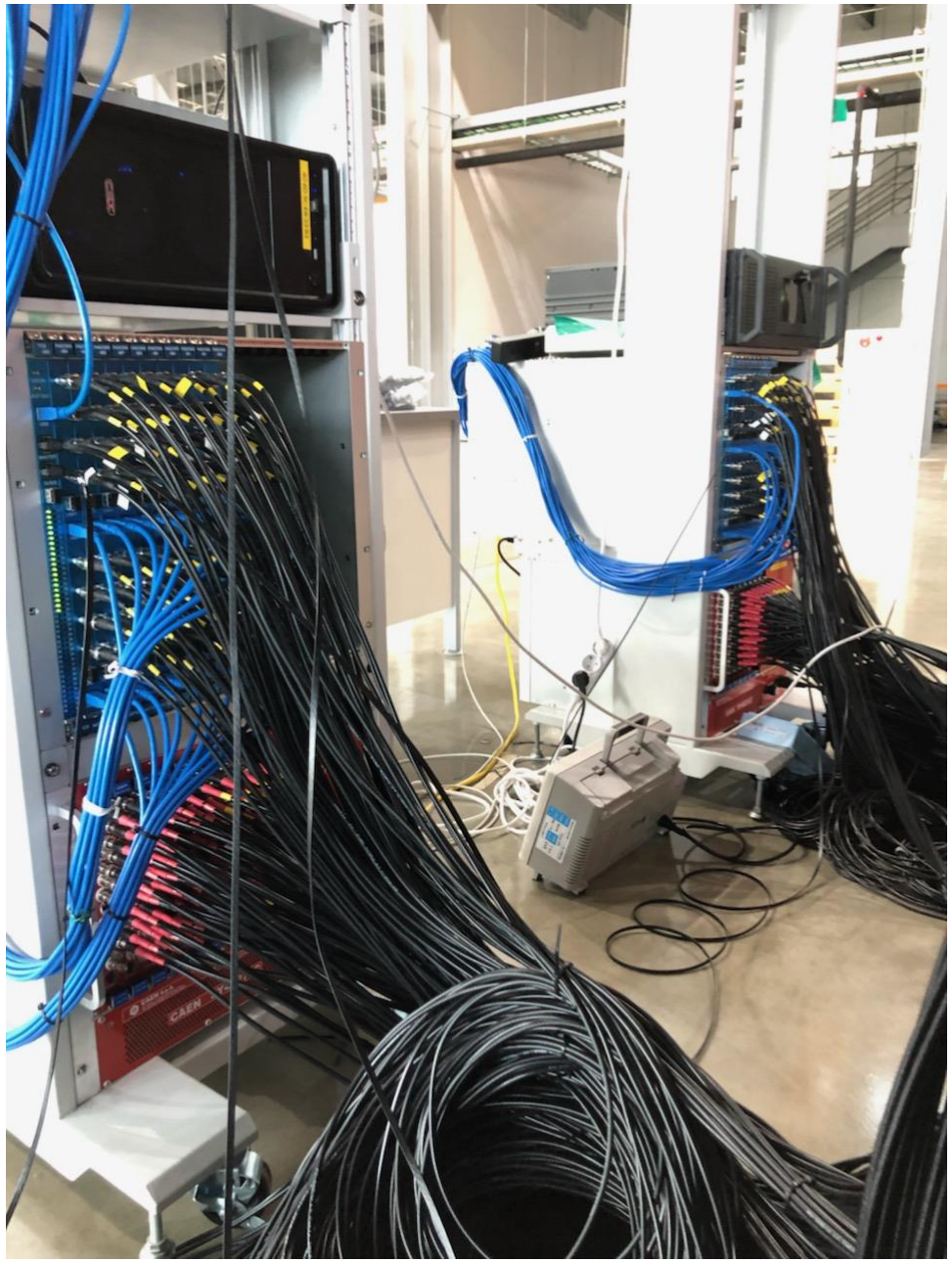
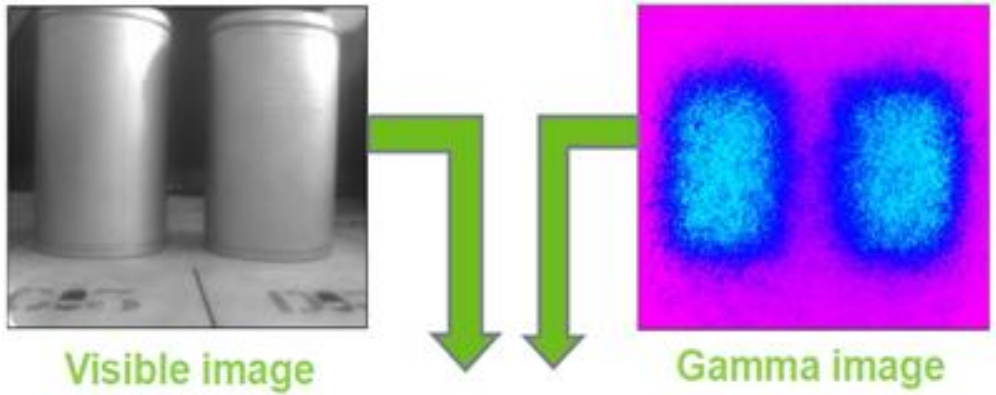
# 감마선 카메라

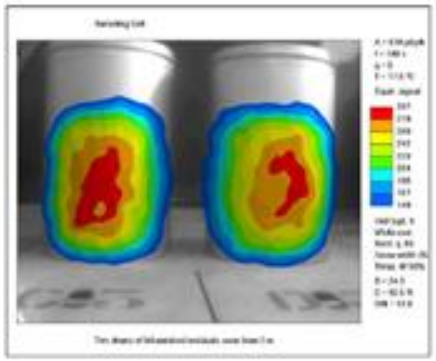
김상열

노티스


NKFADC500
NKFADC500
M64ADC
M64ADC
M64ADC



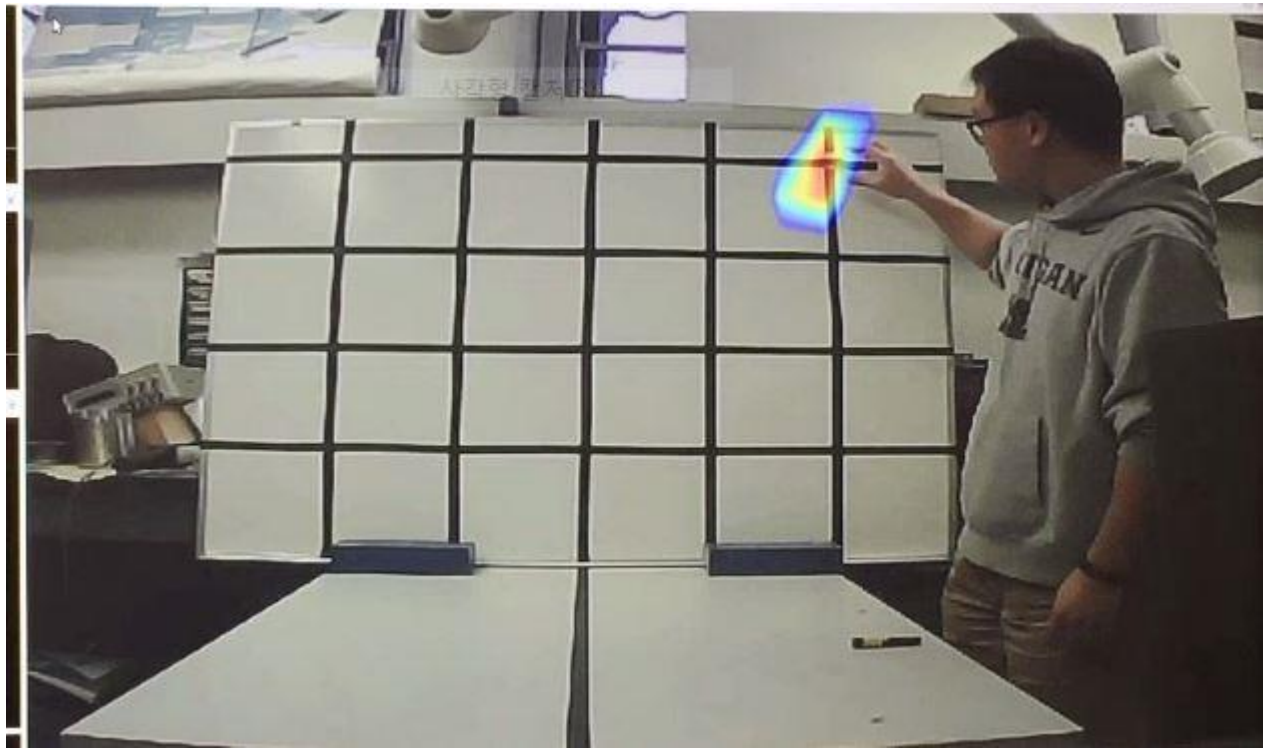


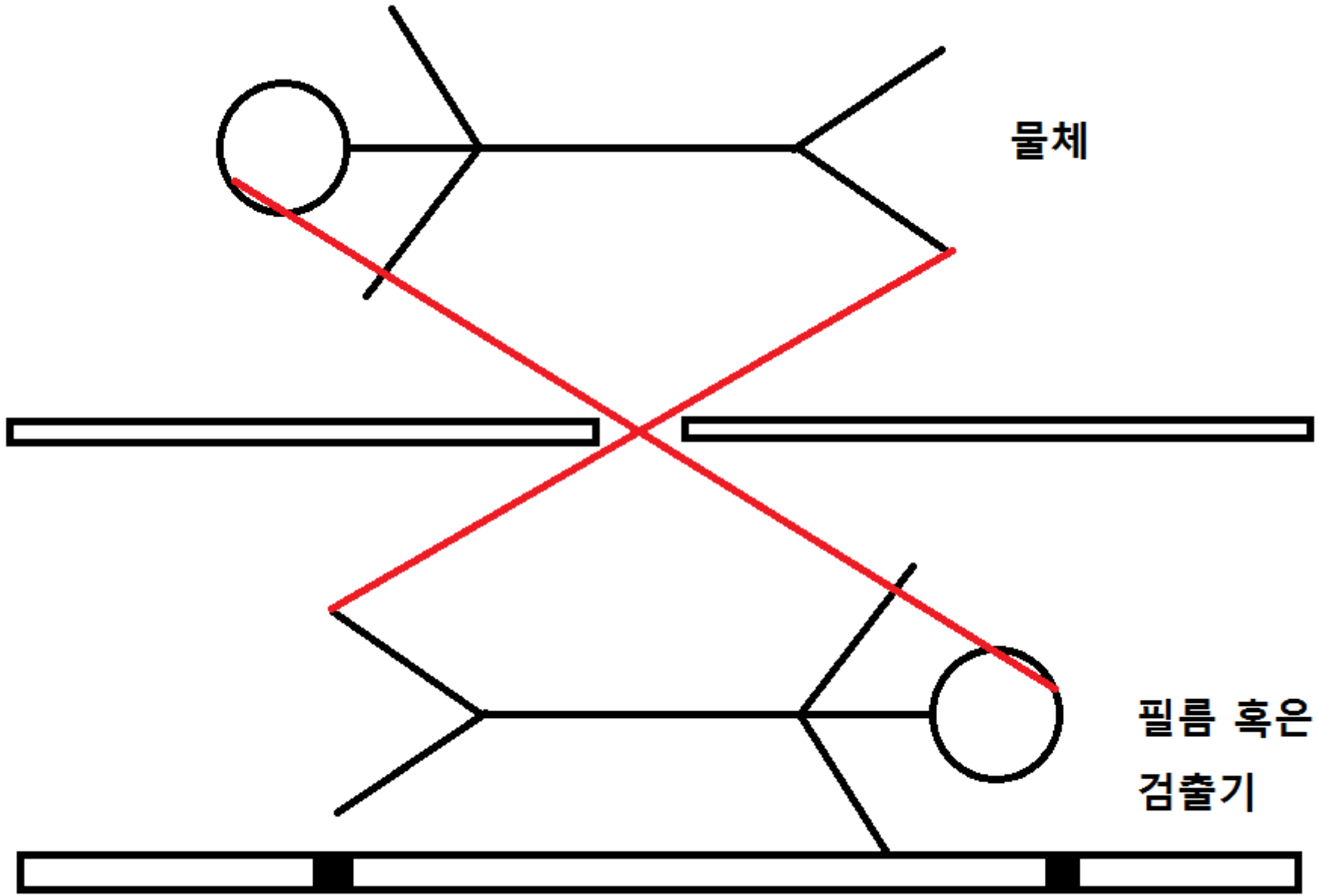



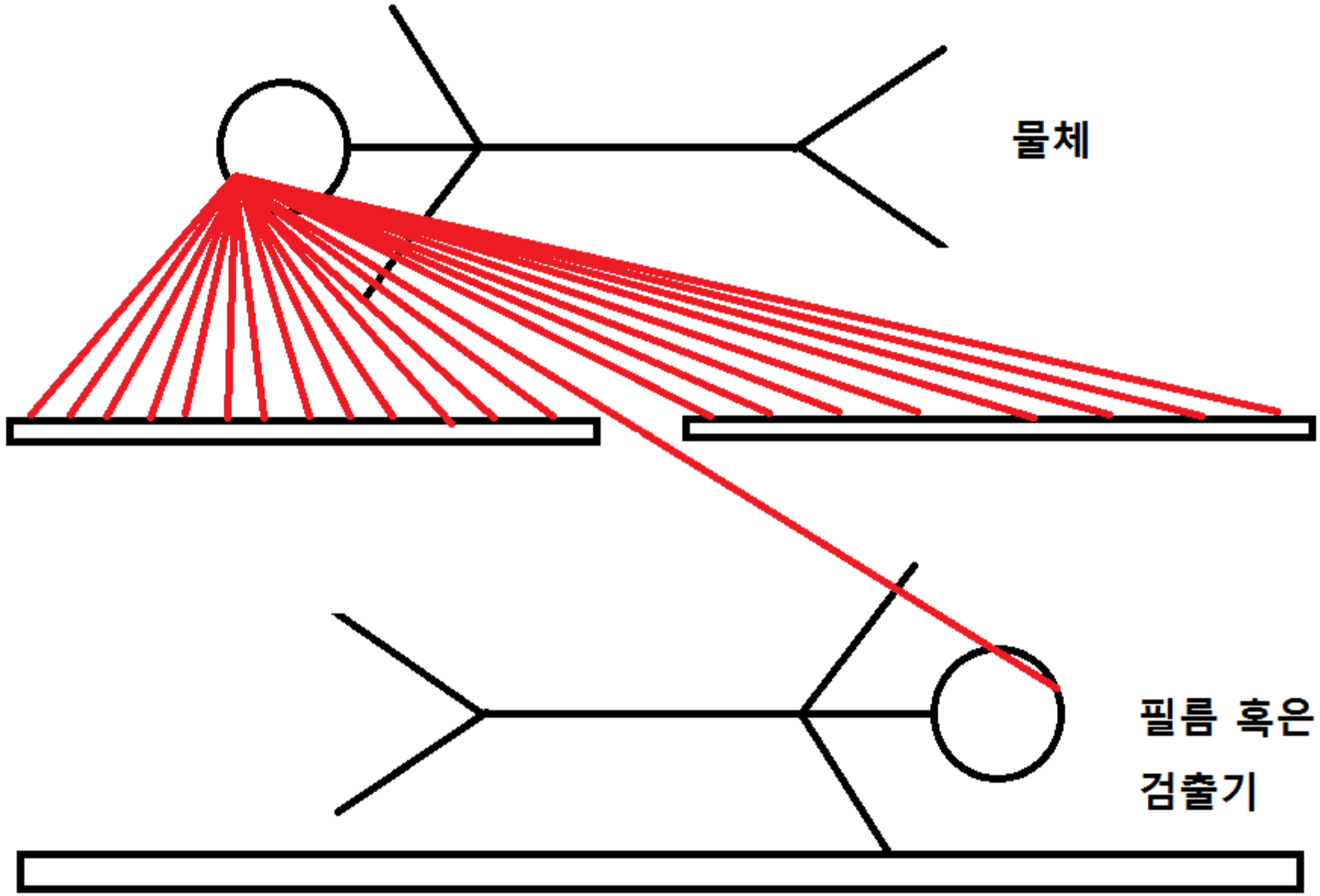
Superimposition

감마선 이미지를 광학사진처럼 보이게 하는 장치

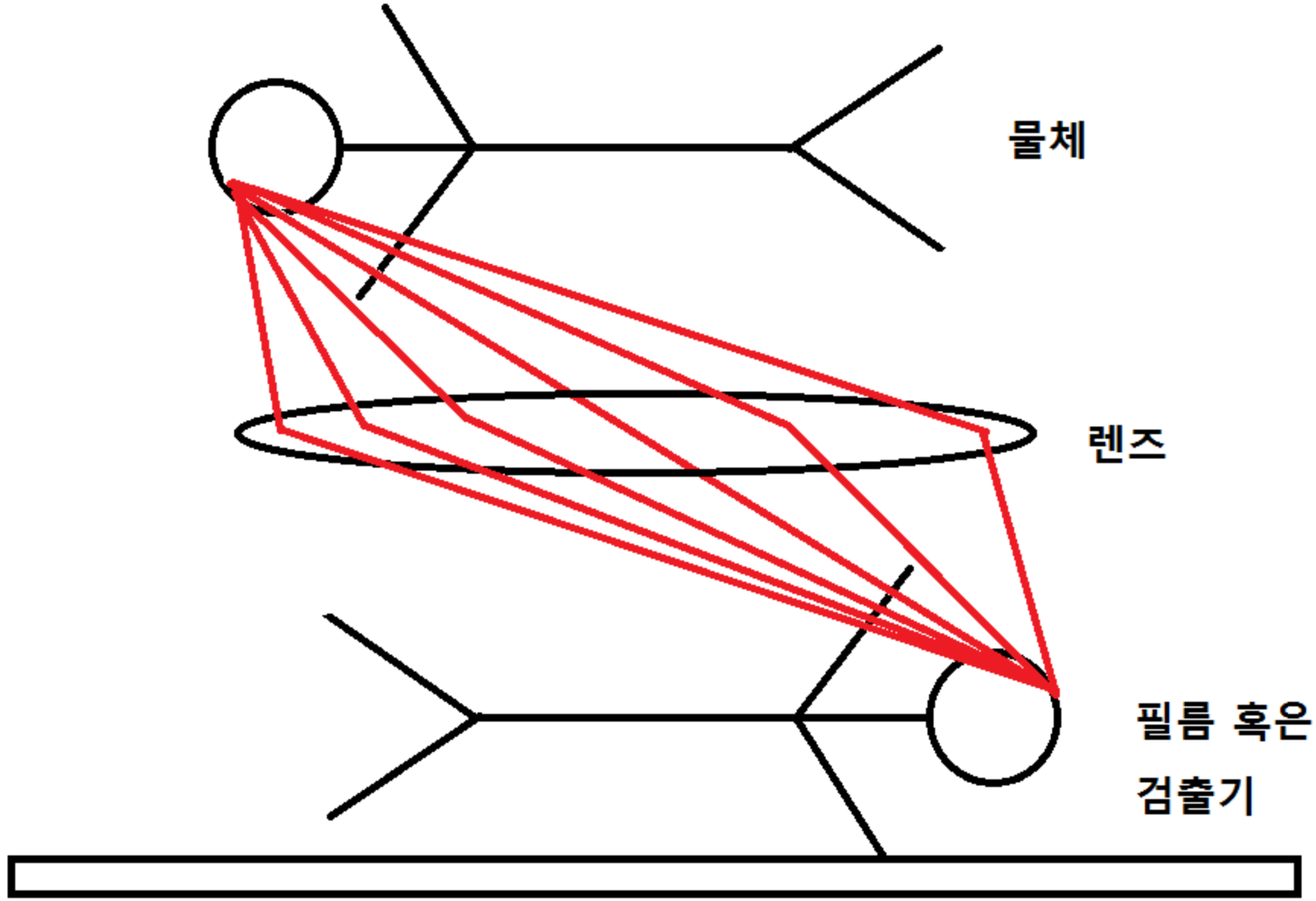
실시간 감마선 동영상 획득이 목표임.



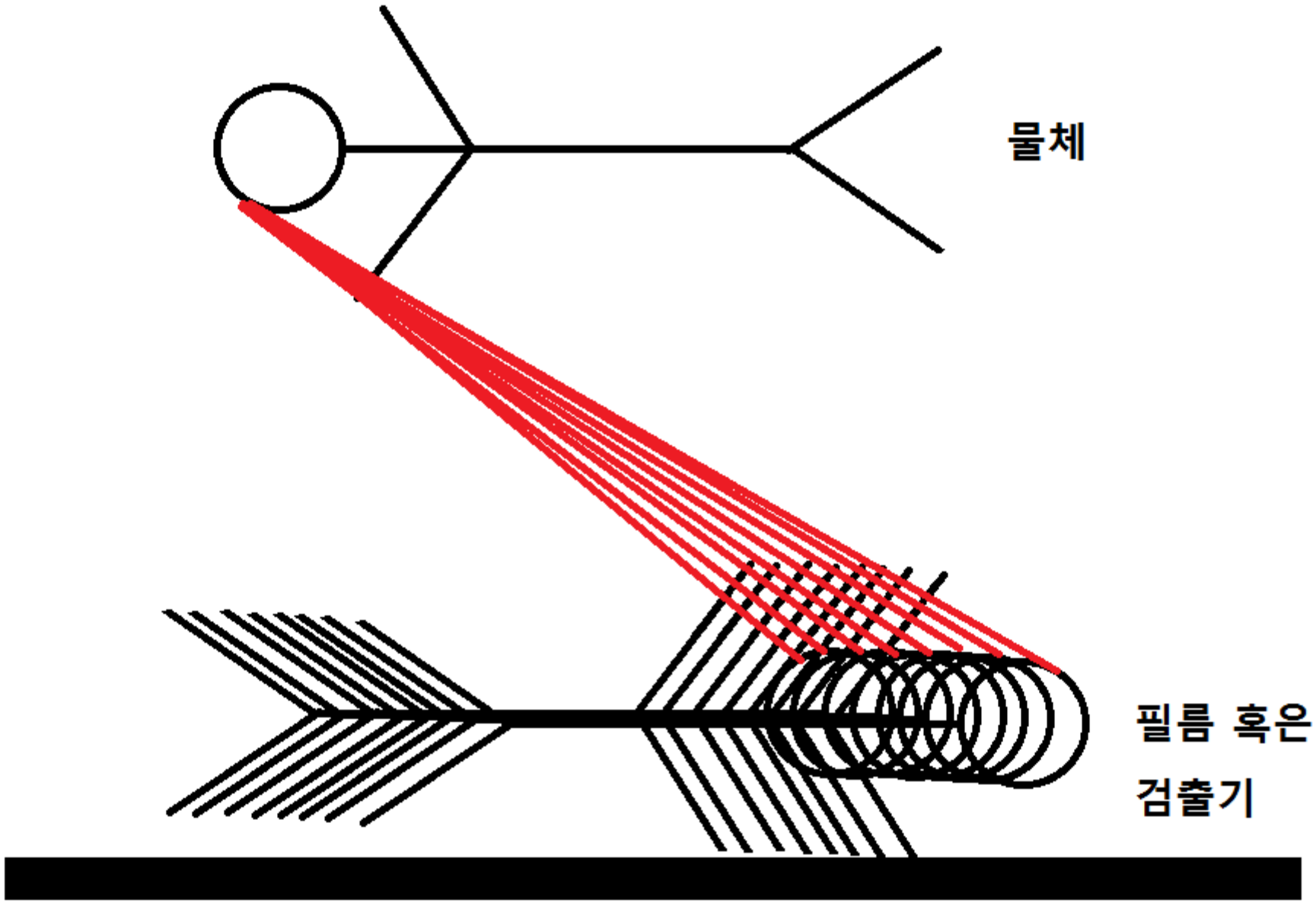

물체
필름 혹은
검출기



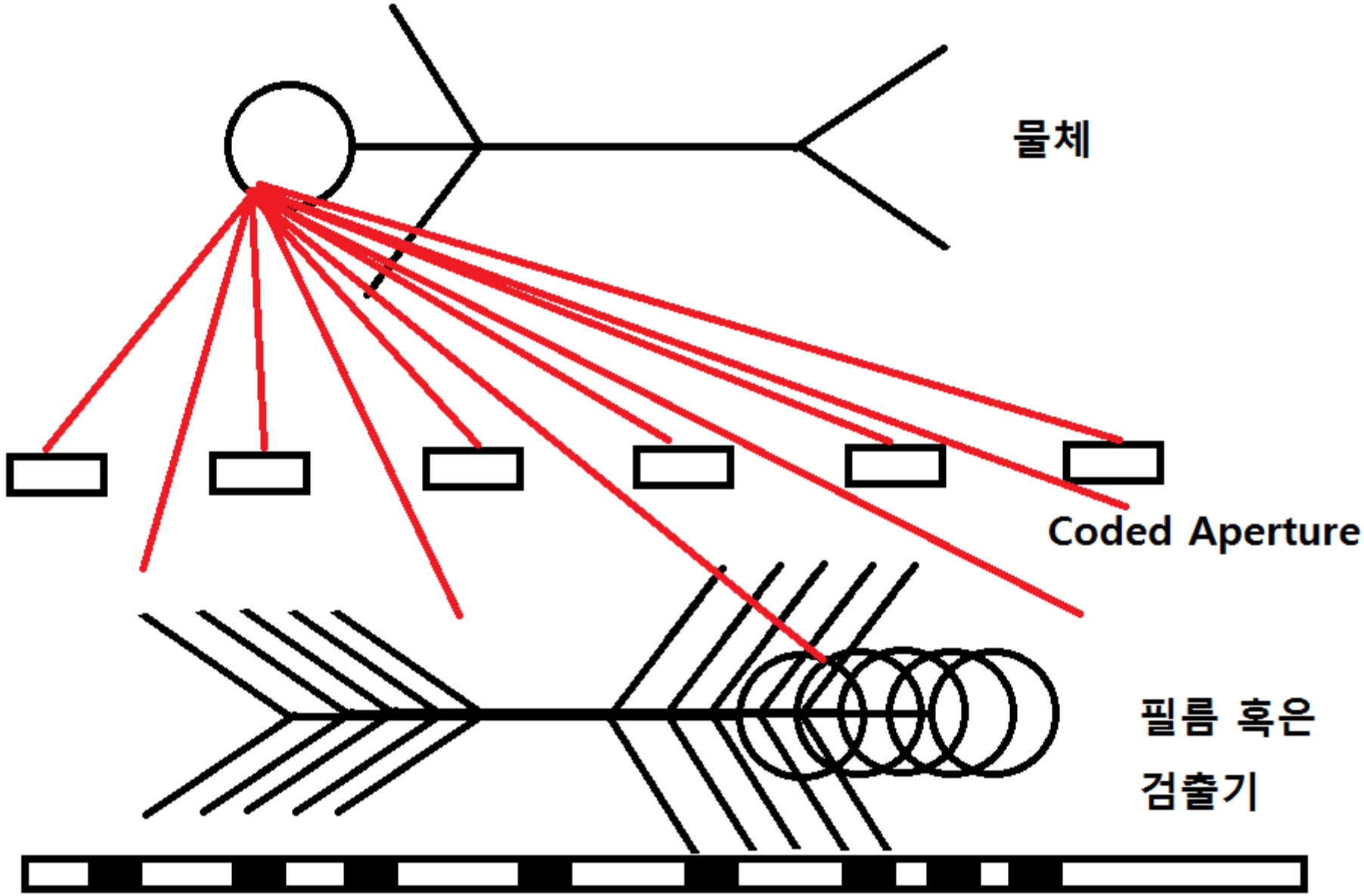

상당히 비효율적이다!!




감마선에는 이런게 없다!!

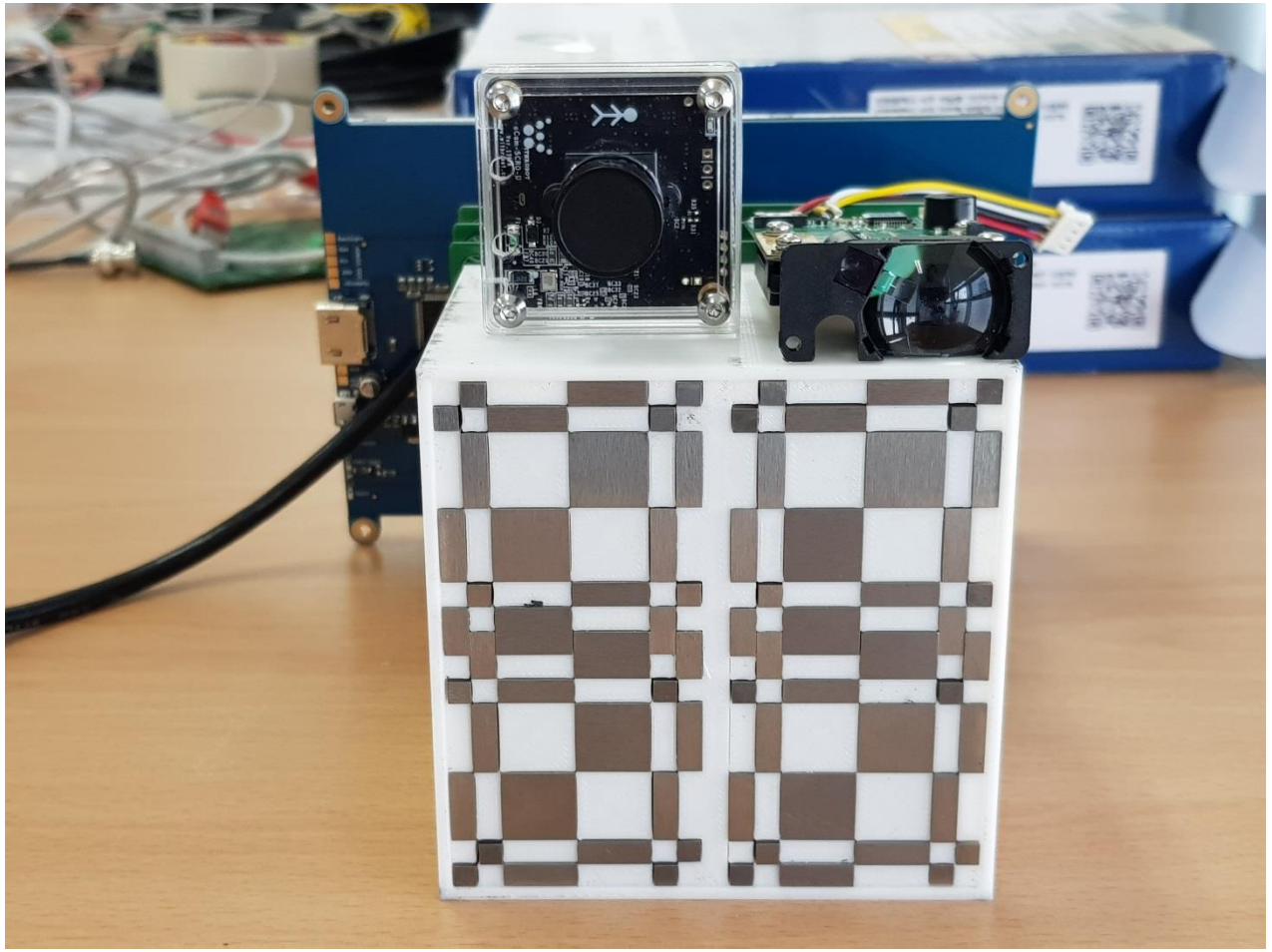



이미지가 안 나옴!!




구멍을 반 정도 뚫어서 이미지를 얻는다!!

MURA(Modified Uniformly Redundant Array) Mask



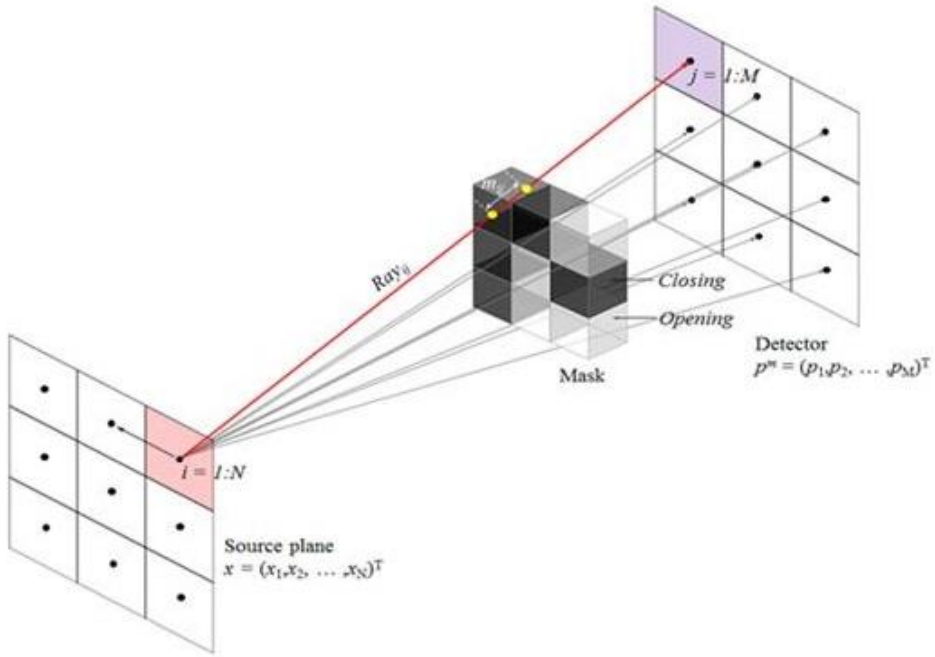
$$A_{ij} = \begin{cases} 0 & if\ i=0, \\ 1 & if\ j=0,\ i\neq 0, \\ 1 & if\ C_i C_j = +1, \\ 0 & otherwise \end{cases}$$

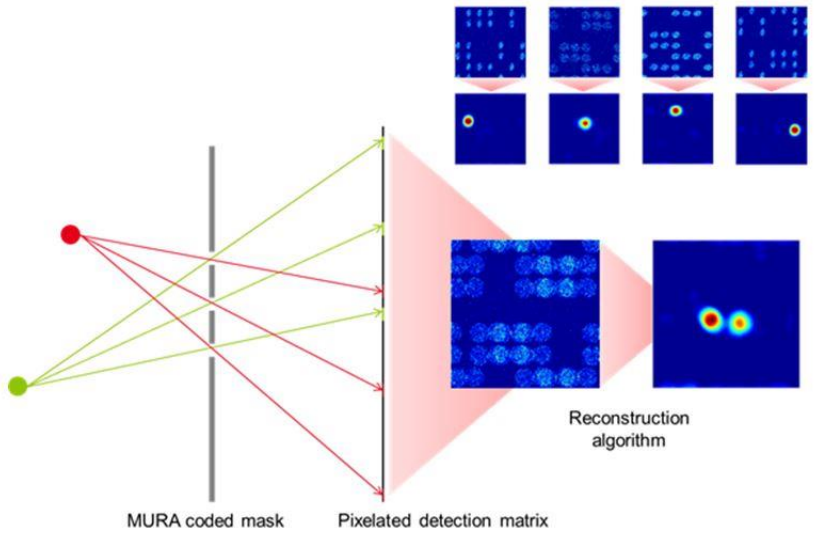
where,

$$C_i = \begin{cases} +1 & if\ i\ is\ a\ quadratic\ residue\ modulo\ p, \\ -1 & otherwise \end{cases}$$

뚫린 구멍/막힌 구멍 = ~ 1
입사 각도에 따른 검출기 cell contrast가 가장 좋음.

# 영상재구성(Image Reconstruction)




- 검출기 평면 행렬은 검출기 cell 수로 정해짐.

- 이미지 평면은 임의로 등분하여 설정 (통상 검출기 평면 행렬의 2~3 배 정도)

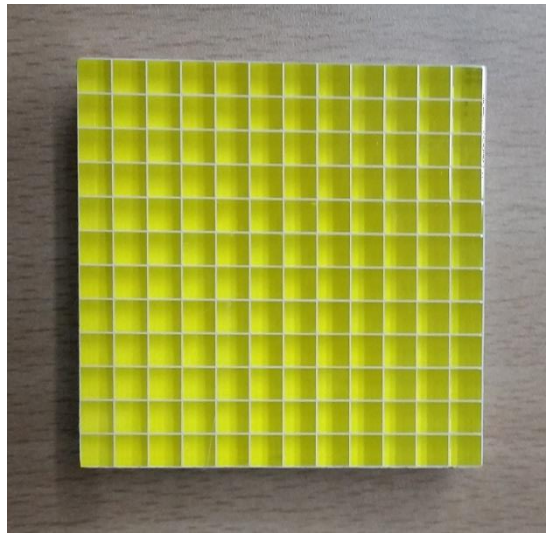
- 시뮬레이션(MCNP 혹은 GEANT4) 또는 실험을 통해 각각의 이미지 평면 위치에 감마선원이 있을 때 검출기 평면의 각각 셀에서 검출될 확률을 구한다. (System Matrix)

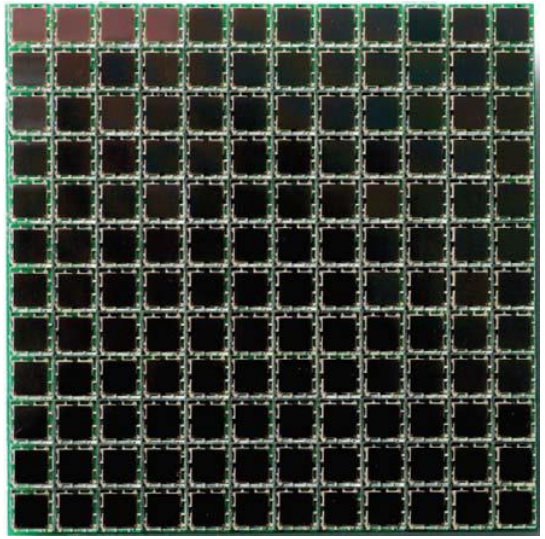
- System matrix를 전자회로 혹은 컴퓨터에 테이블로 저장하고 있다가 일정 카운트 이상의 감마선이 검출되면 영상을 재구성한다.

- MLEM(Maximum Likelihood Expectation Maximization) 방법으로 감마선원 위치재구성

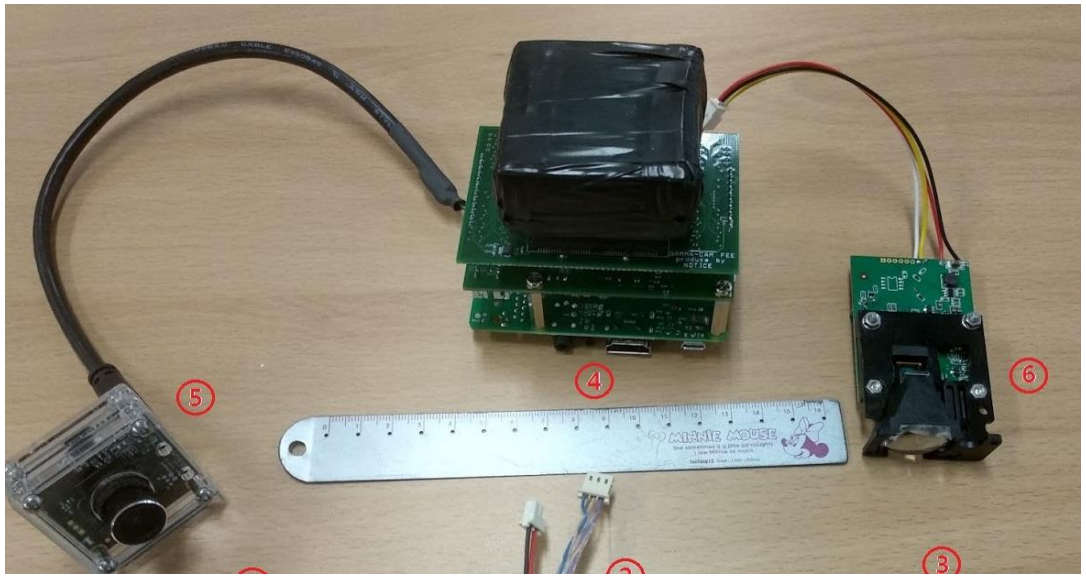
$$\lambda_j^{new} = \frac{\lambda_j^{old}}{\sum_i A_{ij}} \sum_i A_{ij} \frac{y_i}{\sum_k A_{ik}\lambda_k + b}$$

# 하드웨어



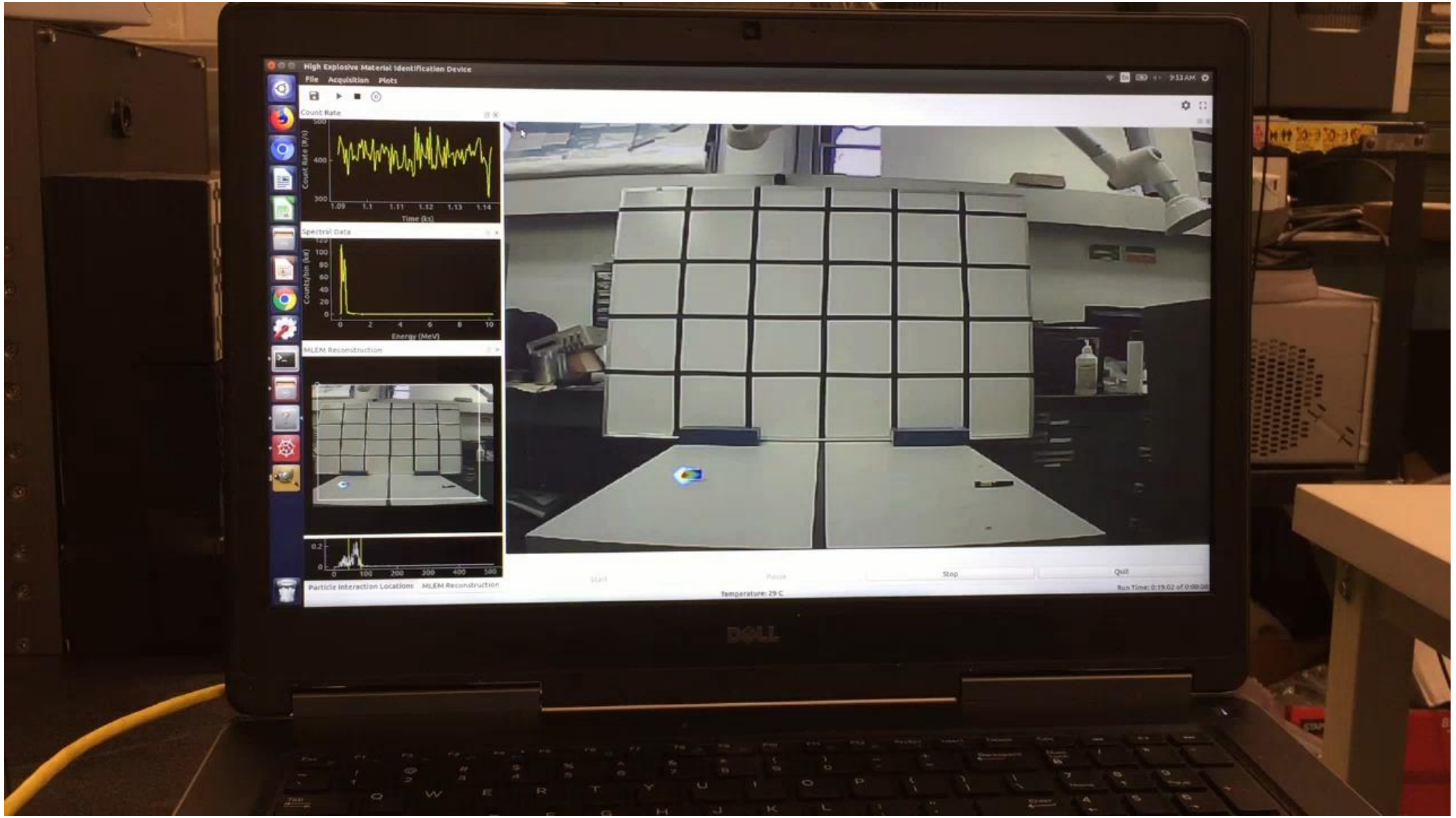



GAGG 크리스털 + SiPM array + Electronics =

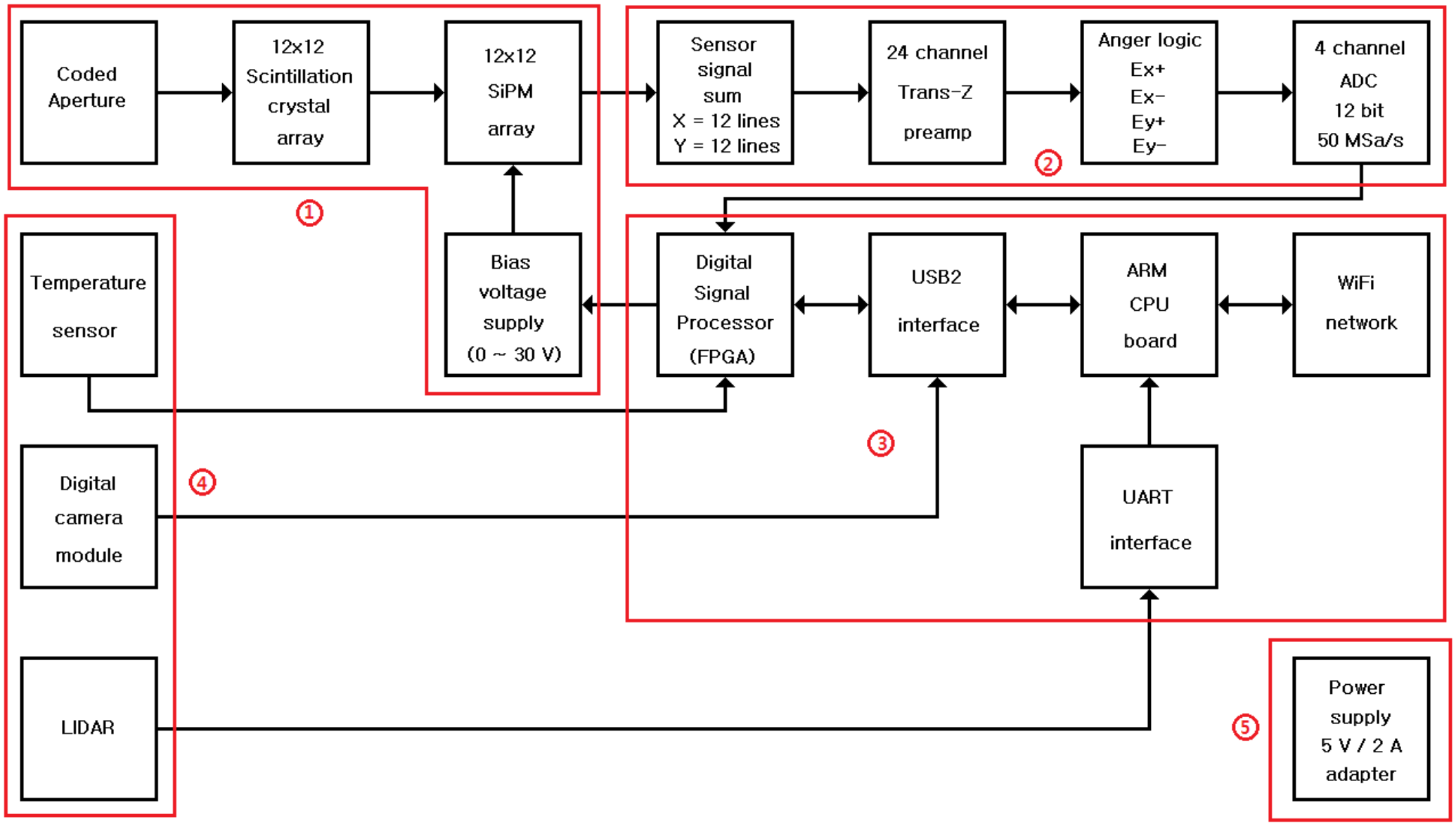


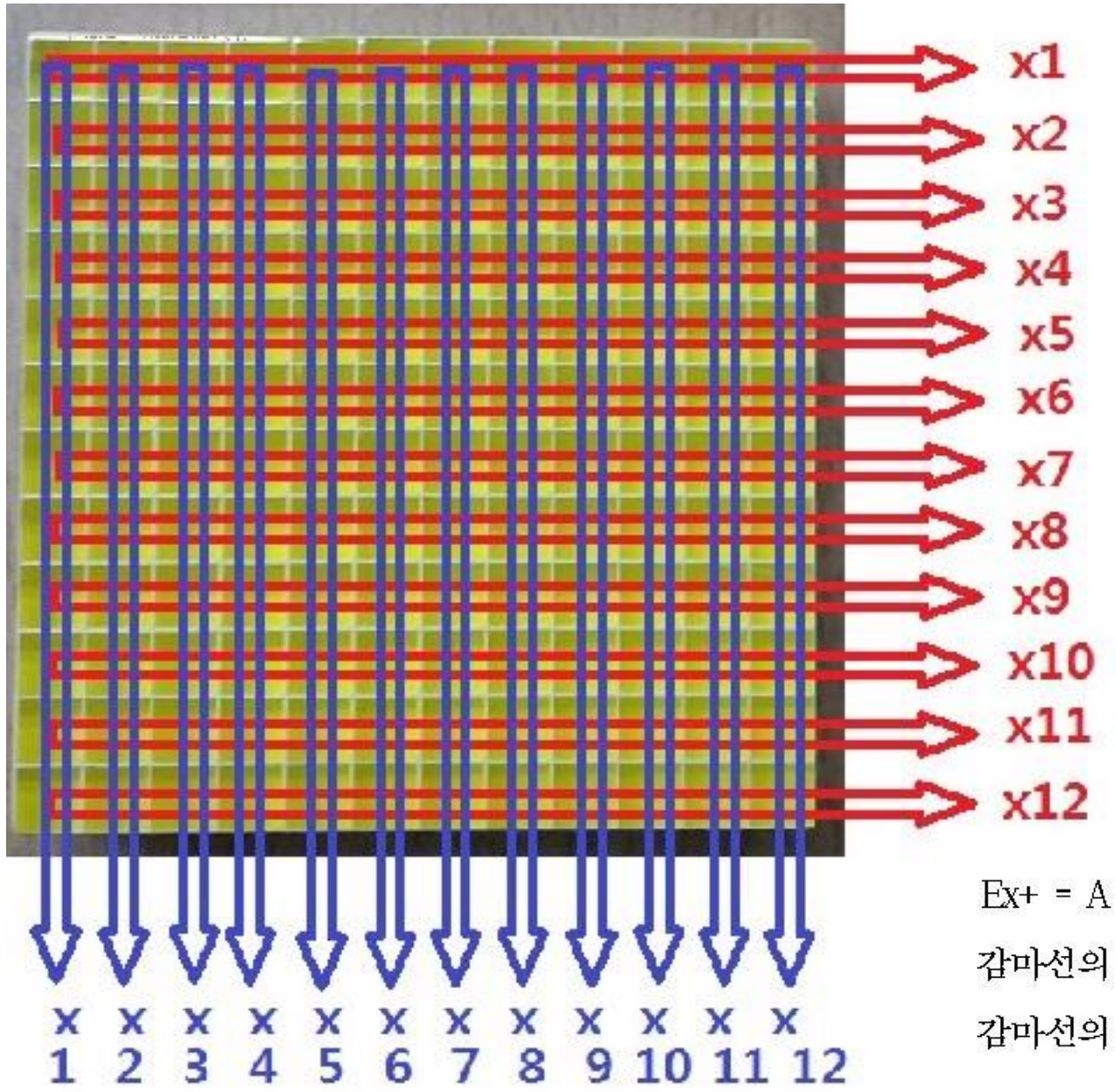

12 x 12 sensor array (50 mm x 50 mm x 20 mm)

# 프로토타입 감마선 카메라 동작



# Electronics





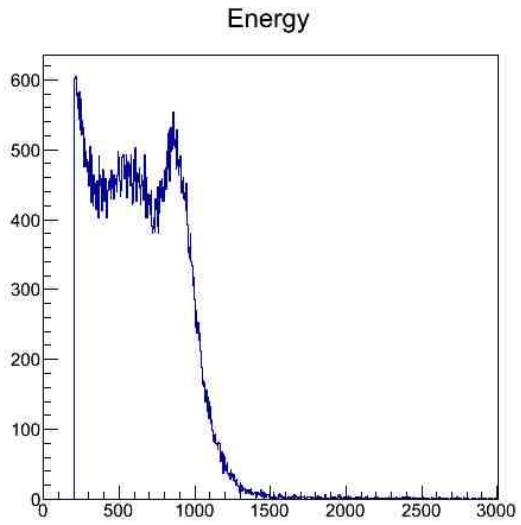

Ex+ = A * X, Ex- = A * (13 - X), Ey+ = A * Y, Ey- = A * (13 - Y)

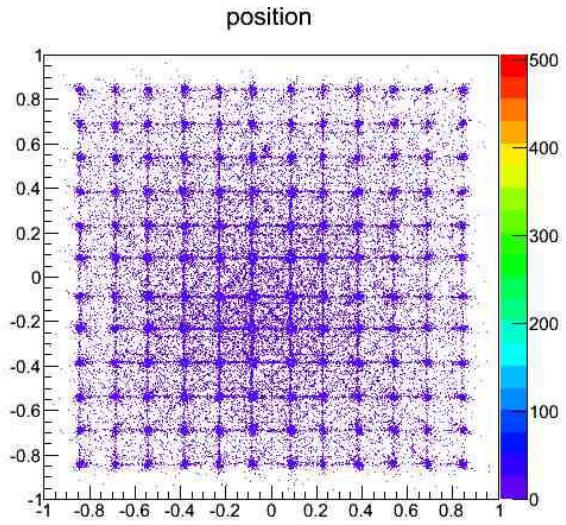
감마선의 에너지는 E = Ex+ + Ex- = Ey+ + Ey- = A * 13,

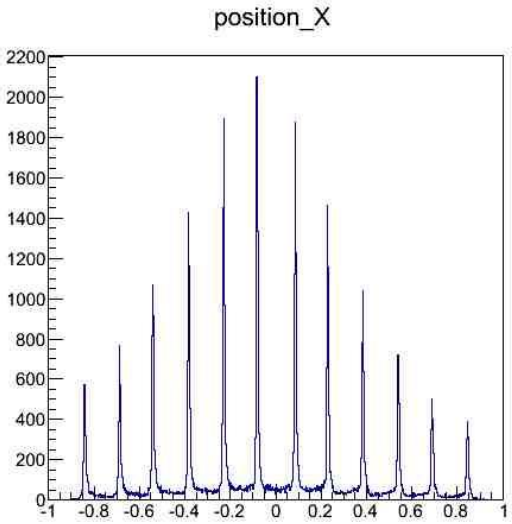
감마선의 검출위치는 Px = (Ex+ - Ex-) / E = (2 * X - 13) / 13

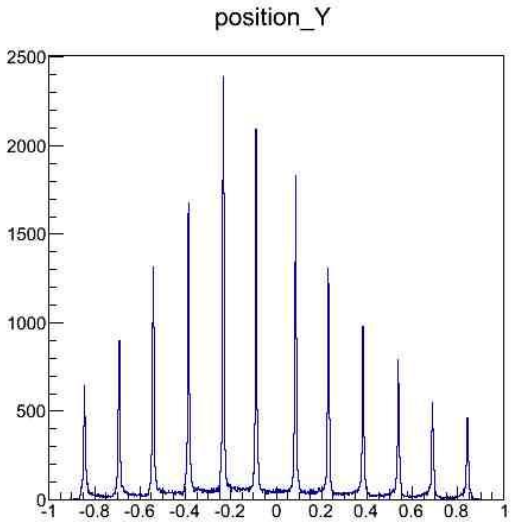
Py = (Ey+ - Ey-) / E = (2 * Y - 13) / 13 가 됨.

# Flood image

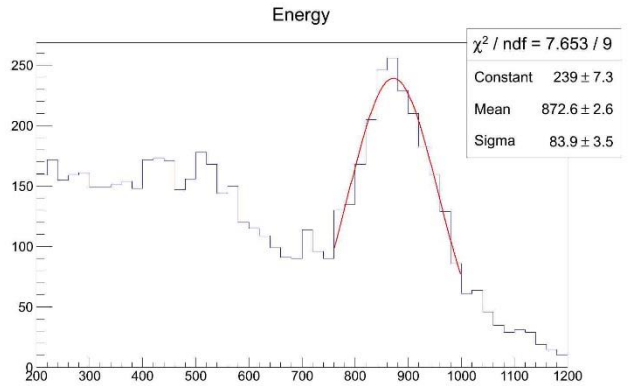

Energy
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000


position
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
500
400
300
200
100
0

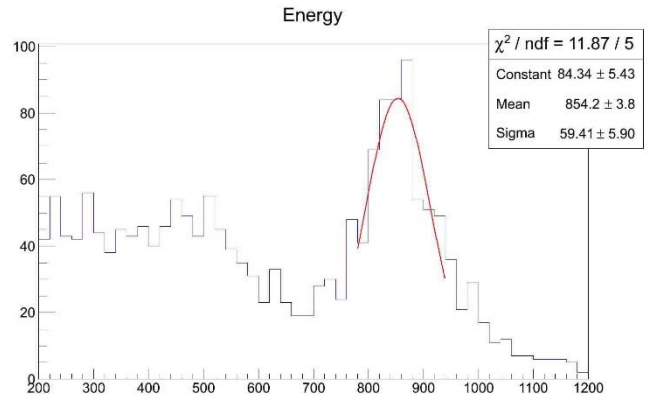

position_X
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1


position_Y
2500
2000
1500
1000
500
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

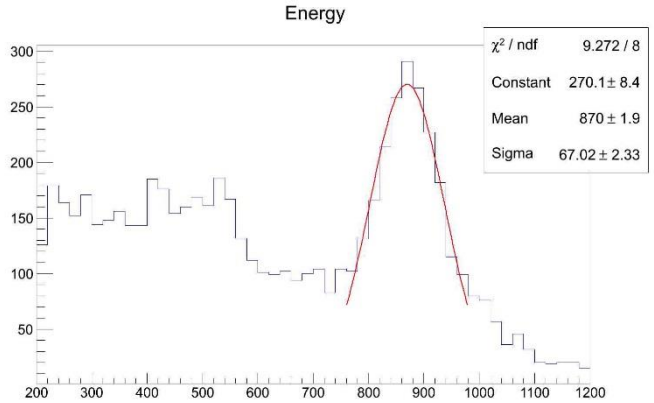
# 에너지 분해능



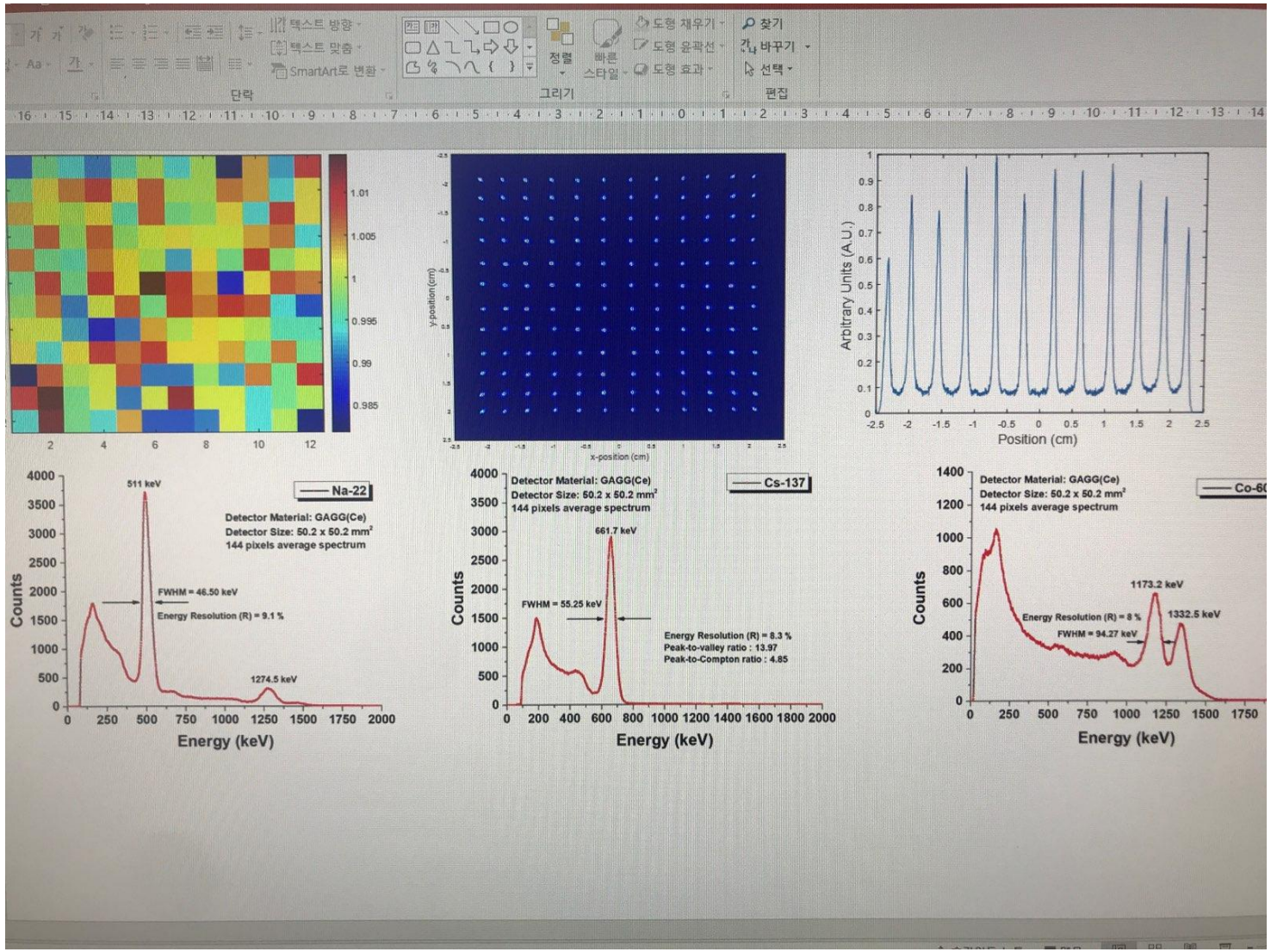

보정 전




1 cell




보정 후




~ 8% FWHM @ Cs-137 662 keV

| 판매사(국가) | H3D(미국) | PHDS(미국) | Acrorad(일본) | Canberra (프랑스) | 노티스(한국) |
|---|---|---|---|---|---|
| 제품명 | Polaris | GeGI | ASTROCAM | IPIX | 미확정 |
| 에너지 분해능 (% @ 662 keV) | < 1.1 | < 0.3 | 2.2 | 9 | 6~8 |
| 핵종 분석 에너지 범위 | 50 keV ~ 3 MeV | 30 keV ~ 3 MeV | 60 keV ~ 600 keV | 30 keV ~ 1.2 MeV | 50 keV ~ 3 MeV |
| 영상 에너지 영역 | 250 keV ~ 3 MeV | 150 keV ~ 3 MeV | 60 keV ~ 600 keV | 30 keV ~ 1.2 MeV | 50 keV ~ 3 MeV |
| 영상 민감도(10 uCi Cs137 at 1 meter) | < 90 초 | 30 ± 15초 | 제공안함 | 제공안함 | 30 ~ 120 초 |


12
13
14
15
8
9
10
11
4
5
6
7
0
1
2
3