The Spectrometer System at RCNP and Combination with Gamma-Ray Detectors

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Outline

- The Spectrometer System at RCNP

  High-Resolution Beam Line: WS

  High-Resolution Spectrometer: Grand Raiden

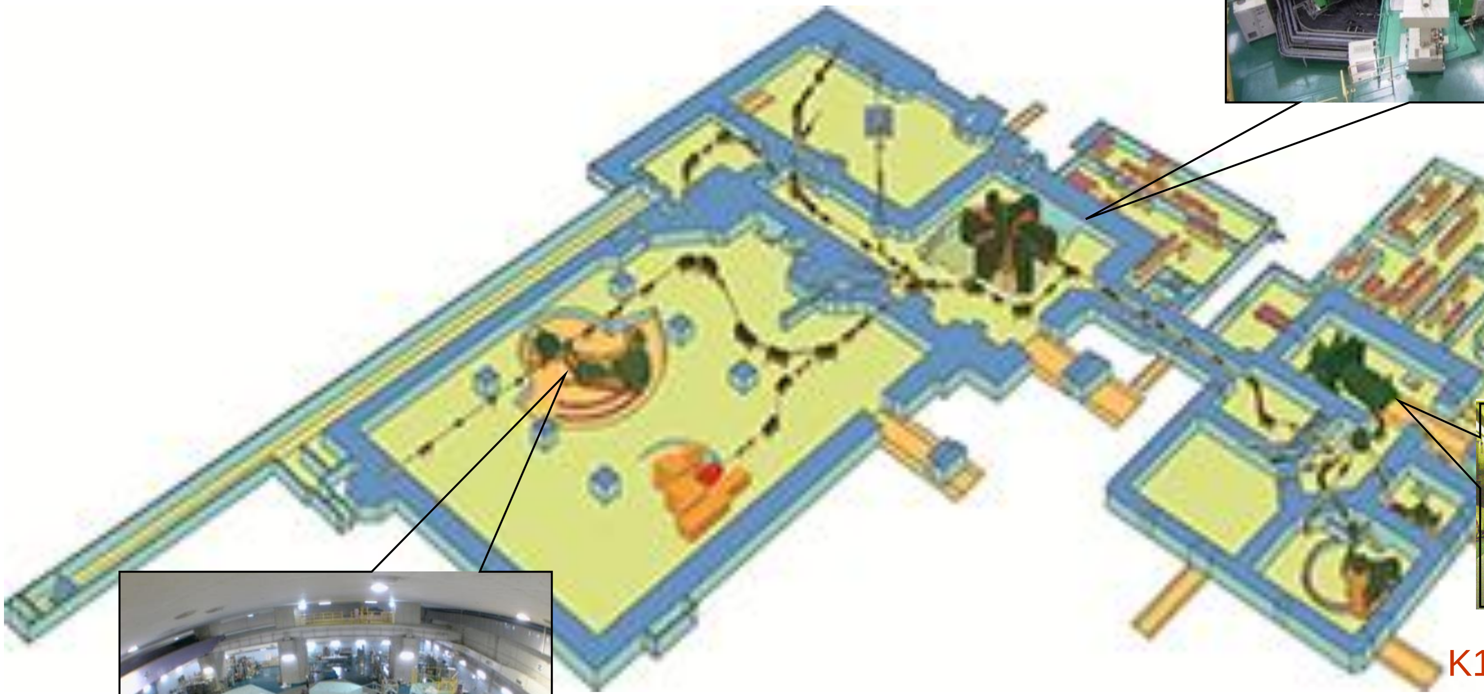
  Large Acceptance Spectrometer: LAS

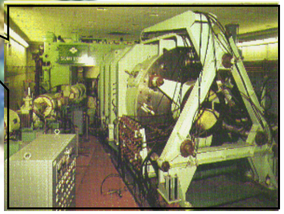
- Experimental Possibilities with Gamma-Ray Detectors

RCNP Cyclotron Facility

K400 ring cyclotron

p: 400MeV
HI:100MeV/u

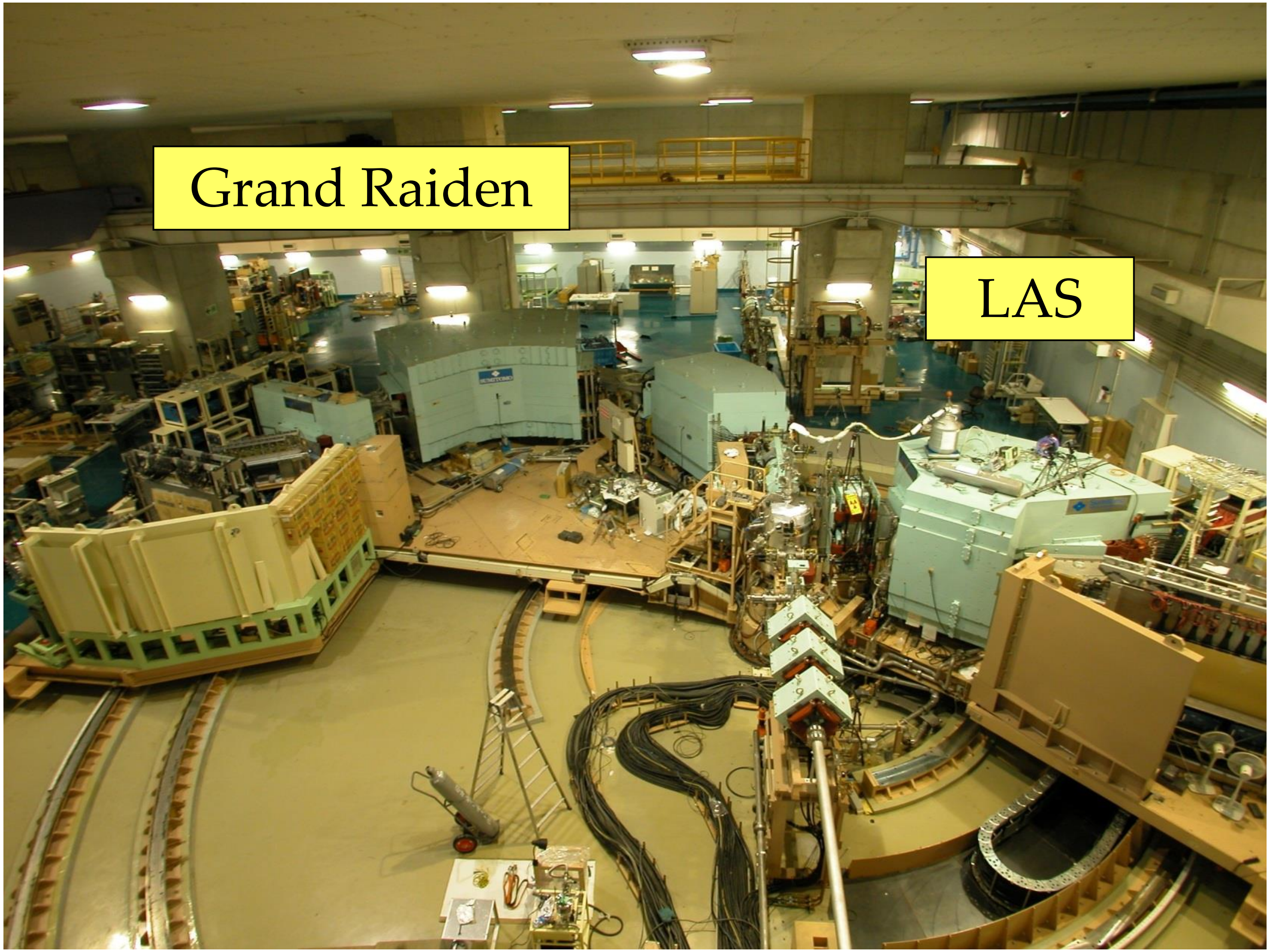




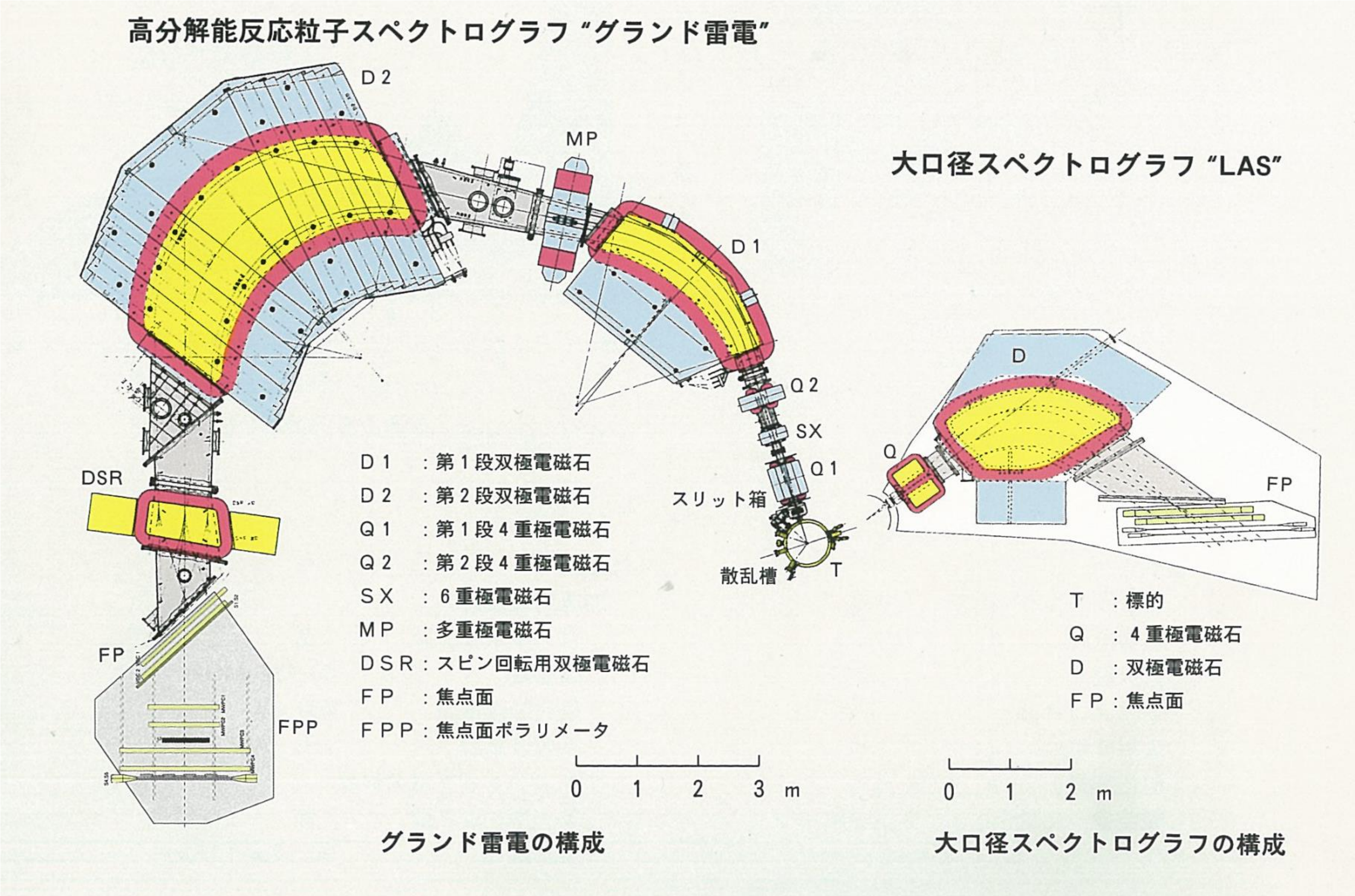
K140 AVF cyclotron
p ~ Xe
Pol. p & d

Double arm spectrometer
(Grand Raiden & LAS)

Double Arm Spectrometer

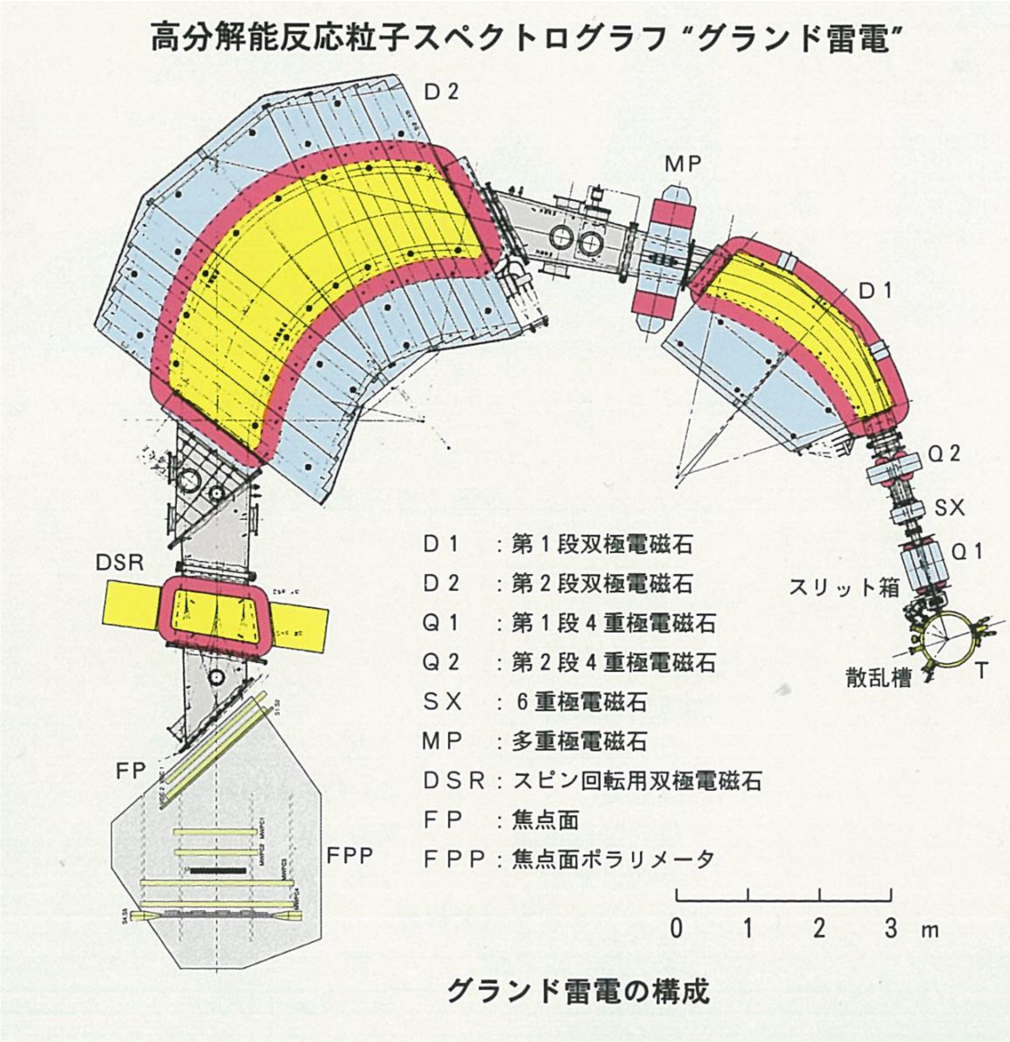


Double-Arm Spectrometer
Grand Riaden and LAS



High-Resolution Spectrometer "Grand Raiden"

M. Fujiwara *et al.*, NIMA422,494(1999)



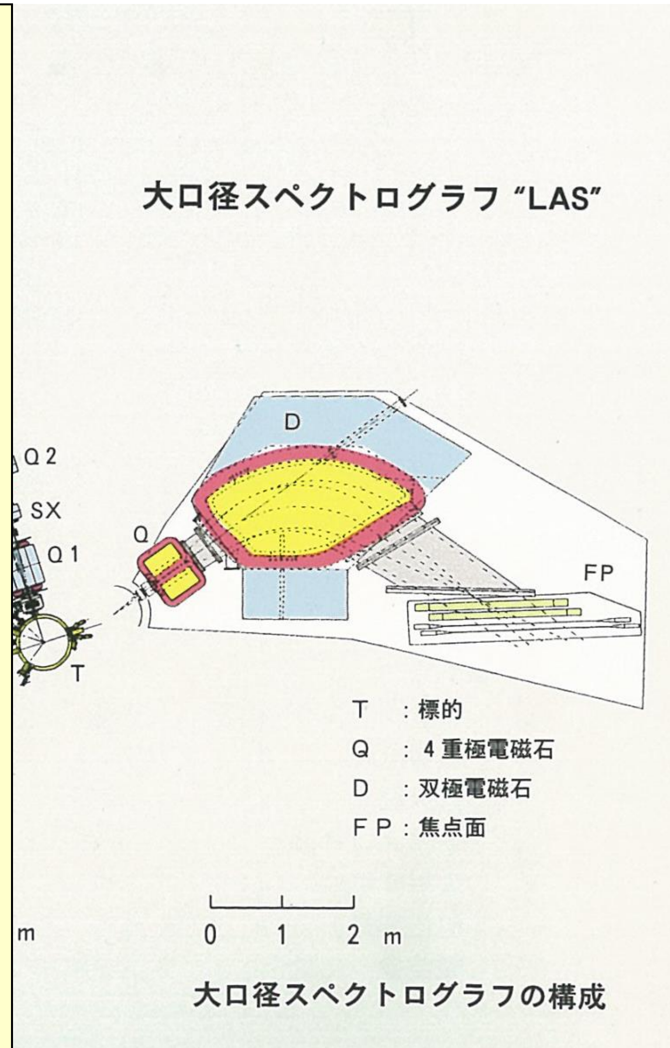
Resolving Power:	37,000
Bending Radius:	3 m
Bending Angle:	162 deg
Bending Power:	5.4 Tm
Dispersion:	15.4 m
Solid Angle:	~4 msr
Momentum Acceptance:	5 %
Horizontal Magnification:	-0.42
Vertical Magnification:	6.0
Angle:	0-70 deg

Two Multi-Wire Drift Chambers
Plastic Scintillators
Focal Plane Polarimeter (for protons)

Large Acceptance Spectrometer (LAS)

H. Matsuoka et al., RCNP Annual Report 1990

Resolving Power:	5,000
Bending Radius:	1.75 m
Bending Angle:	70 deg
Bending Power:	3.22Tm
Dispersion:	2 m
Solid Angle:	~20 msr
Momentum Acceptance:	30 %
Horizontal Magnification:	-0.40
Vertical Magnification:	-7.3
Angle:	0-130 deg



Two Multi-Wire Drift Chambers
Plastic Scintillators

Double-Arm Spectrometer
Grand Riaden and LAS

Grand Raiden

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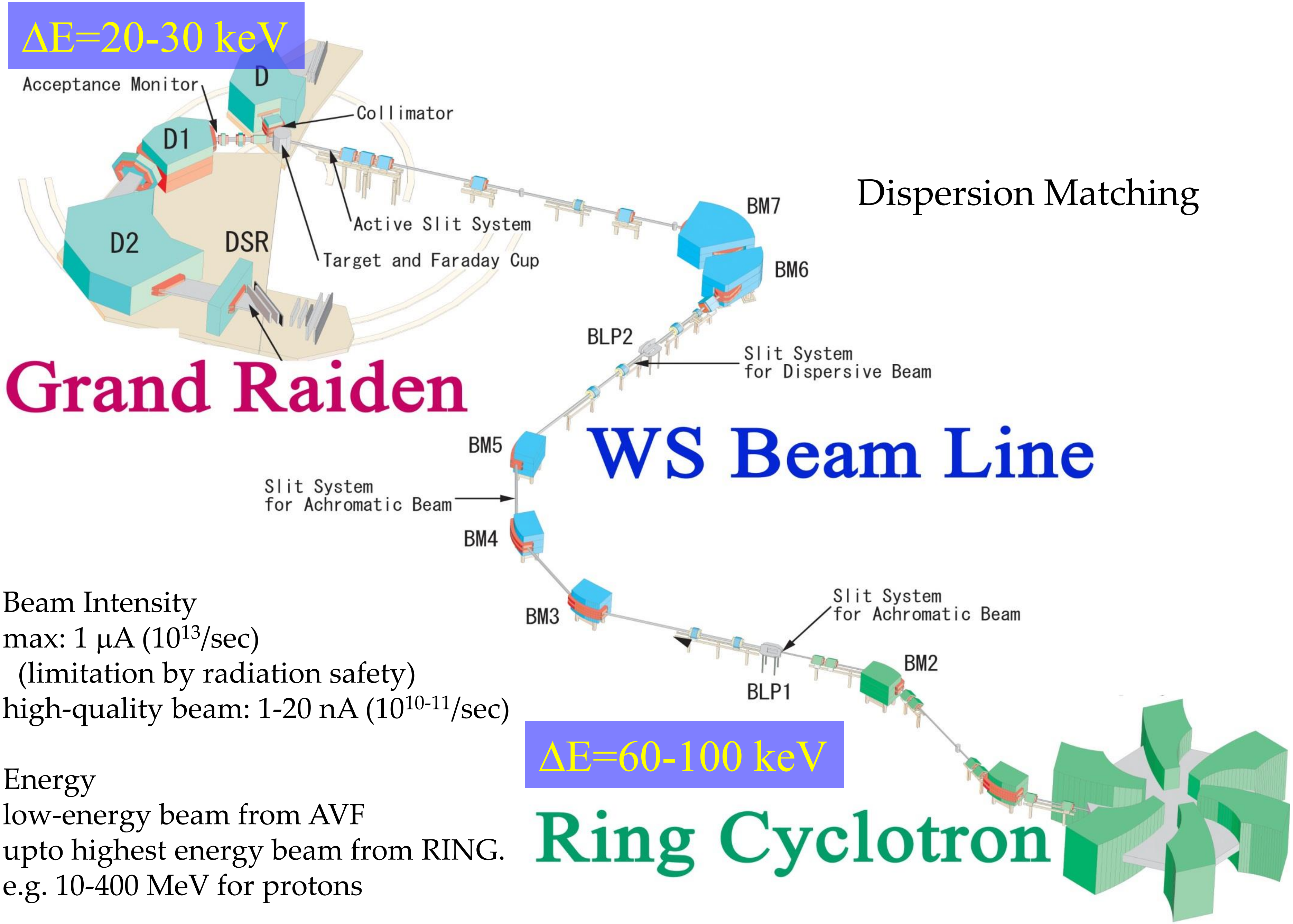
Dispersion Matching



Beam Intensity
max: 1 μA (10^{13}/sec)
(limitation by radiation safety)
high-quality beam: 1-20 nA ($10^{10\text{-}11}$/sec)

Energy
low-energy beam from AVF
upto highest energy beam from RING.
e.g. 10-400 MeV for protons

Unique Features of the Cyclotrons and Spectrometers

Accelerator Complex

•high-quality beams (1-20 nA)
stable, high-resolution, low-background (no beam halo)
•high-intensity beams (up to 1μA)
•low to Intermediate (100-400 MeV/A) Energy (10-400 MeV for p)
•polarized p and d beams
•variety of ion species from H to Xe

Spectrometer System

•high-Resolution
•large magnetic rigidity (triton 150 MeV/A)
•realization of 0-deg measurements including inelastic scattering
•focal plane proton polarimeter
•coincidence measurements with two spectrometers
•coincidence measurements with decay counters (SSD, neutron, (gamma))

High-Quality Beams

High-Quality beams
e.g. the case for a proton beam at 295 MeV

In achromatic mode

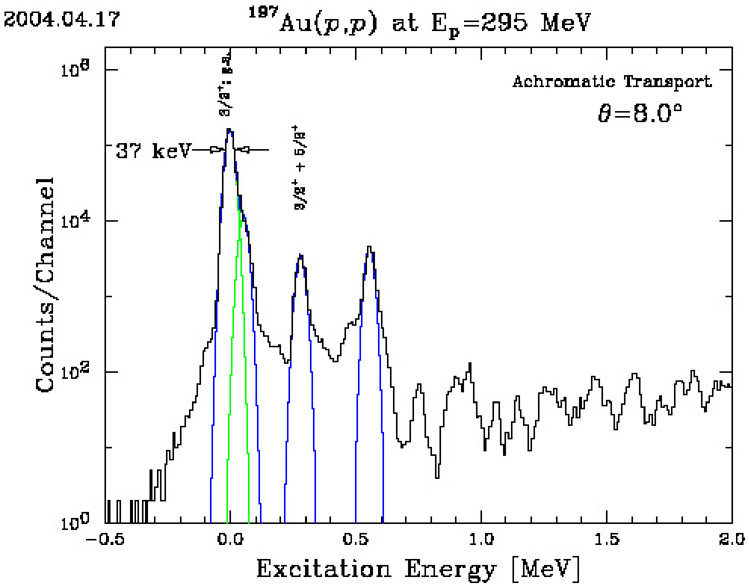
- beam energy spread: 60-100 keV
- beam spot size: < 0.3 mm

In dispersion matching mode

- energy resolution: 20-30 keV
- beam spot size: 3-5 mm^H, 0.3 mm^V

Halo free beam

High-quality beam is essential to realize 0-deg inelastic scattering measurements.
Also for measurements with gamma detectors.



Beam spot in the dispersive mode

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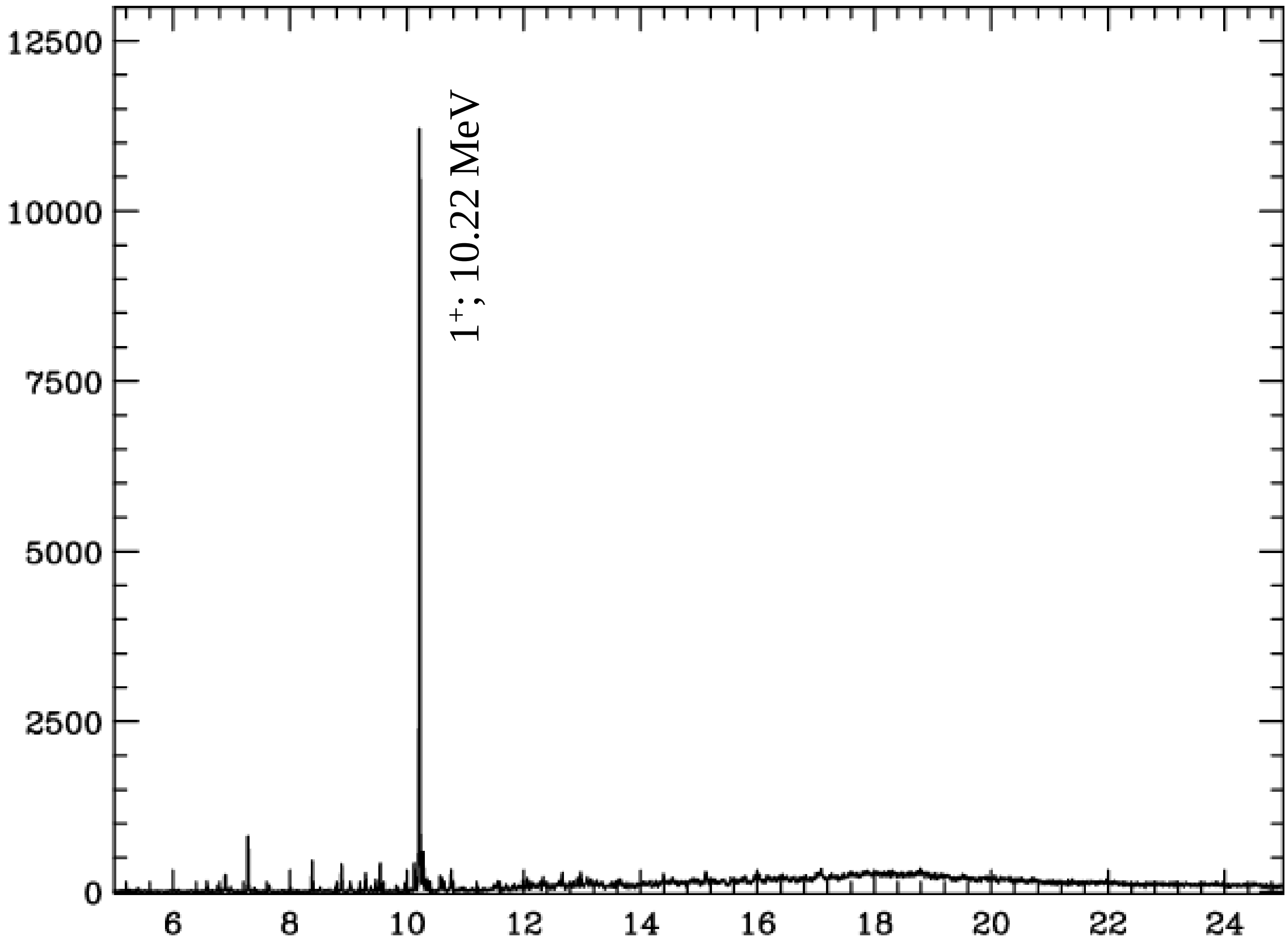
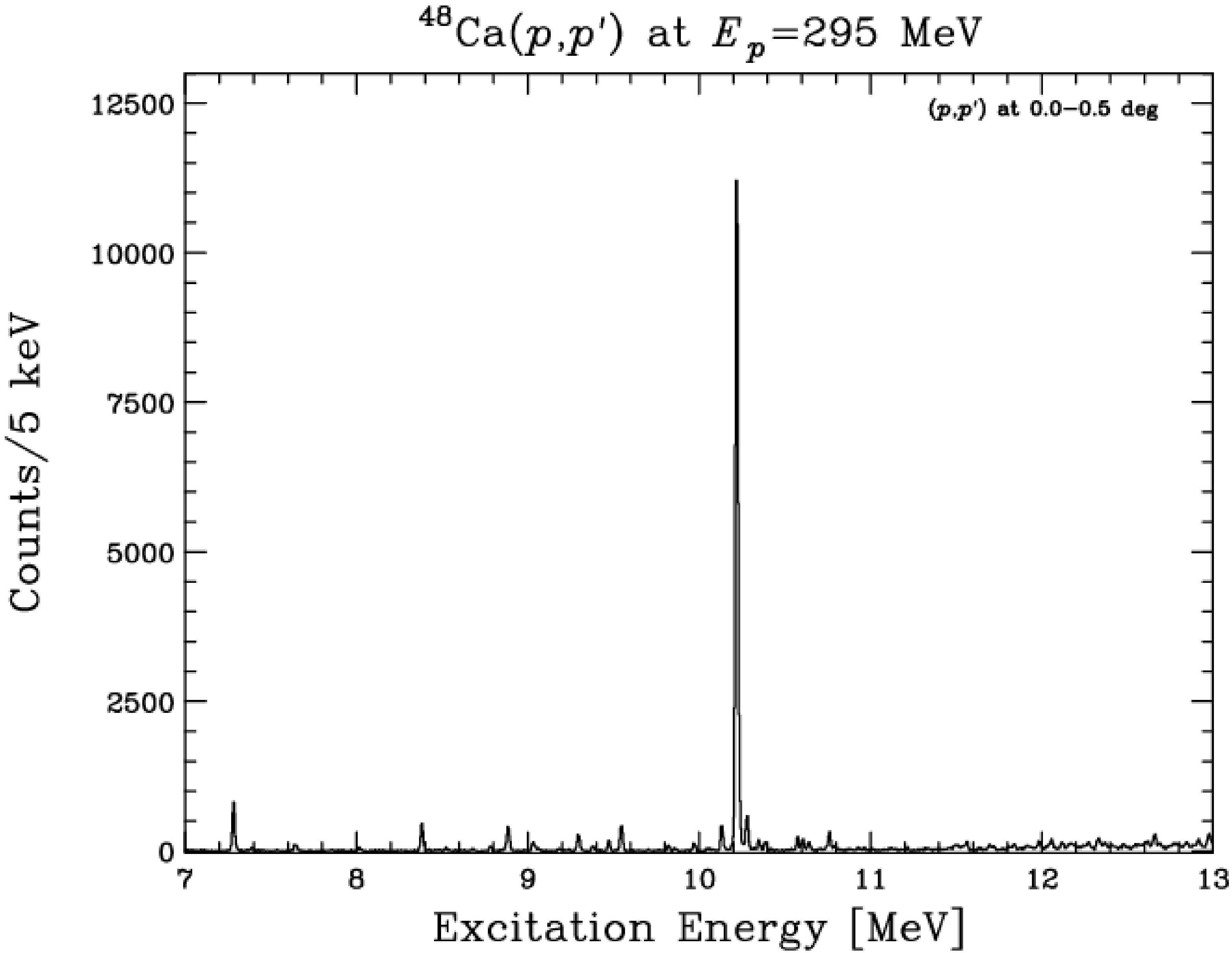
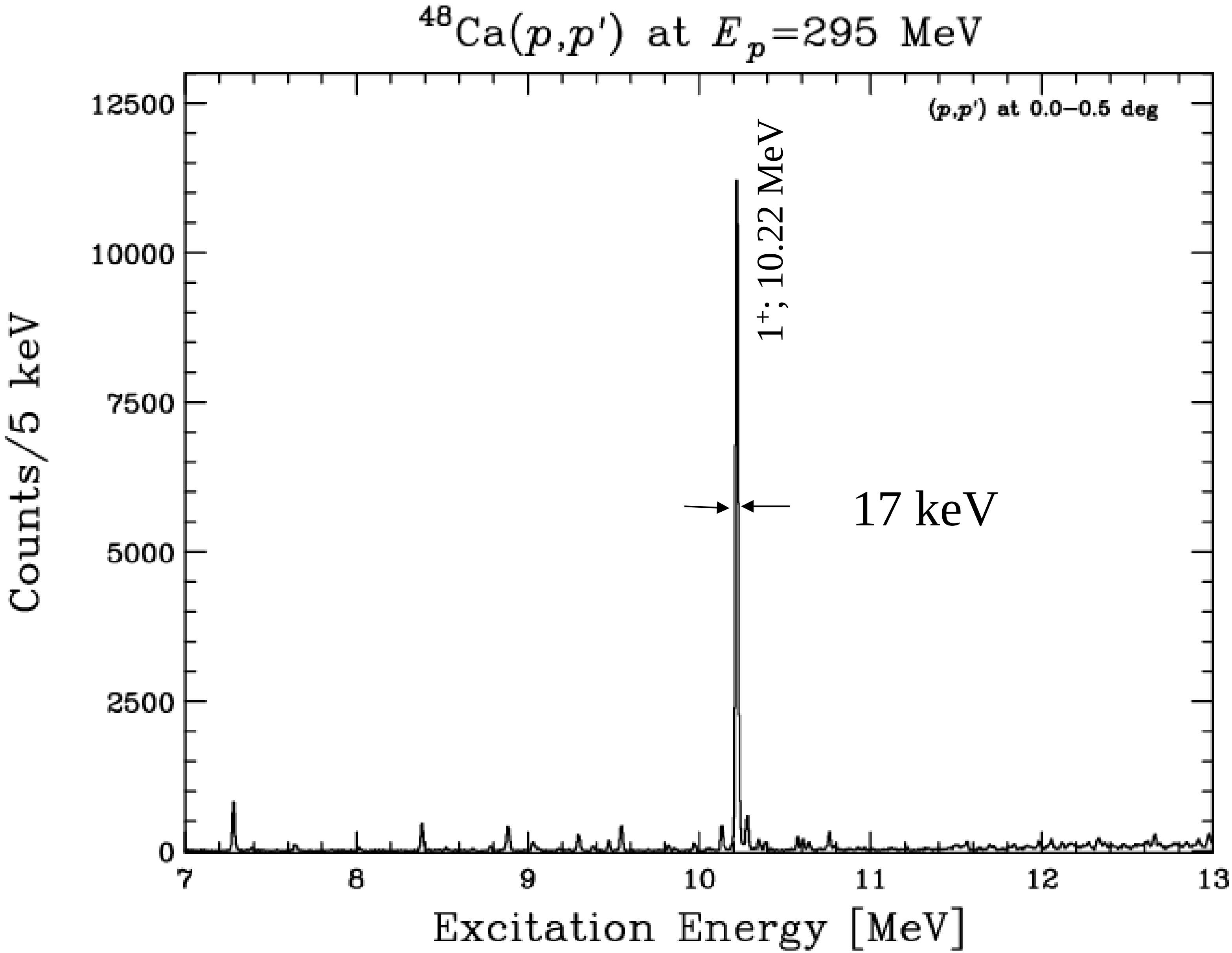


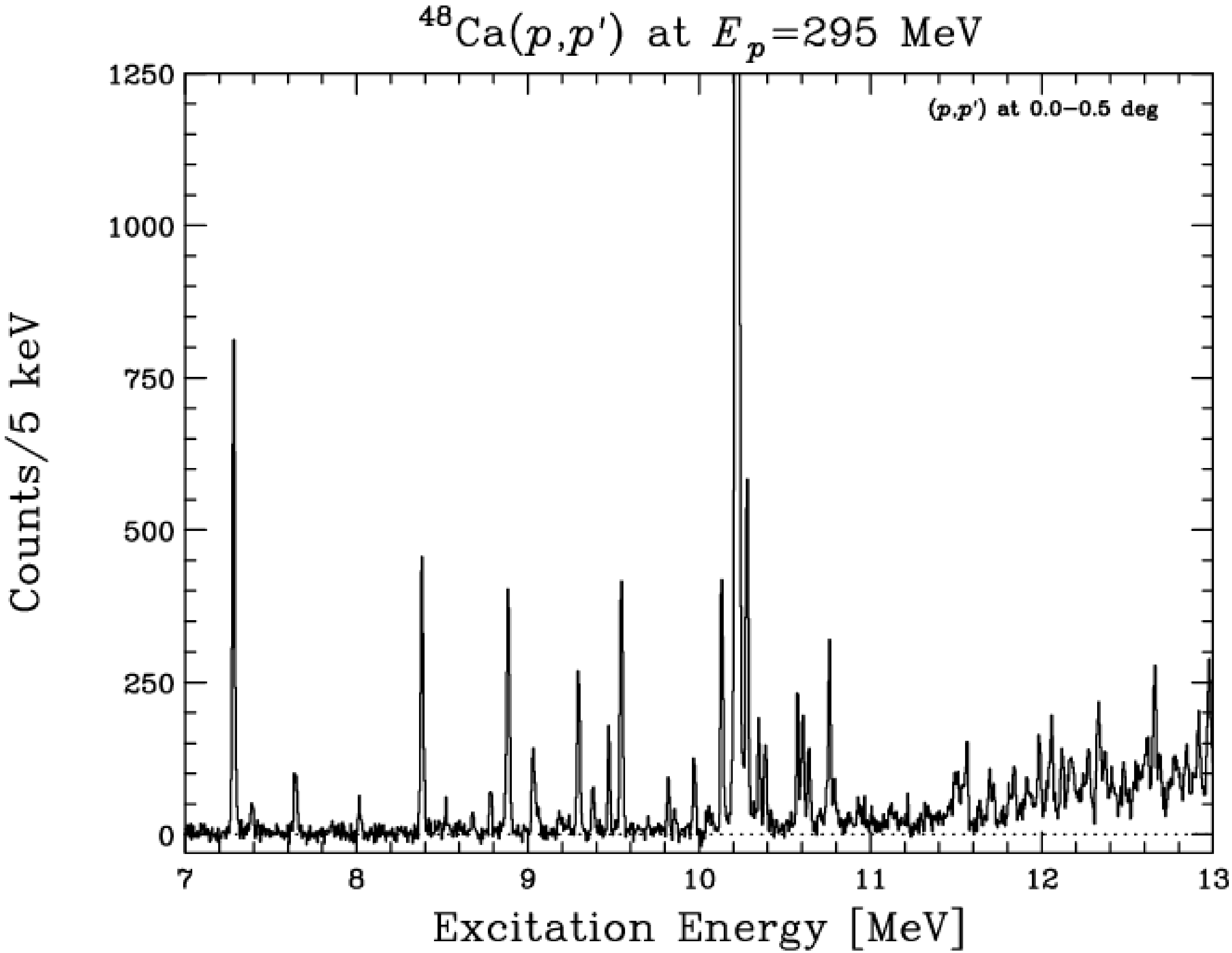
12500
10000
7500
5000
2500
0
6
8
10
12
14
16
18
20
22
24
1+; 10.22 MeV



^{48}Ca(p,p') at E_p=295 MeV
(p,p') at 0.0–0.5 deg
Counts/5 keV
12500
10000
7500
5000
2500
0
7
8
9
10
11
12
13
Excitation Energy [MeV]

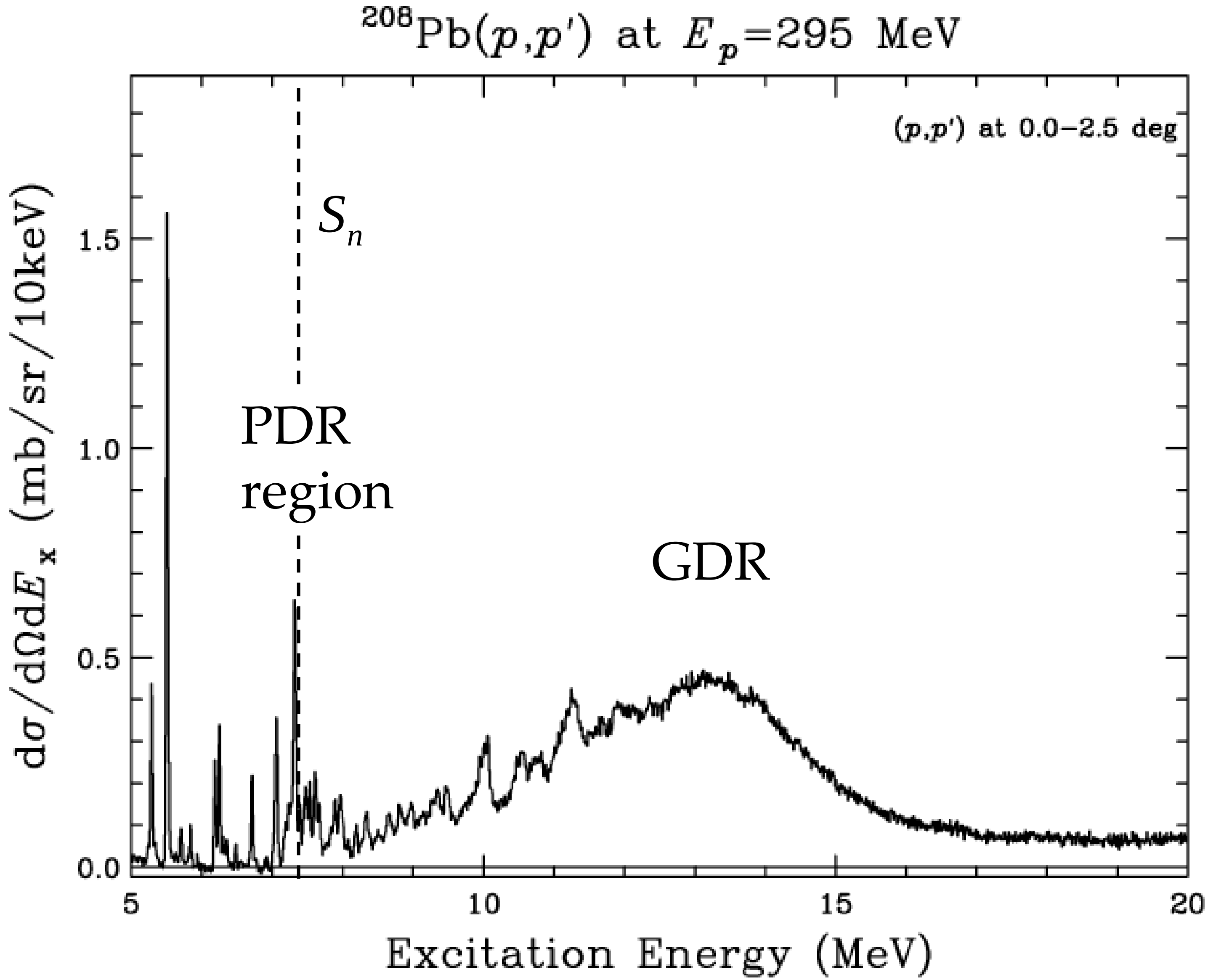


^{48}Ca(p,p') at E_p=295 MeV
(p,p') at 0.0–0.5 deg
1$^+$; 10.22 MeV
17 keV
Counts/5 keV
12500
10000
7500
5000
2500
0
7
8
9
10
11
12
13
Excitation Energy [MeV]

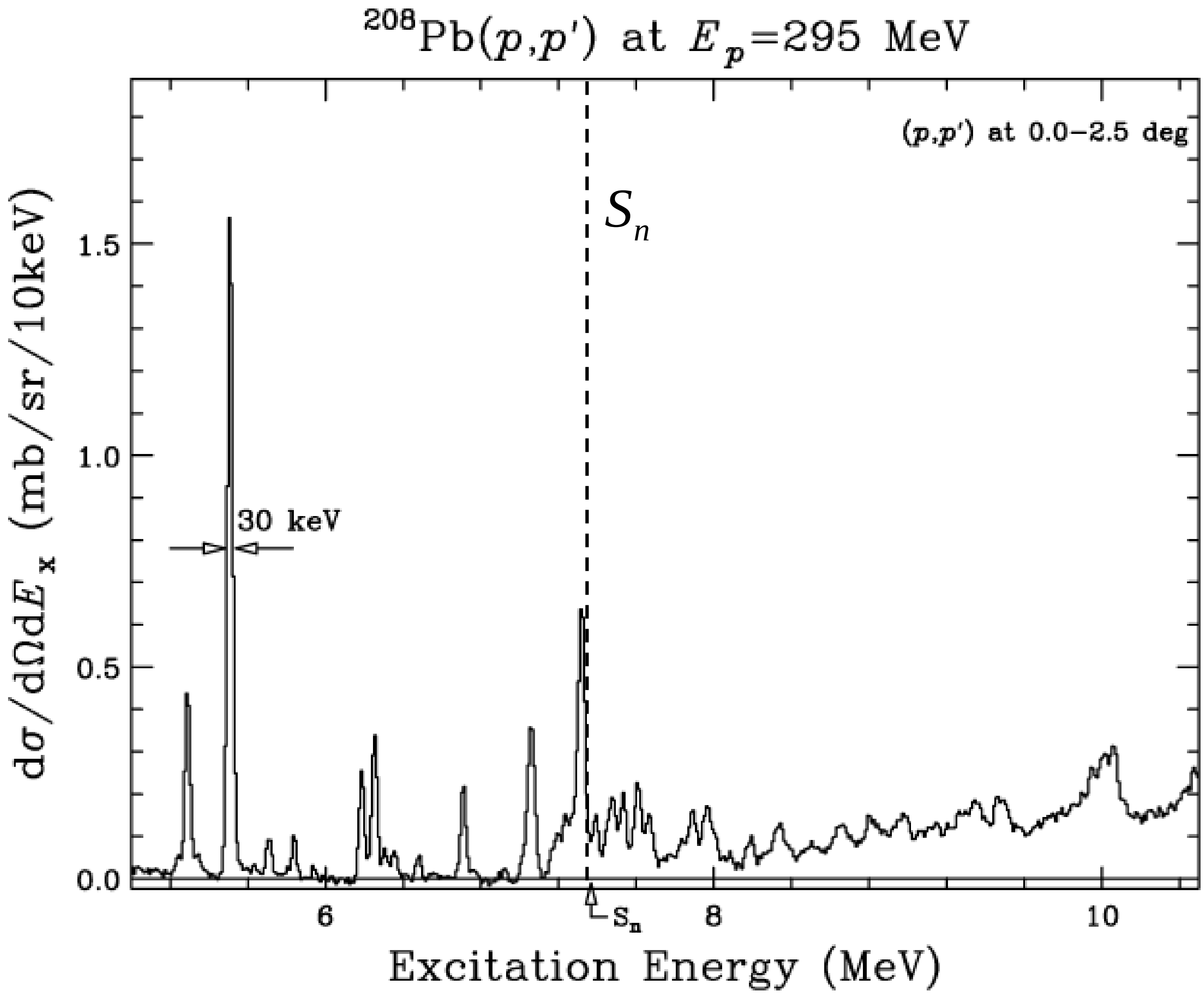


48Ca(p,p') at Ep=295 MeV
(p,p') at 0.0–0.5 deg
Counts/5 keV
Excitation Energy [MeV]
1250
1000
750
500
250
0
7
8
9
10
11
12
13

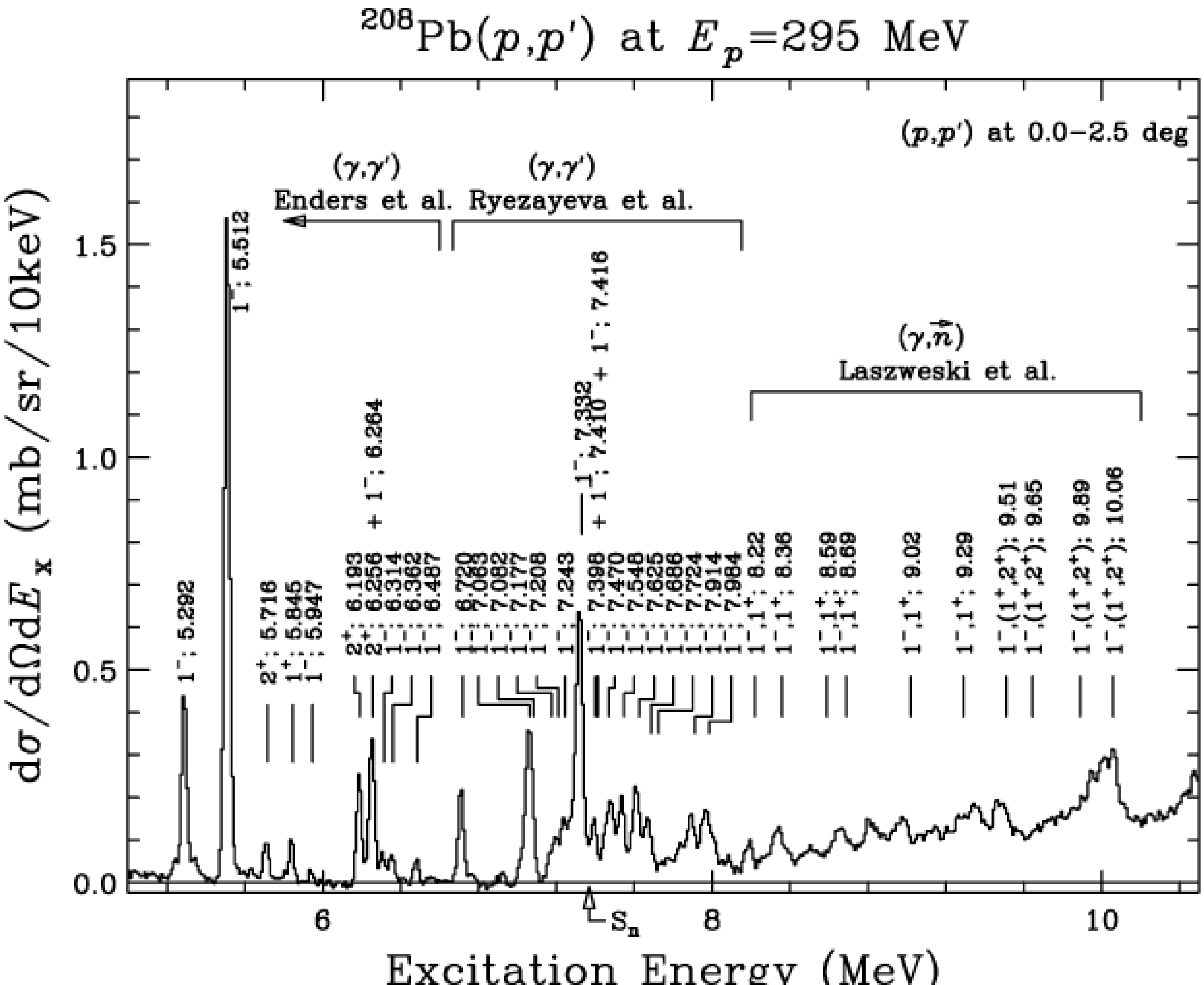
Excitation Energy Spectra



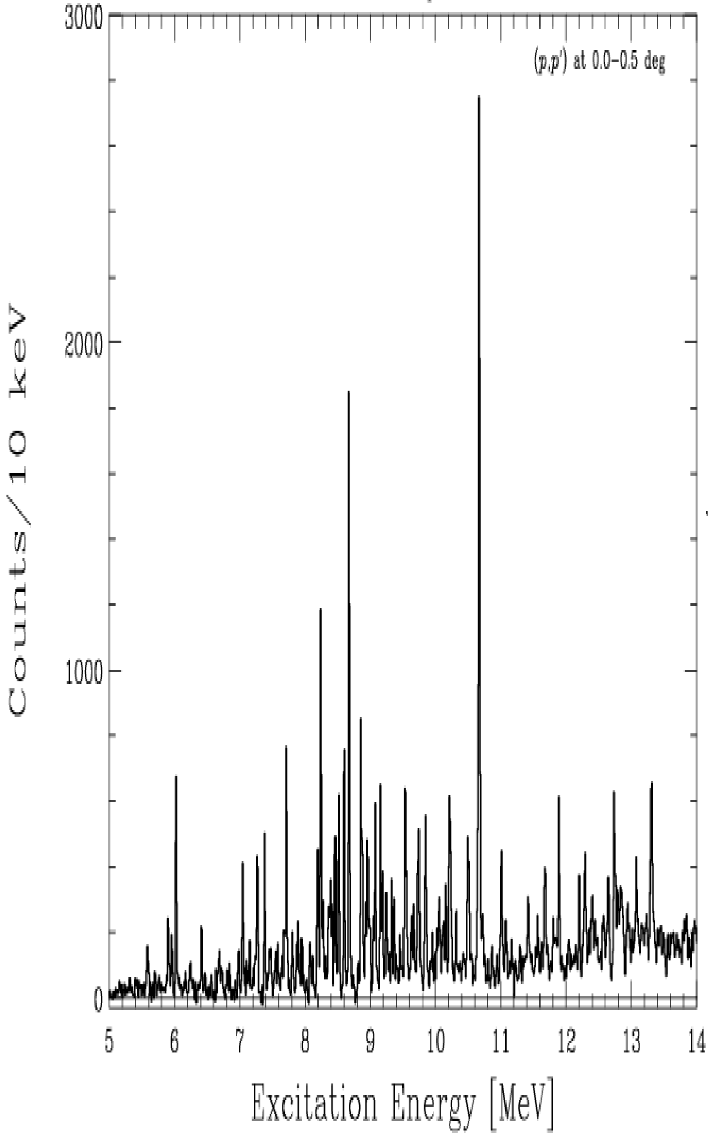
Excitation Energy Spectra



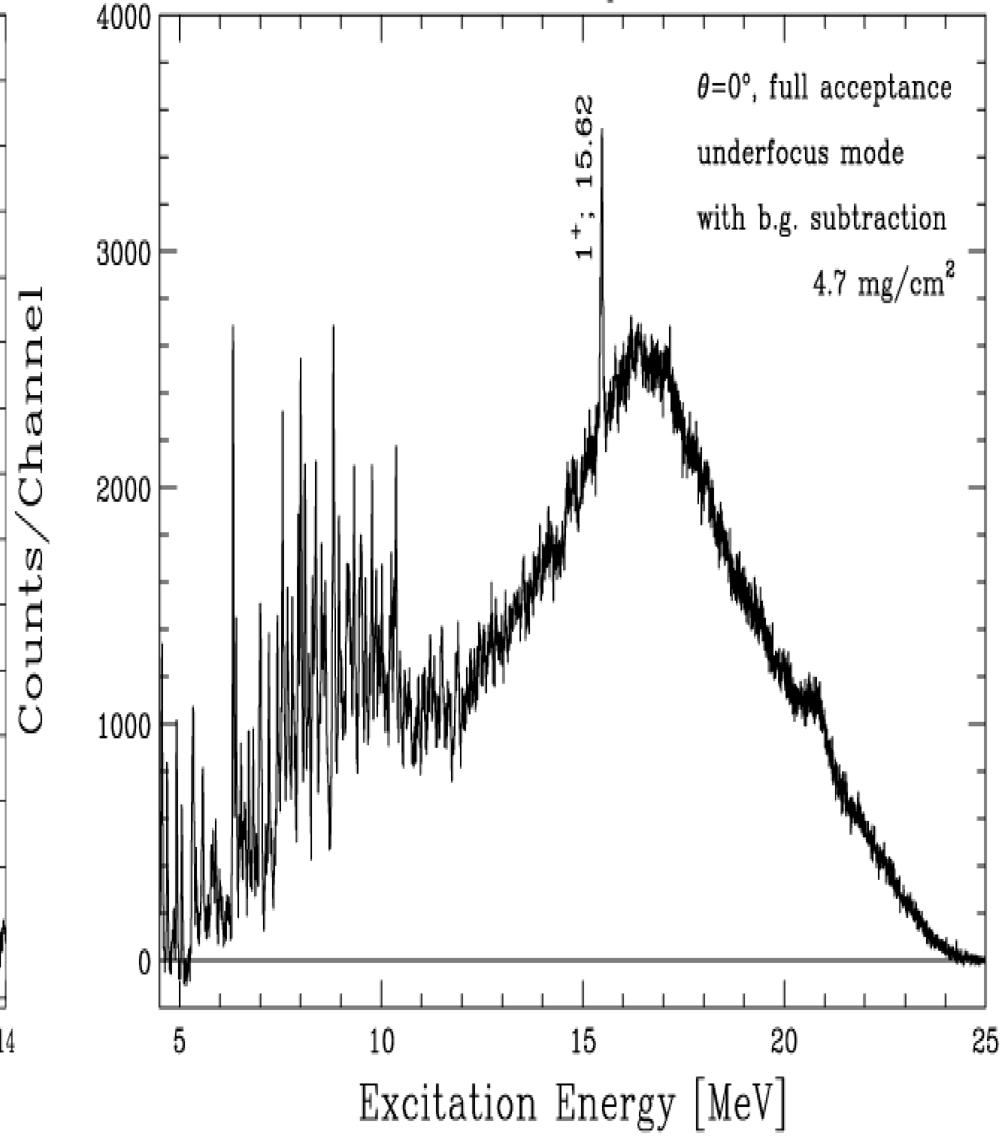
Excitation Energy Spectra

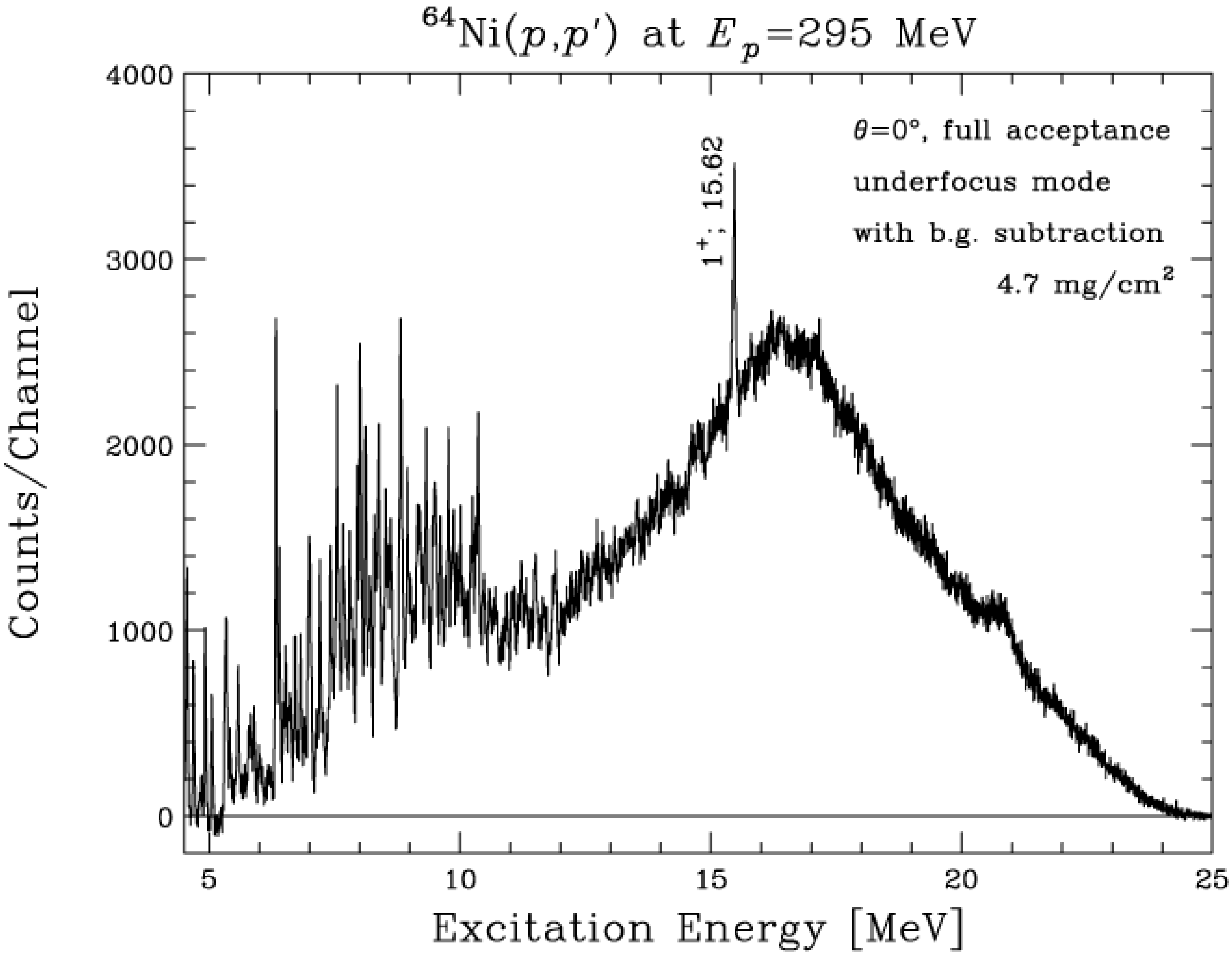


^{58}Ni(p,p') at E_p=295 MeV



^{64}Ni(p,p') at E_p=295 MeV

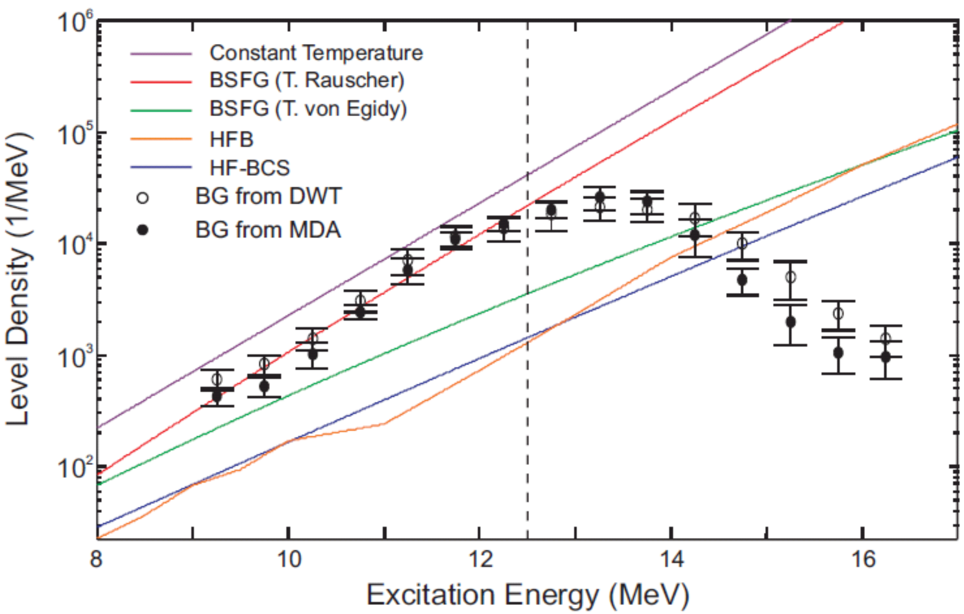




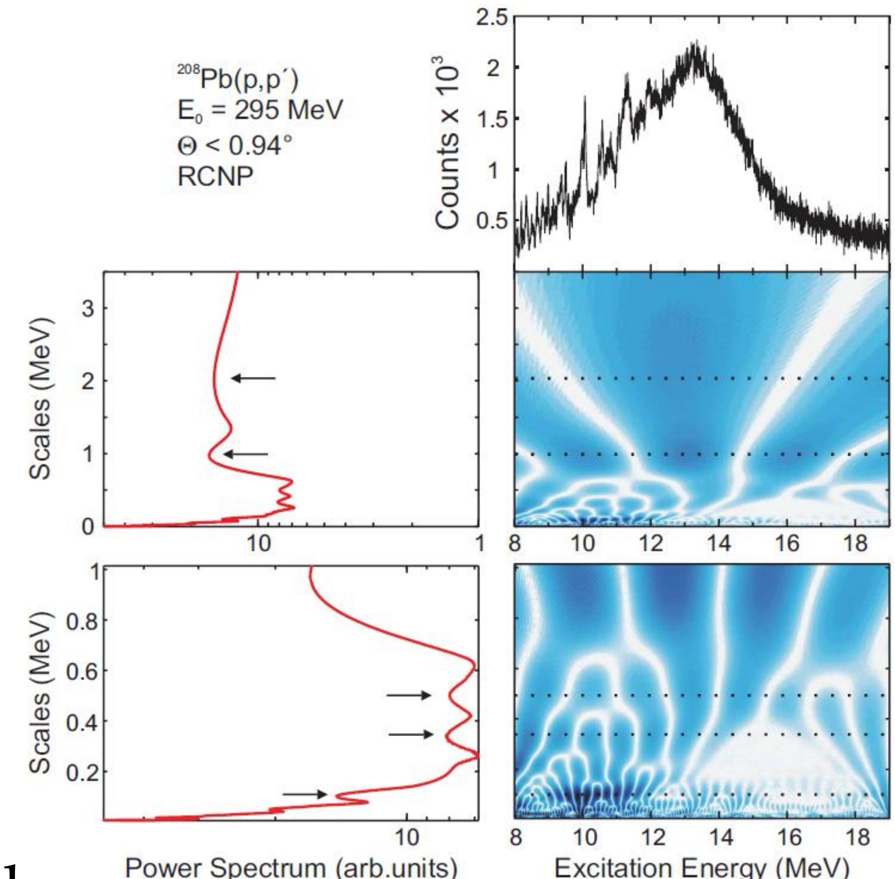
^{64}Ni(p,p') at E_p=295 MeV
θ=0°, full acceptance
underfocus mode
with b.g. subtraction
4.7 mg/cm^2
1$^+$; 15.62
Counts/Channel
Excitation Energy [MeV]
0
1000
2000
3000
4000
5
10
15
20
25

Level density, auto-correlation, wavelet analysis

Experimental limit due to resolution



Resolution: 25 keV

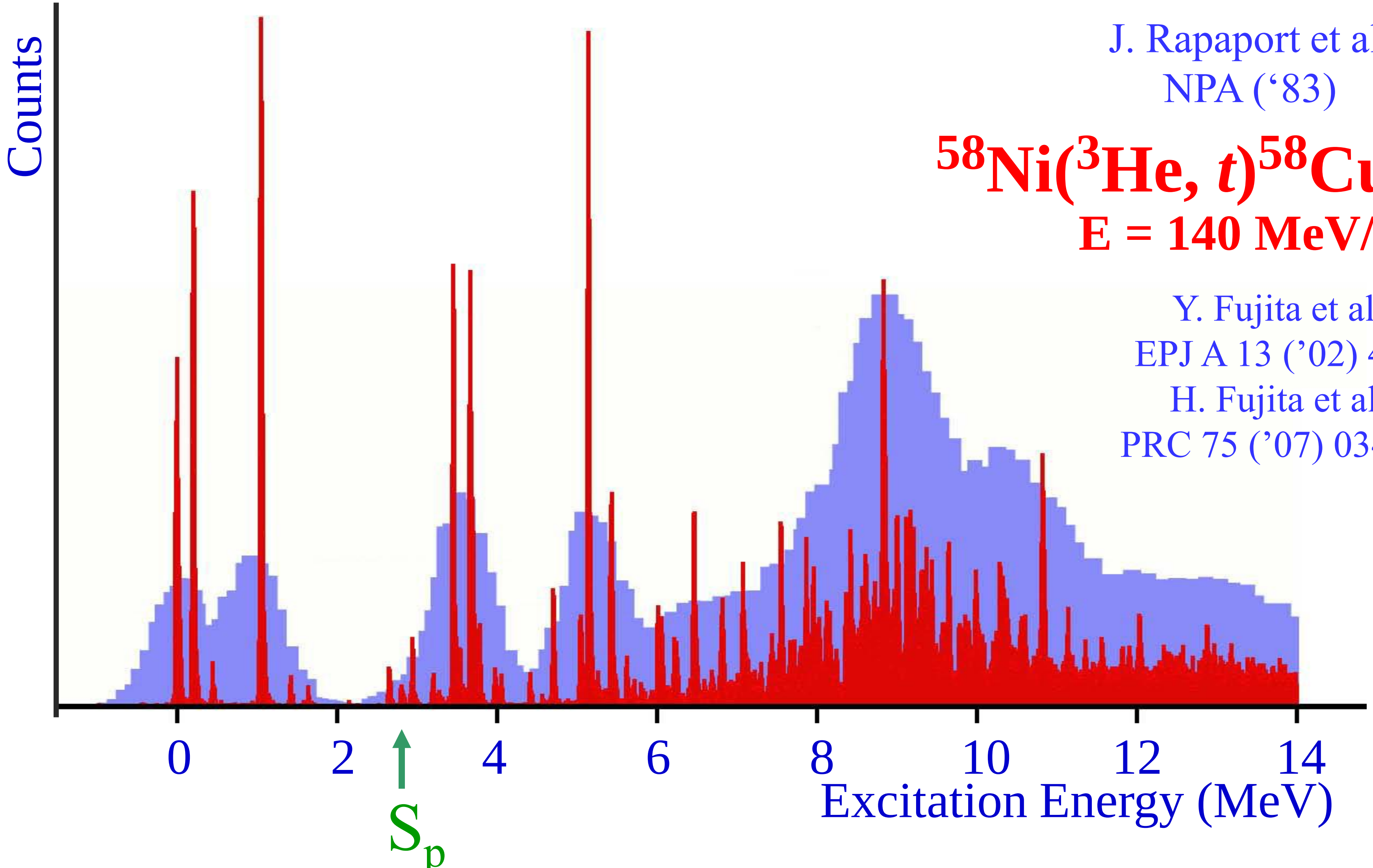


Level density can be extracted up to ~ 10^4/MeV

I. Poltoratska, PhD thesis, 2011

Gamow-Teller Resonance

→ Talk by Fujita



^{58}Ni(p, n)^{58}Cu
E_p = 160 MeV

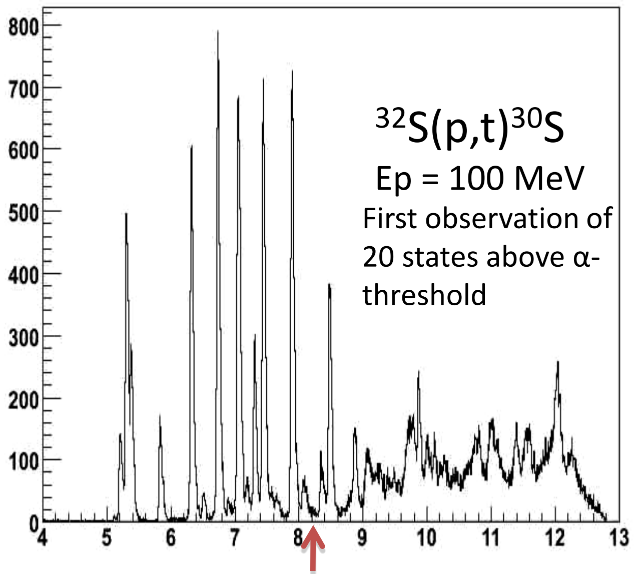
J. Rapaport et al.
NPA ('83)

^{58}Ni(^{3}He, t)^{58}Cu
E = 140 MeV/u

Y. Fujita et al.,
EPJ A 13 ('02) 411.
H. Fujita et al.,
PRC 75 ('07) 034310

(p,t) Measurement

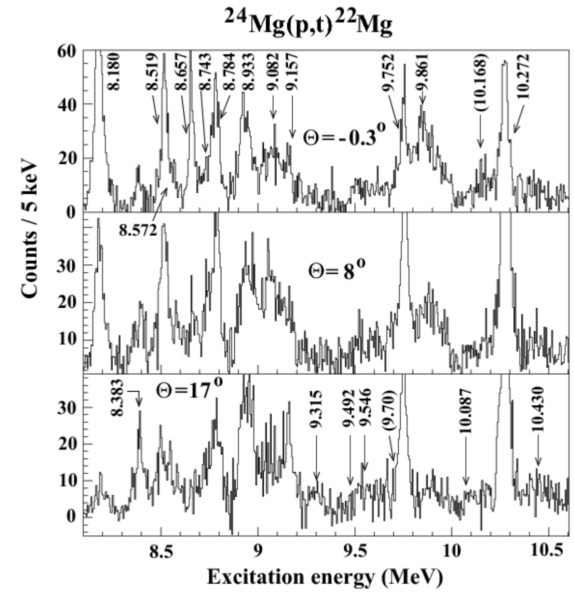
PhD thesis S. O'Brien

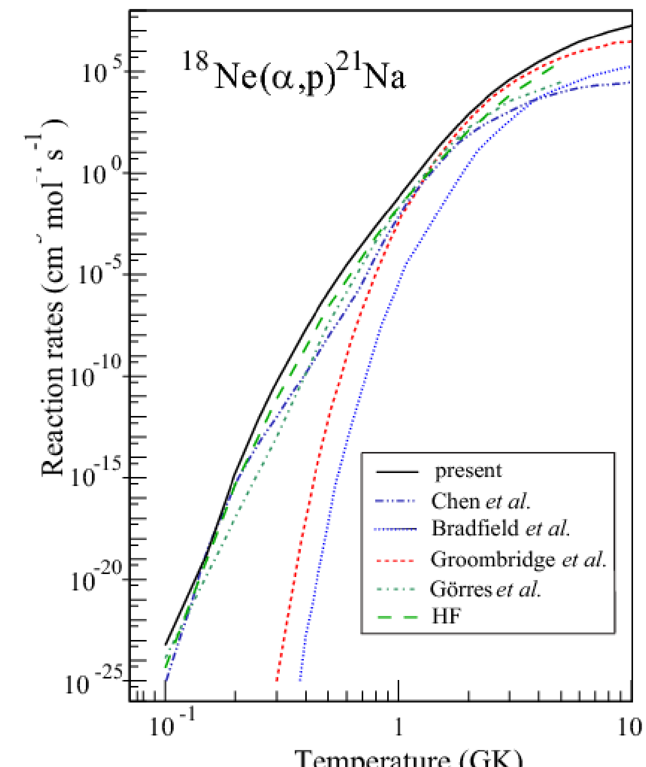


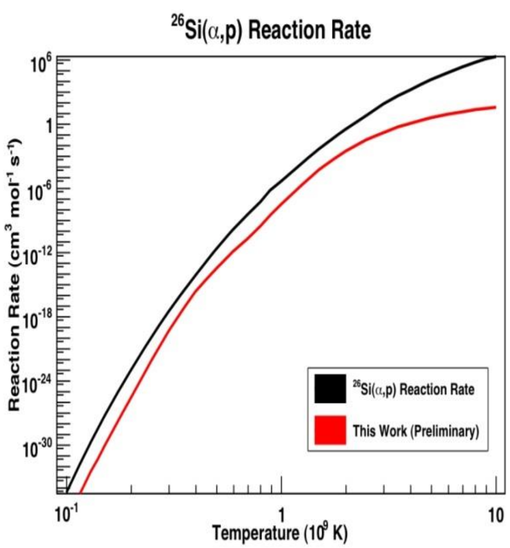
α threshold

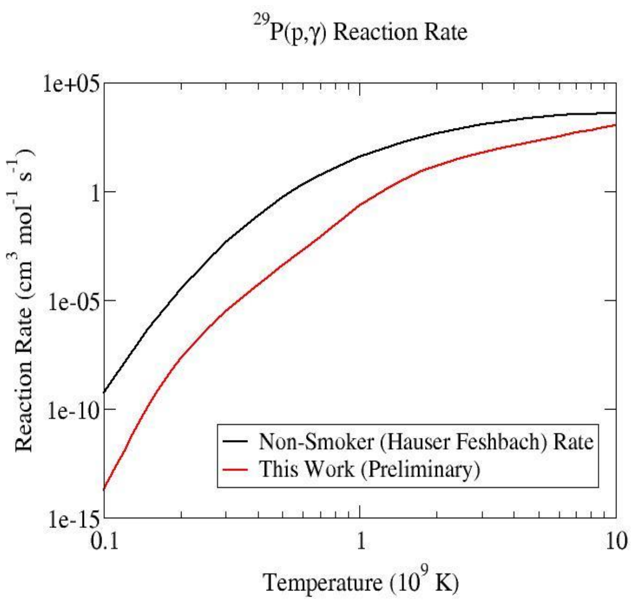
Determination of excited states and its energy with 1 keV resolution

(p,t) Spectra and Stellar Rates

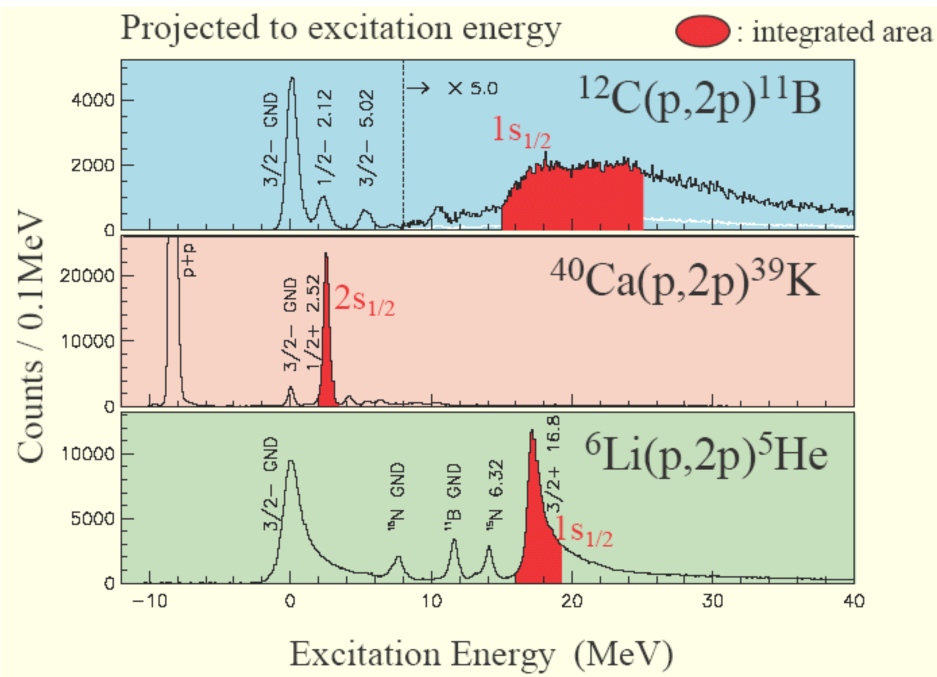


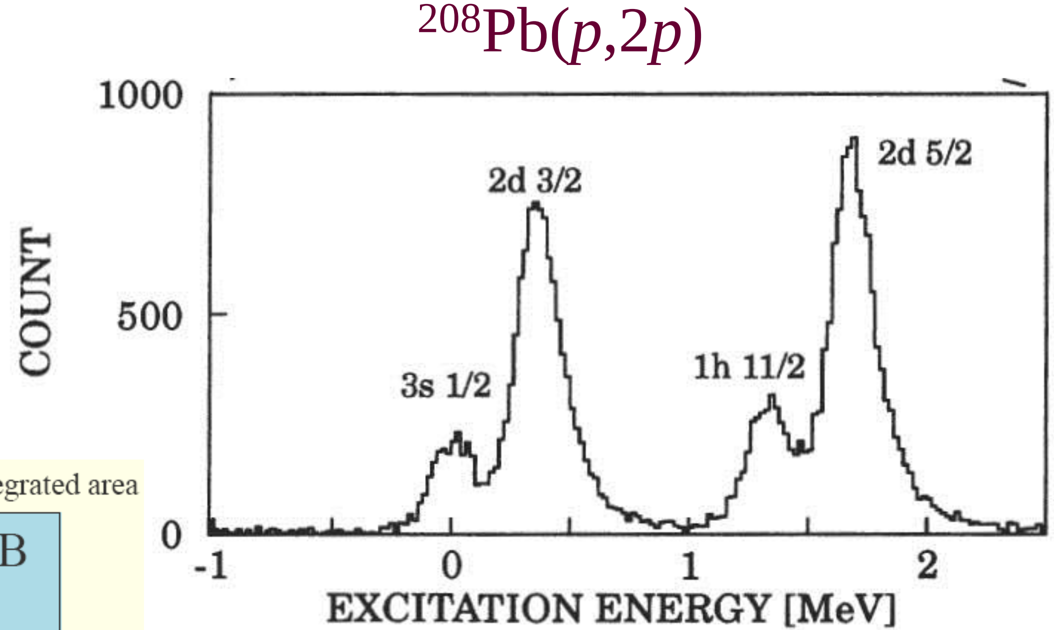


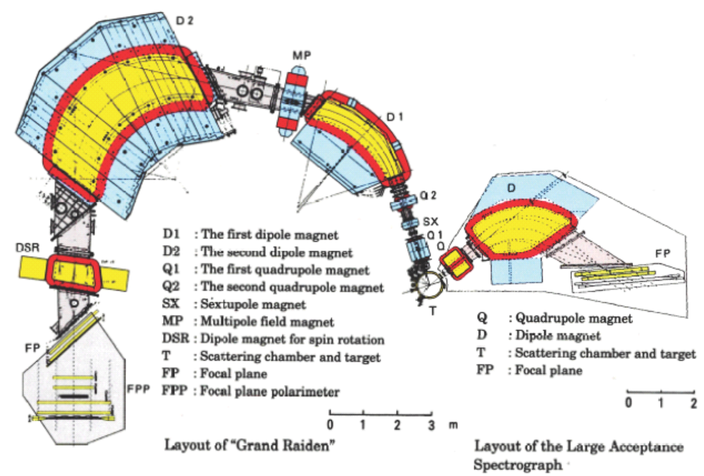




(p,2p) Measurement



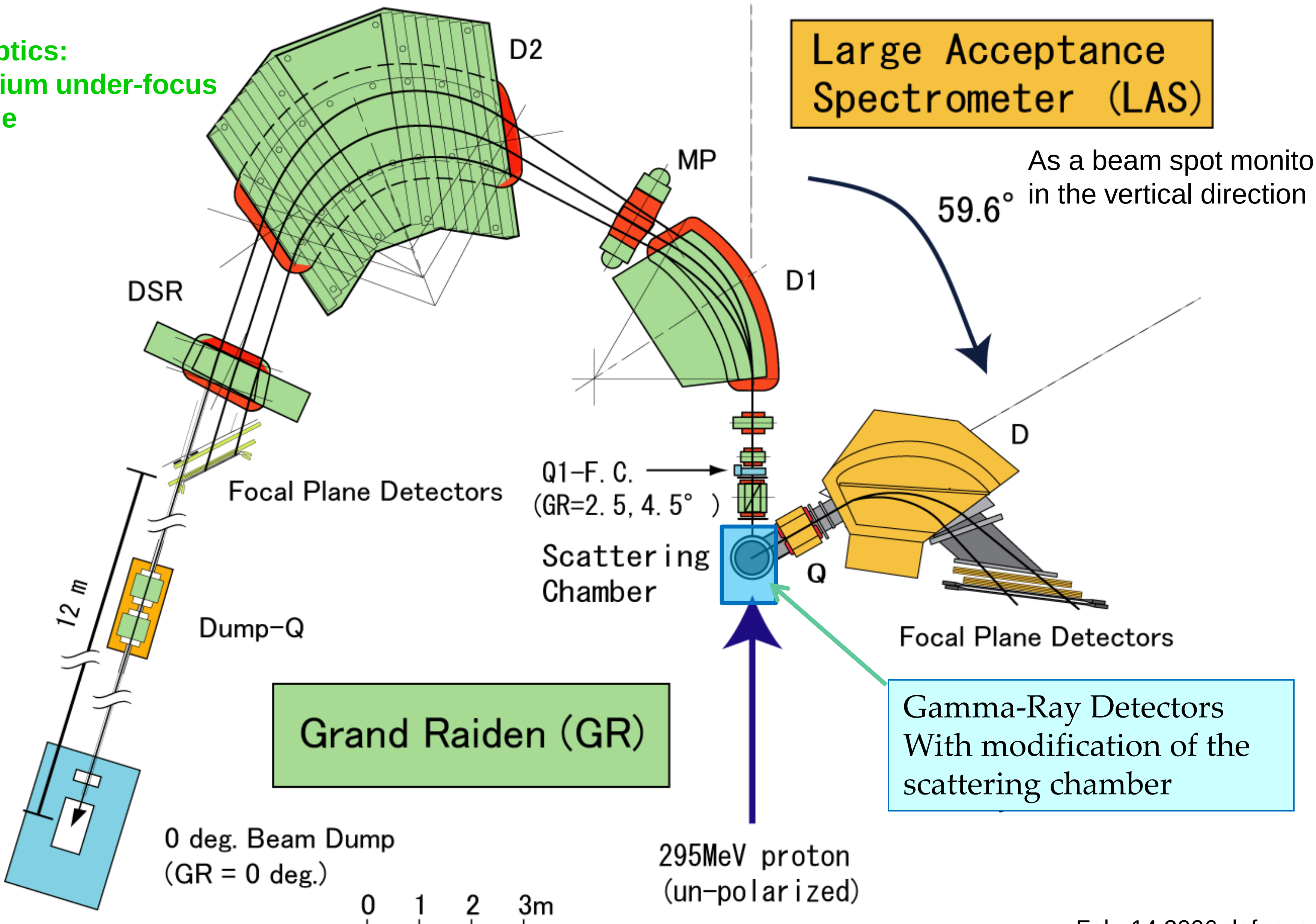




Double Arm Spectrometer

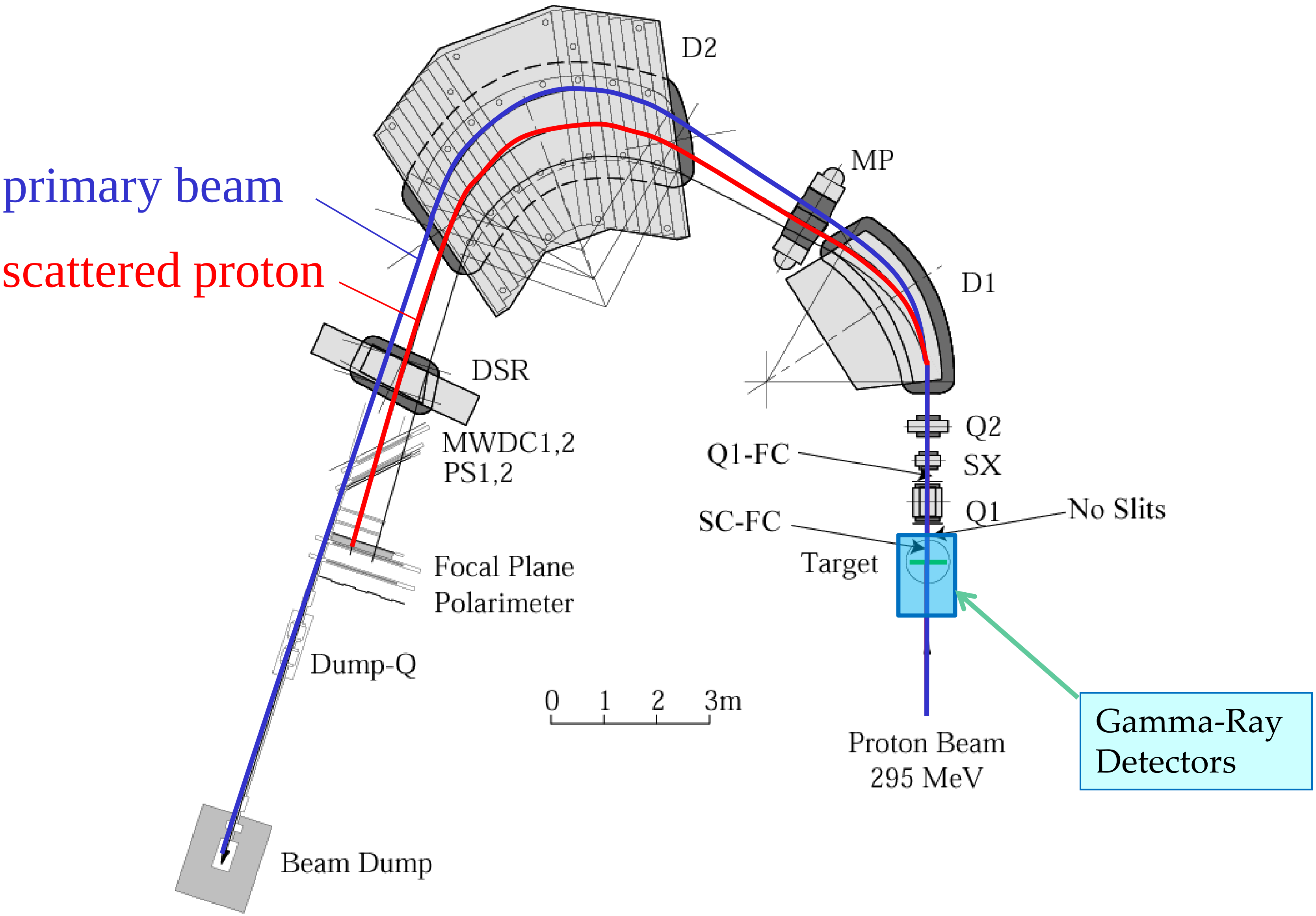
Spectrometers in the 0-deg. experiment setup

Ion optics:
Medium under-focus mode

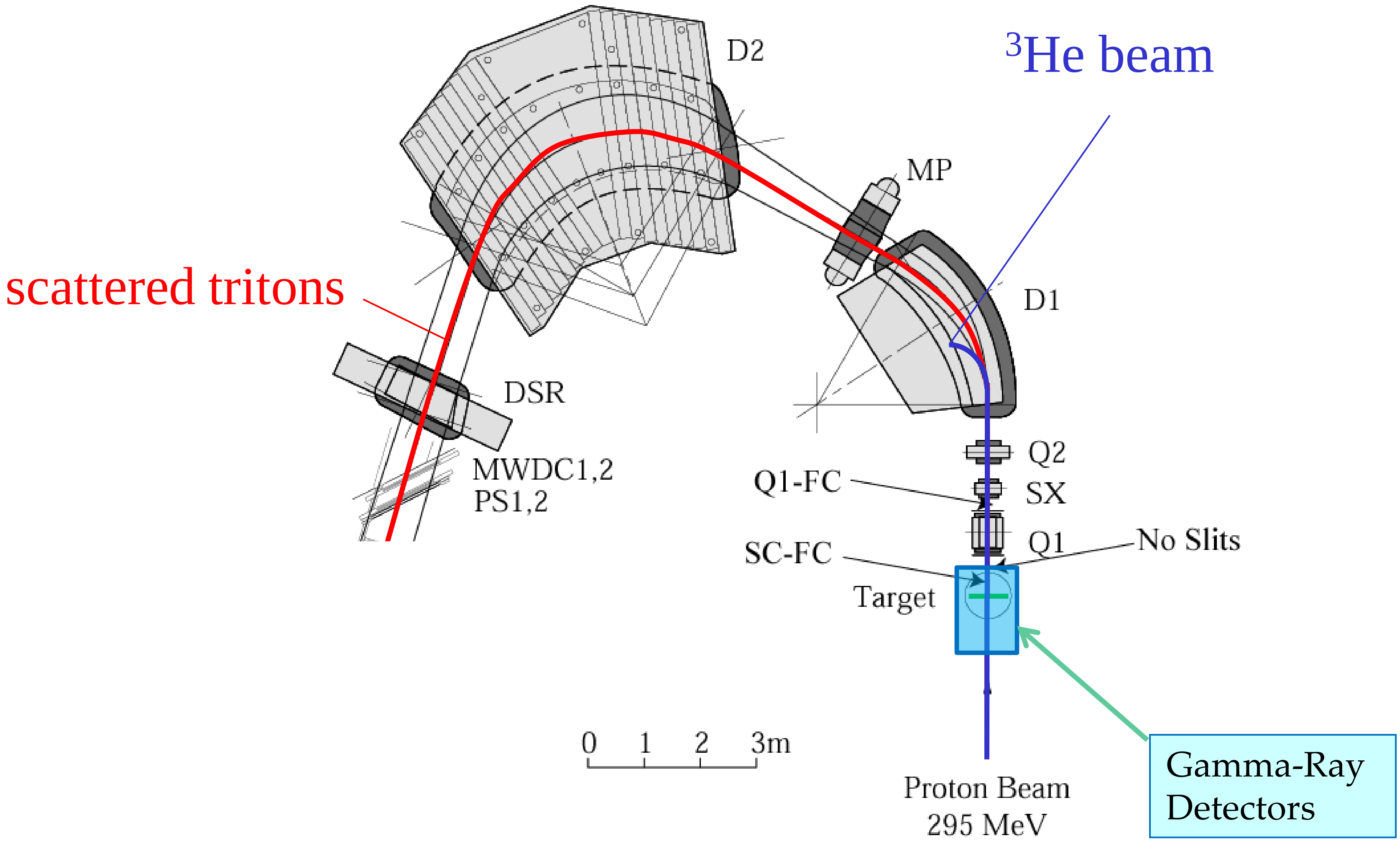


Where to Stop the Beam

Inelastic Scattering at 0 deg

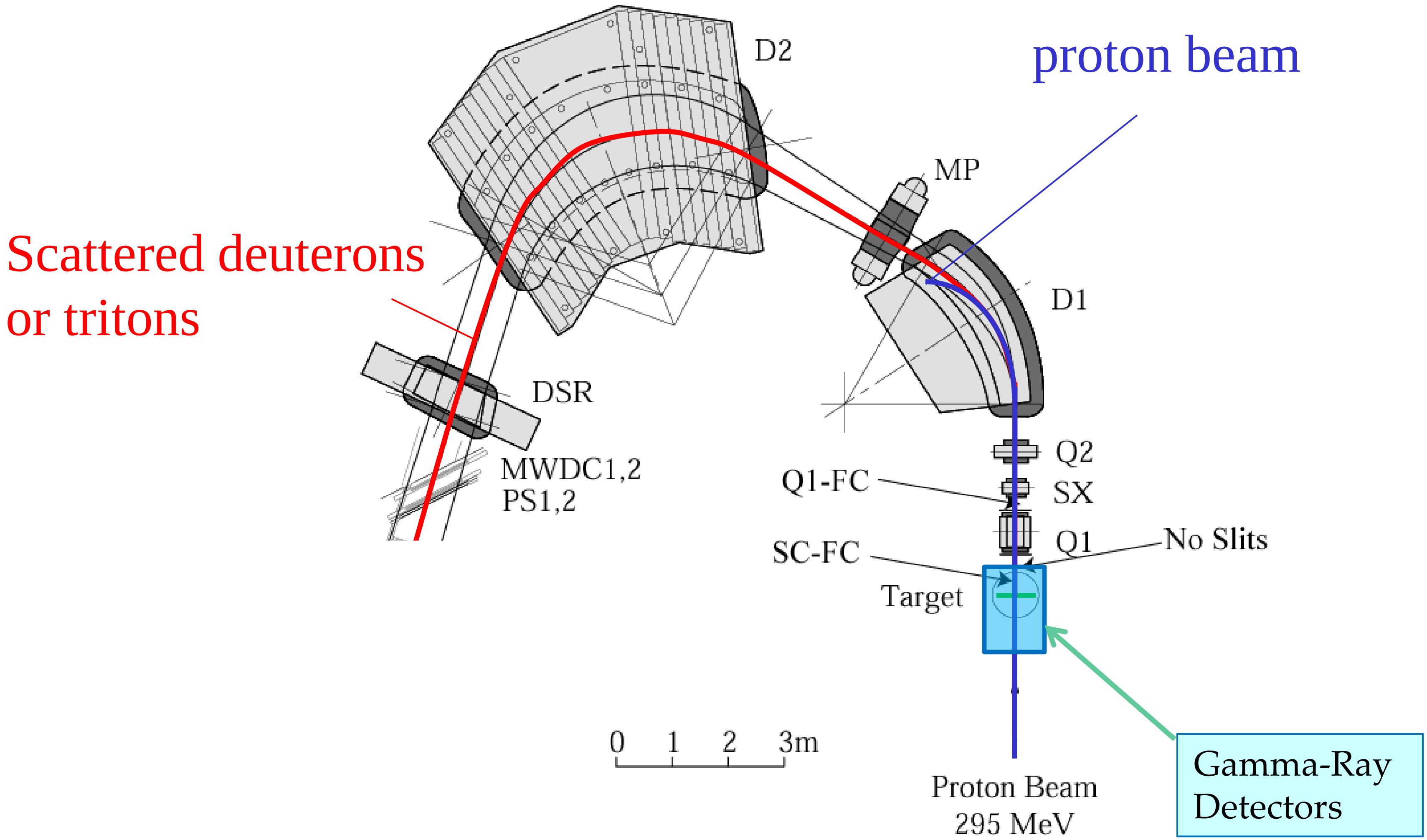


(3He,t) at 0 deg

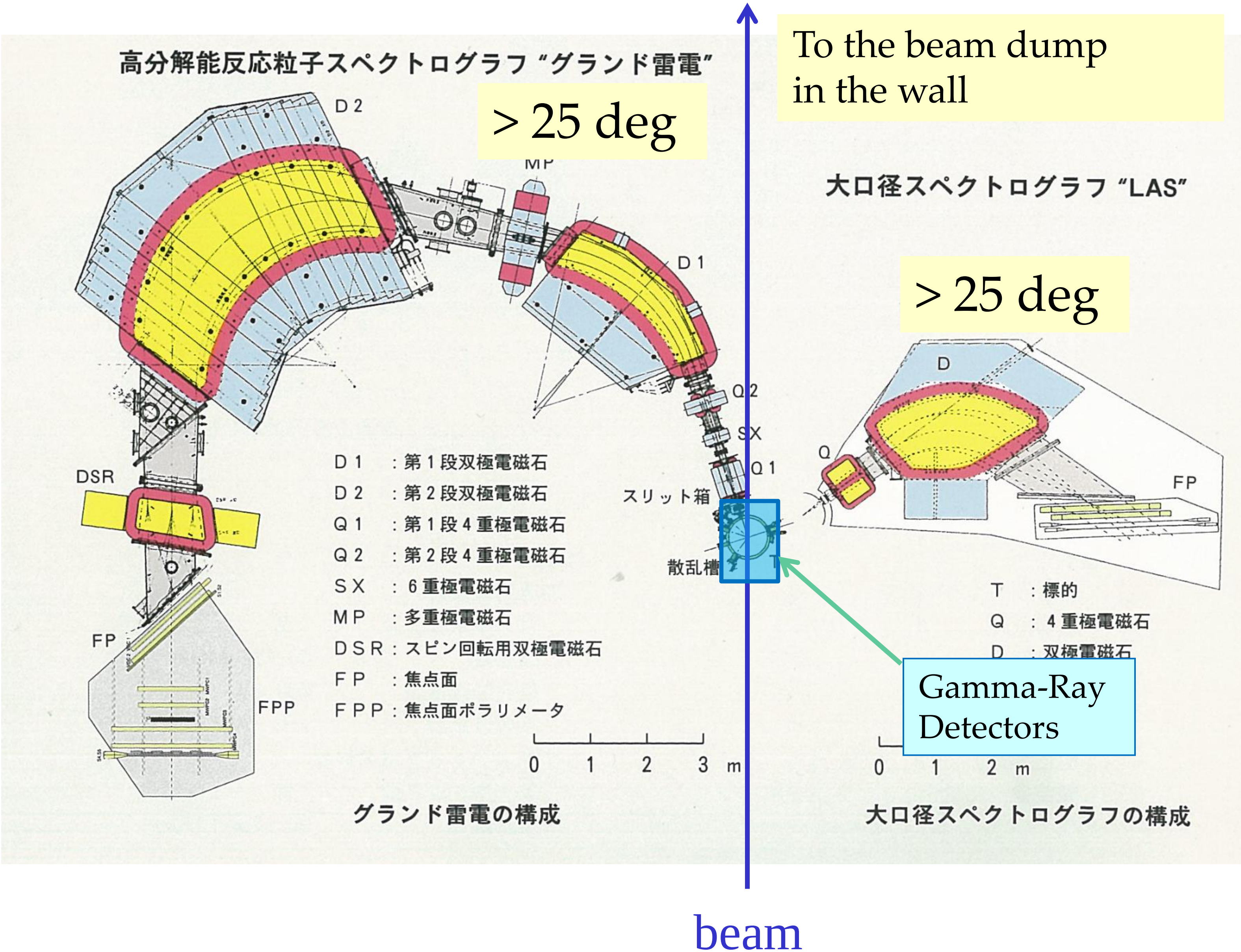


^{3}He beam
scattered tritons
D2
MP
D1
DSR
MWDC1,2
PS1,2
Q2
Q1-FC
SX
Q1
No Slits
SC-FC
Target
0 1 2 3m
Proton Beam
295 MeV
Gamma-Ray
Detectors

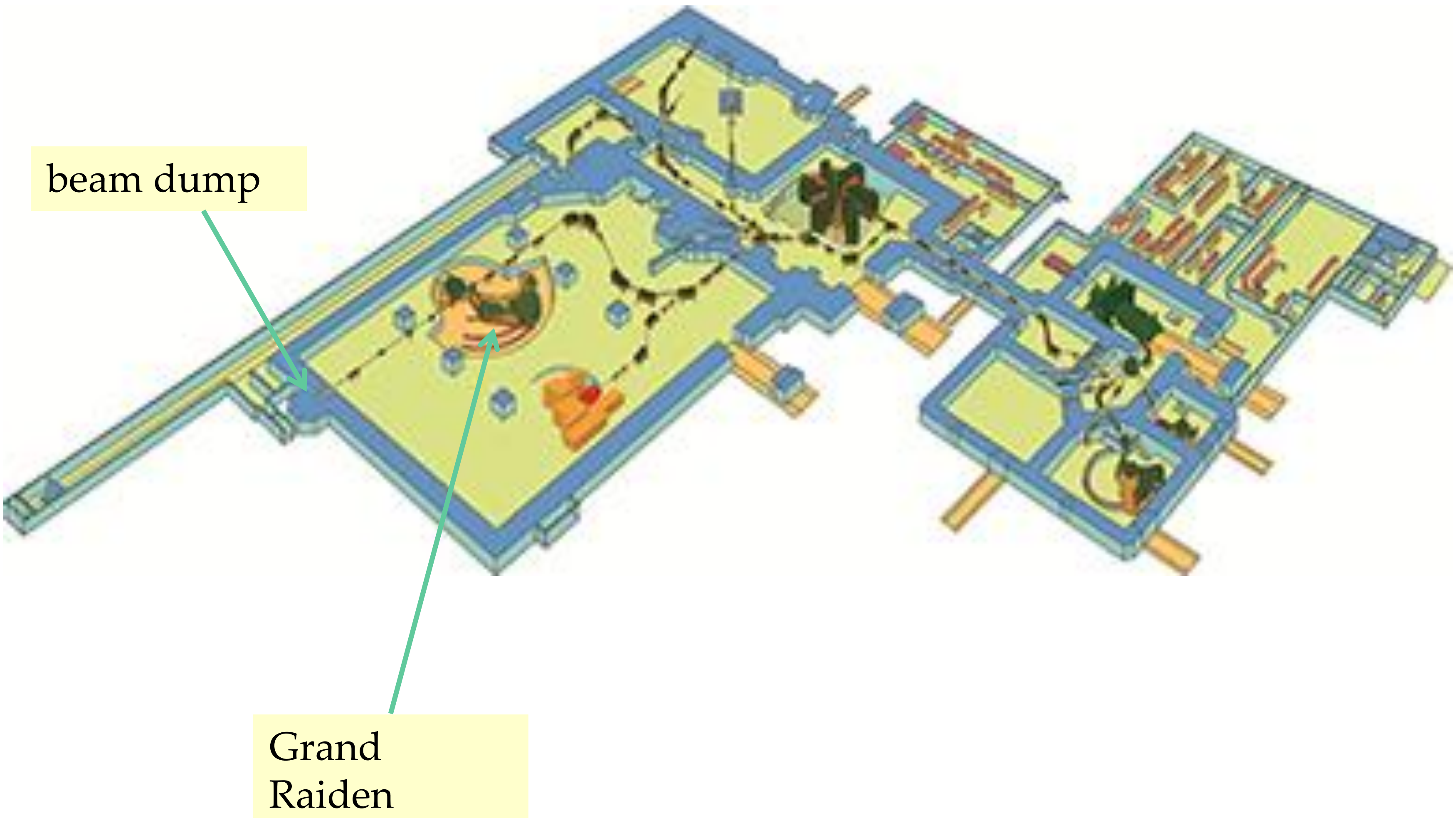
(p,d) or (p,t) at 0 deg



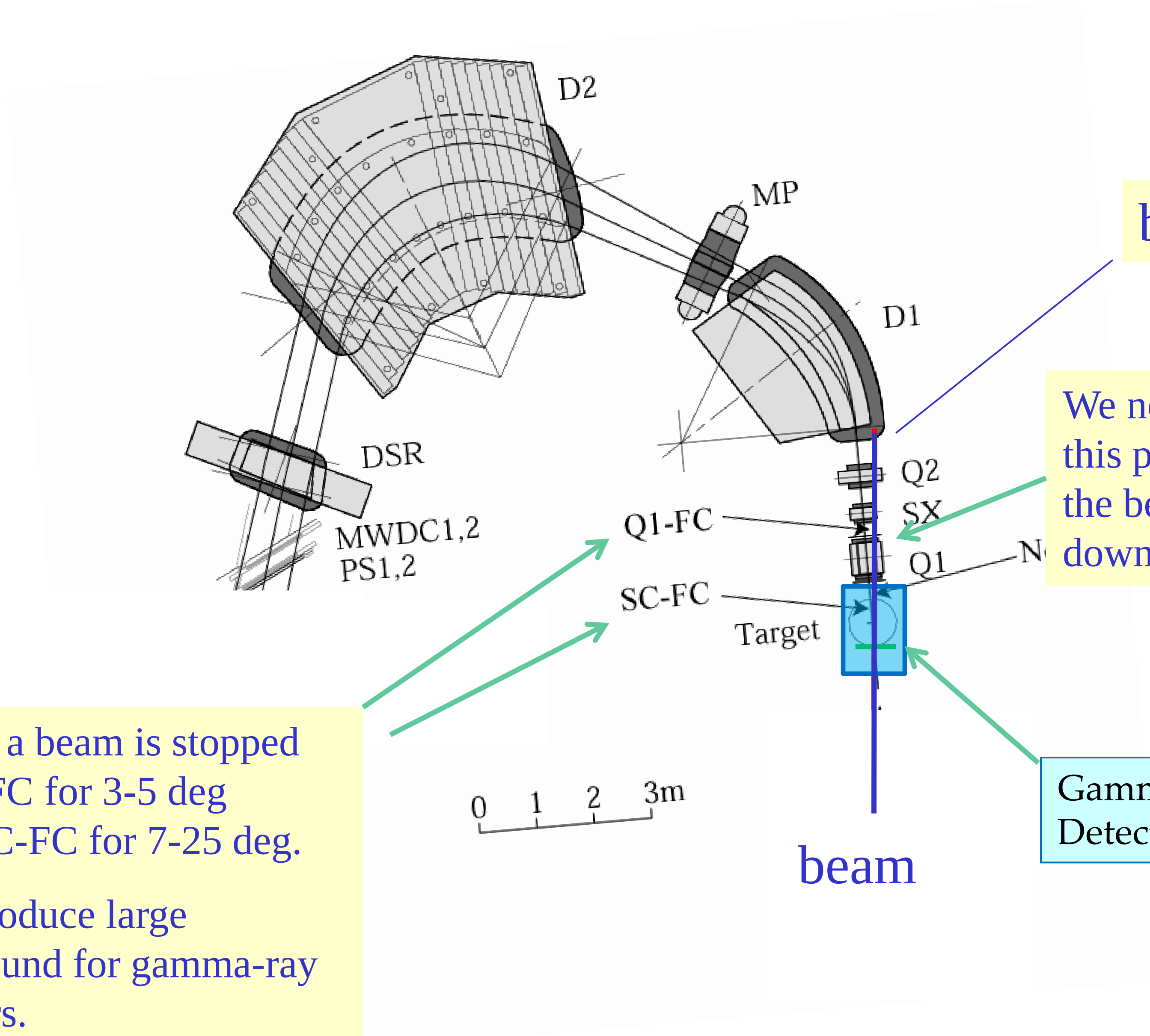
Measurement at angles larger than 25deg



RCNP Cyclotron Facility



Measurement at 5 deg (and 3-25 deg)



beam

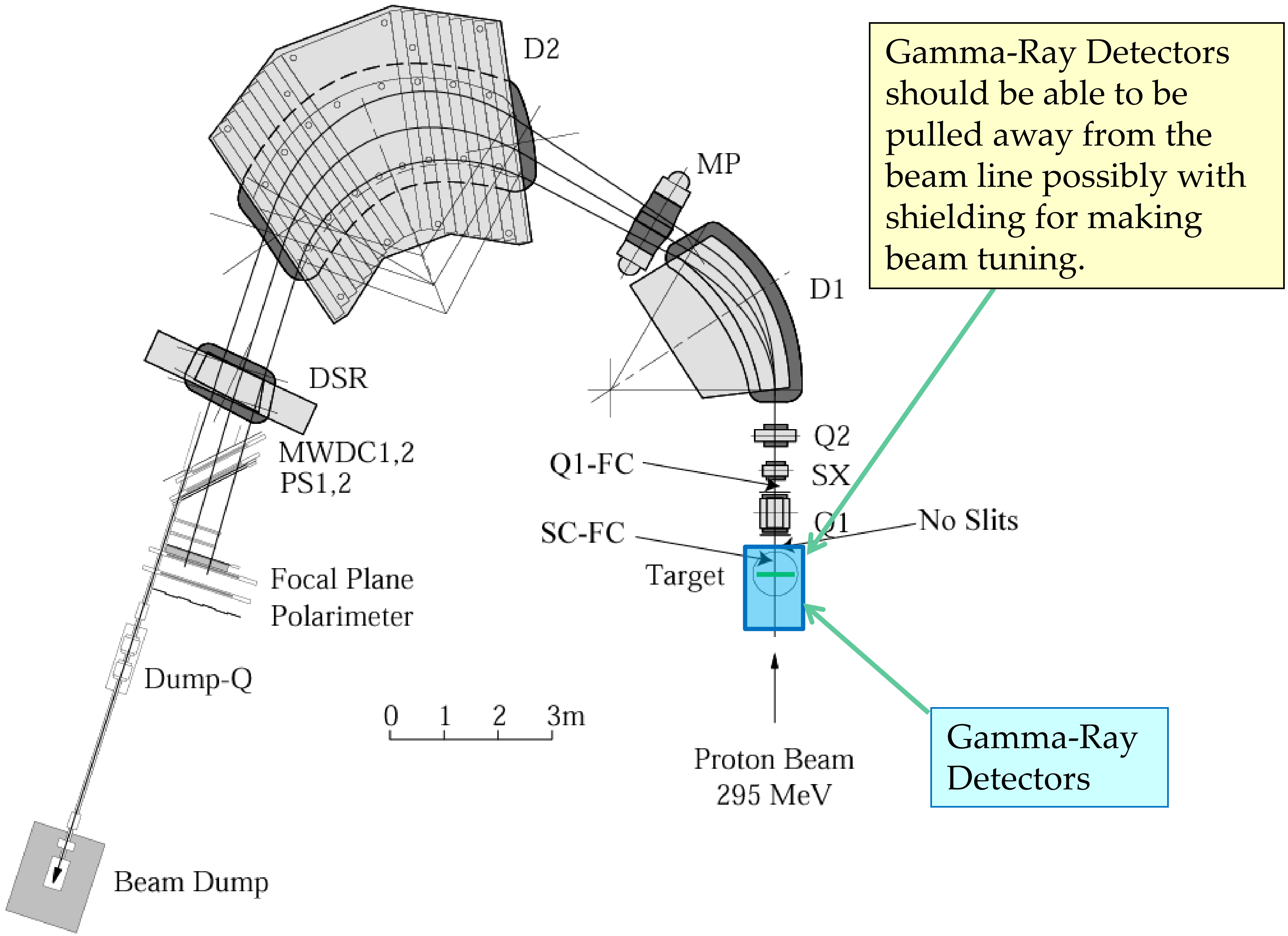
We need to modify this part to transport the beam to further down stream

Usually a beam is stopped by Q1-FC for 3-5 deg or by SC-FC for 7-25 deg.

They produce large background for gamma-ray detectors.

Gamma-Ray Detectors

Gamma-Ray Support System



Research opportunities
Combination of Spectrometer and Gamma-Ray Detectors

(not exclusively by HPGe detectors)

Categories of physics and experimental opportunities

- Study of decay properties of excited states
- Tagging specific excited states by gamma-ray detectors
- Gamma-ray detection as a part of probe for spin-isospin excitations
- Detection of rare gamma-decay
- Higher energy resolution
- Background reduction by coincidence (detection of rare events)
- Spin-parity determination of excited states
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- Life-time measurement
- Excitation of high-spin states with gamma-ray tagging

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Tagging specific excited states by gamma-ray detectors

Study of the Transition Density of the Low-Lying Dipole Strength:

q-dependence, surface nature, and neutron nature

→ Talk by Hashimoto

<u>(p,p'γ) measurement:</u>

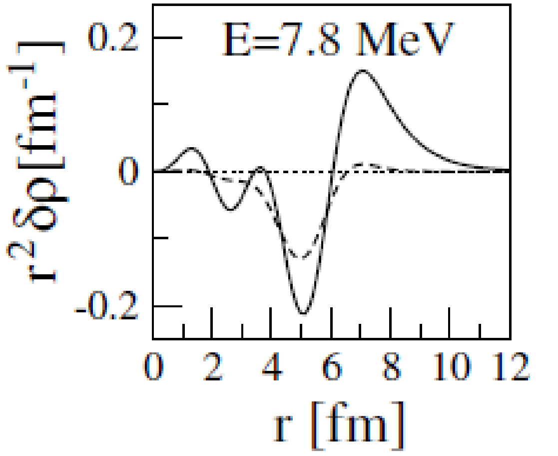
γ detection by HPGe for tagging each E1 excitation.

Measure angular distribution of the (p,p') excitation at angles where the nuclear excitation contributes. (~100 MeV/U? single step dominant, but lower Coulomb Ex.)

<u>(^{3}He,^{3}He'γ) measurement:</u>

Same as above.

^{3}He is more sensitive to the surface transition.



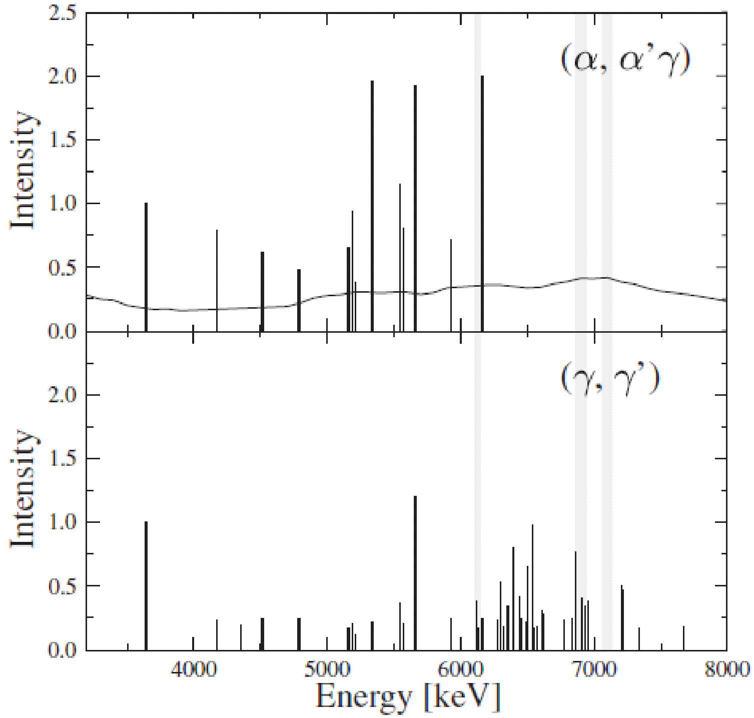
<u>(t,t'γ) ⇔ (3He,3He'g) comparison</u>

Same as above.

Neutron nature of the surface transition density can be studied by the difference.

D. Savran, PRL97, 172502(2006)

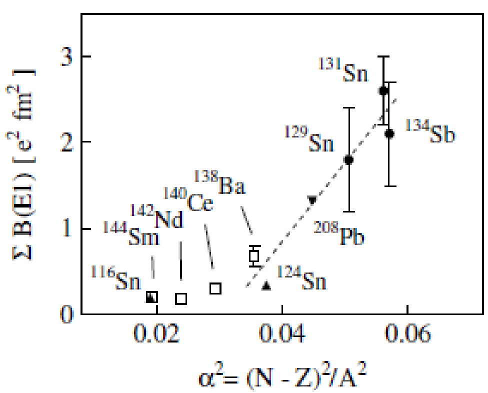
(α,α’γ) at KVI



←ΔT=0 Excitation

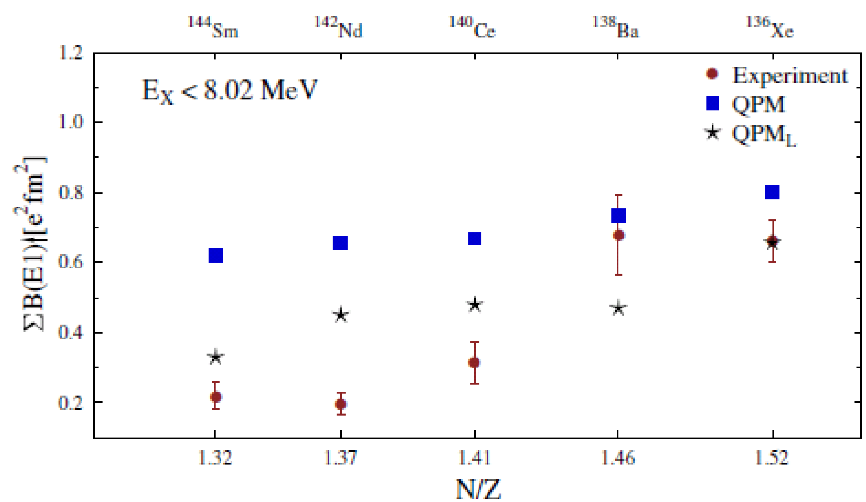
Study of PDR Isospin Structure

←ΔT=0,1 Excitation



D. Savran, PRL100, 232501(2008)

(γ,γ’)



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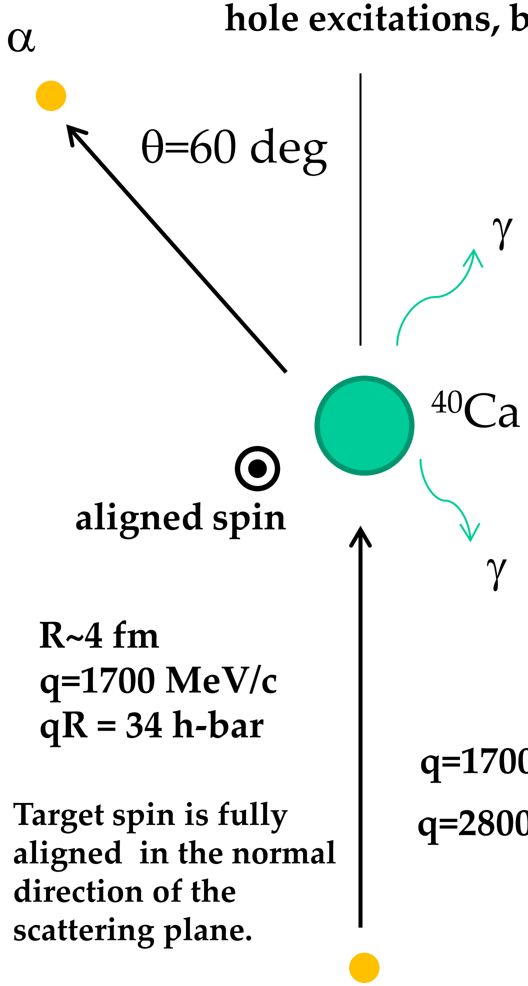
Excitation of high-spin states with gamma-ray tagging

Direct reaction usually doesn't favor many-particle many-hole excitations, but still it might have sizable cross section.



R~4 fm
q=1700 MeV/c
qR = 34 h-bar

Target spin is fully aligned in the normal direction of the scattering plane.

α at 100 MeV/U
(or p or HI)

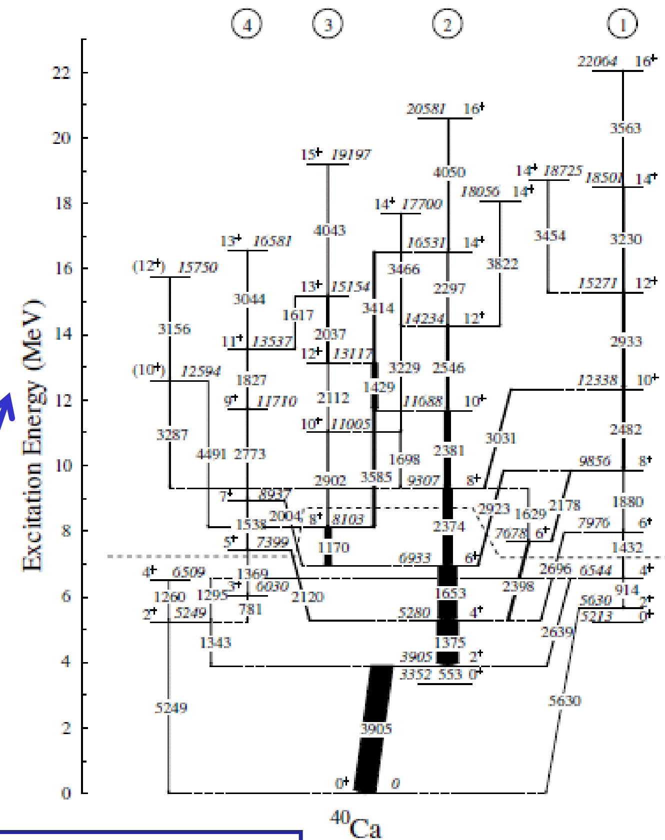
- **Spin parity assignment of low-lying states. (excitation and decay)**
- **Isospin determination**
- **Excited states above the yrast line**
- **Transition strength from the ground state**

also

- **Life-time measurement with Doppler shift attenuation?**

q=1700 MeV/c, β=0.05 at 60 deg

q=2800 MeV/c, β=0.08 at 120 deg



Excitation of high-spin states from the ground state

E. Ideguchi et al., PRL87,222501(2001)

Detection of large angle ion scattering (for high-q) with gamma-ray detection.

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Gamma-ray detection as a part of probe for spin-isospin excitations

(^{6}Li,^{6}Li′γ) measurement:

Probing Isovector Spin-Flip Inelastic Excitations

^{6}Li(0^{+},T=1; 3.563 MeV)

SDR for neutrino process

(^{14}C,^{14}C′γ) measurement:

Parity Transfer Inelastic Reaction ^{14}C(0^{-};6.903 MeV)

0^{-} state search

unnatural parity states

cf. (^{7}Li, ^{7}Beγ) with GSO detector, Nakayama et al.,
Isovector spin-flip/spin-non-flip excitations

^{7}Li($1/2^{-}$; 477 keV)

Research opportunities
Combination of Spectrometer and Gamma-Ray Detectors

(not exclusively by HPGe detectors)

Categories of physics and experimental opportunities

- Study of decay properties of excited states
- Tagging specific excited states by gamma-ray detectors
- Gamma-ray detection as a part of probe for spin-isospin excitations
- Detection of rare gamma-decay
- Higher energy resolution
- Background reduction by coincidence
  detection of rare gamma decay events
- Spin-parity determination of excited states
- Study of reaction mechanism
- Life-time measurement
- Excitation of high-spin states with gamma-ray tagging

Detection of rare gamma-decay

e.g.

Gamma-decay branching ratio of giant resonances

Fundamental properties of the giant resonances

Fine structure

Background process in the Kamiokande/Kamland neutrino detector

Gamma decay of 12C excited states (→ talk by Hashimoto)

Carbon synthesis in supernovae

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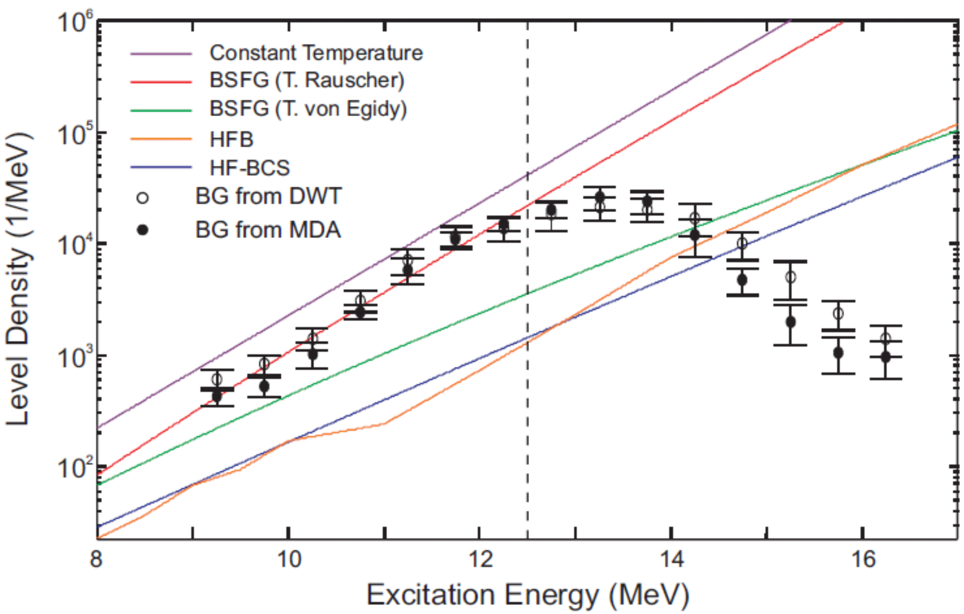
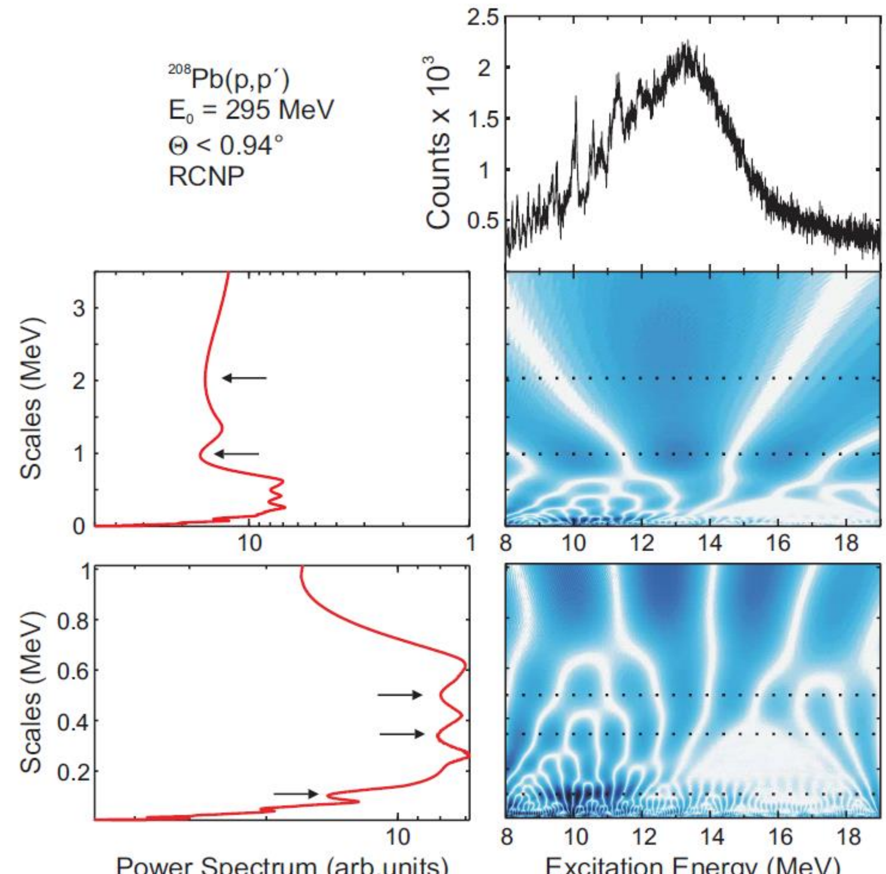
Level density, auto-correlation, wavelet analysis

Experimental limit due to resolution

Resolution: 25 keV





Higher resolution for extracting higher level density!

I. Poltoratska, PhD thesis, 2011

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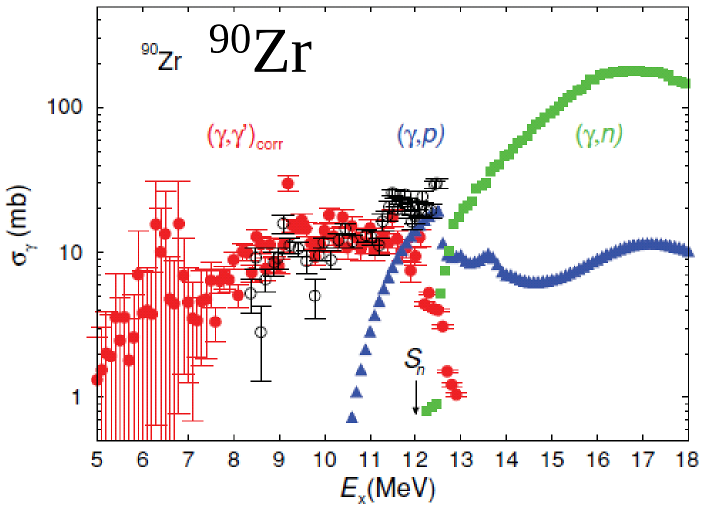
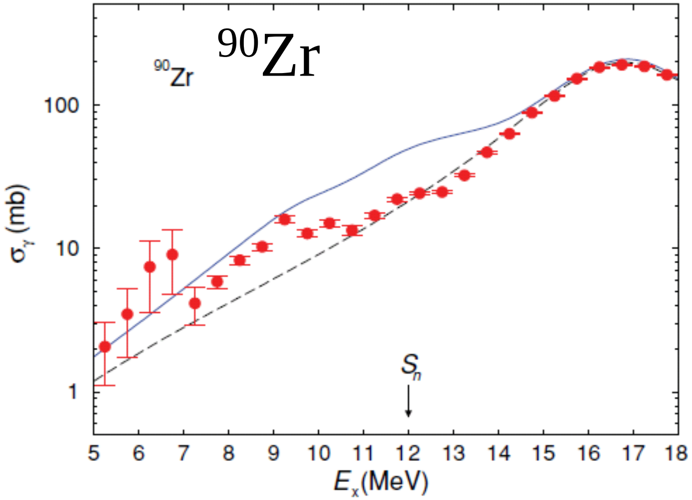
Decay property

R. Schwengner et al., PRC78, 064314(2008)





Bremsstrahlung Gamma ray

Only (single) gamma ray is measured

Correction of cascade decay is necessary for reconstructing the B(E1) distribution.

(TALYS)

Also for gamma-strength function study at Oslo

Thank you