HOW I SPENT MY SABBATICAL 27 YEARS AGO

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IN THE BEGINNING

In 1991, I came to Taiwan to spend 5 months (September, 1991 to January, 1992) for my Sabbatical. I divided my time between Taida (Saturday and Monday), and here at institute of Physics(Tuesday to Friday).

NTU

Taida(NTU):

- 1. I offered a course on Standard Model.
- 2.The course had 9 registered students and a few auditors for a total of 15 to 20 students who came from several universities in Taipei, Hsinchu and Chung-Li.
- 3.I lectured at least 4 hours a week.

INSTITUE OF PHYSICS

- Institute of Physics
- Here at the Institute of Physics, the first thing we did was to form a Study Group of High Energy particle Physics Phenomenology. The first meeting was held on September 20, 1991 following an invitation sent out by Shih-Chang Lee to various universities.

FRIDAY DISCUSSION

- Every Friday afternoon, there was a discussion session. Some people would report their results of research the previous week, and discussion followed.
- I do not remember how many people participated in the discussion group. It was probably about 20.

MEMBERS OF CORE GROUP

- Gradually, a core group formed consisting of 6 physicists:

Hai-Yang Cheng 鄭海揚

Chi-Yee Cheung 張志義

Guey-Lin Lin 林貴林

Tung-Mow Yan 顏東茂

Yu-Chung Yu 林育中

Hoi-Lai Yu 余海礼

Heavy quark symmetry and chiral dynamics (1992)

Tung-Mow Yan, Cheng, Chi-Yee Cheung, Guey-Lin Lin, Yeu-Chung Lin and Hoi-Lai Yu $=(CLY)^2$

RESEARCH TOPIC

- Our research topic, after several weeks of discussion, converged to a study of Heavy Hadrons which contain one heavy quark and a light quark(Heavy Mesons), or a heavy quark and two light quarks (Heavy Baryons).
- These heavy hadrons have interesting symmetries. The heavy quarks have heavy quark symmetry, and the light quarks have chiral symmetry. We can combine both symmetries and we can make interesting predictions. That is what we did .

COLLABORATION CONTINUES

- After I left Taiwan in January 1992, the collaboration continued. I mainly communicated with Hai-Yang and he coordinated the work in Taiwan by the rest of our collaboration. This arrangement worked out very well.

SYMMETRIES

- These combined symmetries led to many predictions. We published 8 papers between 1992 and 1996. The first paper garnered about 350 citations. At the time, it was the most cited paper in High Energy Physics from Taiwan. Now it has been overtaken by papers of other younger people. As it should be.

9^{TH} PAPER

Interestingly, we have published a 9th paper after the first observation of $\Xi_b^- \to \Lambda_b^0 \pi^-$ by LHC and Hai-Yang took the initiative to go back to our earlier work and reexamined these decays and found that predicted rates for

$$\Xi_b^- \to \Lambda_b^0 \pi^-$$

in the MIT bag model and diquark models are consistent with experiment. The paper was published in 2016.

CHIRAL SYMMETRY

- SYMMETRIES

- Chiral Symmetry

The light quarks (u, d, and s) have small masses compared with a typical QCD mass scale of 1GeV. As a first approximation, let us assume the light quarks are massless. Then the QCD Lagrangian for the light quarks split into two independent parts:

LIGHT QUARKS

- $\mathcal{L}_q$=qiDq=q_LiDq_L+q_RiDq_R

Where $D \equiv \gamma^{\mu} D_{\mu}$

q_L=$\frac{1}{2}$(1-γ_5)q

q_R=$\frac{1}{2}$(1+γ_5)q

CHIRAL SYMMETRY BREAKING

- Thus, each hadron has two degenerate states, one from $q_L$and one from q_R. This is the chiral symmetry SU$(3)_L$x$SU(3)_R$. However, we have no such particle degeneracy observed in Nature. It is then said that the chiral symmetry is spontaneously broken with ground state not being invariant under the chiral transformations. The residual symmetry is the ordinary SU(3) flavor symmetry.

GOLDSTONE BOSONS

- One consequence of this is the existence of eight massless Goldstone bosons. But since the quarks are not exactly massless, we have eight light mesons π, η, K and its antiparticle. Here we will concentrate on the interactions of hadrons with the Goldstone bosons, in particular, the lightest members pions where we can use PCAC, partially conserved axial current.

PCAC

- Through PCAC, we can relate the one pion matrix element between hadron states to the matrix element of the axial vector current between hadron states. The properties of the axial vector current then allow us to make predictions, as we will see later.

HEAVY QUARK SYMMETRY

- A heavy meson is very much like a Hydrogen atom, the heavy quark acts as the nucleus, and the light quark behaves as the electron orbiting around the nucleus. For the couplings of a heavy hadron to pions, the only function of the heavy quark is to provide the QCD force required to bind the heavy quark and light quark. Since pions are coupled to light quarks only, it is intuitively clear that the coupling strength of pions to the heavy mesons are universal independent of the heavy quark species. This is the essence of heavy quark symmetry.

HEAVY HADRONS

- For a heavy meson, Qq, its coupling to a single pion can be depicted as q→q'+ π. So there is only one coupling constant in this sector. Thus, the coupling constants for D^* →D+ π,

$D^* \rightarrow D^*$'+π, $B^* \rightarrow$ B+π, are all related.

A heavy Baryon contains a heavy quark and two light quarks which form a diquark. There are two different SU(3) multiplet heavy baryons depending on whether the diquark is in a symmetric sextet or an antisymmetric antitriplet.

SPINS OF HEAVY BARYONS

- If we make the quark model assumption that the symmetries of the spin wave functions and the flavor wave functions are correlated, then the diquark in the flavor symmetric sextet has spin 1, and the diquark in the flavor antisymmetric anti triplet has spin 0. When the diquark combines with a heavy quark, the sextet contains both spin $\frac{1}{2}$ and $\frac{3}{2}$ baryons and the antitriplet contains only spin $\frac{1}{2}$ barons. Also, the ground state baryons have even parity, so the diquark has even parity.

NUMBER OF INDEPENDENT COUPLING CONSTANTS

- The spin 1 diquark can be represented by an axial vector $\emptyset^{\mu}$,
- And the spin 0 diquark by a scalar $\emptyset$.
- Then there are two independent pion veritices: $\emptyset^{\mu} \rightarrow \emptyset^{\mu}$'$+\pi$
- And $\emptyset^{\mu} \rightarrow \emptyset + \pi$.
- The vertex $\emptyset \rightarrow \emptyset' + \pi$ is excluded by parity conservation.
- These two coupling constants and the one in heavy meson sector are determined in the quark model

QUARK MODEL PREDICTION FOR g_A

- Recall that the nucleon couples to the vector and axial vector currents as in
- N($g_V\gamma_\mu V^\mu$+$g_A\gamma_\mu\gamma_5 A^\mu$)N
- The axial vector part g_A is computable in the quark model. It gives
- g_A=$\frac{5}{3}$
- As compared with experimental value g_A=1.25. So the quark model only gives qualitative answer.

COMPLETE MODEL

- The three coupling constants that describe the interactions of heavy mesons or heavy baryons with a pion can be computed exactly in the same way as g_A in the nucleon case. We can expect that the results will be only qualitatively correct. It is interesting, however, to note that the combined symmetries of heavy quark symmetry and chiral symmetry and the quark model completely determine the low energy dynamics of heavy mesons/heavy baryons with pions.

PREDICTIONS

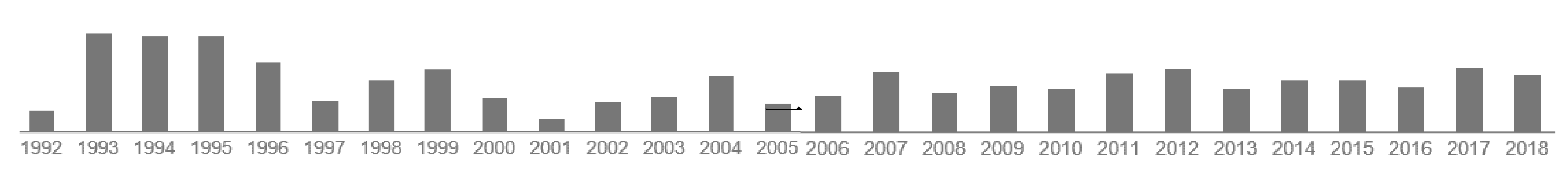
- We have made many predictions. But even after more than 25 years, most of them have not been measured experimentally. I will only mention one example: the branching ratio of the strong decay $D^{*+} \rightarrow D^0$+π^+.
- Our 1993 prediction was
- B($D^{*+} \rightarrow D^0$+π^+)=67.3%
- Compared with CLEO result
- $B_{cleo}(D^{*+} \rightarrow D^0$+$\pi^+$)=68.1$\pm$1.0 $\pm$1.3%
- And PDG average value at the time
- $B_{PDG}(D^{*+} \rightarrow D^0$+$\pi^+$)=55$\pm$4%

COMPARISION WITH EXPERIMENT

- Now, this number has been measured experimentally. It is
- $B_{exp}(D^{*+} \rightarrow D^0+\pi^+)$=67.7$\pm$0.5%
- Which agrees with our 1993 prediction. Our prediction follows from isospin symmetry and the dominance of strong decays of D^{*+}. But it is interesting that the PDG value at the time did not agree with our prediction.

Wise ('92)
Burdman, Donoghue ('92) } heavy meson sector only

# of citation as of 11/07/2018 = 599 (INSPIRES)
754 (Google Scholar)



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Collaboration period: 1991-1996, 8 papers

FINAL REMARKS

- Heavy Quark Symmetry, Chiral Symmetry, and Quark Model together completely determine the dynamics of heavy meson/heavy baryon with low energy pions.
- The Sabbatical 27 years ago was the most productive and enjoyable.
- Many of the collaborators become the best friends.
- THANK YOU!