RAMAN HISTORY

SPONTANEOUS SCATTERING

Raman + Krishnan	1928
Landsberg + Mandelstahm	1928
Smekal	1923

SRS

Woodbury + Ng	1962
Hellwarth	1963

FIBERS

Smith	1972
Stolen, Ippen, Tynes	1972

FIBER RAMAN AMP

Ippen, Patel, Stolen US Pat.	1971
Aoki	1988

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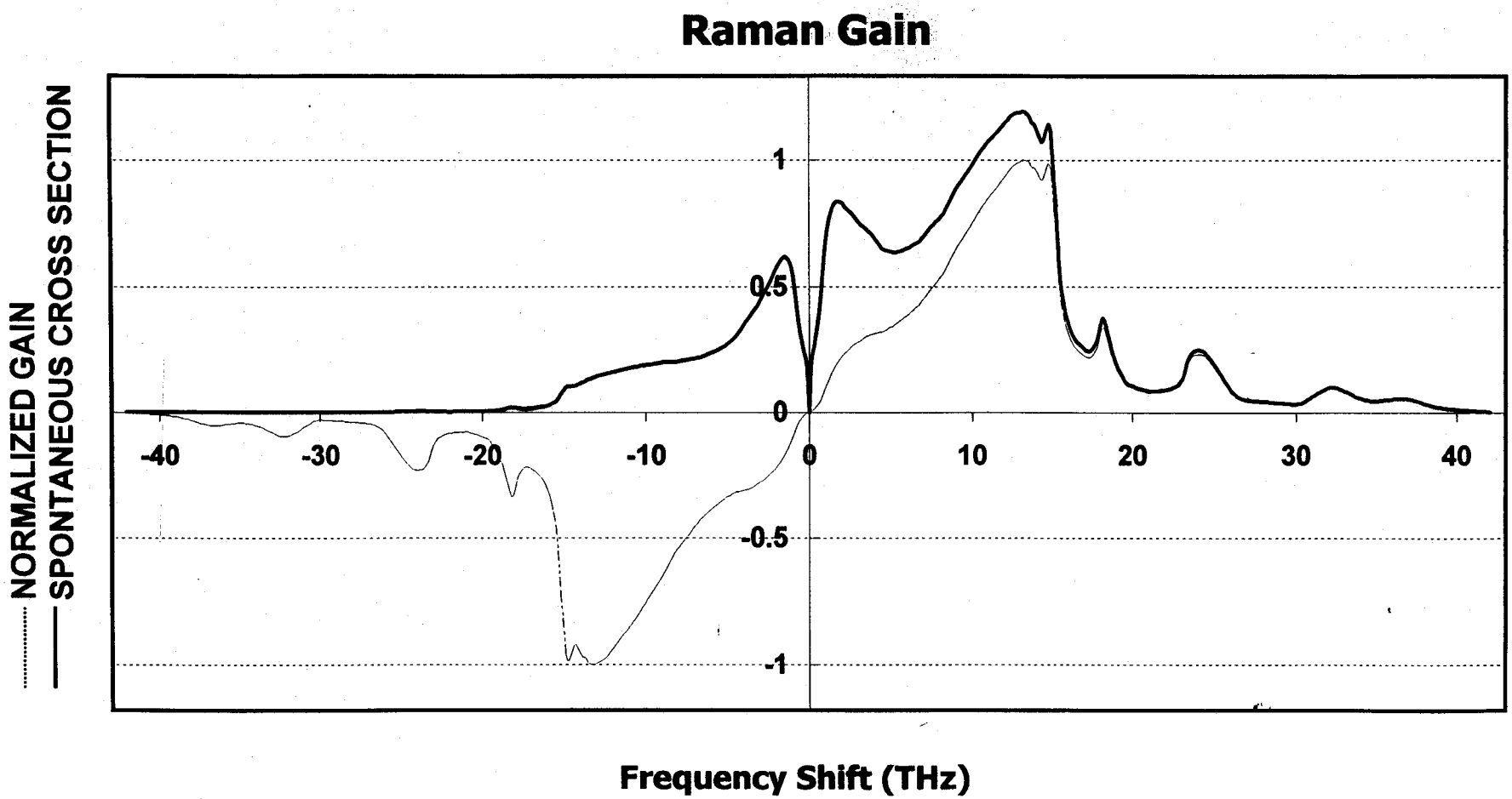
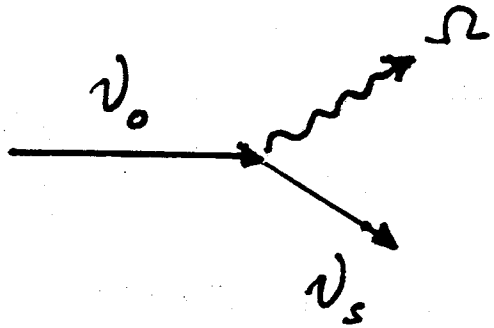

Raman Gain
NORMALIZED GAIN
SPONTANEOUS CROSS SECTION
1
0.5
0
-0.5
-1
-40
-30
-20
-10
0
10
20
30
40
Frequency Shift (THz)

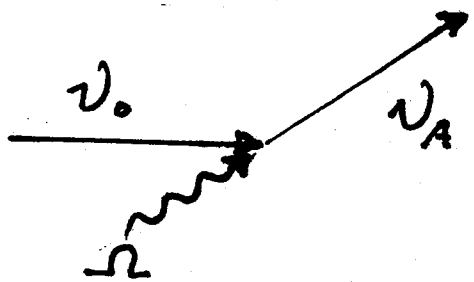
Figure: 1

QUANTUM PICTURE

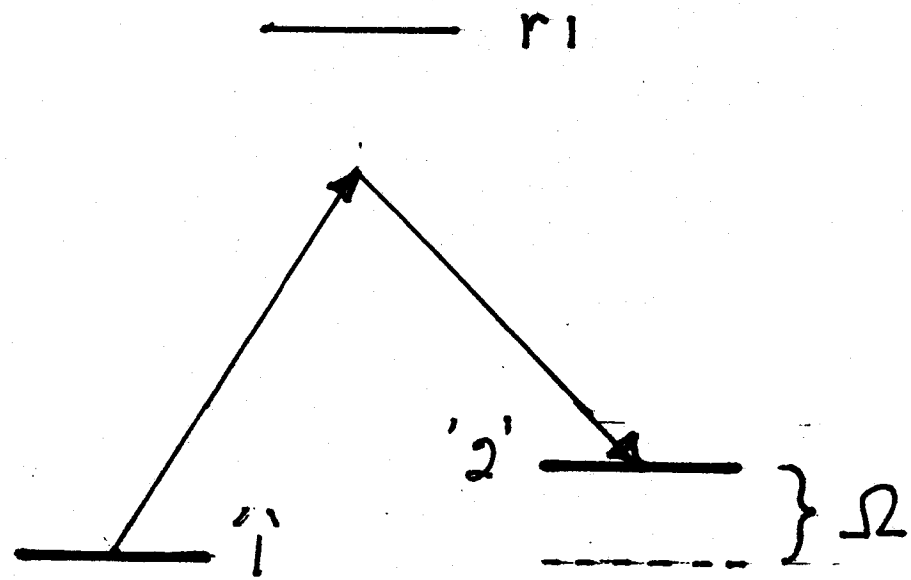


$$N_\Omega = \frac{1}{e^{h\Omega/k_B T} - 1}$$

$W_S \propto N_0(1 + N_\Omega)$ Stokes

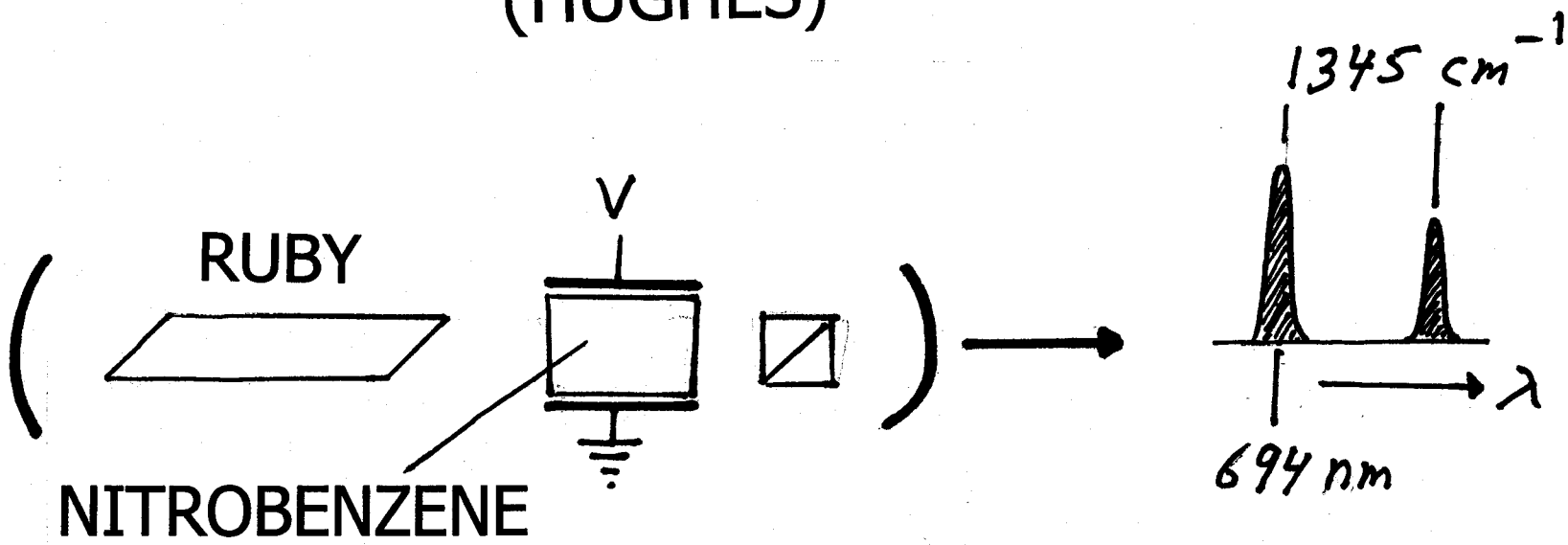


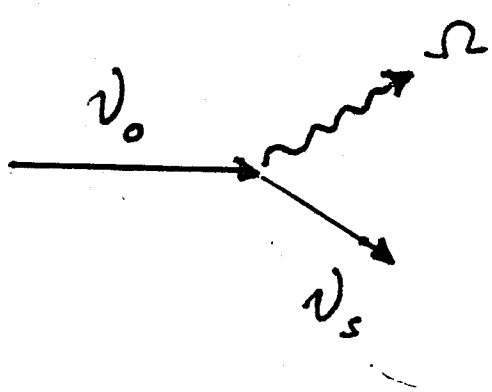
$W_A \propto N_0 N_\Omega$ anti - Stokes



HELLWARTH- SRS

(HUGHES)

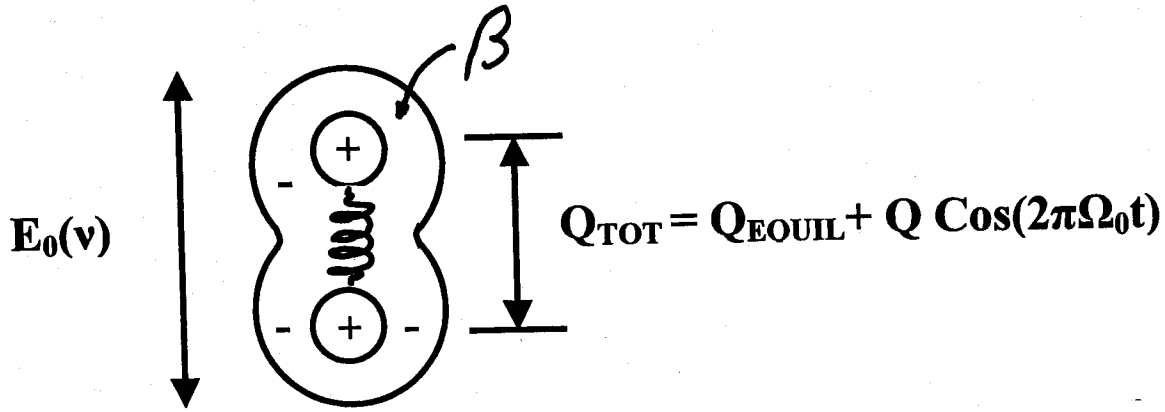




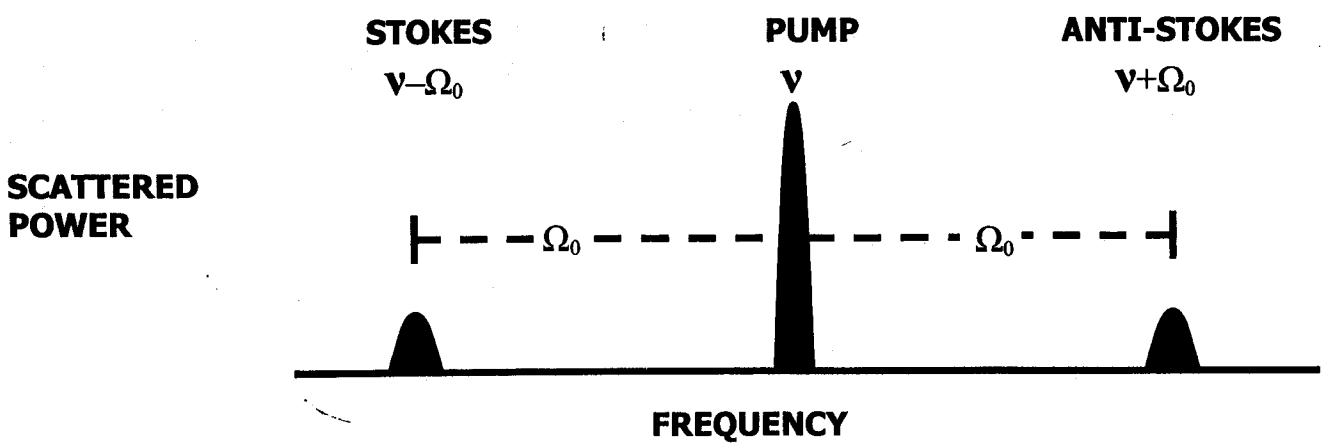
$$\frac{dN_S}{dt} = SN_0(1 + N_\Omega + N_S)$$

$$\frac{dN_S}{dz} = GN_S \qquad G = \frac{n_S S N_0}{c}$$

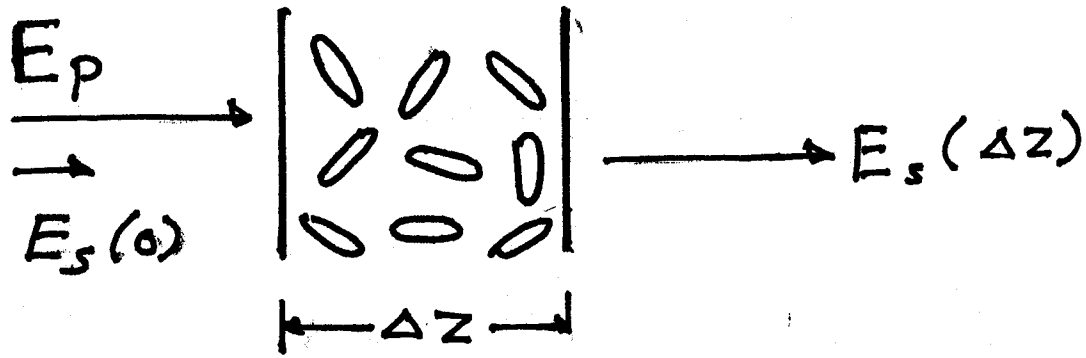
PLACZEK MODEL



$$\mathcal{P} = \beta E(2\pi\nu_0 t) = [\beta_0 + (\partial\beta/\partial Q)Q_0\cos(2\pi\Omega_0 t)]E_0\cos(2\pi\nu_0 t)$$



RAMAN AMPLIFICATION



$$\Delta E_s = \frac{\partial \beta}{\partial Q} E_p Q N \Delta z$$

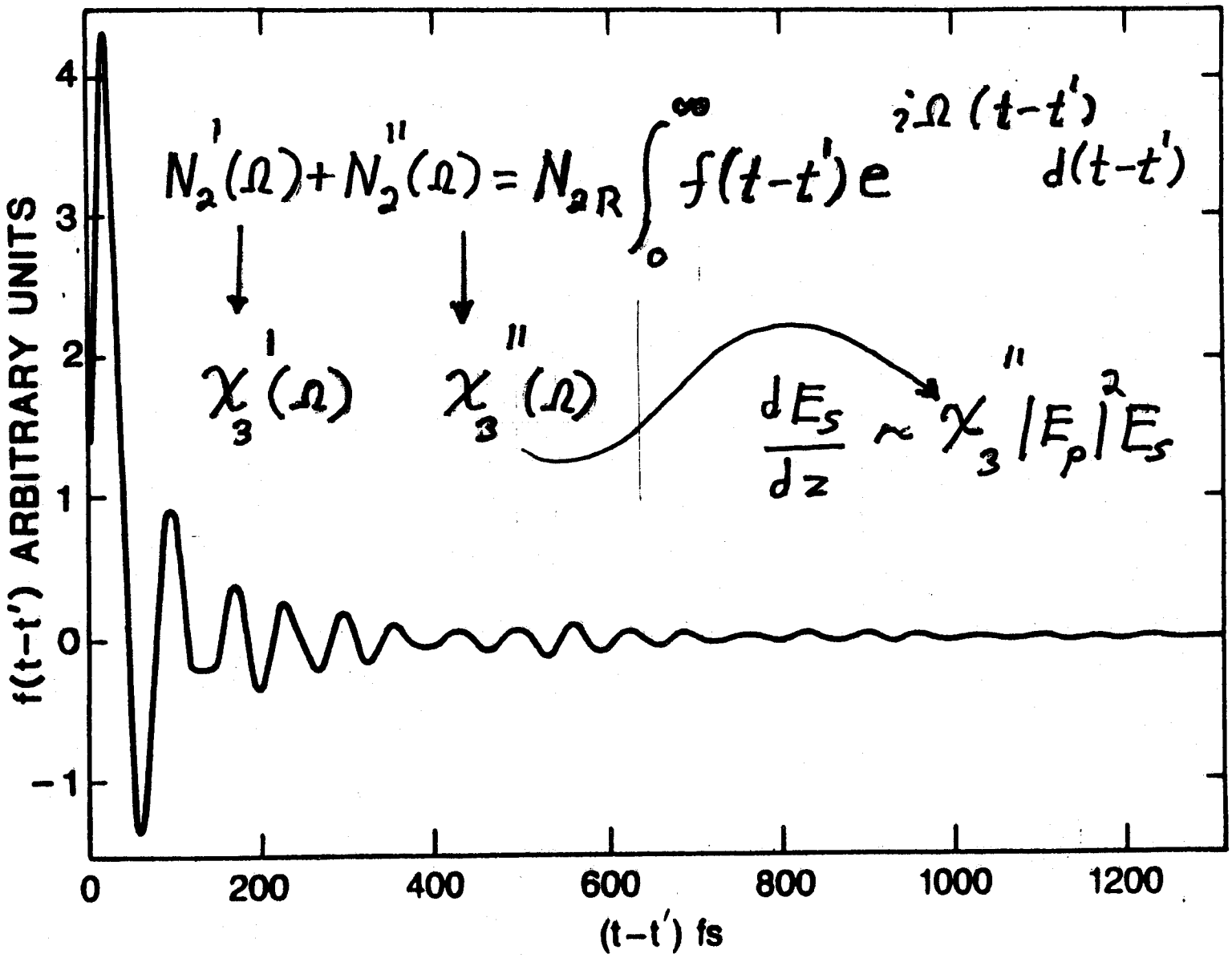
$$Q \sim \frac{\partial \beta}{\partial Q} E_p E_s$$

$$\boxed{\begin{aligned} F &= \partial U / \partial Q \\ U &= N p \cdot E \end{aligned}}$$

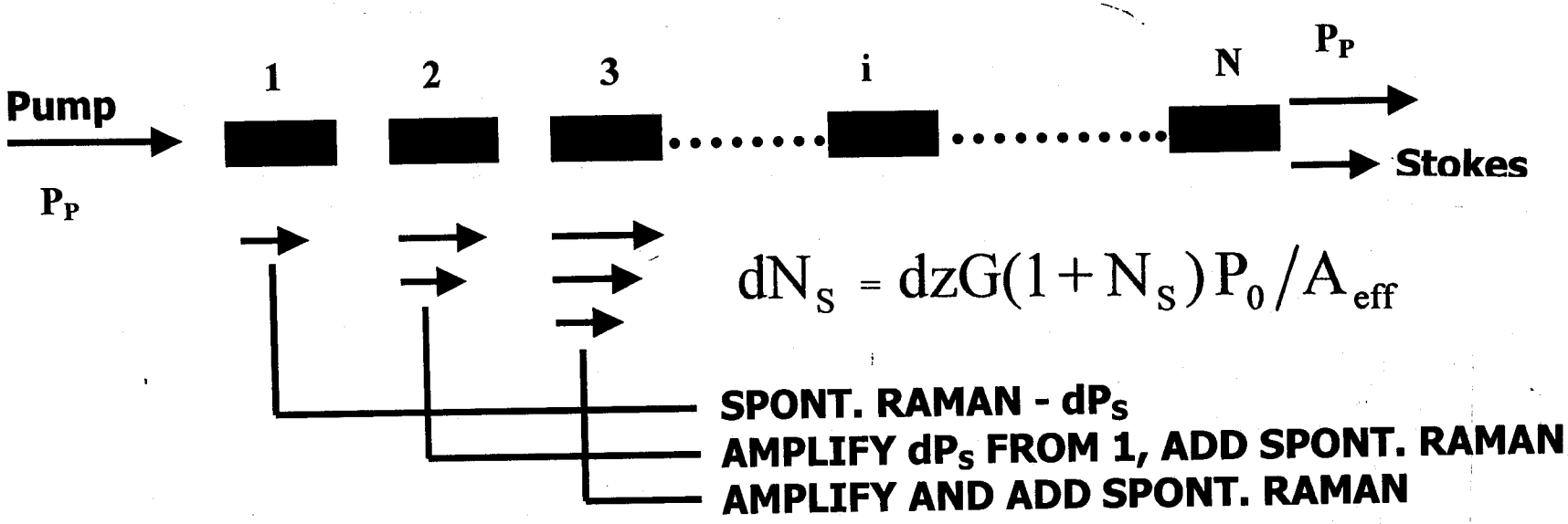
$$\frac{\Delta E_s}{\Delta z} = \underbrace{N \left(\frac{\partial \beta}{\partial Q} \right)^2 |E_p|^2}_{g I_p} E_s$$

$$E_s(z) = E_s(0) e^{g I_p z}$$

RESPONSE FUNCTION



SMITH- SRS - FIBERS



$$dN_S = dzG(1+N_S)P_0/A_{eff}$$

$$N_S(L) = \left[1 - e^{-GP_0L/A_{eff}}\right]e^{GP_0L/A_{eff}}$$

$$\frac{GP_0(crit)L}{A_{eff}} \approx 16$$

$$N_S(L) = [N_S(0) + N_S(noise)]e^{GP_0L/A_{eff}}$$

$$P_S = h\upsilon_S \Delta\upsilon N_S$$

RAMAN GAIN COEFFICIENT

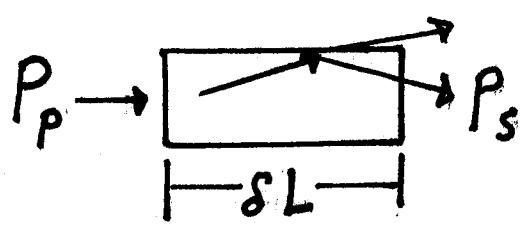
$$g\,(\mathrm{cm}/\mathrm{W}) = \frac{\sigma(0)\,\lambda_s^3}{h\,n_s\,c^2\,(1+N_\Omega)} \sim \frac{1}{\lambda_s}$$

$$\sigma(0) \sim (1+N_\Omega)/\lambda_s^4$$

SPONTANEOUS SCATTERING

CLASSISCAL

$$\sigma_T\, n\, P_p \frac{\Delta\nu}{\epsilon}\,\delta L = dP_{SPONT} = h\nu_s \frac{g\,P_p}{A_{eff}}(1+N_\Omega)\,\Delta\nu\,\delta L$$

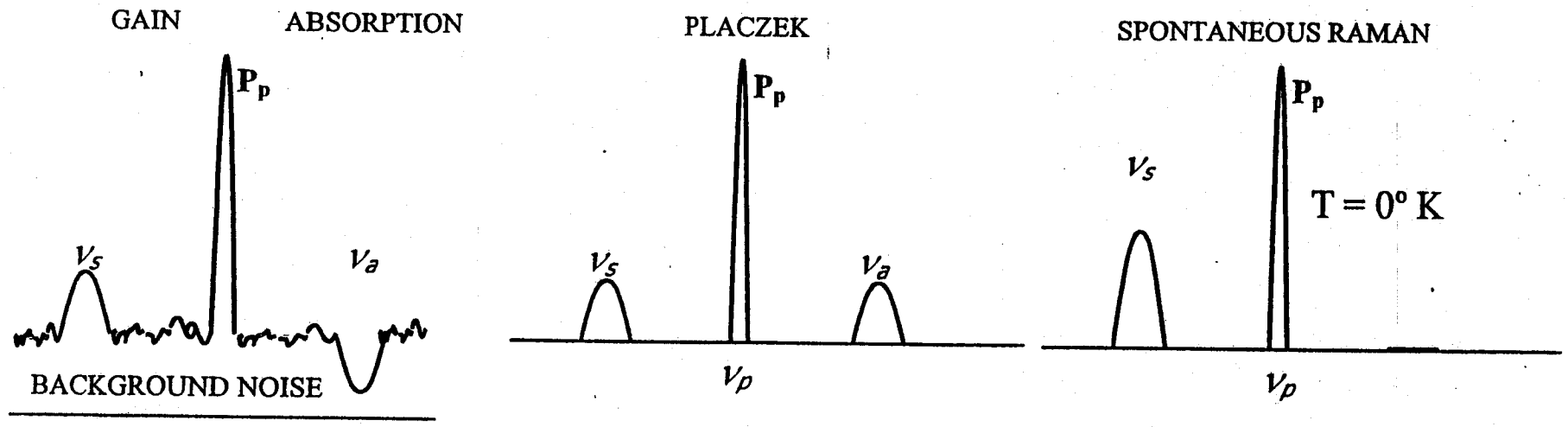


QM

$$n \sim \lambda_s^2/A_{eff}$$

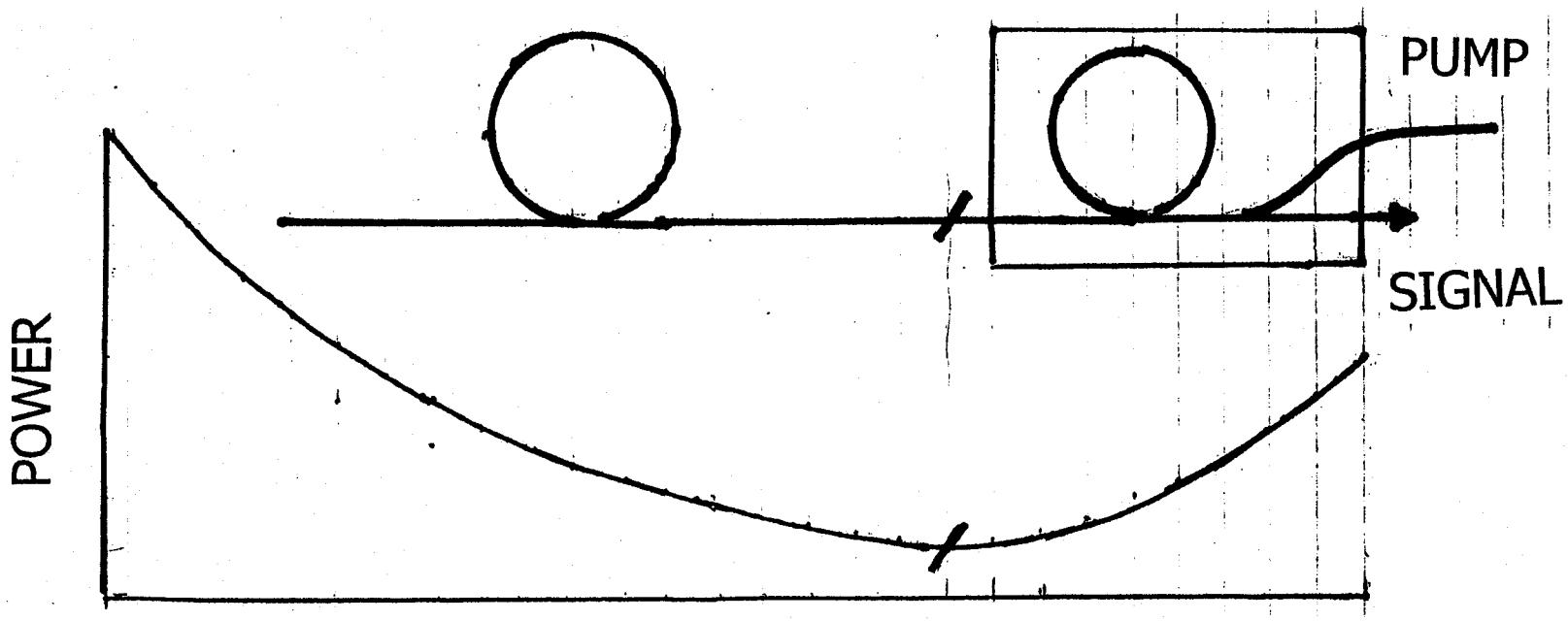
$$\sigma(0) \sim \sigma_T$$

2-COMPONENT MODEL



$\frac{1}{2} h \nu_s \Delta\nu$ $\frac{1}{2} h \nu_s \Delta\nu$ $h \nu_s \Delta\nu$

DISCRETE RAMAN AMP.



$$I_d = I_s + I_N = \mathcal{R} P_{opt} \propto (E_s + E_N)^2$$

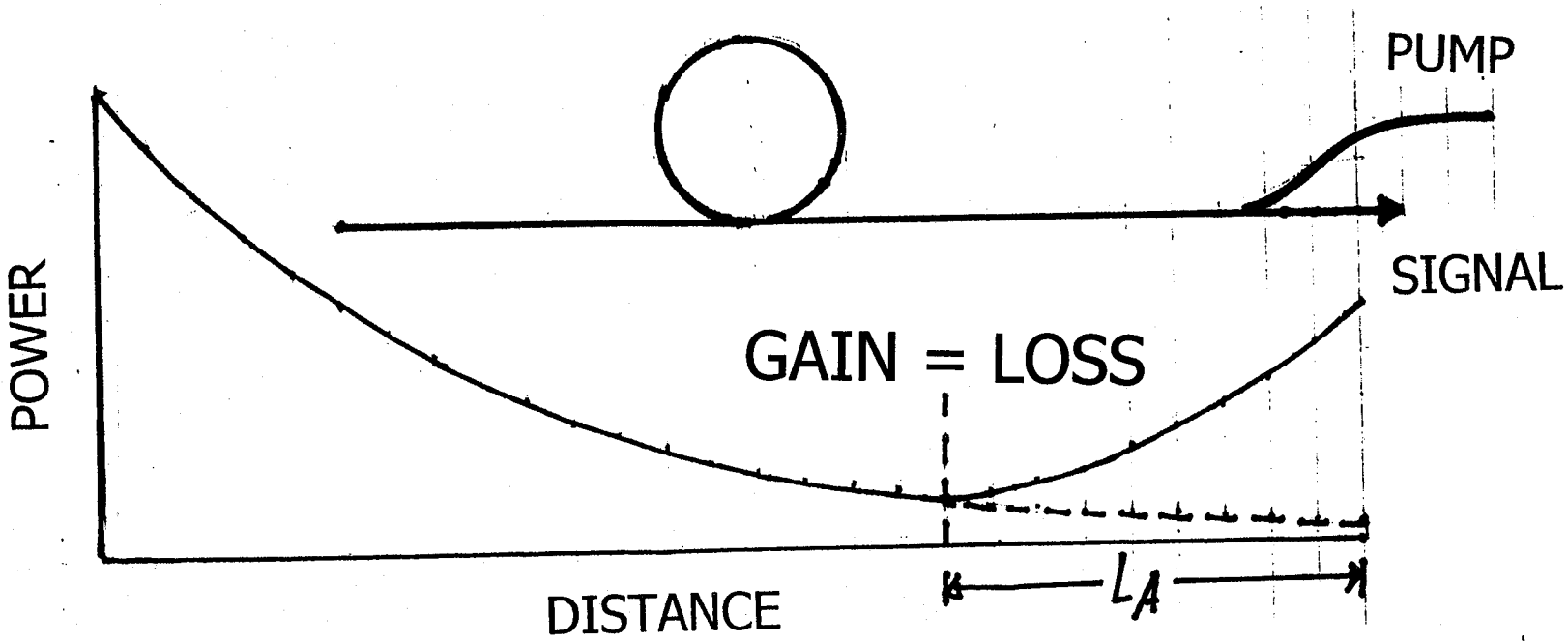
$$S/N = \frac{I_s^2}{I_N^2} = \frac{P_s^2}{4 P_s P_N} = \frac{1}{2} \cdot \frac{P_s}{2h\nu_s \Delta\nu_B}$$

3dB

$$NF = 10 \log [2(1+N_n)]$$

[SHOT LIMIT]

TRANSMISSION RAMAN AMP.



$$S/N = \frac{P_s(-L_A)}{4h\nu_s \Delta\nu_B}$$

$$NF = 3.0 - 10 \log \left[\frac{g_s P_p(L)}{\alpha_s A_{eff}} \right]$$

SUMMARY

CLASSICAL (PLACZEK) MODEL → RAMAN GAIN

QM ZERO PT. FLUCTUATIONS → NOISE

→ STOKES : ANTI-STOKES ASYMMETRY