INVESTIGATION INTO WHETHER QUANTUM ENTANGLEMENT CAN BE USED TO SEARCH FOR QUANTUM GRAVITY IN PARTICLE COLLIDERS

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INTRODUCTION

- Using quantum information theory in particle physics is new
- Importance of quantum gravity
- Quantum entanglement
- Is quantum entanglement sensitive enough to allow us to detect weak forces, even as weak as gravity?

LITERATURE REVIEW

- Einstein-Podolsky-Rosen-Bohm experiment with relativistic massive particles, M. Czacor (*Physics Review A, 1997*)
- Einstein-Podolsky-Rosen correlation seen from moving observers, H. Terashima and M. Ueda (*Quantum Information & Computation, 2003*)
- Relativistic entanglement and Bell's inequality, D. Ahn, H. Lee, YH. Moon and SW. Hwang (*Physics Review A, 2003*)
- Quantum entanglement under Lorentz boost, D. Lee and E. Chang-Young (*New Journal of Physics, 2004*)
- Relativistic Bell Test within Quantum Reference Frames, LF. Streiter, F. Giacomini, and C. Brukner (*Physical Review Letters, 2021*)
- Relativistic entanglement of two massive particles, N. Friis, RA. Bertlmann, M. Huber, Marcus and BC. Hiesmayr. (*Physical Review A, 2010*)
- Single particle entanglement in the mid- and ultra-relativistic regime, M. Ondra and BC. Hiesmayr. (*Journal of Physics A: Mathematical and Theoretical, 2021*)

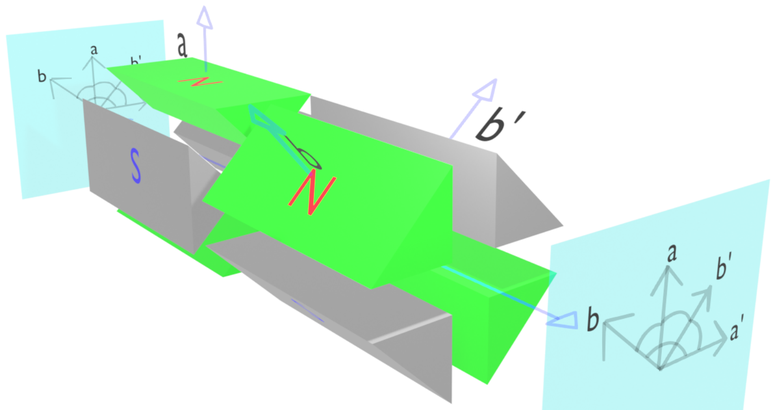
BELL'S THEOREM

Realism

Locality

"Free Will"

CHSH inequality



Measurement by Alice and Bob

$$\left| E\left(\vec{a},\vec{b}\right) - E\left(\vec{a},\vec{b'}\right) + E\left(\vec{a'},\vec{b}\right) + E\left(\vec{a'},\vec{b'}\right) \right| \leqslant 2$$

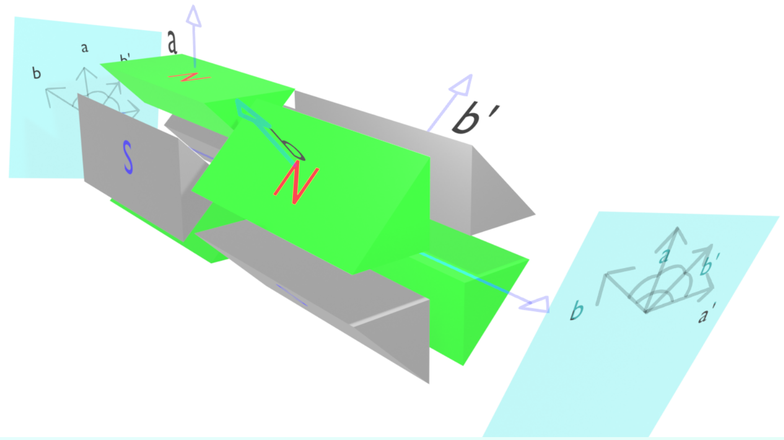
Quantum mechanics predicts

$$\left| E\left(\vec{a},\vec{b}\right) - E\left(\vec{a},\vec{b'}\right) + E\left(\vec{a'},\vec{b}\right) + E\left(\vec{a'},\vec{b'}\right) \right| = 2\sqrt{2}$$

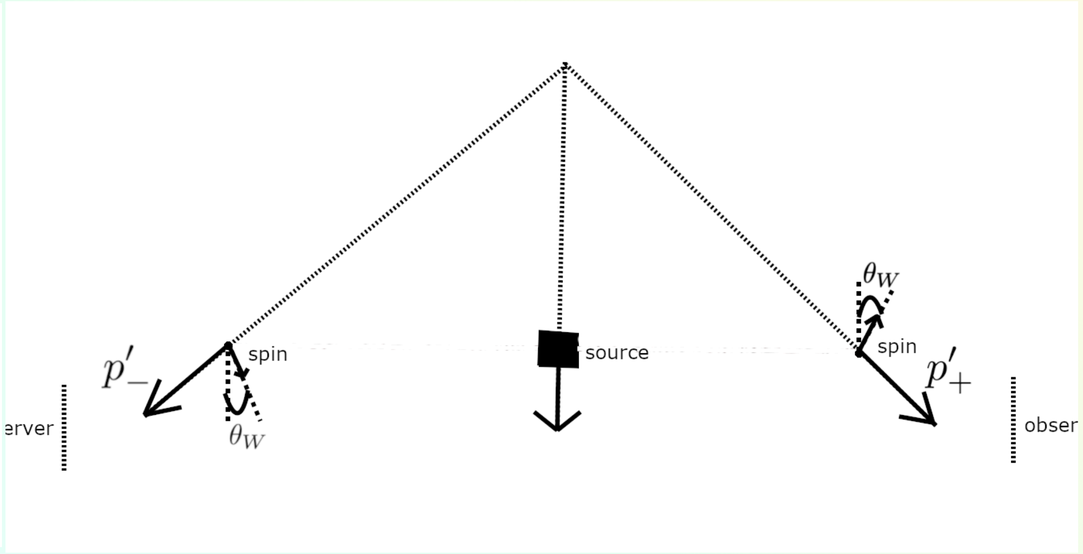
A(a)	A(a')	B(b)	B(b')	E(a,b)	E(a,b')	E(a',b)	E(a',b'
1		1		1			
1			-1		-1		
	-1	-1				1	
-1		1			-1		
	-1		1				-1
1	1			1			
-1		-1				1	
	1		1	1			
				0.3	**-0.5**	**0.5**	**-0.1**

THOMAS ROTATION

Special relativity rotates Alice's and Bob's coordinate systems with respect to each other in the lab frame.



Thomas Rotation and Quantum entanglement



Thomas Rotation, Alice and Bob

RELATIVISTIC BELL INEQUALITY

Define two variables:

$S_1 = E\left(\vec{a}, \vec{b}\right) - E\left(\vec{a}, \vec{b'}\right) + E\left(\vec{a'}, \vec{b}\right) + E\left(\vec{a'}, \vec{b'}\right)$ and $S_2 = E\left(\vec{a}, \vec{b}\right) - E\left(\vec{a}, \vec{b'}\right) - E\left(\vec{a'}, \vec{b}\right) - E\left(\vec{a'}, \vec{b'}\right)$

If Alice and Bob choose their settings such that Alices two settings are perpendicular and likewise that Bob's two settings are perpendicular, then the following inequality holds

$|S_1| + |S_2| \leqslant 2$

However, for the directions given previously, quantum mechanics predicts

$|S_1| + |S_2| = 2\sqrt{2}$

THOMAS PRECESSION AND ENTANGLEMENT

Gravitational attraction between 2 relativistic particles:

$$\vec{a} = \frac{(c+v)\left(c^2-v^2\right)}{4cr}\left(\frac{1}{2}-\sqrt{\frac{Gm}{cr\,(c+v)}+\frac{1}{4}}\right)\hat{r}$$

Thomas Rotation and Precession:

$$\tan\left(\theta_W+\Delta\theta_W\right)=\sqrt{\frac{S_2}{S_1}}$$

$$\tan\theta_W=\frac{\sinh\xi\sinh\chi}{\cosh\xi+\cosh\chi}$$

CONCLUSION

Derived a new Bell inequality.

Investigating the uses of quantum entanglement in particle colliders

Trying to determine whether it can be used to test quantum gravity.