Flavor Physics and Flavor Anomalies Beyond the Standard Model

Matthias Neubert — Mainz Institute for Theoretical Physics (MITP) and PRISMA Cluster of Excellence
Johannes Gutenberg University, Mainz

Quark Confinement and the Hadron Spectrum XII
Thessaloniki, Greece, 28 August - 4 September 2016
Based on work with M. Bauer, PRL 116 (2016) 141802 [arXiv:1511:01900]
Is Nature natural?

Hierarchie problem suggested that a “natural” theory of electroweak symmetry breaking should contain new colored particle near the weak scale

Existence of dark matter suggested that there should be new weakly interacting particles near the weak scale (WIMP miracle)

Where are they?
Overview

1. Hints for New Physics
2. Flavor Anomalies
3. Diphoton Resonance
   (arXiv:1512:06828 with Martin Bauer)
4. Outlook

Many related talks during this conference:

- Thomas Blake (plenary TUE)
- M. Chrzaszcz, S. Jäger, L. Hofer, Z. Liu (parallel TUE)
- Round table presentations & discussion on TUE
  (M. Gersabeck, R. Zwicky, Z. Liu, T. Blake, L. Hofer, S. Jäger)
Hints for New Physics

Dark matter, flavor anomalies and diboson resonances
On the verge of another discovery?

While we have not observed any of the expected faces of new physics, there exist several tantalizing hints of effects which cannot be explained by the Standard Model

- Dark matter
- Neutrino masses and mixings
- Anomalous magnetic moment of the muon
- Various anomalies in the flavor sector
- (Disappearing) hints of new heavy resonances
<table>
<thead>
<tr>
<th>Anomaly</th>
<th>(\sim 3.5\sigma)</th>
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<tbody>
<tr>
<td>((g - 2)_\mu) anomaly</td>
<td></td>
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<tr>
<td>non-standard like-sign dimuon charge asymmetry</td>
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<tr>
<td>enhanced (B \rightarrow D^{(*)}\tau\nu) rates</td>
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<tr>
<td>suppressed branching ratio of (B_s \rightarrow \phi \mu^+ \mu^-)</td>
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<td>tension between inclusive and exclusive determination of (</td>
<td>V_{ub}</td>
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<td>tension between inclusive and exclusive determination of (</td>
<td>V_{cb}</td>
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<tr>
<td>anomaly in (B \rightarrow K^* \mu^+ \mu^-) angular distributions</td>
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<tr>
<td>SM prediction for (\epsilon'/\epsilon) below experimental result</td>
<td></td>
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<tr>
<td>lepton flavor non-universality in (B \rightarrow K \mu^+ \mu^-) vs. (B \rightarrow K e^+ e^-)</td>
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<td>non-zero (h \rightarrow \tau\mu)</td>
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</table>
Flavor anomalies: Enhanced $B \to D^{(*)}\tau\nu$ rates

Semileptonic decays with tau leptons are $3.5\sigma$ higher than SM prediction!
Flavor anomalies: Suppressed $B_s \rightarrow \Phi \mu^+ \mu^-$ branching ratio

Branching ratio in region $1 \text{GeV}^2 < q^2 < 6 \text{GeV}^2$ is $3.5\sigma$ lower than SM prediction!
Flavor anomalies: $B \to K^* \mu^+ \mu^-$ angular distributions

2.8σ deviation in $q^2$ bin between [4, 6] GeV$^2$ (3.0σ in bin [6, 8] GeV$^2$)!

Altmannshofer, Straub (arXiv:1503:06199)
Flavor anomalies: $B \rightarrow K \mu^+\mu^-$ vs. $B \rightarrow K e^+e^-$

![Graph showing $R_K$ vs. $q^2$](image)

$LHCB$ 1406.6482

- **$R_K$**

$$R_K = \frac{\Gamma(B \rightarrow \bar{K}\mu^+\mu^-)}{\Gamma(B \rightarrow Ke^+e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

2.6σ hint for a violation of lepton flavor universality!
The flavor anomalies in rare $B$-meson decays are:

- in many cases statistically significant
- seen by more than one experiment
- provide a coherent picture when interpreted in terms of new physics contributions to one or two operators in the effective weak Hamiltonian

\[ \mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V^*_{ts} \sum C_i O_i \]

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Best fit</th>
<th>$1\sigma$</th>
<th>$3\sigma$</th>
<th>Pull$_{SM}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C^\text{NP}_7$</td>
<td>$-0.02$</td>
<td>$[-0.04, -0.00]$</td>
<td>$[-0.07, 0.04]$</td>
<td>$1.1$</td>
</tr>
<tr>
<td>$C^\text{NP}_9$</td>
<td>$-1.11$</td>
<td>$[-1.32, -0.89]$</td>
<td>$[-1.71, -0.40]$</td>
<td>$4.5$</td>
</tr>
<tr>
<td>$C^\text{NP}_{10}$</td>
<td>$0.58$</td>
<td>$[0.34, 0.84]$</td>
<td>$[-0.11, 1.41]$</td>
<td>$2.5$</td>
</tr>
<tr>
<td>$C^\text{NP}_{7'}$</td>
<td>$0.02$</td>
<td>$[-0.01, 0.04]$</td>
<td>$[-0.05, 0.09]$</td>
<td>$0.7$</td>
</tr>
<tr>
<td>$C^\text{NP}_{9'}$</td>
<td>$0.49$</td>
<td>$[0.21, 0.77]$</td>
<td>$[-0.33, 1.35]$</td>
<td>$1.8$</td>
</tr>
<tr>
<td>$C^\text{NP}_{10'}$</td>
<td>$-0.27$</td>
<td>$[-0.46, -0.08]$</td>
<td>$[-0.84, 0.28]$</td>
<td>$1.4$</td>
</tr>
<tr>
<td>$C^\text{NP}<em>9 = C^\text{NP}</em>{10}$</td>
<td>$-0.21$</td>
<td>$[-0.40, 0.00]$</td>
<td>$[-0.74, 0.55]$</td>
<td>$1.0$</td>
</tr>
<tr>
<td>$C^\text{NP}<em>9 = -C^\text{NP}</em>{10}$</td>
<td>$-0.69$</td>
<td>$[-0.88, -0.51]$</td>
<td>$[-1.27, -0.18]$</td>
<td>$4.1$</td>
</tr>
<tr>
<td>$C^\text{NP}<em>9 = -C^\text{NP}</em>{9'}$</td>
<td>$-1.09$</td>
<td>$[-1.28, -0.88]$</td>
<td>$[-1.62, -0.42]$</td>
<td>$4.8$</td>
</tr>
</tbody>
</table>

Descotes-Genon, Hofer, Matias, Virto (arXiv:1510:04239)

\[
\mathcal{O}_9 = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell) \\
\mathcal{O}_{9'} = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell) \\
\mathcal{O}_{10} = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell) \\
\mathcal{O}_{10'} = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)
\]
Flavor anomalies — reason for excitement

The flavor anomalies in rare $B$-meson decays are:

- in many cases statistically significant
- seen by more than one experiment
- provide a coherent picture when interpreted in terms of new physics contributions to one or two operators in the effective weak Hamiltonian

\[
\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_i C_i O_i
\]

Descotes-Genon, Hofer, Matias, Virto (arXiv:1510:04239)

\[
\begin{align*}
O_9 &= \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell) \\
O_{10} &= \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell) \\
O_{9'} &= \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell) \\
O_{10'} &= \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)
\end{align*}
\]
A new diboson resonance near 2 TeV in Run-I?
A new diphoton resonance near 750 GeV in Run-II?

**ATLAS Preliminary**

- Data
- Background-only fit

\[ \sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1} \]

**Local p-value**

\[ \begin{array}{cccc}
\text{Data - fitted background} & \text{1} & -10 & \text{2} & -10 & \text{3} & -10 & \text{4} & -10 \end{array} \]

**Excess at 750 GeV**

<table>
<thead>
<tr>
<th></th>
<th>Local</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>NWA</td>
<td>3.6(\sigma)</td>
<td>2.0(\sigma)</td>
</tr>
<tr>
<td>(\Gamma \approx 45 \text{ GeV})</td>
<td>3.9(\sigma)</td>
<td>2.3(\sigma)</td>
</tr>
</tbody>
</table>

**CMS Preliminary**

\[ \sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1} \]

- Expected limit
- \(\pm 1\sigma\)
- \(\pm 2\sigma\)
- Observed limit
- \(P_{\text{LS}} \rightarrow \gamma\gamma\) (LO)

\[ \begin{array}{cccc}
\text{90\% CL limit } d\sigma / dm\gamma & 1 & -10 & 2 & -10 & 3 & -10 & 4 & -10 \end{array} \]

**ATLAS Preliminary**

\[ \sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1} \]

**Local p-value**

**Excess at 750 GeV**

\[ \begin{array}{cccc}
\text{Data - fitted background} & \text{1} & -10 & \text{2} & -10 & \text{3} & -10 & \text{4} & -10 \end{array} \]

**CMS Preliminary**

\[ \sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1} \]

- \(P_{\text{LS}} \rightarrow \gamma\gamma\)
- \(\tilde{\kappa} = 0.01\)
- \(1\sigma\)
- \(2\sigma\)

**Largest excess:** \(M_{\gamma\gamma} = 750\text{GeV}\), local significance 3\(\sigma\)

**Global significance:** < 1.7\(\sigma\)
One Leptoquark to Rule them All

Based on work with M. Bauer, PRL 116 (2016) 141802 [arXiv:1511:01900]
A minimal leptoquark model

We add a single leptoquark $\phi \sim (3, 1)_{-1/3}$ to the Standard Model, with couplings:

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

After rotation to the mass basis, we have:

$$
\mathcal{L}_\phi \equiv \bar{u}_L^c \lambda^{L}_{ue} e_L \phi^* - \bar{d}_L^c \lambda^{L}_{dv} \nu_L \phi^* + \bar{u}_R^c \lambda^{R}_{ue} e_R \phi^* + \text{h.c.}
$$

with:

$$
V^T_{CKM} \lambda^L_{ue} = \lambda^L_{dv} U_e
$$

**UV completion**: $\phi$ could be the right-handed sbottom of a split SUSY model, with left-handed couplings derived from the R-parity violating terms in the superpotential (expect $|\lambda^R| \ll |\lambda^L|$)

At tree level, this gives rise to e.g.:

Will need:

$$
\lambda^L_{ue} = V^*_{CKM} \lambda^L_{dv} U_e \approx \begin{pmatrix}
\ldots & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot
\end{pmatrix}
$$

$$
10^{-1} - 10^{-3}
$$

$$
\lambda^R_{ue} \sim \begin{pmatrix}
\ldots & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot
\end{pmatrix}
$$
Explanation of the enhanced $B \rightarrow D^{(*)}\tau\nu$ rates

Semileptonic decays with tau leptons are $3.5\sigma$ higher than SM prediction!

Model-independent operator analysis:

$$\mathcal{H} = \frac{4G_F}{\sqrt{2}} V_{cb} \mathcal{O}_{VL} + \frac{1}{\Lambda^2} \sum_i C_i^{(\nu,\nu)} \mathcal{O}_i^{(\nu,\nu)}$$

Freytsis, Ligeti, Rudermann (arXiv:1506:08896)
Explanation of the enhanced $B\rightarrow D^{(*)}\tau\nu$ rates

Leptoquark contribution:

$$\begin{align*}
\frac{\lambda_{ct}^L \lambda_{uL}^L}{M_{\phi}^2} & \approx \frac{0.35}{\text{TeV}^2} = C_{SR}''
\frac{\lambda_{ct}^R \lambda_{uL}^L}{M_{\phi}^2} & \approx -\frac{0.03}{\text{TeV}^2} = C_{SL}''
\end{align*}$$

$q^2$ distribution:

Model-independent operator analysis:

$$\mathcal{H} = \frac{4G_F}{\sqrt{2}} V_{cb} \mathcal{O}_{VL} + \frac{1}{\Lambda^2} \sum_i C_{i}^{(t,\mu)} \mathcal{O}_{i}^{(t,\mu)}$$

Freytsis, Ligeti, Rudermann (arXiv:1506:08896)
Leptoquark contribution:

\[
\mathcal{L}^{(\phi)}_{\text{eff}} = \frac{1}{2 M_\phi^2} \lambda^L_{s\nu_i} \lambda^L_{b\nu_j} \bar{s} \gamma_\mu b \bar{\nu}_L \gamma^\mu \nu_L
\]

Interference with SM yields for \( R_{\nu\bar{\nu}} = \Gamma/\Gamma_{\text{SM}} \):

\[
R^{(\phi)}_{\nu\bar{\nu}} = 1 - \frac{2r}{3} \text{Re} \left( \frac{\lambda^L \lambda^{L\dagger}}{V_{tb} V_{ts}^*} \right)_{bs} + \frac{r^2}{3} \left( \frac{\lambda^L \lambda^{L\dagger}}{V_{tb} V_{ts}^*} \right)_{ss}
\]

with:

\[
r = \frac{s^4_W}{2 \alpha^2} \frac{1}{X_0(x_t)} \frac{m_W^2}{M_\phi^2} \approx 1.91 \frac{\text{TeV}^2}{M_\phi^2}
\]

\[
(\lambda^L \lambda^{L\dagger})_{bs} = \sum_i \lambda^L_{b\nu_i} \lambda^{L*}_{s\nu_i}
\]

Current BaBar bound \( R_{\nu\bar{\nu}} < 4.3 \) @ 90% CL implies:

\[
-\frac{1.2}{\text{TeV}^2} < \frac{1}{M_\phi^2} \text{Re} \left( \frac{\lambda^L \lambda^{L\dagger}}{V_{tb} V_{ts}^*} \right)_{bs} < \frac{2.3}{\text{TeV}^2}
\]
Constraints from $B_s$ mixing and $B \to X_s \gamma$

Leptoquark contribution:

Correction to SM mixing amplitude:

$$C_{B_s}^{(\phi)} e^{2i\phi_{B_s}} = 1 + \frac{1}{g^4 S_0(x_t)} \frac{m_W^2}{M_\phi^2} \left[ \frac{\left(\lambda L \lambda \lambda^\dagger\right)_{bs}}{V_{tb} V_{ts}^*} \right]^2$$

Best fit value:

$$\frac{1}{M_\phi} \left(\frac{\left(\lambda L \lambda \lambda^\dagger\right)_{bs}}{V_{tb} V_{ts}^*}\right) \approx 1.87 + 0.45i \text{ TeV}$$

Bona et al., UTfit collaboration (arXiv:0707.0636)

Leptoquark contribution:

Correction to SM amplitude:

$$C_{7\gamma} = C_{7\gamma}^{\text{SM}} + \left(\frac{v}{12M_\phi}\right)^2 \frac{\left(\lambda L \lambda \lambda^\dagger\right)_{bs}}{V_{tb} V_{ts}^*}$$

Correction to branching ratio of order 1% or less, below current level of sensitivity

Matthias Neubert: Flavor Physics and Flavor Anomalies: BSM
Explanation of the $R_K$ and $B \rightarrow K^*\mu^+\mu^-$ anomalies

Model-independent operator analysis:

$$\mathcal{H}_{\text{eff}} = -\frac{4 G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha_e}{4\pi} \sum_i C_i(\mu) O_i(\mu)$$

with:

$$O_9 = [\bar{s}\gamma_\mu P_L b] [\bar{\ell} \gamma^{\mu} \ell], \quad O_{10} = [\bar{s}\gamma_\mu P_L b] [\bar{\ell} \gamma^{\mu} \gamma_5 \ell]$$

Take new linear combinations:

$$O_{LL}^\ell \equiv (O_9^\ell - O_{10}^\ell) / 2, \quad O_{LR}^\ell \equiv (O_9^\ell + O_{10}^\ell) / 2$$
$$O_{RL}^\ell \equiv (O_9^{\ell \dagger} - O_{10}^{\ell \dagger}) / 2, \quad O_{RR}^\ell \equiv (O_9^{\ell \dagger} + O_{10}^{\ell \dagger}) / 2$$

A good fit is obtained for:

$$C_{LL}^{\mu} \approx -1, \quad C_{ij}^{\mu} \approx 0 \text{ otherwise}$$

Hiller, Schmaltz (arXiv:1408.1627)
**Explanation of the $R_K$ and $B \to K^*\mu^+\mu^-$ anomalies**

Leptoquark contributions:

Contributions to Wilson coefficients:

\[ C_{LL}^{(\phi)} = \frac{m_t^2}{8\pi\alpha M_\phi^2} |\lambda_{\mu\mu}^L|^2 - \frac{1}{64\pi\alpha} \frac{\sqrt{2}}{G_F M_\phi^2} \frac{(\lambda^L\lambda^L)_\mu\mu}{V_{tb} V_{ts}^*} \frac{1}{\ln \frac{M_\phi^2}{m_t^2} - f(x_t)} \]

\[ C_{LR}^{(\phi)} = \frac{m_t^2}{16\pi\alpha M_\phi^2} |\lambda_{\mu\mu}^R|^2 \left[ \ln \frac{M_\phi^2}{m_t^2} - f(x_t) \right] - \frac{1}{64\pi\alpha} \frac{\sqrt{2}}{G_F M_\phi^2} \frac{(\lambda^L\lambda^L)_\mu\mu}{V_{tb} V_{ts}^*} \frac{1}{\ln \frac{M_\phi^2}{m_t^2} - f(x_t)} \]

Best fit values can be obtained for:

\[
\sqrt{|\lambda_{\mu\mu}^L|^2 + |\lambda_{\mu\mu}^R|^2} + \left( 1 - \frac{0.77}{M_\phi^2} \right) |\lambda_{\mu\mu}^L|^2 > 2.36
\]

Model-independent operator analysis:

\[
H_{\text{eff}} = -\frac{4 G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha_e}{4\pi} \sum_i C_i(\mu) O_i(\mu)
\]

with:

\[
O_9 = [\bar{s}\gamma\mu P_L b] [\bar{\ell}\gamma^\mu \ell], \quad O_{10} = [\bar{s}\gamma\mu P_L b] [\bar{\ell}\gamma^\mu \gamma_5 \ell]
\]

Take new linear combinations:

\[
O_{LL}^\ell \equiv (O_9^\ell - O_{10}^\ell)/2, \quad O_{LR}^\ell \equiv (O_9^\ell + O_{10}^\ell)/2
\]

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O_{RL}^\ell \equiv (O_9^\mu - O_{10}^\mu)/2, \quad O_{RR}^\ell \equiv (O_9^\mu + O_{10}^\mu)/2
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A good fit is obtained for:

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Hiller, Schmaltz (arXiv:1408.1627)
Leptoquark contributions:

Contributions to Wilson coefficients:

\[ C_{LL}^{\mu(\phi)} = \frac{m_t^2}{8\pi\alpha M^2_\phi} |\lambda_{t\mu}^L|^2 - \frac{1}{64\pi\alpha G_F M^2_\phi} \frac{\sqrt{2}}{V_{tb} V_{ts}^*} (\lambda^{L\dagger} \lambda^L)_{\mu\mu} \]

\[ C_{LR}^{\mu(\phi)} = \frac{m_t^2}{16\pi\alpha M^2_\phi} \left[ |\lambda_{t\mu}^R|^2 \ln \frac{M^2_\phi}{m_t^2} - f(x_t) \right] - \frac{1}{64\pi\alpha G_F M^2_\phi} \frac{\sqrt{2}}{V_{tb} V_{ts}^*} (\lambda^{R\dagger} \lambda^R)_{\mu\mu} \]

Best fit values can be obtained for:

\[ \sqrt{|\lambda_{L\mu\mu}^L|^2 + |\lambda_{L\mu\mu}^R|^2 + \left(1 - \frac{0.77}{M^2_\phi}\right)|\lambda_{t\mu}^L|^2} > 2.36 \]

Allowed parameter space for \( M_\phi = 1 \text{ TeV} \):

\[ R_{K} = \text{Re}[\lambda (\lambda^\dagger)_{bs}] \]

Mathias Neubert: Flavor Physics and Flavor Anomalies: BSM
Other observables

With a modest right-handed coupling

$$|\lambda_{c\mu}^R| \sim 0.03$$

our model can explain the anomalous magnetic moment of the muon!

Without much fine-tuning, our model survives the bounds from:
- rare $D$-meson decays such as $D \to \mu\mu$
- precision data on Z-boson couplings to muons
- rare decays of the tau lepton, such as $\tau \to \mu\gamma$
- ...
Collider bounds
Outlook
One the verge of another discovery?

- The discovery of the Higgs boson has opened a new era in exploration of fundamental structures of Nature.
- While precision Higgs measurements make a compelling mid-term physics case, the future of our field will likely depend on a discovery of some truly “new” physics.
- The flavor anomalies give us hope that such a discovery may be within reach of present experiments.
Mainz Institute for Theoretical Physics

SCIENTIFIC PROGRAMS

Amplitudes: Practical and Theoretical Developments
Fabrizio Casali (CERN), Herbert Gielke (DESY Hamburg), Janoshe Tungl (JGU Mainz), Johannes Henn, Stefan Müller-Stach, Stefan Weidert
February 6-17, 2017

Quantum Vacuum and Gravitation: Testing General Relativity in Cosmology
Manuel Asorey (UNIZAR), Emil Mottola (LANL), Ilya Shapiro (Max-Planck-Institute for Physics, Munich), Andras Wipf (Johannes Gutenberg Universität Mainz)
March 13-24, 2017

Low-Energy Probes of New Physics
Peter Fließinger, Martin Jung (University of Kentucky), Susan Gardner (University of Kentucky)
May 2-24, 2017

The TeV Scale: A Threshold to New Physics?
Cesare Conti (INFN), Christophe Gosson (JGU Mainz, Erasmus Universiteit Rotterdam), Andreas Walter (Institute for Nuclear Physics, Karlsruhe), Pedro Schwaller (Johannes Gutenberg Universität Mainz)
June 13-27, 2017

Diagrammatic Monte Carlo Methods for QFTs in Particle, Nuclear, and Condensed Matter Physics
Christof Gattringer (JGU Mainz), Alex Dewitt (North Carolina State University), Shalock Chandrashekar (University of Florida)
September 18-29, 2017

TOPOICAL WORKSHOPS

Quantum Methods for Lattice Gauge Theories Calculations
Igliorino Cirio (MPI für Quantum Optics), Simone Montangero (Uni-Vienna, Peter Zoller (Uni-Vienna)
February 6-10, 2017, Schloss Waldthausen

Women at the Intersection of Mathematics and High Energy Physics
Sylvie Paycha (Universität Potsdam), Kasia Rejzner (University of York), Katrin Wendland (University of Freiburg), Gabriele Honecker (Johannes Gutenberg Universität Mainz)
March 6-10, 2017

Geometry, Gravity and Supersymmetry
Volker Gritsi (University of Hamburg), Udi Figueroa-O’Farrill (University of Edinburgh), George Papadopoulos (King’s College London)
April 24-28, 2017

Foundational and Structural Aspects of Gauge Theories
Claudio Dappiaggi (Universita di Pavia), Marco Benini (Universita di Potsdam), Klaus Fredenhagen (Universita di Hamburg)
May 29-June 6, 2017, Schloss Waldthausen

Supernova Neutrino Observations: What can we learn and do?
Hans Thomas (University of Hamburg), Georg Raffelt (Max Planck Institute for Nuclear Physics), Lutz Kopp (Johannes Gutenberg Universität Mainz), Matthias Weidert (Johannes Gutenberg Universität Mainz)
October 9-13, 2017

MITP SUMMER SCHOOL

Joachim Kopp, Felix Fu, Anna Kamenka, Marcell De Vries, Matthias Weidert
August 2017, Erbacher Hof Mainz

For more details: http://www.mitp.uni-mainz.de
Thank you!

ERC Advanced Grant (EFT4LHC)
An Effective Field Theory Assault on the Zeptometer Scale: Exploring the Origins of Flavor and Electroweak Symmetry Breaking