Triton implantation simulation using GEANT4

1. Set physics : Scattering and Energy Loss of triton

1.1 Interaction with electron

- Aspects of scattering were not taken into account
- dE/dx
  - from PSTAR parametrization for gold, aSi
  - from ICRU'49 for He3

$$S_{ei}(T) = Z_i^2 \cdot S_{ep}(T_p)$$
$$T_p = T\frac{M_p}{M_i}$$

1.2 Interaction with nucleus

- Classical screened Coulomb scattering : G4ScreenedNuclearRecoil(example : em/extended/Test7)
  - physicsCutOff : 0.01eV -> determine length of step, scattering angle, energy transfer
  - recoil happens down to 30 eV

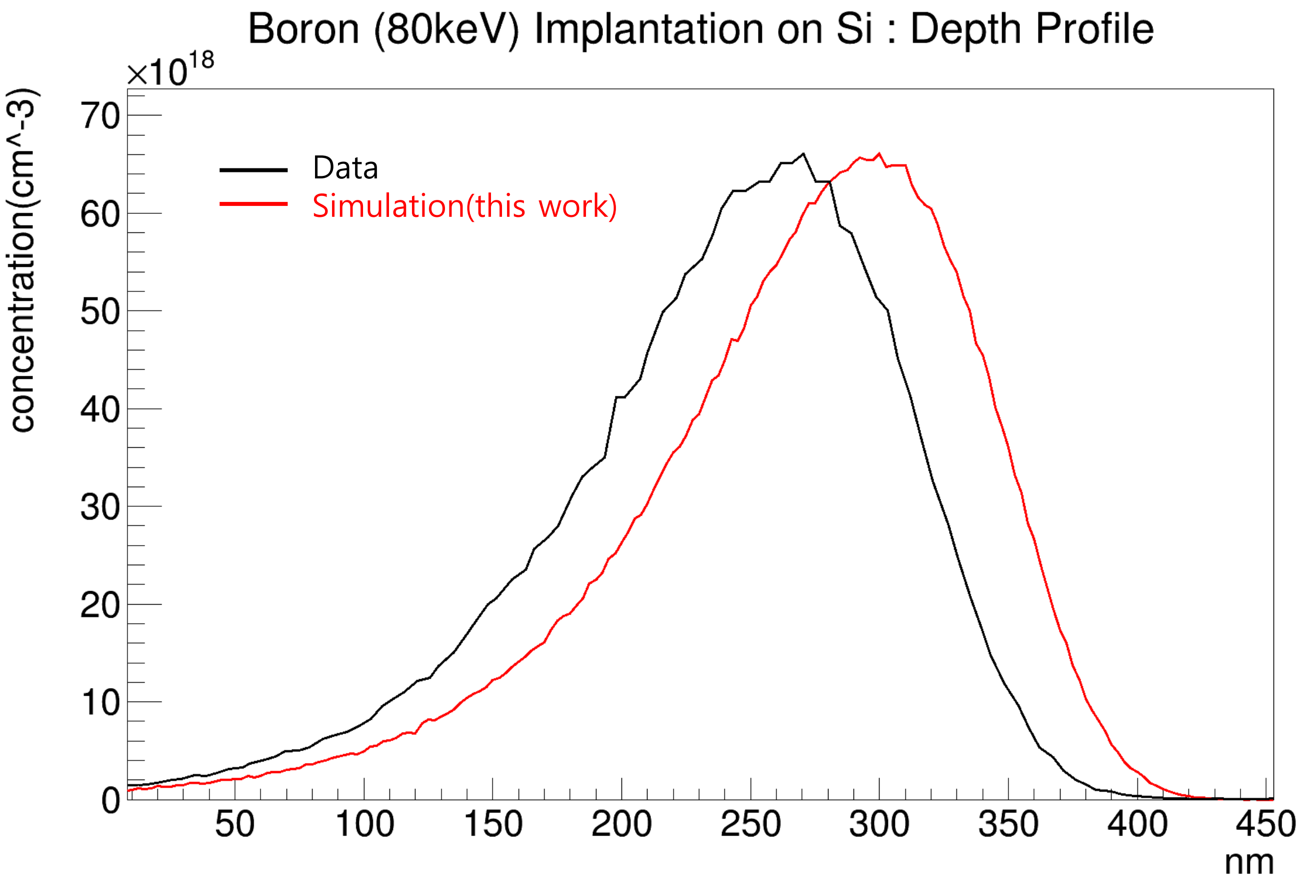
- Binary collision is assumed

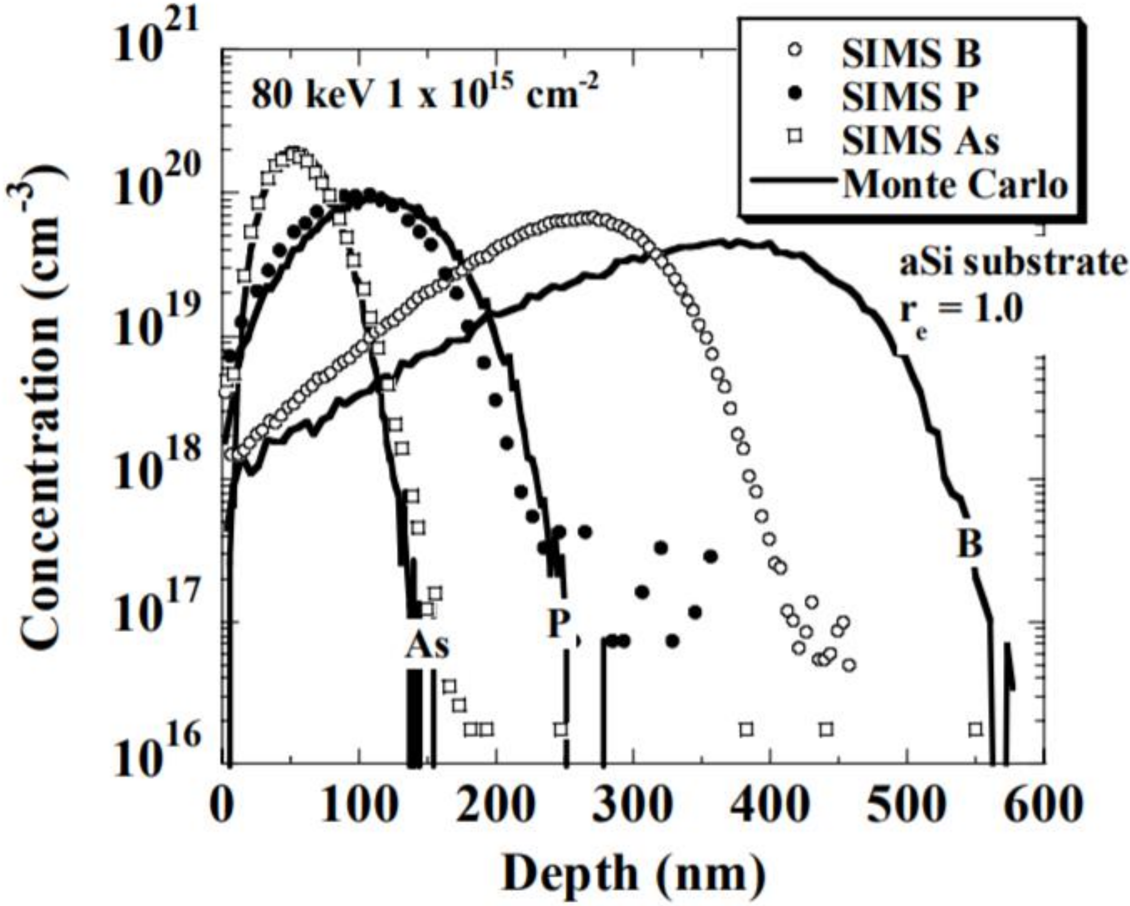
- No lattice structure(channeling effect is neglected now)

2. Check validity : depth profile

"Monte Carlo Simulation of Ion Implantation Profiles Calibrated for Various Ions over Wide Energy Range", JOURNAL OF SEMICONDUCTOR TECHNOLOGY AND SCIENCE, VOL.9, NO.1, MARCH, 2009

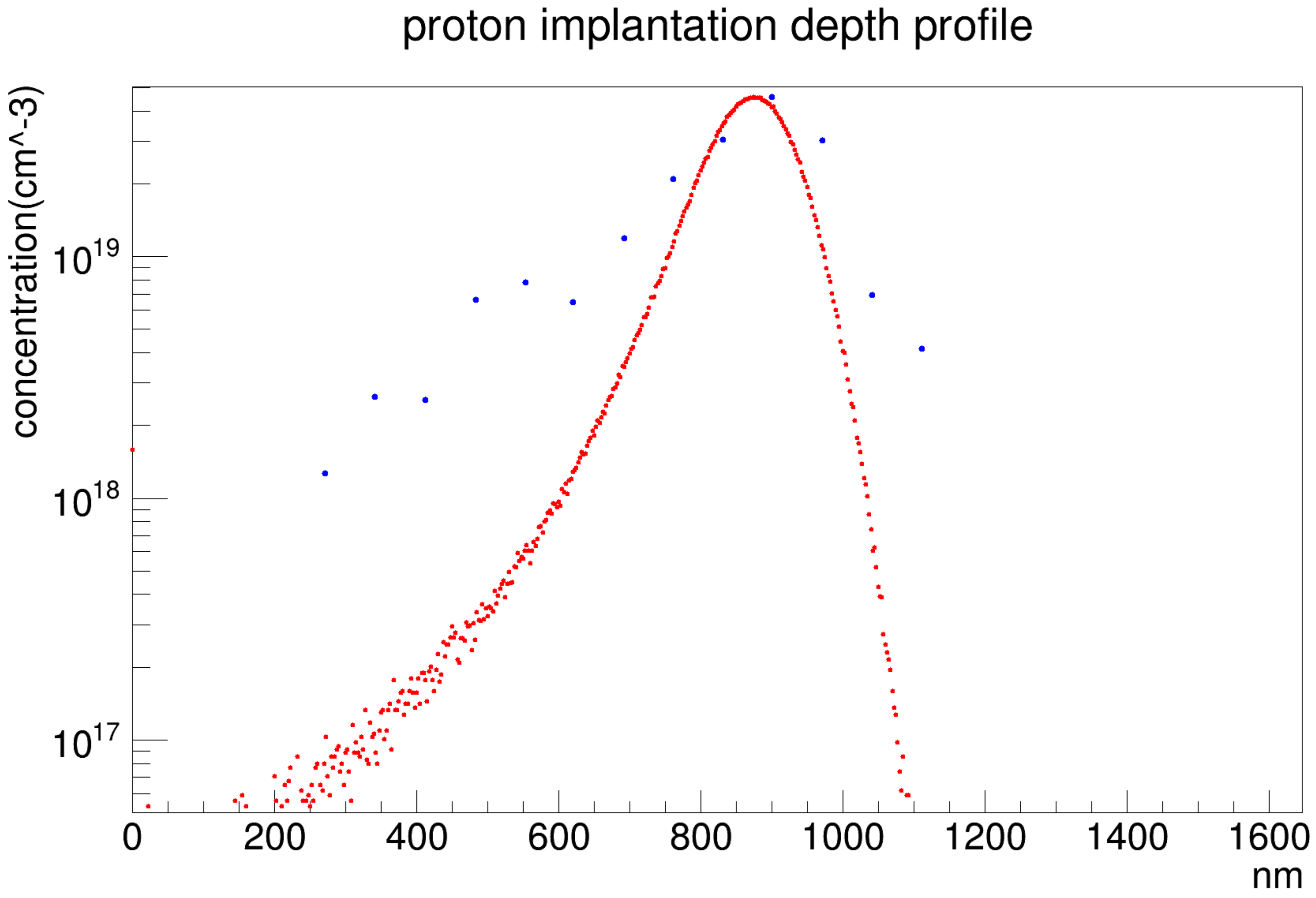
2.1 Boron : electronic stopping scaled by both charge and mass





2.1 Proton implantation

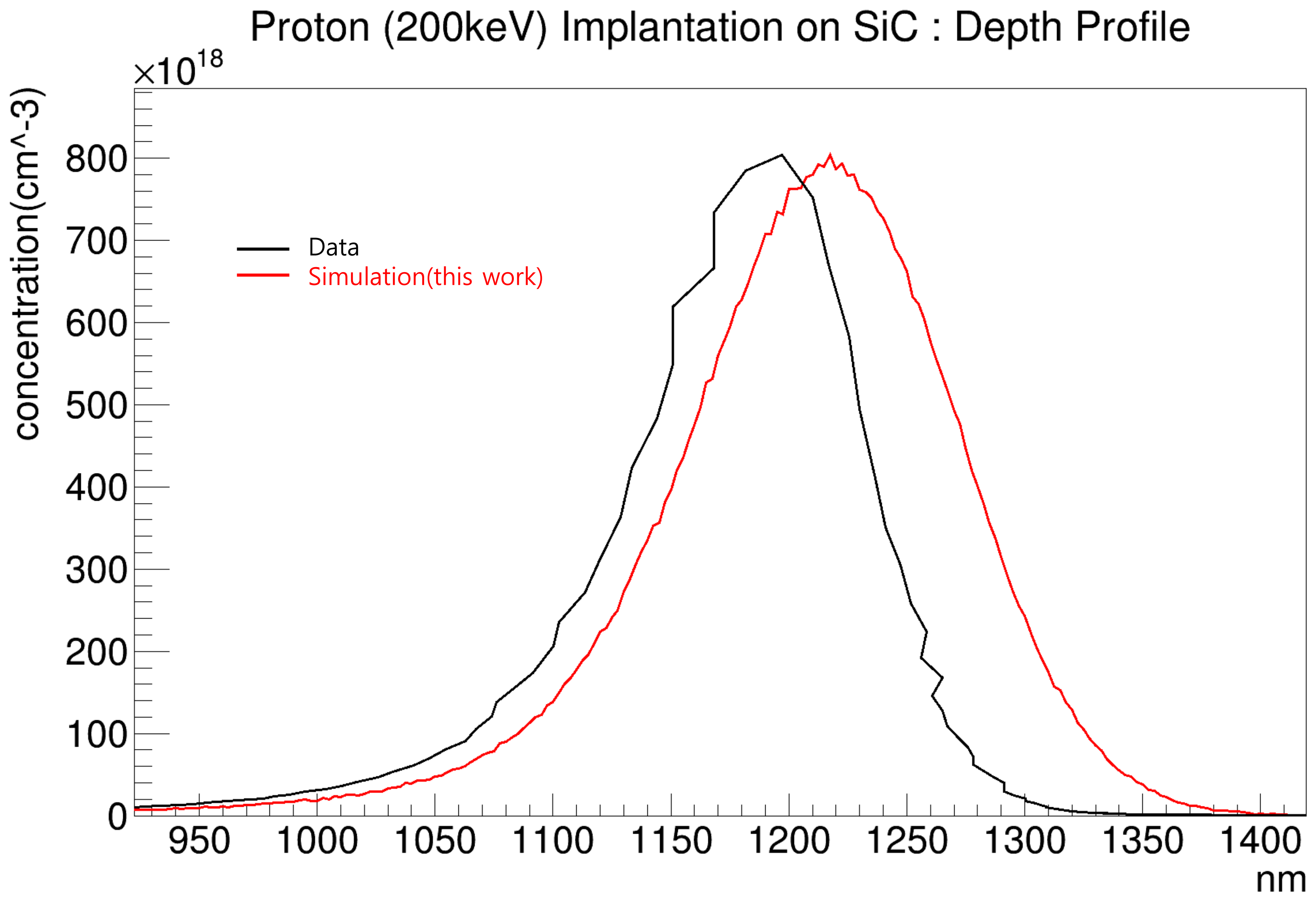
"Hydrogen implantation and diffusion in silicon and silicon dioxide", Applied Physics A, D. Fink et al, October 1995, Volume 61, Issue 4, pp 381–388



Data from NRA(nuclear reaction analysis)

$^{15}N + {}^{1}H \rightarrow {}^{12}C + \alpha + \gamma$ (4.43 MeV)

“Diffusion and impurity segregation in hydrogen-implanted silicon carbide”, A. Barcz et al. , Journal of Applied Physics, 115, 223710 (2014)



- SiC : silicon crystal
- Proton was irradiated with relative angle of 11 degree to (100) direction to avoid channeling effect

3. Neutron source and setup

- Thermal neutron flux at HANARO

: $10^{7-9} neutrons \ / \ cm^2 \ / \ s$ (10^{13} at core)

- ${}^3_2He + n \rightarrow {}^1_1H(191 \ keV) + {}^3_1T(573 \ keV)$ ($\sigma = 5337 \ barn$)

- Helium-3 gas

- Density : 0.125mg/cm^3 (1atm, $21^{\circ}C$)
- Atomic weight : 3.016g/mol

-> mean free path : 7.5cm

-> Tritium production rate from 5*5*5 cm^3 (0.016g of Helium-3) $\sim 1.7 * 10^8 \ tritium$ / s (for neutron flux of 10^7)

- Neutron capture for setup material

https://www.ncnr.nist.gov/resources/n-lengths/

- Gold

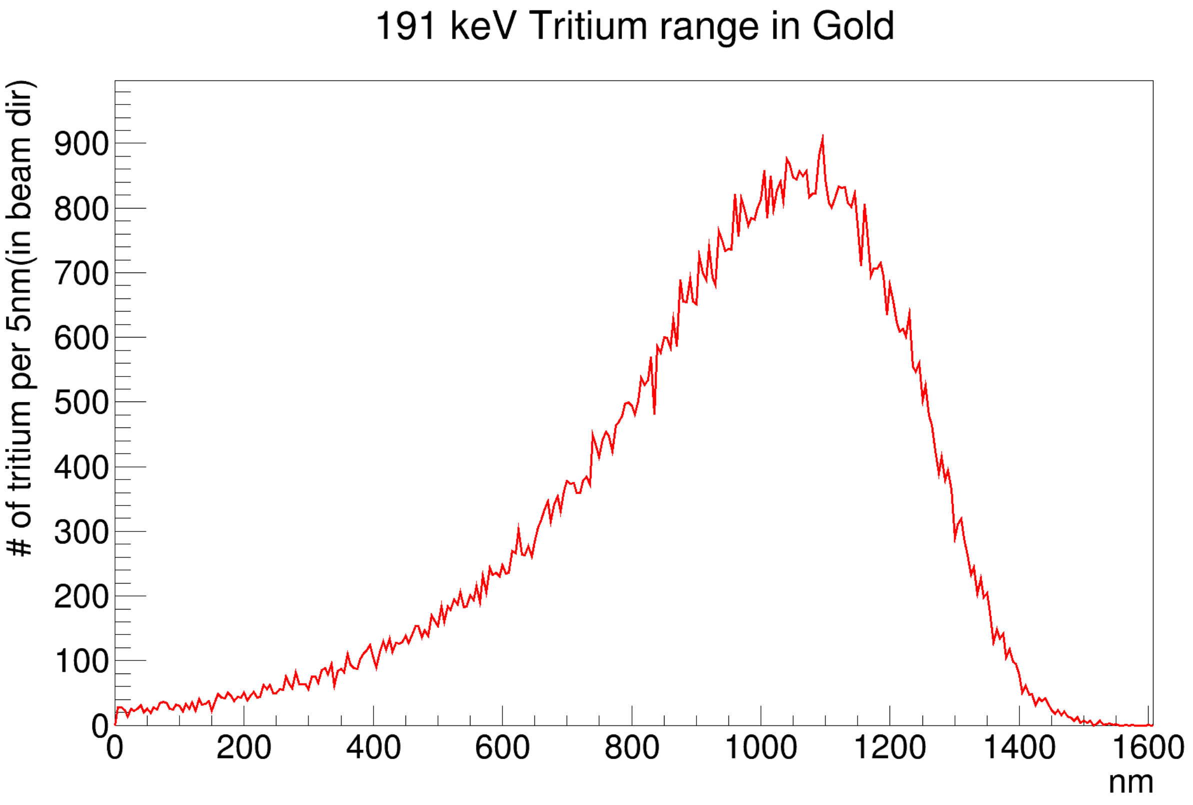
Density = 19.32g/cm^3 (atomic weight : 196.97)
Thermal neutron capture cross section : 98.7 barn

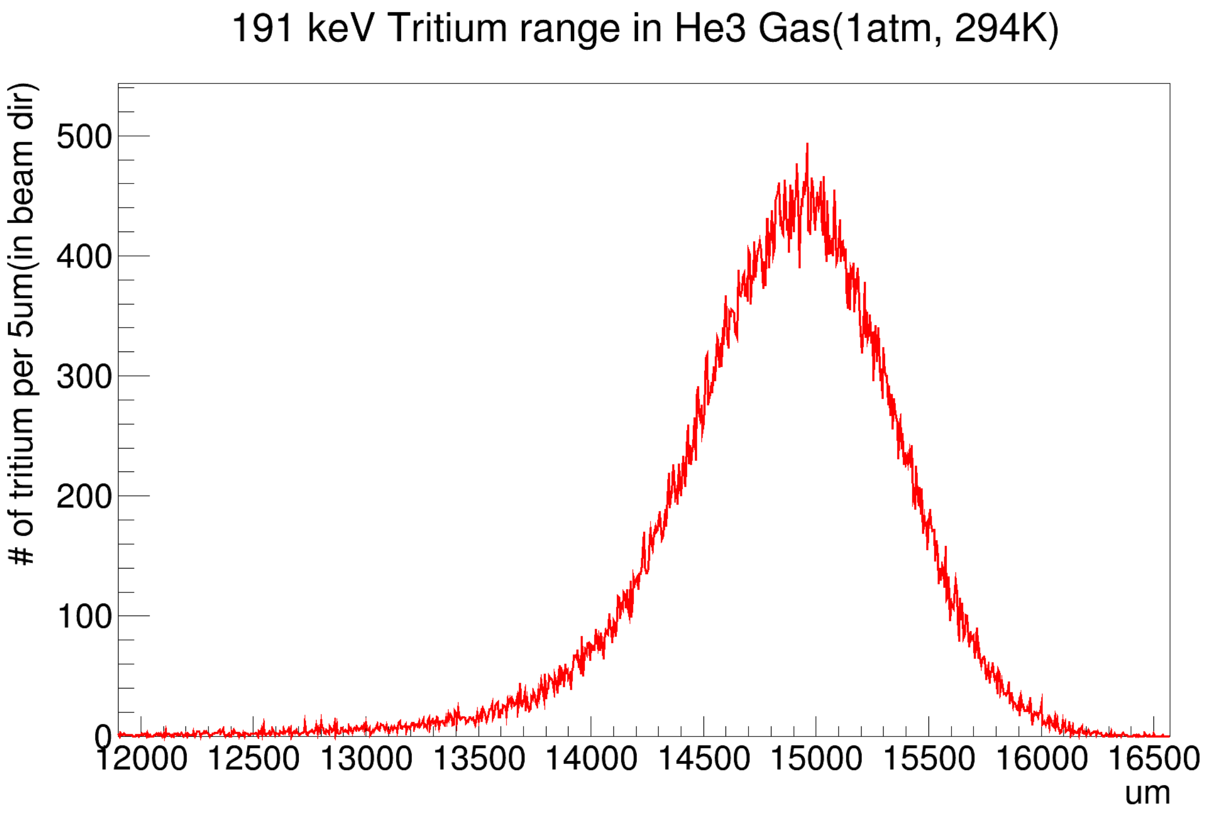
-> mean free path : 0.17 cm

- Stainless steel

Mean free path : 4.5 cm (assume 100% Fe56) ->98%, 94% penetration prob. For 1mm and 3mm thickness

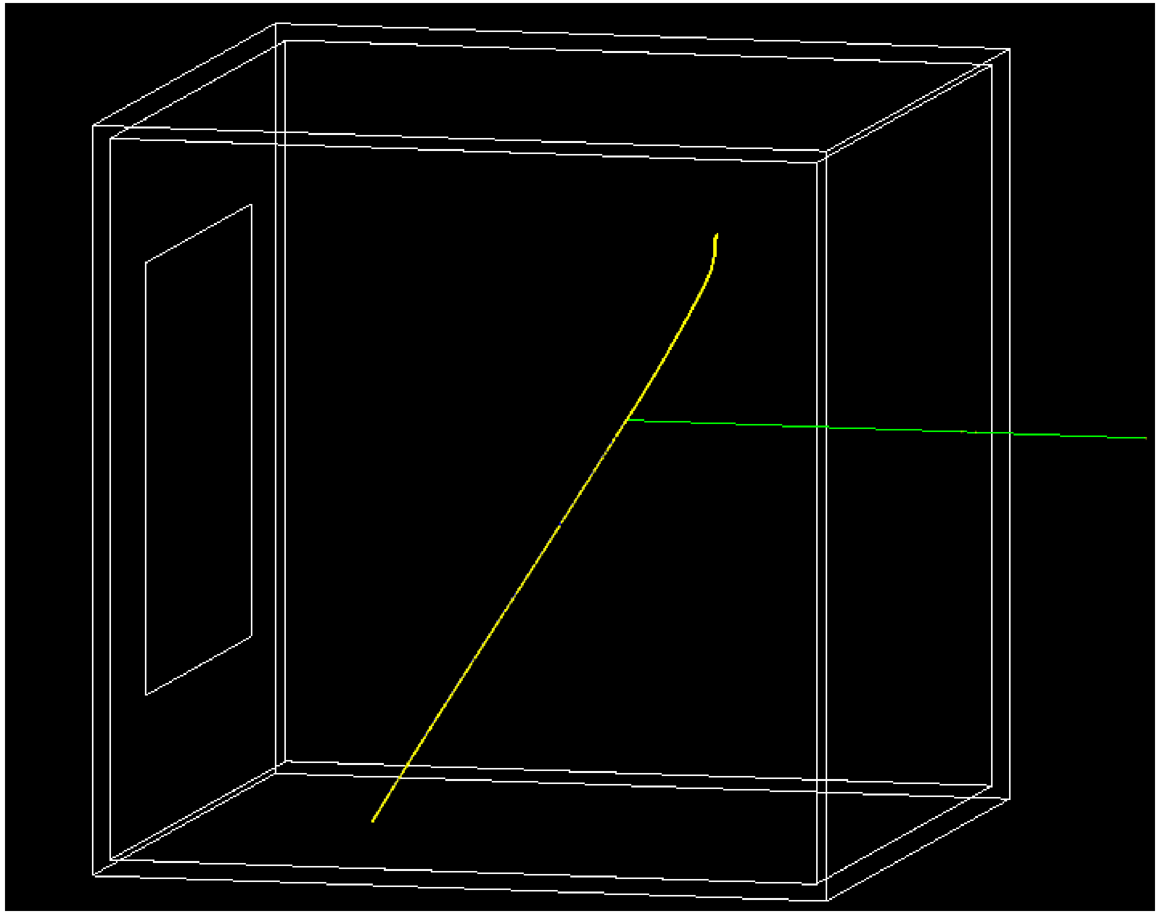
- Tritium range in setup material





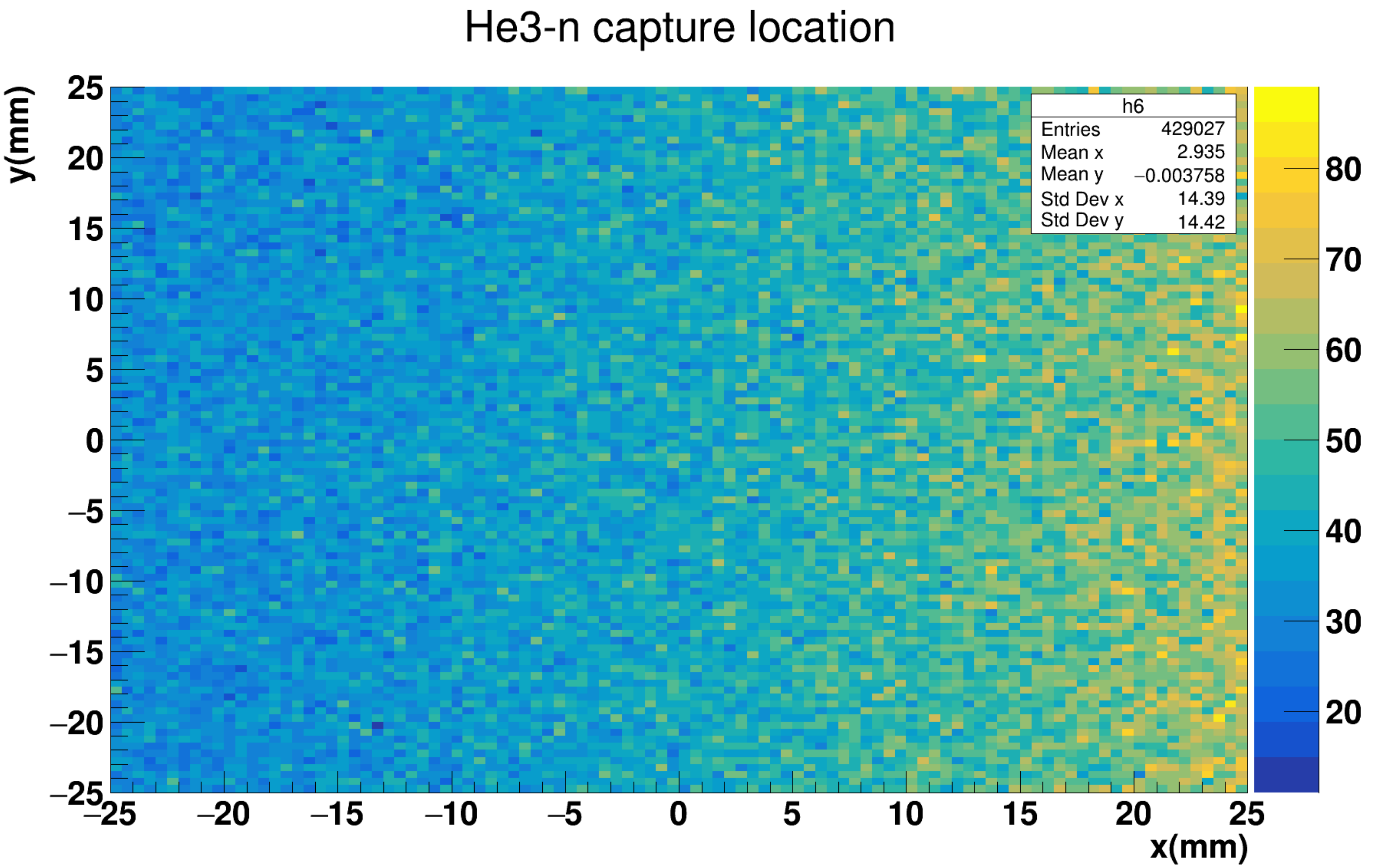
- Setup

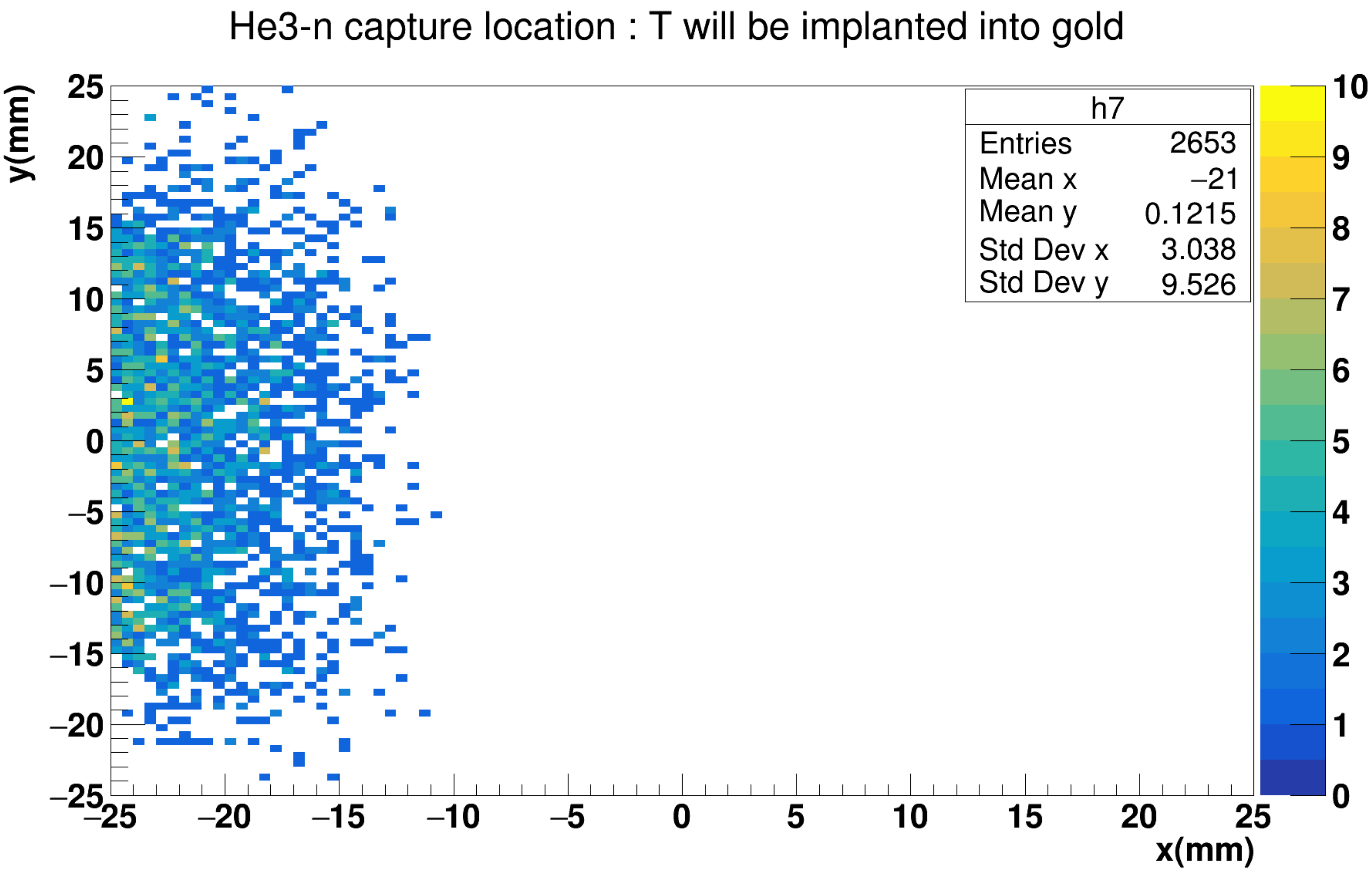
- Gold film (inner stainless steel plate) : 3cm*3cm*2um
- He3 gas : 1atm, room temp.
- Stainless steel : 5cm*5cm*5cm, 1mm width



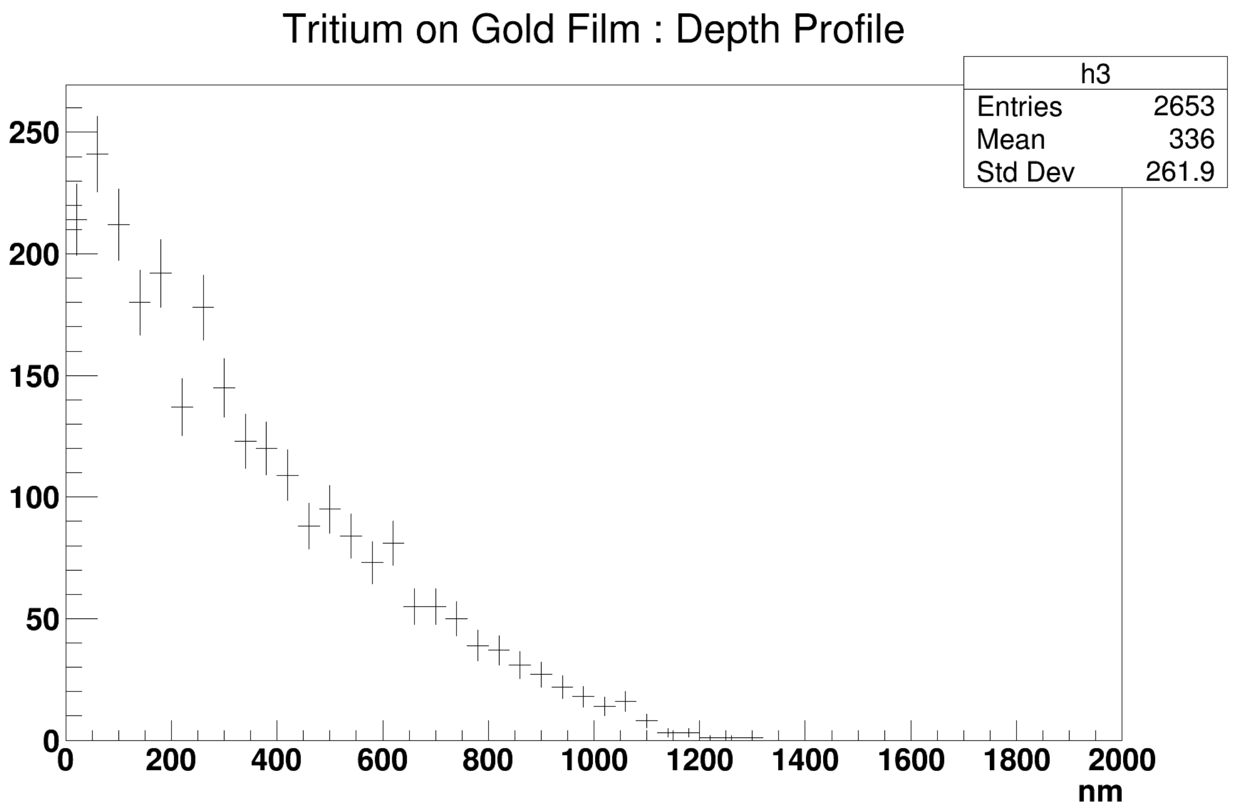
4. Result

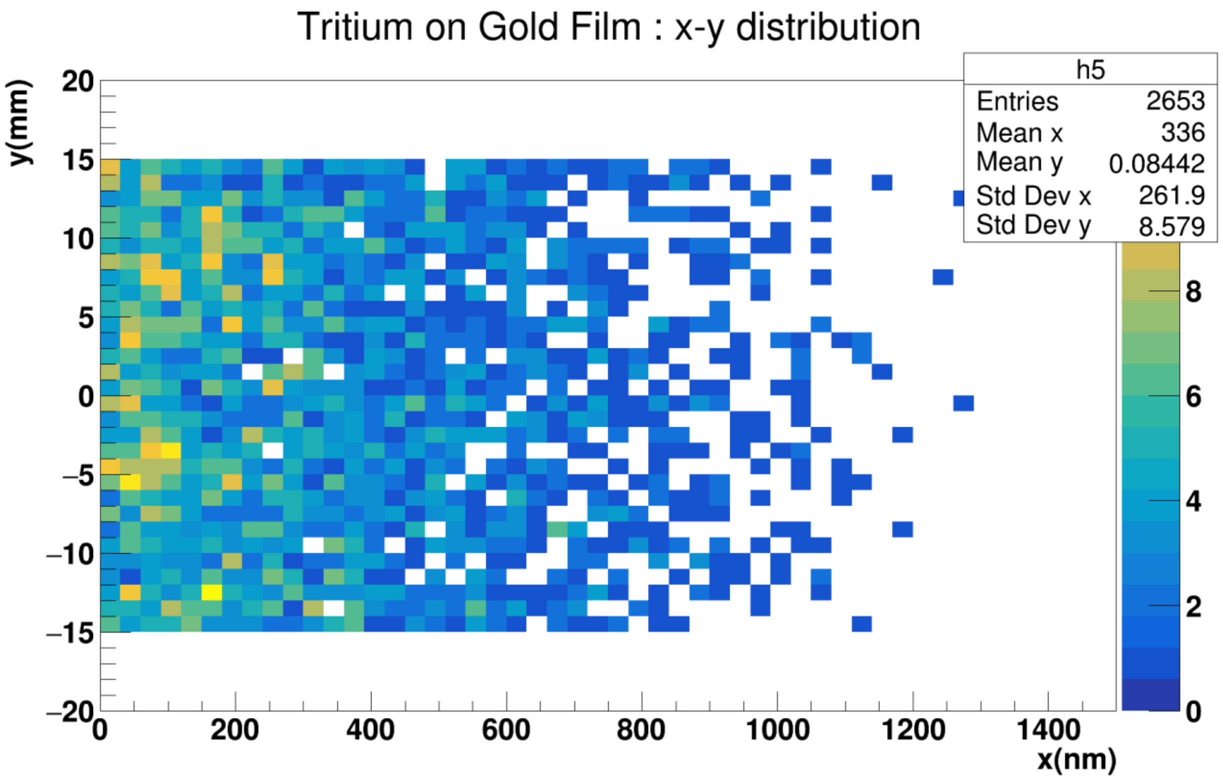
For neutron event of 1*10^6 (= 4*10^-3 second implantation time)




He3-n capture location : T will be implanted into gold
h7
Entries 2653
Mean x −21
Mean y 0.1215
Std Dev x 3.038
Std Dev y 9.526
y(mm)
x(mm)

For neutron event of 1*10^6 (= 4*10^-3 second implantation time)





- 2653 tritium per 4*10^-3 second -> tritium implantation rate = 6.6*10^5 / s
- Decay rate of 1 atom : 1.78*10^-9 / s

-> for total 1K Bq, 5.62*10^11 tritium atom is needed
-> implantation of 9.9 days is needed

Tritium Diffusion In Gold

Backup

Gold lattice displacement energy : 34 eV

“Evaluation of effective threshold displacement energies and other data required for the calculation of advanced atomic displacement cross-section”, A.Yu.Konobeyev et al, Nuclear Energy and Technology 3 (2017) 169-175

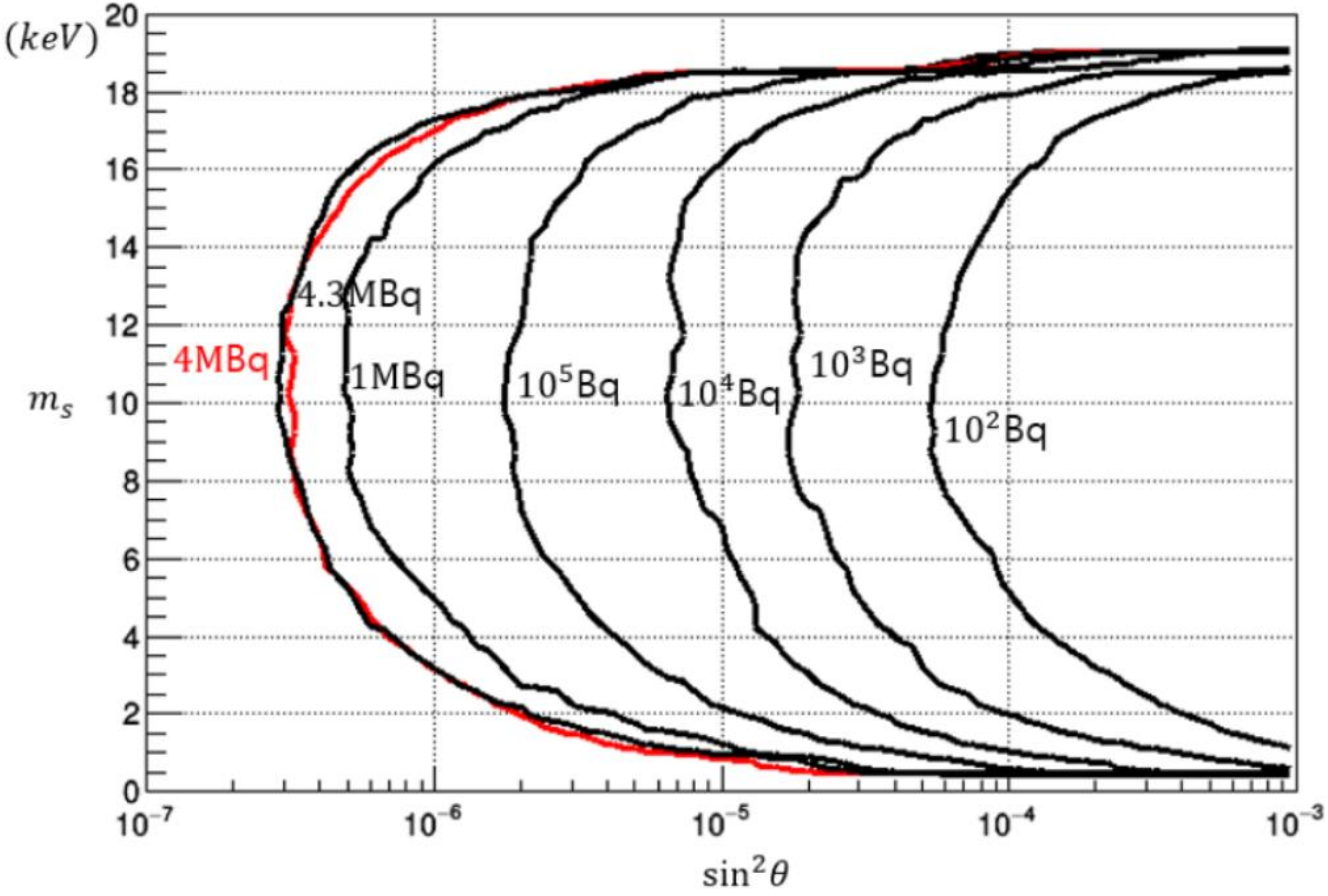


그림12. 3장 표3의 붕괴율과 에너지 분해능에 대한 검출 민감도(90% exclusion curve)