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Feb. 2003

Nuclear-structure studies with fast exotic beams

Tohru Motobayashi (RIKEN)

Ring Cyclotron (1987) + RIPS (~1990) - RIKEN

fast exotic beam or RI beam by projectile fragmentation

v/c ~ 0.3 (40-90 MeV/nucleon)

c.f. RIBF => 200-300 MeV/nucleon, wide range of nucl.

“In-beam” γ- and particle spectroscopy

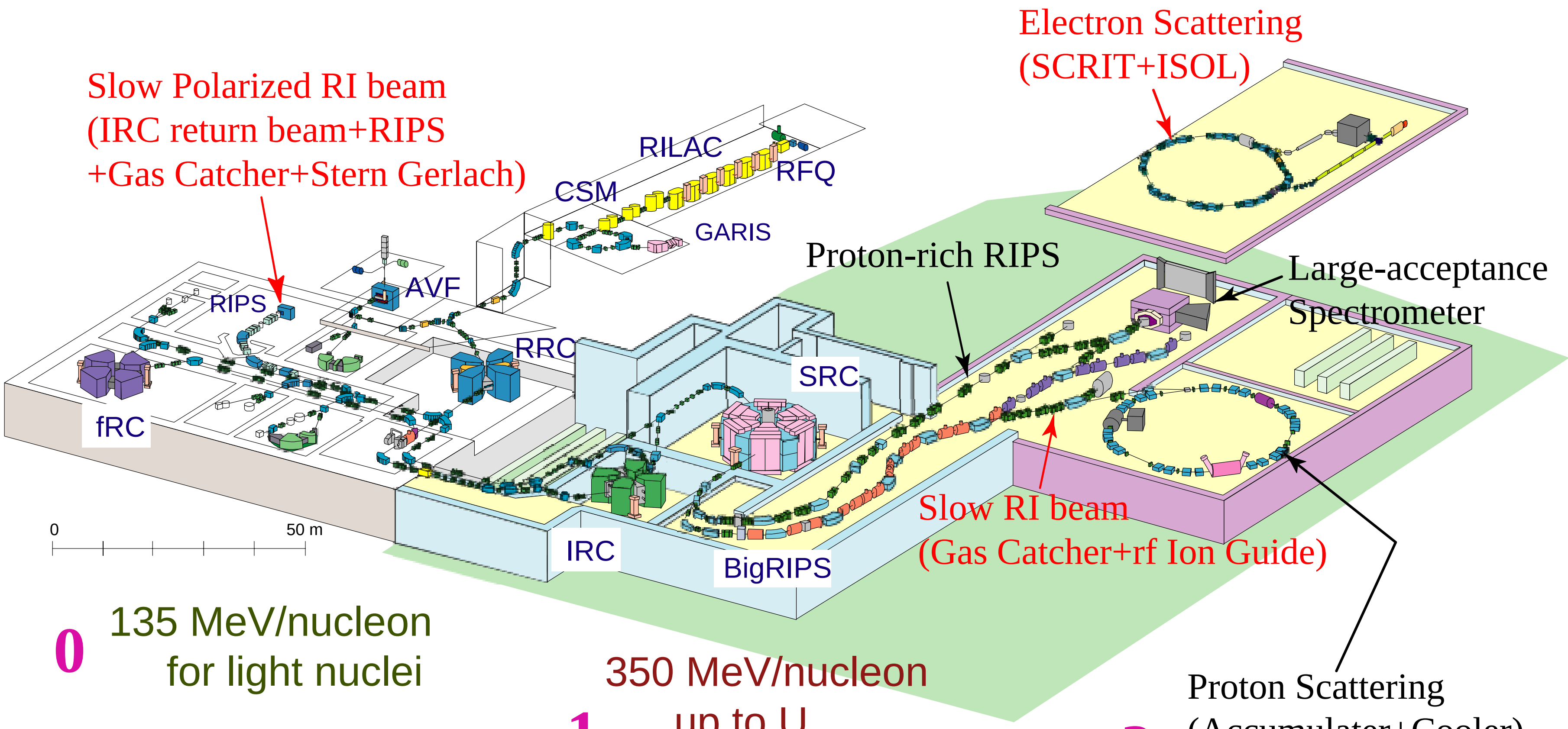
=> nuclear structure of unstable nuclei

magicity loss in n-rich nuclei with *N*=8, 20

=> reactions involved in (explosive) nuclear burning

solar neutrino production, novae burning

RIKEN Accelerator Research Facility
and RI Beam Factory Project



0 135 MeV/nucleon
for light nuclei

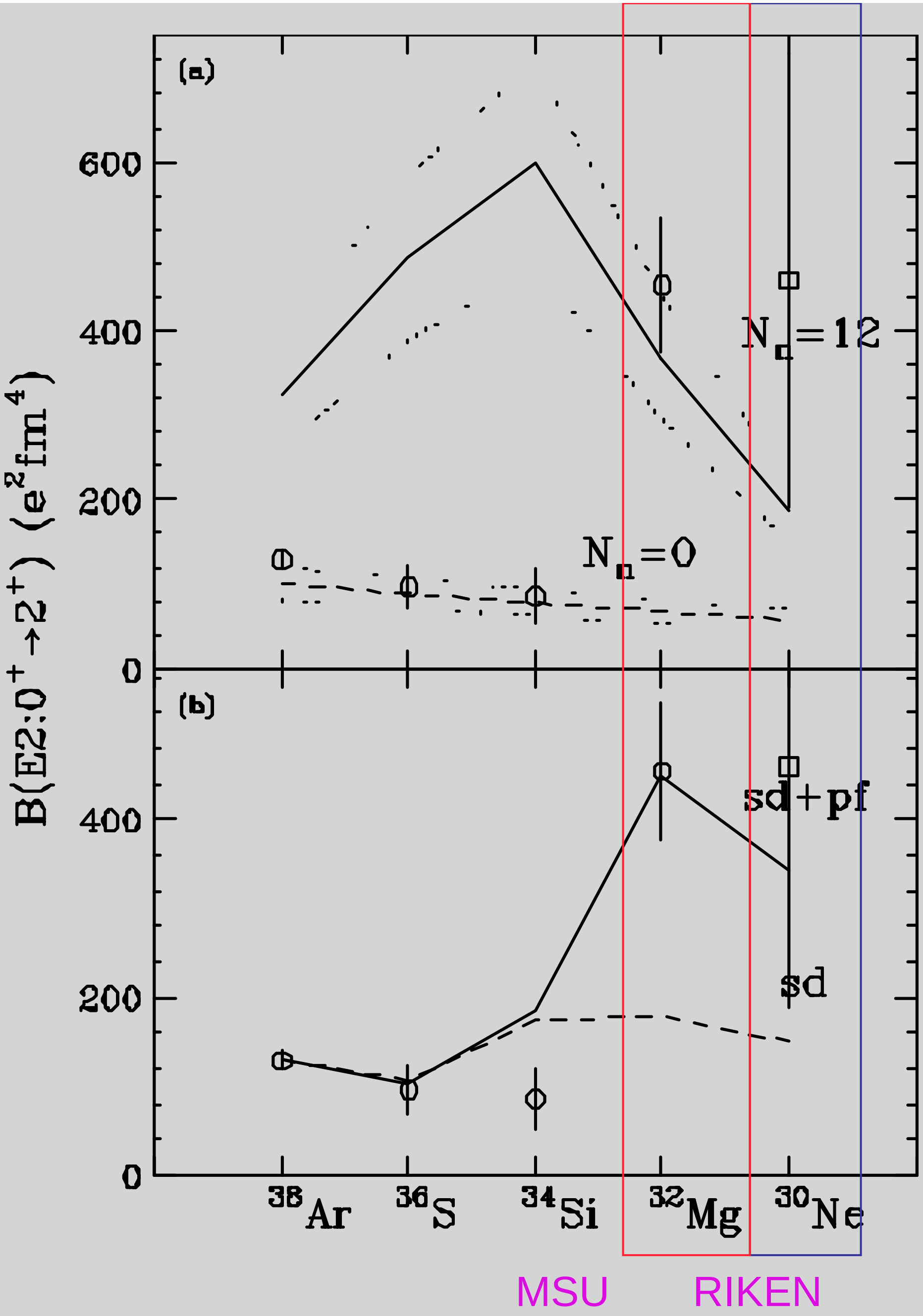
1 350 MeV/nucleon
up to U
1st beam in 2006

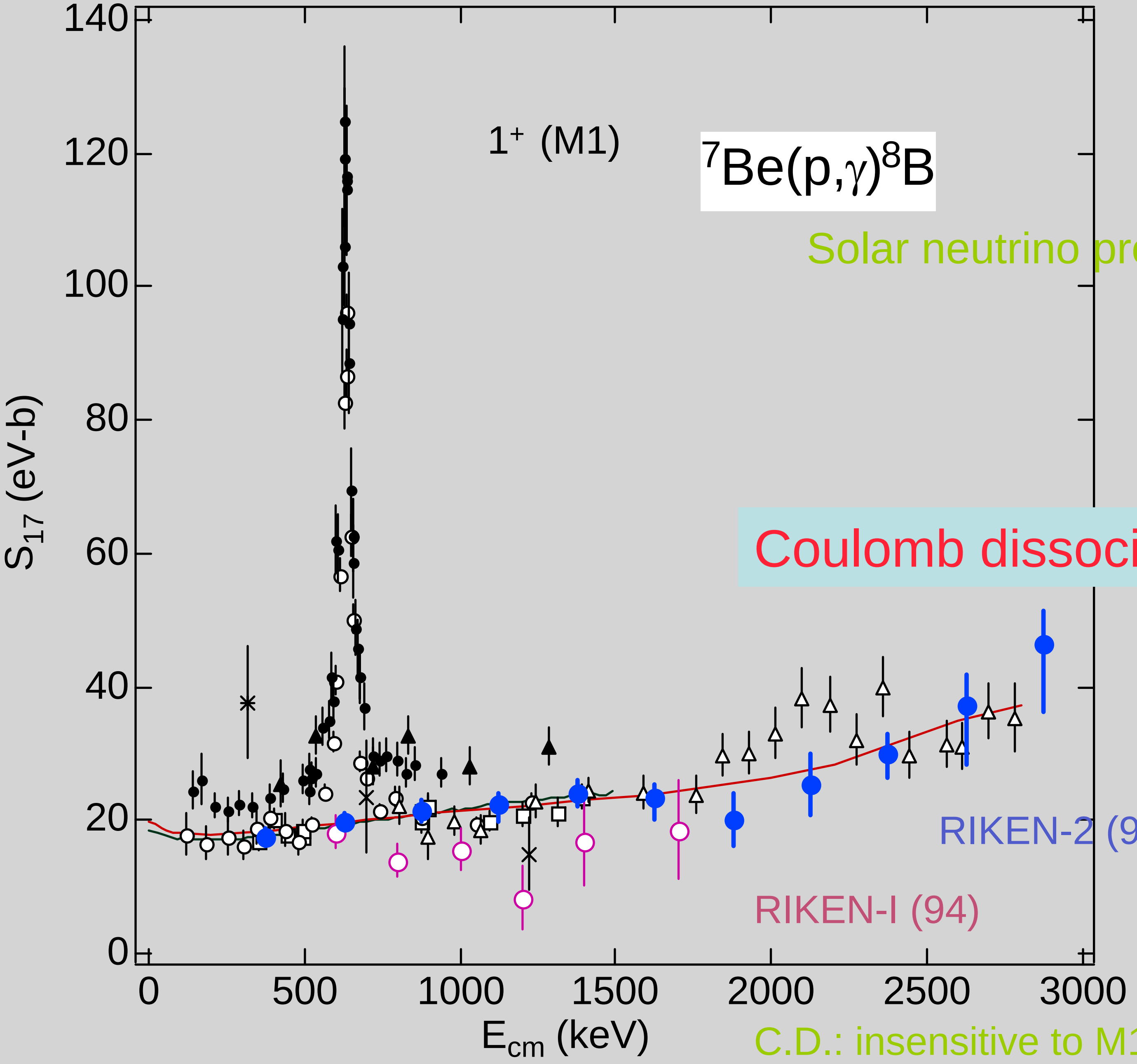
2 under consideration

Coulomb excitation of N = 20 nuclei

↓

Disappearance of the sd-pf shell gap for ^{32}Mg and ^{30}Ne





$^7Be(p,\gamma)^8B$

Solar neutrino production

Coulomb dissociation of ^8B

C.D.: insensitive to M1 resonance

How can we study nuclear structures with fast Radio-isotope (RI) beams ?

1) Direct reactions for nuclear-structure studies

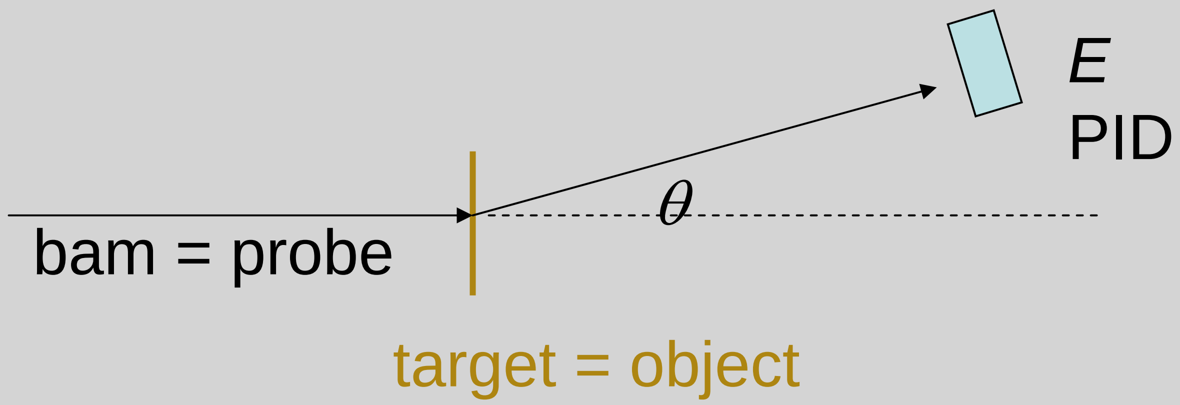
2) RI beams of fragmentation scheme

3) Inverse kinematics

4) Two methods of spectroscopy
   Doppler-shifted g-rays
   Particle decays from unbound states

5) Some examples

direct reaction => nuclear structure information



examples: (p,p'), (d,p), …

reaction channel: PID of ejectile

excited level: *E* (θ)

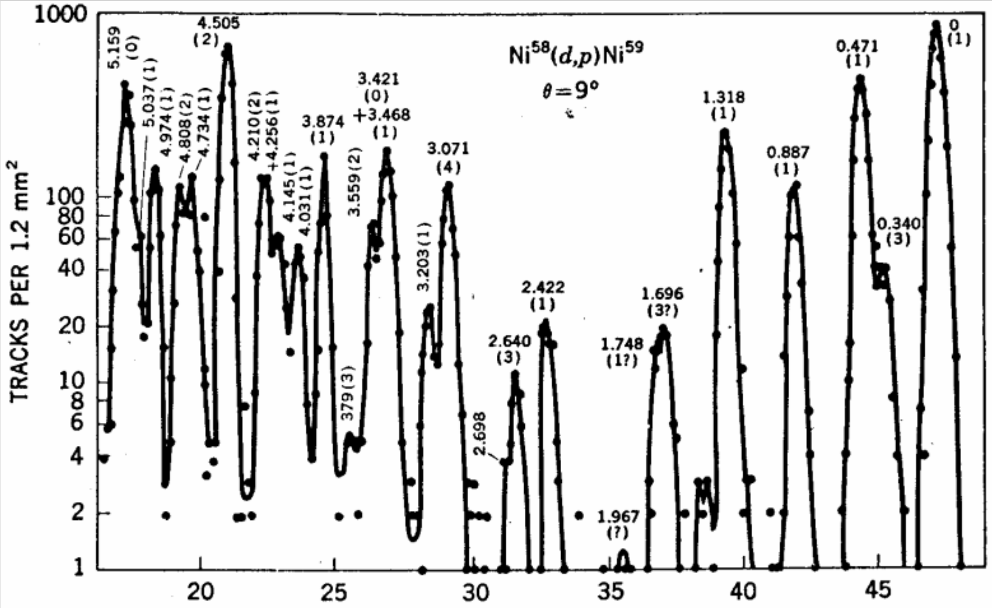
cross section => deformation

single particle strength

angular distribution => angular momentum

↑

direct (first-order) mechanism

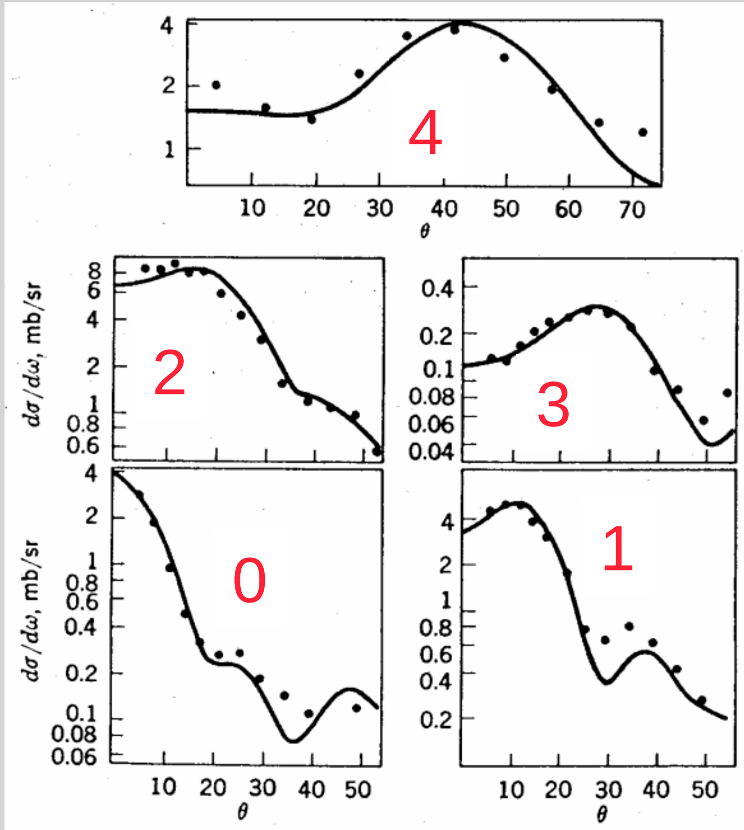


distance along the focal plane (momentum)

^{58}Ni(d,p)^{59}Ni

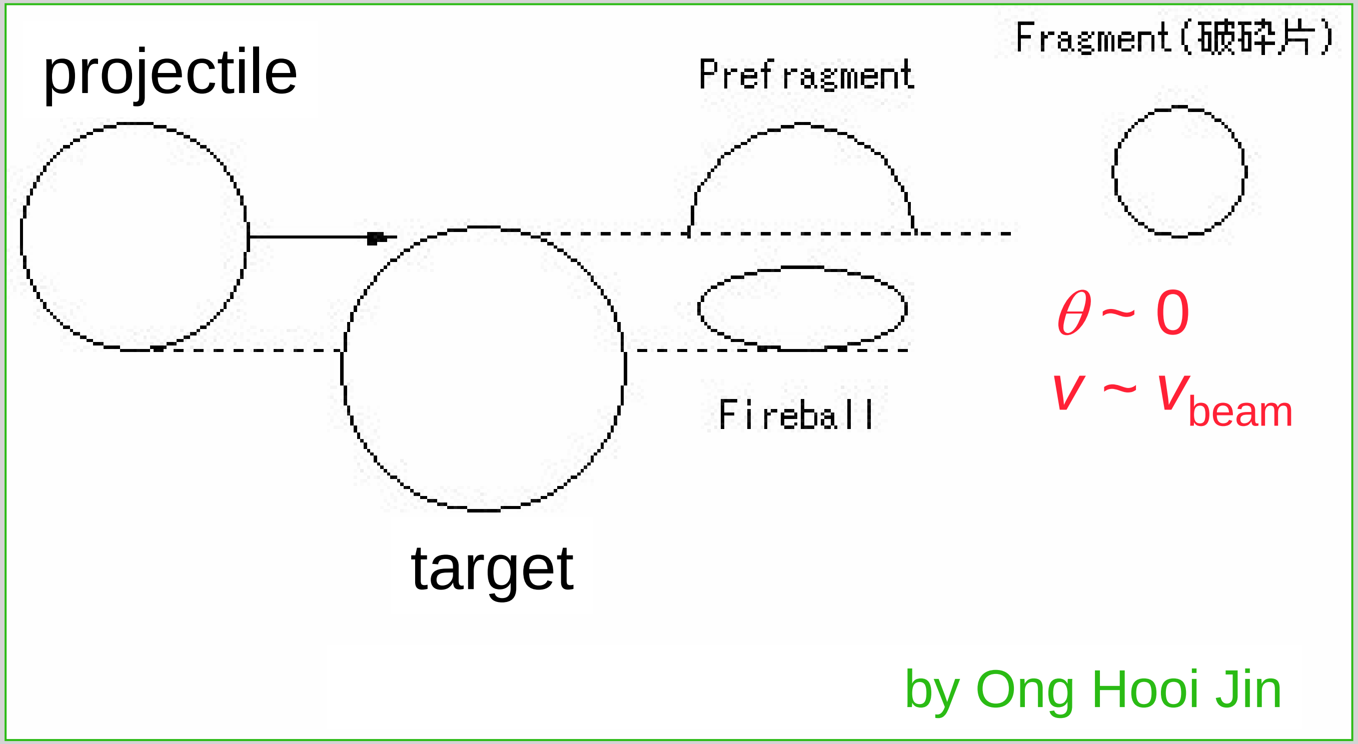
E =15 MeV

(1962)



l - dependence of angular distribution

projectile fragmentation



wide range of (unstable) nuclei
regardless of chemical properties

E > 50 MeV/nucleon

inverse kinematics / methods of spectroscopy

RI (beam) + target (probe)

-----> projectile-like products

γ decays (bound)

particle decays (unbound)

------> target-like products

recoil particles

target-γ

reaction-channel ID: PID of the projectile-like product

state ID: γ ray (Doppler-shifted)

invariant mass

reaction: inelastic (Couex, C.D., (p,p') …

cex, fratmentation, knockout

transfer

Advantage / disadvantage of fast RI beams

poor (intensity)

0.1 - 10^5 pps ← efficient setups, good reactions (large σ)

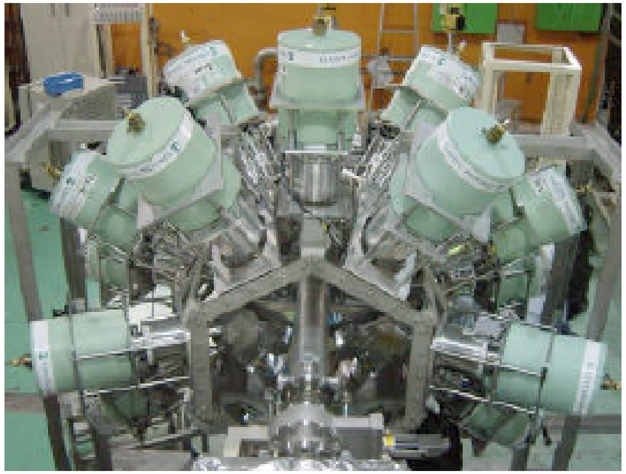
dirty (emittance)

2cm ϕ, 1~2 deg. Spread ← γ-ray measurement, invariant mass

high energy → thick targets, forward focusing

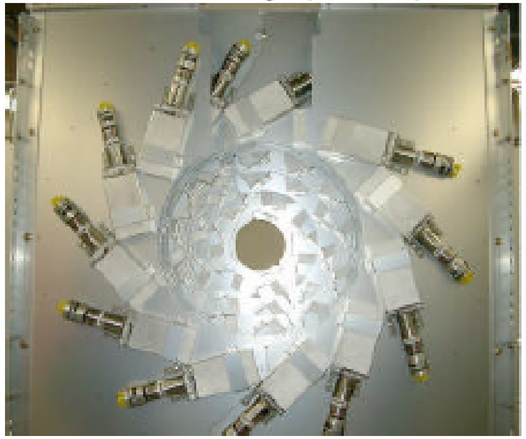
Detector arrays

Ge Array (720ch)

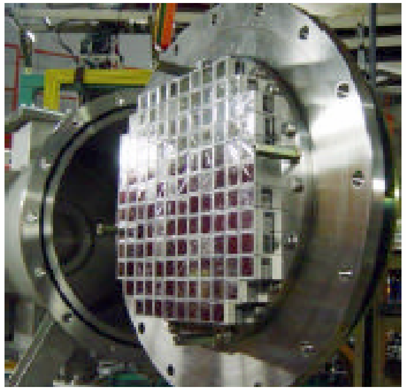


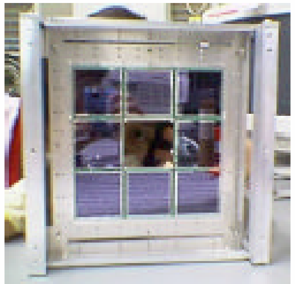
Neutron wall (~500ch)

NaI Array (320ch)



NaI Wall(264ch)

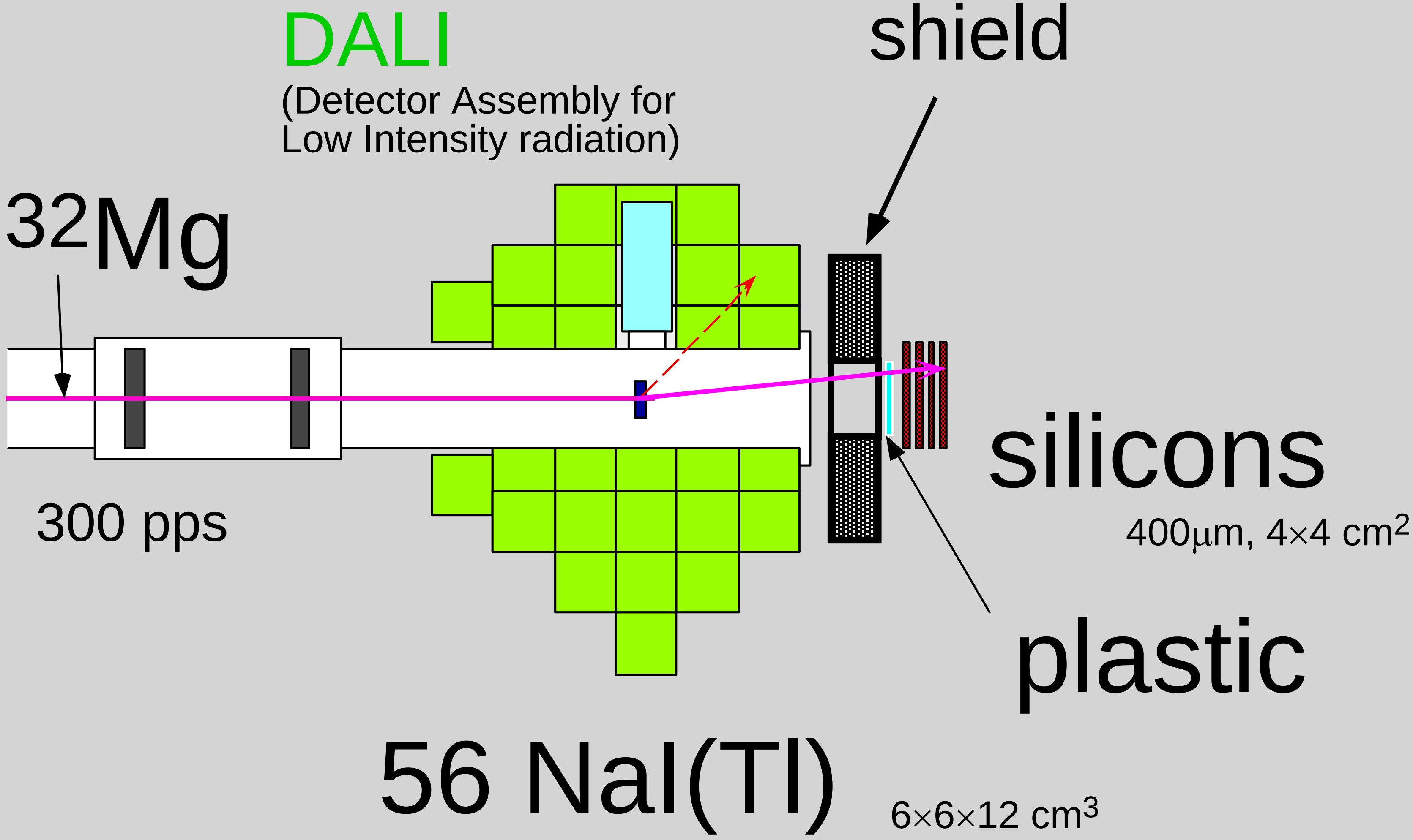




Stripped SSD
(120 → 300?ch)

HODO Scope (168ch)

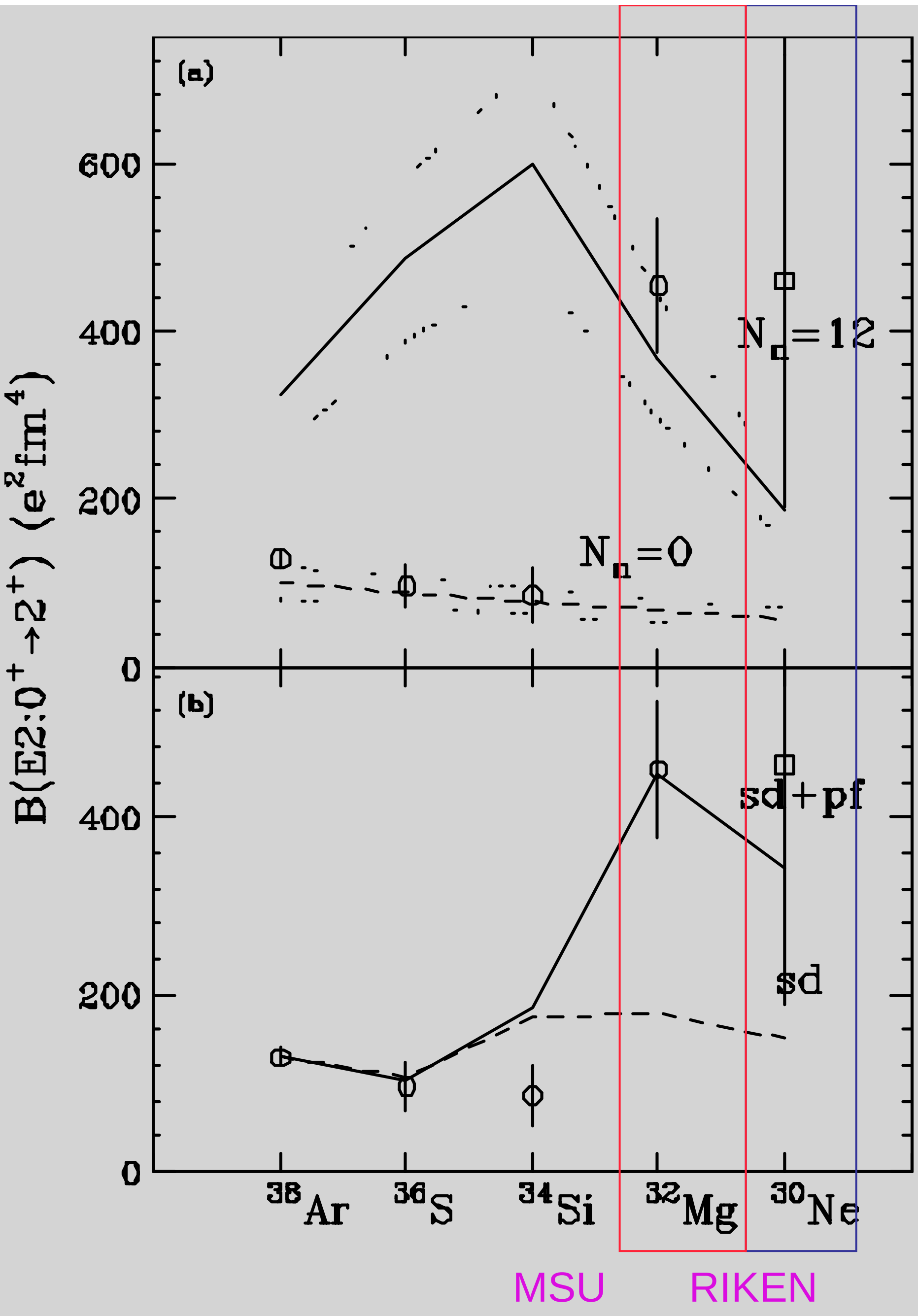
CsI ball (320ch?)


DALI
(Detector Assembly for
Low Intensity radiation)
shield
32Mg
300 pps
silicons
400μm, 4×4 cm2
plastic
56 NaI(Tl)
6×6×12 cm3

Coulomb excitation of N = 20 nuclei

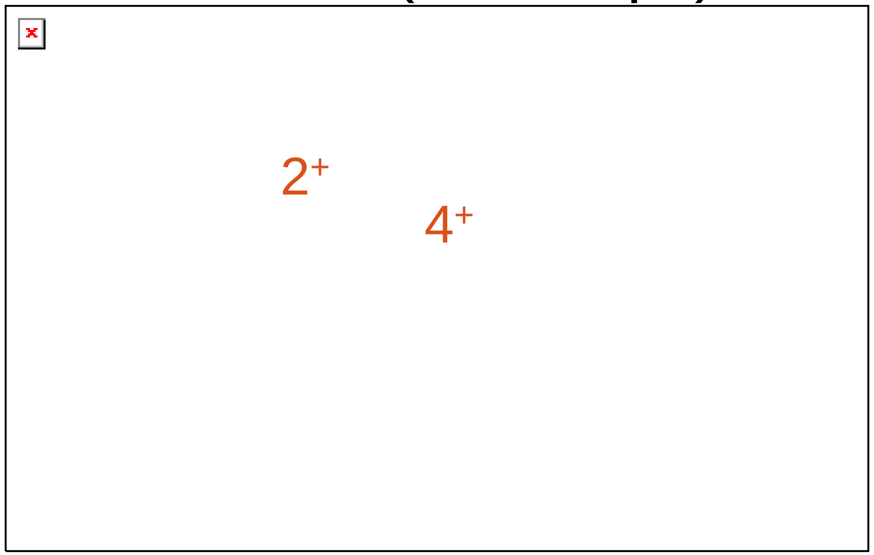
↓

Disappearance of the sd-pf shell gap for ^{32}Mg and ^{30}Ne



Locations of 2^+ / 4^+ states of n-rich around N=20
- “Island of inversion” -

^{34}Mg (Z=12, N=22)
Fragmentation
of ^{36}Si (2x10^4 cps)



Yoneda *et al.*, Phys. Lett. B566 (2003)84

^{30}Ne (Z=10, N=20)
proton inelastic
^{30}Ne (0.2 cps)

2^+

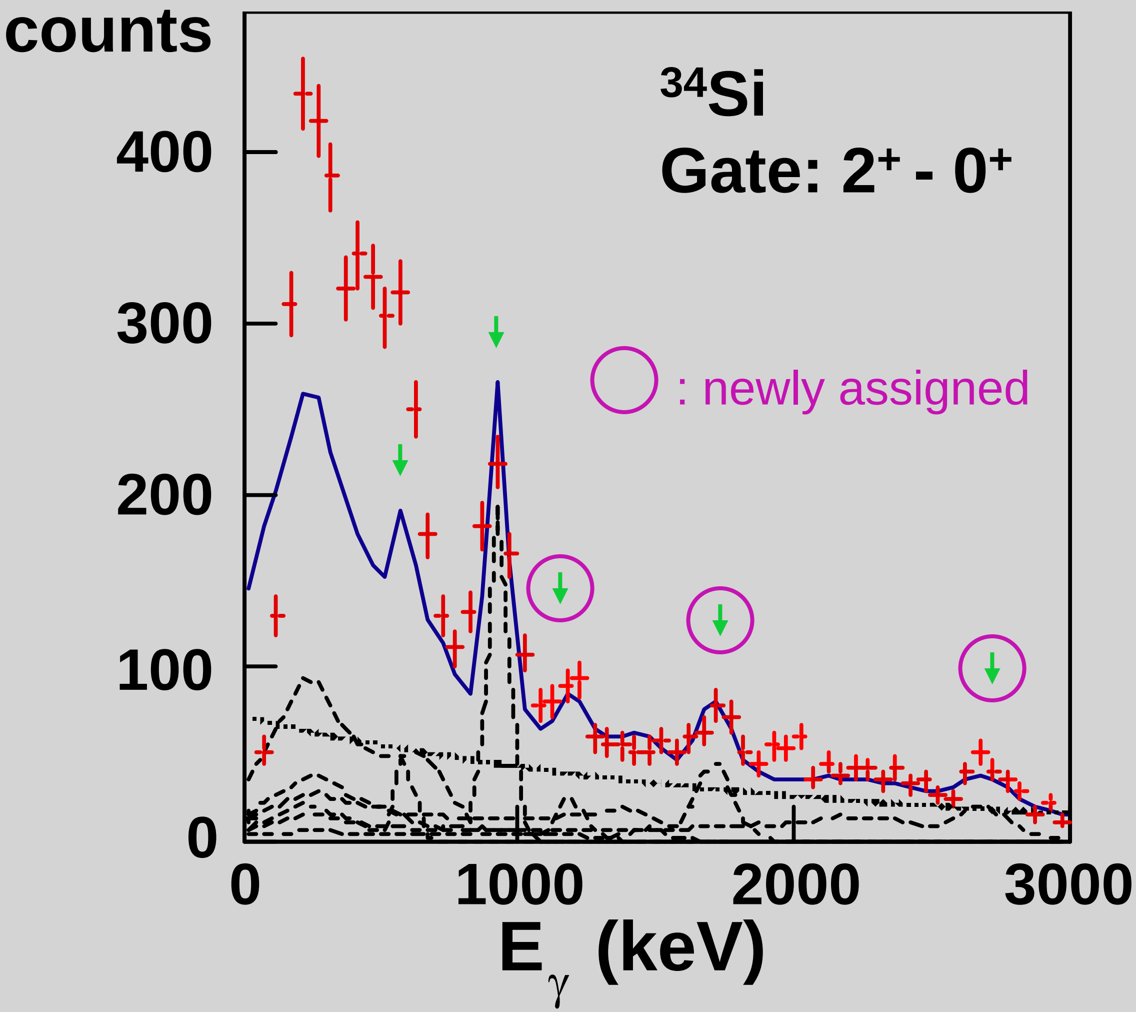
Yanagisawa *et al.*, Phys. Lett. B566 (2003)84

$^{34}Si + ^{2}H \rightarrow ^{34}\underline{Si} + \gamma + X$

(2x10^4 cps)

(Z=14, N=20)

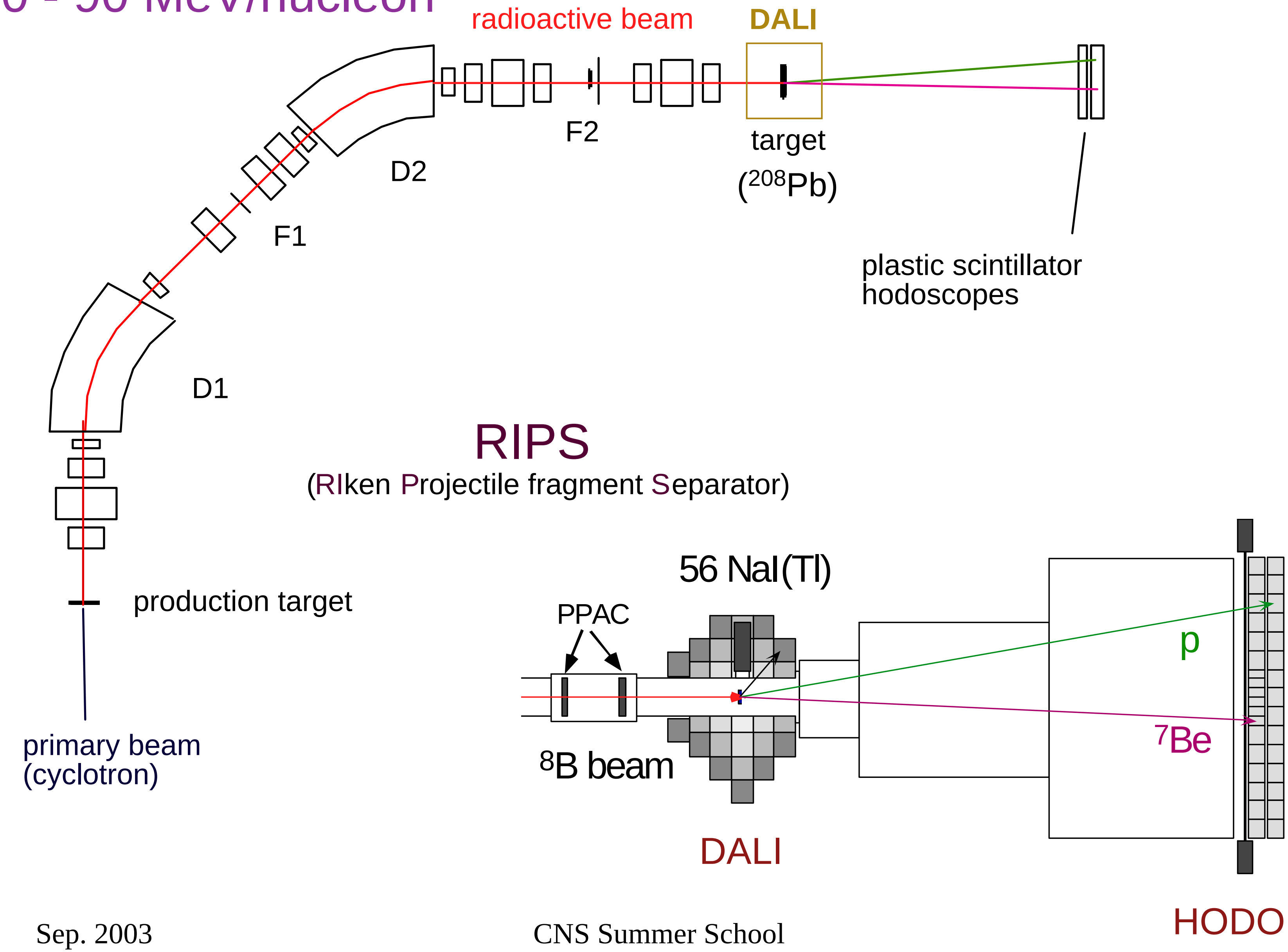
γ-γ coincidence



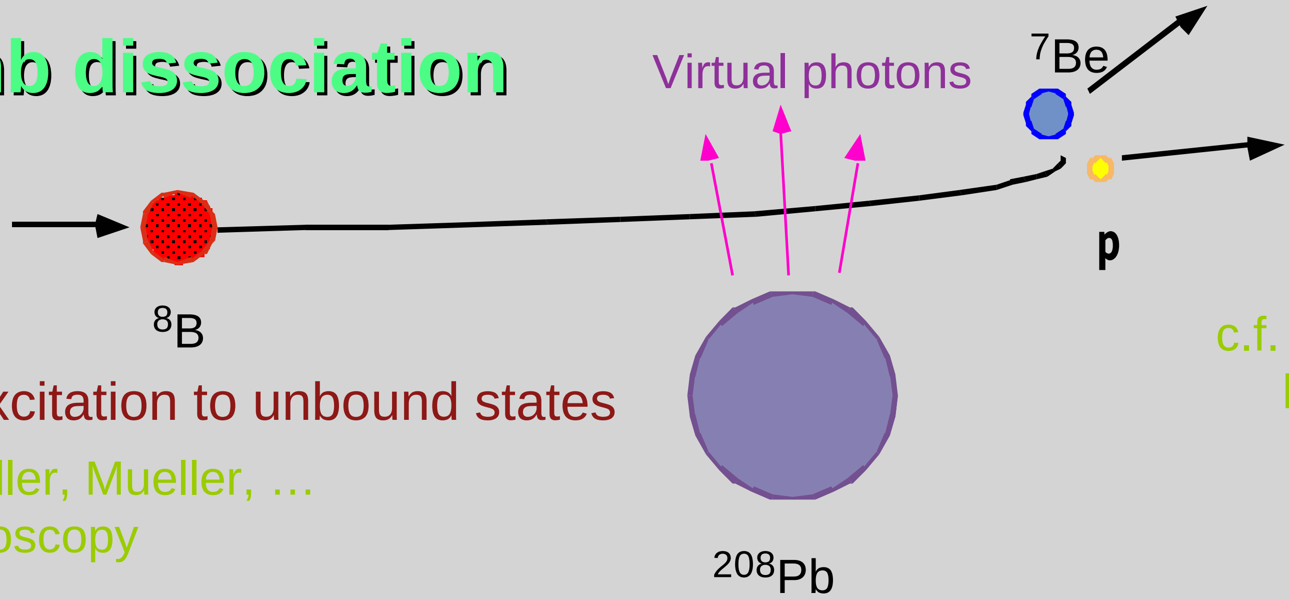
Iwasa *et al*., Phys. Rev. C67 (2003) 064315

^{8}B Coulomb dissociation

50 - 90 MeV/nucleon



Coulomb dissociation



= Coulomb excitation to unbound states

c.f. Mueller, Mueller, …
spectroscopy

c.f. Nakamura
halo nuclei

^{8}B+^{208}Pb –> ^{7}Be+p+^{208}Pb (C.D.)

↓ virtual photon theory or DWBA

^{8}B(γ,p)^{7}Be (abs.)

↓ detailed balance

^{7}Be(p,γ)^{8}B (capt.)

large σ
thick target (intermediate energy)

experiments with R.I. beams

Large yield

detailed balance

$$\sigma_{(\gamma,\mathrm{p})} = \frac{(2j_7+1)(2j_1+1)}{2(2j_8+1)} \frac{k_{17}^2}{k_\gamma^2} \sigma_{(\mathrm{p},\gamma)}$$

100 ~ 1000

virtual photon number (intermediate energy)

$$\left(\frac{d\sigma}{dE_\gamma}\right)_{\mathrm{C.D.}} = \frac{n}{E_\gamma}\sigma_{(\gamma,\mathrm{p})}$$

100 ~ 1000

thick target

charged particle detection

but

indirect *i.e.* nucl. force / higher order / E2 kinematics

E_{rel} <= p_{p}, p_{7Be}, $\theta_{\mathrm{p\text{-}Be}}$

ΔE_{rel} : Independent of ΔE_{in}

$$\Delta E_{\mathrm{rel}} \approx 2\sqrt{\frac{A_1 A_2}{A_1 + A_2}}\sqrt{T_0 E_{\mathrm{rel}}}\,\Delta\chi$$

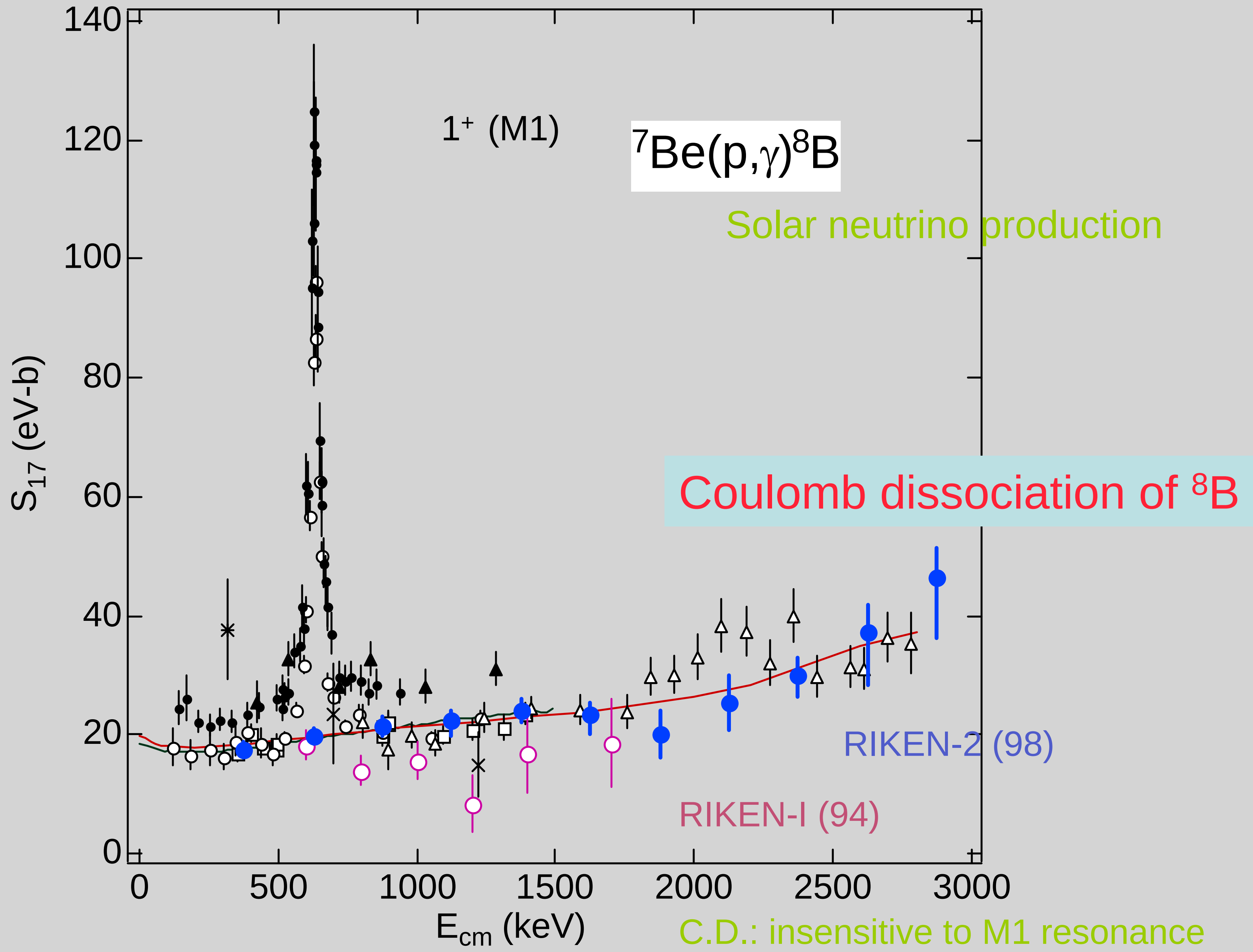
$$\Delta\chi = \Delta\theta,\ \Delta v / v$$

p+X, T_0=100 AMeV, E_{rel}=1 MeV,

$\Delta\theta$=0.5 deg. Δv=1%

↓

ΔE_{rel}=200 keV



140
120
100
80
60
40
20
0
S17 (eV-b)
0
500
1000
1500
2000
2500
3000
Ecm (keV)
1+ (M1)
7Be(p,γ)8B
Solar neutrino production
Coulomb dissociation of 8B
RIKEN-2 (98)
RIKEN-I (94)
C.D.: insensitive to M1 resonance

spectroscopy with fast exotic beams

RI (beam) + target (probe) - inverse kinematics

-----> projectile-like products

γ decays (bound)

particle decays (unbound)

------> target-like products

recoil particles

target-γ

reaction-channel ID: PID of the projectile-like product

good state ID: γ ray (Doppler-correction)

invariant mass

reaction w. large σ: inelastic (Couex, C.D., (p,p') …

cex, fratmentation, knockout

transfer

forward focusing, thick target, efficient detectors =>