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Renormalization constants of fermionic operators in lattice QCD with N_f=4 dynamical Wilson quarks

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Lattice QCD calculations provide today some of the most precise and model-independent estimates of the parameters of the Standard Model (see the CKM matrix on the right). But – in order to compare with the experiments – most quantities computed on a lattice regularization need to be **renormalized**.

$$\begin{pmatrix} \mathbf{V_{ud}} & \mathbf{V_{us}} & \mathbf{V_{ub}} \\ \pi\to\ell\nu & K\to\ell\nu & B\to\ell\nu \\ & K\to\pi\ell\nu & \\ \mathbf{V_{cd}} & \mathbf{V_{cs}} & \mathbf{V_{cb}} \\ D\to\ell\nu & D_s\to\ell\nu & B\to D\ell\nu \\ D\to\pi\ell\nu & D\to K\ell\nu & B\to D^*\ell\nu \\ \mathbf{V_{td}} & \mathbf{V_{ts}} & \mathbf{V_{tb}} \\ \langle B_d|\overline{B_d}\rangle & \langle B_s|\overline{B_s}\rangle & \end{pmatrix}$$

Most CKM matrix elements are obtained from the lattice computation of the processes listed above.

A convenient renormalization prescription, which is valid also non perturbatively, is the RI'MOM scheme (Martinelli et al NPB445 '94). In the case of bilinear observables it reads:

$$S_f(p) = a^4 \sum_x e^{-ipx} \langle \psi_f(x)\overline{\psi_f}(0)\rangle \quad \text{(Propagator)}$$

$$Z_q = \frac{-i}{12\sum_{\nu|p_\nu\neq 0} 1} \sum_{\nu|p_\nu\neq 0} \left(\frac{Tr[\gamma_\nu S_f(p)^{-1}]}{q_\nu}\right)_{q^2=\mu^2} \quad \text{(Field Renormalization)}$$

$$\text{where} \quad q_\nu = \frac{1}{a}\sin(ap_\nu)$$

$$G_\Gamma^{(f,f')}(p,p) = a^8 \sum_{x,y} e^{-ip(x-y)} \langle \psi_f(x)(\overline{\psi_f}\Gamma\psi_{f'})(0)\overline{\psi_{f'}}(y)\rangle \quad \text{(Green Function)}$$

$$\Lambda_\Gamma^{(f,f')}(p,p) = S_f^{-1} G_\Gamma^{(f,f')}(p,p) S_{f'}^{-1} \quad \text{(Amputated Green Function)}$$

$$Z_\Gamma^{(f,f')} = Z_q \left(Tr\left[\Lambda_\Gamma^{(f,f')}(p,p) P_\Gamma\right]_{q^2=\mu^2}\right)^{-1} \quad \text{(Renormalization of the } \Gamma \text{ Bilinear)}$$

The scheme is mass independent and this is achieved via an extrapolation to the chiral limit of the N_f=4 degenerate quarks.

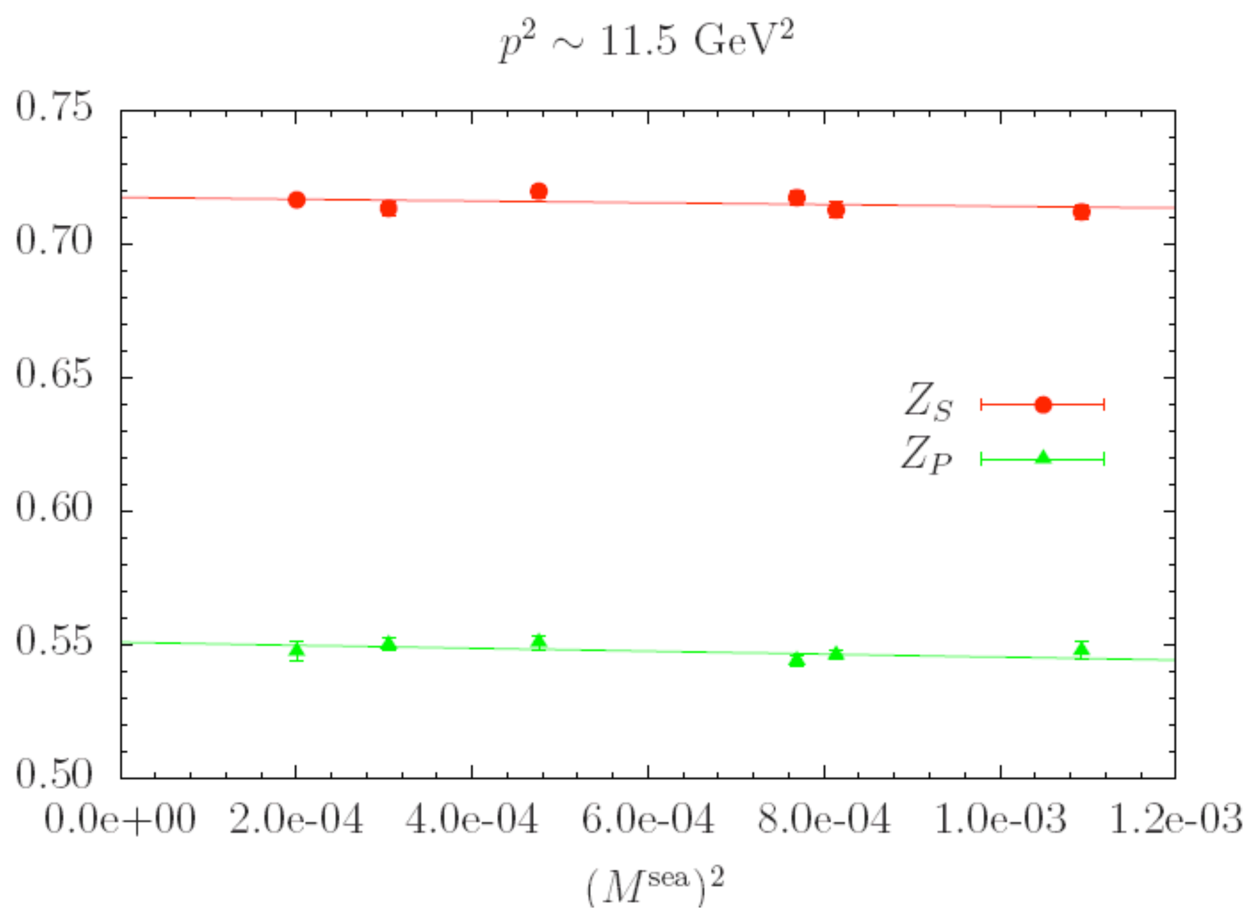
ETMC is one of the largest lattice QCD collaborations worldwide (~20 institutions, ~20 arXiv posts last year) and it has an ambitious physics program with N_f =2+1+1 flavors of quark in the twisted mass regularization (for an updated status, see the contributions of *D.Palao, V.Drach, N.Carrasco-Vela, Xining Du, E.Garcia-Ramos, F.Burger, S.Dinter, F.Sanfilippo* at the Lattice 2011 conference). The renormalization constants (RCs) must be computed in the chiral limit of the **twisted mass lattice QCD** action (tmLQCD) with N_f = 4 degenerate quarks.

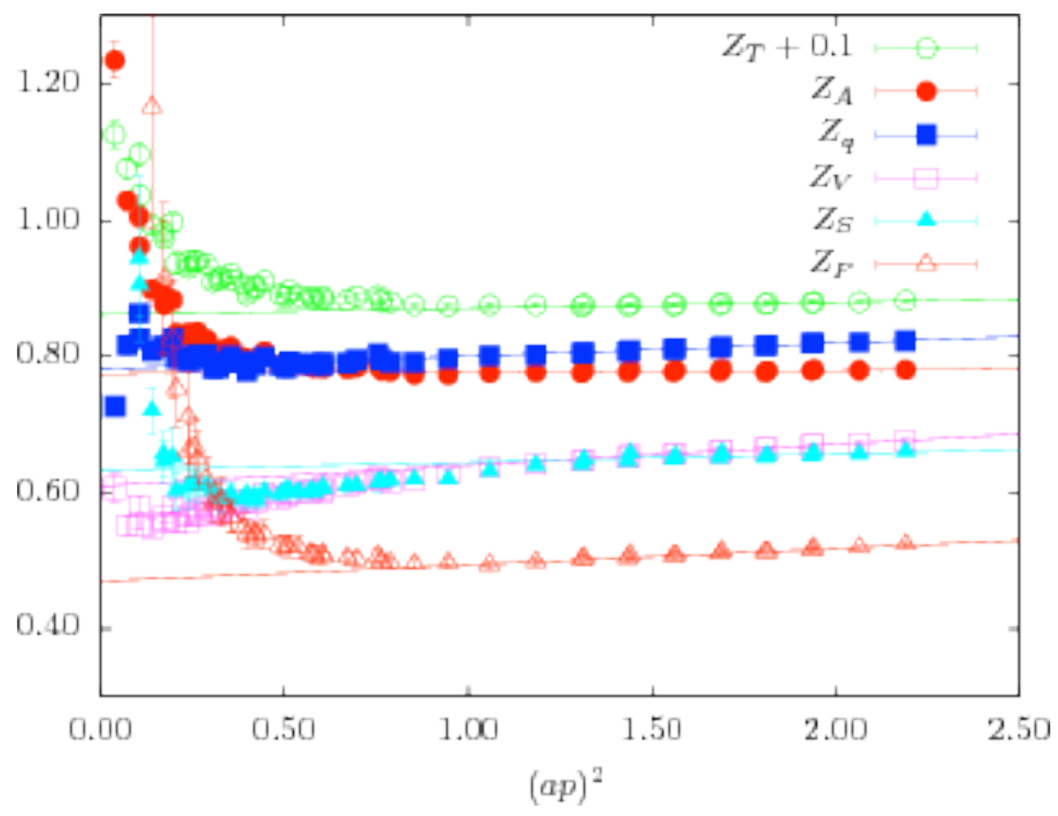
In order to extract the RCs with small lattice artifacts, we simulate different quark masses (M) and different twisting angles (θ). In particular the θ dependence in the RCs appears only in lattice artifacts and, thanks to the symmetries of the tmLQCD action, averaging the results obtained with opposite θ reruces the O(*a*) lattice artifacts to O(a^2).

After extracting the chiral limit of the RCs in both in the *sea* and the *valence* quark masses (M^{sea}, M^{val} →0), we have used two alternative methods: In the **first method (M_1)** we subtract the O(q^2a^2) artifacts with the help of a perturbative computation (Constantinuo et al, JHEP 0910 (2009) 064), and the residual O(a^2) lattice artifacts are reduced by extrapolating the (q^2a^2) dependence to zero. In the **second method (M_2)** we choose a sufficiently high momentum q^2 =12.2 GeV^2, which is eventually kept fixed in physical units.

Below we show an example of chiral extrapolation (M^{sea} →0) for Z_P, Z_S, (left) and an example of the *(qa)*^{2} dependence on the RCs (right)

Results at *a*=0.078 fm (β=1.95) are presented here. Simulations at a=0.09 fm (β=1.90) a=0.06 fm (β=2.10) are in progress. The Table shows the results obtained with methods **M_1** and **M_2** and, where available, the Ward Identity method (**WI**)





RCs	M_1	M_2	WI
Z_A	0.738(05)	0.7131(17)	
Z_V	0.610(02)	0.6143(16)	0.6120(05)
Z_P (μ=1/*a*)	0.428(04)	0.4603(18)	
Z_S (μ=1/*a*)	0.585(07)	0.6820(30)	

The tmLQCD code has been optimized for the Aurora architecture within the AuroraScience project, with a gain of ~50% over the previous most efficient version of the code.