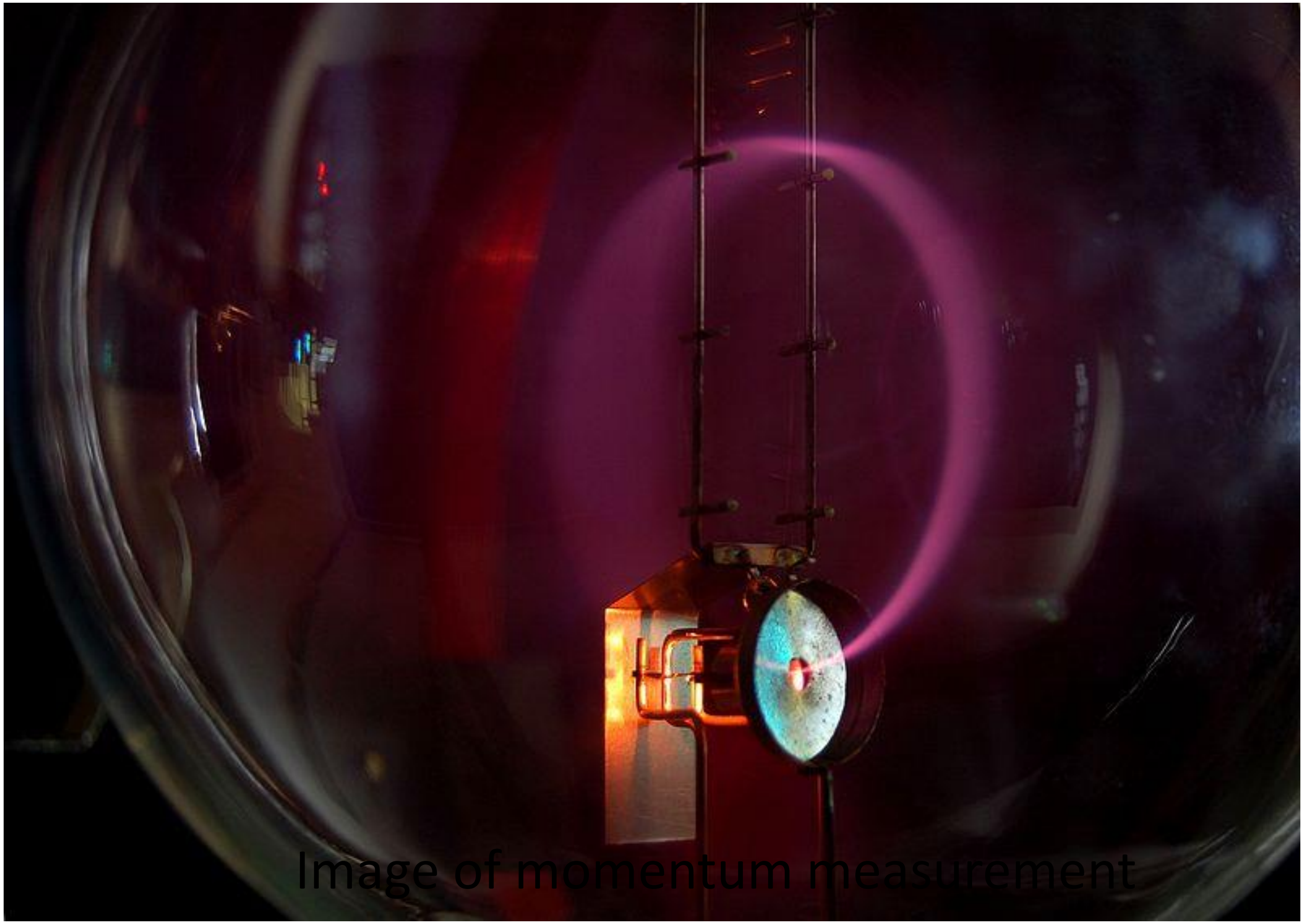
How can physicists explore the particle world?(II+)

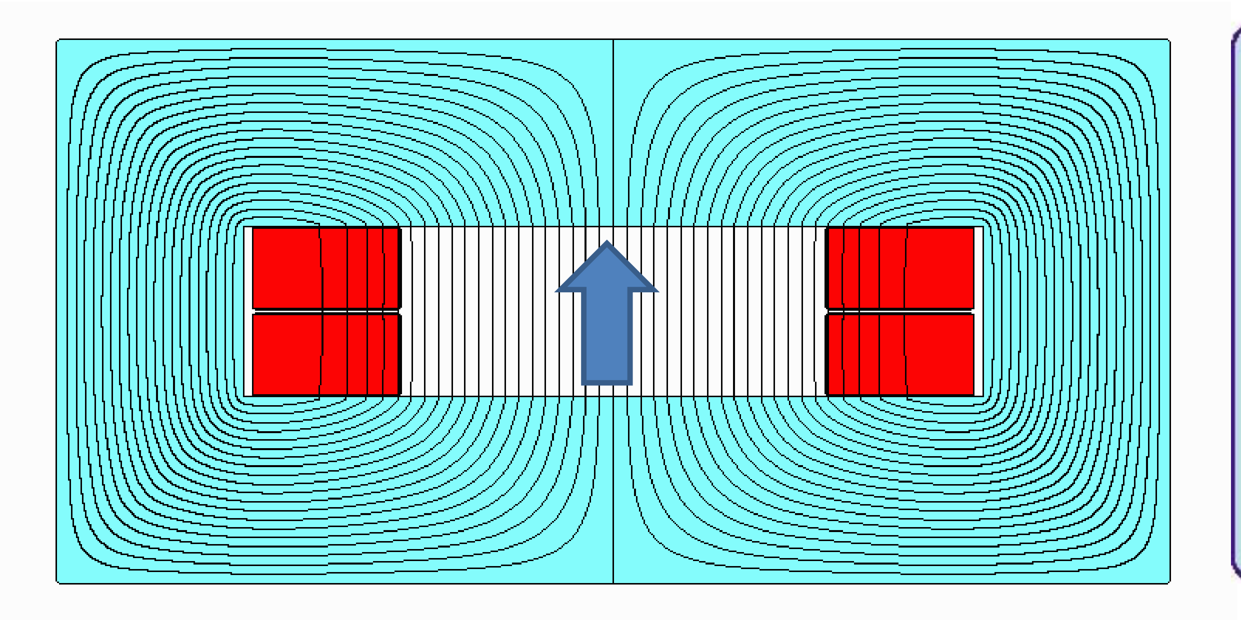
Junji Haba (KEK)

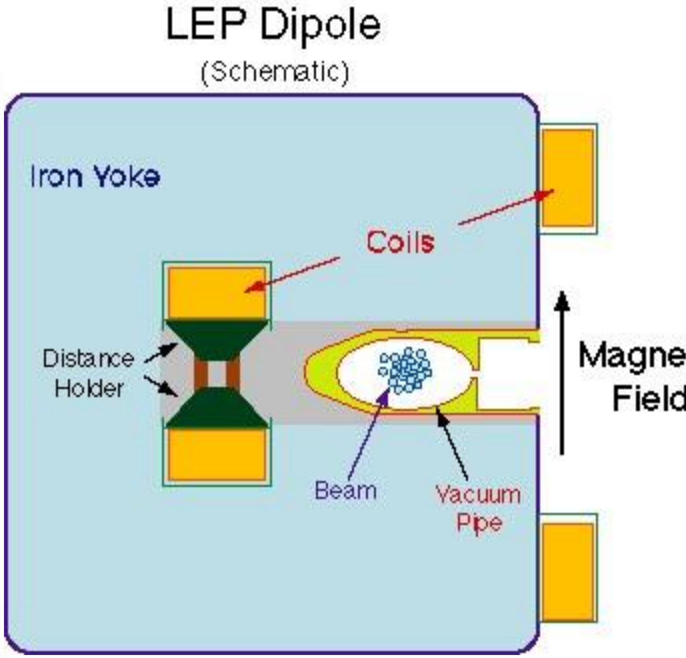
The 4th Asia Europe Pacific School of HEP @Quy Nhon, Vietnam

Very important components to measure momentum, **magnetic field**



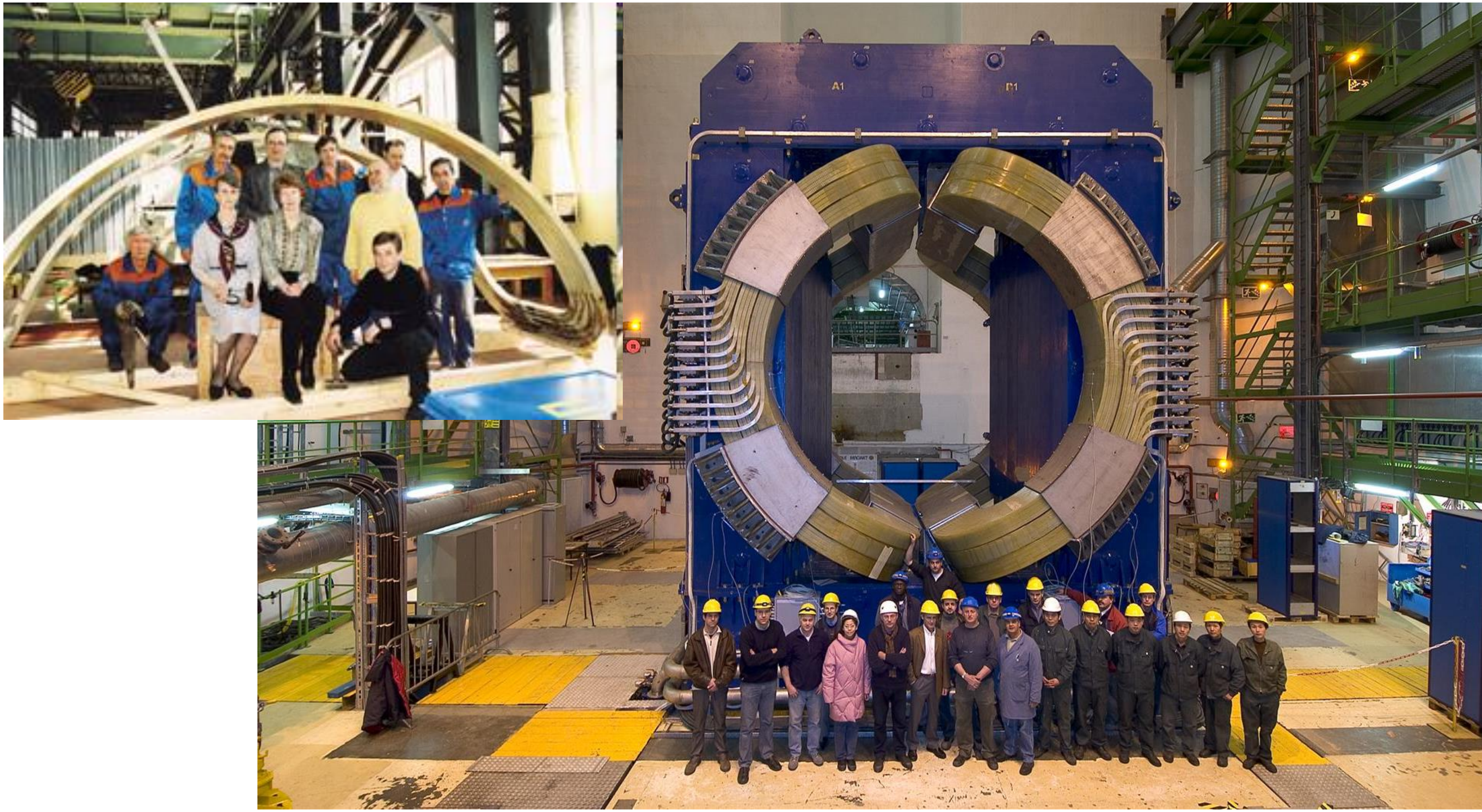
Magnetic field gereration





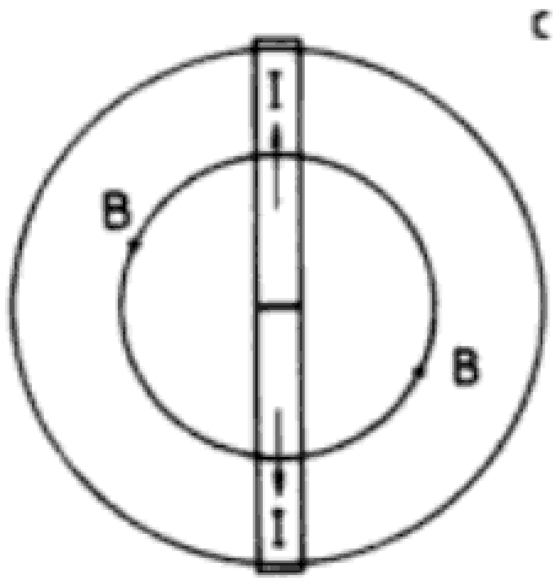
Dipole configuration

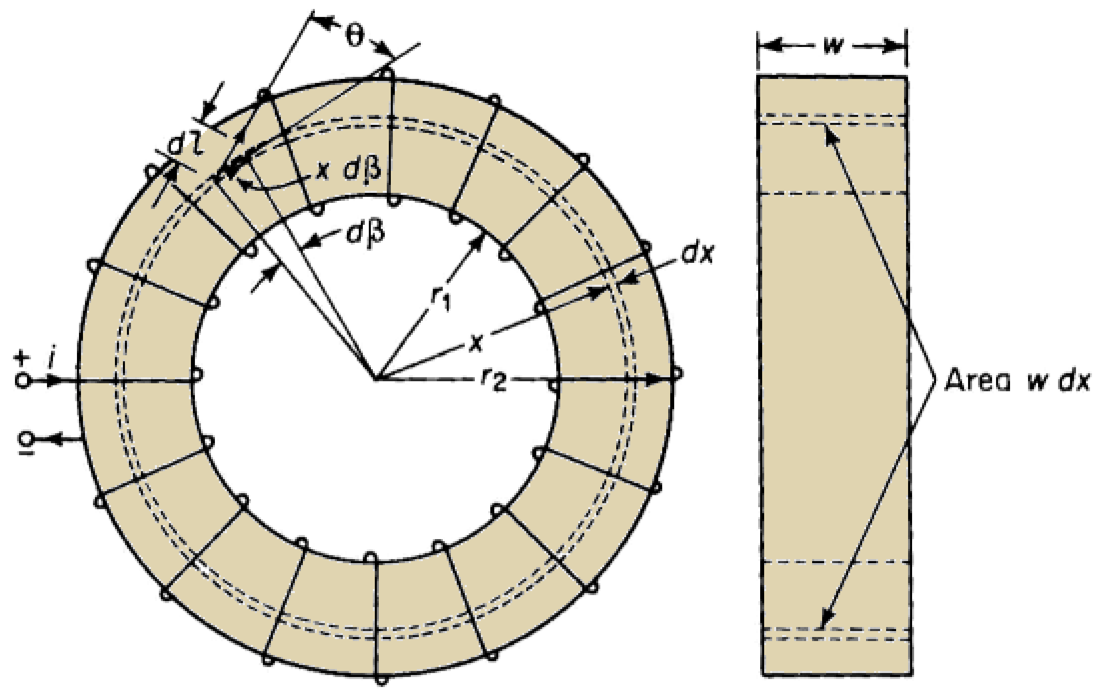
ALICE muon dipole



One of the biggest warm dipoles in the world
(free gap between poles ≈ 3 m, height of the yoke ~ 9 m
Designed for 0.7T w/6000A @600V).

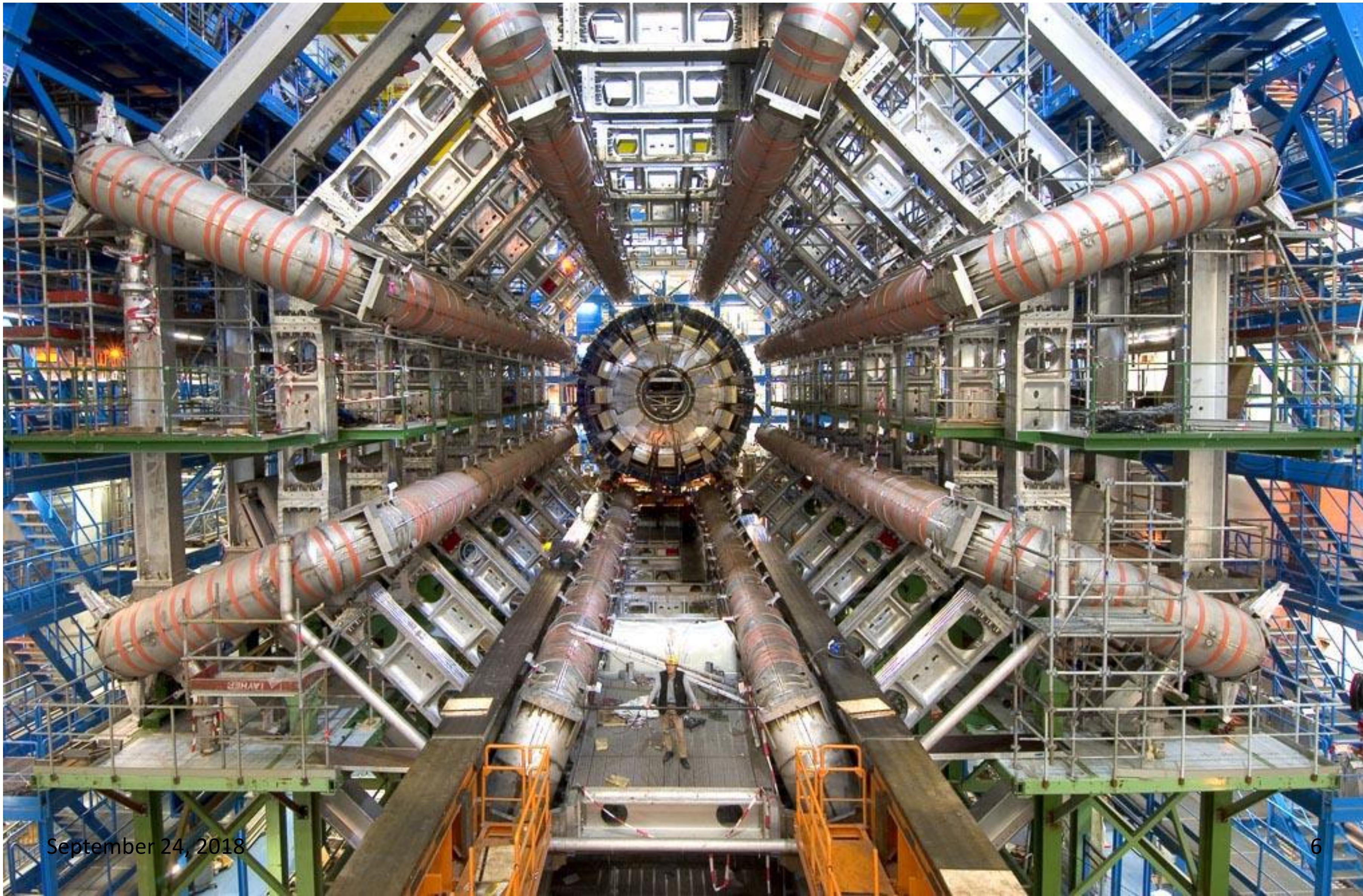
Toroidal magnets





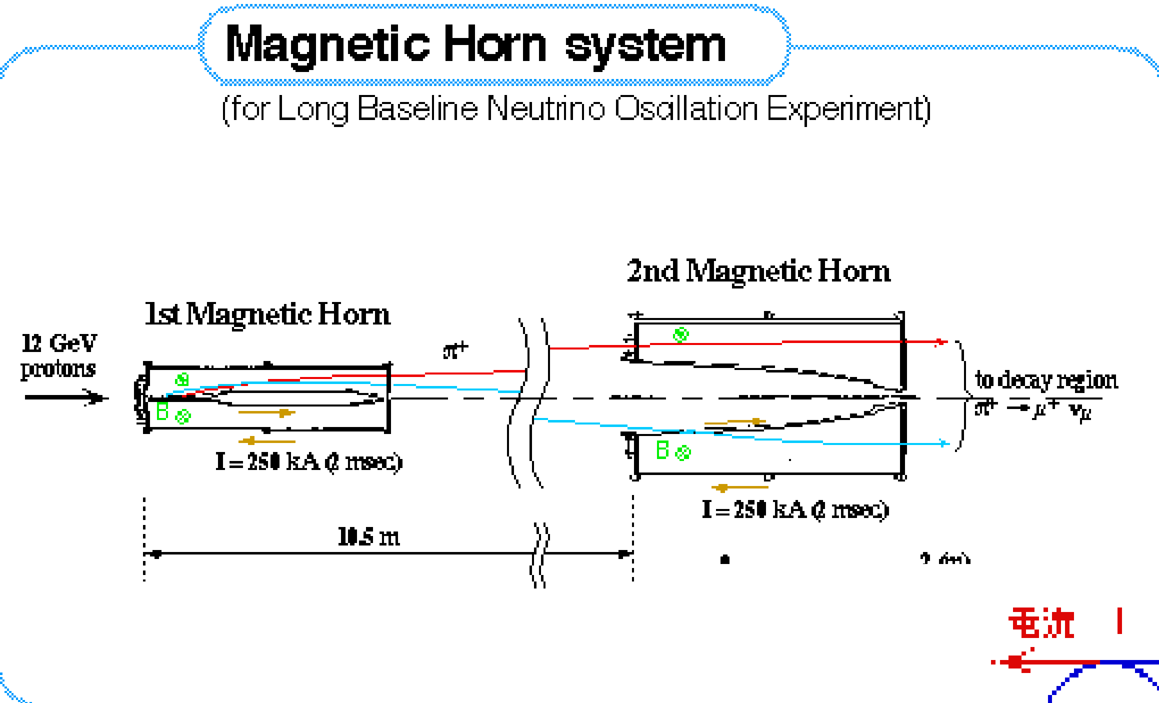
(a)

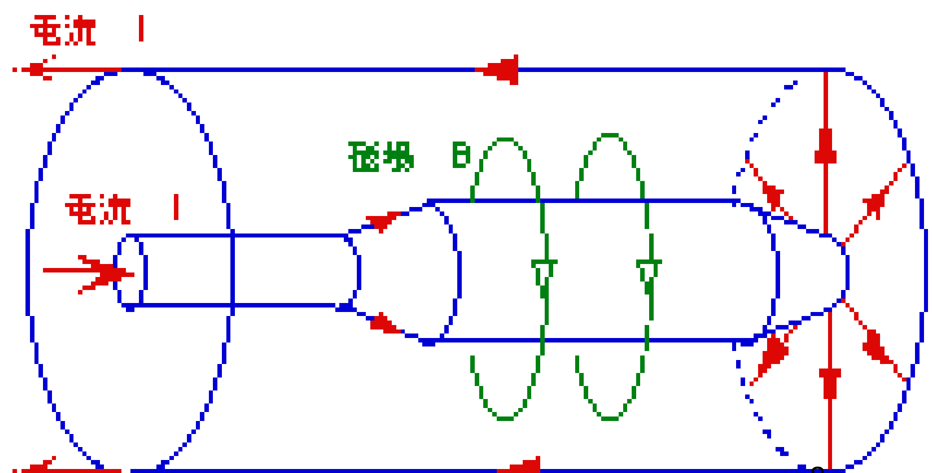
ATLAS Toroidal magnet



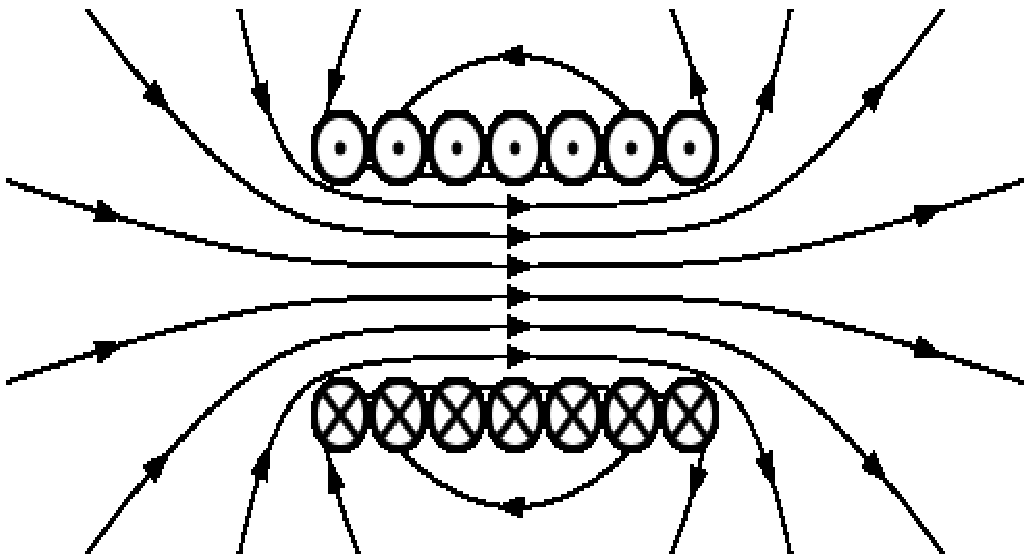
Toroidal magnet for neutrino experiment

Toroidal (horn) magnet for neutrino production

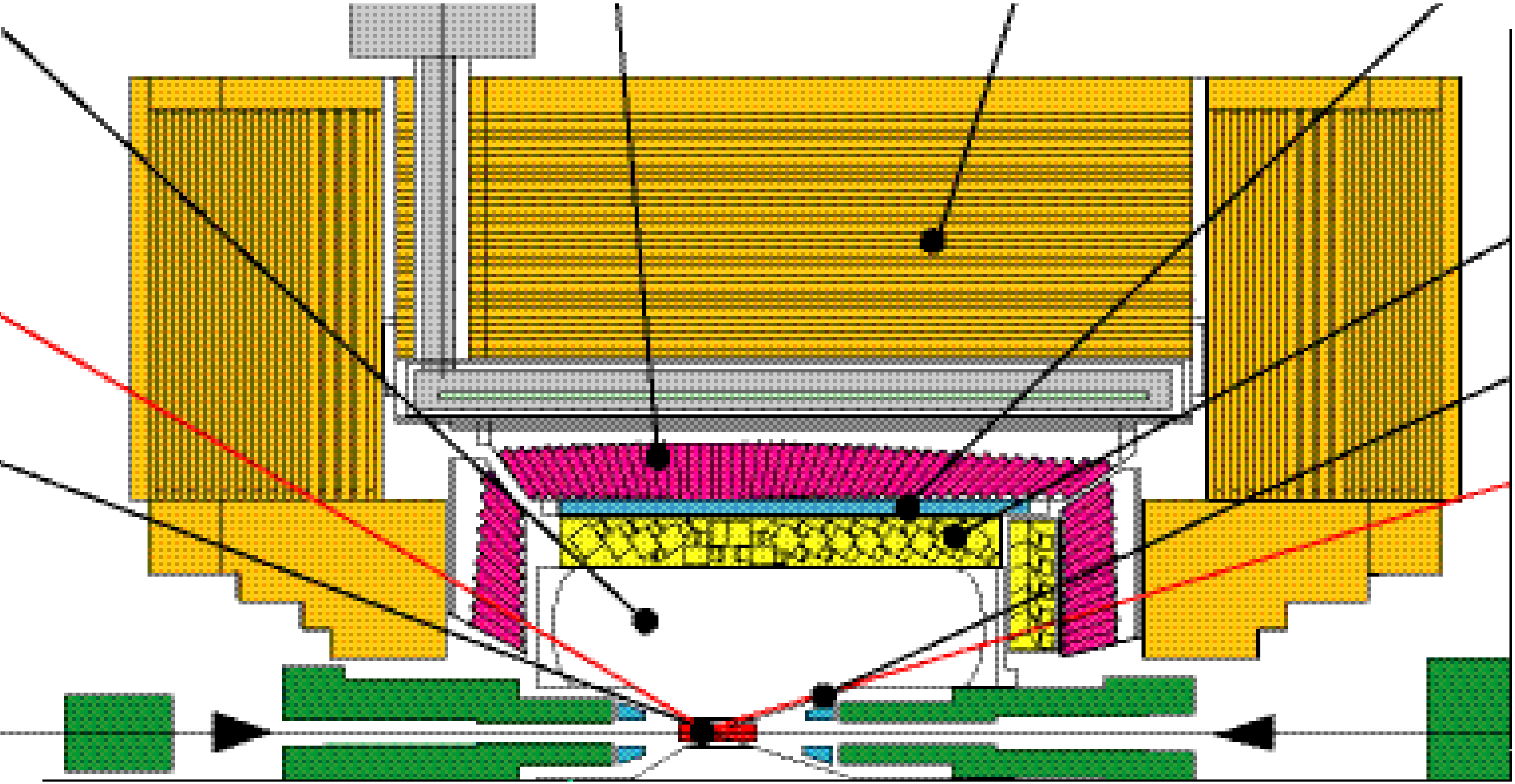




Solenoid magnet most standard magnet for collider detectors

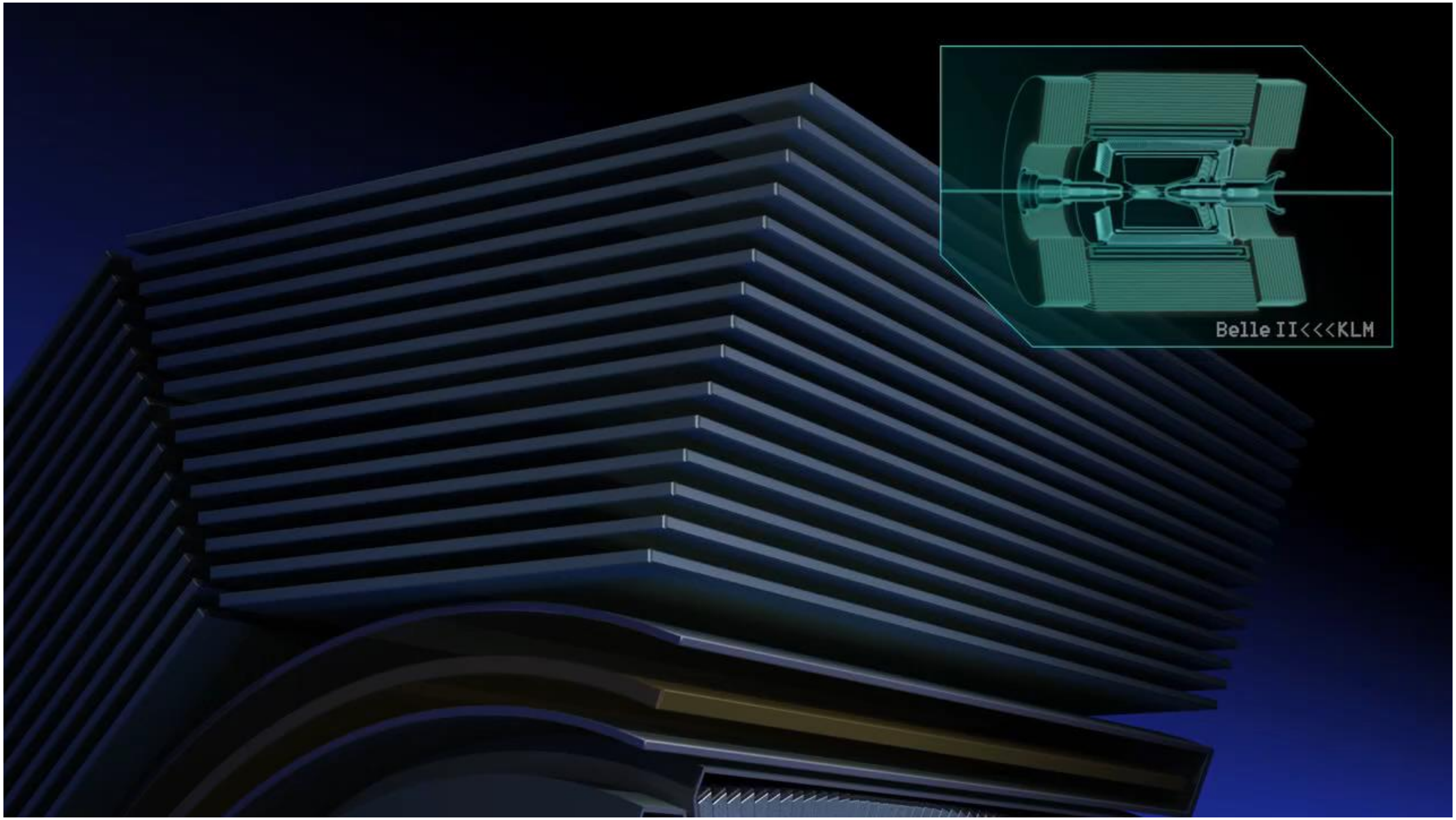


Solenoid magnet: Belle



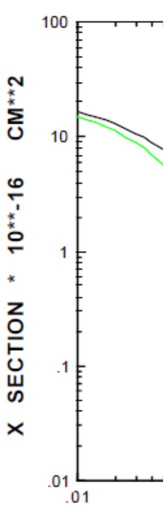
Non-uniformity below 5% inside tracking volume.
Field mapping with 0.3% precision.

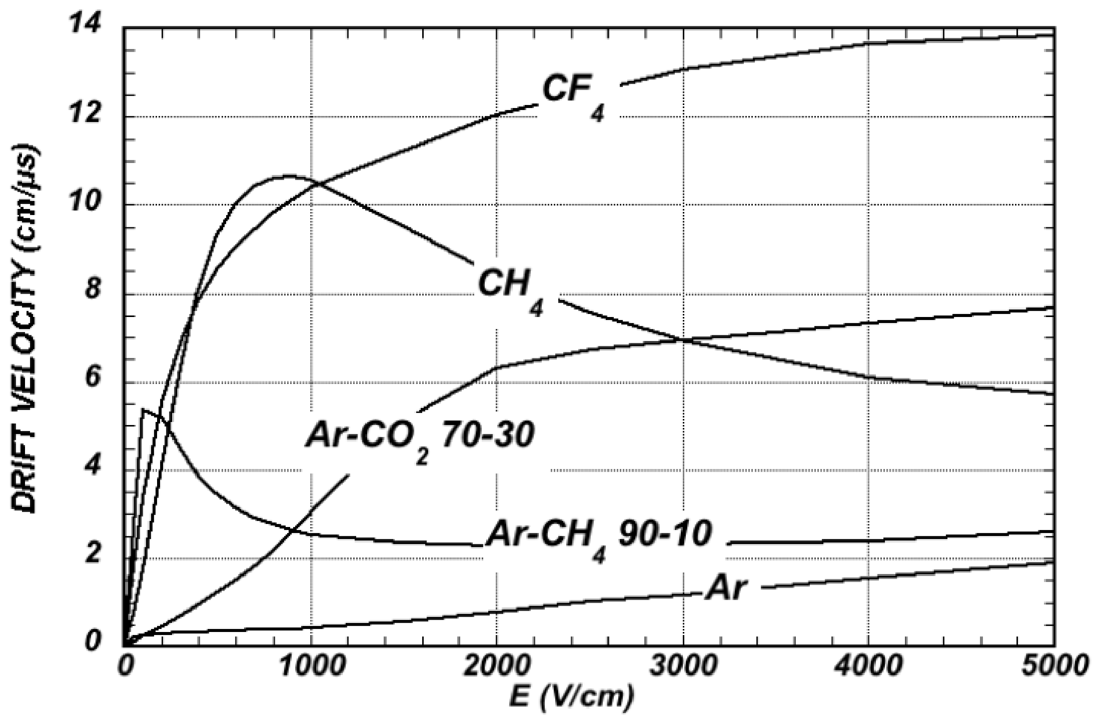
Muon Identification using Instrumented flux return



Comments from the last lecture

- Drift velocity is not always monotonically increasing with external electrical field. Why?





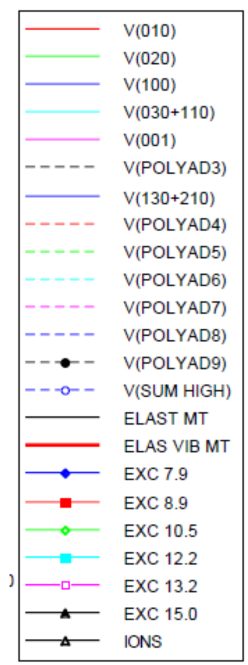


Figure 28.4: Computed electron drift velocity as a function of electric field in several gases at NTP [67].

How can physicists explore the ~~particle~~ world?(III)

REAL

Junji Haba (KEK)

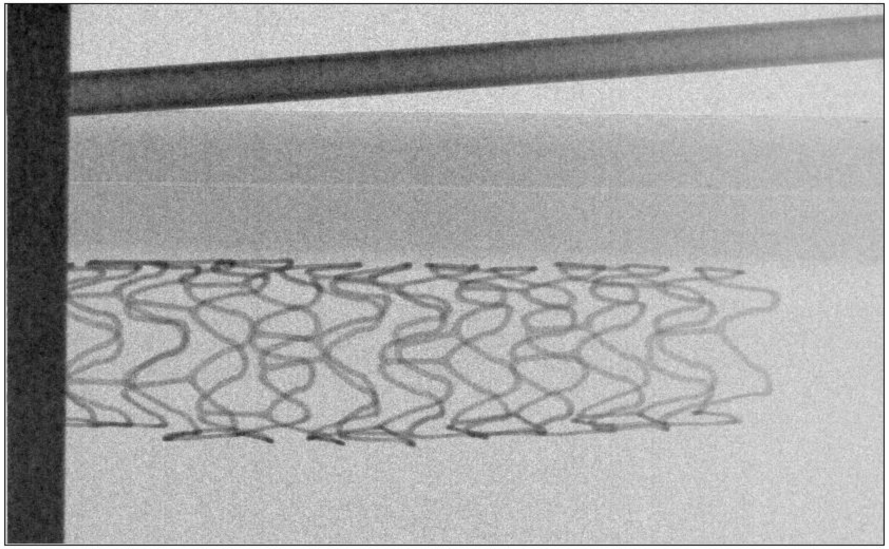
The 4th Asia Europe Pacific School of HEP @Quy Nhon, Vietnam

Applications of HEP detector technology to society

- At Hospitals…
  - X-ray, g-ray, ＰＥＴ diagnosis, Cancer therapy
- At Aiports or Boarder gates….
  - X-ray inspection
- At factories, infrastructures as bridges, power plants….
  - X-ray or Neutron Non–destructive defect/damage inspection
- At the Fukushima site
  - Mapping and Identification of radioactive substances

X-ray

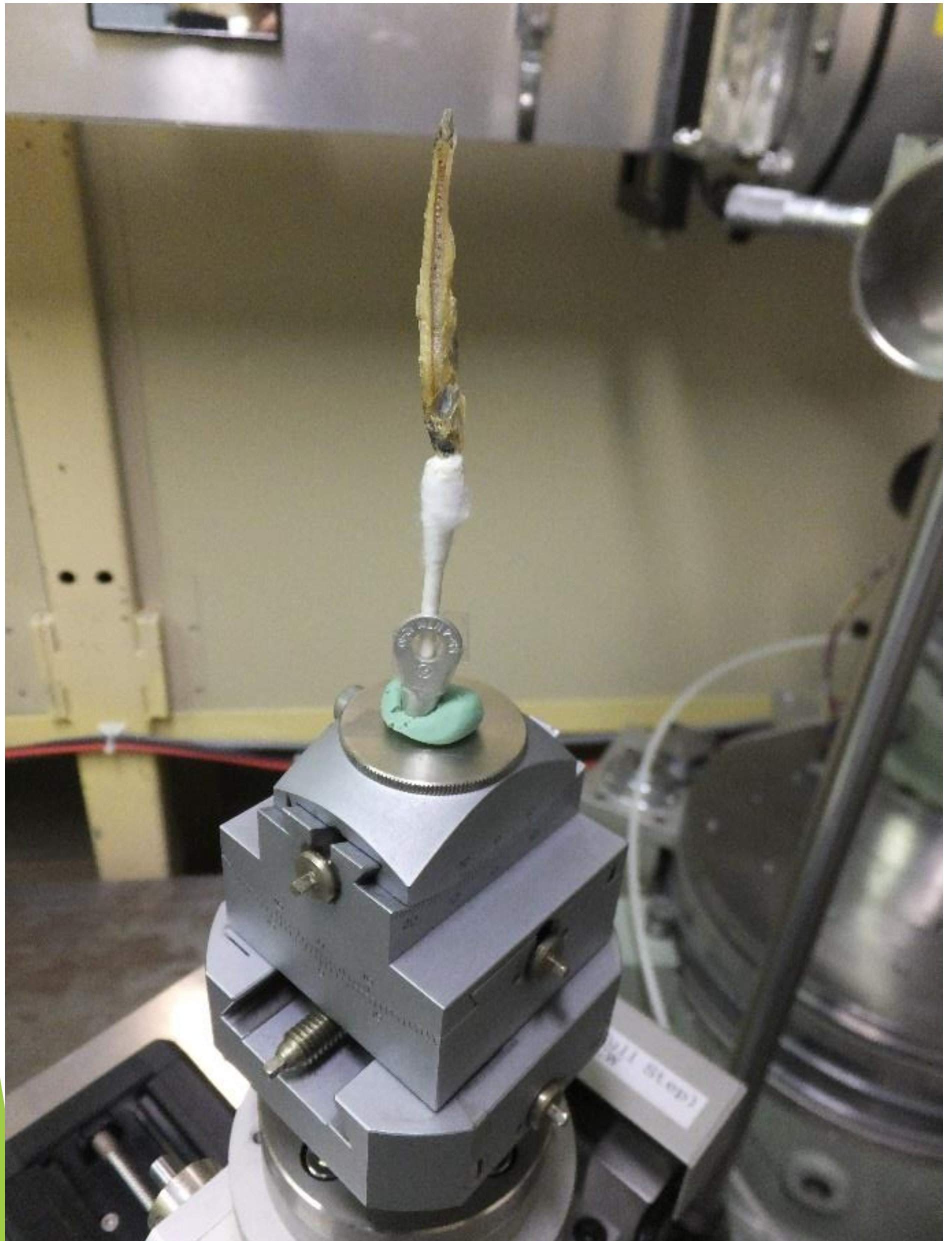
X-ray imaging device with the most advanced technology developped in Particle detectors



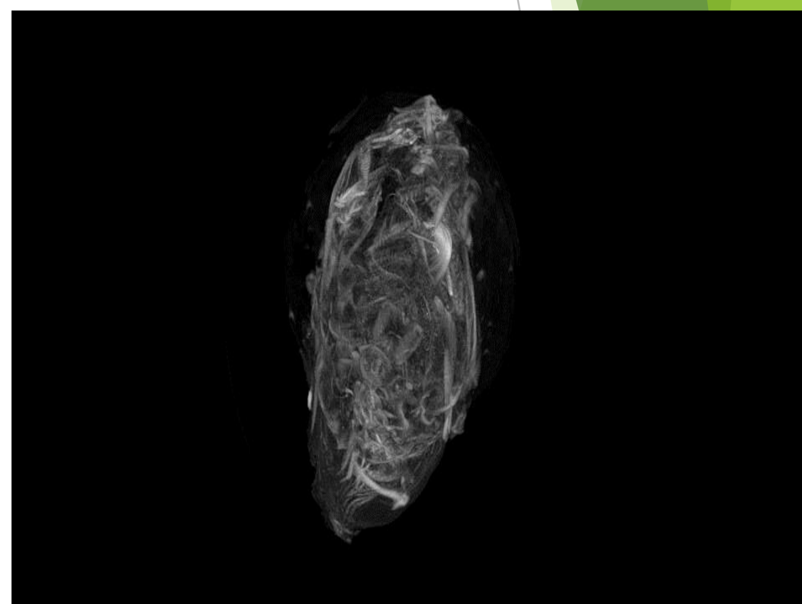
For safety Flights:

IN A TRUCK This backscatter X ray spotted 37 illegal immigrants being smuggled out of Chiapas, Mexico, in a shipment of bananas

3D X-ray CT

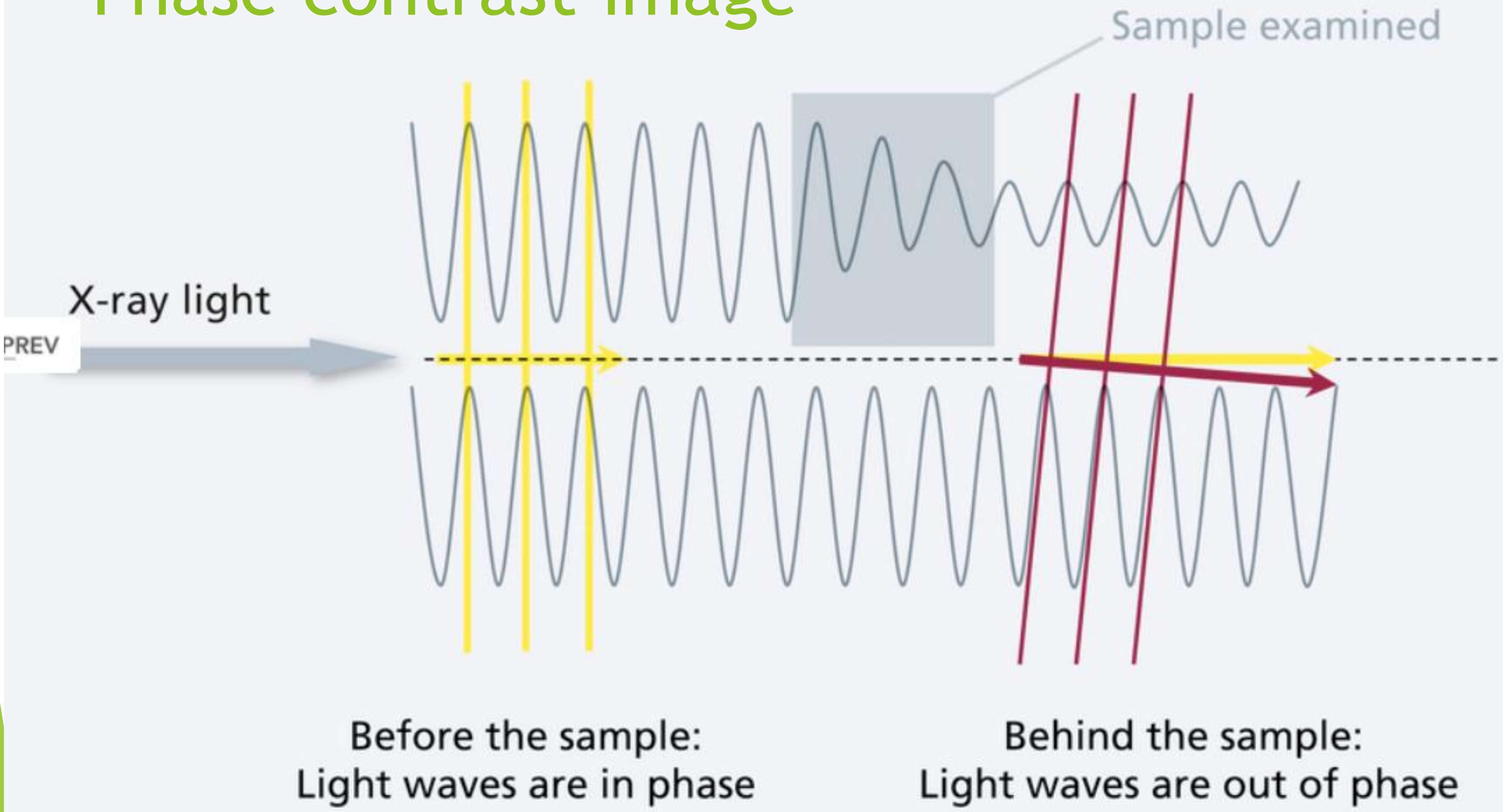


- Sensor chip INTPIX4 NFZ (5JA-FZ-1407) Back illumination
- HV : 200V、integration/frame : 1ms、ScanTime : 320ns/pix
- Calibration : 500frame、Event : 1000frame
- X-ray energy : 9.5keV



(by R. Nishimura, K. Hirano)

New technique of X-ray imaging: Phase contrast image



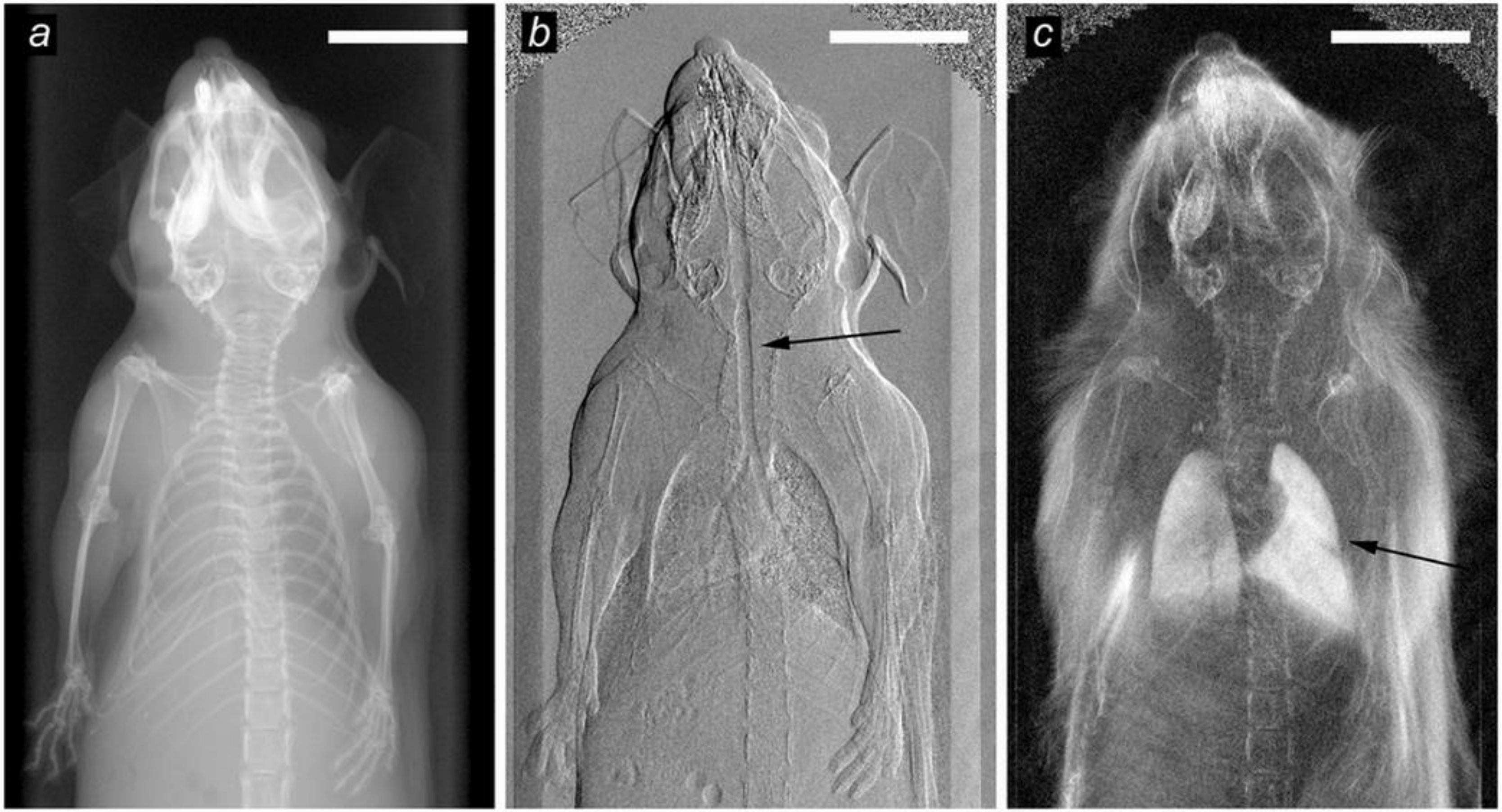
From

In-vivo dark-field and phase-contrast x-ray imaging

M. Bech, A. Tapfer, A. Velroyen, A. Yaroshenko, B. Pauwels, J. Hostens, P. Bruyndonckx, A. Sasov & F. Pfeiffer

Scientific Reports **3**, Article number: 3209 | doi:10.1038/srep03209

Received 04 June 2013 | Accepted 29 October 2013 | Published 13 November 2013



(a) Conventional x-ray image based on attenuation. (b) Differential phase-contrast image based on x-ray refraction. (c) Dark-field image based on x-ray scattering. All three images are intrinsically perfectly registered as they are extracted from the same data recorded with a grating interferometer. Examples of regions of enhanced contrast are marked with arrows, showing the refraction of the trachea (b) and the scattering of the lungs (c). The white bars correspond to 1 cm.

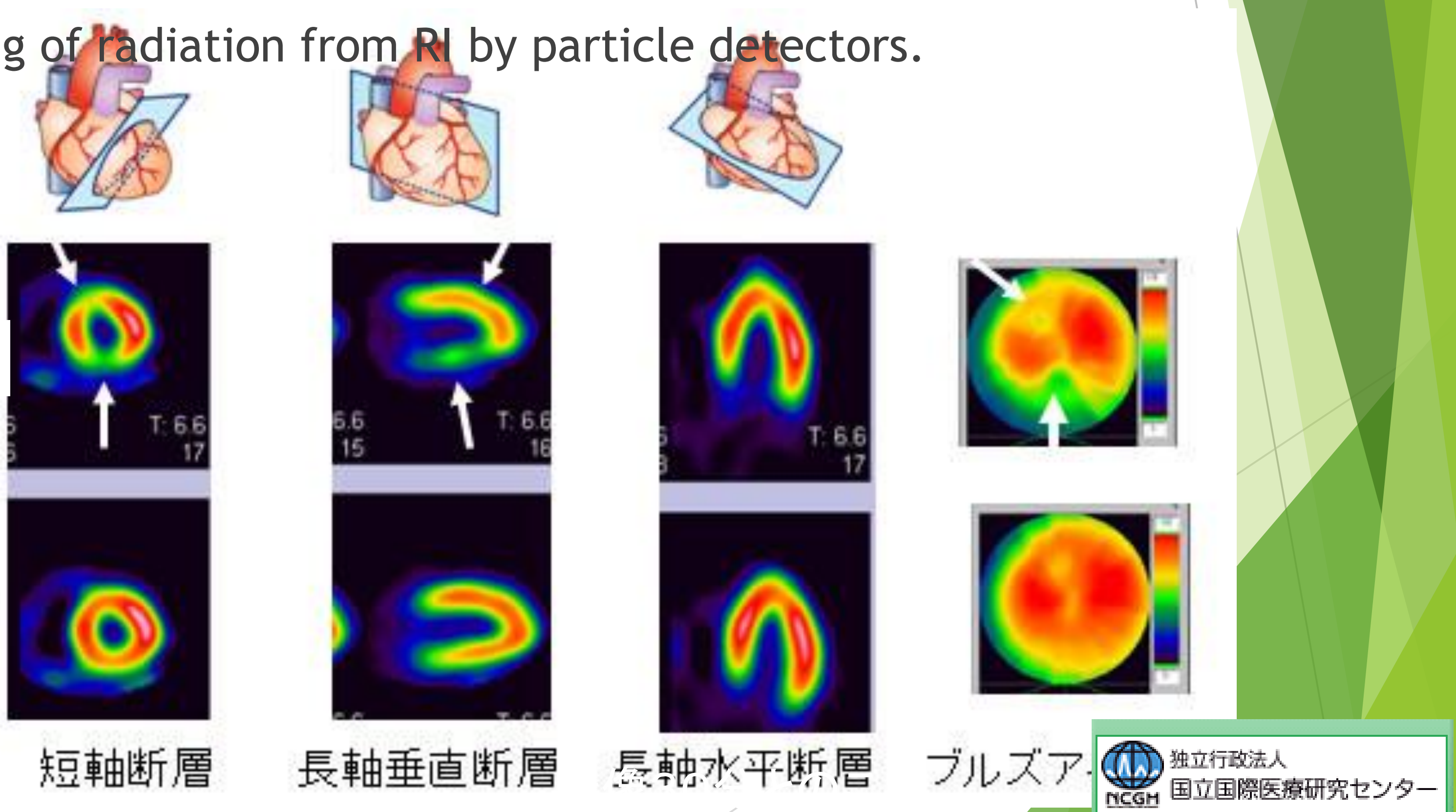
Gamma Ray

Scintigraphy

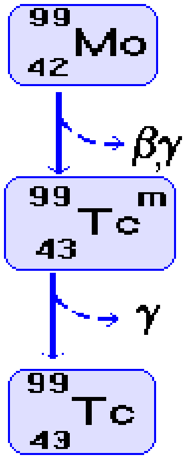
- Blood flow can be observed externally by radio isotope (RI) labelling.
- Imaging of radiation from RI by particle detectors.

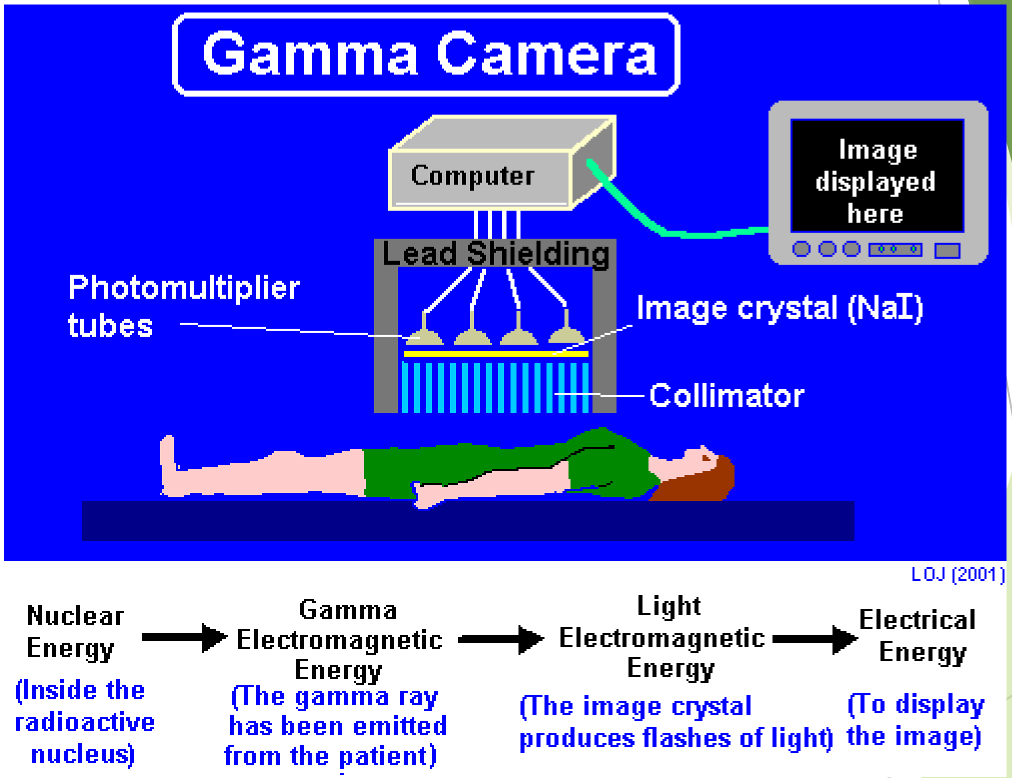
After exercise

At rest



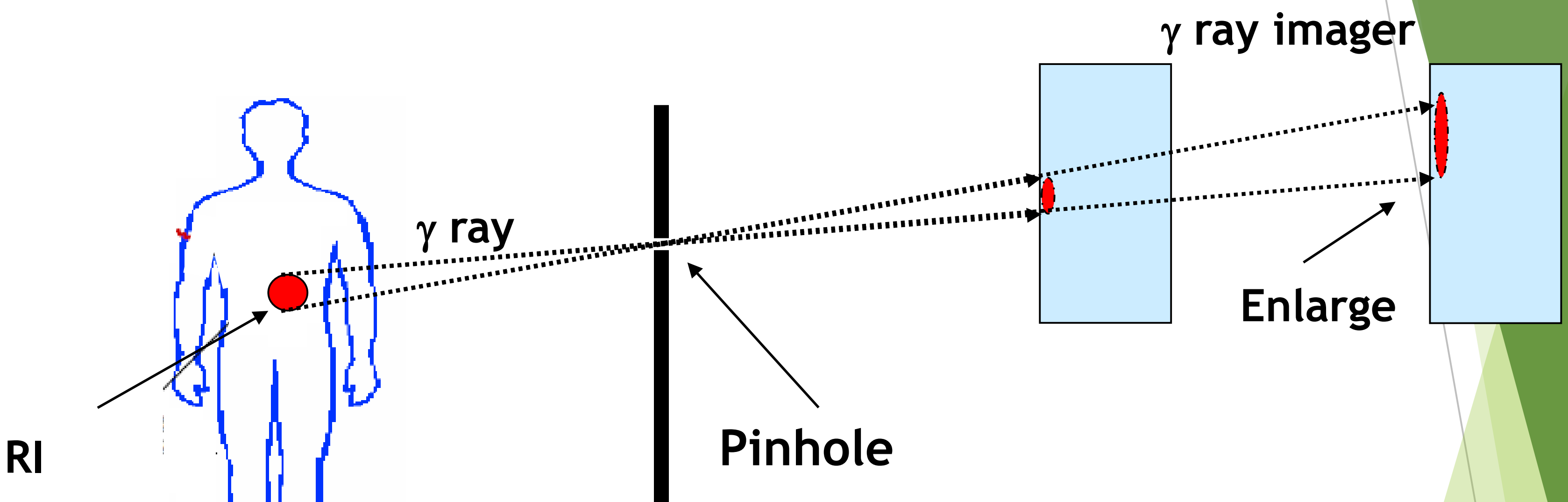
Standard Gamma "camera"

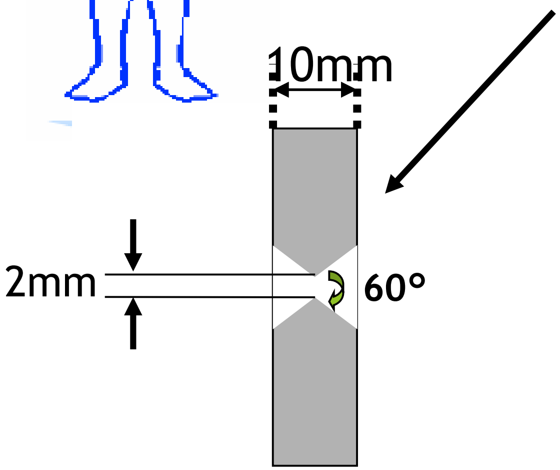


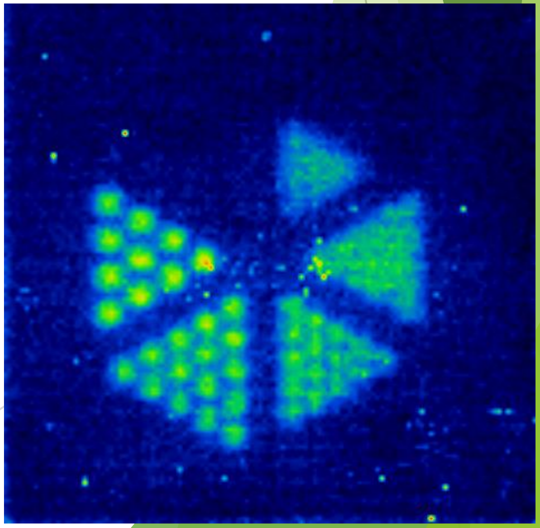


- Not very efficient. Most of gamma rays are absorbed in collimators.

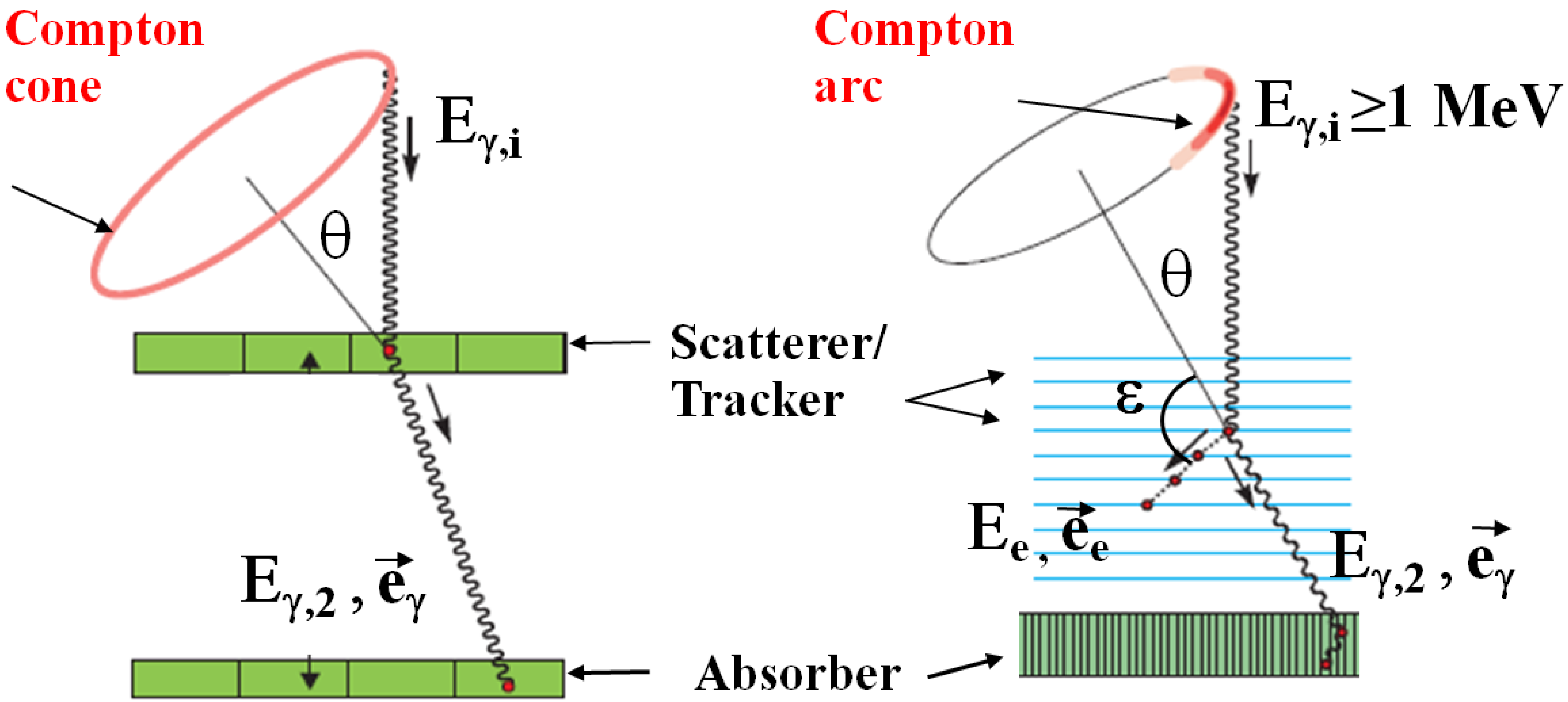
Gamma Pin hole camera



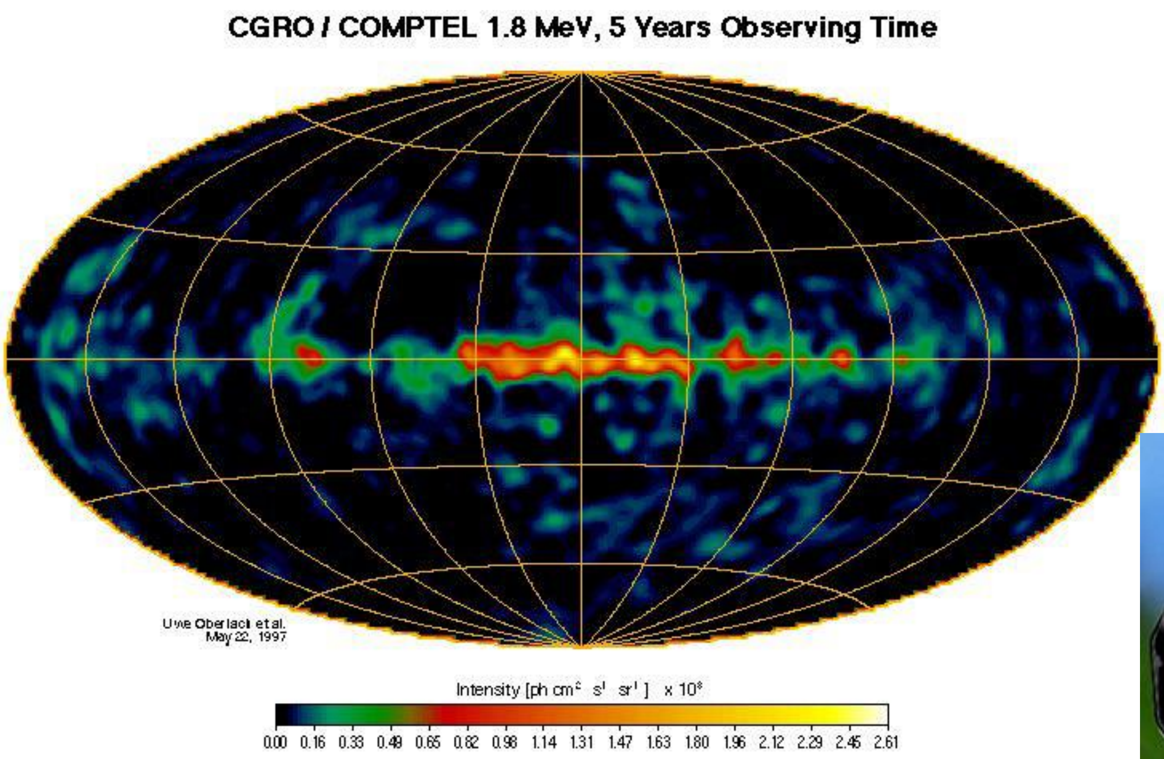




Further attempt: Compton camera



Application of Gamma camera developed for Gamma ray astronomy to Fukushima NP restoration

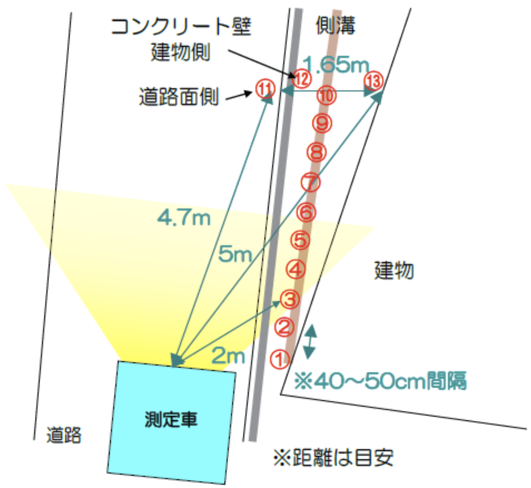


平成24年11月15日
宇宙航空研究開発機構
三菱重工業株式会社
国立大学法人 名古屋大学
独立行政法人 科学技術振興機構

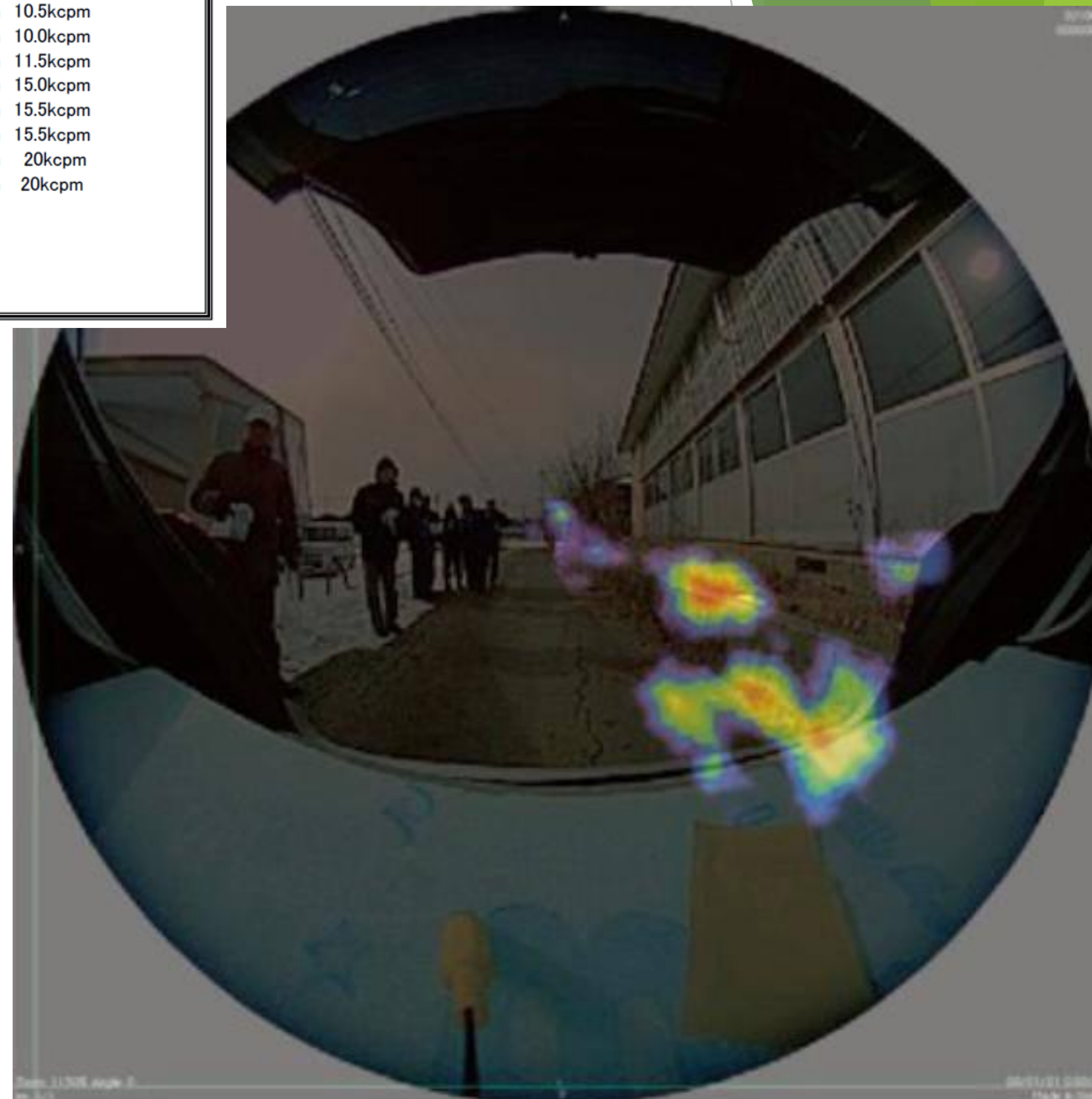
①飯館村公民館近くのスーパー裏手

放射線測定結果

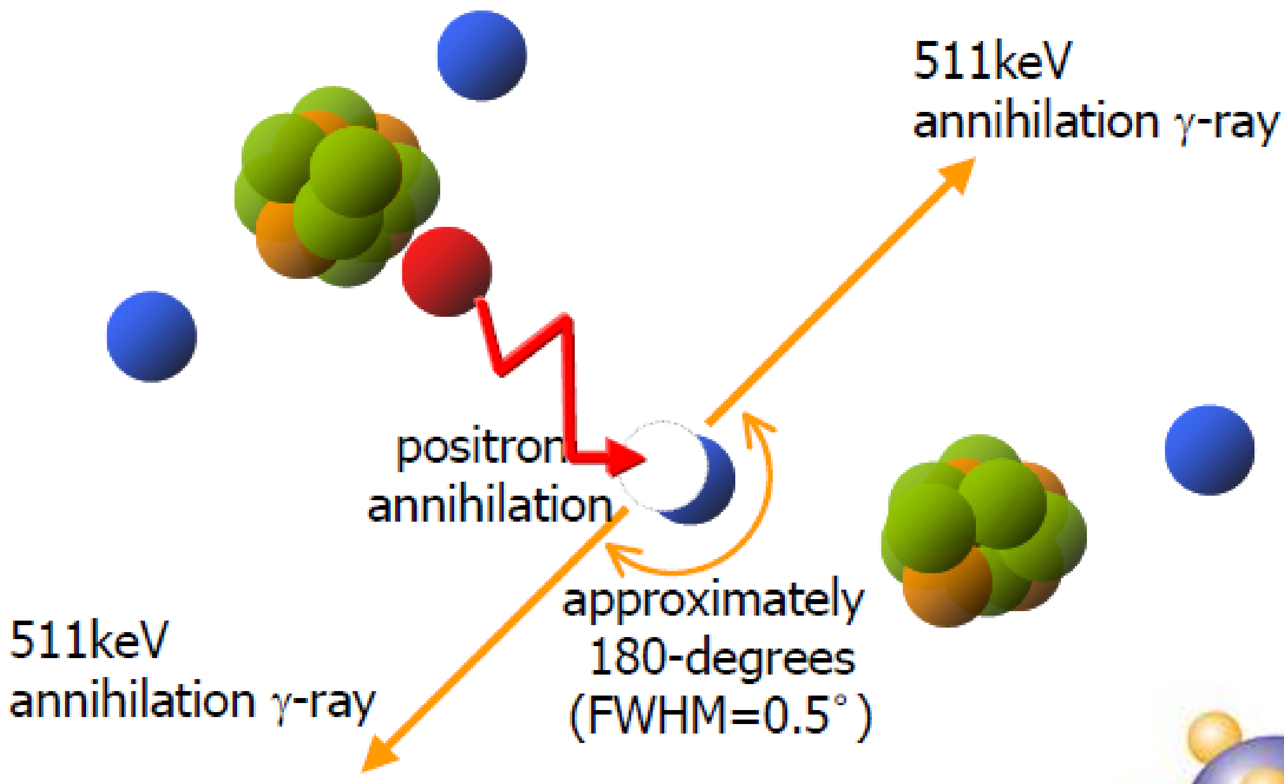
使用測定機器：電離箱（ICS-323C）、GM 管（TGS-133）、 環境バックグラウンド：～3 μSv/h、 測定高さ：地表上1cm

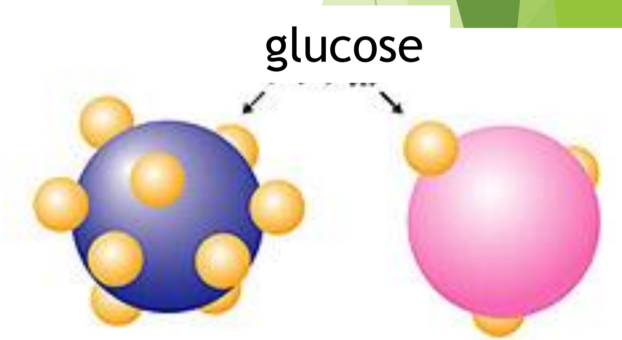


⑬	6.8 μSv/h	3.5kcpm
⑫	5.3 μSv/h	3.2kcpm
⑪	4.5 μSv/h	4.3kcpm
⑩	25.3 μSv/h	12.5kcpm
⑨	10.3 μSv/h	9.0kcpm
⑧	19.6 μSv/h	10.5kcpm
⑦	21.2 μSv/h	10.0kcpm
⑥	21.1 μSv/h	11.5kcpm
⑤	30.2 μSv/h	15.0kcpm
④	26.4 μSv/h	15.5kcpm
③	31.0 μSv/h	15.5kcpm
②	31.1 μSv/h	20kcpm
①	28.0 μSv/h	20kcpm

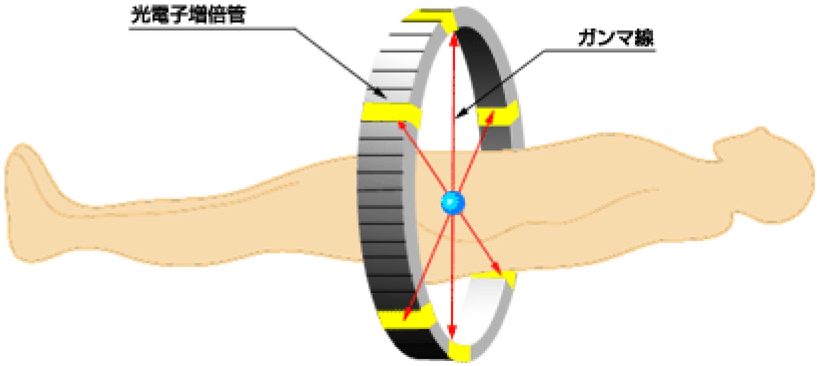


Very useful for medical application
P E T (Positron Emission Tomography)

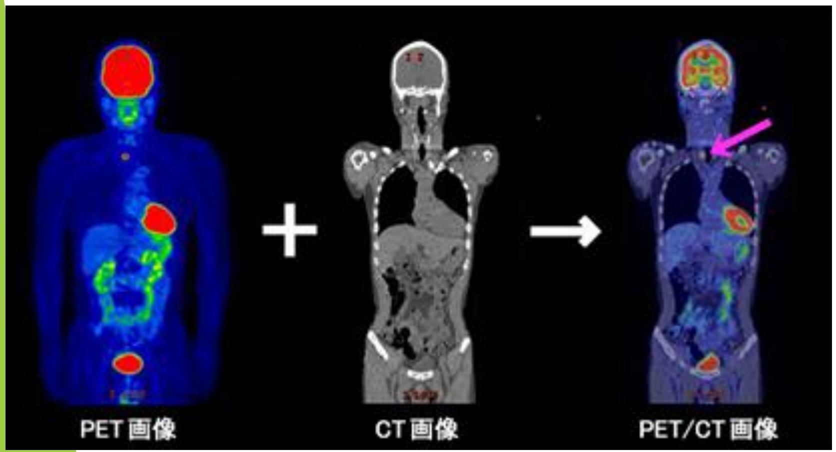


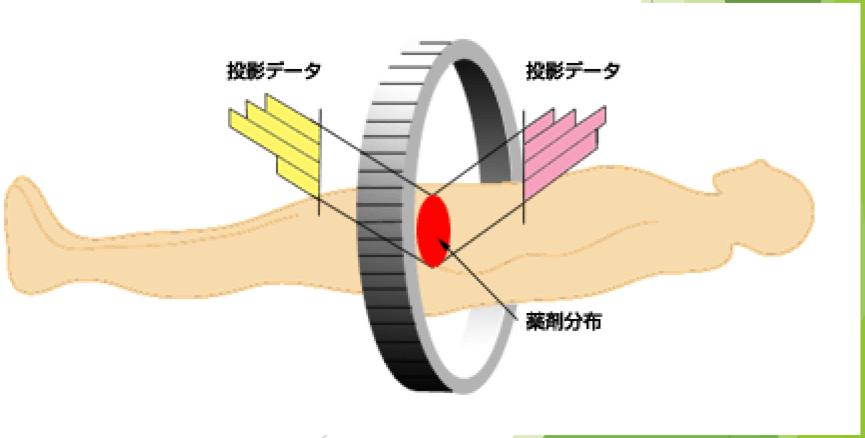


Just like a barrel calorimeter of collider detectors



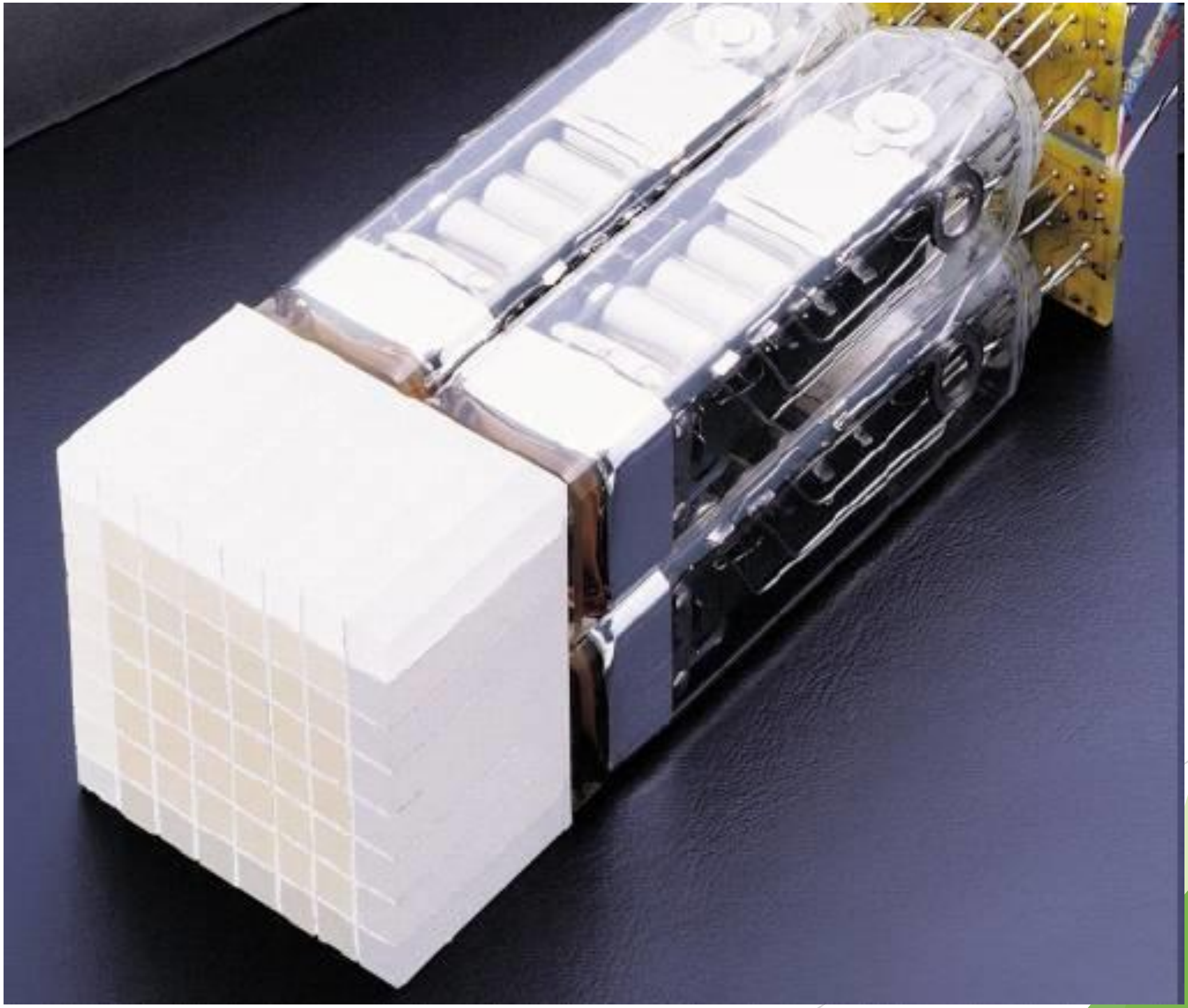
From the photo gallery cmsinfo.cern.ch





Higher resolution/efficiency can make exposure dose less.

PET γ detector module



Neutron

Imaging with neutron beam

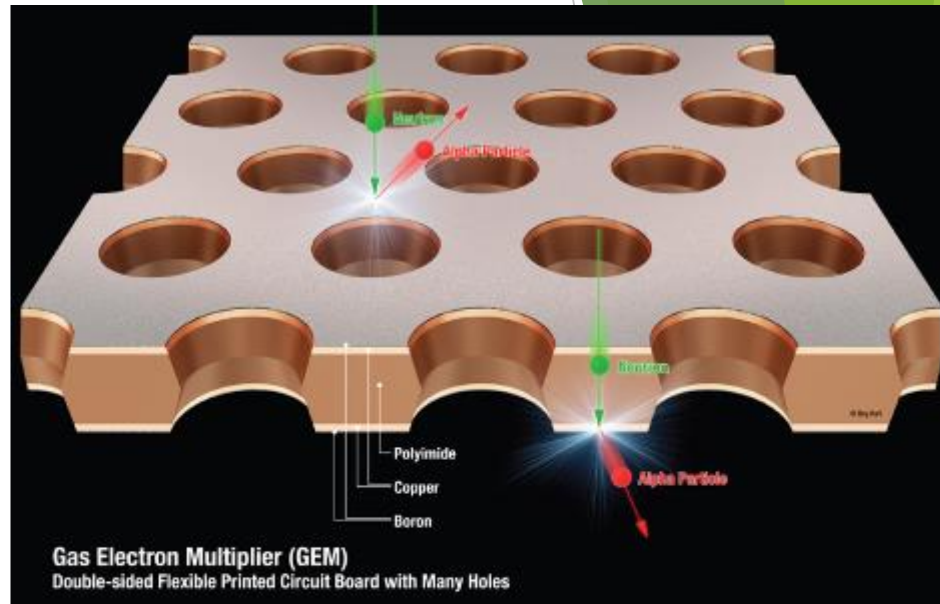
Left: X-ray image
Right: Neutron imaging. Organic material buried inside , invisible with X-ray, can be visualized by neutron.

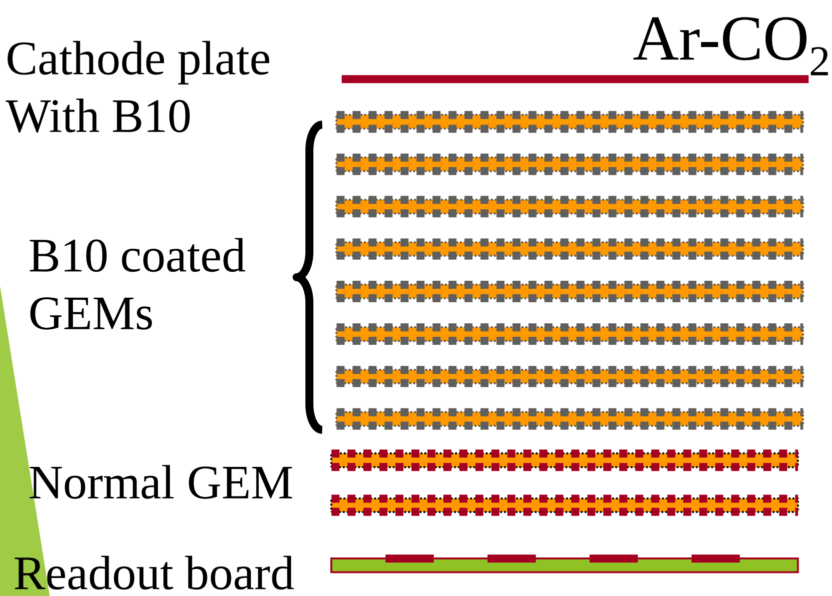
(photo: example of Sakyamuni, Bhumisparsa Mudra, West-tibet, 14.- 15. century).

Application to Neutron Detector

$^{10}B + n \rightarrow {}^{7}Li + \alpha + 2.792\ MeV \quad 3840\ b$

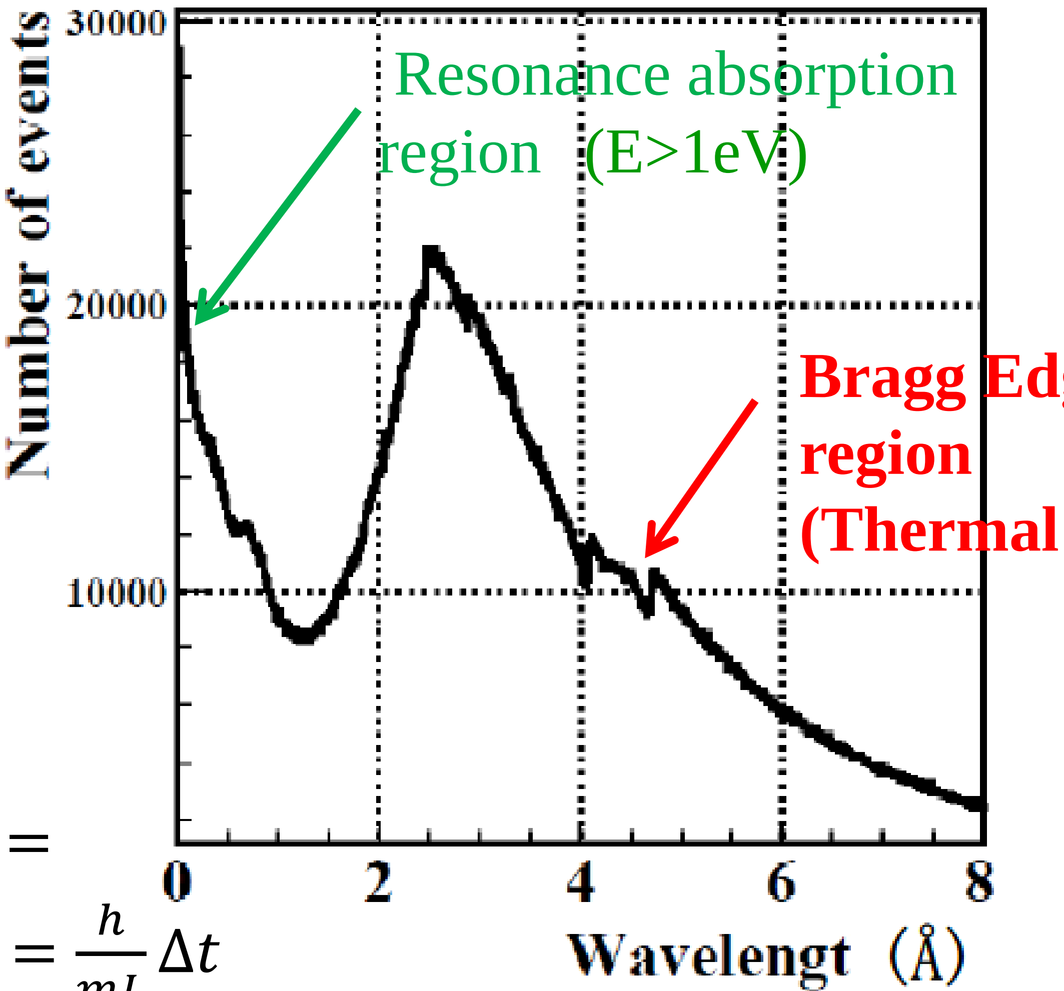
$^{7}Li^{*} + \alpha + 2.310\ MeV$





- Expensive ^{3}He Gas is not necessary.
  - No pressure vessel
- Free readout pattern
- High resolution
  - Position and **Time**
- Insensitive against g-ray
- Capability against high counting rate

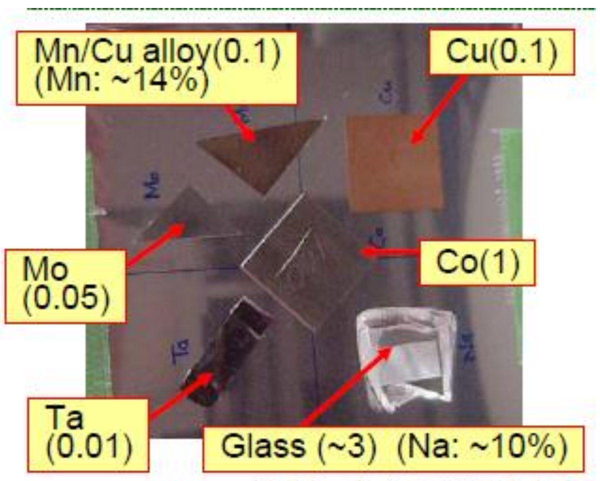
Pulse neutron and Energy Selective Neutron Radiography

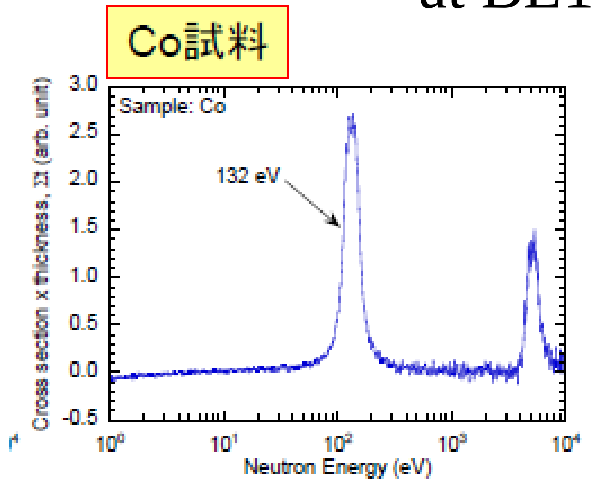


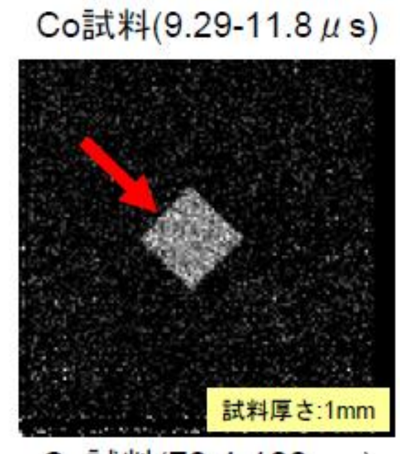
$$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{2mE}} = \frac{h}{mL}\Delta t$$

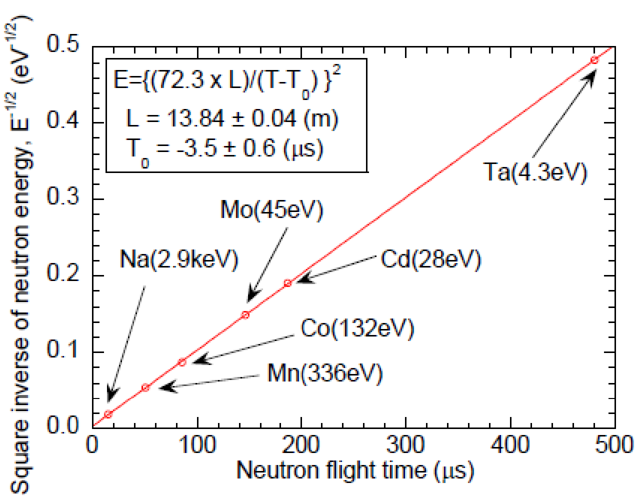
Resonance absorption imaging

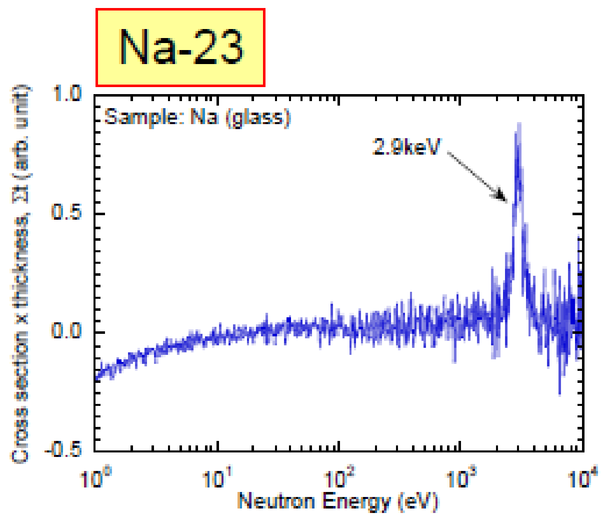
By T. Kai (JAEA) et al.
at BL10 in J-PARC

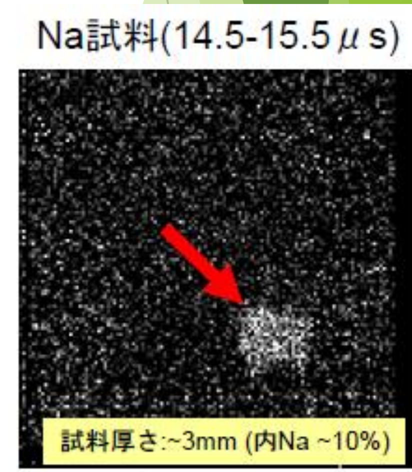












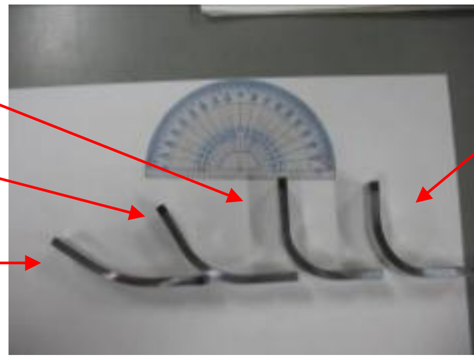
Imaging for bended iron plates at LINAC in Hokkaido University

Sample

90° Bend

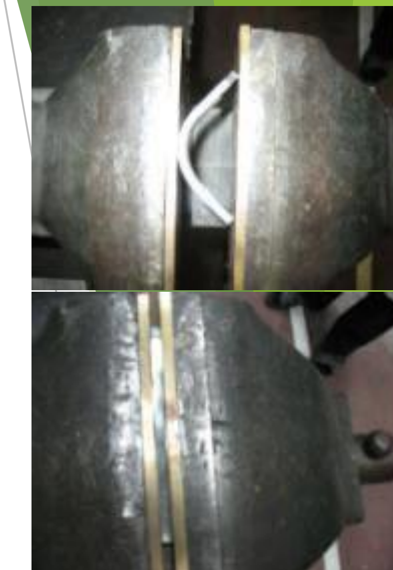
60° Bend

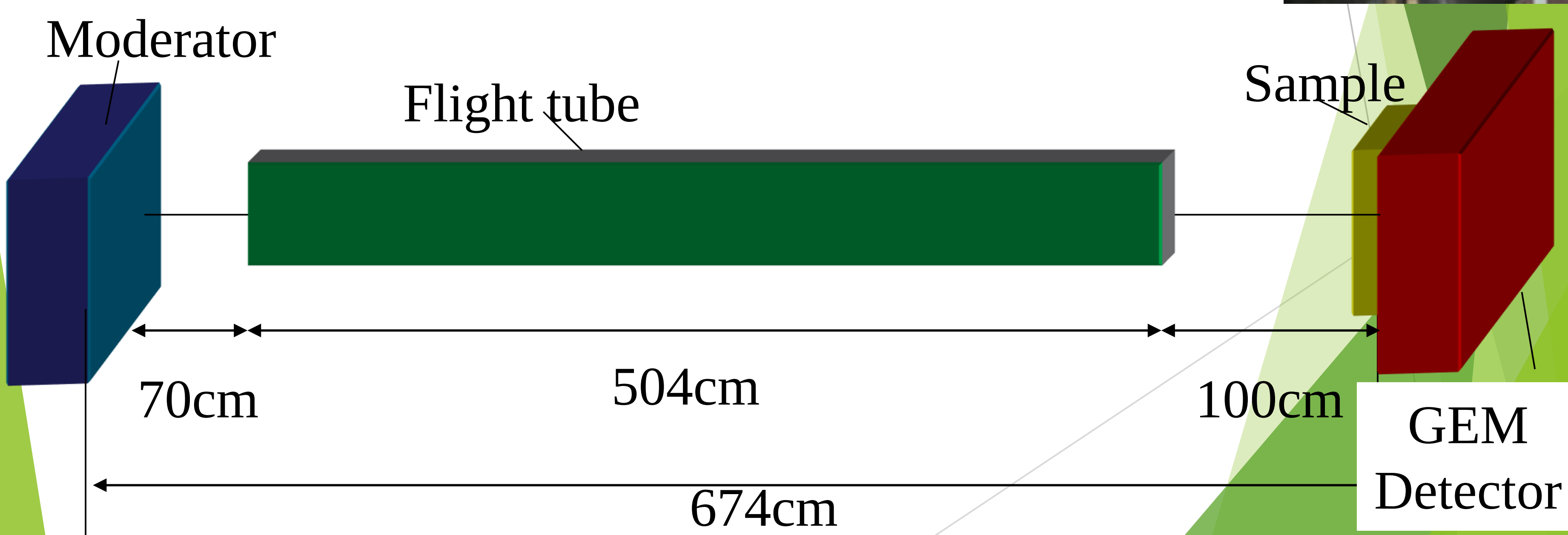
30° Bend



90° Bending and Re-flattening

+Reference (without bending)





Results

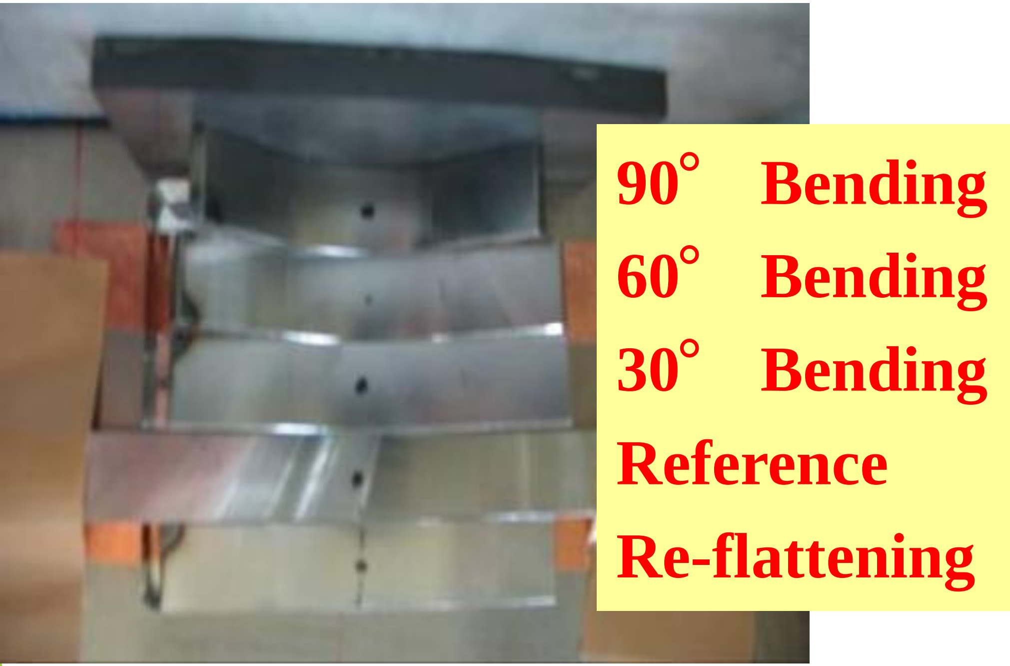
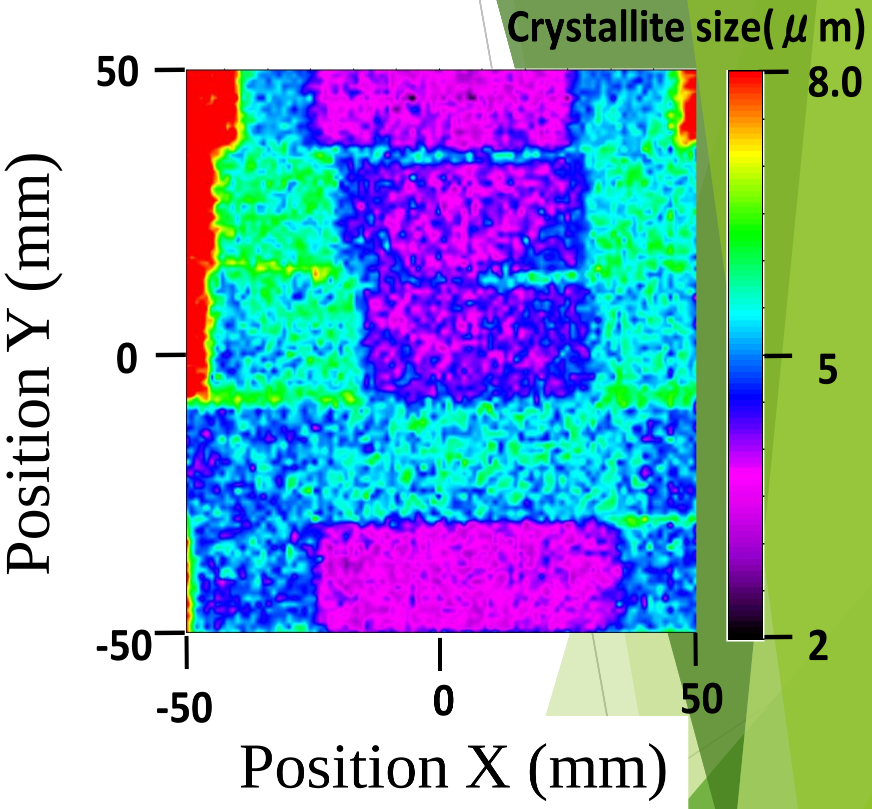


Photo of iron plates

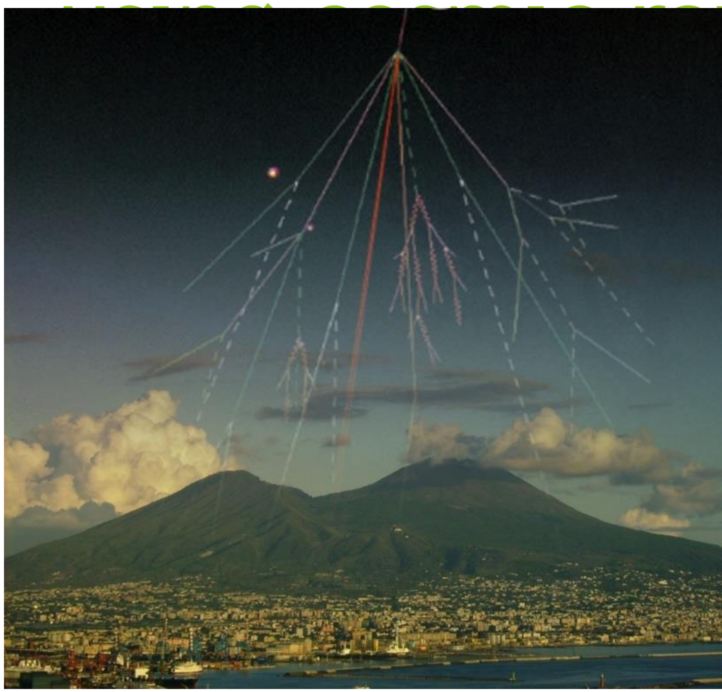


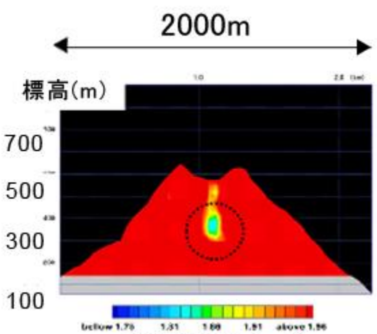
Two dimensional imaging of crystallite size in the bended iron plates can be done clearly.

Visualization of microstructure for heavy material can be performed with the gaseous neutron detector.

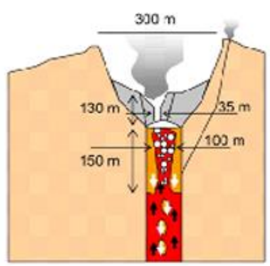
Others

See through mega structure using cosmic ray

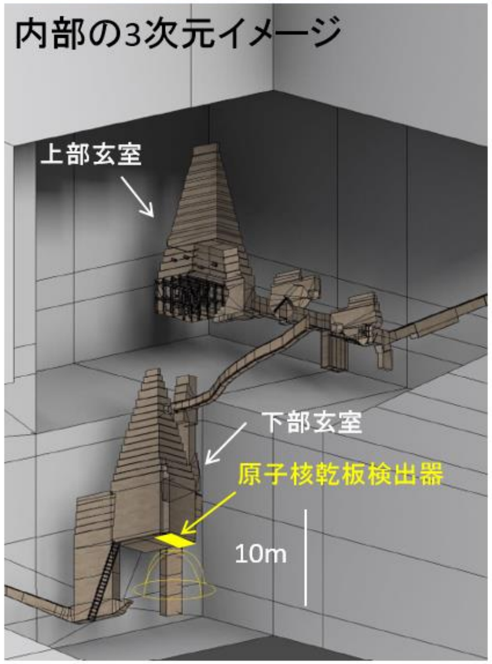


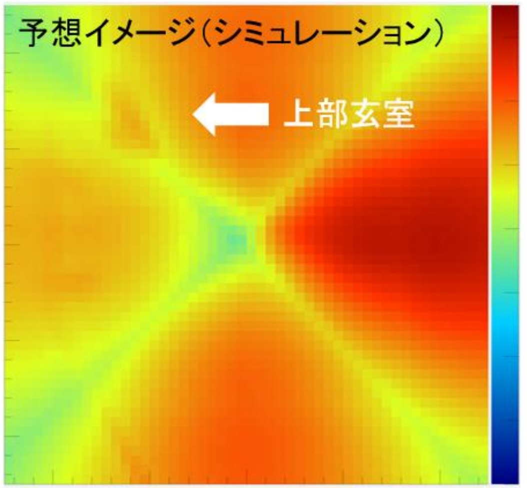


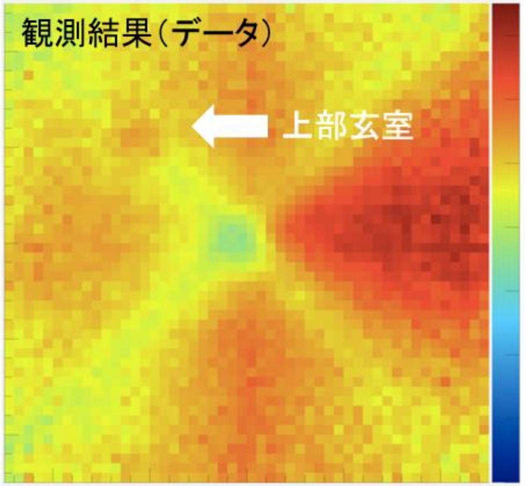
火口下300mに、ガスの発砲による低密度マグマが見える。



Tanaka et al. (2008) GRL





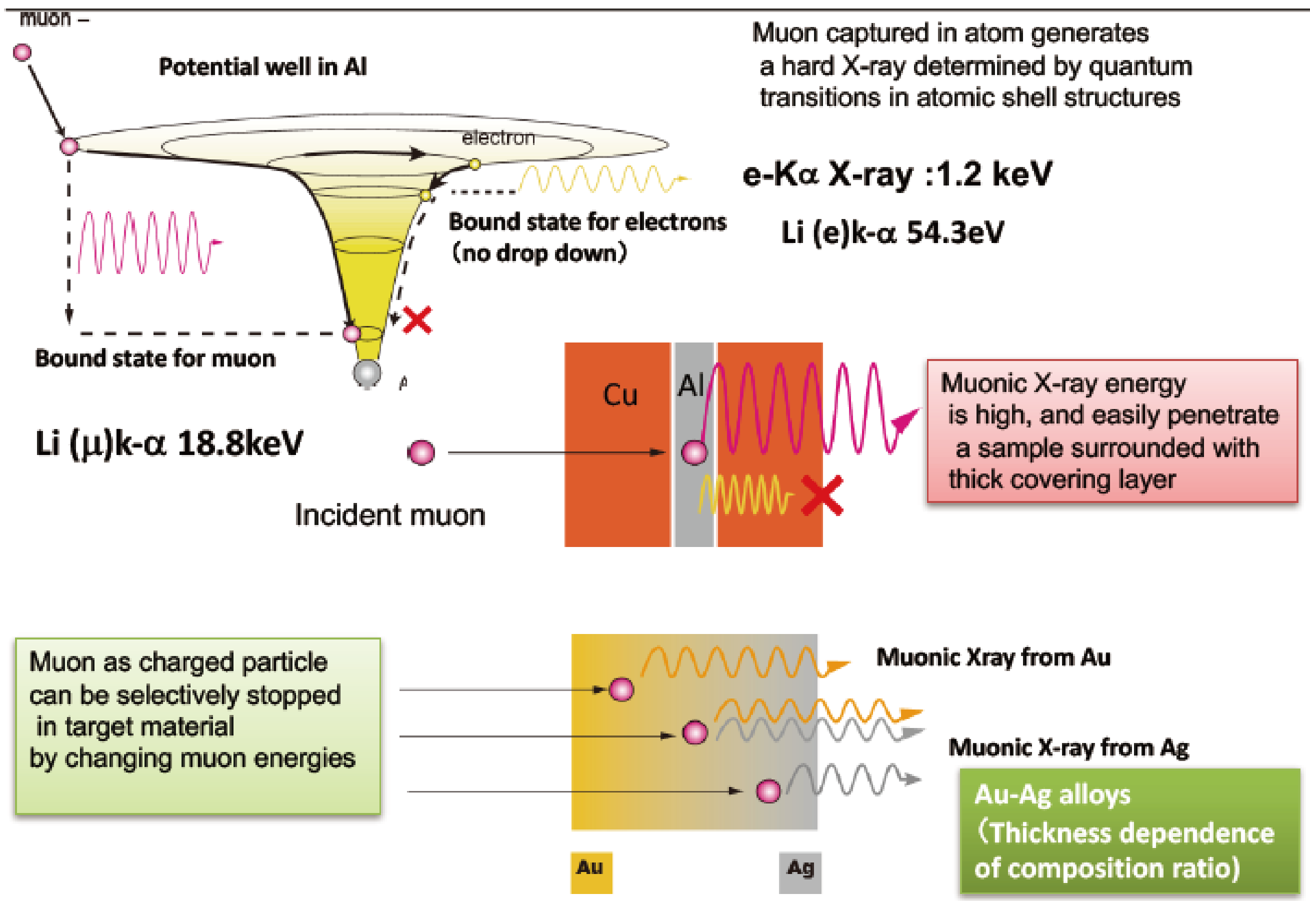


K.Morishima (Nagoya U.)

東大地震研HPより

Low energy negative muon can probe inside material

Muonic X-ray is unique and strong probe beam in non destructive elemental analysis



3D imaging of material composition

Summary

- Huge detector system for HEP is very important tool to investigate Law of Nature together with a large accelerators.
- The system is a complex of advanced radiation measurement devices.
- Those “advanced” system enables very quick diagnose with higher precision using much less radiation dose. They are also very useful to visualize the hidden structure /defect /dangerous substance inside material clearly.
- The advanced detector technology originally developed for particle physics are now being applied to innovate the instrumentations in society like medical or industrial equipment. Higher resolution, higher sensitivity and lower dose exposure for human is expected.

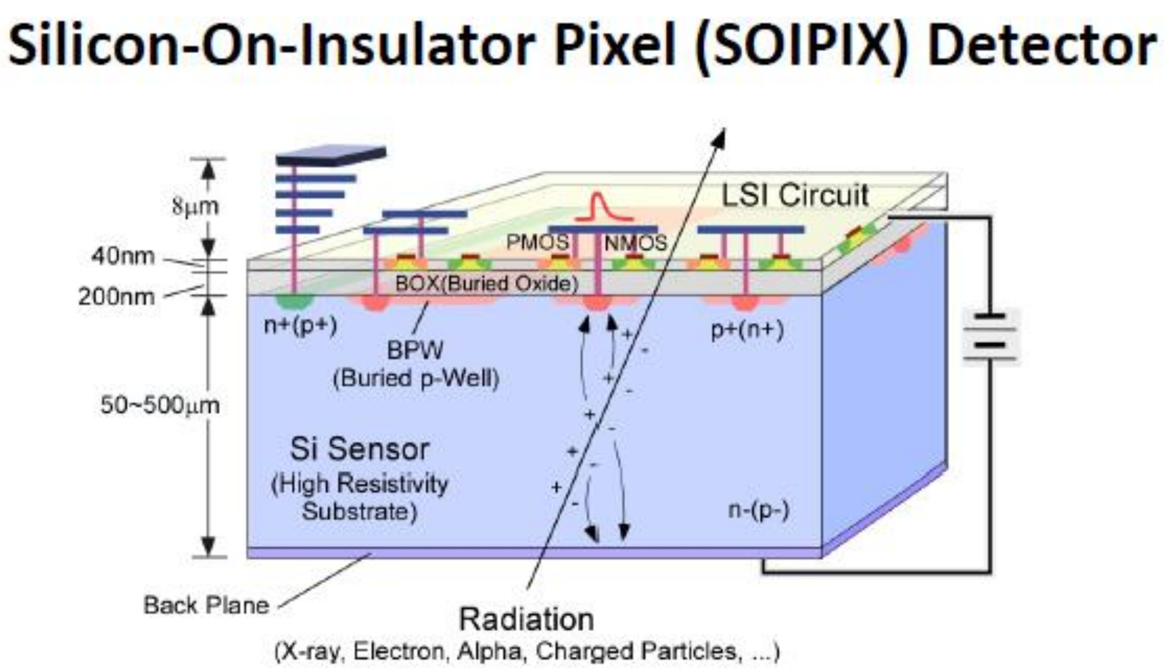
What is the next generation tracking system?

- One of the question raised in the discussion sessions.
- My answer is that it should be
  - Better precison in position resolution
  - Thinner
  - Higher functionality (good timing and/or dE/dx information, local tracking, trigger, …)
  - Better timing resolution
  - dE/dX information hopefully
  - Tolerance for higher particle flux

One of promising candidates: Monolithic pixel sensor using SOI

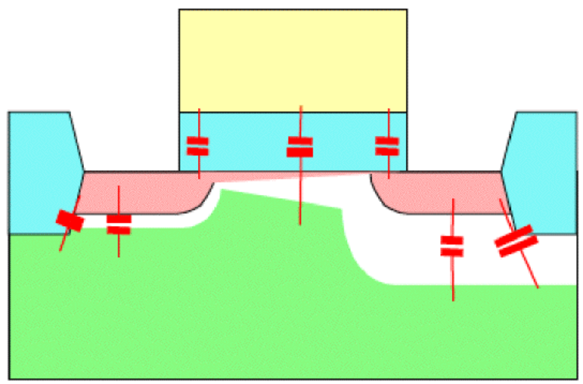
My very personal view

- Monolithic pixel sensor
  - Silicon sensor with read out CMOS electronics on chip
- SOI: Silicon-On-Insulator

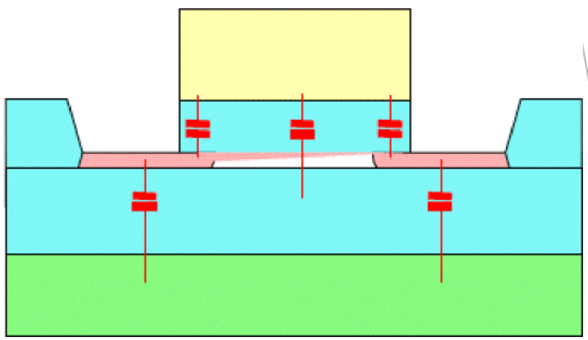


SOI Performance : Smaller Junction Capacitance

Bulk



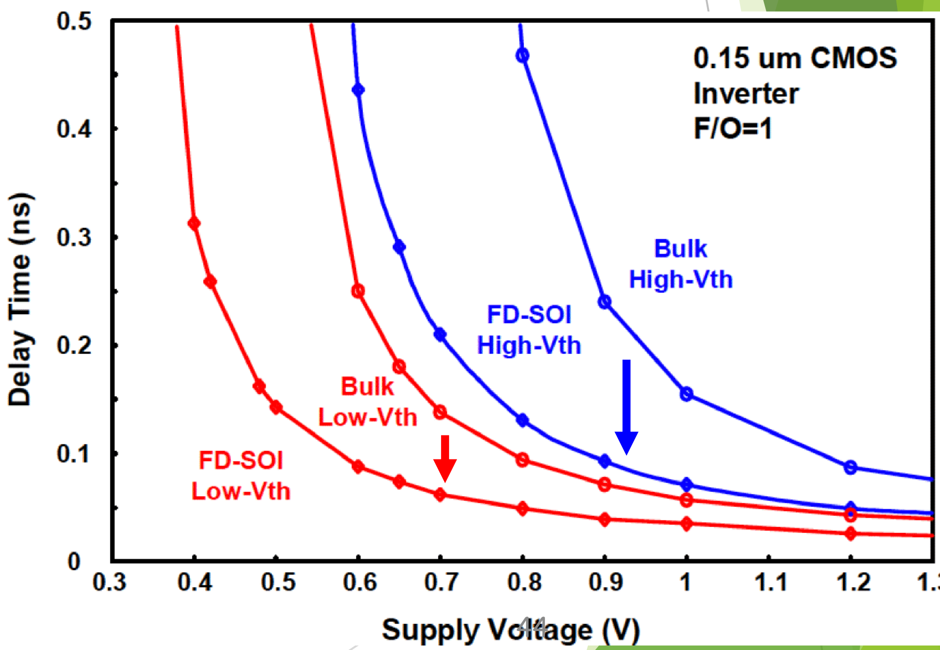
SOI



Cj is 1/10 of Bulk technology.

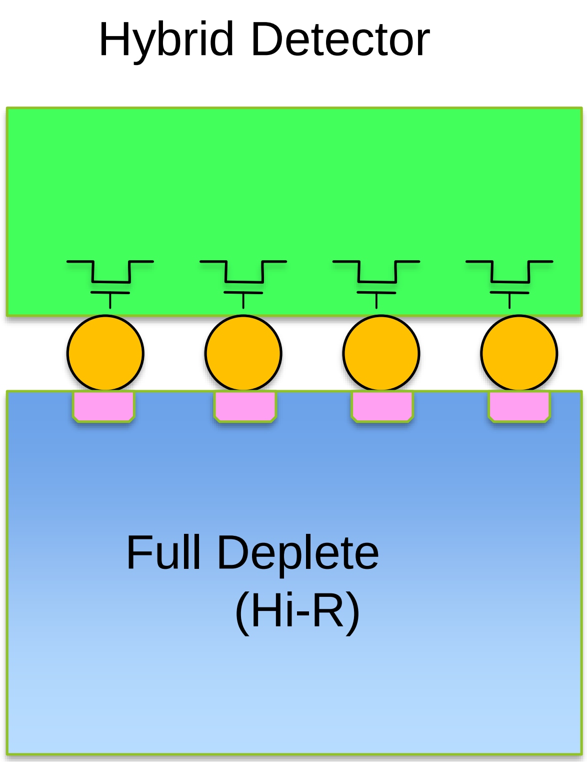
Gate Capacitance is 30-40% Lower.

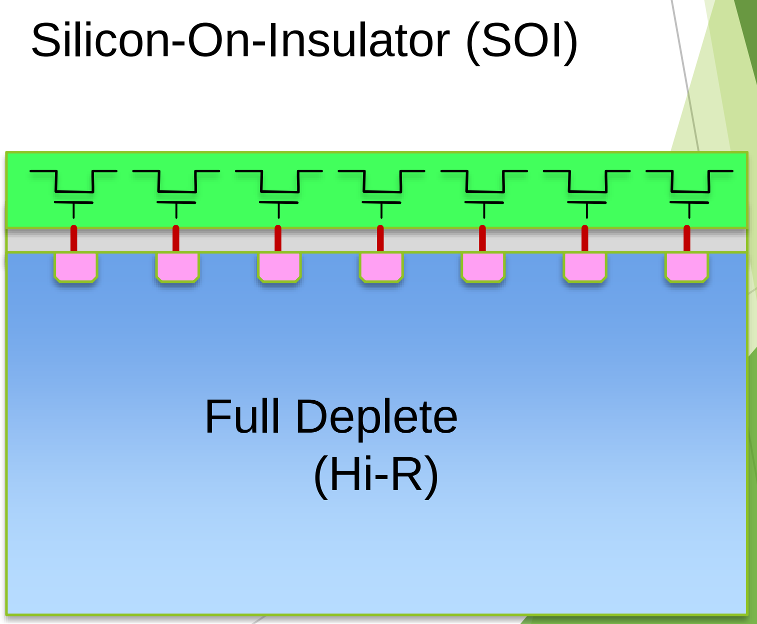
High Speed / Low Power



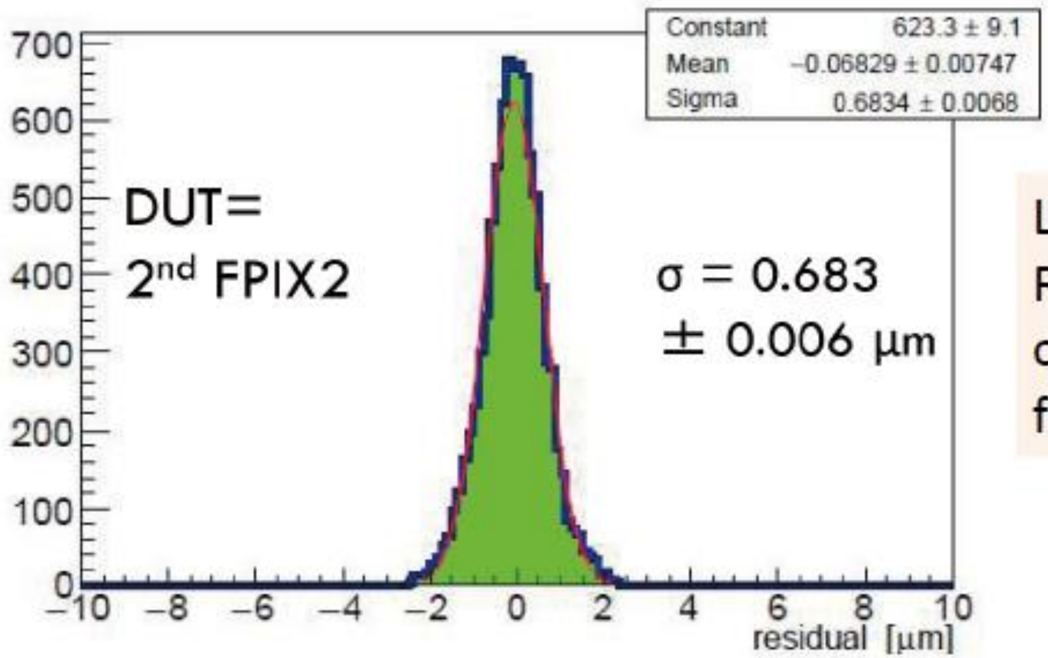
Thinner than Hybrid pixel applied in the LHC experiment

- No bump bonding at all





Tracking Resolution (cont.)

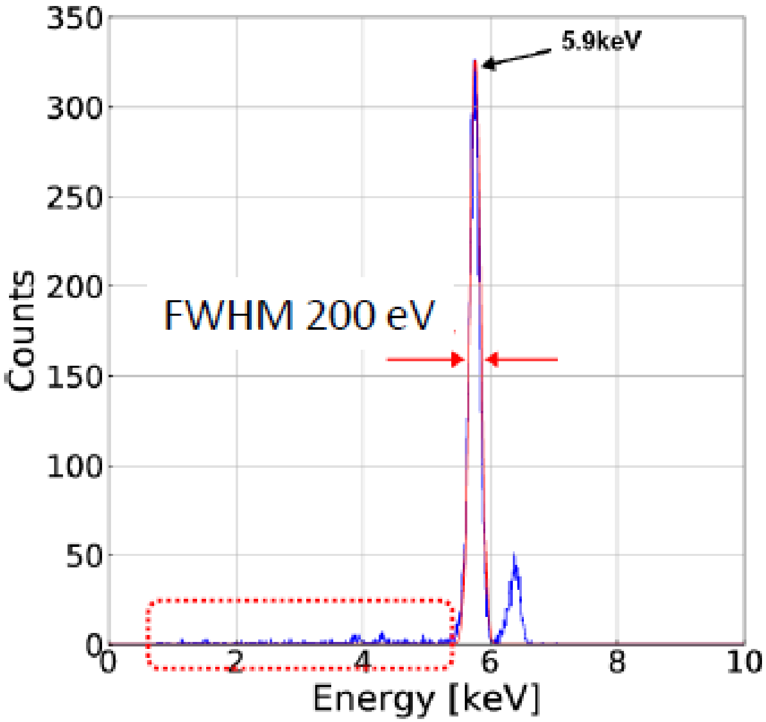


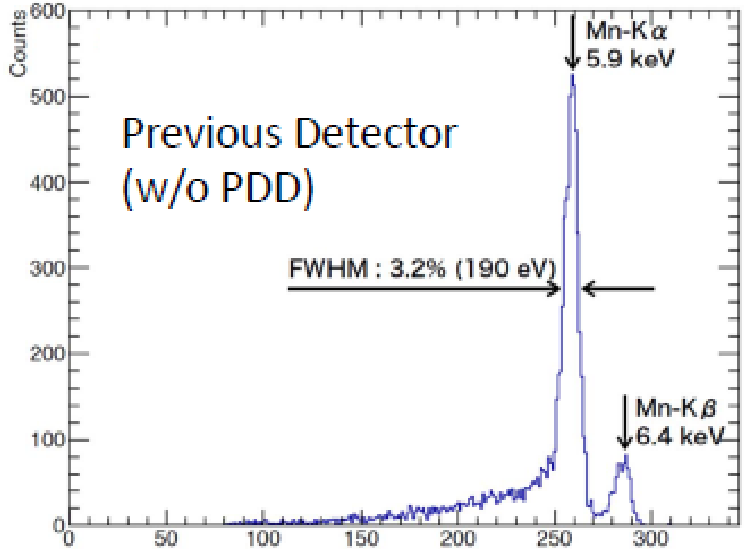
Pix size 8um
No bump bonding

Less than 1 μm Position Resolution for high-energy charged particle is achieved first in the world .

(K. Hara et al., Development of Silicon-on-Insulator Pixel Detectors, Proceedings of Science, to be published) **Springer Proc.Phys. 213 (2018) 331-338**

Energy Resolution: X-ray Spectrum of ^{55}Fe using the SOIPIX-PDD





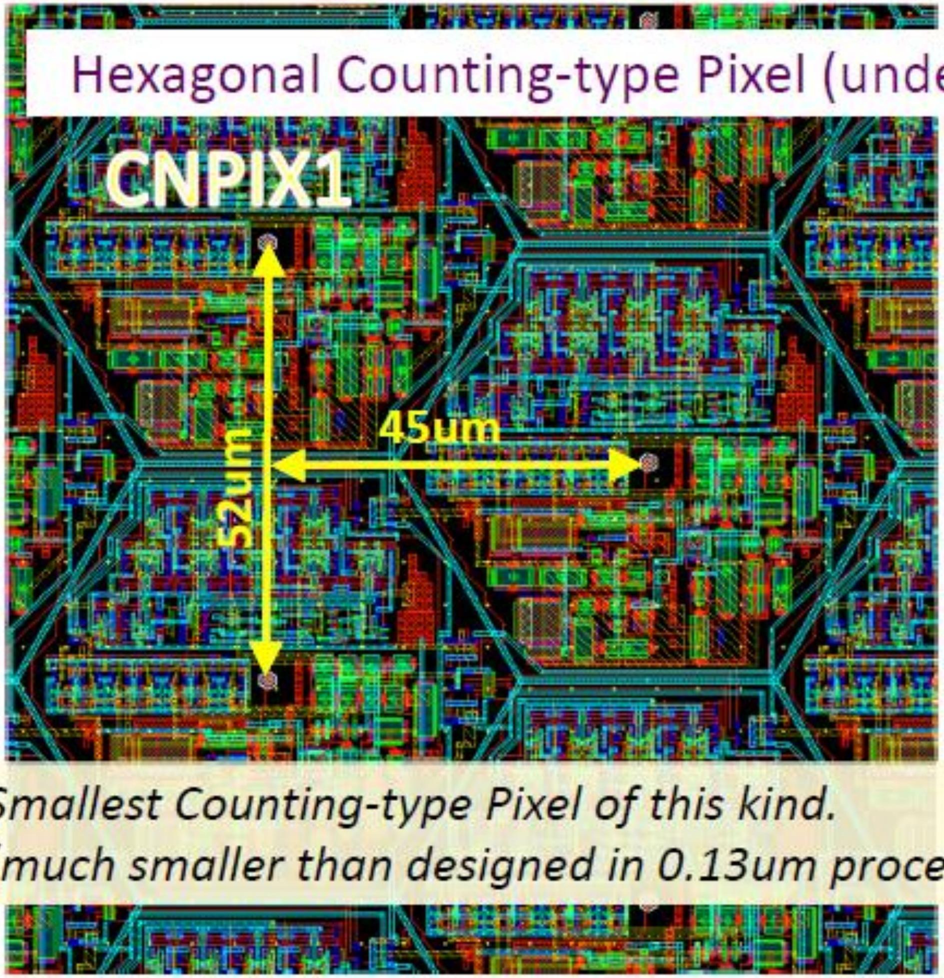
Gain = 70 μV/e-
Noise = 11.0 e-
Dark Current = 56 pA/cm2 @-35˚C

Very good Resolution (low noise) and no tail in the peak (showing perfect charge collection efficiency).

(Shizuoka & Kyoto Univ.)

High functionality On-Chip

Hexagonal Counting-type Pixel (under development)



Smallest Counting-type Pixel of this kind.
(much smaller than designed in 0.13um process)

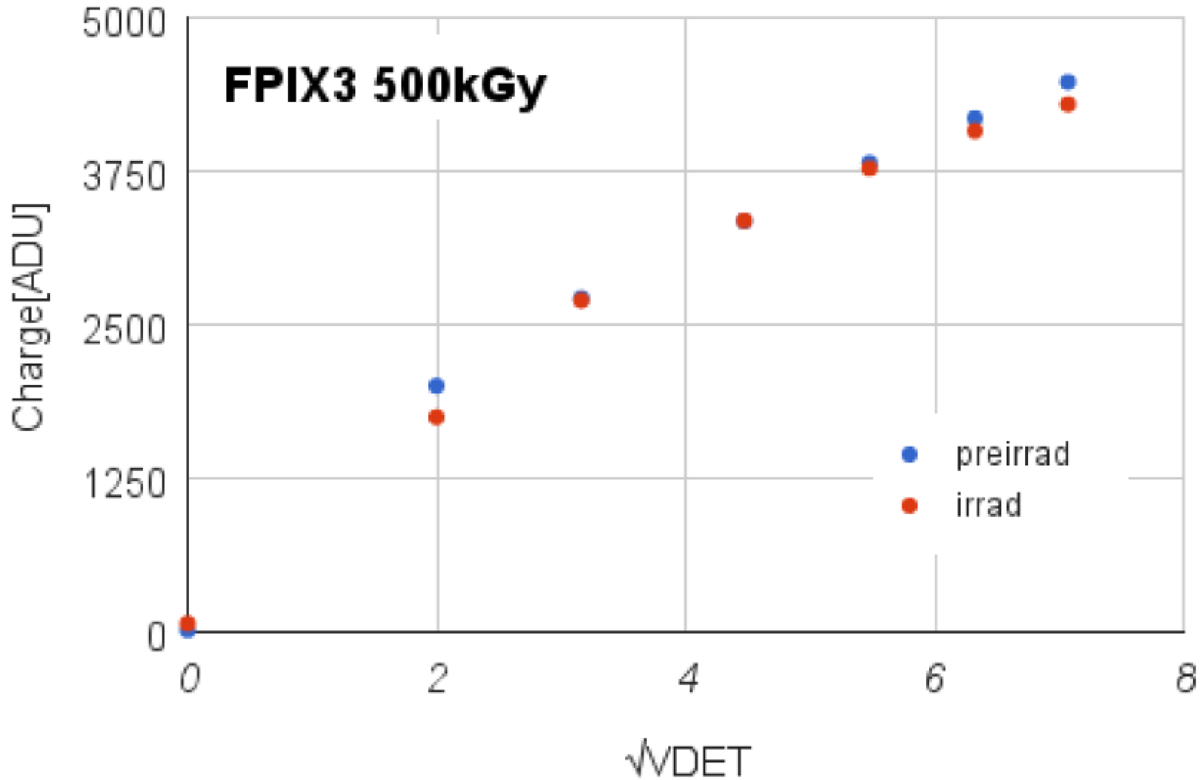
Charge Amp
+
Shaper
+
Discriminator
+
Q Share Handling
+
19bit Counter
+
7bit register

(in 2,340 um^2)

(With IHEP China)

Not very high radiation tolerant so far

It will survive in e+e- collider like SUperKEKB, ILC



Thank you for your attention (and patience).
It has really been a nice experience for me to meet and discuss you all at Quy Nhon.

Please do not hesitate to contact with me
junji.haba@keke.jp if you have any question later.