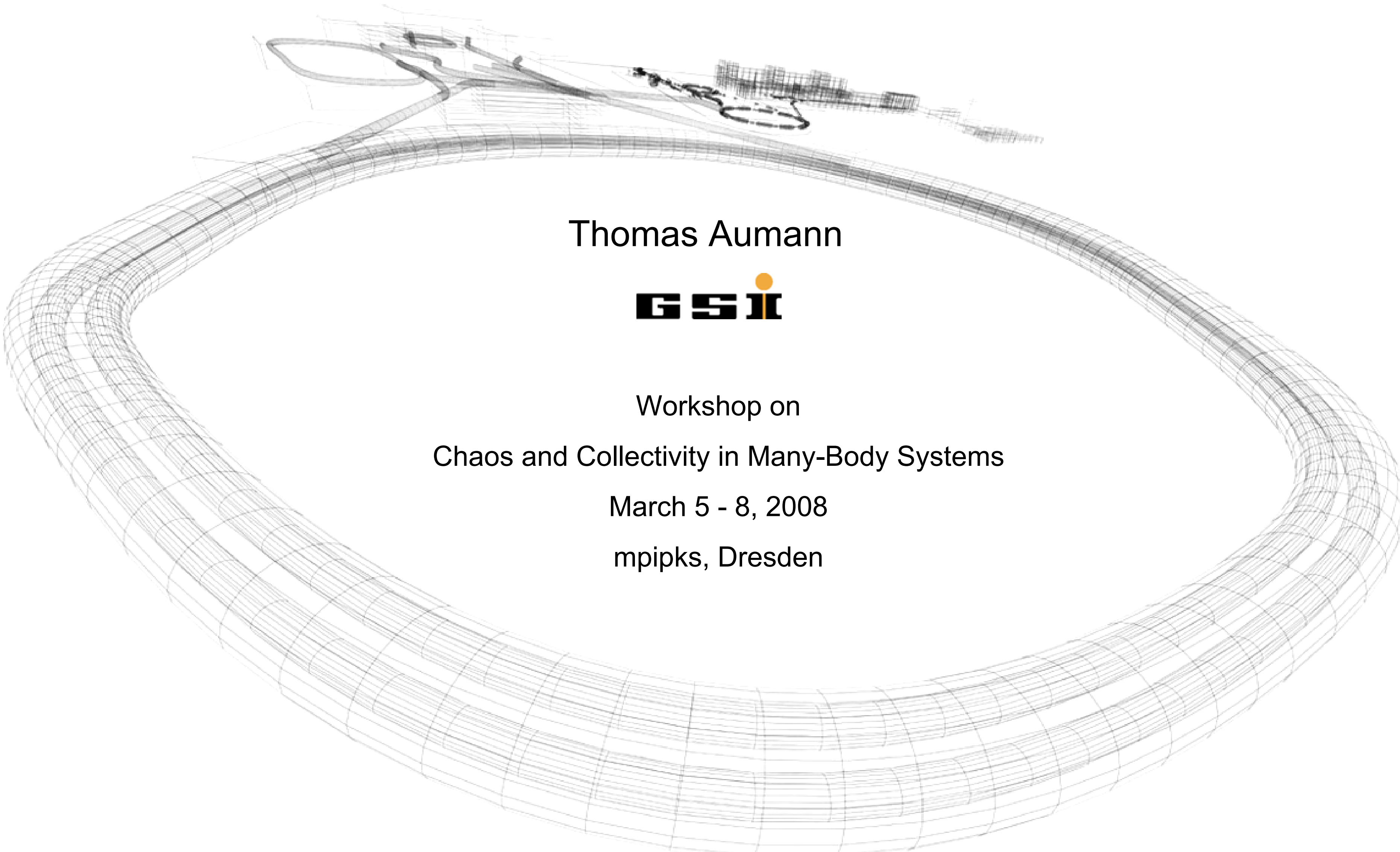
Excitation and decay of multi-phonon giant resonances



Thomas Aumann

GSI

Workshop on

Chaos and Collectivity in Many-Body Systems

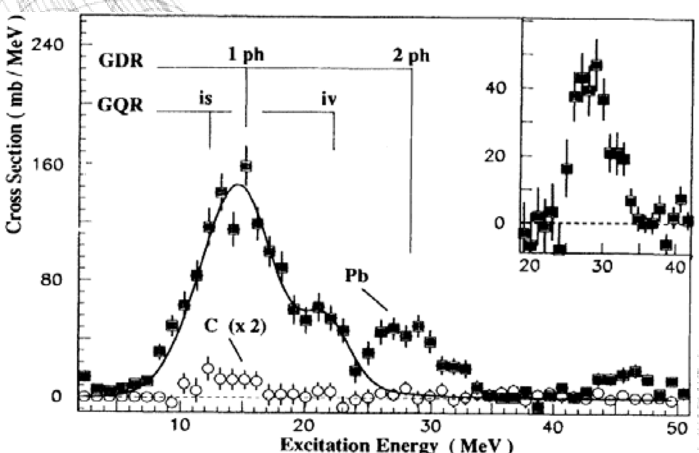
March 5 - 8, 2008

mpipks, Dresden

Excitation and decay of multi-phonon giant resonances

Thomas Aumann

GSI



- Introduction
- Experimental evidence
- Heavy-ion induced electromagnetic excitation
- Harmonicity of giant vibrations
- Decay properties and damping
- Conclusion

The collective response of the nucleus: Giant Resonances

Electric giant resonances

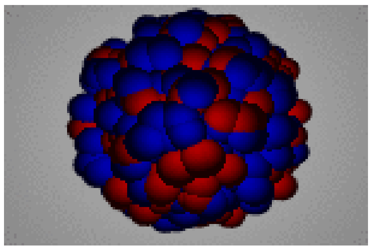
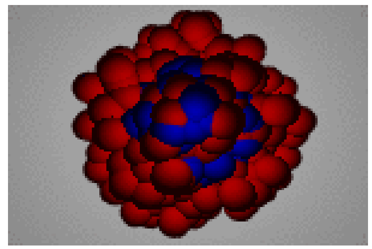
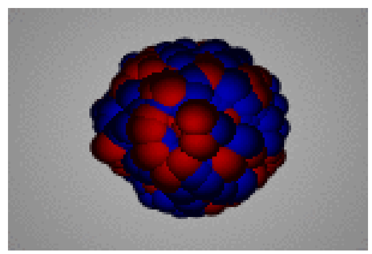
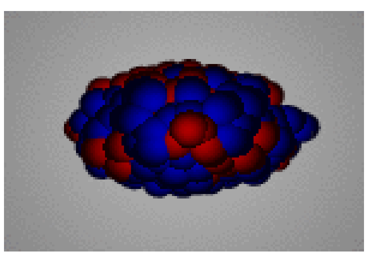
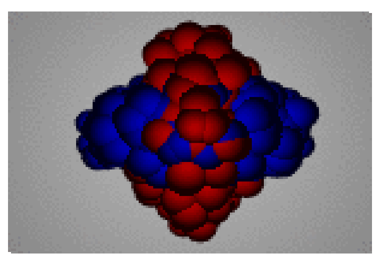
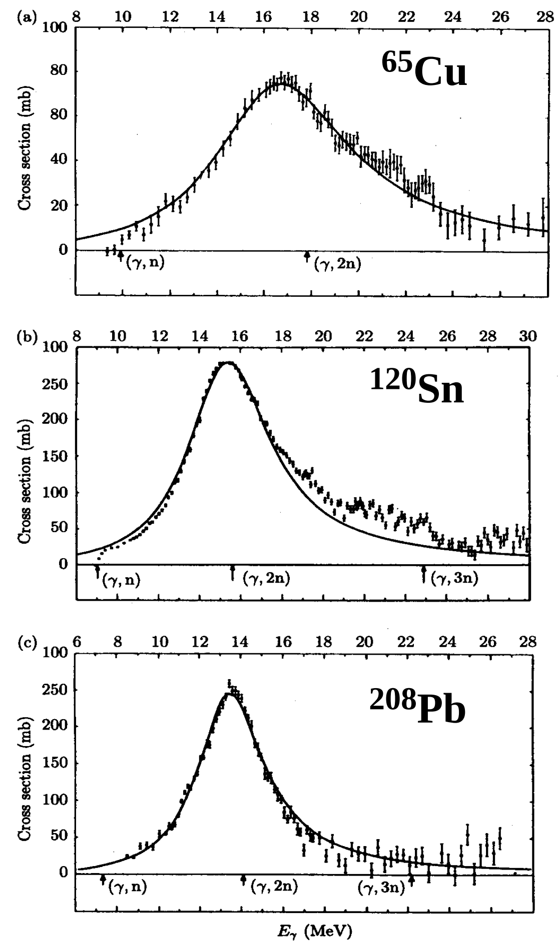
	Isoscalar	Isovector
Monopole (GMR)		
Dipole (GDR)		
Quadrupole (GQR)		

Photo-neutron cross sections

Berman and Fulz, Rev. Mod. Phys. 47 (1975) 47



Multi-phonon giant resonances

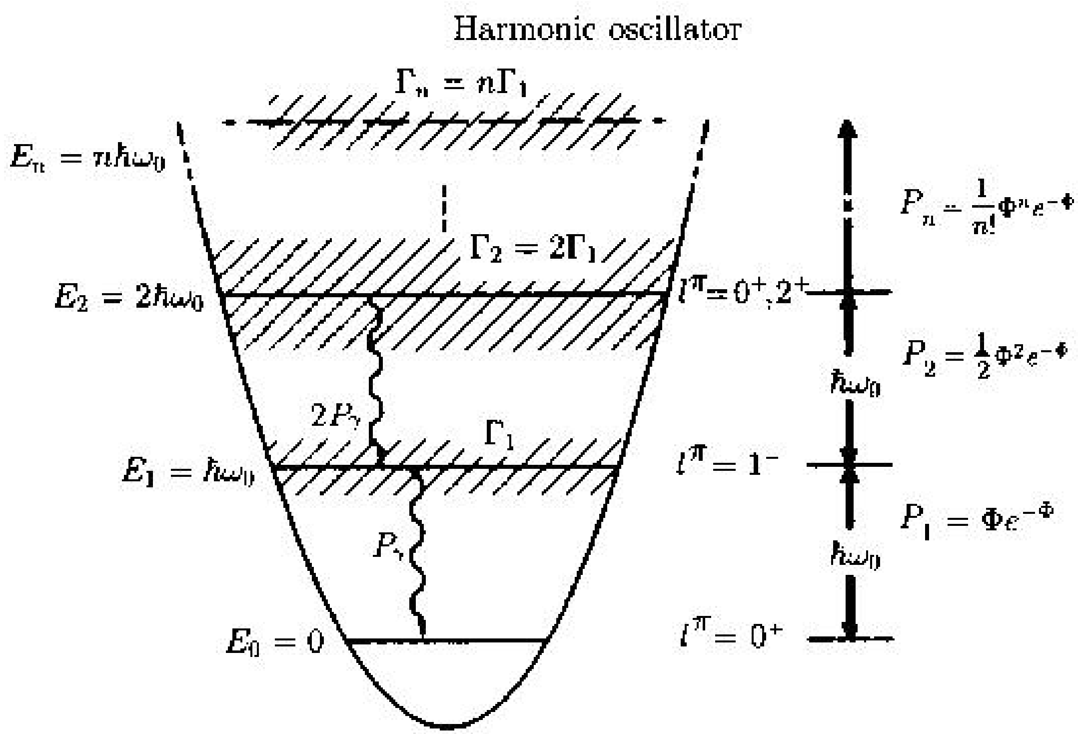


FIG. 9.2. Multiphonon states of a one-dimensional linear harmonic vibrator of $J^\pi = 1^-$ phonons (IVGDR). After (EML94).

Experimental Evidence

<u>Two-phonon giant resonances were observed in:</u>

- Double-charge exchange reactions: DIAS , DGDR (ΔT_z = ± 2) [Los Alamos]

S. Mordechai, H. Fortune, J. O'Donell, G.Lui, M. Burlein, A. Waosmaa, S. Greene, C. Morris, N. Auerbach, S. Yoo, and C. Moore, Phys. Rev. C41, 202 (1990).

- Inelastic heavy-ion scattering : isoscalar DGQR [Orsay]

P. Chomaz and N. Frascaria, Phys. Rep. **252**, 275 (1995)

- Relativistic Coulomb breakup: DGDR DGDR (ΔT_z = 0) [GSI]

T. Aumann, P. F. Bortignon, and H. Emling, Ann. Rev. Nucl. Part. Sci. 48, 351 (1998).

Double charge-exchange reactions

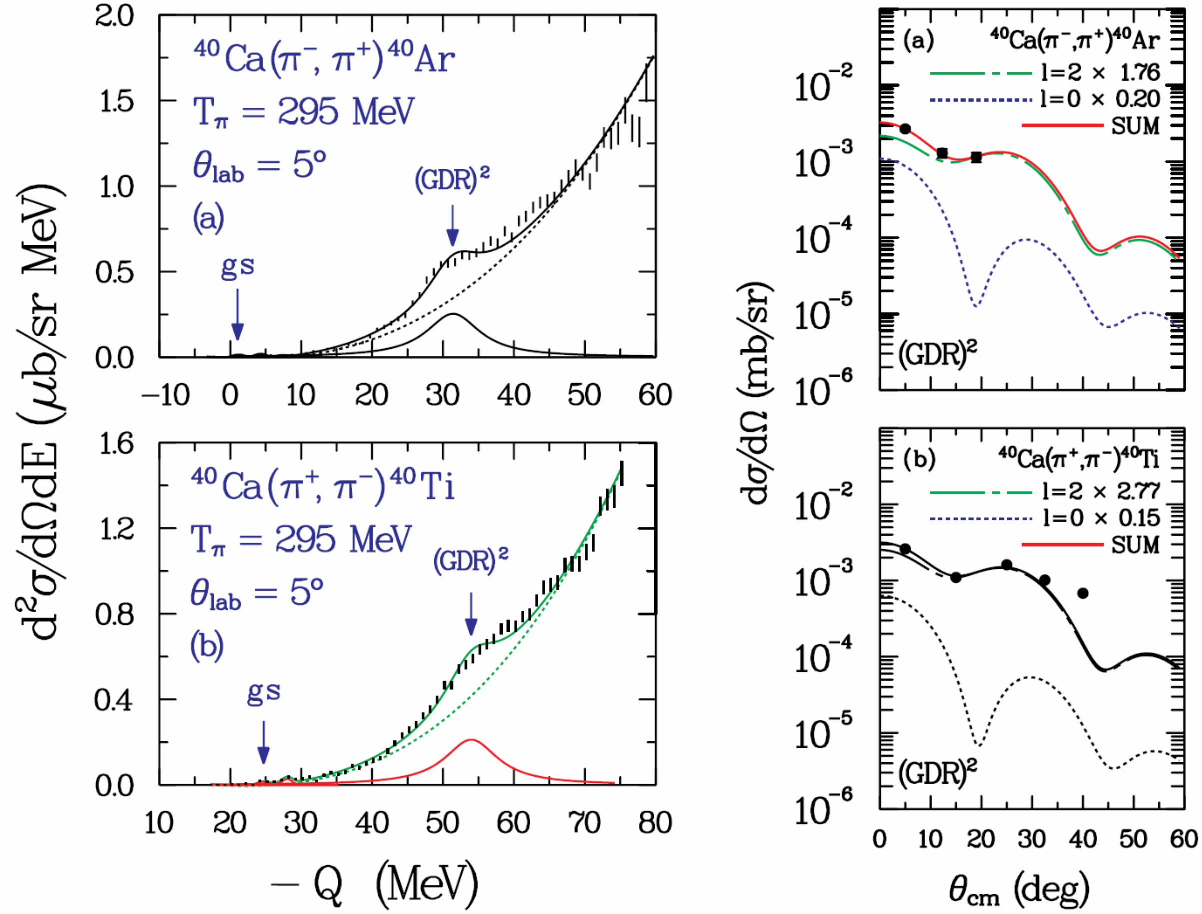
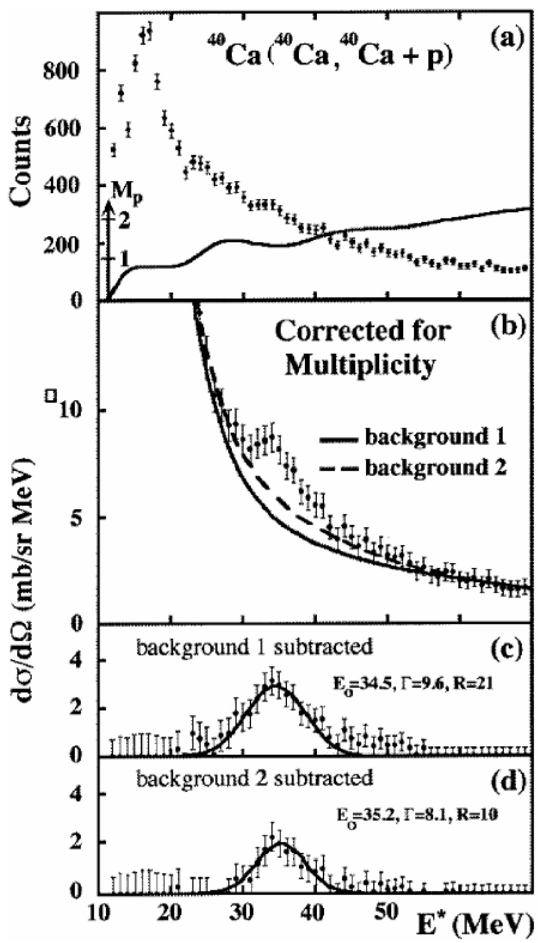
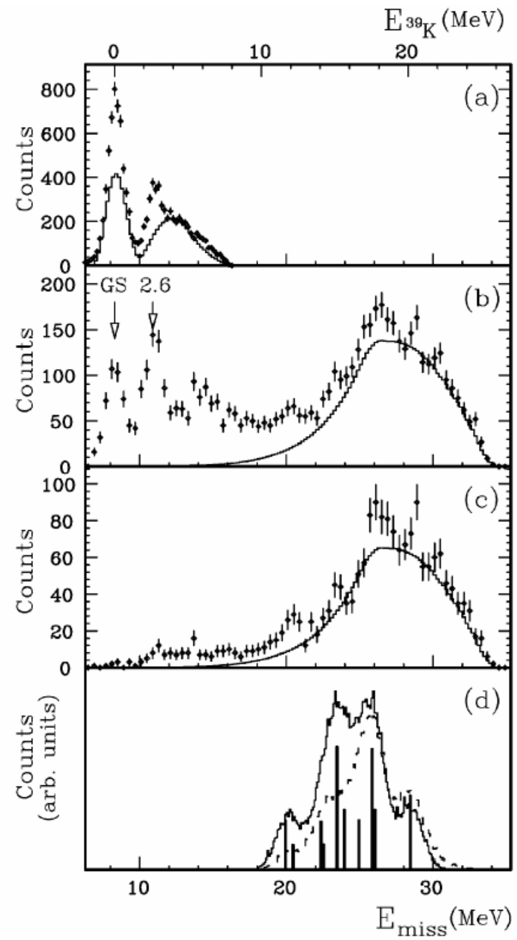


Figure 11 *Left*: Doubly differential cross section for the (π^-, π^+) (*upper panel*) and (π^+, π^-) (*lower panel*) reaction on ^{40}Ca. The position of the ground state and the double giant dipole resonance (DGDR) are indicated by *arrows*. *Right*: Angular distributions for the DGDR in the same reaction. Calculated cross sections for the $l = 2$ and $l = 0$ components, scaled by the indicated factors, are also shown. From Mordechai & Moore (62).

S. Mordechai, H. Fortune, J. O'Donell, G.Lui, M. Burlein, A. Waosmaa, S. Greene, C. Morris, N. Auerbach, S. Yoo, and C. Moore, Phys. Rev. C41, 202 (1990).

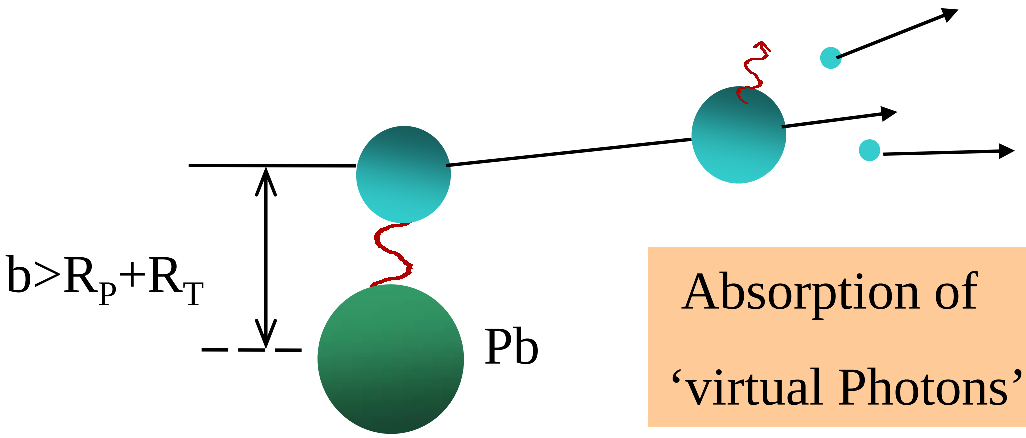
Nuclear excitation of double GQR





P. Chomaz and N. Frascaria, Phys. Rep. 252, 275 (1995)

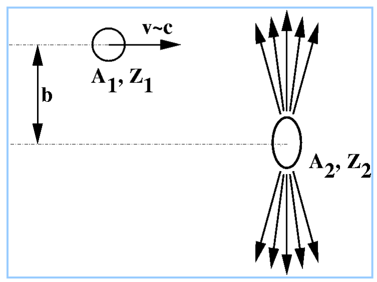
Electromagnetic excitation at high energies



$\sigma_{elm} \sim Z^2$

Absorption of

‘virtual Photons’



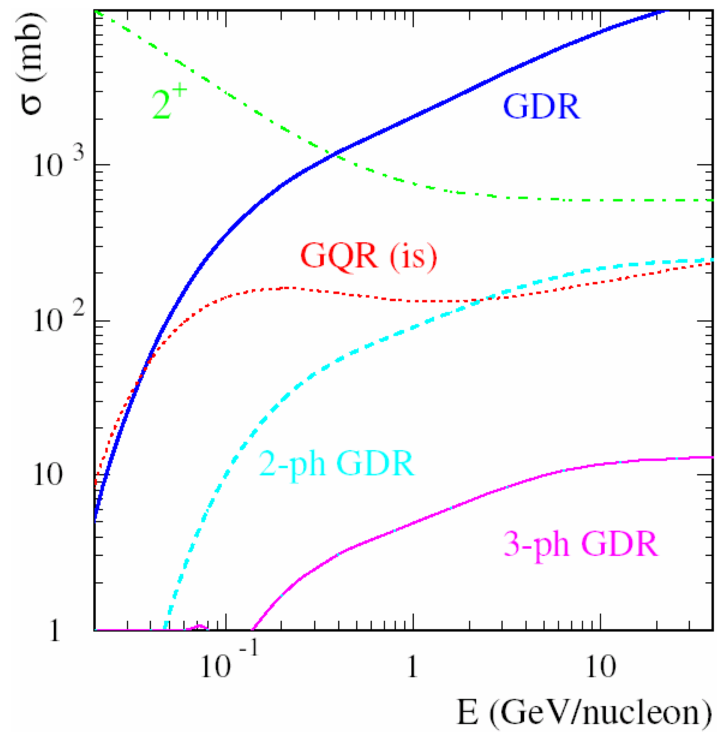
High velocities v/c≈0.6-0.9

⇒ High-frequency Fourier components

$E_{\gamma,max} \approx 25$ MeV (@ 1 GeV/u)

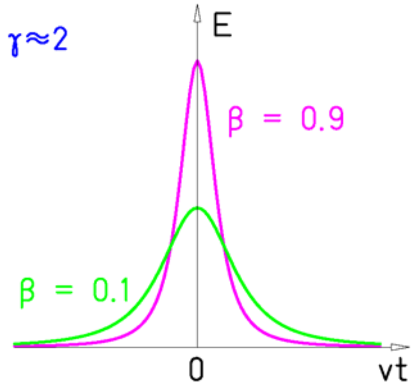
Semi-classical theory:

$d\sigma_{elm} / dE = N_\gamma(E)\, \sigma_\gamma(E)$



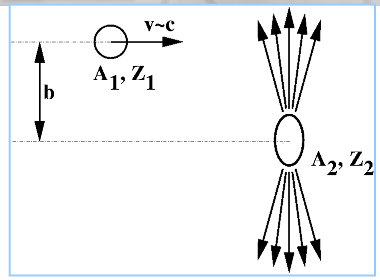
Determination of ‘photon energy’ (excitation energy) via a kinematically complete measurement of the momenta of all outgoing particles (invariant mass)

Electromagnetic excitation at high energies



Two effects:

velocity plus Lorentz contraction

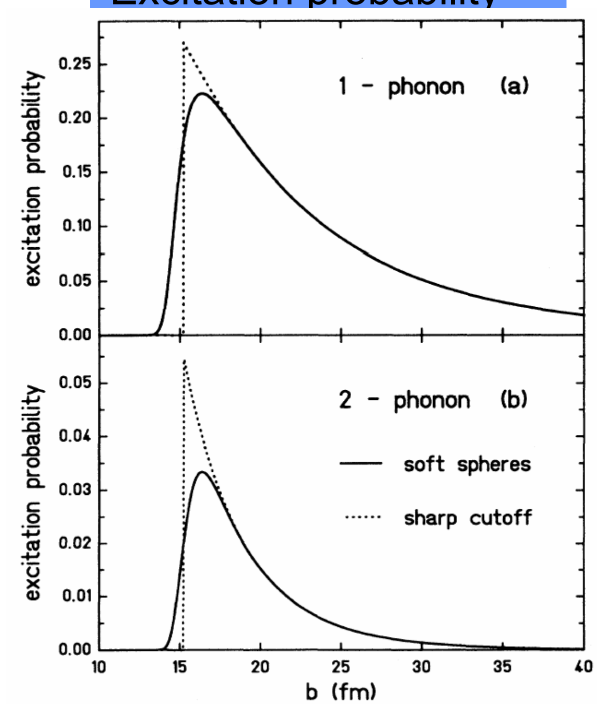


adiabatic cut-off:

$$E_{\max} = \frac{\hbar}{\tau} = \frac{\hbar c \gamma \beta}{b}$$

E_{max}=25MeV for 1 GeV/u

Excitation probability

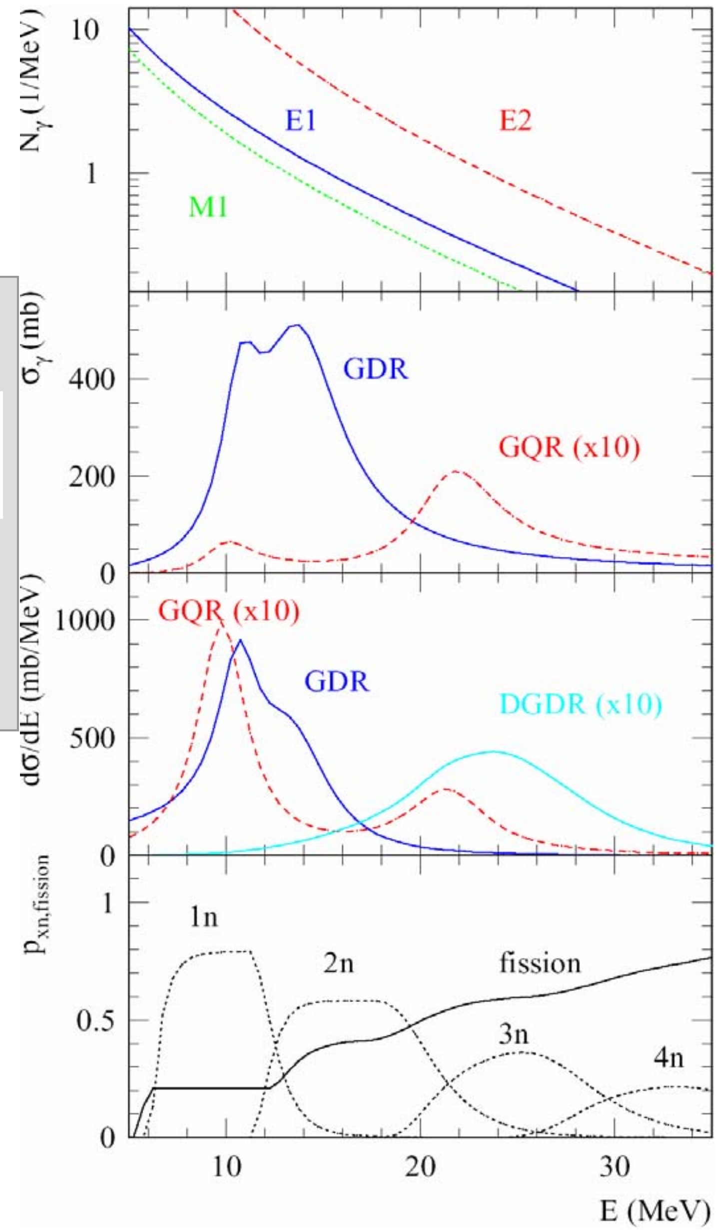


1

approaches plane wave

for $\gamma \gg 1$

all $N_{\pi l}$ equal (as for real photon beams)



Inclusive measurements

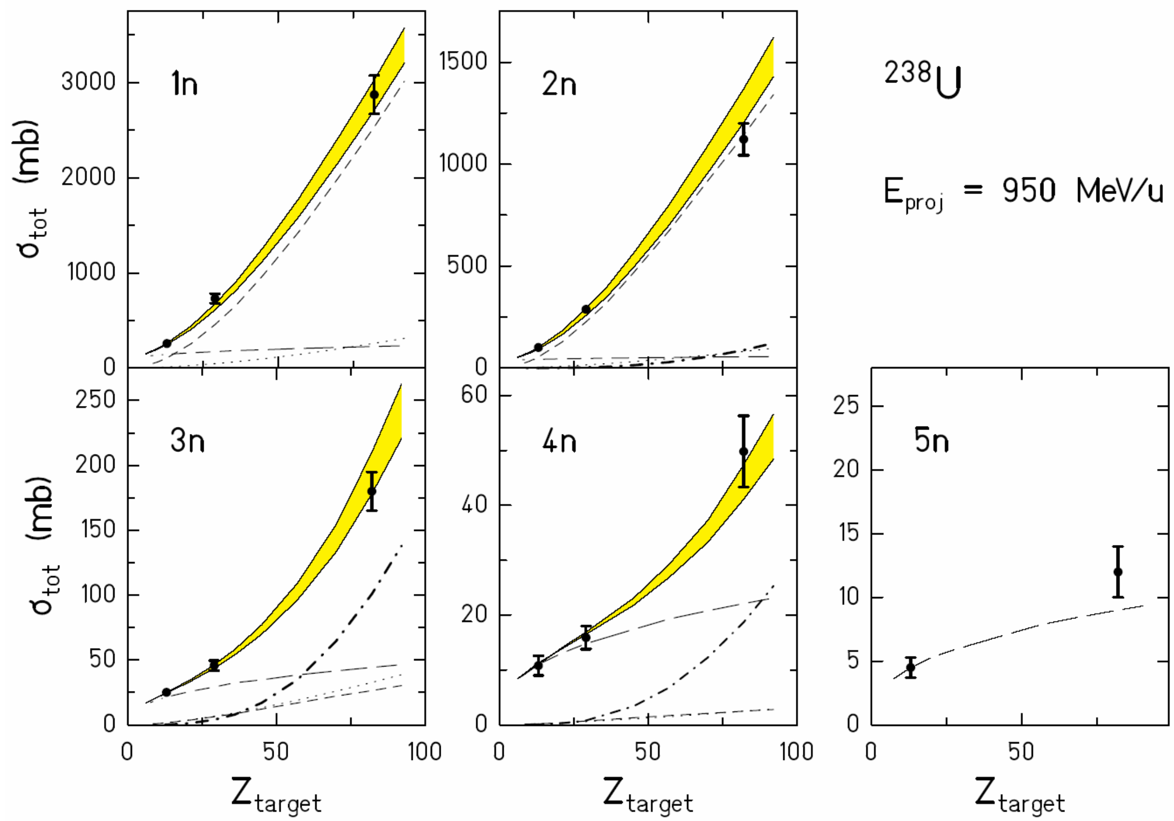


Figure 12 Cross sections for the $1n$- to $5n$-removal products from ^{238}U projectiles at about 950 MeV/u incident on targets of nuclear charge Z_{target} (74). The *full curves* delineating the *hatched areas* denote calculations using two different experimental giant dipole resonance (GDR) parameter sets (76, 77). They represent the sum of the nuclear contribution (*long-dashed curve*) and the electromagnetic contributions due to excitation of the GDR (*short-dashed curve*), giant quadrupole resonance (*dotted curve*), and double GDR (*dot-dashed curve*). For the $4n$ channel the dotted curve coincides with the short-dashed one.

Direct photon decay

Elm excitation

GSI - SIS

Jim Ritman et al.

TAPS

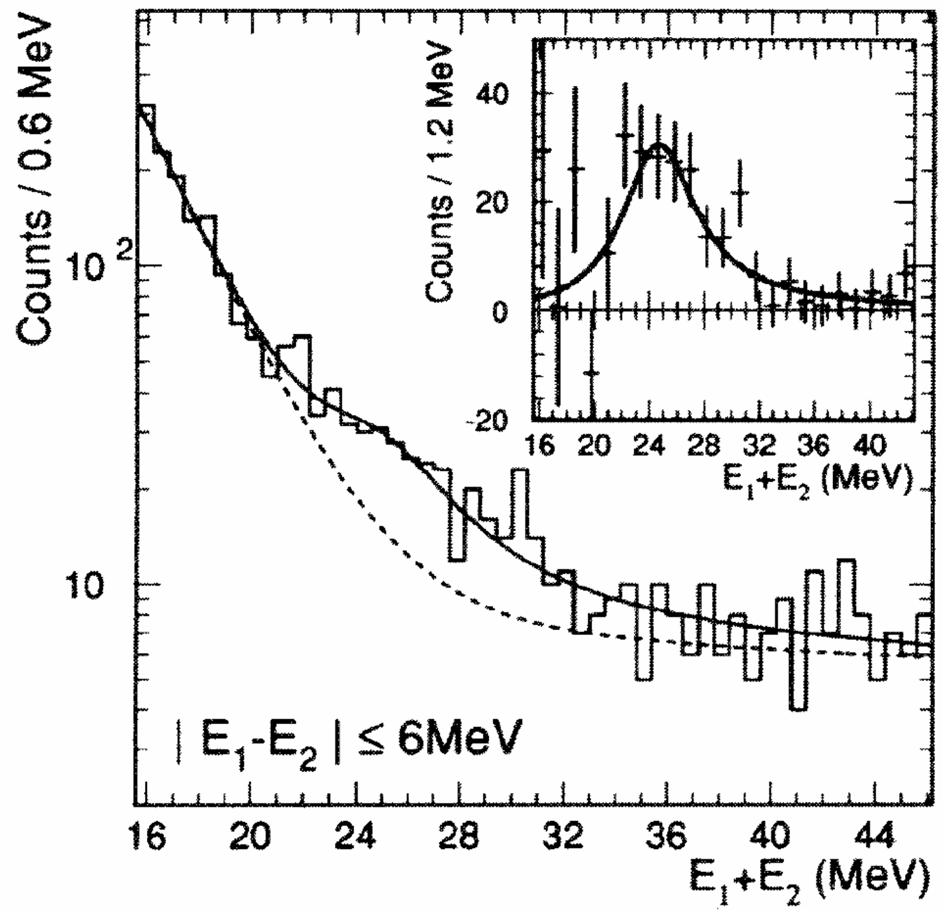
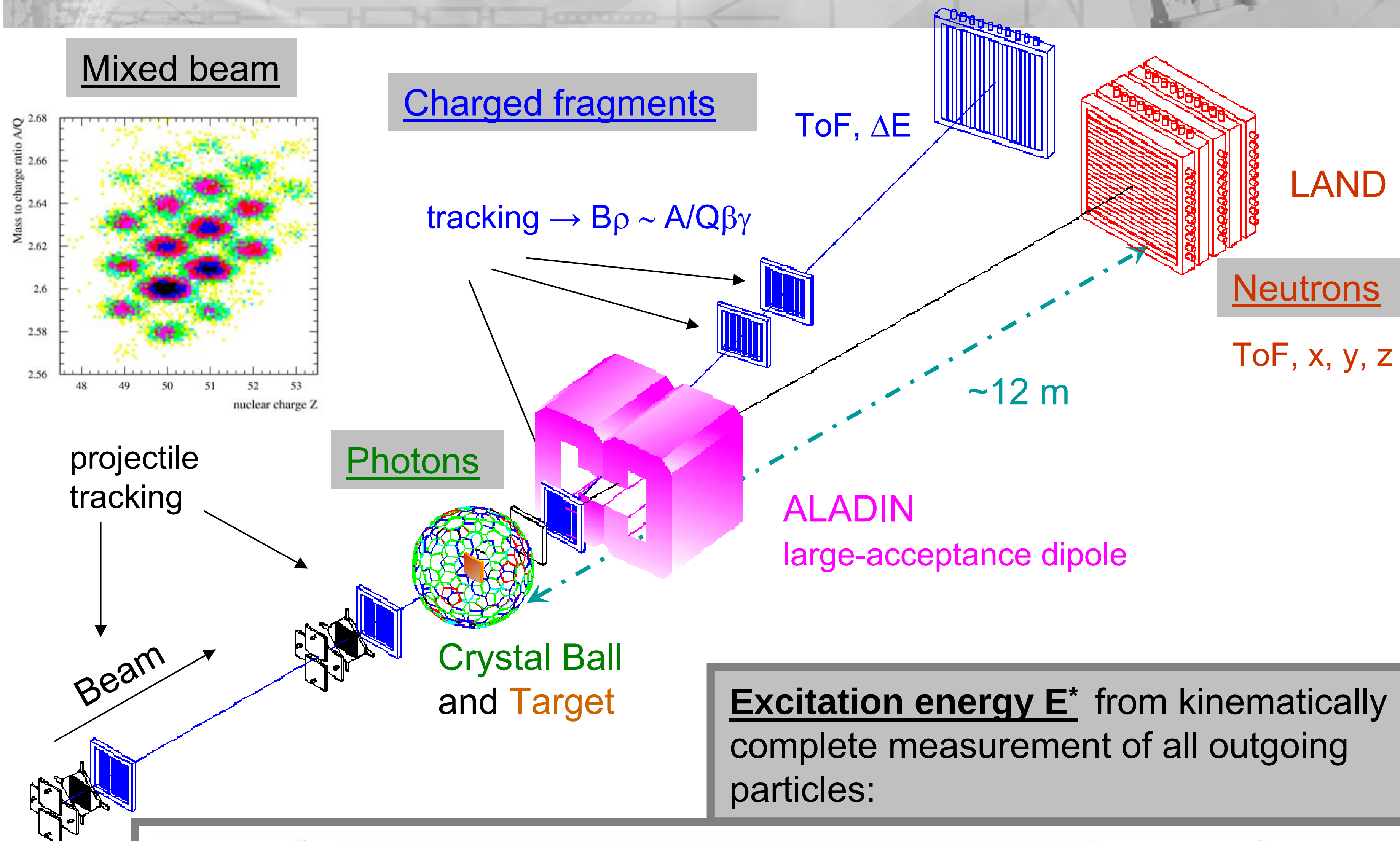


Figure 15 Sum energy of coincident photon pairs measured in the reaction 1 GeV/u ^{209}Bi on ^{208}Pb (87). The structure at around 26 MeV is assigned to the two-photon decay of the DGDR excited in the ^{208}Pb target nuclei. The inset shows a Lorentzian fit to the yield obtained after subtracting the background shown as *dotted curve*.

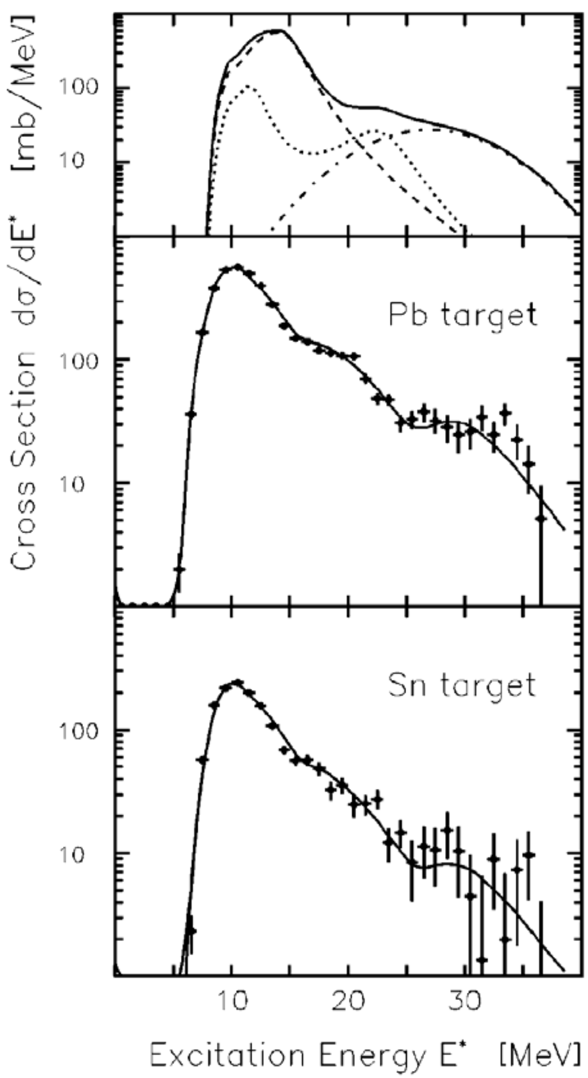
The LAND reaction setup @GSI

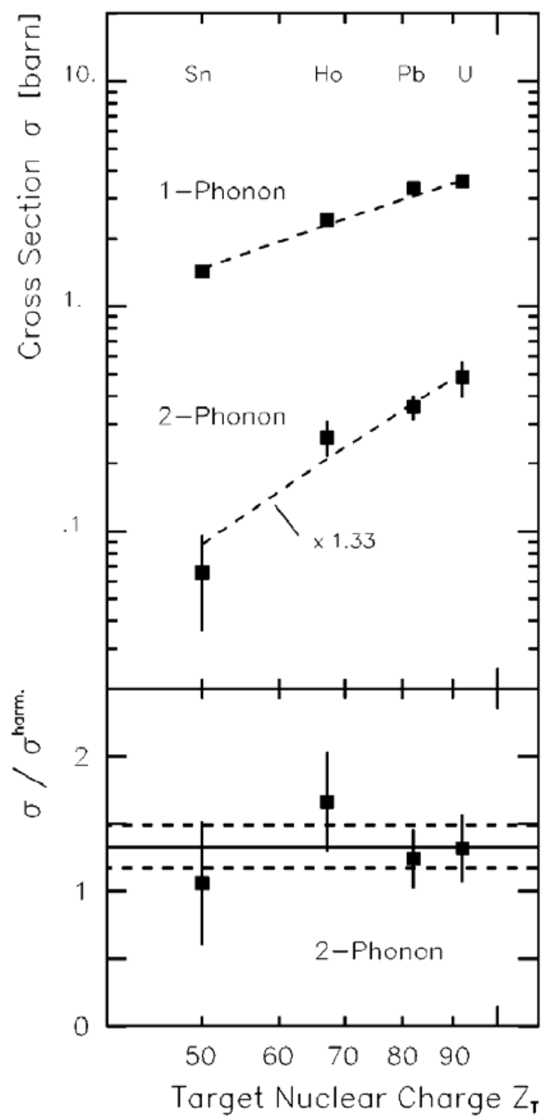


Excitation energy E* from kinematically complete measurement of all outgoing particles:

$$E^* = \left(\sqrt{\sum_i m_i^2 + \sum_{i \neq j} m_i m_j \gamma_i \gamma_j (1 - \beta_i \beta_j \cos\theta_{ij})} - m_{proj}\right) c^2 + E_\gamma$$

LAND data: DGDR in Pb





Harmonicity of giant vibrations

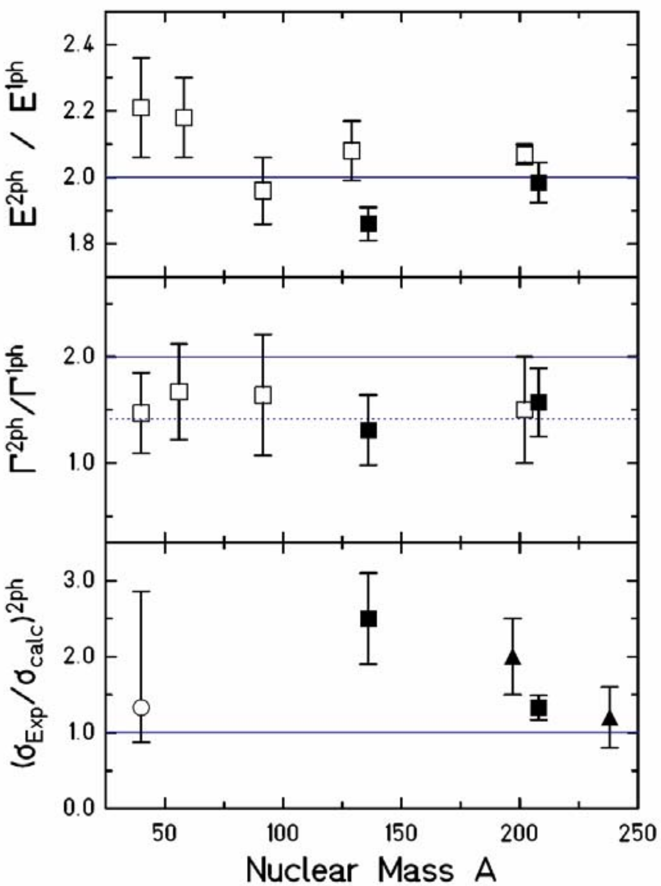


Figure 16 *Top*: Peak energies E of two-phonon states relative to those of one-phonon states. *Full* and *open symbols* denote data for dipole resonances from heavy-ion experiments and from pion charge exchange reactions, respectively. The *solid line* indicates the value expected in the harmonic limit. *Middle*: Same as above, but for the width Γ. The *dashed lines* correspond to a value of $\sqrt{2}$. *Bottom*: Ratio of experimental to calculated electromagnetic cross sections for the double giant dipole resonance (*triangles*: inclusive measurements; *squares*: exclusive measurements). The calculations were made in the harmonic approximation using the folding model. The *circle* denotes a corresponding value for the double giant quadrupole resonance.

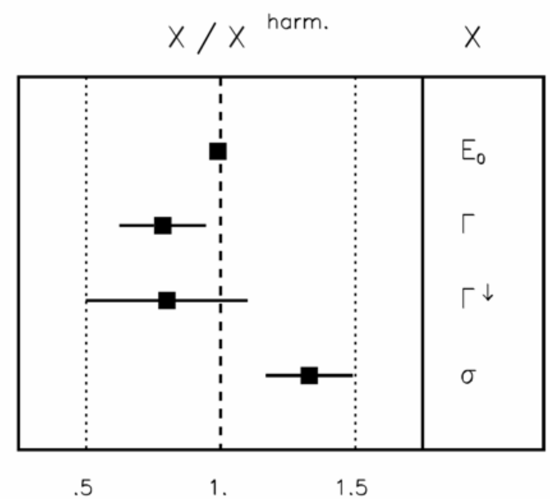
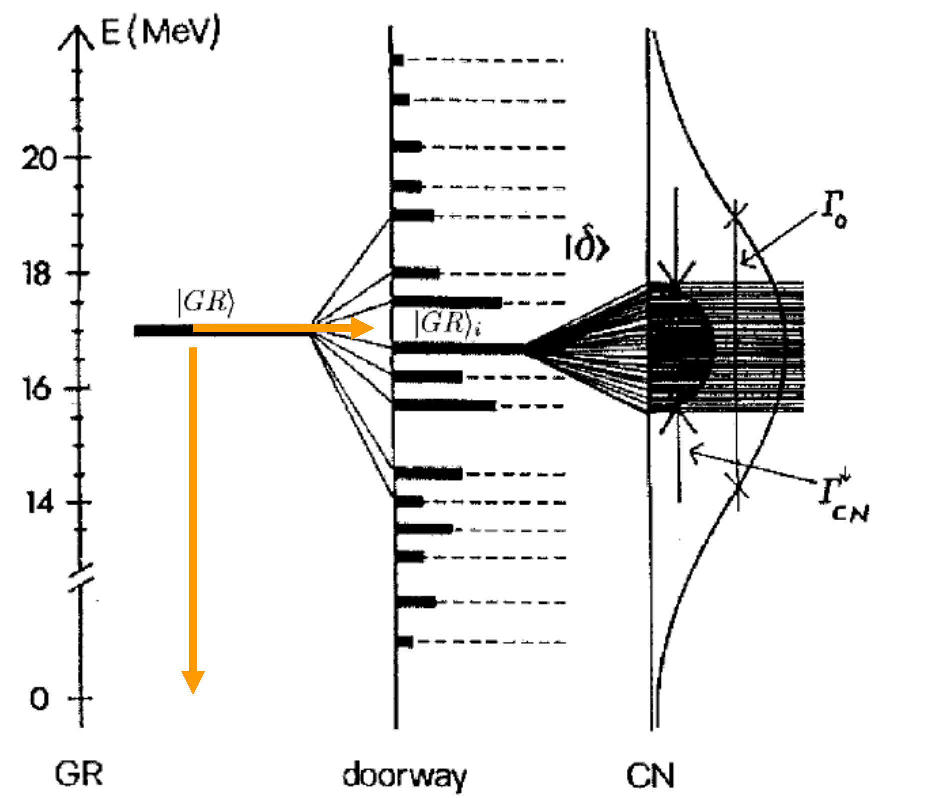


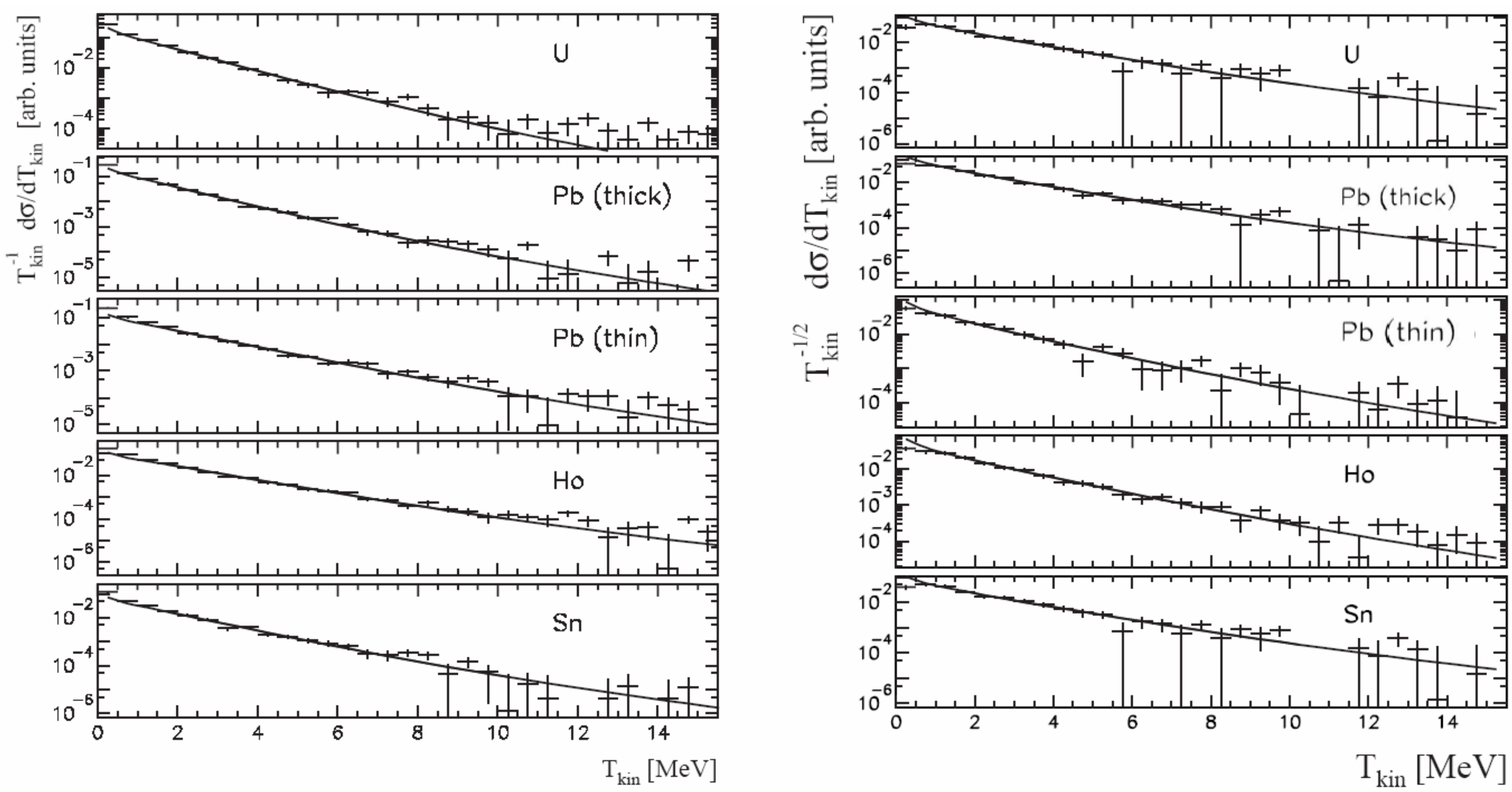
Figure 17 Comparison of experimental quantities X for the two-phonon giant dipole resonance in ^{208}Pb with those ($X^{harm.}$) obtained in the independent phonon model. Results for the resonance peak energy E_0, width Γ, and the electromagnetic cross section σ are taken from Boretzky et al (51). The value for the spreading width $\Gamma^{\downarrow}$ is derived in Section 5.4. The values $X^{harm.}$ are obtained from the experimentally known properties of the single dipole resonance.

Decay properties and damping



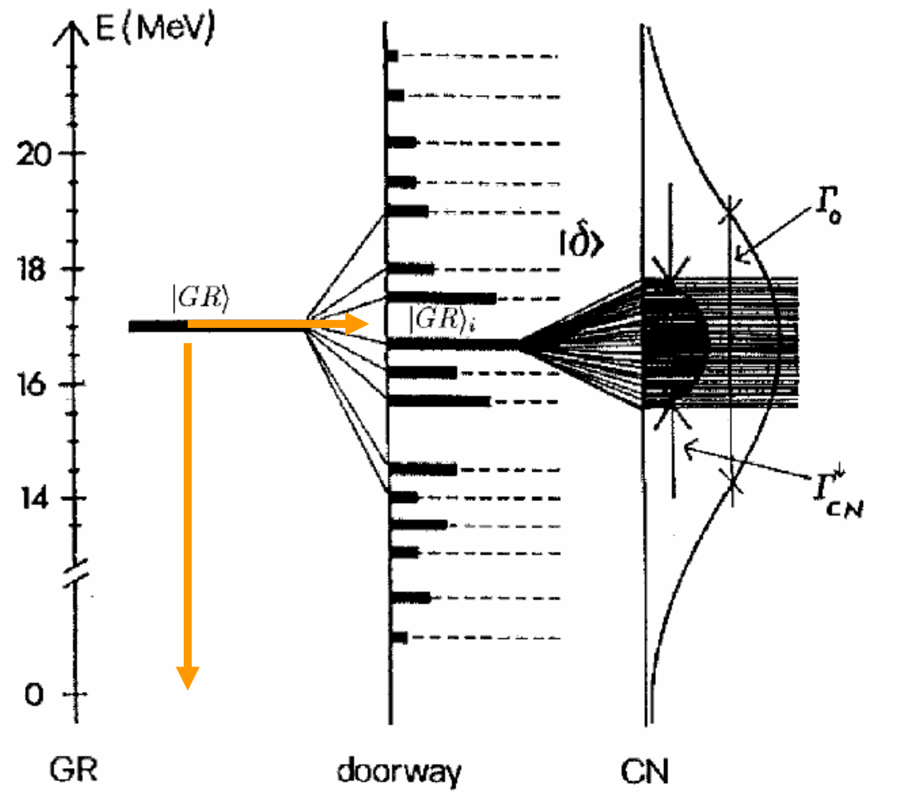
Decay properties and damping

Neutron kinetic-energy spectra



Statistical decay, very little direct neutron decay

LAND data, K. Boretzky et al.



$$BR^{1ph}_{\gamma/n} = 0.019 \pm 0.002$$

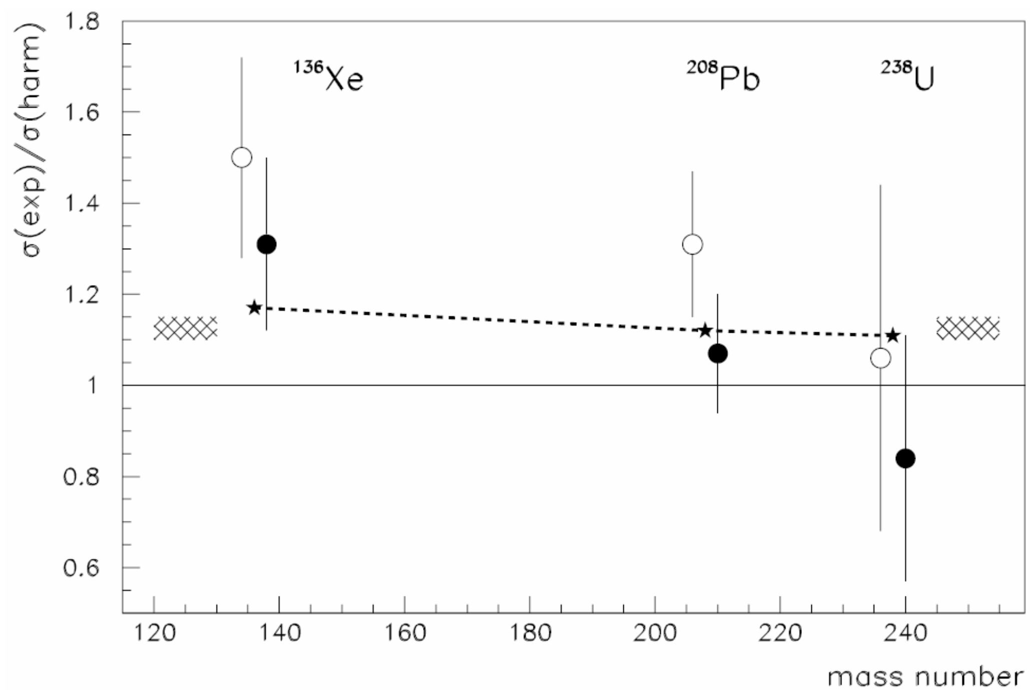
$$R^{2ph}_{2\gamma/n} = (4.5 \pm 1.5) \cdot 10^{-4}$$

$$BR^{2ph}_{2\gamma/n} = \frac{\Gamma^{2ph}_{\gamma}}{(\Gamma\downarrow)^{2ph}} \frac{\Gamma^{1ph}_{\gamma}}{(\Gamma\downarrow)^{1ph}} = 2 \cdot \frac{(\Gamma\downarrow)^{1ph}}{(\Gamma\downarrow)^{2ph}} \left[\frac{\Gamma^{1ph}_{\gamma}}{(\Gamma\downarrow)^{1ph}} \right]^2$$

Independent determination of spreading width

$$(\Gamma^{\downarrow})^{2ph}/(\Gamma^{\downarrow})^{1ph} = 1.6 \pm 0.5$$

Cross section enhancement: unharmonicity?



Cross section enhancement: unharmonicity?

PHYSICAL REVIEW C VOLUME 56, NUMBER 1 JULY 1997

Anharmonic effects in the excitation of double-giant dipole modes in relativistic heavy-ion collisions

P. F. Bortignon[1] and C. H. Dasso[2]
[1]*Dipartimento di Fisicà and INFN, Universita di Milano, Milano, Italy*
[2]*The Niels Bohr Institute, Blegdamsvej 17, Copenhagen Ø, Denmark and ECT*, Strada delle Tabarelle 286, I-38050, Villazzano, Trento, Italy*
(Received 27 December 1996)

We investigate the consequences of anharmonic terms in the vibrational spectrum of giant dipole resonances for the double Coulomb excitation of such modes in relativistic heavy-ion collisions. It is found that apparent discrepancies between the results of two separate experiments can be put in harmony assuming minor departures from the harmonic limit because of the special features of the reaction mechanism.

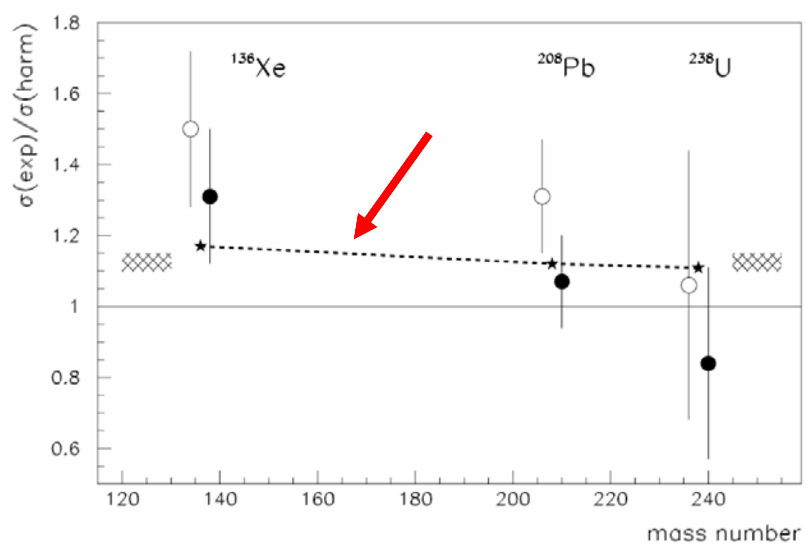
Cross section enhancement: unharmonicity?

PHYSICAL REVIEW C, VOLUME 64, 064605

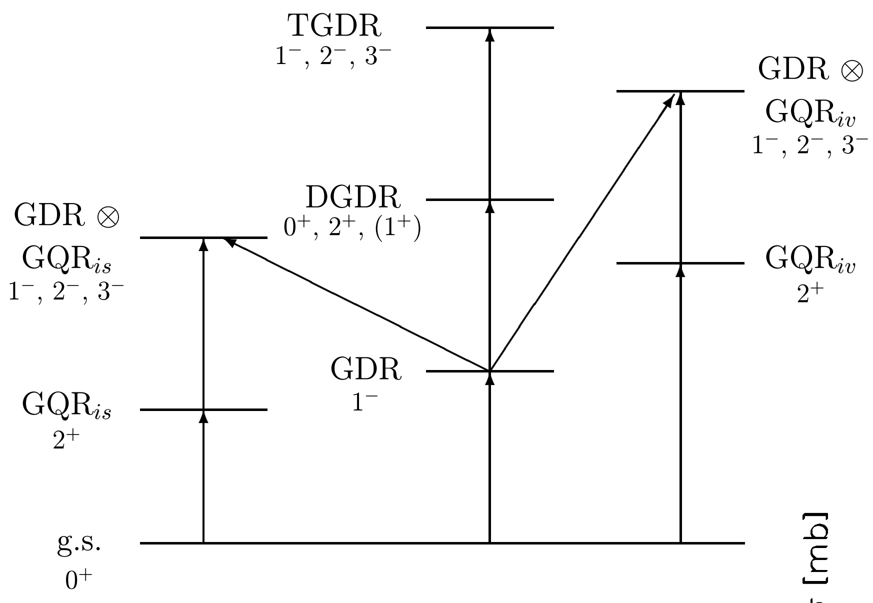
Anharmonicities of giant dipole excitations

D. T. de Paula,[1] T. Aumann,[2] L. F. Canto,[1] B. V. Carlson,[3] H. Emling,[2] and M. S. Hussein[4]
[1]*Instituto de Física, Universidade Federal do Rio de Janeiro, Caixa Postal 68528, 21945-970 Rio de Janeiro, Brazil*
[2]*Gesellschaft für Schwerionenforschung (GSI), Planckstrasse 1, D-64291 Darmstadt, Germany*
[3]*Departmento de Física, Instituto Tecnológico de Aeronáutica CTA, 12228-900 São José dos Campos, São Paulo, Brazil*
[4]*Instituto de Física, Universidade de São Paulo, Caixa Postal 66318, 05389-970 São Paulo, Brazil*
(Received 26 July 2001; published 16 November 2001)

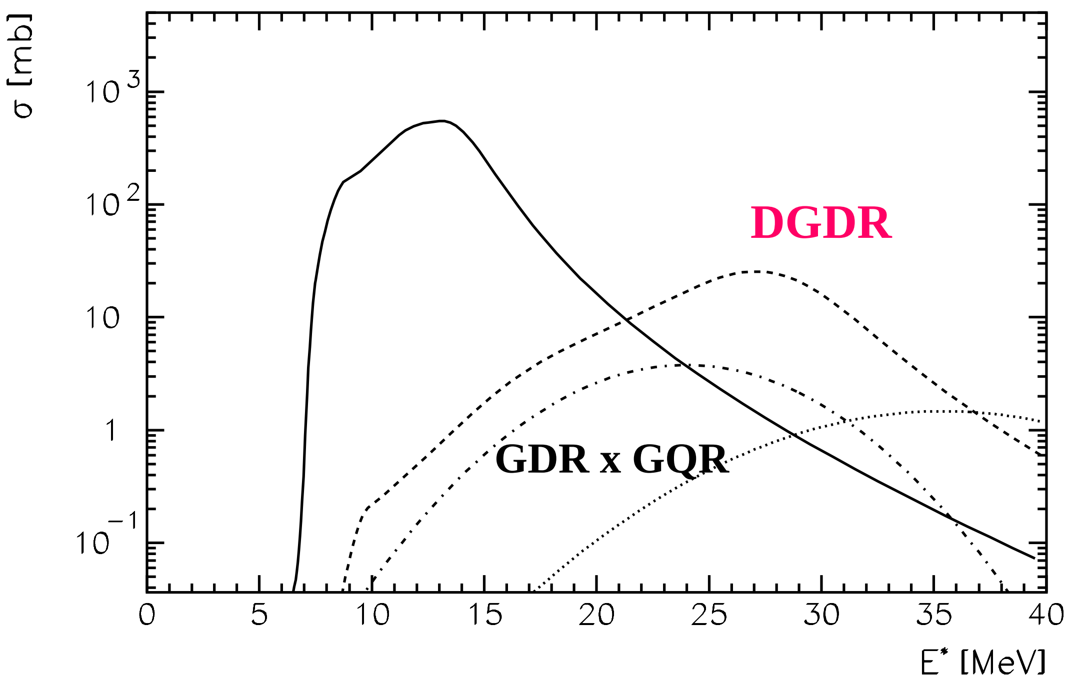
Effect of unharmonicity on cross section is small if frequeny of GDR is kept at experimental value



Mixed-phonon contributions



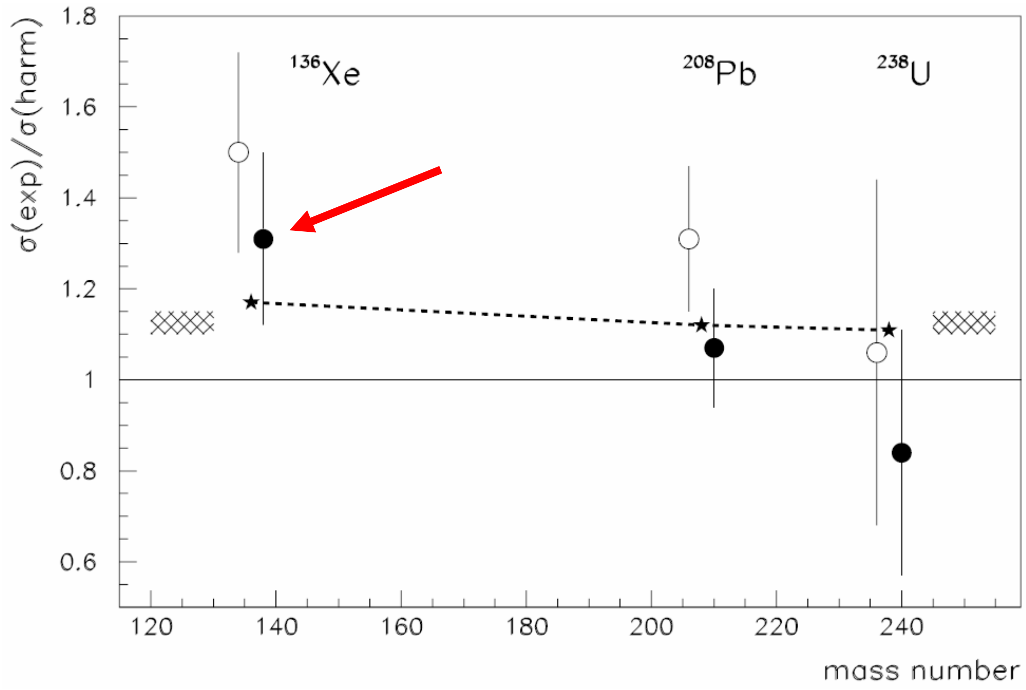
Lanza, Volpe, Chomaz et al.



contributions from mixed-phonon states typically on a 10% level

in the following, tentatively subtracted

Cross section enhancement: unharmonicity?



Dynamical effects

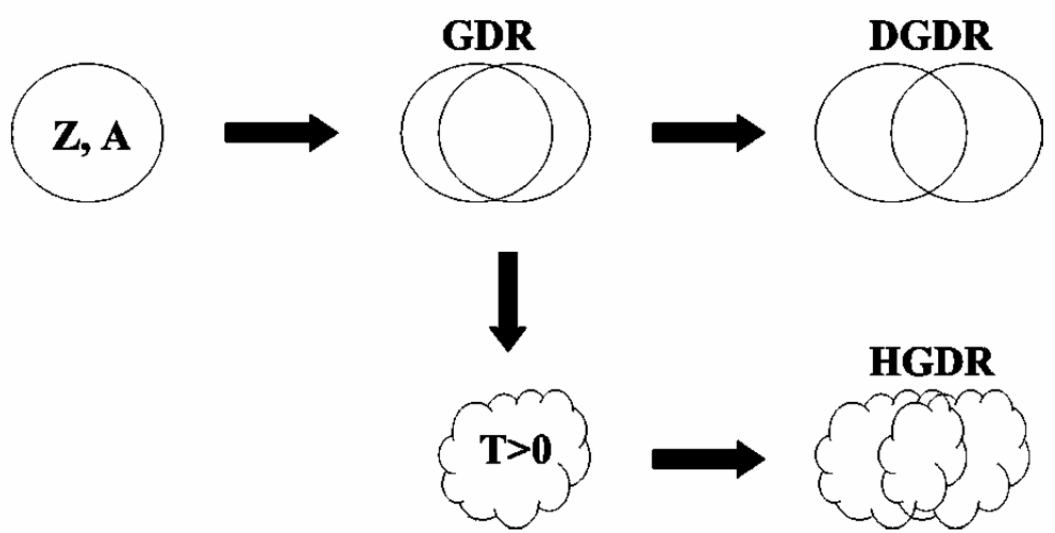
Theory of multiple giant dipole resonance excitation

B. V. Carlson
Departamento de Física, Instituto Tecnológico de Aeronáutica - CTA, 12228-900 São José dos Campos, SP, Brazil

M. S. Hussein and A. F. R. de Toledo Piza
Instituto de Física, Universidade de São Paulo, C.P. 66318, São Paulo, 05315-970, Brazil

L. F. Canto
Instituto de Física, Universidade do Rio de Janeiro, CP 68528, 21945-970 Rio de Janeiro RJ, Brazil
(Received 30 November 1998; published 16 June 1999)

A semiclassical description of multiple giant resonance excitation that incorporates incoherent fluctuation contributions of the Brink-Axel type is developed. Numerical calculations show that the incoherent contributions are important at low to intermediate bombarding energies. [S0556-2813(99)01705-7]



$\Gamma/h \sim 10^{21}\ s^{-1}$

$t_{int} \sim 10^{-22}\ s^{-1}$

see also

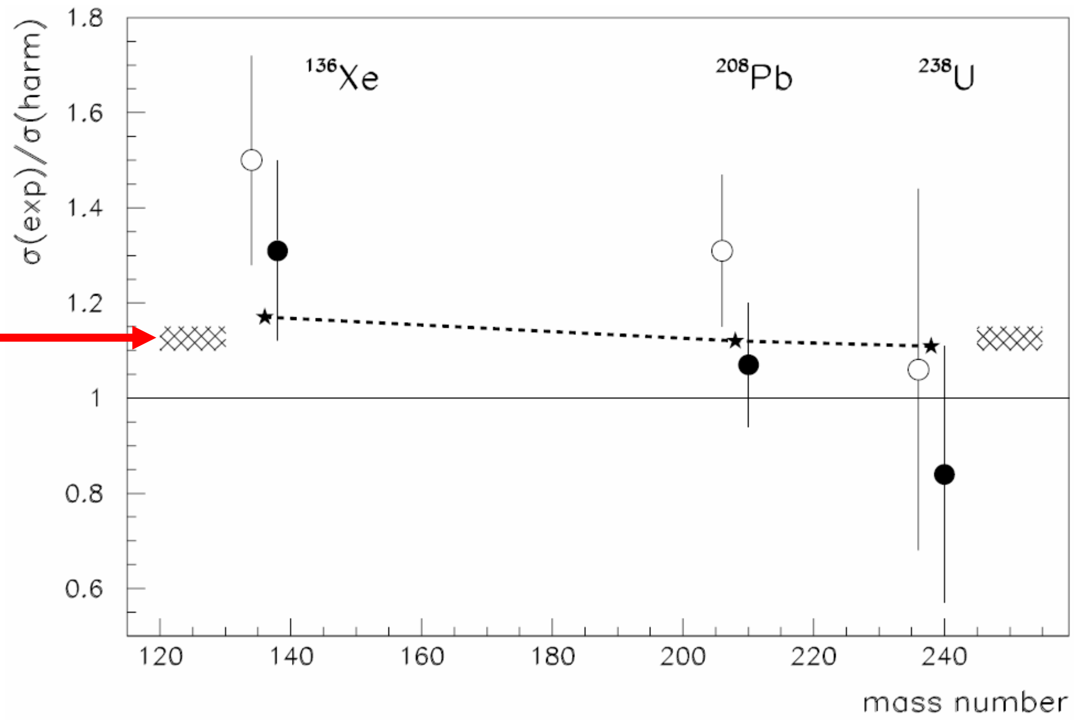
Gu and Weidenmüller

~ 10 %

should have a much more significant effect at lower beam velocities

Cross section enhancement

dynamical effects



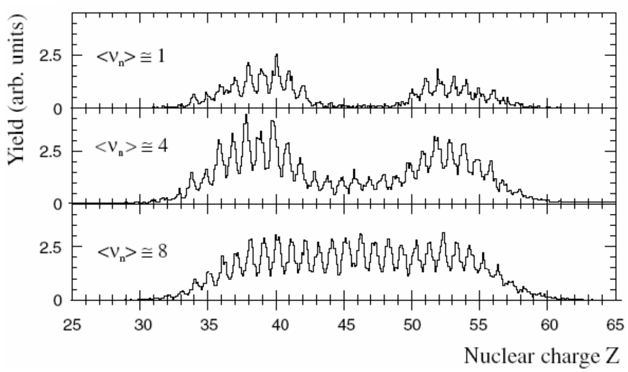
Multi-phonon giant resonances in 238U

VOLUME 92, NUMBER 11 PHYSICAL REVIEW LETTERS week ending 19 MARCH 2004

Evidence for Multiphonon Giant Resonances in Electromagnetic Fission of ^{238}U

S. Ilievski,[1,2] T. Aumann,[2] K. Boretzky,[1,3] Th.W. Elze,[1] H. Emling,[2] A. Grünschloß,[1] J. Holeczek,[4] R. Holzmann,[2] C. Kozhuharov,[2] J.V. Kratz,[3] R. Kulessa,[4] A. Leistenschneider,[1] E. Lubkiewicz,[4] T. Ohtsuki,[3,5] P. Reiter,[6] H. Simon,[7] K. Stelzer,[1] J. Stroth,[2] K. Sümmerer,[2] E. Wajda,[4] and W. Waluś[4]

(LAND Collaboration)



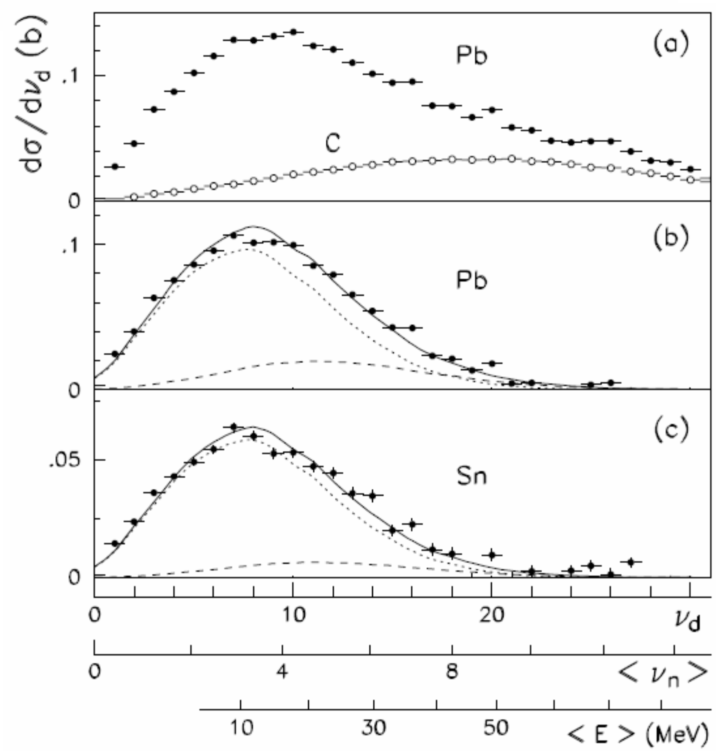


TABLE II. Calculated partial electromagnetic fission cross sections σ/σ^{emf} and their peak energies E_p for single- and multiphonon giant resonances in ^{238}U (500 MeV/nucleon) on Pb and Sn targets.

Resonance	E_p (MeV)	σ/σ^{emf} (Pb)	σ/σ^{emf} (Sn)
GDR	13.5	0.66	0.75
GQR_{is}	9.5	0.07	0.07
GQR_{iv}	21.0	0.06	0.07
GDR ⊗ GDR	23.0	0.15	0.09
GDR ⊗ GQR_{is}	21.0	0.02	0.01
GDR ⊗ GQR_{iv}	32.0	0.013	0.008
GDR ⊗ GDR ⊗ GDR	35.5	0.023	0.006

Conclusion

- Giant resonances are collective harmonic vibrations of the nucleus
- Multi-phonon excitations observed
- Excitation energy, decay properties and damping width in agreement with harmonic oscillator expectation
- Cross section enhancement explained by various mechanisms

Neutron-proton asymmetric nuclei

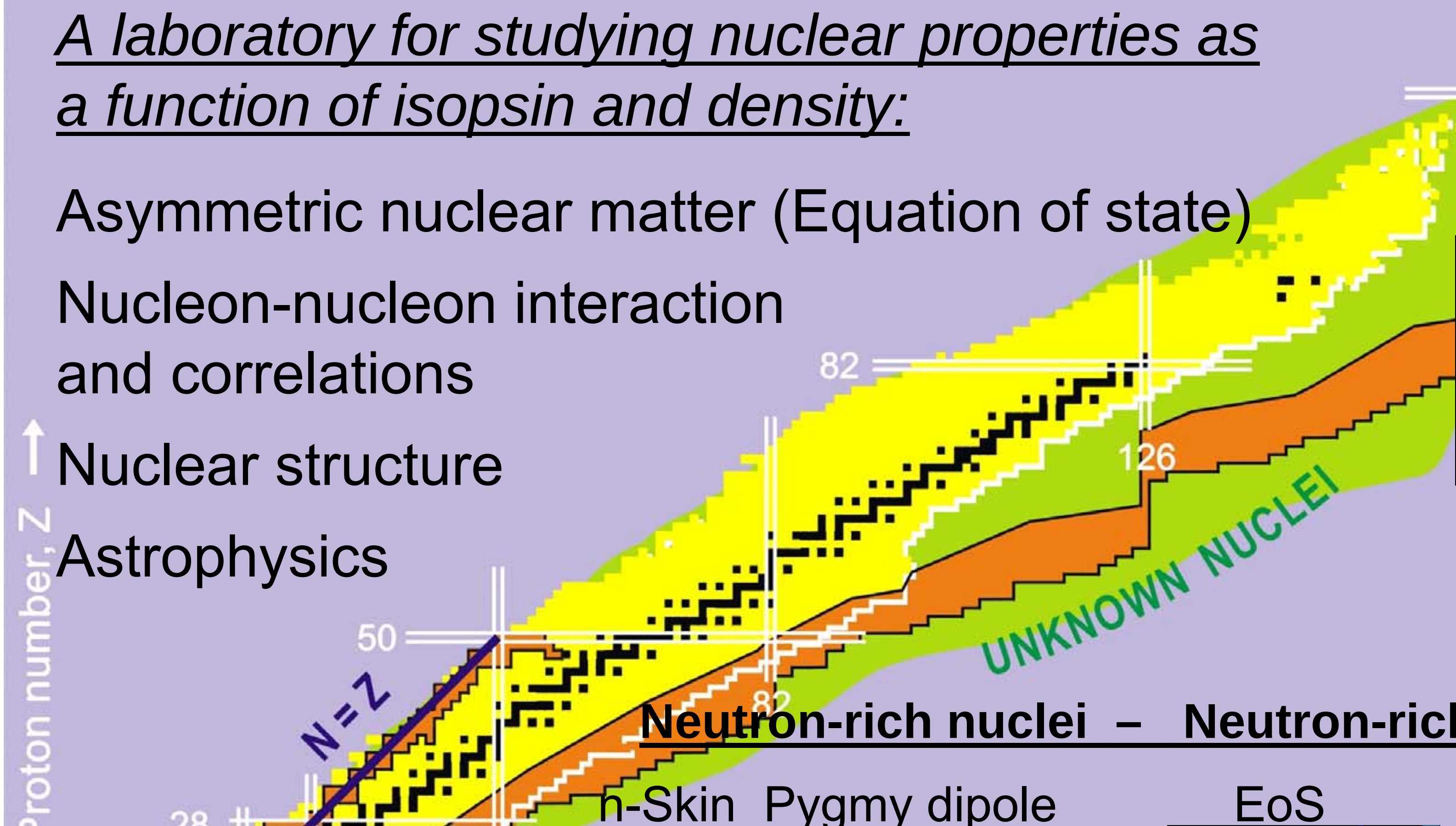
<u>*A laboratory for studying nuclear properties as a function of isopsin and density:*</u>

Asymmetric nuclear matter (Equation of state)

Nucleon-nucleon interaction and correlations

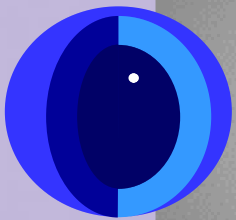
Nuclear structure

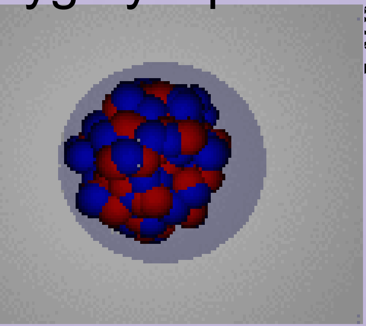
Astrophysics



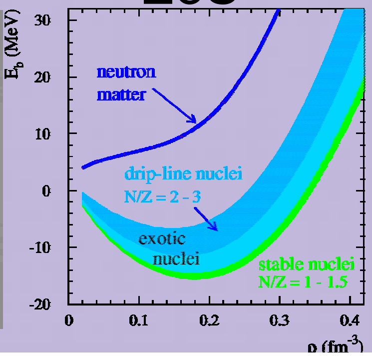
<u>Neutron-rich nuclei – Neutron-rich Matter</u>

n-Skin Pygmy dipole





EoS



Neutron Star