

The Ratio Problem In Nanotube Fluorescence Spectroscopy

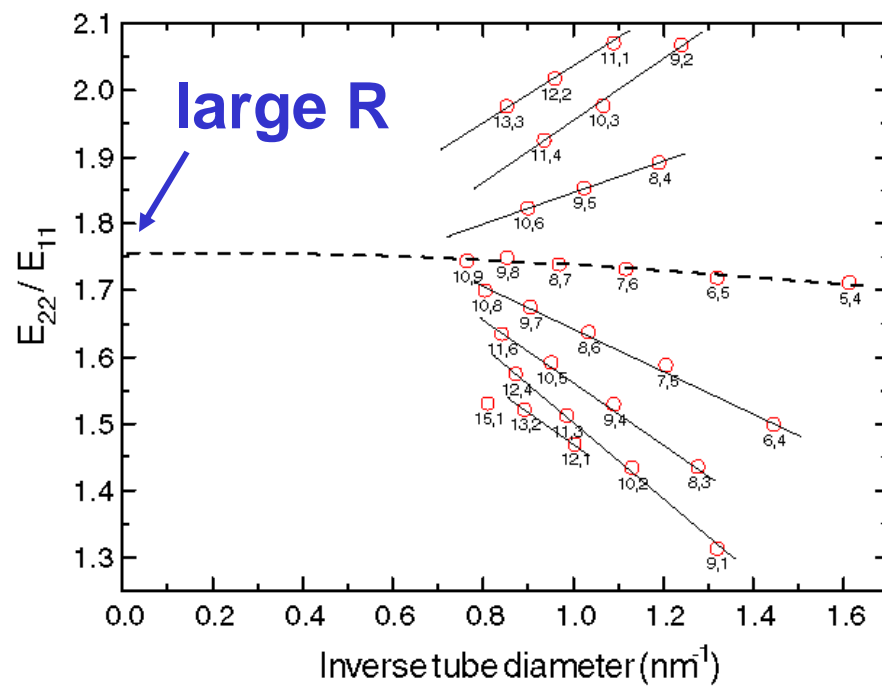
E. J. Mele & C. L. Kane

*Department of Physics
Laboratory for Research
On the Structure of Matter*

**What is the ratio problem ?
(previous talk & next slide)**

**What causes the ratio problem ?
(e-h interaction in excited state)**

Plot of Ratios of Absorption/Emission Frequencies



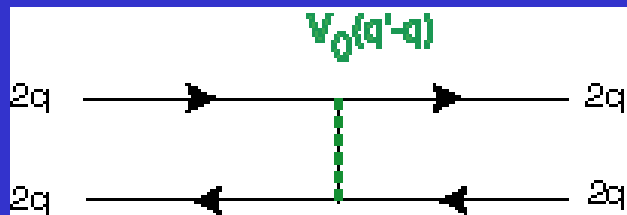
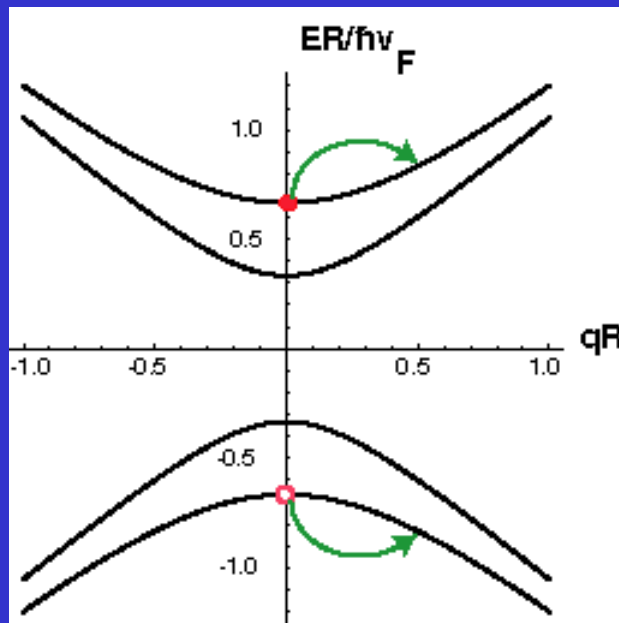
One particle excitations on NT's:

- quantized subbands (m)
- conserved crystal momentum (q)
- $E_m(q)$

Interacting e-h's on NT's:

- Intraband scattering:
only *total* crystal momentum is conserved
($q_e - q_h = 0$)
- Intersubband scattering:
 m is not conserved & higher subband
e-h's *resonate*
- Mix e-h @ 2e-2h configurations
This is Ratio Problem

Intraband scattering ↻



binds e-h pair

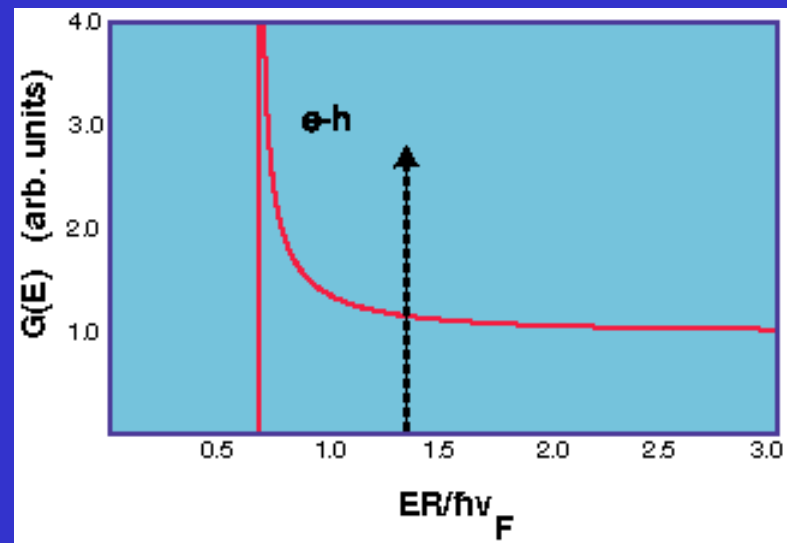
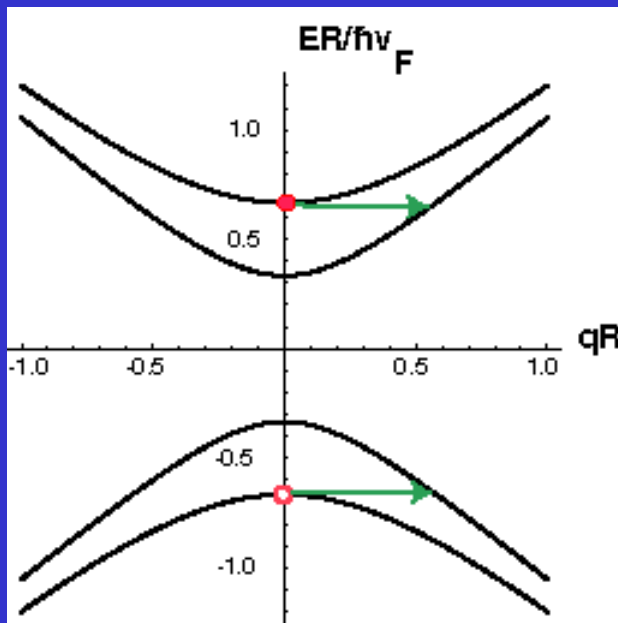
$$\psi(z) = \frac{1}{\sqrt{\xi}} \exp\left(-\frac{|z|}{\xi}\right)$$

with scaling rules

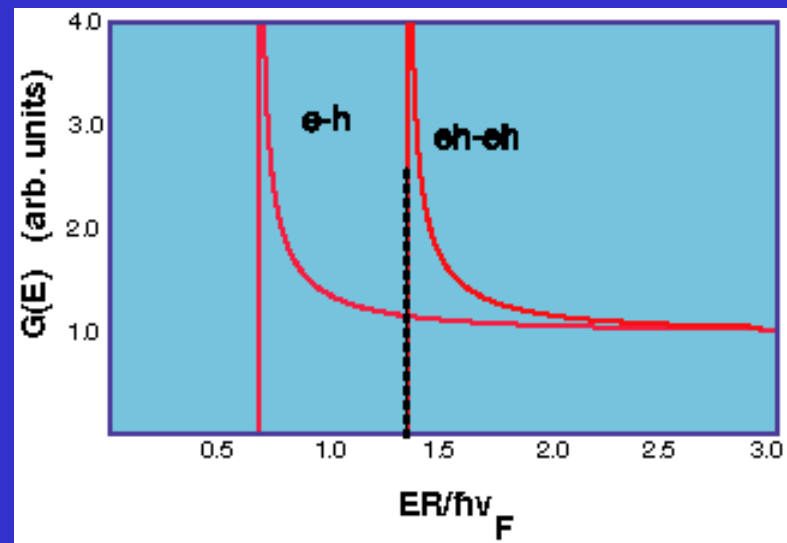
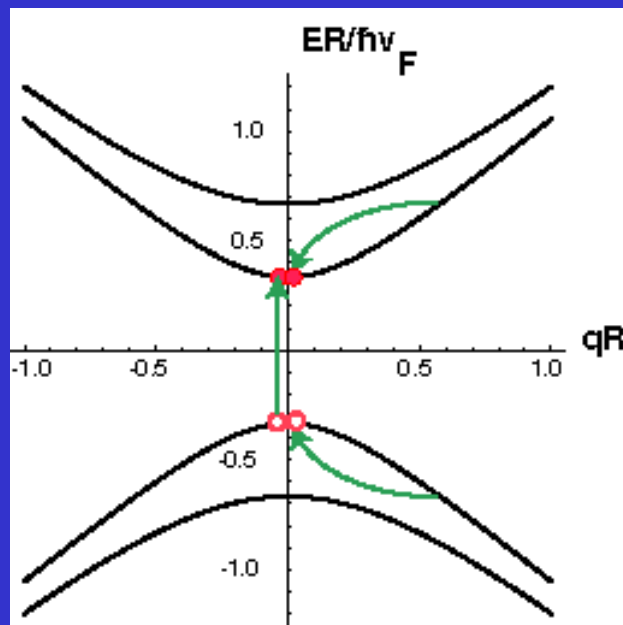
$$\xi_n \propto \frac{1}{n} \quad \Delta E \propto n$$

Interband Scattering ↻

Intrinsic Width (Resonant Exciton)

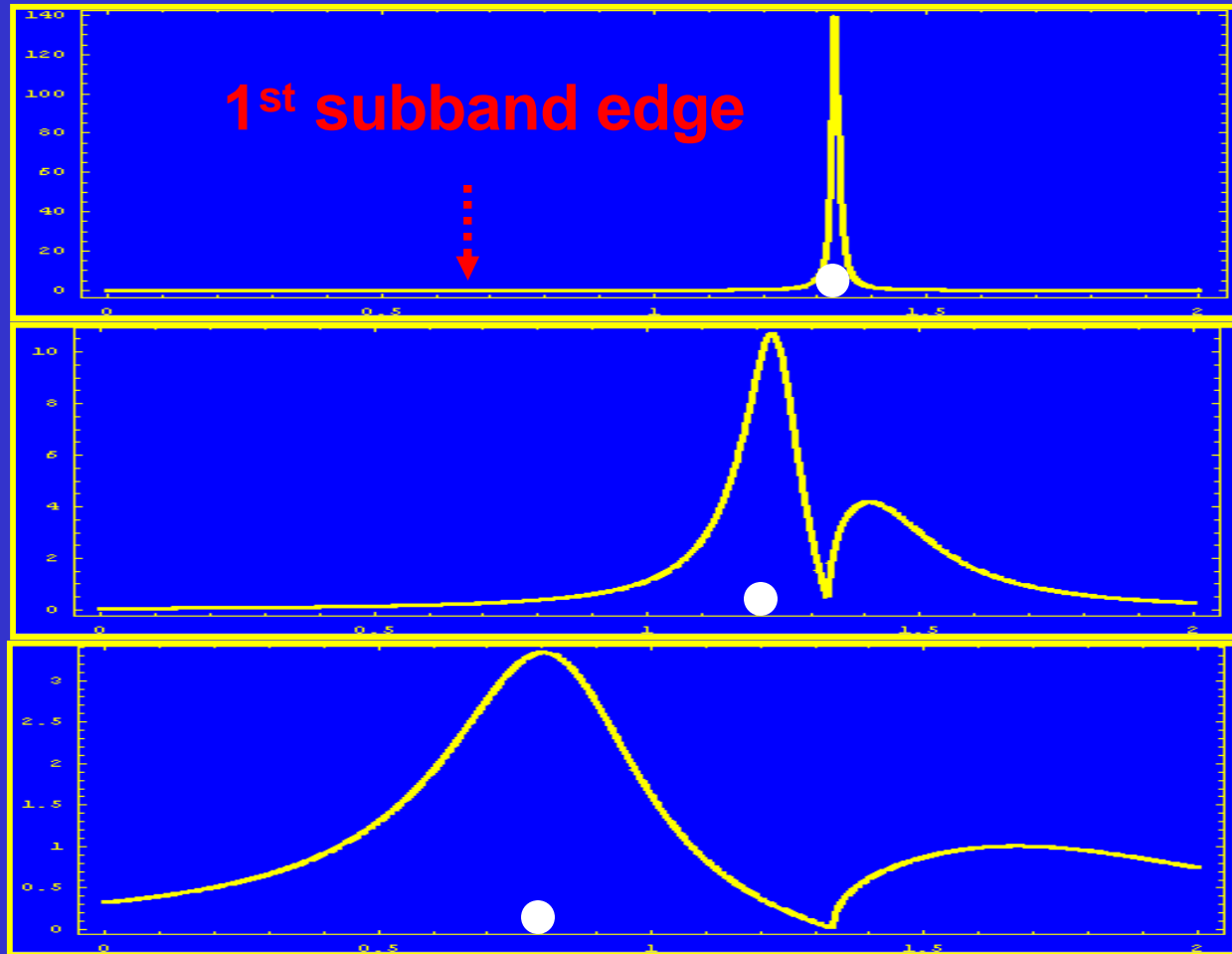


Hybridization of e-h and 2e-2h excitations



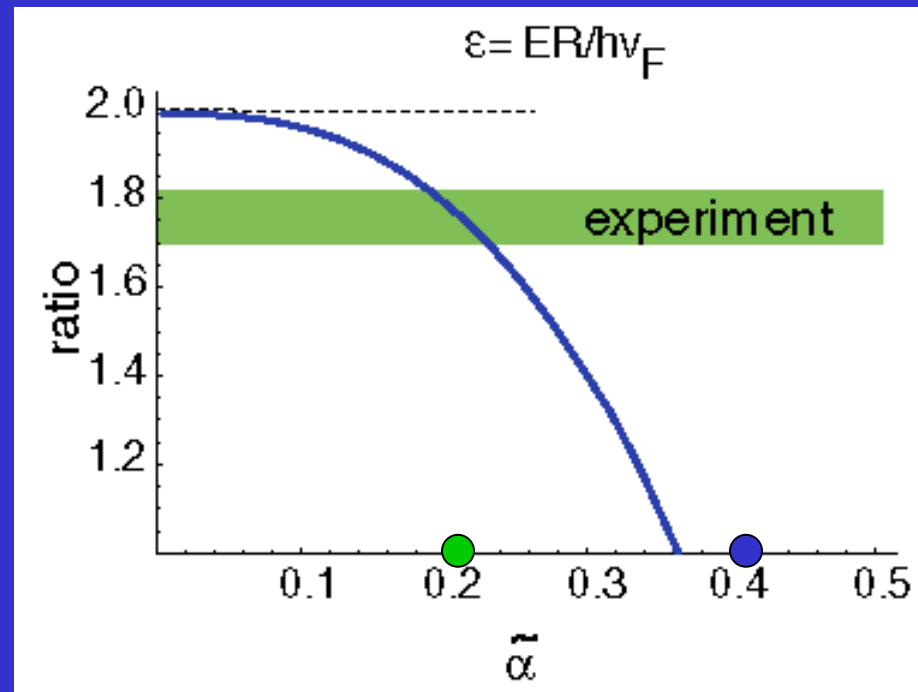
Exciton Lineshape

Im $G(\varepsilon)$



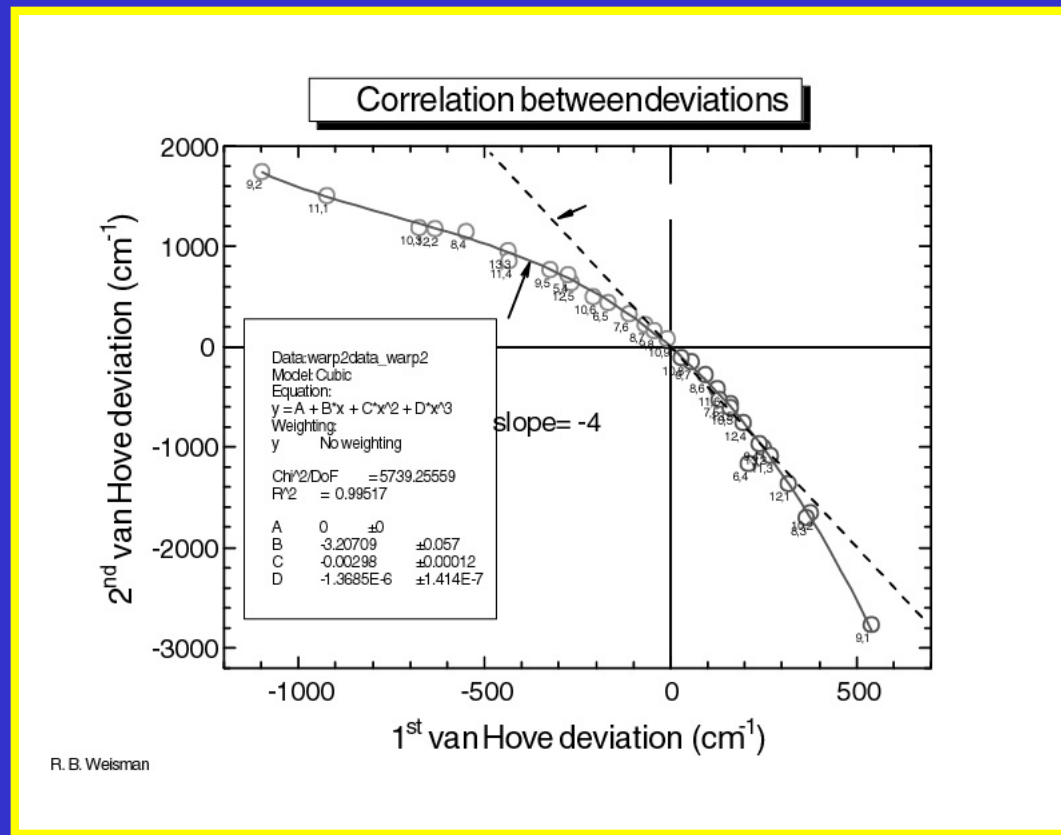
$$\varepsilon = ER / \hbar v_F$$

Nanotube Fluorescence Spectroscopy

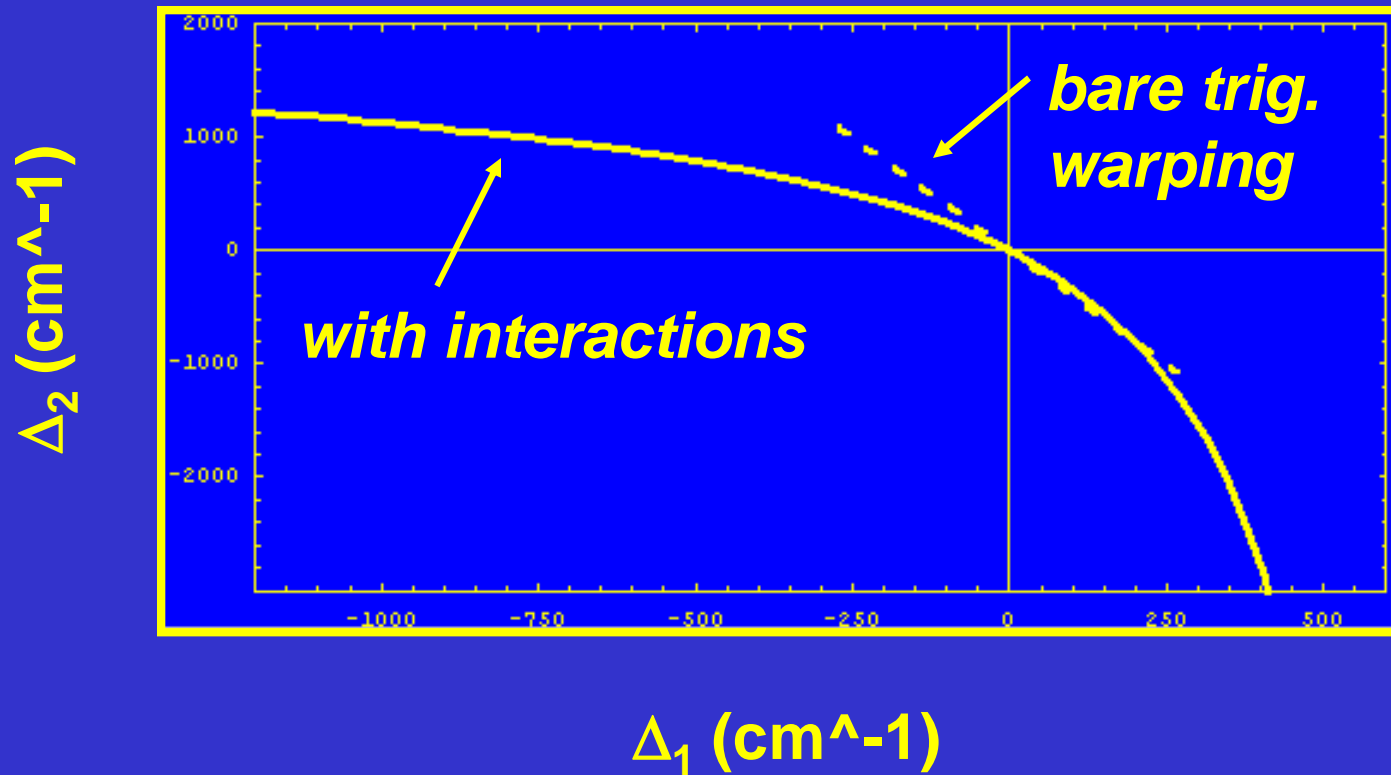


Correlations of `Mod 3` Gap Deviations

(from *Structure Assigned Optical Spectra of Single Wall Carbon Nanotubes*,
S. Bachilo et al., *Science* 298, 2361 (2002))



Nonlinear Scaling of 1st and 2nd Subband Deviations Due to Coulomb & Trigonal Warping



Summary

- FS reveals electronic gap structure outside the conventional band model.
- The “ratio problem”

Gap Ratio < 2 (asymptote for large diameter tubes)

Hybridize e-h and 2e-2h excitations

1D + degeneracy from tube wrapping.

**Long Range
Interaction**

- “Mod 3” gap deviations

They are very large... with \pm asymmetry

Curvature, Trig. Warping + Coul. Anisotropy
(distinguished by scaling with R, n)

Nonlinear Scaling in Data gives Coul. Anis. ⌚
Trig. Warping