Charge exchange reaction(s), hadronic probe for neutrino-nucleus reactions

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Contents

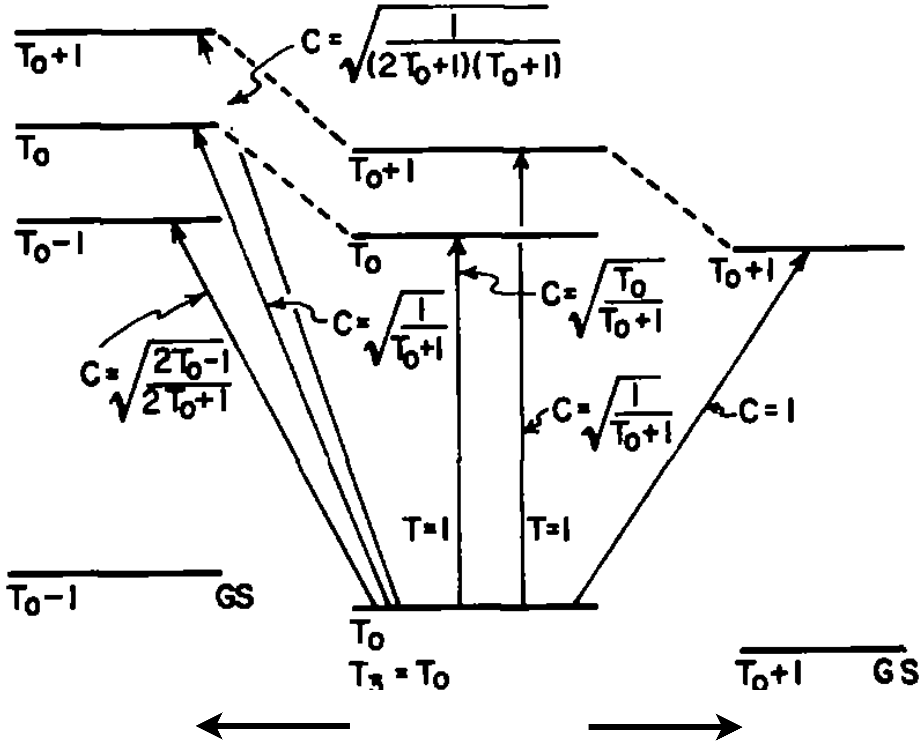
- (n,p)-type Charge Exchange Reaction
- Development of CNS Active Target

Neutrino-nucleus reaction

$$\bar{\nu}_e +_Z A \quad \rightarrow \quad e^+ +_{Z-1} A \quad \text{GT+ (n,p)}$$
$$\nu_e +_Z A \quad \rightarrow \quad e^- +_{Z+1} A \quad \text{GT- (p,n)}$$
$$\nu +_Z A \quad \rightarrow \quad \nu^{'} +_Z A^*$$

Charged Current νN reaction
=> Charge Exchange Reaction

Charge Exchange Reaction



n-rich	(p,n)	(n,p)
p-rich	(n,p)	(p,n)
N=Z		(n,p)/(p,n) ← In N=Z nuclei, B(GT+) ~ B(GT-)? cf. Sasano-san

G.A. Needham et. al, NPA385(1982)349

Electron Capture Rate of Iron-group Nuclei

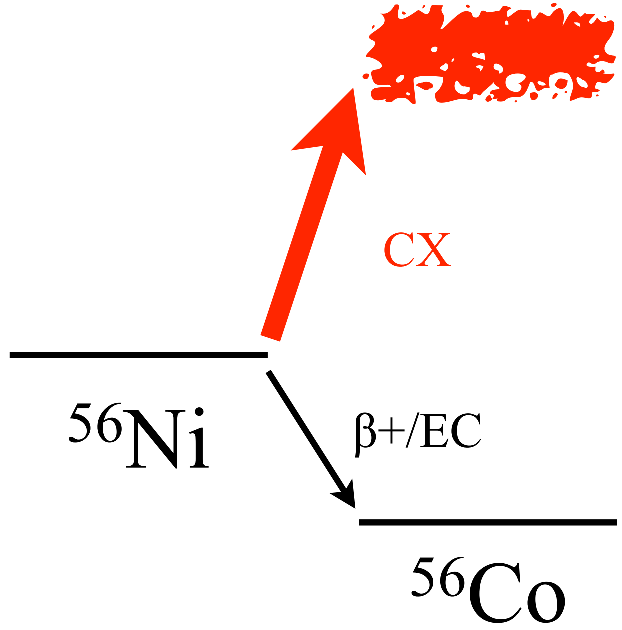
- Life time and scale of Supernova explosion
- Nucleosynthesis in Supernova explosion

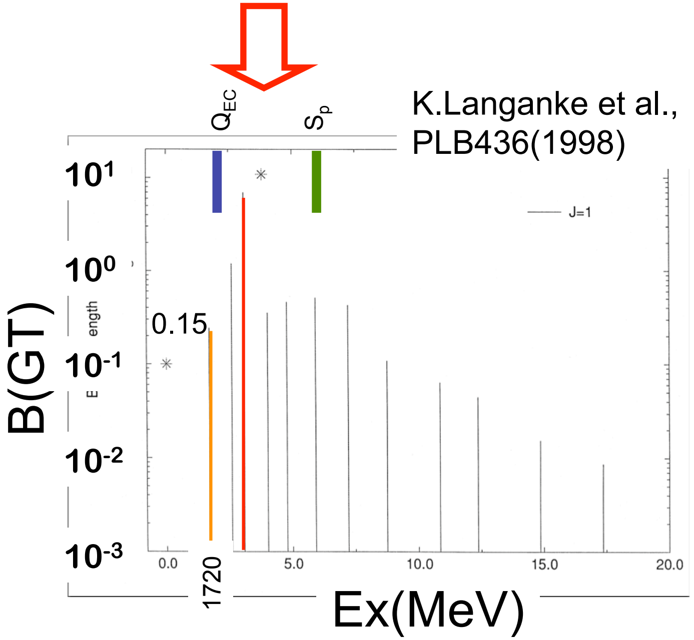
$$\bar{\nu}_e + p \rightarrow e^+ + n; \quad n + {}^{64}\mathrm{Ge} \rightarrow {}^{64}\mathrm{Ga} + p; \quad {}^{64}\mathrm{Ga} + p \rightarrow {}^{65}\mathrm{Ge}; \ldots$$

- B(GT+) strengths above the electron capture threshold in Iron-group and heavier (^{56}Ni, ^{64}Ge etc.) nuclei are needed
- Gamow Teller (GT) transition
  - ΔT=1, ΔS=1, ΔL=0

Measurement of B(GT+) strengths

- β^+ decay / Electron Capture
  - below $Q_{\beta/EC}$
  - gives the absolute value of B(GT+) from log*ft* value
- **(n,p) type charge exchange (CX) reactions**
  - bound and unbound excited states
  - gives a relative strength distribution
  - needs "unit cross section"

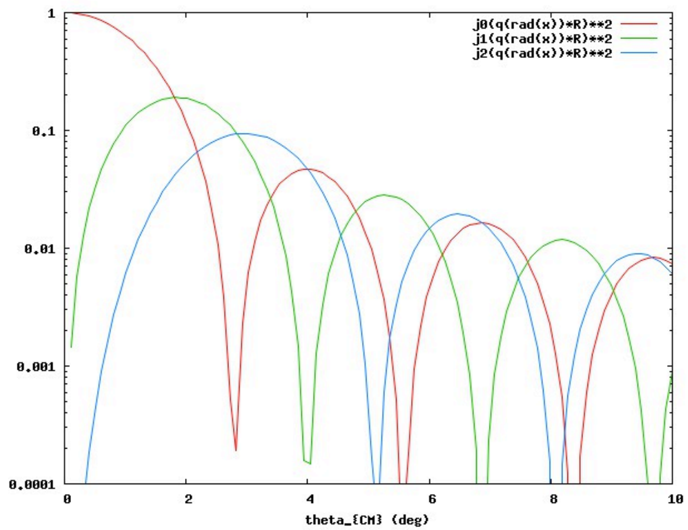




(n,p) type CE reactions

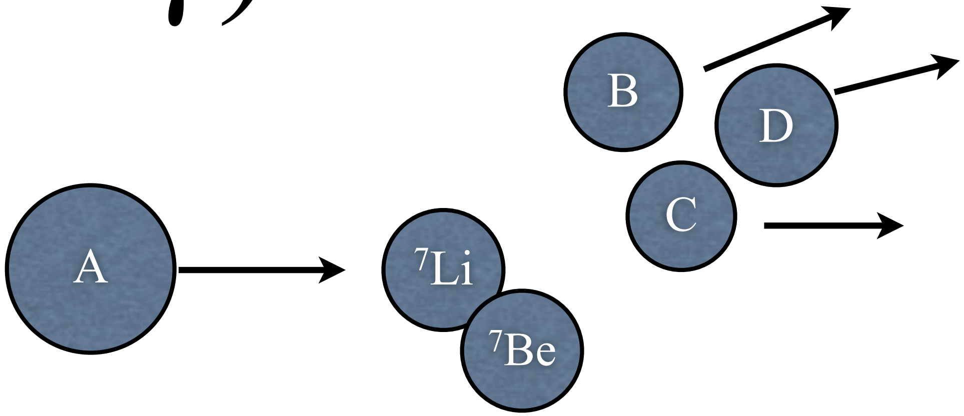
- normal kinematics
  - (n,p), (d,^{2}He), (t,^{3}He)
- inverse kinematics
  - (n,p), **(d,^{2}He)**, (t,^{3}He), (^{7}Li,^{7}Beγ)
    - n/t targets are difficult
- Extraction of GT strength
  - $\Delta T = 1$, $\Delta S = 1$ are tagged by reaction selectivity
  - ΔL is extract or decomposed by using angular distribution of differential cross section

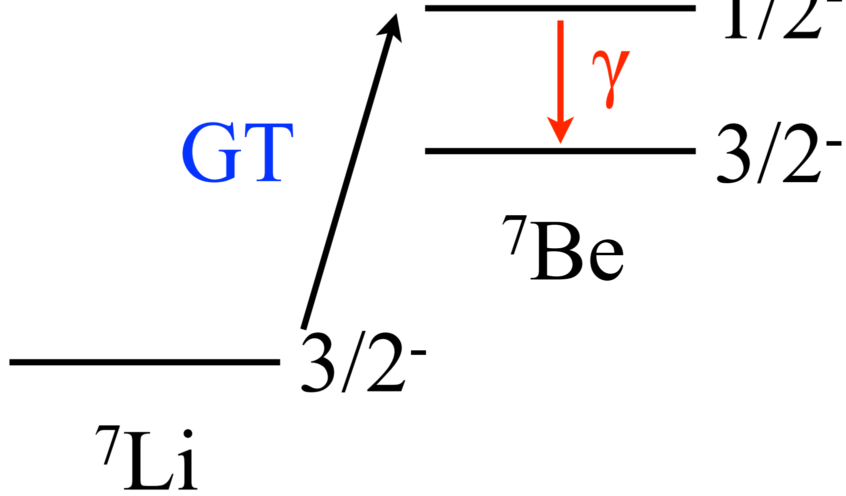
Angular distribution
^{56}Fe + d (elastic) @250MeV/u



(^{7}Li,^{7}Beγ)

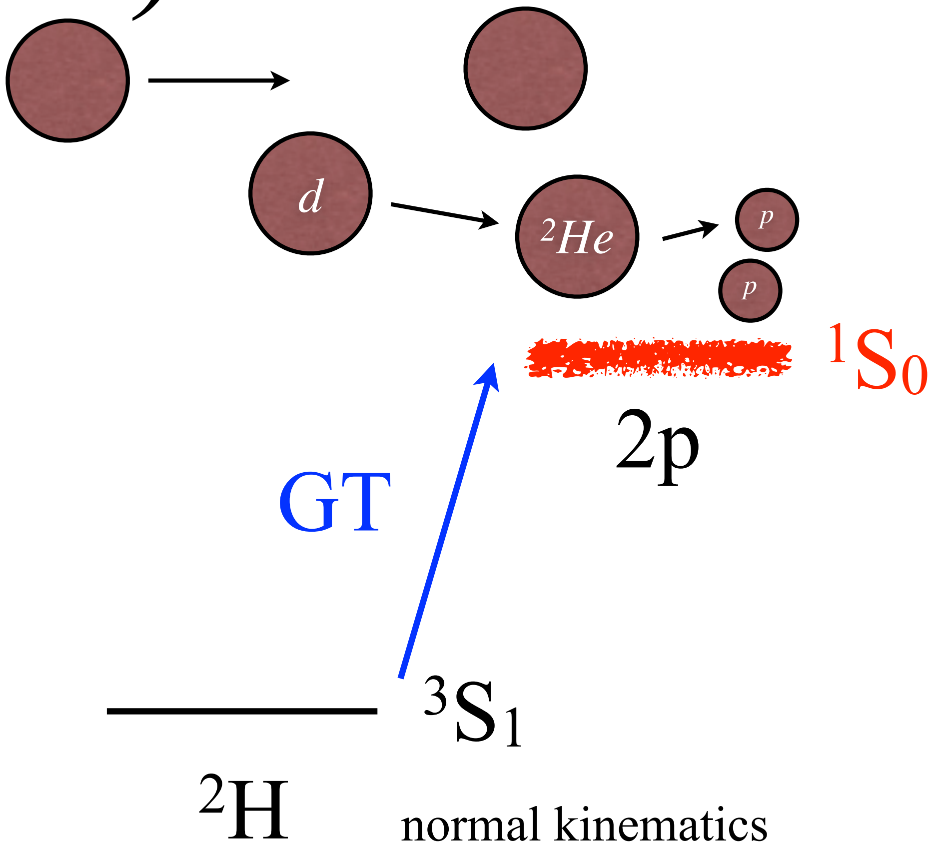
- Invariant mass and/or gamma spectroscopy
  - Inv. mass for unbound states
  - Gamma for bound states
- GT Transition is tagged by 0.43 MeV gamma ray
  - Needs good S/N for gamma detection
- Angular resolution of 0.1 deg in lab. frame is required
- Resolution of excitation energy depends on mainly angular resolution



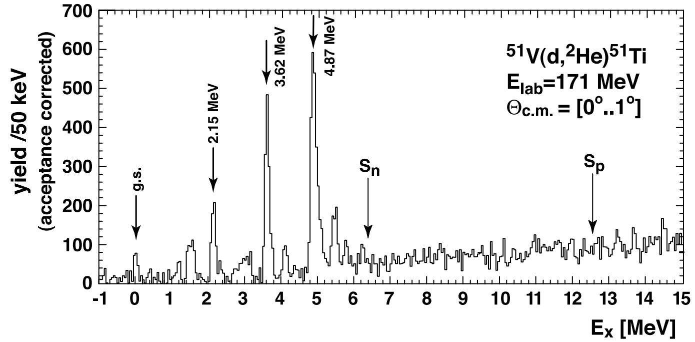


(d,^{2}He)

- Missing mass spectroscopy in inverse kinematics
  - Momentum of ^{2}He is reconstructed by invariant mass
  - Bound and unbound states are measurable at the same time
- GT Transition is tagged by $^{1}S_{0}$ proton pair (called ^{2}He)
- δEx depends on angular and energy resolution
- S/N becomes better due to vertex measurement



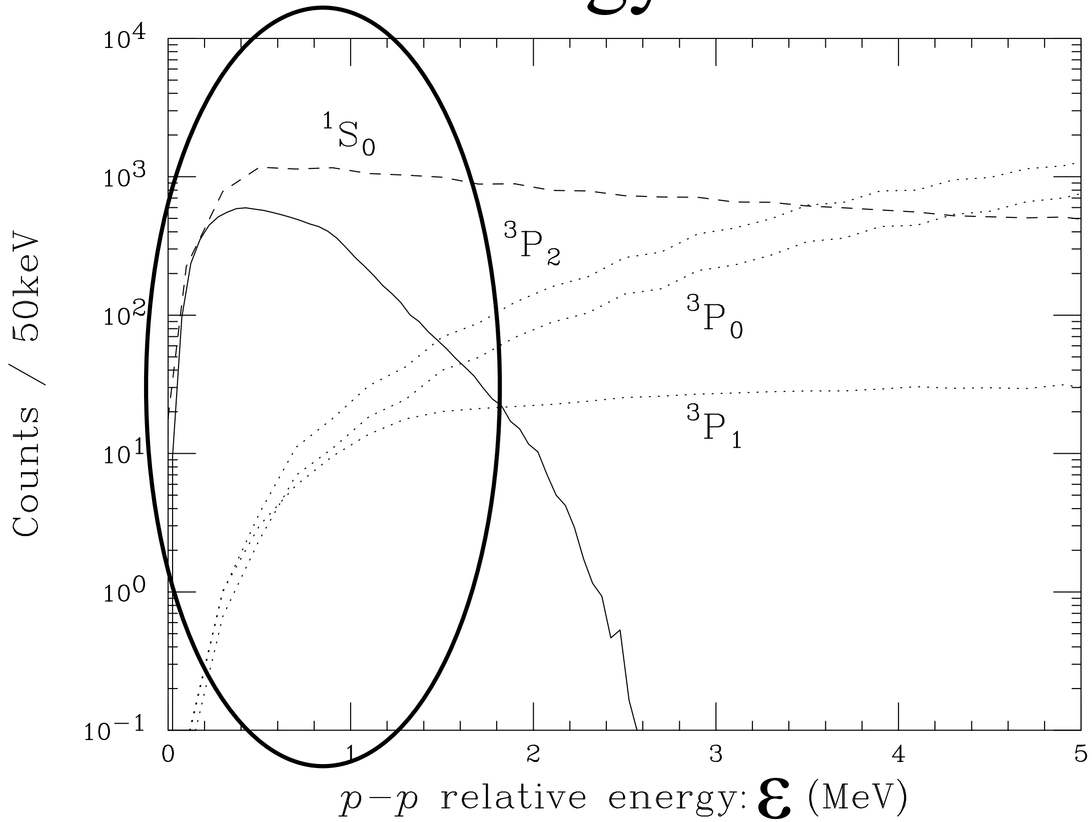
normal kinematics

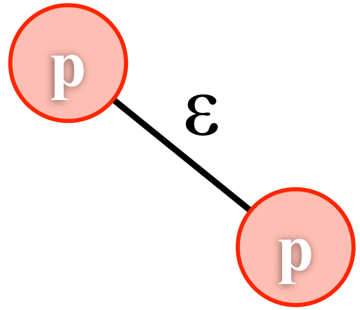


C. Bäumel et al. (2003)

2p system

relative energy distribution



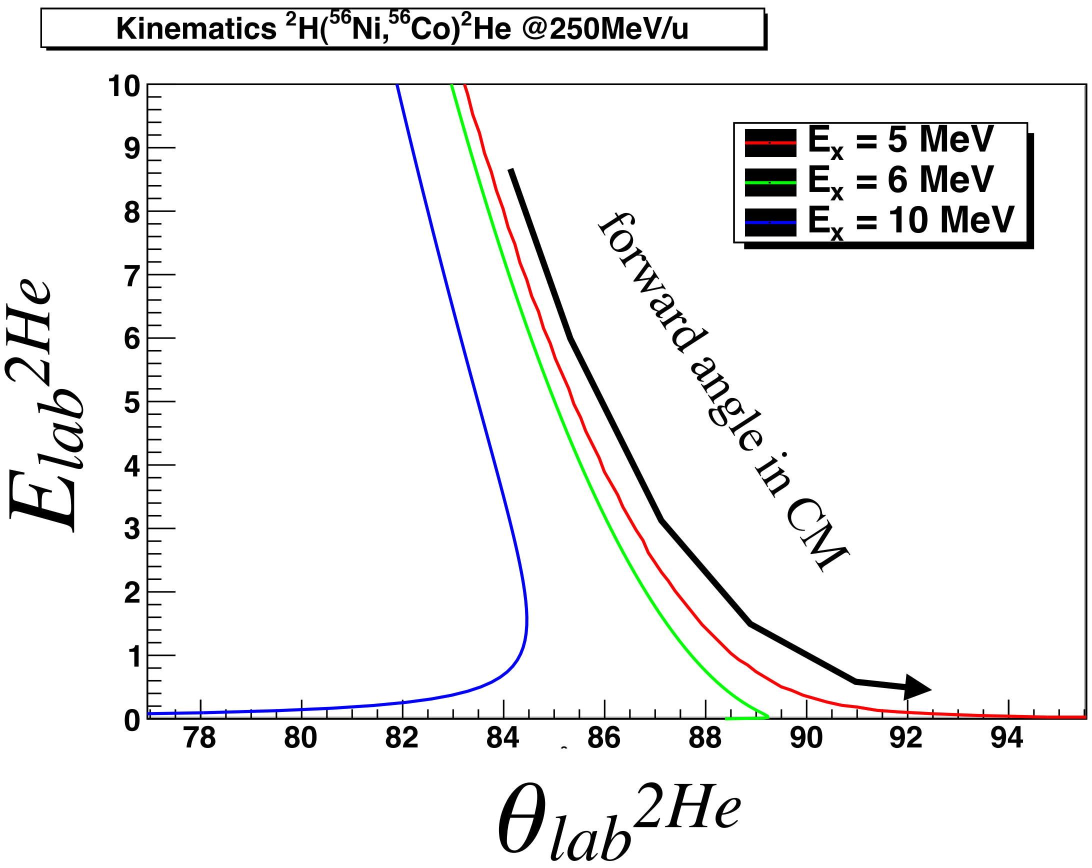


Migdal-Watson formulation
T. Onishi, D-thesis

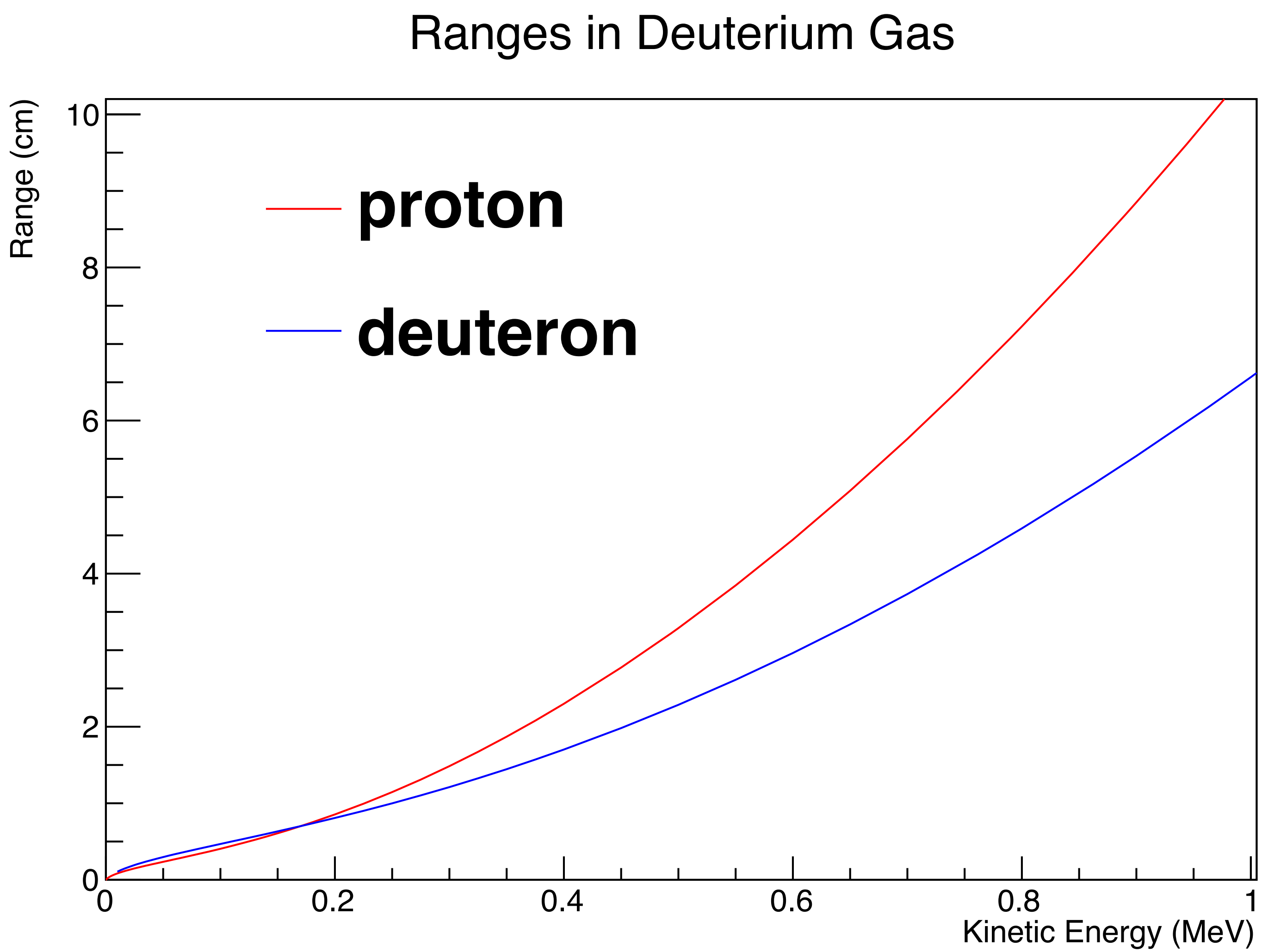
ε < 0-2 MeV $^1S_0$ is dominant

Kinematics in inverse kinematics

- *$^2H(^{56}Ni,^{56}Co)^2He$*
  - *most recoils emitted around 80-90 deg. (sideway)*
  - *$\delta\theta$~14 mrad for dEx =1MeV @E_{lab} = 1 MeV*
  - *δEx~0.5 MeV*
- *angular resolution is important*
  - *multiple scattering*

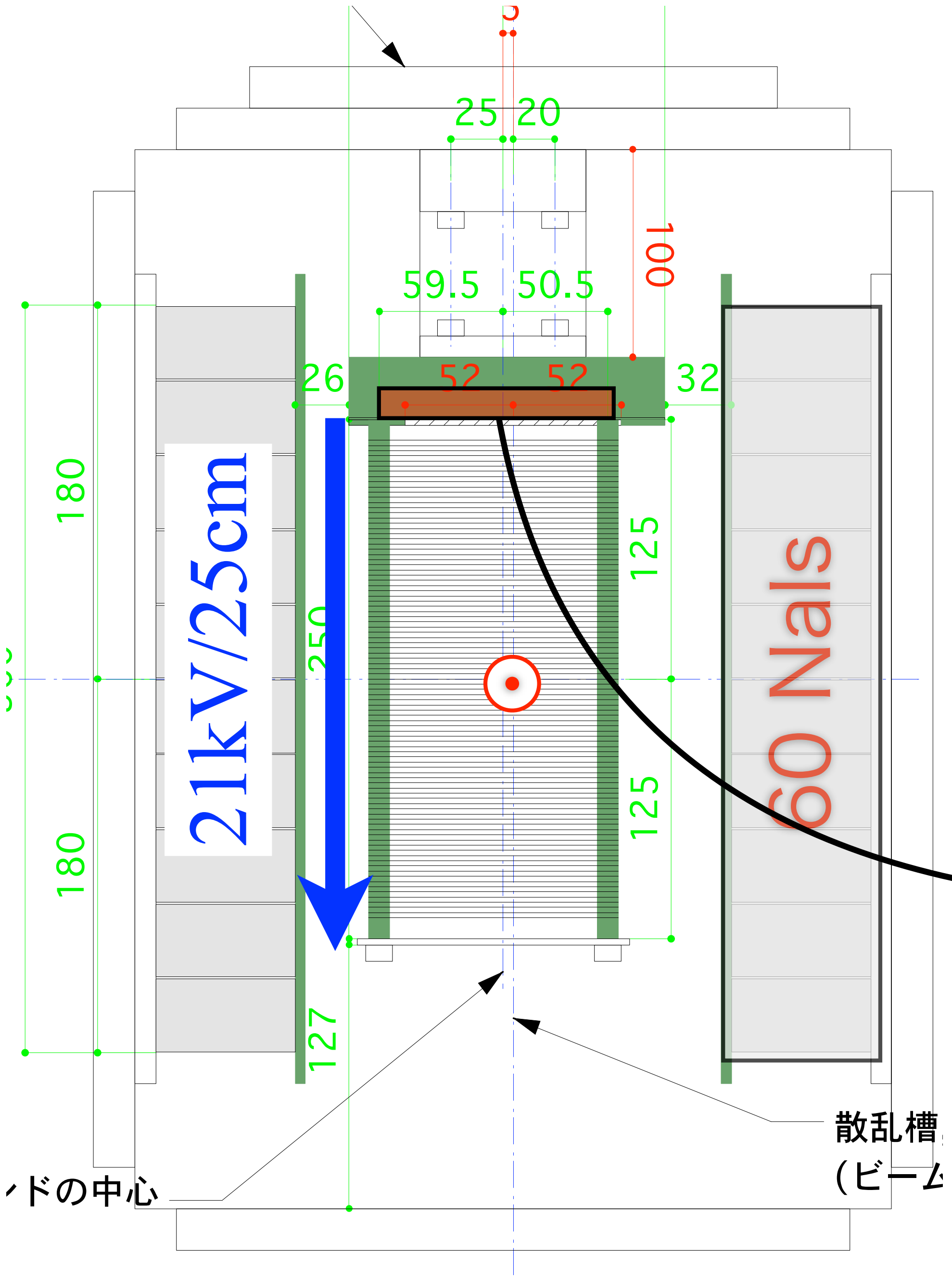


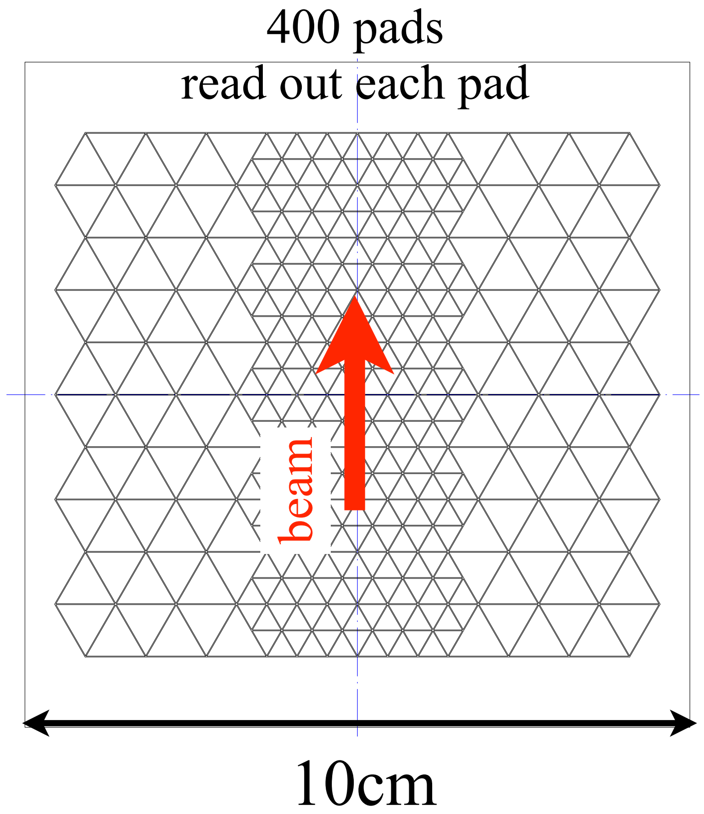
Range of low energy recoiled particles



We need to use gas target and vertex detector

Configuration of CNS Active Target

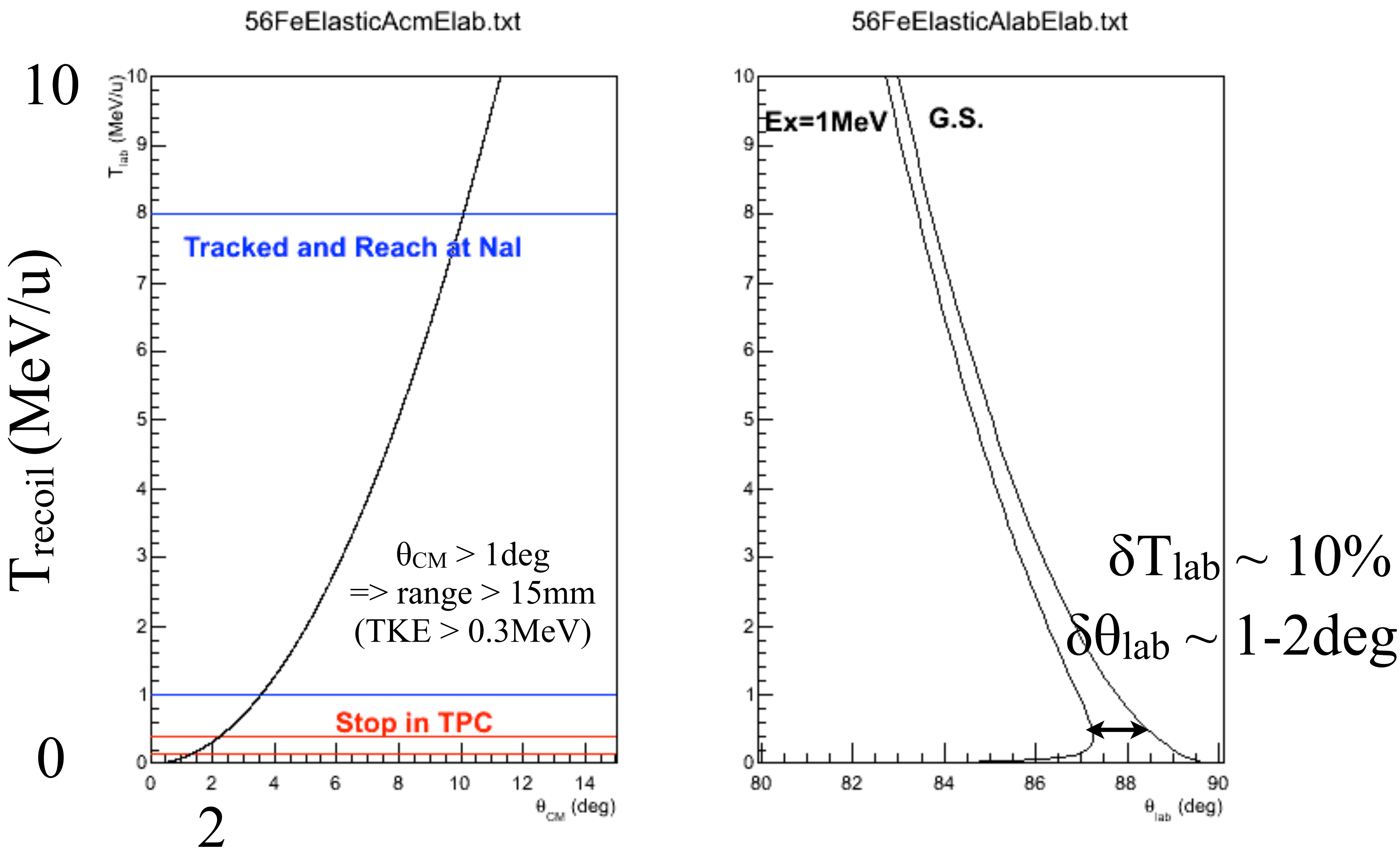




election multiplier : 3 GEMs
discharge occurs with >300kpps beam

1-atm. Pure D_2 gas

Requirement from kinematics

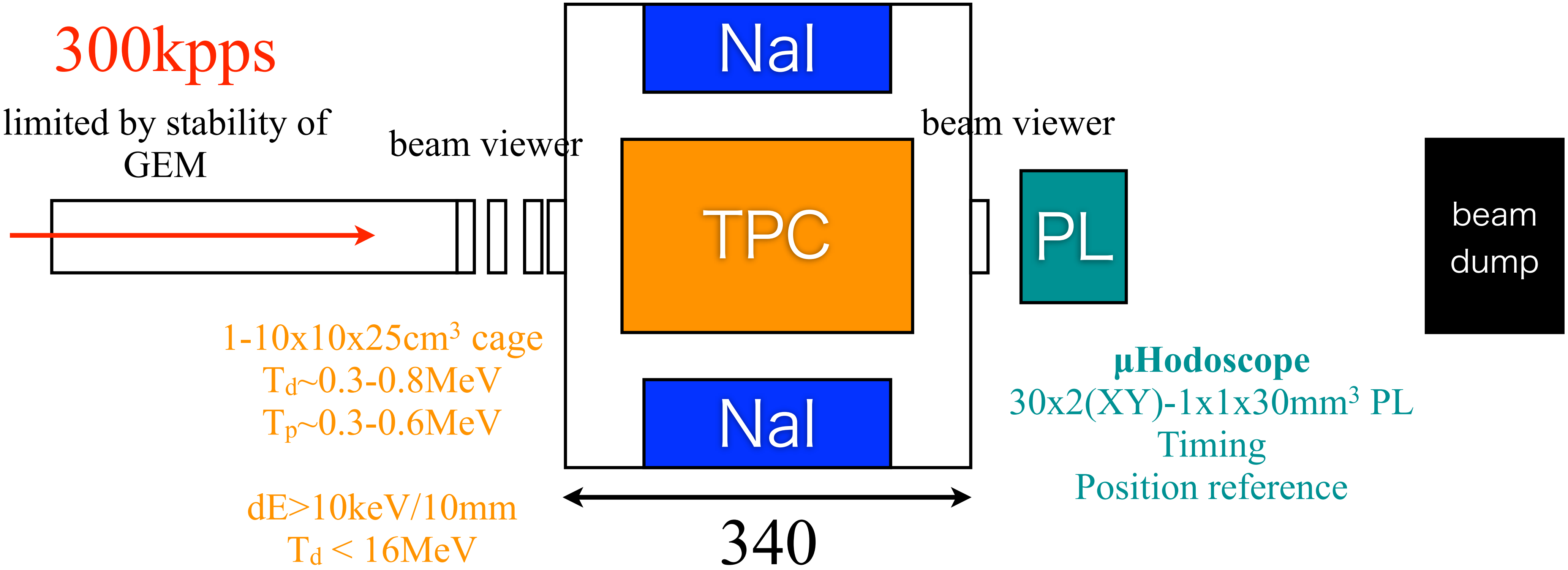


Test exp. at HIIMAC

^{56}Fe
250MeV/u
300kpps
limited by stability of GEM

60x2-31x31x70 mm^3 NaI
T_d>2MeV
T_p>1.6MeV

@PH2
Jan. 2012



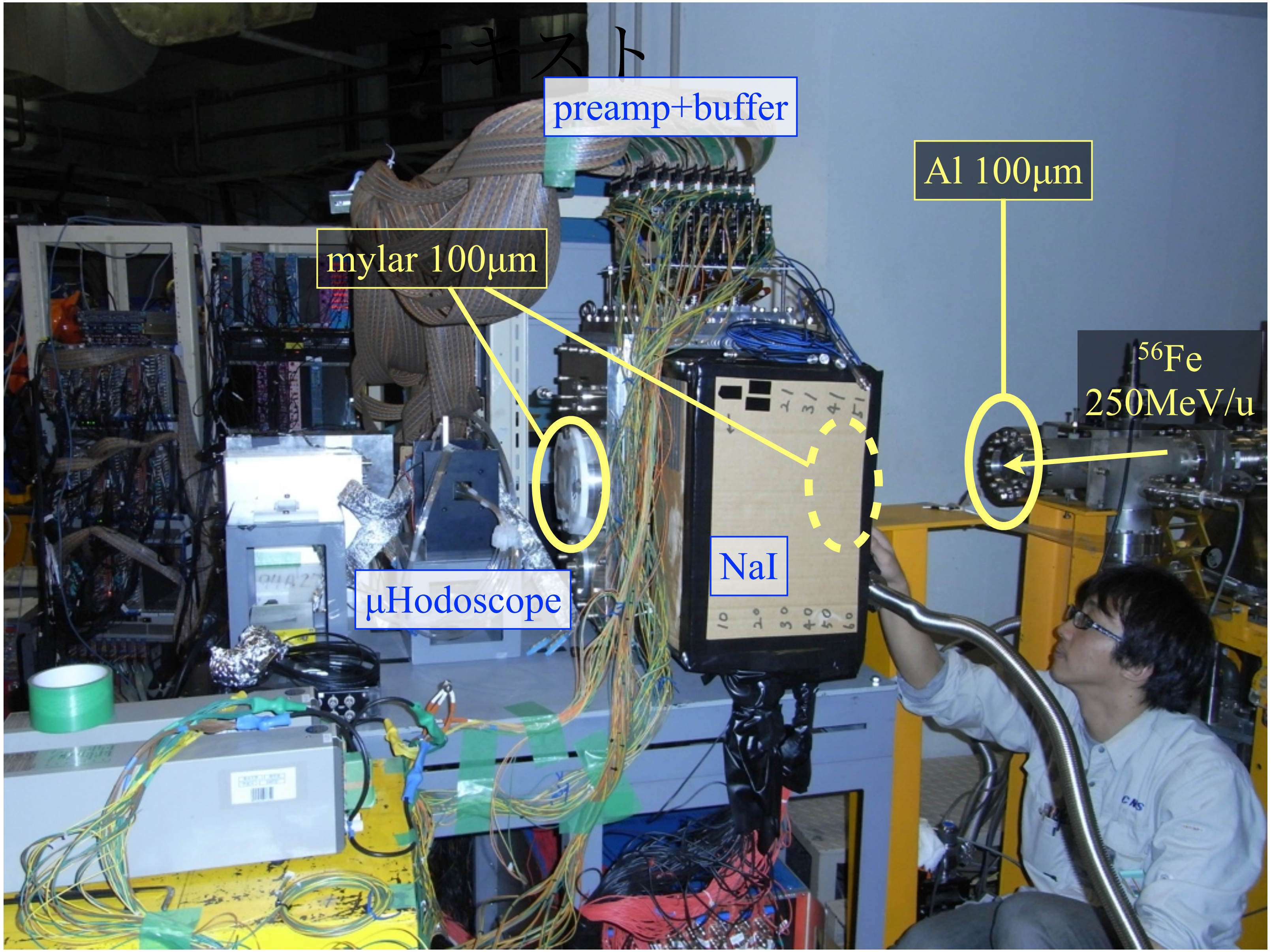
1-10x10x25cm^3 cage
T_d~0.3-0.8MeV
T_p~0.3-0.6MeV

dE>10keV/10mm
T_d < 16MeV
T_p<8MeV

μHodoscope
30x2(XY)-1x1x30mm^3 PL
Timing
Position reference

Deuterium gas with 3 GEMs

Setup photo

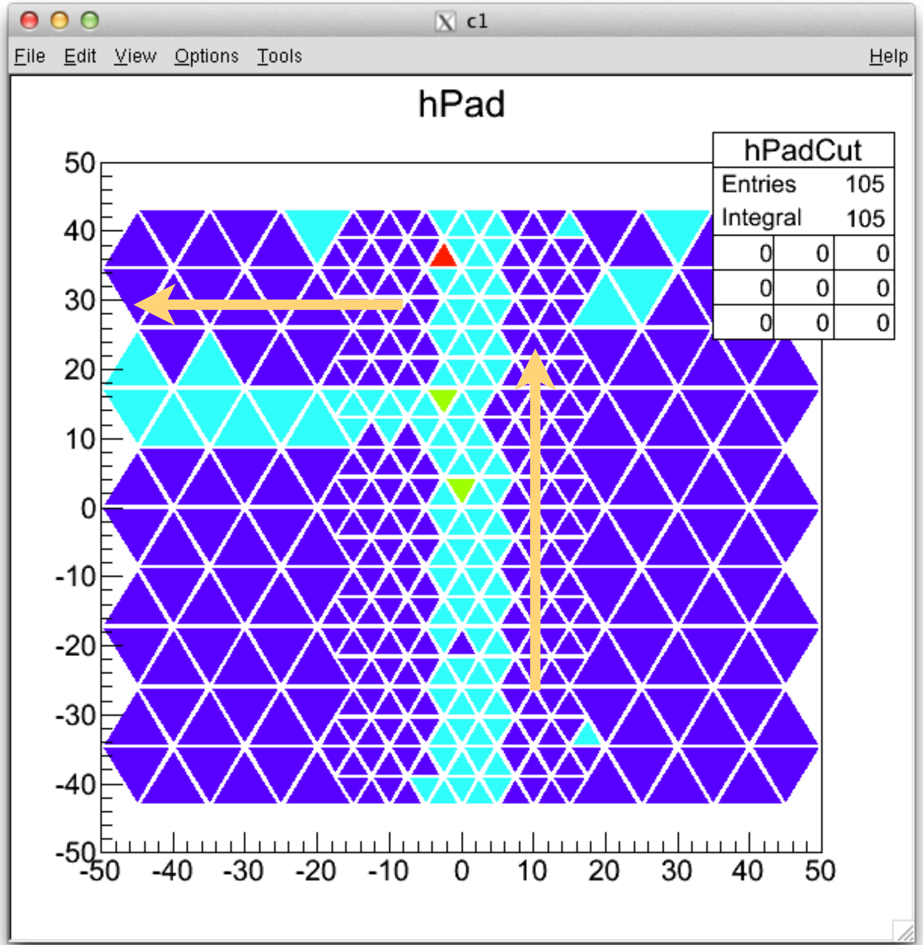


テキスト
preamp+buffer
Al 100µm
mylar 100µm
56Fe
250MeV/u
NaI
µHodoscope

Typical Event

- 100kPa D_2
- 20-21kV at top plate of field cage
- 3 GEMs
- recoiled event found
- total 30-hr data
- data size is not so large since lower-intensity beam is used than expected

3U	2550
3D	2000
2U	1700
2D	1150
1U	850
1D	300



Summary

- B(GT+) measurement w/ (n,p) type reaction
  - (d,^{2}He) by measuring two protons which have small relative energy
- Active Target is under development
  - designed so as to detect low (>300 keV) protons
  - test experiment w/ pure D_2 target was done