Analog Quantum Computing (AQC) by Revisiting The Underling Physics

- (to NSF) How AQC changes the game on the ultimate limits of general-purpose computing
- Computing with entangled |θ>: the way forward
- **To get started: need massive step-by-step improvement to model, let alone design, ≥3 entangled continuous spins, in photonics first**
- More near-term benefits: imaging, communications, energy (e.g. as we move to better Dis modeling)

But before we design/model networks of photons entangled in |θ>, do we know how they work?

- Only three groups have physically entangled >2 photons of general polarization (like GHZ states): (1) Zeilinger (Austria); (2) Yanhua Shih (Maryland); (3) Zeilinger's student in Sichuan
- There exist two competing models which get the right result for two photon experiments (Bell) but disagree beyond 2, in lumped calculations:
  - Traditional collapse of the wave function (Clauser etc)
  - Time-symmetric physics (MRF)

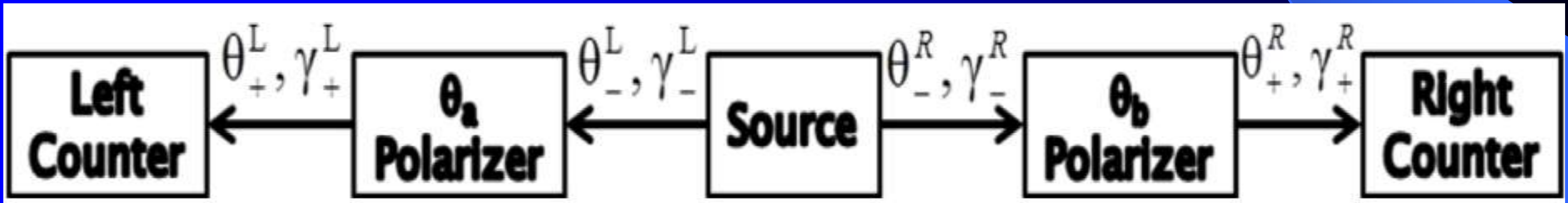
What is Time-Symmetric Physics?

- Idea has evolved over many years: Werbos 73, DeBeauregard, Klyshsko (key theorist behind much of Yanhua Shih's past success), Aharanov
- NOT an alternative to quantum mechanics – only to traditional quantum mechanical measurement theory, like collapse of the wave function
- **Central idea** (Werbos IJTP 2009): DERIVE the predictions for measurement FROM the dynamics you assume – whether Schrodinger equation, PDE, Feynmann path or probability theory variation of Feynmann path. For QED, those dynamics are time-symmetric!!

How could we derive measurement from dynamics? (IJTP 2009)

- Everett/Wheeler (DeWitt) tried to derive the usual projection measurement from Schrodinger equation in forwards time – but to does not follow (T)!
- Start with a question: how can we explain the local forward arrow of time if dynamics are time-symmetric? Boundary conditions – from Big Bang to creation of sun, forward time free energy
- Implications: model all parts of an experiment, even at lumped macroscopic level, as time-symmetric except:
  – At nodes where free energy enters the system
  – Where we know backtime terms are truly negligible (like probability of a motionless ball falling up)

Example: How to Model Bell experiment without exploiting collapse of wave function
Ref [5] in abstract: a local realistic model!



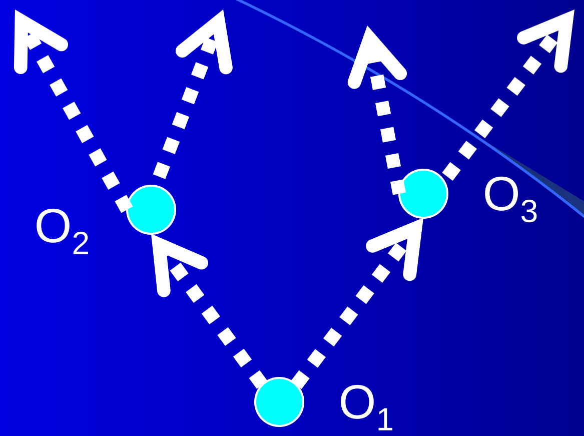
Bell's Theorem (CHSH) experiments rule out correct predictions from computational models which are:

- "Hidden variable models" ("realism," actual state variables
- Local (like PDE simulations)
- "Causal"
- The "causality" assumption is a type of time-forwards statistical causality, wherein all noise comes from initial conditions. AN EXOGENOUS CLASSICAL ASSUMPTOIN, NOT DERIVED FROM LAGRANGE-EULER EQS! See IJTP.

Two Types of "Causality" in Probability Theory

- Example of discrete time systems: **S**(t+Δt)=f(**S**(t),**e**(t)). Two choices:
  - Classical: assume $\langle \mathbf{e}(t)\mathbf{S}(\tau)\rangle=0$ whenever $t>\tau$
  - Symmetric: assume {**e**(t)} "simulated in advance", then solve for {**S**(t)} (with boundary conditions). Widely used in economics and control. See Siemens (Zimmerman) economic forecasting.
- El-Kauoi *Backwards Stochastic Differential Equations*.
- Note similarity to Feynmann path, and to Glimm-Jaffe

What Is a Cross-Time MRF Model?



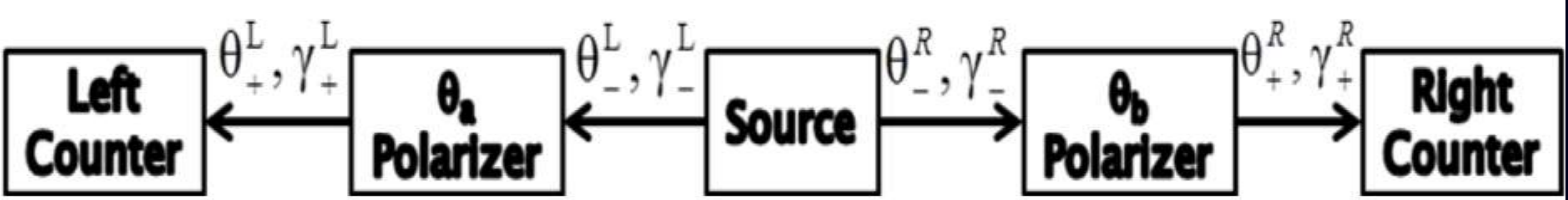
Probability of a path or scenario or trajectory X (set of values of all the macroscopic values) at the three quantum transitions is:

$$P^*(X) = p_1(X)p_2(X)p_3(X)$$

$$Pr(X) = P^*(X)/Z$$

Equivalent to Bayesian convolution in forwards time at O2 and O3, but such convolutions are "nonlocal"!

First MRF Model (MRF1) of Bell experiment -- Review of CHSH experiments and algebra $R_2/R_0 = ½ \cos^2(\theta_a-\theta_b)$

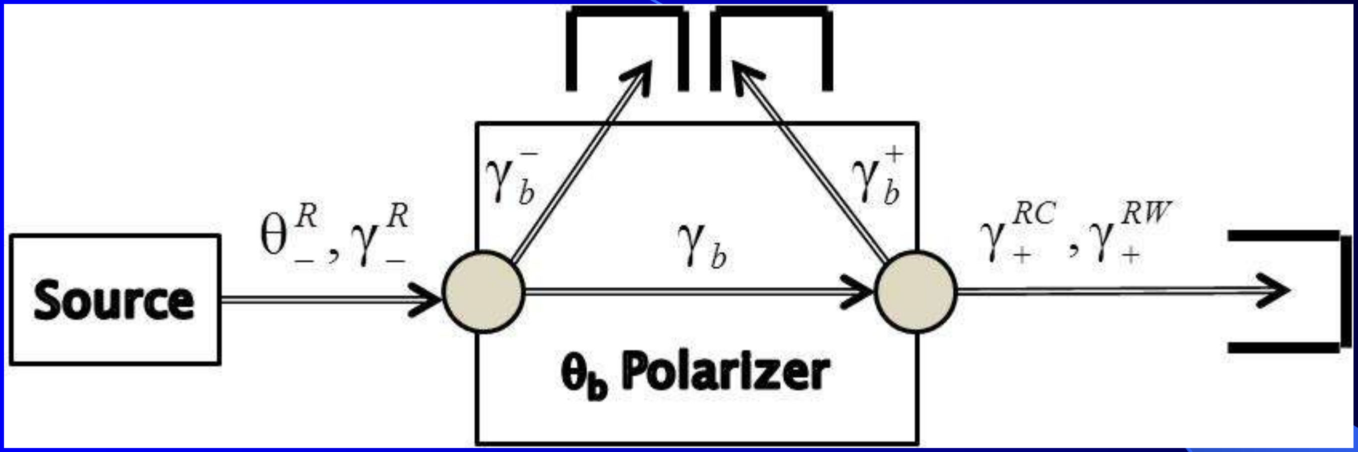


X is the set of eight variables in this picture – four θ variables for linear polarization and four γ variables for presence or absence of a photon.

The probability models for polarizer and counter are basically time-symmetric, but not source where forwards time free energy enters (IJTP).

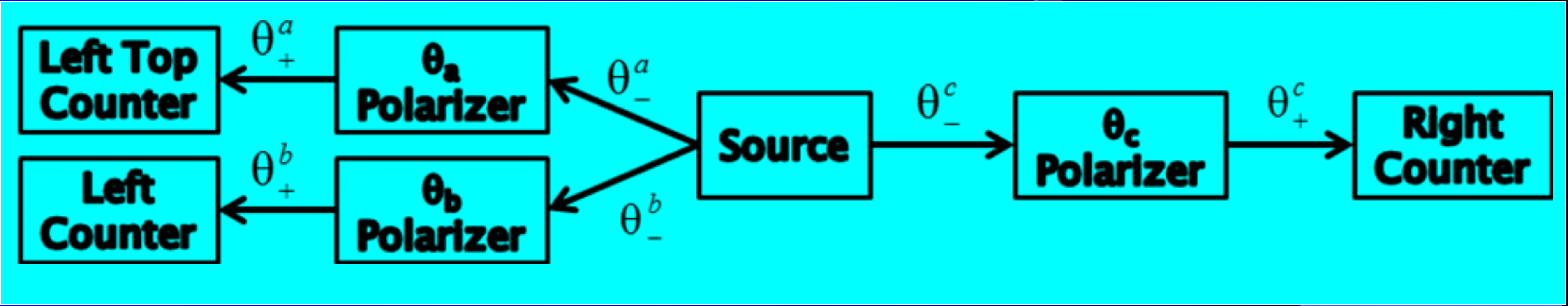
Correct result in limit as $\alpha \rightarrow 0$. (Boltzmann P paper.)

A More Realistic MRF Model (MRF3)



- 14 variables in X, 7 on each channel, but probability calculations actually end up simpler!
- Fits nicely with what we know of how optical crystals like calcite actually work here! Polarizer is not treated as a total black box!

Triphoton Experiment To Do Study $R_3/R_0(\theta_a, \theta_b, \theta_c, p)$ where p is choice of 6 orders of arrival



- When source is GHZ < Φ| state, i.e. c(<0|<1|<1| + <1|<0|<0|), "collapse of wave function" model of polarizer allows dependence on p, but for now consider arrival at a and b before c.
- MRF models imply new nonlinear measurement model of polarizer for QM, which is neuron-like

New Results: Full Predictions for $R_3/R_0(\theta_a, \theta_b, \theta_c, p)$

- Collapse of Wave Function Predicts:

  $R_3/R_0=½ (\cos \theta_a \cos \theta_b \sin \theta_c + \sin \theta_a \sin \theta_b \cos \theta_c)^2$
- MRF models Predict:

  $R_3/R_0 = k \cos^2(\theta_c - \theta_a - \theta_b)$
- Simple Excel suggests no trigonometric equivalence
- For details, see my arxiv papers.
- AQC demands many replications, modeling more and more spin entangled photons, spirit of Zeilinger

Beyond Lumped Parameter Discrete Time Models: e.g. photon in polaroid polarizer

- For collapse of the wave function, a new master equation (some inspiration from Binder) “SPIE”:

$$\dot{r} = ga(q_p + \tfrac{p}{2})\, r\, a^{+}(q_p + \tfrac{p}{2})$$

- For time-symmetric physics, a new general alternative to Feynman path, Continuous-Time MRF CMRF:

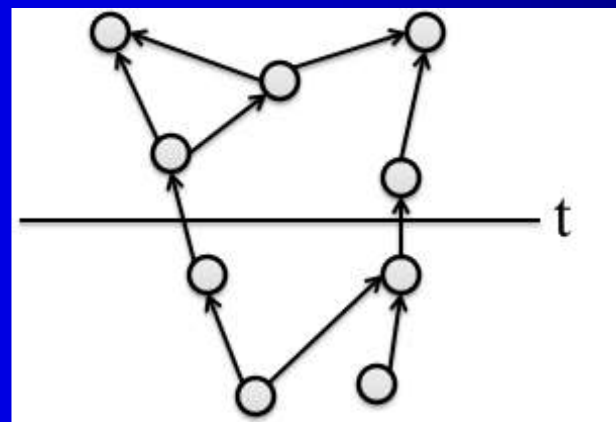
$$\frac{d}{dt}\Pr^{+}(X) = -Z_{+}(t)\Pr^{+}(X) + \int G(X,Y)\Pr^{+}(Y)\,dY \qquad \textbf{(1)}$$

$$\frac{d}{dt}\Pr^{-}(X) = -Z_{-}(t)\Pr^{-}(X) + \int G(X,Y)\Pr^{-}(Y)\,dY \qquad \textbf{(2)}$$

- Run 1 in forward time, Bayesian convolution with 2.

Equation 2 gives correct CQED without ZPE at time t.

Beyond continuous time, a more general stochastic path formulation of physics (functional field integrals)



- Given a possible path of fields <u>X</u>(t) across space-time:
  - Feynmann: $$\psi(\{X(t)\}) = Z^{-1} e^{i\hbar \int L(X(t))dt}$$
  - Stochastic path: $$\Pr(\{X(t)\}) = Z^{-1} e^{-\int L(X(t))dt}$$