MiniDIRC

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DIRC Collaboration Meeting, 2-July-2025

Interaction Region 8

Downstream Ion Focus

- Proposed IR-8 beamline for a second EIC detector includes a high-dispersion focus in the ion beamline 45m downstream from the IP.
- This enables detection/tracking of ions with magnetic rigidity deviating as little as ±1% from beam rigidity. This is an order of magnitude greater acceptance than the IR-6 beamline.
- Goal: prove the principle that a high precision (thin SiO_2) Cherenkov detector could identify the charge of any ion from proton to uranium detected by the tracking detectors at the 2nd focus.
  - For any beam ion A>1, protons will not read the second focus, for deuterons will
- Nuclear fragments reaching the Roman Pot detectors are essentially spectators, travelling at beam velocity.
  - Beamline spectrometer analyzes magnetic rigidity, which essentially separates fragments by A, but not Z.

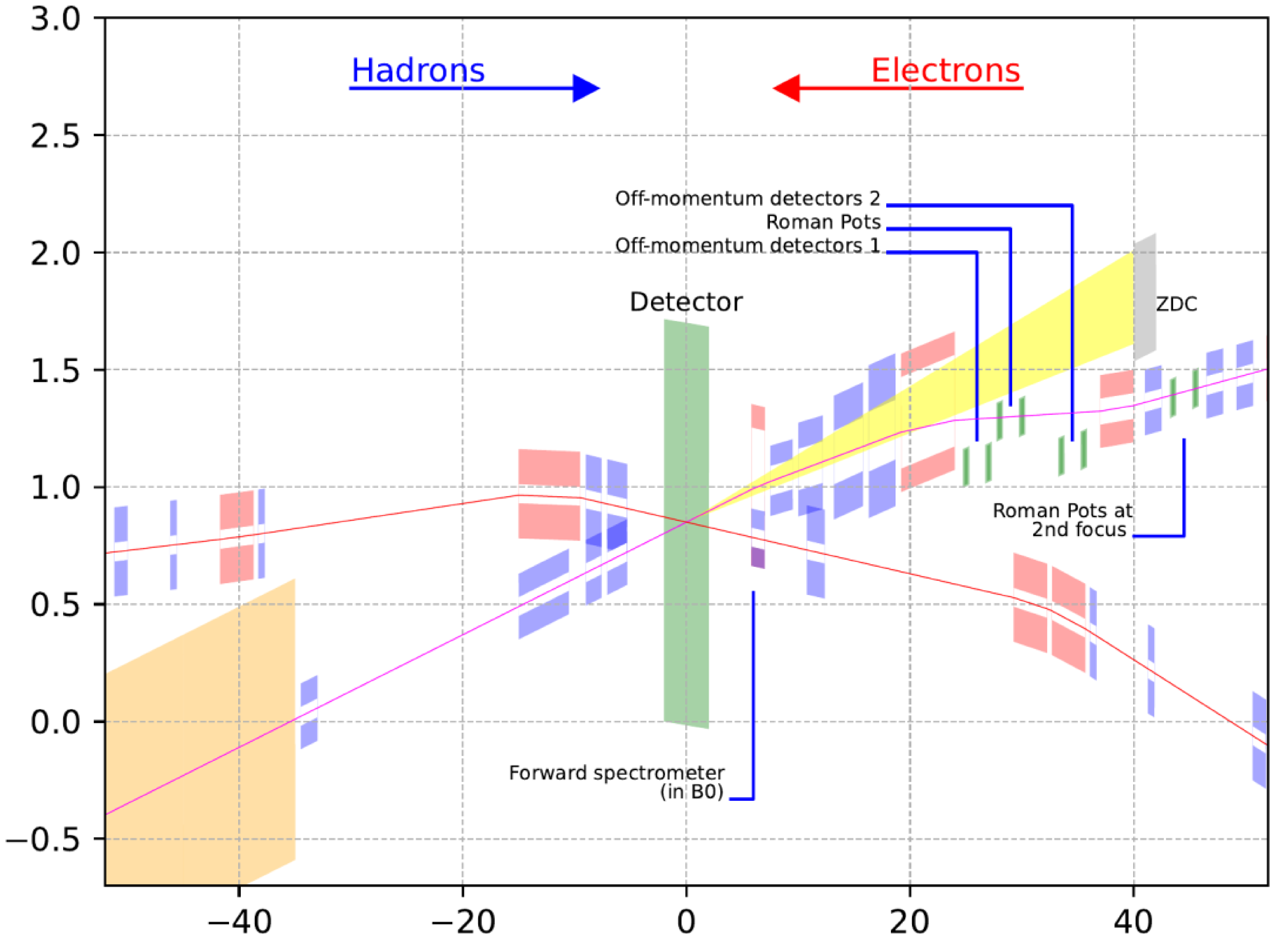
IR-8 Layout

Preliminary

Second Focus
D_x = Dispersion = 0.48 m/100%
$1\text{-}x_L$ = ±Beam-Stay-Clear ≤1%

Parameters at the 2nd focus for different energies

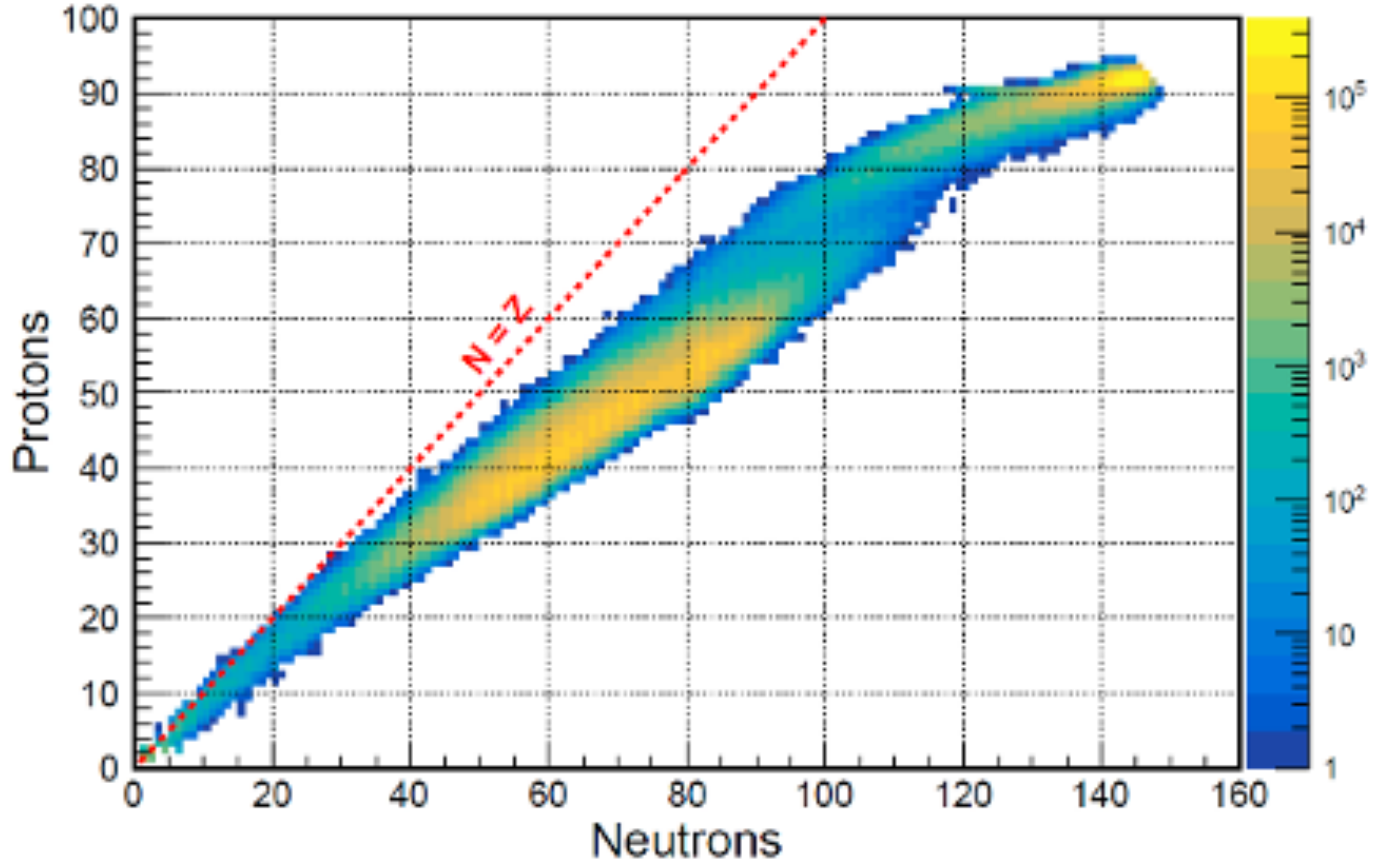
Parameter	Value at 41 GeV	100 GeV	275 GeV	Units
β_x	0.85	0.8	0.5	m
D_x	0.48	0.48	0.47	m
ϵ_x	44	30	11.3	nm
σ_δ (10^{-4})	10.3	9.7	6.8	-
$1 - x_L$ (10^{-3})	4.16	10.2	7	-

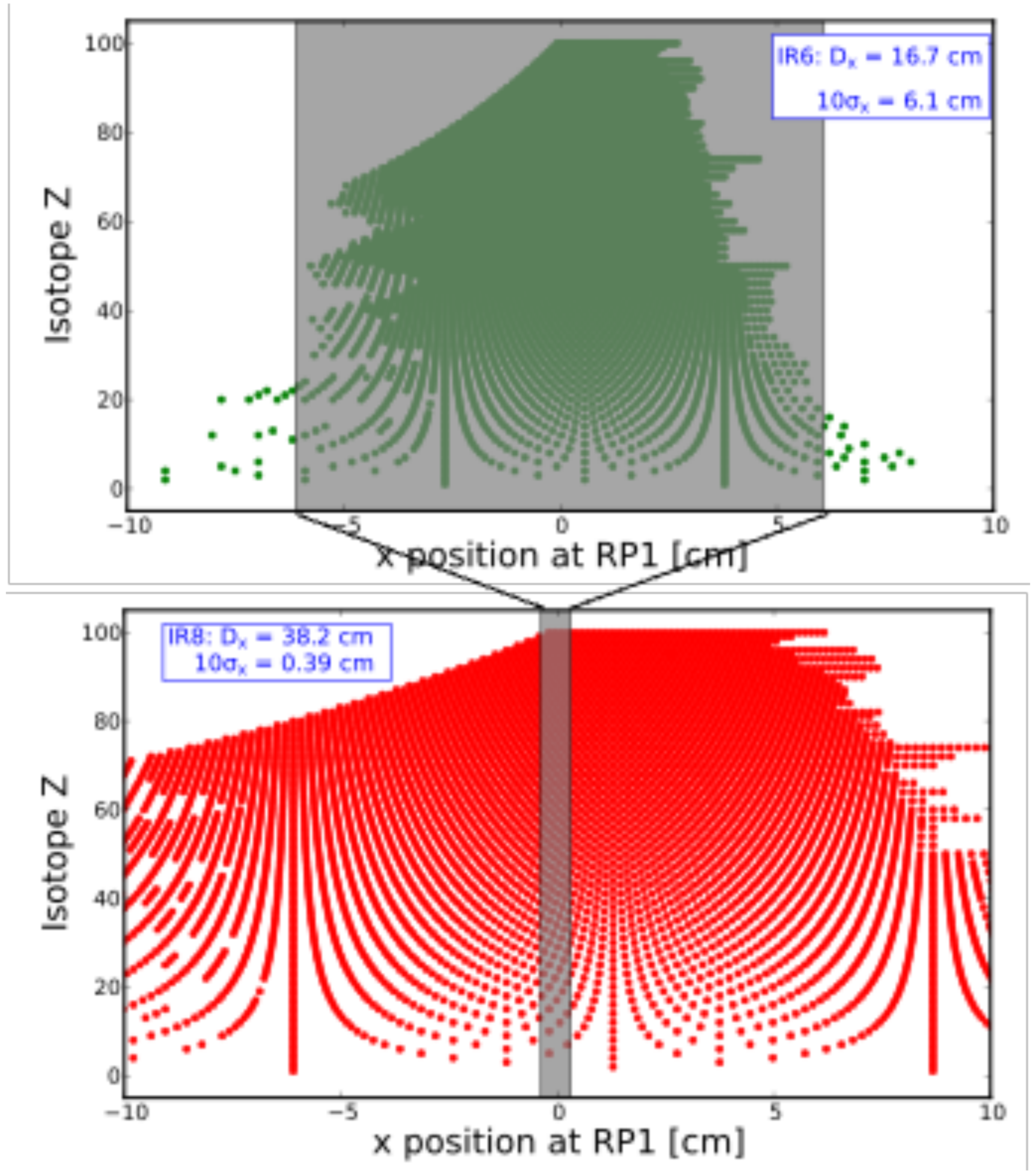


Fragmentation Study

Brynna Moran, MS Thesis, SBU

- Ion Fragmentation from $^{238}U(e,e')$

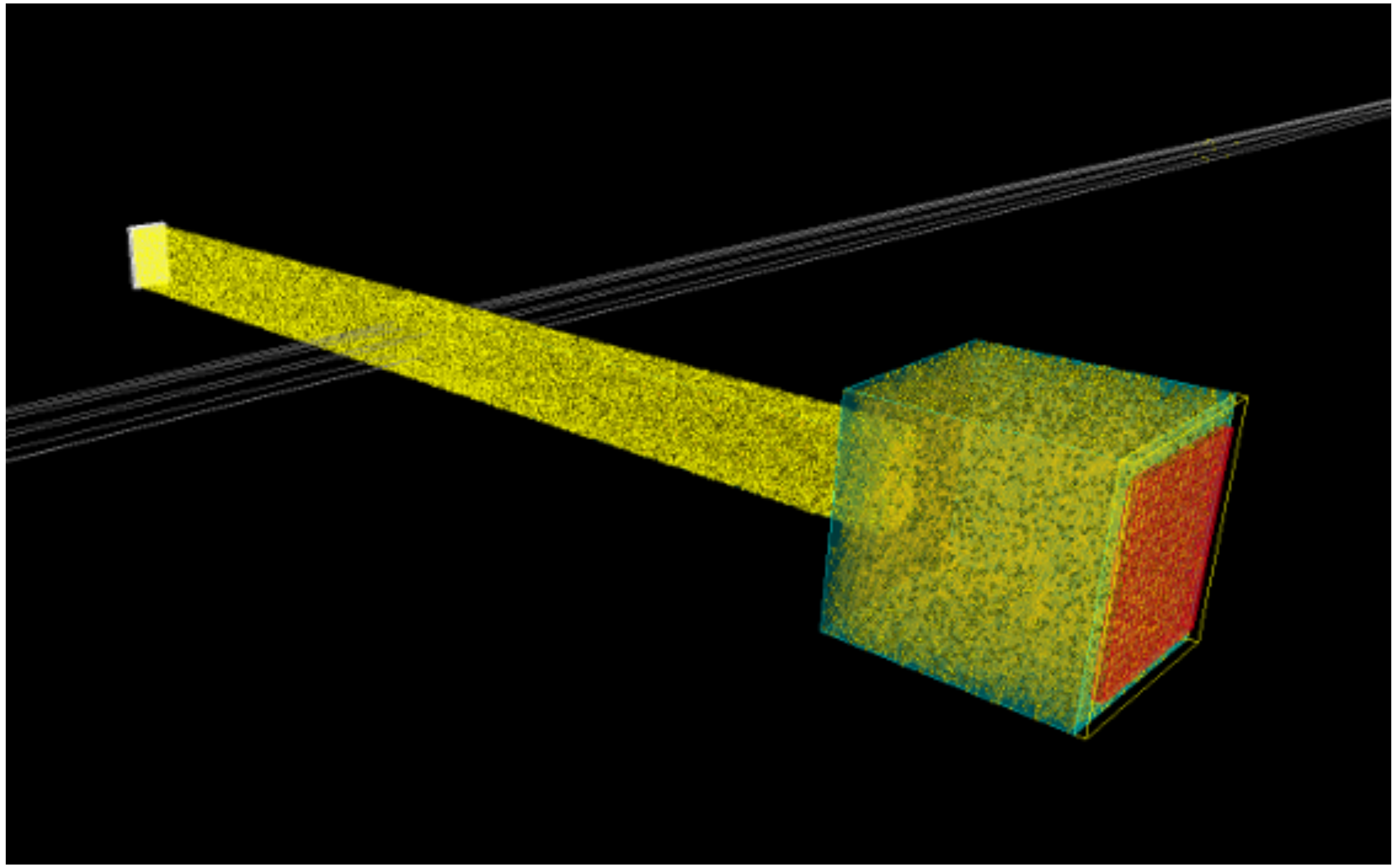




Initial MiniDIRC Studies

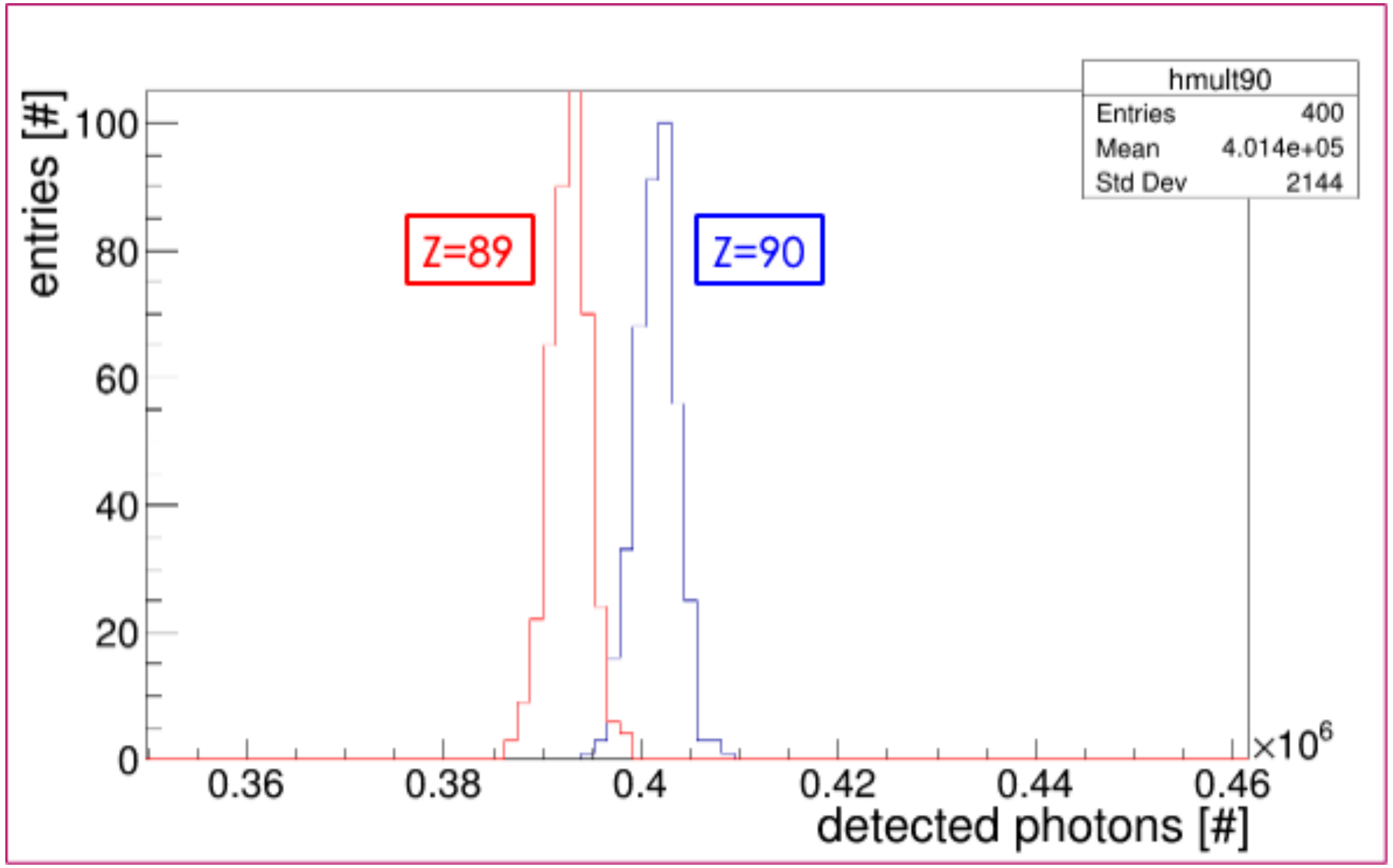
Completed Oct 2024

- Roman Dzhygadlo minidirc simulation code
- SiO_2 Radiator
  - $6x10x150\ mm^3$
  - Photon yield $\propto Z^2$
- Expansion volume $(25\ mm)^3$
- Photosensor $20x20\ mm^2$



Simulation of Z=90 & Z=89 daughter ions

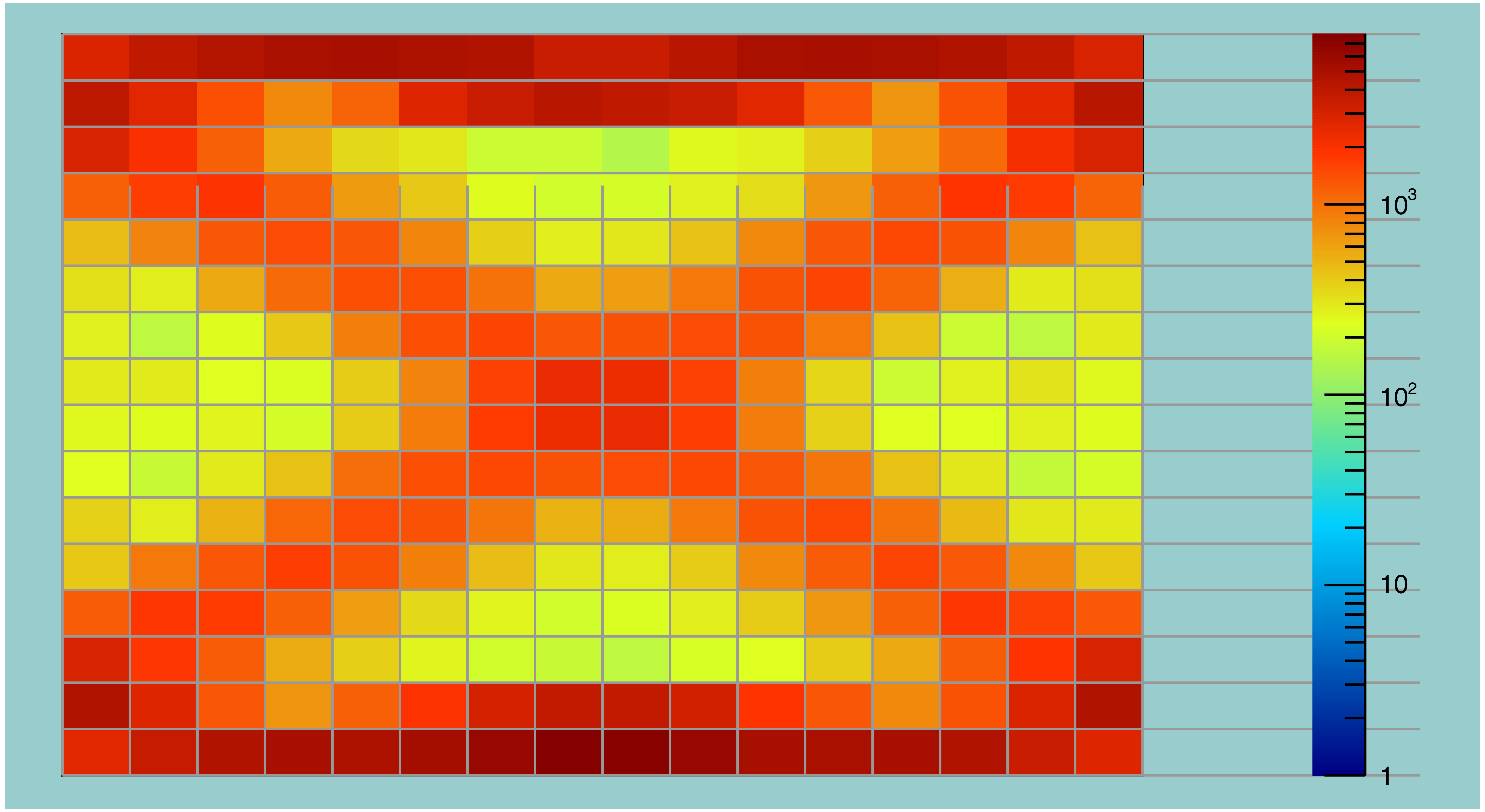
- Detected phot-statistics cleanly separate the two species
- Follow-up studies required
  - Z^2 production of delta-ray secondaries not considered
  - Saturation of photo-sensor pixels



Variations in Expansion Volume

AuraTek MCP

- EV 25x55x55 mm3
- Up to 6000 p.e. per pixel
  - Hits strongest at edges (reflections?)



Delta-ray secondaries from Ionization

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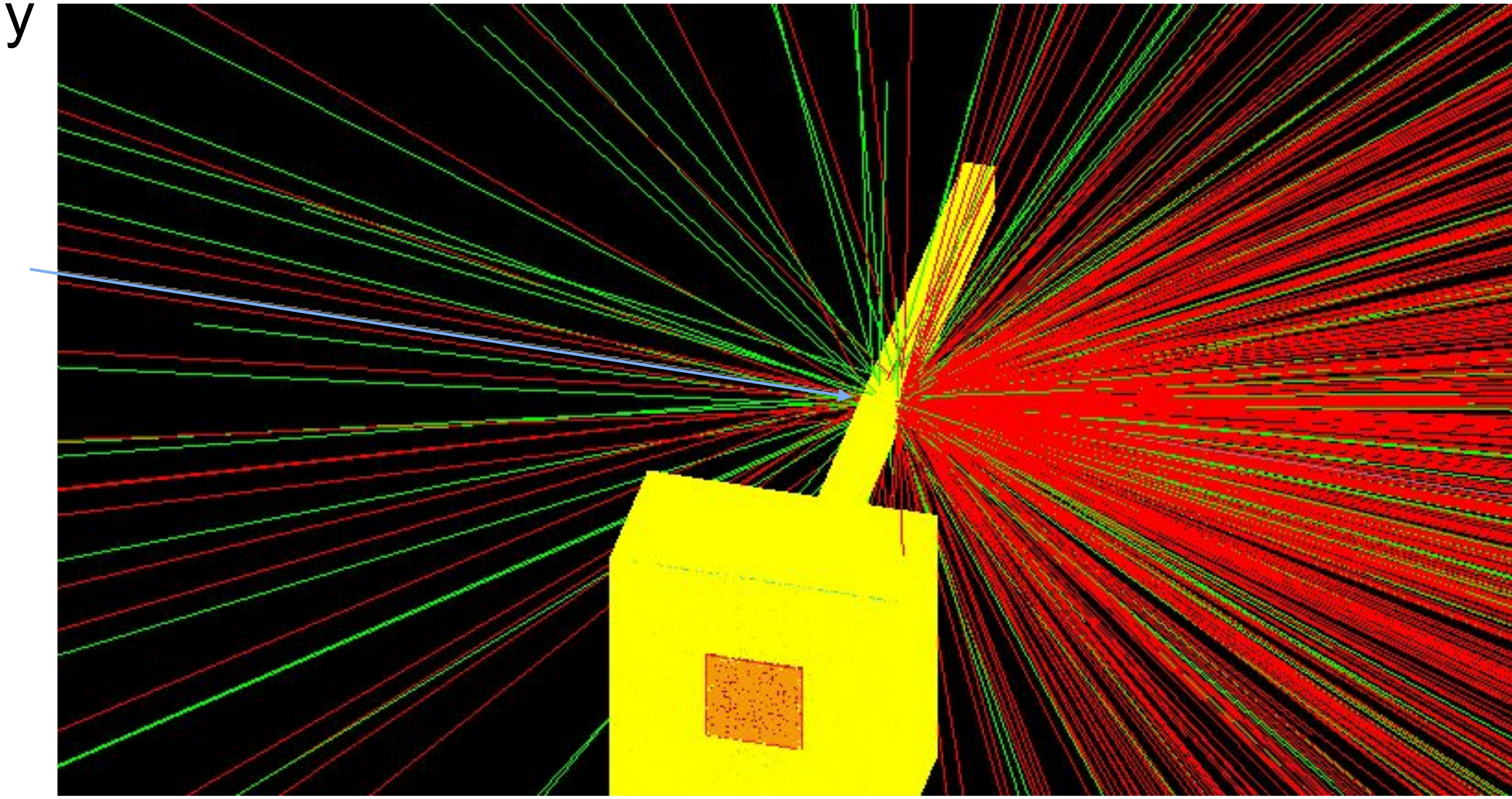
- Huge number of secondaries (probably most below Cherenkov threshold)
  - Increase in light yield
  - Broadening of light yield statistics
  - Z=89/90 separation > 3-sigma



Photosensors

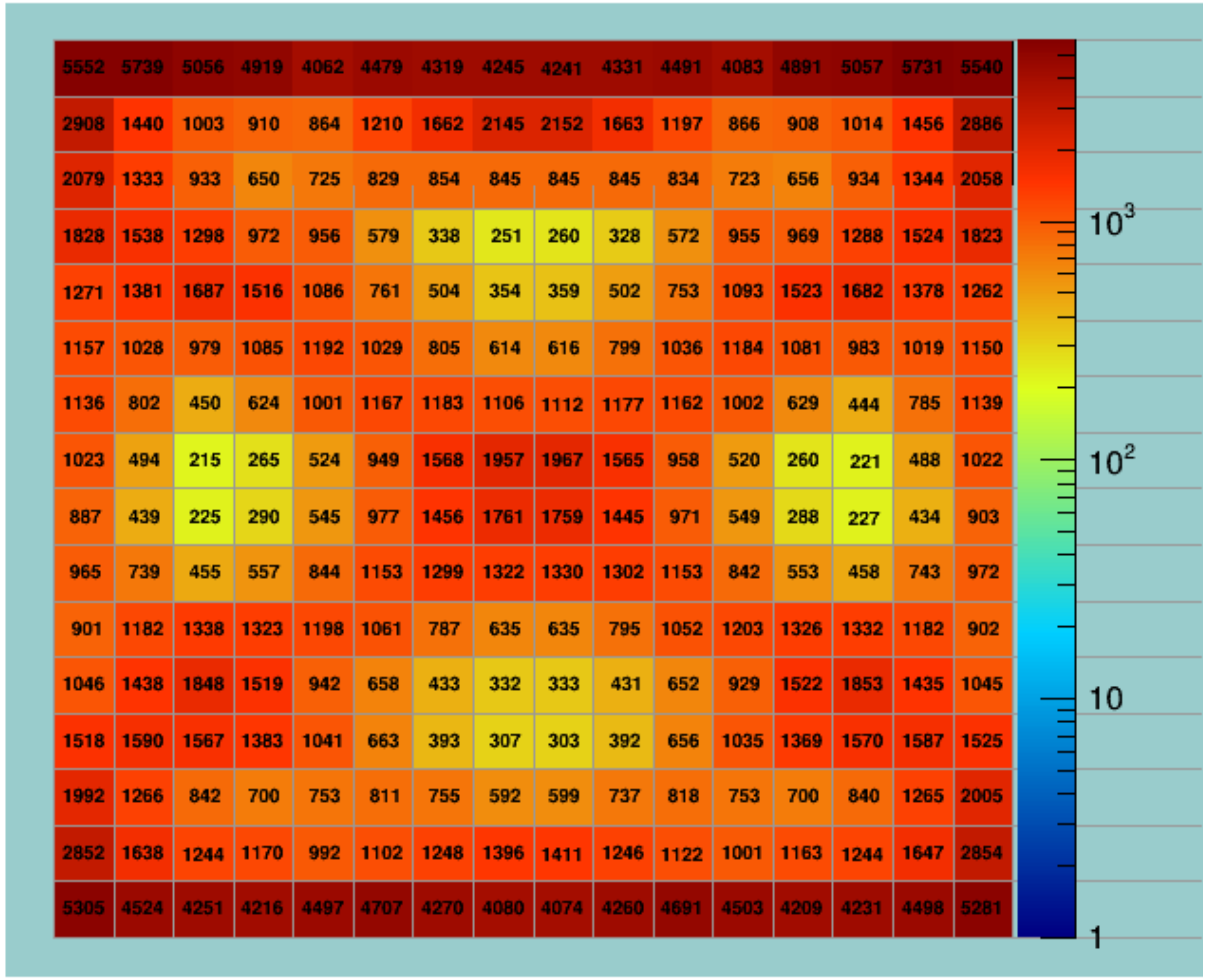
Hamamatsu MPPC/SiPM

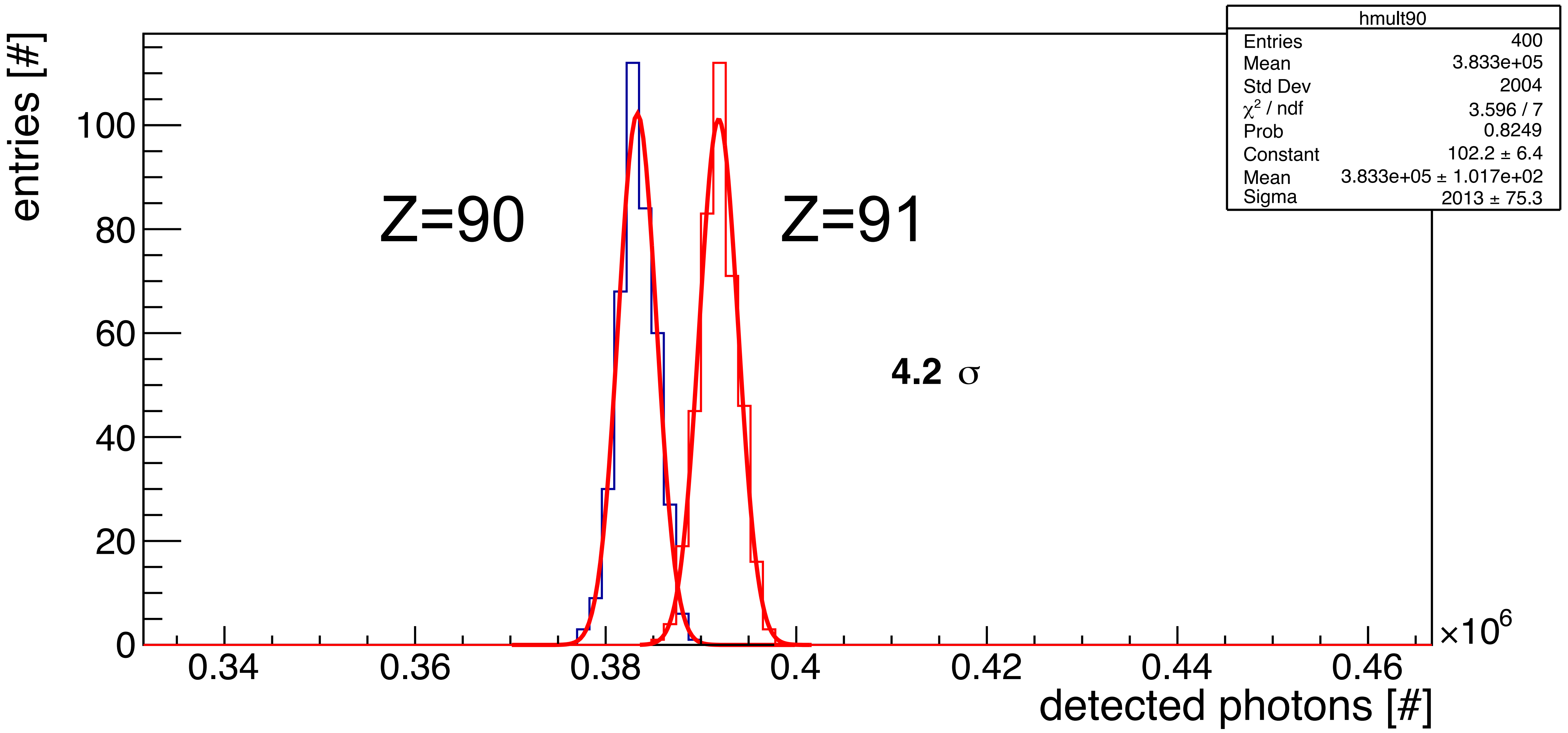
- S14161-3050HS-08
  - 8x8 array of 3x3 mm^2 pixels compatible with tiling, 74% fill factor
    - $50 \times 50\, \mu m^2$ micro pixels (3150 out of nominal 3600 per pixel)
    - Overall size 25.8 x 25.8 mm^2
- S13360-25
  - Single 3x3 mm^2 pixel module with 14400 micropixels (25 microns),
  - 5.9 x 6.5 mm^2 external size: 47% fill factor
  - Lower fill factor is not an issue since we have an ‘excess’ of photons.
  - Higher micro pixel density to reduce saturation effects

Variation in EV

30x60x60 Internally Reflective Faces

- No saturation effect applied
- Maximum Pixel occupancy 4700 p.e
  - Driven by reflections?





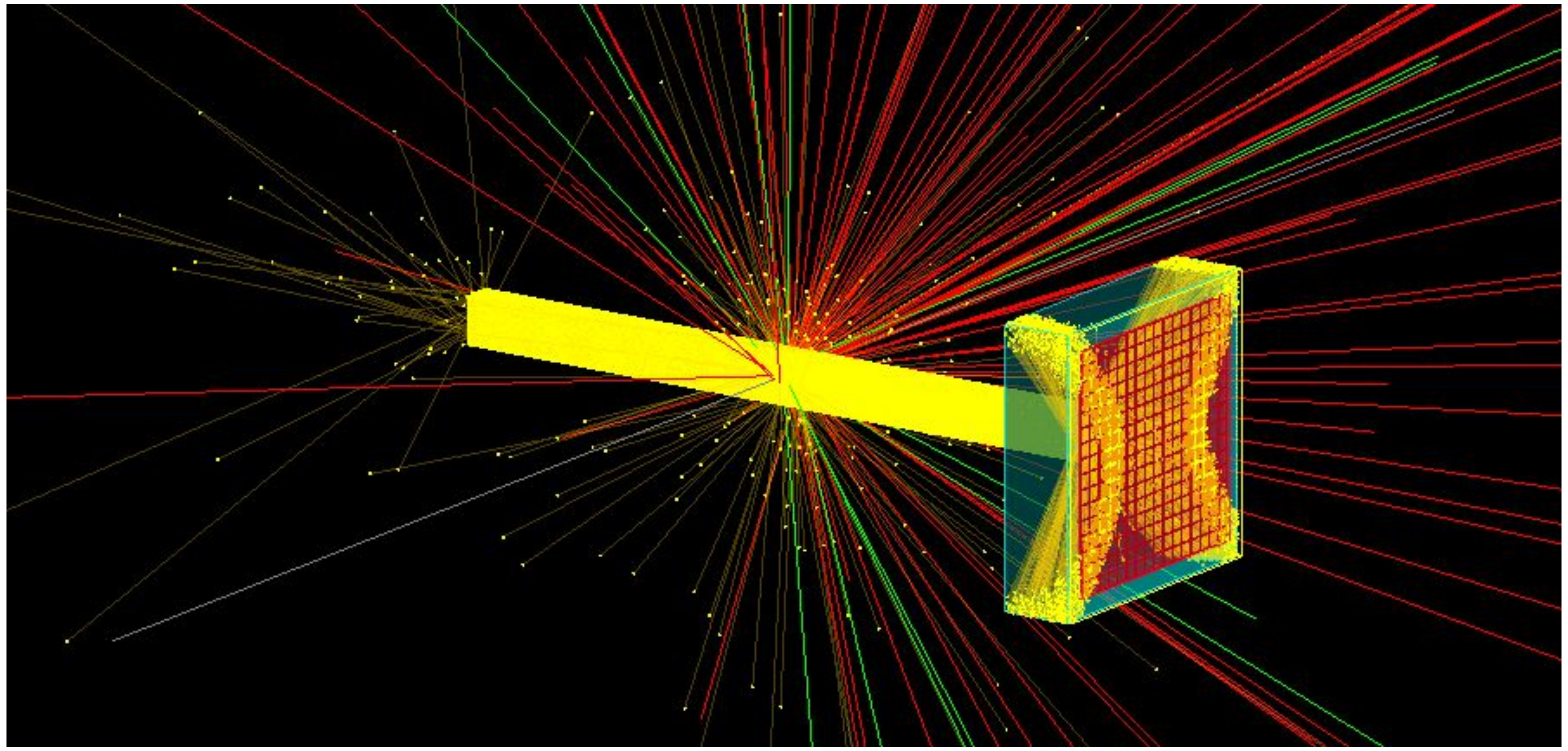
Includes secondaries

-w 3

Variation in EV

15x60x60 mm3

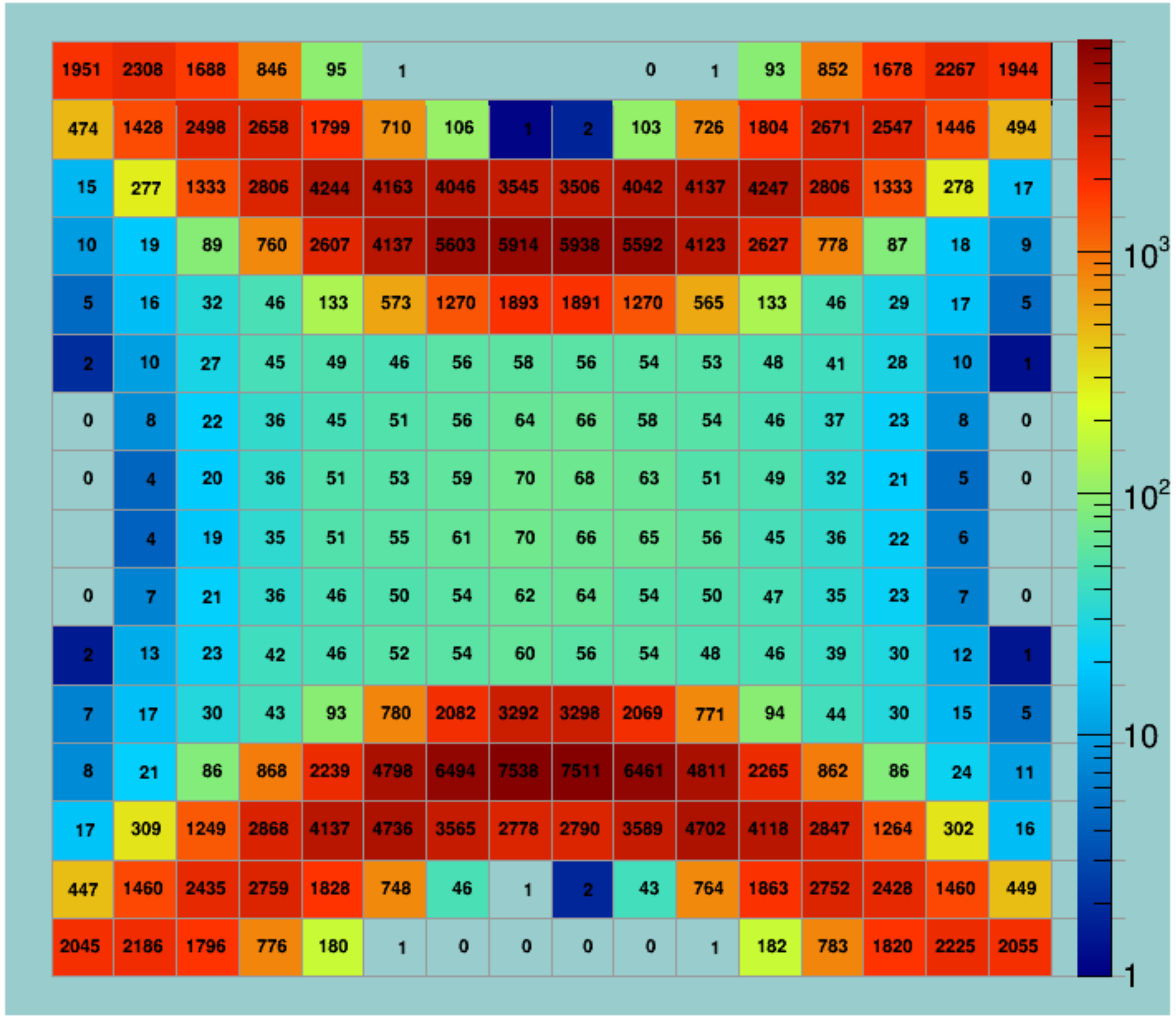
- Short EV: Naively expected this to suppress reflections on sides
- However, this is not the case, so made the sides black
- Example of Z=40 ion
  - Black EV illustrates first bounce
  - Large number of photons emitted near vertical plane



Z=90 Hit Pattern

EV 15x60x60, black

- Up to 7500 photo-electrons in a single pixel (only 3150 micro-pixels)
- Possible solutions
  - Change EV to better diffuse illumination
  - Apply optical filter to reduce photon intensity x10.
  - Small 5deg angle to end of radiator
  - Small angle off 90deg of bar to beam
    - This would be OK for everything from He to U, but would reduce Deuterons to ~4 p.e.



Simplistic Saturation Study

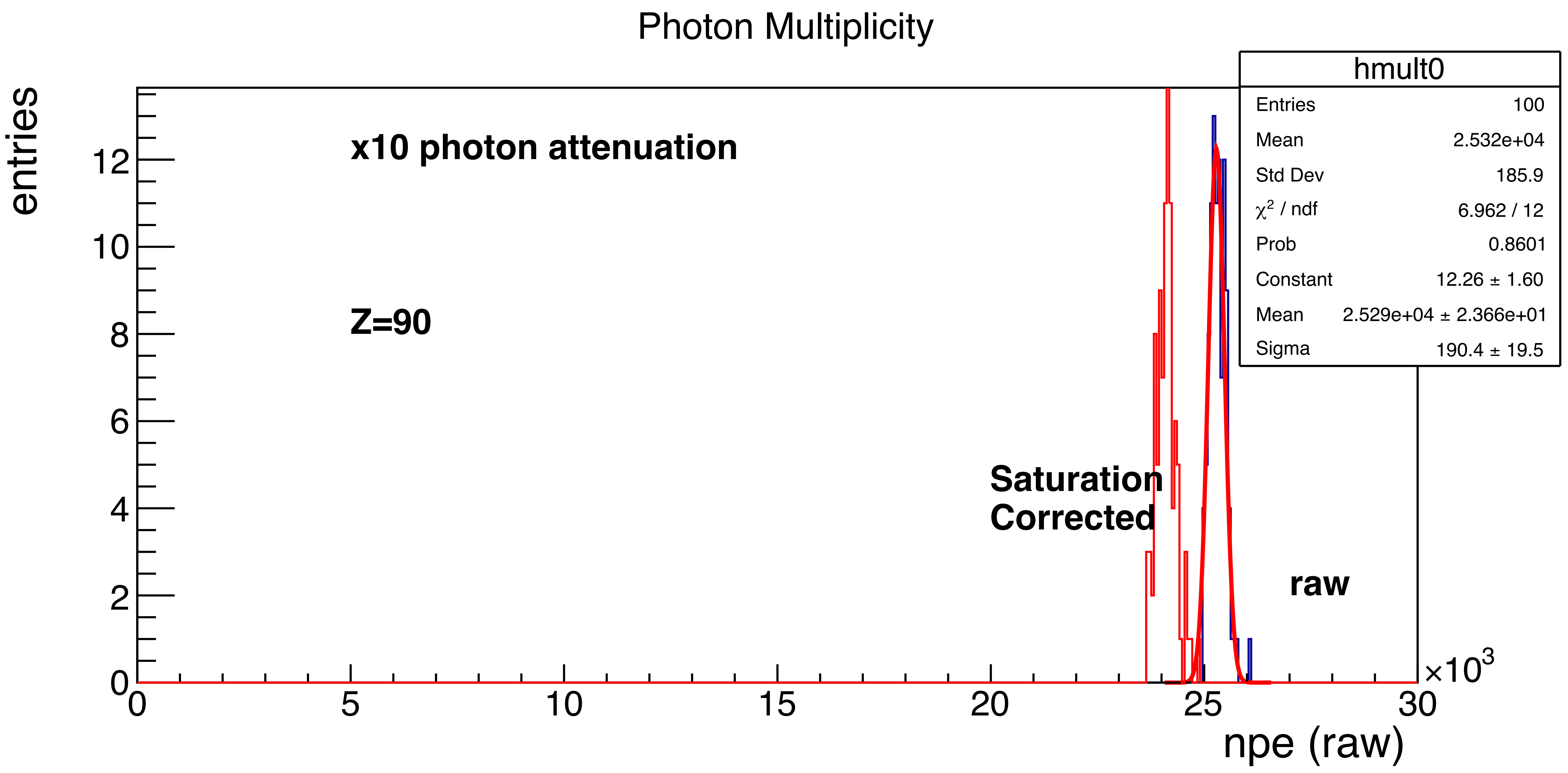
Binomial distribution

- Given *M* p.e. uniformly produced in *N* micro-pixels
  - Probability of *m* p.e. in one micro-pixel is Poisson $e^{-\mu}\mu^{m}/m!$ with $\mu = M/N$
  - Probability of *m>0* is $p = 1 - e^{-\mu}$
  - The SiPM amplitude distribution is Binomial $p^{n}(1-p)^{N-n}\dfrac{N!}{(N-n)!\,n!}$, where *n* is the effective number of photo-electrons (signal = n*Gain)

Saturation Example

Saturation study with factor of 10 attenuation of photons

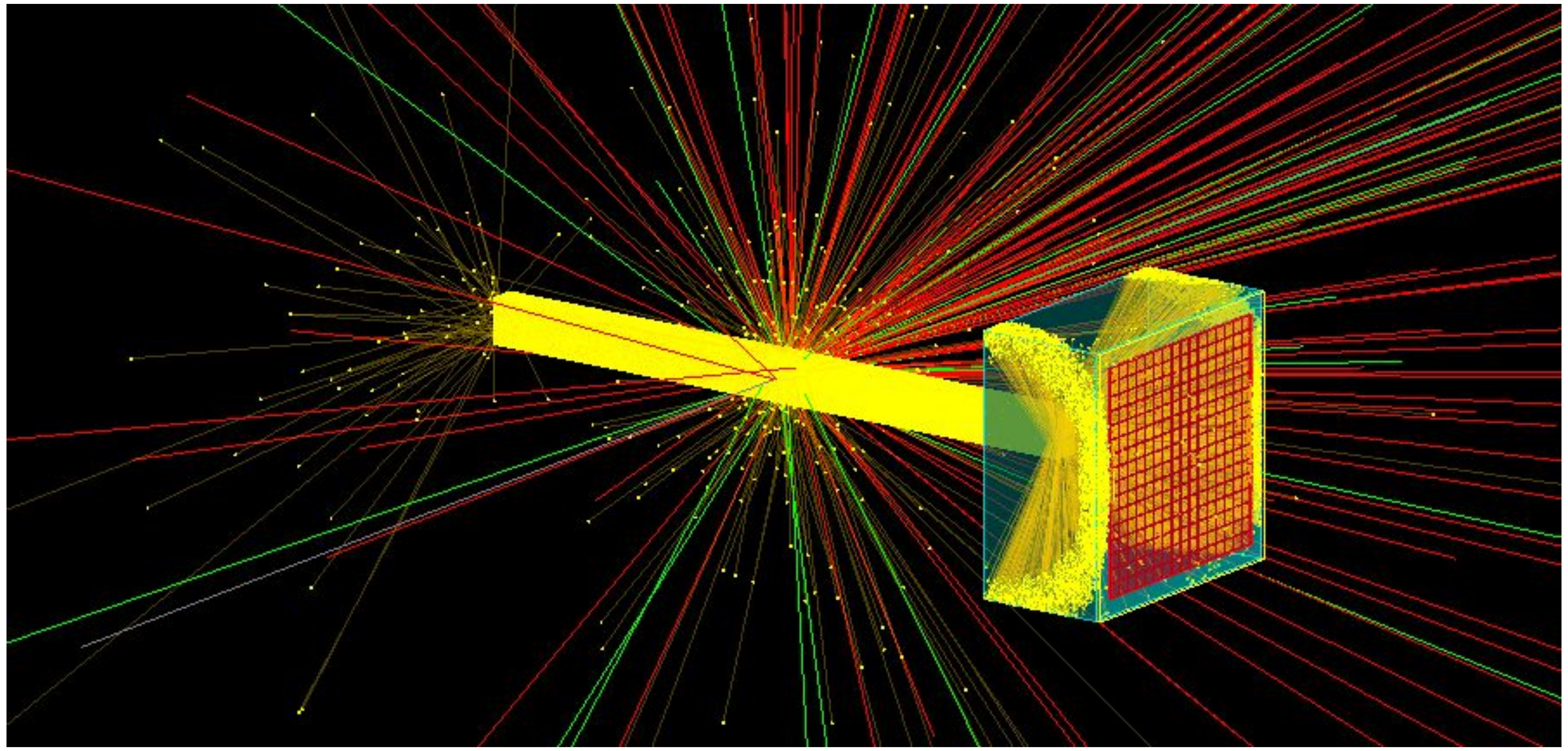
- Z=90 Example
  - (Mean, σ) = (25290, 190) shifted to (24094, 230)
- Repeat for Z=91, compare saturation multiplicities
  - 3.2 σ separation of Z=90,91 reduces to 2.3 σ



Variation in Expansion Volume

30x60x60

- Almost no photons make it to back.
- Better to put photo-sensors on sides?
  - One set for high-Z, one for low-Z??
- Extreme reduction in photon yield, but still highly concentrated



Outlook for Simulations

Variations in EV and Photosensor

- Restore regular (internally-reflective) surfaces
  - How to reduce concentration at edges (slide 10)?
  - Diffusive surfaces?
- Shrink EV area to more closely match photosensor?
- Suggestions?
  - Split EV into 4 quadrants to enhance dispersive quality of reflections
  - Diffusing filter or surfaces
  - Filter to reduce photon intensity
  - Lower fill-factor SiPM with 4x higher micro pixel density
  - Lens? Air gap?
- SiPM/MCP lifetime?

Beam Tests?

Minidirc tests only needs ion beam energies > 1.3 GeV/nucleon

- Discussion to develop ion beam lines at AGS following RHIC shutdown
  - Space radiation effects (DOD, NASA interest)
  - Detector tests
  - Physics
  - Limited funding to BNL from DOD for feasibility study
- workshop announced for February 2025 then ~indefinitely postponed
  - Contact person at BNL: Xiaodong Jiang
  - Proposed beams proton≤25 GeV, He - Bi up to 9.8 GeV/u
  - Long term discussions still ongoing with DOD/MDA
  - NSRL (Booster injector to AGS) ion beams up to 1 GeV/u

Prototype?

Funds still available from Generic R&D project

- Hamamatsu quote, $6000 for SiPM array
  - Without DAQ, maybe better to try a single ordinary 2” PMT?
- DAQ?
- Specs for radiator?
  - Parallelism to 2mr?
  - Corner radii?
  - Smoothless criteria?
  - Thickness uniformity over e.g. separation of Z=90 & Z=91 fragments
  - 0.1 to 0.5 mm bevel on long edge of radiator?