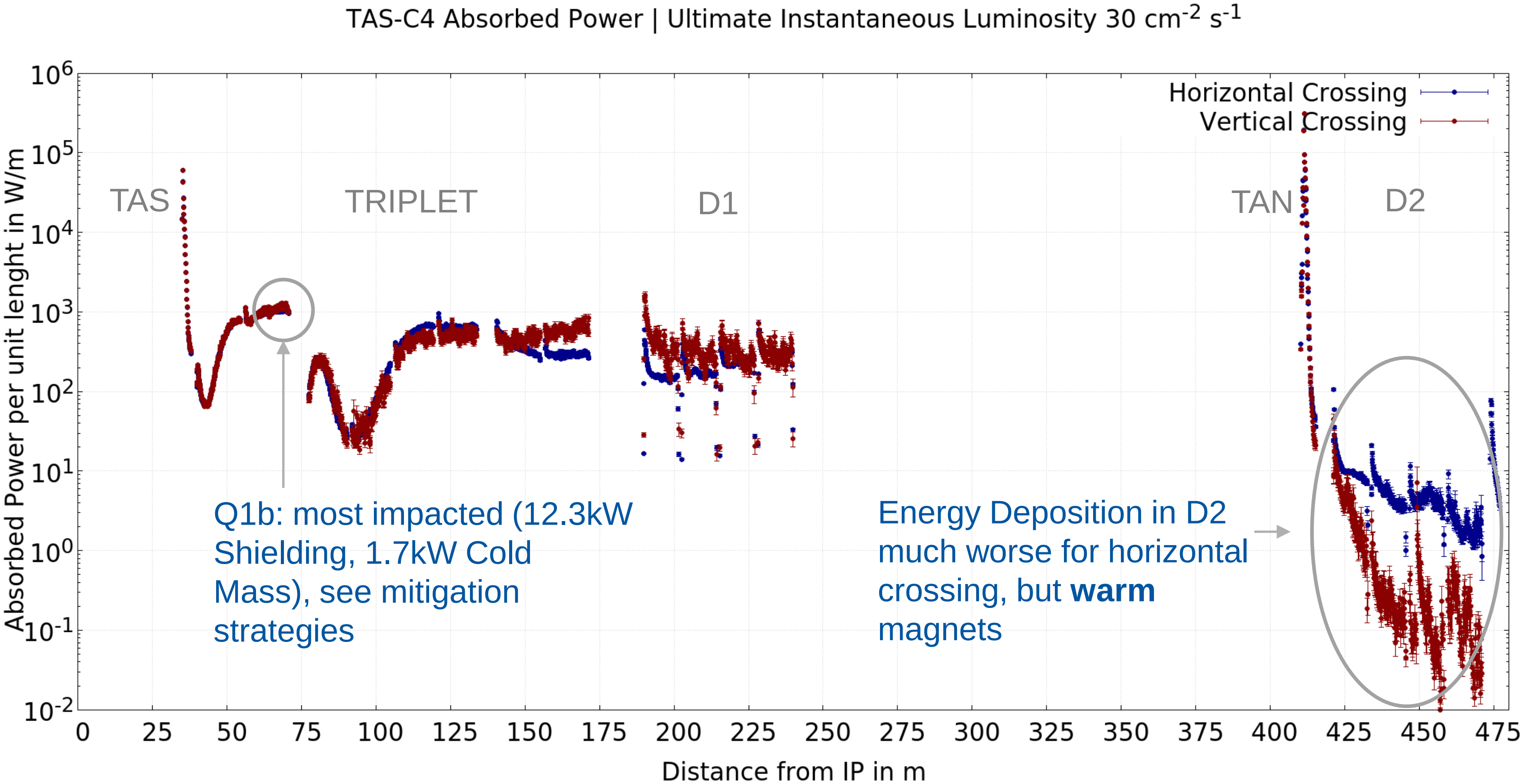
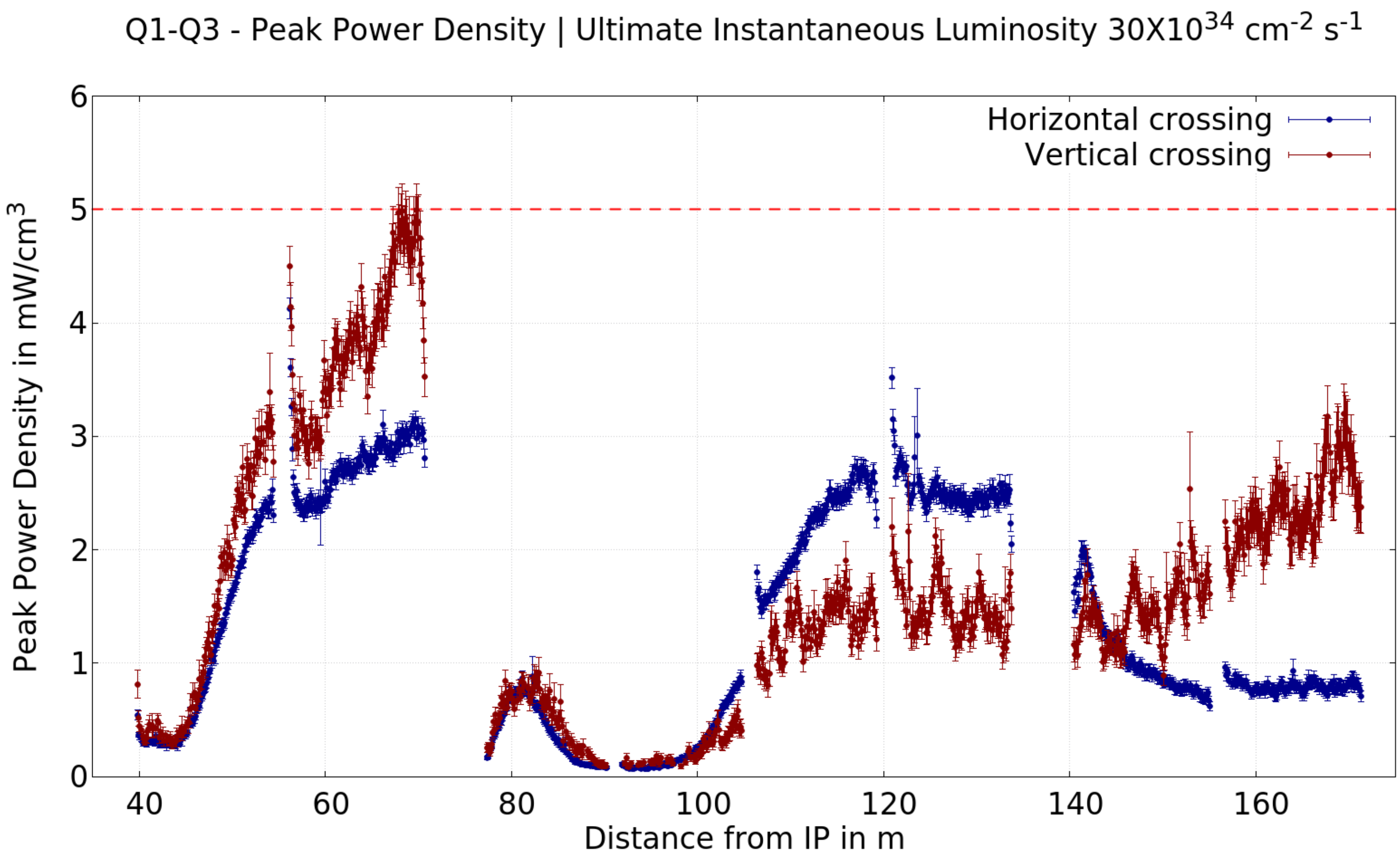
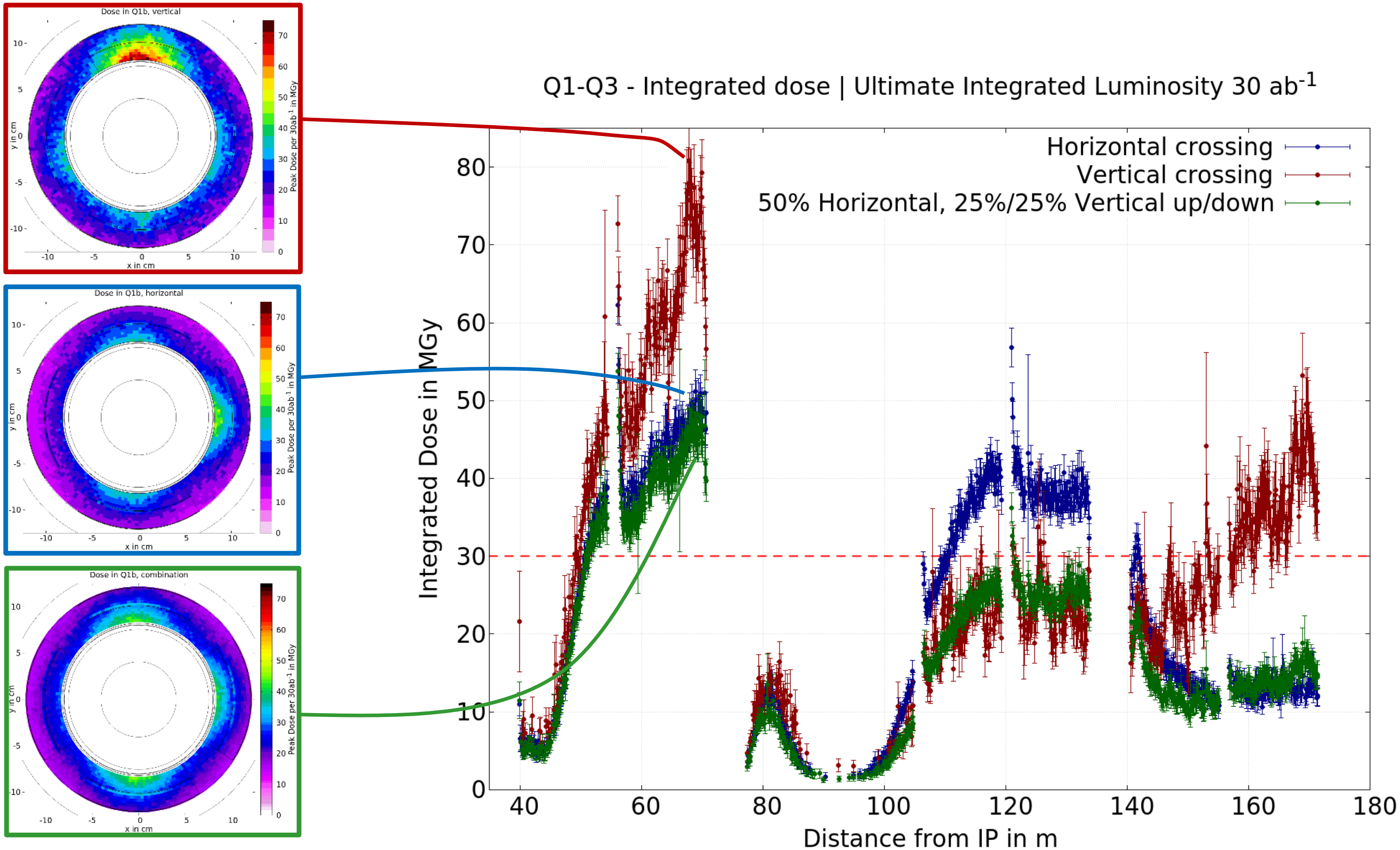


Horizontal vs Vertical Crossing: Peak Power Density



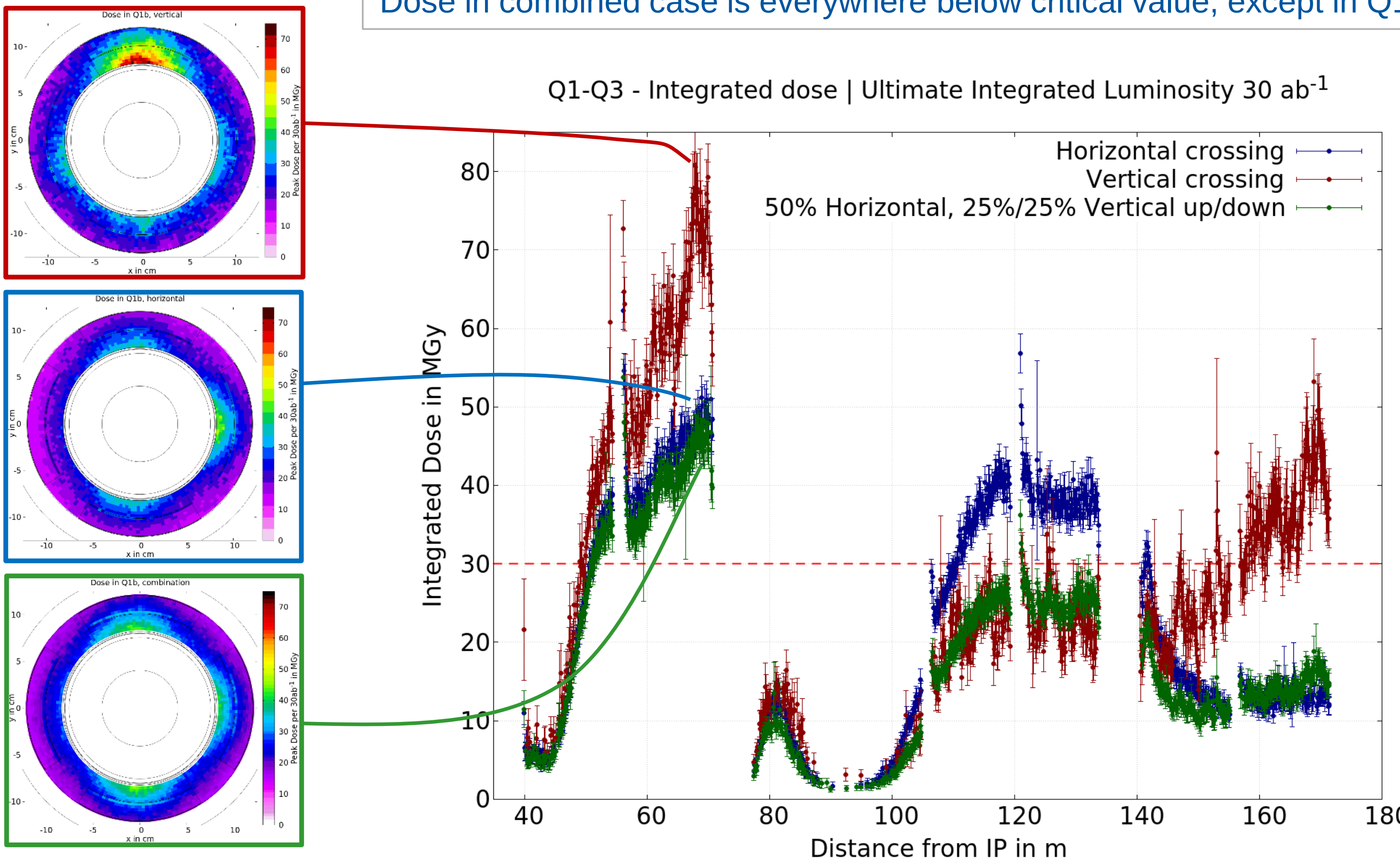
Horizontal vs Vertical Crossing: Integrated Dose



Idea of S. Fartoukh

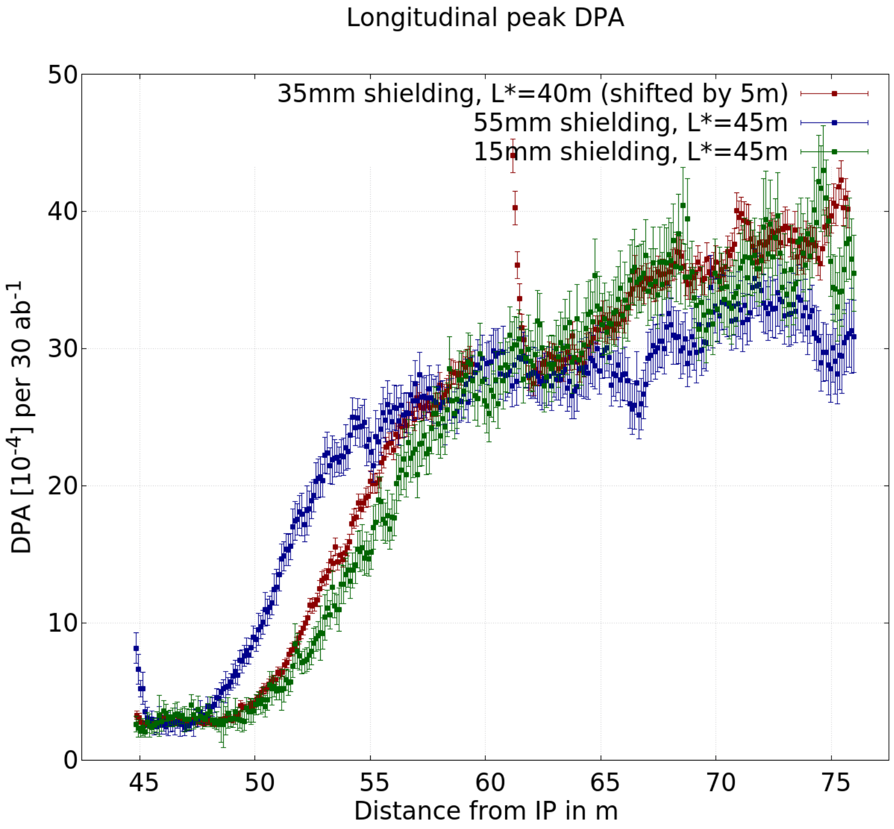
Horizontal vs Vertical Crossing: Integrated Dose

Dose in combined case is everywhere below critical value, except in Q1



Idea of S. Fartoukh

DPA (Displacement per atom) in Q1b



Irradiation of superconducting materials leads to displacement of atoms and therefore to deterioration of material critical properties

- DPA ~90% of DPA caused by neutrons
- Thicker shielding is not effective in reducing DPA

- Displacement per Atom:

$$dpa \equiv \frac{A}{V N_A \rho} N_F$$

A: molar mass in g/mol, V: volume in cm^3, N_A: Avogadro number in mol^{-1}, ρ: mass density in g/cm^3

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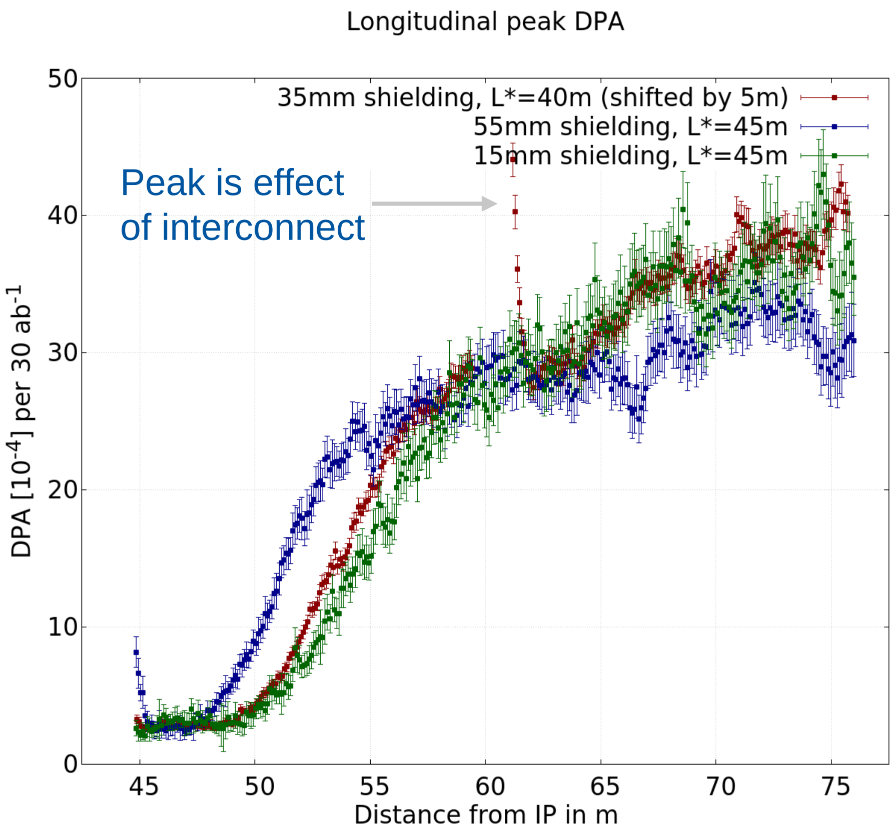

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Mitigation Strategy for Q1b (i)

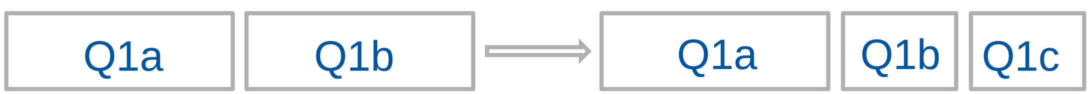
	Magn. length in m		Aperture in mm		Shielding in mm		Gradient in T/m	
	old	new	old	new	old	new	old	new
Q1a	14.3	14.3	164	150	35	38	126	139
Q1b	14.3	7.15	164	180	35	47	126	119
Q1c	-	7.15	-	190	-	47	-	111

Motivation:

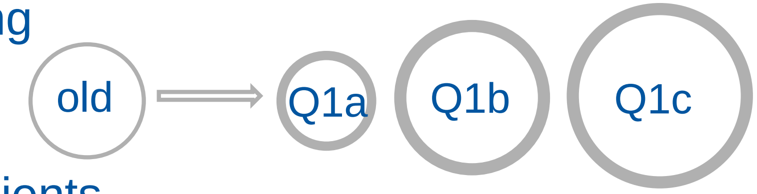
- Reduce **heat load** in Q1b
- Reduce **dose** in Q1b
- Reduce **DPA** in Q1b

Changes:

- Split of former Q1b into two magnets (Q1b, Q1c) (Idea of R. Martin)

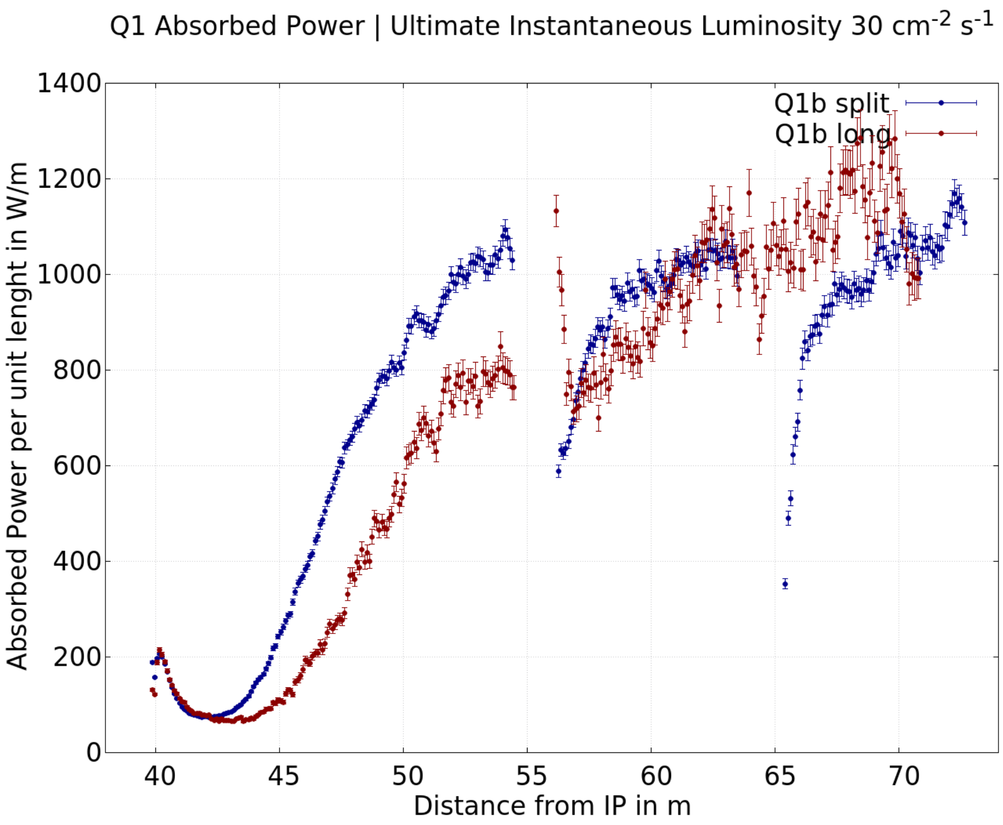


- Smaller aperture in Q1a; larger aperture in Q1b, Q1c
- Thicker shielding



- Change in gradients

Mitigation Strategy of Q1b (ii)



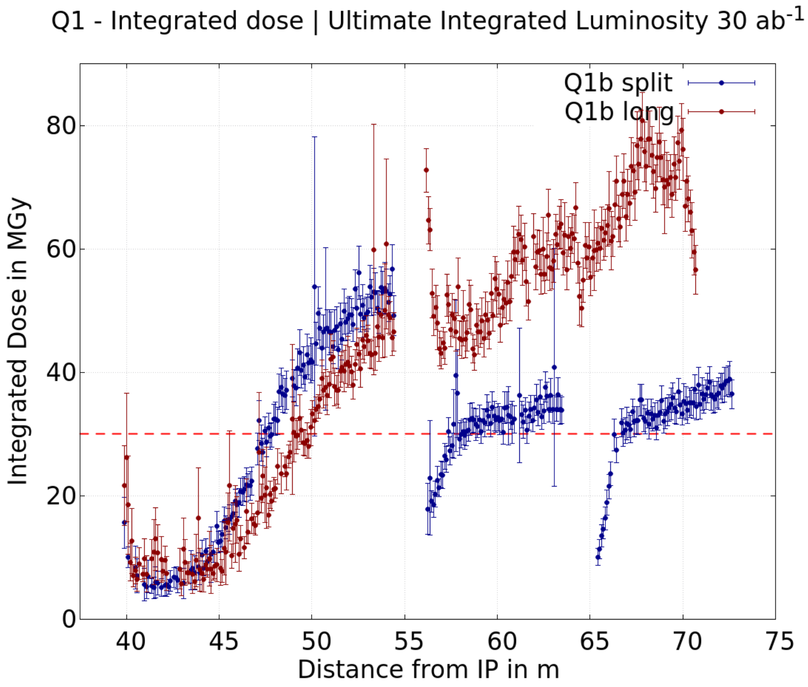
<u>Note</u>: vertical crossing

Absorbed power in cold mass

In kW	Original	Split
Q1a	0.8	1.0
Q1b	2.0	0.7
Q1c		0.6

Manageable values for cryogenics system (C. Kotnig, https://indico.cern.ch/event/727555/contributions/3427601/)

Dose & DPA Q1b split:



- Slightly higher dose in Q1a, but much lower dose in Q1b and Q1c
- Q1b and Q1c hardly exceed the limit of 30MGy

Note: vertical crossing

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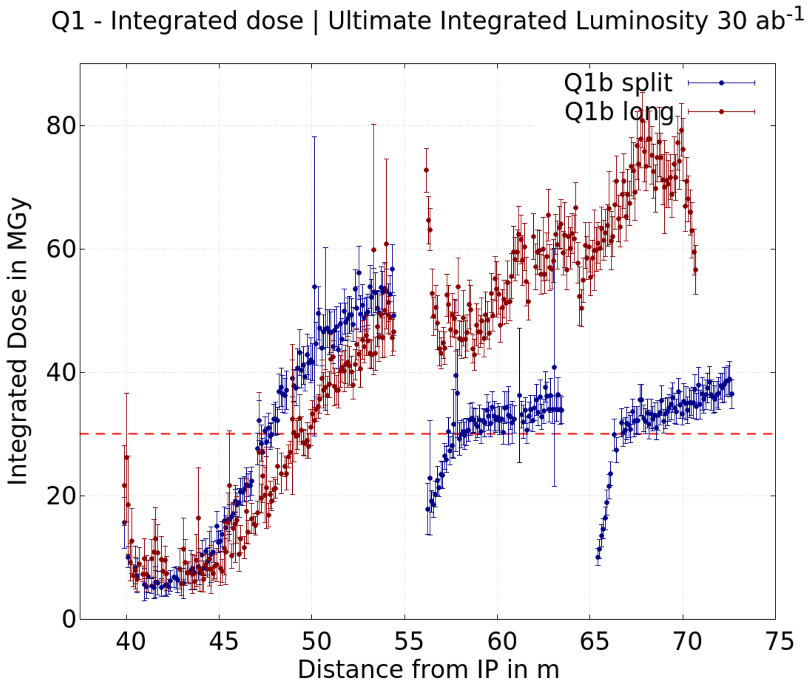

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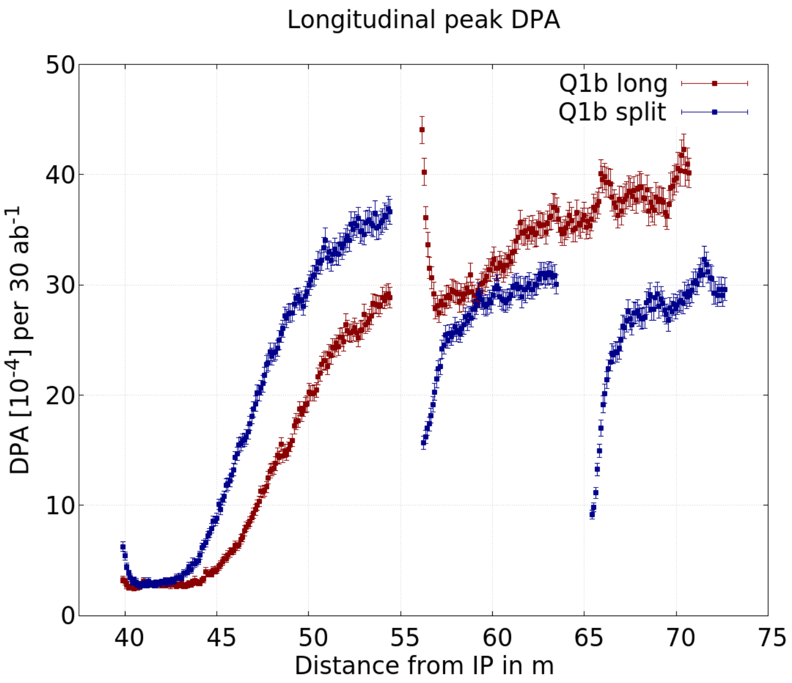
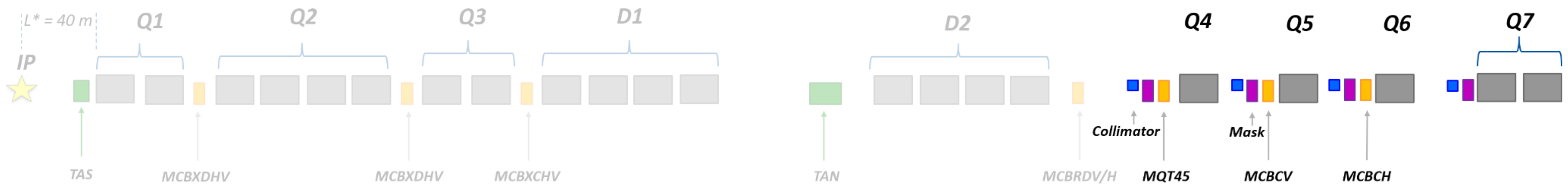


- Higher DPA in Q1a but reduction of DPA in area of former Q1b
- Peak on front face in Q1b in old layout is cured

Note: vertical crossing

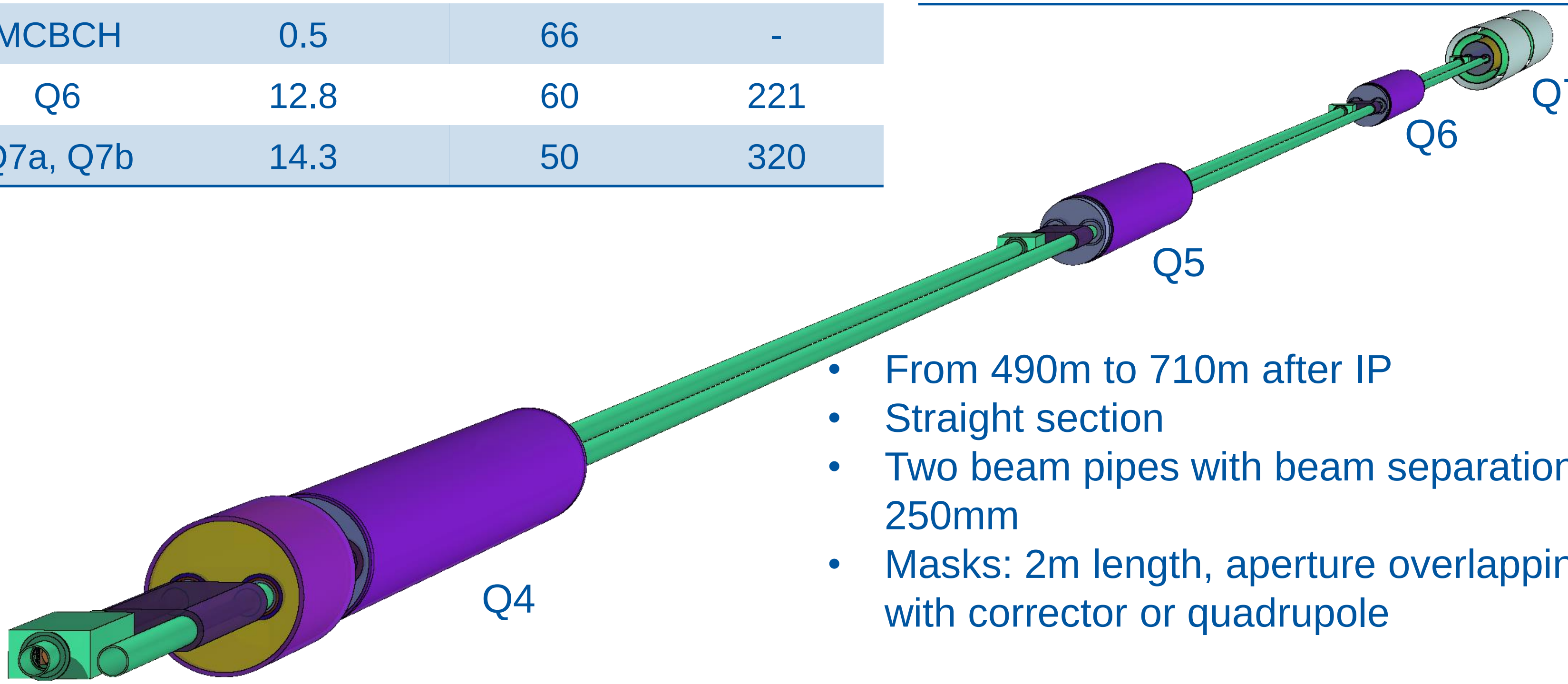
Matching Section



The Geometry – Matching Section

	(Magn.) Length in m	Aperture in mm	Gradient in T/m
MQT45	1.6	76	-
Q4	9.1	70	33
MCBCV	0.5	66	-
Q5	12.8	60	67
MCBCH	0.5	66	-
Q6	12.8	60	221
Q7a, Q7b	14.3	50	320

TCL	Length in m	Halfgap in mm	Sigma
Q4	1.48	8.1	15
Q5	1.48	5.8	15(V)/16(H)
Q6	1.48	1.9	15
Q7	1.48	1.3	30



- From 490m to 710m after IP
- Straight section
- Two beam pipes with beam separation of 250mm
- Masks: 2m length, aperture overlapping with corrector or quadrupole

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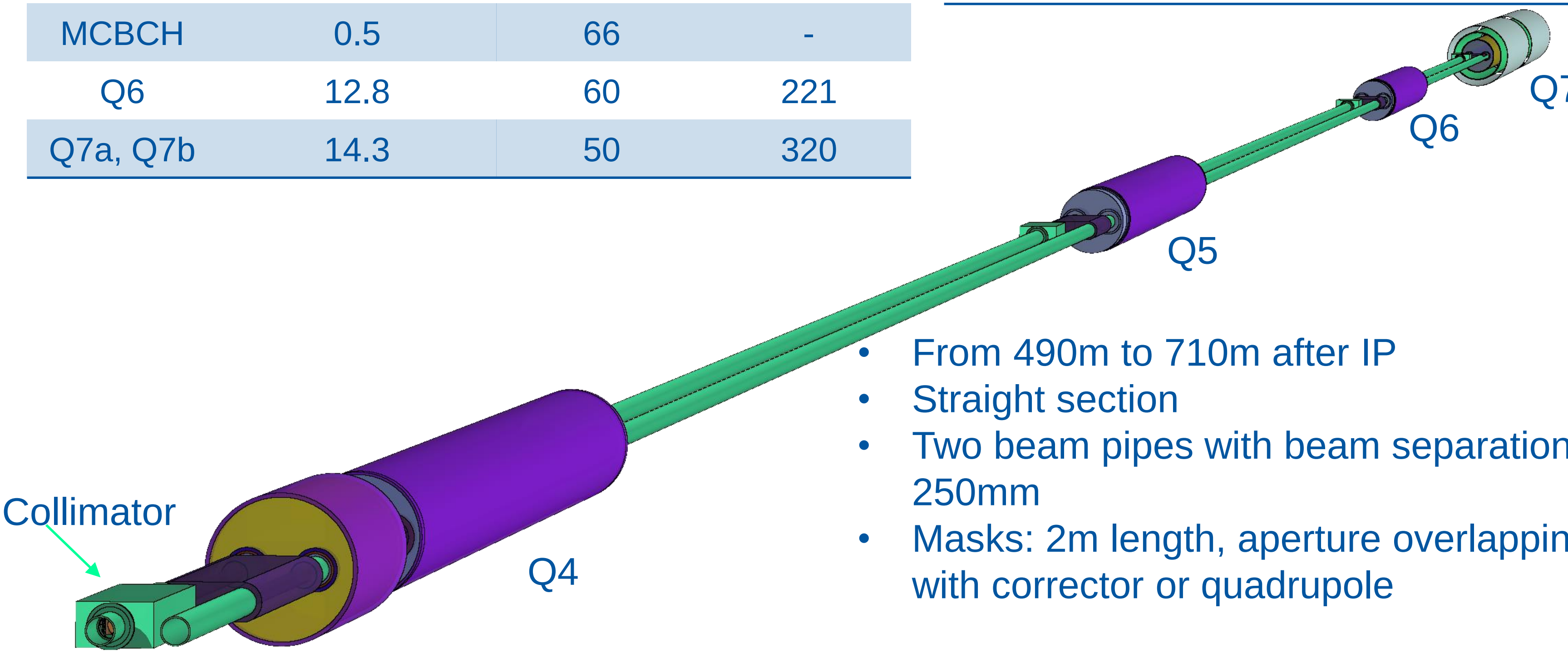

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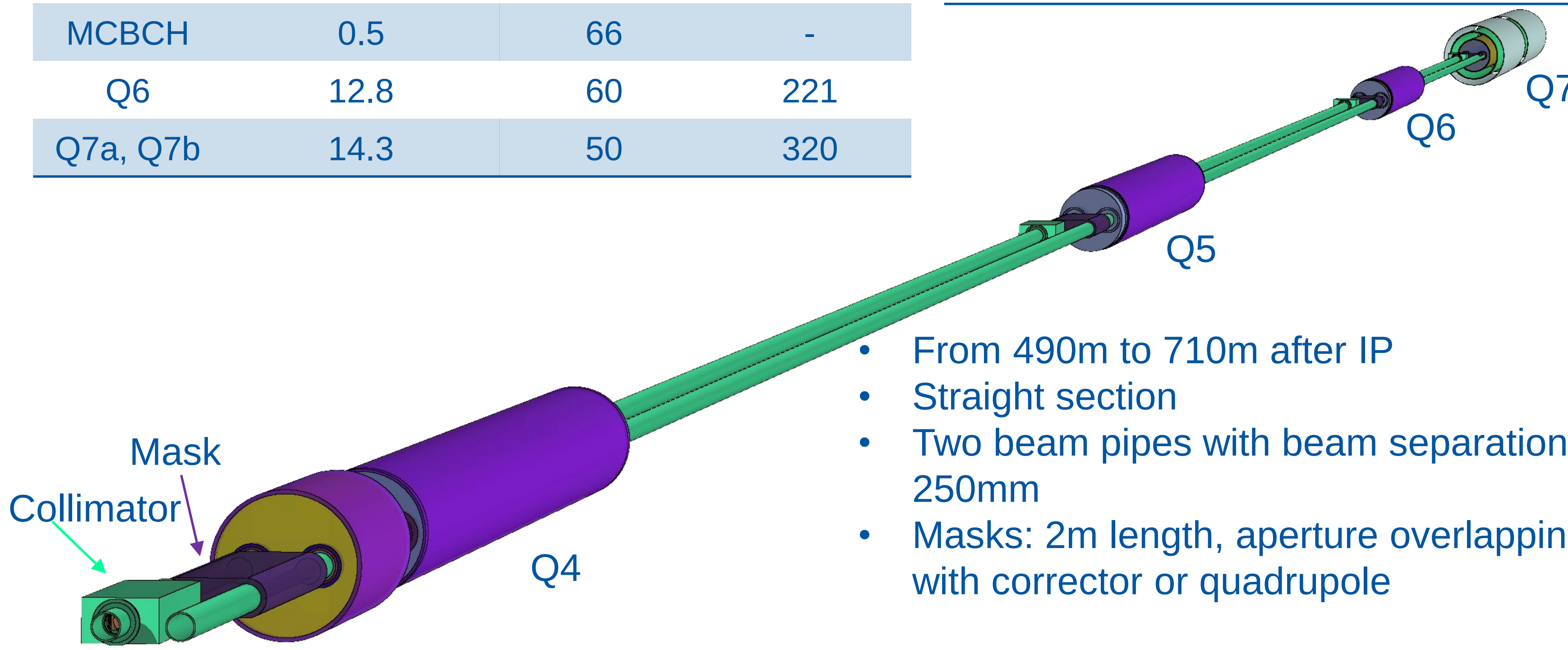

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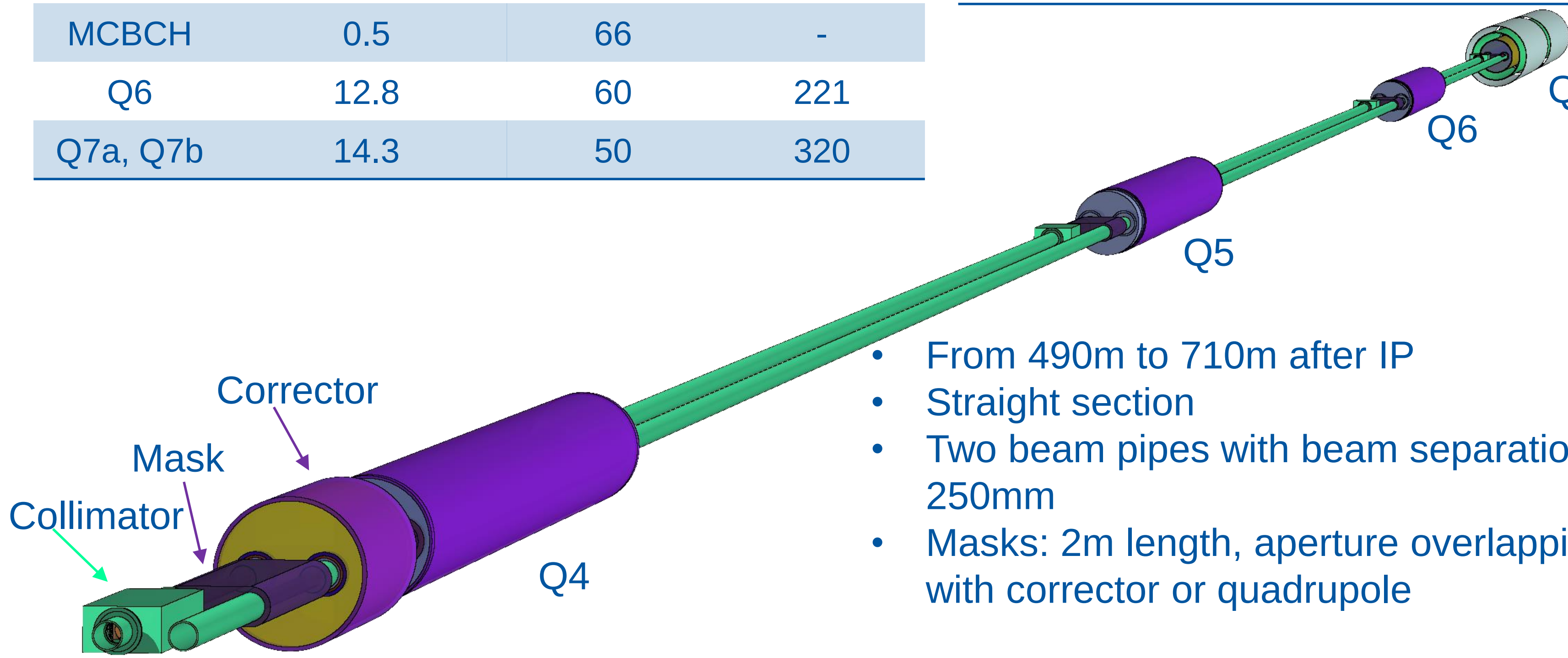

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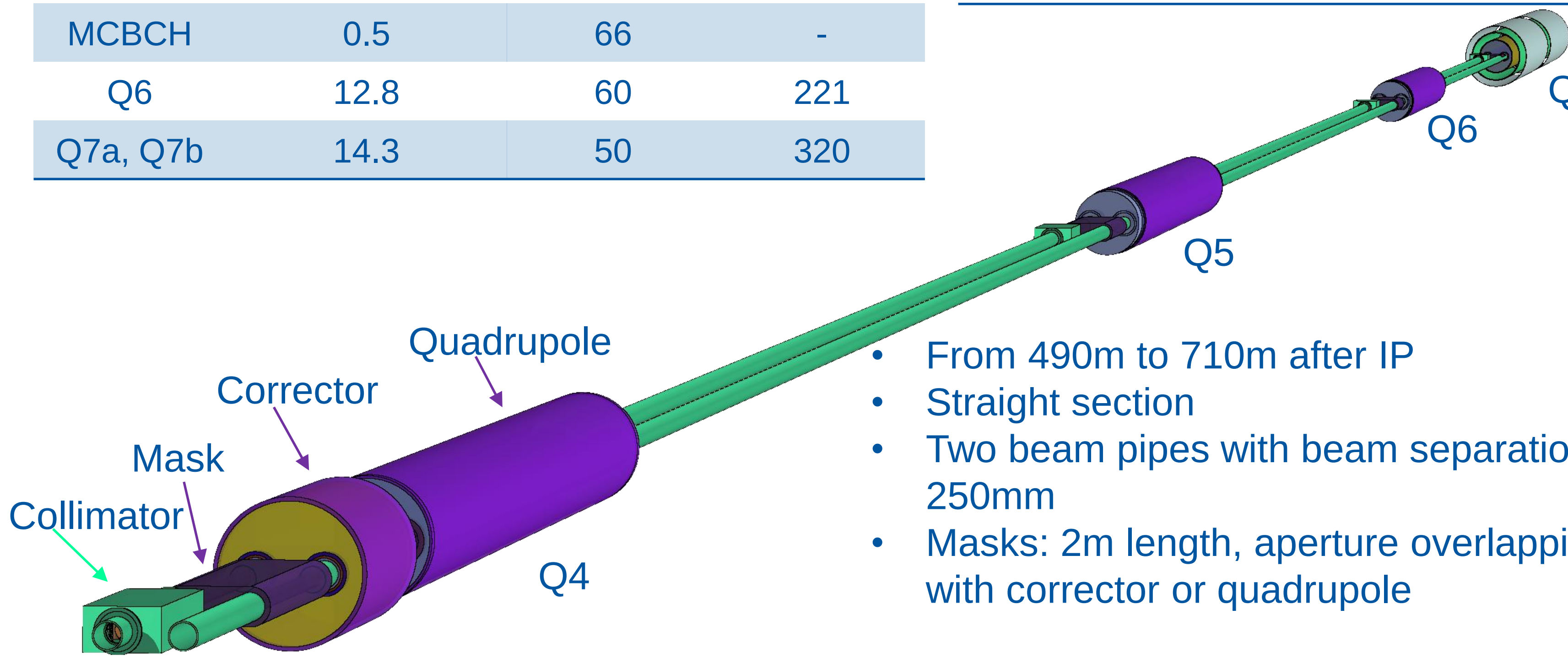

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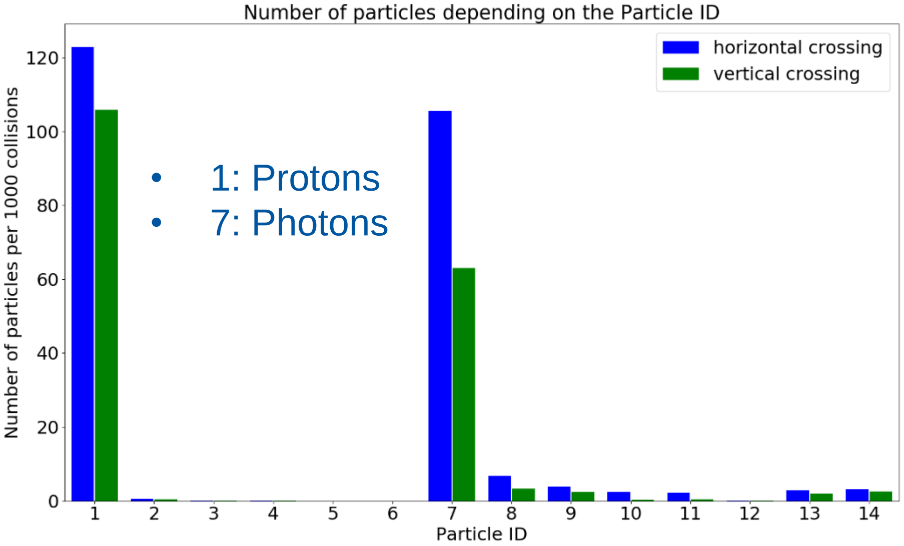
Particle types in the matching section



- Dominated by protons and photons
- More particles with horizontal crossing – TAN is more effective for vertical crossing

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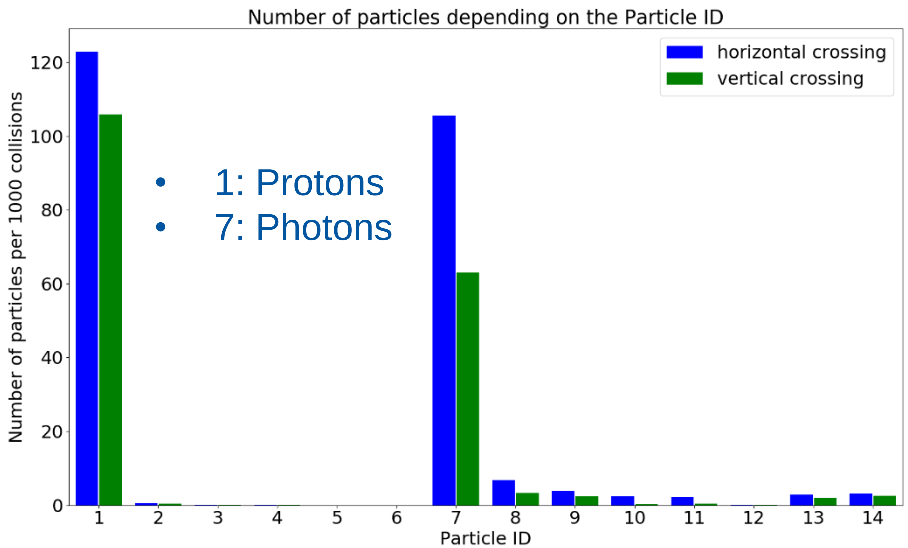

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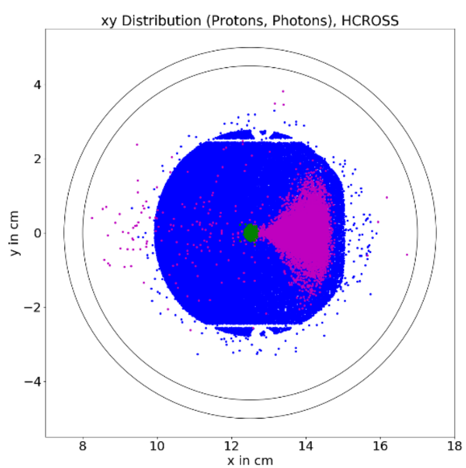
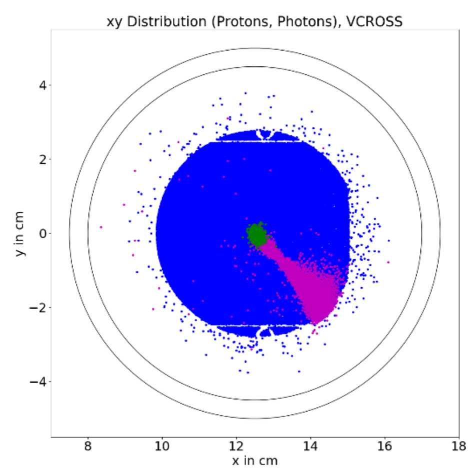




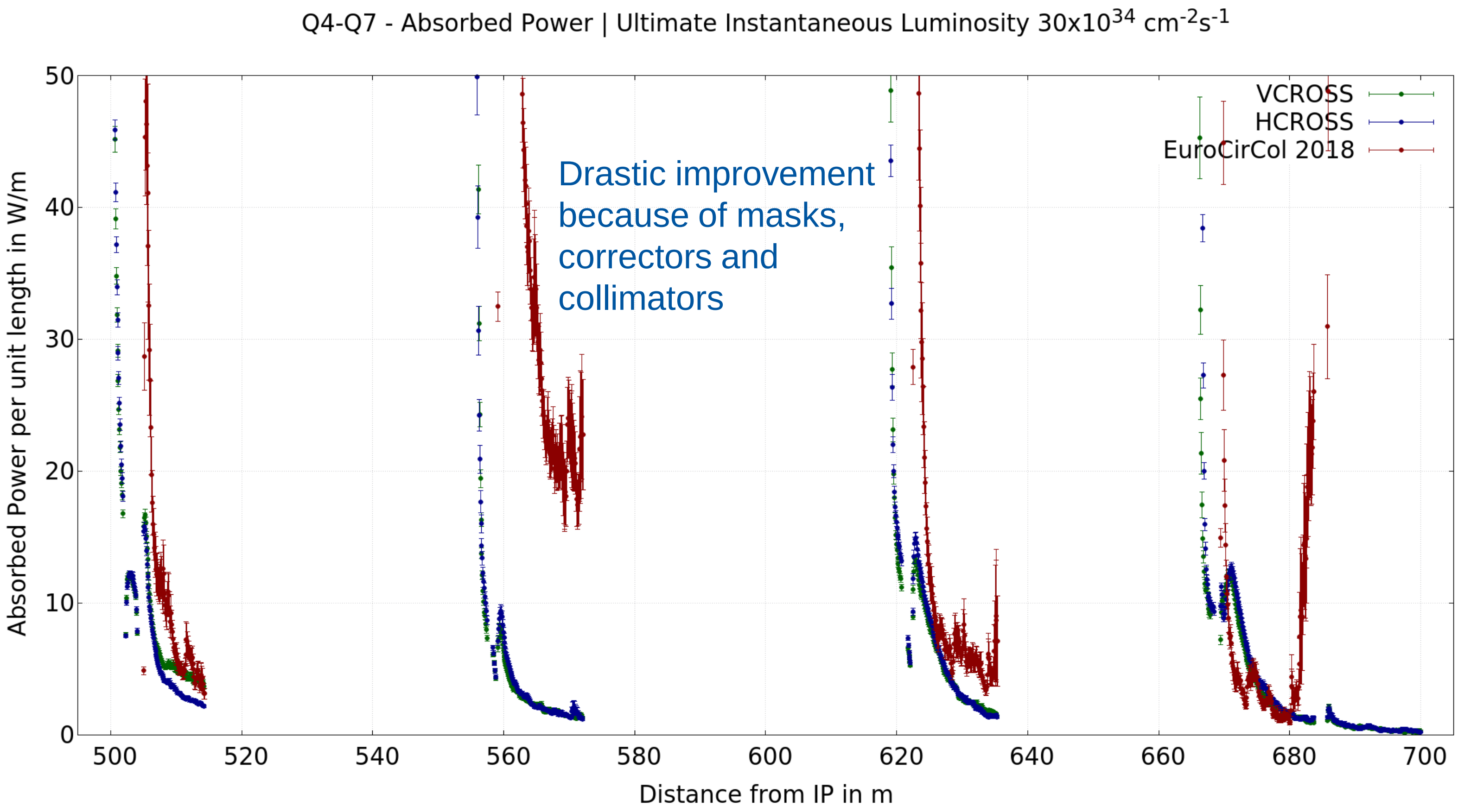
Protons within $\delta_p < 1\%$ (green):

- Vertical Crossing: 66%
- Horizontal Crossing: 57%

with $\delta_p = \frac{|p - p_0|}{p_0}$

● Photons
● Low energy protons
● High energy protons

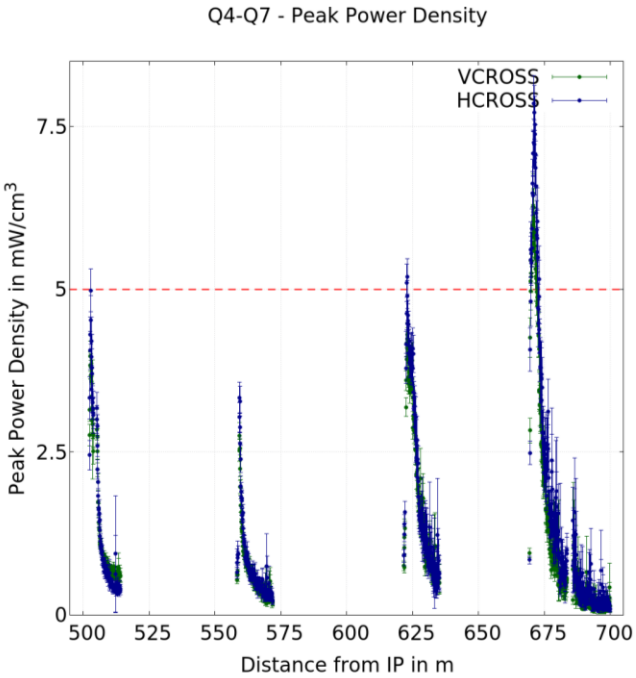
Absorbed Power



Most impacted: collimators (~1-2kW) and masks (~60-100W), but warm. Cold quadrupoles and correctors are in a range up to ~75W absorbed power.

2kW more absorbed in horizontal case – difference mainly in collimators

Peak Power Density & Integrated Dose



- Peak power density mostly below 5mW/cm^3, except in Q7a (not higher than 8mW/cm^3)
- Peak always at front face of the magnets

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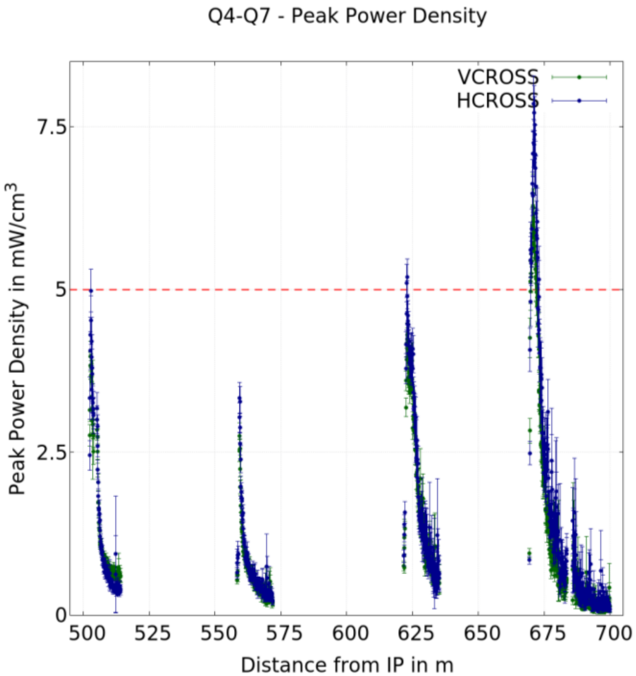

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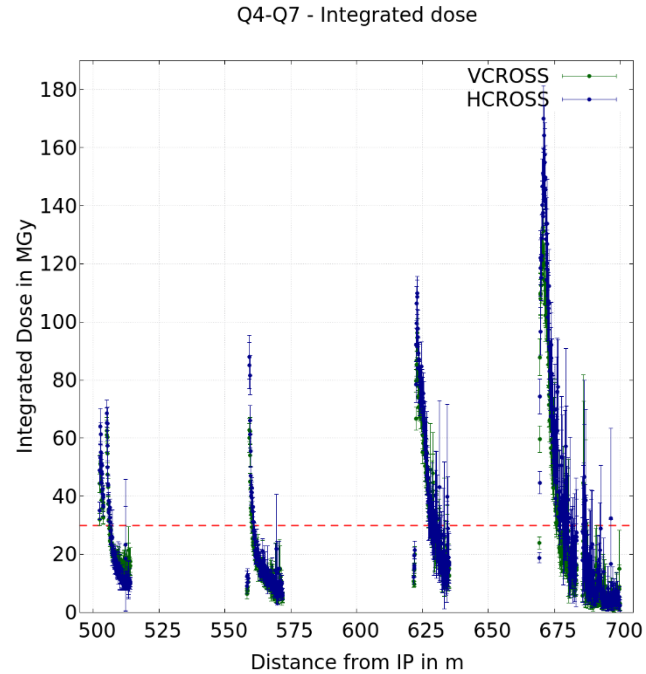


- Limit of 30MGy always exceeded
- Shift of critical value, due to change of insulator material?
- Further split of Q7 to reduce integrated dose? Shieling in Q7?

Critical situation in Q7: change half gap or position of collimator

Conclusion

- Complete study of the triplet and matching section
  - Horizontal and vertical crossing angle scheme
  - Absorbed power, peak power density, integrated dose, DPA
  - Mitigation strategies: combination of crossing schemes (polarity, plane), split of Q1b

- Next steps:
  - Energy deposition studies on the dispersion suppressor
  - Simulation of the incoming beam

Backup Slides

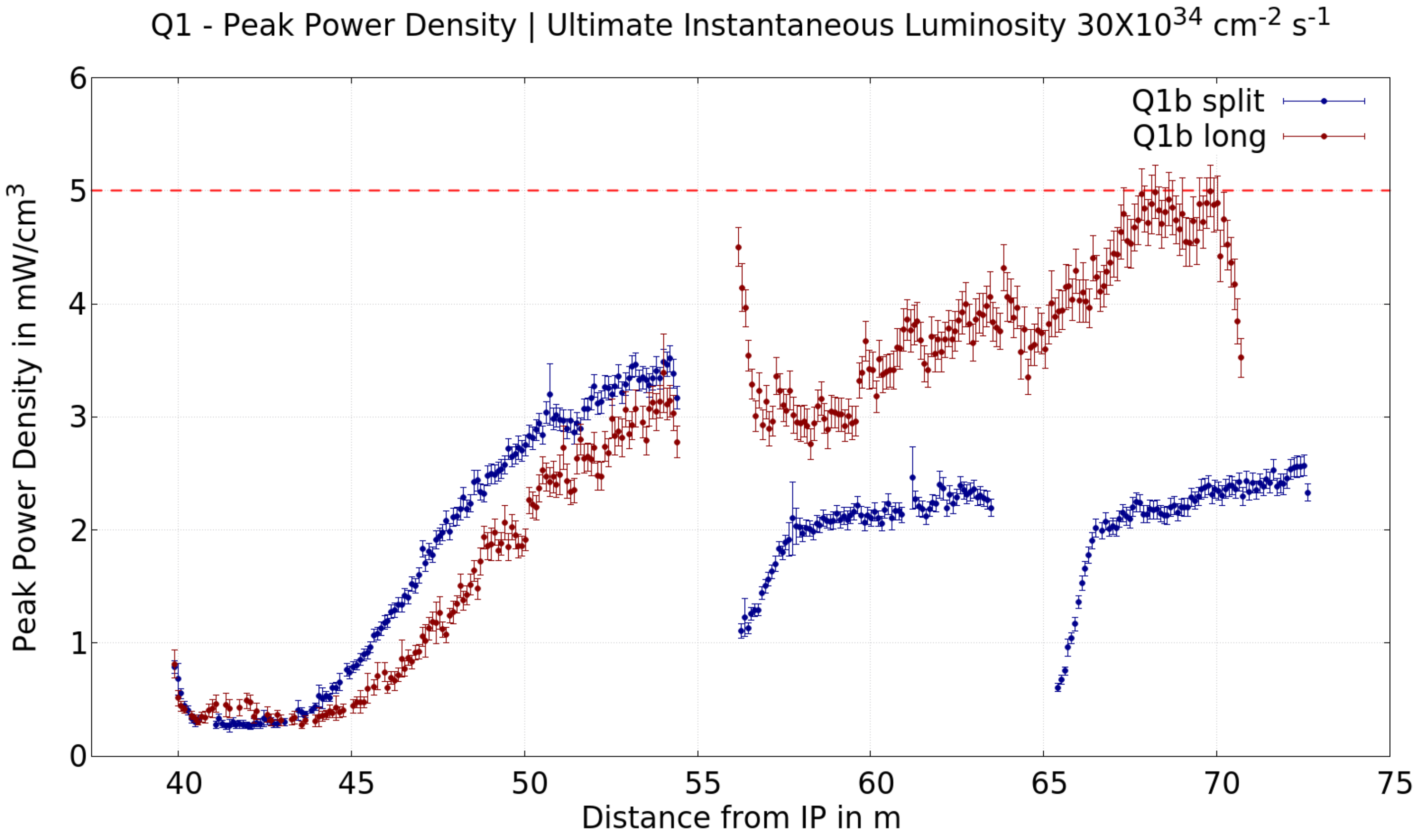
Horizontal vs Vertical Crossing: Total Power (i)

In kW	Horizontal Crossing (APR19)			Vertical Crossing (SEP18)		
Element	Cold Shielding	Cold Mass	Warm Mass	Cold Shielding	Cold Mass	Warm Mass
TAS			26.8 (±0.4%)			26.5 (±0.9%)
Q1a	4.6 (±0.4%)	0.7 (±0.3%)		4.6 (±1.1%)	0.78 (±1.2%)	
Q1b	12.3 (±0.4%)	1.69 (±0.3%)		13 (±1.0%)	1.92 (±0.8%)	
C1	0.06 (±1.7%)	0.058 (±1.0%)		0.06 (±4.5%)	0.06 (±2.5%)	
Q2a	1.47 (±1.2%)	0.2 (±0.9%)		1.53 (±3.2%)	0.32 (±2.7%)	
Q2b	0.91 (±1.5%)	0.11 (±1.1%)		0.7 (±4.2%)	0.09 (±3.1%)	
Q2c	6.3 (±0.7%)	0.83 (±0.5%)		4.6 (±2.1%)	0.63 (±1.5%)	
Q2d	7.64 (±0.8%)	0.974 (±0.6%)		5.93 (±2.3%)	0.81 (±1.7%)	
C2	0.714 (±2.0%)	0.076 (±2.2%)		0.51 (±5.1%)	0.05 (±4.5%)	
Q3a	5.07 (±0.9%)	0.632 (±0.7%)		6.02 (±2.2%)	0.77 (±1.6%)	
Q3b	3.97 (±1.1%)	0.41 (±0.9%)		7.8 (±2.3%)	0.95 (±1.7%)	
C3	0.43 (±2.5)	0.04 (±2.2%)		0.94 (±4.5%)	0.17 (±3.8%)	

Horizontal vs Vertical Crossing: Total Power (ii)

In kW	Horizontal Crossing (APR19)	Vertical Crossing (SEP18)
Element	Warm Mass	Warm Mass
D1a	2.0 (±0.9%)	4.99 (±1.7%)
D1b	2.1 (±1.0%)	3.57 (±2.0%)
D1c	2.7 (±0.9%)	3.57 (±2.1%)
D1d	3.8 (±0.7%)	3.96 (±2.1%)
TAXN	110 (±0.2%)	107 (±0.6%)
D2a	0.138 (±2.1%)	0.07 (±10.7%)
D2b	0.064 (±3.2%)	0.01 (±18.5%)
D2c	0.052 (±5.0%)	0.003 (±13.9%)
D2d	0.026 (±6.0%)	0.003 (±14.5%)

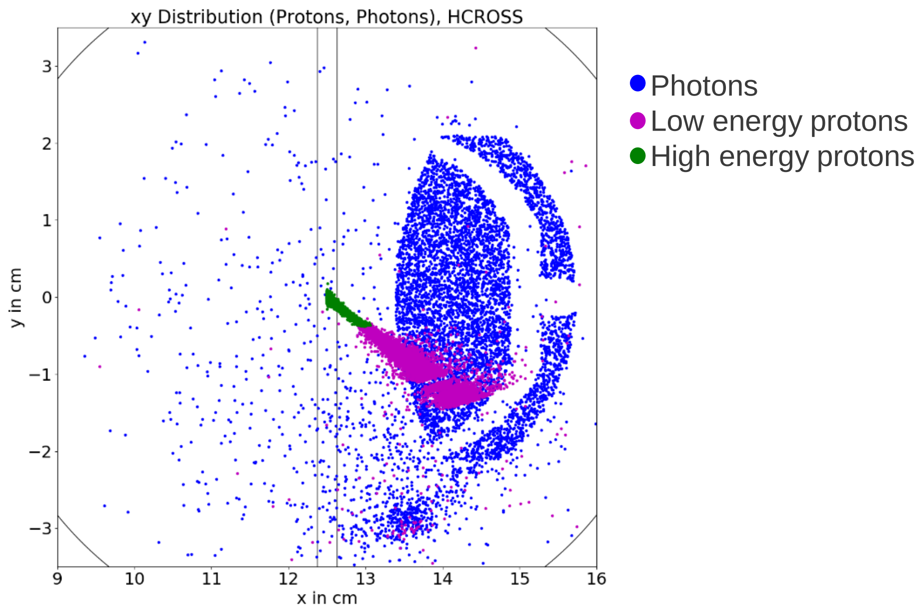
Mitigation Strategy: Peak Power Density

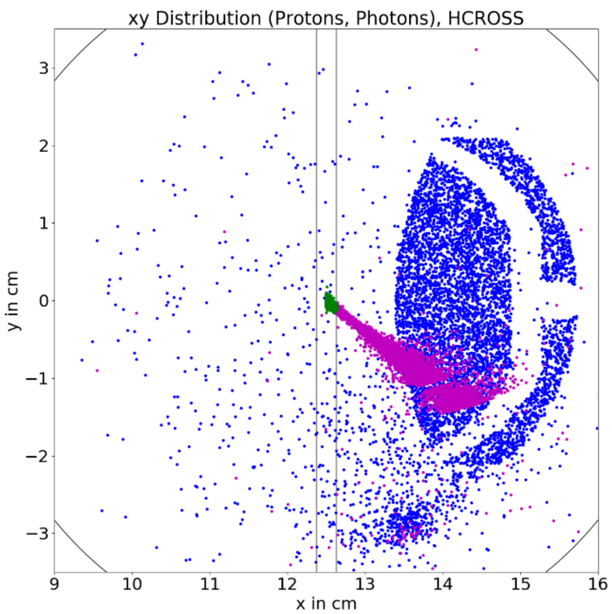


Absorbed Power Matching Section

In kW	Vertical Crossing (8kW deposited)		Horizontal Crossing (10kW deposited)	
Element	Cold M	Beam Interc Dev	Cold M	Beam Interc Dev
Coll Q4		2.89 (±1.0%)		4.62 (±0.9%)
Mask Q4		0.15 (±1.5%)		0.15 (±1.4%)
MQT45	0.019 (±0.7%)		0.02 (±0.8%)	
Q4	0.057 (±0.8%)		0.045 (±0.7%)	
Coll. Q5		1.02 (±1.7%)		1.1 (±2.0%)
Mask Q5		0.16 (±1.8%)		0.11 (±2.5%)
MCBCH	0.002 (±%1.3)		0.002 (±1.6%)	
Q5	0.035 (±0.9%)		0.038 (±1.2%)	
Coll. Q6		1.89 (±1.2%)		2.2 (±1.5%)
Mask Q6		0.087 (±2.3%)		0.074 (±1.8%)
MCBCV	0.003 (±%1.0)		0.003 (±1.3%)	
Q6	0.064 (±%0.7)		0.067 (±0.9%)	
Coll Q7		1.17 (±1.7%)		1.33 (±1.9%)
Mask Q7		0.062 (±2.5%)		0.048 (±2.2%)
Q7A	0.063 (±%1.1)		0.069 (±1.2%)	
Q7B	0.007 (±2.4%)		0.008 (±2.9%)	

Q7 – Particle analysis





- δ_p = 3% (48.5 TeV)
- 82% of all protons are in this range
- Halfgap should be opened to 1 cm (equals 224σ)

- δ_p = 0.8% (49.6 TeV)
- 70% of all protons are in this range
- Halfgap at 1.3 mm (equals 30σ)