Physics Beyond Standard Model

- Standard Model
- Neutrino Search
- Big Bang Dark Matter
- Big Bang Dark Energy
- Quantum entanglement (量子纠缠)
- SUBSTRUCTURE of Fundamental PARTICLES ?

J. Ulbricht ETHZ Lecture USTC 2017

History Quantum entanglement

- 1935 Einstein studies in a paper with Boris Podolsky and Nathan Rosen (Phys. Rev. 47, 777 – Published 15 May 1935) predictions of quantum mechanics about strongly correlated systems. They formulated the EPR paradox (Einstein, Podolsky, Rosen paradox), a thought experiment that attempted to show that quantum mechanical theory was incomplete.
- 1935 Erwin Schrödinger wrote a letter to Einstein in which he used the word *entanglement* to describe the correlations between two particles that interact and then separate, as in the EPR experiment (Kumar, M., *Quantum*, Icon Books, 2009, p. 313). It follows a paper recognized the importance of the concept (Mathematical Proceedings of the Cambridge Philosophical Society; https://doi.org/10.1017/S0305004100013554)
- 1947 Einstein and Schrödinger was dissatisfied with the concept of entanglement, because it seemed to violate the speed limit of light in the theory of relativity (*CiteSeerX 10.1.1.20.8324*)
- 1964 John Stewart Bell proved that one of the key assumptions, the principle of locality, was mathematically inconsistent with the predictions of quantum theory. In the Bell inequality he demonstrated an upper limit theory predicts violations of this limit for certain entangled systems (*J. S. Bell (1964). "On the Einstein-Poldolsky-Rosen paradox". Physics)*

History Quantum entanglement

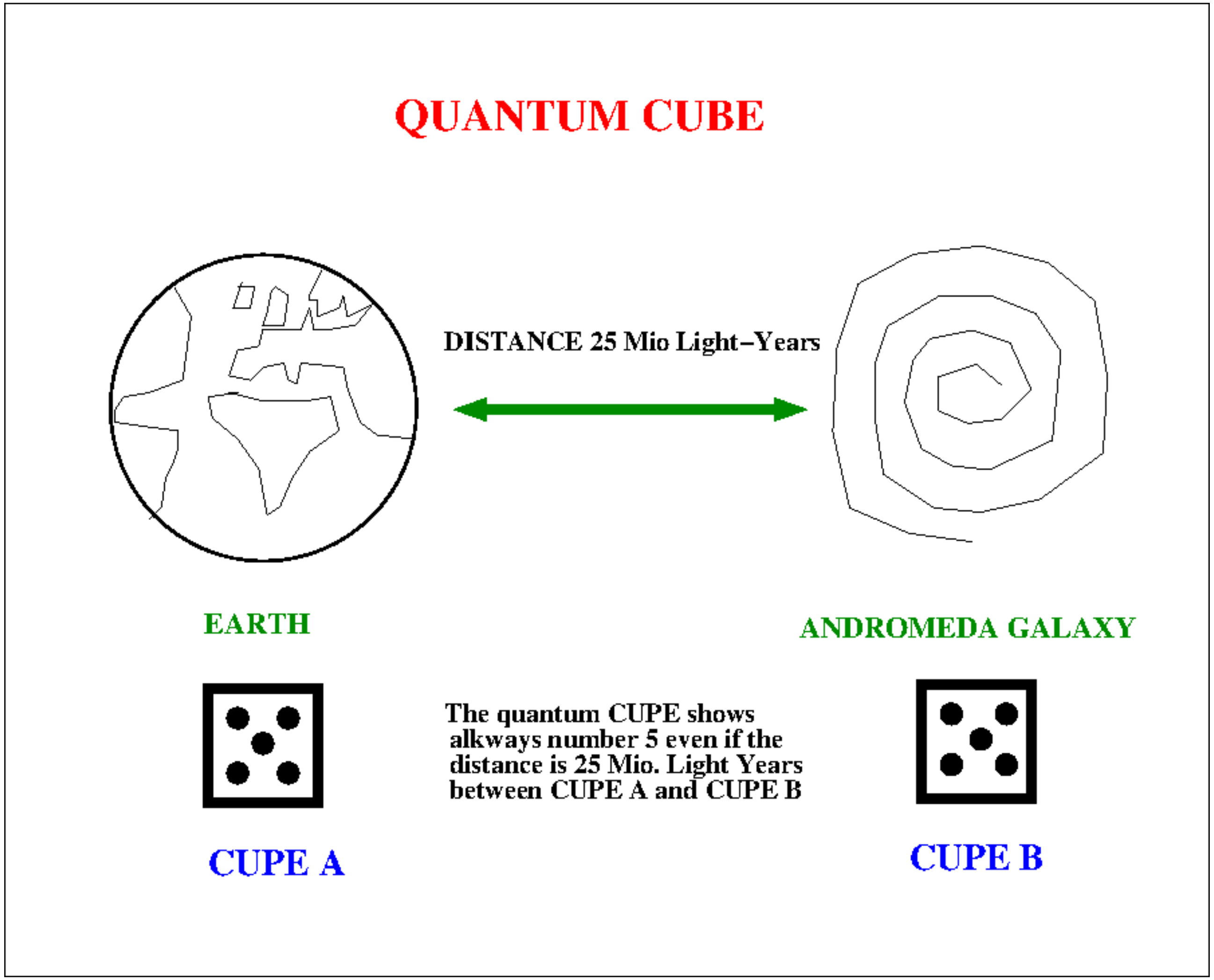
- 1972 Stuart Freedman and John Clauser test the John Stewart Bell inequality (Physical Review Letters. 28 (14) 938).
- 1982 Alain Aspect perform experiments with the same aspect as Stuart Freedman and John Clauser (Review Letters. **49** (2) 91).
- 1998 Anton Zeilinger collaboration demonstrates "Violation of Bell's Inequality under Strict Einstein Location Conditions" (arXiv:quant-ph/9810080v1 26 Oct 1998)
- 2007 After Anthony James Leggett aggravated the Bell inequality. Anton Zeilinger demonstrated in the article from Nature (*Nature.* 446, 2007, S. 871) that even under this aggravated conditions the John Stewart Bell inequality is confirmed.
- 2008 Nicolas Gisin show in one experiment that entanglement photons measured in two detectors must communicated with 10.000 times speed of light (Nature. 454, 2008, 861).
- 2016 Discussion about space - time as a result of quantum entanglement (R. Cowen Nature 527 page 290-293 2015)
- 2016 China launches the satellite Micius from Jianquang, with the 600 kg heavy experiment „Quantum Experiment at Space Scale" (QUESS) on board.
- 2016 Quantum computing was initiated P. Benioff and Y. Manin in 1980, R. Feynman in 1982 and D. Deutsch in 1985. Experiments have been carried with a very small number of quantum bits. (*J.of stat. phys..* ***22*** *(5) 563; Sov.Radio. pp. 13–15; Int. J. of Theor. Phys.* ***21*** *(6): 467–488; Pro. of the Royal Society of London A.* ***400*** *(1818): 97–117; Phys.org. Retrieved 2014-10-26.)*

Introduction

Already in 1935 Einstein concluded after some time, that Quantum Mechanics is not perfect.

QUANTUM CUPES shows permanent for example number 5 even if the CUPES are separated by many LIGHT YEARS.

The QUANTUM CUPES behaves NOT LOCAL.



Polarized PARTICLES

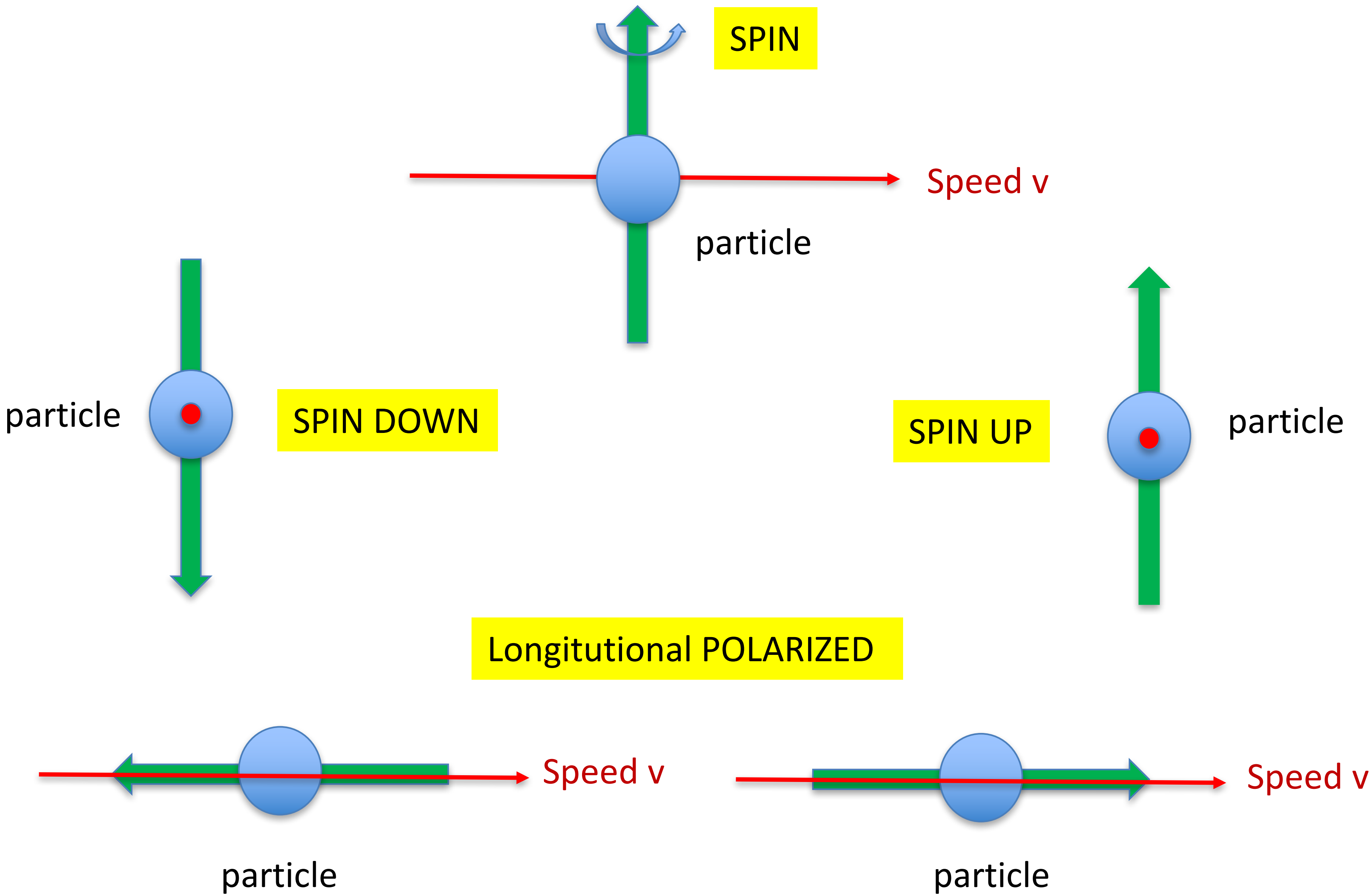
The spin of particles is an very important quantum number for the discussion of quantum entanglement. The spin of a fundamental particle is an absolute stable quantum number. Concerning about the spin 3 types of particle exist, fermion with spin 1/2 , gauge bosons with spin 1 and scalar bosons with spin zero.

To perform an experiment, stable particles like electron, proton and gammas are of interest. Technologies exist to generate a beam of particles with a defined angle of the spin axes to the vector of the velocity of the spin, so called polarized beam.

For electron, protons (For example: W. Arnold, H. Berg, H.H. Krause, J. Ulbricht and G. Clausnitzer, Nucl. Instr. and Meth. 143 (1977) 441) and deuterons exist polarized beam sources.

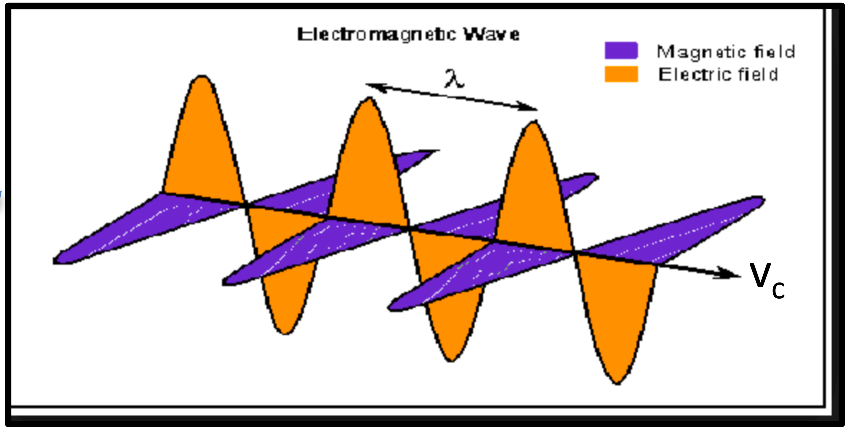
More flexible for an experiment are the gamma sources because the existing technology allows to generate many different types of polarized beams.

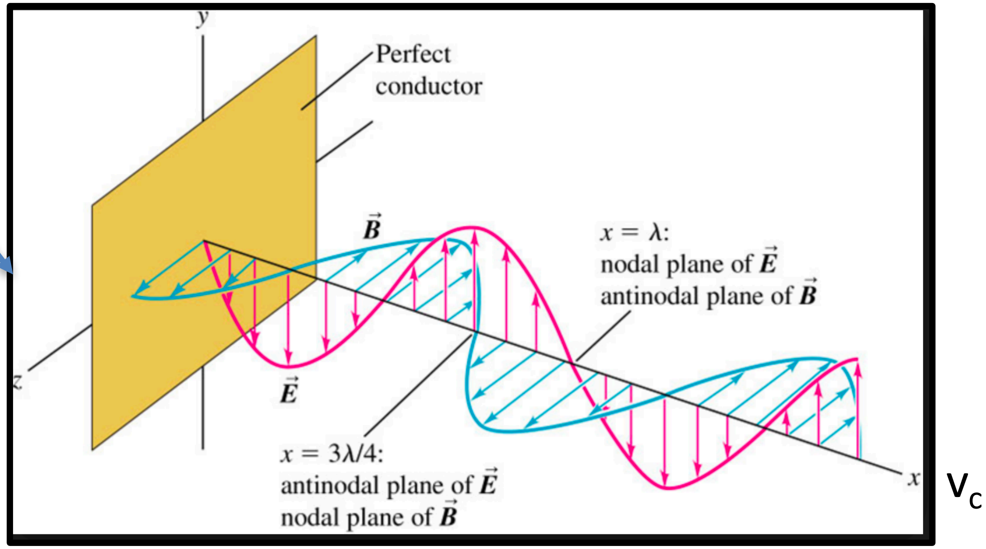
Polarized PARTICLE



E – B field of PHOTONS

The E – field is perpendicular to the B– field and direction of velocity v_c





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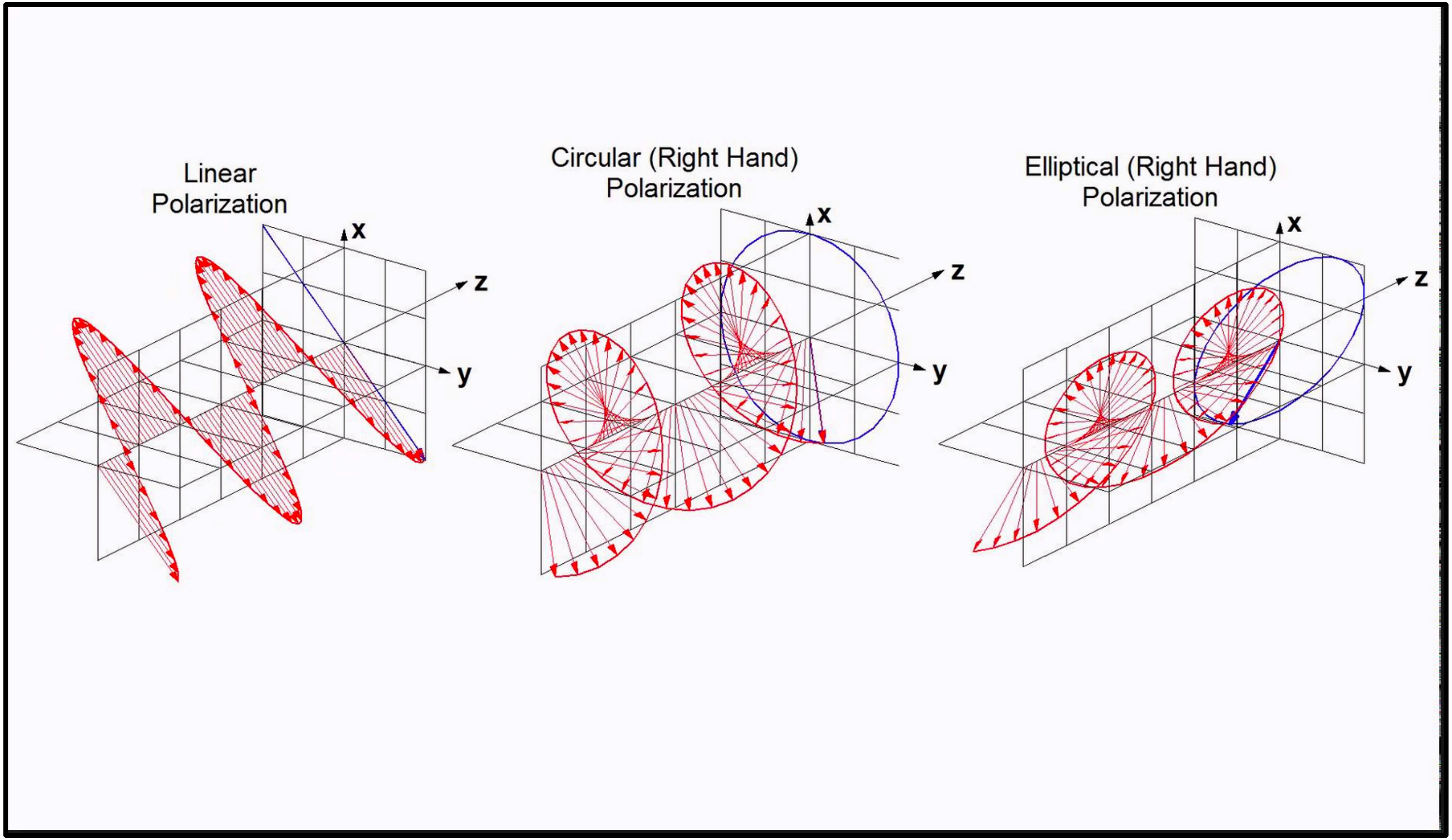
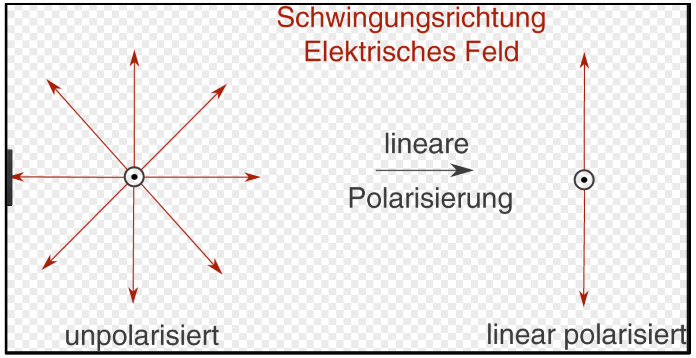
Polarized PHOTONS



Polarized PHOTONS

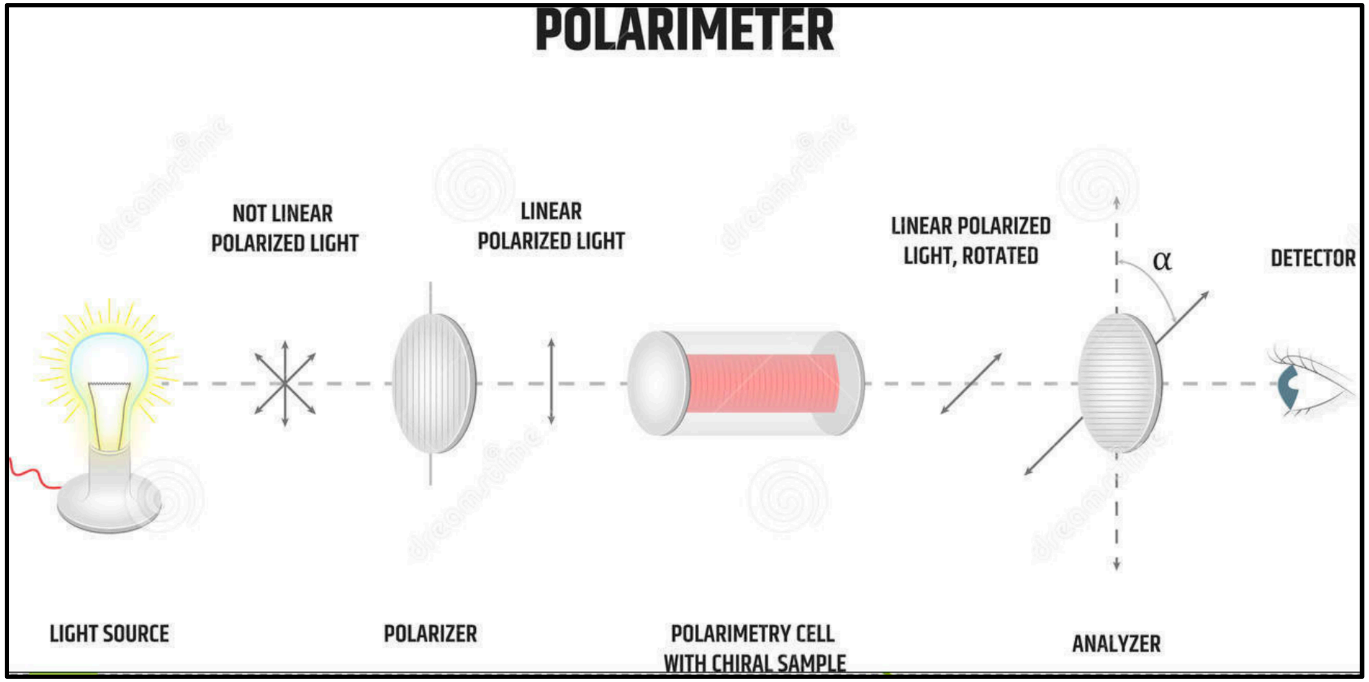
A linear polarized Light has a defined angle α for the direction of the electric field vector.



With a polarimetry cell it is possible to change the

angle α

and measure this angle in an analyser.



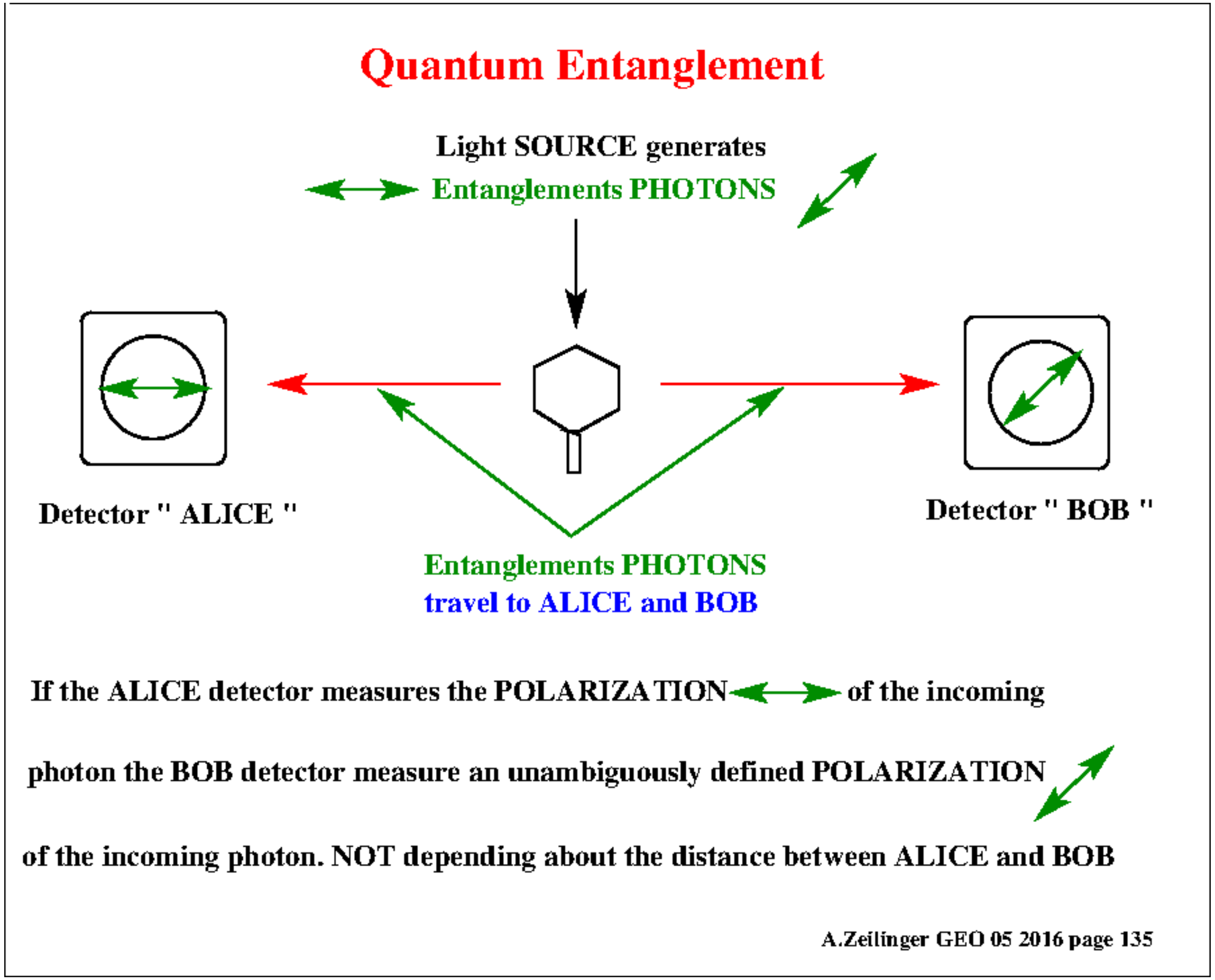
https://www.google.com.hk/search?q=Polarimeter&newwindow=1&safe=strict&
client=firefox-b-ab&tbm=isch&imgil=Etjx-uCe09TRaM%253A%253BkWRh5vvOsRK7XM

Polarized Photons used to test Quantum Entanglement

An consequence of the non locality, of the quantum CUPE is the Quantum Entanglement.

If a pair of particles get generated with a definite defined direction of the spin axis, as initial state, this axis will stay constant independently of the distance between both particles.

Most important. If at the same time the polarization of one particle is measured the measurement of the second particle will show the spin of the initial state.



Experiments to TEST Quantum entanglement

The collaboration of A. Zeilinger in Austria is one of the very well acknowledged group to study Quantum Entanglement. As an example out of the many in the history discussed papers, the experiment from 1998 is described.

Violation of Bell's Inequality under Strict Einstein Location Conditions

arXiv:quant-ph/9810080v1 26 Oct 1998

The Location Conditions:

- The condition of locality in the Bell's theorem requires that the individual detectors Alice and Bob measuring the entanglement photons are spacelike separated, in this experiment by 400 m.
- The individual measurement has to be fast enough that NO information could travel from Alice to Bob until the measurement is finished. This request that the measuring time has to be shorter as 1.3 µs , the time for direct communication at the speed of light.
- The individual events must be registered on both sides independently and compared only after the measurement is completed.
- This was achieved using high speed physical random number generators and fast electro-optic modulators.
- Independent data registration was performed by each observer having his own time interval analyzer and atomic clock.

The fig 1: Selecting a random analyzer direction, Alice's side must fully lie inside the shaded region. This region must be invisible during Bob's measurement. This request for the experimental set up, that the experiment must start after point "X" if the corresponding photons are detected at spacetime points "Y" and "Z" respectively. In the experiment the measurement process (indicated by a short black bar) including the choice of a random number only took less than a tenth of the maximum allowed time.

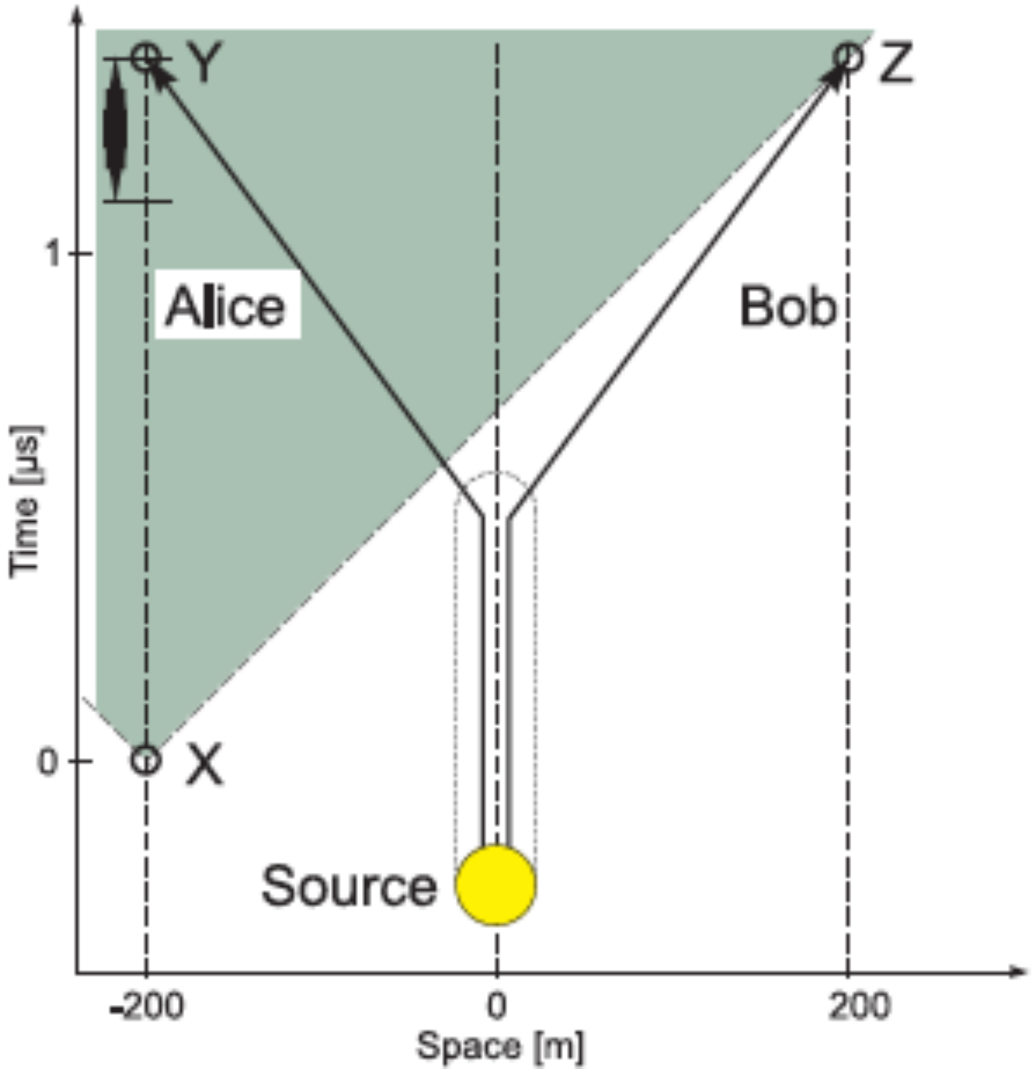


Fig. 1 Spacetime diagram of the Bell experiment

A random number generator is driving the electro-optic modulator. Silicon avalanche photodiodes are used as detectors. A "time tag" is stored for each detected photon together with the corresponding random number "0" or "1" and the code for the detector "+" or "−" corresponding to the two outputs of the Wollaston prism polarizer. All alignments and adjustments were pure local operations that did not rely on a common source or on communication between the observers.

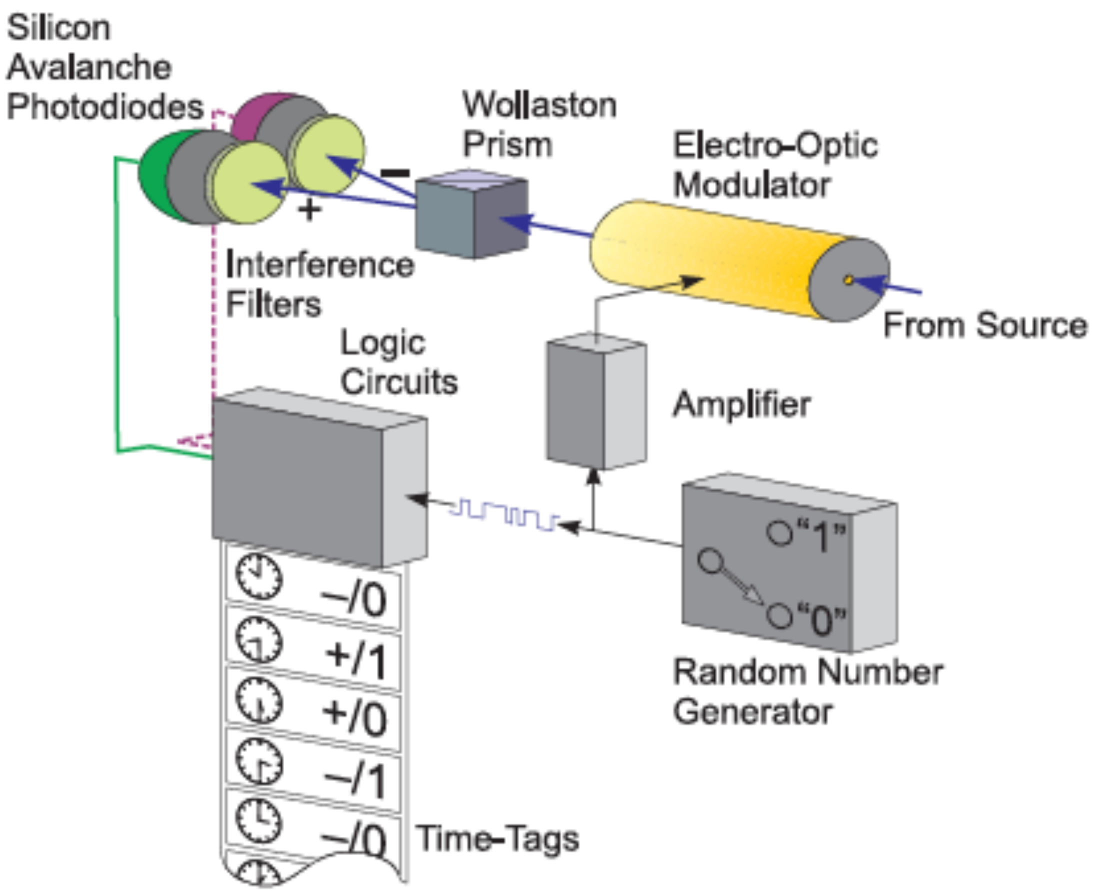


FIG. 2. One of the two observer stations.

Details of the experimental SET-UP:

- The source of polarization entangled photon pairs is degenerate type-II parametric down-conversion [Phys. Rev. Lett. 75, 4337 (1995)] which pump a BBO-crystal with 400 mW of 351 nm light from an Argon-ion-laser.
- Each of the observers switched the direction of local polarization analysis with a transverse electro-optic modulator. It's optic axes was set at 45° with respect to the subsequent polarizer. Applying a voltage causes a rotation of the polarization of light passing through the modulator by a certain angle proportional to the voltage. For the measurements the modulators were switched fast between a rotation of 0° and 45° .
- The actual orientation for local polarization analysis is determined independently by a physical random number generator.
- The electronic circuit sets its output to "0"("1") upon receiving a pulse from photomultiplier "0"("1").
- The photons were detected by silicon avalanche photodiodes.
- Each observer station featured a PC which stored the tables of time tags accumulated in an individual measurement. After the measurements the files for coincidences with a third computer get analyzed . Coincidences were identified by calculating time difference between Alice's and Bob's time tags and comparing these with a time window (typically a few ns).

Bell's theorem

The version of Bell's inequalities from Clauser et al. [Phys. Rev. Lett. 23, 880 (1969)] is used for the experiment, because it applies directly to used the experimental configuration.

The number of coincidences between Alice's detector i and Bob's detector j is denoted by

$$C_{ij}(\alpha,\beta)$$

with $i, j \in \{+,-\}$ where α and β are the directions of the two polarization analyzers and "+" and "− " denote the two outputs of a two-channel polarizer respectively.

The normalized expectation value $E(\alpha,\beta)$ of the correlation between Alice's and Bob's is.

$$E(\alpha,\beta) = \left[C_{++}(\alpha,\beta) + C_{--}(\alpha,\beta) - C_{+-}(a,\beta) - C_{-+}(\alpha,\beta)\right] / N$$

N sum of all coincidence. Bell's inequality is finally (NO coordinates x, y, z exist)

$$S(\alpha,\alpha',\beta,\beta') = \left|E(\alpha,\beta) - E(\alpha',\beta)\right| + \left|E(\alpha,\beta') + E(\alpha',\beta')\right| \leq 2$$

Bell's theorem

Quantum theory predicts a sinusoidal dependence for the coincidence rate

$$C_{++}^{qm}(\alpha,\beta) \propto \sin^2(\beta-\alpha)$$

on the difference angle of the analyzer directions in Alice's an Bob's experiments. The same behavior is seen in the expectation value

$$E^{qm}(\alpha,\beta) = -\cos\left[2(\beta-\alpha)\right]$$

For various combinations of analyzer directions α,β,α',β' these functions violate Bell's inequality. Maximum violation is obtained using the following set of angles

$$S_{\max}^{qm} = S^{qm}(0^0, 45^0, 22.5^0, 67.5^0) = 2\sqrt{2} = 2.82 > 2$$

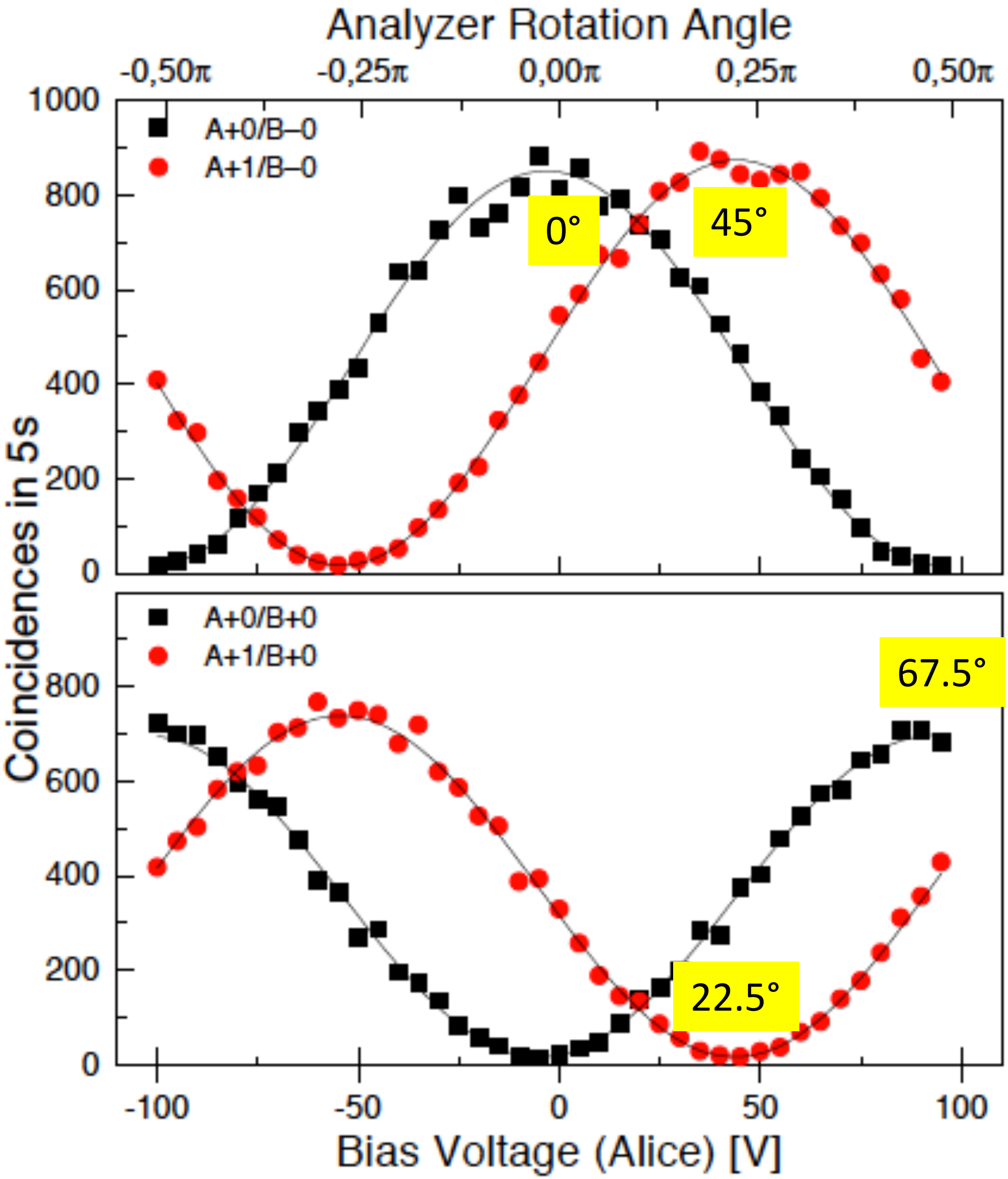
The MEASUREMENT

The data presented in Fig. 3 are the result of a scan of the DC bias voltage in Alice's modulation system over a 200 V range in 5 V steps. At each point a synchronization pulse triggered a measurement period of 5 s on each side. From the time-tag series extracted are coincidences after all measurements had been finished.

Fig. 3 shows four of the 16 resulting coincidence rates as functions of the bias voltage. Each curve corresponds to a certain detector and a certain modulator state on each side. A nonlinear 2 -fit showed perfect agreement with the sine curve predicted by quantum theory.

FIG. 3. Four coincidence sets out of sixteen coincidence rates between various detection channels, as functions of bias voltage (analyzer rotation angle) on Alice's modulator. A+1/B−0 for example are the coincidences between Alice's "+" detector with switch having been in position "1" and Bob's "−" detector with switch position "0".

The Alice POLARIZER retunes the ENTANGLEMENT condition for Alice and Bob in 5 Volt steps. The sin, cos behaviour of the Bell Theorem predicts a MAXIMUM of the coincidence rate at α = (0°,45°,22.5°,67.5°) clear visible in Fig.3



Final RESULT

Bell's inequality with better statistics, we performed in experimental runs with the settings 0°, 45° for Alice's and 22. 5°, 67. 5° for Bob's polarization analyzer. A typical observed value of the function S in such a measurement was

$$S = 2.73 \pm 0.02 > 2 \qquad \left(S_{\max}^{qm} = 2.82\right)$$

for 14700 coincidence events collected in 10 s. This corresponds to a violation of the CHSH inequality of

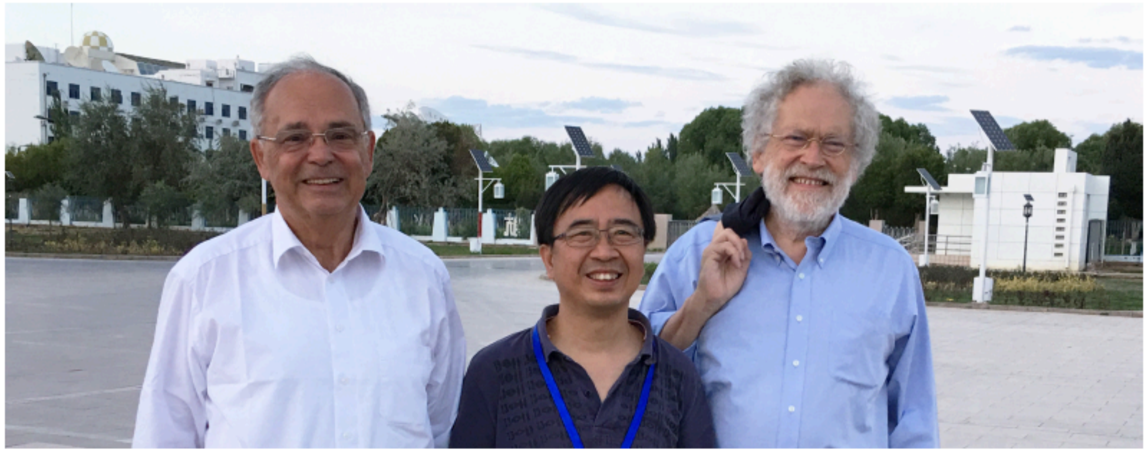
30 standard deviations

assuming only statistical errors.

Information transfer via Quantum Entanglement

Technical the Quantum Entanglement opens the possibility to transfer information from a position A in space to a position B. A big advantage is that this information transfer is interception safe, because if on polarization is measured the second one will defined and the connection is disturbed.

In 2016 China launches the satellite Micius from Jainquang, with the 600 kg heavy experiment “Quantum Experiment at Space Scale” (QUESS) on board, to use the discussed technology to transfer information from point A to point B.

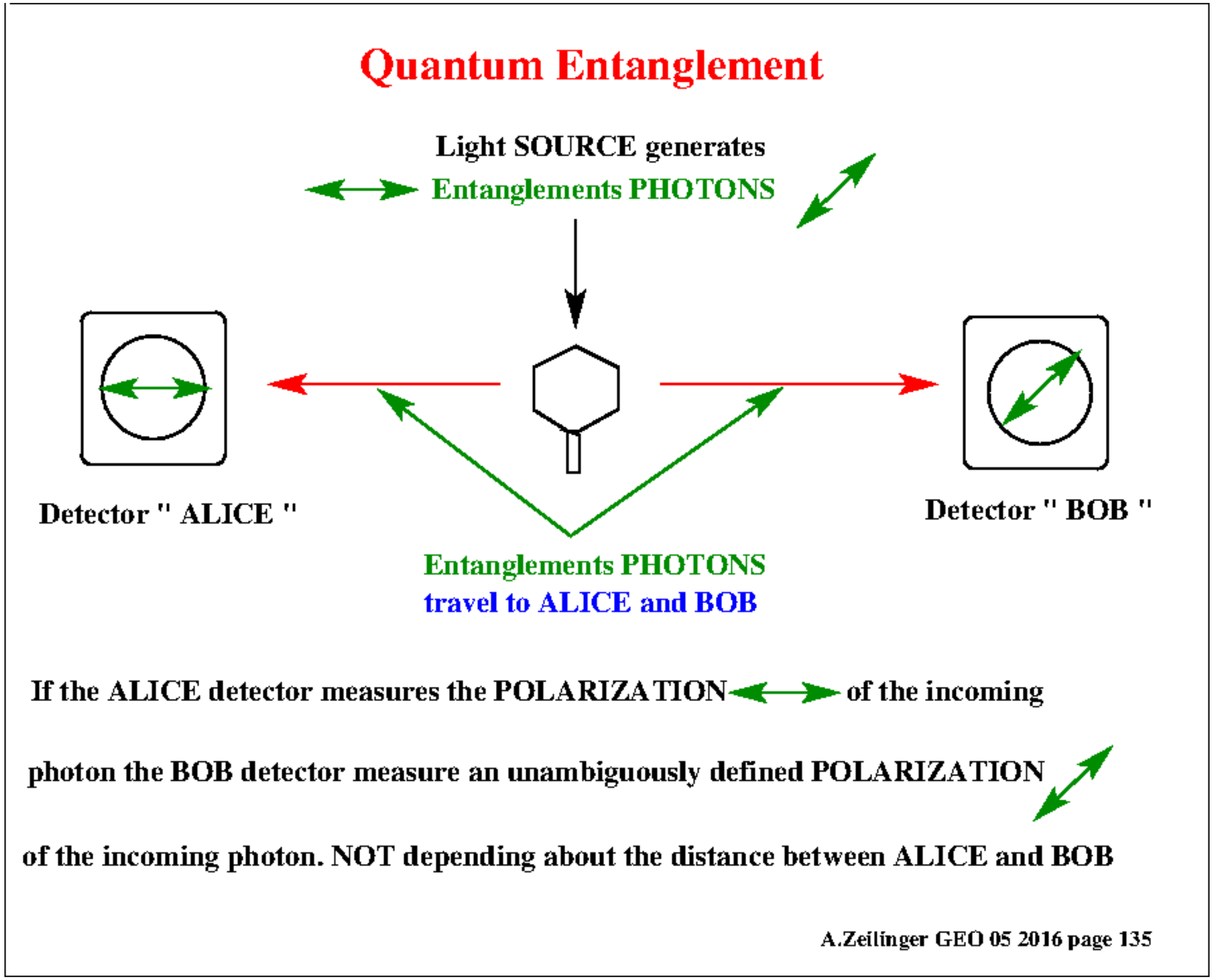


Pan Jianwei (USTC), A. Zeilinger and H. W. Engl (Vienna)

(http://www.oeaw.ac.at/en/events-communication/public-relations-communication/public-relations-communication /ausgewaehlte-oeaw-pressemeldungen/press-releases/first-quantum-satellite-successfully-launched/)

Information transfer via Quantum Entanglement

The light source is installed in the satellite Micius and the stations to measure the signal on earth at position ALICE and BOB.

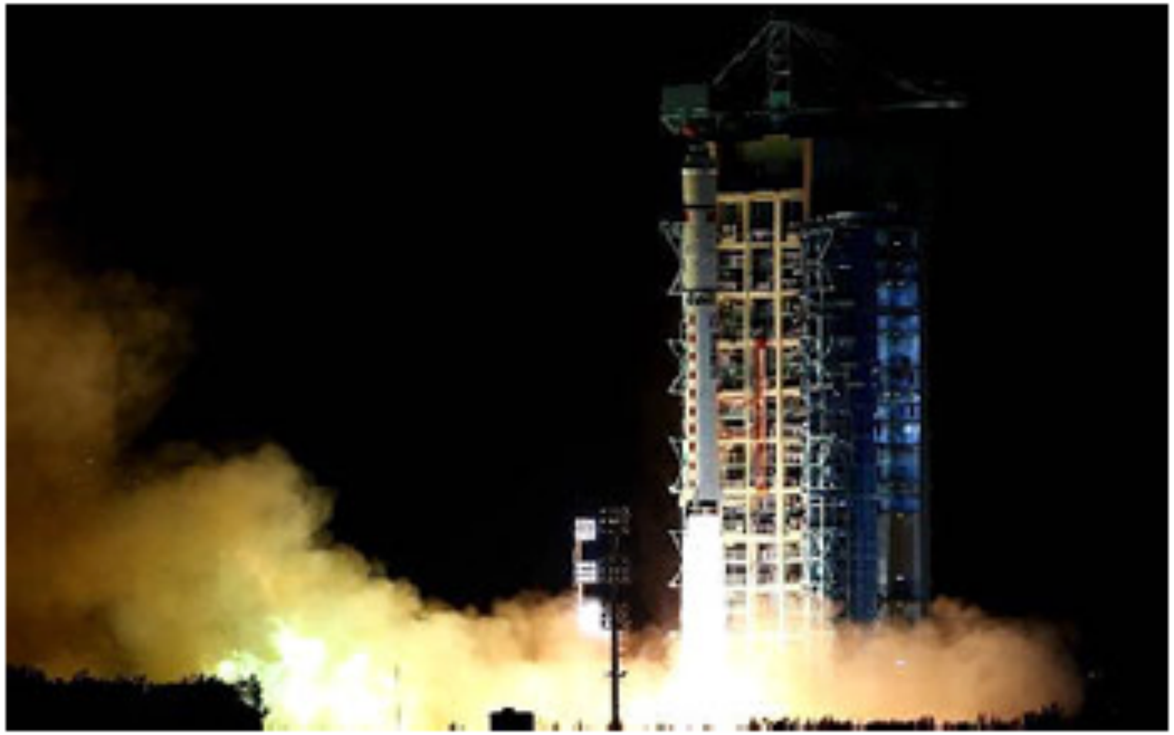


The light source generator

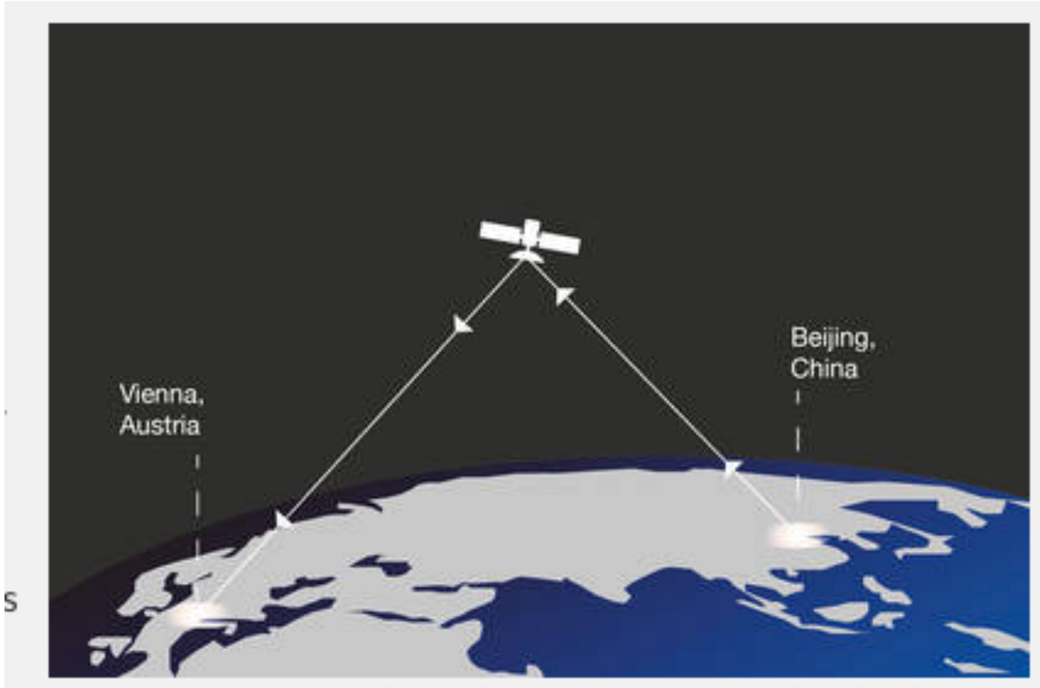
The 600 kg heavy satellite is positioned in 500 km distance from the earth surface. The light source generator is an interferometer which generates with not linear optical crystal entangled infrared photons.

The receiver Alice and BOB

The "Hedy Lamarr Quantum Communication Telescope" at the ground stations of QUESS project will receive entangled photons from the satellite (© ÖAW/Pichler).



China has launched the world's first satellite dedicated to testing the fundamentals of quantum communication in space. The Quantum Experiments at Space Scale (QUESS) mission was launched from the Jiuquan Satellite Launch Center in northern China. For the next two years, "Micius" will demonstrate the feasibility of quantum communication between Earth and space, and test quantum entanglement over unprecedented distances.
(http://physicsworld.com/cws/article/news/2016/aug/16/china-launches-world-s-first-quantum-science-satellite)



The experiment will attempt to demonstrate quantum key distribution between the Xinjiang Astronomical Observatory Observatory near Ürümqi and Xingong Observatory near Beijing – a great-circle distance of approximately 2,500 kilometres (1,600 mi) and possibly other European stations.

CONCLUSION QUANTUM ENTANGLEMENT

- Under the circumstances that quantum entanglement is known since 1935 it is very astonishing that it took 82 years to investigate the problem on a scientific level.
- After the extensive work of the the collaboration of Anton Zeilinger it looks like that the physics community starts to take more attention to extent the quantum mechanics.
- Extension of quantum entanglement on the space-time of the whole universe are under discussion.
- Even under the circumstances that many detail of the quantum transportation are still under investigation. Today the first technical applications for data transfer with entangled photons are on the way.
- Also many countries start to use this knowledge for quantum computers.

CONCLUSION of Physics beyond the Standard Model I

- The discovery of the Higgs was the last missing cornerstone of the Standard Model. All data today confirm the discovery of the Higgs.
- The neutrino oscillations are experimental very well established. Still the absolute mass of the neutrinos is missing.
- Many experimental measurements support the existence of Dark Matter. But the nature of Dark Matter is still not known. Big experimental effort is on the way, do test different theoretical assumptions of the nature of Dark Matter.
- Experimental evidence of Dark Energy exist. But this sector is still very mystical.

CONCLUSION of Physics beyond the Standard Model II

- Quantum Entanglement is experimental well established. The first technical applications are under investigations.
- First experimental evidence of gravitational waves was reported 2016.
- Some interesting open questions:
- In the Pauli exclusion principle, two or more identical fermions with half-integer spin cannot occupy the same quantum state, within a quantum system simultaneously. Bosons with spin one are not under control of this exclusion principle. Exist between spin half and spin one particles an different interaction to explain this principle ?
- In the Wave–particle duality. Particles up to the size of a molecule behave in experiments like a particle and simultaneously like a wave. This is in experiments of Photoelectric effect and double slit experiment very well confirmed. Exist an logical explanation of the contradiction.?
- All fundamental Particles in the Standard Model are a POINT with diameter zero what pushes the density to infinite. Are the fundamental PARTICLES really a PIONT ?