GEM-based polarimeter detector development for storage ring EDM experiment

Seongtae Park

Center for Axion and Precision Physics(CAPP)
of Institute for Basic Science (IBS), South Korea

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Outline

1. Introduction to storage ring EDM search
2. Polarimeter for EDM search
3. CAPP GEM detector development
4. COSY beam test results
5. Summary and plans

About IBS/CAPP

- Center for Axion and Precision Physics Research (CAPP) at Institute for Basic Science (IBS) (Director: Yannis Semertzidis)
- Web site: http://capp.ibs.re.kr/html/capp_en/
- Located at KAIST Munji campus in Daejeon, South Korea

We are working on:

- **Axion-dark matter search**
  - Cavities, Cryogenics, Electronics, Super conducting magnet, SQUID, etc.
  - ARIADNE, GNOME
- **Storage ring Proton/Deuteron/electron EDM**
  - Polarimeter, Beam position monitoring (with magnetic shielding), Beam dynamics, etc.
- **Axion-coupled oscillating EDM search using storage ring method**
- **Muon g-2 experiment**
  - System design, Systematics
- **Others (COMET, etc)**

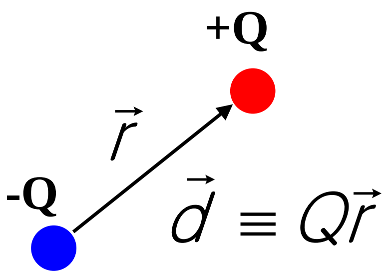
Introduction to EDM

❖Motivation

- ✓Strong CP problem, Θ_{QCD}
- ✓Matter-antimatter asymmetry (Baryogenesis)

➢ P, T violation due to an EDM

Electric Dipole Moment



$$H = -\mu\vec{\sigma}\cdot\vec{B} - d\vec{\sigma}\cdot\vec{E}$$

$$T(\vec{B},\vec{\sigma}\ sign\ change): H = -\mu\vec{\sigma}\cdot\vec{B} + d\vec{\sigma}\cdot\vec{E}$$

$$P(\vec{E}\ sign\ change): H = -\mu\vec{\sigma}\cdot\vec{B} + d\vec{\sigma}\cdot\vec{E}$$

$$\mu = g\frac{q}{2m}, d = \eta\frac{q}{2mc}$$

A nonzero particle EDM violates P, T, and assuming CPT conservation, also CP violation.

The first direct measurement of EDM in neutron and it's sensitivity improvement

PHYSICAL REVIEW VOLUME 108, NUMBER 1 OCTOBER 1, 1957

Experimental Limit to the Electric Dipole Moment of the Neutron

J. H. Smith,* E. M. Purcell, and N. F. Ramsey
Oak Ridge National Laboratory, Oak Ridge, Tennessee, and Harvard University, Cambridge, Massachusetts
(Received May 17, 1957)

1957

An experimental measurement of the electric dipole moment of the neutron by a neutron-beam magnetic resonance method is described. The result of the experiment is that the electric dipole moment of the neutron equals the charge of the electron multiplied by a distance $D=(-0.1\pm2.4)\times10^{-20}$ cm. Consequently, if an electric dipole moment of the neutron exists and is associated with the spin angular momentum, its magnitude almost certainly corresponds to a value of D less than 5×10^{-20} cm.

PRL **97,** 131801 (2006) PHYSICAL REVIEW LETTERS week ending 29 SEPTEMBER 2006

Improved Experimental Limit on the Electric Dipole Moment of the Neutron

C. A. Baker,[1] D. D. Doyle,[2] P. Geltenbort,[3] K. Green,[1,2] M. G. D. van der Grinten,[1,2] P. G. Harris,[2] P. Iaydjiev,[1,*] S. N. Ivanov,[1,†] D. J. R. May,[2] J. M. Pendlebury,[2] J. D. Richardson,[2] D. Shiers,[2] and K. F. Smith[2]
[1]*Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 0QX, United Kingdom*
[2]*Department of Physics and Astronomy, University of Sussex, Falmer, Brighton BN1 9QH, United Kingdom*
[3]*Institut Laue-Langevin, BP 156, F-38042 Grenoble Cedex 9, France*
(Received 9 February 2006; revised manuscript received 29 March 2006; published 27 September 2006)

2006

An experimental search for an electric dipole moment (EDM) of the neutron has been carried out at the Institut Laue-Langevin, Grenoble. Spurious signals from magnetic-field fluctuations were reduced to insignificance by the use of a cohabiting atomic-mercury magnetometer. Systematic uncertainties, including geometric-phase-induced false EDMs, have been carefully studied. The results may be interpreted as an upper limit on the neutron EDM of $|d_n| < 2.9\times10^{-26}e$ cm (90% C.L.).

DOI: 10.1103/PhysRevLett.97.131801 PACS numbers: 13.40.Em, 07.55.Ge, 11.30.Er, 14.20.Dh

Current EDM bounds and plan

- Current EDM bounds
  - SM predicts non-vanishing EDM
    - $|d_e| < 10^{-38}$ e.cm
    - $|d_{n,p}| < 10^{-31}$ e.cm
    - Beyond current experiment limit
  - SUSY prediction: 10^{-25}~10^{-28} e·cm (nEDM limit)
  - Neutron EDM bound: $|d_n|<2.9\text{x}10^{-26}$ e.cm ('06, ultracold neutrons)
  - Proton EDM bound: $|d_p| <7.9\text{x}10^{-25}$ e.cm ('09, ^{199}Hg)
  - Electron EDM bound: $|d_e| <8.7\text{x}10^{-29}$ e. cm ('14, ThO)
- Target sensitivity level in the storage ring pEDM experiment
  - High statistics (10^{11} protons/store) is achievable using storage ring
  - Goal **10^{-29} e·cm** (statistical limit in about one year)
  - → 10^{-30} e·cm (with an upgrade)
- Physics reach $>10^3$ TeV

How to measure EDM?

You need...

Particles(EDM)
+
Electric field

→ **Spin precession!**
(how fast?) $\frac{d\vec{s}}{dt} = \vec{d} x \vec{E}$

p,d,e etc. (EDM)

Where are my protons?

You need storage ring!
(high statistics!)

Charged particle in an electric field? → **F=qE** → **Lost from the observation area**

MDM, EDM and spin precession

❖ **Spin dynamics (with EDM and MDM) in magnetic+electric field (T-BMT equation)**

$$\frac{d\vec{s}}{dt} = \vec{\mu} x \vec{B} + \vec{d} x \vec{E} = \vec{s} \times (\vec{\omega}_s + \vec{\omega}_{edm}) \quad \text{(for particle at rest)}$$

$$\mu = (ge/2m)s = ge\hbar/4m, \; d = (\eta e/2mc)s = \eta e\hbar/4mc$$

$$with \; \vec{\beta} \cdot \vec{E} = \vec{\beta} \cdot \vec{B} = 0$$

(T-BMT equation: for moving particle)

$$\vec{\omega} = -\frac{e}{m}\left[a\vec{B} - \left(a - \frac{m}{p} \right) \frac{\vec{\beta} \times \vec{E}}{c} + \frac{\eta}{2} \left(\frac{\vec{E}}{c} + \vec{\beta} \times \vec{B} \right) \right], a = \frac{g-2}{2}$$

MDM in B-field MDM in induced B-field EDM term

$\vec{\omega}_a$ (MDM in B-field + MDM in induced B-field) $\vec{\omega}_{edm}$ (EDM term)

Storage ring technique for EDM search

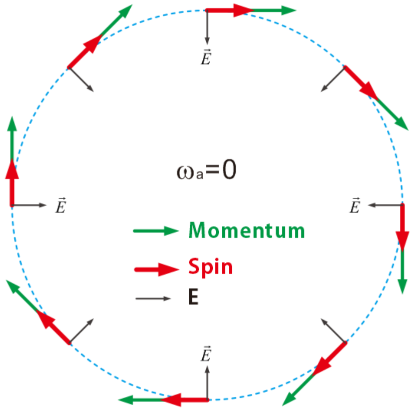
g-2 precession in **pure electric ring**

$$\Rightarrow \vec{\omega}_a = \frac{e}{m}\left[a - \left(\frac{m}{p}\right)^2\right]\frac{\vec{\beta}\times\vec{E}}{c}$$

for the proton (a=1.792847357(23)) >0

$$\vec{\omega}_a = 0 \quad at \quad p = \frac{m}{\sqrt{a}} = 0.700740 \text{ GeV/c}$$: magic momentum

- **Use frozen spin method (static EDM measurement)**
  - ✓ Spin freezes to the momentum direction
  - ✓ a>0 particles (p,e, etc.): use magic momentum
  - ✓ a<0 (deuteron) : use E+B field
  - ✓ spin precesses only on the vertical plane!
  - ✓ No precession on the ring plane



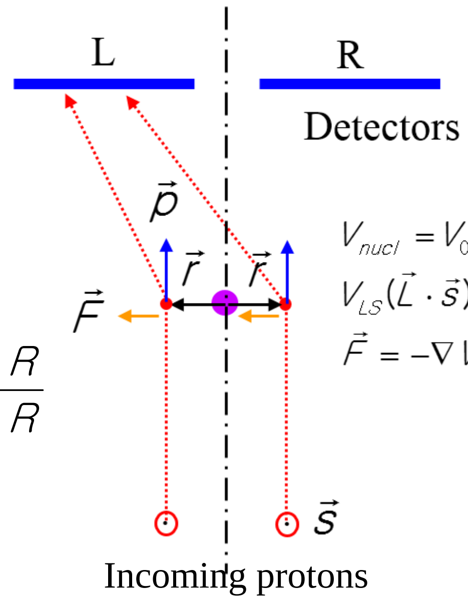
$$\vec{\omega}_{EDM} = -\frac{e\eta}{2m}\frac{\vec{E}}{c}$$

- Storage ring EDM collaboration is trying to establish the experiment at CERN
  - ✓**EDM Kick-off meeting at CERN in Mar. 2017**
  - ✓About 50 participants

Polarimeter and asymmetry

❖ **Use asymmetrical proton scattering on Carbon target**

- Hadronic elastic scattering(spin-orbit interaction)
- Asymmetrical proton hit distribution on the detector plane
- L/R (U/D) asymmetry for vertical (horizontal) component of proton polarization



$V_{nucl} = V_0 + V_{LS}(\vec{L}\cdot\vec{s})$

$V_{LS}(\vec{L}\cdot\vec{s}) = -\vec{\mu}\cdot\vec{B}$

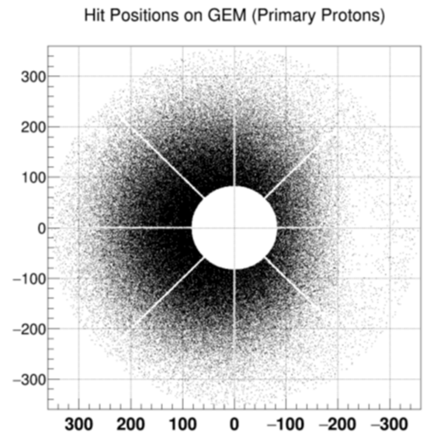
$\vec{F} = -\nabla V_{nucl}$

➢ For spin 1/2 particle

$$\sigma(\theta) = \sigma_{unpol}(\theta)\,[1 + P_y A_y]$$

$$L/R\ asymmetry\quad \varepsilon_{LR} = P_y A_y = \frac{L-R}{L+R}$$

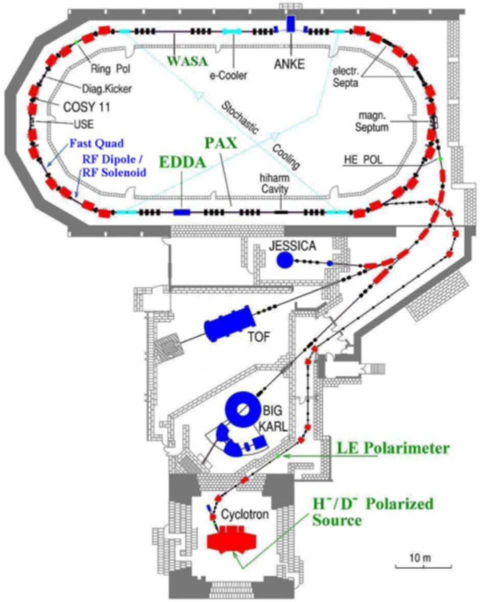
$$P_y = \frac{1}{A_y}\frac{L-R}{L+R}$$

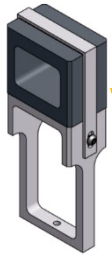


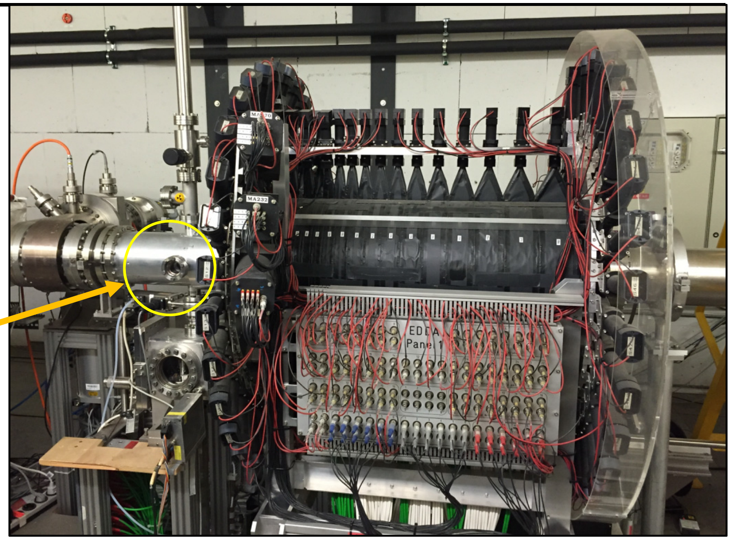
Simulation by Hoyong Jeong

- P_y is calculated from the asymmetry with known A_y
- P_y changes in time due to the precession in E field.

COSY ring and EDDA polarimeter



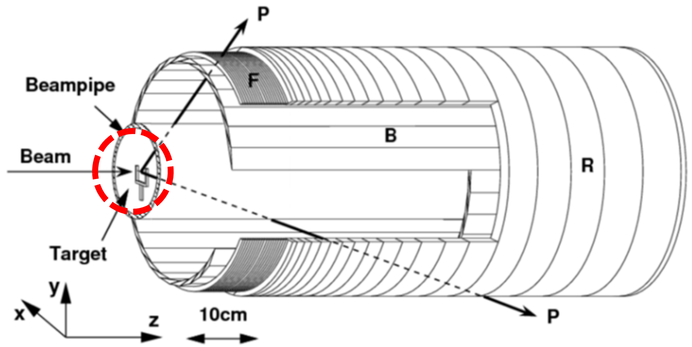




COSY carbon tube target

COSY ring (Juelich, Germany)

Carbon block target (17 mm thick)

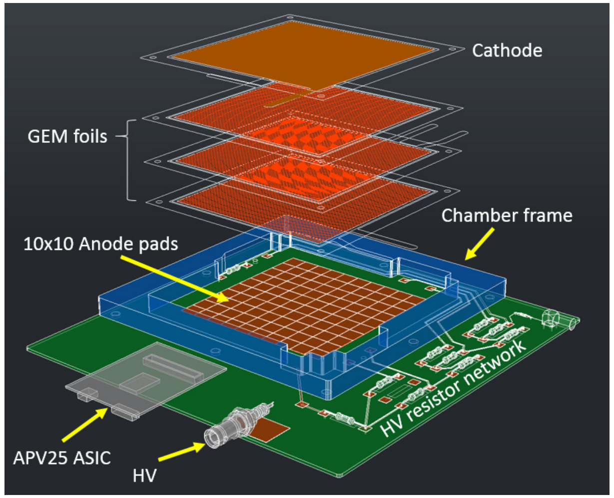


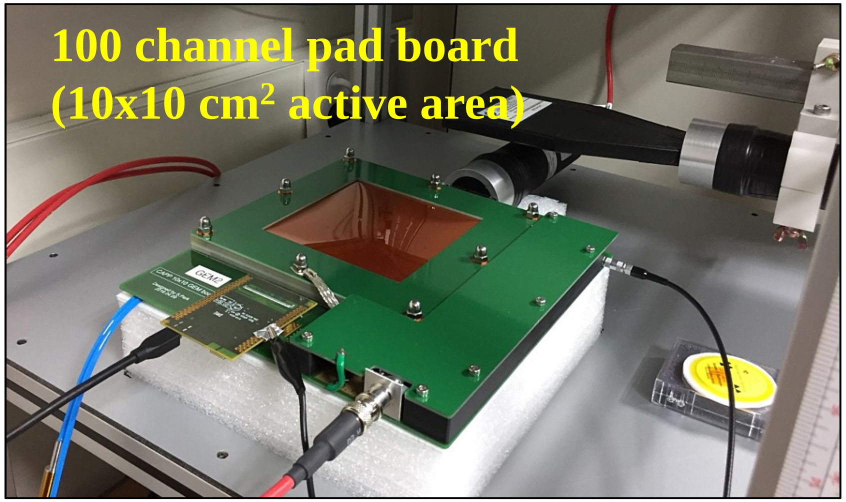
COSY EDDA detector
FZJ, Juelich, Germany

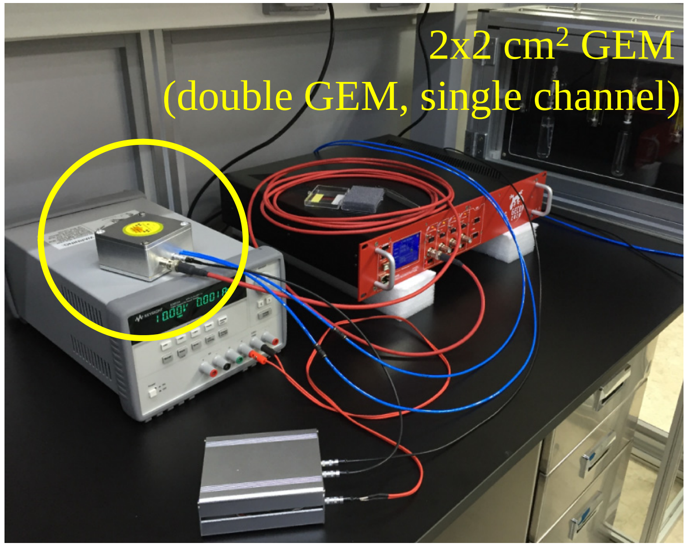
CAPP GEM detectors

for Asymmetry measurement, Tracking

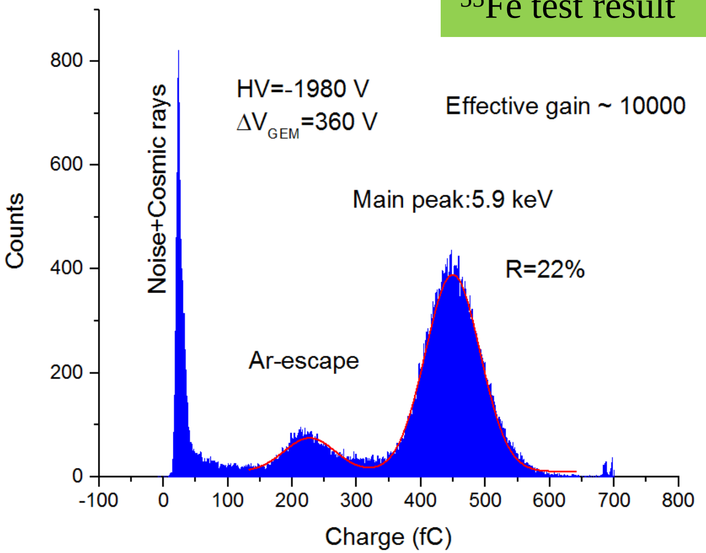
CAPP GEM detectors



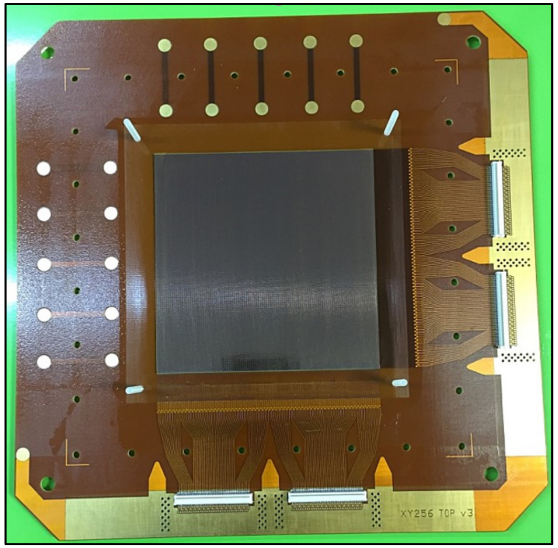


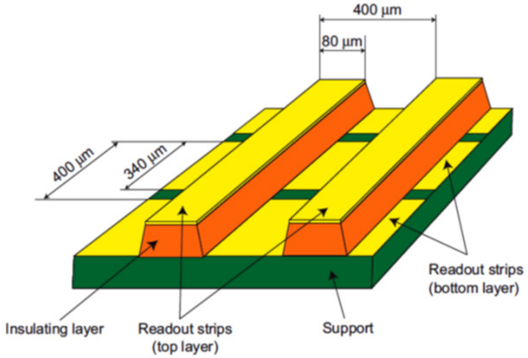


^{55}Fe test result

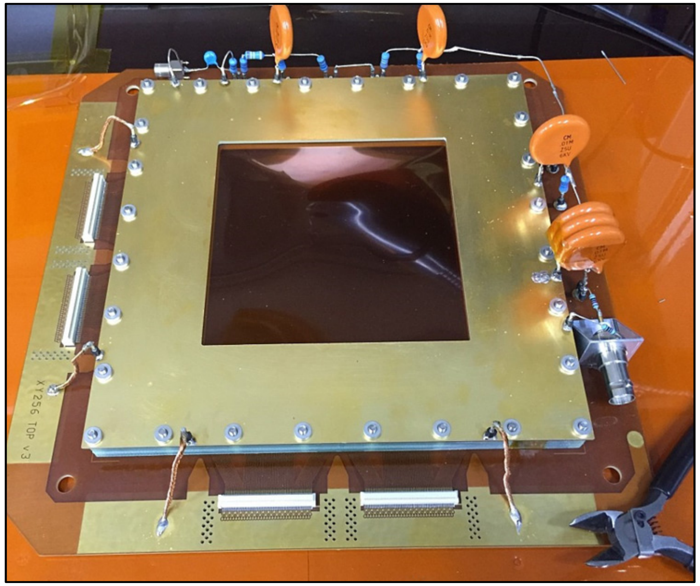


CAPP GEM detectors





512 channel X_Y strip board
(R~115 μm), CERN PCB workshop

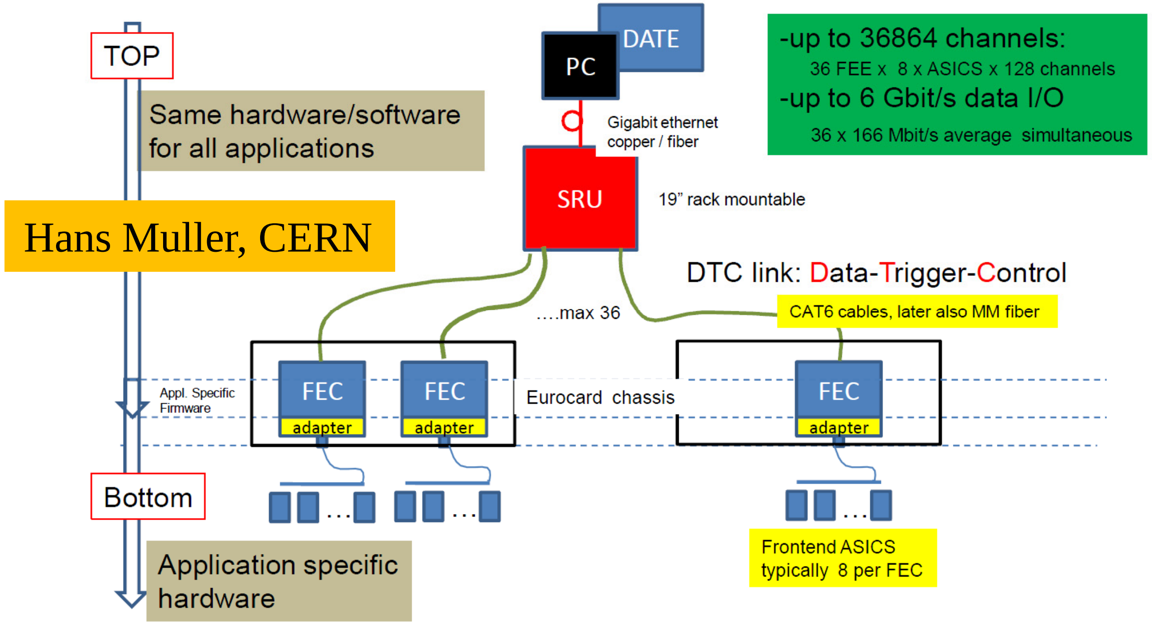


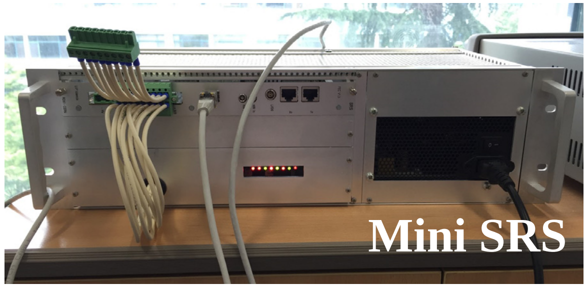
10x10 cm^2 GEM detector assembly

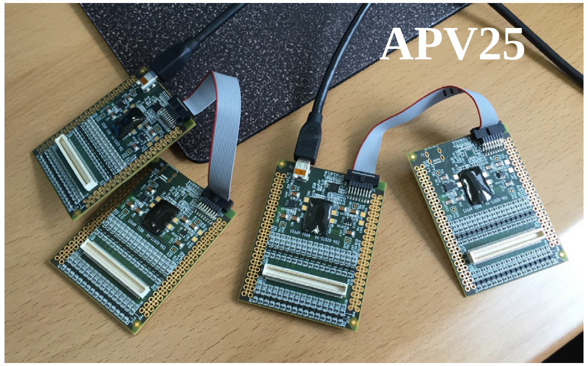
⇩

to beam test at COSY, Germany

DAQ system for GEM test



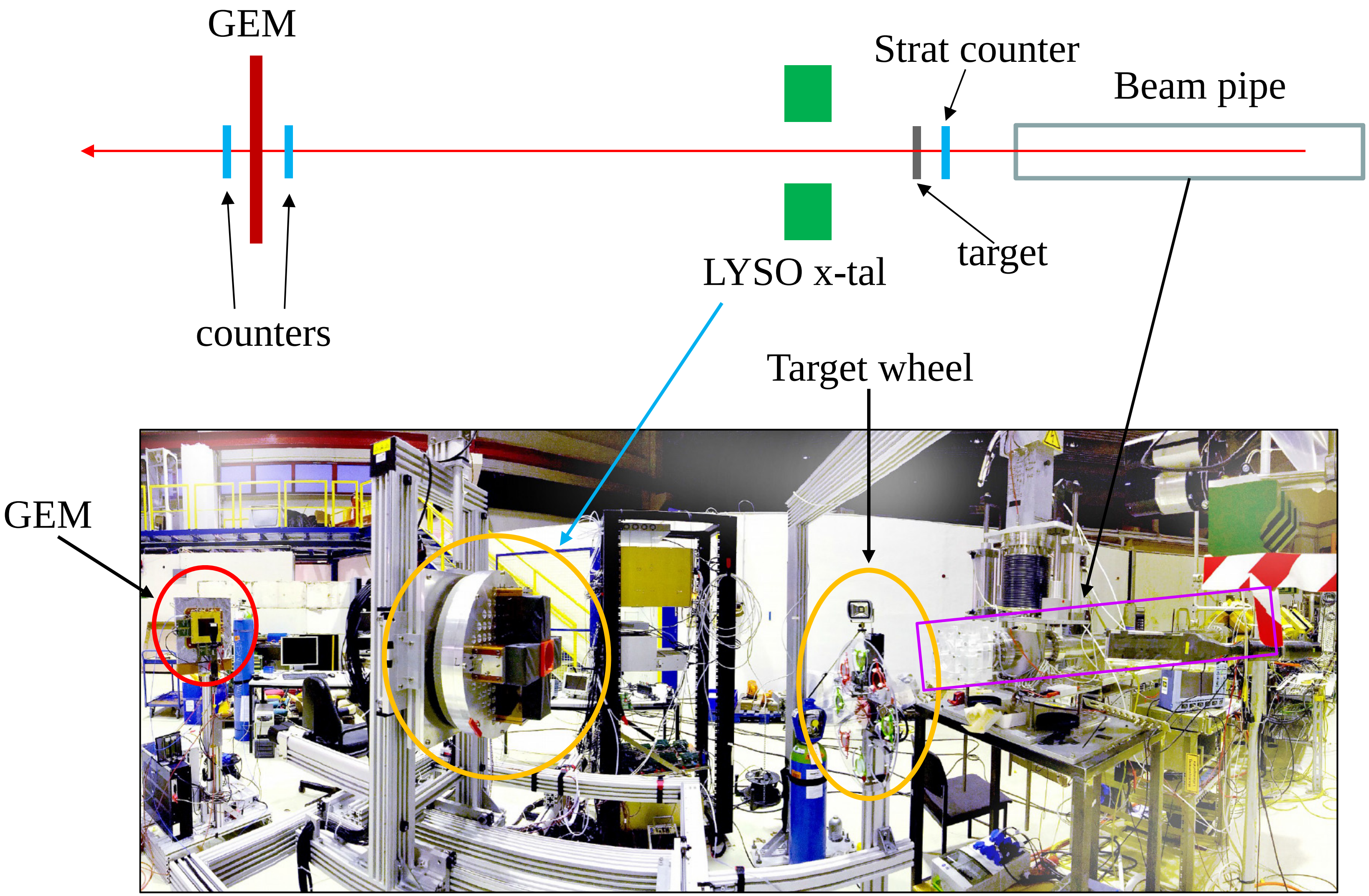




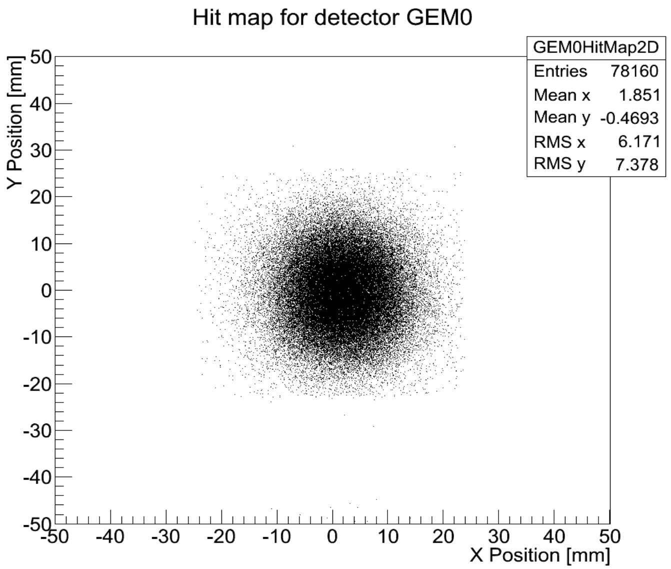
- ❖ SRS: Scalable Readout System
- ✓ Developed and distributed by the RD51 collaboration
- ✓ FE Hybrid+ adapter card+FEC+DAQ PC
  - Hybrid: **APV25**, **VMM**, GEMROC, Beetle, etc
  - APV: analog chip
  - VMM: digital chip with peak detection and time information

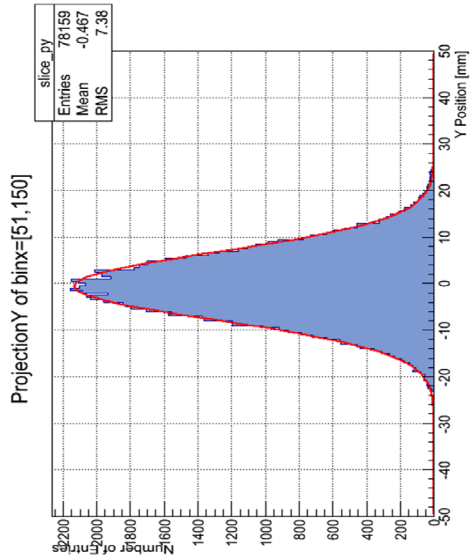
❖ **Special thanks to CERN GDD lab. for providing SRS system (Hans Muller, Eraldo Oliveira)**

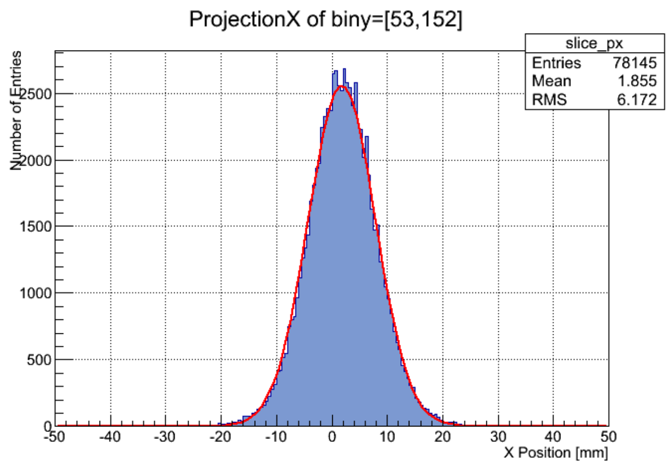
Beam test setup at COSY(Big Karl room)



Deuteron beam profile

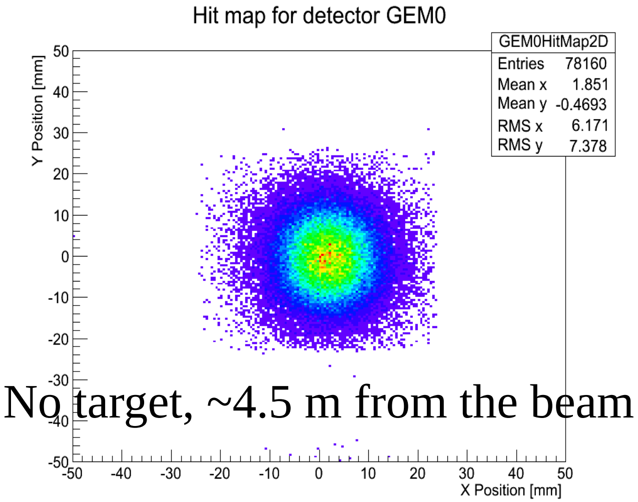




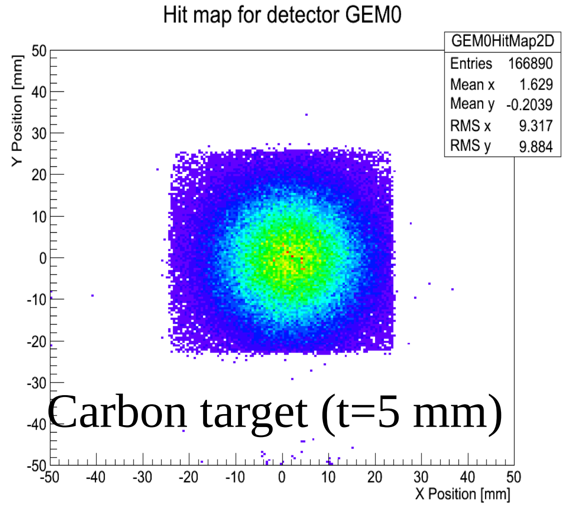


Triple GEM detector
512 channel X-Y strip board
270 MeV Deuteron beam

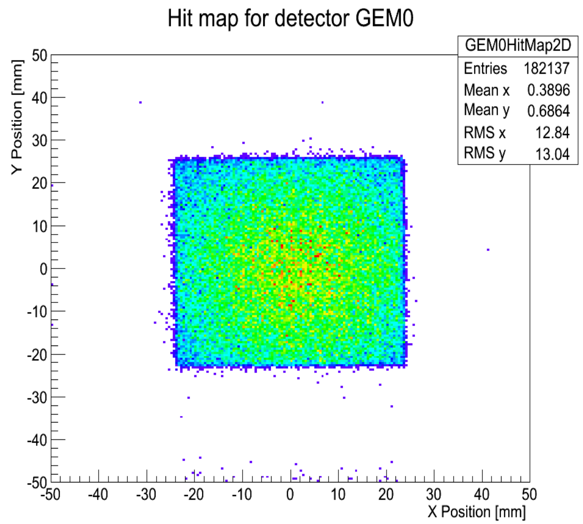
Deuteron beam spread by materials



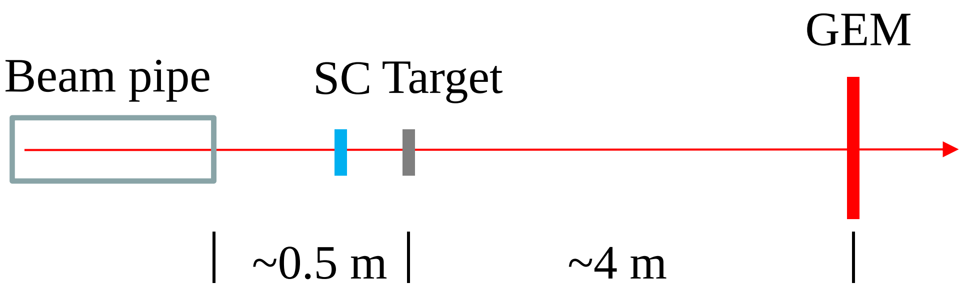
No target, ~4.5 m from the beam exit



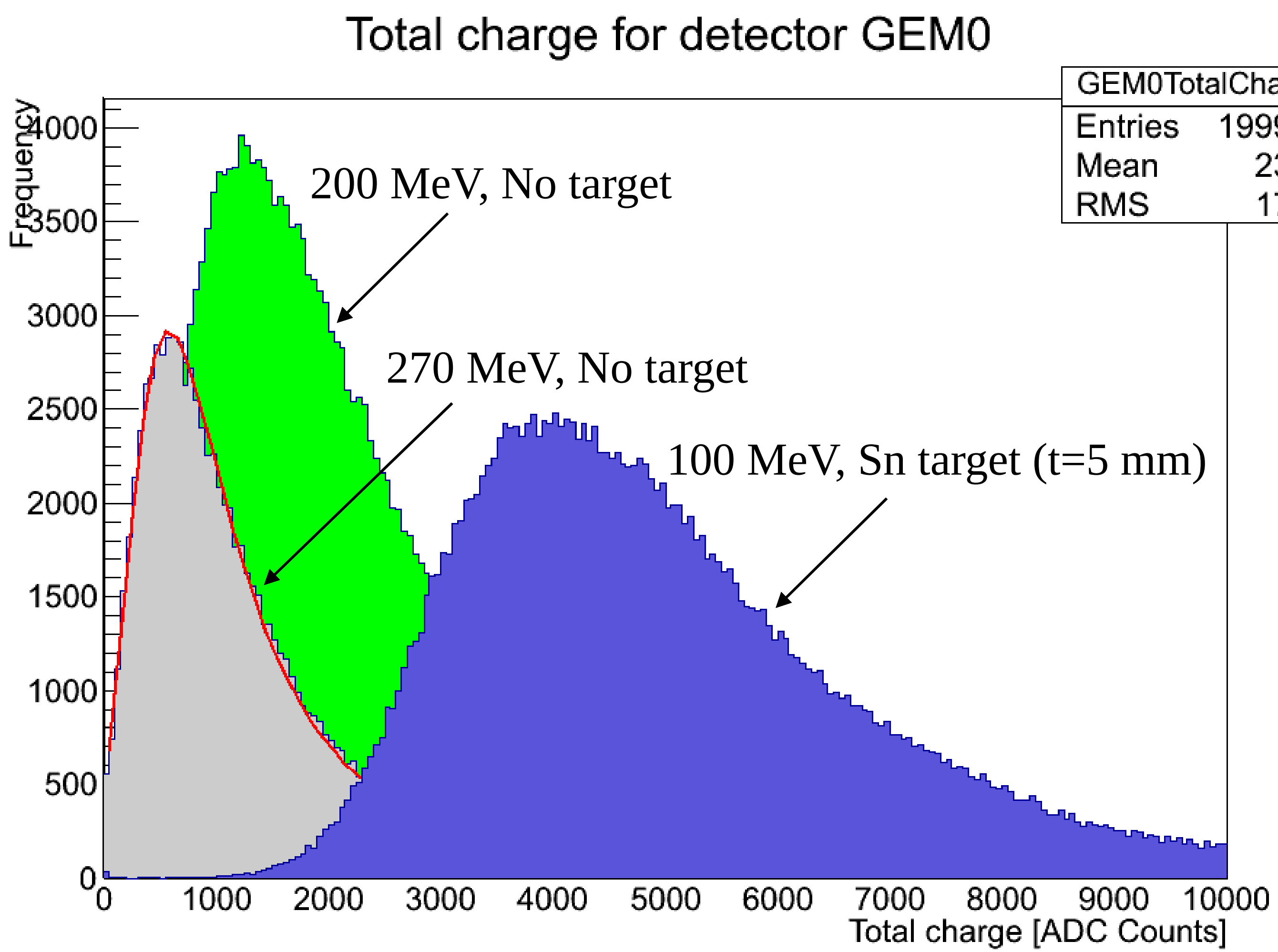
Carbon target (t=5 mm)



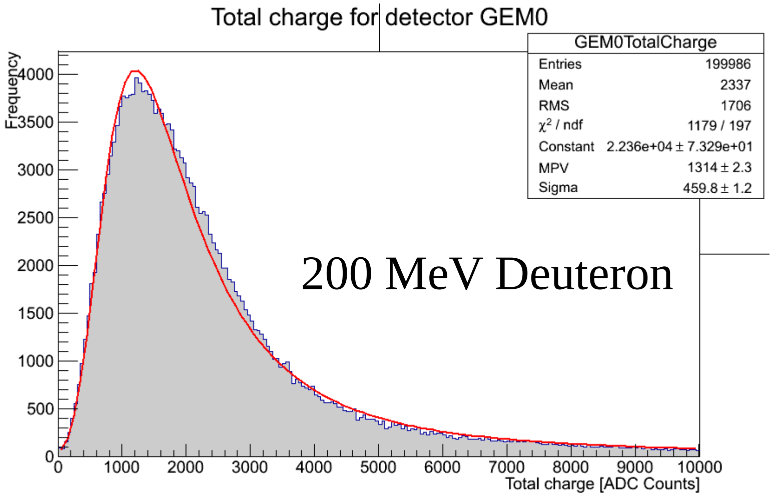
Carbon target (t=5 mm)+ plastic scintillator (t=10 mm)

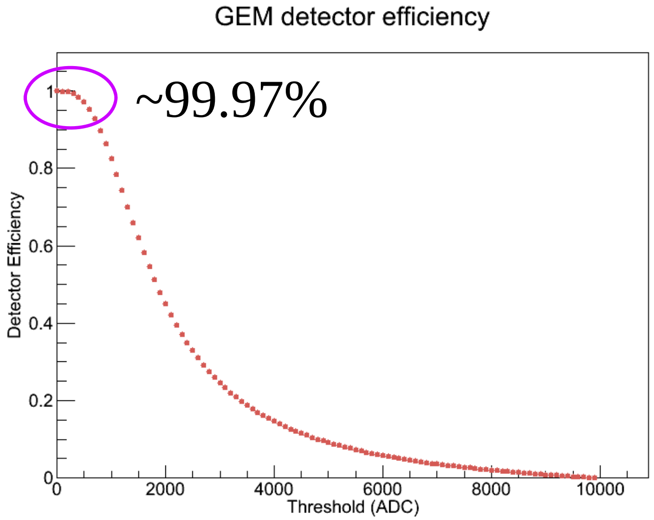


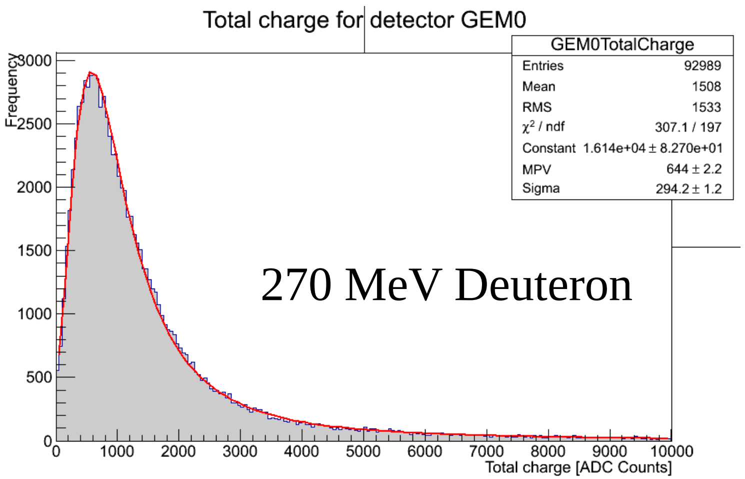
GEM response to Deuteron beam

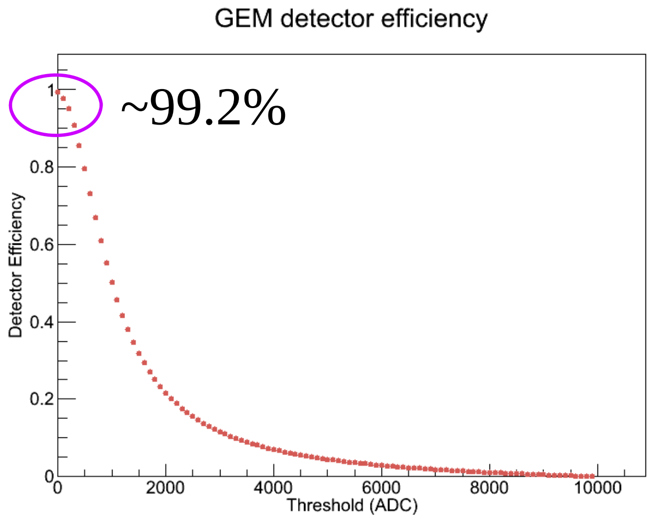


Detection efficiency



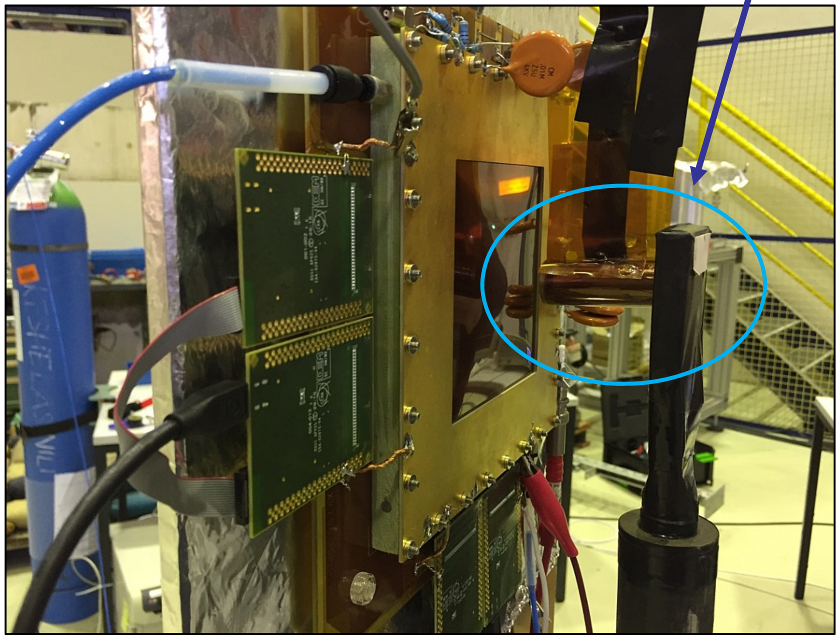


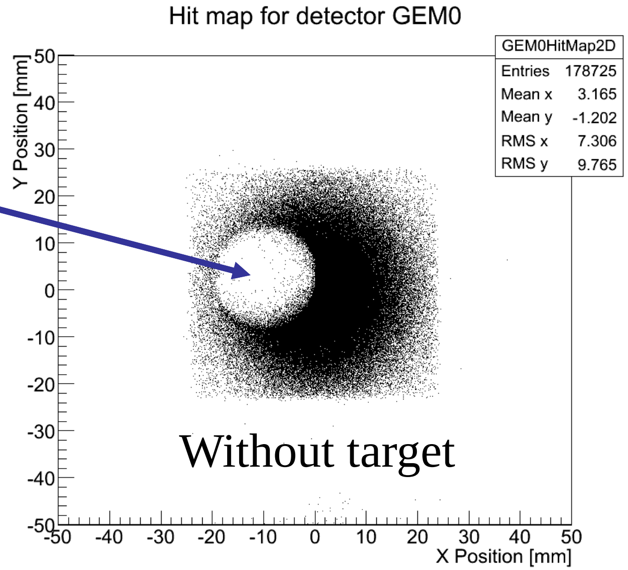


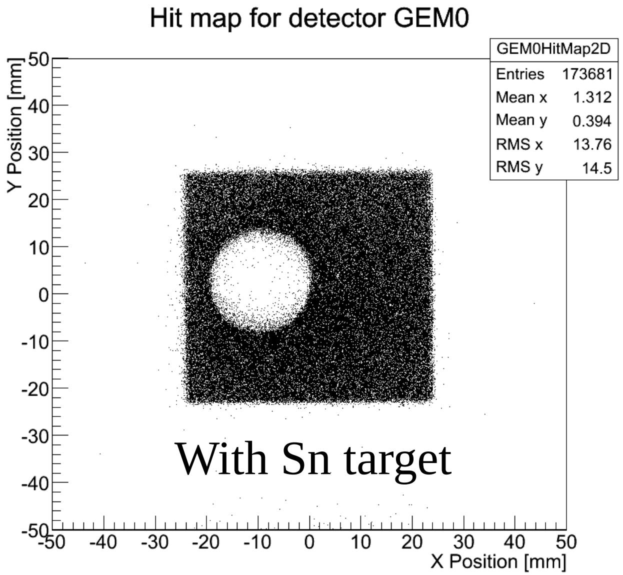


GEM digital imaging

Cupper rod







Summary and Plans

- ❖ IBS/CAPP is developing GEM-based polarimeter detectors for storage ring proton EDM experiment
- ❖ Successful beam test at COSY, Germany

➢ Plans:

- ❖ Asymmetry measurement with polarized proton/deuteron beams
- ❖ Tracking test with multiple GEM planes (3~4)
  - ✓ Beam profile monitor during the measurement
- ❖ More test at KOMAC(Gyeongju, Korea)
  - ✓ In the second half of 2018?

Thank you!