Elastic neutrino-electron scattering in effective field theory

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NEUTRINO 2020

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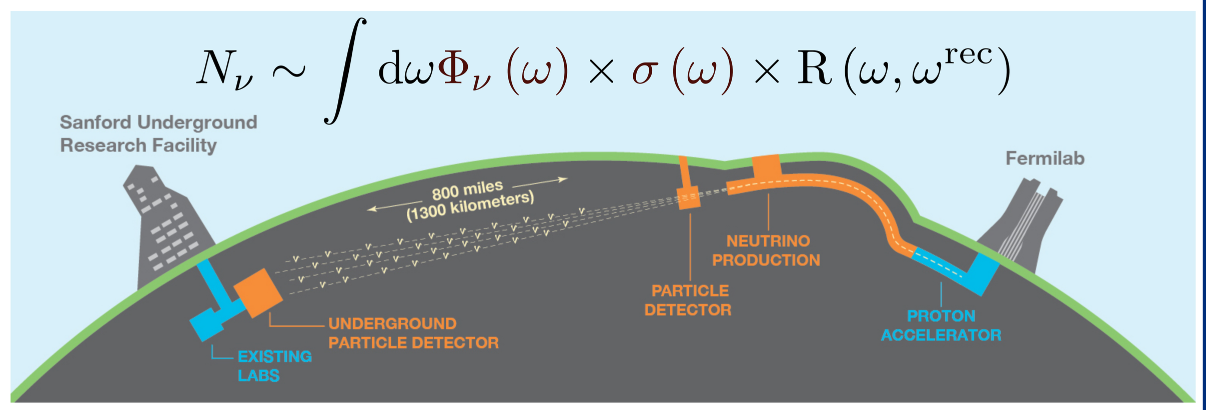
νe helps neutrino physics

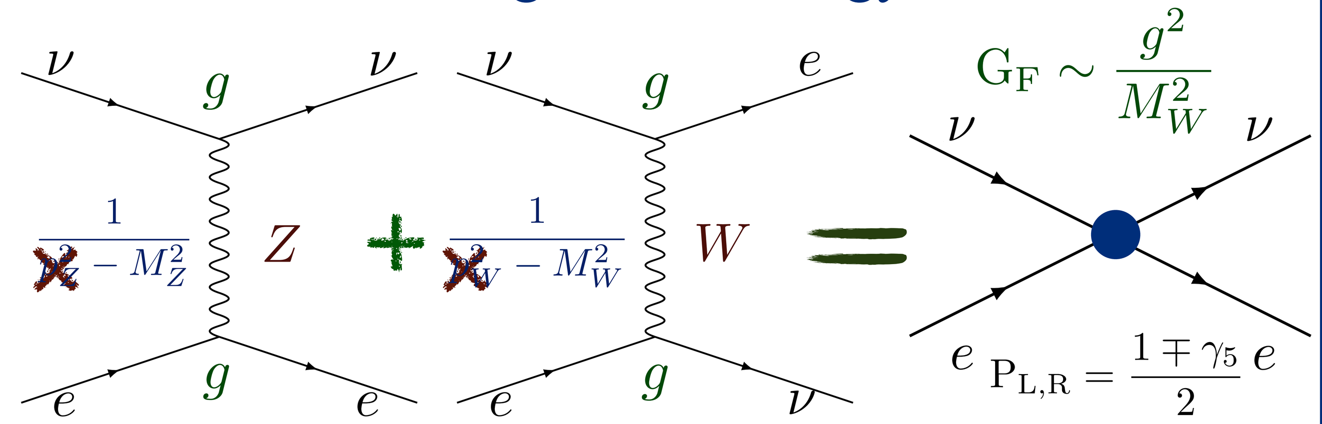
- CP phase in lepton sector?
- neutrino mass hierarchy?
- precise oscillation parameters, θ_{23}
- DUNE: leading-edge ν science experiment



- flux and ν-nucleus cross sections required
- νe cross section is small but free from nuclear effects
- νe: standard candle to constrain ν flux 7.5%→4%: MINERvA data at NUMI beam
  MINERvA (2016, 2019), NOvA analysis is ongoing
- clean tool to study flux in DUNE
  Ch. Marshall et al., PRD (2020)

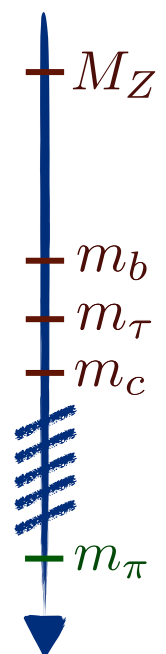
Matching and running

- tree level matching to low-energy EFT

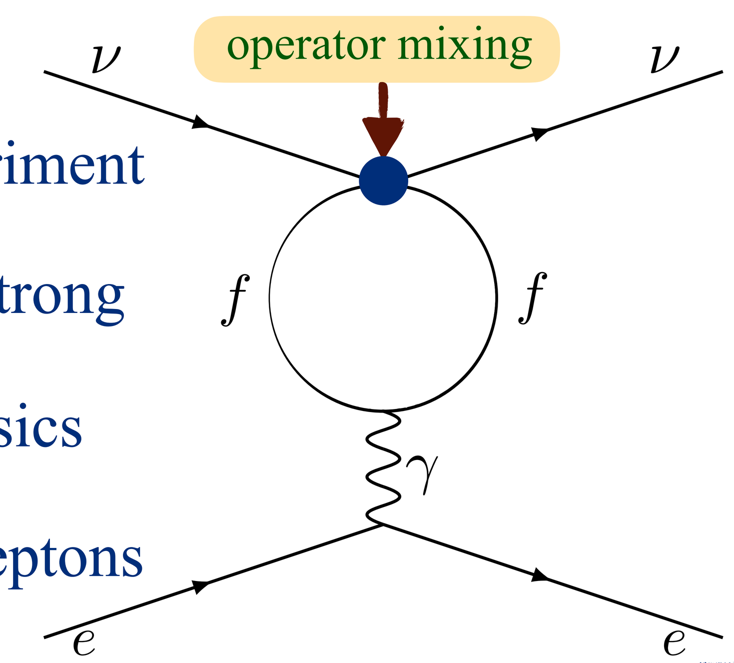


$$\mathcal{L}_{\text{eff}} = -\bar{\nu}\gamma_\mu P_L \nu \cdot \bar{e}\gamma^\mu (c_L P_L + c_R P_R) e$$

- $\alpha \alpha_S$ two-loop $\overline{\text{MS}}$ matching at electroweak scale

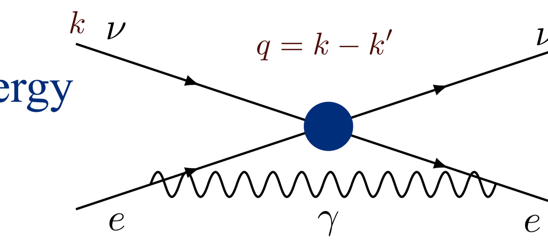


- running to scales of experiment
- α_S becomes strong
- hadronic physics
- theory with leptons



Virtual QED corrections

neutrino energy E_ν



momentum transfer $Q^2 = -q^2$

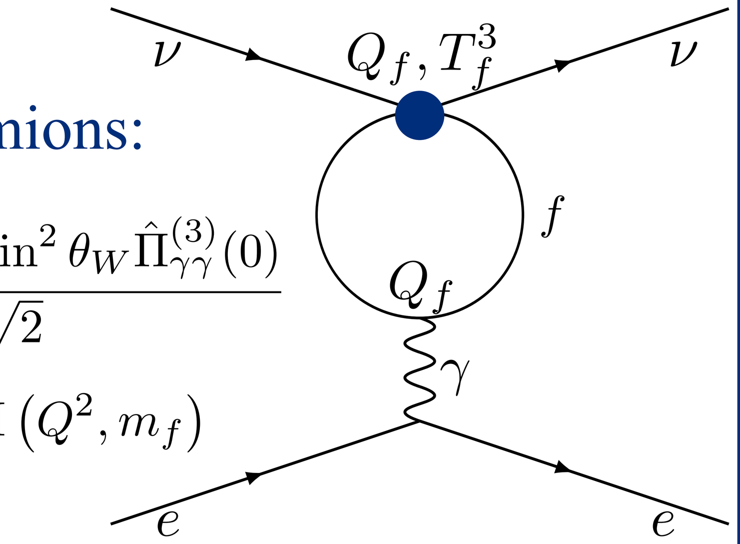
- vertex correction given by QED form factors

$$s, Q^2 \lesssim 2mE_\nu \ll \Lambda^2_{\text{QCD}}$$

- description in terms of light quarks is invalid
- hadrons and fermions:

$$c^h = G_F \frac{\hat{\Pi}^{(3)}_{3\gamma}(0) - 2\sin^2\theta_W \hat{\Pi}^{(3)}_{\gamma\gamma}(0)}{\sqrt{2}}$$

$$c^f = Q_f \left(c^f_L + c^f_R\right) \Pi\left(Q^2, m_f\right)$$

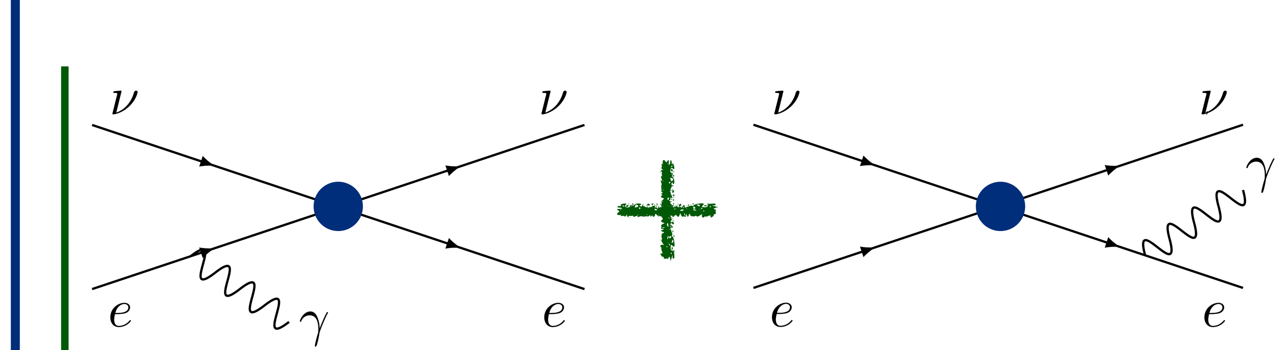


- light quarks: $\hat{\Pi}^{(3)}_{3\gamma}(0) = (1 \pm 0.2)\hat{\Pi}^{(3)}_{\gamma\gamma}(0)$

  nonperturbative treatment using $SU(3)_f$

Bremsstrahlung cross sections

- at least one real photon for % precision



- new distributions beyond E_e, E_{EM} spectra

E_e, E_γ, θ_e → E_{EM}, θ_e; E_e, θ_e; E_e, E_γ

E_{EM}, θ_ν; E_{EM}, θ_e → E_{EM}

E_e, θ_e → E_e

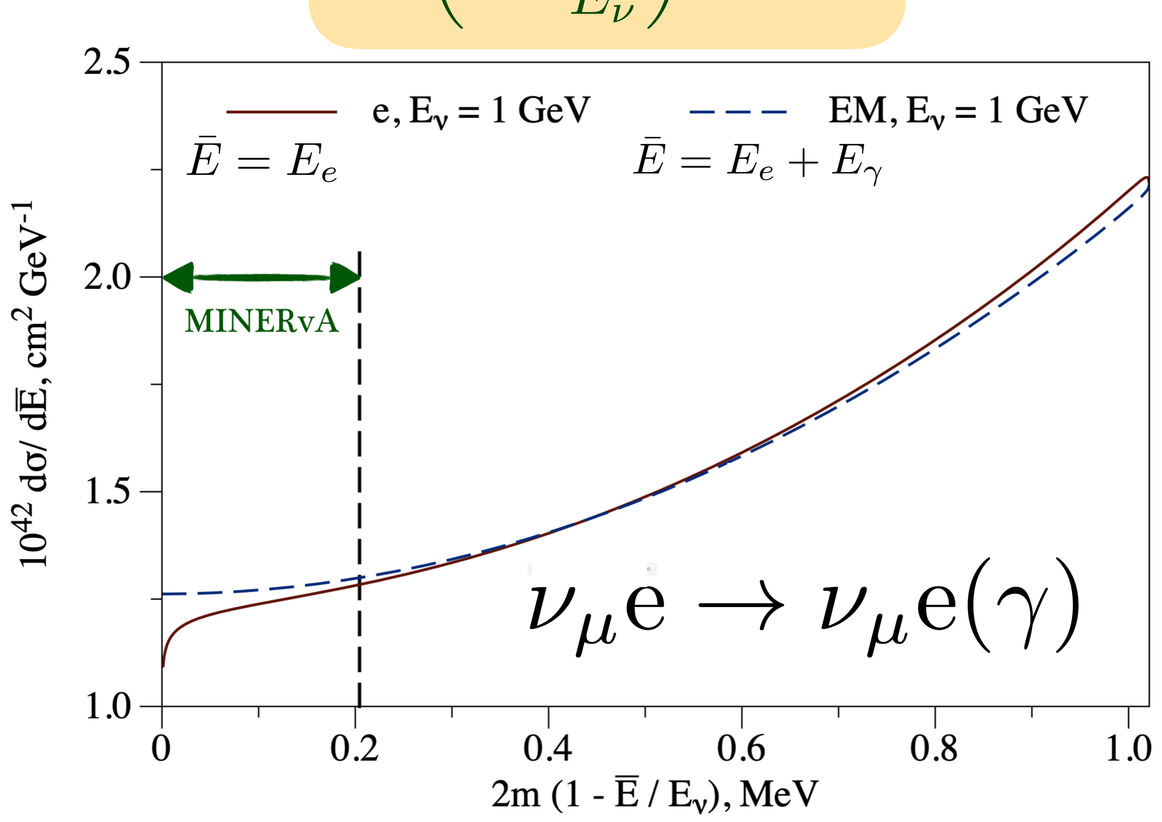
E_e, E_γ; E_γ, θ_γ → E_γ

E_{EM}, E_e → total cross section

Electron vs electromagnetic energy spectra

- compare two experimental setups
- forward νe scattering events are peaked at small variable

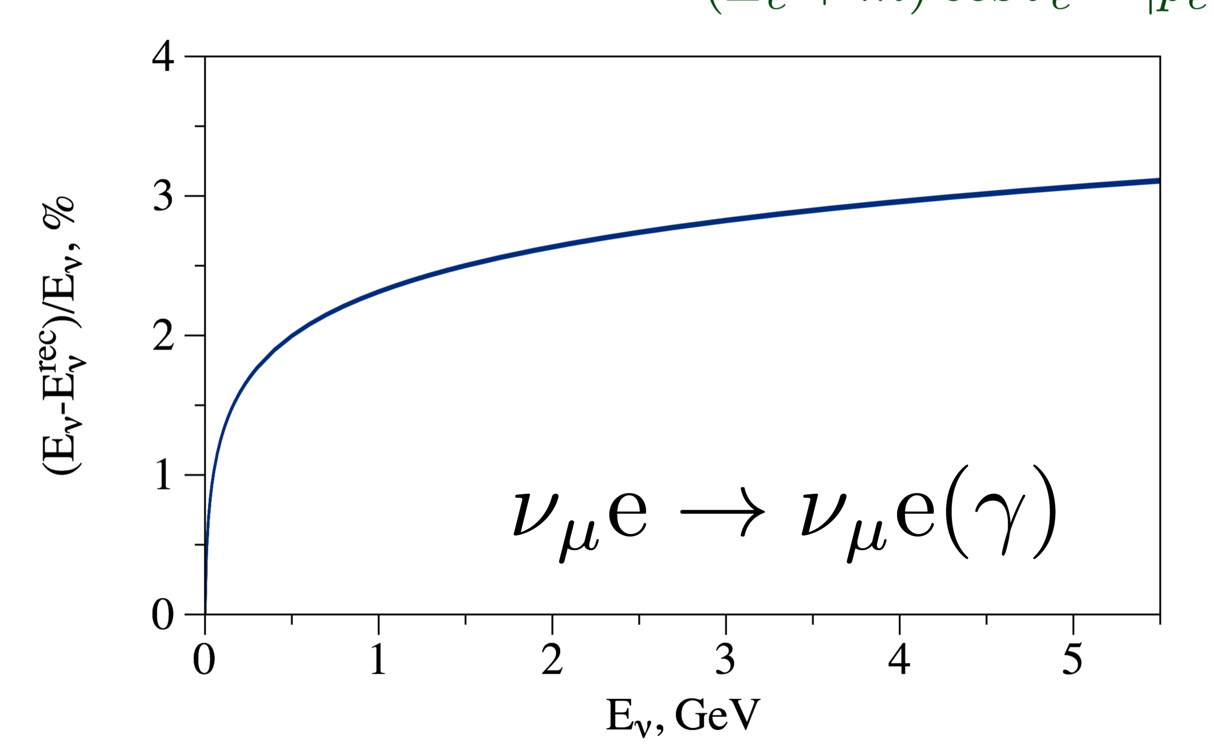
$$2m\left(1 - \frac{\bar{E}}{E_\nu}\right) \approx E_e \theta_e^2$$

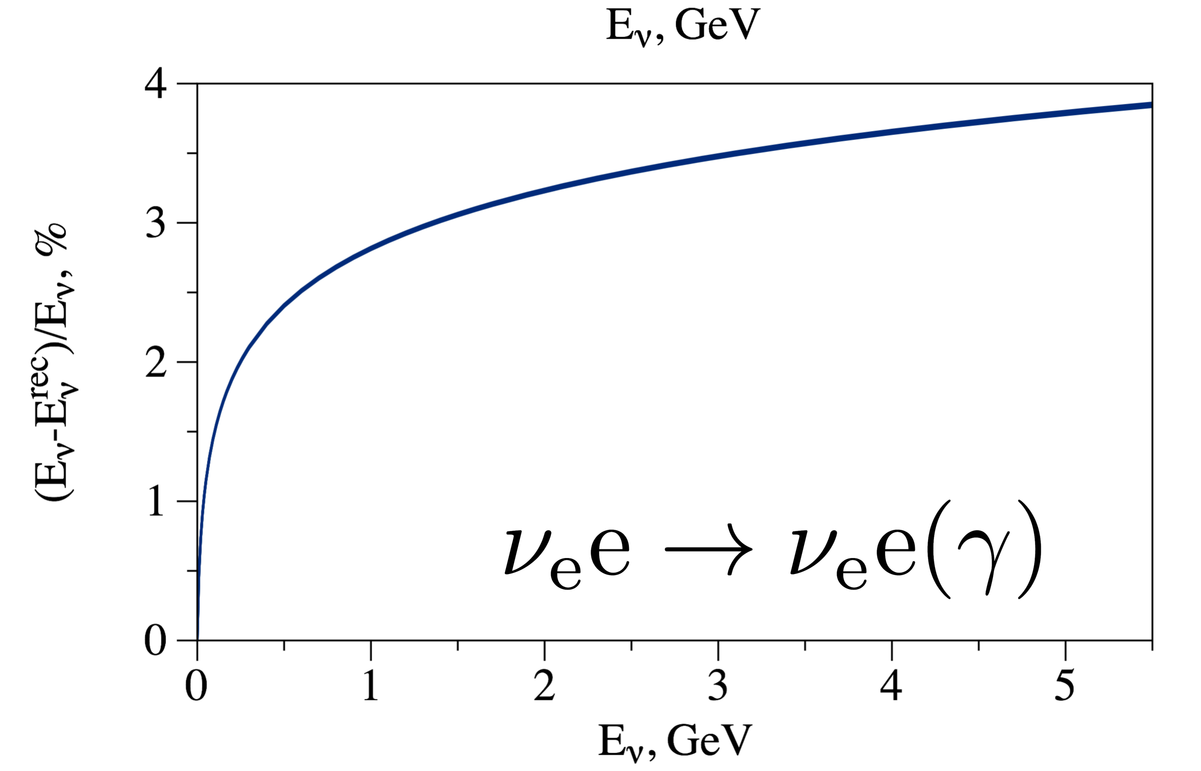


- rad. corrections important applying cuts

Effect on E_ν reconstruction

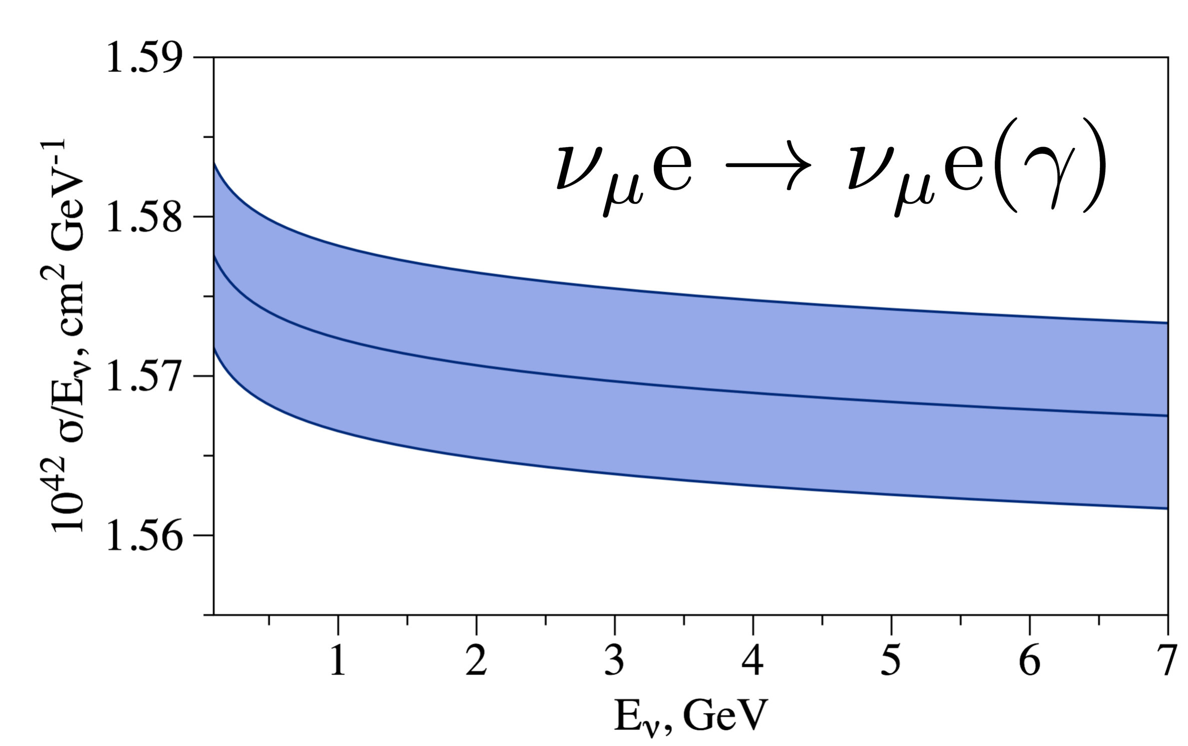
- elastic kinematics: $E_\nu^{\text{rec}} = \frac{m|\vec{p}_e|}{(E_e + m)\cos\theta_e - |\vec{p}_e|}$

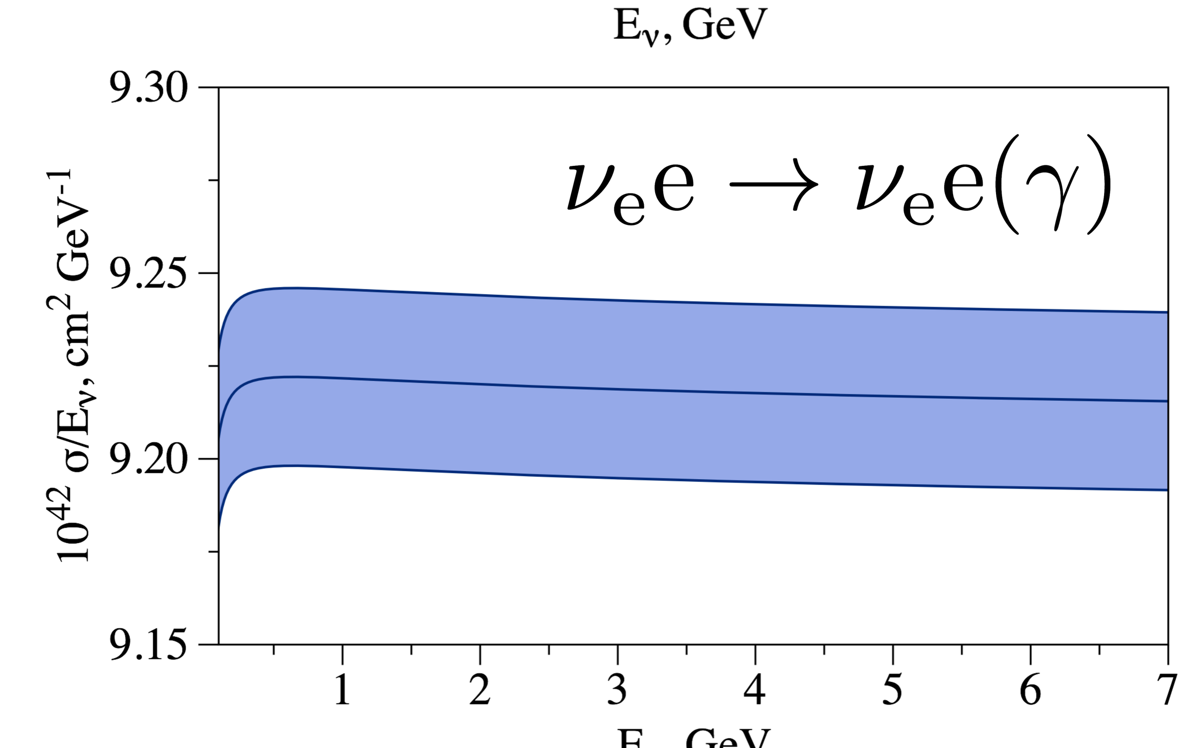




Absolute cross section

- 1st-ever error analysis: 0.2-0.4% from $\hat{\Pi}^{(3)}_{3\gamma}$





Conclusions

- **precise EFT for ν scattering**
- **νe error ~ stat. error of DUNE**
- **main uncertainty: hadronic loops**
- **energy spectra and distributions**
- **analytical results, finite e mass**

Outlook

- **study $\Pi_{3\gamma}$ by dispersive methods**
- **evaluate correlators on lattice**
- **relation to running α and g-2**
- **implement to modern generators**
- **applications to solar neutrinos**