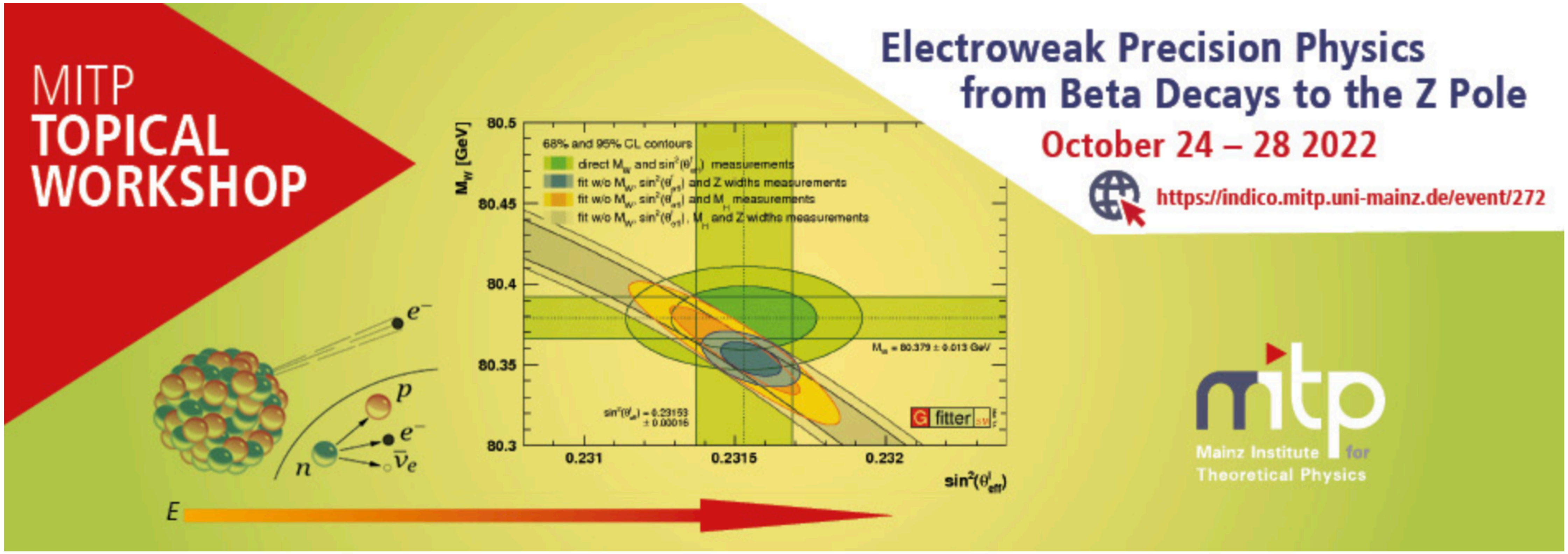
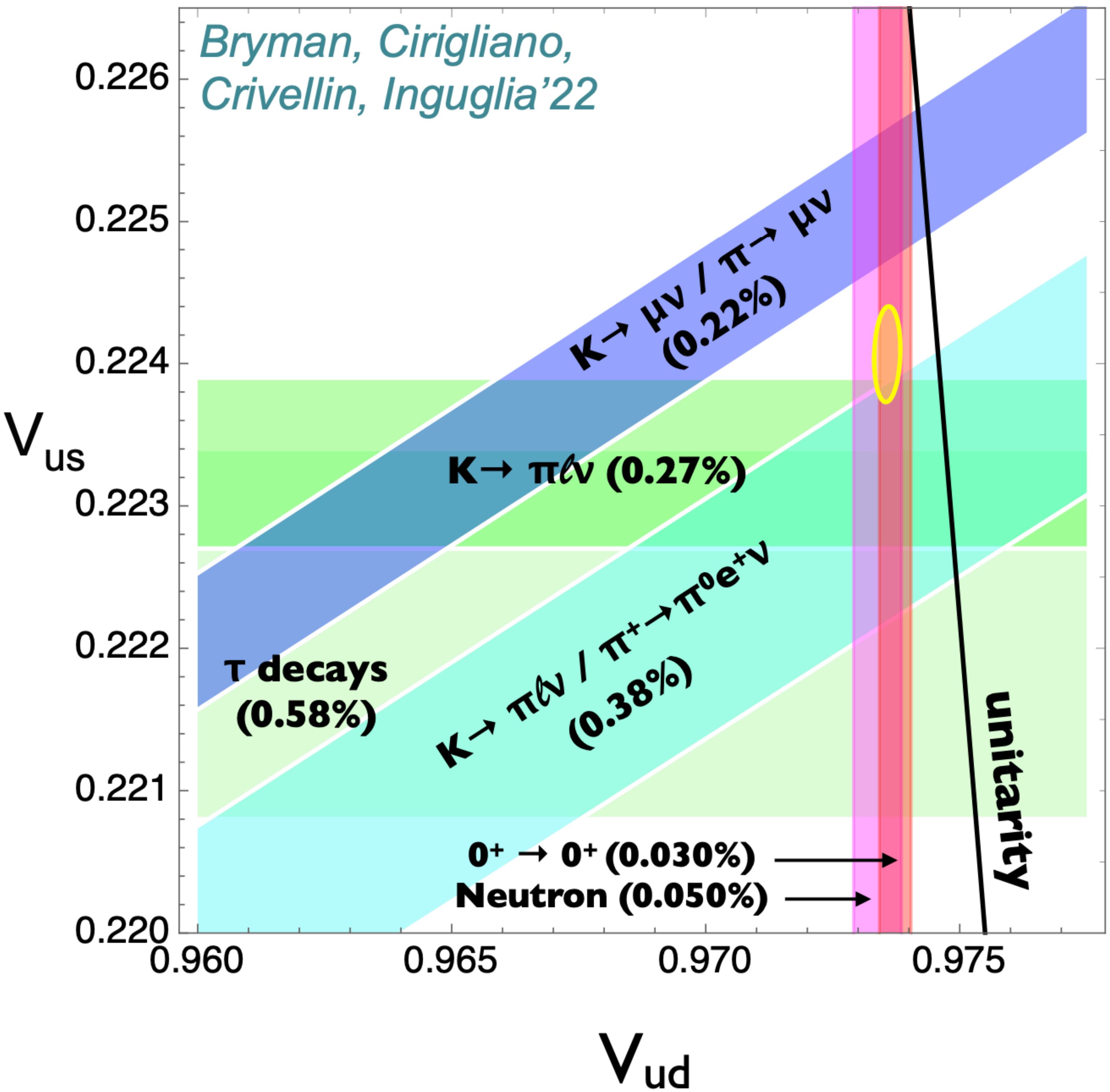


Electroweak Precision Physics from Beta Decays to the Z Pole

Future Directions & Implications for Other Observables

Bernat Capdevila & Javier M. Lizana

Cabibbo angle anomaly



Fit results:

$$V_{ud} = 0.97365\,(30)$$

$$V_{us} = 0.22414\,(37)$$

$$\chi^2 / dof = 6.6/1 \quad (1\%)$$

$$\delta_{\mathrm{CKM}} = V_{ud}^2 + V_{us}^2 + V_{ub}^2 - 1$$

$$= -\,0.0018(6)$$

$$2.7\,\sigma$$

EFT description

Vincenzo Cirigliano

VC, Gonzalez-Alonso, Jenkins 0908.1754, NPB

VC, Graesser, Gonzalez-Alonso 1210.4553, JHEP

Leptonic interactions

$$\mathcal{L}_{CC}^{(\mu)} = -\frac{G_F^{(0)}}{\sqrt{2}} \left(1 + \epsilon_L^{(\mu)}\right) \bar{e}\gamma^\rho(1-\gamma_5)\nu_e \cdot \bar{\nu}_\mu \gamma_\rho (1-\gamma_5)\mu \; + \; \ldots$$

Semi-leptonic interactions

$$\begin{aligned} \mathcal{L}_{\rm CC} \;=\; -\frac{G_F^{(0)} V_{ud}}{\sqrt{2}} \times \Big[& \left(\delta^{ab} + \epsilon_L^{ab}\right) \; \bar{e}_a \gamma_\mu (1-\gamma_5)\nu_b \cdot \bar{u}\gamma^\mu (1-\gamma_5) d \\ & + \; \epsilon_R^{ab} \; \bar{e}_a \gamma_\mu (1-\gamma_5)\nu_b \cdot \bar{u}\gamma^\mu (1+\gamma_5) d \\ & + \; \epsilon_S^{ab} \; \bar{e}_a (1-\gamma_5)\nu_b \cdot \bar{u} d \\ & - \; \epsilon_P^{ab} \; \bar{e}_a (1-\gamma_5)\nu_b \cdot \bar{u}\gamma_5 d \\ & + \; \epsilon_T^{ab} \; \bar{e}_a \sigma_{\mu\nu} (1-\gamma_5)\nu_b \cdot \bar{u}\sigma^{\mu\nu} (1-\gamma_5) d \Big] + \text{h.c.} \end{aligned}$$

$\varepsilon_i \sim (v/\Lambda)^2$ → $\Lambda \approx 5 - 20\,\text{TeV}$

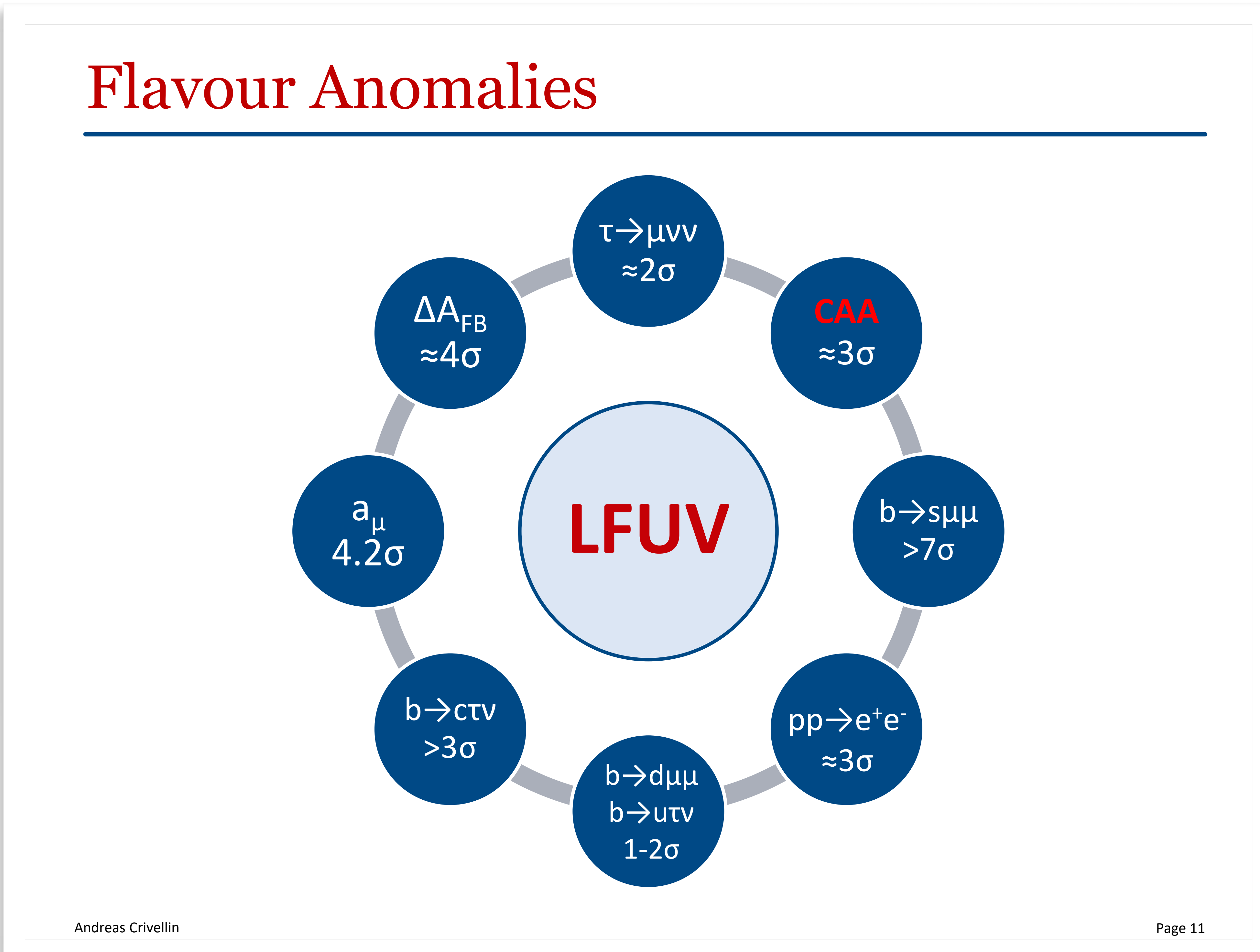
SMEFT: $\mathcal{O}_{Hud}$, $\mathcal{O}_{Hq}^{(3)}$, $\mathcal{O}_{Hl}^{(3)}$ — 4-fermion op.

Possible mediators

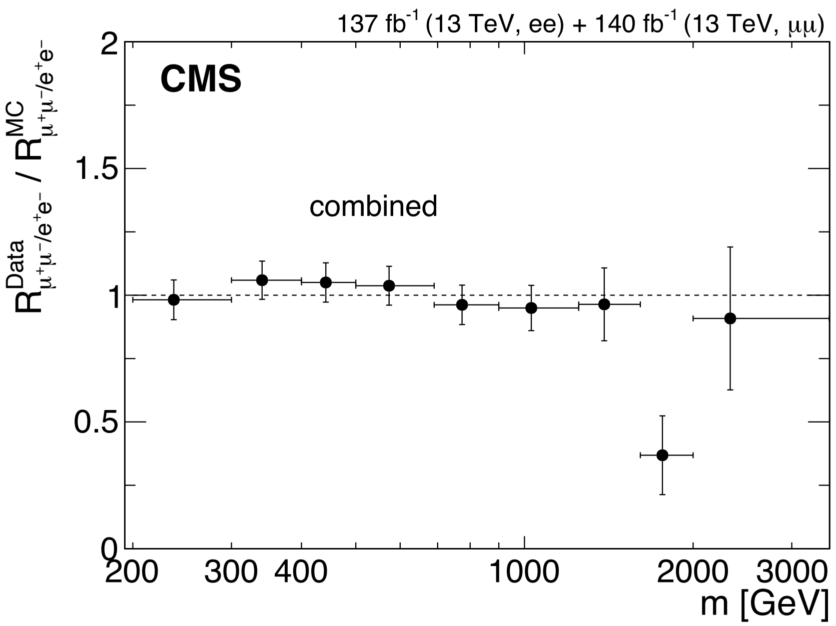
• Vector bosons	SMEFT Op.	UV completions
$W'_L \sim (\mathbf{1},\mathbf{3})_0$	$\mathcal{O}^{(3)}_{Hq},\ \mathcal{O}^{(3)}_{Hl},\ \mathcal{O}_{ll},\ \mathcal{O}^{(3)}_{lq}$	$SU(2)_1 \times SU(2)_2 \to SU(2)_L,\ \ldots$
$W'_R \sim (\mathbf{1},\mathbf{1})_1$	$\mathcal{O}_{Hud},\ \mathcal{O}_{ud}$	$G \to U(1)_Y:$ $SU(2)_R \times U(1)_{B-L} \to U(1)_Y,\ \ldots$
• Vector-like fermions		
$Q \sim (\mathbf{3},\cdot\,)_Y$	$\mathcal{O}_{Hud},\ \mathcal{O}^{(3)}_{Hq}$	Composite sector?
$L \sim (\mathbf{1},\cdot\,)_Y$	$\mathcal{O}^{(3)}_{Hl}$	

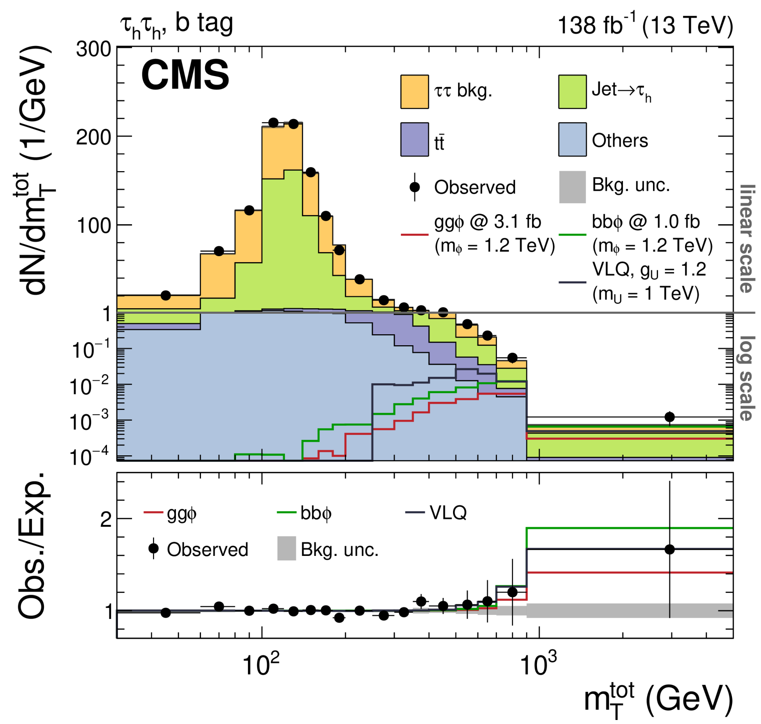
- Scalar fields?
- Loop level?

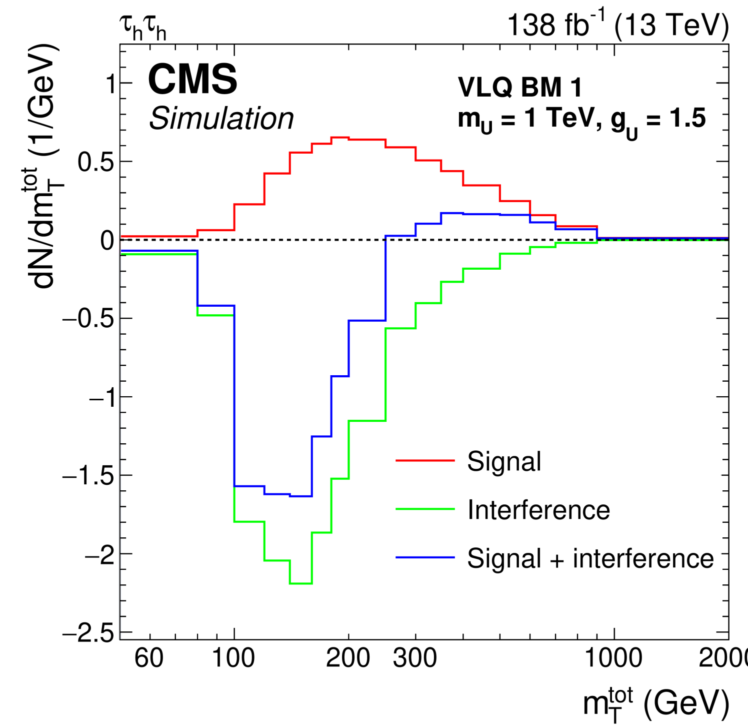
Connection to other anomalies?



Collider searches







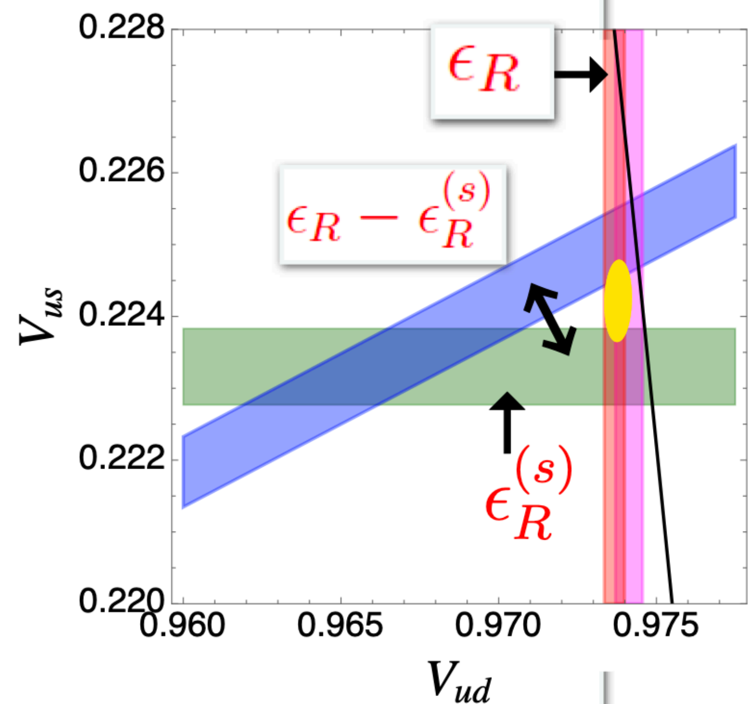
- Plenty of channels to be explored with different signatures
- Interplay with signals coming from the low energy / precision physics regimes

Backup: RH solution

- Right-handed currents (in the 'ud' and 'us' sectors)

Grossman-Passemar-Schacht
1911.07821 JHEP
Alioli et al 1703.04751, JHEP

$$
\begin{aligned}
|\bar{V}_{ud}|^2_{0^+\to 0^+} &= |V_{ud}|^2 \left(1 + 2\,\epsilon_R\right) \\
|\bar{V}_{ud}|^2_{n\to pe\bar{\nu}} &= |V_{ud}|^2 \left(1 + 2\,\epsilon_R\right) \\
|\bar{V}_{us}|^2_{Ke3} &= |V_{us}|^2 \left(1 + 2\,\epsilon_R^{(s)}\right) \\
|\bar{V}_{ud}|^2_{\pi e3} &= |V_{ud}|^2 \left(1 + 2\,\epsilon_R\right) \\
|\bar{V}_{us}|^2_{K\mu 2} &= |V_{us}|^2 \left(1 - 2\,\epsilon_R^{(s)}\right) \\
|\bar{V}_{ud}|^2_{\pi\mu 2} &= |V_{ud}|^2 \left(1 - 2\,\epsilon_R\right)
\end{aligned}
$$



- CKM elements from vector (axial) channels are shifted by $1+\varepsilon_R$ ($1-\varepsilon_R$). V_{us}/V_{ud} , V_{ud} and V_{us} shift in correlated way, can resolve all tensions!