Flavor anomalies & the lattice

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

outline

- Flavor "Anomalies"
- Role of lattice
- Belle-II + LHCb[upgrades]: Gorilla + Godzilla
- Because of expt + new lattice methodology=>
  new observables: illustrative examples
- Summary+ outlook

- C also, Theory Summary, FPCP2018 at
- https://indico.cern.ch/event/698482/contributions/3064865/attachments/1693970/2726174/FPCP18-final.pdf

The RBC & UKQCD collaborations

BNL and BNL/RBRC

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York University (Toronto)

Renwick Hudspith

Anomalies galore!

- RD(*) *~ 4σ (?)*
- RK(*): *2.6σ (RK) ; ~ $\sqrt{2}$ * 2.6 => 3.5σ*
- g -2…BNL'06 =>FNAL expt. *~ 3.6σ* *major lattice progress by RBC-UKQCD & others*
- Ɛ': a personal obsession….for a long^3 time=>'cause of the strong conviction that it is super-sensitive to NP *EVER LOOMING*

  216[RBC-UKQCD PRL 2015] => ~1400 *C. Kelly*

[2.1σ (2.9σ Buras; Nierste) => ??] …..few more months to new results

REAL or fake : Lattice + EXPT DECIDERS

In decoding SM or not, lattice input is vital for each case!

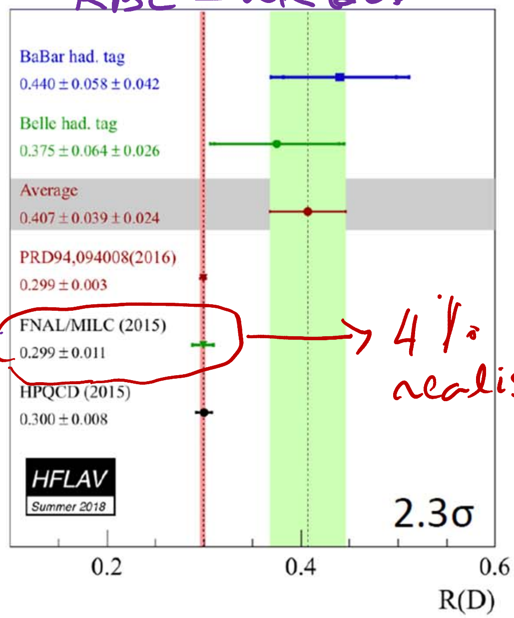
Status of R(D$^{(*)}$) results

also WITZEL et al RBC – UKQCD

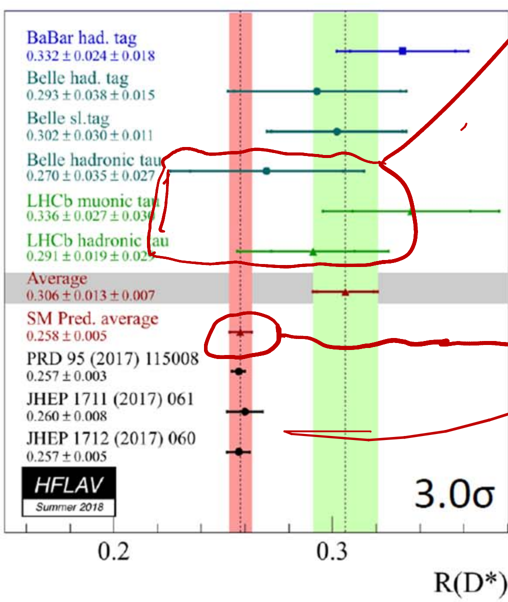
A

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

POTENTIALLY VERY SERIOUS EXPTAL PROBLEM

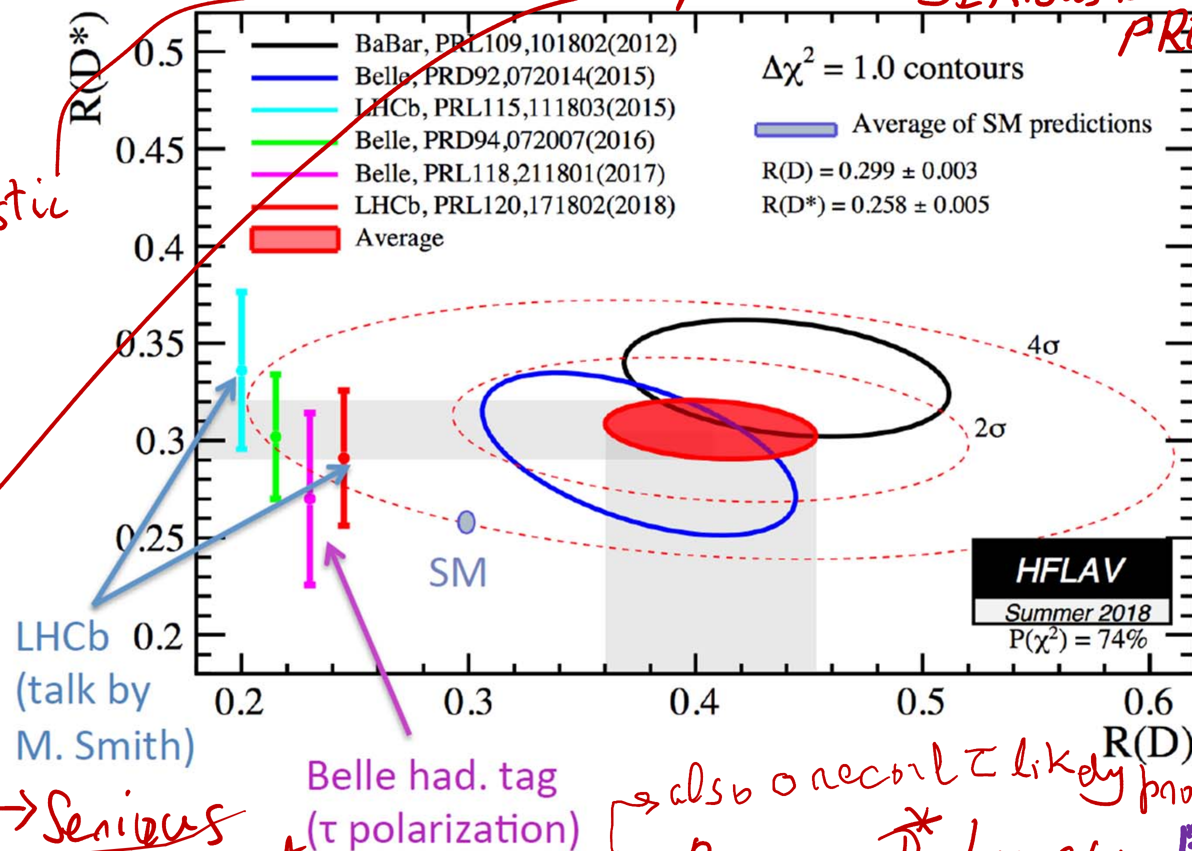


4% realistic



Serious

Likely also affects V_{cb}



also on recoil τ likely problem

no Theory errors Because D* has spin B

Deviation from SM prediction: 3.9 σ

V Likely OVERESTIMATE

Lepton Flavour Universality

c also Shoji H

Arantza Oyanguren

- In the SM all leptons are expected to behave in the sa

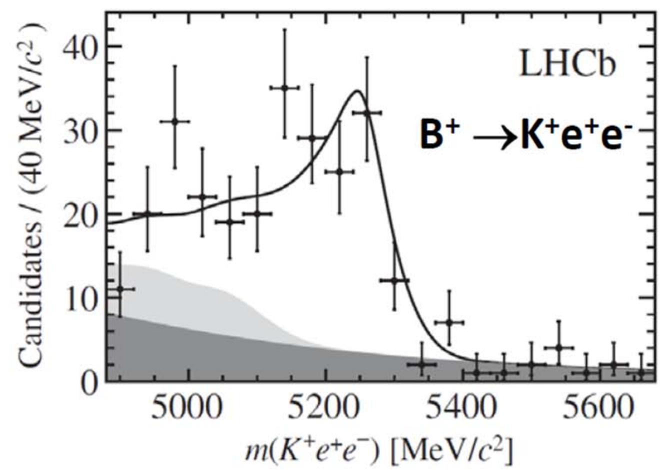
THEORY IRrelevant here

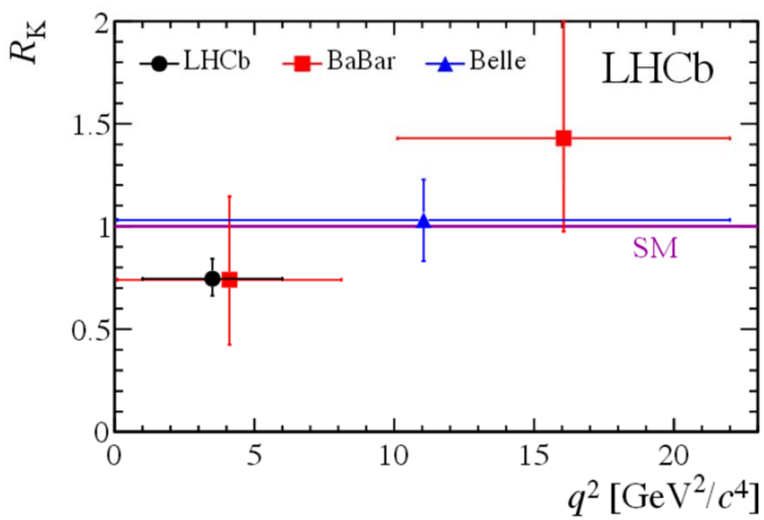
$$R_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ e^+ e^-)}$$ = 1.000 + $O(m_\mu^2/m_b^2)$ (SM) so long as $m_{ee} > 500$ meV ✓

[PRL 113 (2014) 151601]

- Experimentally, use the $B^+ \to K^+ J/\psi(\to e^+e^-)$ and $B^+ \to K^+ J/\psi(\to \mu^+\mu^-)$ to perform a double ratio

- Precise theory prediction due to cancellation of hadronic form factor uncertainties





1 GeV < q^2 < 6 GeV

$$R_K = 0.745^{+0.090}_{-0.074}\,(\text{stat}) \pm 0.036\,(\text{syst})$$!

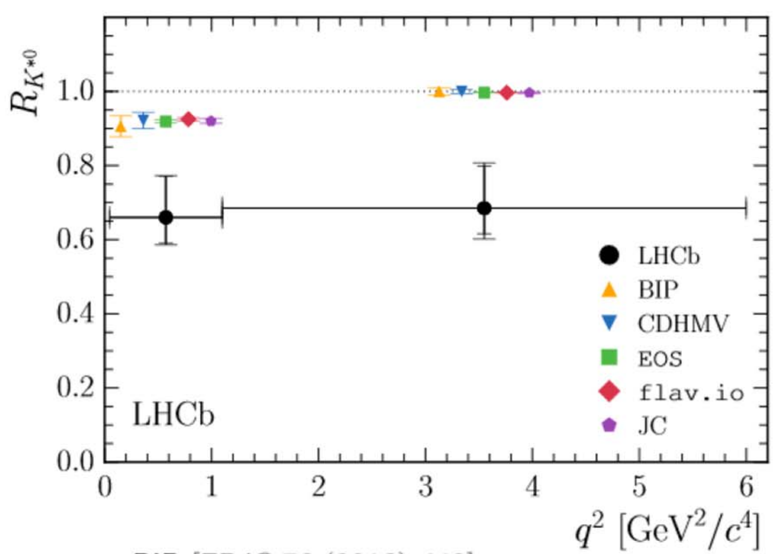
→ Consistent, but lower, than the SM at **2.6σ**

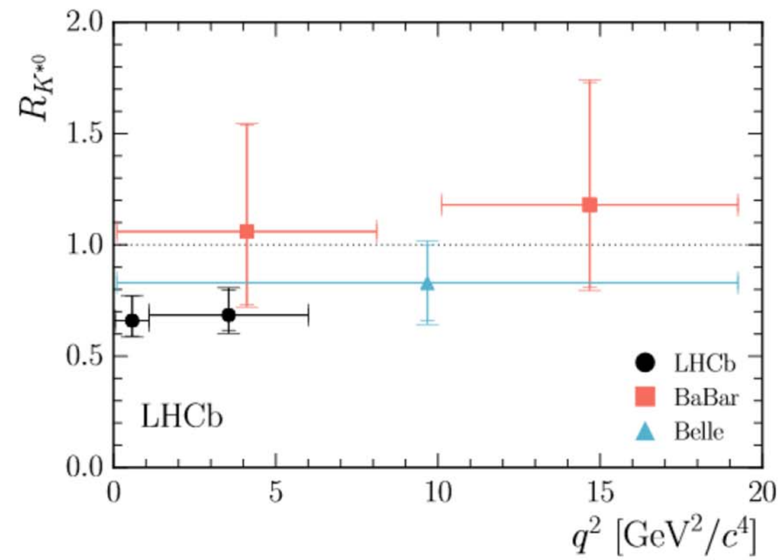
Arantza Oyanguren

Lepton Flavour Universality

LHCb, JHEP08(2017)055

- Results:





- ▲ BIP [EPJC 76 (2016) 440]
- ▼ CDHMV [JHEP 04 (2017) 016]
- ■ EOS [PRD 95 (2017) 035029]
- ◆ flav.io [EPJC 77 (2017) 377]
- ⬟ JC [PRD 93 (2016) 014028]

- ● LHCb [PRL 113 (2014) 151601]
- ▲ Belle [PRL 103 (2009) 171801]
- ■ BaBar [PRD 86 (2012) 032012]

Low q^2 [0.045-1.1 GeV^2]: SM▼ = 0.922(22)

$$R_{K^{*0}} = 0.66 \,{}^{+\,0.11}_{-\,0.07}\,(\text{stat}) \pm 0.03\,(\text{syst})$$

Central q^2: [1.1-6 GeV^2]: SM▼ = 1.000(6)

$$R_{K^{*0}} = 0.69 \,{}^{+\,0.11}_{-\,0.07}\,(\text{stat}) \pm 0.05\,(\text{syst})$$

Radiative Corr

→ Consistent, but lower than the SM at **2.1-2.3σ** (low q^2) and **2.4-2.5σ** (central q^2)

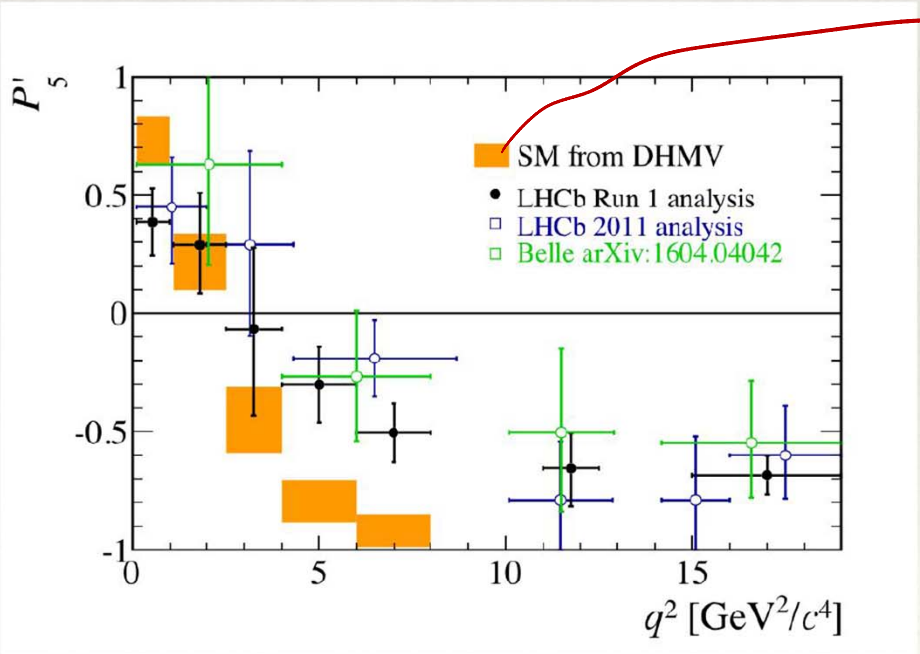
C: ISIDORI et al 2016 EPJC

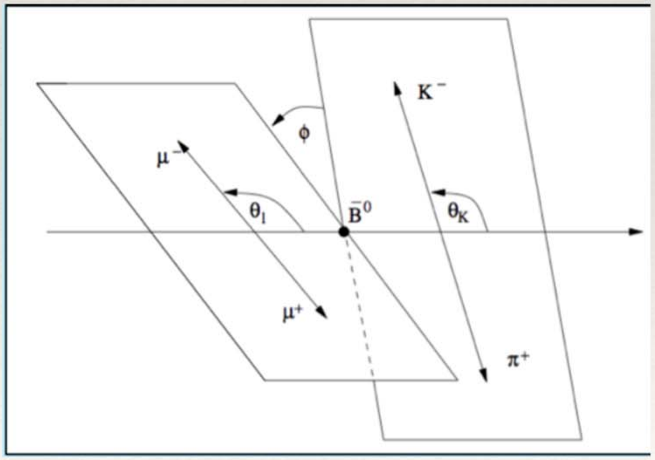
B-flavor anomalies: P_5'

REMAIN CONCERNED ABOUT NON-local contributions

- Several angular observables measured as functions of q^2
- Some, like P_5', are optimized to be insensitive to hadronic uncertainties: [Descotes-Genon, Matias, Ramon, Virto: 1207.2753]

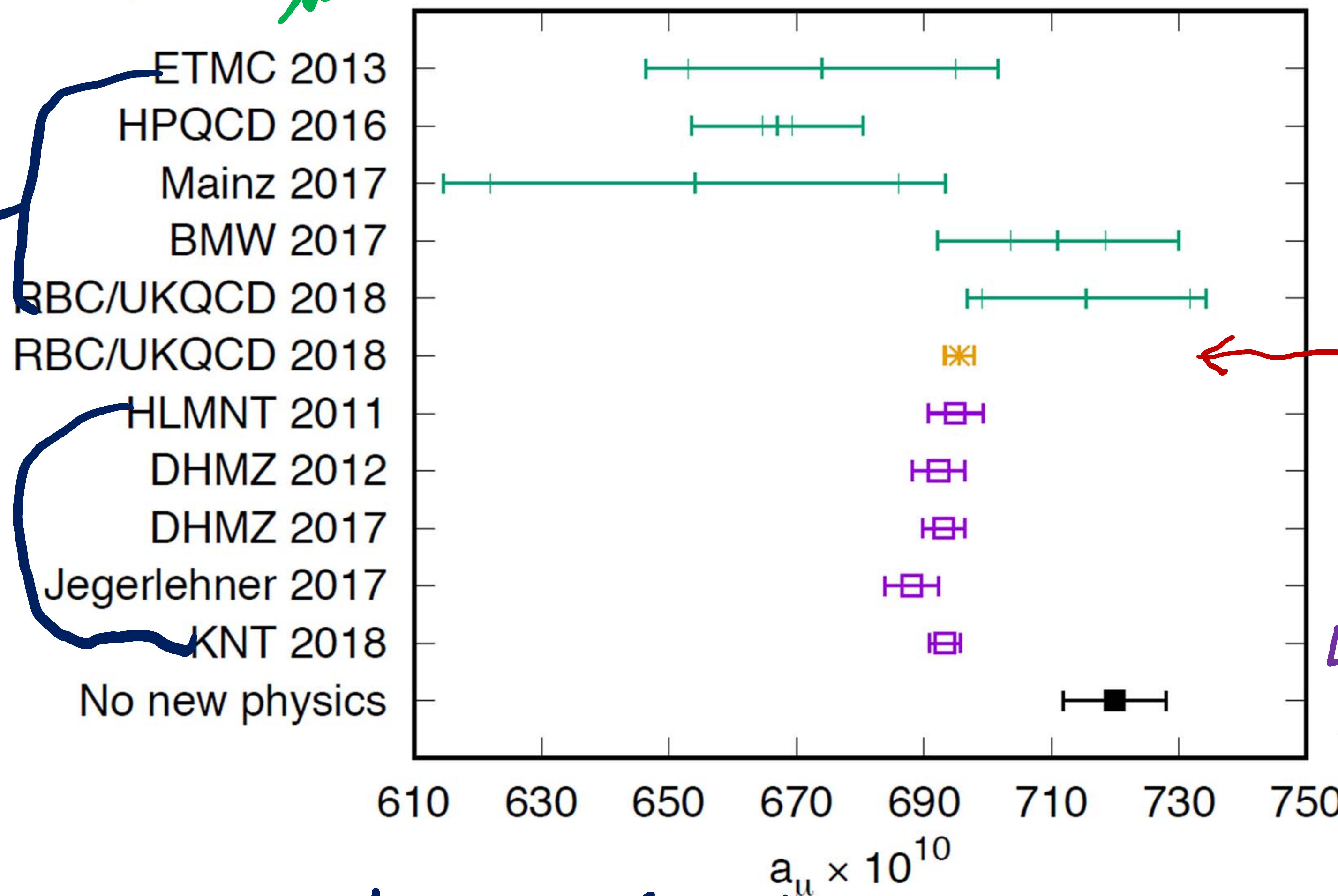
unreliable





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

PURE Lattice



Pheno

C Lehner et al RBC=UKQCD HYBRID

Lattice use INITIATED BY T. BLUM ~2004 while@BNL

SUMMARY: C. LEHNER (BNL)

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.

HET Lunch Seminar 03/09/18

MUON MAY NOT BE JUST A HEAVY ELECTRON: KILE, KOBACH AND AS

PRD 2015

Table 1

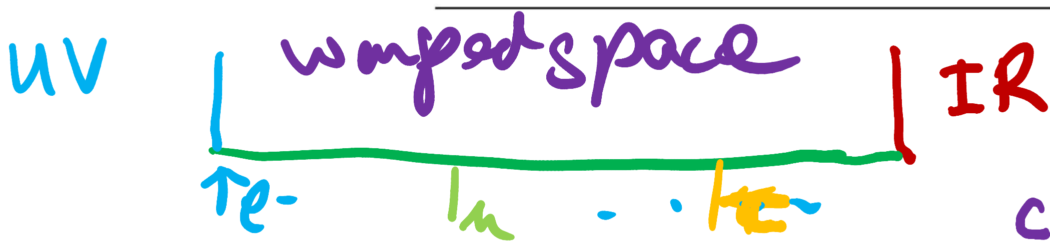
Constraints on lepton-flavor violating and conserving processes. For the last four observables, the experimental null results are given in terms of a dimension-6 operator, suppressed by two orders of Λ, which can be interpreted as the nominal scale of new physics.

Observable	Limit
$\mathrm{Br}(\mu \to 3e)$	$< 1.0 \times 10^{-12}$ [1]
$\mathrm{Br}(\mu \to e\gamma)$	$< 5.7 \times 10^{-13}$ [1]
$\mathrm{Br}(\tau \to 3e)$	$< 2.7 \times 10^{-8}$ [1]
$\mathrm{Br}(\tau \to e^-\mu^+\mu^-)$	$< 2.7 \times 10^{-8}$ [1]
$\mathrm{Br}(\tau \to e^+\mu^-\mu^-)$	$< 1.7 \times 10^{-8}$ [1]
$\mathrm{Br}(\tau \to \mu^-e^+e^-)$	$< 1.8 \times 10^{-8}$ [1]
$\mathrm{Br}(\tau \to \mu^+e^-e^-)$	$< 1.5 \times 10^{-8}$ [1]
$\mathrm{Br}(\tau \to 3\mu)$	$< 2.1 \times 10^{-8}$ [1]
$\mathrm{Br}(\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$ [1]
$\mathrm{Br}(\tau \to e\gamma)$	$< 3.3 \times 10^{-8}$ [1]
μ–e conversion	$\Lambda \gtrsim 10^3$ TeV [5]
$e^+e^- \to e^+e^-$	$\Lambda \gtrsim 5$ TeV [3]
$e^+e^- \to \mu^+\mu^-$	$\Lambda \gtrsim 5$ TeV [3]
$e^+e^- \to \tau^+\tau^-$	$\Lambda \gtrsim 4$ TeV [3]

1st gen not sensitive to NP + $(g-2)_\mu$

Kile, Kobach + AS PRD 2015 ⇓ Speculation

Maybe 1st gen. is fundamental & its protection from NP



c ALSO A. Iyer & Lyon

Bottom line

- **NP or not depends critically not just on precise experiment but also reliable SM prediction from the lattice become mandatory**
- **Experiment + Lattice M.E. has the last word….[of course should be stressed that the lattice calculations often require sophisticated and demanding and essential input from perturbation theory]**
- **Experimental results often attained at huge cost can be used effectively, iff commensurate theory predictions are available…….mantra for past several decades**

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]

Testing LUV in the era of Belle-II

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

Toru Iijima @ SCGP May 31, 2018

SuperKEKB/Belle II

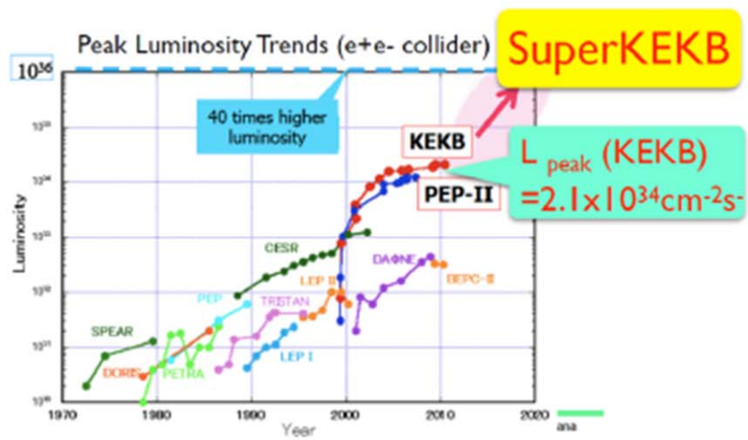
New intensity frontier facility at KEK

- 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 !

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

Calmo Shoji



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 !

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…**

Importance of the "IF": score card

- Beta decay => Gf => W….
- Huge suppression of KL => mu mu; miniscule ΔmK=> charm
- KL =>2 pi but very rarely; mostly to 3pi =>CP violation => 3 families
- Largish Bd –mixing => large top mass
- etc…….
- => 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

Testing LUV in the era of Belle-II

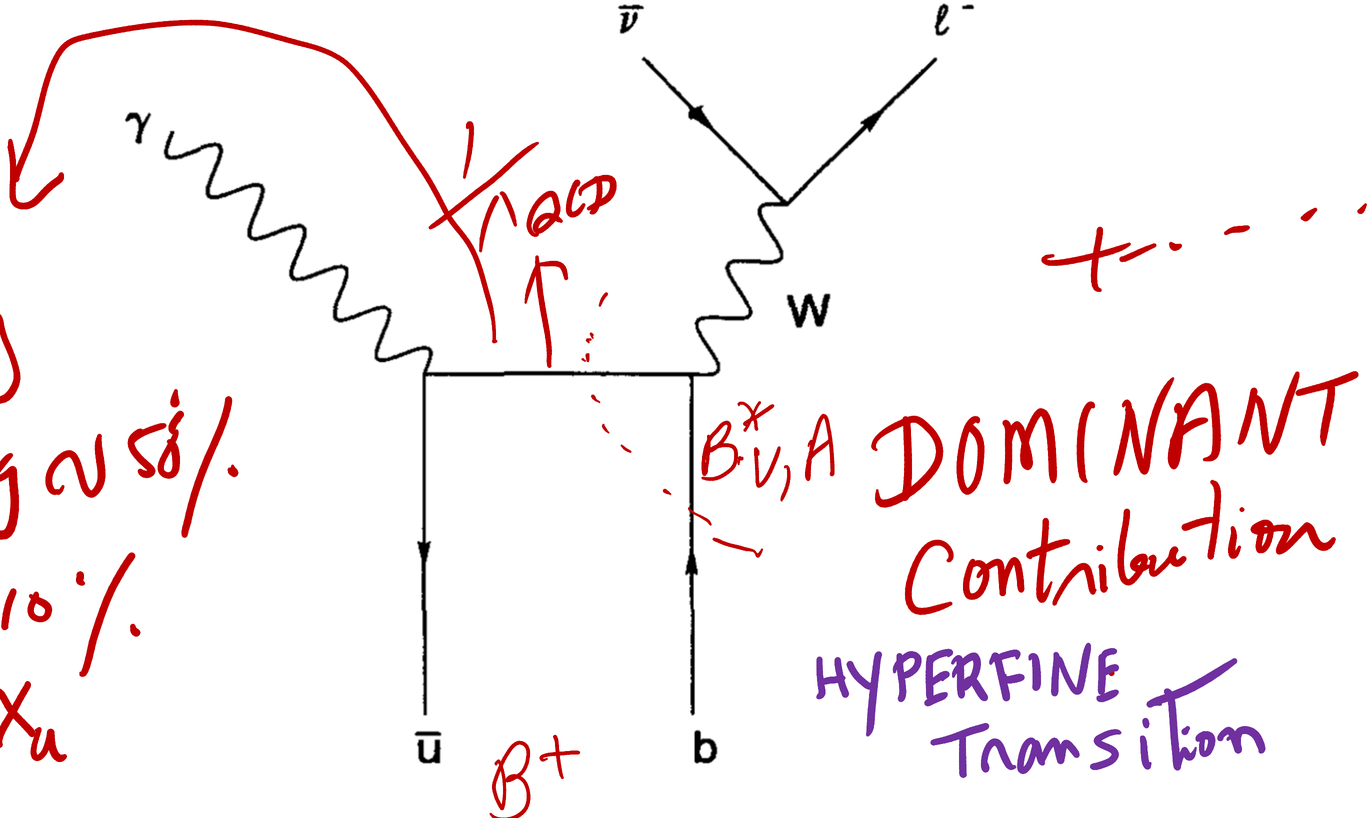
- II. **On the lattice technical front, RBC-UKQCD collab**

has developed the methodology over the past ~6 years for calculating from 1^{st} 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 M_hl =>** $\tau/\ell\, \nu\, \gamma$
- **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** → Atwood, Eilam, AS hep-ph/9411367
- **Br [B => mu nu gamma]/Br[B=> mu nu] ~16**

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

Radiative leptonic decays of heavy-light mesons



Non-local [RBC-UKQCD]

$\delta m_K \to$ Bigeng ~ 5%

$\epsilon_K^{LD} \sim 5-10\%$

$K^+ \to \pi^+ \nu\bar{\nu}$ X_u ~ 5-10%

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

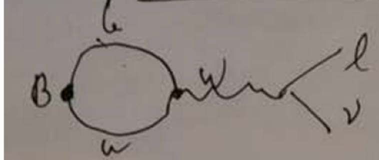
c.also, AOKI + X_uF + S.H. . . . $\pi^0 \to 2\gamma$ PRL 2012

Radiative leptonic decays of heavy-light mesons

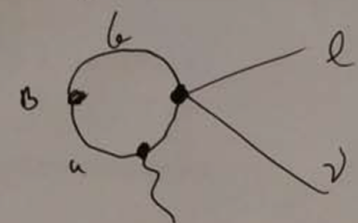
- These are distinctly 3-body final state not to be confused with soft photons that necessarily accompany physical processes and their treatment is strictly linked to detector resolution….also typically these are brehmms with steeply falling spectrum GM+ CTS et al
- In contrast, the 3-body final state such as Ds, B+ => l nu gamma are important corrections to pure leptonic decays l + nu have whose importance has been stressed due to their ability to overcome helicity suppression via hyperfine transitions
- To get a clear intutive understanding it may help to think in terms of the naïve quark model [though from the outset one recognizes its limitation in accuracy esp for a heavy-light system]
- In that naïve picture, one can resort to the Weisskopf-Van Royen text book approx and clearly identify the underlying physical processes:

Essentially solvable approx model

Dim - Analysis



$$\Gamma_2 \sim \frac{G_F^2}{8\pi} m_B^2 f_B^2 m_\ell V_{ub}^2 \qquad \frac{m_\ell}{m_B} \to 0$$



$$\Gamma_3 \sim \frac{G_F^2 m_B^3 f_B^2}{192\pi^3} \left(\frac{m_B}{\Lambda_{eff}}\right)^2 \alpha 4\pi V_{ub}^2$$

For $m_\ell = m_\mu$

$$\frac{\Gamma_3}{\Gamma_2} \sim \frac{\alpha}{\pi} \left(\frac{m_B}{m_\ell}\right)^2 \left(\frac{m_B}{\Lambda_{eff}}\right)^2 \frac{1}{48} \quad \sim 15$$

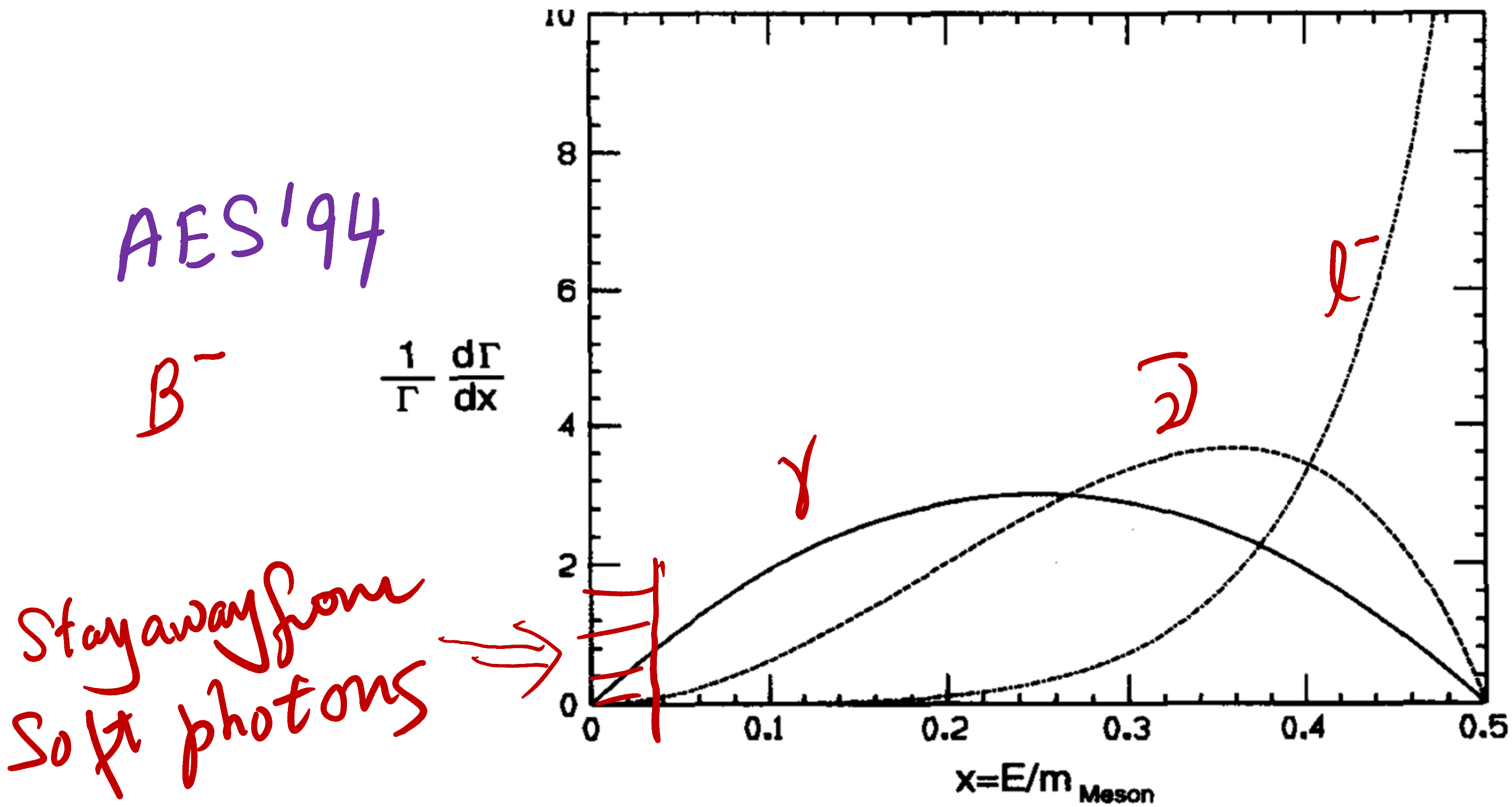


Fig. 2. $B \to \ell^- \bar{\nu}\gamma$ normalized energy spectra are shown. Solid line is for the photon energy, the dashed is for the neutrino energy (which is directly related to invariant mass of the electron–photon combination) and the dash-dot for the electron energy. For the case of $D_s \to \ell^+\nu\gamma$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

D_s^+

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

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]	$\|V_{ub}\|^{\rm excl}$	$(3.70 \pm 0.16) \times 10^{-3}$ [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.

9 non-pert params!!
HOLY Buffalo!

Beneke et al
'2018

On the lattice

- **On the lattice this calculation of B^+ [Ds^-]=>l ν γ is rather similar to π^0 => 2 γ [see Xu Feng et al, PRL] and to RBC-UKQCD recent attempts at LBL contribution to muon g-2 via the π^0 exch.** *
- **Except now 1 photon gets replaced by the V, A**

[heavy –light states] which dominate the transition to the final l + nu [w/o helicity suppression]

- **The dominant graph is when the light quark emits the photon, though of course [QED] gauge invariance requires emission from all charged legs.**
- **The emission of photon off the charged lepton will be helicity suppressed so it will also be an important contributor when emitted from tau**
- **The details of Minkowski-Euclidean connection closely follow pi^0 => 2 gamma with appropriate changes**

* c also X d Ji + C W Jung PRL '01

$$M_{\mu\nu}^{\rm mink}(p_1, p_2) = i \int d^4x e^{ip_1x} \langle 0|T\{j_\mu(x) j_\nu(0)\}|\pi^0(q)\rangle \tag{1}$$

EM C

$$= \varepsilon_{\mu\nu\alpha\beta} p_1^\alpha p_2^\beta \mathcal{F}_{\pi\gamma\gamma}(m_\pi^2, p_1^2, p_2^2) \tag{2}$$

CL NOTES

$p_1 = (\omega, \vec{p}_1)$

$q = [E_{\pi,\vec{q}}, \vec{q}]$; $E_\pi^2 = m_\pi^2 + \vec{q}^{\,2}$

$p_2 = [E_{\pi,\vec{q}} - \omega, \vec{q} - \vec{p}_1]$

$$M_{\mu\nu}^{\rm mink}(p_1, p_2) = i \int d^3x e^{-i\tilde{p}_1\tilde{x}} \Bigg[\sum_n \int_{-\infty}^{0} dt e^{i(\omega + \tilde{E}_n - i\varepsilon)t} \langle 0|j_\nu(0)|n\rangle \langle n|j_\mu(\tilde{x})|\pi^0(q)\rangle$$

$$+ \sum_n \int_0^\infty dt e^{i(\omega - E_n + i\varepsilon)t} \langle 0|j_\mu(\tilde{x})|n\rangle \langle n|j_\nu(0)|\pi^0(q)\rangle \Bigg] \tag{7}$$

$$= \sum_n \frac{1}{\tilde{E}_n + \omega} \langle 0|j_\nu(0)|n\rangle \langle n|j_\mu(-\tilde{p}_1)|\pi^0(q)\rangle$$

$$+ \sum_n \frac{1}{E_n - \omega} \langle 0|j_\mu(-\tilde{p}_1)|n\rangle \langle n|j_\nu(0)|\pi^0(q)\rangle \, . \tag{8}$$

with $j_\mu(t, \tilde{x}) = e^{iHt} j_\mu(\tilde{x}) e^{-iHt}$, $\tilde{E}_n = E_n - E_{\pi,\tilde{q}}$, $H|n\rangle = E_n|n\rangle$, and

$$j_\mu(\tilde{p}) \equiv \int d^3x e^{i\tilde{p}\tilde{x}} j_\mu(\tilde{x}) \, . \tag{9}$$

$$M^{\rm eucl}_{\mu\nu}(p_1,p_2) = \int d^3x e^{-i\tilde{p}_1\tilde{x}} \int dt e^{\omega t} \langle 0|T\{j_\mu(\tilde{x},t) j_\nu(0)\}|\pi^0(q)\rangle \tag{10}$$

$$= \sum_n \int_{-\infty}^{0} dt e^{(\omega+\tilde{E}_n)t} \langle 0|j_\nu(0)|n\rangle\langle n|j_\mu(-\tilde{p}_1)|\pi^0(q)\rangle$$

$$+ \sum_n \int_0^{\infty} dt e^{(\omega-E_n)t} \langle 0|j_\mu(-\tilde{p}_1)|n\rangle\langle n|j_\nu(0)|\pi^0(q)\rangle \tag{11}$$

$$= \sum_n \frac{1}{\tilde{E}_n+\omega} \langle 0|j_\nu(0)|n\rangle\langle n|j_\mu(-\tilde{p}_1)|\pi^0(q)\rangle$$

$$+ \sum_n \frac{1}{E_n-\omega} \langle 0|j_\mu(-\tilde{p}_1)|n\rangle\langle n|j_\nu(0)|\pi^0(q)\rangle\,, \tag{12}$$

with Euclidean $j_\mu(t,\tilde{x}) = e^{Ht} j_\mu(\tilde{x}) e^{-Ht}$ and where both integrals converge as long as $-\tilde{E}_n < \omega < E_n$. With this restriction of domain of ω, we can therefore relate Minkowski and Euclidean space

$$M^{\rm mink} = M^{\rm eucl}\,. \tag{13}$$

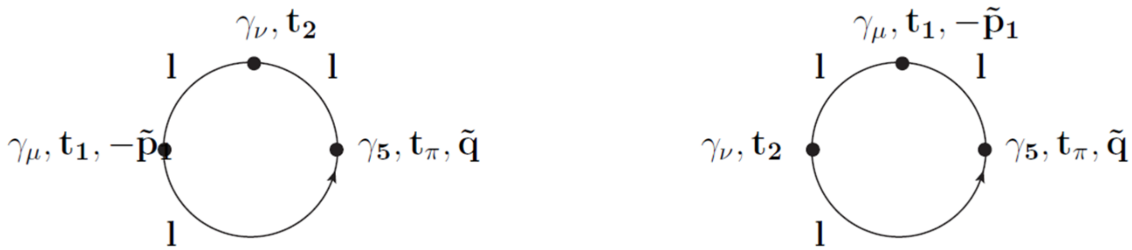


Figure 1: $\pi^0 \to \gamma\gamma$ diagram A (left) and B (right). There are additional disconnected diagrams not yet drawn here.

EM Weak V,A

$$T_{\mu\nu} = -i \int d^4x e^{iPx} \langle 0|T\{j_\mu(x) j_\nu^W(0)\}|B^-(P+Q)\rangle \qquad (19)$$

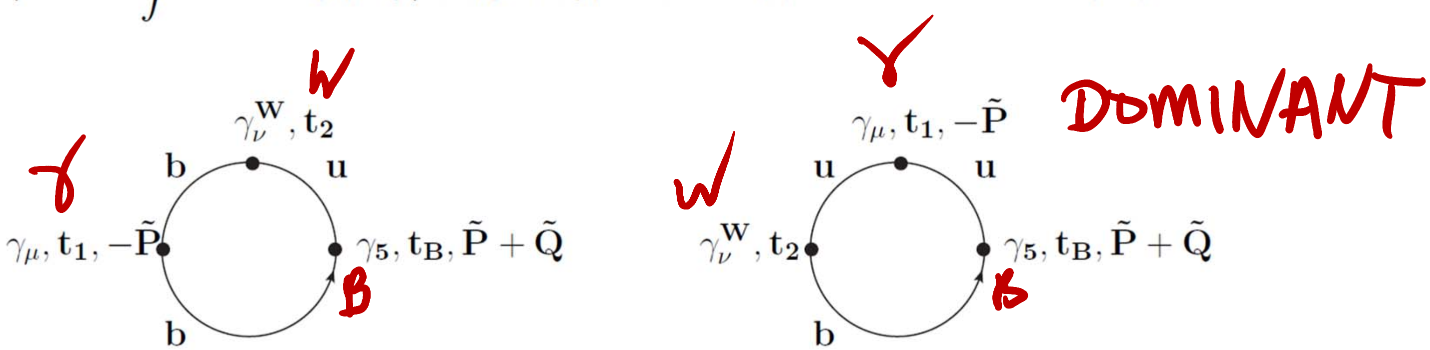
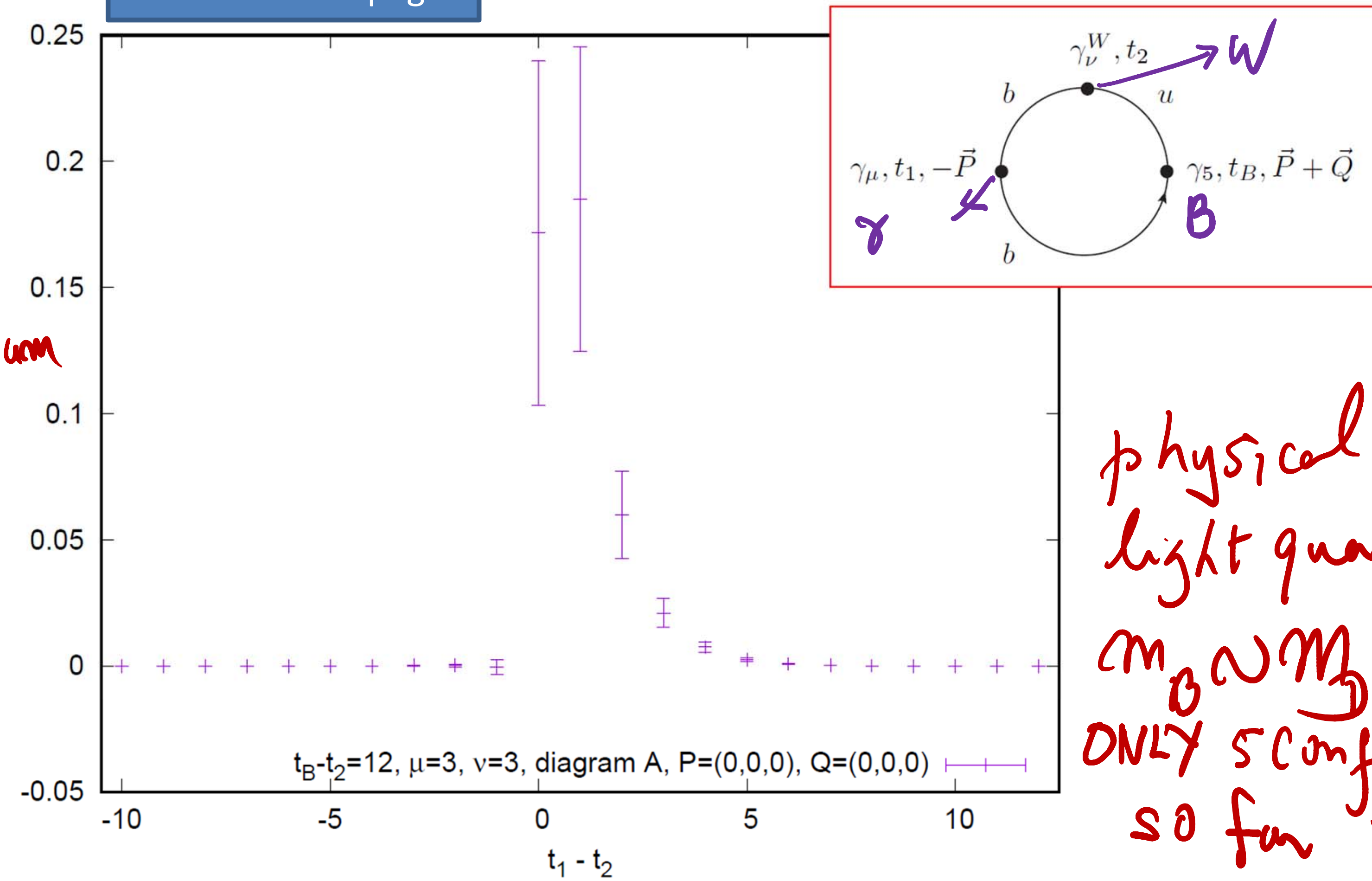


Figure 3: Radiative leptonic B decay diagram A (left) and B (right). There are additional disconnected diagrams not yet drawn here.

C some lattice
Details in back pages



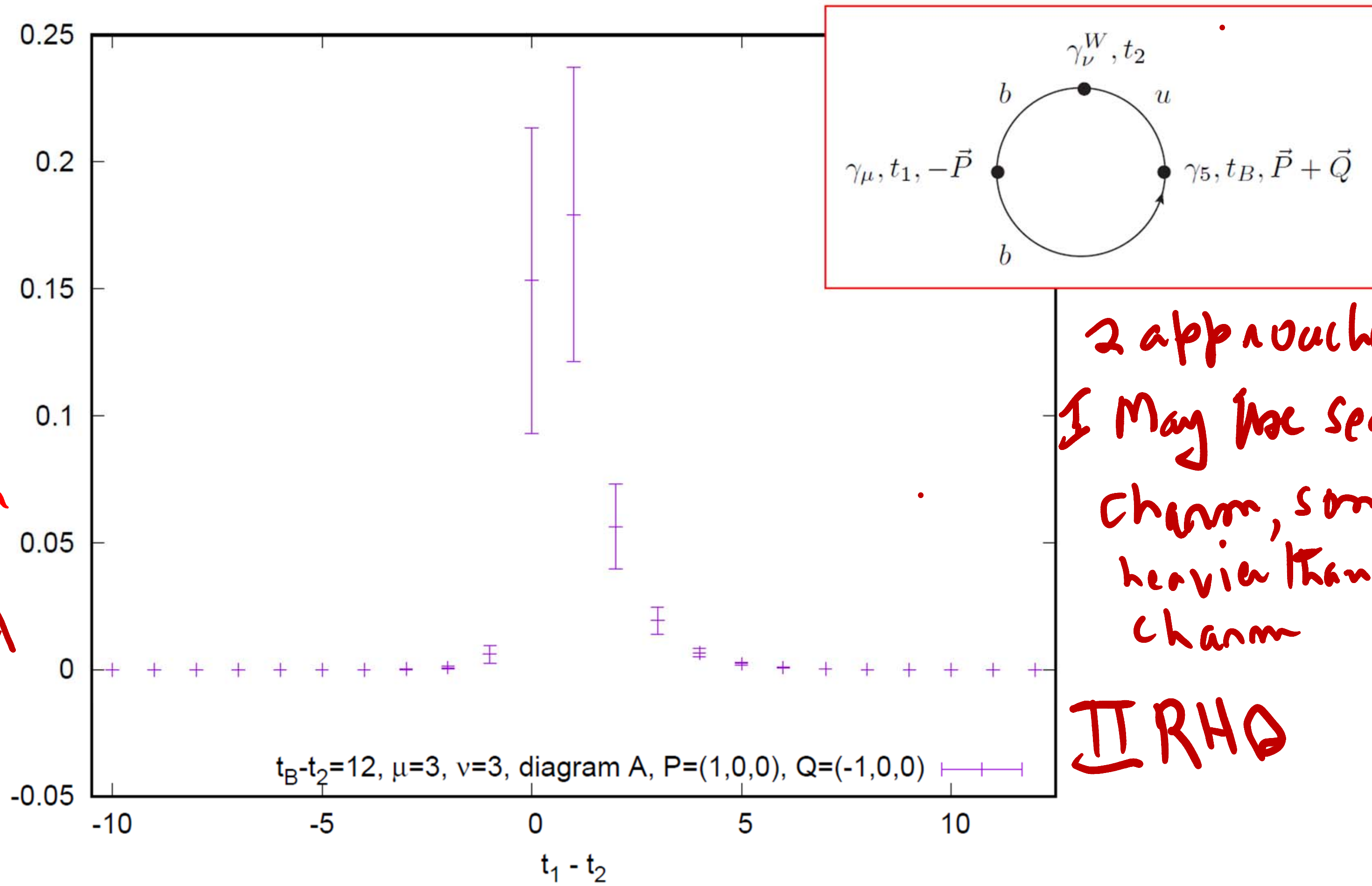
0 Momentum

diagram A
6 quark emits γ

physical light quarks
$m_B \sim m_D$;
ONLY 5 configs so far

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; MDWF, $m_5 = 1.4$, $b = .75$, $c = 0.25$

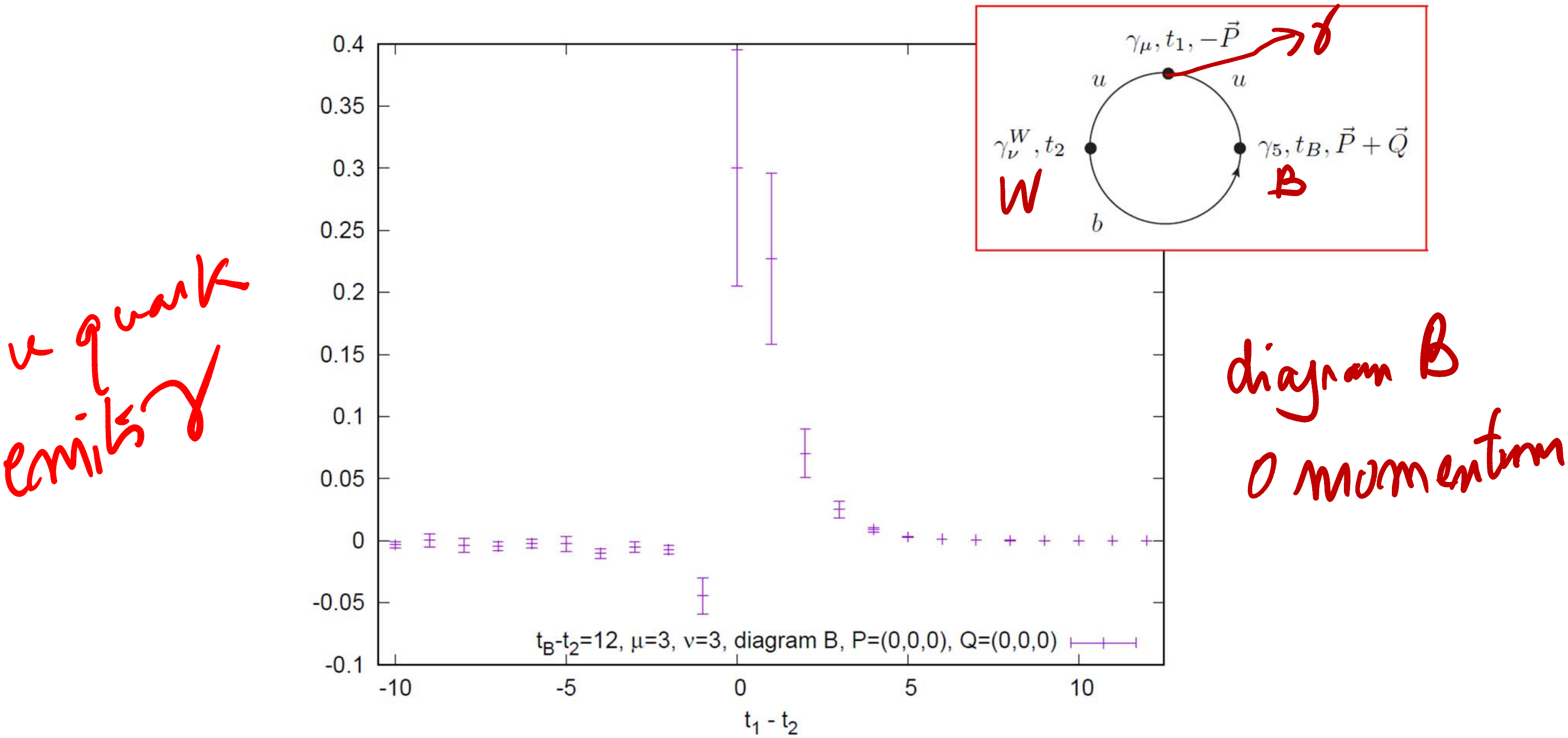
$48^3 \times 96$



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

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

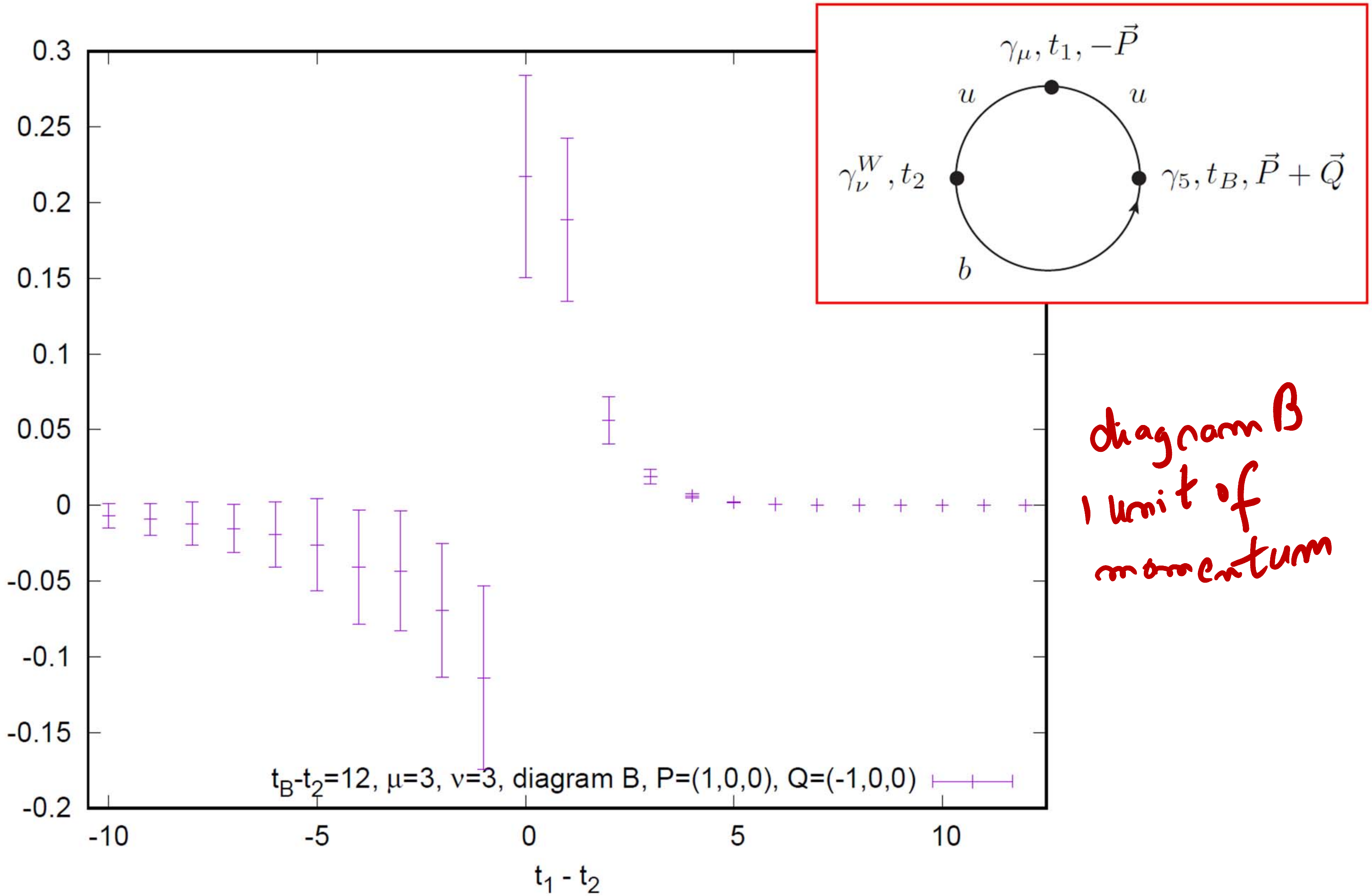


diagram B
1 unit of momentum

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

BSM-CP searches in the era of Belle-II and LHCb [upgrades]

- Recall that the single-CP phase in the SM-CKM-paradigm is rather unnatural…i.e **as soon as NP enters then mass and new interactions basis will no longer be aligned just as what happens due to weak interactions in the SM**
- This is indeed the rationale for the long quest for epsilon' in addition to the fact that it is extremely small
- And in fact in part its smallness results from unnatural cancellation between contributions from QCD and EW interactions.
- For a nice pedagogical explicit example see Agashe, Perez and AS [PRD'04]

- **Given various current indications of NP in semi-leptonic c.c, fcnc, and in muon g-2, should motivate us for vigorous searches for a BSM-CP-phase**

BSM-CP searches…2 illustrative examples

- **The presence of the tau [its decays are self-analyzers of its spin] provides a powerful tool in tau/l nu gamma FS….**
- **Both Tn even [say photon energy and rates, differential or integrated, …] and Tn-odd [tau polarization say transverse]**
- **Accurate calculation of photon energy specrum may be also useful for this CP test**
- **Many null tests become of interest due Belle-II + LHCb[upgrade]**

Null tests:Dir CP

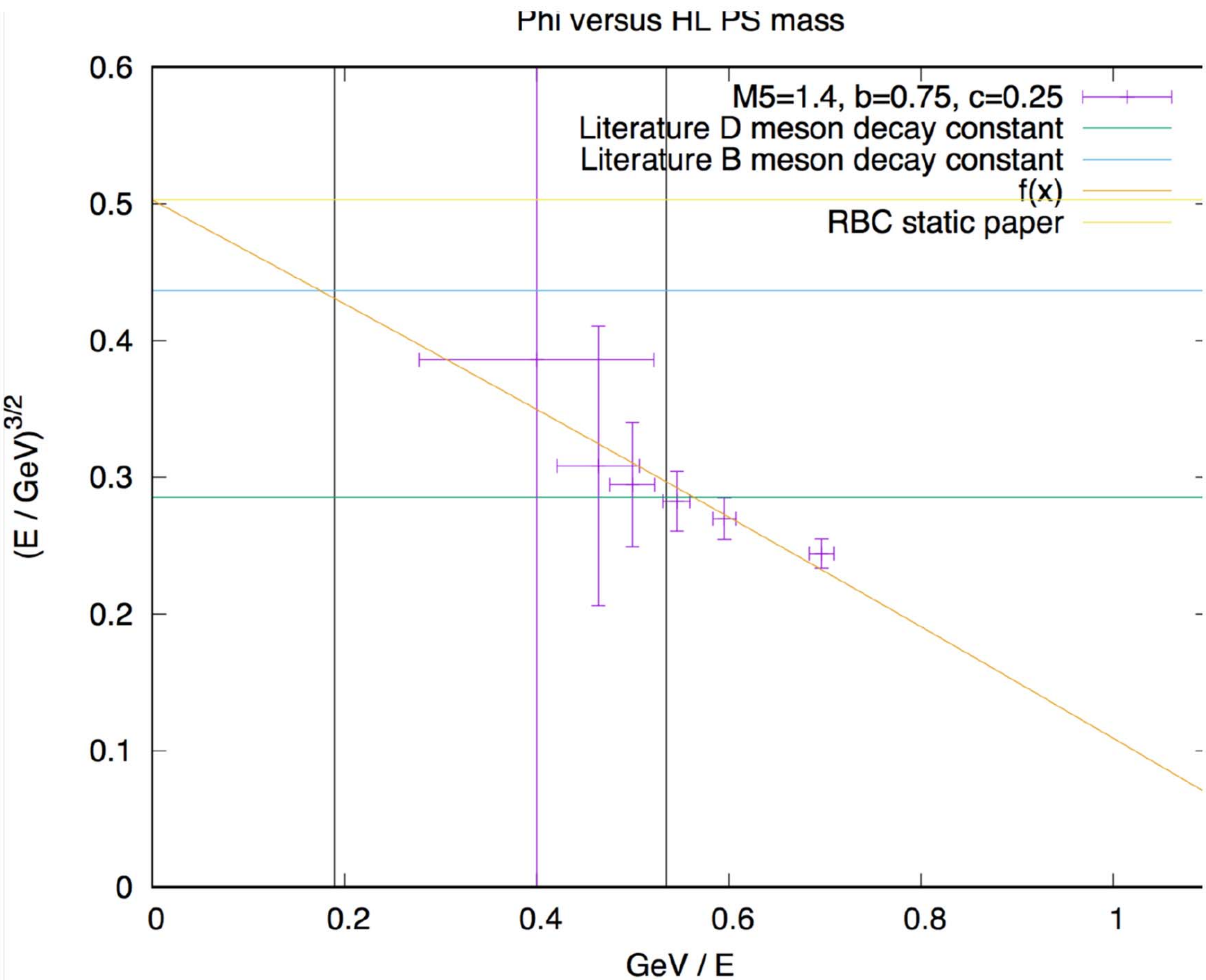
- A very powerful class of null tests relevant for the era of the huge data sets on the horizon and esp suited for lattice calculations is
- D, B => pi[K] l^+ l^- [diff. rate and Dir CP]
- K+, D+, B+ => pi^+ pi0
- FS is I=2 and transitions are all Delta I=3/2
- Therefore to the extent isospin is conserved
- gluonic penguins cannot contribute [only tree + (8,8) ops enter]
- Calculations are a lot simpler than eps' because disconnected diagrams cannot contribute
- However EMIV [electro –mag + isospin violations] are essential for non-vanshing SM-CPV thus rendering these as approx null tests….
- Quantitative calculation of these non-perturbative effects become essential
- One is encouraged by the fact that calculations of EMIV are becoming standard tools in many lattice calculations

Summary

- Although over 3 sigma anomalies in each class of sl cc, fcnc and in g-2 ; DO NOT THINK as yet THESE PROVIDE COMPELLING EVIDENCE FOR LUV
- In each case have reservations….A plausible resolution may well be few exptal results suffer from few sigma fluctuations and also possibly underestimated theory errors….
- Need improvements in theory and even more so in expt. Belle-II, Lhcb-Run II [upgrade] and new Fermilab g-2 expt[X2BNL already!] are all very timely
- Esp. Belle-II, huge new gorilla for searching NP
- should think of lattice calculations to facilitate `old/new tests
- In addition to improving accuracy of traditional FF calculations in sl cc and FCNC
- Suggest Ds, B^+ => tau/l nu gamma a distinct and powerful avenue to test LUV (and CP) for tau/mu/e many ways
- Direct CP null tests,K, D, B =>pi+ pi0; SM prediction needed.
- D, B => pi[K] l l diff rate[high m_ll] and dir-CP; again SM prediction needed.

Useful refs

- A: 1803.05881
- B) 1806.06997; 1806.09853


Phi versus HL PS mass
M5=1.4, b=0.75, c=0.25
Literature D meson decay constant
Literature B meson decay constant
f(x)
RBC static paper
(E / GeV)^3/2
GeV / E
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1

Bit on operator renorm.

Operator renormalization for heavy-light case: either use unmixed action with heavy quarks using M5=1.8 Mobius, or normalize everything w.r.t. fB such that ZV/ZA cancels.

Or better: for light-ish quarks (0.9 GeV or so) do both calculations and calculate ratio of mixed versus unmixed action decay constants to get ZV/ZA up to discretization errors.

Few more details on the lattice calculation

- It means P_x=2pi/48 * 1.73 GeV = 226 MeV, P_y=P_z=0. Average is not needed due to lattice symmetries and is here not advisable because of cost/error analysis (would be more correlated than just solving with new z2 source at W insertion)
-
- It is indeed nice that the error does not grow much.
-
- 3) We will use AMA but the data that I have sent you so far are only
- exact solves. We start at the W insertion and then do a sequential solve over the B meson either through the light or heavy quark (diagram A/B). The source is z2-wall and it looks like this works quite well noise-wise (it has a full volume average at the B meson and the photon and a stochastic volume average at the W). In this way we also get all 16 spinors at both gamma and W position for free.
- And finally, so far the B meson is a point operator and we are optimizing
- a smeared operator right now so that we could have multiple operators for
- excited state studies.

Improved treatment of D*inB =>D* tau/l nu

- Since D* is NOT spinless its production and decay vertices cannot be factorized in a proper construction of QM amplitude, very likely results in some error otherwise
- This may effect extraction of Vxb [esp Vcb since

  B to rho is rarely used whereas B to D* is more common place
- Extraction of RD* especially vulnerable since MD + Mtau ~ 4 Gev, suspect 0 – recoil suffers large correction ….proper pheno treatment …Jaiswal, Nandi +A S, WIP
- Rigorously speaking one should be dealing with a production vertex of B=>D* tau/l nu followed by the detection vertex D* =>D + pi
- Or D*=>D + gamma…These 2 space time points are connected by a propagating D* with a finite width