How to call the method?

" Measuring and Correcting E_V/E_R-perturbations in the Dedicated d_μ Experiment Using

(1) Transformation of a permanent E_V into the oscillating one;

(2) Amplification of the amplitude of these oscillations;

(3) Electrons instead μ's, to have a synchrotron light signal and other....."

So, "Control of the Vertical Electric Field Perturbations in the Dedicated Muon EDM Experiment by Using Trapping-into-Resonance Effect," —

— <u>using radiation damping.</u>

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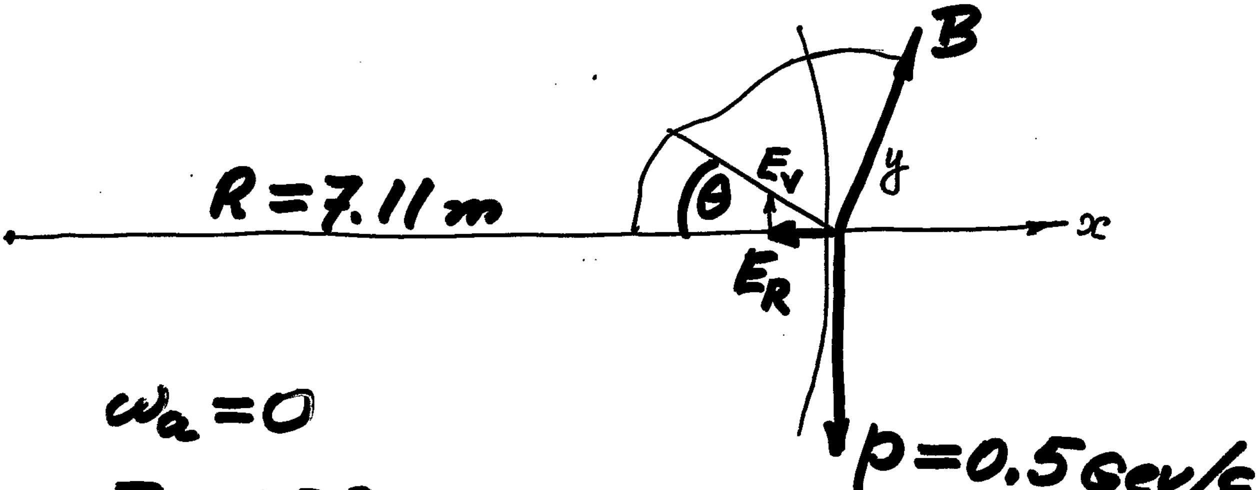
BNL

The goal.



$\omega_a = 0$

$B = 0.23\ T$

$E_R = 0.028\, B = 2\ MV/m$

$E_V = \theta E_R$, perturbation.

The vertical spin equation:

$$\frac{ds_V}{dt} = \frac{e}{mc}\left[\frac{1+a}{\beta\gamma^2} E_V + \frac{\eta}{2}(E_R - \beta B)\right] S_L$$

To measure $\eta < 2.7\times10^{-11}$, $d_\mu < 1.2\times10^{-24}$, we need $\theta < 1.2\times10^{-8}$.

We may try to measure:

(1) $y''_{B,E} + n y_{B,E} = R\left(\frac{B_R}{B} + \theta\frac{E_V}{\beta B}\right)$, minus

(2) $y''_B + n y_B = R\frac{B_R}{B}$

$\Delta y = y_{B,E} - y_B = \frac{1}{n} R\theta E_R/\beta B$; $\theta < 1.2\times10^{-8}$

However, this Δy is too small, $(0.002/n)\,\mu m$ for muons

Main ideas.

1. To use electrones, 0.5 Gev/c, because of the easily observable synchrotron radiation,

$$\hbar\bar{\omega}_\gamma \approx 40\,\mathrm{ev},$$

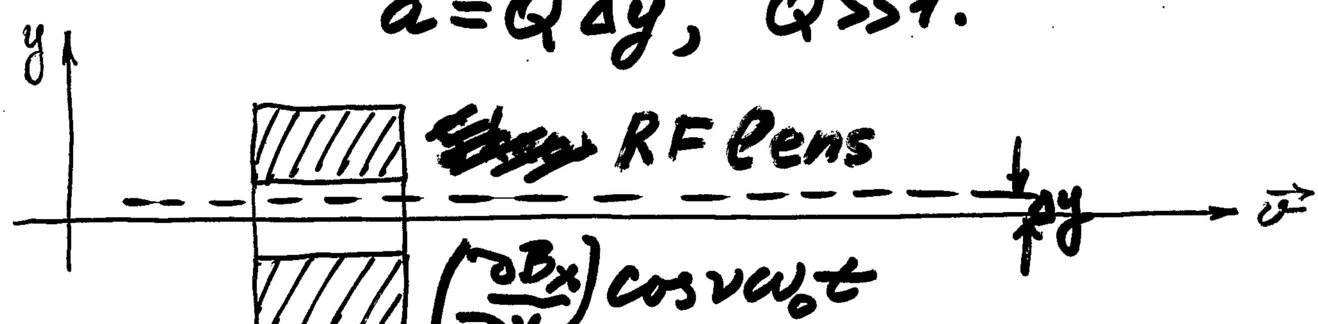
and a small vertical width of the beam because of the radiation damping,

$$\tau_\gamma \approx 0.2\,\mathrm{s}$$

2. $n = 0.01$, so $\Delta y = \frac{1}{n} R\theta E_R / \beta R = 0.2\,\mu m$ (for $\theta = 1.2 \times 10^{-8}$).

3. To introduce an artificial resonance perturbation, $\underline{n_1 y \cos\nu\omega_0 t}$, which transforms the permanent Δy into the <u>oscillating</u> vertical deviations — $a\cos\nu\omega_0 t$, which thereby can be much better observed — and amplifies these deviations, so

$$a = Q\,\Delta y, \quad Q \gg 1.$$



When $y = \Delta y + \cdots$, we have the resonance force, $n_1 \Delta y \cos\nu\omega_0 t$, if $\nu \sim \sqrt{n}$.

Different approach to the same effect.

Let $h=0$

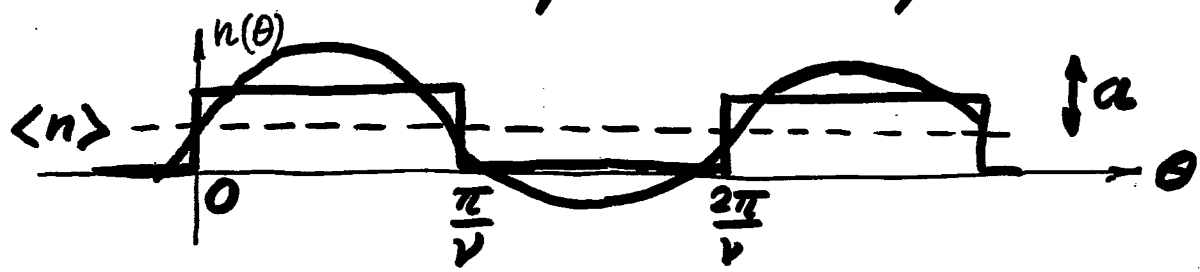
$$\ddot{y}+\omega_0^2(n-n_1\cos\nu\omega_0 t)y=\omega_0^2\epsilon_\nu\,,$$

We want $y=D_\nu(\theta)\epsilon_\nu$, $D_\nu(\theta)\gg 1$,

where $D_\nu(\theta)$ is analogous to $D_R(\theta)$,

$$\frac{x}{R}=D_R(\theta)\frac{\Delta p}{p}\,.$$

To see how this is possible ($D_\nu \gg 1$), consider a simple example:



$$y''_{\theta^2}+n(\theta)y=\epsilon_\nu\,;\quad y_{equil}(\theta)=D_\nu(\theta)\epsilon_\nu\,;$$

$$n=\langle n\rangle+n_1(\theta)$$

$$D_{\nu\,max}=\frac{1}{n_{max}}\left[1+\frac{\varkappa/2}{\sin\varkappa/2}\right]\equiv\frac{Q}{n_{max}}$$

$$\varkappa=\frac{\pi\sqrt{n_{max}}}{2\nu}$$

$Q\gg 1$ when $\varkappa/2\approx\pi$, $\nu\approx\dfrac{\sqrt{n_{max}}}{2}$

Relations between $\langle B_R \rangle$ and $\langle E_V \rangle$.

In the absence of the electric field, $\vec{E}$ off, $\langle B_R \rangle = 0$ at the actual (i.e., perturbed) equilibrium orbit.

If $\vec{E}$ is on, then, in general, both $\langle B_R \rangle \neq 0$, $\langle E_V \rangle \neq 0$ at the actual orbit. But $\langle F_V \rangle = \langle F_{B_R} \rangle + \langle F_{E_V} \rangle = 0$, so

$$\frac{ds_V}{dt} = \frac{e}{mc}\left[\frac{1+a}{\beta\gamma^2} E_V + \frac{\eta}{2}\left(E_R - \beta B\right)\right] s_L .$$

Therefore,

if we correct E_V, $E_V \to 0$ in this equation, using any convenient lattice (we want $\eta = 0.01$) and any convenient particles (we want $e^\pm$), and then immediately go back to the lattice designed for muons <u>without touching the electric field E</u>, E_V will still be zero, and s_V will still not be perturbed, — independently of our change of the magnetic lattice.

A more complicated reality:

$$\ddot{y}+\omega_0^2(n-n_1\cos\nu\omega_0 t)y=\omega_0^2\epsilon_v+\underbrace{\omega_0^2 h\cos 2\nu\omega_0 t}_{\text{will be explained}}$$

$$y=z+\Delta y_1+a\cos\nu\omega_0 t,\quad \underline{\text{if}}\ \ h=-\frac{n_1}{2}a$$

(that means, we need a feedback — from the observed amplitude a to h)

$$a=Q\,\Delta y,\quad \Delta y=\epsilon_v/n,\quad \epsilon_v=R\,E_v/\beta B=R\,\theta E_R/\beta B$$

$$Q=\frac{(n_1/n)}{\left[1-\frac{\nu^2}{n}-(n_1/n)^2/2\right]}\equiv\frac{n_1/n}{D_{res}}$$

$$\Delta y_1=\frac{(1-\nu^2/n)}{\left[1-\frac{\nu^2}{n}-(n_1/n)^2/2\right]}\frac{\epsilon_v}{n}\equiv\frac{1-\nu^2/n}{D_{res}}\frac{\epsilon_v}{n}$$

$$0\leq n_1/n<1$$

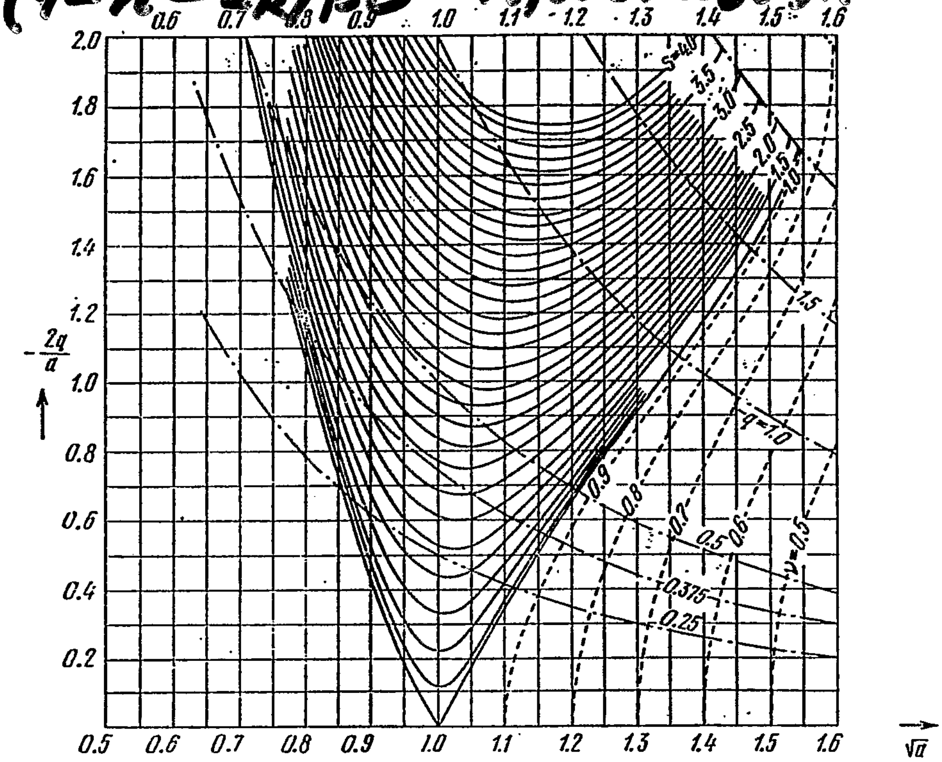
Obviously, to get $Q\gg 1$, we need $n_1/n\sim 1$, $D_{res}\ll 1$, $\nu<\sqrt{n}$.

In more precise equations, we need take into account small electric fields caused by $n_1\cos\nu\omega_0 t$, $h\cos 2\nu\omega_0 t$

Stability-Instability regions of the Mathieu equations,

$$\ddot{z}+(n-n_1\cos\nu\omega_0 t)z=0$$

$$\ddot{x}+(1-n-E_R/\beta B-n_1\cos\nu\omega_0 t)x=0$$



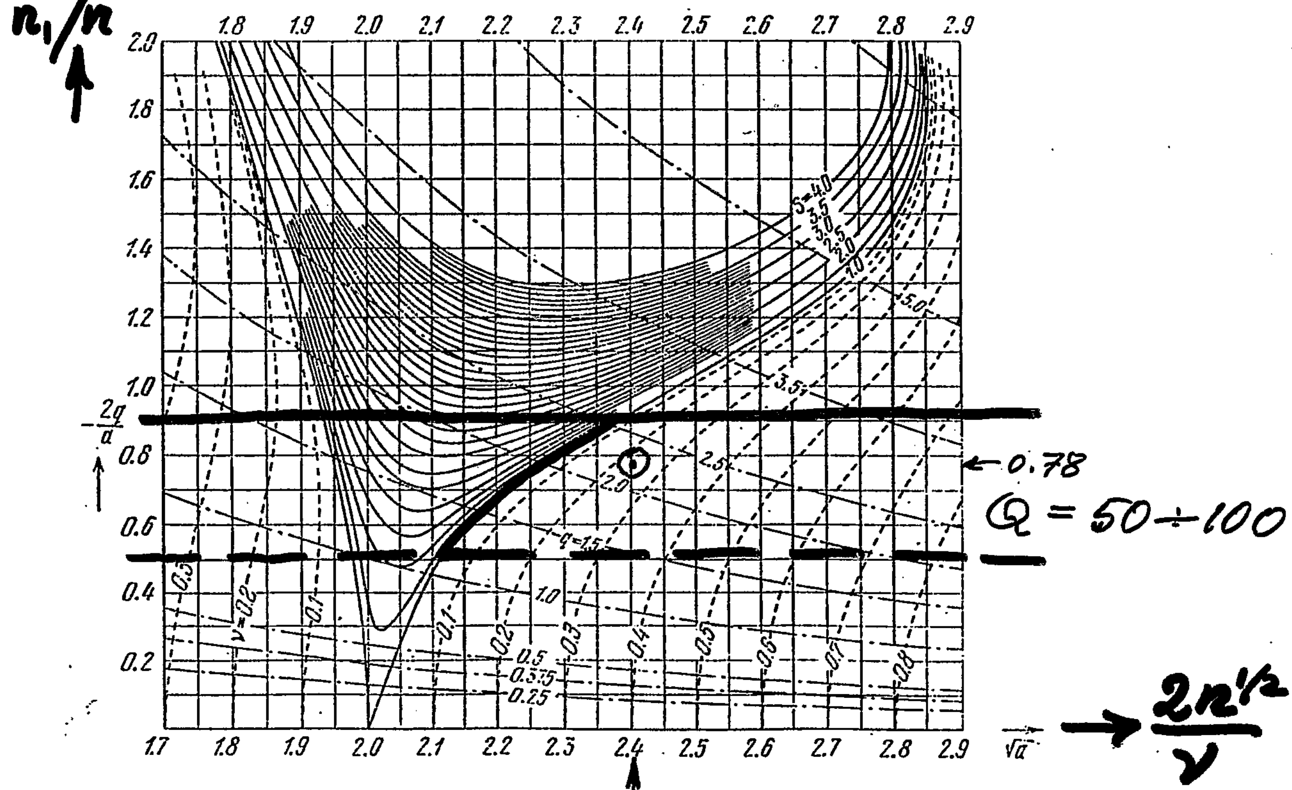


Рис. 20.8, Рис. 20.9. Карты характеристических показателей.
— $s = e^{i\nu\pi}$ = const, в областях неустойчивости,
— — — ν = const, в областях устойчивости, —·—·— линии постоянных значений — q.

How great can Q be?

The uncertainty of the denominator of Q, D_{res}, is due to $\frac{\Delta p}{p}$,

$$\sqrt{\left\langle \left(\frac{\Delta p}{p}\right)_{\gamma} \right\rangle} = 1.3 \times 10^{-3}, \quad p = 0.5 \frac{\text{GeV}}{c}$$

With $\nu^2/n \sim 0.7$, $\Delta D_{\gamma} \sim 10^{-3}$. Then

$$1 - \frac{\nu^2}{n} - \frac{(n_1/n)^2}{2} \approx 0.01 \text{ is permitted,}$$

$$Q = 78.$$

Hence, $50 < Q < 100$ is possible,

$$10\,\mu m < a < 20\,\mu m$$

$$\Delta y_1 \approx 0.3 Q \, \Delta y_0 \gg \Delta y = \epsilon_v / n$$

(The same estimate of Q-value gives the condition to keep n-value in D_{res} between the instability border and the first synchro-betatron resonance if

$$\nu_s \sim 0.02,$$

as it is when $\hat{V}_{RF} \sim 10$ kV.)

Parameters:

$\mathcal{E}_e = 0.5$ Gev, $\gamma = 980$, $R = 7.11$ m

$B = 0.23$ T, $E_R = 0.028\,B$

$\Delta\mathcal{E}_\gamma / \Delta N = 0.775$ kev

$d\mathcal{E}_\gamma / dt = 5.2 \times 10^3$ Mev/s

$\hbar\overline{\omega_\gamma} = 39$ ev

Damping, $\tau_y = 0.19$ s

$\tau_x = 200$ s (when $E_R = \eta_1 = 0$)

$\nu_s = 0.024$ if $V_{RF} = 10$ KV, $\lambda_{RF} = 25$ cm

4 RF ~~elec~~ quad's,

$\langle n_1 \rangle \approx 0.7\, n = 0.0078$

$4 \times 0.5\, m$

$$\left\langle \frac{R}{B} \frac{\Delta B}{\Delta R} \right\rangle = 0.0078$$

$\Delta B \sim 5$ gauss

$f \sim 0.6$ MHz

Measurements of d_e in the same dedicated d_μ ring.

$B = 0$. Only E_R.

$\gamma = \gamma_m = 29.3$. $\mathcal{E}_e = 15$ MeV

$E_R = 70$ gauss $= 2.1$ MeV/m

No problems with E_γ.

$\frac{\Delta E_\gamma}{\Delta N} = 0.62$ meV ; $\hbar \omega_\gamma = 0.66$ meV

Sensitivity:

If the goal is $\delta d_e \lesssim 10^{-27}$ e cm, then

$$\theta_t \lesssim \frac{2eE_R}{\hbar} 10^{-27} t,$$

and with $t = 10^5$ s (one day),

$$\theta_t = 4.2 \text{ mrad}$$

Problems:

1. Dephasing due to $\gamma \neq \gamma_m$
(FeedBack with the help of the Compton scattering of the laser-light on <u>one</u> of electron bunches ??)

2. B_R-perturbation due to E_{RF}-field.
(q as low as possible.
A special type of RF electrodes ??)

3.

4.