Possible new physics opportunities in tau's

Amarjit Soni
HET-BNL

tau 2018 @ AMSTERDAM

09/25/18

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

outline

- **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**
- **Look for BSM-CP via edm-like effects**
- **Summary & outlook**

PHYSICS IS AN EXPTAL SCIENCE

Testing SM in the era of Belle-II

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

Toru Iijima @ SCGP May 31, 2018

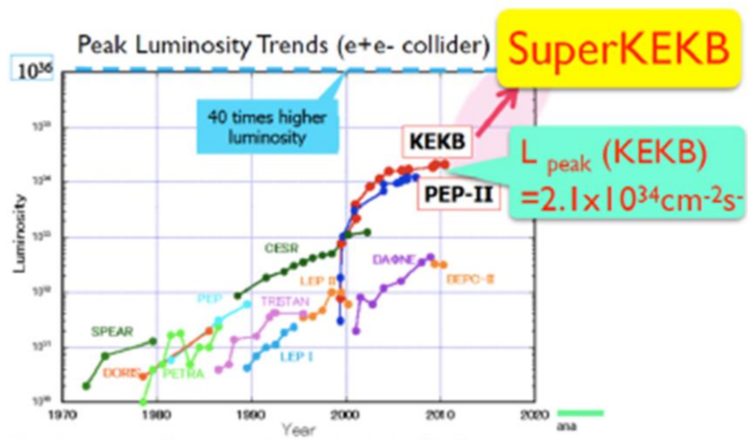
SuperKEKB/Belle II

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 !

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



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 !

Looking forward at LHCb

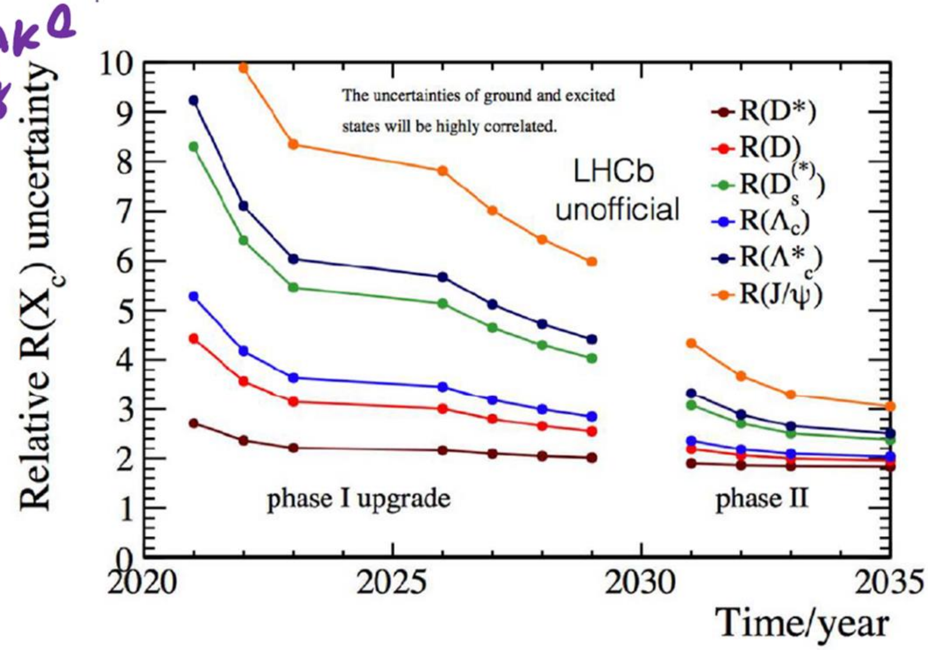
7 - 8 TeV	13 TeV	14 TeV	HL-LHC →	
Run 1 2010 - 2012	Run 2 2015 - 2018	Run 3 2021 - 2023	Run 4 2026 - 2029	Run 5 2031 -
$3\,\text{fb}^{-1}$	$9\,\text{fb}^{-1}$	$23\,\text{fb}^{-1}$	$50\,\text{fb}^{-1}$	$300\,\text{fb}^{-1}$

Upgrade I (before Run 3) — Upgrade II (before Run 5)

Mark Smith @ FPCP2018

c also T SZUMLAKa FPCP 2018

Upgrade I:
CERN-LHCC-2012-007
Upgrade II:
CERN-LHCC-2017-003



Continued improvement reliant on:

- Simulation size
- Theory collaboration
- Experimental input

→ 2006

Table 1

Number of events expected for one year of running. STCF expectations

Physics channel	Center-of-mass energy (GeV)	Peak luminosity (10^{33} cm^{-2} s^{-1})	Physics cross section (nb)	Number of events per year
J/ψ	3.097	0.6	~ 3400	10×10^9
τ	3.67	1.0	~ 2.4	12×10^6 → 10^7?
$\psi(2S)$	3.686	1.0	~ 640	3.0×10^9
D	3.770	1.0	~ 5	25×10^6 →
D_s	4.030	0.6	~ 0.32	1.0×10^6
D_s	4.140	0.6	~ 0.67	2.0×10^6

Expect # of τ's, D's $\gtrsim 10^9$ in the coming years

ADVENTURES @ THE IF

Contrarian/Complementary view

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

- **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**

Recapitulate 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
- Complementary info from IF can be a crucial guide

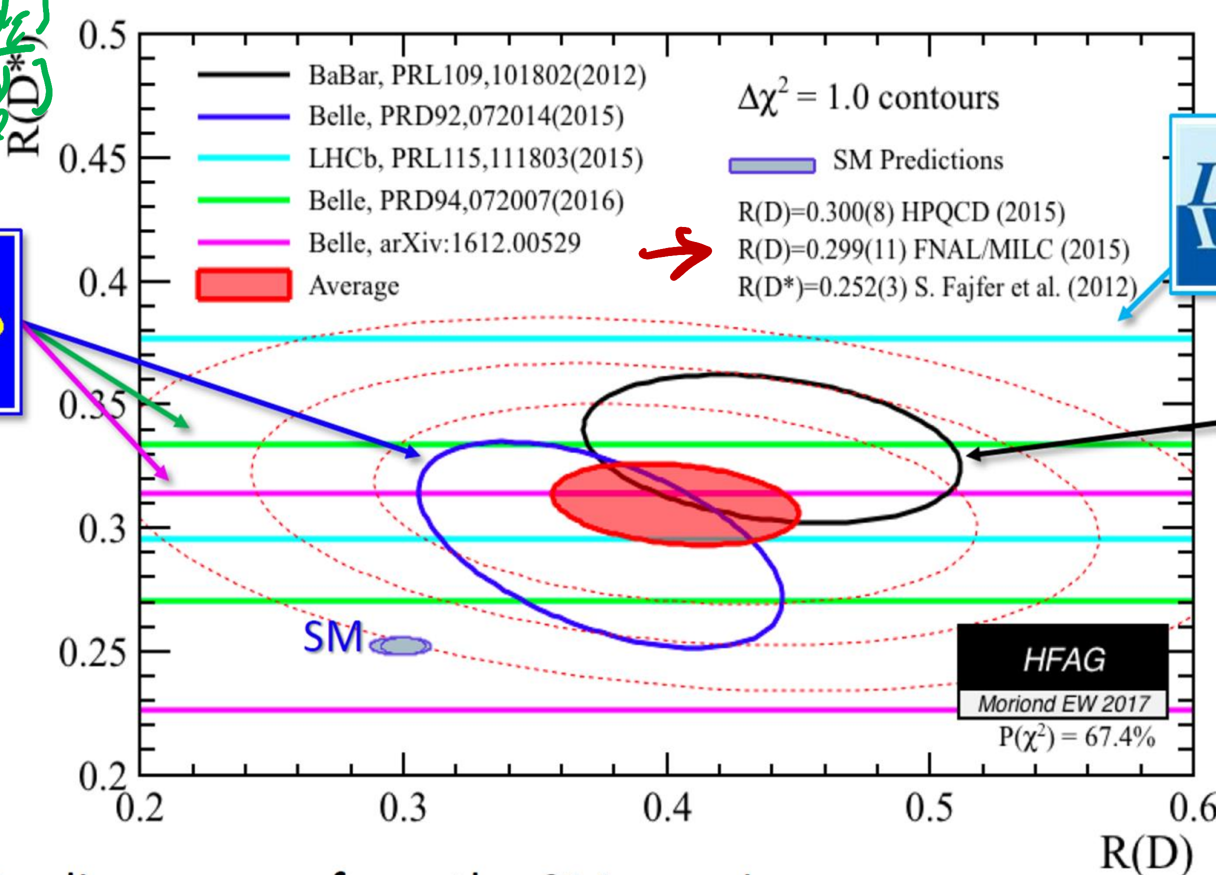
  for pointing to new thresholds as well as provide important clues to the nature of the signals there from

Anomalies galore!

- RD(*) ~ 4σ (?) probably lot less
- RK(*): 2.6σ (R_K); probably ~ 3.5σ but only LHCb
- g -2…BNL =>FNAL expt… ~ 3.6σ major lattice progress by RBC-UKQCD & others

■ $R\left(D^{(*)}\right)$ by HFAG

Hirose [BELLE]@EW MORIOND Mar. 2017

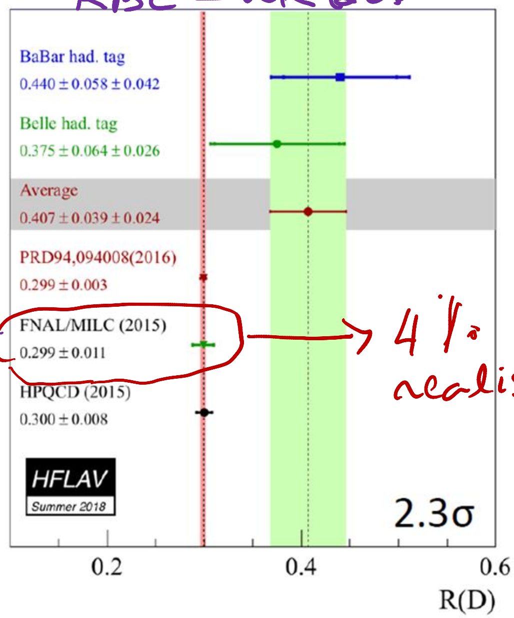


- ~4σ discrepancy from the SM remains
  - All the experiments show the larger $R\left(D^{(*)}\right)$ than the SM
- More precise measurements at Belle II and LHCb are essential

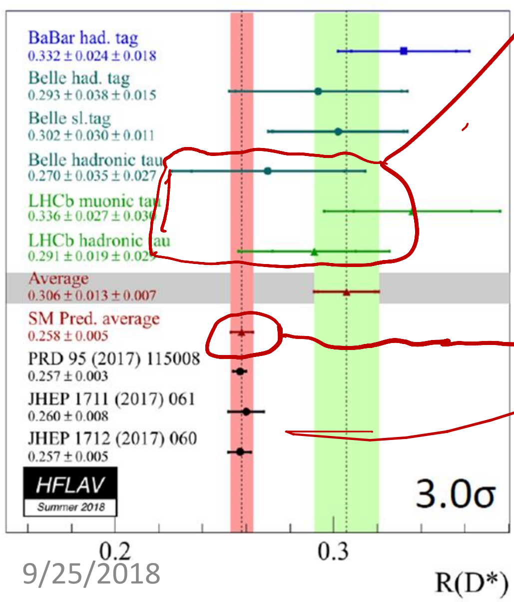
Belle deviations quite mild

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

also WITZEL et al RBC – UK QCD



4% realistic

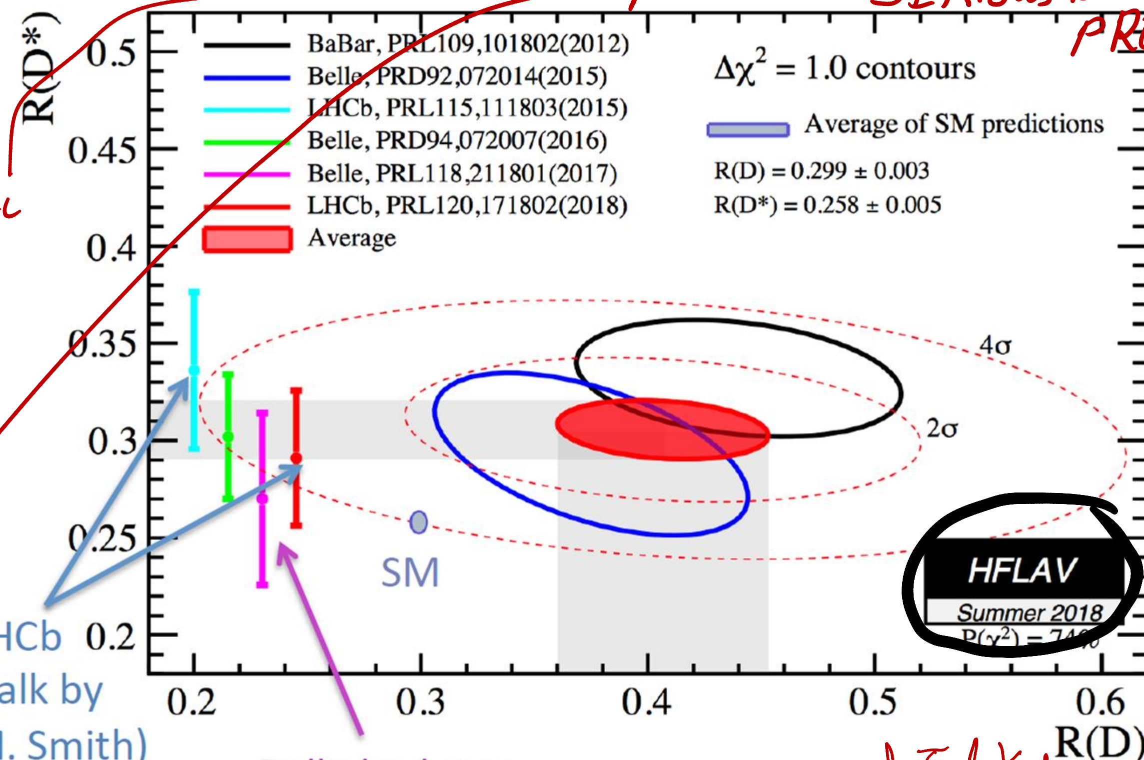


Serious

Likely also affects V_{cb}

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

POTENTIALLY VERY SERIOUS EXPTAL PROBLEM



LHCb (talk by M. Smith)

Belle had. tag (τ polarization)

also on recoil τ likely problem

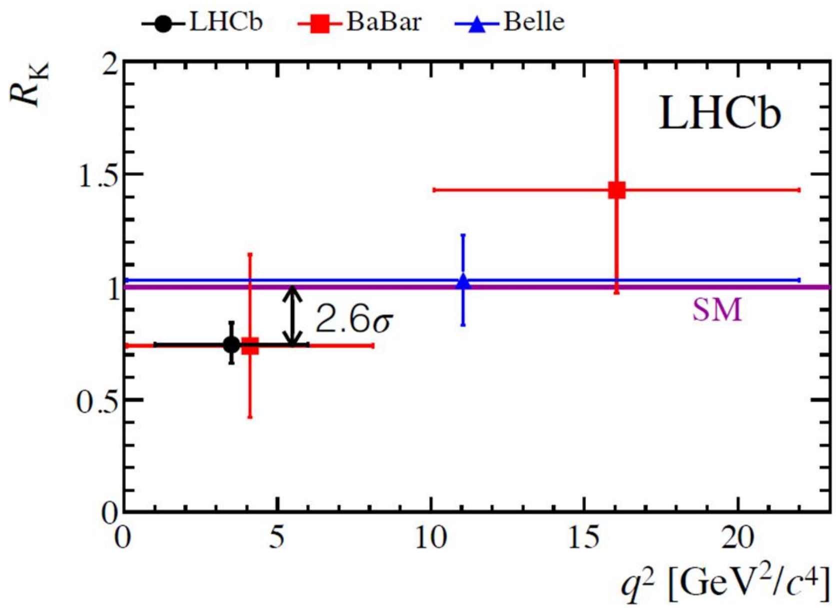
Theory errors Because D^* has spin

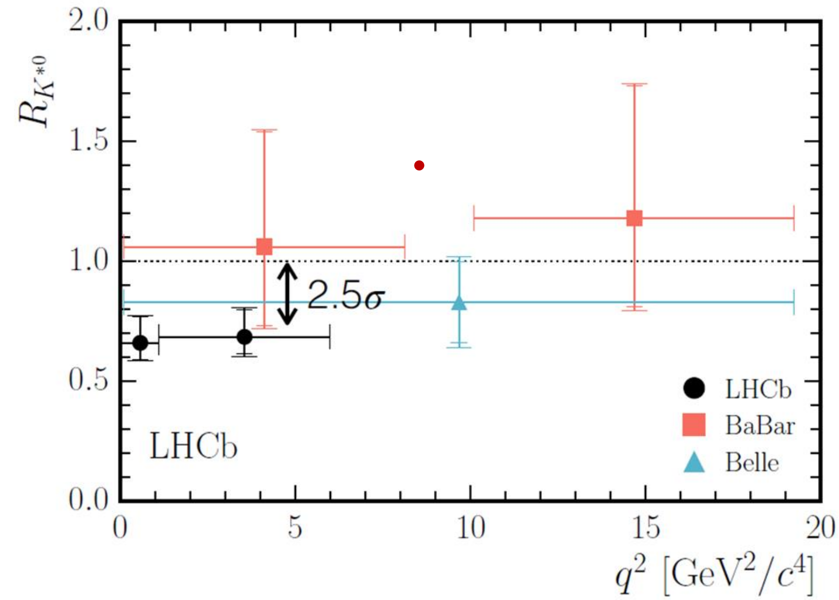
Deviation from SM prediction 3.9 σ

V LIKELY OVERESTIMATE

Lepton universality tests

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





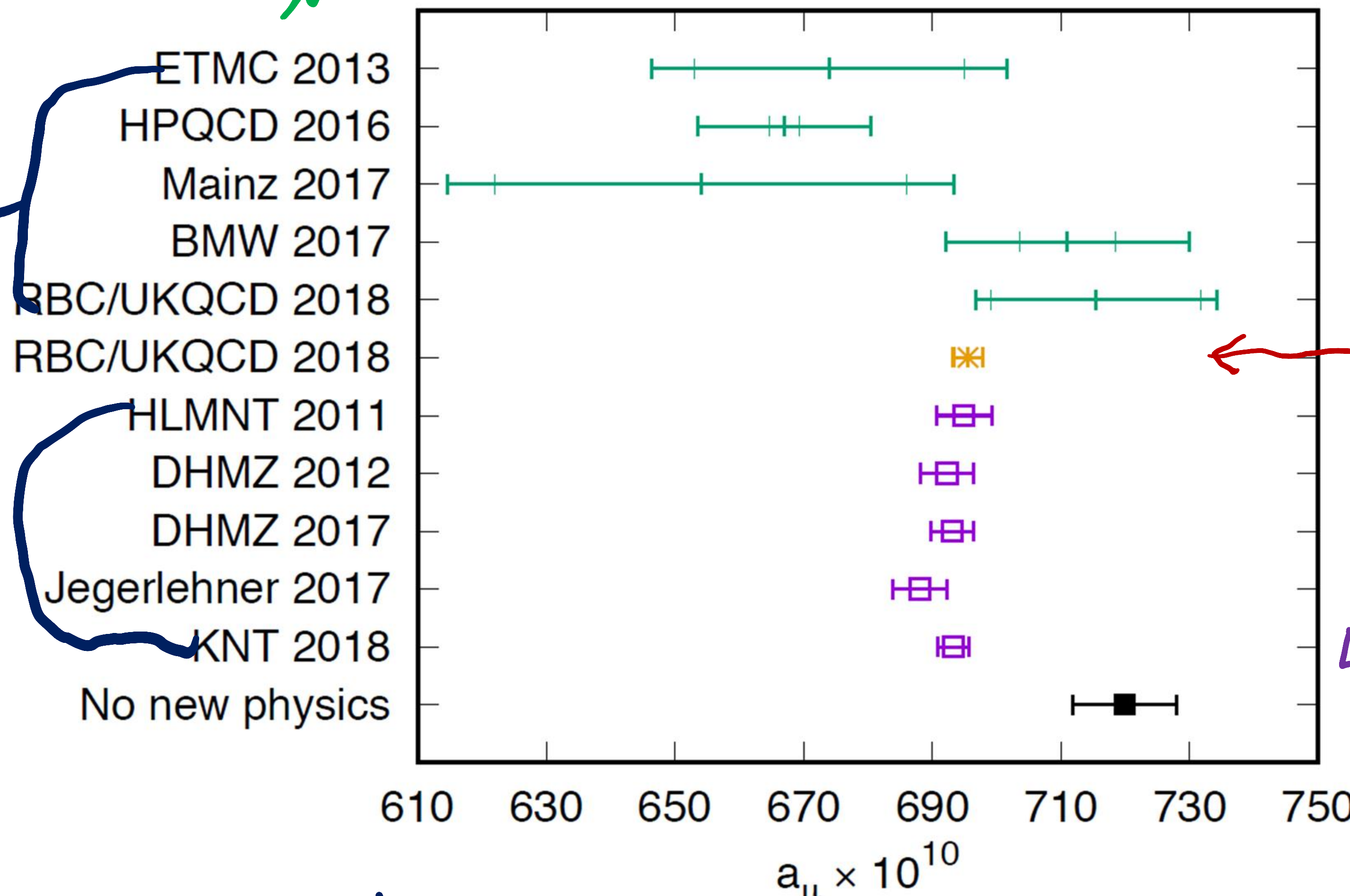
[LHCb , PRL113 (2014) 151601]
[LHCb, LHCb-PAPER-2017-013]
[BaBar, PRD 86 (2012) 032012]
[Belle, PRL 103 (2009) 171801]

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 HYBERID

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

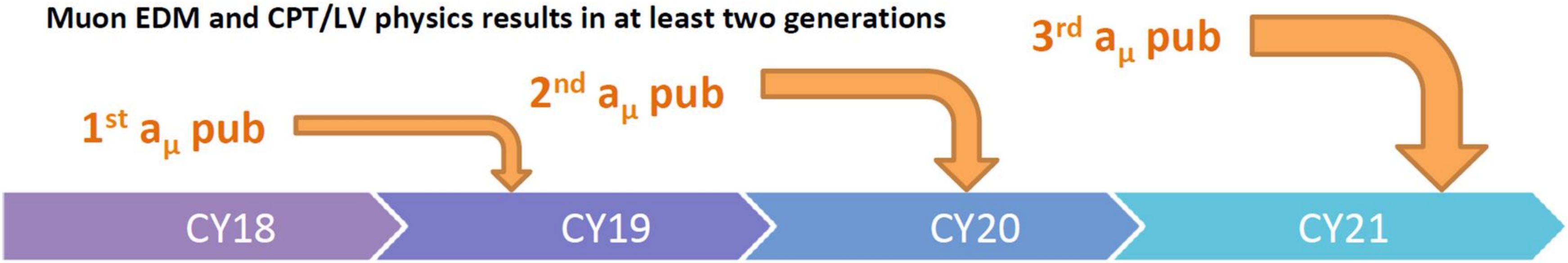
SUMMARY: C. LEHNER (BNL)

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.

Lunch Seminar 03/09/18

Fermilab Muon g-2 Experiment publication plan:

- 3 generations of a_μ publications
  - ~2 × BNL data (~400 ppb) collected in FY18 with 2019 publication goal
  - 5-10 × BNL data (~200 ppb) collected over FY18+FY19 with 2020 publication goal … caveat that we now enter unknown regime
  - 20+ × BNL data (~140 ppb) collected by end of FY20 with 2021 final publications goal
- Muon EDM and CPT/LV physics results in at least two generations



2 caveats to publications plan:

LIANG LI
@ FPCP18

- BNL publications lagged 2-3 years behind acquiring data
  - Understanding systematics and fixing for next run take priority
  - However, we benefit from BNL experience and analysis tools much more advanced
- Likely 2020 running will be required to complete μ^+ statistics

Fermilab Accelerator Experiments' Run Schedule

		FY 2017	FY 2018	FY 2019	FY 2020	
NuMI	MI	MINERvA	MINERvA	MINERvA ?	OPEN	ν
		NOvA	NOvA	NOvA	NOvA	
BNB	B	MicroBooNE	MicroBooNE ?	SBN: MicroBooNE	SBN: MicroBooNE	
		SBN: ICARUS	SBN: ICARUS	SBN: ICARUS / SBN:ICARUS	SBN: ICARUS	
		SBN: SBND	SBN: SBND	SBN: SBND	SBN: SBND	
Muon Campus		g-2	g-2	g-2	OPEN	μ
		Mu2e	Mu2e	Mu2e	Mu2e	
SY 120	MT	FTBF - MTEST	FTBF - MTEST	FTBF - MTEST	FTBF - MTEST	p
	MC	OPEN / LArIAT	FTBF - MC	FTBF - MC	FTBF - MC	
	NM4	SeaQuest	OPEN	OPEN	OPEN	

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

PRD 2015

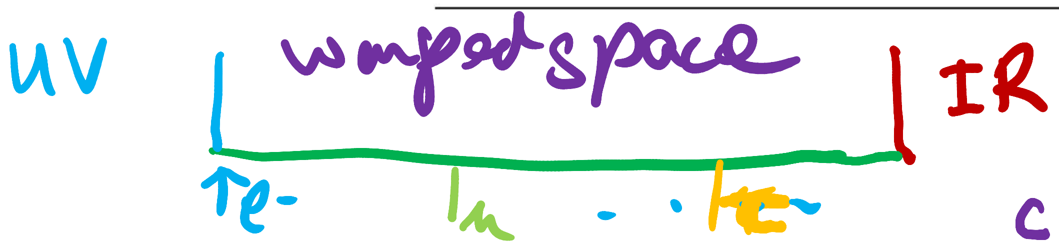
Table 1
Constraints on lepton-flavor violating and conserving processes. For the last four observables, the experimental null results are given in terms of a dimension-6 operator, suppressed by two orders of Λ, which can be interpreted as the nominal scale of new physics.

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]

KILE, KOBACH + AS PRD 2015 ⇓ Speculation

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

May be 1st gen. is fundamental & its protection from NP



c ALSO A. IYER & LYON

ILLUSTRATIVE EXAMPLES OF BSMS

Minimal Leptoquark Explanation for the $R_{D^{(*)}}$, R_K, and $(g-2)_\mu$ Anomalies

Martin Bauer[1] and Matthias Neubert[2,3]

We show that by adding a single new scalar particle to the standard model, a TeV-scale leptoquark with the quantum numbers of a right-handed down quark, one can explain in a natural way three of the most striking anomalies of particle physics: the violation of lepton universality in $\bar{B} \to \bar{K}\ell^+\ell^-$ decays, the enhanced $\bar{B} \to D^{(*)}\tau\bar{\nu}$ decay rates, and the anomalous magnetic moment of the muon. Constraints from other precision measurements in the flavor sector can be satisfied without fine-tuning. Our model predicts enhanced $\bar{B} \to \bar{K}^{(*)}\nu\bar{\nu}$ decay rates and a new-physics contribution to $B_s - \bar{B}_s$ mixing close to the current central fit value.

801 (2015) PHYSICAL REVIEW LETTERS week ending 6 MARCH 2015

Lepton Flavor Violation in *B* Decays?

Sheldon L. Glashow,[1,*] Diego Guadagnoli,[2,†] and Kenneth Lane[1,‡]
partment of Physics, Boston University, 590 Commonwealth Avenue, Boston, Massachusetts 02215, USA
boratoire d'Annecy-le-Vieux de Physique Théorique UMR5108, CNRS et Université de Savoie, BP 110, F-74941 Annecy-le-Vieux Cedex, France
(Received 15 November 2014; published 3 March 2015)

The LHCb Collaboration's measurement of $R_K = \mathcal{B}(B^+ \to K^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+e^+e^-)$ lies 2.6σ elow the Standard Model prediction. Several groups suggest this deficit to result from new lepton onuniversal interactions of muons. But nonuniversal leptonic interactions imply lepton flavor violation in B ecays at rates much larger than are expected in the Standard Model. A simple model shows that these rates ould lie just below current limits. An interesting consequence of our model, that $\mathcal{B}(B_s \to \mu^+\mu^-)_{\rm exp}/$ $\mathcal{B}(B_s \to \mu^+\mu^-)_{\rm SM} \cong R_K \cong 0.75$, is compatible with recent measurements of these rates. We stress the nportance of searches for lepton flavor violations, especially for $B \to K\mu e$, $K\mu\tau$, and $B_s \to \mu e$, $\mu\tau$.

19, 151801 (2017) PHYSICAL REVIEW LETTERS week en 13 OCTOBE

Minimal Unified Resolution to $R_{K^{(*)}}$ and $R(D^{(*)})$ Anomalies with Lepton Mixing

Debajyoti Choudhury,[1] Anirban Kundu,[2] Rusa Mandal,[3] and Rahul Sinha[3]
[1]*Department of Physics and Astrophysics, University of Delhi, Delhi 110007, India*
[2]*Department of Physics, University of Calcutta, 92 Acharya Prafulla Chandra Road, Kolkata 700009, India*
[3]*Institute of Mathematical Sciences, HBNI, Taramani, Chennai 600113, India*
(Received 30 June 2017; published 12 October 2017)

It is a challenging task to explain, in terms of a simple and compelling new physics scenario, the intriguing discrepancies between the standard model expectations and the data for the neutral-current observables R_K and R_{K^*}, as well as the charged-current observables $R(D)$ and $R(D^*)$. We show that this can be achieved in an effective theory with only two unknown parameters. In addition, this class of models predicts some interesting signatures in the context of both B decays as well as high-energy collisions.

leptoquark interactions follow from the Lagrangian

$$\mathcal{L}_\phi = (D_\mu \phi)^\dagger D_\mu \phi - M_\phi^2 |\phi|^2 - g_{h\phi} |\Phi|^2 |\phi|^2 + \bar{Q}^c \boldsymbol{\lambda}^L i\tau_2 L \phi^* + \bar{u}_R^c \boldsymbol{\lambda}^R e_R \phi^* + \text{H.c.}, \qquad (3)$$

where Φ is the Higgs doublet, $\boldsymbol{\lambda}^{L,R}$ are matrices in flavor space, and $\psi^c = C\bar{\psi}^T$ are charge-conjugate spinors.

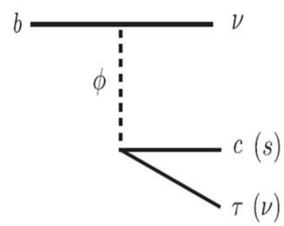


FIG. 1. Tree-level diagrams contributing to weak decays.

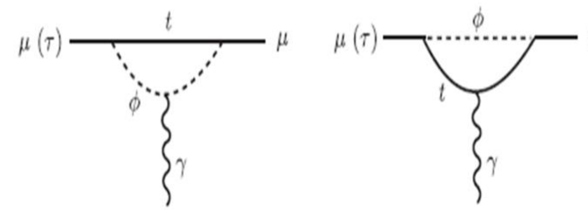
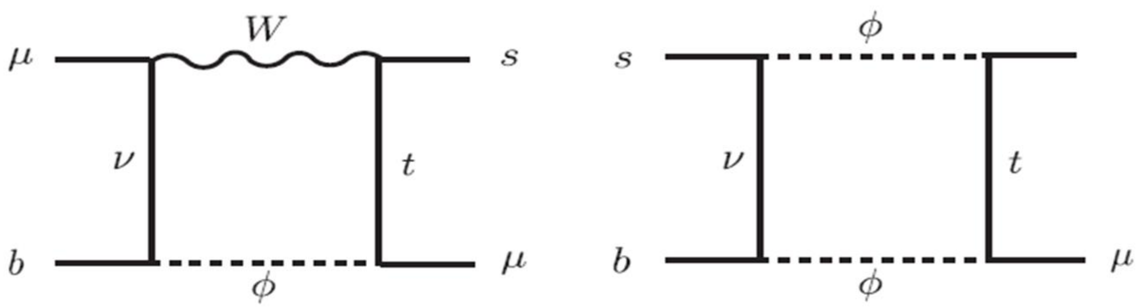


FIG. 3. Loop diagrams contributing to $(g-2)_\mu$ and $\tau \to$



G. 2. Loop graphs contributing to $b \to s\mu^+\mu^-$ transitions.

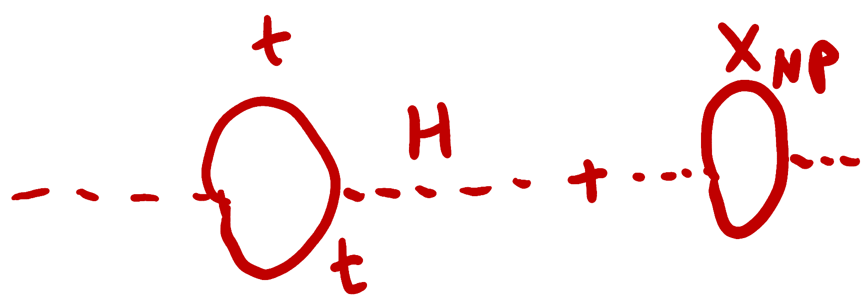
IF LQ'S BECOME A REALITY EVEN THOUGH PATI-SALAM 1ST BROUGHT THEM IN FOR UNIFICATION ….RPV IS BETTER WAY TO GO

Altmannshofer, Dev, A.S. 2017
+ WIP

ANOMALY: POSSIBLY A HINT FOR (NATURAL) SUSY-WITH RPV

- 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 [and respectable] & also LFV
- Moreover, RPV should be viewed as an umbrella i.e. under appropriate limits other models are incorporated

$m_H \simeq 126$ GeV



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

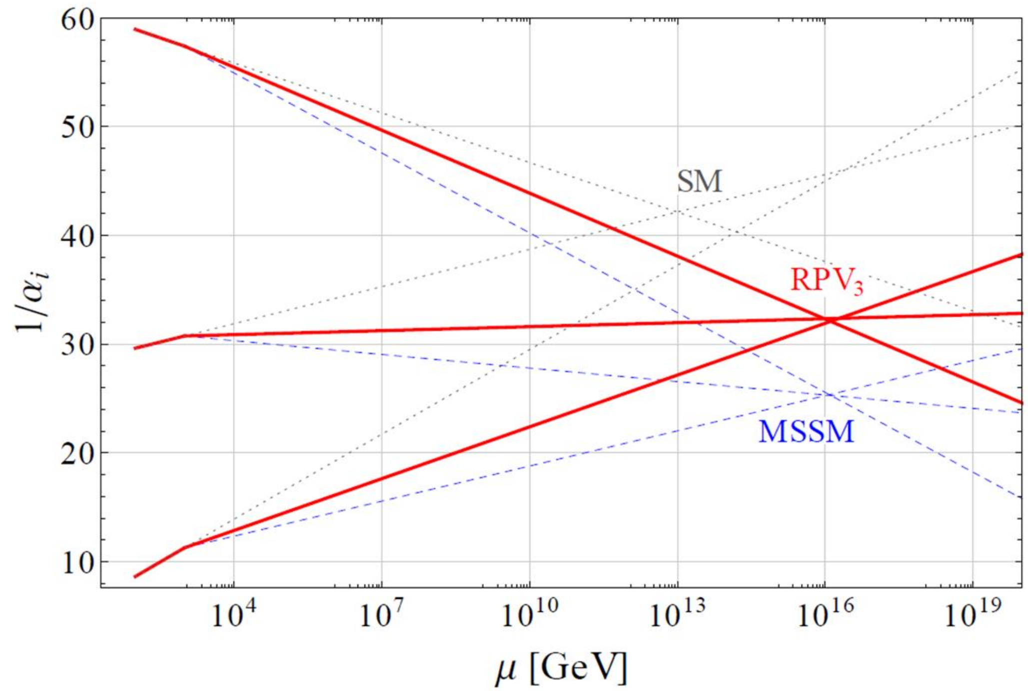


FIG. 2. RG evolution of the gauge couplings in the SM, MSSM and with partial supersymmetrization.

Unification scale ~ stays same, only value of couplings shifts

For pheno relevant terms:

ADS' PRD 2017

$$\mathcal{L} = \lambda'_{ijk}\left[\tilde{\nu}_{iL}\bar{d}_{kR}d_{jL} + \tilde{d}_{jL}\bar{d}_{kR}\nu_{iL} + \tilde{d}^*_{kR}\bar{\nu}^c_{iL}d_{jL} - \tilde{e}_{iL}\bar{d}_{kR}u_{jL} - \tilde{u}_{jL}\bar{d}_{kR}e_{iL} - \tilde{d}^*_{kR}\bar{e}^c_{iL}u_{jL}\right] + \text{H.c.}$$

} RPV$_3$ interaction

Dim 6

$$\mathcal{L}_{\text{eff}} \supset \frac{\lambda'_{ijk}\lambda'^*_{mnk}}{2m^2_{\tilde{d}_{kR}}}\left[\bar{\nu}_{mL}\gamma^\mu\nu_{iL}\bar{d}_{nL}\gamma_\mu d_{jL} - \nu_{mL}\gamma^\mu e_{iL}\bar{d}_{nL}\gamma_\mu\left(V^\dagger_{\text{CKM}}u_L\right)_j + \text{h.c.}\right] - \frac{\lambda'_{ijk}\lambda'^*_{mjn}}{2m^2_{\tilde{u}_{jL}}}\bar{e}_{mL}\gamma^\mu e_{iL}\bar{d}_{kR}\gamma_\mu d_{nR} \,,$$

→ For $R_{D(*)}$

NOTE: ITS SM-like!

For addressing RK(*) in RPV, see e.g. Das et al , 1705.09188

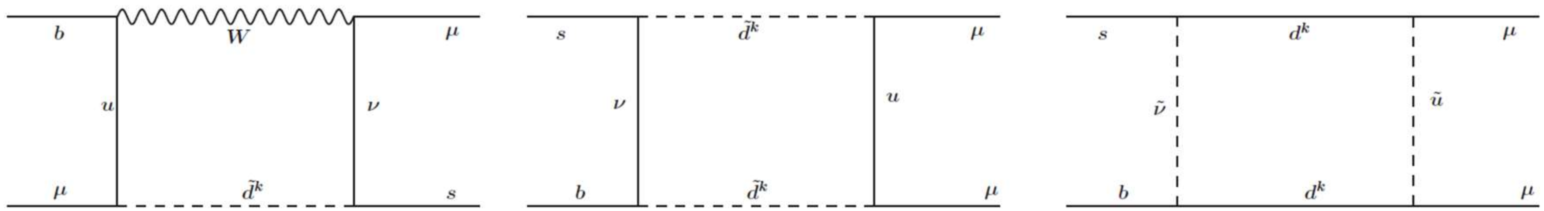


FIG. 1: Representative diagrams for $b \to s\mu^+\mu^-$ transition in R-parity violating interactions.

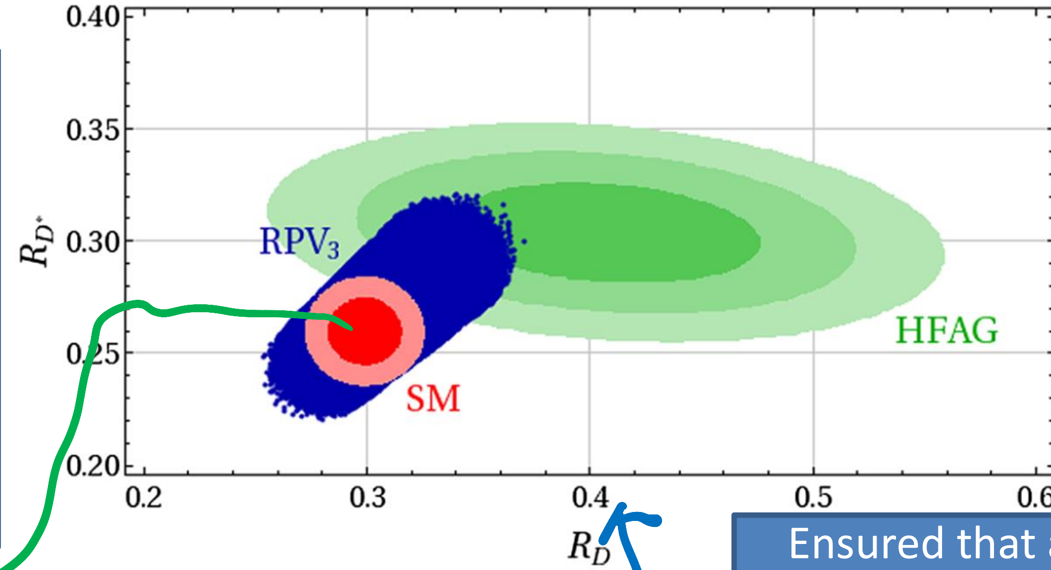
g-2 with RPV has a long history, see, e.g.Kim, Kyae and Lee, PLB 2001

We [ALTMANNSHOFER+DEV+AS] are examining + update in light of current flavor anomalies

WORK IN Progress

ALTMANNSHOFER, BHUPAL DEV, and SONI PRD 2017

RPV3 allows
RD=(.254-.371)
RD*=(.220-.320)
Contrast Fuentes-Martin:
$\frac{\Delta R_{D^*}}{\Delta R_D} \approx 0.45$



HFAG dec2016
RD=.403+-.040+-.024
RD*=.310+-.015+-.008
LHCb 06/06/17
RD* 0.305

Ensured that all RPV3 couplings stay perturbative up to GUT

More Realistic SM Blob

FIG. 4. The SM predictions (red), experimental world average (green), and accessible values in our RPV-SUSY scenario (blue) in the R_D vs. R_{D^*} plane. For the SM, bearing in mind recent works [17,20,22] we are taking $(R_D^{SM}, R_{D^*}^{SM}) = (0.299 \pm 0.011, 0.260 \pm 0.010)$.

all constraints……RPV(blue) region obtained by scanning with sbottom mass 680-1000Gev, 0<λ333<2;|λ323|<0.1;|λ313|<0.3 ….

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]….**

- **This possibility we will explore a bit further**

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 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]

tau=> Ks pi nu

- **Moreover, Babar seems to have ~3 sigma indication of BSM CP in this channel.**

- **On the lattice the rate calculation can be normalized to tau=>K nu ….another strikingly simple lattice calculation, in part a path for high precision.**
- **Yet another way to normalize would be via Kl3 form-factors, e.g. f+(0)…very precise lattice studies nowadays available, see RBC-UKQCD, FermiL/MILC, ETWM……claimed accuracy O(1/2%)**
- **Perhaps use both…**
- **Main objective of such normalization(s)…minimize discretization and other errors**

↗ $K^{\pm}$

- **Both modes, tau =>K nu and K0 pi nu have relative high [~1/2 to ~1%] Br**

$\pi^+\pi^- \to \pi^{\pm}$ All Charged

Great for BELLE-II & STCF

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

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

(BABAR Collaboration)

Asy ~ -4×10^{-3}

(Received 9 September 2011; published 13 February 2012)

We report a search for *CP* violation in the decay $\tau^- \rightarrow \pi^- K_S^0(\geq 0\pi^0)\nu_\tau$ 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 $Br[\tau \rightarrow \nu \pi^- \bar{K}^0] = (8.40 \pm .14) \times 10^{-3}$ ~2%

$N_\tau \sim 10^9$ needed

relevant weak hadronic current is just

$$J_\mu^{u,s} \equiv \bar{u}\gamma_\mu(1-\gamma_5)s$$

leads to one major well known exclusive mode ⇒ pseudo scalar decay

$$\tau \to \nu K^+ \text{ via } \langle 0|\bar{u}\gamma_\mu\gamma_5 s|K\rangle$$

From expt. $B_r(\tau \to \nu K) = 6.96 \times 10^{-3}$

So now we also want $\langle 0 | J_\mu^{W,s} | K_S \pi^+ \rangle$

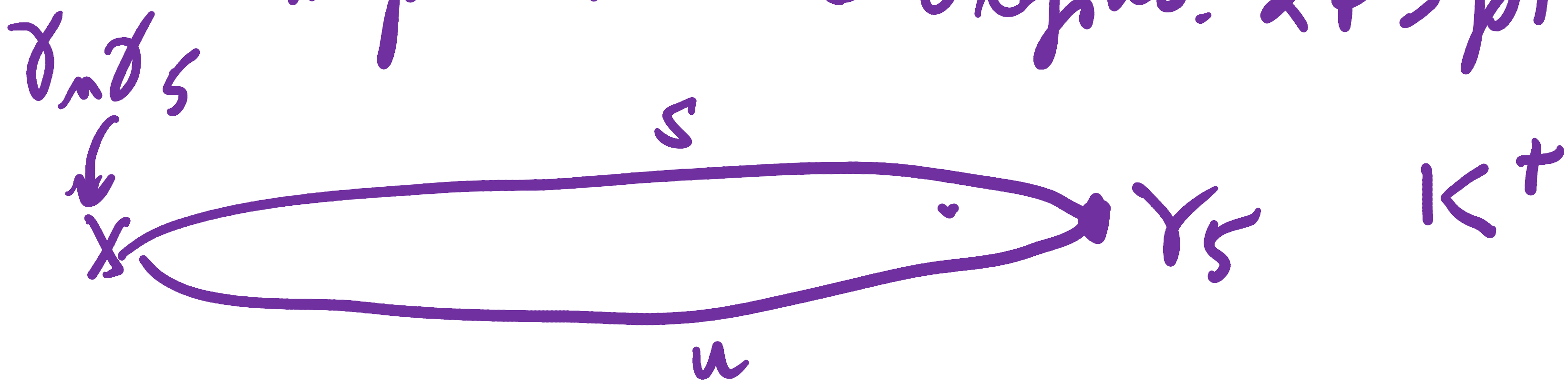
Normalizing with experimental measured Br

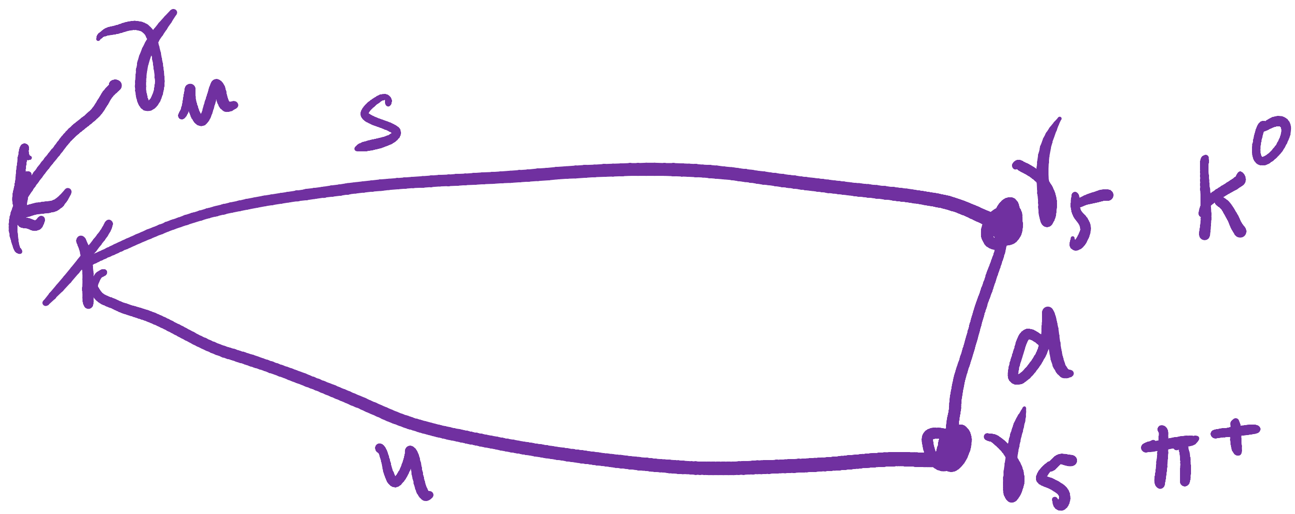
$$Br[\tau \to \nu K_S \pi^+] / Br[\tau \to \nu K^+]$$

we may be able to get rid of several of the errors.

A precise calculation of the rate provides an important test of the SM in itself.

Simple LATTICE Graphs: 2+3 pt functions



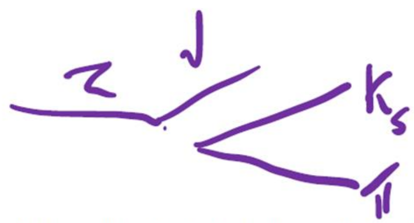


gluons not shown

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

Related by X Sym

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

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**

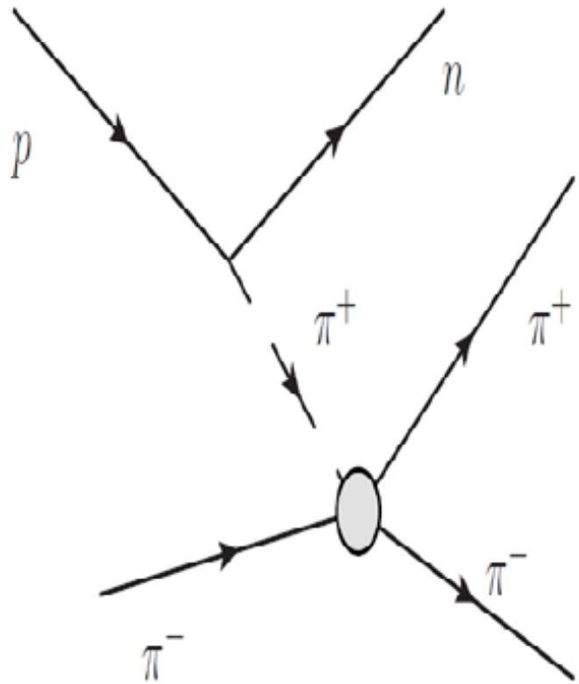
for K, pi scattering see RBC-UKQCD [exploratory for K-pi; see T.Janowski et al, Lattice 2014]

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

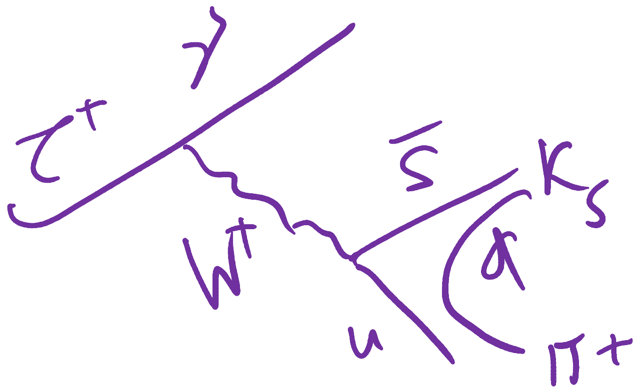
- **T.W. talk at Lattice 2018 shows pi pi I=0 phases in good agreement with Colangelo**



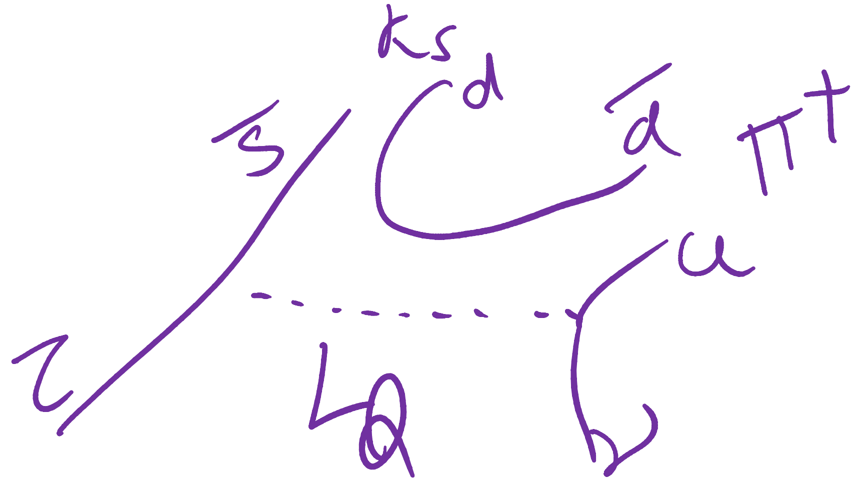
Data
~1GeV

See G. Colangelo et al

Possible NP in tau=> Ks pi nu



SM



RPV

See Altmannshofer, Dev + AS [ADS']
1704.06659

WIP ON AND OFF THE LATTICE ON THIS CLASS OF STUDY

Meantime can use continuum methods for estimates

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Nuclear Physics B (Proc. Suppl.) 218 (2011) 140–145

NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS

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Dispersive representation of the scalar and vector $K\pi$ form factors for $\tau \to K\pi\nu_\tau$ and $K_{\ell 3}$ decays

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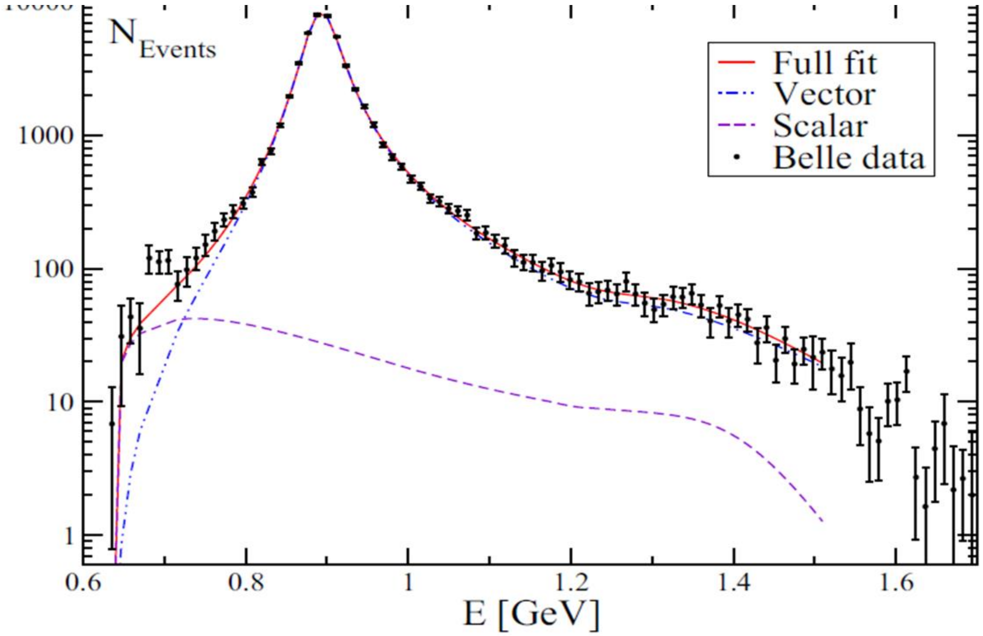
Recently, the $\tau \to K\pi\nu_\tau$ decay spectrum has been measured by the Belle and BaBar collaborations. In this work, we present an analysis of such decays introducing a dispersive parametrization for the vector and scalar $K\pi$ form factors. This allows for precise tests of the Standard Model. For instance, the determination of $f_+(0)|V_{us}|$ from these decays is discussed. A comparison and a combination of these results with the analyses of the $K_{\ell 3}$ decays is also considered.

7. D. R. Boito, R. Escribano and M. Jamin, JHEP **1009** (2010) 031.



c. E. Passemar et al

Figure 1. Fit result for the spectrum of $\tau \to K\pi\nu_\tau$. The data in black are from Belle Collaboration [2]. The dashed violet line represents the scalar form factor contribution fixed from the $K_{\mu 3}$ results, see text. The dot-dashed blue line is the vector form factor contribution and the solid red line gives the full result.

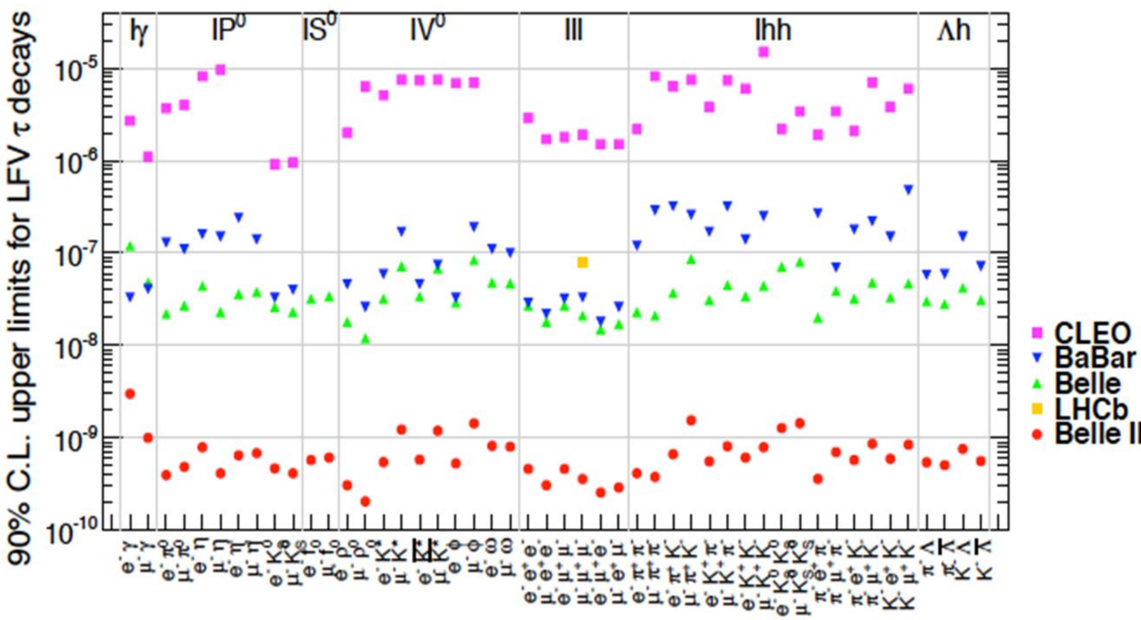
In 1st lattice study stay $E \lesssim 850$ MeV

Lepton flavor violation tests

BSM explanations for current anomalies

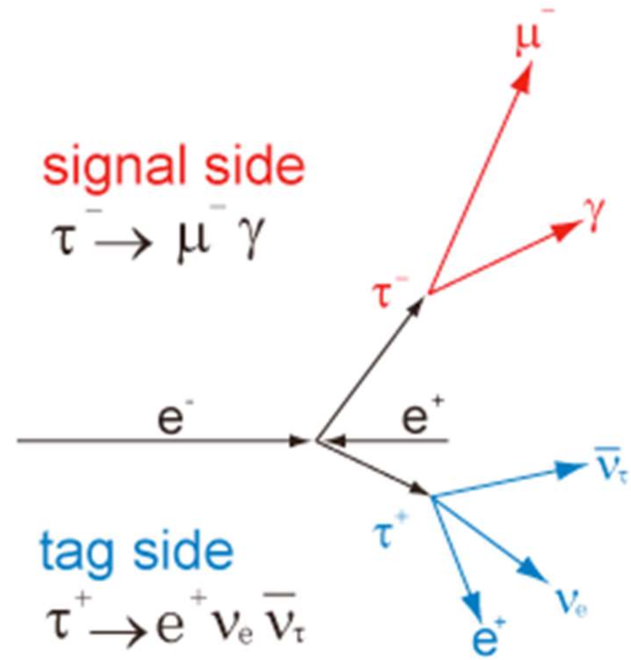
- Implications of pheno. operator analysis, see e.g. Mandal et al; Pich et al .....
- LQ's: see e.g. Fajfer et al; Bauer& Neubert; Greljo et al
- RPV: see e.g. ADS'; Mahajan et al ....
- Practically all BSMs predict enhanced LFV in tau as well as in B (and possibly also in D) decays…
- Esp. Interesting modes: B=>K(*) mu tau, Bs=>mu tau….;tau =>mu gamma, 3 mu, mu phi, mu hh…..
- In many cases predicted rates not too far from current bounds but this is not a reliable prediction as new [un-constrained] couplings occur, nevertheless exptal searches are timely and well motivated

τ Lepton Flavor Violation



Note vertical log-scale (50 ab^{-1} assumed for Belle II; 3 fb^{-1} result for LHCb

Example of the decay topology



__Belle II will push many limits below 10^{-9}__; But for some FS also

LHCb, CMS and ATLAS have ~~very limited~~ some capabilities.

LHC high pt: The modes τ→μγ and τ →μ h+ h- ; 3μ .....
provide important constraints on H→μτ

Opportunities in tau

- **Improving determination of magnetic and electric diploe moments.**
- **Key point : Borrow ideas determination for the top quark….i.e an “elementary fermion”**

PHYSICAL REVIEW D VOLUME 45, NUMBER 7 1 APRIL

Analysis for magnetic moment and electric dipole moment form factors of the top quark via $e^+e^- \to t\bar{t}$

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(Received 15 November 1991)

Phenomenological analysis for determining the magnetic moment and electic dipole moment form factors of the top quark via the reaction $e^+e^- \to t\bar{t}$, followed by the decays $t \to bW^+$ and $\bar{t} \to \bar{b}W^-$, is presented, with analytic expressions for the differential cross section and decay given. Various experimental observables are studied and their efficacy for the determination of form factors is considered and compared with the optimal resolution of form factors in the $t\bar{t}\gamma$ and $t\bar{t}Z$ vertices. We find that with a sample of 10 000 events it is possible to put limits of 10^{-18}–10^{-19} e cm for the form factors considered, evaluated at $q^2 = s$ when $\sqrt{s} \approx 500$ GeV.

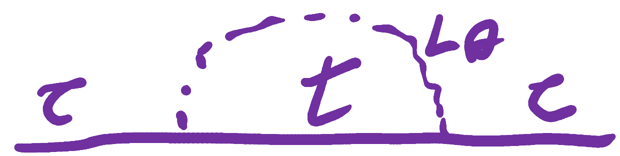
PACS number(s): 13.40.Fn, 13.10.+q, 14.80.Dq

C also W. Bernreuther et al, PLB 1997

Because of heightened interests in LQ's

- Note that

- Electric dipole moments of leptons can scale in LQ models:

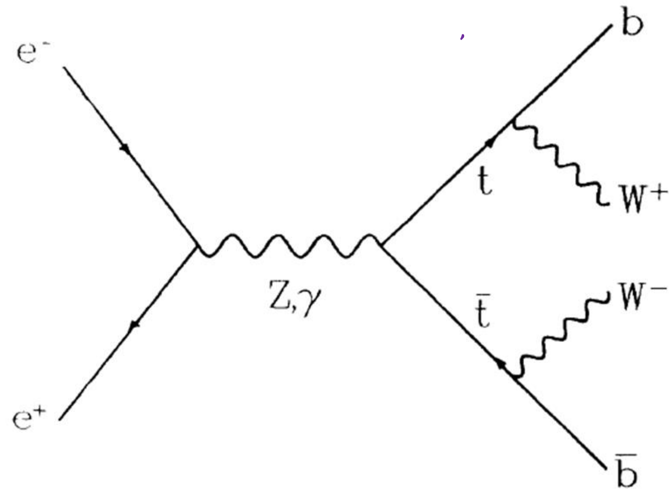


- d_tau ~ mt^2 m_tau
- So may be many^2 orders of magnitude larger than d_e
- Which is exptally bounded by < few times 10^-27 ecm

⇒ masses a challenge in these constructions

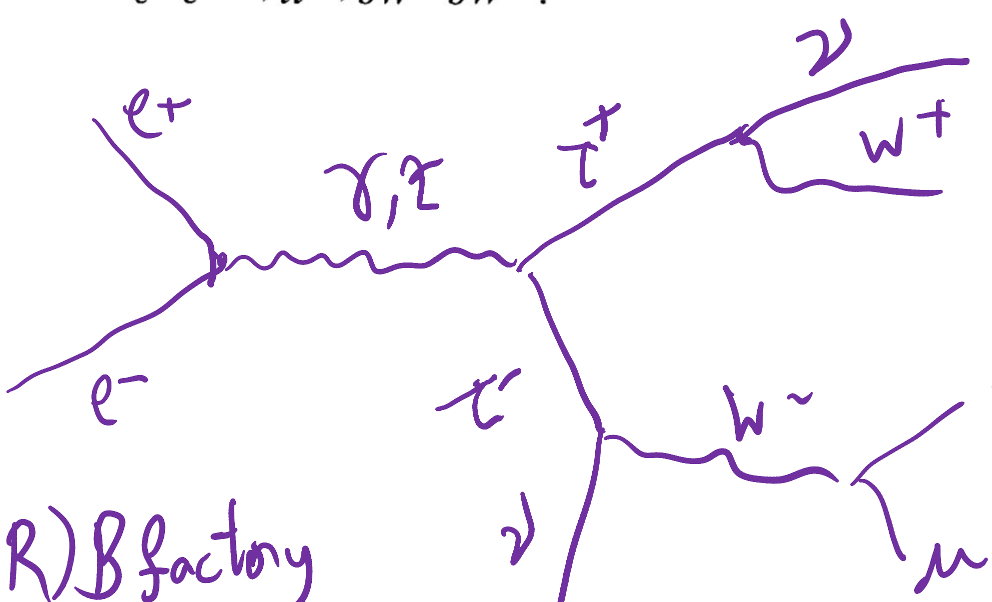
Beams may be polarised

$t\bar{t}$ e+LC



Construct CPV observables

FIG. 1. Feynman diagrams for the process $e^+e^- \to t\bar{t} \to bW^+\bar{b}W^-$.



μν, eν

π+

π0, K0π+...

eν, ππ, K*......

(SUPER) B factory

LHC POSSIBILITIES

Simplest is using Z => tau tau
Diificult due to backgounds but since tau's are boosted a lot may be possible
via searches of displaced vertices
See Sarah Demurs et al [ATLAS]

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……

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

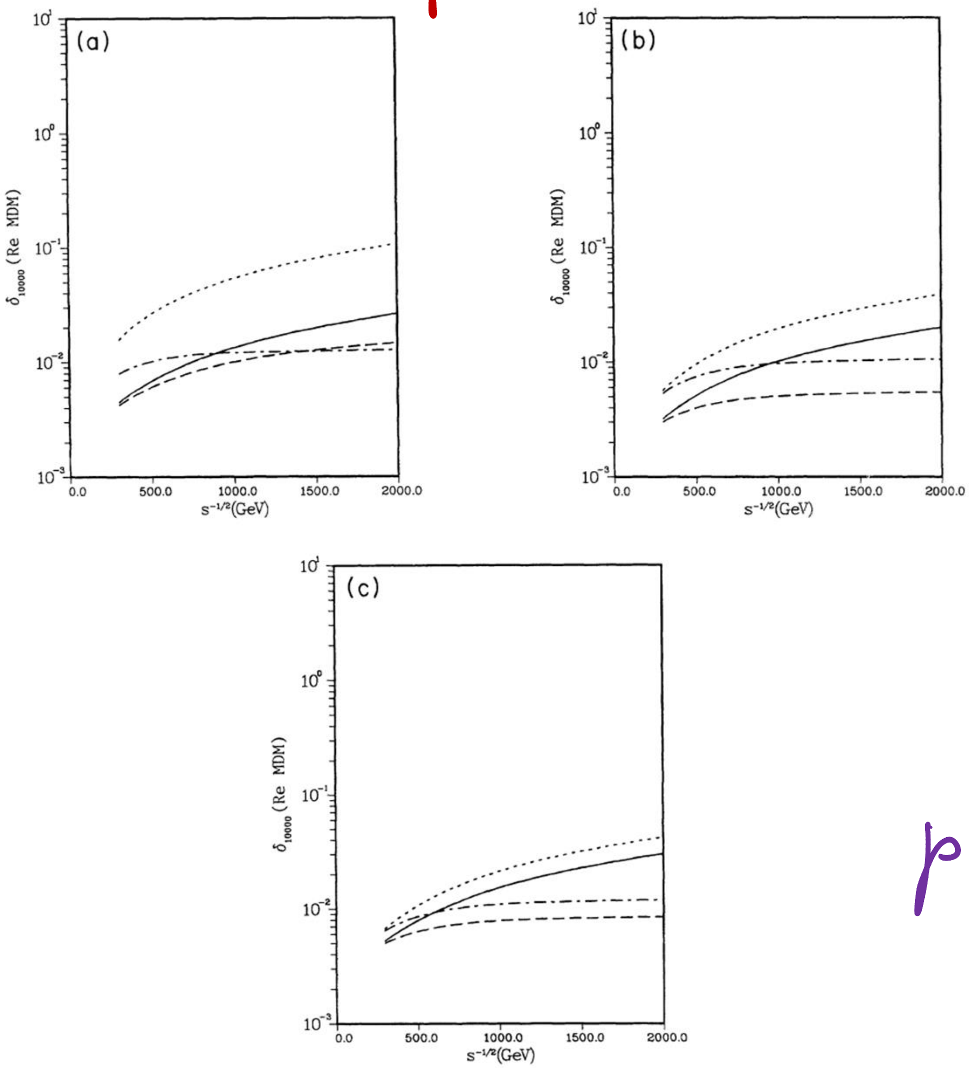


FIG. 2. δ_{10000} vs $\sqrt{s}$ is shown for various observables sensitive to Re(C). The curves shown are as follows: the dashed curve is δ_{10000} for the optimized observable for Re(C_t^{γ}); the solid curve is δ_{10000} using the total cross section to measure Re(C_t^{γ}); the dash-dot curve is δ_{10000} for the optimized observable for Re(C_t^{Z}); and the dotted curve is δ_{10000} 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 optimized w.r.t statistical errors only

Magnetic γ

Electric γ

Op. obs can often do ~ X10 better

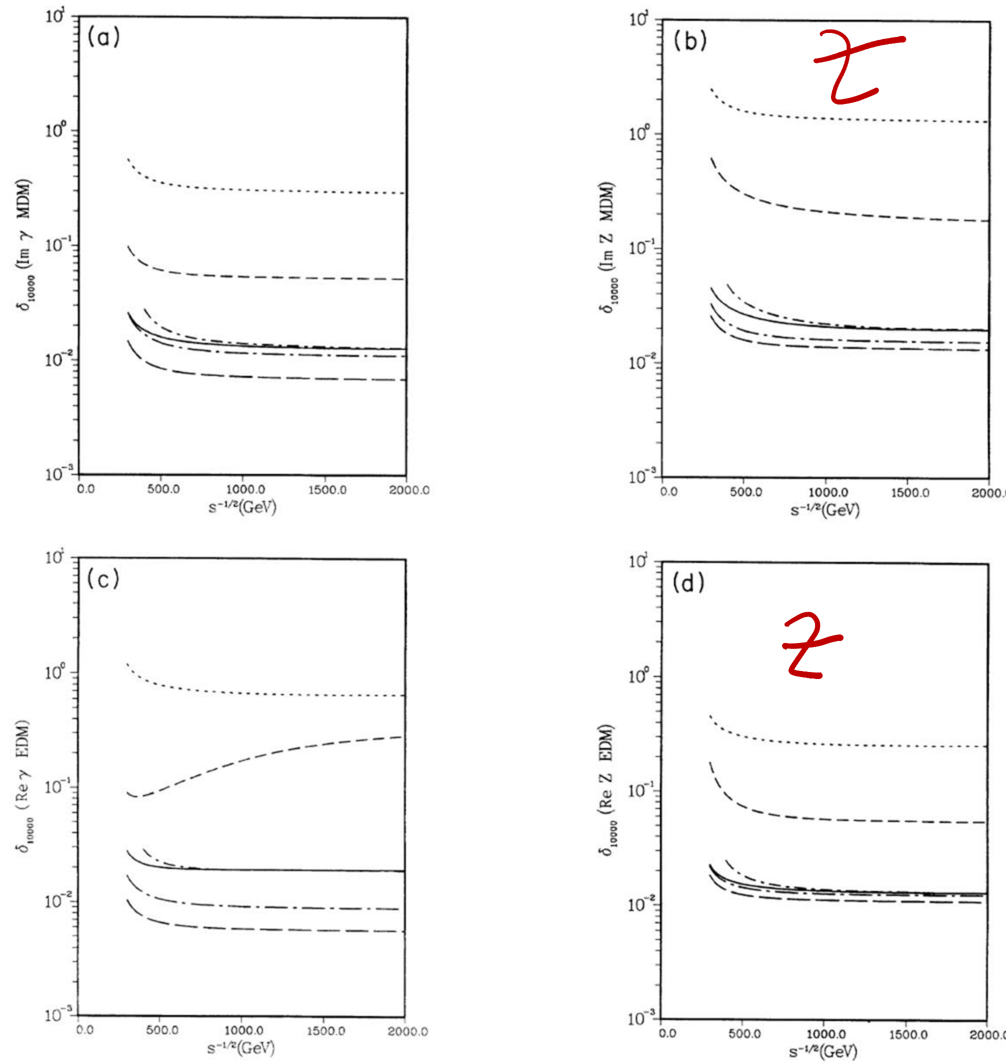
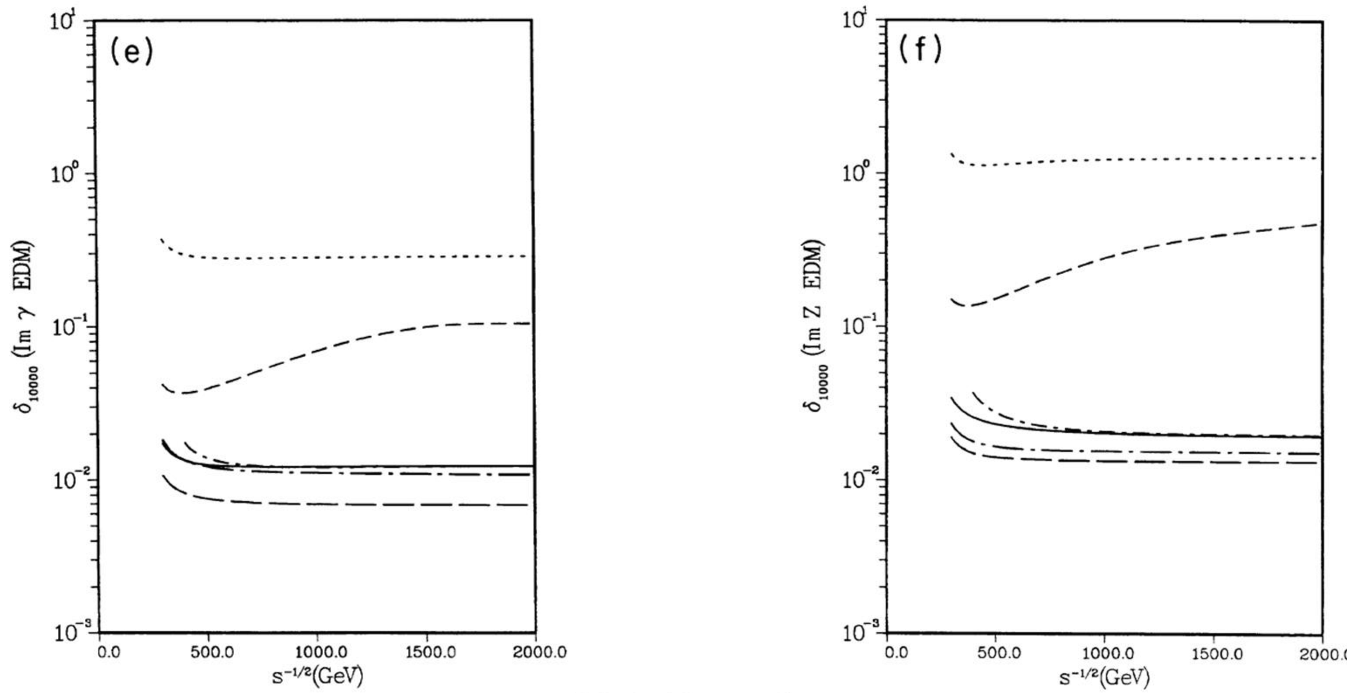


FIG. 3. Shown here is $\delta_{10\,000}$ vs $\sqrt{s}$ with respect to various couplings. The cases shown are (a) Im(C_t^γ); (b) Im(C_t^Z); (c) Re(D_t^γ); (d) Re(D_t^Z); (e) Im(D_t^γ); and (f) Im(D_t^Z). In each case the optimal observable for unpolarized beams using $m_t = 120$ GeV is shown with the 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 curve; the optimal case where W boson polarization is not measured is shown with the dotted curve. The best that can be achieved

E γ



E Z

FIG. 3. (*Continued*).

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

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

Theorem on optimised observables.

See Atwood + S
PRD 92

$$f = f_{opt} = \frac{\Sigma_1}{\Sigma_0} \quad . \tag{17}$$

Usually Σ_1 is a linear combination of naive observables.

WITH 10^{10} τ pairs should be able to probe easily $\sim 10^{-20}$ e cm

of tau's vs Br & Asymm

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

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

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

THE POWER OF EXPTAL DATA

BABAR Phy Book '97

Table 13-6. *Model-dependent effects of new physics in various processes.*

Model	CP Violation: B_d^0–$\overline{B}_d^0$ Mixing	CP Violation: Decay Ampl.	Rare Decays	D^0–$\overline{D}^0$ Mixing
MSSM	$\mathcal{O}(20\%)$ SM Same Phase	No Effect	$B \to X_s\gamma$ – yes $B \to X_s l^+ l^-$ – no	No Effect
SUSY – Alignment	$\mathcal{O}(20\%)$ SM New Phases	$\mathcal{O}(1)$	Small Effect	Big Effect
SUSY – Approx. Universality	$\mathcal{O}(20\%)$ SM New Phases	$\mathcal{O}(1)$	No Effect	No Effect
R-Parity Violation	Can Do	Everything	Except Make	Coffee
MHDM	$\sim$ SM/New Phases	Suppressed	$B \to X_s\gamma$, $B \to X_s\tau\tau$	Big Effect
2HDM	$\sim$ SM/Same Phase	Suppressed	$B \to X_s\gamma$	No Effect
Quark Singlets	Yes/New Phases	Yes	Saturates Limits	$Q = 2/3$
Fourth Generation	$\sim$ SM/New Phases	Yes	Saturates Limits	Big Effect
LRM – $V_L = V_R$	No Effect	No Effect	$B \to X_s\gamma$, $B \to X_s l^+ l^-$	No Effect
– $V_L \neq V_R$	Big/New Phases	Yes	$B \to X_s\gamma$, $B \to X_s l^+ l^-$	No Effect
DEWSB	Big/Same Phase	No Effect	$B \to X_s\ell\ell$, $B \to X - s\nu\overline{\nu}$	Big Effect

though in many cases further data may limit the available parameter space. In the more exciting eventuality that the results are not consistent with Standard Model predictions, the full pattern of the discrepancies both in rare decays and in CP-violating effects will help point to the preferred extension, and possibly rule out others. In either case there is much to be learned.

CONSTRAINTS: TIGHTENING EXPT'S NOOSE AGAINST SPECIFIC MODELS

The wealth and power of the experimental data

- **Our version of RPV3 ability considerably clipped over the past 2 decades**
- **And potentially may face trouble**

constraints

- Direct searches via $pp \to \tilde{b}\tilde{b} \to \tau^+\tau^- t\bar{t}$

Indirect constraints considered due B=>τ ν; π τ ν; π(K) ν ν….

Also B_C =>τν….

To a/c (within 1σ) of expt for RD(*) needs largish λ'333 ~1 – 2 range with quite heavy sbottoms but such large couplings develop landau pole below GUT scale.We require couplings stay perturbative below GUT so with λ'333 < ~1 ,

⇒ TAKE HOME: This version of RPV is actually (surprisingly) well constrained

⇒ With improved measurements RD(*) in RPV3 may be difficult

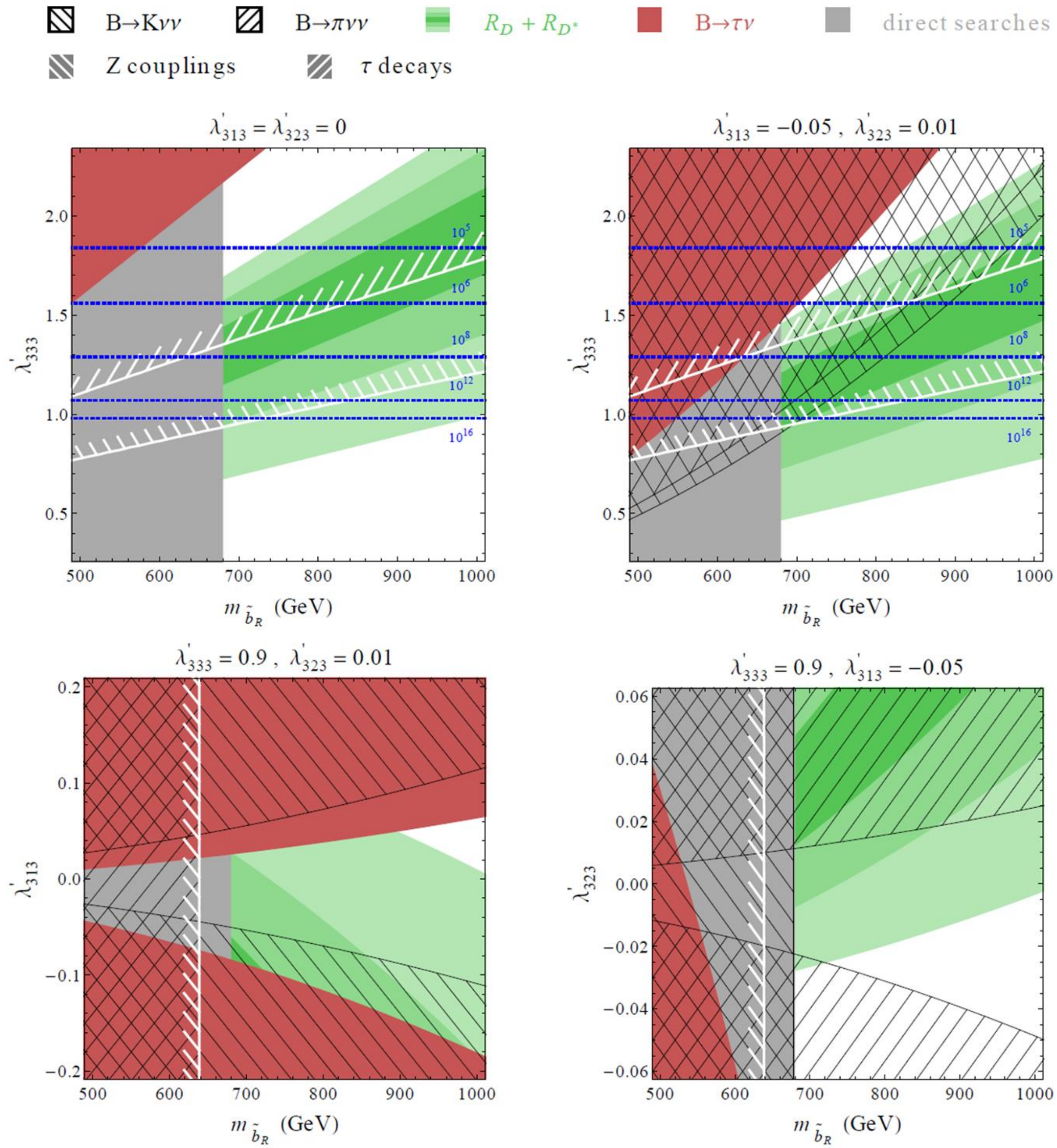
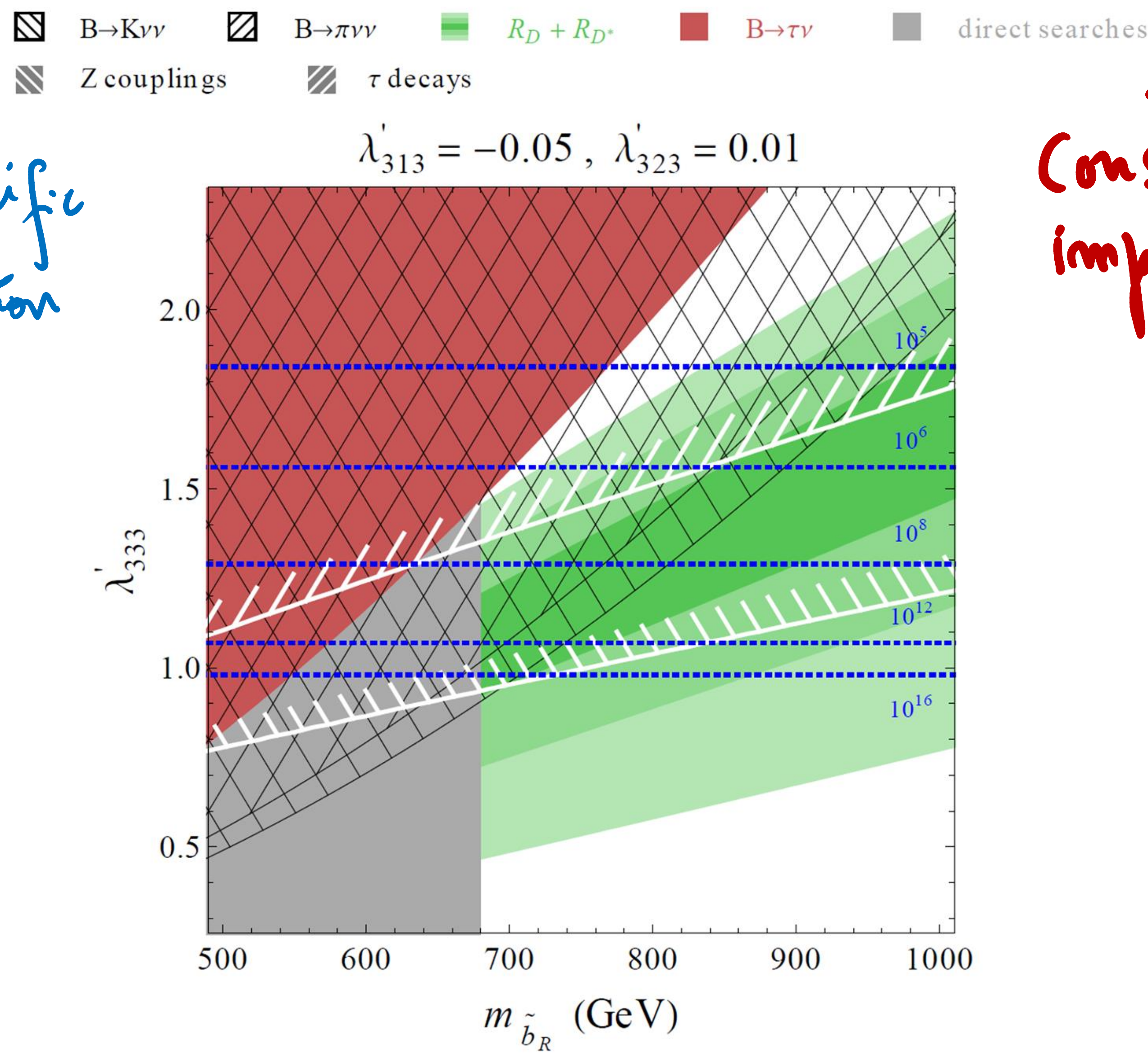


FIG. 3. RPV parameter space satisfying the $R_{D^{(*)}}$ anomaly and other relevant constraints.

As a specific illustration



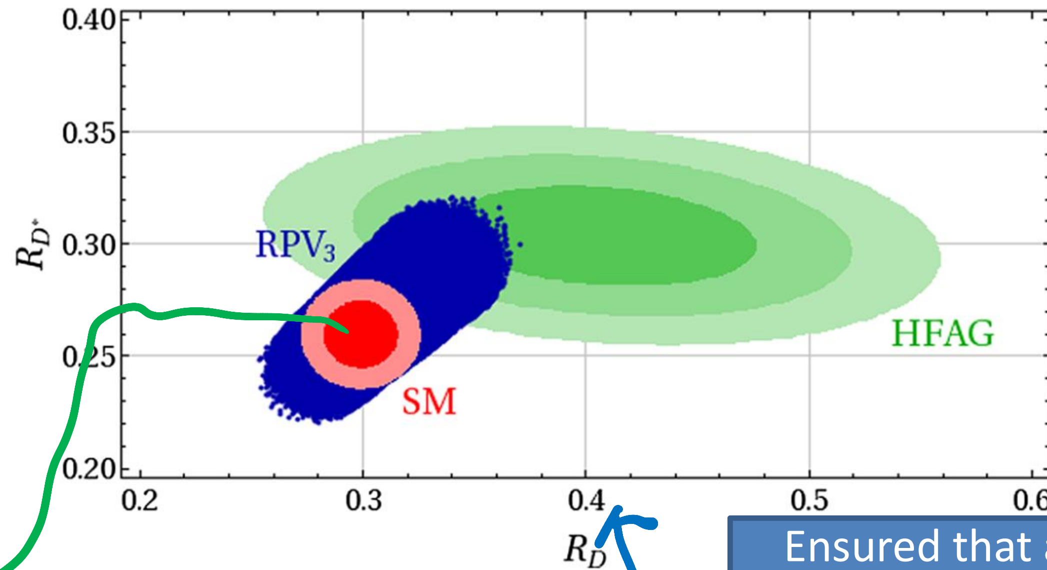
Constraints imposed

FIG. 3. RPV parameter space satisfying the $R_{D(*)}$ anomaly and other relevant constraints.

ALTMANNSHOFER, BHUPAL DEV, and SONI PRD 2017

RPV3 allows
RD=(.254-.371)
RD*=(.220-.320)
Contrast Fuentes-Martin:

$\frac{\Delta R_{D^*}}{\Delta R_D} \approx 0.45$



More Realistic SM Blob

FIG. 4. The SM predictions (red), experimental world average (green), and accessible values in our RPV-SUSY scenario (blue) in the R_D vs. R_{D^*} plane. For the SM, bearing in mind recent works [17,20,22] we are taking $(R_D^{SM}, R_{D^*}^{SM}) = (0.299 \pm 0.011, 0.260 \pm 0.010)$.

HFAG dec2016
RD=.403+-.040+-.024
RD*=.310+-.015+-.008
LHCb 06/06/17
RD* 0.305

Ensured that all RPV3 couplings stay perturbative up to GUT

all constraints……RPV(blue) region obtained by scanning with sbottom mass 680-1000Gev, 0<λ333<2;|λ323|<0.1;|λ313|<0.3 ….

Summary + Outlook

- 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. For example for RD(*) possibility of appreciable systematic difference between tau => l nu nu and tau => hadrons + nu must be resolved..This requires more data
- Belle-II, Lhcb-Run II [upgrade] and new Fermilab g-2 expt[X2BNL already!] are all very timely for clarifications on these anomalies.
- In particular. Belle-II, huge new gorilla for searching NP esp via intensive tau studies
- For e.g. tau => K0 pi+- nu precise rate via on and off the lattice seems a very interesting target to search for BSM; also via CP-violating observables
- Current anomalies esp. motivate LFV searches in tau decays to mu gamma, 3 mu, mu phi , mu + hh….;B=>K mu tau…;Bs=>phi mu tau, mu tau…
- tau pair production and decays to multitude of states can be used for CP violation (and conserving) studies via intrinsic tau-dm…may get bounds <10^-20 ecm
- **Very good chance that in the next ~5 years, via IF machines, LHCb, Belle-II, STCF along with precise computations …major advances in our understandings of Particle Physics will be made**

XTRA

items

- Physics is an exptal science
- Iijima + LHCb + STCF
- BelleII + LHCb, RUN I + II + III…and upgrades+ STCF
- Adventures with IF
- Signs of BSM: pros + cons
- No-go theorem(s)……… and their nullification(s)
- 3 illustrtative topis
- A) tau => nu + Ks + pi+-
- B) tau + LFV: tau => 3 mu, mu + gamma, mu+ ee; B=>K mu tau……..
- C) seeking signs of (E,M) dipole moments

relevant weak hadronic current is just

$$J_\mu^{W,S} \equiv \bar{u}\gamma_\mu(1-\gamma_5)s$$

leads to one major well known exclusive mode

$$\tau \to \nu K^+ \text{ via } \langle 0|\bar{u}\gamma_\mu\gamma_5 s|K\rangle$$

From expt. $B_r(\tau \to \nu K) = 6.96 \times 10^{-3}$