$$f = \sum_{i=1}^{n} c_i \underbrace{\varphi_i(x)}_{\text{FE basis}} \in V_h$$

$$\|f\|_{L^2}^2 = \int_\Omega \left(\sum_i c_i \varphi_i \right)^2 dx$$

$$= \sum_{i,j} c_i c_j \underbrace{\int_\Omega \varphi_i \varphi_j \, dx}_{= M_{ij}}$$

$$= c^T M c$$

$$\Rightarrow \|f\|_{L^2} = \sqrt{c^T M c}$$

$$g = \sum_{i=1}^{n} d_i \varphi_i$$

$$\|f - g\|_{L^2} = \sqrt{(c-d)^T M (c-d)}$$