第10回QUATUO研究会

2024年1月6日(日)@高知工科大学永国寺キャンパス

最近の活動と宇宙の謎

Senior Professor, University of Tokyo

井元 信之

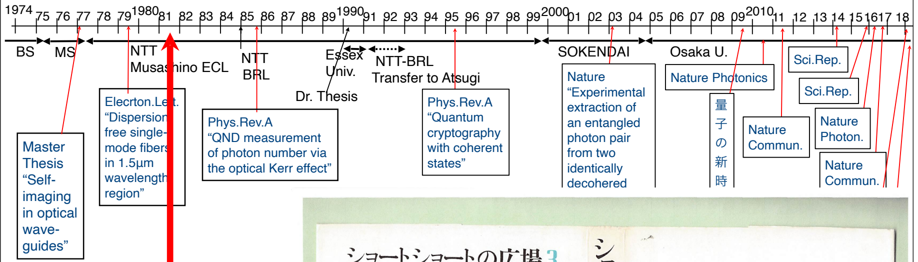
http://subarutelescope.org/Pressrelease/j_index_2001.html#010213
「すばるが見つめる星のゆりかご」より背景引用

最近の活動：

東大における量子コンピューターのQII活動

各種研究支援スキームの総括・委員長・アドバイザー等
種々関係しているスキームの中で、今日は学術変革領域研究(A)
「極限宇宙の物理法則を創る」（領域代表：高柳匡教授）で紹介した
話題を取り上げたい。

- 空間反転を伴うワームホールはあるか?
- フィードバック共振器内の交換関係
- 時間領域の共振器は実現するか?



第3回星新一ショートショートコンテストにて、約5000の応募作品から55篇の作品が選ばれ出版された。(1981)

「エイリアン」のあらすじ

行方不明になっていた宇宙探査船 ホルン号 が無事に戻って来た。
しかし待っていた人々は、間近にホルン号 とその内部を見て驚いた。右と左がすっかり入れかわっているのだ。
出て来た乗組員達も以前と一見変わりないが、右利きと左利きが入れかわり、よく調べると心臓は右胸についている。
排気口などの回転装置の羽根は逆向きだし、コイル類も磁石も極性が変わっている。
一番目立ったのは船体に書いてある探査船の名前だ。それは

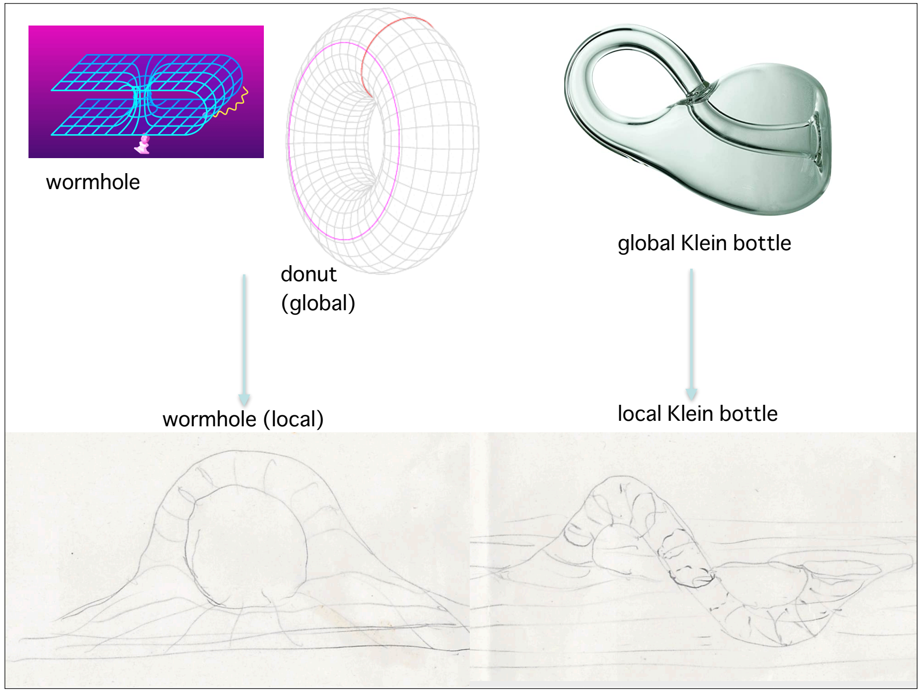
"ИЯОН"

と描いてあった。最初はソビエト連邦の宇宙船が侵入してきたと思った人もいたくらいだ。

何が起こったのか調査する長い会議が開かれた。乗組員達の中でもとびきり鋭いミシェルが口を開いた。
「HORN号は局所的なクラインの壺状のワームホールを通過したんだと思います」
「えっ!? あっそうか、それしか考えられない」
人々は口々にミシェルを褒め讃えた。

長い会議のあと、ミシェルは恋人のマルタと会った。マルタはどんなにミシェルの無事を祈っていたことか。
二人はできるだけ早く結婚式を挙げることを誓った。

ところが翌日、ミシェルは宇宙局の局長に呼び出された。
「君にはもう一度あのクラインの壺を通過する調査に参加して欲しいんだ」
あまりのことにミシェルは怒った。
「何ですって? あんな危険なところにもう一度行けと? 結婚をひかえているのに?」
「では説明しよう。人間を含むあらゆる生物のDNAが同じ向きの二重螺旋になっていることは知っているね?」
「あっ」
「そのコイルが逆向きに巻いているとどうなるね? 子供ができないだろう? つまり君を含めた乗組員達はもう一度
あのクラインの壺を通過しない限り、遺伝子が逆巻きの、エイリアンなのだよ」



あり得る議論：

パリティ非保存はどうなる? 弱い相互作用のパリティ依存性が逆になってしまう。

→ CPTで保存するから、C xor Tも逆になればよい。Tが逆になった生物は想像しにくいが。
年寄りは段々赤ちゃんになって行くのか?

Cが逆だったら反物質だから、握手すると消滅してしまうのではないか。

通常のワームホールは存在していても理論上の矛盾は生じないらしいが、クラインの壺状のワームホールは理論上存在不可能ということはないのか?（この点は前回の極限宇宙年会での立ち話で訊いたが、その人は「存在自体は不可能ではないのではないか」とおっしゃっていた。）

紹介：第3回「極限宇宙」定例年会にて

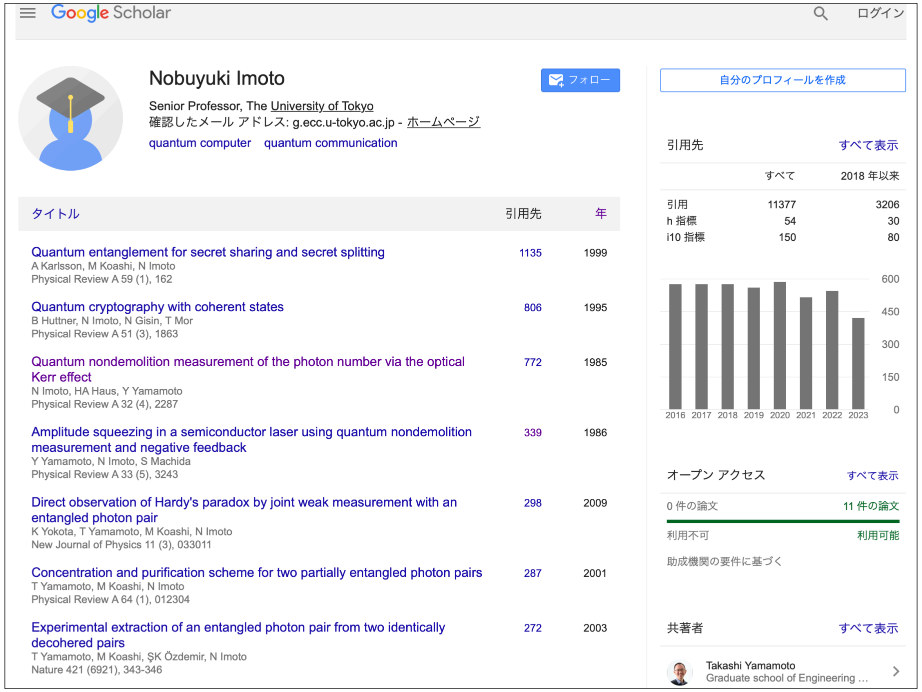
Sept. 11, 2023@Panasonic Auditorium
in Yukawa Hall

Time and space issues that appeared in my quantum information research

Senior Professor, University of Tokyo

Nobuyuki Imoto

http://subarutelescope.org/Pressrelease/j_index_2001.html#010213
「すばるが見つめる星のゆりかご」より背景引用



Nobuyuki Imoto

Senior Professor, The University of Tokyo
確認したメール アドレス: g.ecc.u-tokyo.ac.jp - ホームページ
quantum computer　quantum communication

タイトル	引用先	年
Quantum entanglement for secret sharing and secret splitting A Karlsson, M Koashi, N Imoto Physical Review A 59 (1), 162	1135	1999
Quantum cryptography with coherent states B Huttner, N Imoto, N Gisin, T Mor Physical Review A 51 (3), 1863	806	1995
Quantum nondemolition measurement of the photon number via the optical Kerr effect N Imoto, HA Haus, Y Yamamoto Physical Review A 32 (4), 2287	772	1985
Amplitude squeezing in a semiconductor laser using quantum nondemolition measurement and negative feedback Y Yamamoto, N Imoto, S Machida Physical Review A 33 (5), 3243	339	1986
Direct observation of Hardy's paradox by joint weak measurement with an entangled photon pair K Yokota, T Yamamoto, M Koashi, N Imoto New Journal of Physics 11 (3), 033011	298	2009
Concentration and purification scheme for two partially entangled photon pairs T Yamamoto, M Koashi, N Imoto Physical Review A 64 (1), 012304	287	2001
Experimental extraction of an entangled photon pair from two identically decohered pairs T Yamamoto, M Koashi, ŞK Özdemir, N Imoto Nature 421 (6921), 343-346	272	2003

引用先　すべて表示

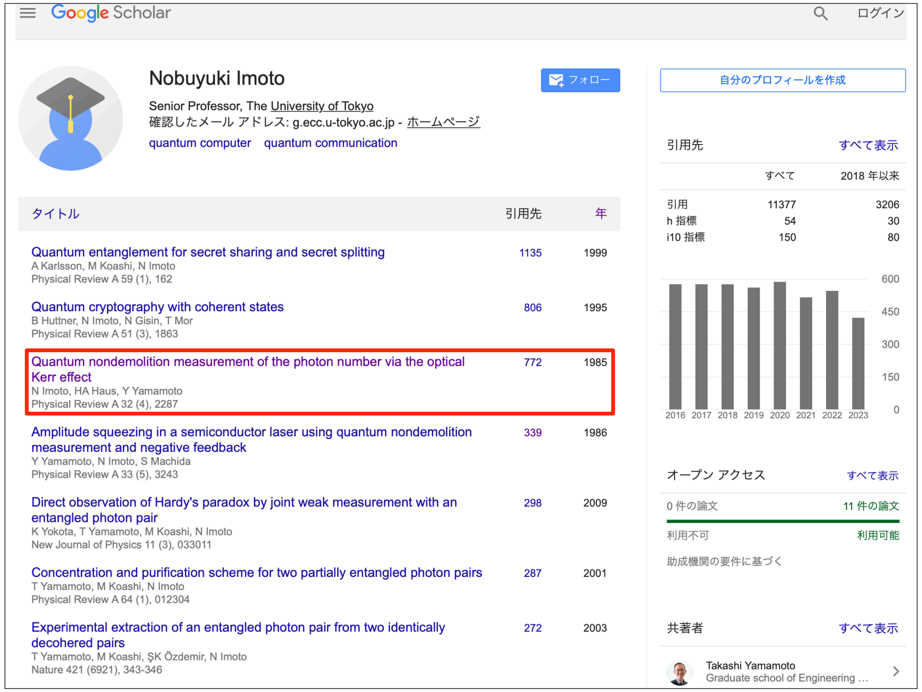
	すべて	2018 年以来
引用	11377	3206
h 指標	54	30
i10 指標	150	80

オープン アクセス　すべて表示

0 件の論文　11 件の論文
利用不可　利用可能
助成機関の要件に基づく

共著者　すべて表示

Takashi Yamamoto
Graduate school of Engineering …



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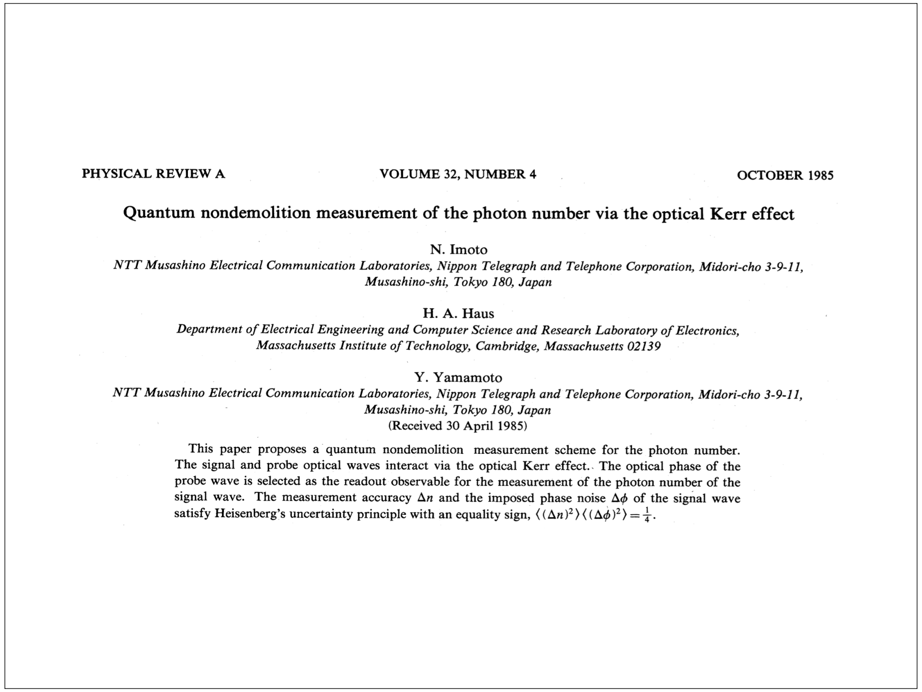

PHYSICAL REVIEW A VOLUME 32, NUMBER 4 OCTOBER 1985

Quantum nondemolition measurement of the photon number via the optical Kerr effect

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(Received 30 April 1985)

This paper proposes a quantum nondemolition measurement scheme for the photon number. The signal and probe optical waves interact via the optical Kerr effect. The optical phase of the probe wave is selected as the readout observable for the measurement of the photon number of the signal wave. The measurement accuracy Δn and the imposed phase noise $\Delta\phi$ of the signal wave satisfy Heisenberg's uncertainty principle with an equality sign, $\langle(\Delta n)^2\rangle\langle(\Delta\phi)^2\rangle=\frac{1}{4}$.

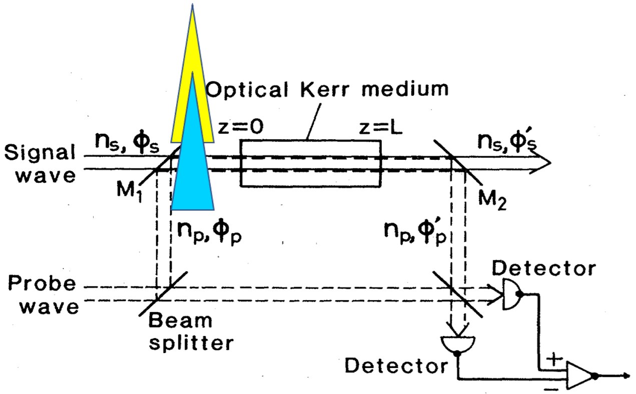

FIG. 1. Configuration for the QND measurement of the signal photon number. Transmissions of mirrors $M1$ and $M2$ are unity for signal frequency. Signal wave passes through the optical Kerr medium without changing its photon number. Phase of the probe wave is modulated by the signal photon number.

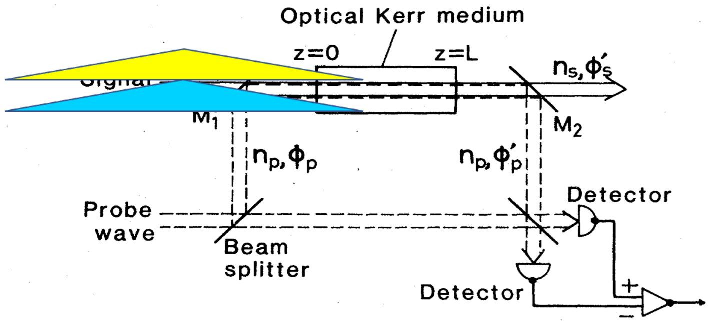

FIG. 1. Configuration for the QND measurement of the signal photon number. Transmissions of mirrors $M1$ and $M2$ are unity for signal frequency. Signal wave passes through the optical Kerr medium without changing its photon number. Phase of the probe wave is modulated by the signal photon number.

IV. SELF-PHASE-MODULATION EFFECT

Equations (8)—(10) are idealized in the sense that they do not include the self-modulation of the phase caused by the signal and probe waves. In order to treat the Kerr medium more realistically, we must consider the full Hamiltonian. We shall then show that it is possible to arrive at a QND measurement arrangement which is describable in terms of the ideal Hamiltonians (8)—(10).

The perturbation energy due to the third-order nonlinear effect is

$$H'=\int\int\int\left[\int E\,dP_{\rm NL}\right]dV$$
$$=\tfrac{3}{4}\int\int\int\sum\chi^{(3)}_{ijkl}E_iE_jE_kE_l\,dV\ . \qquad (26)$$

Here, $\chi^{(3)}$ is defined not only for the optical Kerr effect but also for every process in which four photons are emitted or absorbed. In contrast, it should be noted that $\chi^{(3)}$ in (6) is phenomenologically defined for the optical Kerr effect, especially for the phase modulation of the probe wave by the signal wave.

V. MEASUREMENT ACCURACY AND THE IMPOSED PHASE NOISE

In general quantum measurements, the product of the measurement accuracy and the additional uncertainty imposed on the conjugate observable is expected to satisfy the inequality of Heisenberg's uncertainty principle. However, whether the equality sign is achievable or not in a QND measurement has not yet been investigated. We will show that the proposed QND measurement scheme provides the minimum uncertainty product of measurement accuracy for photon number and imposed phase noise.

Consider the case without the self-phase-modulation effect for both the signal and probe waves. The output phase of the signal is, in analogy with (22),

$$\phi_s'=\phi_s+\sqrt{F}\,n_p\ , \qquad (36)$$

APPENDIX

In this appendix the output of the proposed interferometer—balanced-mixer detector is derived. The observed photon number is defined as the output current divided by a normalized factor which changes the current into the photon number. Equations (23)—(25) are derived by the obtained formula for the observed photon-number operator.

Figure 3 shows the present scheme in which the annihilation operator for each part of the interferometer is specified. The probe laser output a is divided by beam splitter

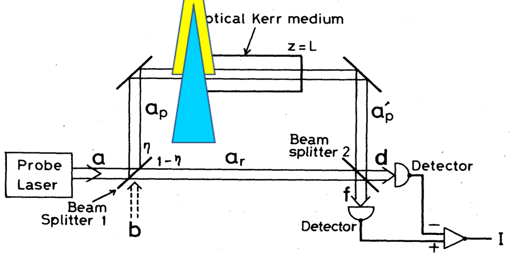

FIG. 3. Detailed description of the annihilation operators in the interferometer—balanced-mixer detector. Probe wave and reference wave are denoted as a_p and a_r, respectively. Zero-point fluctuation, b, is mixed at beam splitter 1.

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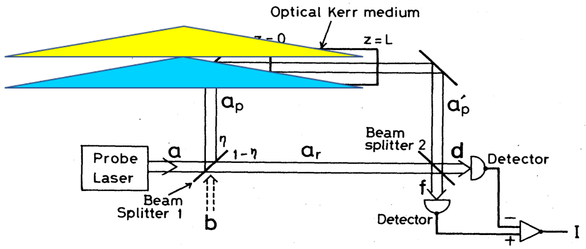

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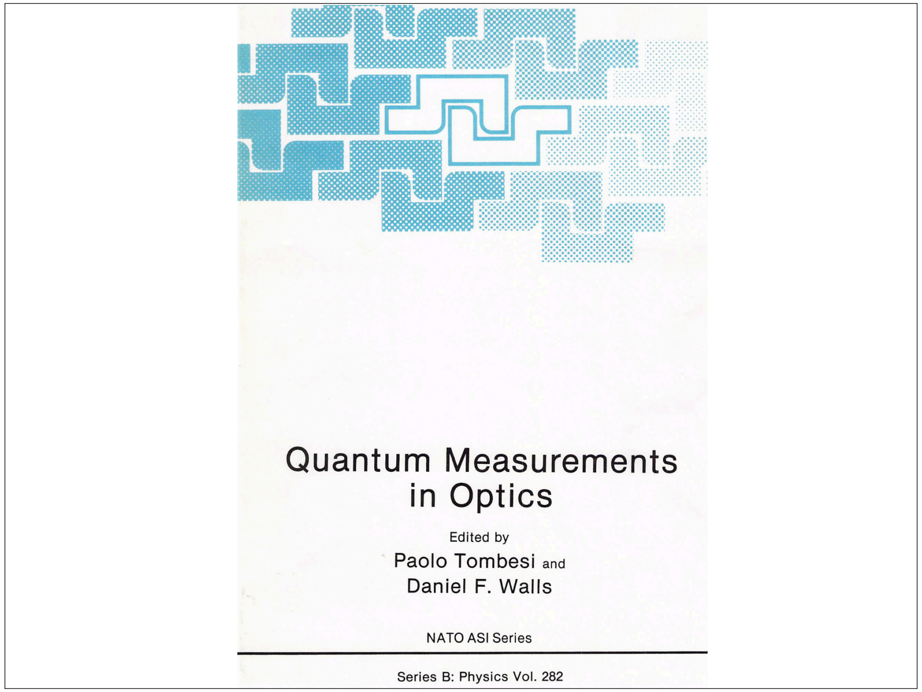
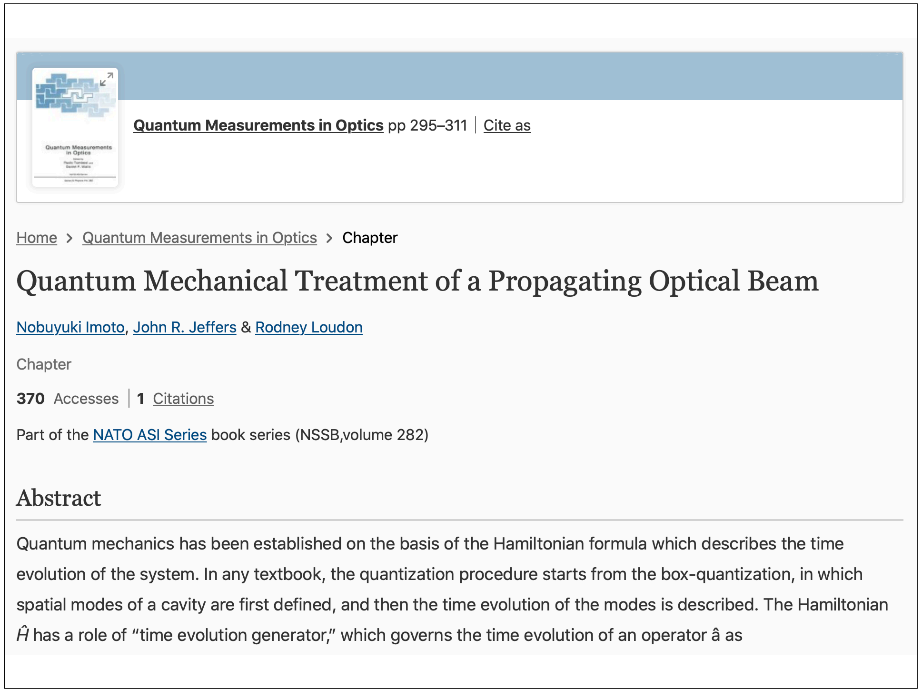


Quantum Measurements
in Optics

Edited by
Paolo Tombesi and
Daniel F. Walls

NATO ASI Series

Series B: Physics Vol. 282



Quantum Measurements in Optics pp 295–311 | Cite as

Home > Quantum Measurements in Optics > Chapter

Quantum Mechanical Treatment of a Propagating Optical Beam

Nobuyuki Imoto, John R. Jeffers & Rodney Loudon

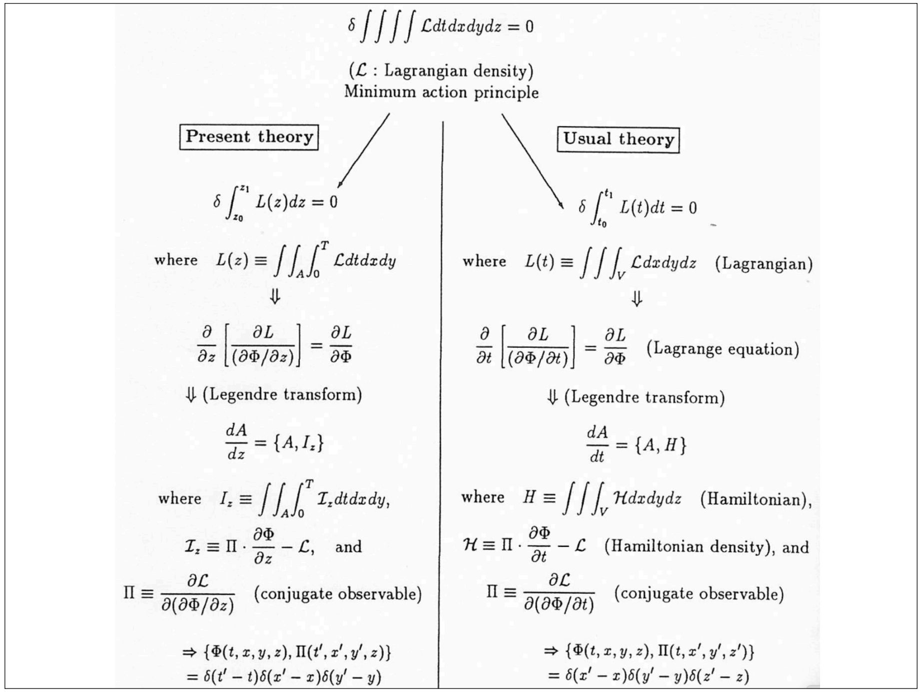
Chapter

370 Accesses | **1** Citations

Part of the NATO ASI Series book series (NSSB,volume 282)

Abstract

Quantum mechanics has been established on the basis of the Hamiltonian formula which describes the time evolution of the system. In any textbook, the quantization procedure starts from the box-quantization, in which spatial modes of a cavity are first defined, and then the time evolution of the modes is described. The Hamiltonian $\hat{H}$ has a role of "time evolution generator," which governs the time evolution of an operator â as



$$\delta \int\!\!\int\!\!\int\!\!\int \mathcal{L}\,dt\,dx\,dy\,dz = 0$$

($\mathcal{L}$: Lagrangian density)
Minimum action principle

Present theory

$$\delta \int_{z_0}^{z_1} L(z)dz = 0$$

where $L(z) \equiv \int\!\!\int_A \int_0^T \mathcal{L}\,dt\,dx\,dy$

$$\Downarrow$$

$$\frac{\partial}{\partial z}\left[\frac{\partial L}{(\partial\Phi/\partial z)}\right] = \frac{\partial L}{\partial \Phi}$$

$\Downarrow$ (Legendre transform)

$$\frac{dA}{dz} = \{A, I_z\}$$

where $I_z \equiv \int\!\!\int_A \int_0^T \mathcal{I}_z\,dt\,dx\,dy$,

$\mathcal{I}_z \equiv \Pi \cdot \frac{\partial \Phi}{\partial z} - \mathcal{L}$, and

$\Pi \equiv \frac{\partial \mathcal{L}}{\partial(\partial\Phi/\partial z)}$ (conjugate observable)

$$\Rightarrow \{\Phi(t,x,y,z), \Pi(t',x',y',z)\} = \delta(t'-t)\delta(x'-x)\delta(y'-y)$$

Usual theory

$$\delta \int_{t_0}^{t_1} L(t)dt = 0$$

where $L(t) \equiv \int\!\!\int\!\!\int_V \mathcal{L}\,dx\,dy\,dz$ (Lagrangian)

$$\Downarrow$$

$\frac{\partial}{\partial t}\left[\frac{\partial L}{(\partial\Phi/\partial t)}\right] = \frac{\partial L}{\partial \Phi}$ (Lagrange equation)

$\Downarrow$ (Legendre transform)

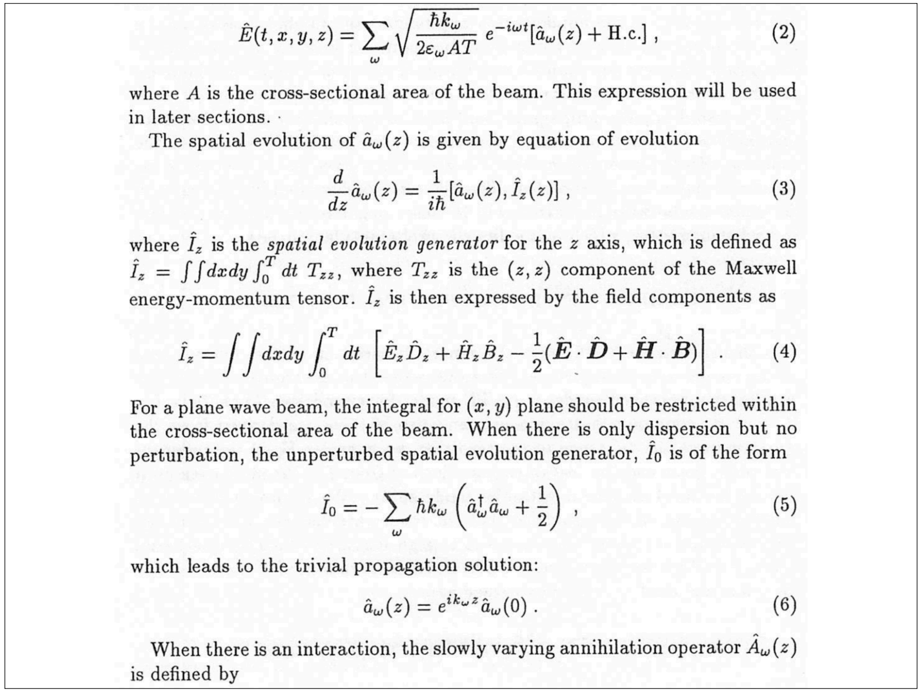
$$\frac{dA}{dt} = \{A, H\}$$

where $H \equiv \int\!\!\int\!\!\int_V \mathcal{H}\,dx\,dy\,dz$ (Hamiltonian),

$\mathcal{H} \equiv \Pi \cdot \frac{\partial \Phi}{\partial t} - \mathcal{L}$ (Hamiltonian density), and

$\Pi \equiv \frac{\partial \mathcal{L}}{\partial(\partial\Phi/\partial t)}$ (conjugate observable)

$$\Rightarrow \{\Phi(t,x,y,z), \Pi(t,x',y',z')\} = \delta(x'-x)\delta(y'-y)\delta(z'-z)$$



$$\hat{E}(t,x,y,z) = \sum_{\omega} \sqrt{\frac{\hbar k_\omega}{2\varepsilon_\omega AT}}\, e^{-i\omega t}[\hat{a}_\omega(z) + \mathrm{H.c.}]\,, \qquad (2)$$

where A is the cross-sectional area of the beam. This expression will be used in later sections.

The spatial evolution of $\hat{a}_\omega(z)$ is given by equation of evolution

$$\frac{d}{dz}\hat{a}_\omega(z) = \frac{1}{i\hbar}[\hat{a}_\omega(z), \hat{I}_z(z)]\,, \qquad (3)$$

where $\hat{I}_z$ is the *spatial evolution generator* for the z axis, which is defined as $\hat{I}_z = \int\!\int dxdy \int_0^T dt\ T_{zz}$, where T_{zz} is the (z,z) component of the Maxwell energy-momentum tensor. $\hat{I}_z$ is then expressed by the field components as

$$\hat{I}_z = \int\!\!\int dxdy \int_0^T dt\ \left[\hat{E}_z\hat{D}_z + \hat{H}_z\hat{B}_z - \frac{1}{2}(\hat{\boldsymbol{E}}\cdot\hat{\boldsymbol{D}} + \hat{\boldsymbol{H}}\cdot\hat{\boldsymbol{B}})\right]\,. \qquad (4)$$

For a plane wave beam, the integral for (x,y) plane should be restricted within the cross-sectional area of the beam. When there is only dispersion but no perturbation, the unperturbed spatial evolution generator, $\hat{I}_0$ is of the form

$$\hat{I}_0 = -\sum_{\omega} \hbar k_\omega \left(\hat{a}^\dagger_\omega \hat{a}_\omega + \frac{1}{2}\right)\,, \qquad (5)$$

which leads to the trivial propagation solution:

$$\hat{a}_\omega(z) = e^{ik_\omega z}\hat{a}_\omega(0)\,. \qquad (6)$$

When there is an interaction, the slowly varying annihilation operator $\hat{A}_\omega(z)$ is defined by

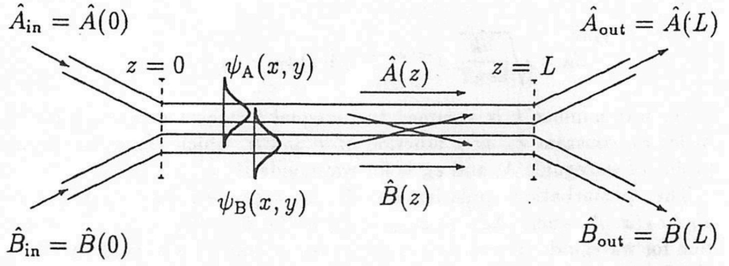


FIG. 1. Schematic view of a directional coupler

$$\frac{d}{dz}\hat{A}_\omega(z) = \frac{1}{i\hbar}[\hat{A}_\omega(z), \hat{I}_{\rm int}(z)] \,. \tag{10}$$

$\hat{I}_{\rm int}$ is expressed using the perturbation polarization $\hat{\boldsymbol{P}}$ as

$$\hat{I}_{\rm int} = \int\!\!\int\!\!\int_0^T \left(E_z P_z - \frac{1}{2}\hat{\boldsymbol{E}}\cdot\hat{\boldsymbol{P}} \right) dt dx dy \,. \tag{11}$$

Since $\hat{\boldsymbol{P}}$ is a function of the field, $\hat{I}_{\rm int}$ is expressed by $\hat{A}_\omega(z)$'s and $\hat{A}^\dagger_\omega(z)$'s, using the quantized expression of the field. Equation of evolution (10) thus gives a set of coupled-mode equations for relevant $\hat{A}_\omega(z)$'s and $\hat{A}^\dagger_\omega(z)$'s. The above formula is consistently used in solving specific problems described hereafter.

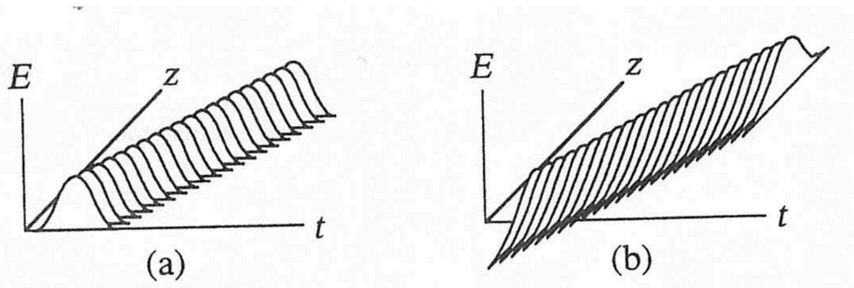
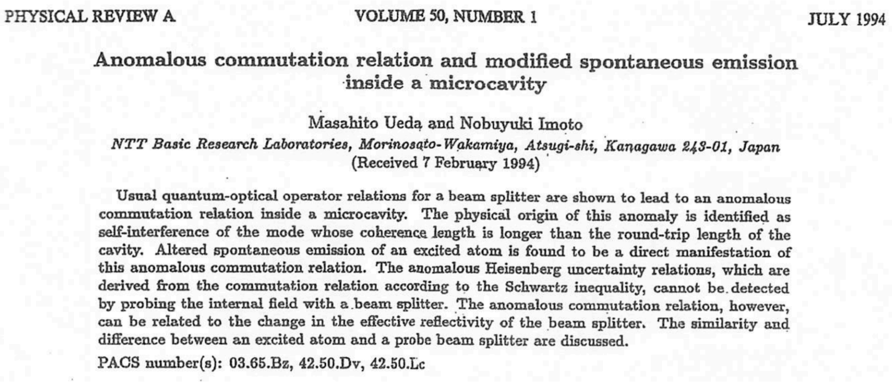


FIG. 5. Stationary pulse propagation in a non-dispersive medium. (a) Spatial evolution of a temporal pulse mode. (b) Time evolution of a spatial pulse mode.



PHYSICAL REVIEW A VOLUME 50, NUMBER 1 JULY 1994

Anomalous commutation relation and modified spontaneous emission inside a microcavity

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(Received 7 February 1994)

Usual quantum-optical operator relations for a beam splitter are shown to lead to an anomalous commutation relation inside a microcavity. The physical origin of this anomaly is identified as self-interference of the mode whose coherence length is longer than the round-trip length of the cavity. Altered spontaneous emission of an excited atom is found to be a direct manifestation of this anomalous commutation relation. The anomalous Heisenberg uncertainty relations, which are derived from the commutation relation according to the Schwartz inequality, cannot be detected by probing the internal field with a beam splitter. The anomalous commutation relation, however, can be related to the change in the effective reflectivity of the beam splitter. The similarity and difference between an excited atom and a probe beam splitter are discussed.

PACS number(s): 03.65.Bz, 42.50.Dv, 42.50.Lc

The commutation relation can be ≷ 1 inside a cavity

Ueda & Imoto PRA50, 89(1994)

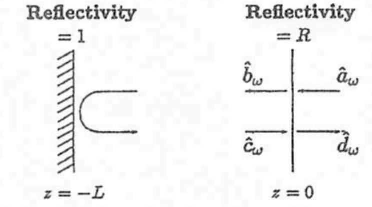


FIG. 1. Microcavity and field operators.

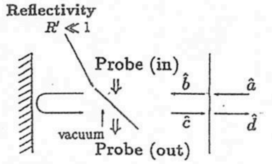


FIG. 3. Microcavity with a probe beam splitter insi

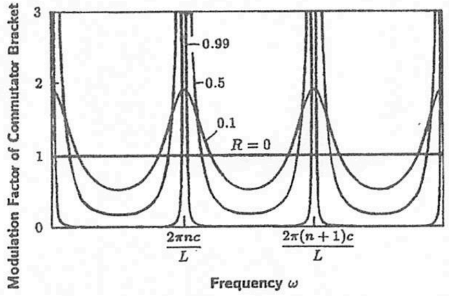
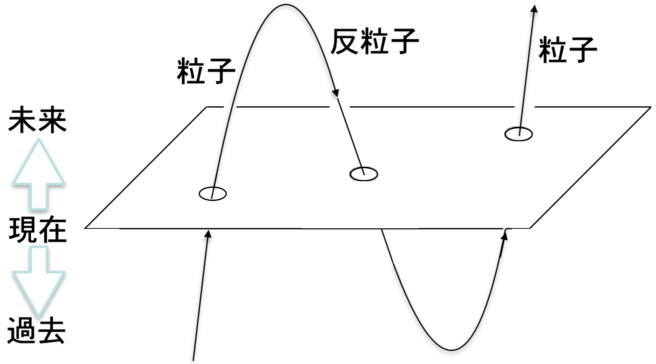


FIG. 2. The commutator-bracket value inside a microcavity as a function of the wave number k for several values of the reflectivity R.

Question:
How about "cavity in time domain"?

ホイーラーとファインマンの会話

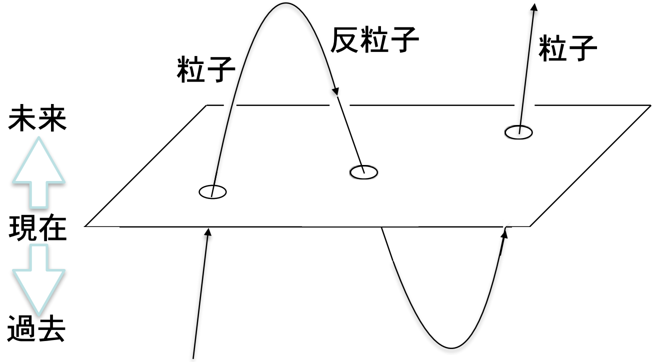
「ファインマン君、電子はなぜ見分けがつかないかわかるか?
　簡単なことさ。全ての電子はたった1つの電子の化身だからさ」



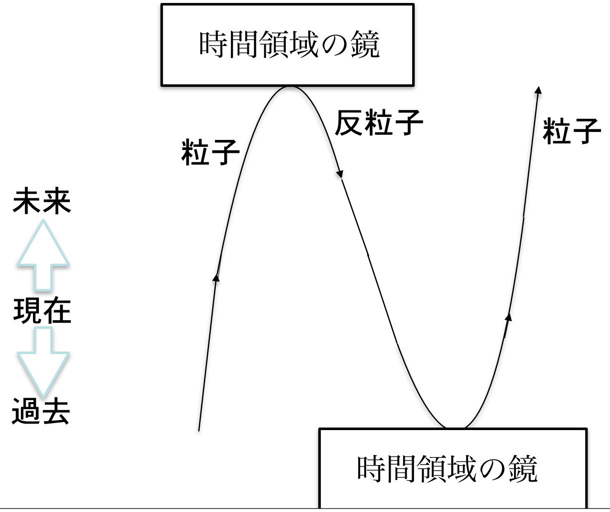
実際にこの現象を見ようと思ったら、どういう実験をしたらよいか?

普通に考えたら、粒子と反粒子の対生成が(右側で)起き、その
反粒子が別の粒子と(左側で)対消滅するのを気長に待つしかない。

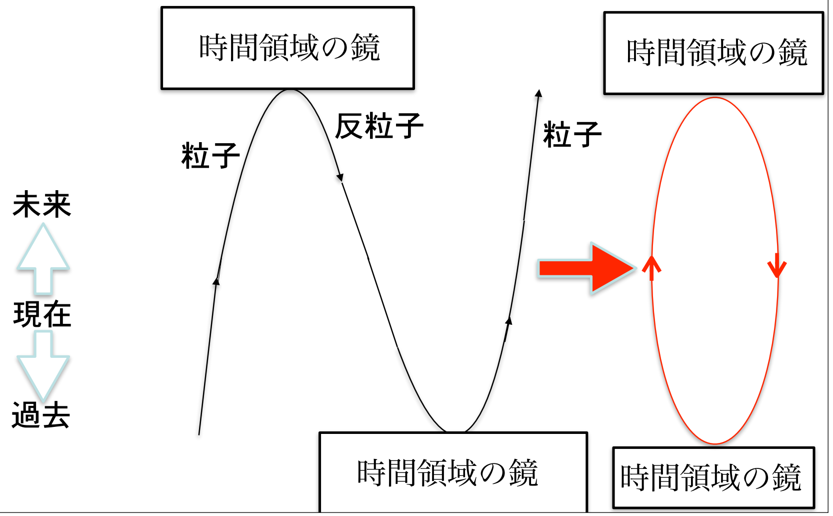
しかし、この現象を意図的に起こす(engineeringする)実験はできないか?



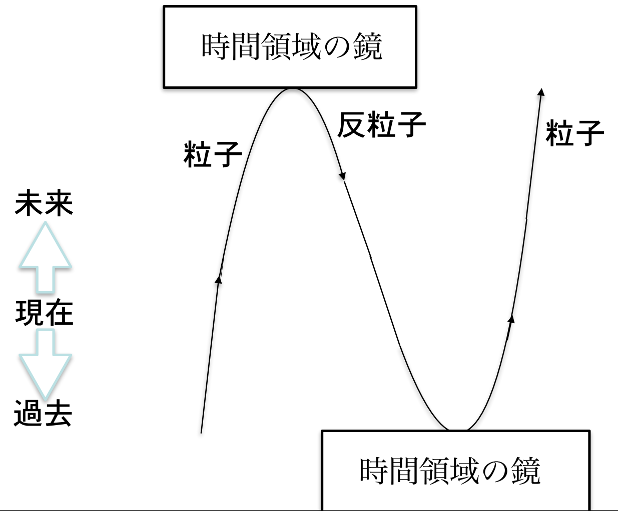
もし、時間領域の鏡があれば、できるのではないか?



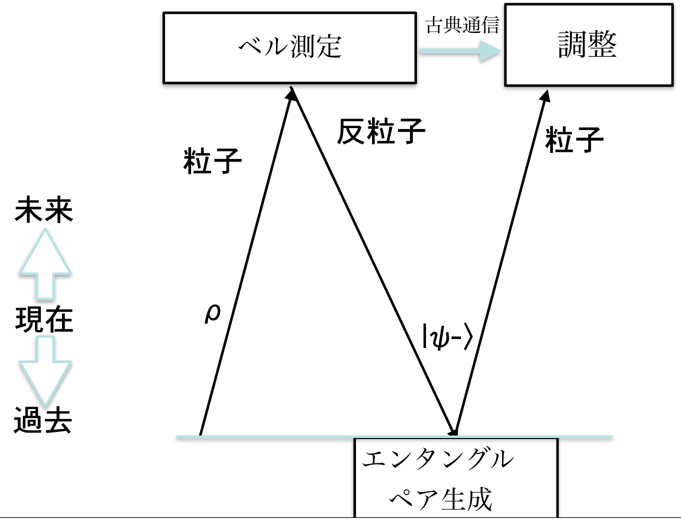
そのような鏡が2枚あれば、時間領域の共振器もできるのではないか?



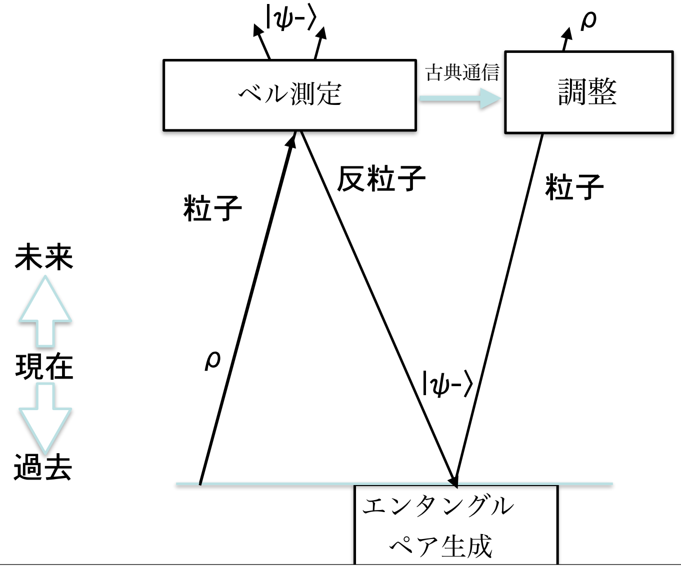
これは量子テレポーテーションだ！

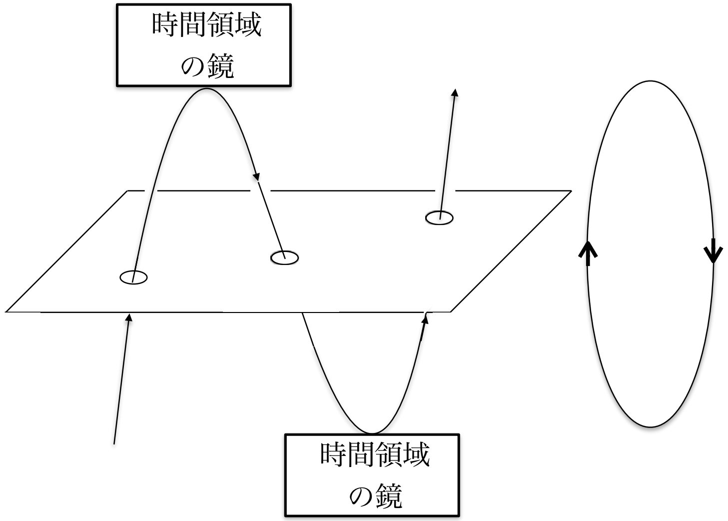

時間領域の鏡
粒子
反粒子
粒子
未来
現在
過去
時間領域の鏡

これは量子テレポーテーションだ！

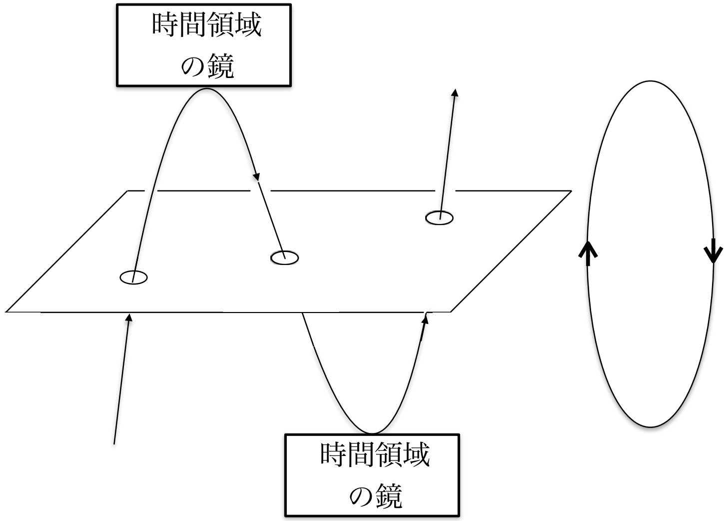

ベル測定
古典通信
調整
粒子
反粒子
粒子
未来
ρ
$|\psi-\rangle$
現在
過去
エンタングル
ペア生成

これは量子テレポーテーションだ！


$|\psi-\rangle$
ρ
ベル測定
古典通信
調整
反粒子
粒子
粒子
未来
現在
ρ
$|\psi-\rangle$
過去
エンタングル
ペア生成


時間領域
の鏡
時間領域
の鏡

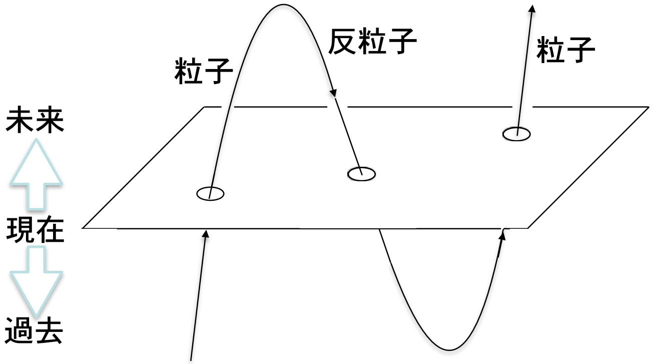
空間的に動いて行かないようにすれば、
時間領域の共振器ができる！



（どうやってクローズドループにするかは
future problem）

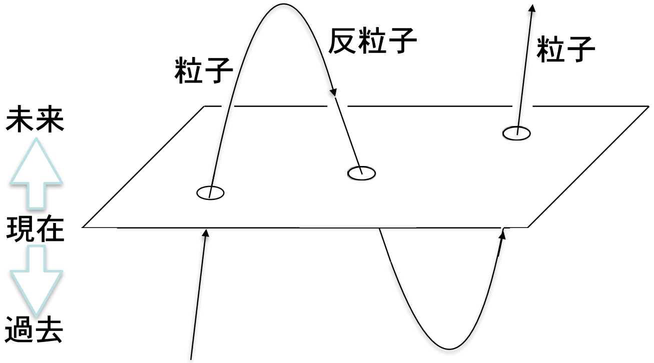
ホイーラーとファインマンの会話の続き

「ファインマン君、電子はなぜ見分けがつかないかわかるか?
簡単なことさ。全ての電子はたった1つの電子の化身だからさ」



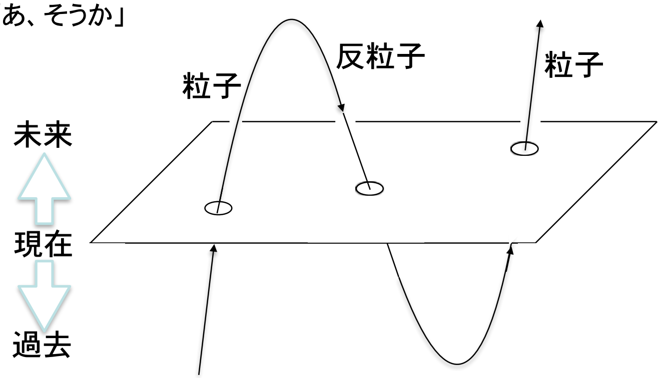
ホイーラーとファインマンの会話の続き

「ファインマン君、電子はなぜ見分けがつかないかわかるか?
簡単なことさ。全ての電子はたった1つの電子の化身だからさ」
「でも先生、それではこの宇宙が粒子ばかりで反粒子が圧倒的に少ない
ことを説明できません」

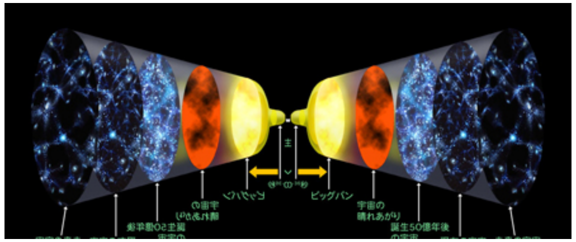


ホイーラーとファインマンの会話の続き

「ファインマン君、電子はなぜ見分けがつかないかわかるか?
簡単なことさ。全ての電子はたった1つの電子の化身だからさ」
「でも先生、それではこの宇宙が粒子ばかりで反粒子が圧倒的に少ない
ことを説明できません」
「あ、そうか」



そこで話は少し変わるが、なぜ粒子反粒子数はアンバランス?

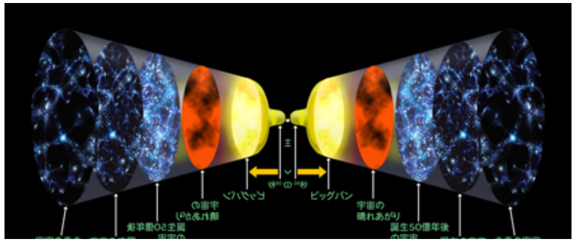


郡山市ふれあい科学館のサイトの図を対称に加工

安易ではあるが、宇宙は対生成ビッグバンを起こし、そのとき粒子反粒子数がアンバランスになったかもしれない・・・

どのようにどのくらいアンバランスになったかは確率的な相転移
→元々はほとんどバランスしていたが対消滅で格差が拡がった。

そこで話は少し変わるが、なぜ粒子反粒子数はアンバランス?



郡山市ふれあい科学館のサイトの図を対称に加工

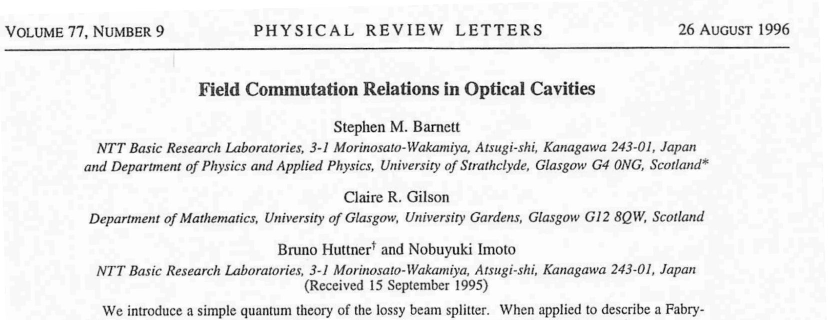
相転移で確率的に・・・というところに、必然でなく偶然の要素が現れる。すると「宇宙は整数論と解析接続から隙間無く埋まった」のではなく、サイコロが振られ（または神様の意図が反映され）たフリーパラメーターs が含まれていてもおかしくない。
宇宙定数など・・・

「共振器の固有周波数と無関係のモードの異常交換関係」の話の続き

Appendix: Field commutators are always normal even in cavities.

As discussed in slide 7, we derived that the commutator $[a(\omega), a^\dagger(\omega')]$ becomes anomalous, which is because the ω modes are incompatible with the resonator modes [PRA50,89 (1994)]. (This anomaly is related to the Purcell effect.)

In this appendix, we show that the field commutators are normal even inside the resonator. This was published in PRL77, 1739 (1996). (See below).



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Field Commutation Relations in Optical Cavities

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(Received 15 September 1995)

We introduce a simple quantum theory of the lossy beam splitter. When applied to describe a Fabry-Pérot cavity this leads to apparently anomalous commutation relations for the intracavity operators. We show that these unfamiliar properties are nevertheless consistent with the fundamental canonical commutator for the vector potential and electric field operators. This result is derived as a consequence of causality as applied to the properties of mirror reflection coefficients. [S0031-9007(96)00953-2]

PACS numbers: 42.50.Dv, 03.65.Ca, 42.50.Lc

場の交換関係（モードに依存しない）は共振器内でも正常であることを示した。