Flavor-Changing Light Bosons with Accidental Longevity

Kun-Feng Lyu
School of Physics and Astronomy, University of Minnesota

In collaboration with Yohei Ema, Zhen Liu and Maxim Pospelov

JHEP **02 (2023) 135** arXiv:2211.00664

Phenomenology Conference 2023

Outline

- Motivation
- Model
- Muon Magnetic Moment
- e-mu case
- mu-tau case

Motivation

- The latest muon g-2 measurement shows 3.7 sigma deviation from SM prediction.
- There have been many BSM scenarios to explain.
- We propose a simple scalar flavor off-diagonally coupled to leptons. A new mass window is probed.
- In the mass window, it becomes accidentally long-lived and thus can be probed in various experiments.

Model

- Consider a complex scalar phi carrying +1 muon number and -1 l number

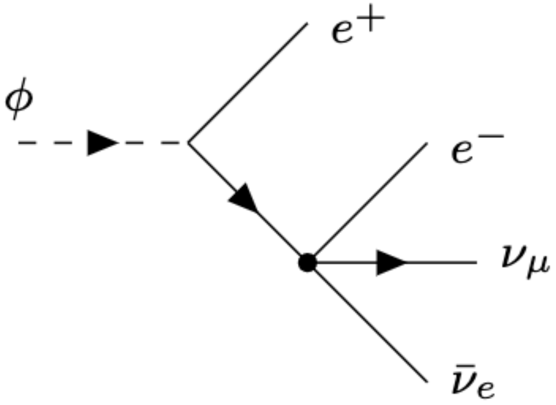
$$\mathcal{L} = |\partial\phi|^2 - m_\phi^2 |\phi|^2 + \phi\,\bar{\mu}\,(g_V + g_A\gamma_5)\,l + \phi^*\bar{l}\,(g_V^* - g_A^*\gamma_5)\,\mu,$$

- In the mass range, it can become long-lived accidentally

$$|m_\mu - m_l| < m_\phi < m_\mu + m_l$$

$m_\phi < m_\mu + m_l$ phi can not decay to mu + l

$|m_\mu - m_l| < m_\phi$ Avoid lepton decay branching ratio.

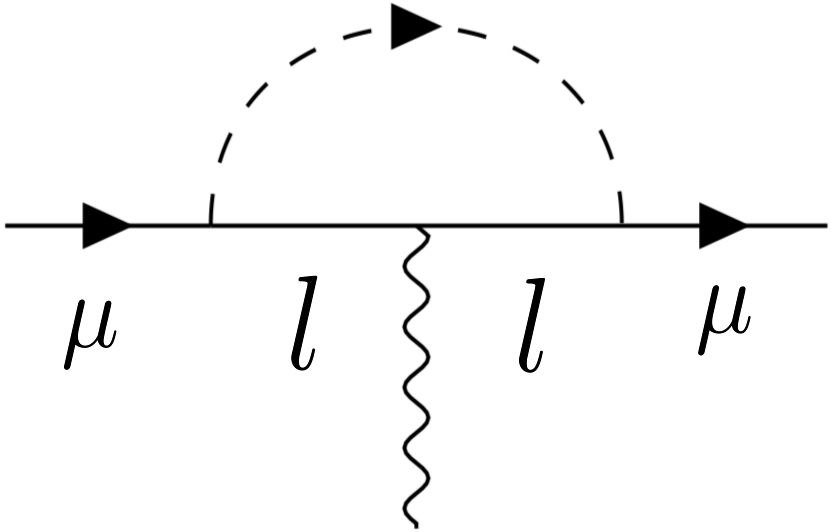


Muon Magnetic Moment

- The latest measurement

$$\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} = (251 \pm 59) \times 10^{-11}$$

2104.03281

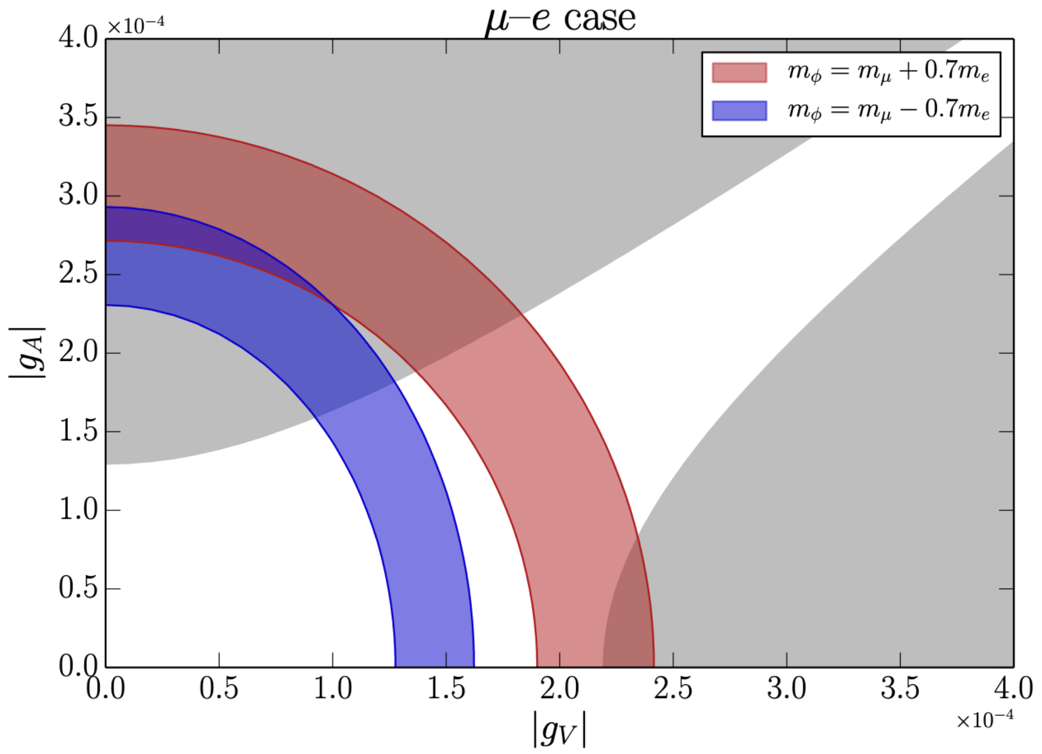


$$a_\mu^{(\phi)} = \frac{m_\mu}{8\pi^2}\int_0^1 dz \frac{(1-z)^2\left[(|g_V|^2+|g_A|^2)zm_\mu + (|g_V|^2-|g_A|^2)m_l\right]}{-z(1-z)m_\mu^2 + (1-z)m_l^2 + zm_\phi^2}$$

To avoid EDM, we require $\mathrm{Im}[g_V^* g_A] = 0$

e-mu case

Muon g-2 constraint



Shaded: electron g-2 exclusion region

At this region, the decay length is around 10^{10} km

- Muonium

  the quasi-bound state of mu and e, can decay to phi plus a photon.

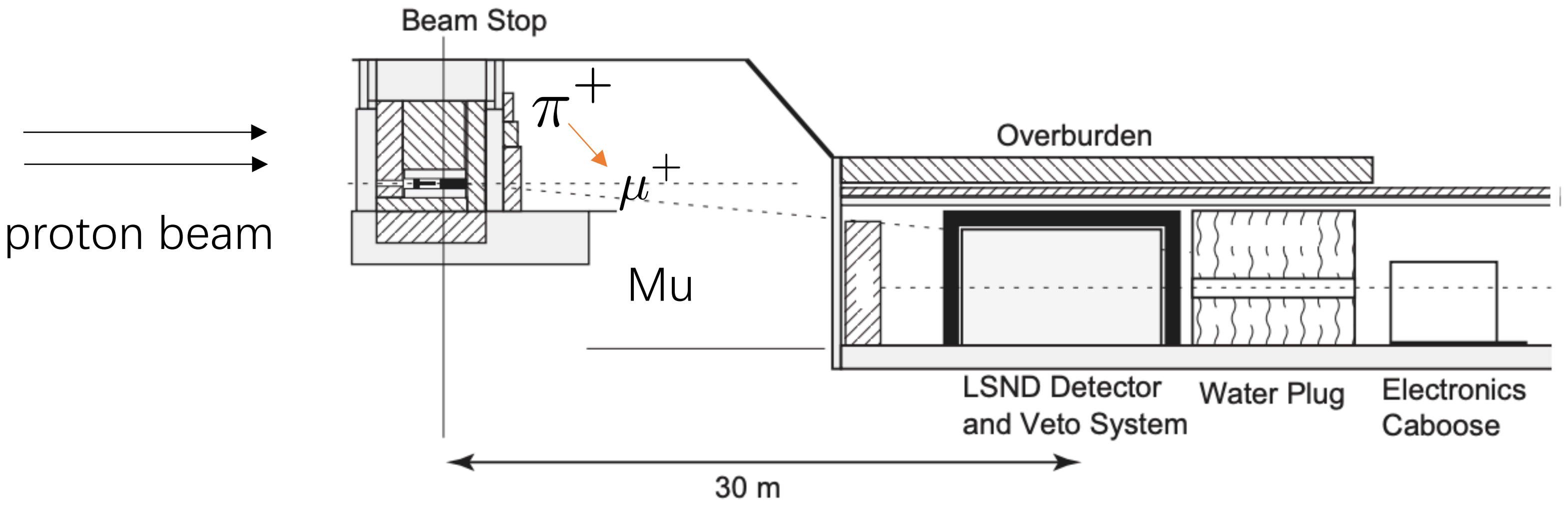
$$\mathrm{Br}(\mathrm{Mu}^{(S=1)} \to \text{invisible}) < 5.7 \times 10^{-6}$$

1209.0060

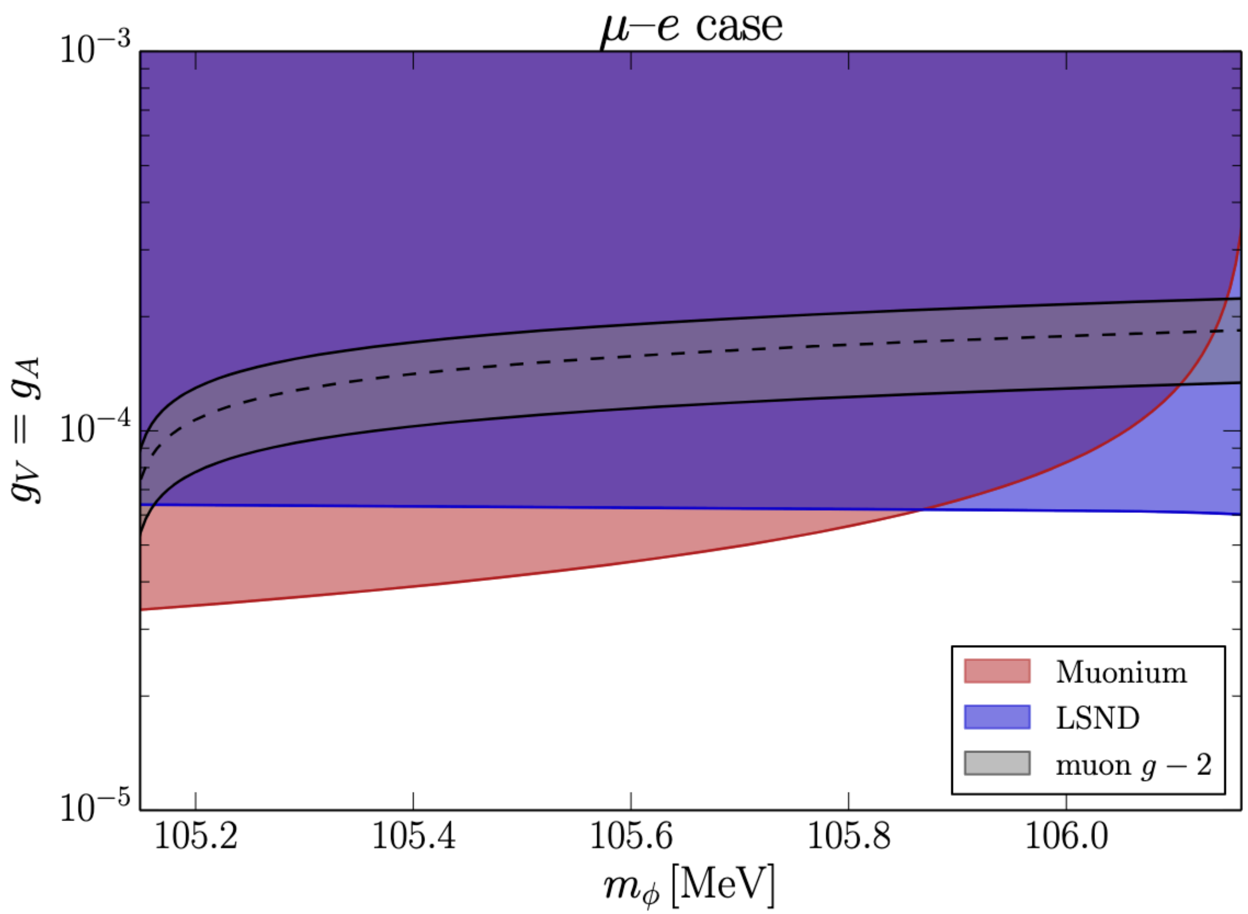
LSND Experiment

- We need intense muon source.
- Originally to measure mu-neutrino to e-neutrino oscillation.
- Mu+ can be produced by the meson pi+, it can form muonium when traveling through the water.
- muonium decay -> phi

  Phi decay in the LSND detector.



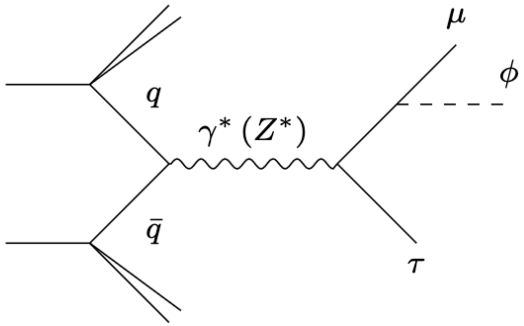
hep-ex/0104049



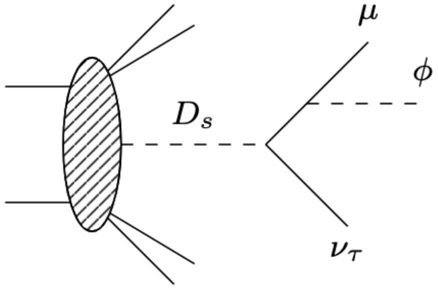
The parameter space that can explain muon g-2 is excluded by the LSND!

mu-tau case

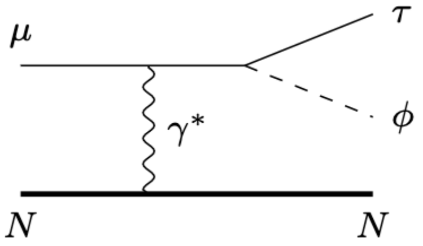
- Phi is heavier than that in e-mu case.
- We can probe it in the higher energy proton beamdump experiments.
- There are mainly 3 channels for the production.



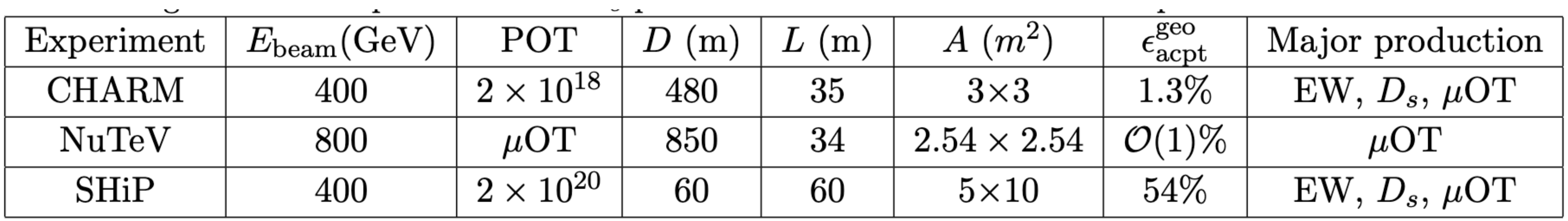
“Direct EW”



“D_s decay”

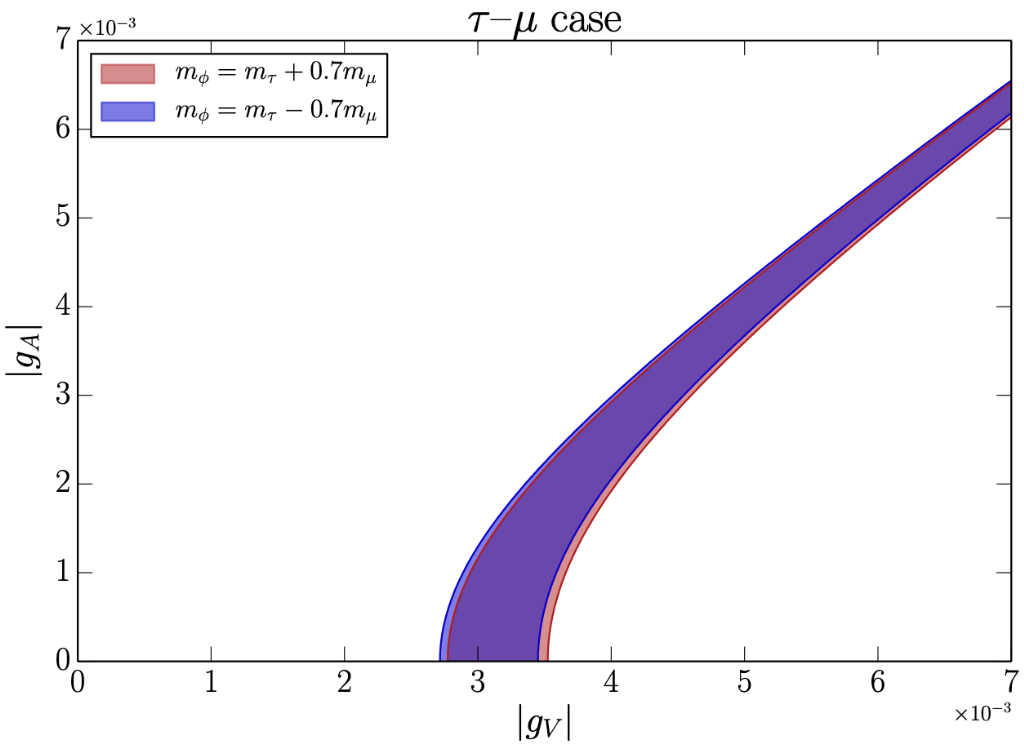


“μ on target”



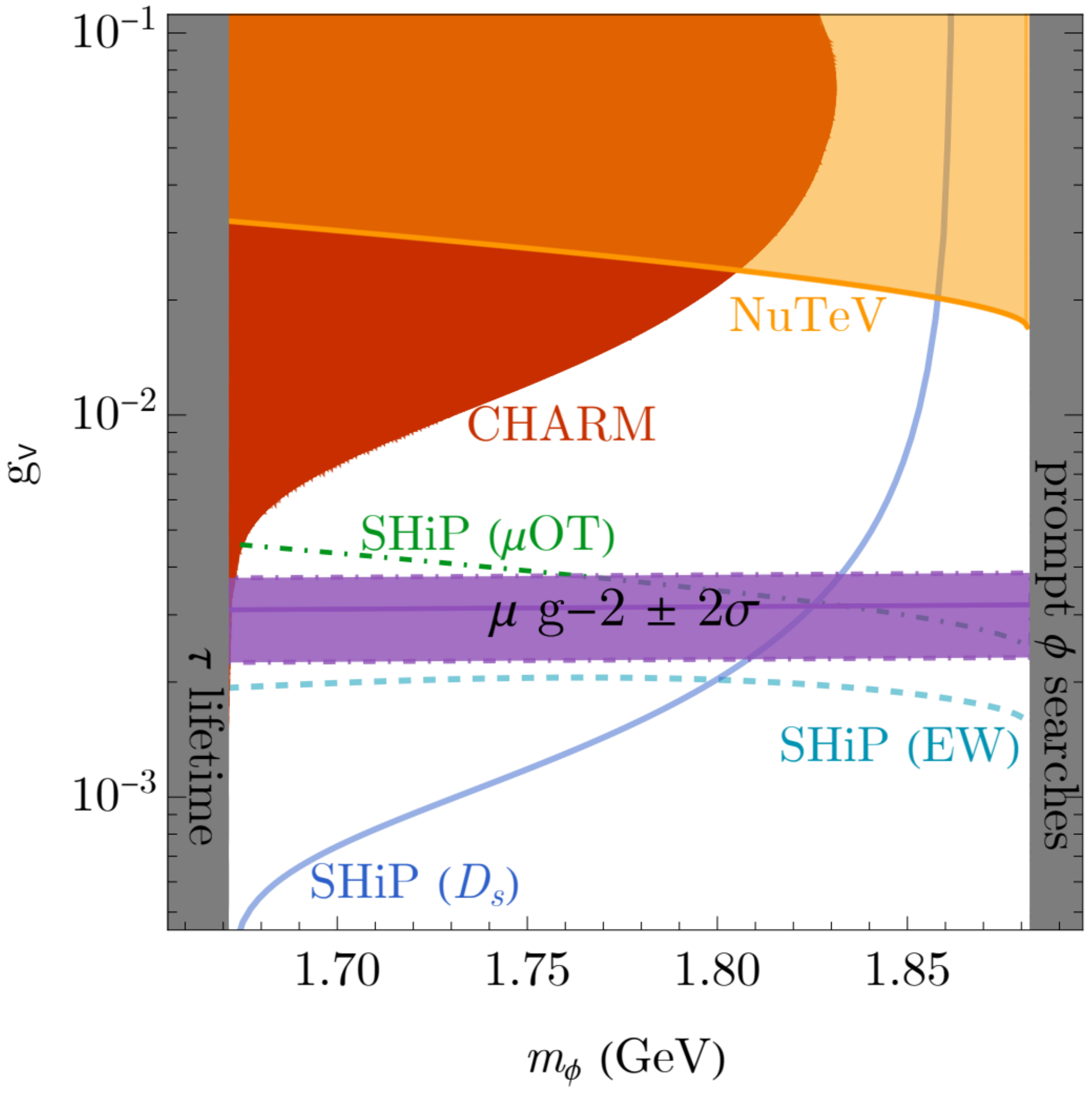
Experiment	E_{beam}(GeV)	POT	D (m)	L (m)	A (m^2)	$\epsilon_{\text{acpt}}^{\text{geo}}$	Major production
CHARM	400	2×10^{18}	480	35	3×3	1.3%	EW, D_s, μOT
NuTeV	800	μOT	850	34	2.54×2.54	$\mathcal{O}(1)$%	μOT
SHiP	400	2×10^{20}	60	60	5×10	54%	EW, D_s, μOT

Muon g-2



The corresponding decay length is around 10 km.

Can be detected in the far detector.



- CHARM and NuTeV cannot exclude the parameter region that explains the muon g − 2 anomaly.
- While the future SHiP experiment covers the whole parameter space.

Conclusion

- We study the phenomenology of a complex scalar coupled to mu and either e or tau motivated by muon g-2.
- The scalar becomes long-lived in the mass window we considered.
- For e-mu case, phi can be produced by the muonium that is formed in LSND proton beamdump experiment. The excess events shows the the g-2 allowed region is excluded.
- For mu-tau case, phi can be produced by the Drell-Yan process, heavy meson decay and muon-target. The future SHiP can cover most parameter space.

Thank you!

Backup

A real scalar will induce the Muonium anti-muonium transition.

Also it can induce the same sign lepton signals.

phi can induce EDM

$$d_\mu = -\frac{\mathrm{Im}(g_V^* g_A) m_l}{8\pi^2} \int_0^1 dz \frac{(1-z)^2}{-z(1-z)m_\mu^2 + (1-z)m_l^2 + z m_\phi^2},$$

$$d_l = -\frac{\mathrm{Im}(g_V^* g_A) m_\mu}{8\pi^2} \int_0^1 dz \frac{(1-z)^2}{-z(1-z)m_l^2 + (1-z)m_\mu^2 + z m_\phi^2}.$$

$$\mathrm{Im}[g_V^* g_A] = 0$$

The high-intensity 798 MeV proton beam from the linear accelerator generated a large pion flux from the water target.