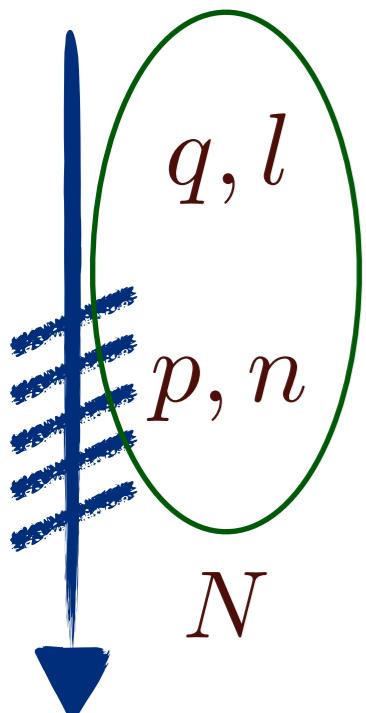


Theory frontier virtual
Kick-Off Town Hall meeting

30 July, 2020

TFo6



Prospects in precise neutrino interactions (at MeV-GeV energies)



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O.T. and R. J. Hill, PRD2020, PLB2020, (arXiv:1907.03379, arXiv:1911.01493)
Kaushik Borah, Richard J. Hill, Gabriel Lee and O. T. (arXiv: 2003.13640)

Neutrino-lepton, neutrino-quark scattering

- couplings of effective Lagrangian are precisely determined

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

$$\mathcal{L}_{\text{eff}}^{\text{CC}} = -2\sqrt{2}G_F \sum_{\ell \neq \ell'} \bar{\nu}_{\ell'} \gamma^\mu P_L \nu_\ell \bar{\ell} \gamma_\mu P_L \ell' - c^{qq'} \sum_{q \neq q'} \bar{q} \gamma^\mu P_L \nu_\ell \bar{q} \gamma_\mu P_L q'$$

- neutrino-electron scattering is used to normalise the neutrino flux

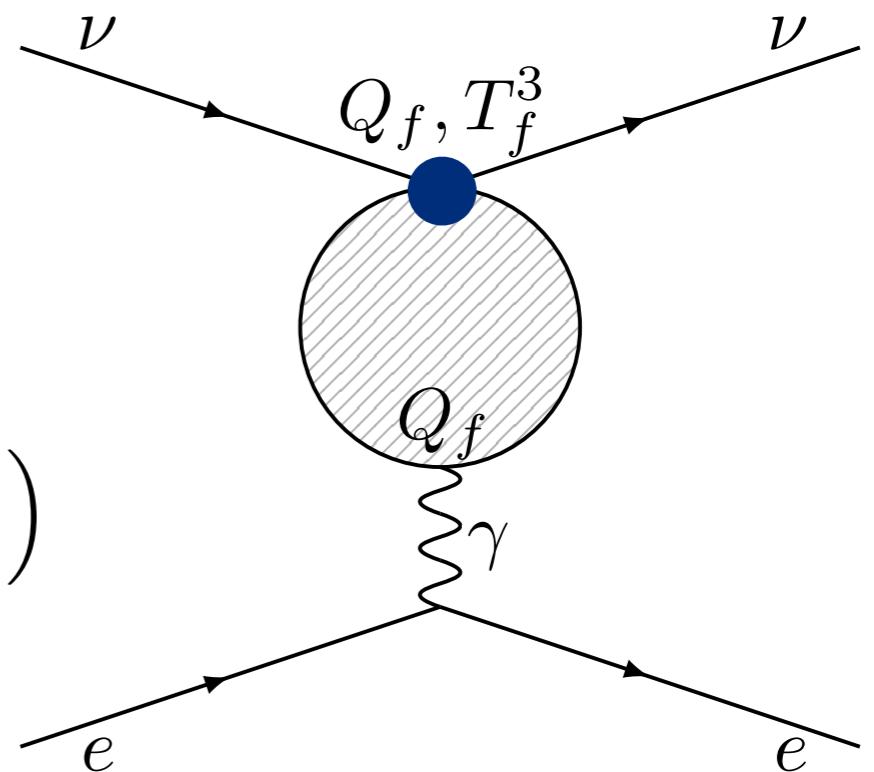
- cross section is known up to 0.2-0.4%

- source of error: hadronic contributions

$$c^h \bar{\nu} \gamma^\mu P_L \nu \cdot \bar{e} \gamma_\mu e$$

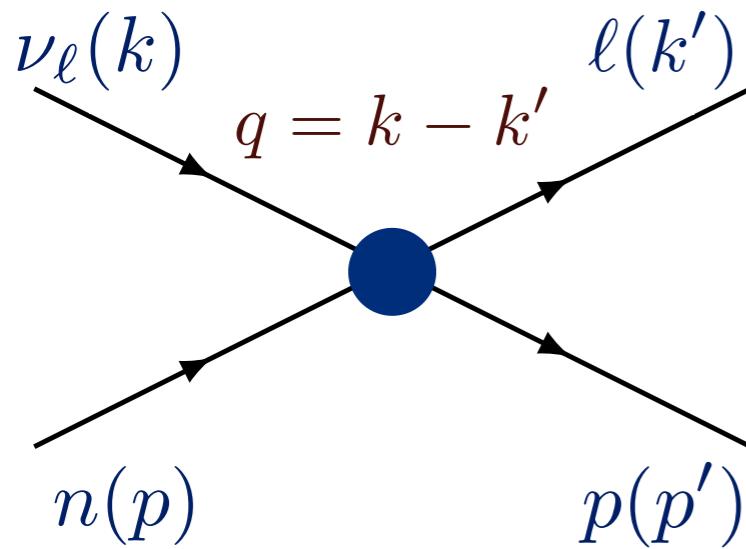
$$c^h = \frac{\sqrt{2}\alpha G_F}{\pi} \left(2 \sin^2 \theta_W \Pi_{\gamma\gamma}^{(3)}(0) - \Pi_{3\gamma}^{(3)}(0) \right)$$

- charge-isospin correlator is uncertain



- hadronic physics limits our knowledge of the simplest process

CCQE scattering on free nucleon



neutrino energy

$$E_\nu$$

momentum transfer

$$Q^2 = -q^2$$

contact interaction at GeV energies

- assuming isospin symmetry, nucleon current:

$$\Gamma^\mu(Q^2) = \langle p | \bar{u} (\gamma^\mu - \gamma^\mu \gamma_5) d | n \rangle$$

$$\Gamma^\mu(Q^2) = \gamma^\mu F_D^V(Q^2) + \frac{i\sigma^{\mu\nu}q_\nu}{2M} F_P^V(Q^2) + \gamma^\mu \gamma_5 F_A(Q^2) + \frac{q^\mu}{M} \gamma_5 F_P(Q^2)$$

form factors: isovector Dirac and Pauli axial and pseudoscalar

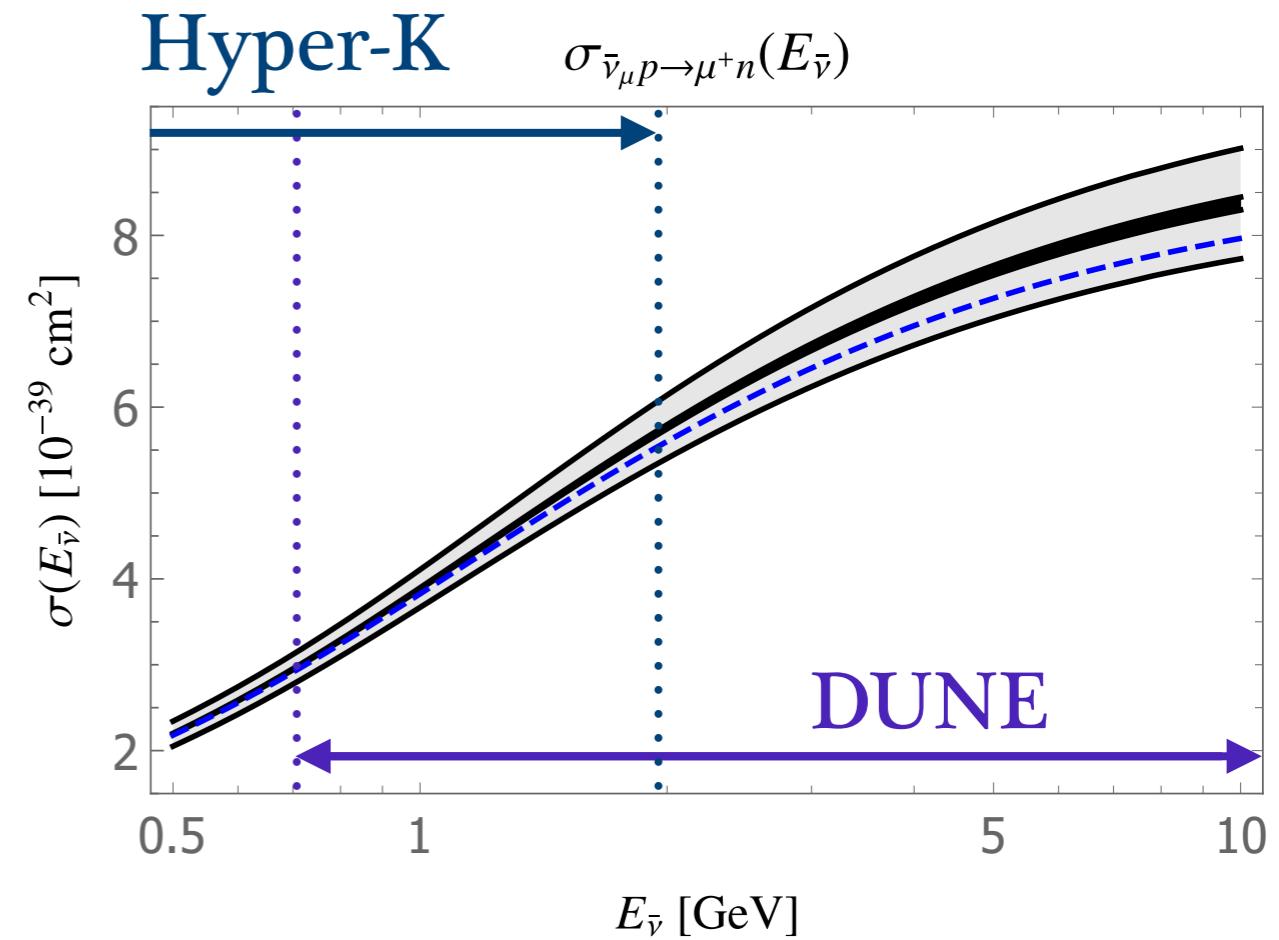
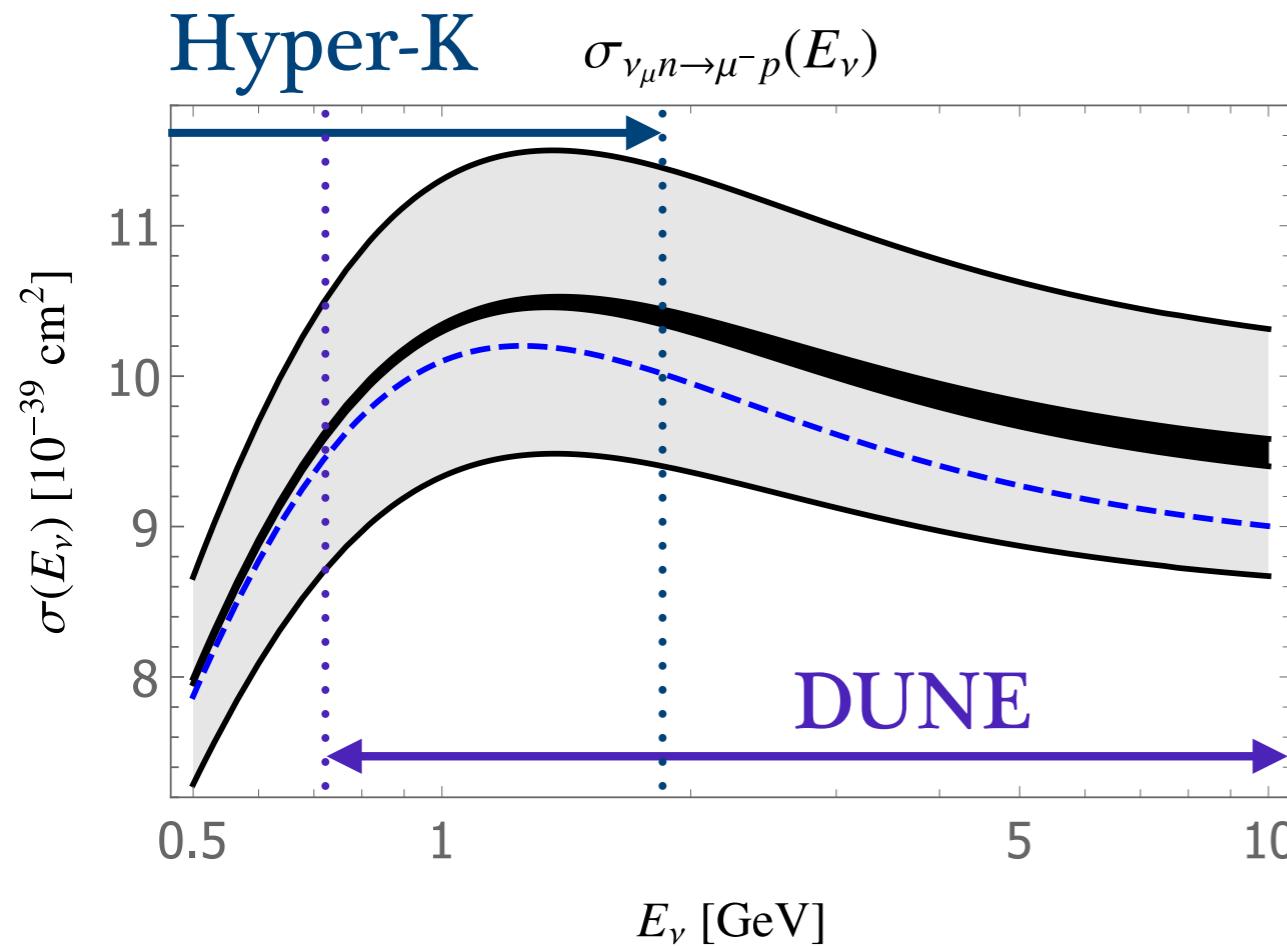
$$F_{D,P}^V = F_{D,P}^p - F_{D,P}^n$$

tree-level amplitude

$$T = \frac{G_F V_{ud}}{\sqrt{2}} (\bar{\ell}(k') \gamma_\mu (1 - \gamma_5) \nu_\ell(k)) (\bar{p}(p') \Gamma^\mu(Q^2) n(p))$$

CCQE scattering cross section

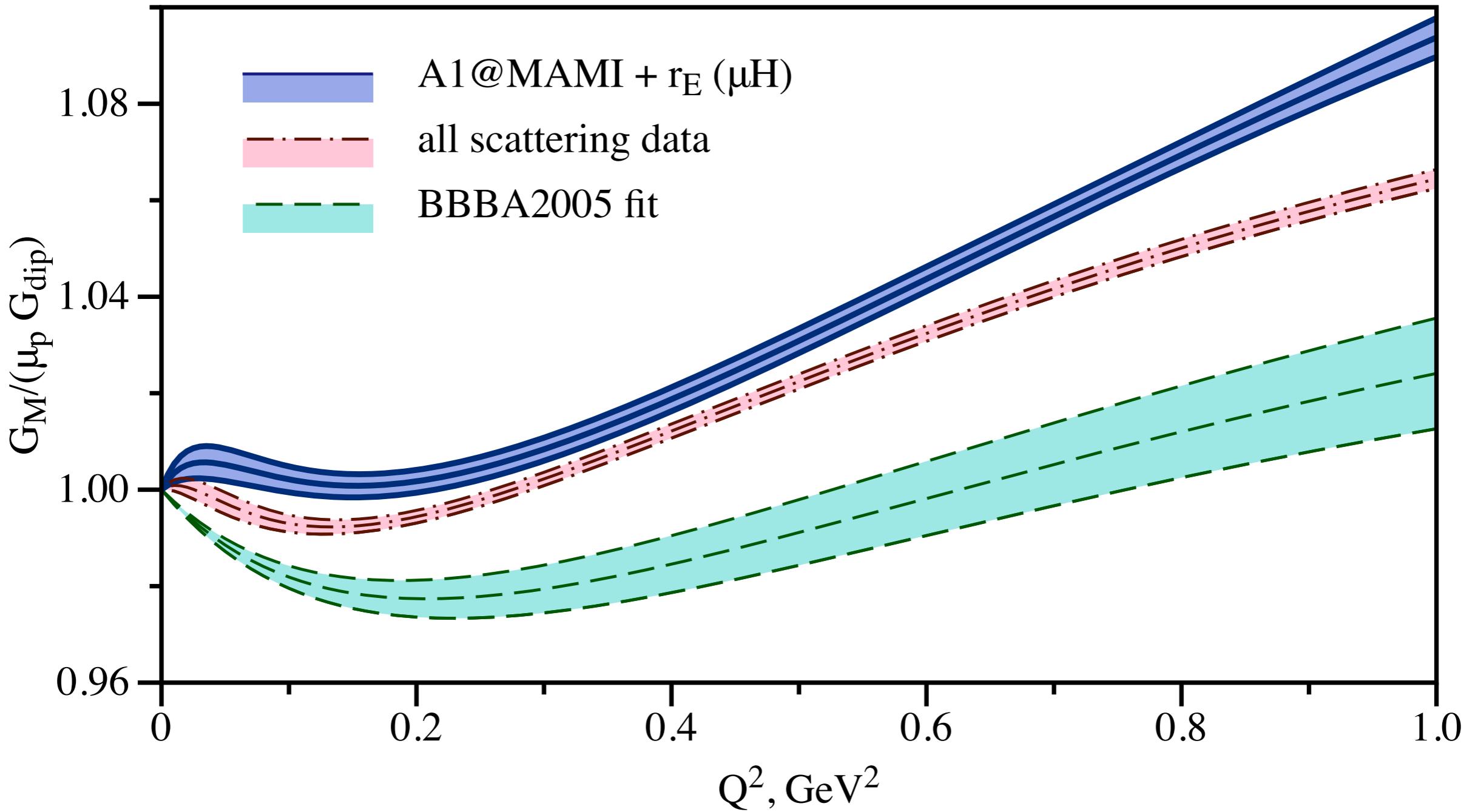
- dark band: uncertainty of iso 1 fit
- light band: uncertainty of axial form factor
- blue line: BBBA2005 fit of electromagnetic form factors



- axial radius and form factor: high-statistics measurement is needed
- knowledge of vector structure stops a progress in studies of axial

Origin of difference

- fits of proton magnetic form factor:



- proton magnetic form factor has to be precisely measured again

Precision of neutrino interactions

	needs	way of progress
scale-independent four-fermion couplings	mixed QCD/EW diagrams	calculation
elastic neutrino-electron scattering	hadronic contributions to γZ mixing	lattice QCD
	radiative corrections	done
CCQE on nucleons	axial form factor	experiment, lattice QCD
	proton magnetic from factor	experiment
	radiative corrections	ongoing
	nuclear physics input for deuterium	
coherent (CEvNS) and neutrino-nucleus scattering	radiative corrections	ongoing
	nuclear physics input	done/ongoing by other groups