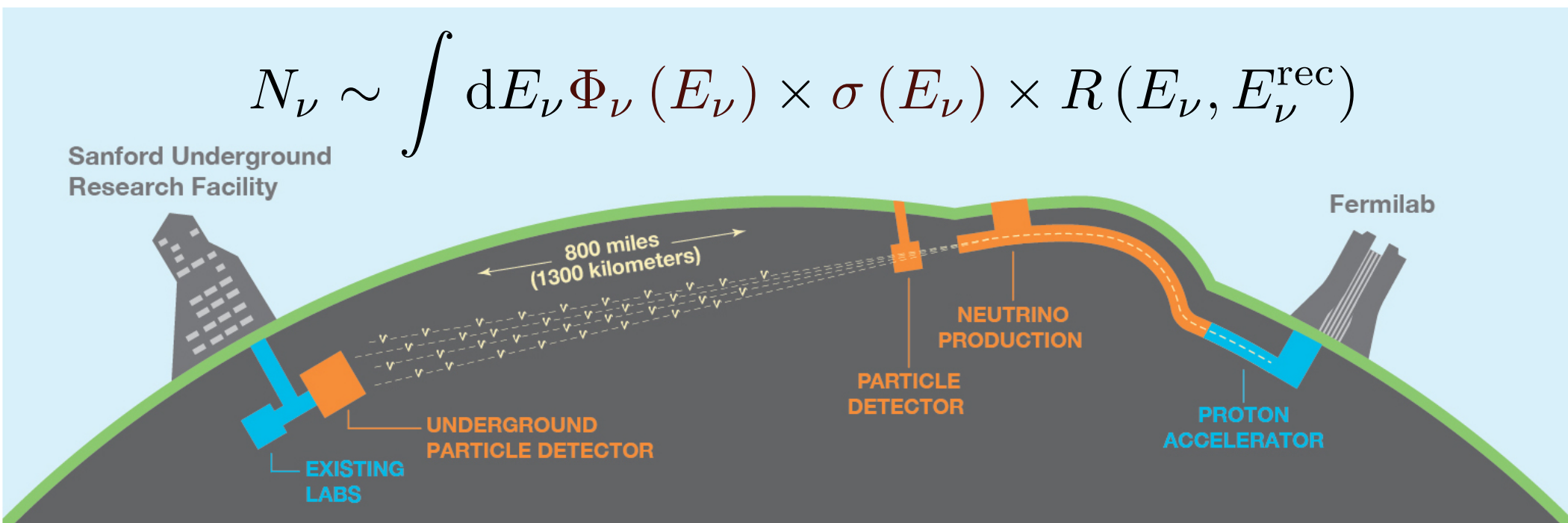# QED corrections to charged-current neutrino-nucleon elastic scattering

Oleksandr Tomalak, Qing Chen, Richard J. Hill and Kevin S. McFarland, arXiv: 2105.07939
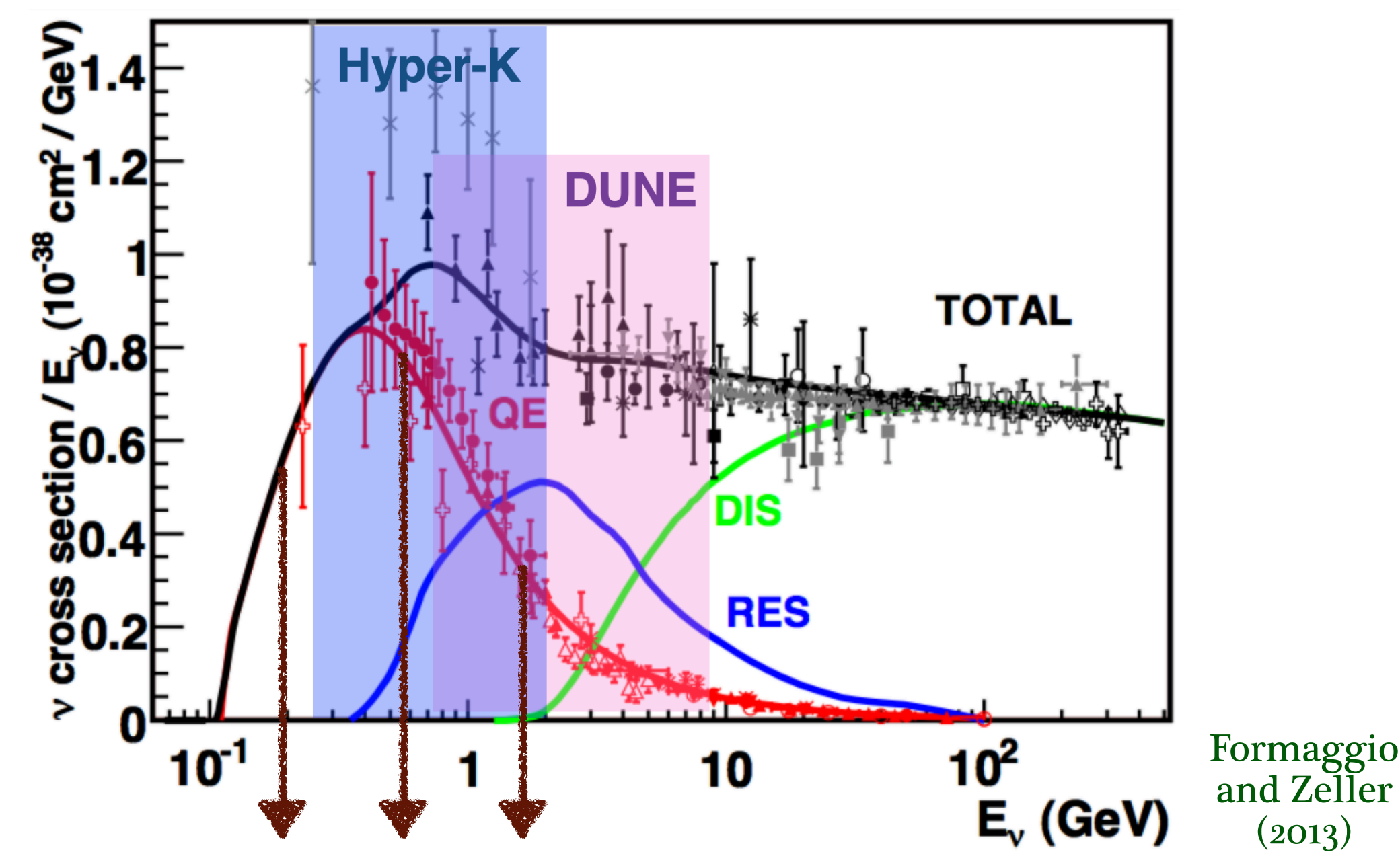
Radiative corrections in oscillation experiments?

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

$$N_\nu \sim \int dE_\nu \Phi_\nu(E_\nu) \times \sigma(E_\nu) \times R(E_\nu, E_\nu^{rec})$$

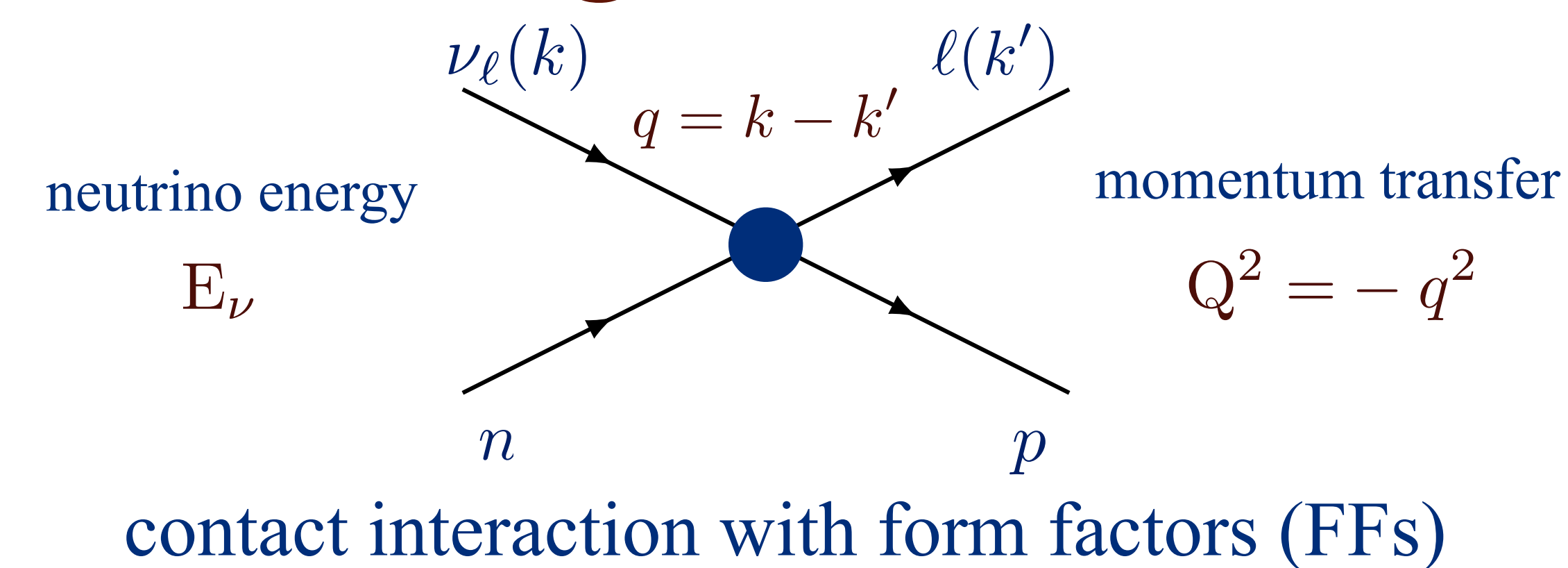Sanford Underground Research Facility — 800 miles (1300 kilometers) — Fermilab

- ν-nucleus cross sections required at % level
- radiative corrections suppressed by coupling
  $\frac{\alpha}{\pi} \sim 0.2\%$ too small?
- enhanced by large logarithms at GeV energy
  $\ln \frac{E_\nu}{m_e} \sim 6 - 10$!!!   for electron flavor
- cuts on phase space: even double logarithms
  $\ln^2 \frac{E_\nu}{m_e} \sim 36 - 100$!!!   ~1-20 % correction
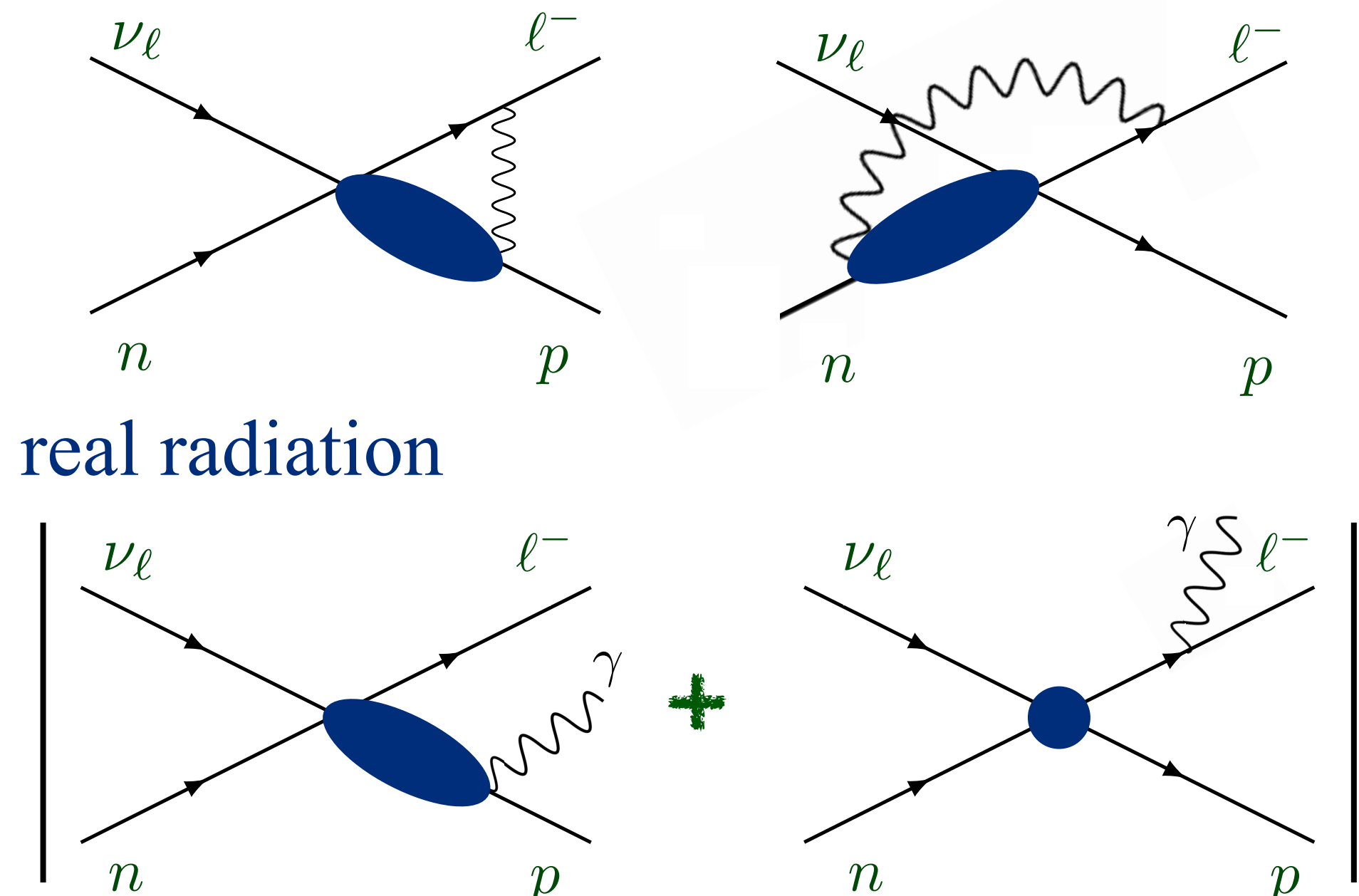
ν interactions at GeV energy

Formaggio and Zeller (2013)

bulk of events in modern and future experiments
channel for reconstruction of neutrino energy

Scattering on free nucleons

neutrino energy E_ν $\nu_\ell(k)$ $\ell(k')$ $q = k - k'$ momentum transfer $Q^2 = -q^2$

n p

contact interaction with form factors (FFs)

Radiative corrections

- virtual corrections to νn and $\bar\nu p$ scattering
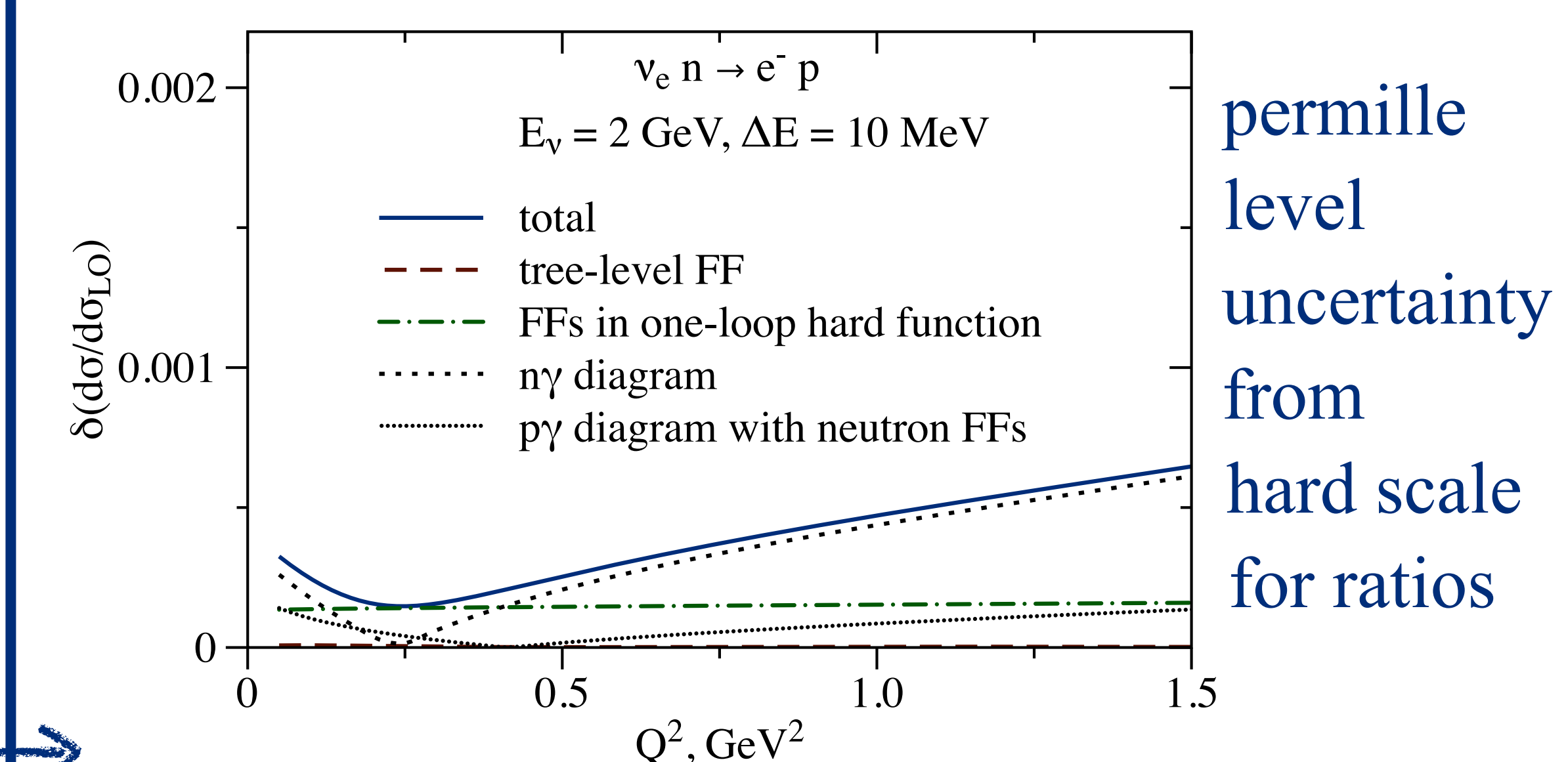

- real radiation

Hadronic model

- onshell form for each vertex with dipole FFs and free-nucleon propagator
- self energy for external charged particles for correct soft contributions
- counter terms in electroweak vertex for correct collinear contributions
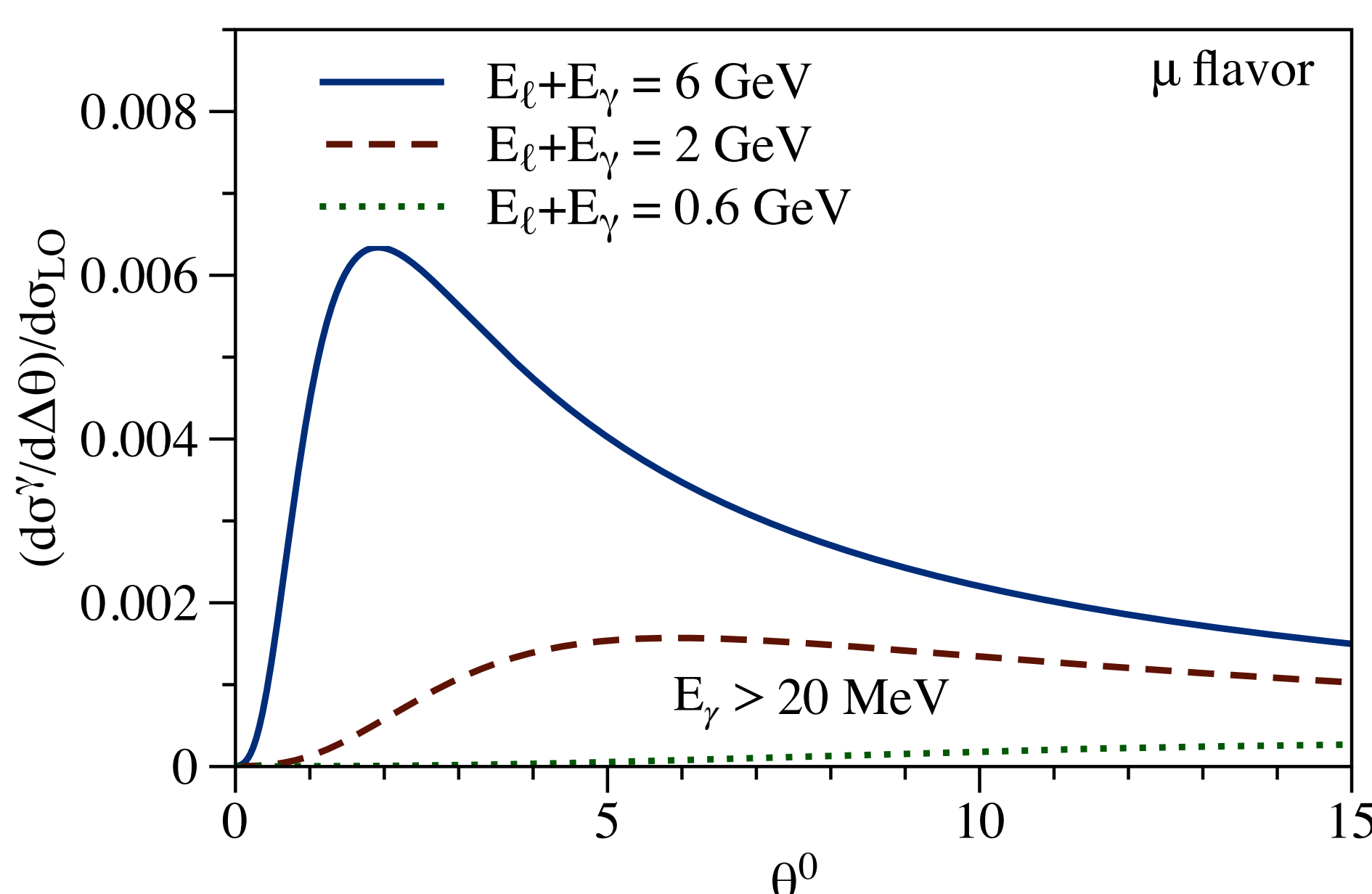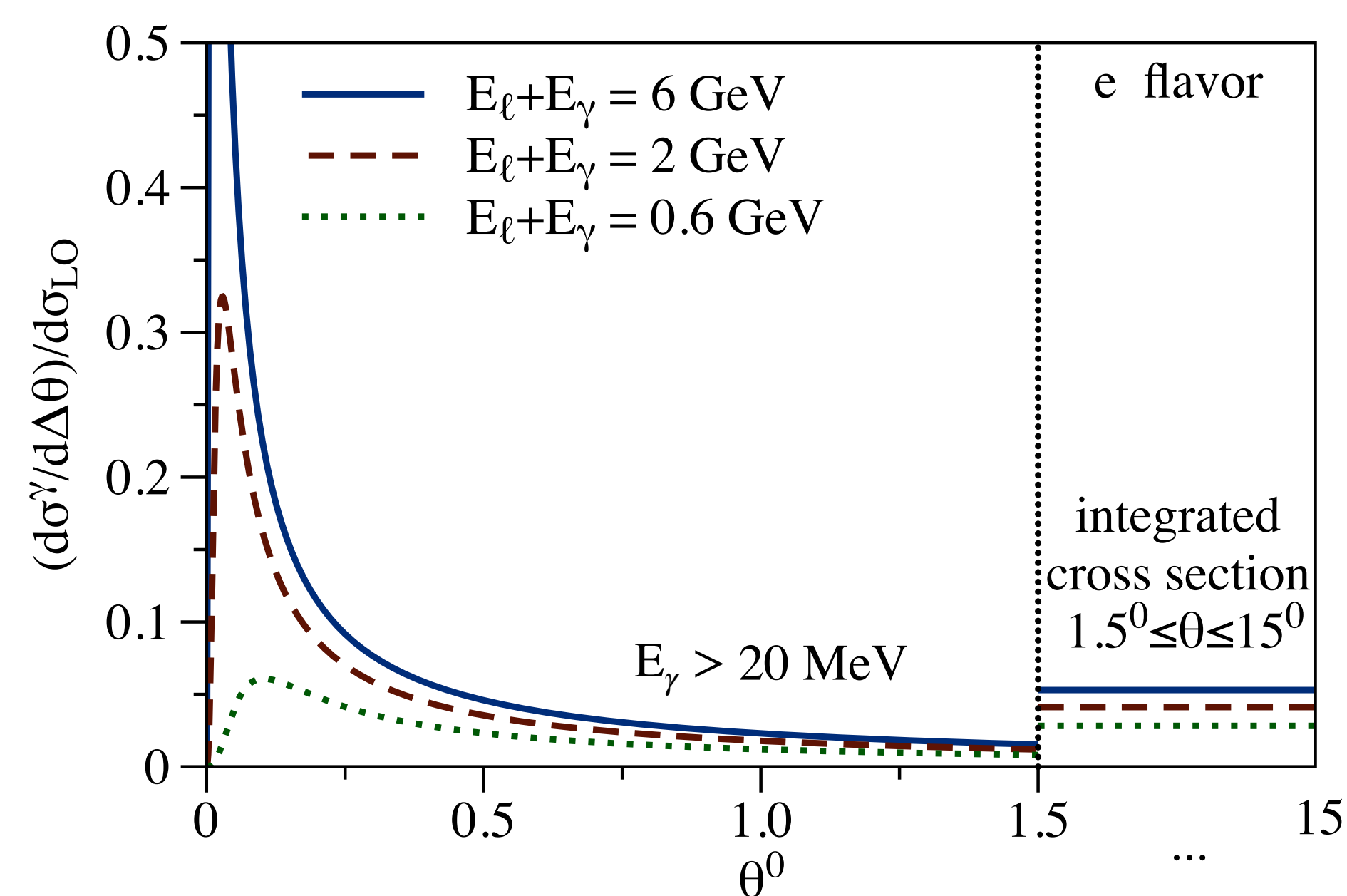
Factorization framework

- factorization formula for cross section
  $$d\sigma \sim S\left(\frac{\Delta E}{\mu}\right) J\left(\frac{m_\ell}{\mu}\right) H\left(\frac{M}{\mu}\right)$$
- RGE evolution of the hard function
- calculate cross section at low energies accounting for perturbative logarithms
- soft and collinear functions: analytic
- hard function from hadronic model at GeV

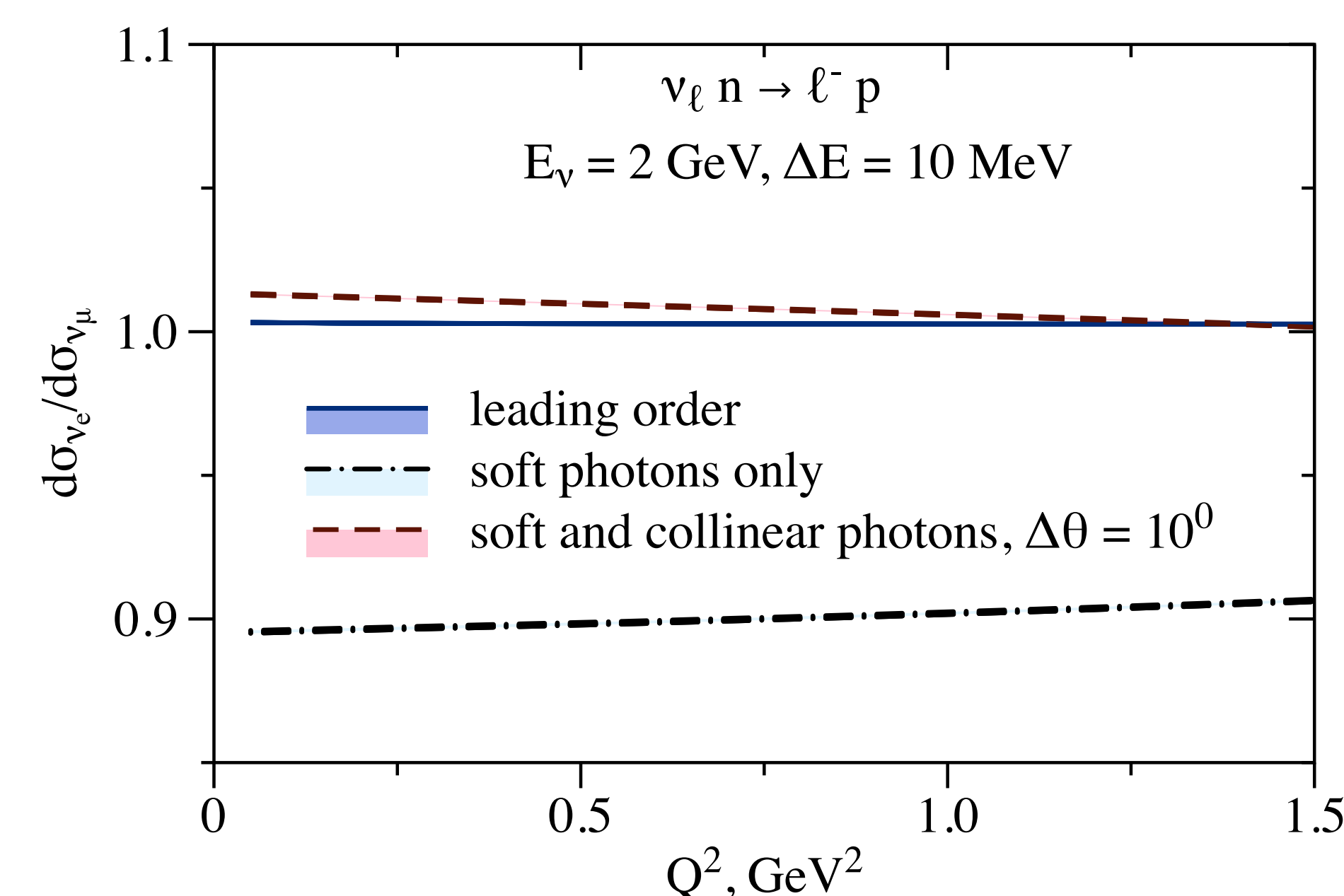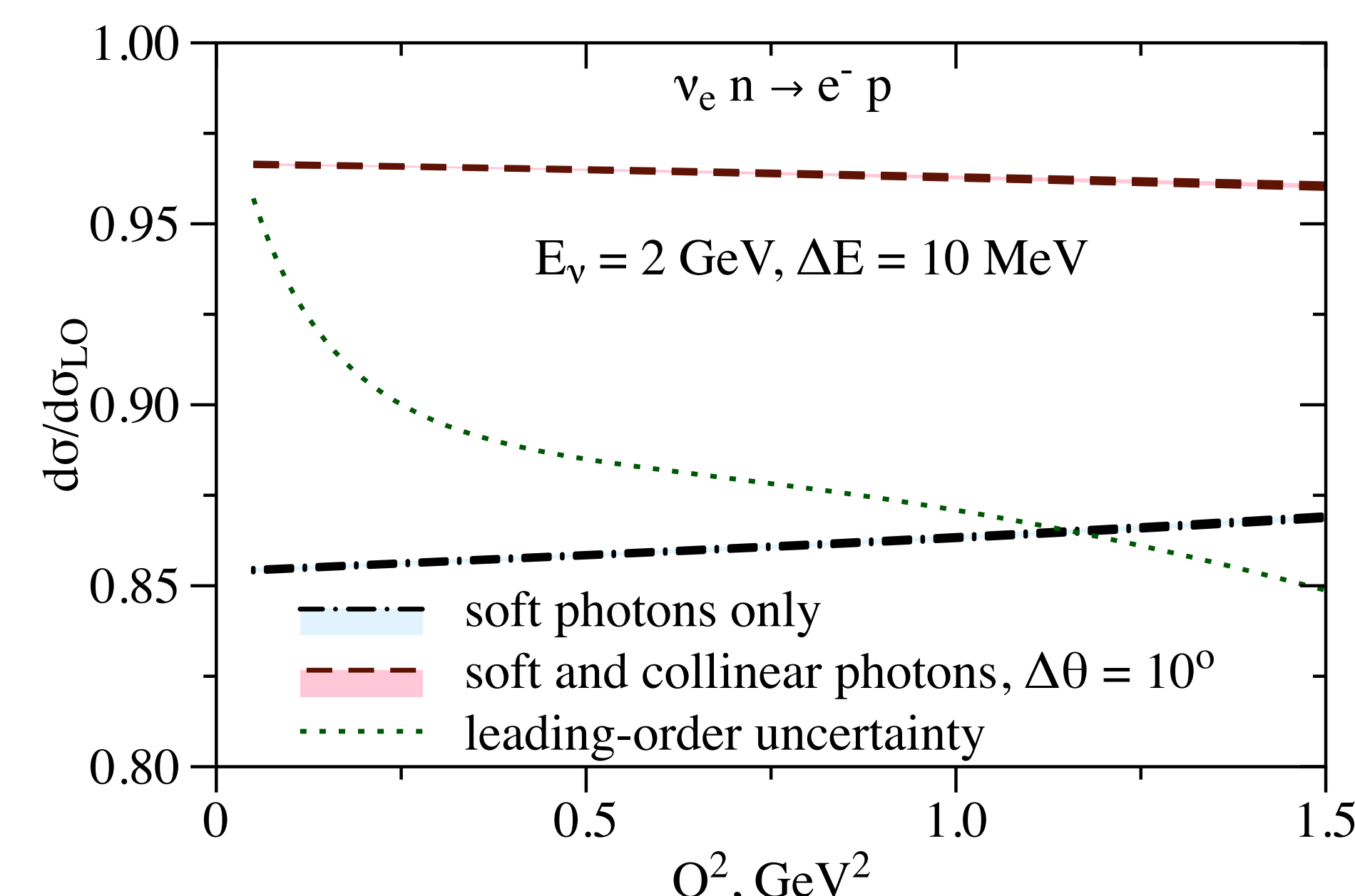M m_μ ΔE m_e

Error budget

permille level uncertainty from hard scale for ratios

Electron vs muon jets

- angular distribution of one energetic γ
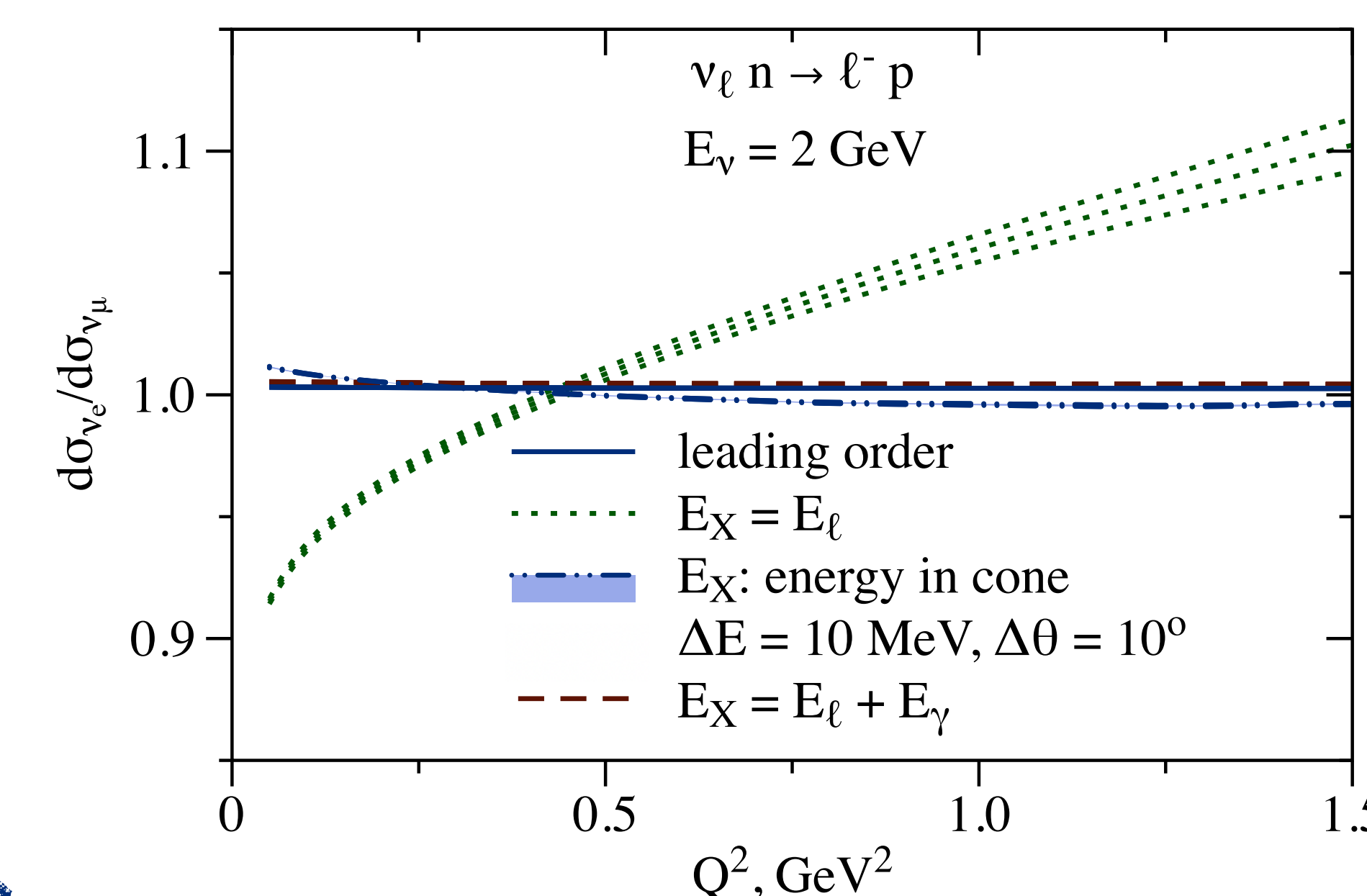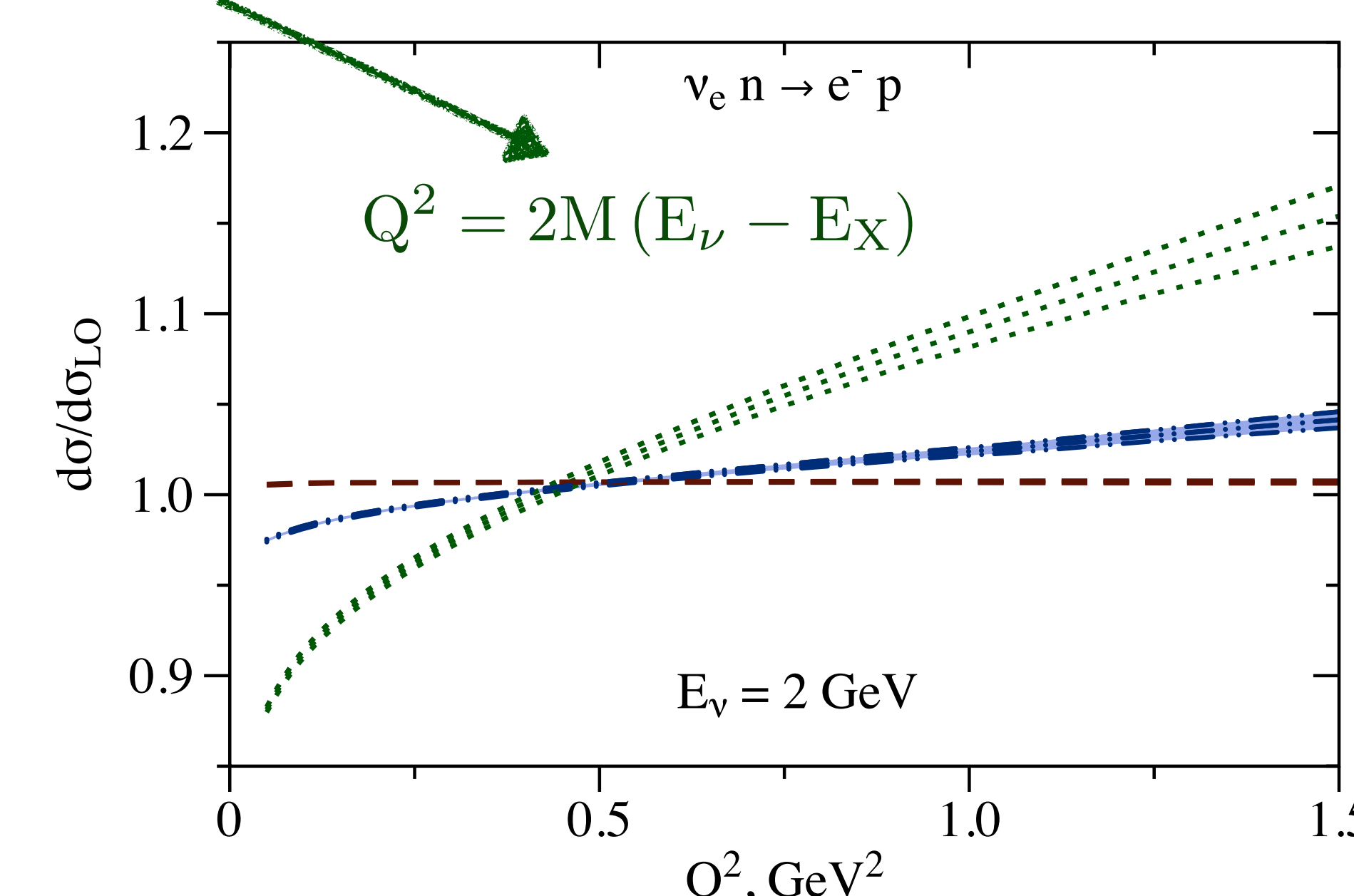- smaller radiation for μ with shifted peak

Exclusive observables

- phase-space cuts on radiation of multiple γ
- small uncertainty for e/μ and ratio to LO

Inclusive observables

- fixed order calculation includes one hard γ
- kinematics reconstructed with 3 different E_X

$Q^2 = 2M(E_\nu - E_X)$

Conclusions

- **radiative corrections formulated in factorization framework**

- **model-independent perturbative contributions are calculated**

- **ν-nucleon hard function model for percent-level predictions**

- **hard function uncertainties cancel in cross-section ratios**

- **σ_{ν_e} can be predicted from σ_{ν_μ} data with ν_μ neutrino beams**