Title: Unruh-DeWitt detectors in RQI: from the basics to frontiers

Date: May 19, 2015 02:00 PM

URL: http://pirsa.org/15050106

Abstract: <p>In relativistic quantum information (RQI) we study quantum information in relativistic systems to obtain more insights to both quantum and gravitational physics on the one hand, and to find new ideas for quantum information processing on the other. One of the popular models in RQI is the Unruh-DeWitt (UD) detector theory, in which localized objects, called detectors, are coupled to and moving in relativistc quantum fields. In this mini-course I will discuss the UD detector theory in detail, mainly on the nonperturbative methods and their applications to RQI.</p>

<p> </p>

Q. Brownian Motion

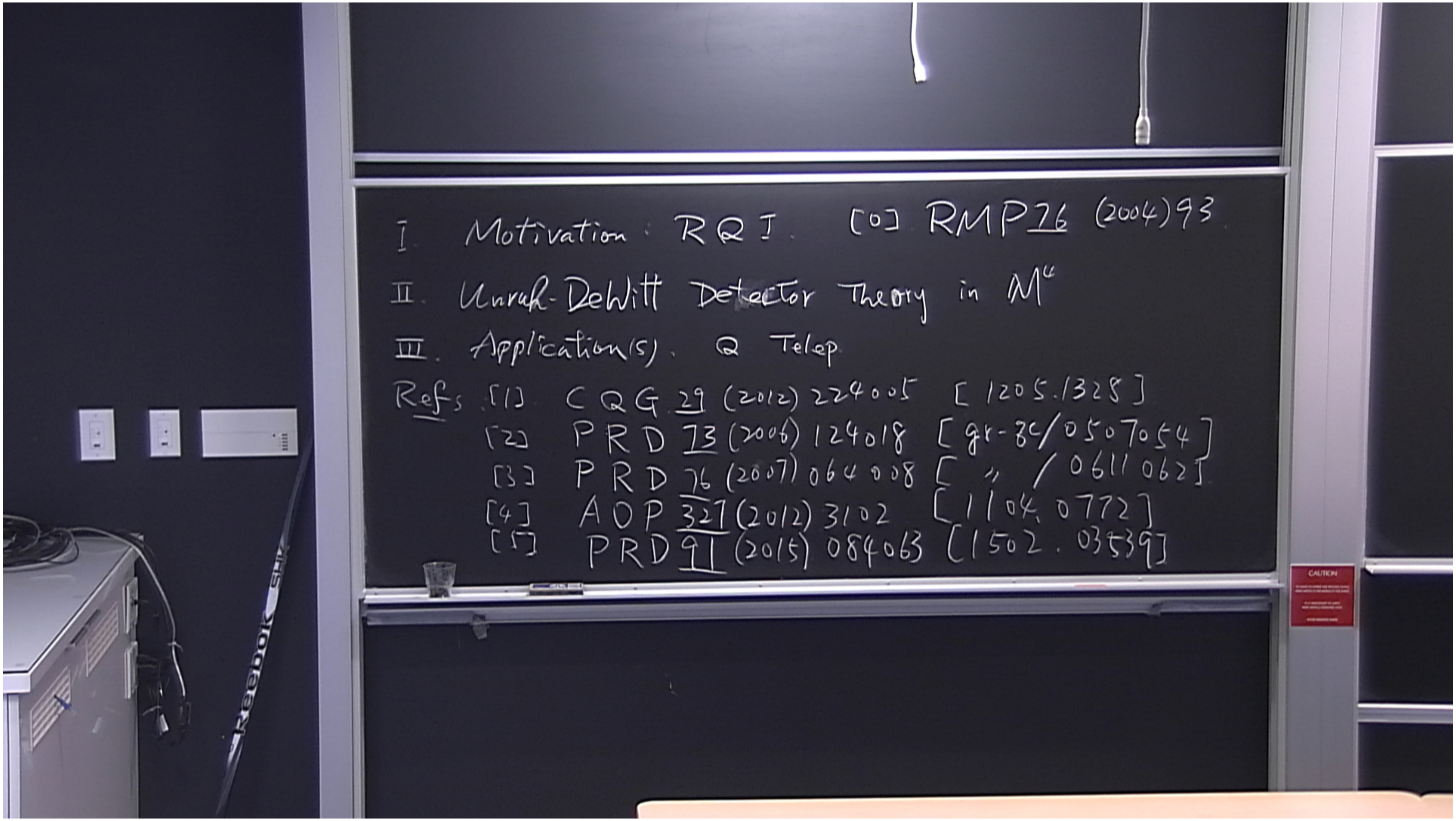
$$H_{tot} = H_{sys} + H_{bath} + H_{int}$$

$$\begin{cases} H_{sys} = \dfrac{P^2}{2m} + \dfrac{m}{2}\Omega^2 Q^2 \\ H_{bath} = \sum_n \left(\dfrac{p_n^2}{2m_n} + \dfrac{m_n}{2}\omega_n^2 \xi_n^2 \right) \\ H_{int} = x \sum_n C_n \xi_n \end{cases}$$

Lorentz electron

$$S = m \int d\tau \sqrt{v_\mu v^\mu} - \frac{1}{4}\int d^4x\, F_{\mu\nu}F^{\mu\nu} + \int d^4x\, j_\mu A^\mu$$

$$j_\mu = e\, v_\mu = e\, \dot{z}_\mu$$


I. Motivation: RQI. [0] RMP 76 (2004) 93
II. Unruh-DeWitt Detector Theory in M^4
III. Application(s). Q Telep.
Refs [1] CQG 29 (2012) 224005 [1205.1328]
[2] PRD 73 (2006) 124018 [gr-qc/0507054]
[3] PRD 76 (2007) 064008 [" / 0611062]
[4] AOP 327 (2012) 3102 [1104.0772]
[5] PRD 91 (2015) 084063 [1502.03539]

[5] PRD 91 (2015) 084063 [1502.03539]

I. Motivation

QIS

- Q. Computing
- Q Comm.
- Q Telep.
- ...

Q. Entanglement
Q. Measurement
Q. Nonlocality

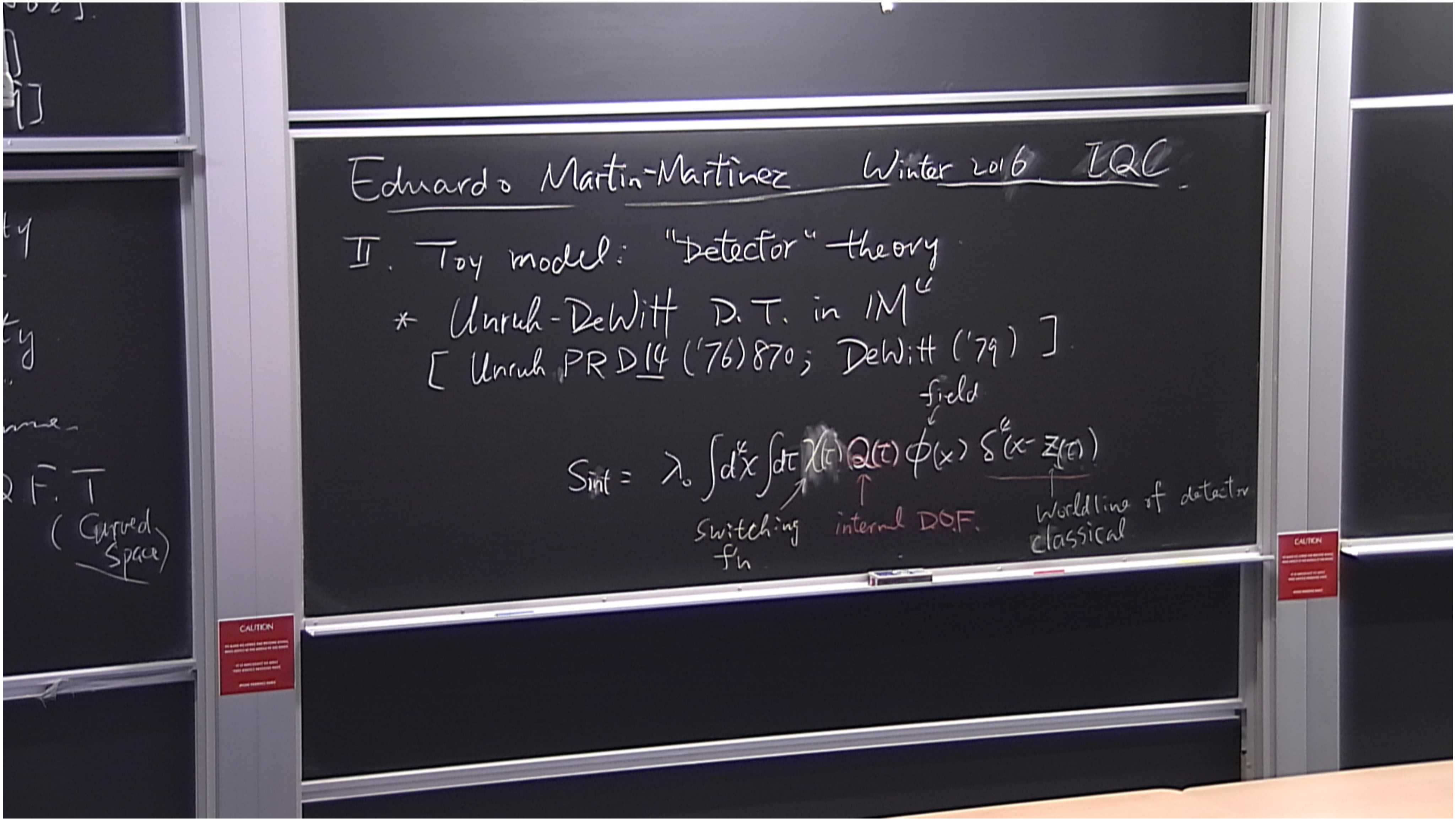
Rela. model with localized QM obj + QF
(e.g. UD detector theory)

- Unruh effect

(Dynamical) Casimir effect.

Relativity

- Causality
- ref. frame "C"
- Rela. QFT (Curved Space)


Eduardo Martin-Martinez Winter 2016 IQC
II. Toy model: "Detector" theory
* Unruh-DeWitt D.T. in $\mathbb{M}^4$
[Unruh PRD 14 ('76) 870; DeWitt ('79)]
field
$S_{int} = \lambda_0 \int d^4x \int d\tau\, \chi(\tau)\, Q(\tau)\, \phi(x)\, \delta^4(x - z(\tau))$
Switching fn
internal D.O.F.
Worldline of detector classical
Q.F.T
(Curved Space)

$$S = S_\phi + S_Q + S_{int}$$

$$S_{int} = \lambda_0 \int d^4x \int d\tau\, \chi(\tau)\, Q(\tau)\, \phi(x)\, \delta^4(x - z(\tau))$$

Switching fn

internal D.O.F.

Worldline of detector
classical

$$\begin{cases} S_\phi = -\frac{1}{2}\int d^4x\, \partial_\mu\phi\, \partial^\mu\phi \\ S_Q = \frac{m_0}{2}\int d\tau \left[(\partial_\tau Q)^2 - \Omega_0^2 Q^2 \right] \end{cases}$$

(Curved Space)

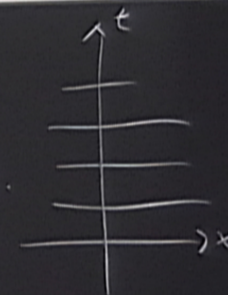
$$S = S_\phi + S_Q + S_{int}$$

$$S_{int} = \lambda_0 \int d^4x \int d\tau\, \chi(\tau)\, Q(\tau)\, \phi(x)\, \delta^4(x - z(\tau))$$

Switching fn — internal D.O.F. — Worldline of detector classical

$$S_\phi = -\frac{1}{2}\int d^4x\, \partial_\mu\phi\, \partial^\mu\phi$$

$$S_Q = \frac{m_0}{2}\int d\tau \left[(\partial_\tau Q)^2 - \Omega_0^2 Q^2 \right] \qquad \partial_\tau Q$$



→ linear theory

Conj. mtm

$$P = \frac{\partial S}{\partial(\partial_t Q)} = \frac{\partial S}{\partial\left(\left|\frac{d\tau}{dt}\right| \partial_\tau Q\right)} \overset{!!}{=} m_0 \dot{Q}$$

$$\pi^{\vec{x}}(t) = \pi(t, \vec{x}) = \frac{\delta S}{\delta(\partial_t \phi_{\vec{x}})} = \partial_t \phi_{\vec{x}}(t)$$

⇒ Hamiltonian

$$H = \frac{1}{\left|\frac{d\tau}{dt}\right|}\frac{P^2}{2m_0} + \left|\frac{d\tau}{dt}\right| \frac{m_0}{2}\Omega_0^2 Q^2 + \frac{1}{2}\int d^3x \left[(\pi^{\vec{x}})^2 + |\vec{\nabla}\phi_{\vec{x}}|^2 \right] - \lambda_0 \left|\frac{d\tau}{dt}\right| \chi\, Q\, \phi_{\vec{z}(\tau(t))}$$

Curved Space)

Q. Brownian Motion

$$H_{tot} = H_{sys} + H_{bath} + H_{int}$$

$$\begin{cases} H_{sys} = \frac{P^2}{2m} + \frac{m}{2}\Omega^2 Q^2 \\ H_{bath} = \sum_n \left(\frac{p_n^2}{2m_n} + \frac{m_n}{2}\omega_n^2 q_n^2 \right) \\ H_{int} = Q \sum_n c_n q_n \end{cases}$$

Lorentz electron

$$S = m \int d\tau \sqrt{v_\mu v^\mu}$$

$$- \frac{1}{4} \int d^4x \, F_{\mu\nu} F^{\mu\nu}$$

$$+ \int d^4x \, j_\mu A^\mu$$

$$j_\mu = e v_\mu = e \dot{z}_\mu$$

$S = S_\phi + S_Q + S_{int}$

$$S_{int} = \lambda_0 \int d^4x \int d\tau\, \chi(\tau)\, Q(\tau)\, \phi(x)\, \delta^4(x - z(\tau))$$

Switching fn   internal D.O.F.   Worldline of detector classical

$\Rightarrow$ Hamiltonian

$$T^{00}:\quad H = \frac{1}{\left|\frac{d\tau}{dt}\right|}\frac{P^2}{2m_0} + \left|\frac{d\tau}{dt}\right| \frac{m_0}{2}\Omega_0^2 Q^2 + \frac{1}{2}\int d^3x \left[(\pi^{\vec{x}})^2 + |\vec{\nabla}\phi_{\vec{x}}|^2\right] - \lambda_0 \left|\frac{d\tau}{dt}\right| \chi\, Q\, \phi_{\vec{z}(\tau(t))}$$

$$\phi_{\vec{x}} = \int d^3k\, e^{i\vec{k}\cdot\vec{x}}\, \phi_{\vec{k}}$$

$$C_n \to -\lambda_0 e^{i\vec{k}\cdot\vec{z}}$$

$$H_\phi = \frac{1}{2}\sum_{\vec{k}}\left[(\pi^{\vec{k}})^2 + \underbrace{k^2}_{q_n}\phi_{\vec{k}}^2\right]$$

Curved Space)

Rmk Derivative Coupling in $\mathbb{M}^2$

[Unruh, Zurek '89, Raine, Sciama, Grove '91]

$$S = -\int d^2x\, \frac{1}{2}\partial_\mu\phi\, \partial^\mu\phi + \frac{m_0}{2}\int d\tau \left[\dot{Q}^2 - \Omega_0^2 Q^2\right]$$

$$+\lambda \int d^2x \int d\tau\, \dot{Q}(\tau)\, \phi(x)\, \delta^2(x - Z(\tau))$$

or $Q(\tau)\, \partial_t \phi(x)$

1) IR div under control

Q. Brownian Motion

$$H_{tot} = H_{sys} + H_{bath} + H_{int}$$

$$\begin{cases} H_{sys} = \frac{P^2}{2m} + \frac{m}{2}\Omega^2 Q^2 \\ H_{bath} = \sum_n \left(\frac{p_n^2}{2m_n} + \frac{m_n}{2}\omega_n^2 q_n^2 \right) \\ H_{int} = Q \sum_n c_n q_n \end{cases}$$

ϕ

Lorentz electron

$$S = m \int d\tau \sqrt{v_\mu v^\mu}$$

$$- \frac{1}{4} \int d^4x \, F_{\mu\nu} F^{\mu\nu}$$

$$+ \int d^4x \, j_\mu A^\mu$$

$$\qquad\quad \| $$

$$\dddot{z}(\tau) \qquad e v_\mu = e \dot{z}_\mu$$

Rmk Derivative Coupling in $\mathbb{M}^2$

[Unruh, Zurek '89, Raine, Sciama, Grove '91]

$$S = -\int d^2x \, \frac{1}{2} \partial_\mu \phi \, \partial^\mu \phi + \frac{m_0}{2} \int d\tau \left[\dot{Q}^2 - \Omega_0^2 Q^2 \right]$$

$$+ \lambda \int d^2x \int d\tau \, \dot{Q}(\tau) \, \phi(x) \, \delta^2(x - Z(\tau))$$

or $Q(\tau) \, \partial_t \phi(x)$

1) IR div under control