Latest Results with Coulomb Dissociation Techniques

- inverse of radiative captures -

T. Motobayashi (RIKEN)

Unstable nuclei in astrophysics

Indirect methods - radiative capture

- Coulomb dissociation
- "ANC" method

c.f. Brune

$^{7}Be(p,\gamma)^{8}B$ reaction - a "bench-mark" *c.f.* Gai

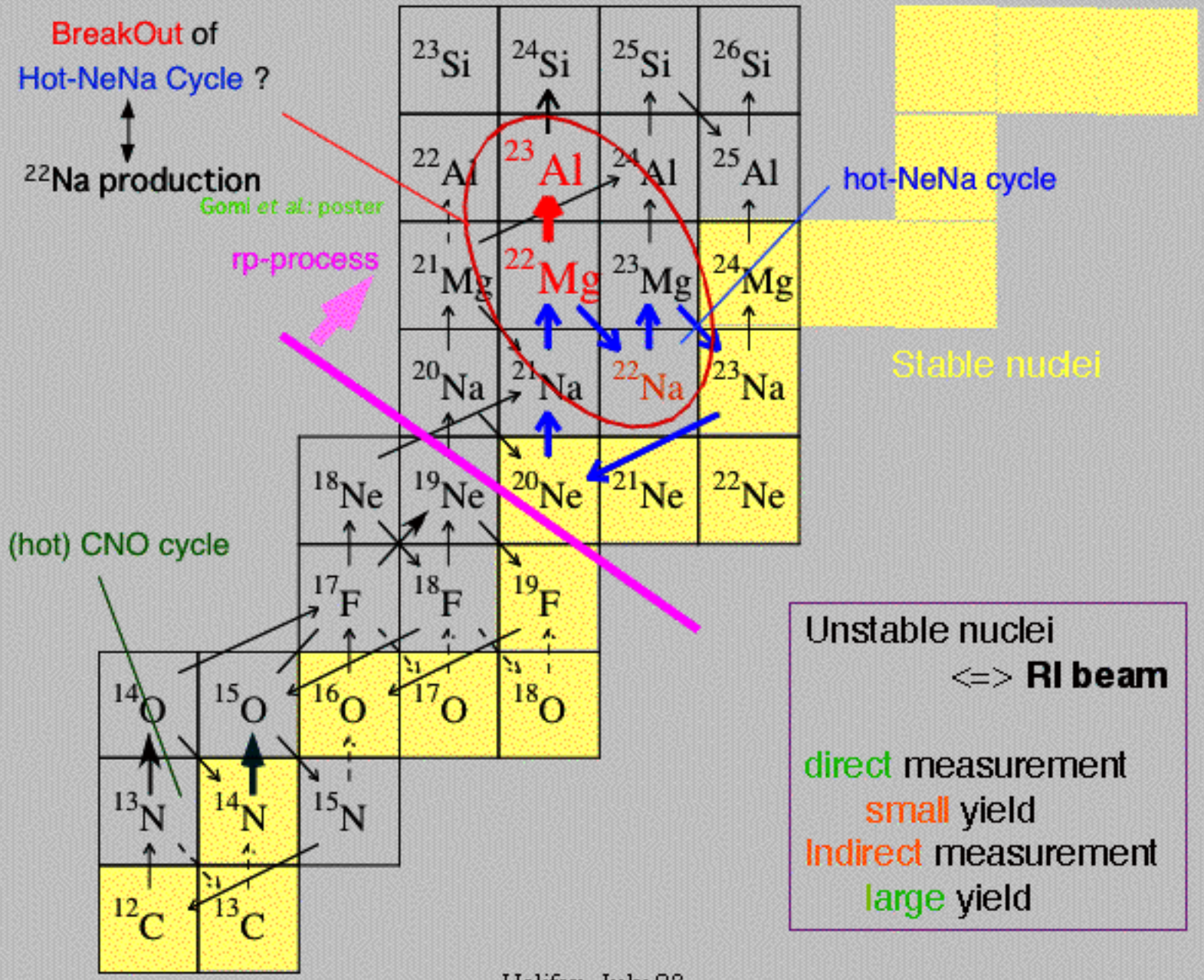
- pp chain / solar neutrino

Reactions in explosive hydrogen burning

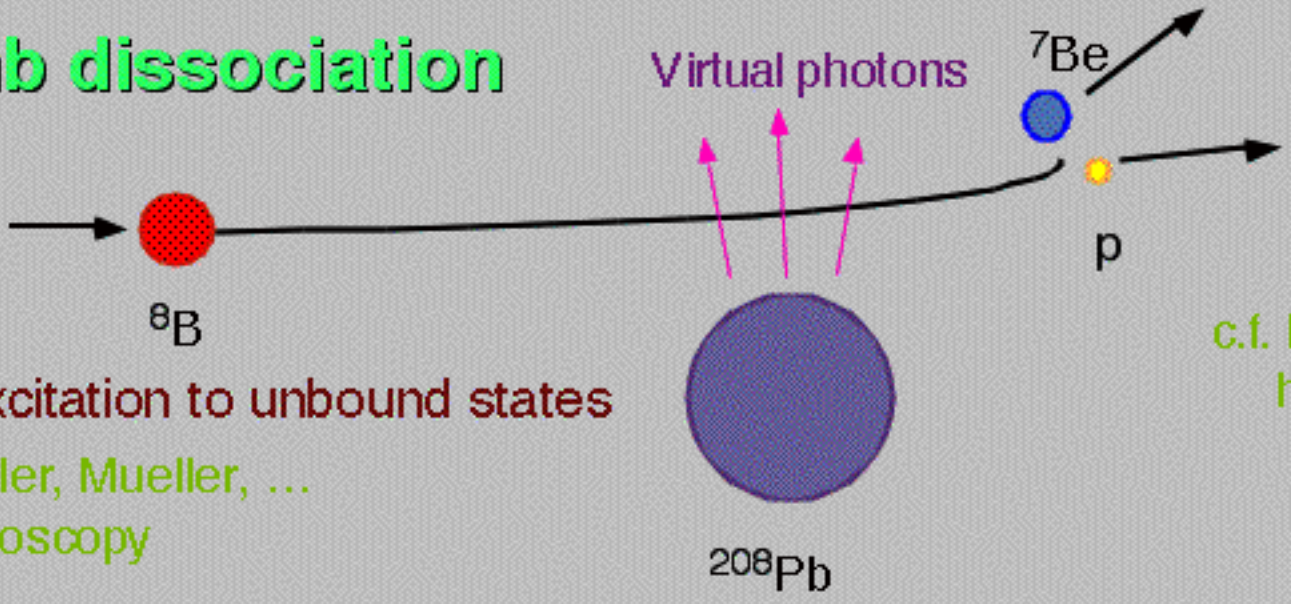
- hot pp mode, rp process

Coulomb excitation for subthreshold states

- $^{14}N(p,\gamma)^{15}O$ (CNO cycle)


BreakOut of
Hot-NeNa Cycle ?
22Na production
Gomi et al.: poster
rp-process
hot-NeNa cycle
Stable nuclei
(hot) CNO cycle
23Si
24Si
25Si
26Si
22Al
23Al
24Al
25Al
21Mg
22Mg
23Mg
24Mg
20Na
21Na
22Na
23Na
18Ne
19Ne
20Ne
21Ne
22Ne
17F
18F
19F
14O
15O
16O
17O
18O
13N
14N
15N
12C
13C
Unstable nuclei
<=> RI beam
direct measurement
small yield
Indirect measurement
large yield

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)

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

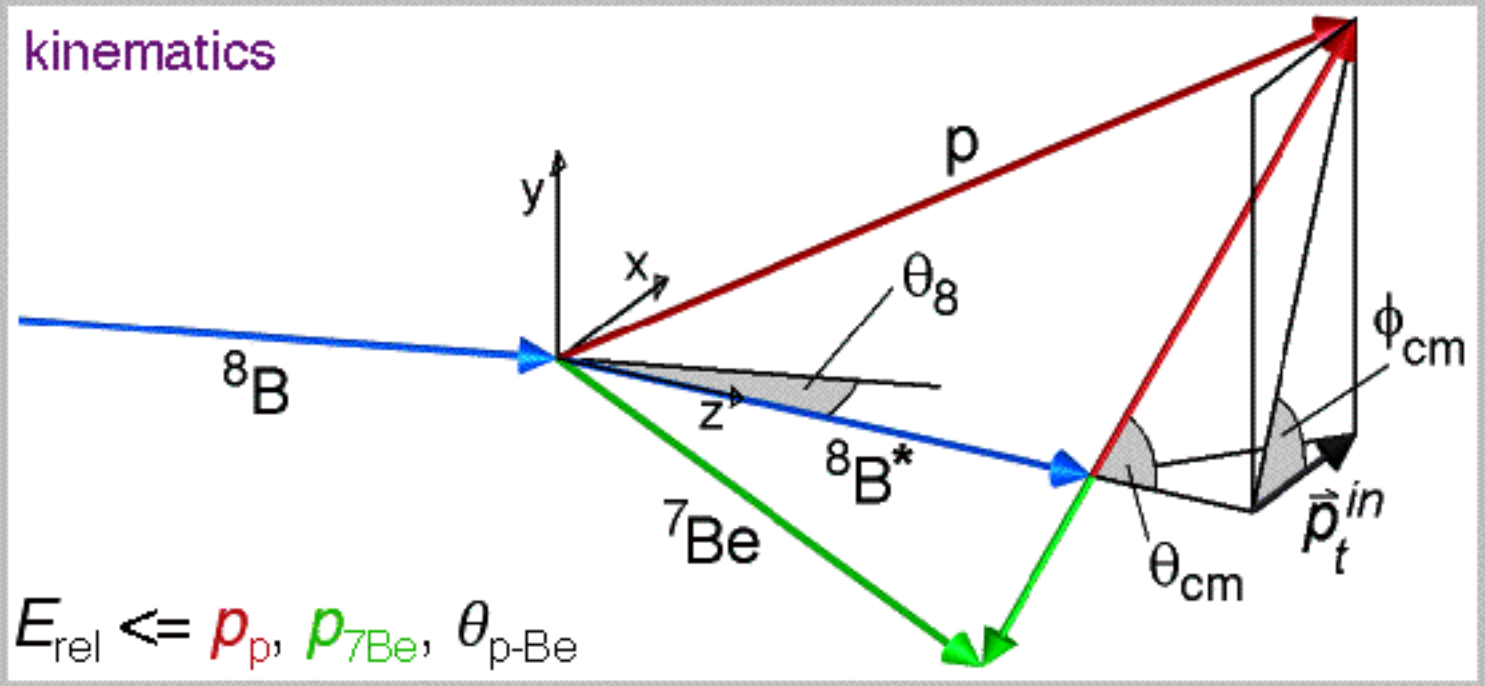
100 ~ 1000

thick target

charged particle detection

but

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



ΔE_{rel} : Independent of ΔE_{in}

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

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

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

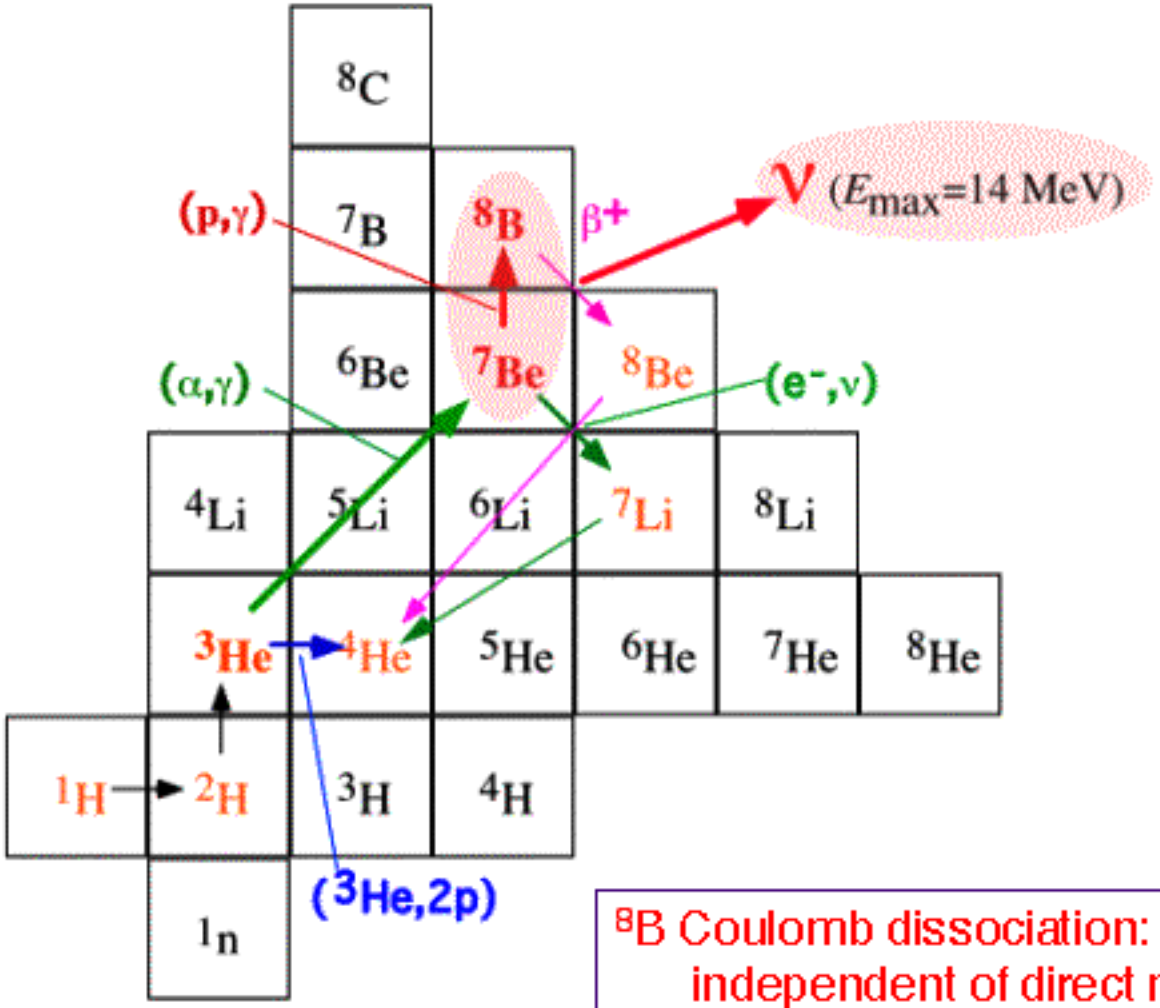
$\Delta\theta$=0.5 deg. Δv=1%

↓

ΔE_{rel}=200 keV

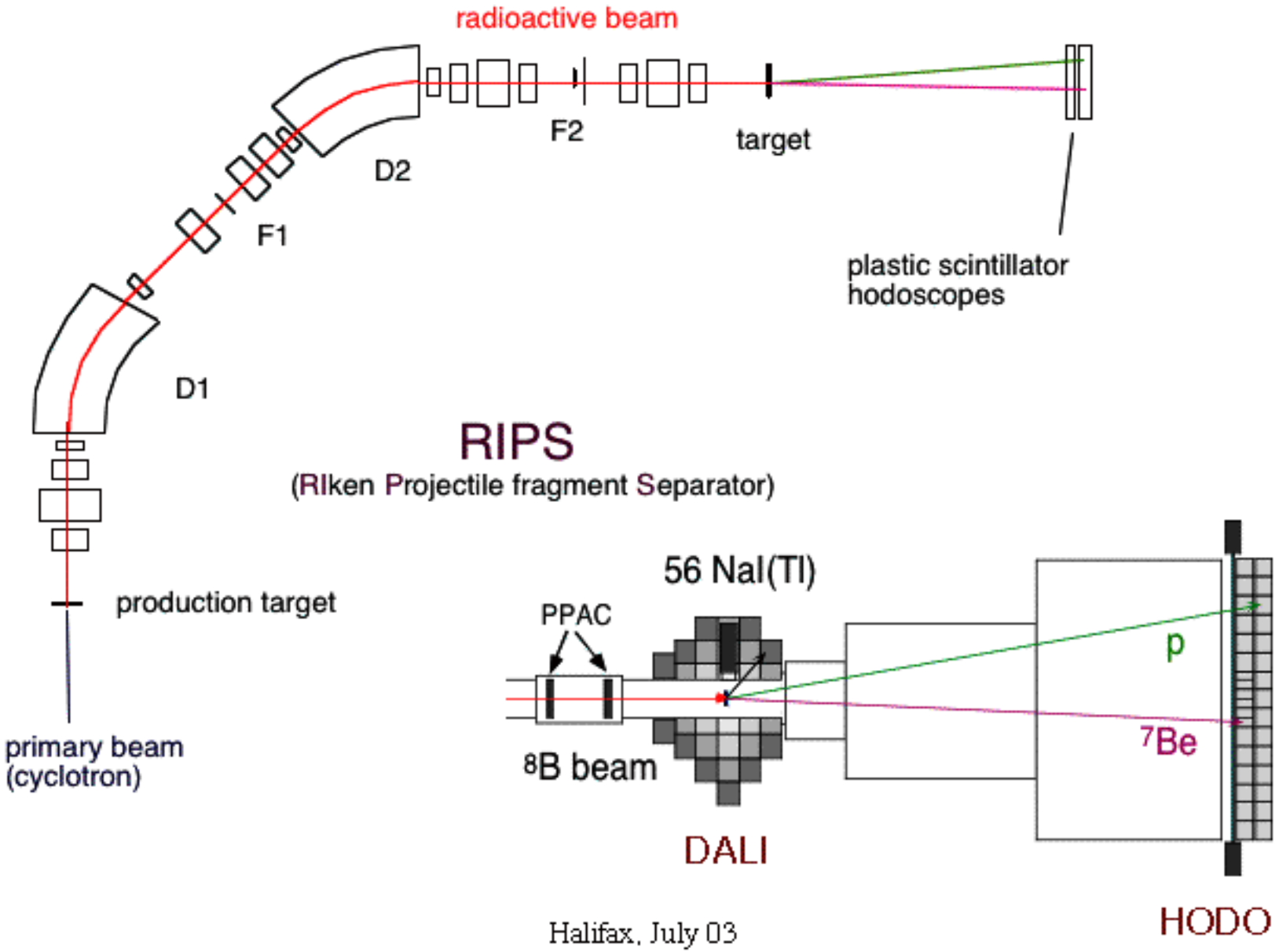
$^{7}Be(p,\gamma)^{8}B$

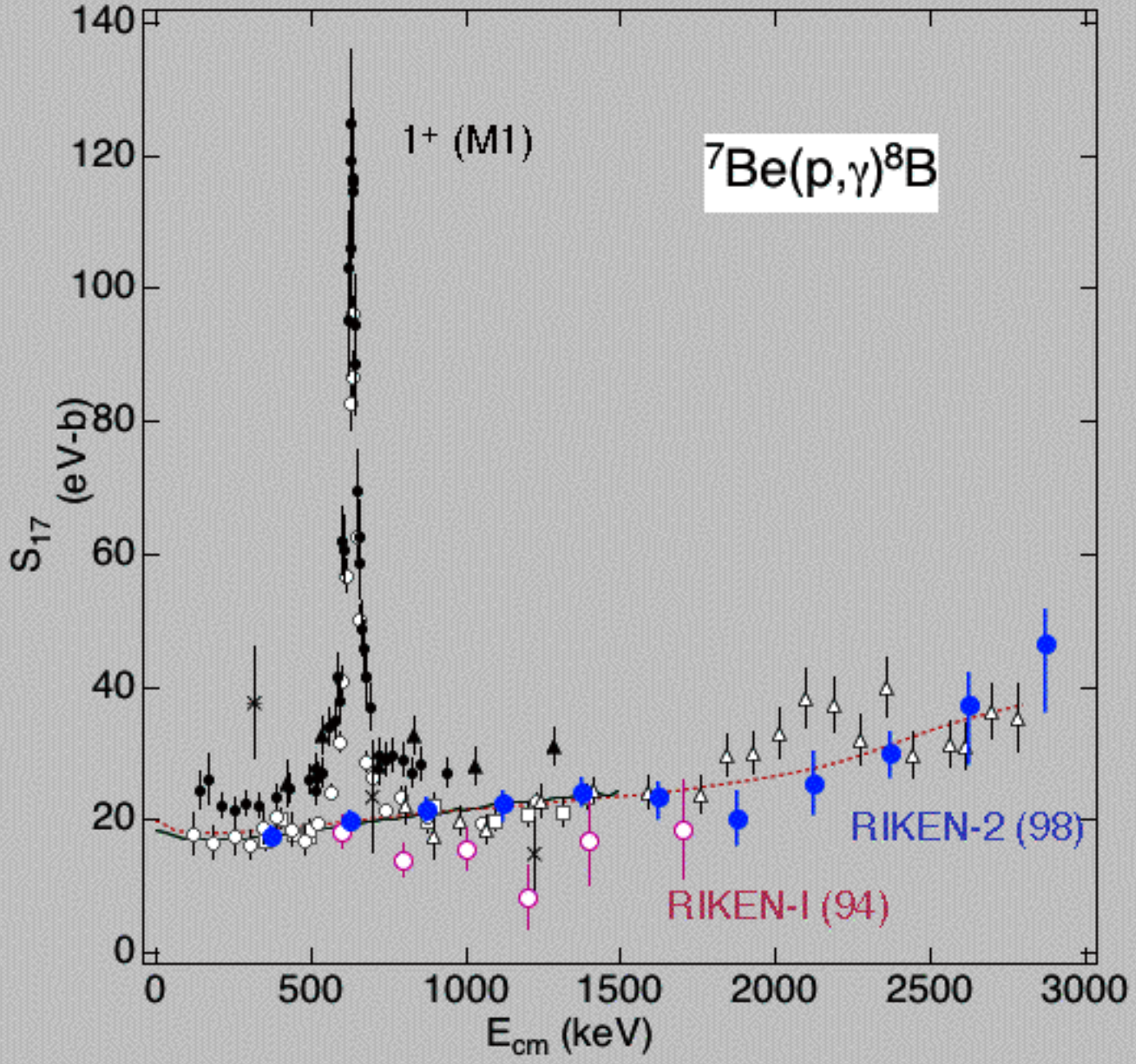
p-p chain in the sun



^{8}B Coulomb dissociation:
independent of direct measurements

@ RIKEN ~50 MeV/nucleon





Halifax, July 03

C.D.: insensitive to M1 resonance

Questions (in 10-15%)

Nuclear contribution (E1) small but $l=2$?

Higher order effects

Different multipolarities

$^{7}Be(p,\gamma)^{8}B$ E1 + M1 (4-15 %?) + E2 (~0.1%)

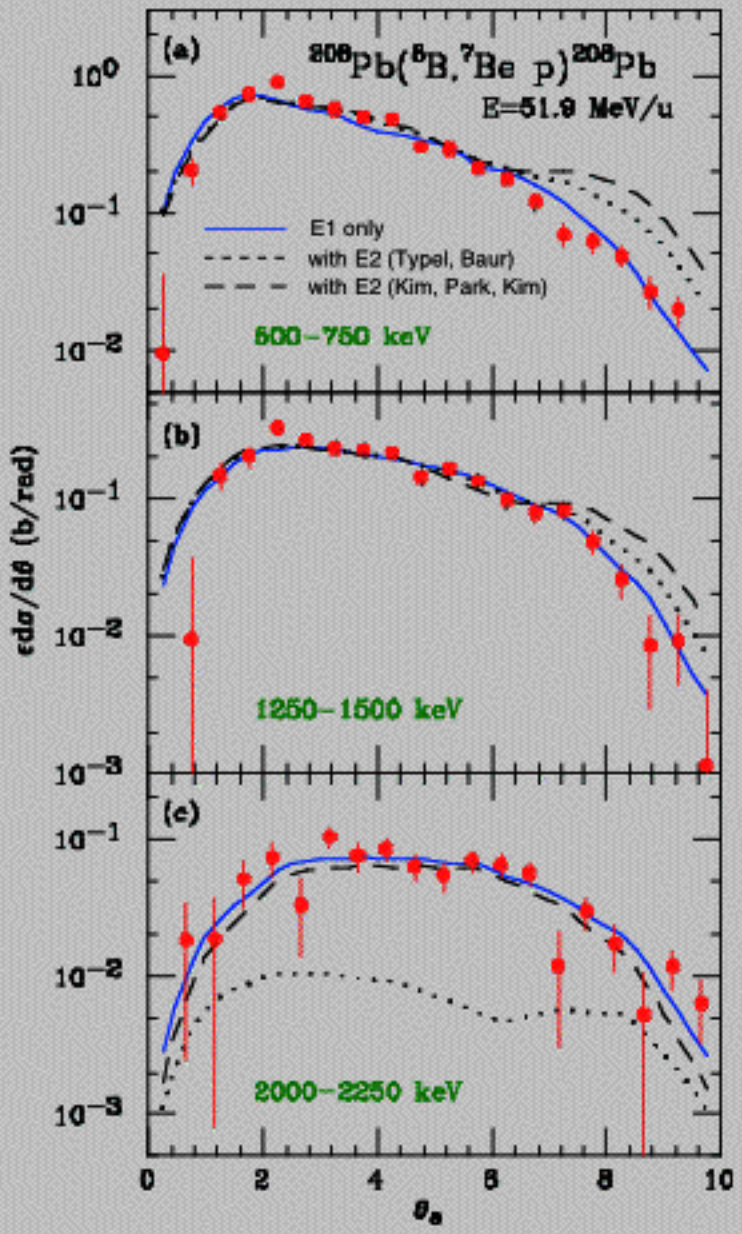
$^{208}Pb(^{8}B,p\ ^{7}Be)^{208}Pb$ E1 + E2 (4-15 %?) + M1(~0.1%)

angular (θ_8) distribution => RIKEN-2, (GSI-1)

angular correlation => GSI-2, (MSU p//)

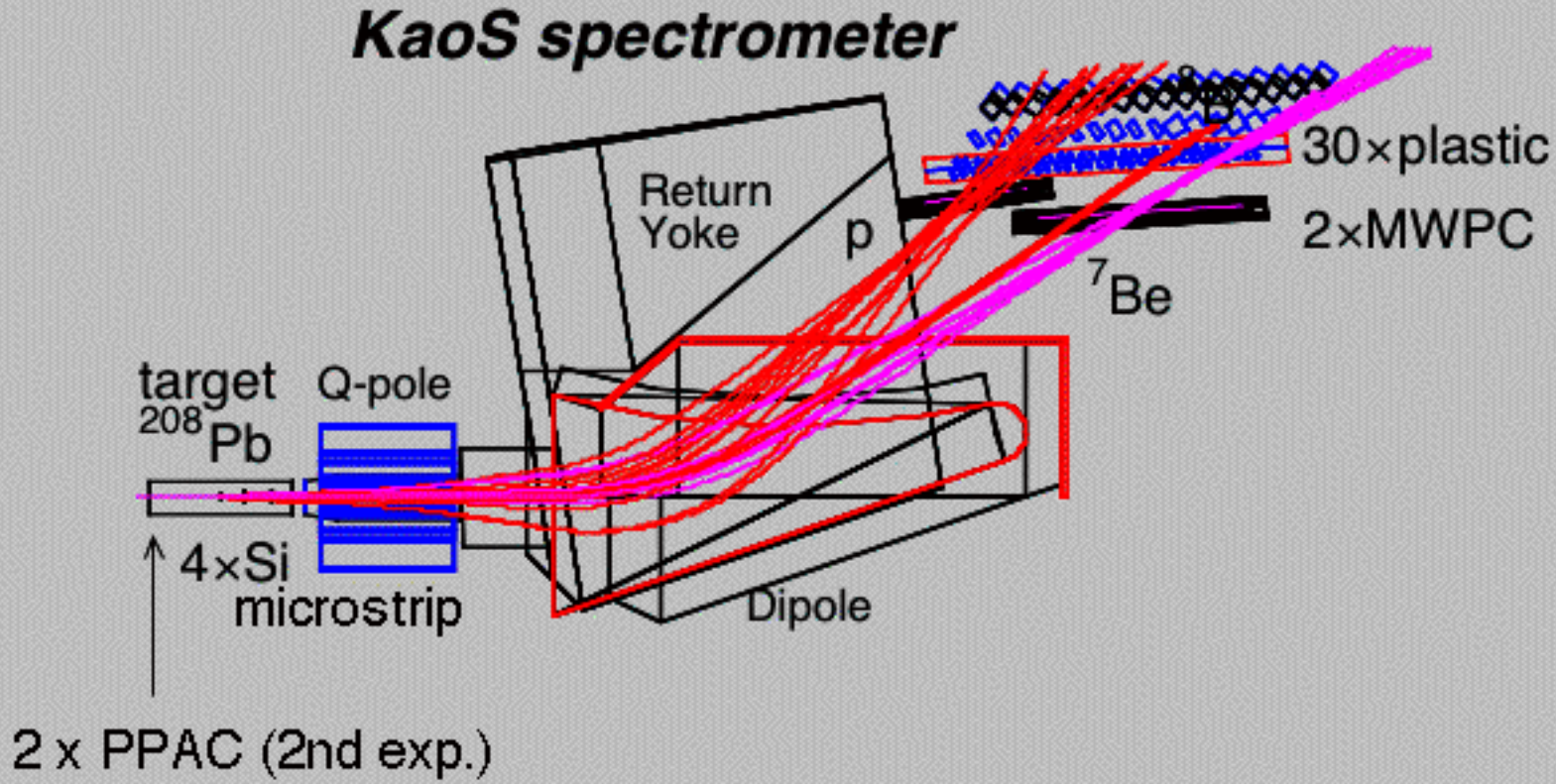
RIKEN-2

θ_8 distribution



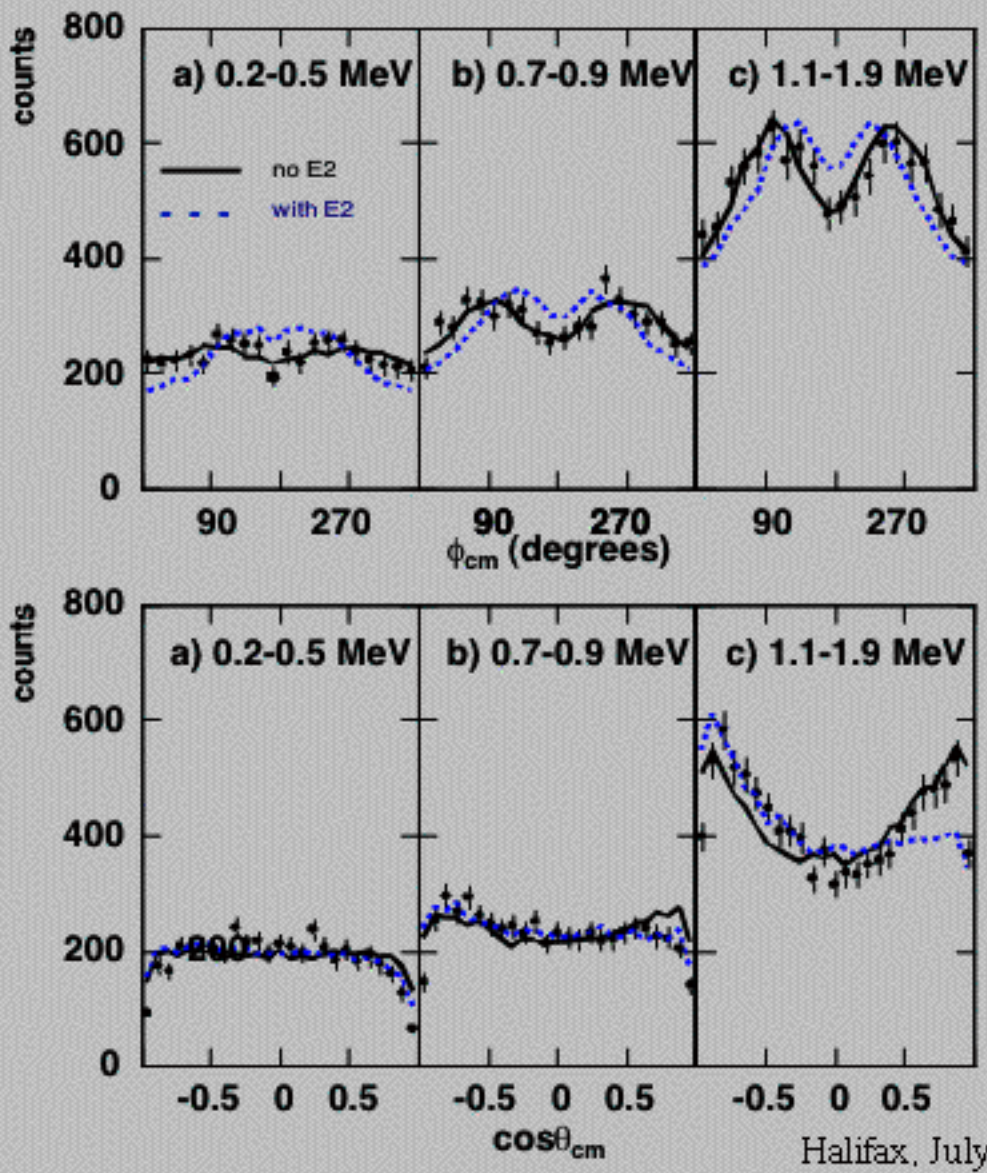
small E2 (l=2)

@ GSI 254 MeV/nucleon



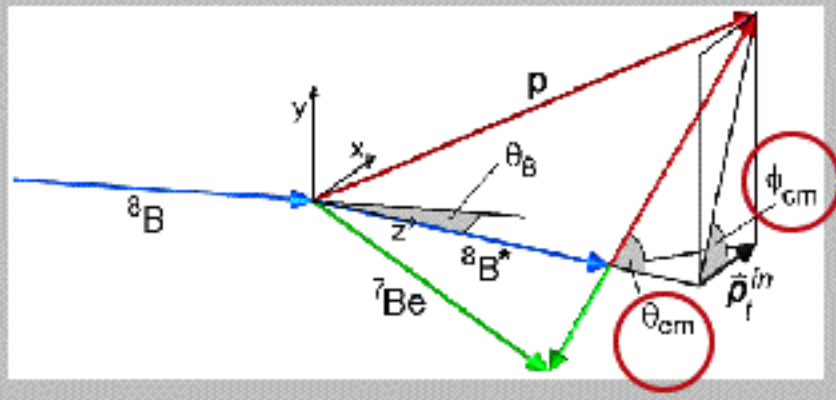
azimuthal- / polar-angle distributions

$\theta_8 < 1°$



ϕ

θ

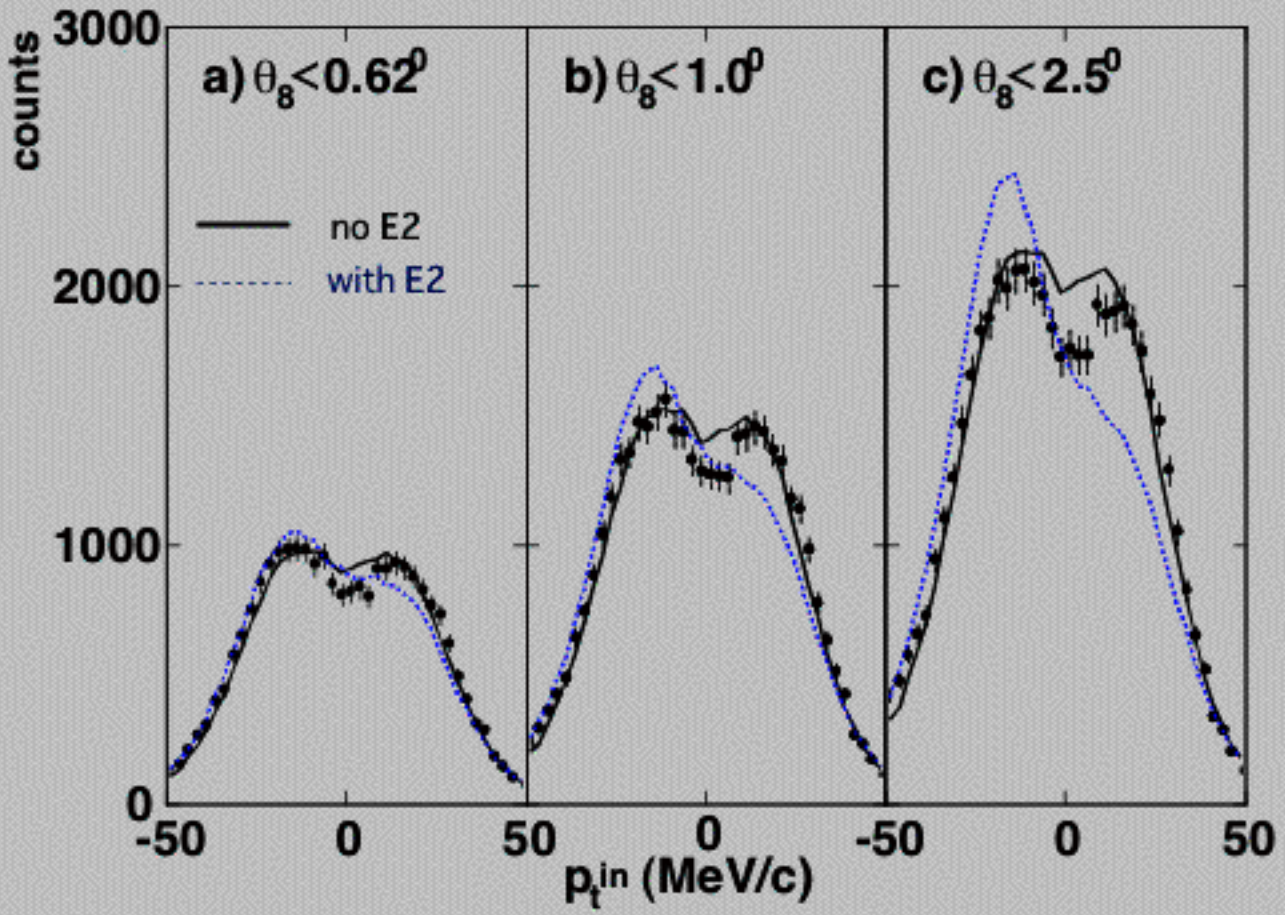


GSI-2

Phys. Rev. Lett. 90, 232501 (2003)

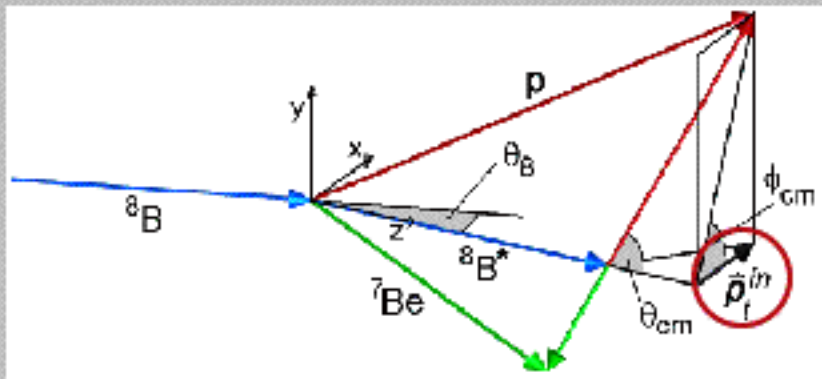
Halifax, July 03

transverse momentum distributions



GSI-2

consistent with small E2 contribution



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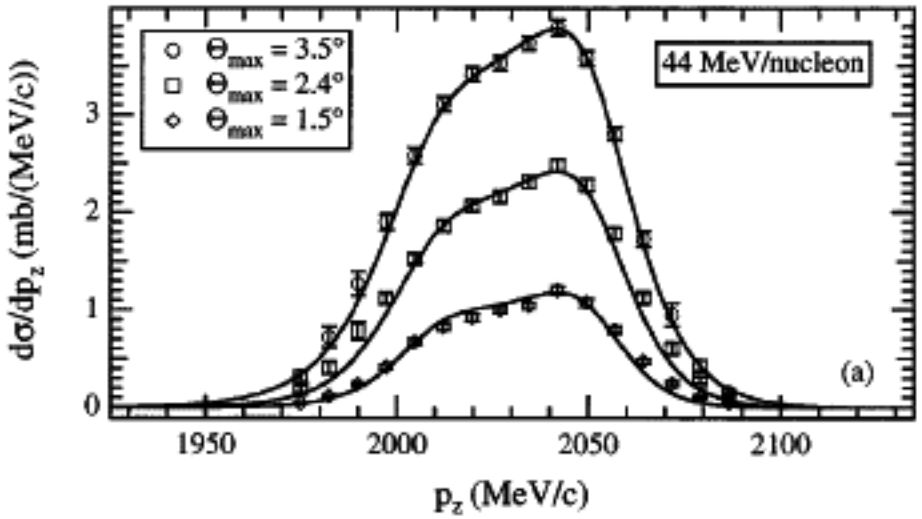
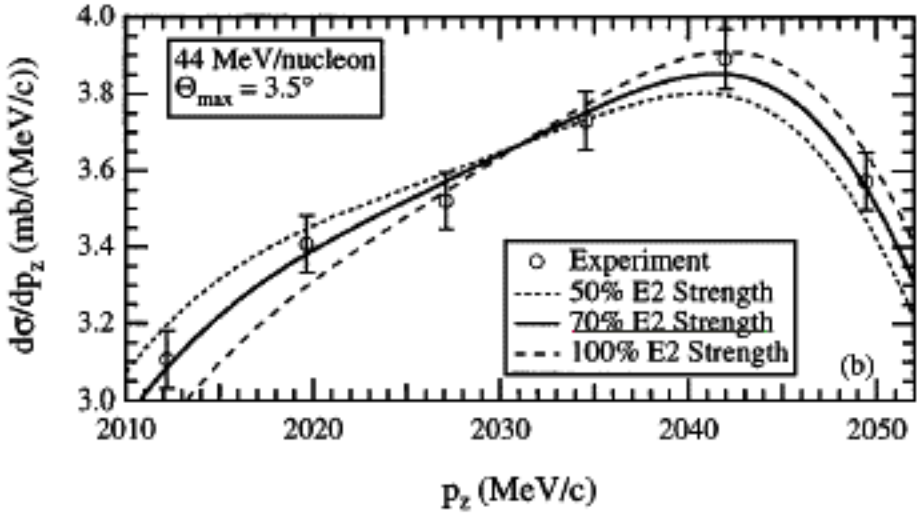
parallel momentum distribution (MSU)

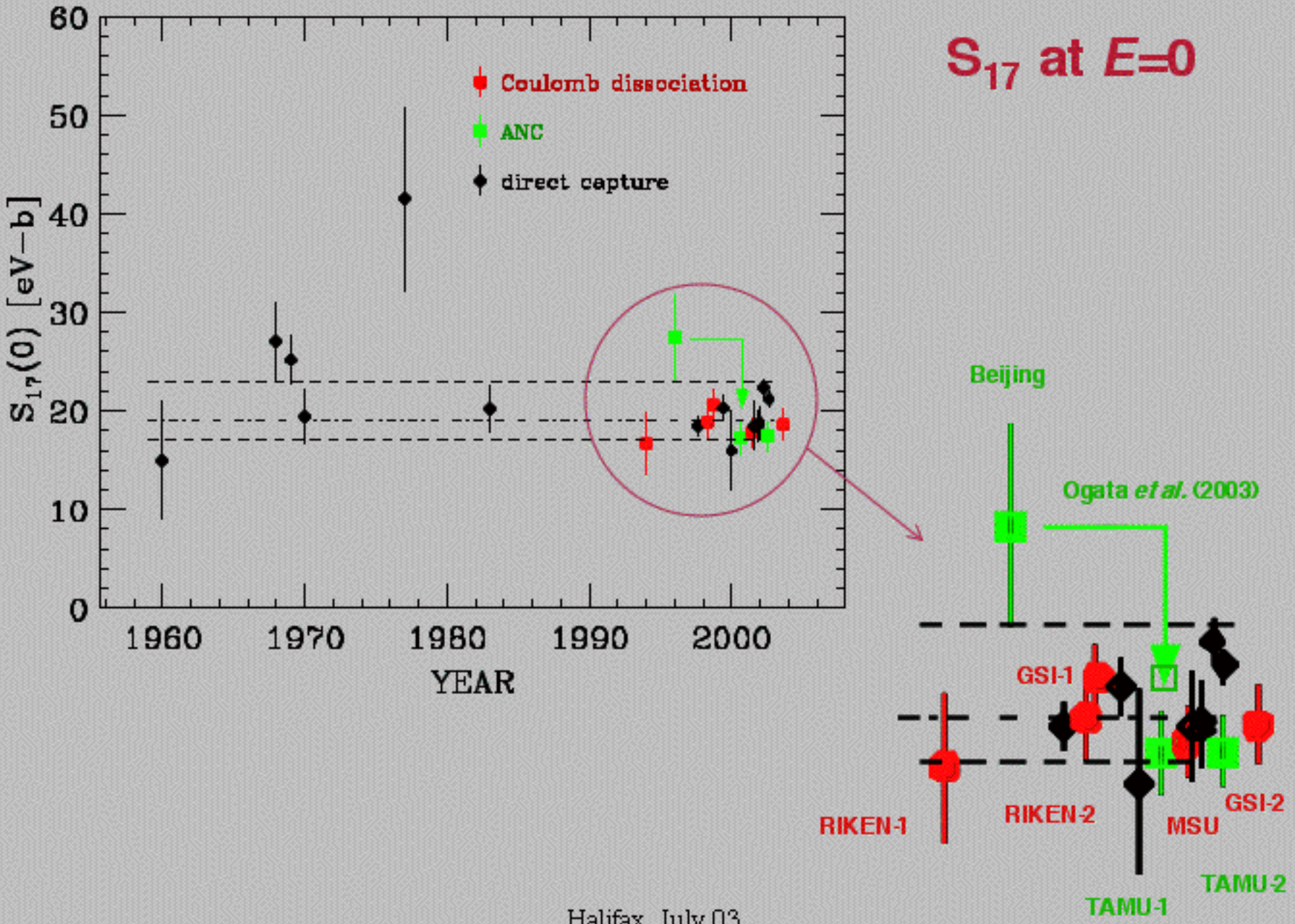




E1/E2 inteference

sizable E2

Davids *et al.*, Phys. Rev. Lett. 81 (1998) 2209


S_{17} at E=0
Coulomb dissociation
ANC
direct capture
$S_{17}(0)$ [eV−b]
YEAR
1960
1970
1980
1990
2000
0
10
20
30
40
50
60
Beijing
Ogata *et al.* (2003)
GSI-1
RIKEN-1
RIKEN-2
MSU
GSI-2
TAMU-1
TAMU-2

possible corrections (10-15%)

Multipolarities

- E1 dominance: OK in 90% for Coul. Diss.
- E2 : controversy ?
  - angular distribution (RIKEN) small
  - $P_{//}$ distribution (MSU) 10-15%
  - Angular correlation (GSI) small
- M1: only near the resonance

Nuclear contribution

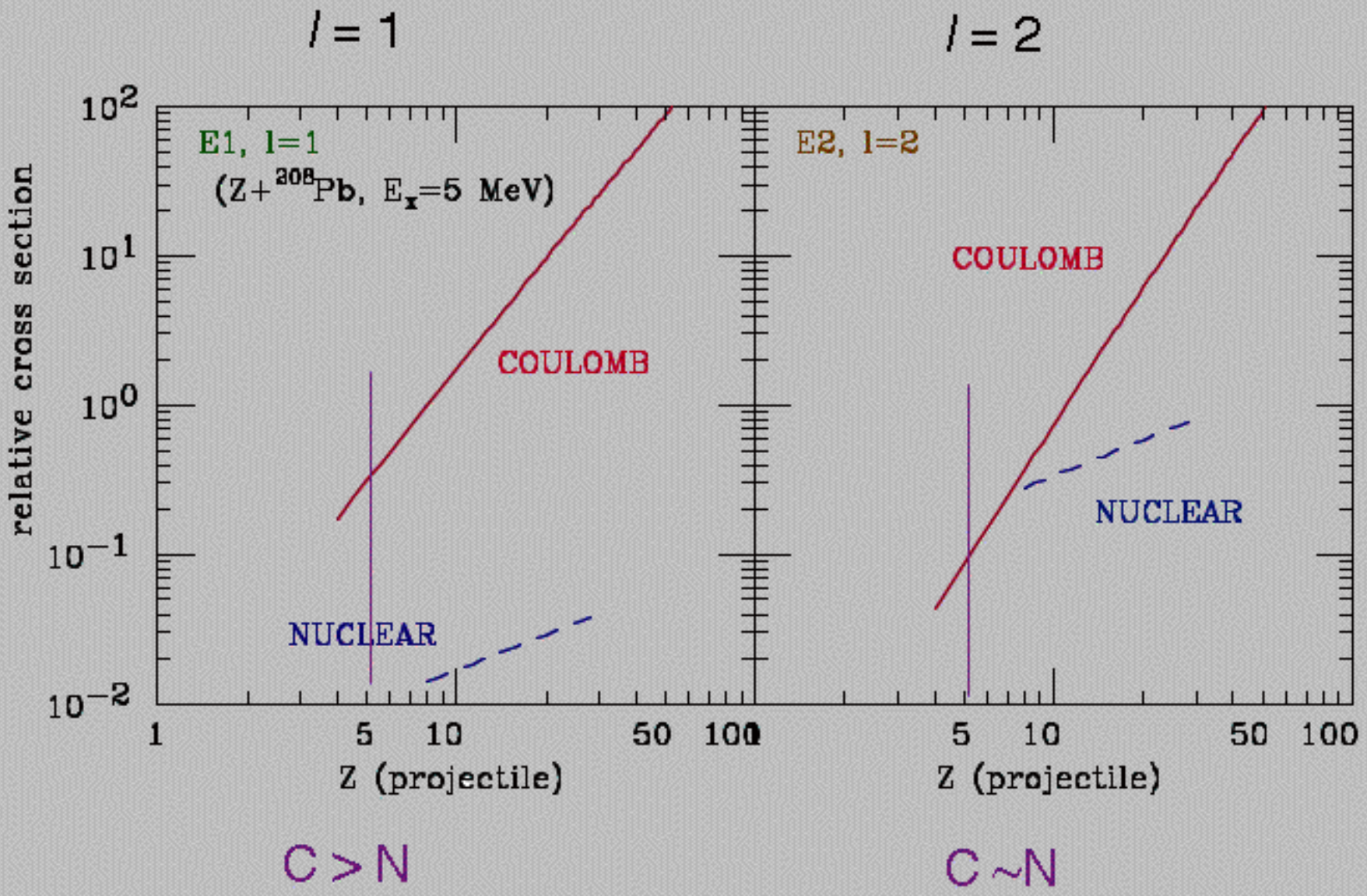
- ~1% (E1) <– microscopic calc.
- large ? (E2) <- collective form factor

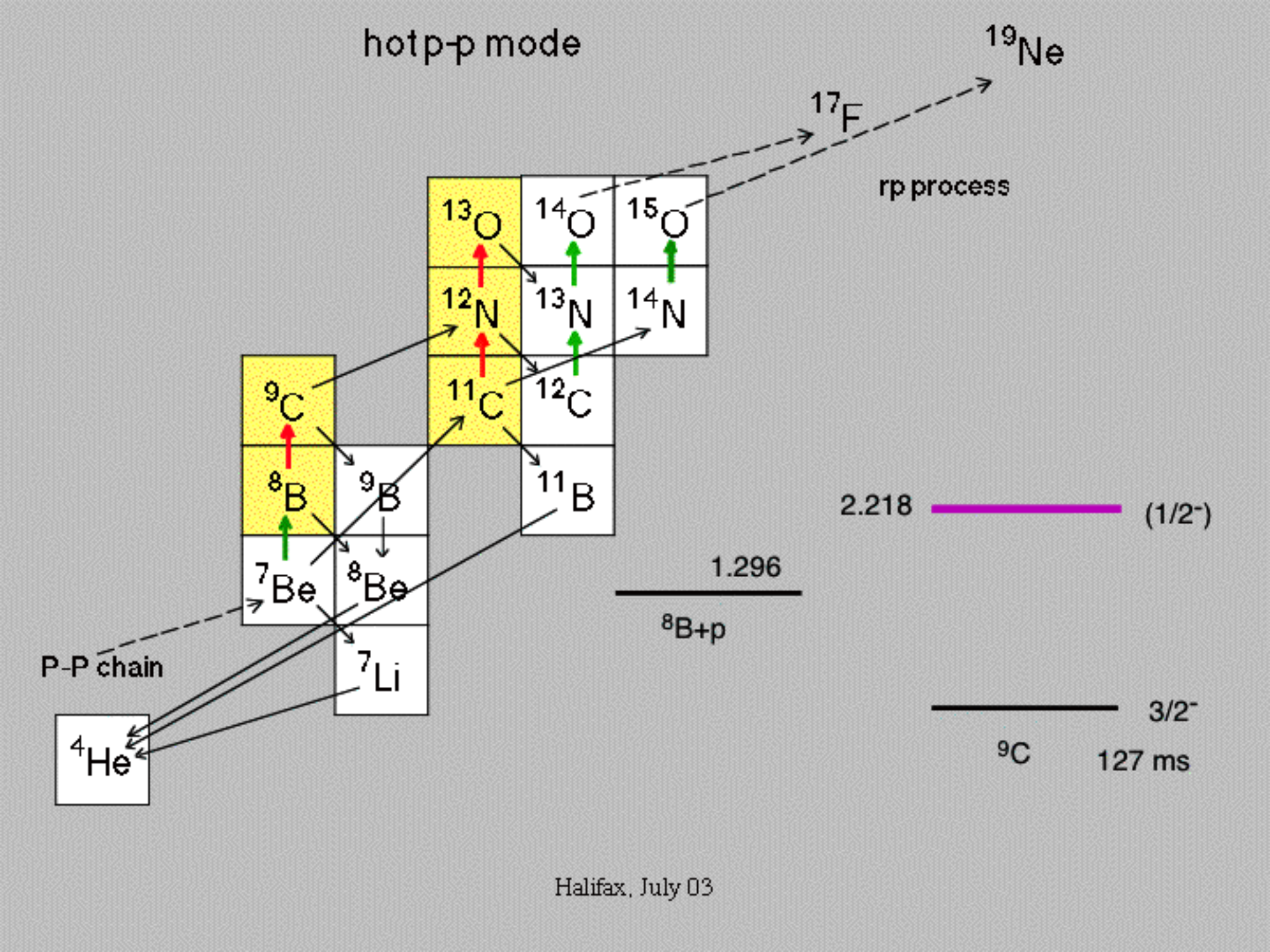
--> calc.w. microscopic f.f. / CDCC / exp.

Higher order effects

- Post Coulomb acceleration: small
- multistep excitation: E1-E2 interference

--> dynamical calc. / CDCC

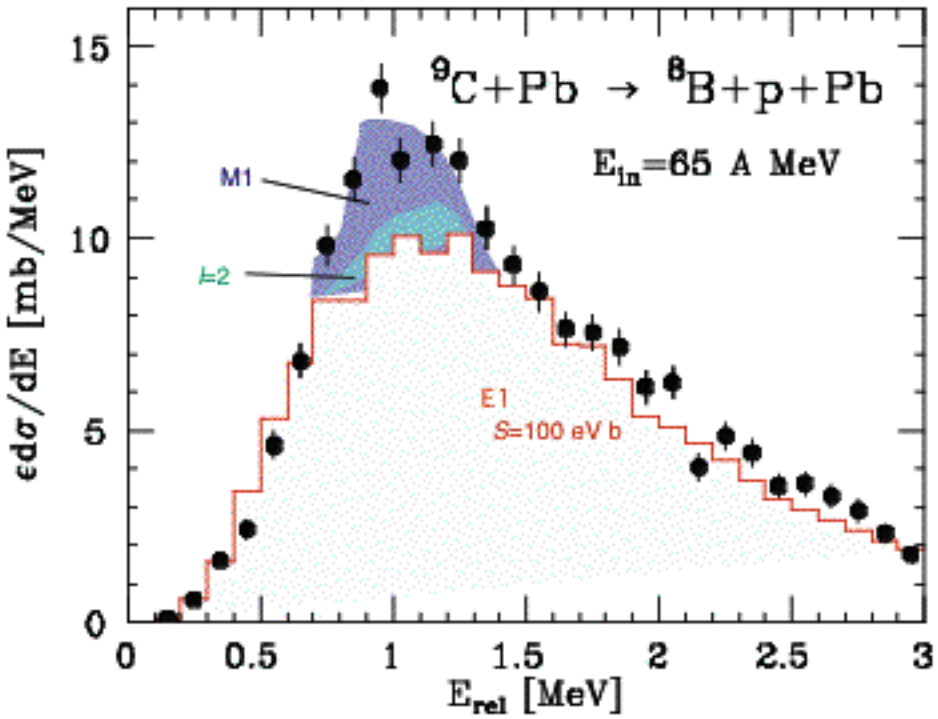

l = 1
l = 2
E1, l=1
(Z+208Pb, Ex=5 MeV)
E2, l=2
COULOMB
NUCLEAR
COULOMB
NUCLEAR
relative cross section
Z (projectile)
Z (projectile)
C > N
C ~N

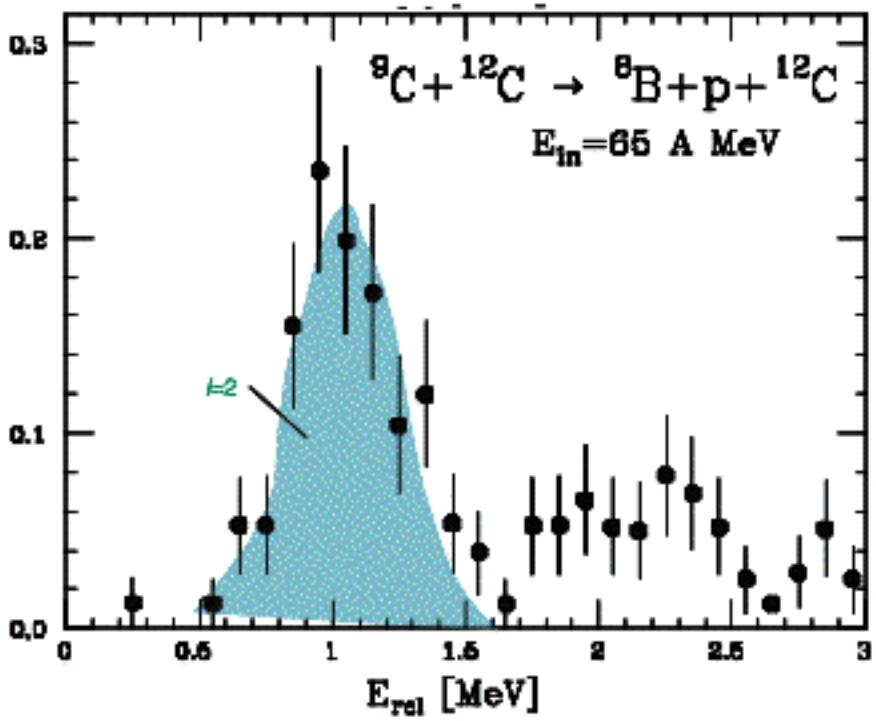

hot p-p mode
^{19}Ne
^{17}F
rp process
^{13}O
^{14}O
^{15}O
^{12}N
^{13}N
^{14}N
^{9}C
^{11}C
^{12}C
^{8}B
^{9}B
^{11}B
^{7}Be
^{8}Be
^{7}Li
^{4}He
P-P chain
2.218
(1/2$^-$)
1.296
^{8}B+p
3/2$^-$
^{9}C
127 ms

$^{8}B(p,\gamma)^{9}C$ in hot pp mode

- continuum & resonance !

Coulomb dissociation @ RIKEN





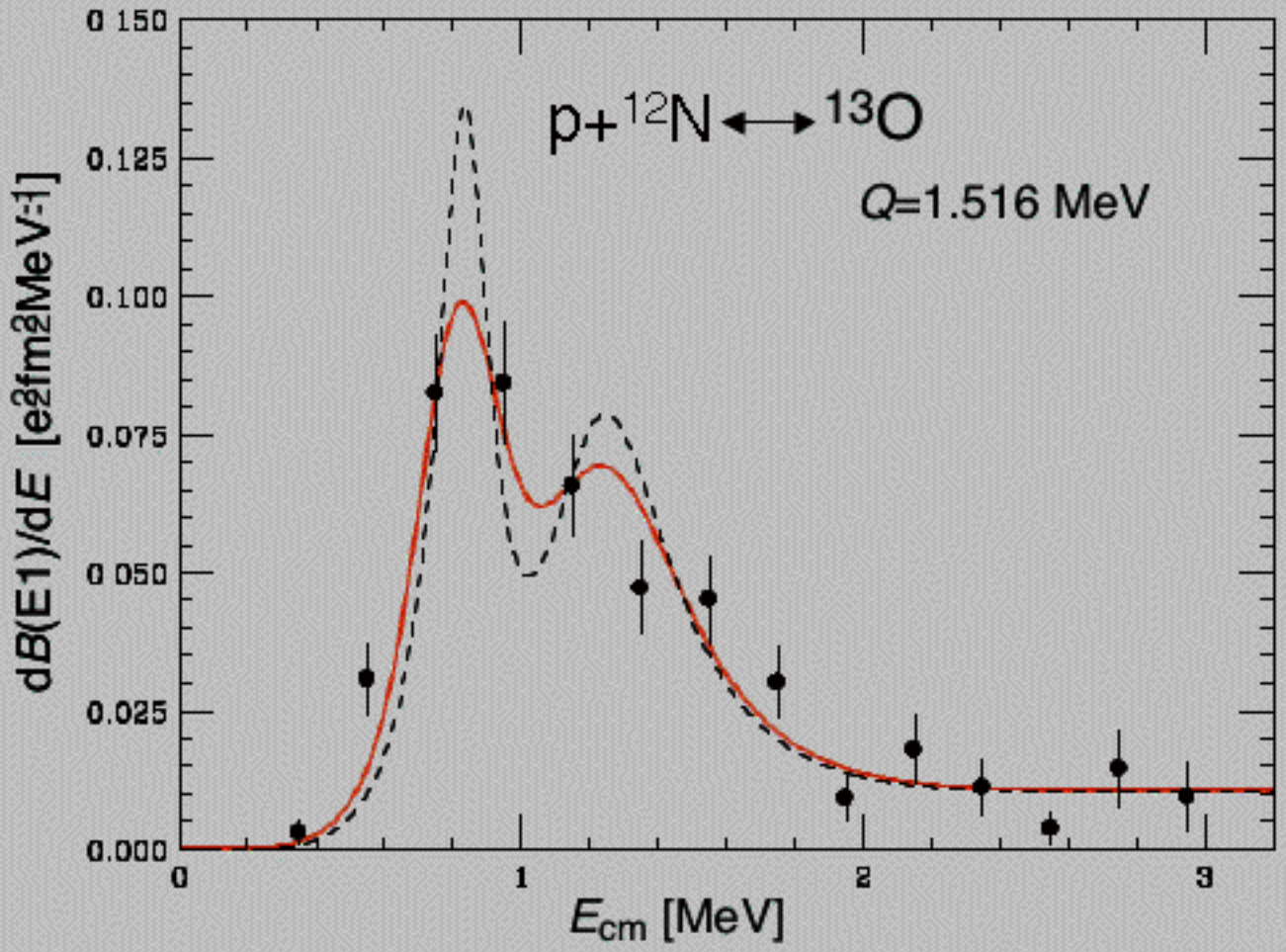
S_{18} at $E \approx 0$

	S_{18} [eV b]	E	method
RIKEN 03	77±15	(0.2 - 0.5)	Coul. diss.
RIKEN 01*	45±13	(0 - 0.1)	ANC
TAMU 02**	46±6		ANC'
Wiescher *et al.*	210	(0-0.8)	shell model
Descouvemont	≈80		cluster model

* Beaumel *et al.* ** Trache *et al.*

Resonance yield

	Γ_γ(M1) [meV]	Γ_γ(E2) [μeV]	J^π
RIKEN 03	21±6	4.3±1.0	
Wiescher *et al.*	34		$1/2^-$
Kanada-En'yo		4.6	$1/2^-$
Descouvemont 93	100	600	$5/2^-$
Descouvemont 99		very small	$1/2^-$

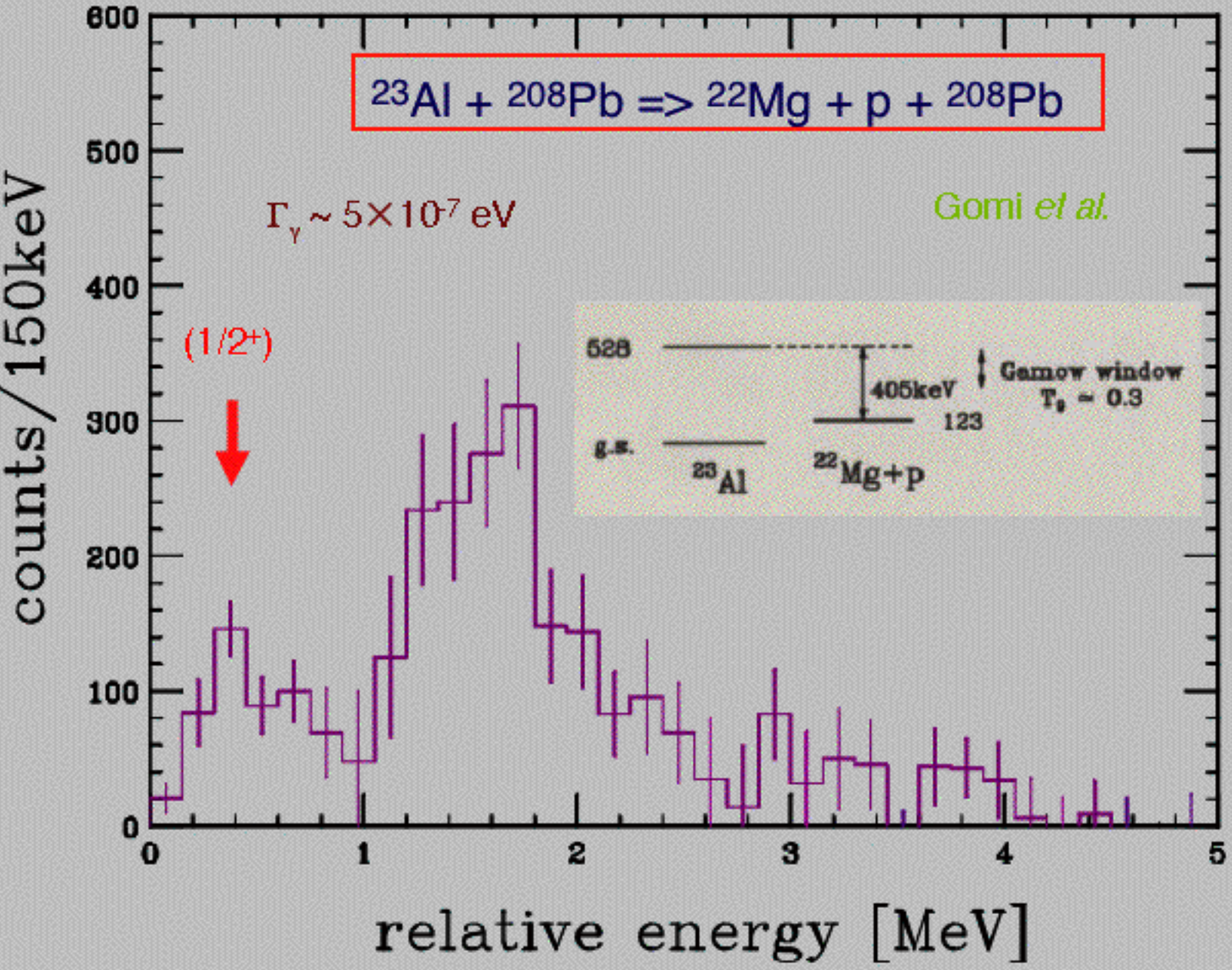


two E1 resonances ?

B(E1;0.5-2 MeV) ~ 0.08 e^2fm^2 ↔ 0.056 e^2fm^2 by Sagawa *et al.*

S ~ 0.2 keV-b ↔ 40 keV-b (Wiescher *et al.**)

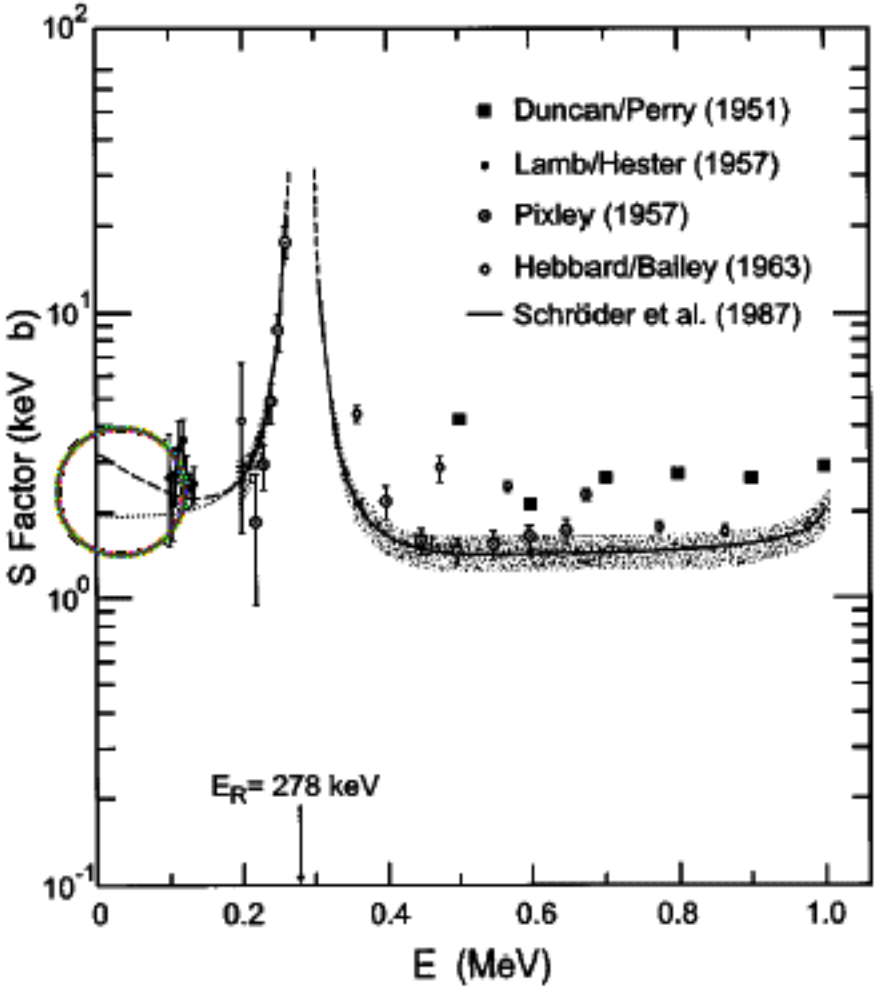
* new estimate: 1/100


$^{23}Al + ^{208}Pb => ^{22}Mg + p + ^{208}Pb$
$\Gamma_\gamma \sim 5\times10^{-7}$ eV
Gomi *et al.*
(1/2+)
528
405keV
123
g.s.
^{23}Al
$^{22}Mg+p$
Gamow window
$T_0 \sim 0.3$
counts/150keV
relative energy [MeV]
0
100
200
300
400
500
600
0
1
2
3
4
5

$^{14}N(p,\gamma)^{15}O$ (CNO cycle)

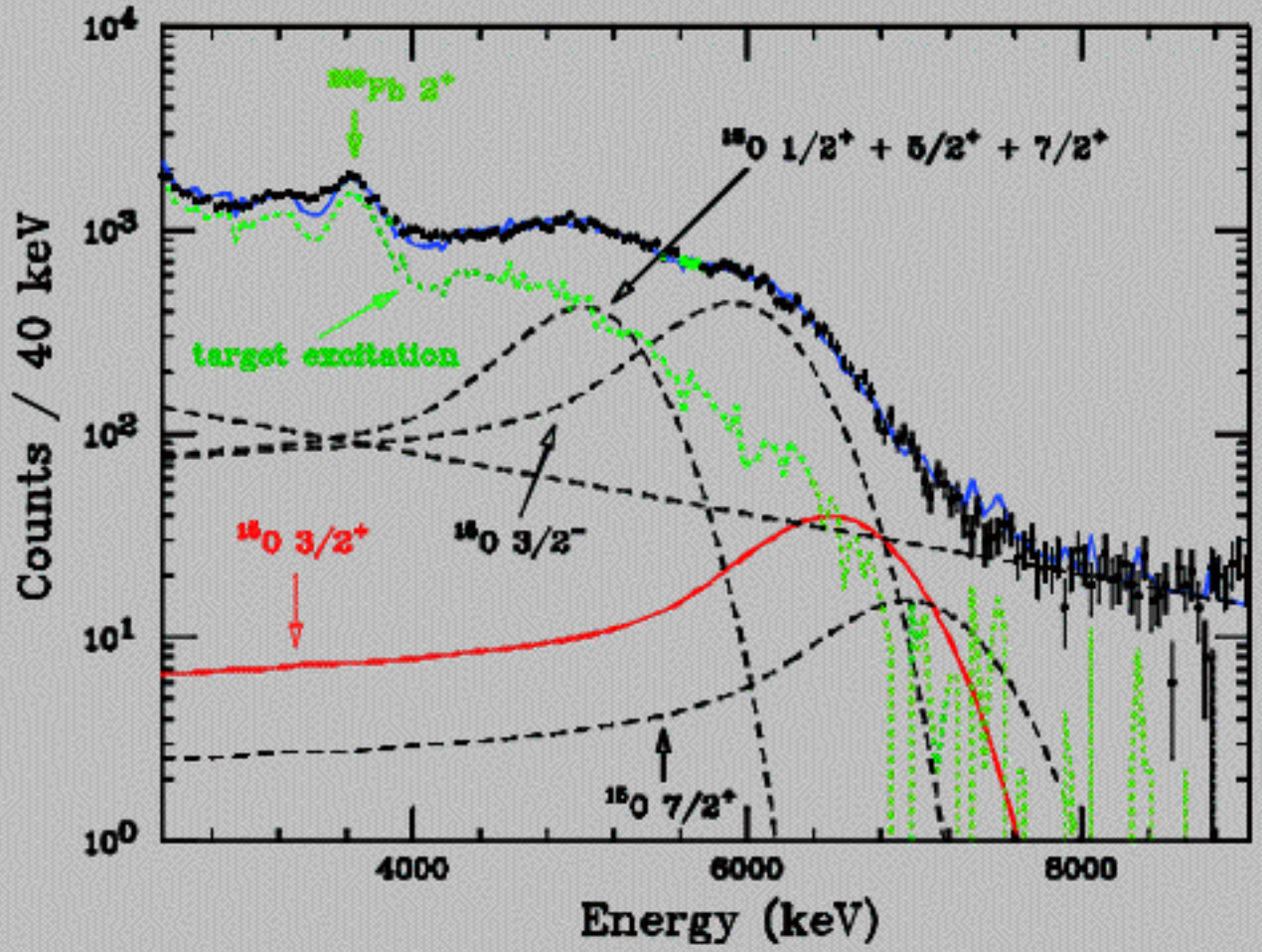
$3/2^+$ in ^{15}O
Ex = 6.79 MeV

Γ_γ ?



from Adelberger *et al.*,
Rev. Mod. Phys. 70 (1998) 1265

Doppler-corrected γ-spectrum



^{15}O + ^{208}Pb
85 MeV/nucleon

N. Yamada *et al.*

$\Gamma_\gamma(3/2^+) < 1.5$ eV

$0.41^{+0.34}_{-0.13}$ eV
Bertone *et al.* 2001

Minor contribution of the 6.79 MeV state to the ^{14}N(p,γ)^{15}O rate

Summary

continuum
resonance: E1, E2, M1

RI-beam

$^{7}Be(p,\gamma)^{8}B$ - pp chain ; $^{14}N(p,\gamma)^{15}O$ - CNO cycle

$^{13}N(p,\gamma)^{14}O$ - hot CNO ; $^{8}B(p,\gamma)^{9}C$, $^{11}C(p,\gamma)^{12}N$, $^{12}N(p,\gamma)^{13}O$ - hot pp
$^{22}Mg(p,\gamma)^{23}Al$, $^{26}Si(p,\gamma)^{27}P$ - rp

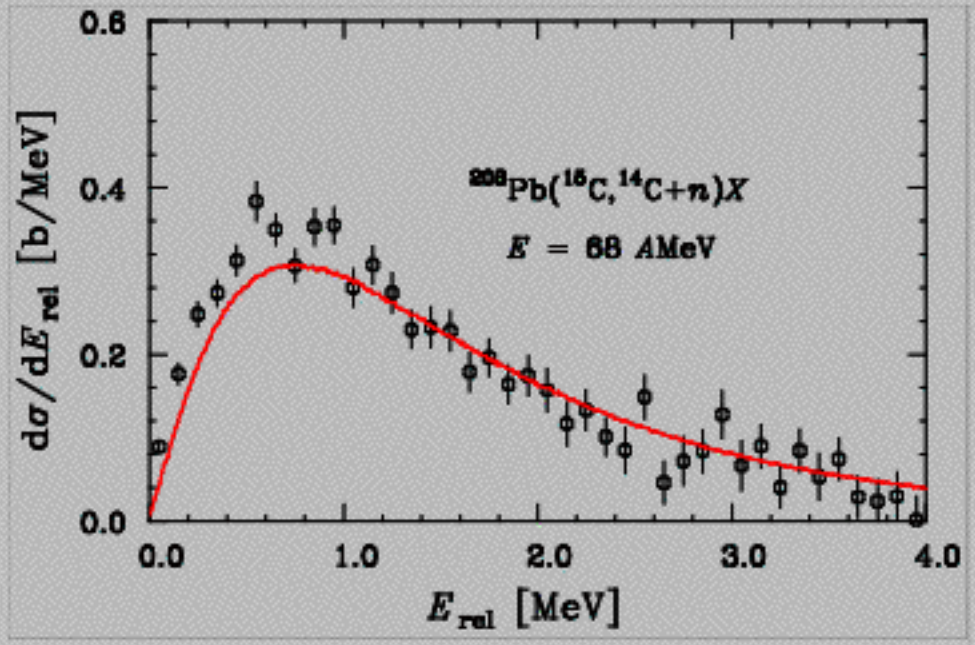
control of reaction mechanism
higher order / E2-related corrections /
nuclear excitations

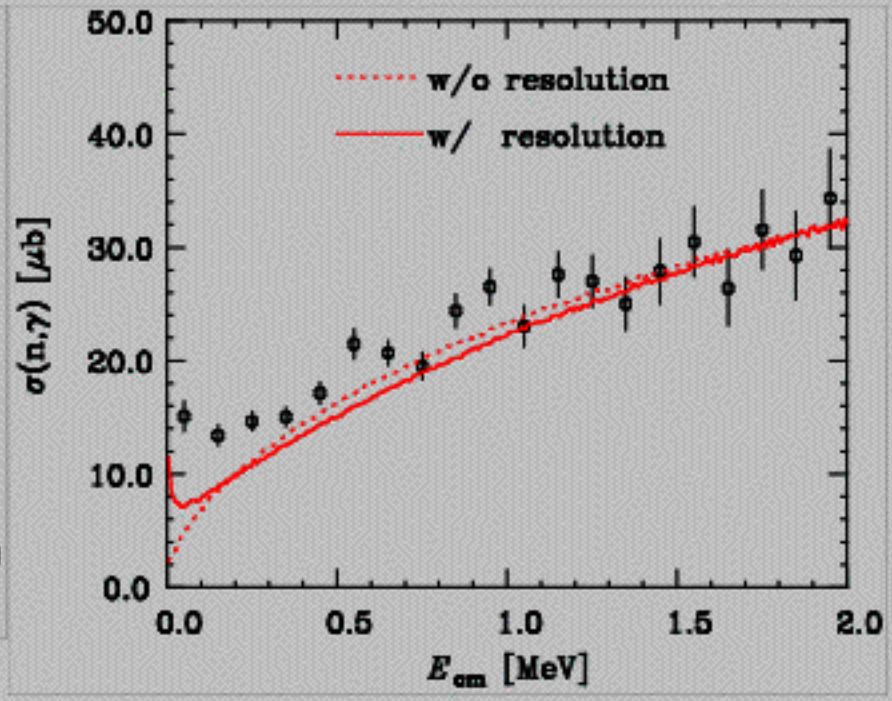
theory
experiment

Intense beam
efficient setup

Coulomb dissociation of ^{15}C

Nakamura *et. al.*





direct measurement
Beer et al., Astrophys. J. **38**, 258 (992)

Coulomb dissociation
A. Horvath et al., Astrophys. J. **570**, 926 (2002)

RIKEN Accelerator Research Facility and RI Beam Factory Project