On experimental testing Foundations of Quantum Mechanics

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INRIM, Italy

Physics Reports 413 (2005) 319-396
Adv. Sci. Lett. 3, 249–258 (2010)

INRIM Quantum Optics Research program "Carlo Novero lab"

Responsible: M. Genovese

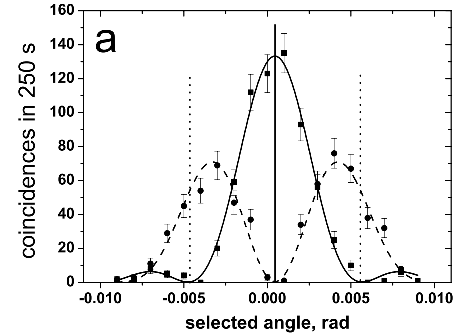
8 labs on quantum optics
5 permanent researchers (M.G., G. Brida, I. Degiovanni, M. Gramegna, S.Castelletto)
5 post docs (A. Meda, F. Piacentini, I. Ruo-Berchera, P.Traina, A. Sherupukov);
1 Visiting Professor (M. Chekhova)
3 PhD students (A. Florio,G.Mingolla,A.Avella)
various undergraduate students, ….

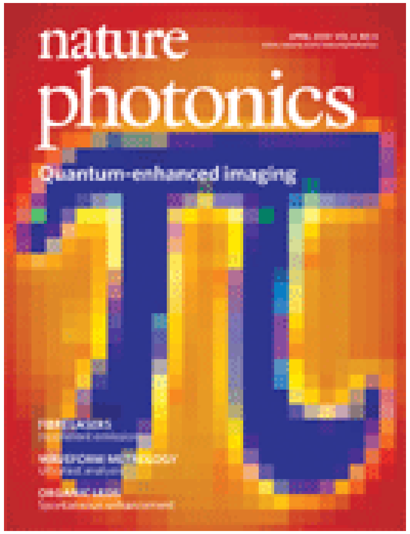
Our main sponsors:
- **Minister of Education**
- **Piedmont Region**
- **Bank Foundation San Paolo**
- ASP, Lagrange Found.
-NATO,…

Main activities:

-Characterization of spatial and spectral properties of PDC sources of entangled photons

(in collaboration with Moscow Univ.Univ. Milano), **PRL** 105 010404 (2010), **Optics Express** Vol. 18 (2010) 12915, **PRL** 104, 100501 (2010),**PRL** 103, 193602 (2009), **EPL** 87 (2009) 64003, **PRL** 96 (06) 143601





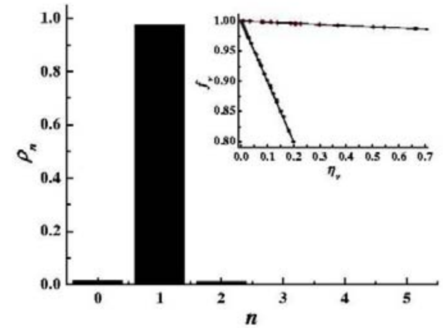
-Quantum Imaging of weak objects

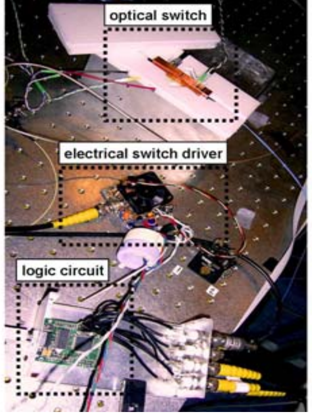
(in collaboration with Como Univ., sponsors: MIUR), **Nature Photonics** 4 227 (2010), **PRL** 102, 213602 (2009).

- Reconstruction of the statistics of quantum optical states by on/off detectors

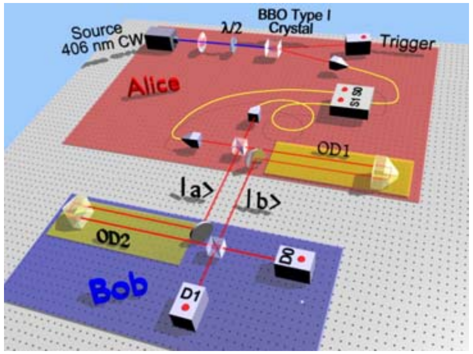
(in collaboration with UniMi,UniCo)

PRA 80 (2009) 022114, **PRL** 95 063602 (2005)

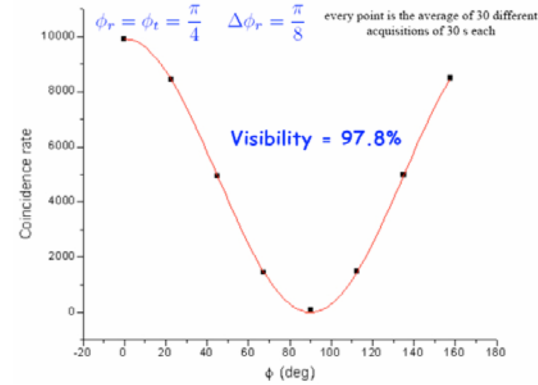




-Detector calibration, multiplexed detectors…(in collaboration with NIST, Moscow) **Opt.Exp**. 18 (2010) 20572.



- **QKD**: channel effects, standardisation and innovative protocols (in collaboration with PoliTo, sponsors: Piedmont region,NATO; ETSI) **Laser Phys. Lett** 17 (2007) 1389



- **Experiments on LR** (tests on specfic LHVT, Alicki's test,…) **Physics Reports** 413/6 (2005) 319, **Opt. Exp**. 16 (2008) 11750, **EPJ D** 44 (07) 577

- and much more, TES single photon detectors, 4-wave mixing,…..

Quantum Mechanics **one of the pillars of modern physics confirmed by very accurate experimental data**

A theory at the basis of a large spectrum of researches ranging from solid state physics to particle physics, from bio-physics [M.Arndt et al., HFSP J. 3 (09) 386] to cosmology [M. G., Advanced Science Letters 2, (2009) 303.]

In the last years the possibility of manipulating single quantum states has fostered the development of promising quantum technologies as quantum information (calculus, communication, etc.), quantum metrology, quantum imaging, ...

Nevertheless, even after a pluri-decennial debate many problems related to the foundations of this theory persist

In particular the problem of measurement and the related problem of macro-objectivation (but also others, e.g. validity of Pauli Principle see VIP experiment, etc.)

The measurement problem

The **von Neumann chain**:
($|a1\rangle$,$|a2\rangle$ quantum states,
$|M0\rangle$ initial state of detection apparatus
$|M1\rangle$, $|M2\rangle$ final states of detection apparatus)

$|a1\rangle\, |M0\rangle \rightarrow\ |a1\rangle\, |M1\rangle$
$|a2\rangle|M0\rangle \rightarrow\ |a2\rangle|M2\rangle$

QM is linear:

$(a\, |a1\rangle + b\, |a2\rangle\,)\, |M0\rangle \rightarrow a\, |a1\rangle\, |M1\rangle + b\, |a2\rangle\, |M2\rangle$

The detection apparatus is entangled as well!!

Various possible solutions to this problem

[M.G. arXiv:1002.0990, Adv. Sci. Lett. 3, 249–258 (2010)]

As every scientific theory QM has a formalism and an interpretative component.

-Some solution try to solve the problem through a reinterpretattion

- Many worlds
- Decoherence
- Quantum Hystories
- Informational approach
- Modal Interpretations
- Relational QM …

- Some solution requires some change in the theory: in this case an experimental falsification becomes possible.

Incompleteness of quantum mechanics

- Reduction by consciousness
- Spontaneous reduction models
- Hidden variable theories

Spontaneous localization models

Ghirardi – Rimini- Weber

$$\Psi(x_1, ..., x_N) j(x - x_i)/R$$

$$j(x - x_i) = A \exp[-(x - x_i)^2/(2a)^2]$$

$$|R(x)|^2 = \int dx_1 ... dx_N |\Psi(x_1, ..., x_N) j(x - x_i)|^2$$

a ☢ 10^{-7} m , rate ● ☢ 10^{-17} s^{-1}

Possible experimental tests:

-

Upper bounds on λ	
Laboratory experiments	**Decades above the conventional value**
Fullerene diffraction experiments	13
Decay of supercurrents	14
Spontaneous x-ray emission from Ge	6
Proton decay	18
Mirror cantilever interferometric experiment	9
Cosmological data	**Decades above the conventional value**
Dissociation of cosmic hydrogen	17
Heating of intergalactic medium (IGM)	8
Heating of interstellar dust grains	15

From S. Adler and A. Bassi Science 325 (2009) 275

Hidden Variable Theories

- Local Hidden Variable Theories

✹ Bell Theorem

- locality loophole
- detection loophole

Example : the CH inequality

$$P(\theta_1,\theta_2)+P(\theta'_1,\theta'_2)+P(\theta'_1,\theta_2)-$$
$$-P(\theta_1,\theta'_2)-P(\theta'_1)-P(\theta_2)\leq 0$$

$P(\theta_i)=$ **Probability of finding a single particle in detector** i **with a certain property** θ_i **(e.g. spin/polarization direction with respect to a selected axis);**

$P(\theta_i,\theta_j)=$ **Joint probability of observing both one particle in** i **with a property** θ_i **and the other in** j **with** θ_j **.**

In a Local HVT:

$$P(\theta_i) = \int P(\theta_i, x)\rho(x)dx$$

$$P(\theta_i, \theta_j) = \int P(\theta_i, \theta_j, x)\rho(x)dx = \int P(\theta_i, x) \cdot P(\theta_j, x)\rho(x)dx$$

Consider 4 real variables $x, x', y, y' \in [0,1]$

$$xy + x'y' + x'y - xy' - x' - y \leq 0 \qquad ??$$

$$x \geq x' \quad \Rightarrow \quad y(x-1) + x'(y-1) + y'(x'-x) \leq 0$$

$$x \leq x' \quad \Rightarrow \quad y(x'-1) + x'(y'-1) + x(y-y') \leq x'(y'-1) + x(y-1) \leq 0$$

$$\Downarrow$$

$P(\theta_i), P(\theta_i, \theta_j) \in [0,1] \quad \Rightarrow$ ***The CH inequality holds***

Non Classicality tests: a hierarchy

Given any two positive real functions $\mathcal{A}, \mathcal{B}$ obeying the relation

$$0 \leq \mathcal{A}(x) \leq \mathcal{B}(x)$$

that for any probability distribution $\rho(x)$ it must be true that

$$\langle \mathcal{A}^2 \rangle \equiv \int \mathcal{A}^2(x)\rho(x)dx \leq \int \mathcal{B}^2(x)\rho(x)dx \equiv \langle \mathcal{B}^2 \rangle$$

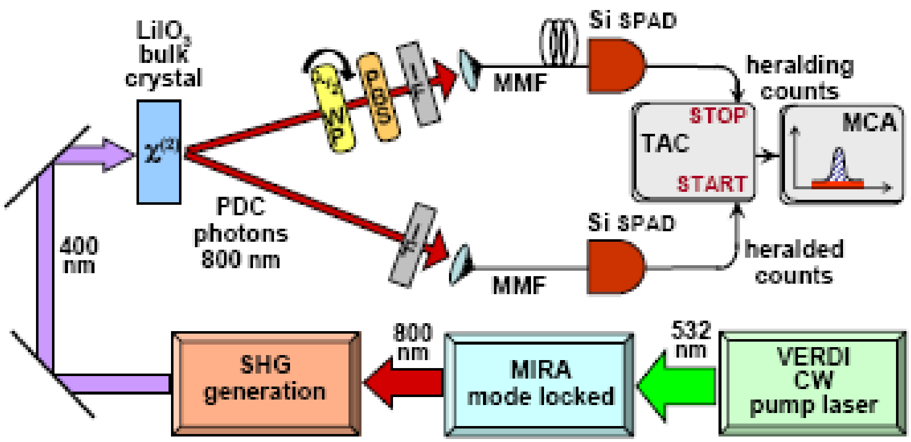
A. Alicki, J. Phys. A: Math. Theor., 41, 062001 (2008)

For **quantum systems**, one can find pairs of observables $\widehat{A}, \widehat{B}$ such that $0 \leq \widehat{A} \leq \widehat{B}$

the classical approach lead to $\langle \widehat{A}^2 \rangle \leq \langle \widehat{B}^2 \rangle$

while to the contrary,
quantum theory allows that for certain quantum states $\langle \widehat{A}^2 \rangle > \langle \widehat{B}^2 \rangle$

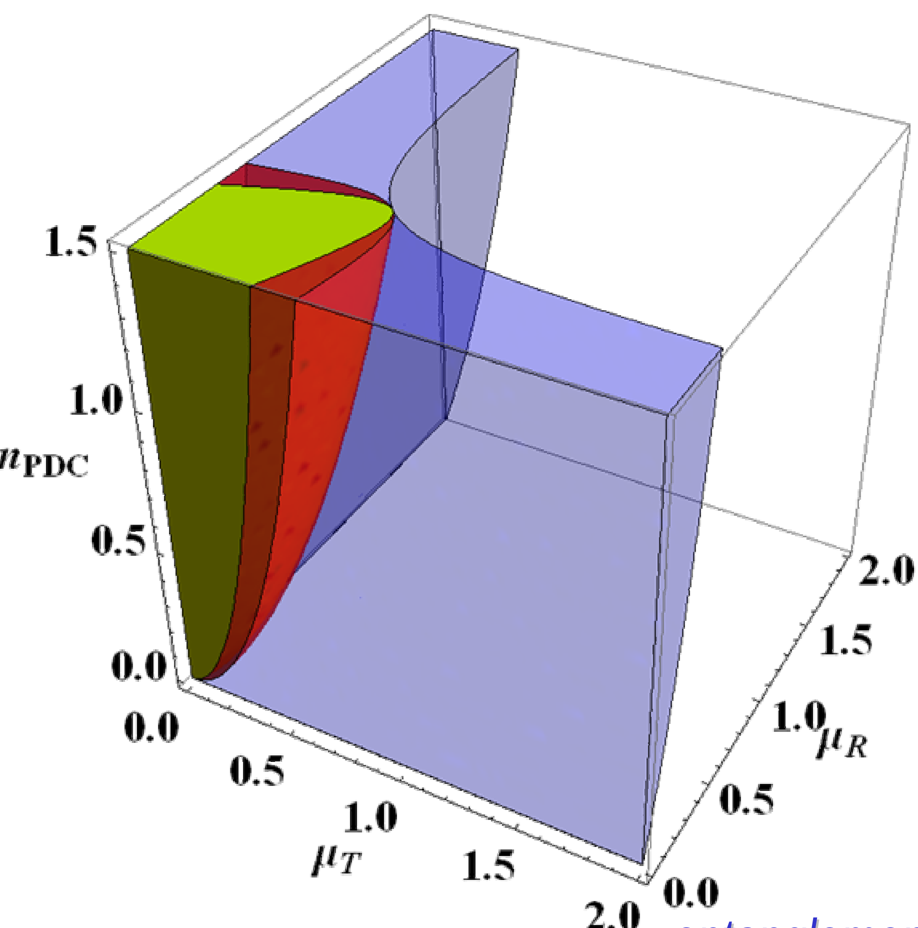
Equivalent to calssical states excluded by von Neumann th.
[M. Zukowsky PhysRevA.79.024103]

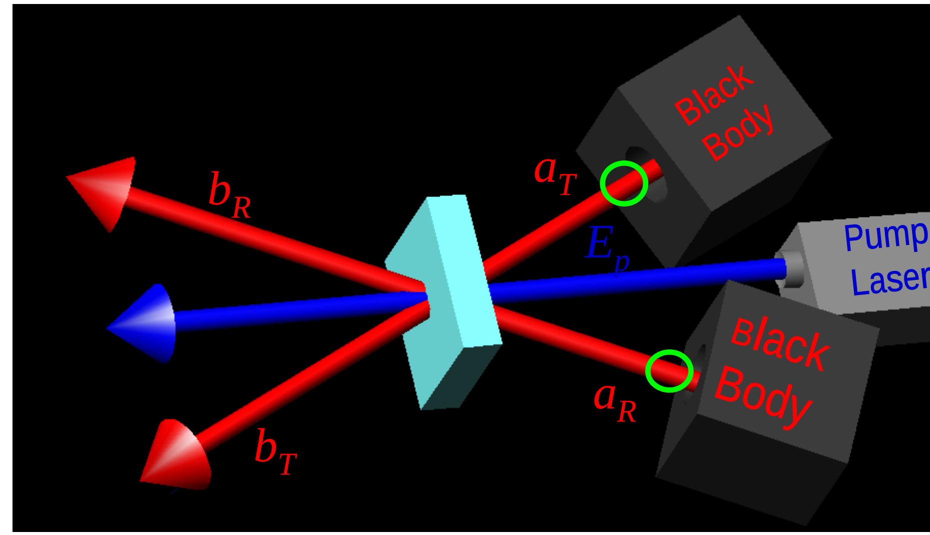


Quantity	Measurement	QM theory
$\mathcal{E}[\langle\widehat{B}\rangle - \langle\widehat{A}\rangle]$	0.0701 ± 0.0015	0.0685
$\mathcal{E}[\langle\widehat{B}^2\rangle - \langle\widehat{A}^2\rangle]$	-0.0461 ± 0.0010	-0.0449
		$(> 0$ HVTs$)$

G. Brida, I. Degiovanni, M. Genovese, F. Piacentini, V. Schettini, N. Gisin, S. Polyakov, and A. Migdall; Phys. Rev. A 79 (2009) 044102.

Thermal Seeded PDC [M.Bondani, I. Degiovanni, M. Genovese, M. Paris and I. Ruo Berchera,V. Schettini. Found. of Phys. DOI: 10.1007/s10701-009-9396-4]





- Subshot noise [G.Brida, M. Genovese, I. Ruo Berchera, Nature Photonics 4 (10) 227]
- Lee Criteria (→ P-function negativity) [Lee,PRA 41 (1990) 1569]
- Entanglement

entanglement is a necessary *condition for sub-shot noiseness*

Sub-shot-noiseness is a necessary *condition for quantumness (in the Lee sense)*

TESTS OF BELL INEQUALITIES

In 70's experiments with **cascade atomic decay**

82 Orsay experiment *[A. Aspect et al., PRL. 49 (1982) 1804]*

Entangled photons from J=0 → J=1 → J=0 Calcium 40 decays

Addressed to detectors separated of 6 m

Space-like separation through acousto-optic switches

$$CH = 0.101 \pm 0.020$$

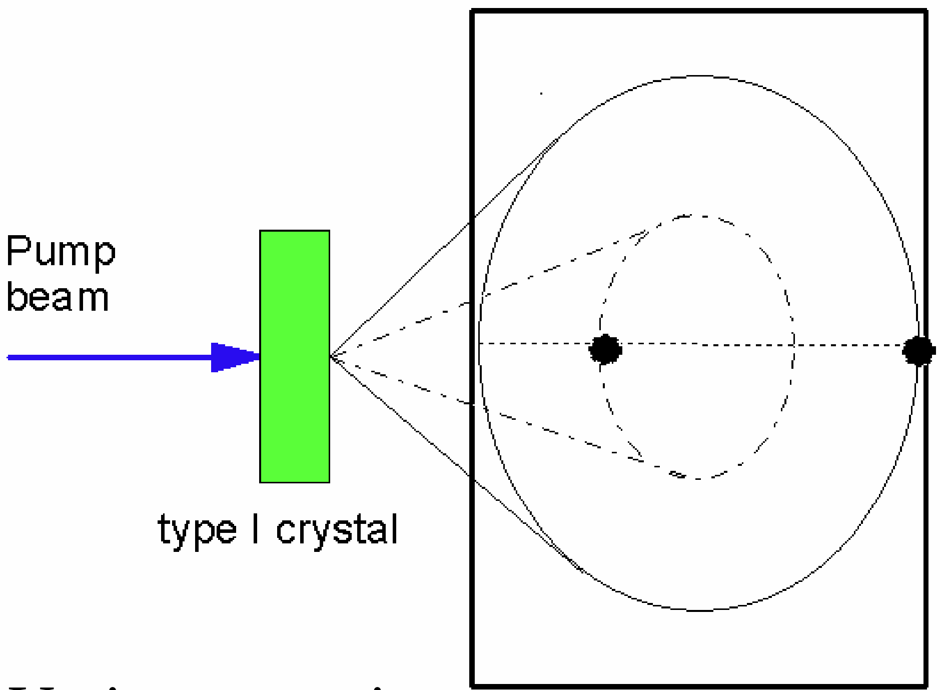
Very low detection efficiency

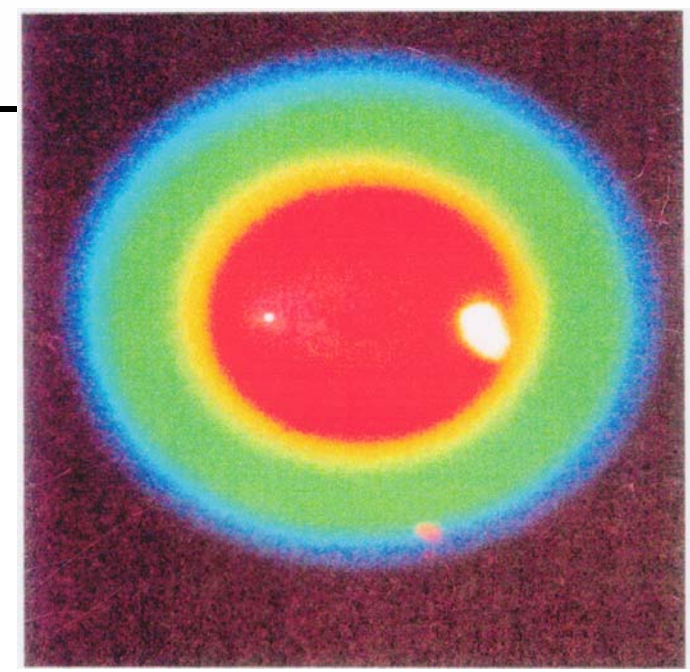
(e.g. 40 coincidence per second against typical production rate of 10^7 pairs per second)

Parametric fluorescence

"Decay" inside a nonlinear medium (NL) of an UV photon (ω_p) in couples of photons (ω_i, ω_s) at longer wavelengths.

- Energy conservation: $\omega_p = \omega_s + \omega_i$
- Momentum conservation: $\vec{k}_p = \vec{k}_s + \vec{k}_i$
- ω_s and ω_i are emitted **at the same time**





Various experiments: J. G. Rarity and P. R. Tapster, PRL 64 (90) 2495; J. Brendel et al., EPL 20 (92) 275; P. G. Kwiat et al., PRA 41 (90) 2910; W. Tittel et al, quant-ph 9806043.

Test with equalities

$$\Psi_{\mathrm{GHZ}} = \frac{1}{\sqrt{2}}\left(|H\rangle|H\rangle|H\rangle + |V\rangle|V\rangle|V\rangle\right)$$

GHZ

$$\Psi_{\mathrm{GHZ}} = \tfrac{1}{2}\left(|R\rangle|L\rangle|45\rangle + |L\rangle|R\rangle|45\rangle + |R\rangle|R\rangle|-45\rangle + |L\rangle|L\rangle|-45\rangle\right)$$

$$\Psi_{\mathrm{GHZ}} = \tfrac{1}{2}\left(|45\rangle|45\rangle|45\rangle + |45\rangle|-45\rangle|-45\rangle + |-45\rangle|45\rangle|-45\rangle + |-45\rangle|-45\rangle|45\rangle\right)$$

LHVT: -45 for 2,3 $\Rightarrow$

Since 3 is -45 $\Rightarrow$ 2,1 equal circular pol.

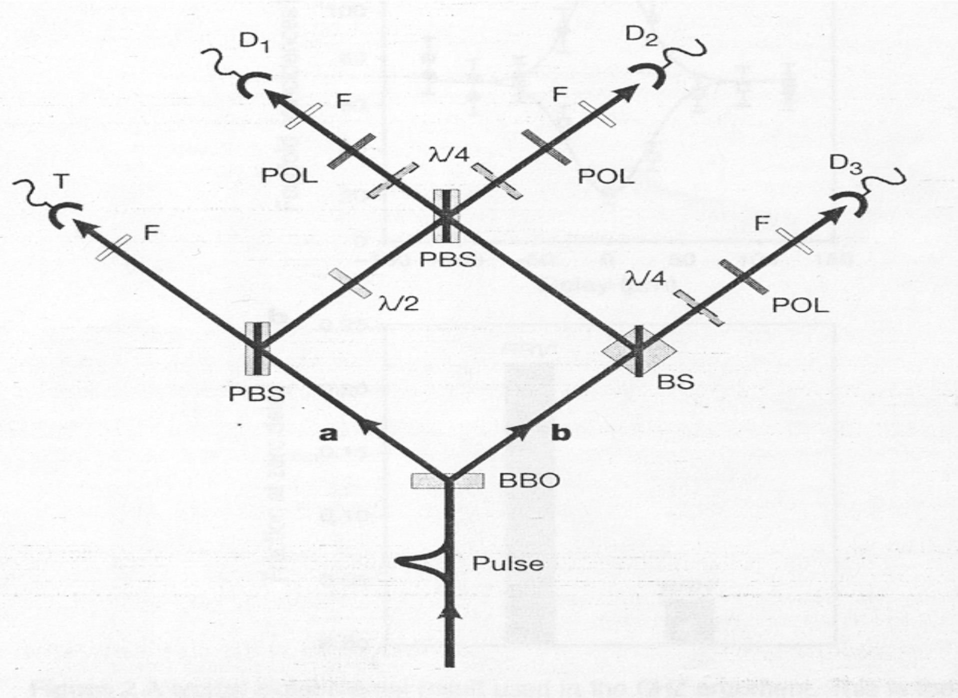
Since 2 is -45 $\Rightarrow$ 3,1 equal circular pol.

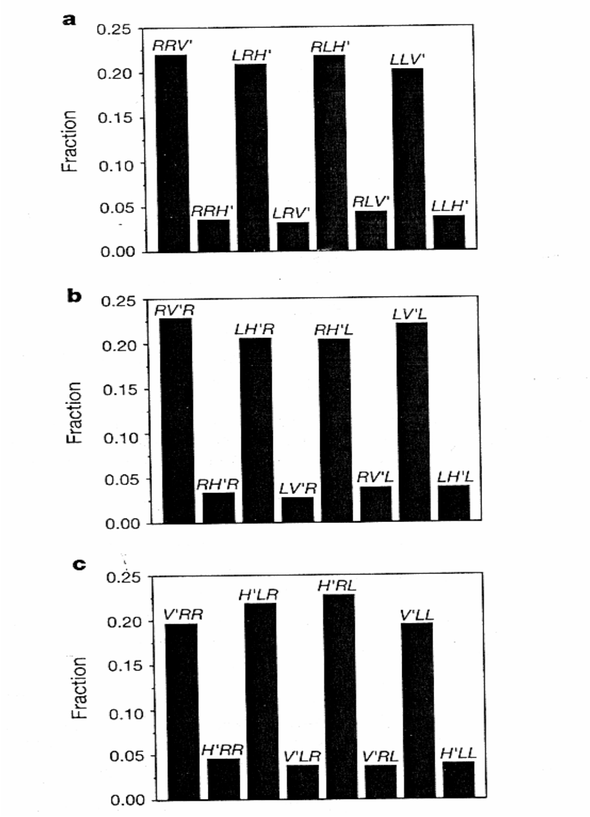
$\Rightarrow$ All have the same circular pol.

$\Rightarrow$ 2,3 identical circula pol.

$\Rightarrow$ 1 is –45 <u>in disagreement with SQM</u>

[Pan et al., Nature 403 (00) 505]



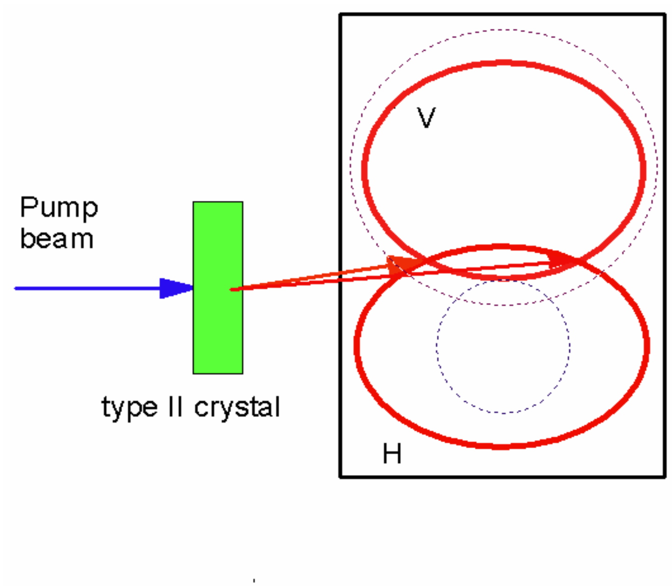


Agreement with SQM,
but detection loophole here as well!!

Other tests with equalities: Hardy.

Experiment: G.Di Giuseppe et al., PRA 56 (97)176

Brilliant sources:

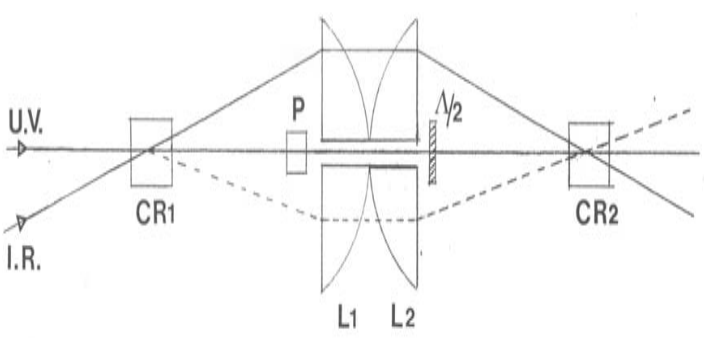


Type II PDC

$$\frac{[(|H>|V>+|V>|H>)]}{\sqrt{(2)}}$$

Th: A. Garuccio
EXP: Zeilinger,
Sergienko, Kwiat et al.PRL 75 (95) 4337

102 standard deviations violation of CHSH ineq. [P. Kwiat et al.,]



$$\frac{[(|H>|H>+f|V>|V>)]}{\sqrt{(1+|f|^2)}}$$

Two type I PDC
Th: Hardy
Exp: P. Kwiat et al., PRL 83 (99) 3103
G. Brida, M.G., C. Novero and E. Predazzi, PLA 268 (2000) 12

CH = 513 ± 25

-Locality loophole

Closed

[W. Tittel et al., PRA 59 (1999)4150; G. Weihs et al., PRL 81 (1998) 5039]

-Detection loophole

Maximally entangled states: 82% detection efficiency

Non maximally entangled states: 67 %

[P.H. Eberhard, PRA 47 (1993) R747]

Highest efficiencies with photons around 30%

P.G. Kwiat et al., PRL 75 (1995) 4337

Cryogenic High efficiency detectors?

Other systems?

i) Ions: Experiment with Berillum ions

High efficiency (98%), but subsystems are not separated during measurement *(Rowe et al., Nature 409 (01) 791)*

Improvement more recently: 1 m [Monroe et al., qph 0801.2184]

One needs many km (detection time around 50 μs)

ii) Neutrons *[Rauch]*

iii) Mesons (K,B) *[Foadi,Selleri PRA 61 (99) 012106-1,EPJ C14 (00) 469; Di Domenico NP B 450 (95) 293;Bramon,Garbarino, PRL 89 (02) 160401,Hiesmayr Fpl 14 (01)231]*

$$|\Psi\rangle = \frac{|K^0\rangle|\bar{K}^0\rangle - |\bar{K}^0\rangle|K^0\rangle}{\sqrt{2}} = \frac{|K_L\rangle|K_S\rangle - |K_S\rangle|K_L\rangle}{\sqrt{2}}$$

Some violation of Bell inequalities osserved by Belle [A.Go, JMO 51 (04) 991]

detection-loophole reappears as HV can also determine

a) decay channel *[M.G. et al., PLB 513 (01) 401, FP 32 (02) 589]*

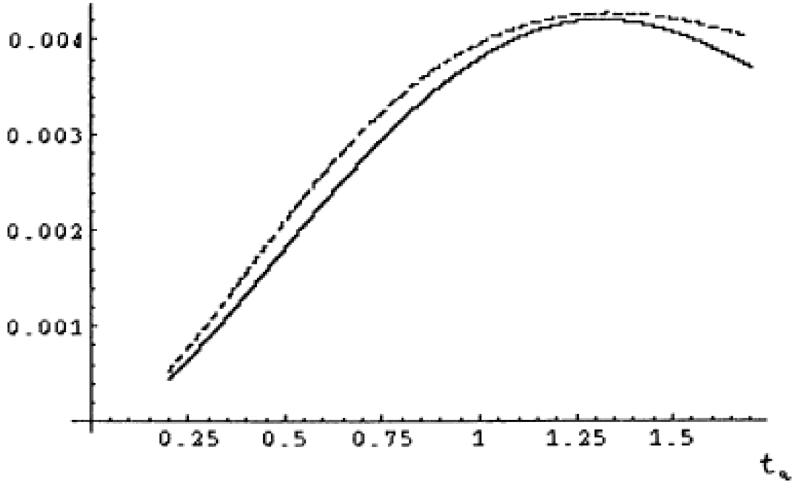
b) time of decay *[MG, PRA 69 (04) 022103]*

An example: **Selleri model** [PRA 56 (97) 3493]

A specific LHV model is built with 2 HV: one associated to CP value the other to S value.

Impossible to reproduce all the results of QM

Nevertheless when it is considered that only a fraction of mesons is detected QM curve can be reproduced [M.G.,C. Novero and E. Predazzi, PLB 513 (01) 401]



Comparison of QM and LHV for detection efficiency 0.3

CP-violations parameters and LR

[F.Benatti,R.Floreanini PRD 57 (98) R1332]

CH inequality transformed in an inequality on CP violation parameters

$$|\mathrm{Re}\{\varepsilon'\}| \leq 3|\varepsilon'|^2$$

and other similars

The analysis pertains specific decay channels:
in M.G. EPJ C 2005 was shown that detection loophole reappears

Non maximally entangled States

[A.Bramon and G.Garbarino, PRL 89 (2002) 160401]

$$|\Phi\rangle = \frac{|K_S\rangle|K_L\rangle - |K_L\rangle|K_S\rangle + R|K_L\rangle|K_L\rangle + R'|K_S\rangle|K_S\rangle}{\sqrt{2+|R|^2+|R'|^2}} \qquad R = -r\exp[-(i\Delta m + (\Gamma_S - \Gamma_L)/2)T]$$

After 10 τ_s

$$|\Phi\rangle = \frac{R|K^0\rangle|K^0\rangle + R|\overline{K}^0\rangle|\overline{K}^0\rangle + (2-R)|\overline{K}^0\rangle|K^0\rangle - (2+R)|K^0\rangle|\overline{K}^0\rangle}{2\sqrt{2+|R|^2}}$$

QM predicts:

$$P_{QM}(K^0,\overline{K}^0) = \eta\eta'/12, \qquad P_{QM}(K_L,\overline{K}^0) = 0,$$

$$P_{QM}(K^0,K_L) = 0, \qquad P_{QM}(K_S,K_S) = 0,$$

IN HVT:

$$P_{LR}(K^0,\overline{K}^0) = \int da\,\rho(a)p_l(K^0|a)p_r(\overline{K}^0|a)$$

$$= \eta\eta'/12 \leqslant \int_{A_{0,\bar{0}}} da\,\rho(a),$$

If a K0 right a KS left (etc.): $p_r(K_S|a) = 1$

….

$$P_{LR}(K_S,K_S) = \int da\,\rho(a)p_l(K_S|a)p_r(K_S|a) \geqslant \int_{A_{0,\bar{0}}} da\,\rho(a)$$

At variance with QM even with very small detection efficiencies η

But, hidden variables concern decay channels C,C' as well **[M.G.PRA 69 (04) 022103]**

$$P_{LR}(K_S,K_S) = \sum_C \int_{T_0}^{T_1} dt \sum_{C'} \int_{T_0}^{T_1} dt' \int da\,\rho(a)$$

$$\times p_l(K_S|a)p_r(K_S|a)p_{l,C}(t|a)p_{r,C'}(t'|a)$$

The few identified $K^0, \overline{K}^0$ could correspond to values of HV with not identifiable decays

Pseudoscalar mesons : a high energy physics resource for quantum information protocols

-Quantum eraser [A.Bramon et al., PRL 92 (04) 020405]

-Teleportation [Shi PLB 641 (06) 75, Shi Wu EPJ C 55 (08) 477]

-Decoherence [Bertlmann et al., PRA 68 (03) 011211]

-Entanglement distances [M.G. EPJ C 55 (2008) 683]

…...

Room for specific LHVT

- Schemes that consider a situation where one has no control of the exact number of emitted particles

[A. Khrennikov, Adv. Sci.Lett. 2 (2009) 488; C. Garola and S. Sozzo, EPL 86(2009) 20009; L. Accardi, K. Imafuku and M. Regoli, quant-ph 0112067., Deraedt]

- Stochastic Electrodynamics

- …

TESTS OF SPECIFIC LHVT

Test of Stochastic Electrodynamics

Stochastic optics

A. Casado et al., quant-ph 0202097; JOS A B 14 (1997) 494, PRA 55 (1997) 3879, PRA 56 (1997) 2477, JOS A. B 15 (1998) 1572, EPJ D11 (2000) 465, D13 (2001) 109.

There is a minimal light signal level which may be reliably detected:

Single detection Rate $> (R^2 F^2 \eta) / (2 L d^2 \lambda \sqrt{(\tau T)})$

F = focal length of lens before detector, R radius of active area of NLC, L active depth of detector, T photon absorbtion time; τ = coherence time, d distance between NLC and detector

EXPERIMENTAL TEST

G.Brida, M.Genovese,M. Gramegna, C. Novero ed E. Predazzi. Phys. Lett. A 299 (2002) 121.

All the former parameters are well known

η is measured by using biphoton calibration technique

The former inequality is strongly violated (would require T > 1s), but:

V = 0.98 $\pm$ 0.01 **CH = 513** $\pm$ 25

Also an **up conversion emission** was predicted with analogous intensity of PDC [Dechoum et al., JMO 47 (00) 1273]

No emission osserved both with a 789 and 1064 nm pump in $LiIO_3$ and BBO crystals up to 160 ratio with PDC [Brida et al., JMO 11 (03) 1757]

Detection loophole free tests of specific LHVT

[EPJD, G.Brida, M.G., F.Piacentini , 44 (07) 577]

Santos proposed other two HVT not excluded by present Bell inequalities experiments, and two “detection loophole” free tests of them [E.Santos, PLA 327 (04) 33]

They predict specific inequalities that must be satisfied

First model

$$V_A = \frac{R_{12}(0) - R_{12}(\pi/2)}{R_{12}(0) + R_{12}(\pi/2)} \qquad V_B = \sqrt{2}\frac{R_{12}(\pi/8) - R_{12}(3\pi/8)}{R_{12}(\pi/8) + R_{12}(3\pi/8)}$$

$$\frac{V_B}{V_A} \geq F = 1 + \cos^2\left(\frac{\pi\eta}{2}\right)\left[V_B - \frac{\sin^2(\pi\eta/2)}{(\pi\eta/2)^2}\right]$$

violated in quantum mechanics where, in the ideal case,

$$V_B/V_A = 1$$

Second model

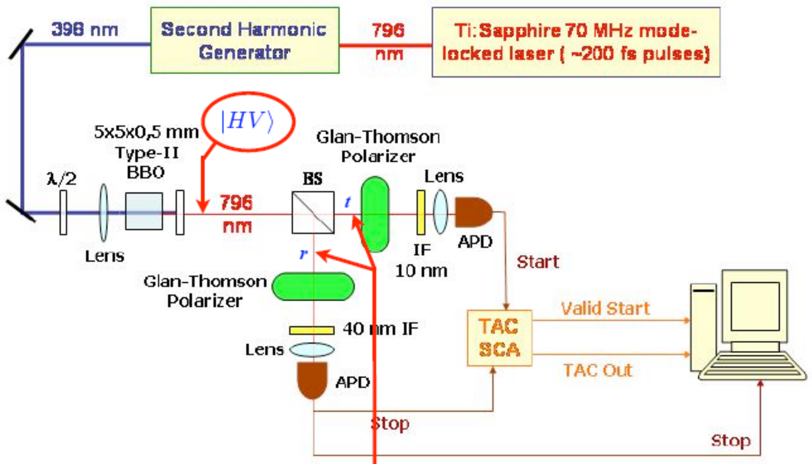
$$D(\eta) \equiv \frac{4}{3\pi}\sqrt{\frac{2}{3\eta} - \frac{1}{2} - \frac{\sin^4(\pi\eta/2)}{(\pi\eta/2)^4}}\left(V - \frac{\sin^2(\pi\eta/2)}{(\pi\eta/2)^2}\right)_+^{\frac{3}{2}}$$

$$V = 2\frac{\sum_{j=1}^{n} R_{12}(\phi_j)\cos(2\phi_j)}{\sum_{j=1}^{n} R_{12}(\phi_j)}$$

$$\Delta_{min} = \left[\frac{n\sum_{j=1}^{n} R_{12}^2(\phi_j)}{\left(\sum_{j=1}^{n} R_{12}(\phi_j)\right)^2} - 2\frac{\left(\sum_{j=1}^{n} R_{12}(\phi_j)\cos(2\phi_j)\right)^2}{\left(\sum_{j=1}^{n} R_{12}(\phi_j)\right)^2} - 1\right]^{(1/2)} \geq D(\eta)$$

$$\phi_j = \pi \cdot (j-1)/n$$

The experimental set-up



$$\frac{1}{2}\Big(|H_rV_r\rangle + |H_tV_t\rangle + |V_rH_t\rangle + |H_rV_t\rangle\Big)$$

$$|\psi_+\rangle = \frac{1}{\sqrt{2}}\Big(|V_rH_t\rangle + |H_rV_t\rangle\Big)$$

[G. Brida, M. Genovese, F.Piacentini. Eur. Phys. Journ. D 44 (07) 577]

-Violation of first inequality

$V_B/V_A > F$ $\quad F = 1.0876 \pm 0.0009 \quad V_B/V_A = 1.0205 \pm 0.0048$

-Violation of II inequality

$$D(\eta) - \Delta_{min} = 0,0073 \pm 0,0022$$

still violated !!!

even without background subtraction

NON LOCAL HVT

Leggett Model: *[Leggett Found. Phys. 33 (2003) 1469]*

A source emits photon pairs with polarizations **u** and **v** in Alice and Bob lab. One requires:

$$\overline{A}(\vec{u}) = \int d\lambda \rho_{\vec{u},\vec{v}}(\lambda) A(\vec{a},\vec{b},\lambda) = \vec{u}\cdot\vec{a}$$

$$\overline{B}(\vec{v}) = \int d\lambda \rho_{\vec{u},\vec{v}}(\lambda) B(\vec{b},\vec{a},\lambda) = \vec{v}\cdot\vec{b}$$

$$\overline{AB}(\vec{u},\vec{v}) = \int d\lambda \rho_{\vec{u},\vec{v}}(\lambda) A(\vec{a},\vec{b},\lambda) B(\vec{b},\vec{a},\lambda)$$

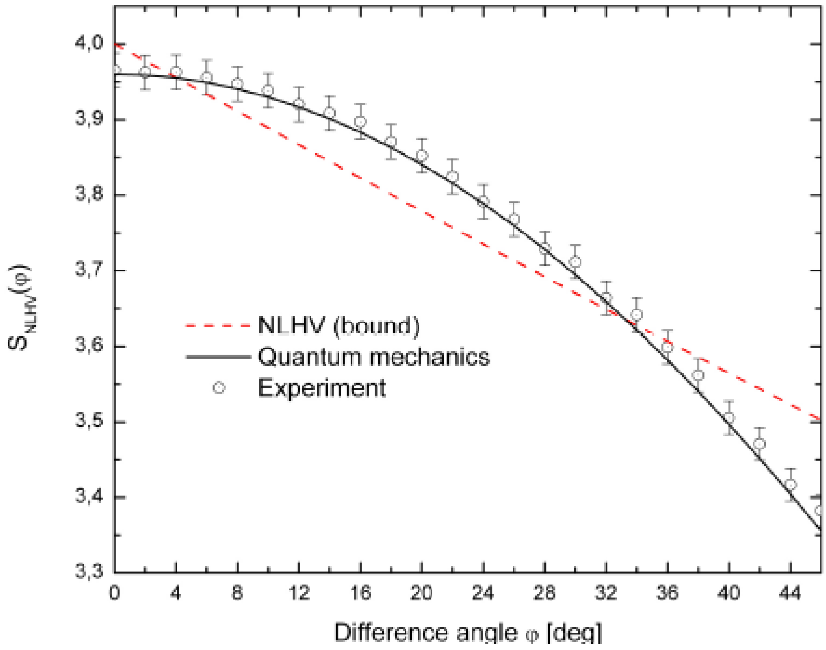
There exist subensembles of definite polarizations and the predictions agree with Malu’s law

Cannot reproduce all the correlations of QM

Experimental tests:

S.Groblacher aet al. Nature 446 (2007) 871

C. Branciard et al., PRL 99 89ì07) 210407; Nat. Phys 3 (07) 830;



Various attempt to build non-local HVT non in conflict with relativity:

-de Broglie- Bohm
-Nelson stochatic model
-Bohm-Bub
....

Anyway all of them have non-classical aspects (contestuality etc.)

De Broglie Bohm model

$$i\hbar\frac{\partial\Psi(x,t)}{\partial t} = \left[-\frac{\hbar^2}{2m}\Delta + V(x)\right]\Psi(x,t)$$

$$\Psi = R(x,t)\exp[iS(x,t)/\hbar]$$

We obtain the "Hamilton – Jacobi" equation and continuity equation

$$\frac{\partial S}{\partial t} + \frac{(\nabla S)^2}{2m} + V + Q = 0$$

$$\frac{\partial\rho}{\partial t} + \nabla\cdot(v\rho) = 0$$

With the "quantum" potential

$$Q = -\frac{\hbar^2}{2m}\frac{\Delta R}{R}$$

First tests to dBB and its variants:

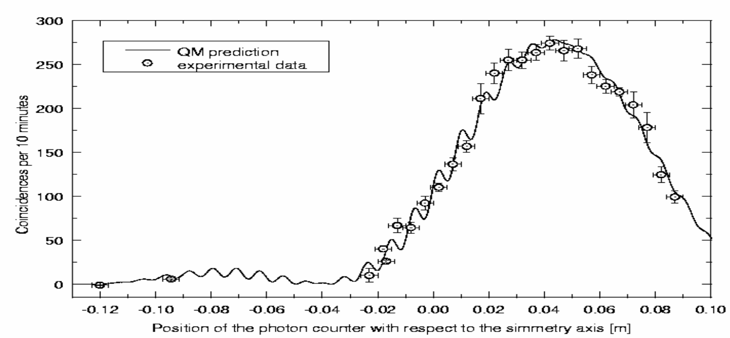
-Empty wave model:

Theory: Croca et al., FP 3 (1990) 557
Exp.: Mandel et al., PRL 68 (1992) 3814

S.Wechsler arXiv1008.4849

Differences from SQM when considering relativistic extension?

[A.Szczepansky arXiv1002.1568; H.Nikolic, Found. of Phys. Lett. 18 (05) 549; L.Feligioni et al., quant-ph 0202045; N. Redington et al., Nuovo Cim. 109B (1994) 116;]



-Ghose, Golshani test of dBB

Theory:P. Ghose et al., PLA 290 (2001) 205
Golshani et al., JPA 34 (2001) 5259
Exp.: G.Brida et al., J. Phys. B 35 (2002) 4751.
Theoretical dicussion : Marchlldon,Oriols,.....]

HIDDEN VARIABLE THEORIES NOT CONCERNED BY BELL INEQUALITIES

- Determinism at Planck scale [t' Hooft]

A physical system can evolve deterministically at Planck scale, but a probabilistic theory can derive at larger spatial scales due to loss of information (a quantum state is defined as a class of equivalence of states all having the same future).
Nowadays Bell inequalities do not involve the rigth degrees of freedom.

[Elze, Biro', Blasone et al., …]

Let us consider a discrete system with four states e_1; e_2; e_3; e_4 whose deterministic evolution is after every step

$$e_1 \rightarrow e_2,\ e_2 \rightarrow e_1,\ e_3 \rightarrow e_3,\ e_4 \rightarrow e_1,$$

$$U = \begin{pmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

After a short lapse of time only the states e_1; e_2; e_3 survive. Thus one can simply erase the state e_4 and considering e_1; e_2; e_3 as the "quantum“ system with a unitary evolution described by the upper 3x3 part of U

This system may therefore be described in three equivalence classes:

$$E_1 = \{e_1\}, E_2 = \{e_2, e_4\}, E_3 = \{e_3\},$$

with unitary evolution operator

$$U' = e^{-iH} = \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

This simple model shows how, if information is allowed to dissipate, one has to define quantum states as equivalence classes of states, where two states are equivalent if, some time in the future, they evolve into one and the same state.

Some further new idea

-PRE QUANTUM FIELD THEORY [KHRENNIKOV]:

violation of Born's rule (experiment of Weihs going on)

-INFORMATIONAL QM (DISCRETE SPACE-TIME) [D'ARIANO]:

Vacuum mass dependent refraction index

CONCLUSIONS

Still much to be done in Foundations of Quantum Mechanics

- New theoretical ideas

- New experiments for testing them


a Pozzi
Entangled Fields
2009