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Solutions to the MiniBooNE Anomaly from New Physics in Charged Meson Decays

Magnificent CEνNS Workshop
October 7, 2021

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Publication forthcoming

MiniBooNE Anomaly

Can we correlate the excess to charged meson physics?

- Excess events seen in neutrino mode
- Proportionally smaller in anti-neutrino mode
- No significant excess in the dump mode

Solutions:

- Solutions in the neutrino sector or from DM sourced by π^0 & dark brem are popular
- However, the relative production of + vs. - mesons and their focusing by the magnetic horns could play a role in the asymmetry of the excess

- **MiniBooNE**, 2021 [2006.16883]
- **MiniBooNE**, 2019 [1807.06137]
- **MiniBooNE**, 2018 [1805.12028]

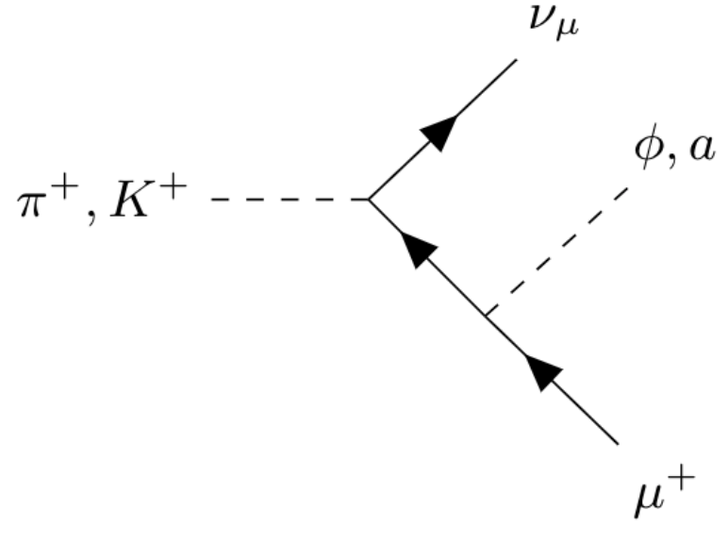
		Excess	POT	Mesons Focused?
Target Mode	Neutrino Mode	560.6±119.6	1.875E+21	π^+, K^+
	Anti-neutrino Mode	77.4±28.5	1.127E+21	π^-, K^-
Dump Mode		None	1.86E+20	None

Phenomenological Model

Long-lived Scalar or Pseudoscalar

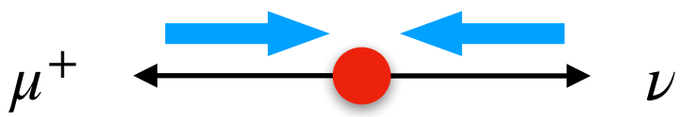
$$\mathscr{L}_S \supset g_\mu \phi \bar{\mu}\mu + g_n Z'_\alpha \bar{u}\gamma^\alpha u + \frac{\lambda}{4}\phi F'_{\mu\nu}F^{\mu\nu} + i\kappa Z'_\mu \phi \partial^\mu \phi^* + \frac{1}{2}m_\phi^2 \phi^* \phi + \frac{1}{2}m_{Z'}^2 Z'_\alpha Z'^\alpha + \text{h.c.}$$

$$\mathscr{L}_P \supset i g_\mu a \bar{\mu}\gamma^5 \mu + g_n Z'_\alpha \bar{u}\gamma^\alpha u + \frac{\lambda}{4}a F'_{\mu\nu}\tilde{F}^{\mu\nu} + i\kappa Z'_\mu a \partial^\mu a^* + \frac{1}{2}m_a^2 a^* a + \frac{1}{2}m_{Z'}^2 Z'_\alpha Z'^\alpha + \text{h.c.}$$

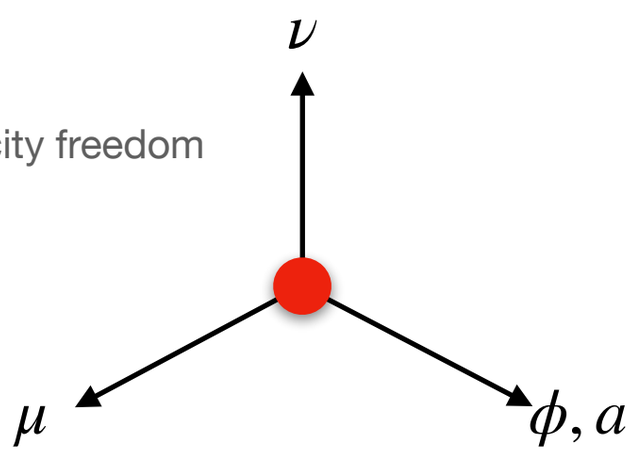


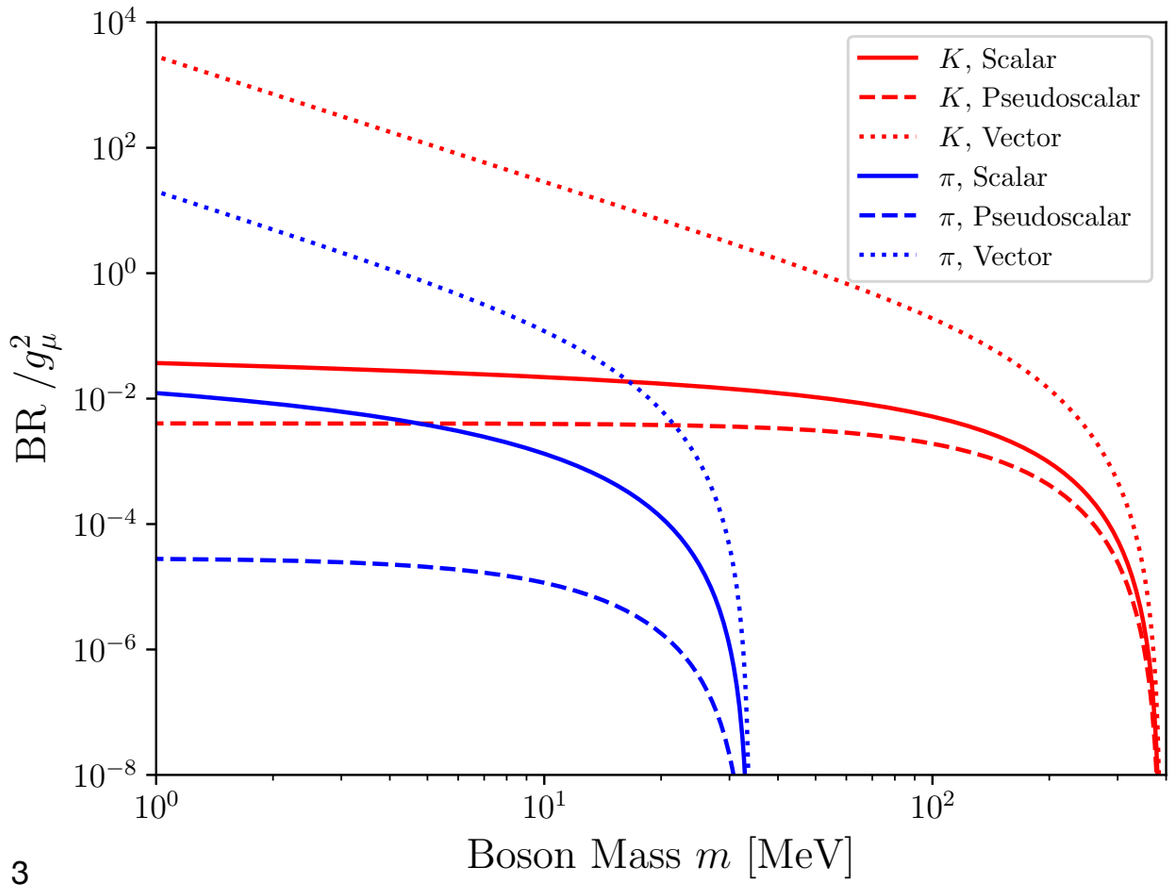
- Scalar or pseudo scalar coupled to muons permits the 3-body decay of the charged mesons
- The 3-body decay ***isn't necessarily phase-space suppressed;***

2-body: Only one helicity combination selected out



3-body: helicity freedom





Scattering Physics

Primakoff-like Signal

$$\mathscr{L}_S \supset g_\mu \phi \bar{\mu}\mu + g_n Z'_\alpha \bar{u}\gamma^\alpha u + \frac{\lambda}{4}\phi F'_{\mu\nu}F^{\mu\nu} + i\kappa Z'_\mu \phi \partial^\mu \phi^* + \frac{1}{2}m_\phi^2 \phi^*\phi + \frac{1}{2}m_{Z'}^2 Z'_\alpha Z'^\alpha + \text{h.c.}$$

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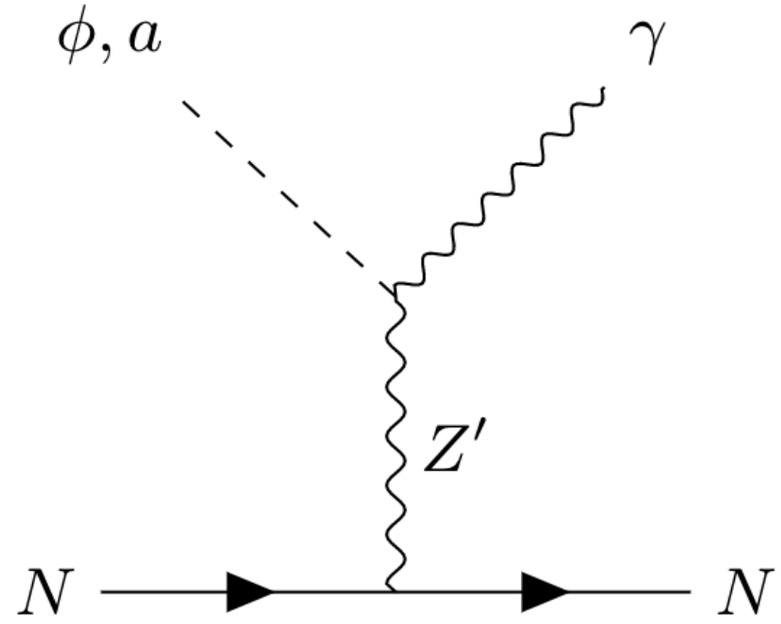
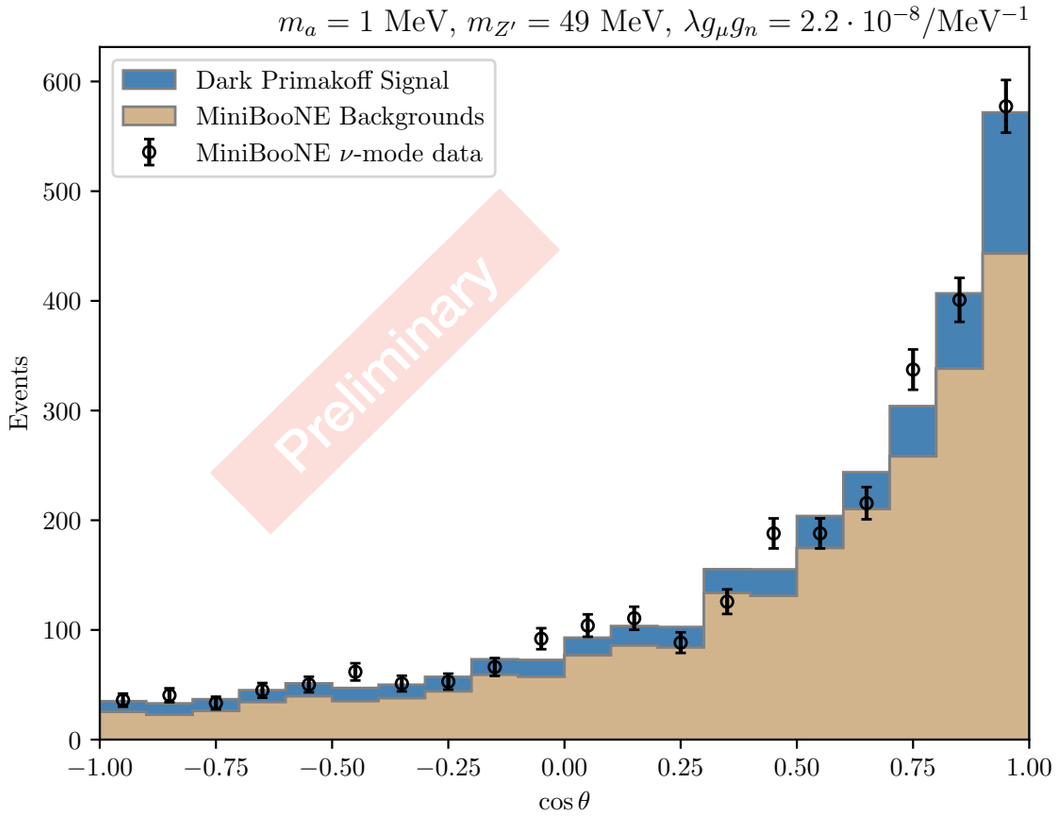


- Long-lived bosons arrive at the MB detector and can undergo a ``Primakoff-like" scattering process via a heavy mediator Z' with mass $O(100)$ MeV
- The massive mediator gives the model an articulate degree of freedom to accommodate the observed forward, but not too-forward, cosine spectrum

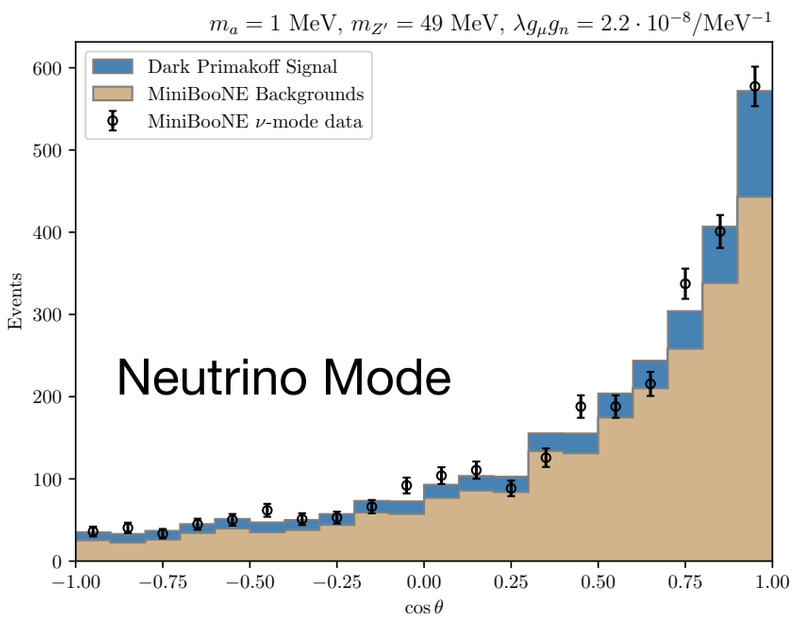
Constraints

- Constraints on the scalar-Z'-γ coupling from BaBar can be avoided if the Z' decays dominantly to $\phi\phi$ or aa
- Loop couplings to $\gamma\gamma$ suppressed if the scalar mass is light enough



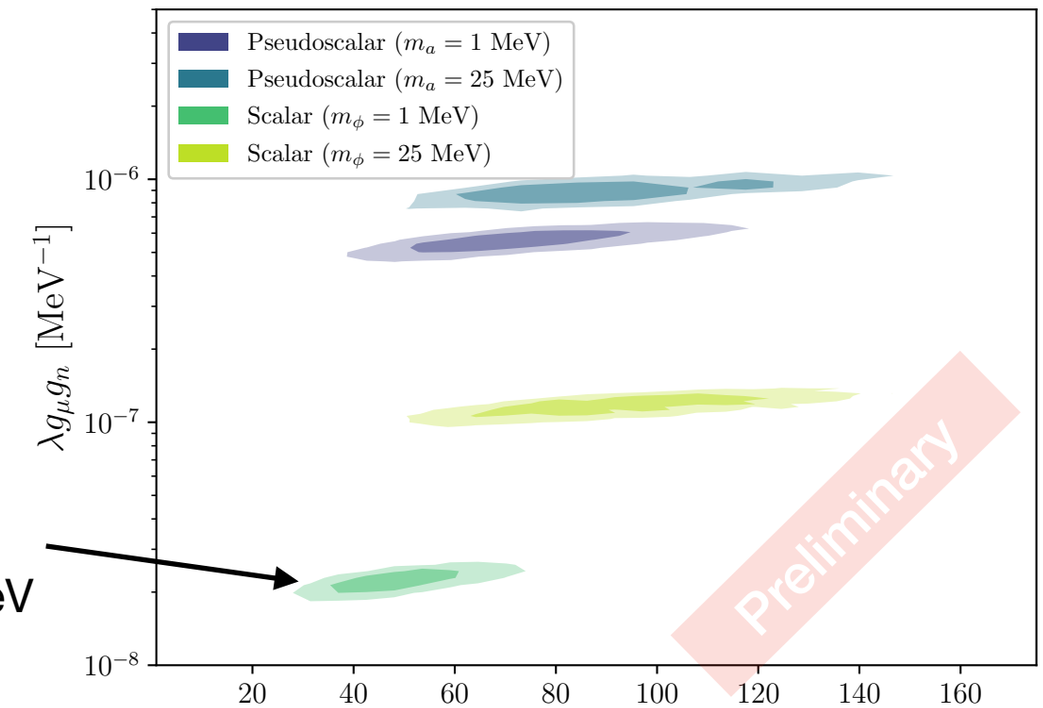
MiniBooNE Fit

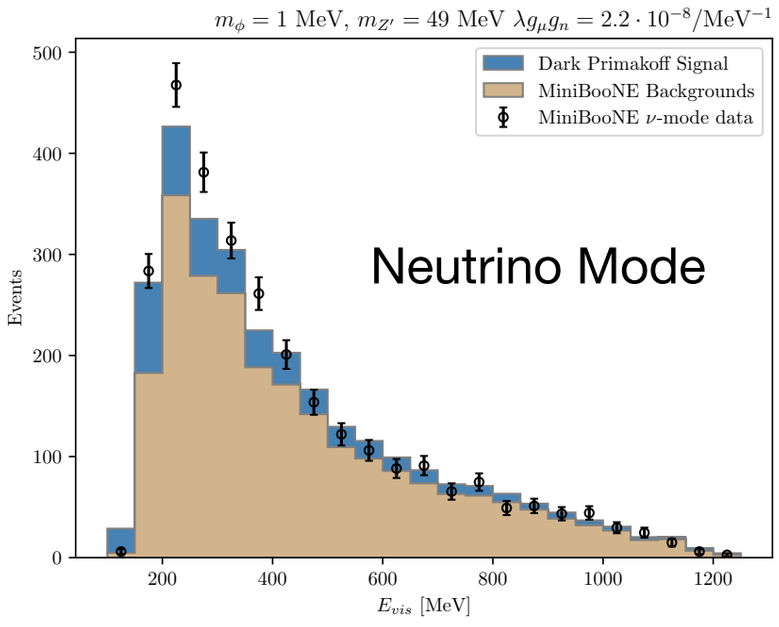
Fit to cosine / visible energy

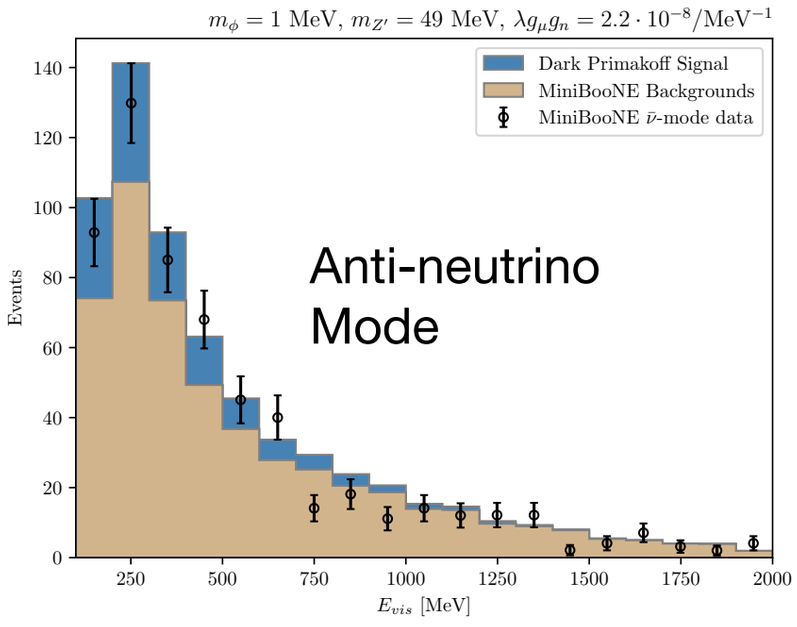


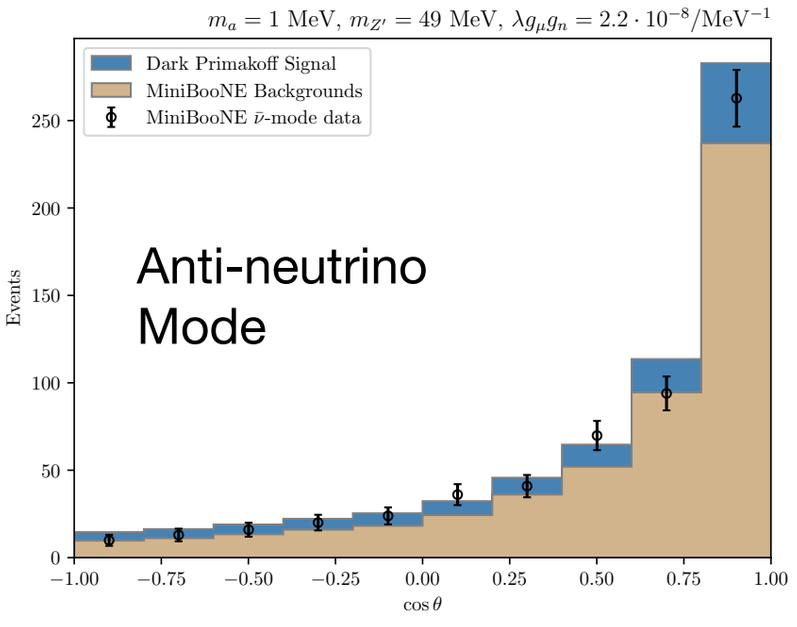
Scalar, 1 MeV:

$g_n g_\mu \lambda \sim 2 \cdot 10^{-8}/\text{MeV}$





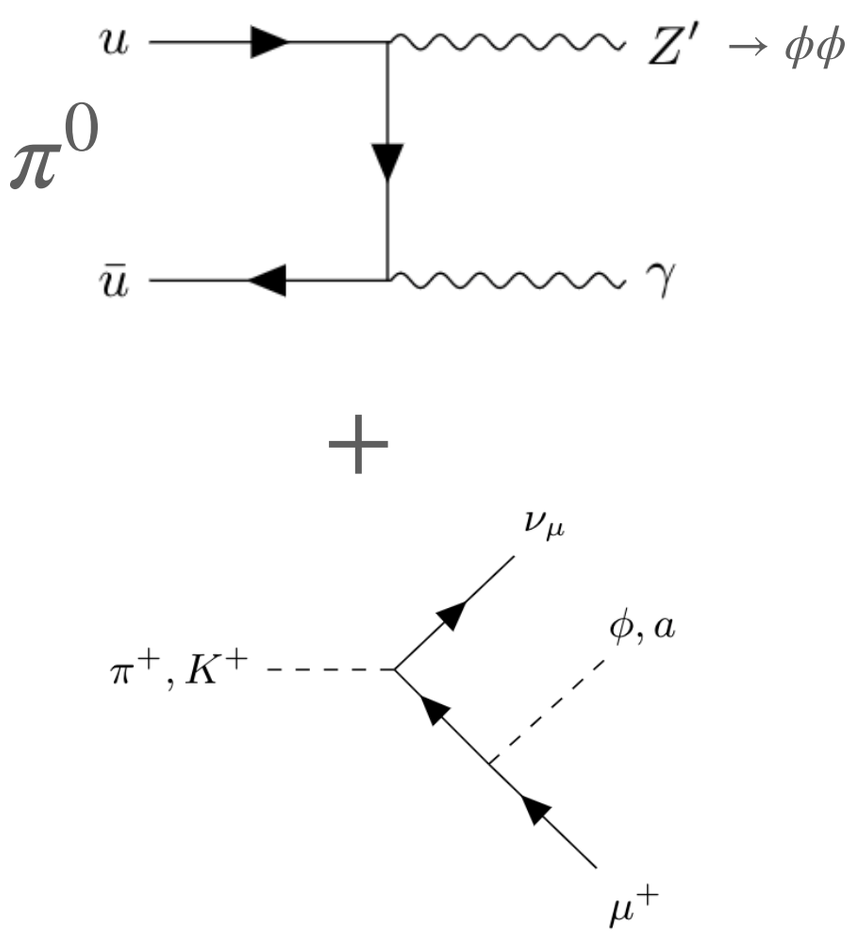




Opportunities for CEνNS Experiments

$$\mathscr{L}_S \supset g_\mu \phi \bar{\mu}\mu + g_n Z'_\alpha \bar{u}\gamma^\alpha u + \frac{\lambda}{4}\phi F'_{\mu\nu}F^{\mu\nu} + i\kappa Z'_\mu \phi \partial^\mu \phi^* + \frac{1}{2}m_\phi^2 \phi^*\phi + \frac{1}{2}m_{Z'}^2 Z'_\alpha Z'^\alpha + \text{h.c.}$$

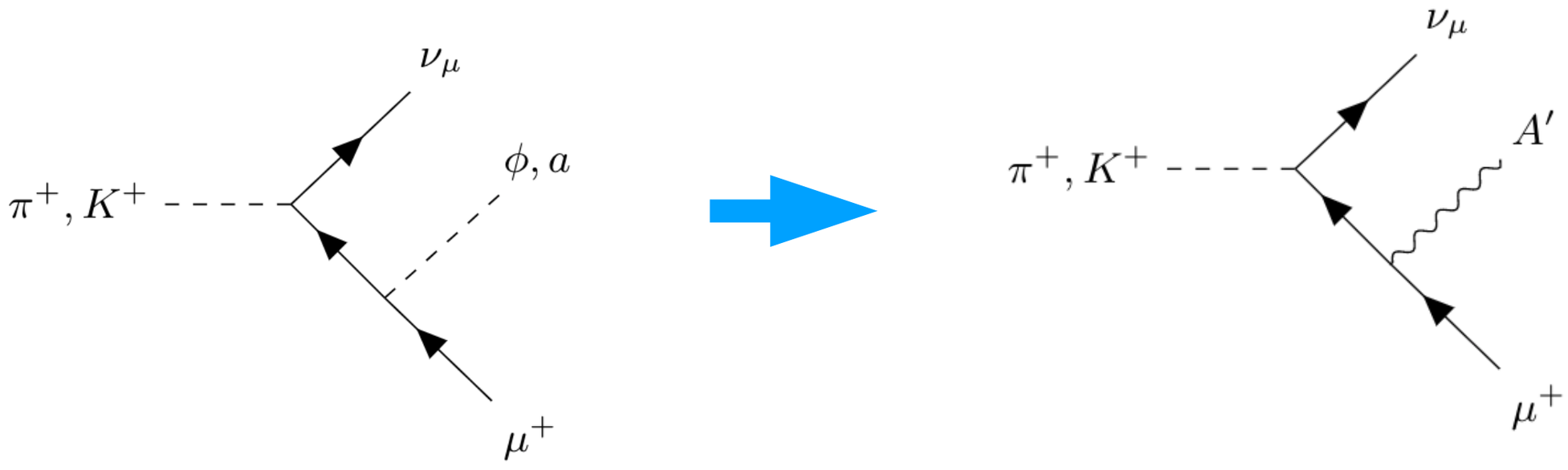
$$\mathscr{L}_P \supset i g_\mu a \bar{\mu}\gamma^5 \mu + g_n Z'_\alpha \bar{u}\gamma^\alpha u + \frac{\lambda}{4} a F'_{\mu\nu}\tilde{F}^{\mu\nu} + i\kappa Z'_\mu a \partial^\mu a^* + \frac{1}{2}m_a^2 a^* a + \frac{1}{2}m_{Z'}^2 Z'_\alpha Z'^\alpha + \text{h.c.}$$



- MiniBooNE / Beam dumps:
  - charged mesons focused, neutral mesons unfocused
- CEνNS experiments (CCM, JSNS2, COHERENT):
  - no focusing, but much closer baseline
- This opens up sensitivity to both 3-body charged meson decay $M \to \mu\nu\phi$ as well as neutral meson production of the heavy mediator $\pi^0 \to \gamma Z'(Z' \to \phi\phi)$

Thank You!

See Doojin Kim's talk for an alternative approach:



Long-lived boson

Short-lived decay to DM

$A' \to \chi\chi$