不安定核停止標的を用いた核物理と天体反応の研究

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東海・重イオン科学シンポジウム

– タンデム加速器成果報告会 –

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BRILLIANT

不安定核停止標的を用いた順運動学反応による核分光

Beam system for Reaction of Isotopes of Long-life
with Light-Ions Applying Normal kinemaTics

不安定核・安定核のインプラント標的

不安定核停止標的

軽イオン散乱による励起状態や共鳴状態の測定

順運動学

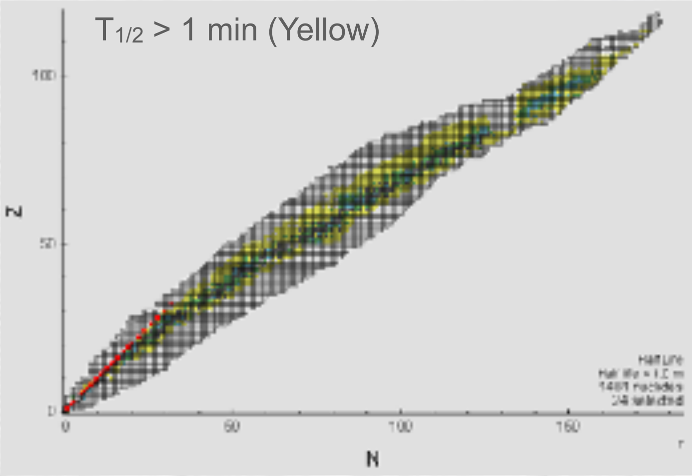
質量欠損法

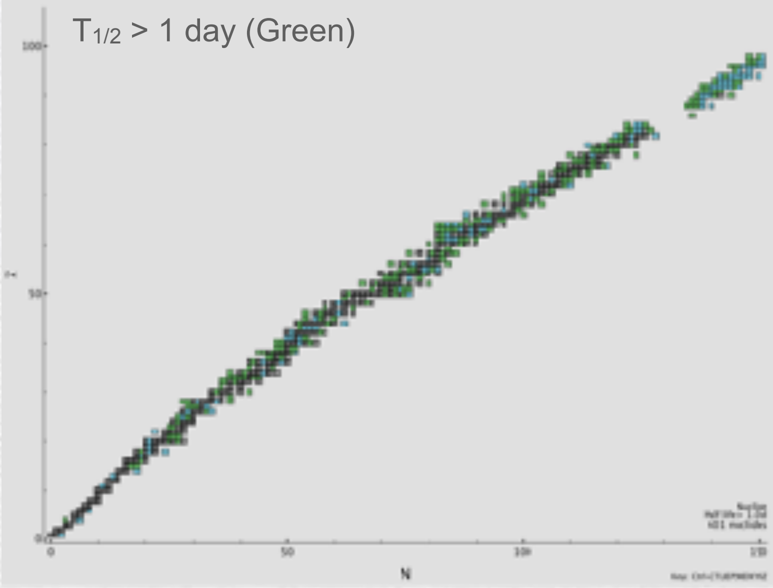
マイクロスポット高強度ビーム

スペクトメータを用いた高分解能・低運動量移行実験

高品質高強度ビーム

BRILLIANT





Dramatically expands the research field of nuclear excited states with light-ion reactions!

- N=Z Nuclei
- Odd-Odd Nuclei
- Long-life Isomer / High-Spin Nuclei
- Dual targets of the ground state and an isomer
- Largely deformed nuclei
- Momentum-Transfer-Less Reaction
- Direct comparison of β-decay and CEX reactions
- Polarization, Decay Meas., Unstable+Unstable

		Phase-I	Phase-II
	Stable-10^{10}y	$T_{1/2}$ > 1 day	$T_{1/2}$ > 1 min
Nuclides	282	624	1480
Isomers	1	50	310
N=Z Nuclei	13	17	24
Odd-Odd	4	92	333
Max Spin	9	16	37/2
Ni Isotopes	58-64	56-66	56-66
Zr Isotopes	90-96	88-96	84-97
Sn Isotopes	112-124	112-126	106-130
Pb Isotopes	204-208	202-210	190-214

534 nuclides for $T_{1/2}$ > 5 days

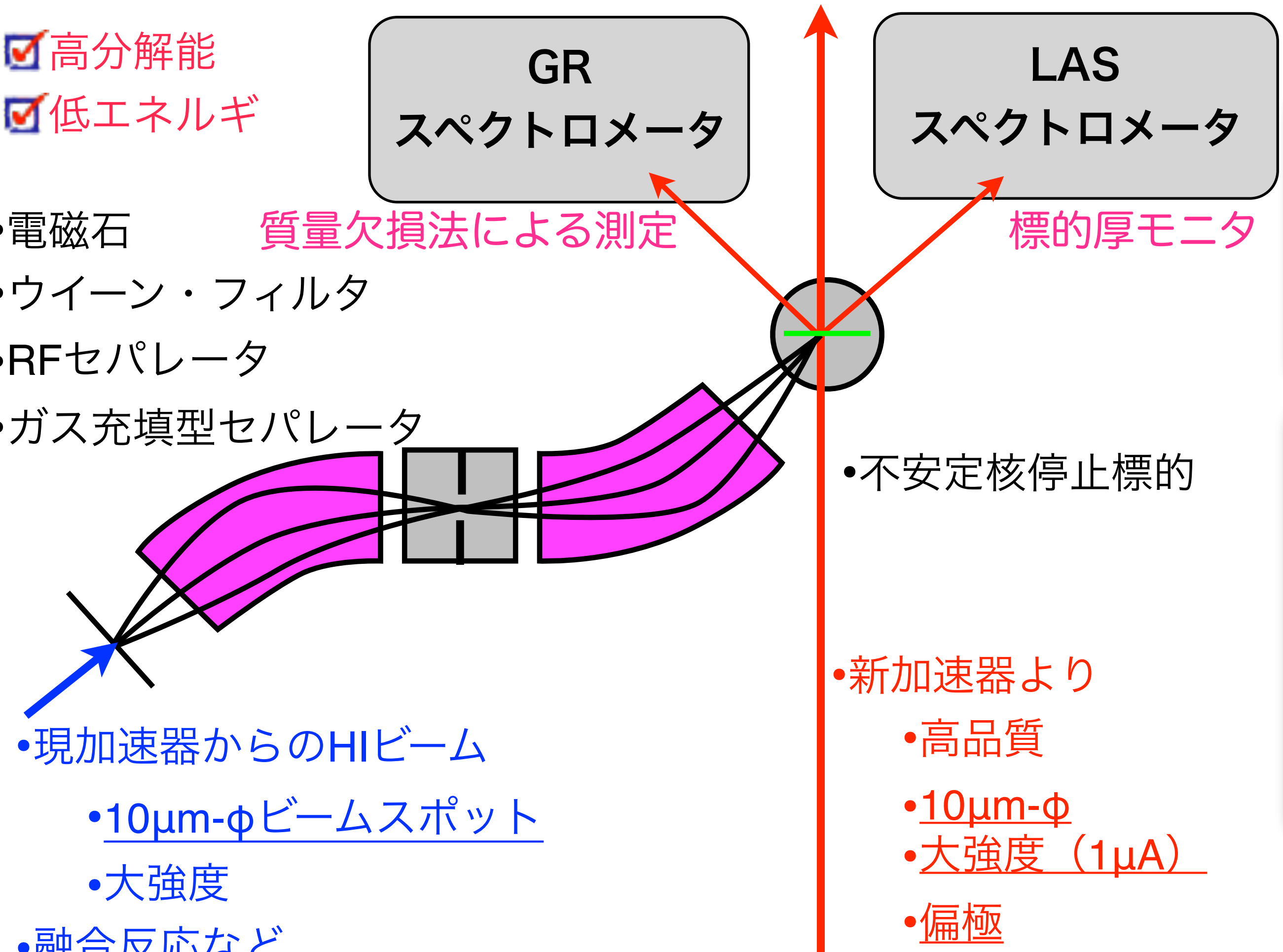
BRILLIANT計画@RCNP

<u>B</u>eam system for <u>R</u>eaction of <u>I</u>sotopes of <u>L</u>ong life with <u>L</u>ight <u>I</u>ons <u>A</u>pplying <u>N</u>ormal kinematics

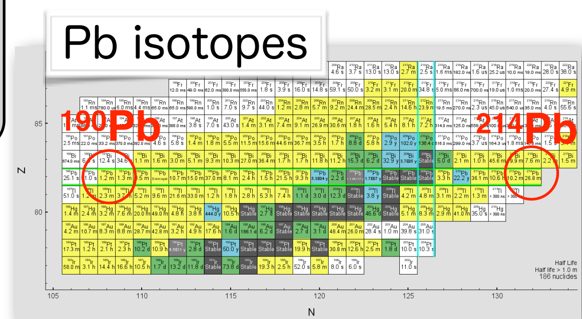
☑質量欠損法で励起状態を一気に測定（崩壊粒子の同時測定も重要）

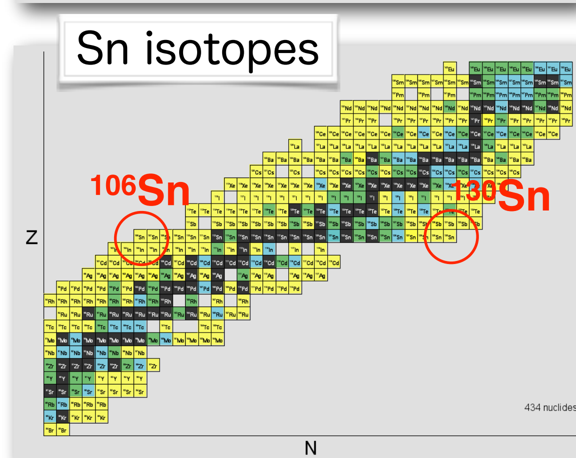
☑高分解能

☑低エネルギ



寿命 > 1分の原子核





BRILLIANT計画@RCNP

Beam system for Reaction of Isotopes of Long life with Light Ions Applying Normal kinematics

☑質量欠損法で励起状態を一気に測定（崩壊粒子の同時測定も重要）

☑高分解能

☑低エネルギ

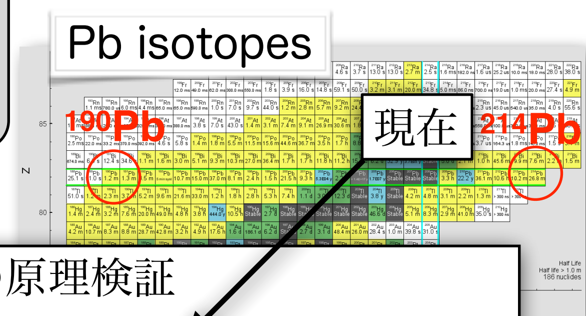
GR スペクトロメータ

LAS スペクトロメータ

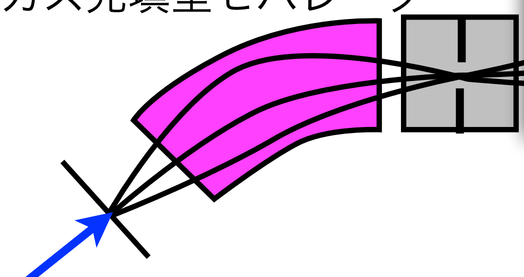
質量欠損法による測定

標的厚モニタ

寿命 > 1分の原子核



- 電磁石
- ウイーン・フィルタ
- RFセパレータ
- ガス充填型セパレータ

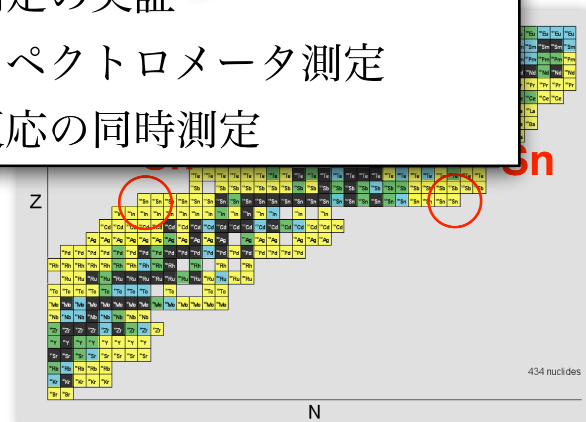


Phase-0:　安定核インプラント標的での原理検証

Phase-1:　不安定核停止標的を用いた測定の実証

不安定核停止標的を用いたスペクトロメータ測定

Phase-2:　不安定核停止標的の生成と反応の同時測定



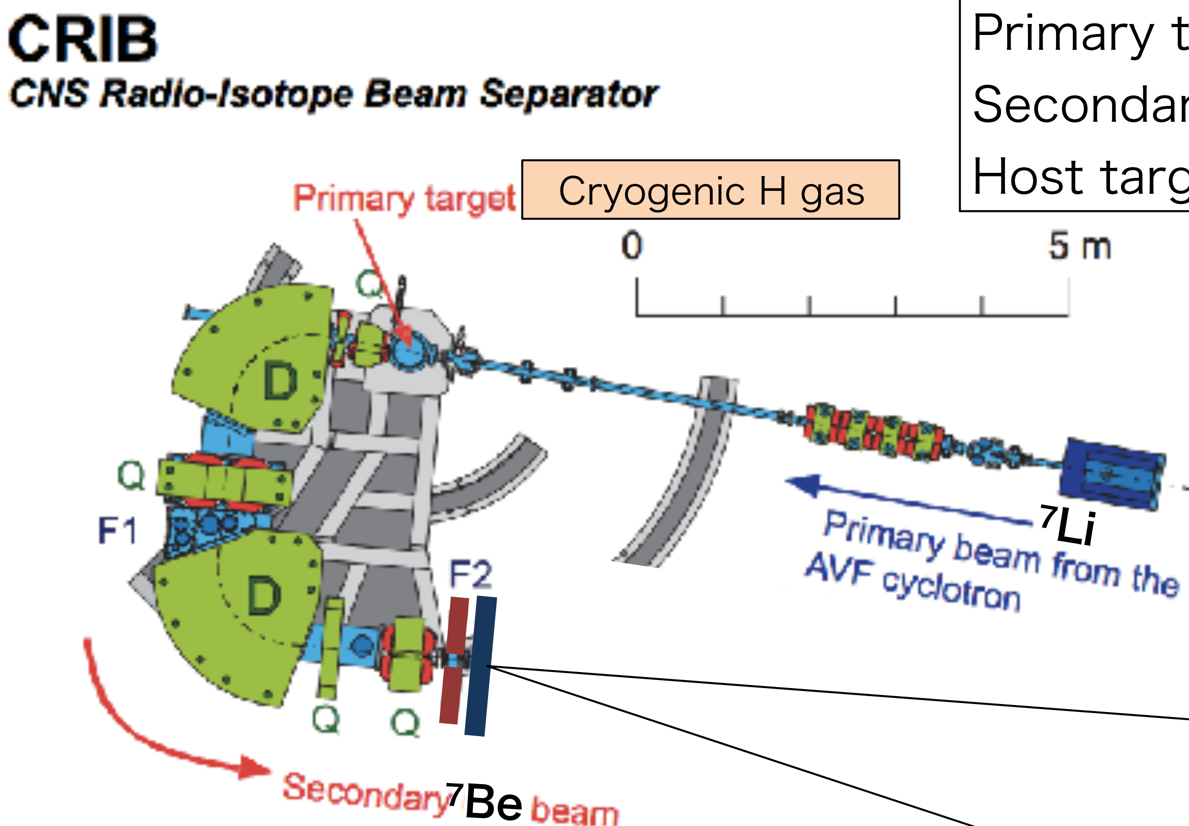
- 現加速器からのHIビーム
  - 10μm-φビームスポット
  - 大強度
- 融合反応など

- 新加速器より
  - 高品質
  - 10μm-φ
  - 大強度（1μA）
  - 偏極

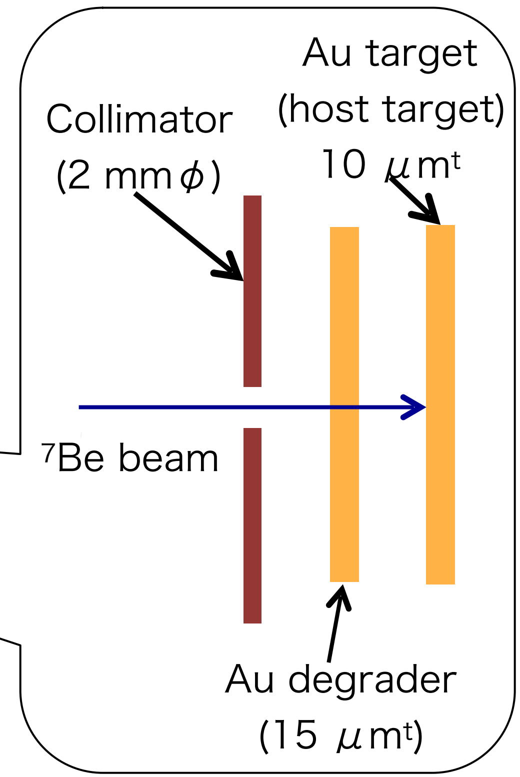
Stopped RI Target: Implantation

◇ Implantation exp. at CRIB (May 2018)

Primary beam: ^{7}Li 5.6 MeV/u
Primary target: Cryogenic H gas
Secondary beam: ^{7}Be 4.0 MeV/u
Host target: Au (10 μm)



In the F2 chamber



◇ Secondary ^{7}Be beam intensity was checked time to time during the experiment by the PPAC detector and a plastic scintillator.

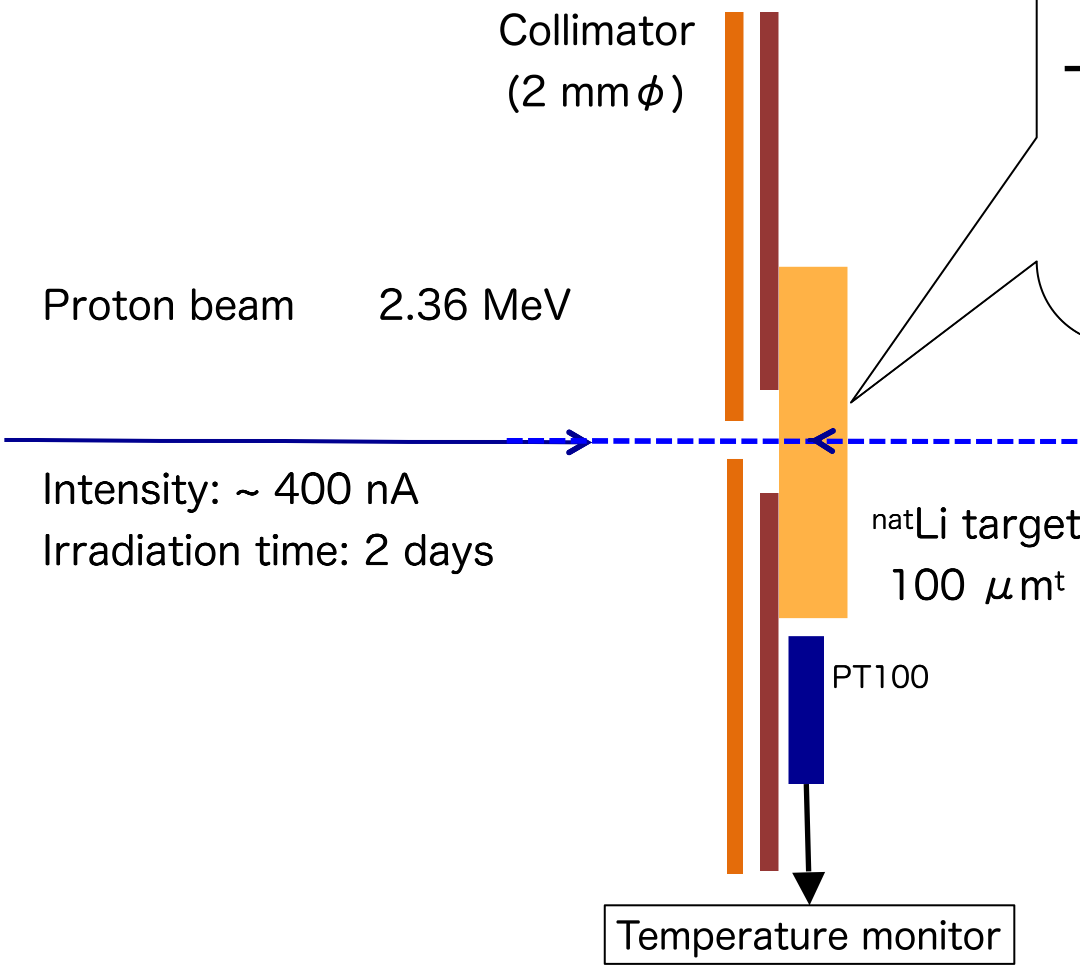
one day of irradiation

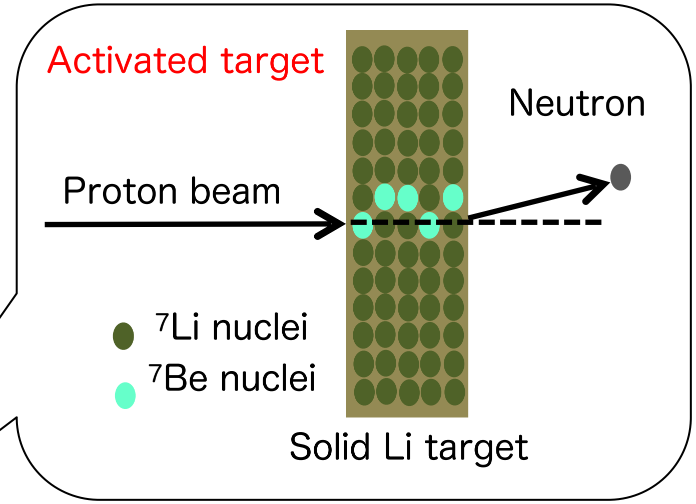
^{7}Be: 1.9×10^{12} in 2mmφ

by A. Inoue

Stopped RI Target: Activation

Tandem facility, Kobe Univ. (Aug. 2018)





After the irradiation, the number of ^{7}Be was measured by using a $LaBr_3$ detector.

2 days of irradiation: **2.6×10^{13} ^{7}Be in 2mmϕ**

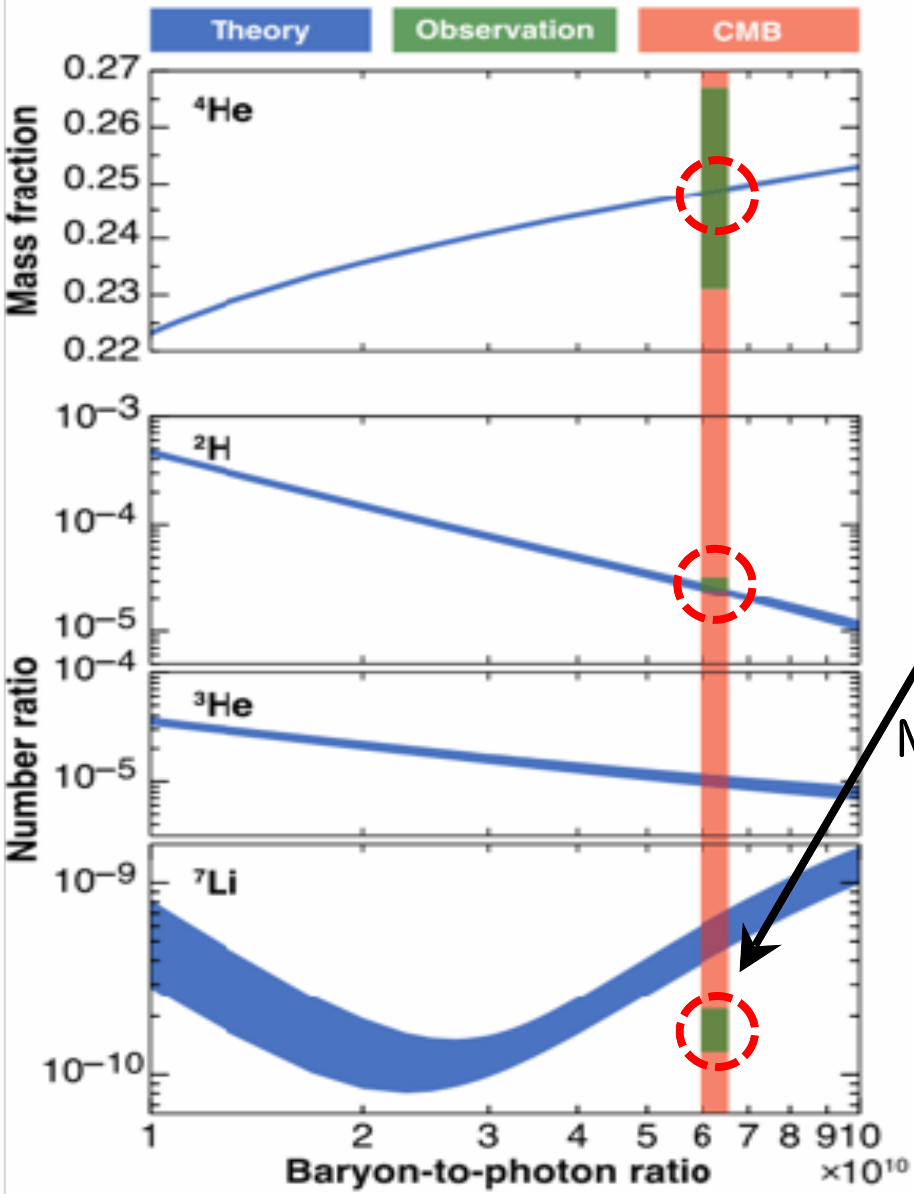
by A. Inoue

Study of the contribution of the ^{7}Be(d, p) reaction to the ^{7}Li problem in the Big-Bang Nucleosynthesis

Azusa INOUE
RCNP, Osaka University, Japan

and the BRILLIANT collaboration

^{7}Li problem

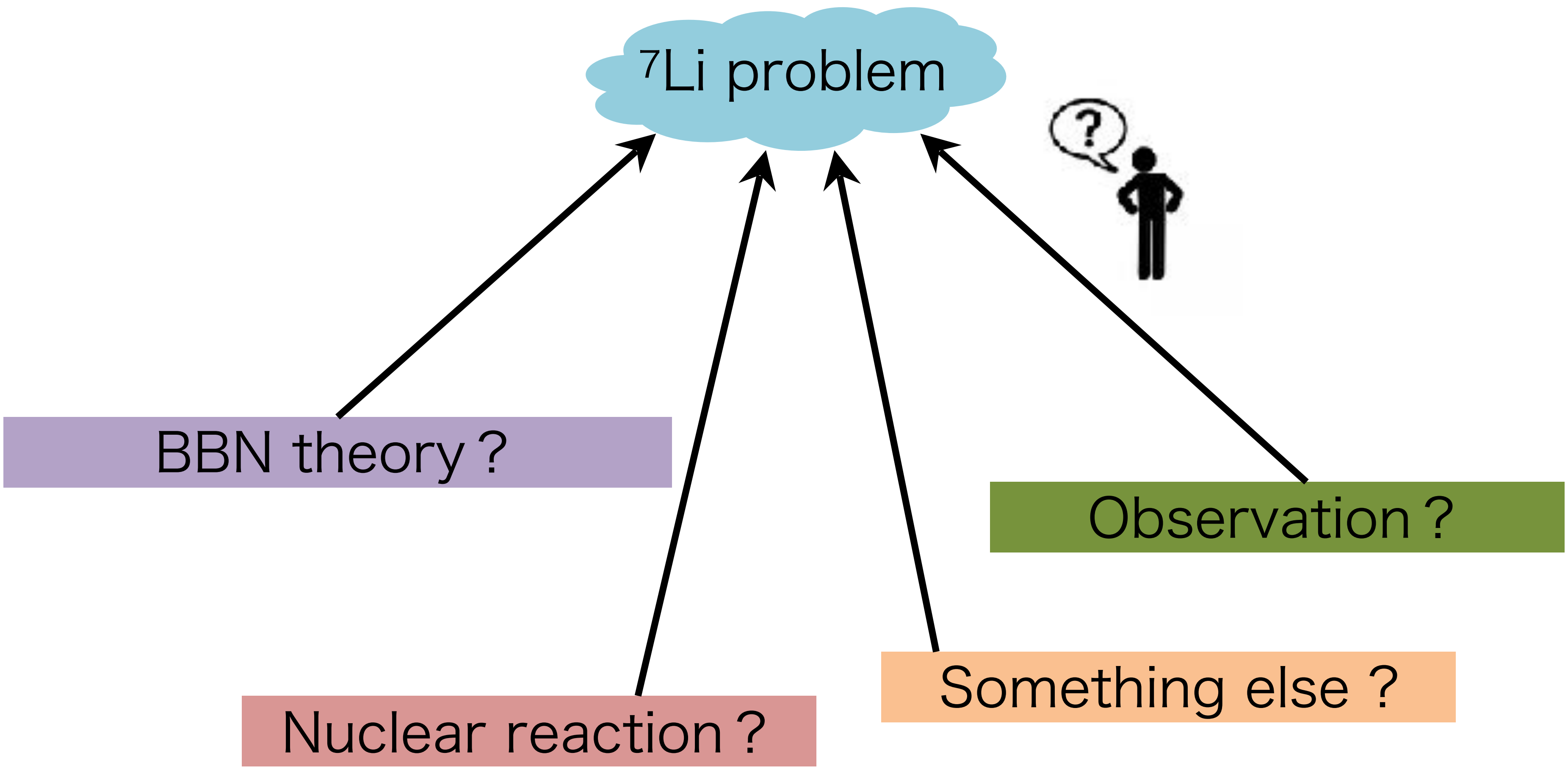


Abundance of ^{7}Li
Theoretical calc.
3 times higher than observation

Main pass of the ^{7}Li production is
β-decay of ^{7}Be

http://courses.atlas.illinois.edu/spring2010/ASTR/ASTR596/Lectures/Lect24.html

How to solve the problem



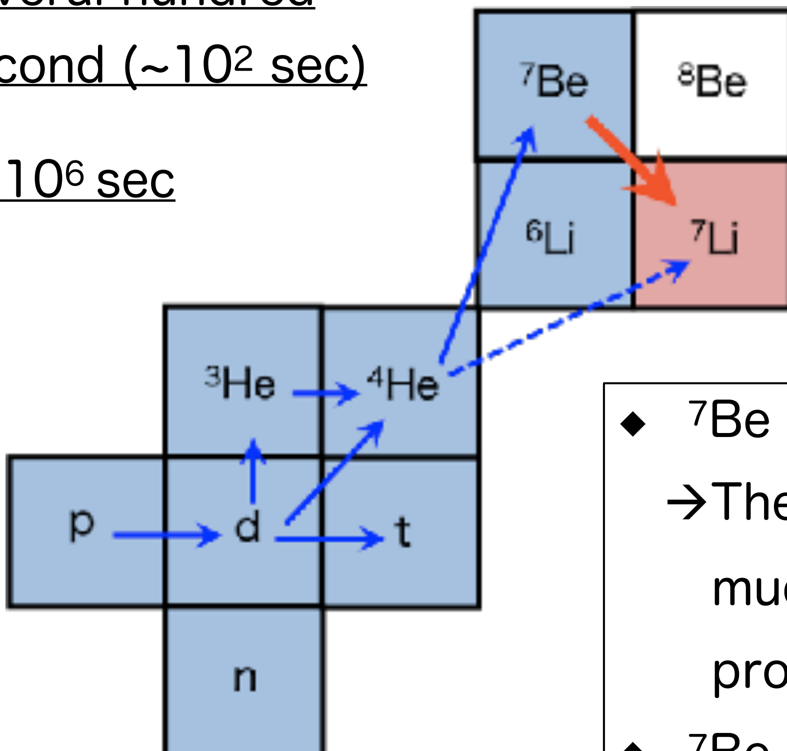
✓ To know the cross section of the nuclear reaction is important.
✓ We focus on to approach from nuclear reaction.

^{7}Li production

◆ Main component of ^{7}Li production is the β decay of ^{7}Be

several hundred second (~10^2 sec)

5×10^6 sec



- ^{7}Be β-decay half life = 5×10^6 sec
  →The time scale of the β decay is much longer than the light isotope production.
- ^{7}Be 99% depleted after 10^8 sec

^{7}Be is destroyed before it decays into ^{7}Li → The abundance of ^{7}Li is also decreased

^{7}Be destruction

✓ Destructive process of ^{7}Be

- ✓ ^{7}Be(n, α)^{8}Be...
- ✓ ^{7}Be(n, p)^{7}Li...
- ✓ ^{7}Be(d, p)^{8}Be...

✓ <u>Why we are focusing on ^{7}Be(d, p)?</u>

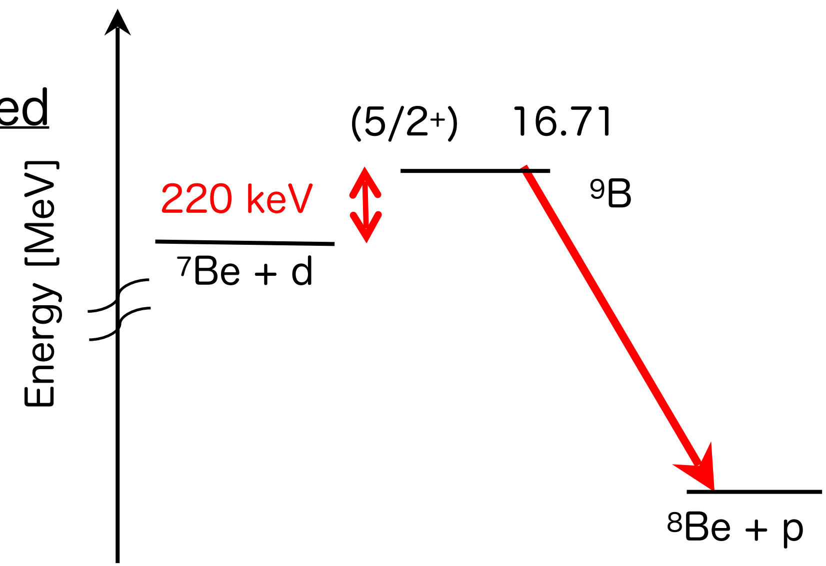
<u>-> cross section might be largely enhanced at 220 keV</u>

[S. Q. Hou et al., Phys. Rev. V91, 055802 (2015)]

◇ Big Bang temperature : 0.8 GK

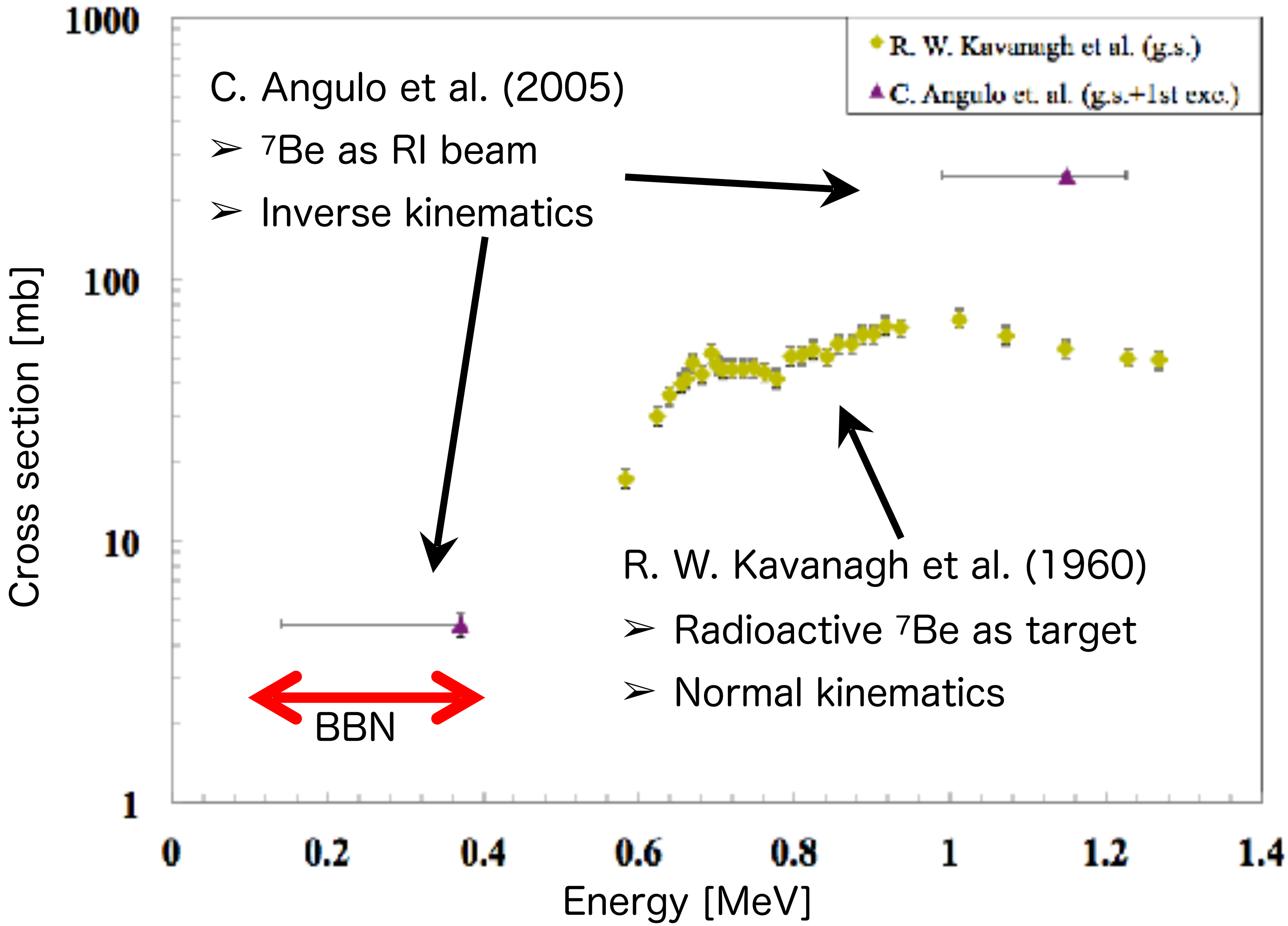
◇ Energy : 100 – 400 keV

◇ -> The predicted resonance state is in Big Bang energy region!



^{7}Be(d, p) cross section have to be measured at the BBN energy.

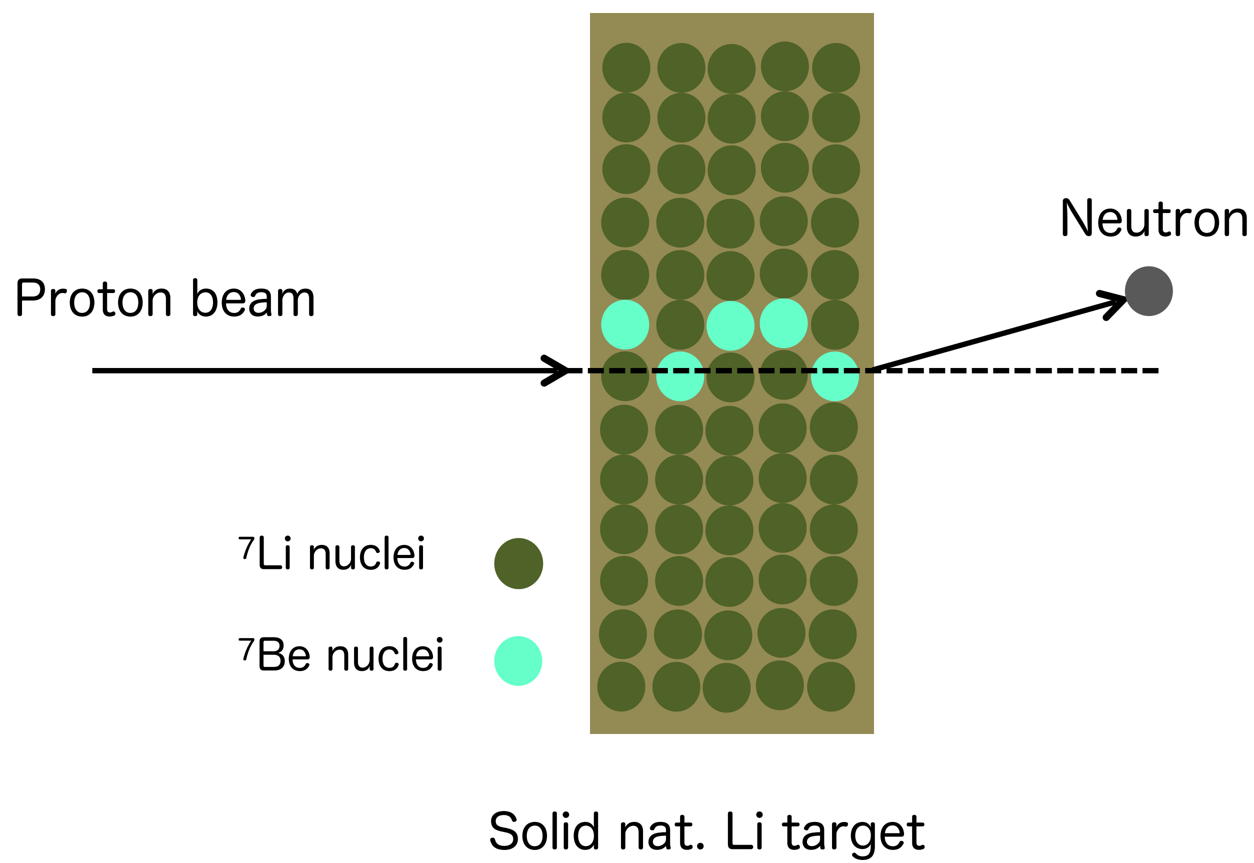
Present status of ^{7}Be(d, p) study



Activation method

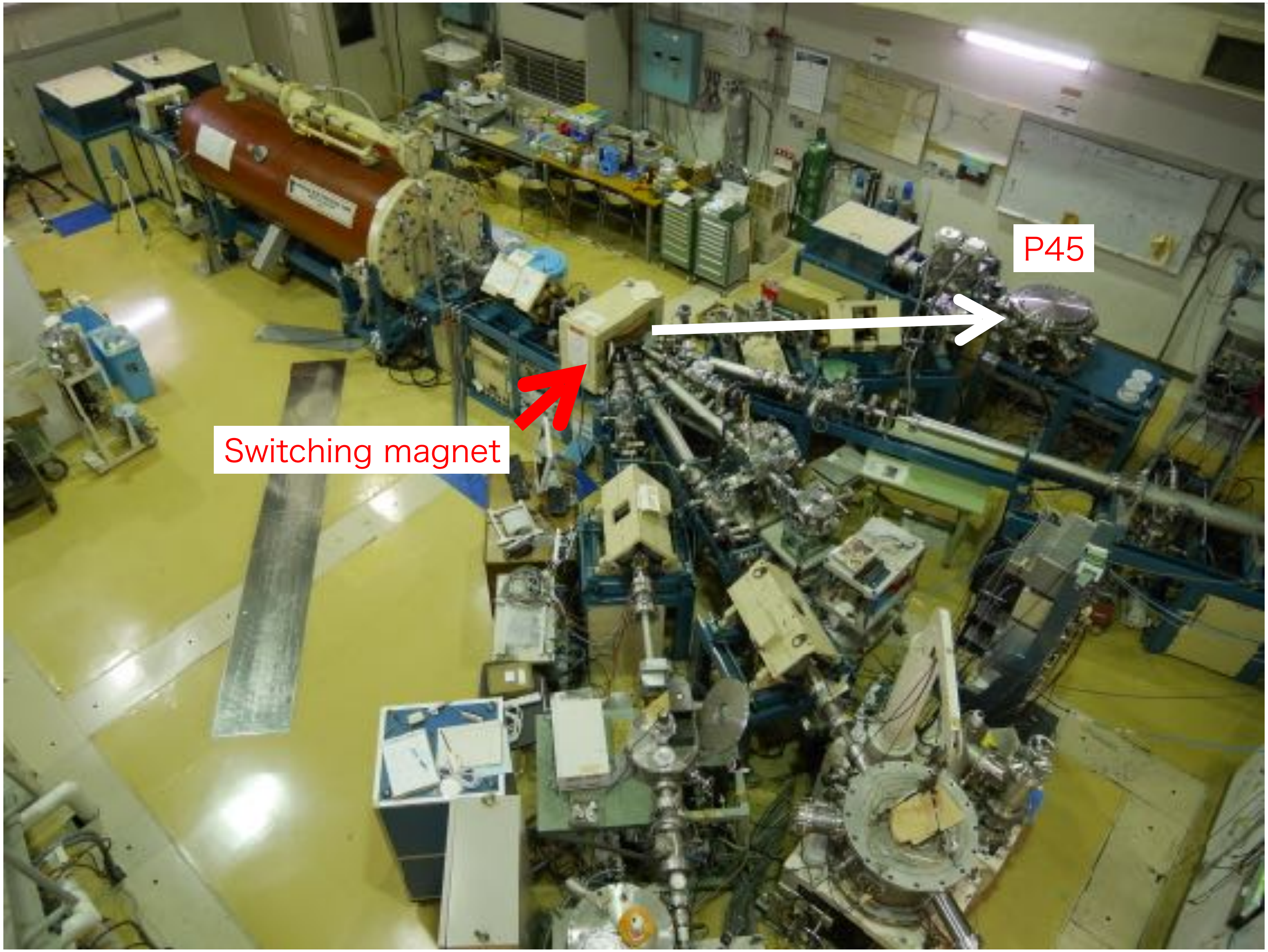
Irradiate solid natural Li target using a proton beam

^{7}Be is created via $^{7}Li(p, n)^{7}Be$ reaction



Experiment - ^{7}Be target production

Tandem facility, Kobe Univ. (Feb. 2019)



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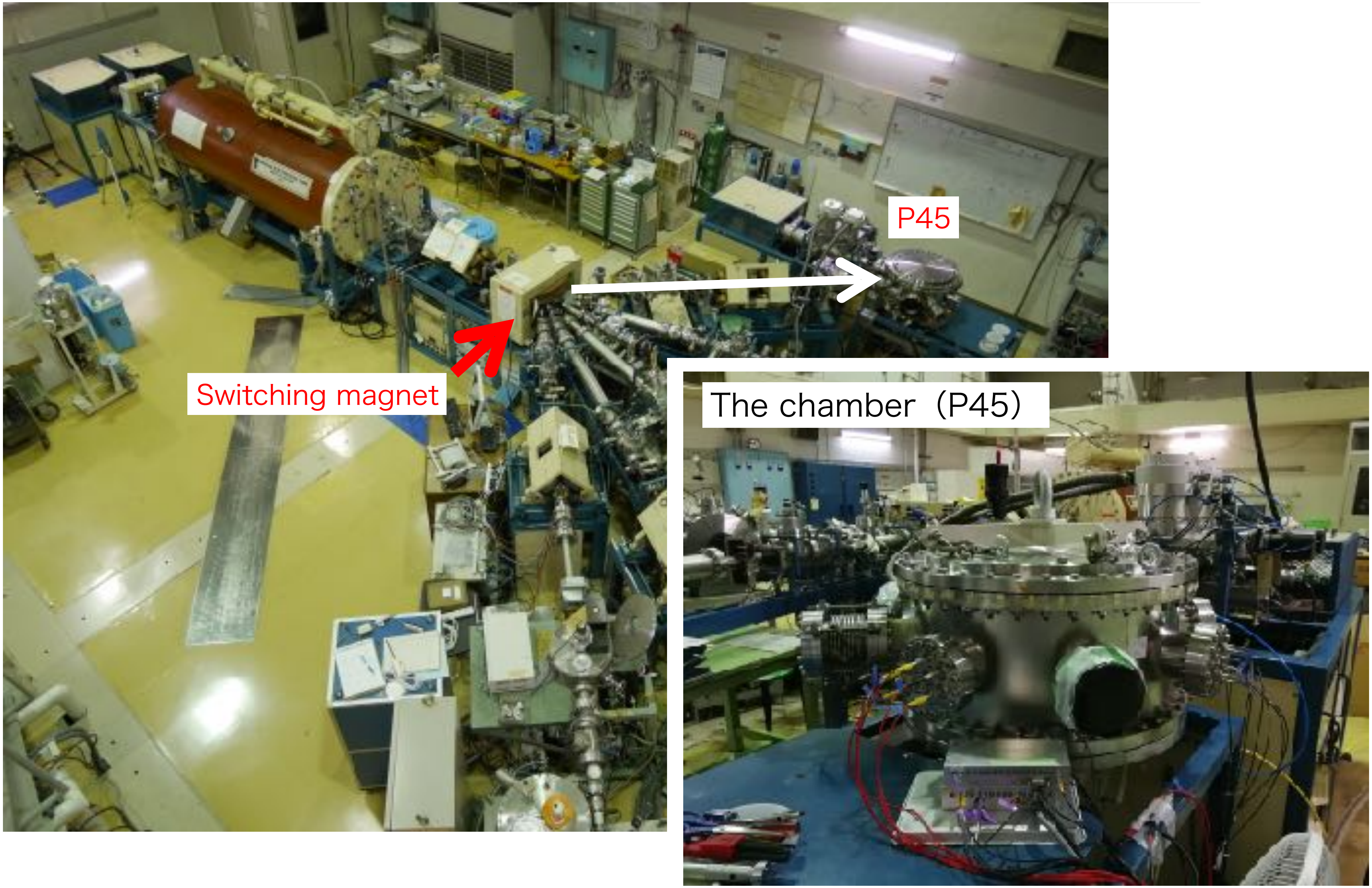

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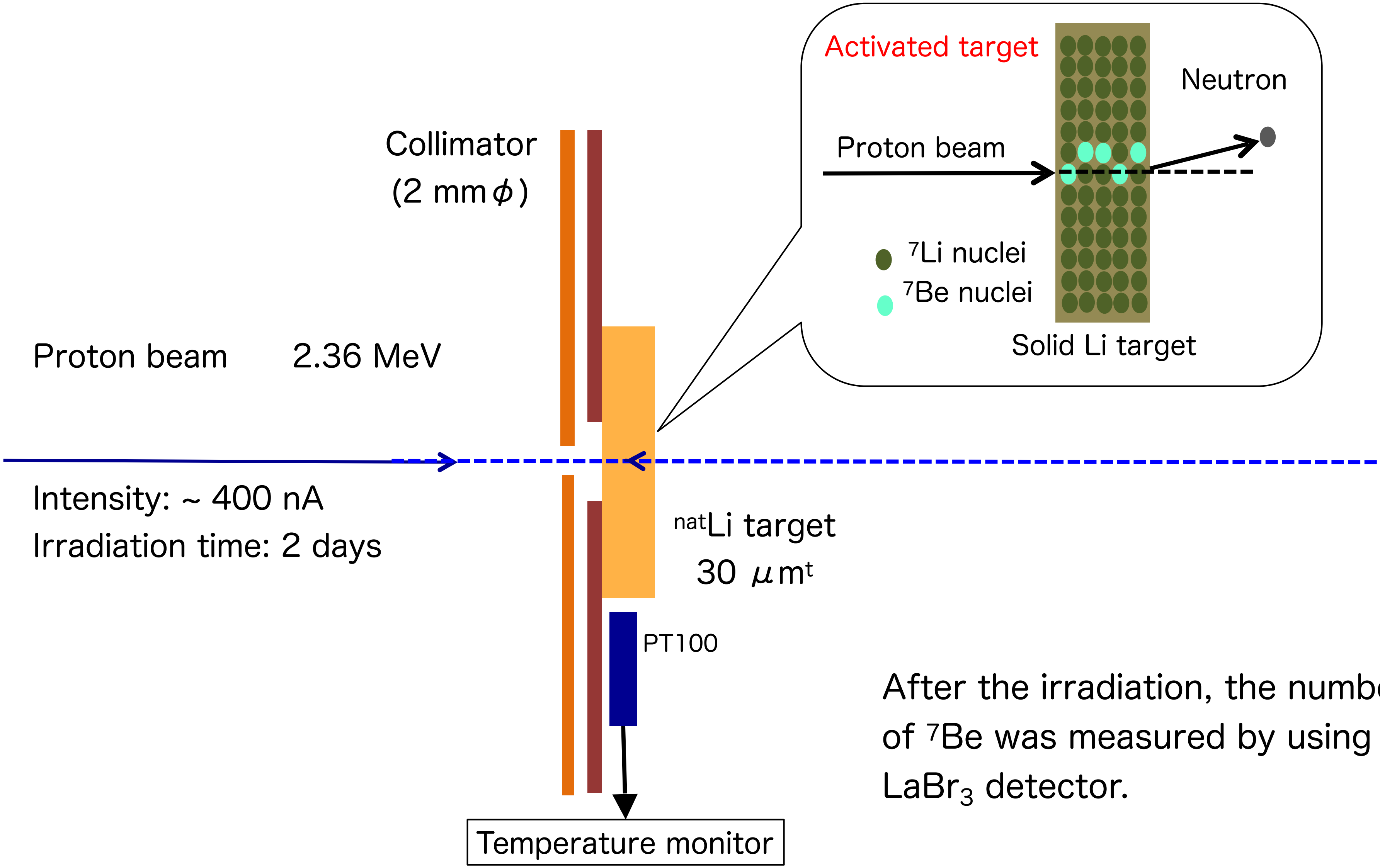
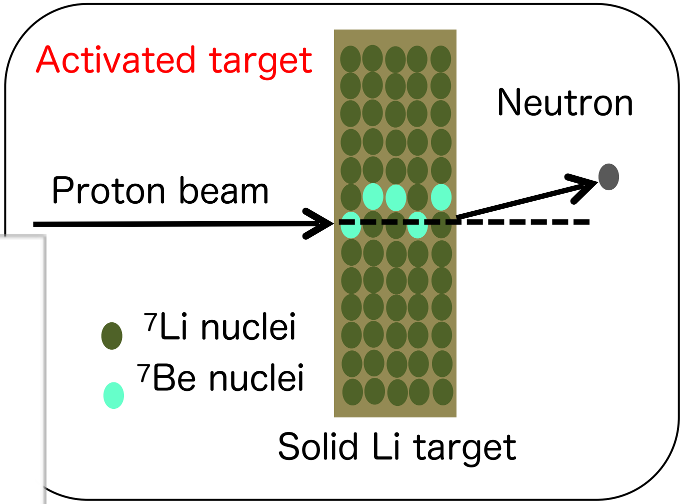


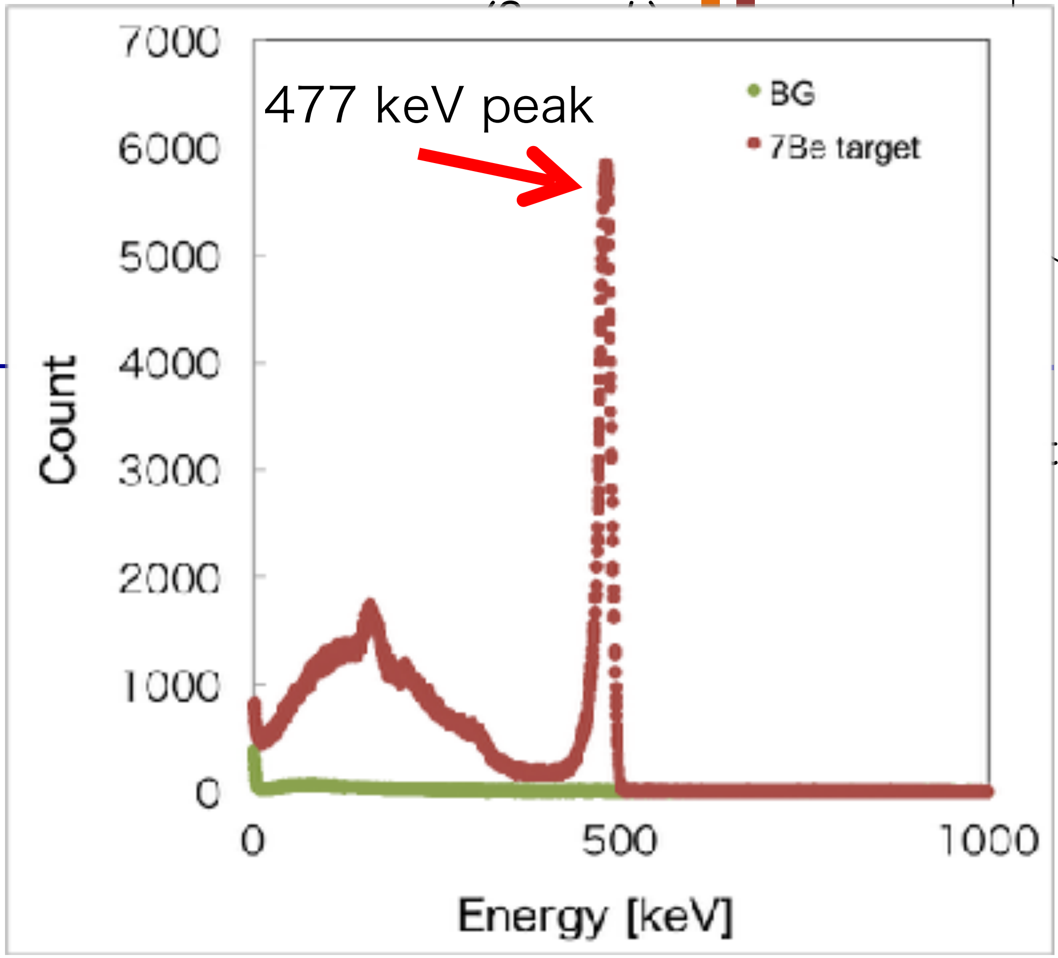
After the irradiation, the number of ^{7}Be was measured by using a $LaBr_3$ detector.

Experiment - ^{7}Be target production

Tandem facility, Kobe Univ. (Feb. 2019)



Collimator



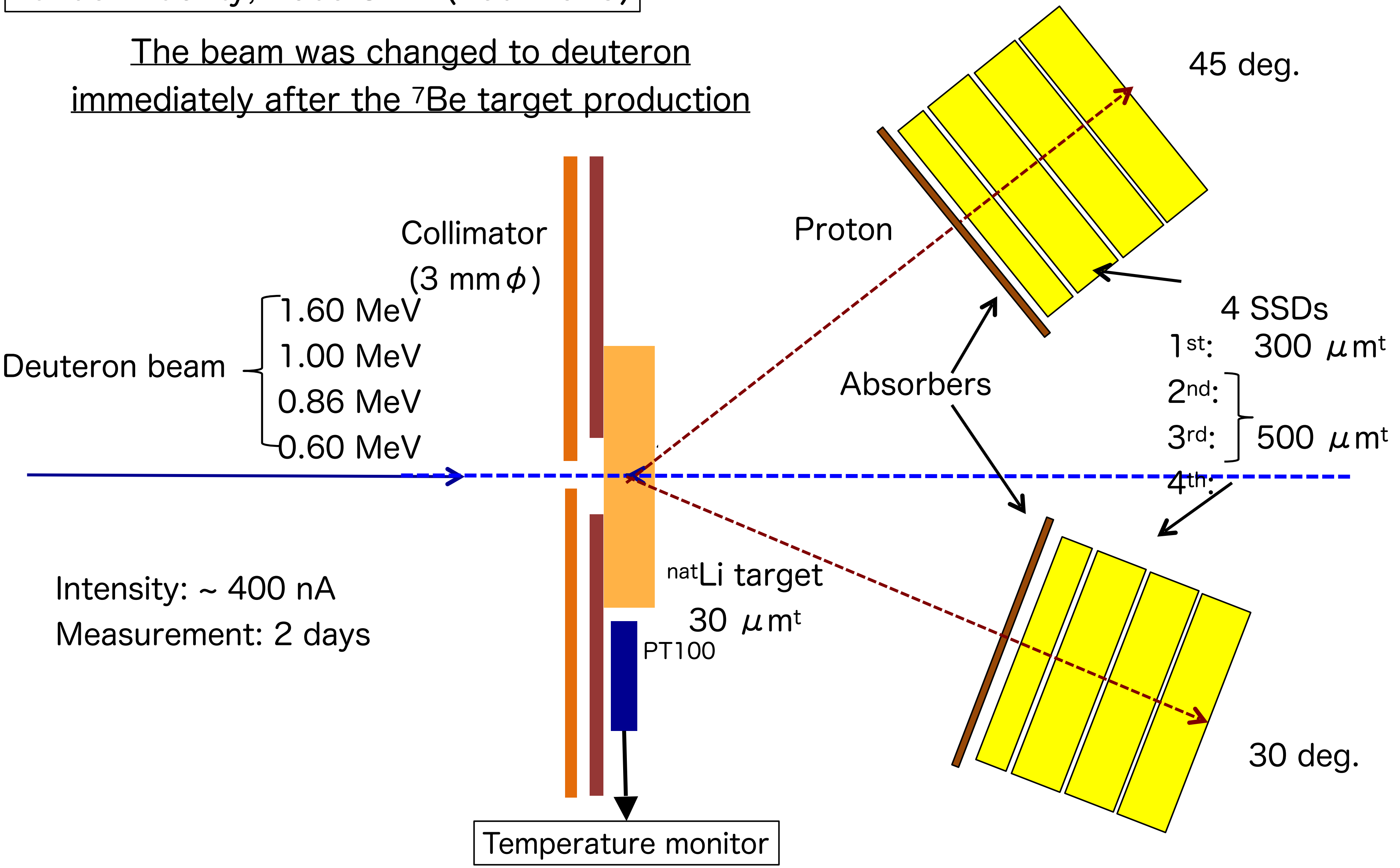
After the irradiation, the number of ^{7}Be was measured by using a $LaBr_3$ detector.

2.6 × 10^{13} ^{7}Be in 2mmϕ

Experiment - (d, p) reaction measurement

Tandem facility, Kobe Univ. (Feb. 2019)

The beam was changed to deuteron immediately after the ^{7}Be target production

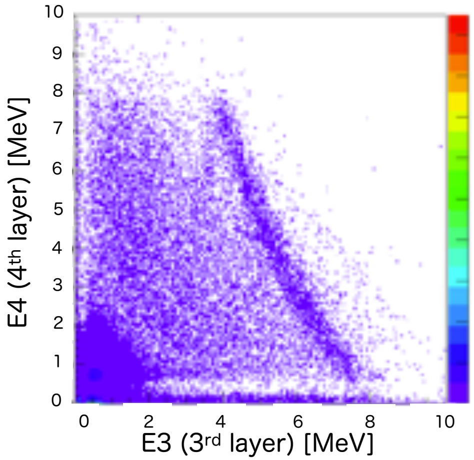


Intensity: ~ 400 nA

Measurement: 2 days

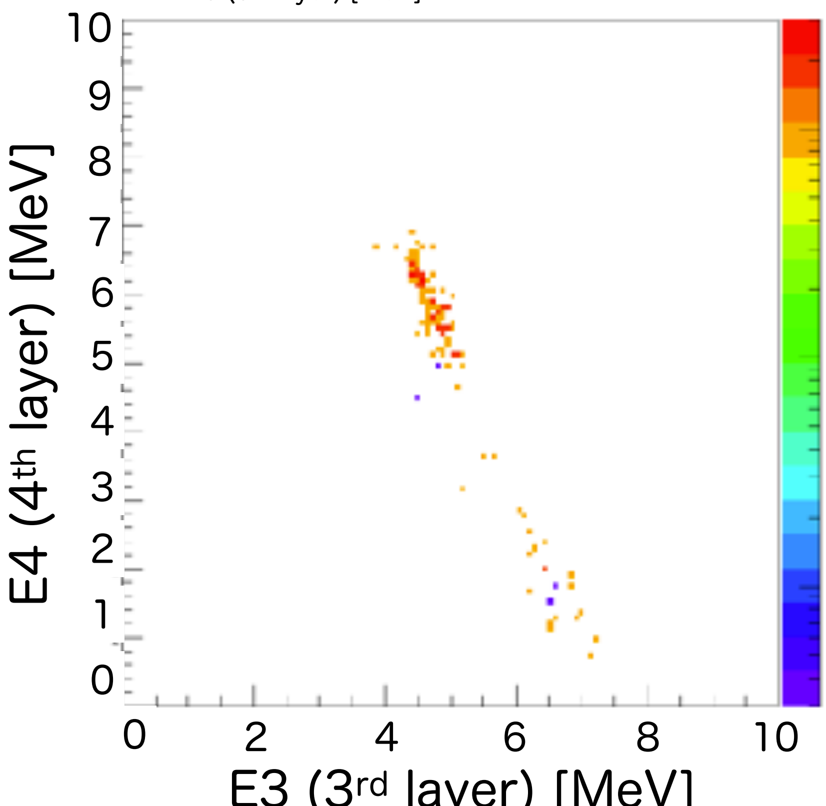
Analysis is done by the thick target method.

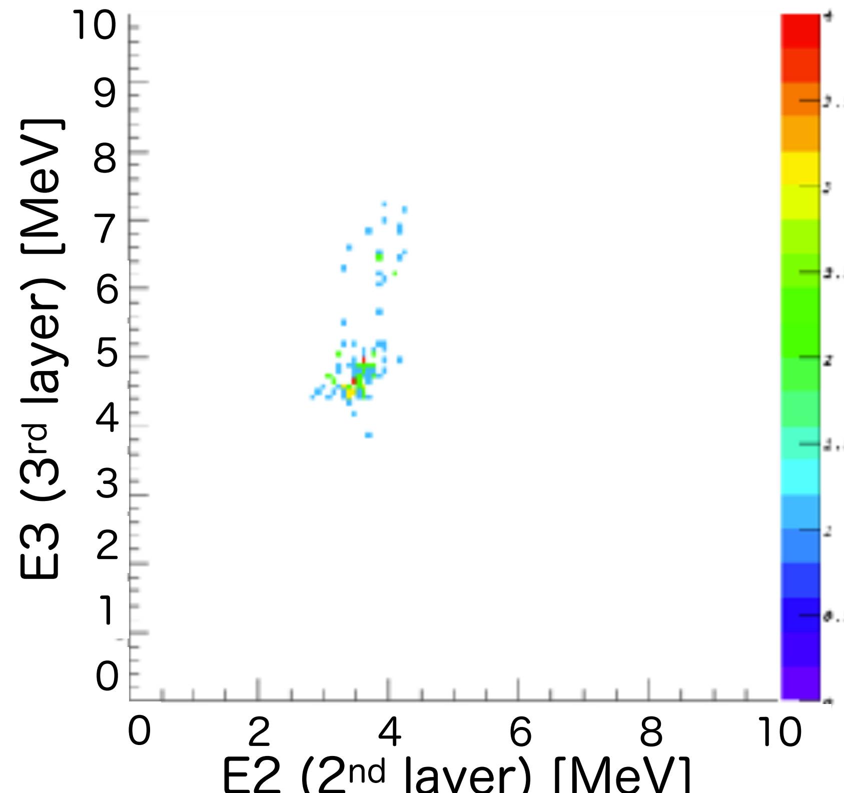
Experiment -Data



← Raw data (No gate)

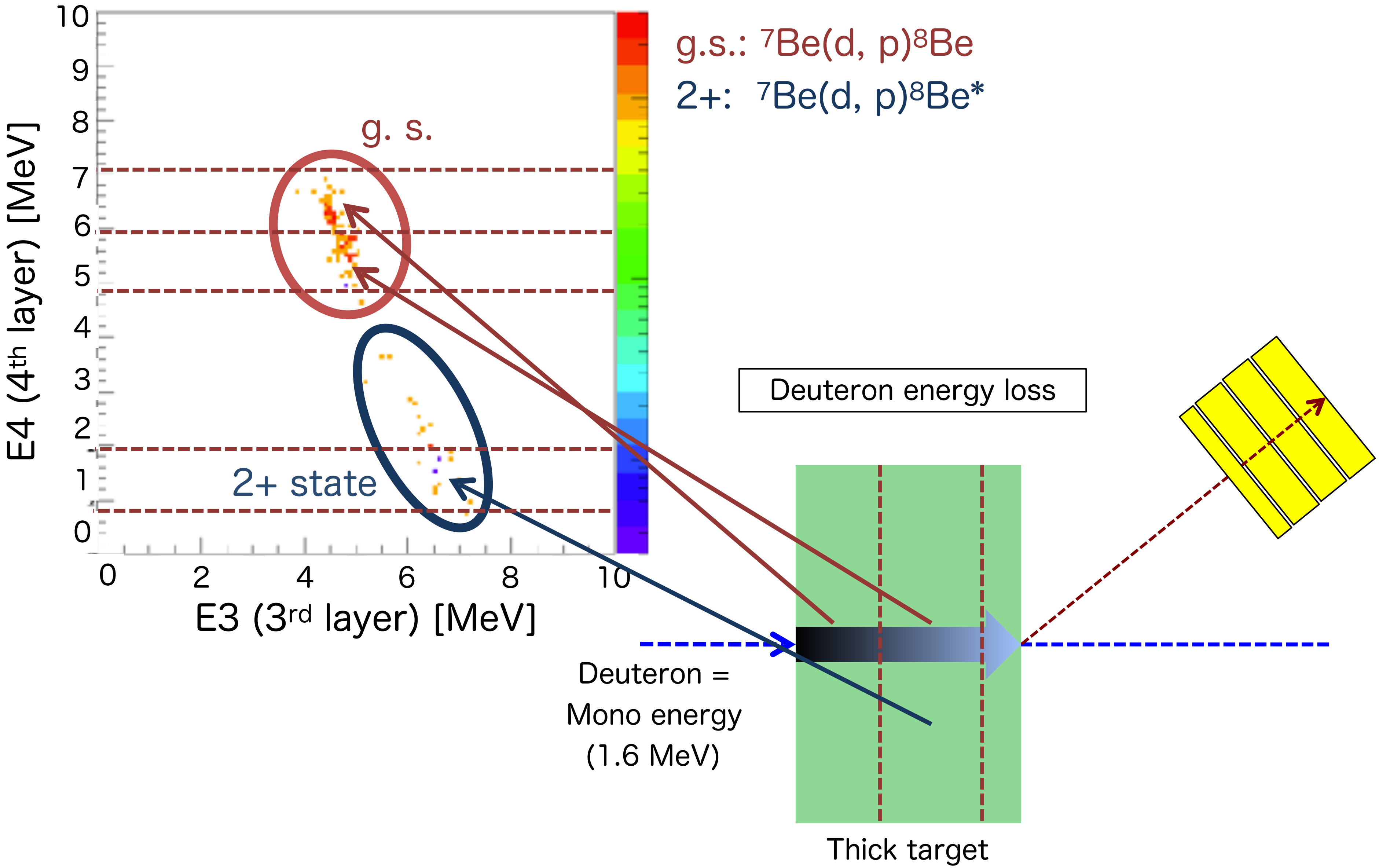
- Coincidence gates
- Background subtraction





Experiment -Data

Thick target method



Summary

Motivation

◇ Study of the cosmological ^{7}Li problem from nuclear reaction.

◇ Measurement of the ^{7}Be(d, p) reaction in the BBN energy region.

◇ Unstable ^{7}Be target

Achievement and Result

◇ We succeeded in producing a ^{7}Be target (2.6×10^{13} particles)

◇ Obtained the preliminary cross section

◇ The ^{7}Be(d, p) reaction would not contribute to solve the ^{7}Li problem.

Remaining works

◇ The 2+ state (^{7}Be(d, p)^{8}Be* data)

◇ Analysis of E_d = 0.86, 1.00 MeV

◇ More precise result will be coming soon.