25th WRMISS
in Mons, Belgium

September 6 -8, 2022

Local Organizing Team:
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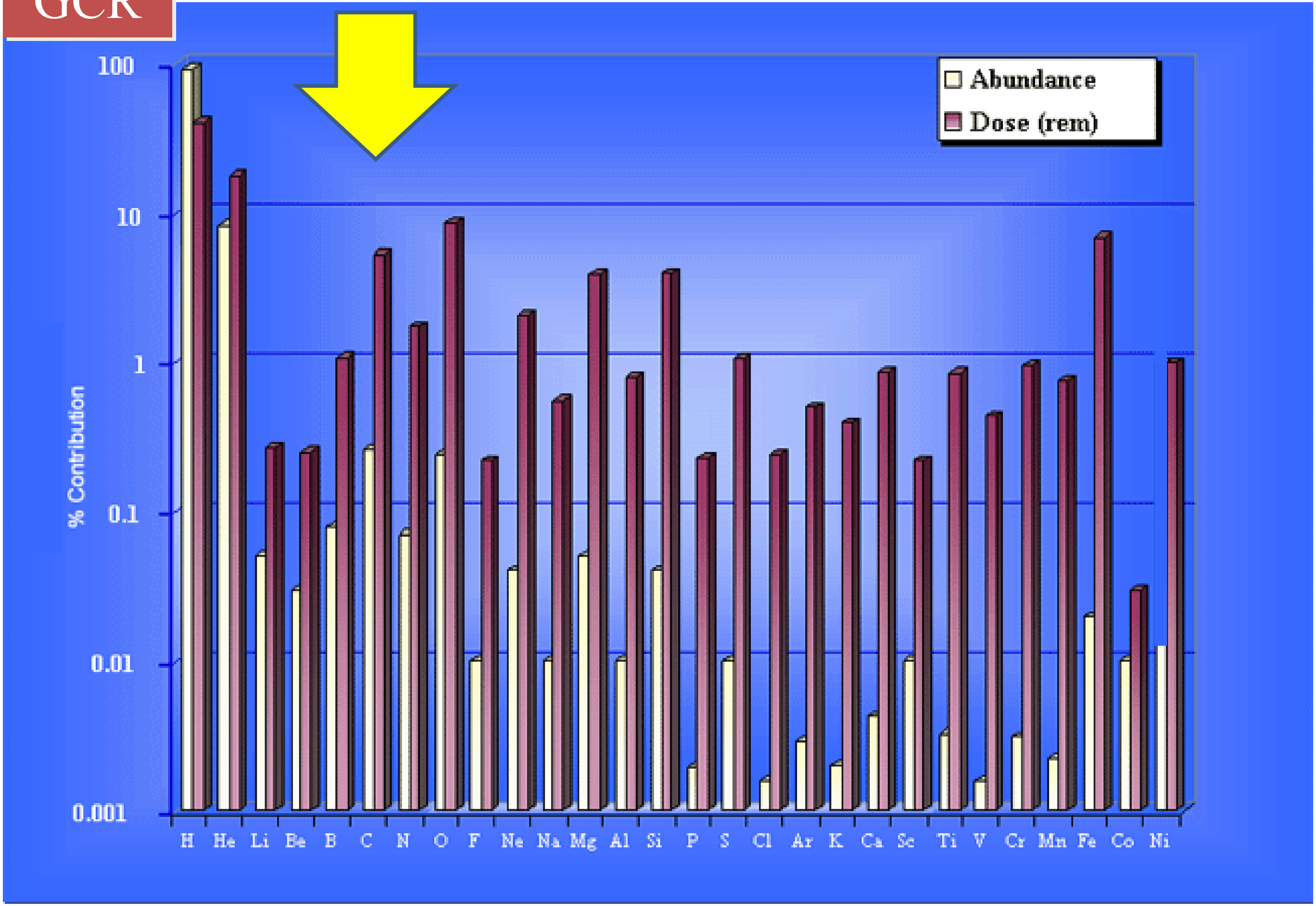
Imaging Radiation Particle Trajectories at Micron Resolution: Applications for ISS and Beyond

Premkumar B. Saganti, Ph. D.

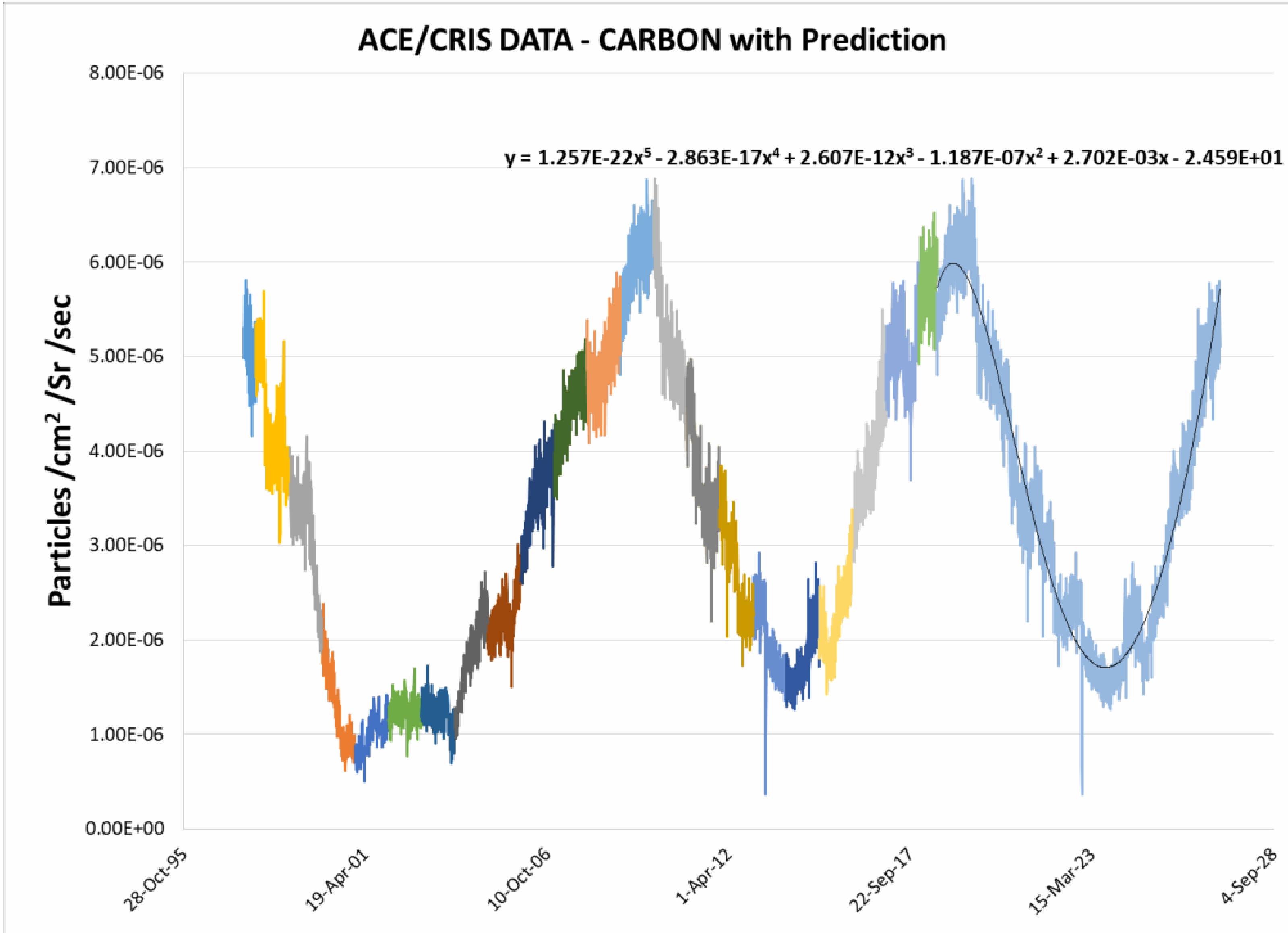
Regents Professor – Texas A&M University System
Radiation Institute for Science and Engineering (RaISE)
A Texas A&M Chancellor's Research Initiative (CRI)
Prairie View A&M University
www.pvamu.edu/raise

GCR



Cucinotta / Saganti: 2001

http://srhp.jsc.nasa.gov/



ACE: Example of Carbon data (~ 25 years) with prediction for solar cycle # 25

Credit: Frank Cucinotta, Johnson Space Center, and Prem Saganti, Lockheed Martin

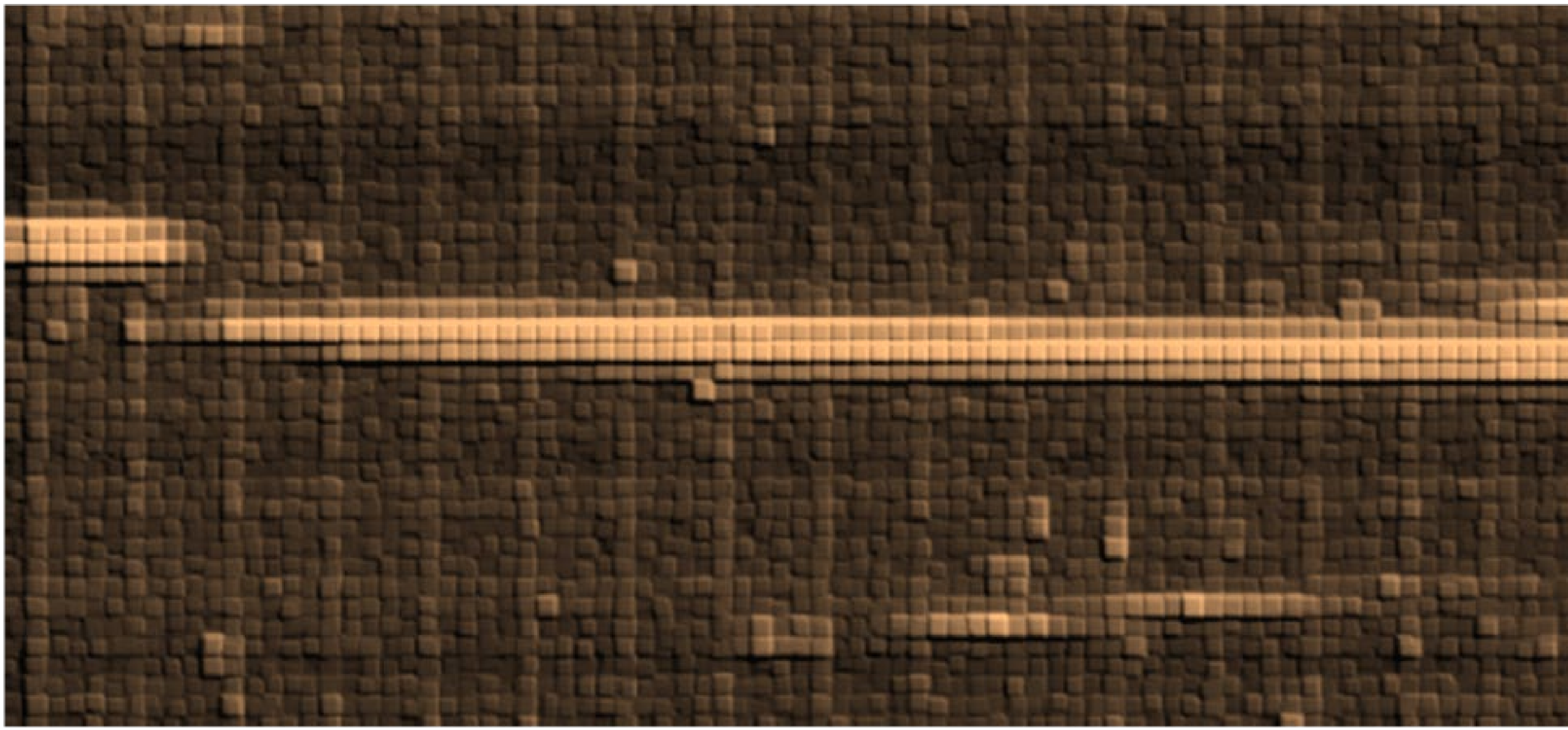
Peggy Whitson
3rd Longest Duration with **289** days at ISS in 2017
More time in space by any American / woman **~ 666** days (over 3 expeditions)
10 EVAs (~ **60** hrs outside ISS)
Next Mission – on Axiom-02 (2023)

EXPERIMENTS WITH CARBON IONS

BNL (USA)
HIMAC (JAPAN)

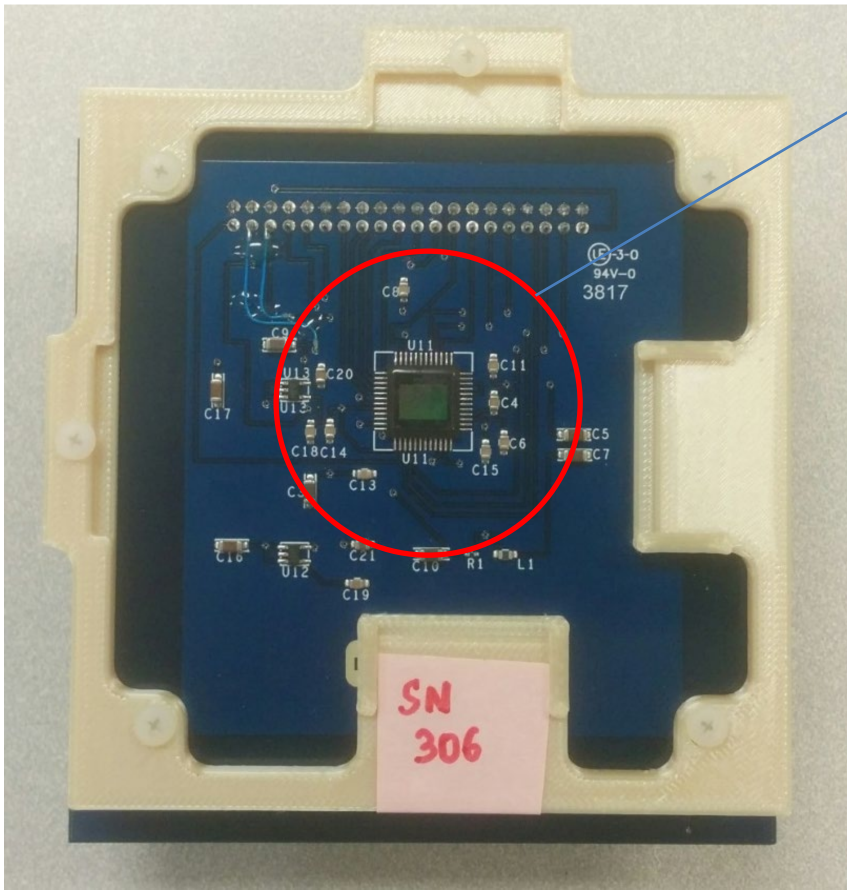
An Overview -

Radiation Track Structure at Micron Level of Carbon Ions

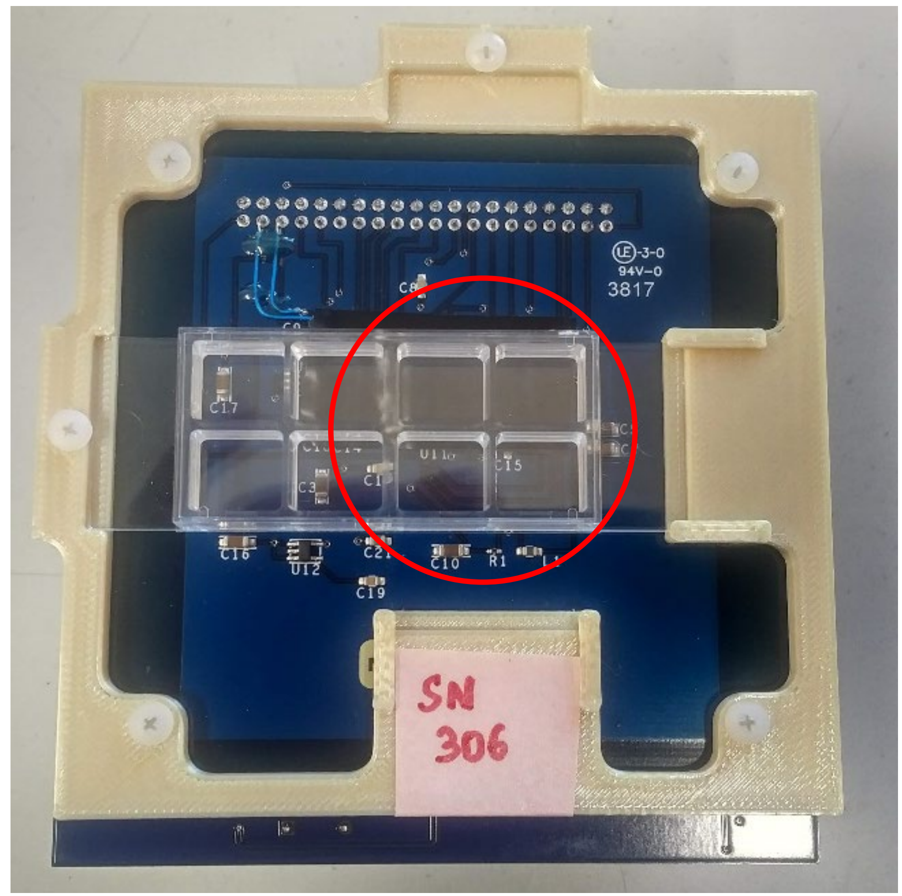


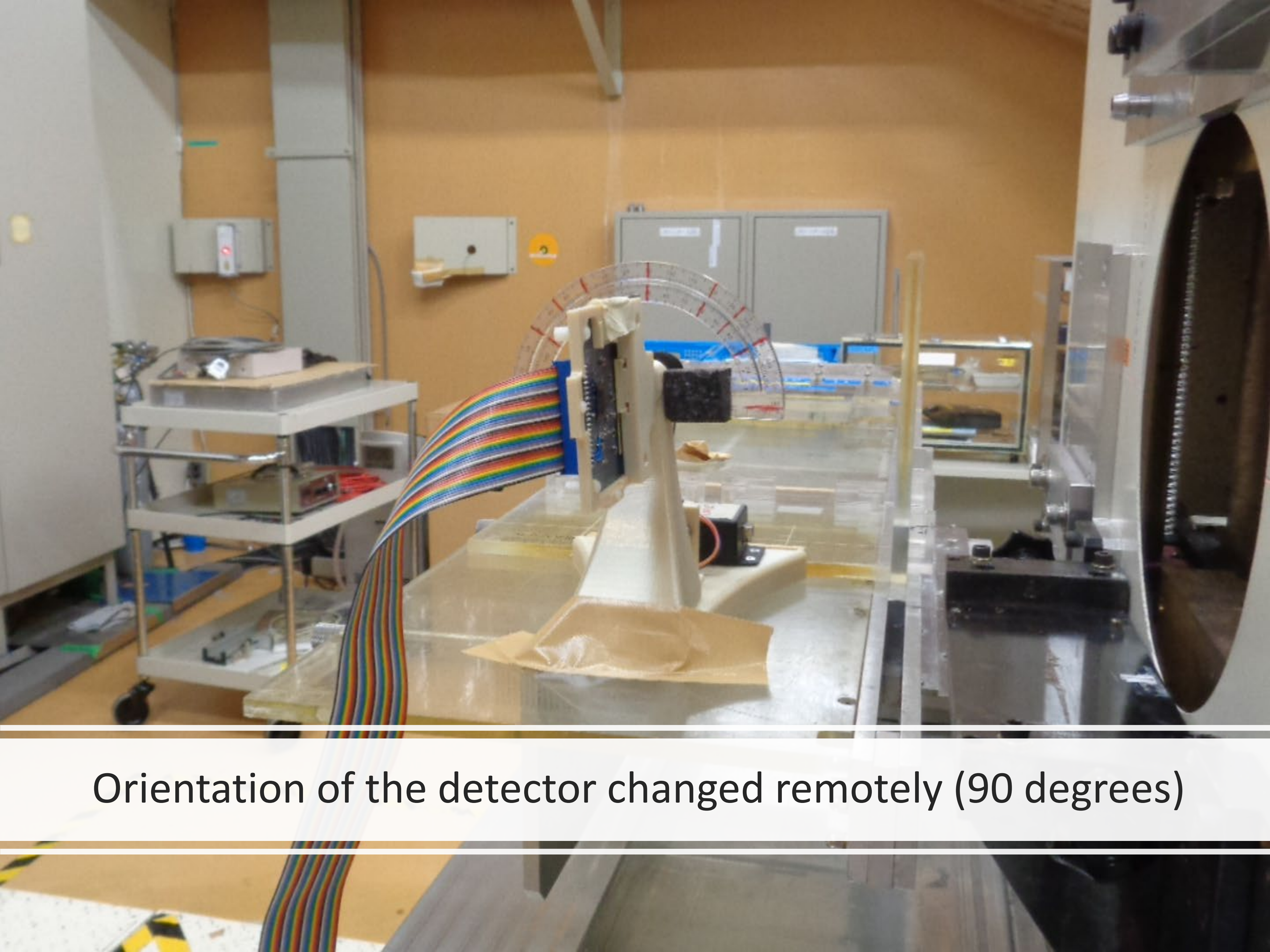
Radiation Track at 1.67 micron per pixel resolution for carbon ion with 300 MeV/n and LET 50 keV/µm (approximately 100x50 pixels are shown from about 3600x2700 pixel image)

Track Structure Detector

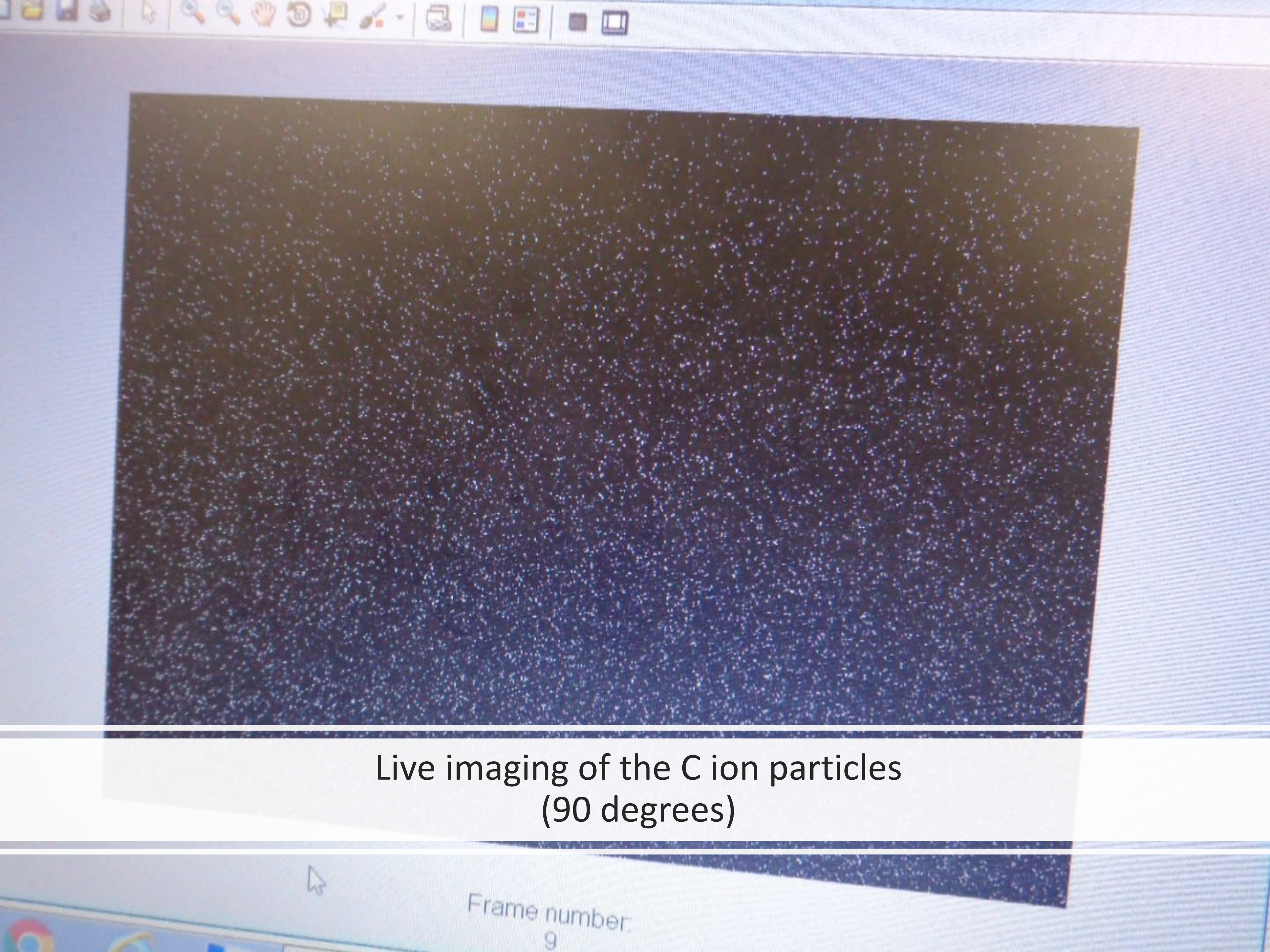


Sensor Dimensions: 0.644 cm (H) x 0.461 cm (V)
Active Pixels: 3664(H) x 2748(V); 10,068,672
Pixel Size: 1.67 x 1.67 µm

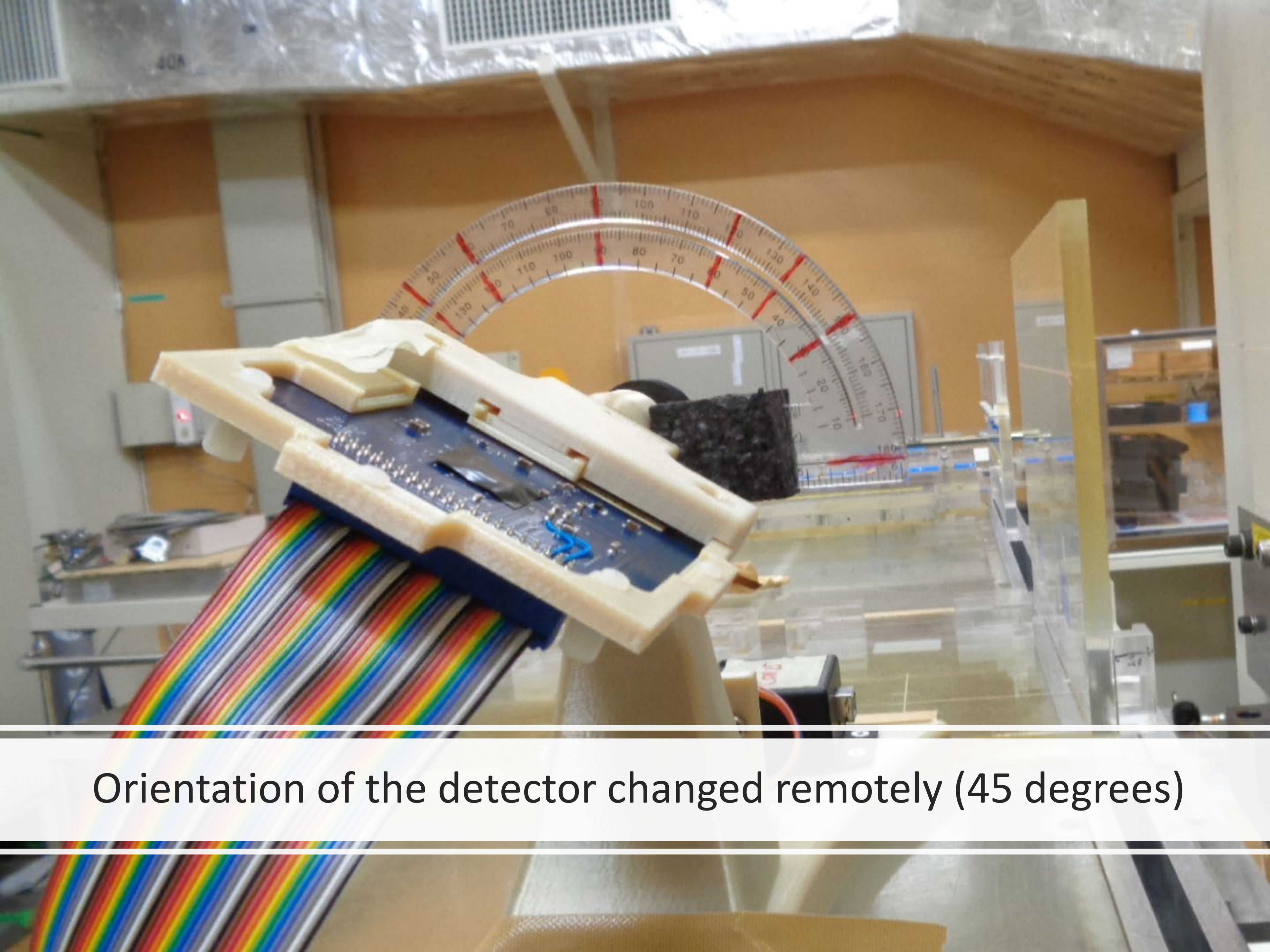




Orientation of the detector changed remotely (90 degrees)

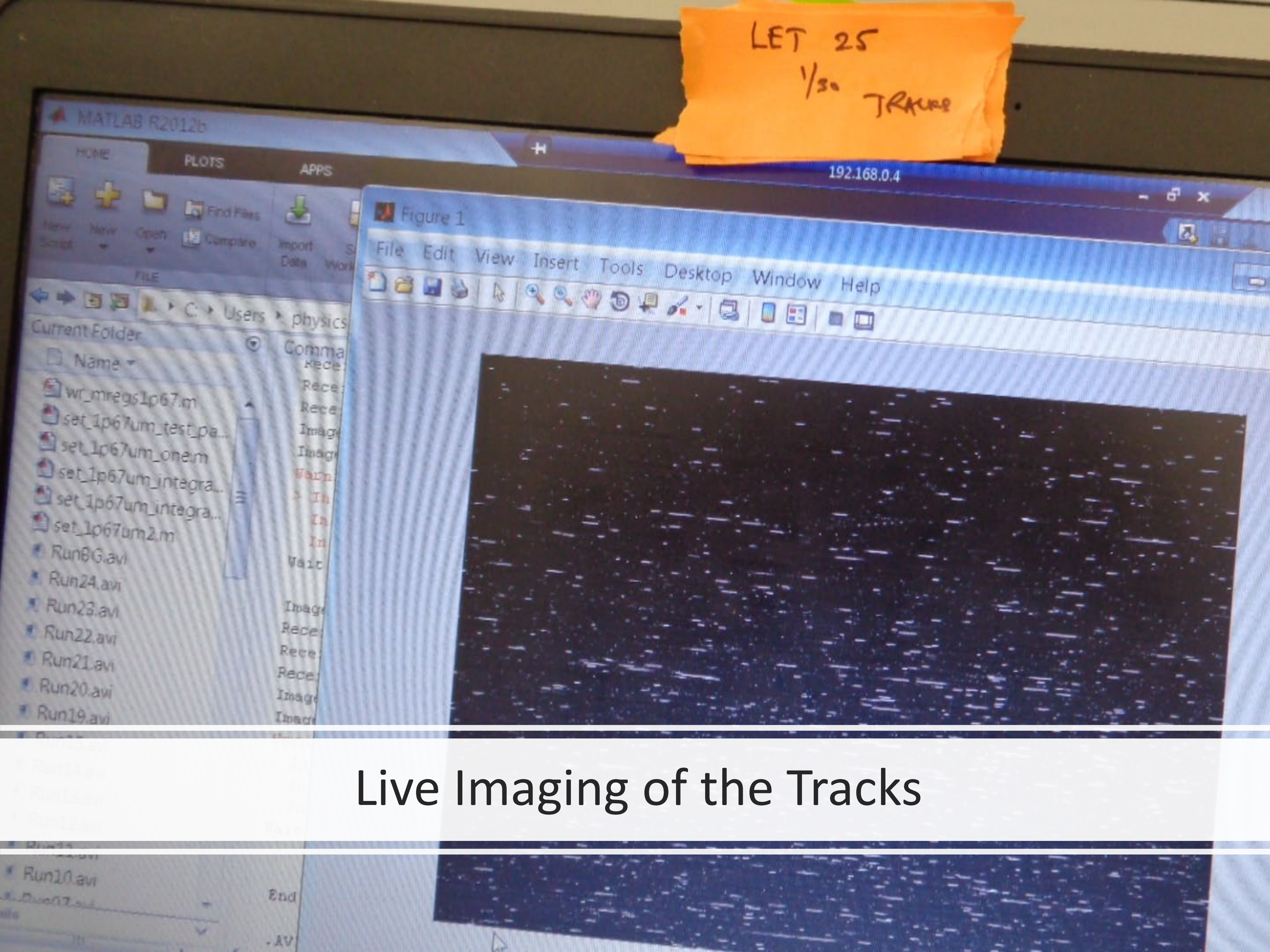


Live imaging of the C ion particles
(90 degrees)



Orientation of the detector changed remotely (45 degrees)

Orientation of the detector changed remotely
(0 degrees)



Live Imaging of the Tracks

Track Structure for LET 13 and 25 (keV/μm)

Detector	LET (keV/μm)	Attenuation	Dose-Rate (Gy/min)	Count	Reference
0 degrees	**13**	1/300	0.00066	2	Run-19
0 degrees	**13**	1/100	0.03910	70	Run-20
0 degrees	**13**	1/30	0.41752	525	Run-21

Detector	LET	Attenuation	Dose-Rate	Count	Reference
0 degrees	**25**	1/300	0.00066	2	Run-22
0 degrees	**25**	1/100	0.03910	70	Run-23
0 degrees	**25**	1/30	0.41752	525	Run-24

Detector	LET	Attenuation	Dose-Rate	Count	Reference
0 degrees	**50**	1/300	0.00066	2	Run-25
0 degrees	**50**	1/100	0.03910	70	Run-26
0 degrees	**50**	1/30	0.41752	525	Run-27

C-290

(LET = **13 keV/µm** and attenuation, ATT = 1/300)

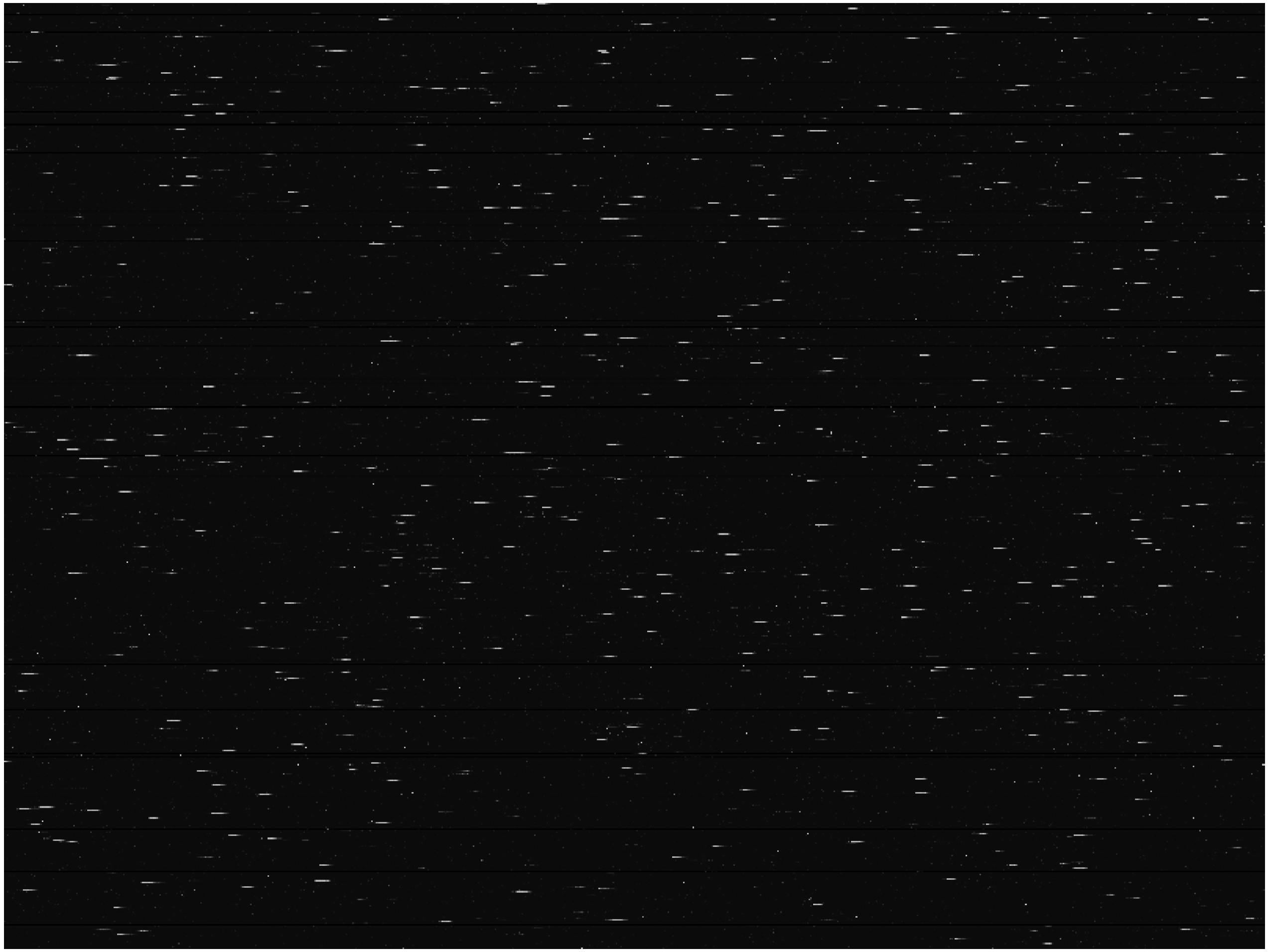
3664x2748 pixels @ 1.67 microns/pixel

A total of 10,068,672 pixels in an array of 0.644 cm x 0.461 cm

C 290

Count = 2 ions

C-290
(LET = **13 keV/µm** and attenuation, ATT = 1/100)

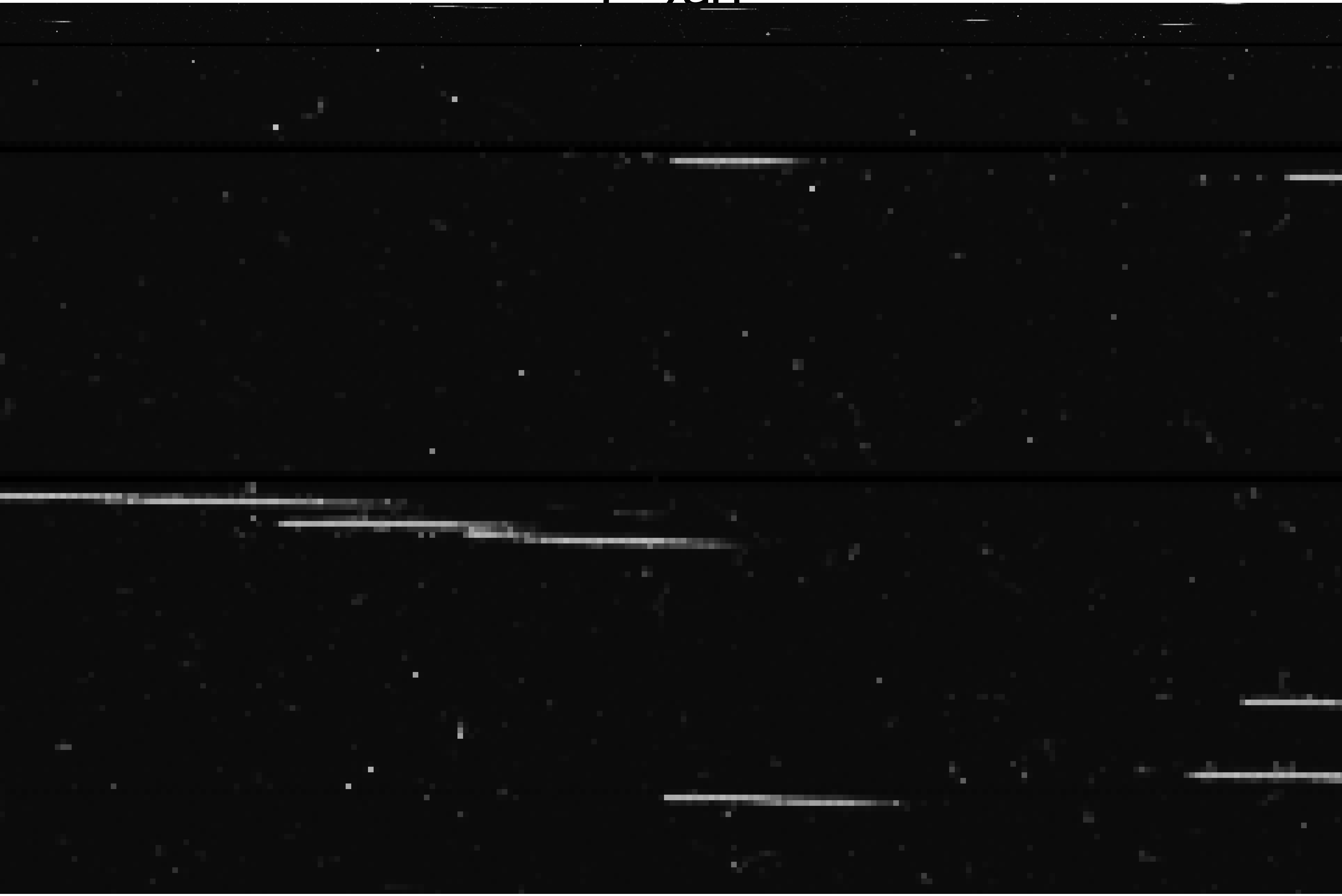


3664x2748 pixels @ 1.67 microns/pixel

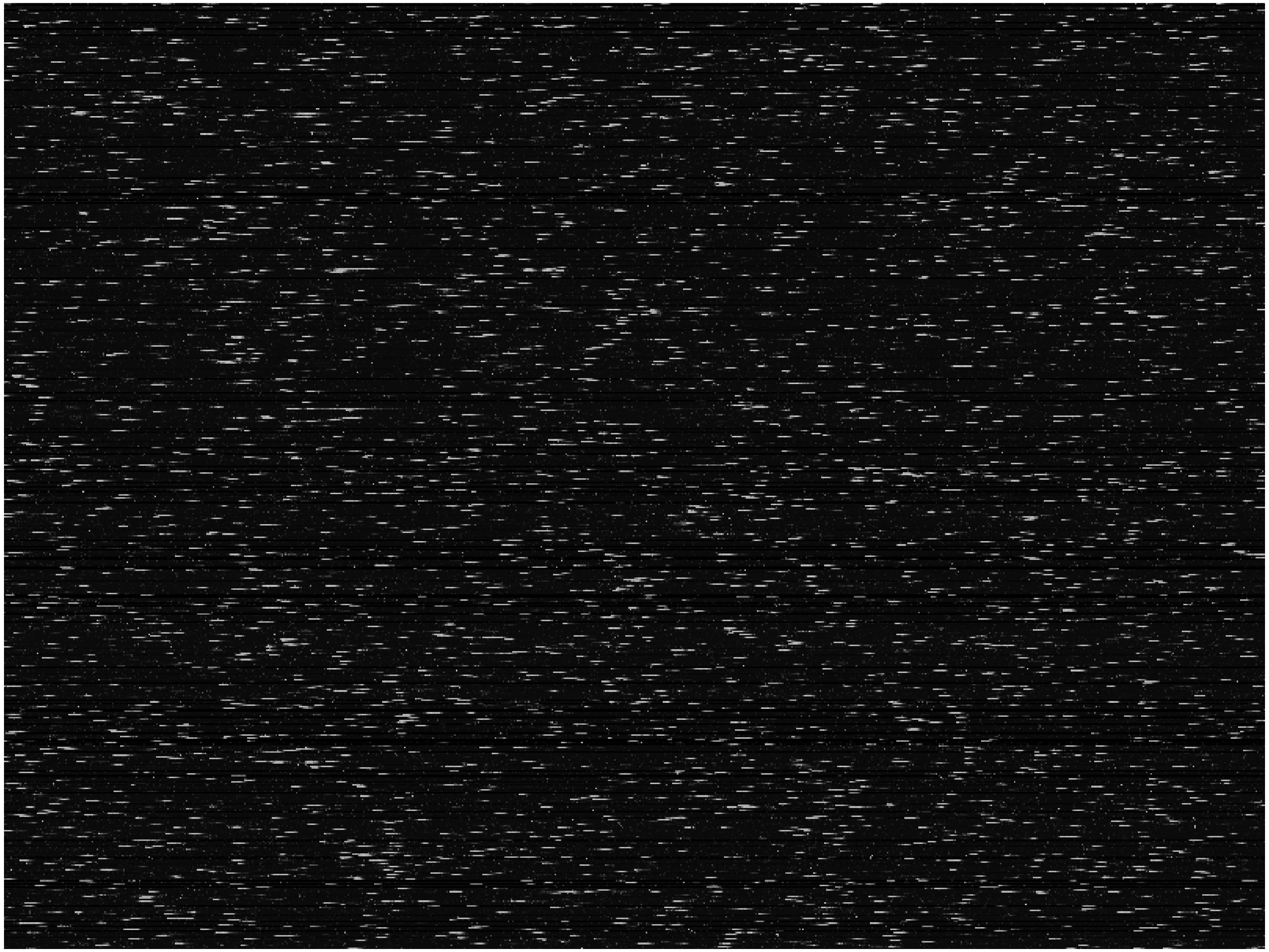
A total of 10,068,672 pixels in an array of 0.644 cm x 0.461 cm

Count = 70 ions

C 290



C-290
(LET = **13 keV/µm** and attenuation, ATT = 1/30)

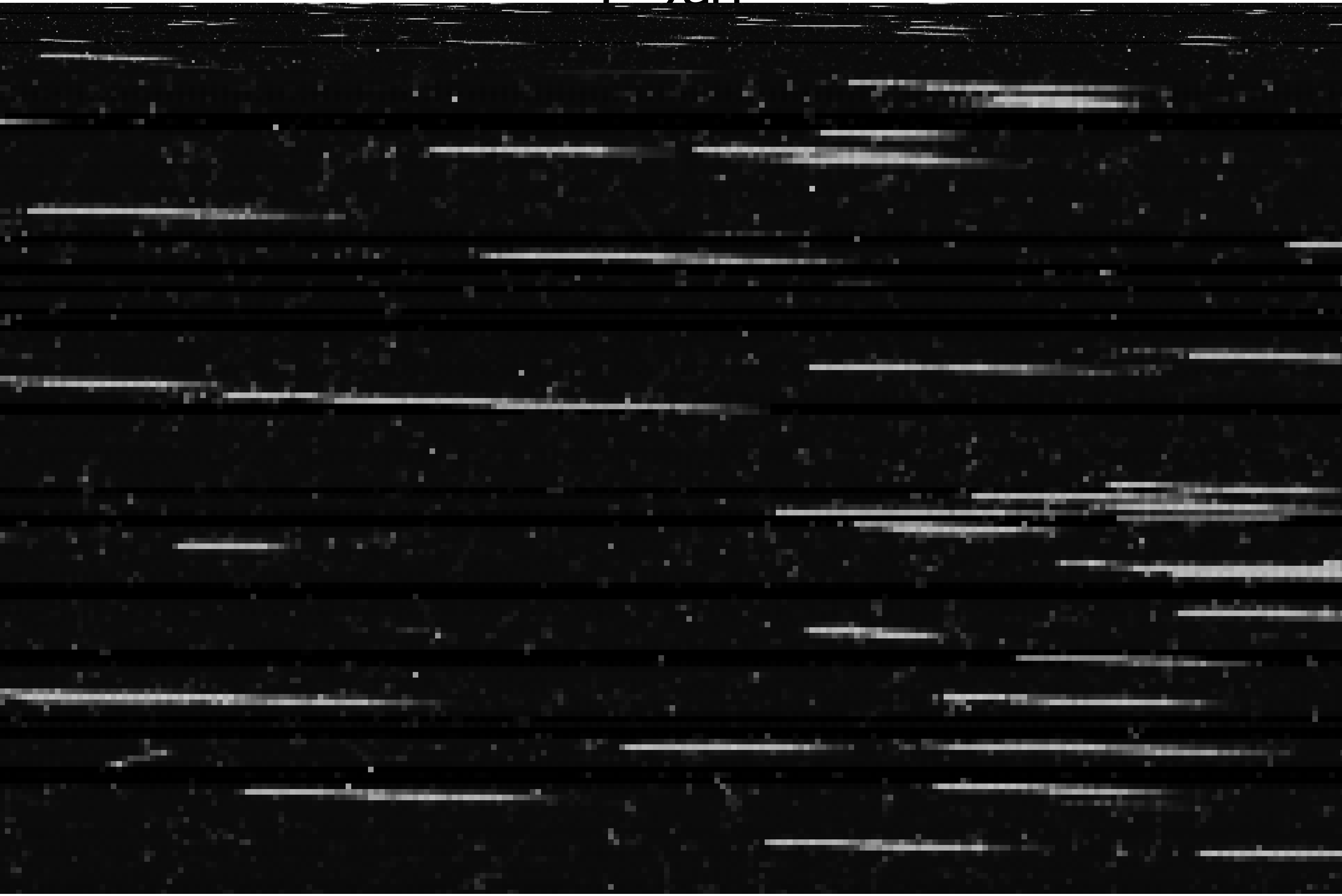


3664x2748 pixels @ 1.67 microns/pixel

A total of 10,068,672 pixels in an array of 0.644 cm x 0.461 cm

Count = 525 ions

C-290



C-125

(LET = **25 keV/µm** and attenuation, ATT = 1/300)

3664x2748 pixels @ 1.67 microns/pixel

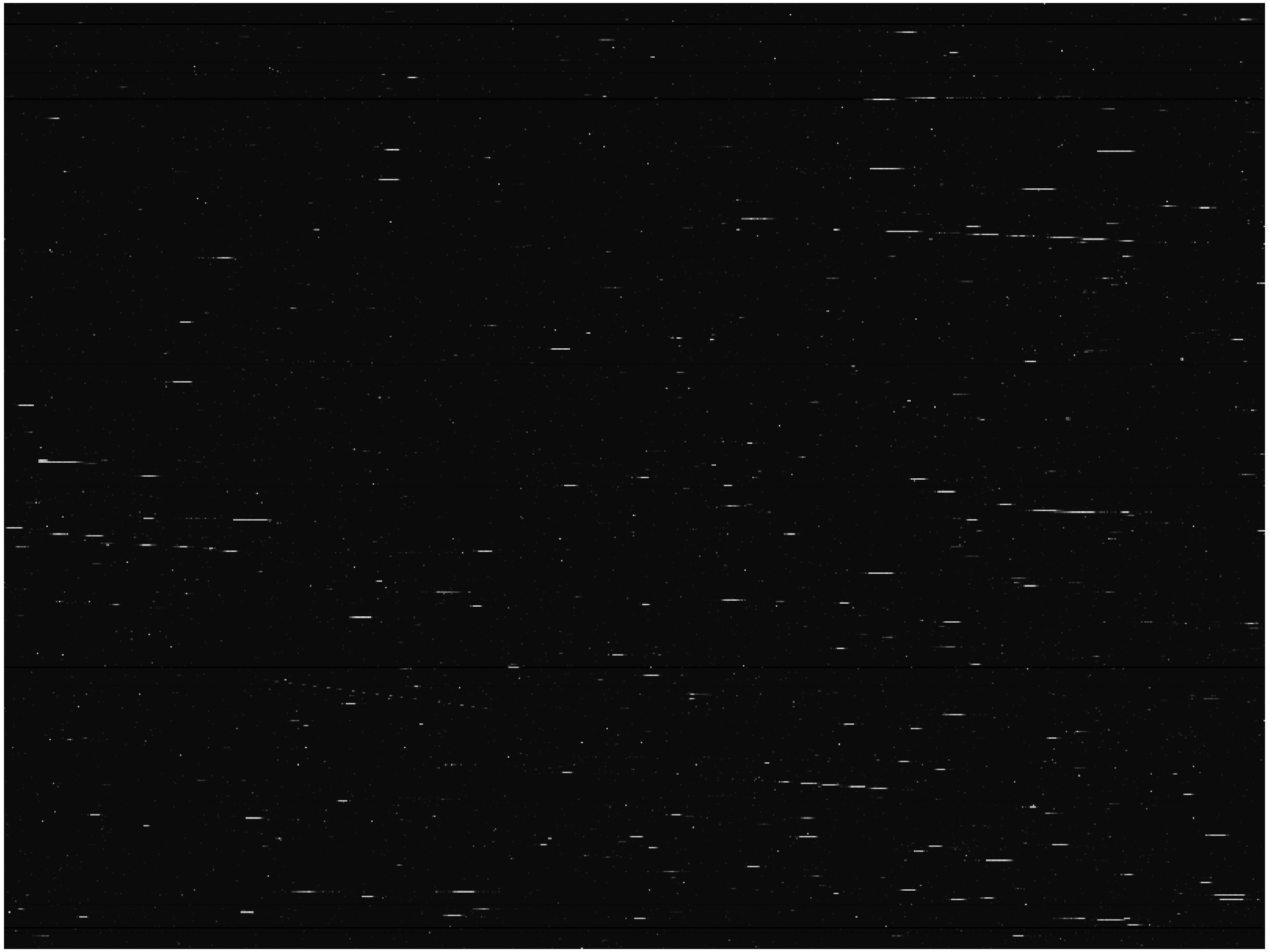
A total of 10,068,672 pixels in an array of 0.644 cm x 0.461 cm

Count = 2 ions

C 125

C-125

(LET = **25 keV/μm** and attenuation, ATT = 1/100)

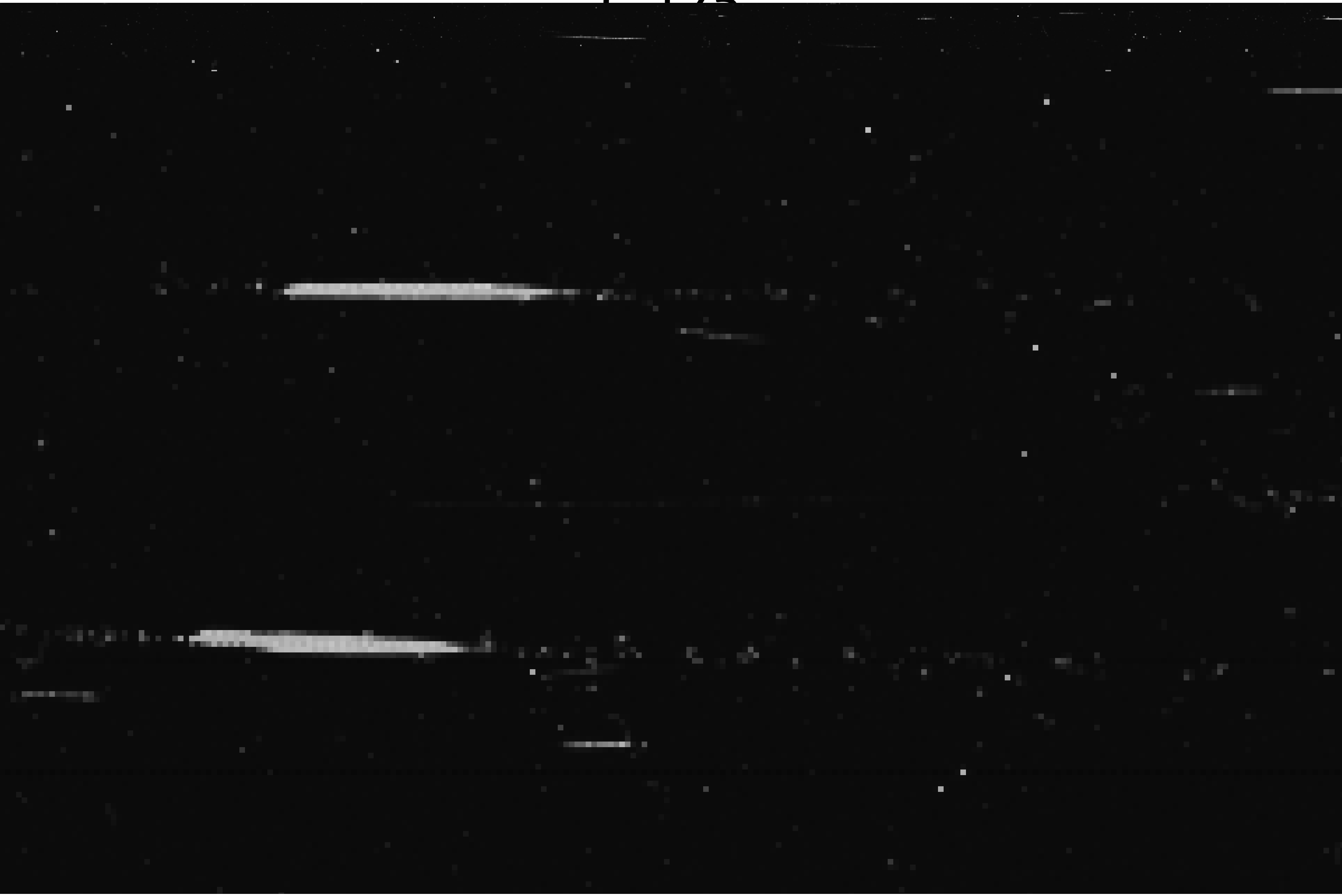


3664x2748 pixels @ 1.67 microns/pixel

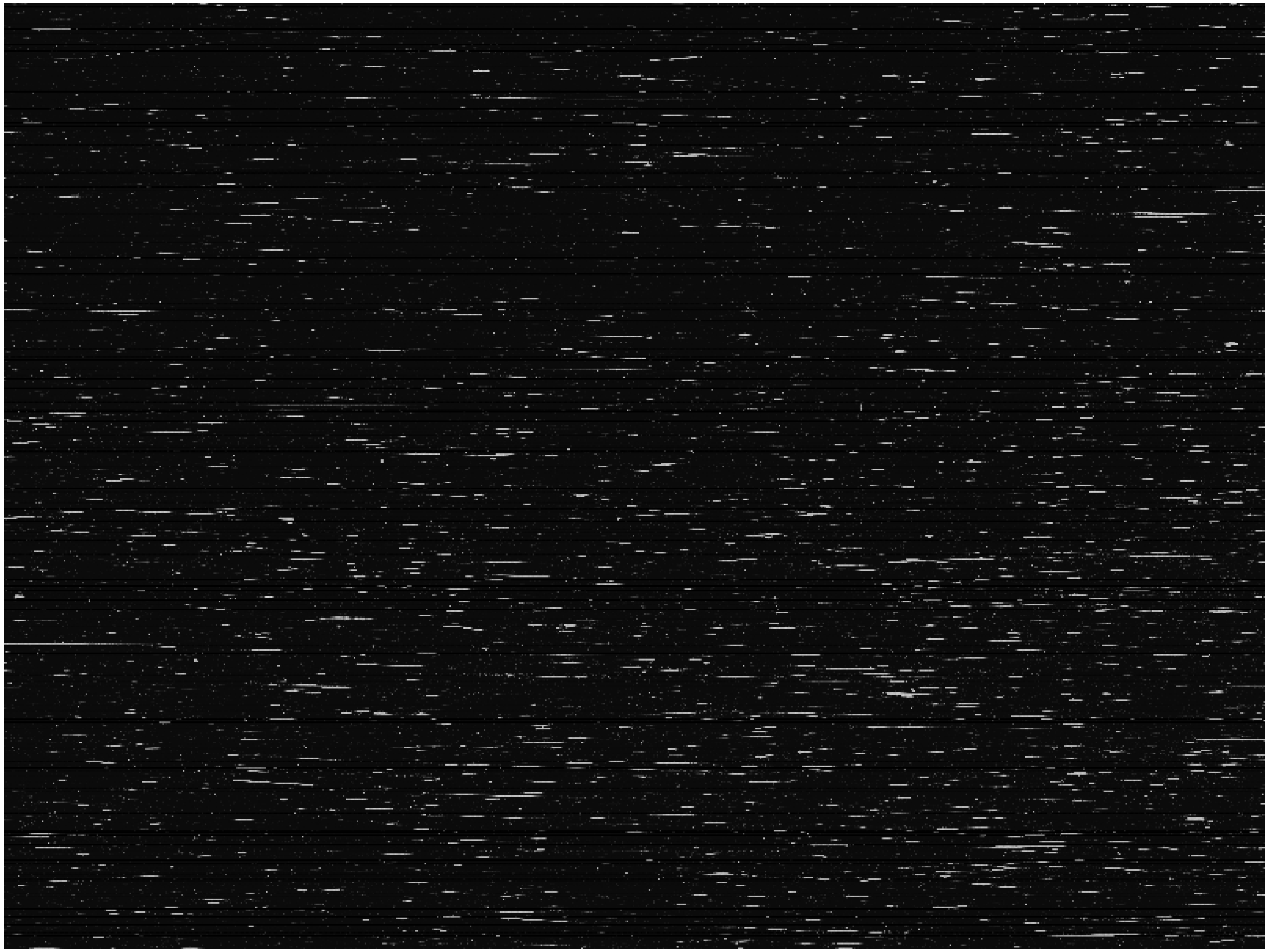
A total of 10,068,672 pixels in an array of 0.644 cm x 0.461 cm

Count = 70 ions

C 125



C-125
(LET = **25 keV/µm** and attenuation, ATT = 1/30)

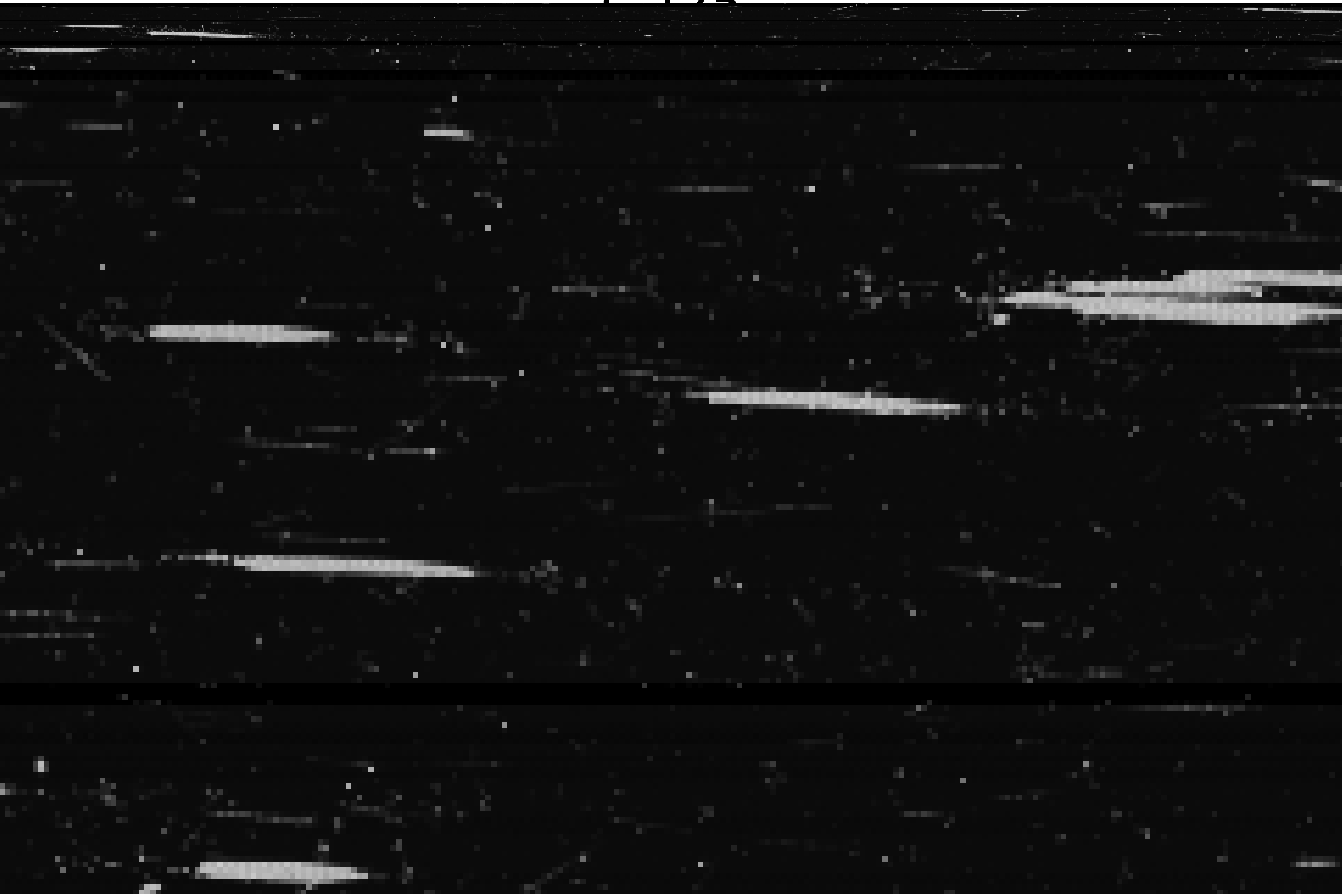


3664x2748 pixels @ 1.67 microns/pixel

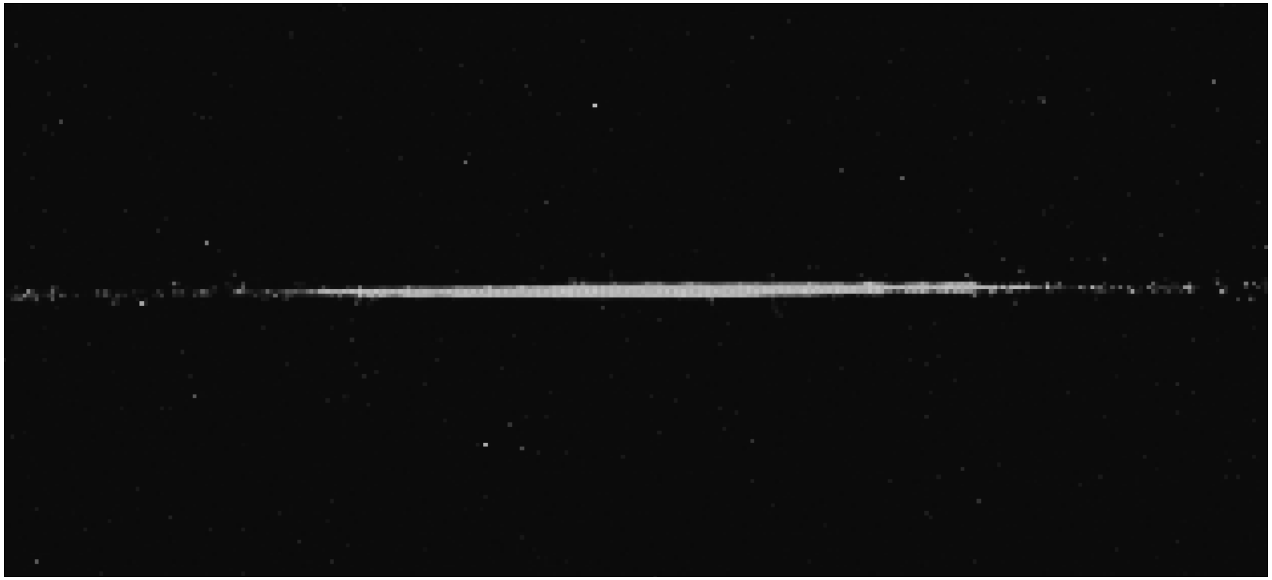
A total of 10,068,672 pixels in an array of 0.644 cm x 0.461 cm

C 125

Count = 525 ions



Individual Tracks (13 vs 25 keV/μm)



13 keV/µm

R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11
R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11
R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 13 G: 13 B: 13	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11
R: 40 G: 40 B: 40	R: 32 G: 32 B: 32	R: 51 G: 51 B: 51	R: 36 G: 36 B: 36	R: 45 G: 45 B: 45	R: 72 G: 72 B: 72	R:130 G:130 B:130	R: 53 G: 53 B: 53	R: 26 G: 26 B: 26	R: 30 G: 30 B: 30	R: 28 G: 28 B: 28	R: 58 G: 58 B: 58	R: 20 G: 20 B: 20	R: 14 G: 14 B: 14
R:182 G:182 B:182	R:181 G:181 B:181	R:188 G:188 B:188	R:170 G:170 B:170	R:179 G:179 B:179	R:179 G:179 B:179	R:175 G:175 B:175	R:178 G:178 B:178	R:183 G:183 B:183	R:174 G:174 B:174	R:182 G:182 B:182	R:170 G:170 B:170	R:179 G:179 B:179	R:169 G:169 B:169
R: 17 G: 17 B: 17	R: 16 G: 16 B: 16	R: 19 G: 19 B: 19	R: 18 G: 18 B: 18	R: 19 G: 19 B: 19	R: 27 G: 27 B: 27	R: 32 G: 32 B: 32	R: 36 G: 36 B: 36	R: 16 G: 16 B: 16	R: 16 G: 16 B: 16	R: 15 G: 15 B: 15	R: 16 G: 16 B: 16	R: 13 G: 13 B: 13	R: 14 G: 14 B: 14
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R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11
R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 10 G: 10 B: 10	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 10 G: 10 B: 10	R: 11 G: 11 B: 11

C-290
(LET = 13 keV/μm and attenuation, ATT = 1/300)

R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11
R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11
R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 13 G: 13 B: 13	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11
R: 12 G: 12 B: 12	R: 29 G: 29 B: 29	R: 39 G: 39 B: 39	R: 40 G: 40 B: 40	R: 32 G: 32 B: 32	R: 51 G: 51 B: 51	R: 36 G: 36 B: 36	R: 45 G: 45 B: 45	R: 72 G: 72 B: 72	R:130 G:130 B:130	R: 53 G: 53 B: 53	R: 26 G: 26 B: 26	R: 30 G: 30 B: 30	R: 28 G: 28 B: 28	R: 58 G: 58 B: 58	R: 20 G: 20 B: 20	R: 14 G: 14 B: 14	R: 30 G: 30 B: 30	R: 17 G: 17 B: 17	R: 26 G: 26 B: 26
R: 70 G: 70 B: 70	R:173 G:173 B:173	R:188 G:188 B:188	R:182 G:182 B:182	R:181 G:181 B:181	R:188 G:188 B:188	R:170 G:170 B:170	R:179 G:179 B:179	R:179 G:179 B:179	R:175 G:175 B:175	R:178 G:178 B:178	R:183 G:183 B:183	R:174 G:174 B:174	R:182 G:182 B:182	R:170 G:170 B:170	R:179 G:179 B:179	R:169 G:169 B:169	R:173 G:173 B:173	R:170 G:170 B:170	R:177 G:177 B:177
R: 12 G: 12 B: 12	R: 14 G: 14 B: 14	R: 18 G: 18 B: 18	R: 17 G: 17 B: 17	R: 16 G: 16 B: 16	R: 19 G: 19 B: 19	R: 18 G: 18 B: 18	R: 19 G: 19 B: 19	R: 27 G: 27 B: 27	R: 32 G: 32 B: 32	R: 36 G: 36 B: 36	R: 16 G: 16 B: 16	R: 16 G: 16 B: 16	R: 15 G: 15 B: 15	R: 16 G: 16 B: 16	R: 13 G: 13 B: 13	R: 14 G: 14 B: 14	R: 20 G: 20 B: 20	R: 21 G: 21 B: 21	R: 25 G: 25 B: 25
R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11
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R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 10 G: 10 B: 10	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 10 G: 10 B: 10	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11

25 keV/μm

R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 26 G: 26 B: 26	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 10 G: 10 B: 10
R: 14 G: 14 B: 14	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 18 G: 18 B: 18	R: 13 G: 13 B: 13	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12
R: 60 G: 60 B: 60	R: 51 G: 51 B: 51	R: 49 G: 49 B: 49	R: 44 G: 44 B: 44	R: 46 G: 46 B: 46	R: 43 G: 43 B: 43	R: 67 G: 67 B: 67	R: 95 G: 95 B: 95	R: 54 G: 54 B: 54	R: 55 G: 55 B: 55	R: 52 G: 52 B: 52	R: 46 G: 46 B: 46	R: 54 G: 54 B: 54	R: 59 G: 59 B: 59
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R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 50 G: 50 B: 50	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11

C-290
(LET = 25 keV/μm and attenuation, ATT = 1/300)

R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 26 G: 26 B: 26	R: 12 G: 12 B: 12	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 10 G: 10 B: 10	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11
R: 33 G: 33 B: 33	R: 11 G: 11 B: 11	R: 20 G: 20 B: 20	R: 14 G: 14 B: 14	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 18 G: 18 B: 18	R: 13 G: 13 B: 13	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 11 G: 11 B: 11	R: 12 G: 12 B: 12	R: 12 G: 12 B: 12	R: 13 G: 13 B: 13	R: 11 G: 11 B: 11
R: 90 G: 90 B: 90	R: 42 G: 42 B: 42	R:100 G:100 B:100	R: 60 G: 60 B: 60	R: 51 G: 51 B: 51	R: 49 G: 49 B: 49	R: 44 G: 44 B: 44	R: 46 G: 46 B: 46	R: 43 G: 43 B: 43	R: 67 G: 67 B: 67	R: 95 G: 95 B: 95	R: 54 G: 54 B: 54	R: 55 G: 55 B: 55	R: 52 G: 52 B: 52	R: 46 G: 46 B: 46	R: 54 G: 54 B: 54	R: 59 G: 59 B: 59	R: 73 G: 73 B: 73	R:115 G:115 B:115	R: 99 G: 99 B: 99
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R:176 G:176 B:176	R:191 G:191 B:191	R:177 G:177 B:177	R:197 G:197 B:197	R:177 G:177 B:177	R:197 G:197 B:197	R:176 G:176 B:176	R:190 G:190 B:190	R:176 G:176 B:176	R:189 G:189 B:189	R:181 G:181 B:181	R:187 G:187 B:187	R:176 G:176 B:176	R:191 G:191 B:191	R:178 G:178 B:178	R:182 G:182 B:182	R:177 G:177 B:177	R:187 G:187 B:187	R:179 G:179 B:179	R:181 G:181 B:181
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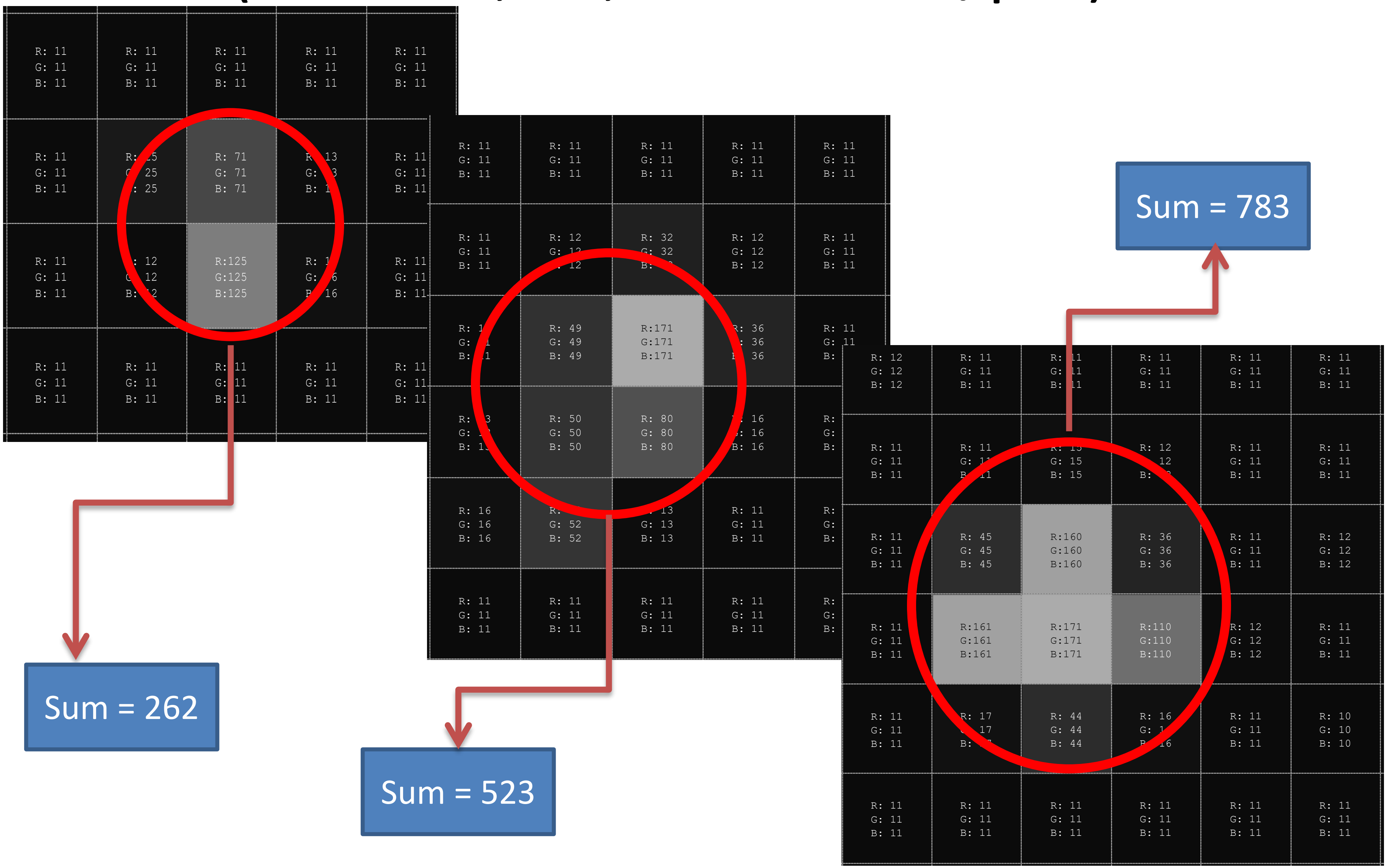
Track Structure for LET 13, 25, and 50 (keV/μm)

Detector	LET (keV/μm)	Attenuation	Dose-Rate (Gy/min)	Count	Reference
0 degrees	**13**	1/300	0.00066	2	Run-19
0 degrees	**13**	1/100	0.03910	70	Run-20
0 degrees	**13**	1/30	0.41752	525	Run-21

Detector	LET	Attenuation	Dose-Rate	Count	Reference
0 degrees	**25**	1/300	0.00066	2	Run-22
0 degrees	**25**	1/100	0.03910	70	Run-23
0 degrees	**25**	1/30	0.41752	525	Run-24

Detector	LET	Attenuation	Dose-Rate	Count	Reference
0 degrees	**50**	1/300	0.00066	2	Run-25
0 degrees	**50**	1/100	0.03910	70	Run-26
0 degrees	**50**	1/30	0.41752	525	Run-27

Individual Track Cross-Sections (LET = 13, 25, and 50 keV/µm)



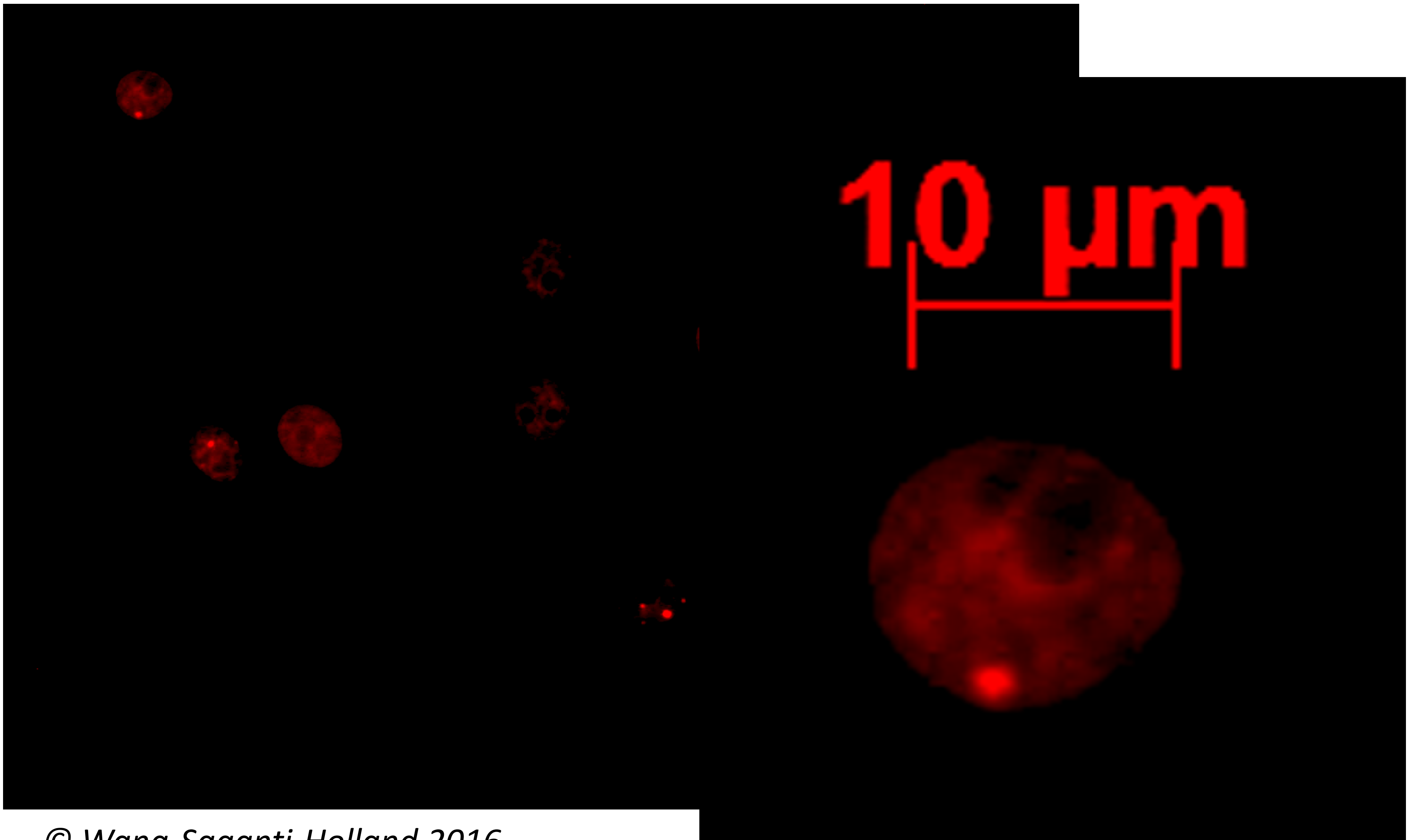
BIOLOGICAL APPLICATIONS

An Overview

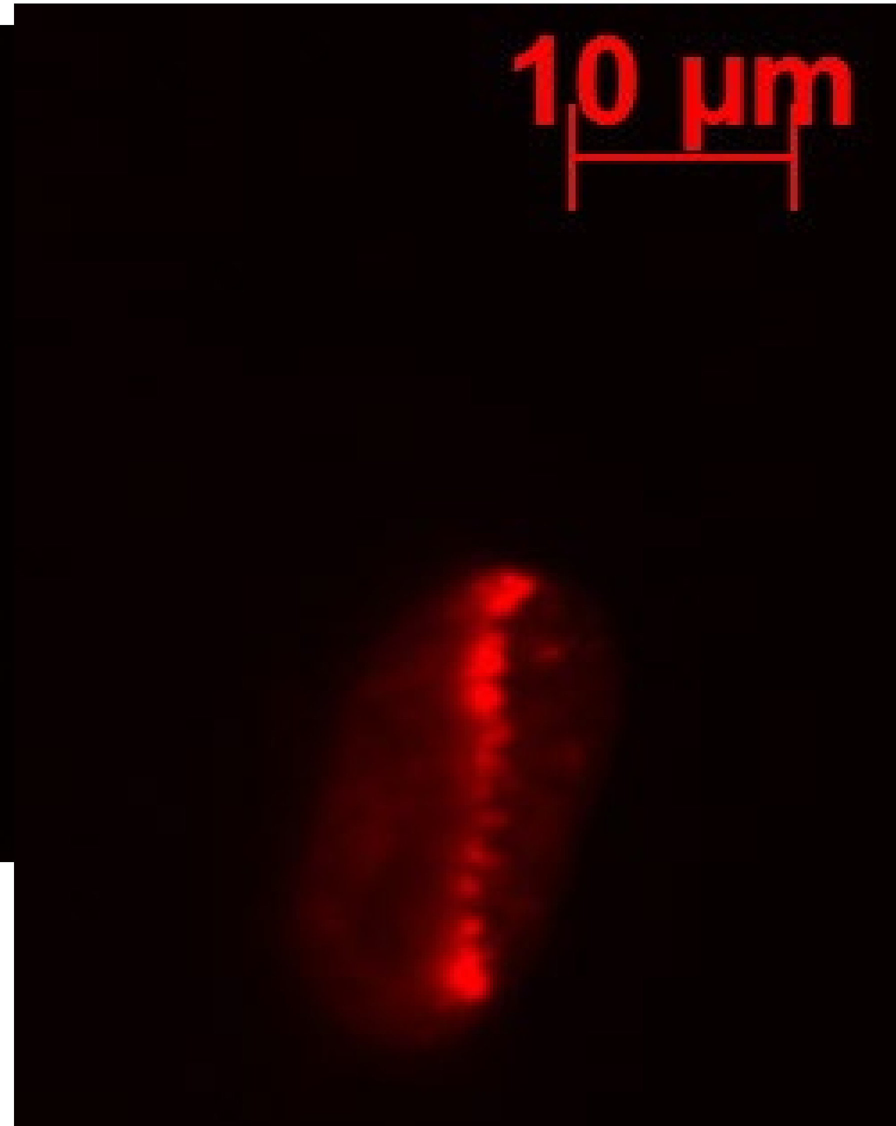
Example - DNA damage foci and pixel image (Wang / Saganti)

- DNA damage foci
  - Live imaging mCherry - 53BP1 in mouse hippocampal neuronal cells
  - Staining 53BP1 in mouse hippocampal neuronal cells
  - Zeiss Fluorescent microscope at NSRL
  - Leica Confocal microscope at RaISE
- Pixel image
  - 1.67 um/pixel
  - 10 um each pixel spot and 100 um pixel track
- Foci image
  - 0.16 um/pixel
  - about 1 um each focal spot and 10 um foci track

C-300 MeV: Detector along the beam line (90° alignment)
Beam: Dose-Rate = 1 cGy/min, Total Dose = 2cGy

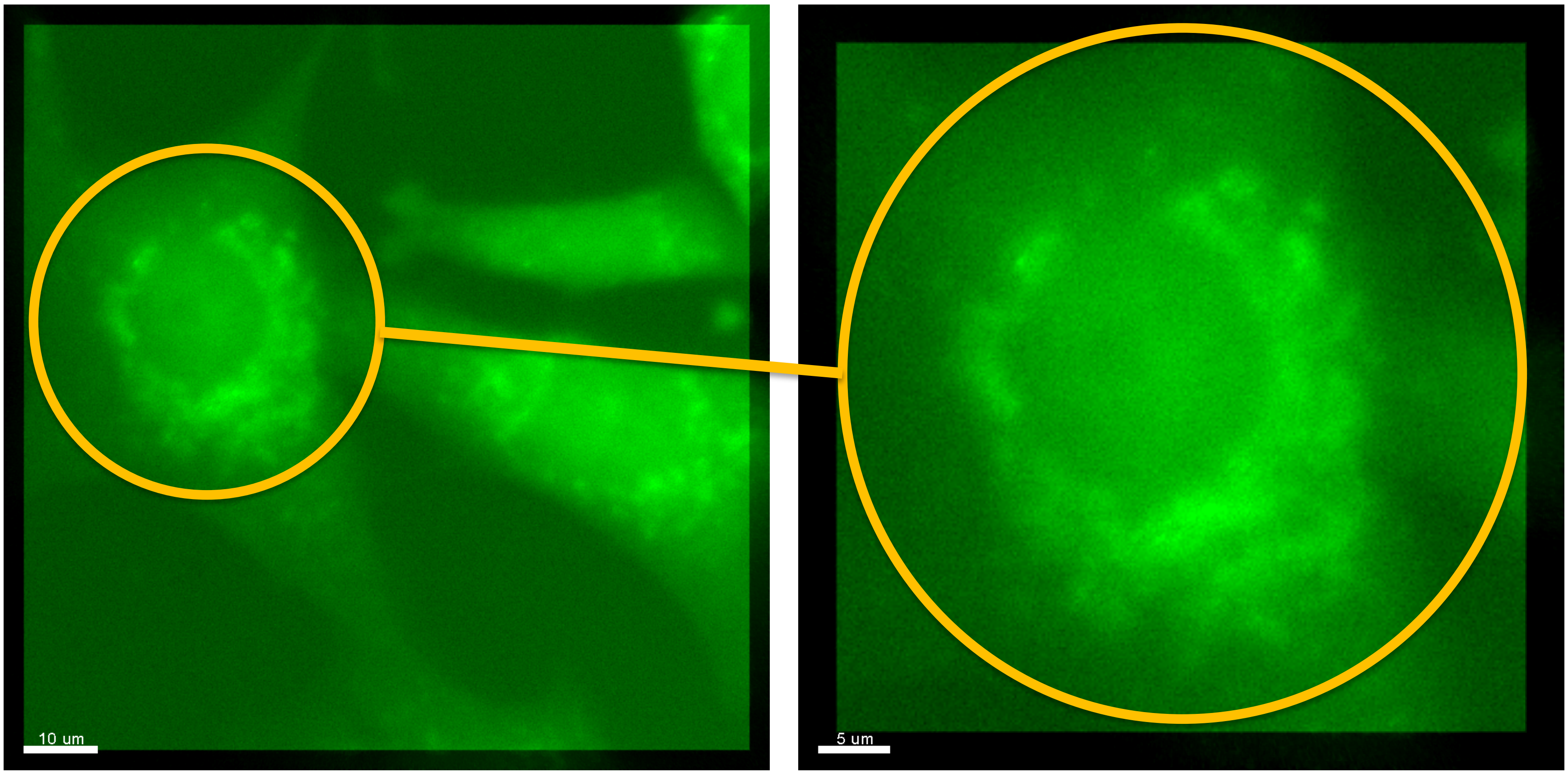


C-300 MeV: Detector along the beam line (0° alignment)
Beam: Dose-Rate = 1 cGy/min, Total Dose = 2cGy



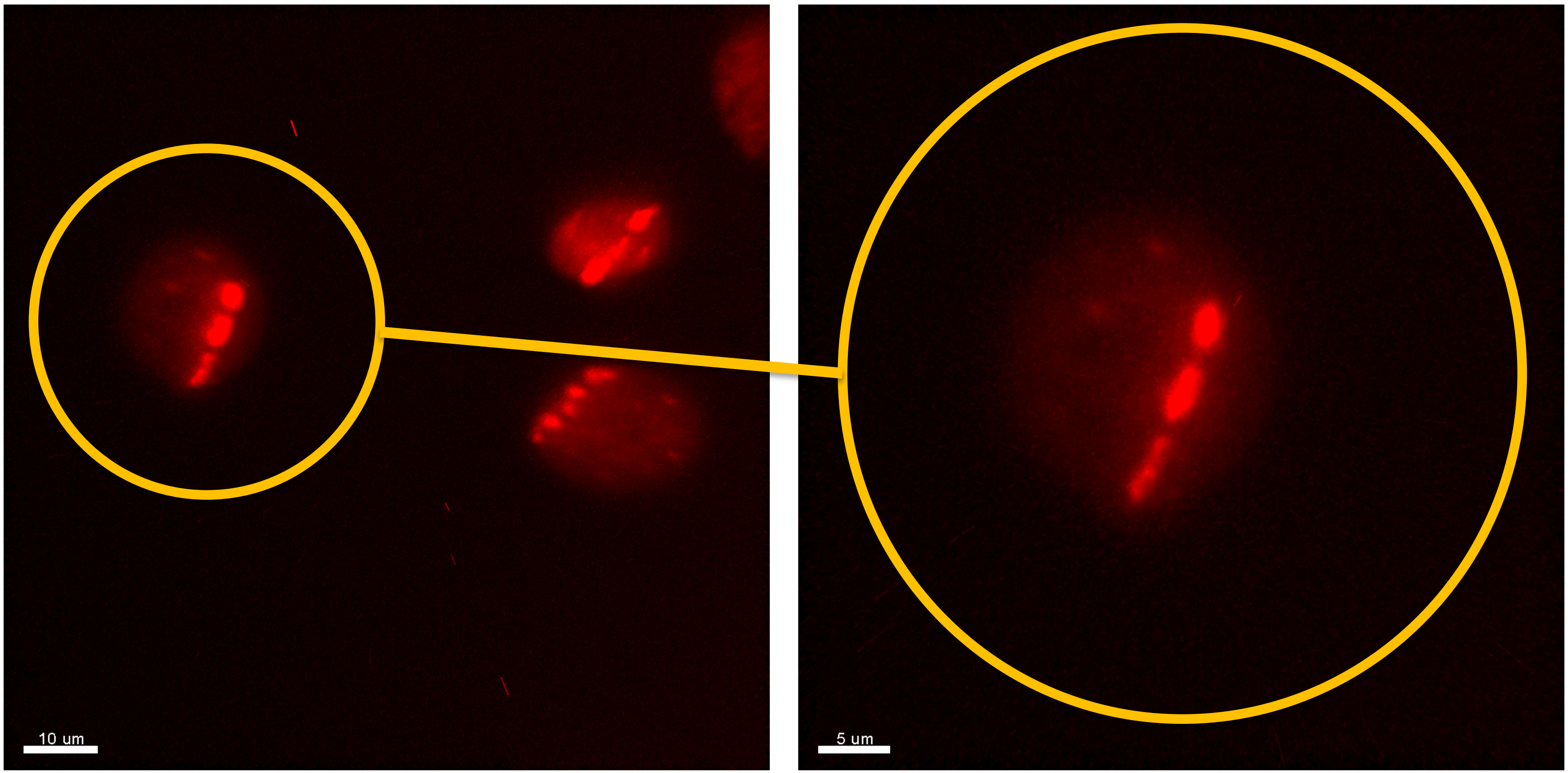
Mouse Hippocampal neuronal cells (HT22) and Radiation Particle Trajectory (C ions, LET = 50 keV/um)

(GFP-LC3)



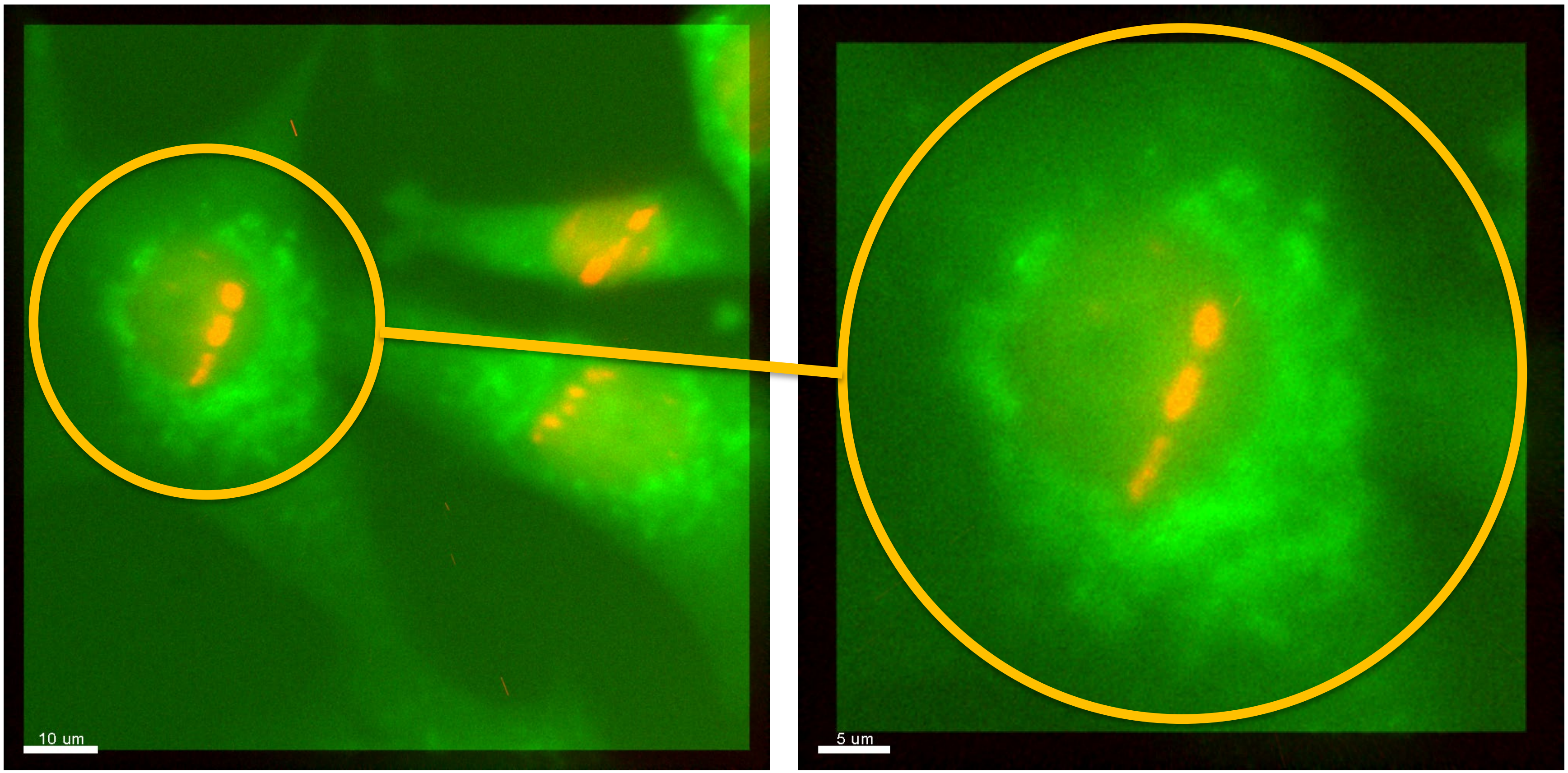
Mouse Hippocampal neuronal cells (HT22) and Radiation Particle Trajectory (C ions, LET = 50 keV/um)

(mCherry-53BP1)



Mouse Hippocampal neuronal cells (HT22) and Radiation Particle Trajectory (C ions, LET = 50 keV/um)

[(GFP-LC3) + (mCherry-53BP1)]



© Inage Credit – Leica SP8 Confocal System at CRI / RaISE

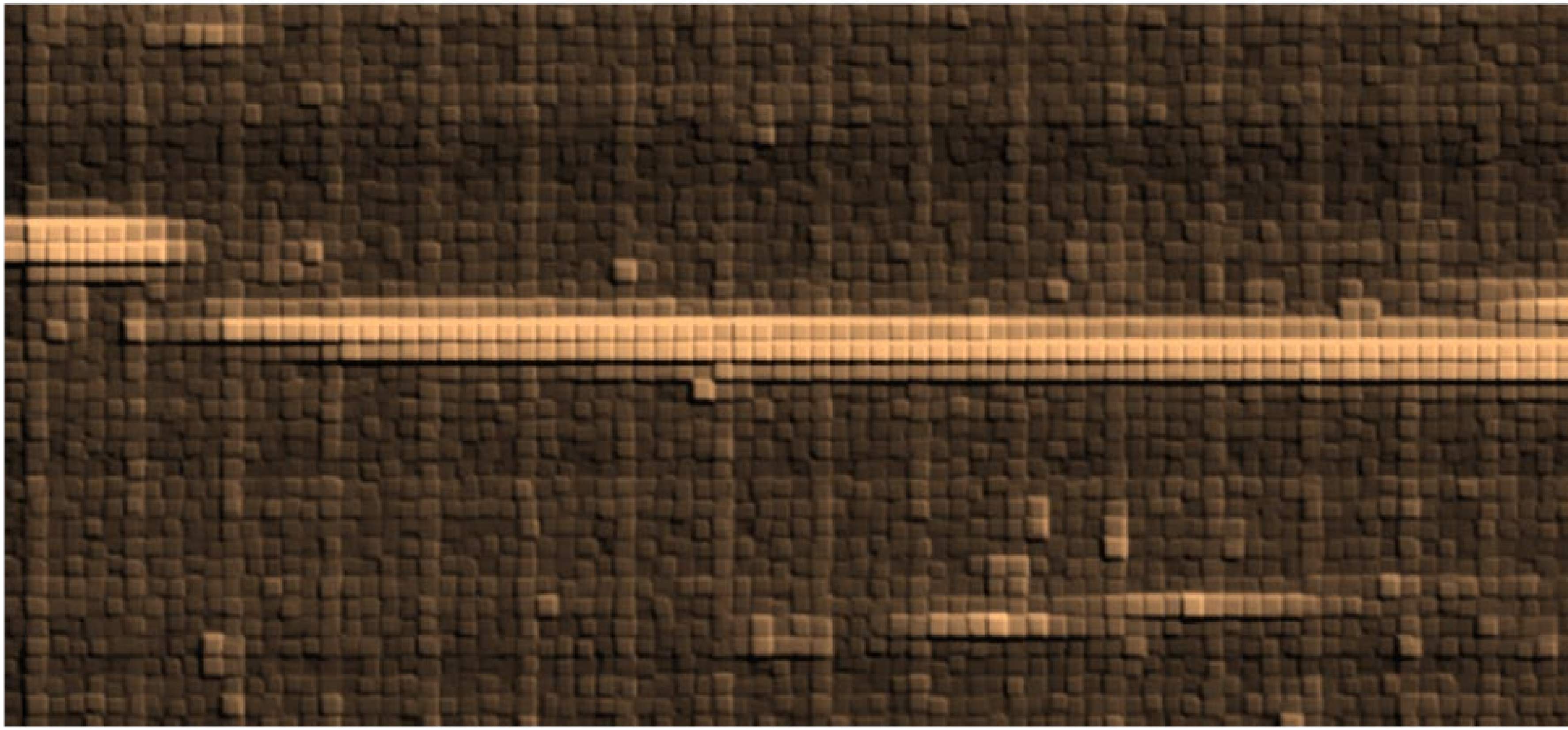
Carbon Ion Facilities in the WORLD (Year Commissioned)

	COUNTRY	WHO, WHERE	PARTICLE	Max Energy (MeV)	Start of Treatment
1	Japan	HIMAC, QST, Chiba	C-ion	S 800/u	1994
2	Japan	HIBMC, Hyogo	C-ion	S 320/u	2002
3	Germany	HIT, Heidelberg	C-ion	S 430/u	2009
4	Japan	GHMC, Gunma	C-ion	S 400/u	2010
5	Italy	CNAO, Pavia	C-ion	S 480/u	2012
6	Japan	SAGA-HIMAT, Tosu	C-ion	S 400/u	2013
7	China	SPHIC, Shanghai	C-ion	S 430/u	2014
8	Germany	MIT, Marburg	C-ion	S 430/u	2015
9	Japan	iRKCC, Yokohama	C-ion	S 430/u	2015
10	Japan	OHITC, Osaka	C-ion	S 430/u	2018
11	Austria	MedAustron, Wiener Neustadt	C-ion	S 403/u	2019
12	China	HICTC, Wuwei, Gansu	C-ion	S 400/u	2019

~ 12 Facilities
Around the World
In **5** Countries
(1994 – Present)

Data Taken From PTCOG

Radiation Track Structure at Micron Level of Carbon Ions



Radiation Track at 1.67 micron per pixel resolution for carbon ion with 300 MeV/n and LET 50 keV/µm (approximately 100x50 pixels are shown from about 3600x2700 pixel image)

Conclusions / Summary

- Current Results - Promising Future
  - We developed detectors to capture carbon ion tracks (and several other ions) at micron level
  - We showed how to discriminate low LET variations
  - We are now developing 3D visualization of ion track and trajectory
  - We expect to aid in understanding biological effects and aid with (and for) model calculated assistance
  - We anticipate future heavy ion treatment capabilities to be of higher accuracy with our target data assessment

Imaging Radiation Particle Trajectories at Micron Resolution: Applications for ISS and Beyond

PB Saganti[1*]

H Wang[1], M Hada[1], SM Kolluri[1], Md Rahman[1], SE Saganti[1], GM Erickson[1], N. Kallur[1], JR Rhone[1,4], KM Menezes[1,6], Y Furusawa[2], R Hariyama[2], M Seivert[3], A. Rusek[3], SD Holland[1,4,5], and FA Cucinotta[1,7]

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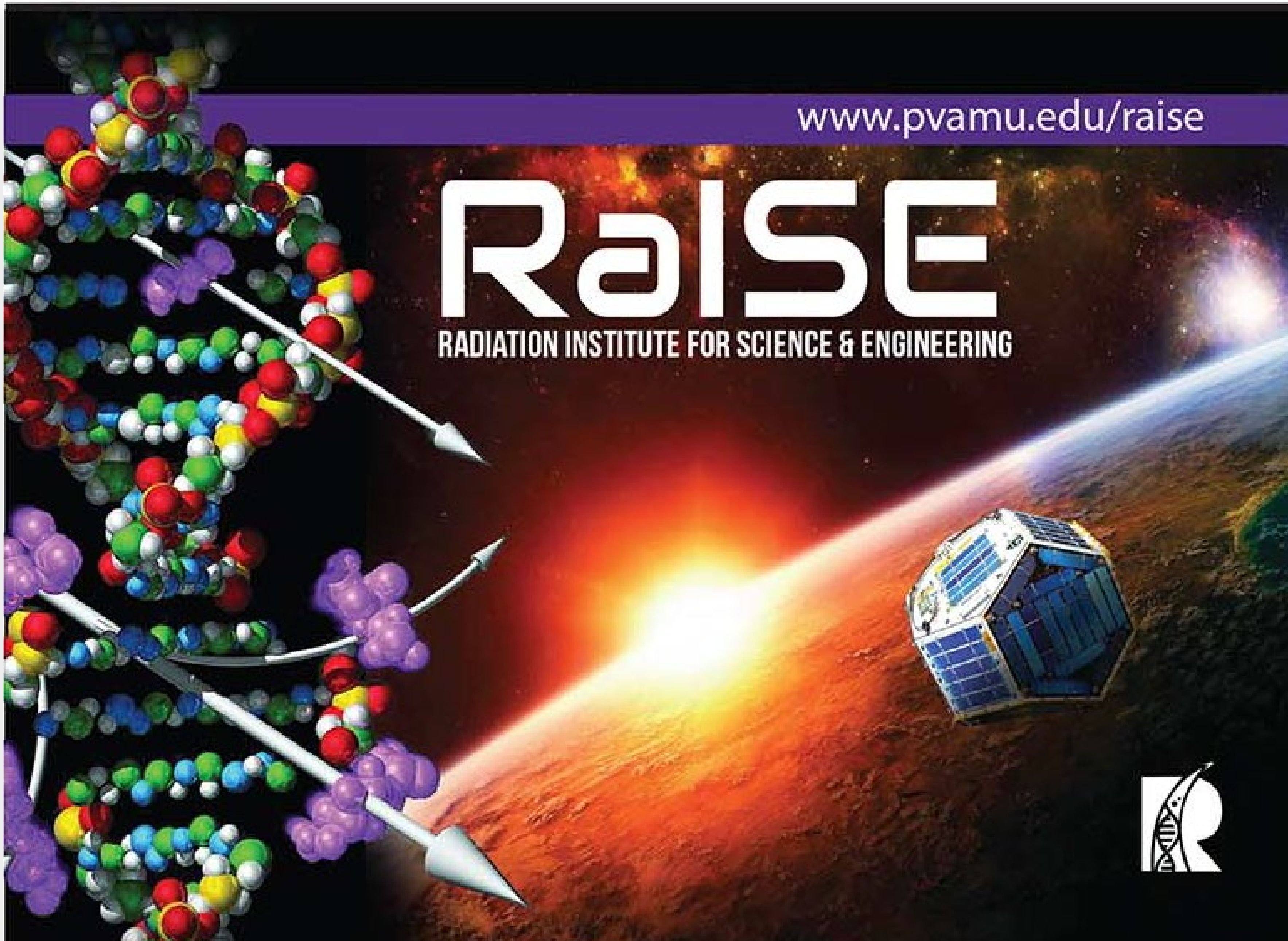

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