Current activities in Roma

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17 February 2020, Flavour Physics Workshop, Rome

The past

1. **A Model of Leptons**
(12114) Steven Weinberg (MIT, LNS). Nov 1967. 3 pp.
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2. **Particle Creation by Black Holes**
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3. **Partial Symmetries of Weak Interactions**
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4. **The Inflationary Universe: A Possible Solution to the Horizon and Fl**
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5. **Asymptotic Freedom in Parton Language**
(6953) Guido Altarelli (Ecole Normale Superieure), G. Parisi (IHES, Bures-sur-Yvette). Mar 197
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DOI: 10.1016/0550-3213(77)90384-4
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6. **Unitary Symmetry and Leptonic Decays**
(6270) Nicola Cabibbo (CERN). Jun 1963. 3 pp.
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7. **New generation of parton distributions with uncertainties from global**
(6163) J. Pumplin, D.R. Stump, J. Huston, H.L. Lai, Pavel M. Nadolsky, W.K. Tung (Michigan State
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8. **Weak Interactions with Lepton-Hadron Symmetry**
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10. **Dynamical Model of Elementary Particles Based on an Analogy with Su**
(5303) Yoichiro Nambu, G. Jona-Lasinio (Chicago U., EFI). 1961. 14 pp.
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The present

- 3 main areas of interest in flavour physics:

1) Standard Model (this morning, talk by Ciuchini, Polosa)

2) Lattice (next talk)

3) New Physics (briefly now)

LQCD123

Lattice QCD (LQCD123)

The research activity of the LQCD123 group in Tor Vergata concerns the study of the strong interactions in the non-perturbative regime and their effects in certain processes (decays, meson-antimeson oscillations, vacuum polarization) of utmost relevance for the phenomenology of the Standard Model (SM) of Particle Physics. Monte Carlo simulations of the basic theory (QCD, recently also including QED corrections at the leading order in alpha_em) cleverly regulated on spacetime lattices of sufficiently large volume allow for a rigorous and systematically improvable study of the non-perturbative observables of interest, e.g. masses

and widths of the lightest hadrons as well as matrix elements of the effective electroweak Hamiltonian (in the SM and beyond) between hadron states. Besides providing a first-principle test of QCD as the correct theory of strong interactions, these computations enable extraction of the free parameters of the SM and its possible extensions from the experimental data with a controlled accuracy at the level of few-percents or better, which is the precision required to detect possible signals of New Physics.

Among the main current research topics we recall:

1) renormalized charm and bottom quark masses and leptonic decays constants f_D, f_Ds, f_B, f_Bs;

2) oscillation parameters of K-Kbar, D-Dbar and B-Bbar and constraints on SM extensions;

3) leading isospin breaking effects (LIBE) in meson masses and leptonic decay rates;

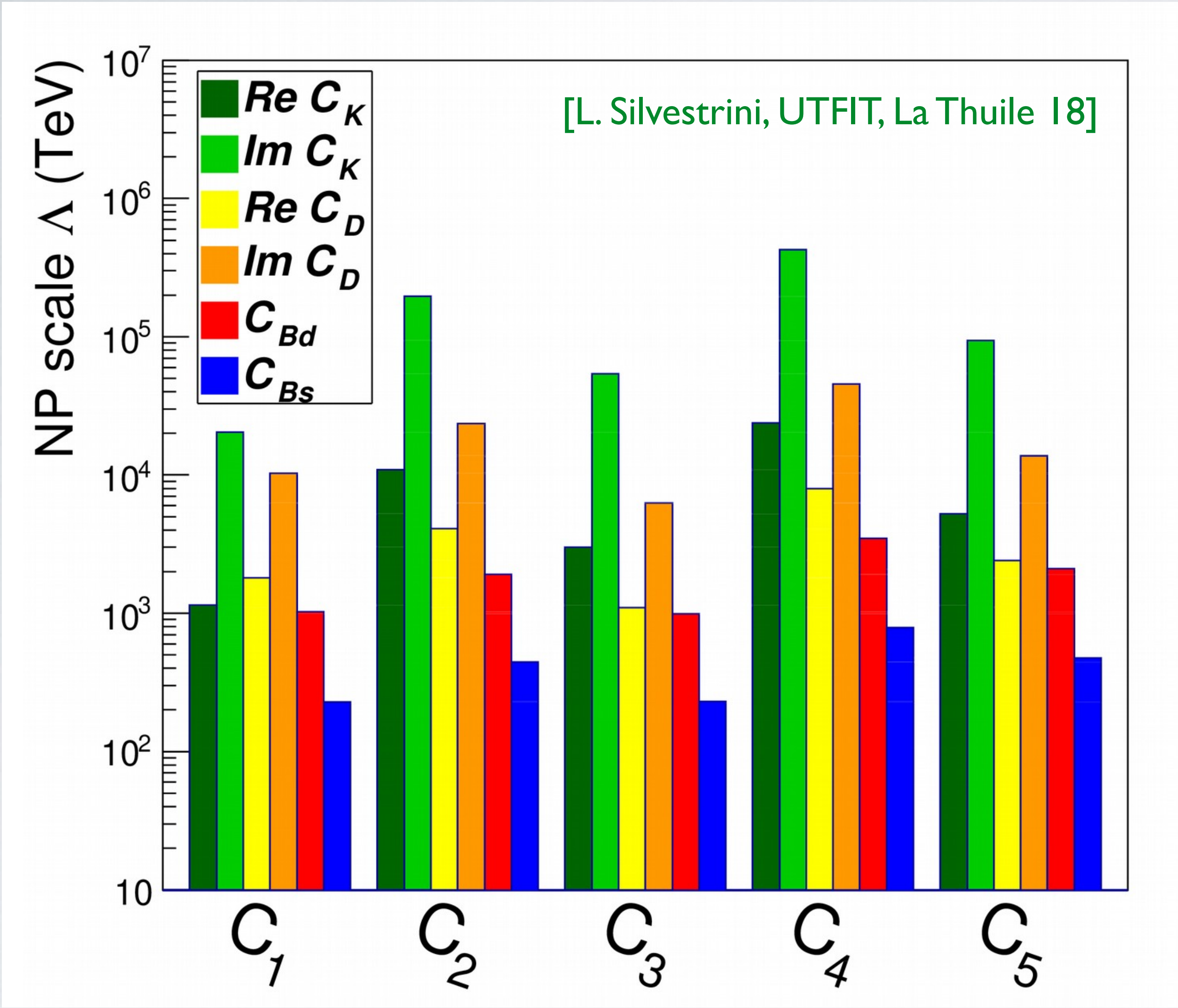
4) QED+QCD with strict locality and C* boundary conditions: from constructive quantum field theory to LIBE computations with reduced finite size effects;

5) advanced methods for non-perturbative renormalization.

Staff members involved in this research activity: G.M. de Divitiis, R. Frezzotti, N. Tantalo - in collaboration with prof. G.C. Rossi, dr. A. Vladikas, dr. P. Dimopoulos and many other researchers in the Rome area and in several European research institutions.

New Physics

Flavour physics as NP probe



$$\mathcal{A}_{i\to j} = \mathcal{A}_{ij}^{\rm SM} + \frac{c_{ij}}{\Lambda^2}$$

- What can we probe indirectly?

$$\frac{c_{ij}}{\Lambda^2}$$

Model dependent part

C= (loops) x (couplings) x (flavour)

On-shell effects @ colliders

- No evidence of NP in ΔF=2 processes

$$\Lambda > \begin{cases} 4.3\cdot 10^5 \text{ TeV} \times |c_{sd}|^{1/2} & \epsilon_K \\ 4.5\times 10^4 \text{ TeV} \times |c_{cu}|^{1/2} & D \text{ mixing} \\ 3.5\times 10^3 \text{ TeV} \times |c_{bd}|^{1/2} & B_d \text{ mixing} \\ 7.9\times 10^2 \text{ TeV} \times |c_{bs}|^{1/2} & B_s \text{ mixing} \end{cases}$$

$$\begin{aligned} Q_1^{q_iq_j} &= \bar{q}^\alpha_{jL}\gamma_\mu q^\alpha_{iL}\bar{q}^\beta_{jL}\gamma^\mu q^\beta_{iL}\,, \\ Q_2^{q_iq_j} &= \bar{q}^\alpha_{jR}q^\alpha_{iL}\bar{q}^\beta_{jR}q^\beta_{iL}\,, \\ Q_3^{q_iq_j} &= \bar{q}^\alpha_{jR}q^\beta_{iL}\bar{q}^\beta_{jR}q^\alpha_{iL}\,, \\ Q_4^{q_iq_j} &= \bar{q}^\alpha_{jR}q^\alpha_{iL}\bar{q}^\beta_{jL}q^\beta_{iR}\,, \\ Q_5^{q_iq_j} &= \bar{q}^\alpha_{jR}q^\beta_{iL}\bar{q}^\beta_{jL}q^\alpha_{iR}\,. \end{aligned}$$

$\Lambda?$

- “Large” effects still possible $\left|\frac{\mathcal{A}_{NP}}{\mathcal{A}_{SM}}\right| \lesssim 20\%$
- To progress we need extra theoretical input

Flavour Anomalies

$b \to s\mu\mu$ (LHCb from 2013)

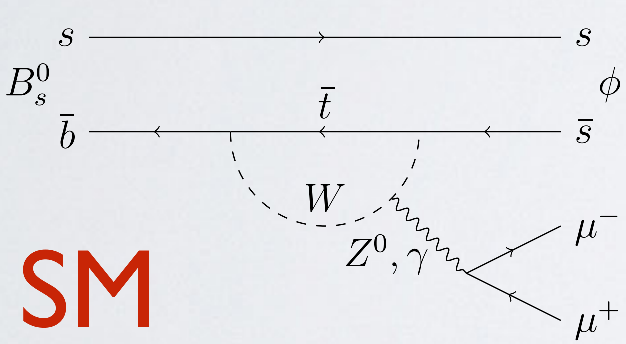
1) Angular observables in $B \to K^* \mu^+ \mu^-$ $\sim 4\sigma$ (?!)

2) Branching ratios $\gtrsim 3.5\sigma$ (?!)

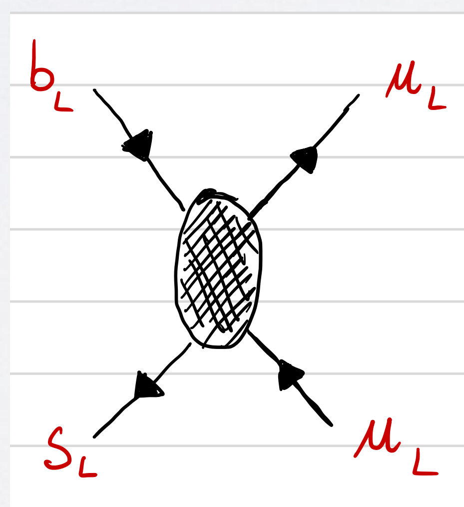
3) LFU violation in R_K 2.6σ

4) LFU violation in R_{K^*} (2 bins) $2.3\sigma,\ 2.6\sigma$

"clean" only $\approx 4\sigma$



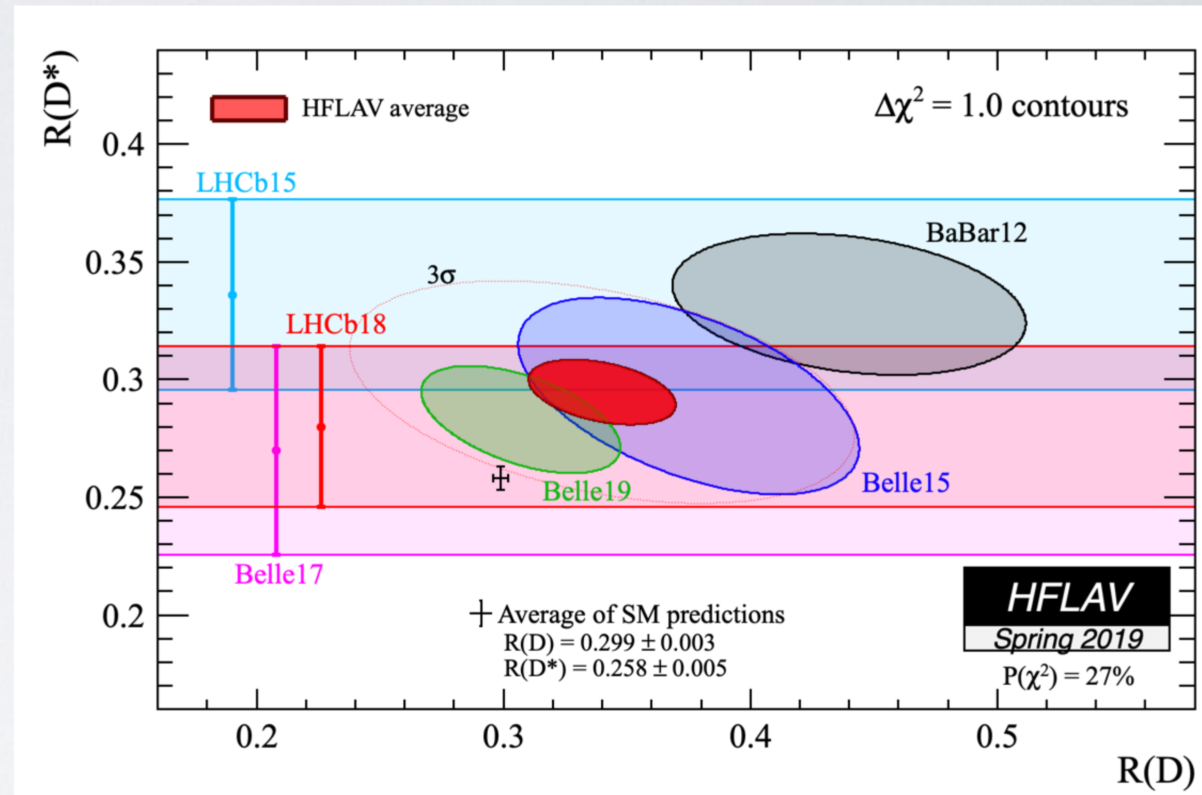
SM

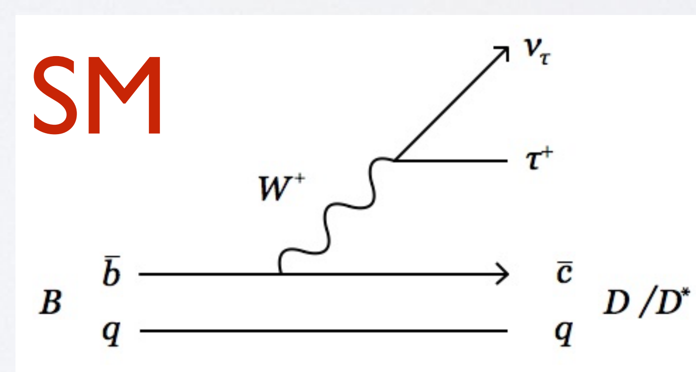


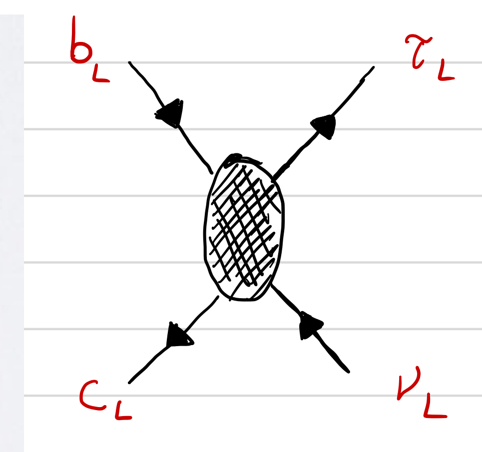
$$\mathcal{L}_{eff} = \frac{1}{\Lambda_{R_K}^2} \bar{s}_L \gamma^\mu b_L \, \bar{\mu}_L \gamma_\mu \mu_L + h.c.$$

$|C_\mu^{\rm NP}| \gg |C_e^{\rm NP}|$ $\Lambda_{R_K} = 37$ TeV

$b \to c\tau\nu$ Babar+Belle+LHCb from 2012







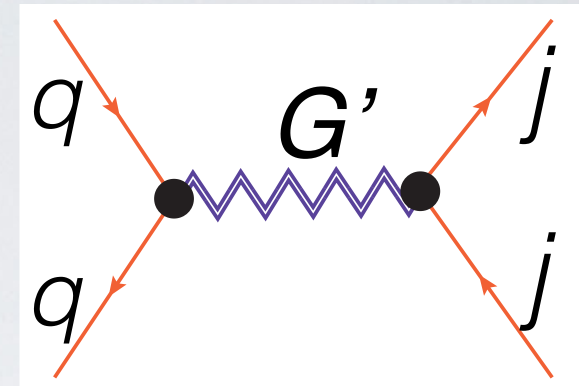
$$\mathcal{L}_{eff} = -\frac{2}{\Lambda_{R_D}^2} \bar{c}_L \gamma^\mu b_L \, \bar{\tau}_L \gamma_\mu \nu_L + h.c.$$

$|C_\tau^{\rm NP}| \gg |C_\mu^{\rm NP}|, |C_e^{\rm NP}|$ $\Lambda_{R_D} = 3.7$ TeV

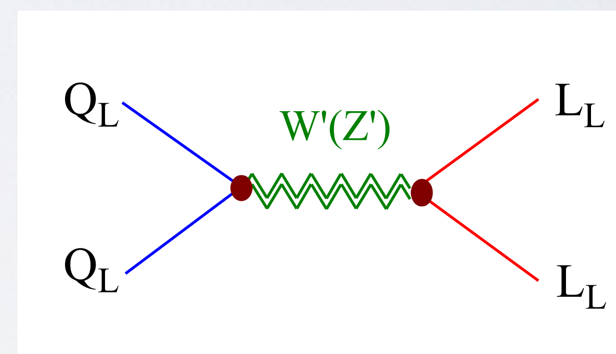
Bottom-up path

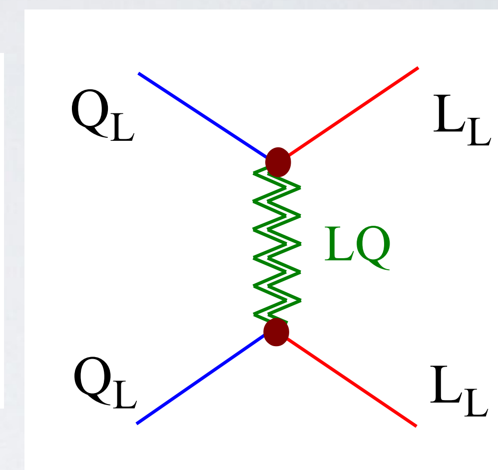
Theoretical input / bias

"Motivated" Models — Address more questions/open problems: naturalness, origin of flavour, renormalizability/accidental symmetries.….

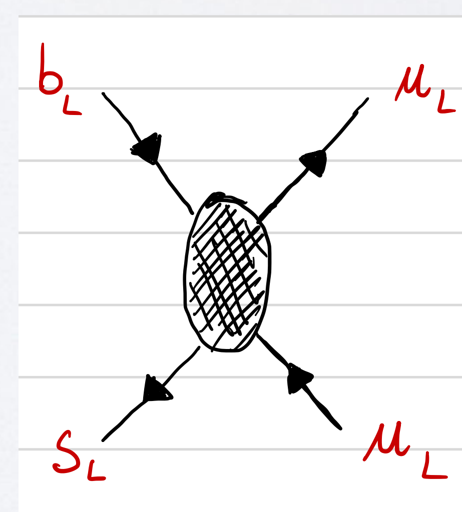


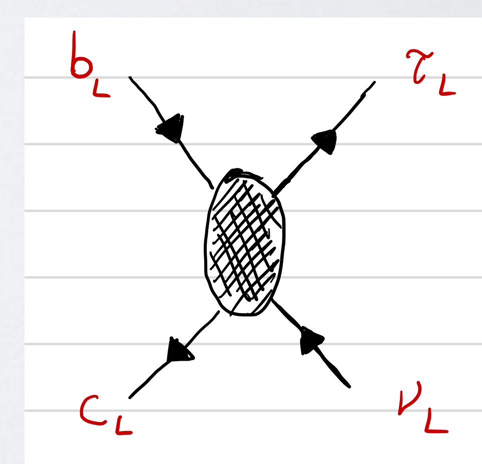
Simplified Models — Introducing explicitly New Physics, in the simplest way as possible





EFT — New Physics in a model independent way





$\Lambda_{R_K} = 37\ \text{TeV}$ $\Lambda_{R_D} = 3.7\ \text{TeV}$

Experimental input

Implications for low-energy measurements

If the anomalies are due to NP, we should expect to see several other BSM effects in low-energy observables

E.g.: correlations among down-type FCNCs [*using the results of* U(2)-*based EFT*]:

	$\mu\mu$ (ee)	$\tau\tau$	$\nu\nu$	$\tau\mu$	μe
$b \to s$	R_K, R_{K^*} O(20%)	$B \to K^{(*)} \tau\tau$ $\to$ 100×SM	$B \to K^{(*)} \nu\nu$ O(1)	$B \to K \tau\mu$ $\to \sim 10^{-6}$	$B \to K \mu e$???
$b \to d$	$B_d \to \mu\mu$ $B \to \pi \mu\mu$ $B_s \to K^{(*)} \mu\mu$ O(20%) [$R_K = R_\pi$]	$B \to \pi \tau\tau$ $\to$ 100×SM	$B \to \pi \nu\nu$ O(1)	$B \to \pi \tau\mu$ $\to \sim 10^{-7}$	$B \to \pi \mu e$???
$s \to d$	*long-distance pollution*	*NA*	$K \to \pi \nu\nu$ O(1)	*NA*	$K \to \mu e$???