2023 workshop on CEPC, Nanjing

Application of the glass scintillator

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Outline

1. Introduction of glass scintillator

2. Application for neutron/gamma detection

3. for neutron/gamma imaging

1. overview of scintillators

crystal

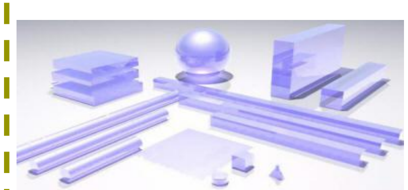
- High yield
- good resolution
- expensive
- limited size
- not easy to manufact

Transparent ceramics

- High yield
- very stable
- not expensive
- limited size
- not easy to manufact

organic

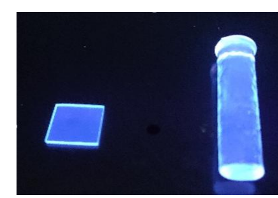
- low yield
- low cost
- limited absorption length
- sensitive to radiation



glass

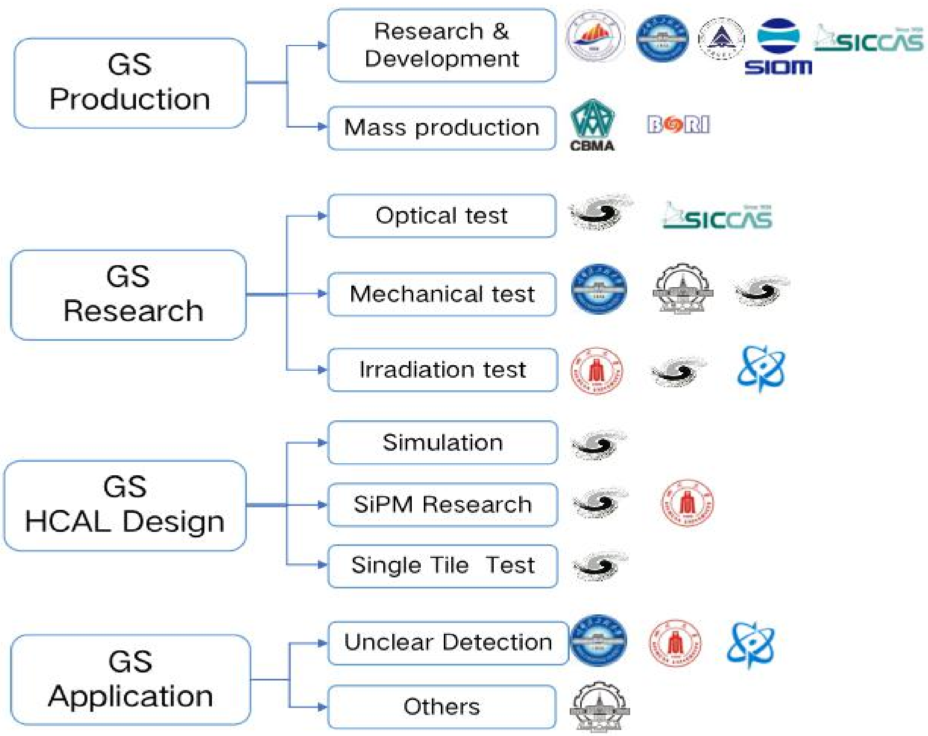
glass ceramics

- low yield
- low cost
- large area
- easy to manufact
- very stable



- No perfect scintillator material yet

Large Area Glass Scintillator Collaboration



- Institute of High Energy Physics，CAS 中国科学院高能物理研究所
- Jinggangshan University 井冈山大学
- Beijing Glass Research Institute 北京玻璃研究院
- China Building Materials Academy 中国建筑材料研究院
- China Jiliang University 中国计量大学
- Harbin Engineering University 哈尔滨工程大学
- Harbin Institute of Technology 哈尔滨工业大学
- Sichuan University 四川大学
- Shanghai Institute of Ceramics，CAS 中国科学院上海硅酸盐研究所
- Shanghai Institute of Optics and Fine Mechanics，中国科学院上海光学精密机械研究所
- CNNC Beijing Unclear Instrument Factory 中核（北京）核仪器有限责任公司

闪烁玻璃合作组
Glass Scintillator Collaboration

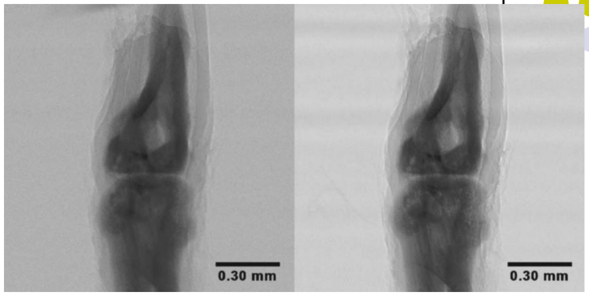
-- The Glass Scintillator Collaboration Group established in Oct.2021;

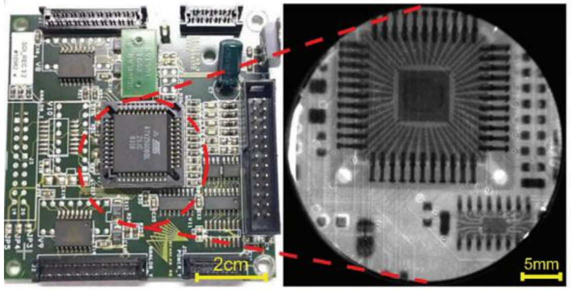
-- There are 3 Institutes of CAS, 5 Universitys, 3 Factorys join us for the R&D of GS;

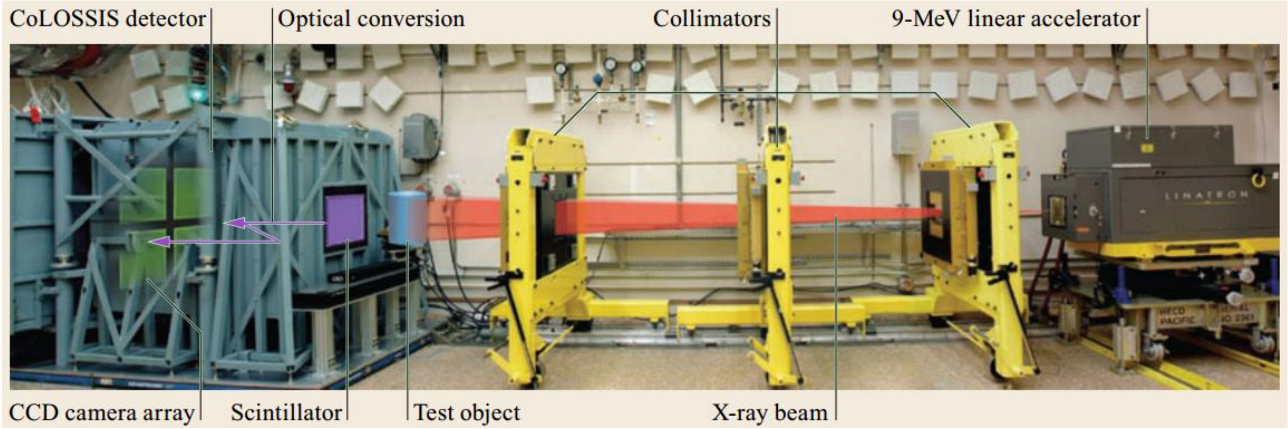
-- The Experts of the GS in the University, Institute and Industry are still welcomed to join (qians@ihep.ac.cn).

Potential application of glass scintillator

- High energy physics
- radiation detection
  - X-ray， gamma， neutron
  - dose, safety, rad protection
- imaging
  - X-ray, gamma, neutron





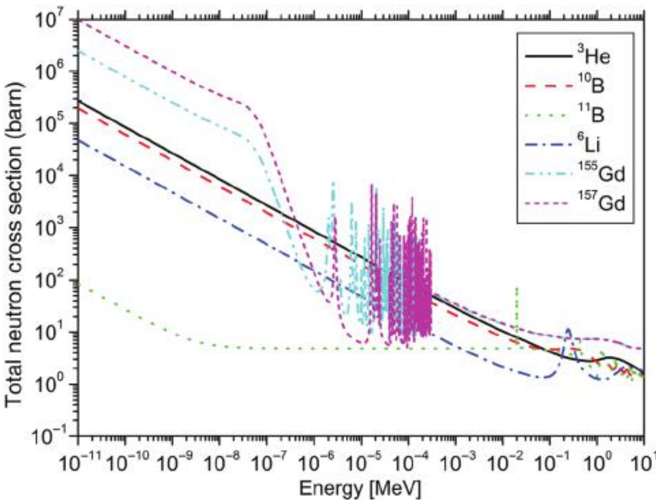


LLNL,large area neutron imager

2. for neutron/gamma detection

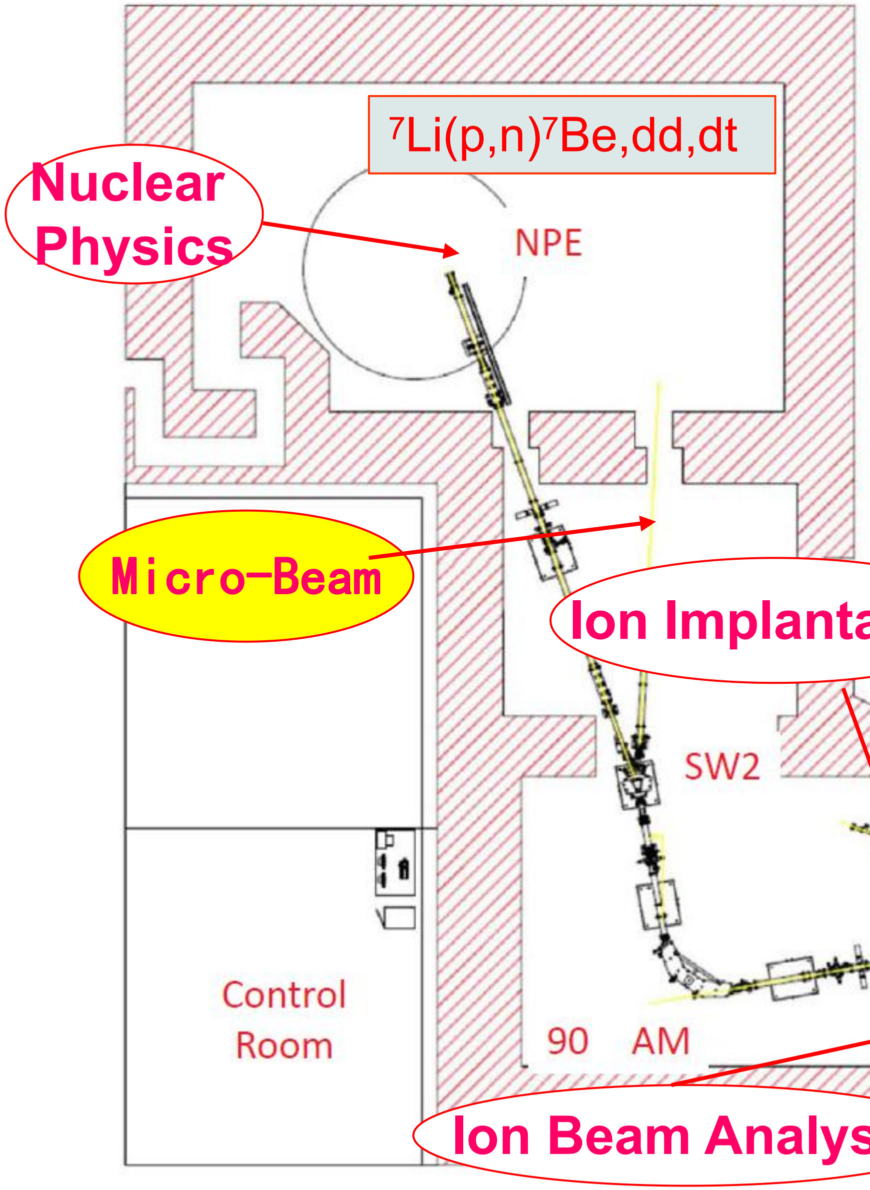
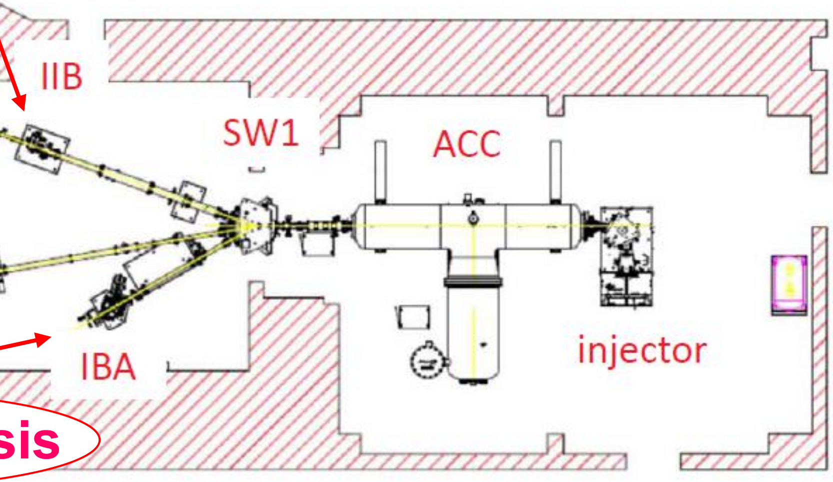
- thermal neutron detection
  - high fraction of Li/B/Gd
- gamma detection
  - high density
  - acceptable light yield
- compare with GS10/GS20
  - similar thermal neutron efficiency
  - better gamma energy resolution
  - substitute of crystal for same case

- glass scintillator:
  - high fraction: Li, B, Gd
  - high density (6 g/cm3)
  - light yield (1100 ph/MeV)
  - resolution (<25%)
  - Li-glass: close to GS10/20



3MV accelerator in Sichuan University

mono-energy neutron source

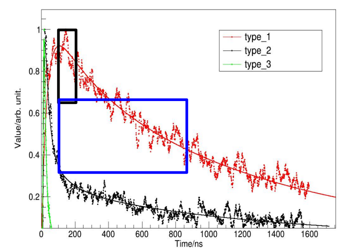
Nucl. Instr. Meth. B 418 (2018) 68–73

p, He,
C, Si,
Cu, Au
......

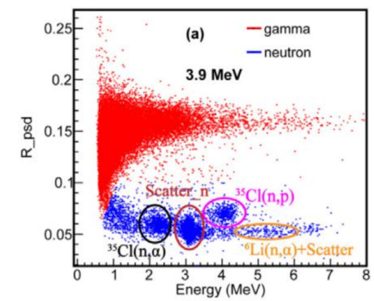
Multi-mode neutron gamma detection

- **CLYC(Cs_2LiYCl_6) crystal**
  - **complex radiation field, safety**
- **by using ANN, realize**
  - **thermal neutron detection, ^{6}Li(n,t)α**
  - **n/g PSD FOM>2, piled FOM>1.1@3E6cps**
  - **fast neutron spectrum, ^{35}Cl(n,p), ER 15%, efficiency, ~0.1%**
  - **gamma ER, ~5%@662 keV**
  - **discrim of Li(n,t), Cl(n,p), 95% acc**

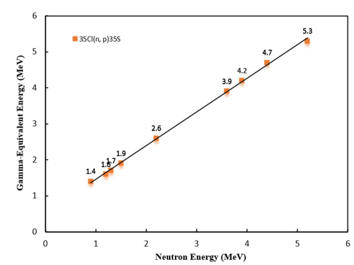
IEEE T Nucl Sci, 2023, 70, 2148
Nucl Instr Meth A, 2023, 1055, 168561
Nucl Instr Meth A, 2023, 1055, 168533
Nucl Instr Meth A, 2022, 1028, 166328



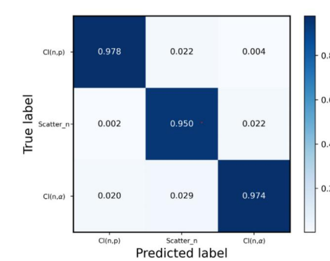
n/γ pulses



E vs PSD



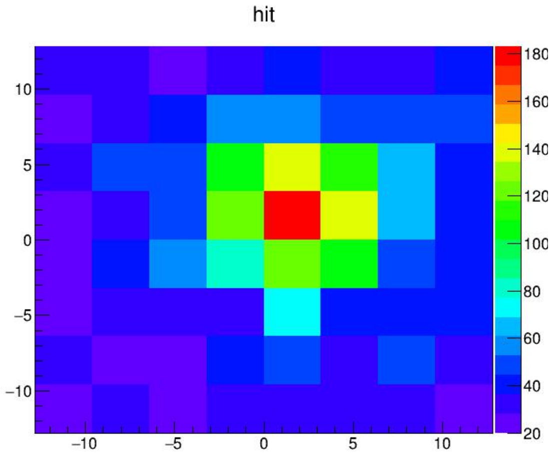
E_(n,p) vs En

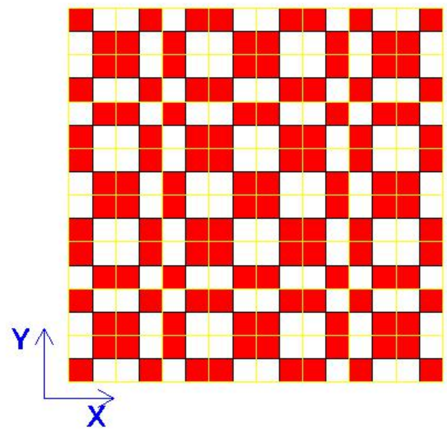


Discrim of reaction channels

3.neutron imager

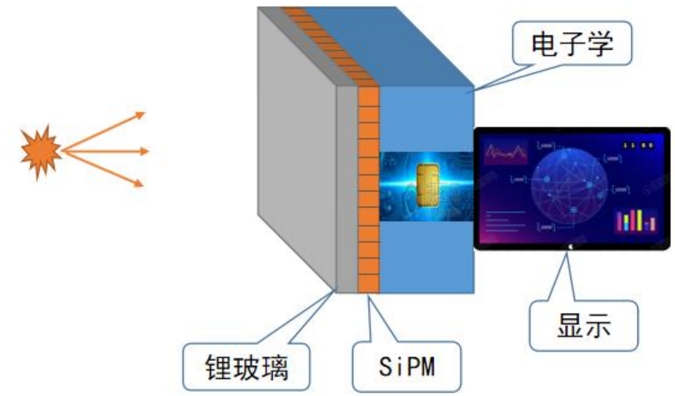
- based on lithium glass
  - 2D/3D array, thermal neutron, gamma
  - energy, position, imaging
  - readout by SiPM array
  - MURA encoding board
- contents
  - design (optical simulation)
  - electronics, ASIC
  - algorithm, ANN

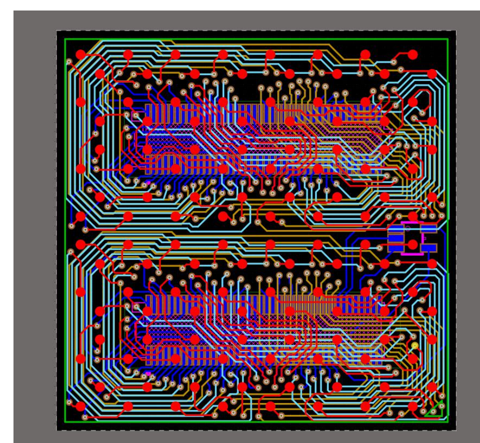




schemitic of the neutron/gamma imager

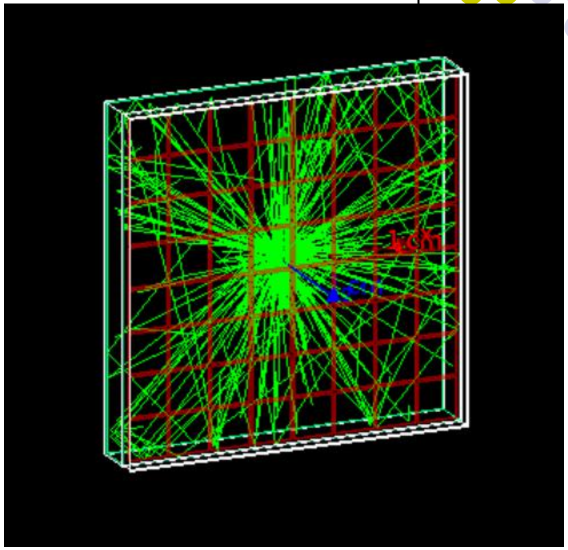
- scintillator
  - lithium glass, 3mm
  - GAGG, 10mm
  - mono-block, easy to manufact
- photoelectric device
  - SiPM, 3mm+0.2mm gap
  - 8×8 array, 25×25mm^2
- electronics
  - ASIC+ADC+FPGA

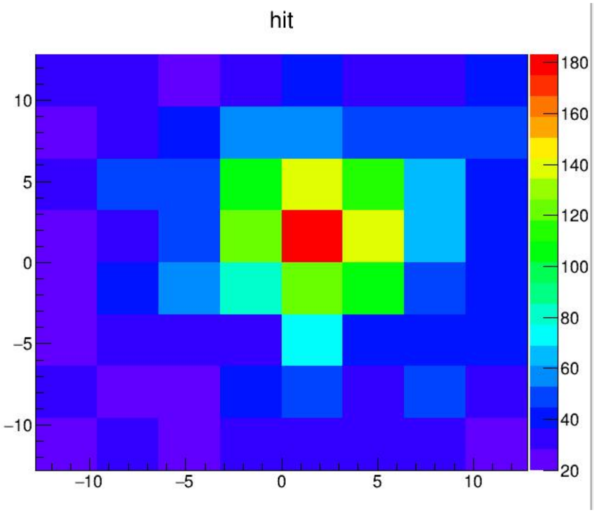




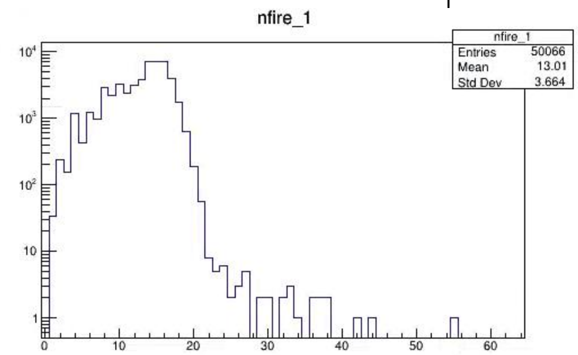
Geant4 MC simulation

- optical simulation by G4
  - full detector setup (glass + SiPM)
  - physics: FTFP_BERT_HP + G4Optical
  - photon transport, SiPM photon-electric effi
  - Output, PE of 64 SiPMs
- condition
  - various injected position
  - obtain 2D PE image of SiPM array
  - test position reconstruction algorithm

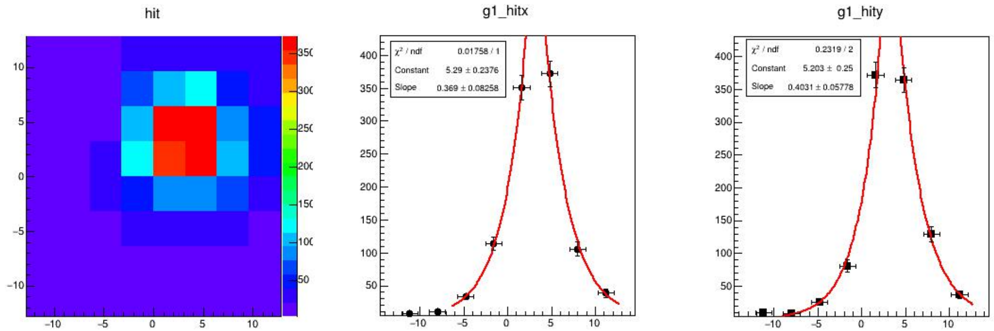




position reconstruction

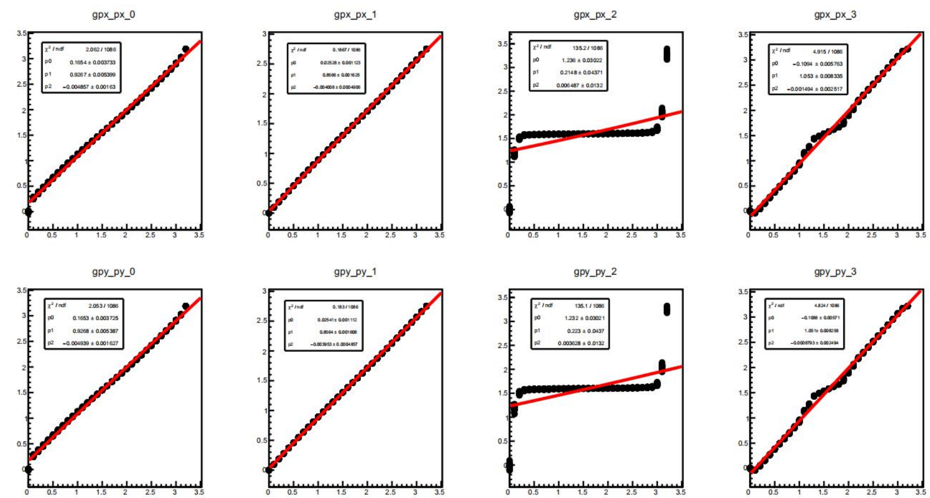


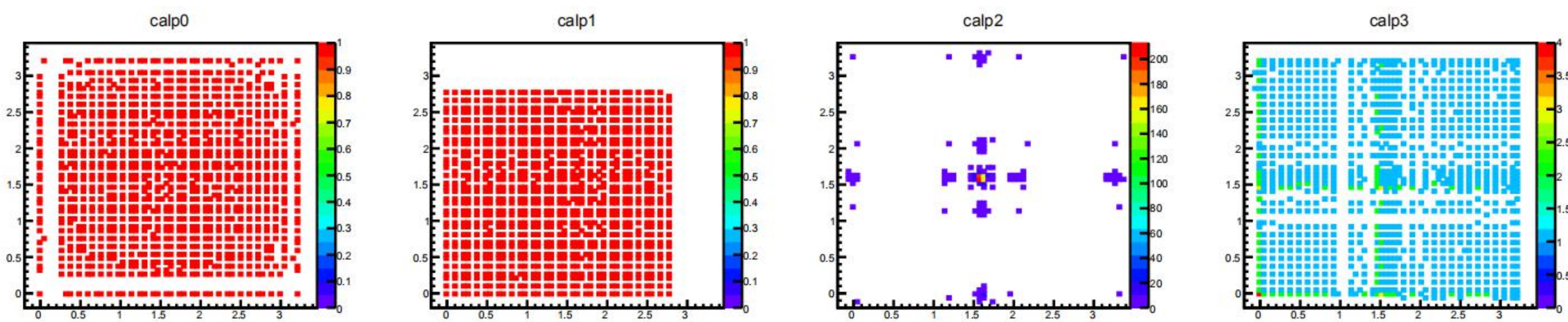
- using SiPM 2D array
  - hit numbers, 4-64, get x/y seperately
- algorithm
  - maximum value(MAX)
  - center of mass(CoM), get CoM from 8*8 array
  - Regional CoM(RCoM), CoM near the maximum region(-3, 3)
  - fitting method(FIT), exponential function, obtain cross-points on 2 sides



position reconstruction accuracy for center area (0, 3.2mm)

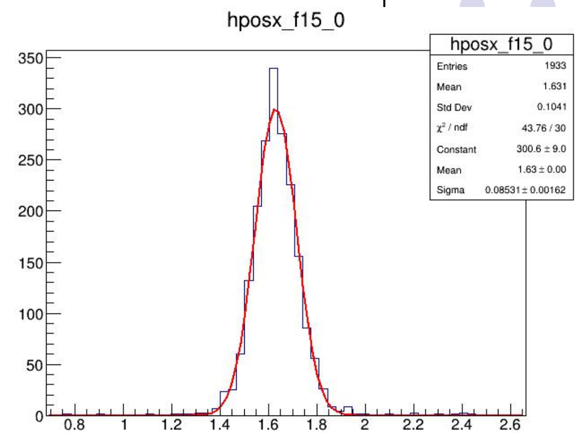
- accuracy (mean value)
  - RCoM, FIT better, linear, largest deviation 0.2mm
  - CoM, good linear ability, large offset on boundary ~ 0.5mm
  - MAX, lost resolution

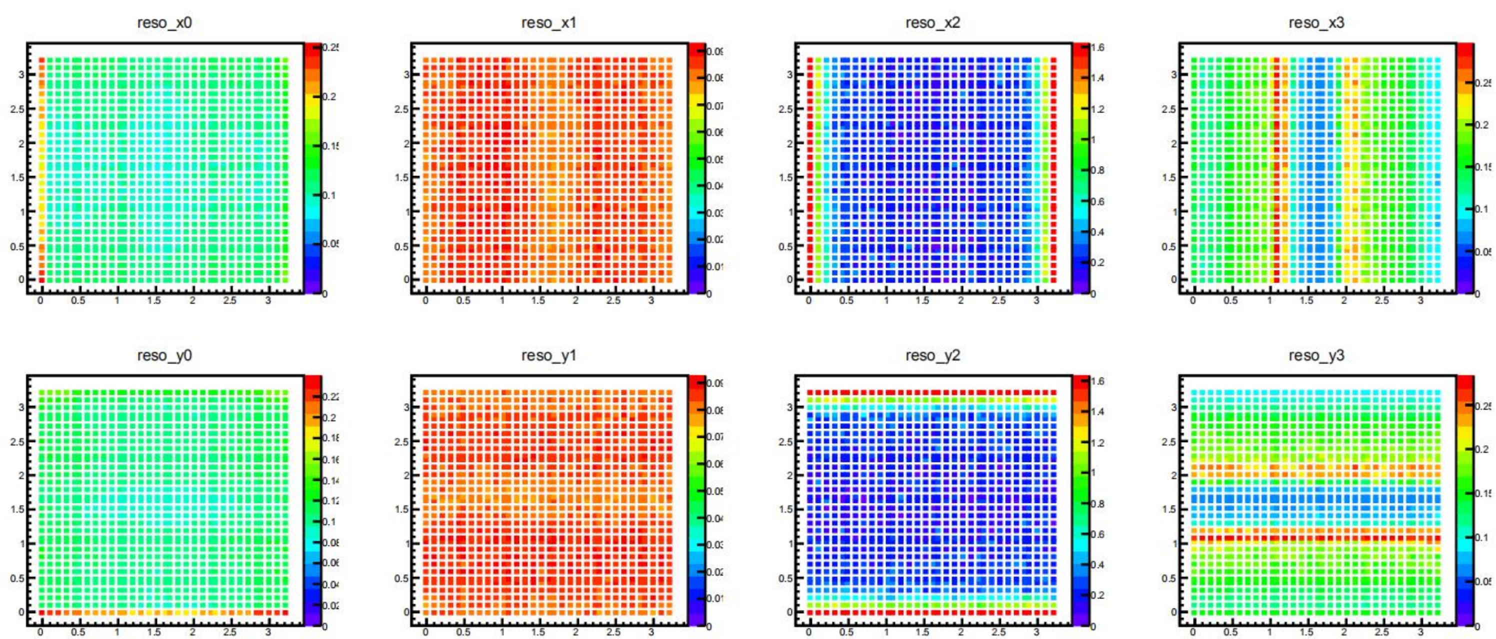




spatial resolution for center area(0, 3.2mm)

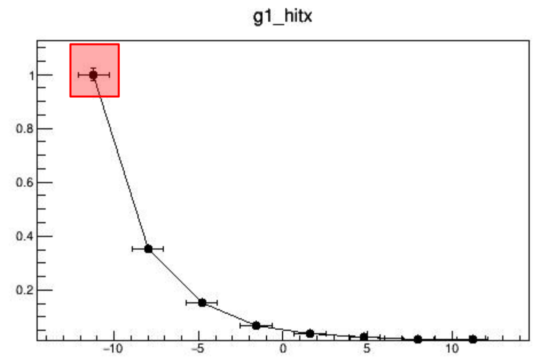
- resolution (sigma, RMS)
  - RCoM, FIT, about 0.25mm
  - CoM, about 0.1mm, but large offset
  - MAX, 1.5mm, bad

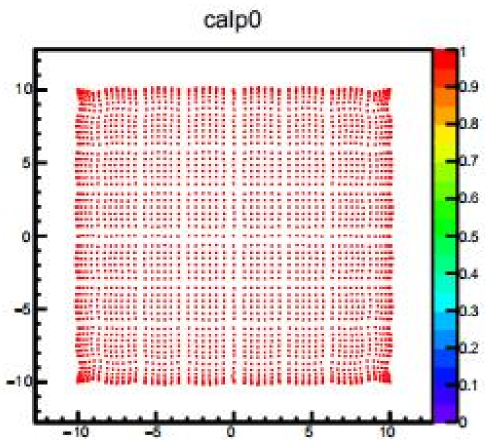


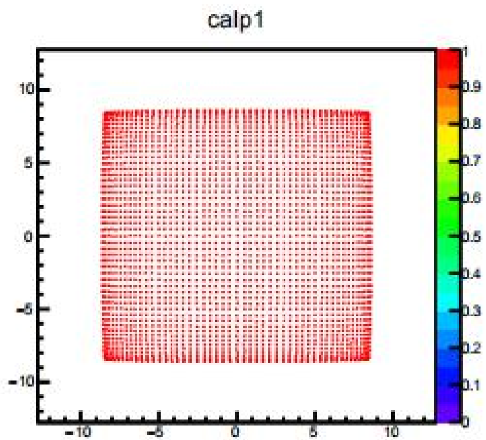


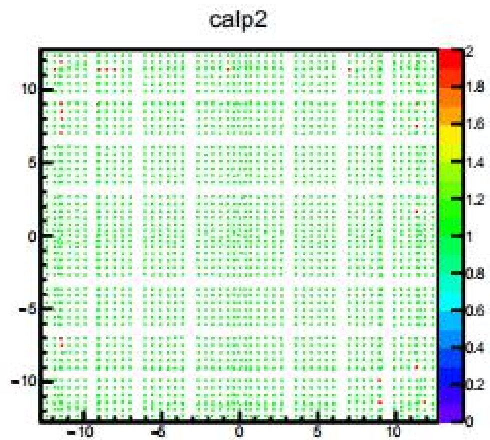
results for full area(same to gs)

- input range (-12.5mm, 12.5mm）
  - output FOV small, RCoM (-10,10) 64%, CoM (-8.5,8.5）46%
  - FIT not usable for boundary, half side
  - MAX method lost resolution
  - need new algorithm



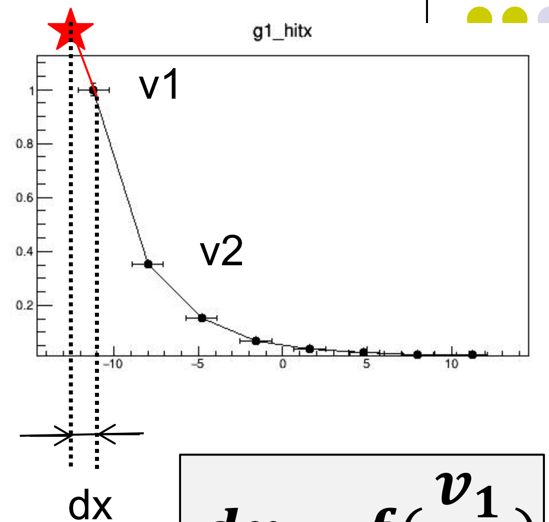




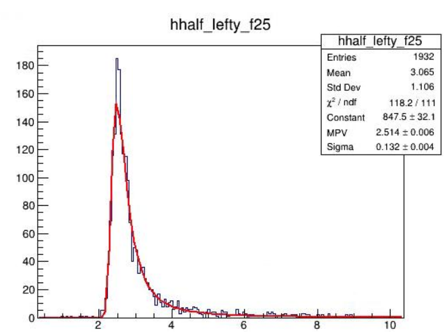


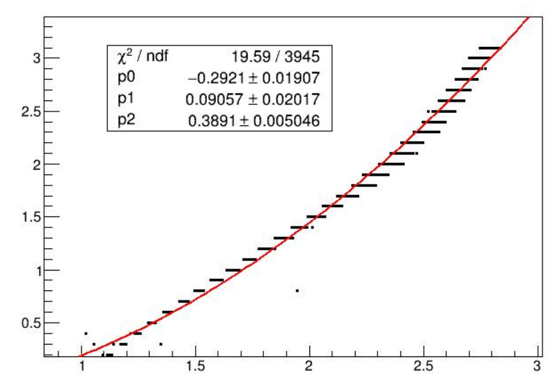
method for boundary area

- problem
  - only half side information
  - how to reconstruct dx using the curve
- method
  - dx -> decrease velocity
  - fast velocity, large dx
  - obtain calibration function, width 0.15mm
  - constructed maximum error 0.25mm



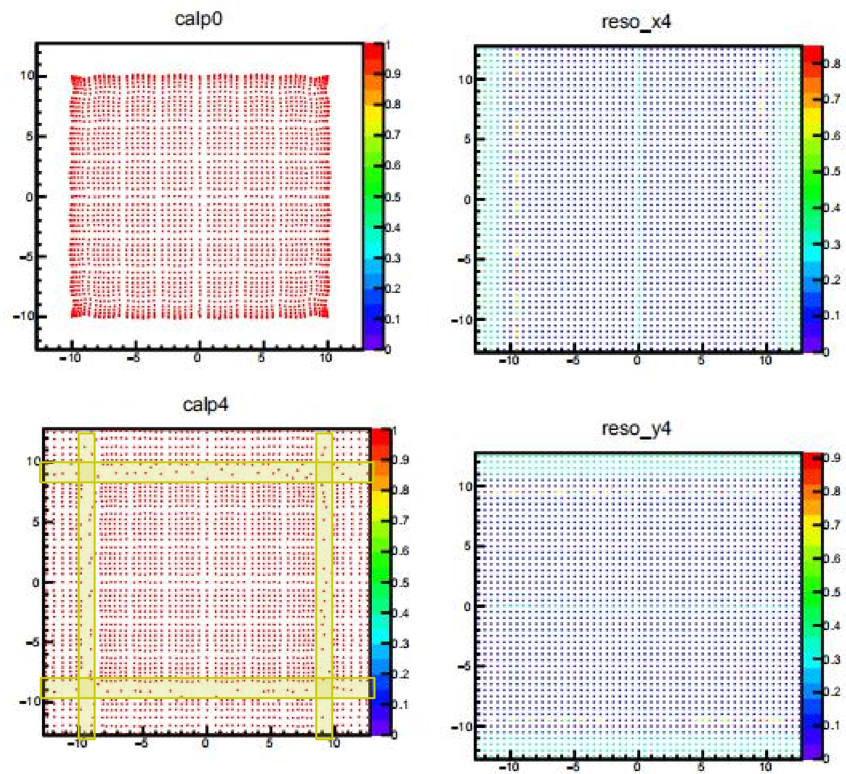
$$dx = f\left(\frac{v_1}{v_2}\right)$$



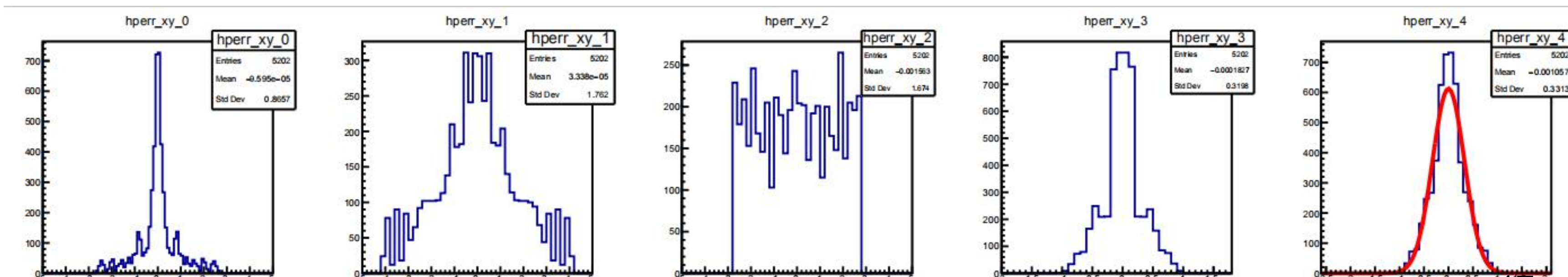


reconstructed results for boundary

- modified RCoM
  - center, RCoM
  - boundary, modified with dx
- results
  - more correct than RCoM
  - 2nd ring problem (need consider)
  - sigma became bad, ~0.6mm



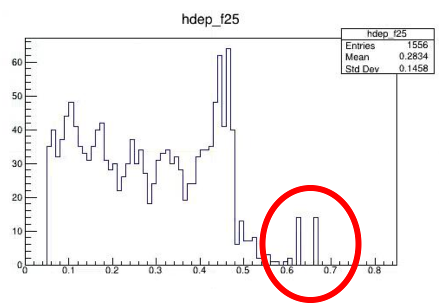
offset

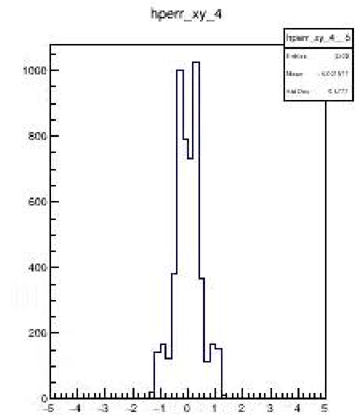


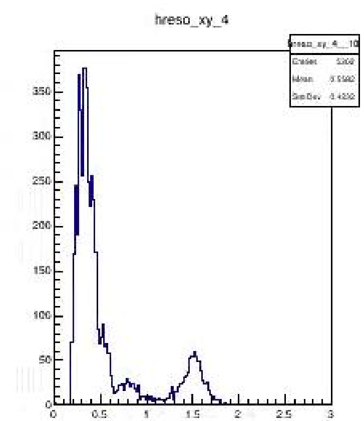
Regional CoM　　CoM　　MAX　　FIT　　Modified RCoM

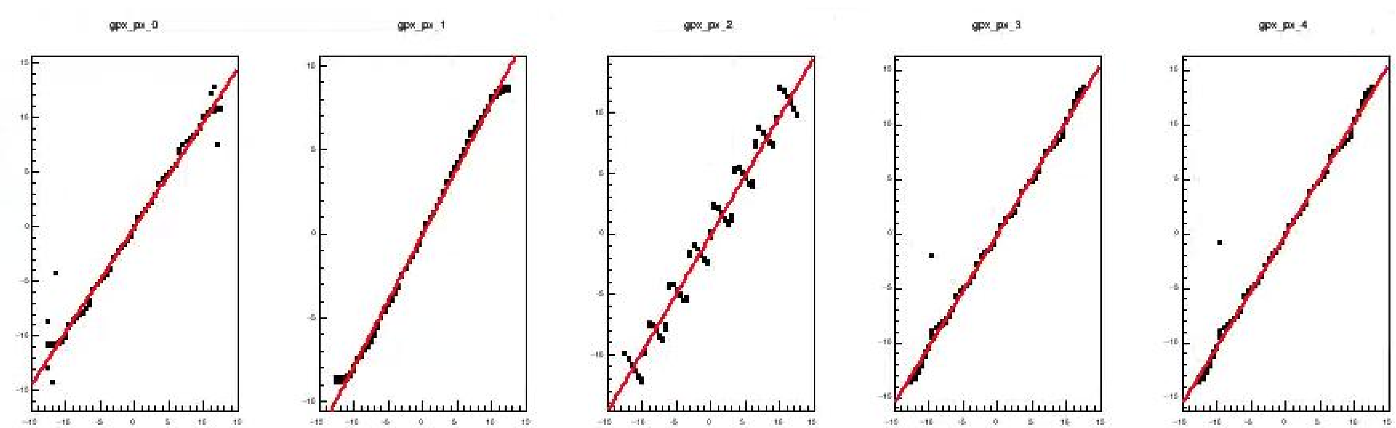
gamma imager for Cs137

- Glass, low photon-electric CS, none full energy peak
  - detectioin efficiency ~6% (5 keV threshold)
  - cal E using compton edge
- effect of compton scatter
  - position accuray 1mm
  - sigma 1mm



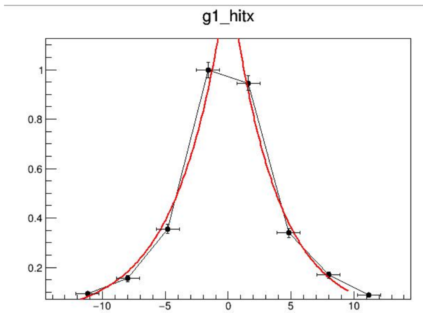


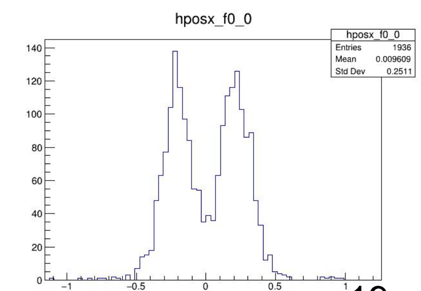




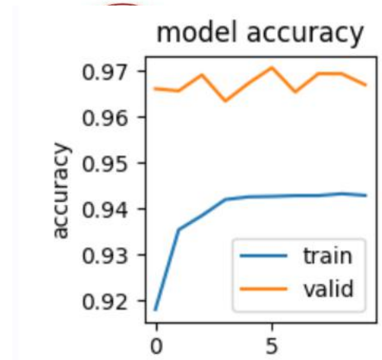
summary of analytical algorithm

- 5 methods
  - Modified Regional Center of Mass, best, easy, fast
  - FIT method good, time consuming
  - CoM, low FOV, best sigma (reduce noise fluctation)
  - MAX, lost resolution, quick
- problem: injected inside the gap of SiPMs
  - equal PE for 2 nearly SiPM in theory
  - large impact for fluctation
  - obtain two peaks, make resolution bad

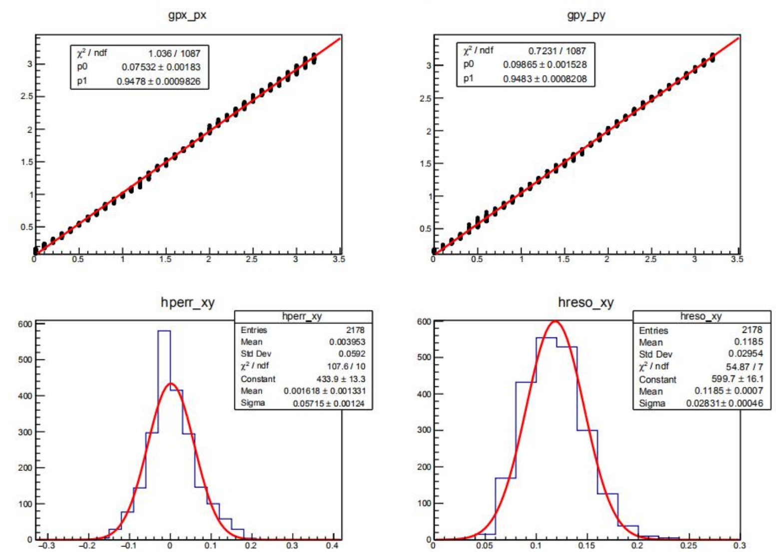


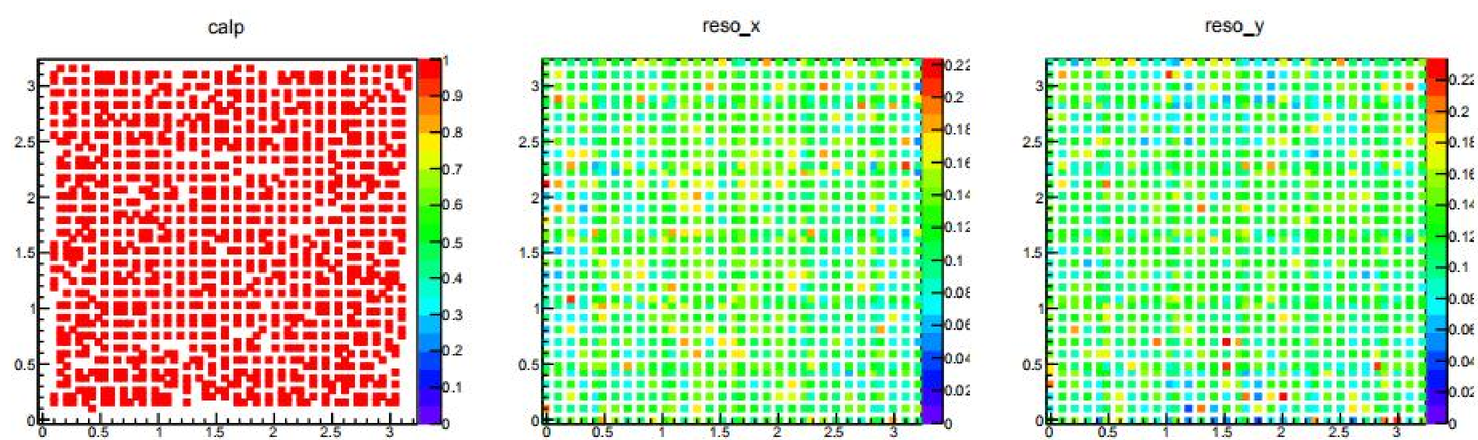


reconstruction using ANN center area (0, 3.2mm)



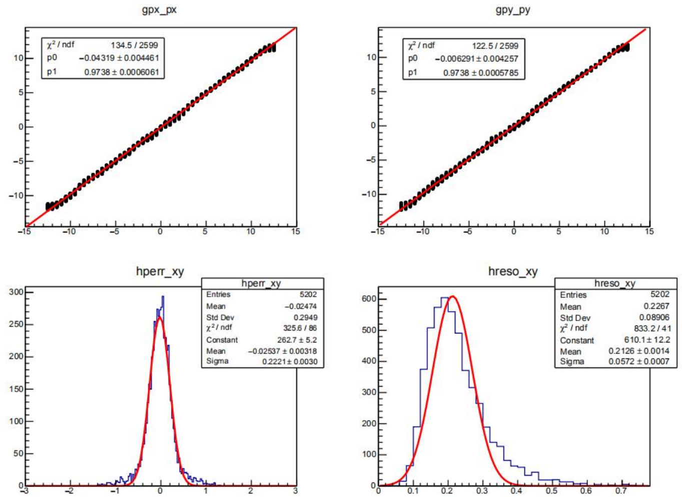
- fully connected network
  - dataset, 2,000,000
  - pos (0,3.2) with 0.1mm step
  - very good performance
  - accuracy, 0.06mm
  - precision, 0.12mm

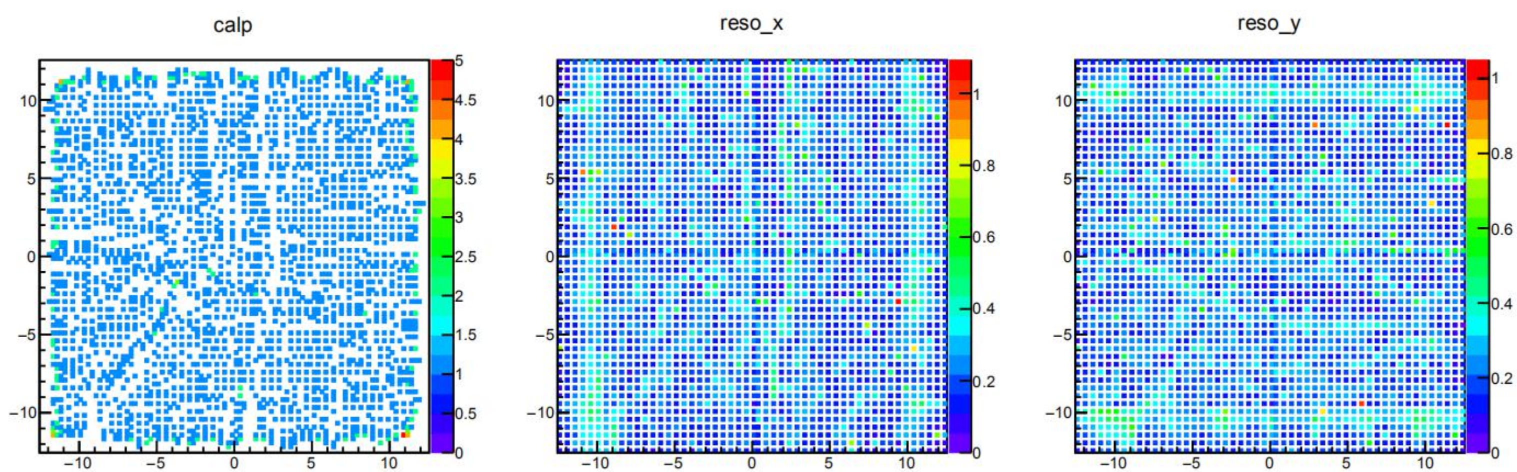




reconstruction using ANN full range (-12.5mm, 12.5mm)

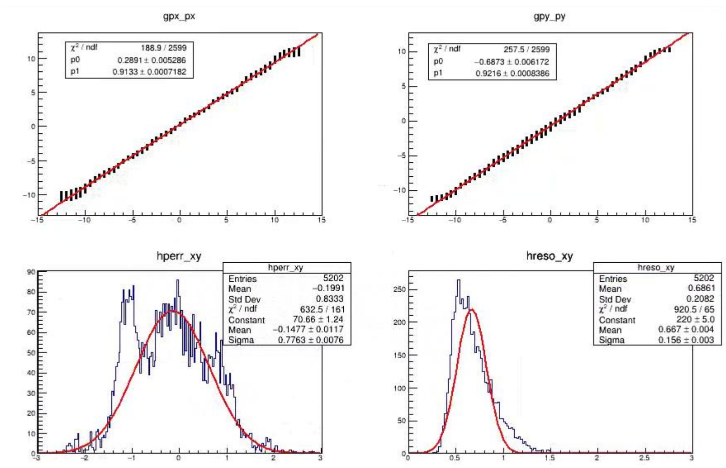
- fully connected network
  - accuracy, 0.2mm
  - precision, 0.2mm
  - better than analytical method
- very large dataset
  - 5,200,000

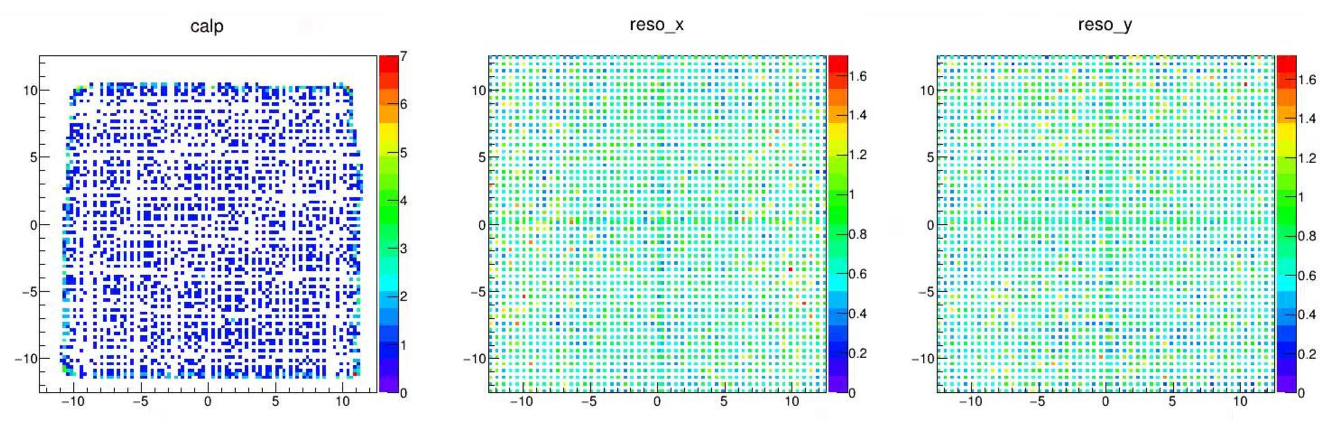




GS20 imager
gamma reconstruction using ANN

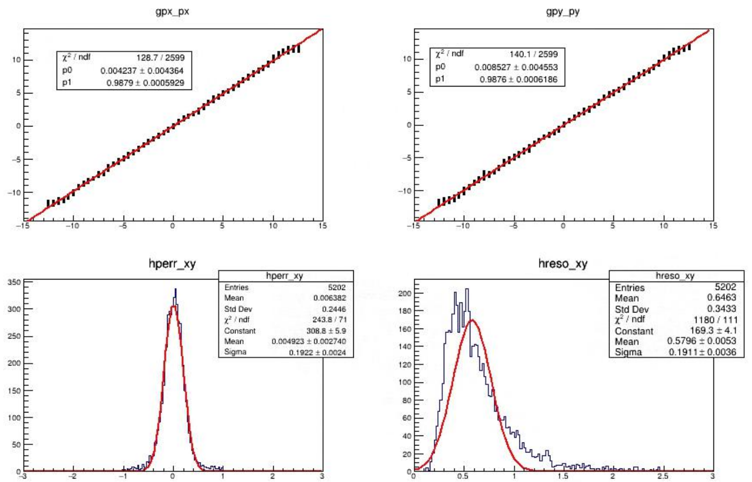
- Glass 3mm
  - accuracy, 0.8mm
  - precision(sigma), 0.7mm
  - FOV（-11，11）
- worse than neutron
  - low energy deposition
  - compton scattering, >1 interaction points

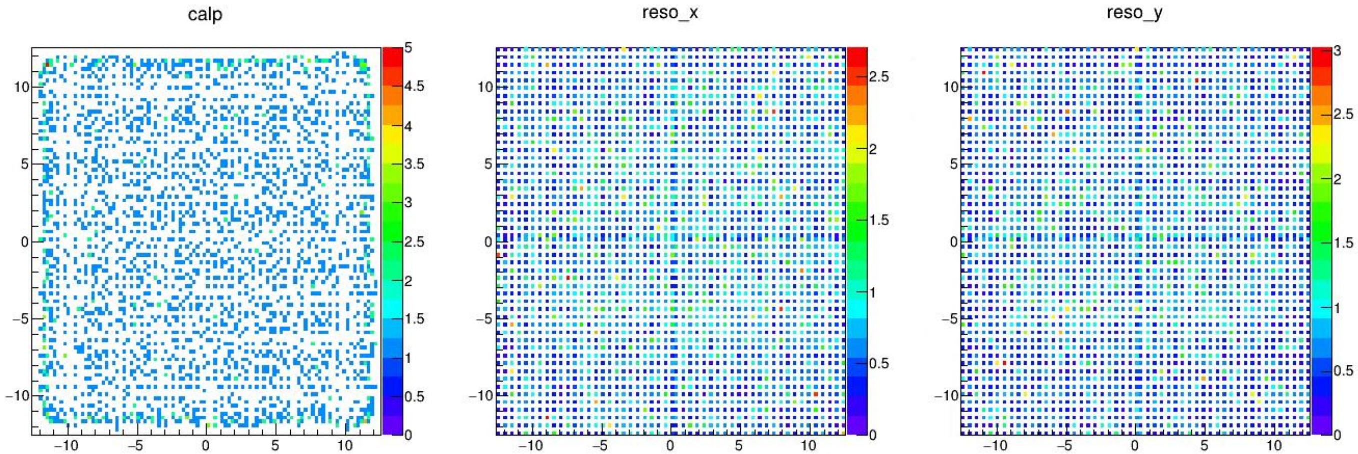




GAGG imager
gamma reconstruction using ANN

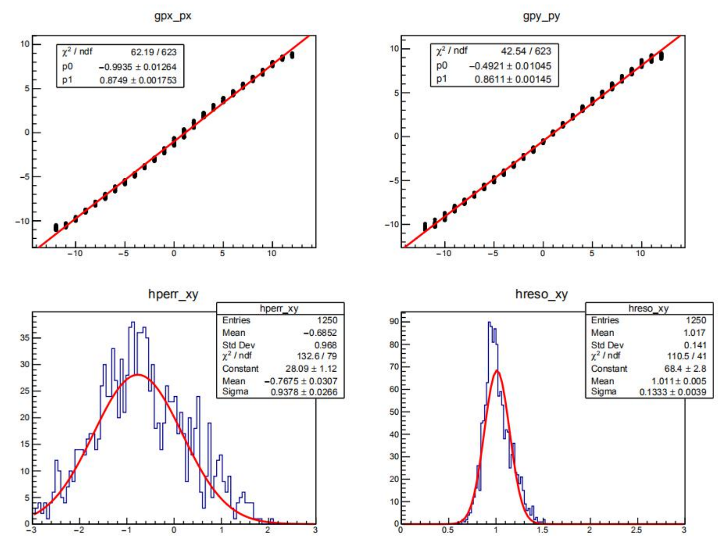
- GAGG 3 mm
  - accuracy 0.2 mm
  - precision(sigma), 0.6 mm
  - FOV (-12, 12)
  - detection efficiency low: ~30%

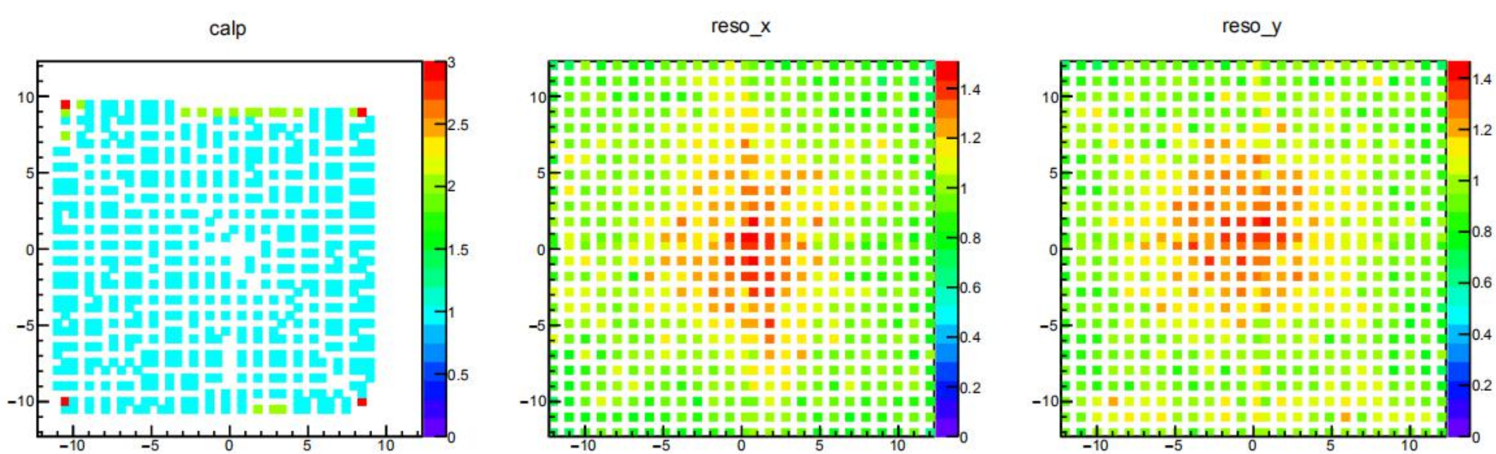




GAGG imager
gamma reconstruction using ANN

- GAGG 10 mm
  - accuracy 1mm
  - precision(sigma), 1mm
  - 10mm thickness render resolution bad
  - FOV (-10, 10), need further study
  - detection efficiency higher: ~60%





summary

- glass scintillator have lots of application potential
- thermal neutron imager
  - efficiency 96%, accuracy 0.3mm
  - precision, center 0.3mm, boundary 0.6mm
  - ANN method very effective, accuracy 0.2mm, precision 0.2mm, large dataset
- gamma imager(Li_glass+GAGG)
  - accuracy 1mm, precision 1mm
  - need further study

谢谢！

Thanks!

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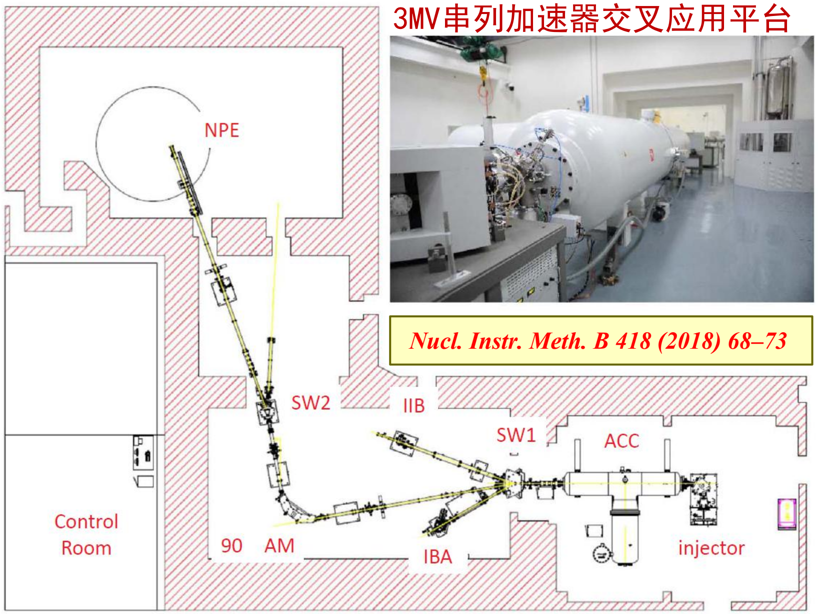
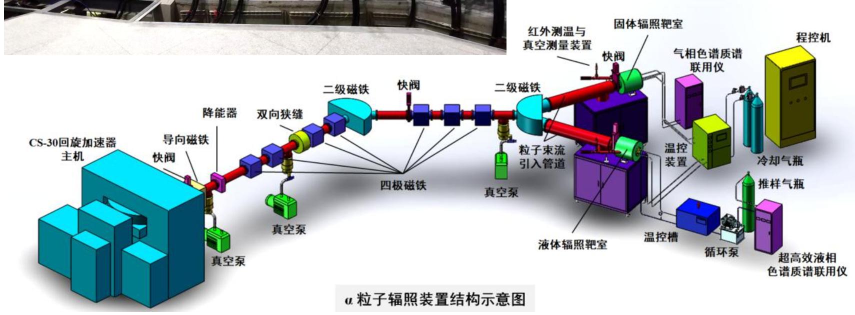


3MV串列加速器交叉应用平台

Nucl. Instr. Meth. B 418 (2018) 68–73

CS30回旋加速器综合应用平台



α粒子辐照装置结构示意图

- 3MV串列加速器，产生H-U的几乎所有离子、单能中子
- 离子辐照、离子束分析、核物理、中子、微束等终端

- 中能回旋加速器, p/d/α
- H(26MeV)，α(30MeV)，约100μA
- 同位素制备、α辐照等