IF & the lattice

Amarjit Soni, BNL-HET

03/25/19

US-Japan IF meeting@BNL

outline

- Desperately seeking lucy
- CPV in heavy quark systems
- CPV in charm — Decipher latest expt results
- Strong phases
- UT
- B=> l nu gamma
- tau on the lattice
- Summary

Physics is an experimental science

- I. **A new thousand pound gorilla is in our midst:**

Toru Iijima @ SCGP May 31, 2018

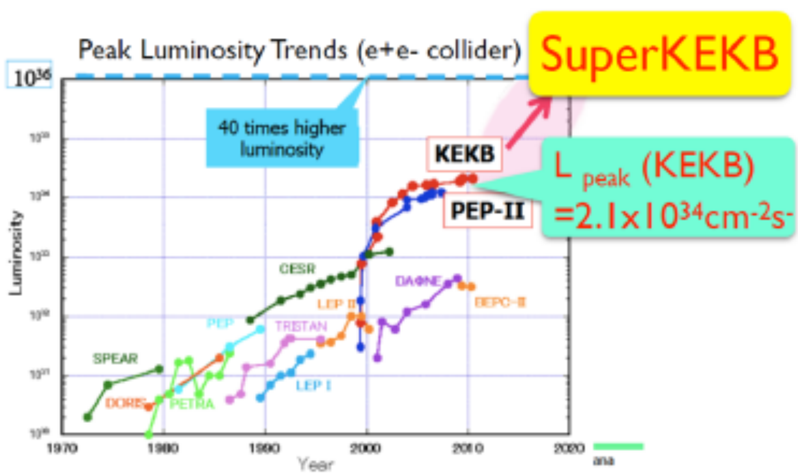
SuperKEKB/Belle II

New intensity frontier facility at KEK

- Target luminosity ; $L_{peak} = 8 \times 10^{35} cm^{-2}s^{-1}$

  $\Rightarrow \sim 10^{10}$ $B\bar{B}$, $\tau^+\tau^-$ and charms per year !

  $L_{int} > 50\ ab^{-1}$



IN MY VIEW

New physics discovery potential is no less than when we moved From Tevatron to LHC!!!

The first particle collider after the LHC !

Importance of the "IF": score card

- Beta decay => Gf => W….
- Huge suppression of KL => mu mu; miniscule ΔmK=> charm $\Delta m_K / m_K \sim 10^{-15}$!!
- KL =>2 pi but very rarely; mostly to 3pi =>CP violation => 3 families
- Largish Bd –mixing => large top mass
- etc……. History may repeat yet again!
- => extremely unwise to put all eggs in HEF
- info from IF complementary to HEF can be a crucial guide for pointing to new thresholds as well as to provide important clues to the nature of the signals there from

An important message from the tree-level CC anomaly [RD(*)]

- Likely scale is relatively low

  [same sign dileptons]

- Yet clean signal from a LQ of mass ~ TeV may or may not be readily seen @ LHC13

See Bar-Shalom, Cohen, AS + Wudka; 1812.01378

LQ mass > 1.5 TeV become v difficult @ LHC13

=> Confirmation at the IF may well be essential!

LHCb or Belle II

Focus just on 1 outstanding question of our times

- **CP Violation i. p. BSM-CP-odd phase(s)**
- **Lattice + IF have a very imp role in addressing this fundamental issue of our times**

CP violation

- **BSM-CP phase(s) expected on naturalness grounds ……(remember the ν & even more so for BSM-CP phase);popular models of flavor, e.g. warpedXDim[see Agashe, Perez, AS'04] explicitly show**
- **My license plate, used to be OSCILL8 (before '89 in CA, UCLA)**
- **A firm believer in neutrino mass, a decade or more before oscillations were discovered.**

So, we should hunt this BSM phase wherever we can and as vigorously as we can

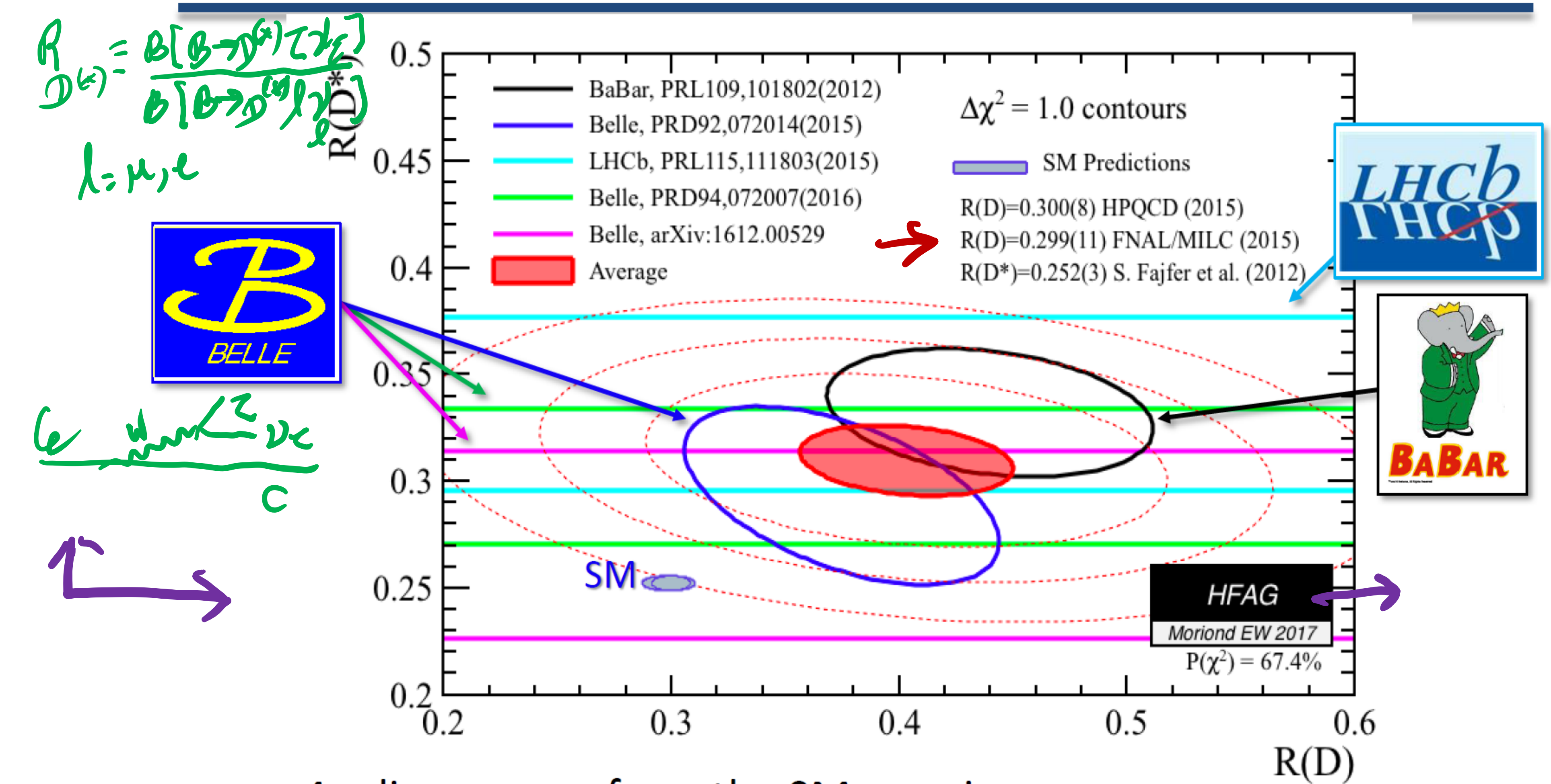
Search for BSM-phase: Multi-prong

- Any room via redundant, precise measurements & precise (lattice) computations for UT & more
- Charm decays — approx null test (ANT)
- b => d (s) ; SM- max (ANT)
- B => D(*) tau nu ; tau pol — NT
- B => gamma l/tau nu; tau pol — NT
- Mixing induced CP via radiative B decays to excl FS — ANT
- eps' since ~ '83 (originally with C Bernard) again over-riding motivation was/is naturalness

BEST CHANCE IN A VERY LONG TIME OF POSSIBLE SIGHTINGS OF NP

■ $R\left(D^{(*)}\right)$ by HFAG

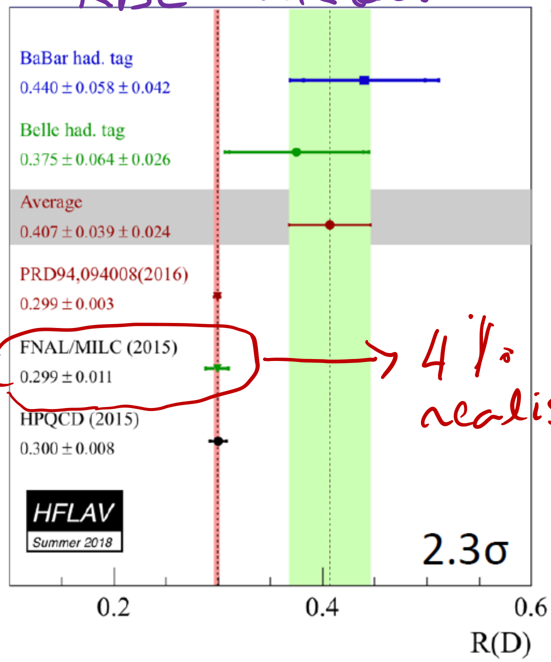
Hirose [BELLE]@EW MORIOND Mar. 2017

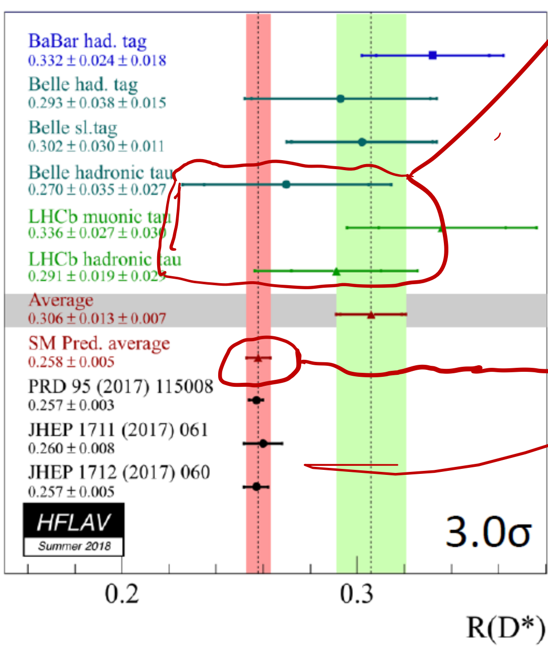


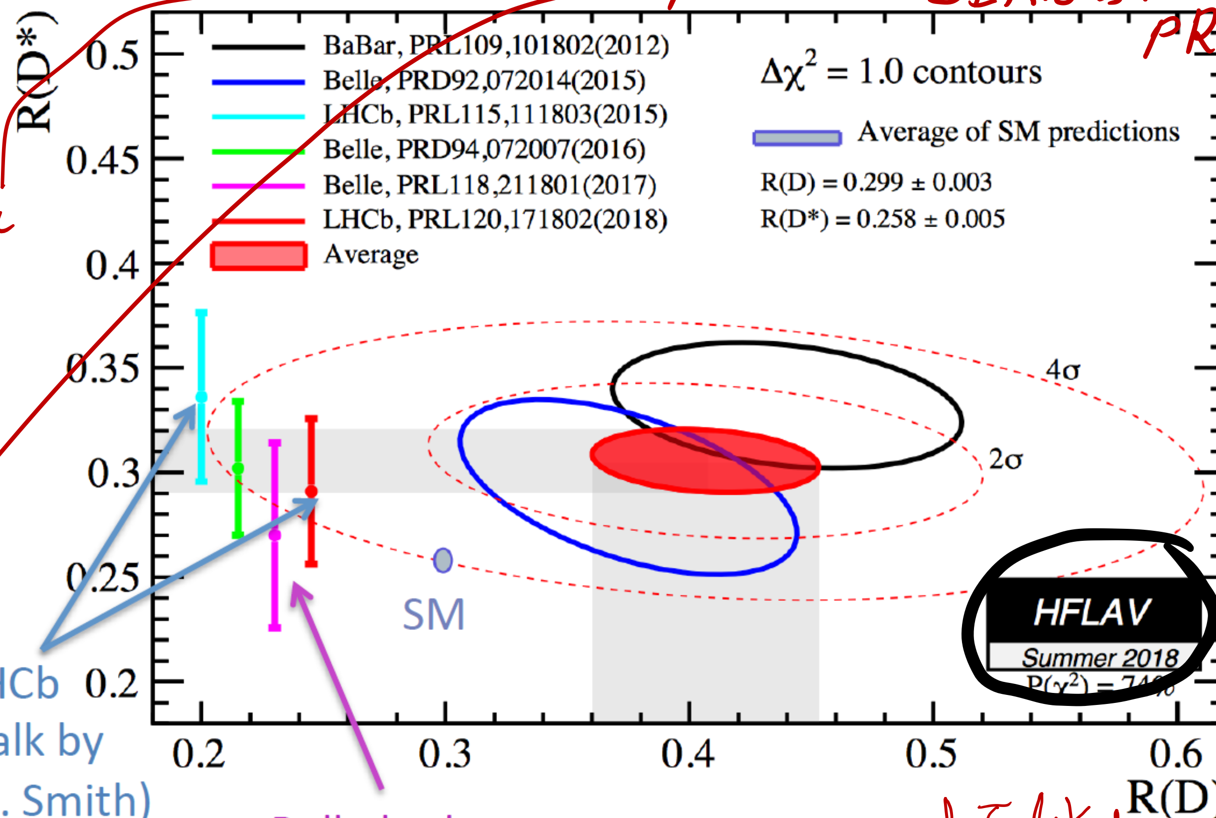
- ~4σ discrepancy from the SM remains
  - All the experiments show the larger $R\left(D^{(*)}\right)$ than the SM
- More precise measurements at Belle II and LHCb are essential

Belle deviations quite mild

Status of $R(D^{(*)})$ results







LHCb (talk by M. Smith)

Belle had. tag (τ polarization)

Deviation from SM prediction 3.9 σ

11

also WITZEL et al RBC–UKQCD

R_D Theory much cleaner but QED radiative corr needed. More expt effort on R_D needed

POTENTIALLY VERY SERIOUS EXPTAL PROBLEM

4% realistic

Serious

Likely also affects V_{cb}

also recoil τ likely problem

Theory errors Because D* has spin

v Likely OVERESTIMATE

A

B

28

Measurement of R(D) and R(D*) with a semileptonic tag at Belle

EW Moriond 2019

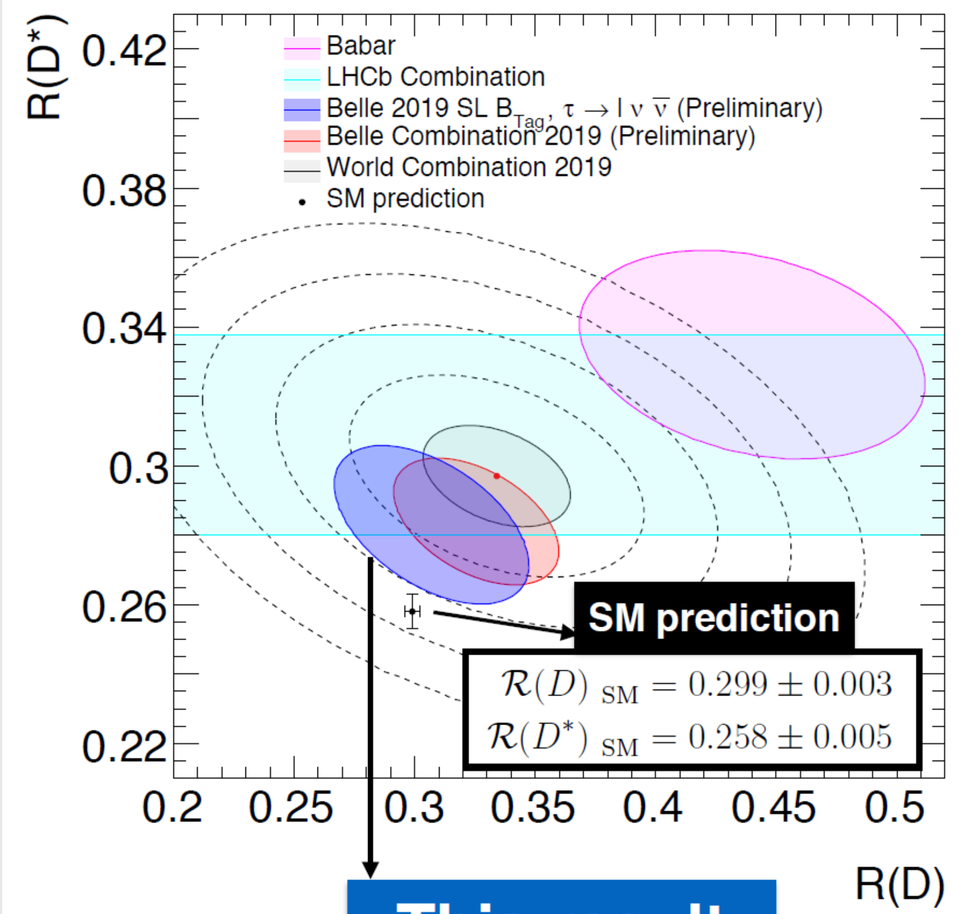
Giacomo Caria
on behalf of the Belle collaboration

54th Rencontres de Moriond, EW
22/03/2019

THE UNIVERSITY OF MELBOURNE

Conclusion / Preliminary $R(D^{(*)})$ averages

- **Most precise measurement** of R(D) and R(D*) to date
- First **R(D)** measurement performed with a **semileptonic tag**
- Results **compatible with SM** expectation within **1.2σ**
- **R(D) - R(D*) Belle average** is now within **2σ** of the SM prediction
- **R(D) - R(D*) exp. world average** tension with SM expectation **decreases from 3.8σ to 3.1σ**

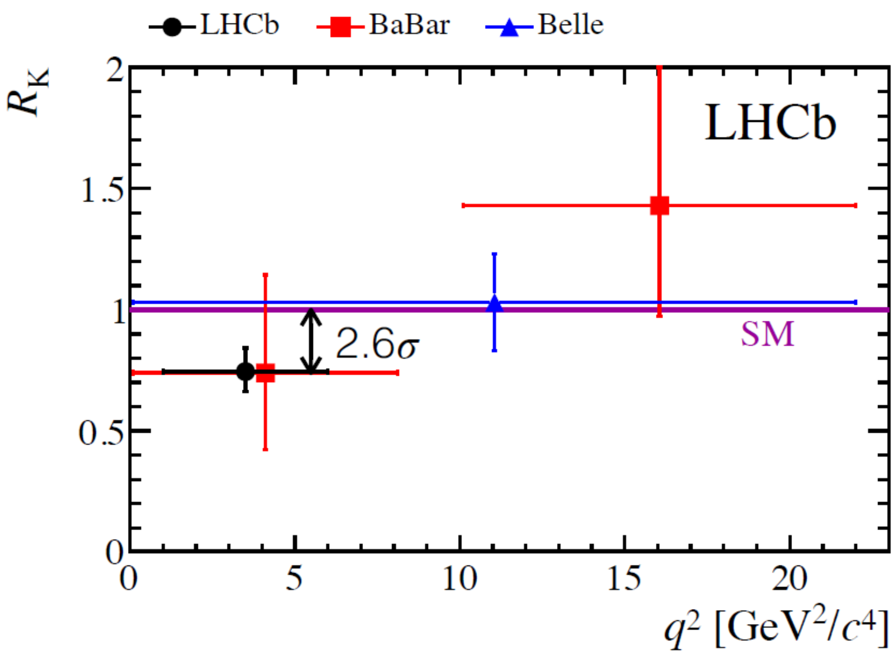


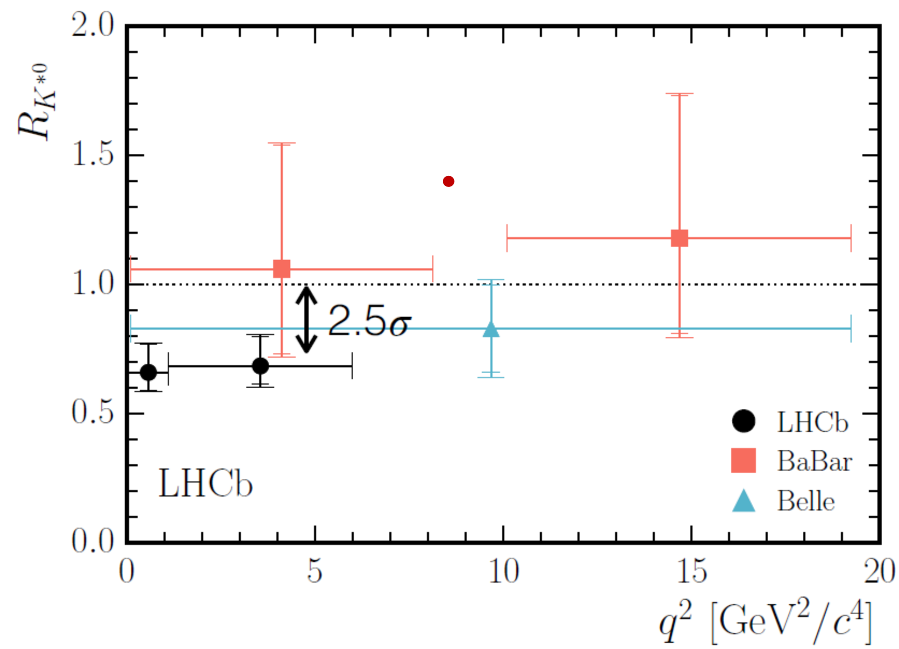
This result

$$\mathcal{R}(D) = 0.307 \pm 0.037 \pm 0.016$$
$$\mathcal{R}(D^*) = 0.283 \pm 0.018 \pm 0.014$$

Lepton universality tests

- We have interesting hints of non-universal lepton couplings in LHCb run 1 dataset:





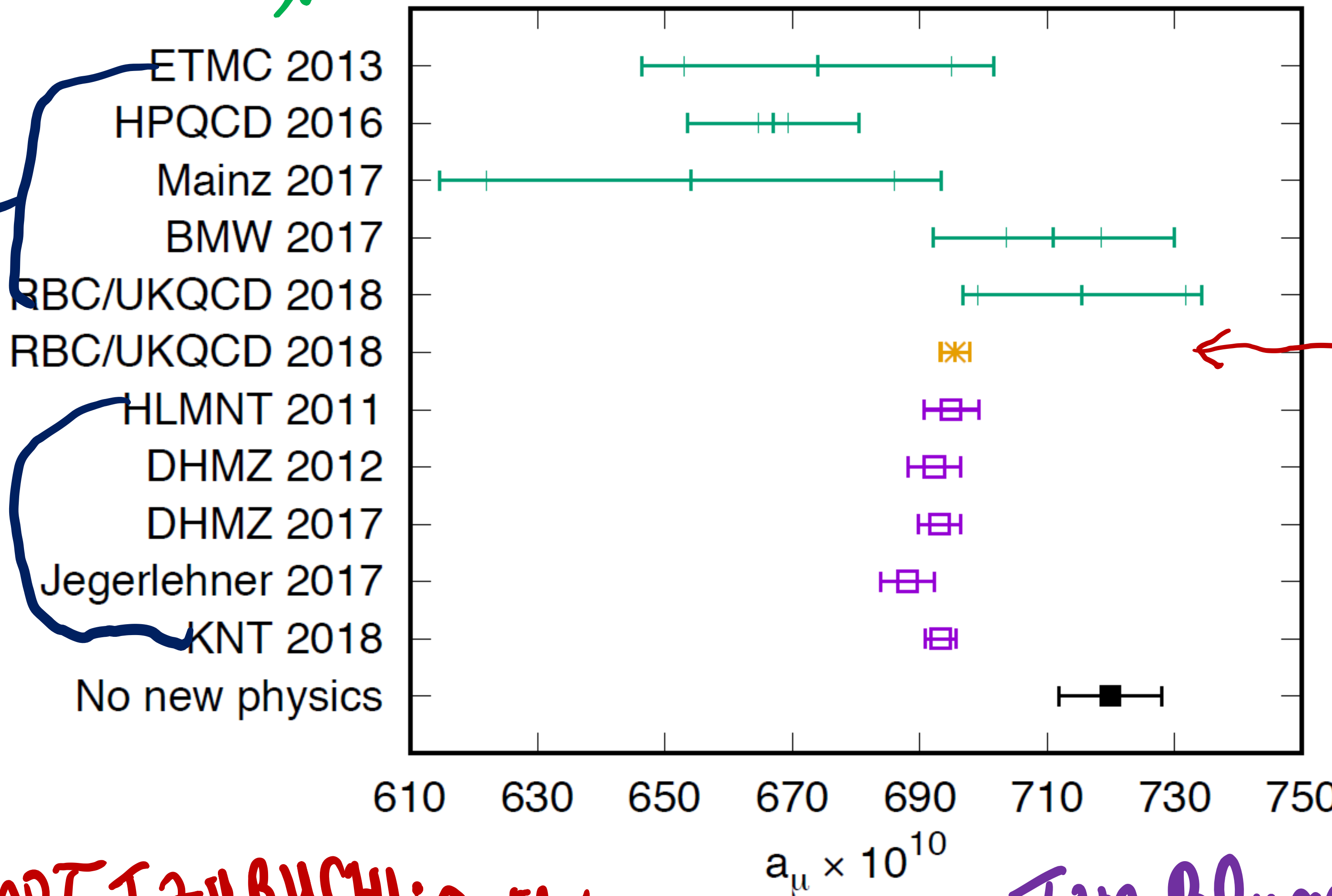
[LHCb , PRL113 (2014) 151601]
[LHCb, LHCb-PAPER-2017-013]
[BaBar, PRD 86 (2012) 032012]
[Belle, PRL 103 (2009) 171801]

Radiative Correction See Isidori et al

NB $R_K \simeq 0.8$ is a prediction of one class of model explaining the $B^0 \to K^{*0}\mu^+\mu^-$ angular observables, see L_μ - L_τ models **W. Altmannshofer et al. [PRD 89 (2014) 095033]**

$(g-2)_\mu$ on + off the Lattice

PURE Lattice



Pheno

C Lehner et al RBC-UKQCD HYBRID

C also T. IZUBUCHI; A. El-Khadra

Tom Blum Lattice ~2004

We need to improve the precision of our pure lattice result so that it can distinguish the "no new physics" results from the cluster of precise R-ratio results.

Possible sightings of new physics

- **An extremely important consequence of NP is that it is highly unlikely (i.e. unnatural) that it will not be accompanied by new CP-odd phase[s]….**

IN MEMORIAM

For many decades now, my professional life has centered around B-physics!

My 1st paper on B-PHYSICS

PRL

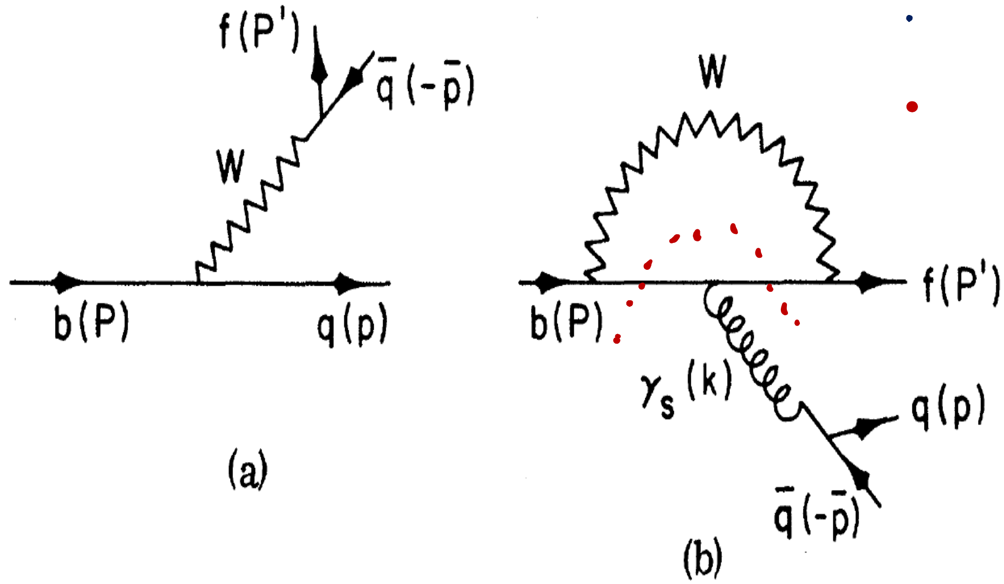
CP Noninvariance in the Decays of Heavy Charged Quark Systems

Myron Bander, D. Silverman, and A. Soni
Department of Physics, University of California, Irvine, California 92717

(Received 9 May 1979)

Within the context of a six-quark model combined with quantum chromodynamics we study the asymmetry in the decay of heavy charged mesons into a definite final state as compared with the charge-conjugated mode. We find that, in decays of mesons involving the *b* quark,

Simple ex. Of DCP in B-Physics: Tree-Penguin Interference



Bander, Silverman and A. S. PRL '79

"measurable asymmetries may arise. This would present the first evidence for *CP* noninvariance in charged systems."

$$A = |A_1| \exp[i(\delta_1 + \phi_1)] + |A_2| \exp[i(\delta_2 + \phi_2)]$$

$$\bar{A} = |A_1| \exp[i(\delta_1 - \phi_1)] + |A_2| \exp[i(\delta_2 - \phi_2)] \,.$$

$$\alpha_{PRA} = \frac{\mathcal{B}(B \to f) - \mathcal{B}(\bar{B} \to \bar{f})}{\mathcal{B}(B \to f) + \mathcal{B}(\bar{B} \to \bar{f})} = \frac{2|A_1|\,|A_2| \sin\delta \sin\phi}{|A_1|^2 + |A_2|^2 + 2|A_1|\,|A_2| \cos\delta \cos\phi},$$

Babar, Belle 1st obs ~2007

$$A_{CP}(B^0 \to K^+\pi^-) = -0.082 \pm 0.006$$

5 orders of mag ✗ ϵ'_K !!

By now many modes with 10%'s

REGRETTABLY still CANNOT BE USED TO RELIABLY TEST THE SM-CKM

A great personal treat; thanks to LHCb

ADS: $B^{\pm} \to Dh^{\pm}, D \to \pi^+ K^-$

$$A^{\pi K}_{\mathrm{ADS}(K)} = -0.403 \quad \pm 0.056 \quad \pm 0.011$$

8σ

Malcolm John@EW MORIOND '16

Huge *direct CP* [tailor made] ~20 ago!

ADS PRL'97

[Recall ε' ~ 10^{-6} !]

DELIBERATELY DESIGNED for MAXIMAL INTERFERENCE

DATA DRIVEN methods

ALSO ADS PRD~01

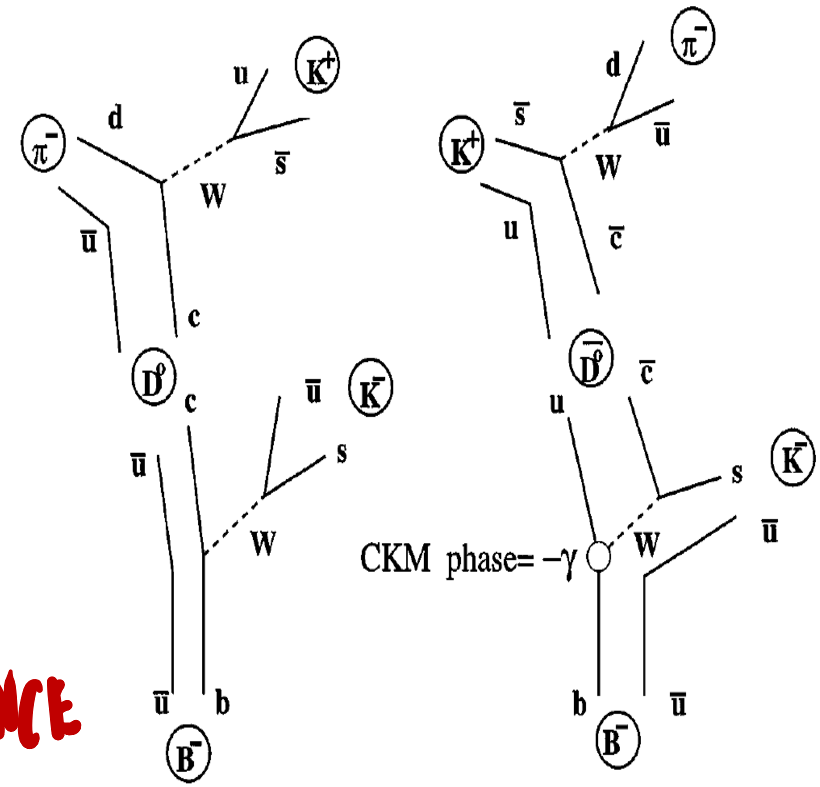
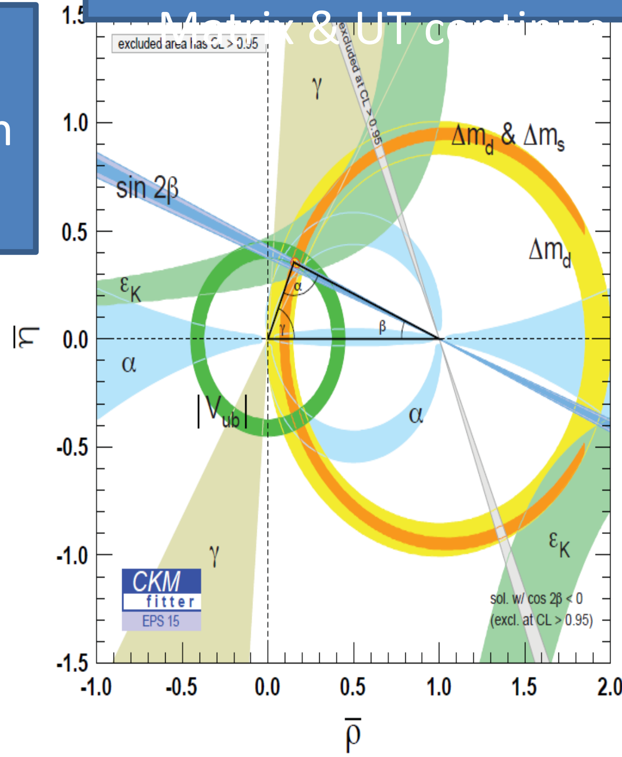


FIG. 1. Diagrams for the two interfering processes: $B^- \to K^- D^0$ (color-allowed) followed by $D^0 \to K^+\pi^-$ (doubly Cabibbo suppressed) and $B^- \to K^- \overline{D}^0$ (color-suppressed) followed by $\overline{D}^0 \to K^+\pi^-$ (Cabibbo allowed).

Efforts to overconstrain the CKM Matrix & UT continue

Andreas Hoecker & Malcolm John EW Moriond '16



Key new results from LHCb

DATA DRIVEN Methods

Precision on $\sin(2\beta)$ approaches that of B-factories: $0.73 \pm 0.04 \pm 0.02$

ITE ~ 1% Mannel et al

- A world-leading measurement of γ is made from a combination of LHCb analysis, concluding with

$$\gamma = 70.9^{+7.1}_{-8.5}$$

Brod Zupan'14 STD.

which improved the previous LHCb-only conclusion by 2°

CANDLE

- Inline with B-factory conclusions from $B \to DK$,
  - BaBar: $\gamma = (70 \pm 18)^\circ$
  - Belle: $\gamma = (73^{+13}_{-15})^\circ$

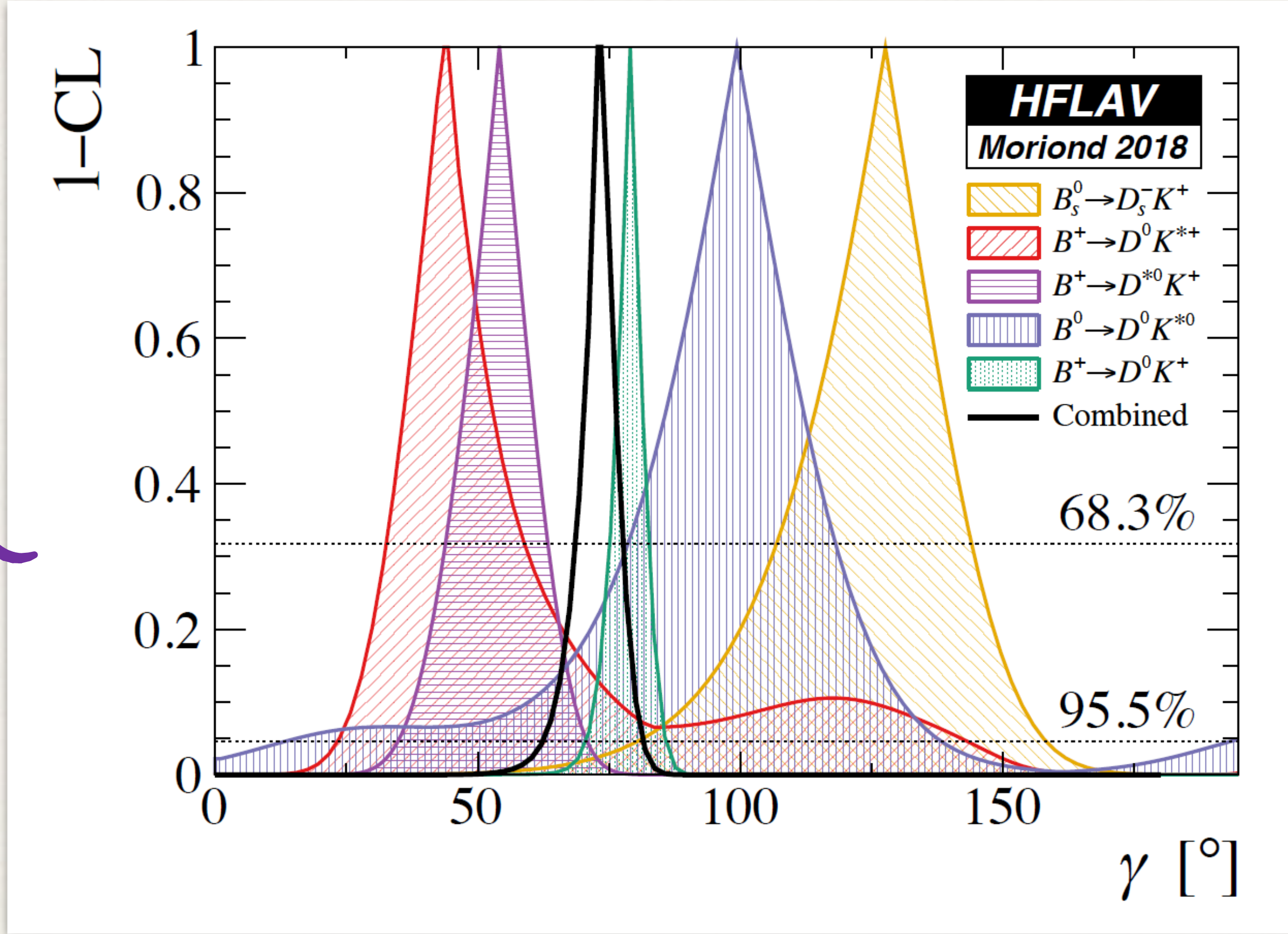
Compatible with SM-CKM to ~15% accuracy

O(5-10%) new physics is possible and is HUGE

BELLE-II & LHCb(upgrade) ~ δγ ~ 1°, still long way to go before ultimate precision

World average (HFLAV)

UTFIT: 65.8+-2.2; M. Bona fpcp2018



γ Now pretty well determined

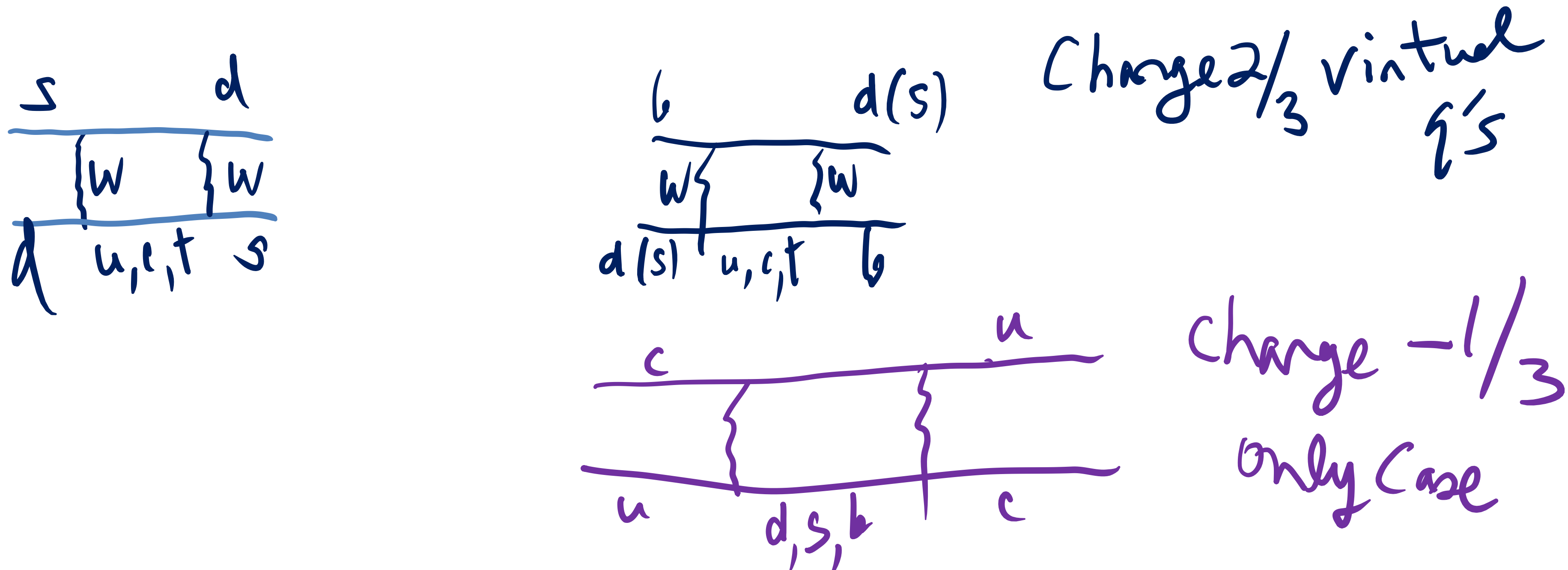
$$\gamma = (73.5^{+4.2}_{-5.1})^\circ$$

Naive 1.6σ divergence from indirect predictio

$$\gamma_{\text{indirect}} = (65.3^{+1.0}_{-2.5})^\circ \quad \text{(CKMfitter)}$$

Charm system is unique

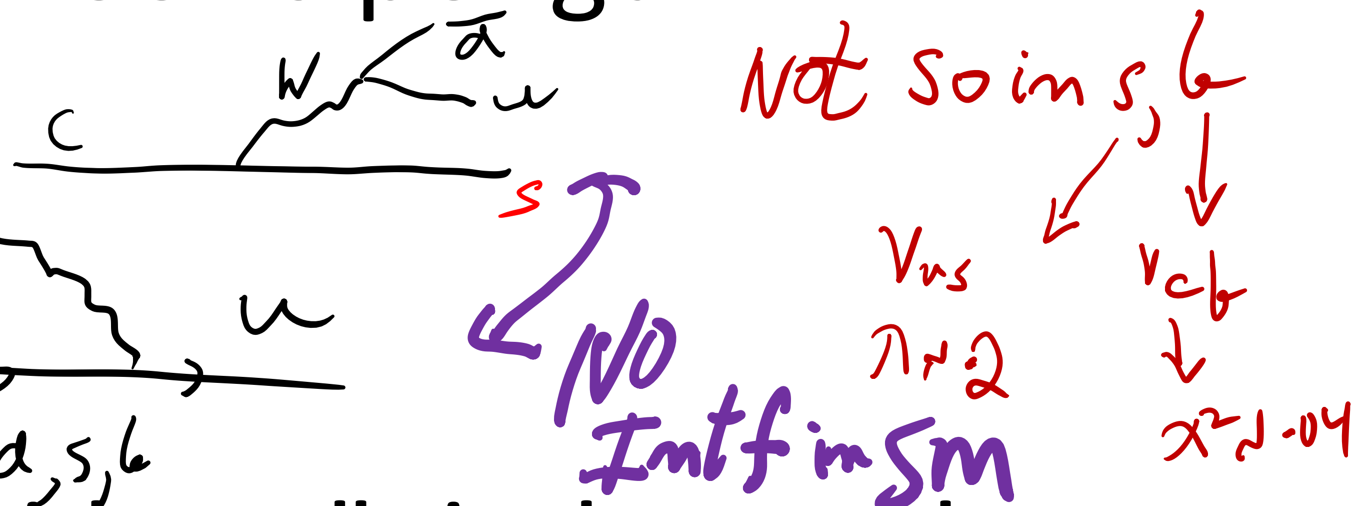
- **Distinct from K and B-mixings**

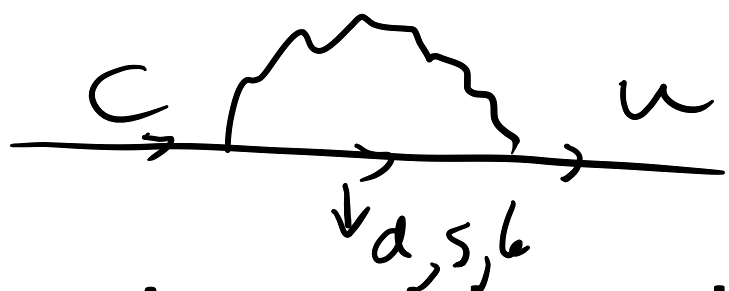


Delta F=2 mixings are an extremely valuable treasure in providing stringent constraints on NP scenarios……….

Tree vs penguin

- **CBA tree**





- **Penguin..partial cancellation between d,s**
- **Also $(mb/mW)^2 << (mt/mW)^2$**
- **So corrections due to c-penguin are much muted compared K and B decays**
- **Charm penguin is universal (~20%) due SU(3) flavor symmetry [not so b-penguin]**

In charm decays the tree rules!

- **Tree goes as lambda ~0.22** in charm decays
- **Penguin as lamda^5 so is exceedingly small**
- **Moreover lattice studies have demonstrated over and over again even for K =>pi pi decays,**

And Delta I=1/2 enhancement,

Penguin contribution is <O(%) of tree at scales >~1.5 GeV

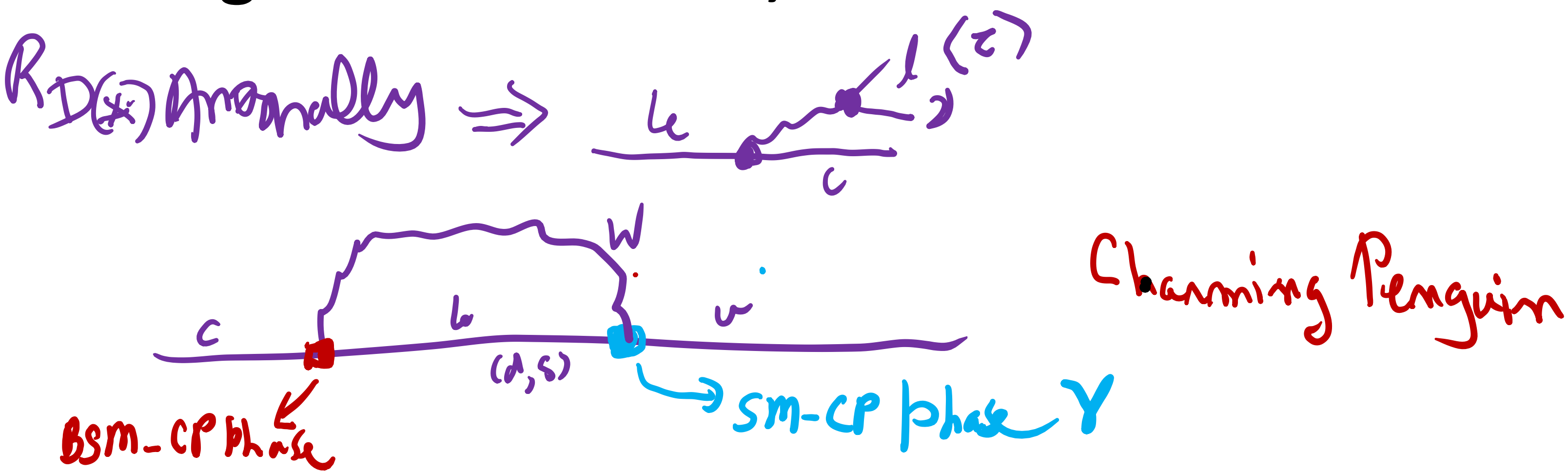
$V_{ub} \sim \lambda^3$; $V_{cb} \sim \lambda^2$

Thus for charm T >> P in so far as rates go

I. OPTIMIZING SEARCH STRATEGIES FOR DIR-CP IN CHARM DECAYS

c.f. also A. Soni CKM'18; 6th Flavor Fact KEK FEB'19

Bearing all that in mind, Let's stare some more at c-penguin



- cb has no SM-CP ...whereas likely it has BSM-CP

  ↳ Because of B→Dτν anomally

- ub does have SM-CP ...whereas likely it has no BSM-CP
- **MORAL...no matter what charm –penguin is; it is essential for DCP observation**

Partial rate asymmetry

EWP ⇒ 0
∴ No $\Delta I = 1/2$ enh
m_b not m_t
No 8,8 enh

$P \to \sum O^J_{4q}$, $J = 3,4,5,6$ | $T = \sum O^J_{4q}$, $J = 1,2$

$$\alpha_{PRA} = [Br[i \to f] - Br[\bar{i} \to \bar{f}]]/[Br[i \to f] + Br[\bar{i} \to \bar{f}]]$$
$$= 2[|P|(\sin\delta)(\sin\gamma)/|T|] \quad (7)$$

δ = CP even $\pi\pi$, KK, phase; QCD
Lattice

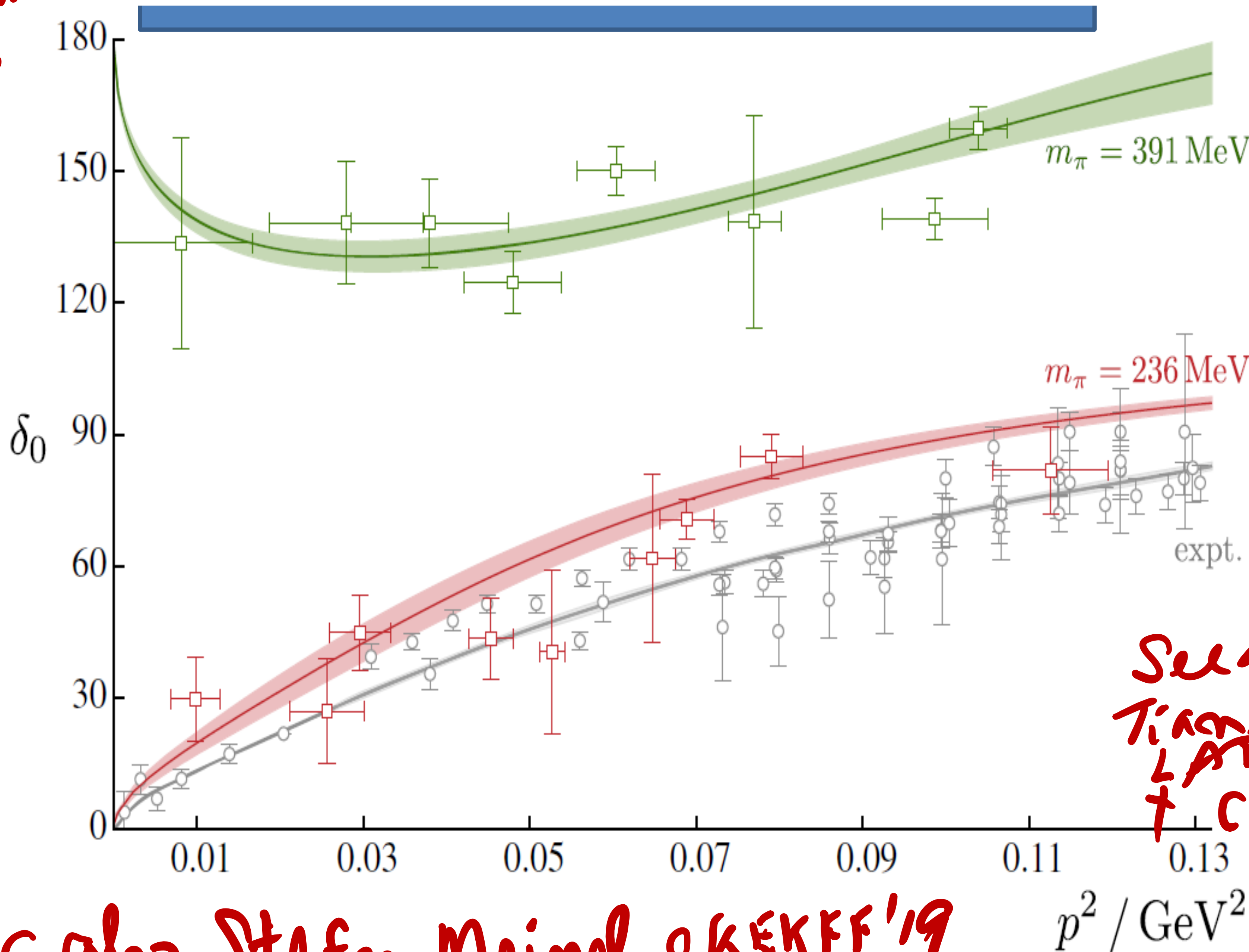
$\downarrow$ CP-odd phase
$\gamma \sim 73^\circ$
$\sin\gamma \simeq 0.956$!

JLAB Lattice group

PRL'17

Isoscalar $\pi\pi$ Scattering and the σ Meson Resonance from QCD

Raul A. Briceño,[1,*] Jozef J. Dudek,[1,2,†] Robert G. Edwards,[1,‡] and David J. Wilson[3,§]
(for the Hadron Spectrum Collaboration)



See also Tianle W LAT'19 + CK

c also Stefan Meinel @ KEKFF'19

Tianle Wang [RBC-UKQCD]
@ LATT2015 Proc

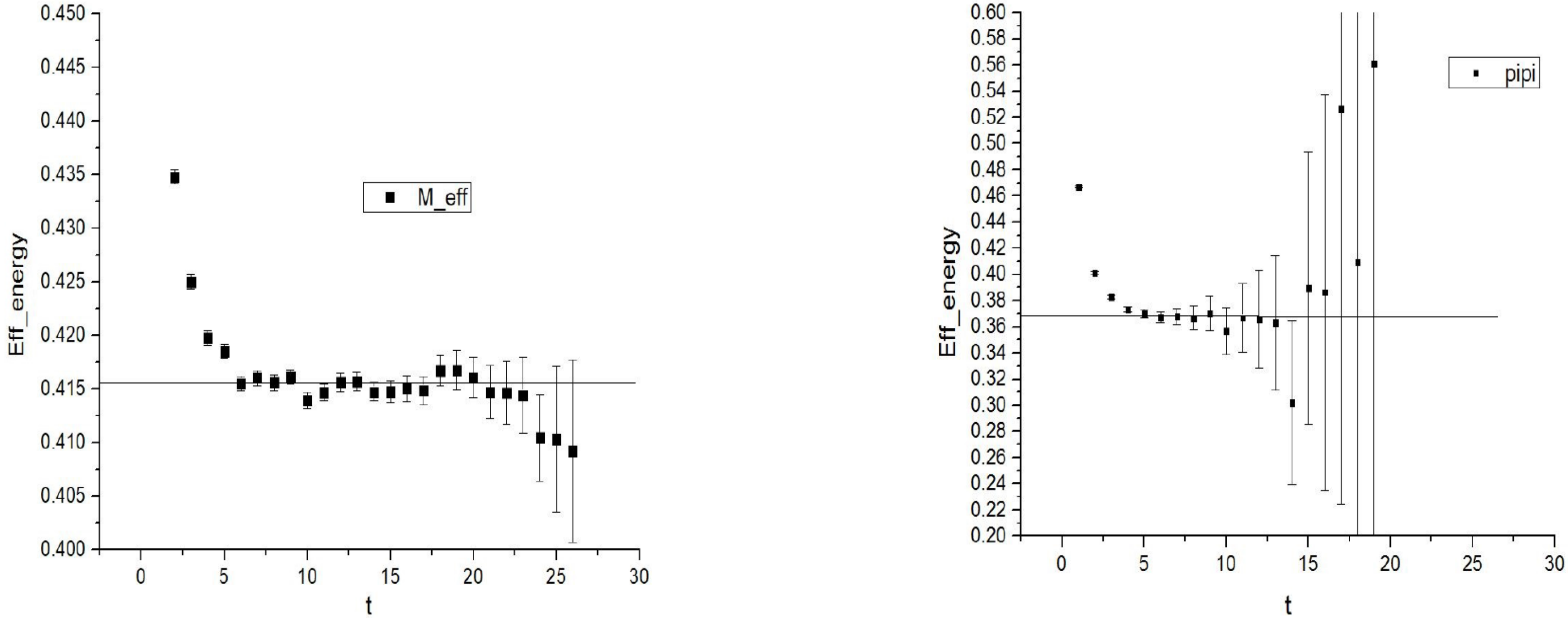


Figure 3: Left: effective mass plot for I=2 pipi correlator; right: effective mass plot for I=0 pipi correlator.

RBC-UKQCD phases WIP

- From diff points of view:
- Mattia Bruno
- Dan Hoying
- Chris Kelly
- Aaron Meyer
- Tianle Wang
- Applications for K=> pi pi & Beyond

Understanding ΔA_{CP}^{dir}

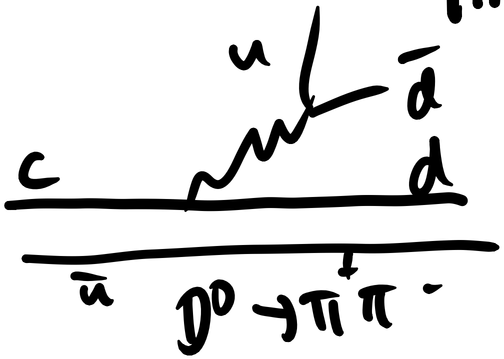
LHCb observable

$$\Delta A_{CP}^{dir} \equiv A_{CP}^{dir}(K^+K^-) - A_{CP}^{dir}(\pi^+\pi^-)$$

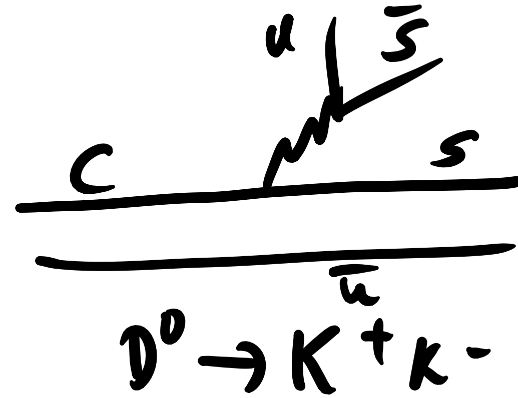
↓ PRA in K^+K^-

↓ PRA in $\pi^+\pi^-$

Implications of CPT



ILLUSTRATIVE EXAMPLE



4

$\Gamma_D = \Gamma_{\bar{D}}$

See ATWOOD + AS PTEP 2012

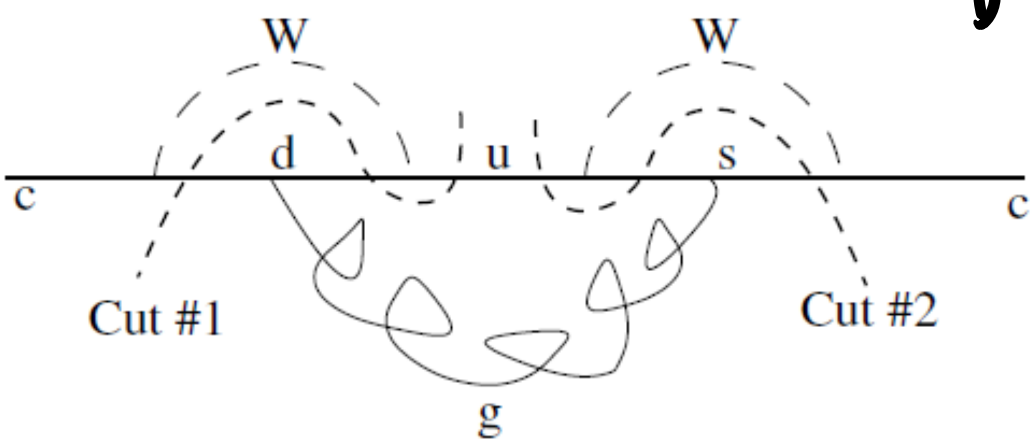


FIG. 1: The unitarity graph showing the CPT identity Eqn. 6 for the quark level SCS charm decay. Cut #1 indicated in the figure shows the case where the decay is $c \to d\bar{d}u$ with a $s\bar{s}u$ intermediate state providing the strong phase. Conversely, cut #2 indicated in the figure shows the case where the decay is $c \to s\bar{s}u$ with a $d\bar{d}u$ intermediate state providing the strong phase. The interfering tree graphs are not shown but are implied

$$\text{CPT} \Rightarrow \sum_X \Delta\Gamma(D \to X) \equiv \sum_X [\Gamma(D \to X) - \Gamma(\bar{D} \to \bar{X})] = 0$$

AT the quark level:

$$\Delta\Gamma(c \to d\bar{d}u) = -\Delta\Gamma(c \to s\bar{s}u).$$

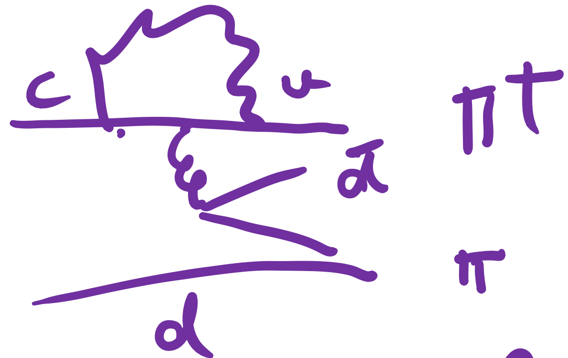
$\pi^+\pi^-$; K^+K^-

Due to CPT restrictions

BR $D^0 \to K\bar{K} \sim 4\times10^{-3}$

$D^0 \to \pi\pi \quad 1.4\times10^{-3}$

$T_{\pi\pi}$



$$\alpha_{\pi\pi} \Rightarrow \frac{\mathrm{Im}\,P * T_{\pi\pi}}{|T_{\pi\pi}|^2} \sim \frac{\mathrm{Im}\,P}{T_{\pi\pi}} \sim \frac{\mathrm{Im}\,P}{\sqrt{B \sim D \to \pi\pi}}$$

$$\frac{|\alpha_{\pi\pi}|}{|\alpha_{KK}|} \sim \sqrt{\frac{4}{1.4}} \sim 1.7$$

$$\alpha_{KK} \Rightarrow \frac{\mathrm{Im}\,P * T_{KK}}{|T_{KK}|^2} \sim \frac{\mathrm{Im}\,P}{T_{KK}} \sim \frac{\mathrm{Im}\,P}{\sqrt{B \sim D \to KK}}$$

PLB 767 (2017) 177-187

$A_{CP}(D^0 \rightarrow K^+K^-)$ & $A_{CP}(D^0 \rightarrow \pi^+\pi^-)$

- Individual A_{CP}(KK), pion-tagged sample

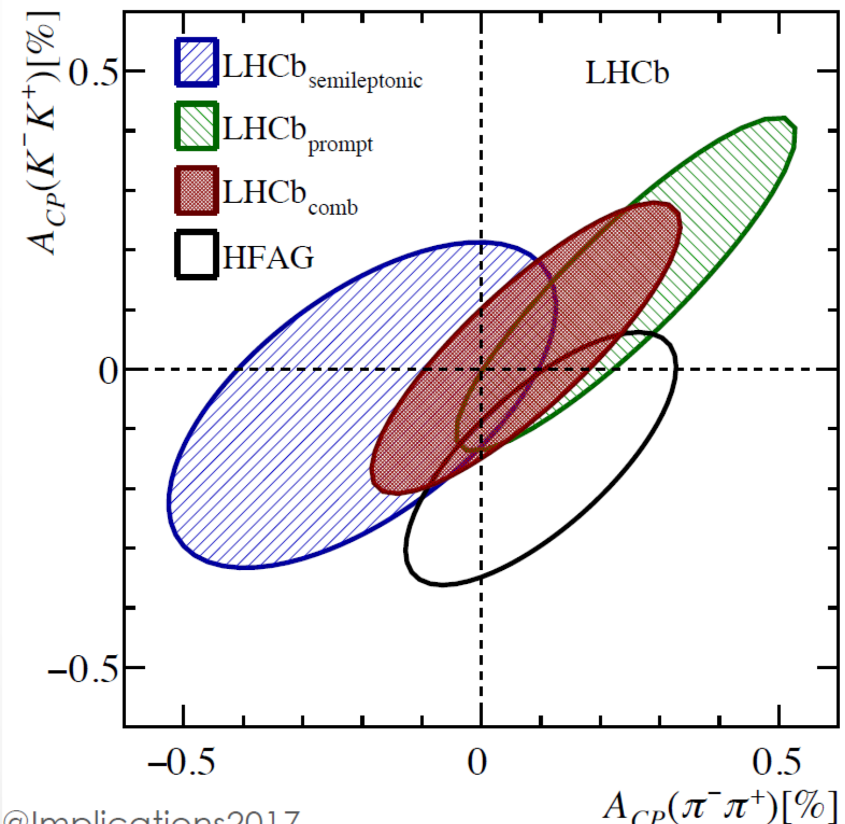
$$A_{CP}(K^+K^-) = (0.14 \pm 0.15 \pm 0.10)\%$$

- Combine with ΔA_{CP} ⇨

$$A_{CP}(\pi^+\pi^-) = A_{CP}(K^+K^-) - \Delta A_{CP} = (0.24 \pm 0.15 \pm 0.11)\%$$

± 0.15%

Central values seem consistent with expectation from CPT but errors large



- Combine with results from muon-tagged sample JHEP07, 041 (2014)
  ⇨ LHCb combination

- Both A_{CP}'s consistent with zero

DeltaA_CP likely close to current value i.e. ~ fewX10^{-3}

Results

NEW

LHCb-PAPER-2019-006

$$\Delta A_{CP}^{\pi-\text{tagged}} = [-18.2 \pm 3.2\,(\text{stat.}) \pm 0.9\,(\text{syst.})] \times 10^{-4}$$

$$\Delta A_{CP}^{\mu-\text{tagged}} = [-9 \pm 8\,(\text{stat.}) \pm 5\,(\text{syst.})] \times 10^{-4}$$

- Compatible with **previous** LHCb results and the **WA**
- **Combination** with LHCb Run 1 gives:

$$\boldsymbol{\Delta A_{CP} = (-15.4 \pm 2.9)\times 10^{-4}}$$

CP violation observed at $\boldsymbol{5.3\sigma}$!!

F. Betti - INFN Bologna, University of Bologna Moriond EW 2019 - 21/03/2019 24

SM expectation…DCP

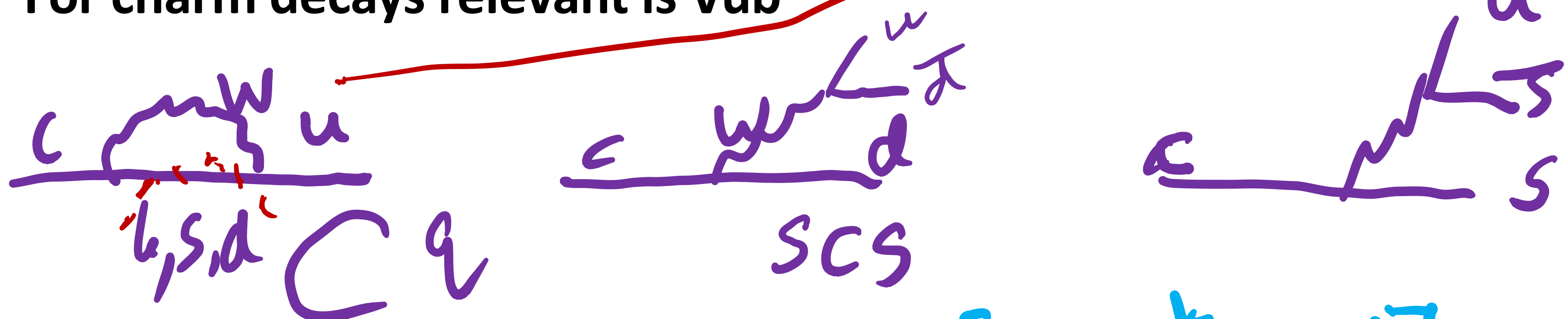
- Dir CP….. See Bander, Silverman + AS, PRL 1979 for DCP when

mq >> lamda_QCD…anticipate large corrections for charm from s-quark[K-decays]

- Key points: Penguin-Tree interference; SCS modes……Hall mark of BSS'79
- Need suitable simple changes
- SM CKM phase either in Vub or in Vtd
- For charm decays relevant is Vub

non-perturbative

$m_c^2 > 4[m_s^2, m_d^2]$



4CLA → DCP ~ $\frac{Im[V_{cb} V_{ub}^* * \lambda]}{\lambda^2} \sim \lambda^4 \sim 10^{-3}$

→ K^+K^-, $\pi^+\pi^-$

Enhance by CLS Tree etc $\lesssim N*10^{-3} \lesssim 10^{-2}$!!

→ $\pi^0\pi^0$

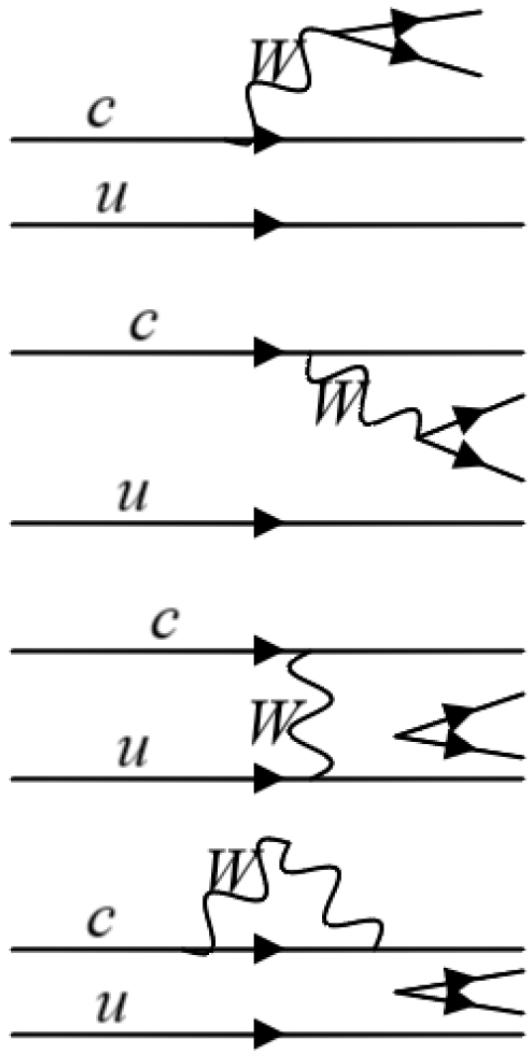
DIFFICULT

DOM. Cont.

$\pi^+\pi^-$, K^+K^- — CLA

$\pi^0\pi^0$ — CLS

$K_S K_S$ — W-Anni



$P \lll T_{CLA}$

$\Rightarrow BR \propto |T|^2$

FIG. 1. Some diagrams contributing to charm decay; gluons causing pair creation are not shown. Top to bottom: color-allowed tree; color-suppressed tree; weak annihilation and penguin. Since $\alpha_{s(m_{charm})}$ is not that small, these distinct topologies especially for the color-suppressed tree and the weak annihilation can receive large corrections due to final state interactions.

Published for SISSA by Springer

Received: *March 4, 2012*
Revised: *April 22, 2012*
Accepted: *May 16, 2012*
Published: *June 1, 2012*

Repercussions of flavour symmetry breaking on CP violation in D-meson decays

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Abstract: We investigate to what extent the recently measured value for a non-vanishing direct CP asymmetry in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays can be accommodated in the Standard Model (SM) or extensions with a constrained flavour sector, for instance from a sequential 4^{th} generation of quarks (4G). From the comparison with $D^0 \to K^-\pi^+$ branching ratios, we establish large U-spin symmetry ($d \leftrightarrow s$) breaking effects with large strong phases between different interfering amplitudes. On the basis of conservative estimates on amplitude ratios — which are supported by an analysis of the breaking of a $c \leftrightarrow u$ symmetry in non-leptonic B^0 decays — we find that, in the SM, direct CP asymmetries in the $\pi^+\pi^-$ or K^+K^- modes (or in their difference) of the order of several per mille are still plausible. Due to the constraints on the new CP phases in the 4G model, only moderate effects compared to the SM estimates are possible. We suggest CP studies at LHCb as well as at (Super)B-factories of several distinctive modes, such as $D^+ \to \bar{K}^{(*)0}\pi^+, \phi\pi^+$ and $D_s \to K^{(*)0}\pi^+, \phi\pi^+(K^+)$ etc., which should shed more light on the short- and long-distance

JHEP06(2012)007

Summary on charm CP

- Useful Inequality [ABS mays]

$ACP(K^+K^-) \le ACP(\pi^+ \pi^-) \le ACP(\pi^0 \pi^0) \le ACP(K_s^0 K_s^0)$

- ΔACP is expected to be close to its current limit around few x 10^{-3} and in SM its extremely difficult for it to get to 1%. ← FNS JHEP '12
- ACP(2 pi0), ACP(2Ks) may well be around ½ to 1%
- LHCb, Belle-II in a few years should be able to reduce the current error (~0.15%) by a factor of few and thus see non-vanishing asymmetries in several channels
- Multibody modes are very powerful for exploiting the full power of CPV phenomena

Lattice & the IF

- Search for NP via redundant precise measurements & precise lattice studies via the UT
  impt to make further progress on LATTICE ∵ of Belle II, LHCb.....
- lattice on-going [for a long, long, long time] eps' effort
  See CK
- progress in non-local, LD, Matrix elements
  See BW
- some new applications of LQCD to pheno

HOW BEST TO USE EXPTAL DATA ?

Starting pts for the onward march to precise determination of UT

Lattice computation of the decay constants of B and D mesons

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(Received 1 July 1993)

Semileptonic decays on the lattice: The exclusive 0^- to 0^- case

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(Received 21 December 1990)

PHYSICAL REVIEW D VOLUME 45, NUMBER 3 1 FEBRUARY 1992

Lattice study of semileptonic decays of charm mesons into vector mesons

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(Received 30 September 1991)

We present our lattice calculation of the semileptonic form factors for the decays $D \to K^*$, $D_s \to \phi$, and $D \to \rho$ using Wilson fermions on a $24^3 \times 39$ lattice at $\beta = 6.0$ with 8 quenched configurations. For $D \to K^*$, we find for the ratio of axial form factors $A_2(0)/A_1(0) = 0.70 \pm 0.16^{+0.20}_{-0.15}$. Results for other form factors and ratios are also given

PHYSICAL REVIEW D, VOLUME 58, 014501

SU(3) flavor breaking in hadronic matrix elements for B-$\bar{B}$ oscillations

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(Received 28 January 1998; published 5 May 1998)

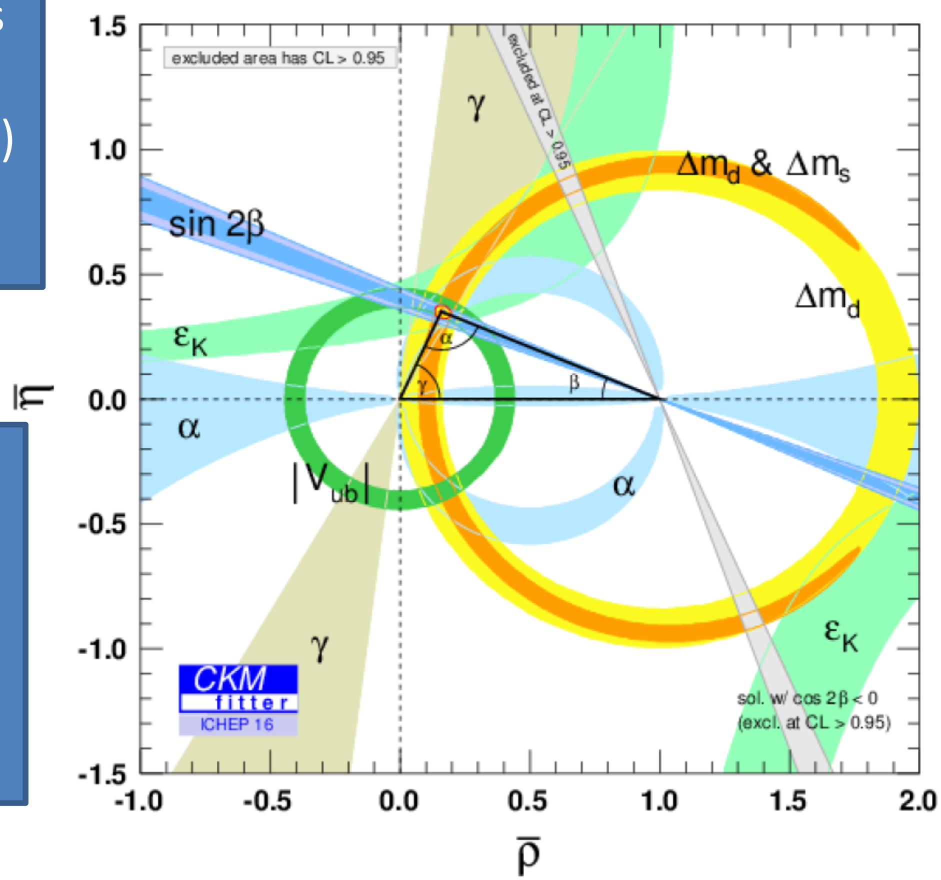
Later ΔM_s CDF, D0

PIONEERING WORKS leading to modern Day UT ?

Use exptal data + lattice WME to test SM & search for new physics

http://ckmfitter.in2p3.fr
see also http://www.utfit.org

Looks great; but looks can be deceiving…
In fact at level of O(2σ) tension(s) exist



O(10-15%) new physics is possible and is HUGE!

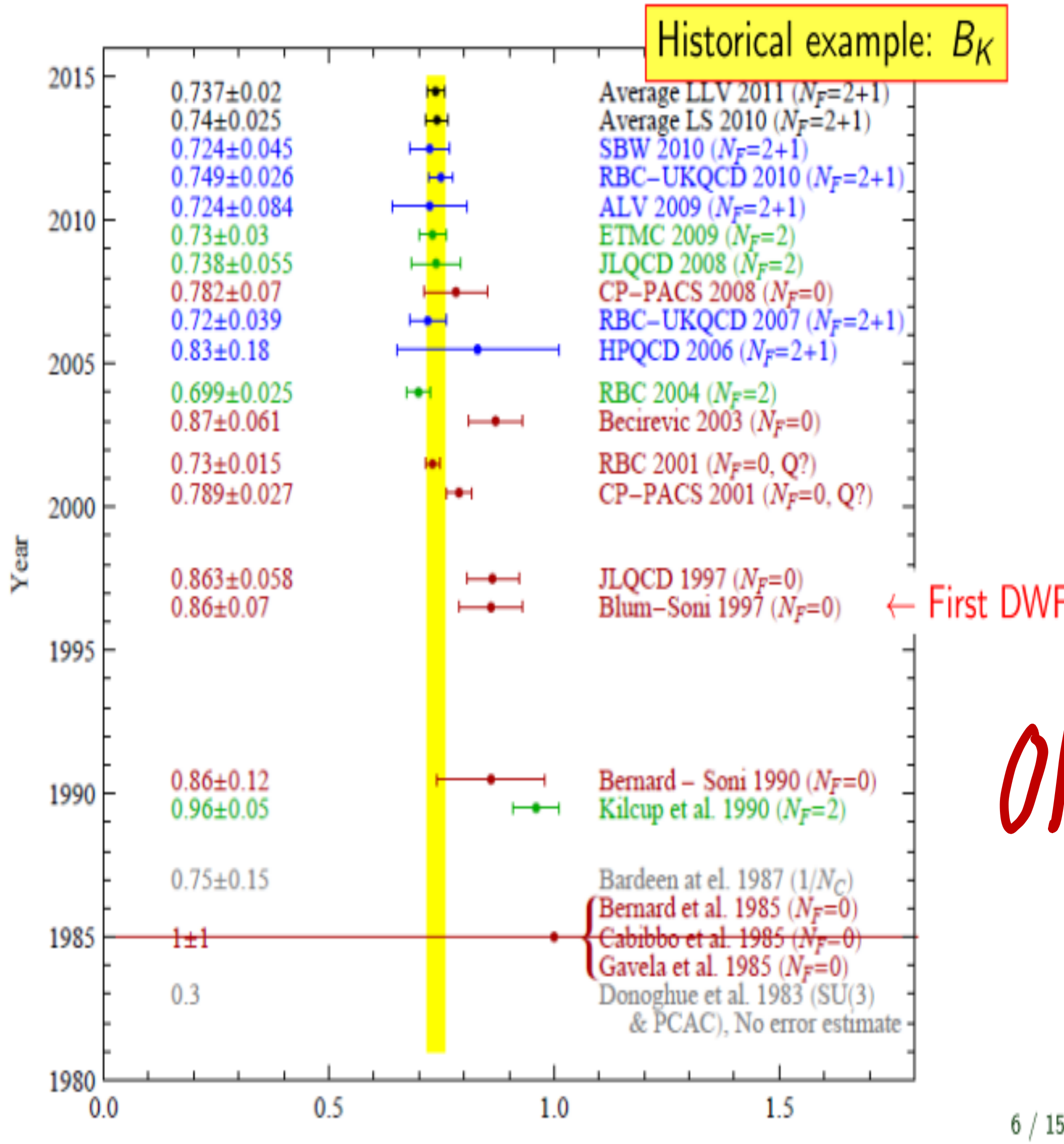
Courtesy: Tom Browder

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

Power of the lattice: Only method to systematically reduce the NP error!



AB-initio Calculat

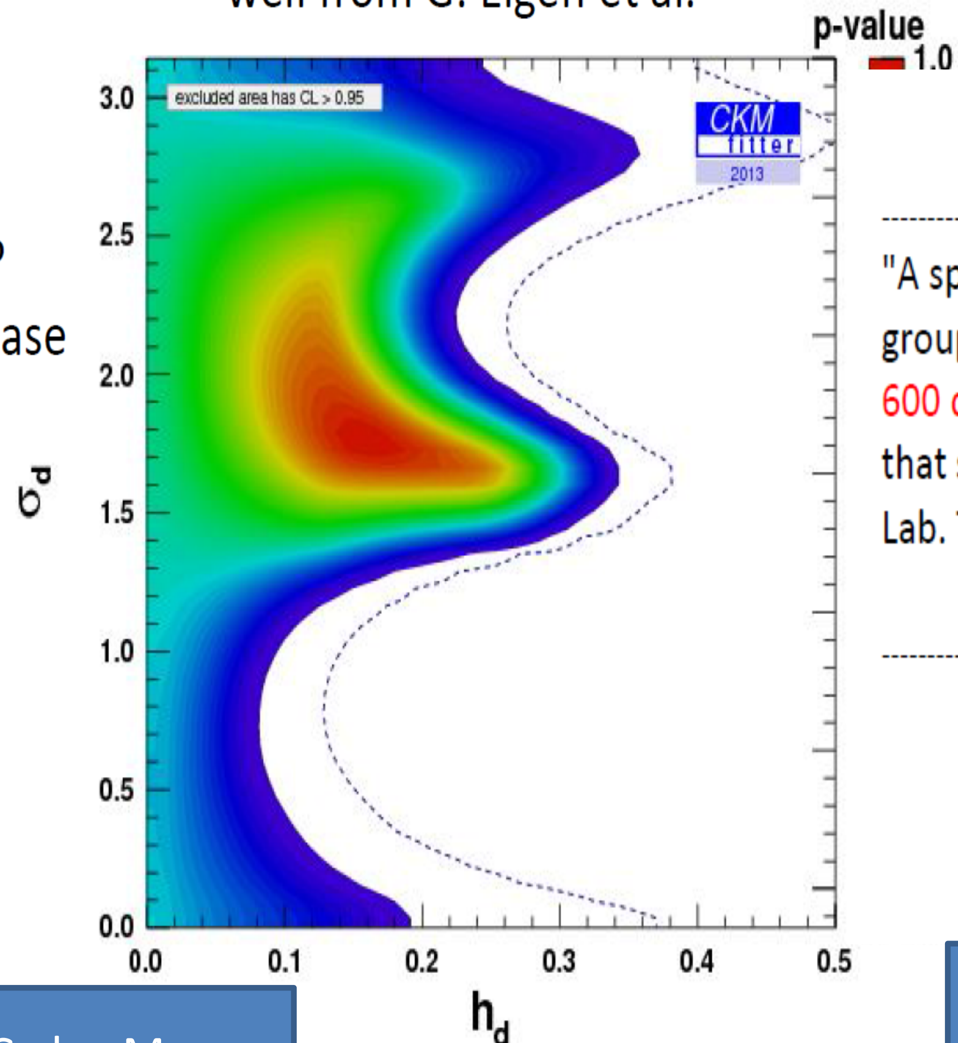
$$B_K = \frac{\langle K | (\bar{s}d)^2 | \bar{K} \rangle}{8/3 \, f_K^2 \, m_K^2}$$

ONE ILLUSTRATION

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

Current O(few%) tests are far away from O(0.1%) asymmetry in KL=>pi pi

NP Phase



NP/SM amplitude ratio

C also Marco C, Monika B….

A lesson from history (I)

Courtesy of Tom Browder

"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 ?

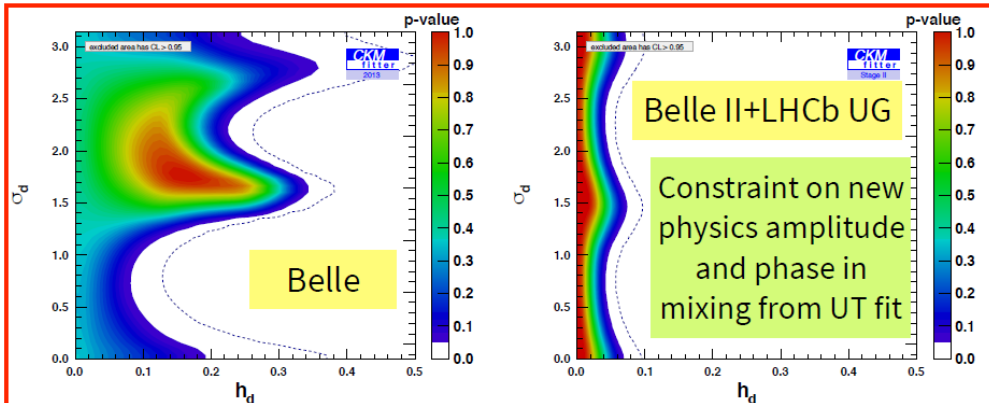
Had KL=>pi pi been abandoned, history of Particle Physics would have been significantly altered!

V_{CKM} - Summary

URQUIJO @ ICHEP2018

- **|V_{cb}| puzzle addressed by Belle**
  - **$B \to D^{(*)} \tau \nu$ anomaly needs new $B \to D^{**} l \nu$ background studies**
- |V_{ub}|/|V_{cb}| at LHCb has **better understood form factors!**
- |V_{ub}| **inclusive-exclusive puzzle** - final B-factory results awaited.
- |V_{cd}| & |V_{cs}| direct constraints from BES III are world best. **Outstanding test of LQCD! No LFUV found.**

- **CPV for SM phase measurements (WA HFLAV)**
  - $\sin 2\Phi_1 = 0.70 \pm 0.02$
  - $\Phi_2 = (84.9^{+5.1}_{-4.5})°$
  - **$\Phi_3 = (73.5^{+4.2}_{-5.1})°$**
  - All measurements are statistics limited.
- **CPV for new physics searches:**
  - Large local asymmetries. Switching gear to amplitude analyses.
  - Baryon decays a new window to CPV (see backup)
  - $\Phi_s = -0.021 \pm 0.031$ WA HFLAV 2018 (see backup)



$$M_{12}^{d,s} = (M_{12}^{d,s})_{\rm SM} \times \left(1 + h_{d,s} e^{2i\sigma_{d,s}}\right)$$

- **LHCb upgrade & Belle II will push 1 order of magnitude further on searches for CPV sources. 20-30% NP amplitude still allowed in CKM ΔB=2.** !!

ICHEP Seoul 2018 Phillip URQUIJO 23 THE UNIVERSITY OF MELBOURNE

IMPROVED LATTICE INPUT in coming years VITAL

NON-LOCAL MATRIX ELEMENTS EVALUATION….1ST APPLICATION TO B(D)$_{(S)}$ - PHYSICS

similar to Δm_K Bigeng W talk

ALSO $\pi^0 \to \gamma\gamma$ X_u Feng...

Testing LUV in the era of Belle-II

- II. **On the lattice technical front, RBC-UKQCD collab**

has developed the methodology over the past ~6 years for calculating from 1st principles contributions from non-local operators

- **Here we illustrate this use in the simplest example that can have important phenomenological impact in light of larger data samples that will become available in the era of Belle-II**
- **The simplest illustrative reaction to display developments in the exptal and in the lattice front that we choose is B,Ds =>** $\tau/\ell \; \nu \; \gamma$
- **Lets start with a very simple observation that LUV is very difficult to test with respectable accuracy via the simplest reaction**
- **Br** $B \to \tau\nu/\mu\nu$ **because the denominator suffers from severe helicity suppression. Indeed,**
- **Br[B+ =>mu+ nu] ~ 2 X 10^-7**
- **Note, however that naïve models seem to suggest**
- **Br [B => mu nu gamma]/Br[B=> mu nu] ~16**

$[B \Rightarrow e \nu \gamma]/[B \to e \nu] \sim 5 \times 10^5$!

→ Atwood, Eilam, AS hep-ph/9411367

$Br(B \to \ell \nu \gamma)_6 \sim 3 \times 10^{-6}$

$Br(D_s \to \ell \nu \gamma) \sim 2 \times 10^{-5}$

Radiative leptonic decays of heavy-light mesons

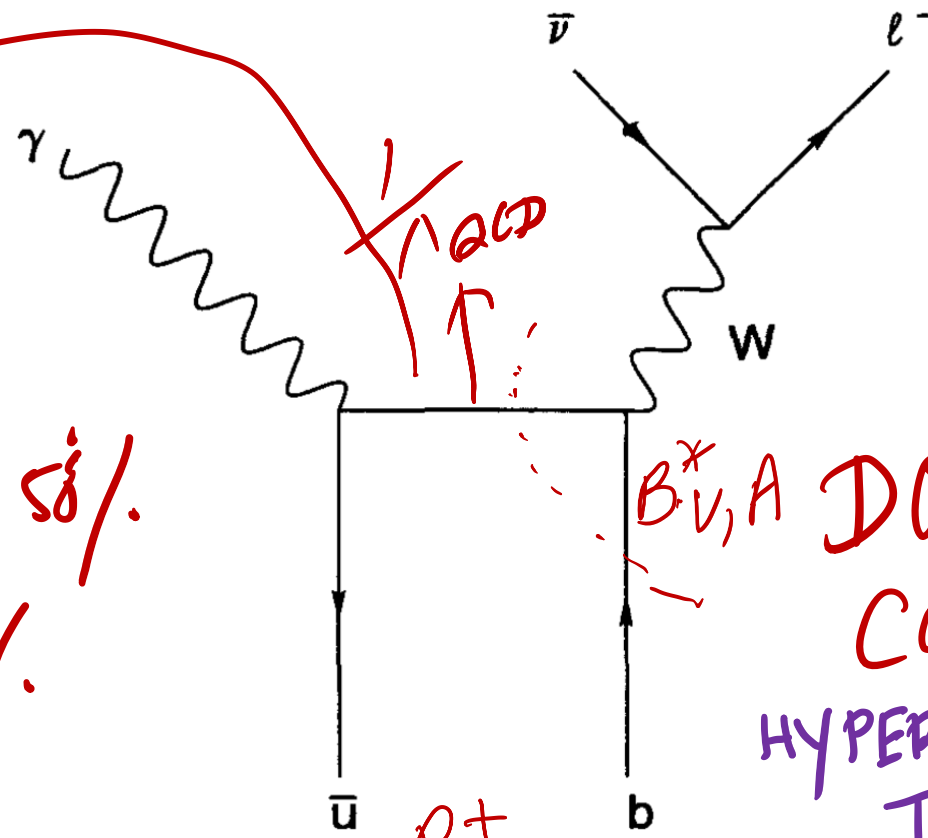


Fig. 1. Feynman graph for the dominant contribution to $B \to \ell\nu\gamma$.

Non-local [RBC-UKQCD]
Δm_K → Bigeng ~ 50%
ϵ_K^{LD} ~ 5-10%
$K^+ \to \pi^+ \nu\bar{\nu}$ X_u ~ 5-10%

$1/\Lambda_{QCD}$
$B^*_{V,A}$ DOMINANT Contribution
HYPERFINE Transition
B^+
+ . . . .

c. also AOKI + X. F + S.H. . . . $\pi^0 \to 2\gamma$ PRL 2012

BSS PRL '80

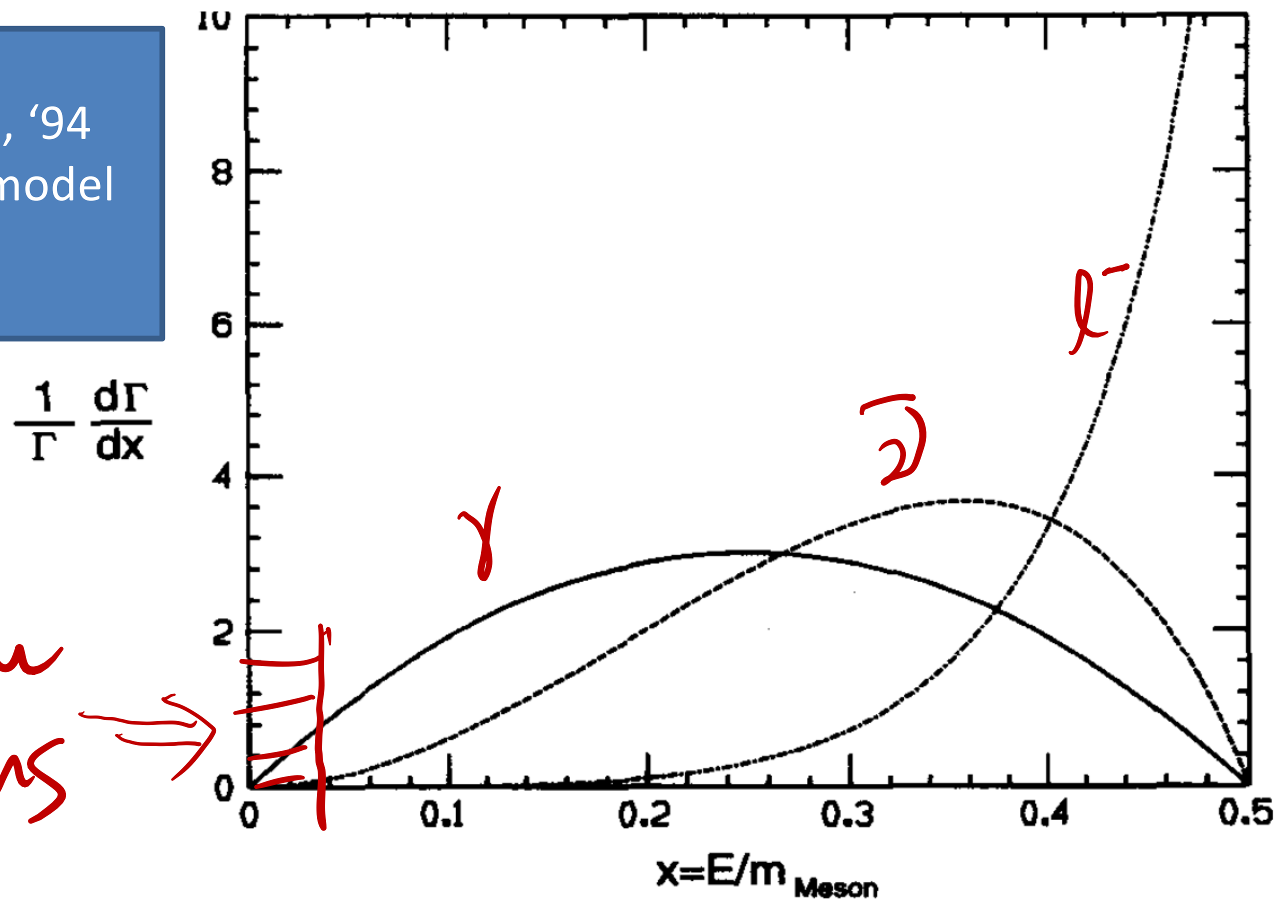
$$A = \frac{g_s G_{\rm eff}}{q^0\sqrt{2}}\left[F_A(q_\mu p_\nu - q\cdot p g_{\mu\nu}) + iF_V\epsilon_{\mu\nu\alpha\beta}p^\alpha q^\beta\right] \times \frac{\epsilon^\nu(q) l^\mu}{[2\omega_D(2\pi)^3]^{1/2}}, \qquad (4)$$

where ϵ^ν is the polarization of the gluon and l^μ the weak current of the light quarks:

$$l^\mu = \bar{u}_s(q_1)\gamma^\mu(1-\gamma_5)v_d(q_2). \qquad (5)$$

Atwood, Eilam + AS, '94
Toy-soluble-approx model calculation

$B^-(D_s)$



Stay away from soft photons

Fig. 2. $B \rightarrow \ell^- \bar{\nu}\gamma$ normalized energy spectra are shown. Solid line is for the photon energy, the dashed is for the neutrino energy (which is directly related to invariant mass of the electron–photon combination) and the dash-dot for the electron energy. For the case of $D_s \rightarrow \ell^+ \nu \gamma$ the dashed curve represents the neutrino energy spectrum while the dash-dot curve represents the lepton energy since in this case the roles of the lepton and neutrino are reversed.

BESIII (HUIJING LI)
Belle (II) Felix Metzner

$D_s^+ \Rightarrow \gamma \ell \nu_\ell$
$B^+ \rightarrow \gamma \ell \nu_e$

The radiative leptonic B-meson decay amplitude[1]

$$A(B^- \to \gamma \ell \bar{\nu}_\ell) = \frac{G_F V_{ub}}{\sqrt{2}} \langle \ell \bar{\nu}_l \gamma | \bar{\ell}\, \gamma^\nu (1-\gamma_5) \nu_\ell \bar{u} \gamma_\nu (1-\gamma_5) b | B^- \rangle \tag{2.1}$$

can be written in terms of two form factors, F_V and F_A, defined through the Lorentz decomposition of the hadronic tensor

$$\begin{aligned} T_{\mu\nu}(p,q) &= -i \int d^4x\, e^{ipx} \langle 0 | T\{ j_\mu^{em}(x)\, \bar{u}(0) \gamma_\nu (1-\gamma_5) b(0)\} | B^-(p+q) \rangle \\ &= \epsilon_{\mu\nu\tau\rho} p^\tau v^\rho F_V + i \big[-g_{\mu\nu}(pv) + v_\mu p_\nu \big] F_A - i \frac{v_\mu v_\nu}{(pv)} f_B m_B + p_\mu\text{-terms}\,. \end{aligned} \tag{2.2}$$

Here p and q are the photon and lepton-pair momenta, respectively, so that $p + q = m_B v$ is the B-meson momentum in terms of its four-velocity. In the above $j^\mu_{\rm em} = \sum_q e_q \bar{q} \gamma_\mu q$ is the electromagnetic current. The $v_\mu v_\nu$ term is fixed by the Ward identity [9, 17]

$$p^\mu T_{\mu\nu} = -i f_B m_B v_\nu \tag{2.3}$$

Beneke et al 1804.04962
(also DESCOTES-GENON + CTS '03
(also Bundman et al PRD '95

9 non-pert params!!

μ_0	1 GeV		
$\Lambda^{(4)}_{\rm QCD}$	0.291552 GeV	$\alpha_s(\mu_0)$	0.348929
μ	(1.5 ± 0.5) GeV	μ_h	$m_b/2 \div 2m_b$
m_b	(4.8 ± 0.1) GeV	$\bar{\Lambda}$	$m_B - m_b$
λ_E^2/λ_H^2	0.5 ± 0.1	$2\lambda_E^2 + \lambda_H^2$	(0.25 ± 0.15) GeV^2
s_0	(1.5 ± 0.1) GeV^2	M^2	(1.25 ± 0.25) GeV^2
$\langle \bar{u}u \rangle(\mu_0)$	$-(240 \pm 15$ MeV$)^3$		
m_B	5.27929 GeV	m_ρ	0.77526 GeV
G_F	1.166378×10^{-5} GeV^{-2}	τ_B	$1.638 \times 10^{-12} s$
f_B	(192.0 ± 4.3) MeV [23]	$\lvert V_{ub}\rvert^{\rm excl}$	$(3.70 \pm 0.16) \times 10^{-3}$ [24]

Beneke et al '2018

Table 1. Central values and ranges of all parameters used in this study. The four-flavour $\Lambda_{\rm QCD}$ parameter corresponds to $\alpha_s(m_Z) = 0.1180$ with three-loop evolution and decoupling of the bottom quark at the scale m_b.

Amarjit Soni

BNL-HET

Lattice 2018 MSU 07/27/18

Based in part on
C. Lehner, S. Meinel + A. S
+ disc with Taku Izubuchi[WIP] ; RBC-UKQCD

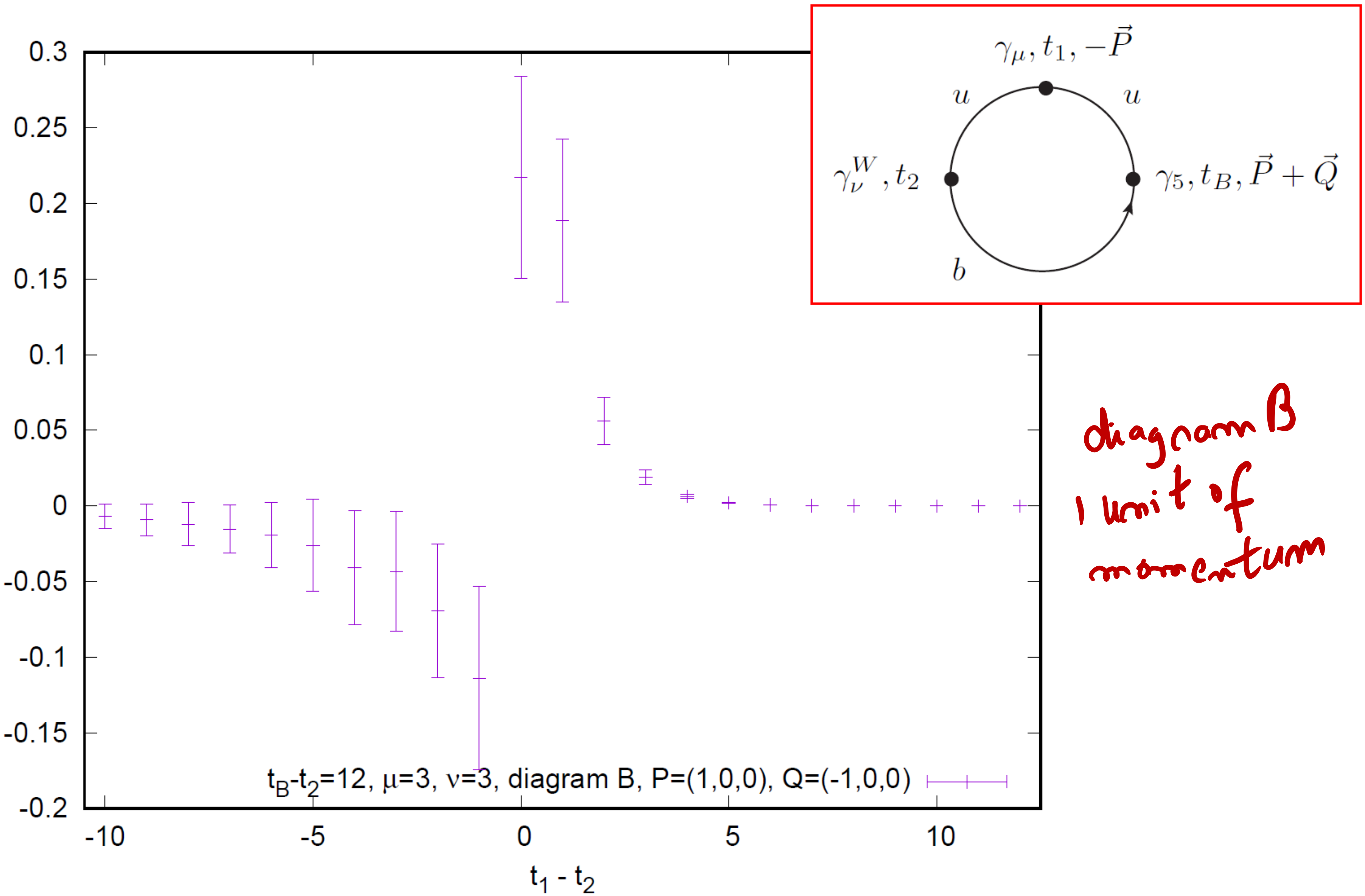
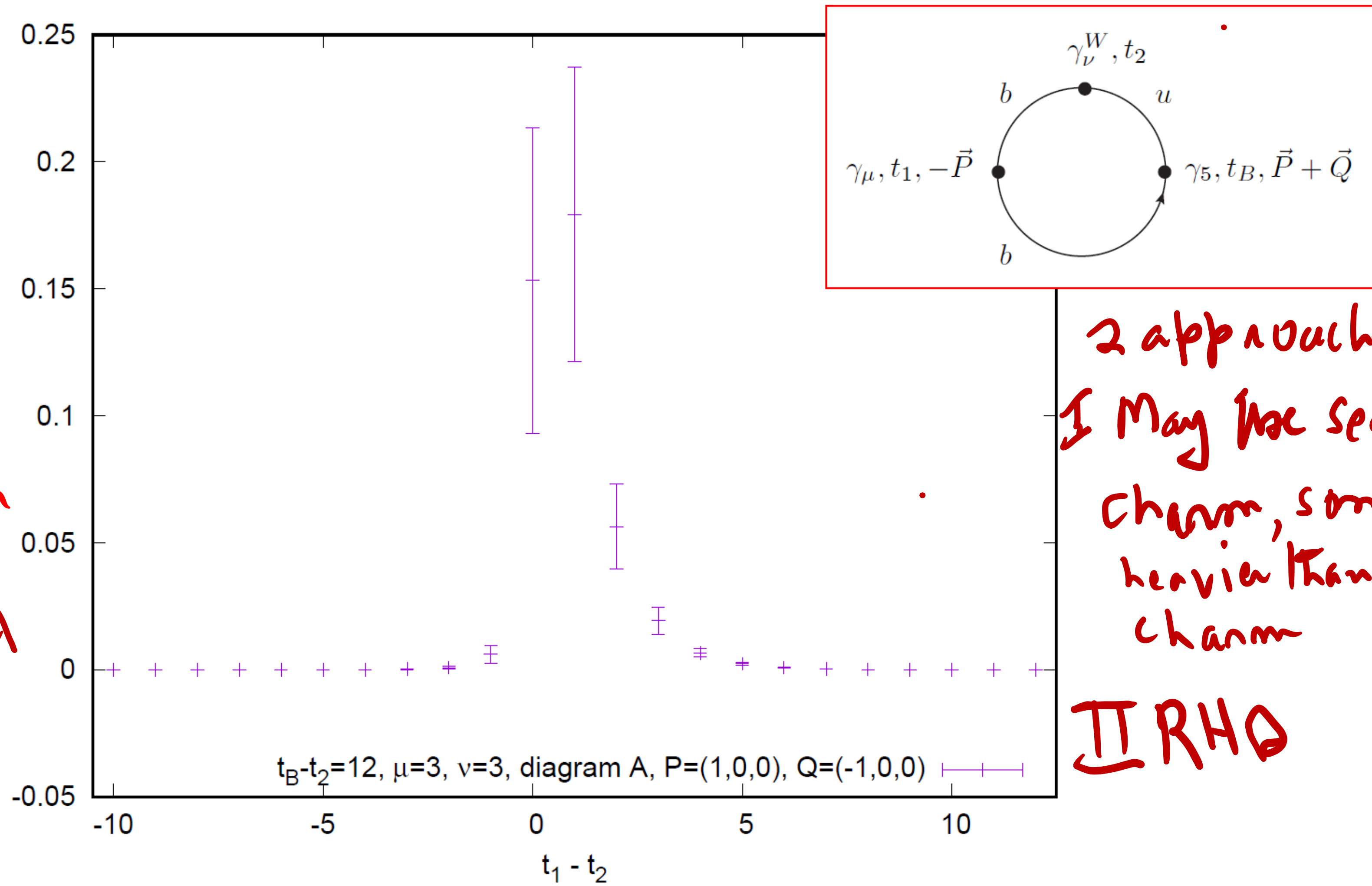


diagram B
1 unit of
momentum

Show $\sum_{\vec{x}} e^{-i\vec{p}_1\vec{x}} \langle 0| T\{j_\mu(\vec{x}, t_1) j_\nu^W(\vec{0}, t_2)\} |B^-(P+Q)\rangle$ for $m_\pi = 139$ MeV, $m_B \approx m_D$, $a^{-1} = 1.73$ GeV

C. Lehner RBC-UKQCD



1 unit of momentum ~210 MeV diagram A

2 approaches
I May use seq of charm, some heavier than phys charm
II RHQ

Show $\sum_{\vec{x}} e^{-i\vec{p}_1\vec{x}} \langle 0| T\{j_\mu(\vec{x}, t_1) j_\nu^W(\vec{0}, t_2)\} |B^-(P+Q)\rangle$ for $m_\pi = 139$ MeV, $m_B \approx m_D$, $a^{-1} = 1.73$ GeV

Actually good for D

WE HOPE TO HAVE RESULTS OF 1ST LATTICE CALCULATION OF L NU GAMMA AS A FUNCTION OF PHOTON ENERGY IN THE NEAR FUTURE FOR B^+ AND FOR D_S

Possible new physics opportunities in tau's

- Huge increase in fluxes of tau's=>monitor tau closely
- Rather serious several anomalies => NP esp 3rd family => also BSM-CP
- Charge current: tau is the central character
- A very interesting special case: tau => nu Ks pi+
- Lattice can calculate rather precisely
- Moreover, Babar claimed [BSM]CP
- Most models for anomalies imply LFV in tau and in B-decays
- Also Look for BSM-CP in tau via edm-like effects

Great for BELLE-II & STCF

PHYSICAL REVIEW D **85,** 031102(R) (2012)

Search for *CP* violation in the decay $\tau^- \to \pi^- K_S^0(\geq 0\pi^0)\nu_\tau$

(*BABAR* Collaboration)

$Asy \sim -4\times10^{-3}$

(Received 9 September 2011; published 13 February 2012)

We report a search for *CP* violation in the decay $\tau^- \to \pi^- K_S^0(\geq 0\pi^0)\nu_\tau$ using a data set of 437×10^6 τ-lepton pairs, corresponding to an integrated luminosity of 476 fb^{-1}, collected with the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- storage rings. The *CP*-violating decay-rate asymmetry is determined to be $(-0.36 \pm 0.23 \pm 0.11)\%$ approximately 2.8 standard deviations from the standard model prediction of $(0.36 \pm 0.01)\%$.

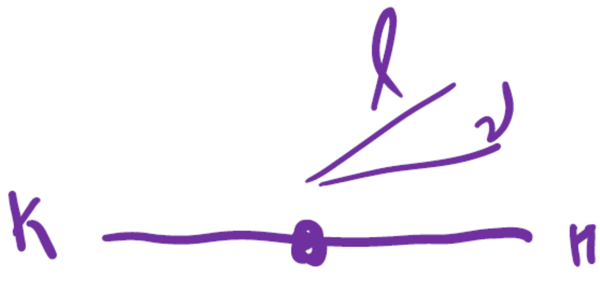
NOTE $Br[\tau \to \nu \pi^- \bar{K}^0] = (8.40 \pm .14)\times10^{-3}$ $\sim 2\%$

$N_{\tau\tau} \sim 10^9$ needed

There is an interesting Crossing-Symmetry connection between the K=> pi semi-leptonic [Kl3] form factors and tau => nu Ks pi^+ ....~~by exploiting flavor~~ SU3. For Kl3

ANALOGOUS TO Kl3

$\langle K | J_\mu^{W,S} | \pi \rangle$



q^2 [with q= p_K – p_pi], q^2 >~ 0 is positive, while in the decay amplitude relevant to tau => nu Ks pi, Q^2 [with Q = p_K + p_pi], Q^2 > ~0, is positive.

But Complex amplitude
Kπ scatt phase needed

In the tau decay calculation, final-state interaction phase enters and it'd be very interesting if this complex amplitude can be calculated on the lattice.

It'd also be very useful to study the case when pi^+ can be replaced with rho^+,

if possible.

LQ Revival Circa 2018

Are There Anomalous Lepton-Hadron Interactions?

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and

Abdus Salam
International Centre for Theoretical Physics, Trieste, Italy, and Imperial College, London, England

(Received 5 February 1974)

It is remarked that the recently observed near constancy of $\sigma(e^+e^- \to \text{hadrons})$ over a large range of center-of-mass energy may reflect the presence of a new class of short-range lepton-hadron interactions. This can be tested by a comparison of e^-p versus e^+p scatterings and a study of the spin, parity, and charge conjugation of the final product in annihilation as well as apparent deviations from scaling in $e^\pm p$ and $\mu^\pm p$ scatterings.

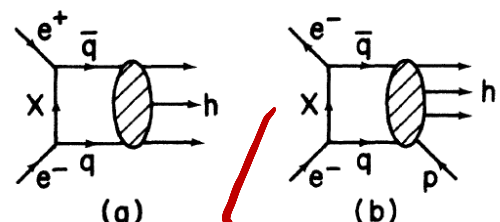
Recent experimental studies[1] of the electron-positron-annihilation cross section into hadrons $[\sigma_h(s)]$ as a function of s, the square of the total center-of-mass energy, seem to reveal a remarkable feature—that it is nearly constant at about 25–30 nb (within 30%) from $s \simeq 9$ to $s \simeq 25$ [in units of $(\text{BeV})^2$]. On the other hand, $\sigma(e^+e^- \to \mu^+\mu^-) \equiv \sigma_\mu(s)$ appears to fall according to the quantum-electrodynamic (QED) s^{-1} law. The near "constancy" of $\sigma_h(s)$ over such a wide region of s does not seem to obtain a simple explanation in terms of the familiar one-photon mechanism.[2] We consider in this note an alternative explanation for the behavior of $\sigma_h(s)$ based on a new class of short-range lepton-hadron interactions (leading to process such as $e^-e^+ \to q\bar{q}$, etc.) which may arise within the class of gauge schemes[3] proposed by us earlier, and point out that this leads to a variety of testable predictions; these should enable one to distinguish our explanation from all others based on the one-photon mechanism.[4]

heavy exotic[6] spin-1 mesons X (with nonzero baryon and lepton numbers) coupled to electron-quark (and possibly also to muon-quark[7]) currents as follows:

$$\mathcal{L}^X = f(\bar{e}\gamma_\mu q)X_\mu + \text{H.c.} \qquad (1)$$

There could, of course, be a triplet of X's corresponding to three baryonic colors. It is possible that there are vector and axial-vector mesons X_V and X_A coupled to currents $\bar{e}\gamma_\mu q$ and $\bar{e}\gamma_\mu\gamma_5 q$ with strengths f_V and f_A, respectively. For the present, we need not specify the $(\mathcal{P}, \mathfrak{N}, \lambda)$ indices of q.

Let us assume that the effective low-energy

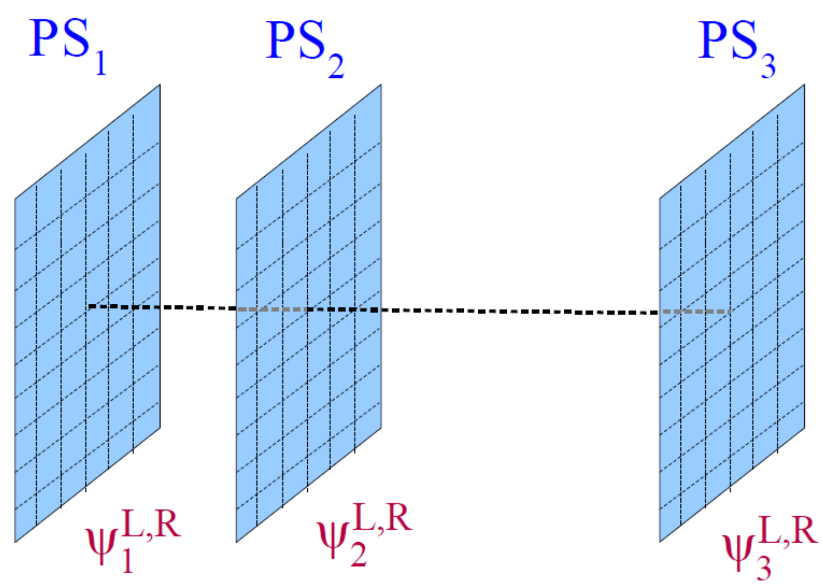


LQs: New Game in town

See also Fajfer et al, Greljo et al + many more

New Focus 3G LQ!

My (*currently*) favorite UV completion

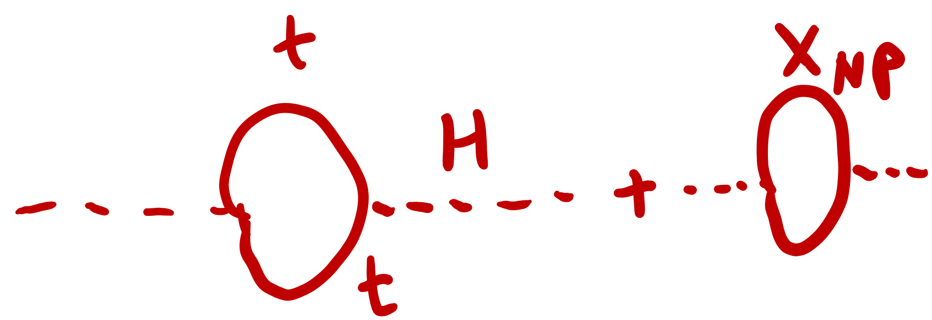


RPV_3

Altmannshofer, Dev, AS

- ASSUMING the anomaly is REAL & HERE TO STAY [BIG ASSUMPTION due to caveats mentioned]
- Anomaly involves simple tree-level semi-leptonic decays
- Also b => tau (3rd family)
- Speculate: May be related to Higgs naturalness
- Seek minimal solution: perhaps 3rd family super-partners(a lot) lighter than other 2 gens > proton decay concerns may not be relevant=> RPV ["natural" SUSY]
- RPV natural setting for LUV ...can accommodate g-2 and eps' if needs be
- Collider signals tend to get a lot harder than (usual-RPC) SUSY
- RPV makes leptoquarks natural
- Moreover, RPV should be viewed as an umbrella i.e. under appropriate limits other models are incorporated

$m_H \lesssim 126$ GeV



RPV$_3$ preserves gauge coupling unification irrespective of # of effective gens. 1, 2 or 3.

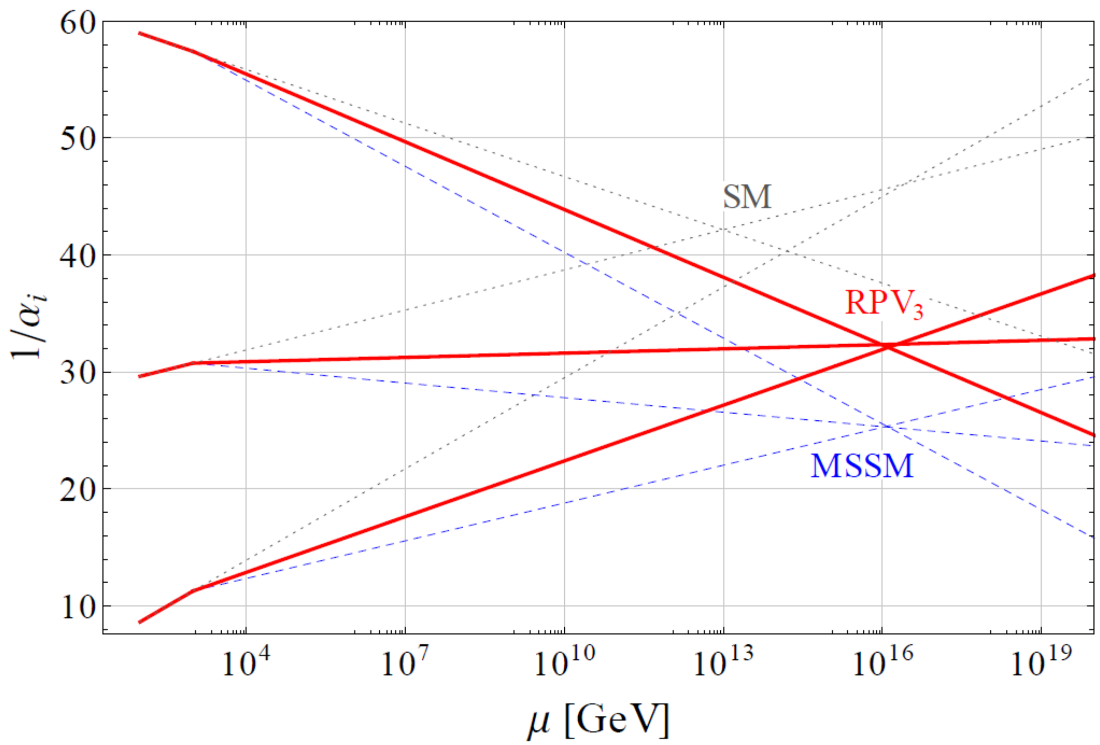
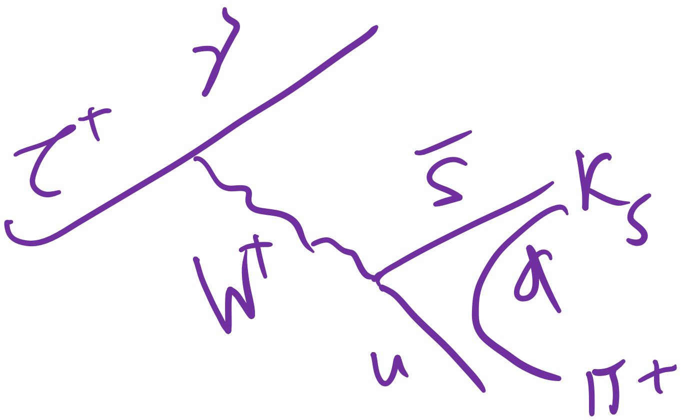


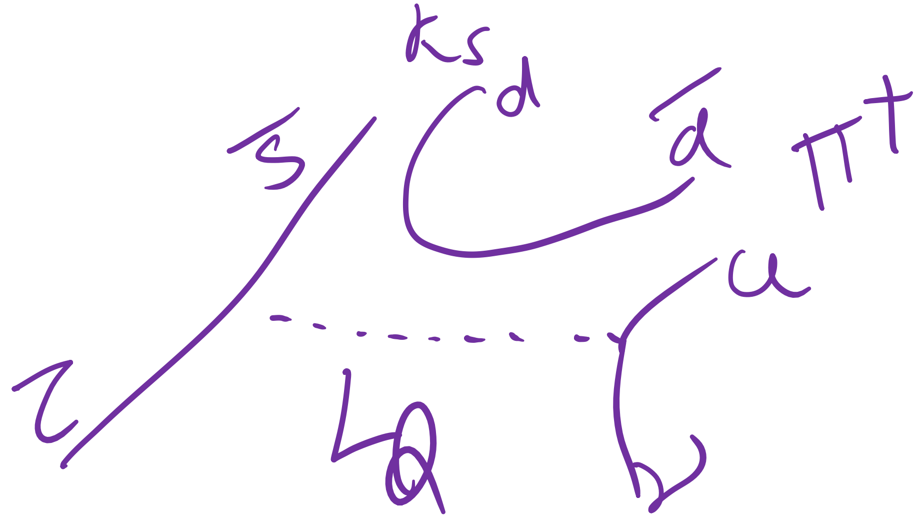
FIG. 2. RG evolution of the gauge couplings in the SM, MSSM and with partial supersymmetrization.

Unification scale ~ stays same; only value of couplings shifts

Possible NP in tau=> Ks pi nu



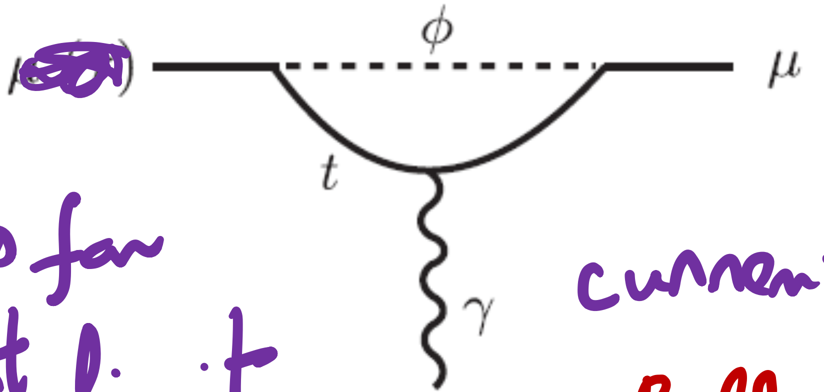
SM



RPV

See Altmannshofer, Dev + AS [ADS']
1704.06659

Bauer + Neubert PRL'16 τ



↙ LQ

SIMILARLY in ADS'-RPV'17

maybe not too far from current limit

current $\lesssim 4\times10^{-8}$

Belle-II $\Rightarrow \gtrsim 10^{-9}$

Belle-II can improve many bounds by 1-2 ords of mag.

Even more interest in such models, $\gamma \to g$'s

$\tau \to \mu$ glues, $\mu\phi$ (η'....) KK, hh.... + τ-EDM [c below]

Br's maybe larger than $\mu\gamma$. ALSO μll

HOST of POSSIBILITIES for EXPT Constraints

In many LQ models for anomalies, e.g. Bauer+Neubert, Mandal et al, ADS'-RPV3 B=>K mu tau and or Bs=>tau tau enhanced

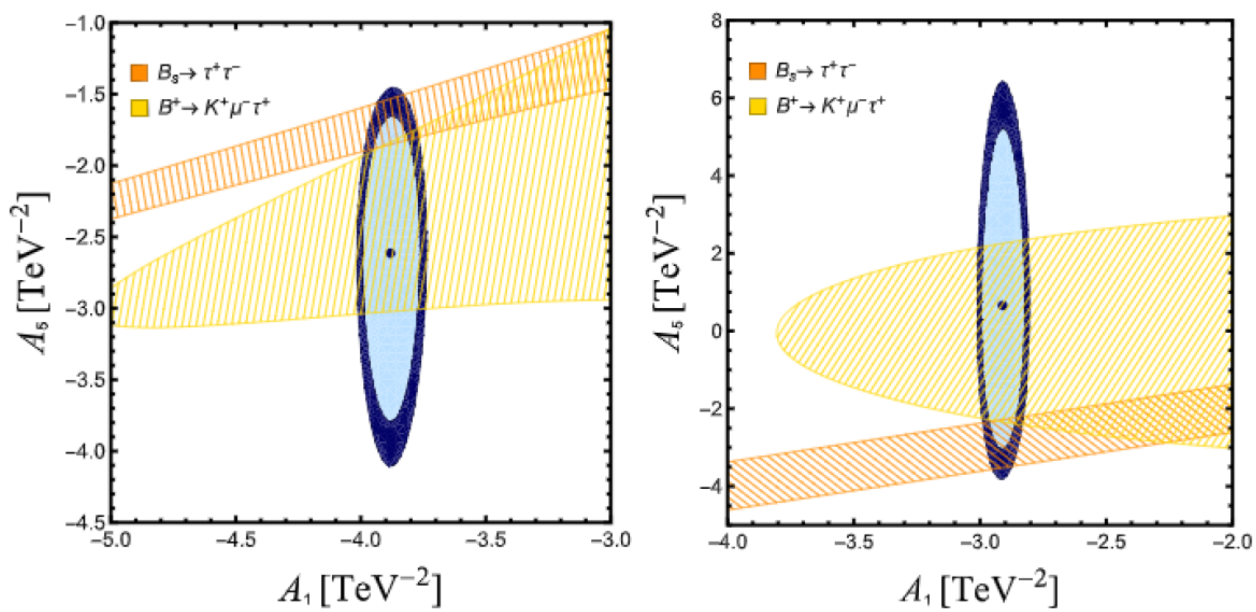


Fig. 1. The viable parameter space for two different models i.e., model IV and model V are shown in left and right panel, respectively. The point represents the minimum of the χ^2, whereas the light and dark blue ellipses denote 95% and 99% C.L. regions, respectively. The orange and yellow shaded regions are allowed by the BR($B_s \to \tau^+\tau^-$) and BR($B^+ \to K^+\mu^-\tau^+$) bounds. The overlaps denote the finally allowed portion of the parameter space. (For interpretation of the colours in the figure(s), the reader is referred to the web version of this article.)

$B \to K\mu\tau$ & or $B_s \to \tau\tau$ enhanced in many LQ models close to current bounds

Because of heightened interests in LQ's

- **Note that tau magnetic & e dipole moments enhanced**
- Magetic,electric dipole moments of leptons can scale in LQ models:

c. also M. HOFERICHTER

- d_tau ~ mt^2 m_tau
- So may be many^2 orders of magnitude larger than d_e
- Which is exptally bounded by < few times 10^-27 ecm

HIGH HOPES FOR IF NEXT ~ 5 YEARS

Anomalies or not

These likely another sightings of GODOT!

Summary + take home mssgs (2 pages)

- Time is ripe for charm CP: Delta ACP should be not far from current bound. 2 pi0, 2Ks may have asymmetries ~1/2 to 1% …..all may well be accessible to Belle-II
- 3 body, 4 body modes very powerful for c and also for b…Belle-II has promising reach
- So also for Fcnc leptonic channels, c, b => h ll, hhll…lattice progress scatt phases
- Time dependent CP in radiative excl B decays,

e.g. gamma Ks eta(pi) excellent approx null test for SM-CP..Belle-II can improve by 10 or even more

- Tau (&D*, rho) polarization (including transverse tau) in B=>D(*)[pi,rho] tau nu should also be targetted esp in view of RD(*) anomaly
- For tests of LUV / CPV B => l nu gamma ……quantitative rate prediction from lattice on the horizon…. Should be an important target of Belle-II
- B=>K mu tau (e); Bs=>tau tau important to pursue vigorously
- Tau =Ks pi nu for NP/CP via precise rate and Dalitz studies..lattice feasible
- LFV tau => mu gamma[ll, phi, hh…..] Belle-II can improve significantly
- Tau mag and electric dipole moments…should be targetted by Belle-II
- Moreover, (lattice) developments in ε' and the GOLD-PLATED KL => pi0 nu nu (@Jparc) have significant consequences……

Take home mssgs

- **In the next few years due primarily to Belle-II, LHCb and because of computational advances we should be able to make significant progress in:**
- **far better understanding of QCD dynamics pertaining to weak decays**
- **in part. lattice can play a crucial role in quantifying SM direct CP in K, D,B, tau…**
- **& thus on our quest for BSM-CP-odd phase**
- **& possibly also on our quest for LFV**
- **& May be just may be with some luck the IF will lead us, once again, to the gem of NP, and as many times in the past, guide collider physics et al**

XTRAS

Improvements in lattice ε' determination underway for past ~3 years

- Statistics X [> ~ 5] now aiming for
- Systematics…..some already done..
- EM+ isospin….
- Completely diff method(s)
- A) excited pipi state
- B) Revisit ChPT

[Previous result uses 215 configs]
$\delta[\mathrm{Im}\,A_0]$ ~ (15±8)% EM
Cirigliano et al '04
TB student
BDSPW '84; LAIHO+AS ~'04
LOχPT NLO
D. HOYING
RBC-UKQCD Dmurphy et al [1911.01950]

75%   15%

$Q_2 =$ 

LARGE DOUBLE cancellation

i	$\text{Re}(A_0)(\text{GeV})$	$\text{Im}(A_0)(\text{GeV})$
1	$1.02(0.20)(0.07) \times 10^{-7}$	0
2	$3.63(0.91)(0.28) \times 10^{-7}$	0
3	$-1.19(1.58)(1.12) \times 10^{-10}$	$1.54(2.04)(1.45) \times 10^{-12}$
4	$-1.86(0.63)(0.33) \times 10^{-9}$	$1.82(0.62)(0.32) \times 10^{-11}$
5	$-8.72(2.17)(1.80) \times 10^{-10}$	$1.57(0.39)(0.32) \times 10^{-12}$
6	$3.33(0.85)(0.22) \times 10^{-9}$	$-3.57(0.91)(0.24) \times 10^{-11}$
7	$2.40(0.41)(0.00) \times 10^{-11}$	$8.55(1.45)(0.00) \times 10^{-14}$
8	$-1.33(0.04)(0.00) \times 10^{-10}$	$-1.71(0.05)(0.00) \times 10^{-12}$
9	$-7.12(1.90)(0.46) \times 10^{-12}$	$-2.43(0.65)(0.16) \times 10^{-12}$
10	$7.57(2.72)(0.71) \times 10^{-12}$	$-4.74(1.70)(0.44) \times 10^{-13}$
Tot	$4.66(0.96)(0.27) \times 10^{-7}$	$-1.90(1.19)(0.32) \times 10^{-11}$

<1%   dominant

$\mu = 1.53$ GeV

TABLE I. Contributions to A_0 from the ten continuum, $\overline{\text{MS}}$ operators $Q_i(\mu)$, for $\mu = 1.53$ GeV. Two statistical errors are shown: one from the lattice matrix element (left) and one from the lattice to $\overline{\text{MS}}$ conversion (right).

$\text{Re}\, A_0^{\text{expt}} = 3.32 \times 10^{-7}$ GeV

parenthetically

- **Using our lattice calculations as input [our est. ~2.1 σ] + etc**

- **1. Buras, Gorbahn, Jaeger and Jamin, [1507.06345] ~2.8 σ**
- **2. Kitahara, Nierste & Tremper, 1604,074002….~2.9 σ**

} under study

- **Its great that others think significance of our result is more than we claim; would be concerned if it was the other way around**
- **More importantly, X5 more stats underway….**

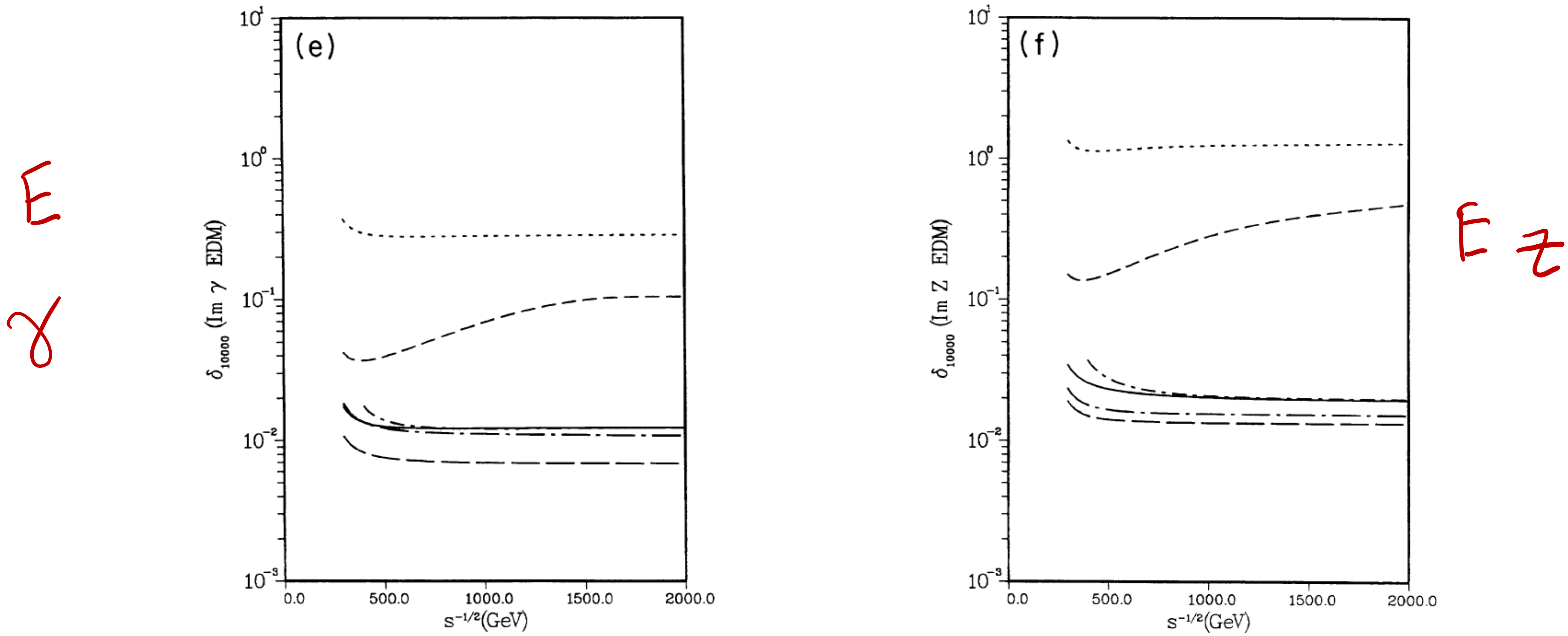


FIG. 3. (*Continued*).

- Total error on Re(ε'/ε) is ~3x the experimental error
- Find reasonable (2.1σ) consistency with Standard Model
- "This is now a quantity accessible to lattice QCD"!
- Focus since has been to improve statistics and reduce / improve understanding of systematic errors.

↳ use much larger stats

Calculation of $K \to \pi\pi$ decay amplitudes with an improved Wilson fermion action in a nonzero momentum frame in lattice QCD

BRAVO!

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(Dated: December 24, 2018)

CPS sym a la B+S '87

Improved attempt

Abstract

We present our result for the $K \to \pi\pi$ decay amplitudes for both the $\Delta I = 1/2$ and $3/2$ processes with the improved Wilson fermion action. In order to realize the physical kinematics, where the pions in the final state have finite momenta, we consider the decay process $K(\mathbf{p}) \to \pi(\mathbf{p}) + \pi(\mathbf{0})$ in the nonzero momentum frame with momentum $\mathbf{p} = (0, 0, 2\pi/L)$ on the lattice. Our calculations are carried out with $N_f = 2+1$ gauge configurations generated with the Iwasaki gauge action and nonperturbatively $O(a)$-improved Wilson fermion action at $a = 0.091\,\mathrm{fm}$ ($1/a = 2.176\,\mathrm{GeV}$), $m_\pi = 260\,\mathrm{MeV}$, and $m_K = 570\,\mathrm{MeV}$ on a $48^3 \times 64$ ($La = 4.4\,\mathrm{fm}$) lattice. For these parameters the energy of the K meson is set at that of two-pion in the final state. We obtain $\mathrm{Re}A_2 = 2.431(19) \times 10^{-8}\,\mathrm{GeV}$, $\mathrm{Re}A_0 = 51(28) \times 10^{-8}\,\mathrm{GeV}$, and $\epsilon'/\epsilon = 1.9(5.7) \times 10^{-3}$ for a matching scale $q^* = 1/a$ where the errors are statistical. The dependence on the matching scale q^* of these values is weak. The systematic error arising from the renormalization factors is expected to be around 1.3% for $\mathrm{Re}A_2$ and 11% for $\mathrm{Re}A_0$. Prospects toward calculations with the physical quark mass are discussed.

PACS numbers: 11.15.Ha, 12.38.Gc, 13.25.Es

HOPE they continue tackling this challenge!

$\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$

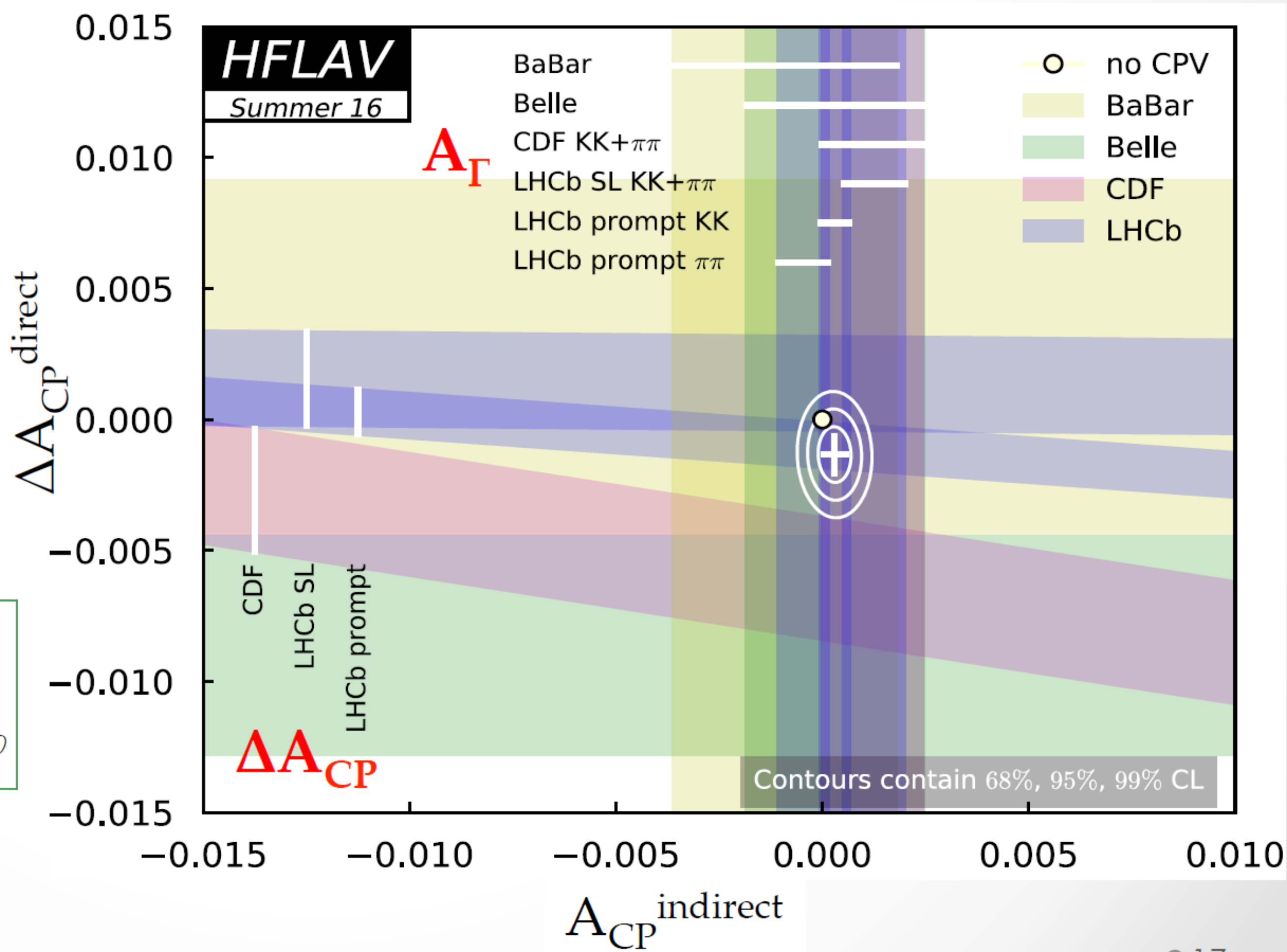
- Simple & sensitive

$$\Delta A_{CP} \simeq \left[A_{CP}^{\text{direct}}(KK) - A_{CP}^{\text{direct}}(\pi\pi)\right] + \frac{\Delta\langle t\rangle}{\tau_D} A_{CP}^{\text{indirect}}$$

- In SM: $|\Delta A_{CP}^{\text{direct}}| \leq 0.6\%$

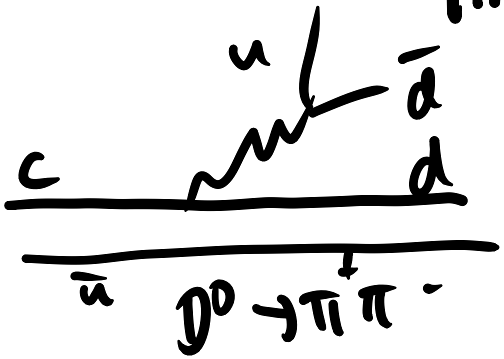
- HFLAV average

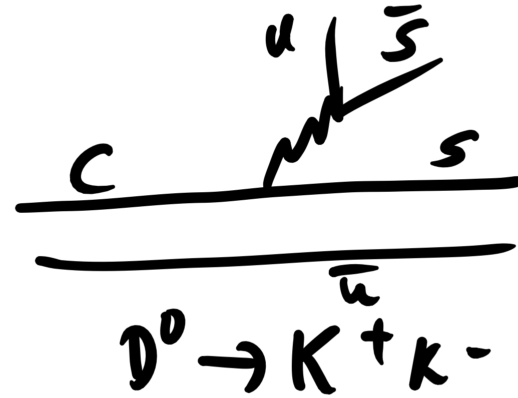
$$\Delta A_{CP}^{direct} = (-0.13 \pm 0.07)\%$$
$$A_{CP}^{indirect} = (0.030 \pm 0.026)\%$$



Implications of CPT

ILLUSTRATIVE EXAMPLE





4

$\Gamma_D = \Gamma_{\bar{D}}$

See ATWOOD + AS PTEP 2012

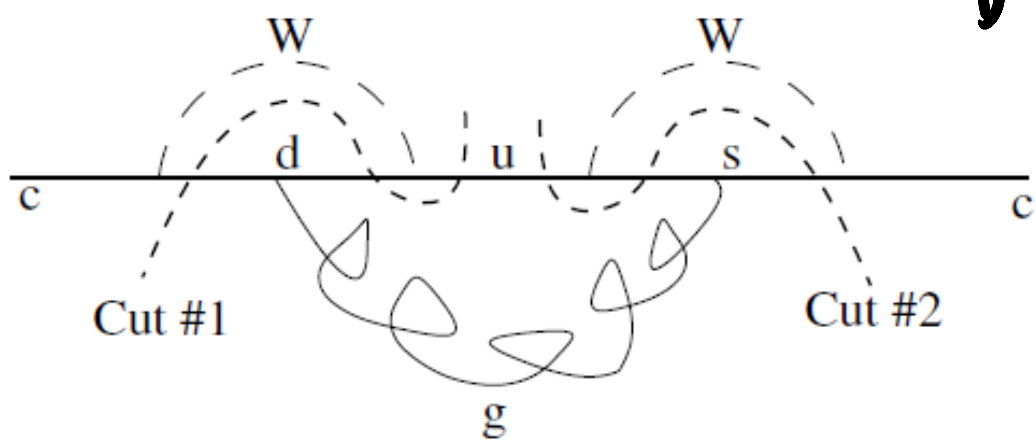
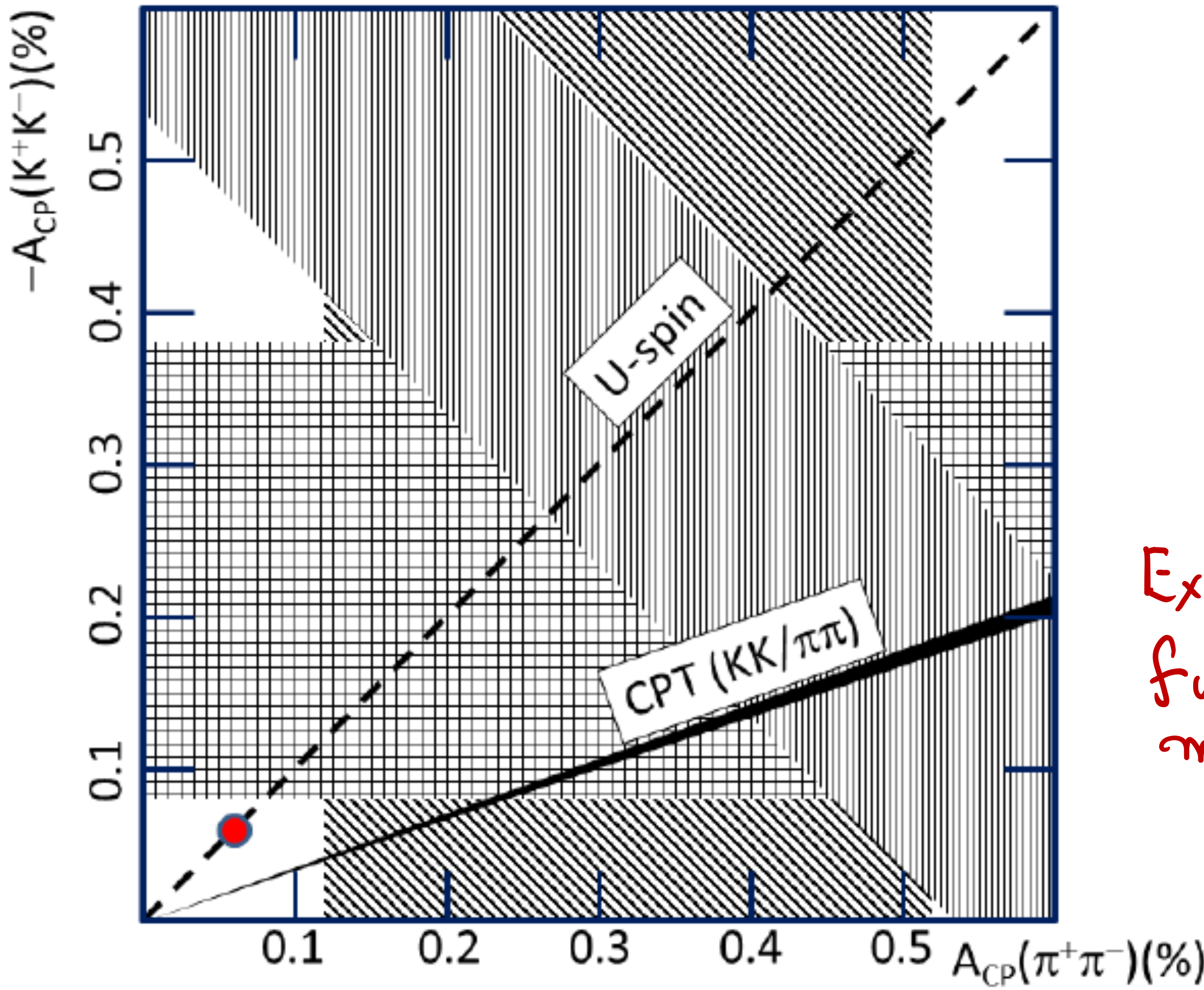


FIG. 1: The unitarity graph showing the CPT identity Eqn. 6 for the quark level SCS charm decay. Cut #1 indicated in the figure shows the case where the decay is $c \to d\bar{d}u$ with a $s\bar{s}u$ intermediate state providing the strong phase. Conversely, cut #2 indicated in the figure shows the case where the decay is $c \to s\bar{s}u$ with a $d\bar{d}u$ intermediate state providing the strong phase. The interfering tree graphs are not shown but are implied

CPT $\Rightarrow$ $\sum_X \Delta\Gamma(D \to X) \equiv \sum_X [\Gamma(D \to X) - \Gamma(\bar{D} \to \bar{X})] = 0$

AT the quark level: $\Delta\Gamma(c \to d\bar{d}u) = -\Delta\Gamma(c \to s\bar{s}u).$



Expectation for future measurements

FIG. 2: The current experimental results for $A_{CP}(\pi^+\pi^-)$ and $A_{CP}(K^+K^-)$. The vertically hatched band shows the

Measurement reach of Asymms

$$N = N_\sigma^2/(\mathrm{Br}A_{\mathrm{CP}}^2) \propto \frac{N_\sigma^2}{|A|^2|a/A|^2} \propto \frac{N_\sigma^2}{|a|^2}. \qquad (11)$$

So that, generally, N depends on a but is independent of A, but a smaller value of A does enhance A_{CP}; N is not affected because this is at the expense of the branching ratio. Going to a mode that has a smaller branching ratio with higher asymmetry has the advantage of reducing the effects of systematic errors and other errors that are not statistical in nature, *all other things being equal*.

With $Br \sim O(10^{-3})$, $A_{CP} \sim 10^{-2}$; $N_\sigma = 3$, $\eta_{eff} \sim \frac{1}{10}$

$N \gtrsim 10^9$ puts things in interesting region

$Br \sim 10^{-2}$, $A_{CP} \sim 10^{-3}$ $\Rightarrow$ $N \geq 10^{10}$ for 3-σ observation

LFV

- **Accidental symmetry……….**

PHYSICAL REVIEW D VOLUME 8, NUMBER 7 1 OCTOBER 1973

Radiative Corrections to $p + p \to l^+ + l^- +$ "Anything" and Application to Muon-Electron Symmetry*

A. Soni
Columbia University, New York, New York, 10027

(Received 20 February 1973)

Radiative corrections, to order α, are carried out to the lepton lines in the process $p + p \to l^+ + l^-$ + "anything." Expressions are derived which relate the radiative corrections, due to the emission of soft photons, and of hard photons from the lepton lines, to the observed cross section for production of electron or muon pairs. These expressions are used to predict the difference, based purely on electromagnetic interactions, between the cross sections for production of electron and muon pairs. As a specific example, computations are done using the BNL data for production of lepton pairs in hadron-hadron collisions.

a Student's Curiosity '73!

Contrarian/Complementary view

- **flavor physics is actually hanging by perhaps the weakest link i.e. a single CP-phase endowed by the 3g –SM.**

- **[This is infact my rationale for going after eps' for over 35 continuous years and the effort is sill continuing!]**

- **In many ways this is a contrarian (or complementary) point of view, in sharp contrast to the overwhelming majority following the naturalness lamp post via Higgs radiative stability.**

- **In this context it is useful to stress**

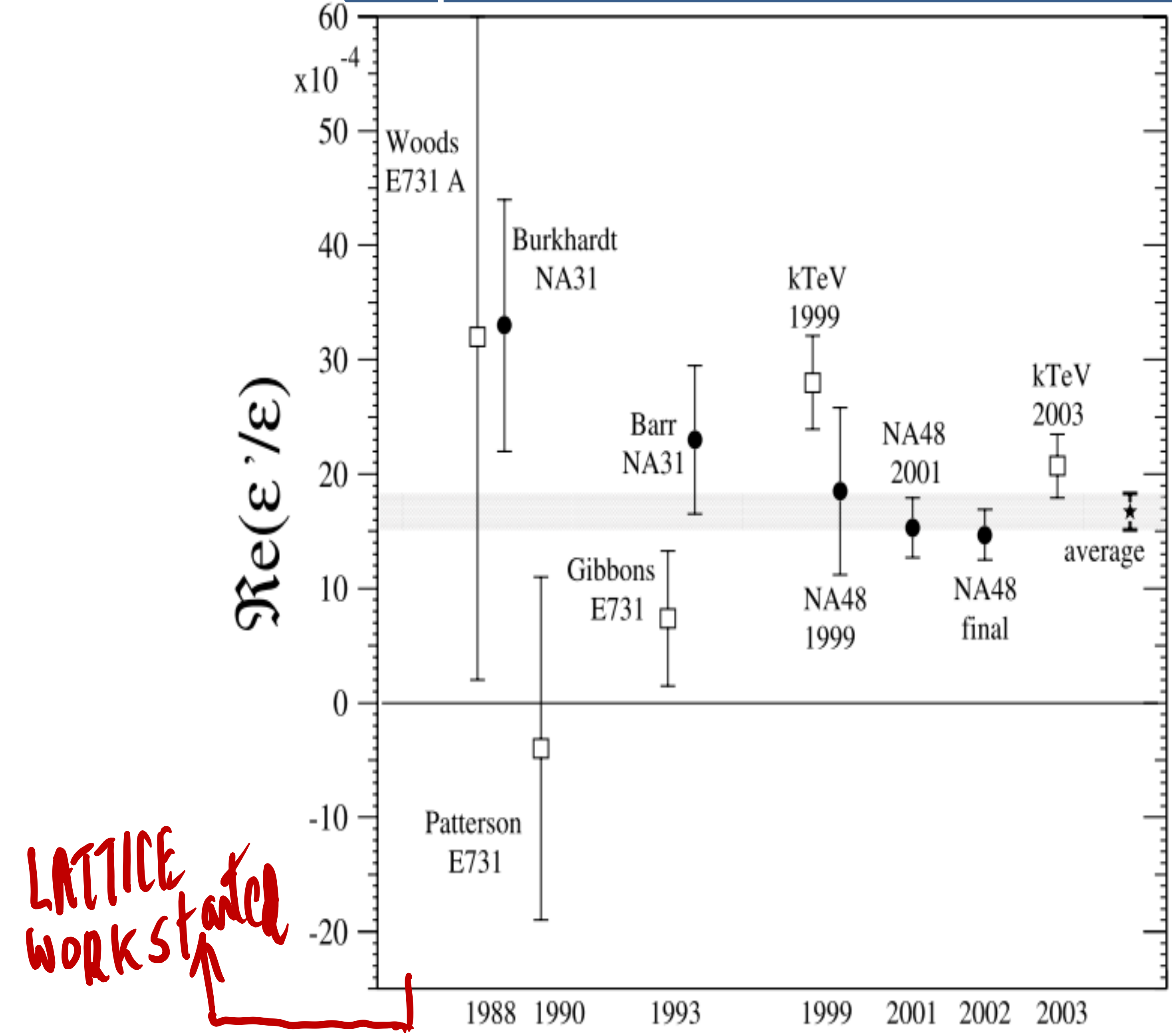
- **We hold these truths to be self-evident…**

ODE to YESTERYEARS!

35+ yrs ee' !

e' an obsession for long!

A monumental experimental achievement!



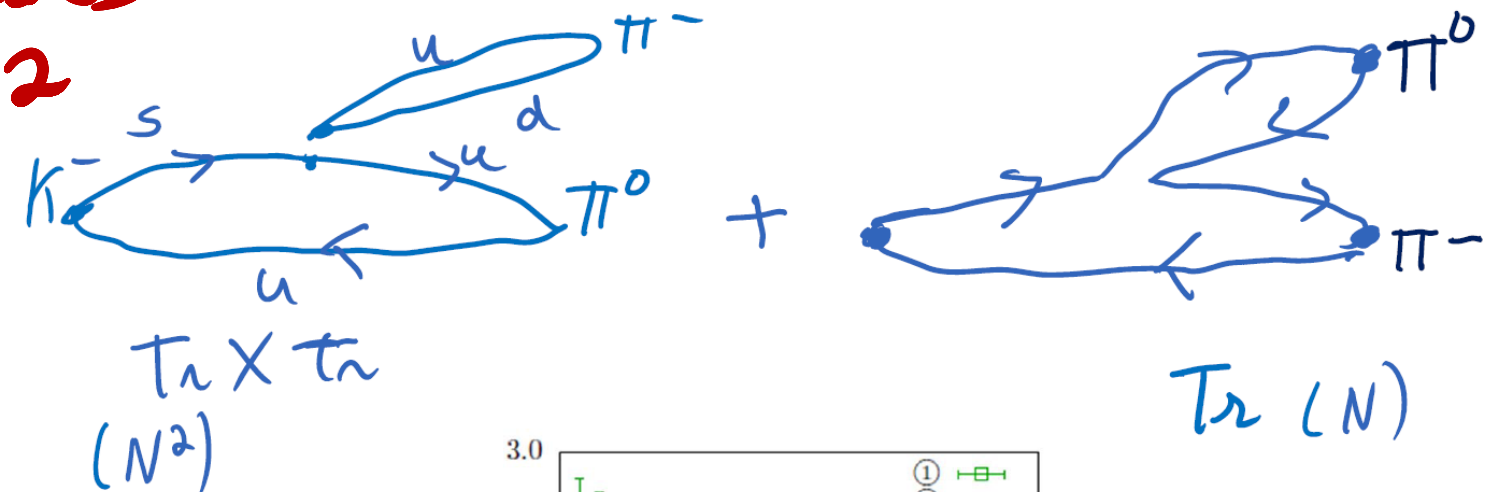
Konrad Kleinknecht "Uncovering CPV"

16.6(2.3) x10^-4
PDG 2014

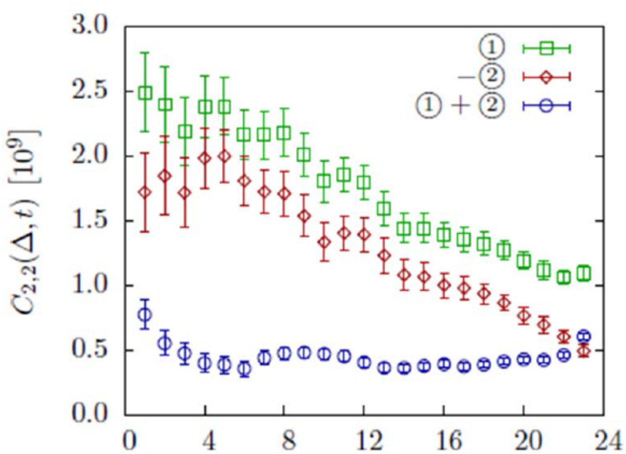
Understanding the text book puzzle of $\Delta I = 1/2$ enhancement

Dissecting 3/2 Amp on the lattice

RBC-UKQCD PRL'12



Simplest basic step is Significantly different from phenomenological expectations

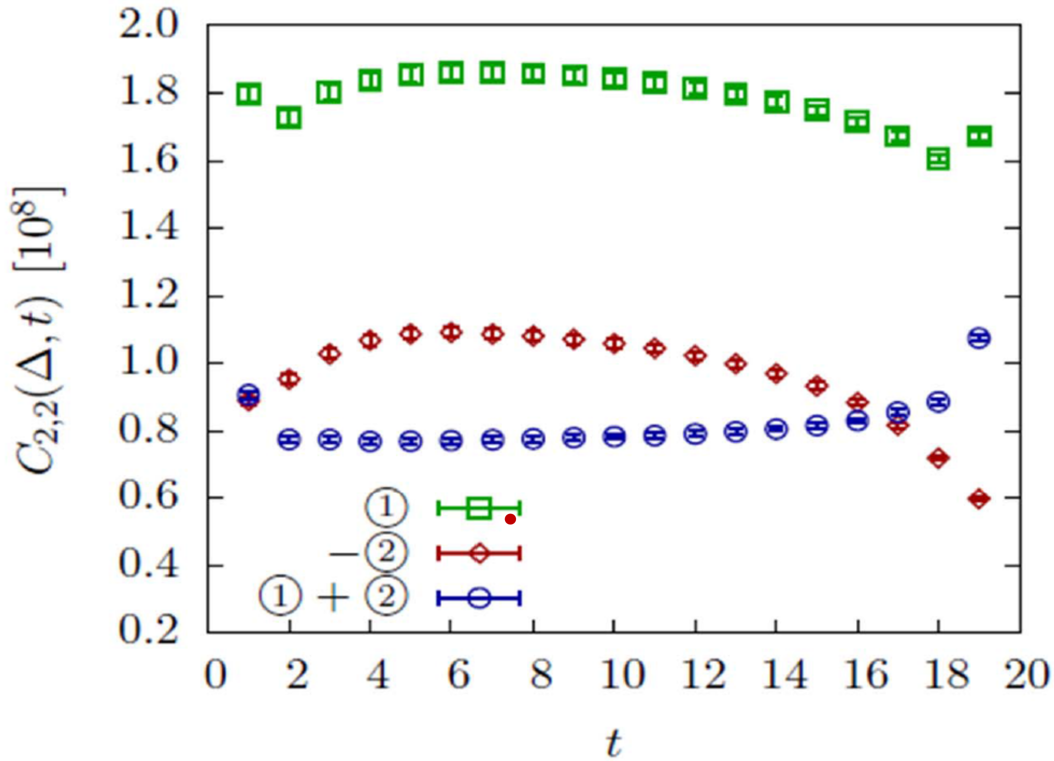


DRAMATIC CANCELLATION!

for $m_\pi \sim 140$ MeV

97

RBC-UKQCD
PRL'12



Much less Cancellation for heavier pions ~330MeV

FIG. 3: Contractions ①, -② and ① + ② as functions of t from the simulation at threshold with $m_\pi \simeq 330$ MeV and $\Delta = 20$.

In many LQ models for anomalies, e.g. Bauer+Neubert, Mandal et al, ADS'-RPV3
B=>K mu tau and or Bs=>tau tau enhanced

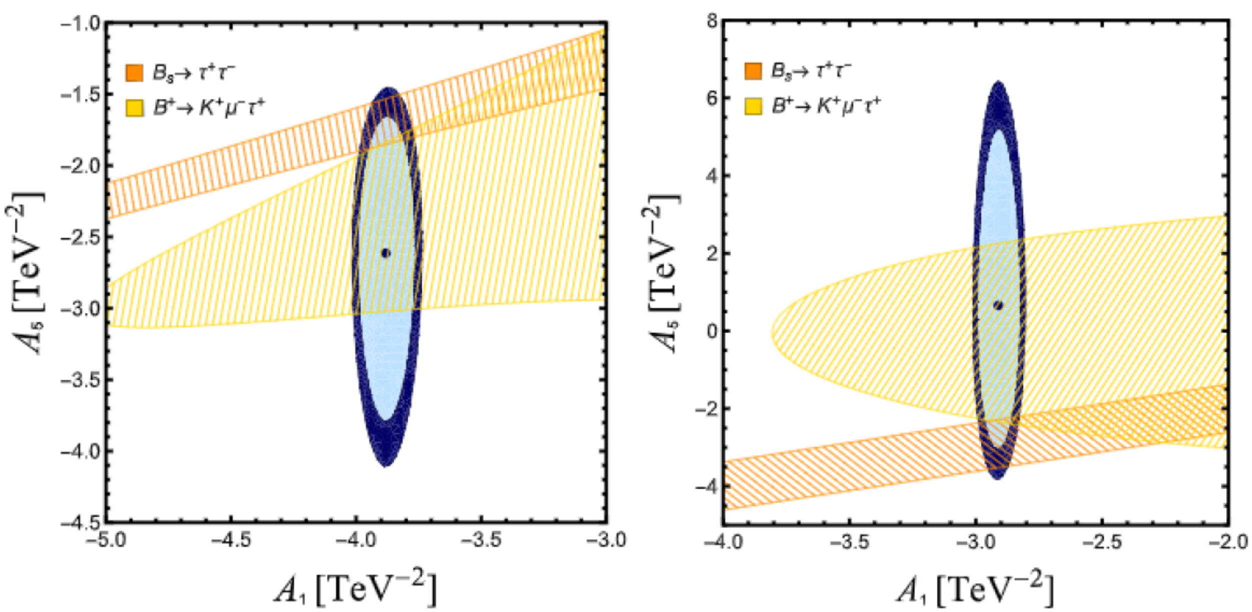


Fig. 1. The viable parameter space for two different models i.e., model IV and model V are shown in left and right panel, respectively. The point represents the minimum of the χ^2, whereas the light and dark blue ellipses denote 95% and 99% C.L. regions, respectively. The orange and yellow shaded regions are allowed by the BR($B_s \to \tau^+\tau^-$) and BR($B^+ \to K^+\mu^-\tau^+$) bounds. The overlaps denote the finally allowed portion of the parameter space. (For interpretation of the colours in the figure(s), the reader is referred to the web version of this article.)

$B \to K\mu\tau$ & or $B_s \to \tau\tau$ enhanced in many LQ models close to current bounds

II. tau => Ks pi^- nu on and off the lattice

- **Motivation ……**
- **tau plays a central role in indications of LUV from semi-leptonic charge current RD(*) anomaly**
- **If these indications of new physics become a reality, then naturalness arguments strongly suggest the new physics will entail also a new**

CP-odd phase.

tau => Ks pi^+ nu is an excellent final state for experimental study and a good candidate for BSM phase or not

$\tau \to \nu K^- \rho^0$ Also very good

Can test for BSM also via CP-conserving observables

- **Select a FS where [CP conserving observables] like rate or differential distributions can be calculated precisely…**
- **Usually use of lattice to calculates mass /rates, I find boring and stay away as they are not my primary interest…[i can look up PDG]**

- **But a good example is tau => Ks pi^+ nu total or partial rate, or Ks pi invariant mass distribution; in the SM this can be calculated PRECISELY using lattice [and to some extent off the lattice methodology]**

SEARCH FOR NP VIA REDUNDANT PRECISE MEASUREMENTS & PRECISE LATTICE STUDIES VIA THE UT; LATTICE ON-GOING EPS' EFFORT ; PROGRESS IN NON-LOCAL, LD, MATRIX ELEMENTS & SOME NEW APPLICATIONS

CK@CKM'18

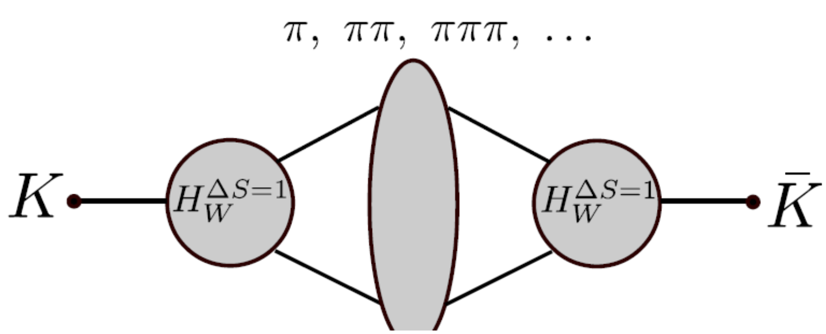
- Neutral kaon mixing induced by 2nd order weak processes gives rise to mass difference between K_L and K_S

B.Wang @ LAT'18

$$\Delta M_K = 2\sum_n \frac{\langle \overline{K}^0|H_W|n\rangle\langle n|H_W|K^0\rangle}{M_K - E_n}$$

- FCNC → highly suppressed in SM due to GIM mechanism: $\Delta m_K = 3.483(6)\times 10^{-12}$ MeV small and highly sensitive to new BSM FCNC.
- PT calc using weak EFT with $\Delta S=2$ eff. Hamiltonian (charm integrated out) dominated by $p\sim m_c$: poor PT convergence at charm scale → ~36% PT sys error.
- PT calc neglects long-distance effects arising when 2 weak operators separated by distance $\sim 1/\Lambda_{QCD}$.
- Use lattice to evaluate matrix element of product of $H_W^{\Delta S=1,\ \mathrm{eff}}$ directly:

$$\frac{\Delta m_K}{m_K} \sim 10^{-15}\,!!$$



Incomplete Sample of refs.

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- **Bigi et al; in particular Bigi + Ayan Paul, Several papers**
- **Hou & Gerard; PRL, 1989, systematic implement CPT**
- **Feldmann, Nandi and A.S. JHEP 2012**
- **Atwood + A. S, PTEP 2013…….update now**
- **Atwood, Bar-Shalom, Eilam and A.S, Phys Rept 2001**
- **Nierste & Schacht, PRL 2017**
- **Jolanta Brodzicka, Implications workshop, CERN, 2017 [talk]….many very useful experimental updates**
- **Marco Gersabeck, talks at FPCP 18 & at Weihai-18**
- **A S lecture III @ 2018 Weihai**

These anomalies in near future, <~3 yrs

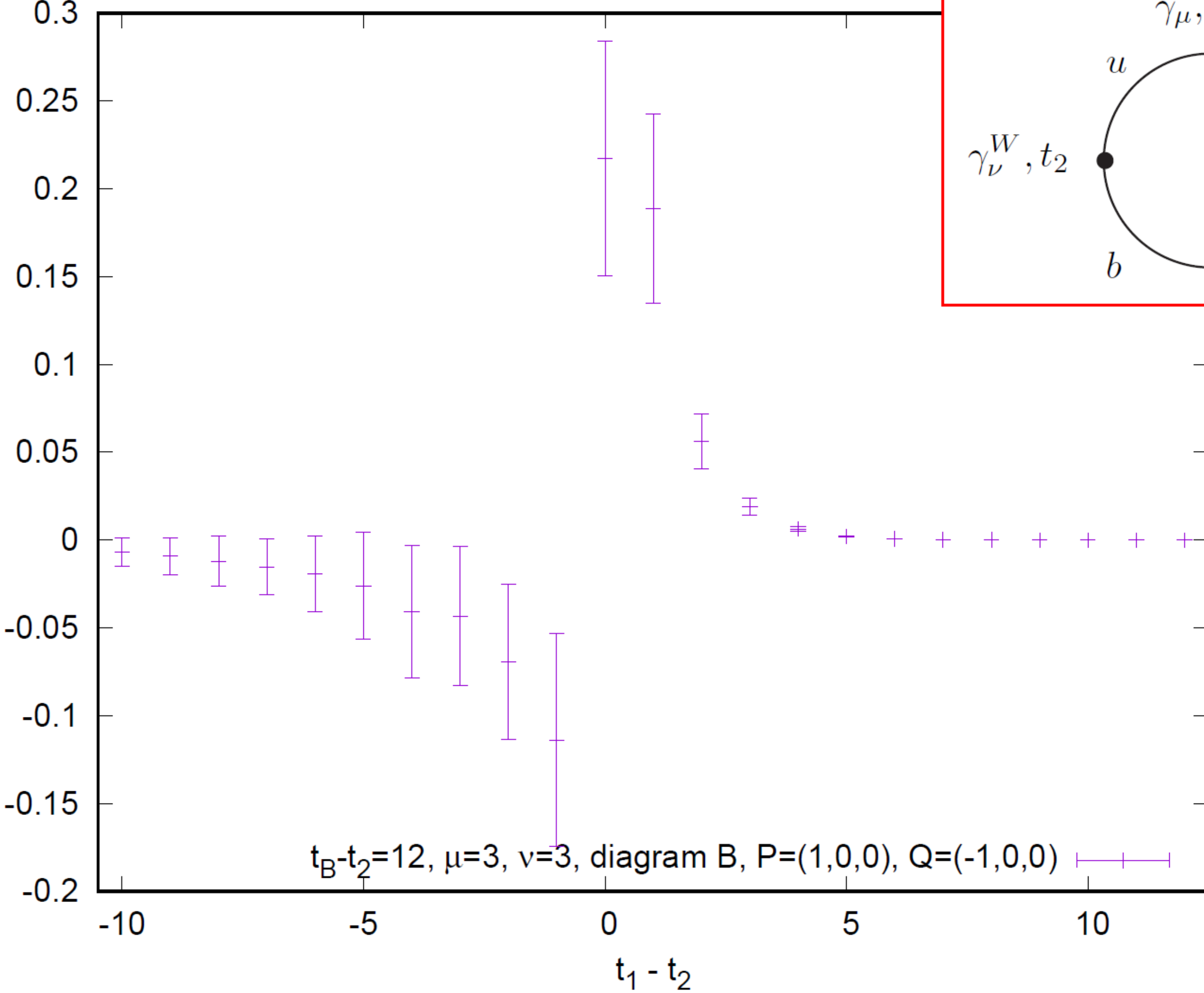
- Although stated significance of each of the 3 anomalies is over 3 sigma, have reservations in each case; so not yet compelling
- On RD(*), RK(*) expect significant progress (including possible discoveries!) from LHCb Runs 1+2 and/or Belle-II may be with ~5 /ab coupled with

  further refinements from lattice
- On g-2, fermilab should have finished analysys

  of over X2 compared to original BNL; also expect lattice reduction of errors by another factor of 2 to 3 soon
- Outcome uncertain in so far as NP is concerned

Reg multi-body modes

- **2 body modes only allow PRA and these are severely restricted by CPT**
- **3 body modes allow in addition, e.g. energy asymmetries….these asyms can be a lot bigger than PRA as rescattering of states onto themselves can give rise to energy asyms [unlike PRA]**
- **4 (or more) bodies allow also TCA; these do NOT require FS phases as they are CP-odd, TN-odd observables..see Atwood, Bar-shalom, Eilam +AS, Phys Report’01**



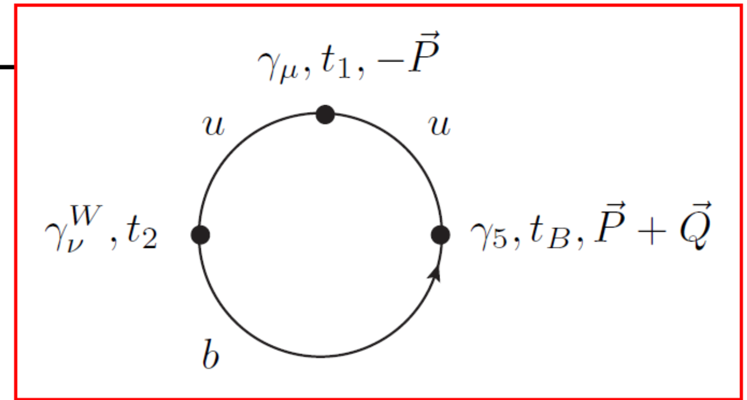


diagram B
1 unit of
momentum

Show $\sum_{\vec{x}} e^{-i\vec{p}_1\vec{x}} \langle 0| T\{j_\mu(\vec{x}, t_1) j_\nu^W(\vec{0}, t_2)\} |B^-(P+Q)\rangle$ for $m_\pi = 139$ MeV, $m_B \approx m_D$, $a^{-1} = 1.73$ GeV complicated equations given in the Appendix. It would also be desirable to consider an observable which, although not optimal, is of a simple form. Consider first the case of the imaginary MDM-type couplings [Im(C_t)]. In this case we have considered observables of the form

$$\epsilon_{\mu\nu\sigma\rho} k_1^\mu k_2^\nu k_3^\sigma k_4^\rho (k_5 \cdot k_6) \ , \tag{25}$$

where

$$k_i \in \{P_t, Q_Z, P_e, P_b, Q_b, H^+, H^-\} \ , \tag{26}$$

which have the correct symmetry (even under CP, odd under P_n). The momenta mentioned above in the notation of the Appendix are

$$\begin{aligned} &P_t = \bar{p}_t - p_t, \quad Q_z = p_e^+ + p_e^- \ , \\ &P_e = p_e^+ - p_e^- \ , \\ &H^\pm = 2E_W^+ \cdot p_t \, E_W^+ \pm 2E_W^- \cdot p_t \, E_W^- \ . \end{aligned} \tag{27}$$

Of all the operators of the above type, it was found that the operator

$$\epsilon_{\mu\nu\sigma\rho} P_b^\mu Q_z^\nu H^{+\sigma} H^{-\rho} (P_b \cdot Q_z) \tag{28}$$

is the best in both the cases of Im(C_t^γ) and Im(C_t^Z). The results for this operator are shown with the dashed curve in Fig. 3(a) for the case of $\mathrm{Im}(C_t^\gamma)$ and Fig. 3(b) for the case of $\mathrm{Im}(C_t^Z)$ assuming unpolarized e^+e^- beams. Note that this operator gives precision a factor of 5–10 poorer than the optimal operator.

In Fig. 3(c) we consider the measurement of the EDM, $\mathrm{Re}(D_t^\gamma)$. The curves we give are similar to those described above except that the form of the best simple operator indicated on the graph by the dashed line is

$$\epsilon_{\mu\nu\sigma\rho} P_b^\mu Q_z^\nu H^{+\sigma} H^{-\rho} \ . \tag{29}$$

Likewise, Fig. 3(d) shows a similar set of curves for the coupling $\mathrm{Re}(D_t^Z)$, where the best simple operator represented by the dashed curve is

$$\epsilon_{\mu\nu\sigma\rho} P_e^\mu Q_z^\nu H^{+\sigma} H^{-\rho} \ . \tag{30}$$

For the case of the imaginary EDM couplings, we have considered operators of either the form

$$(k_1 \cdot k_2)(k_3 \cdot k_4)$$

or

$$k_1 \cdot k_2 \ , \tag{31}$$

with the correct symmetry (CP odd, P_n even), k_i chosen as above. In both the γ and Z cases, the best operator of this form we found was

$$H^- \cdot Q_z \ . \tag{32}$$

In Figs. 3(e) and 3(f) we produce the corresponding dashed curves for the couplings $\mathrm{Im}(D_t^\gamma)$ and $\mathrm{Im}(D_i^Z)$, respectively.

From the above calculations we conclude that in the case of the real MDM couplings, $\mathrm{Re}(C_t)$, the use of an optimized operator instead of just looking at the change in the total cross section gives a factor of about 3 improvement in resolution, while using right-polarized beams gives another factor of about 3, giving a total gain using both improvements of about an order of magnitude. In the cases of $\mathrm{Im}(C_t)$, $\mathrm{Re}(D_t)$, and $\mathrm{Im}(D_t)$, we wish to

Magnetic Dipole moment determinations

Unpolarised

polarized

polarized

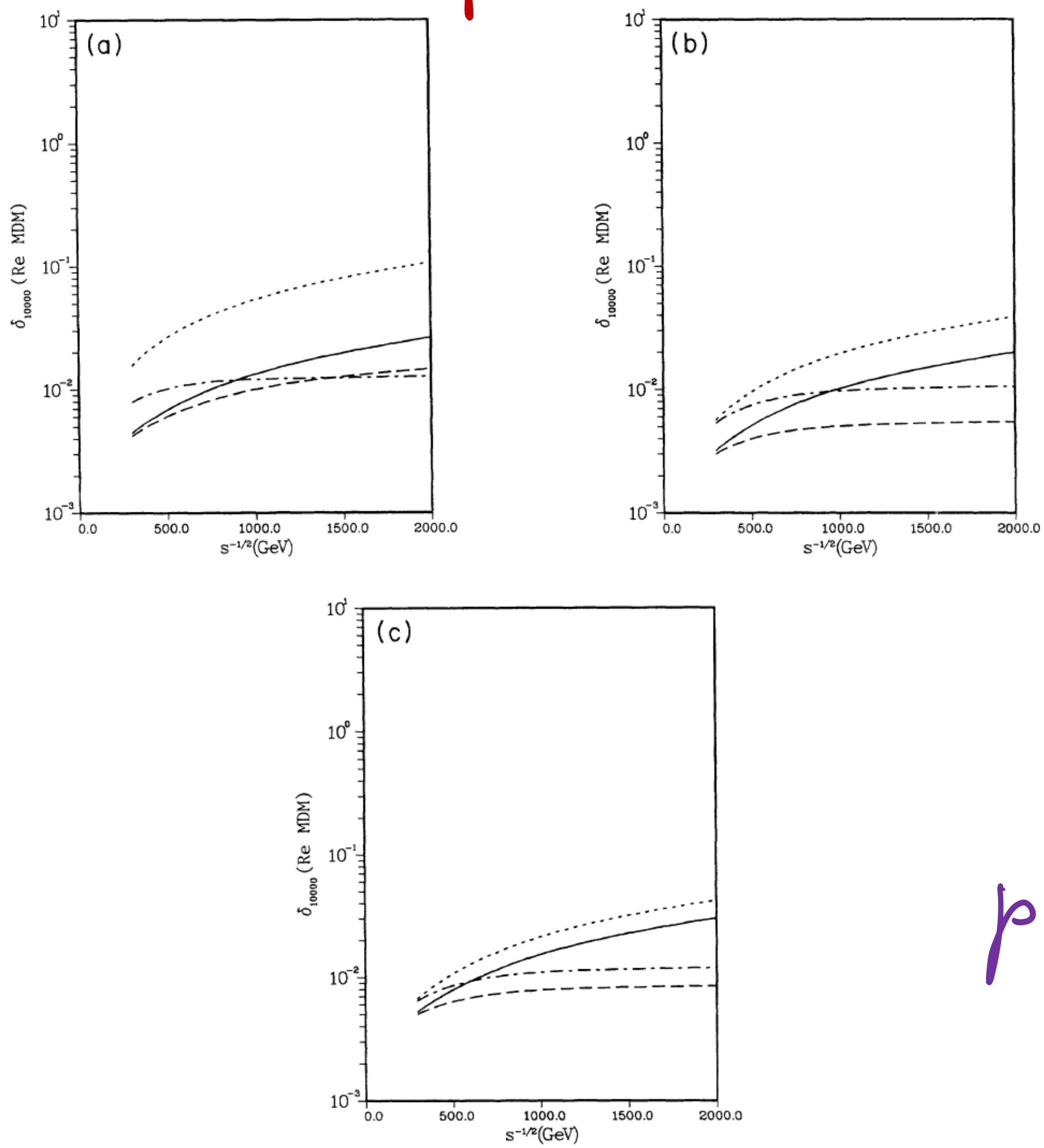


FIG. 2. $\delta_{10\,000}$ vs $\sqrt{s}$ is shown for various observables sensitive to Re(C). The curves shown are as follows: the dashed curve is $\delta_{10\,000}$ for the optimized observable for Re(C_t^γ); the solid curve is $\delta_{10\,000}$ using the total cross section to measure Re(C_t^γ); the dash-dot curve is $\delta_{10\,000}$ for the optimized observable for Re(C_t^Z); and the dotted curve is $\delta_{10\,000}$ using the total cross section to measure Re(C_t^Z). The polarization of the e^+e^- beams is taken to be unpolarized in (a), right polarized in (b), and left polarized in (c).

NOTE: It is optimised w.r.t statistical errors only

Magnetic γ

Electric γ

OPTIMIZED OBSERVABLE can do ~ X10 better

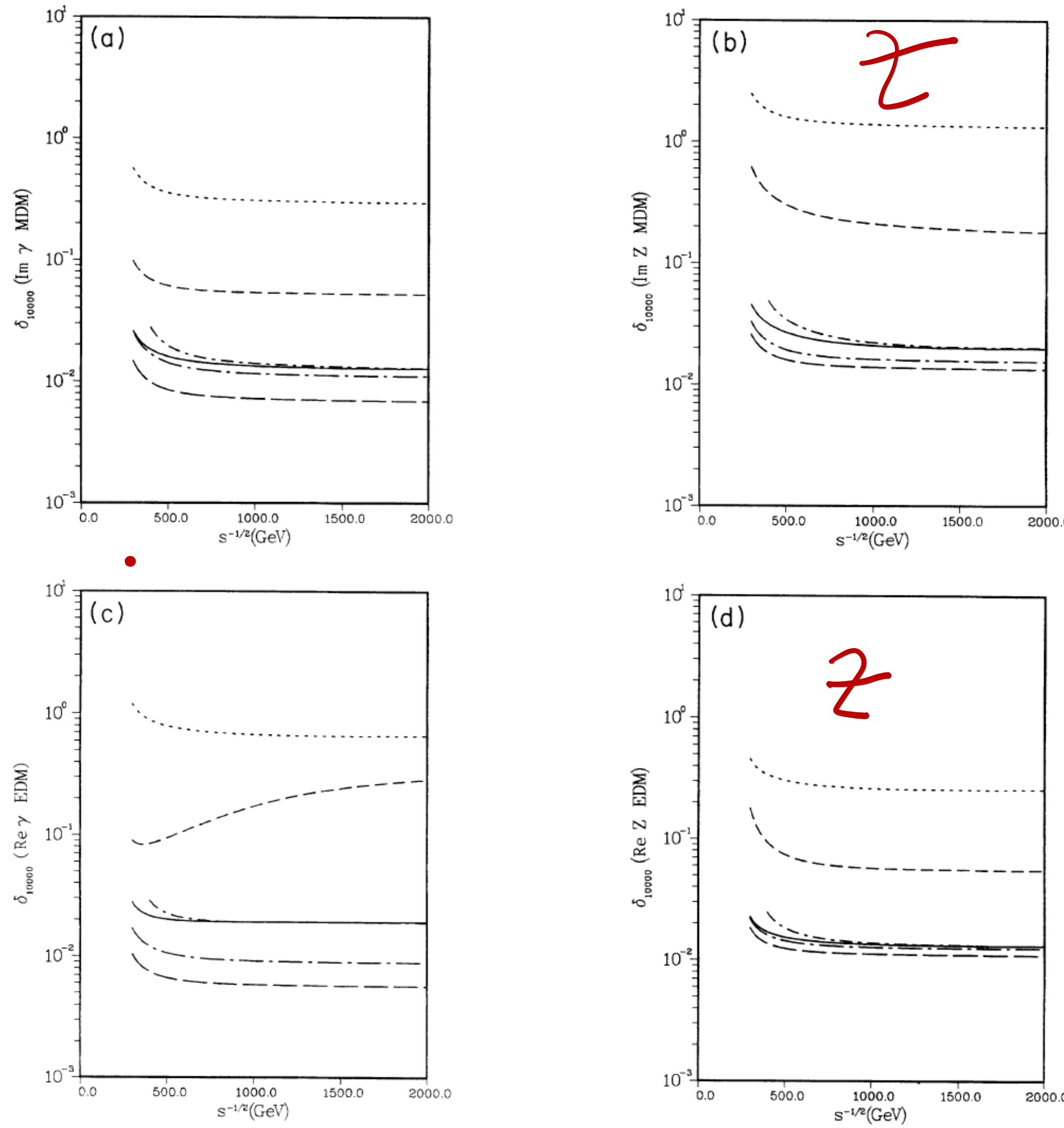
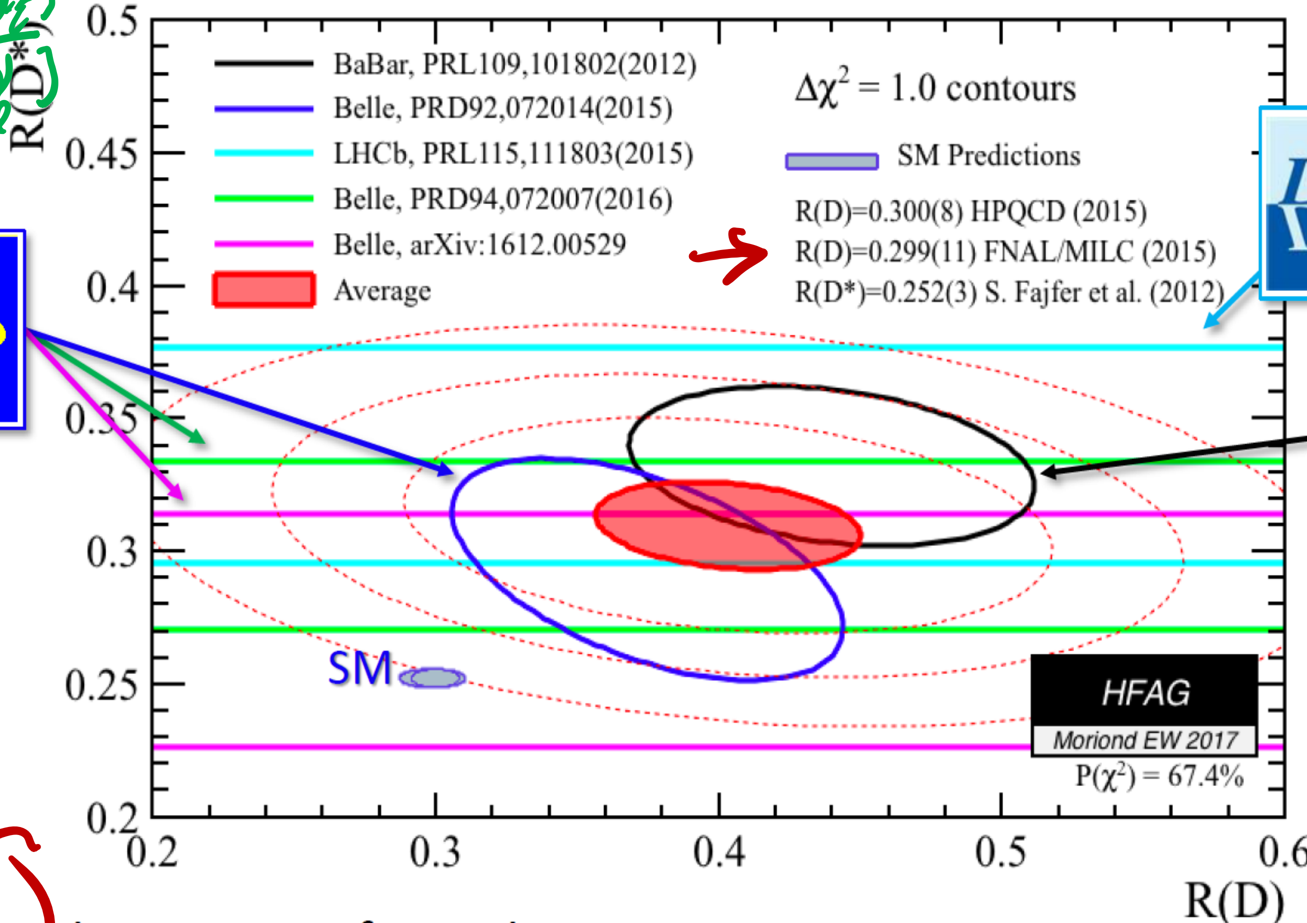


FIG. 3. Shown here is $\delta_{10\,000}$ vs $\sqrt{s}$ with respect to various couplings. The cases shown are (a) Im(C_t^{γ}); (b) Im(C_t^{Z}); (c) Re(D_t^{γ}); (d) Re(D_t^{Z}); (e) Im(D_t^{γ}); and (f) Im(D_t^{Z}). In each case the optimal observable for unpolarized beams using $m_t=120$ GeV is shown with the solid curve; the optimal with left-polarized beams is shown with the long dash-dot curve; the optimal with right-polarized beams is shown with the long dash curve. The optimal curve using unpolarized beams and $m_t=160$ GeV is shown with the short dash-dot

■ $R\left(D^{(*)}\right)$ by HFAG

Hirose [BELLE]@EW MORIOND Mar. 2017



- $\sim 4\sigma$ discrepancy from the SM remains
  - All the experiments show the larger $R\left(D^{(*)}\right)$ than the SM
- More precise measurements at Belle II and LHCb are essential

Belle deviations quite mild

The radiative leptonic B-meson decay amplitude[1]

$$A(B^- \to \gamma \ell \bar{\nu}_\ell) = \frac{G_F V_{ub}}{\sqrt{2}} \langle \ell \bar{\nu}_l \gamma | \bar{\ell} \, \gamma^\nu (1-\gamma_5) \nu_\ell \bar{u} \gamma_\nu (1-\gamma_5) b | B^- \rangle \tag{2.1}$$

can be written in terms of two form factors, F_V and F_A, defined through the Lorentz decomposition of the hadronic tensor

$$\begin{aligned} T_{\mu\nu}(p,q) &= -i \int d^4x \, e^{ipx} \langle 0 | T\{ j_\mu^{em}(x) \, \bar{u}(0) \gamma_\nu (1-\gamma_5) b(0) \} | B^-(p+q) \rangle \\ &= \epsilon_{\mu\nu\tau\rho} p^\tau v^\rho F_V + i \big[-g_{\mu\nu}(pv) + v_\mu p_\nu \big] F_A - i \frac{v_\mu v_\nu}{(pv)} f_B m_B + p_\mu\text{-terms} \,. \end{aligned} \tag{2.2}$$

Here p and q are the photon and lepton-pair momenta, respectively, so that $p + q = m_B v$ is the B-meson momentum in terms of its four-velocity. In the above $j_{\rm em}^\mu = \sum_q e_q \bar{q} \gamma_\mu q$ is the electromagnetic current. The $v_\mu v_\nu$ term is fixed by the Ward identity [9, 17]

$$p^\mu T_{\mu\nu} = -i f_B m_B v_\nu \tag{2.3}$$

μ_0	1 GeV		
$\Lambda^{(4)}_{\rm QCD}$	0.291552 GeV	$\alpha_s(\mu_0)$	0.348929
μ	(1.5 ± 0.5) GeV	μ_h	$m_b/2 \div 2m_b$
m_b	(4.8 ± 0.1) GeV	$\bar{\Lambda}$	$m_B - m_b$
λ_E^2/λ_H^2	0.5 ± 0.1	$2\lambda_E^2 + \lambda_H^2$	(0.25 ± 0.15) GeV^2
s_0	(1.5 ± 0.1) GeV^2	M^2	(1.25 ± 0.25) GeV^2
$\langle \bar{u}u \rangle(\mu_0)$	$-(240 \pm 15$ MeV$)^3$		
m_B	5.27929 GeV	m_ρ	0.77526 GeV
G_F	1.166378×10^{-5} GeV^{-2}	τ_B	$1.638 \times 10^{-12} s$
f_B	(192.0 ± 4.3) MeV [23]	$\lvert V_{ub}\rvert^{\rm excl}$	$(3.70 \pm 0.16) \times 10^{-3}$ [24]

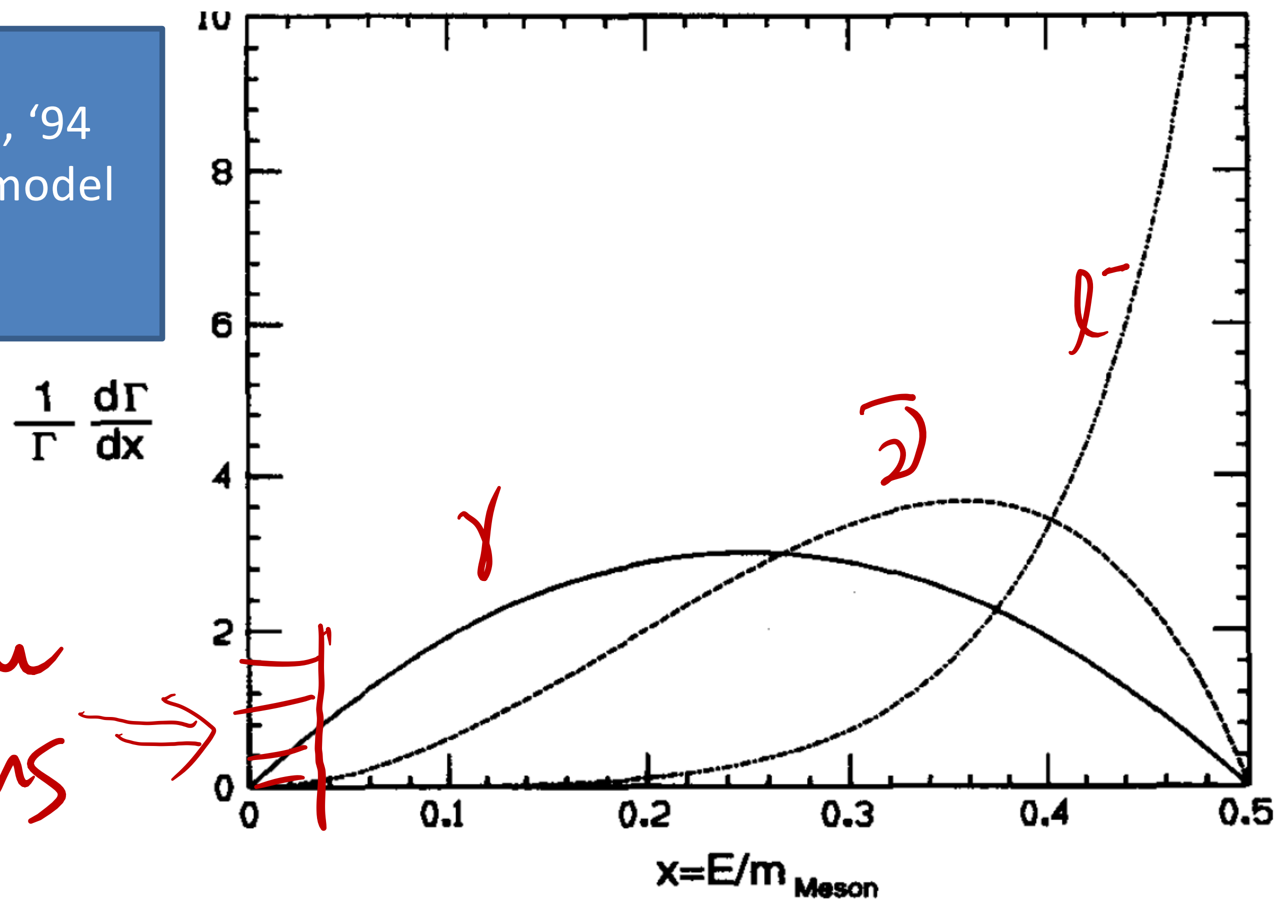
Table 1. Central values and ranges of all parameters used in this study. The four-flavour $\Lambda_{\rm QCD}$ parameter corresponds to $\alpha_s(m_Z) = 0.1180$ with three-loop evolution and decoupling of the bottom quark at the scale m_b.

Beneke et al
1804.04962
(also DESCOTES-GENON + CTS '03
(also Burdman et al PRD '95

9 non-pert params!!

Beneke et al
'2018

Atwood, Eilam + AS, '94
Toy-soluble-approx model calculation



Stay away from soft photons

Fig. 2. $B \to \ell^- \bar{\nu}\gamma$ normalized energy spectra are shown. Solid line is for the photon energy, the dashed is for the neutrino energy (which is directly related to invariant mass of the electron–photon combination) and the dash-dot for the electron energy. For the case of $D_s \to \ell^+\nu\gamma$ the dashed curve represents the neutrino energy spectrum while the dash-dot curve represents the lepton energy since in this case the roles of the lepton and neutrino are reversed.

BESIII (HUIJING LI)

Belle (II) Felix Metzner

$D_s^+ \Rightarrow \gamma \ell \nu_\ell$

$B^+ \to \gamma \ell \nu_e$

Improved strategy for DCP

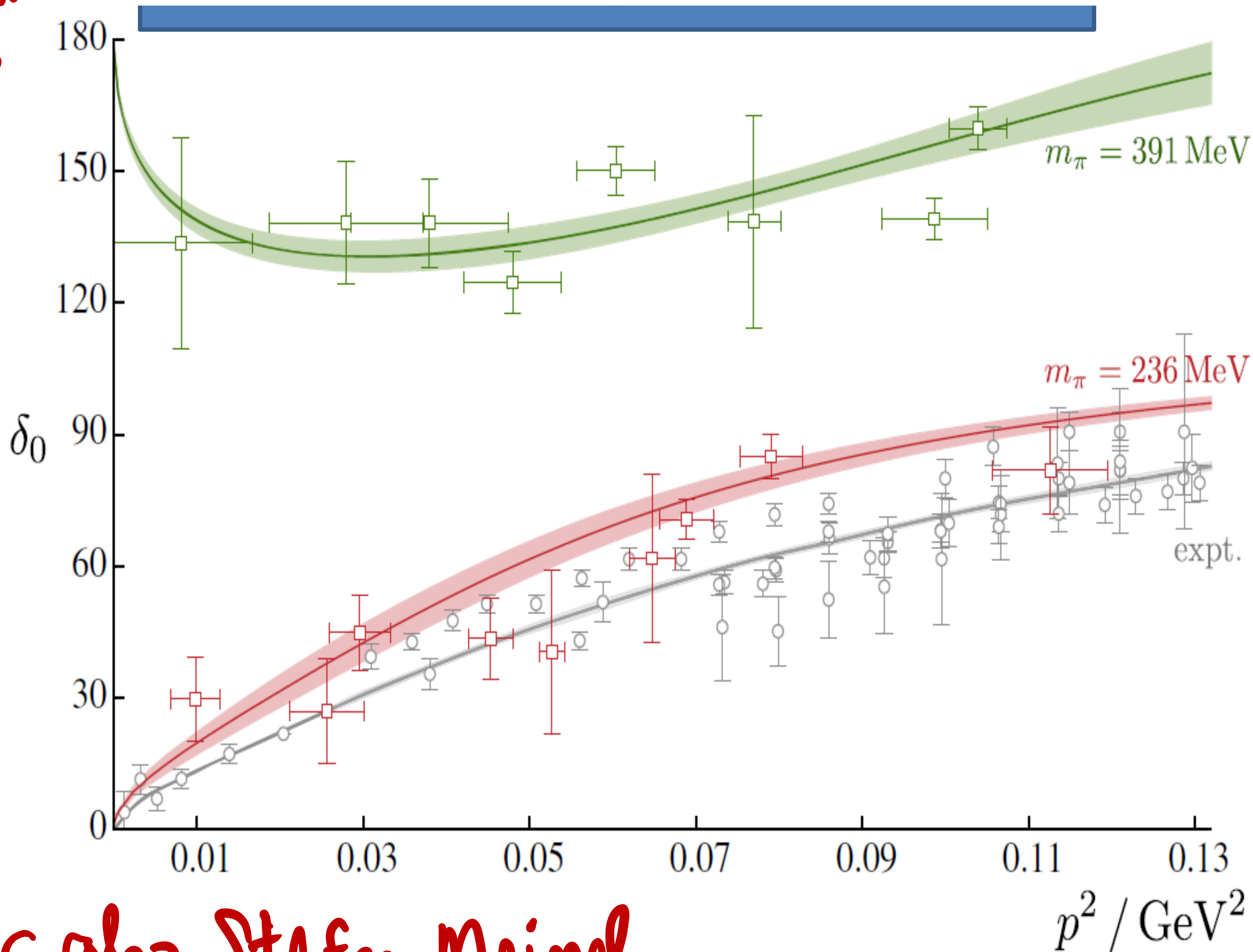
- **Improved a bit over DA+AS, PTEP 2013, Tab I**
- **Ds=> ρ^0 $K^{+(*)}$; K^+ ϕ [NOT K+*]**
- **D+ => ϕ π^+ (ρ^+) ; $K^{0(*)}$ K^+ [NOT K+*]**
- **D+ => ρ^0 π^+ ; π^0 π^+ …;[NOT ρ+]**
- **D0 => K^+ $K^{-(*)}$ [NOT K+*] ; ϕ ρ^0**
- **D0 => ρ^0 ρ^0 ; ρ^0 π^0 ; $\pi^+\pi^-$; $\pi^+\rho^-$ [Not ρ^+ π^-; ρ^+ ρ^-]**
- **NOTES:**
- **1)many FS all charged;**
- **2) Some VV good for TCA esp. Ds=> ρ^0 $K^{+(*)}$, D0 => ϕ ρ^0; 2K0***
- **3) all π^0 always also imply $\eta^{(')}$;**
- **4) Special Note: ρ^0 broad width not a problem for CP tests as can always replace it with π^+ π^- in a mass window so long as done C-symmetrically with the antiparticle decay as well.**

JLAB Lattice group

Isoscalar $\pi\pi$ Scattering and the σ Meson Resonance from QCD

Raul A. Briceño,[1,*] Jozef J. Dudek,[1,2,†] Robert G. Edwards,[1,‡] and David J. Wilson[3,§]
(for the Hadron Spectrum Collaboration)

PRL'17



c also Stefan Meinel

3 g & New Physics

- How can we use the non-perturbative set-up of the lattice to look for clues?
- t, b, tau, nu_tau
- Suitable targets b and tau
- Because of its mass b is often a challenge though progress is constantly being made
- tau is the BEST: lattice has no excuses
- Lattice can check that every aspect of tau agrees (or not wth SM)

gave 1 simple example;
MORE to COME

Strategy to enhance charm-CP

- **For charm-CP extremely important to suppress tree and maximize interference**
- A) avoid W-> ud or us making charge vector state…. e.g. rho^{+-} or K$^{*(+-)}$ …..field-current ….Sakurai VMD ideas B) go for CLS ….color suppressed FS…from tree
- C) go for CBS….cabibbo suppressed FS =>Singly Cabibbo Suppressed [SCS]….**atomatically forced by T-P interference a la Bander, Silverman and A.S PRL 1979**

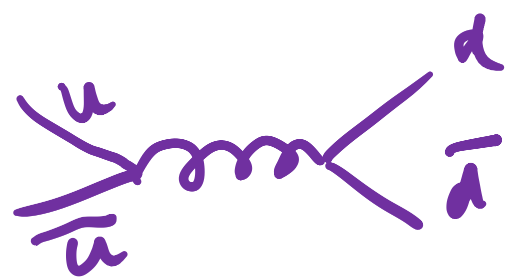
4^{th} rule

- **Zweig suppressed + CLS**
- **Only class of modes seem possible here:**
- **D0 => Ks Ks, K0 K0*, K0* K0***
- **Feynman graph**

See DA+AS PTEP ~ 2012-13

See also Nierste + Schacht '17

; $\phi\pi^0(S^0)$; CLS



CLS+ZWS

$\alpha_{K^+K^-} < \alpha_{\phi\pi^0(S^0)} < \alpha_{K_SK_S,\ K_S\bar{K}_0^*,\ 2K_0^*}$

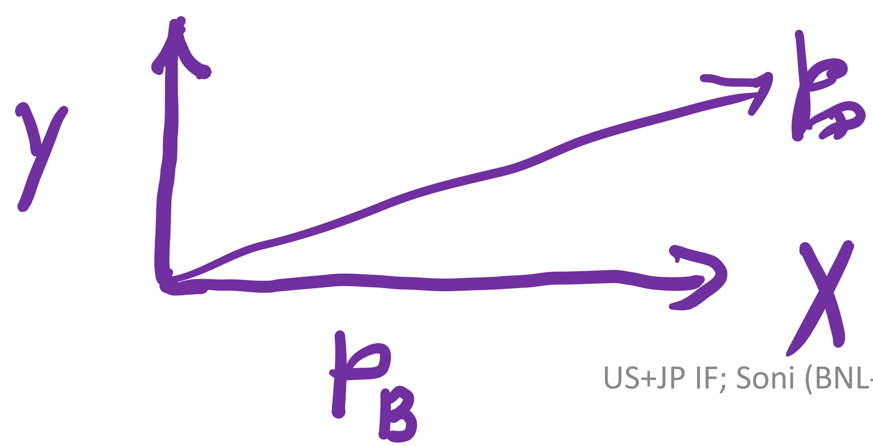
$K_SK_S,\ K^0K^{0(*)},\ 2K^{0*}$

CP studies in b=>c [D,D*..] tau nu

- **Studied long ago in Atwood, Eilam, +AS, PRL(93); c also Phys. Rept'01**
- **In addition to PRA, and energy asymmetry,**
- **Tau polarization is extremely useful**
- **There are 2 transverse polarization of the tau**
- **Along the y-axis [TN-even], along Z[TN-odd]**

τ REST Frame

$i\epsilon(a,b,c,d)$



C also T Kitahara et al '18;
A. Alok et al '17

More Opportunities in tau

- Techniques to Improve determination of magnetic and electric dipole moments of tau

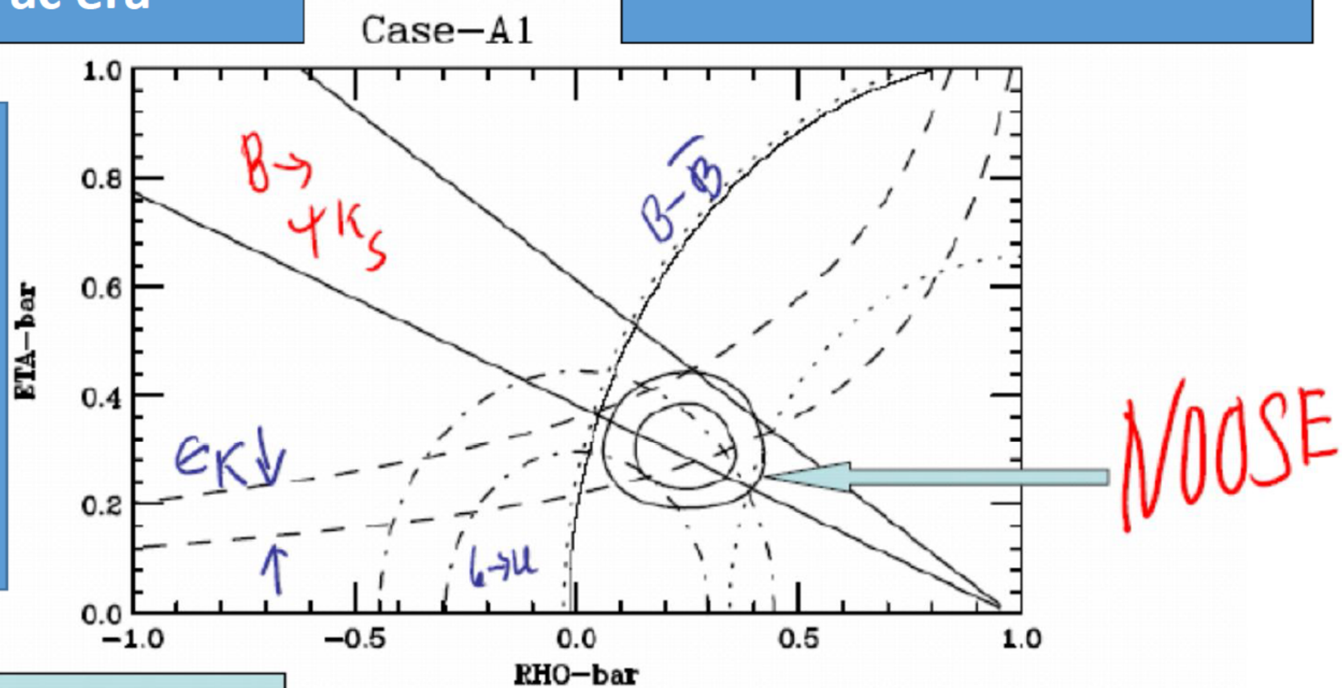
- Key point : Borrow ideas determination for the top quark….i.e an “elementary fermion”

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.

Lattice Calculations have come a very long way ----

Nowadays.. all include $\bar{q}q$ loops; Many use physical masses....

D. Atwood, A. Soni / Physics Letters B 508 (2001) 17–24 2001

Table 1

Fits using "nominal" and "conservative" values for the four input parameters. The QCD correction coefficients η_1, η_2, η_3 and
from [31] and $V_{cb} = 0.040 \pm 0.002$ [3]

Input quantity	Nominal	Conservative	
$R_{uc} \equiv \lvert V_{ub}/V_{cb}\rvert$	0.085 ± 0.017	0.085 ± 0.0255	3
$f_{B_d}\sqrt{\widehat{B}_{B_d}}$	230 ± 50 MeV	217 ± 50 MeV	23
ξ	1.16 ± 0.08	1.16 ± 0.10	9%
$\widehat{B}_K$	0.86 ± 0.15	0.90 ± 0.15	17%

Most of the calculations at the time ~ '01 were in the Quenched approx.

Nowadays, full-QCD, fB, ¥xi, Bk <~2%; Vub ~5% & Lattice being used in many new pheno. Appls.

TABLE I. Final states which can be used to probe $b \to s\gamma$ and $b \to d\gamma$ transitions in B_d and B_s decays. This list is not exhaustive; in particular, other neutral (pseudo-)scalar particles (η, η', f_0) may be used in the place of π^0.

	$K_S\pi^0\gamma$	$K_SK_S\gamma$	$\pi^+\pi^-\gamma$	$K^+K^-\gamma$	$K_SK_L\gamma$
$B_d/\overline{B}_d$	$b \to s\gamma$	$b \to d\gamma$	$b \to d\gamma$	$b \to d\gamma$	$b \to d\gamma$
$B_s/\overline{B}_s$	$b \to d\gamma$	$b \to s\gamma$	$b \to s\gamma$	$b \to s\gamma$	$b \to s\gamma$

Table actually covers a huge menu waiting to be explored with the full power of Belle-II

EXPTS
Belle (II): B
BES III: D_s

Amarjit Soni

BNL-HET

Lattice 2018 MSU 07/27/18

$D_s, B \to \ell \nu \gamma$

Based in part on
C. Lehner, S. Meinel + A. S
+ disc with Taku Izubuchi[WIP] ; RBC-UKQCD

Possible new physics opportunities in tau's

Ack: lattice disc with local [RBC-UKQCD] Bruno, Izubuchi, Lehner and Meyer.

A.S. in Proceedings of Lattice '85 (FSU)..1st Lattice meeting ever attended

The matrix elements of some penguin operators control in the standard model another CP violation parameter, namely ϵ'/ϵ.[6,8) Indeed efforts are now underway for an improved measurement of this important parameter.[10) In the absence of a reliable calculation for these parameters, the experimental measurements, often achieved at tremendous effort, cannot be used effectively for constraining the theory. It is therefore clearly important to see how far one can go with MC techniques in alleviating this old but very difficult

With C. Bernard [UCLA]

Serves as a template for the need of Lattice calculations for more economical use of almost all experimental data From IF

There is an interesting Crossing-Symmetry connection between the K=> pi semi-leptonic [Kl3] form factors and tau => nu Ks pi^+ ....~~by exploiting flavor SU3~~. For Kl3

ANALOGOUS TO Kl3

q^2 [with q= p_K – p_pi], q^2 >~ 0 is positive, while in the decay amplitude relevant to tau => nu Ks pi, Q^2 [with Q = p_K + p_pi], Q^2 > ~0, is positive.

But Complex amplitude Kπ scatt phase needed

In the tau decay calculation, final-state interaction phase enters and it'd be very interesting if this complex amplitude can be calculated on the lattice.

It'd also be very useful to study the case when pi^+ can be replaced with rho^+,

if possible.

Strong [i.e. CP-conserving] FS interaction phases

- We can calculate these phases on the lattice

for K, pi scattering see RBC-UKQCD [exploratory for K-pi; see T.Janowski et al, Lattice 2014]

and also now for pi pi

Tianle Wang [RBC-UKQCD]
Talk @ Lattice 2018

However, for an approximate result flavor SU(3) can also be used to relate them to pi pi scattering phases from Kl4 and from pi N => N pi pi following Colangelo et al.....get K pi phases upto SU(3) corrections

- T.W. talk at Lattice 2018 shows pi pi I=0 phases in good agreement with Colangelo

— Kπ phases also being studied by S Meinel + Collabs.

LQ Revival Circa 2018

Are There Anomalous Lepton-Hadron Interactions?

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Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742

and

Abdus Salam
International Centre for Theoretical Physics, Trieste, Italy, and Imperial College, London, England

(Received 5 February 1974)

It is remarked that the recently observed near constancy of $\sigma(e^+e^- \to \text{hadrons})$ over a large range of center-of-mass energy may reflect the presence of a new class of short-range lepton-hadron interactions. This can be tested by a comparison of e^-p versus e^+p scatterings and a study of the spin, parity, and charge conjugation of the final product in annihilation as well as apparent deviations from scaling in $e^\pm p$ and $\mu^\pm p$ scatterings.

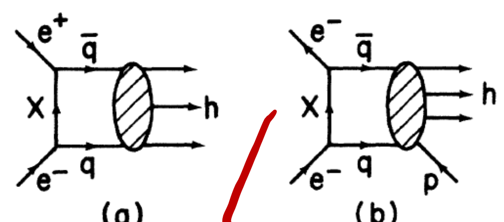
Recent experimental studies[1] of the electron-positron-annihilation cross section into hadrons $[\sigma_h(s)]$ as a function of s, the square of the total center-of-mass energy, seem to reveal a remarkable feature—that it is nearly constant at about 25–30 nb (within 30%) from $s \simeq 9$ to $s \simeq 25$ [in units of $(\text{BeV})^2$]. On the other hand, $\sigma(e^+e^- \to \mu^+\mu^-) \equiv \sigma_\mu(s)$ appears to fall according to the quantum-electrodynamic (QED) s^{-1} law. The near "constancy" of $\sigma_h(s)$ over such a wide region of s does not seem to obtain a simple explanation in terms of the familiar one-photon mechanism.[2] We consider in this note an alternative explanation for the behavior of $\sigma_h(s)$ based on a new class of short-range lepton-hadron interactions (leading to process such as $e^-e^+ \to q\bar{q}$, etc.) which may arise within the class of gauge schemes[3] proposed by us earlier, and point out that this leads to a variety of testable predictions; these should enable one to distinguish our explanation from all others based on the one-photon mechanism.[4]

heavy exotic[6] spin-1 mesons X (with nonzero baryon and lepton numbers) coupled to electron-quark (and possibly also to muon-quark[7]) currents as follows:

$$\mathcal{L}^X = f(\bar{e}\gamma_\mu q)X_\mu + \text{H.c.} \qquad (1)$$

There could, of course, be a triplet of X's corresponding to three baryonic colors. It is possible that there are vector and axial-vector mesons X_V and X_A coupled to currents $\bar{e}\gamma_\mu q$ and $\bar{e}\gamma_\mu\gamma_5 q$ with strengths f_V and f_A, respectively. For the present, we need not specify the $(\mathcal{P}, \mathfrak{N}, \lambda)$ indices of q.

Let us assume that the effective low-energy



(a) (b)

In charm decays the tree rules!

- **Tree goes as lambda ~0.22**
- **Penguin as lamda^5 so is exceedingly small**
- **Moreover lattice studies have demonstrated over and over again even for K =>pi pi decays,**

And Delta I=1/2 enhancement,

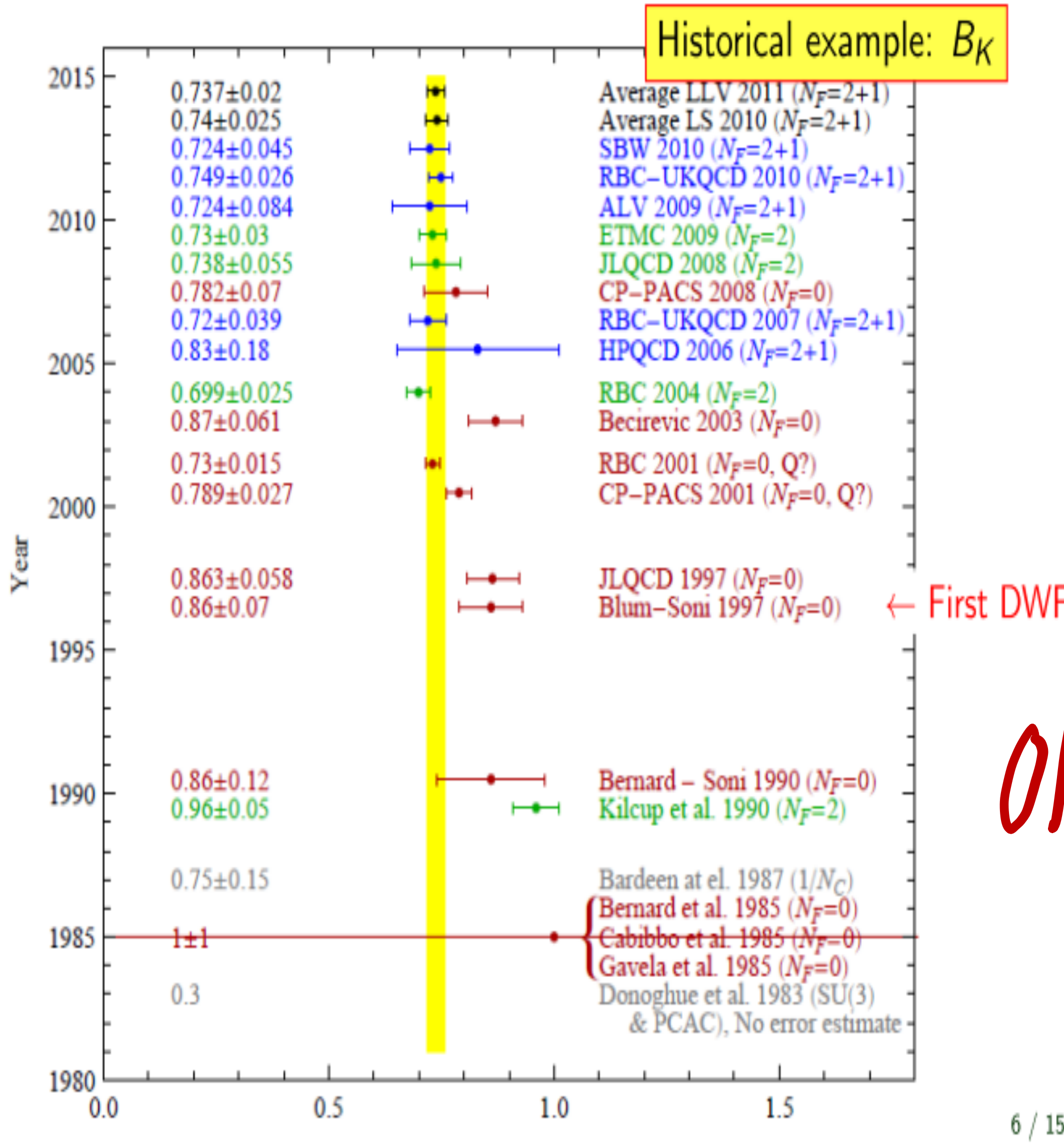
Penguin contribution is <O(%) of tree at scales >~1.5 GeV; so for charm T >> P

=>To enhance dir CP must make tree as small as possible

in so far as rates go

STAREING MORE AT CHARMIMG PENGUINS

Power of the lattice: Only method to systematically reduce the NP error!

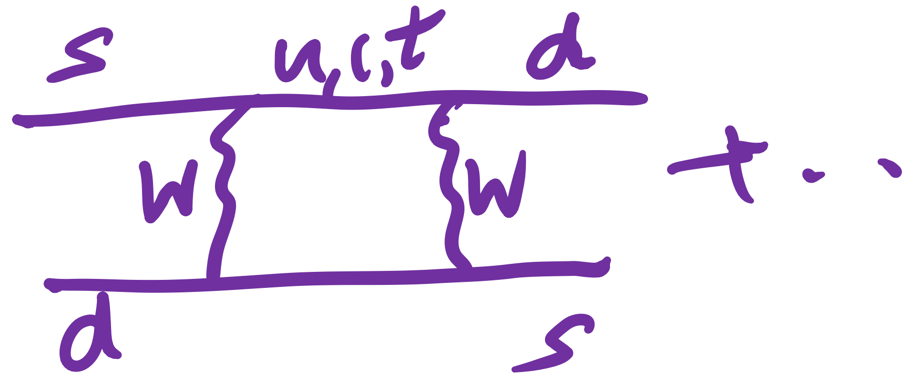


AB-initio Calculat[ion]

$$B_K = \frac{\langle K|(\bar{s}d)^2|\bar{K}\rangle}{8/3\, f_K^2\, m_K^2}$$

ONE ILLUSTRATION

Why B_K is needed?



$$|\varepsilon_K| = \frac{G_F^2 m_W^2 f_K^2 m_K}{12\sqrt{2}\pi^2 \Delta m_K^{\exp}} \hat{B}_K \kappa_\varepsilon \, \mathrm{Im}\Big(\eta_1 S_0(x_c)\,(V_{cs}V_{cd}^*)^2 + 2\eta_3 S_0(x_c, x_t) V_{cs}V_{cd}^* V_{ts}V_{td}^*$$

$$+\eta_2 S_0(x_t)\,(V_{ts}V_{td}^*)^2\Big)\,. \qquad (2.3)$$

η_i = QCD Corrections

$x_j = m_j^2 / m_W^2$

$$B_K \equiv \frac{\langle K | [\bar{s}\gamma_\mu(1-\gamma_5)d]^2 | \bar{K} \rangle}{8/3\, f_K^2 m_K^2}$$

Many possible decay channels

- **Allows you to construct many observables**

- **So both TN-even [e.g. energy asymmetry] as well as TN-odd [Triple Correlation Asymmetries]….are possible**
- **These studies are at large CM energy**
- **Need to connect to s=>0 for conventional [magnetic, electric] dipole moments interpretations…….**

III. OPTIMIZED OBSERVABLE QUANTITIES

Before defining how to measure the EDM or MDM couplings, let us consider the general problem of observing the change in the differential cross section due to the addition of any small coupling. Here, we denote the differential cross section by

$$\Sigma(\phi)d\phi \ , \tag{5}$$

where ϕ represents the relevant phase-space variables being considered (including angular and polarization variables). Suppose now that there is a small contribution to this differential cross section controlled by a parameter λ (for example, λ could be the EDM or MDM) so that if we expand the total differential cross section in terms of λ we have

$$\Sigma = \Sigma_0 + \lambda \Sigma_1 \ . \tag{6}$$

Mixing induced CP in radiative exc. B decays [Atwood, Gronau + AS, PRL’97; Atwood, Gershon, Hazumi +AS, PRD’05]

- γ in b=> s γ is predominantly LH [SM]
- γ in ¥bar b=> ¥bar s γ is predominantly RH [SM]
- Thus B^0 and ¥bar B0 cannot access common FS so they cannot MIX….=>Clean way to search NP!
- In 3 body exclusive modes, γ energy can monitor QCD complications

  e.g. $B_d \to \gamma K_s \pi^0$ . . . . . .
- On and off resonance FS can be combined so long as CP even and odd can be separated
- Many BSM models, such as LRS, WEXD, LQ’s can cause mixing and non-vanishing asymmetries
- Cleanliness of e+e- -(super)B factories gives a big edge for this class of searches!

C also Grinstein, Grossman, Ligeti, Pirjol, PRD’05; c also E. Kou et al

BELLE-2018

Abstract

We report a measurement of time-dependent CP violation parameters in $B^0 \to K_S^0 \eta \gamma$ decays. The study is based on a data sample, containing $772 \times 10^6 B\bar{B}$ pairs, that was collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. We obtain the CP violation parameters of $\mathcal{S} = -1.32 \pm 0.77(\text{stat.}) \pm 0.36(\text{syst.})$ and $\mathcal{A} = -0.48 \pm 0.41(\text{stat.}) \pm 0.07(\text{syst.})$ for the invariant mass of the $K_S^0\eta$ system up to 2.1 GeV$/c^2$.

BELLE-2004

We report measurements of CP violation parameters in $B^0 \longrightarrow K_S^0 \pi^0 \gamma$ transitions based on a data sample of $535 \times 10^6 B\bar{B}$ pairs collected with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. One neutral B meson is fully reconstructed in the $B^0 \longrightarrow K_S^0 \pi^0 \gamma$ mode. The flavor of the accompanying B meson is identified from its decay products. We obtain time-dependent and direct CP violation parameters $\mathcal{S}$ and $\mathcal{A}$ for a $K_S^0\pi^0$ invariant mass up to 1.8 GeV$/c^2$ as $\mathcal{S}_{K_S^0\pi^0\gamma} = -0.10 \pm 0.31 \pm 0.07$ and $\mathcal{A}_{K_S^0\pi^0\gamma} = -0.20 \pm 0.20 \pm 0.06$. For a $K_S^0\pi^0$ invariant mass near the $K^{*0}(892)$ resonance, we obtain $\mathcal{S}_{K^{*0}\gamma} = -0.32^{+0.36}_{-0.33} \pm 0.05$ and $\mathcal{A}_{K^{*0}\gamma} = -0.20 \pm 0.24 \pm 0.05$.

Belle-II should be sensitive to $S \gtrsim 0.10$ + perhaps even $S \sim 0.05$