

# The axial-vector form factor of the nucleon from two flavor Lattice QCD ensembles

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- ✓ Chiral symmetry for the  $\pi N \Delta$  system
- ✓ Lattice results from two flavour ensembles
- ✓ Global fits and  $\chi$ PT convergence issues
- ✓ Summary and outlook

# Chiral extrapolation for QCD with up and down quarks

- ✓ consider  $m_{u,d} \simeq 2 - 5$  MeV to be small in QCD
  - approximate  $SU(2)_{L \otimes R}$  chiral symmetry
  - apply  $\chi$ PT in terms of the chiral Lagrangian
- ✓ how-to power count in the presence of heavy fields?
  - controversial how to deal with the  $\Delta(1232)$  baryon
  - conventional expansion schemes appear very slow (if at all) convergent
- ✓ novel expansion scheme in terms of on-shell masses
  - pioneered for various hadrons on flavour  $SU(3)$  ensembles
  - chiral expansion is not necessarily smooth - first order transitions are possible
  - revisited for flavour  $SU(2)$  chiral expansions

U. Sauerwein, MFML, RGE Timmermans, arXiv:2105.06755

MFML, U. Sauerwein, RGE Timmermans, [arXiv:2003.10158](https://arxiv.org/abs/2003.10158) main paper for this talk

X. Guo, Y. Heo, MFML, arXiv:1907.00714

MFML, Y. Heo, X. Guo, arXiv:1907.00237

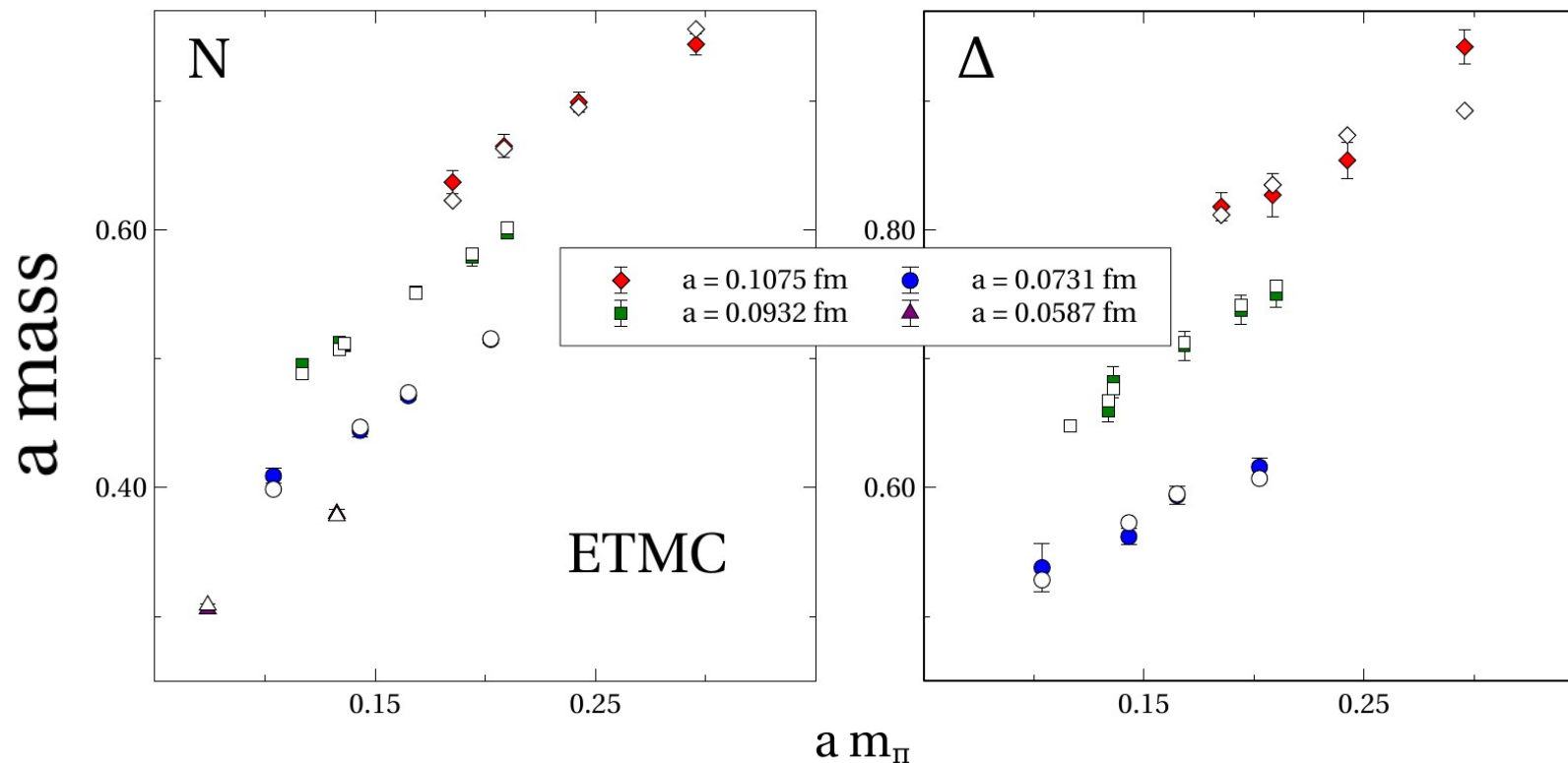
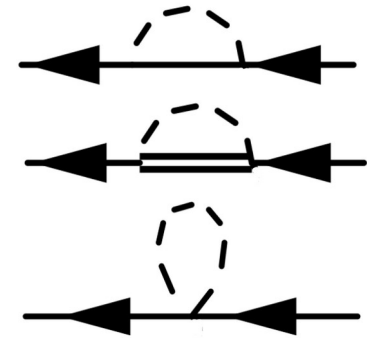
MFML, Y. Heo, X. Guo, arXiv:1801.06417

A. Semke, MFML, arXiv:nucl-th/0606027

# Chiral extrapolation for QCD with up and down quarks

✓ baryon masses at the one-loop level

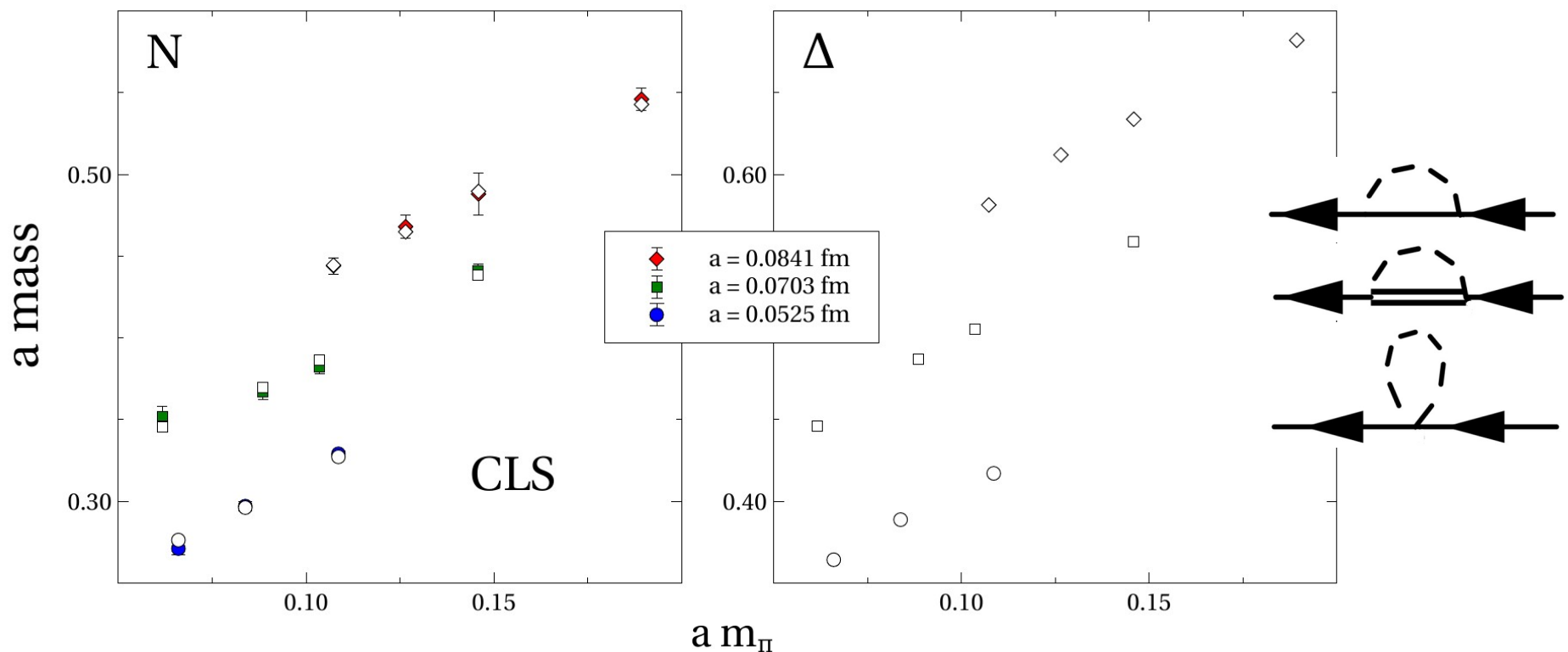
- pioneered computation with on-shell masses in loops
- converging chiral expansion of loop contributions
- possibility of parametric phase transitions



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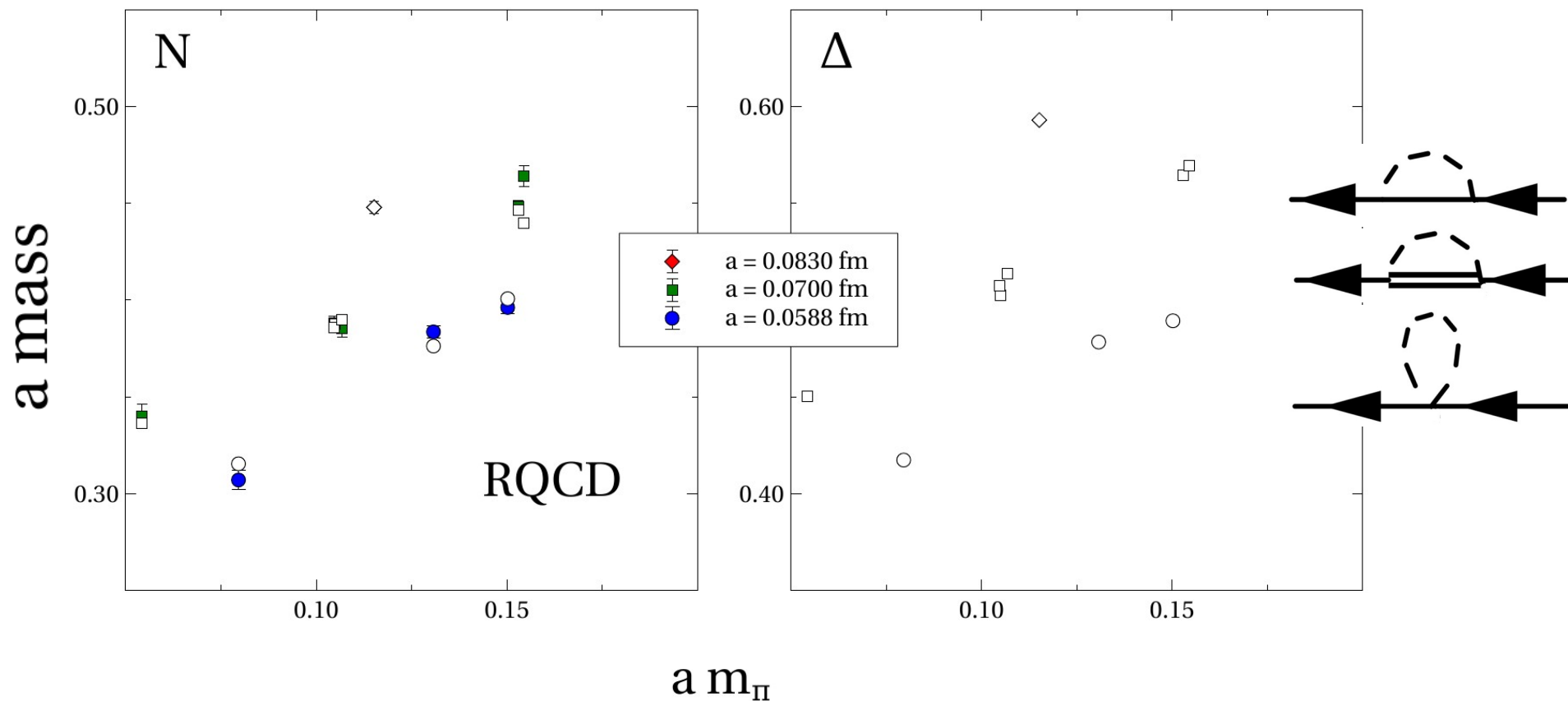
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- accurate reproduction of nucleon mass on CLS ensembles (predict  $\Delta$  masses)



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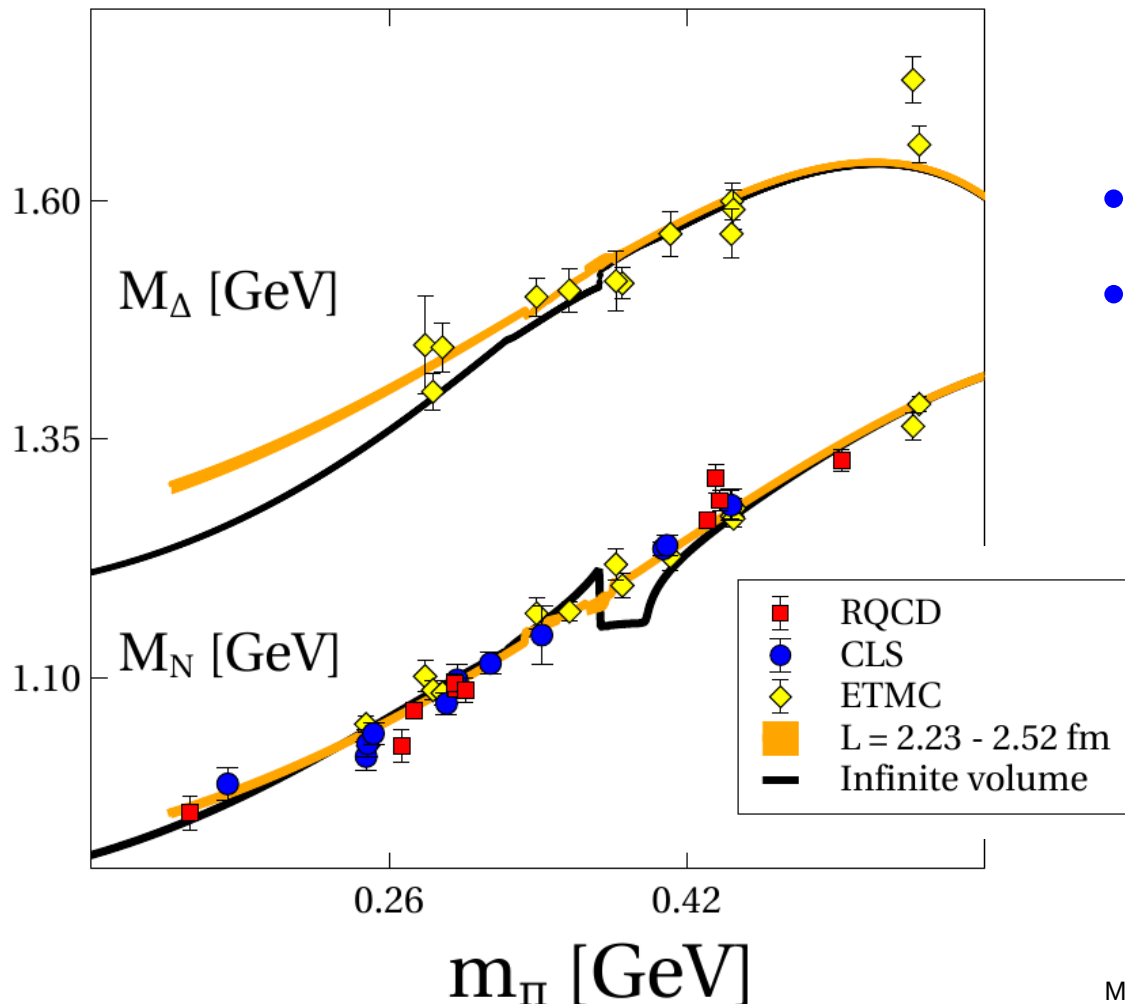
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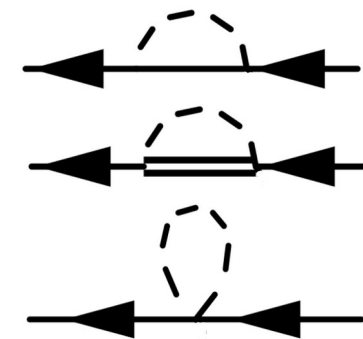
# Chiral extrapolation for QCD with up and down quarks

✓ baryon masses at the one-loop level

- accurate reproduction of baryon masses on lattice ensembles
- predict parametric phase transition at large pion masses



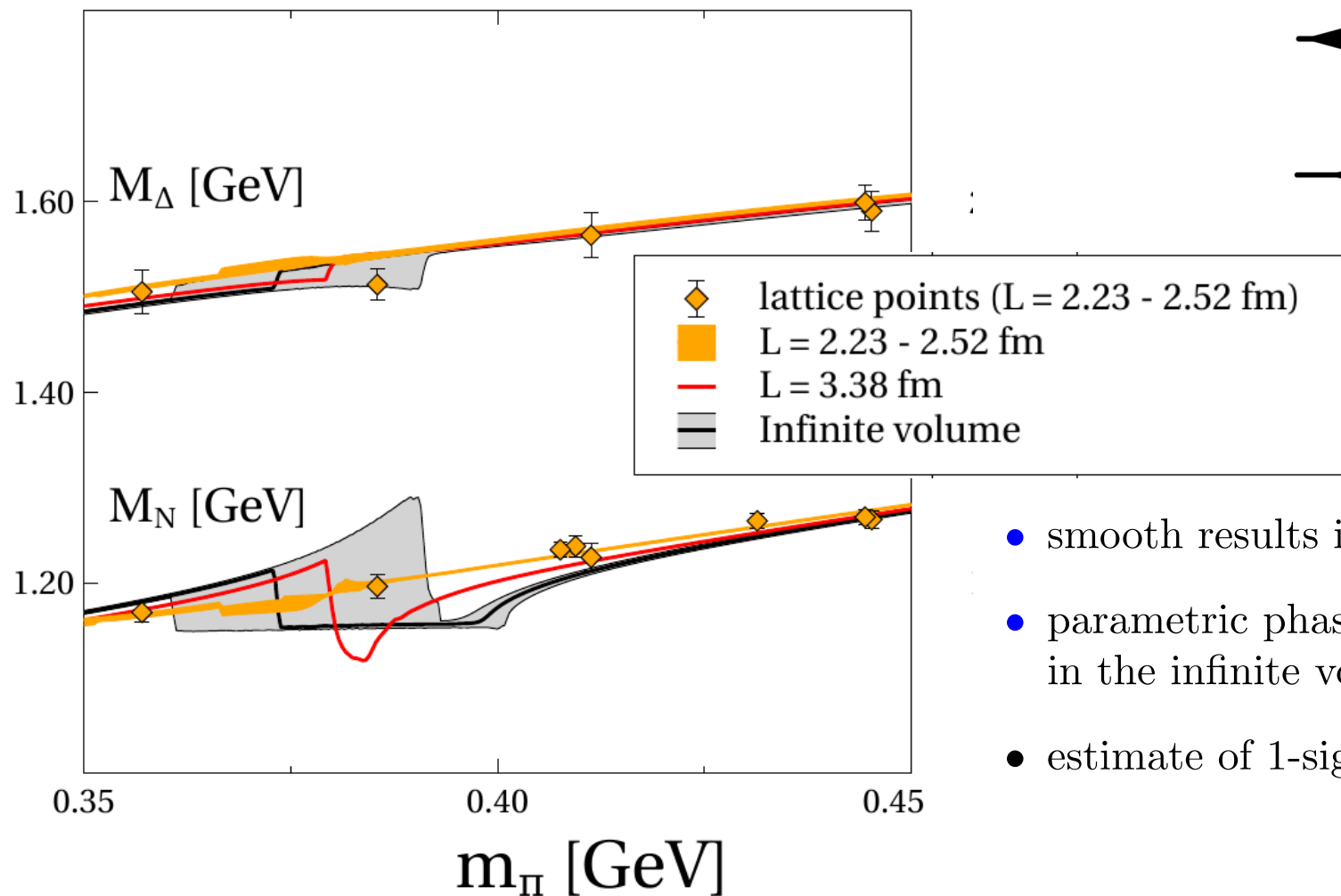
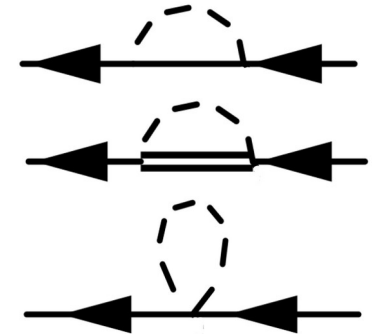
- smooth results in finite box
- parametric phase transition in the infinite volume



# Chiral extrapolation for QCD with up and down quarks

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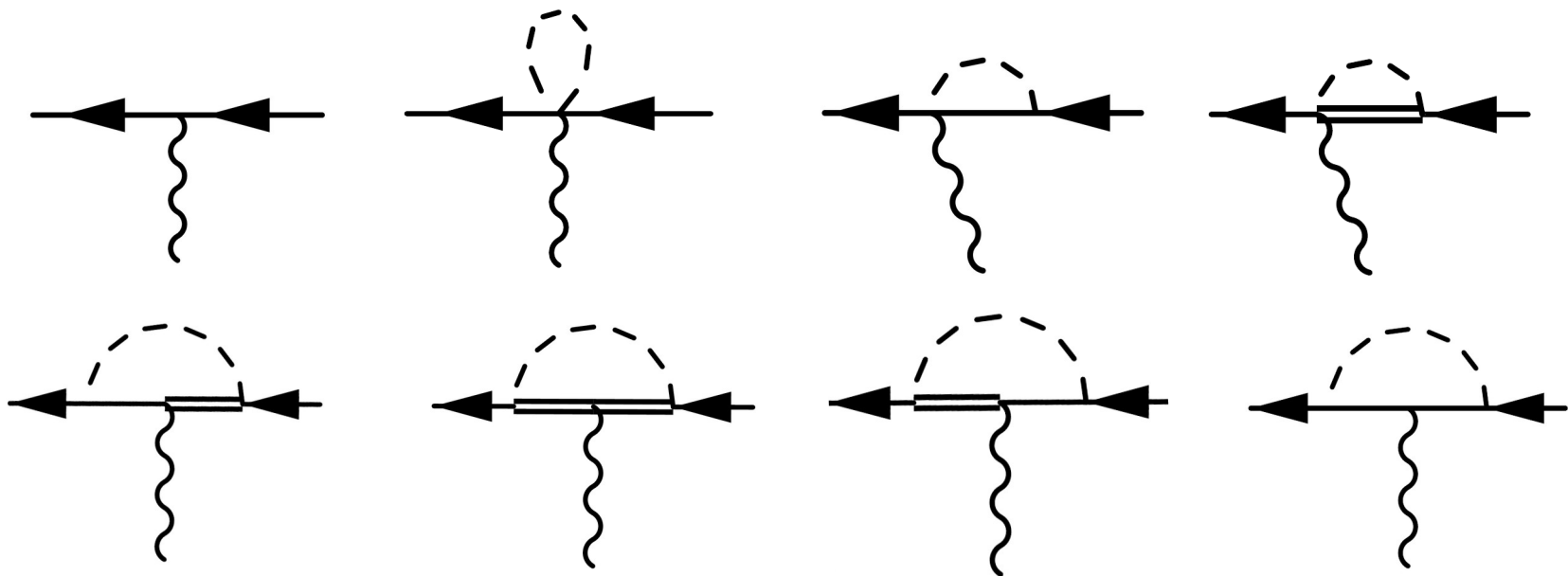
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- smooth results in finite box
- parametric phase transition in the infinite volume
- estimate of 1-sigma uncertainty

# Chiral extrapolation for QCD with up and down quarks

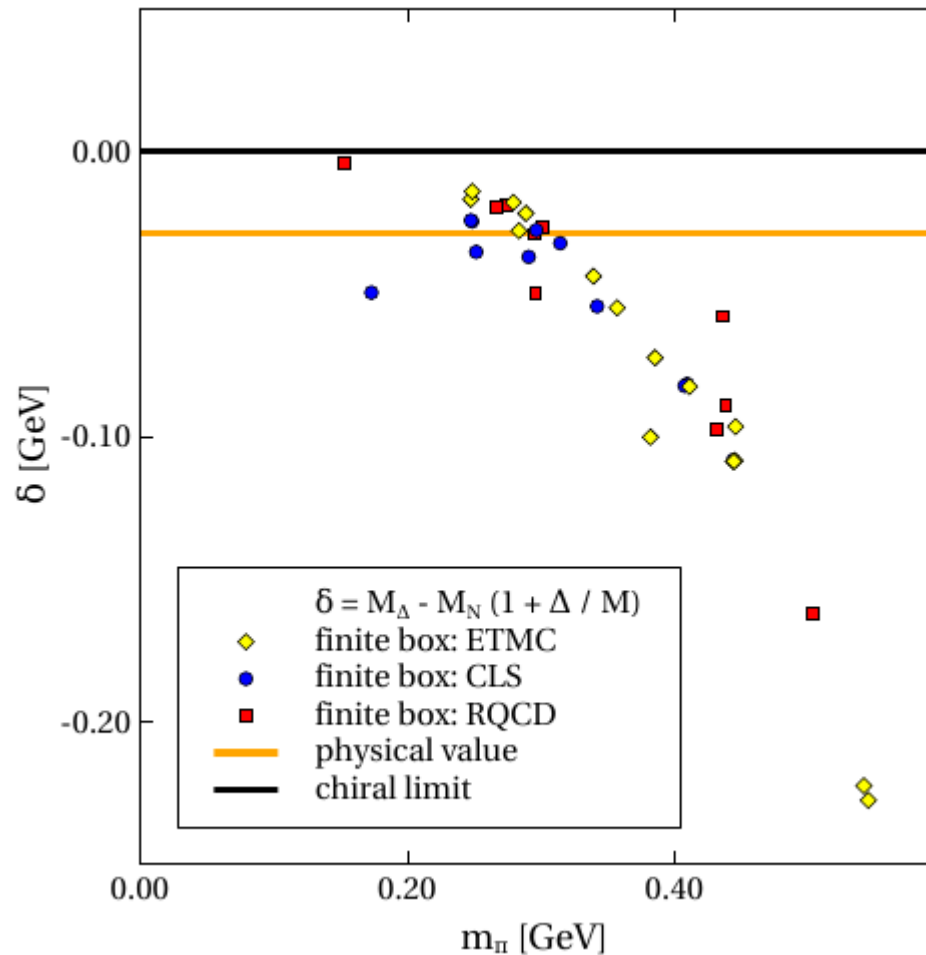
- ✓ axial-vector formfactor at the one-loop level
  - pioneered computation with on-shell masses in loops
  - converging chiral expansion of loop contributions
  - revisited for flavour SU(2) chiral expansions





# Novel expansion parameters

- $m_{u,d} \sim m_\pi^2 \sim Q^2$   $M_N \sim Q^0$
- $\delta = M_\Delta - M_N (1 + \Delta/M) \sim Q^2$   $\Delta/M \sim Q^0$
- with  $M$  and  $M + \Delta$  from  $M_N$  and  $M_\Delta$  in the chiral limit



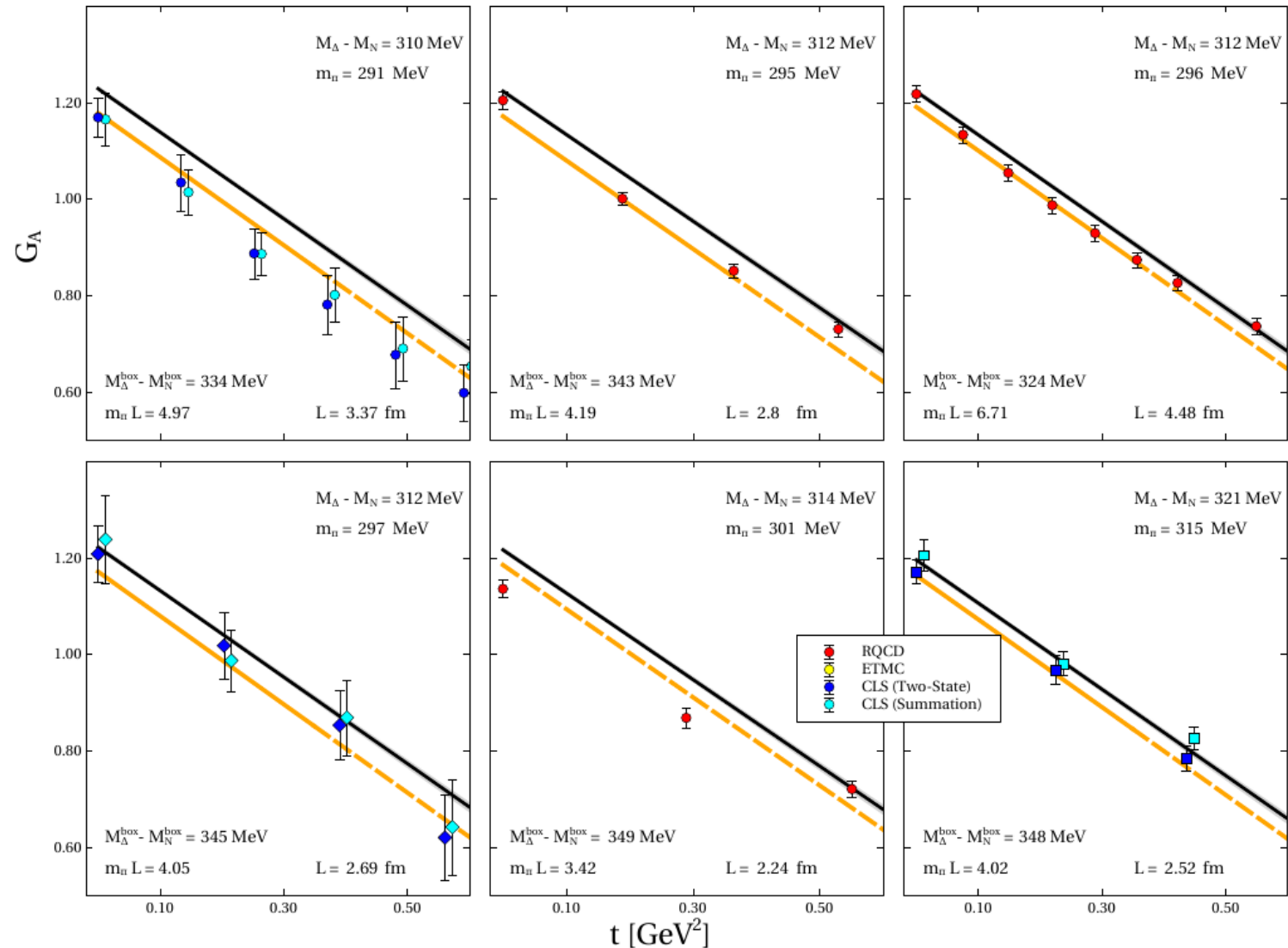
# Global fit to lattice data from ETMC, CLS and RQCD

- consider masses ( $M_N$ ,  $M_\Delta$ ) and axial-vector form factor

- 99 data points with  $\chi^2/N_{df} \simeq 1.40$

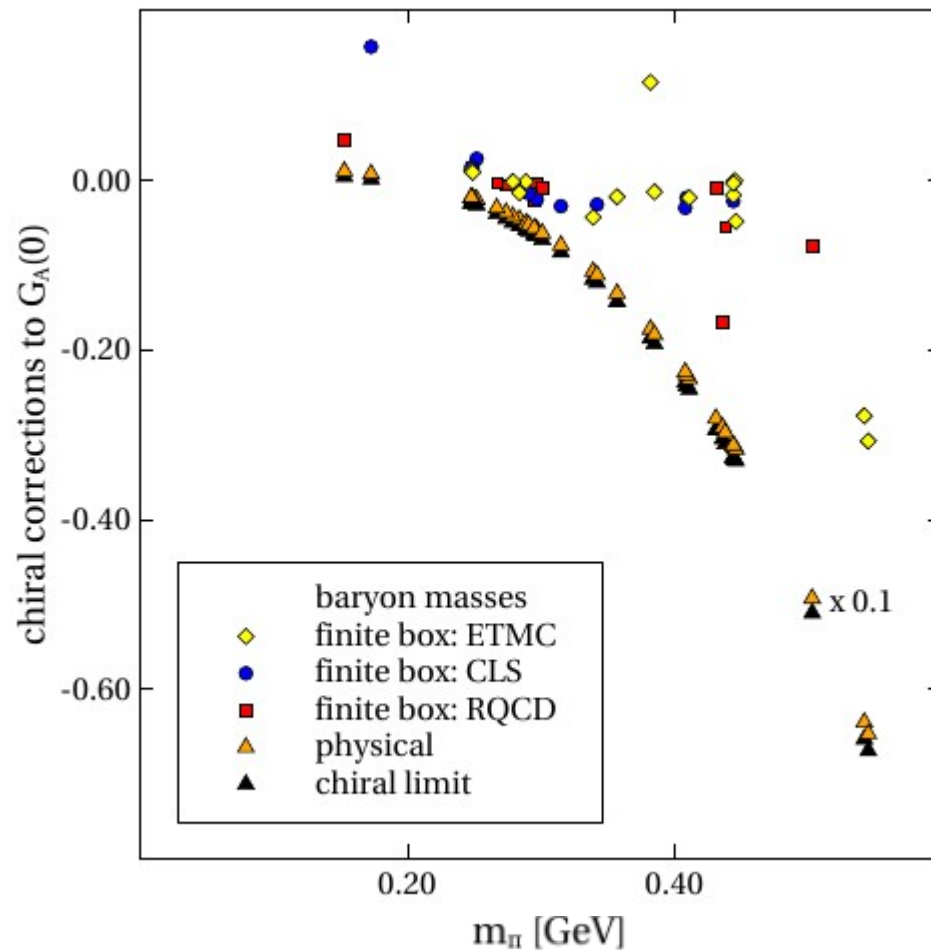
large impact of box size

- finite-box (orange)
- infinite-box (black)
- mass of  $\Delta$  matters!



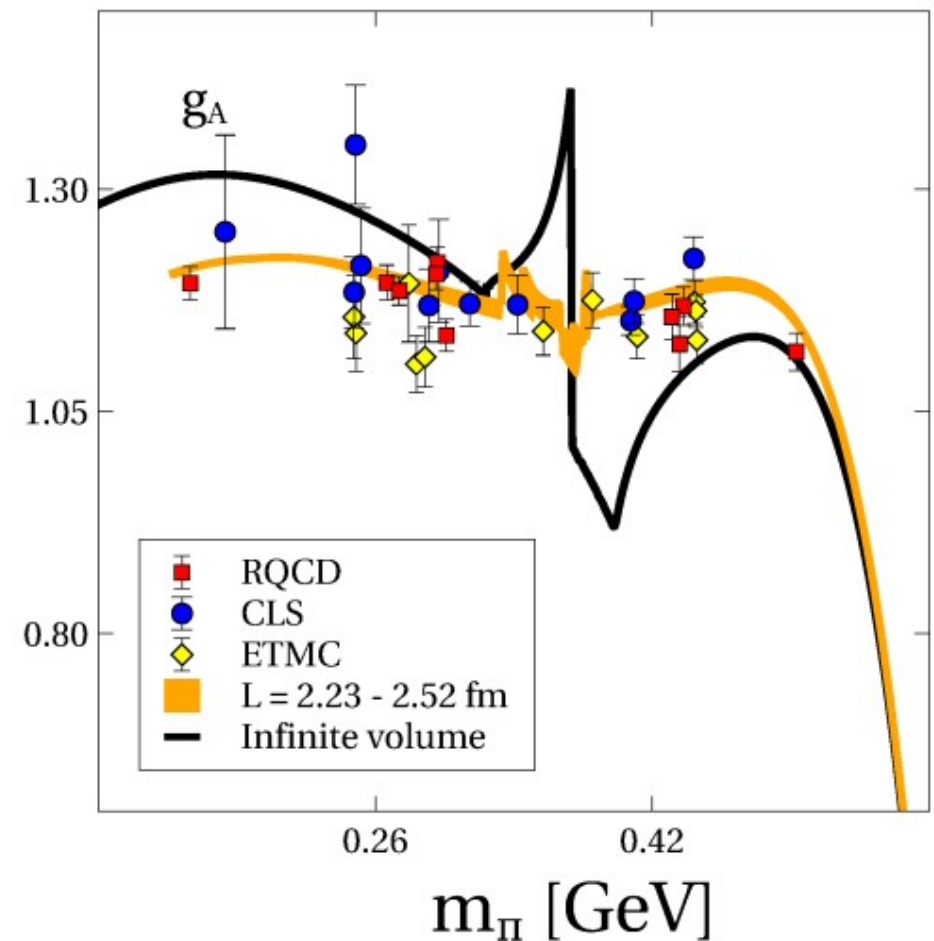
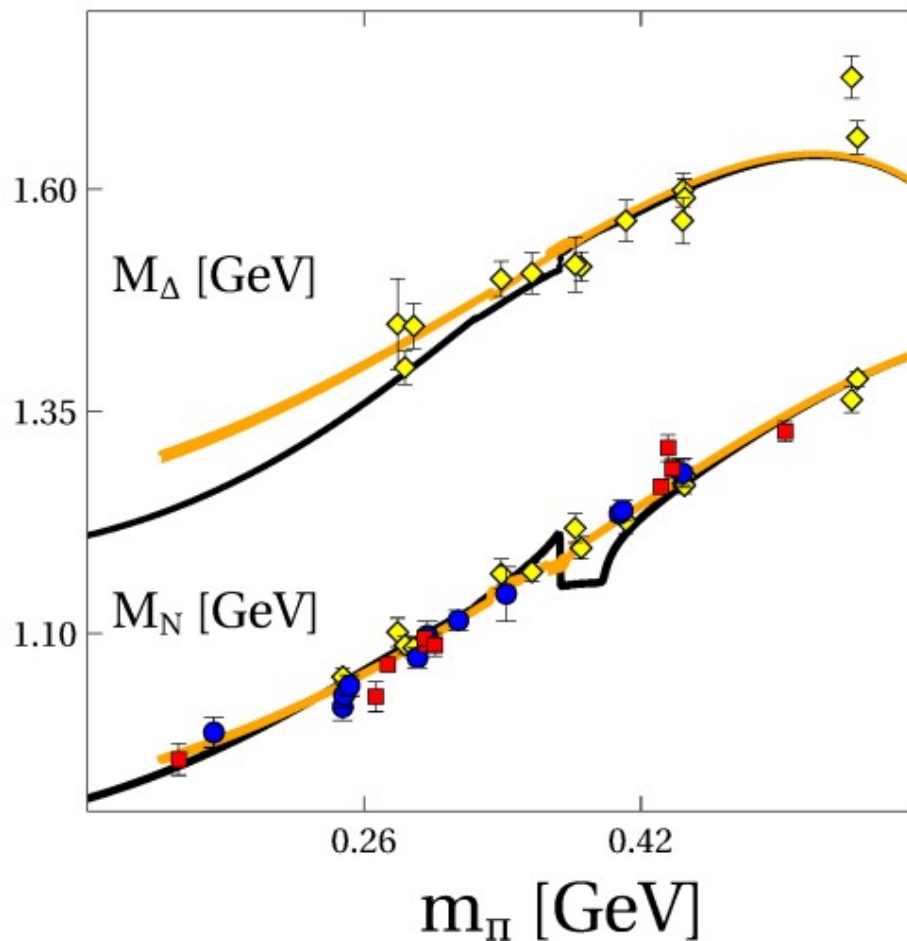
# Chiral corrections for the axial form factor

- $\delta = M_\Delta - M_N (1 + \Delta/M) \sim Q^2$   
with  $M$  and  $M + \Delta$  from  $M_N$  and  $M_\Delta$  in the chiral limit
- consider different assumptions for  $M_N$  and  $M_\Delta$  (one-loop level)
- convergence only with on-shell  $M_N$  and  $M_\Delta$



# QCD lattice results on two flavour ensembles

- predict phase-transition at unphysical quark masses (infinite volume case)
- smooth behavior in finite box
- lattice results do not exclude such a behavior so far



# Summary and Outlook

## ✓ Chiral extrapolation of hadron masses and form factors

- chiral expansion with up and down quarks is well convergent  
iff expansion parameters are used in terms of on-shell hadron masses
- quantitative reproduction of two-flavour lattice data sets (ETMC, RQCD, CLS)
- predict low-energy constants of the chiral Lagrangian

## ✓ Precision extrapolation results for baryons ?

- should use ensembles at physical strange quark mass  
we predicted the isobar strangeness sigma terms to be large  
form factor have a significant dependence on the isobar mass
- need more precision data on the isobar

## ✓ Parametric phase transitions in QCD ?

- are not ruled out by current lattice data
- ensembles at large boxes and large pion masses would be needed
- in flavour SU(3) ensembles at smaller strange quark mass
- such a phase transition could be a candidate for strange dark matter

