Geant4 Uniformity Simulation

Modified based on OpNovice2

Xiaocheng Zhu 06/16

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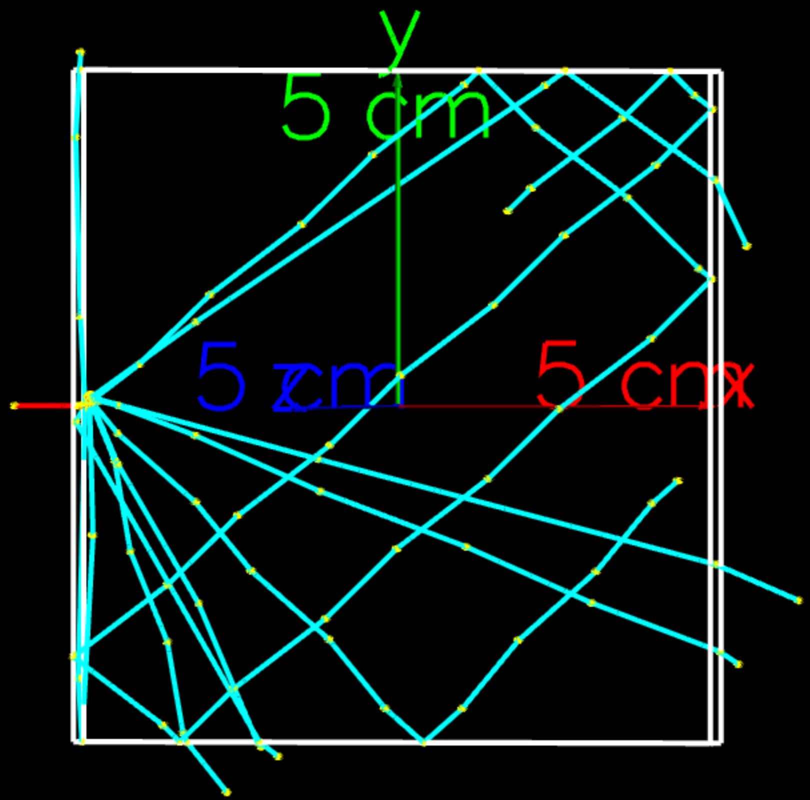


Obtained on 06-03.

First visualization picture taken off from Geant4, shooting a 1 MeV electron to the tank (from -x). For demonstration purposes, I lowered the scintillation yield to 10 photons / MeV instead of EJ-200's real property 10000 photons / MeV.

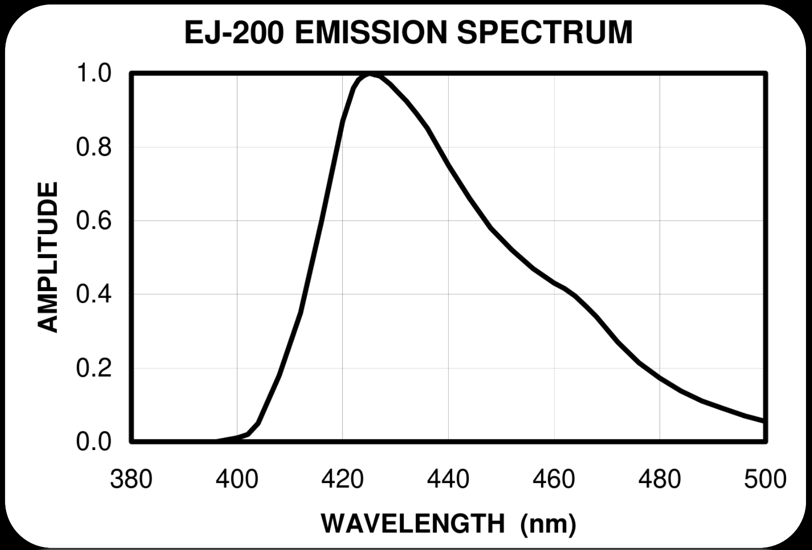
EJ-200 Definitions

Physical and Scintillation Constants:

Light Output, % Anthracene 64
Scintillation Efficiency, photons/1 MeV e^- 10,000
Wavelength of Max. Emission, nm 425
Rise Time, ns 0.9
Decay Time, ns 2.1
Pulse Width, FWHM, ns .... ~2.5
No. of H Atoms per cm^3, x 10^{22} 5.17
No. of C Atoms per cm^3, x 10^{22} 4.69
No. of Electrons per cm^3, x 10^{23} 3.33
Density, g/cc: 1.023

Polymer Base: .... Polyvinyltoluene
Refractive Index: 1.58
Vapor Pressure: .... Is vacuum-compatible
Coefficient of Linear Expansion: .... 7.8 x 10^{-5} below +67°C

Light Output vs. Temperature:
At +60°C, L.O. = 95% of that at +20°C
No change from +20°C to -60°C



Initial **ej200_electron_boundary.mac** macro

```
# ---------------------------
# EJ-200 (Box) Property
# ---------------------------

# Light output (% Anthracene): 64
# ...

# Scintillation efficiency (photons / 1 MeV e-): 10000
/opnovice2/boxConstProperty SCINTILLATIONYIELD 10000/MeV
/opnovice2/boxConstProperty SCINTILLATIONYIELD1 1.0
/opnovice2/boxConstProperty RESOLUTIONSCALE 1.0

# Wavelength of Maximum Emission (nm): 425
# The data points are taken from EJ-200 emission sheet.
/opnovice2/boxProperty SCINTILLATIONCOMPONENT1 2.4982*eV
0.069 2.5419*eV 0.109 2.5623*eV 0.134 2.5838*eV 0.174 2.6039*eV 0.214
2.6273*eV 0.274 2.6495*eV 0.335 2.6823*eV 0.415 2.7196*eV 0.468
2.7700*eV 0.582 2.8458*eV 0.851 2.9033*eV 0.991 2.9173*eV 1.000
2.9313*eV 0.985 2.9383*eV 0.960 2.9516*eV 0.881 3.0092*eV 0.352
3.1001*eV 0.017

# Light Attenuation Length (cm): 380
# The energy range is set to accommodate 380nm~600nm (see EJ-200
emission spectrum)
/opnovice2/boxProperty ABSLENGTH 2.0*eV 380*cm 3.3*eV 380*cm
```

EJ-200 definitions

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The Photon Model of Light

The energy carried by a photon in Einstein's model

$$E = hf = \frac{hc}{\lambda}$$

, where f is the frequency of the (monochromatic) (!) light. This equation **only** applies to *photons*. Also $hc = 1240\,\mathrm{eV}\cdot\mathrm{nm}$.

Planck's constant

$$h = 6.63 \times 10^{-34}\,\mathrm{J}\cdot\mathrm{s} = 4.15 \times 10^{-15}\,\mathrm{eV}\cdot\mathrm{s}$$

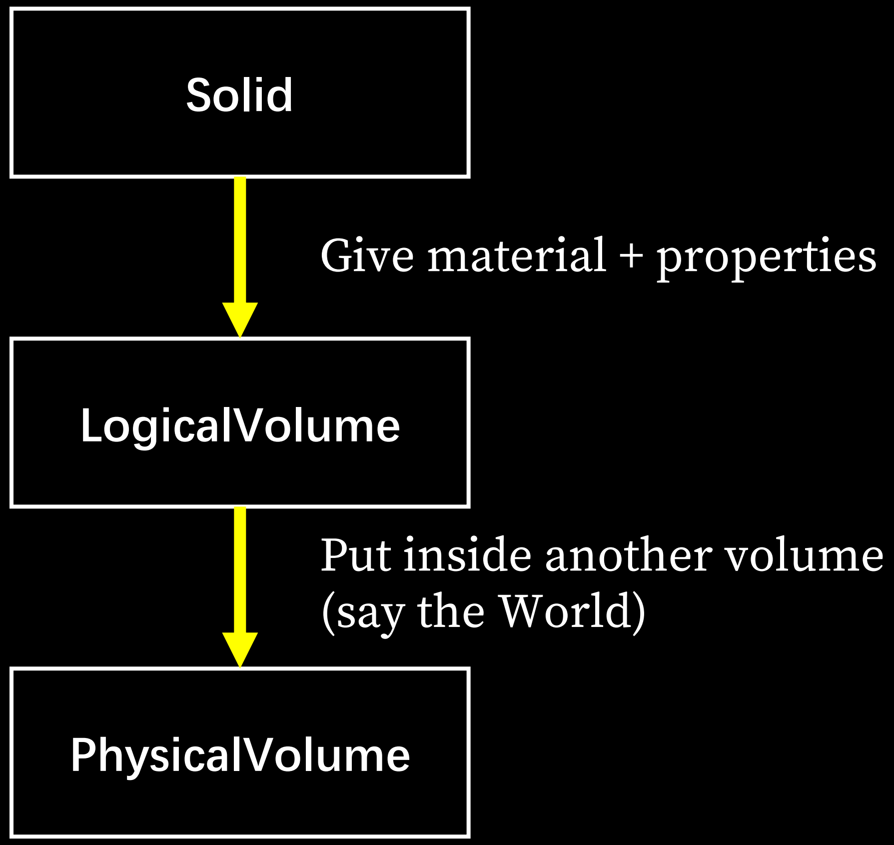
```
# Light Attenuation Length (cm): 380
# The energy range is set to accommodate 380nm~600nm (see EJ-200 emission spectrum)
/opnovice2/boxProperty ABSLENGTH 2.0*eV 380*cm 3.3*eV 380*cm

# Rise Time (ns): 0.9
/opnovice2/boxConstProperty SCINTILLATIONRISETIME1 0.9*ns

# Decay Time (ns): 2.1
/opnovice2/boxConstProperty SCINTILLATIONTIMECONSTANT1 2.1*ns

# Pulse Width, FWHM (ns): 2.5
# ...

# Density (g / cm3): 1.023
# ...

# Refractive Index: 1.58
/opnovice2/boxProperty RINDEX 2.0*eV 1.58 3.3*eV 1.58
```

$$\frac{1240}{600} \approx 2.0667 \qquad \frac{1240}{380} \approx 3.2632$$

After this macro ran successfully, by adding a visual part, and off-screen using **/vis/tsg/export gl2ps_pdf out.pdf**, I got my first picture (shown before).

Simulating SiPM

Volume model of Geant4



DetectorConstruction.hh

Only showing key changes

```
/// Adding SiPM
// Physical Volume & Logical Volume
G4VPhysicalVolume* fSiPM = nullptr;
G4LogicalVolume* fSiPM_LV = nullptr;

// Material & Properties Table
G4Material* fSiPMMaterial = nullptr;
G4MaterialPropertiesTable* fSiPMMPT = nullptr;

// Half-lengths
G4double fSiPM_x = 0.5 * CLHEP::mm;
G4double fSiPM_y = 1.5 * CLHEP::mm;
G4double fSiPM_z = 1.5 * CLHEP::mm;
```

Note: the initial assumption for SiPM is **3mm × 3mm**, but the latest model changed to **2mm × 2mm**, measured from a real SiPM taken in the lab.

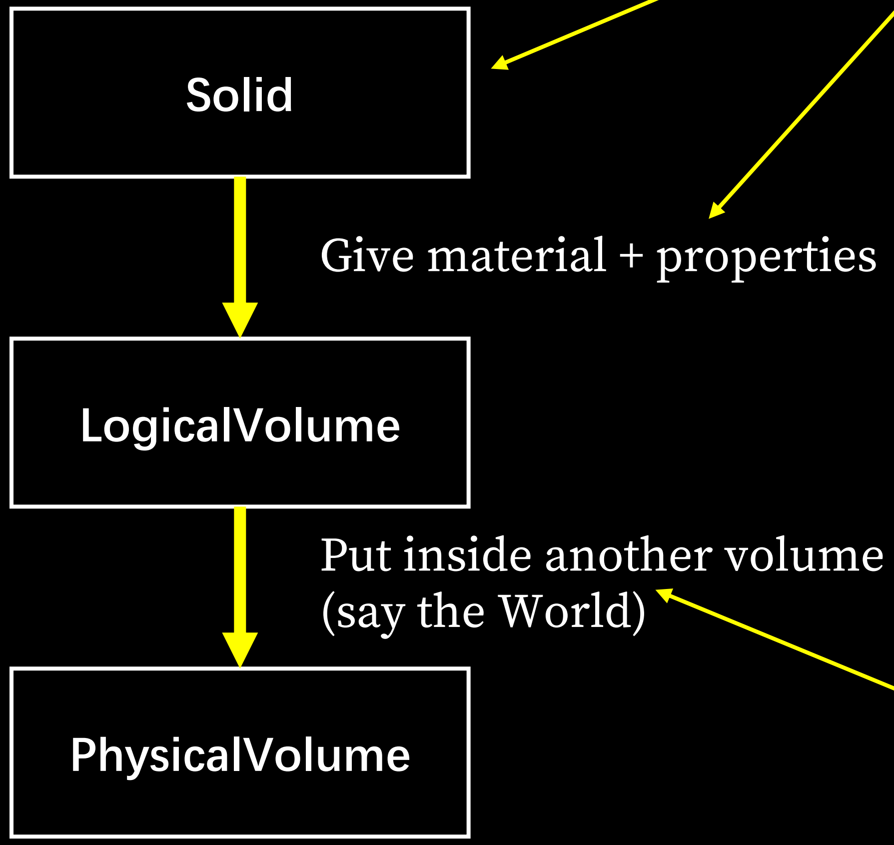
This follows the style of the original file.

Simulating SiPM

DetectorConstruction.cc

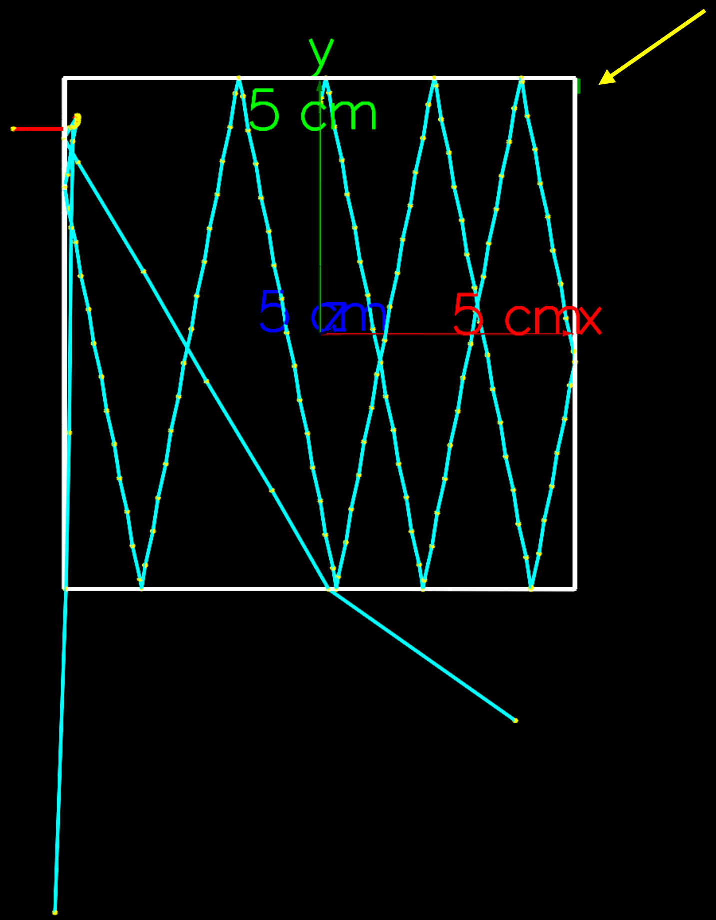
Only showing key changes

Volume model of Geant4




```
// The SiPM
auto sipm_box = new G4Box("SiPM_Box", fSiPM_x, fSiPM_y, fSiPM_z);

fSiPM_LV = new G4LogicalVolume(sipm_box, fSiPMMaterial, "SiPM");

// SiPM attached to +X, +Y corner of the tile.
// x = tile + SiPM half-depth
// y = top edge minus SiPM half-width
// z = centered in tile thickness
G4ThreeVector sipmPos(fTank_x + fSiPM_x,
                      fTank_y - fSiPM_y,
                      0.0);

fSiPM = new G4PVPlacement(nullptr,
                          sipmPos,
                          fSiPM_LV,
                          "SiPM",
                          fWorld_LV,
                          false,
                          0,
                          true);       // overlap check
```

Simulating SiPM



SiPM in this figure is placed on the +X, +Y corner.

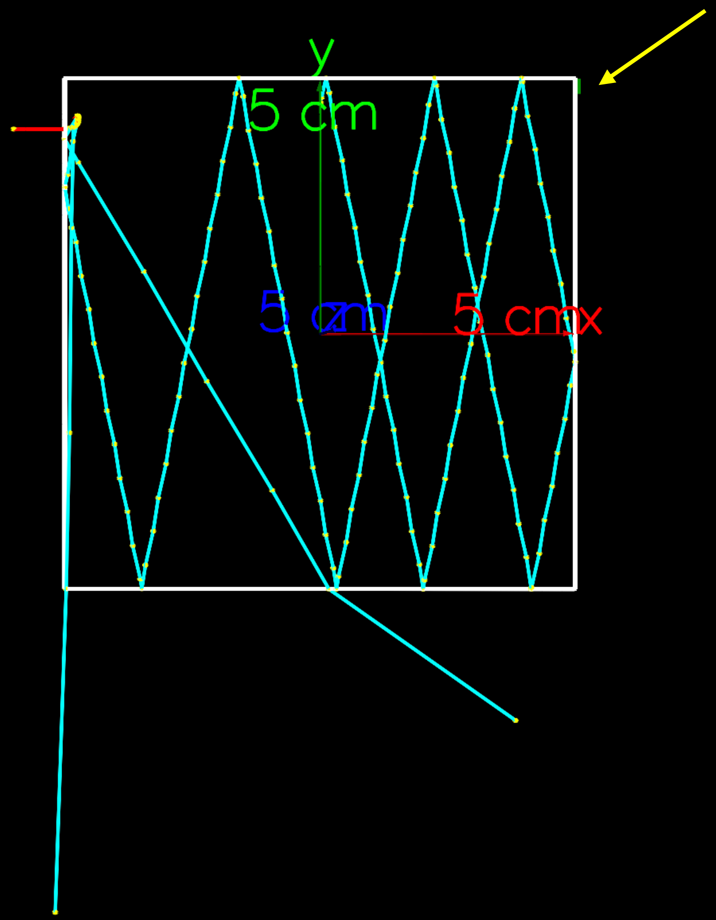
Run.hh / Run.cc

Only showing key changes

```
// SiPM Detection
void AddSiPMDetection() { fSiPMDetectionCount += 1; }

// SiPM counting
G4int fSiPMDetectionCount = 0;


// SiPM count
fSiPMDetectionCount += localRun->fSiPMDetectionCount;

// SiPM summary
G4cout << "Average number of photons detected by SiPM per event: "
  << fSiPMDetectionCount / TotNbofEvents << G4endl;
```

Simulating SiPM

SteppingAction.cc
Only showing key changes

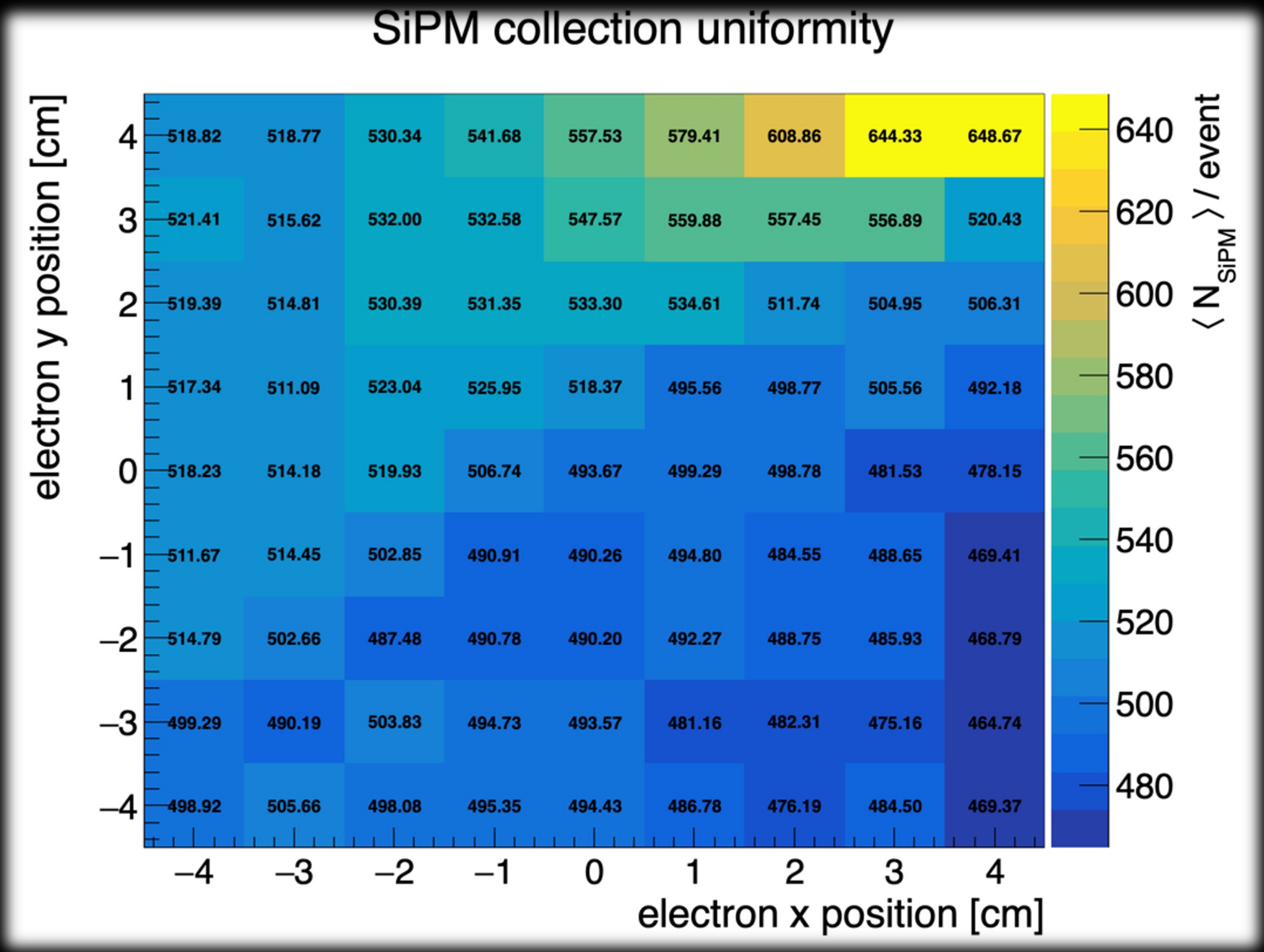


SiPM in this figure is placed on the +X, +Y corner.

```
if (particleDef == opticalphoton) {
  // SiPM detection
  auto prePV = startPoint->GetPhysicalVolume();

  if (prePV && prePV->GetName() == "SiPM") {
    run->AddSiPMDetection();

    G4double en = track->GetKineticEnergy();
    analysisMan->FillH1(27, en / eV);  // detected photon energy

    G4double time = track->GetGlobalTime();
    analysisMan->FillH1(28, time / ns);  // detected photon arrival time

    track->SetTrackStatus(fStopAndKill);
    return;
  }
...
```

The added code here detects whether the previous step, the photon is inside the SiPM. If yes, then it will be counted and killed.

Uniformity Scan

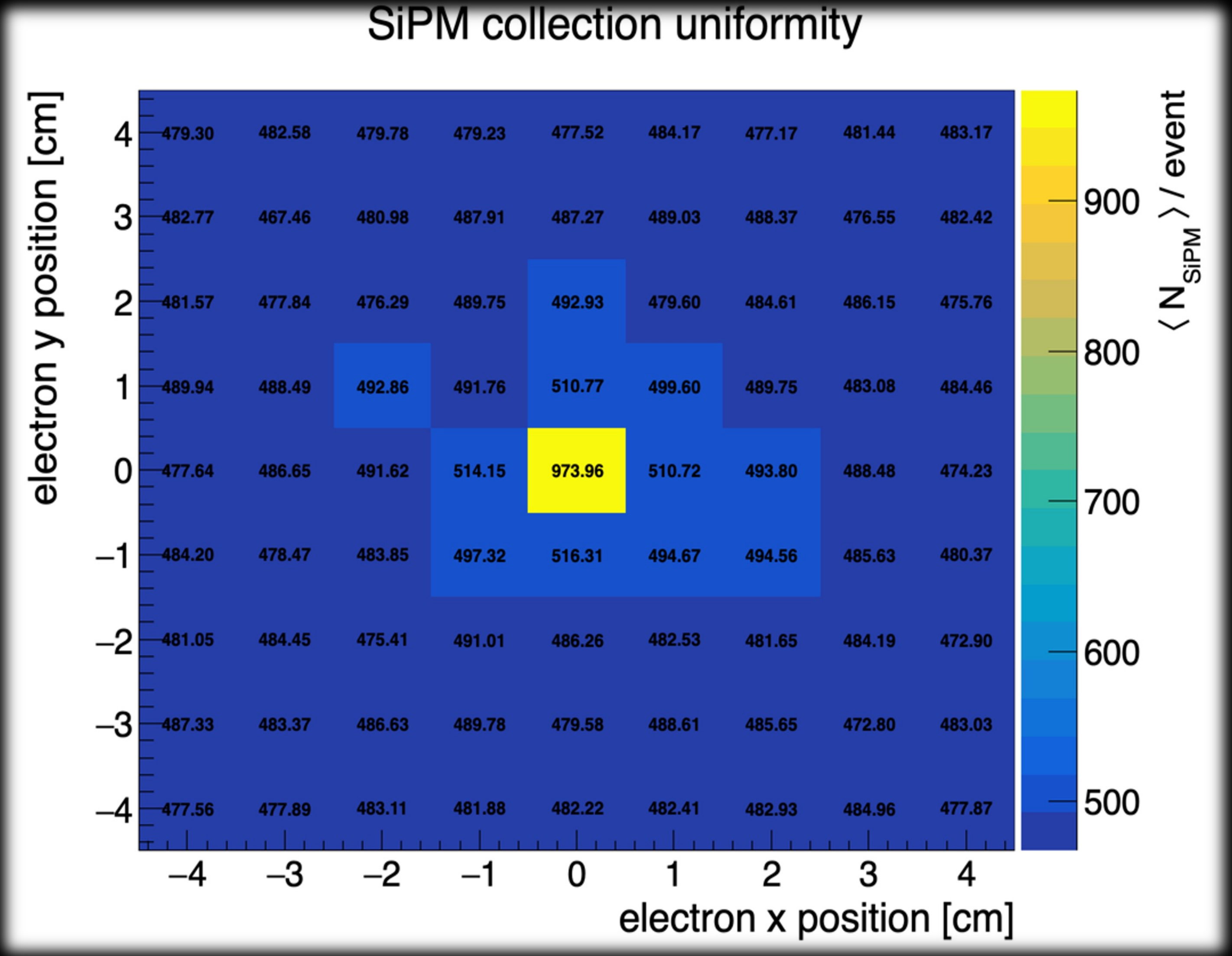


The SiPM still located in the previous spot, +X and +Y corner.

This is a uniformity scan that 100 electrons shooting from 0.4 cm height from different positions. Each position is simulated 100 events.

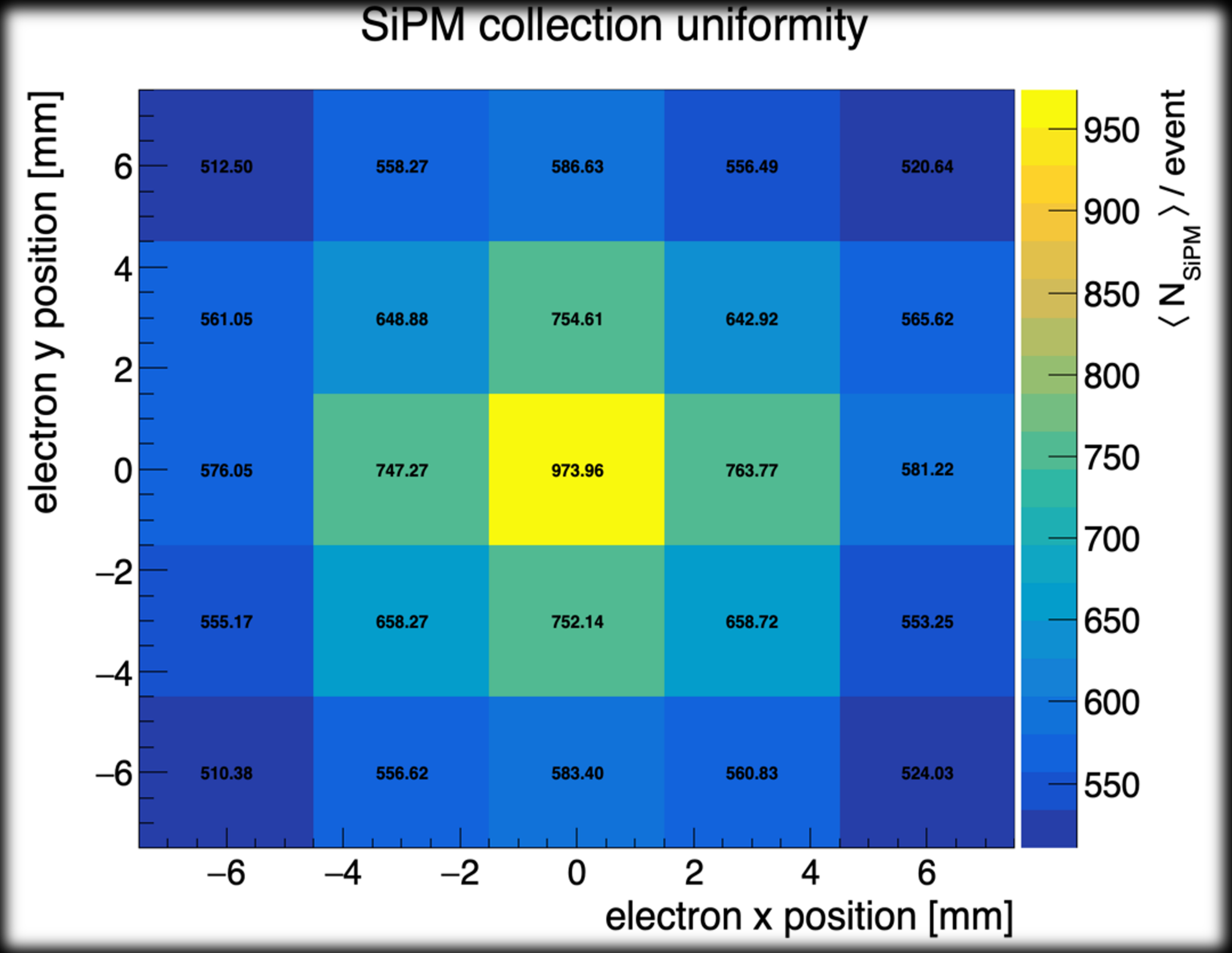
The number on each block shows the average number of photons SiPM detected per event. Since the SiPM is located at the top-right corner, the top-right corner has higher counts.

Uniformity Scan



Now, the SiPM is located at the bottom center with other parameters same.

Uniformity Scan



Now, the SiPM is located at the bottom center with other parameters same.

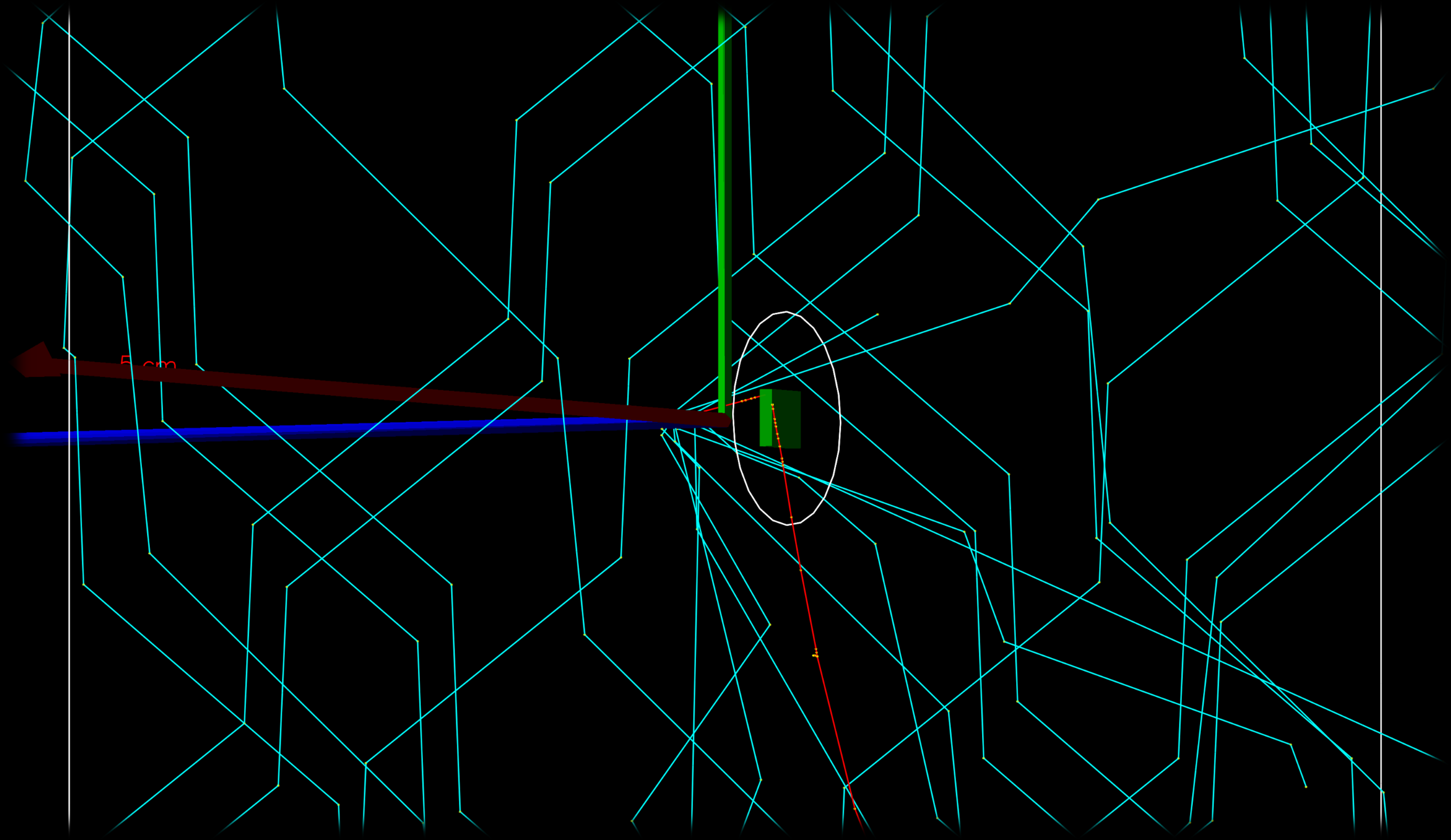
Take a closer look. This is a near-field scan, with stepping length equal to SiPM's side length (that time **3mm**).

Uniformity Scan

What if we add a **dimple**?

Uniformity Scan

What if we add a dimple?

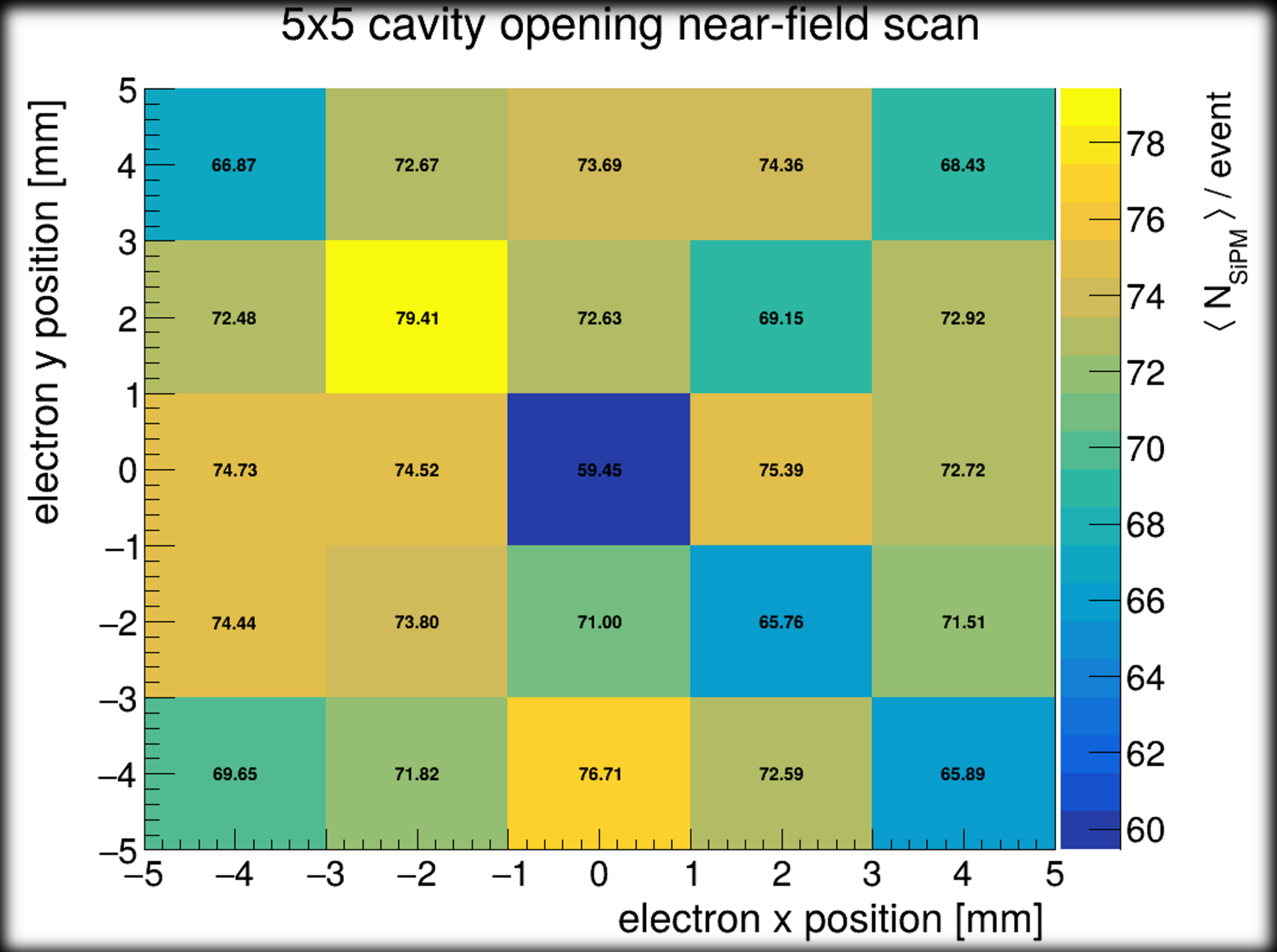


A dimple located at the bottom of the EJ-200, created by bool calculation using a hemisphere with ¾ thickness radius.

The bottom of the SiPM and the bottom of EJ-200 is same height.

Uniformity Scan

What if we add a dimple?



This is using Sr 90 Beta energy distribution (sampled from the curve), with the dimple.

Although this cannot directly compare to previous results (since this is also an experiment of testing whether my Sr90 Beta is working), this shows that the dimple is affecting the center!

Thanks for listening!