Emerging lattice approach to K-Unitarity Triangle

Lehner + Lunghi + AS in prep

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Lattice 2015; 07/17/15

Kobe-Japan

Outline

- **Reminiscences: Lattice & *the* UT = "SUT" for Standard UT**

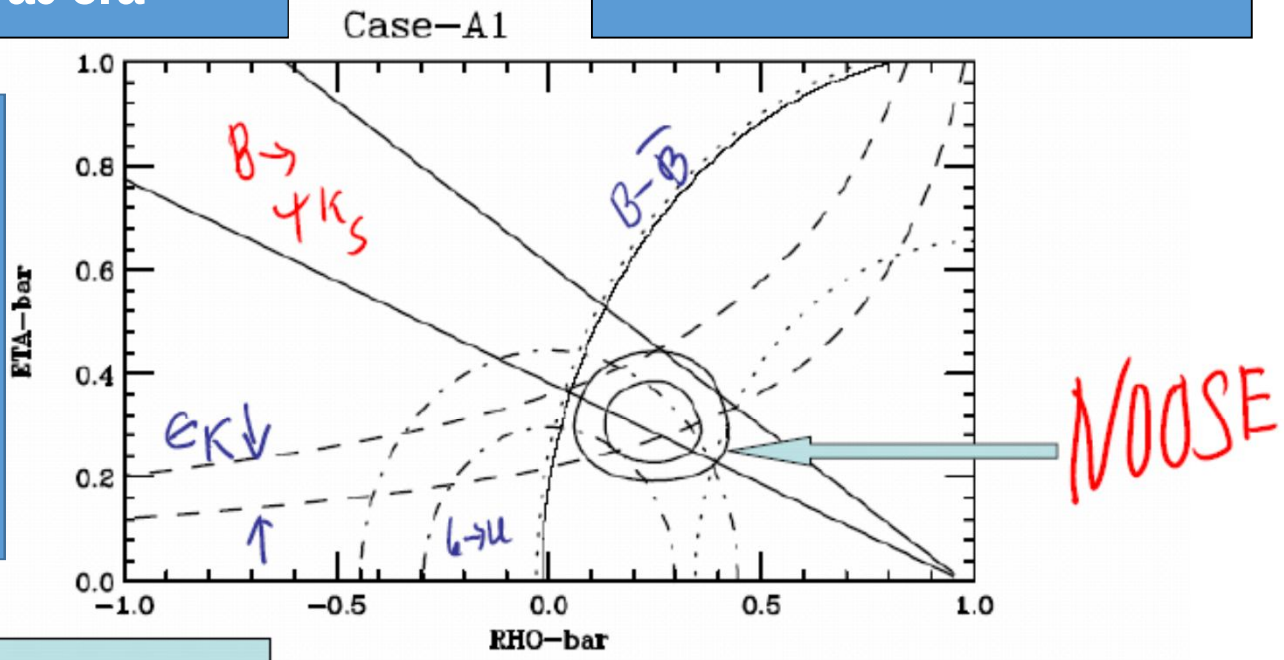
- **Recent developments on the lattice in tackling long-standing non-perturbative challenges in K-decays**
- **In concert with expts path towards a K-UT**
- **Its potential relevance: a particularly picturesque illustration**
- **Implications**

In the "beginning" "Dawn " of the asymmetric B-Fac era

Atwood &AS, hepph/0103197

B-CP Feb'01 Ise, Japan

1st Hint of confirmation of CKM CP description



Most bands due To theory errors

New physics will be a perturbation, important to use clean theory and lots of statistics.

Lunghi+AS,arXiv.0707.0212

(Sin 2 β = 0.78+-.04)

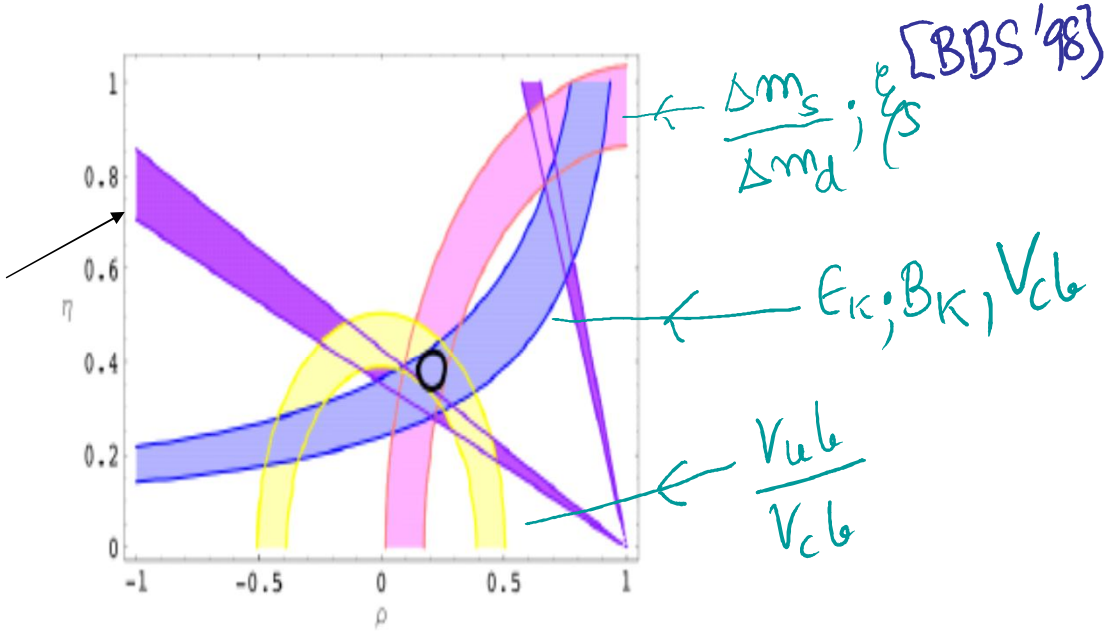


Figure 1: Unitarity triangle fit in the SM. The constraints from $|V_{ub}/V_{cb}|$, ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ are included in the fit; the region allowed by $a_{\psi K}$ is superimposed.

CKMFITS '07

Courtesy: Tom Browder

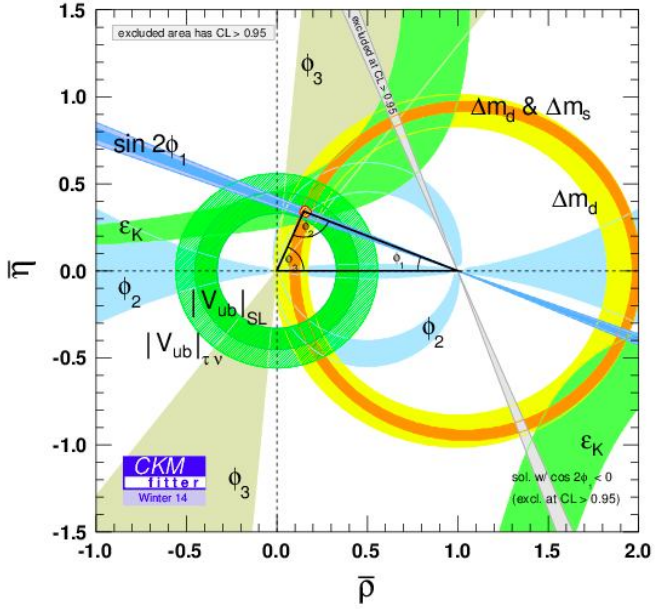
Critical Role of the B factories in the verification of the KM hypothesis was recognized and cited by the Nobel Foundation

A single irreducible phase in the weak interaction matrix accounts for most of the CPV observed in kaons and B's.

CP violating effects in the B sector are O(1) rather than $O(10^{-3})$ as in the kaon system.

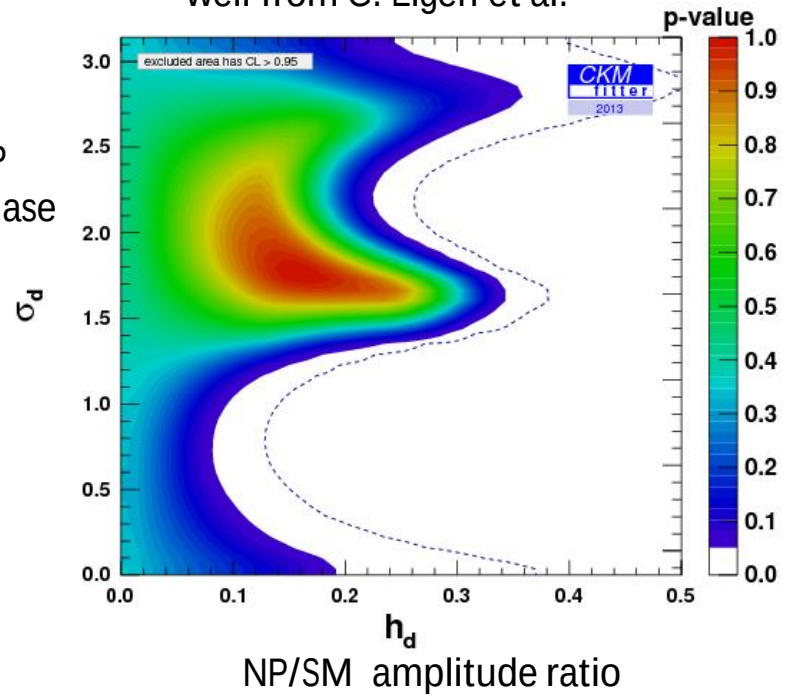
Results from Global Fits to Data (CKMFitter Group)

Great progress on φ_3 or γ (first from B factories and now in the last two years from LHCb (several new results at ICHEP2014). These measure the phase of V_{ub}



Looks good
(except for an issue with $|V_{ub}|$)

ICHEP2014: Similar results from UTFIT (D. Derkach) as well from G. Eigen et al.



But a 10-20% NP amplitude in B_d mixing is perfectly compatible with all current data.

A lesson from history (I)

"A special search at Dubna was carried out by E. Okonov and his group. They did not find a single $K_L \rightarrow \pi^+ \pi^-$ event among 600 decays into charged particles [12] (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the Lab. The group was unlucky."

-Lev Okun, "The Vacuum as Seen from Moscow"

1964: BF= 2×10^{-3}

A failure of imagination ? Lack of patience ?

Christenson, Cronin, FITCH & TURLAY BNL '64

=> Precision! Precision! Precision!
Need of the day.

Analogously can lattice sharpen tests now via K's?

- In B's, in conjunction with experiments, Lattice WME helped in attaining a milestone in our understanding of CP
- Since m_K is ~10 times lighter, the non-perturbative effects are much more difficult and quantitatively a lot bigger, can the lattice meet this long-standing challenge and render K-tests become precise?

A dream for some

Blucher, Winstein and Yamanaka '09

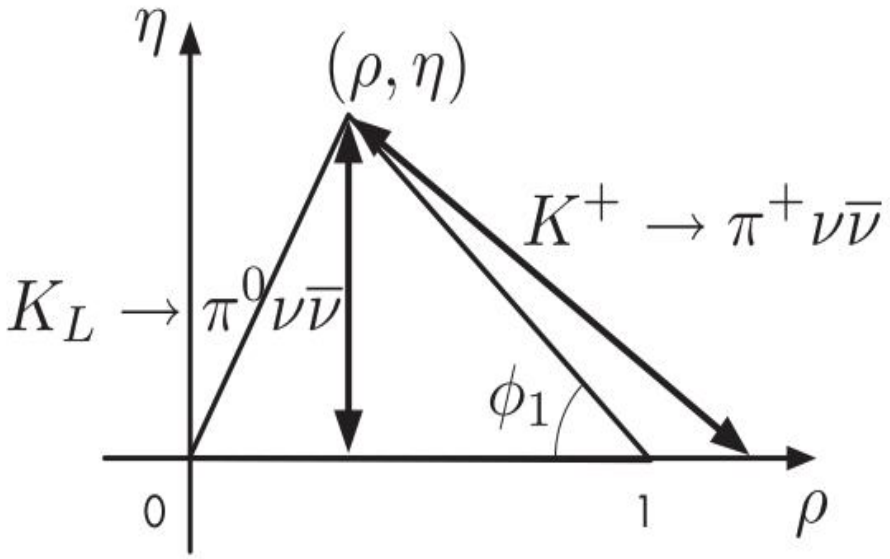


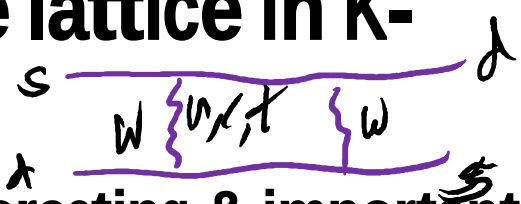
Fig. 14. Unitarity triangle.

A faster way in the offing?

Promising developments on the lattice in K-decays.....RBC-UKQCD (1 of 4 pages)

- ε'/ε .....C. Kelly talk
- Personal perspective: a quest for ~1/3 of a century! O(8 grads)
- Started with CWB (Wilson); for this physics Chiral symm on the lattice is a pre-requisite [off-shoot B-physics] => on to DWF (with Tom B)=> RBC [with BNT became flagship project] use ChPT + quenched => huge quench[GP] pathlogies=full QCD is mandatory for this physics not just χS ; full QCD + ChPT=> large chiral corrections => RBC-UKQCD[esp CP] direct K=> 2 π a la Lellouch- Luscher @ threshold=> @physical kinematics.....

Promising developments on the lattice in K-decays.....RBC-UKQCD



- Long-distance (non-local) effects; most interesting & important in Δm_K because of extreme sensitivity to chiral structure of Heff see Beall, Bander + AS, PRL '82 ....δO(40%) Brod & Gorban

  See N.Christ talk here & many more.....Look forward to

Δm_K from lattice as a useful observable for constraining NP.

- ε_K LD .....δO(7%).....N.Christ talk here & many more → Buras, Guadagnoli, Isidori '10
- K+ => π ν ν.....δO(few%).....Xu Feng talk
- K => π e e.....A. Lawson talk here; [A.Portelli]; C. Sachrajda @LAT'14
- => Pathways to K-UT

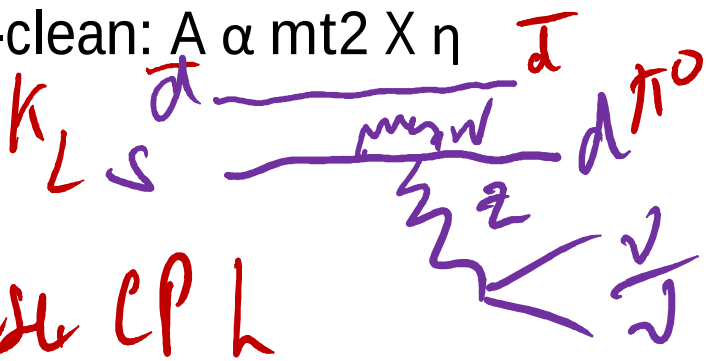
More on K-decays=>rare K's

Taku Yamanaka @ CKM 2014

- KL => π0 ν ν ...Gold-plated, i.e Theory super-clean: A α mt2 X η

LITTENBERG PRD '89

Nothing → Nothing

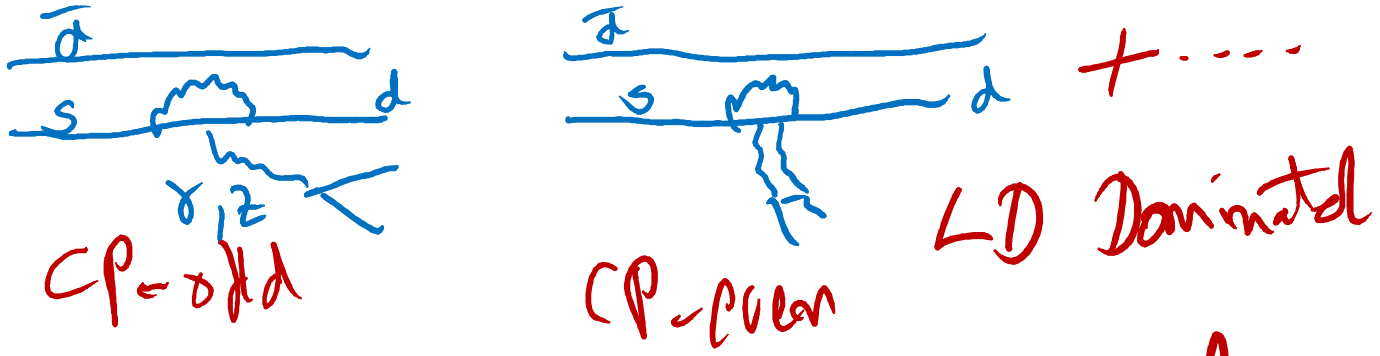


USE CPL

- **Observe: The above expt is exceedingly challenging (esp for precision) and expensive.**
- **Assertion: Once the (exptal) community realizes we mean business by reducing errors on Im A0 to around ~ 20% they will get the message loud and clear: It is much more cost effective to invest in better lattice calculation(s) of eps' .....**

$K_L \Rightarrow \pi^0 e e$

- Much more readily (seems) can do essentially the same physics as KL=>πνν
- Very rich; e.g can study energy asymm....
- Long-standing challenge for theory: Reliably quantify CP-conserving contamination



- Challenge for expt: huge background from ee gamma gamma [H. Greenlee PRD'90

Br [K_L => **π^0 e e]dir- CP ~ 6X10^{-12} ; CPC ~ 2X10^{-12}**

Br [KL =>γ γ ee] ~ 5.95X10^{-7} !! PDG Imposes severe demands on energy resolution

AJB '93

Why bother: Flavor alignment

- In the SM as you switch on weak interactions, gauge eigenstates no longer stay aligned with the mass eigenstates; CKM-matrix infact monitors this mis-alignment

- As you go to BSMs, naturalness arguments strongly suggest a similar mis-alignment => new mixing matrix and likely O(1) new CP-odd phase(s)

- While examples of this abound in specific models most telling perhaps is to consider the case of a geometric theory of flavor, based on warped extra-dim a la RS as its just about the most compelling

RANDALL+SUNDRUM '99

Points along 5th dim correspond to diff. eff. 4d scale!

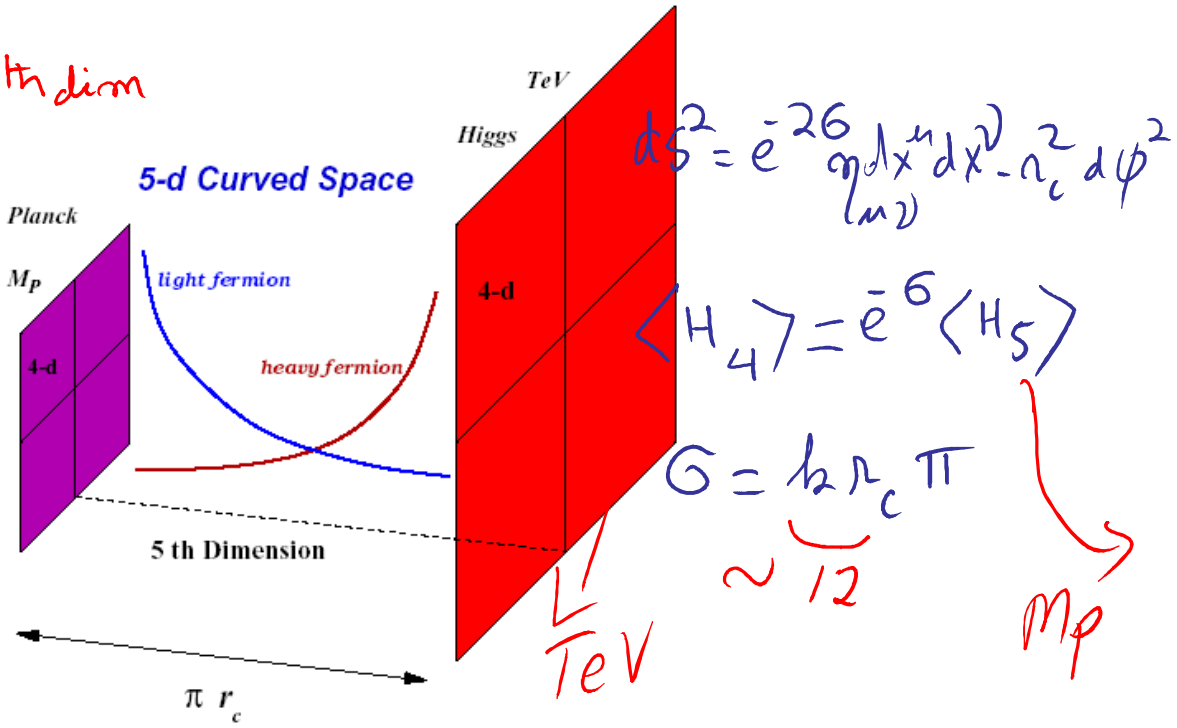


Figure 1: Warped geometry with flavor from fermion localization. The Higgs field resides on the TeV-brane. The size of the extra dimension is $\pi r_c \sim M_P^{-1}$.

Simultaneous resolution to hierarchy and flavor puzzles

See Grosman + Neubert; Gherghetta + Pomarol; Davoudaisl, Hewett+ Rizzo

Fermion "geography" (localization) naturally explains:

- **Why they are light (or heavy)**
- **Flavor structure examined in detail in (Agashe, Perez,AS'04) :**
- **FCNC for light quarks are severely suppressed automatically**
- **RS-GIM MECHANISM flavor changing transitions though at the *tree level* (resulting from rotation from interaction to mass basis)are suppressed roughly to the same level as the loop in SM=> CKM mixings (& mass) hierarchy.**
- **O(1) CP ubiquitous;.....nedm, in fact ALL DIR-CP [ε'/ε, γ, ΔACP(B=>Kπ),Δ(Sin2β);S[B=>K* $\rho\gamma$]; ΔACP(D)..] are an exceedingly important path to BSM-phase and new physics**
- **Most flavor violations are driven by the top**
-

Gedalia, Isidori + Perez '09

$\varepsilon_K, \Delta m_K : 10^3$ TeV $\Rightarrow$ RS$_{KI} \sim 10$ TeV!

EXTENSIVE STUDIES by Blanke et al , '09; and by Cassagrande et al '08; &.....

Localization parameters of the 3-families of quarks

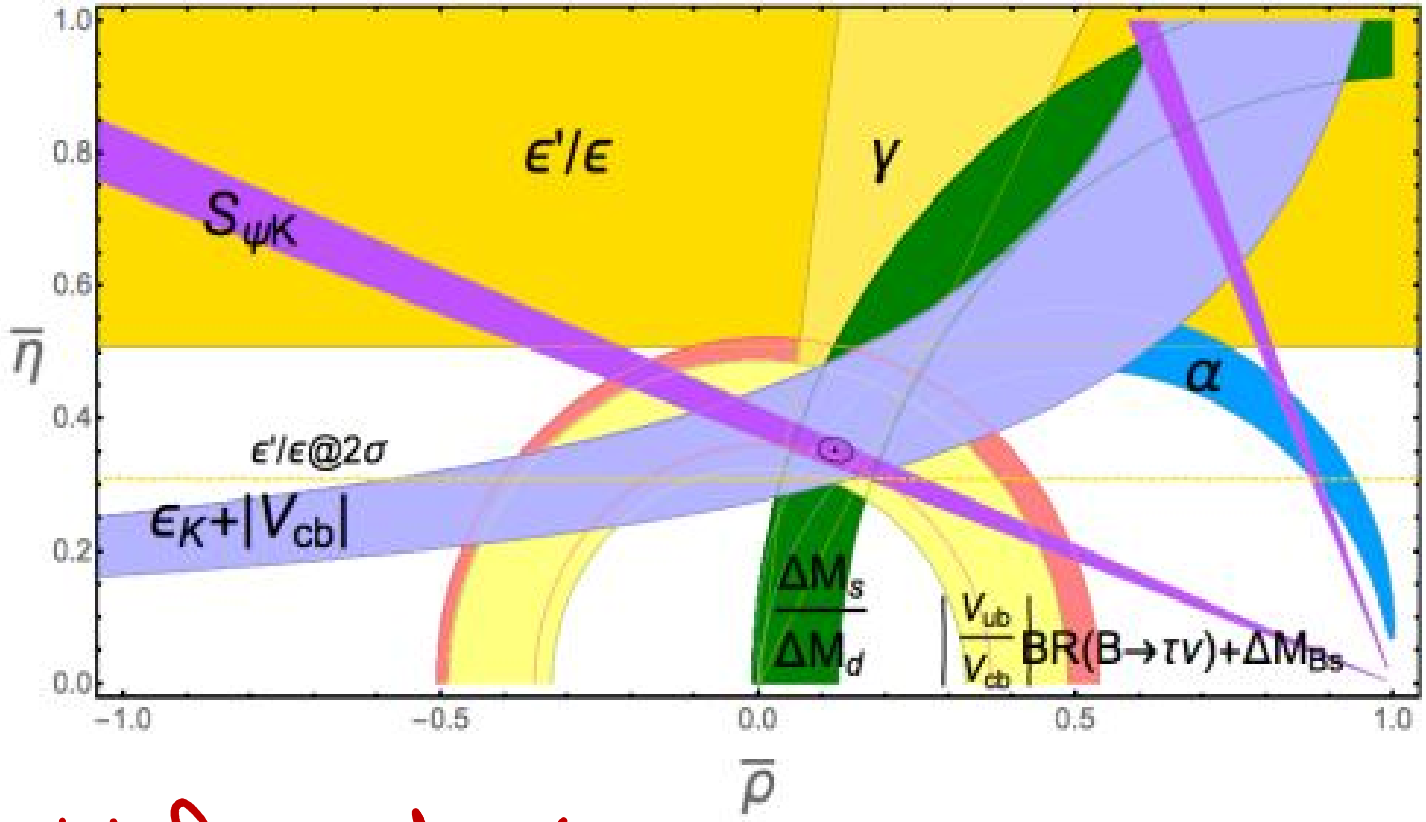
$$c_{Q_1} = -0.579\,, \quad c_{Q_2} = -0.517\,, \quad c_{Q_3} = -0.473$$
$$c_{u_1} = -0.742\,, \quad c_{u_2} = -0.558\,, \quad c_{u_3} = +0.339$$
$$c_{d_1} = -0.711\,, \quad c_{d_2} = -0.666\,, \quad c_{d_3} = -0.553$$

Table from M. Neubert @Moriond09

⇒ masses of the 6 quarks in RS!

⇒ However, (1) RS does not predict masses.

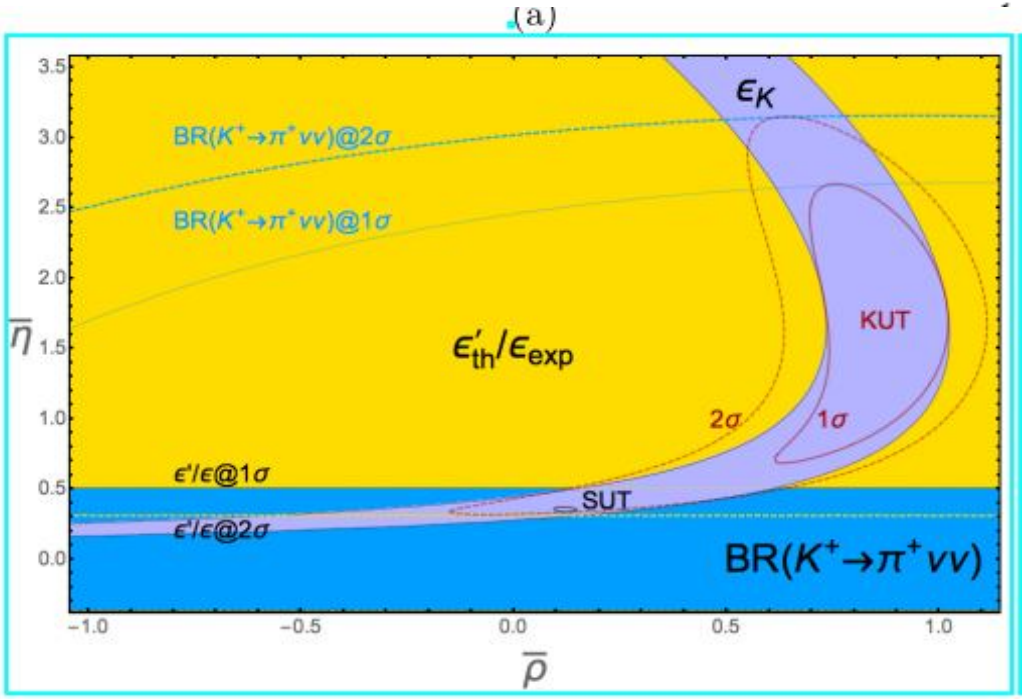
Lattice ϵ'/ϵ & SUT



LLS in prep

Sketch of an emerging K-UT

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = \begin{cases} (8.64 \pm 0.60) \times 10^{-11} & \text{SM} \\ (17.3^{+11.5}_{-10.5}) \times 10^{-11} & \text{E949} \end{cases}$$ BNL



LLS '15

$$\mathrm{Re}\left(\frac{\varepsilon'}{\varepsilon}\right)_K = \begin{cases} (16.7 \pm 1.6) \times 10^{-4} & \text{PDG2015} \\ (1.36 \pm 5.21_{\text{stat}} \pm 4.49_{\text{syst}}) \times 10^{-4} & \end{cases}$$

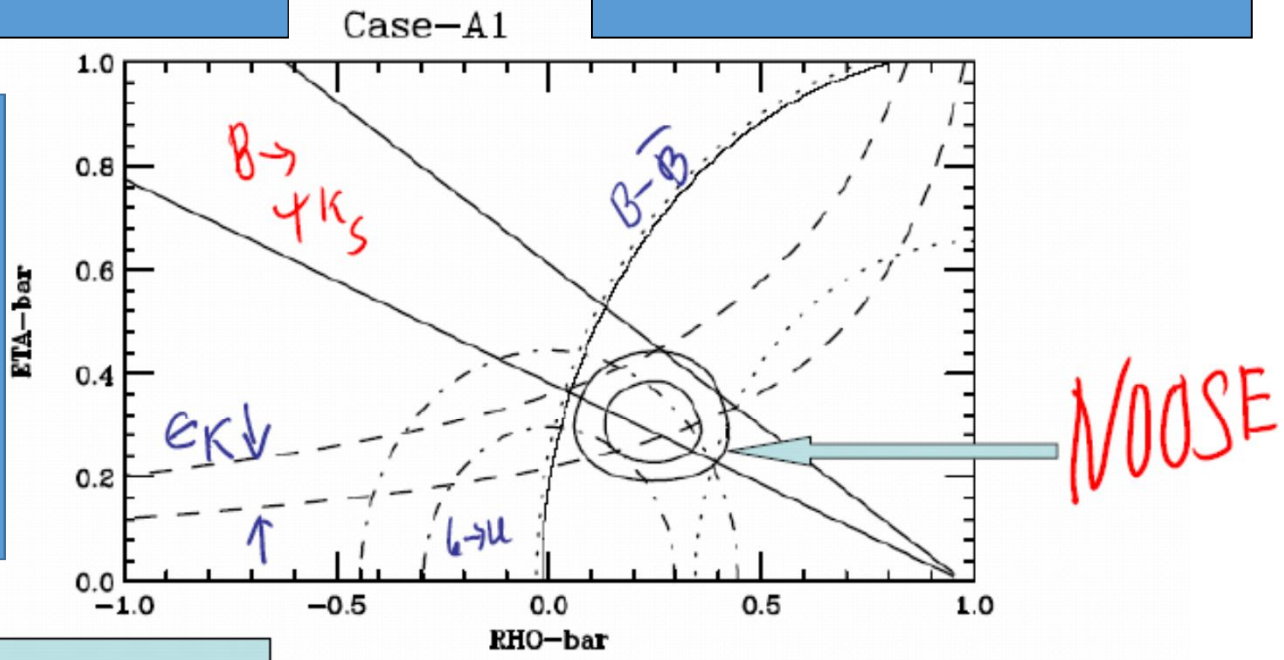
RBC+UKQCD '15

In the "beginning"

Atwood &AS, hepph/0103197

B-CP Feb'01 Ise, Japan

1st Hint of confirmation of CKM CP description



Most bands due To theory errors

New physics will be a perturbation, important to use clean theory and lots of statistics.

Legendary American Philosopher

Yogi Berra

Catcher / Manager/ Outfielder
Born: May 12, 1925 St. Louis, Missouri
Batted: Left — **Threw:** Right
MLB debut
September 22, 1946 for the New York Yankees
Last MLB appearance
May 9, 1965 for the New York Mets
Career statistics
▪ New York Yankees (1964, 1984-1985) ▪ New York Mets (1972-1975)
Career highlights and awards
▪ 15× All-Star selection (1948, 1949, 1950, 1951, 1952, 1953, 1954, 1955, 1956, 1957, 1958, 1959, 1960, 1961, 1962) ▪ 13× World Series champion (1947, 1949, 1950, 1951, 1952, 1953, 1956, 1958, 1961, 1962, 1969, 1977, 1978) ▪ 3× AL MVP (1951, 1954, 1955) ▪ New York Yankees #8 retired ▪ Major League Baseball All-Century Team
Member of the National
☆☆☆ Baseball Hall of Fame ☆☆☆
Induction — 1972
Vote — 85.61% (second ballot)

The Future

- Yogi Berra: "Its difficult to make predictions, especially about the future"

Stolen from Sheldon Stone

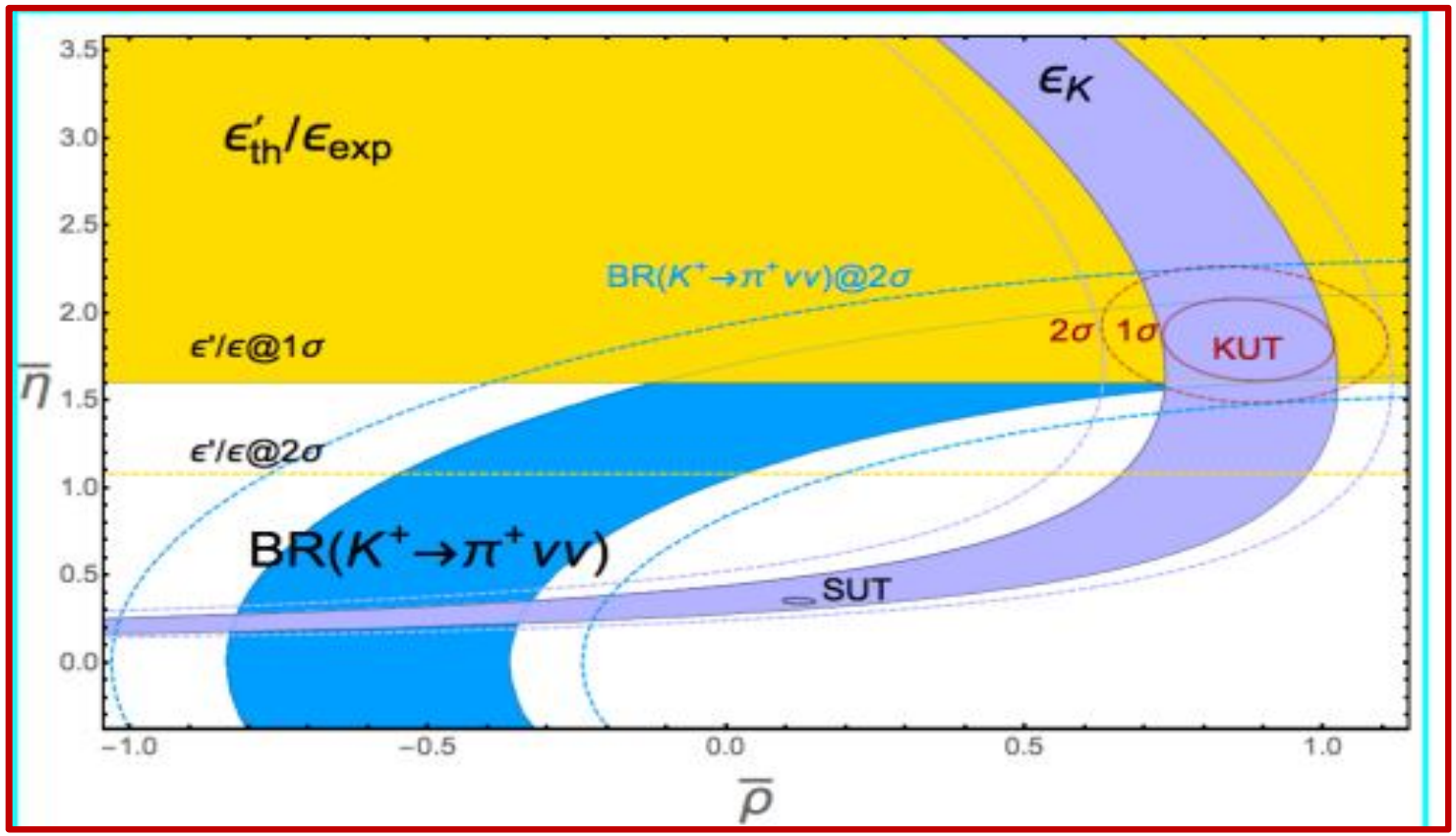
Proof of the pudding: underlying method is systematically improvable

- BK in full QCD with DWF '07 error O(7%)
- ~2012 many discretizations , WA error O(1-2%)
- Kl3, A2, fB's , BB's.....
- mq's....

- 0 doubt that A0, A2 for eps' will not go that way for quite sometime to come.....to ~10% total

After that EM& isospin effects need to be ascertained quantitatively.

POSSIBLE KUT CIRCA 2020

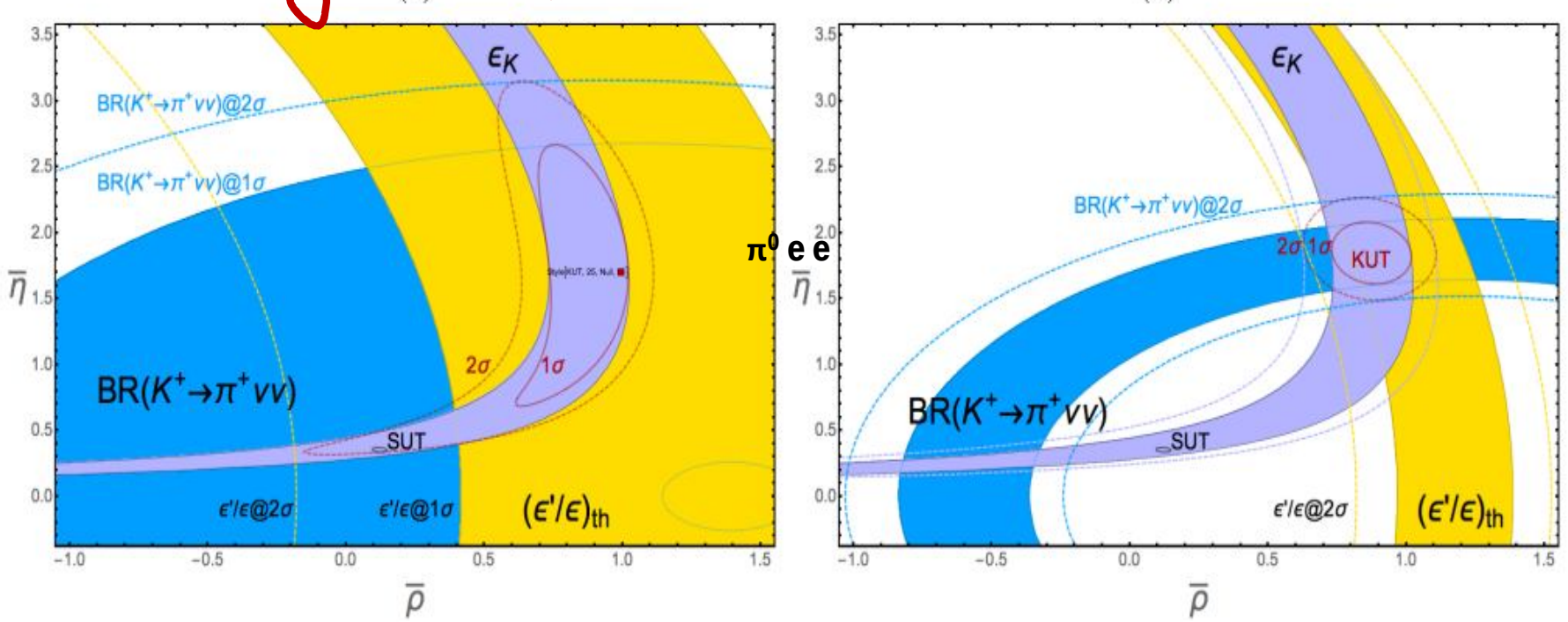


NO unique S, η !

A new observable on the horizon

CP conserving observable

ϵ'_K/ϵ_K



π^0 e e

See Lehner, Lunghi, A.S in prep

Summary & Outlook

- In the past ~2 decades, in conjunction with experiments, lattice calculation of weak matrix elements, played a significant role in establishing that the SM-CKM paradigm of CP violation works to about an accuracy of ~ 15%.
- In the past few years, significant progress on the lattice has been made in tackling long-standing problems of ε'/ε, LD non-local contributions to

Δm_K, ε_K, $K^+ \to \pi^+ \nu\nu$, $K \to \pi ee$....

- In conjunction with existing expt info and with further improvements therein, a unitarity triangle based primarily on K-decays will become available.
- Advantage?: When searching for small effects, diff. perspectives may be useful. [Moreover, have reservations of global fits; e.g B &α have issues]
- This [combined] strategy should lead to more stringent tests of the SM and for clues to new phenomena