

DDX measurement for charge particle production reaction by gridded ionization chamber

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Scope of this talk

- DDX measurement for charged particle production reactions by gridded ionization chamber
 - Experimental apparatus and procedure for “ Measurement of DDX of helium production for several MeV neutron induced reaction”
 - Why do we need to measure (n, α) DDX
 - D-T fusion reactor design and operation
 - Estimate damage on material due to accumulation of gas
 - Estimate nuclear heating
 - Neutronics, design

How can we measure the DDX

- Items should be prepared
 - Neutron production from 4 MeV to 14 MeV
 - Neutron production reaction
 - Neutron measurement
 - Yield estimation
 - Target thickness
 - Solid angle
 - Detector
 - Gridded ionization chamber
 - Electronics and analysis

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Neutron production

- From 100 keV to 20MeV
 - Electro static accelerator (High stability, High current)
 - Dynamitron, peretron

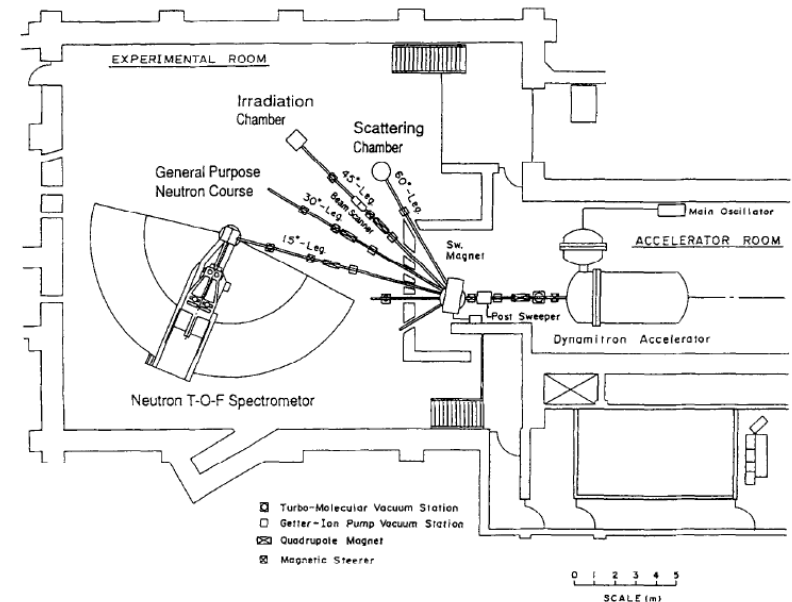
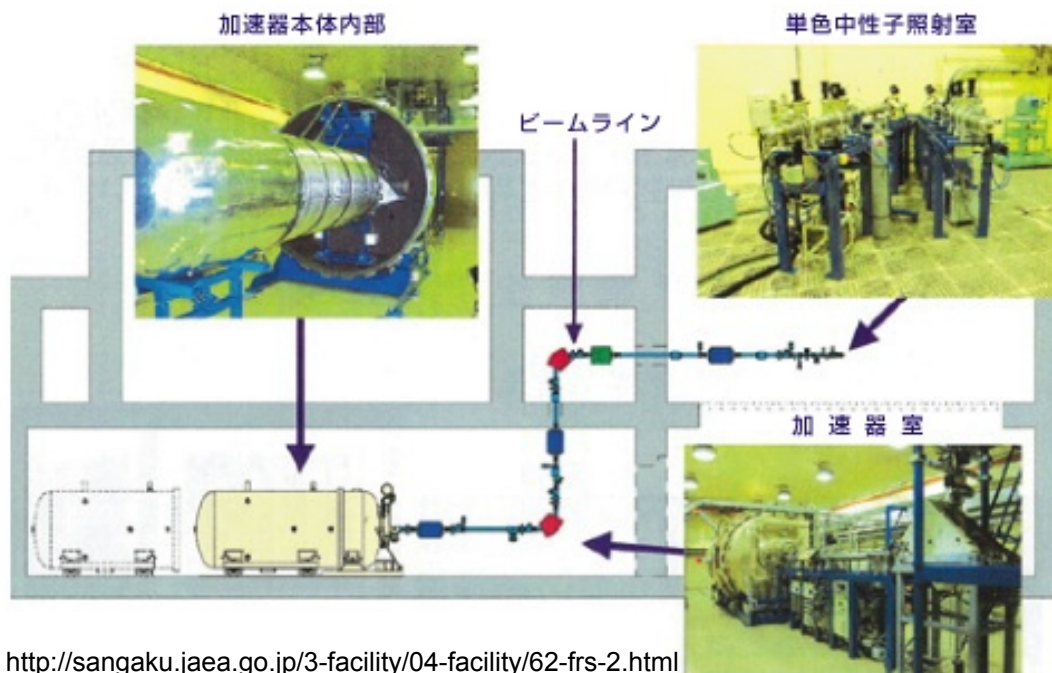


Fig. 1. Layout of the Tohoku University Dynamitron laboratory.

M. Baba et al. / Nucl. Instr. and Meth. in Phys. Res. A 376 (1996) 115–123

- 3 to 4 MV acceleration voltage
 - We can produce various energy neutrons

Neutron production reactions

- Various energy neutron can be produced by choosing neutron production reactions

Reaction	Q-value [MeV]	Neutron energy [MeV]	Target	Typical neutron flux @ 10cm from target [n/cm ² /μC]
T(d,n)	17.6	14.1-18	Ti-T foil	8.0×10 ⁴ (15MeV)
D(d,n) ³ He	3.27	4-6	D ₂ gas	2.2×10 ⁴ (5MeV)
T(p,n) ³ He	-0.76	0.5-2.5	Ti-T foil	2.2×10 ⁴ (2MeV)
⁷ Li(p,n) ⁷ Be	-1.64	0.15-0.6	LiF Vacuum evaporation	3.2×10 ⁴ (0.55MeV)
⁴⁵ Sc(p,n)	-2.84	8-30	Sc Vacuum evaporation	1.0×10 ² (8keV)

Neutron production target

- Target cell

- Gas target

- Target gas is sealed
 - The cell has thin window
 - Harvor-foil 2.2 μm
 - Mo foil 5 μm

- Ti-T target

- Ti-T metal foil is supported by double tubes

- Vacuum evaporation target

- LiF, Sc

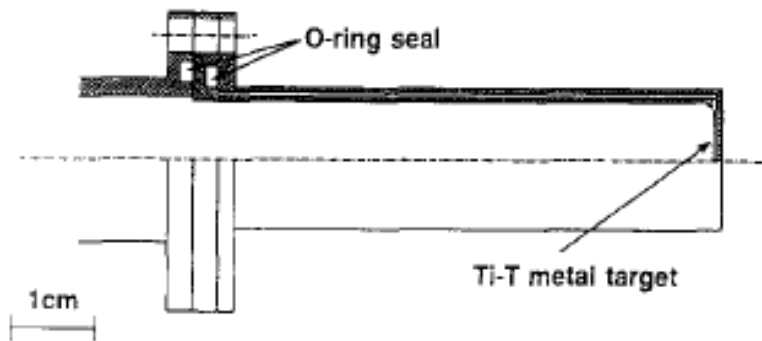
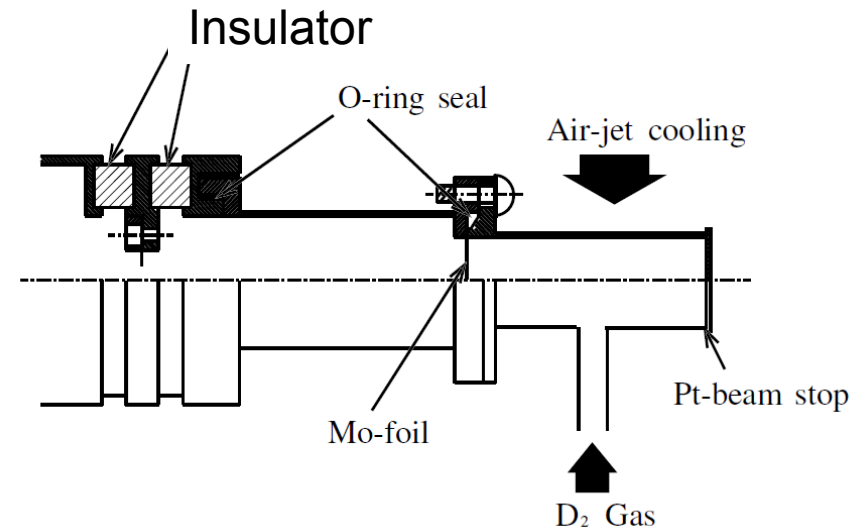
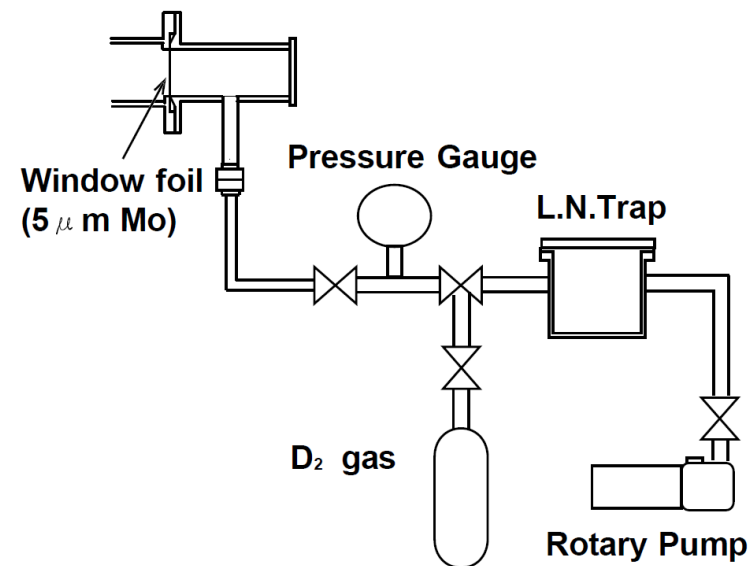


Fig. 3. Schematic view of the target chamber of a T-Ti target.

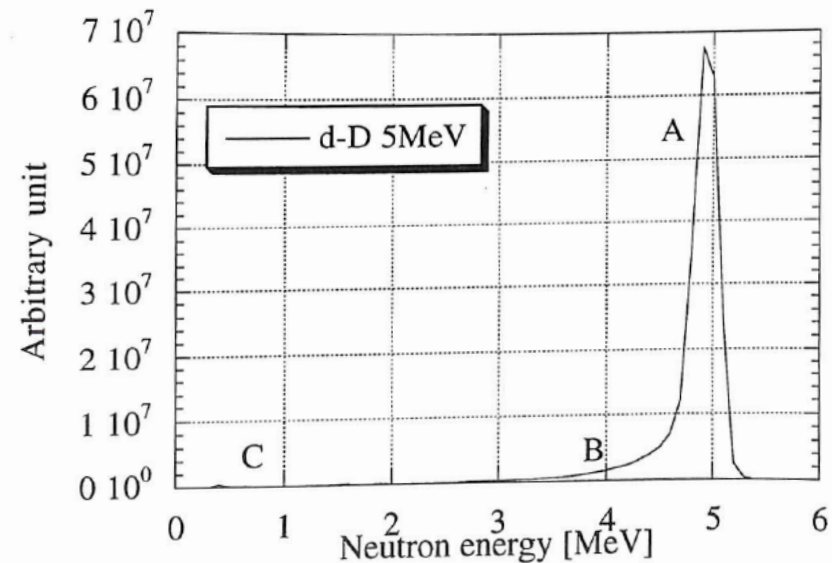
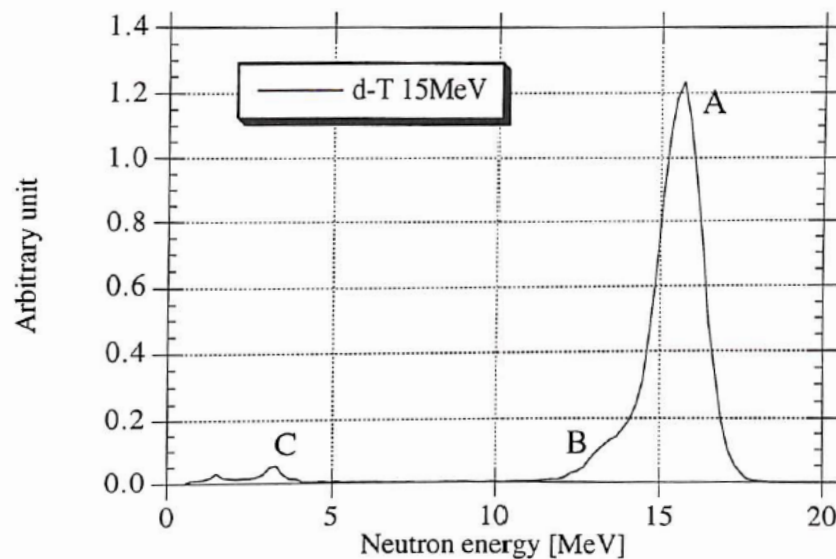
M. Baba et al. / Nucl. Instr. and Meth. in Phys. Res. A 376 (1996) 115–123



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Neutron energy spectrum



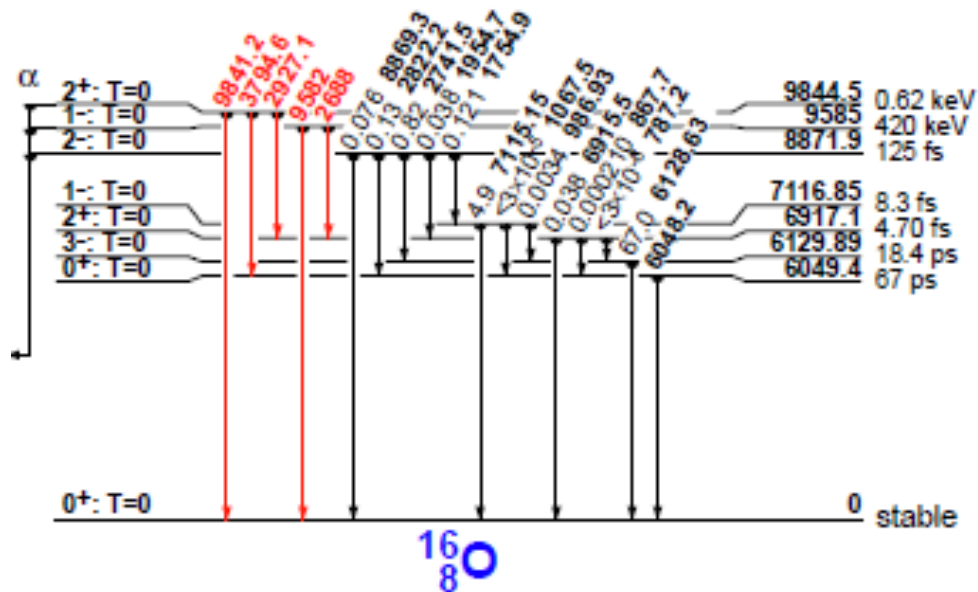
M. Baba et al. / Nucl. Instr. and Meth. in Phys. Res. A 376 (1996) 115–123

- Measured by neutron time-of-flight
 - NE213 liquid scintillator, 2" in diameter and 2" length
- d-T
 - Commercially available tritium loaded Ti foil
 - 1.5 MeV D_3^+ ion
- d-D
 - 5 μm Mo window, 1 atm

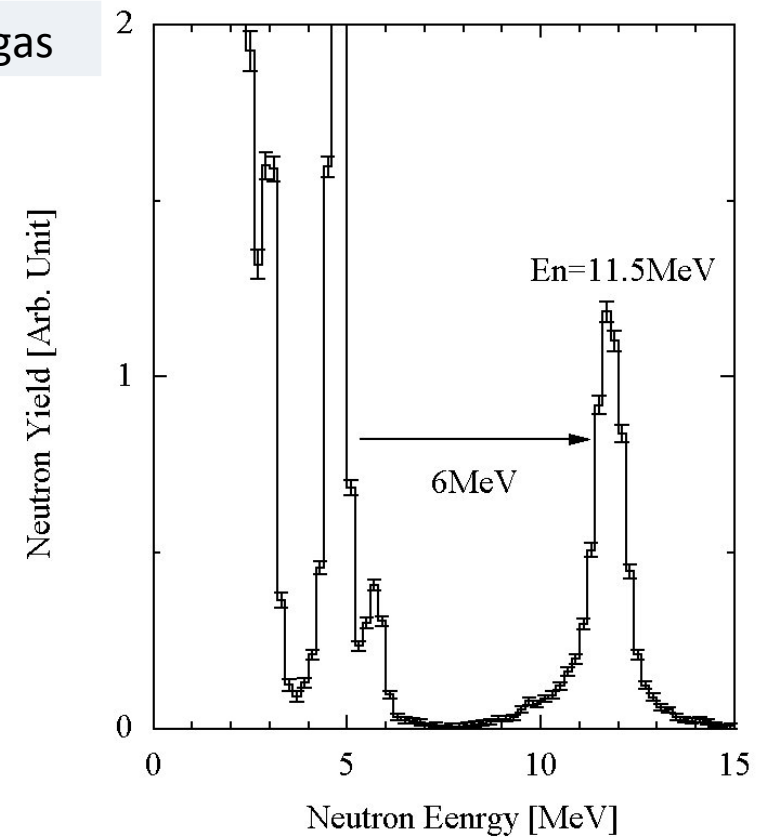
Neutron between 6 to 14 MeV

- 7.7 and 11.5 MeV quasi-mono energetic source
 - ^{15}N , ^{14}N gas target with deuteron beam

Reaction	Q-value	Neutron energy	Target
$^{15}\text{N}(\text{d},\text{n})^{16}\text{O}$	9.90 MeV	11.5 MeV	$^{15}\text{N}_2$ gas
$^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$	5.07 MeV	7.7 MeV	$^{14}\text{N}_2$ gas



Tables of isotopes 6th edition

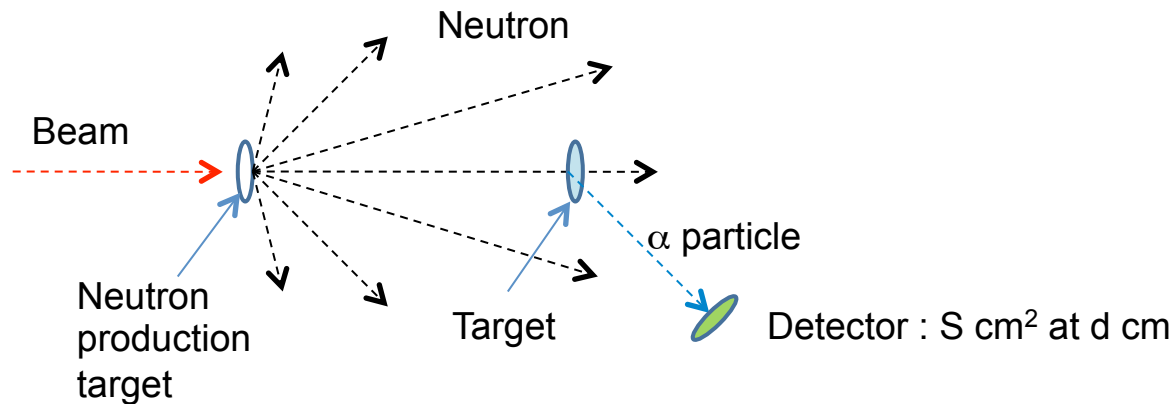


How can we measure the DDX

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How to measure α particles

- Total production only
 - Activation method (Residual should be radioactive)
 - Helium accumulation
- Double differential cross section
 - Counter telescope
 - Si semiconductor detector, scintillator



- Background (Proton, neutron, γ)
- Solid angle

Parameter for target preparation

- Production rate
- Energy resolution
- Background

- Thin target
 - Low count rate
 - High energy resolution
 - Backing foil

- Thick target
 - High count rate
 - Degrade energy resolution
 - Self support

- Target thickness should be chosen with considering experimental condition

Yield estimation

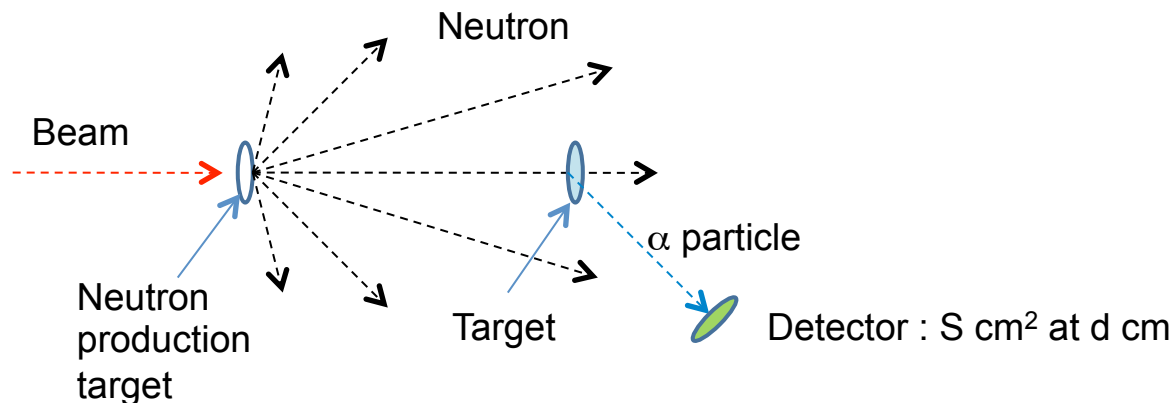
- Production rate
 - Cross section 1 [barn]
 - Neutron flux 2.2×10^4 [n/cm²/s]
 - » d-D neutron source, 1 μ A beam
 - Target thickness 1 μ m
 - Material Ni($\rho=8.9$ gcc, $A=58$)
 - » 9.2×10^{18} [# /cm²]

$$Y = N\sigma\phi \qquad Y = 0.20 \text{ [# /cm}^2\text{/s]}$$

which corresponds 720 events/hour in 4π solid angle

Solid angle

- Solid angle subtended by a detector
 - Charged particle detector has $\sim 500 \text{ mm}^2$ ($= 1''$ in diameter)
 - Trade-off between solid angle and angular resolution
- Assuming 500 mm^2 detector at 10 cm away from the target
 - Solid angle : 0.05 [sr]
 - Angular width : $\pm 7.2 \text{ degree}$
 - » Count rate goes down to 36 cts/hour



Energy loss in target

- Energy loss of charged particles

$$-\frac{dE}{dx} = \frac{4\pi e^4 z^2}{m_e v^2} \frac{N_0}{A} \rho Z \left\{ \ln \frac{2m_e v^2}{I} - \ln(1 - \beta^2) - \beta^2 \right\}$$

<http://www.srim.org/>

- α particle up to 10 MeV $\beta < 0.073$

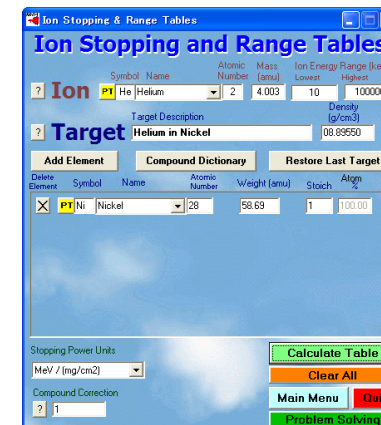
- Thus energy loss is

- Proportional to z^2 , Inverse proportional to v^2

- Range-Energy data from data table or SRIM code

α in Ni..... 4.5 MeV 8.04 μm , 5.0 MeV 9.23 μm

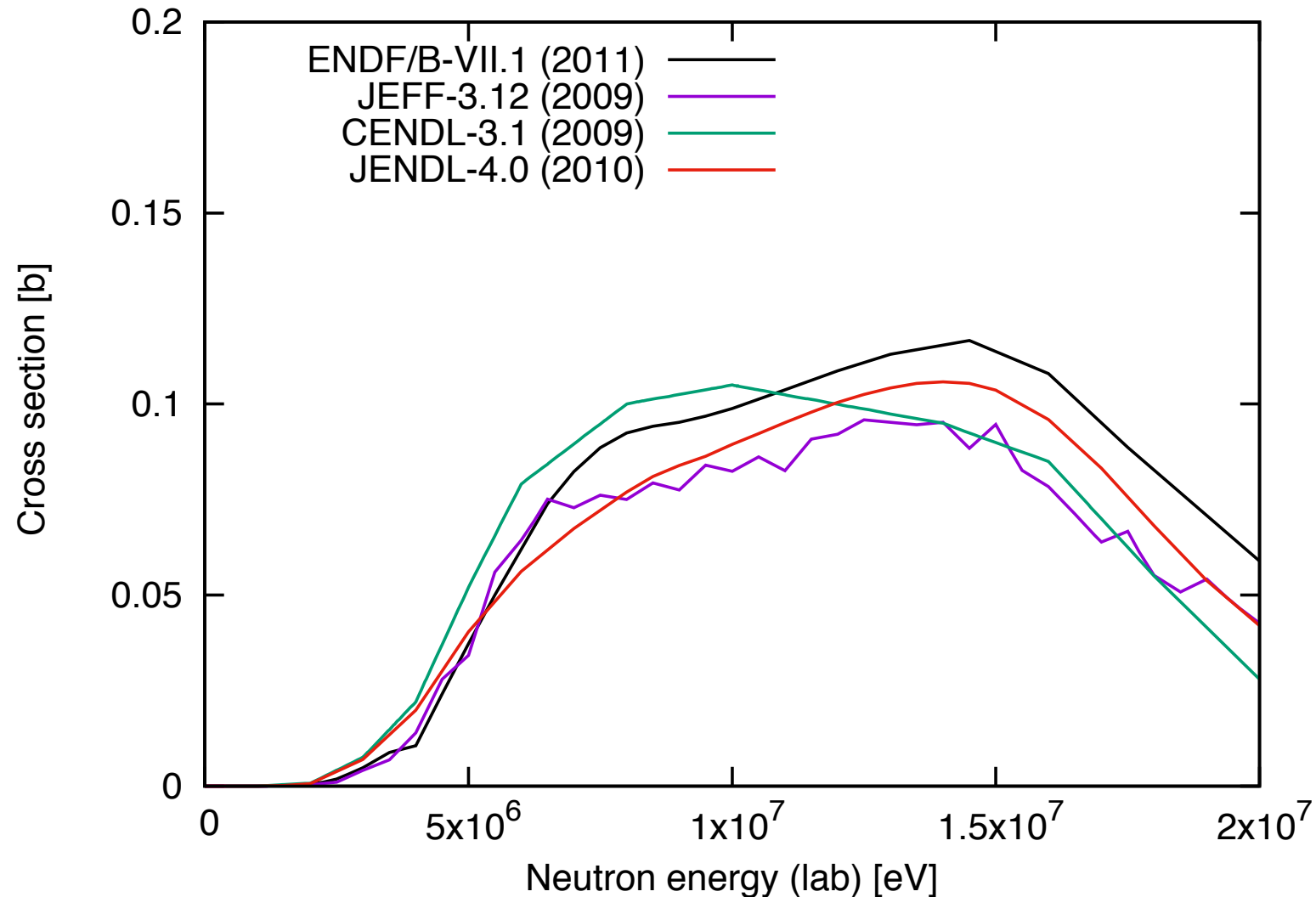
→ 5 MeV α particle lose 0.5 MeV for 1 μm in thickness Ni foil



Helium production cross section

- The cross section is around 0.05-0.1 barn
- Starts at a few MeV

<http://www.ndc.jaea.go.jp/index.html>



Yield estimation for (n,α) reaction

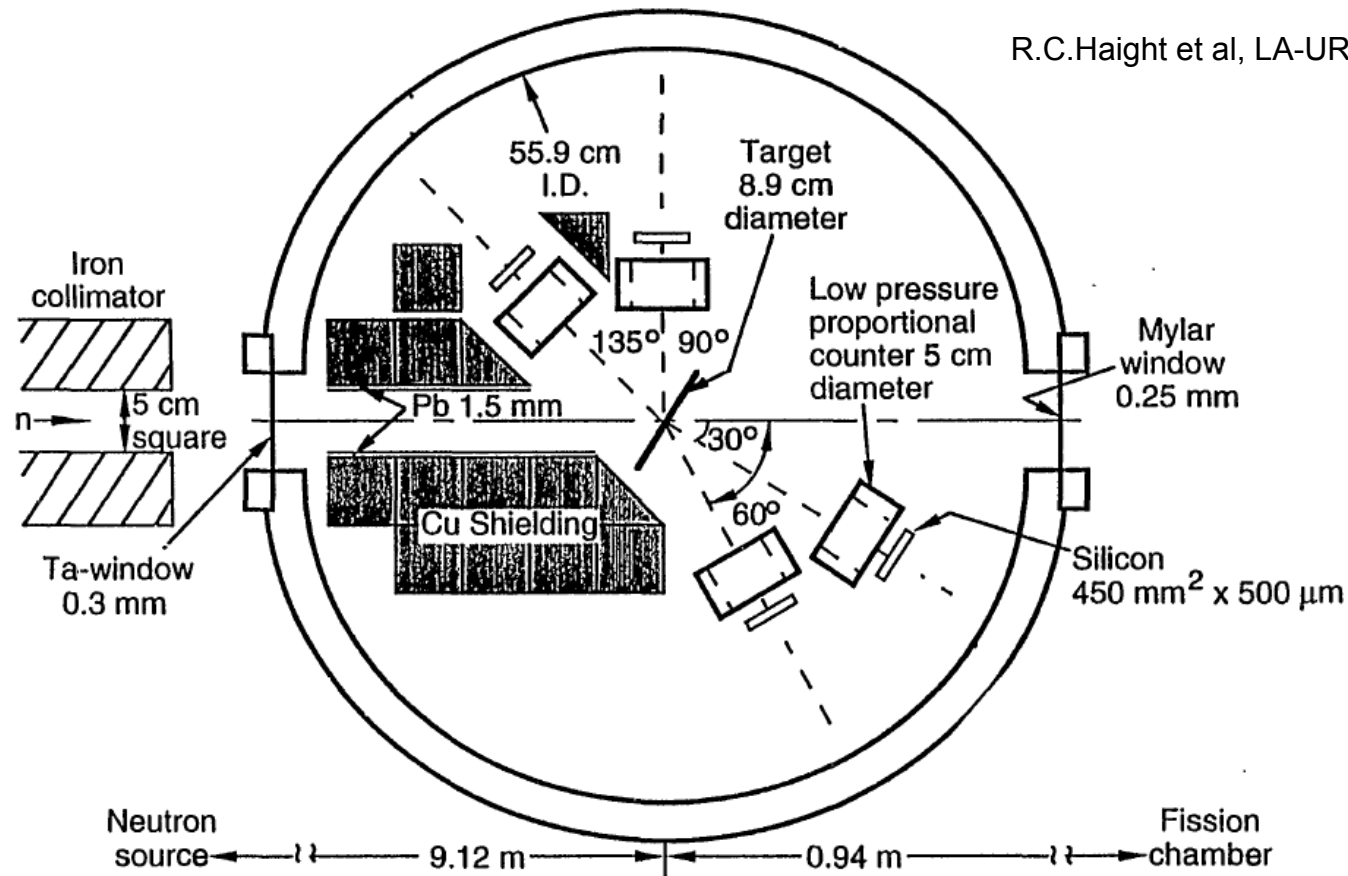
- Production rate
 - Cross section 0.1 [barn]
 - Neutron flux 6.6×10^4 [n/cm²/s]
 - » d-D neutron source, 3 μ A beam
 - Target thickness 0.25 μ m
 - » $Y=0.015$ [# /cm²/s] for 4π [sr]
- Solid angle
 - 0.05 [sr] for typical counter
 - » $Y = 0.2$ cts/hour
- This fact is main motivation to use Gridded Ionization Chamber
 - 4π [sr] counting, $Y = 54$ cts/hour
- Or intense neutrons source
 - LANSCE-WNR

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ΔE -E telescope

R.C.Haight et al, LA-UR 95-4297



- 800 MeV proton on tungsten target
- 90 degree course for 1-50 MeV neutron
- Proportional counter, SSD, CsI(Tl)

Particle identification

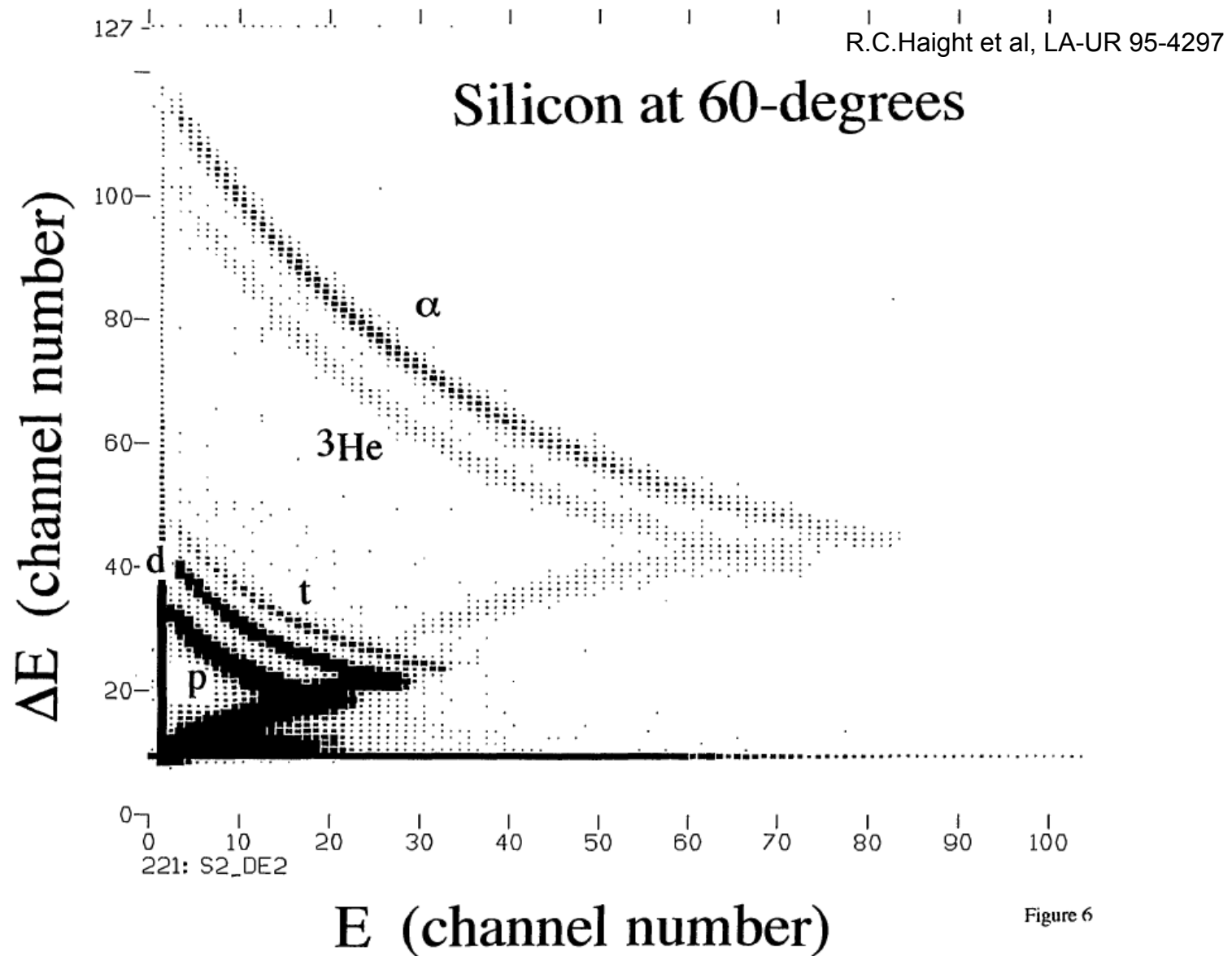
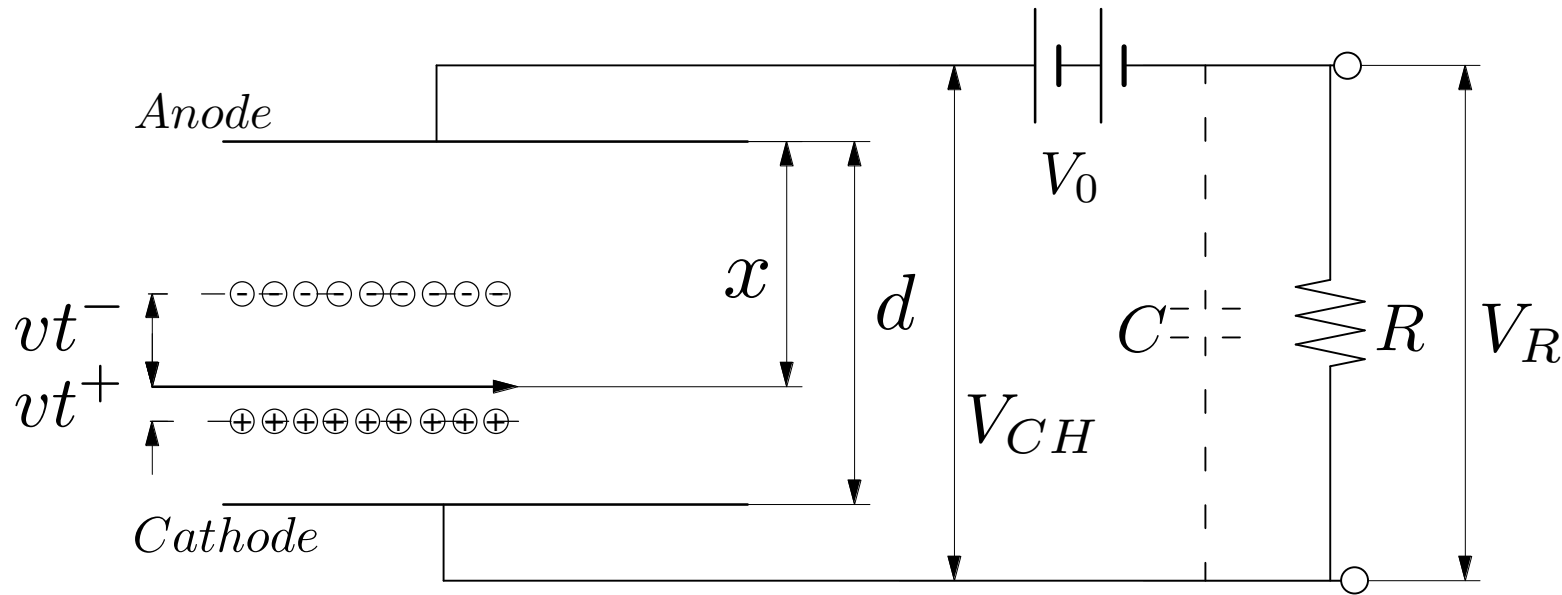


Figure 6

What is Gridded Ionization Chamber ?

- Parallel plate, pulse mode ionization chamber with grid
 - Ionization chamber
 - Output signal depends on the position of interaction
 - Gridded ionization chamber
 - Remove the dependency by introducing grid
 - To apply Gridded ionization chamber for DDX measurement
 - Install sample on the cathode
 - Combine anode and cathode signals to deduce E and θ

Ion chamber



G.F.Knoll, Radiation detection and measurement, Third edition

C : Capacitance of ion chamber and associated stray capacitance

V_0 : Applied voltage

n_0 : Number of ion pairs

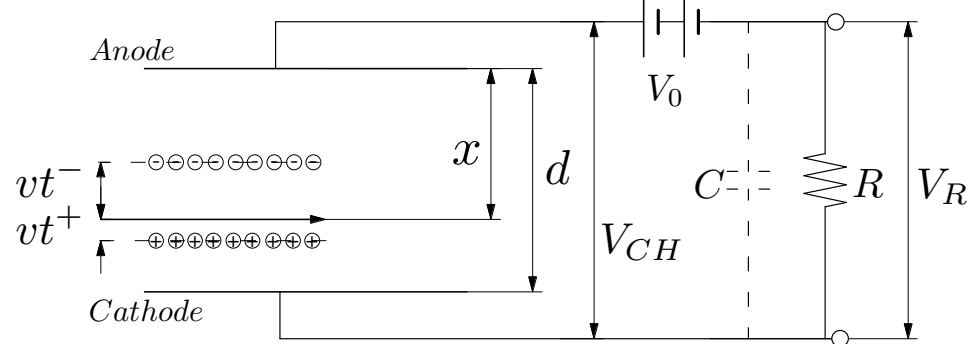
E : Electric field between electrodes

v^+t : Distance of ion traveling

V_{ch} : Voltage difference between electrodes

Ion chamber output

- Output of parallel plate ionization chamber



Energy conservation law

$$\underbrace{\frac{1}{2}CV_0^2}_{\text{Initial energy}} = \underbrace{n_0eEv^+t}_{\text{Energy for ion drift}} + \underbrace{n_0eEv^-t}_{\text{Energy for electron drift}} + \underbrace{\frac{1}{2}CV_{ch}^2}_{\text{Remaining energy}}$$

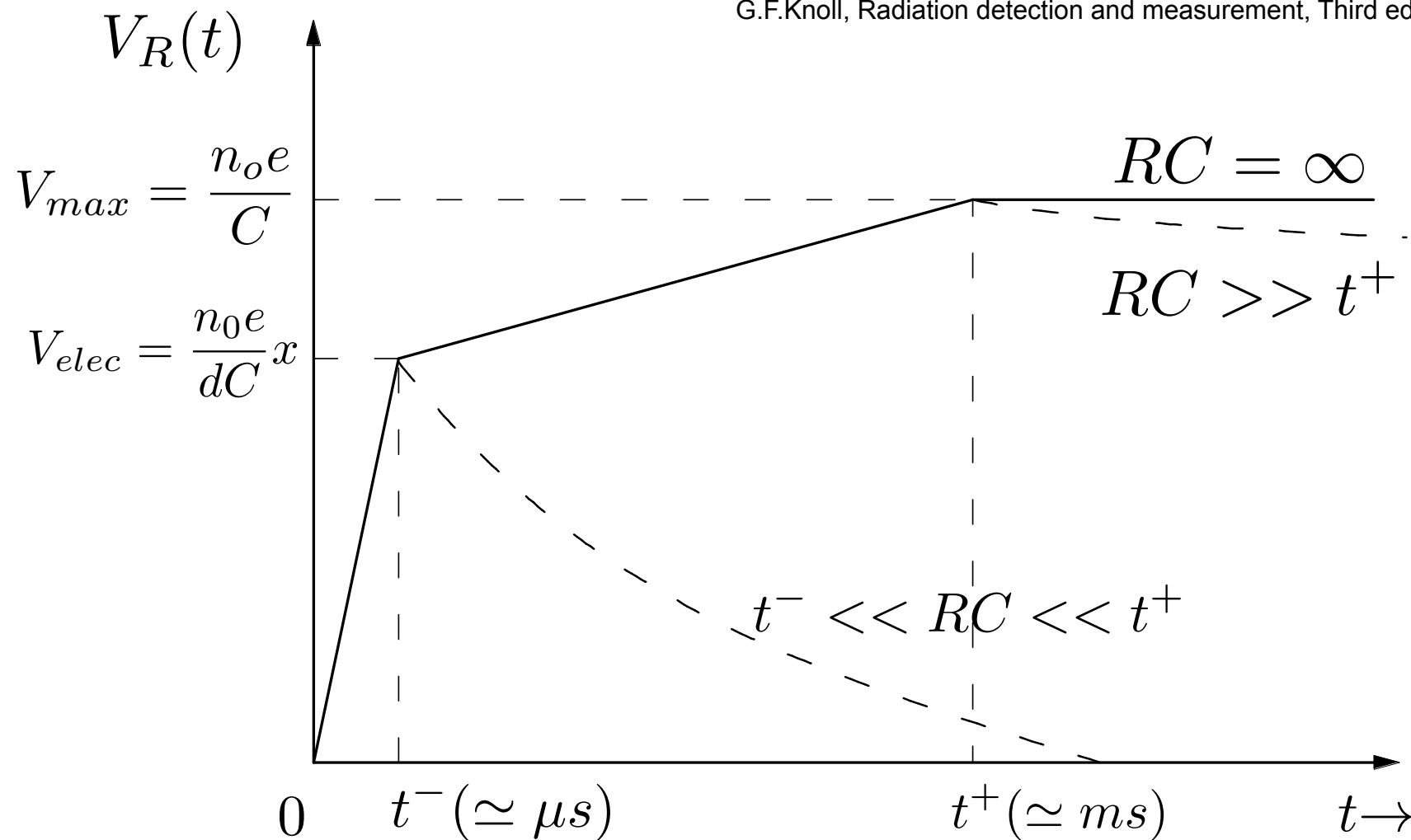
Approximation of $V_0 + V_{ch} \cong 2V_0$ $\frac{V_{ch}}{d} \cong \frac{V_0}{d}$

and $V_0 - V_{ch} = V_R$

$$V_R = \frac{n_0e}{dC} (v^+ + v^-) t$$

Output of parallel plate ionization chamber

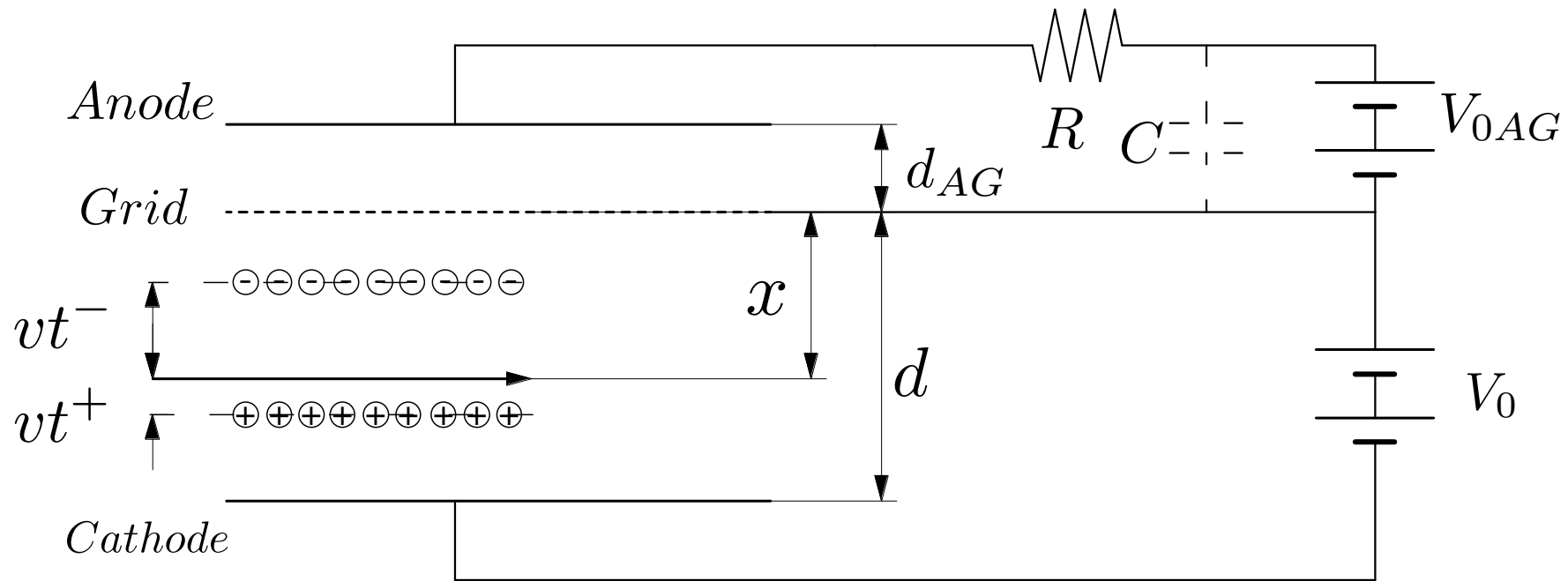
G.F.Knoll, Radiation detection and measurement, Third edition



$$V_R = \frac{n_0 e}{dC} (v^+ + v^-) t$$

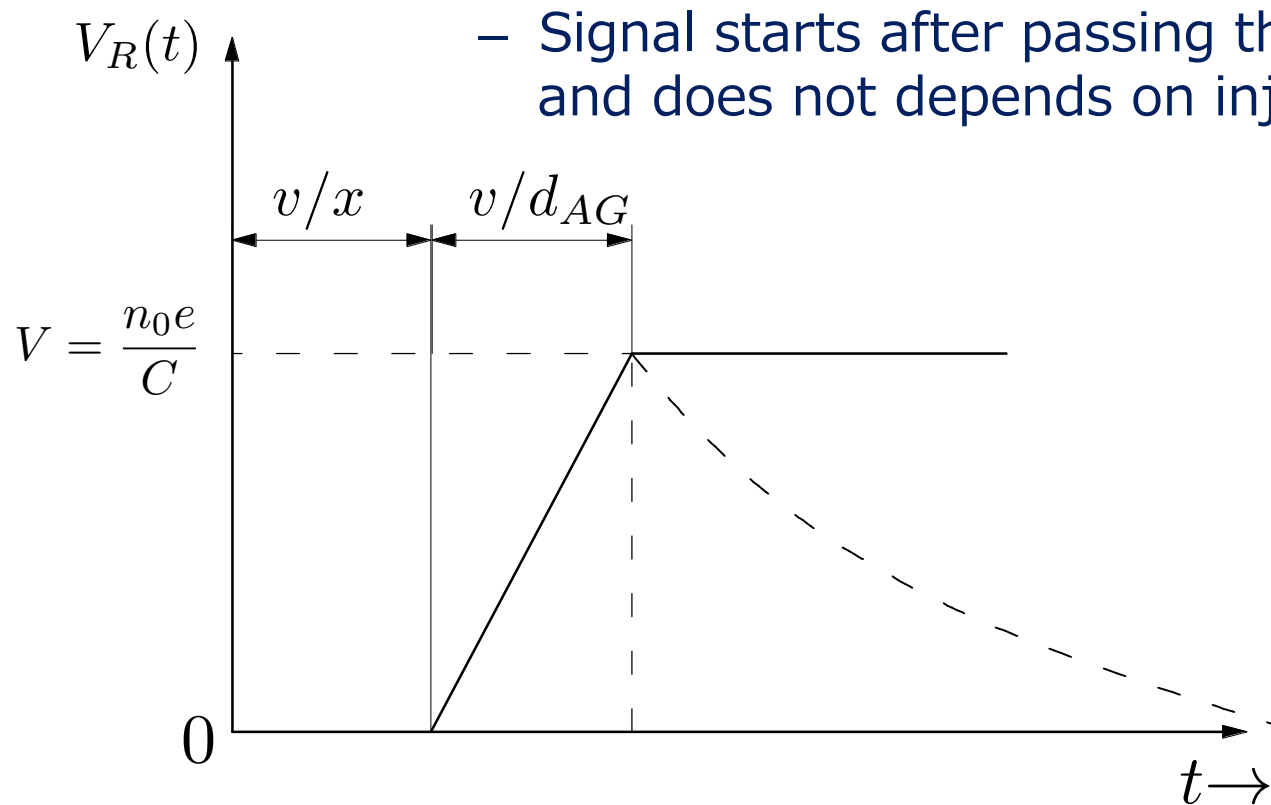
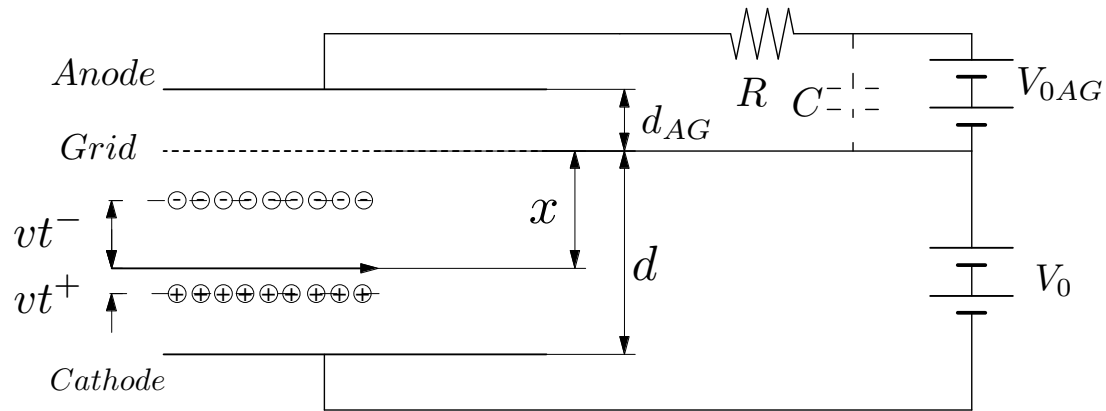
v^+ Ion drift velocity ms/cm
 v^- Electron drift velocity $\mu s/cm$

Gridded ion chamber

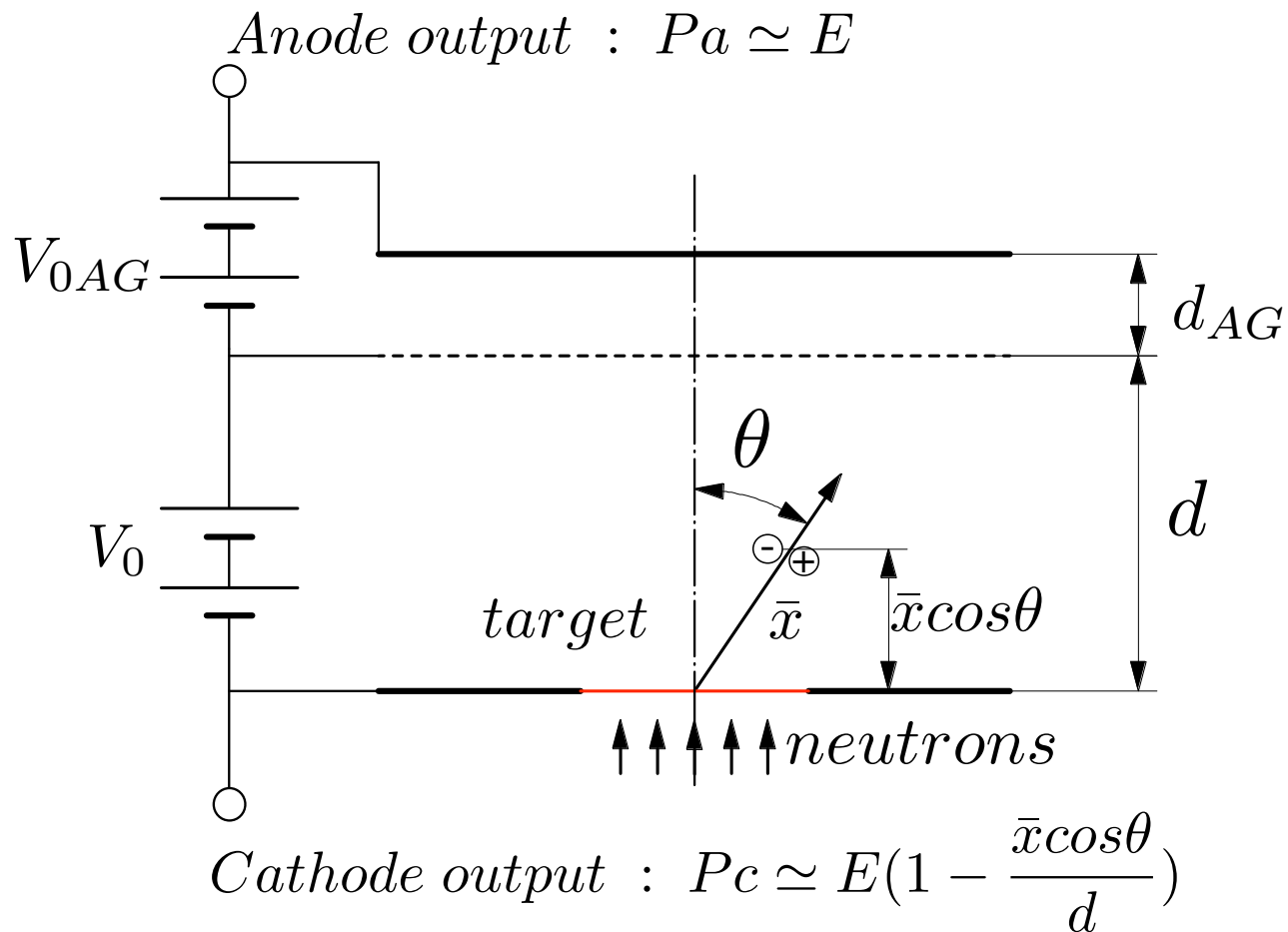


- Add grid in front of anode plate
 - The grid is set to be
 - Transparent to electrons
 - Shield electric field of C-G to A-G
 - Under this condition
 - Electron travel length between A-G does not depends on x

Output of Gridded ion chamber



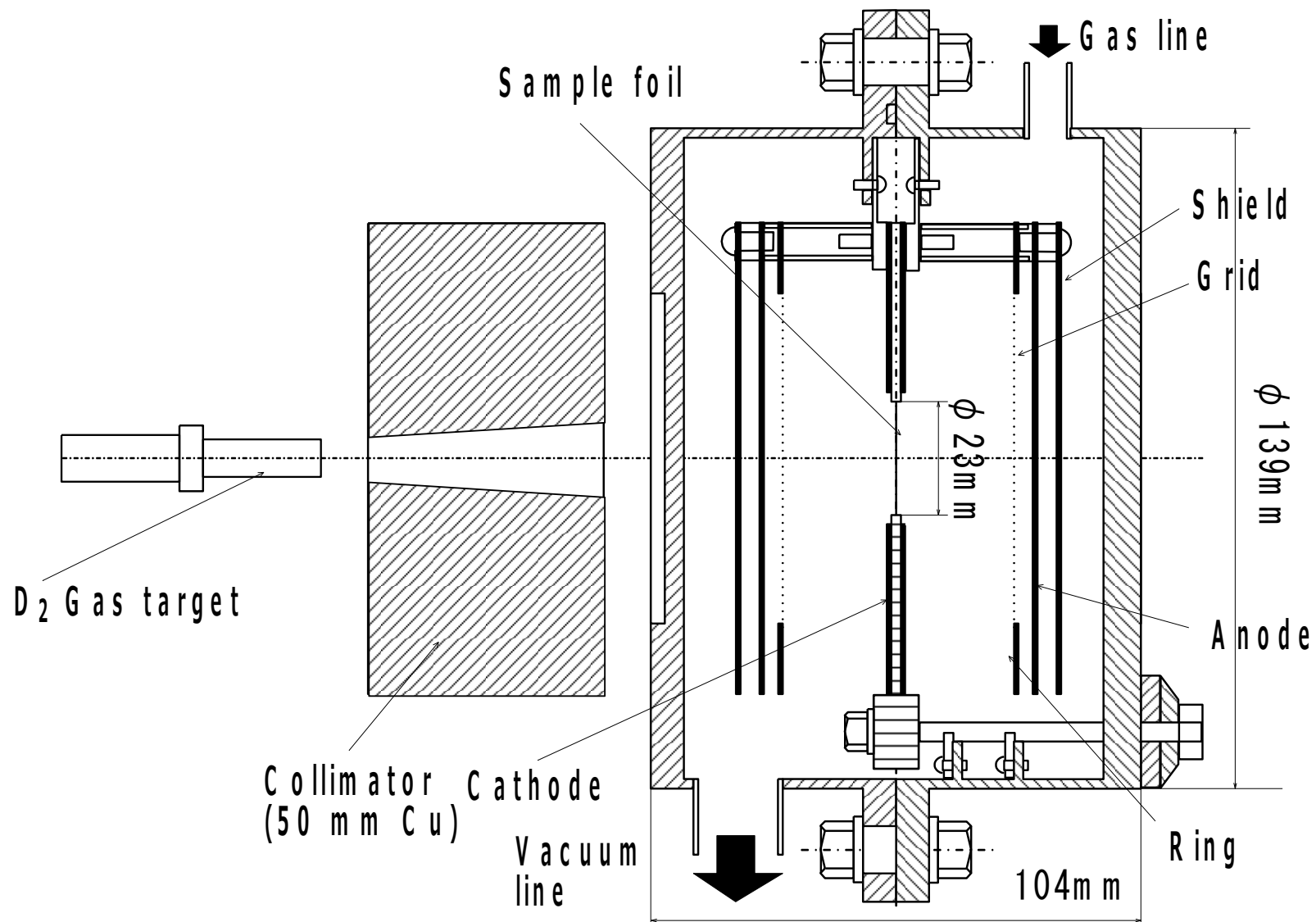
Gridded ionization chamber for neutron DDX



Anode, Cathode simultaneous measurement
→ energy and angle information, noise reduction

Significant large solid angle

Actual preparation of gridded ionization chamber

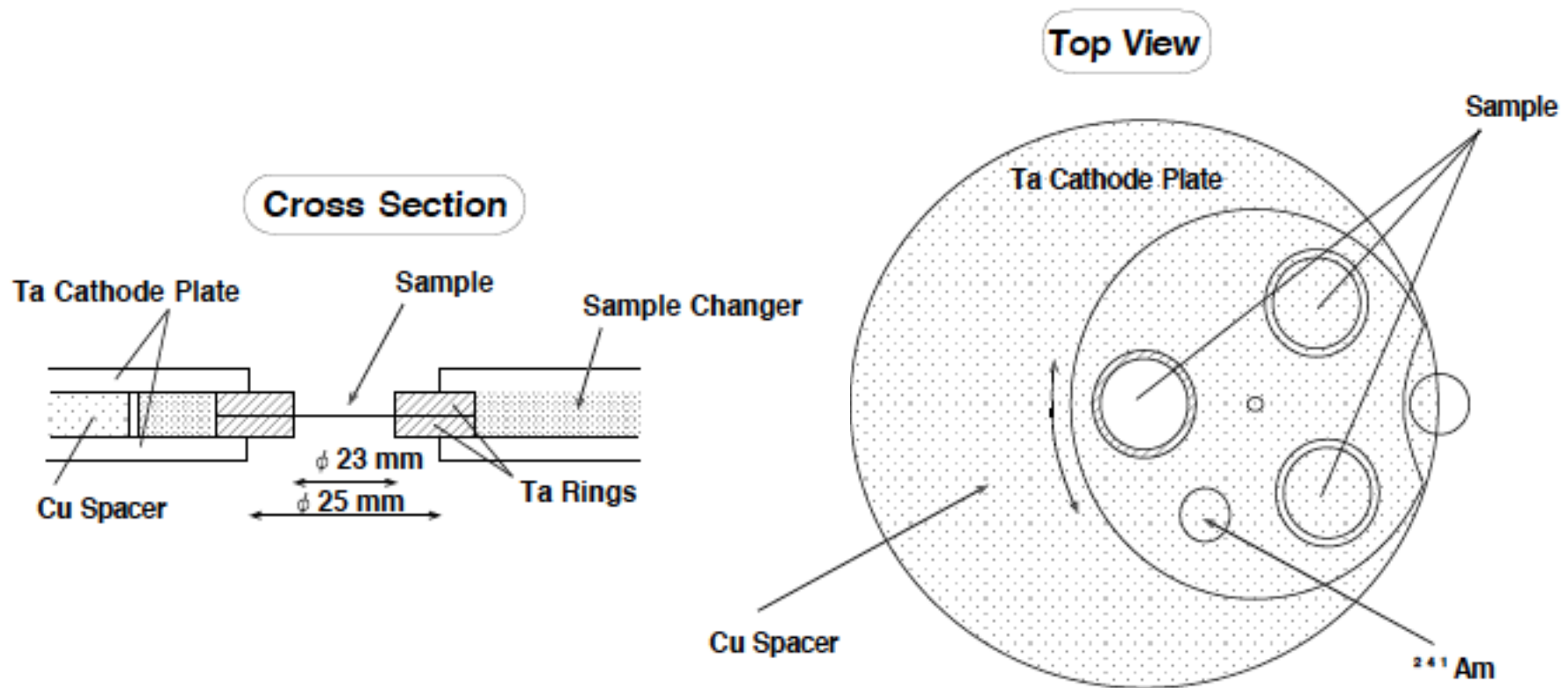


– 4π geometry, Sample changer

T.Sanami, M.Baba, T.Kawano
J. Nucl. Sci Technol 35,851(1998)

Sample changer

- Sample could be changed outside without changing condition



Detector parameters

- Target diameter : 25 mm ϕ
 - Distance between electrodes : 25 mm
 - Diameter of electrode : 75 mm
- Distance between grid and anode : 5 mm
 - Shielding inefficiency

$$\sigma \cong \frac{d_0}{d'} \ln \frac{d_0}{2r_0}$$

d_0 = Wire spacing d' = Distance between anode and grid

r_0 = wire radius

Maximum gas pressure : 10 atm, 0.25 kV/cm/atm

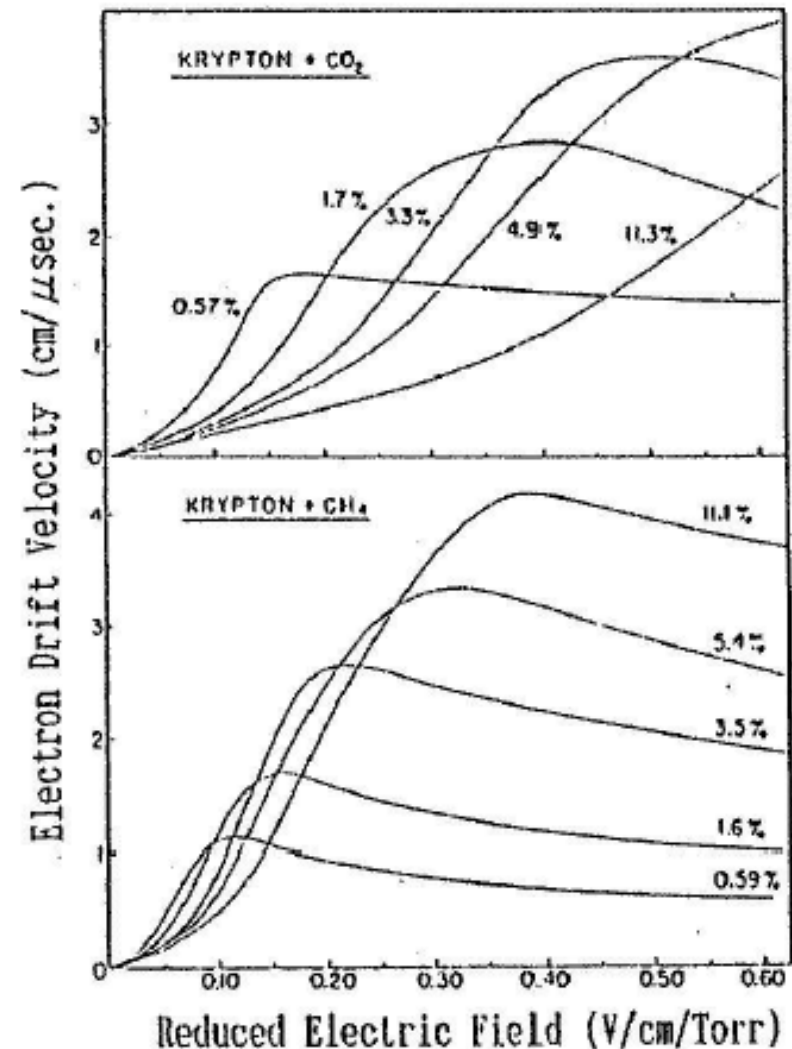
→ 6.25 kV for Grid, 9.4 kV for Anode

→ 3 cm/ μ s, 2 μ s pulse shaping

The gas pressure must be adjusted to the max energy of particle should be measured

Filling gas

- Nobel gas with a few % of molecular gas
 - Avoid electron attachment and recombination
 - Reduce background due to gas induced reaction
- Electron drift velocity
 - 3 cm/ μ s for 0.2 kV/cm/atm
 - ex) 1 atm gas pressure, 5 cm distance, 1 kV at maximum drift velocity.
 - 2 μ s collection time

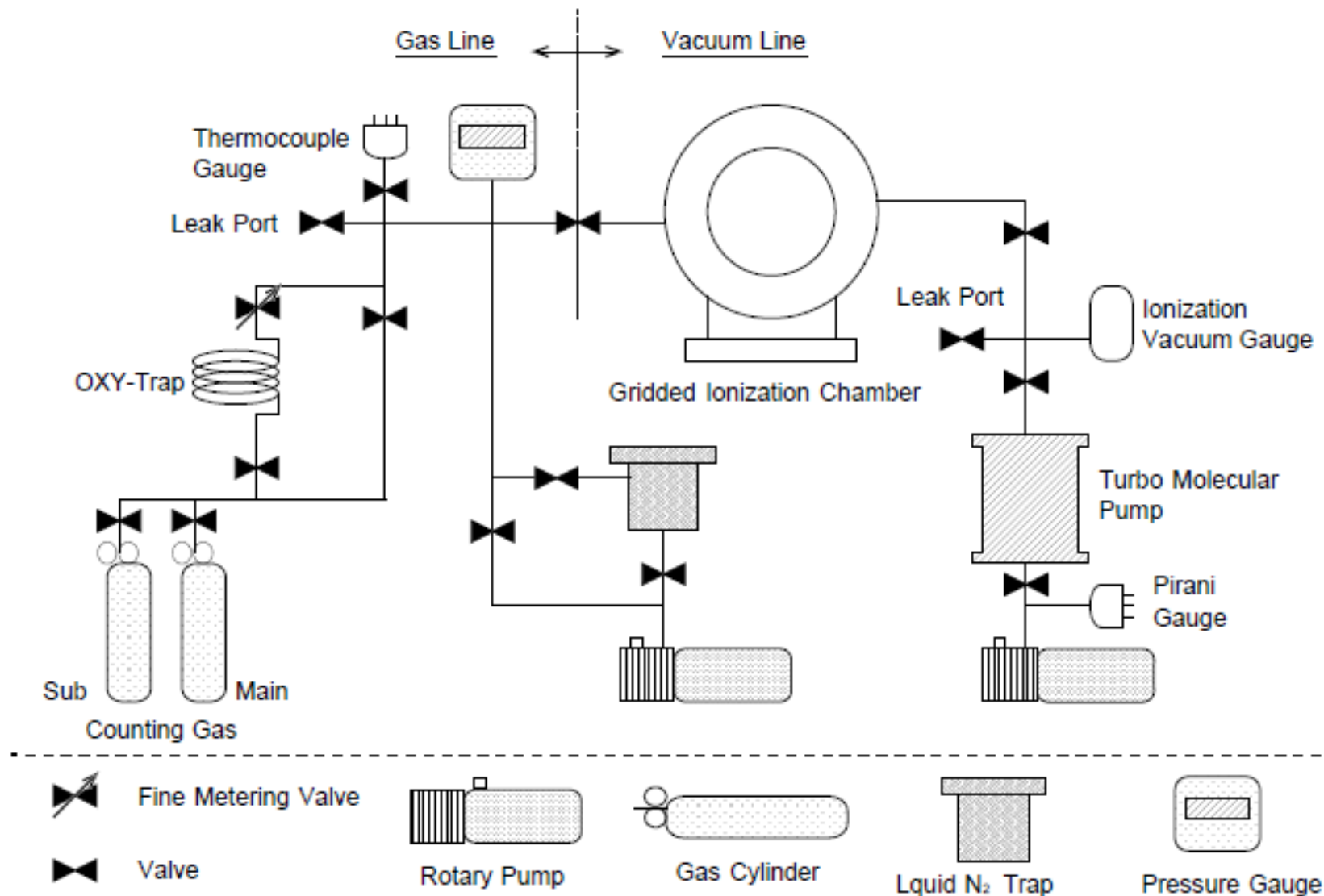


Gas pressure

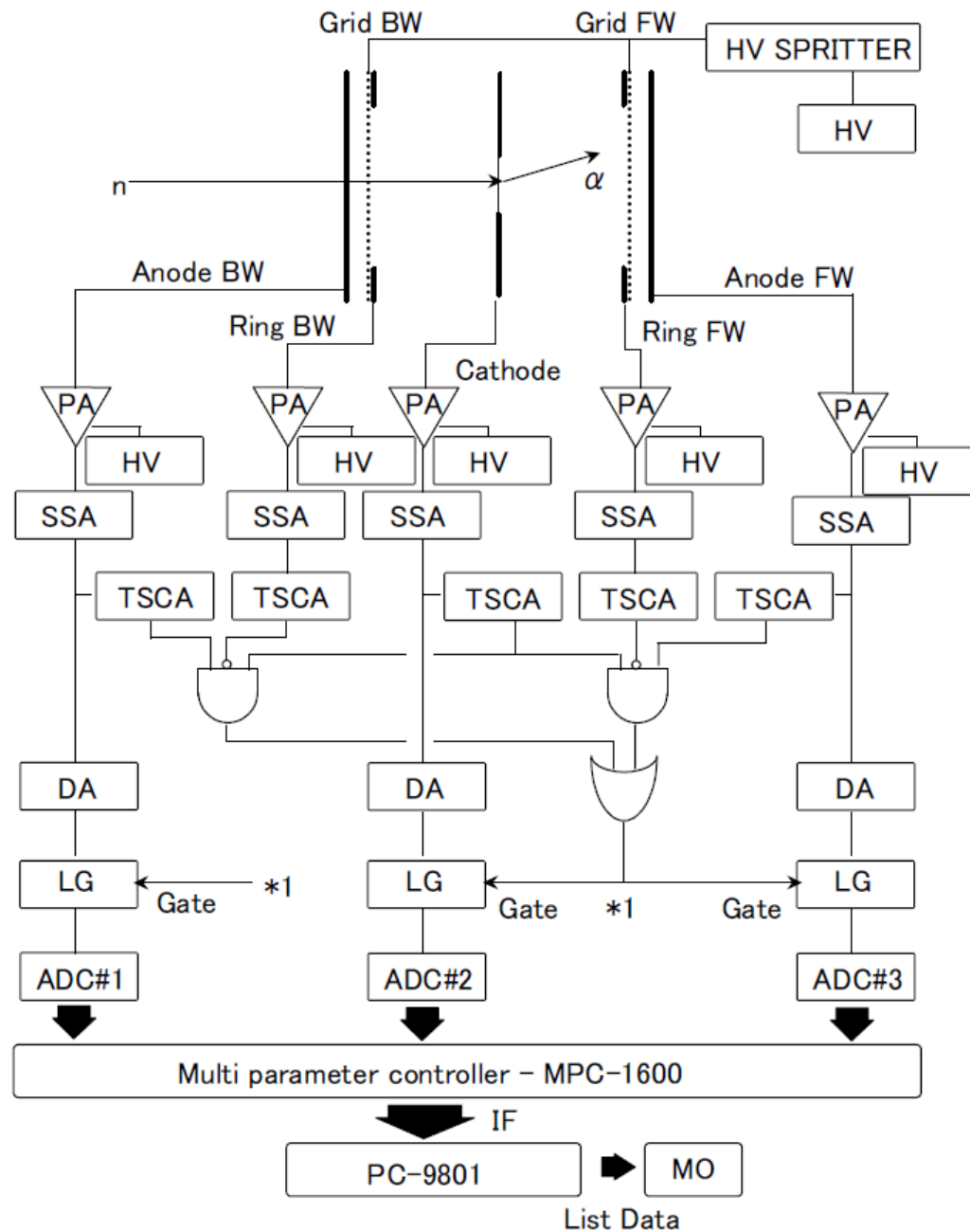
- α particle in Kr-gas
 - $E_a=10$ MeV 69.85 mm in Kr-gas
 - Cathode-grid distance is 25 mm
 - $69.85/25 = 2.8$ atm gas pressure required to stop
 - Under this pressure, 2.5 MeV proton could be stopped.
 - If we use 10 atm Kr-gas, 5.5 MeV proton could be stopped
 - It reduces energy range for α particle
 - Minimum gas pressure should be chosen for measurement

Gas filling system

- High pressure operation



Electronics for data taking



HV : High voltage power supply
 SSA : Spectroscopy amplifier
 DA : Delay amplifier
 IF : Interface
 PA : Preamplifier
 TSCA : Timing single channel analyzer
 LG : Linear gate
 MO : Magnet optical disk drive

Saturation

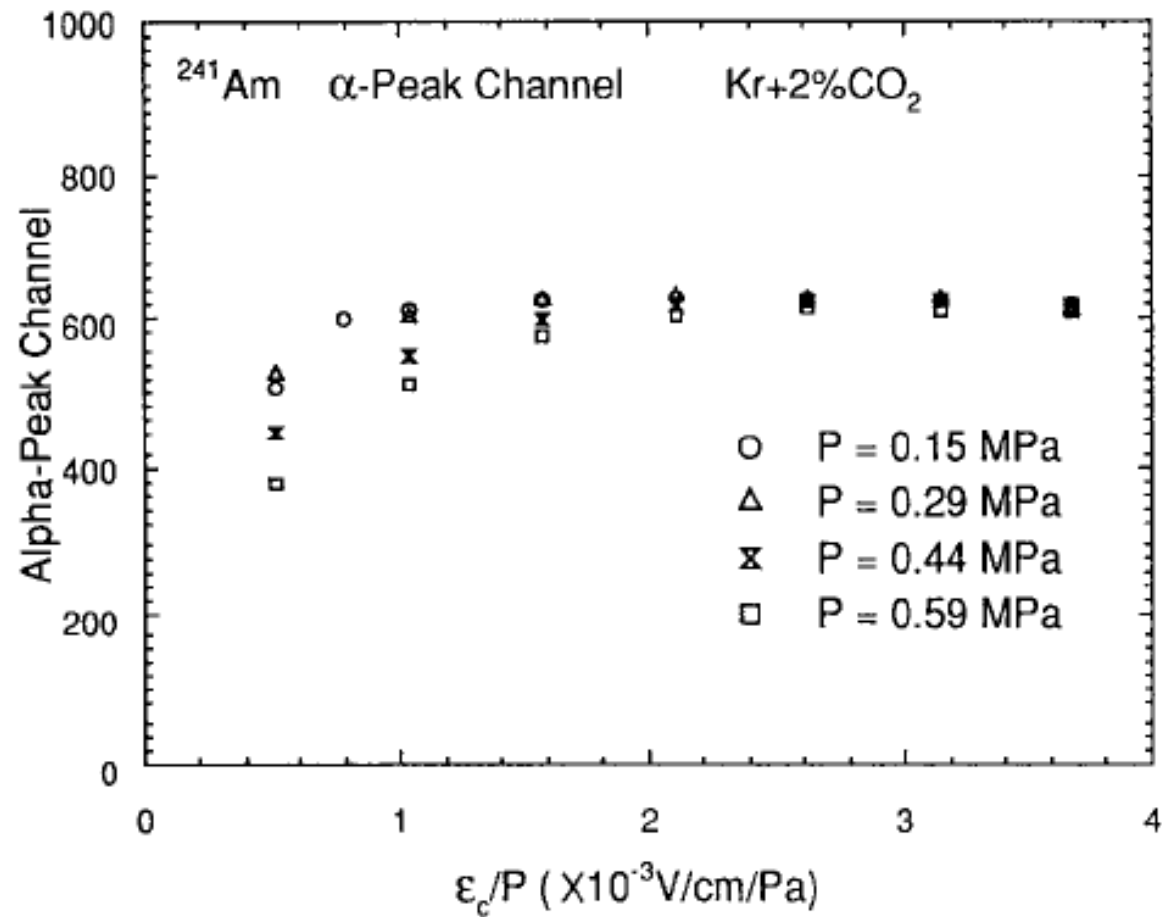
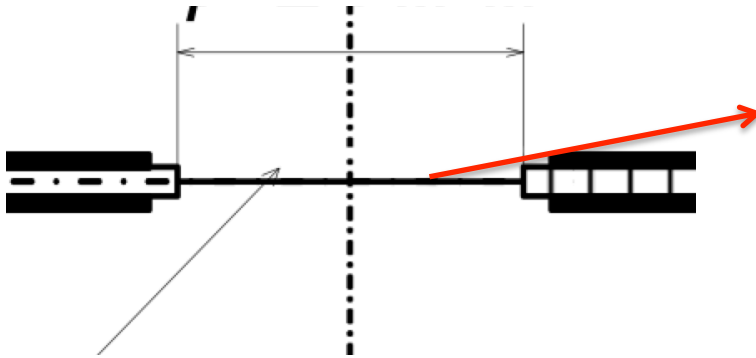


Fig. 9. Saturation curves for Kr + CO₂(2%) counting gas; peak channels for ^{241}Am α -particles are plotted as a function of the reduced field strength (ϵ_c/P) between the cathode and the Frisch-grid.

Geometrical inefficiency

- Angled particles are not detected due to structure around target



- This geometrical inefficiency is compensated using Monte-Carlo calculation
- Experimentally confirmed through $\text{Li}(p,t)\alpha$ reaction

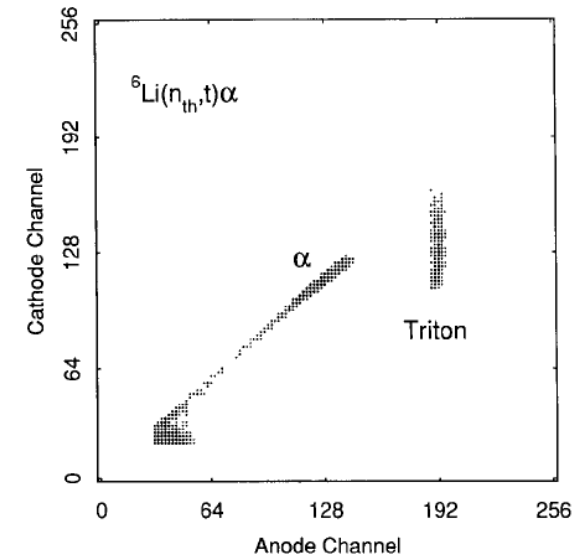


Fig. 8. Two-dimensional spectrum of anode versus cathode for the ${}^6\text{Li}(n_{th}, t)\alpha$ reaction.

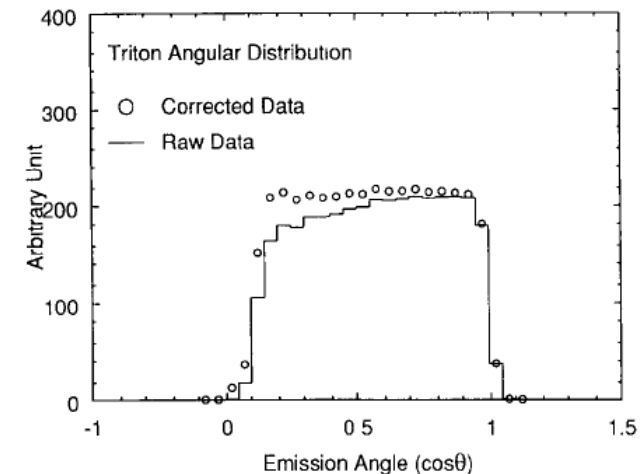


Fig. 10. Triton angular distributions obtained by the Eqs. (3) and (4); histograms and circles present the distributions before and after the correction for the geometrical efficiency, respectively.

Background from counting gas

- **Ar+5%CO₂**
 - O(n,α) $E_{th} = 3 \text{ MeV}$, $Q = -2.2 \text{ MeV}$
 - Ar(n, α) $E_{th} = 5 \text{ MeV}$, $Q = -2.5 \text{ MeV}$
- **Kr+3%CO₂**
 - O(n,α) $E_{th} = 3 \text{ MeV}$, $Q = -2.2 \text{ MeV}$
 - Kr(n,α) $E_{th} = 11 \text{ MeV}$, $Q = -0.4 \text{ MeV}$
- **Kr+5%CH₄**
 - H(n,p) $E_{th} = 0 \text{ MeV}$, $Q = 0 \text{ MeV}$
 - Kr(n,α) $E_{th} = 11 \text{ MeV}$, $Q = -0.4 \text{ MeV}$
- **Chamber and electrode**
 - Ta electrode
 - Ta(n,α) $E_{th} = 13.5 \text{ MeV}$, $Q = 7.6 \text{ MeV}$

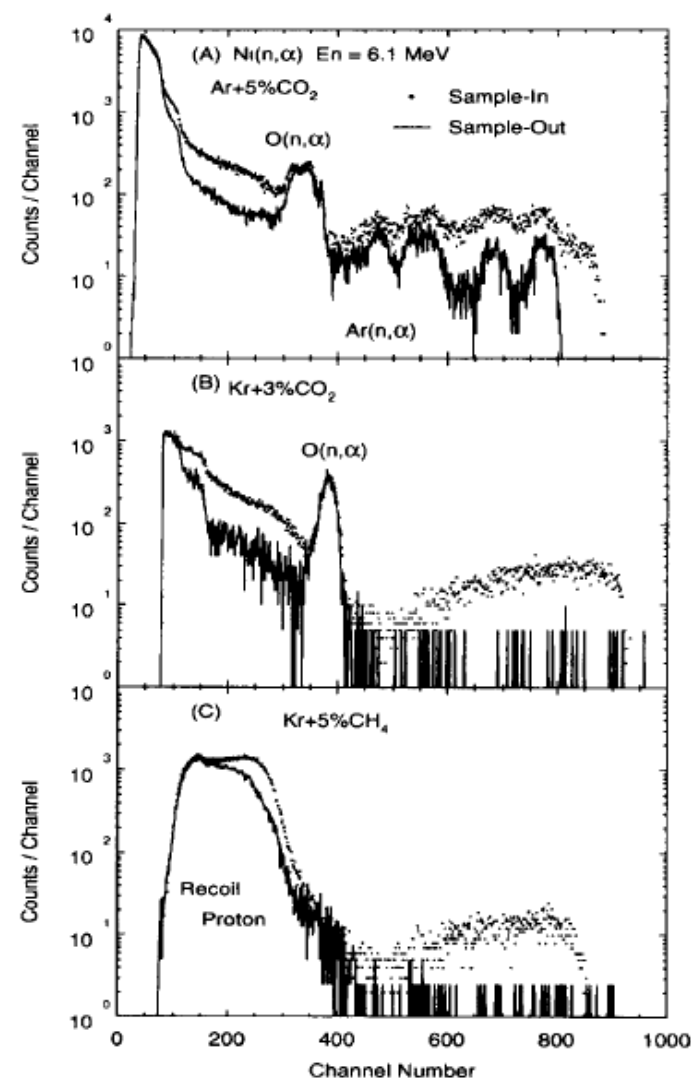
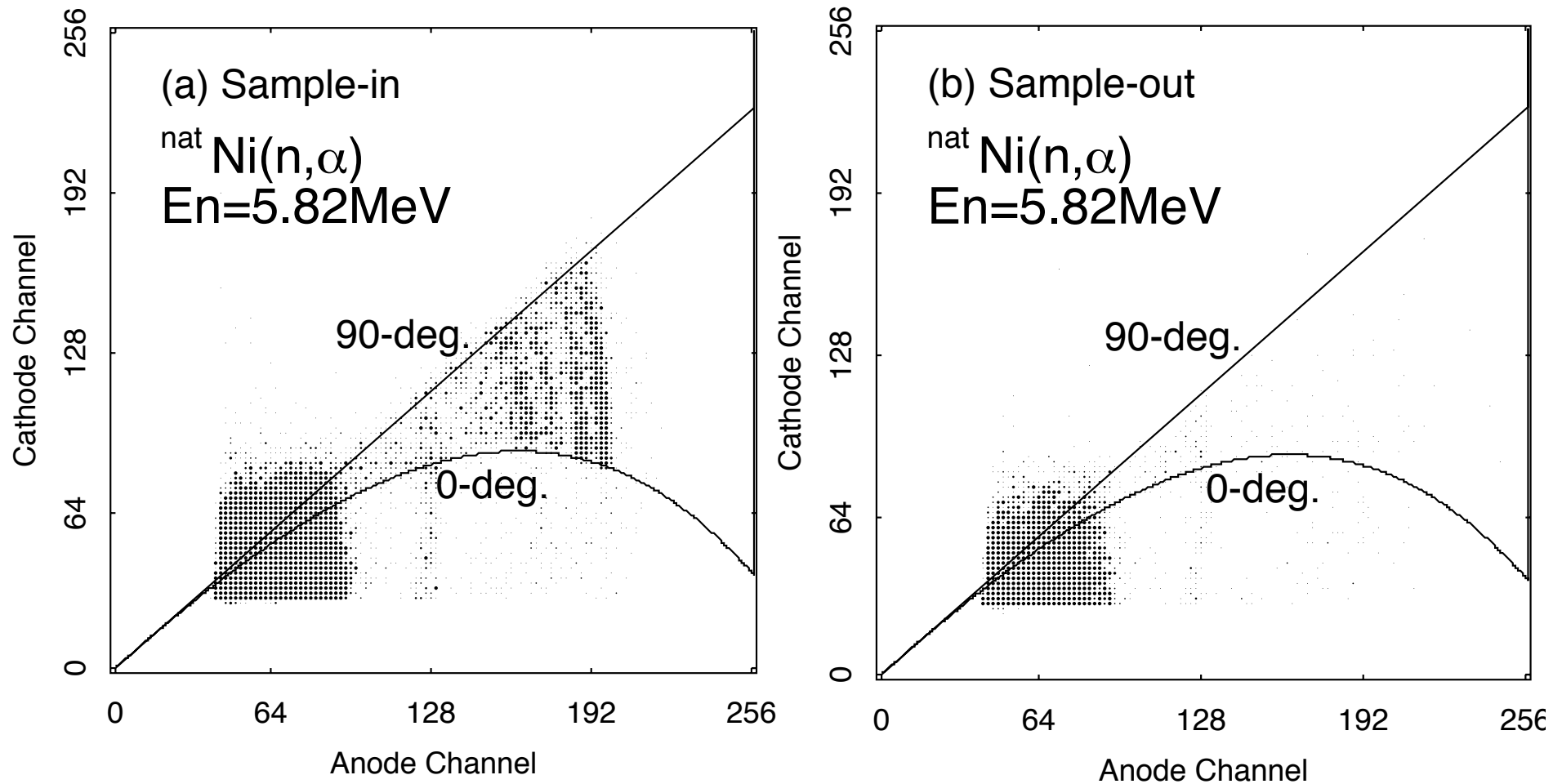


Fig. 5. Typical anode spectra for the measurements of the Ni(n, α) cross section at $E_n = 6.1 \text{ MeV}$; the counting gases are Ar + CO₂, Kr + CO₂ and Kr + CH₄ for (a), (b) and (c), respectively.

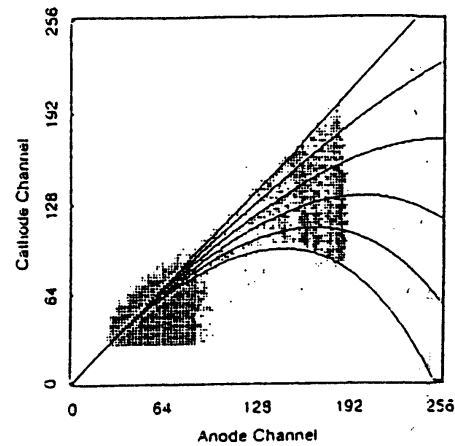
N.Ito, M.Baba, S.Matsuyama, I.Matsuyama, N.Hirakawa, Nucl. Instrum. Meth. A337 (1994) 474-485

2D scatter plot

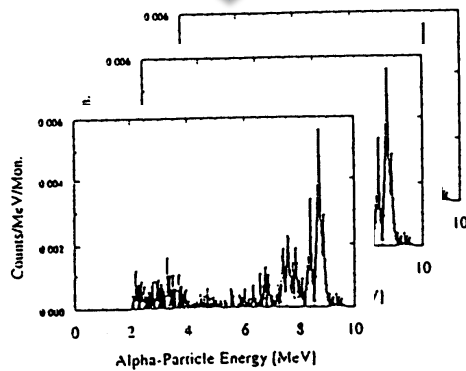
- With target and without target
- 300 $\mu\text{g}/\text{cm}^2$ on 10 μm in thickness Ta foil



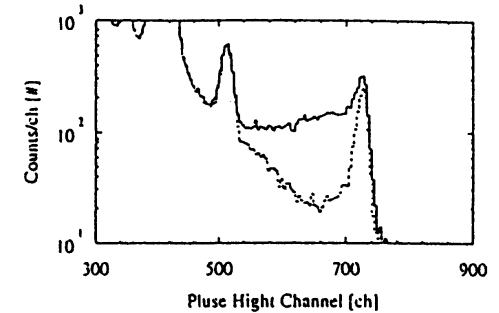
Data analysis



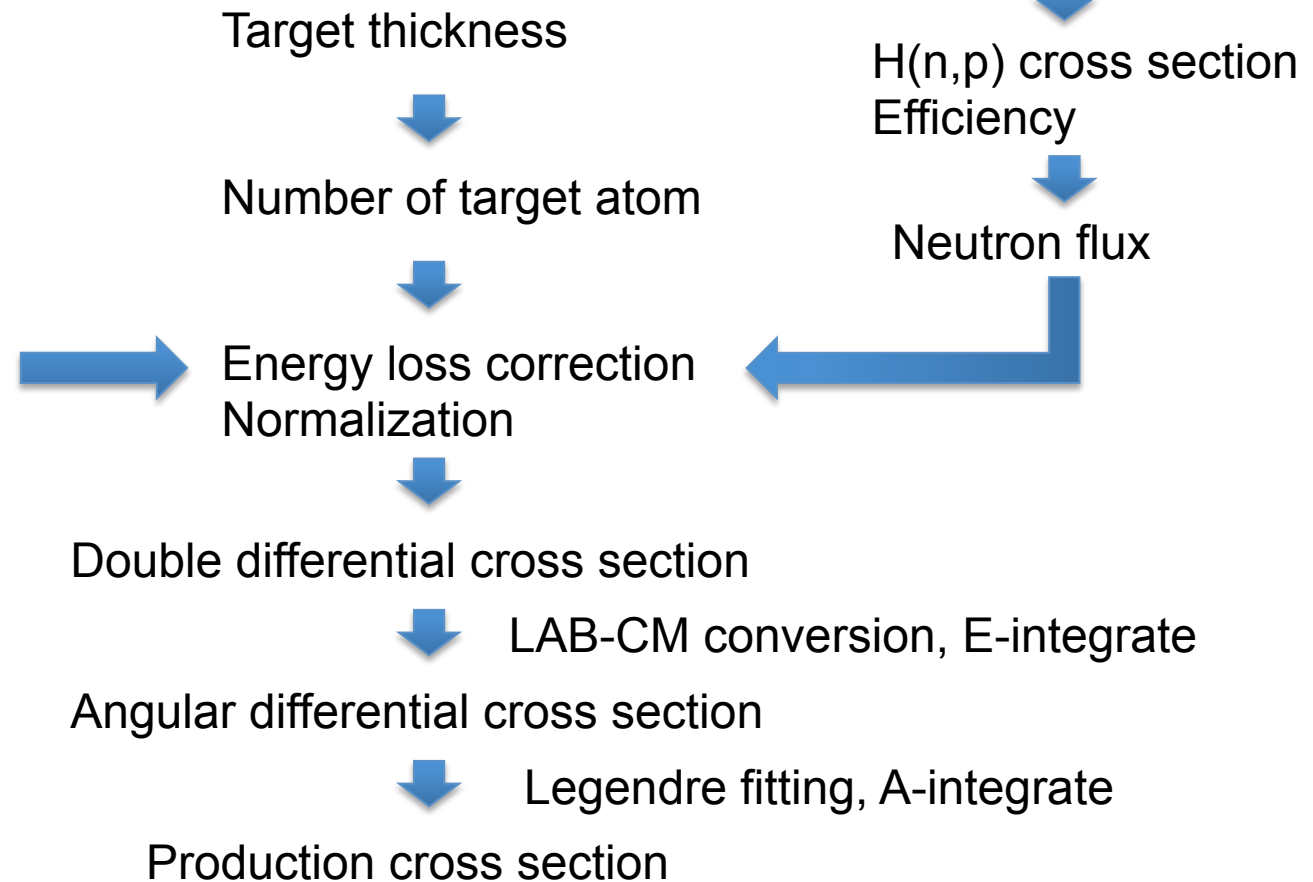
2D sorting



1D spectrum

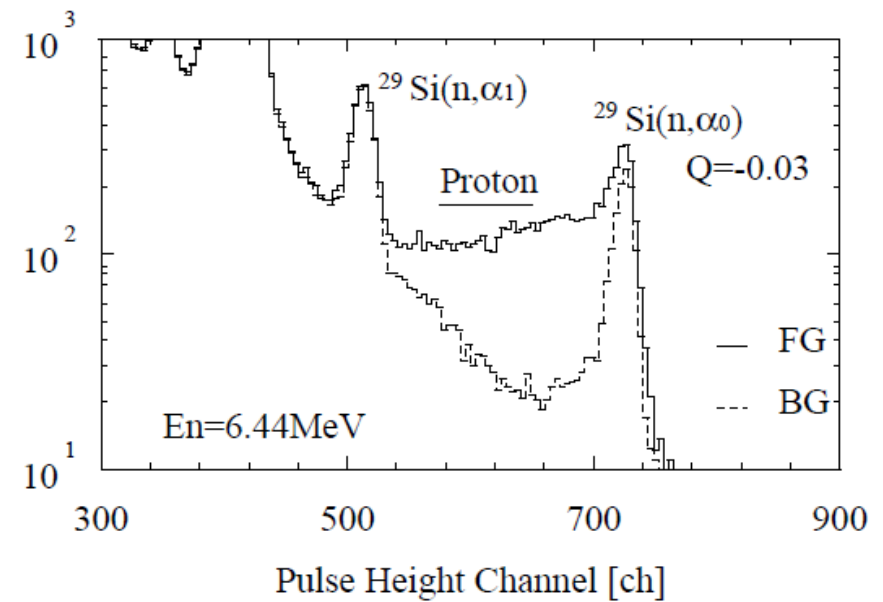
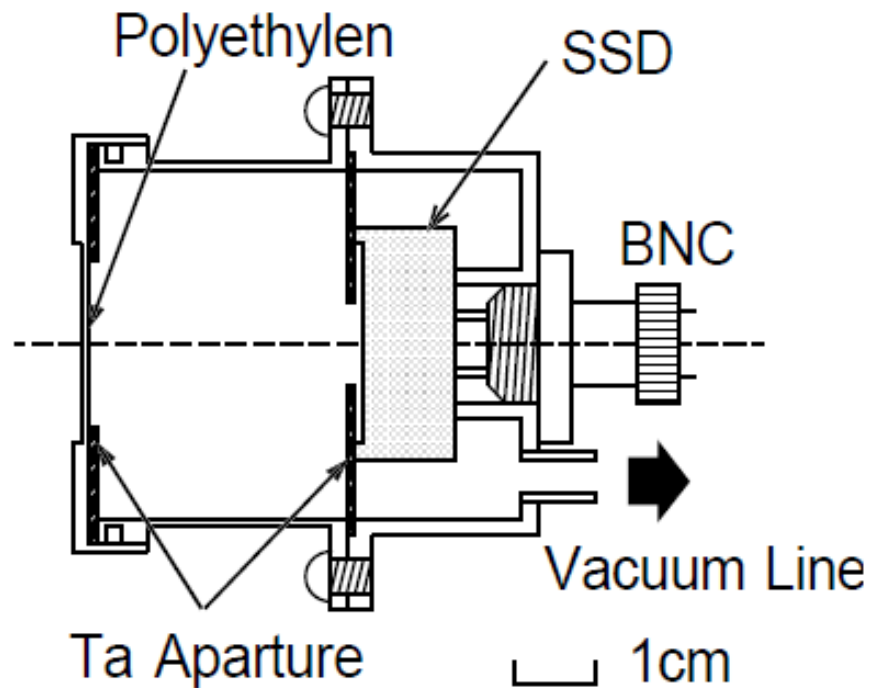


Recoil proton yield

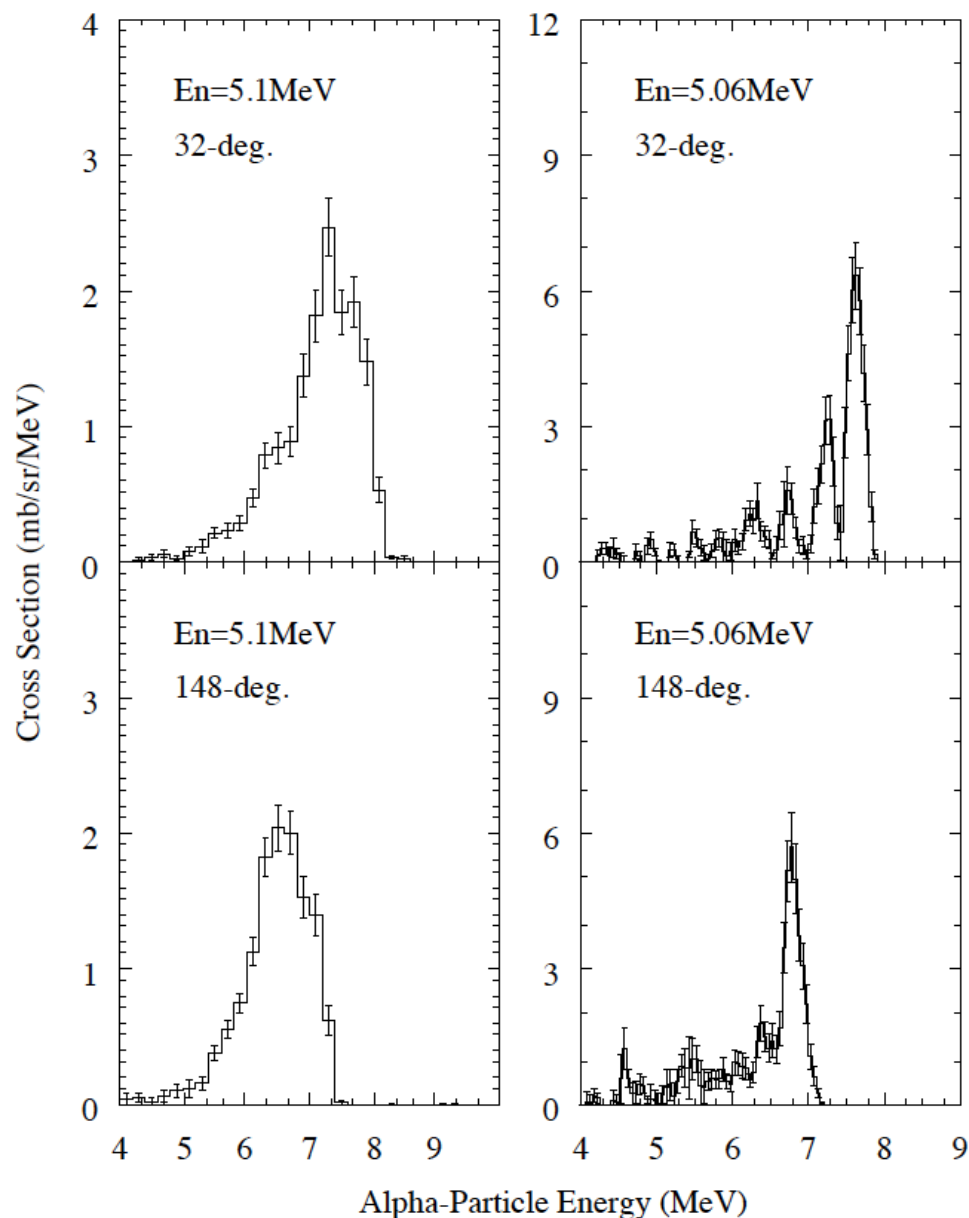


Neutron flux measurement

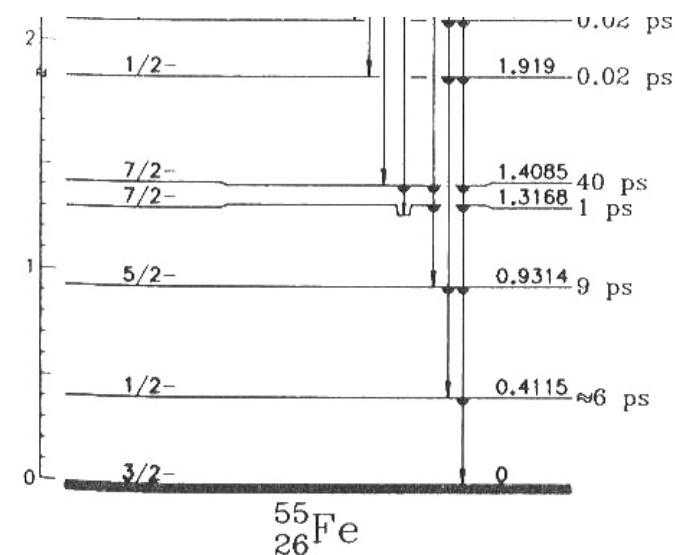
- Standard cross section
- $H(n,p)$ $Q=0.0$ MeV



Energy resolution

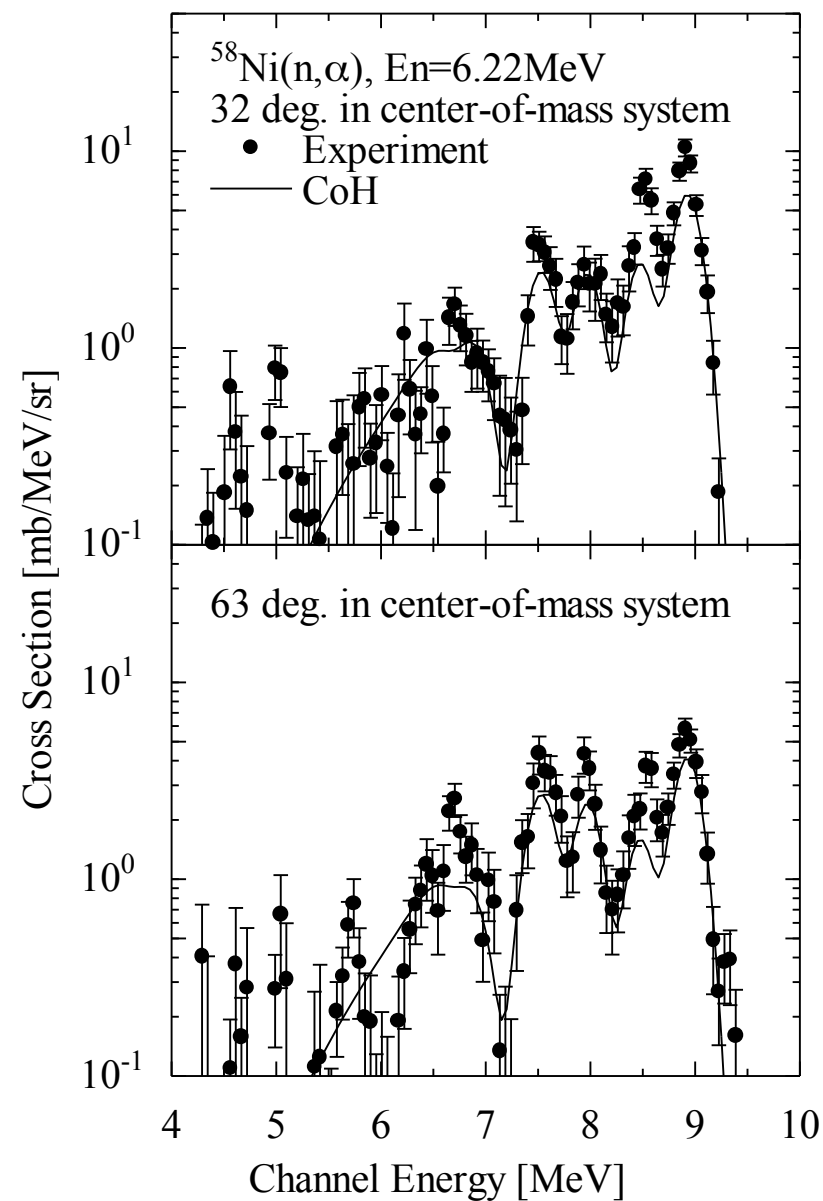
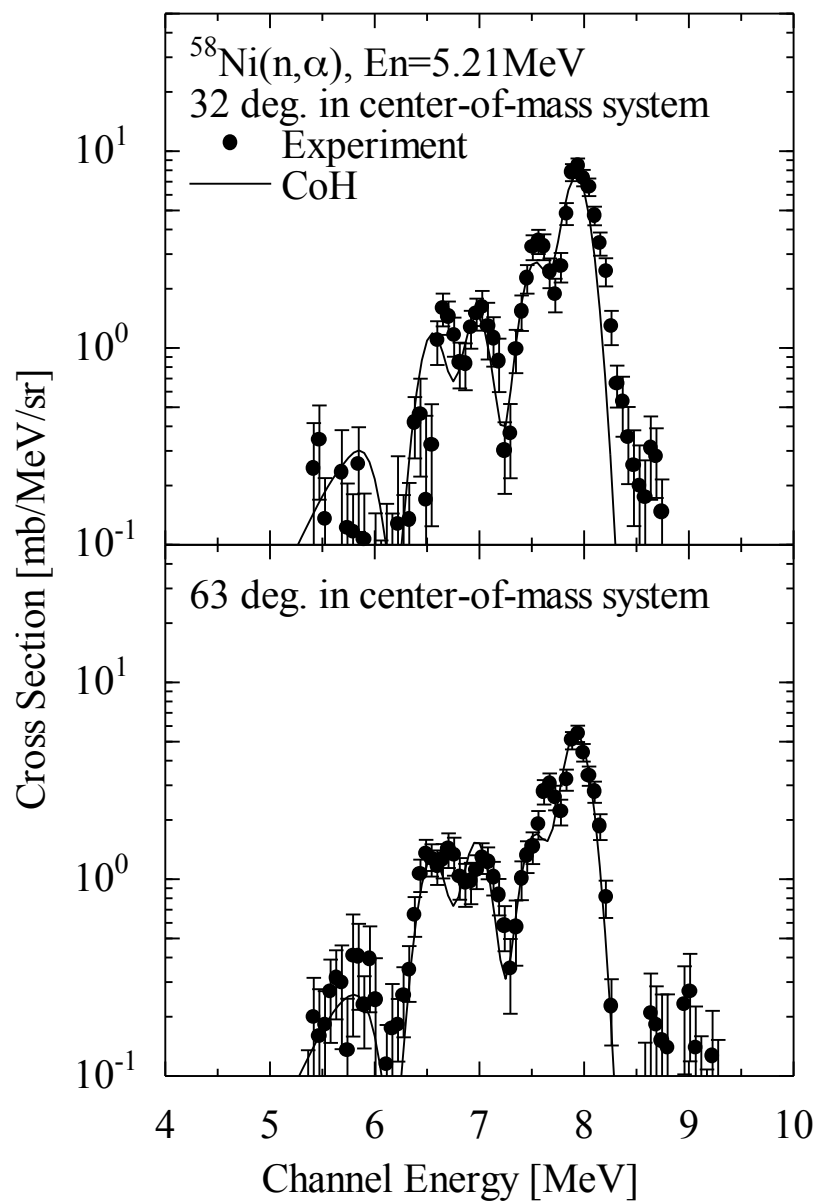


Tables of isotopes 6th edition

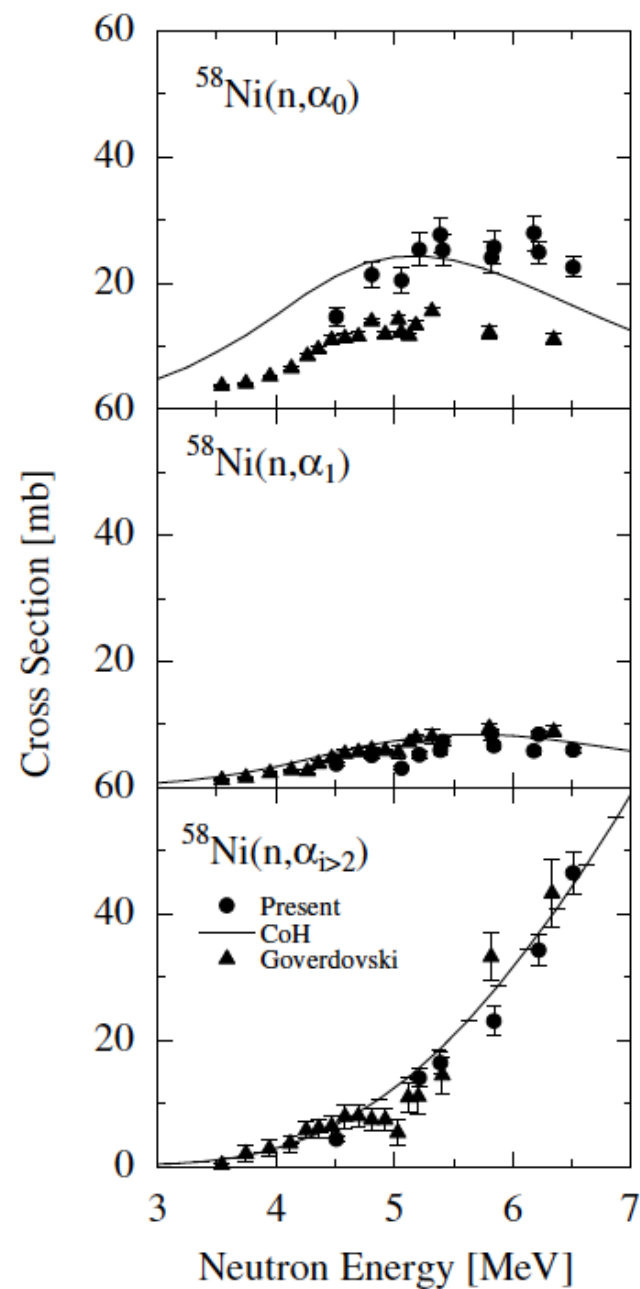
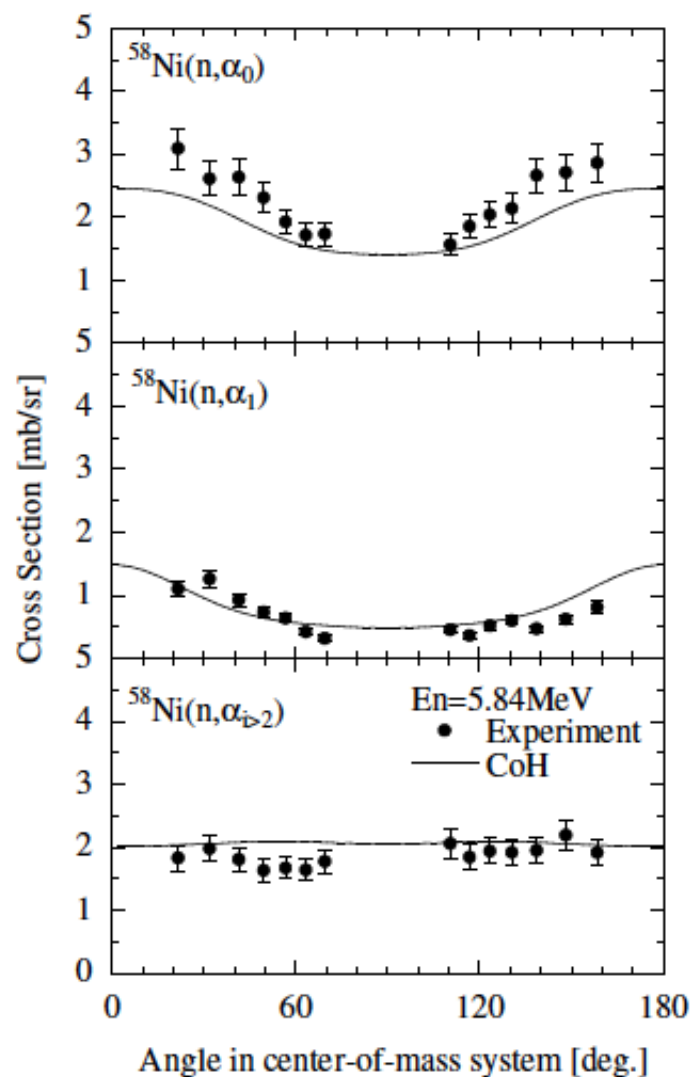


- Target thickness
 - Left: 3 mg/cm^2
 - Right: 0.3 mg/cm^2
 - Low lying levels of residual were observed

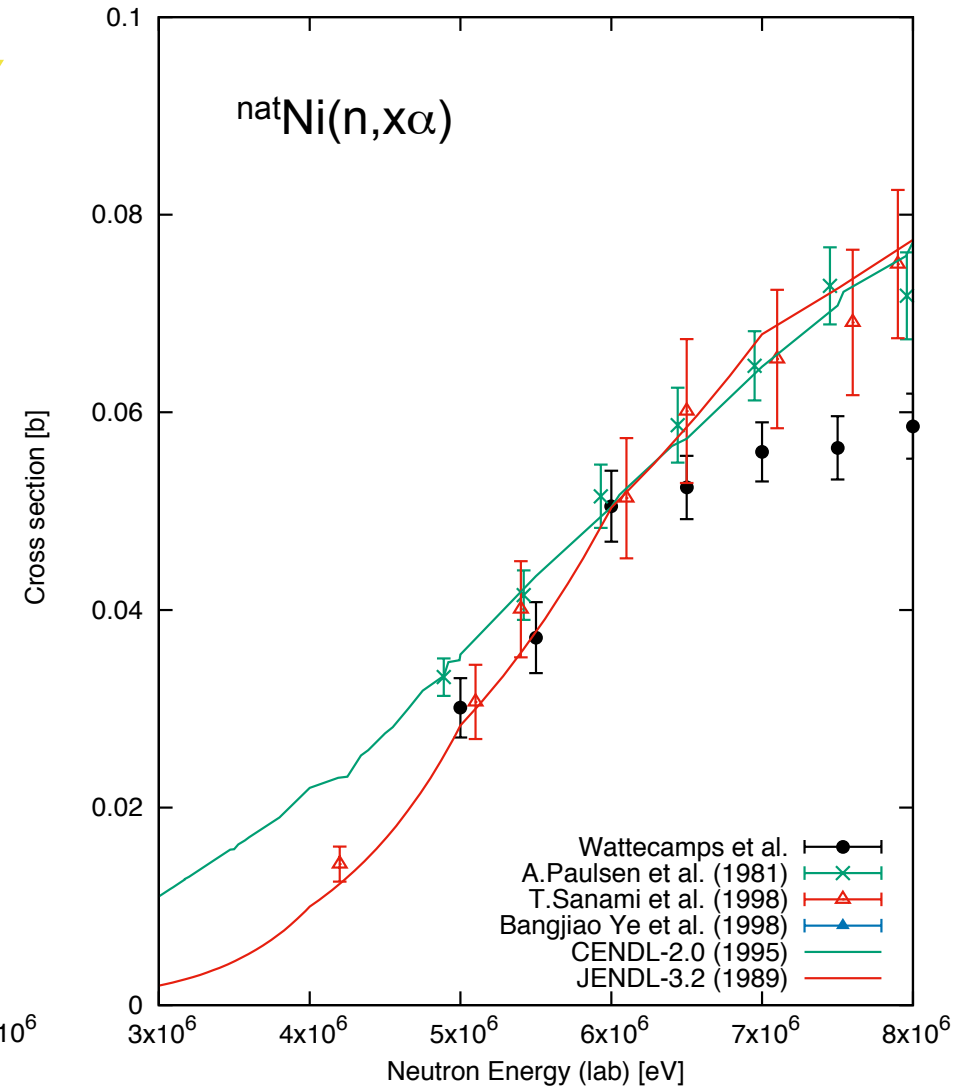
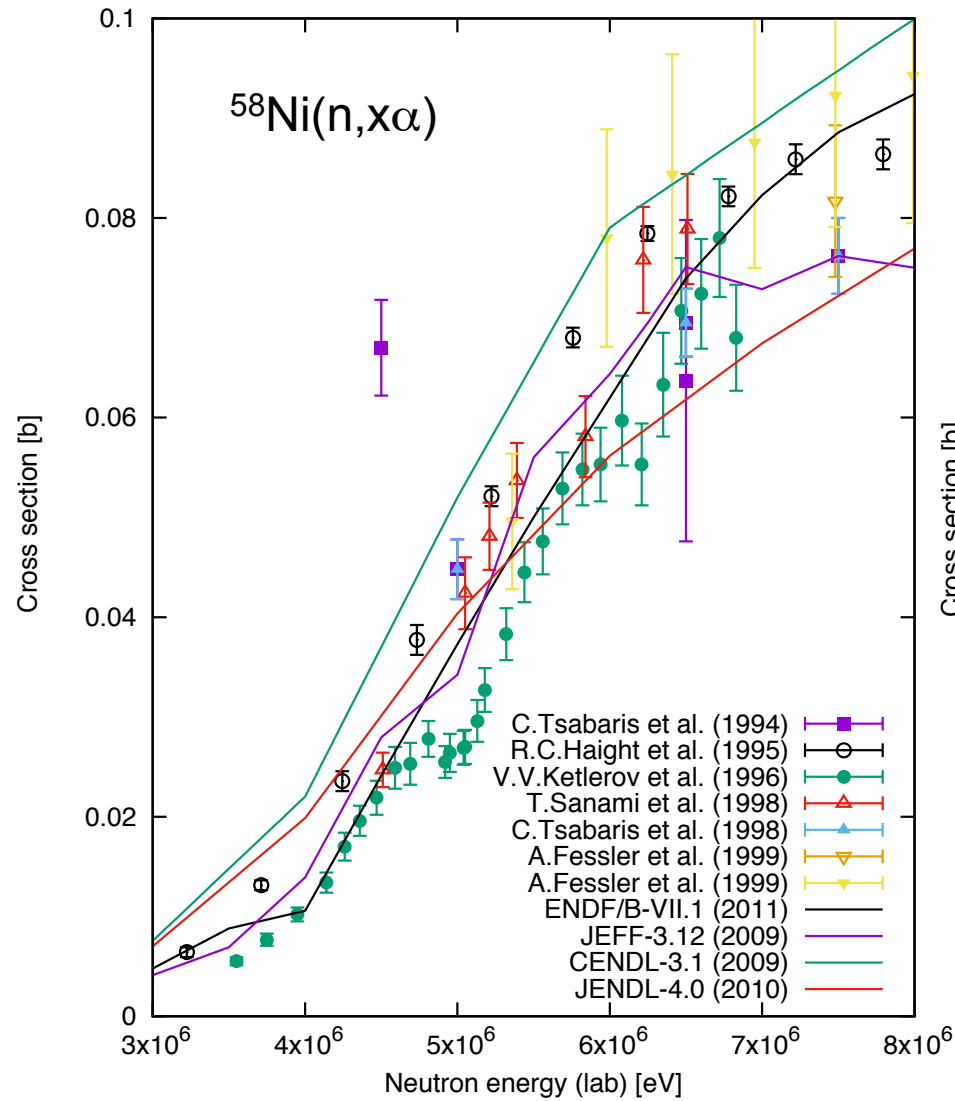
Double differential cross section



Angular distribution and partial reaction cross section



$^{58}\text{Ni}(n,\alpha)$ cross section



Summary

- Items should be prepared
 - Neutron production from 4 MeV to 14 MeV
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 - Yield estimation
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 - Electronics and analysis