Light Baryon Spectroscopy

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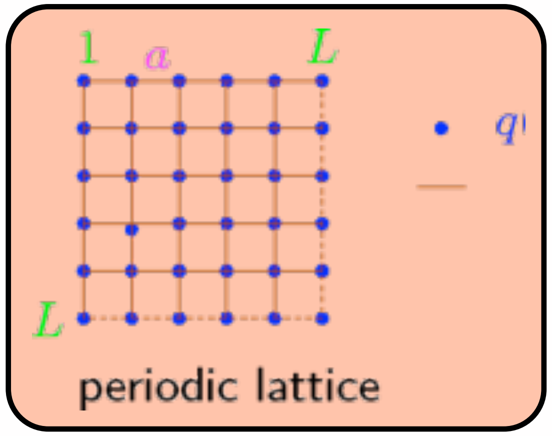
with
Gernot Eichmann, Helios Sanchis-Alepuz, Richard Williams

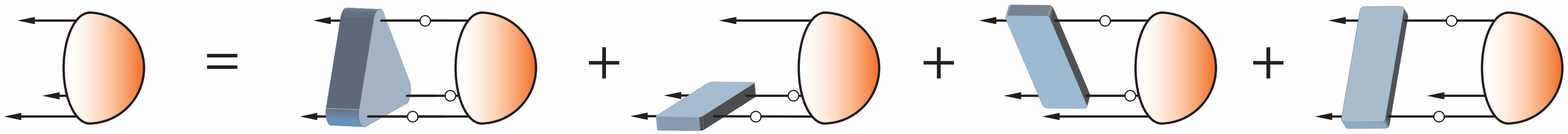
Overview

1. Introduction

2. Results from Lattice-QCD



3. Results and perspective from DSE/Faddeev-approach

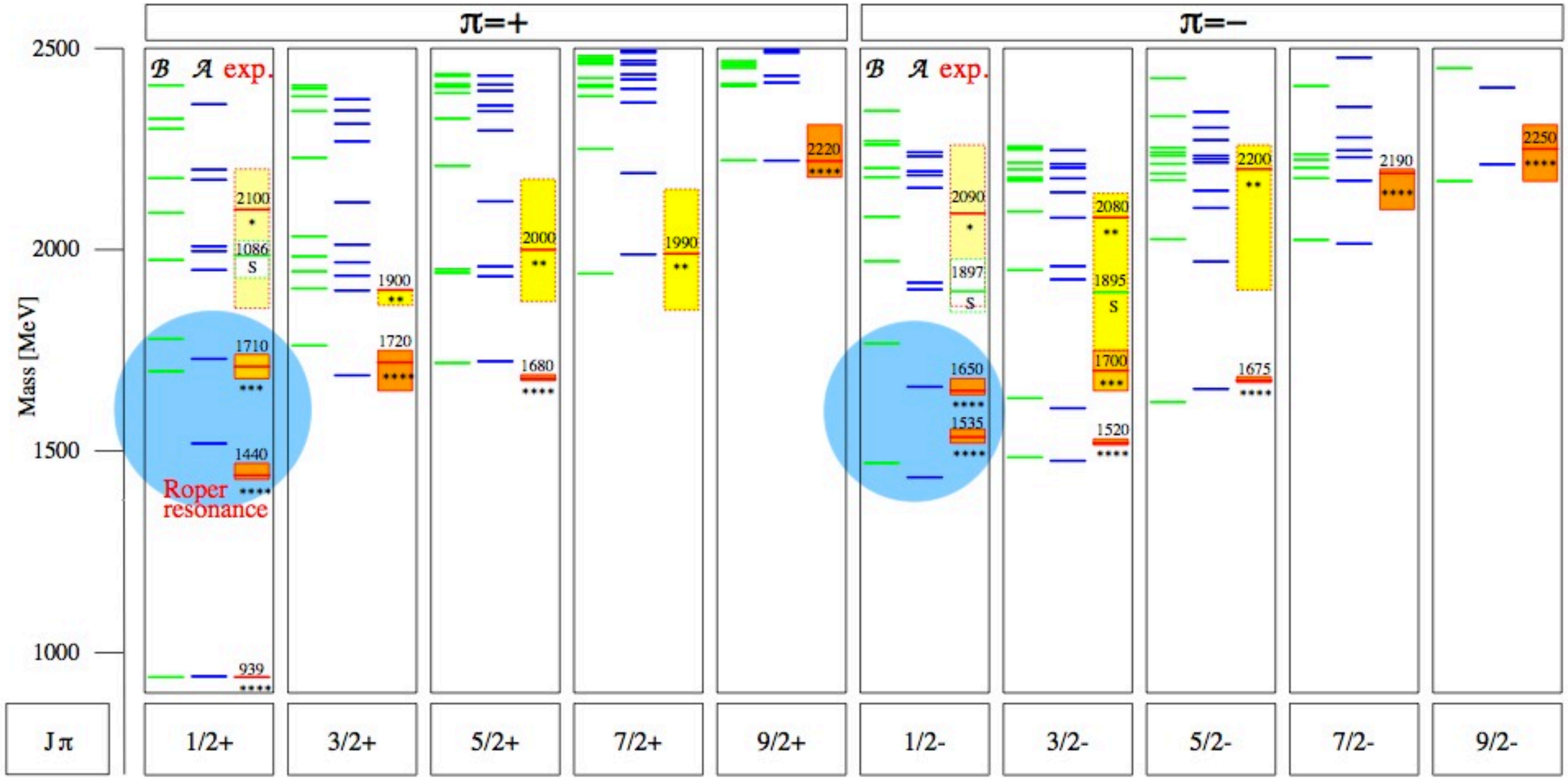


Light baryon spectroscopy

TAG: Light-baryon sector → Antiproton-proton reaction dynamics
Light-baryon sector → Light-baryon sector (spectroscopy, form factors)

- Underlying QCD forces
  - two-body vs. three-body ⟶ Δ vs Y - configuration
  - confinement ⟶ Regge trajectories ?!
  - spin structure
  - meson cloud effects ⟶ GB-exchange vs QCD
- 'Missing resonances' ⟶ 3-quark vs. quark-diquark
- Heavy/heavy-light systems ⟶ Differences to light baryons
- Coupled-channel effects

Klemt, Richard, Rev.Mod.Phys. 82 (2010) 1095



Loring, Metsch, Petry, EPJA 10 (2001) 395

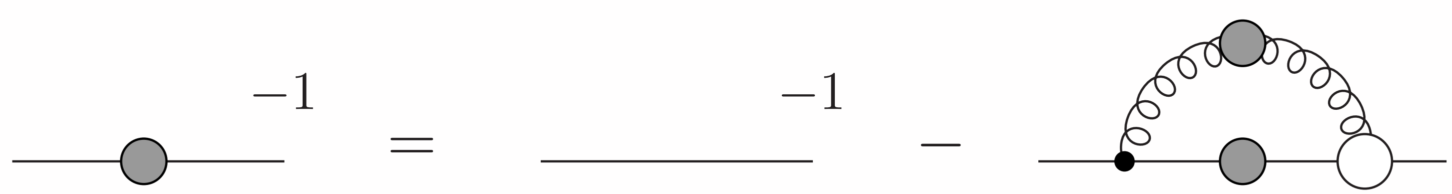
- ‘missing resonances’ ?!
- parity doubling ?!
- level ordering: $N\frac{1}{2}^{\pm}$ vs. $\Lambda\frac{1}{2}^{\pm}$

Properties of QCD: Dynamical mass generation

Dynamical quark masses
via weak and strong force

Yoichiro Nambu,
Nobel prize 2008

	u	d	s	c	b	t
M_{weak} $[MeV/c^2]$	3	5	80	1200	4500	176000
M_{strong} $[MeV/c^2]$	350	350	350	350	350	350
M_{total} $[MeV/c^2]$	360	360	450	1600	4900	176000



$$S^{-1}(p) = [i\not{p} + M(p^2)]/Z_f(p^2)$$

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Input parameters in N_f=2+1+1 QCD

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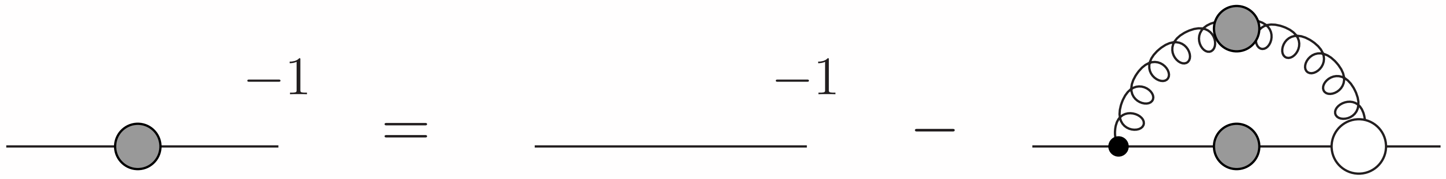
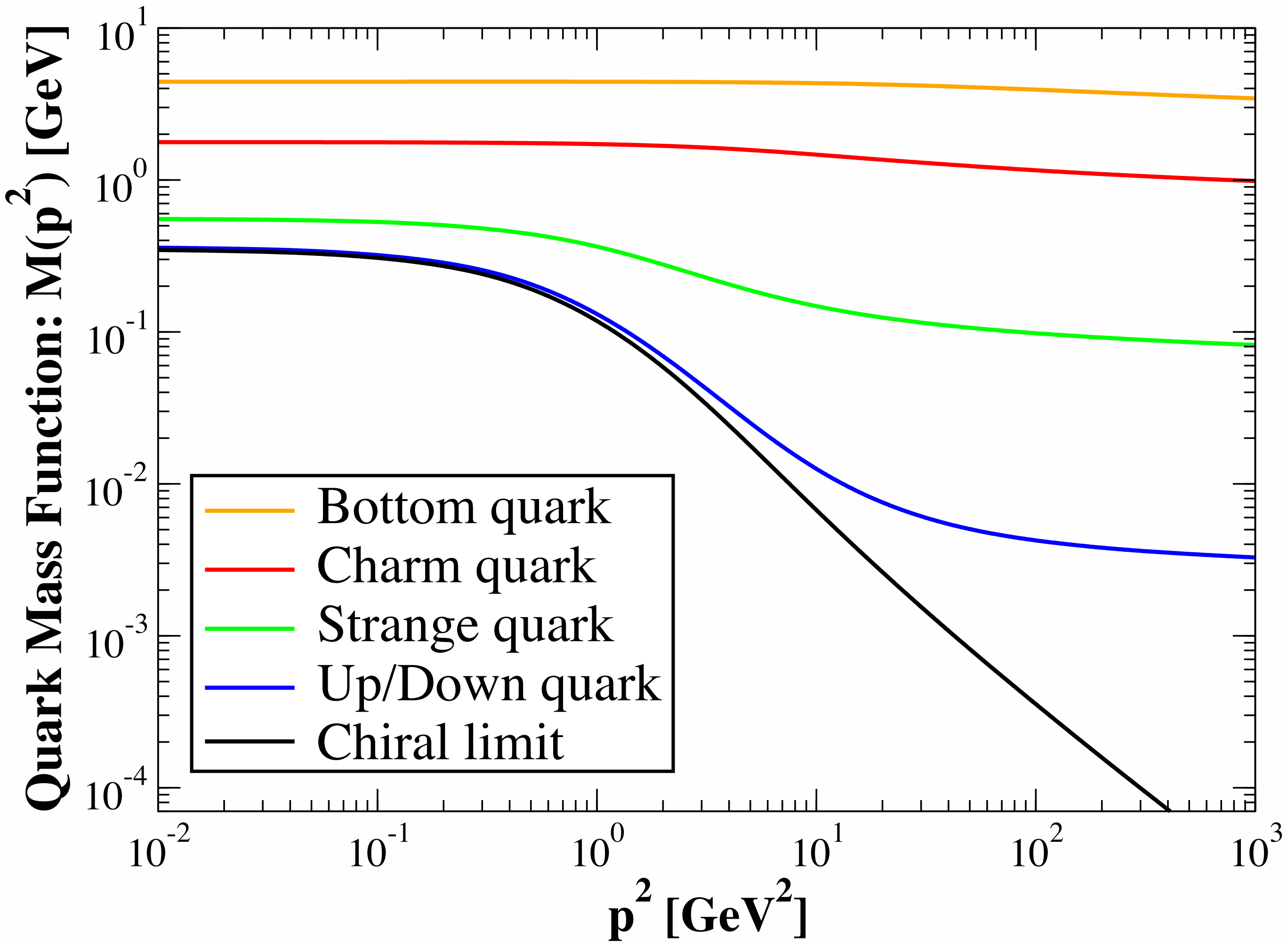


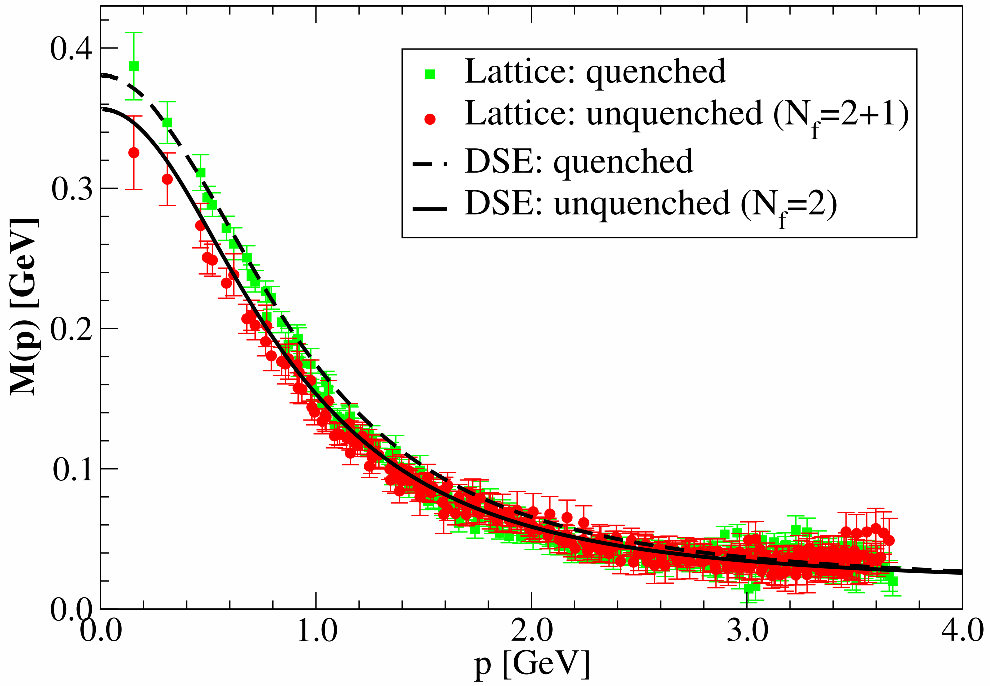
$$S^{-1}(p) = [i\not{p} + M(p^2)]/Z_f(p^2)$$

Quark mass: flavor dependence

Typical solution:



CF, JPG 32 (2006) R253



- $M(p^2)$: momentum dependent!
- Dynamical mass: $M_{strong} \approx 350$ MeV
- Flavour dependence because of M_{weak}
- Chiral condensate: $\langle \bar{\Psi}\Psi \rangle \approx (250\,\mathrm{MeV})^3$

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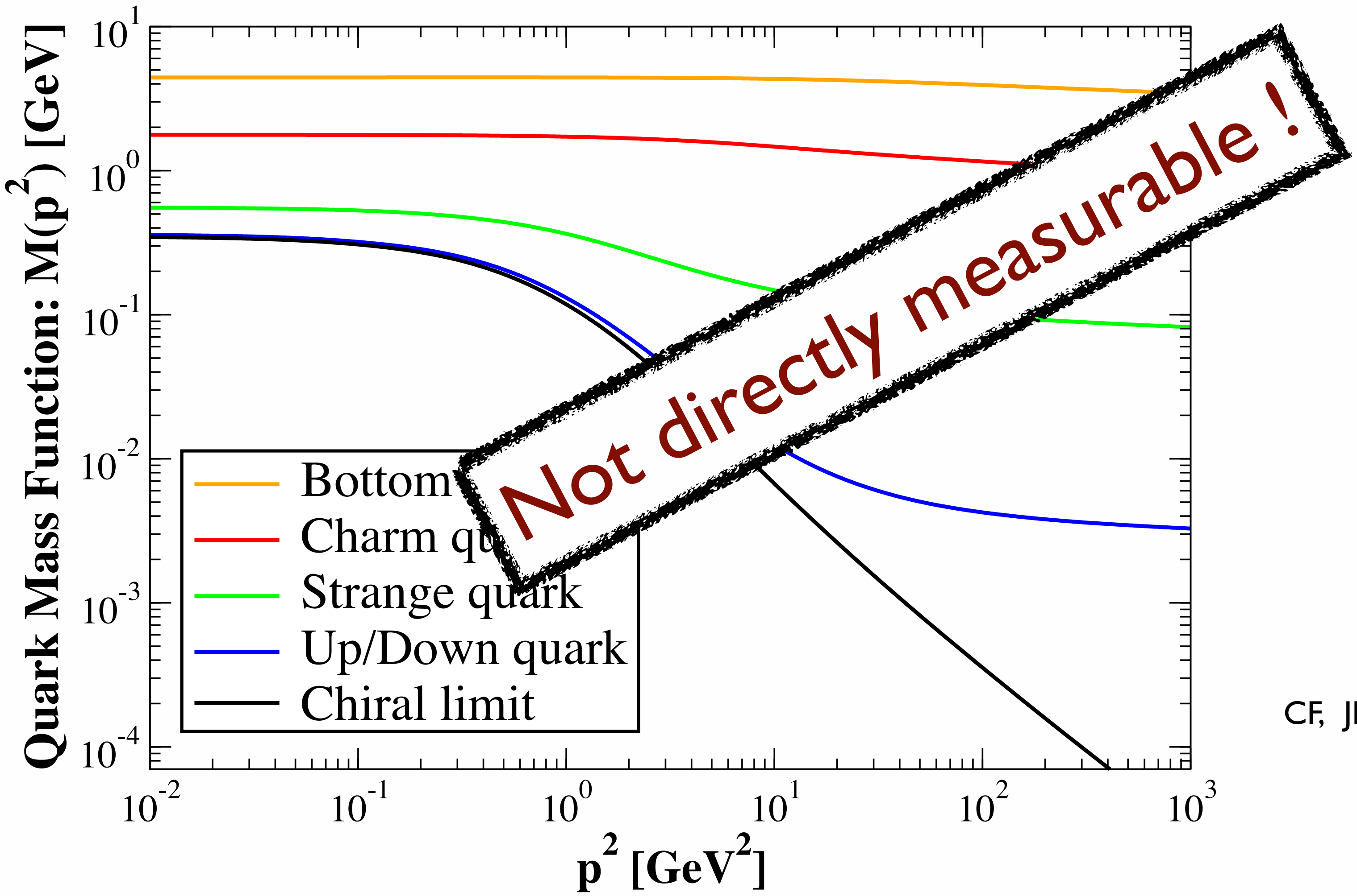

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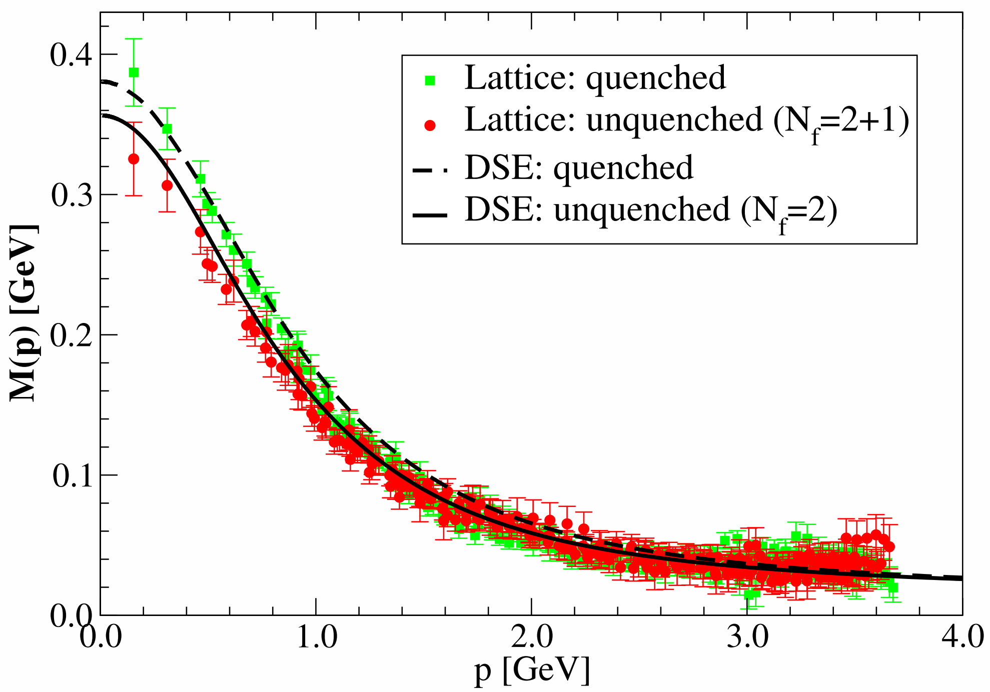

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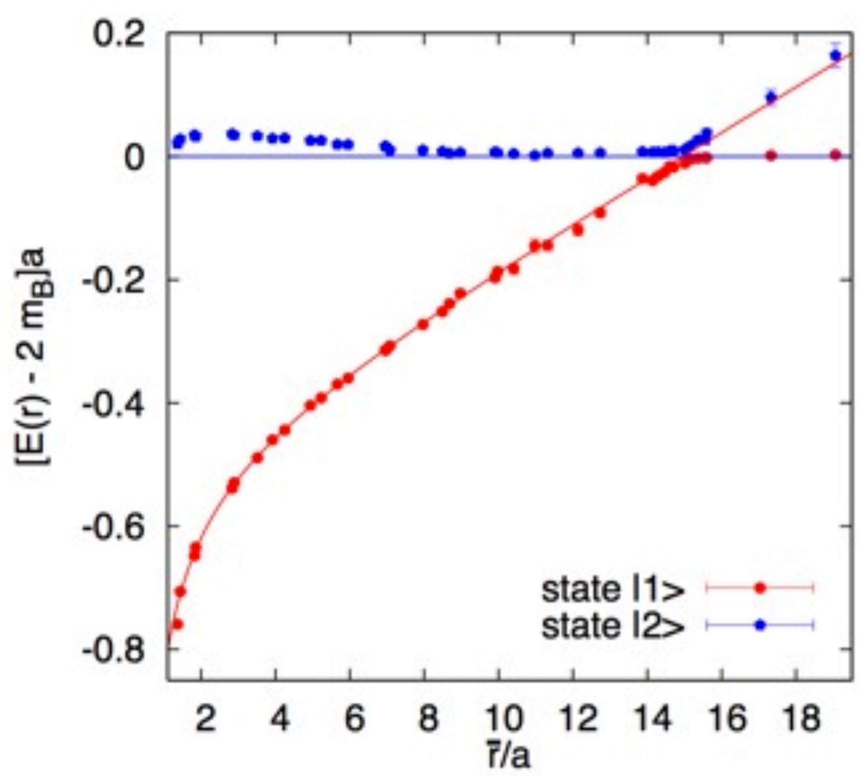
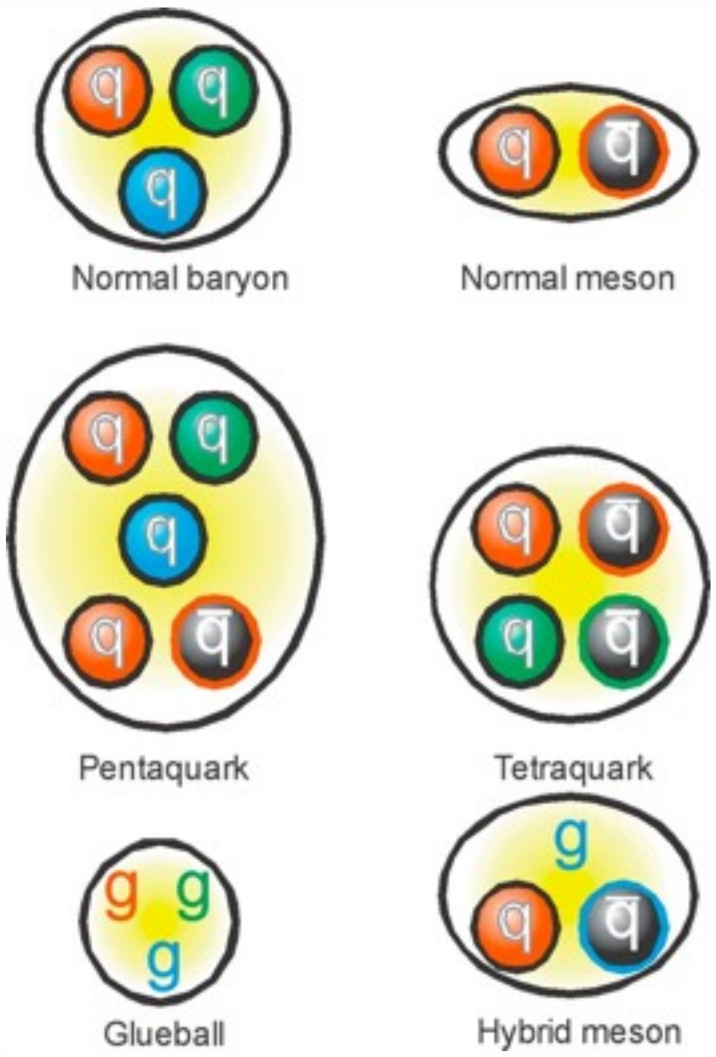
Color confinement:



Bali et al. [SESAM Collaboration], PRD 71 (2005) 114513



Strategies to deal with this situation:

- Nonperturbative QCD: Lattice, Functional methods
- Effective theories with hadronic dof

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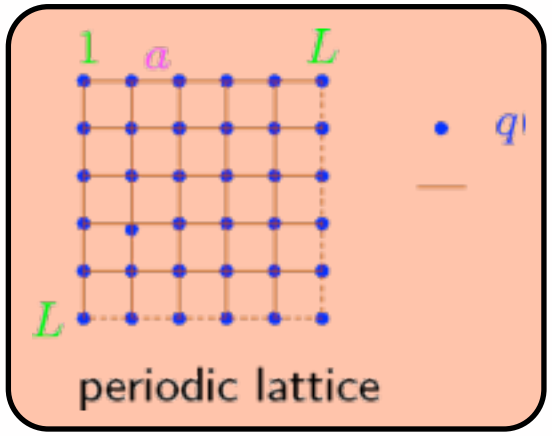

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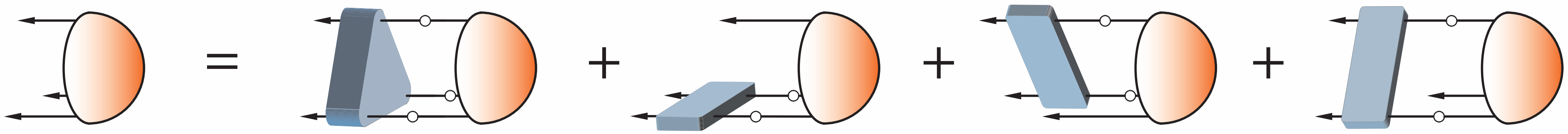
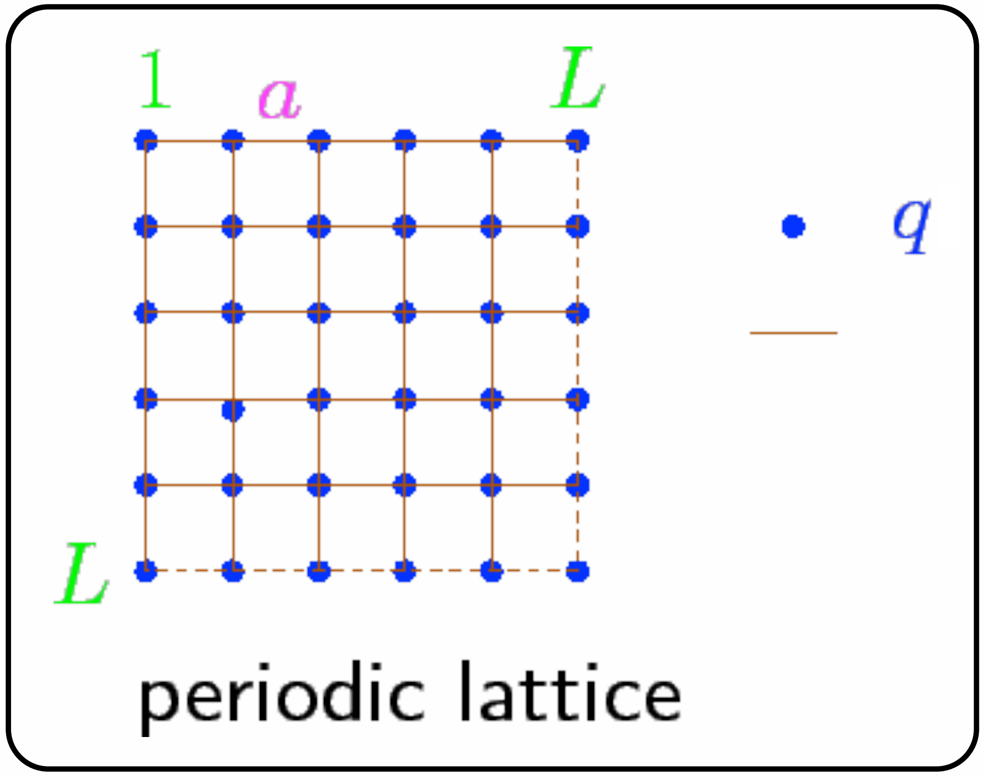
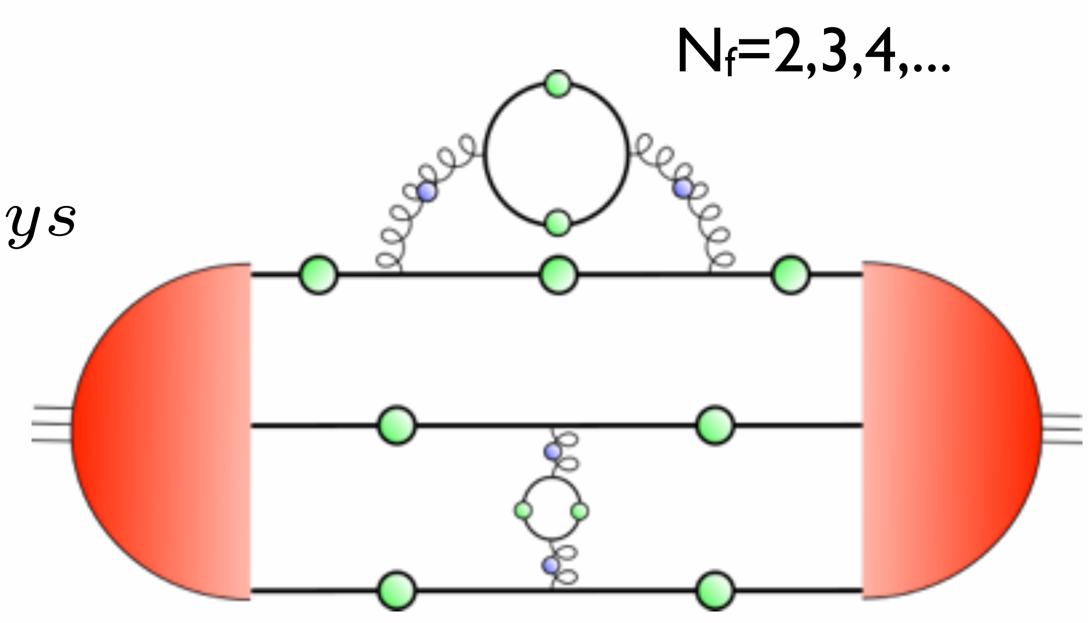


Lattice QCD

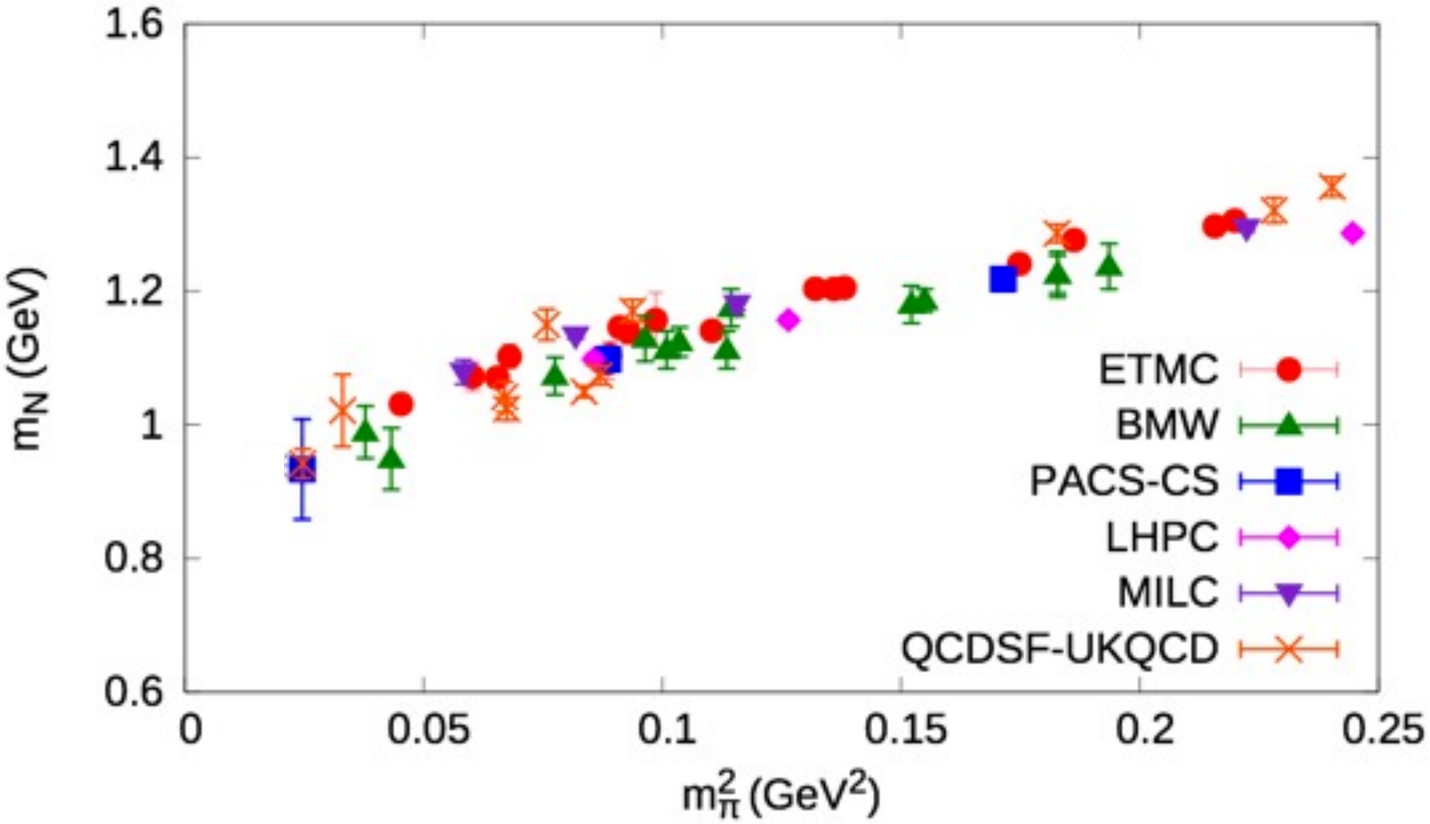
QCD on a space-time lattice



- Continuum extrapolation: $a \to 0$
- Volume extrapolation: $L \to \infty$
- Chiral extrapolation: $m_q \to m_q^{phys}$
- Valence vs. sea ('dynamical') quarks:
- # operators for a given channel
  - related to statistical error of results

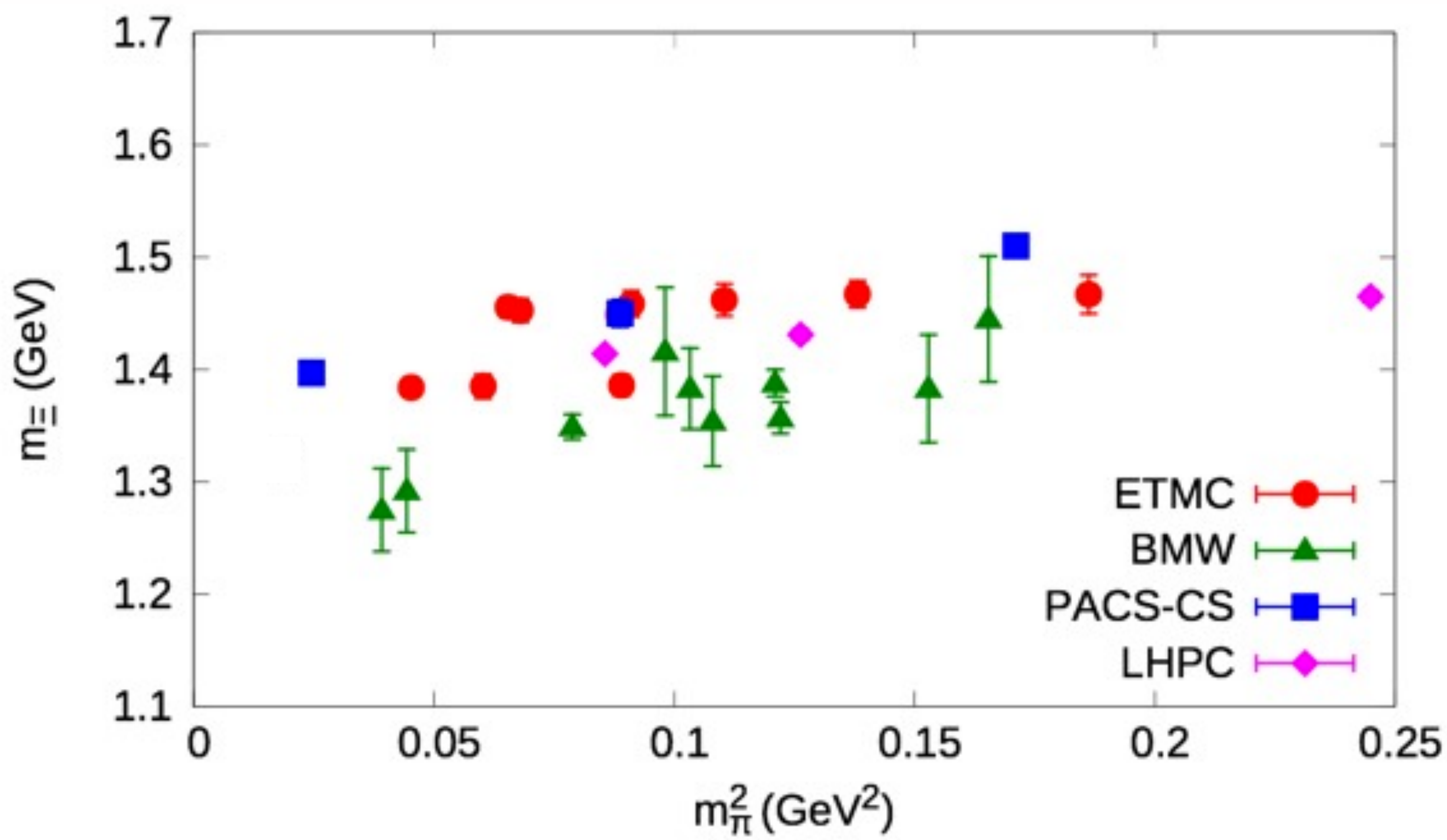


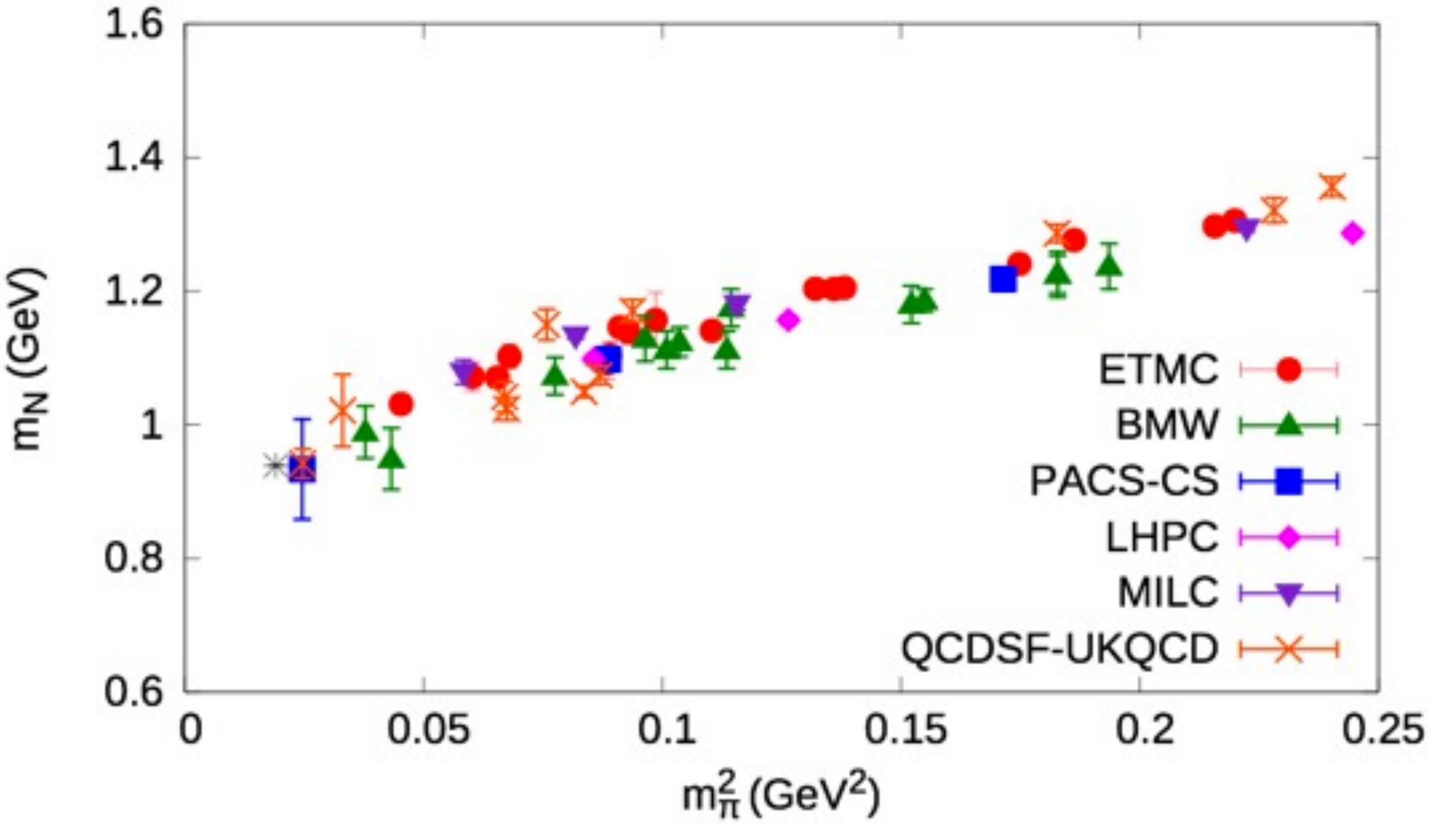
Extrapolation towards the physical point, N_f=2+1+1



Alexandrou et al. (ETMC), PRD 90 (2014) 7

- m_N often used to set scale





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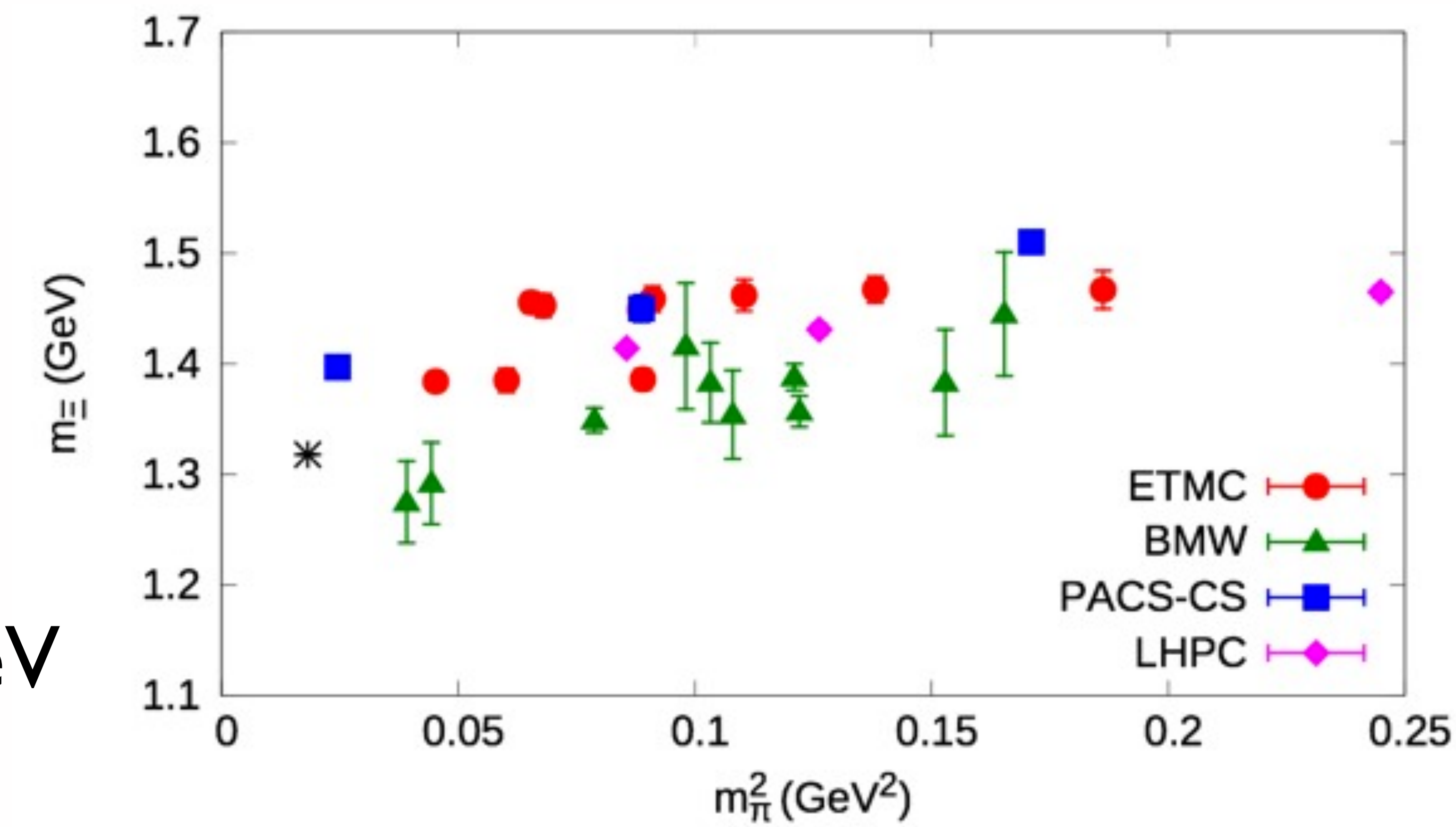
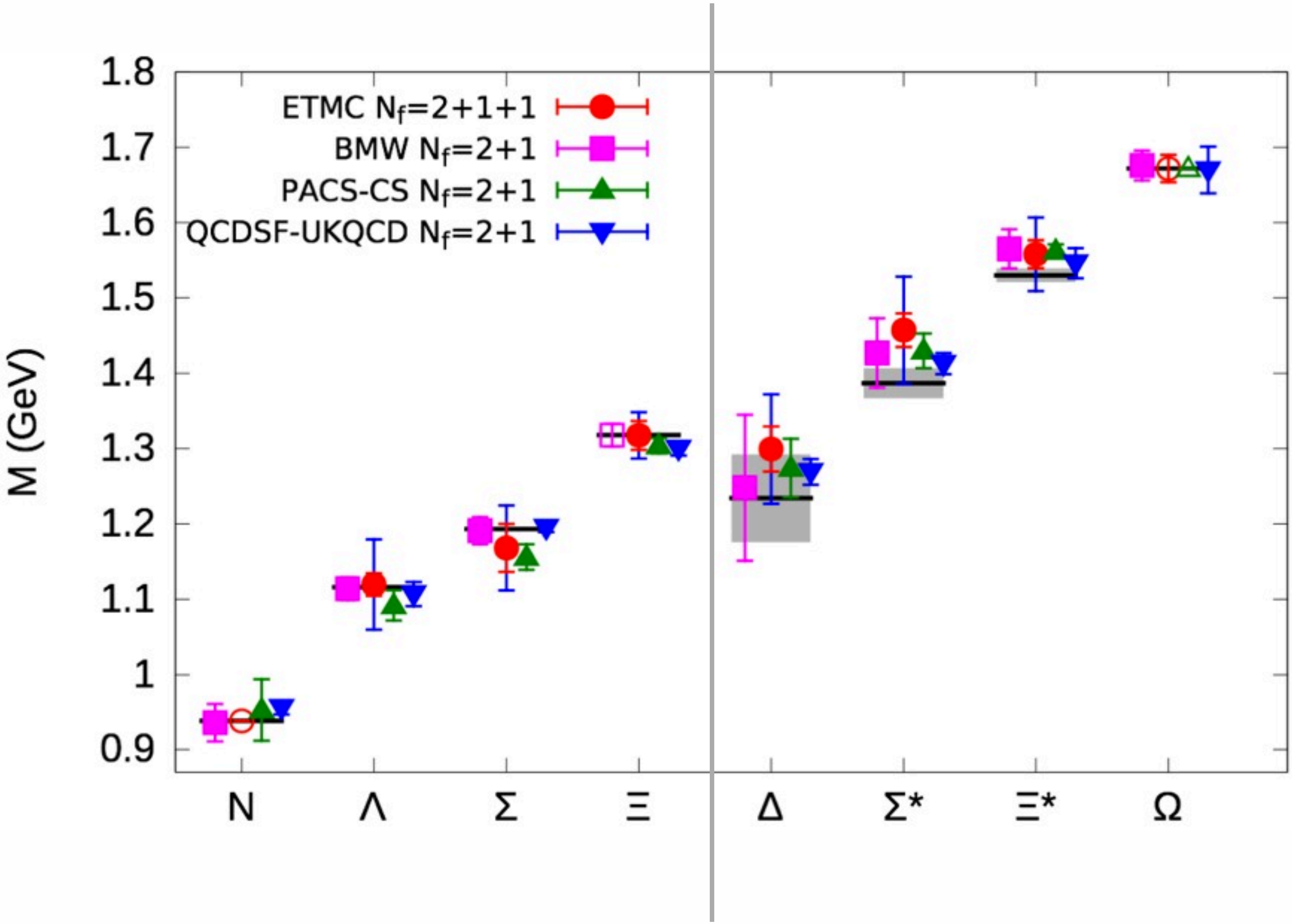


- m_Ξ = 1.318(19)(23)(9) GeV

Ground states



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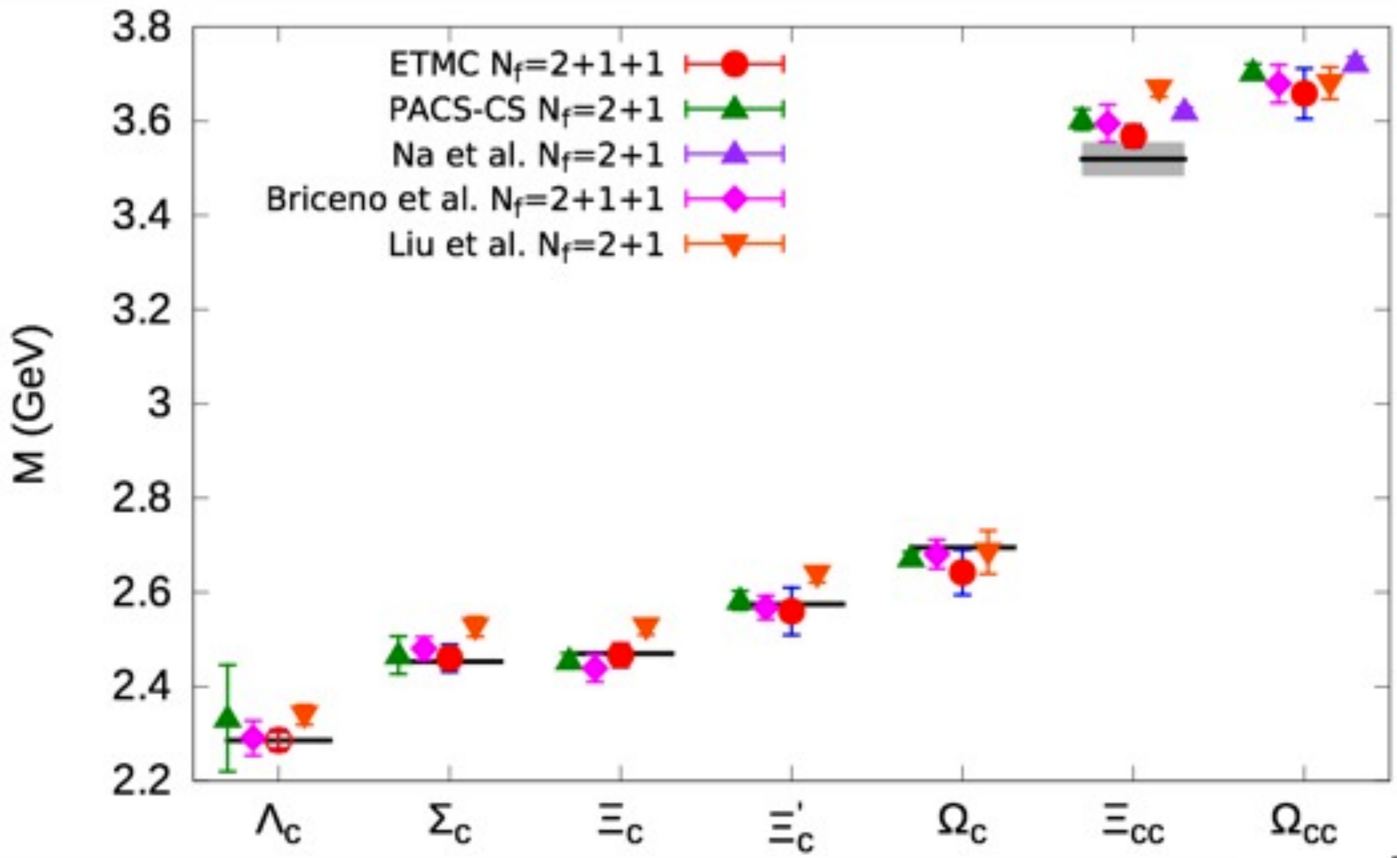
Ground states - charm sector



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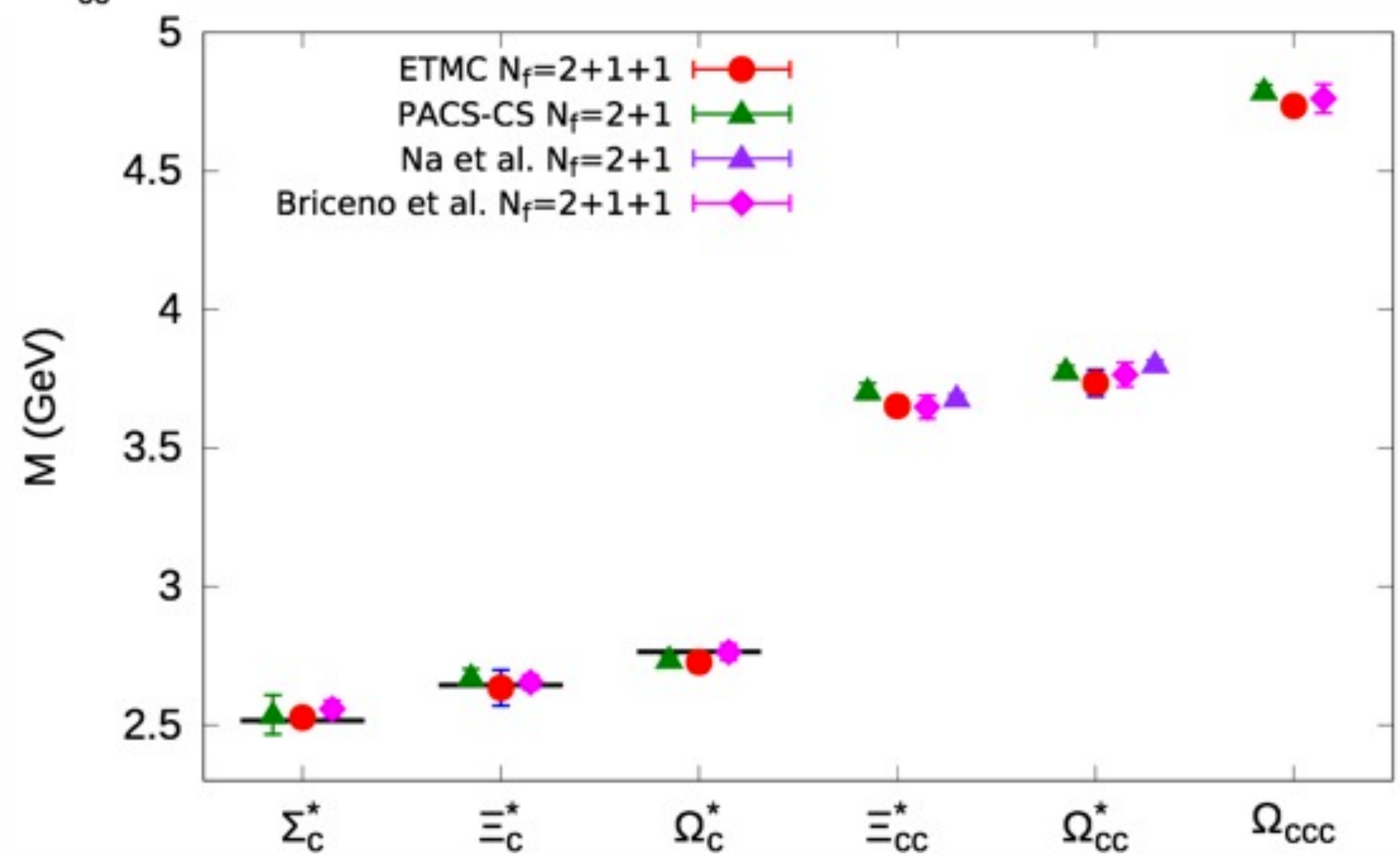

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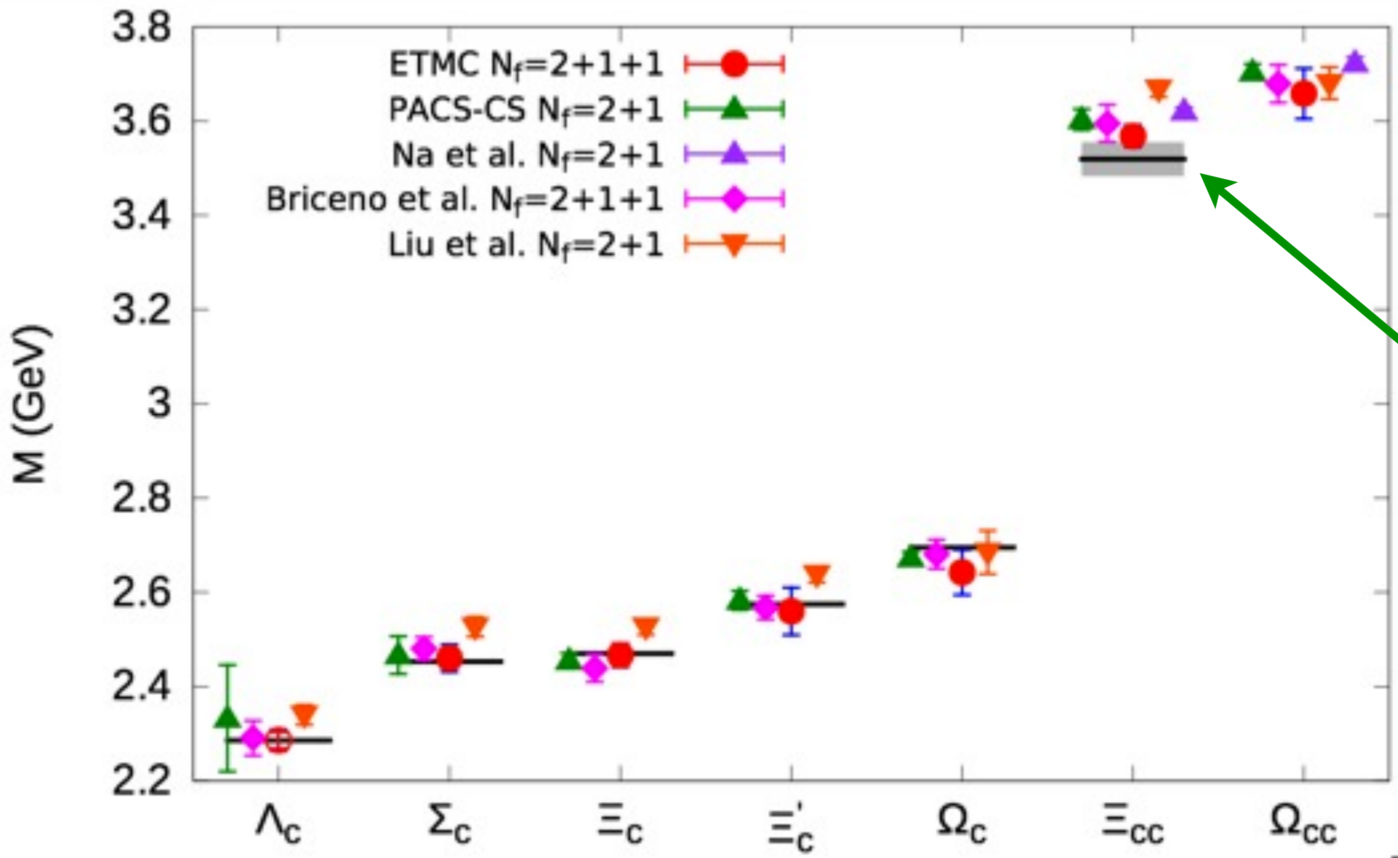
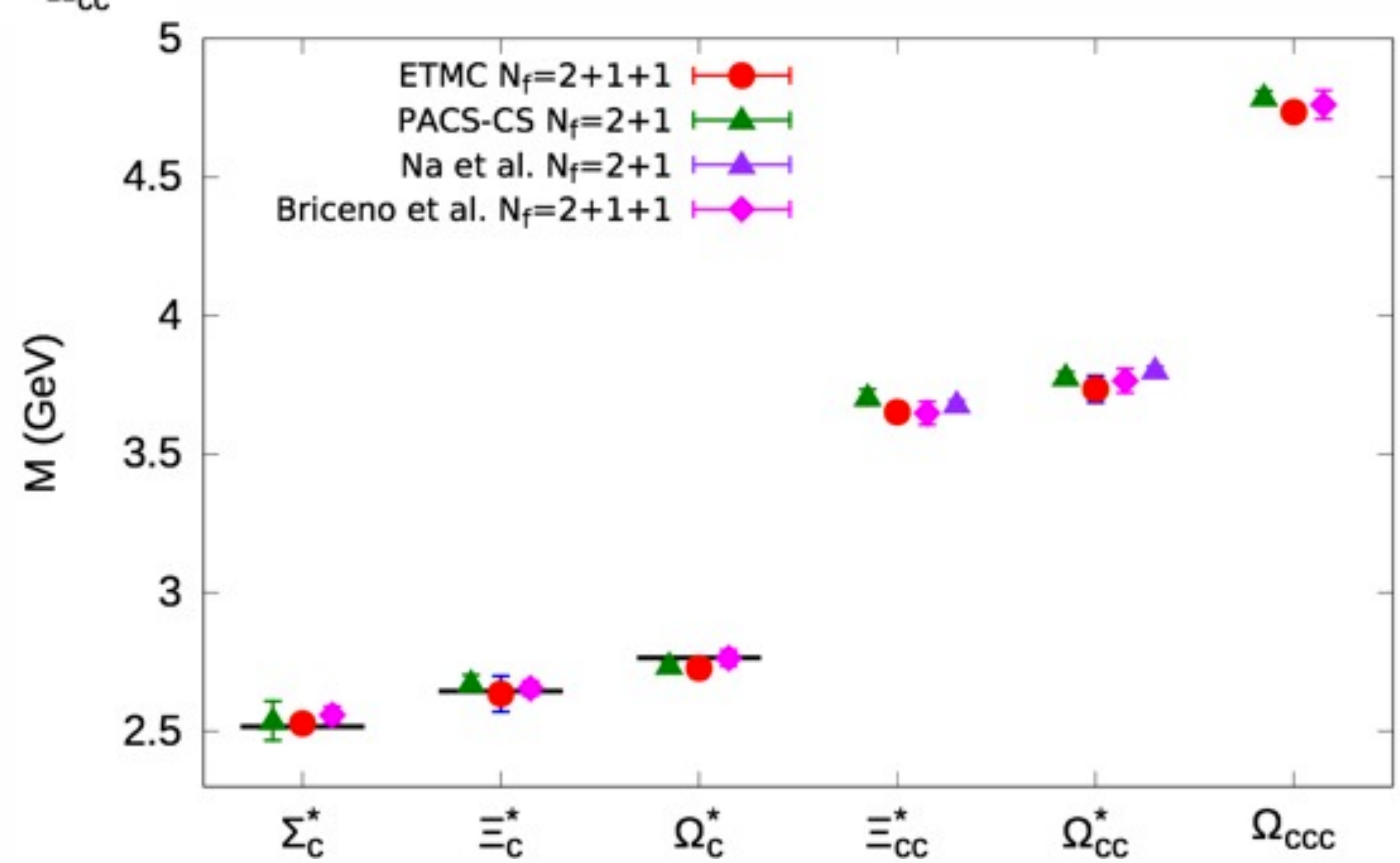


Ξ_{cc} measured by SELEX, not found by others

Alexandrou et al. (ETMC), PRD 90 (2014) 7



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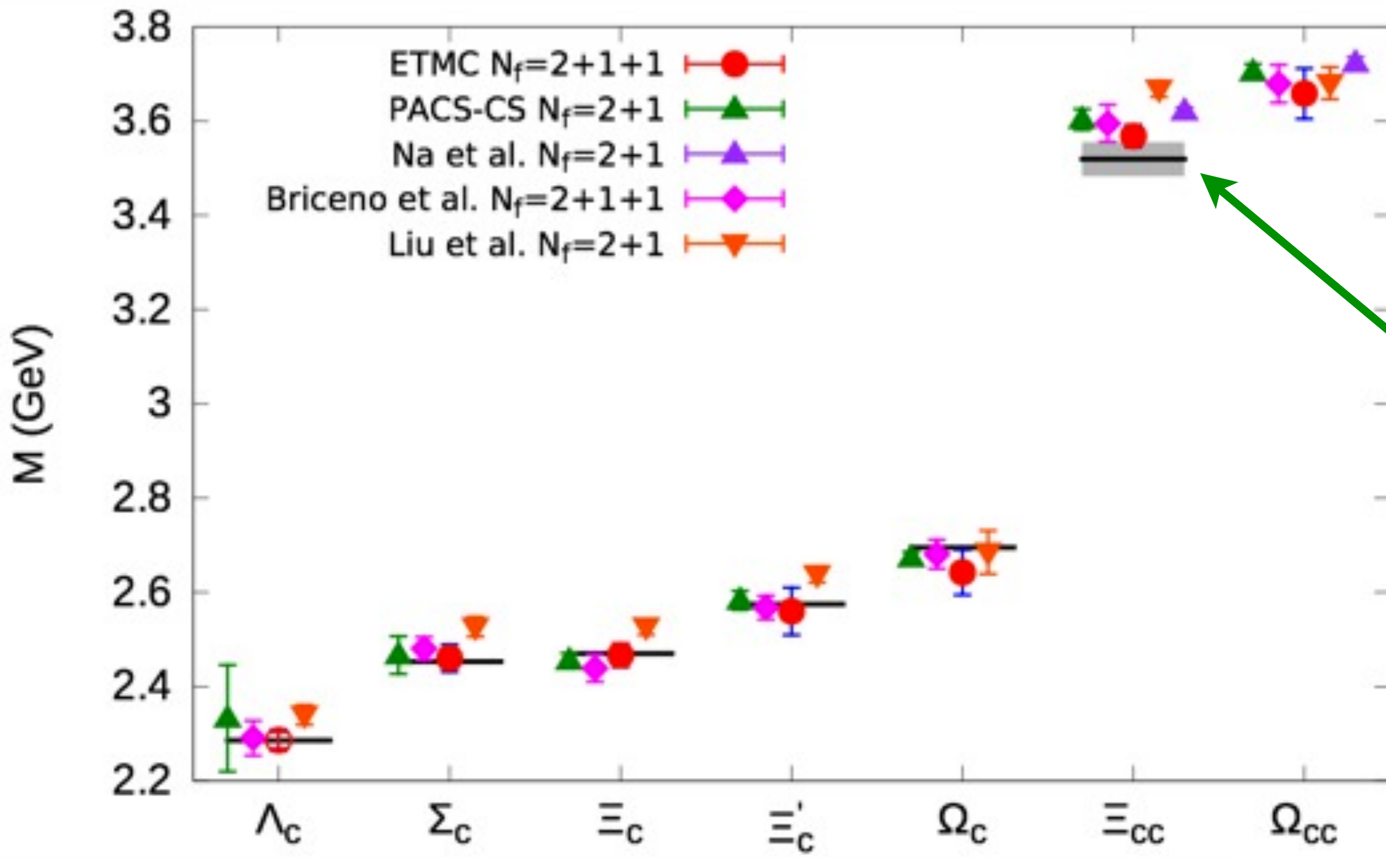

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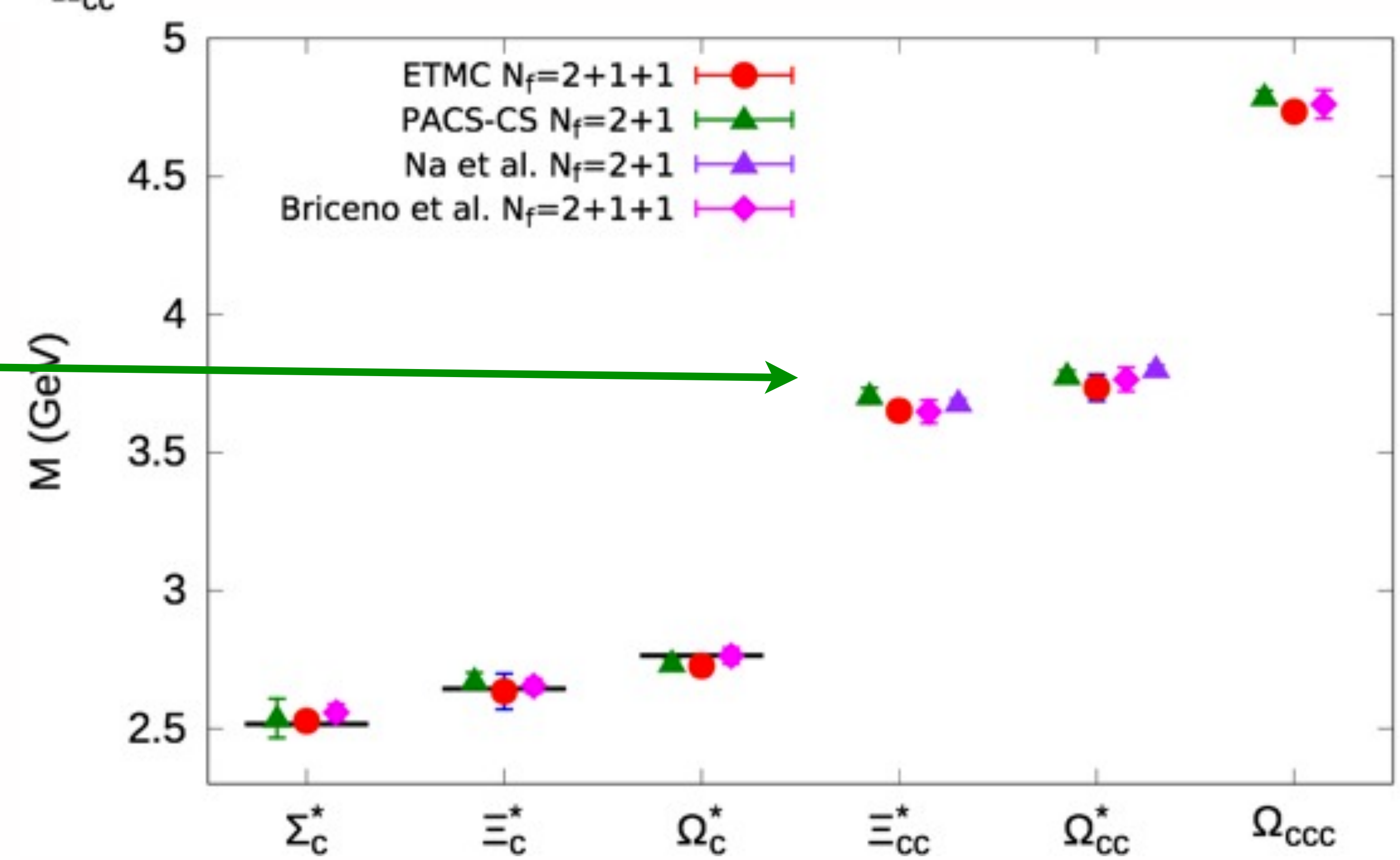
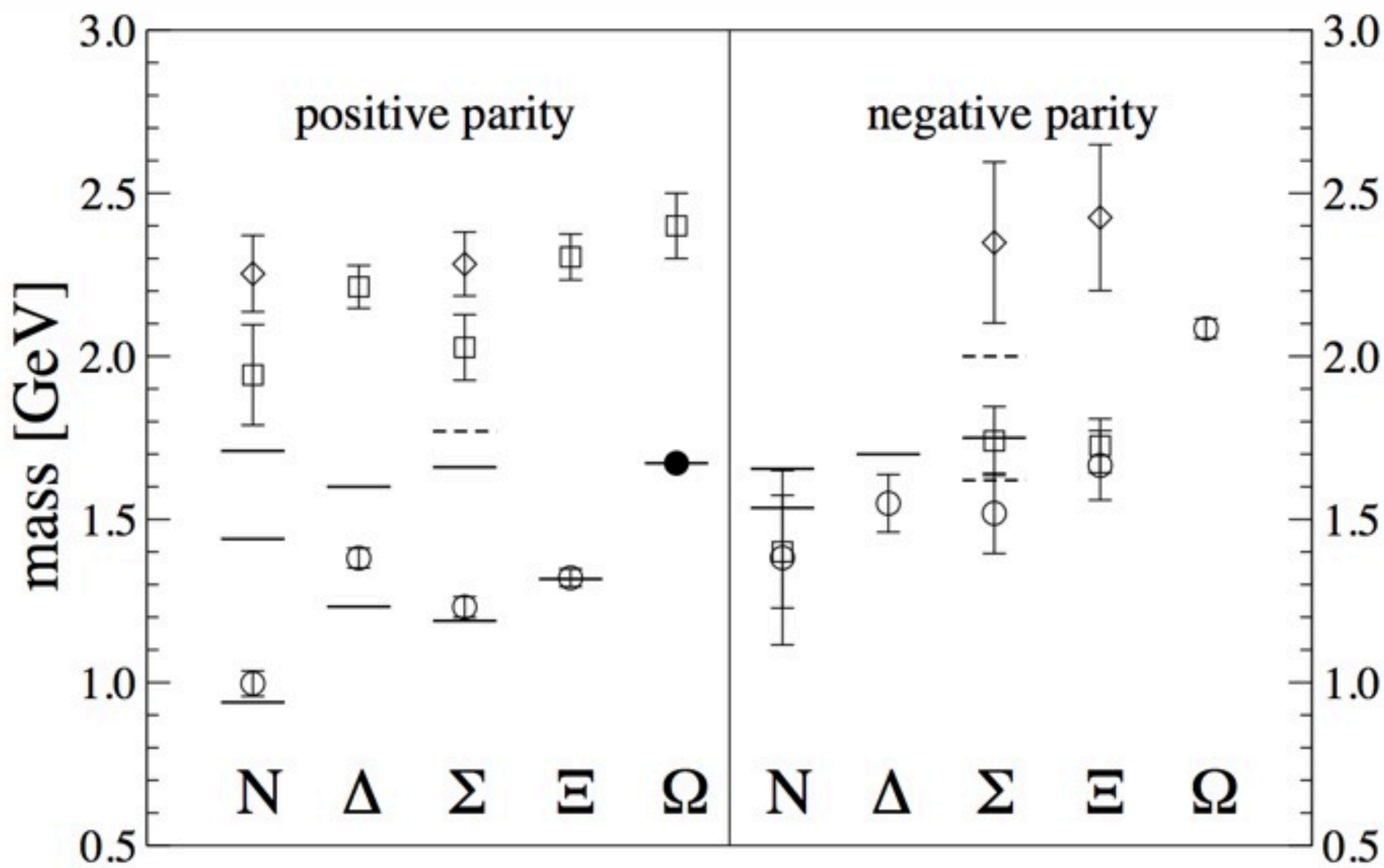
Alexandrou et al. (ETMC), PRD 90 (2014) 7

Predictions !



Excited states, N_f=2

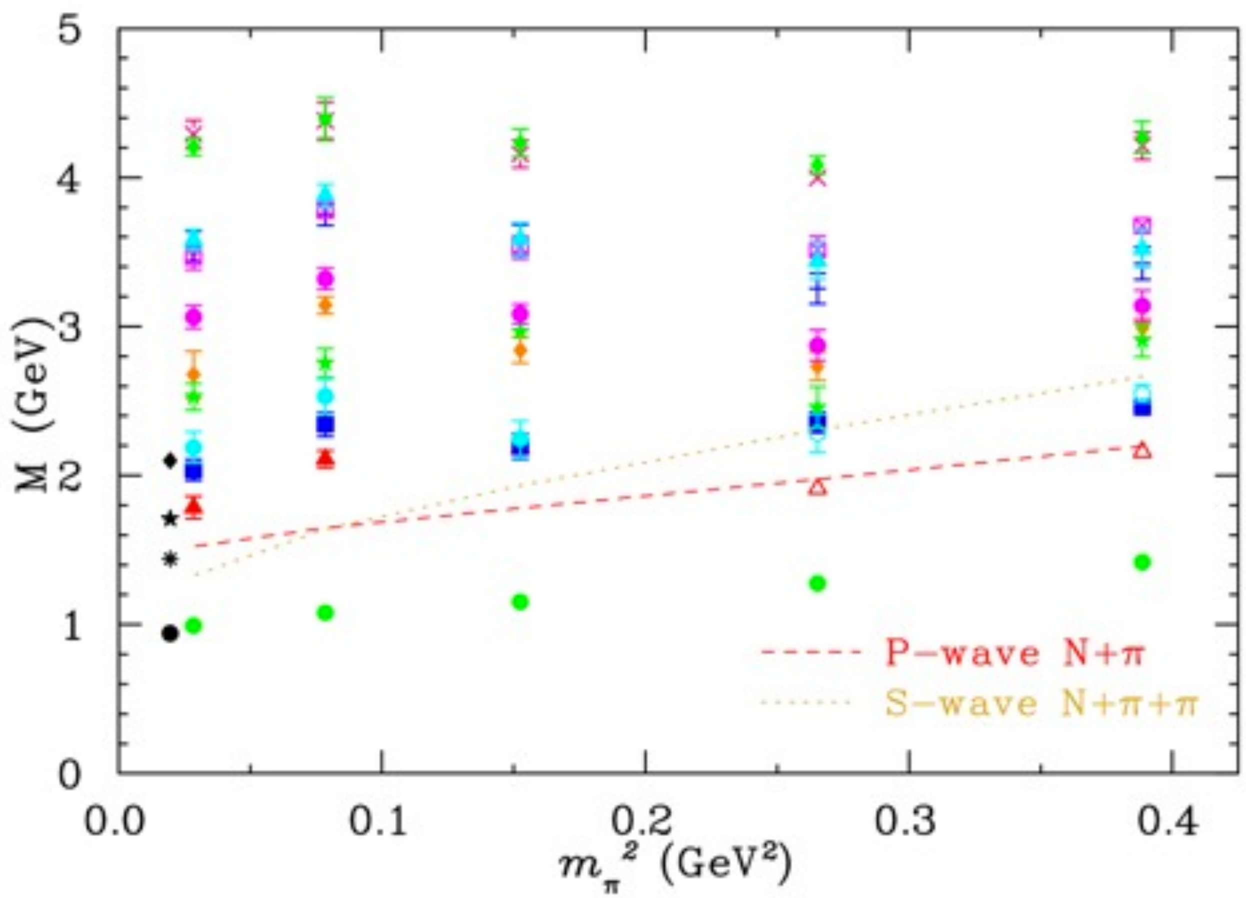


Engel et al. (BGR), PRD82 (2010) 034505

- Diquark-Quark-pattern ruled out
- No sign of parity doubling
- Large pion mass, m_π=322 MeV, extrapolated:
  - Positive parity: excited states systematically too large
  - Negative parity: ground states systematically too low

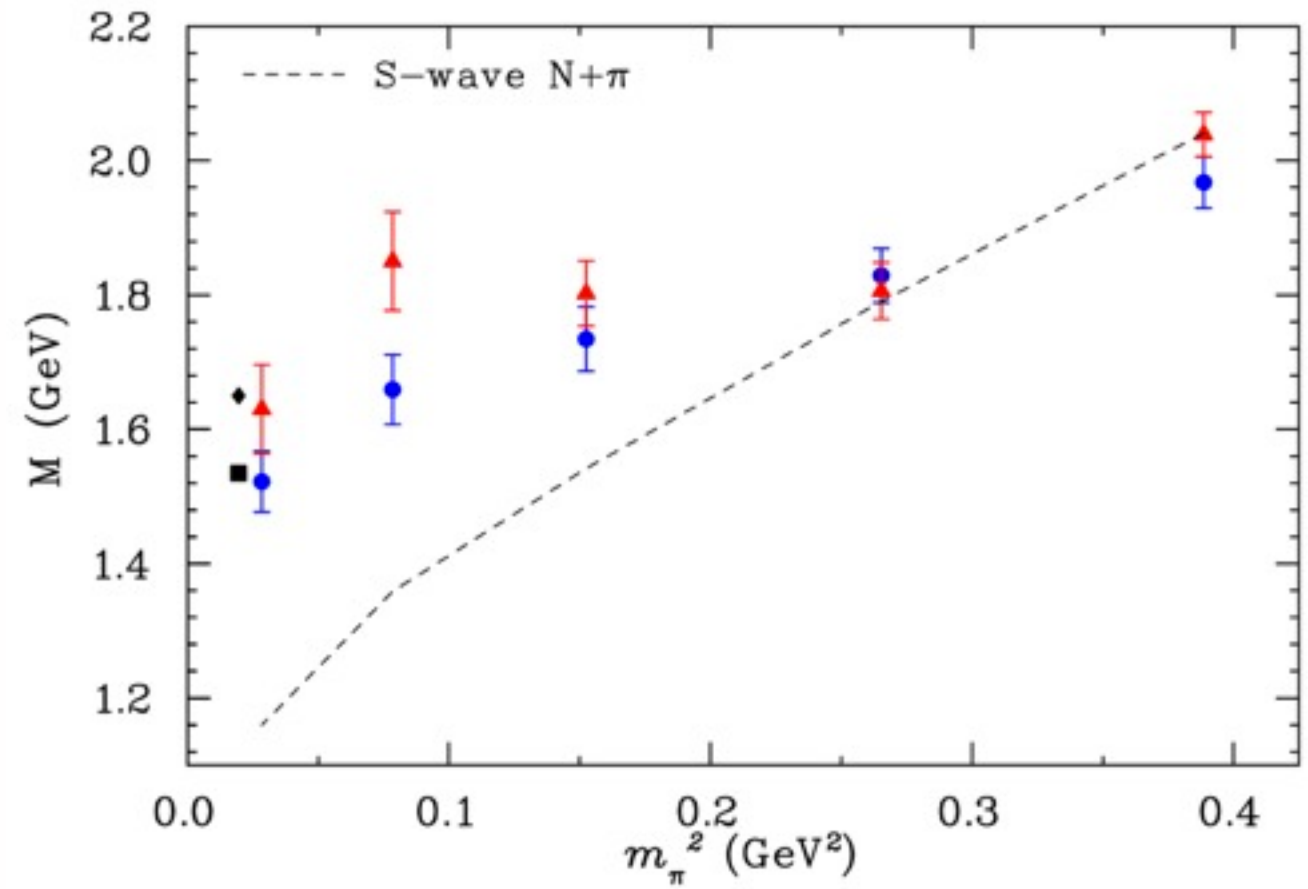
Positive/negative parity octet states

$N\frac{1}{2}^{+}$



Mahbub et al. (CSSM), PLB707 (2012) 389

$N\frac{1}{2}^{-}$

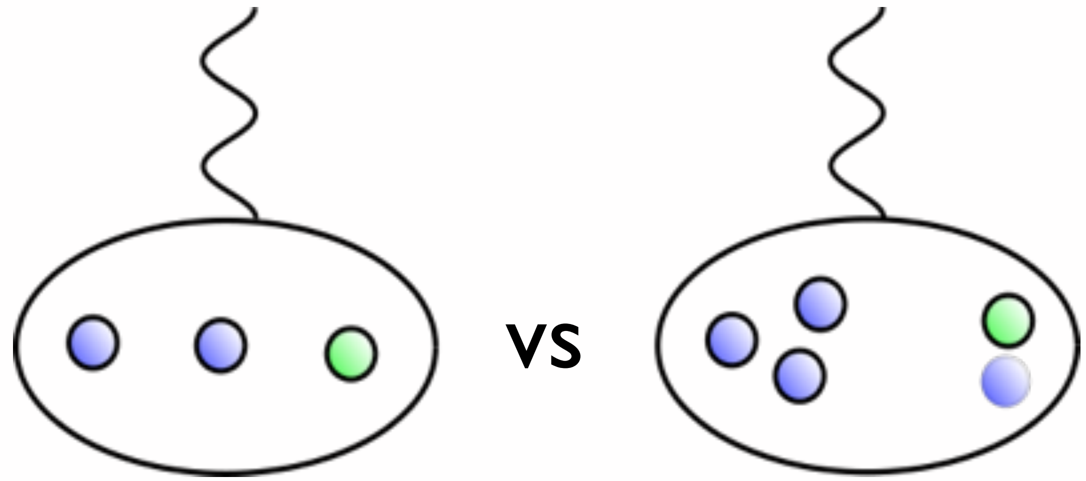


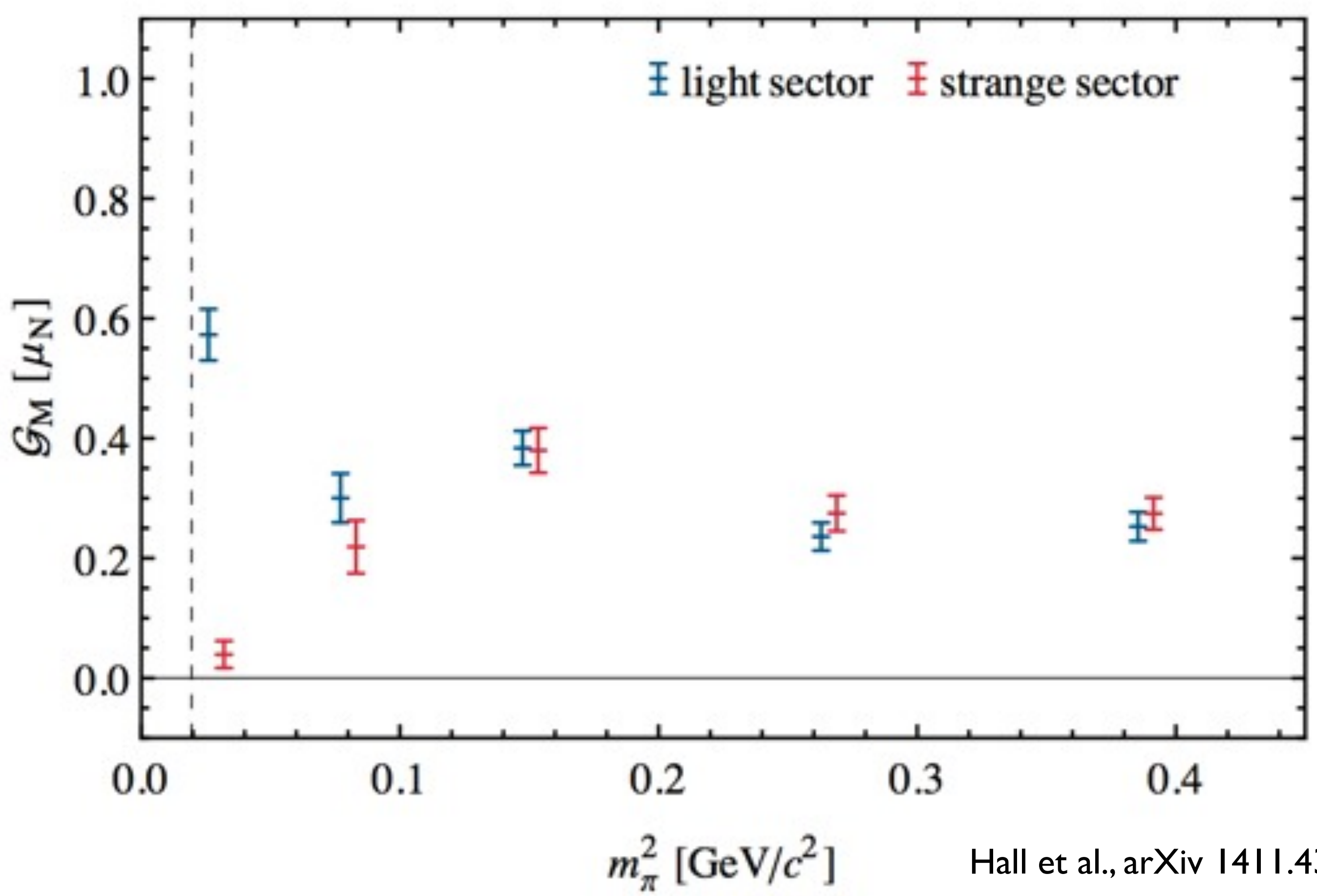
Mahbub et al. (CSSM), PRD87 (2013) 1

- m_π=156 MeV
- considerable 'chiral curvature'
- small operator basis...

The $\Lambda(1405)$ as a $\bar{K}N$-molecule

- Basic idea: calculate flavour contributions to magnetic form factors





Hall et al., arXiv 1411.4302

- looks like $\bar{K}N$-molecule !
- caveat: operator basis

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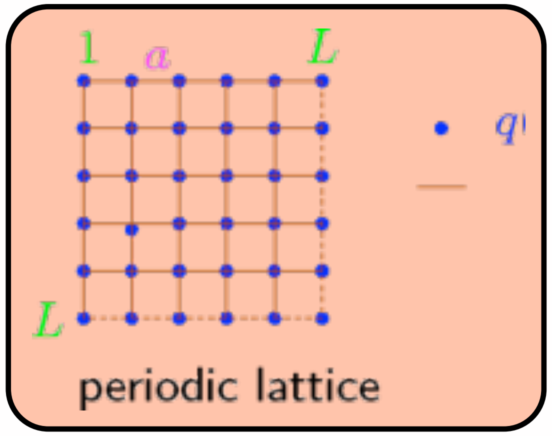

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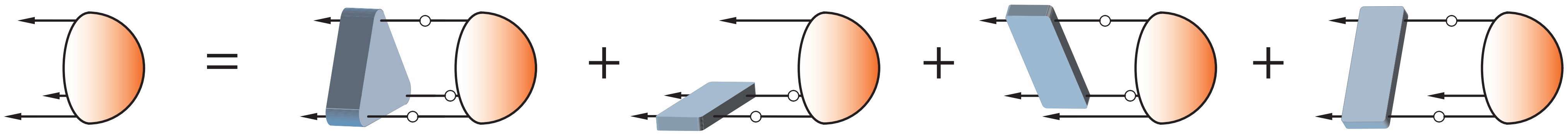
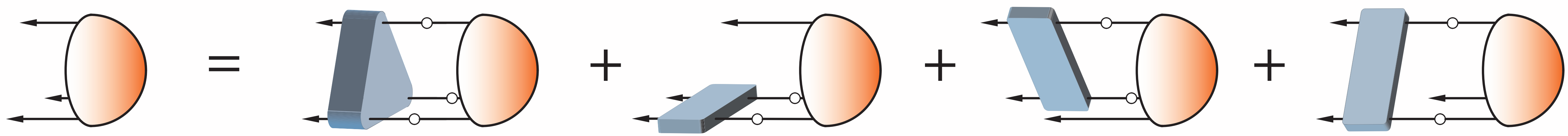
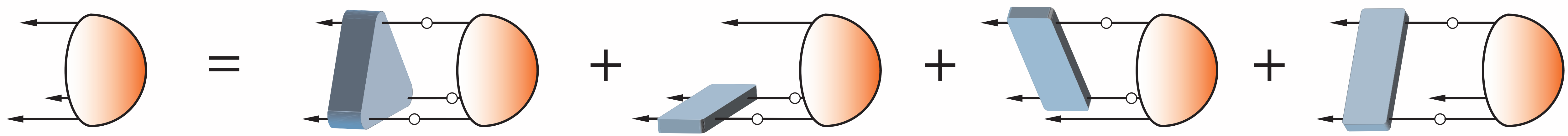


Faddeev - equation



- two and three-body forces:
  - dominance of two-body forces: quark-diquark picture
  - three-body forces relevant ? most likely yes…
- relativistic bound state:
  - 64 tensor structures for nucleon: s, p, d - wave
  - 128 tensor structures for Delta: s, p, d, f - wave

Faddeev - equation



- irreducible three-body forces

Sanchis-Alepuz, Williams, work in progress…

- two-body interactions:
  - non-perturbative one-gluon exchange

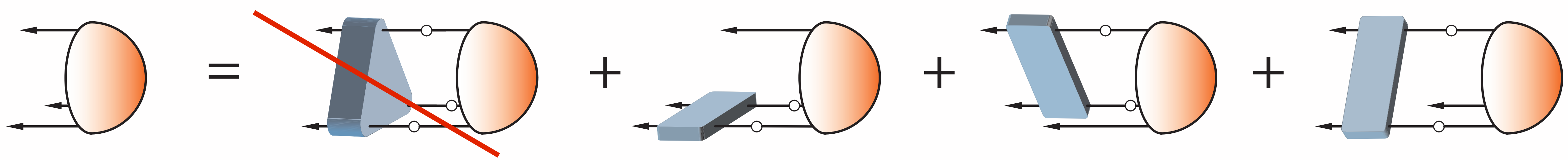
    Eichmann, Alkofer, Krassnigg, Nicmorus, PRL 104 (2010)
  - meson exchange

    Sanchis-Alepuz, CF, Kubrak, PLB 733 (2014)
  - two-body forces beyond one-particle exchange

    CF, Sanchis-Alepuz, Williams, work in progress…

- numerically expensive but manageable !

Faddeev - equation



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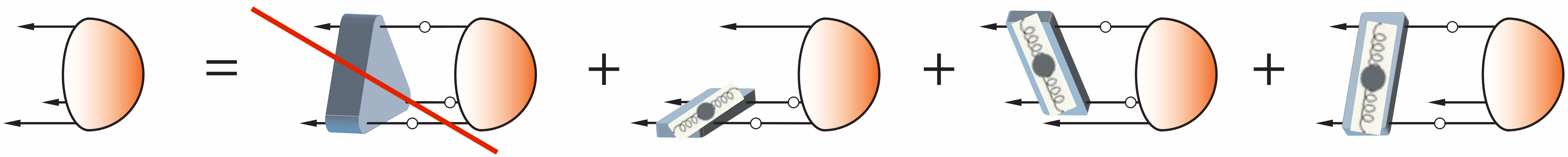

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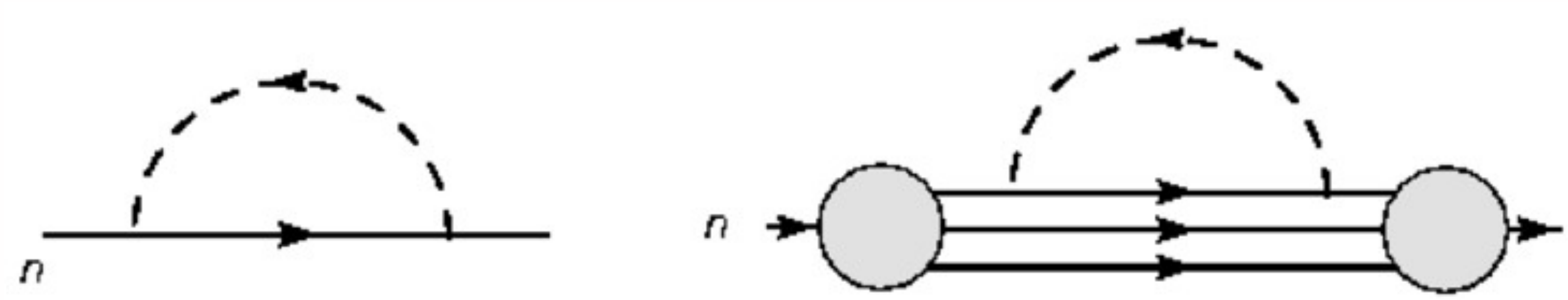
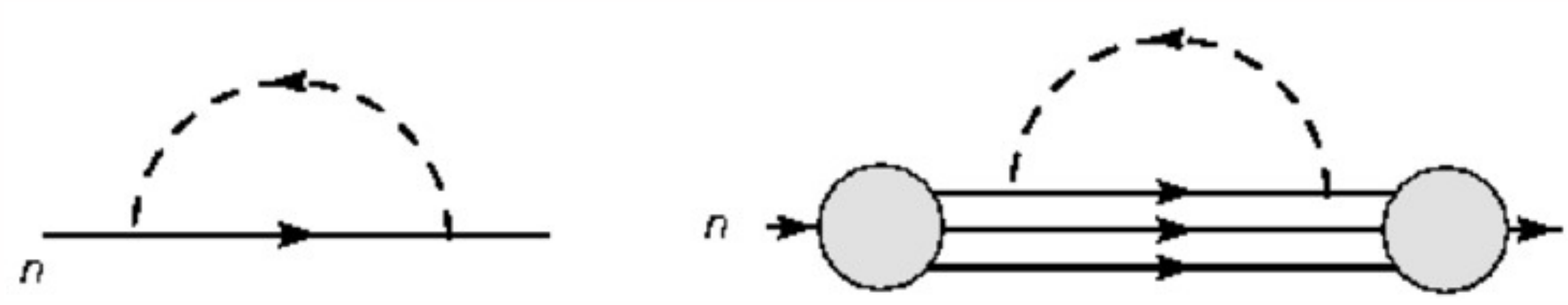
Pion cloud effects



- Hadron level: πN-contributions to nucleon self-energy
- Quark-level: π-contributions to quark self-energy and interactions

Pion cloud effects



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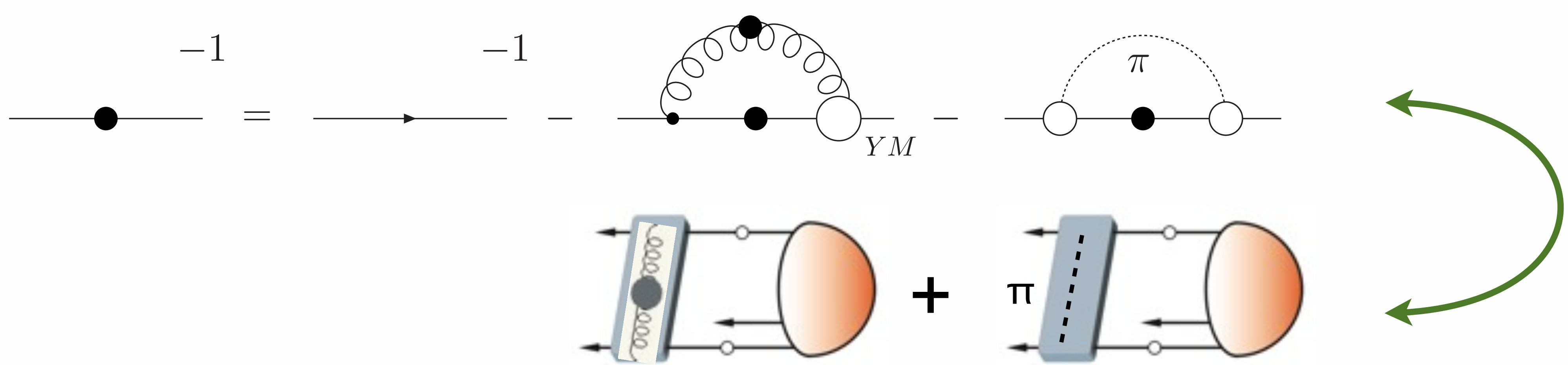
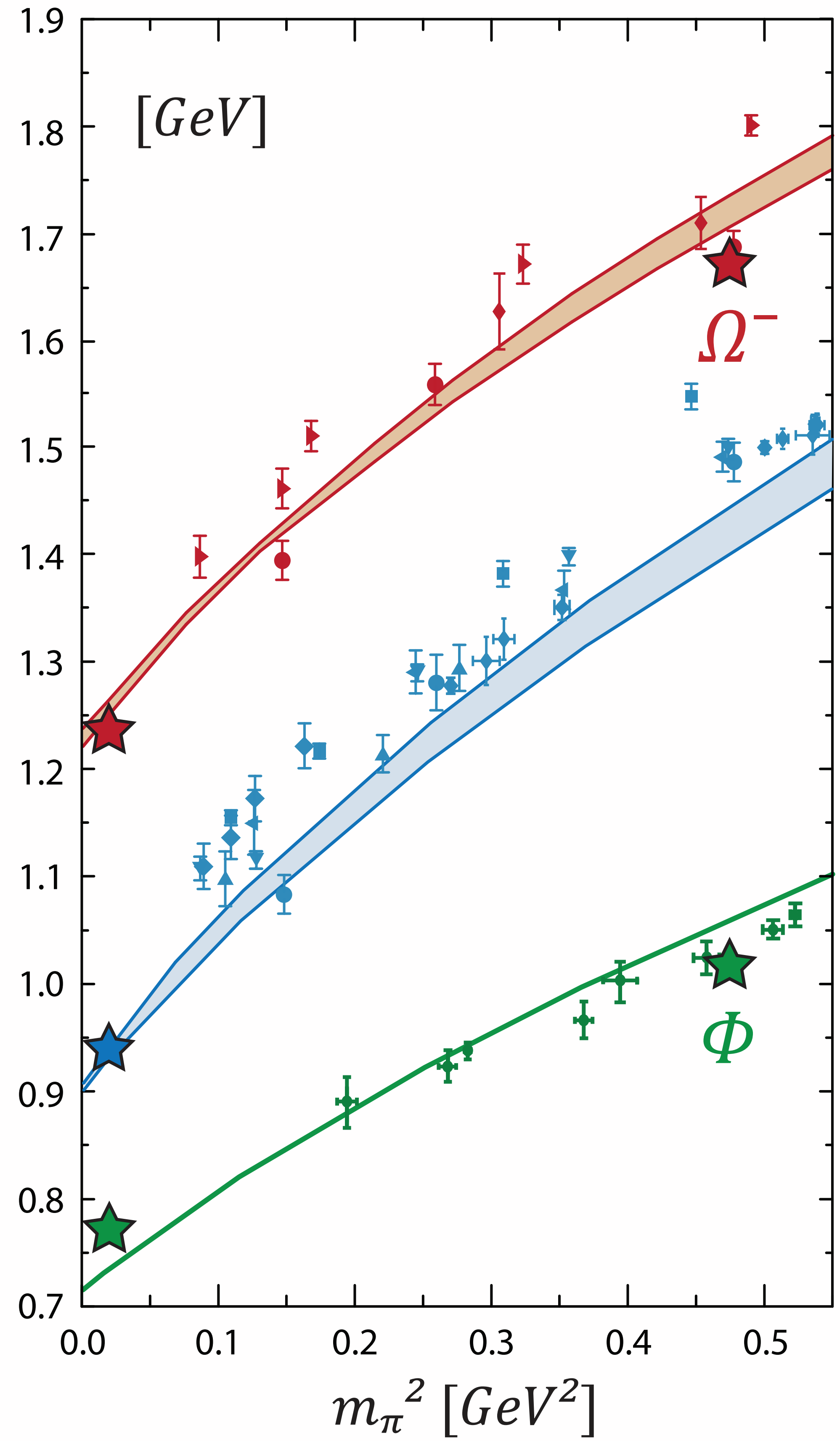


Pion not an elementary field!
Derived from DSE for quark-gluon interaction!

CF, Nickel and Wambach, PRD 76 (2007) 094009

Baryon masses - gluon exchange only

- first covariant three-body calculations !
- grosso modo: consistent description of mesons and baryons
- wave functions contain sizable p-wave contributions



Delta:
Sanchis-Alepuz et al.,
PRD 84 (2011)

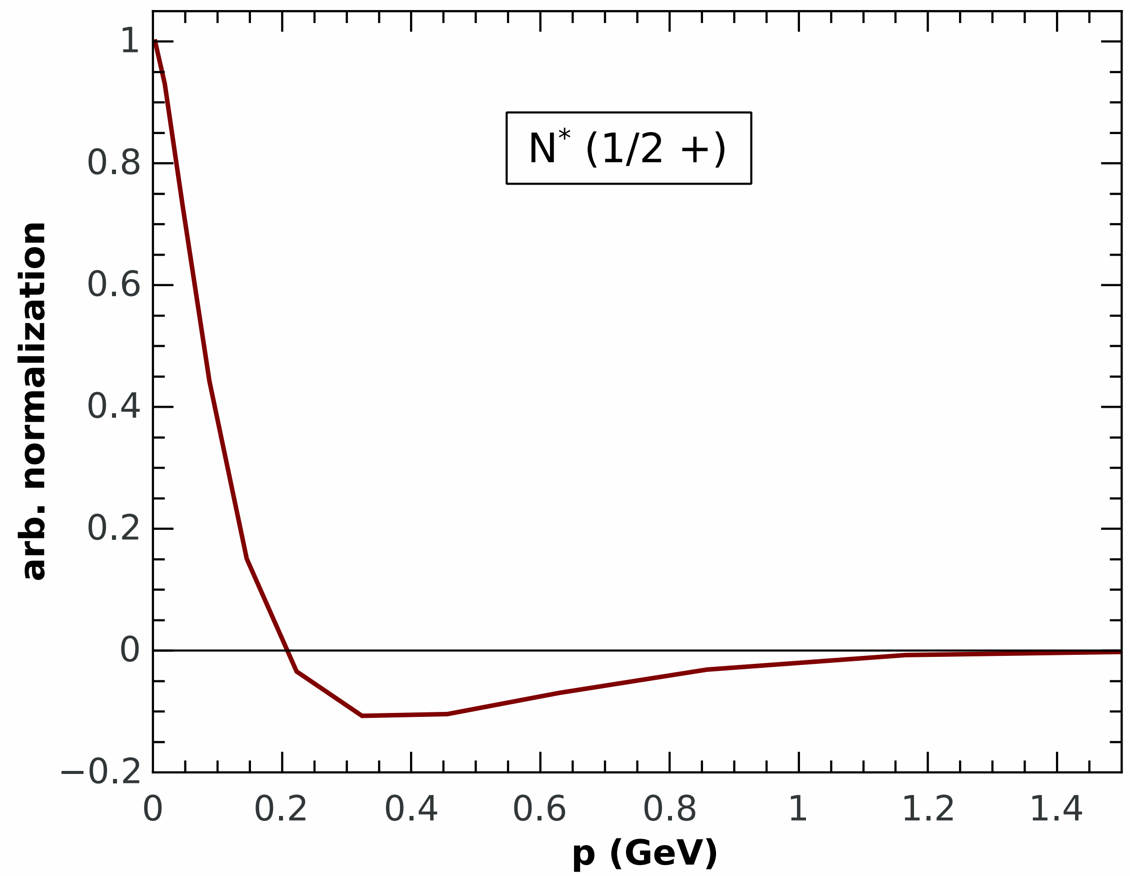
Nucleon:
Eichmann et al.,
PRL 104 (2010),
PRD 84 (2011)

ρ–meson:
Maris & Tandy,
PRC 60 (1999)

Eichmann, Alkofer, Krassnigg, Nicmorus, PRL 104 (2010)
Eichmann, PRD 84 (2011)
Sanchis-Alepuz ,Eichmann, Villalba-Chavez, Alkofer, PRD (2012)

Baryon resonances - gluon exchange only

Roper: $M_{N*} = 1.26 - 1.41\,\mathrm{GeV}$



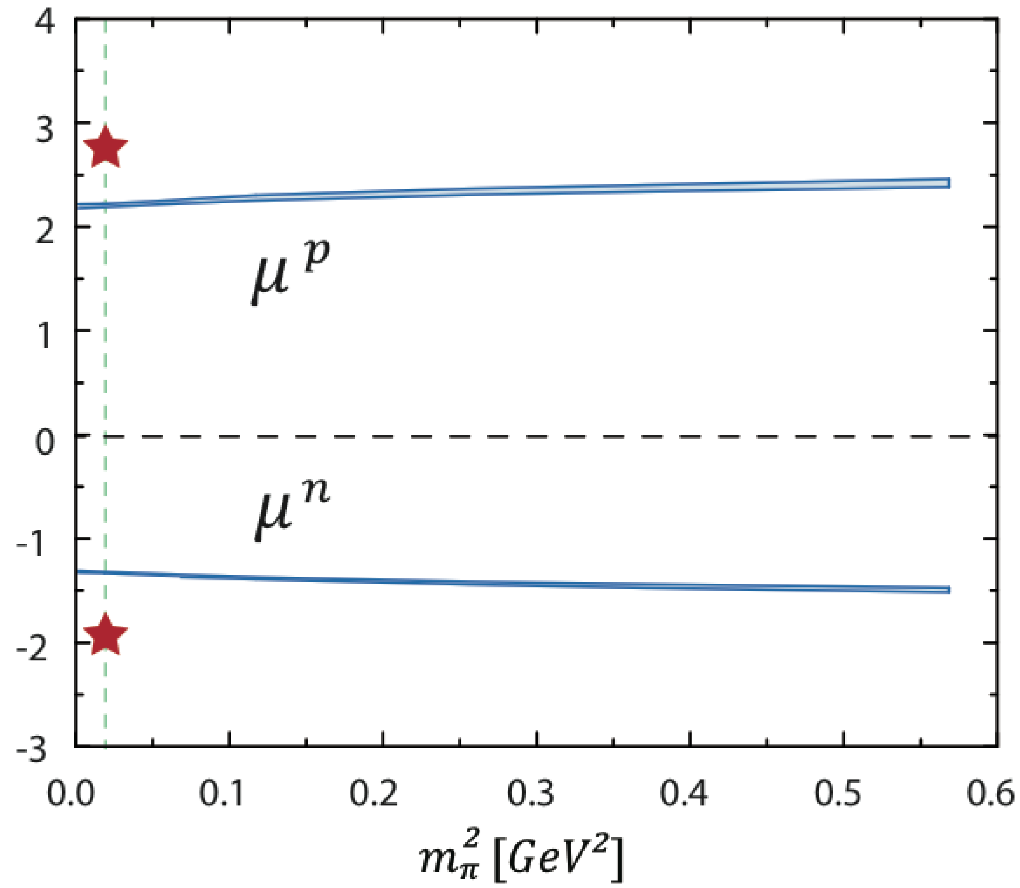
Sanchis-Alepuz, CF, in preparation

Preliminary: almost pure s-wave

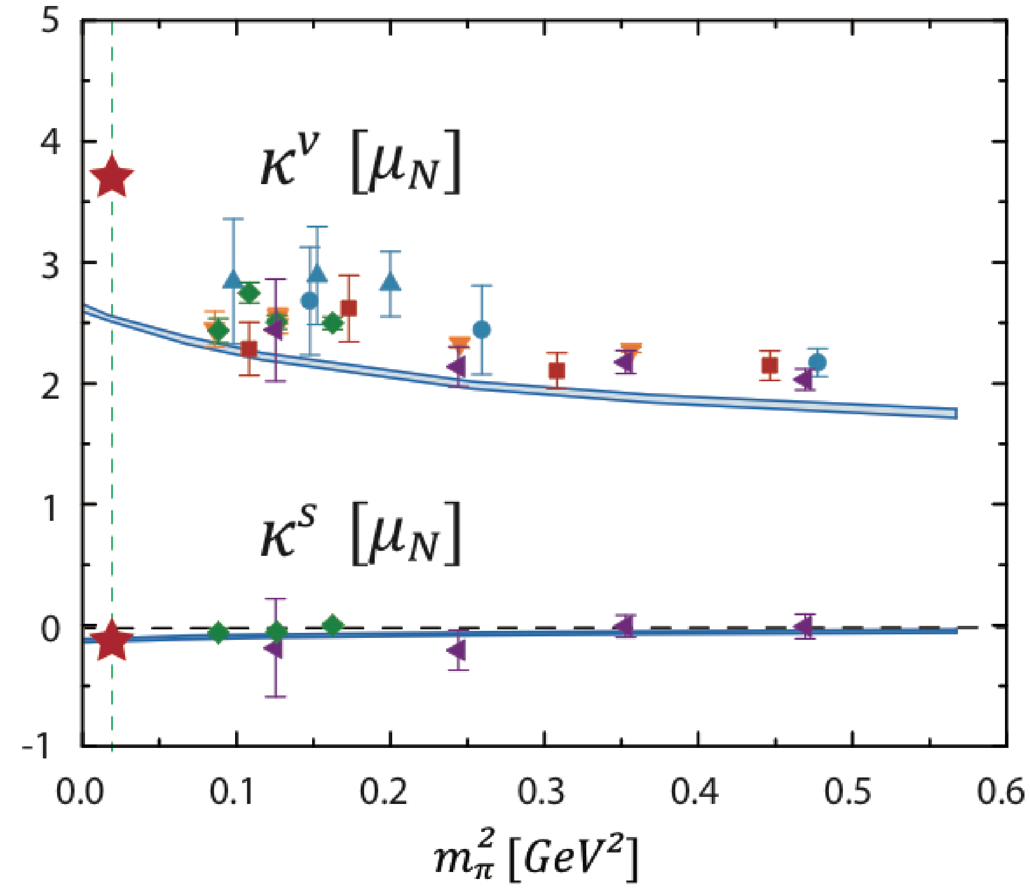
- $N\frac{1}{2}^{\pm}$ same level ordering as in quark model

Magnetic moments - gluon exchange only

Magnetic moments (p, n):



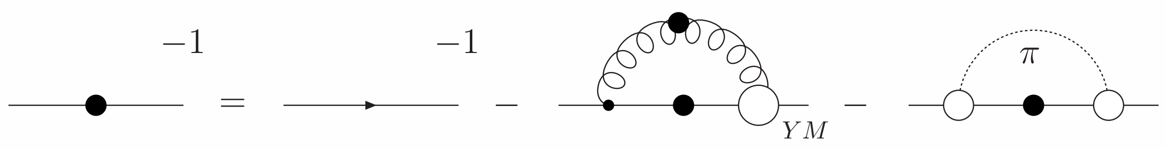
Isovector (p-n), isoscalar (p+n):

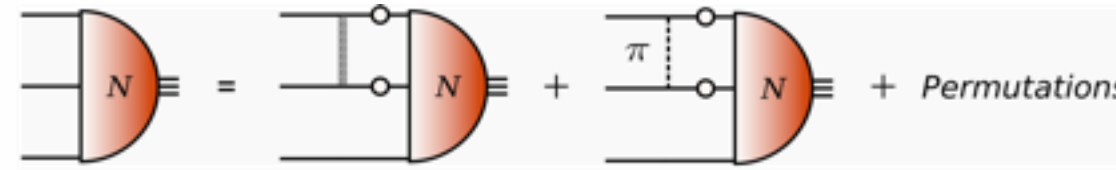


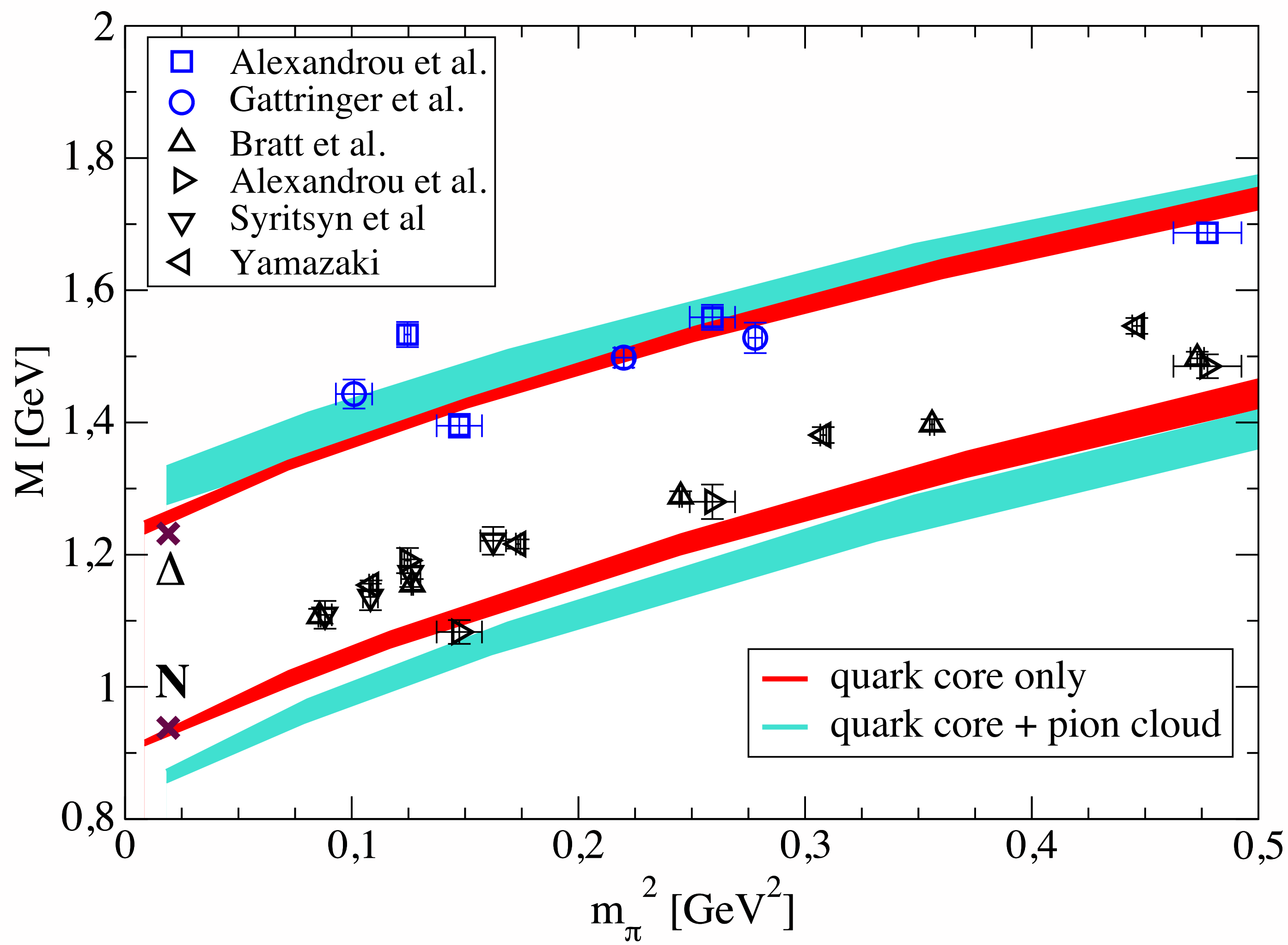
- missing pion cloud effects in isovector moment κ^v
- no pion cloud effects in isoscalar moment κ^s

Eichmann, PRD 84 (2011)

Baryon masses- including pion cloud







Sanchis-Alepuz, CF, Kubrak, PLB 733 (2014) [1401.3183]

- fix Λ by f_π, vary η s.t. f_π still ok
- effects of the order of 50-100 MeV
- missing: gluon self-interaction effects

$$\alpha(k^2) = \pi\eta^7\left(\frac{k^2}{\Lambda^2}\right) e^{-\eta^2\left(\frac{k^2}{\Lambda^2}\right)} + \alpha_{UV}(k^2)$$

Pion cloud effects in baryons: structure

	Nucleon			Delta			
	s-wave	p-wave	d-wave	s-wave	p-wave	d-wave	f-wave
quark core	75	24	1	61	31	7	0,2
quark core plus pion cloud	75	24	1	60	31	8	0,2

$$\sigma_{\pi N} = 30(3)\,\mathrm{MeV} \quad \text{(quark core only)}$$

$$\sigma_{\pi N} = 31(3)\,\mathrm{MeV} \quad \text{(quark core + pion cloud)}$$

Sanchis-Alepuz, CF, Kubrak, PLB 733 (2014) [1401.3183]

- pion cloud does not change shape of nucleon: uniform skin
- sigma-term probably too small...

Outlook

Lots of interesting physics still to be explored !!

Agenda for DSE/BSE/Faddeev framework:

- Electromagnetic form factors with pion cloud
- Three-body forces
- Compton scattering

Other activities of our group related to PANDA:

- Light and heavy mesons
- Tetraquarks
- *Glueballs: to be published, arXiv:xxxxx*