Theory working group

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University of Virginia

Theory working group

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Comments, questions, and members welcome!

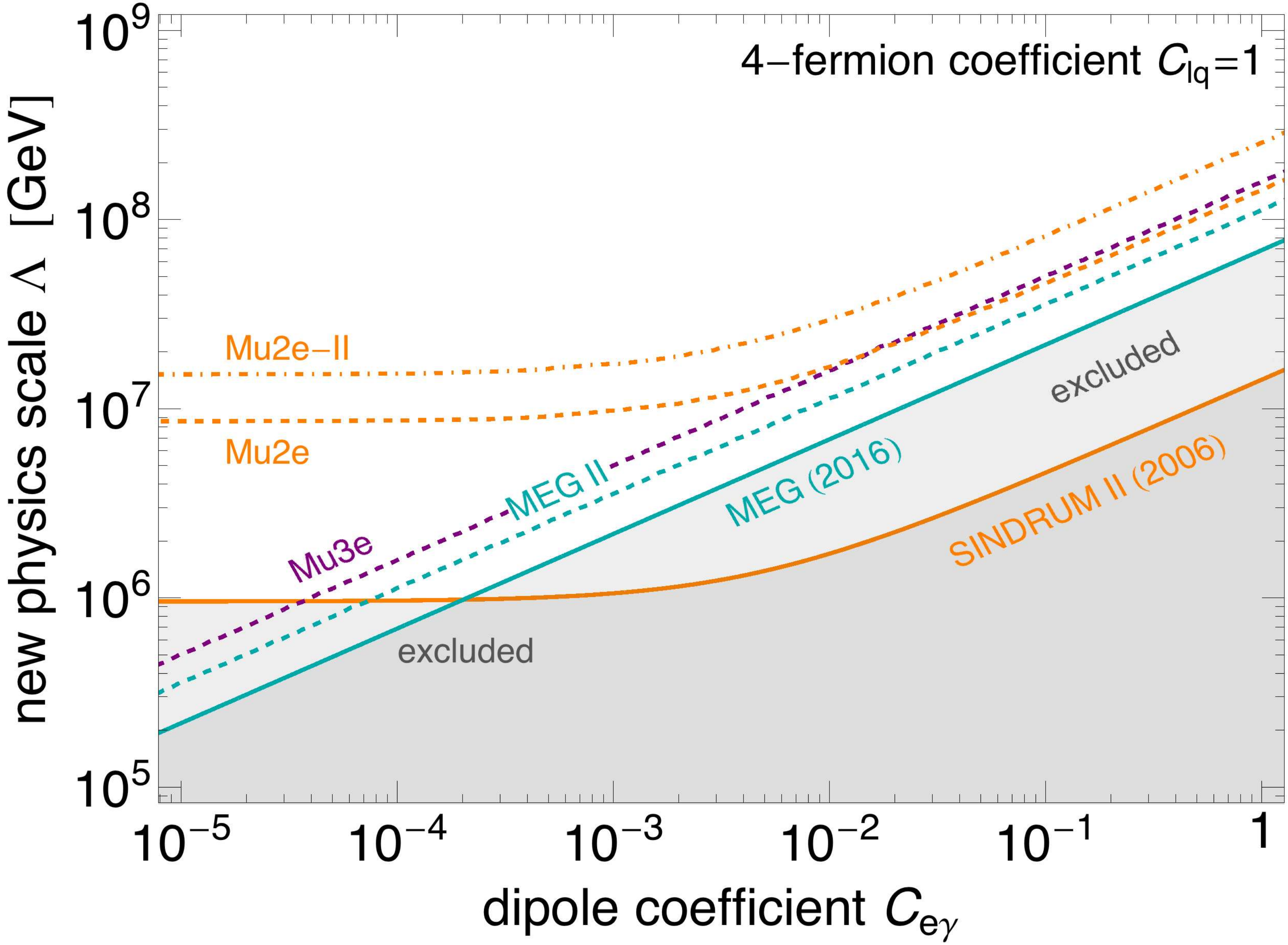
White paper theory section

- General motivation for LFV
- Specific motivation for Mu2e upgrade
- Isotope dependence of muon-to-electron conversion and identification of next targets
- Isotope dependence of muon decay in orbit background
- Motivation for other searches ($\mu \to e\, X$ & $\mu^- \to e^+$)

General motivation for LFV

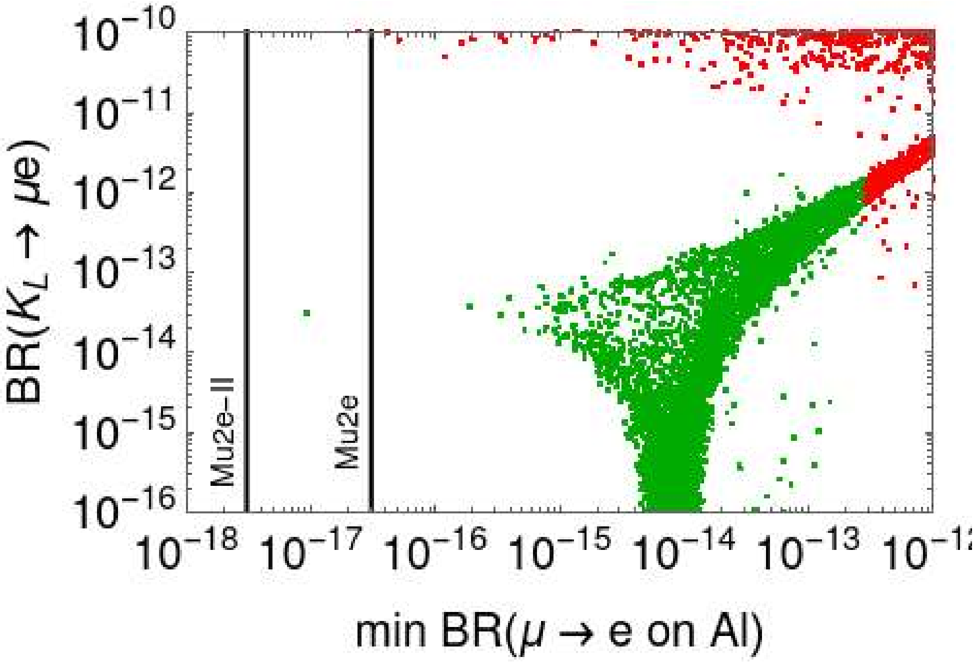
- Standard arguments:
  - neutrino oscillations motivate LFV
  - different models/operators give $\mu\to e\gamma$, $\mu\to 3e$, $\mu\to e$ con.
  - μLFV probes scales far above colliders
- Motivation by anomalies:
  - anomalies in $(g\text{-}2)_\mu$ and B-meson decays hint at special status of muons
  - models generically predict μLFV

$$\mathcal{L}_{\text{eff}} = \frac{C_{e\gamma}}{\Lambda^2} \langle H \rangle \, \bar{e}_L \, \sigma^{\mu\nu} \mu_R \, F_{\mu\nu} + \frac{C_{\ell q}}{\Lambda^2} (\bar{e}_L \, \gamma^\mu \mu_L) (\overline{Q} \, \gamma_\mu Q)$$

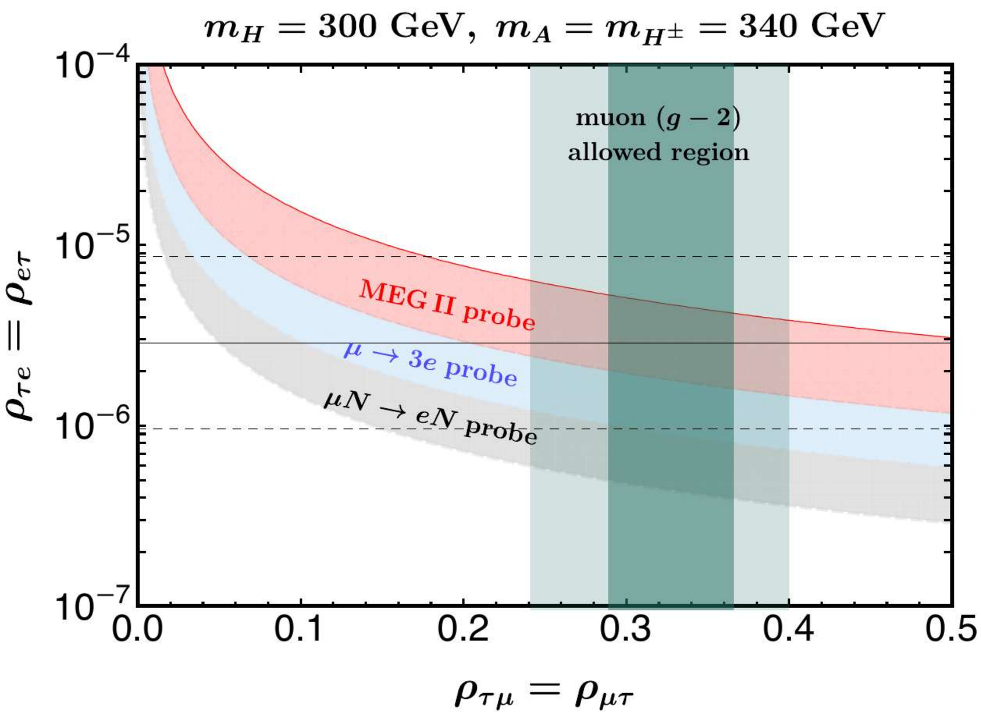


Specific motivation for Mu2e-II

- B-meson anomalies hint at leptoquarks, which generically enhance $\mu \to e$ conversion over $\mu \to e\gamma$, $\mu \to 3e$.
- Mu2e-II can fully exclude some models:



[Heeck & Teresi, 1808.07492]



[Hou & Kumar, 2107.14114]

Isotope dependence of mu-to-e conversion & identification of next targets

- If mu→e conversion is observed (yeay!), we can start looking for the underlying operator.

$$\mathcal{L}_{\mu e} = -\frac{4G_F}{\sqrt{2}} \sum_{X=L,R} \Bigg[m_\mu C_{D,X}\, \bar{e}\sigma^{\alpha\beta} P_X \mu\, F_{\alpha\beta} + \sum_{N=p,n} \Big(C^N_{S,X}\, \bar{e} P_X \mu\, \bar{N} N + C^N_{P,X}\, \bar{e} P_X \mu\, \bar{N}\gamma_5 N$$

$$+ C^N_{V,X}\, \bar{e}\gamma^\alpha P_X \mu\, \bar{N}\gamma_\alpha N + C^N_{A,X}\, \bar{e}\gamma^\alpha P_X \mu\, \bar{N}\gamma_\alpha\gamma_5 N$$

$$+ C^N_{Der,X}\, \bar{e}\gamma^\alpha P_X \mu\, \bar{N} \overleftrightarrow{\partial}_\alpha i\gamma_5 N + C^N_{T,X}\, \bar{e}\sigma^{\alpha\beta} P_X \mu\, \bar{N}\sigma_{\alpha\beta}\gamma_5 N \Big) \Bigg] + \text{h.c.}$$

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spin independent

$$R_{\mu e} = \frac{32 G_F^2}{\Gamma_{\mathrm{capture}}} \left[|\tilde{v} \cdot \tilde{C}_L|^2 + |\tilde{v} \cdot \tilde{C}_R|^2 \right]$$

Nuclear overlap integrals

Wilson coefficients

Isotope dependence of mu-to-e conversion & identification of next targets

- mu → e conv. for a given nucleus measures C projection.
- For small Z, ~5% errors on overlap integrals.

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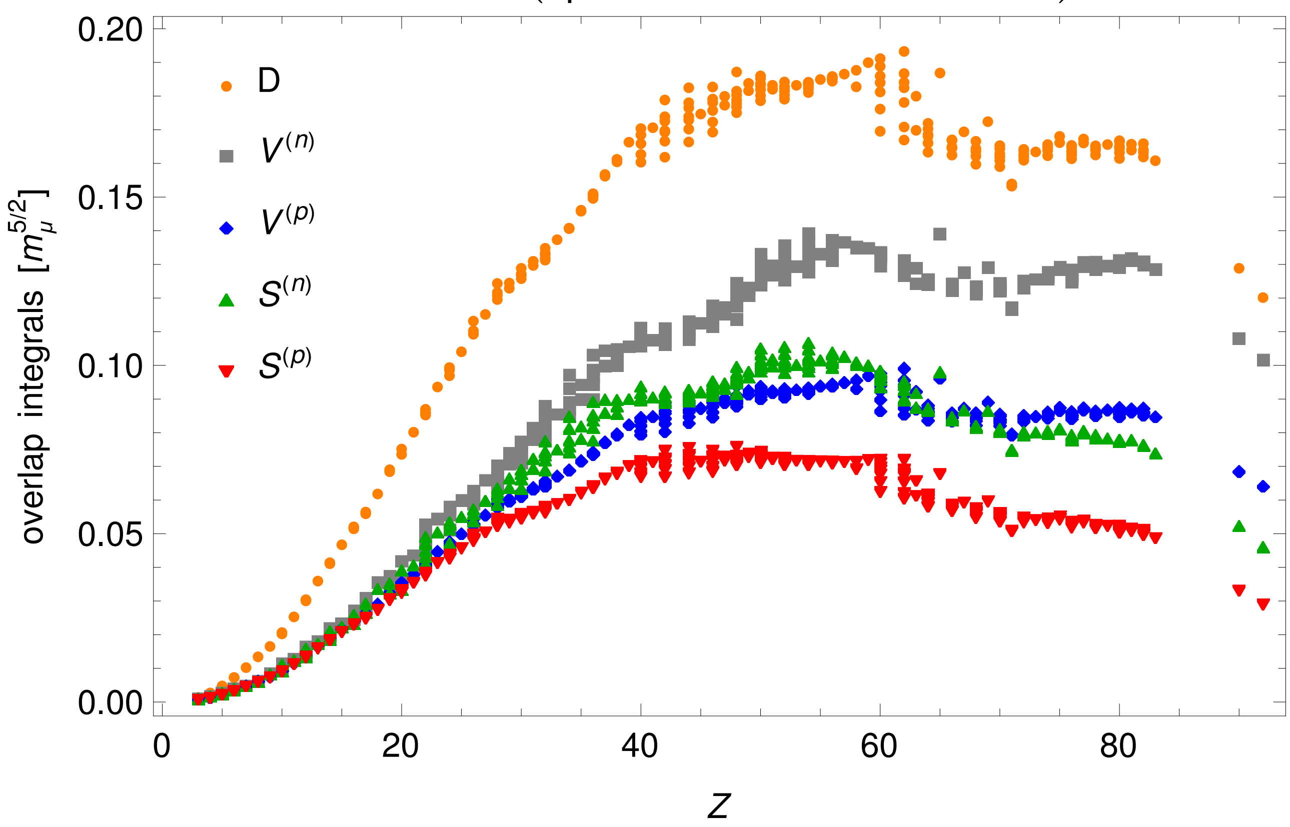
Nuclear overlap integrals — Wilson coefficients

$$\tilde{v} \equiv \left(\frac{D}{4}, V^{(p)}, S^{(p)}, V^{(n)}, S^{(n)} \right)$$



Isotope dependence of mu-to-e conversion & identification of next targets

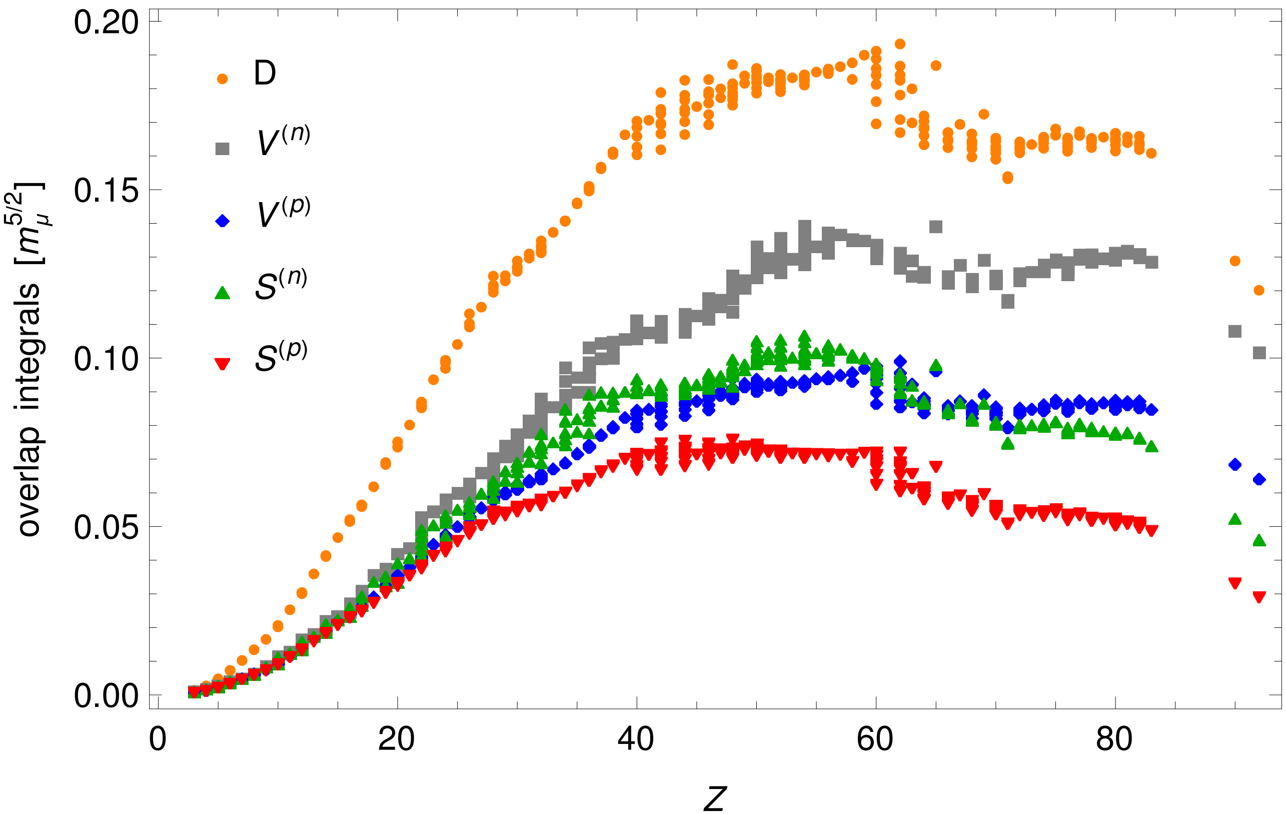
- mu→e conv. for a given nucleus measures C projection.
- For small Z, ~5% errors on overlap integrals.
- Complementarity with Al:

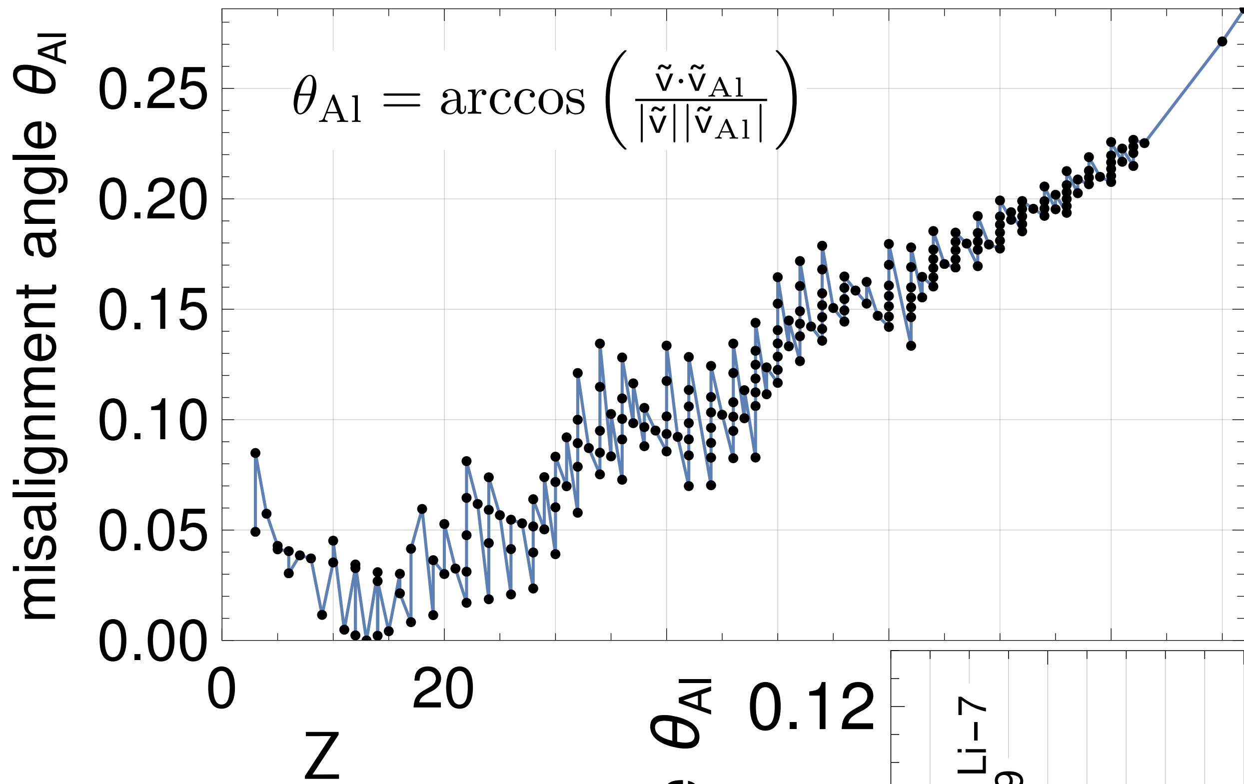
$$\theta_{\mathrm{Al}} = \arccos\left(\frac{\tilde{v}\cdot\tilde{v}_{\mathrm{Al}}}{|\tilde{v}||\tilde{v}_{\mathrm{Al}}|}\right)$$

$$R_{\mu e} = \frac{32 G_F^2}{\Gamma_{\mathrm{capture}}}\left[|\tilde{v}\cdot\tilde{C}_L|^2 + |\tilde{v}\cdot\tilde{C}_R|^2\right]$$

Nuclear overlap integrals   Wilson coefficients

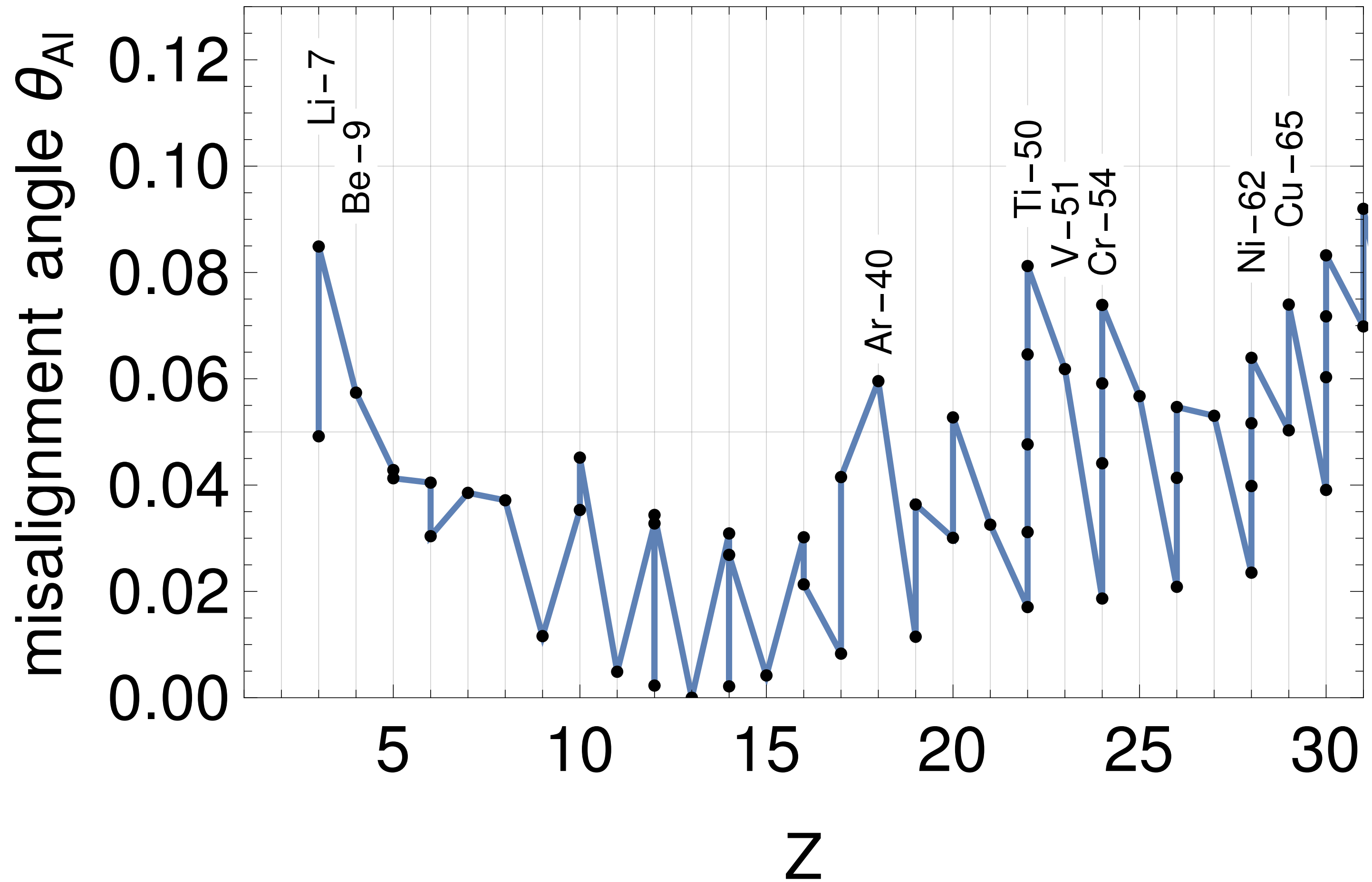
$$\tilde{v} \equiv \left(\frac{D}{4}, V^{(p)}, S^{(p)}, V^{(n)}, S^{(n)}\right)$$





Best second target has large Z, as expected.

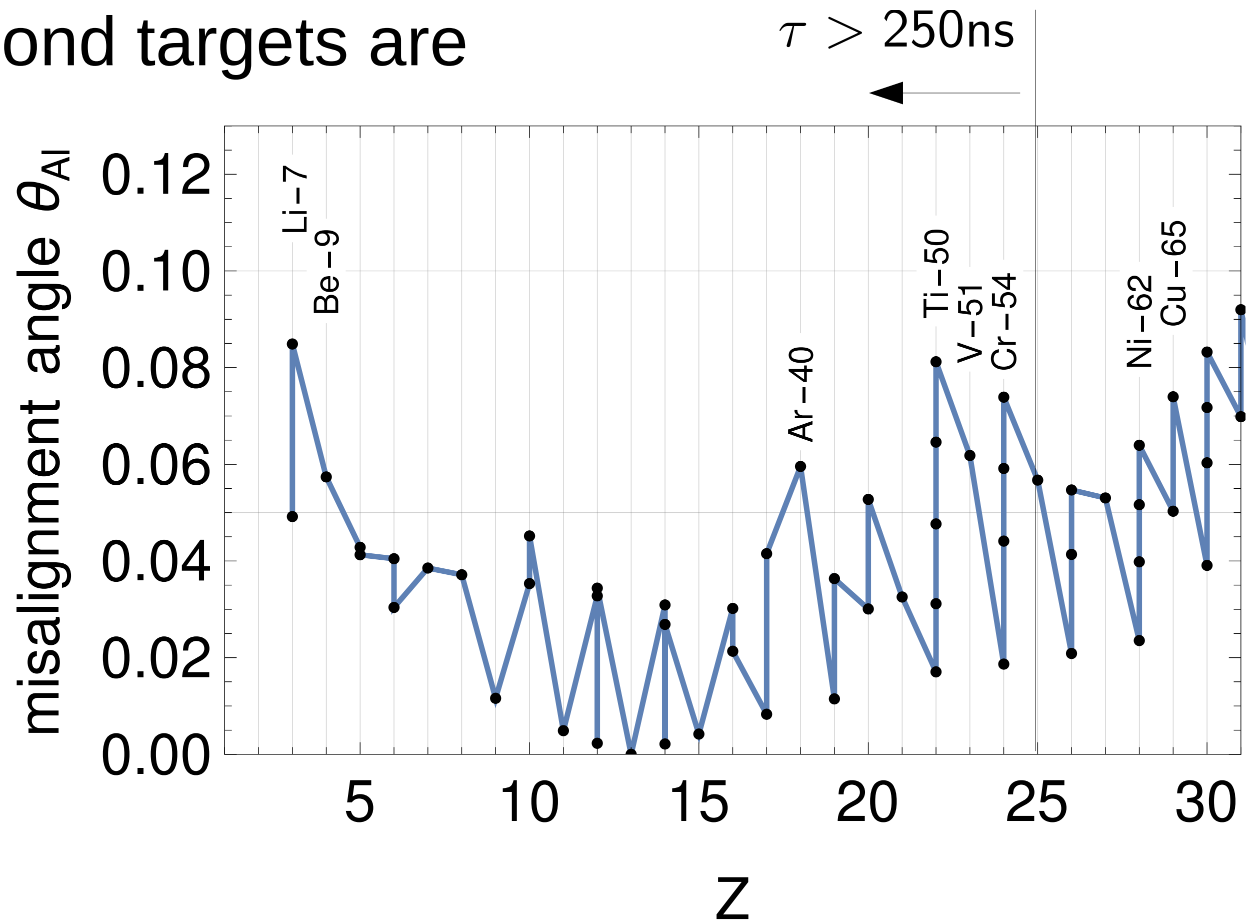
Small Z:



Isotope dependence of mu-to-e conversion & identification of next targets

- For small Z, best second targets are
  - Li-7
  - Ti-50 (49)
  - Cr-54
  - V-51

  because of larger N/Z ratios.
- Sensitive to proton vs. neutron operators.



- Conclusions are robust, error in percent regime.

Isotope dependence of muon DIO

- Near endpoint, improved approximate electron spectrum,

$$\frac{1}{\Gamma_0}\frac{\mathrm{d}\Gamma}{\mathrm{d}E_e}\bigg|_{E_e\sim E_\mathrm{end}} = B\,E_\mathrm{end}^5\left(1-\frac{E_e}{E_\mathrm{end}}\right)^{5.023},$$

  with

$$E_\mathrm{end} \equiv m_\mu - E_b - E_\mathrm{recoil} + \frac{\alpha m_\mu (Z\alpha)^2}{\pi}\left(\frac{11}{9}-\frac{2}{3}\log\left[\frac{2m_\mu Z\alpha}{m_e}\right]\right).$$

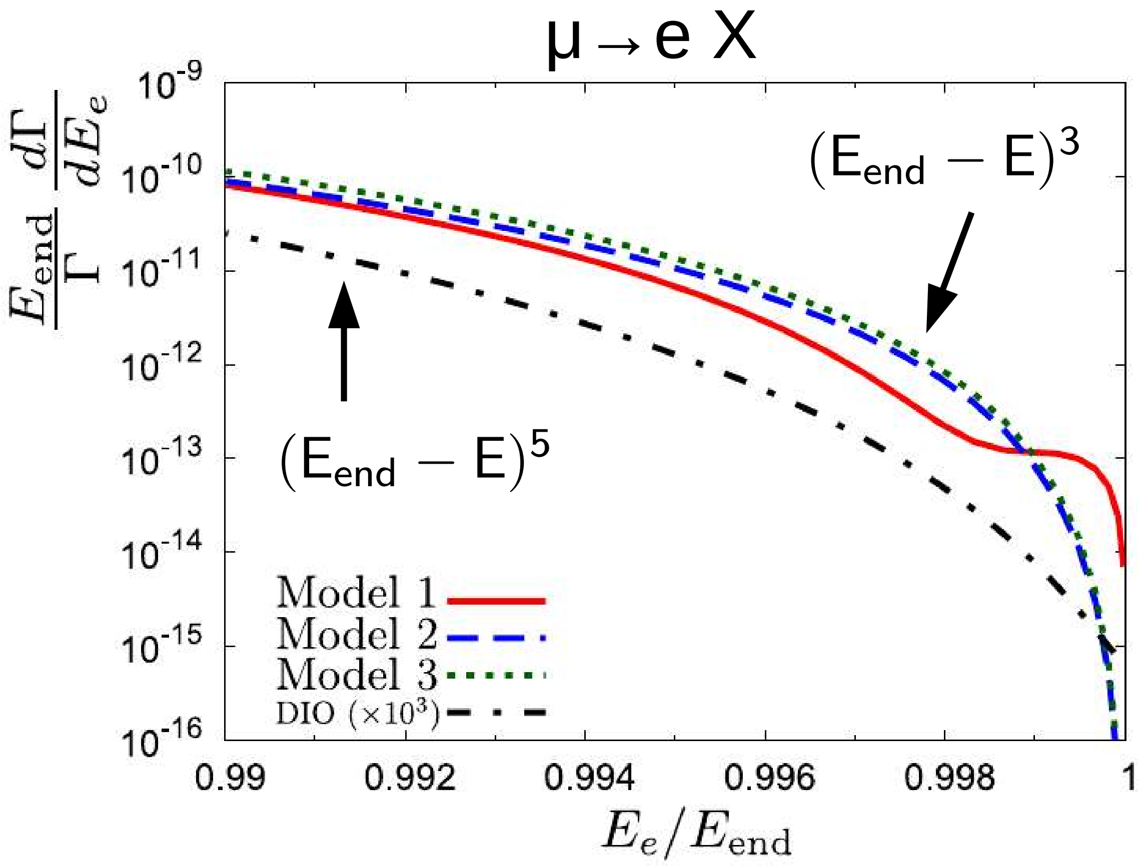
- Endpoint calculated precisely for all isotopes, uncertainty for B around 5% for small Z.
- Could be improved for second target with electron-nucleon scattering at q ~ m_μ.

Best second targets at low Z

	spin	NA/%	E_{end}/MeV	B/MeV^{-6}	τ_μ/ns	$\Gamma_{\text{cap}}/s^{-1}$
$^{6}_{3}$Li	1	7	104.64	1.3×10^{-19}	2175.3	4680
$^{7}_{3}$Li	$\frac{3}{2}$	93	104.78	1.3×10^{-19}	2186.8	2260
$^{27}_{13}$Al	$\frac{5}{2}$	100	104.97	8.9×10^{-17}	864	662×10^{3}
$^{46}_{22}$Ti	0	8	104.25	5.2×10^{-16}		
$^{47}_{22}$Ti	$\frac{5}{2}$	7	104.26	5.3×10^{-16}		
$^{48}_{22}$Ti	0	74	104.26	5.3×10^{-16}	329.3	2.59×10^{6}
$^{49}_{22}$Ti	$\frac{7}{2}$	5	104.26	5.4×10^{-16}		
$^{50}_{22}$Ti	0	5	104.26	5.4×10^{-16}		
$^{51}_{23}$V	$\frac{7}{2}$	100	104.15	6.3×10^{-16}	284.5	3.07×10^{6}
$^{50}_{24}$Cr	0	4	104.04	7.1×10^{-16}	233.7	3.82×10^{6}
$^{52}_{24}$Cr	0	84	104.04	7.2×10^{-16}	256.0	3.45×10^{6}
$^{53}_{24}$Cr	$\frac{3}{2}$	10	104.05	7.1×10^{-16}	266.6	3.30×10^{6}
$^{54}_{24}$Cr	0	2	104.05	6.9×10^{-16}	284.8	3.06×10^{6}

Motivation for other searches

- Motivate $\mu \to e X$ as a general process and its signature in Mu2e-II compared to other experiments.
- Motivate $\mu \to e^+$. Difficult to motivate, could not find realistic models.



Summary

- General motivation for LFV
- Specific motivation for Mu2e upgrade
- Summary of DIO results
- Summary of new-physics isotope dependence and identification of good second target
- Motivation for for $\mu \to e X$ & $\mu \to e^+$

Writing done, will adjust depending on rest of paper.