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Institute for Laser Technology

GAMMA RAY BEAM TRANSMUTATION

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Y. Asano, Spring8, Hyogo.

June 6th 2007 , Istanbul Turkey.

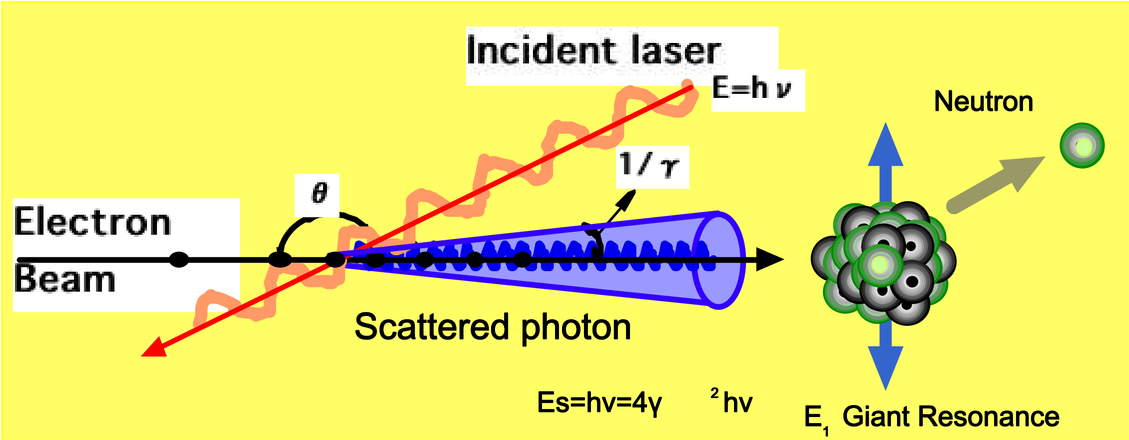
Brief summary of this work

- Transmutation of Iodine-129 from fission reactor
- Energy balance of transmutation
- Enhanced laser Compton scattering

  Super cavity

  Bunched E-beam Compton Scattering

Laser Compton Scattering



Characteristic γray by laser Compton scattering

1. Sharp shooting 1/γ

2.Tunability hνγ² for E1 Giant Resonance

But cross section of photon and electron is very small in usual case!

⇨ **SUPER CAVITY, Bunched E-beam**

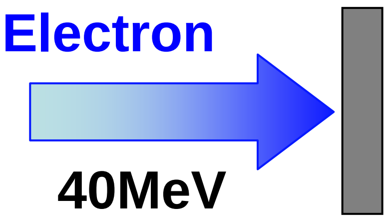
High Level Nuclear Waste
⇨FP and TRU are produced.

Nuclei	Half decay (year)	Neutron cross section (b)	Production (Ci / year)	Amount (kg / year)
FP				
85Kr	11	1.7	3.0×10^{5}	0.79
90Sr	29	0.014	25×10^{6}	17.8
93Zr	1.5×10^{6}	2.6	61	24.0
99Tc	2.1×10^{5}	20	433	25.5
107Pd	6.5×10^{6}	1.8	3.6	7.0
129I	1.6×10^{7}	27	1.0	5.8
135Cs	2.3×10^{6}	8.7	13.5	11.7
137Cs	30	0.25	3.5×10^{6}	39.5
151Sm	90	15000	1.1×10^{4}	0.4
TRU				
237Np	2.1×10^{6}	181	11	14.4
241Am	432	603	5.0×10^{3}	1.46
243Am	7380	79	601	3.03
243Cm	28.5	720	55	0.01
244Cm	18	15	5.8×10^{4}	0.72
245Cm	8500	2347	4.1×10^{3}	0.03

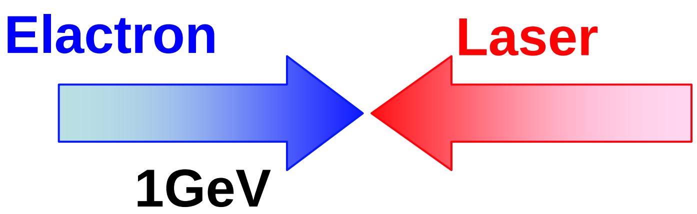
Iodine 129 is an element of the longest active life time as 16 million years and small absorption cross section for neutron. Besides these, iodine boiling point is much lower than the component for geologic repository package.

Compton Gamma: More efficient coupling for E1 G— R than Bremsstrahlung

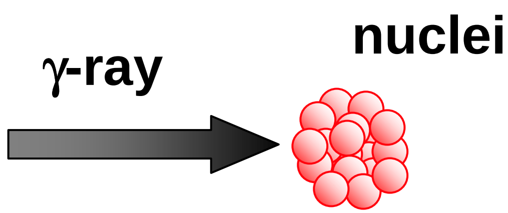
Bremsstrahlung



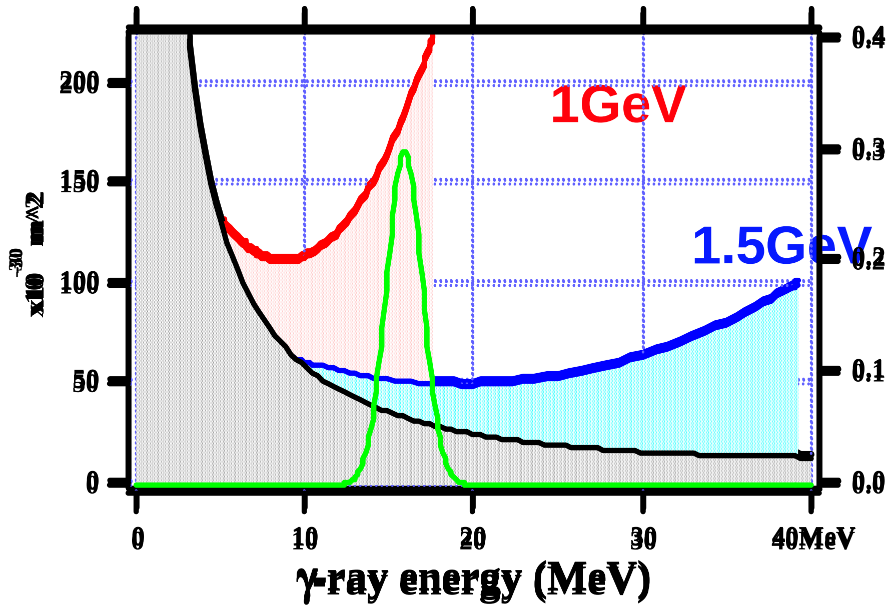
Compton Scattering Gamma Ray



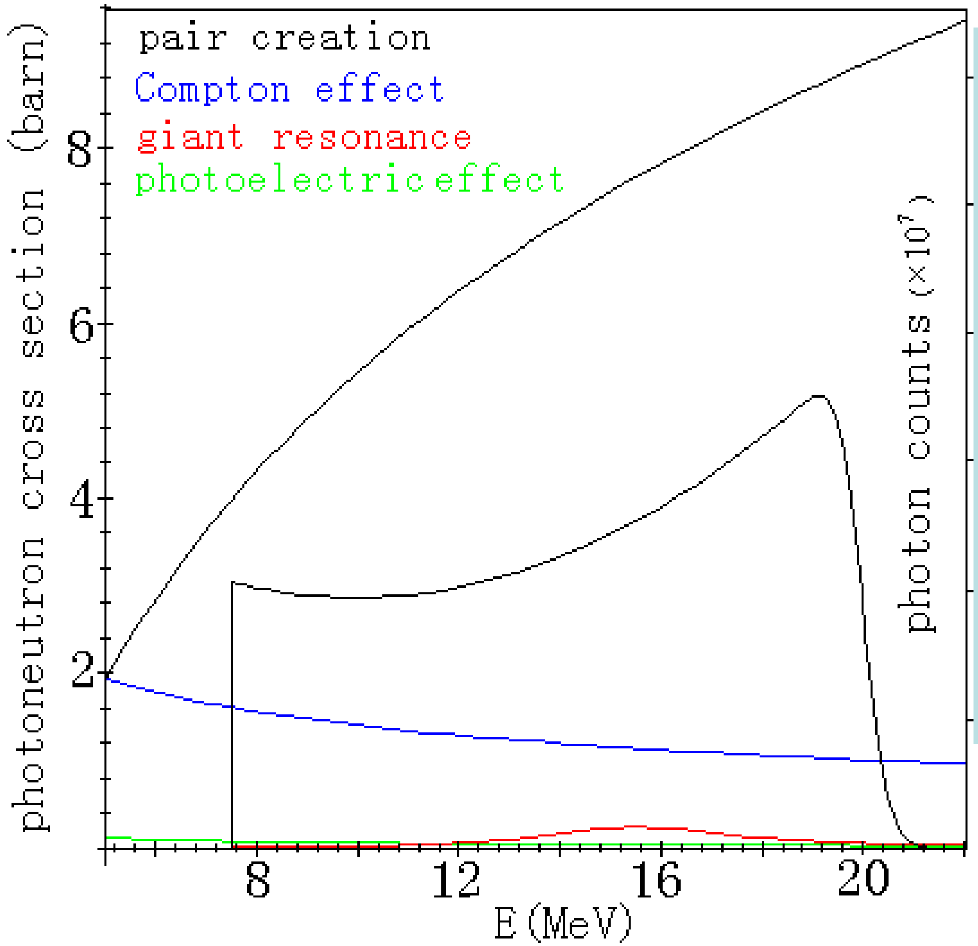
Giant resonance



(γ,n)reaction



Pair Creation & Compton scattering by target electrons >> Giant Resonance



Only few per cent of gamma photon goes to the transmutation in this scheme.

Energy balance?

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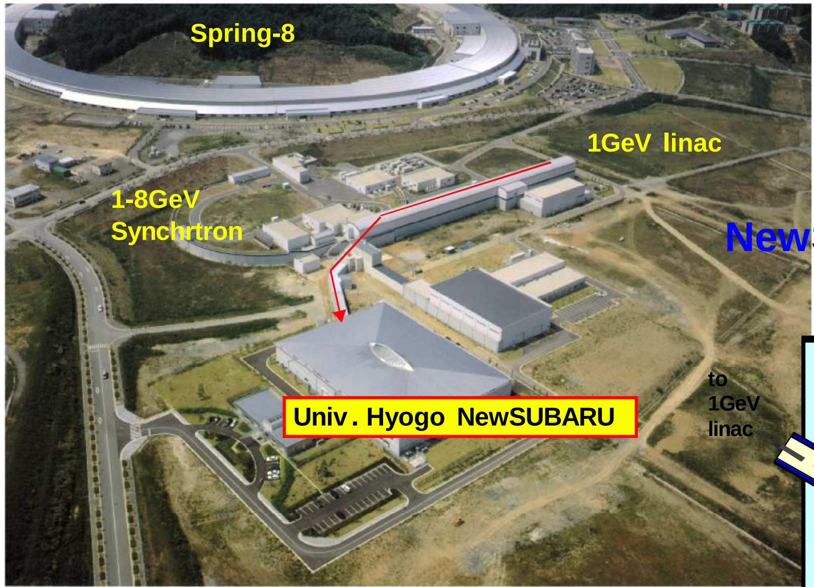
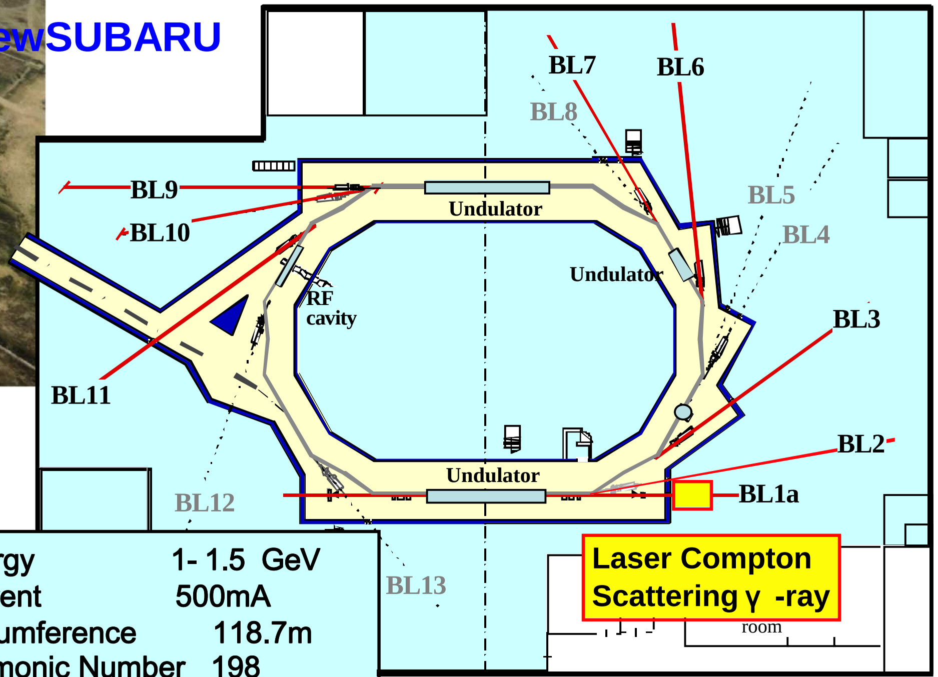
Neutrons for energy multiplication

Gamma ray beam
Sharp shooting and tunability



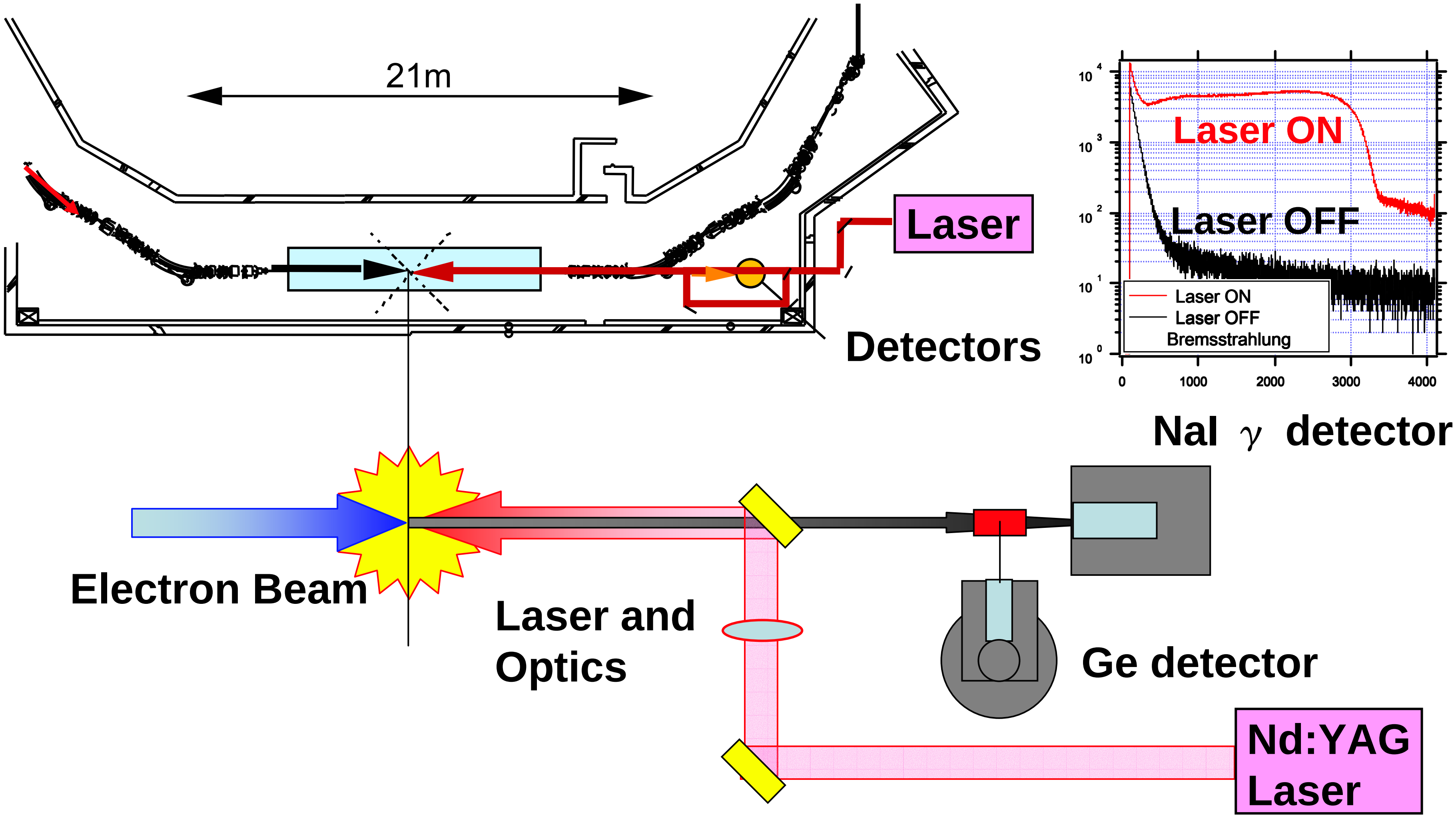
NewSUBARU



Energy	1- 1.5 GeV
Current	500mA
Circumference	118.7m
Harmonic Number	198

On New Subaru BL1, we obtained 10^{15}/Y photon with 2W CW YAG laser.

Experimental set up on BL1 at NEW SUBARU

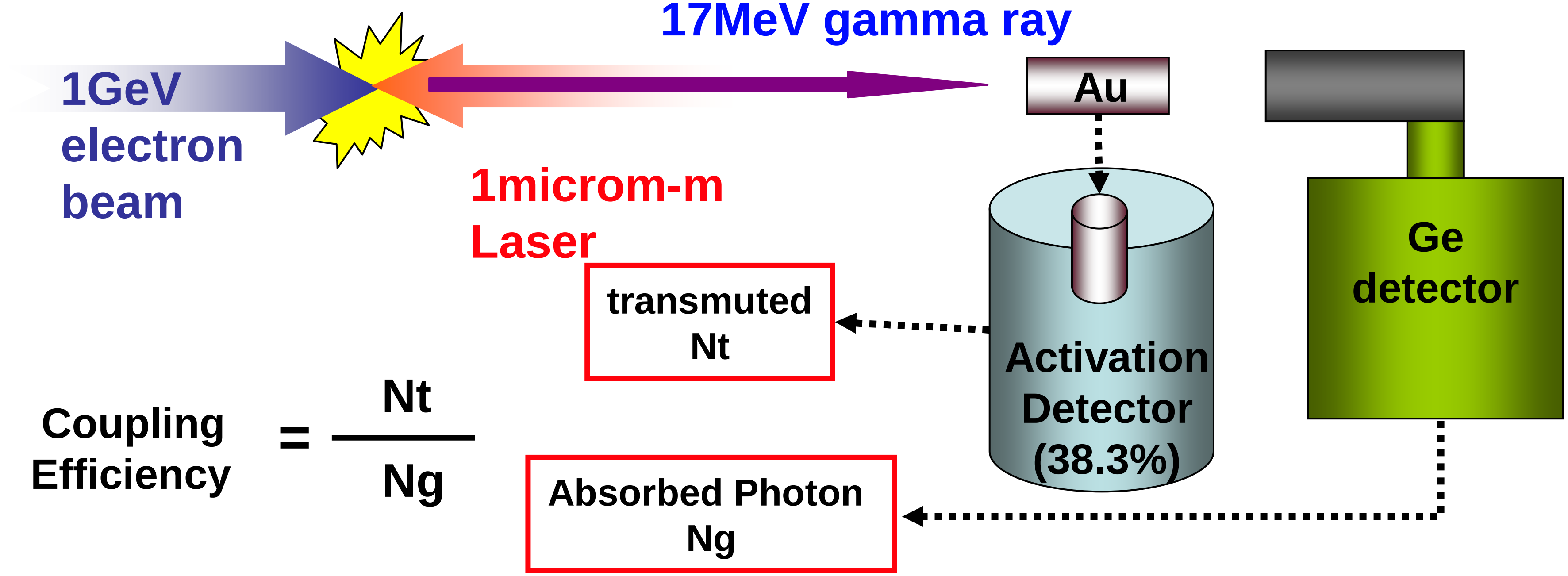


Au target to obtain the transmutation rate

target

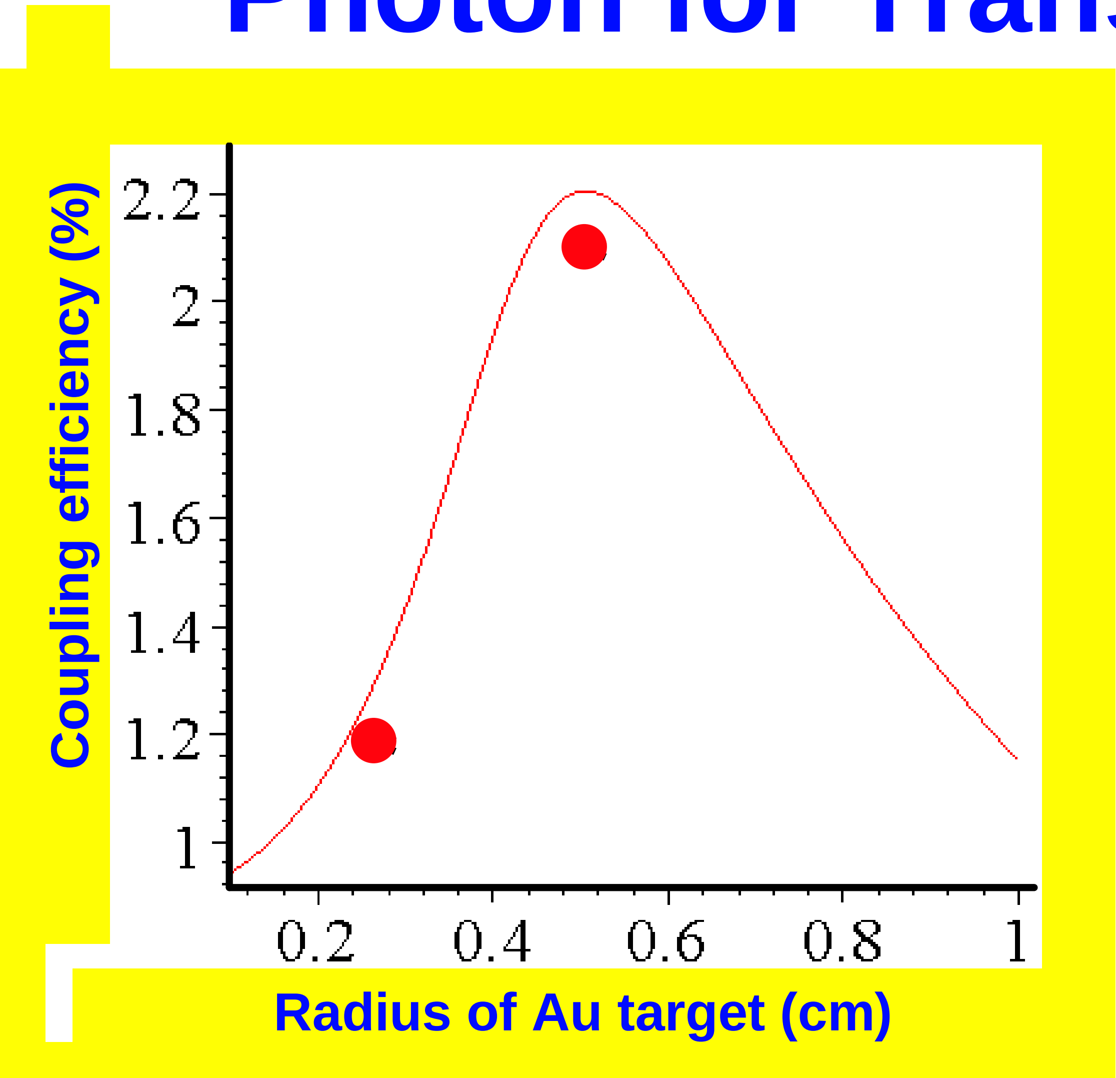
$^{197}Au\ (\gamma,n)\ ^{196}Au$ → EC ⇨ ^{196}Pt (92.5%)

^{196}Au → β^- ⇨ ^{196}Hg (7.5%)



$$\text{Coupling Efficiency} = \frac{Nt}{Ng}$$

Coupling Efficiency of Gamma Photon for Transmutation



- Gamma ray size at 15m distance is 0.7cm. Target size was changed to couple the generated gamma ray.

- Experimental results corresponded well to the calculated curve.

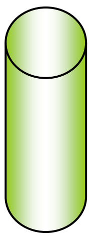
- In this calculation, Self-absorption was included.

Iodine Target

Iodine129

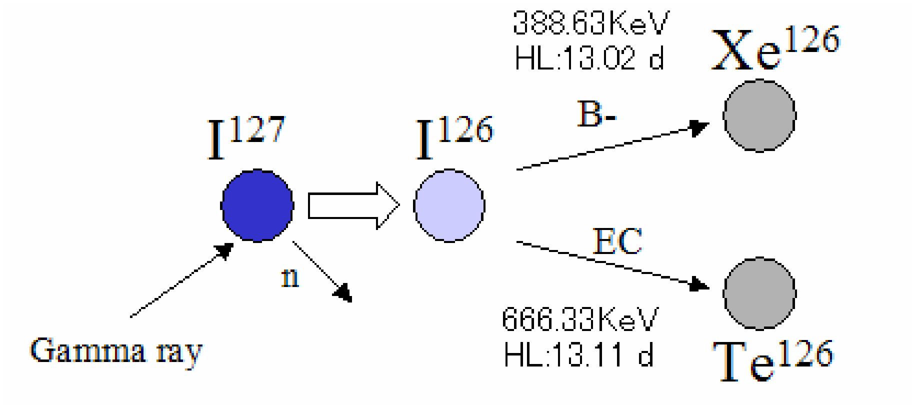
Iodine127

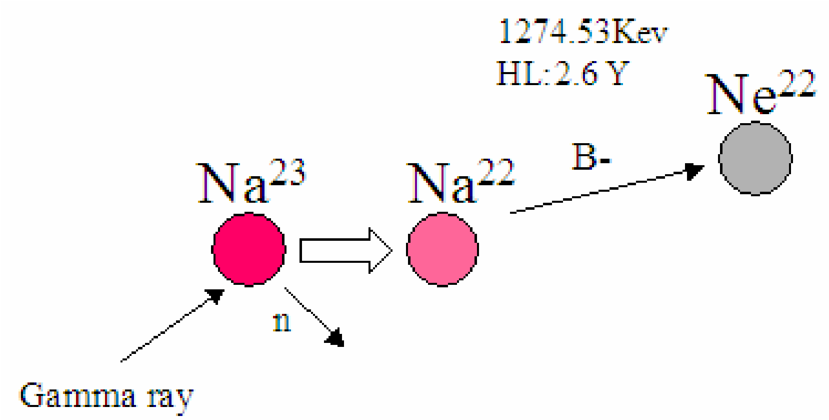
target：NaI



radius：0.5ｃｍ

length：5ｃｍ

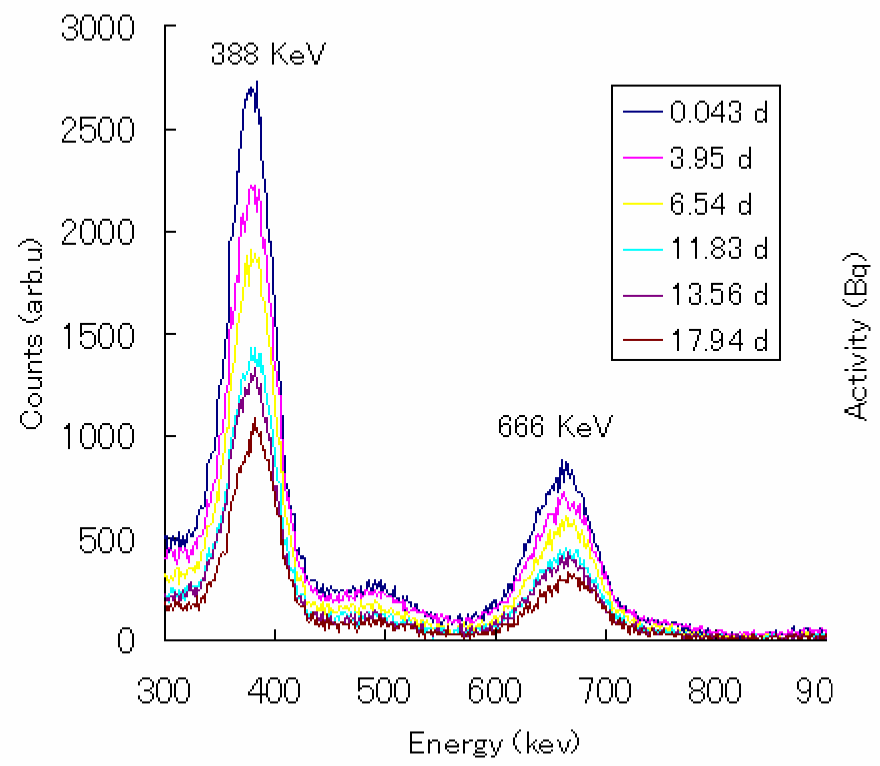




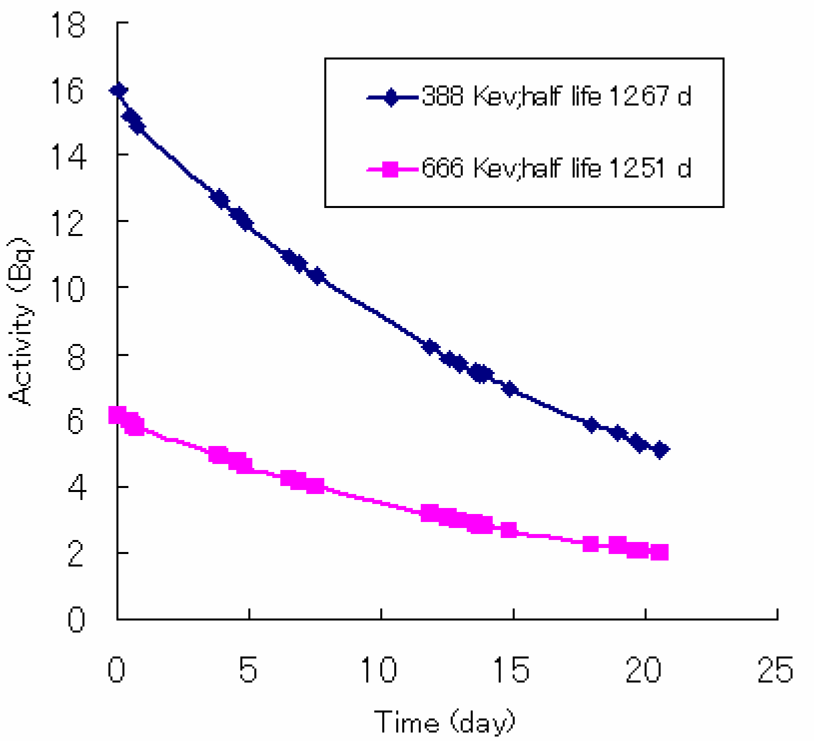
NaI target Experiments

1. NT cross section of ^{23}Na is more than50 times smaller than that of ^{127}Iodine at 16MeV. ^{22}Na decay time is 73times longer than that of ^{126}Iodine
2. ^{127}Iodine nuclear transmutation can be measured using natural NaI target.
3. We can estimate NT-rate of ^{129}Iodine from this experiment.

I-126 Radioactive Decay

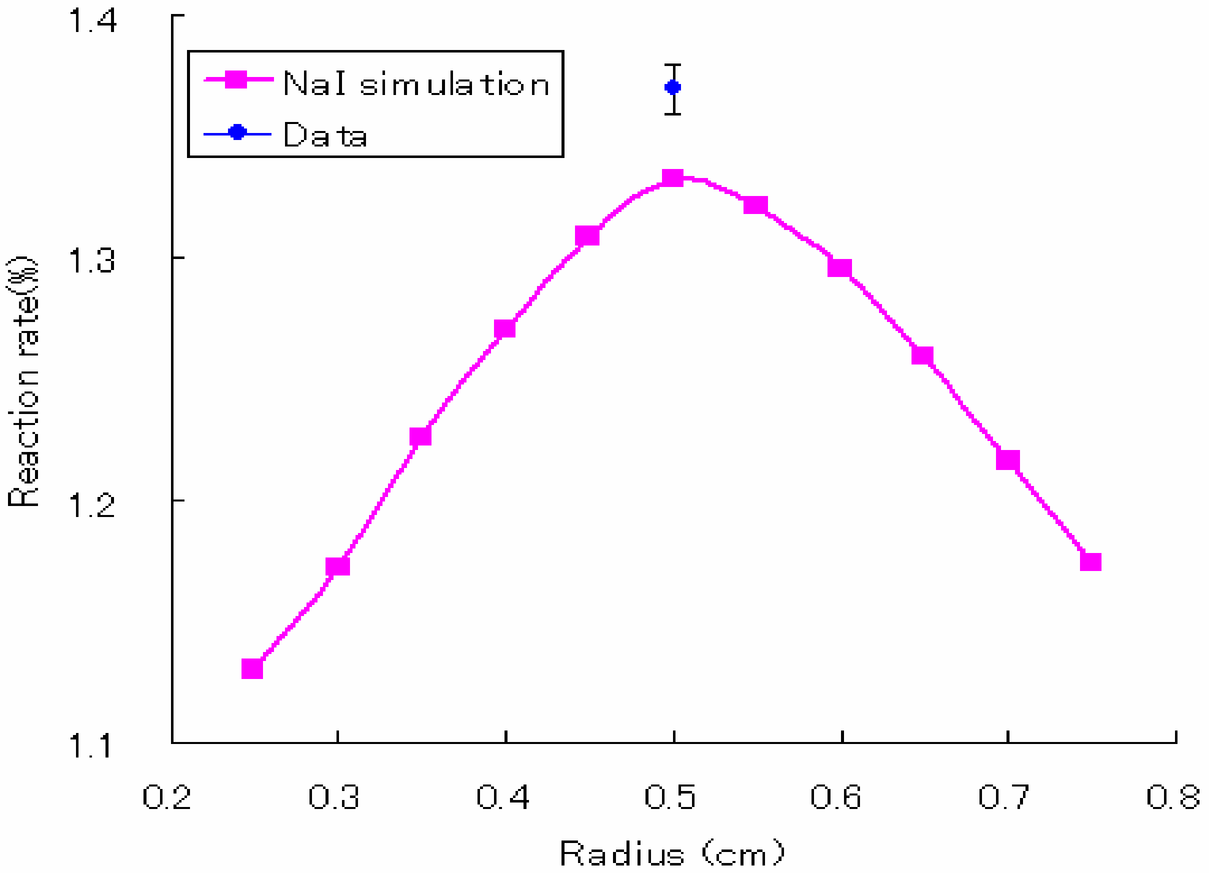


I-126 radiation energy spectrum



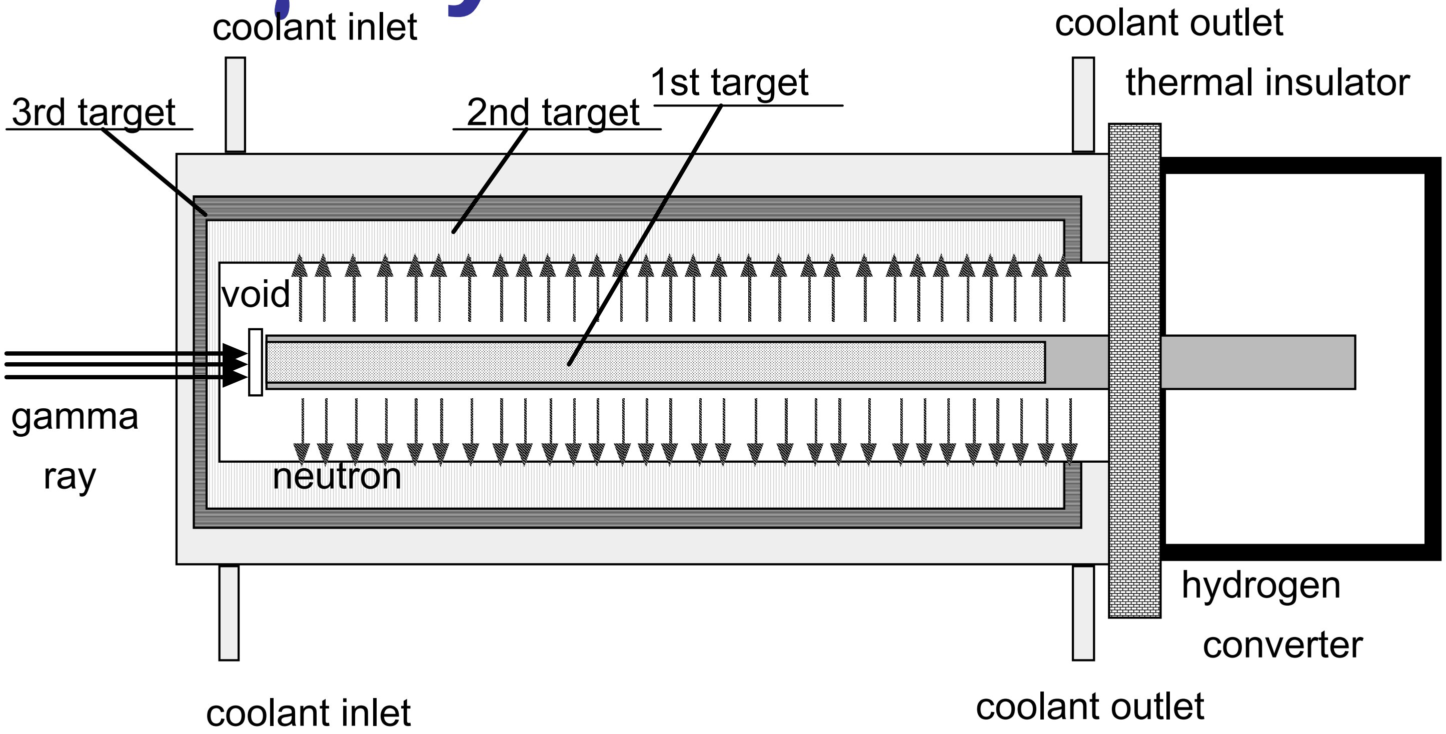
I-126 radiation activity

Reaction rate of NaI on experiments and simulation



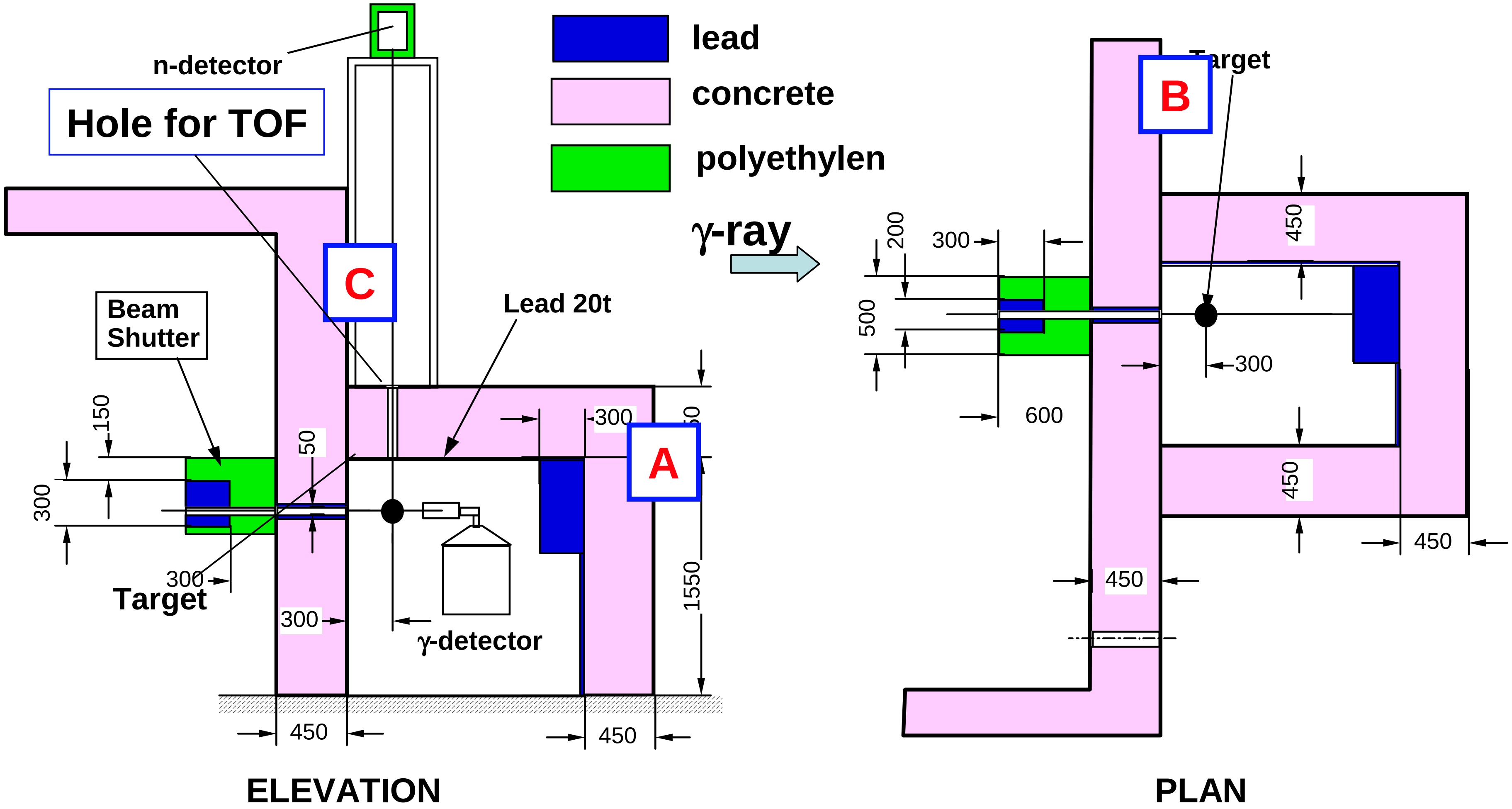
Reaction rate for simulation and experimental result

Schematic drawing of targets for γ ray transmutation



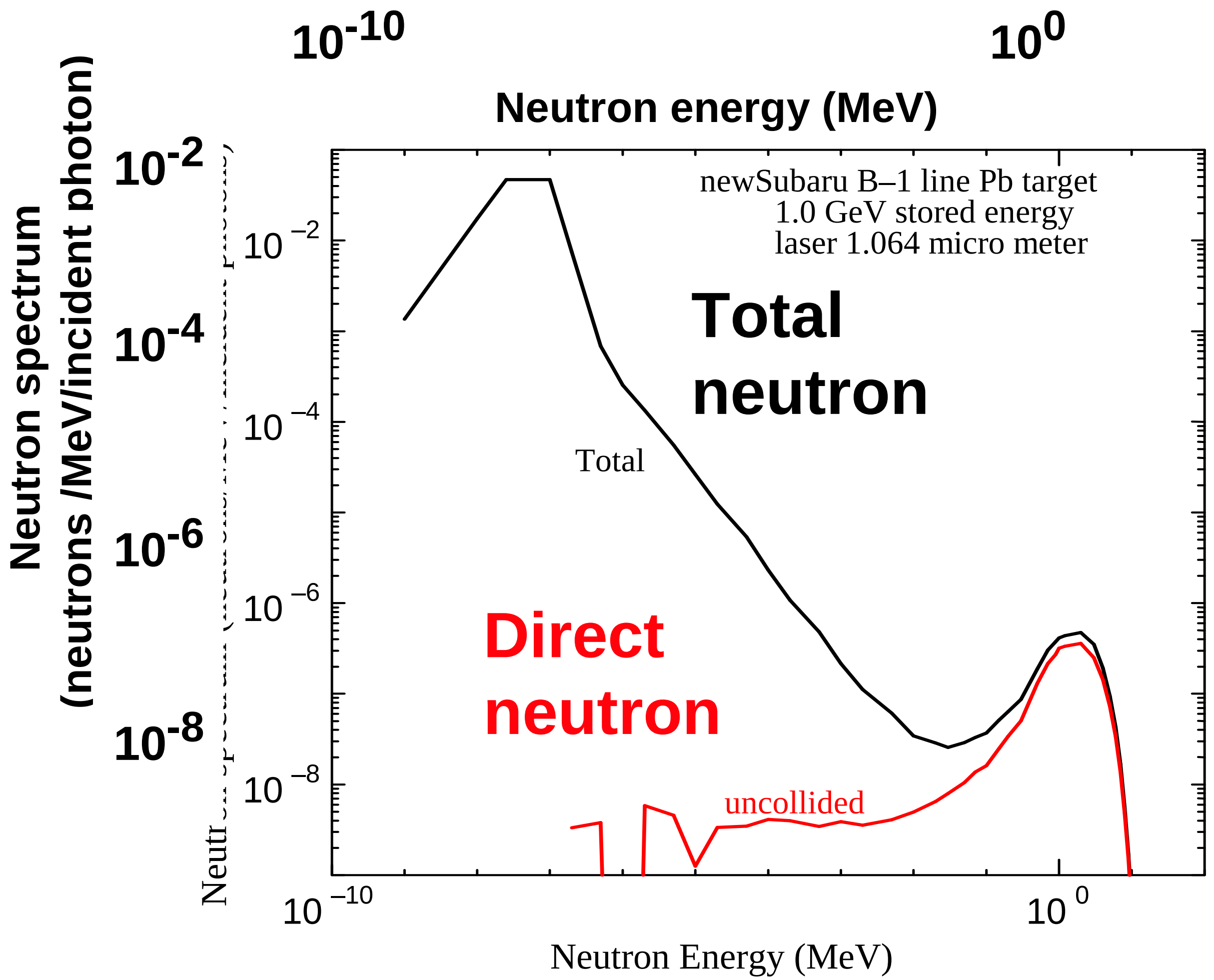
Sharp shooting of γ ray
By-production of neutron for energy multiplication
Self-hearing of target by electrons and positrons

Neutron measurement box for TOF



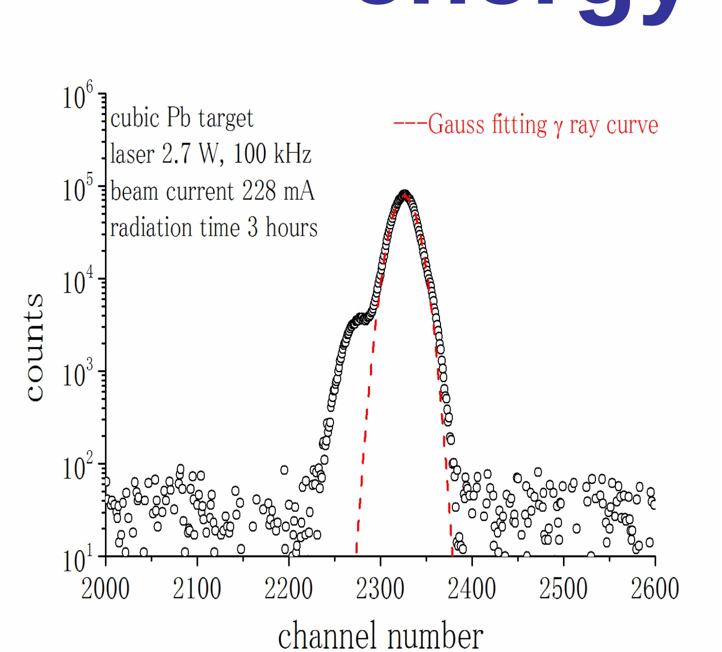
Neutron spectrum is estimated by TOF for energy balance.

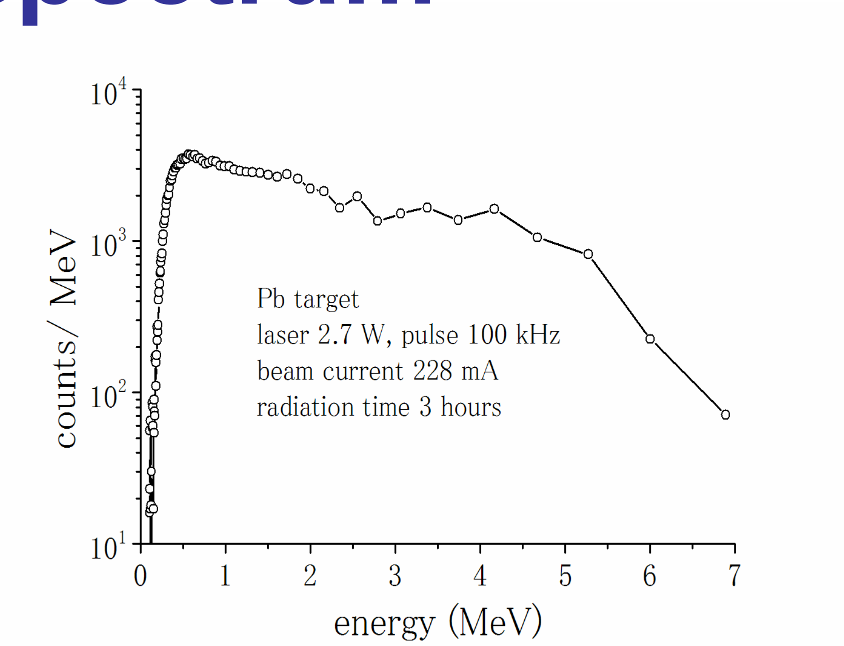
Neutron spectrum on TOF neutron detector



Target(lead)
2cm cubic
Distance from the target to detector
3.2 m
Stored electron energy
1 GeV
Laser wave length
1.064 μm

Neutron production and energy spectrum





Experiment results for neutron spectrum were obtained. Scattered γ ray overlapped the leading edge of neutron waveform. So the neutron energy spectrum was corrected and was estimated.

Compton cross section is very small in usual case!

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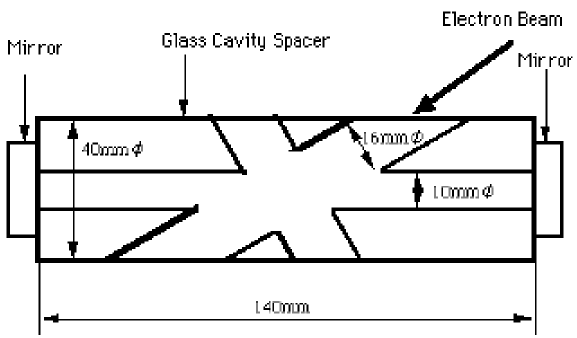
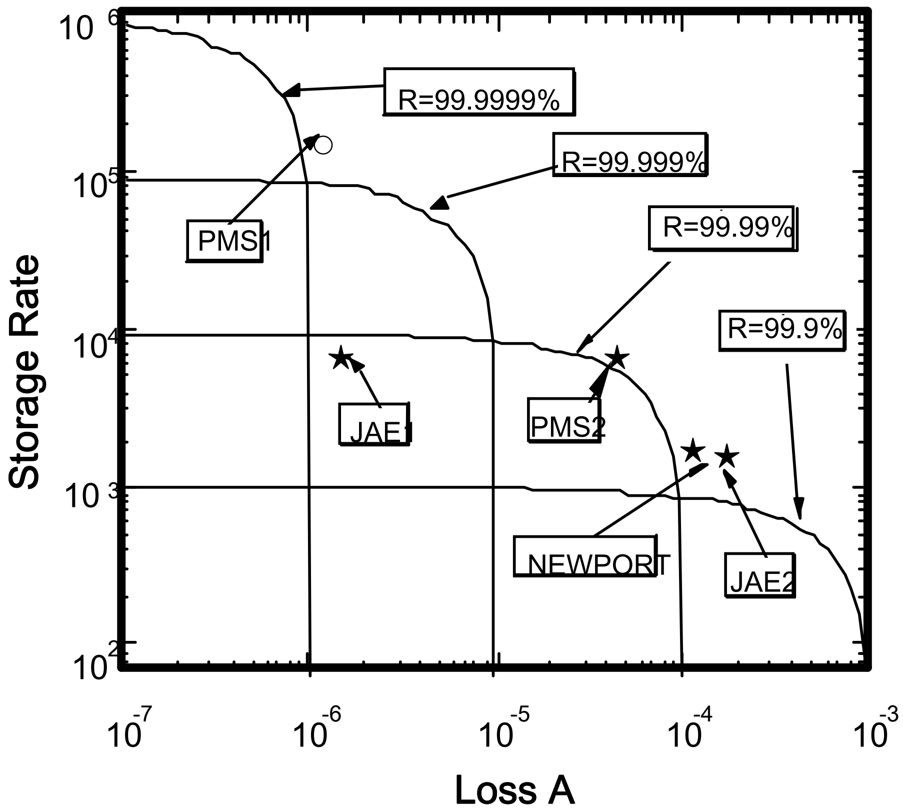
- SUPER STORAGE CAVITY
- Total reflection from bunched E-beam

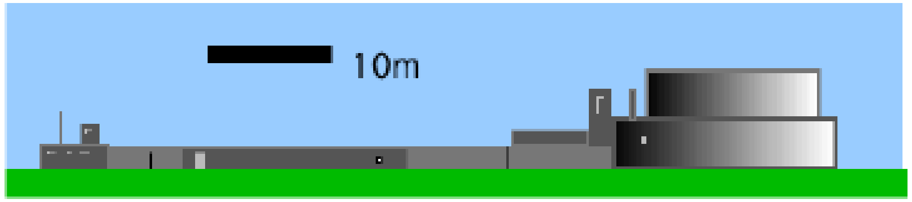
is required for practical design of transmutation system even when target is only Iodine.

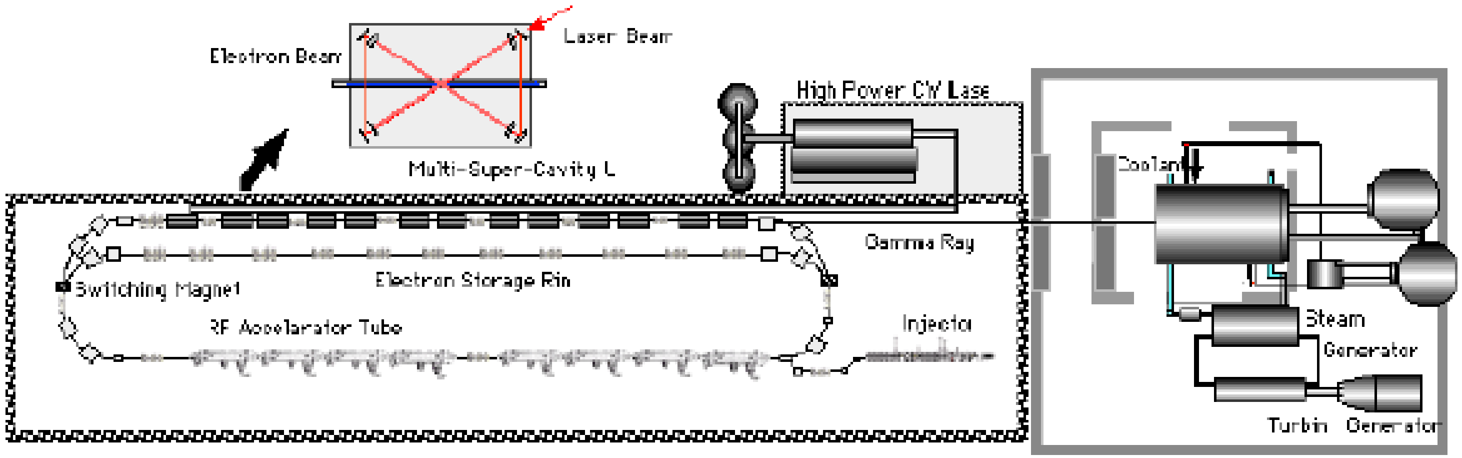
Storage Cavity and Rate





γ ray transmutation system

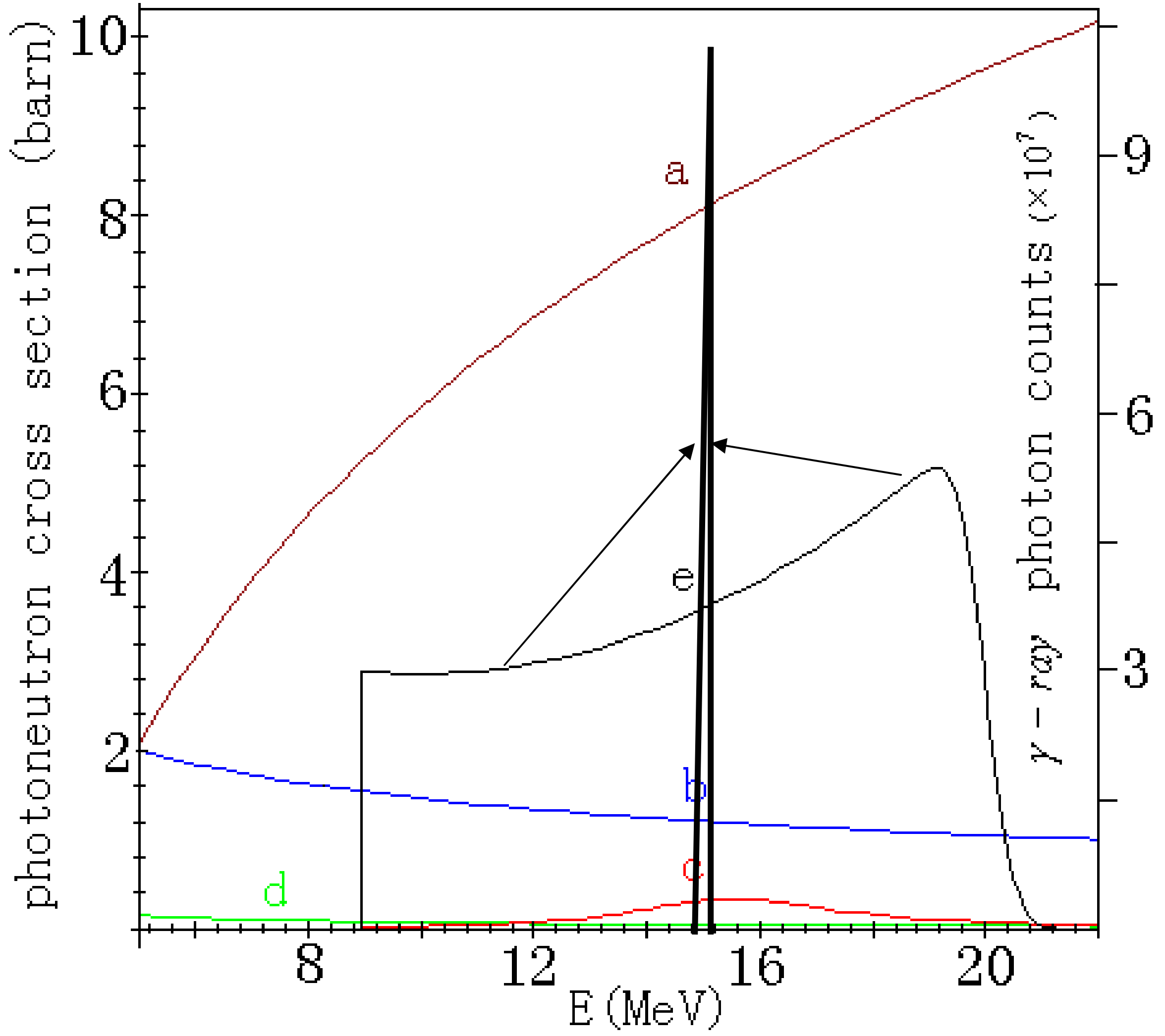




Total efficiency for γ ray generation is close to accelerator efficiency.

Multi-Compton-scattered tail of electron is one of serious issues of the system.

Total reflection by electron beam of tight bunching = mirror flying with light velocity = super Compton scattering



Narrow spectrum
High reflectivity

Complete tuning at peak

Fine Structure

Spectrum narrowing induces the reaction rate increment up to 5.8%. Strong bunched electron beam of density more than $10^{19}/cm^3$, cut off of CO_2 laser density, is considerable as a total mirror.

Metal mirror moving with light velocity

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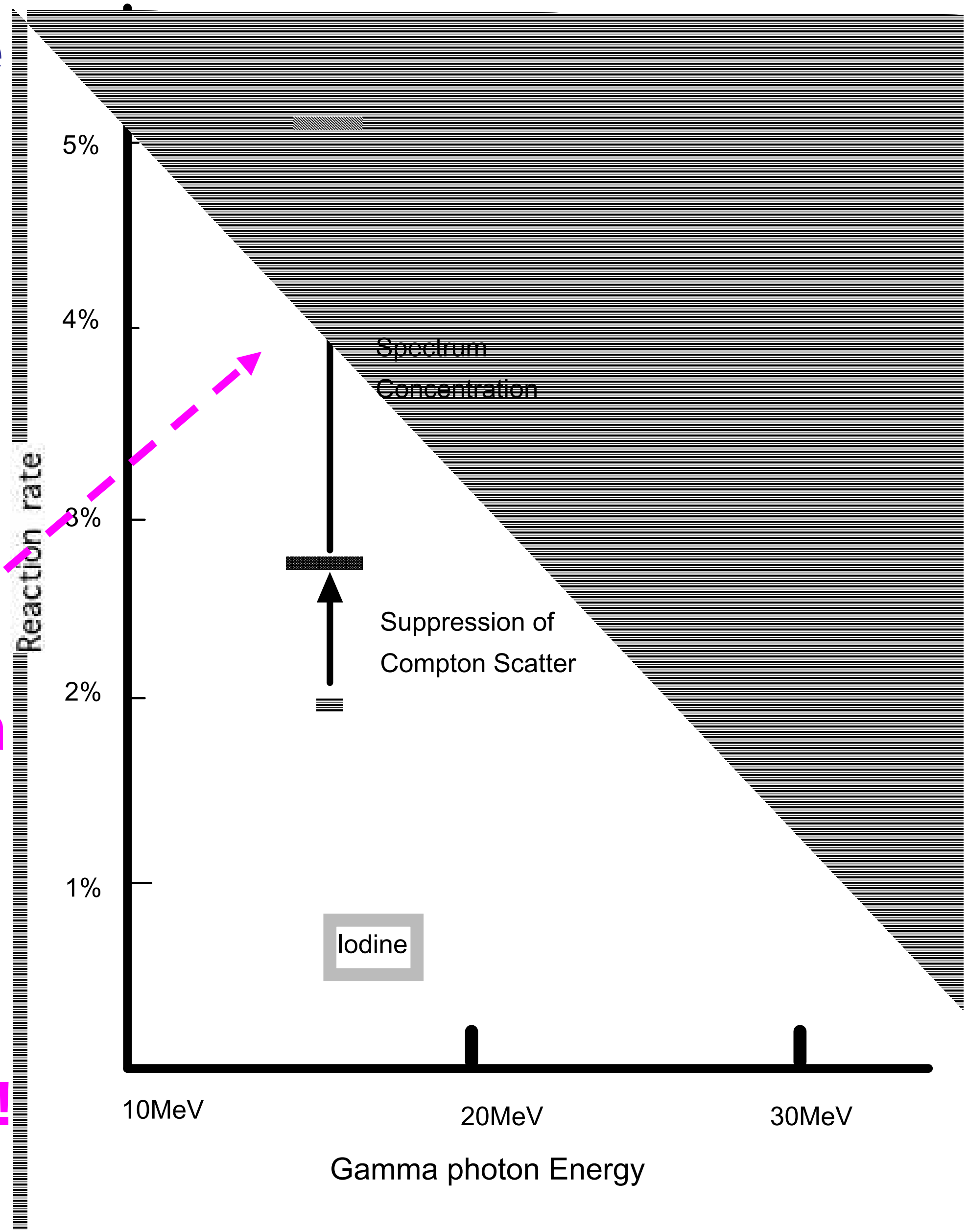
Super high brightness γ ray !

Reaction rate increment !



Summary of this work

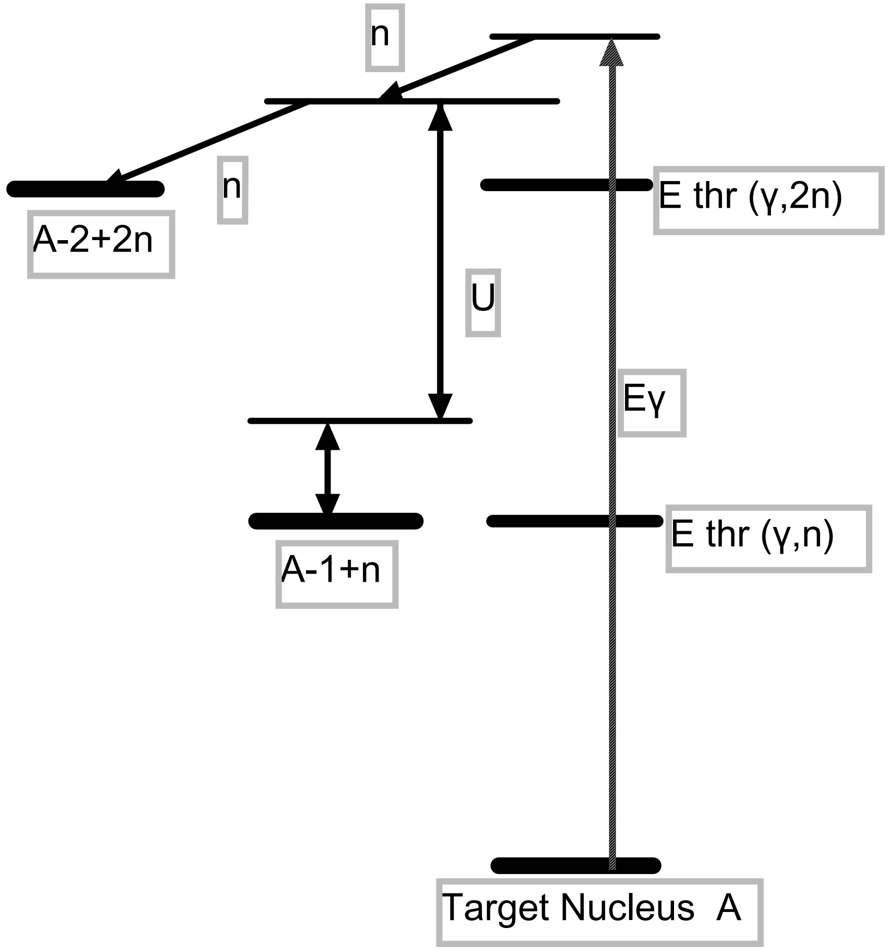
- Transmutation of Iodine from fission reactor was demonstrated by γ ray.($^{127}I \Leftrightarrow {}^{129}I$)
- Energy balance of transmutation is expected by by-product neutron.
- Enhanced laser Compton scattering

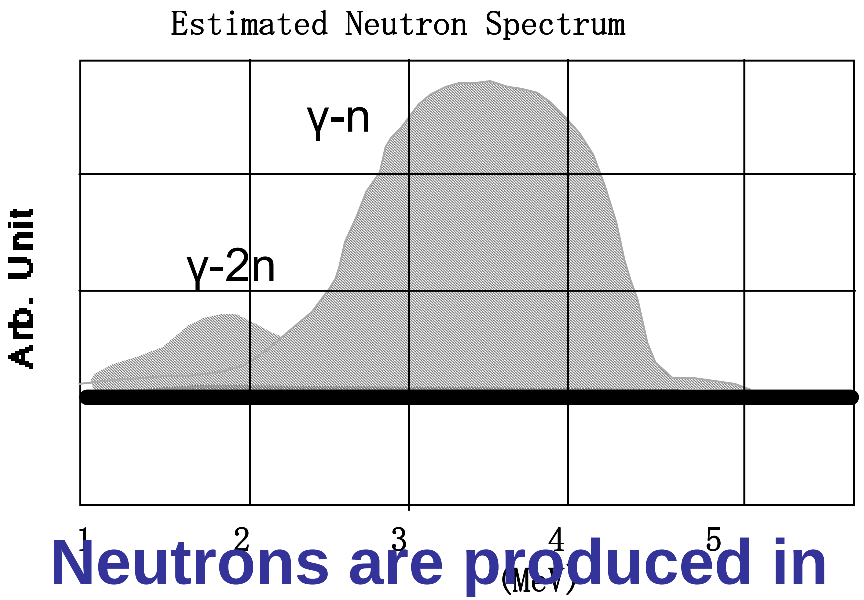
  by Super cavity

  by Bunched E-beam Compton Scattering

have been investigated for actual system.

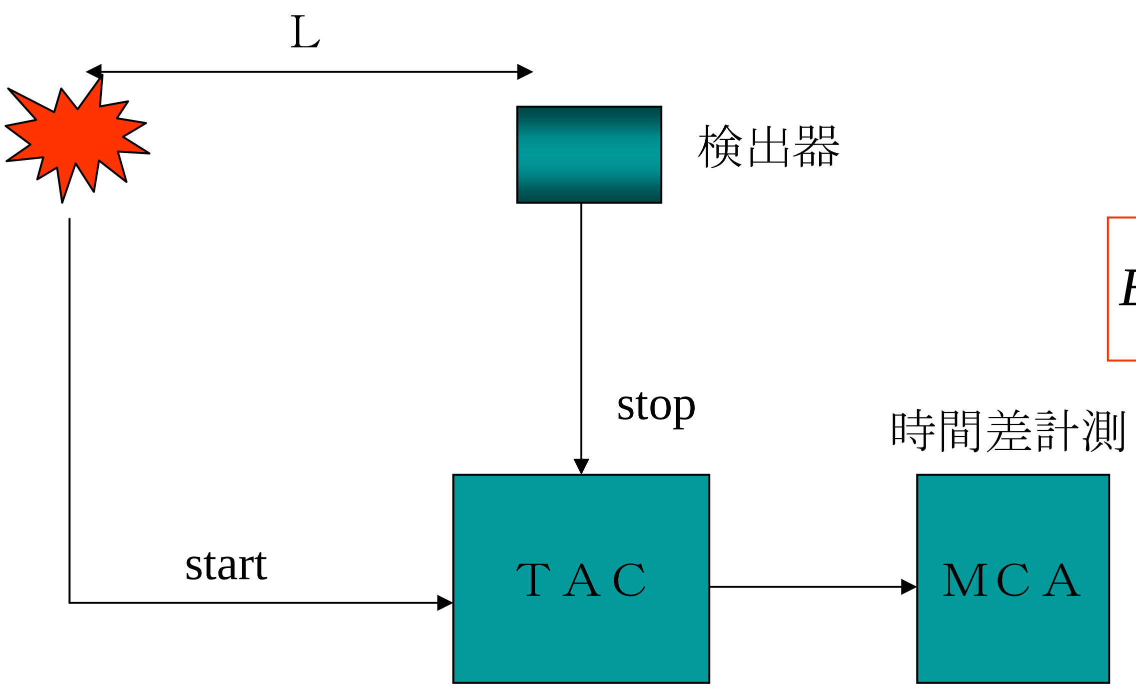
Nuclear Level and Neutron Spectrum from GRR



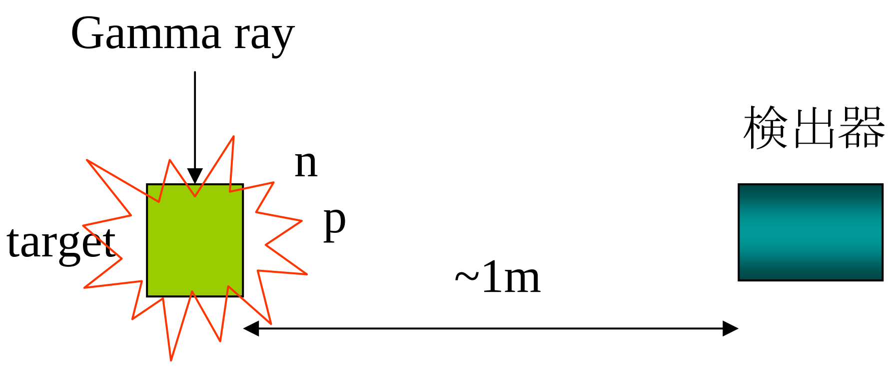


Neutrons are produced in the first reaction with energy of several MeV. This neutron plays an important role to induce the energy multiplication.

ＴＯＦ方法で計測



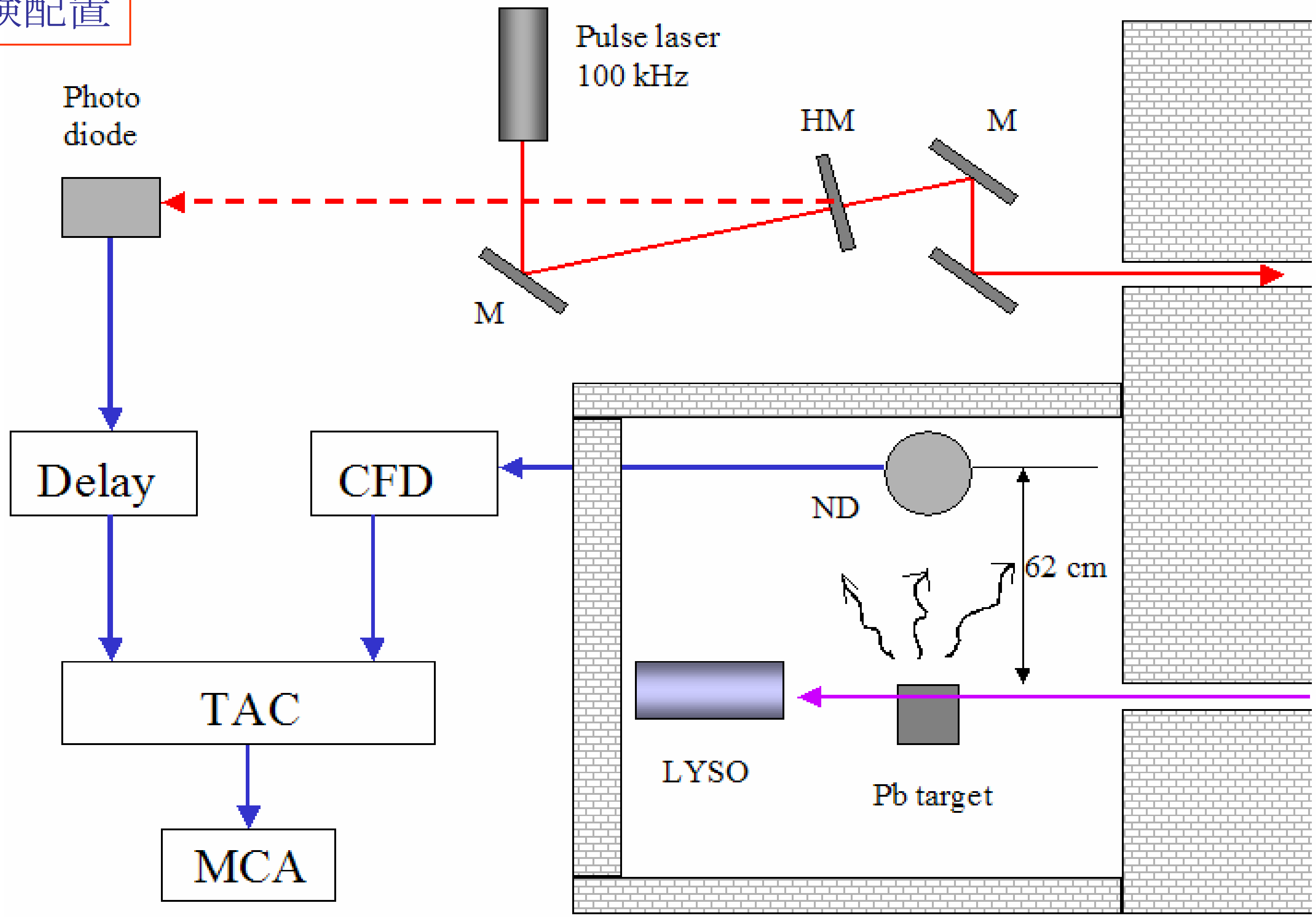
$$E = \frac{1}{2} m v^2$$



ｎとｐの時間差

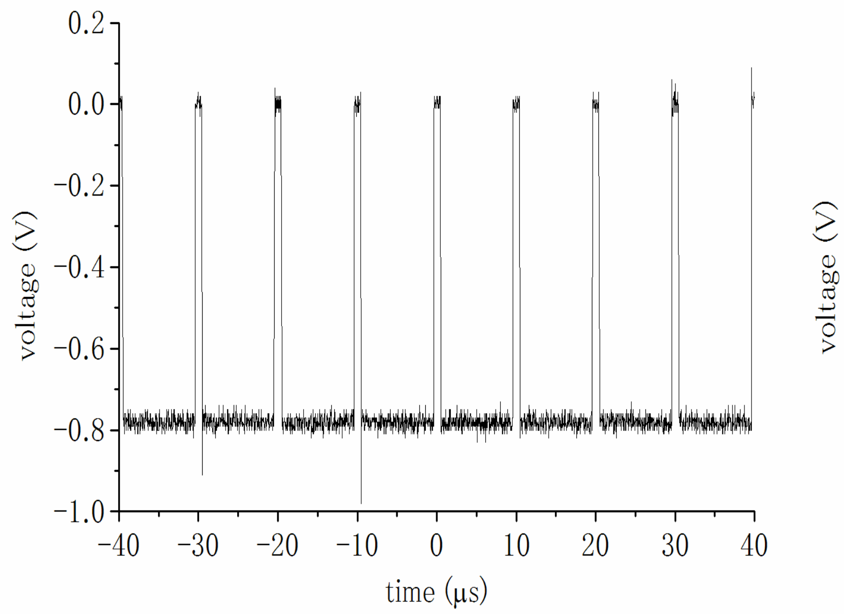
鉛ターゲットによる中性子発生

実験配置

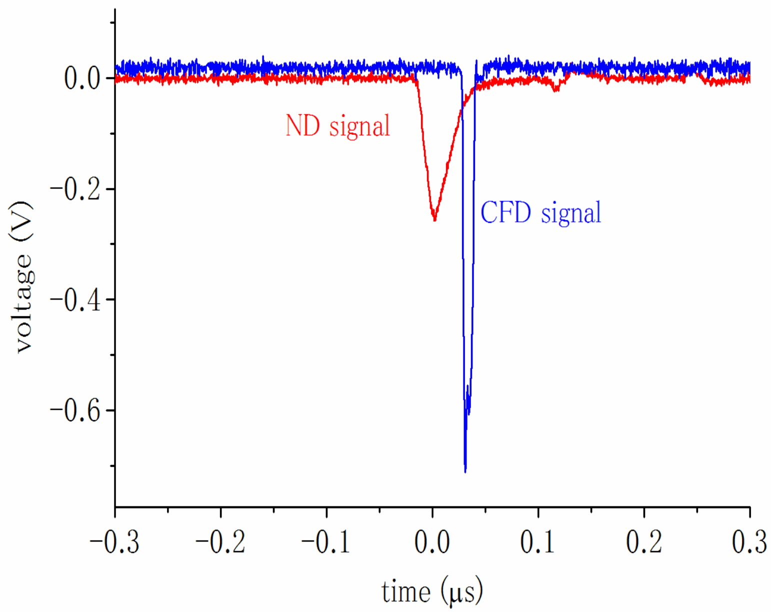


鉛ターゲットによる中性子発生

Start と　stop　信号



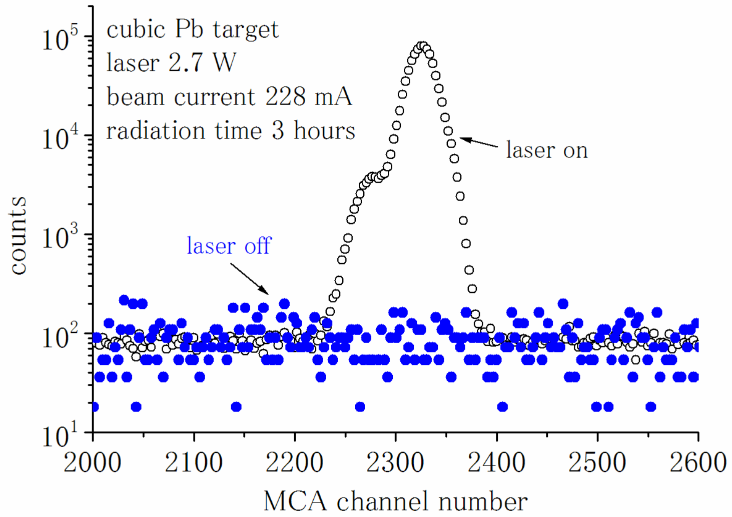
Stop: Photodiode から信号

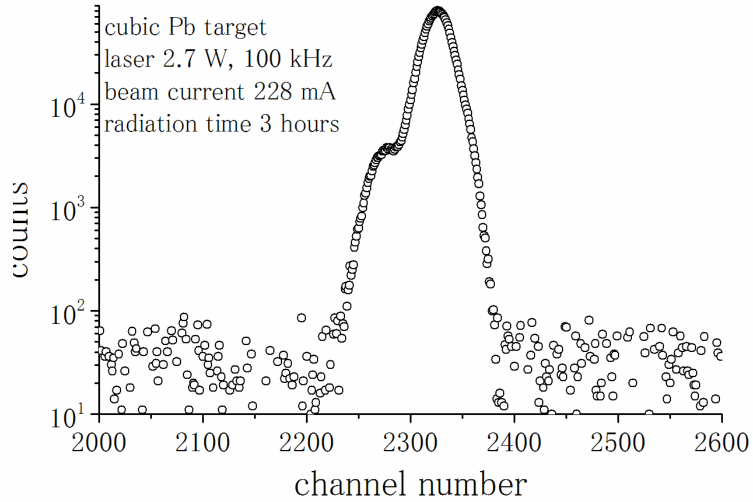


Start: 検出器から信号

鉛ターゲットによる中性子発生

実験データ処理



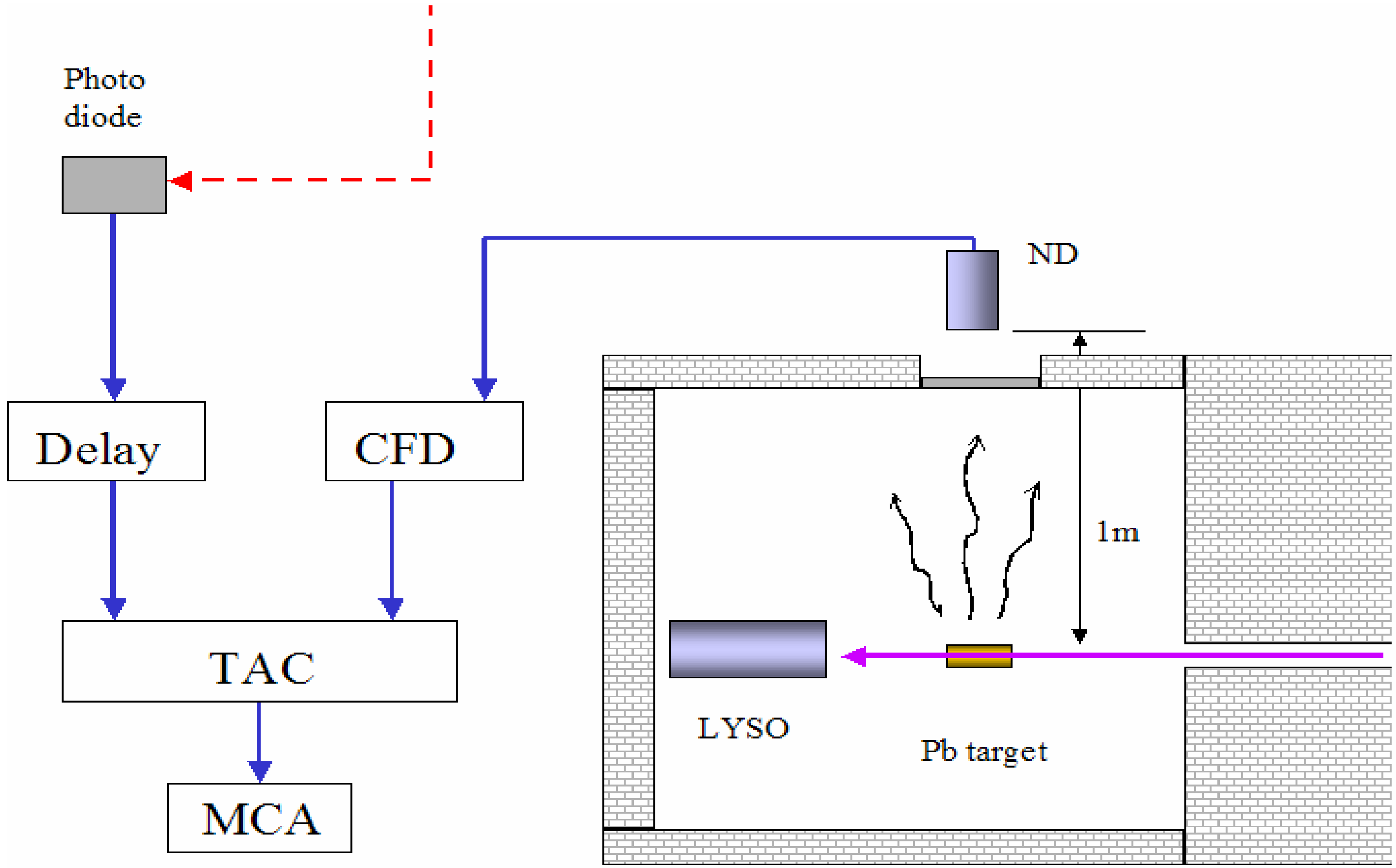


実験データ（１チャネル当り１．２２ns）

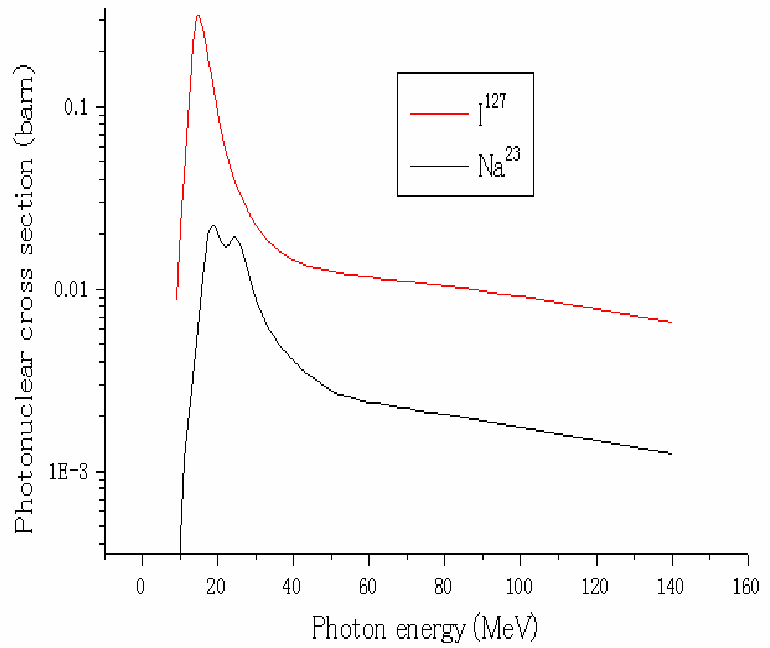
背景信号を減った

金ターゲットによる中性子発生

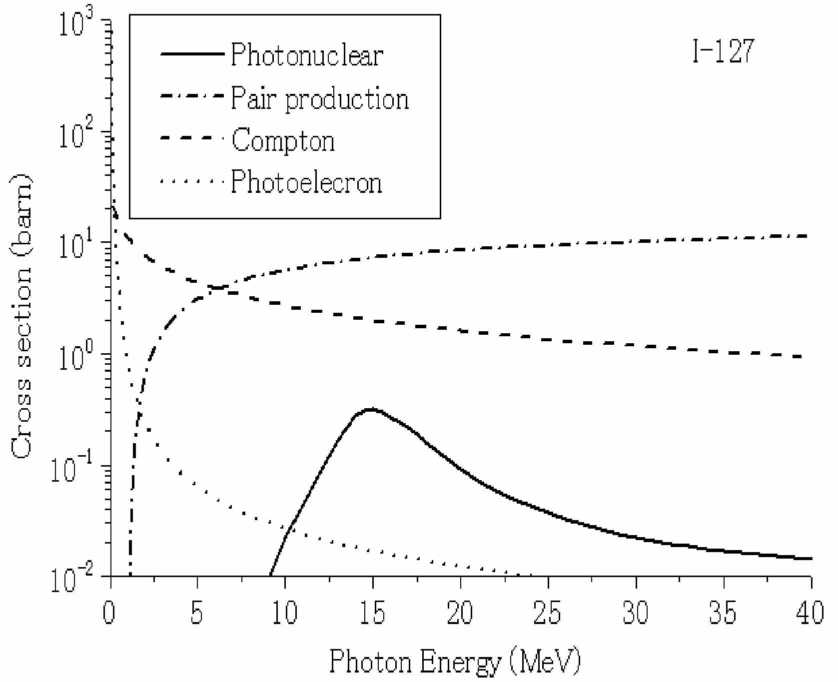
実験配置



Reaction cross section ratio for I-127



Photonuclear cross section vs. photon energy



I-127 cross section vs. photon energy

Fine Structure of E1-GR

Collective motion

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Cluster

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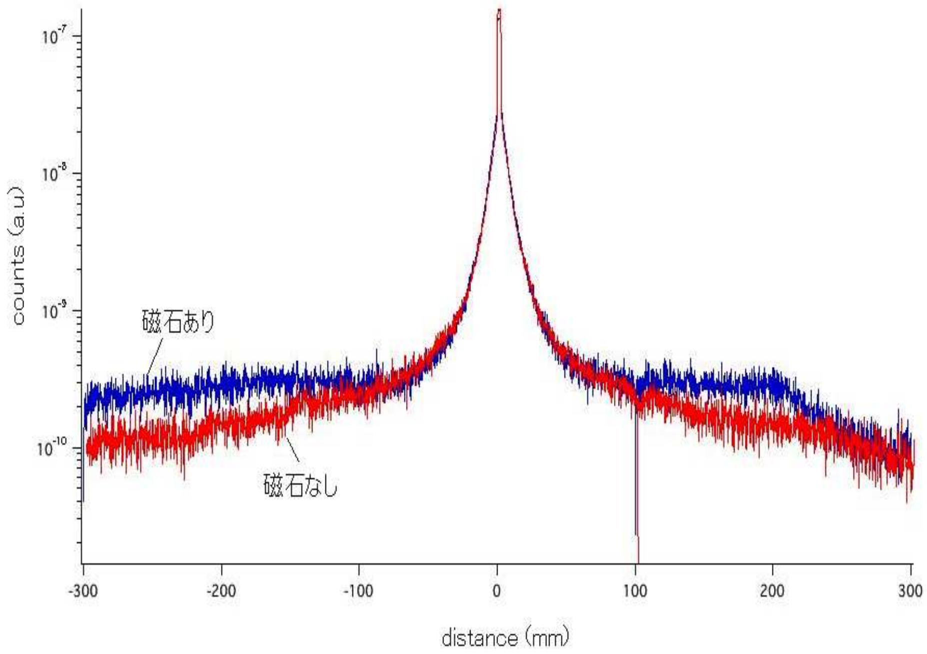
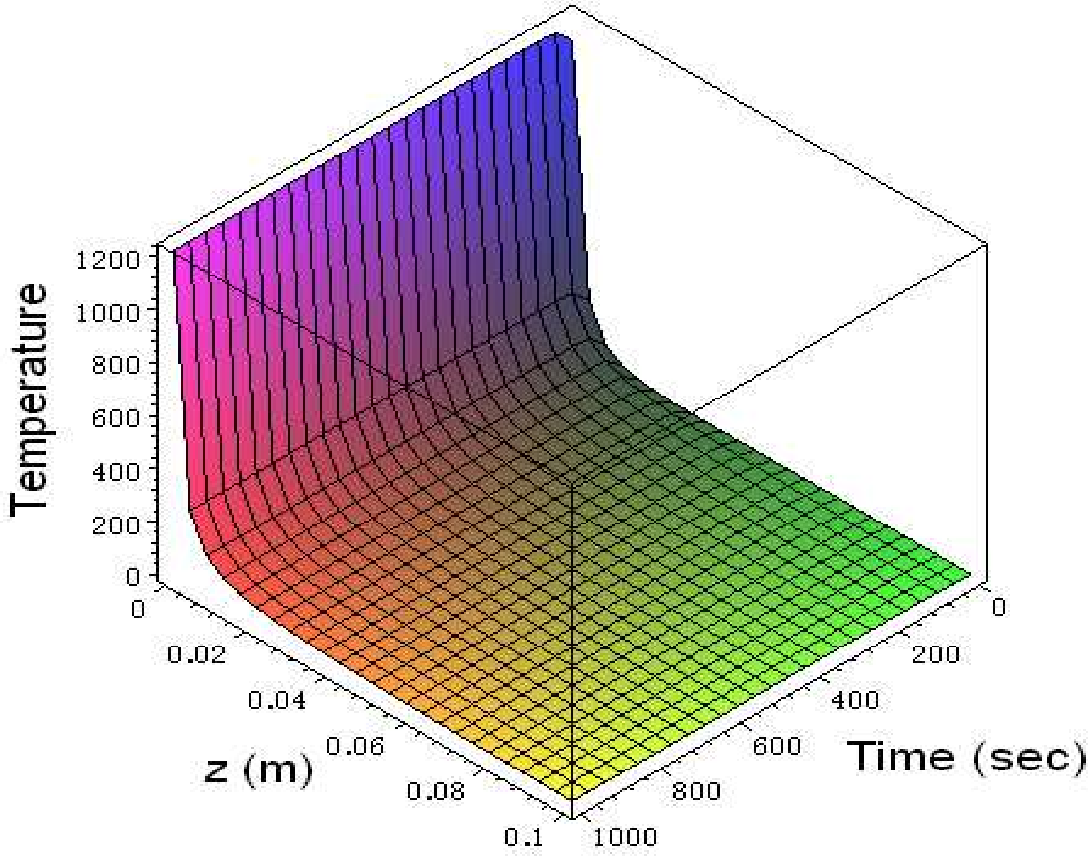
磁場エネルギー分析器による
電子ー陽電子エネルギースペクトル



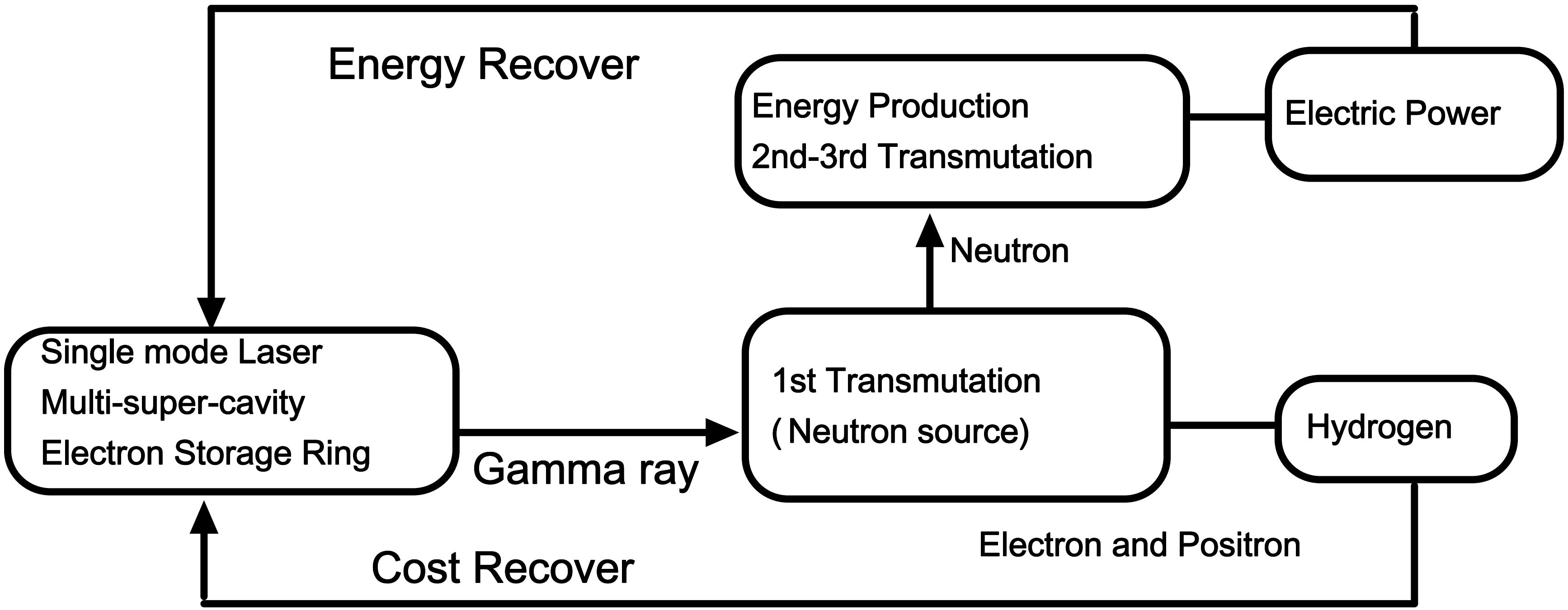
- ターゲット内での電子＆陽電子の熱的挙動
- ヨウ素の相状態

ターゲットにおける電子ー陽電子（対創成）による自己加熱



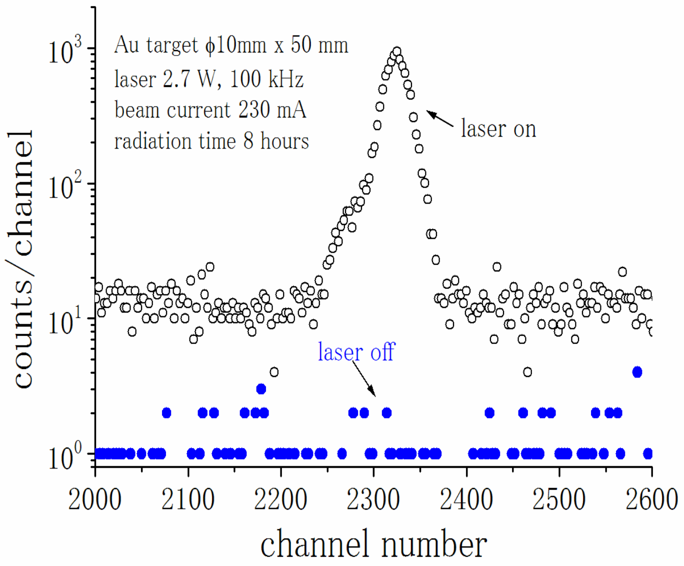
電子ー陽電子により1200Kまで容易に上昇する。これを用いると水素生成が可能である。

Energy Flow in System

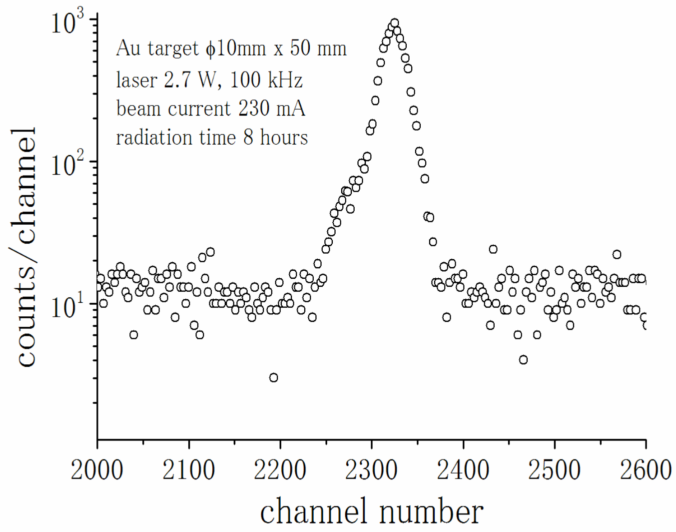


金ターゲットによる中性子発生

実験データ処理



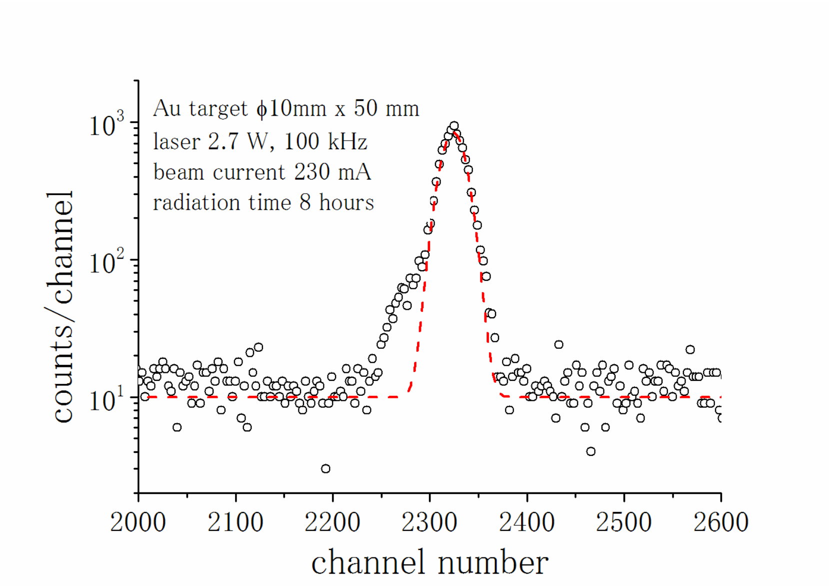
実験データ（１チャネル当り１．２２ns）



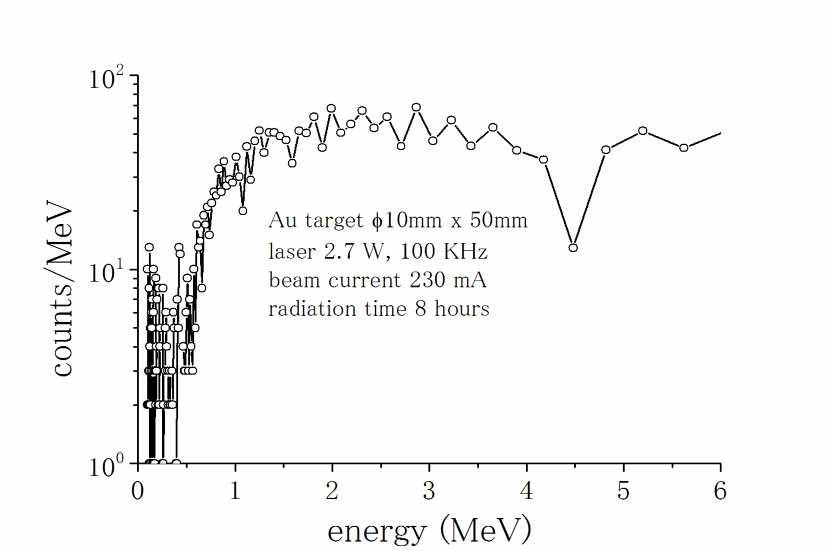
背景信号を減った

金ターゲットによる中性子発生

実験データ処理

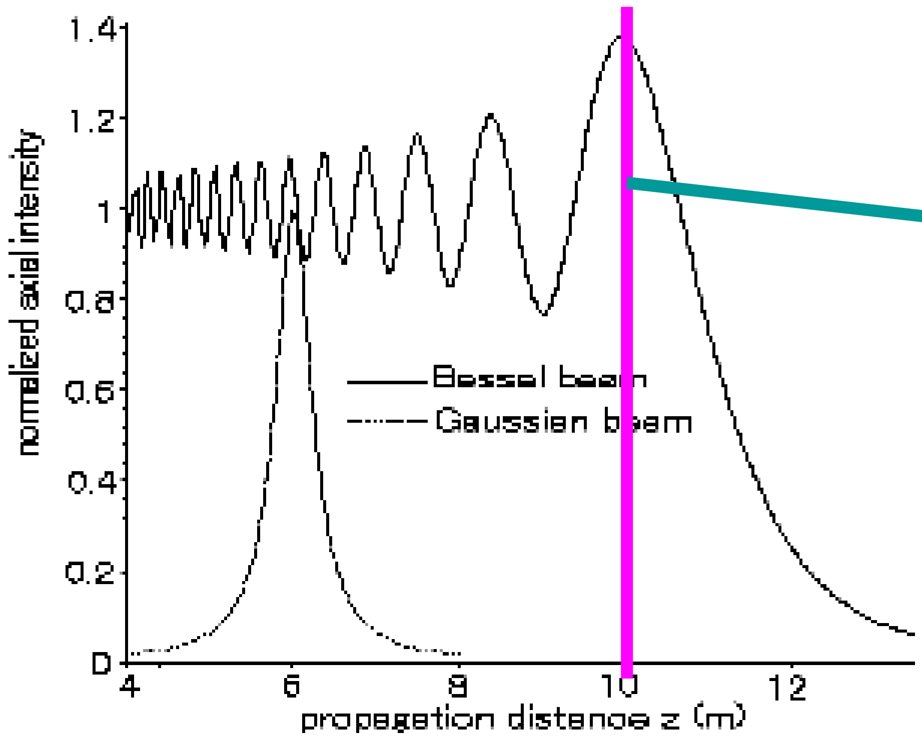


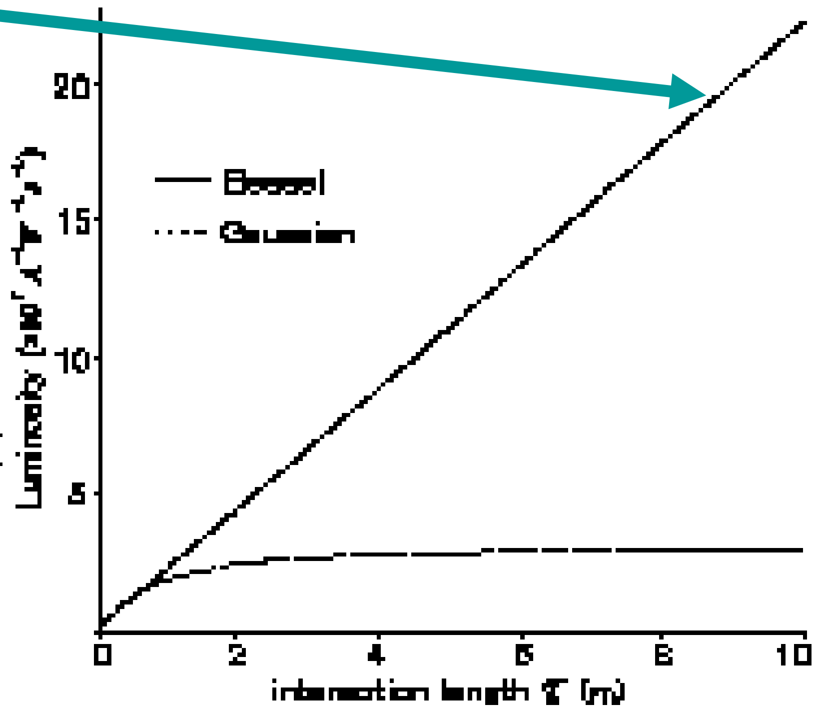
光子部分fitting



中性子スペクトル

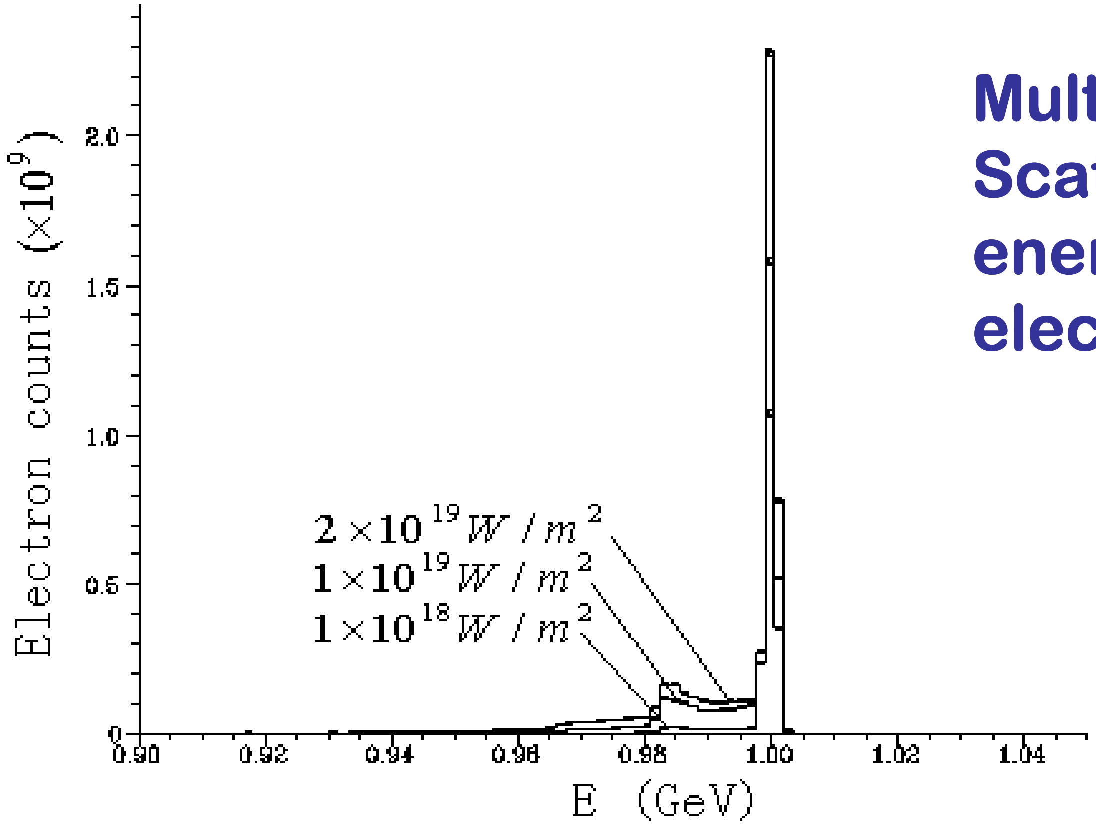
ベッセルビーム は長焦点を有し 電子ビームとの結合性がよい





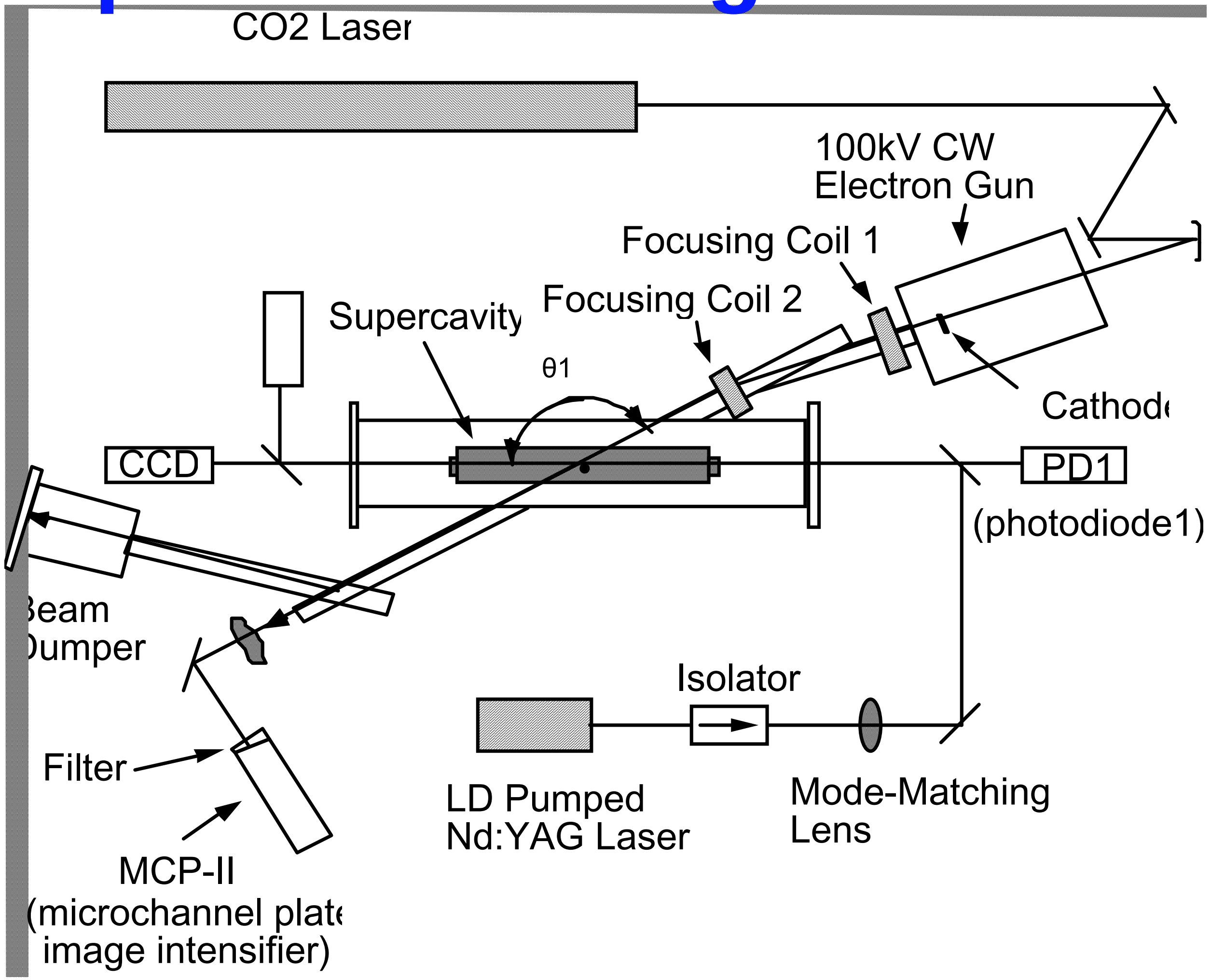
ベッセルビーム
光蓄積が可能か？

Electron spectrum after Compton scatter in storage ring with the laser power density of 10^{18}w/m^2 to $2\text{x}10^{19}$w/m^2.

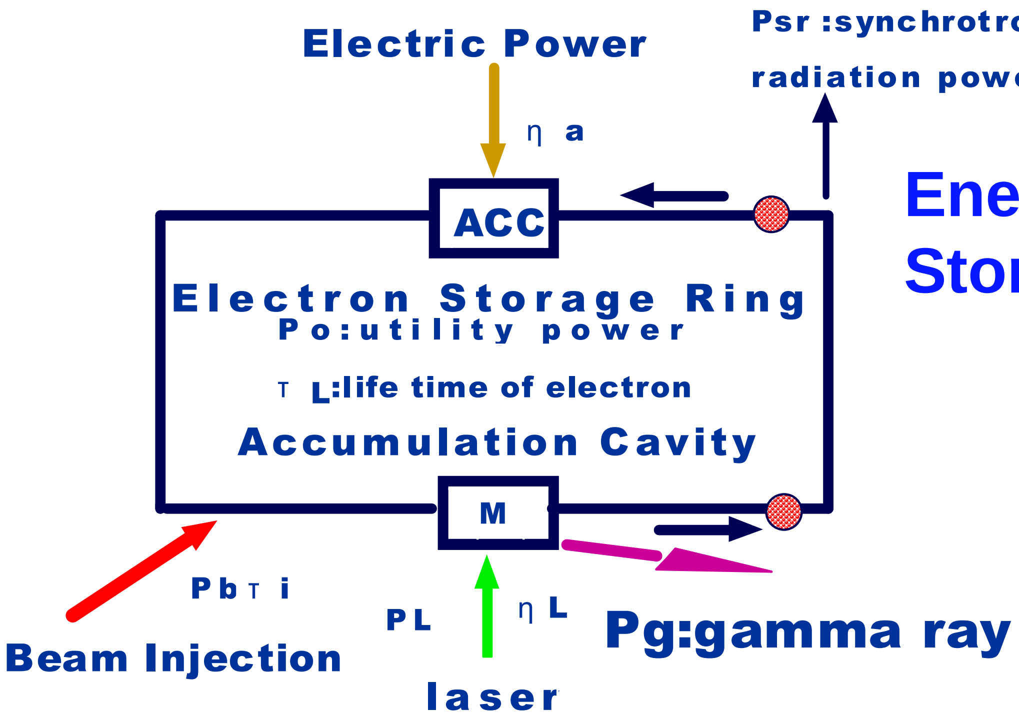


Multiple Compton Scattering induce wide energy spectrum of electron beam.

Experiment of Photon Storage and Compton scattering in the cavity



Principal of Total System　1

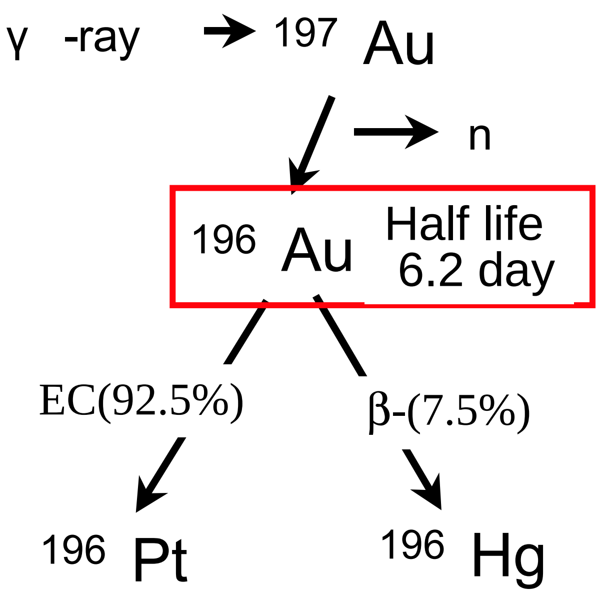


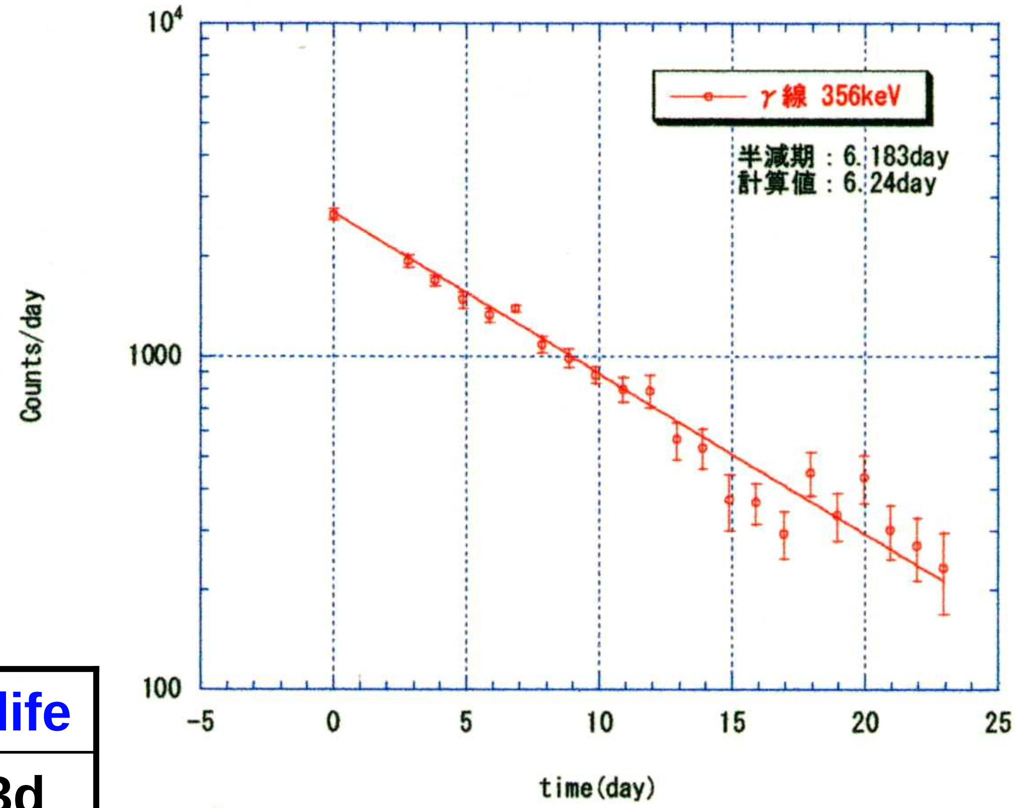
Energy Recovered Linac/ Storage Ring with by-pass

Efficient Conversion is expected when the electron beam is circulated.

$$\eta_g = Pg\left[\, Po + Pb\,\tau_i/\tau_L + (Psr+Pg)/\eta_a + PL/(\eta_L M)\,\right]^{-1}$$

Au Target





γ(keV)	Rate(%)	Decay	Half life
333.03	22.9	EC	6.183d
355.73	86.9	EC	6.183d
426.1	7.2	β^-	6.183d

Nt: Number of Transmuted

$= 3.2 \times 10^6$