What Can We Learn? FROM ENTANGLEMENT AND QUANTUM TOMOGRAPHY

THE RENAISSANCE OF QUANTUM MECHANICS AND HAND-MADE SLIDES

John Ralston

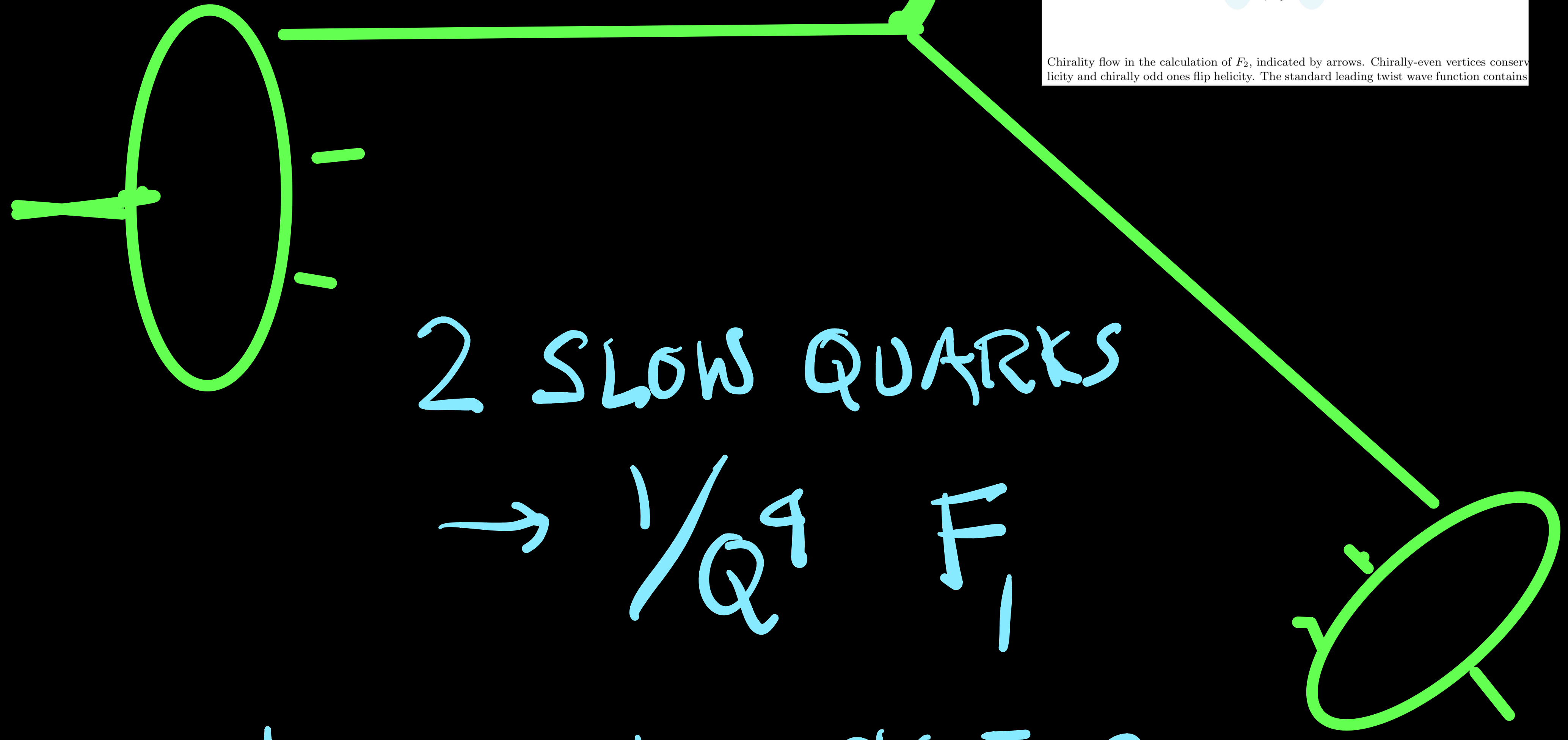
JOHN C. MARTENS

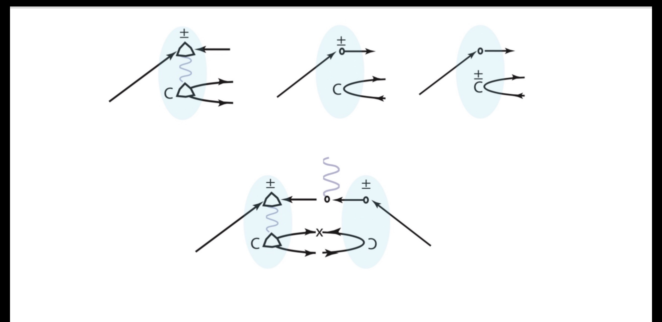
DANIEL TAPIA TAKAKI

THE FEYNMAN ENDPOINT MODEL PREDICTS CONSTITUENT QUARK COUNTING RULES

THANKS FOR THE RECENT SUPPORT FROM GERRY AND LEONIA, EXPLAINED BY 'TOLY

$\pi\pi \to \pi\pi$, $\pi p \to \pi p$, $pp \to pp$, F_π, F_1, F_2





Chirality flow in the calculation of F_2, indicated by arrows. Chirally-even vertices conserv
licity and chirally odd ones flip helicity. The standard leading twist wave function contains

2 SLOW QUARKS

$\to 1/Q^4 \; F_1$

1 SLOW HELICITY FLIP

$F_2 \sim \frac{1}{Q} F_1$

NOT SHORT DISTANCE!

Uncovering the Scaling Laws of Hard Exclusive Hadronic Processes in a Comprehensive Endpoint Model #3

Sumeet K. Dagaonkar (Indian Inst. Tech., Kanpur), Pankaj Jain (Indian Inst. Tech., Kanpur), John P. Ralston (Kansas U.) (Apr 23, 2014)

Published in: *Eur.Phys.J.C* 74 (2014) 8, 3000

#2

The Dirac Form Factor Predicts the Pauli Form Factor in the Endpoint Model #2

Sumeet Dagaonkar (Indian Inst. Tech., Kanpur), Pankaj Jain (Indian Inst. Tech., Kanpur), John P. Ralston (Kansas U.)
(Mar 24, 2015)

Published in: *Eur.Phys.J.C* 76 (2016) 7, 368

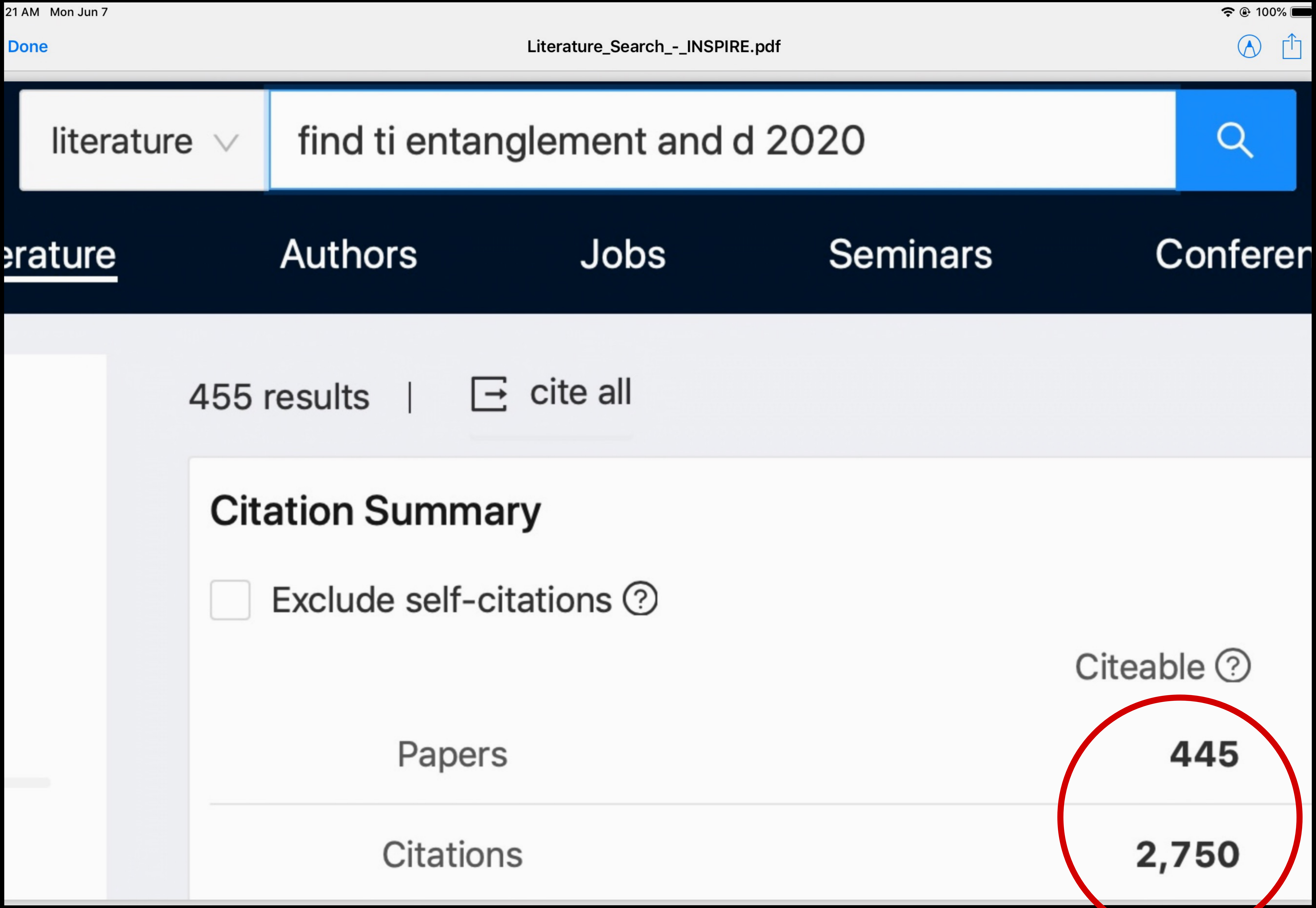
Endpoint Model of Exclusive Processes #1

Sumeet Dagaonkar (Indian Inst. Tech., Kanpur), Pankaj Jain (Indian Inst. Tech., Kanpur), John P. Ralston (Kansas U.) (May 8, 2018)

Published in: *Few Body Syst.* 59 (2018) 4, 71

PREDICT FILTERING NOT TRANSPARENCY

Entanglement is HOT!



TITLE "CONFINEMENT"

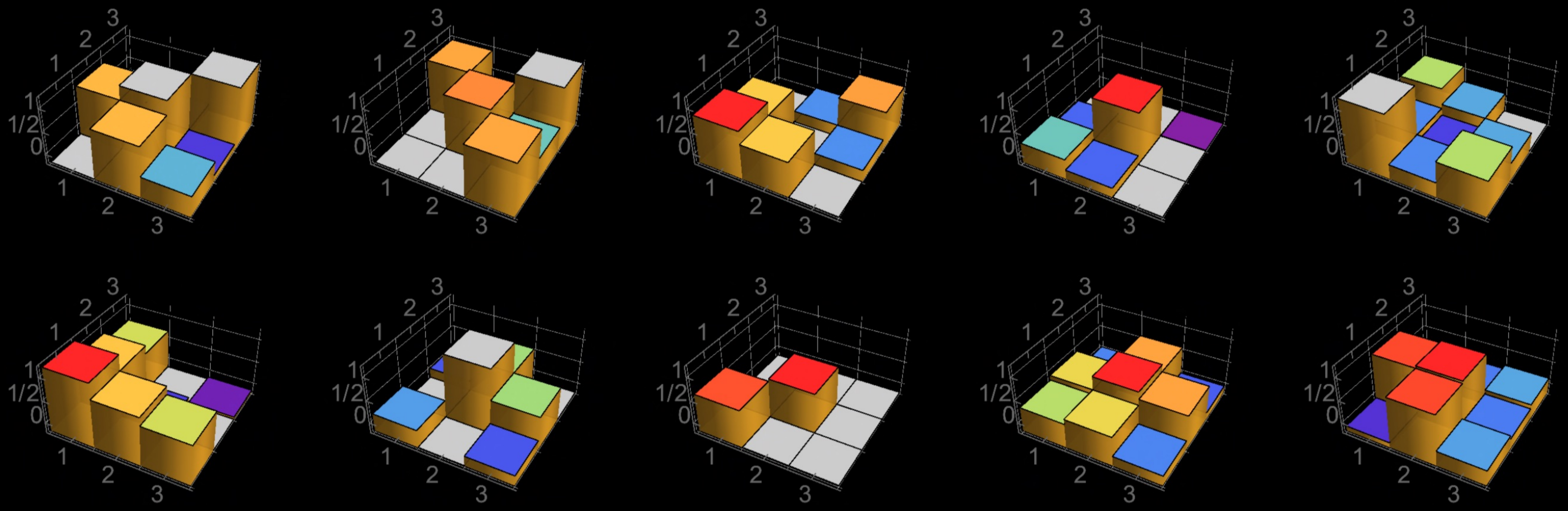
81 PAPERS

Executive Summary

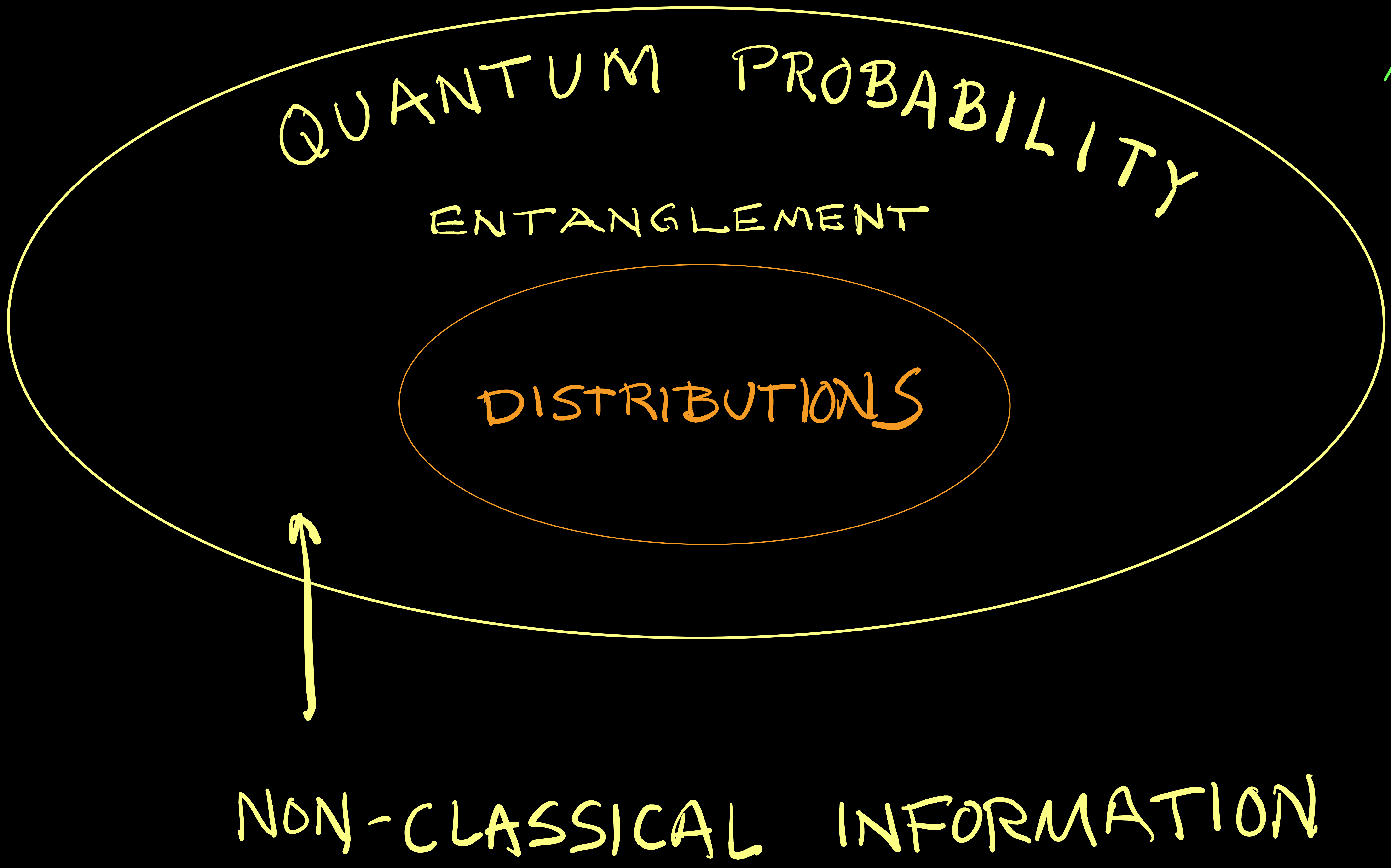
WE BYPASS 75 YEARS OF
FIELD THEORETIC SUPERSTRUCTURE
TO DESCRIBE SYSTEMS
USING QUANTUM MECHANICS
WITHOUT NEEDING MODELS

GIVE US DATA WE'LL FIND A DENSITY MATRIX

10 EVENTS, 10 DENSITY MATRICES



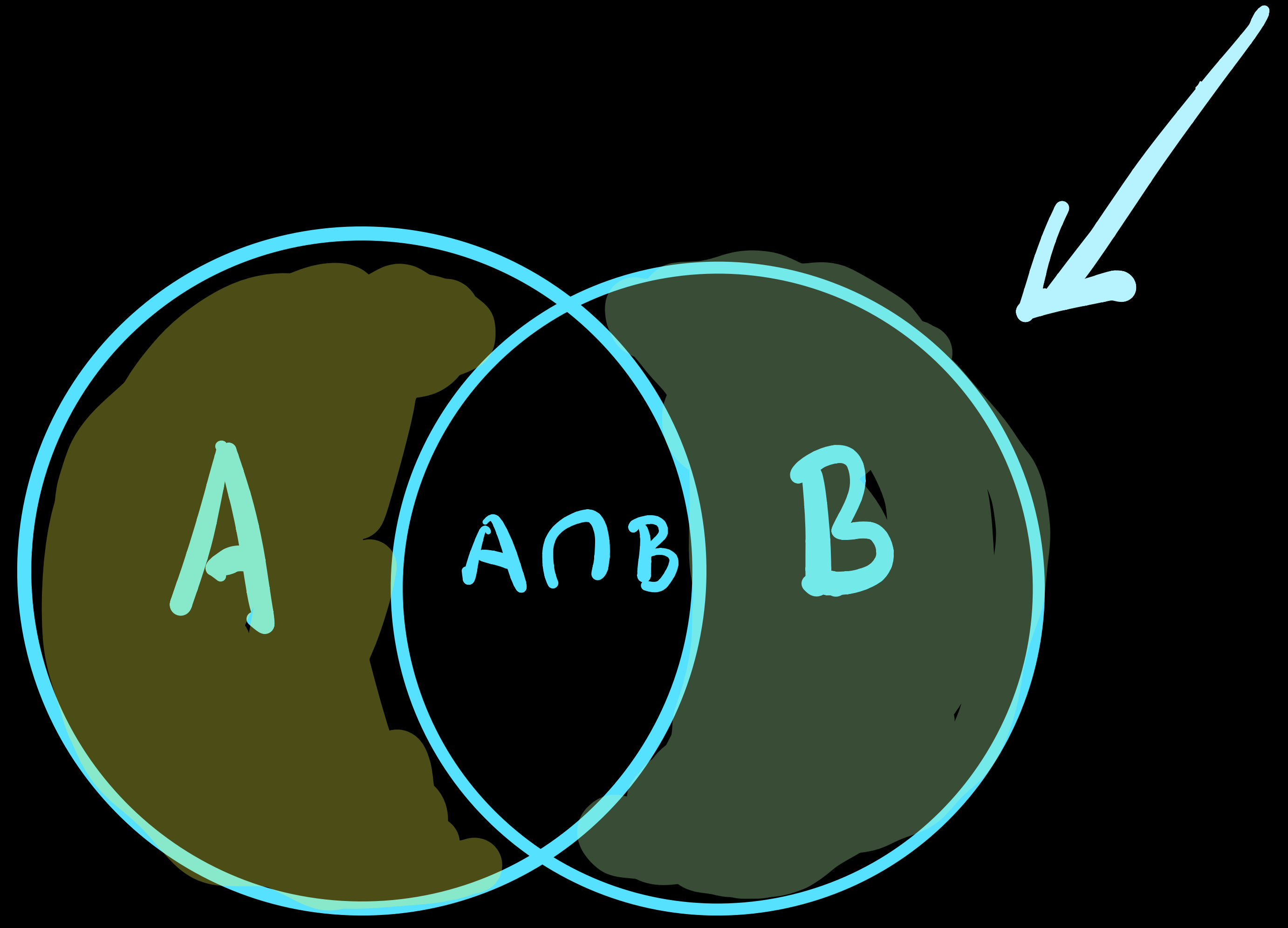
QUANTUM INFORMATION FROM 4-MOMENTA



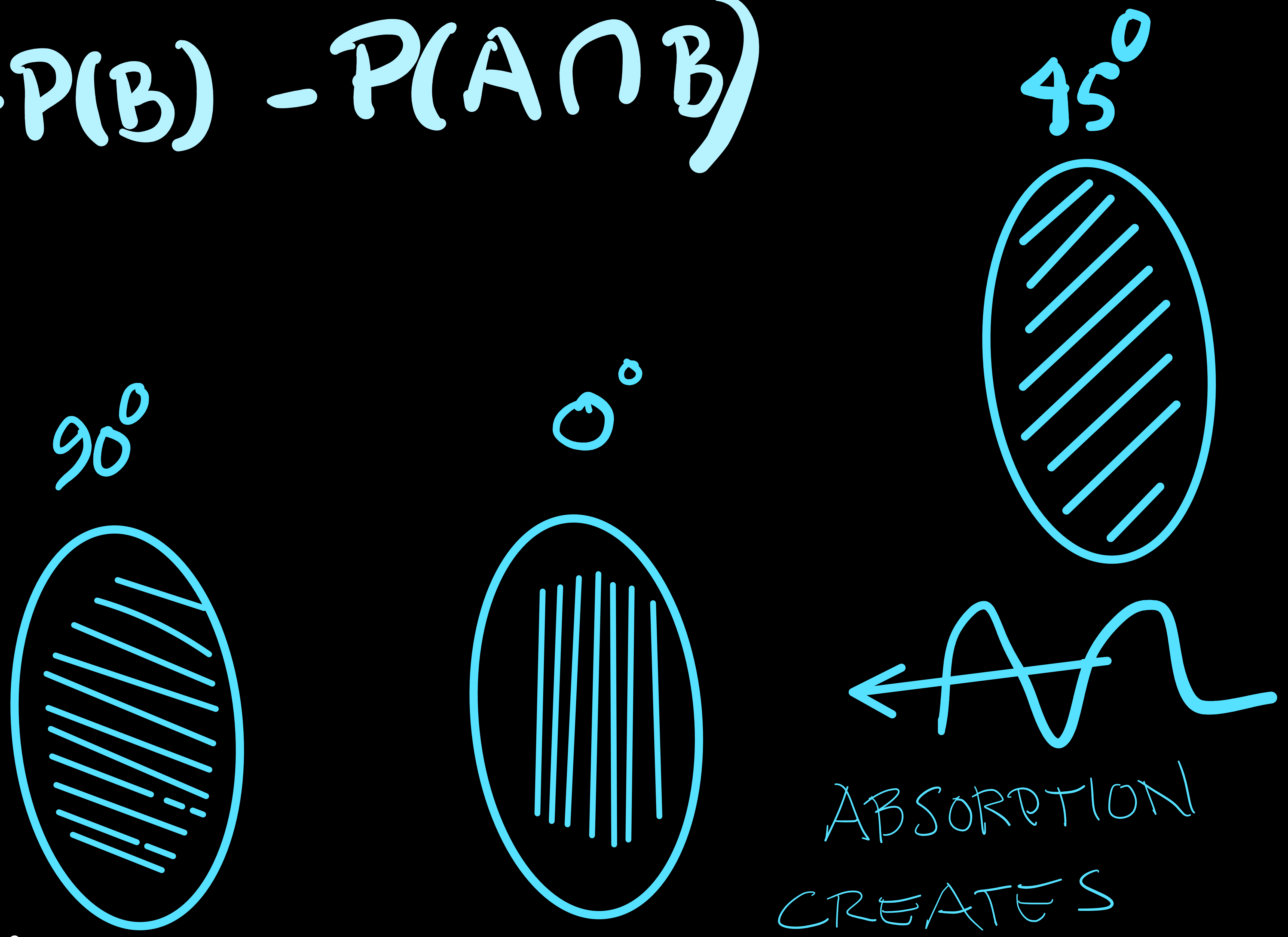
THERE IS MORE TO THE WORLD THAN MAKING CUTS

POLARIZATION, AND OTHER PROJECTIVE OBSERVABLES, VIOLATE KOLMOGOROV'S AXIOMATIC OPINIONS

$$P(A \cup B) = P(A) + P(B) - P(A \cap B)$$



DON'T DEFINE "PROBABILITY" BY COUNTING FREQUENCIES!



ABSORPTION CREATES LIGHT

SCHOOLBOOKS SAY

"PURE STATE"

EXCEPTIONAL

$$\langle A \rangle = \langle \psi | A | \psi \rangle$$

NOT TRUE IN GENERAL

von Neumann

$$= \mathrm{tr}(A|\psi\rangle\langle\psi|)$$

SCHOOLBOOKS SAY

$$\langle A \rangle_{\text{PURE}} = \langle \psi | A | \psi \rangle$$

"PURE STATE"

EXCEPTIONAL

RANK-1

$$= \text{tr}\left(A |\psi\rangle\langle\psi| \right)$$

NOT TRUE IN GENERAL

BETTER BOOKS SAY

$$\langle A \rangle_{\text{GENERAL}} = \sum_\alpha p_\alpha \, \text{tr}\left(A |\psi_\alpha\rangle\langle\psi_\alpha| \right) \qquad p_\alpha \geq 0$$

$$= \text{tr}(A\rho); \qquad \rho = \sum_\alpha |\psi_\alpha\rangle p_\alpha \langle\psi_\alpha|$$

THE DENSITY MATRIX

All You Need To Know

KNOWN PROBE — UNKOWN SYSTEM

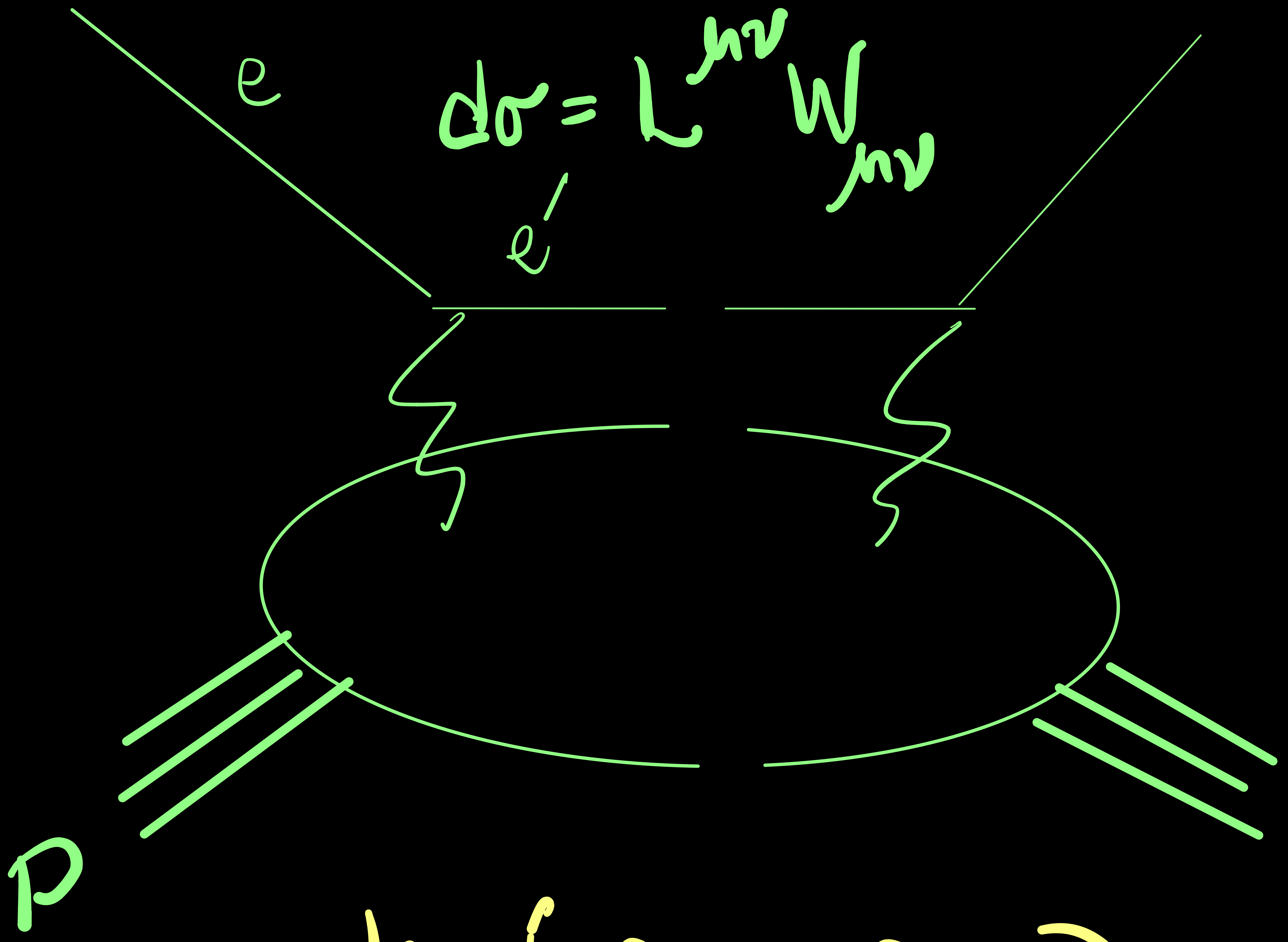
$$\text{rate} = d\sigma = \mathrm{tr}\left(\rho_{\text{PROBE}}\,\rho_X\right)$$

ALSO: THIS IS AN INNER PRODUCT

ALSO: EVERY $\rho_{ij} = (MM^\dagger)_{ij}$

EVERY $d\sigma_{ij} = \sum_X M_{iX} M^*_{jX}$

INCLUSIVE REACTIONS



$$\mathrm{tr}(\rho_{lep}\,\rho_{had})$$

$A(e,e'p)$

$$\mathrm{tr}(\rho_p\,\rho_A)$$ "S"

ENTANGLEMENT DEFINED

BABY VERSION: $\Psi(A,B) \neq \Psi_a(A)\Psi_b(B)$; "SEPARABLE"

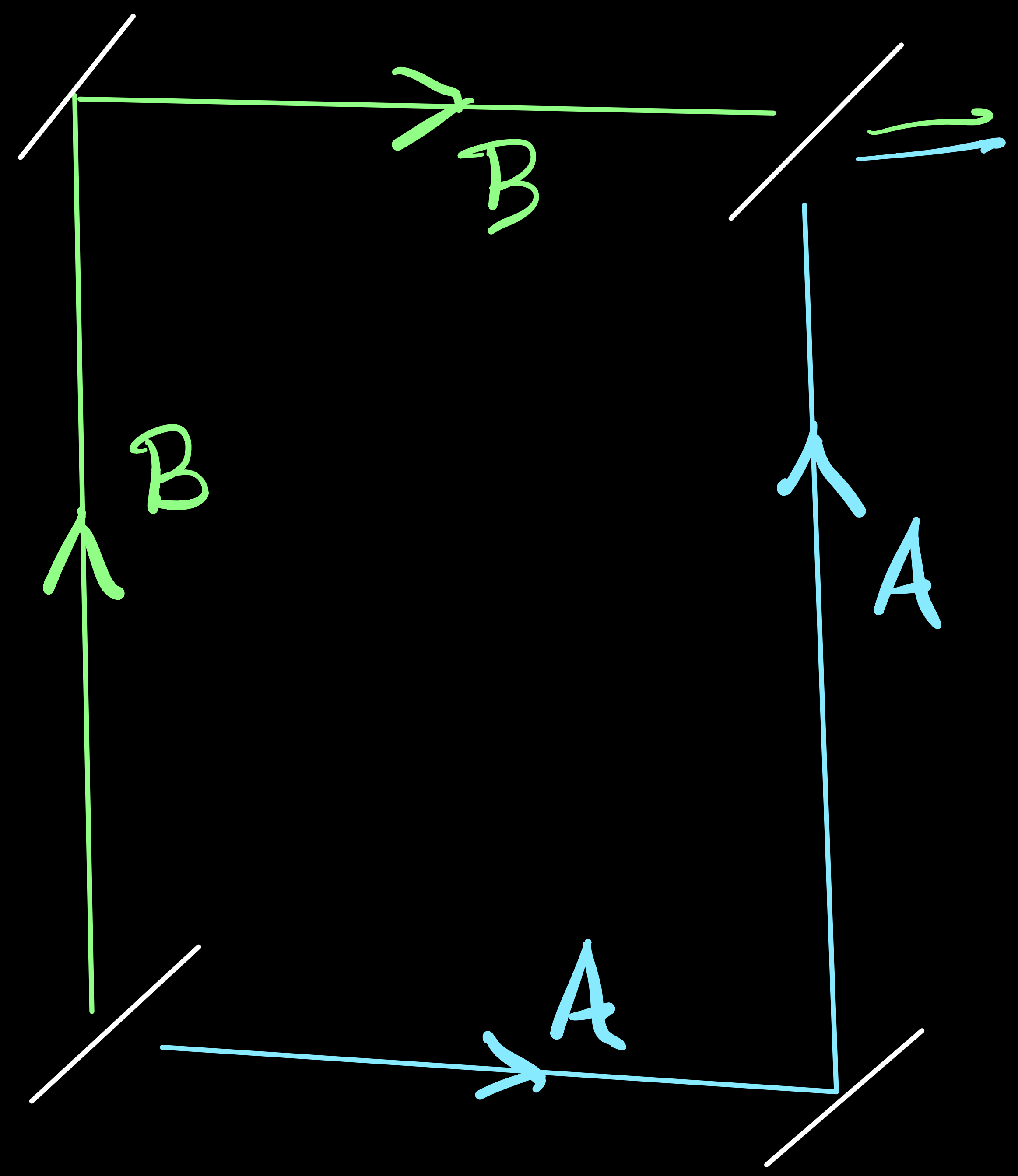
Not Entangled Is Exceptional

WHY GET EXCITED?

ENTANGLED DOES NOT MEAN "INTERACTING"

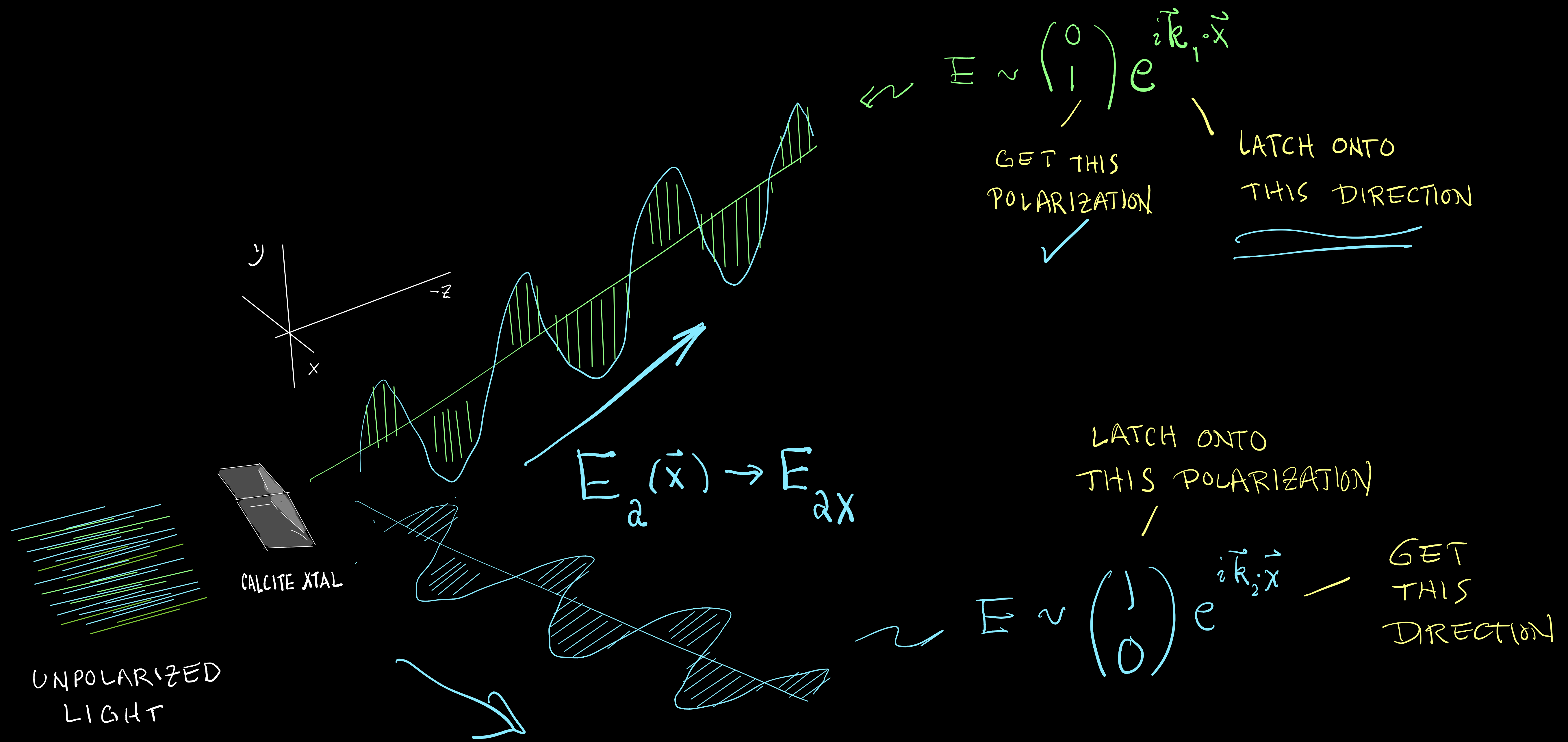
NOT ENTANGLED DOES NOT MEAN "NON-INTERACTING"

THE INTERFEROMETER



$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B\right)$$

THE STERN-GERLACH EXPERIMENT



UNDERSTOOD IN 1830

SINGULAR VALUE DECOMPOSITION

$$E_{ax} = \sum_{\alpha}^{\min(\dim_1, \dim_2)} u_a^{\alpha} \lambda_{\alpha} v_x^{\alpha}$$

ENTANGLEMENT DEFINED

BABY VERSION: $\Psi(A,B) \neq \Psi_a(A)\Psi_b(B)$; "SEPARABLE"

IN GENERAL: $\rho(A,B) \neq \sum_\alpha \rho_\alpha(A)\, p_\alpha\, \rho_\alpha(B)$; 'SEPARABLE'

$p_\alpha \geq 0$

CONVEX SUM

WERNER 1989

57 YEARS AFTER SCHRÖDINGER 1932

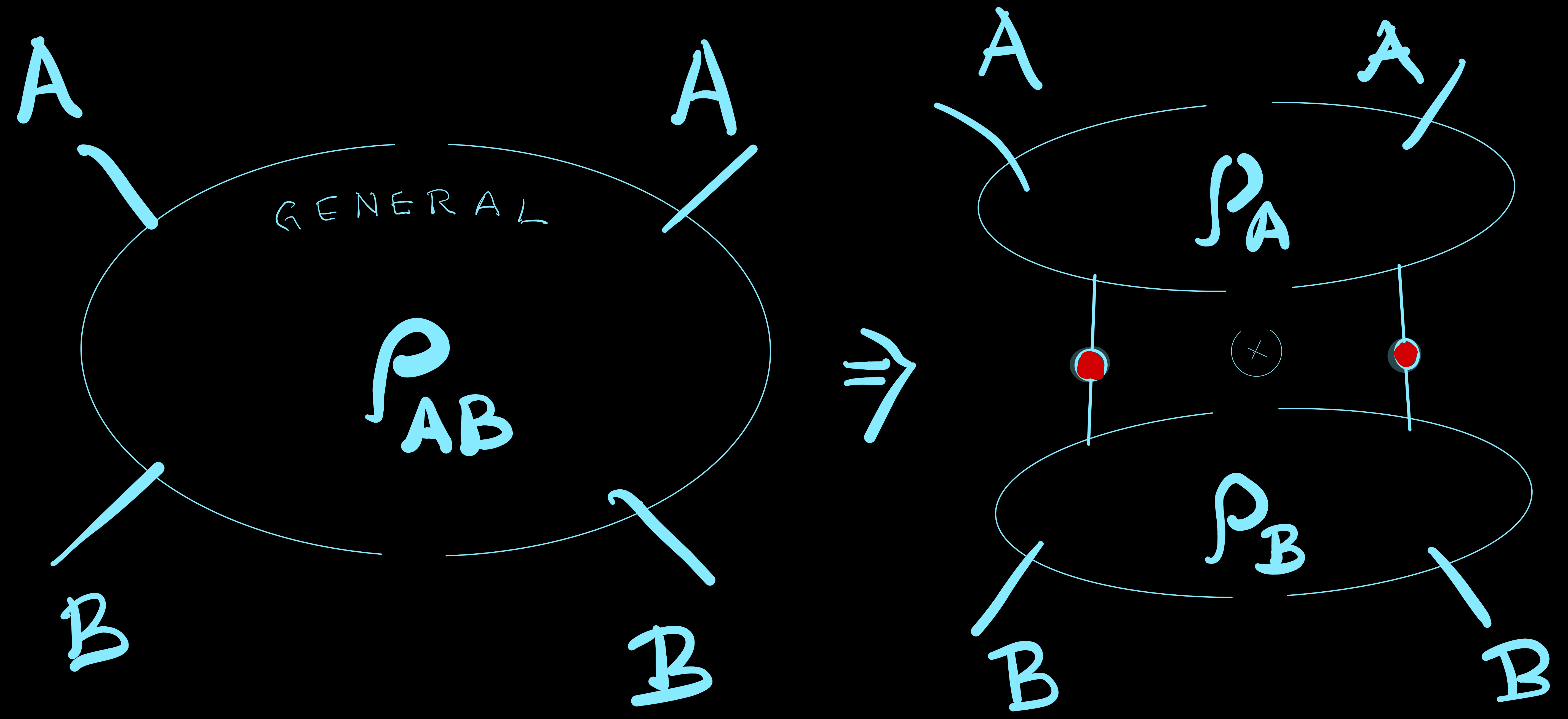
ENTANGLED DOES NOT MEAN "INTERACTING"

NOT ENTANGLED DOES NOT MEAN "NON-INTERACTING"

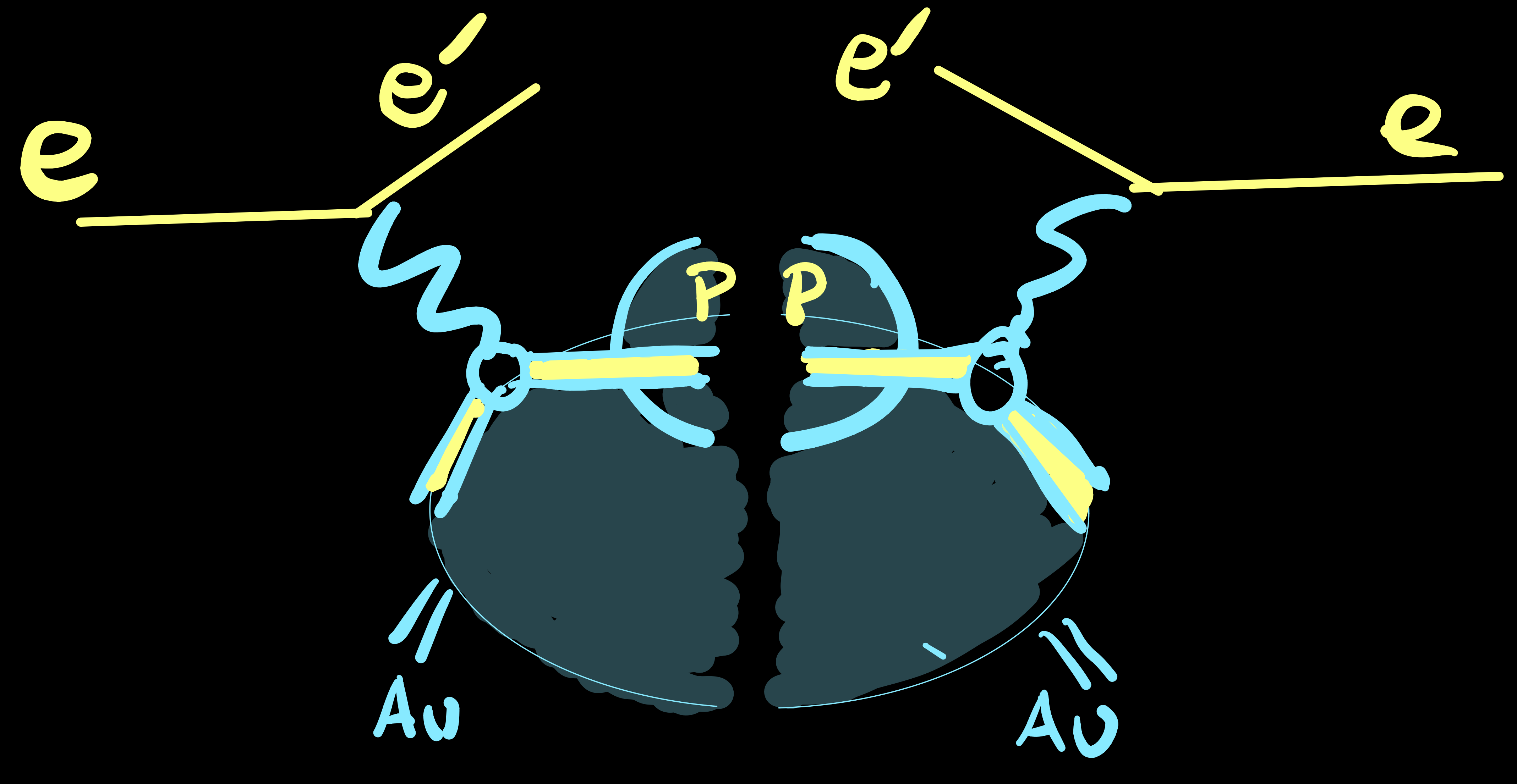
To Find Entanglement,
First Define Entanglement

$$\rho(A,B) = \sum_{\alpha} \rho_{\alpha}(A) \underset{\alpha}{\otimes} \rho_{\alpha}(B)$$

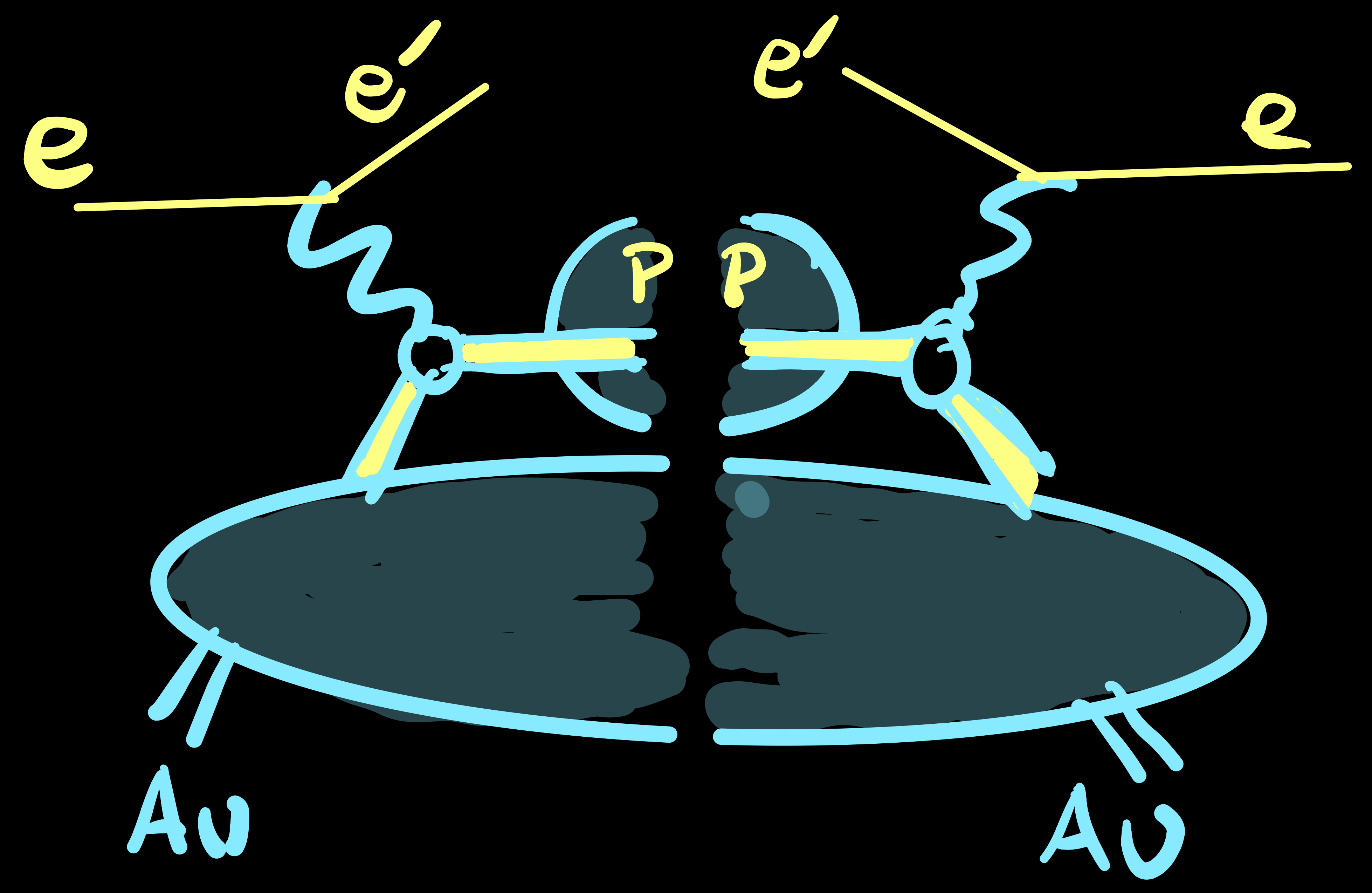
SEPARABLE,
NOT ENTANGLED



FACTORIZATION
HAS A NON-PERTURBATIVE DEFINITION!
THIS IS NEW
AND
PRECLUDES
ENTANGLEMENT



GENERAL



FACTORIZED

MAYBE THAT WAS WRONG

CARBON IS WORTH LESS THAN GOLD

QUANTUM TOMOGRAPHY IN ONE PAGE

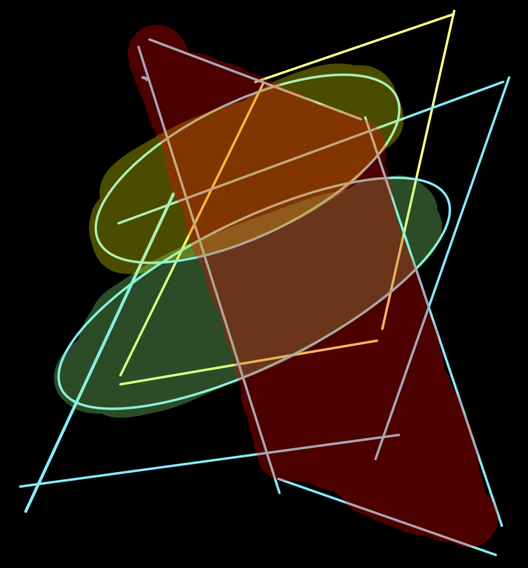
$A=A^\dagger$, $\rho=\rho^\dagger$

"PROBE-ℓ"

$$\langle A_\ell\rangle = tr(A_\ell^\dagger \rho) = \langle A_\ell|\rho\rangle$$

"OBSERVABLE"

A PROJECTION, AN INNER PRODUCT OF OPERATORS



$$\mathbb{1} = \sum_\ell |A_\ell\rangle\langle A_\ell|$$

COMPLETENESS; GENERATORS of U(N)

$$\rho = \sum_\ell |A_\ell\rangle\langle A_\ell|\rho\rangle$$

EXPANSION

NO MODEL OF THE TARGET

QUANTUM TOMOGRAPHY

$$\rho = \sum_\ell |A_\ell\rangle\langle A_\ell\rangle$$

"OBSERVABLE"

Eur. Phys. J. C (2018) 78:5
https://doi.org/10.1140/epjc/s10052-017-5455-8
THE EUROPEAN PHYSICAL JOURNAL C
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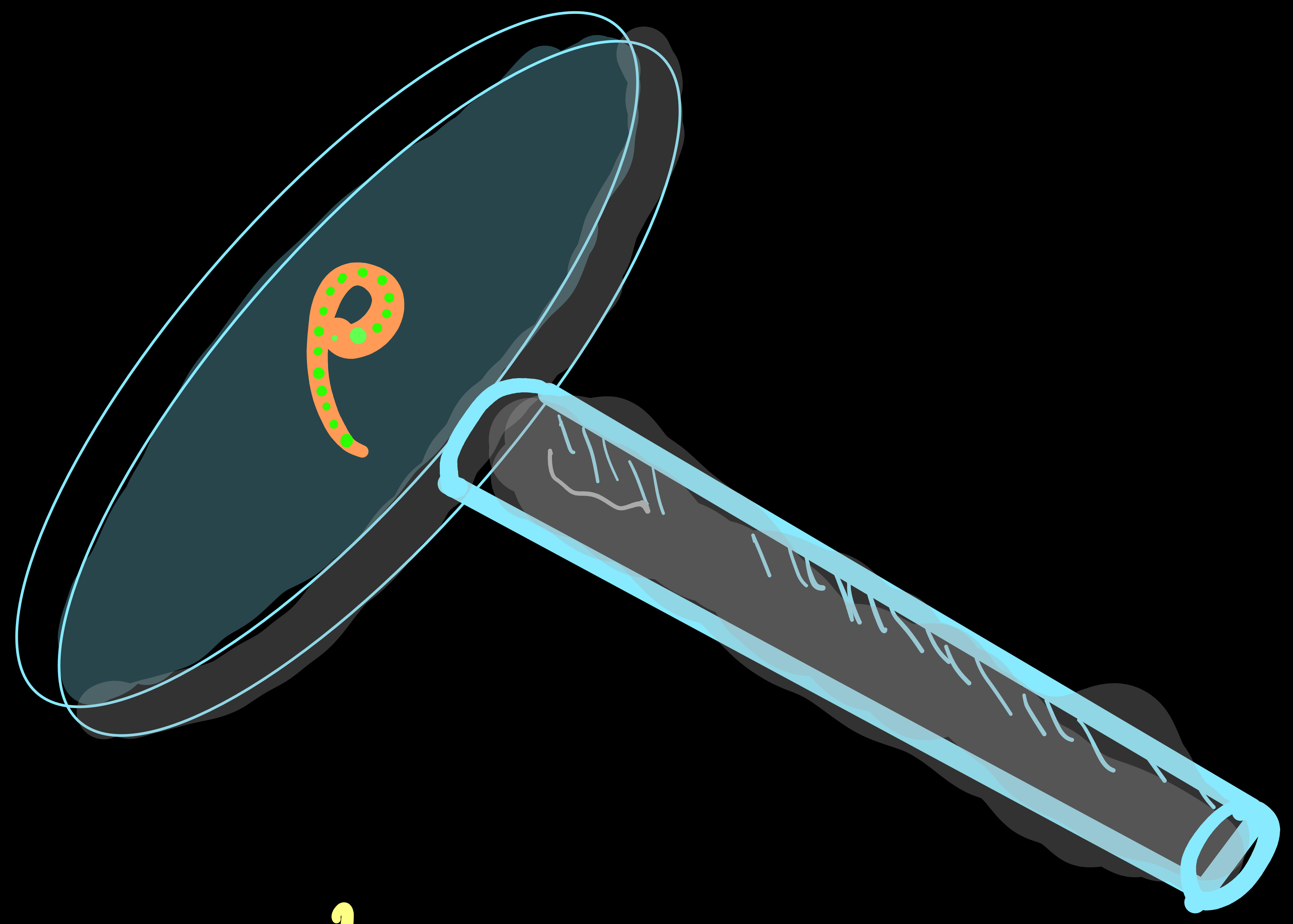
Regular Article - Theoretical Physics

Quantum tomography for collider physics: illustrations with lepton-pair production

John C. Martens[a], John P. Ralston , J. D. Tapia Takaki[b]
Department of Physics and Astronomy, The University of Kansas, Lawrence, KS 66045, USA

THE DENSITY MATRIX IS OBSERVABLE

IT CLASSIFYS WHAT YOU OBSERVE



THE WAVE FUCTION IS OBSERVABLE

OBSERVE 2 REAL NUMBERS FOR EACH COMPLEX NUMBER

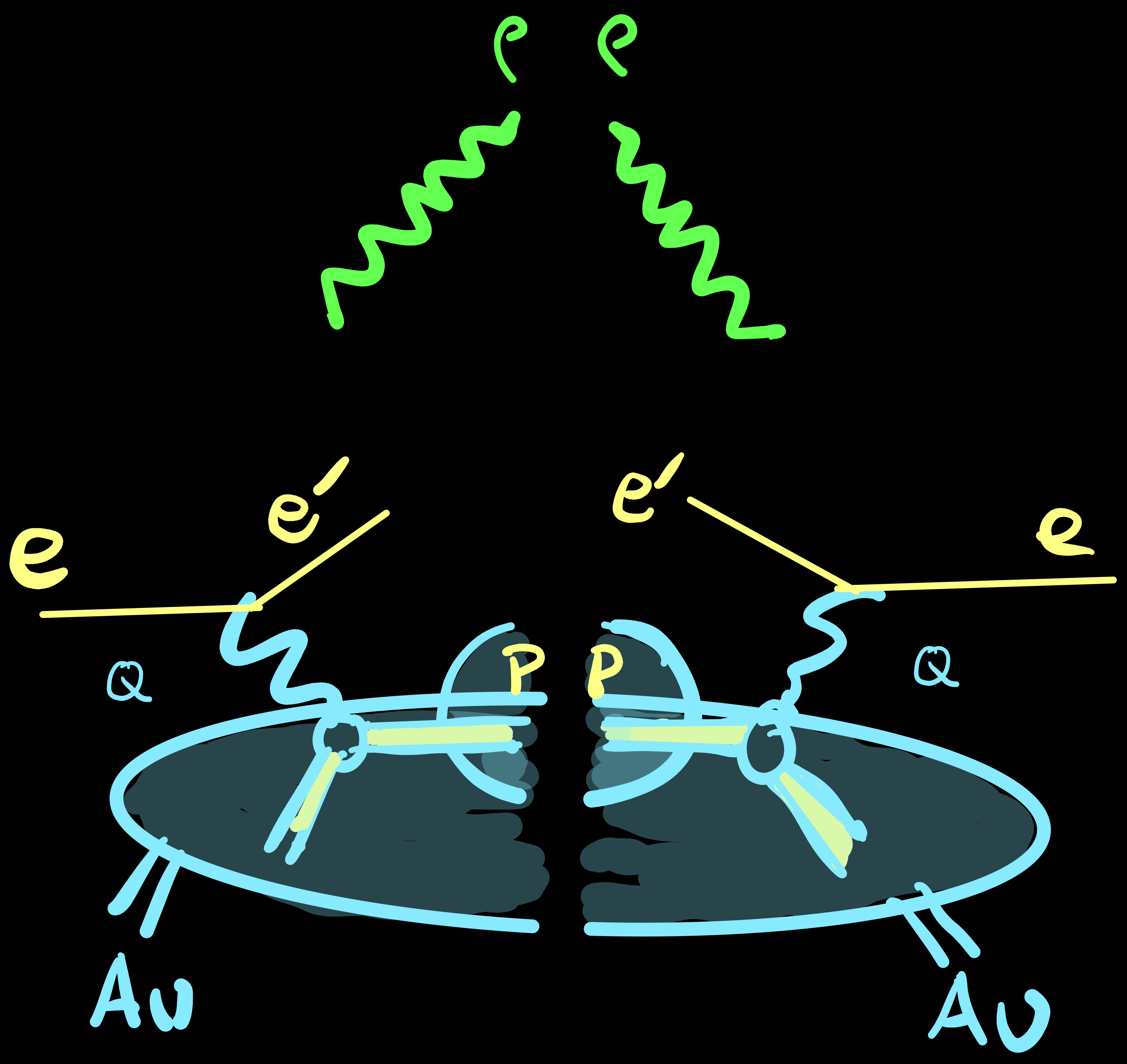
THE MIRROR TRICK

YOU DON'T NEED TO MEASURE EVERYTHING

probe $\rho(\ell) = \frac{1}{d}\mathbb{1} + \square + \triangle + \star + \ldots$

system $\rho(X) = \frac{1}{d}\mathbb{1} + \square + \triangle + \star + \ldots$

$\langle \square | \triangle \rangle = 0$ etc



NEED INFORMATION
ON FINAL STATE INTERACTIONS

DIRTY EVENTS

CAN WE GET

$\square$ e, e' p ρ^0?

RHO THE MESON

GARTH HUBER TALK

$\pi^+\pi^-$

Polarization

DIS or Exclusive

EVENTS WITH 2, 3, 4 … MOMENTA

→ MIGUEL ARRATIA TALK

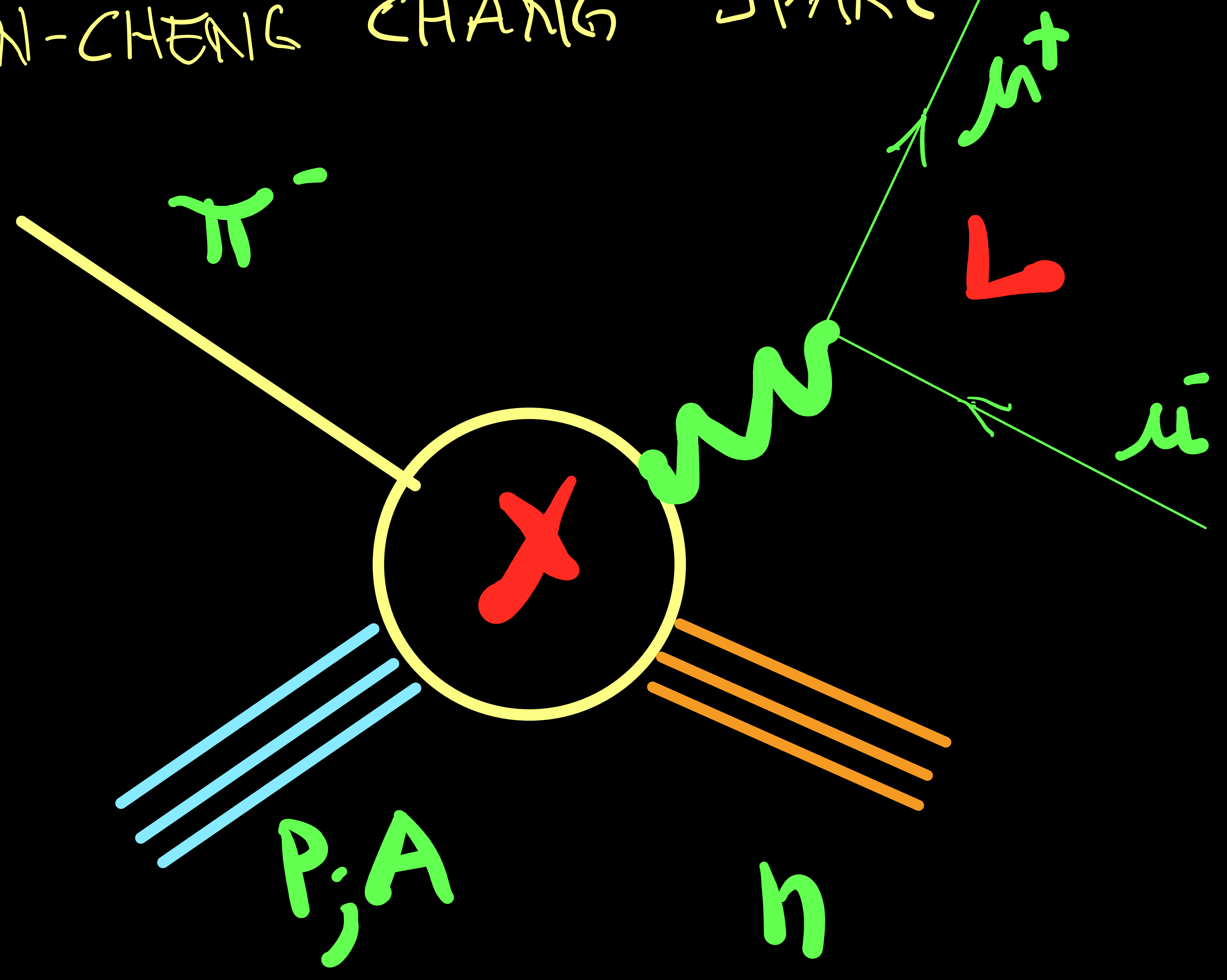
… $3^2, 3^3, 3^4$ QUANTUM DIMENSIONS

MOST INTERESTING EXPERIMENT : JPARC

KUMANO

EXCLUSIVE DRELL-YAN

WEN-CHENG CHANG JPARC



$$k_0 k_0' \frac{d^6\sigma}{d^3k\, d^3k'} = \frac{d\sigma}{d^4Q\, d\Omega}$$

THEORY WILL PREDICT THIS WRONG

THE ANGULAR DISTRIBUTION

$$\frac{d\sigma}{d\cos\theta\, d\phi} = tr(\rho_X \rho_L)$$

100% LORENTZ INVARIANT

BERGER, DIEHL, PIRE PLB, 523, 265 (2001)

LARIONOV, STRICKMAN, BLEICHER PRC 93, 034618 (2016)

HOW TO EXPLOIT A DENSITY MATRIX

YOU SQUEEZE IT LIKE AN ORANGE

$\neq$ classical entropy

$S_{Gibbs} = -\int dx\, f(x) \log f(x)$

INVARIANTS $\rightarrow$ EIGENVALUES λ_k

VON NEUMANN ENTROPY $S = -\mathrm{tr}(\rho \log(\rho))$

TRUE QM OBSERVABLES $\langle$ ANYTHING $\rangle$

HOW TO EXPLOIT A DENSITY MATRIX

YOU SQUEEZE IT LIKE AN ORANGE

$\neq$ classical entropy $S_{Gibbs} = -\int dx\, f(x) \log f(x)$

INVARIANTS $\rightarrow$ EIGENVALUES λ_k

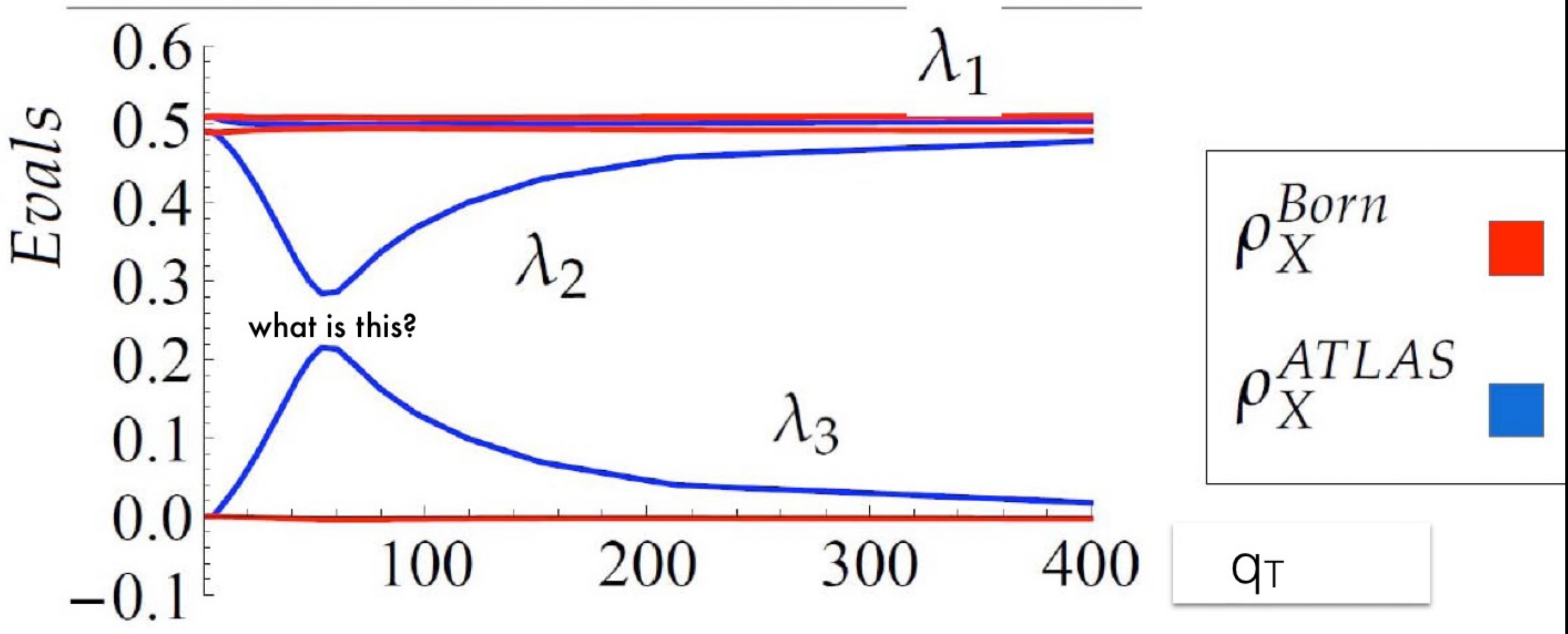
von NEUMANN ENTROPY $S = -\mathrm{tr}(\rho \log(\rho))$

TRUE QM OBSERVABLES $\langle$ ANYTHING $\rangle$

The density matrix eigenvalues are strange

y-integrated data. **arXiv: 1606.00689**

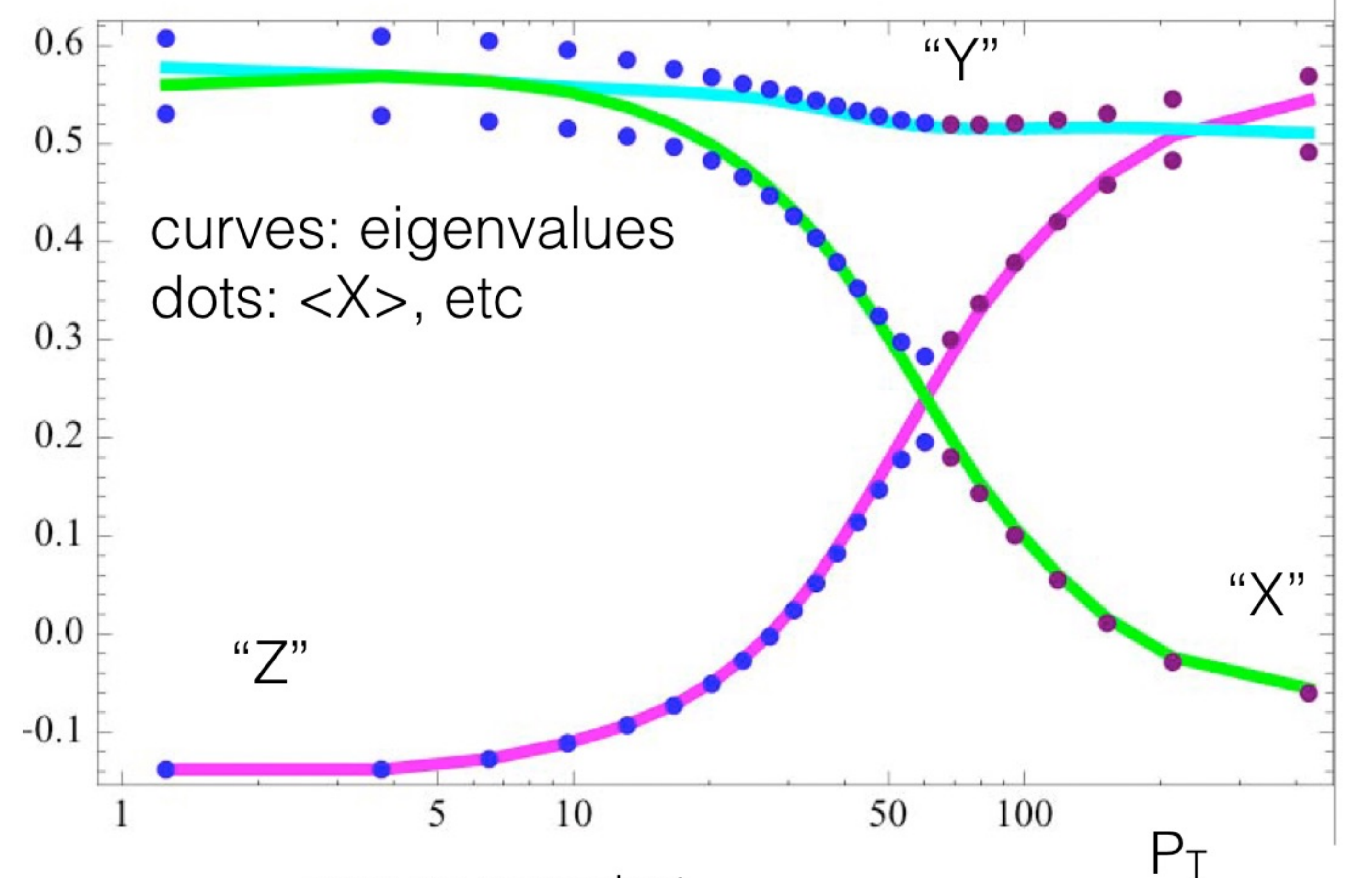
Evals λ_j of ρ_X^{ATLAS} (blue) are very different from evals from Born-level physics (red).



there is no precedent for the resonance-like bump

Avoided level crossing; eigenvectors swap

true QM expectation values <X>, <Y>, <Z> v PT



new: no precedent

P_T of Z = our q_T

WHAT WAS ACCOMPLISHED?

- ✓ NO VERTEX
- ✓ NO MODEL
- ✓ NO QFT
- ✓ NO STRUCTURE FUNCTIONS
- ✓ NO PARTONS
- ✓ NO LO, NLO, N^2LO, N^3LO
- ✓ NOTHING BUT OBSERVABLES

"QUANTUM MECHANICS"
ORGANIZES INFORMATION,
DESCRIPTIVE, NOT PREDICTIVE

AS FEYNMAN MUST HAVE SAID,
"ANY TIME YOU CAN USE LESS FORMALISM, YOU SHOULD!"

CLASSICAL FIT

- ILL CONDITIONED
- MULTIPLE MAXIMA
- ONE DISTRIBUTION

QUANTUM FIT

- ONE MAXIMUM CONVEX OPTIMIZATION
- TWO DISTRIBUTIONS # = RANK - 1
- QUANTUM ENTROPY

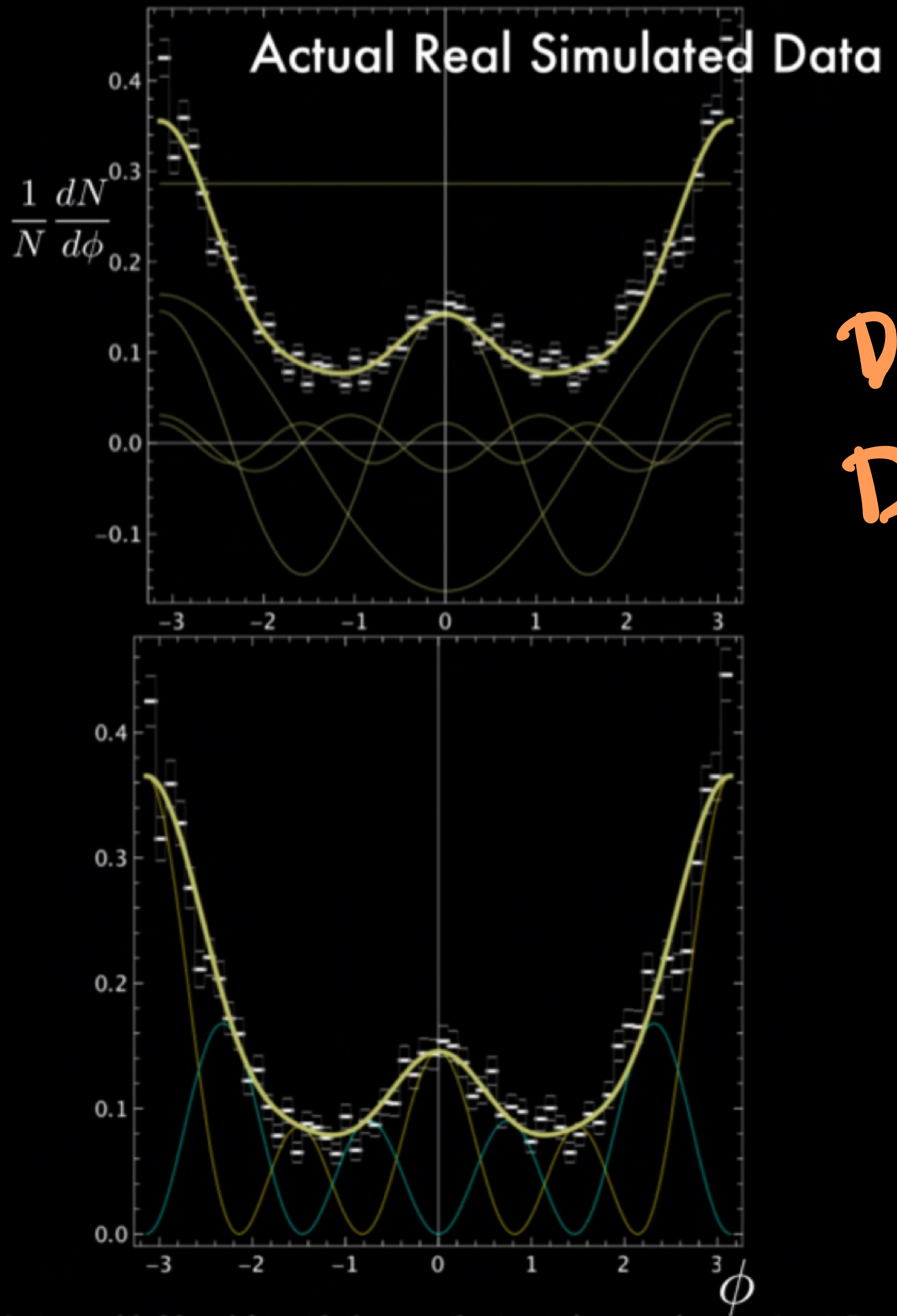


FIG. 4: Top: Maximum likelihood fit, with the contributions of $\cos m\phi$ for $m = 0 - 4$. Bottom: Two weighted distributions defined by $f_+(\phi) = Re(\psi)^2$ (blue) and $f_-(\phi) = Im(\psi)^2$ (red), coming from the eigenstates of the rank two density matrix.

LHC DIFFRACTIVE DIJETS

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How to Understand Quantum Mechanics

John P. Ralston

Cover art by John C. Ralston, the author's son

How to Understand Quantum Mechanics presents an accessible introduction to understanding quantum mechanics in a natural and intuitive way, which was advocated by Erwin Schrodinger and Albert Einstein. A theoretical physicist reveals dozens of easy tricks that avoid long calculations, makes complicated things simple, and bypasses the worthless anguish of famous scientists who died in angst. The author's approach is light-hearted, and the book is written to be read without equations, however all relevant equations still appear with explanations as to what they mean. The book entertainingly rejects quantum disinformation, the MKS unit system (obsolete), pompous non-explanations, pompous people, the hoax of the "uncertainty principle" (it's just a math relation), and the accumulated junk-DNA that got into the quantum operating system by misreporting it.

The order of presentation is new and also unique by warning about traps to be avoided, while separating topics such as quantum probability to let the Schrodinger equation be appreciated in the simplest way on its own terms. This is also the first book on quantum theory that is not based on arbitrary and confusing axioms or foundation principles. The author is so unprincipled he shows where obsolete principles duplicated basic math facts, became redundant, and sometimes were just pawns in academic turf wars. The book has many original topics not found elsewhere, and completely researched references to original historical sources and anecdotes concerning the unrecognized scientists who actually did discover things, did not all get Nobel Prizes, and yet had interesting productive lives.

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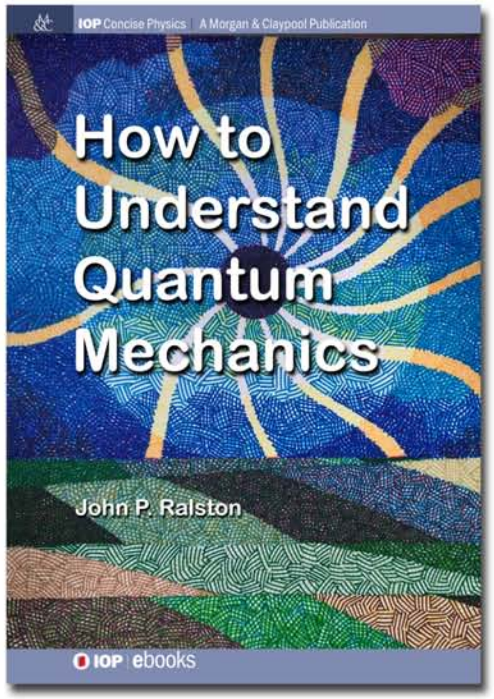
An accessible introduction to understanding quantum mechanics in a natural and intuitive way, which was advocated by Erwin Schroedinger and Albert Einstein



How to Understand Quantum Mechanics

John P. Ralston, *The University of Kansas*

Paperback ISBN: 9781681741628 • eBook ISBN: 9781681742267
May, 2018 • 107 pages
Paperback: $79.95 • eBook: $63.96 • Combo: $99.94

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ABOUT THE AUTHOR
John P Ralston, PhD, is a Professor of Physics and Astronomy at The University of Kansas. He received his PhD in high-energy theory physics from the University of Oregon. His research interests include high energy theory, strong interaction physics, particle astrophysics, cosmology, and practical data analysis.

CONTENTS

- Introduction
- The Continuum Universe
- Everything is a Wave
- There is No Classical Theory of Matter
- Matter Waves

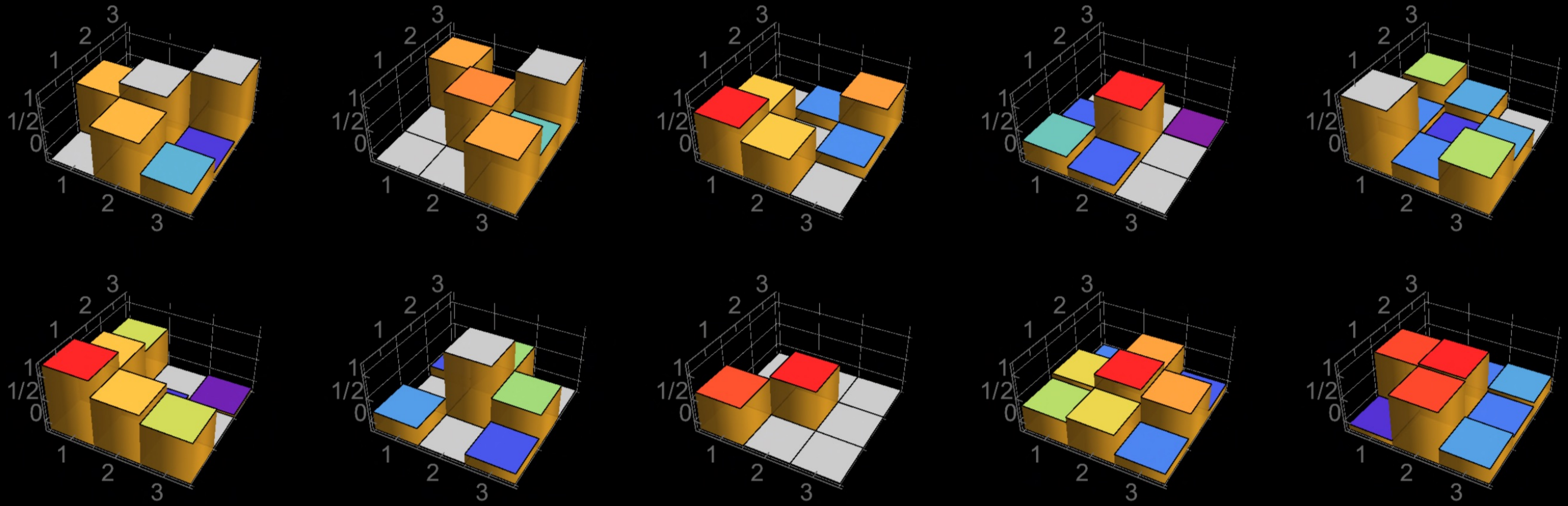
Made to correct disinformation given to students and all of us

No principles!
No postulates !
Quantum mechanics itself is *descriptive*, not *predictive*

Institute of Physics series will be in your library.

You don't need to buy it

THANKS!



PARAMETERIZING POSITIVITY

$$\rho = MM^\dagger$$

POSITIVE EIGENVALUES GUARANTEED

REAL NUMBERS

$$M = \begin{pmatrix} m_1 & m_4 + i m_5 & m_6 + i m_7 \\ 0 & m_2 & m_8 + i m_9 \\ 0 & 0 & m_3 \end{pmatrix}$$

$$d\sigma = \mathrm{tr}\left(MM^\dagger \hat{A} \right)$$

EXPERIMENTAL PROBE

$$\frac{d\sigma}{d\Omega} = \frac{1}{4\pi}\left(1+m_3^2\right)$$

$$+\frac{1}{4\pi}\left(1-3m_3^2\cos^2\vartheta\right)$$

$$-\frac{1}{2}m_3 m_6 \sin 2\vartheta \cos\varphi$$

$$-\frac{1}{2}m_3 m_8 \sin 2\vartheta \sin\varphi$$

$$+ \;\dots$$

... 2 JETS

2 OF ANYTHING ...

FIT m_ℓ WITH LIKELIHOOD

$-1 < m_\ell < 1$

NO LOCAL MAXIMA

CONVEX FUNCTIONS

POSITIVITY IS EXACT

QUANTUM vs CLASSICAL ENTROPY

distribution $f(x)$: $S_{CL} = -\int dx\, f(x) \ln(f(x))$

density matrix $S_{QM} = tr(\rho \ln(\rho))$

NOT THE SAME CONCEPTS

QUANTUM TOMOGRAPHY

$$\rho = \sum_l |A_l\rangle\langle A_l|$$

the density matrix is observable

IF RANK = 1,

$$\rho = |\psi\rangle\langle\psi|$$

the wave function is observable

NEEDS $N = (\dim\psi)$ VALUES $\langle A_l \rangle$
-1

$$\rho|\psi\rangle = |\psi\rangle$$

$$|\psi\rangle = z|\psi\rangle$$

RAY REPRESENTATION DERIVED
NOT A POSTULATE