Lecture 16: EPR

"There is a troubling weirdness about Quantum Mechanics." -S. Weinberg

multiparties state that are separable can be another as 14), 0 10), State that are not separable are said to be entangled. For example,

Partide prepared in an entenged state exhibit

Example: 70 -7 et et 70 har Jes so et et must be in antargled spein 5 tate 10,07.

Momentum state is also entangled.

4 = (space) 80 10,00>

Question mon-locality does not conflict with special relativity, as it consist be used to strong for a signal with original

Hovern, non-locality does conflict with local realism: Measureport of state of partiel 1 can not offer state of partiel 2 without a physical articles (which propagate at V & c).

Quatron Non-Queality. The Schrödinger.

does not relate 4 at different space-time points.

Worm function 4 is non-local.

Hidden Variable Harry: Quantum medanci is incomplete. Local realism can be restoud by antroducing "hidden" vanishe. A hidden vanishe state has value prosi to

To be consistent with non-commutary (incompatible)
observable (e.g. [Sx, S,] ≠0) must assure
that only 1 of incompatible observable a
measurable at a time, other remain hidden.

Example: $|W| = \sqrt{1-2}$ $|SG_2| = |SG_2|$ $|SG_$

** * * * ***** ** ** ***

Tomasonamentes or other re-	local realist; 4 possible state, each.
	Local realist: 4 possible state, each
garannagar non a gen e e e e e e e e e e e e e e e e e e	{+=,+x}, {+=,-x}, {-=,+x}, {-=,-x}
universal and associated supplies of the following of the	1 (1 + 2 + 2) (1 + 3 - 2) 4 = 3 - 21
gy go karan suuragut kautuu ka guran ka yuu ka Guudo ka k	SG2
er filmosom userve oddi usprenskih e e e e e e e e e e e e e e e e e e e	1 SGE much district nider & value
rancoco y high	$\frac{2}{\sqrt{1+\epsilon^2}} \left(\frac{1}{2} + \frac{1}{2$
VA-દ્રકૃષ્ણ પર ૧૫ સ્ટ-૧૧:સ્પલન લગ્ગરાસ્ટરના સ્વત્રના ૧૫ કનો સરક્ષાસ્ત્રના સ્વ	Z [SGZ]+2,+xs, 1+3-2]
and gradient spatialists designed strengt of the strength of t	disturbed
nntancompatitivistavistina nega (n. 1914).	
PERCONANCE OF CODE A SAME S CODE SAME	Local realist consider the descriptioni Preferable to quantum not-locality
	Bell-type "experient:
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Write state (0,0) is a basis:

12/10,0) = 12 (140), 1-52 + 1-02/140/2)

(0,01 0,0 =

\$ ({+a1 {-a1 - {-a1 {+a1}} \ \tau_{6}^{2} (ka) ka_{2} + ka_{2}})

= 2 (\(\frac{1}{2} \rightarrow \rightarro

when we weed (++1=2)=0, (++1+2)=1

without loss of generality take $\hat{q} = \hat{z}$ and $\hat{b} = coe \hat{z} + sin \hat{z}$

 $\hat{\mathcal{G}} = \begin{pmatrix} c & S \\ S & -\delta \end{pmatrix}$

/20143 G1/203 = evo = evo

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Probabilities en Bell-type experiment
   4 possible outcome for portable (1,2) -
(+a,+b) (+a,+b) (-a,+b) (-a,+b)
                               Without loss of generality:

\frac{1}{3} \left( \frac{1}{16} \right), \left( \frac{1}{1-16} \right) = \left( \frac{1}{160} \right), \left( \frac{1}{160} \right), \left( \frac{1}{160} \right) = \left( \frac{1}{160} \right), \left( \frac{1}{160} \right), \left( \frac{1}{160} \right) = \left( \frac{1}{160} \right), \left( \frac{1}{160} \right), \left( \frac{1}{160} \right) = \left( \frac{1}{160} \right), \left( \frac{1}{160} \right), \left( \frac{1}{160} \right), \left( \frac{1}{160} \right) = \left( \frac{1}{160} \right), \left(
                                                                     1+6/= a= 1+0/+ a=0/21-a>
                                                                   (-6) = -anighta> + con & L-a>
                          uniteal state
/0,0/= 12-(1+9,-9)-1-9,+9)
          A(+a,+b) = \langle +a,+b \rangle = \langle +a,+b \rangle = \sqrt{2} \leq +b \langle -c \rangle = (1/\sqrt{2})\sin(\theta/2)
A(+9,-b) = (+9,-1190)= 市人人山(-9)2
                                                                                                                                                                                          Amplitude
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                       outcome
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                              1,2
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                  -a,-b +1/12 (6)40)
                                                                                                                                                                          & wave function forth
             note Z P; = 1
                  (fife;) = P(+a,+b) + P(-c,-b) - P(+a,-b) - P(-a,+b)
                                                                                                                                = SLi<sup>2</sup>92 - Cn<sup>2</sup> 1/2 = - Cn B es before
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	outcore bidden variable state + a, + b
	+a,+b {+g-b}, 2-a,+b};
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ALB - AND ERROGENSON AS ABOVE ENVIRONMENT A	Somehow, the probabilities for each
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	set in alone to correspond to P.M. Nexult: Very implausible to me! Classical correlations are set in advance.
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m. See the States and reson to see	Example Be	& Iraquality:	The state of the control distance of the tent of the control of th
	Consider a	your entangled ap	en state
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NEW THE STATE STATE	a surana, makanaman sanaran sa	e obte	19 +6 -c - P(+c,1+1) 19 +6 +c fit experiment,

	However, we must always have
* ··· A	P(49,+62) & P(+9,+62) + P(46,+62)
, in the secondary	Benei N3+N4 = (N2+N4)+ (N3+N7)
	Q.M. prediction a
entrette samme er kundelingere eine alled	之此"(是) 至文的"(是)+主心"(至)
**	Which will violate inequality. For example, take $\gamma = 2\pi - \alpha - \beta$ (3 directions in a plane)
	$\gamma = 2\pi - \alpha - \beta$ (3 directions in a plane)
e e saderil vo	2 2 4 3
	$\frac{1}{2} = \frac{1}{2} = \frac{1}$
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Experimental test of Bell Inequality
Aspect et d. PRZ 47 (460) 1981 Aspect et d. PRZ 49 (1804) 1982
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Aspect et cl. PRL 49 (1804) 1982 Coincidence rute =6.5m L/c = 21.7 ns
=0.5111
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measure PMT coincidence tates: a, b, a, b.
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Switch Synchronously between 4 possibilities
\\I=\OS < 1 \(\C \)
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Two Photon State has total J=0
(0,0) = TE (1RR) + (LL)
+ sign not obvious see the 5.13
2 /
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that with
(→) ← > →2 161) J=0
7 72

Be clareful about direction of rotation of classical E yestor palarization
$ R\rangle = (1\times2+i19), r\rangle = L\rangle$ $ L\rangle = (1\times2+i19), r\rangle = R\rangle$ $ L\rangle = (1\times2+i19), r\rangle = R\rangle$ See $H_N = 5.13$
100) = 1/2 (1x> 1x> + 14), 14/2
(X), 17) basis refer to polarization dony
(b) polarization is however combination or left hended votation of components from
$\chi to \delta$: $1 \times 7 \rightarrow (\delta) y\rangle = 7 \binom{9}{1}$ $1 / 5 / 2 / 6 / 2 / 7 + 6 / 4 / 7$
$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} C - s \\ + s \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} C \cap B \\ + s \cap O \end{pmatrix}$
orthogral State polarized 1 & & wi
161) = - Sin 0 x 7 + Con 9 4) I along 161) = 640 x 7 + Sin 9 4) 6 direction

Expect (b, x | 0,0) = 1/2 (b | x) = 1/2 CAS X= a \(\langle \alpha | \operator \rangle \alpha | \operator \o measured coincidence rate agree with their (PRL 1981) Bell inequality is generalized "CHSH" Rellinguality R(9,6) normalized coincidence Parte $S \geq R(\hat{a}, \hat{b}) - R(\hat{a}, \hat{b}) + R(\hat{a}, \hat{b})$ $+R(\hat{q},\hat{b}')-R(\hat{q}'-)-R(-,\hat{b})$ where "-" means corresponding polarizer bemoved Bell inequality -1 4 5 4 0 Sex = 0,126 ±0.014 PRL 1981 Sqm = 0.118 ± 0.005 -2 45 4 2 Sex = 2.697 ± 0,015 PRL 1982 different Rell S SHam = 2.70 + 0,05

	Veins et al., PRL 81 (5039) 1998
4	ogholn O'mefficient detection O speculike separation of "observer" (not sinisandal suntiling like Aspect)
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And the second s	IV> = to (HW> - WH>)
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	*(H) 0,1 0: 8 1: 8+45°
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	to 0 to 300 m/ps = 1,9 /45
Expectation valu	ie E is
	$(C_{+}) = \frac{1}{2} \left(C_{+} + C_{-} - C_{+} - C_{-} \right) C = C_{0} + C_{0}$
	$R^{m} \propto \sin^{2}(\beta - \alpha)$ QM predicted counts $R^{m} (\alpha \beta) = -\cos(2(\beta - \alpha))$

-13-Bob ∆t is time between - 200 M files 250 m legth generalized Bell viegnality S(X,X', BB') = | E(X,B) - E(X',B) | [E(4,B')+E(K',B')] =Z computed consolution "visibility"

"Expecting that any improved experiment will also agree with quantum theory, a shift of our classical philosophical positions seems necessary." Hensen et al.

N = 14700

"Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometres", Hensen et al., 682 I NATURE I VOL 526 I 29 OCTOBER 2015