FNAL Neutrino

Joint Theory-Experiment

Working Group

11 March, 2021

Radiative corrections and neutrino scattering

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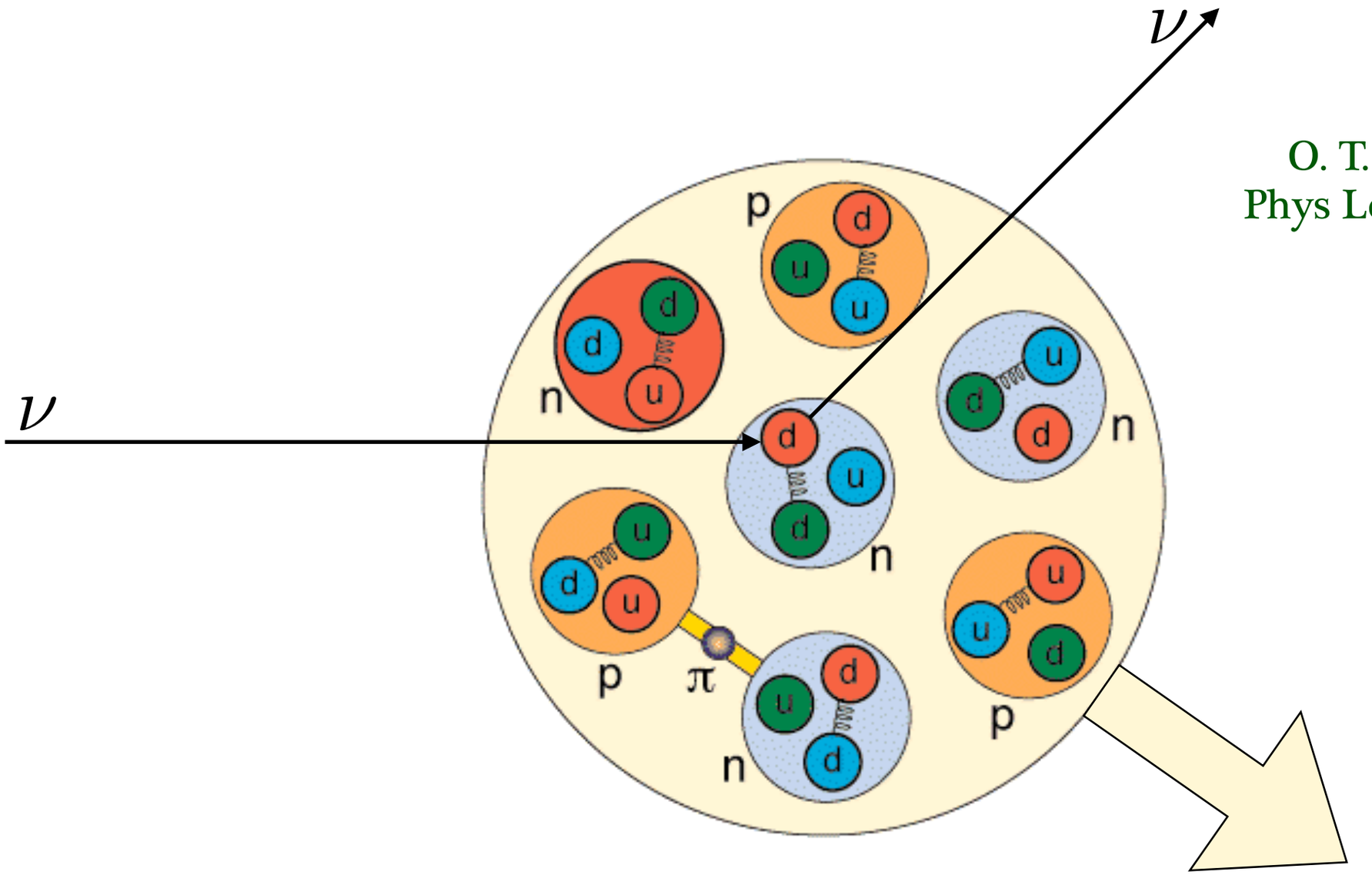
Radiative corrections in coherent elastic neutrino-nucleus scattering

O.T., P. Machado, V. Pandey and R. Plestid, JHEP 2102, 097 (2021)

neutrino energy < 100 MeV

From quarks to nuclei



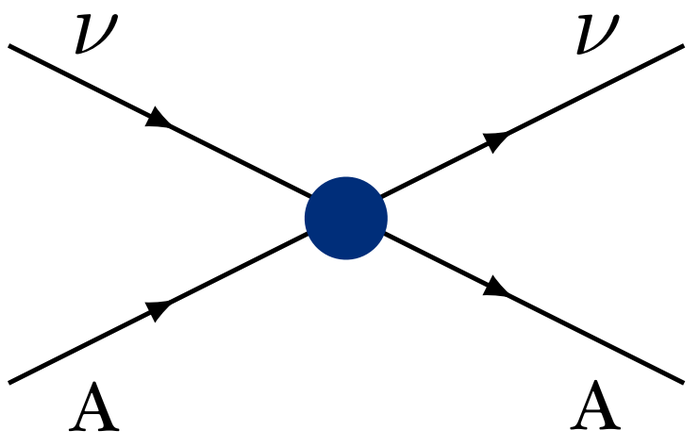
quark level

O. T. and Richard J Hill,
Phys Lett B 805 (2020) 135466

fafnir.phyast.pitt.edu

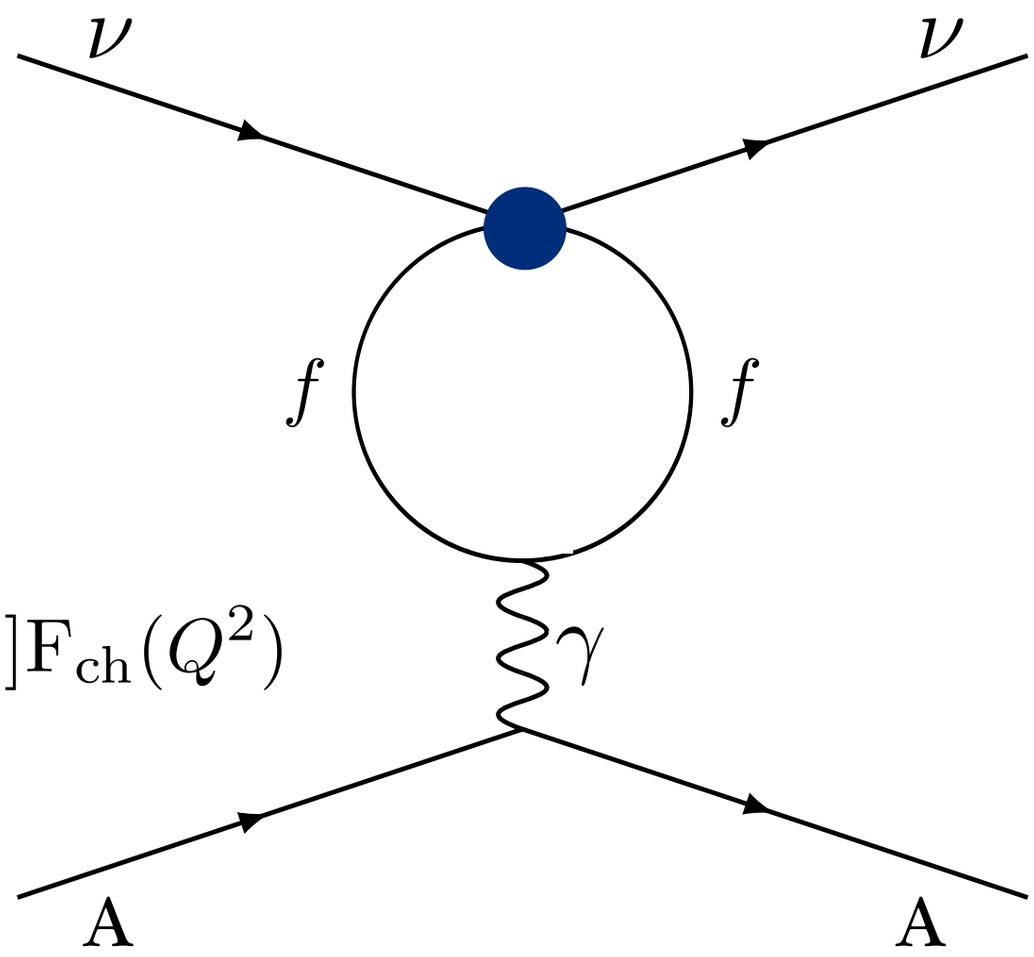
- scattering on quarks in nucleons in nucleus

CEvNS cross section on spin-0 nuclei



- tree-level cross section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}T} = \frac{\mathrm{G_F^2} M_\mathrm{A}}{4\pi}\left(1 - \frac{T}{E_\nu} - \frac{M_\mathrm{A} T}{2E_\nu^2}\right)\mathrm{F_W^2}\left(Q^2\right)$$



- effect of radiative corrections

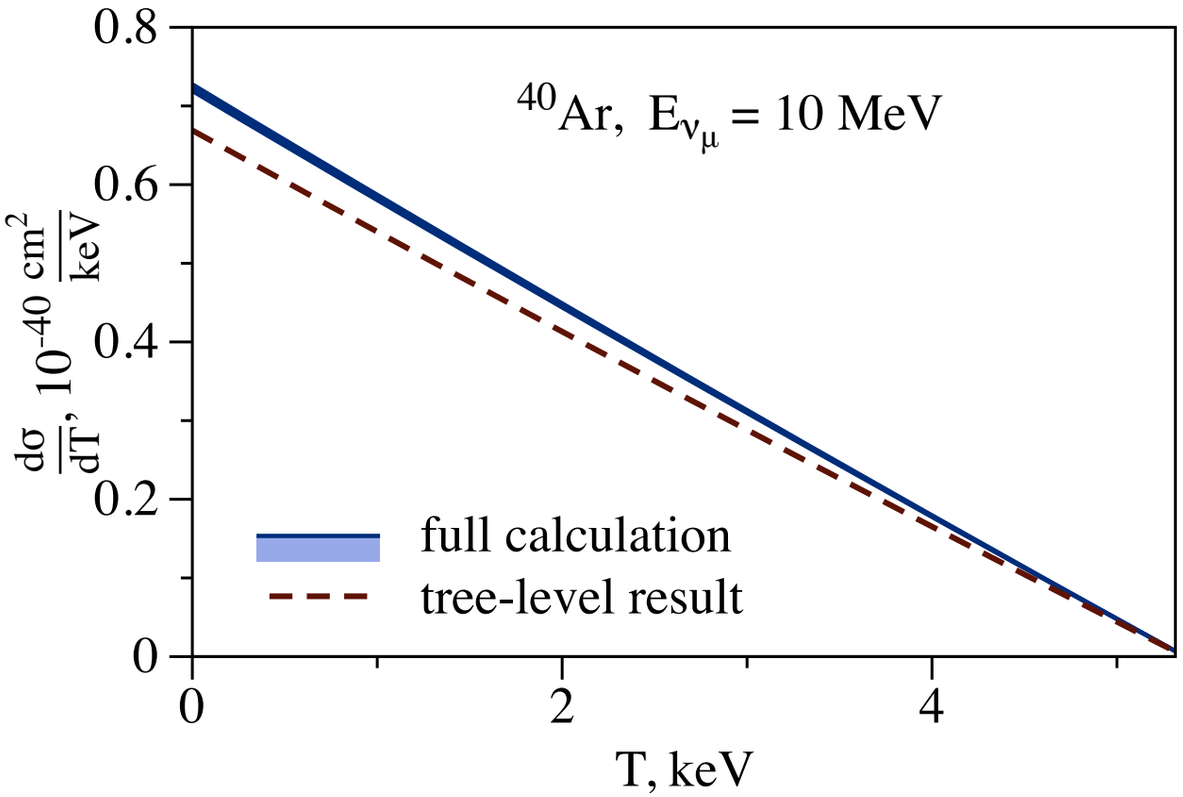
$$\mathrm{F_W}\left(Q^2\right) \to \mathrm{F_W}\left(Q^2\right) + \frac{\alpha}{\pi}[\delta^{\nu_\ell} + \delta^{\mathrm{QCD}}]\mathrm{F_{ch}}(Q^2)$$

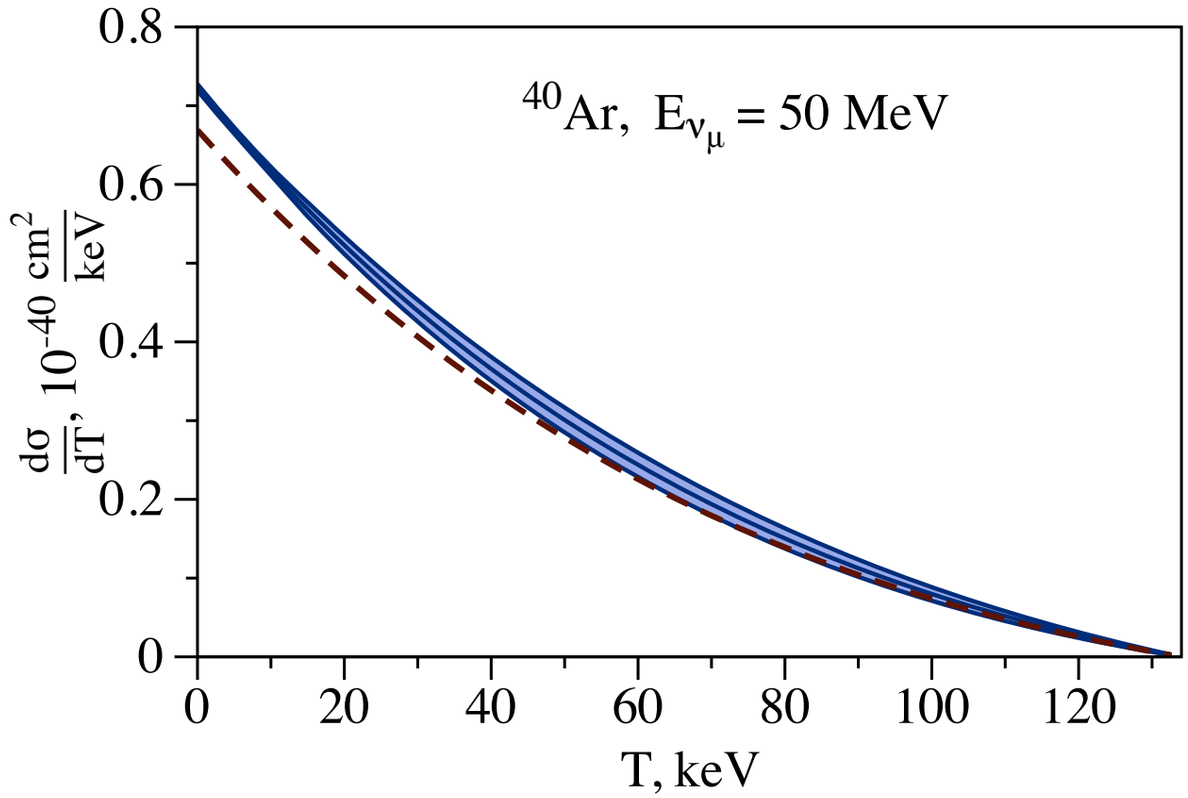
- radiative corrections enter with the nucleus charge form factor

Total and differential cross section

- recoil nucleus energy spectrum: one-loop vs tree level

nuclear models for point-nucleon form factors:
Yang et al. (2019), Payne et al. (2019), Hoferichter et al. (2020), Van Dessel et al. (2020)





- % effect of radiative corrections on cross sections

Radiative corrections in CCQE on free nucleons

Qing Chen, Richard J. Hill, Kevin S. McFarland and O. T. (arXiv: to appear)

soft-collinear-hard factorization framework

neutrino energy ~ GeV

Radiative corrections in CCQE

- large kinematical logarithms enhance radiative corrections

$\frac{\alpha}{\pi} \sim 0.2\ \%$ multiplied by $\ln \frac{E_\nu}{m_\ell} \sim 6 - 10$

$E_\nu \gg m_e$

- CCQE with electron flavor is subject to large corrections

- phase-space restrictions enhance radiative corrections

$\frac{\alpha}{\pi} \sim 0.2\ \%$ multiplied by $\ln^2 \frac{E_\nu}{m_\ell} \sim 36 - 100$

$E_\gamma < \Delta E$ soft photons $2 \ln \frac{E_\nu}{m_\ell} \ln \frac{\Delta E}{m_\ell} \sim 35 - 60$

smaller collinear logarithms

- crucial dependence on detector details

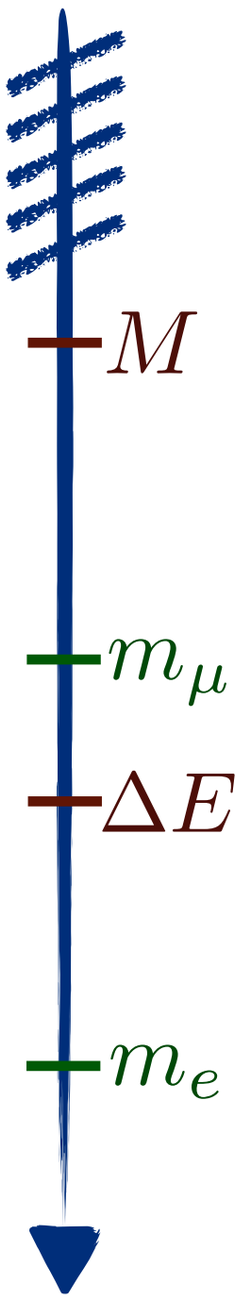
- radiative corrections crucial for %-level oscillation program

Factorization approach

- cross section is given by factorization formula

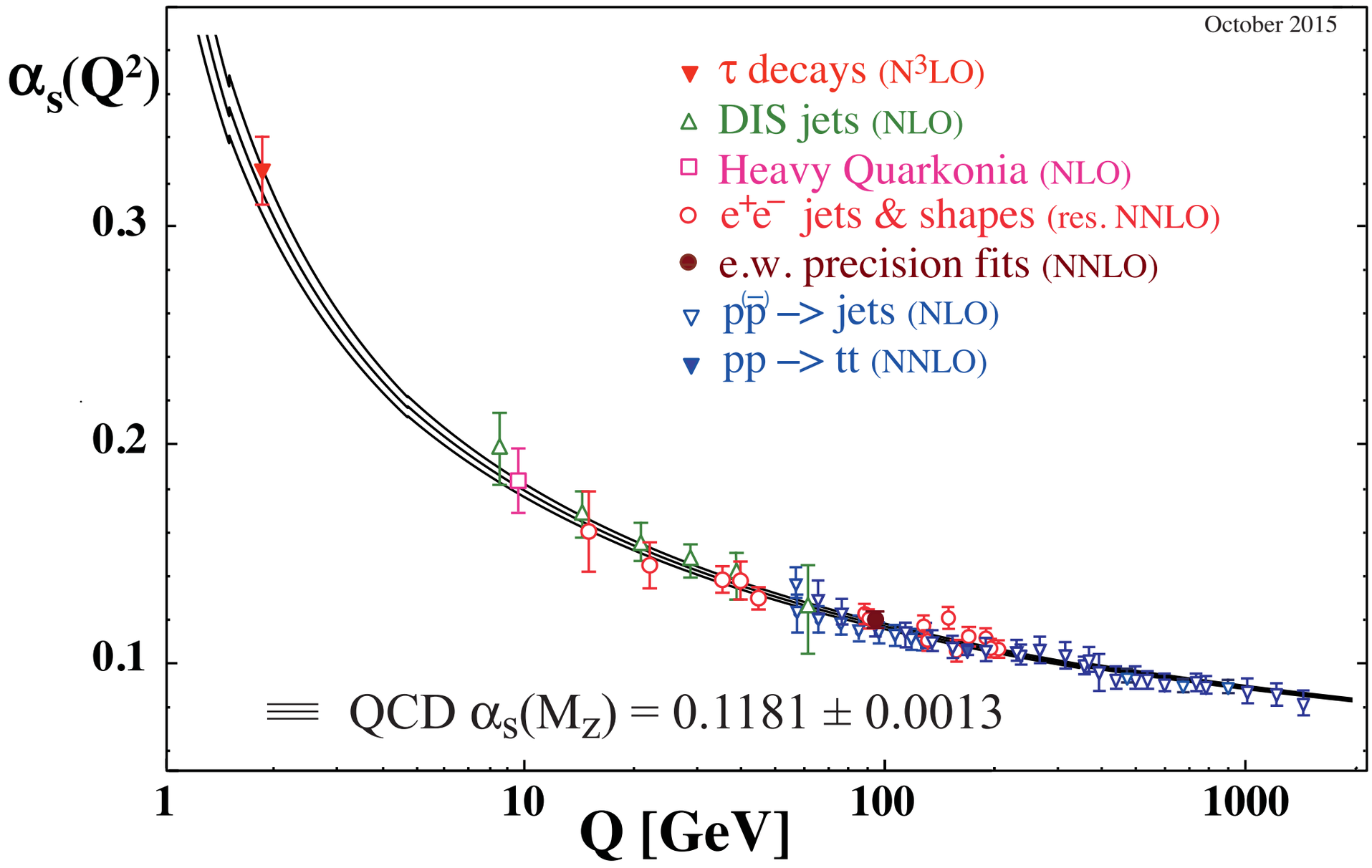
$$\mathrm{d}\sigma \sim S\left(\frac{\Delta E}{\mu}\right) J\left(\frac{m_\ell}{\mu}\right) H\left(\frac{M}{\mu}\right) + \frac{\alpha}{\pi}\mathrm{O}\left(\frac{\Delta E}{E_\nu}, \frac{m_\ell^2}{M^2}, (\Delta\theta)^2\right)$$

- determine hard function at hard scale by matching experiment or model to the theory with heavy nucleon



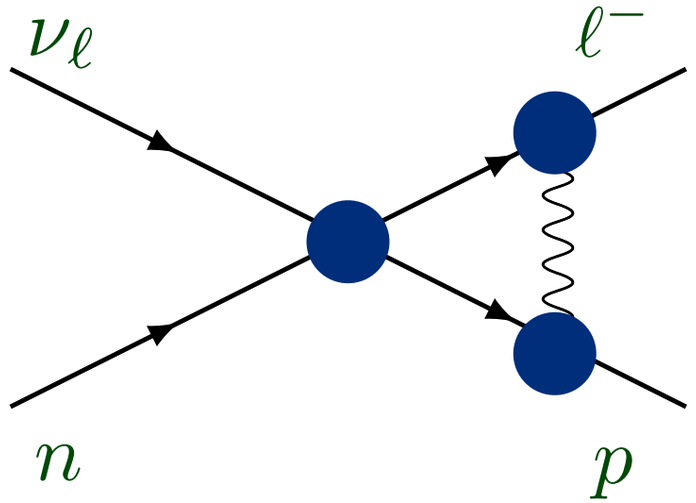
Interaction with nucleons

- QCD running coupling



- hadrons are correct degrees of freedom at GeV energy

Hadronic model at GeV scale



- exchange of photon between the charged lepton and nucleon

commonly used for 2γ, discussed for CCQE: Krzystof M. Graczyk (2013)

- assume onshell form for each interaction vertex

- best determination of hard function

Factorization approach

- cross section is given by factorization formula

$$\mathrm{d}\sigma \sim S\left(\frac{\Delta E}{\mu}\right) J\left(\frac{m_\ell}{\mu}\right) H\left(\frac{M}{\mu}\right) + \frac{\alpha}{\pi}\mathrm{O}\left(\frac{\Delta E}{E_\nu}, \frac{m_\ell^2}{M^2}, (\Delta\theta)^2\right)$$

- determine hard function at hard scale by matching experiment or model to the theory with heavy nucleon

- RGE evolution of the hard function to scales $\Delta E, m_\ell$

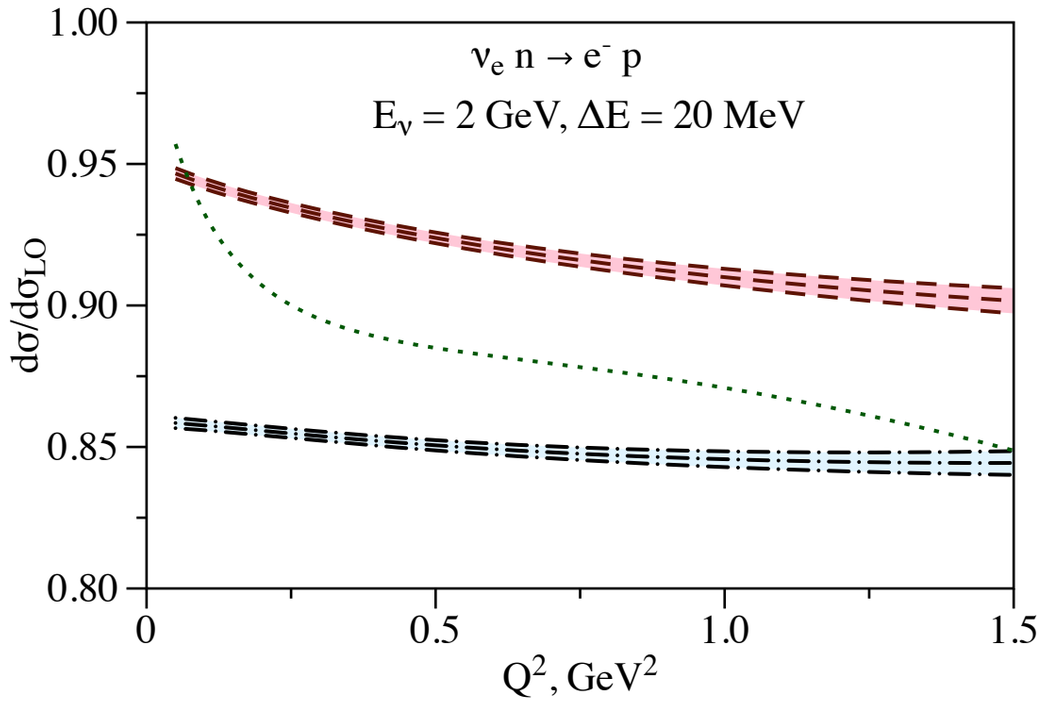
- soft and collinear functions are evaluated perturbatively

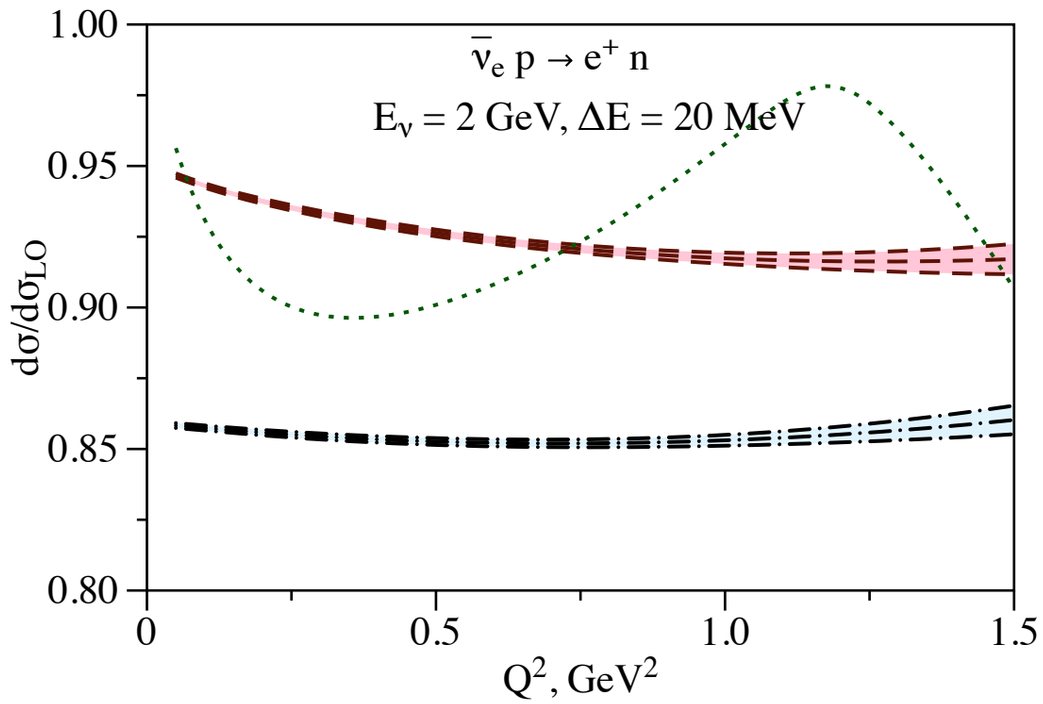
- calculate cross section at low energies accounting for all large logs

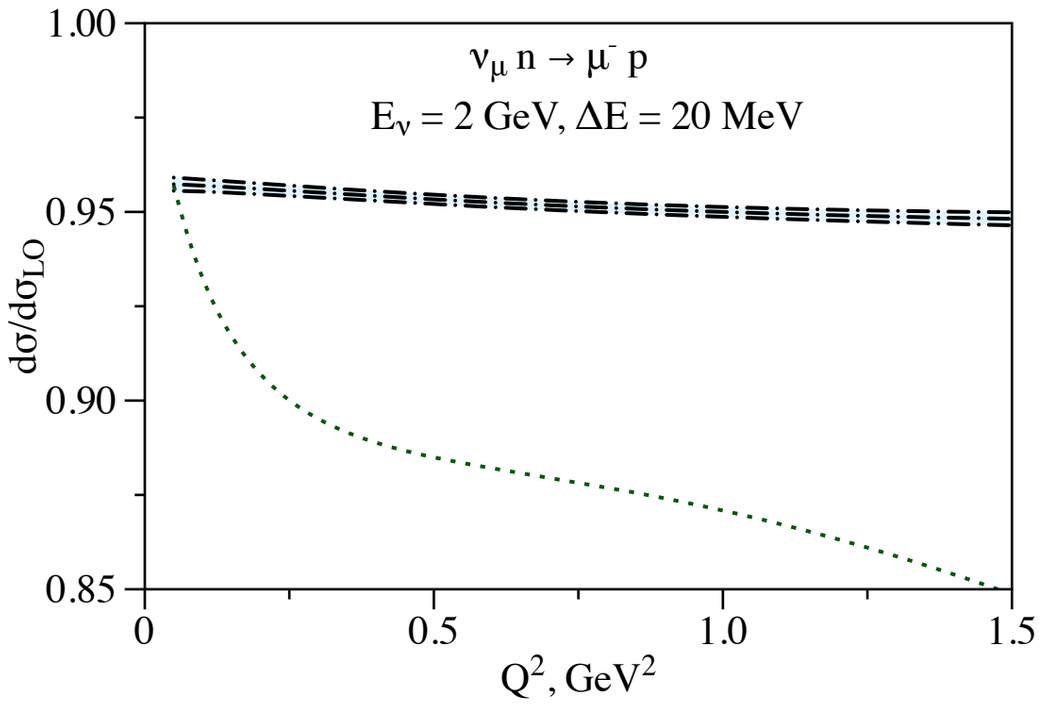
ep scattering with soft radiation only: R.J. Hill (2016)

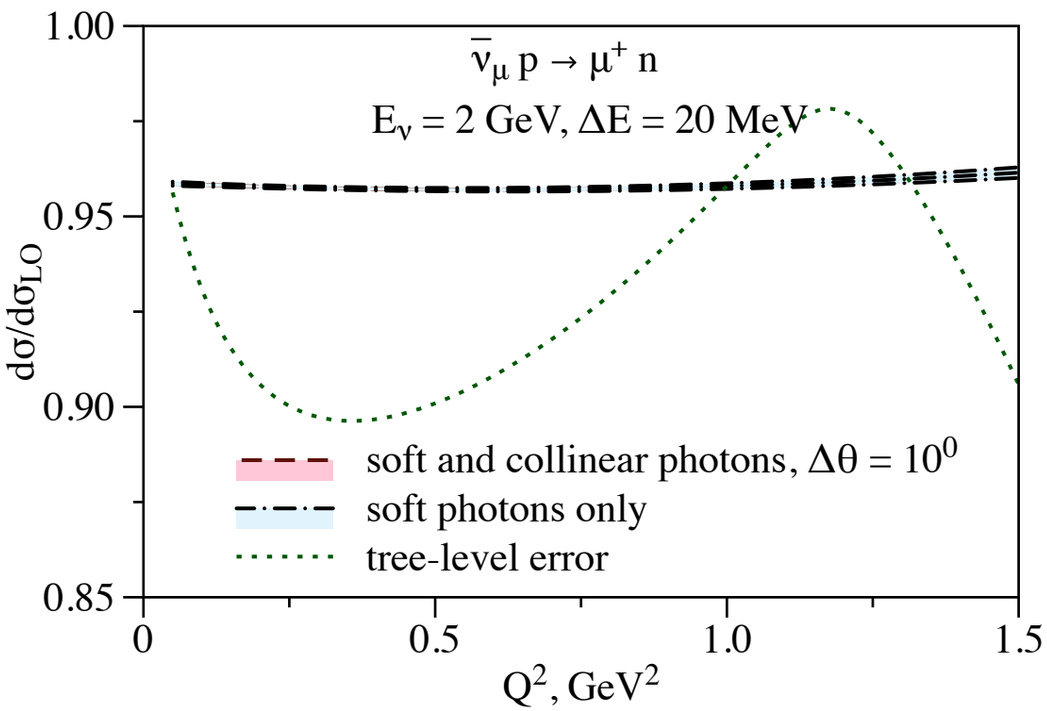
- soft and collinear functions obtained analytically
- hard function describes physics at GeV energies

Cross sections









- corrections with e larger; cancellation virtual vs real

Radiative corrections

- more details at NDNN 2021 Workshop next week

Outlook

- phenomenological applications

- importance of resonances and resonance production

Ongoing work

Coulomb corrections in CCQE

Ryan Plestid, Richard J. Hill and O. T. (ongoing)

high-energy expansion

enhancement by nucleus charge Z

Stay tuned

Thanks for your attention!