A glimpse into Feynman’s contributions to the debate on the foundations of quantum mechanics

M. Di Mauro
Dipartimento di Matematica, Università di Salerno, Via Giovanni Paolo II, Fisciano (SA), 84084, Italy
E-mail: madimauro@unisa.it

S. Esposito* and A. Naddeo**
INFN, Sezione di Napoli, C. U. Monte S. Angelo, Via Cintia, Napoli, 80125, Italy
*E-mail: sesposit@na.infn.it
**E-mail: anaddeo@na.infn.it

The broad debate on foundational issues in quantum mechanics, which took place at the famous 1957 Chapel Hill conference on The Role of Gravitation in Physics, is here critically analyzed with an emphasis on Richard Feynman’s contributions. One of the most debated questions at Chapel Hill was whether the gravitational field had to be quantized and its possible role in wave function collapse. Feynman’s arguments in favor of the quantization of the gravitational field, based essentially on a series of gedanken experiments, are here discussed. Then the related problem of the wave function collapse, for which Feynman hints to decoherence as a possible solution, is discussed. Finally, another topic is analyzed, concerning the role of the observer in a closed Universe. In this respect, Feynman’s many-worlds characterization of Everett’s approach at Chapel Hill is discussed, together with later contributions of his, including a kind of Schrödinger’s cat paradox, which are scattered throughout the 1962-63 Lectures on Gravitation. Philosophical implications of Feynman’s ideas in relation to foundational issues are also discussed.

Keywords: Gedanken experiment; Wave function collapse; Many-worlds.

1. Introduction: the Chapel Hill conference

Richard Feynman’s most famous contribution in quantum theory is undoubtedly his celebrated path integral approach[1]. His contributions to the debate on interpretational issues are instead much less well known[2,3]. The first such contributions took place in the wide discussions which characterized the 1957 Chapel Hill conference[4], whose title was: The Role of Gravitation in Physics. The Chapel Hill conference, which played a key role in triggering the so called Renaissance of general relativity[5] was of capital importance in establishing the future research lines in the field. Broadly, the main tracks were[6]: classical gravity, quantum gravity, and the classical and quantum theory of measurement (as a link between the previous two topics). In particular, foundational quantum issues were widely discussed by researchers attending the conference. The main motivation for addressing them came from the fundamental question of whether the gravitational field had to be quantized, like other fundamental fields, or not. As its title declares, the ambitious goal of the
conference was the merging of general relativity with the rest of physics and, especially, with the world of elementary particle physics, which was ruled by quantum mechanics, hence it was (and it still is, of course) very important to understand physics in regimes where both gravity and quantum mechanics become important. This was clearly stated by Peter G. Bergmann in the opening session of the second half of the conference, which was in fact focused on problems within the quantum domain (Ref. 4, p. 165):

Physical nature is an organic whole, and various parts of physical theory must not be expected to endure in “peaceful coexistence.” An attempt should be made to force separate branches of theory together to see if they can be made to merge, and if they cannot be united, to try to understand why they clash. Furthermore, a study should be made of the extent to which arguments based on the uncertainty principle force one to the conclusion that the gravitational field must be subject to quantum laws: (a) Can quantized elementary particles serve as sources for a classical field? (b) If the metric is unquantized, would this not in principle allow a precise determination of both the positions and velocities of the Schwarzschild singularities of these particles?

The answer to these questions was expected to lead to a novel perspective on the ordinary notions of space and time, by introducing uncertainty relations for quantities such as distances and volumes. Physicists hoped that, as a result, the divergences which plagued quantum field theory would get suppressed by the gravitational field. Along with the formal discussion on the main approaches to the quantization of the gravitational field (namely the canonical, the functional integral and the covariant perturbative approaches), which would have been developed in the following decades, a lot of time was devoted to conceptual issues, especially in discussion sessions. A broad debate arose on the problem of quantum measurement, the main conceptual question being:

What are the limitations imposed by the quantum theory on the measurements of space-time distances and curvature? (Ref. 4, p. 167)

or, equivalently

What are the quantum limitations imposed on the measurement of the gravitational mass of a material body, and, in particular, can the principle of equivalence be extended to elementary particles? (Ref. 4, p. 167)

As the editors of the written records of the conference emphasized, an answer to the above questions could not be simply found in dimensional arguments, since the Planck mass does not set a lower limit to the mass of a particle whose gravitational field can be measured. Indeed, a simple argument shows that the gravitational field of any mass can in principle be measured, thanks to the “long tail” of the
Newtonian force law (Ref. 4, pp. 167-8).

The great part of the discussions of interest to us here developed in Section VIII of the conference (Ref. 4, pp. 243-60), where the focus was mainly on the contradictions eventually arising in the logical structure of quantum theory if gravity quantization is not assumed, but in fact many even more fundamental issues for quantum physics in general were touched as well. Feynman greatly contributed to these discussions, proposing several gedanken experiments in order to argue in favor of the necessity of gravitational quantization, and hinting to decoherence as a viable solution to the problem of wave function collapse. His contributions in fact triggered a wide debate on the quantum measurement problem and on the existence and meaning of macroscopic quantum superpositions. Further, in the subsequent session of the conference, which was the closing one (Ref. 4, pp. 263-278), he gave a “many-worlds” characterization of Hugh Everett III’s relative state interpretation of quantum mechanics, which had just been described for the first time by Everett’s advisor, John A. Wheeler. It is interesting to notice that, in fact, the Chapel Hill conference was one of the few places where Feynman was directly involved in discussions about the foundations and interpretation of quantum mechanics.

The Chapel Hill discussions played a pivotal role in triggering subsequent research on foundational issues, mainly on the quantum measurement problem and on the various possible interpretations of quantum mechanics, with an emphasis on the consequences of Everett’s one. In this respect it is worth mentioning further contributions by Feynman, who despite not being often involved with foundational quantum issues, nonetheless kept thinking deeply on them also in the following years, especially when working on gravity, as hinted for example in a letter written in 1961 to Viktor Weisskopf:

How can we experimentally verify that these waves are quantized? Maybe they are not. Maybe gravity is a way that quantum mechanics fails at large distances.

as well as in several suggestions and considerations scattered throughout his 1962-63 graduate lectures on gravitation.

In this paper, we historically and critically analyze Feynman’s contributions to the debate about the foundations of quantum mechanics and gravity, with an emphasis on the Chapel Hill discussions, which constitute the main source about his thoughts on the matter. In particular, Section 2 deals with the problem of the quantization of the gravitational field while in Sections 3 and 4 the focus is on wave function collapse following a measurement and on Everett’s relative state interpretation of quantum mechanics. Finally our concluding remarks are summarized in Section 5.
2. Quantization of the gravitational field: gedanken experiments

In this Section we report on Feynman’s arguments in favor of the quantization of the gravitational field. As a matter of fact, Feynman believed that nature cannot be half classical and half quantum and shared Bergmann’s general ideas, as recalled by himself in some concluding remarks made at the end of the conference:

The questions raised in the last three days have to do with the relation of gravity to the rest of physics. We have gravity - electrodynamics - quantum theory - nuclear physics - strange particles. The problem of physics is to put them all together. The original problem after the discovery of gravity was to put gravity and electrodynamics together since that was essentially all that was known. Therefore, we had the unified field theories. After quantum theory one tries to quantize gravity (Ref. 4, p. 272).

In particular, for Feynman gravity, like the other fundamental interaction that we experience at the macroscopic, classical level, i.e. electromagnetism, has a quantum foundation (see e.g. Refs. 10–12). Coherently with this, he developed an approach to quantum gravity (whose first hints were given at Chapel Hill, cf. Ref. 4, pp. 271-276) which was characterized by being fully quantum from the beginning.\(^9,13\)

Feynman’s arguments in favor of the quantization of gravity were totally different from the usual dimensional arguments, which rely on the assumption that gravity has to dominate over all other interactions at the Planck scale. According to him quantum effects involving gravity should be subject to probing without invoking such high scales. He provided further evidence to support this claim by putting forward thought experiments designed to show that, if quantum mechanics is required to hold for objects massive enough to produce a detectable gravitational field (the opposite would require a modification of quantum mechanics), then the gravitational field has to be quantized, in order to avoid contradictions. This view supported the hope that quantization of the metric would help taming the divergences present in quantum field theory and, in this way, it was relevant also for the theory of elementary particles. Let us thus retrace the discussion in more detail.

Section VIII began with Thomas Gold stating that, in the absence of phenomena not explainable by classical gravity, the only way to argue in favor of quantization of gravity is the presence of logical contradictions, of which he was not convinced (Ref. 4, pp. 243-244). Bryce S. DeWitt pointed out that difficulties may arise in the presence of quantized matter fields depending on the choice of the quantum expectation value of the stress-energy tensor as the source of the gravitational field (Ref. 4, p. 244). Indeed a measurement may change this expectation value, which implies a change of the gravitational field itself. The classical theory of gravitation is valid because fluctuations are negligible at the scale where gravitational effects become sizeable. At this point Feynman put forward his first thought experiment, which was a variant of the two-slit diffraction experiment, in which a mass indicator has been put behind the two-slit wall. Within a space-time region whose linear
dimensions are of order $L$ in space and $L/c$ in time, the uncertainty on the gravitational potential (divided by $c^2$ so that it is dimensionless and thus homogeneous to a metric) is in general $\Delta g = \sqrt{\frac{\hbar c^2}{G^2}} = L_P$, where $L_P = \sqrt{\frac{\hbar c^2}{G}}$ is the Planck length. The order of magnitude of the potential generated by a mass $M$ within the spatial part of the considered region is $g = \frac{MG}{Lc^2}$, which implies $\Delta g = \frac{\Delta M G}{Lc^2}$. A comparison with the previous general expression gives a mass uncertainty $\Delta M = \frac{c^2L_P}{G} \approx 10^{-5}$ grams, if the time of observations is less than $L/c$. On the other side, by allowing an infinite time, $M$ would be obtained with infinite accuracy. This option, according to Feynman, could not take place for a mass $M$ fed into the two-slit apparatus, so that the apparatus will not be able to uncover the difficulty unless $M$ is at least of order $10^{-5}$ grams. Thus he concluded that

Either gravity must be quantized because a logical difficulty would arise if one did the experiment with a mass of order $10^{-4}$ grams, or else [...] quantum mechanics fails with masses as big as $10^{-5}$ grams (Ref. 4, p. 245).

Subsequent discussions moved on more formal matters such as the meaning of the equivalence principle in quantum gravity, with Feynman contrasting Helmut Salecker’s suggestion of a possible violation of the equivalence principle in the quantum realm. Then a further remark by Salecker himself brought the participants’ attention back to the topical issue, the necessity of gravitational quantization. In particular, as explained by an Editor’s note (see Ref. 4, p. 249), Salecker hinted to the possibility to build up an action-at-a-distance theory of gravitation in whole analogy to the electromagnetic case, with charged quantized particles acting as a source of a unquantized Coulomb field. At this stage Frederik J. Belinfante proposed the quantization of both the static part and the transverse part of the gravitational field (the last one describing gravitational radiation) as a way to circumvent difficulties related to the choice of the expectation value of the stress energy tensor as the source of the gravitational field. As noticed by Zeh\(^2\), Belinfante’s proposal reflects his ideas on the ontology of quantum mechanics, which point toward an epistemic rather than ontic interpretation of the wave function:

“There are two quantities which are involved in the description of any quantized physical system. One of them gives information about the general dynamical behavior of the system, and is represented by a certain operator (or operators). The other gives information about our knowledge of the system; it is the state vector [...] the state vector can undergo a sudden change if one makes an experiment on the system. The laws of nature therefore unfold continuously only as long as the observer does not bring extra knowledge of his own into the picture.” (Ref. 4, p. 250).

\(^a\)This follows from an argument given by Wheeler in Ref. 4 pp. 179-180, involving a path integral for the gravitational field.
Belinfante’s description used the Heisenberg picture, at variance with Feynman who reasoned in terms of wave functions as dynamical objects. Indeed, according to Belinfante “the wave function [...] must change for reasons beyond the system’s physical dynamics. He does not refer to ensembles of wave functions or a density matrix in order to represent incomplete knowledge” (Ref. 2, p. 65).

Feynman promptly replied with his second gedanken experiment, a Stern-Gerlach experiment with a gravitational apparatus. More in detail, he considered a spin-1/2 particle going through a Stern-Gerlach apparatus and then crossing the first or the second of two counters (denoted as 1 and 2, respectively), each one connected by means of a rod to an indicator. He took the indicator as a little ball with a diameter of 1 cm, going up or down depending on the position of the object, at counter 1 or 2, respectively. Quantum mechanics, as underlined by Feynman, provides in principle an amplitude for the ball up and an amplitude for the ball down. However, the ball is chosen to be macroscopic, so as to be able to produce a detectable gravitational field, which in turn can move a probe ball. In other words a channel between the object and the observer is established via the gravitational field. This ideal experiment led Feynman to infer the following conclusion about gravity quantization:

Therefore, there must be an amplitude for the gravitational field, provided that the amplification necessary to reach a mass which can produce a gravitational field big enough to serve as a link in the chain does not destroy the possibility of keeping quantum mechanics all the way. There is a bare possibility (which I shouldn’t mention!) that quantum mechanics fails and becomes classical again when the amplification gets far enough, because of some minimum amplification which you can get across such a chain. But aside from that possibility, if you believe in quantum mechanics up to any level then you have to believe in gravitational quantization in order to describe this experiment (Ref. 4, p. 251).

A subsequent answer to a question by Hermann Bondi further highlighted, according to Zeh (Ref. 2 p. 67), Feynman’s position against the epistemic interpretation of the wave function:

I don’t really have to measure whether the particle is here or there. I can do something else: I can put an inverse Stern-Gerlach experiment on and bring the beams back together again. And if I do it with great precision, then I arrive at a situation which is not derivable simply from the information that there is a 50 percent probability of being here and a 50 percent probability of being there. In other words, the situation at this stage is not 50-50%

\footnote{Zeh points out how Feynman’s description of the measurement process is very close to the standard measurement and registration device proposal by John von Neumann.}

\footnote{“What is the difference between this and people playing dice, so that the ball goes one way or the other according to whether they throw a six or not?” (Ref. 4, p. 252).}
that the die is up or down, but there is an amplitude that it is up and an amplitude that it is down – a complex amplitude – and as long as it is still possible to put those amplitudes together for interference you have to keep quantum mechanics in the picture. (Ref. 4, p. 252, our emphasis)

3. Wave function collapse

The aim of this Section is to highlight Feynman’s ideas about the quantum measurement problem. Indeed, from the last sentence of the last quote, one can infer a clear reference to the problem of wave function collapse, as well as a hint to decoherence as a possible solution. A further suggestion can be found in a subsequent remark:

Well, it’s a question of what goes on at the level where the ball flips one way or the other. In the amplifying apparatus there’s already an uncertainty - loss of electrons in the amplifier, noise, etc. - so that by this stage the information is completely determined. Then it’s a die argument. You might argue this way: Somewhere in your apparatus this idea of amplitude has been lost. You don’t need it any more, so you drop it. The wave packet would be reduced (or something). Even though you don’t know where it’s reduced, it’s reduced. And then you can’t do an experiment which distinguishes interfering alternatives from just plain odds (like with dice). (Ref. 4, p. 252, our emphasis)

According to Feynman, wave packet reduction occurs somewhere in his experimental apparatus thanks to the amplifying mechanism, so that a huge amount of amplification (via the macroscopic gravitational field of the ball) may be effective in changing amplitudes to probabilities. Then he wondered about the possibility to devise an experiment able in principle to avoid the wave packet reduction due to the amplification process. Subsequent criticism by Leon Rosenfeld and Bondi further stimulated Feynman’s intuition. So he was led to envisage a sort of quantum interference in his experiment, driven by the gravitational interaction between macroscopic balls, which could be described by means of a quantum field with suitable amplitudes taking a value or another value, or to propagate here and there. But, as Bondi suggested, any irreversible element should be removed, such as for instance the possibility of gravitational links to radiate. Probably, this is another point in which a further hint to the role of decoherence in destroying quantum interference can be recognized, even if in Bondi’s and Feynman’s words a reference is made only to classical irreversibility. In fact the meaning of decoherence, its origin and its role in smearing out phase relations as well as in triggering the transition to classicality, were still unclear in the late 1950s. The discussion went on with Feynman arguing that quantum interference might eventually take place with a mass of macroscopic

\[^{4}\text{For a historical and research account on decoherence, see Ref. 15 and references therein}\]
size, say about $10^{-5}$ gram or 1 gram, and hinting to the possible role of gravity in destroying quantum superpositions. In his words:

There would be a new principle! It would be fundamental! The principle would be: – roughly: Any piece of equipment able to amplify by such and such a factor ($10^{-5}$ grams or whatever it is) necessarily must be of such a nature that it is irreversible. It might be true! But at least it would be fundamental because it would be a new principle. There are two possibilities. Either this principle – this missing principle – is right, or you can amplify to any level and still maintain interference, in which case it’s absolutely imperative that the gravitational field be quantized... I believe! or there’s another possibility which I have’t thought of (Ref. 4, pp. 254-255, emphasis in original).

The same ideas would have been pursued later by Feynman in his Lectures on Gravitation, where he considered “philosophical problems in quantizing macroscopic objects” and hinted to the possibility of a failure of quantum mechanics induced by gravity:

I would like to suggest that it is possible that quantum mechanics fails at large distances and for large objects. Now, mind you, I do not say that I think that quantum mechanics does fail at large distances, I only say that 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 $\frac{GM^2}{\hbar c} = 1$, of $M$ near $10^{-5}$ grams, which corresponds to some $10^{18}$ particles (Ref. 9, pp. 12-13).

Within the same set of lectures (Ref. 9, p. 14), the possibility is recognized that amplitudes may reduce to probabilities for a sufficiently complex object, thanks to a smearing effect on the evolution of the phases of all parts of the object. Such a smearing effect could have a gravitational origin. A similar idea is expressed in the end of the letter to Weisskopf, as already mentioned in the Introduction. This shows how Feynman was open-minded with respect to all possibilities, despite his strong belief in the quantum nature of reality.

The debate on gravity quantization here highlighted and, in particular, Feynman’s deep insights, triggered subsequent research on the possibility of a gravity-induced collapse of wave function, as a viable solution to the measurement problem in quantum mechanics. The idea is attractive since gravity is ubiquitous in nature, and gravitational effects depend on the size of objects, so it has been greatly developed in the subsequent years up to the present day. Along this line of thinking, Roger Penrose suggested that a conflict emerges when a balanced superposition of two separate wave packets representing two different position of a massive object is considered. In his words (see Ref. 26, p. 475): “My own point of view is that as soon as a significant amount of space-time curvature is introduced, the rules of
quantum linear superposition must fail”. Clearly the conflict is the result of putting together the general covariance of general relativity and the quantum mechanical superposition principle. By assuming in each space-time the validity of the notions of stationarity and energy, and by taking the difference between the identified time-translation operators as a measure of the ill-definiteness of the final superposition’s energy, the decay time for the balanced superposition of two mass distributions can be estimated:

\[ t_D = \frac{\hbar}{\Delta E_{\text{grav}}} \]  

(1)

Here \( \Delta E_{\text{grav}} \) is the gravitational self-energy of the difference between the mass distributions of each of the two locations of the object. This means that massive superpositions would immediately undergo collapse. The same idea led Penrose to introduce the so called Schrödinger-Newton equation\(^\text{24} \), which governs a peculiar non-linear evolution of the center-of-mass wave function. Its soliton-like dynamics is the result of a competition between a partial shrinking due to the non-linear term and a partial spreading due to the usual dynamical term.

More recently, other collapse models (called dynamical collapse models) have been put forward\(^\text{27–30} \), where the collapse of the wave function is induced by a different mechanism, i.e. the interaction with a random source such as an external noise source.

From the experimental side, a lot of proposals have been made as well, mainly aimed to explore a parameter range where both quantum mechanics and gravity are significant. For instance it has been possible to create a quantum superposition state with complex organic molecules with masses of the order \( m = 10^{-22} \text{ kg} \)\(^\text{31,32} \). Recent experimental proposals involve matter-wave interferometers\(^\text{33–35} \), quantum optomechanics\(^\text{36–39} \) and magnetomechanics\(^\text{40} \). Today a major challenge is, on one hand, to design viable experiments at the interface between the quantum and classical worlds, while on the other hand to reveal and discriminate gravity-induced decoherence from environmental decoherence in such experiments. However, despite such a huge theoretical and experimental effort, a definite answer to the quantum measurement problem as well as to the problem of the emergence of classical from the quantum world is still lacking.

4. The role of the observer in a closed Universe

In this Section we deal with the issue of the role of the observer in a closed Universe, as emerged from discussions carried out in the closing session of Chapel Hill conference. Here Wheeler gave the first public presentation of Everett’s relative-state interpretation of quantum mechanics\(^\text{7,41} \), as follows:

General relativity, however, includes the space as an integral part of the physics and it is impossible to get outside of space to observe the physics. Another important thought is that the concept of eigenstates of the total
energy is meaningless for a closed Universe. However, there exists the proposal that there is one “universal wave function”. This function has already been discussed by Everett, and it might be easier to look for this “universal wave function” than to look for all the propagators (Ref. 4, p. 270).

Feynman promptly replied by characterizing of Everett’s approach as “many-worlds”:

The concept of a “universal wave function” has serious conceptual difficulties. This is so since this function must contain amplitudes for all possible worlds depending on all quantum-mechanical possibilities in the past and thus one is forced to believe in the equal reality of an infinity of possible worlds (Ref. 4, p. 270).

The same idea will be presented some years later in the Lectures on Gravitation (Ref. 9, pp. 13-14), where Feynman also discussed the role of the observer in quantum mechanics. The Schrödinger’s cat paradox allowed him to illustrate the difference between the results of a measurement carried out by an external as well as an internal observer. While the external observer describes his results by an amplitude, with the system collapsing into a well-defined final state after the measurement, according to the internal observer the results of the same measurement are given by a probability. Clearly the absence of an external observer leads to a paradox, which is much more effective when considering the whole Universe as described by a complete wave function. This Universe wave function is governed by a Schrödinger equation and implies the presence of an infinite number of amplitudes, which bifurcate from each atomic event. In other words, according to Feynman, the Universe is constantly spitting into an infinite number of branches, as a result of the interactions between its components. Here the key observation is that interactions play the role of measurements. As a consequence, an inside observer knows which branch the world has taken, so that he can follow the track of his past. Feynman’s conclusion brings into play a conceptual problem:

Now, the philosophical question before us is, when we make an observation of our track in the past, does the result of our observation become real in the same sense that the final state would be defined if an outside observer were to make the observation (Ref. 4, p. 14)?

A further discussion of the meaning of the wave function of the Universe is carried out later in the Lectures on Gravitation (Ref. 9, pp. 21-22). Here Feynman restated his “many-worlds” characterization of Everett’s approach with reference to a “cat paradox on a large scale”, from which our world eventually could be obtained by a “reduction of the wave packet”. Concerning this reduction, he wondered about the relation between Everett’s approach and collapse mechanisms of whatever origin. Perhaps it may be relevant to quote a comment by John P. Preskill, within a talk...
about the Feynman legacy, given at the APS April Meeting (cf. Ref. 42, slide 29):

When pressed, Feynman would support the Everett viewpoint, that all phenomena (including measurement) are encompassed by unitary evolution alone. According to Gell-Mann, both he and Feynman already held this view by the early 1960s, without being aware of Everett’s work. However, in 1981 Feynman says of the many-worlds picture: “It’s possible, but I am not very happy with it”.

Historically, Everett’s proposal was the first attempt to go beyond the Copenhagen interpretation in order to apply quantum mechanics to the Universe as a whole. To this end, the well known separation of the world into “observer” and “observed” has to be superseded by promoting the observer to be part of the system, while the usual quantum rules are still effective in measuring, recording or doing whatever operation. Quantum fluctuations of space-time in the very early Universe have also to be properly taken into account. On the other hand, this proposal lacks an adequate description of the origin of the quasi-classical realm as well as a clear explanation of the meaning of the branching of the wave function.

Everett’s work has been further developed by many authors and its more recent generalization is known as *decoherent histories approach to quantum mechanics of closed systems*. A characterizing feature of this formulation is that neither observers nor their measurements play a prominent role. Furthermore the so called *retrodiction*, namely the ability to construct a history of the evolution of the Universe towards its actual state by using today’s data and an initial quantum state, is allowed. The process of prediction requires to select out decoherent sets of histories of the Universe as a closed system, while decoherence in this context plays the same role of a measurement within the Copenhagen interpretation. Decoherence is a much more observer-independent concept and gives a clear meaning to Everett’s branches, the main issue being to identify mechanisms responsible for it. In particular, it has been shown that decoherence is frequent in the Universe for histories of variables such as the center of mass positions of massive bodies.

5. Concluding remarks

In this paper we have retraced Feynman’s thoughts on foundational issues in quantum mechanics. Such ideas were rarely expressed by him, who mainly linked his name to his masterful application of this theory, but they clearly emerged whenever he focused on the problem the interface of quantum mechanics and gravity, with the ensuing great conceptual questions. These problems, such as that of the collapse of the wave function, of macroscopic superpositions and of observers which are parts of the observed system itself, are of course not limited to the gravitational

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*We do not agree that Feynman was not aware of Everett’s work in the 1960s, since he commented on it at Chapel Hill in 1957.*
realm, but lie at the very heart of quantum physics. Despite much progress having been achieved since Feynman’s times, part of which had been anticipated by him and other participants to the Chapel Hill conference, much work still needs to be done, before his most famous remark “I think I can say that nobody understands Quantum Mechanics” can be considered to be no longer true.

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