



Axial Form Factor of the Nucleon: Implications for Neutrino-Nucleus Cross Sections

Kevin Quirion (Indiana University)

In collaboration with:

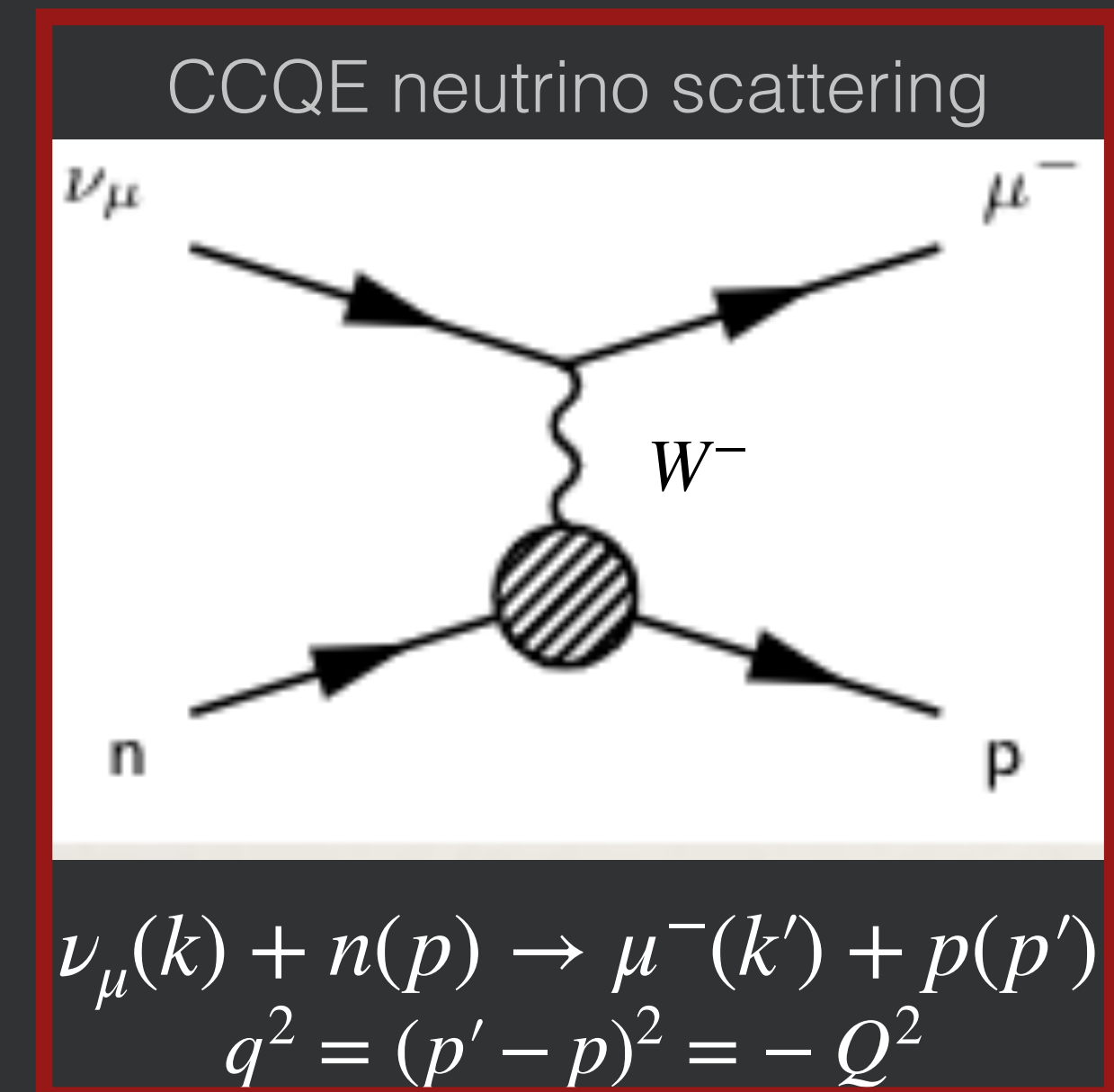
Alexander Friedland (SLAC) , Sergi Gonzalez-Solis (IU), Emilie Passemar (IU)

Free Nucleon Cross Section

Problem with the Free Nucleon cross section

- Weak Interaction $\implies V - A$ structure
- Depends on EM and Axial vector form factors

- F_1, F_2, F_A, F_P



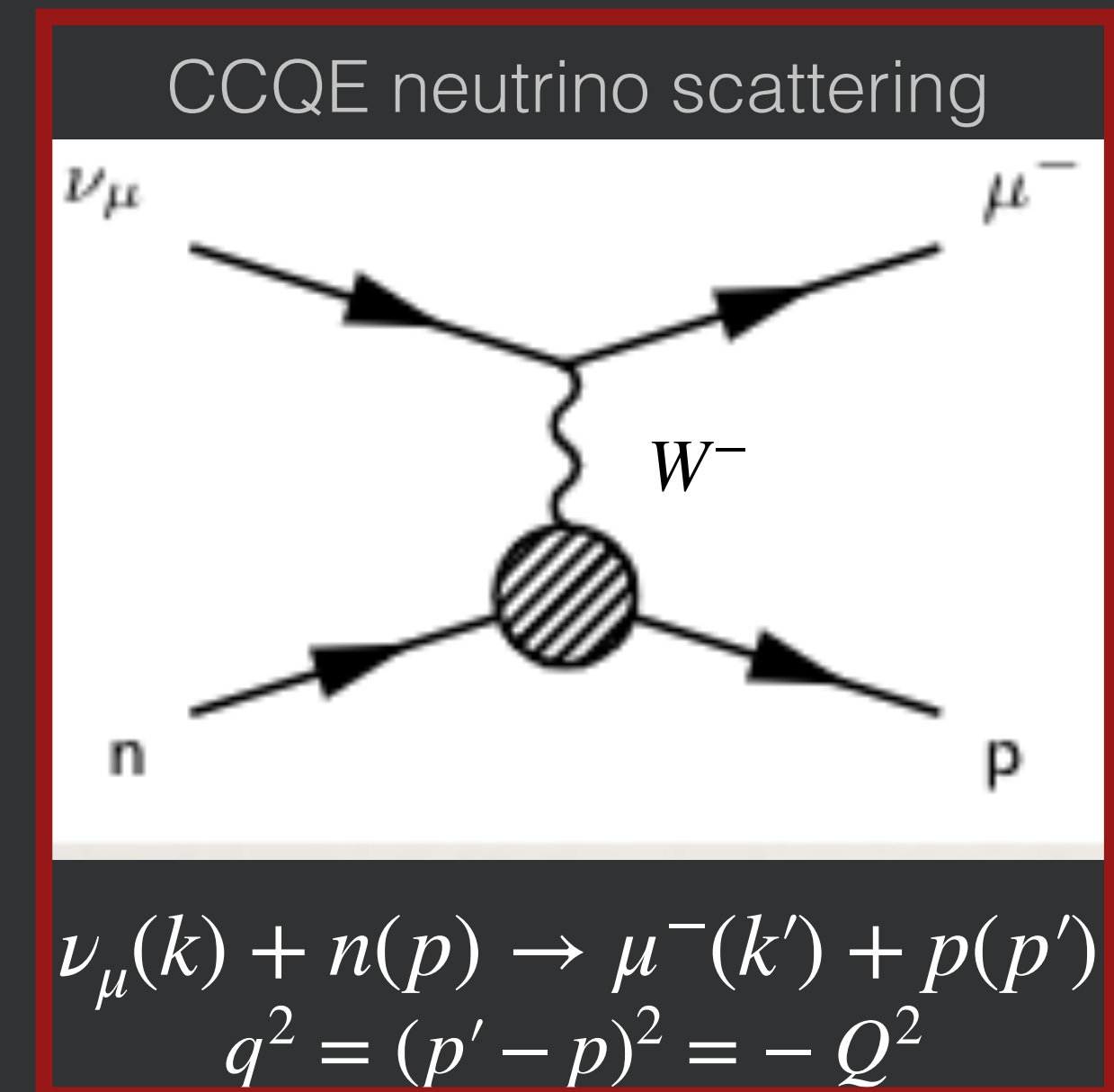
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Precisely measured and modeled
From electron scattering



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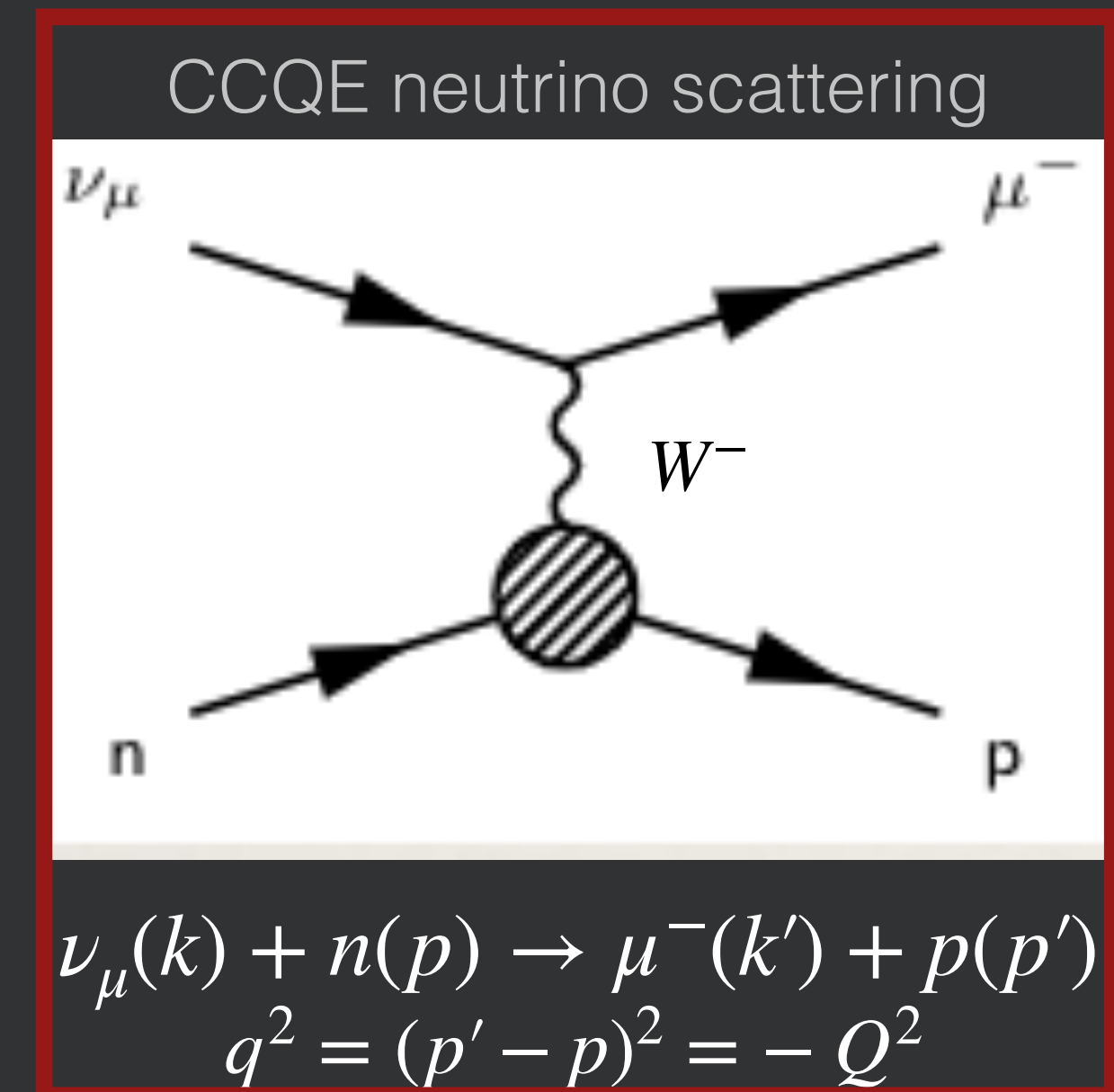
Problem with the Free Nucleon cross section

- Weak Interaction $\implies V - A$ structure
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- F_1, F_2, F_A, F_P

Dominant contribution to amplitude.
Less precisely known

Precisely measured and modeled
From electron scattering



Dipole Ansatz

Since the 70s it has been conventional to model the axial form factor as

$$F_A(Q^2) = \frac{g_A}{\left(1 + \frac{Q^2}{M_A^2}\right)^2}, \quad g_A \equiv F_A(Q^2 = 0)$$

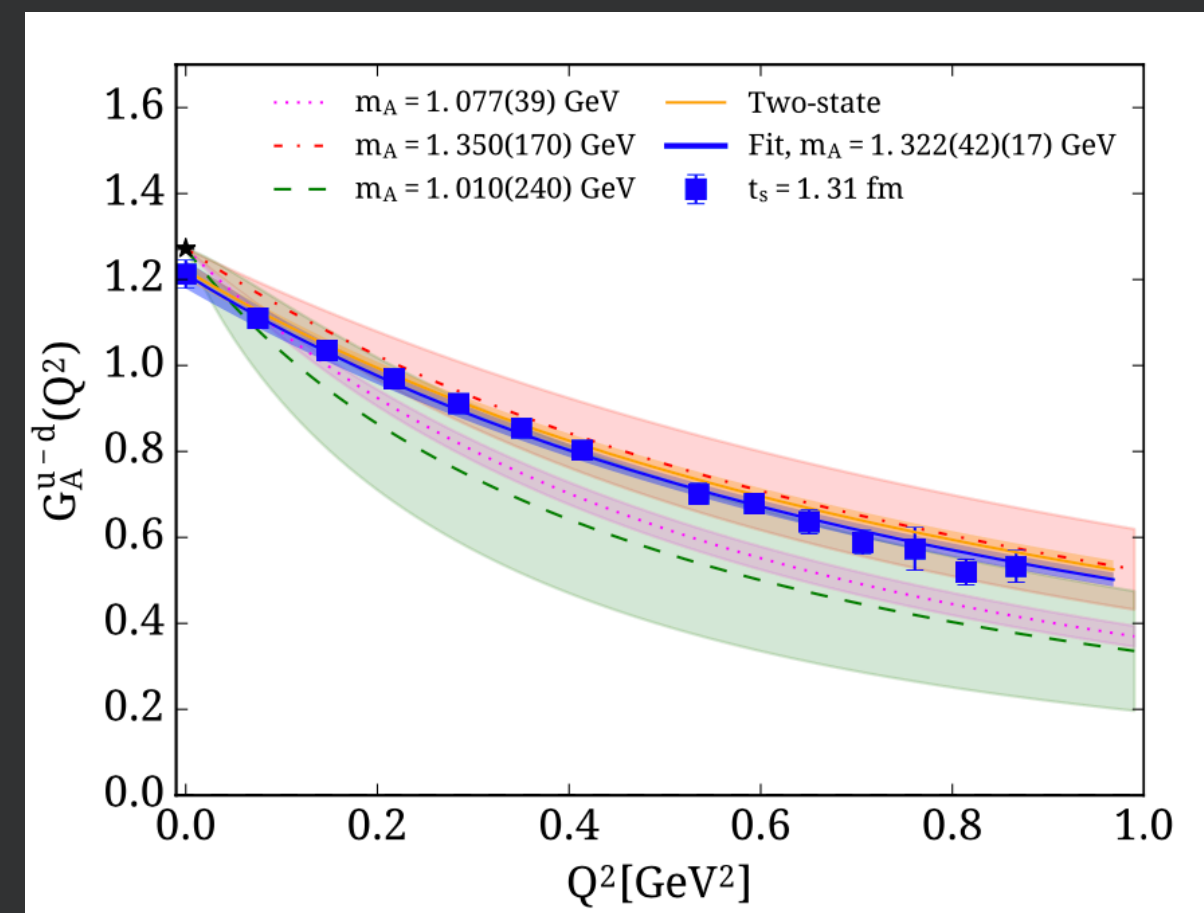
Used by experiments with varying M_A values

Little theoretical motivation

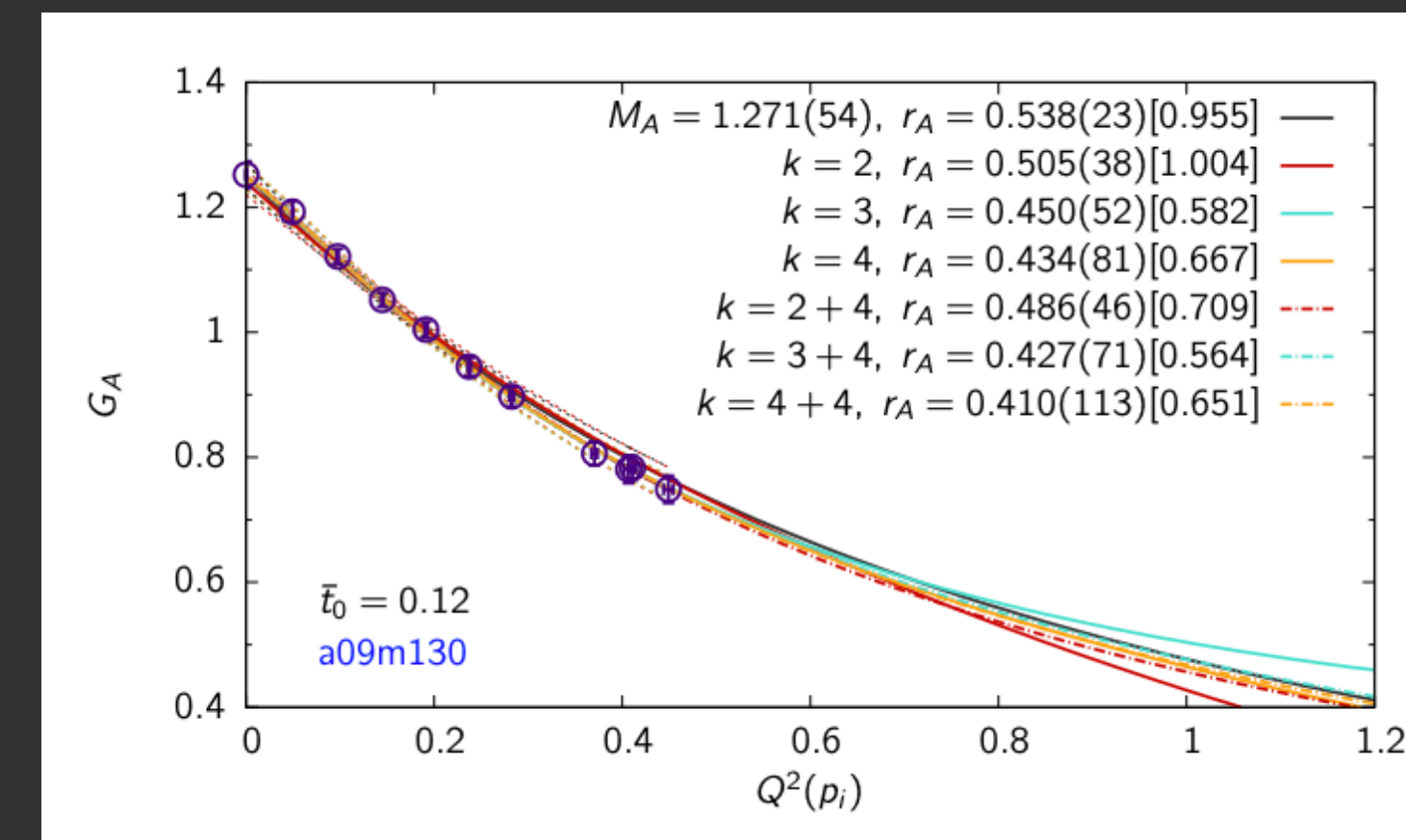
Lattice Calculations

For direct calculations of the axial form factor we look to lattice QCD

- Large effort currently in lattice community to calculate the Q^2 dependence of the axial form factor precisely



Alexandrou et al (2017)

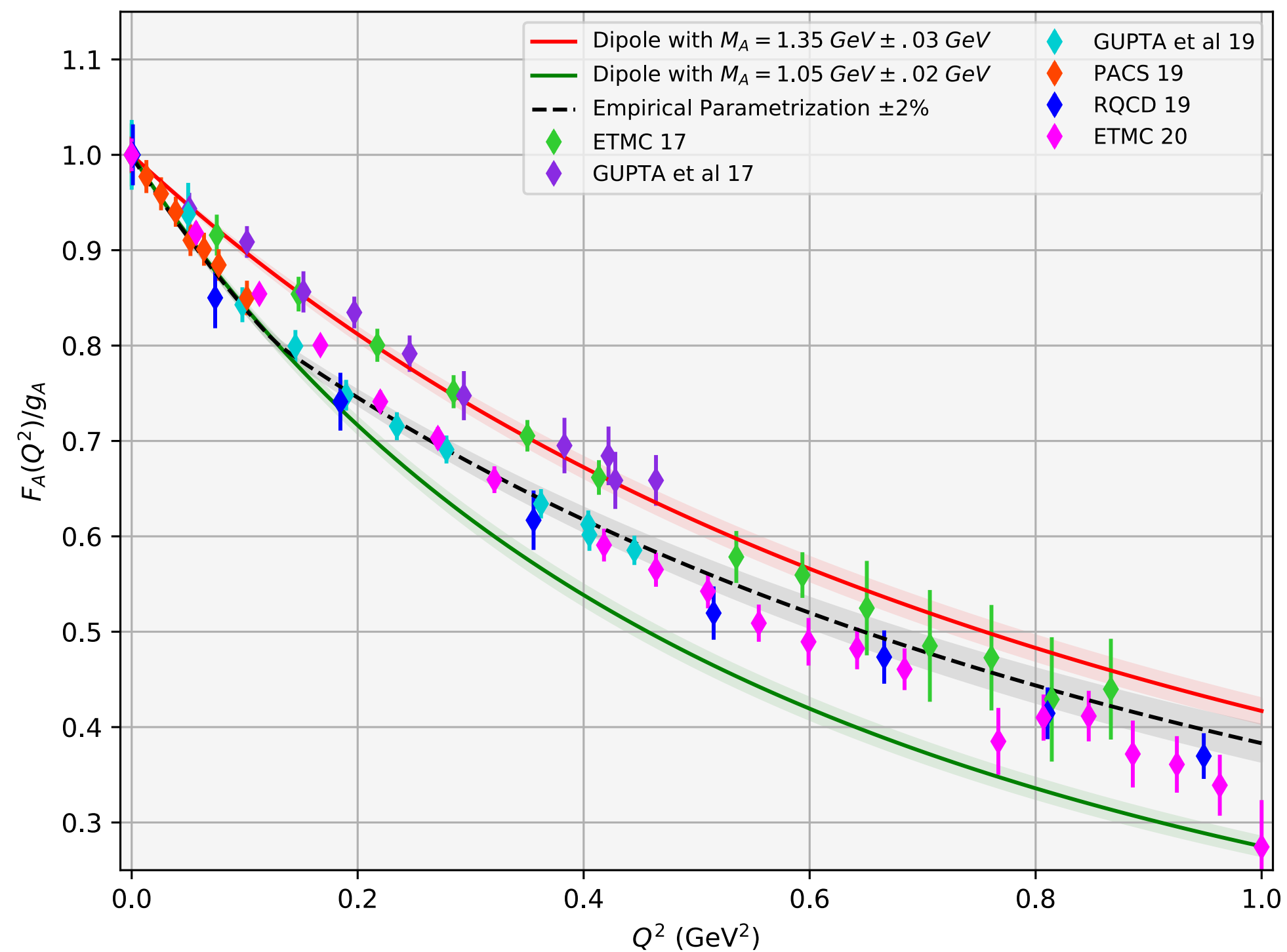


Gupta et al (2017)

Face many challenges such as excited state contamination and error from extrapolation to continuum

More Recent Calculations

Lattice calculations known to suffer from excited state contamination (i.e. πN). Recently several independent efforts to remove this contamination have led to a reassessment of the lattice predictions for $F_A(Q^2)$



Bär

1705.02806

Int. Journal of Modern Physics A Vol. 32 (2017) 1730011

Shintani et al. (PACS)

1811.07292

PRD 99, 014510 (2019)

Bali et al. (RQCD)

1810.05569

PLB 789 (2019)

Jang et al.

1905.06470

PRL 124, 072002 (2020)

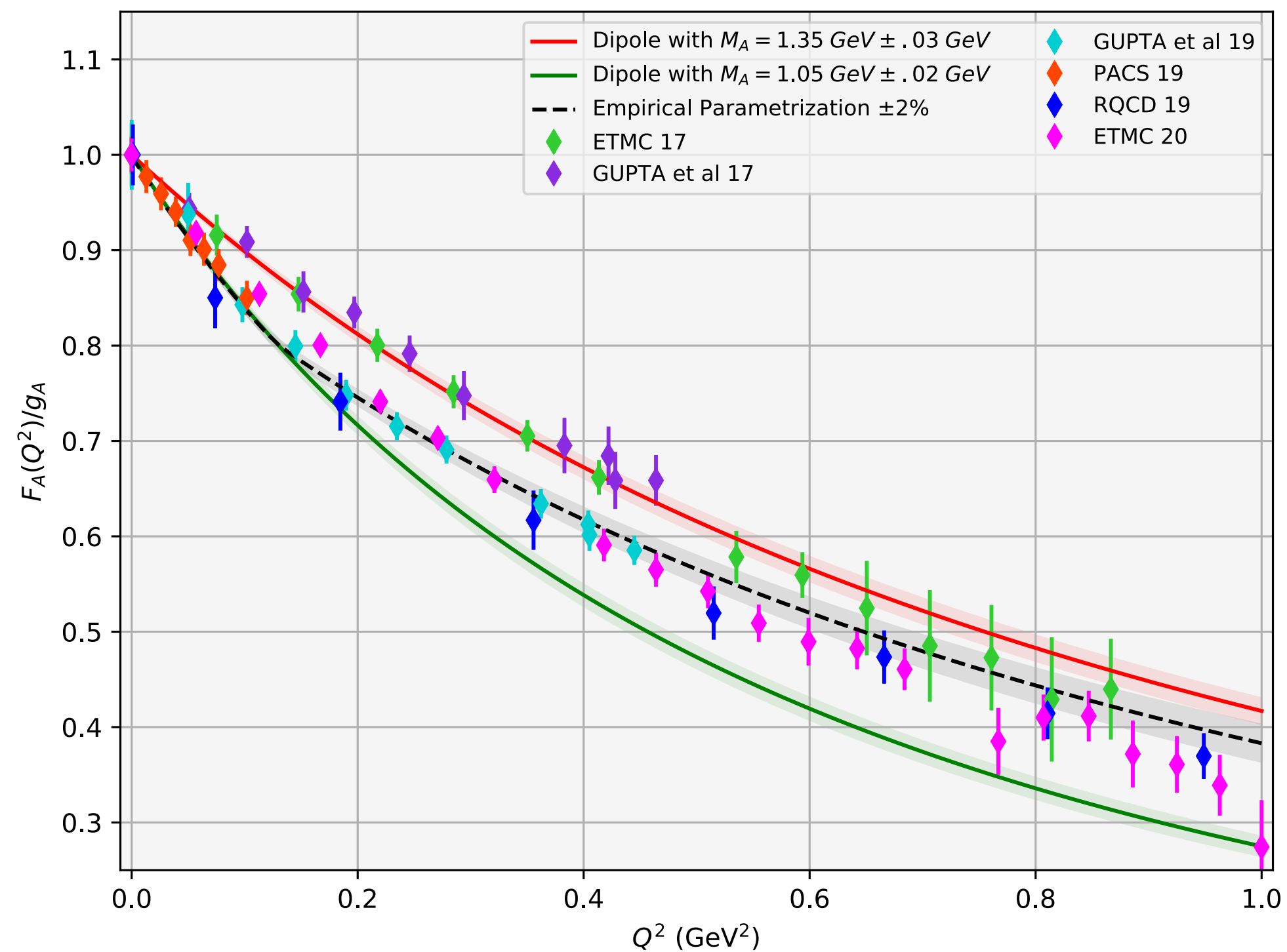
Alexandrou et al. (ETMC)

2011.13342

PRD 103, 034509 (2021)

Failures of the simple Dipole

The dipole form factor is not compatible with recent lattice results



Lattice supports a form factor that behaves as low M_A at low Q^2 and higher M_A at higher Q^2

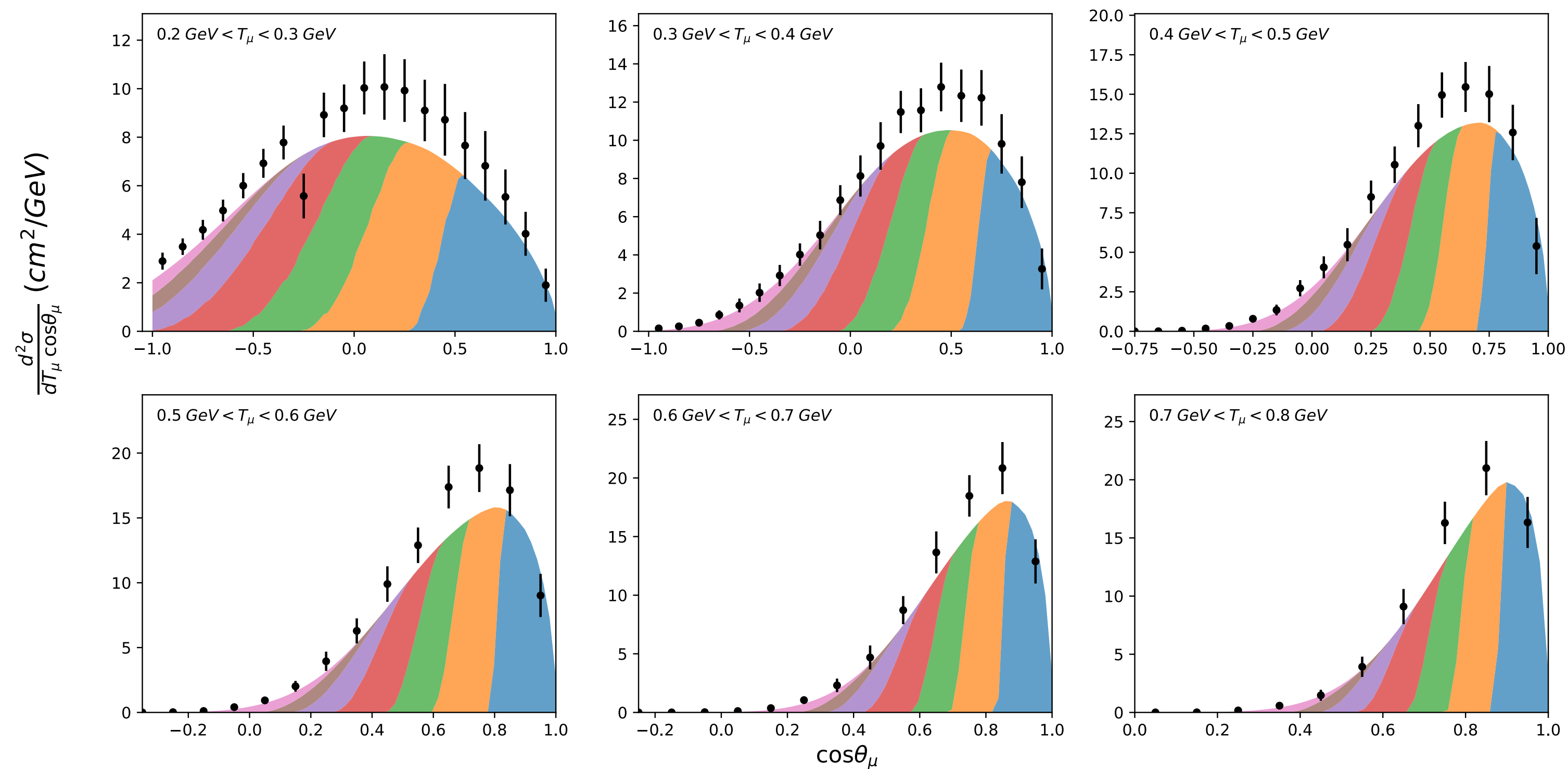
Note: $F_A(Q^2)$ has been normalized in the figure to $F_A(0) = 1$

Implications on Cross Sections

Comparison with MiniBooNE data

Mapping Q^2 behavior to double differential cross section

Double Differential Cross Section with Empirical Form Factor



Shows us where the data is not described well by our axial form factor parametrization

Q^2 Key

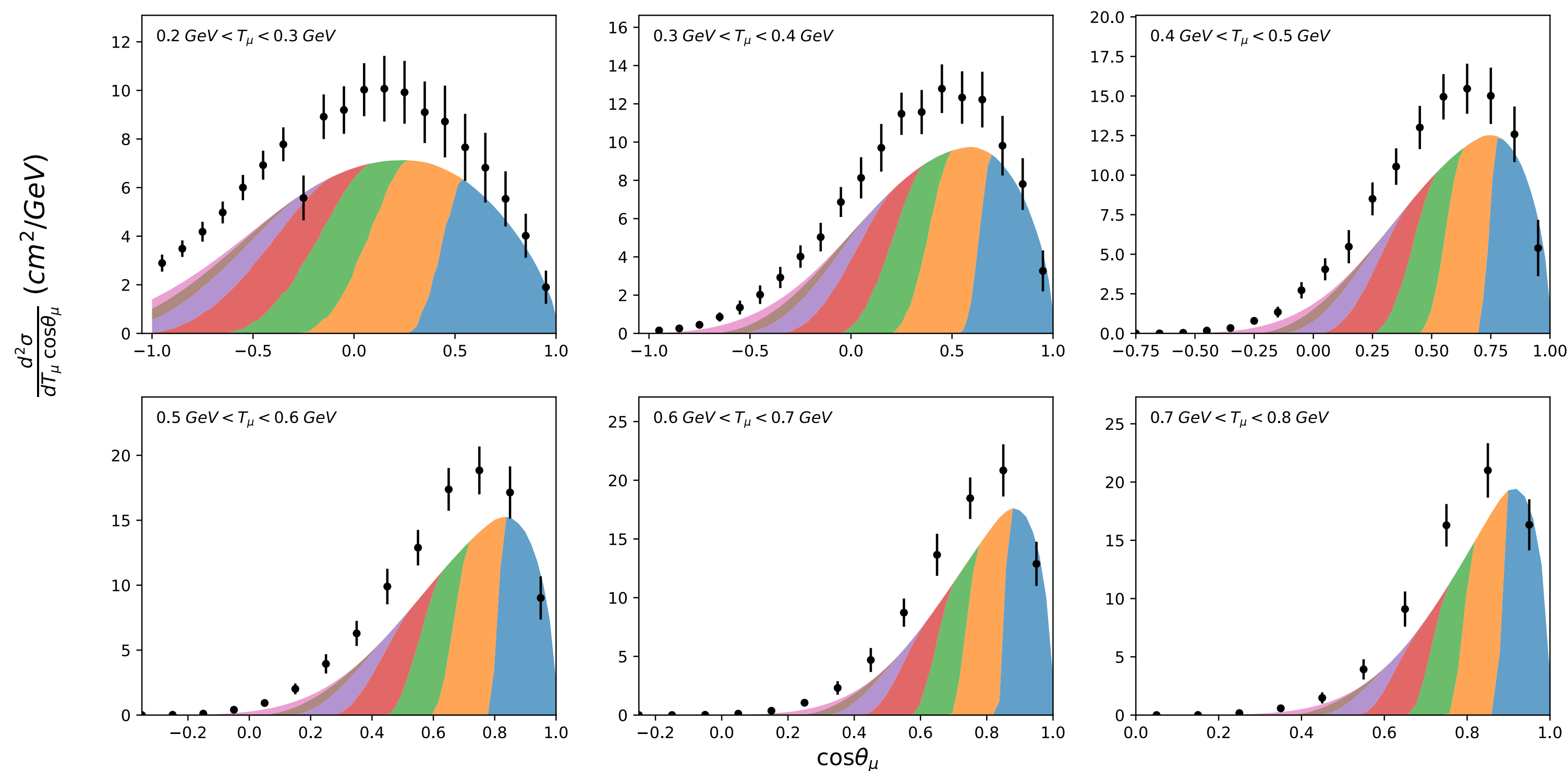
- $0.0 \leq Q^2 < 0.2 \text{ GeV}^2$
- $0.2 \leq Q^2 < 0.4 \text{ GeV}^2$
- $0.4 \leq Q^2 < 0.6 \text{ GeV}^2$
- $0.6 \leq Q^2 < 0.9 \text{ GeV}^2$
- $0.9 \leq Q^2 < 1.2 \text{ GeV}^2$
- $1.2 \leq Q^2 < 1.5 \text{ GeV}^2$
- $1.5 \leq Q^2 < 100.0 \text{ GeV}^2$

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Mapping Q^2 behavior to double differential cross section

Double Differential Cross Section with $M_A = 1.05$ GeV



Shows us where the data is not described well by our axial form factor parametrization

Summary

- According to state-of-the-art lattice results the dipole ansatz for the form factor is insufficient to describe the axial form factor
- What is supported is a form factor which acts as a dipole with low axial mass at low Q^2 and a higher axial mass at higher Q^2
- This form factor behavior agrees relatively well with recent data from MiniBooNE and MINERvA across the range of angles and muon energies, while still leaving some room for nuclear effects and improvements to the axial form factor

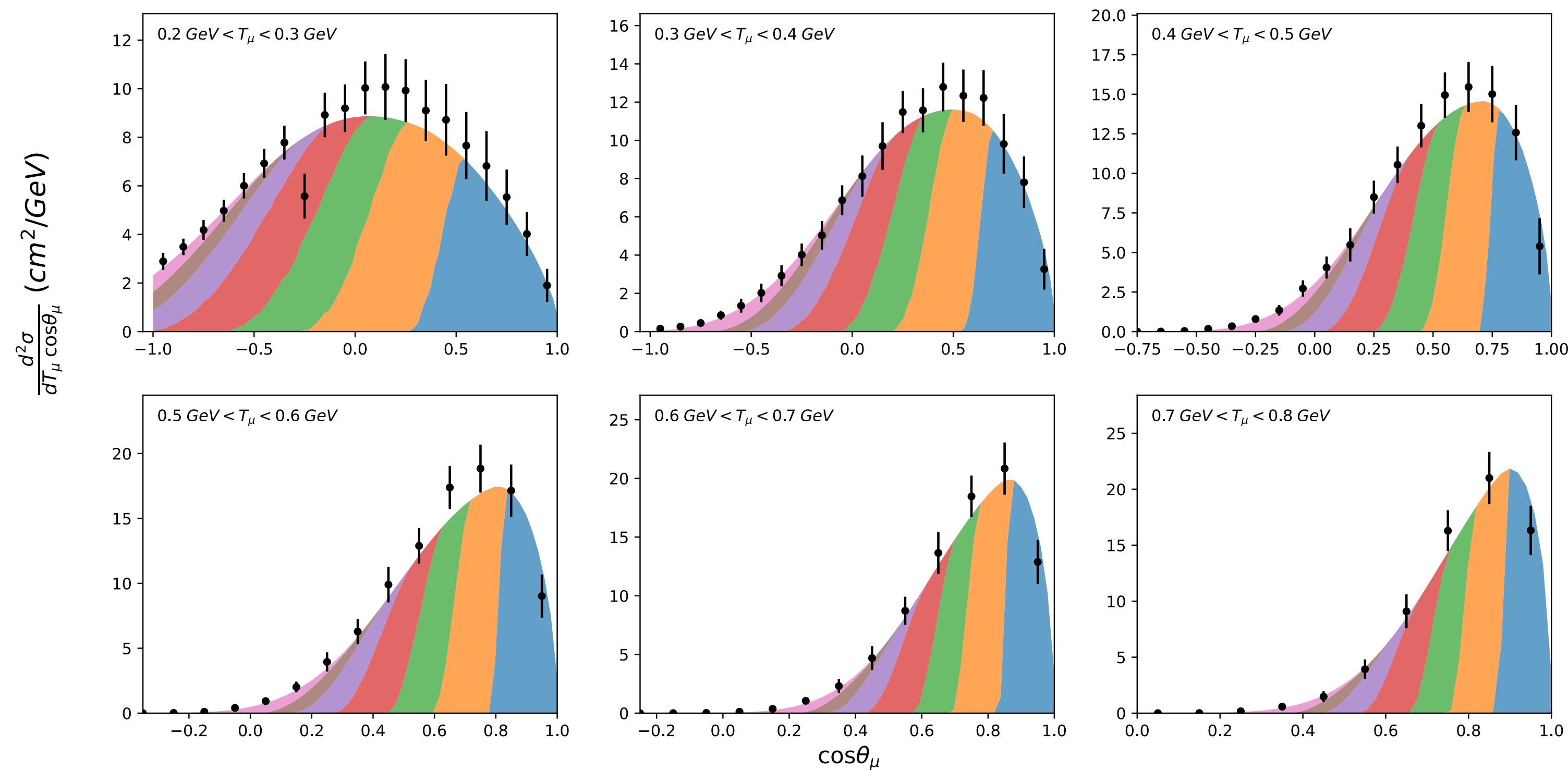


Implications on Cross Sections

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Double Differential Cross Section with $M_A = 1.35$ GeV



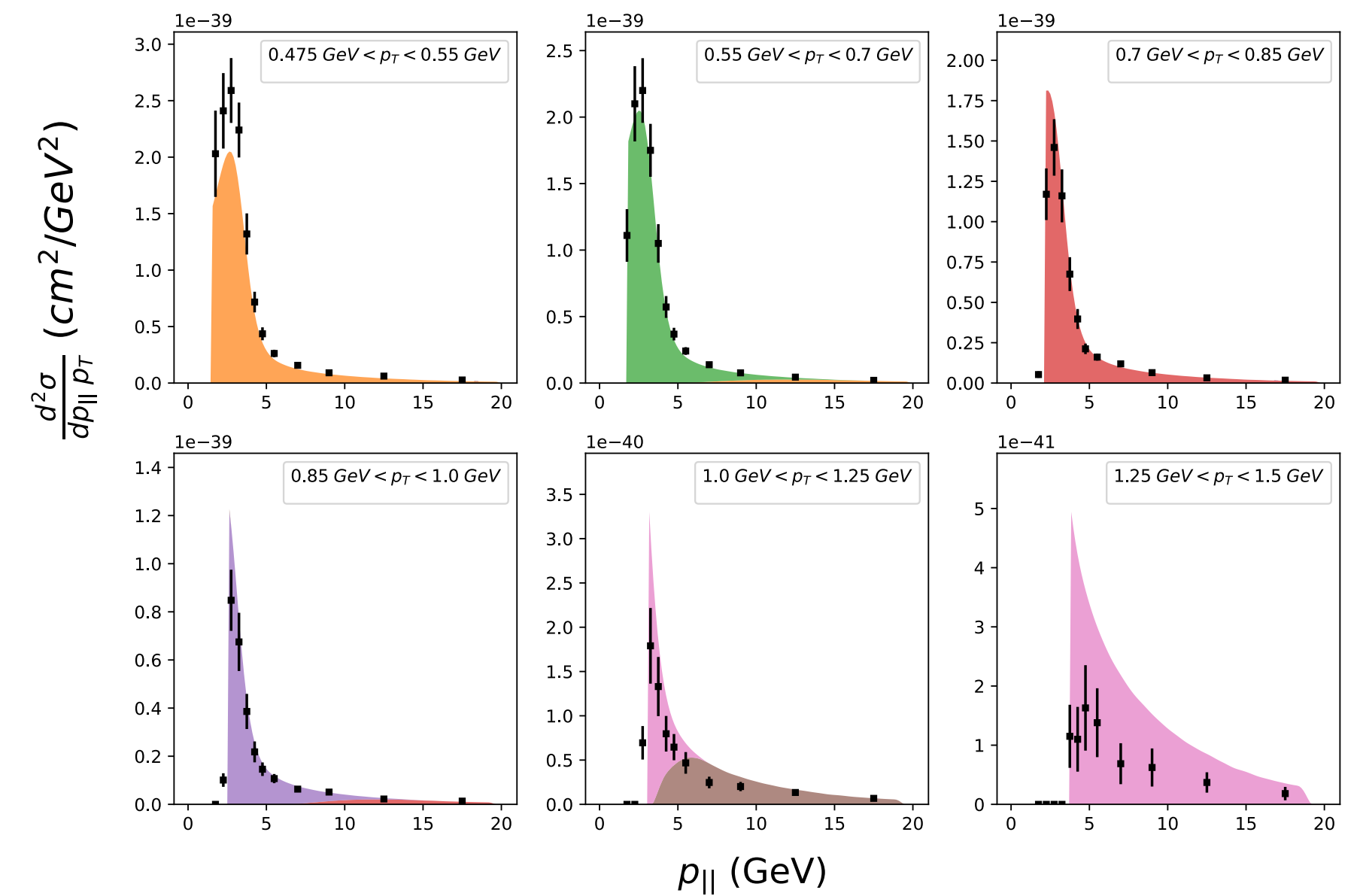
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Q^2 Key

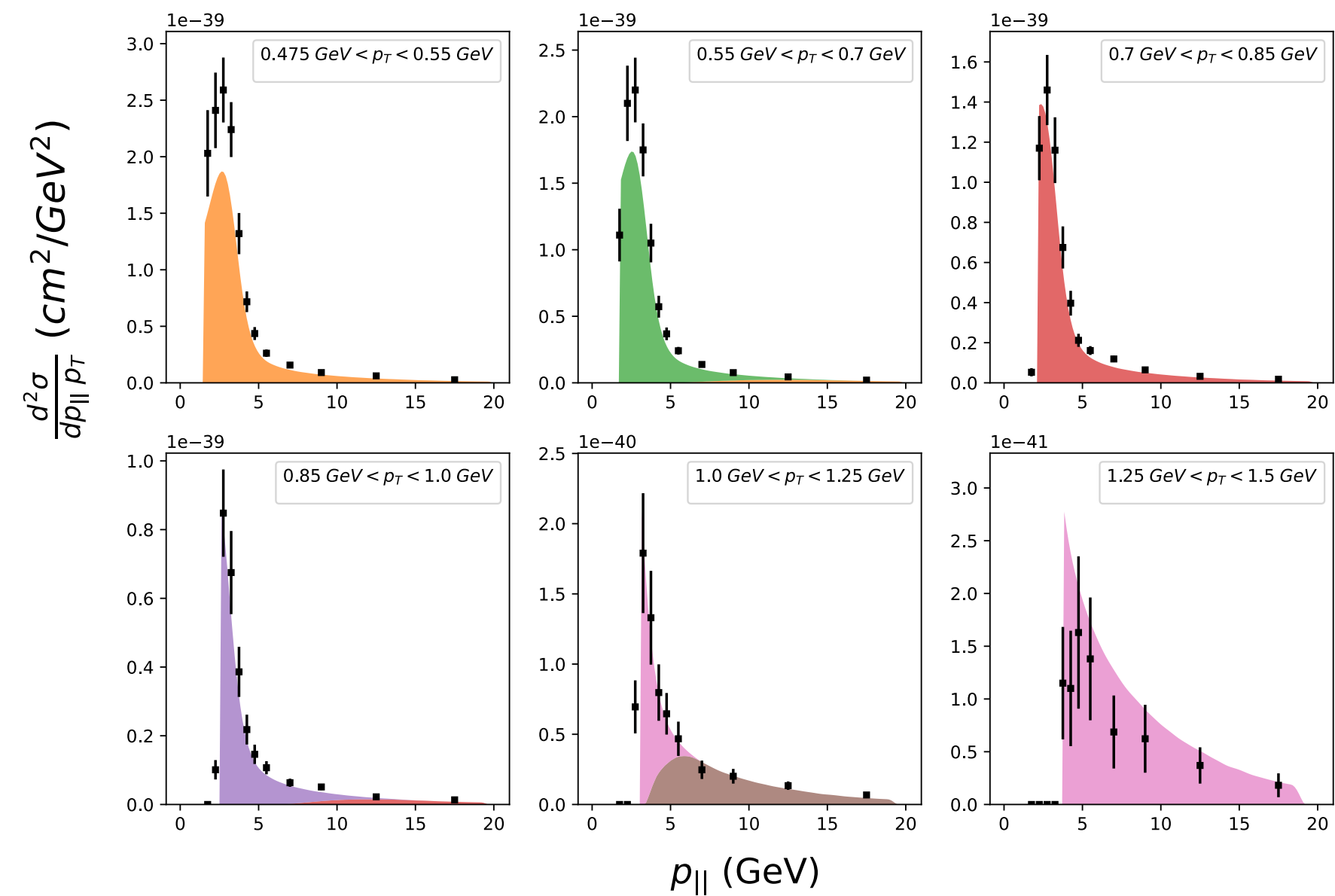
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Comparison with MINERvA data

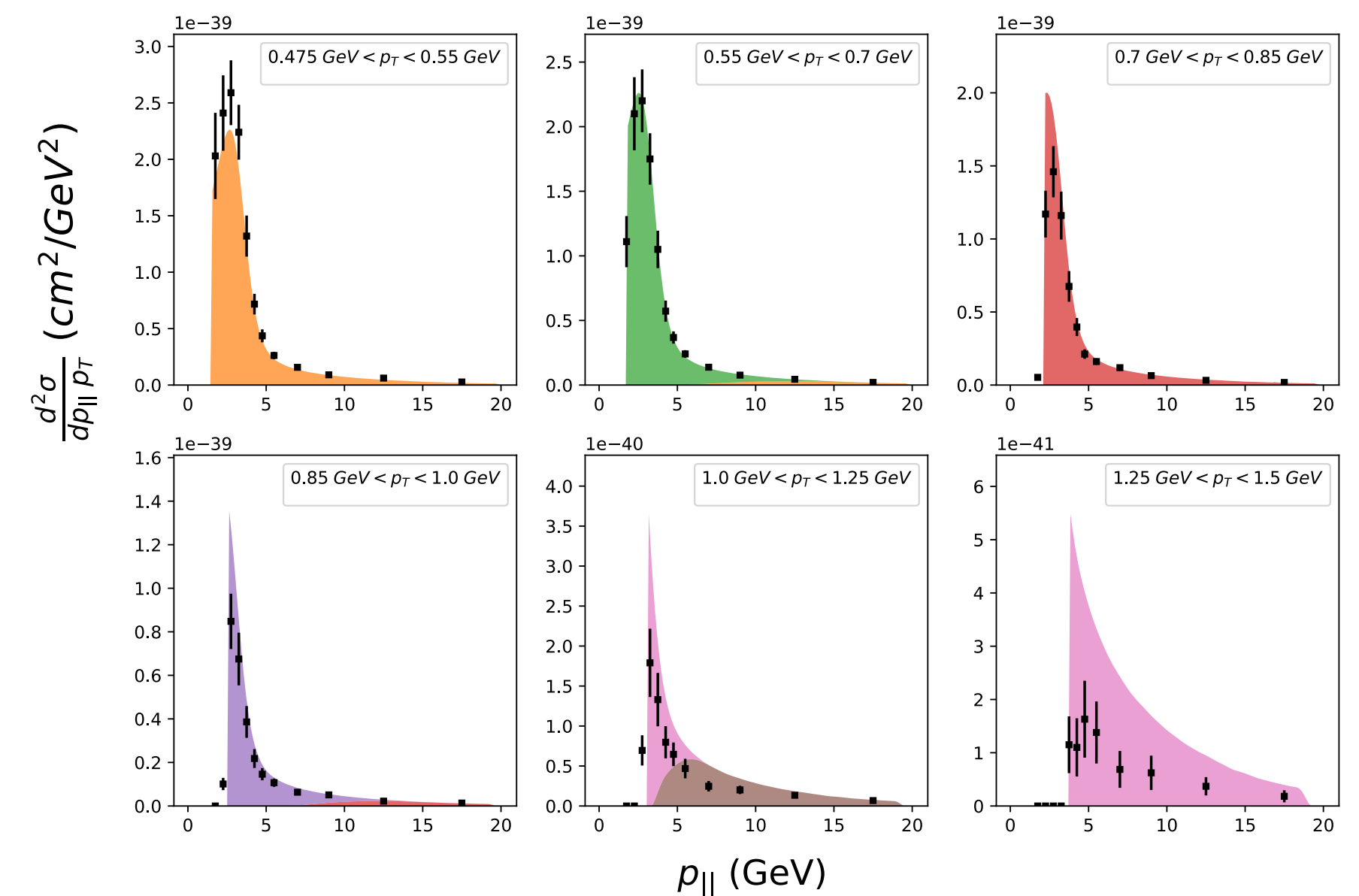
Double Differential Cross Section with Empirical Form Factor



Double Differential Cross Section with $M_A = 1.05 \text{ GeV}$

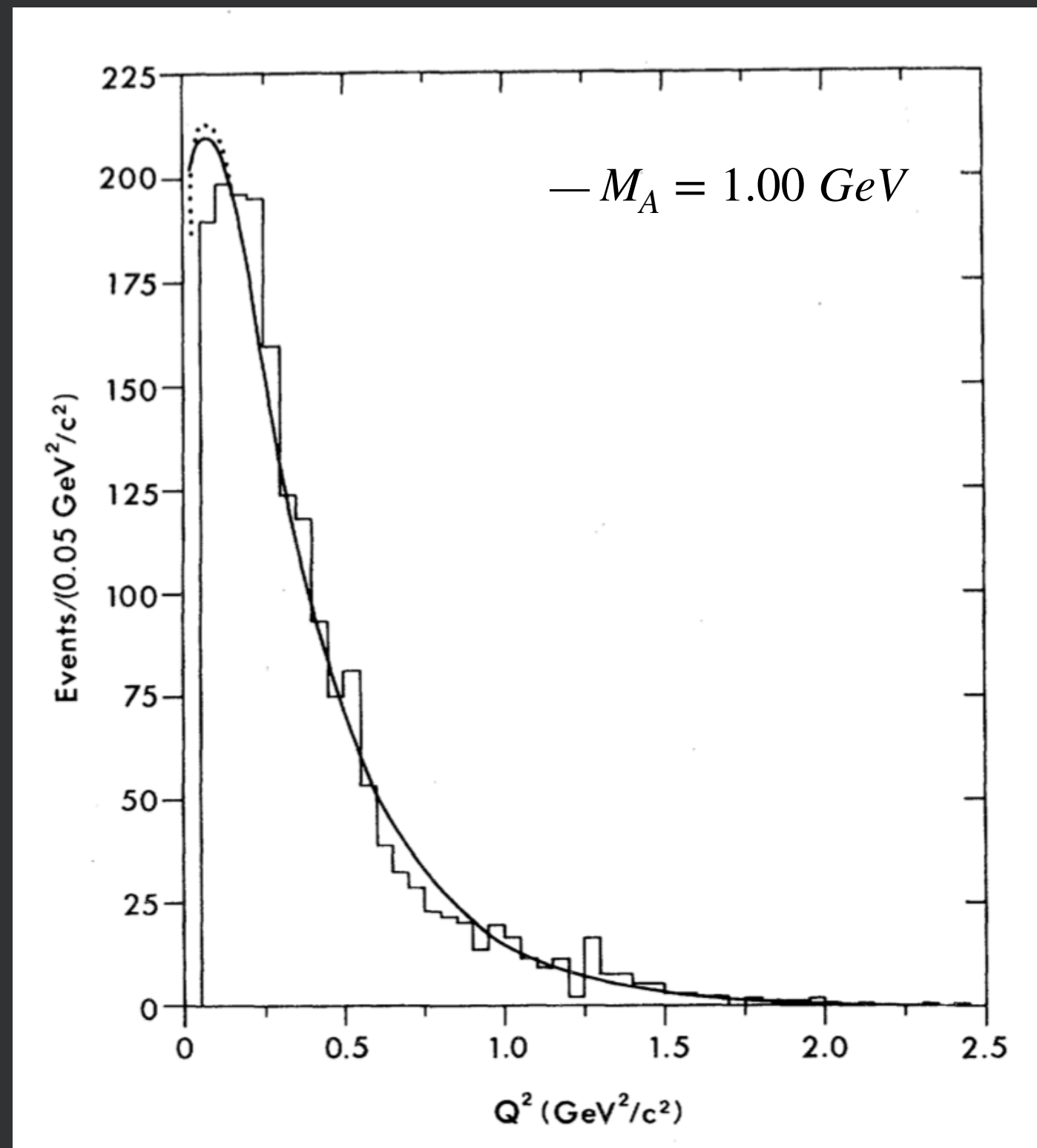


Double Differential Cross Section with $M_A = 1.35 \text{ GeV}$

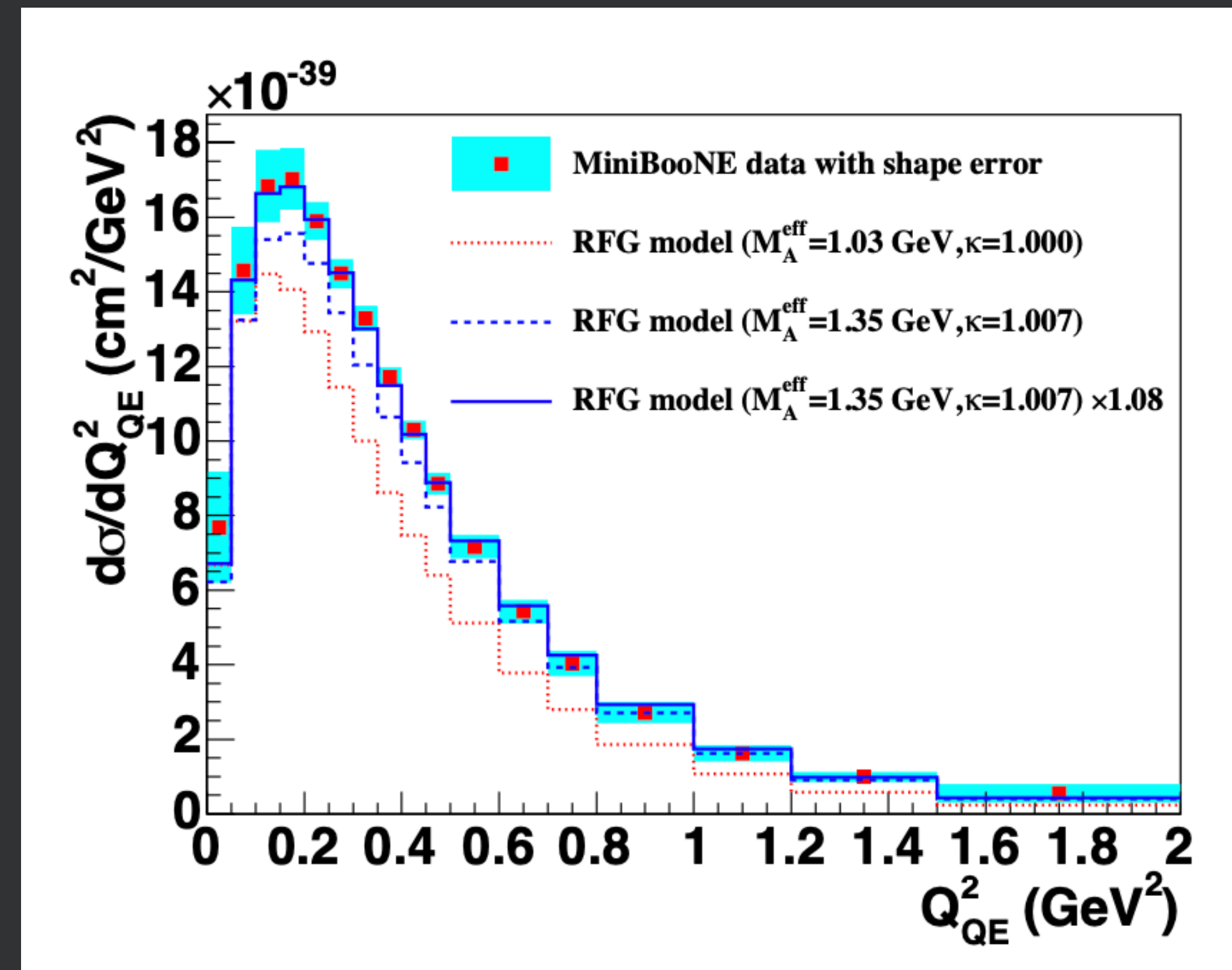


Dipole Ansatz

Why two different M_A values?

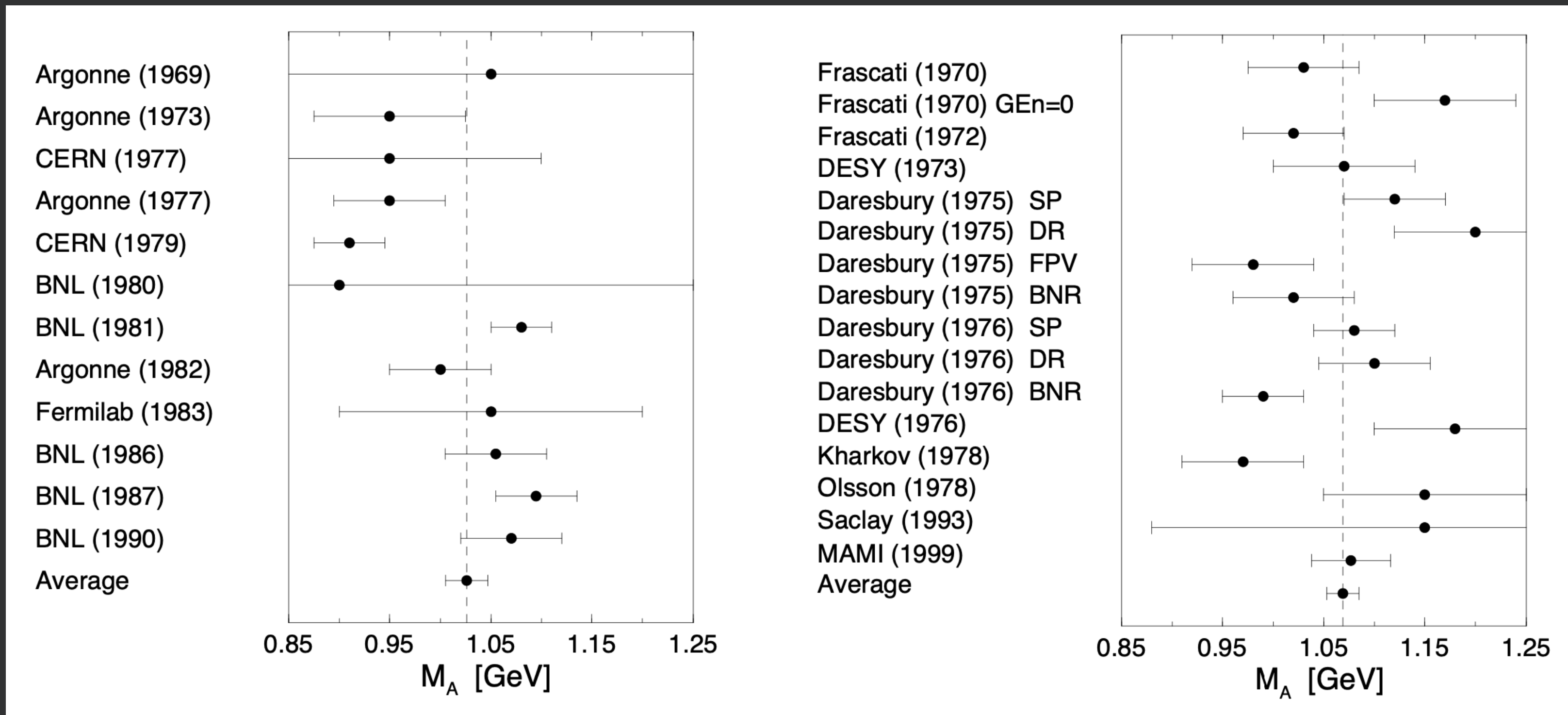


ANL 1982 deuterium data



MiniBooNE 2010 hydrocarbon data

Status of $F_A(Q^2)$ in Early 2000s

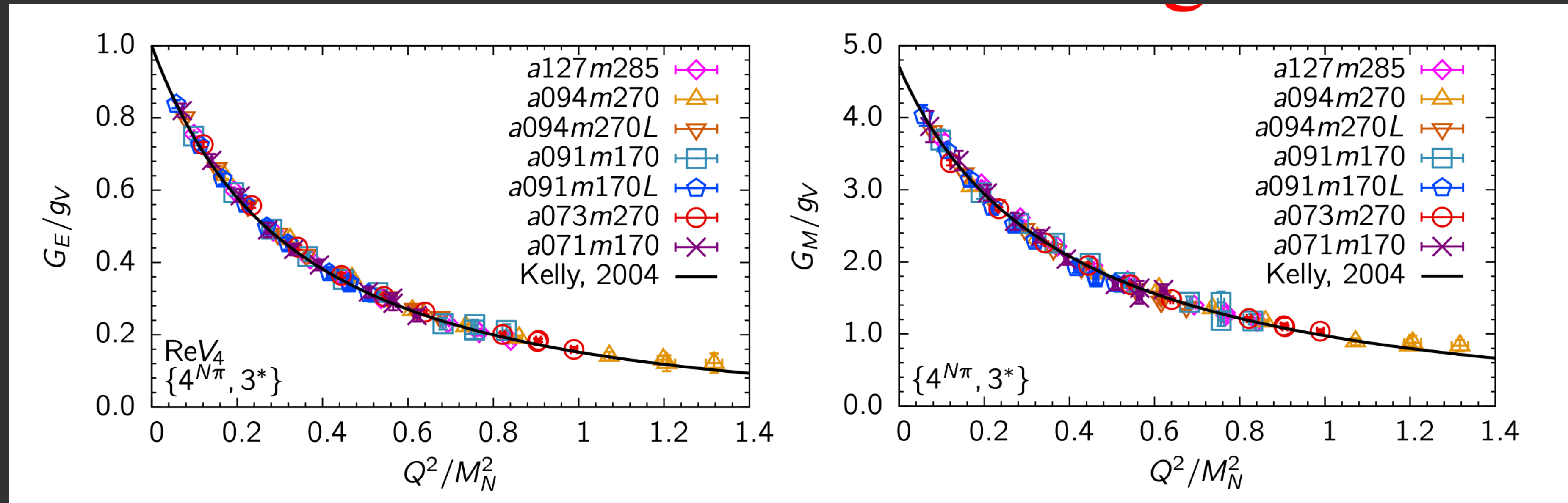


Took averages of scattering and bubble chamber data and got very small error bars. Showed that they agree with each other using chiral perturbation theory

Bernard, Elouadrhiri, Meißner 2001

0107088

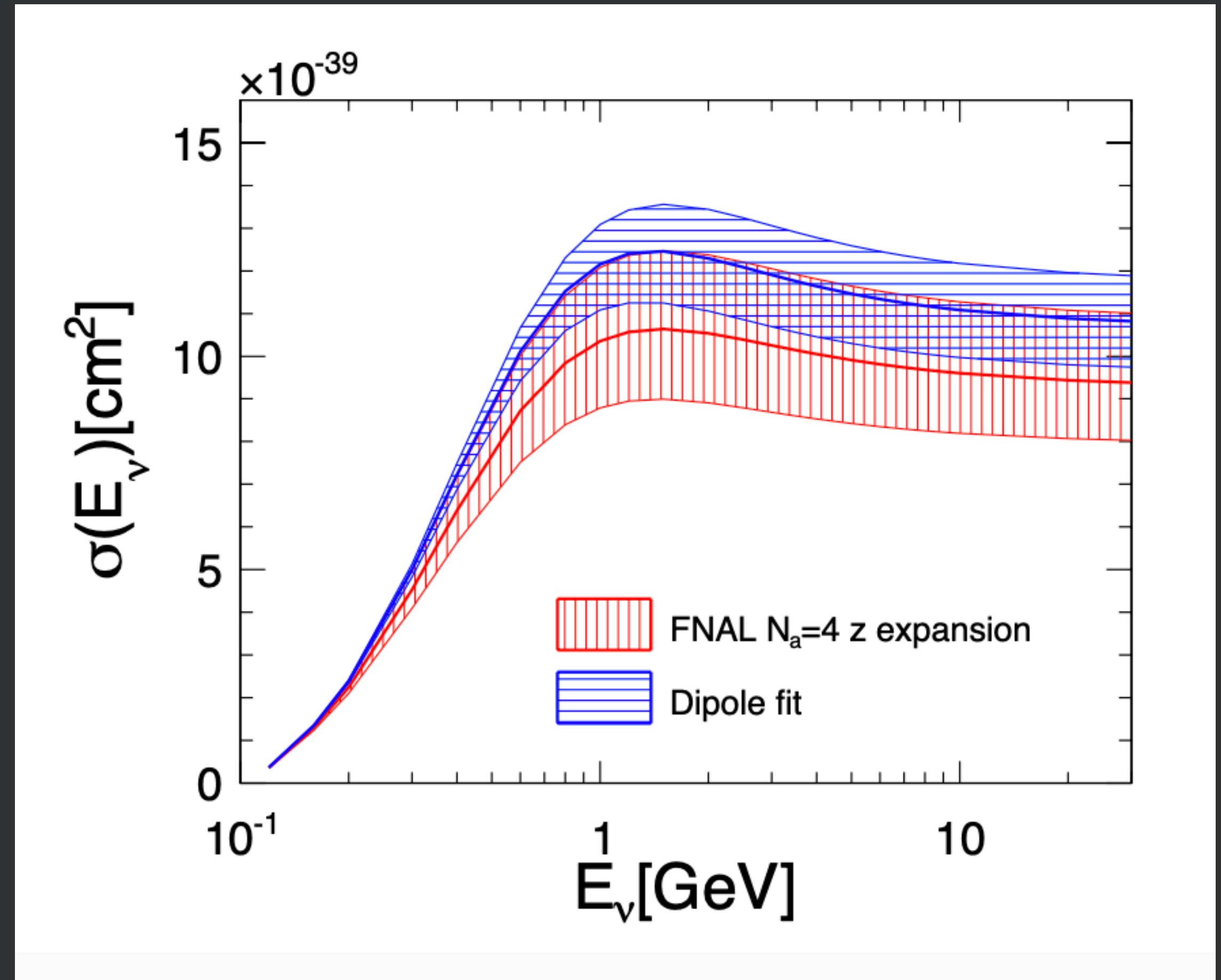
Agreement of Lattice with Vector Form Factors



R. Gupta Snowmass 2020 slides

Z - Parametrization

Different way of fitting the data
using conformal mapping.
Has large errors when many
terms are included



Meyer, Betancourt, Gran, Hill 2016
1603.03048

Deuterium Data

Large M_A not necessarily excluded by deuterium data

