Snowmass RF2 LOI

PIENUXE: Testing Lepton Flavor Universality and CKM Unitarity with Rare Pion Decays

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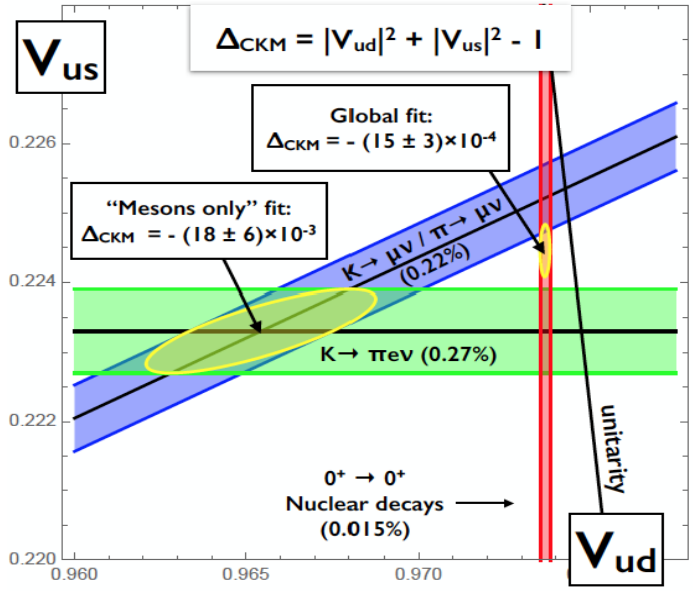
Flavor in the News!

Several lingering unconfirmed flavor anomalies

- Muon g-2 (~3+ σ)
- Lepton universality in B decays (R(K),R(D),R(D*)~3σ)
- Unitarity of CKM first row(~2-3 σ)



V. Cirigliano

Tensions in V_{ud} and V_{us}

Possible connections between LFU and CKM unitarity.

Crivellin and Hoferichter 2020

Charged Lepton Flavor Universality

e/μ tested in π and tau decay at precision O(10^{-3})

$$R_{e/\mu}^{theory} = \frac{\Gamma(\pi \to e\nu(\gamma))}{\Gamma(\pi \to \mu\nu(\gamma))} = (1.2353 \pm 0.0002)\, x10^{-4} \quad (\pm 0.016\%)$$

Marciano/Sirlin → Cirigliano

Possibly the most accurately calculated decay process involving hadrons.

Current Result (PDG): $R_{e/\mu}^{\exp \pi} = 1.2327 \pm 0.0023 x10^{-4}$ $(\pm 0.19\%)$

NEXT GENERATION PIENUXE GOAL $(\pm 0.015\%)$

$$\to \frac{g_e}{g_\mu} \sim (\pm 0.0075\%)$$

Sensitive to new pseudoscalar interations at mass scale 2000 TeV.

(Leptoquarks, gauge bosons, compositeness, hidden sectors, ν_H ....)

CKM Unitarity: Vud, Vus/Vud

Tested in super-allowed β and K decays at precision O(10^{-4})

$\pi^+ \to \pi^0 e^+ \nu$: Theoretically cleanest method to obtain V_{ud}

Present result: PIBETA Experiment (2004) $(\pm 0.64\%)$

$$V_{ud} = 0.9739(28)_{exp}(1)_{th}$$

$$B(\pi^+ \to \pi^0 e^+ \nu) = (1.036 \pm 0.004_{stat} \pm 0.004_{syst} \pm 0.003_{\pi e2}) \times 10^{-8} \quad (\pm 0.6\%)$$

NEXT GENERATION EXPERIMENT GOAL: $(\pm 0.06\%)$

$\frac{B(K \to \pi l \nu)}{B(\pi^+ \to \pi^0 e^+ \nu)}$: Theoretically clean method to obtain $\frac{V_{us}}{V_{ud}}$

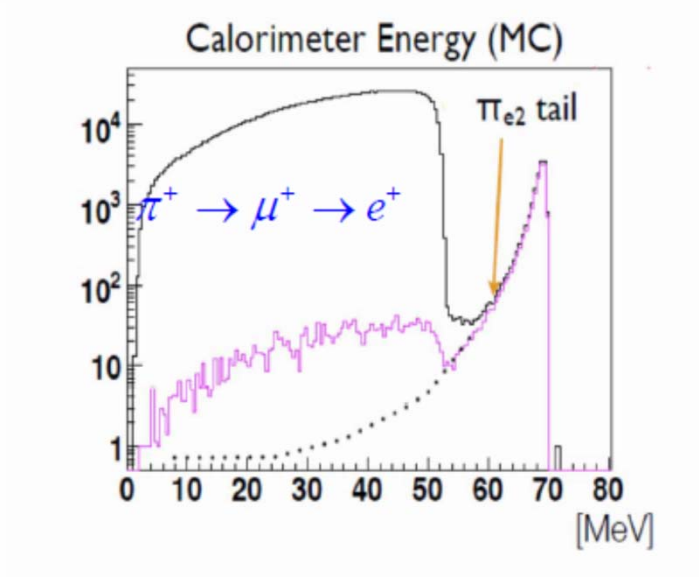
Czarnecki, Marciano , Sirlin (2020)

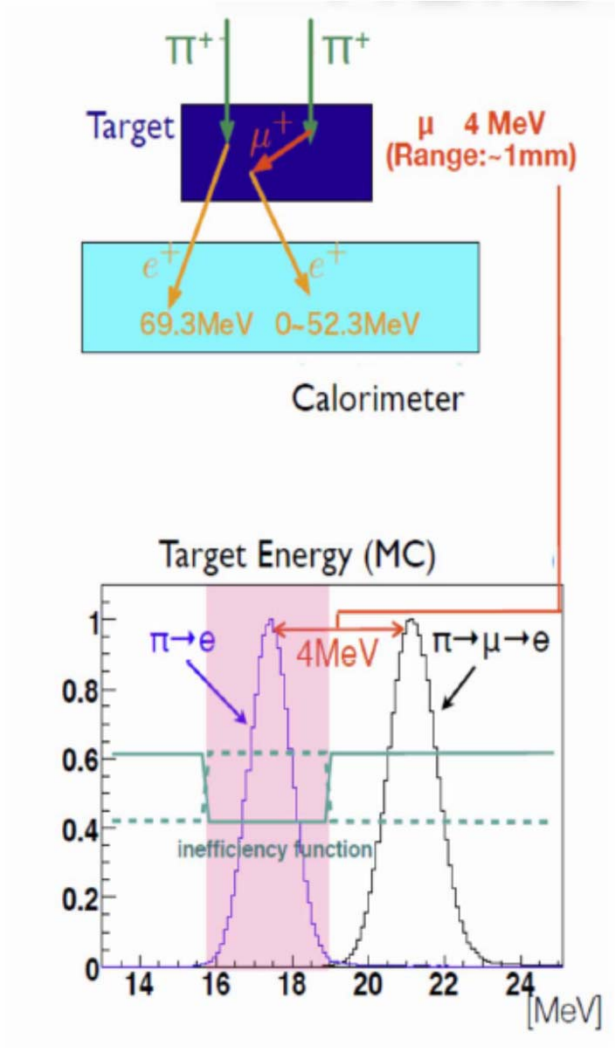
Improve $B(\pi^+ \to \pi^0 e^+ \nu)$ precision by >3x $\to$ $\frac{V_{us}}{V_{ud}} < \pm 0.2\%$

Offers a new complemetary constraint in the $V_{us} - V_{ud}$ plane.

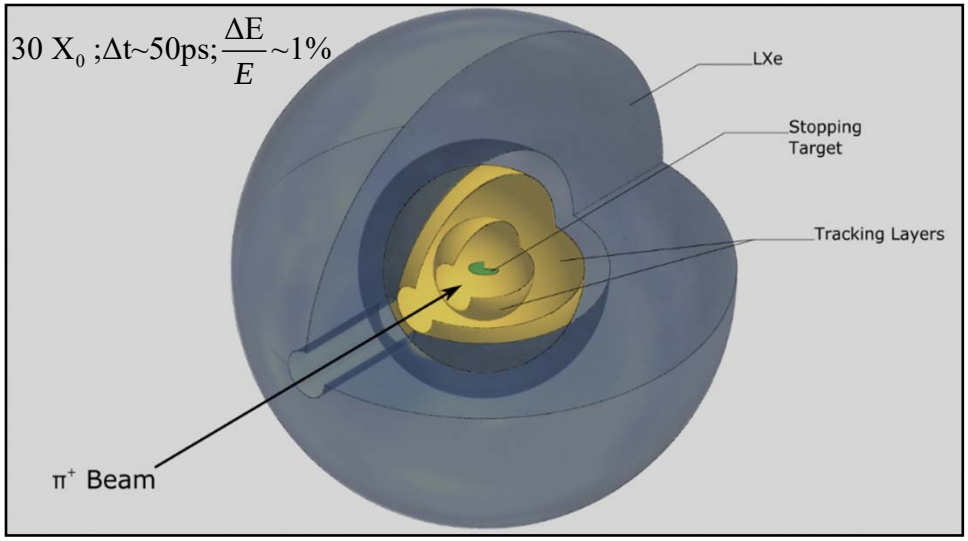
$\pi \to e\nu$: Experimental Method

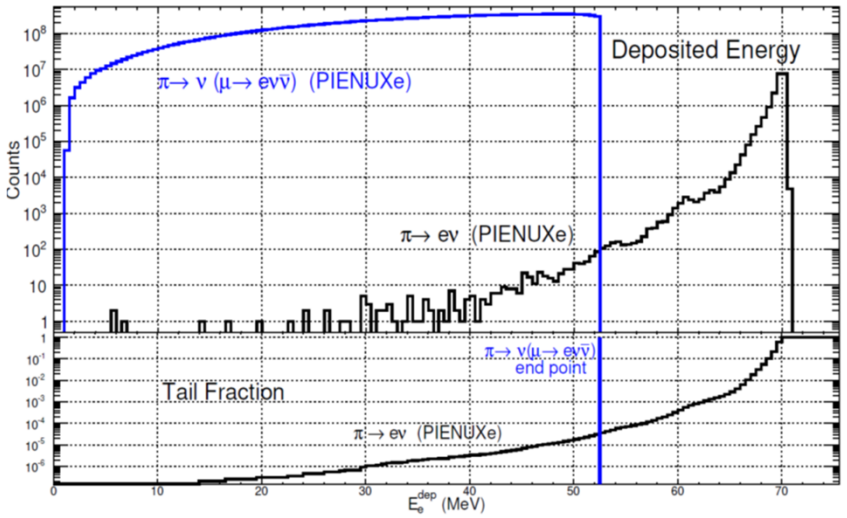
- Pions stopped in an active target
- Positrons tracked and energy measured in a calorimeter
- Decays tagged in target and by energy and timing
- Principal sytematic uncertainty: Low energy "tail" of $\pi \to e\nu$ events under $\mu \to e\nu\nu$ "background".





PIENUXE: New Rare π Decay Experiment with LXe





Faster calorimeter response time x10-100.

Low energy tail reduced x 10

$$\pi^+ \rightarrow e^+ \nu$$

- π^+Beam: 75 MeV/c ; 2x10^5 Hz
- Tracking –SciFi-SiPM, Si pixels
- LXe calorimeter
- Sensitivity, Precision: 10^8 events ±0.015% in 1 yr

$$\frac{g_e}{g_\mu} \sim (\pm 0.0075\%)$$

$$\pi^+ \rightarrow \pi^0 e^+ \nu$$

- π^+Beam: 75 MeV/c ; 3x10^7 Hz
- Sensitivity, Precision: 10^6 events ±0.1% in 1 yr

$$V_{ud} \sim (\pm 0.03\%) \qquad \frac{V_{us}}{V_{ud}} \sim (\pm 0.1\%)$$

PIENUXE: Summary

Exploring the possibility of a new experiment aimed at improving the precision of rare pion decay measurements by an order of magnitude.

$$R_{e/\mu} = \frac{\Gamma\left(\pi^+ \to e^+ \nu(\gamma)\right)}{\Gamma\left(\pi^+ \to \mu^+ \nu(\gamma)\right)} \quad (\pm 0.015\%) \to \frac{g_e}{g_\mu} \sim (\pm 0.0075\%)$$

$$\mathrm{B}(\pi^+ \to \pi^0 e^+ \nu) \quad (\pm 0.06\%) \to V_{ud} \sim (\pm 0.03\%) \quad \frac{V_{us}}{V_{ud}} \sim (\pm 0.1\%)$$

Sensitive to new flavor physics at extremely high mass scales and violations of LFU and CKM unitarity; searches for hidden sector, ν_H ....