Possible hints for minimal RPV3-SUSY in flavor anomalies

HET Lunch 061121

Overview & scope

- Babar (2012): RD(*) => SM + TYPE-II 2HDM
- BELLE (soon thereafter) => no clear confirmation of Babar (2012)
- LHCb (2014) : RK => FV O(2) sigma
- ADS’ (2017) => minimal RPV3 => addresses RD(*) in a highly motivated theoretical framework
- Belle (2019) : RD(*) not 4 sigma but at best around 3sigma
- LHCb(2019) RK =2.5 sigma
- LHCb(2021) RK~ 3.1 sigma! ; FNAL(2021)[+BNL’04]: (g-2)_mu => 4.2 sigma!
- FX et al(2021) : Collider signals of RPV3

outline

- Recapitulate flavor anomalies….Pros & Cons
- Why RPV3
- Tests for IF
- Implications for LHC & beyond
- Summary

muon $g - 2$ and the B-physics anomalies in RPV supersymmetry and the discovery prospect at LHC and future colliders

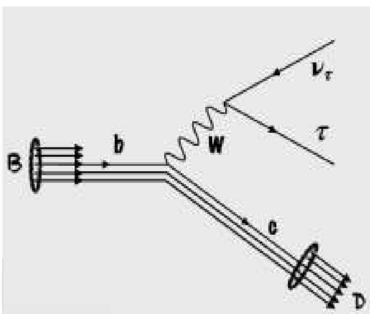
By Fang Xu, Bhupal Dev + A.S to appear soon

Altmannshofer, Dev, A S, Yicong Sui, arXiv:2002.12910 PRD 2020
Altmannshofer, Dev, A. S, arxiv: 1704. 06559; PRD 2017

RD(*) anomally

$$R_{D^{(*)}} = \frac{BR(B \to D^{(*)}\tau\nu)}{BR(B \to D^{(*)}\ell\nu)} \quad (\text{with } \ell = e, \mu)$$

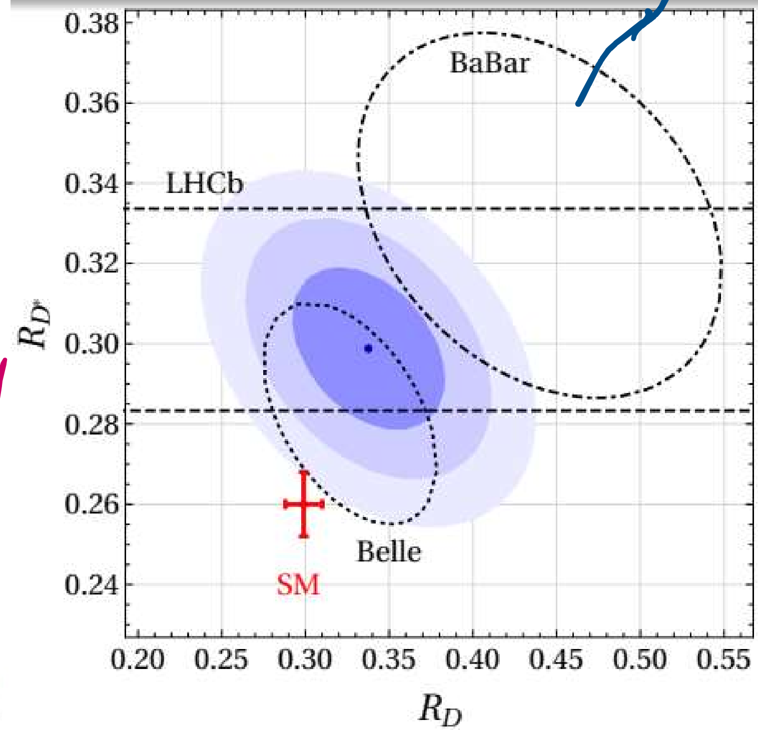
SM
e
Tree
Level



NP ≲ 2 TeV

Manuel F Sevilla (95)

2012



[Altmannshofer, BD, Soni, Sui, 2002.12910 (PRD '20)]

DDRESSING $R_{D(*)}$, $R_{K(*)}$, MUON $G-2$ AND ... PHYS. REV. D **102**, 015031 (2020)

TABLE I. Summary of the anomalies in the observables $R_{D^{(*)}}$, $R_{J/\psi}$, $R_{K^{(*)}}$, and $(g-2)_\mu$. Listed are the pulls of various subsets of observables. The pulls are combined assuming the observables are independent from each other. The values in parentheses exclude the *BABAR* results for $R_{D^{(*)}}$.

Observable	$R_{D^{(*)}}, R_{J/\psi}$	$R_{K^{(*)}}$	$(g-2)_\mu$	All but $(g-2)_\mu$	All
Pull	3.3σ (2.2σ)	3.4σ	3.3σ	4.5σ (3.7σ)	5.3σ (4.6σ)

PHYSICAL REVIEW D VOLUME 56, NUMBER 9 1 NOVEMBER 1997

Improving constraints on $\tan\beta/m_H$ using $B\to D\tau\overline{\nu}$

Ken Kiers* and Amarjit Soni†
Department of Physics, Brookhaven National Laboratory, Upton, New York 11973-5000

(Received 12 June 1997)

FF

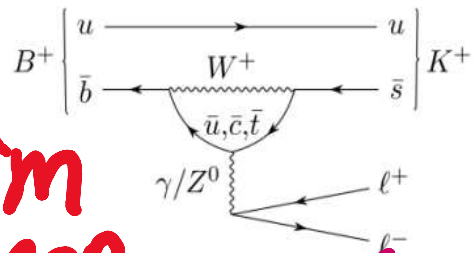
f_1

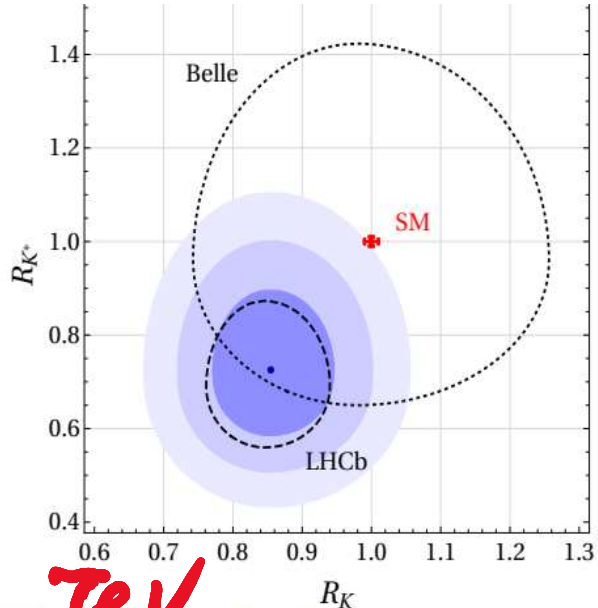
We study the q^2 dependence of the exclusive decay mode $B\to D\tau\overline{\nu}$ in type-II two Higgs doublet models (2HDM's) and show that this mode may be used to put stringent bounds on $\tan\beta/m_H$. There are currently rather large theoretical uncertainties in the q^2 distribution, but these may be significantly reduced by future measurements of the analogous distribution for $B\to D(e,\mu)\overline{\nu}$. We estimate that this reduction in the theoretical uncertainties would eventually (i.e., with sufficient data) allow one to push the upper bound on $\tan\beta/m_H$ down to about 0.06 GeV^{-1}. This would represent an improvement on the current bound by about a factor of 7. We

used HQS ⇒ Followed up by Nierste et al '08; Fajfer et al '12

LHCb Since ~ 2014

$$R_{K^{(*)}} = \frac{BR(B \to K^{(*)}\mu^+\mu^-)}{BR(B \to K^{(*)}e^+e^-)}$$





SM LOOP ⇒ NP ≳ 30 TeV

- Flavor Changing Neutral Current – loop-suppressed in the SM.
- Recent update on R_K measurement from LHCb:

$$R_K^{\text{new}} = 0.846^{+0.042+0.013}_{-0.039-0.012} \quad [2103.11769]$$

$$R_K^{\text{old}} = 0.846^{+0.060+0.016}_{-0.054-0.014} \quad [1903.09252\ (PRL'19)].$$

← 2.56

- 3.4σ net discrepancy.

RK(*) anomally

B. Muon $g-2$

Another interesting observable that has hinted towards BSM physics for a long time is the anomalous magnetic moment of the muon. The existing BNL experimental result [59] for the $(g-2)_\mu$ reads [51]

$$a_\mu^{\rm exp} = (11,659,209.1 \pm 5.4({\rm stat}) \pm 3.3({\rm sys})) \times 10^{-10}. \tag{14}$$

Data driven disp relation - ...

Combining the results collected above leads to a discrepancy between experiment and the SM prediction at the 3.3σ C.L. [90]:

$$\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} = (26.1 \pm 7.9) \times 10^{-10}. \tag{20}$$

The $(g-2)$ experiment at Fermilab [87] is expected to improve the experimental accuracy by a factor of about 4 in the next few years.

The SM prediction for a_μ can be decomposed into contributions from QED, from the electroweak interactions, from hadronic vacuum polarization and from hadronic light-by-light scattering:

$$a_\mu^{\rm SM} = a_\mu^{\rm QED} + a_\mu^{\rm EW} + a_\mu^{\rm VP} + a_\mu^{\rm LbL}. \tag{15}$$

The QED and electroweak contributions are known with high accuracy [88,89]

$$a_\mu^{\rm QED} = (11,658,471.897 \pm 0.007) \times 10^{-10}, \tag{16}$$

$$a_\mu^{\rm EW} = (15.36 \pm 0.10) \times 10^{-10}. \tag{17}$$

The hadronic vacuum polarization contribution can be determined using $e^+e^- \to$ hadrons data and dispersion relations. A recent such analysis gave [90] (see also Ref. [91])

$$a_\mu^{\rm VP} = [(693.9 \pm 4.0) - (9.9 \pm 0.1) + (1.24 \pm 0.01)] \times 10^{-10}, \tag{18}$$

where the first, second and third terms correspond to the leading-, next-to-leading-, and next-to-next-to-leading-

Recent experimental developments

Marco Santimaria (INFN-LNF)
on behalf of the LHCb collaboration
LHC Seminar 23/03/2021, CERN (Virtual)

Today: R_K with the full LHCb dataset

$$R_K = \frac{\int_{1.1\,\mathrm{GeV}^2}^{6.0\,\mathrm{GeV}^2} \frac{\mathrm{d}\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathrm{d}q^2} \mathrm{d}q^2}{\int_{1.1\,\mathrm{GeV}^2}^{6.0\,\mathrm{GeV}^2} \frac{\mathrm{d}\mathcal{B}(B^+ \to K^+ e^+ e^-)}{\mathrm{d}q^2} \mathrm{d}q^2}$$

Measurement performed in $1.1 < q^2 < 6.0\,\mathrm{GeV}^2/c^4$

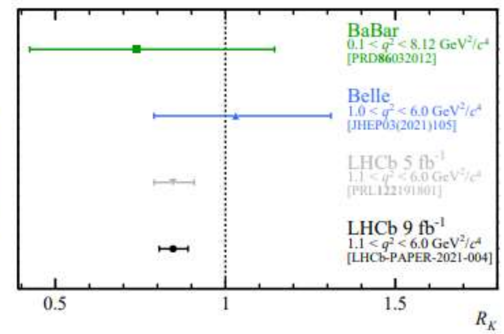
- Previous measurement [PRL122(2019)191801] used $5\,\mathrm{fb}^{-1}$ of data.
  $3\,\mathrm{fb}^{-1}$ of Run1
  $2\,\mathrm{fb}^{-1}$ of Run2 in 2015 and 2016
- This update:
  $\rightarrow$ Add remaining $4\,\mathrm{fb}^{-1}$ of Run2 in 2017 and 2018 .
  $\rightarrow$ $9\,\mathrm{fb}^{-1}$ in total.
  $\rightarrow$ Doubling the number of B's as previous analysis.

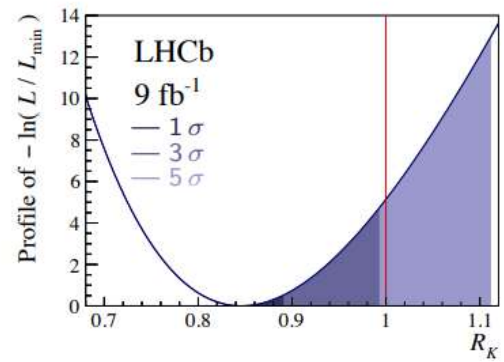
R_K with full Run1 and Run2 dataset

[LHCb-PAPER-2021-004]**Submitted to Nature Physics**

$$R_K = 0.846 \ ^{+0.042}_{-0.039} \ (\text{stat}) \ ^{+0.013}_{-0.012} \ (\text{syst})$$

- p-value under SM hypothesis: 0.0010
  → Evidence of LFU violation at 3.1σ
- Compatibility with the SM obtained by integrating the profiled likelihood as a function of R_K above 1
  - ▷ Taking into account the 1% theory uncertainty on R_K [EPJC76(2016)8,440]





VERY imp. exptal step forward!

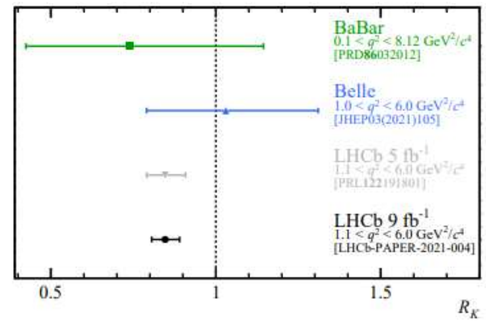
R_K with full Run1 and Run2 dataset

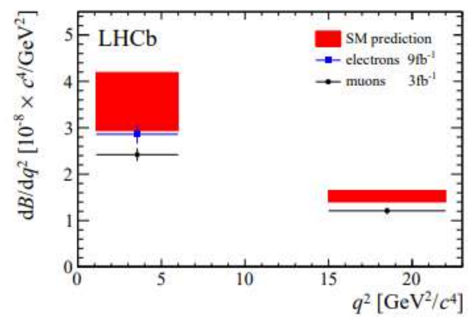
[LHCb-PAPER-2021-004]Submitted to Nature Physics

$$R_K = 0.846 \,^{+0.042}_{-0.039}\,(\text{stat})\,^{+0.013}_{-0.012}\,(\text{syst})$$

- p-value under SM hypothesis: 0.0010
  → Evidence of LFU violation at 3.1σ
- Using R_K and previous measurement of $\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$ [JHEP06(2014)133] determine $\mathcal{B}(B^+ \to K^+e^+e^-)$.
- Suggests electrons are more SM-like than muons.

$\Rightarrow \lambda^{NP}_e \gtrsim \lambda^{NP}_\mu$





$$\frac{d\mathcal{B}(B^+\to K^+e^+e^-)}{dq^2} = (28.6 \,^{+1.5}_{-1.4}(\text{stat}) \pm 1.4(\text{syst})) \times 10^{-9}\; c^4/\,\text{GeV}^2.$$

K.A. Petridis (UoB) | Test of LFU at LHCb | March 2021 | 18 / 20

prev ≃ 2.56 central value to 3 digits identical

LHCb efforts to control the systematics

Cross-check: Measurement of $r_{J/\psi}$

[LHCb-PAPER-2021-004]

- To ensure that the efficiencies are under control, check

$$r_{J/\psi} = \frac{\mathcal{B}(B^+ \to K^+ J/\psi(\mu^+\mu^-))}{\mathcal{B}(B^+ \to K^+ J/\psi(e^+e^-))} = 1,$$

known to be true within 0.4% [Particle Data Group].
→ Very stringent check, as it requires direct control of muons vs electrons.

- Result:

$$r_{J/\psi} = 0.981 \pm 0.020\ (\mathrm{stat} + \mathrm{syst})$$

- Checked that the value of $r_{J/\psi}$ is compatible with unity for new and previous datasets and in all trigger samples.

Cross-check: Measurement of $R_{\psi(2S)}$

[LHCb-PAPER-2021-004]

Measurement of the double ratio

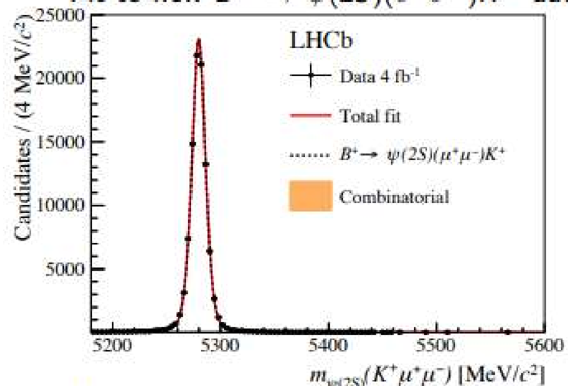
$$R_{\psi(2S)} = \frac{\mathcal{B}(B^+ \to K^+\psi(2S)(\mu^+\mu^-))}{\mathcal{B}(B^+ \to K^+J/\psi(\mu^+\mu^-))} \Big/ \frac{\mathcal{B}(B^+ \to K^+\psi(2S)(e^+e^-))}{\mathcal{B}(B^+ \to K^+J/\psi(e^+e^-))}$$

- Independent validation of double-ratio procedure at q^2 away from J/ψ
- Result well compatible with unity:

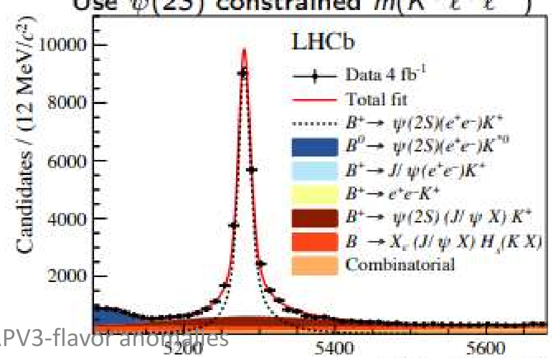
$$R_{\psi(2S)} = 0.997 \pm 0.011\ (\text{stat} + \text{syst})$$

$\rightarrow$ can be interpreted as world's best LFU test in $\psi(2S) \to \ell^+\ell^-$

Fit to new $B^+ \to \psi(2S)(\ell^+\ell^-)K^+$ data



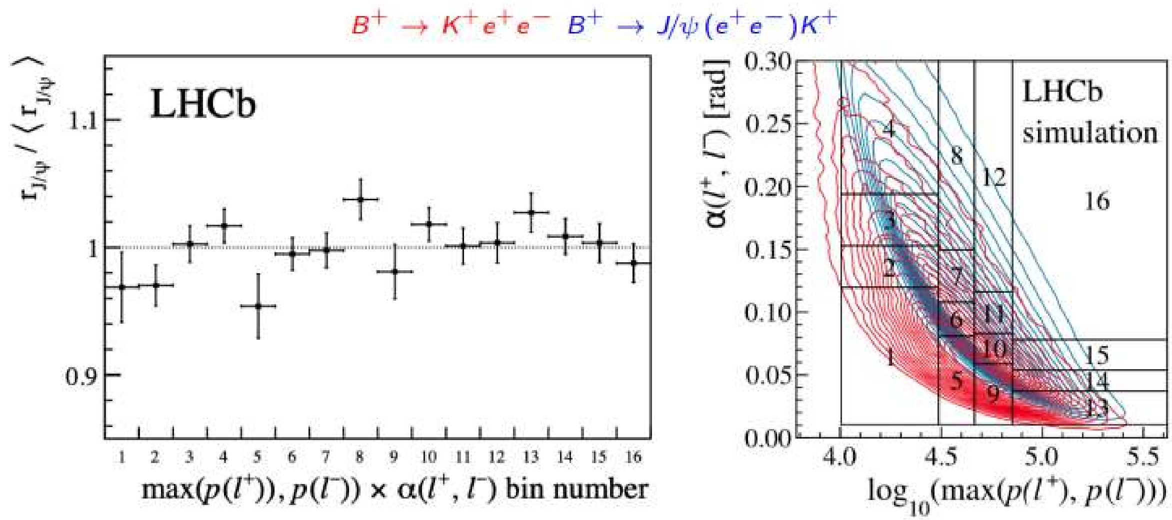
Use $\psi(2S)$ constrained $m(K^+\ell^+\ell^-)$



Cross-check: $r_{J/\psi}$ as a function of kinematics

[LHCb-PAPER-2021-004]

- Test efficiencies are understood in all kinematic regions by checking $r_{J/\psi}$ is flat in all variables examined.



- Flatness of $r_{J/\psi}$ 2D plots gives confidence that efficiencies are understood across entire decay phase-space.

  $\rightarrow$ If take departure from flatness as genuine rather than fluctuations (accounting for rare-mode kinematics) bias expected on R_K is 0.1%

Systematic uncertainties

[LHCb-PAPER-2021-004]

Dominant sources: $\sim 1\%$

- Choice of fit model
  - Associated signal and partially reconstructed background shape
- Statistics of calibration samples
  - Bootstrapping method that takes into account correlations between calibration samples and final measurement

Sub-dominant sources: $\sim 1‰$

- Efficiency calibration

  → Dependence on tag definition and trigger biases

  → Precision of the q^2 and $m(K^+e^+e^-)$ smearing factors

  → Inaccuracies in material description in simulation

  ...

Total relative systematic of 1.5% on the final R_K measurement
→ Expected to be statistically dominated

Muon (g-2): Fermilab seminar

04/07/21

$$a_\mu(\text{FNAL}) = 116\,592\,040(54) \times 10^{-11} \quad (0.46\,\text{ppm}),$$

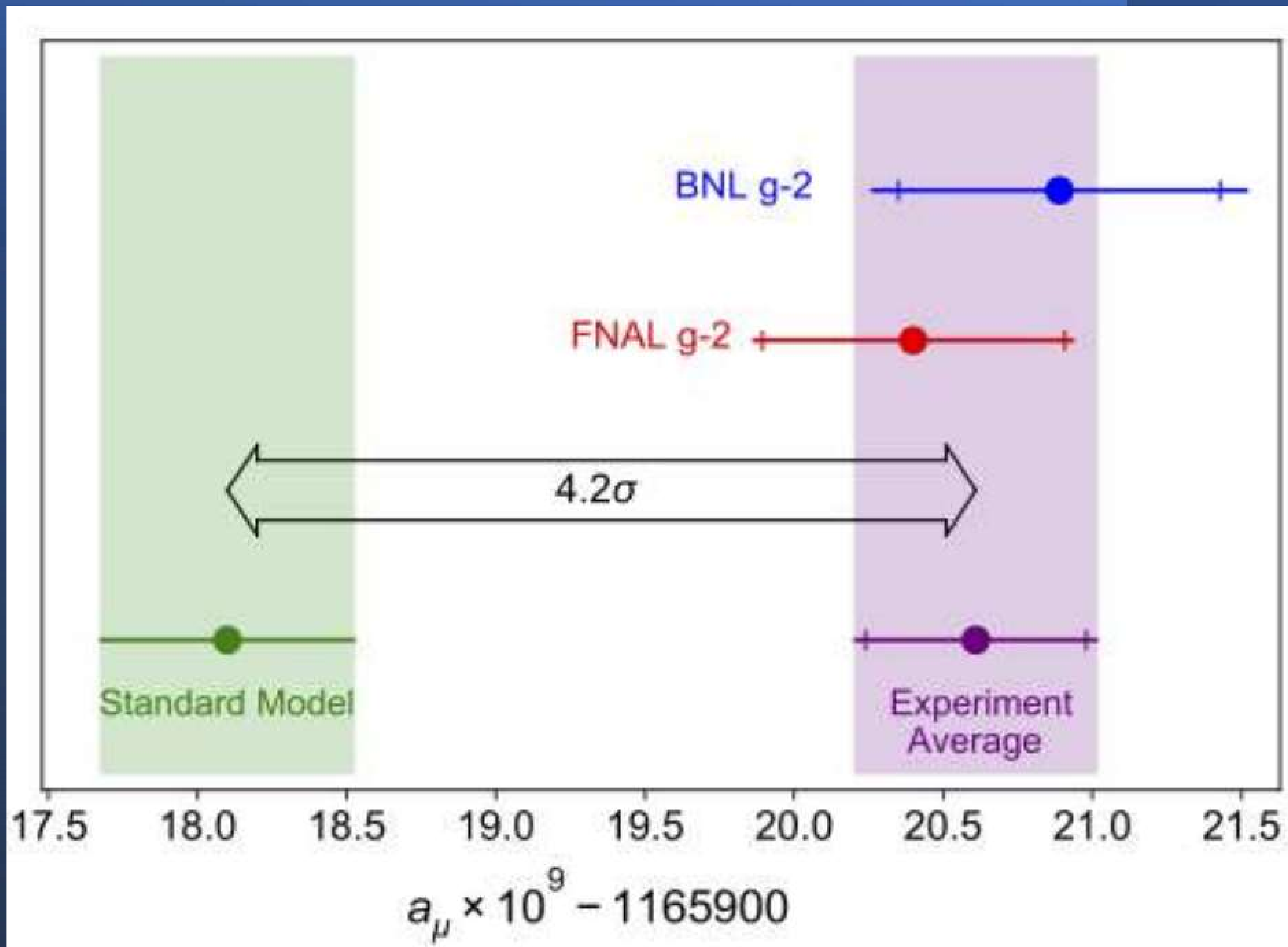
where the statistical, systematic, and fundamental constant uncertainties that are listed in Table II are combined in quadrature. Our result differs from the SM value by $3.3\,\sigma$ and agrees with the BNL E821 result. The combined experimental (Exp) average[68] is

Huge exptal step forward!

$$a_\mu(\text{Exp}) = 116\,592\,061(41) \times 10^{-11} \quad (0.35\,\text{ppm}).$$

" " → DATA Driven

The difference, $a_\mu(\text{Exp}) - a_\mu(\text{SM}) = (251 \pm 59) \times 10^{-11}$, has a significance of $4.2\,\sigma$. These results are displayed in Fig. 4.


BNL g-2
FNAL g-2
4.2σ
Standard Model
Experiment Average
17.5 18.0 18.5 19.0 19.5 20.0 20.5 21.0 21.5
$a_\mu \times 10^9 - 1165900$

VOLUME 86, NUMBER 11 PHYSICAL REVIEW LETTERS 12 MARCH 2001

Precise Measurement of the Positive Muon Anomalous Magnetic Moment

H. N. Brown,[2] G. Bunce,[2] R. M. Carey,[1] P. Cushman,[9] G. T. Danby,[2] P. T. Debevec,[7] M. Deile,[11] H. Deng,[11] W. Deninger,[7] S. K. Dhawan,[11] V. P. Druzhinin,[3] L. Duong,[9] E. Efstathiadis,[1] F. J. M. Farley,[11] G. V. Fedotovich,[3] S. Giron,[9] F. Gray,[7] D. Grigoriev,[3] M. Grosse-Perdekamp,[11] A. Grossmann,[6] M. F. Hare,[1] D. W. Hertzog,[7] V. W. Hughes,[11] M. Iwasaki,[10] K. Jungmann,[6] D. Kawall,[11] M. Kawamura,[10] B. I. Khazin,[3] J. Kindem,[9] F. Krienen,[1] I. Kronkvist,[9] R. Larsen,[2] Y. Y. Lee,[2] I. Logashenko,[1,3] R. McNabb,[9] W. Meng,[2] J. Mi,[2] J. P. Miller,[1] W. M. Morse,[2] D. Nikas,[2] C. J. G. Onderwater,[7] Y. Orlov,[4] C. S. Özben,[2] J. M. Paley,[1] C. Polly,[7] J. Pretz,[11] R. Prigl,[2] G. zu Putlitz,[6] S. I. Redin,[11] O. Rind,[1] B. L. Roberts,[1] N. Ryskulov,[3] S. Sedykh,[7] Y. K. Semertzidis,[2] Yu. M. Shatunov,[3] E. P. Sichtermann,[11] E. Solodov,[3] M. Sossong,[7] A. Steinmetz,[11] L. R. Sulak,[1] C. Timmermans,[9] A. Trofimov,[1] D. Urner,[7] P. von Walter,[6] D. Warburton,[2] D. Winn,[5] A. Yamamoto,[8] and D. Zimmerman[9]
(Muon $(g-2)$ Collaboration)

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(Received 8 February 2001)

A precise measurement of the anomalous g value, $a_\mu = (g-2)/2$, for the positive muon has been made at the Brookhaven Alternating Gradient Synchrotron. The result $a_{\mu^+} = 11\,659\,202(14)(6) \times 10^{-10}$ (1.3 ppm) is in good agreement with previous measurements and has an error one third that of the combined previous data. The current theoretical value from the standard model is $a_\mu(\text{SM}) = 11\,659\,159.6(6.7) \times 10^{-10}$ (0.57 ppm) and $a_\mu(\text{exp}) - a_\mu(\text{SM}) = 43(16) \times 10^{-10}$ in which $a_\mu(\text{exp})$ is the world average experimental value.

BNL
PRL on $g-2_\mu$
2001

~ 2.76

Measurement of the Negative Muon Anomalous Magnetic Moment to 0.7 ppm

G. W. Bennett,[2] B. Bousquet,[9] H. N. Brown,[2] G. Bunce,[2] R. M. Carey,[1] P. Cushman,[9] G. T. Danby,[2] P. T. Debevec,[7] M. Deile,[11] H. Deng,[11] S. K. Dhawan,[11] V. P. Druzhinin,[3] L. Duong,[9] F. J. M. Farley,[11] G. V. Fedotovich,[3] F. E. Gray,[7] D. Grigoriev,[3] M. Grosse-Perdekamp,[11] A. Grossmann,[6] M. F. Hare,[1] D. W. Hertzog,[7] X. Huang,[1] V. W. Hughes,[11,*] M. Iwasaki,[10] K. Jungmann,[5] D. Kawall,[11] B. I. Khazin,[3] F. Krienen,[1] I. Kronkvist,[9] A. Lam,[1] R. Larsen,[2] Y. Y. Lee,[2] I. Logashenko,[1,3] R. McNabb,[9] W. Meng,[2] J. P. Miller,[1] W. M. Morse,[2] D. Nikas,[2] C. J. G. Onderwater,[7] Y. Orlov,[4] C. S. Özben,[2,7] J. M. Paley,[1] Q. Peng,[1] C. C. Polly,[7] J. Pretz,[11] R. Prigl,[2] G. zu Putlitz,[6] T. Qian,[9] S. I. Redin,[3,11] O. Rind,[1] B. L. Roberts,[1] N. Ryskulov,[3] Y. K. Semertzidis,[2] P. Shagin,[9] Yu. M. Shatunov,[3] E. P. Sichtermann,[11] E. Solodov,[3] M. Sossong,[7] L. R. Sulak,[1] A. Trofimov,[1] P. von Walter,[6] and A. Yamamoto[8]

(Muon ($g-2$) Collaboration)

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(Received 10 January 2004; published 23 April 2004)

BNL
PRL '04
$(g-2)_\mu$ II

The anomalous magnetic moment of the negative muon has been measured to a precision of 0.7 ppm (ppm) at the Brookhaven Alternating Gradient Synchrotron. This result is based on data collected in 2001, and is over an order of magnitude more precise than the previous measurement for the negative muon. The result $a_{\mu^-} = 11\,659\,214(8)(3) \times 10^{-10}$ (0.7 ppm), where the first uncertainty is statistical and the second is systematic, is consistent with previous measurements of the anomaly for the positive and the negative muon. The average of the measurements of the muon anomaly is $a_\mu(\text{exp}) = 11\,659\,208(6) \times 10^{-10}$ (0.5 ppm).

Muon (g-2) in units of 10^{-11}

Expt (yr)	Th: Data driven… Disp relation, R-ratio (yr)	Deviation:Expt –Th (significance)	comments
BNL(01): 11659202(15.1) [1.3 ppm]	(01): 11659159.6	43(16) ~ 2.7 б	
BNL(04): 11659214(8.5) [0.7 ppm]		288(80) ~ 3.6 б	
Fermilab (21): 116592040(54) [0.46 ppm]	WP(21): 116591805(50) [0.43 ppm]	235(52) ~ 4.5 б	An experimental Triumph! Very likely an 8th one for BNL!
WA(21): 116592061(41) [0.35 ppm]	WP(21): 116591805(50) [0.43 ppm]	251(59) ~ 4.2 б	How trustworthy are the errors in the WP?

PURE LATTICE Results are eagerly awaited

MUON MAGNETIC MOMENT: NEW PHYSICS OR NOT?

BMWLC

Kalman Szabo

Forschungszentrum Jülich & University of Wuppertal

Budapest-Marseille-Wuppertal collaboration

Borsanyi,Fodor,Guenther,Hoelbling,Katz,Lellouch,Lippert Miura, Parato, Stokes, Toth, Torok, Varnhorst

[2002.12347,Nature (2021)] Leading-order hadronic vacuum polariz ...

virtual SEMINAR @ BNL 05/06/21

MUON MAGNETIC MOMENT: NEW PHYSICS OR NOT?

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Borsanyi,Fodor,Guenther,Hoelbling,Katz,Lellouch,Lippert Miura,
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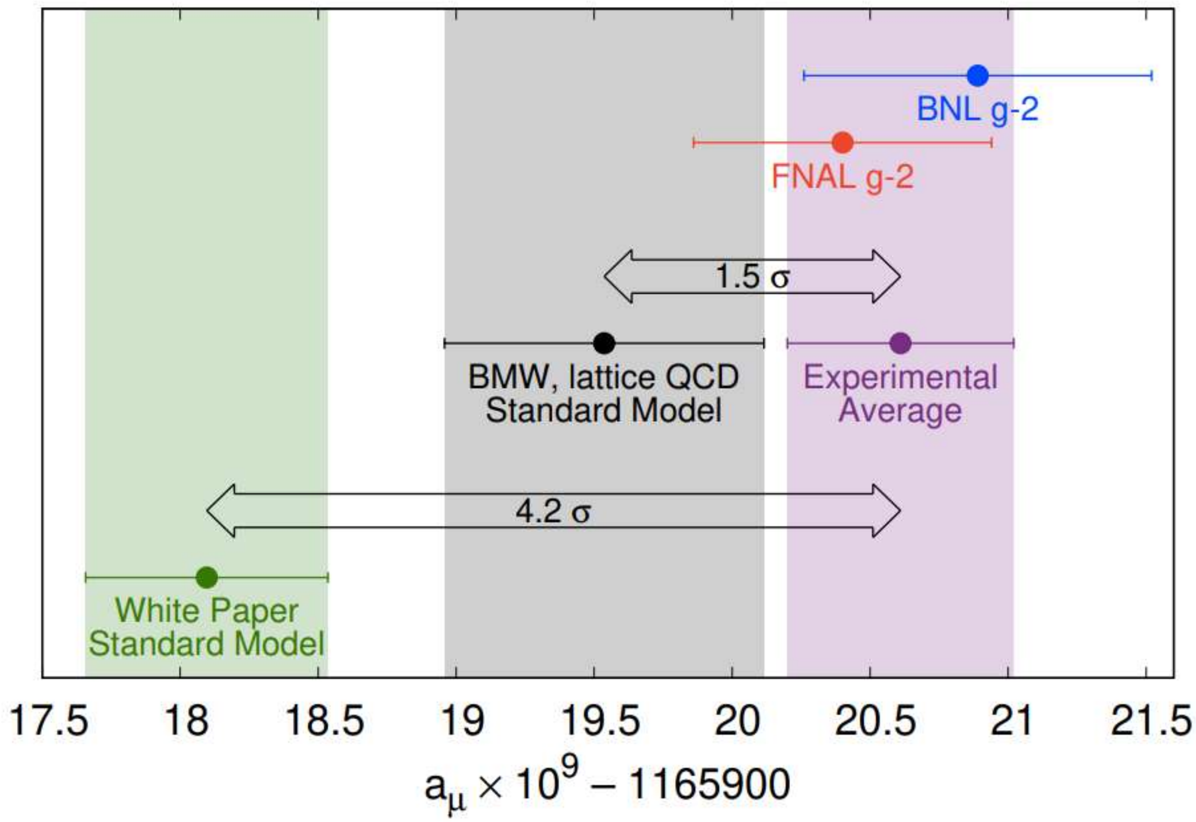
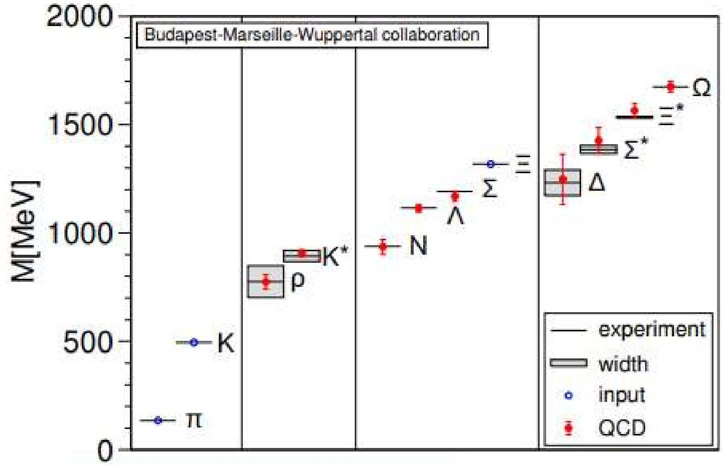
Outline

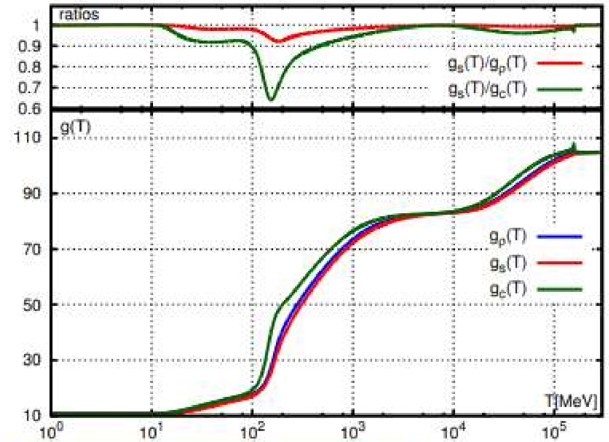


BNL g-2
FNAL g-2
1.5 σ
BMW, lattice QCD
Standard Model
Experimental
Average
4.2 σ
White Paper
Standard Model
17.5 18 18.5 19 19.5 20 20.5 21 21.5
$a_\mu \times 10^9 - 1165900$

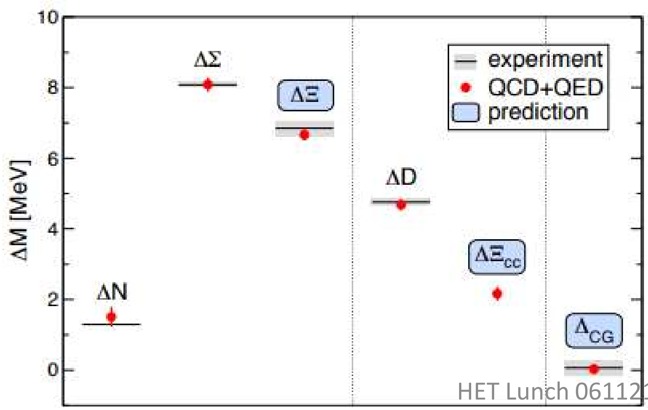
Lattice highlights



hadron spectrum [BMWc'08]



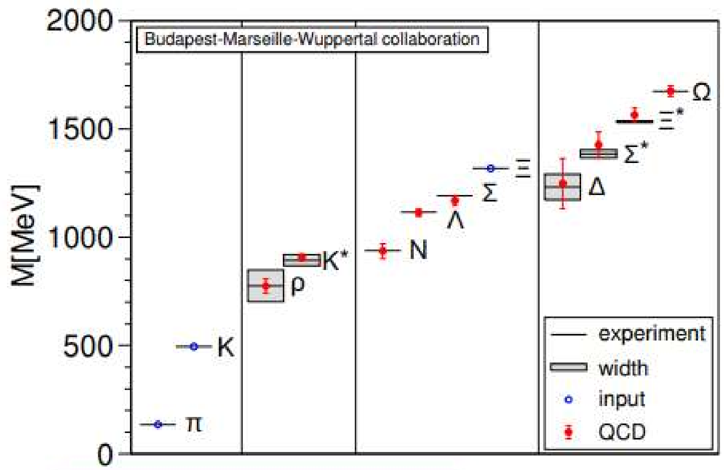
equation of state [WB '16]



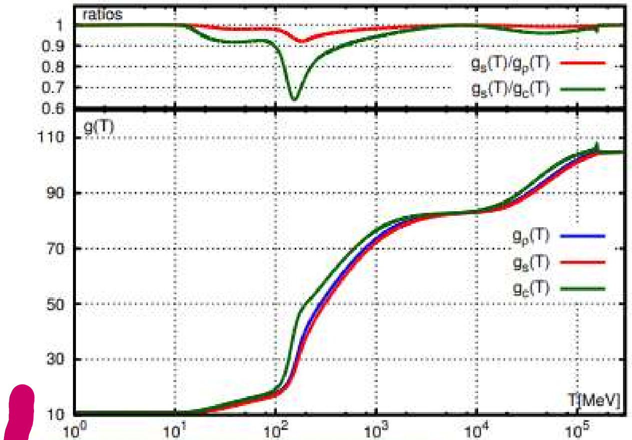
neutron-proton difference [BMWc'14]

- isospin symmetry breaking (strong and QED)

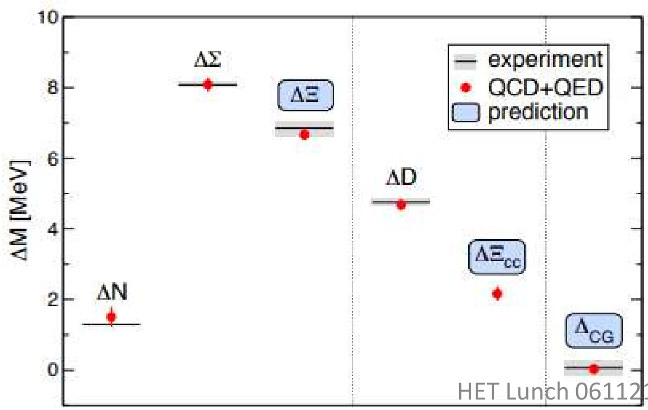
Lattice highlights



hadron spectrum [BMWc'08]



equation of state [WB '16]



neutron-proton difference [BMWc'14]

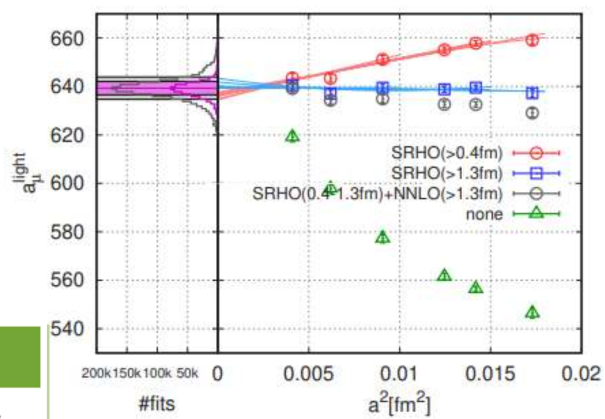
- isospin symmetry breaking (strong and QED)

Continuum limit

Improve continuum extrapolations by models ([HPQCD'16])

$$a_\mu(a) \to a_\mu(a) + \left[a_\mu^{\mathrm{RHO}} - a_\mu^{\mathrm{SRHO}}(a)\right]$$

$\to$ reduced sensitivity to β-cuts; improved slope and curvature



Systematic error:

- skip coarse lattices
- consider different models (SMLLGS/SRHO/SXPT)
- change the point, where we start applying the improvement
- use $a^2\alpha^\Gamma[1/a]$ instead of a
- use linear or quadratic extrapolations

I CONT EXTR??

II ρ 1^{--}

PROCEEDINGS OF SCIENCE

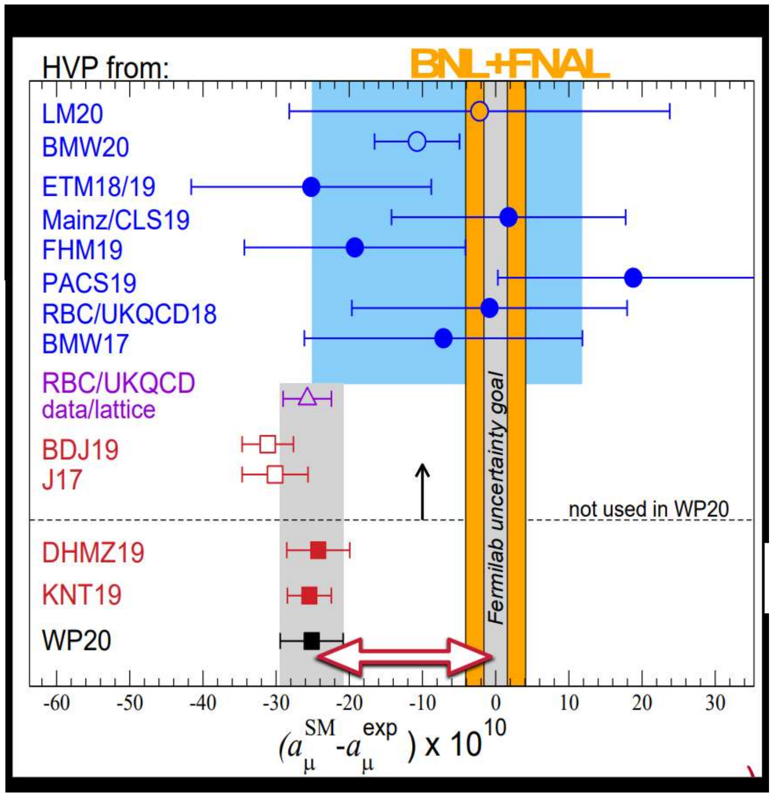
Volume 032 - XXIVth International Symposium on Lattice Field Theory (LAT2006) - Plenary

Rooted staggered fermions: good, bad or ugly?

S.R. Sharpe

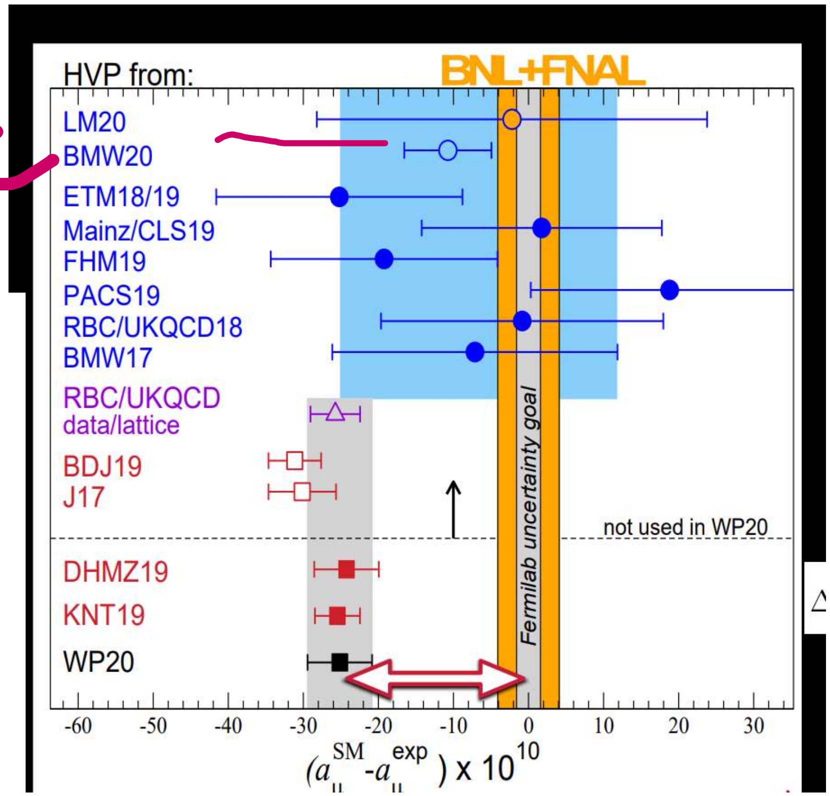
Full text: pdf

Published on: December 18, 2006


HVP from:
BNL+FNAL
LM20
BMW20
ETM18/19
Mainz/CLS19
FHM19
PACS19
RBC/UKQCD18
BMW17
RBC/UKQCD
data/lattice
BDJ19
J17
not used in WP20
Fermilab uncertainty goal
DHMZ19
KNT19
WP20
-60 -50 -40 -30 -20 -10 0 10 20 30
$(a_\mu^{SM} - a_\mu^{exp}) \times 10^{10}$

BDe pheno21

OF Questionable ? Validity



VOLUME 91, NUMBER 5 PHYSICAL REVIEW LETTERS week ending 1 AUGUST 2003

Lattice Calculation of the Lowest-Order Hadronic Contribution to the Muon Anomalous Magnetic Moment

T. Blum

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(Received 18 December 2002; published 30 July 2003)

We present a quenched lattice calculation of the lowest order $[\mathcal{O}(\alpha^2)]$ hadronic contribution to the anomalous magnetic moment of the muon which arises from the hadronic vacuum polarization. A general method is presented for computing entirely in Euclidean space, obviating the need for the usual dispersive treatment which relies on experimental data for e^+e^- annihilation to hadrons. While the result is not yet of comparable precision to those state-of-the-art calculations, systematic improvement of the quenched lattice computation to this level is straightforward and well within the reach of present computers. Including the effects of dynamical quarks is conceptually trivial; the computer resources required are not.

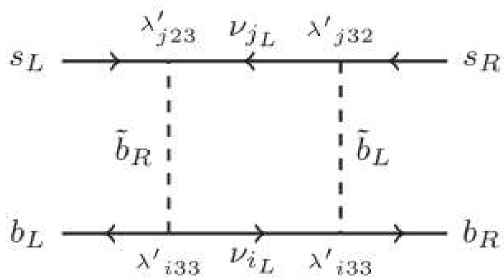
along with David Force Humongous Project 1st lg-scale simuls with DWQ: $K \to 2\pi$, ϵ' → TB + AS ~96-97

Attempt to address anomalies with RPV3

$$\mathcal{L}_{LQD} = \lambda'_{ijk}[\tilde{\nu}_{iL}\bar{d}_{kR}d_{jL} + \tilde{d}_{jL}\bar{d}_{kR}\nu_{iL} + \tilde{d}^*_{kR}\bar{\nu}^c_{iL}d_{jL} - \tilde{e}_{iL}\bar{d}_{kR}u_{jL} - \tilde{u}_{jL}\bar{d}_{kR}e_{iL} - \tilde{d}^*_{kR}\bar{e}^c_{iL}u_{jL}] + \text{H.c.} \tag{21}$$

$$\mathcal{L}_{LLE} = \frac{1}{2}\lambda_{ijk}[\tilde{\nu}_{iL}\bar{e}_{kR}e_{jL} + \tilde{e}_{jL}\bar{e}_{kR}\nu_{iL} + \tilde{e}^*_{kR}\bar{\nu}^c_{iL}e_{jL} - (i \leftrightarrow j)] + \text{H.c.} \tag{22}$$

$$\Delta a_\mu = \frac{m_\mu^2}{96\pi^2}\sum_{k=1}^{3}\left(\frac{2(|\lambda_{32k}|^2 + |\lambda_{3k2}|^2)}{m^2_{\tilde{\nu}_\tau}} - \frac{|\lambda_{3k2}|^2}{m^2_{\tilde{\tau}_L}} - \frac{|\lambda_{k23}|^2}{m^2_{\tilde{\tau}_R}} + \frac{3|\lambda'_{2k3}|^2}{m^2_{\tilde{b}_R}}\right).$$

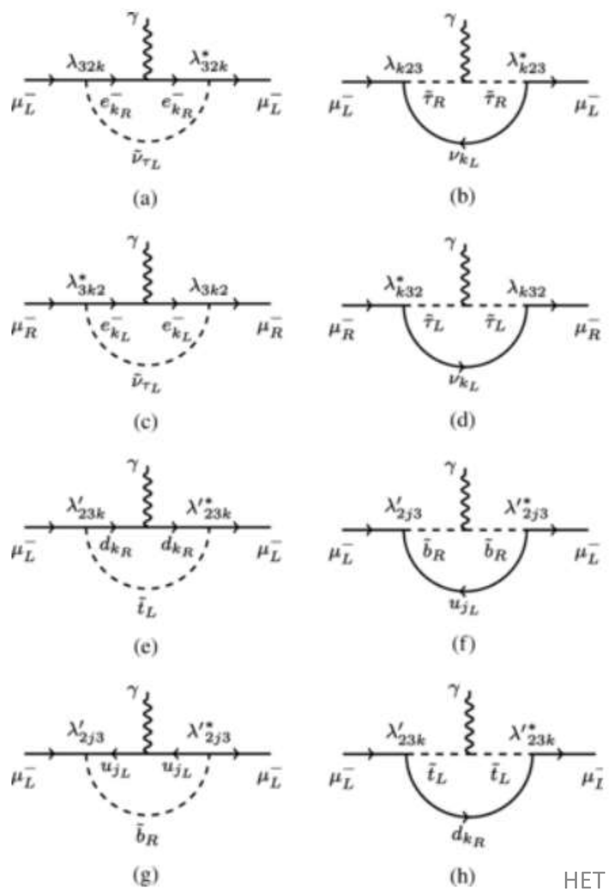


(c)

ADSS '20

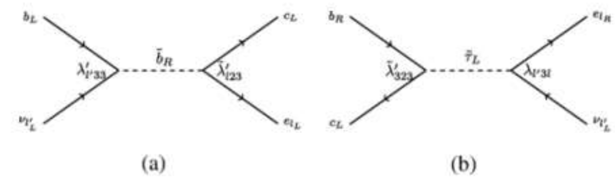
Explanation of anomalies in RPV3 SUSY

$(g-2)_\mu$ Kim, Kyae, Lee (PLB 2001)



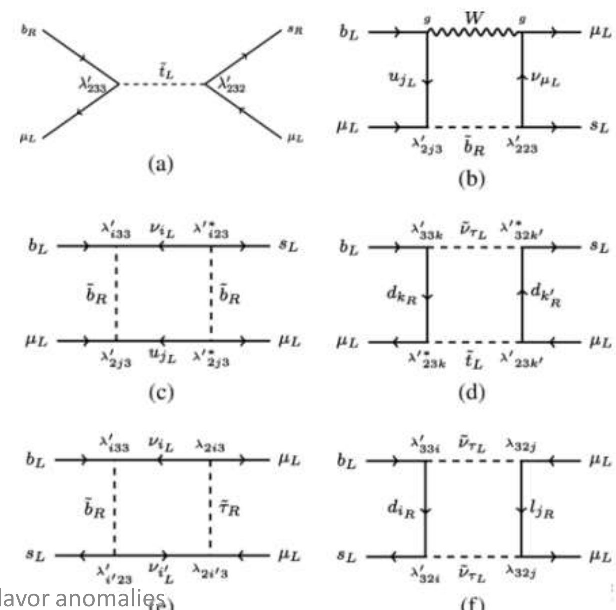
$R_{D^{(*)}}$ Deshpande, He (EPJC 2017); Altmannshofer, Dev, Soni (PRD 2017) etc.

RPV



RPV3

$R_{K^{(*)}}$ Das, Hati, Kumar, Mahajan (PRD 2017); Trifinopoulos (EPJC 2018) etc.



For $R_K + R_{K^*}$ BOTH Tree + LOOP ARE ESSENTIAL

HET Lunch 061121; minimal RPV3-flavor anomalies

36

Possible signals @ LHC & Beyond

Crossing-symmetry on RD(*); RK(*)=> c ADS'[17]; ADSS[20]

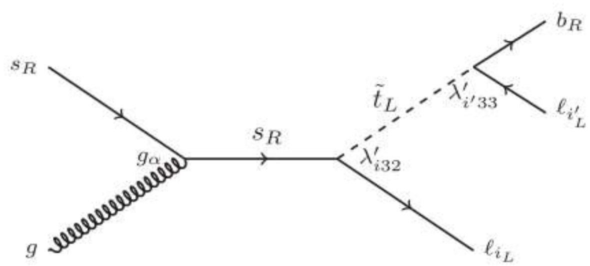


FIG. 22. Dominant contribution to the collider process $pp \to b\ell_i \ell_{i'}$ in RPV3 at tree level.

Specifically, the underlying parton-level process for $R_{K^{(*)}}$ is $b \to s\ell^+\ell^-$ (with $\ell = e, \mu$), and by crossing symmetry, the following processes must also occur in the pp collisions at the LHC: (i) $bs \to \ell^+\ell^-$, (ii) $gb \to s\ell^+\ell^-$ and (iii) $gs \to b\ell^+\ell^-$ (here g stands for gluon and q generically stands for both quarks and antiquarks). So if the $R_{K^{(*)}}$ anomaly were true, we must also have an anomaly in these channels, which might be observable depending on the signal-to-background ratio.

Best way, using XS, to enhance signal @ LHC

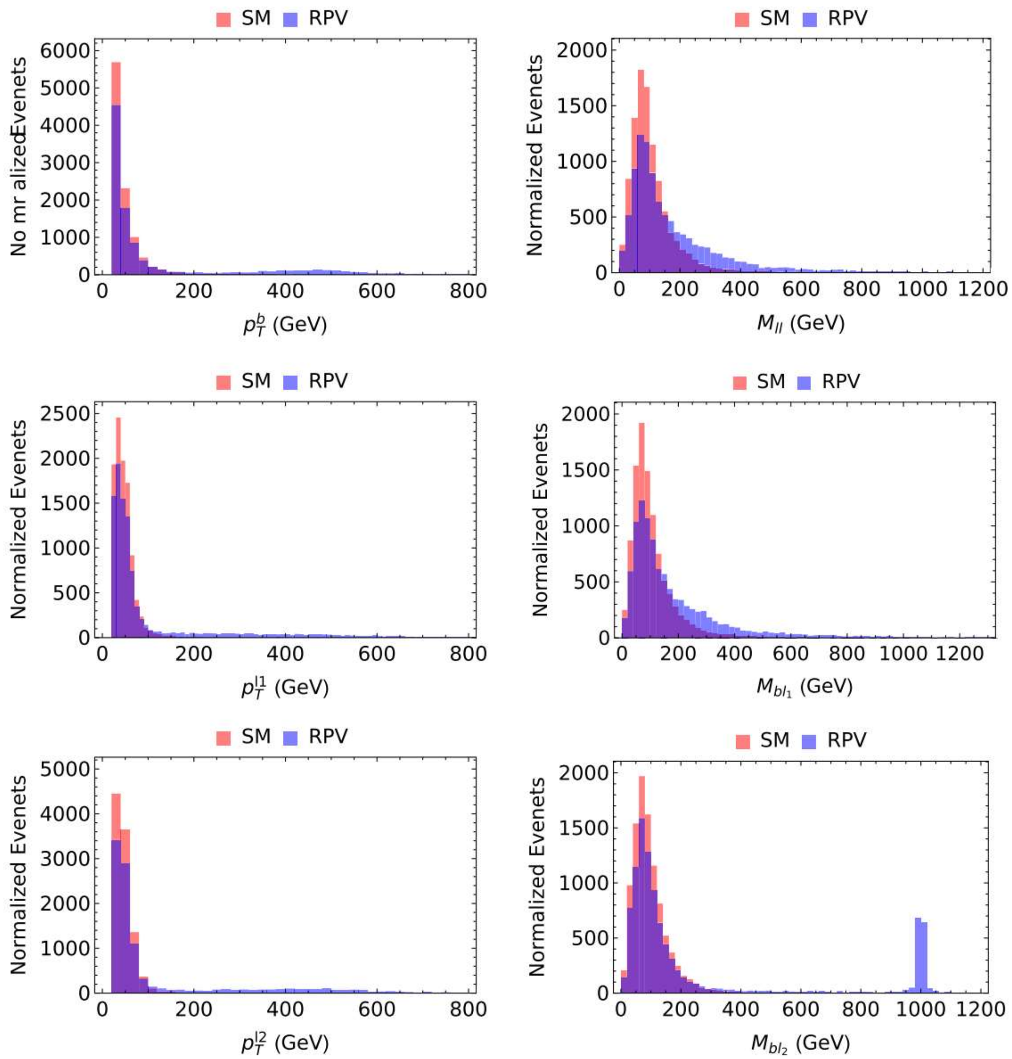


FIG. 23. Kinematic distributions for the $pp \to b\ell_1\ell_2$ signal in the RPV model (blue) and the corresponding SM background (red). The left panels show the transverse momentum distributions for the bottom quark and the two charged leptons, whereas the right panel shows the invariant mass distributions for the dilepton and the two bottom quark–lepton combinations. In the RPV3 model under consideration, the right combination of M_{bl} gives a peak at the squark mass, as shown in the last plot.

$R_{D^{(*)}}$ ANOMALY: A POSSIBLE HINT FOR ... PHYSICAL REVIEW D **96,** 095010 (2017)

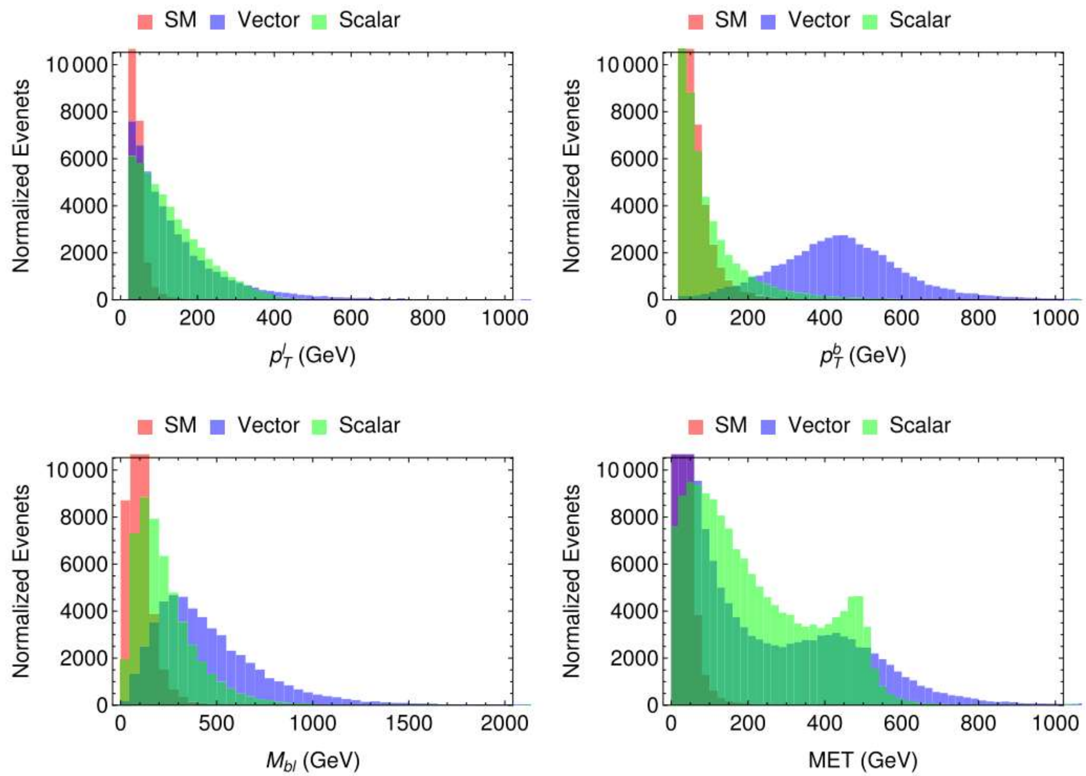
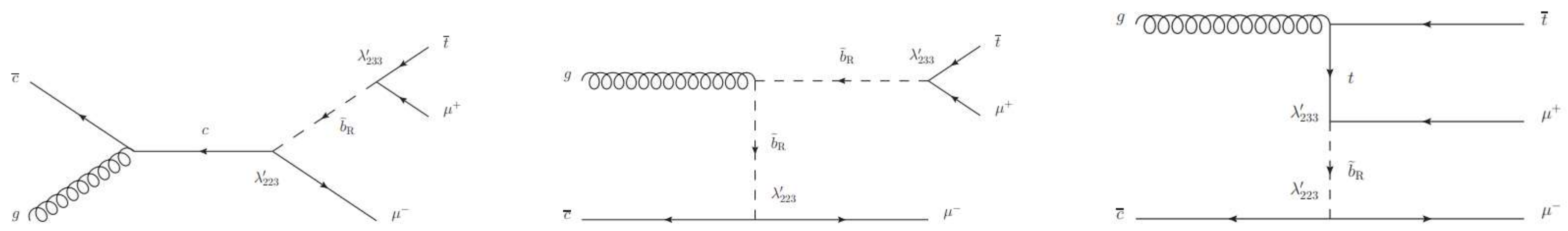


FIG. 1. Normalized kinematic distributions for the $pp \to b\tau\nu \to b\ell + \not{E}_T$ signal and background.

- Signal: Due To

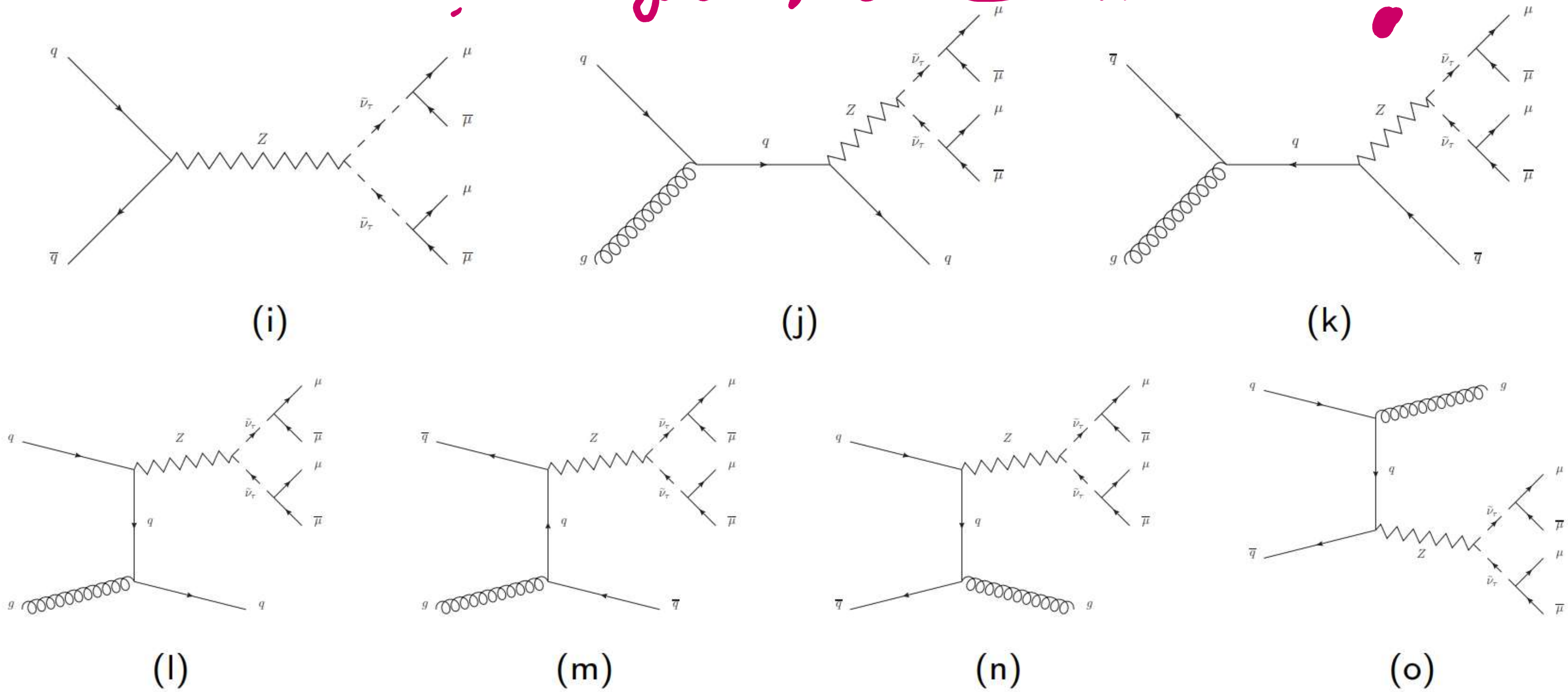


(a)   (b)   (c)

- Only λ'_{233}, λ'_{223} and $m_{\tilde{b}_R}$ contribute to the process $pp \to \bar{t}\mu^+\mu^-$. And what can be probed are actually these parameters, a projection of the scenario.
- Assume the luminosity $\mathscr{L} = 3000\ \mathrm{fb}^{-1}$. $\sqrt{s} = 14\ \mathrm{TeV}, 27\ \mathrm{TeV}, 100\ \mathrm{TeV}$.
- Signal significance $N = \frac{S}{\sqrt{S+B}}$.

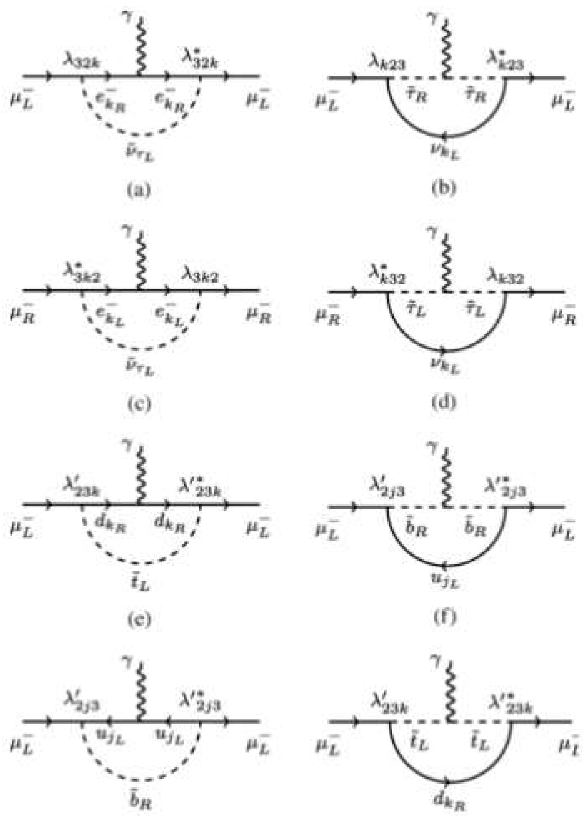
4-lepton signal

Due $\tilde{\nu}\tilde{\nu}$: Very Distinctive 4μ FS!



Explanation of anomalies in RPV3 SUSY FXC PHENO21

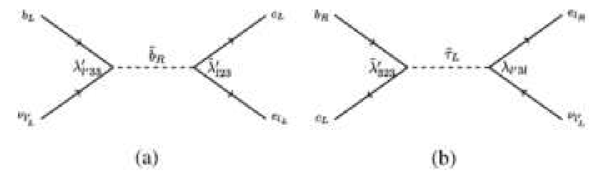
$(g-2)_\mu$ Kim, Kyae, Lee (PLB 2001)



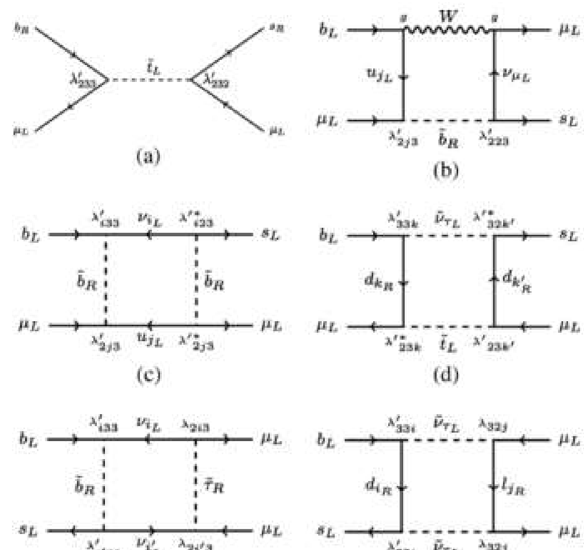
$R_{D^{(*)}}$ Deshpande, He (EPJC 2017); Altmannshofer, Dev, Soni (PRD 2017) etc.

RPV

RPV3



$R_{K^{(*)}}$ Das, Hati, Kumar, Mahajan (PRD 2017); Trifinopoulos (EPJC 2018) etc.



Parameters and benchmark scenario

4   4   8

- Parameters $(\lambda_{232}, \lambda'_{233}, \lambda'_{223}, \lambda'_{232}, m_{\tilde{b}_R}, m_{\tilde{b}_L}, m_{\tilde{\nu}_\tau}, m_{\tilde{\tau}_L})$ ⇒ 8
  - $\lambda_{232} = -\lambda_{322} \neq 0 \Leftarrow$ contribute to muon $g-2$, other λ_{3ij} couplings cannot be large at the same time due to the constraints of $\tau \to \mu\mu\mu$, $\tau \to e\mu\mu$ etc.
  - $\lambda'_{2ij} \neq 0 \Leftarrow$ include μ and free of $m_{\tilde{\nu}_\tau}$, otherwise, λ'_{3ij} combined with λ_{32k} or λ_{3k2}, well measured meson decays $(\bar{d}_i d_j) \to \mu\ell_k$ or $\tau \to \mu K$ and $\tau \to \mu\eta$ decays will prevent λ'_{3ij} to be large.
  - $m_{\tilde{\tau}_R}$ not involved with this choice of couplings.
  - $m_{\tilde{t}_L}$ can only influence $\mathrm{BR}(B_s \to \mu^+\mu^-)$ and the Wilson coefficients $(C'_9)^\mu$ and $(C'_{10})^\mu$ that describe the $R_{K^{(*)}}$ anomaly. But we can assume a relatively larger value to eliminate the influence and it is not considered as a parameter.

Explanation of anomalies in RPV3 SUSY

- The LQD and LLE part of the RPV SUSY Lagrangian which contains the λ' and λ couplings respectively and are relevant for the $R_{D^{(*)}}$, $R_{K^{(*)}}$ and $(g-2)_\mu$ anomalies.

$$\mathcal{L}_{LQD} = \lambda'_{ijk}(\widetilde{\nu}_{i\mathrm{L}}\overline{d}_{k\mathrm{R}}d_{j\mathrm{L}} + \widetilde{d}_{j\mathrm{L}}\overline{d}_{k\mathrm{R}}\nu_{i\mathrm{L}} + \widetilde{d}^*_{k\mathrm{R}}\overline{\nu}^c_{i\mathrm{L}}d_{j\mathrm{L}} - \widetilde{e}_{i\mathrm{L}}\overline{d}_{k\mathrm{R}}u_{j\mathrm{L}} - \widetilde{u}_{j\mathrm{L}}\overline{d}_{k\mathrm{R}}e_{i\mathrm{L}} - \widetilde{d}^*_{k\mathrm{R}}\overline{e}^c_{i\mathrm{L}}u_{j\mathrm{L}}) + \mathrm{H.c.} \quad (1)$$

$$\mathcal{L}_{LLE} = \frac{1}{2}\lambda_{ijk}\left[\widetilde{\nu}_{i\mathrm{L}}\overline{e}_{k\mathrm{R}}e_{j\mathrm{L}} + \widetilde{e}_{j\mathrm{L}}\overline{e}_{k\mathrm{R}}\nu_{i\mathrm{L}} + \widetilde{e}^*_{k\mathrm{R}}\overline{\nu}^c_{i\mathrm{L}}e_{j\mathrm{L}} - (i \leftrightarrow j)\right] + \mathrm{H.c.} \quad (2)$$

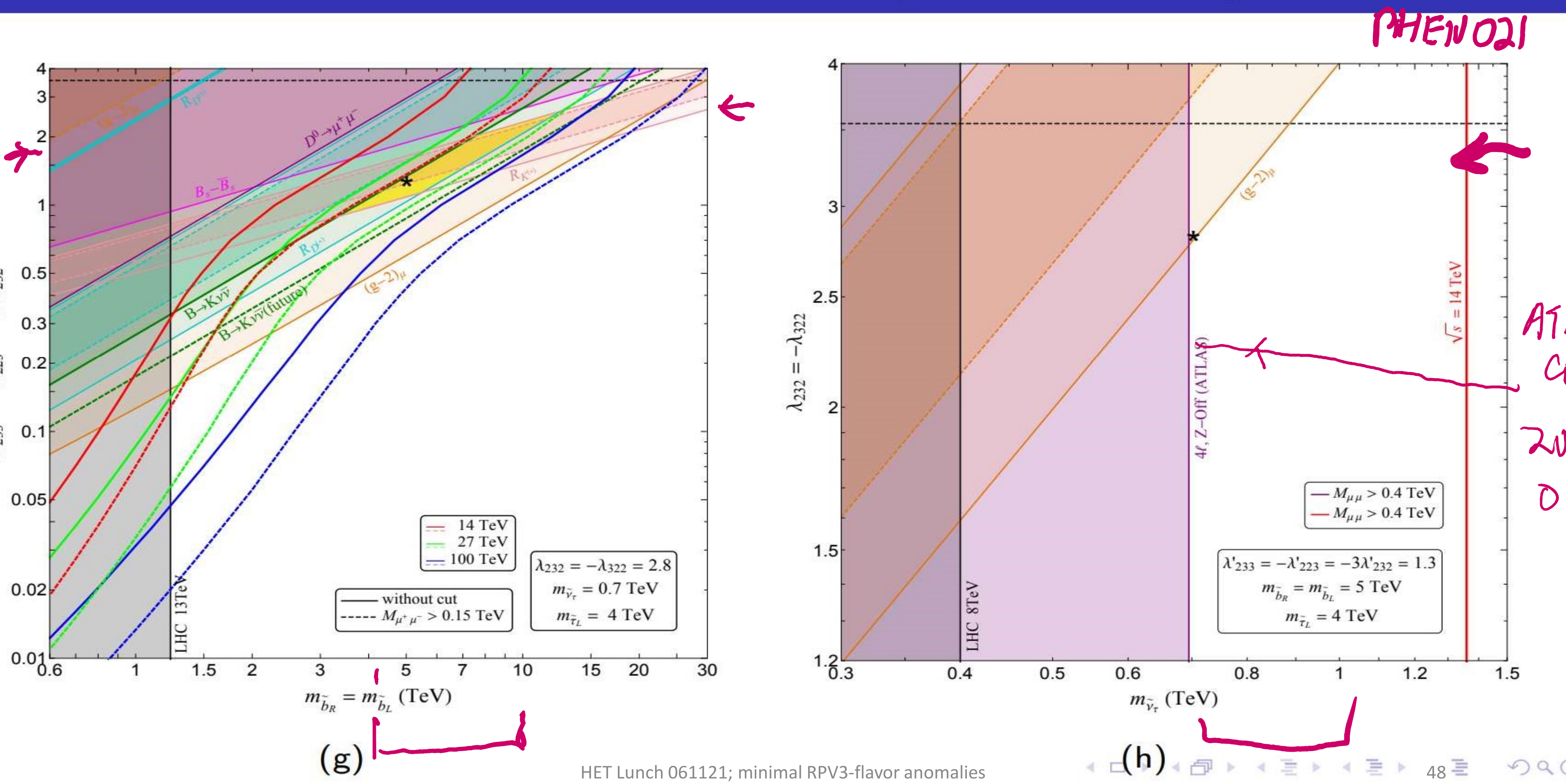
- Following previous discussions (Kim, Kyae, Lee (PLB 2001); Altmannshofer, Dev, Soni, Sui (PRD 2020)), in RPV3 framework, $(g-2)_\mu$ correction can be written as:

$$\Delta a_\mu = \frac{m_\mu^2}{96\pi^2}\sum_{k=1}^{3}\left(\frac{2(|\lambda_{32k}|^2 + |\lambda_{3k2}|^2)}{m^2_{\widetilde{\nu}_\tau}} - \frac{|\lambda_{3k2}|^2}{m^2_{\widetilde{\tau}_\mathrm{L}}} - \frac{|\lambda_{k23}|^2}{m^2_{\widetilde{\tau}_\mathrm{R}}} + \frac{3|\lambda'_{2k3}|^2}{m^2_{\widetilde{b}_\mathrm{R}}}\right) \quad (3)$$

Parameters and benchmark scenario

- Furthermore, assume $(\lambda_{232}, \lambda'_{233} = -\lambda'_{223} = -3\lambda'_{232}, m_{\tilde{b}_R} = m_{\tilde{b}_L}, m_{\tilde{\nu}_\tau}, m_{\tilde{\tau}_L} = 4\text{TeV})$ then we can plot the anomalies and constraints in the two-dimensional parameter space: $(\lambda'_{233}, m_{\tilde{b}_R})$ and $(\lambda_{232}, m_{\tilde{\nu}_\tau})$
  - $m_{\tilde{b}_R} = m_{\tilde{b}_L}$ for simplicity.
  - $m_{\tilde{\tau}_L}$ has opposite contribution for $(g-2)_\mu$. The influence is not important as long as $m_{\tilde{\tau}_L} \gtrsim O(1\text{TeV})$. Here we choose 4 TeV.
  - $\lambda'_{233} = -\lambda'_{223} \Leftarrow \lambda'_{233}$, λ'_{223} and $m_{\tilde{b}_R}$ are the only parameters that influence $R_{D^{(*)}}$ and $R_{K^{(*)}}$ in our scenario. Assuming $\lambda'_{233} = \epsilon_1 \lambda'_{223}$, we found that $\epsilon_1 \sim (-3, -1)$ will give an overlap region of $R_{D^{(*)}}$ and $R_{K^{(*)}}$. When $|\epsilon_1|$ decrease, the coupling λ'_{233} of the overlap region will also decrease, so we choose $\epsilon_1 = -1$ here.
  - $\lambda'_{233} = -\lambda'_{223} = -3\lambda'_{232} \Leftarrow \lambda'_{233}$, λ'_{223}, λ'_{232}, $m_{\tilde{b}_R}$ and $m_{\tilde{b}_L}$ are relevant for the constraints of $B \to K\nu\bar{\nu}$, $B_s - \overline{B}_s$ mixing and $D^0 \to \mu^+\mu^-$. Assuming $\lambda'_{233} \approx -\lambda'_{223} = \epsilon_2 \lambda'_{232}$, we found that $\epsilon_2 \sim (-6, -2)$, where $\epsilon_2 = -3$ gives the best fit.

nomalies and constraints in the parameter space



ADS

PHYSICAL REVIEW D **96,** 095010 (2017)

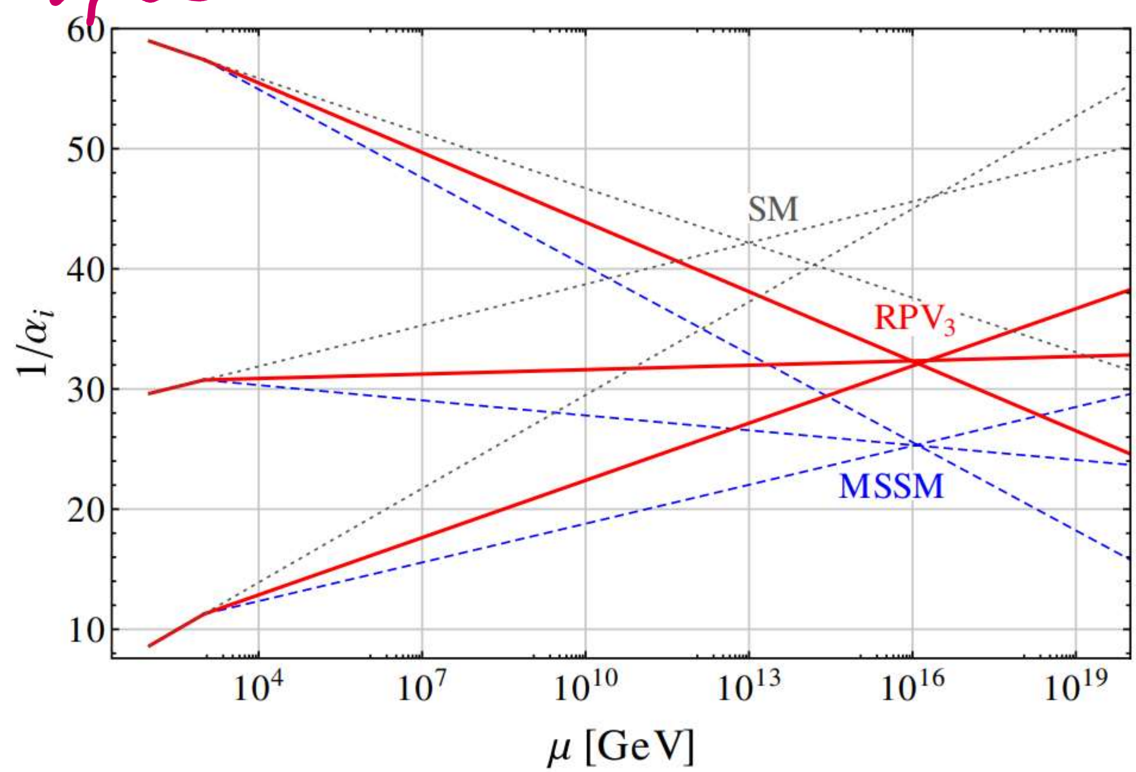


FIG. 2. RG evolution of the gauge couplings in the SM, MSSM and in our natural RPV SUSY scenario.

Simulations

- Consider the processes $pp \to \bar{t}\mu^+\mu^-$ ($pp \to t\mu^+\mu^-$ is similar but with a larger background cross-section)
- Background:

$\mathcal{L} \sim 3000$/fb – yr

Table 1: $pp \to \bar{t}\mu^+\mu^- X$ cross sections (fb)

X	14 TeV	$M_{\mu^+\mu^-} > 0.15$ TeV	27 TeV	$M_{\mu^+\mu^-} > 0.15$ TeV	100 TeV	$M_{\mu^+\mu^-} > 0.15$ TeV
j	0.381	3.35×10^{-3}	1.06	1.05×10^{-2}	5.83	7.11×10^{-2}
b	4.23×10^{-3}	3.64×10^{-5}	9.47×10^{-3}	9.85×10^{-5}	3.84×10^{-2}	3.92×10^{-4}
$W^+ \to jj$	3.76×10^{-3}	2.75×10^{-5}	1.49×10^{-2}	1.33×10^{-4}	0.133	1.58×10^{-3}
$W^+ \to e^+\nu_e$	6.38×10^{-4}	5.68×10^{-6}	2.53×10^{-3}	2.68×10^{-5}	2.24×10^{-2}	2.28×10^{-4}
$W^+ \to \mu^+\nu_\mu$	6.15×10^{-3}	2.67×10^{-3}	2.64×10^{-2}	1.12×10^{-2}	0.242	0.120
$W^+ \to \tau^+\nu_\tau$	6.34×10^{-4}	6.09×10^{-6}	2.52×10^{-3}	3.08×10^{-5}	2.25×10^{-2}	2.81×10^{-4}
Total	0.396	6.10×10^{-3}	1.12	2.20×10^{-2}	6.29	0.194

[a] $p_T^{j,b,l} < 20$ GeV, $E_T^{\text{miss}} < 20$ GeV
[b] $p_T^{t,\mu} > 20$ GeV, $|\eta^{t,\mu}| < 2.5$

~20/yr ~66/yr ~194/yr

PHYSICAL REVIEW D **71,** 016002 (2005)

Flavor structure of warped extra dimension models

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(Received 14 September 2004; published 6 January 2005)

We recently showed that warped extra-dimensional models with bulk custodial symmetry and few TeV Kaluza-Klein (KK) masses lead to striking signals at B factories. In this paper, using a spurion analysis, we systematically study the flavor structure of models that belong to the above class. In particular we find that the profiles of the zero modes, which are similar in all these models, essentially control the underlying flavor structure. This implies that our results are robust and model independent in this class of models. We discuss in detail the origin of the signals in B physics. We also briefly study other new physics signatures that arise in rare K decays ($K \to \pi\nu\nu$), in rare top decays [$t \to c\gamma(Z, \text{gluon})$], and the possibility of CP asymmetries in D^0 decays to CP eigenstates such as $K_S\pi^0$ and others. Finally we demonstrate that with light KK masses, ~3 TeV the above class of models with anarchic 5D Yukawas has a "CP problem" since contributions to the neutron electric dipole moment are roughly 20 times larger than the current experimental bound. Using AdS/CFT correspondence, these extra-dimensional models are dual to a purely 4D strongly coupled conformal Higgs sector thus enhancing their appeal.

X: ΔK decay, K-K̄ ⇒ ~10TeV

DOI: 10.1103/PhysRevD.71.016002 PACS numbers: 11.25.Wx, 11.30.Hv

An xtremely elegant geometric understanding of fermion flavor thru localization in the xtra Dim (warped): hierarchy of fermion mass & in fact CKM, in RS-GIM

Several APS

HD + AS + et al

HD + et al'

Michael Geller + AS: Attempts to lower the scale significantly (WinP 2016)

{ (Technion / BNL) 9 5 of Gad Eilam
Maryland ⇒ Tel. Aviv / Weizmann

FACT OR FARCE? [Charge Current only]

11 exptal results [not all independent]; ALL central values above theory

~ O(6) are independent

4

experiment	tag method	τ decay mode	R_D	R_D^*	R_ψ
Babar (2012)[1]	hadronic	$l\,\nu\nu$	$0.440 \pm 0.058 \pm 0.042$	$0.332 \pm 0.024 \pm 0.0.018$	
Belle (2015)[2]	hadronic	$l\,\nu\nu$	$0.375 \pm 0.064 \pm 0.026$	$0.293 \pm 0.038 \pm 0.015$	
LHCb (2015)[5]	hadronic	$l\,\nu\nu$	-	$0.336 \pm 0.027 \pm 0.030$	
Belle (2016)[2]	semileptonic	$l\,\nu\nu$	-	$0.302 \pm 0.030 \pm 0.011$	
Belle (2017)[4]	hadronic	$\pi(\rho)\nu$	-	$0.270 \pm 0.035 \pm 0.027$	
LHCb (2017)[6]	hadronic	$3\pi\nu$	-	$0.291 \pm 0.019 \pm 0.029$	
Belle (2019)[7]	semileptonic	$l\,\nu\nu$	$0.307 \pm 0.037 \pm 0.016$	$0.283 \pm 0.018 \pm 0.014$	
LHCb(2016) [9]	hadronic	$l\,\nu\nu$	-	-	$0.71 \pm 0.17 \pm 0.18$
SM	-	-	0.299 ± 0.011	0.260 ± 0.008	0.26 ± 0.02

TABLE I: All experimental results announced to date on R_D, R_{D^*} and on R_ψ versus the predictions of those for the SM

ALTMANNSHOfer, DeV+AS, Yicong Sui, see 2002.12910

Historical ~~Aside~~ CAUTION

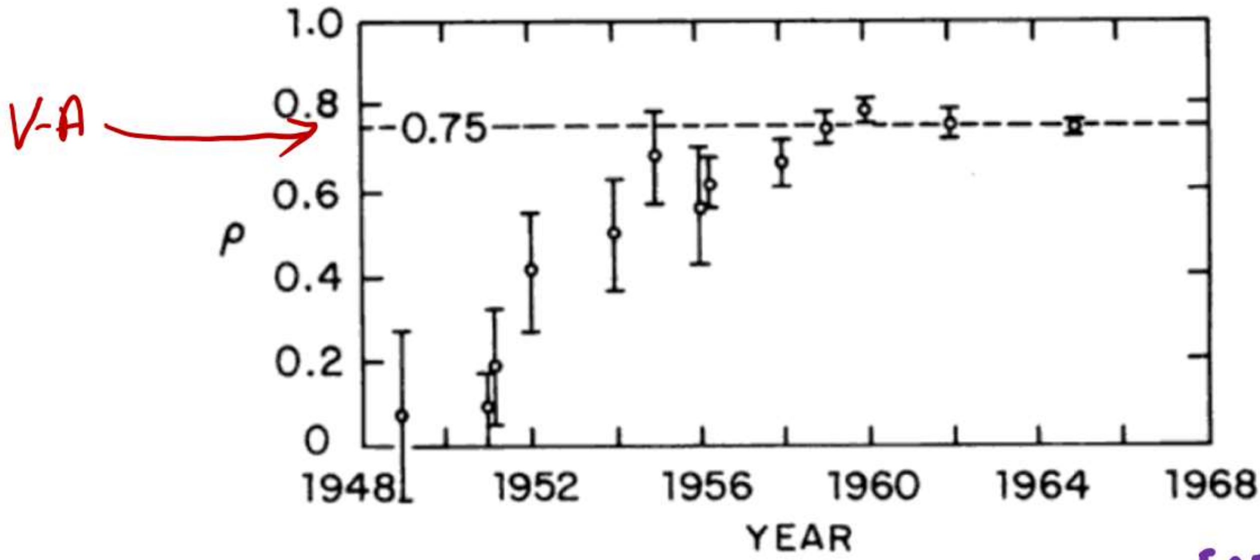

Figure 16. The change of the Michel parameter ρ from year to year.

From T. D. Lee's text

PATHOLOGICAL SCIENCE

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NY 13244-1130, USA
E-mail: stone@phy.syr.edu

I discuss examples of what Dr. Irving Langmuir, a Nobel prize winner in Chemistry, called "the science of things that aren't so." Some of his examples are reviewed and others from High Energy Physics are added. It is hoped that discussing these incidents will help us develop an understanding of some potential pitfalls.

Few Important implications of RPV3 4 LFV

TABLE V. RPV3 contributions to the branching ratios of the flavor-violating decay modes of τ and of B mesons in the three benchmark cases considered here. Also shown are the current experimental bounds at 90% C.L. for each channel. There is no existing bound on $b \to s\tau\tau$, so that entry is labeled as N/A. For the last two decay modes, namely, the inclusive $B \to X_s\mu^+\mu^-$ and exclusive $B_s \to \mu^+\mu^-$, we show the central values of the experimental measurements. The values for Case 1 are calculated with the parameter set in Eq. (53) along with $-\epsilon = 0.02$ and $m_{\tilde{b}_R} = 2.0$ TeV from the overlap region in Fig. 6. For case 2, the parameters are set in Eq. (57), along with $\lambda' = 0.8$ and $m_{\tilde{b}_R} = 2.0$ TeV from the overlap region in Fig. 7. For case 3, the parameters are set in Eq. (59) with $\lambda' = 0.2$ and $m_{\tilde{b}_R} = 3.0$ TeV from the overlap region in Fig. 8.

Flavor-violating decay mode	λ, λ' dependence	RPV3 Prediction Case 1	Case 2	Case 3	Current experimental bound/measurement
$\tau \to \mu\phi$	$\lambda'_{332}\lambda'_{232}$, $\lambda_{323}\lambda'_{322}$	1.9×10^{-15}	3.8×10^{-10}	2.6×10^{-12}	$<8.4 \times 10^{-8}$ [202]
$\tau \to \mu KK$	$\lambda'_{332}\lambda'_{232}$, $\lambda_{323}\lambda'_{322}$	1.2×10^{-17}	2.4×10^{-12}	2.9×10^{-13}	$<4.4 \times 10^{-8}$ [203]
$\tau \to \mu K_s^0$	$\lambda'_{332}\lambda'_{231}$, $\lambda'_{312}\lambda_{323}$	4.5×10^{-19}	8.7×10^{-12}	3.1×10^{-13}	$<2.3 \times 10^{-8}$ [204]
$\tau \to \mu\gamma$	$\lambda'_{333}\lambda'_{233}$, $\lambda_{133}\lambda_{123}$	1.3×10^{-10}	1.3×10^{-8}	2.4×10^{-10}	$<4.4 \times 10^{-8}$ [205]
$\tau \to \mu\mu\mu$	$\lambda_{323}\lambda_{322}$	1.7×10^{-11}	1.2×10^{-9}	1.2×10^{-11}	$<2.1 \times 10^{-8}$ [206]
$B_{(s)} \to K^{(*)}(\phi)\mu\tau$	$\lambda'_{333}\lambda'_{232}$, $\lambda'_{233}\lambda'_{332}$, $\lambda'_{332}\lambda_{323}$	4.1×10^{-9}	1.2×10^{-7}	2.2×10^{-10}	$<2.8 \times 10^{-5}$ [207]
$B_s \to \tau\mu$	$\lambda'_{333}\lambda'_{232}$, $\lambda'_{233}\lambda'_{332}$, $\lambda'_{332}\lambda_{323}$	4.4×10^{-10}	1.3×10^{-8}	2.3×10^{-11}	$<3.4 \times 10^{-5}$ [208]
$b \to s\tau\tau$	$\lambda'_{333}\lambda'_{332}$	3.4×10^{-7}	2.8×10^{-8}	1.3×10^{-13}	N/A
$B \to K^{(*)}\tau\tau$	$\lambda'_{333}\lambda'_{332}$	3.7×10^{-6}	4.2×10^{-8}	9.6×10^{-12}	$<2.2 \times 10^{-3}$ [209]
$B_s \to \tau\tau$	$\lambda'_{333}\lambda'_{332}$	3.7×10^{-8}	3.0×10^{-9}	1.4×10^{-14}	$<6.8 \times 10^{-3}$ [210]
$b \to s\mu\mu$	$\lambda'_{233}\lambda'_{232}$, $\lambda'_{332}\lambda_{232}$	5.9×10^{-9}	3.2×10^{-8}	8.8×10^{-9}	4.4×10^{-6} [211]
$B_s \to \mu\mu$	$\lambda'_{233}\lambda'_{232}$, $\lambda'_{332}\lambda_{232}$	4.1×10^{-11}	6.5×10^{-11}	1.8×10^{-11}	3.0×10^{-9} [212]

4
BELLE-II
LHCb

Click to add text

IN CLOSING

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.**

⇒ No Lose Theorem ~ O(1) TeV new physics.

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

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**
- 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

Conclusion

- RK is theoretically very clean. Also, LHCb has made special efforts to control systematic errors. Their recent result based on the full data set of 9/fb seems to increase the chances for a new physics interpretation and the previous discrepancy with the SM of around 2.5 sigma has now increased to ~ 3.1 sigma.
- Despite all that, this **can NOT be regarded a compelling evidence of new physics.**
- First of all a genuine signal of LFV requires also deviations from the SM in B => K*, Existg R_{K^*} ~ 3.3σ LHCb
- Bs => phi as well as in B-baryons. Even more desirable would be a confirmation of this LFV signal from Belle=II.
- Moreover, O(3.1 sigma) deviations often disappear. Indeed, recall that in fact an LHCb result (2012) in charm CP of roughly the same significance as RK did not survive ~ 2years

CHARM PHYSICS IN THE LHCB EXPERIMENT, FIRST EVIDENCE FOR CP VIOLATION IN CHARM DECAYS*

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(*Received April 17, 2012*)

A search for the time integrated CP violation in the $D^0 \to h^- h^+$ ($h = K, \pi$) decays is presented using 0.62 fb^{-1} of data collected by the LHCb experiment in 2011. The flavour of the charm meson is determined by the charge of the slow pion in the $D^{*+} \to D^0 \pi^+$ and the $D^{*-} \to \bar{D}^0 \pi^-$ decays chain. The difference in CP asymmetry between the $D^0 \to K^- K^+$ and the $D^0 \to \pi^- \pi^+$, $\Delta A_{\rm CP} \equiv A_{\rm CP}(K^- K^+) - A_{\rm CP}(\pi^- \pi^+)$, is measured to be $[-0.82 \pm 0.21({\rm stat}) \pm 0.11({\rm syst})]\%$. This differs from the hypothesis of CP conservation by 3.5 standard deviations. An additional search for the time integrated CP violation in the Cabibbo suppressed decay $D^+ \to K^- K^+ \pi^+$ is also presented. Here no evidence for CP asymmetry is found using a model independent method. The data used here was collected by the LHCb experiment in 2010 and corresponds to an integrated luminosity of 35 pb^{-1}. The normalized Dalitz plot distributions for the D^+ and the D^- are compared using two different binning schemes that are sensitive to different

In 2012 3.5 σ signal

not used

$\Delta A_{CP} \gtrsim 0$

PHYSICAL REVIEW LETTERS **122,** 211803 (2019)

Editors' Suggestion | Featured in Physics

EW Moriond 2019

Observation of *CP* Violation in Charm Decays

R. Aaij *et al.**
(LHCb Collaboration)

(Received 21 March 2019; revised manuscript received 2 May 2019; published 29 May 2019)

A search for charge-parity (*CP*) violation in $D^0 \to K^- K^+$ and $D^0 \to \pi^- \pi^+$ decays is reported, using pp collision data corresponding to an integrated luminosity of 5.9 fb^{-1} collected at a center-of-mass energy of 13 TeV with the LHCb detector. The flavor of the charm meson is inferred from the charge of the pion in $D^*(2010)^+ \to D^0 \pi^+$ decays or from the charge of the muon in $\bar{B} \to D^0 \mu^- \bar{\nu}_\mu X$ decays. The difference between the *CP* asymmetries in $D^0 \to K^- K^+$ and $D^0 \to \pi^- \pi^+$ decays is measured to be $\Delta A_{CP} = [-18.2 \pm 3.2(\text{stat}) \pm 0.9(\text{syst})] \times 10^{-4}$ for π-tagged and $\Delta A_{CP} = [-9 \pm 8(\text{stat}) \pm 5(\text{syst})] \times 10^{-4}$ for μ-tagged D^0 mesons. Combining these with previous LHCb results leads to $\Delta A_{CP} = (-15.4 \pm 2.9) \times 10^{-4}$, where the uncertainty includes both statistical and systematic contributions. The measured value differs from zero by more than 5 standard deviations. This is the first observation of *CP* violation in the decay of charm hadrons.

~ × 10 more Lumi

~2.5 × 10⁻² of 2012 !!

c Stefan Schacht + AS soon to appear

If LFV survives further scrutiny theoretical case for RPV3-SUSY is rather compelling

- O(36) param in RPV3-SUSY, O(20) in SM….What does RPV3 buy for you?
- Radiative stability of the Higgs
- Gauge coupling unification
- A very important accidental symmetry of the SM is “explained”
- Many non-trivial predictions
- RK AND RK*, both are <1 as in SM
- D* polarization remains the same as in SM
- For Dl3 or Kl3 similar R-ratios should stay unity as in SM for a very long time to come ; c BEPS-III arxive:2106.02292

gauge
standard
≈ SM
⇓
RPV

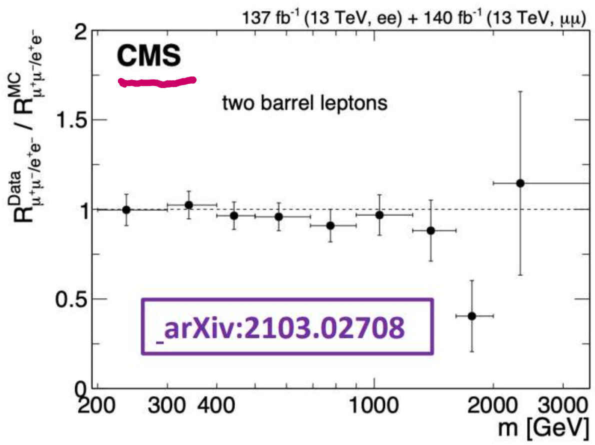
xtras

Exploring lepton flavor anomalies

Lepton universality is tested at TeV scale by comparing the ee & μμ mass spectra!

$$R_{\mu^+\mu^-/e^+e^-} = \frac{d\sigma(q\bar{q} \to \mu^+\mu^-)/dm_{\ell\ell}}{d\sigma(q\bar{q} \to e^+e^-)/dm_{\ell\ell}}$$

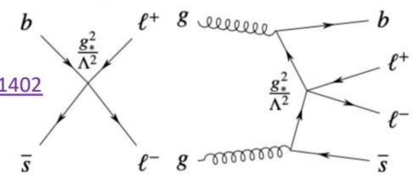
LFU ➔ ratio is unity

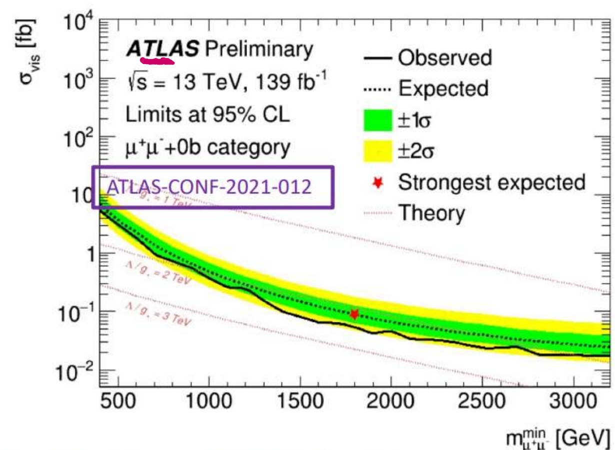


Good agreement with this expectation observed up to 1.5 TeV.

Contact interaction b/w (*b*, *s*) quarks & 2 leptons, inspired by *B*-meson anomalies.

arXiv:1805.11402





CI with Λ/g∗ < 2.0 (2.4) TeV are excluded for e (μ), far from the value favored by *B*-meson decay anomalies (30 TeV).

31

Recall
XS
ADSS ('20

Then there is an SU4 symmetry for each flavor.   Use 4x4bar=15+1 for the u ubar vector mesons to get a SU4 15 rep and one singlet rep.
The 15 and the 1 are not degenerate; i.e. they even have different decay channels and widths.

This is completely parallel to isospin, where q qbar pairs combine to a triplet rho and a singlet omega that are not degenerate.

Since the d dbar has an independent taste symmetry, there will be another 15 and another singlet.

The two singets can combine in the usual way to a flavor symmetric omega and flavor antisymmetric neutral rho.
The serious problems arise with the 15's. The taste symmetries for the up and down quarks are independent, and thus
they are 15's in different groups. They cannot combine.
So our vector spectrum has 2 15 reps and 2 singlet reps, all non-degenerate and with different decay channels.

The only way I can imagine out of this is for the photon not to couple to any of the 15's. But they can always be produced
in pairs, and there are pairs of taste 15 pions out there as well. This is just too much of a mutilation of the spectrum to be believed.

Mike