Neutrino cross sections in the SIS-DIS transition region

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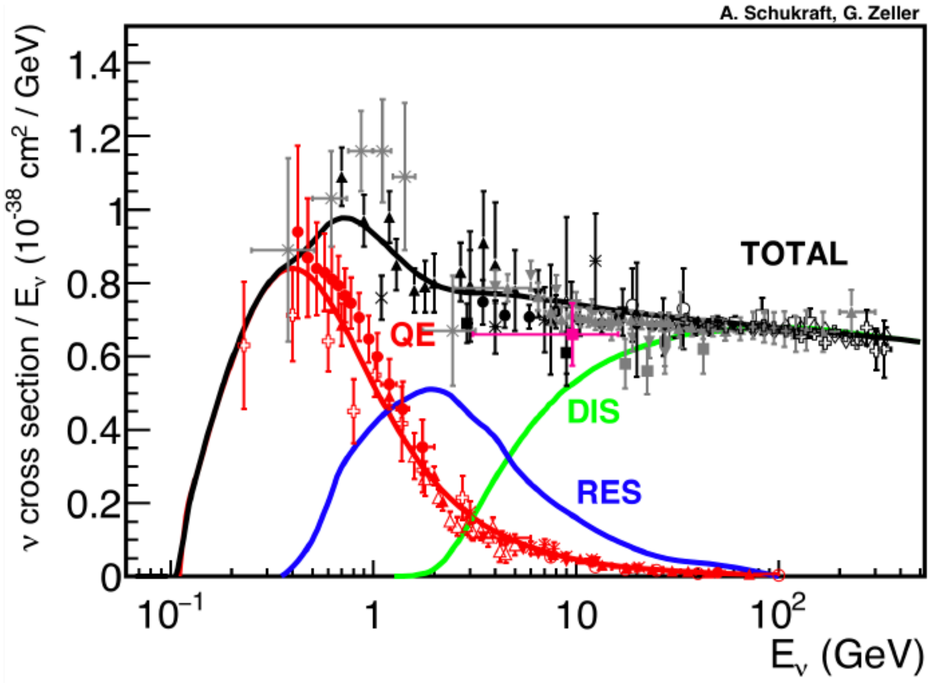
Introduction

- The Forward Physics Facility (FPF) is expected to measure a number of neutrino interactions up to a few TeV energies.
- Considering that the average energy of E_ν is $\mathcal{O}(10^2)$ GeV, neutrino cross sections at the FPF will be largely from deep inelastic scattering (DIS).
- At the FPF, the shallow inelastic scattering events are also expected (Talk by Vishvas Pandey @ the 2nd FPF meeting).



Deep/Shallow - inelastic scattering region

- DIS (deep inelastic scattering)
  - $W > 2$ GeV and $Q^2 > 1$ GeV^2
  - Described at parton level (quark and gluon)

- SIS (shallow inelastic scattering):
  - $m_N + m_\pi$ (or $1.4\,\mathrm{GeV}$) $\lesssim W \lesssim 2$ GeV, all Q^2
  - the kinematic region is not clearly understood both theoretically and experimentally
  - Described at hadron level and parton level (quark-hadron duality)

Ref.: M. S. Athar and J. G. Morfín, J.Phys.G 48 (2021) 3, 034001

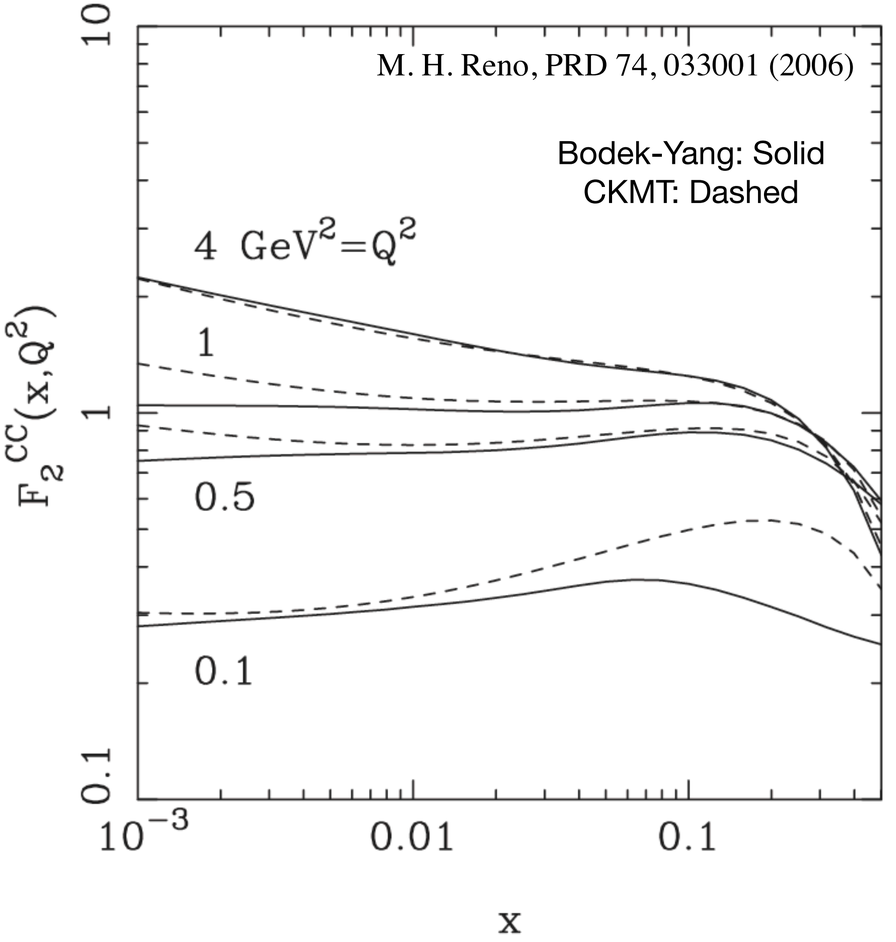
Our work

- Investigated contributions of the low Q^2 and low W on the cross sections.

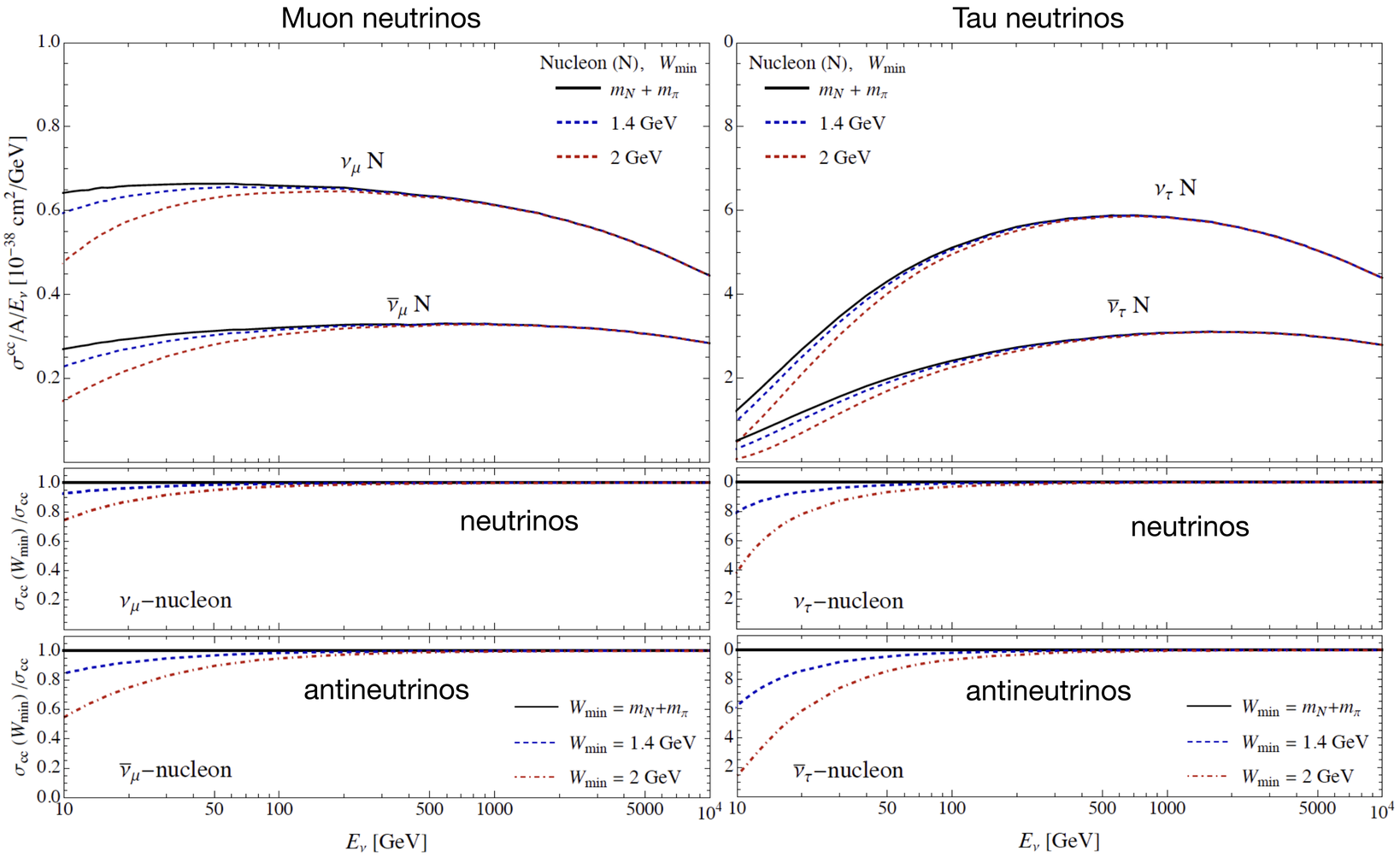
- Probed with the neutrino cross section (ratio) on nucleon target
  - For the FPF, cross section with nuclei target is more relevant.
    - e.g.) for a tungsten target, cross sections per nucleon is larger for neutrinos and smaller for antineutrinos
  - The ratios of the cross sections on tungsten and nucleon are almost the same

Structure functions for low Q — CKMT parameterization

- Bodek-Yang
  - Fit to electromagnetic (EM) scattering data
  - Make the effective PDFs at low Q^2
- CKMT parameterization
  - Phenomenological parameterizations of structure function
  - Fit to EM structure function data

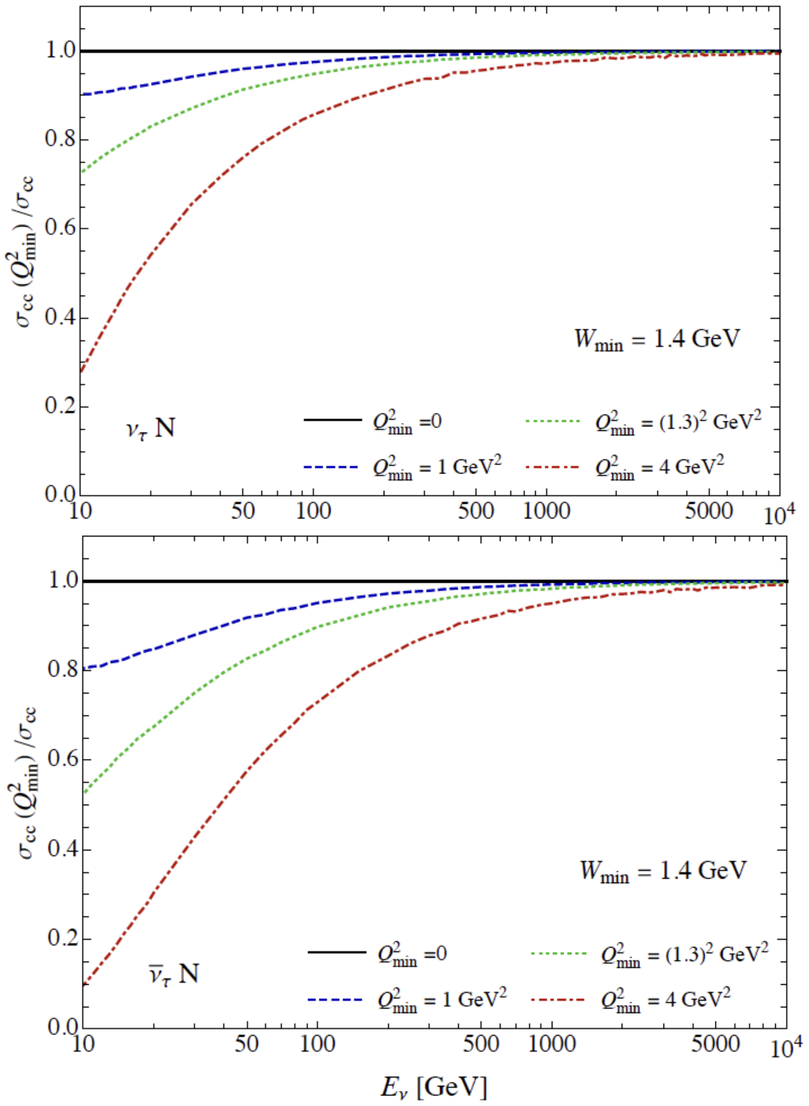


Impact of W_{min} on the neutrino CC cross sections



- $W_{min} = m_N + m_\pi$, 1.4 and 2 GeV
- $$\frac{\sigma\ (W_{min})}{\sigma\ (W_{min} = m_N + m_\pi)}$$
  - Noticeable effect at $E_\nu \lesssim 100$ GeV
  - Larger impact on antineutrinos
  - At 100 GeV, $\sigma^{CC}(W_{min} = 2\ \text{GeV})$ is suppressed by 3% for neutrinos, and by 5-7% for antineutrinos.

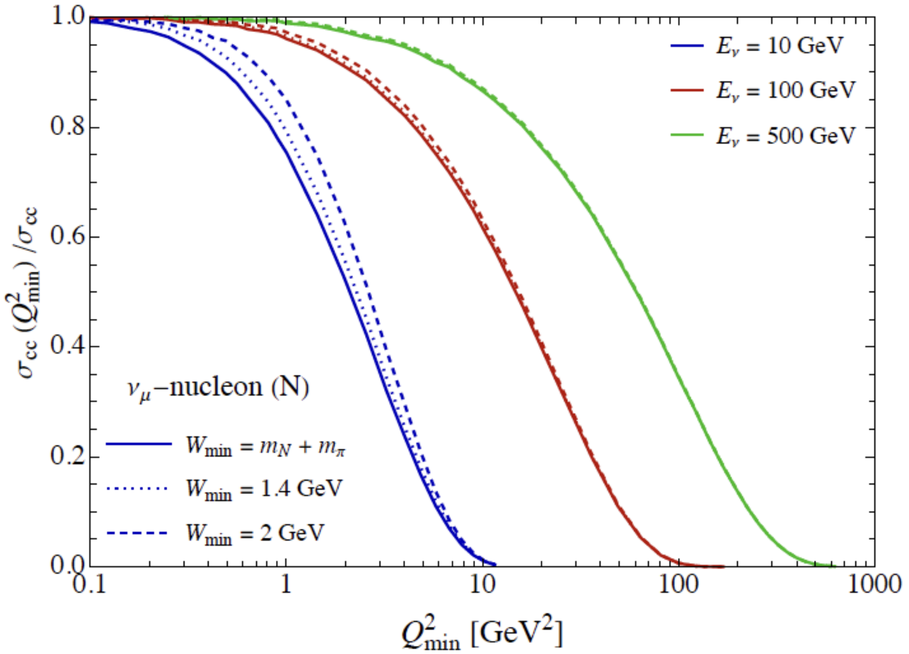
Impact of the Q^2_{min} (1)



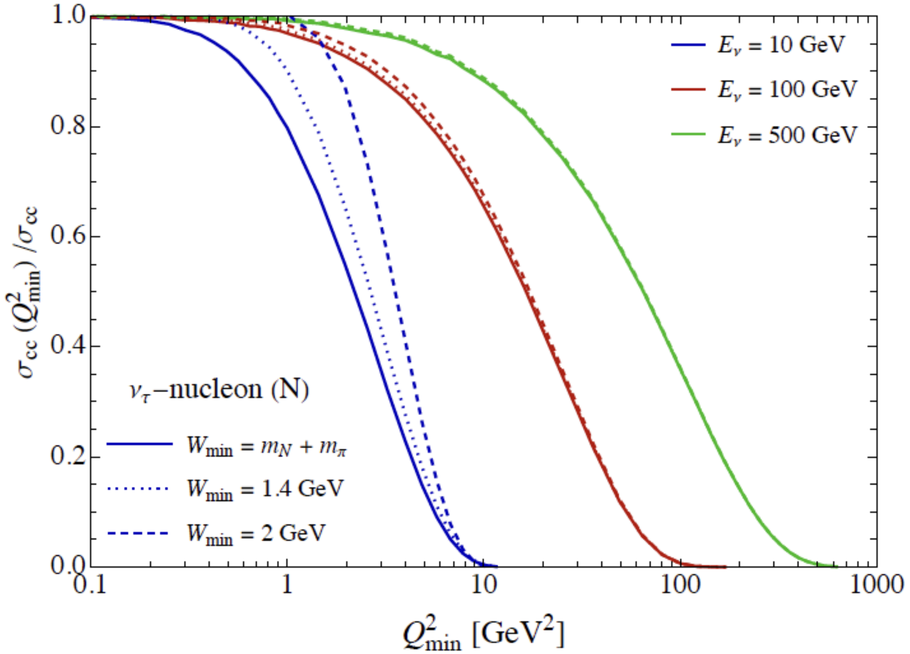
- Cross sections for νN scattering with the cut-off Q^2_{min}, normalized to the cross sections for full Q^2 range.
  - $Q^2_{min} = 1,\ (1.3)^2,\ 4\ \mathrm{GeV}^2$
  - Impact of Q^2 appears on wider energy than W_{min}
  - When W_{min} = 1.4 GeV, the cutoff of $Q^2_{min} = 1\ \mathrm{GeV}^2$ affect 3% for neutrino and 5% for antineutrinos at 100 GeV.
  - For $Q^2_{min} = (1.3)^2\ \mathrm{GeV}^2$, the corresponding effects are 5% and 10%, respectively

Impact of the Q^2_{min} (2)

Muon neutrinos



Tau neutrinos



- The effect of Q^2_{min} is larger for muon neutrinos (apparent at low energies).
- For W_{min} = 1.4 GeV, the contribution from $Q^2_{min} < 1$ GeV^2 to the CC cross section at 100 GeV:
  - 3% and 7% for muon neutrinos and antineutrinos
  - 3% and 5% for tau neutrinos and antineutrinos

Summary

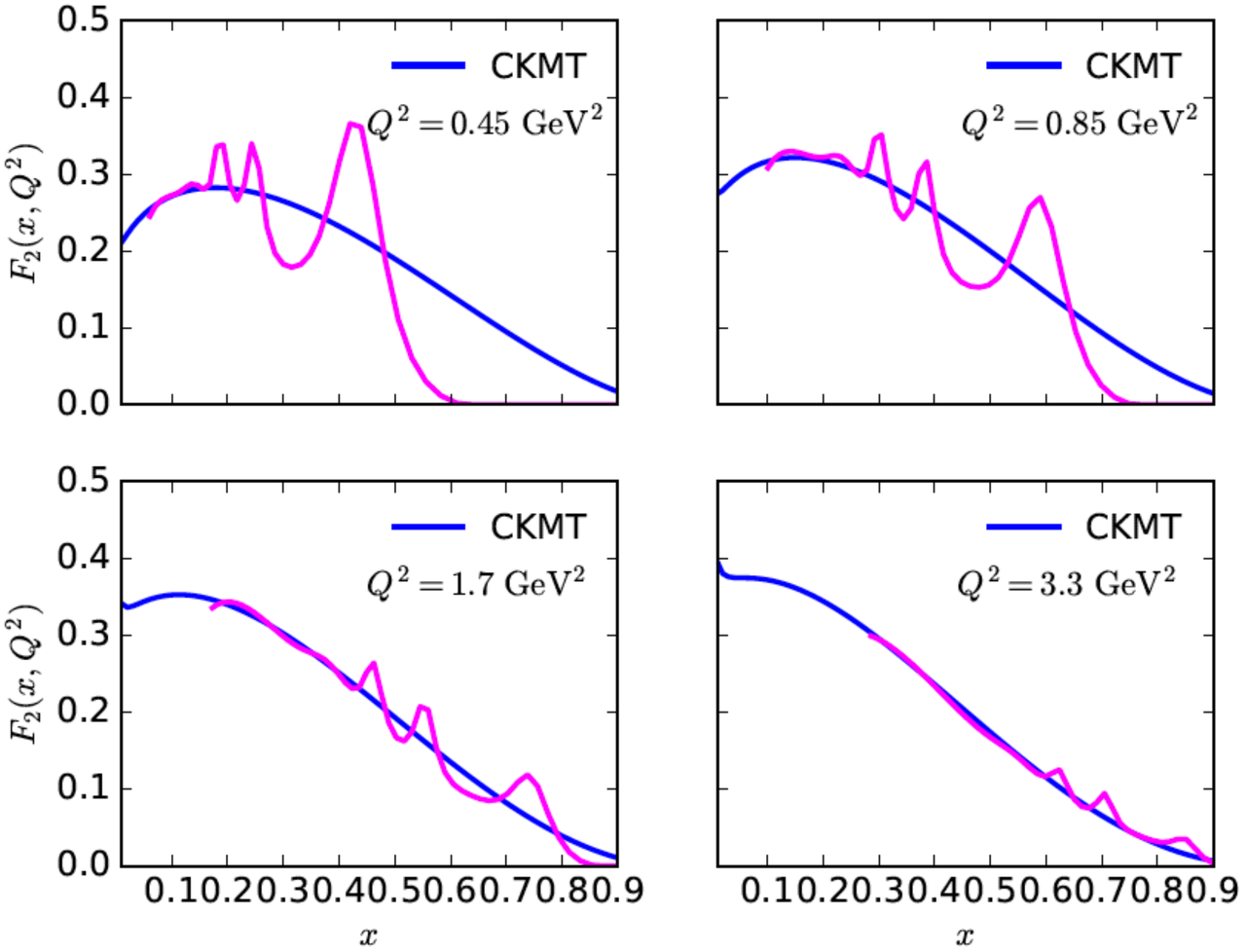
- We have investigated the impact of low Q^2 and low W, which corresponds to the SIS region, on the neutrino CC DIS cross sections.
  - While at very high energies their impact is negligible, they makes difference in the predictions at a few percent level for $E_\nu \sim 100$ GeV.
  - At lower energies, the impact of low Q^2 and low W is greater.

- Further investigation for structure functions/PDFs for $Q_{min} < 1\ (1.3)$ GeV is important to have reliable neutrino cross sections.
  - e.g.) more work in the treatment of the portion of the axial and vector structure functions
    (ref. Bodek-Yang, arXiv:2108.09240)

- The neutrino experiments at the FPF will measure thousands of neutrino events at a few GeV—TeV.
  - The FPF would possibly provide the useful data to probe the SIS kinematic region.

Backup Slides

Comparison: CKMT and CB



- Christy-Bosted (pink)

  : Phys.Rev.C 81 (2010) 055213

  - $1.1 < W < 3.1$ GeV

- CKMT (blue)

Thank you for your attention