# DUAL-SCATTERING FOILS FOR CONFORMAL VHEE RADIOTHERAPY

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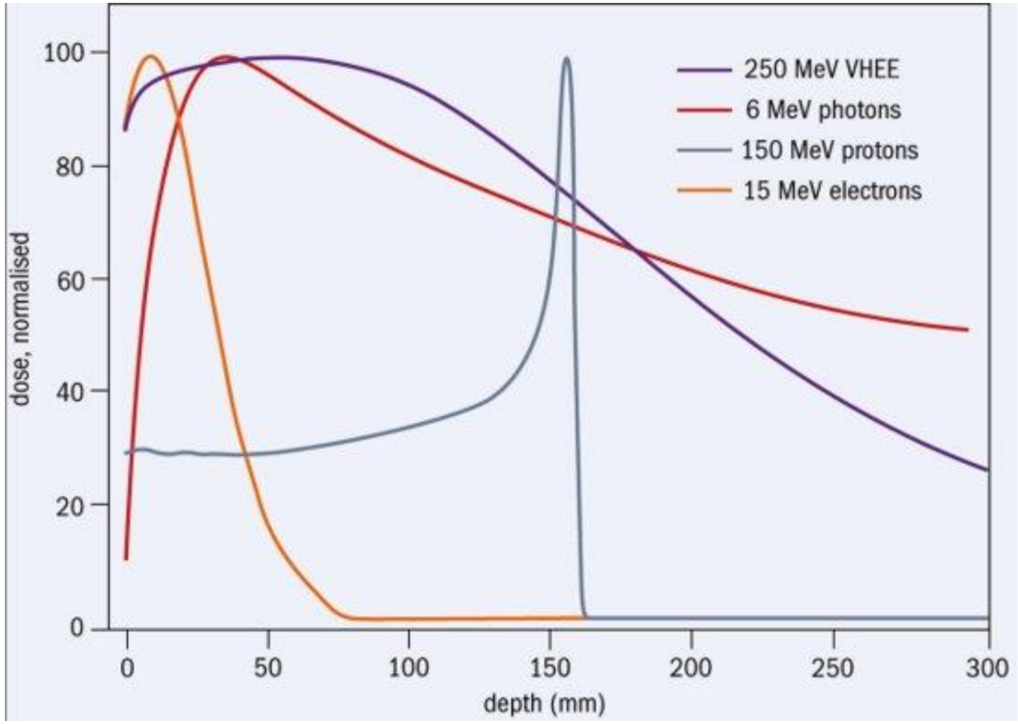
# VHEE RADIOTHERAPY

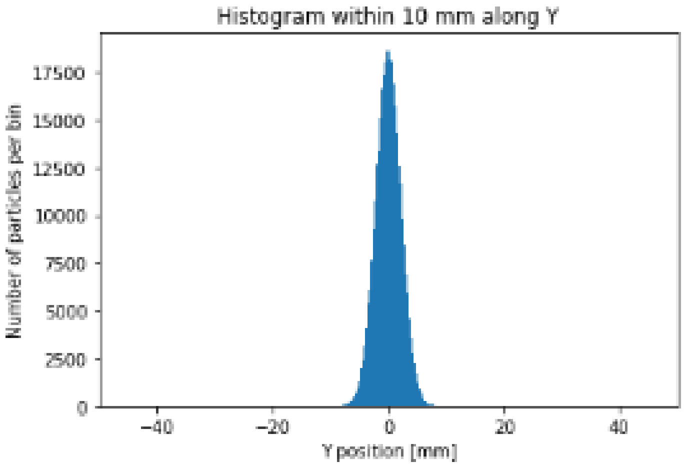
- Very High Energy Electron (VHEE) Therapy – treatment with electrons above clinically available range
  - Capable of reaching deep seated tumours
- Encouraging **simulated evidence** for desirable characteristics
- **Lower magnetic rigidity** than heavy ions for treatment
- Promising modality for the FLASH effect (tissue sparing at Ultra-High Dose Rates)



# CONFORMAL TREATMENT FOR UHDR/FLASH

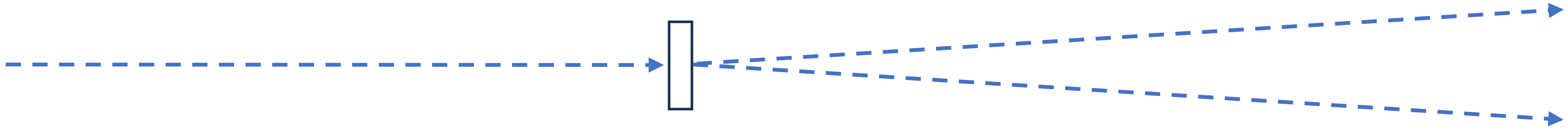
- **Conformality –** targeting and/or shaping beam to maximise dose to tumour whilst minimising dose to healthy tissue
- **Scanning** typically utilised for tumour conformality in particle therapy
  - Dipole used to conform to tumour with small pencil beam
- FLASH requires dose delivery in <0.1s
  - **Very fast,** accurate magnets required for scanning treatment in <0.1s
- **Much uncertainty** in the parameters of the FLASH effect
  - Can the treatment be given in several <0.1s fractions?
- Alternatives to scanning should be studied

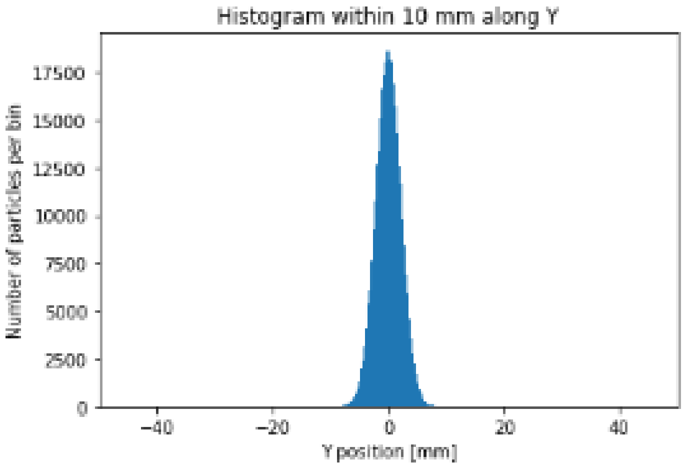
# Dual Scattering Foil

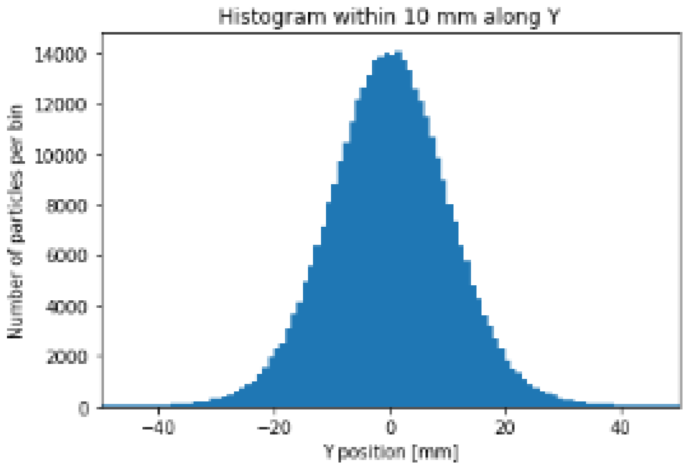


# Dual Scattering Foil

- Insert flat scatterer into beam path to magnify

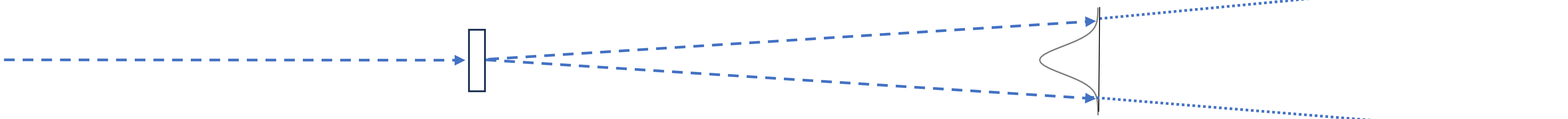


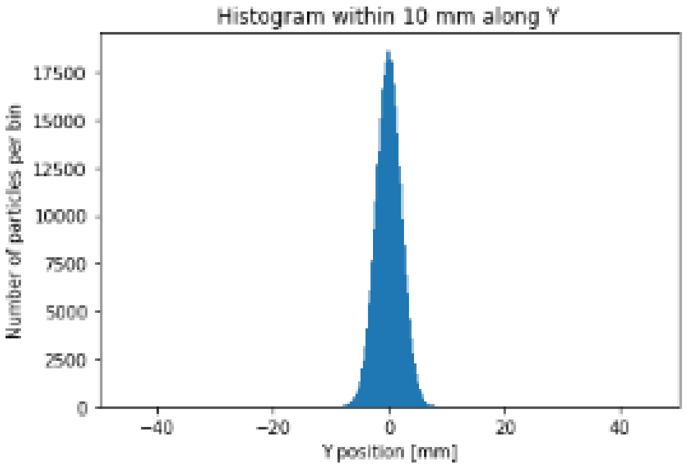


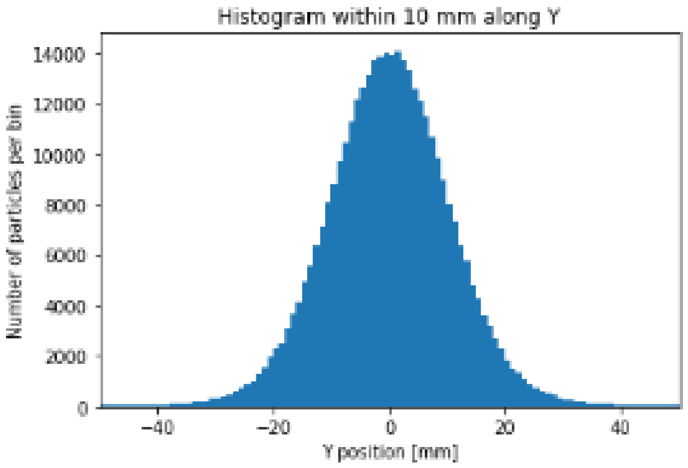



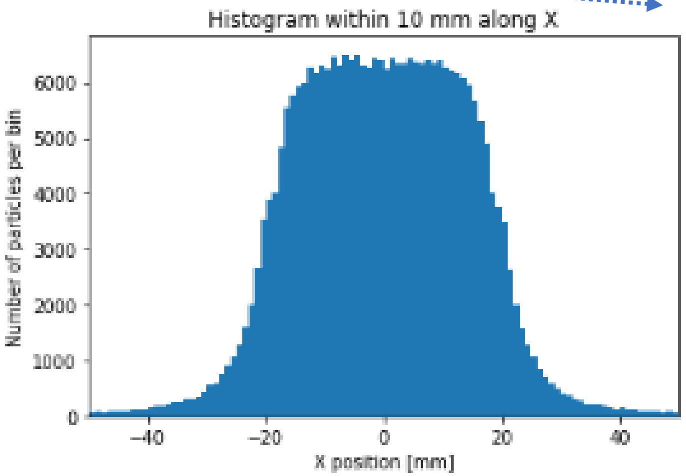
# Dual Scattering Foil

- Insert flat scatterer into beam path to magnify
- Insert second, Gaussian shaped scatterer to flatten beam



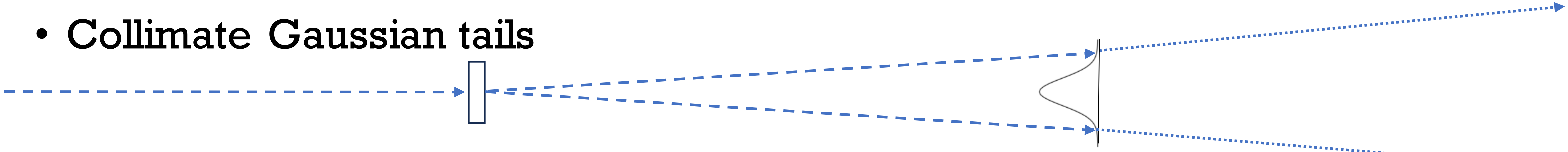


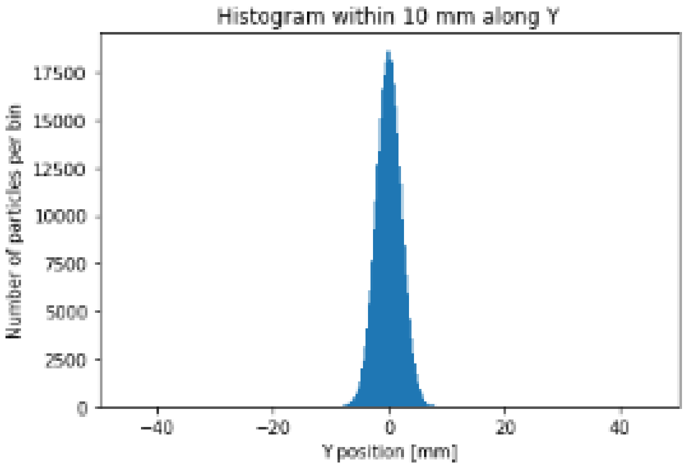



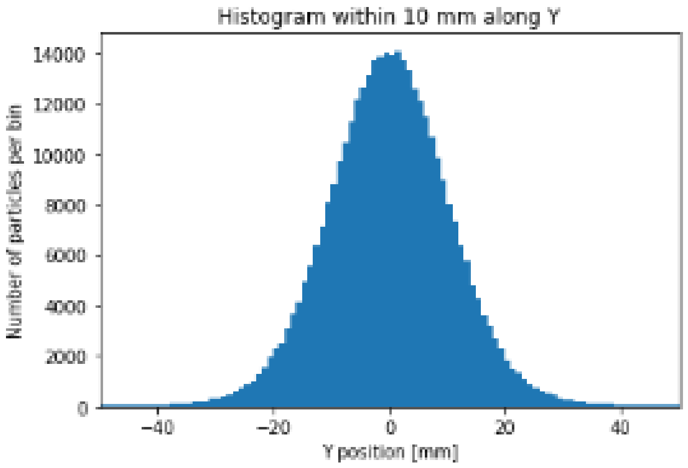



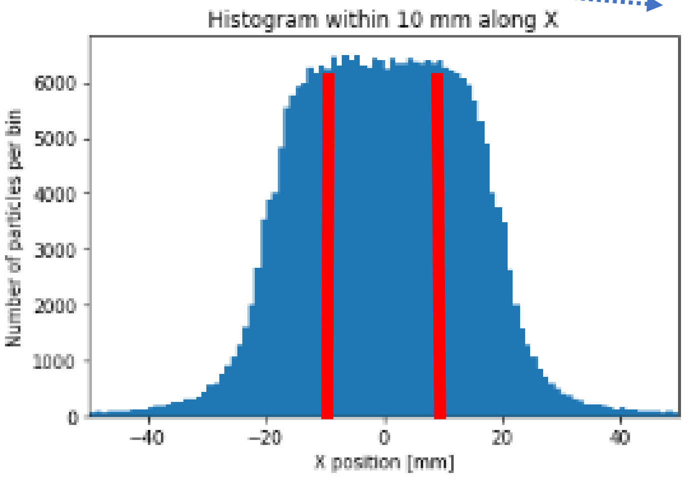
# Dual Scattering Foil

- Insert flat scatterer into beam path to magnify
- Insert second, Gaussian shaped scatterer to flatten beam
- Collimate Gaussian tails

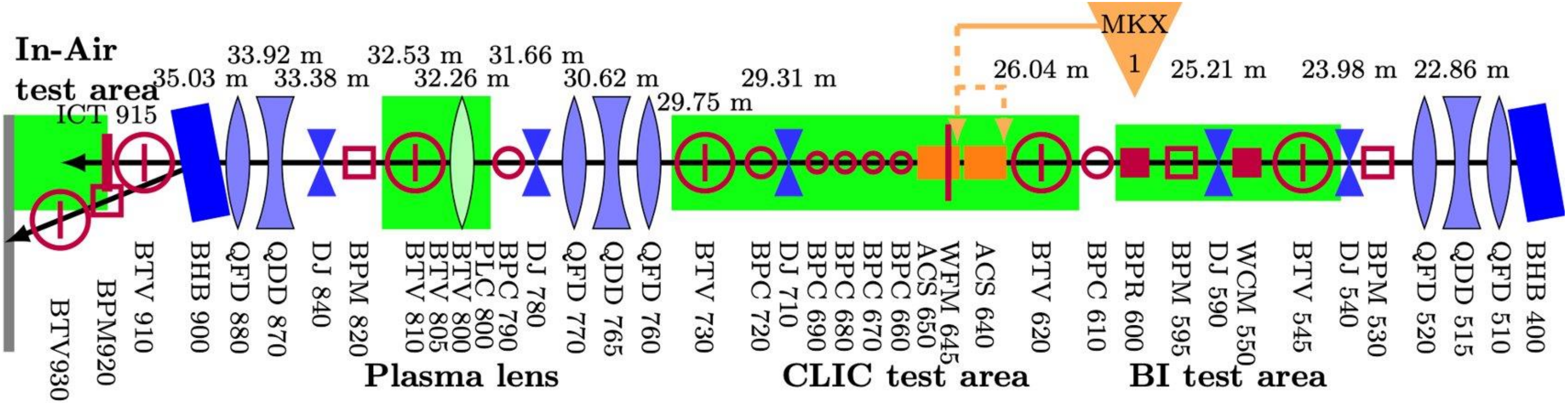




# PRELIMINARY SCATTERING EXPERIMENTS AT CLEAR



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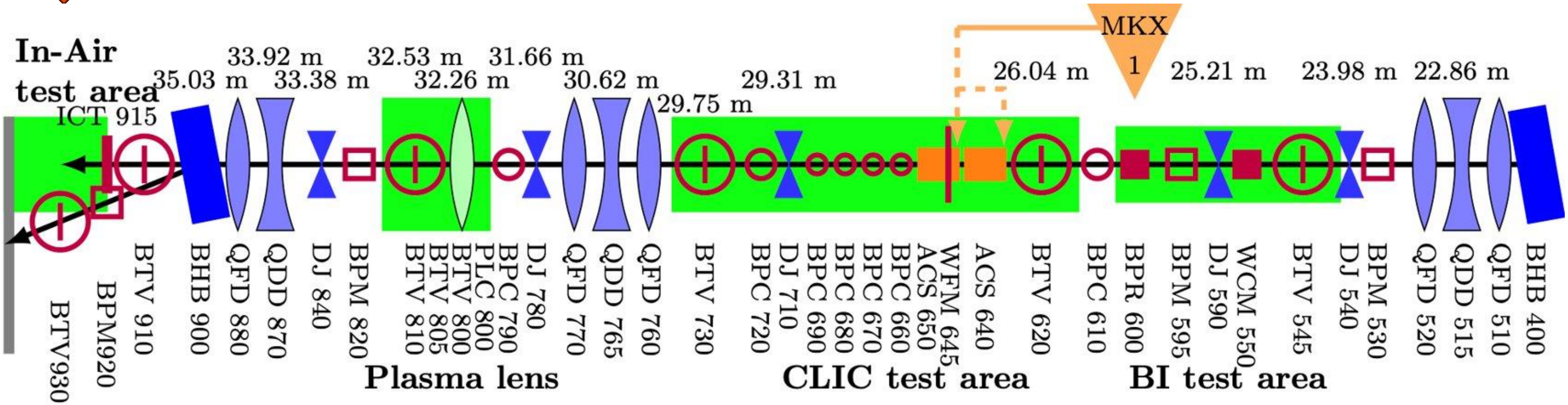
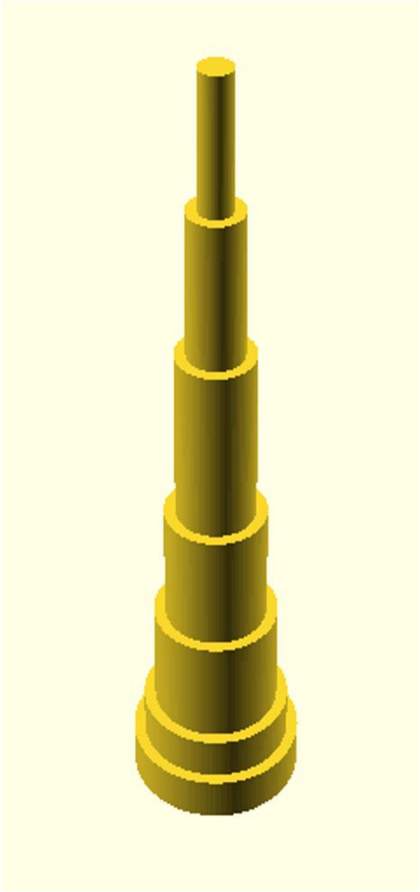


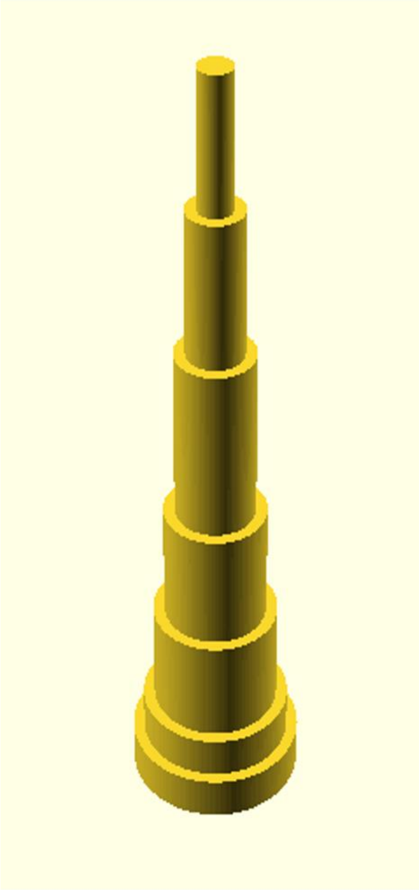
# V1: THE 'BURJ KHALIFA'

- Aim to produce **large beam** with uniform component up to 20mm
- Limited space in CLEAR in-air test stand
- 3D printed scatterers – low Z PLA

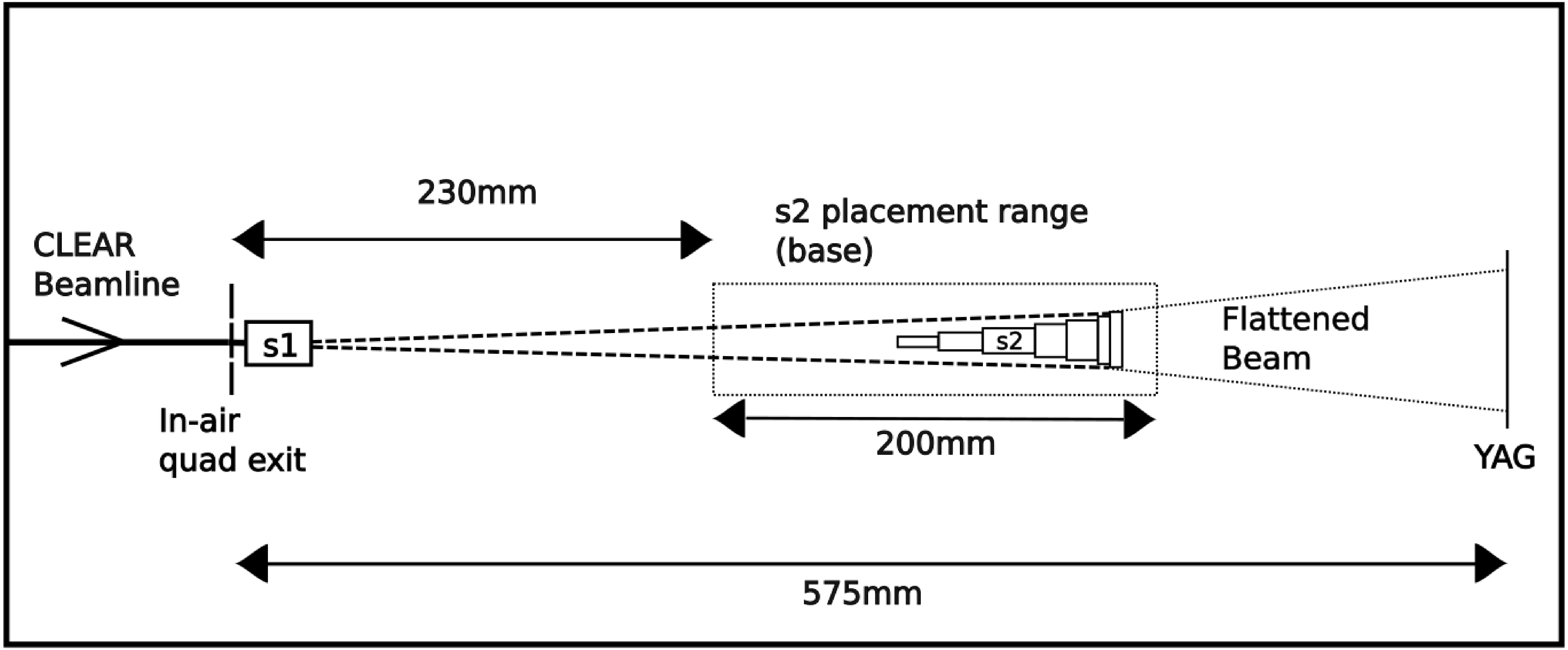


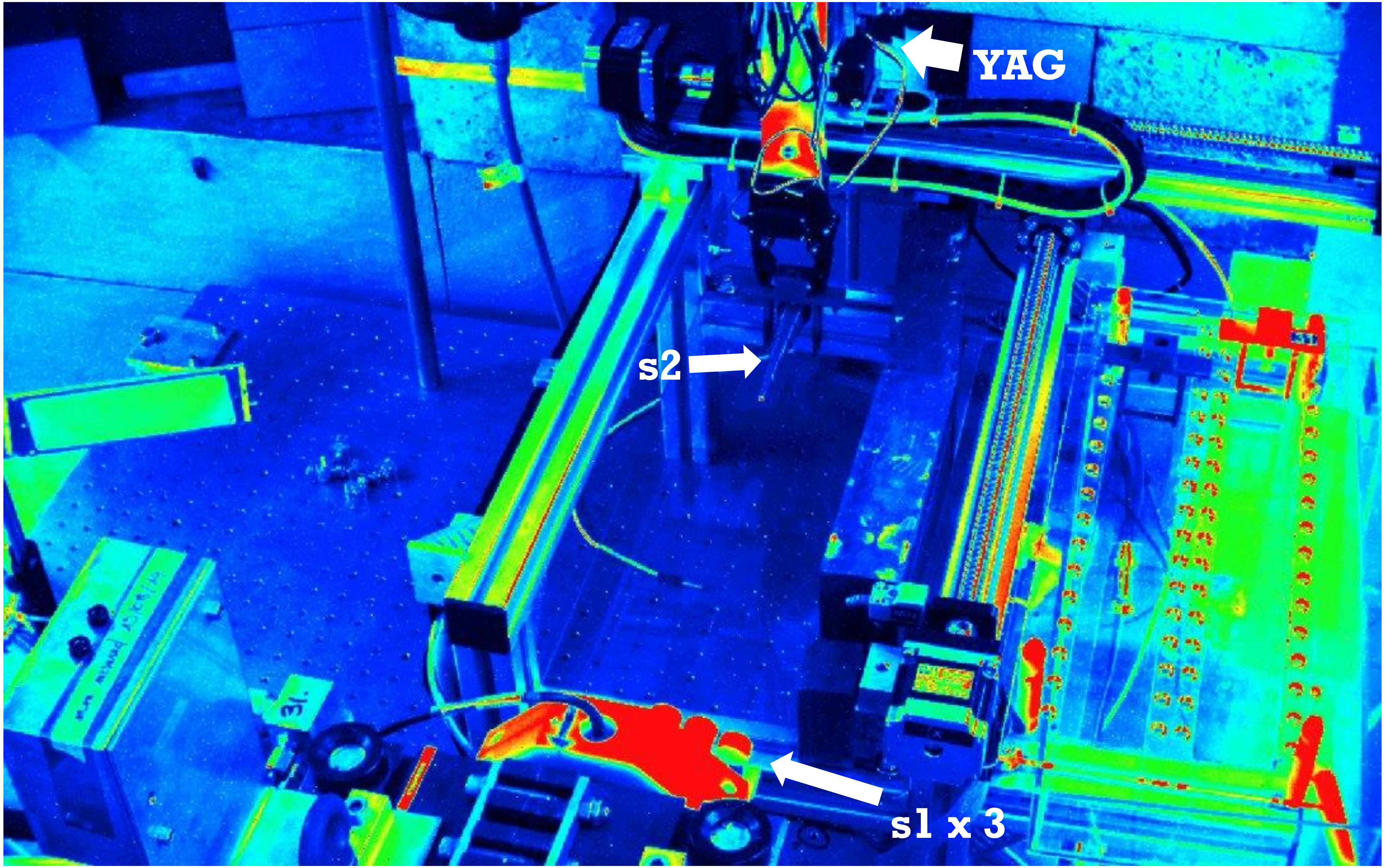
# V1: THE 'BURJ KHALIFA'

- Aim to produce **large beam** with uniform component up to 20mm
- Limited space in CLEAR in-air test stand
- 3D printed scatterers – low Z
- Second scatterer mounted on holder and held by CLEAR C-Robot



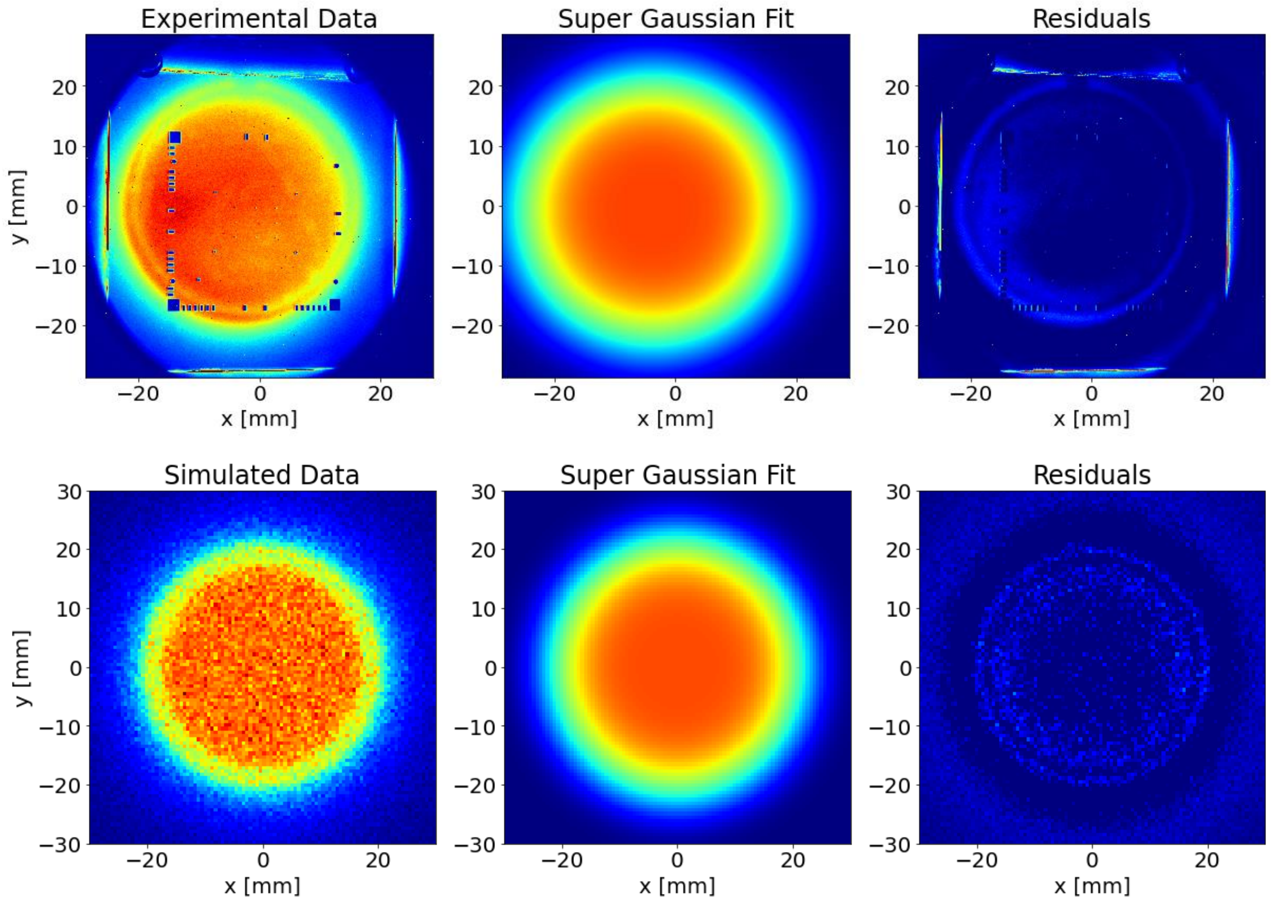
# V1 EXPERIMENTAL LAYOUT




YAG
s2
s1 x 3

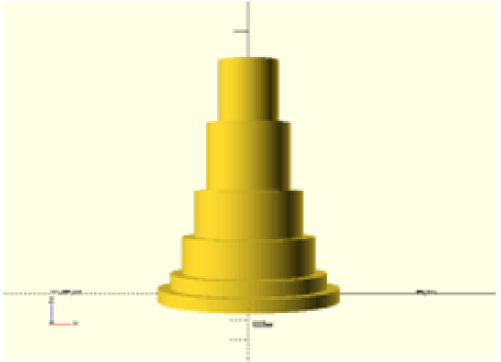
# V1 SUMMARY OF RESULTS

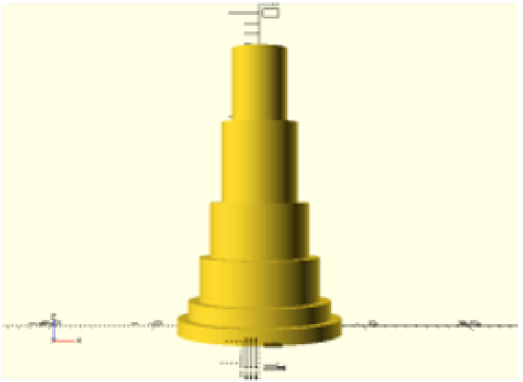
- **Excellent uniformity** and agreement with simulation
- Super-Gaussian used for fitting
  - Flat topped Gaussian
- Various positions and s1 thicknesses used to obtain further profiles for comparison

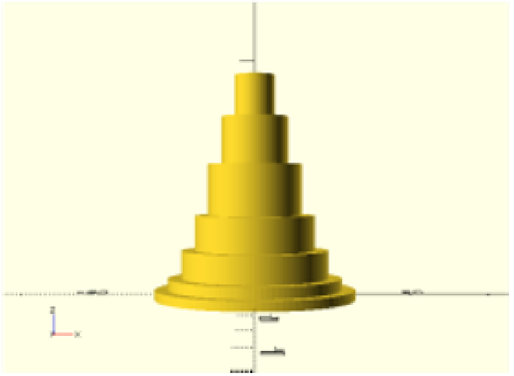


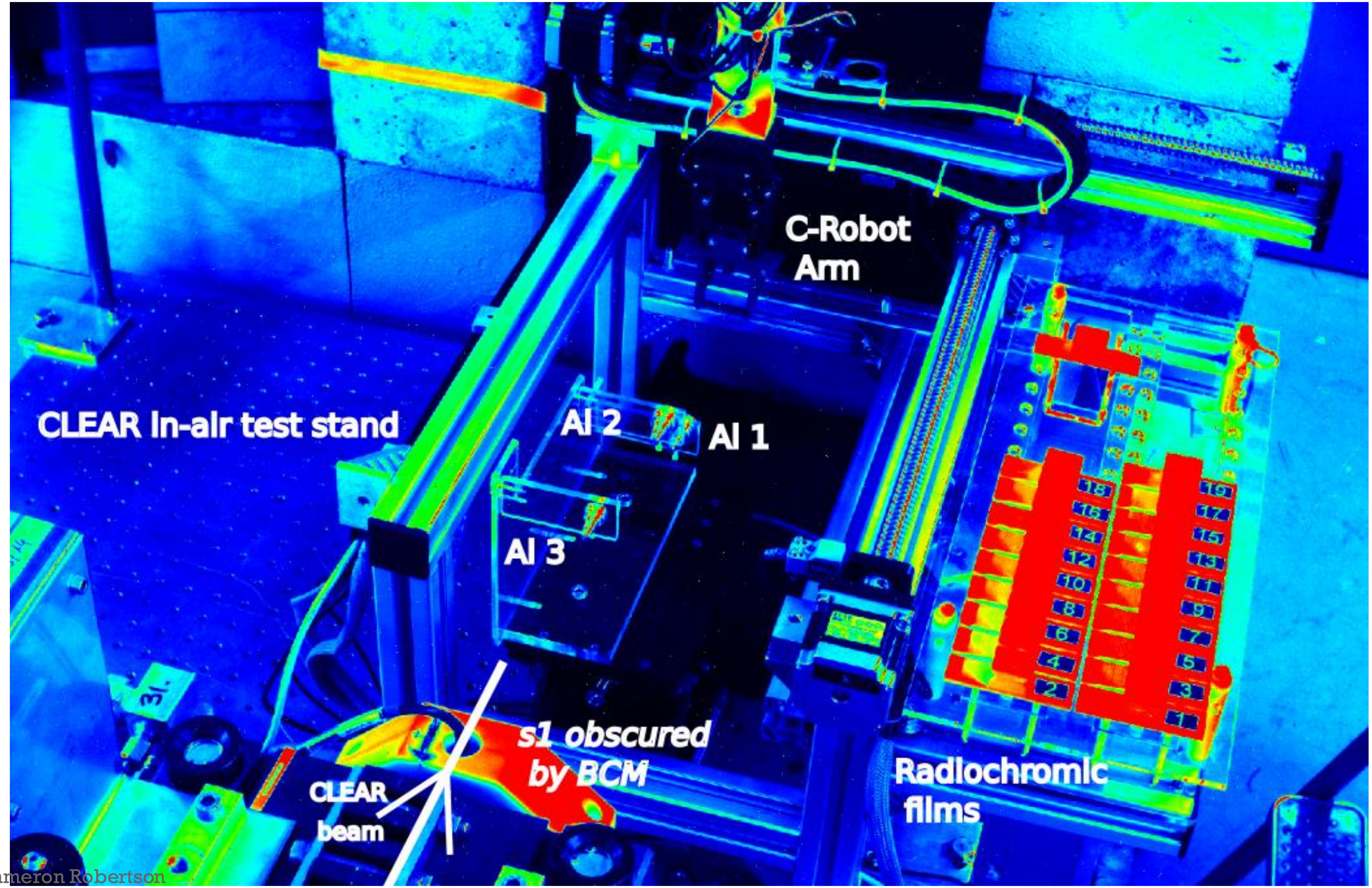
# V2

- Film (dose) measurements desired
- Scatterers in **Aluminium** designed and machined to preserve space
  - Separate designs for different beam sizes and s1 thicknesses
- Mounted on linear stage, C-Robot used to hold EBT-3 films

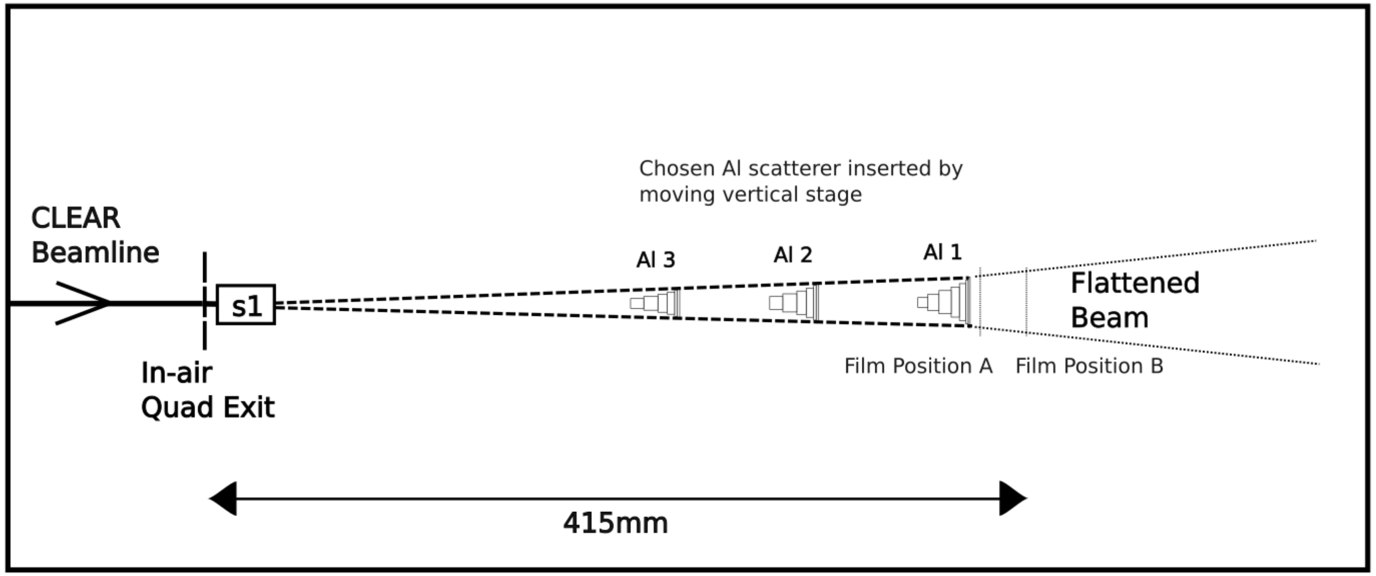






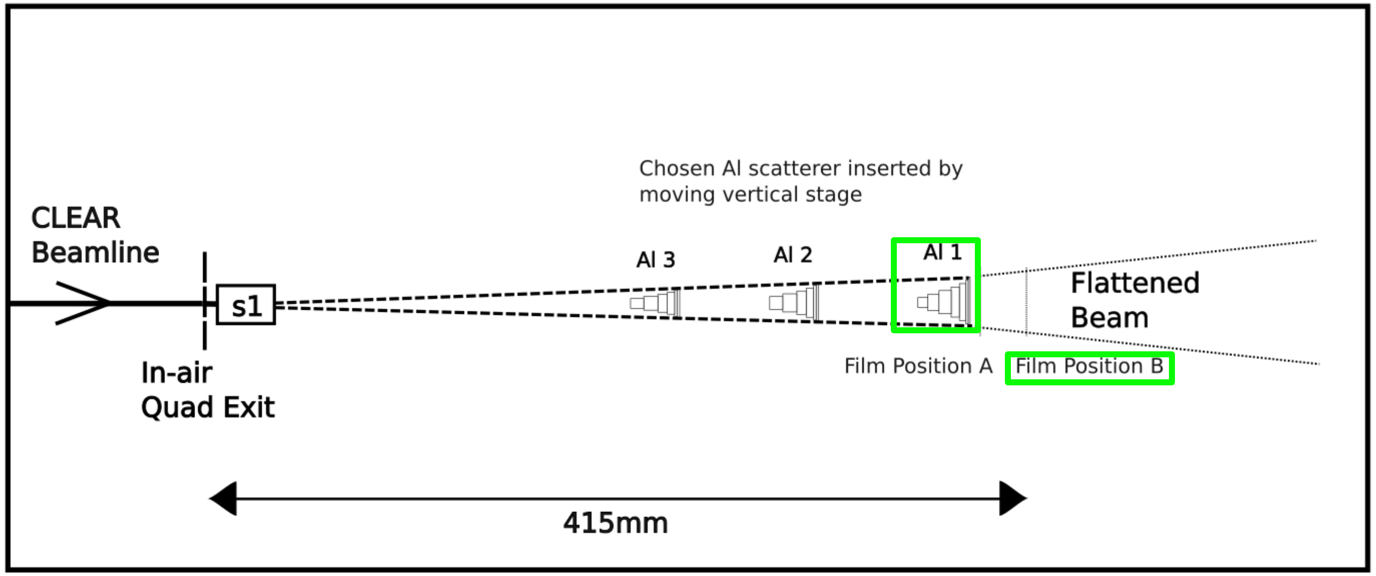

C-Robot
Arm
CLEAR in-air test stand
Al 2
Al 1
Al 3
s1 obscured
by BCM
CLEAR
beam
Radiochromic
films
18
19
16
17
14
15
12
13
10
11
8
9
6
7
4
5
2
3
1

# V2 RESULTS



Chosen Al scatterer inserted by moving vertical stage
CLEAR Beamline
Al 3
Al 2
Al 1
s1
Flattened Beam
In-air Quad Exit
Film Position A
Film Position B
415mm

# V2 RESULTS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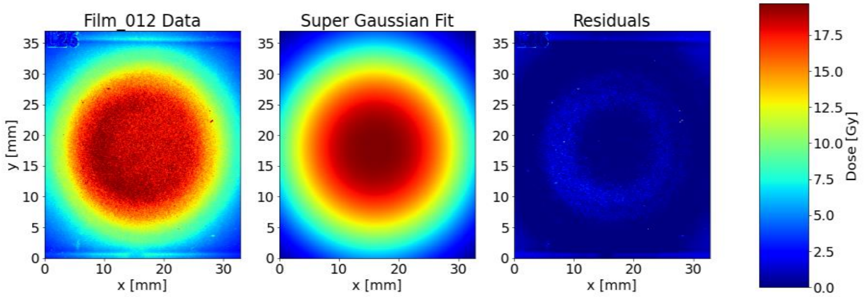
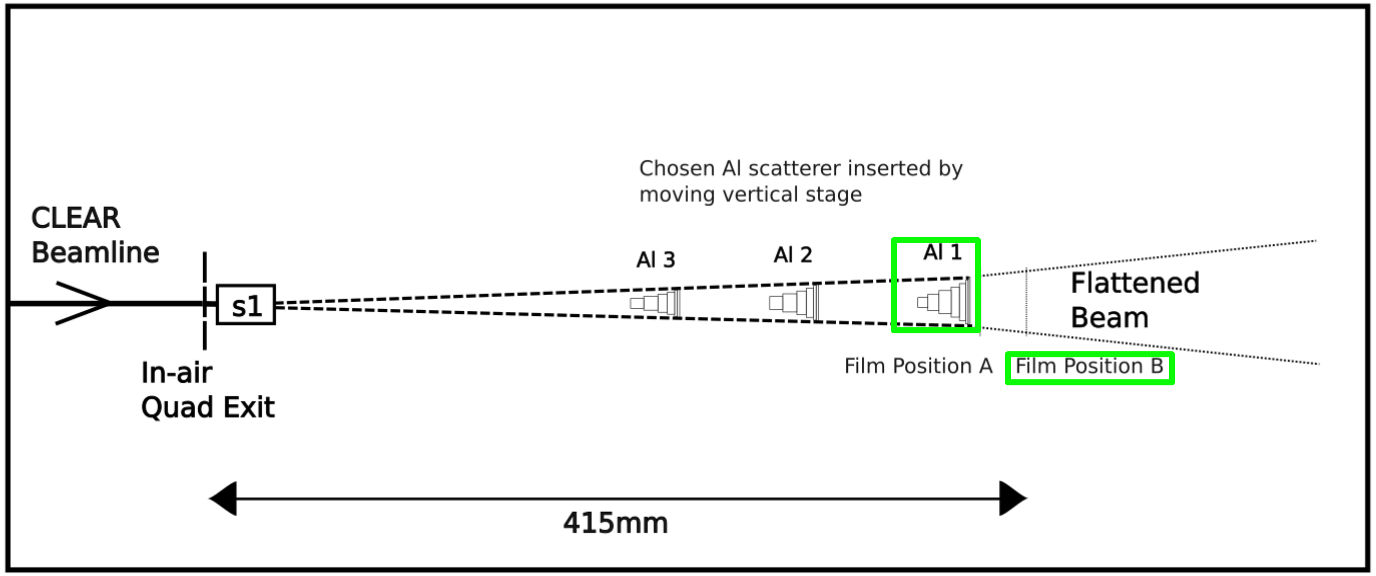
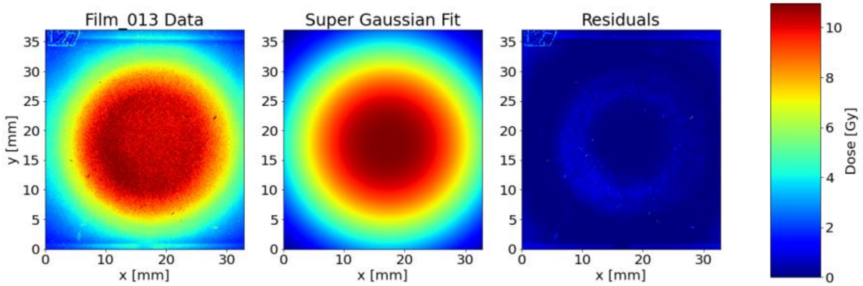



CONV




UHDR



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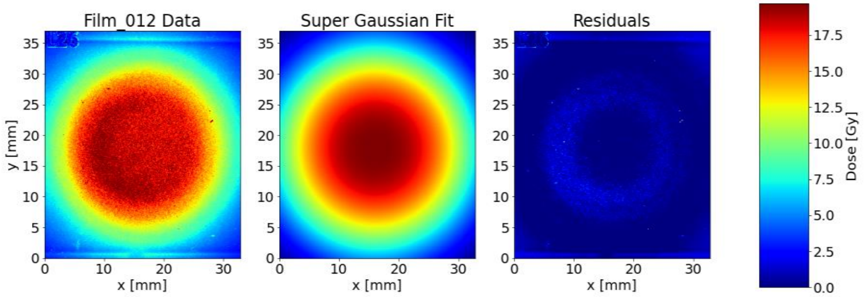


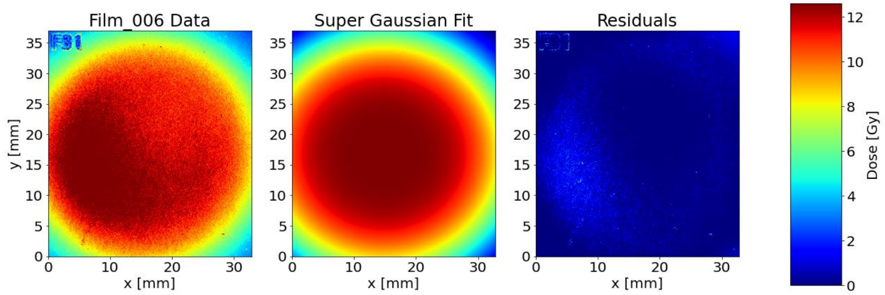


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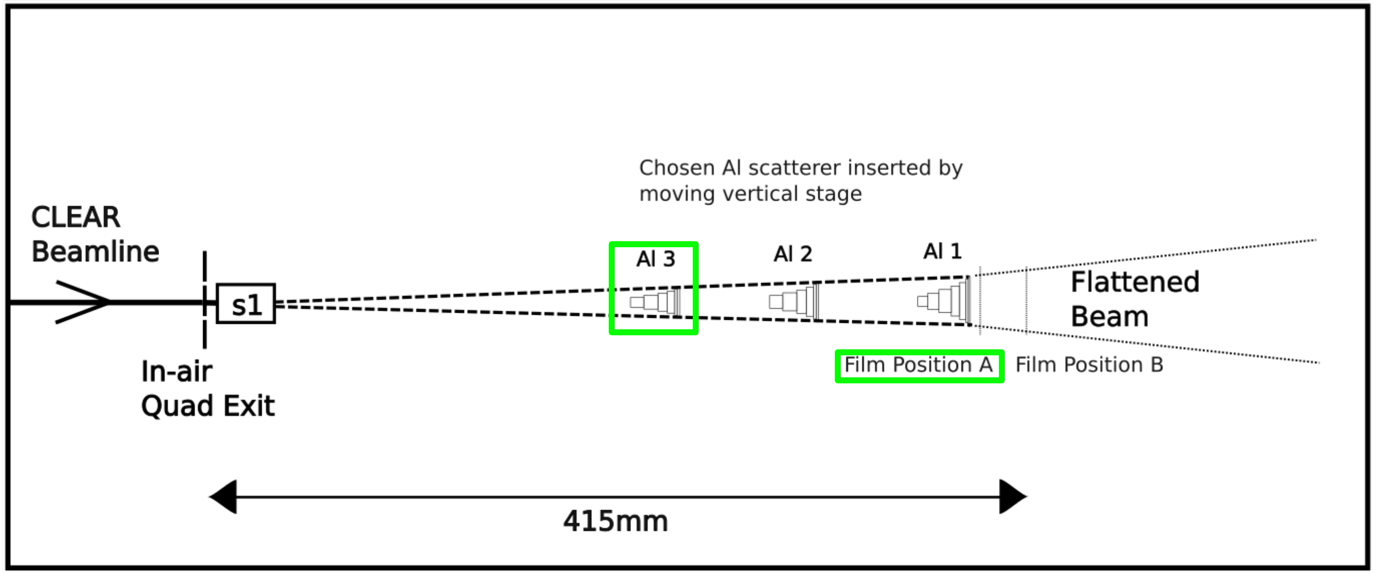


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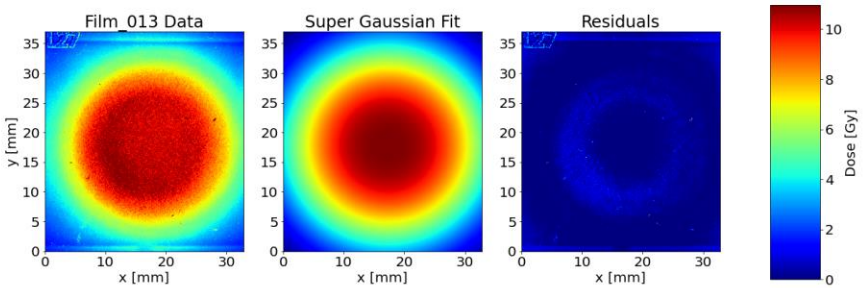
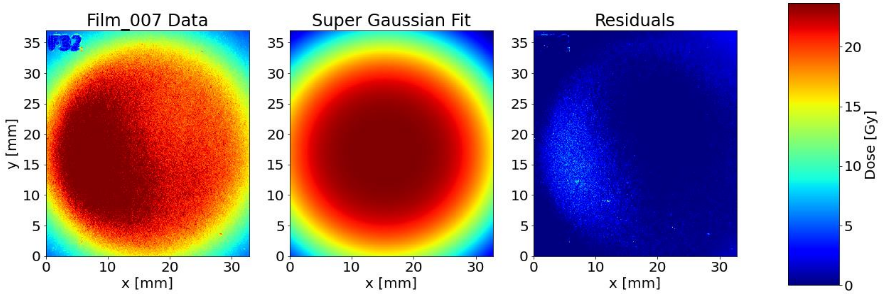



Arbitrary Doses



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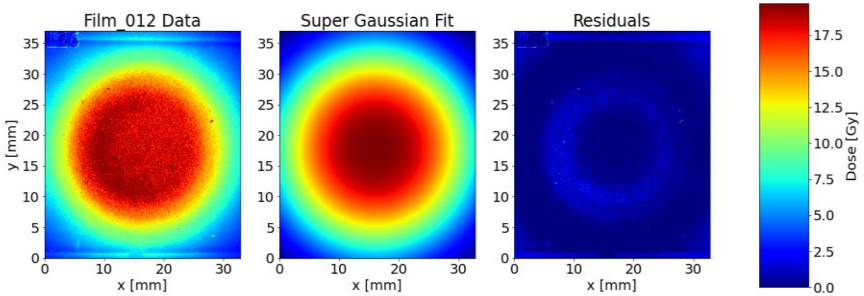


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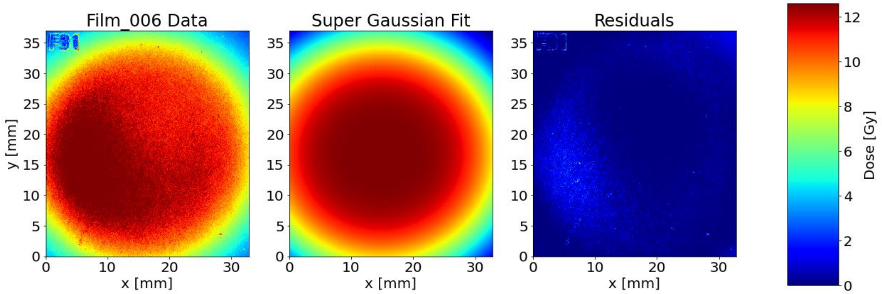


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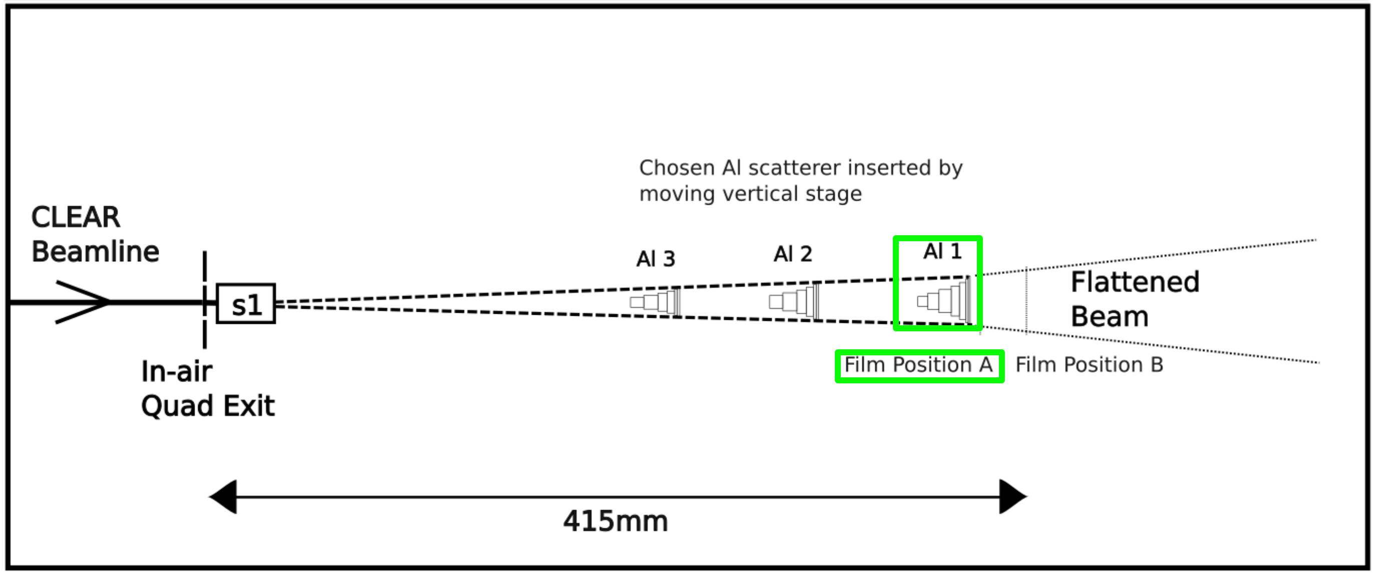


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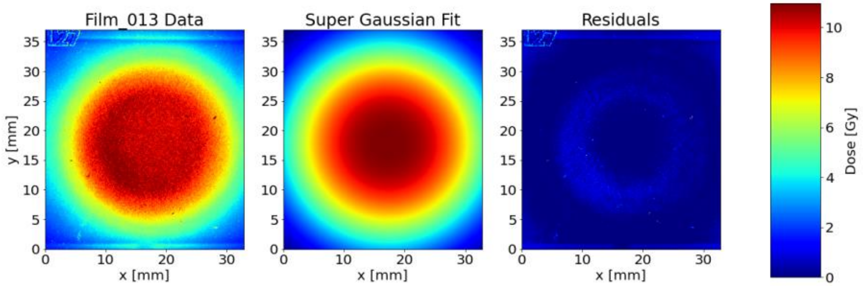


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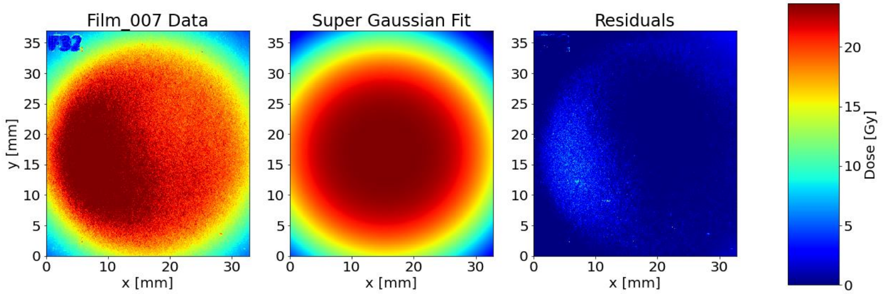

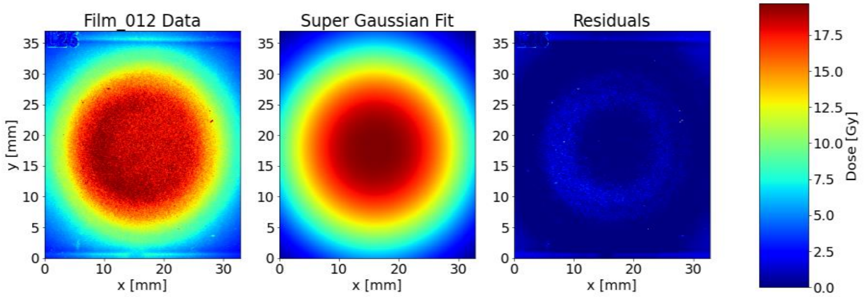


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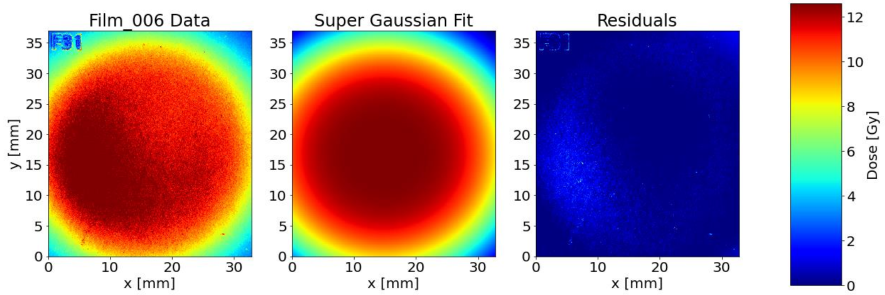


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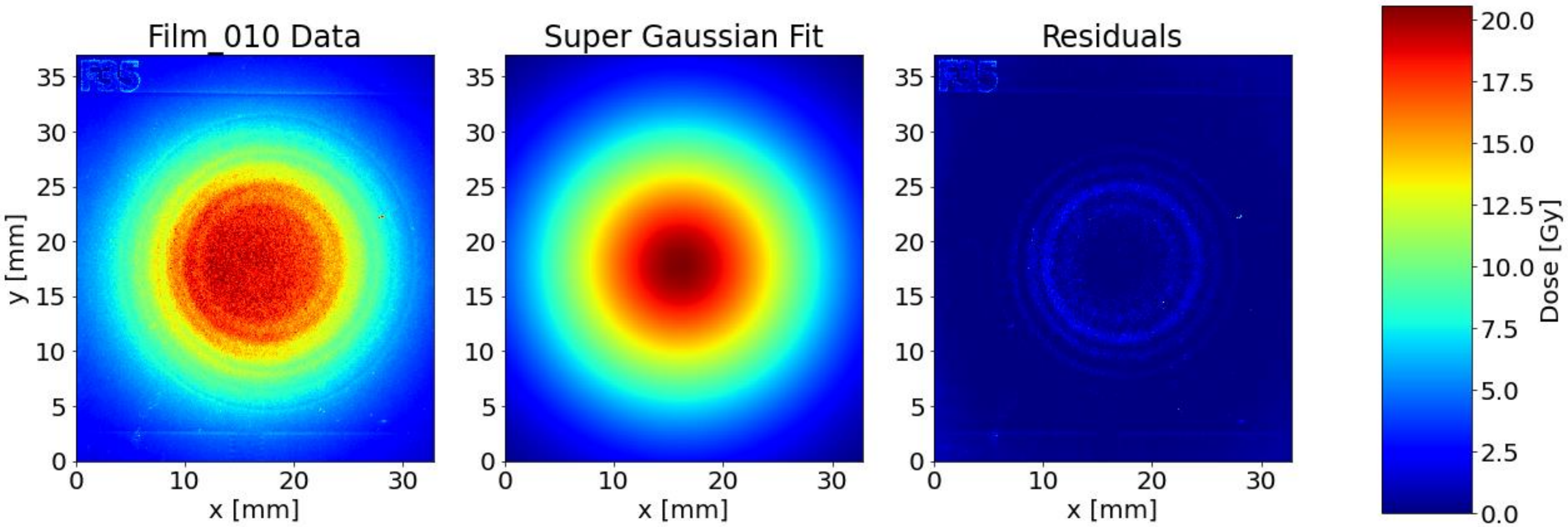
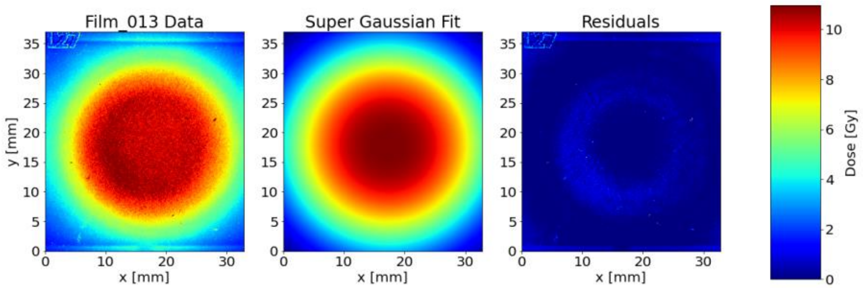



CONV

UHDR

UHDR

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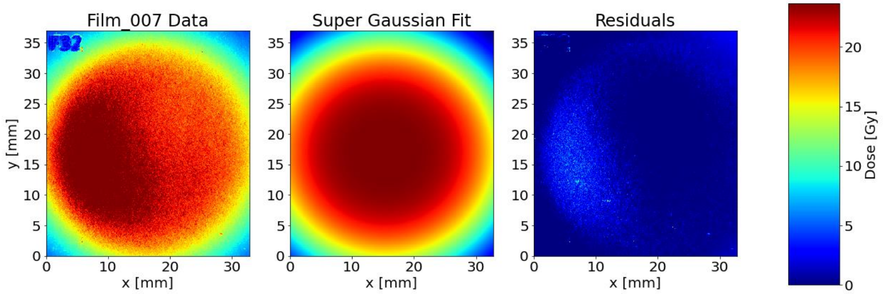
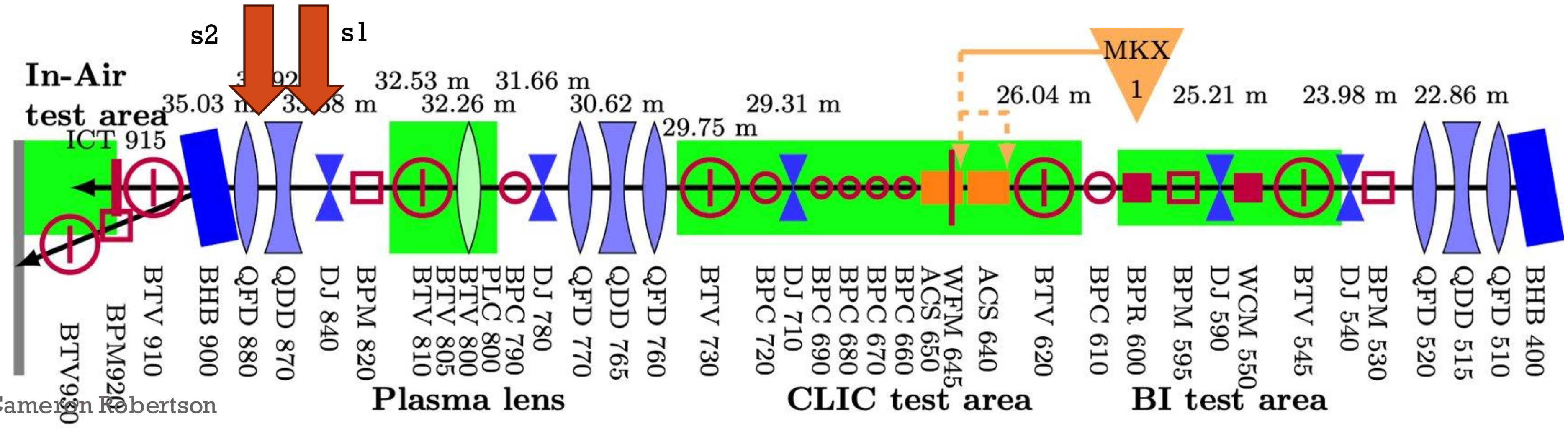


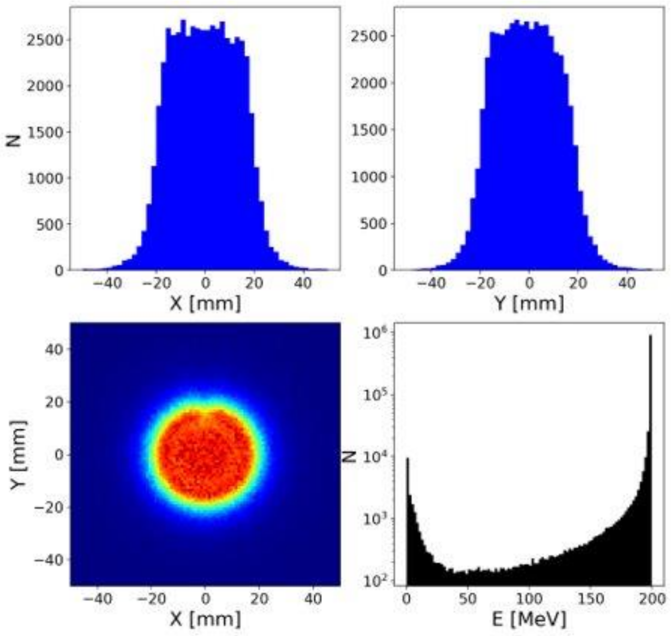
# VACUUM SCATTERING FOILS

- Place foils further upstream to save space in test stand
  - Vacuum broken for install
  - Permanent Installation
- Upstream position, limited beam pipe diameter-> very small scatterers

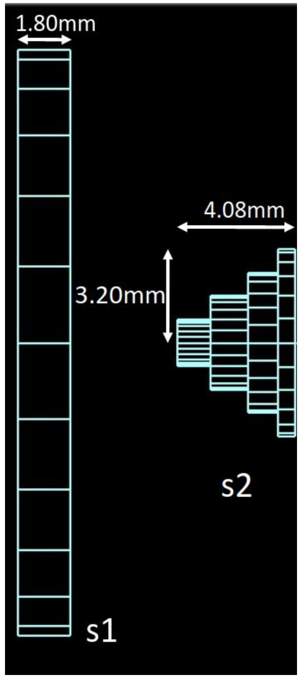


# V3

Predicted Distribution at CLEAR in-air test stand ($10^6$ particles)




- V3 machined in PEEK
- Mounted on steel stems on movable stages for installation
- Installed and aligned in vacuum in CLEAR beamline



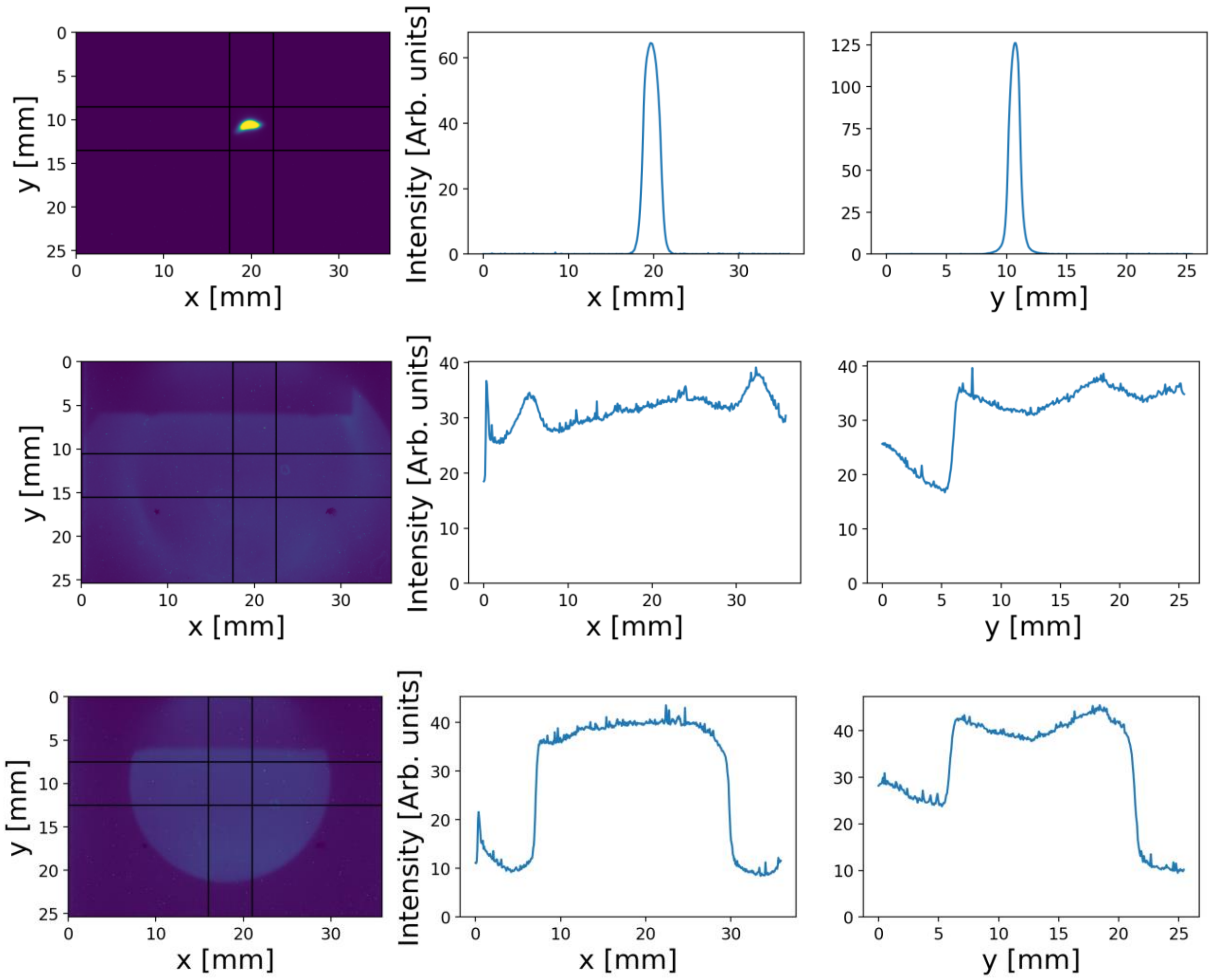
# V3 RESULTS

- Profiles Measured on YAG
  - Beam slightly too large: edge of flat top not visible
- Collimator inserted to produce sharp edges on profiles
  - Several  cm of steel
- Difficult to estimate transmission through collimator

Open beam

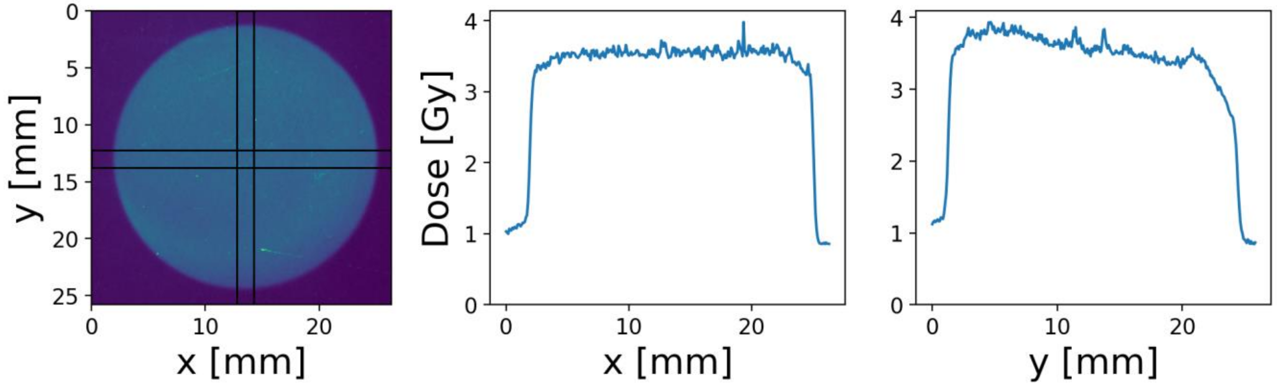
Both scatterers (no collimation)

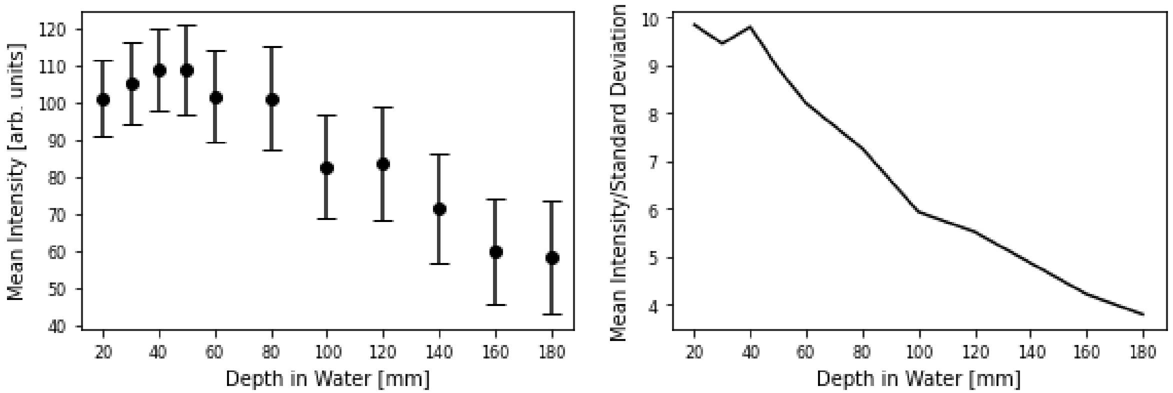
Both scatterers and collimator



# V3 RESULTS

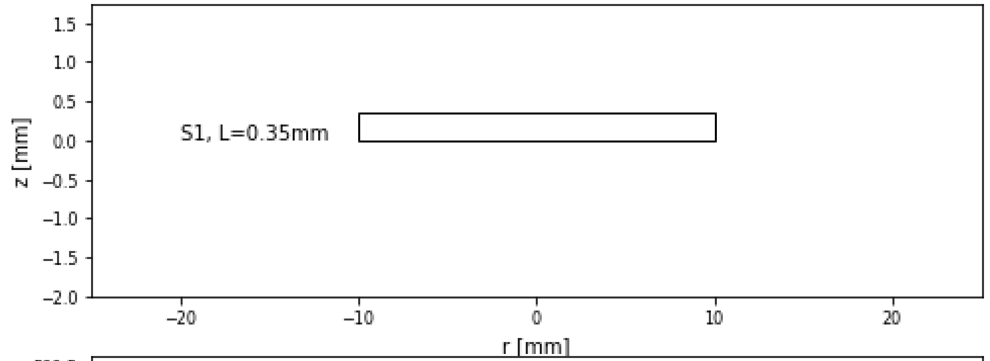
- Dose measurements in air to confirm uniformity of profile
- Measurements of beam profile evolution in air and water taken
  - Low divergence from beam in air
  - Profile loses flatness with depth in water, still non-Gaussian at Xcm
  - Typical VHEE longitudinal intensity/dose profile visible

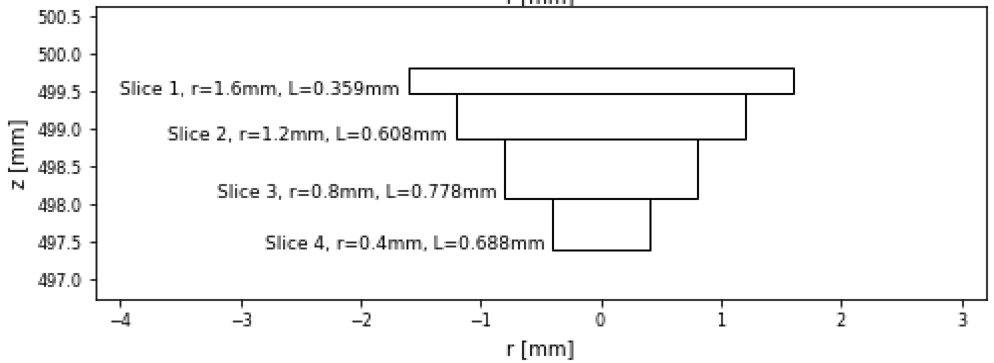


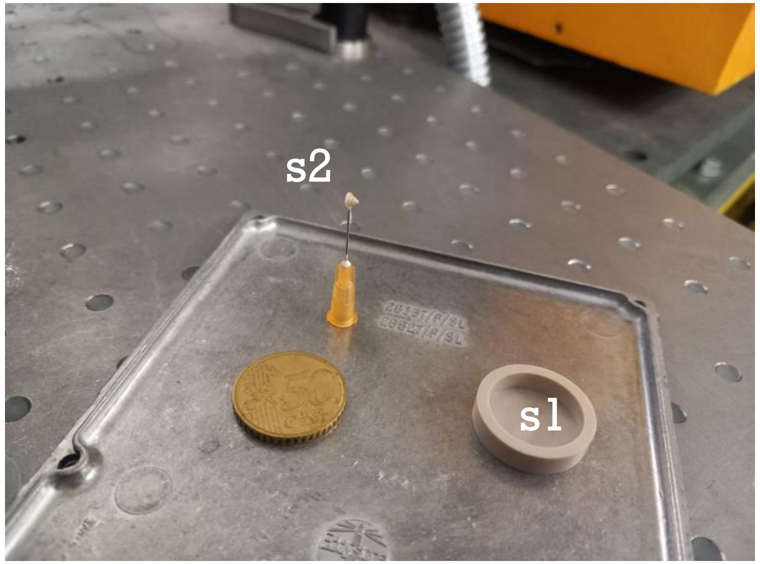



# V4

- Even thinner scatterer designed
  - Aim for profile to be fully visible on screens/films without collimation
- Limited by manufacturing capabilities
- New collimator designed to fully block Gaussian tails

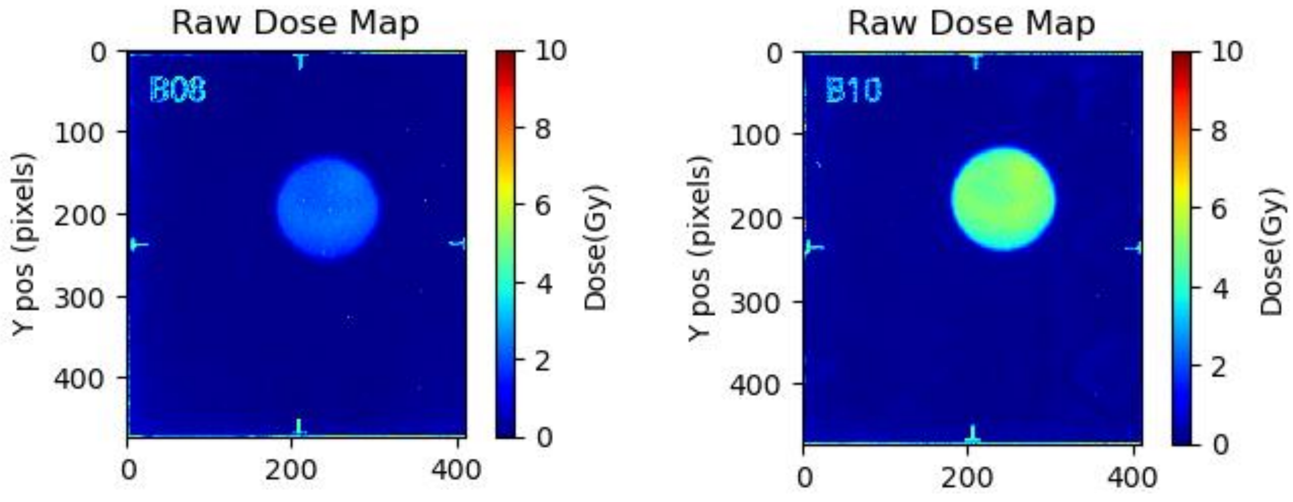


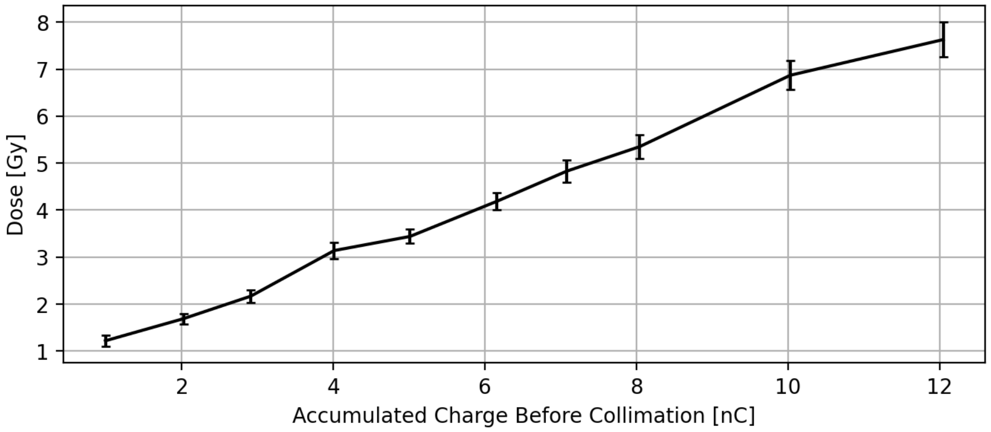



# V4 INITIAL TESTS

- Smaller flat beam retrieved as expected
- Linear mean dose across profile with charge
  - Excellent uniformity shown
- BCM after collimation used to determine losses
  - ~40% total beam retained



# FUTURE WORK

- Alignment and positioning
  - Mounting- steel stem results in some asymmetry
- Dose evolution in water (transverse and longitudinal)
- Effects of initial beam conditions (comparison with MC simulations)
- Experimental data vital for comparison with simulations
  - Results from CLEAR setup can be scaled up for larger beams
  - 75mm radius beam desired for VHEE therapy
  - Particle production, extra dose

# CONCLUSIONS

- Dual-scattering foils are a promising method for providing conformal treatment
- Design process straightforward, flexible and applicable to a range of setups and requirements
- Progressive Installations at CLEAR have demonstrated flat distributions in air and water
  - Thick, high-Z material required to collimate beam
- Characterisation required experimentally and in simulations

# ACKNOWLEDGEMENTS


- Many thanks to the entire CLEAR team for their expertise and support for these studies