Quantum Field Theory
The Future

It's hard to make predictions, especially about the Future

Yogi Berra, N. Bohr, Storm P,.....
[Attribution is hard]

Instead:

What are the problems which may lead to change?

One of the themes in QFT has been the S matrix approach
--The subject is very small-- can look at it from outside

Gravity does not give us this option (although strong attempt to continue to do so). We want to know what happens from the inside, not just seen from the outside.

Measurements are made from the inside, not the outside.

My own approach to particles was driven by a desire to understand where the Hawking particles actually came from

AdS-CFT-- S matrix approach.

My approach to the problems of QFT driven by my interest in gravity, and in particular gravity as expressed by General Relativity

Gravity is the inequable flow of time from place to place.

(Newton: time flows equably from place to place)

Time is the central problem for QFT in the future

Quantum Field Theory-- the Future?

Quantum Mechanics and QFT is probably the most successful set of theory (ies?) in history.

It has been said that no-one really understands Quantum Mechanics-- nonsense

The theory has been developed, and more importantly extended to brand new areas with relative ease.

QM->Spin->Condensed matter->QFT of EM->QFT of non-Abelian theories->....

To claim non-understanding when used with such facility is perverse.

Problem of translation-- people make long arguments about the right way to translate ancient Greek, or any language to another. “Interpretation” discussion looks more like a problem of translating the “formalism” to everyday language.
See for example S Hornblower's review of two translations of Heroditus—
online.wsj.com/news/articles/SB10001424052702303627504579558290151763478

If I cannot find the best way of translating Greek into English does this mean that people who speak (spoke) Greek did not really understand what they were saying?

And users of the original language need not be any better than anyone else in translation, just as practitioners of QM-QFT may not have the best facility for translation.

Perhaps the command”Just calculate” is “Just speak”.

Quantum Gravity

Formal-- renormalization of infinities-- technical

Time, and Unitarity

Time plays very different role in gravity and in Quantum Theory.

GR
Coordinate invariance-- coordinates as a “gauge”.
How does one distinguish one time from another?
(Time arises from interactions of matter?)

Constraints: H0, Hi

Generators of coordinate transformations.

Observables are quantities which commute with the constraints.

Observable must be independent of space and time.

How do we describe the time dependence we see?

Quantum :

Time is crucial in the interpretation of the probabilistic theory

“Time is God's way of stopping everything from happening at once”

Divides observables into complete sets P(ij)=0,

Σ P(i)=1

Unitarity – add uniqueness of evolution-- unique states to unique states.

Quantum Gravity:

The only physical variables should commute with the constraints.

$H0(x)|\Phi\rangle = Hi|\Phi\rangle = 0$

$Hi\ O|\Phi\rangle = O\ H|\Phi\rangle = 0$

O is operator in the subspace of “physical states”

$|\Phi\rangle$ is distributional on original Hilbert space. How do we define an inner product on this subspace? How do we define O to be self adjoint?

Page and Wooters-- relational – One of variables is a clock
Rule gives probability of measuring second variable when first has measured value.

If clock changes in time, it is not a generally covariant operator
Not in subspace and thus not measureable.

If clock does not change in time what does it mean that it is a clock?

Rovelli-- “time dependent constants of motion”
Chose one parameter families of constants of motion
Oj(t) where t is arbitrary parameter-- time.
What does this arbitrary parameter mean?

Pullin et al-- Non-relativistic theory

Assume constraint is invar under translation of one variable

if O(Q0, Qi,Pi) then O(Q0+t,Qi,Pi) is also observable.

Choose one variable as clock (W1), calculate “prob” that this and another variable W2 have values.

$$P(w_1, w_2) = \frac{\int_{-T}^{T} < \phi | \mathcal{P}_{w_1}(t) \mathcal{P}_{w_2}(t) | \phi > dt}{\int_{-T}^{T} < \phi | \mathcal{P}_{w_1}(t) \phi >}$$

$\mathcal{P}(t)_{w1}$ projection operator onto W1(Q0+t,Qi,Pi) having value w1

Reparam. Invar.

Problem-- clock time can have fluctuations-- Probability does not obey exclusivity-- some probablity that system can have two values at once.

Evolution not unitary-- system loses coherence.

(Probability may be small, but non-zero)

Diosi-Penrose.

Intuition (Penrose)-- Matter causes the flow to time to vary. (gravity IS the inequable flow of time from place to place)

Time causes phases of wave to vary – time evolution is the change in phases of components of wave function.

Quantum superposition causes of matter causes quantum superposition of the phases-=dephasing of wave function -- Signature of decoherence.

Different matter distributions have different spacetimes associated with them

No identity of spacetime points-- no unique way of identifying spacetimes, and thus equal times in spacetimes assocated with two matter distributions
Leads to uncertainty in time-- uncertainty in phases-- Loss of coherence.

Non Unitary evolution

$|\psi_1> + |\psi_2>$ Superposition of two energy states

$$\frac{1}{\tau} = \int\int < \psi_1|E(x)|\psi_1 >< \psi_2|E(x')|\psi_2 > \frac{G}{|x-x'|} dx_1 dx_2$$

Decoherence time depends on the distributions of the matter in the two energy distributions in the two states.

Problem:
Any quantum state can be written as superposition of other states. -- which states determine the energy distribution (Orthogonal? Which?) ?

What is the appropriate energy distribution?-- eg, Point particles in E given infinite self energies.
Is it the quantum fields that are important?
Deciding can make many orders of magnitude difference in decoherence times.

Problem: Penrose has never fleshed out his intuition into a theory.
Diosi has argued that an argument I made 35 years ago

$$\Delta g_{\mu\nu} \Delta G^{\mu\nu} \geq \frac{\hbar}{V}$$

leads to that decoherence formula.

Stamp-- Trying to give flesh to intuition and formula in path integral formulation with gravitational interaction between the various paths in a two-time density matrix evolution.

I and student testing quantum GR to see if there is any hint of this in conservative formulation.

gravity waves can easily lead to decoherence.
Spherical symmetric system cannot emit gravity waves.

Shell of matter which can be in different positions quantum mechanically.

If one creates and interferometer of the shell-- eg a 1/2 silvered mirror via potential of transverse stresses in shell
Does interference pattern wash out due to quantum gravity effects?

Black Holes.

Hawking, 40 years ago, predicted thermal radiation from Horizon of black hole.

Form black hole from pure state of matter (eg, a focused pure state pulse of light).
Black hole evaporates emitting thermal high entropy radiation.

Final state of radiation after black hole has evaporated is mixed state.

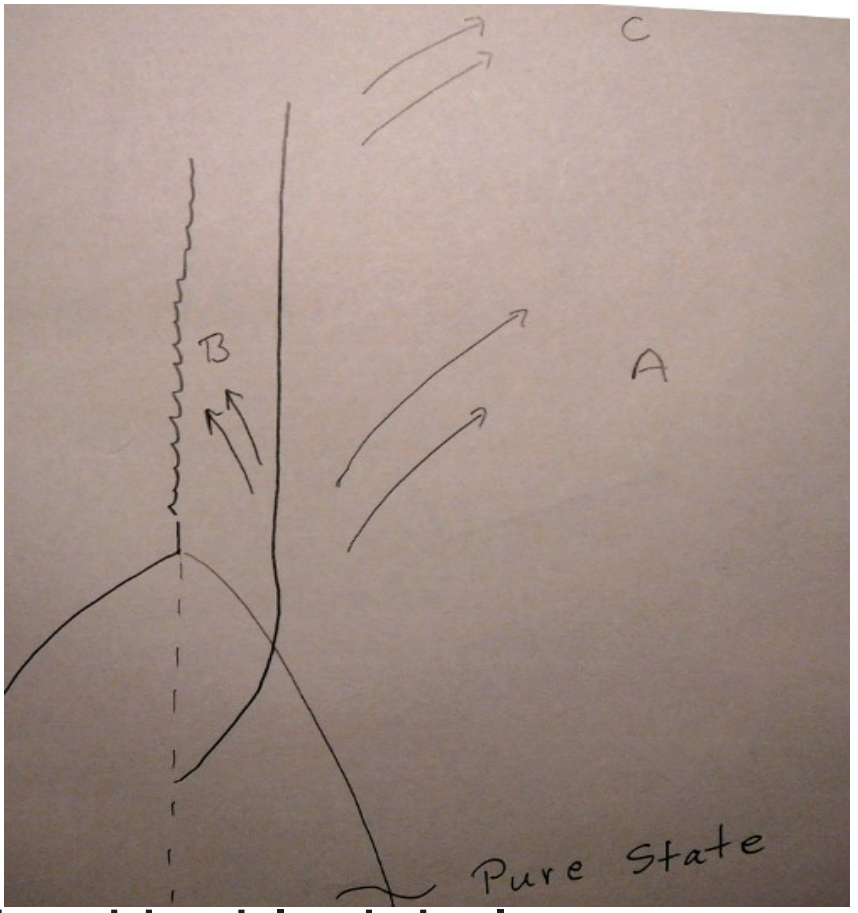
Is this loss of Unitarity. **Black Hole Wars**

Many particle physicists abhor this conclusion.
False arguments – loss of coherence implies energy non-conservation.

Believe that after black hole finishes evaporating must have Unitarity.

Subtle correlations in radiation between early raditiation and late radiation such that result is pure state.

Firewall

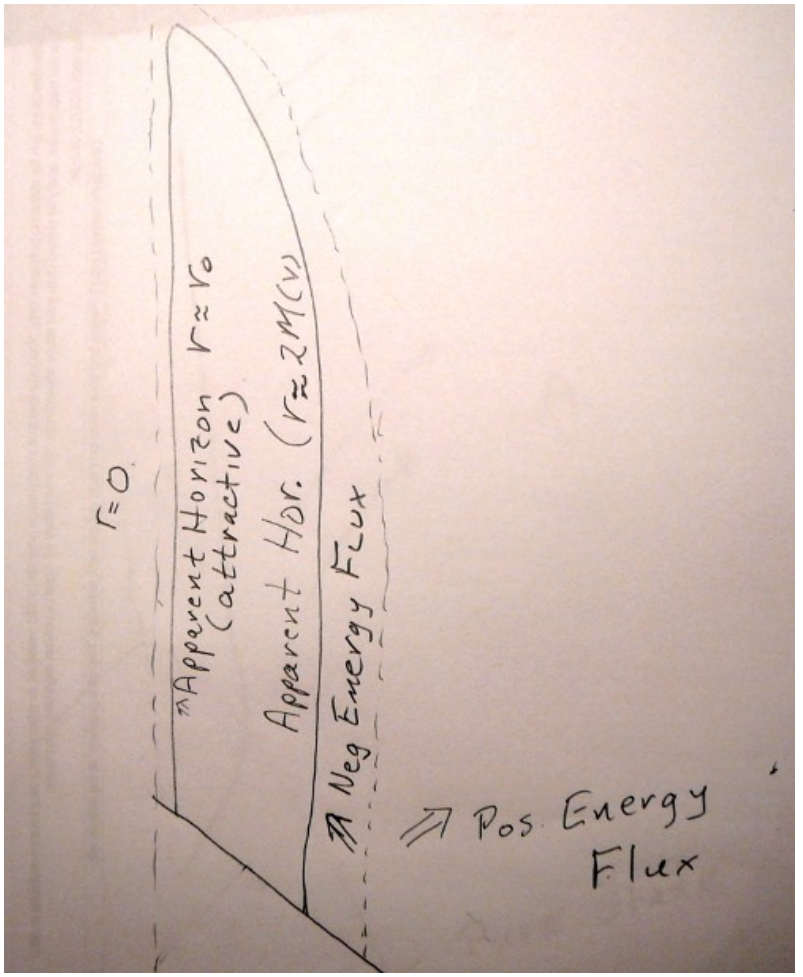


A-- mixed state emitted by black hole

A-B needs to be (relatively) pure state to have smooth energy along horizon

A-C needs to be pure state (Black Hole “Unitarity”)

Cannot have all three.



Hayward, Bardeen, Hawking

Radiation is coherent with inside “apparent horizon” so no firewall.

Inside radiation is trapped but finally comes out when horizons coalesce.

Loss of Unitarity and role or time seem to be a crucial ingredient of any future change to quantum mechanics

I have no idea what a theory like that will be or will look like

Role of probability will have to suffer a change in that new theory.

Almost certainly none of the ideas presented here will be part of that future theory, but it will be in trying to solve them that that new theory will arise.