A Tribute to Roy Glauber

presented at

Initial Stages 2019

Columbia University
June 27th, 2019

W.A. Zajc
Columbia University

This work was supported by the United States Department of Energy Grant DOE-FG02-86ER-40281

The Incredible Lightness of Being

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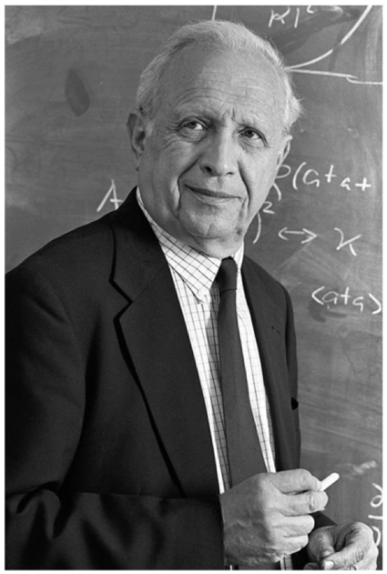
Roy J. Glauber 1925-2018

- We lost Roy Glauber on December 26, 2018.



- Roy was a good friend to the heavy ion community.
- His name is invoked with at least the same frequency as Fermi and Feynman in discussions of heavy ion physics.
- This talk: neither biography nor hagiography
- Rather: Some physics, some anecdotes, some thoughts

Thanks to Brant Johnson, Mike Leitch and Jim Thomas for material !

Roy's Worldline

- Born in New York City September 1, 1925
- Member of first graduating class at Bronx High School of Science (1941)
- Entered Harvard September, 1941
- Recruited to Los Alamos in 1943 at age of 18.
- Harvard B.A. 1946, Ph.D. 1949 (Adviser: Julian Schwinger)
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"My research for the year was devoted to resolving a puzzle they had encountered in studying electron diffraction by molecules. Solving the problem didn't interest me in molecules very much, but it did involve me deeply in scattering problems in which the incident particles were of wavelength much smaller than the ranges of interactions."
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- Intermediate states at IAS and Caltech
- Returned to Harvard 1952
- Nobel Prize in Physics 2005
- Died December 26, 2018

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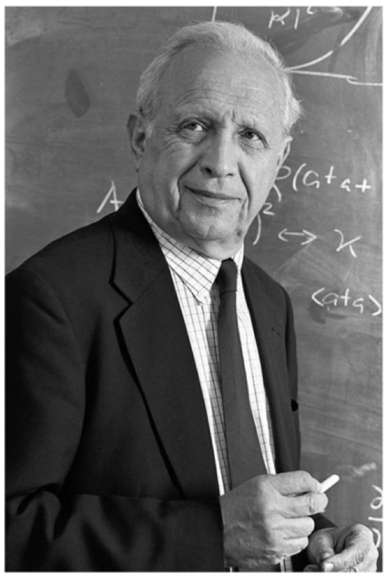

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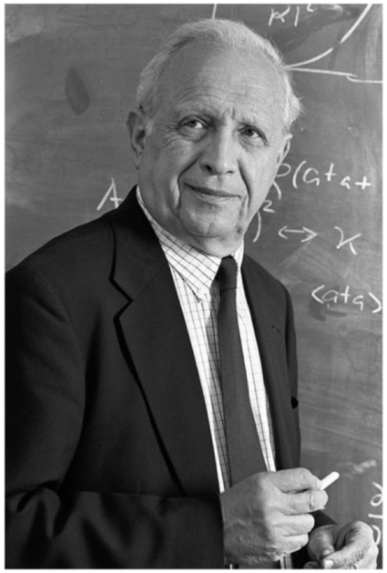

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Evidence For That Statement

- inSPIRE reports 430 records with “Glauber” in the title.
- Roy was wryly amused by this.

Roy’s Renowned Papers

- (According to inSPIRE)
- “Our” Glauber paper *High-Energy Scattering of Protons by Nuclei* has been cited 699 times.

The First "Glauber" calculation

- Actually, it's not really in the eikonal approximation
  - "multiple-diffraction theory"
- Nor is it a Monte Carlo
- But we see familiar objects:

1.E.5
8.A.1
Nuclear Physics B21 (1970) 135-157. North-Holland Publishing Company

HIGH-ENERGY SCATTERING OF PROTONS BY NUCLEI

R. J. GLAUBER *
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts, USA

G. MATTHIAE
Physics Laboratory, Istituto Superiore di Sanità, Istituto Nazionale di Fisica Nucleare, Sottosezione Sanità, Rome, Italy

Received 19 February 1970

Abstract: The theory of high-energy hadron-nucleus collisions is discussed by means of the multiple-diffraction theory. Effects of the Coulomb field are accounted for in elastic scattering by light and heavy nuclei. Inelastic scattering is treated by means of the shadowed single collision approximation at small momentum transfer and the corresponding multiple collision expansion at large momentum transfers. The theory is compared with the measurements of Bellettini et al. on proton-nucleus scattering at 20 GeV/c by finding density distributions for the nuclei which provide least-squares fits to the data. The nucleon densities found are closely comparable in dimensions to the known charge densities. The predicted sums of the angular distributions of elastic and inelastic scattering reproduce the experimental angular distributions fairly closely.

1. INTRODUCTION

An increasing number of experiments has been undertaken in recent years to study the scattering or production of high-energy particles in nuclei. The electron scattering experiments, which are among the earliest of these, furnish an accurate determination of the nuclear charge distribution. The use of protons or pions as projectiles in high-energy nuclear scattering experiments has, on the other hand, hardly been more than begun. We shall try to show in the present paper that such experiments can furnish a determination of the density distributions of nucleons comparable in accuracy with the known charge distributions.

High-energy data on hadron scattering and production processes in nuclei are conveniently analyzed by means of the multiple diffraction theory of Glauber [1,2]. The application of the multiple diffraction theory to data on unstable particle production, for example, makes it possible to evaluate the unstable particle-nucleon cross section [3]. But such applications of the theory require knowledge of the nucleon density distributions in nuclei, and

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- But we see familiar objects:
  - Thickness function

$$T(\mathbf{b}) = \int \rho(\mathbf{b} + z\hat{\mathbf{k}})\; dz$$

  - Probability of n wounded nucleons

$$\mathcal{P}_n \equiv \frac{1}{n!\sigma} \int e^{-\sigma T(\mathbf{b})}\; [\sigma T(\mathbf{b})]^n \; d\mathbf{b}$$

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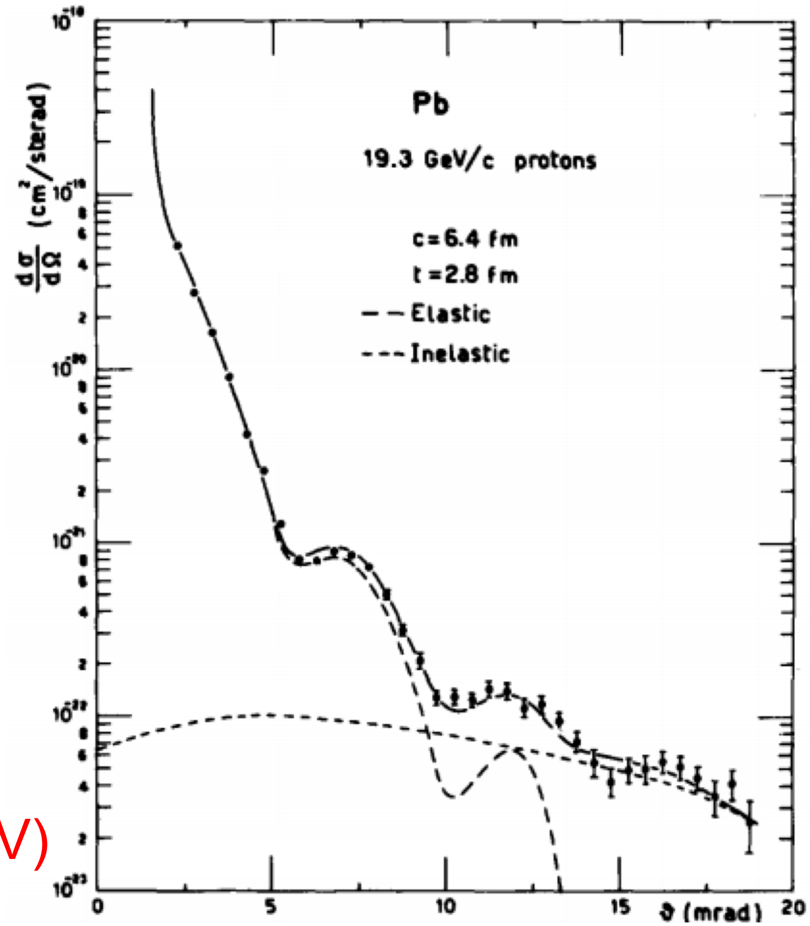

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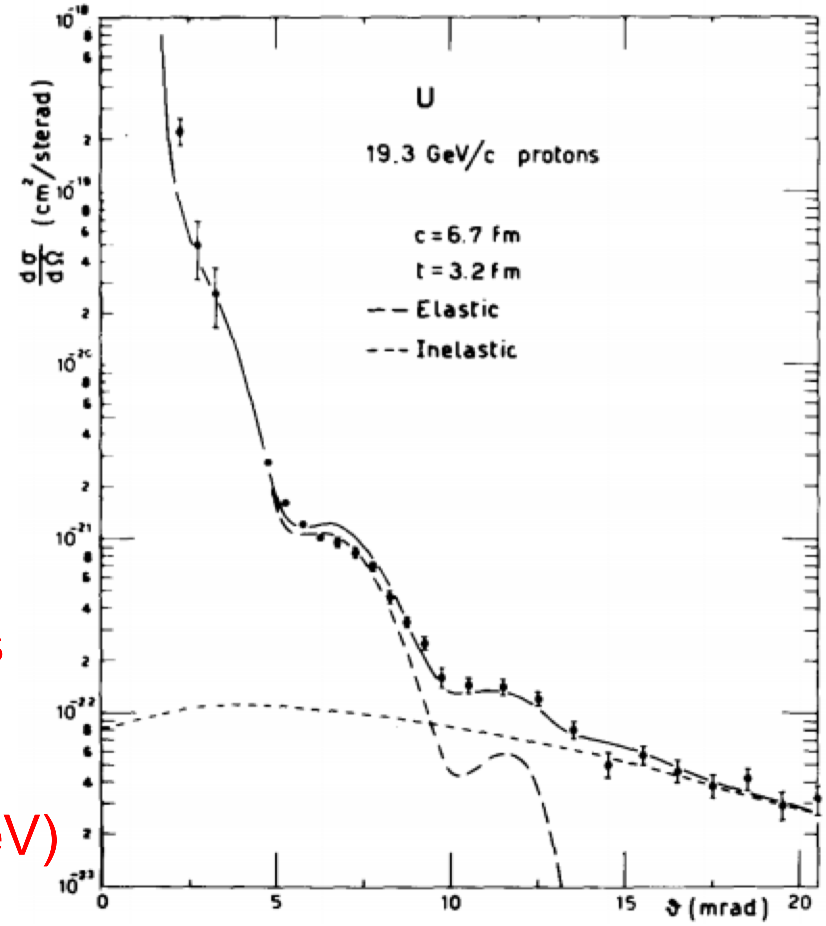
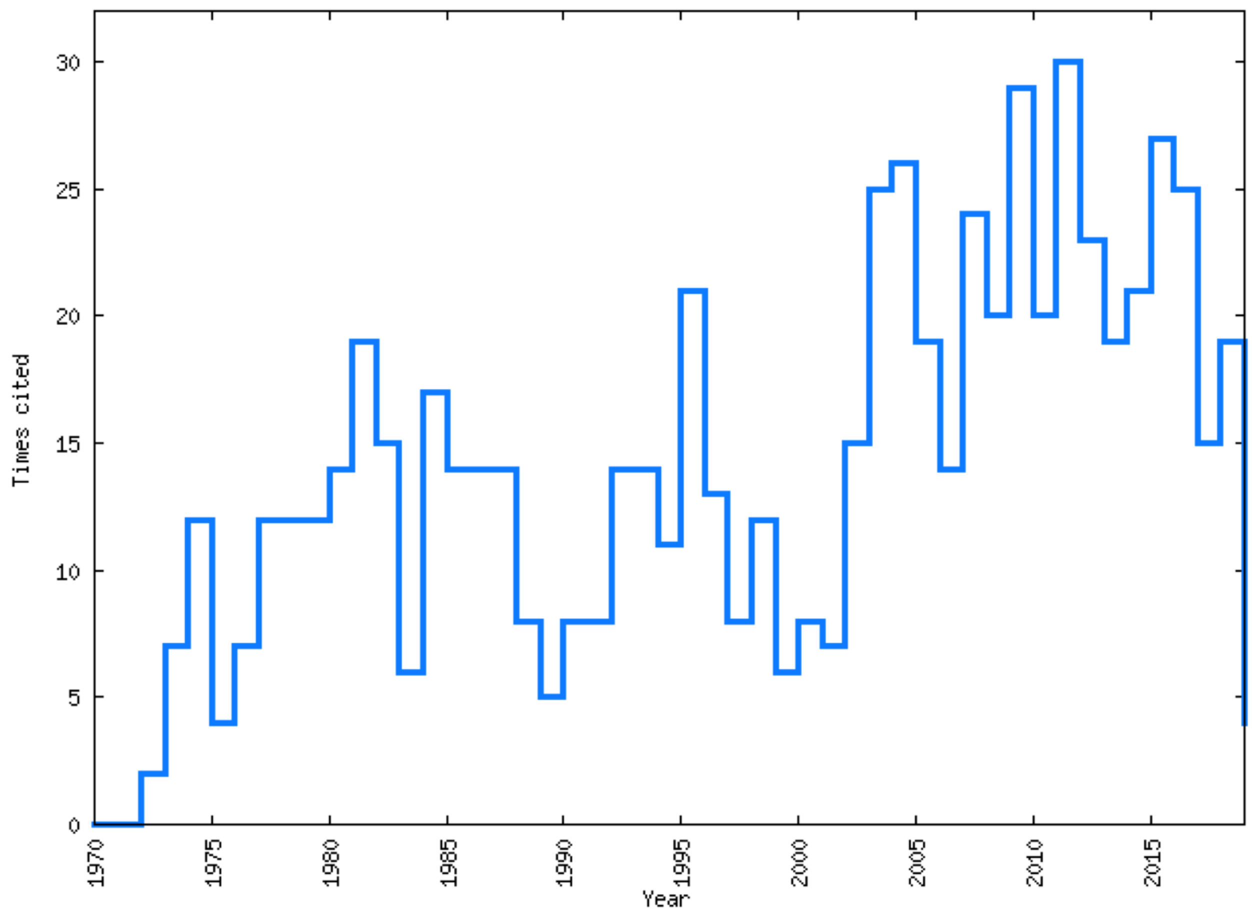
  - p+U collisions (at $\sqrt{s_{NN}}$ = 6.17 GeV)



References to Roy's "Glauber Modeling" Paper



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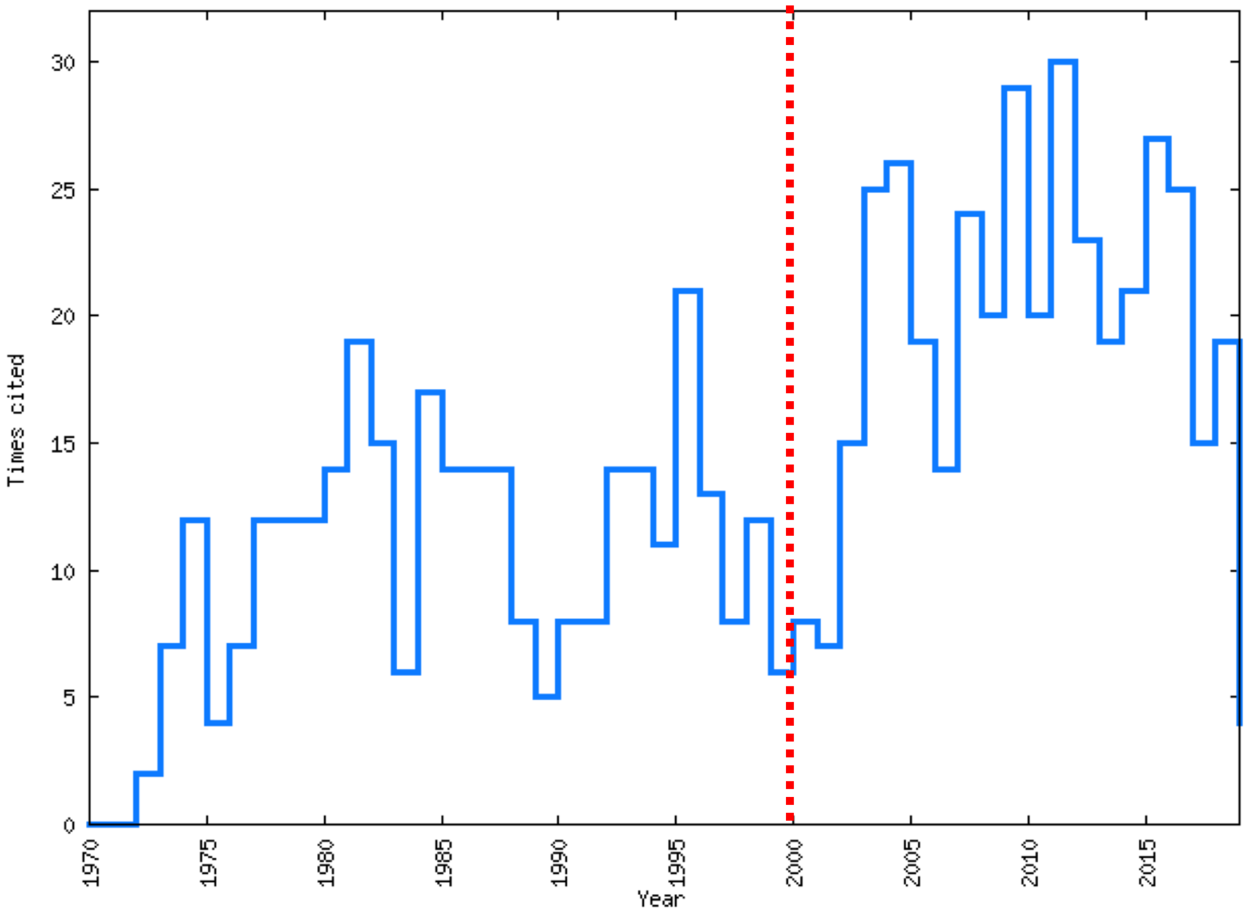
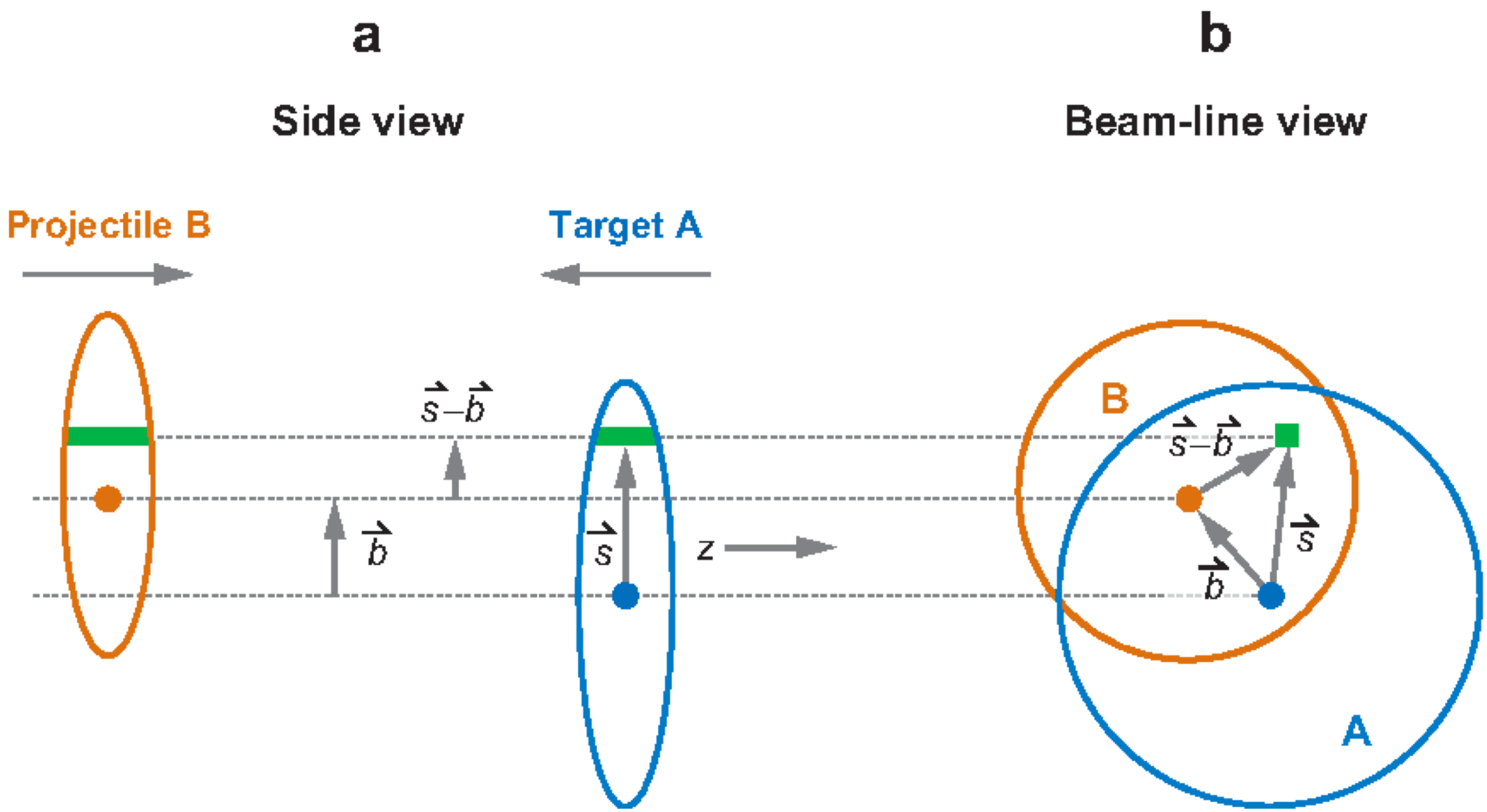


The Now-Standard Reference on “Glauber Modeling”

The Iconic Eikonal Glauber Modeling



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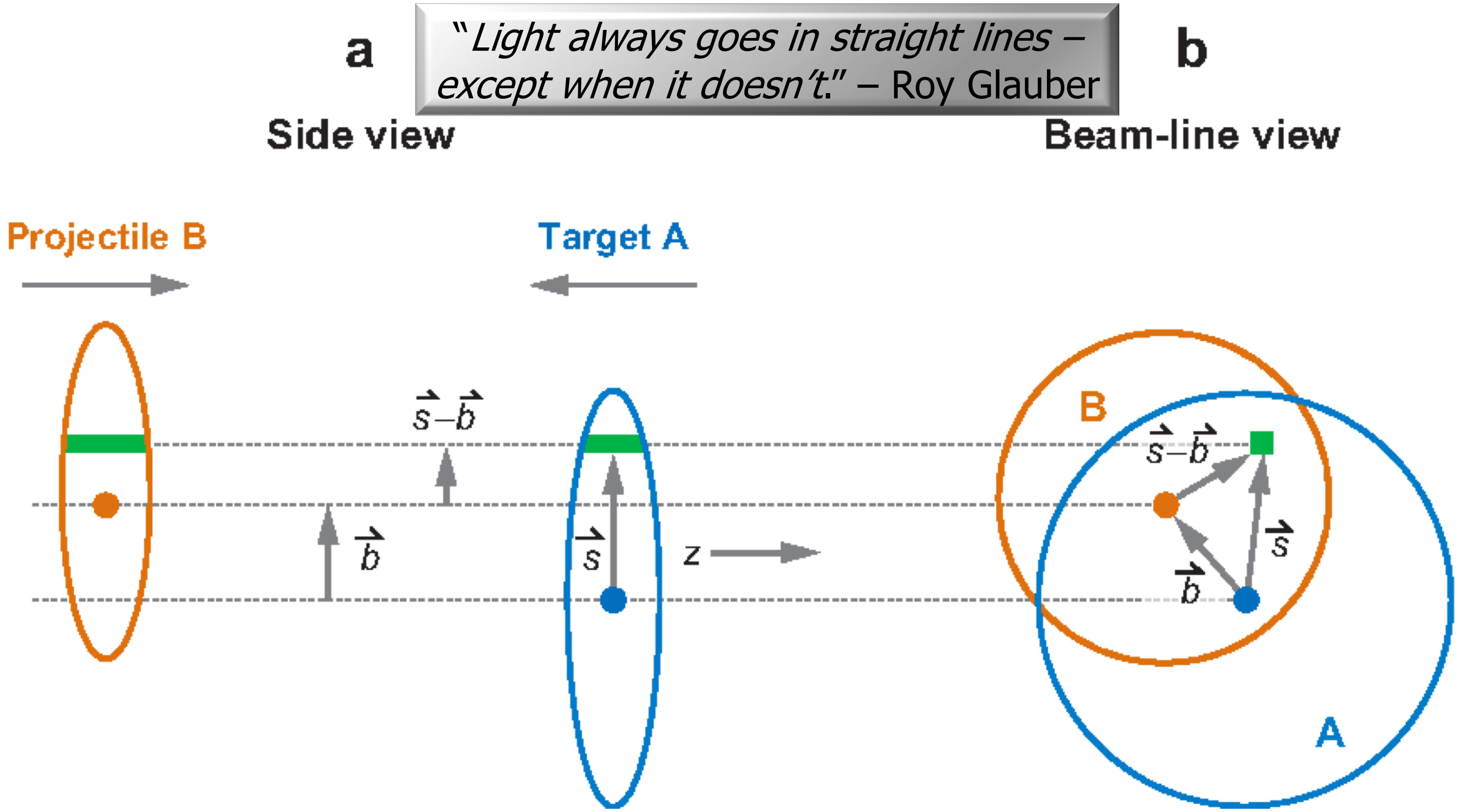
"Light always goes in straight lines – except when it doesn't." – Roy Glauber



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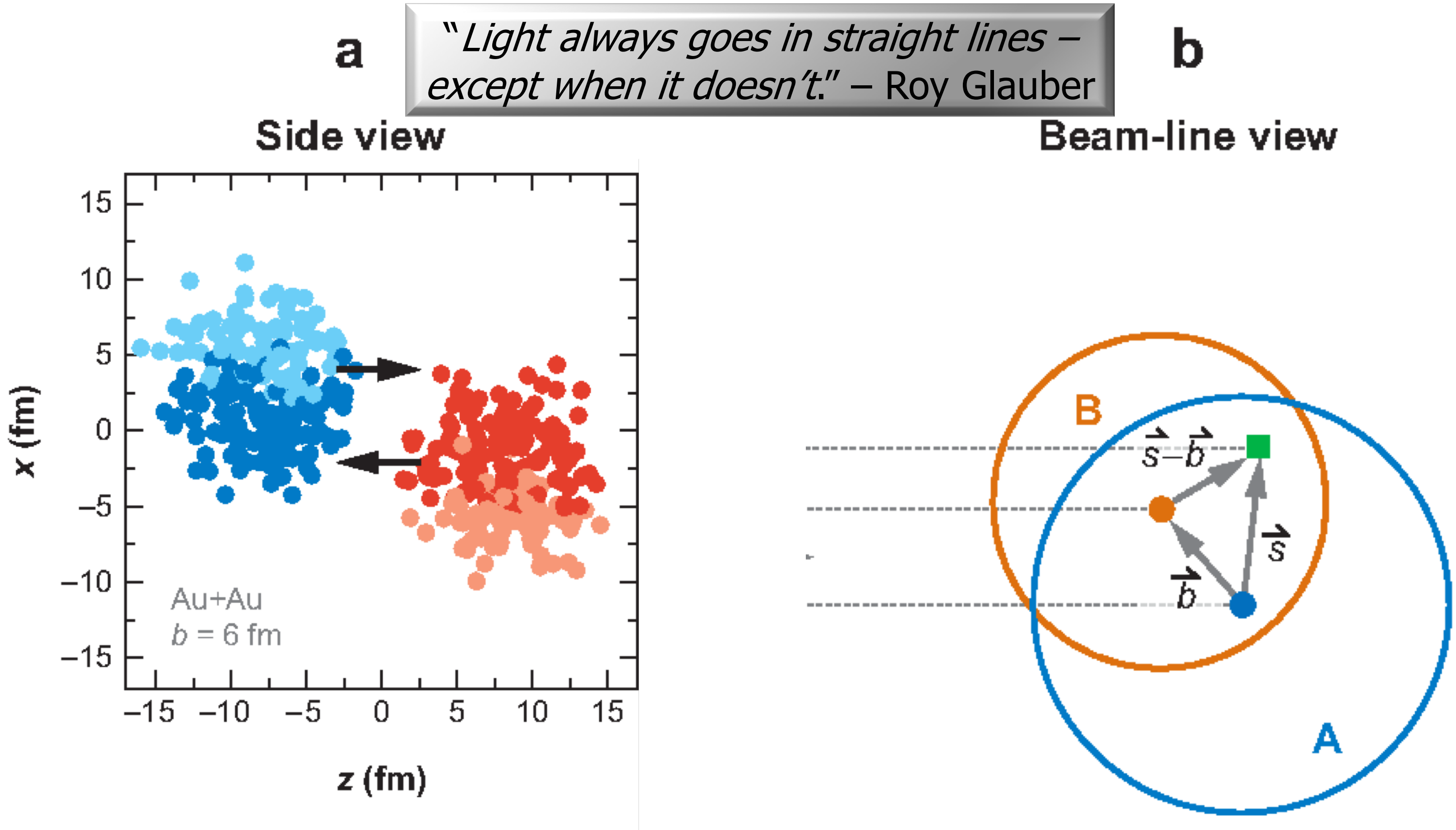

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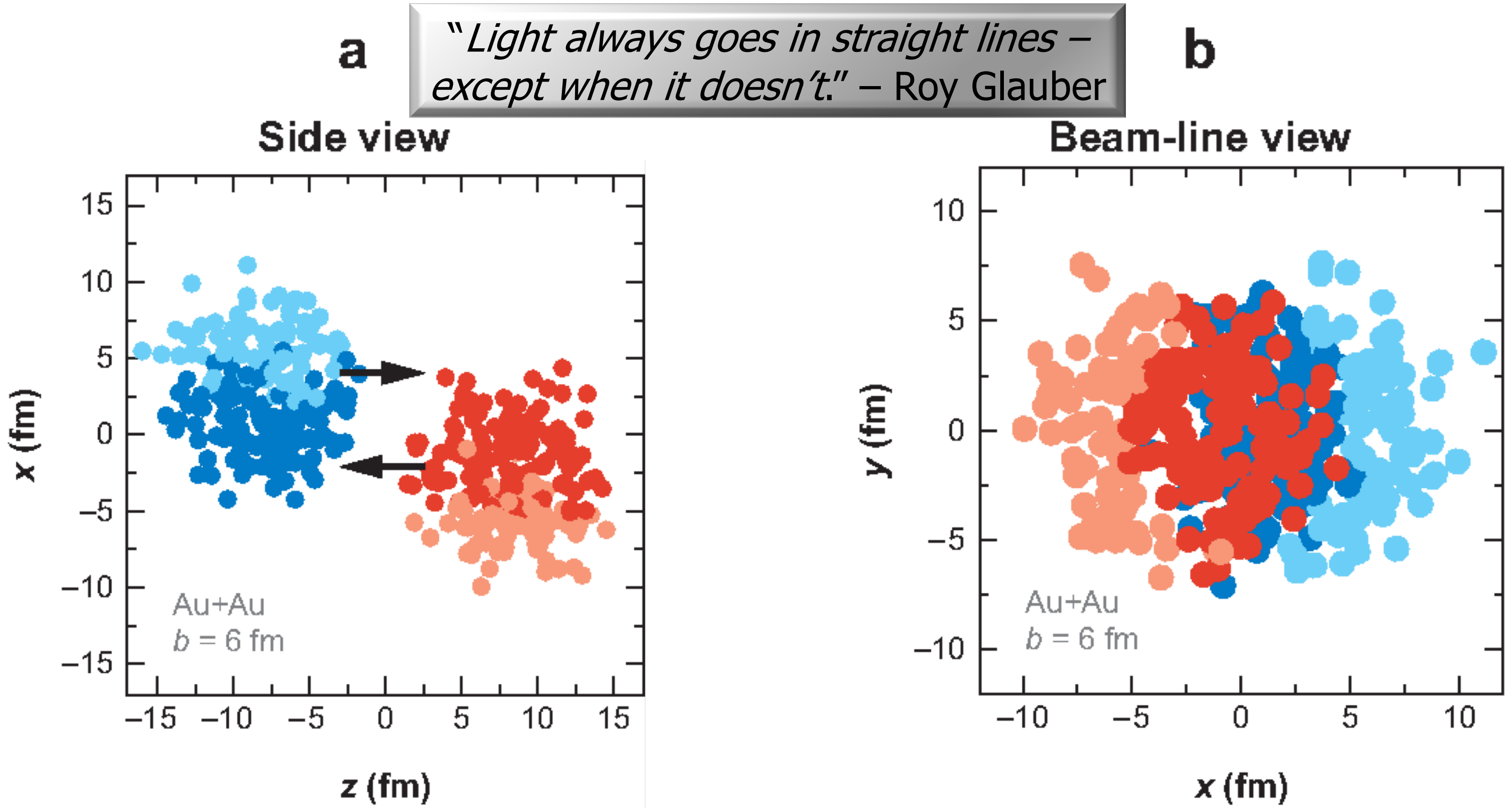

Roy's "Other" Renowned Paper

- (According to inSPIRE)
- "Other" Glauber paper *Coherent and Incoherent States of the Radiation Field* has been cited 842 times.

Let's Be a Little More Careful – Ask Google Scholar

- Coherent and incoherent states of the radiation field, RJ **Glauber** - Physical Review, 1963

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"*Studying light is easy because it's cheap stuff.*" – Roy Glauber

Most Directly Relevant to HB-T Measurements

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Photon Correlations, Roy J. Glauber, PRL **10**, 84 (1963)

PHOTON CORRELATIONS*

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(Received 27 December 1962)

In 1956 Hanbury Brown and Twiss[1] reported that the photons of a light beam of narrow spectral width have a tendency to arrive in correlated pairs. We have developed general quantum mechanical methods for the investigation of such correlation effects and shall present here results for the distribution of the number of photons counted in an incoherent beam. The fact that photon correlations are enhanced by narrowing the spectral bandwidth has led to a prediction[2] of large-scale correlations to be observed in the beam of an optical maser. We shall indicate that this prediction is misleading and follows from an inappropriate model of the maser beam. In considering these problems we shall outline a method of describing the photon field which appears particularly well suited to the discussion of experiments performed with light beams, whether coherent or incoherent.

The correlations observed in the photoionization processes induced by a light beam were given a simple semiclassical explanation by Purcell,[3] who made use of the methods of microwave noise theory. More recently, a number of papers have been written examining the correlations in considerably greater detail. These papers[2,4-6] retain the assumption that the electric field in a light beam can be described as a classical Gaussian stochastic process. In actuality, the behavior of the photon field is considerably more

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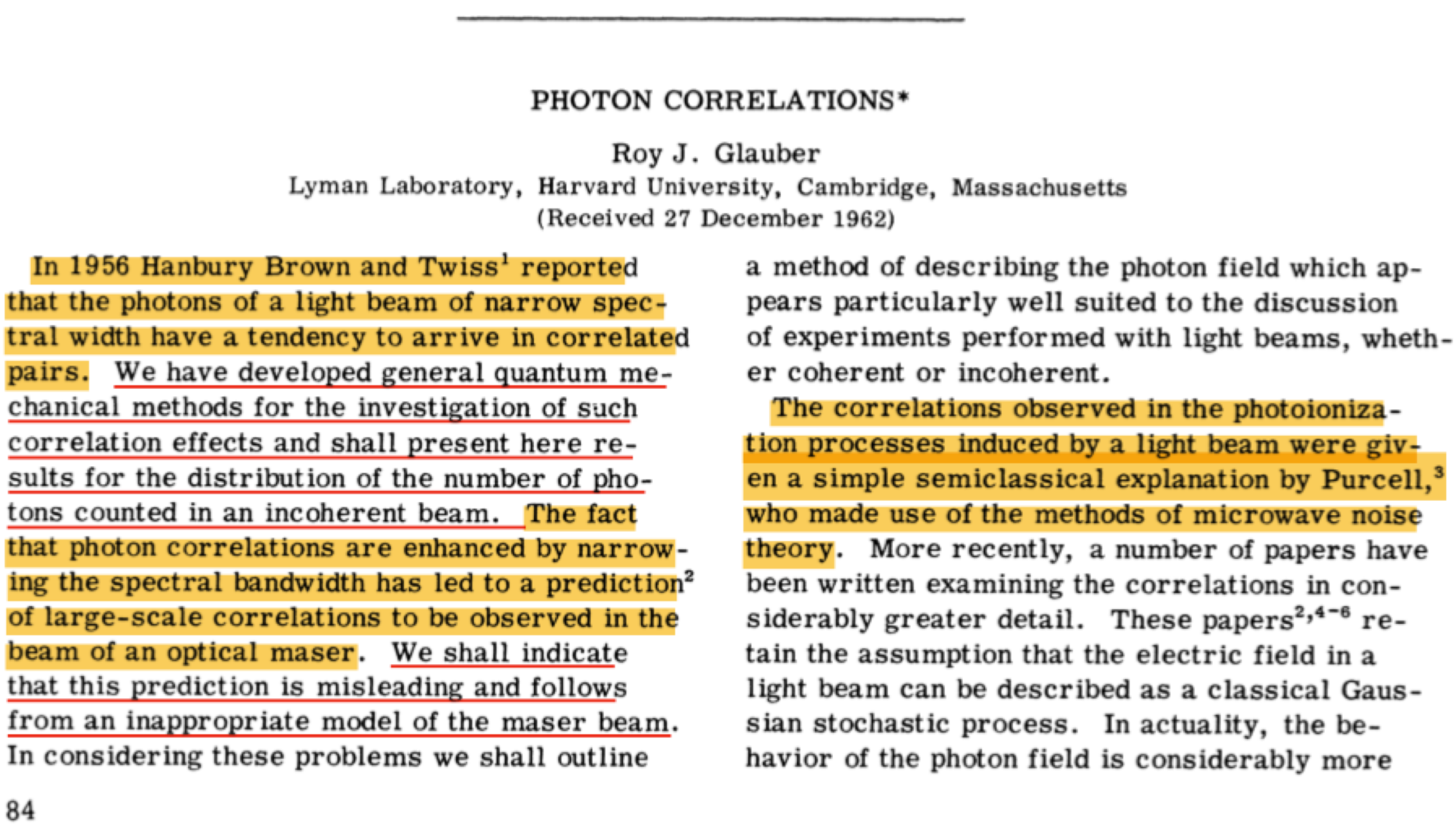
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The Essential Point

$$I(t) = \sum_{i=1}^{100} \left|\mathbf{E}_0 \cos \phi_i\right|^2$$

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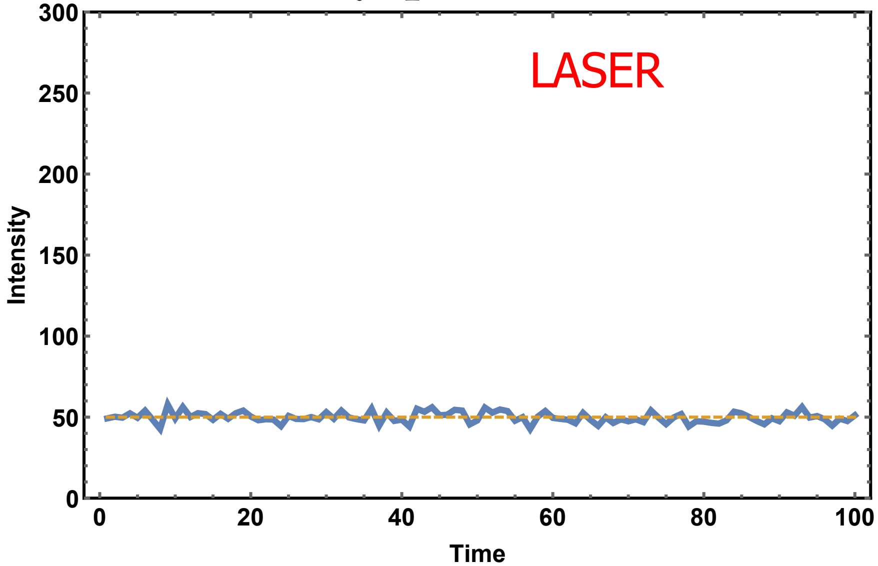

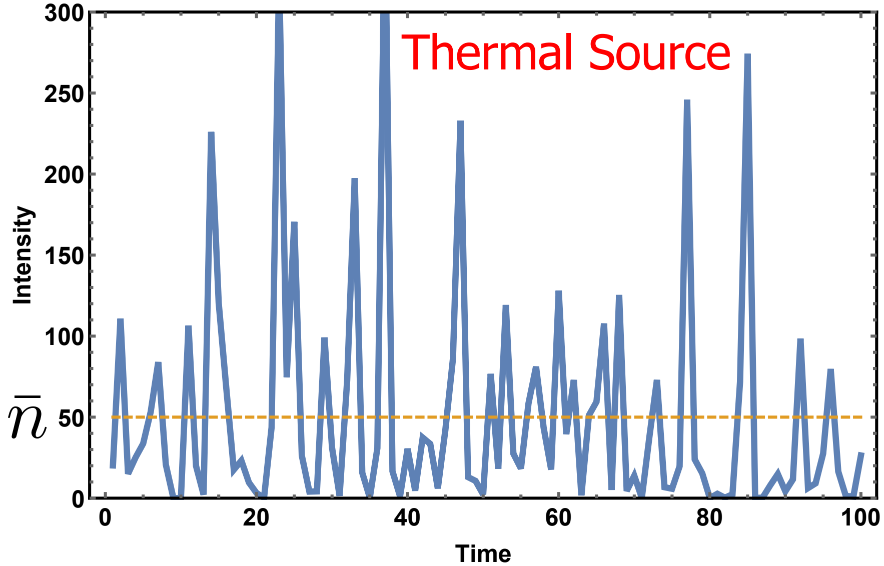

$\bar{n}$ $\bar{n}$

Shot noise

$$(\Delta n)^2 = \bar{n} + \bar{n}^2$$

Wave noise

Roy's Magnus Opus

- Coherent and incoherent states of the radiation field, RJ **Glauber** - Physical Review **131**, 2766 (1963) Cited by 6755

- Development of the complete quantum theory of higher-order coherence of EM field

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During the completion of the present paper a note by Sudarshan[12] has appeared which deals with some of the problems of photon statistics that have been treated here.[22] Sudarshan has observed the existence of what

[22] In an accompanying note, L. Mandel and E. Wolf [Phys. Rev. Letters **10**, 276 (1963)] warmly defend the classical approach to photon problems. Some of the possibilities and fundamental limitations of this approach should be evident from our earlier work. We may mention that the "implication" they draw from Ref. 1 and disagree with cannot be validly inferred from any reading of that paper.

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  And some snark for the snipers:

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The Nobel Prize in Physics 2005

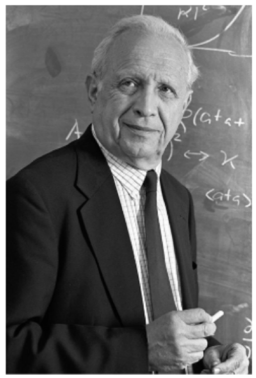


Photo: J.Reed

Roy J. Glauber

Prize share: 1/2

Photo: Sears.P.Studio

John L. Hall

Prize share: 1/4

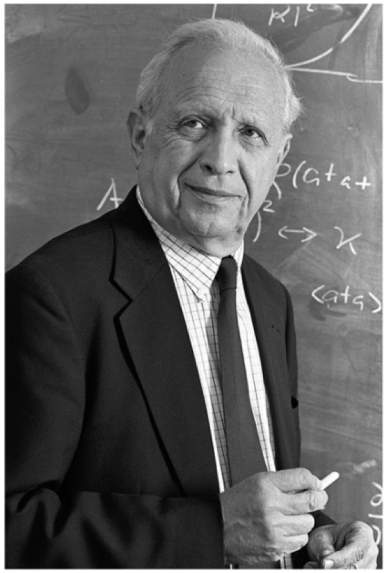
Photo: F.M. Schmidt

Theodor W. Hänsch

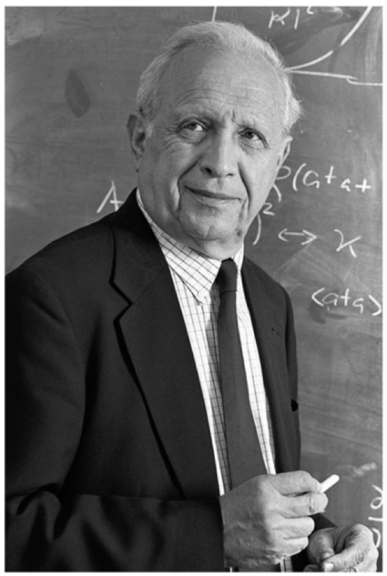
Prize share: 1/4

The Nobel Prize in Physics 2005 was divided, one half awarded to Roy J. Glauber "for his contribution to the quantum theory of optical coherence", the other half jointly to John L. Hall and Theodor W. Hänsch "for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique."

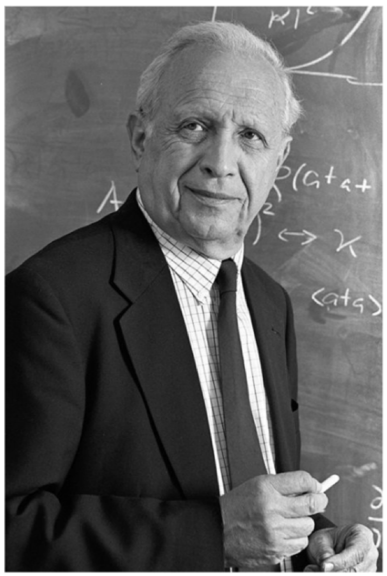
Roy J. Glauber, Nobel Prize in Physics 2005

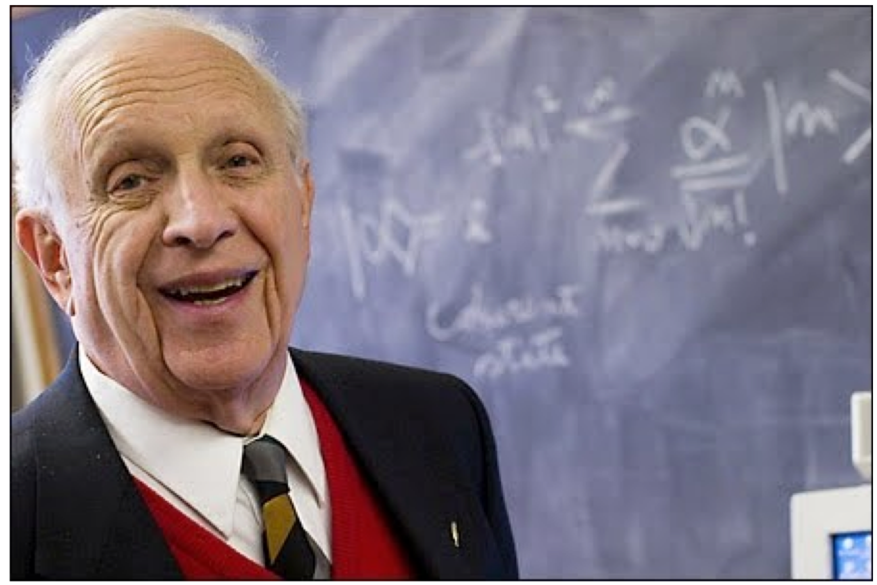


Roy J. Glauber, Nobel Prize in Physics 2005



Roy J. Glauber, Nobel Prize in Physics 2005





Something I Learned from Roy's Nobel Lecture

- Some Notes on Multiple-Boson Processes, RJ **Glauber** - Physical Review **84**, 395 (1951) Cited by 165

- User Schwinger-inspired source methods.
- Shows classical current produces Poisson distribution.
- Background for future work on optical coherence

PHYSICAL REVIEW VOLUME 84, NUMBER 3 NOVEMBER 1, 1951

Some Notes on Multiple-Boson Processes

ROY J. GLAUBER
Institute for Advanced Study, Princeton, New Jersey
(Received July 11, 1951)

Methods of calculation with nonlinear functions of quantized boson fields are developed during the discussion of two problems involving multiple boson processes. In the first of these a simple treatment is given of the multiple radiation of photons by classical current distributions, a special case of which, in effect, is the infrared catastrophe.

In the second illustration, generalizations of the scalar and pseudoscalar meson theories are considered in which the interaction hamiltonian depends exponentially on the meson field. In the pseudoscalar case such hamiltonians are closely related to the familiar form of pseudovector coupling. Assuming the over-all coupling of the nucleon and meson fields to be weak, calculations are made of the nuclear forces, and of the multiple production of mesons in meson-nucleon and in nucleon-nucleon collisions. In the latter events statistical independence of meson emissions is found to prevail.

I. INTRODUCTION

DEFICIENCIES in the mathematical techniques for handling quantized field theories obscure many questions of critical importance, such as the extent to which difficulties of the theory arise from a questionable expansion in powers of a coupling constant, and the importance of higher order corrections. An attempt has, therefore, been made, based on the developments due to Schwinger and others,[1,2] to find improved methods of computing the various matrix elements and expectation values of interest. Ideally these methods should be capable of handling rather general functions of quantized field variables, wherever possible without resorting to power series expansions. Simple rules accomplishing these ends have been found for dealing with functions of fields whose commutators with themselves are *c*-numbers, i.e., boson fields. While the problem of treating spinor fields remains, these methods make possible the simplification of some parts of the theory, and the generalization of others.

To illustrate both aspects of the work, the mathematical methods are developed during a discussion of two problems involving multiple-boson processes. In part II we discuss the radiation of quanta by a classical current distribution and in particular the well-known "infrared catastrophe" (the emission of an infinite number of soft photons when a charged particle is suddenly accelerated). The familiar results of Bloch and Nordsieck[3] are obtained in a rather direct way. In part III we discuss generalizations of the usual neutral scalar and pseudoscalar meson theories in which the interaction hamiltonian is allowed to depend exponentially on the meson field. A particular case of such an exponential hamiltonian involving the pseudoscalar field has been shown by Dyson[4] to result from a contact transformation performed on the familiar hamiltonian for pseudovector coupling of the pseudoscalar field. Couplings of the type introduced bring many high order aspects of the usually treated couplings much closer to the surface of the theory. Among these are higher order corrections to nuclear forces and the multiple production of mesons. We may hope, by treating these processes to gain some insight which the usual theory has not granted us.

II. RADIATION OF PHOTONS BY CLASSICAL CURRENTS

The infrared catastrophe causes low frequency divergences in the calculation of the radiative corrections to any process involving the sudden acceleration of charge, e.g., scattering in a potential field, Compton effect, pair production, etc. Bloch and Nordsieck treated the scattering of an electron by a potential by introducing several approximations, principally the neglect of pair effects and of the electron's recoil in photon emission. These approximations, which are justified by the very low energy of the photons involved, may be epitomized by saying that only the classical properties of the electron current are important. The general class of problems for which this property holds may be treated by considering the interaction of the quantized electromagnetic vector potential $A_\mu(x)$ ($\mu=1\cdots 4$, $x_\mu=\mathbf{r}$, ict) with a classical current distribution $j_\mu(x)$, prescribed as a function of space and time.[5] The state vector $\Psi(\sigma)$ of the system on a space-like surface σ in the interaction representation obeys the Schrödinger equation[6]

$$i\delta/\delta\sigma(x)\Psi=H(x)\Psi, \tag{1}$$

where $H(x)$ is the interaction hamiltonian,

$$H(x)=-j_\mu(x)A_\mu(x). \tag{2}$$

The quantities we shall be interested in calculating are the probability amplitudes for the real emission of any specified number of photons. We may assume that the interaction began in the remote past when the system was in a state with no real photons present. The

[1] J. Schwinger, Phys. Rev. **74**, 1439 (1948).
[2] J. Schwinger, Phys. Rev. **75**, 651 (1949).
[3] F. Bloch and A. Nordsieck, Phys. Rev. **52**, 54 (1937).
[4] F. J. Dyson, Phys. Rev. **73**, 929 (1948).
[5] A treatment of the infrared catastrophe using classical currents has just been published by W. Thirring and B. Touschek, Phil. Mag. **42**, 244 (1951).
[6] We use units in which $\hbar=1$, $c=1$.

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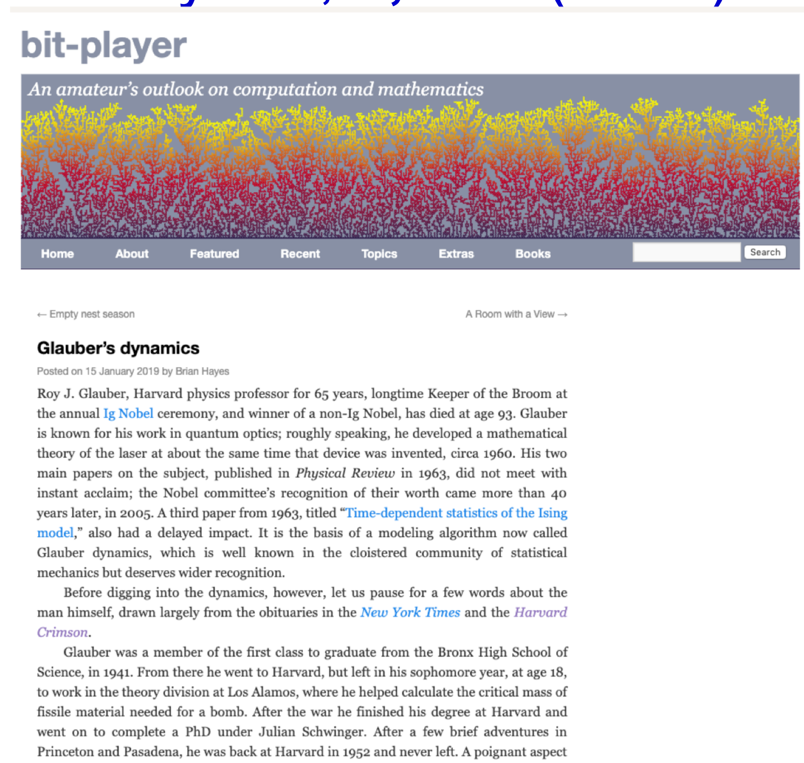
Something Else I Learned in Preparing This Talk

- Time-Dependent Statistics of the Ising Model,
  RJ **Glauber –** Journal of Mathematical Physics, **4,** 294 (1963)
  Cited by 3730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Glauber's dynamics

Posted on 15 January 2019 by Brian Hayes

Roy J. Glauber, Harvard physics professor for 65 years, longtime Keeper of the Broom at the annual Ig Nobel ceremony, and winner of a non-Ig Nobel, has died at age 93. Glauber is known for his work in quantum optics; roughly speaking, he developed a mathematical theory of the laser at about the same time that device was invented, circa 1960. His two main papers on the subject, published in *Physical Review* in 1963, did not meet with instant acclaim; the Nobel committee's recognition of their worth came more than 40 years later, in 2005. A third paper from 1963, titled "Time-dependent statistics of the Ising model," also had a delayed impact. It is the basis of a modeling algorithm now called Glauber dynamics, which is well known in the cloistered community of statistical mechanics but deserves wider recognition.

Before digging into the dynamics, however, let us pause for a few words about the man himself, drawn largely from the obituaries in the *New York Times* and the *Harvard Crimson*.

Glauber was a member of the first class to graduate from the Bronx High School of Science, in 1941. From there he went to Harvard, but left in his sophomore year, at age 18, to work in the theory division at Los Alamos, where he helped calculate the critical mass of fissile material needed for a bomb. After the war he finished his degree at Harvard and went on to complete a PhD under Julian Schwinger. After a few brief adventures in Princeton and Pasadena, he was back at Harvard in 1952 and never left. A poignant aspect

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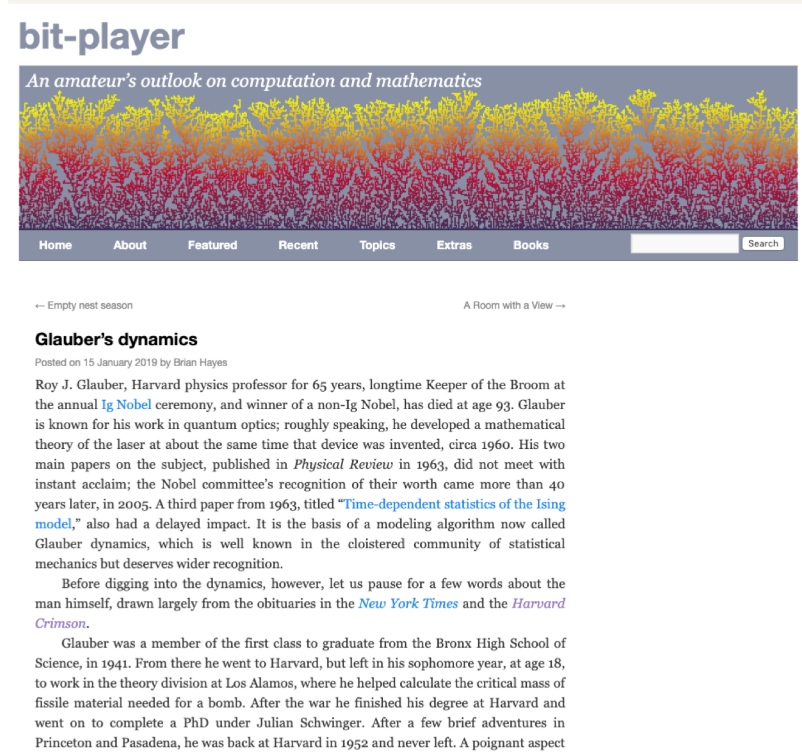
If the mathematical problems of equilibrium statistical mechanics are great, they are at least relatively well-defined. The situation is quite otherwise in dealing with systems which undergo large-scale changes with time. The principles of nonequilibrium statistical mechanics remain in largest measure unformulated. While this lack persists, it may be useful to have in hand whatever precise statements can be made about the time-dependent behavior of statistical systems, however simple they may be.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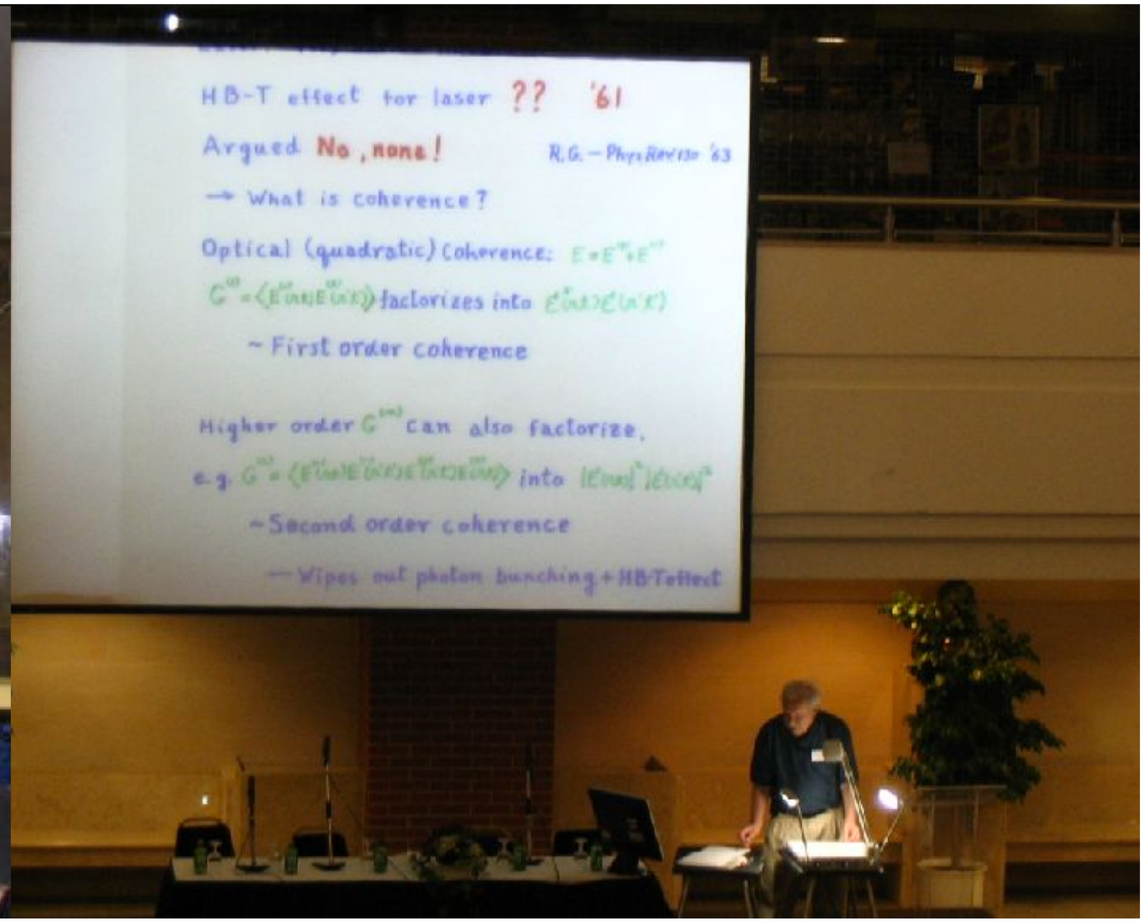
Roy at Quark Matter 2005 (August 4th)



Roy at Quark Matter 2005 (August 7th)

Prior to Installation of the Royal Court

Roy’s Coronation

A Queen Is Chosen

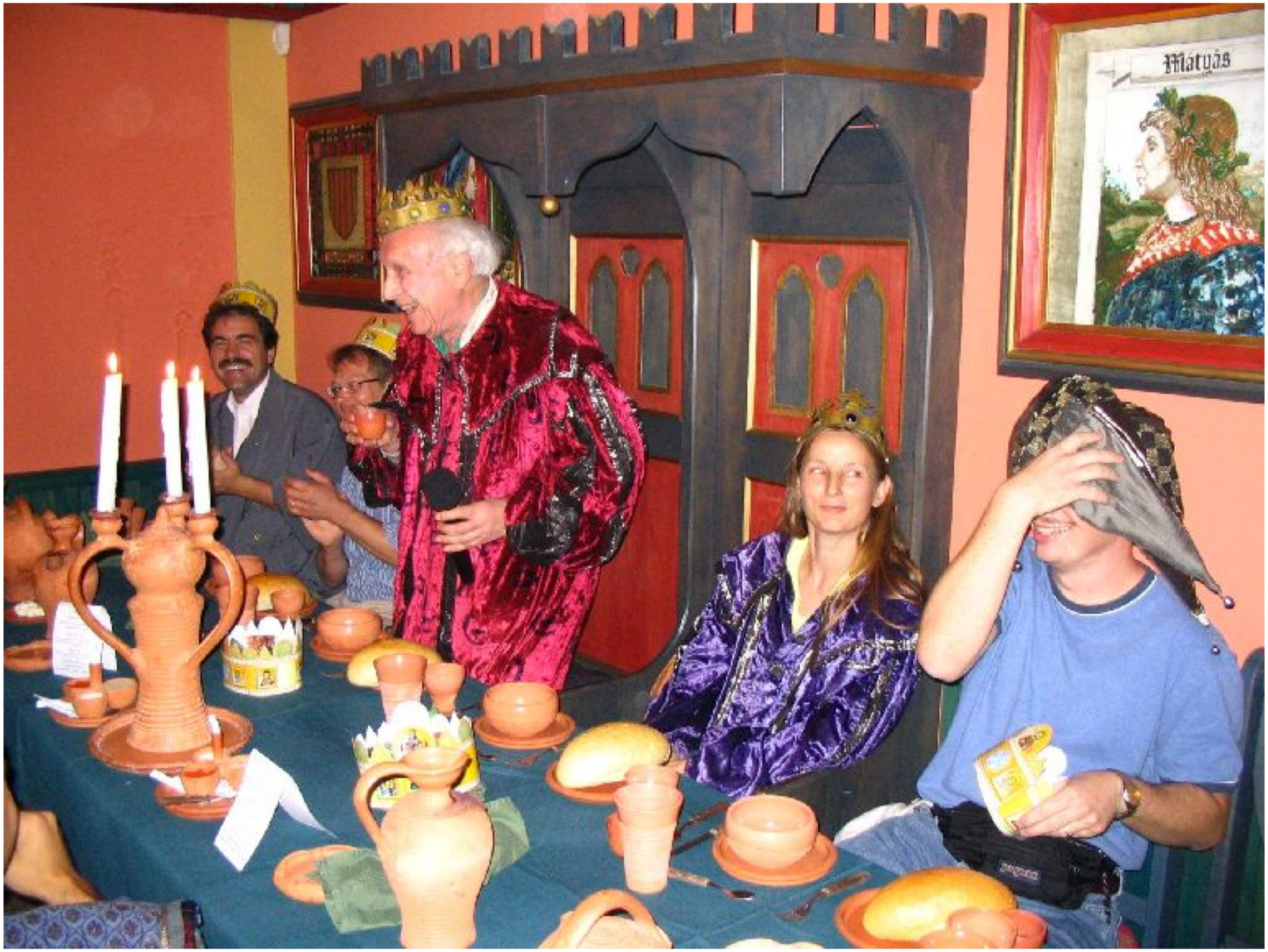
And A Jester…

And …

An Editor !

Who Was Appropriately Sentenced

Festivities Continued Into The Evening



Roy Continued as “The Keeper of the Broom” at Ig Nobels

- Roy at the 2012 Ig Nobels.
- Roy on reporters at the Nobel Ceremony:

Roy Continued as "The Keeper of the Broom" at Ig Nobels

- Roy at the 2012 Ig Nobels.
- Roy on reporters at the Nobel Ceremony:

"But all they wanted to ask about was that damn broom and the paper airplanes."

Roy Continued as "The Keeper of the Broom" at Ig Nobels

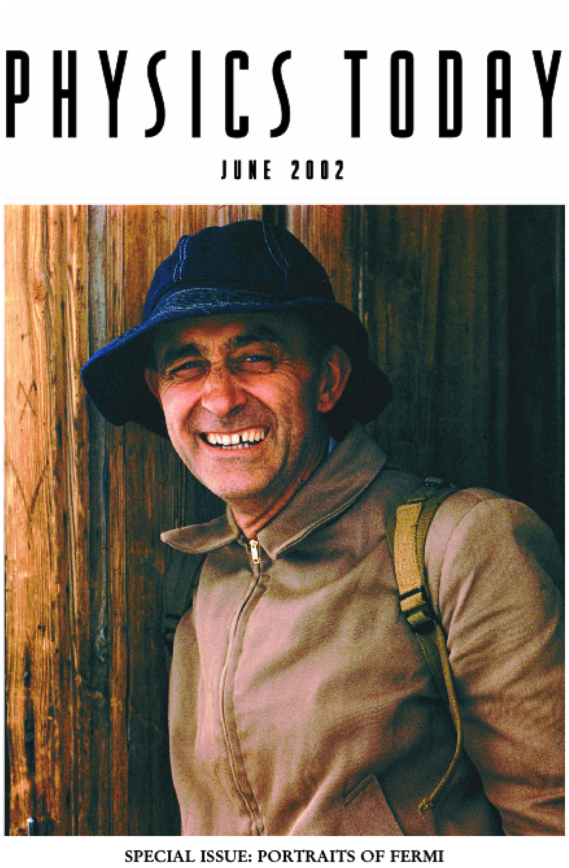
- Roy at the 2016 Ig Nobels

Roy Continued as "The Keeper of the Broom" at Ig Nobels

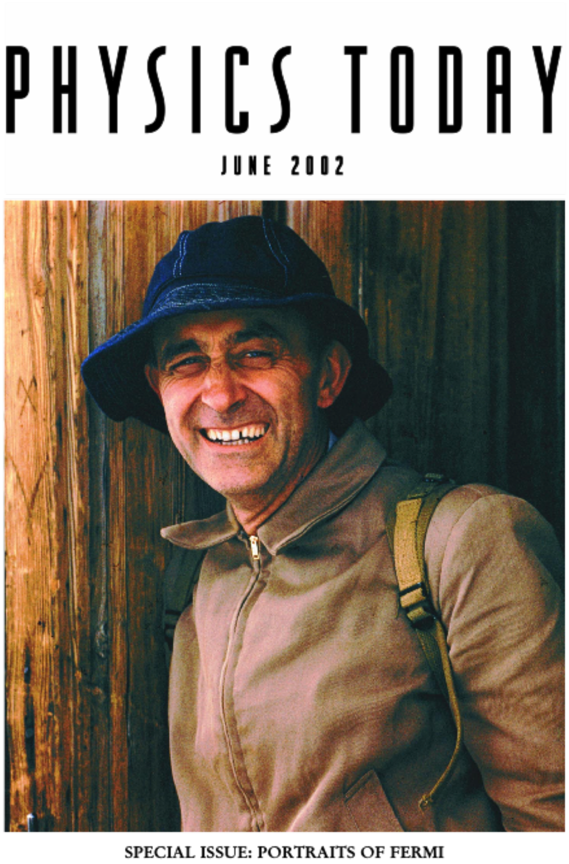
- Roy at the 2016 Ig Nobels

Nobel laureates Eric Maskin, Rich Roberts, Dudley Herschbach, and Roy

Two of Roy’s Other Great Contributions to Physics



Two of Roy's Other Great Contributions to Physics



Some Words on Career Development

- (Induced) Serendipity – those whom I nudged to help me:
  - Abraham Pais
    - Influence of Bose-Einstein statistics in the anti-proton annihilation process,
      G. Goldhaber, S. Goldhaber, W.Y. Lee and A. Pais, Physical Review **120**, 300 (1960)
      Cited by 761
  - Ed Purcell
    - The question of correlations between photons in coherent light rays,
      E.M. Purcell, Nature **178**, 1449 (1956)
      Cited by 347
  - Roy (see this talk)

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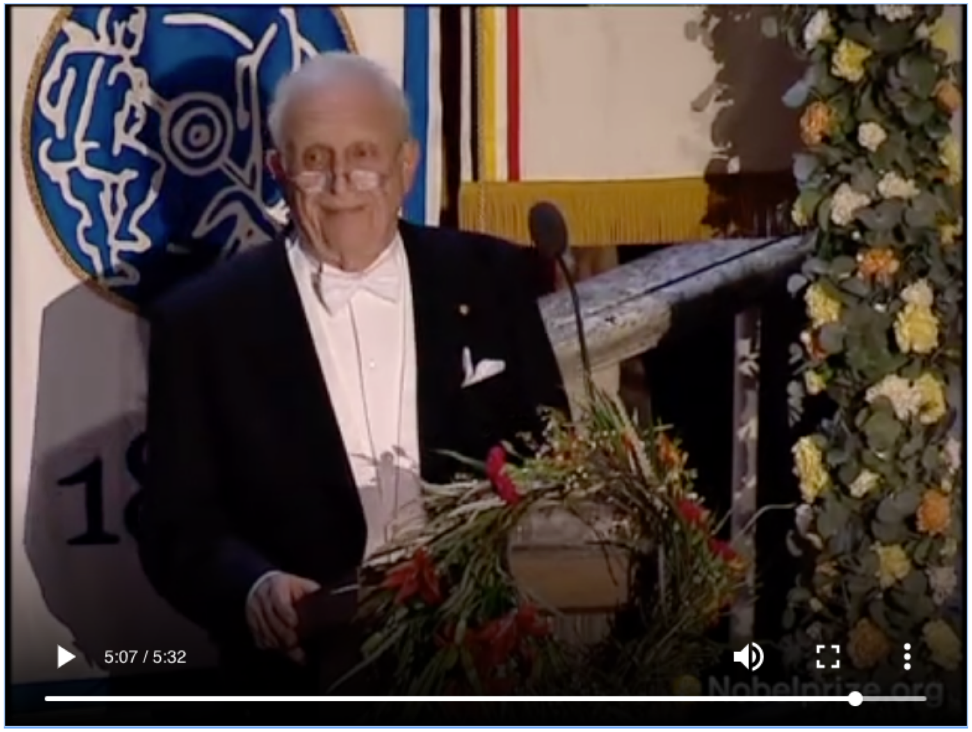
  - Roy (see this talk)
- (Reduced) Productivity – advice on priorities

"I'm sure there is some number of papers I never got to write as a result, but … was not an experience I would trade for the missing papers or any sort of recognition."
Roy Glauber

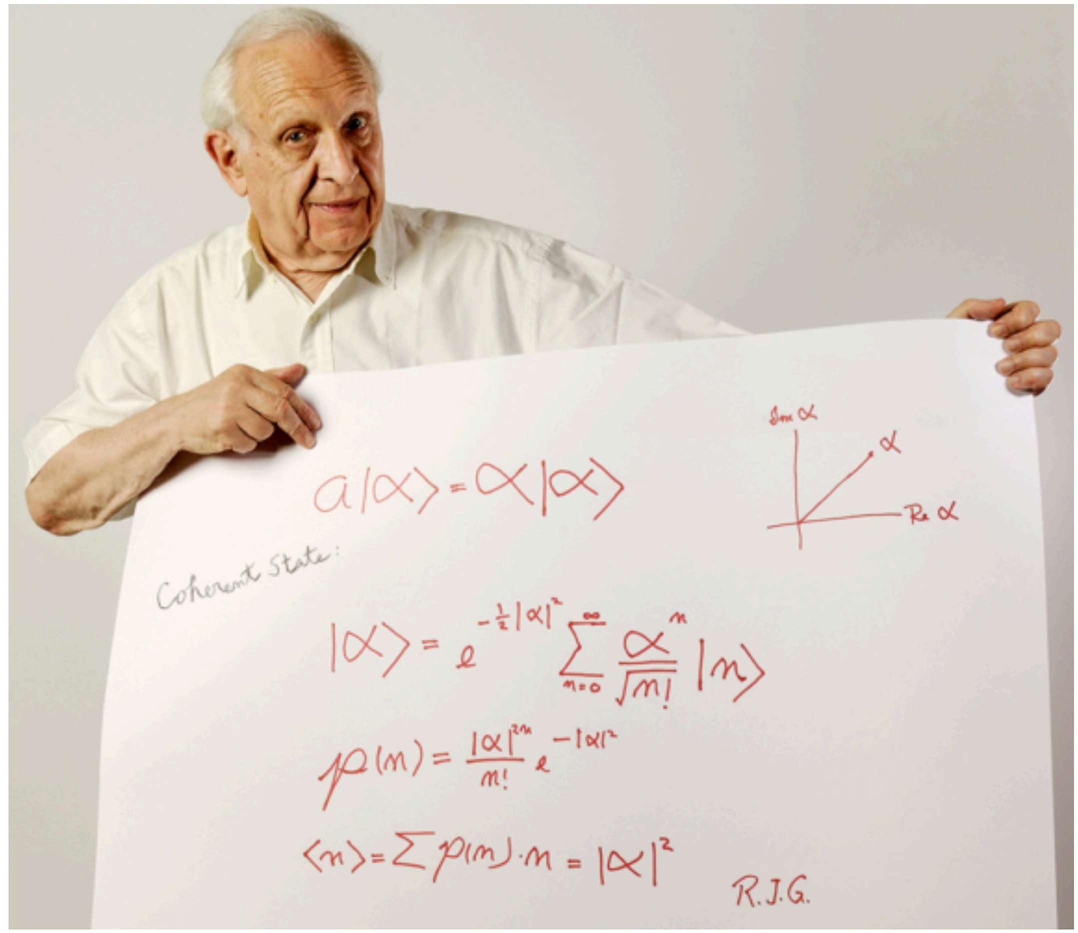
Recommended Resources

- Roy's Nobel lecture:
  https://www.nobelprize.org/prizes/physics/2005/glauber/lecture/
- Roy's wonderful autobiographical essay:
  https://www.nobelprize.org/prizes/physics/2005/glauber/biographical/
- Roy's luminous banquet speech on light:
  https://www.nobelprize.org/prizes/physics/2005/glauber/speech/



In Summary

- Roy – Thank you for lighting the way, and for illuminating our lives with your grace, dignity and geniality.



In Summary

- Roy – Thank you for lighting the way, and for illuminating our lives with your grace, dignity and geniality.

- Our sorrow is tempered by knowing that your light is now shining from a higher place.

Thank You!

We All Know What "Glauber" Is…

https://www.semanticscholar.org/topic/Glauber/300299

Semantic Scholar

All Fields

Search 147,643,511 papers from ArXiv, PubMed, and more...

Glauber

Known as: Glauber (disambiguation)

Glauber is a scientific discovery method written in the context of computational philosophy of science. It is related to machine learning in artificial intelligence. Glauber was written, among other programs, by Pat Langley, Herbert A. Simon, G. Bradshaw and J. Zytkow to demonstrate how scientific discovery may be obtained by problem solving methods, in their book Scientific Discovery, Computational Explorations on the Creative Mind. Their programs simulate historical scientific discoveries based on the empirical evidence known at the time of discovery. In few words, the law:(Less)

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