New Physics in $pp \to e^+e^-$

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Anomalies and Precision in the Belle II Era - Workshop

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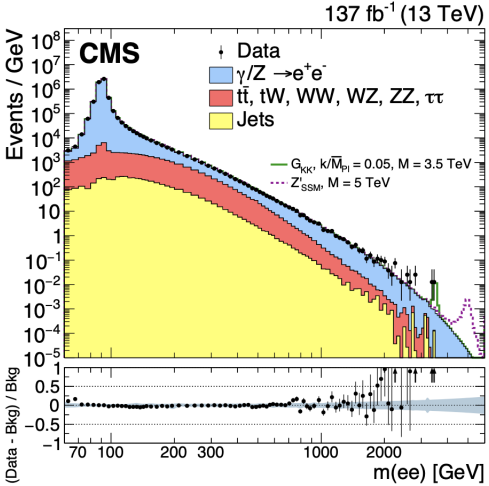
Outline

- Di-lepton Final States Searches
- LFUV tests at high energy
- Di-electron excess & Cabibbo Angle Anomaly
- Conclusions

Dilepton Final States



Traditionally, very important due to the clean and fully reconstructable experimental signature with excellent detection efficiency:

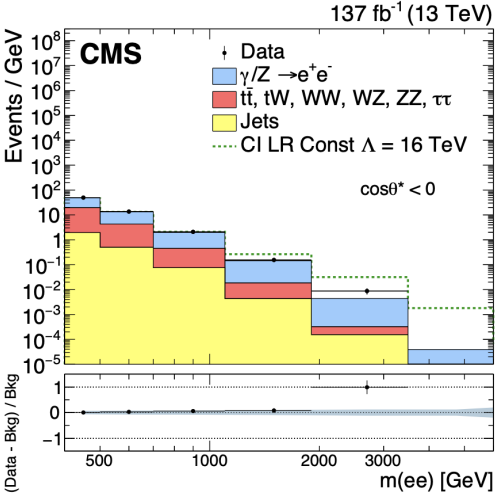
- discovery of new particles: Z^0, J/Ψ, ...;
- precision measurements: $\sin\theta_W$, A_ℓ, ...;
- resonant searches for New Physics beyond the SM: Z', G, ...;
- non-resonant searches

Non-resonant Searches

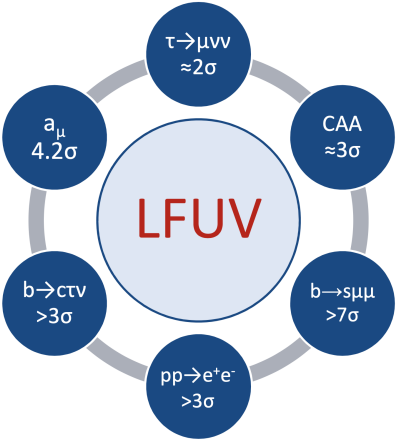
High Energy Lepton tails are the most sensitive to new physics since the signal-to-background ratio is most favorable

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda^2}\eta_{ij}(\bar{q}_i\gamma_\mu q_i)(\bar{\ell}_j\gamma_\mu \ell_j)$$

$$\frac{d\sigma}{dm_{\ell\ell}} = \frac{d\sigma_{\rm SM}}{dm_{\ell\ell}} - \eta_{ij}\frac{F_{\rm I}}{\Lambda^2} + \frac{F_{\rm NP}}{\Lambda^4}$$



LFU test with Non-Resonant Searches



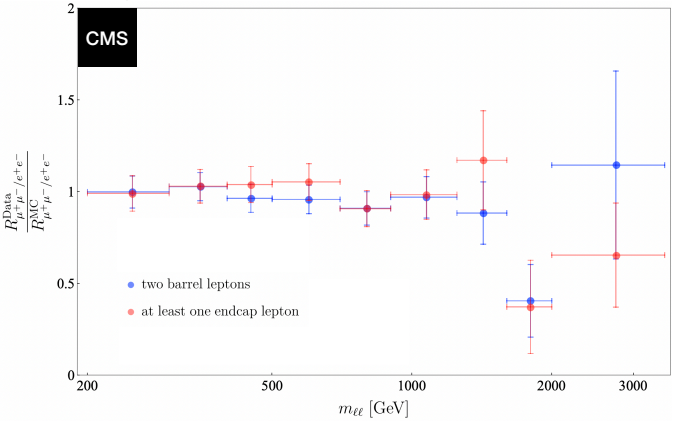
Some of the proposed models would result in a significant deviation from SM of the ratio

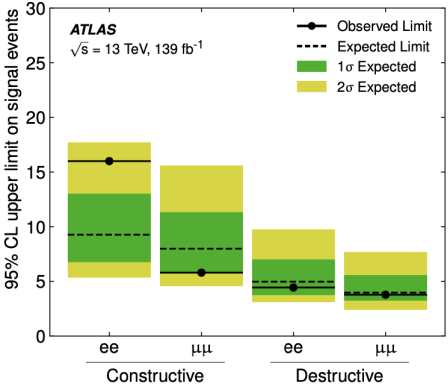
$$R_{\mu\mu/ee} \equiv \frac{d\sigma(pp \to \mu^+\mu^-)/dm_{\mu\mu}}{d\sigma(pp \to e^+e^-)/dm_{ee}}$$

at high $m_{\ell\ell}$.

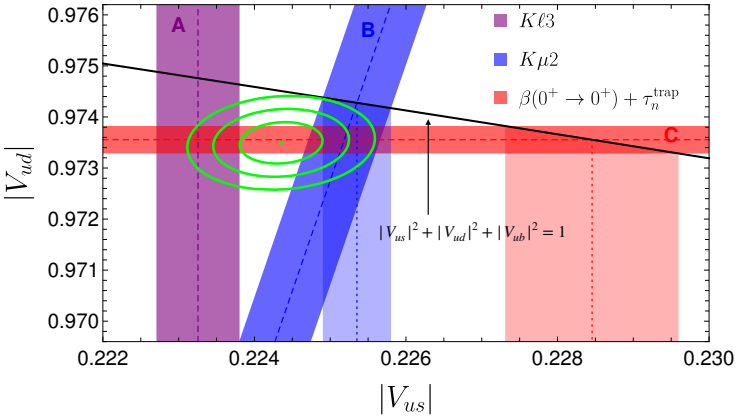
Note: Reduced uncertainties!

ATLAS and CMS Results





Correlation with the Cabibbo Angle Anomaly I



Matthew Kirk's talk

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9985(5)$$

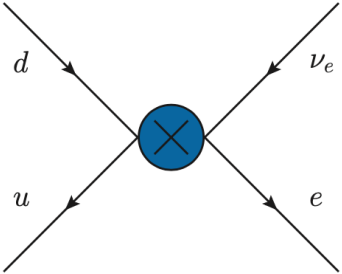
$$\frac{|V_{ud}|^2}{|V_{us}|^2} \approx 20$$

$$|V_{ud}|^2(1-\epsilon)^2 + |V_{us}|^2 + |V_{ub}|^2$$

Note that a deviation from unitarity is also observed in the first column of the CKM matrix $|V_{ud}|^2 + |V_{cd}|^2 + |V_{td}|^2 = 0.9970(18)$, *strengthening the idea of NP related to* V_{ud}

Correlation with the Cabibbo Angle Anomaly II

$$[Q_{\ell q}^{(3)}]_{1111} = (\bar{\ell}_1\gamma^\mu\sigma^I\ell_1)(\bar{q}_1\gamma_\mu\sigma^I q_1)$$



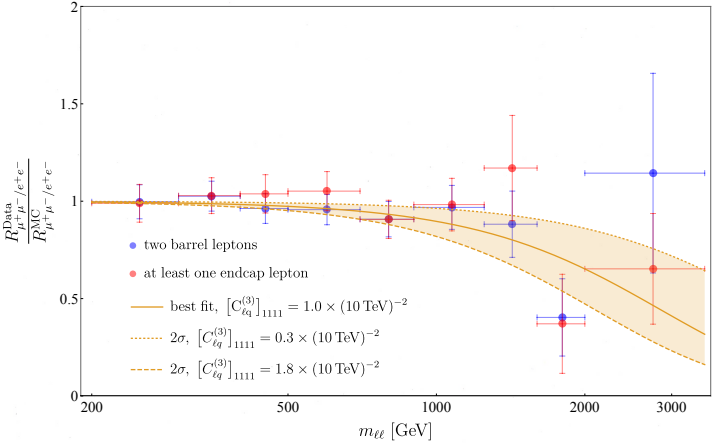
$$\mathcal{L} = \mathcal{L}_{\rm SM} + [C_{\ell q}^{(3)}]_{1111}\Big[(\bar{d}\gamma^\mu P_L d - \bar{u}\gamma^\mu P_L u)\bar{e}\gamma_\mu P_L e + (\bar{u}\gamma^\mu P_L u - \bar{d}\gamma^\mu P_L d)\bar{\nu}\gamma_\mu P_L \nu + 2\left(\bar{d}\gamma^\mu P_L u\bar{\nu}\gamma_\mu P_L e + \bar{u}\gamma^\mu P_L d\bar{e}\gamma_\mu P_L \nu\right)\Big]$$

$$\textbf{CAA}: \ \left[C_{\ell q}^{(3)}\right]_{1111} = \frac{1.22(4)}{(10\,\text{TeV})2}$$

2102.02825 *A.Crivellin, M.Hoferichter, C.A.M.*

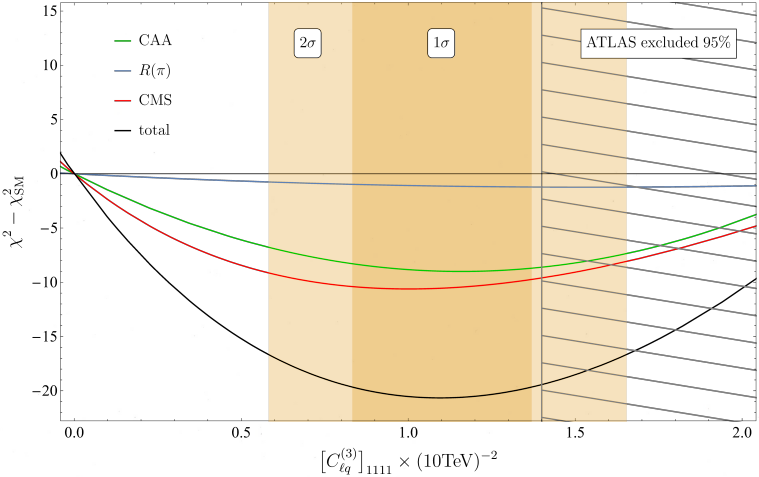
Fitting CMS

- 1st bin normalized to one removes the relative sensitivity to electrons and muons
- cross section dominated by left-handed amplitudes $\Longrightarrow$ changes in the angular distributions small and safely negligible
- $\Delta\chi^2 \equiv \chi^2_{\rm BF} - \chi^2_{\rm SM} \approx -10$



2103.12003 *A.Crivellin, C.A.M., M.Montull*

Combined Result



2103.12003 *A.Crivellin, C.A.M., M.Montull*

$R(\pi)$

$[Q_{\ell q}^{(3)}]_{1111}$ gives a LFUV effect which can be tested by charged pion decay.
At the amplitude level:

$$R(\pi) = \frac{\pi \to \mu\nu}{\pi \to e\nu} = 1 + 0.0006\, [C_{\ell q}^{(3)}]_{1111} \times (10\,\text{TeV})^2$$

CMS + CAA 95% C.L.: $R(\pi)^{\text{exp}} = 1.0010 \pm 0.0009$

$$\frac{0.6}{(10\,\text{TeV})^2} \leq [C_{\ell q}^{(3)}]_{1111} \leq \frac{1.4}{(10\,\text{TeV})^2} \implies 1.0004 \leq R(\pi) \leq 1.0009$$

Future improvements will give a better understanding!

Conclusions I

- So far, no hints for LFUV in high energy searches
- Recently CMS observed an excess in non-resonant di-electrons searches compared to muons!
  ATLAS and HERA also observe more electron events than expected!
- Supporting the idea of NP in β decays to solve the CAA
- A combined explanation of CMS and CAA with $[C_{\ell q}^{(3)}]_{1111}$ improves the agreement with data by $\approx 4.5\sigma$ compared to SM

Conclusions II

Scenario testable:

1. at LHC Run 3 and even more at HL-LHC
2. by improvements in the extraction of V_{us}, V_{ud} and V_{cd}
3. measurements of $R(\pi)$
4. $\tau \to \mu\nu\nu/\tau \to e\nu\nu$

Interesting possibilities arise for model building!

E.g.: Vector triplet for correlations with $b \to s\ell\ell$?