want to calculate: $\langle \boldsymbol{Al(P_f, S_f), e(q,s)|S|\mu Al(P_i, S_i)} \rangle$ (in rel. QFT of leptons and $N \in \{n, p\}$)

for $S \sim \exp\{i\int d^4y\mathcal{L}\} \to I + i\int d^4y \sum_J C_J O_J$, and

$$
\begin{array}{lll}
O_J \in & [\overline{N}\Gamma_N N][\overline{e}\Gamma_l \mu] \;\; \mathrm{for}\Gamma_N \in \{I, \gamma^\alpha, \gamma_5, \gamma^\alpha\gamma_5, \sigma^{\alpha\beta}\} & \\
(eg & [\overline{N}N)[\overline{e_X}\mu] \quad [\overline{N}\gamma^\alpha N][\overline{e_X}\gamma_\alpha\mu)] & , \mathrm{for}\ e_X = P_X e)
\end{array}
$$

enough Os? (?Need pion operators? More nucleons?)

write the bound state of muon with nucleus ($and\ neglect\ spin$)

$$
|\mu Al(\vec{P}_i = 0)\rangle \propto \int \frac{d^3k}{(2\pi)^3}\widetilde{\psi}_\mu(\vec{k})\,|Al(-\vec{k})\rangle \otimes |\mu(\vec{k})\rangle
$$

where $\tilde{\psi}$ is fourier trans of muon wavefunction (can put wavefn for e too; here plane wave)

Is non-rel bound state formalism; are there corrections?

Then S-matrix element becomes:

$$
\int d^4y \int \frac{d^3k}{(2\pi)^3}\overline{u_e}(q)\Gamma_l\widetilde{\psi}_\mu(\vec{k})\langle Al(P_f)|[\overline{\hat{N}}\Gamma_N\hat{N}]|Al(P_i - k)\rangle
$$

if write nucleus in bd state formalism:

$$\langle Al(P_f)| \propto \int \frac{d^3 l}{(2\pi)^3} \tilde{f}_p^*(\vec{l}) \langle A'(-\vec{l} + \frac{A-1}{A} P_f)| \times \langle p(\vec{l} + m_p \vec{v}_f)|$$

then can calculate: $\boldsymbol{\langle Al(P_f, S_f), e(q,s)| \int d^4 y [\overline{\hat{e_X}} \Gamma_l \hat{\mu}][\overline{\hat{p}} \Gamma_N \hat{p}] | \mu Al(P_i, S_i) \rangle}$

$$\begin{aligned} \propto \quad & \int d^4 y \Big\{ \int \frac{d^3 k}{(2\pi)^3} \widetilde{\psi}_\mu(\vec{k}) \langle e(q)| [\overline{\hat{e_X}} \Gamma_l \hat{\mu}] |\mu(k + ..)\rangle \\ & \times \int \frac{d^3 l_f}{(2\pi)^3} \frac{d^3 l_i}{(2\pi)^3} \tilde{f}_p^*(\vec{l_f}) \tilde{f}_p(\vec{l_i}) \langle N(l_f + ..)| [\overline{N} \Gamma_N N] | N(l_i + ..)\rangle \\ & \times \langle A'(\frac{A-1}{A} P_f - l_f) | A'(\frac{A-1}{A} P_i - l_i - k)\rangle \Big\} \end{aligned}$$

1) evaluate QFT-matrix elements as spinor contractions
2) go from 3-momentum $\rightarrow$ position space(do fourier trans), then do 3-p integrals
neglect $\vec{l_i}, \vec{l_f}$ dependence of spinor-stuff to get nice δ-fns...

$$\mathcal{A}(\mu Al \rightarrow Al + e) \quad \propto \quad \int d^3 y \overline{\psi_e} \Gamma_l \psi_\mu |f_N|^2 \overline{u_N} \Gamma_N u_N$$

...then can do non-rel expansion of 4-comp spinors u_N , try to recover spin and go to J-space...

Questions

1. what are the distributions of n and p in "useable" nuclei, with uncertainties?
   "useable" $=$ can make a target with it
2. the rate in a nucleus A is $\propto$ a sum of contributions from different operators, interfering or not.
   $\Rightarrow$ want to identify which series of targets could allow to identify as many quark-operator-coeffiients as possible...
3. ...