Gravity and Decoherence:

the double slit experiment revisited

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GRAVITY AND QUANTUM THEORY

WHAT IS THE RELATION BETWEEN THEM?

GRAVITY IN THE LARGE
PP SCATTERING BH MERGER UNIVERSE

QUANTUM THEORY IN THE SMALL
DOTS CONDENSED MATTER LHC

QUANTUM GRAVITY: NEW THEORIES WHICH
AGREE WITH GR FOR LOW ENERGIES
EXPLORE THE SHORT DISTANCE BEHAVIOUR
OF GRAVITY

STRING THEORY, LOOP QUANTUM GRAVITY
CAUSAL SETS, NONCOMMUTATIVE GEOMETRY….

LACK OF EXPERIMENTAL GUIDANCE
INTERNAL CONSISTENCY AND AESTHETICS
NO CONSENSUS

GRAVITY AND QUANTUM THEORY

ALTERNATE STRATEGY: UNDERSTAND THE
THEORIES WE ALREADY HAVE
QFT AND GR HAVE
EXPERIMENTAL SUPPORT
PUSH THEM TO CONFRONT EACH OTHER
BY THOUGHT EXPERIMENTS

REVERSE THE EMPHASIS
INSTEAD OF THE SHORT DISTANCE BEHAVIOUR
OF GR, STUDY THE LONG DISTANCE BEHAVIOUR
OF QUANTUM THEORY

RATHER THAN LOOK AT GRAVITY THROUGH
A MICROSCOPE, LOOK AT QUANTUM THEORY
THROUGH A TELESCOPE.

GRAVITY AND QUANTUM THEORY

ALREADY CLEAR THAT PUTTING
GR AND QM TOGETHER LEADS TO
STATISTICAL PHYSICS
BLACK HOLE ENTROPY IS EVIDENCE
FOR THIS

Equilibrium only here

MAY BE THAT THE UNIFICATION
IS NOT A UNIFICATION OF FORCES
BUT OF PRINCIPLES. QUANTUM PHYSICS
PLUS GR GIVES STATISTICAL PHYSICS
THE PRINCIPLES OF STAT PHYS INCLUDE SOME
ADMISSION OF IGNORANCE
PARTIAL KNOWLEDGE OF SYSTEMS INFORMATION
LOSS. LET'S KEEP AN OPEN MIND ON THIS

GRAVITY: GR THE IDEA OF SPACETIME AS
LORENTZIAN GEOMETRY
PRINCIPLE OF EQUIVALENCE
RELATIVISTIC GRAVITY

QUANTUM THEORY: NOT THE NR VERSION
STUDIED IN QMI OR EVEN THE RELATIVISTIC
ONE IN QMII. KLEIN PARADOX
BUT THE RELATIVISTIC QUANTUM
FIELD THEORY OF QMIII.
SAY QED.
BASIC INGREDIENTS
PRINCIPLE OF SUPERPOSITION

LEADS TO COUNTERINTUITIVE FEATURES
MACROSCOPIC SUPERPOSITION,
CAT STATES, ENTANGLEMENT

PRELIMINARIES: QM

PHYSICALLY REALISED IN THE DOUBLE SLIT
EXPERIMENT
MATHEMATICALLY IN THE LINEAR STRUCTURE
OF HILBERT SPACE

DESCRIBED BY FEYNMAN AS
THE ONLY MYSTERY OF QUANTUM PHYSICS
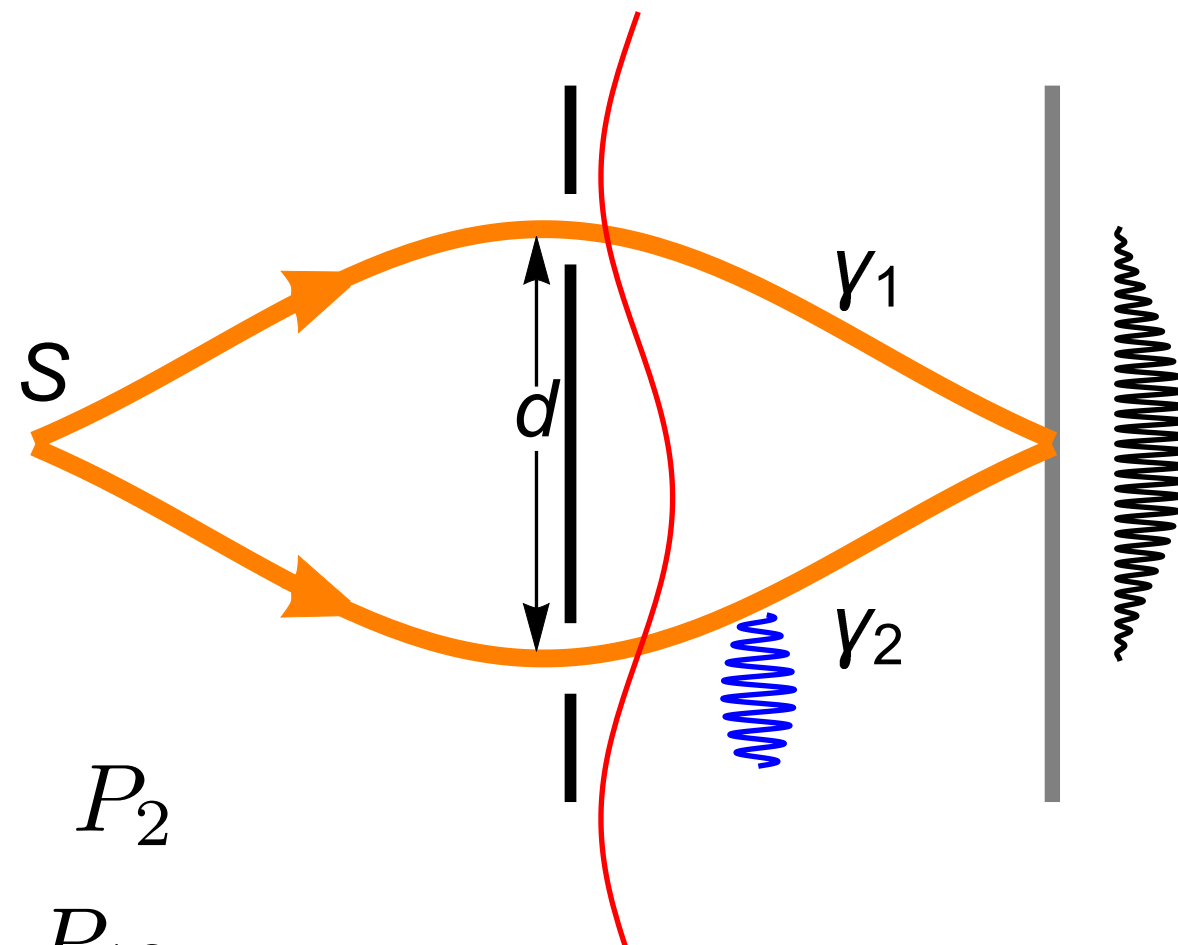
FOUR EXPERIMENTS POSSIBLE

$$I(S_1, S_2) = \mu(S_1 \cup S_2) - \mu(S_1) - \mu(S_2)$$

AT VARIANCE WITH CLASSICAL INTUITION
THAT PROBABILITIES OF EXCLUSIVE EVENTS ADD

PRINCIPLE OF EQUIVALENCE:
GRAVITY REPLACED BY ACCELERATION
RINDLER OBSERVER UNIFORM ACCELERATION
IN GEOMETRY POLAR COORDINATES ARE
DESCRIBED BY CIRCLES AND TRIGONOMETRIC
FUNCTIONS. RINDLER OBSERVERS BY
HYPERBOLIC FUNCTIONS CONSTANT
ACCELERATION

PRELIMINARIES

RINDLER OBSERVER

10
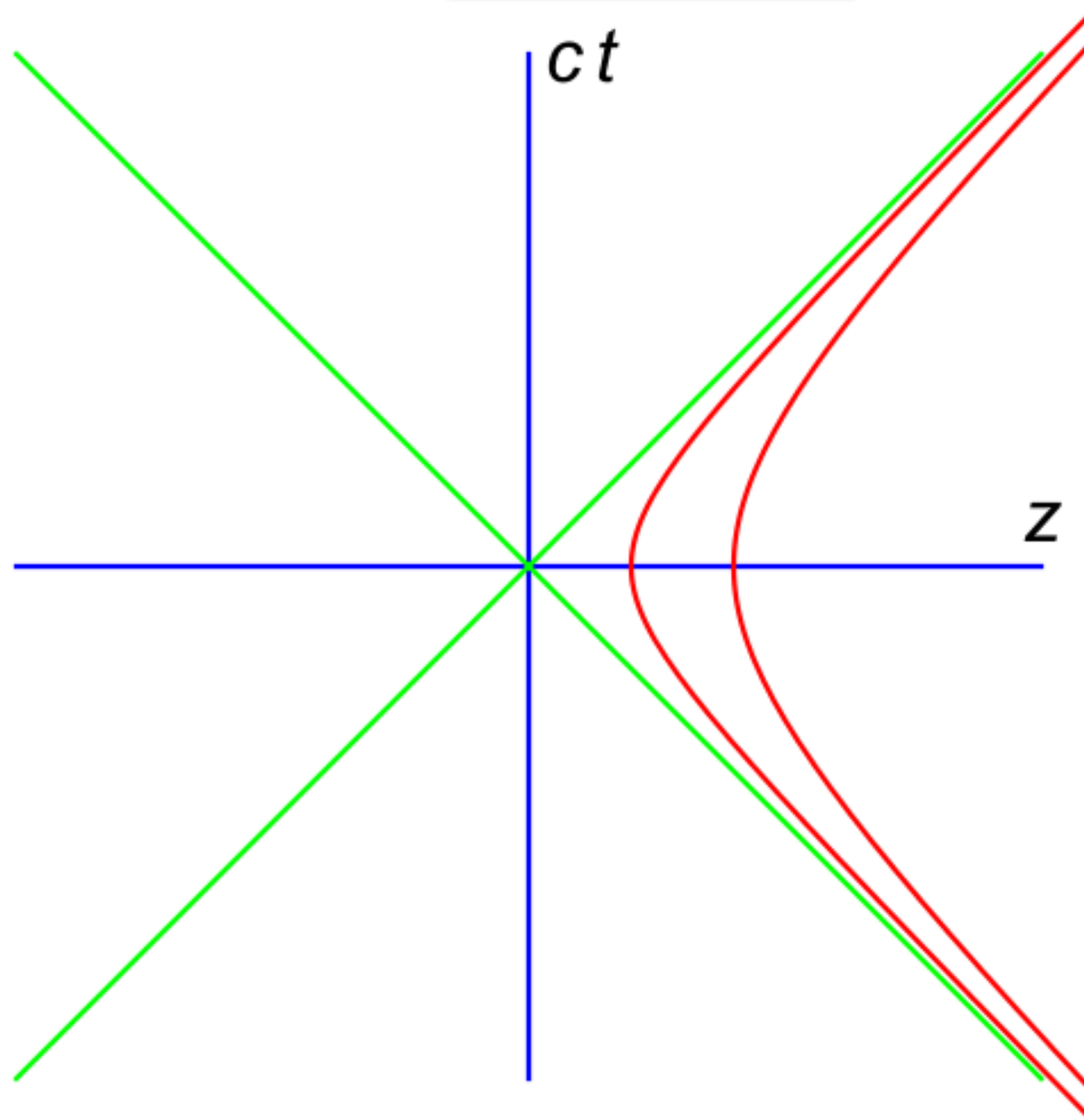
PRELIMINARIES

DOES A PARTICLE AT REST IN THE
RINDLER FRAME RADIATE?

MINKOWSKI OBSERVER: YES THE
LIENARD-WIECHERT POTENTIALS TELL ME SO

RINDLER OBSERVER: NO, THE SAME EM
FIELD EXPRESSED IN RINDLER FRAME
HAS TIME INDEPENDENT ELECTRIC FIELDS
NO MAGNETIC FIELDS
COULOMB FIELD OF A POINT CHARGE

IN THE RINDLER FRAME THE CHARGE
DISTRIBUTION IS STATIC

RADIATION IS A FRAME DEPENDENT NOTION!

THE UNRUH EFFECT: VACUUM IS A FRAME
DEPENDENT NOTION
TIME IS FRAME DEPENDENT
ENERGY IS FRAME DEPENDENT
THE SEPARATION INTO COULOMB AND RADIATION
IS FRAME DEPENDENT

RINDLER OBSERVER SEES THE MINKOWSKI
VACUUM AS A THERMAL BATH

IS THE UNRUH EFFECT REAL?
HAS IT BEEN SEEN EXPERIMENTALLY?

GRAVITY AND DECOHERENCE

Gravity spoils quantum coherence Penrose, Diosi
Feynman Chapel Hill 1957

"I would like to suggest that it is possible that quantum mechanics fails at large distances and for large objects, it is not inconsistent with what we do know. If this failure of quantum mechanics is connected with gravity, we might speculatively expect this to happen for masses such that $GM^2/c^2 = 1$, or M near 10^{-5} grams."

Standard approach in Newtonian gravity
Rimini Weber Ghirardi spontaneous collapse

Penrose interpretation One graviton difference

GRAVITY AND DECOHERENCE

SUGGESTING STOCHASTIC SPONTANEOUS
COLLAPSE SEEMS ARBITRARY, AD HOC
WORKING IN NEWTONIAN GRAVITY AND QM
NEED RELATIVISTIC APPROACH

ONE LONGITUDINAL GRAVITON DIFFERENCE
(PENROSE) SEEMS FRAME DEPENDENT

THE DOUBLE SLIT EXPERIMENT

THE ONLY MYSTERY
OF QUANTUM PHYSICS: RP FEYNMAN

S

γ_1

γ_2

d

$p \sim \hbar/d$

$P_1 \quad P_2$

P_{12}

$P_{12} \neq P_1 + P_2$
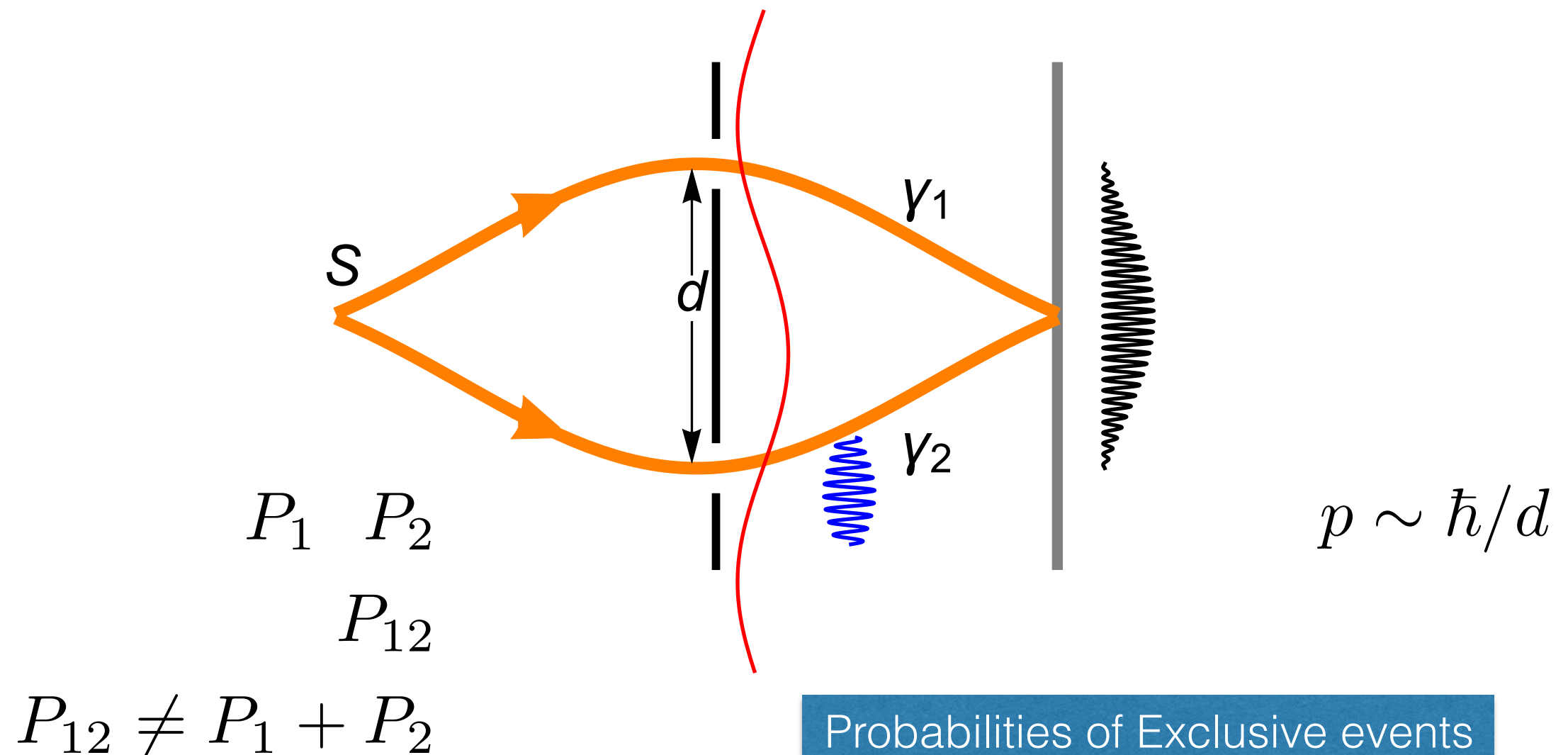
Probabilities of Exclusive events
add in the classical world

PROPOSED EXPERIMENTS E1 E2

E1: Double slit experiment in a thermal environment

E2: Double slit experiment in an accelerated frame

Analyse both experiments using only known physics:
Find in E1: thermal fluctuations of the electromagnetic field cause decoherence in the electron double slit experiment
E2: Vacuum fluctuations of inertial observer appear thermal to the accelerated observer loss of coherence

THE DOUBLE SLIT EXPERIMENT

THE ANALYSIS CAN BE DONE MATHEMATICALLY
AS WELL AS PHYSICALLY
PHYSICAL ARGUMENT 1:
HEISENBERG MICROSCOPE

BLUE PHOTONS CAN BE USED TO LEARN WHICH
SLIT AND SO SPOIL THE PATTERN

PHYSICAL ARGUMENT2:
THERMAL ELECTRIC FIELD HAD
CORRELATIONS OF THE ORDER OF THE WIEN
LENGTH

$$\exp -\frac{(x - x')}{\lambda_W}$$

$$K_B T << m_e c^2 \qquad \lambda_W = \frac{\hbar c}{k_B T}$$

At room temperature about 20 microns

MATHEMATICAL ARGUMENT

Without em field

$$\Psi_1 \quad \Psi_2$$

$$|\Psi_1| = |\Psi_2|$$

$$I = \Psi_2^*\Psi_1 + \Psi_1^*\Psi_2$$

visibility =unity

With em field

$$\Psi_1 \to \Psi_1 \exp \frac{ie}{\hbar c} \int_{\gamma_1} \mathbf{A}(\mathbf{x})\mathbf{dx}$$

$$I \to <\mathcal{W}> I$$

thermal aharonov bohm effect!

$$\mathcal{W} = \exp \frac{ie}{\hbar c} \int_{\gamma} \mathbf{A}(\mathbf{x})d\mathbf{x}$$

visibility is thermal average of wilson loop

$$\mathbf{A}(\mathbf{x}) = \Sigma_l [\mathbf{u}_l(\mathbf{x})\, a_l + \overline{\mathbf{u}_l}(\mathbf{x})\, a_l^\dagger]$$

Expand the em field in modes

MATHEMATICAL ARGUMENT

$$< \mathcal{W} > = \Pi_l \exp i[a_l \alpha_l + a_l^\dagger \overline{\alpha}_l],$$
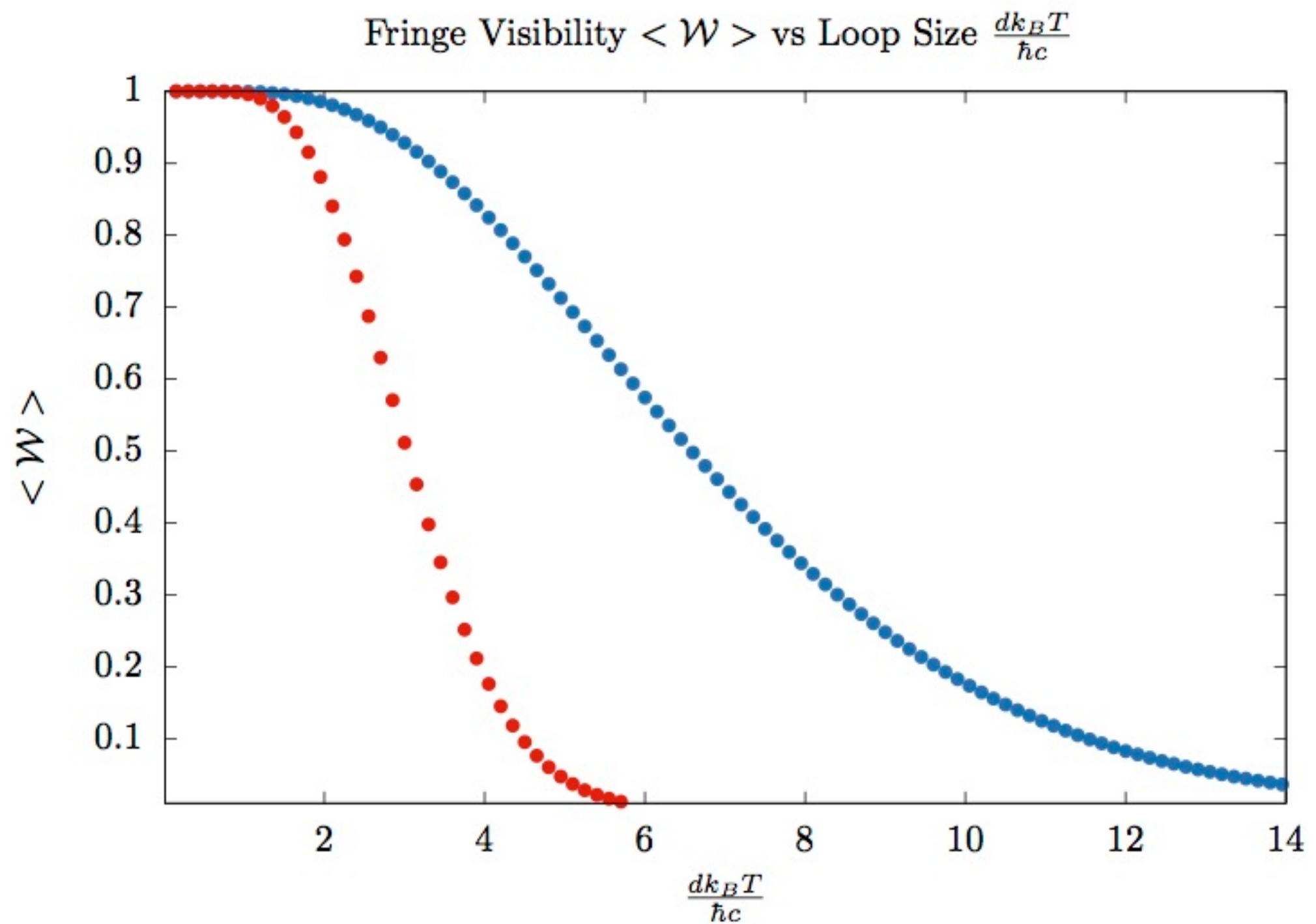
α_l is the form factor of the loop

$$\alpha_l = \oint \mathbf{u}_l . d\mathbf{x}$$

Compute Thermal Average (easy) Find

$$< \mathcal{W} > = \exp \left[-\frac{e^2}{2\hbar c} \sum_l (|\alpha_l|^2 \coth \frac{\hbar \omega_l}{2 k_B T}) \right]$$

For E2 find the same with the mode functions of Rindler and

$$T = g \frac{\hbar}{2\pi k_B c}.$$

$$n_B + 1/2$$

Fringe Visibility $\langle \mathcal{W} \rangle$ vs Loop Size $\frac{dk_B T}{\hbar c}$

Information being carried away by soft photons

Fluctuation Dissipation Relation

$$\rho = \begin{bmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{bmatrix}$$ goes to diagonal form

Entropy increase
information carried away by
soft photons

SOFT MEANS WAVELENGTHS BETWEEN
SLIT WIDTH AND SLIT SEPARATION
PERSISTS AT ABSOLUTE ZERO
SPONTANEOUS EMISSION
POWER LAW
Supurna Sinha
Physics Letters A 228 (1997) 1-6
Mahanty, Rauch follow up

CONCLUSION

SIMPLE MODEL FOR GRAVITY INDUCED DECOHERENCE

EINSTEIN EQUIVALENCE PRINCIPLE RELATES GRAVITY TO ACCELERATION

CONSONANT WITH FEYNMAN PENROSE DIOSI EXPECT SIMILAR DECOHERENCE EFFECTS FOR STATIC OBSERVERS OUTSIDE THE EVENT HORIZON OF A BLACK HOLE

OTHER MODELS ZYCH DECOHERENCE IS REVERSIBLE
E1: PRACTICAL AND FUNDAMENTAL DECOHERENCE
E2: SAME CRITERIA

FINE POINTS : BUNDLES OF PATHS VACUUM EFFECTS

CONCLUSION

only for charged particles
how about neutral ones?

REPLACE EM WITH GRAVITY FIND ANSWER TO FEYNMAN
GRAVITY DECOHERES QUANTUM SYSTEMS EFFECT LARGER FOR LARGER
SYSTEMS AND MORE STRONGLY COUPLED ONES

Both are gauge theories
difference non linear, non abelian
for weak fields this does not matter
expression for form factor is different
else same

CONCLUSION

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IS THE LOSS OF UNITARITY
REAL OR APPARENT?

Simplicio, Sagredo and Sagacio

CONCLUSION

SIMPLE MODEL FOR GRAVITY INDUCED DECOHERENCE

Uses only known physics

FINE POINTS : BUNDLES OF PATHS VACUUM EFFECTS

CONCLUSION

REPLACE EM WITH GRAVITY FIND ANSWER TO FEYNMAN
GRAVITY DECOHERES QUANTUM SYSTEMS EFFECT LARGER FOR LARGER
SYSTEMS AND MORE STRONGLY COUPLED ONES

$$< \mathcal{W} >= \exp\left[-\frac{GM^2}{2\hbar c}\sum_l (|\alpha_l|^2 \coth\frac{\hbar\omega_l}{2k_BT})\right]$$

Has gravity, quantum, relativity and statistical mechanics in it

Decoherence sets in when M is around
Planck Mass exactly as Feynman anticipated

CONCLUSION

Vacuum effects also cause decoherence.
Slower power law fall off not exponential

ENTROPY INCREASE CAUSED BY
VIRTUAL FLUCTUATIONS

IN ALL CASES ENTROPY INCREASE
CAUSED BY TRACING OVER SOME
UNOBSERVED DEGREES OF FREEDOM
RENORMALISATION GROUP
NON EQUILIBRIUM STATISTICAL PHYSICS

THANK YOU