Real Photon Sources for Nuclear Resonance Fluorescence Experiment

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Below the particle threshold (E_γ<8MeV)

Photon scattering (NRF) : selective excitation of low spin state(J=1)

-Excitation Energy

photoabsorption & EM decay

-direct measurement of width ratio

Γ_0^2/Γ

ground-state transition width Γ_0

total width Γ

=>reduced transition probability B↑(E1), B↑(M1)

-spin *J*

-parity

!PROBLEM!

Low scattering cross section - μb

Low detection efficiency in Ge-detector

=> limits target and takes very long machine time

Parity Measurement with Linearly Polarized Photon Beam

Asymmetry $$A(\theta) = \frac{1}{p}\frac{\sigma(\theta,0) - \sigma(\theta,90)}{\sigma(\theta,0) + \sigma(\theta,90)}$$

Multipolarity	Spin Sequence	$A(\theta=90°)$ $P=100\%$
E1	0^{+}-1^{-}-0^{+}	-1
M1	0^{+}-1^{+}-0^{+}	+1
E2	0^{+}-2^{+}-0^{+}	+1

- ref.:R.D.Heil et. al, Nucl. Phys. 506(1990)p223.

Real Photon Source in MeV region

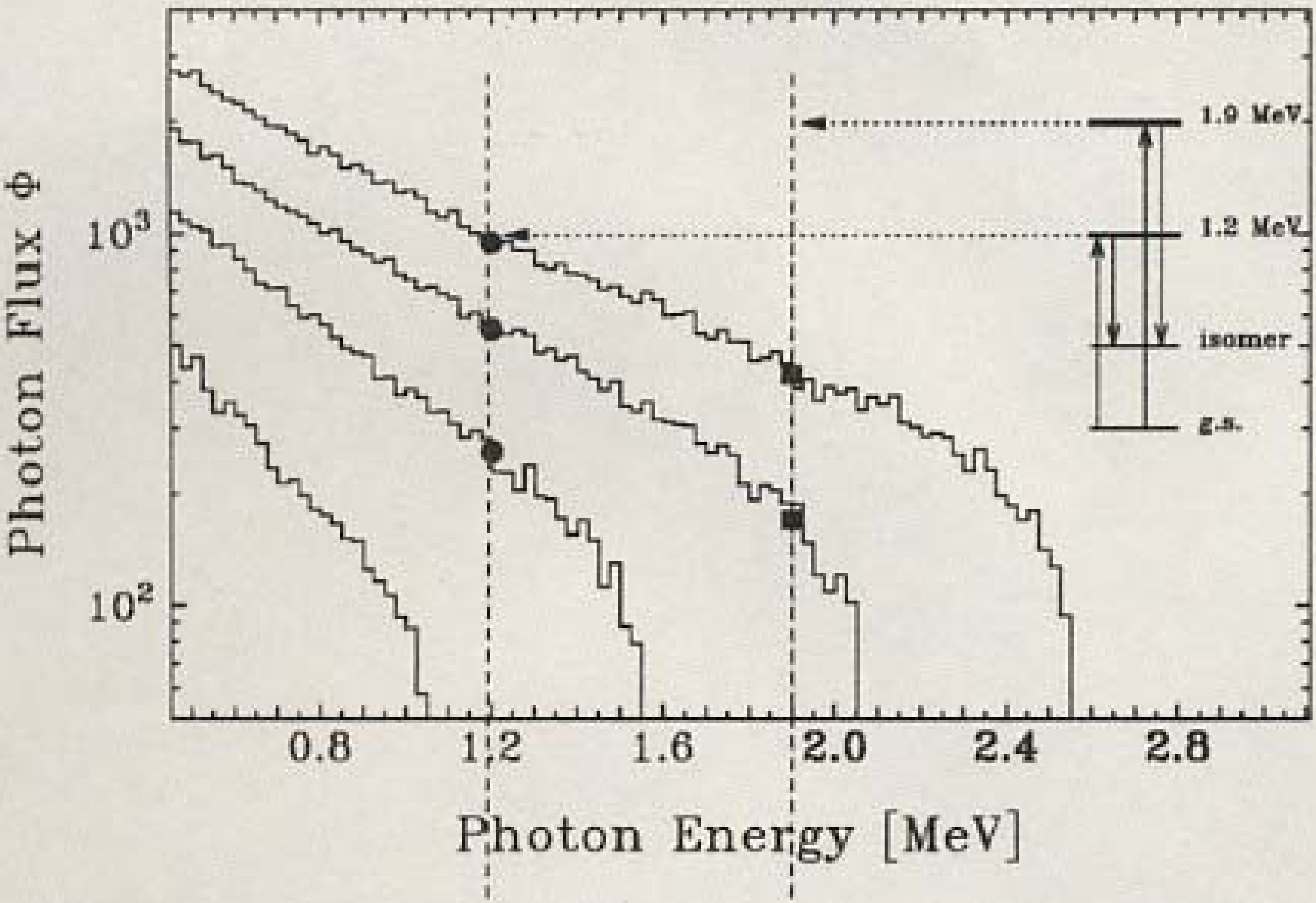
method	intensity	Others
Bremsstrahlung	$-10^{6\text{-}7}$	poor polarization White
Bremsstrahlung + Tagging	$-10^{4\text{-}5}$	poor polarization good energy resolution (<1%)
Laser Compton Gamma	-10^{5}	100% polarized quasi-monochromatic
SC Wiggler light	$-10^{10\text{-}12}$ -5 MeV	100% polarized white

Bremsstrahlung Beam

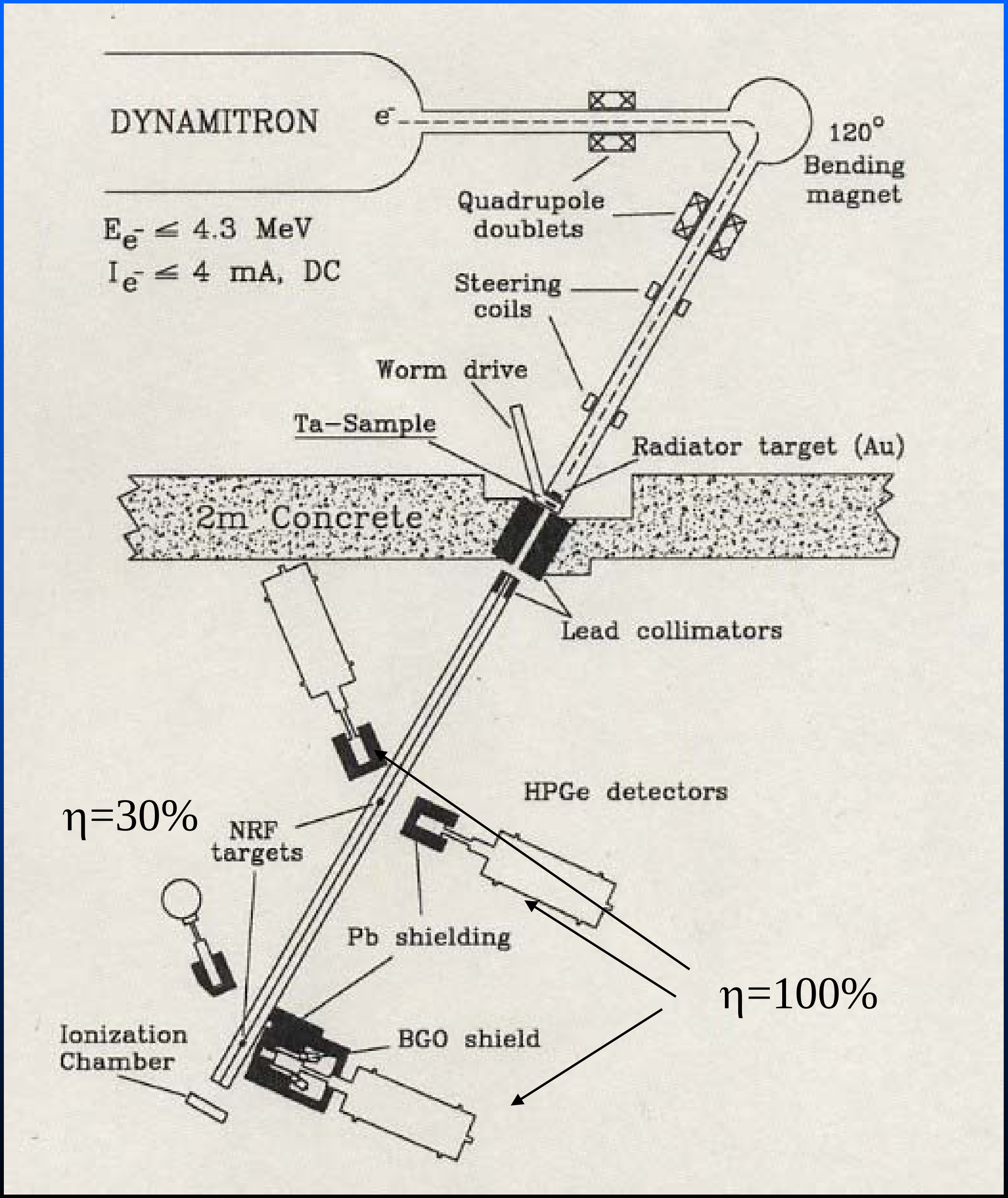
Stuttgart DYNAMITRON

$E_e < 4.3$ MeV
$I_e < 4$ mA, DC

=> Photon production
-0.45 mA, DC

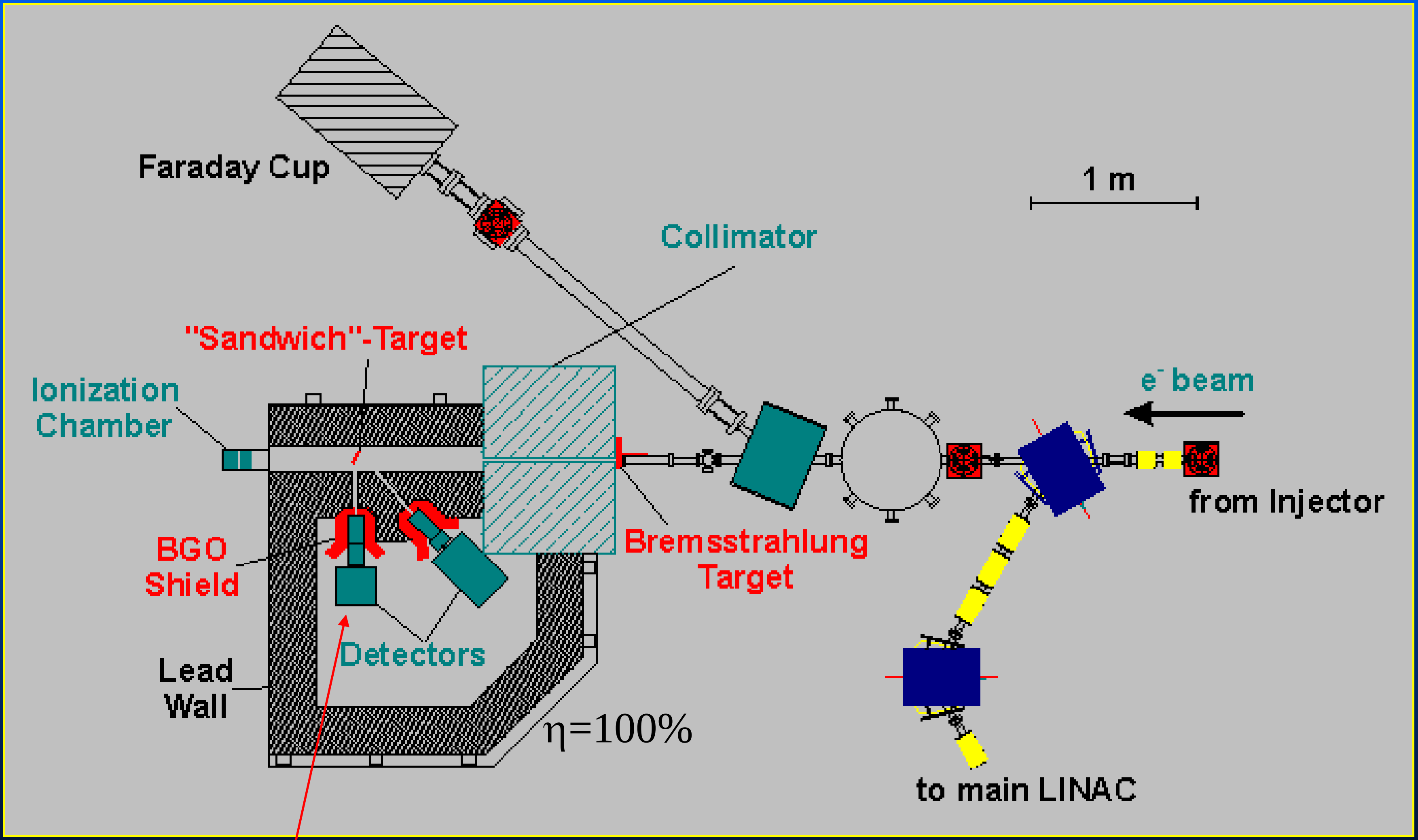


Photon Flux Φ
10³
10²
0.8
1.2
1.6
2.0
2.4
2.8
Photon Energy [MeV]
1.9 MeV
1.2 MeV
isomer
g.s.

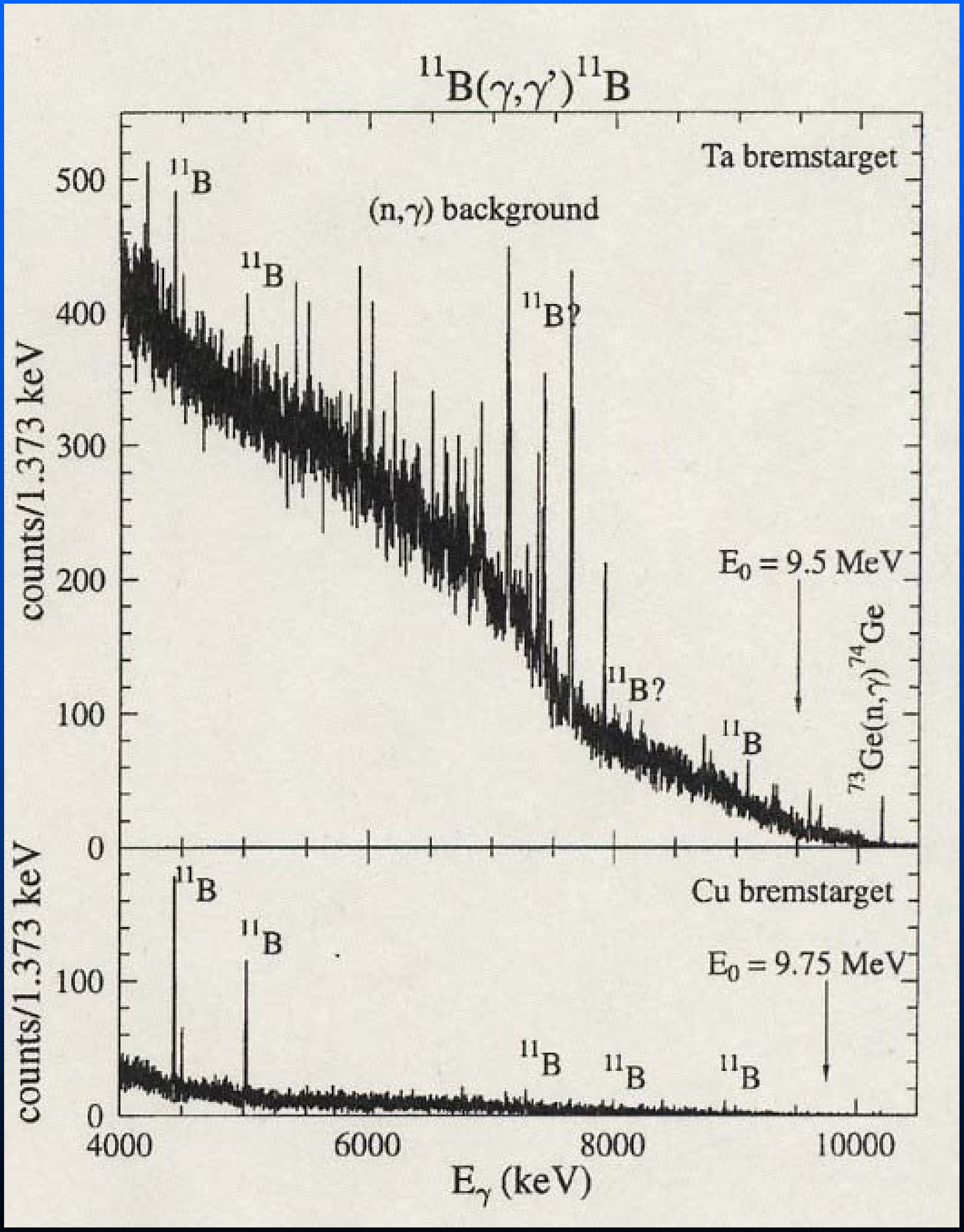

DYNAMITRON
e⁻
$E_{e^-} \leq 4.3$ MeV
$I_{e^-} \leq 4$ mA, DC
120° Bending magnet
Quadrupole doublets
Steering coils
Worm drive
Ta–Sample
Radiator target (Au)
2m Concrete
Lead collimators
HPGe detectors
η=30%
NRF targets
Pb shielding
η=100%
Ionization Chamber
BGO shield

S-DALINAC

Ee < 10 MeV
Ie < 60 μA

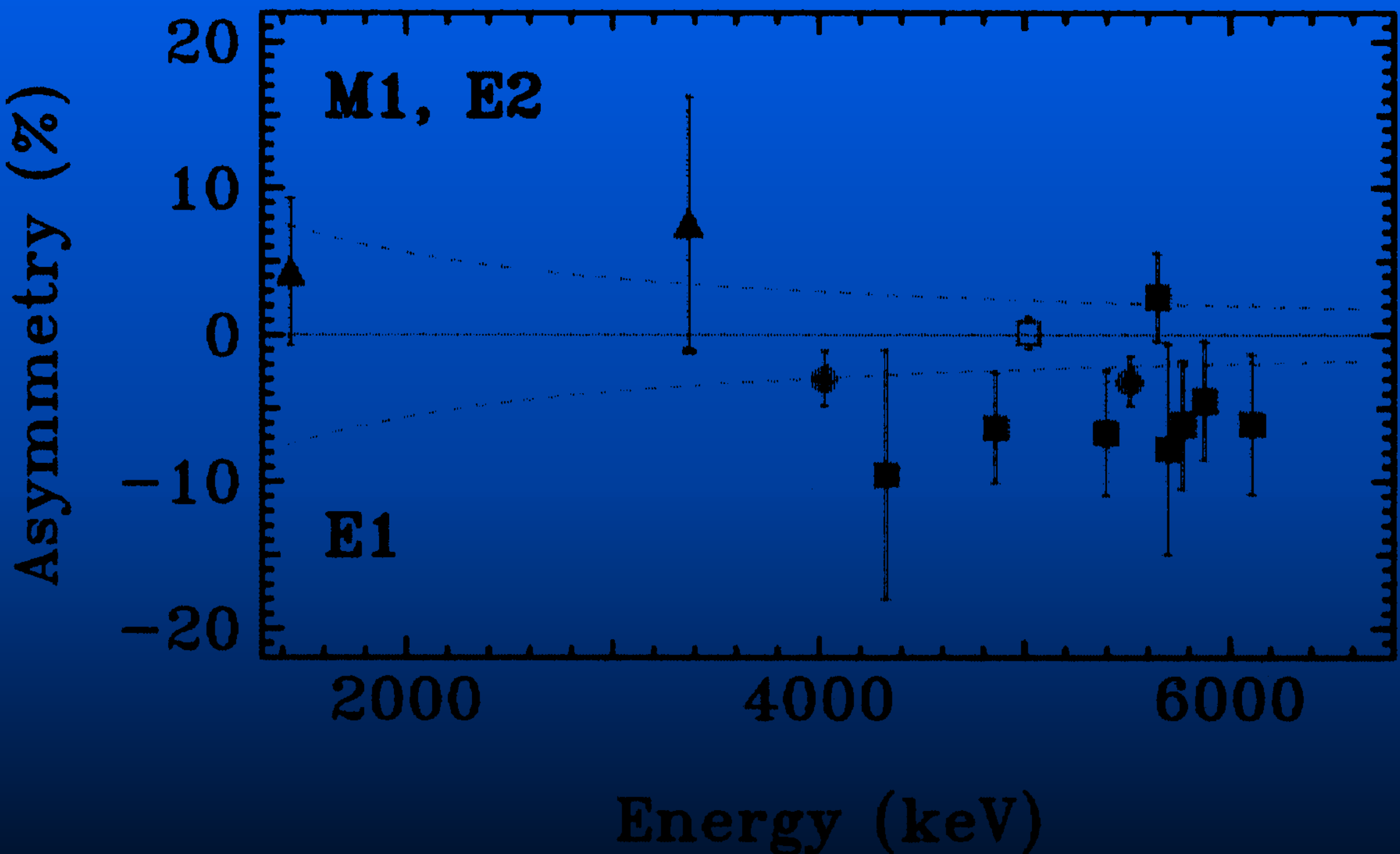


4-segmented Ge

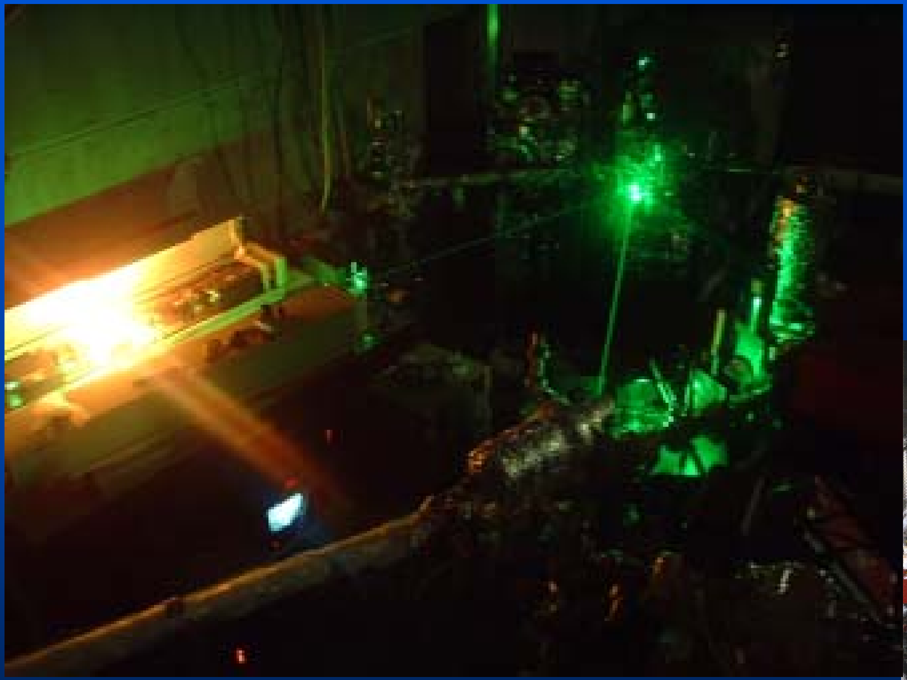


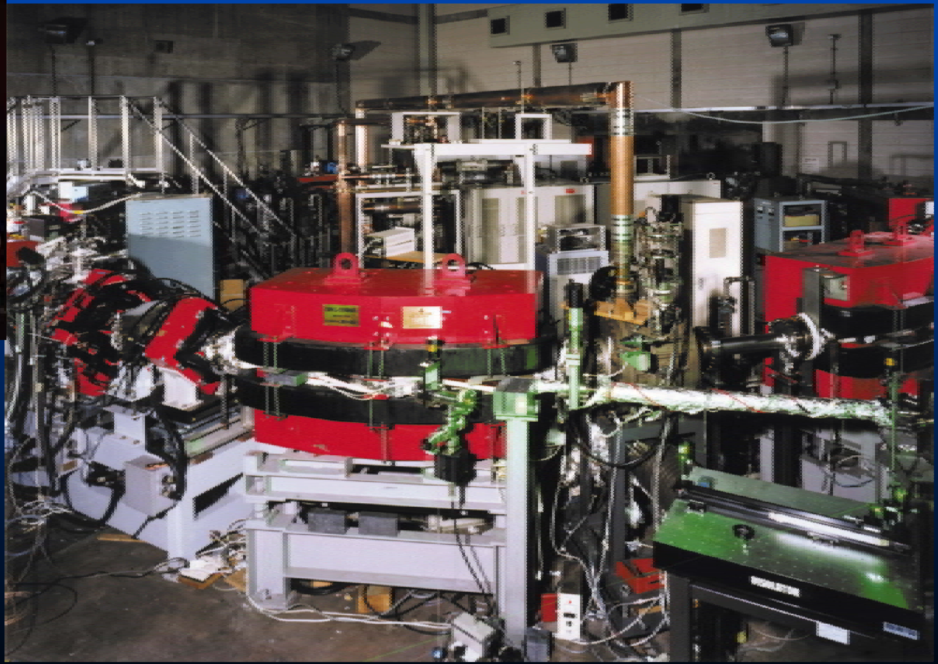
$^{11}B(\gamma,\gamma')^{11}B$
Ta bremstarget
^{11}B
(n,γ) background
^{11}B
^{11}B?
^{11}B?
^{11}B
E_0 = 9.5 MeV
$^{73}Ge(n,\gamma)^{74}Ge$
Cu bremstarget
^{11}B
^{11}B
E_0 = 9.75 MeV
^{11}B
^{11}B
^{11}B
counts/1.373 keV
counts/1.373 keV
500
400
300
200
100
0
100
0
4000
6000
8000
10000
E_γ (keV)

^{138}Ba(γ,γ’) @ Darmstadt

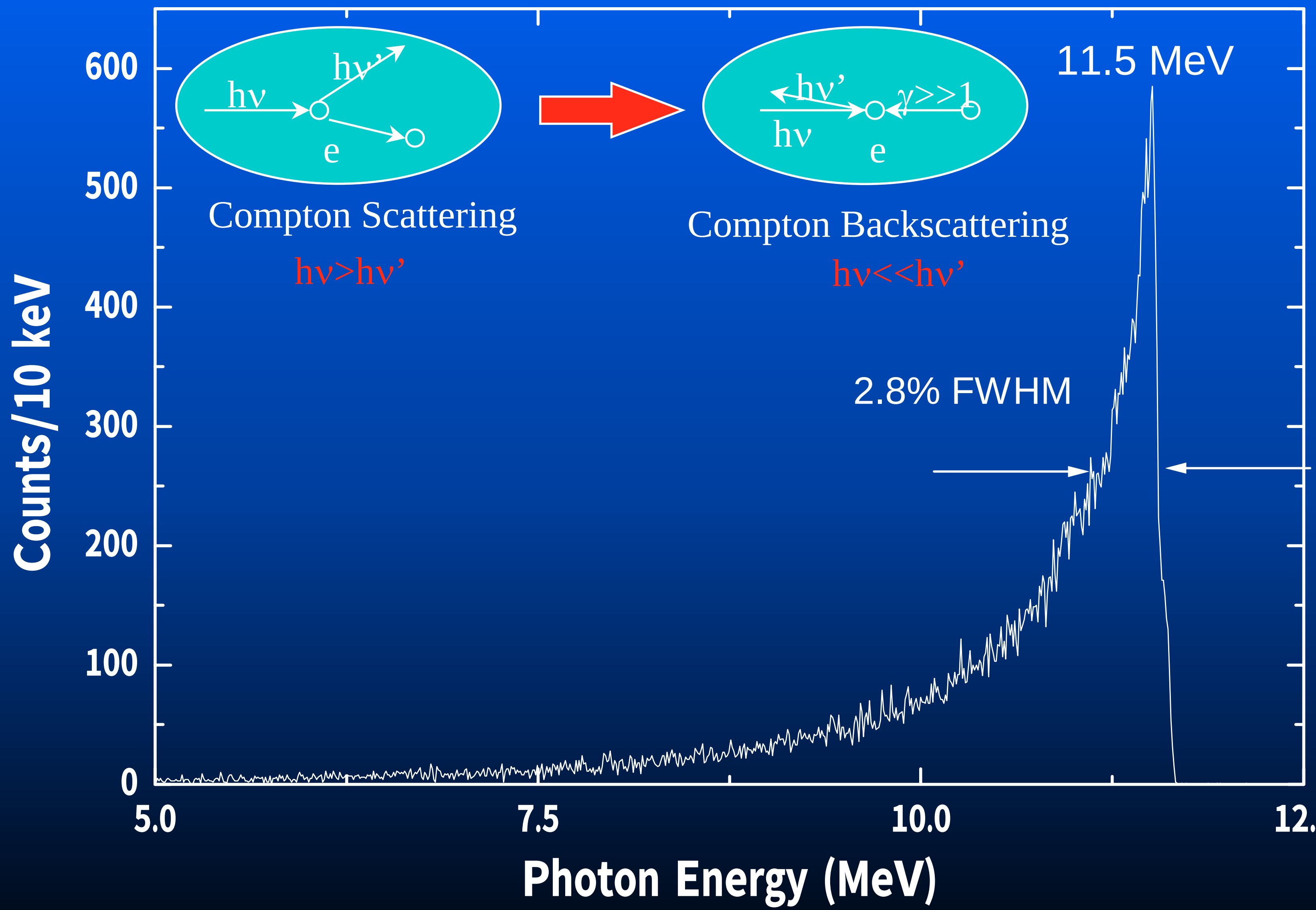


AIST
Laser-Compton Gamma-ray

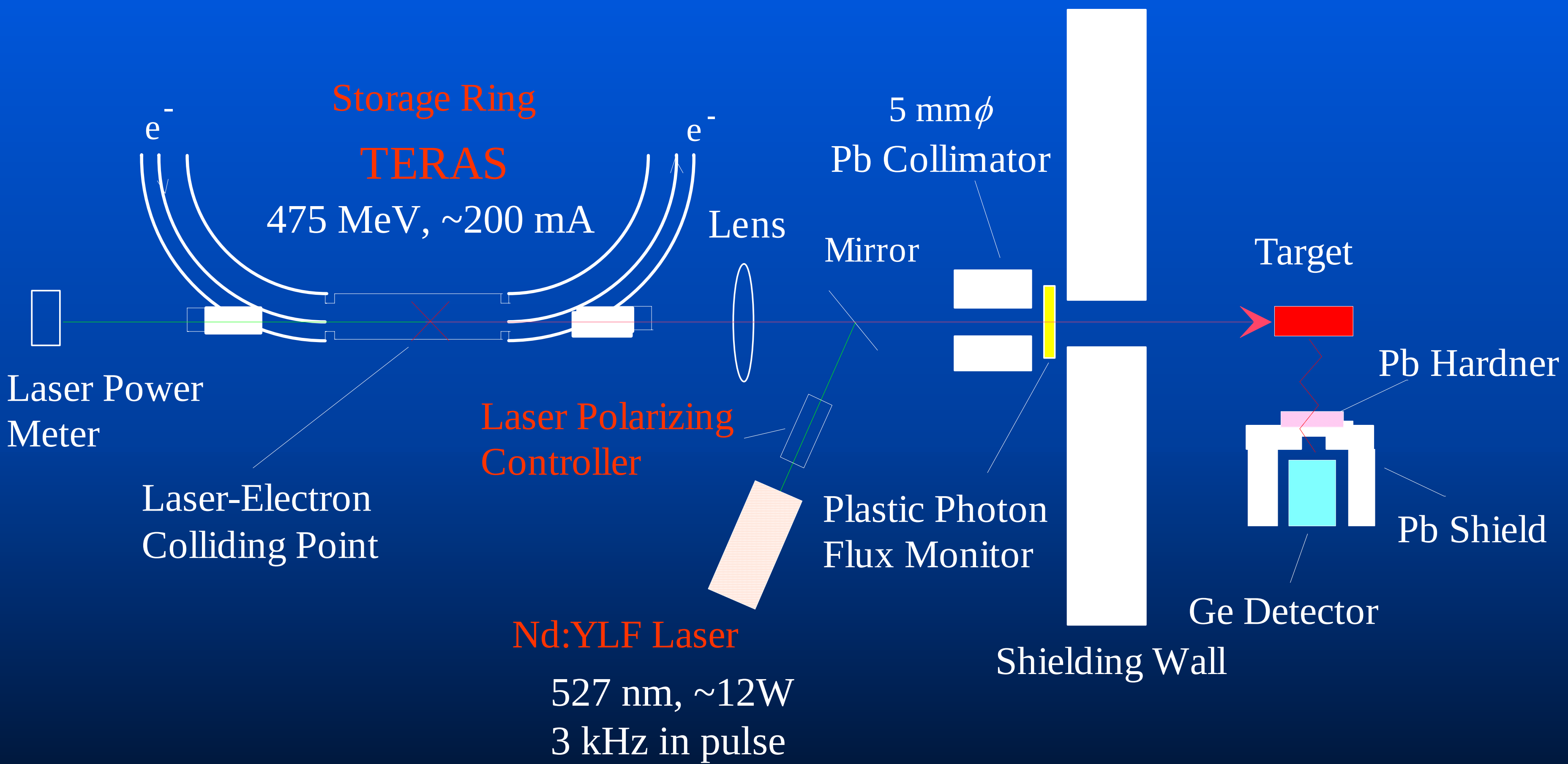


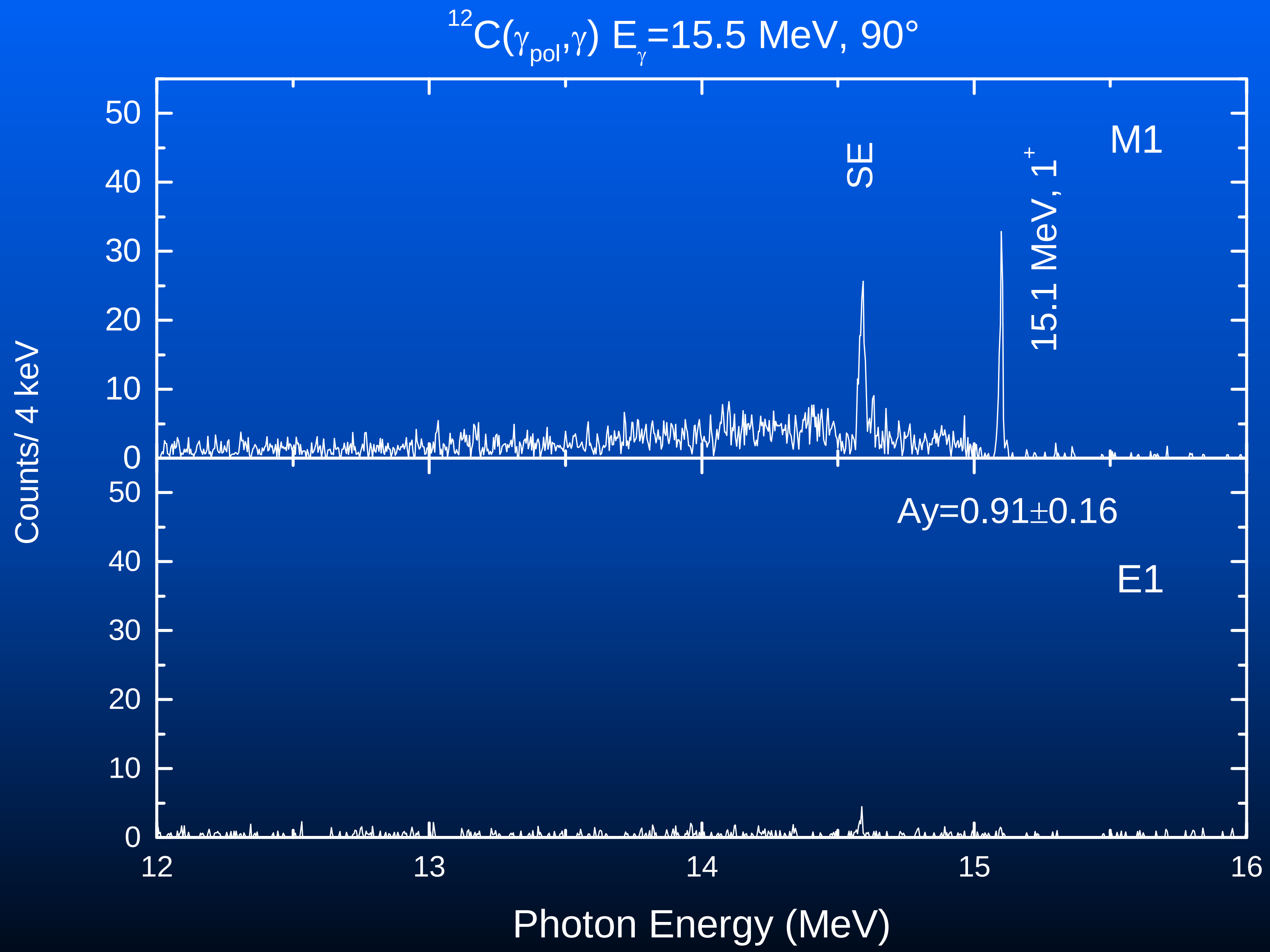


E_e = 561 MeV



hν
hν'
e
Compton Scattering
hν>hν'
hν'
γ>>1
hν
e
Compton Backscattering
hν<<hν'
11.5 MeV
2.8% FWHM
600
500
400
300
200
100
0
Counts/10 keV
5.0
7.5
10.0
12.5
Photon Energy (MeV)


Storage Ring
TERAS
475 MeV, ~200 mA
e -
e -
Lens
Mirror
5 mmϕ
Pb Collimator
Target
Pb Hardner
Laser Power
Meter
Laser Polarizing
Controller
Laser-Electron
Colliding Point
Plastic Photon
Flux Monitor
Pb Shield
Ge Detector
Nd:YLF Laser
527 nm, ~12W
3 kHz in pulse
Shielding Wall



12C(γpol,γ) Eγ=15.5 MeV, 90°
M1
SE
15.1 MeV, 1+
Ay=0.91±0.16
E1
Counts/ 4 keV
Photon Energy (MeV)
0
10
20
30
40
50
12
13
14
15
16

M1 Resonance in Lead Nuclei

	Isoscalar		*Isovector*	
	Ex(MeV)	B(M1)↑	Ex(MeV)	B(M1)↑
^{206}Pb	5.800	1.5 μ_N^2	7.206	1.0 μ_N^2
^{208}Pb	5.846	1.6 μ_N^2	7.279	1.2 μ_N^2

^{208}Pb	TDA[a)]	$\delta+\pi+\rho$[b)]	2p2h +1Δ1h [c)]	1p1h○ phonon [d)]	exp.
Ex (MeV)	7.5	7.31	7.5	7.7	7.3
B(M1)↑ (μ_N^2)	48	19	20.39	11.57	15.6±2
^{206}Pb			QPM [e)]	QPM+ damping [e)]	exp.
B(M1)↑ (μ_N^2)			16.1	13.2	19±2

a)J.D.Vergados, Phys. Lett. 36B, 12(1971).

b)J.Speth et al., Nucl. Phys. A343, 382(1980).

c)D.Cha et al., Nucl. Phys. A430, 321(1984).

d)S.Kamerdzhiev et al., Z. Phys. A 346, 253(1993).

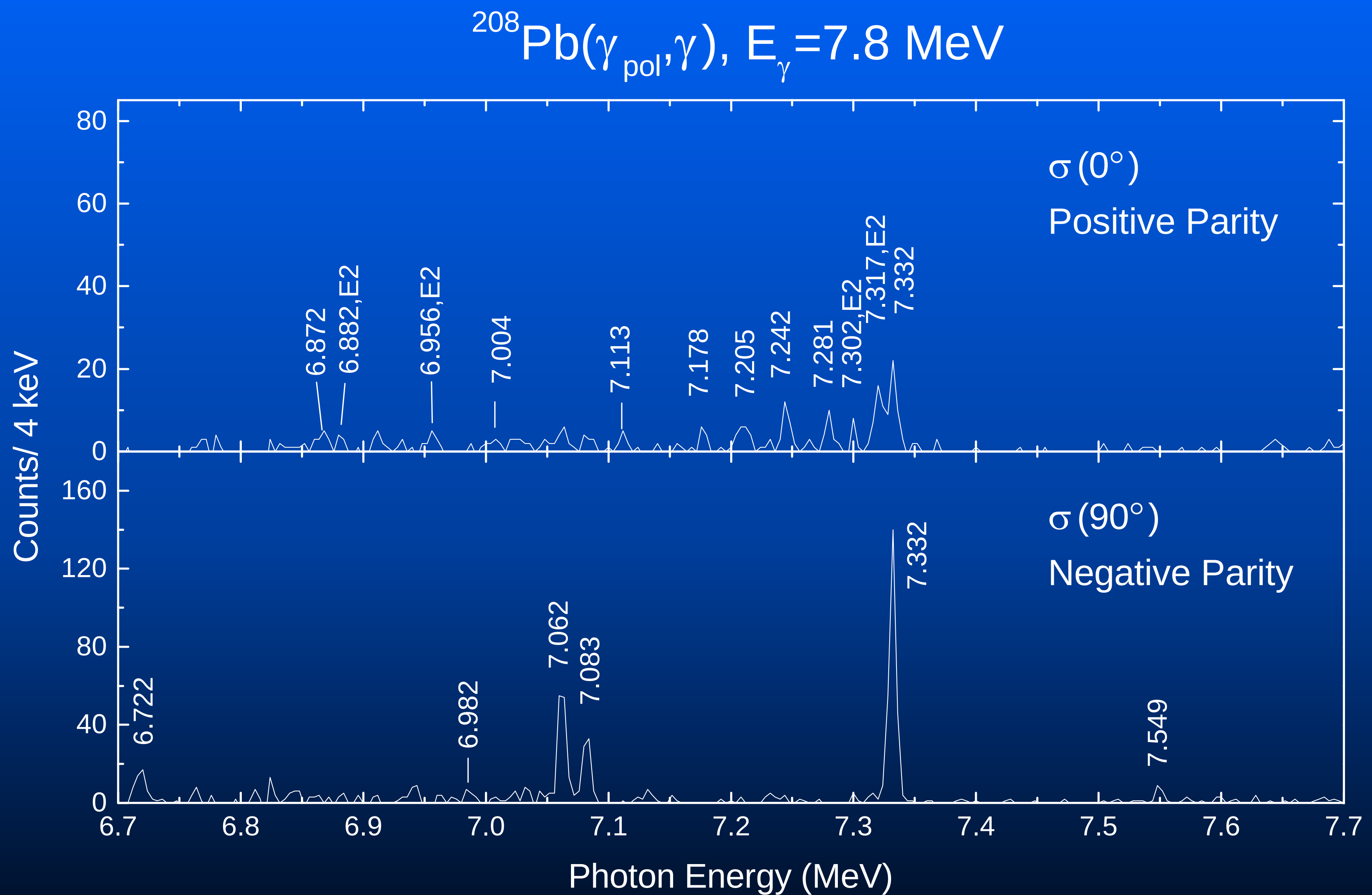
e)V.Ponomarev et al., J.Phys. G13, 1523(1987).

Experimental Conditions

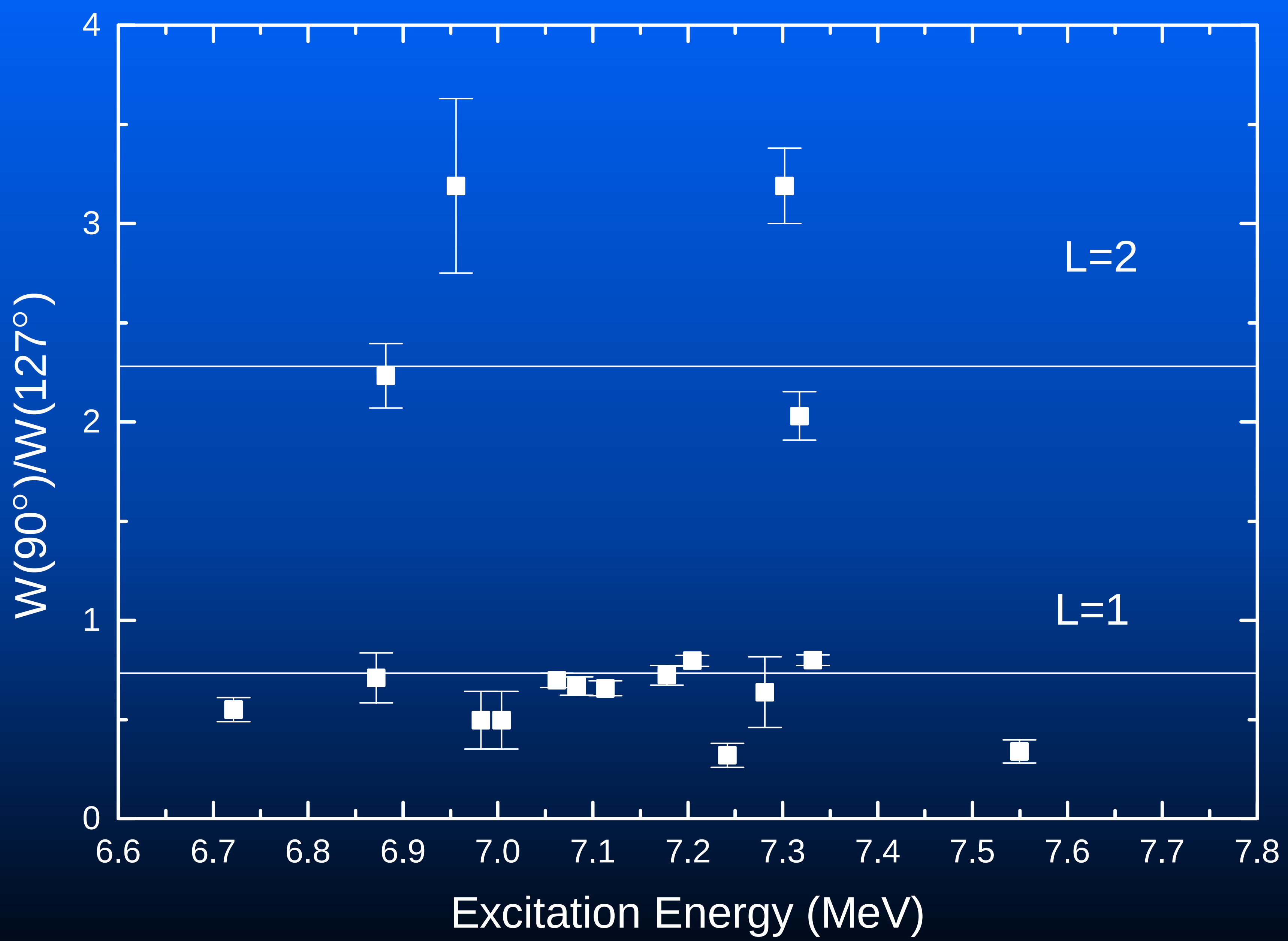
- Photon Beam

	^{208}Pb	^{206}Pb
– top energy:	7.8 MeV	8.1 MeV
– energy spread:	13.4%	21.6%
– intensity:	~10^5 photon/s	
– polarization:	98.2% linear	95.3% linear

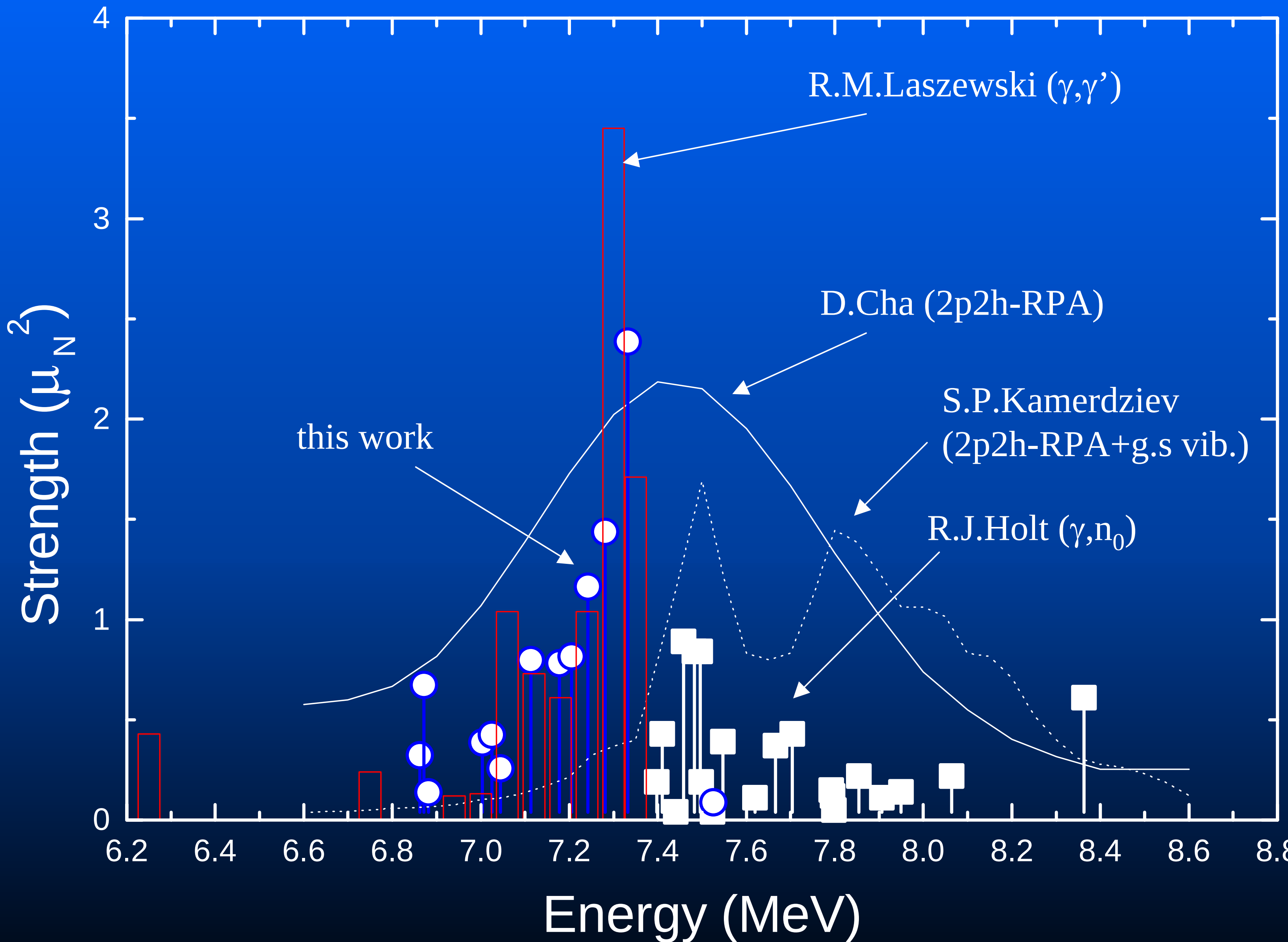
- Target
  - 98.4% enriched ^{208}Pb (7 mmϕ x 15 mm *L*)
  - 99.3% enriched ^{206}Pb (8 mmϕ x 8 mm *L*)
- Detector
  - pure Ge (120% relative detection efficiency)



208Pb(γpol,γ), Eγ=7.8 MeV
σ (0°)
Positive Parity
σ (90°)
Negative Parity
Counts/ 4 keV
Photon Energy (MeV)
6.872
6.882,E2
6.956,E2
7.004
7.113
7.178
7.205
7.242
7.281
7.302,E2
7.317,E2
7.332
6.722
6.982
7.062
7.083
7.332
7.549
0
20
40
60
80
0
40
80
120
160
6.7
6.8
6.9
7.0
7.1
7.2
7.3
7.4
7.5
7.6
7.7

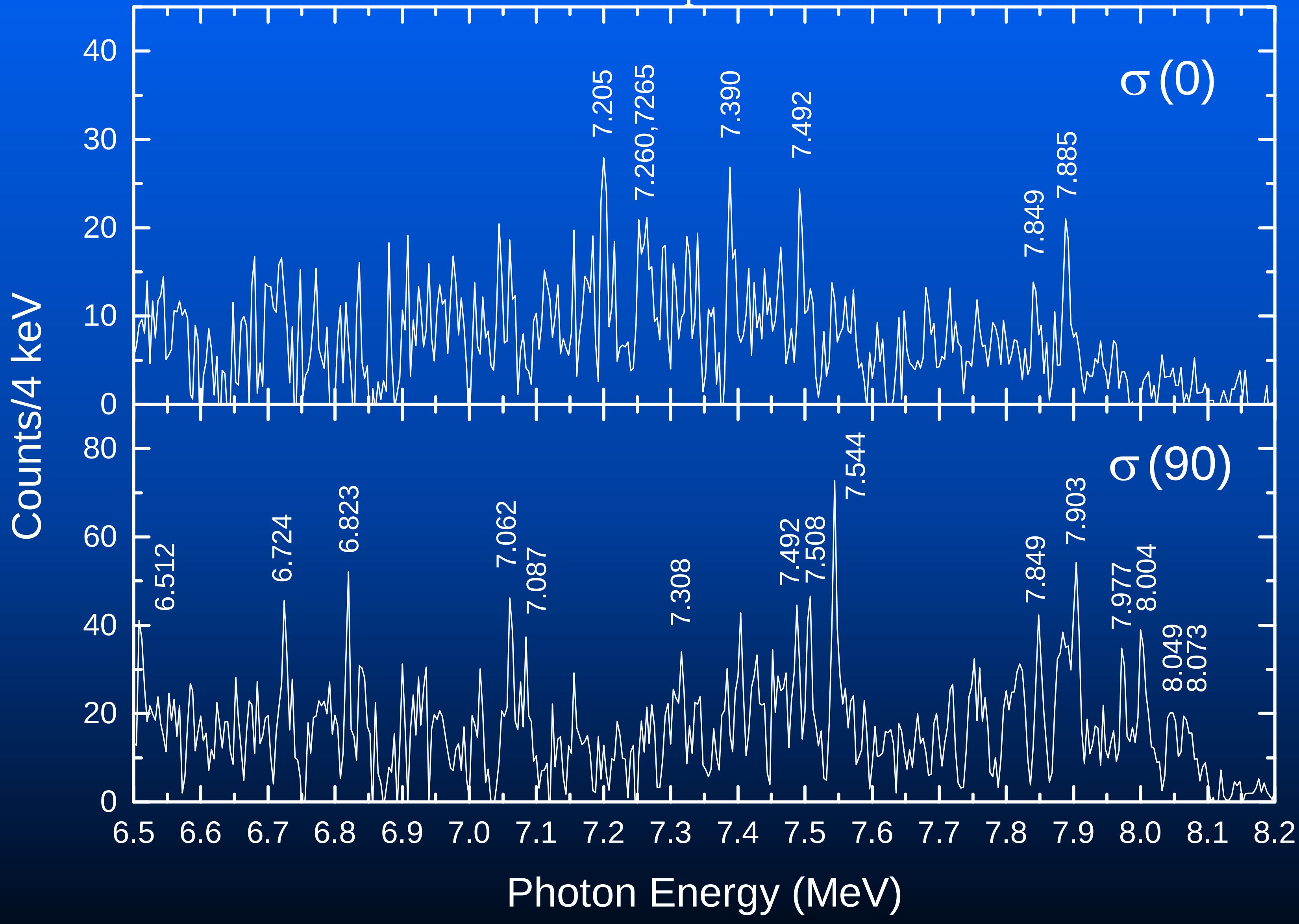


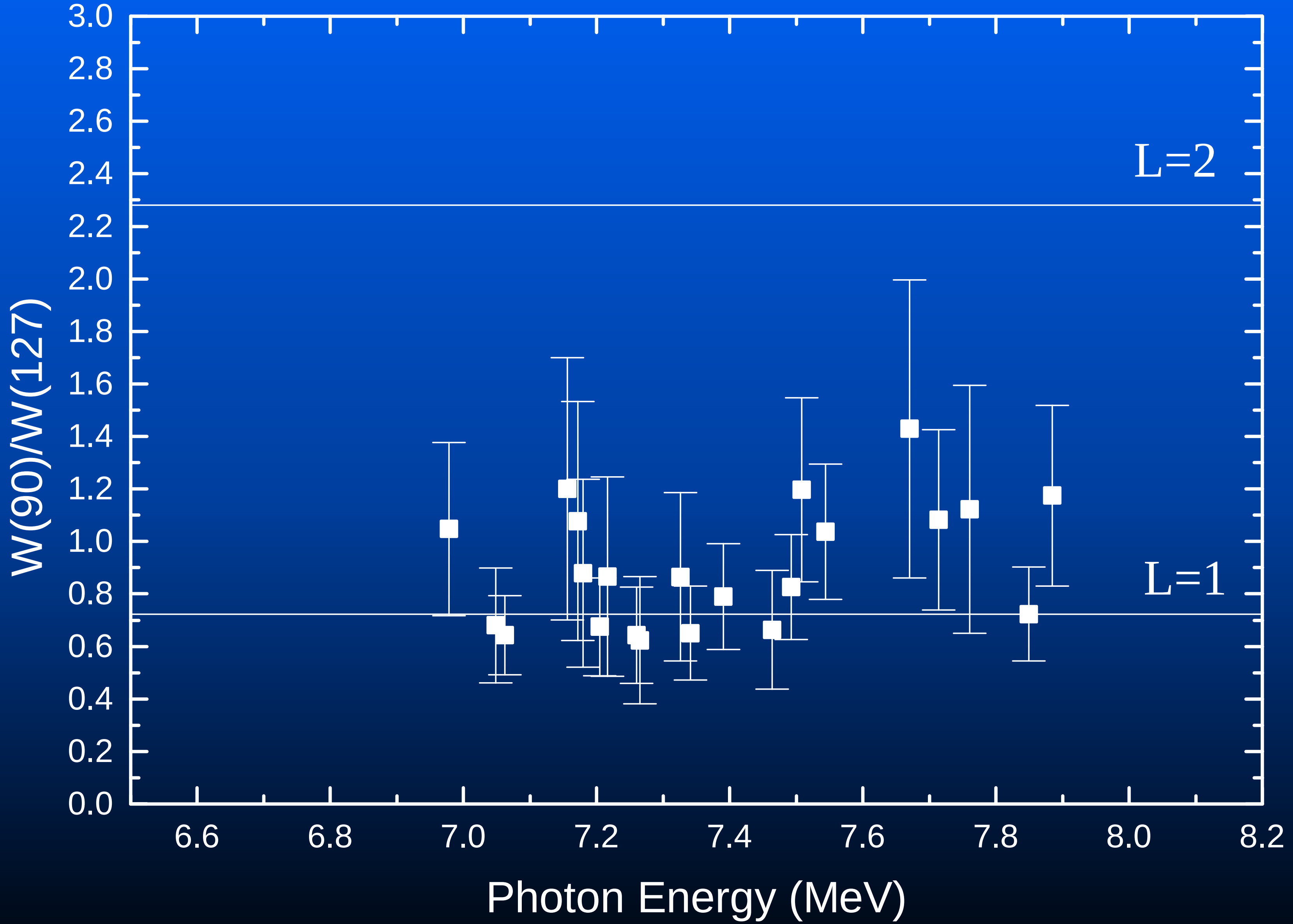
W(90°)/W(127°)
Excitation Energy (MeV)
L=2
L=1
0
1
2
3
4
6.6
6.7
6.8
6.9
7.0
7.1
7.2
7.3
7.4
7.5
7.6
7.7
7.8



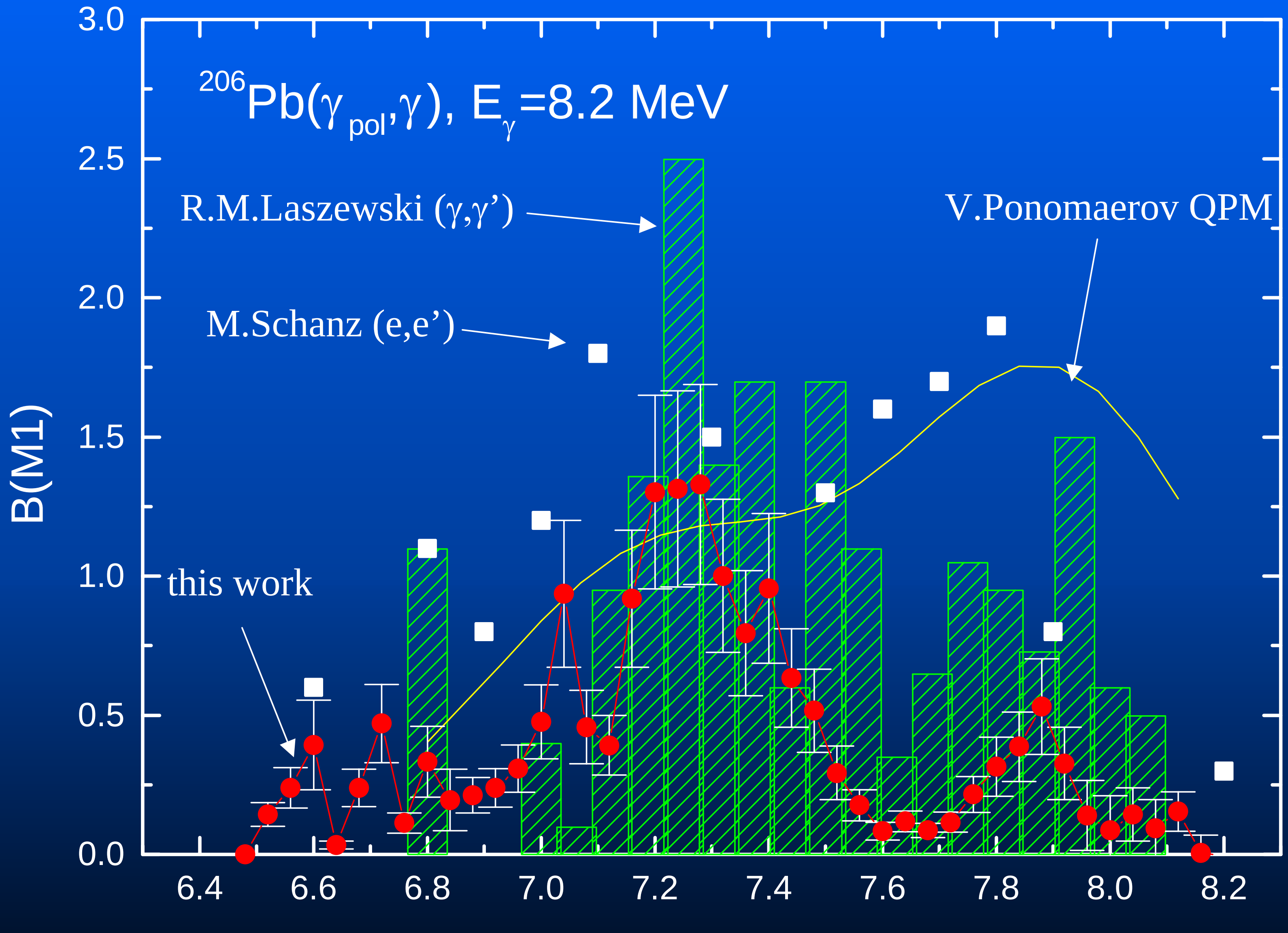
R.M.Laszewski (γ,γ')
D.Cha (2p2h-RPA)
S.P.Kamerdziev
(2p2h-RPA+g.s vib.)
R.J.Holt (γ,n_0)
this work
Strength (μ_N^2)
Energy (MeV)
0
1
2
3
4
6.2
6.4
6.6
6.8
7.0
7.2
7.4
7.6
7.8
8.0
8.2
8.4
8.6
8.8

$^{206}Pb(\gamma_{pol},\gamma)$





W(90)/W(127)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
L=2
L=1
6.6
6.8
7.0
7.2
7.4
7.6
7.8
8.0
8.2
Photon Energy (MeV)



NPA649(1999)

$\Sigma B(M1)_{exp}=17.4(5.6)\mu_N^2$

QPM calc.$=19\mu_N^2$

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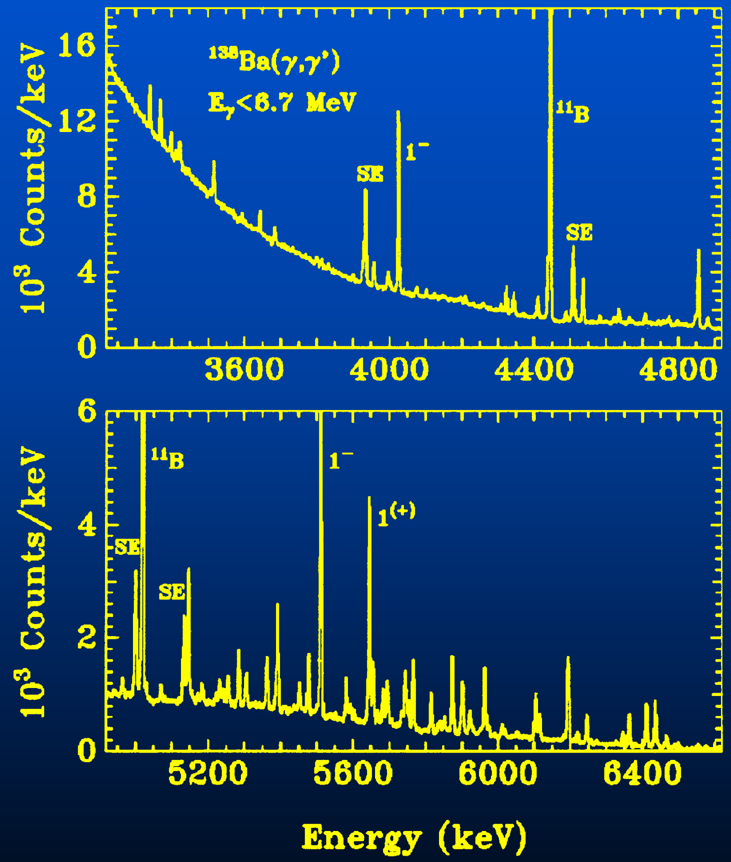
Parity Check for known Dipole States

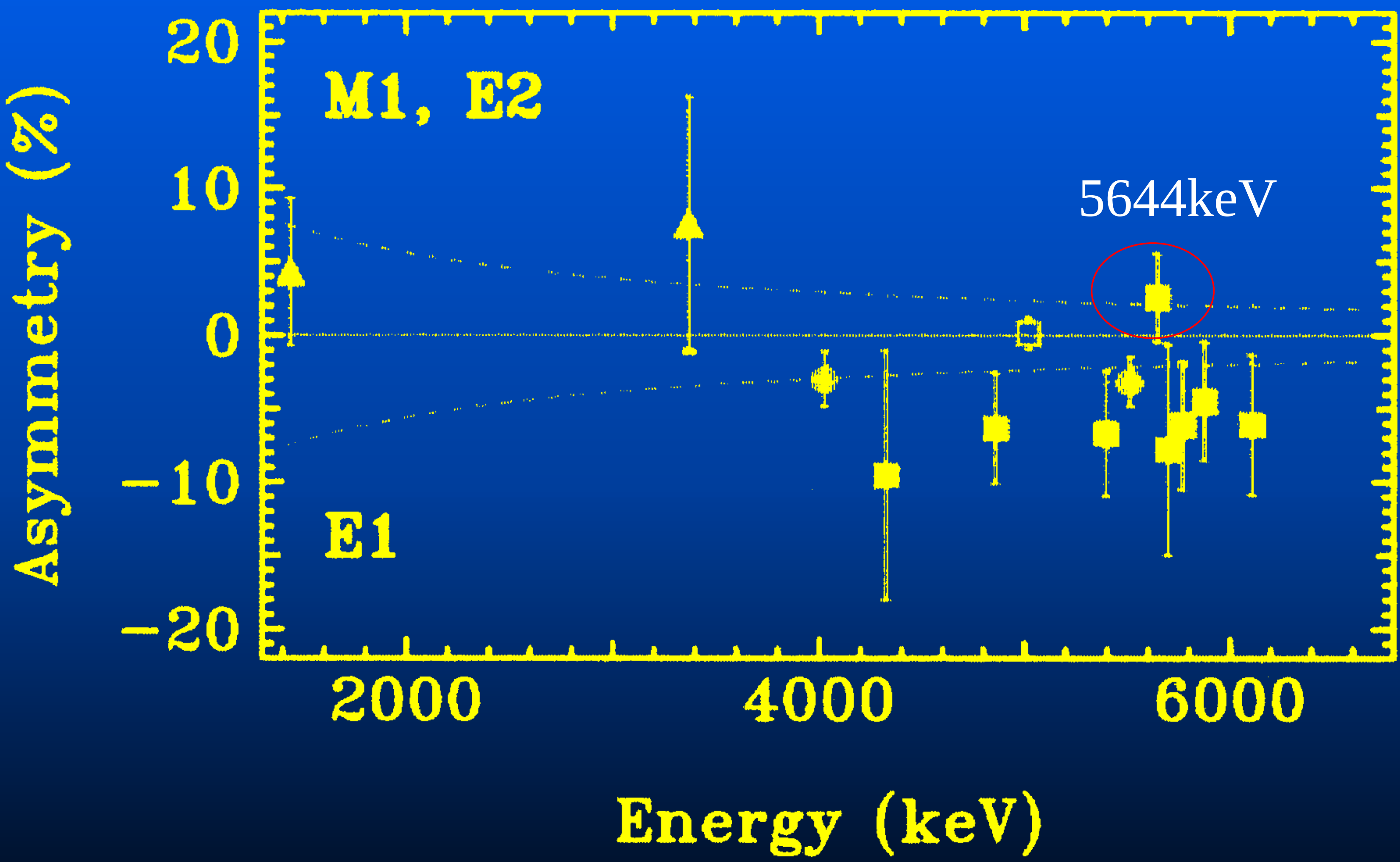
- ^{138}Ba
  - A recent Darmstadt data suggests an extremely a large M1 transition in Ba. But it's not sure, because of their poor analyzing power.

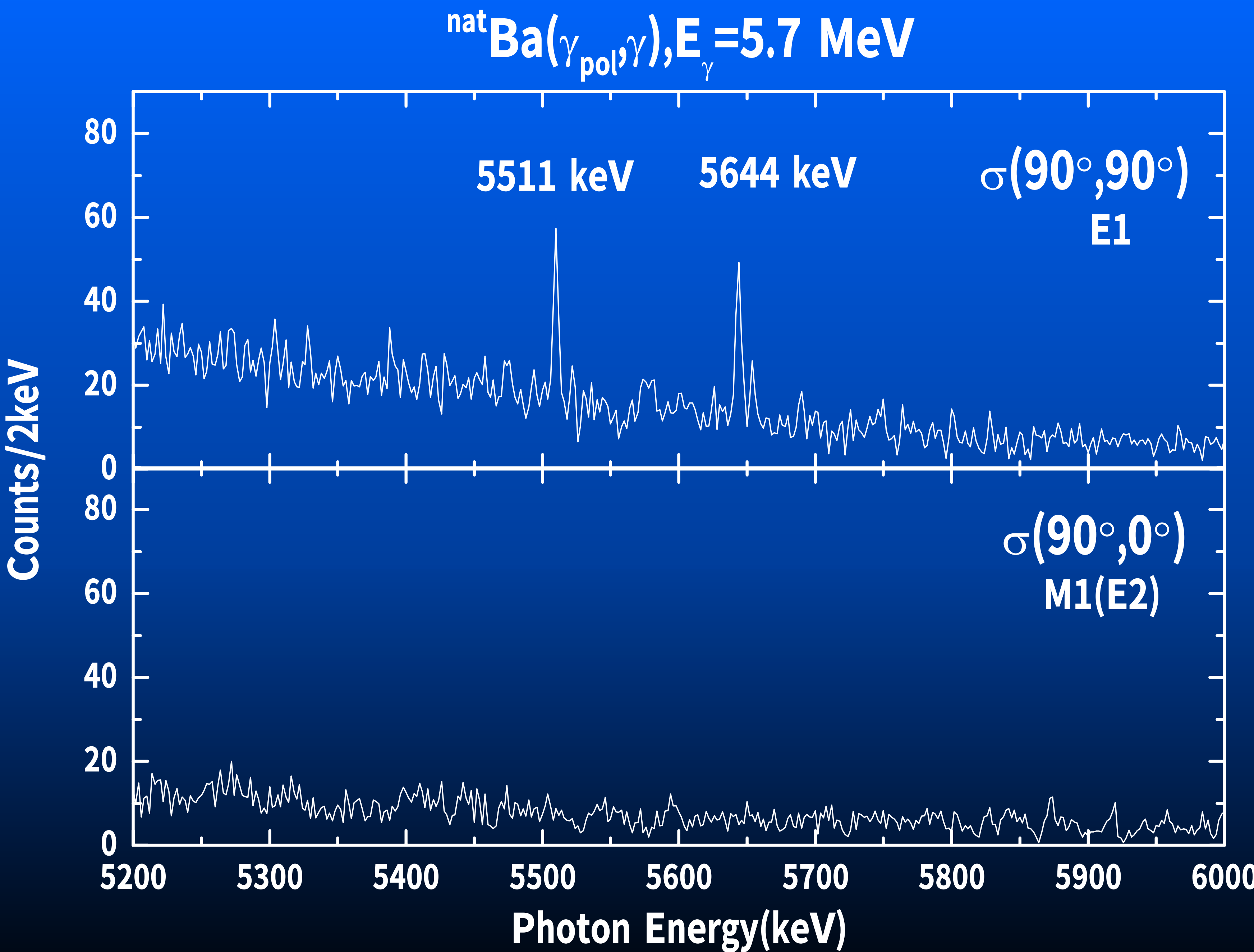
=> Should be checked!

R.-D. HERZBERG *et al.*



$^{138}Ba(\gamma,\gamma')$ @ Darmstadt





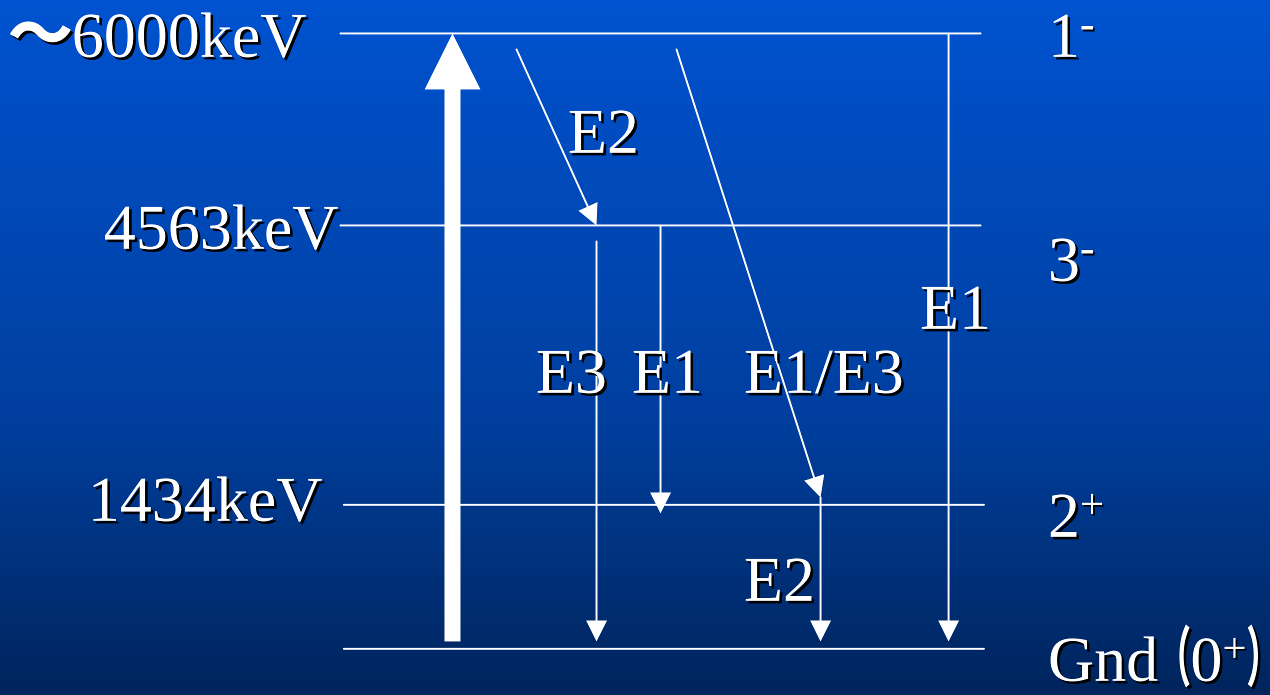
natBa(γpol,γ),Eγ=5.7 MeV
5511 keV
5644 keV
σ(90°,90°)
E1
σ(90°,0°)
M1(E2)
Counts/2keV
0
20
40
60
80
5200
5300
5400
5500
5600
5700
5800
5900
6000
Photon Energy(keV)

Search for two-phonon E1 state

- Two phonon state
  - $|2^+_1 \otimes 2^+_1; 0^+, 2^+, 4^+>$ established
  - $|3^-_1 \otimes 3^-_1; 0^+, 2^+, 4^+, 6^+>$
  - $|2^+_1 \otimes 3^-_1; 1^-, 2^-, 3^-, 4^-, 5^->$ *recent interest: ^{144}Sm, ^{142}Nd*
    - toward lighter nuclei: *how surface effect works?*

      » ^{52}Cr semi-magic nucleus

      - 2^+ phonon : 1434 keV, 3^- phonon : 4563 keV
        - sum energy 6 MeV


～6000keV
4563keV
1434keV
1-
3-
2+
Gnd (0+)
E2
E3
E1
E1/E3
E1
E2

Experiment - $^{nat}Cr(\gamma_{pol},\gamma)$

Target : 99.9% natural Cr

Storage Ring: TERAS at ETL

558 MeV, I_e = 300-100 mA

Laser : 30W 5 kHz Q-switch Nd:YLF Laser (1053 nm)

Linearly Polarized Laser

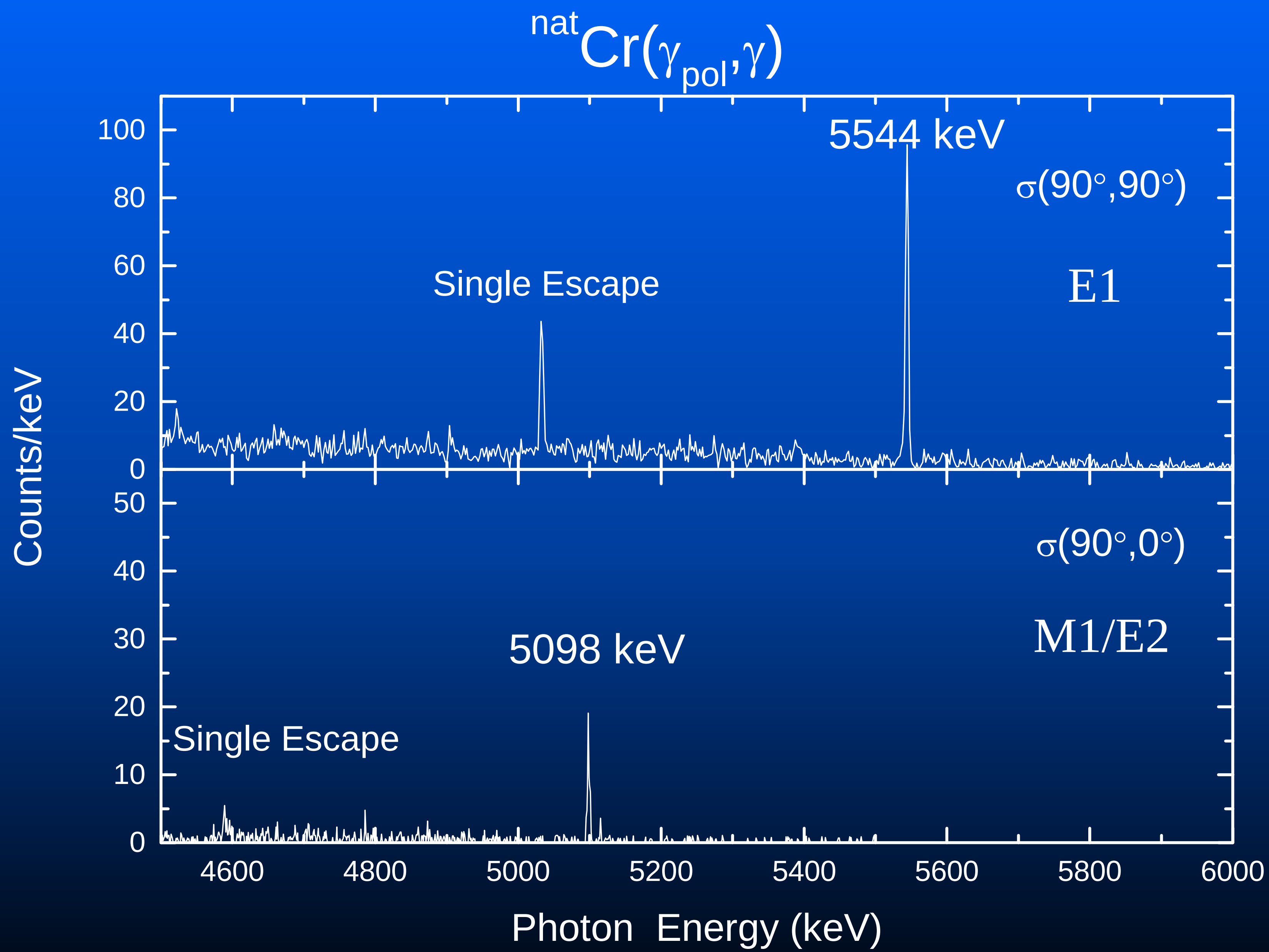
Photon Beam

Top Energy: 5.8 MeV

$\Delta E/E$ = 19% (with 0.4 mrad)

Flux : ~$1x10^5$ γ/s

Detector : ε=120% pure Ge



natCr(γpol,γ)
5544 keV
σ(90°,90°)
E1
Single Escape
σ(90°,0°)
M1/E2
5098 keV
Single Escape
Counts/keV
100
80
60
40
20
0
50
40
30
20
10
0
4600
4800
5000
5200
5400
5600
5800
6000
Photon Energy (keV)

$|1^-\rangle = |2^+ \otimes 3^-\rangle$ Two-Phonon State

QRPA calculation with core polarization

$B\uparrow(E1) = 2.58\ \mathrm{m}e^2\mathrm{fm}^2$

$Ex = 5.328$ MeV

Present experiment

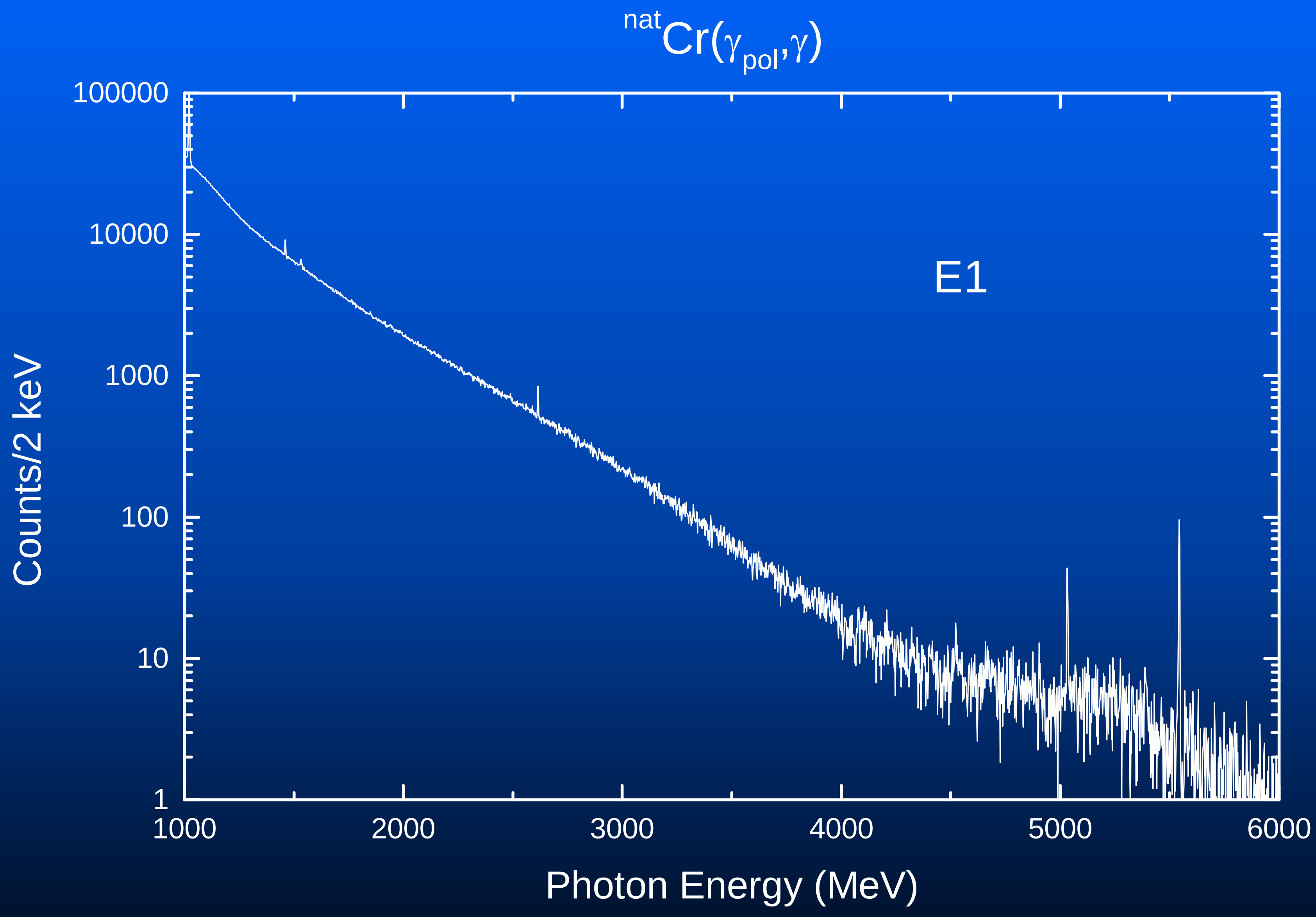
$B\uparrow(E1) = 2.02 \pm 0.34\ \mathrm{m}e^2\mathrm{fm}^2$

$Ex = 5.544$ MeV

(J.Enders et al. $2.1 \pm 0.4\ \mathrm{m}e^2\mathrm{fm}^2$)

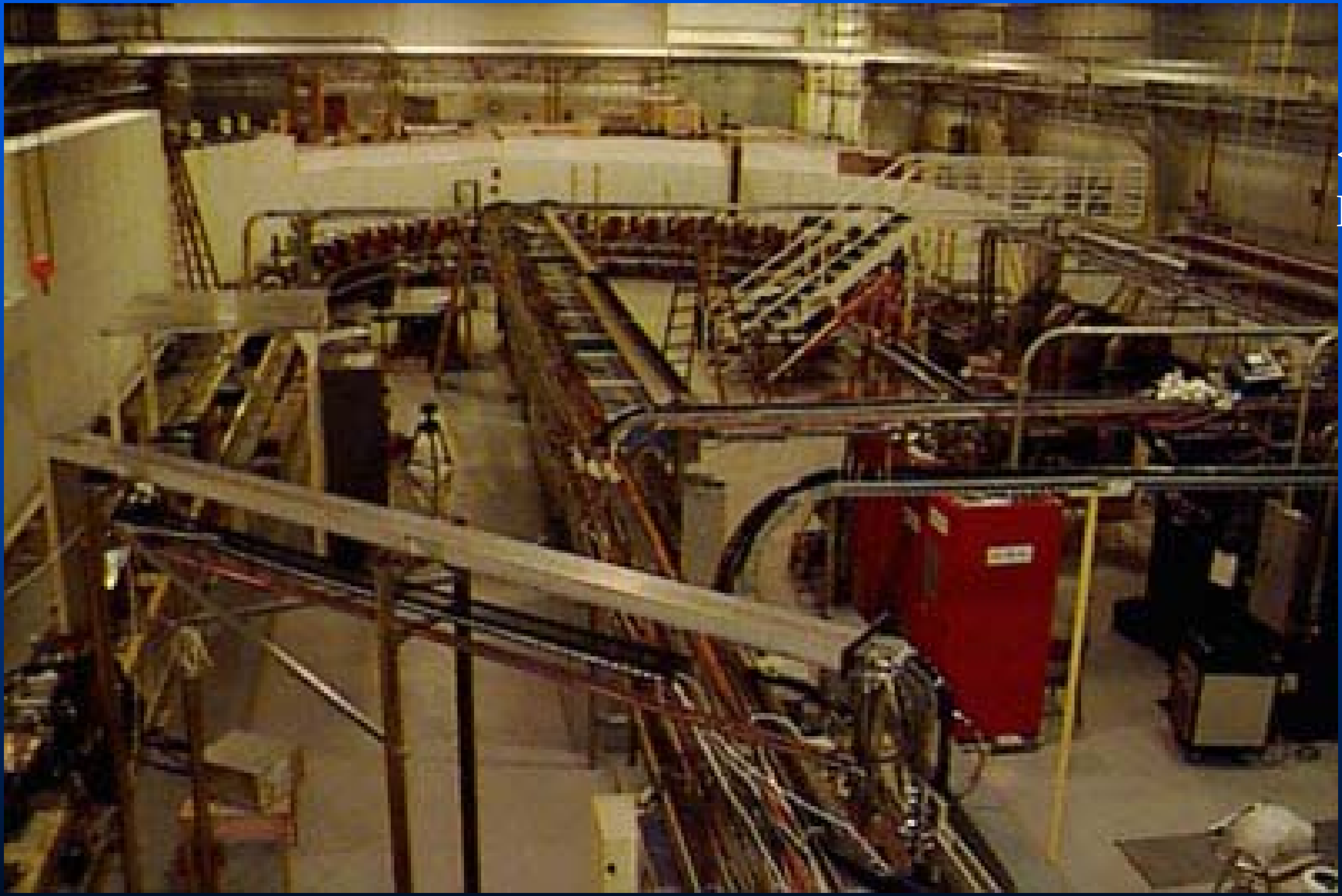
1_1^+ state is predicted at Ex=4.766 MeV
with $B(M1)\uparrow = 0.039\ \mu_N^2$. $(2p_{3/2}^{-1}2p_{1/2})$

1_1^+ state is observed at Ex=5.098 MeV



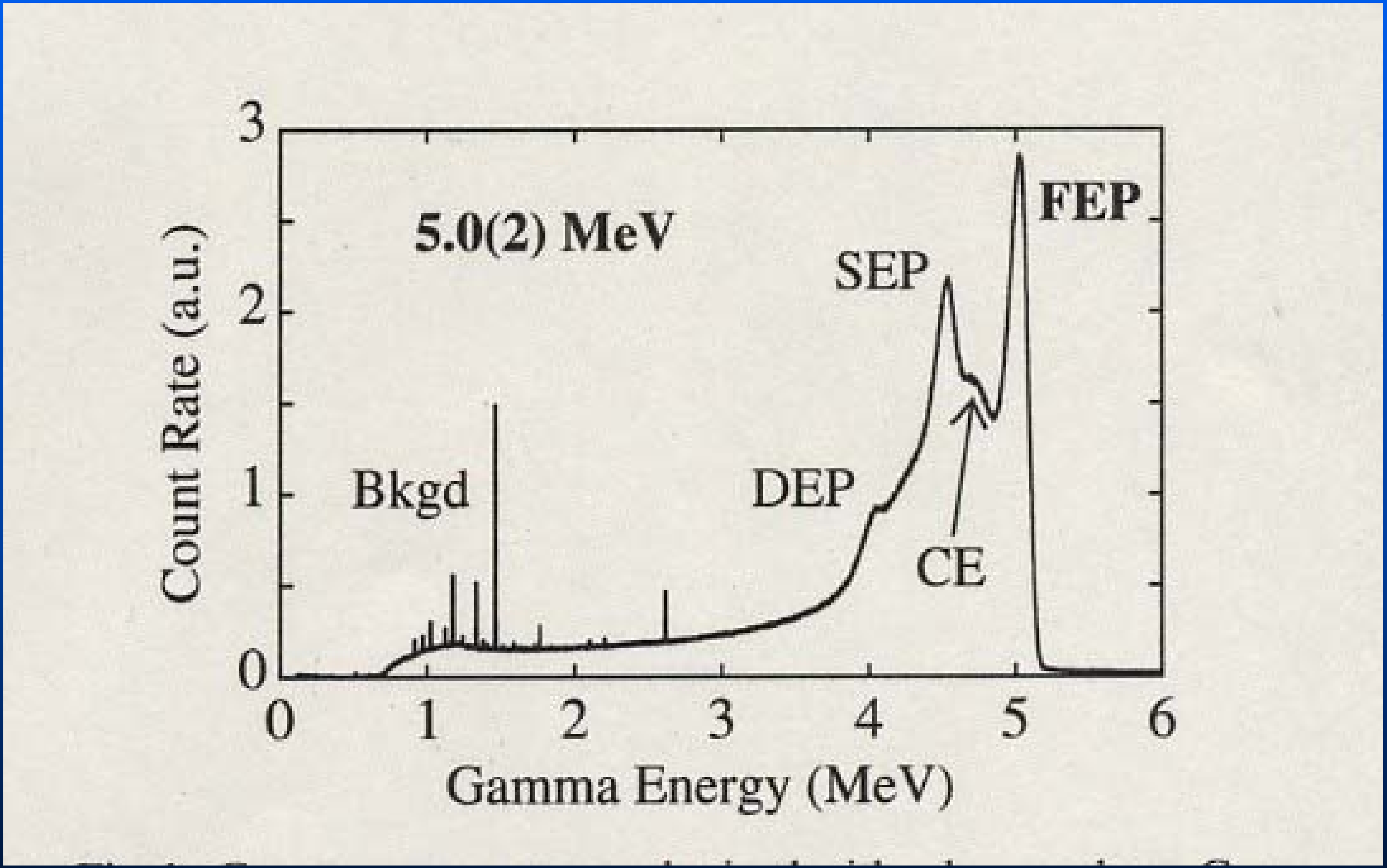
$^{nat}Cr(\gamma_{pol},\gamma)$
Counts/2 keV
100000
10000
1000
100
10
1
1000
2000
3000
4000
5000
6000
Photon Energy (MeV)
E1

HIGS : *FEL-Compton Gamma*

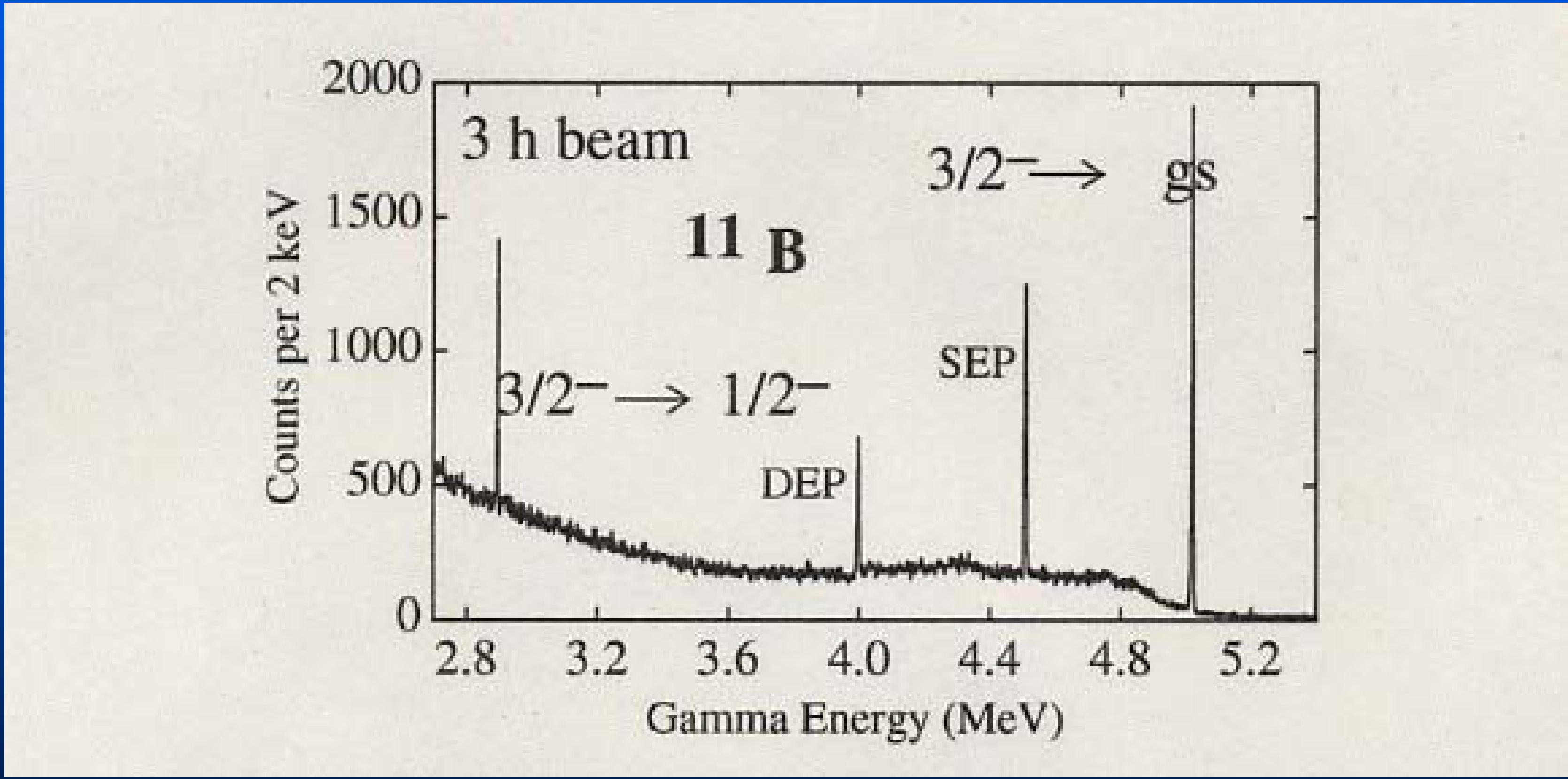


$< 10^7\ \gamma/s$

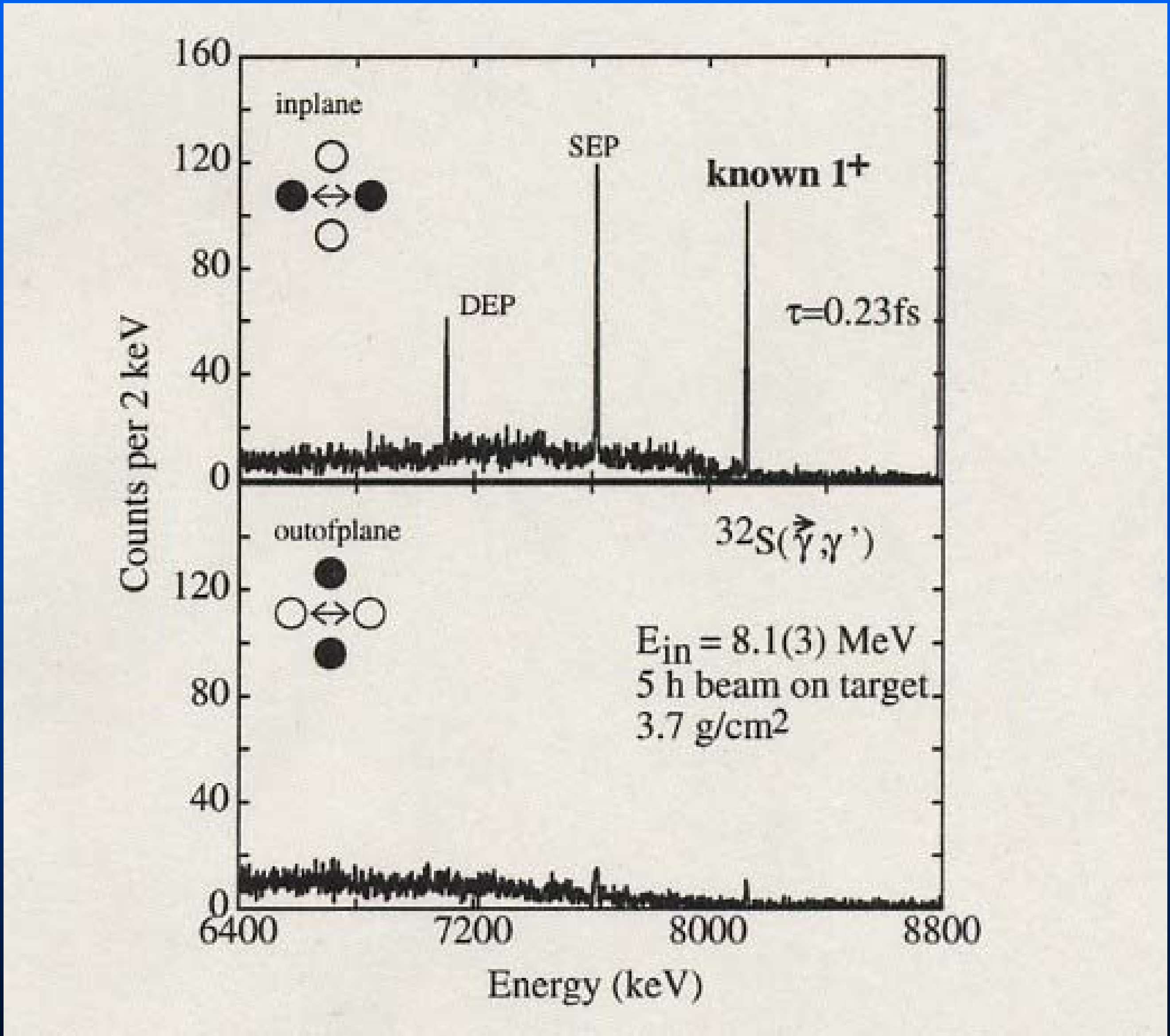
$E\gamma < 120$ MeV


3
2
1
0
Count Rate (a.u.)
5.0(2) MeV
FEP
SEP
DEP
Bkgd
CE
0
1
2
3
4
5
6
Gamma Energy (MeV)

dE/E=1%



3 h beam
11 B
3/2− → gs
3/2− → 1/2−
SEP
DEP
Counts per 2 keV
2000
1500
1000
500
0
2.8
3.2
3.6
4.0
4.4
4.8
5.2
Gamma Energy (MeV)



160
120
80
40
0
inplane
DEP
SEP
known 1+
τ=0.23fs
outofplane
32S(γ,γ')
Ein = 8.1(3) MeV
5 h beam on target
3.7 g/cm2
Counts per 2 keV
6400
7200
8000
8800
Energy (keV)

Beam Dump

Collimator

What can we expect SCW real photon source?

Photon flux of 10^{12}-10^{10} ph/s with -100% polarized beam

=> NRF with small amount of enriched target

(AIST: -X g)

=> fast data taking

(AIST: >several hours)

considerable difficulties

-huge background from target

-Ge counting rate

(AIST: -kHz)

cure

=> optimization of geometric condition

including “*hardner*”