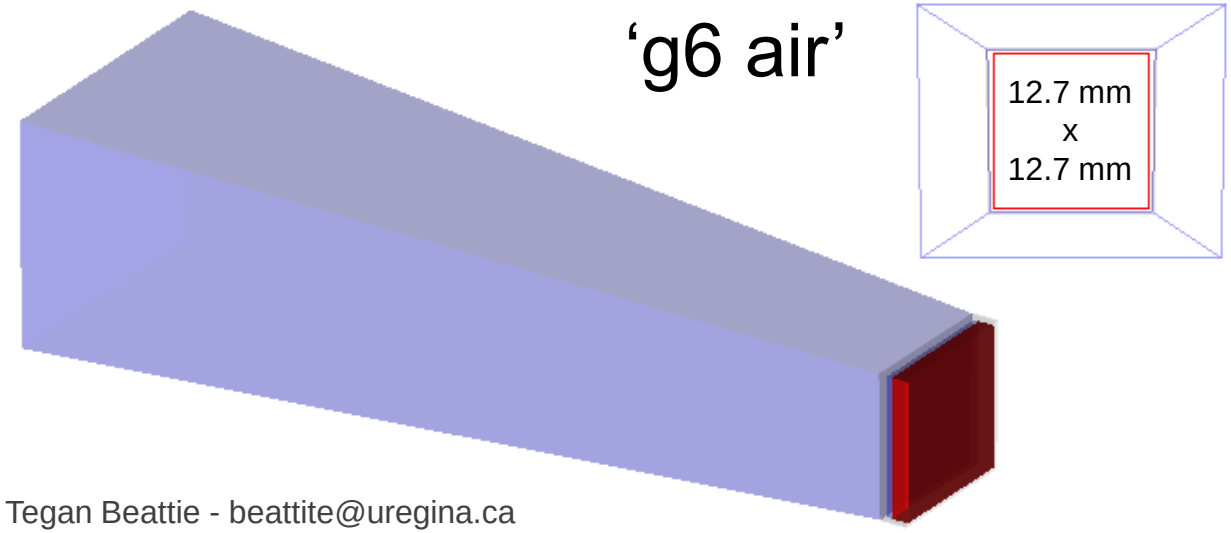
BIC Light Guide Efficiency and Light Mixing

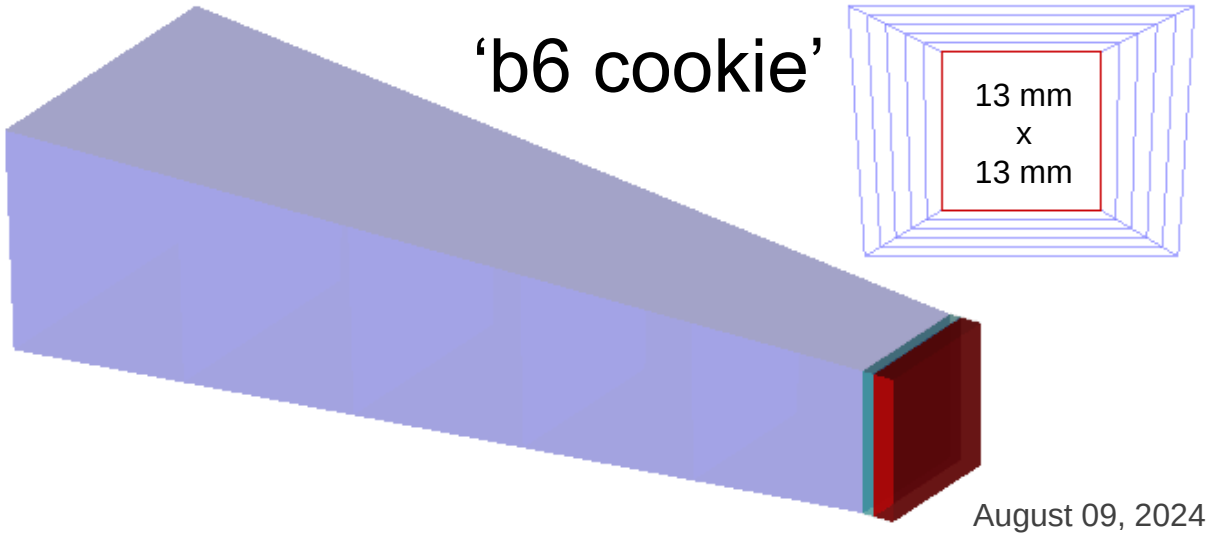
- Previous studies done by Elton Smith for GlueX light guides
  - Recreate and extend to BIC light guides vs. length
- Efficiency: how many photons reach the SiPM face?
- Light mixing: how evenly distributed are photons on the SiPM face?

- BCAL and BIC are both Pb/SciFi matrix EM calorimeters
  - Similar readout design: fiber matrix → light guides → SiPM arrays
  - 0.5 mm air gap (as used in GlueX) or 1 mm silicone optical cookie

‘g6 air’

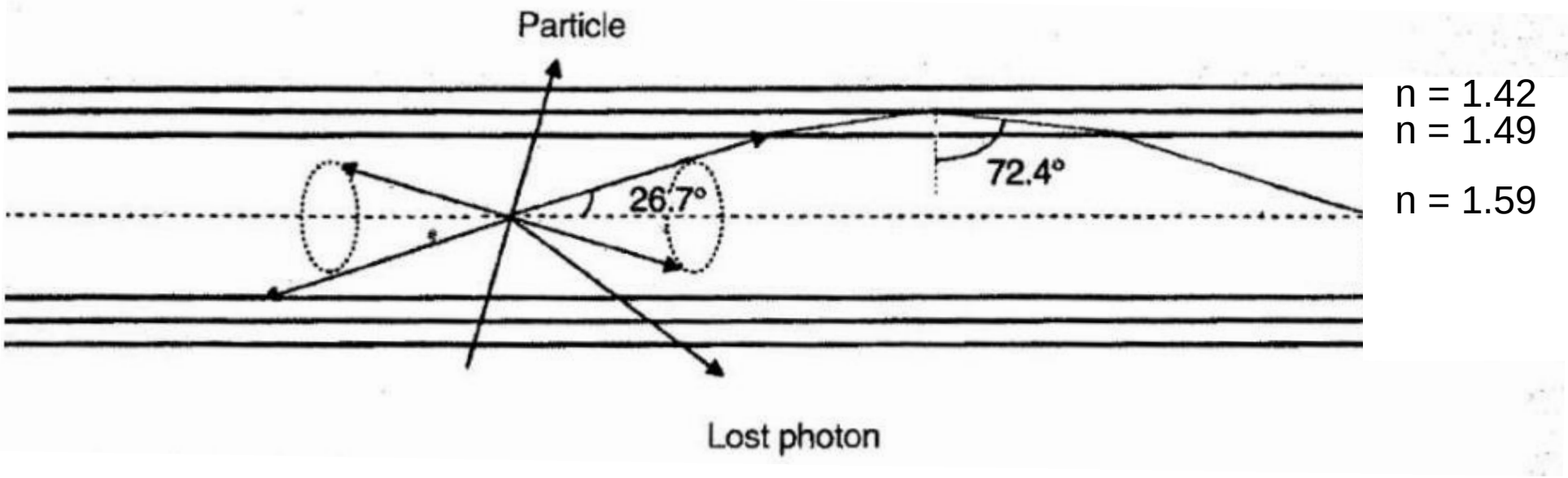


‘b6 cookie’



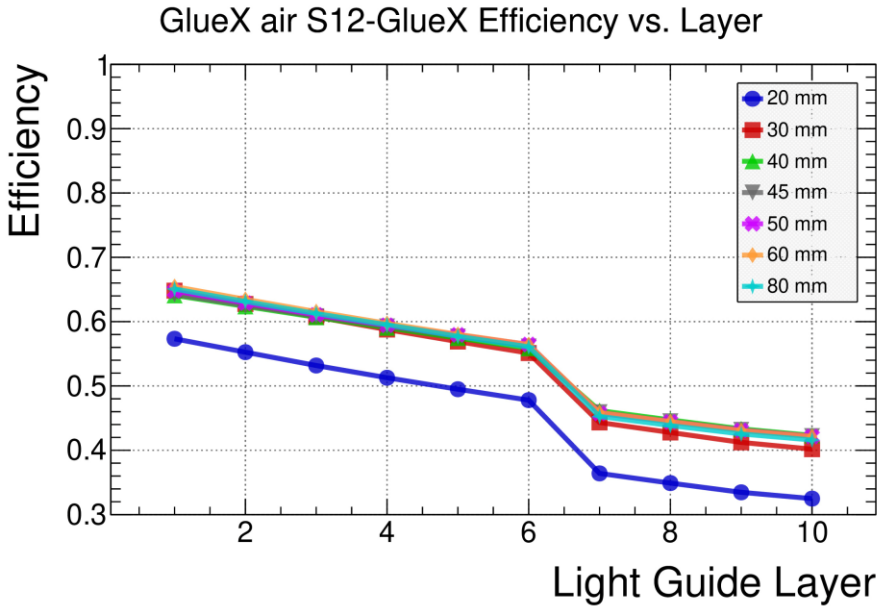
- Geant4, using G4EmStandardPhysics_option4() and G4OpticalPhysics()
- Generating G4OpticalPhotons (450 nm) at input face of light guides
  - Flat in φ, flat in cos(θ)
  - Limited to θ = 26.7 degrees
- Light guides: acrylic (n ~ 1.5)
- Optical cookie: silicone (n = 1.43)
- GlueX SiPM: S12045(X), window is 0.45 mm silicone resin (n = 1.41)
- BIC SiPM: S13361-3050-04, window is 0.1 mm epoxy resin (n = 1.55)

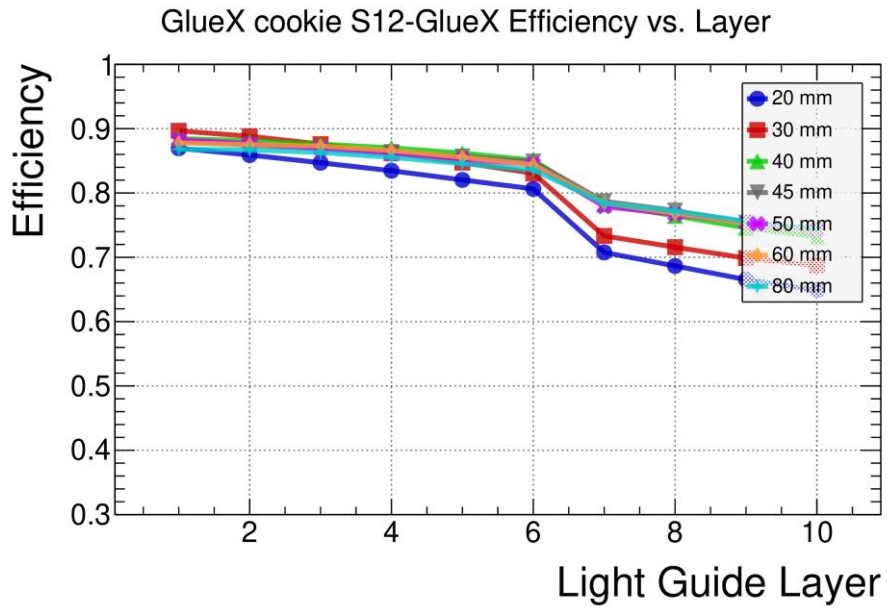
Should be epoxy resin, we'll fix that!

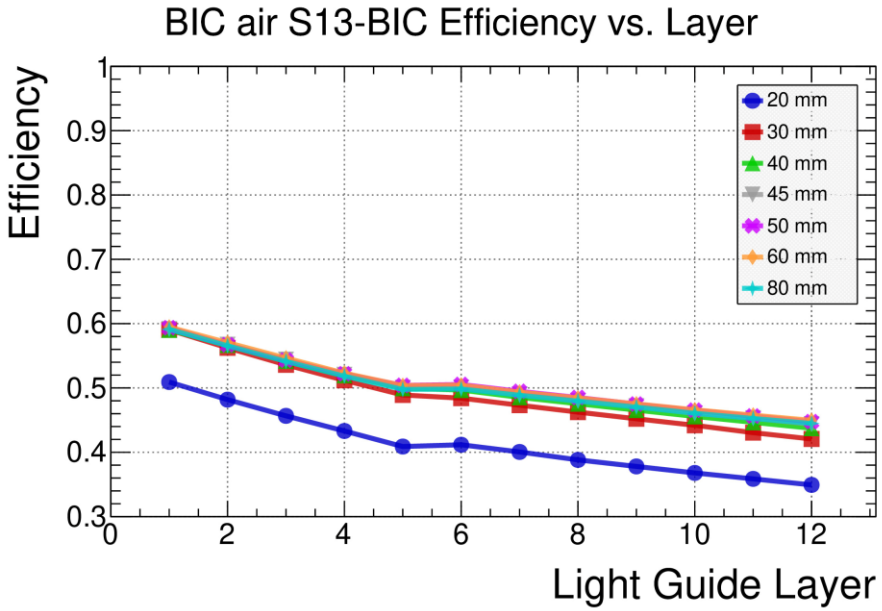


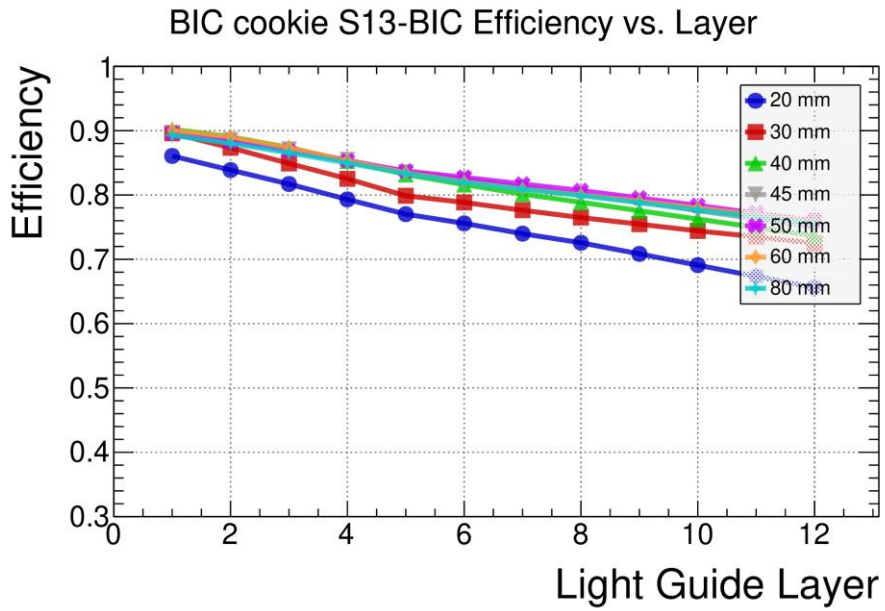
S12045 - https://halldweb.jlab.org/DocDB/0029/002913/005/smith_lasnpa.pdf
S13361-3050 - https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/ssd/s13361-3050_series_kapd1054e.pdf
Figure - GlueX-doc-1432

Efficiencies





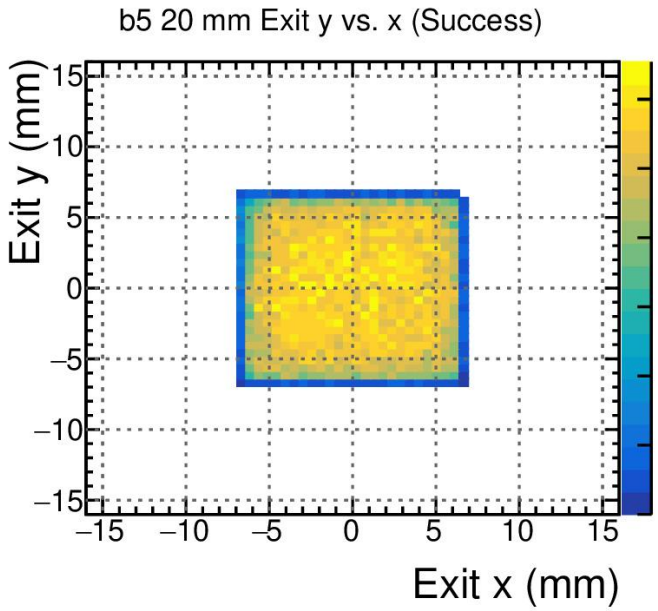


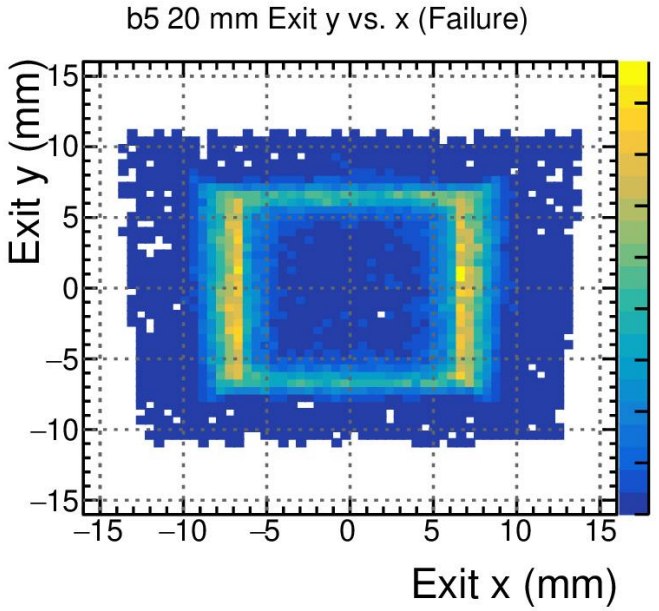


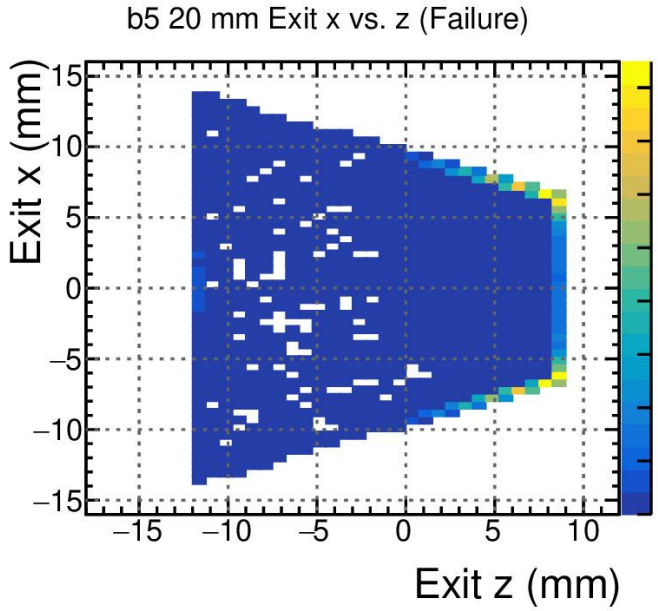
50 mm Efficiencies

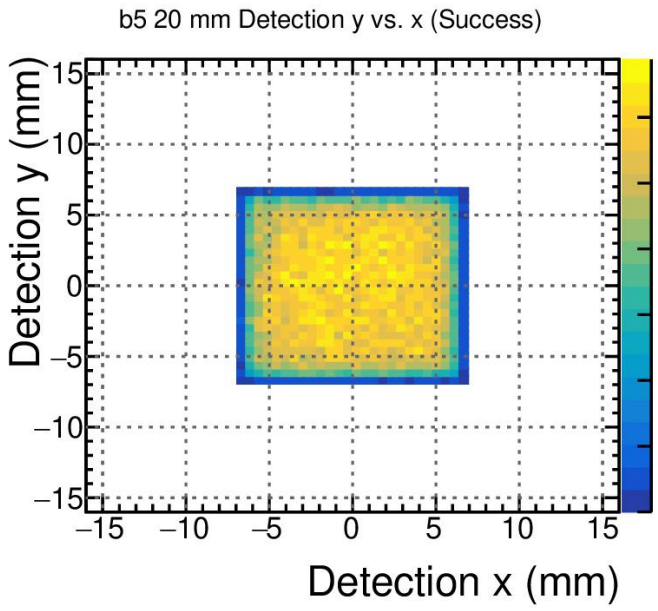
Layer #	GlueX air	GlueX cookie	BIC air	BIC cookie
1	0.647	0.883	0.594	0.896
2	0.629	0.877	0.567	0.883
3	0.611	0.868	0.543	0.869
4	0.594	0.861	0.522	0.853
5	0.579	0.852	0.504	0.837
6	0.564	0.845	0.505	0.827
7	0.457	0.779	0.495	0.817
8	0.444	0.767	0.485	0.807
9	0.431	0.753	0.475	0.795
10	0.421	0.742	0.465	0.784
11	–	–	0.456	0.772
12	–	–	0.448	0.760

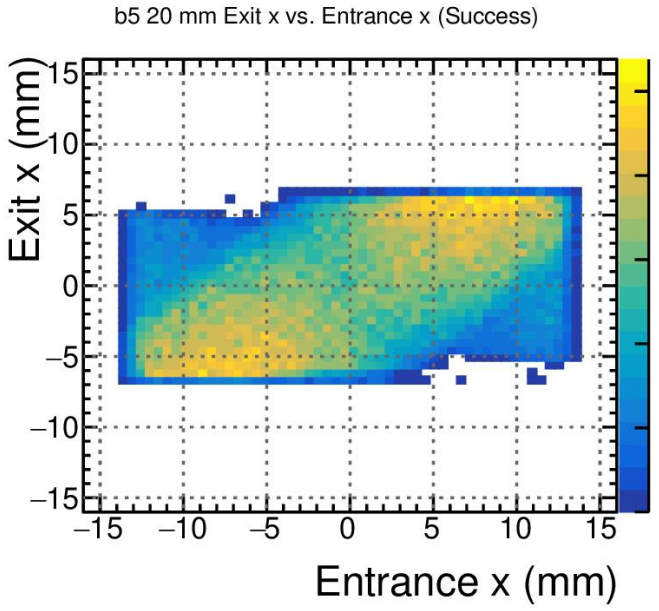
Light Mixing – BIC cookie

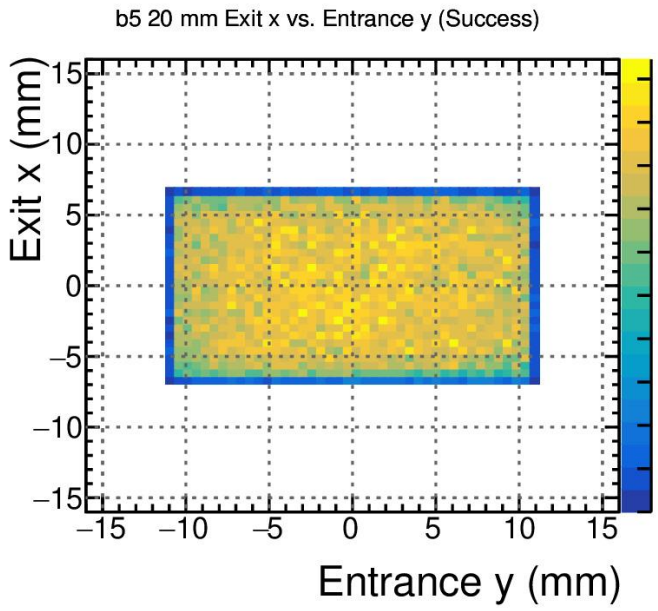












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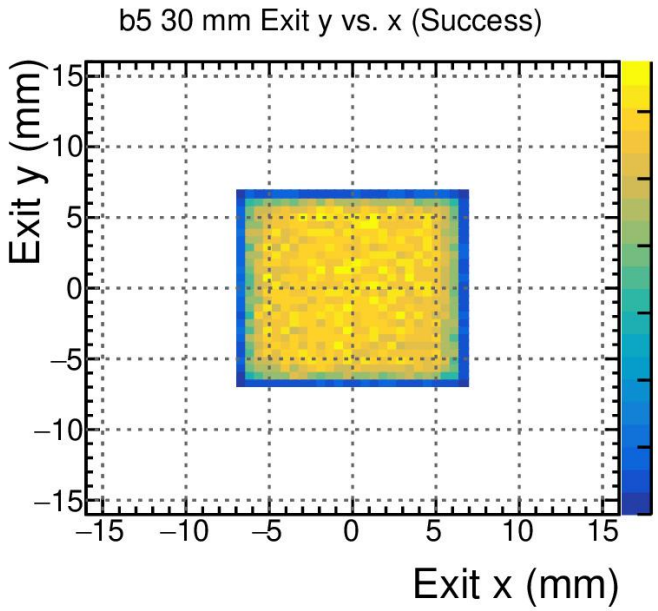

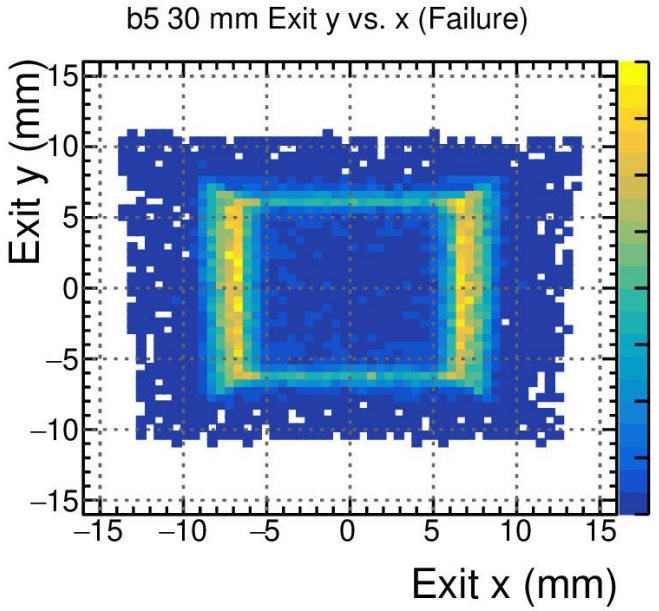

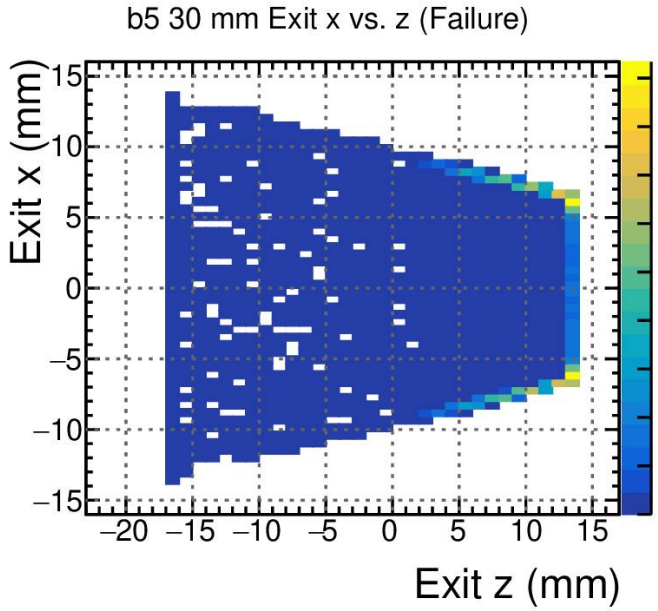

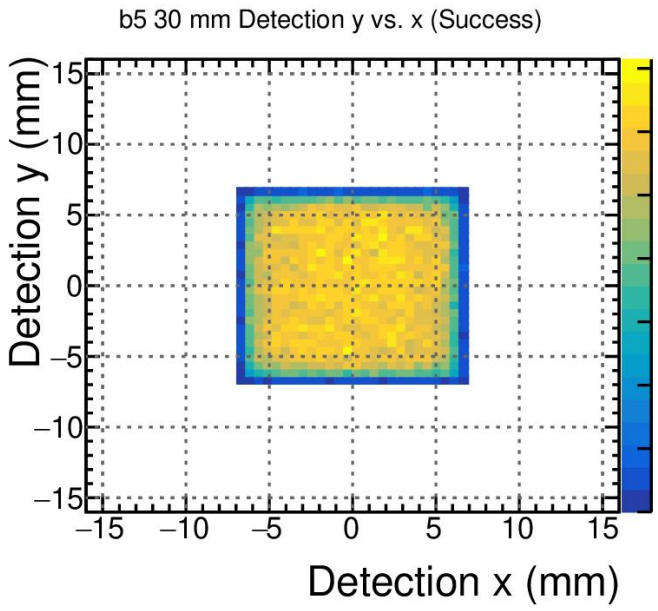

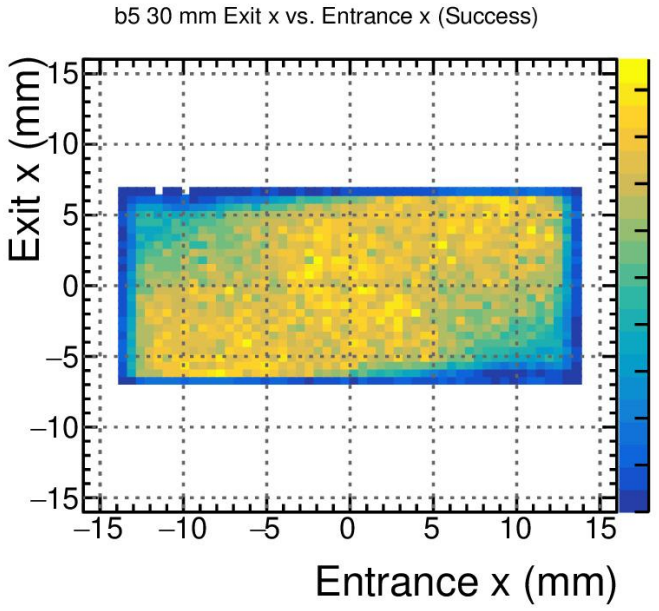

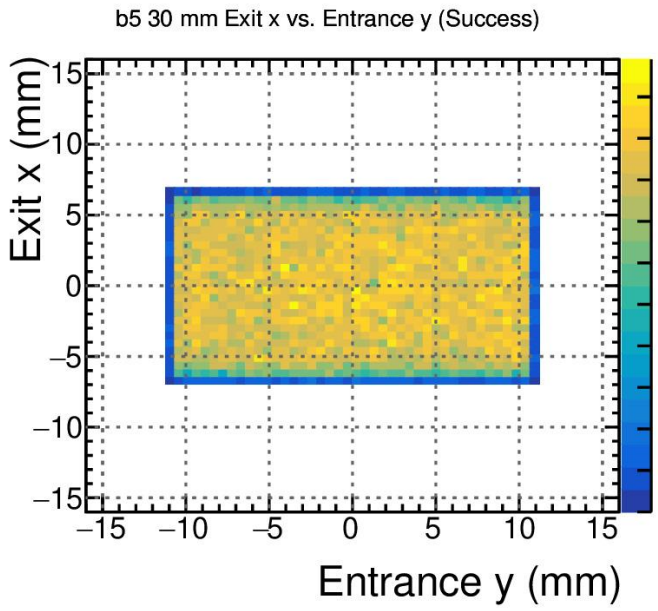

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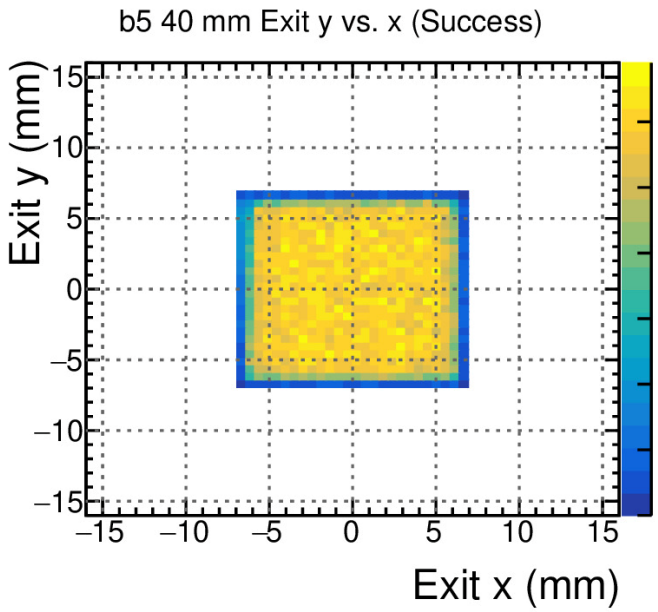

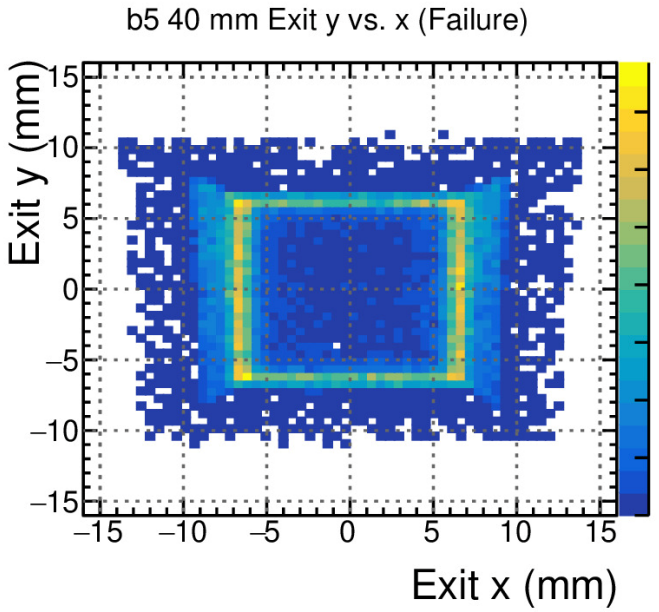

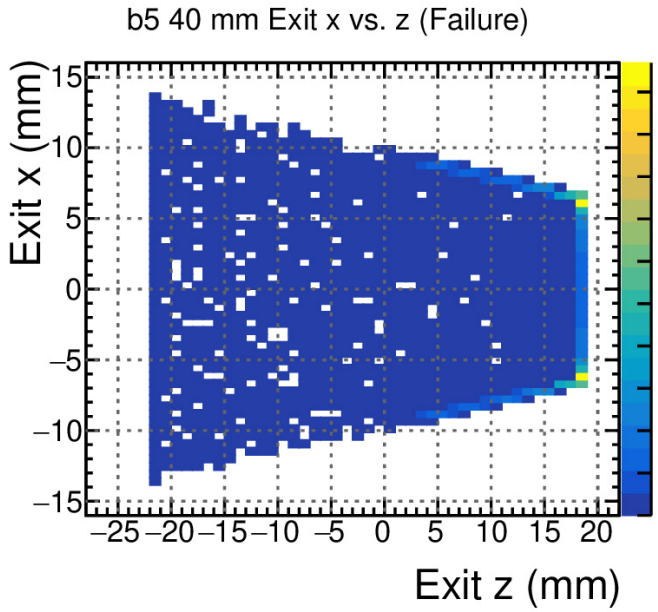

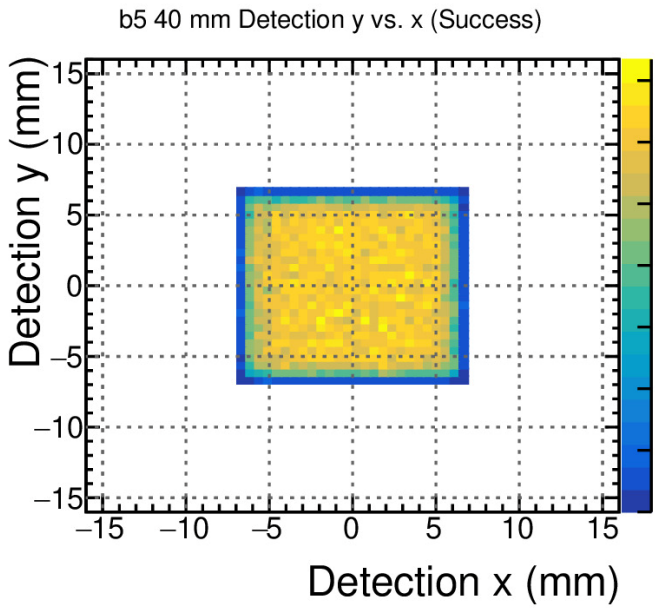

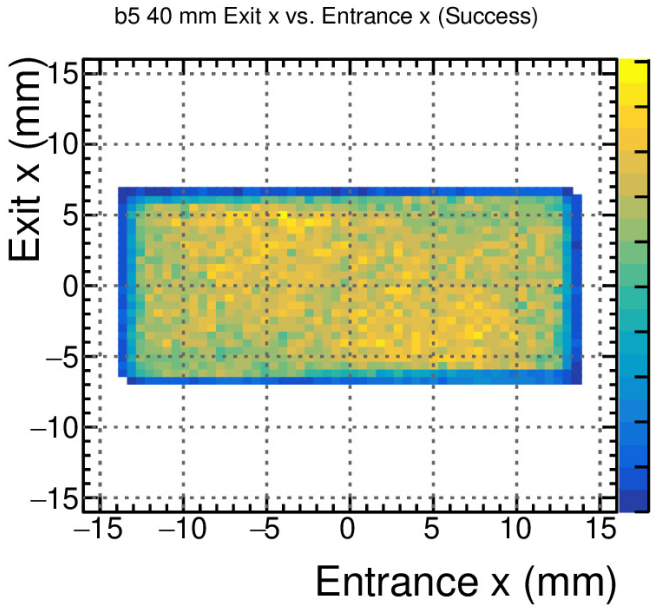

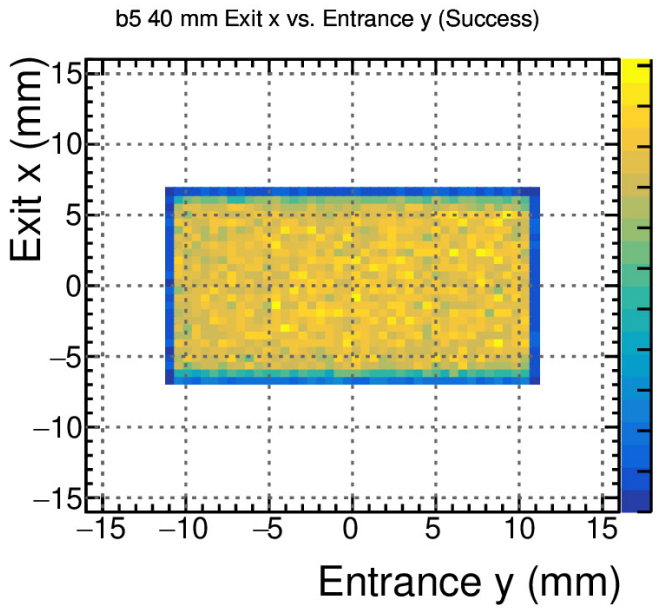

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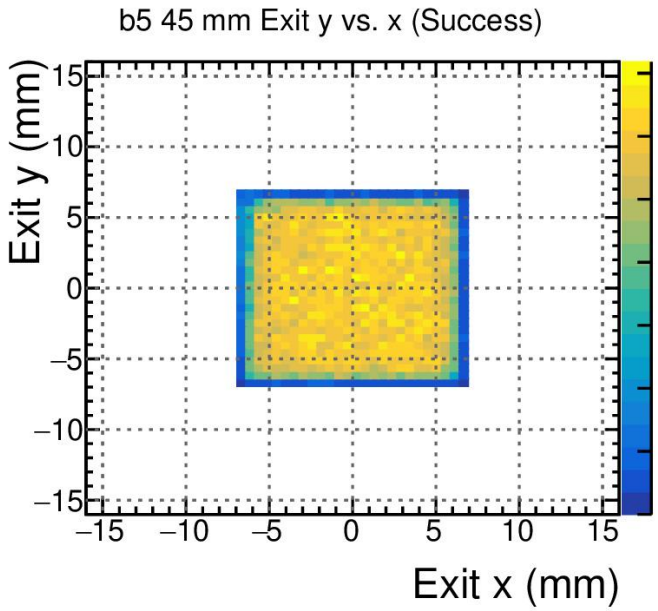

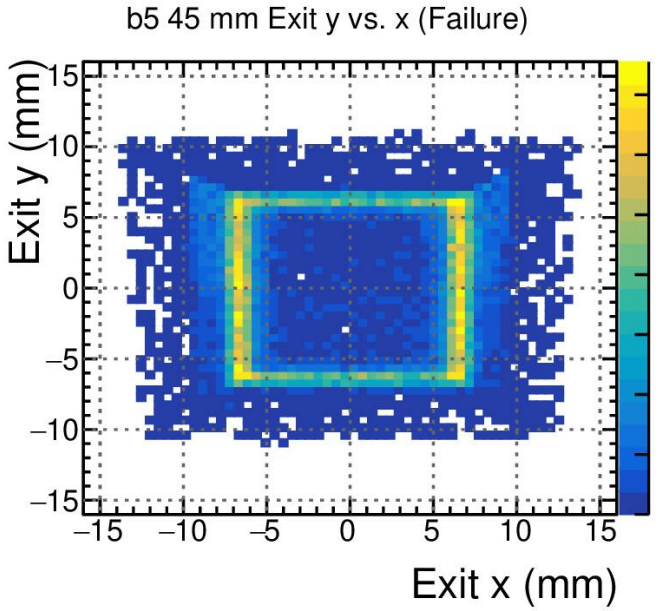

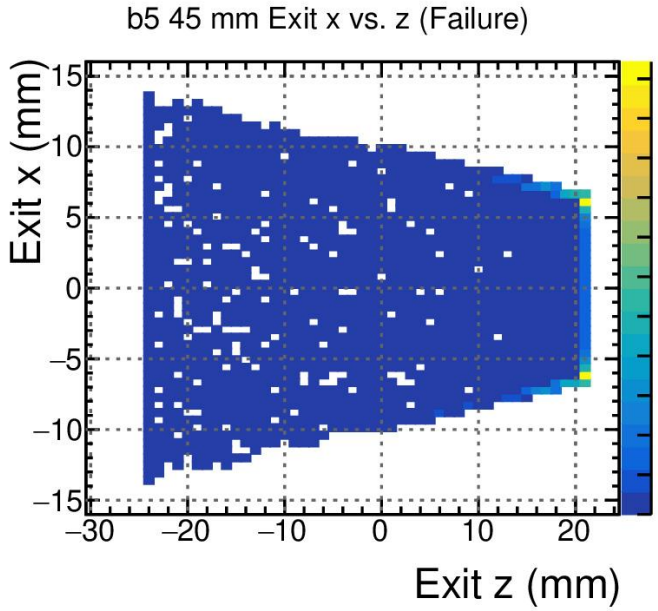

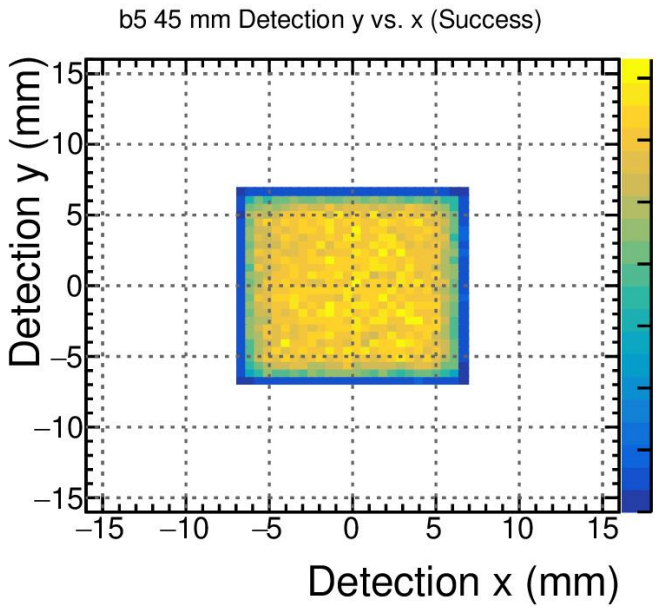

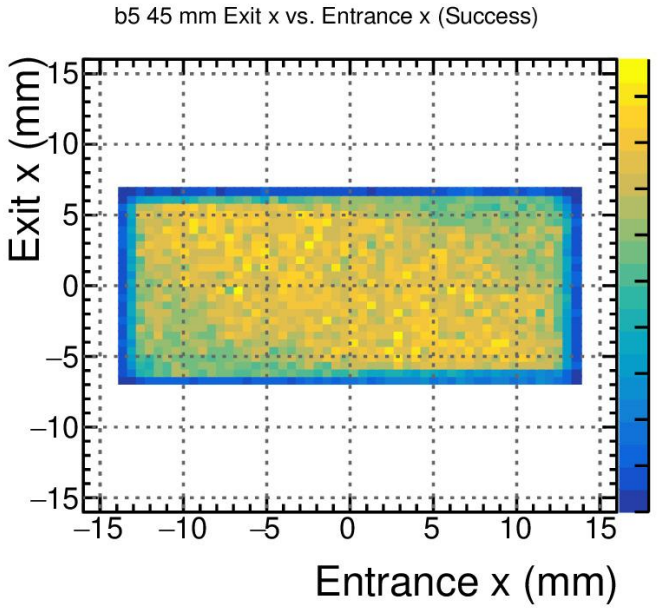

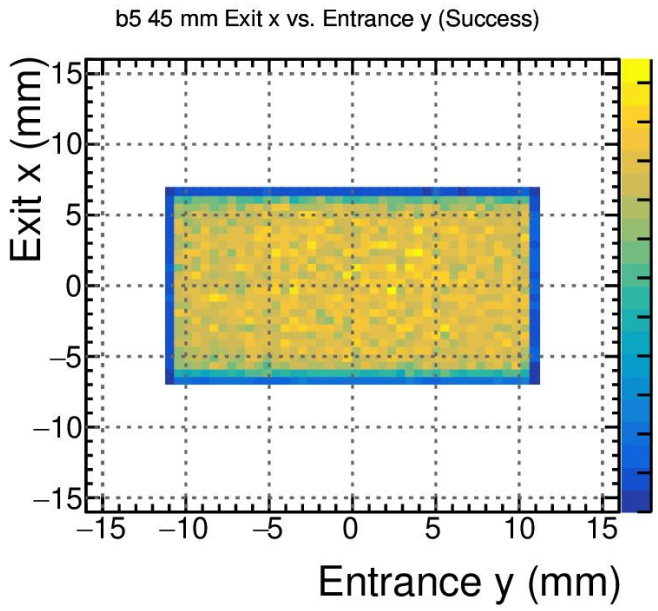

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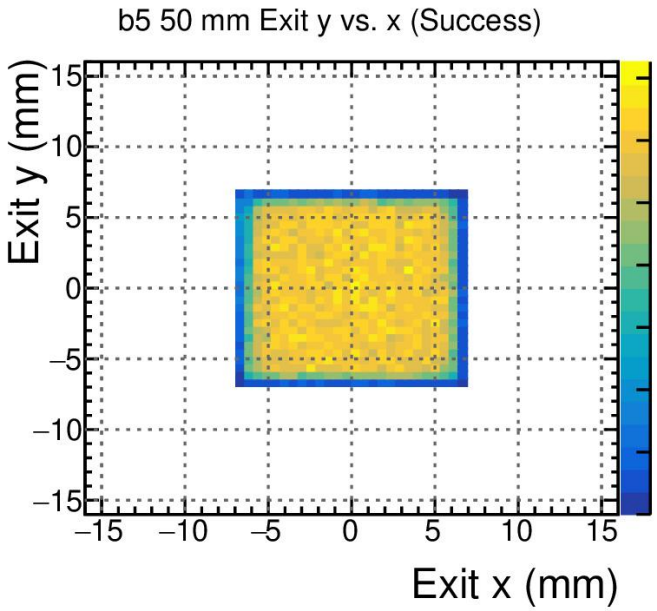

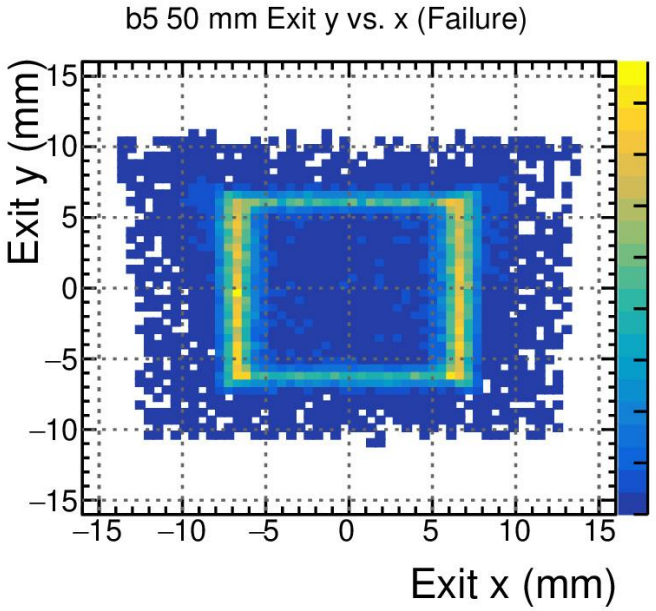

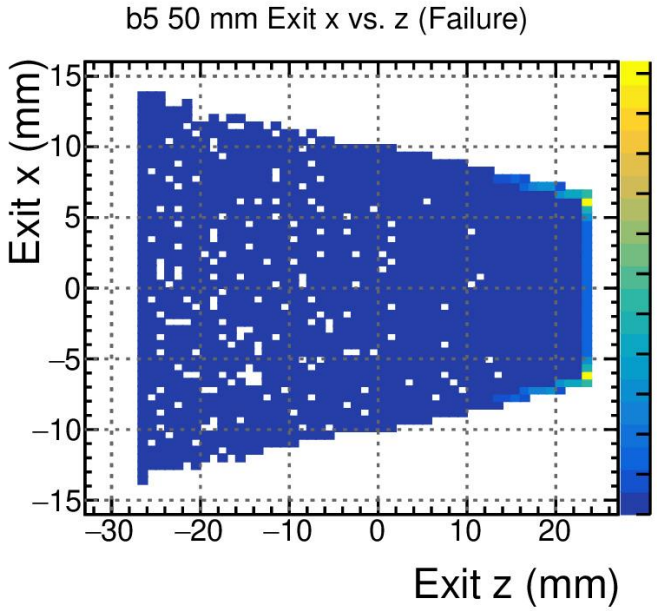

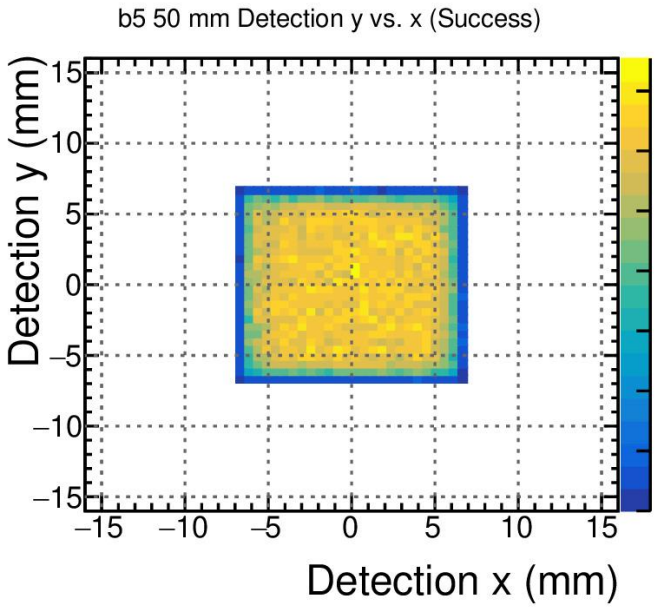

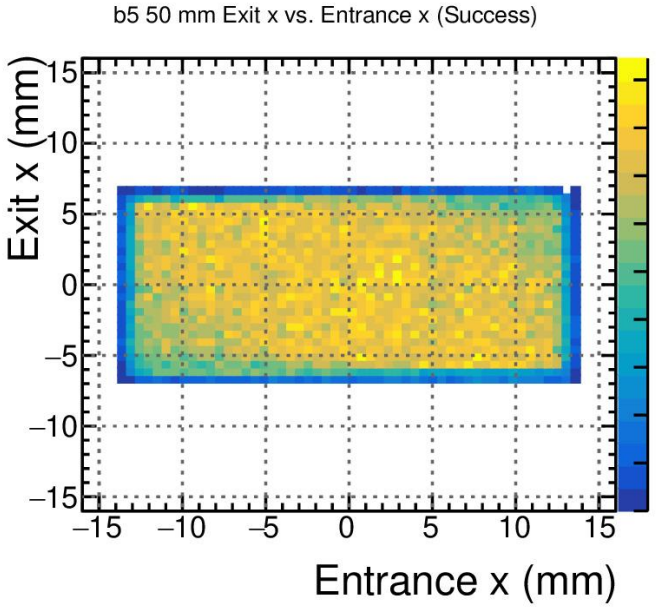

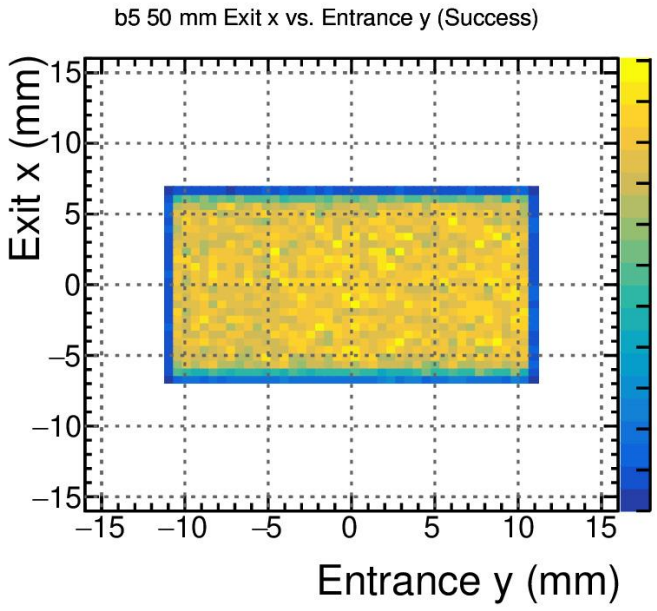

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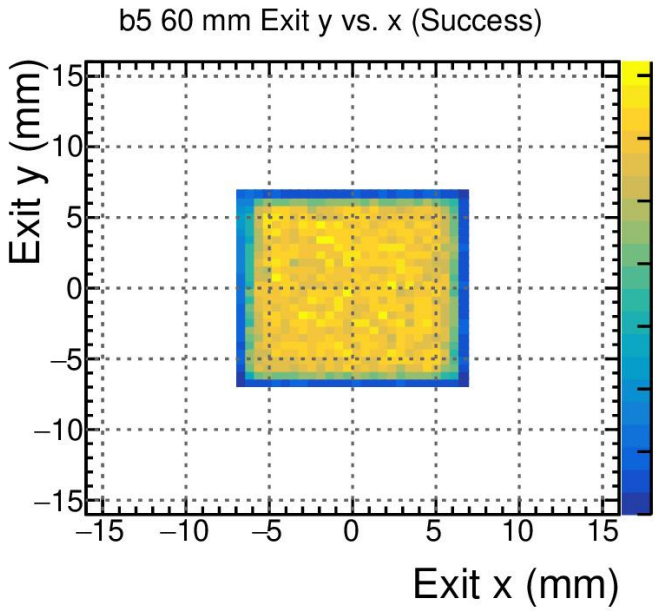

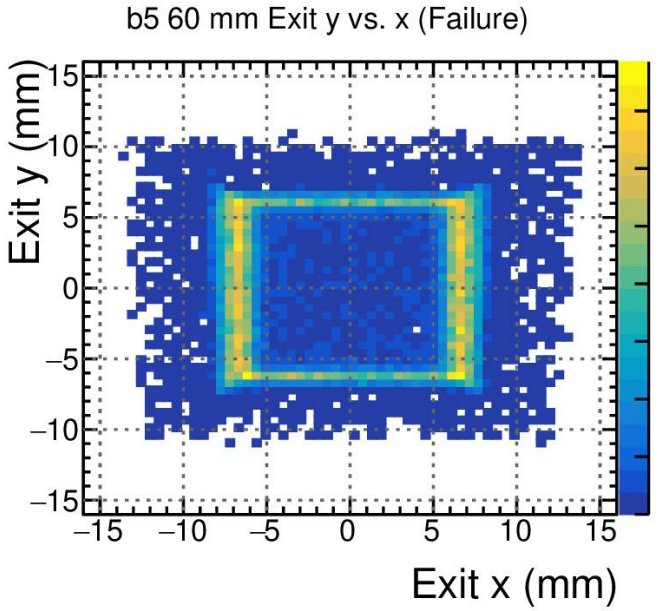

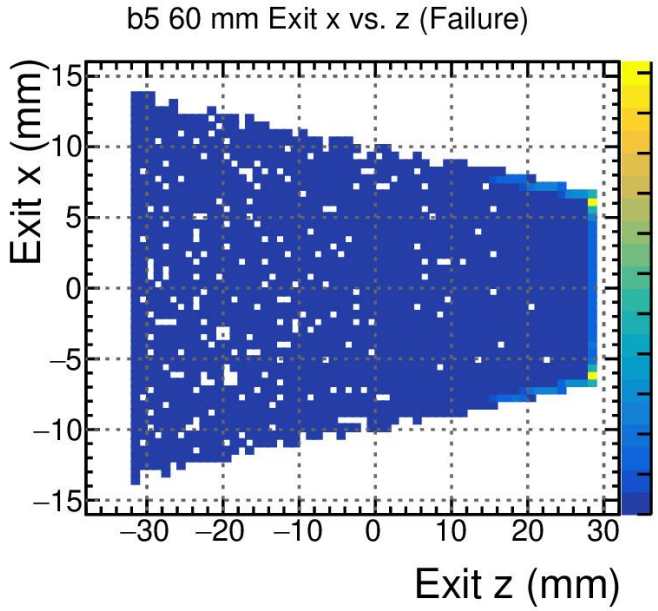

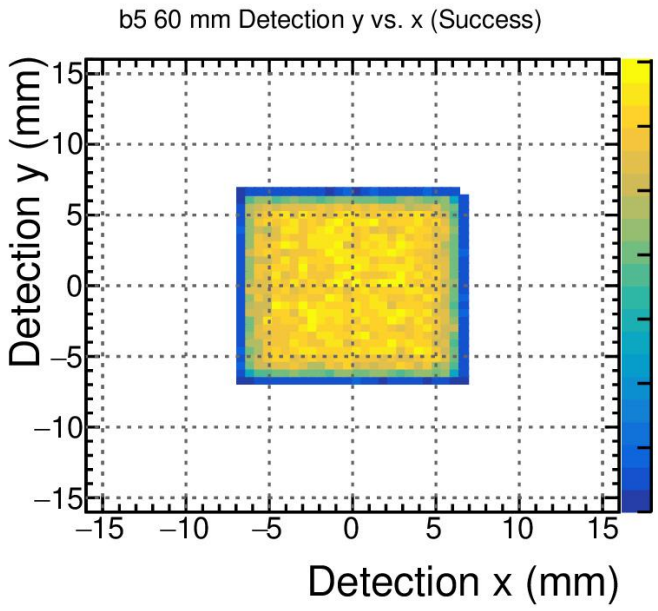

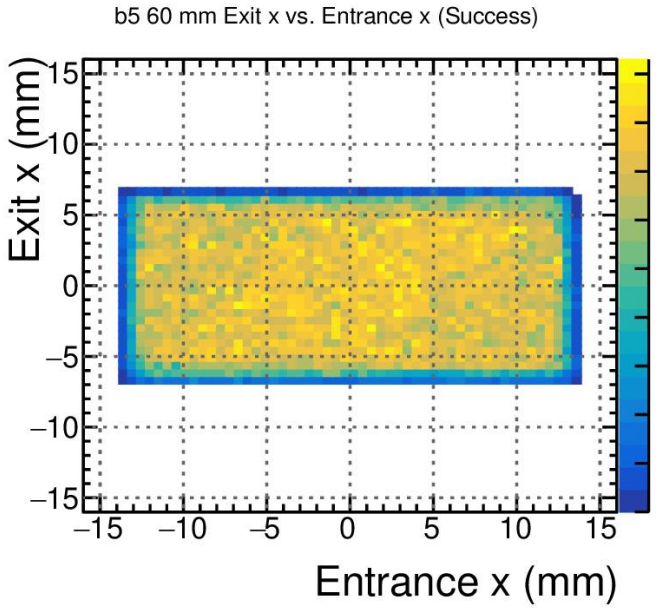

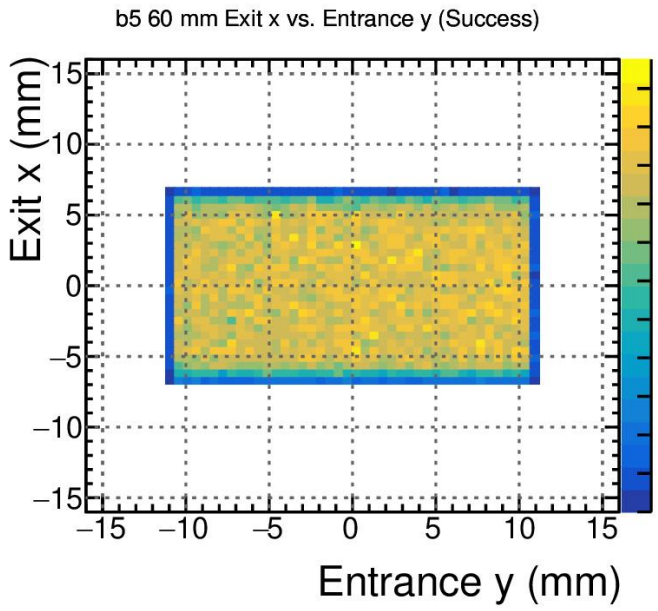

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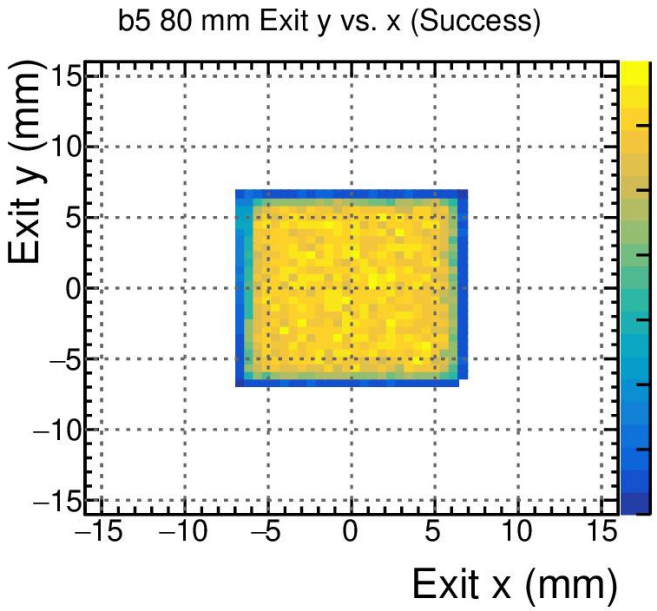
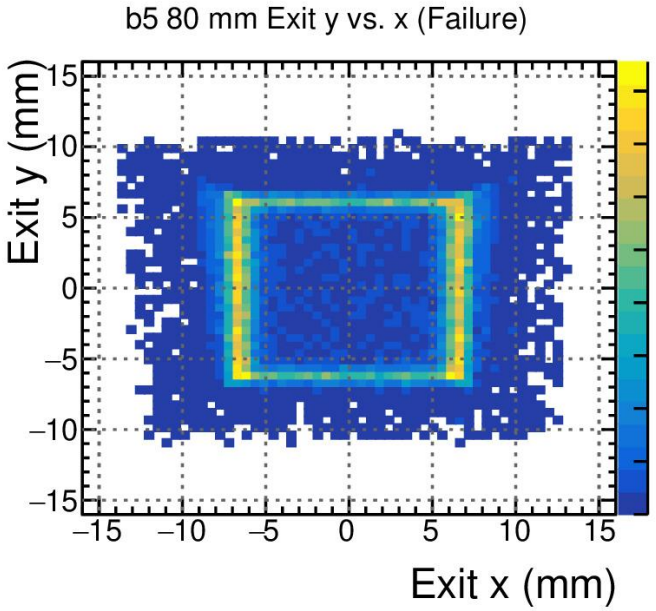
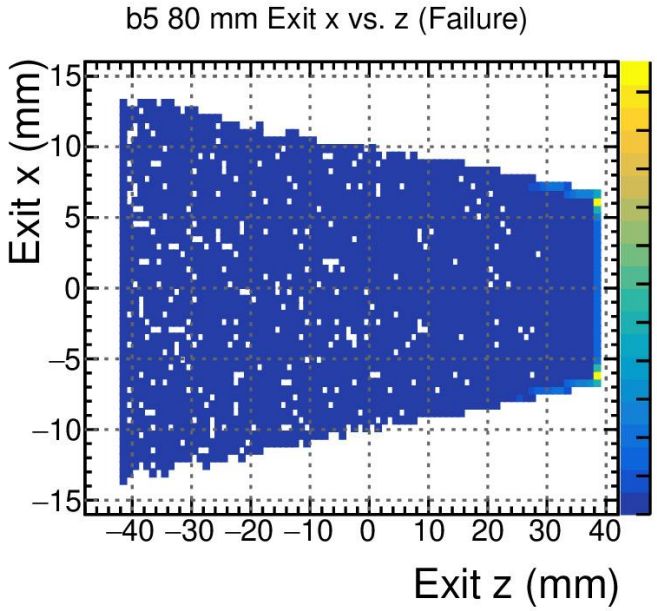
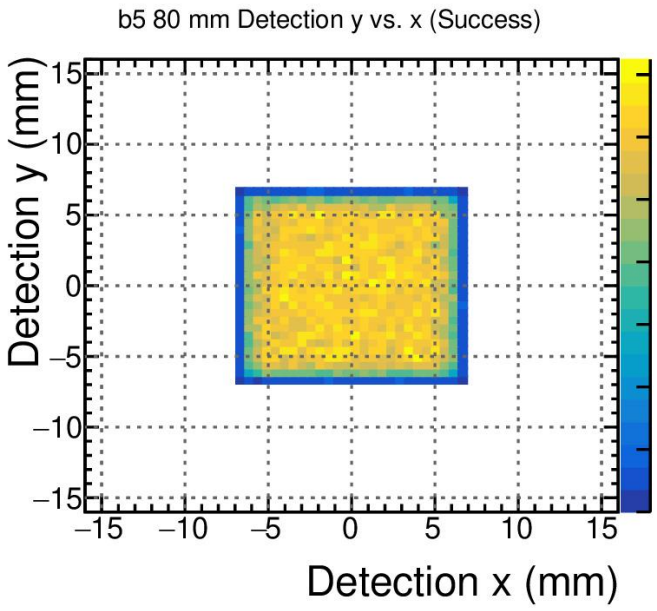
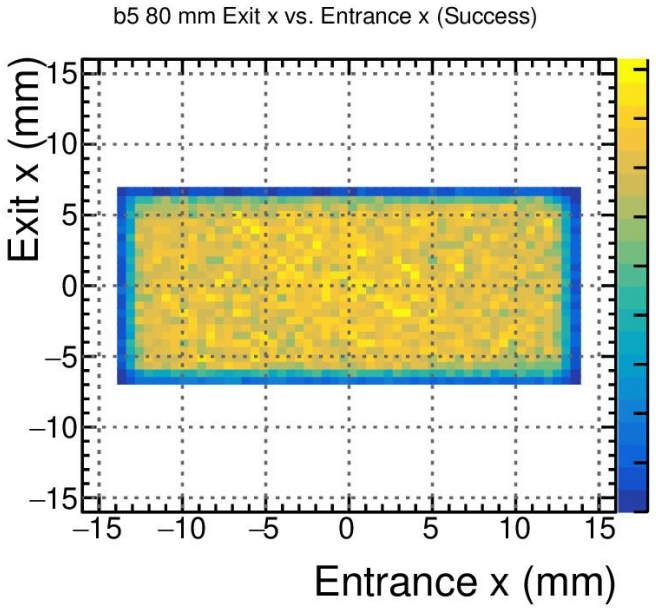
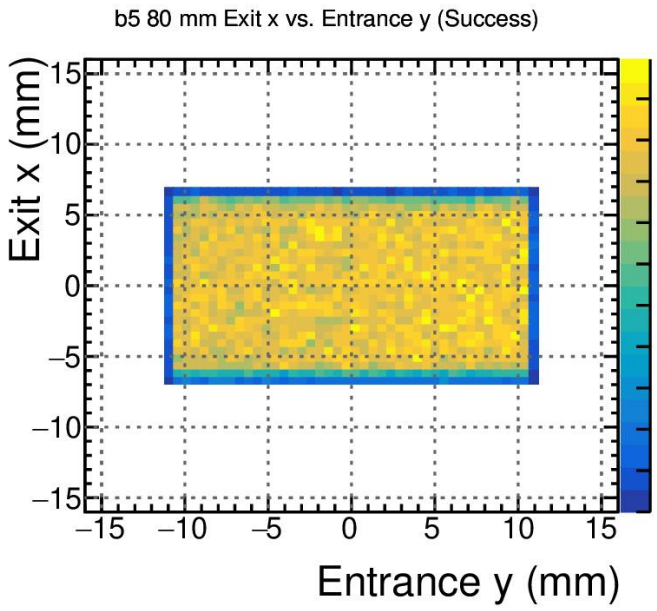




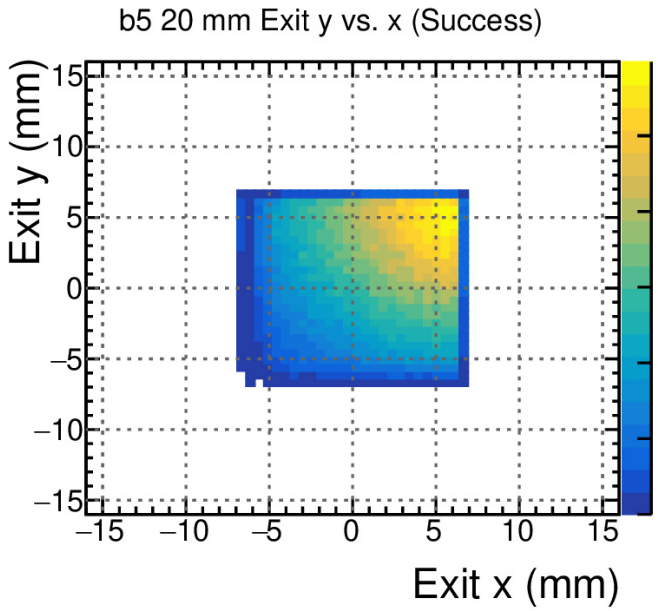


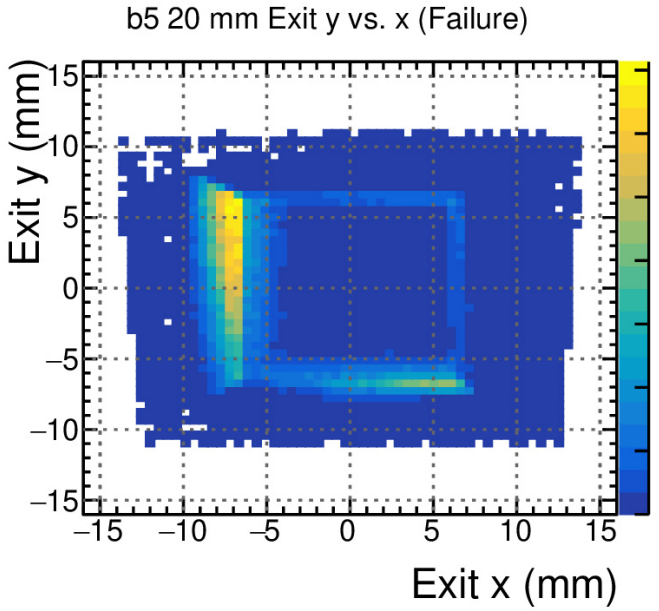


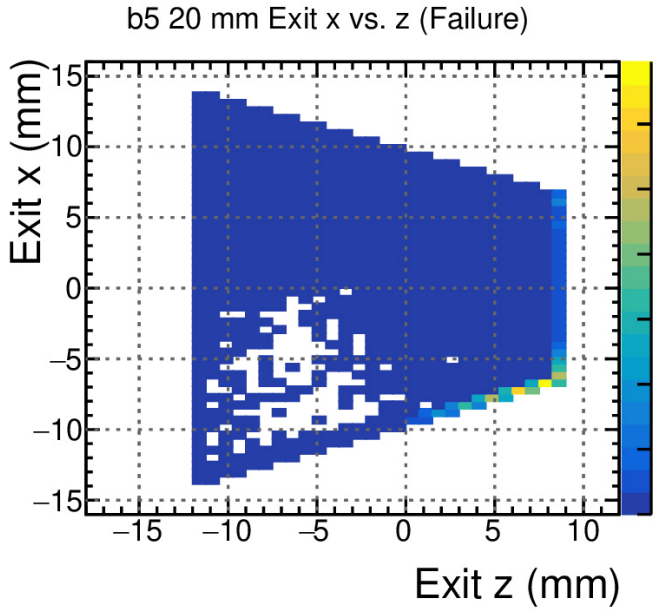


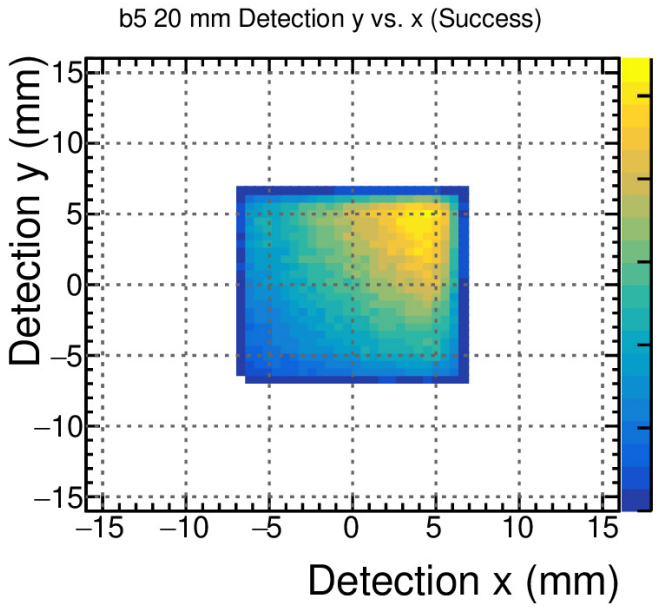


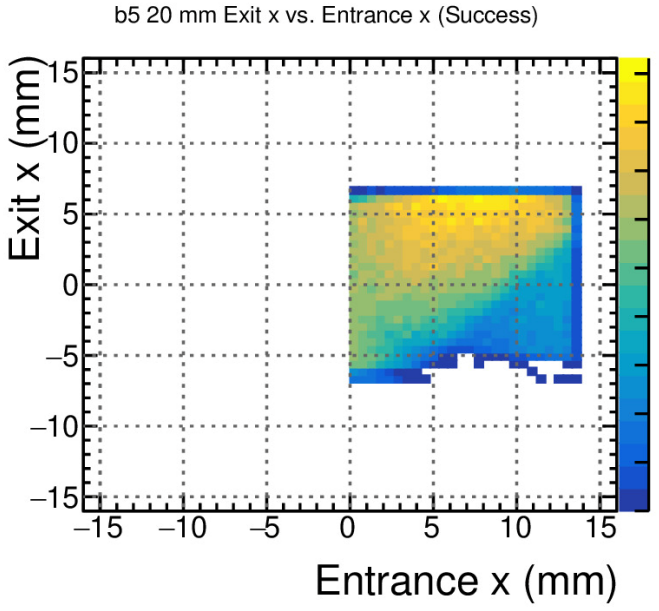
Light Mixing – BIC cookie (single-quadrant source)

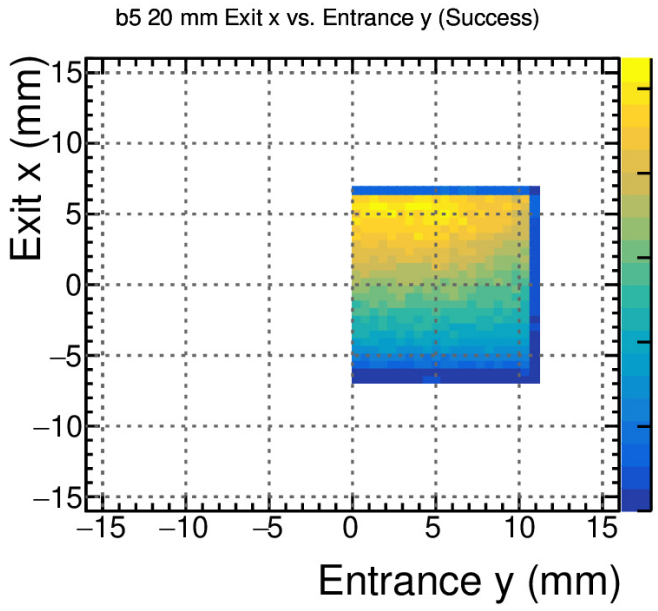




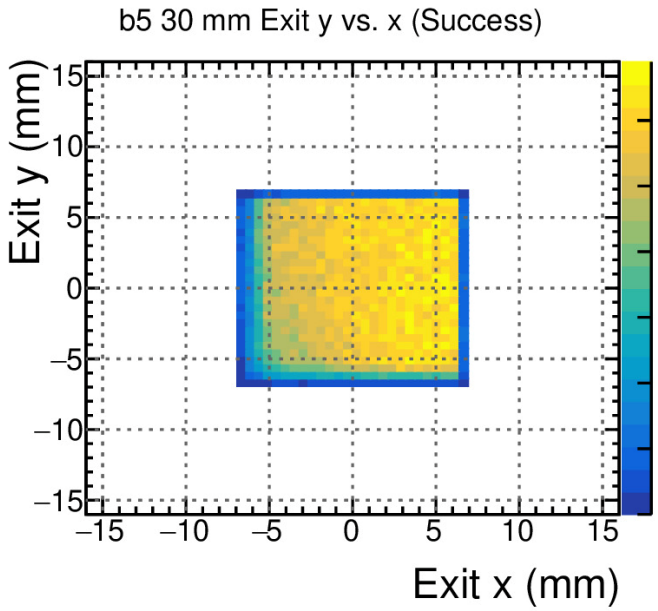


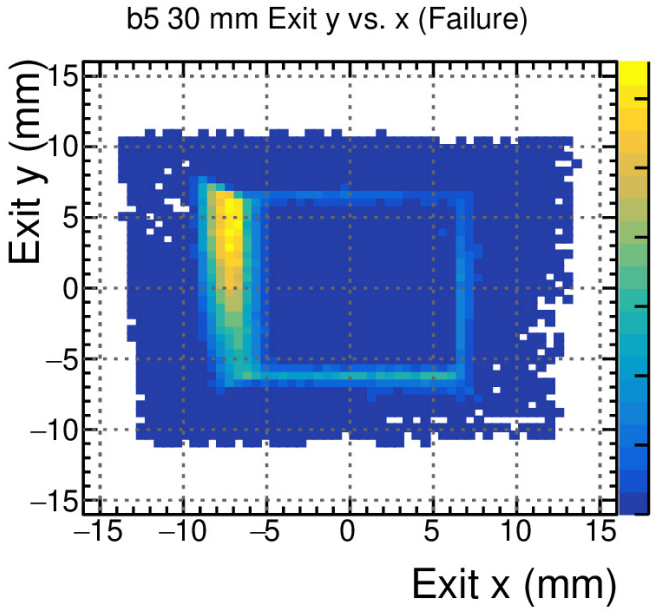


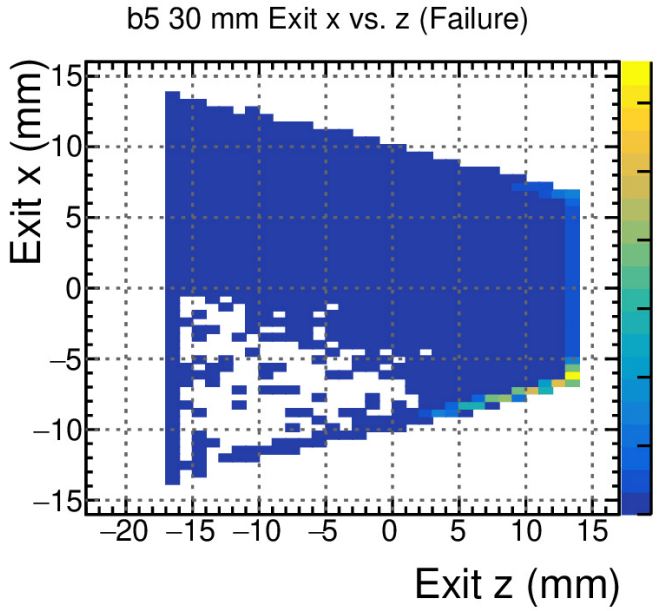


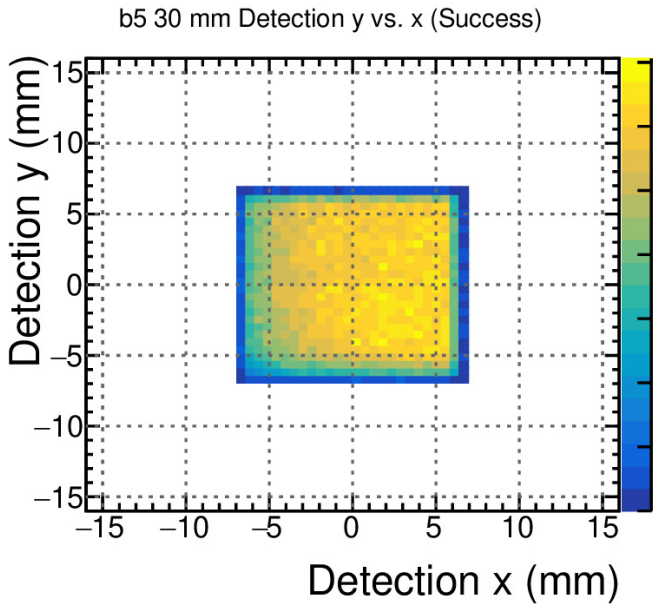


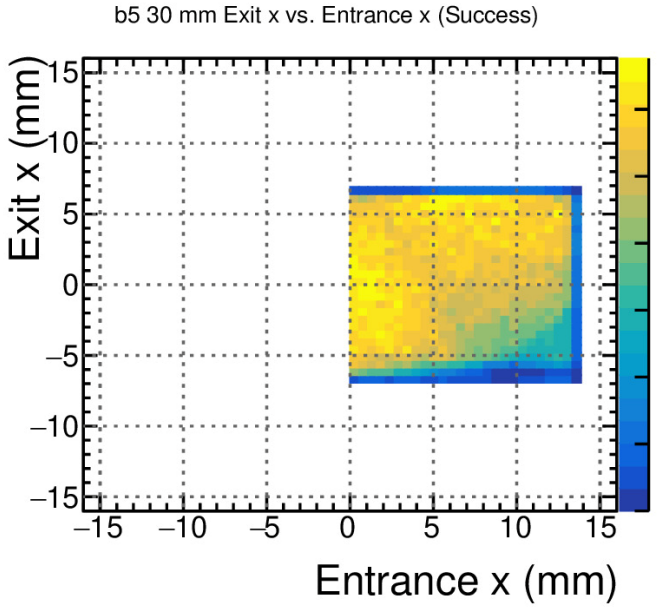
Light Mixing – BIC cookie (single-quadrant source)

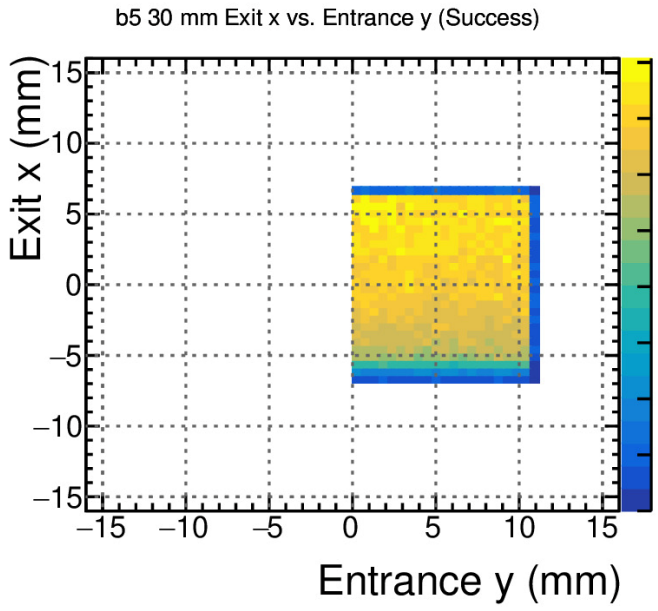




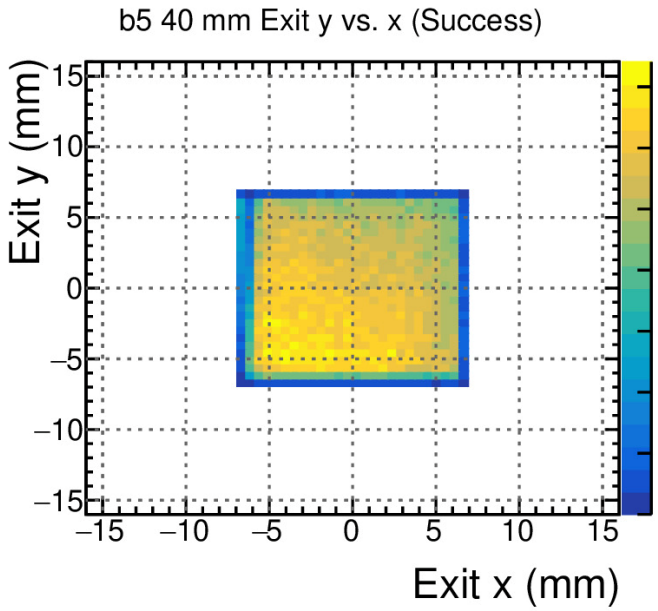


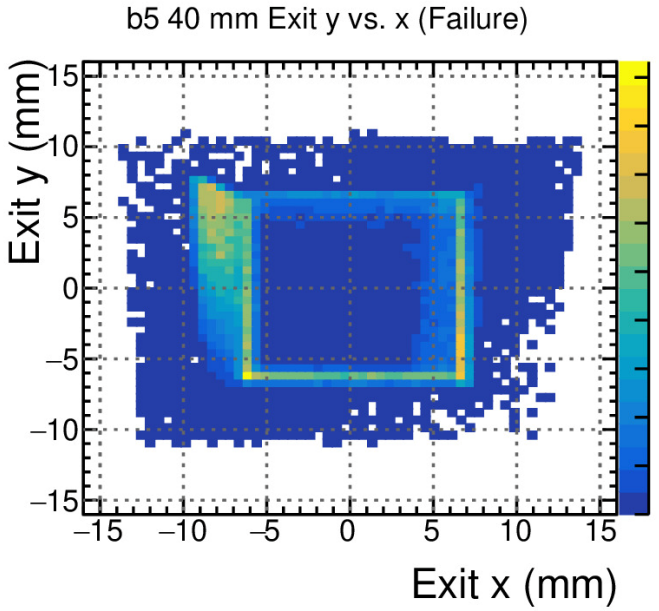


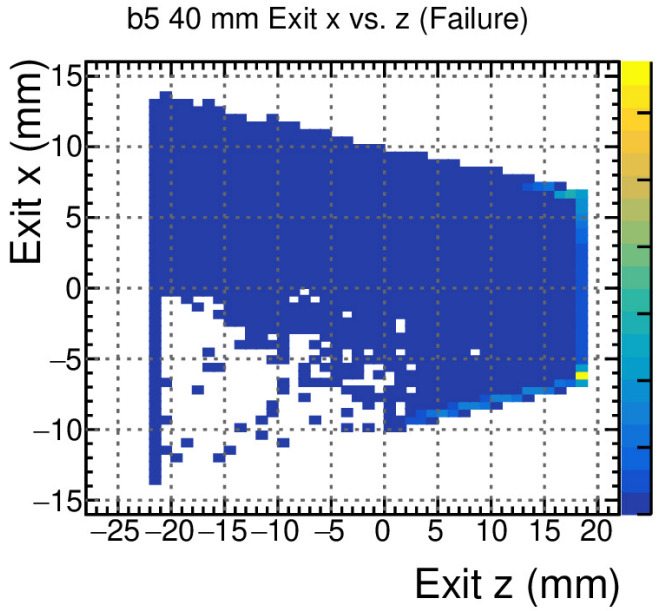


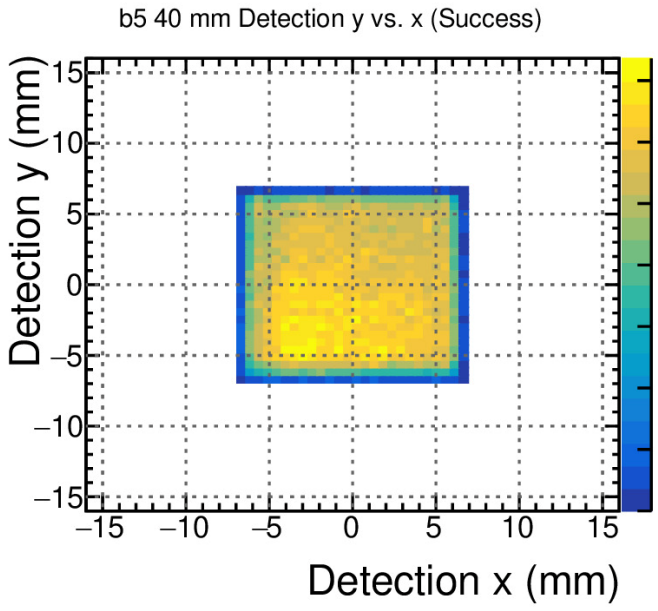


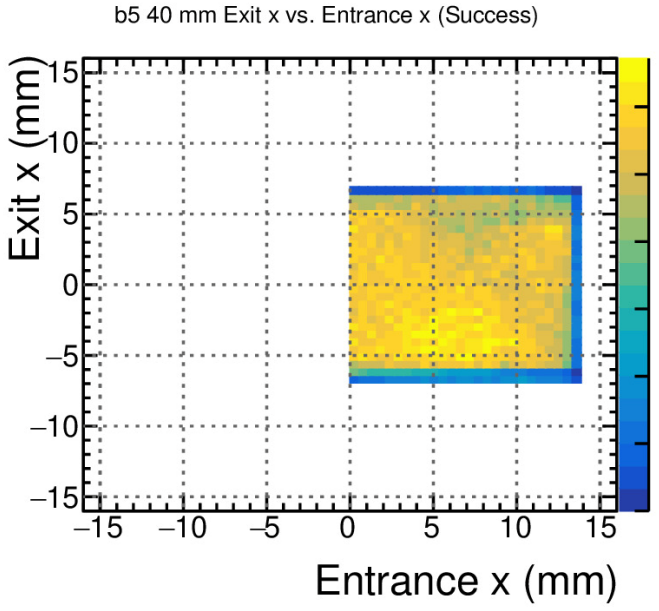
Light Mixing – BIC cookie (single-quadrant source)

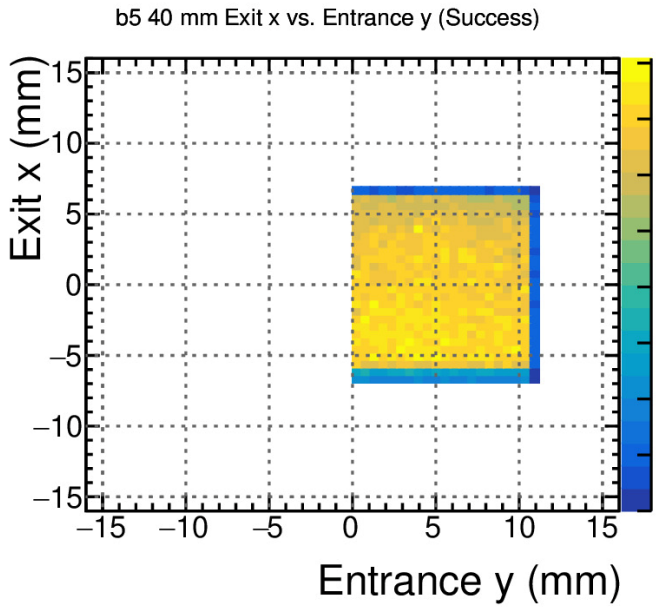




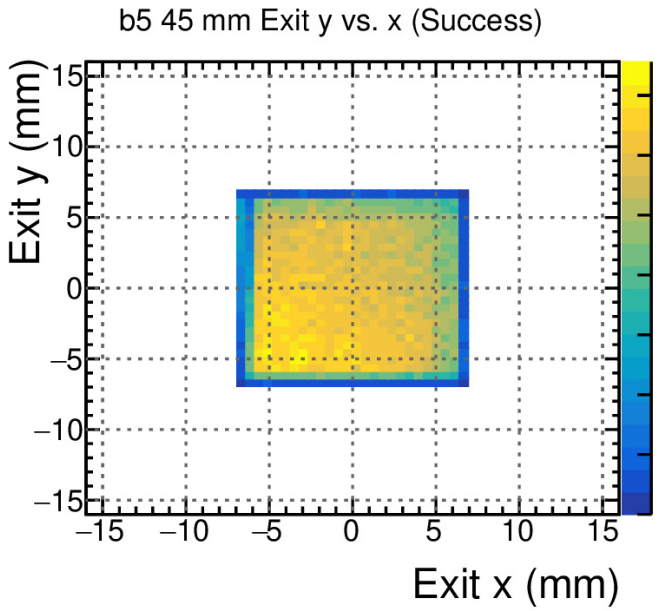


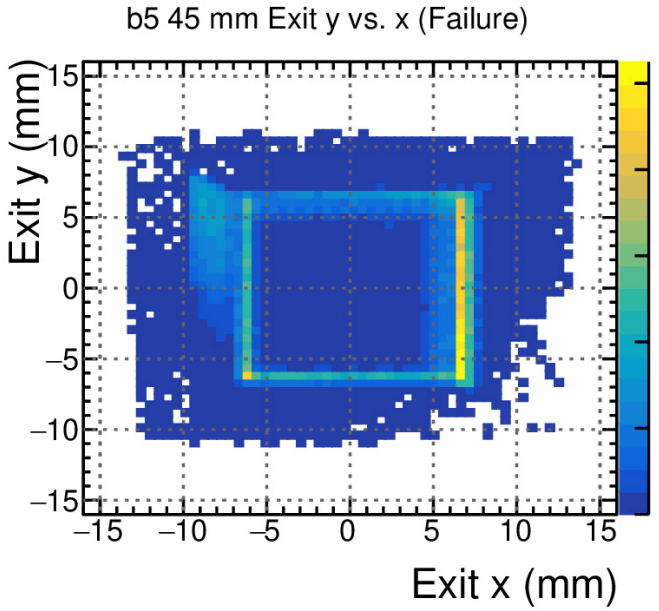


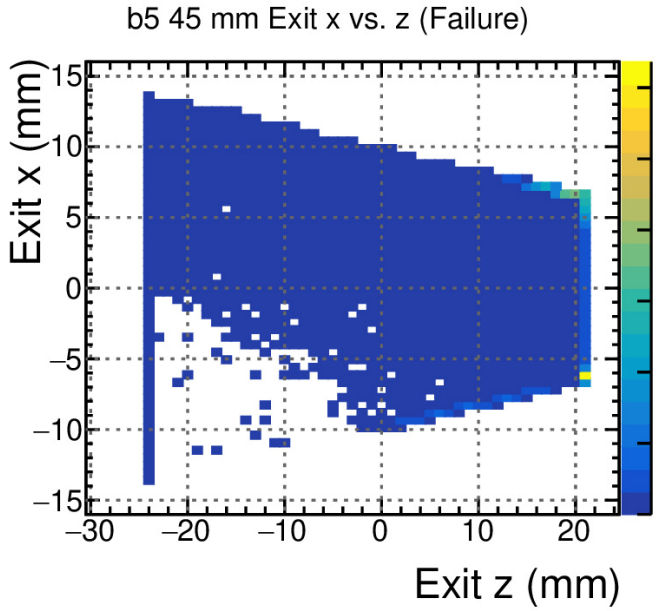


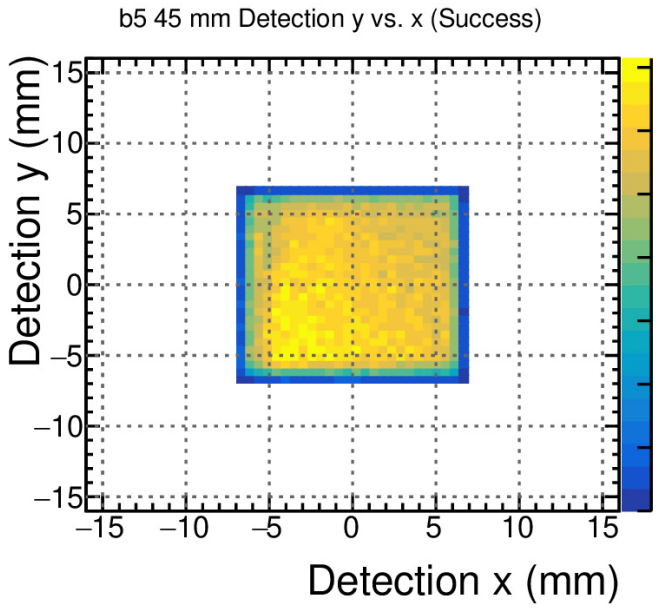


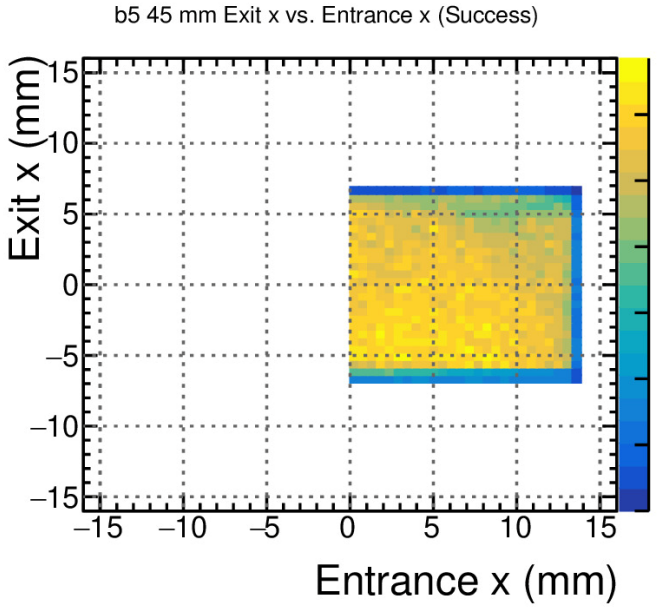
Light Mixing – BIC cookie (single-quadrant source)

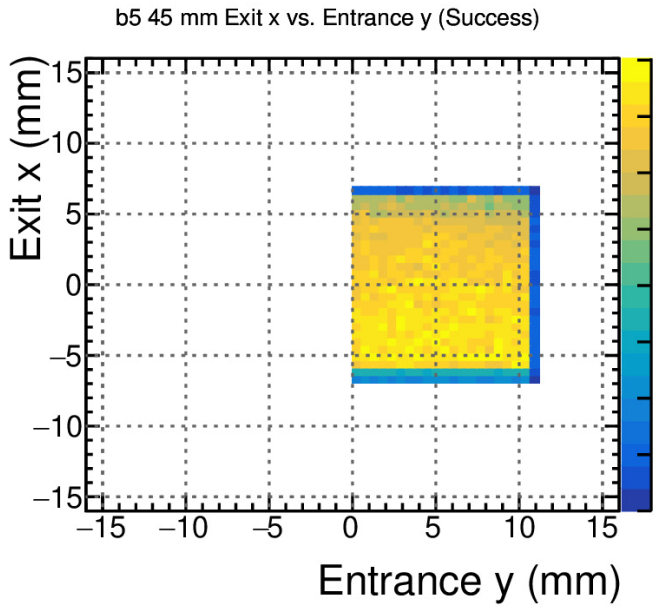




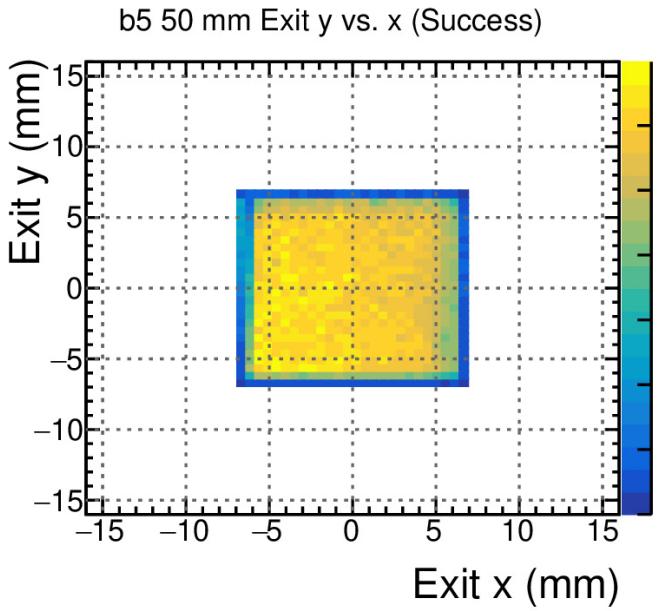


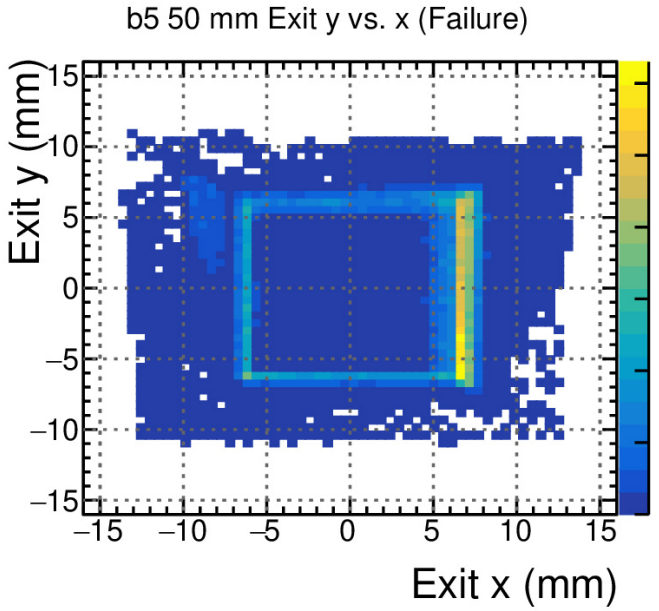


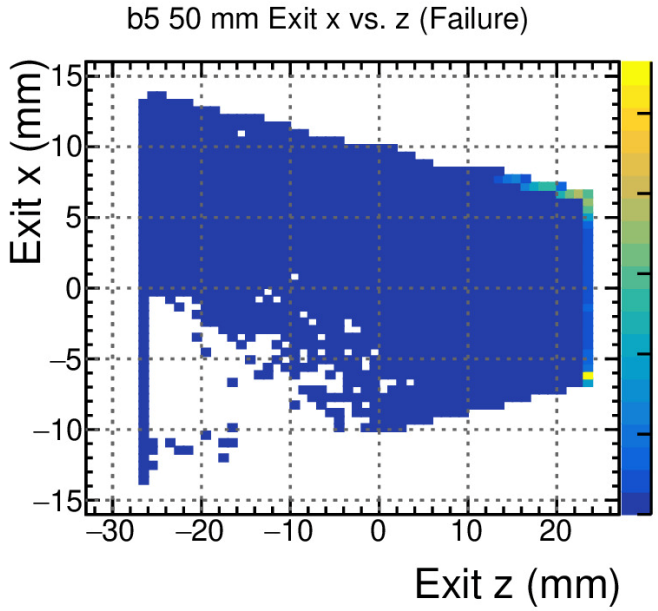


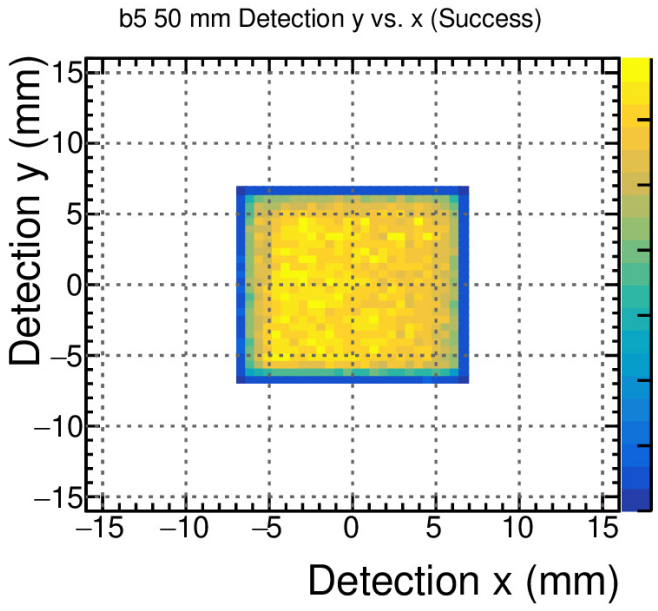


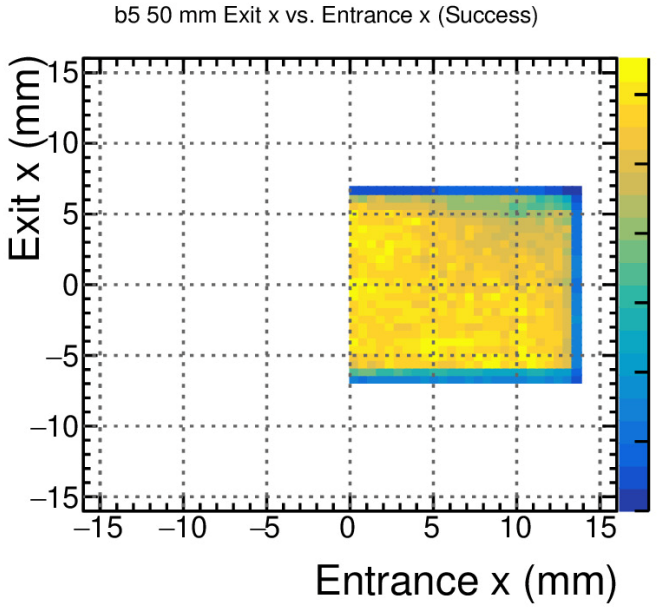
Light Mixing – BIC cookie (single-quadrant source)

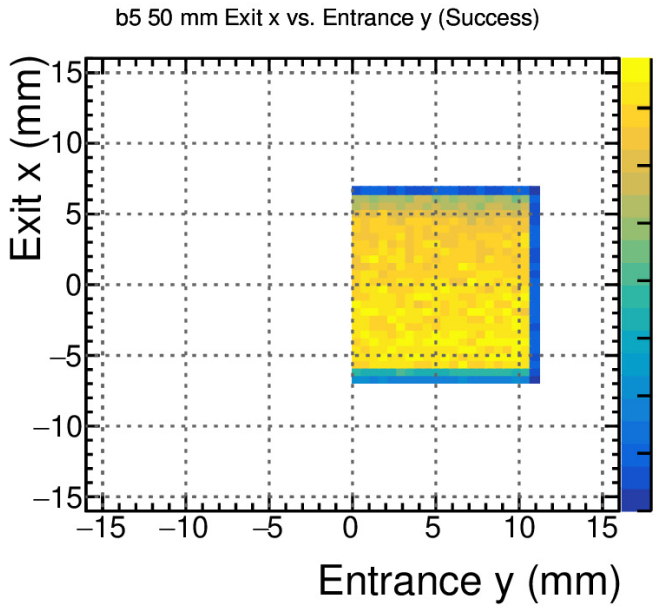




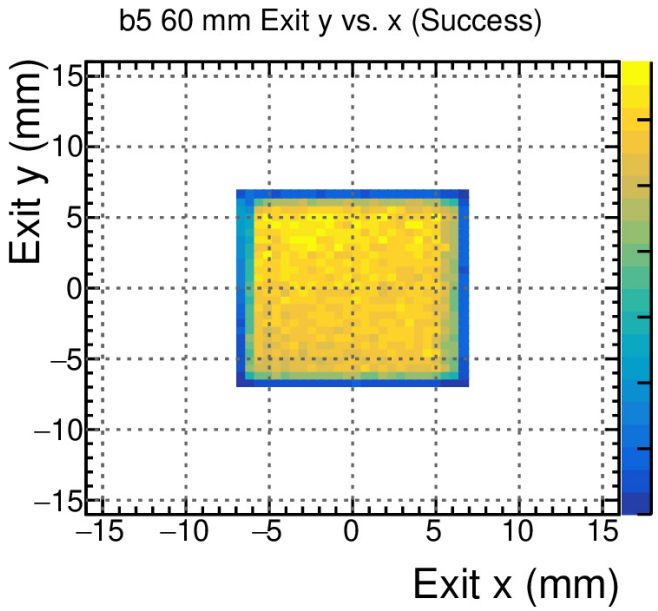


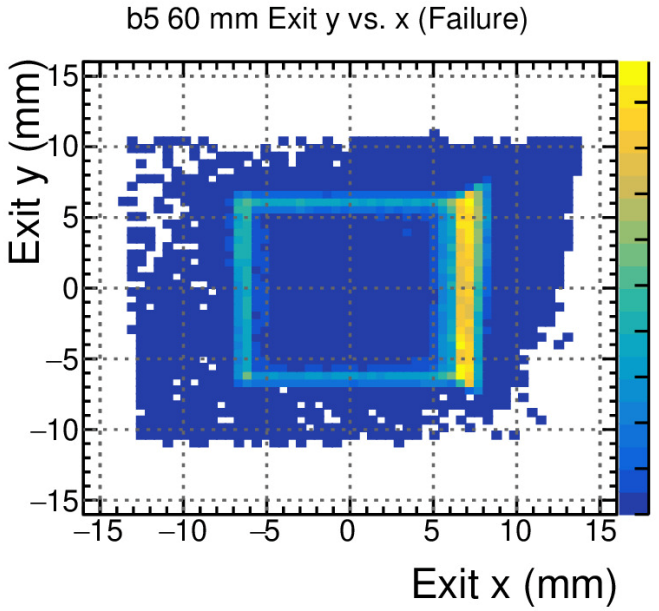


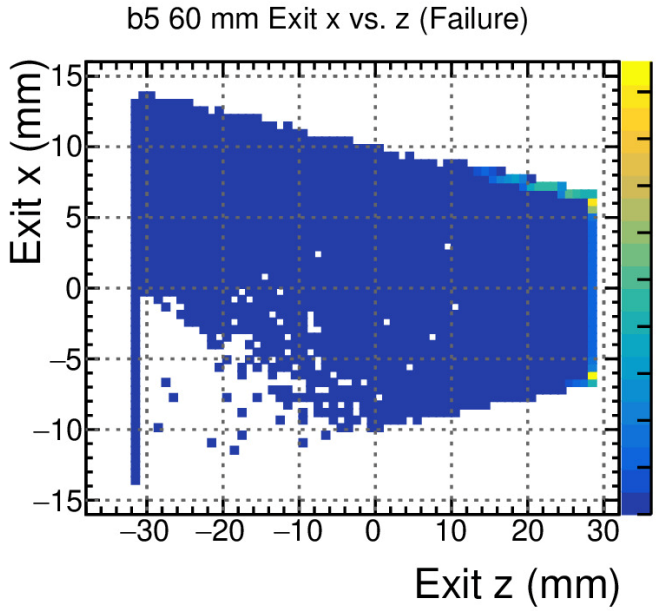


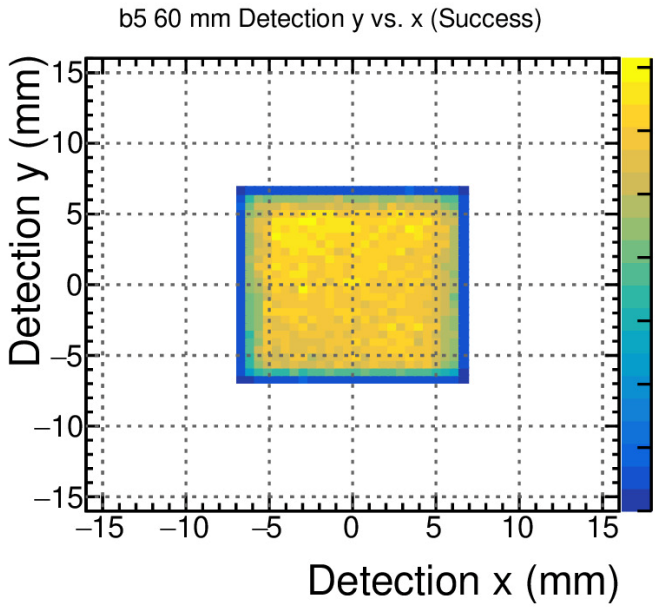


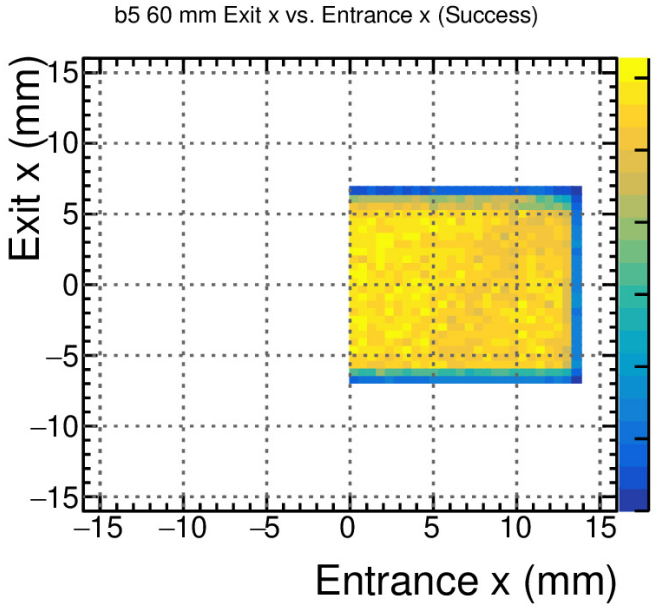
Light Mixing – BIC cookie (single-quadrant source)

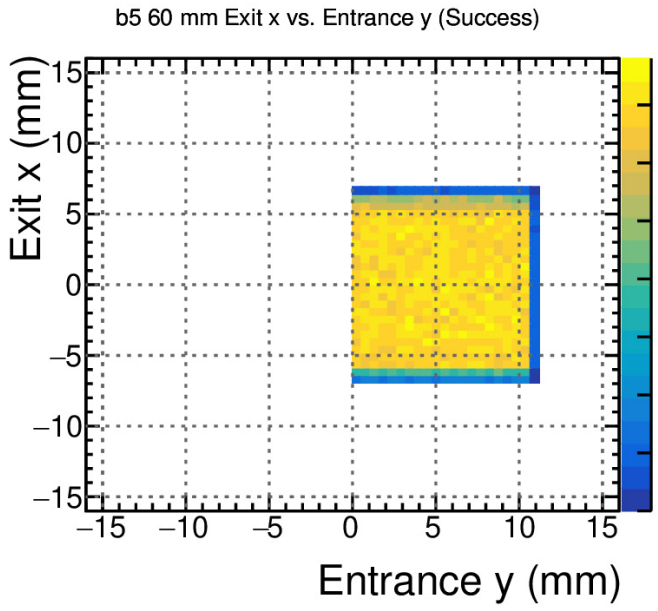




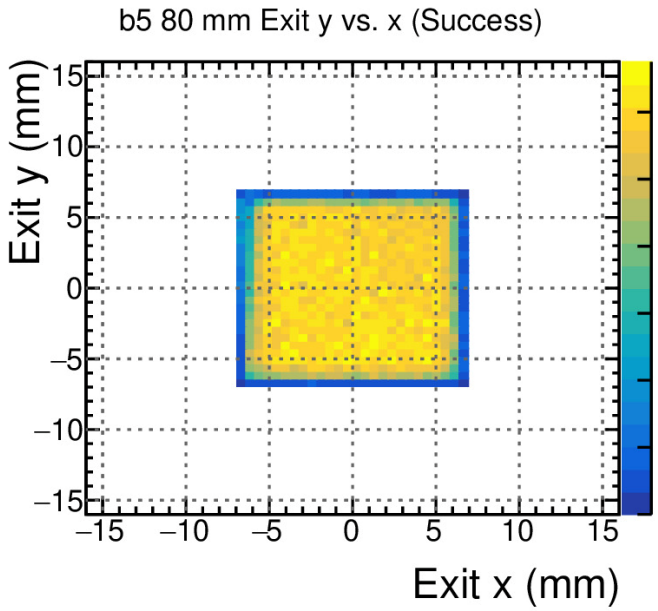


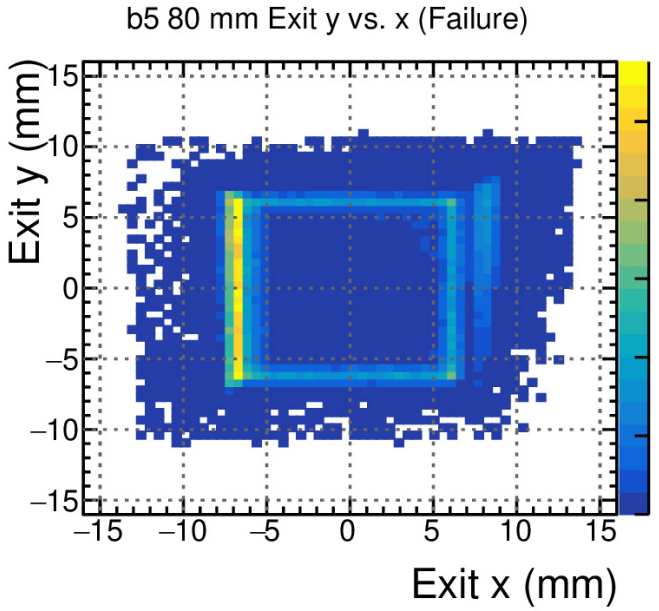


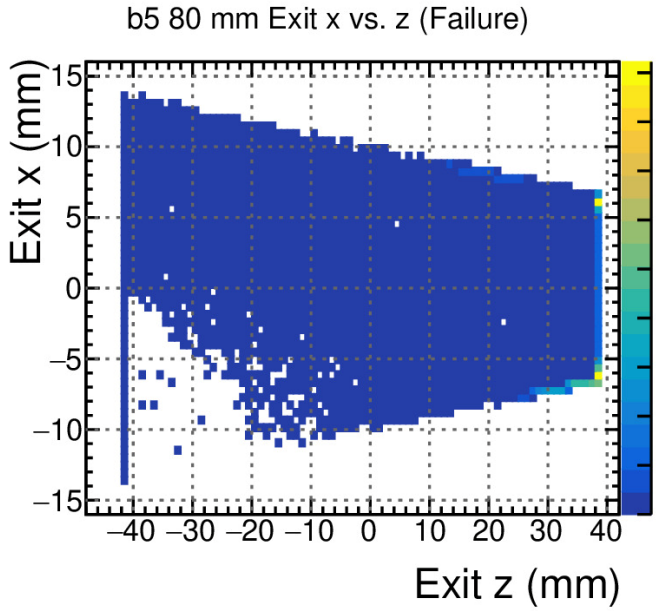


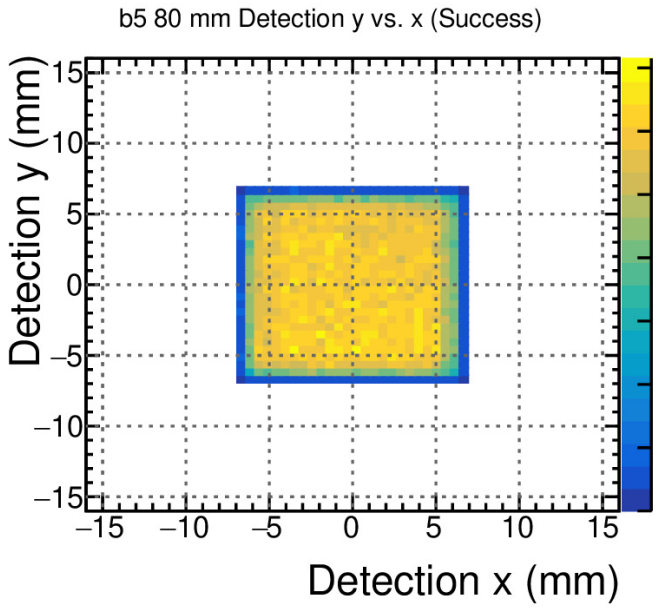


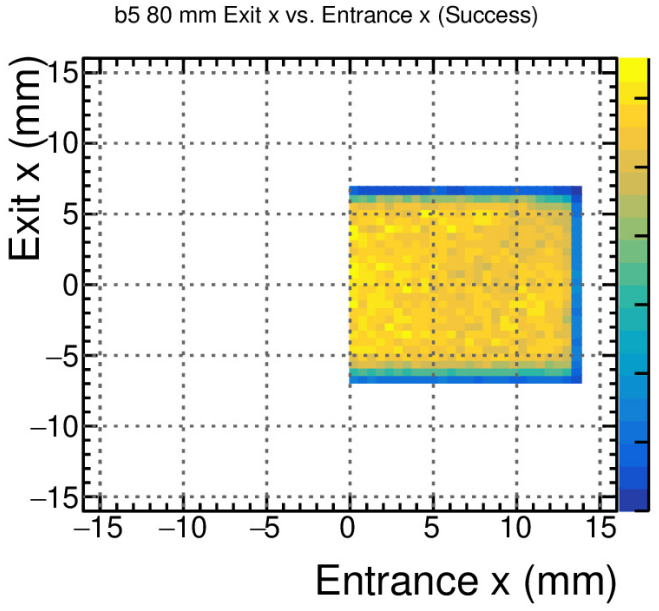
Light Mixing – BIC cookie (single-quadrant source)

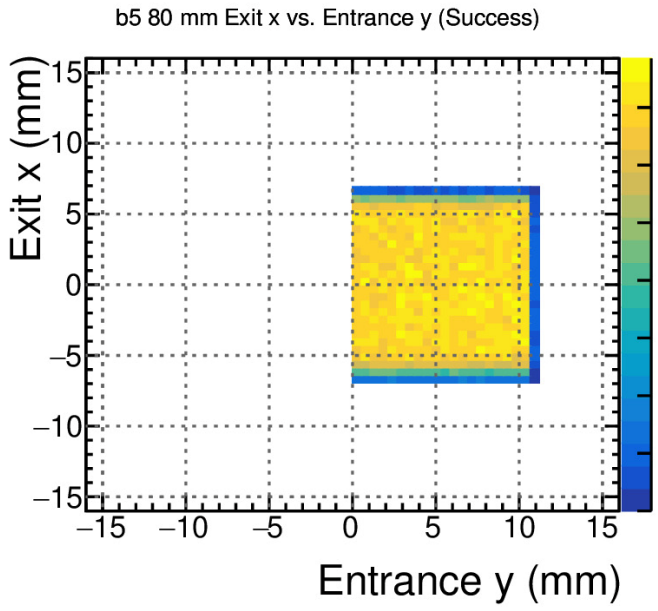




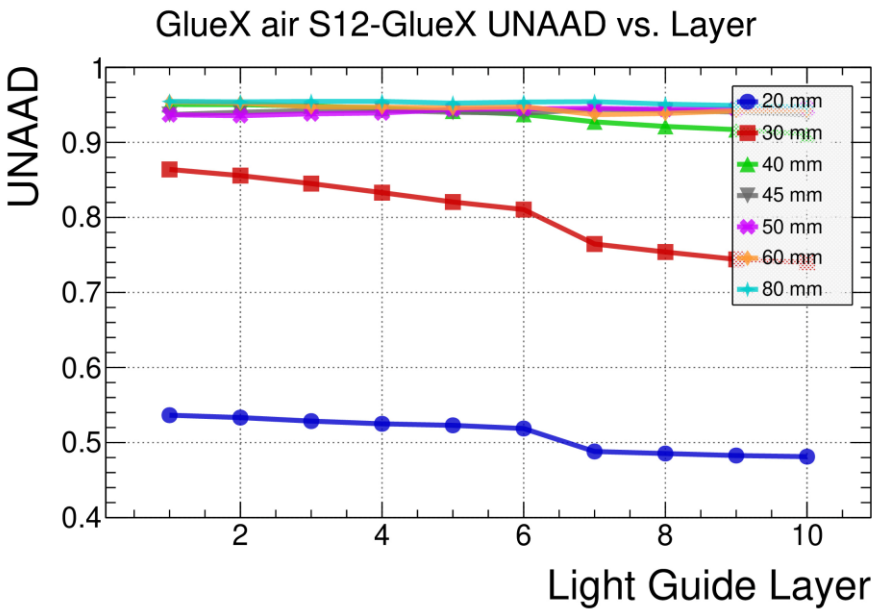


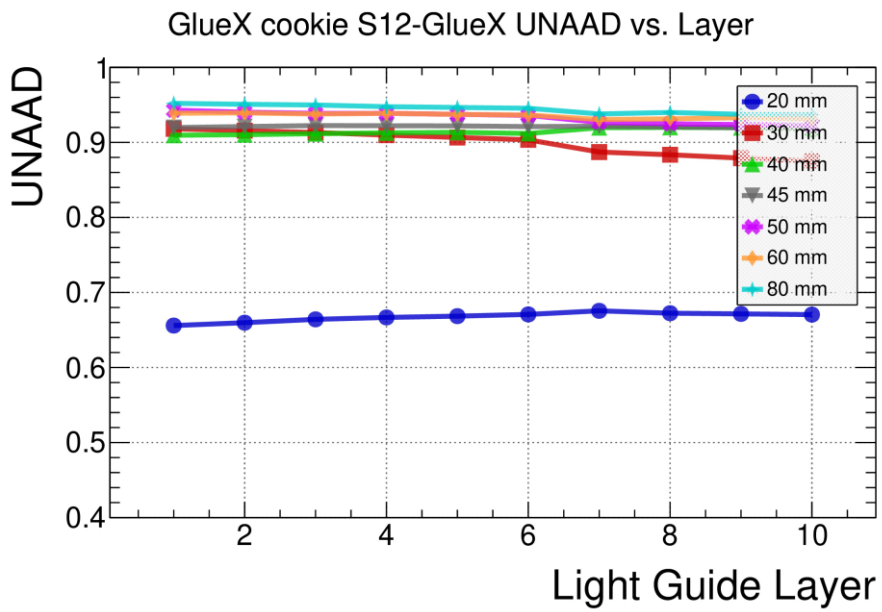


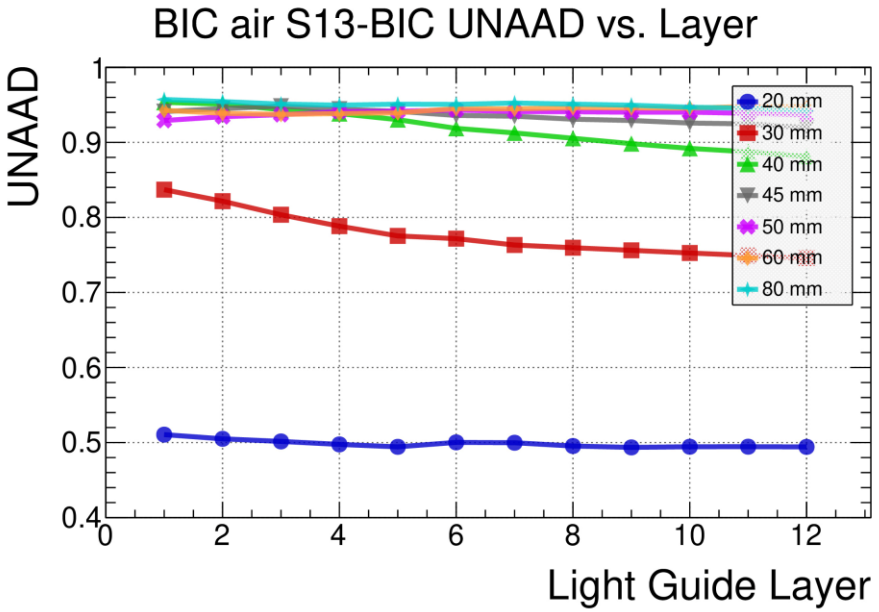


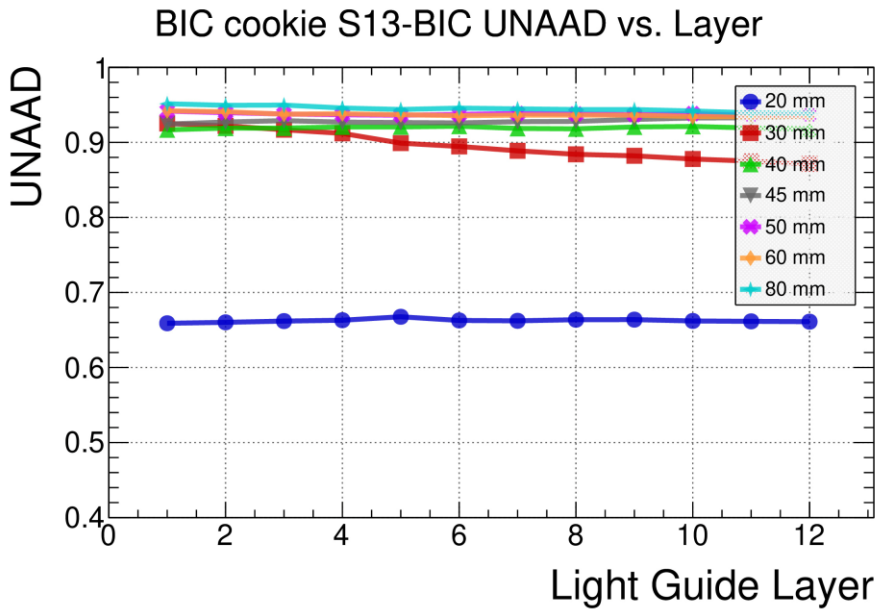


Light Mixing – UNAAD (single-quadrant source)

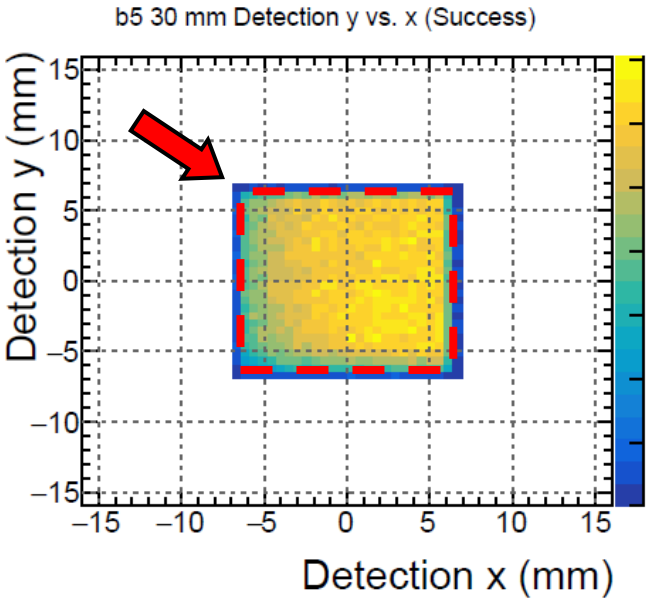








- Normalized Absolute Average Deviation
- Metric for flatness of inner SiPM pixels

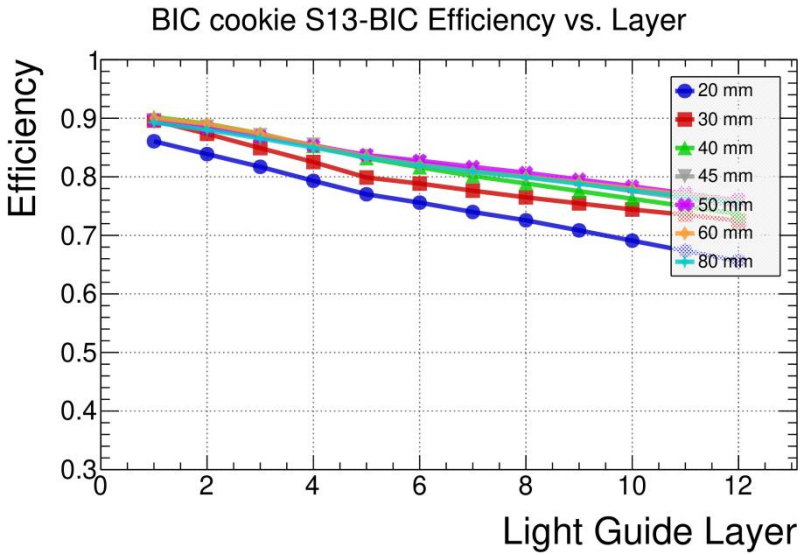


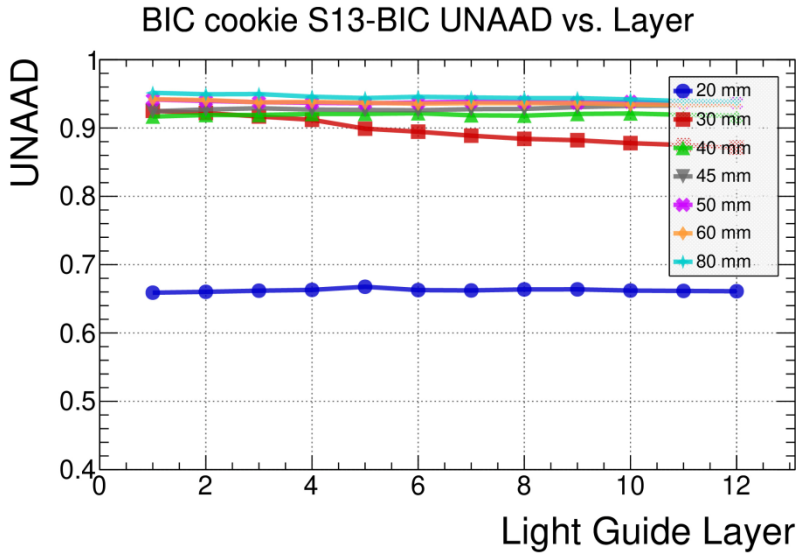
$$1 - \frac{1}{N \cdot \overline{Y}} \sum_{i=1}^{N} |Y_i - \overline{Y}|$$

UNAAD - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3745492/

Conclusions

- ~30% more efficient with silicone cookie than with air gap
- Efficiency begins to drop off at 40 mm length for outer layers
- Spatial correlations between input and detected photons are strong below 40 mm length
- 45 – 50 mm appears reasonable for efficiency and light mixing so far
- Ongoing simulations looking at using 6x6 SiPMs and smaller light guides rather than the 13x13 arrays
- SiPMs currently modeled as one sensitive area (no dead areas)





SiPM form factors:
S12045(X) – 12.7 mm x 12.7 mm
S13631-3050-04 – 13 mm x 13 mm
Active area for both SiPM arrays:
16 x (3 mm x 3 mm tiles)
Active area percentage:
S12045(X) – 89.280 %
S13631-3050-04 – 85.207 %