Constraining Nuclear Currents for Electroweak Processes

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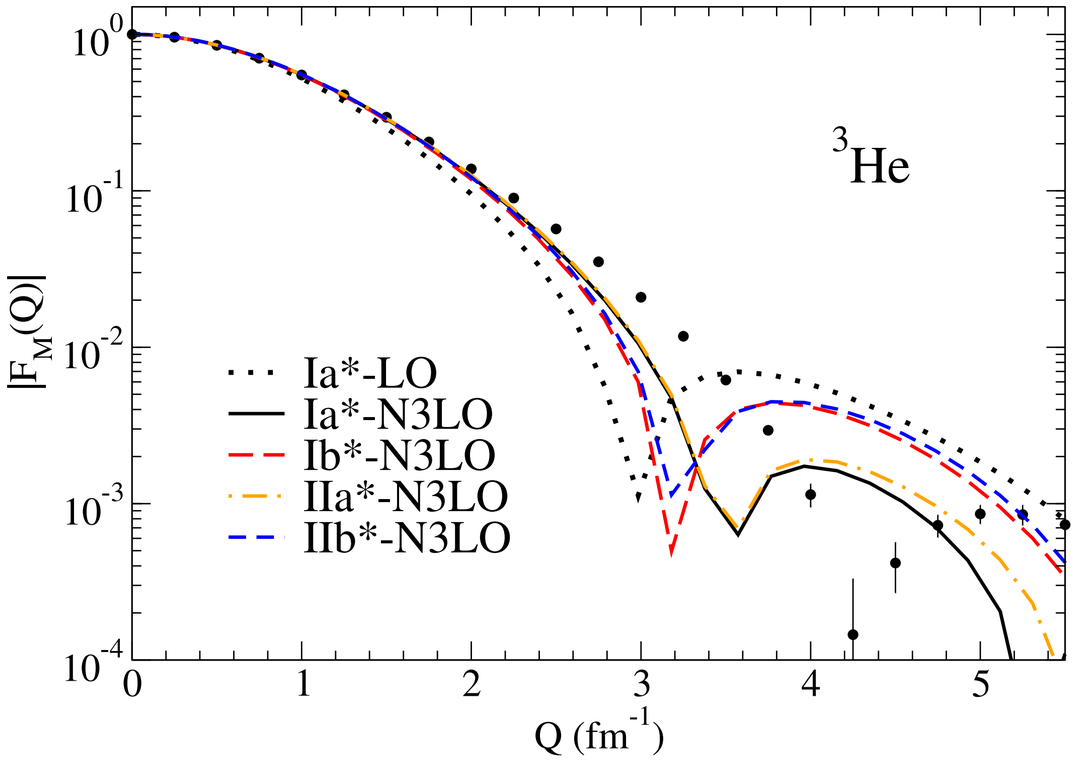
Motivation

The predictive power of χEFT electroweak currents

- We need nuclear currents reliable in a region of momentum transfer of few GeVs (DUNE, HyperKamiokande,…)
- Obtain predictions in an overlap region with higher energy theories
- Which is the limit of χEFT reliability? Compute errors!

Test of the EM Currents on elastic scattering of electrons on nuclei

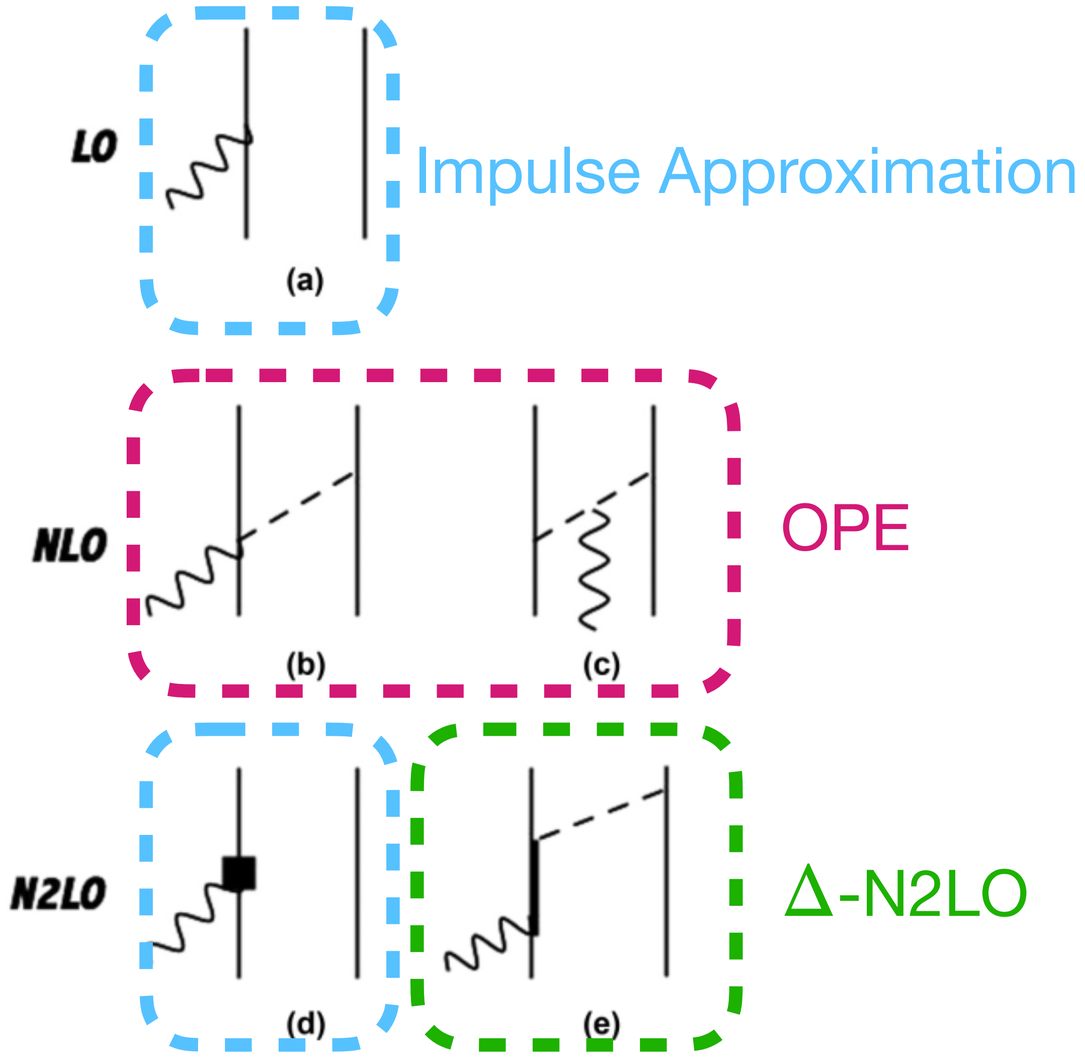
Magnetic form factors (MFF)



[R. Schiavilla et al., PRC 99, 034005 (2019)]

The theory (up to N2LO)

- Chiral expansion of the EM currents
- Two nuclear interactions: Norfolk [1] and EMN [2]
- Currents from [PRC 80, 034004 (2009) and PRC 99, 034005 (2019)]
- Up to N2LO consistent with [H. Krebs, EPJA 56, 234 (2020)]



[1-M. Piarulli, et al., PRC 94, 054007 (2016)]
[2-D.R. Entem, et al. PRC 96, 024004 (2017)]

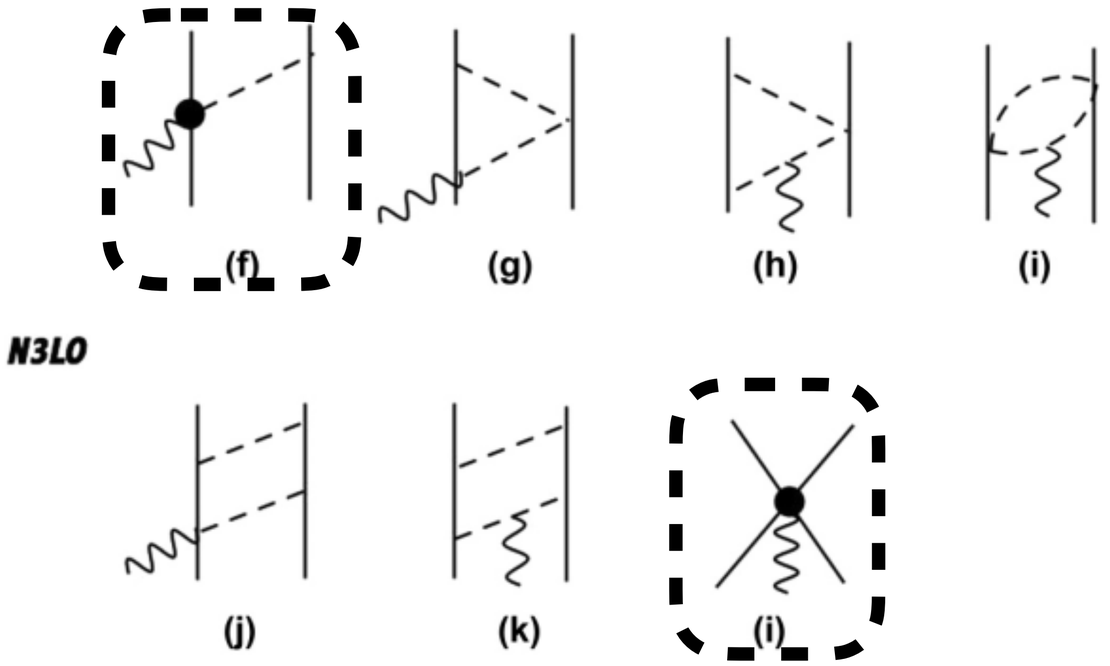
The theory (N3LO)

Some notes on N3LO:

- Unconsistency with Bochum group currents
- Is chiral symmetry violated?
- Current is not fully conserved

“Semi-phenomenological” χEFT currents

d_2^V d_3^V d_2^S N3LO-OPE



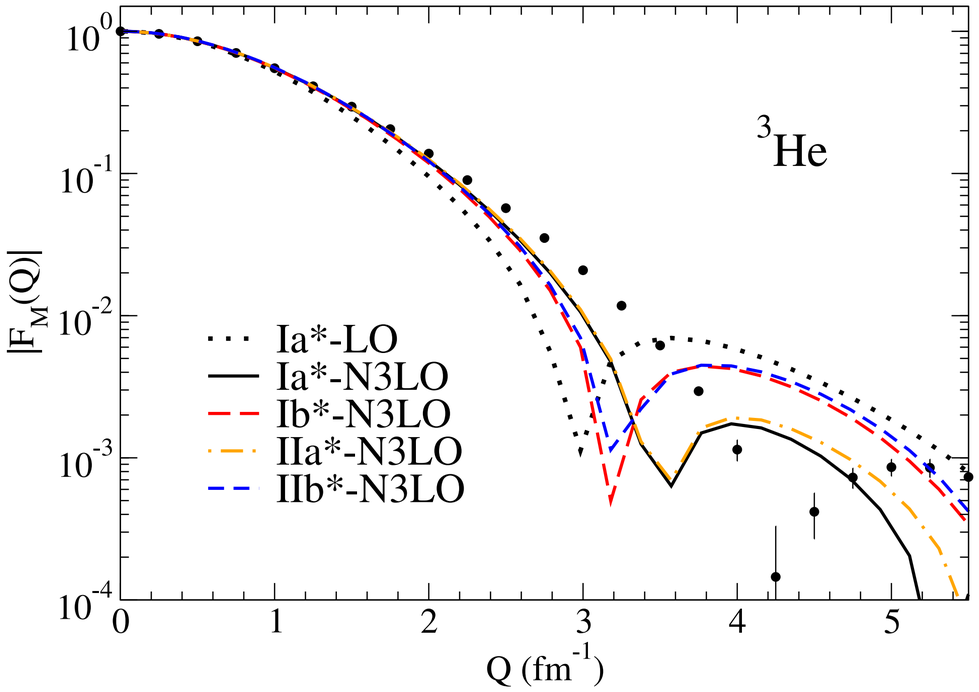
d_1^V d_1^S contact terms

Red: isoscalar Blue: isovector

How to fix the LECs I

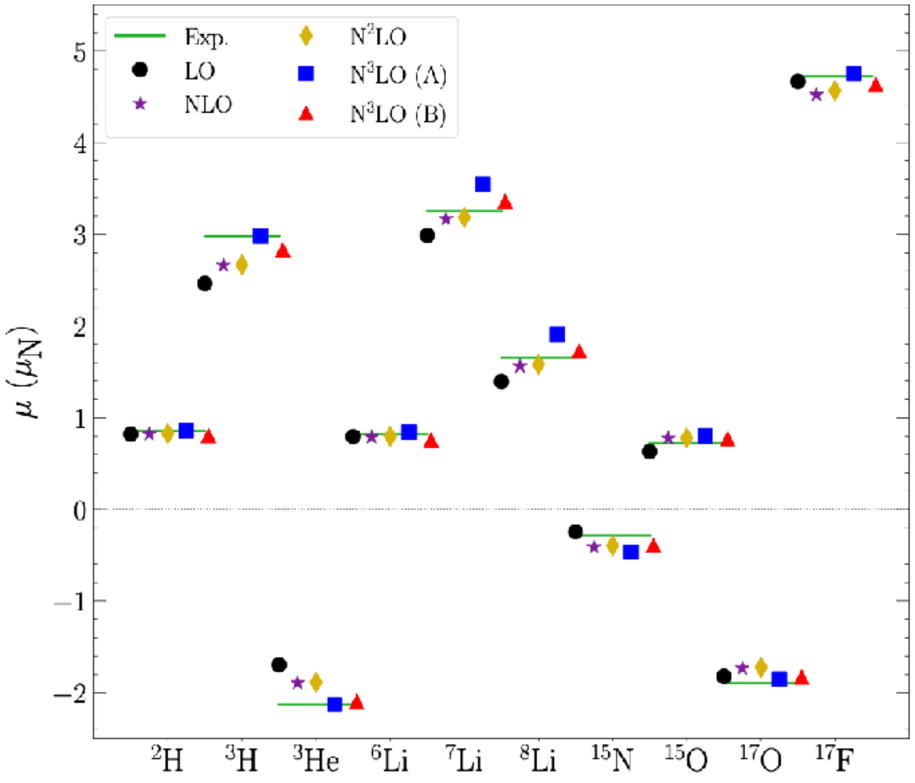
Using the magnetic moments

Δ saturation (fix d_2^V d_3^V)



[R. Schiavilla et al., PRC 99, 034005 (2019)]

Not including (d_2^V d_3^V d_2^S)



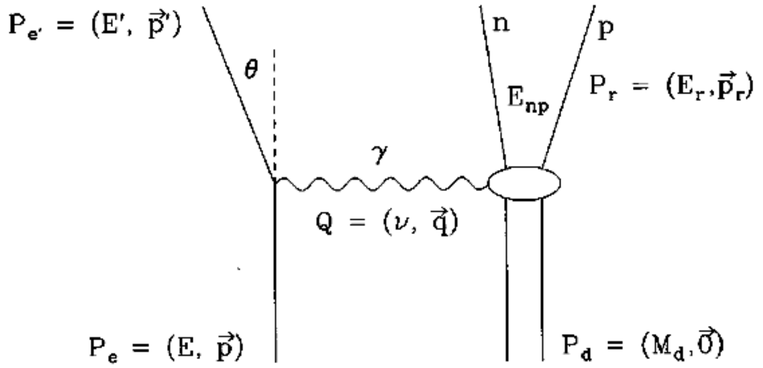
[J.D. Martin *et al.*, arXiv:2301.08349]

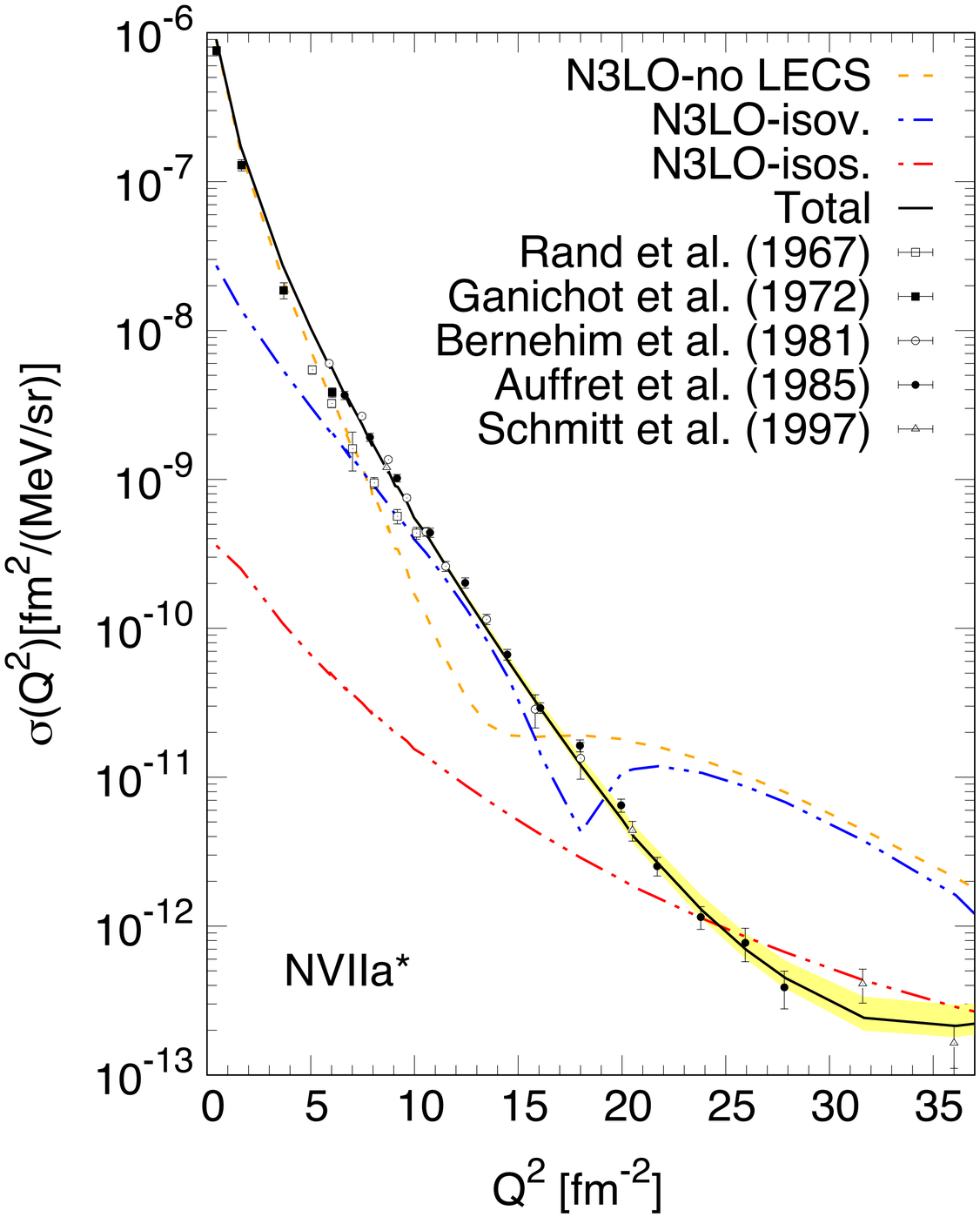
Diffraction generated by tensor forces

How to fix the LECs II

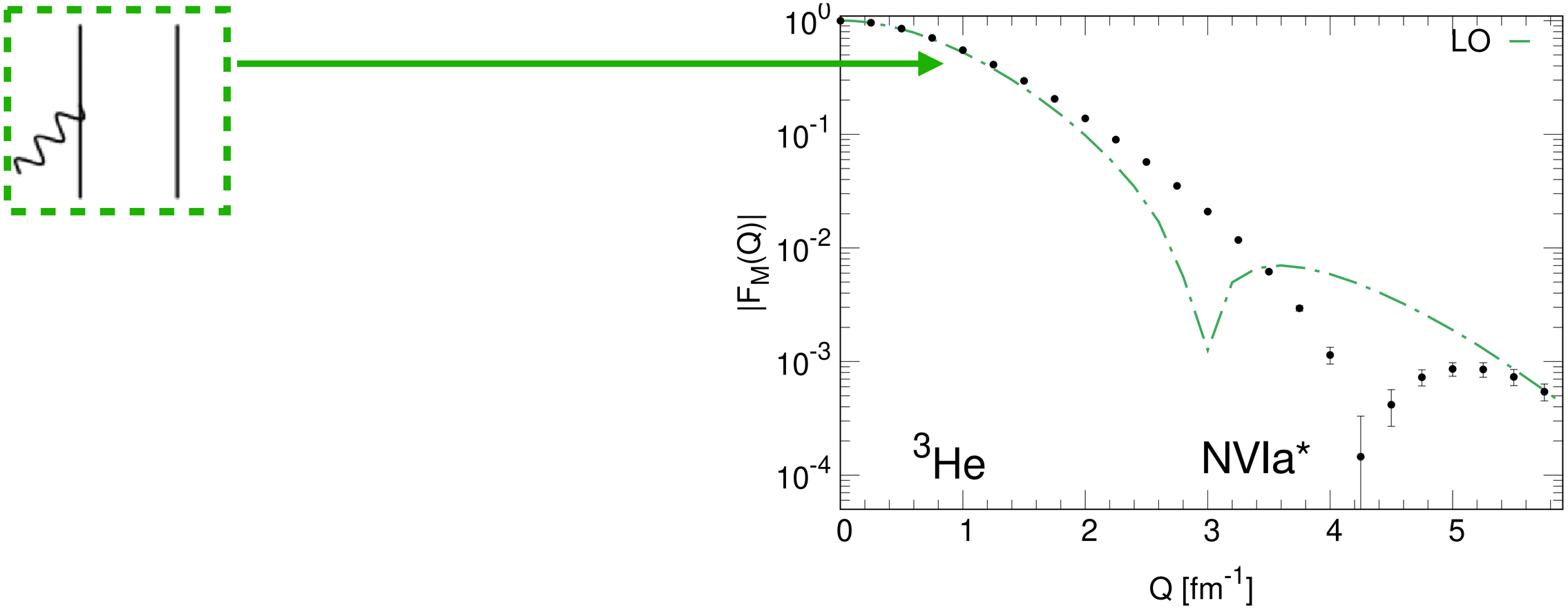
This work

- Magnetic moments of d, ^{3}He, ^{3}H (fix normalization)
- deuteron-threshold electrodisintegration at backward angles (fix dynamics)





Prediction of A=3 Magnetic Form Factors



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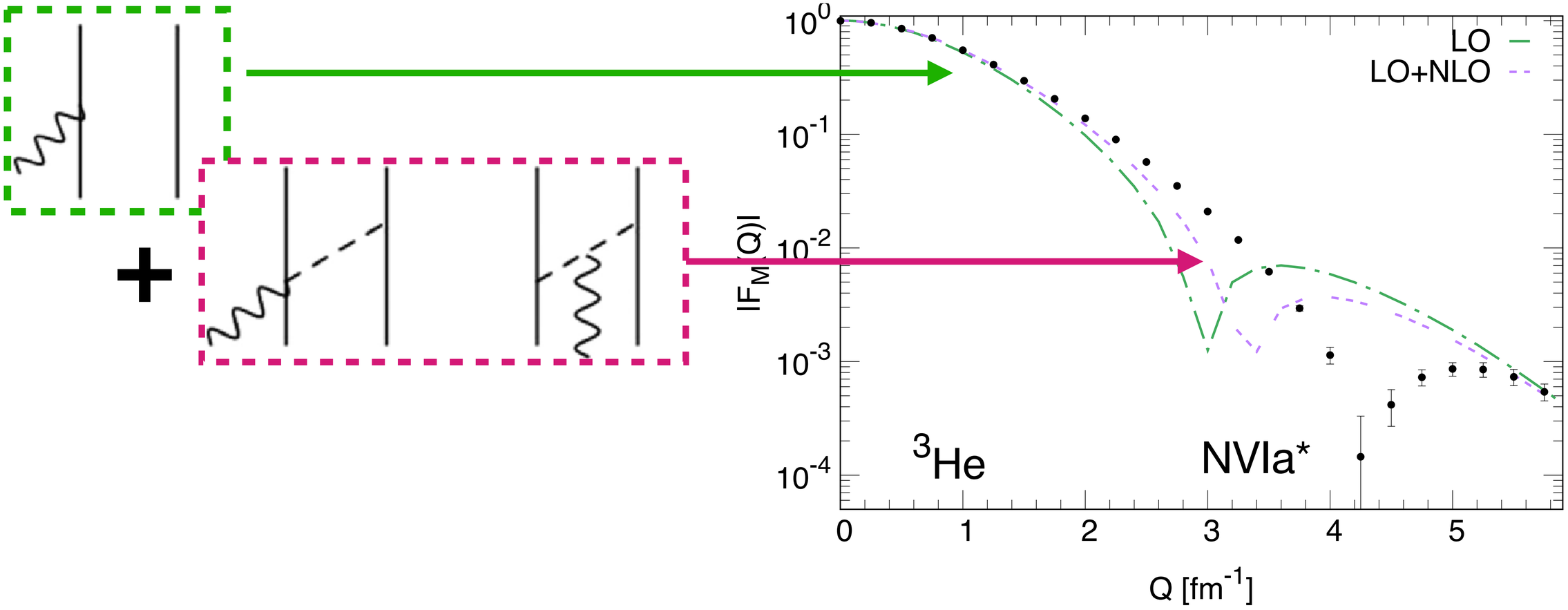

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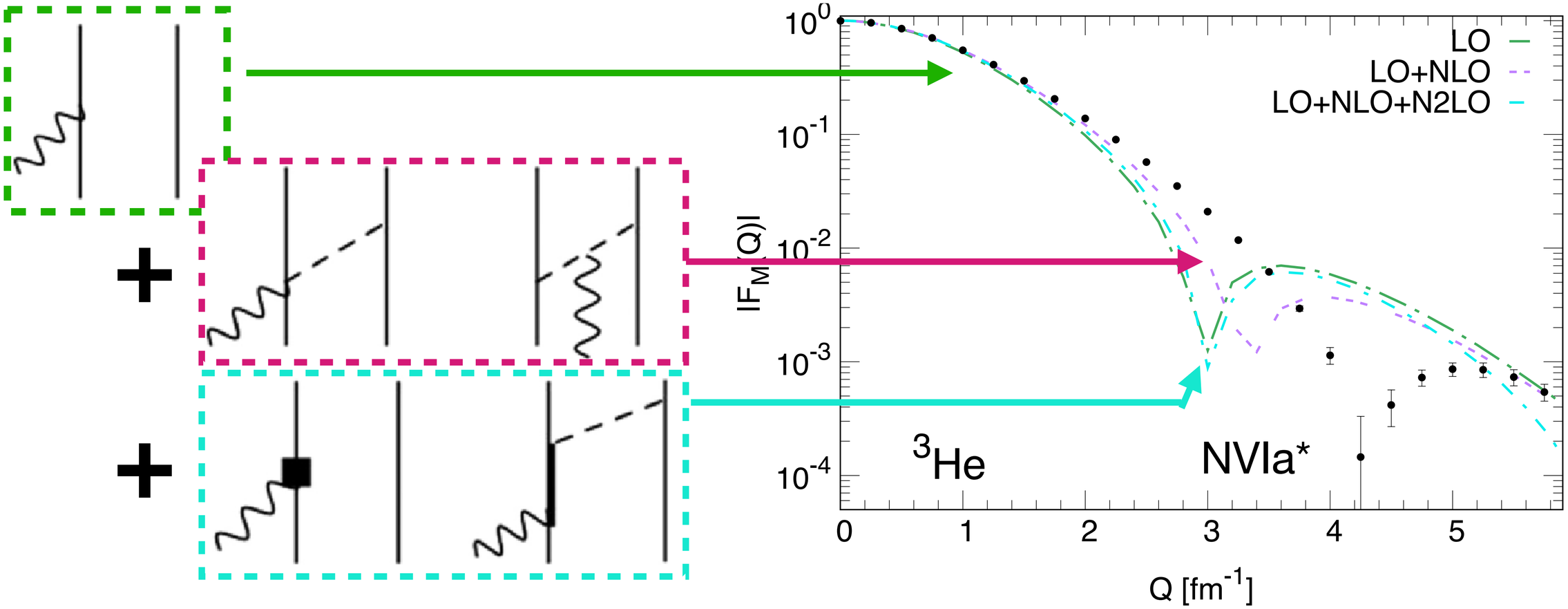

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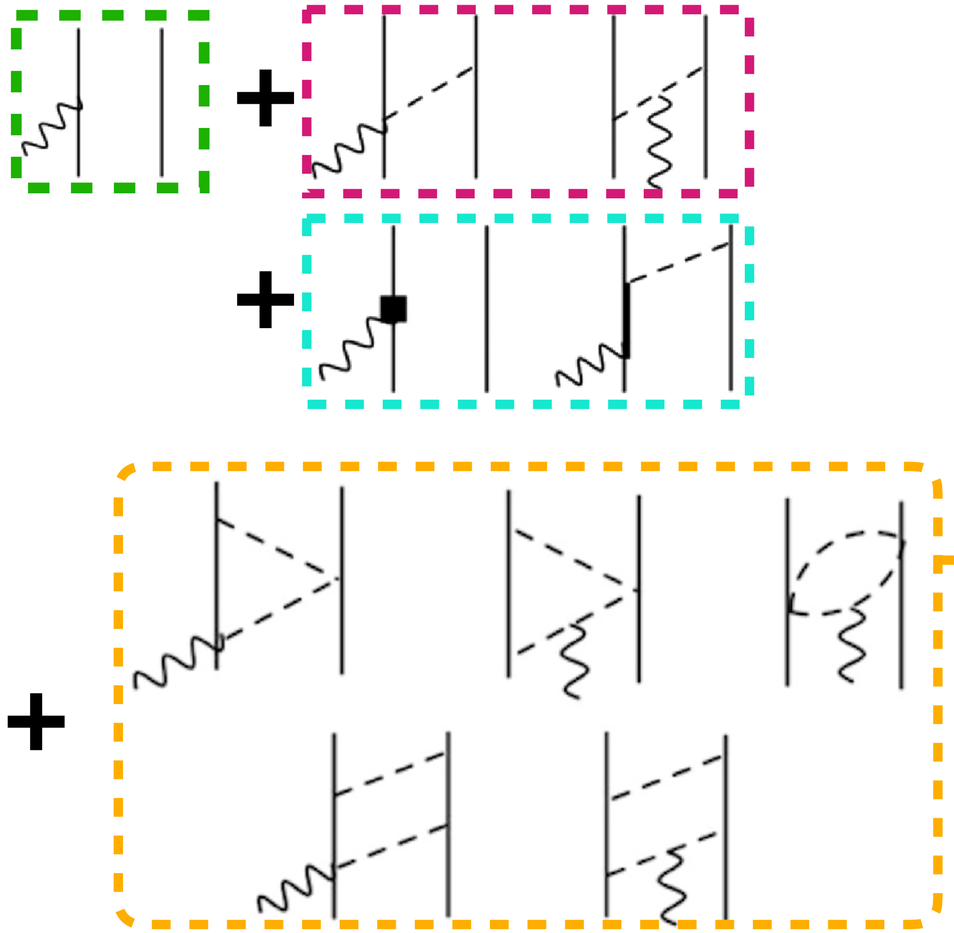

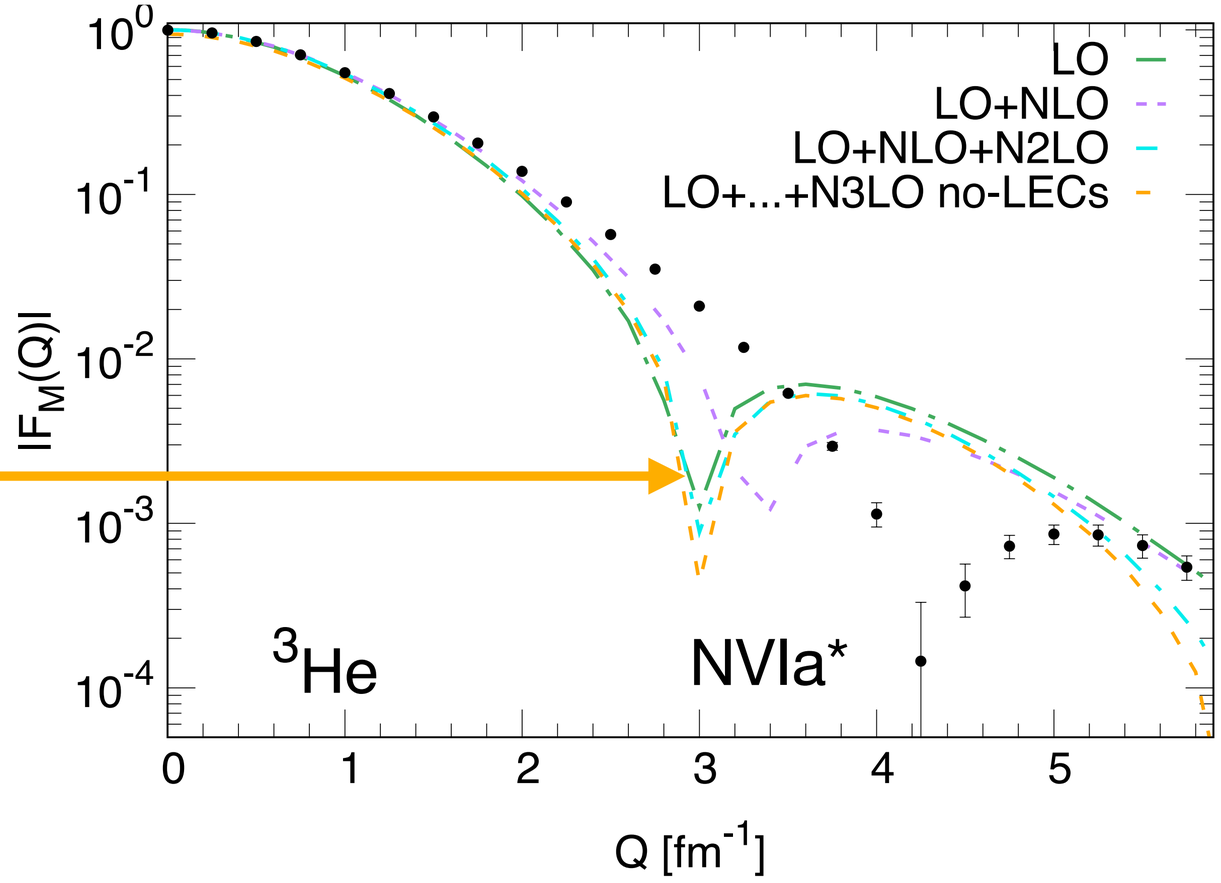

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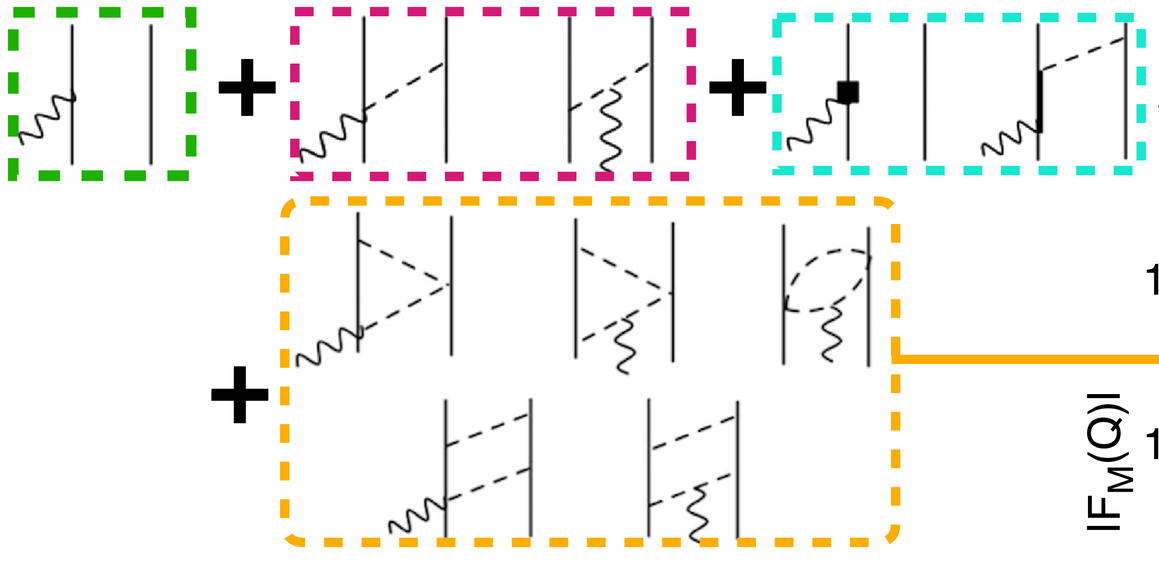
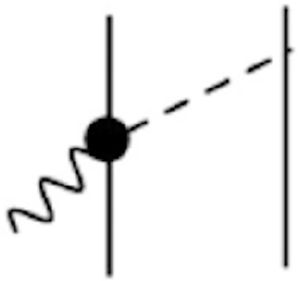
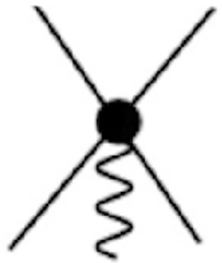
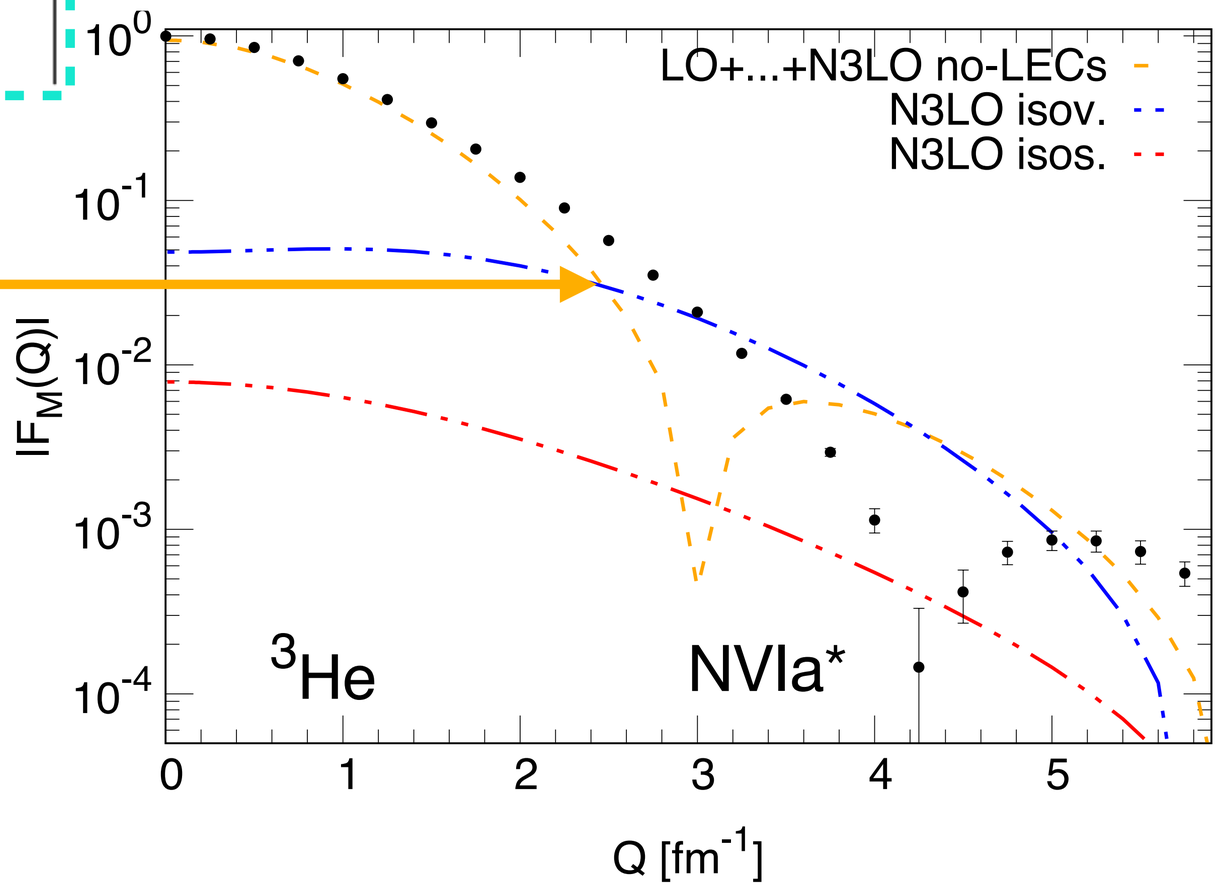




$d_2^V \quad d_3^V \quad d_2^S$



$d_1^V \quad d_1^S$



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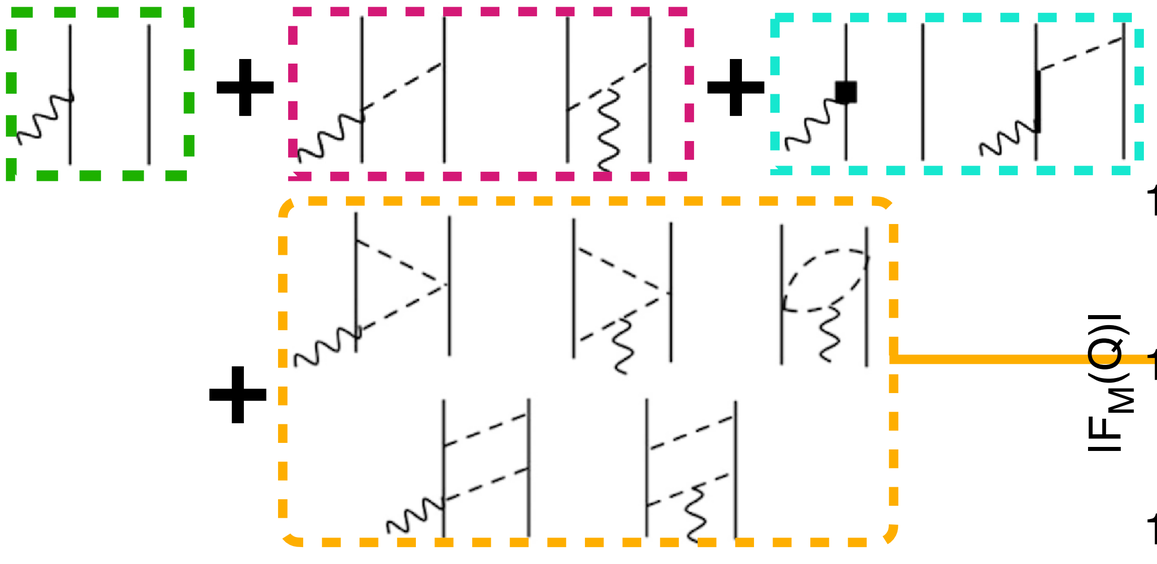
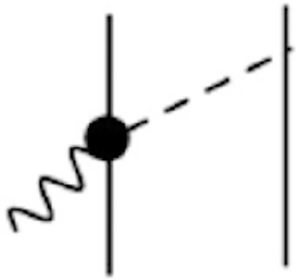
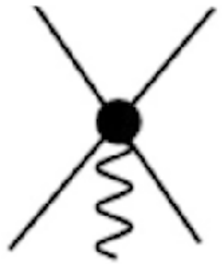




$d_2^V \quad d_3^V \quad d_2^S$



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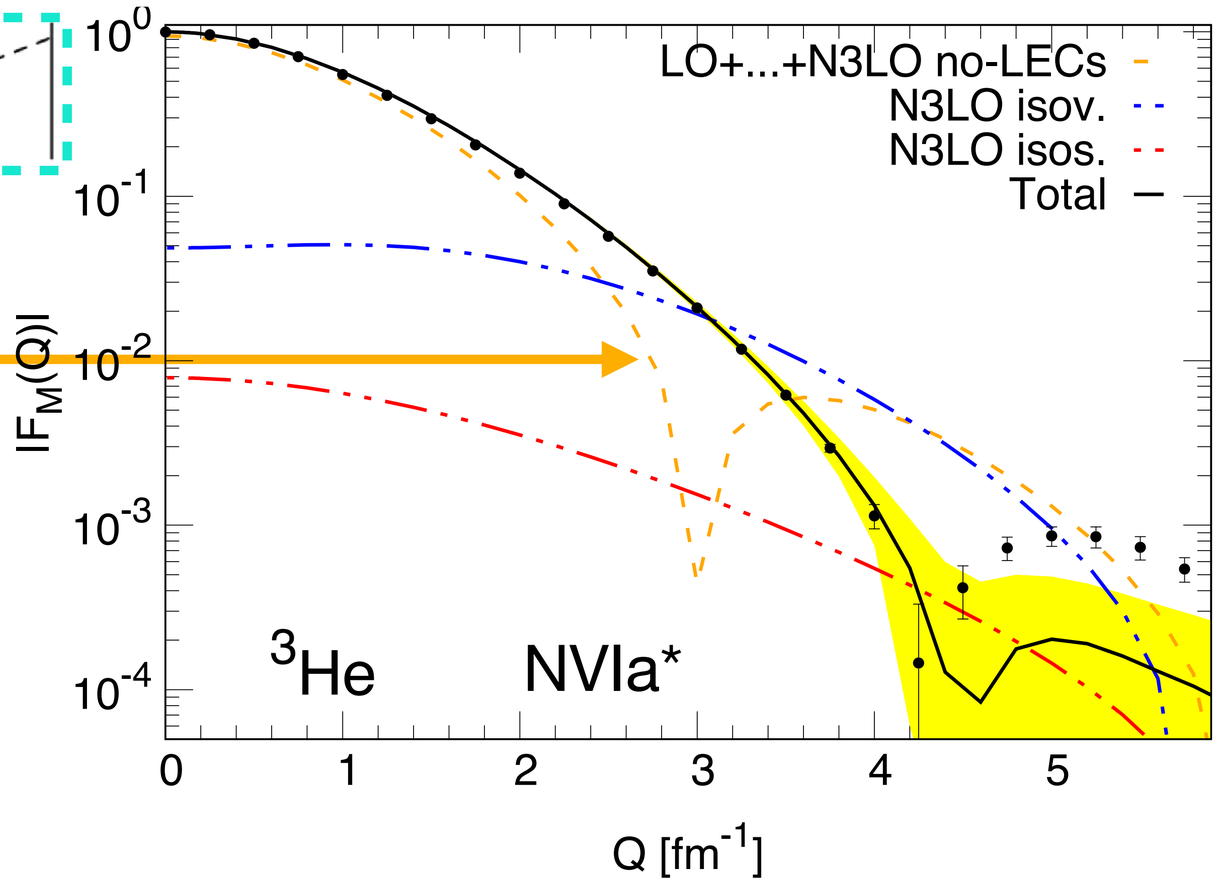


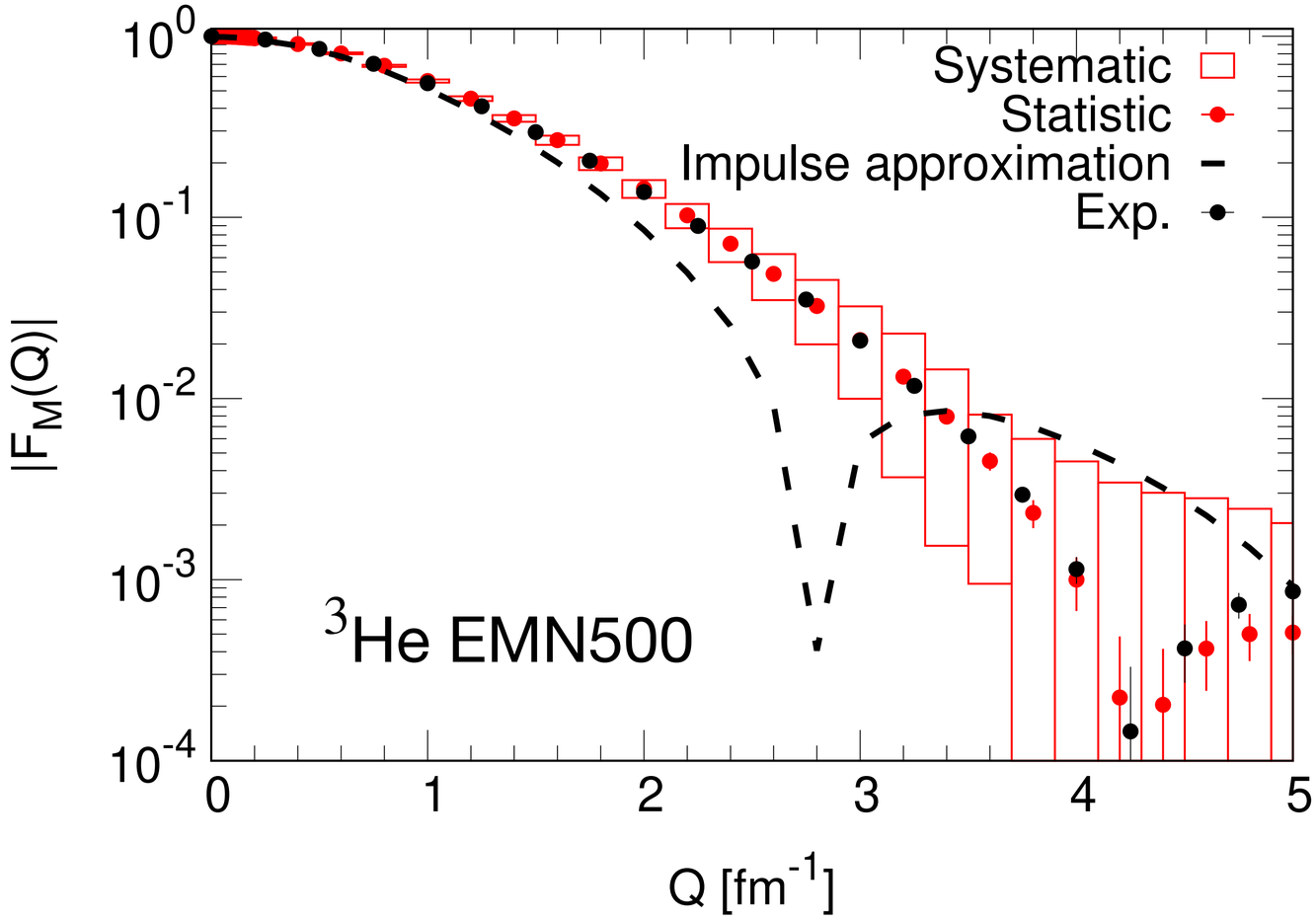
The isovector components fill/generates the diffraction

Naive truncation error estimate

- Truncation errors (as [EPJA 51, 53 (2015)])

$$\alpha = \max\left\{\frac{q}{\Lambda_b}, \frac{m_\pi}{\Lambda_b}\right\} \quad \Lambda_b = 1 \text{ GeV}$$

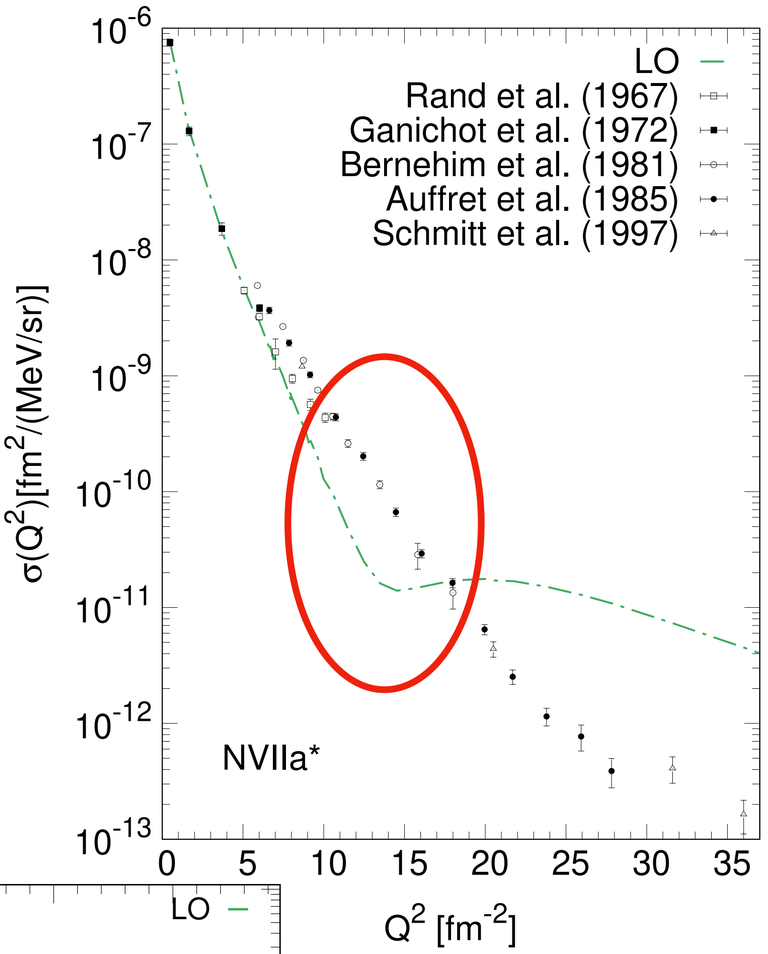
- Nuclear interaction + currents
- Bayesian analysis (slowly) in progress

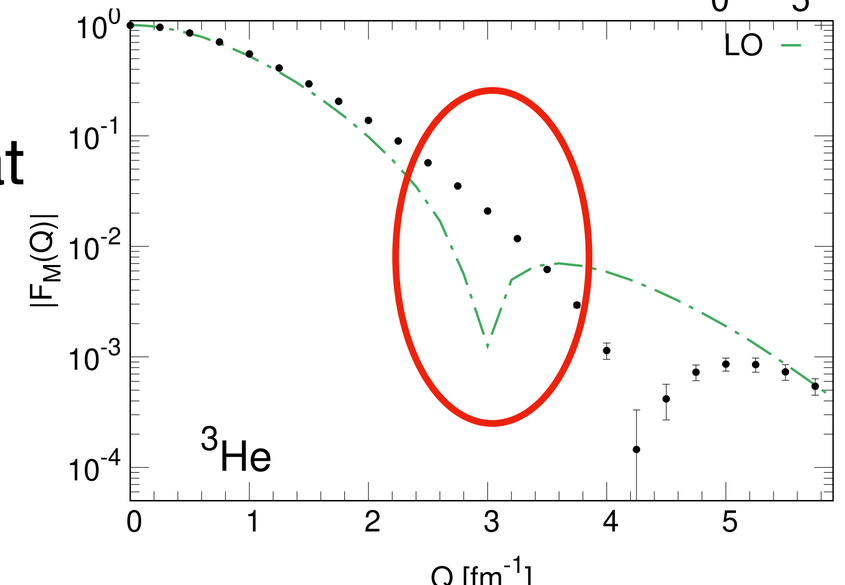


Reliability of the predictions

Is χEFT able to describe such large Q?

- The “diffraction” is in the χEFT validity region (suggested by error estimate)
- The “diffraction” is generated by the S and D wave interference
- There should be a mechanism that explain the absence of the “diffraction”

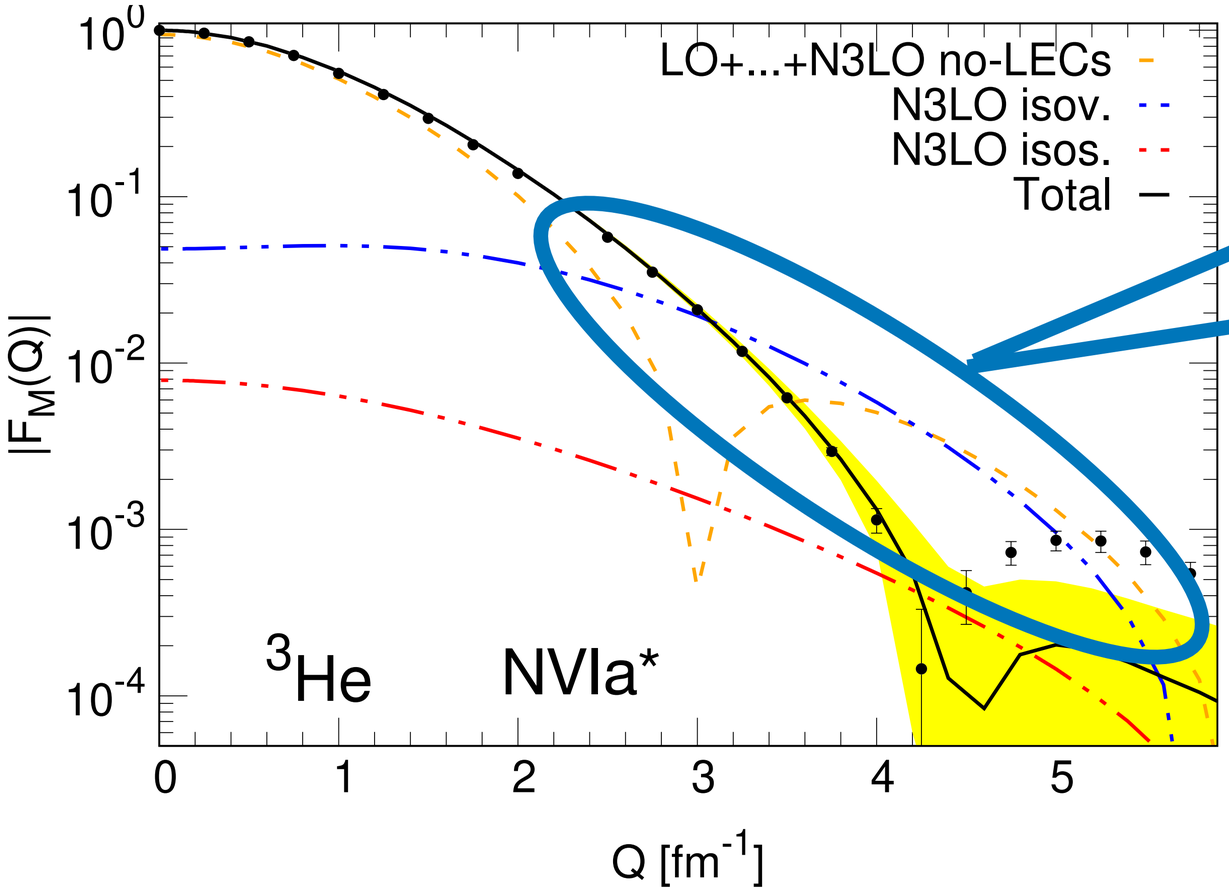




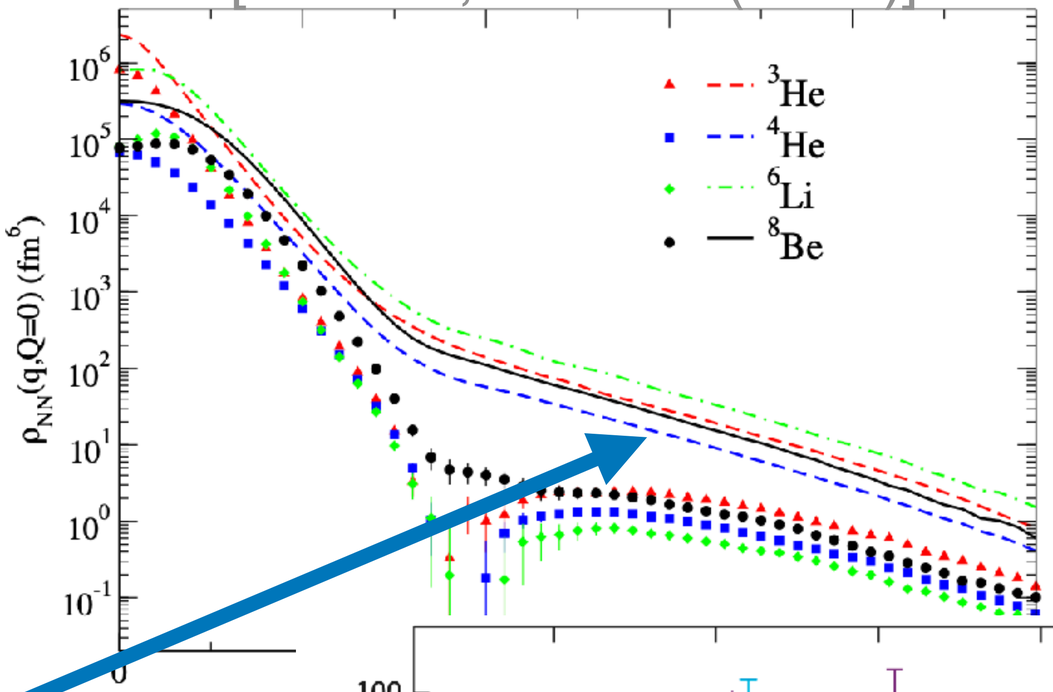
Why does it work?

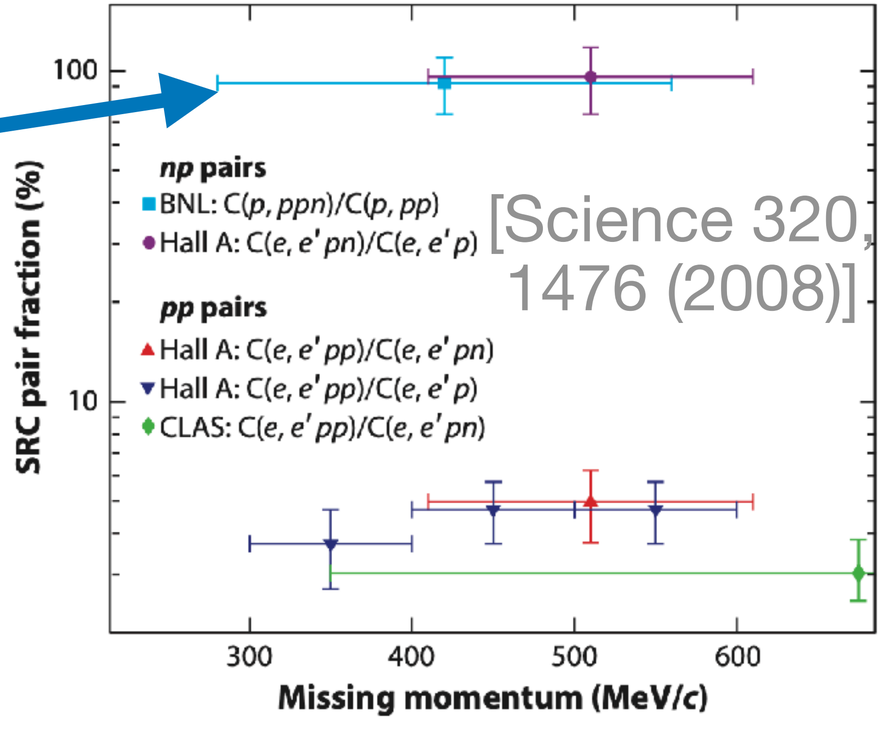
Isovector currents transform S/T=0/1 in S/T=1/0 pairs

np dominance



[PRL 98, 132501 (2007)]



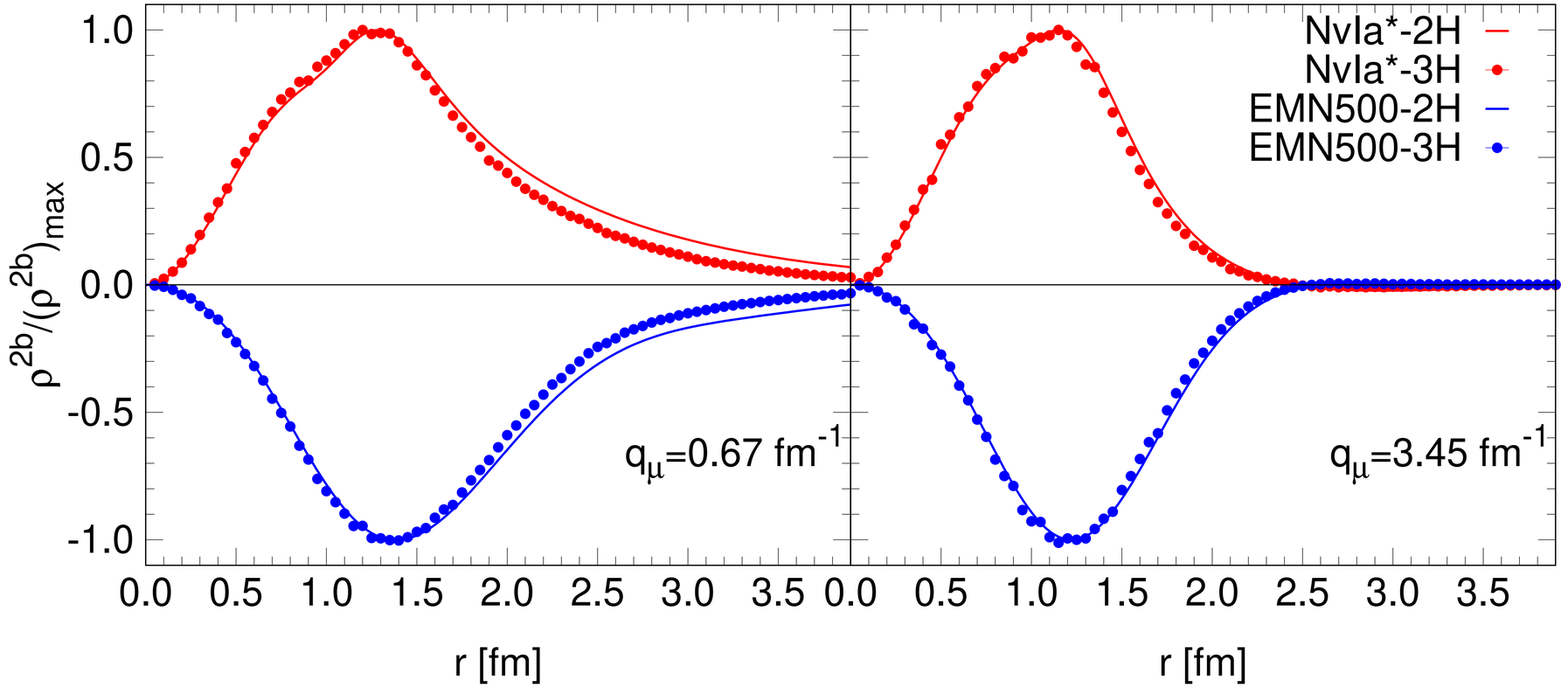


[Science 320, 1476 (2008)]

Why does it work?

Universal behavior of isovector transitions

Correlated np pairs ⟷ **Universal 2-body wave functions** ⟷ **Universal 2-body transition densities**

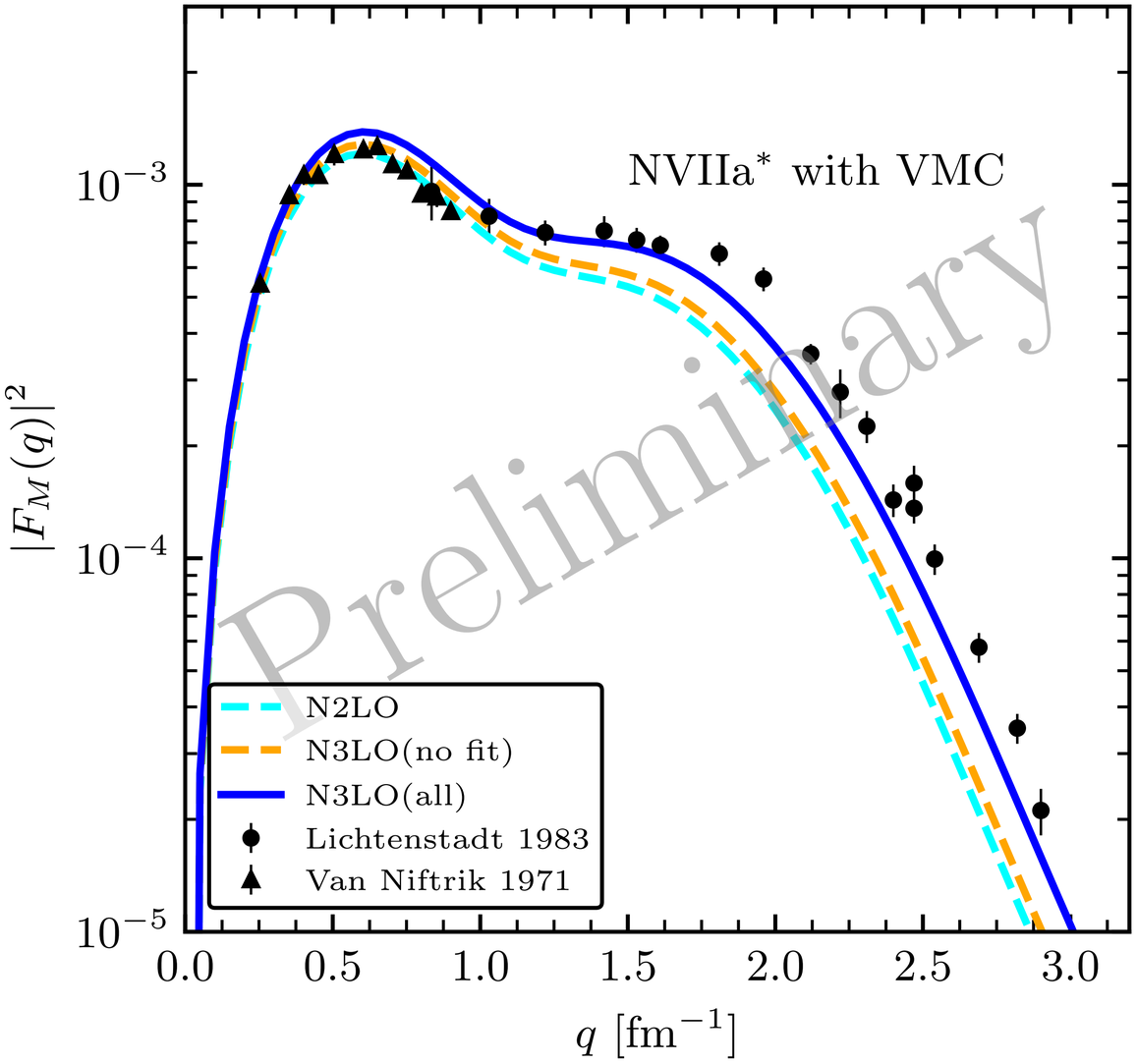


Beyond few-body

Parameter free prediction of ^{7}Li MFF

ft. QMC@WASHU
C.W. Graham, G.B. King,
S. Pastore, M. Piarulli

- No free parameters (we reproduce also the magnetic moment)
- Fitted terms plays a role for Q>0.3 GeV for larger systems
- Data for more nuclei would permit more constraining test
- Prediction up to A<12 with VMC and GFMC in progress



Summary

- New fitting procedure for EM currents LECs
- The isovector currents (OPE+CT @N3LO) seems to be crucial for reproducing the magnetic form factors
- Mechanism can be explained by np dominance in nuclei. Universality of the EM transitions (play a role for heavier nuclei)
- A lot to do for the currents!!

Collaborator: R. Schiavilla

On going work:

- MFF of p-shell nuclei with QMC@WASHU
- Bayesian fit + $np \rightarrow d\gamma$ (B. Acharaya, S. Bacca, M.Viviani, L.E. Marcucci)

National Energy Research Scientific Computing Center

Sparse

Reliability of the predictions

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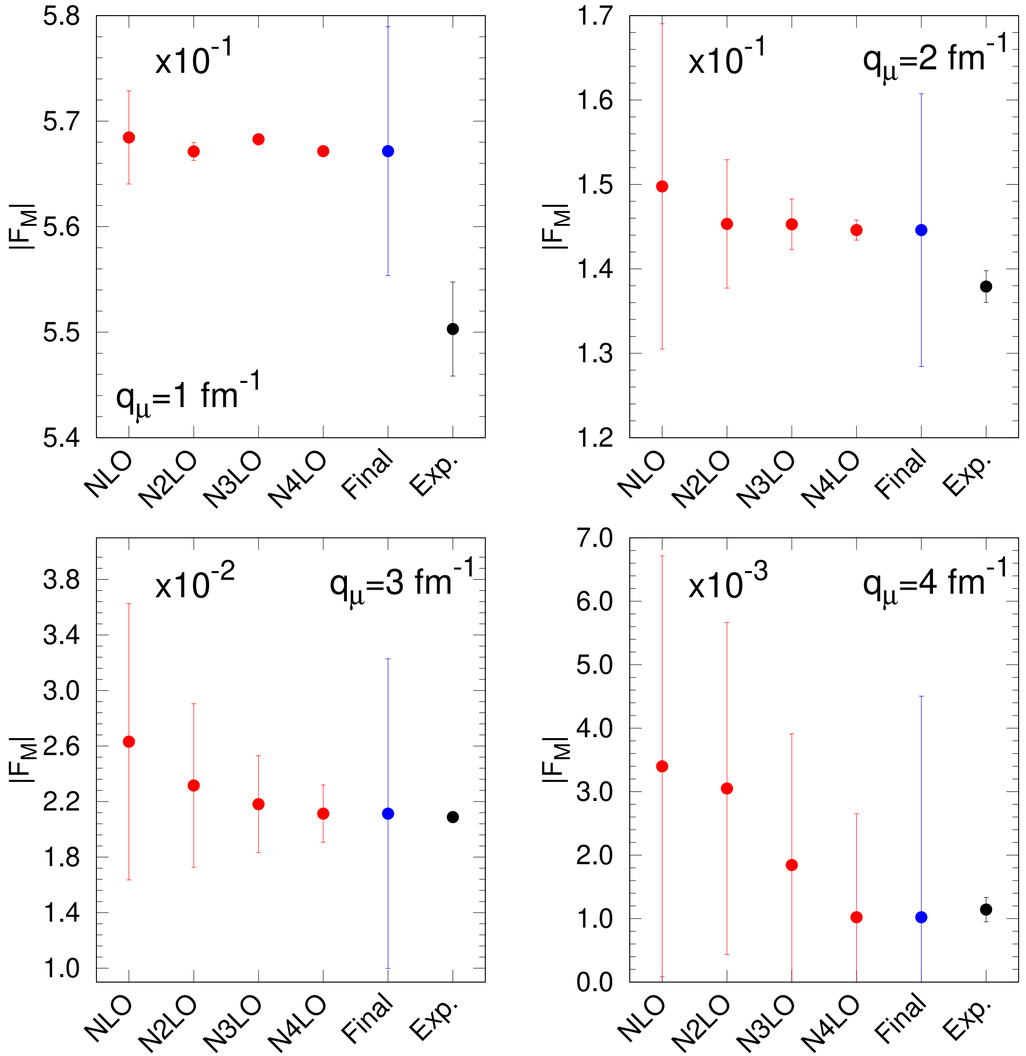
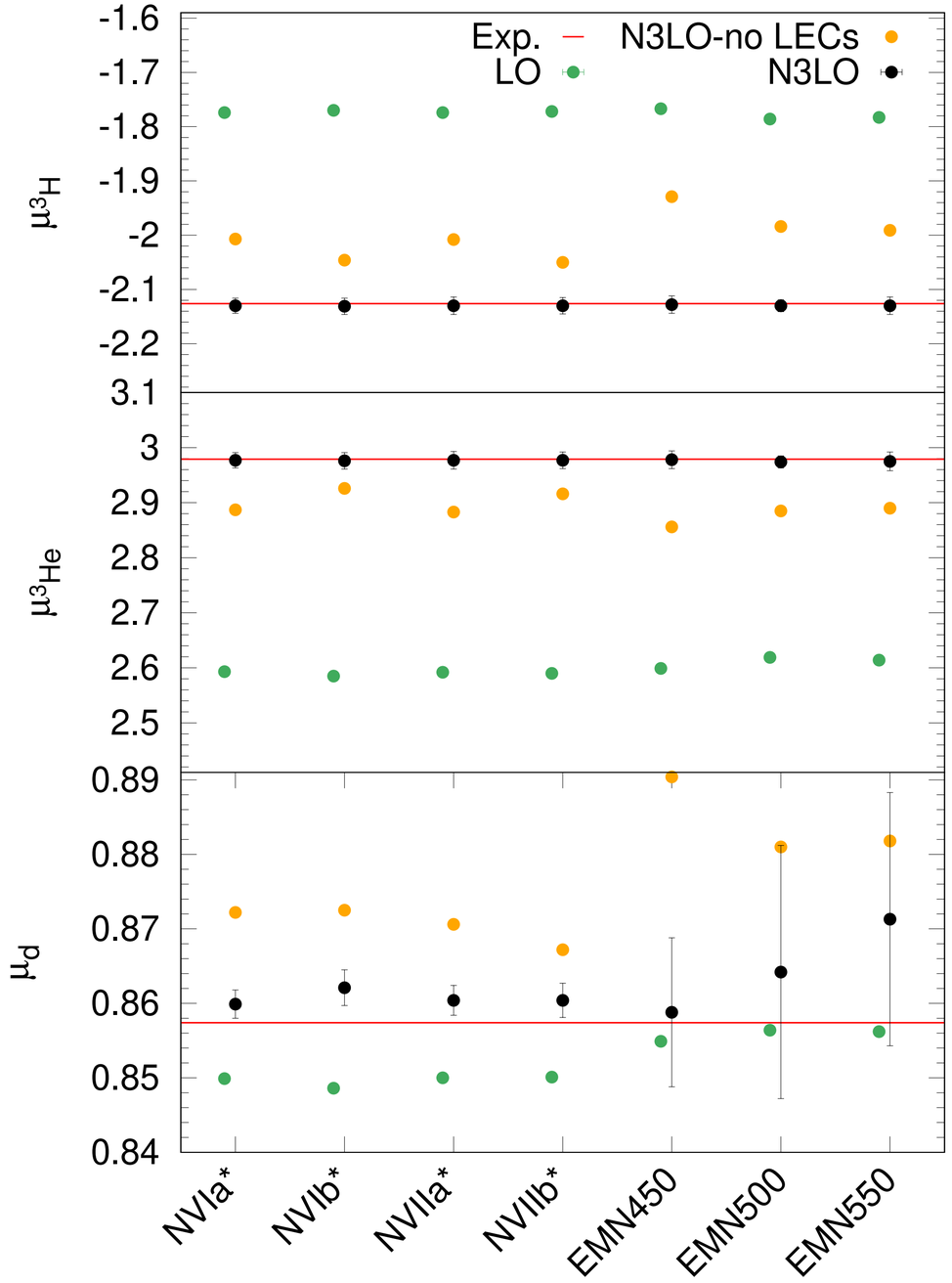


^{3}He EMN500

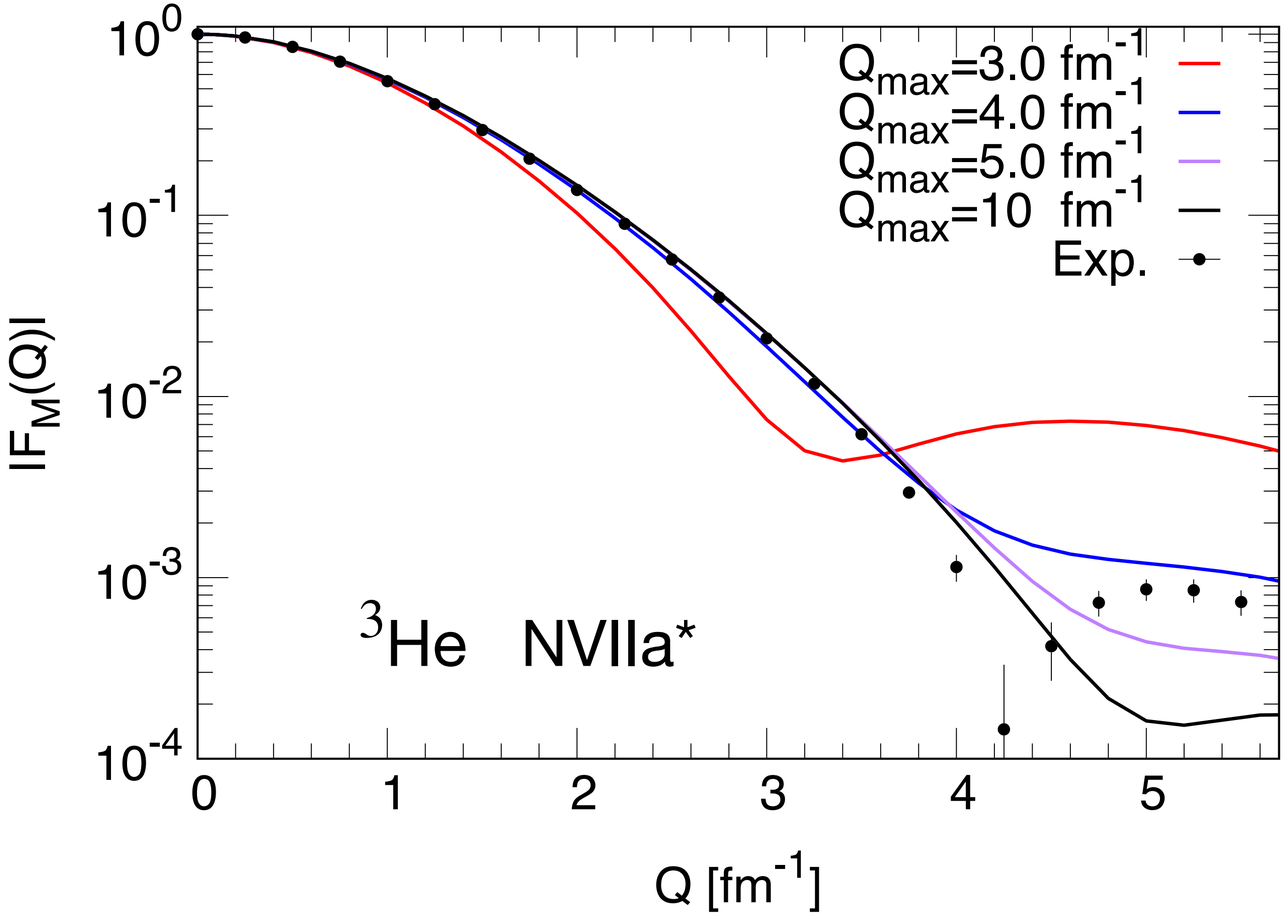
Results of the fit

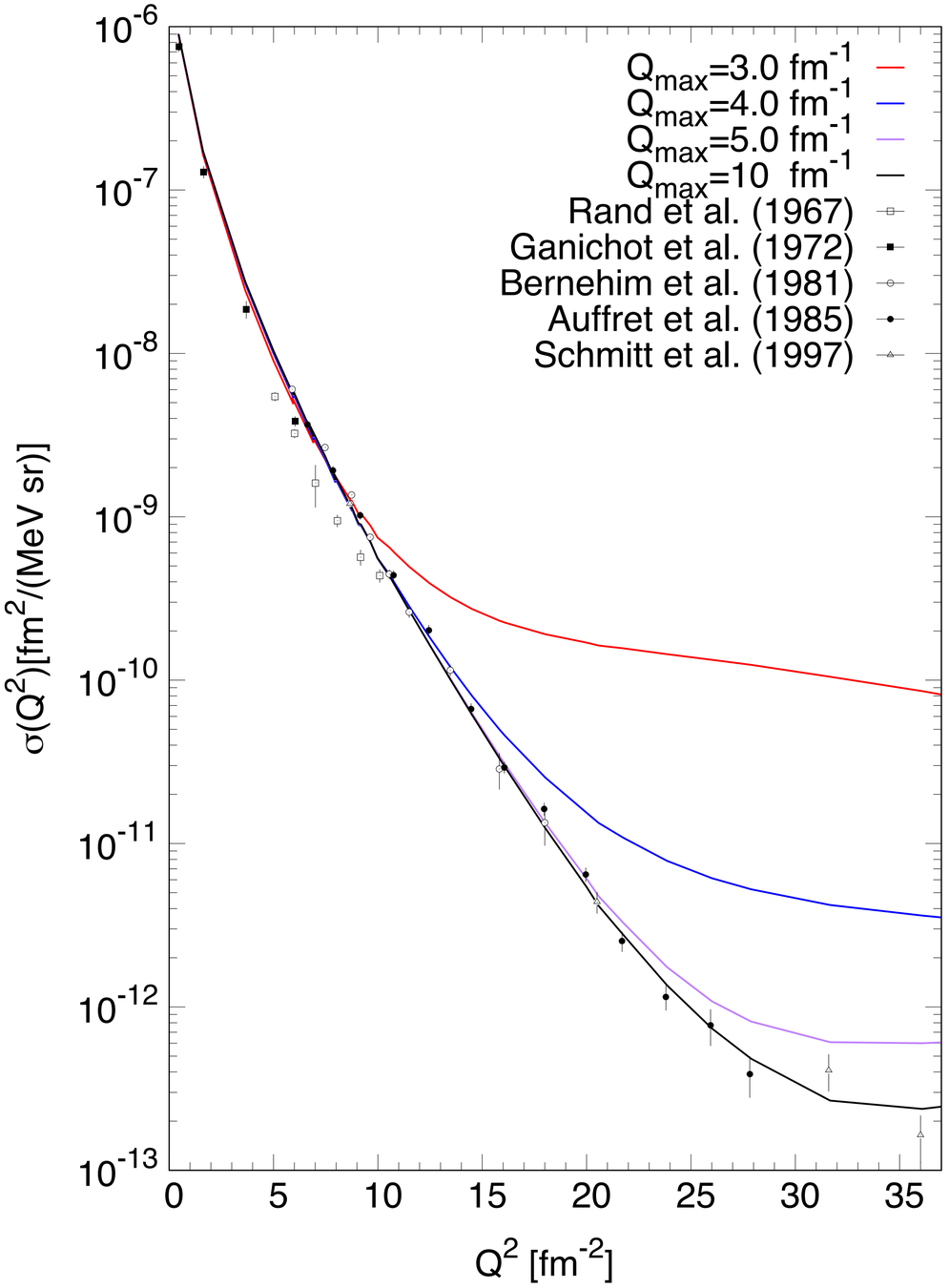
Pot.	χ^2/ndf	χ^2/ndf (no Rand)
NVIa*	9.9	2.0
NVIb*	10.2	2.3
NVIIa*	11.6	2.5
NVIIb*	11.6	2.6
EMN450	11.3	2.8
EMN500	14.7	4.7
EMN550	17.7	7.9

- ndf~40
- Removing Rand *et al.* data, χ^2improves

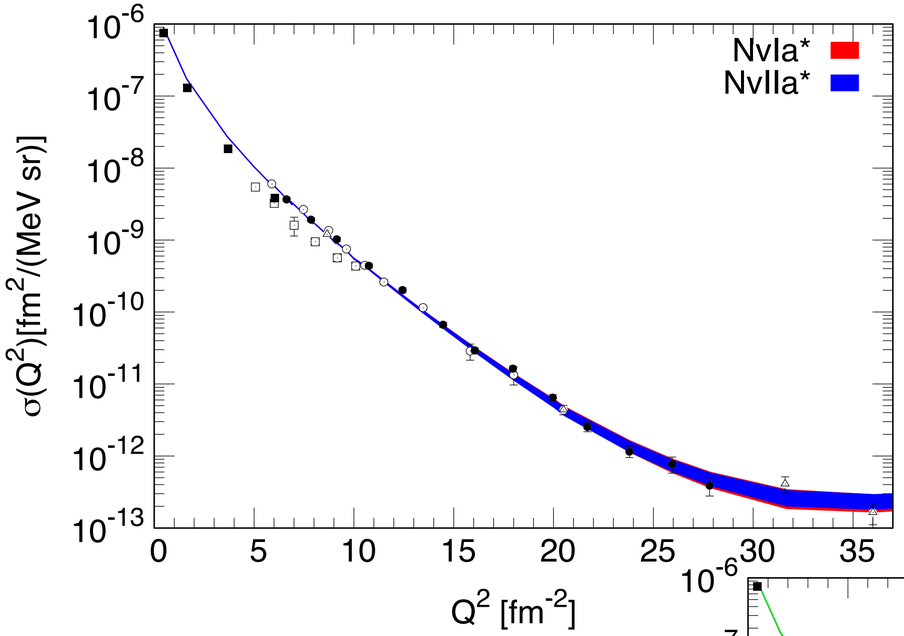


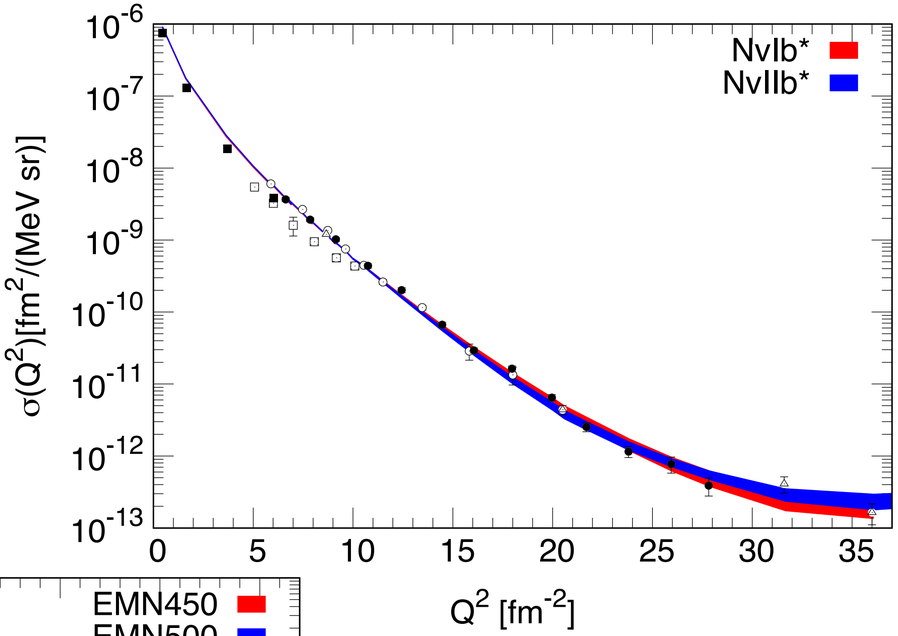
Dependence on Q^2_{max}

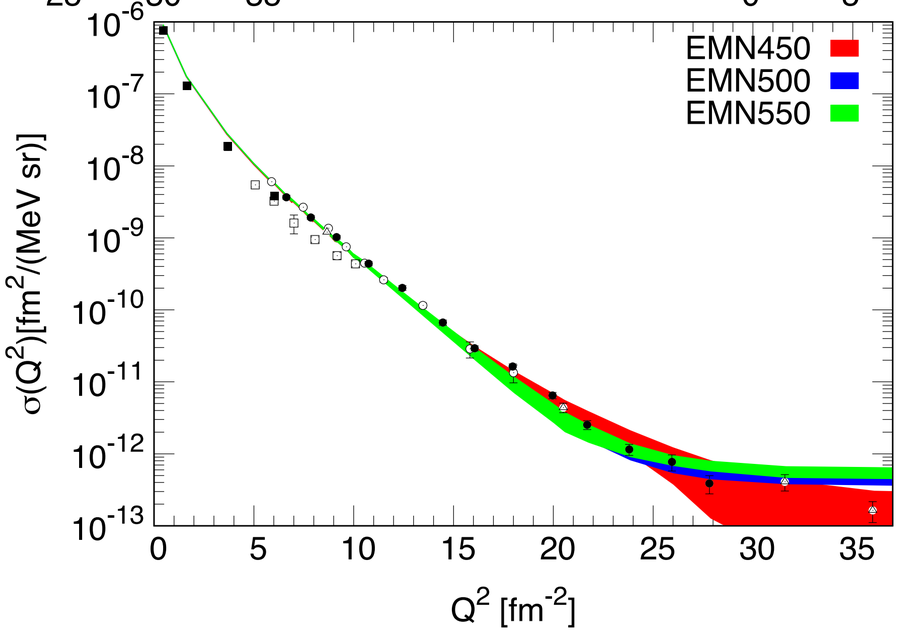




d-threshold


NvIa*
NvIIa*
$\sigma(Q^2)$[fm^2/(MeV sr)]
Q^2 [fm^{-2}]


NvIb*
NvIIb*
$\sigma(Q^2)$[fm^2/(MeV sr)]
Q^2 [fm^{-2}]


EMN450
EMN500
EMN550
$\sigma(Q^2)$[fm^2/(MeV sr)]
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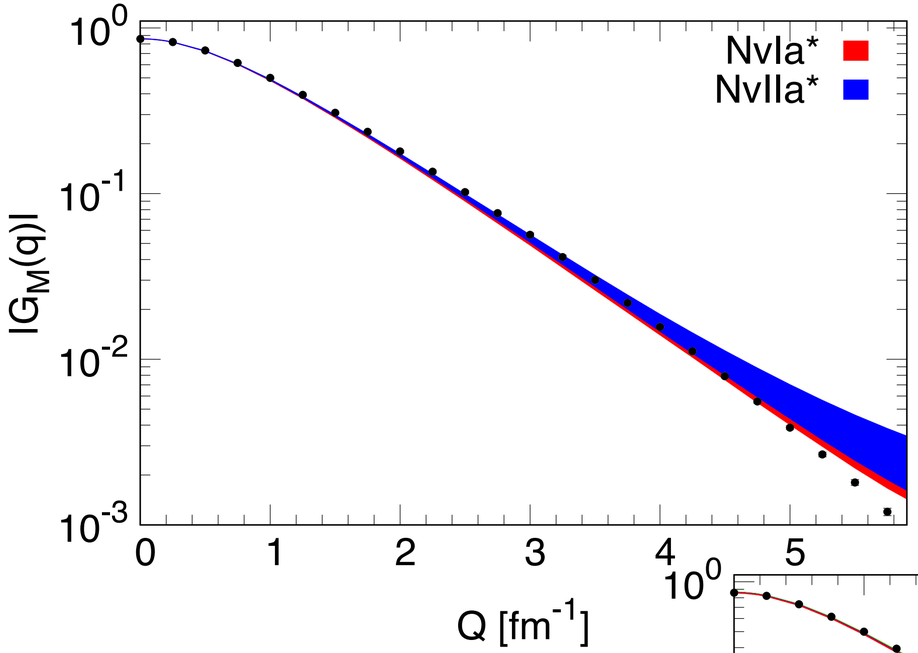
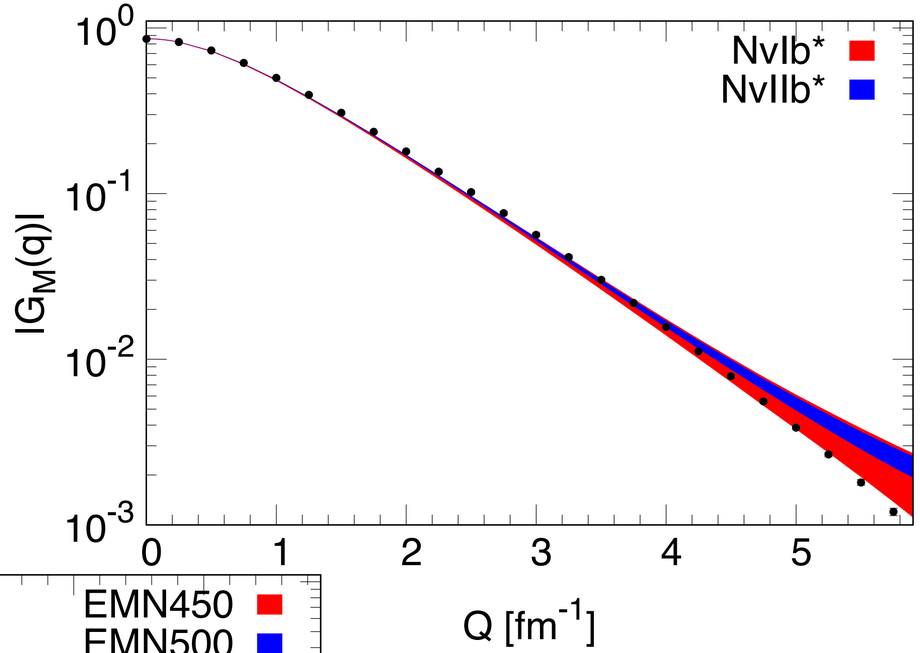
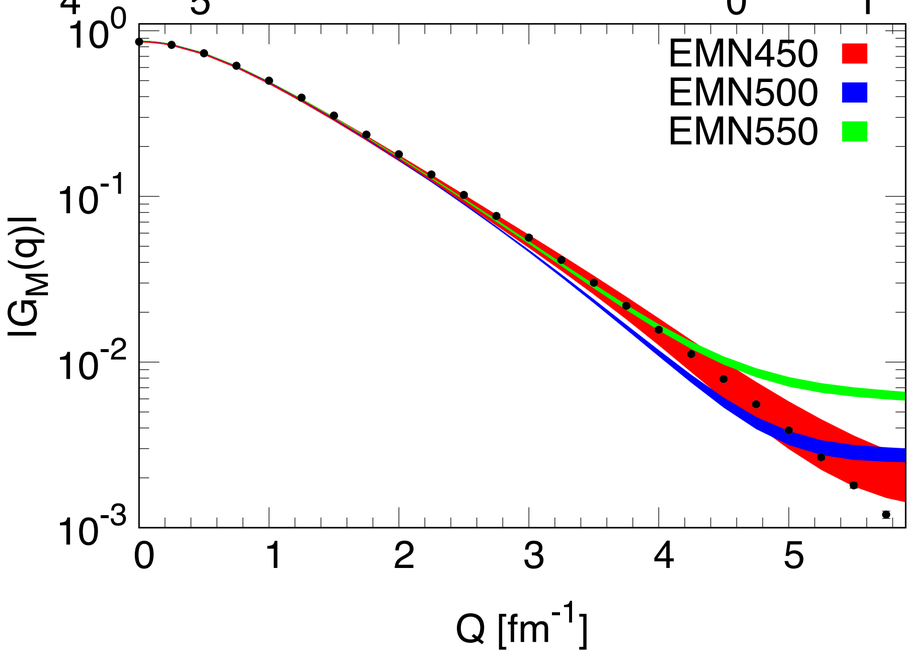
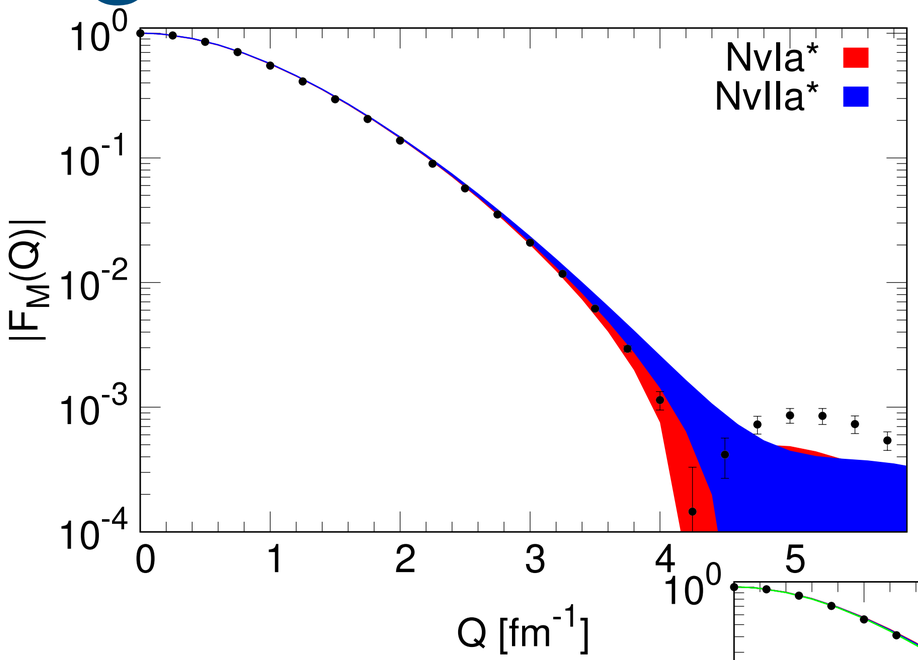
Magnetic form factors of ^{2}H

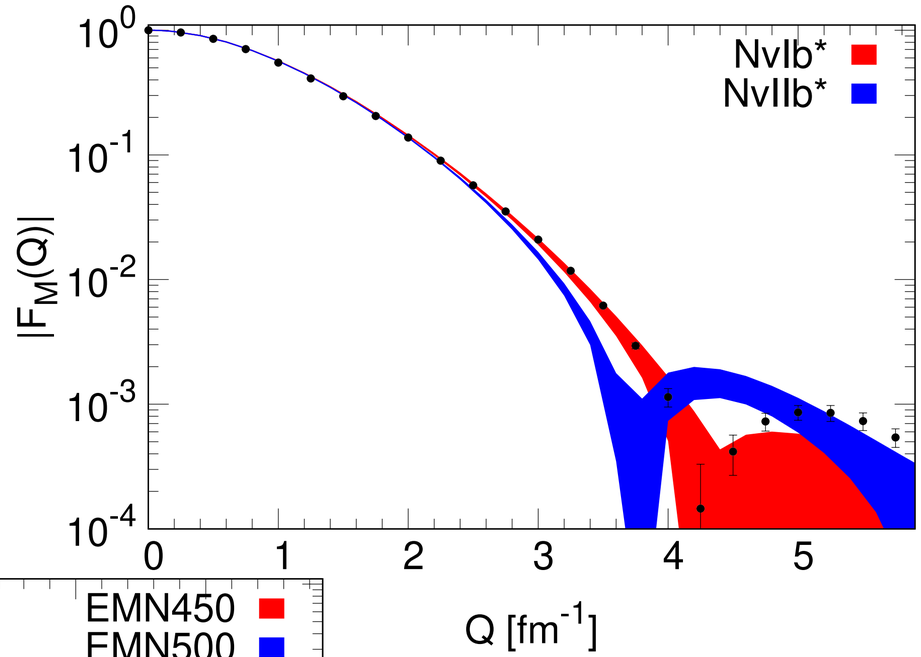


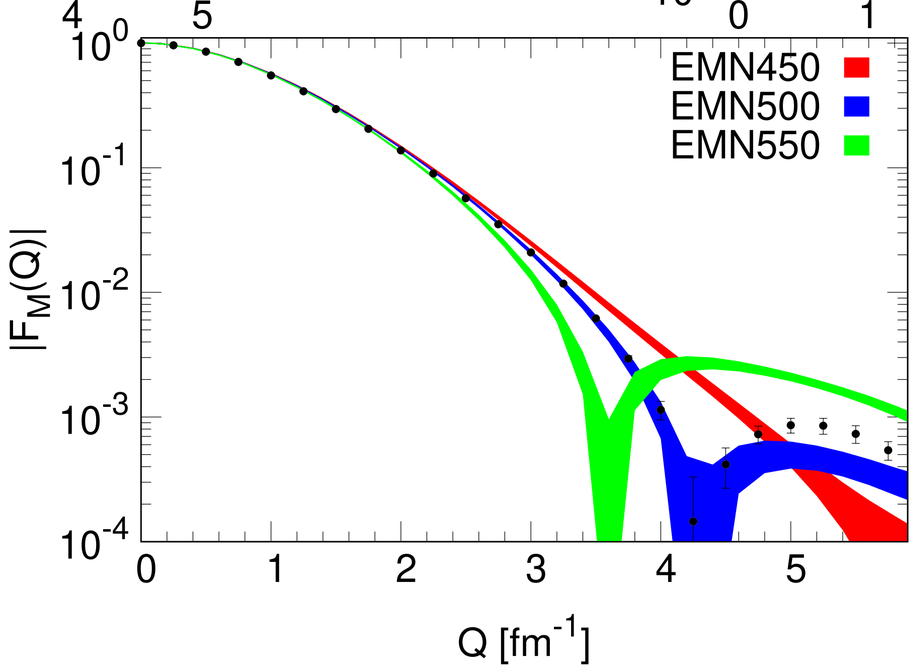




Magnetic form factors of ^{3}He







Magnetic form factors of ^{3}H