Non-Local QED

UNIVERSITY OF ALABAMA

DESMOND VILLALBA

IN COLLABORATION WITH

NOBUCHIKA OKADA

ANUPAM MAZUMDAR

(A MANUSCRIPT IN PROGRESS)

Why Non-Local?

- Non-Local(NL) theories are UV insensitive
- β functions beyond M_{NL} are highly suppressed
- Investigating NL QED is a first step to approaching NL SM
- Could provide framework for remedying the hierarchy problem

Non-Local Refs:
1) Moffat J., Phys.Rev vol D41 pp 1177-1184 [1990]
2) Okada N., Biswas T., ArXiv:1407.3331v3[2015]

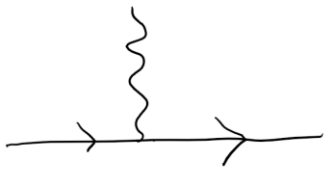
The Model

$$\mathcal{L} = -\frac{1}{4} F^{\mu\nu} \underbrace{e^{-\frac{\partial^2}{M^2}}}_{\text{Non-Local Operator}} F_{\mu\nu} + i\bar{\psi} \underbrace{e^{-\left(\frac{\partial^2 - g^2 A^2}{\mathrm{M}^2}\right)}}_{\text{Non-Local Operator}} \gamma^\mu \left(\partial_\mu + igA_\mu\right)\psi$$

Vertices

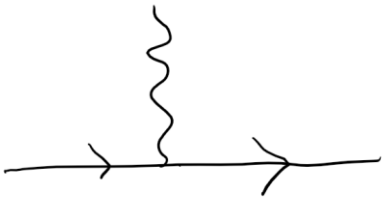
$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}e^{-\frac{\partial^2}{M^2}}F_{\mu\nu} + i\bar{\psi}e^{-\left(\frac{\partial^2 - g^2A^2}{\mathrm{M}^2}\right)}\gamma^\mu(\partial_\mu + igA_\mu)\psi$$

Local Vertices:

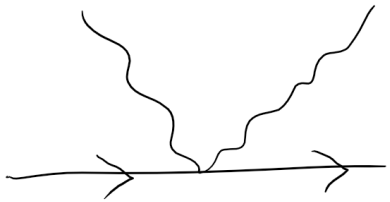


$$V_L = -ig\gamma^\mu$$

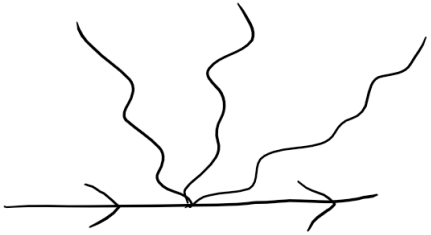
Non Local Vertices(1st order):



$$V_{NL}^{(1)} = -ig\gamma^\mu\underbrace{\left(\frac{p^2}{M^2}\right)}_{\text{External momenta!}}$$



$$V_{NL}^{(1)} = -ig^2\eta_{\alpha\beta}\underbrace{\left(\frac{\gamma^\mu p_\mu}{M^2}\right)}_{\text{External momenta!}}$$

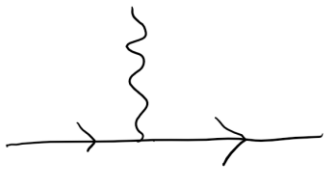


$$V_{NL}^{(1)} = -ig^3\eta_{\alpha\beta}\left(\frac{\gamma^\mu}{M^2}\right)$$

Vertices

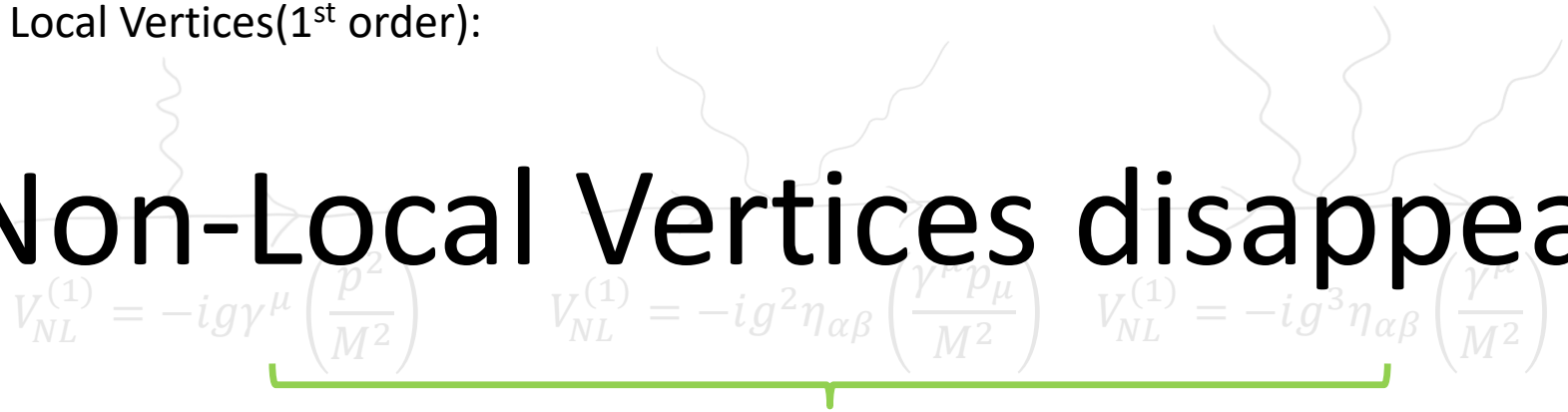
$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}e^{-\frac{\partial^2}{M^2}}F_{\mu\nu} + i\bar{\psi}e^{-\left(\frac{\partial^2 - g^2A^2}{\mathrm{M}^2}\right)}\gamma^\mu\left(\partial_\mu + igA_\mu\right)\psi$$

Local Vertices:



$$V_L = -ig\gamma^\mu$$

Non Local Vertices(1st order):



$$V_{NL}^{(1)} = -ig\gamma^\mu\left(\frac{p^2}{M^2}\right) \qquad V_{NL}^{(1)} = -ig^2\eta_{\alpha\beta}\left(\frac{\gamma^\mu p_\mu}{M^2}\right) \qquad V_{NL}^{(1)} = -ig^3\eta_{\alpha\beta}\left(\frac{\gamma^\mu}{M^2}\right)$$

Non-Local Vertices disappear

$M \rightarrow \infty$ limit

Propagators($\xi = 0$ gauge)

$$\mathcal{L} = -\frac{1}{4} F^{\mu\nu} e^{-\frac{\partial^2}{M^2}} F_{\mu\nu} + i\bar{\psi} e^{-\left(\frac{\partial^2 - g^2 A^2}{\mathrm{M}^2}\right)} \gamma^\mu \left(\partial_\mu + igA_\mu\right)\psi$$

Gauge: $$\Pi_{\mu\nu} = \frac{-i\, e^{-\frac{p^2}{M^2}}}{p^2 + i\epsilon}\left(\eta_{\mu\nu} - \frac{p_\mu p_\nu}{p^2}\right)$$

Fermion: $$S = \frac{-i(\gamma^\mu p_\mu)\, e^{-\frac{p^2}{M^2}}}{p^2 + i\epsilon}$$

Propagators($\xi = 0$ gauge)

$$\mathcal{L} = -\frac{1}{4} F^{\mu\nu} e^{-\frac{\partial^2}{M^2}} F_{\mu\nu} + i\bar{\psi} e^{-\left(\frac{\partial^2 - g^2 A^2}{\mathrm{M}^2}\right)} \gamma^\mu \left(\partial_\mu + i g A_\mu\right)\psi$$

Gauge: $\Pi_{\mu\nu} = \frac{-i\, e^{-\frac{p^2}{M^2}}}{p^2 + i\epsilon}\left(\eta_{\mu\nu} - \frac{p_\mu p_\nu}{p^2}\right)$

$$\Pi_{\mu\nu} = \frac{-i}{p^2 + i\epsilon}\left(\eta_{\mu\nu} - \frac{p_\mu p_\nu}{p^2}\right)$$

Fermion: $S = \frac{-i(\gamma^\mu p_\mu)\, e^{-\frac{p^2}{M^2}}}{p^2 + i\epsilon}$

$$S = \frac{-i\gamma^\mu p_\mu}{p^2 + i\epsilon}$$

$M \to \infty$ limit

Gauge Invariance (**Local QED**)

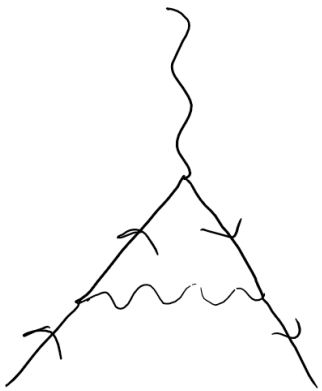
- Considering the quantum corrections to the Lagrangian

$$\mathcal{L} \to \Delta Z_\psi i\bar{\psi}\gamma^\mu \partial_\mu \psi - \Delta g \bar{\psi}\gamma^\mu \psi A_\mu$$

- Gauge invariance requires that

$$\Delta g = g\Delta Z_\psi \qquad \text{or} \qquad \mathcal{L} \to \Delta Z_\psi i\bar{\psi}\gamma^\mu D_\mu \psi$$

- Diagrammatically (1-loop)

g x  = 

Gauge Invariance (**Non-Local QED**)

($\xi = 0$ gauge)

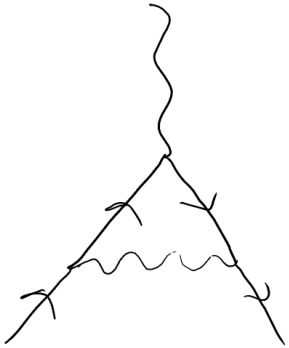
- We expect a similar behavior for the Non-Local scenario

$$\mathcal{L} \to \Delta Z_\psi i\bar{\psi} e^{-\left(\frac{\partial^2 - g^2 A^2}{\mathrm{M}^2}\right)} \gamma^\mu \partial_\mu \psi - \Delta g \bar{\psi} e^{-\left(\frac{\partial^2 - g^2 A^2}{\mathrm{M}^2}\right)} \gamma^\mu \psi A_\mu$$

- Gauge invariance requires that

$$\Delta g = g \Delta Z_\psi \qquad \text{or} \qquad \mathcal{L} \to \Delta Z_\psi i\bar{\psi} e^{-\left(\frac{\partial^2 - g^2 A^2}{\mathrm{M}^2}\right)} \gamma^\mu D_\mu \psi$$

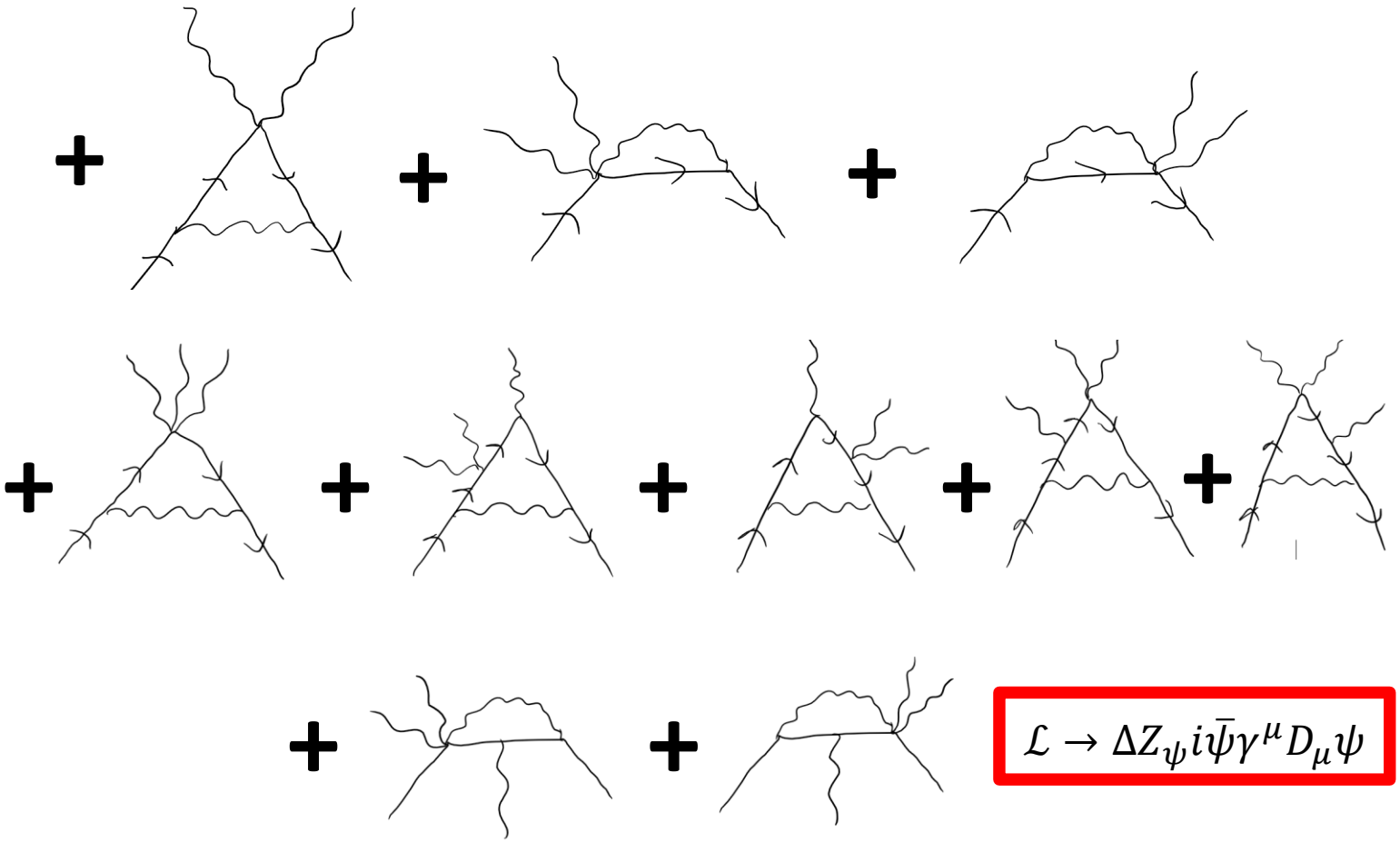
- This was confirmed by considering the following diagrams found from expanding to the lowest NL terms (1 loop)

g x  =  + ...

Gauge Invariance (**Non-Local QED**)

($\xi = 0$ gauge)

- And more diagrams….



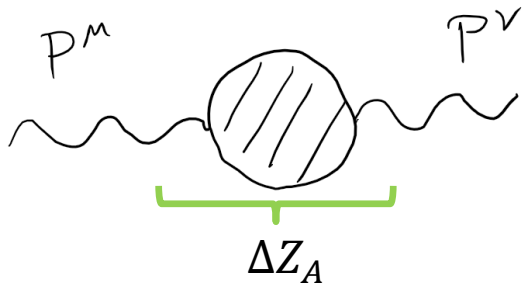
$$\mathcal{L} \rightarrow \Delta Z_\psi i\bar{\psi}\gamma^\mu D_\mu \psi$$

RGE for coupling

- What are the NL effects on the running of g?

$$\mathcal{L} \to -\frac{1}{4}\Delta Z_A F^{\mu\nu} e^{-\frac{\partial^2}{M^2}} F_{\mu\nu}$$

- From QED we know to extract terms $\propto p^\mu p^\nu$ from ΔZ_A
  - Where:



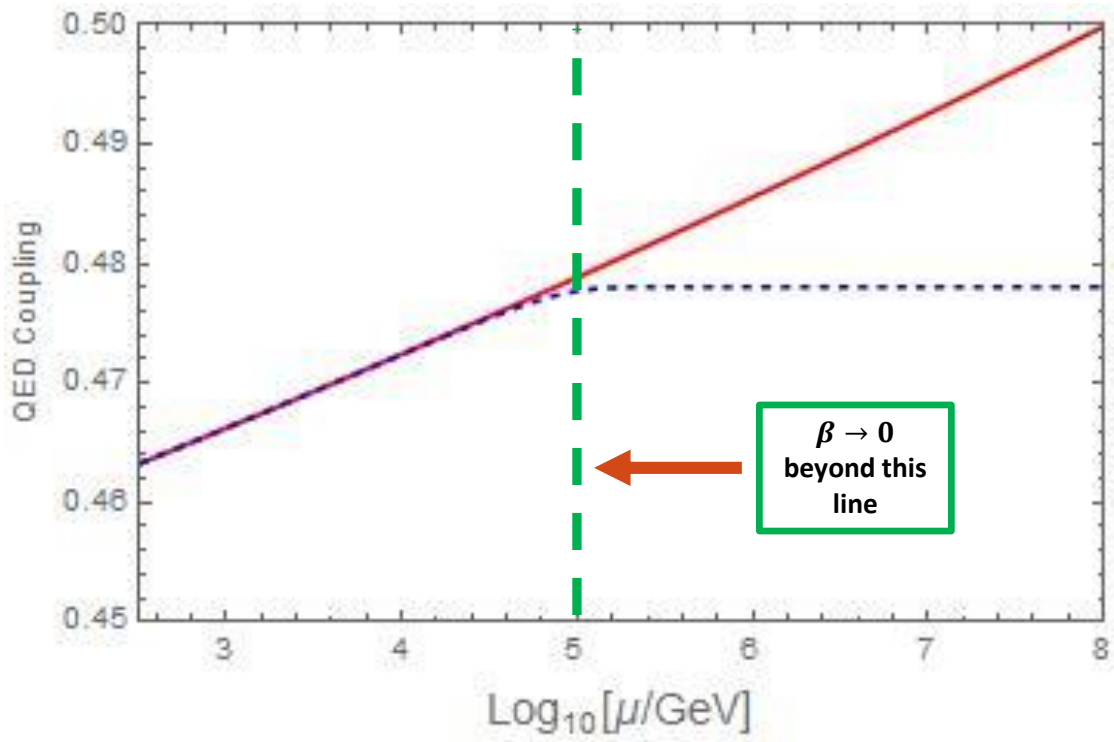
- Assuming that qauge inv. is obeyed to <u>all orders</u>, we can simply extract lowest order NL corrections which are $\propto p^\mu p^\nu$

$$\to \Delta Z_A^{NL} \sim \Delta Z_A^{L} * e^{-\frac{\mu^2}{M^2}}$$

- The Non-Local RGE for the gauge coupling g is

$$\boxed{\mu \frac{dg}{d\mu} = \frac{b\, g^3}{16\pi^2} e^{-\frac{\mu^2}{M^2}}}\, , b = \sum_i \frac{2}{3}\left(Q_i^f\right)^2$$

RGE Running of coupling



$$b = \frac{41}{10}$$

- QED coupling running
  - Local QED in **red**
  - Non Local QED in **blue**, $M_{NL}=10^5$ GeV

Conclusions

- Non Local model shown to be UV insensitive
- NL QED Gauge invariance verified to 1-loop order
- Running of NL gauge coupling becomes fixed beyond M_{NL}
- Next is to investigate Higgs sector and NL effect on $\lambda\phi^4$ running and potentially avoid Higgs vacuum instability problem

Thanks to

Graduate School

Department of Physics & Astronomy
College of Arts & Sciences