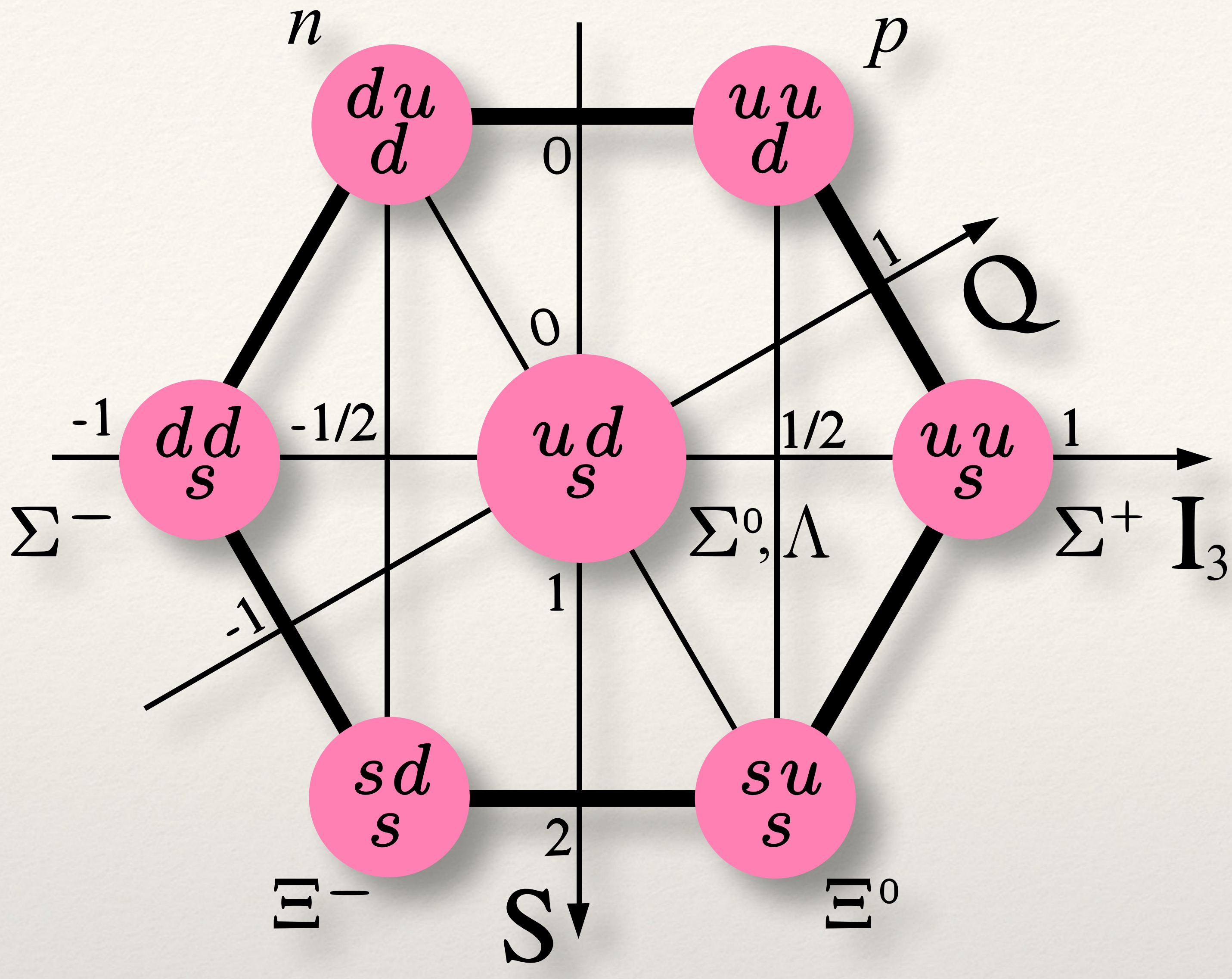

1st of July 2015 — Chiral Dynamics (Pisa, Italy)

Inclusion of isospin breaking effects in lattice simulations

Antonin J. Portelli
(University of Southampton)

What's new ?

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- [Davoudi & Savage, 2014] — **[PRD 90(5), p. 054503]**
  - finite-volume corrections to hadron masses in NREFTs

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- [BMWc, 2015a] — **[Science 347, pp. 1452–1455]**
  - new set of $N_f = 1+1+1+1$ full QCD+QED simulations
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- possible summary of all that: **[AP, 2015, arXiv:1505.07057]**

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- **Stay tuned:** Lattice 2015 (Kobe, Japan) is in two weeks

- Motivations
- Lattice QCD+QED
- Update on electro-quenched results
- Isospin splittings in the hadron spectrum
- Summary & outlook

Motivations

Isospin symmetry breaking

- Isospin symmetric world: up and down quarks are particles with identical physical properties.

Isospin symmetry breaking

- Isospin symmetric world: up and down quarks are particles with identical physical properties.
- Isospin symmetry is explicitly broken by:
  - the up and down **quark mass difference**

    $$|m_u - m_d|/\Lambda_{\mathrm{QCD}} \simeq 0.01$$

  - the up and down **electric charge difference**

    $$\alpha \simeq 0.0073$$

	up	down
Mass (MeV)	$2.3(^{+0.7}_{-0.5})$	$4.8(^{+0.5}_{-0.3})$
Charge (e)	2/3	-1/3

source: [PDG, 2013]

Nucleon mass splitting

- Well known experimentally:

$$M_n - M_p = 1.2933322(4)\ \mathrm{MeV}$$

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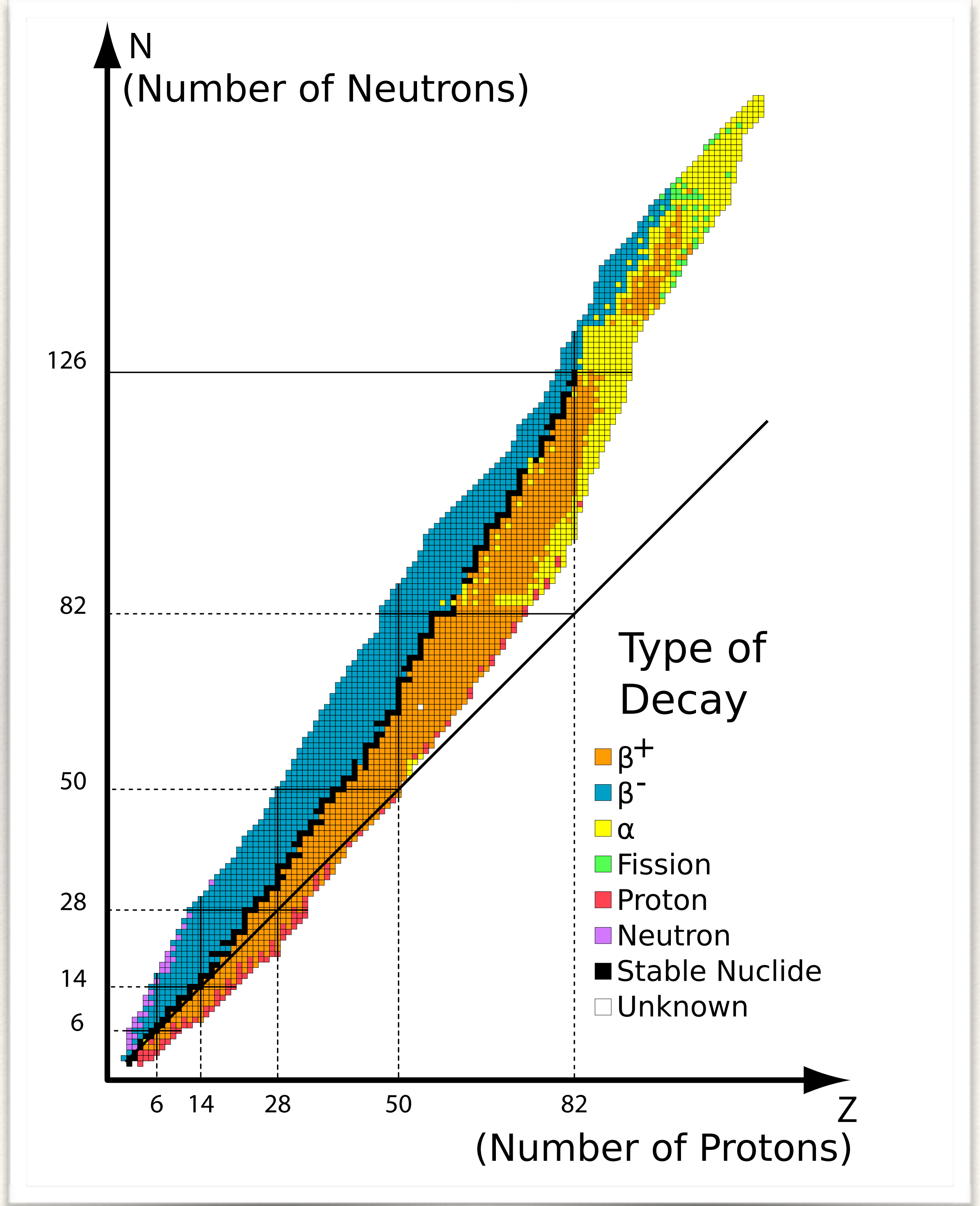

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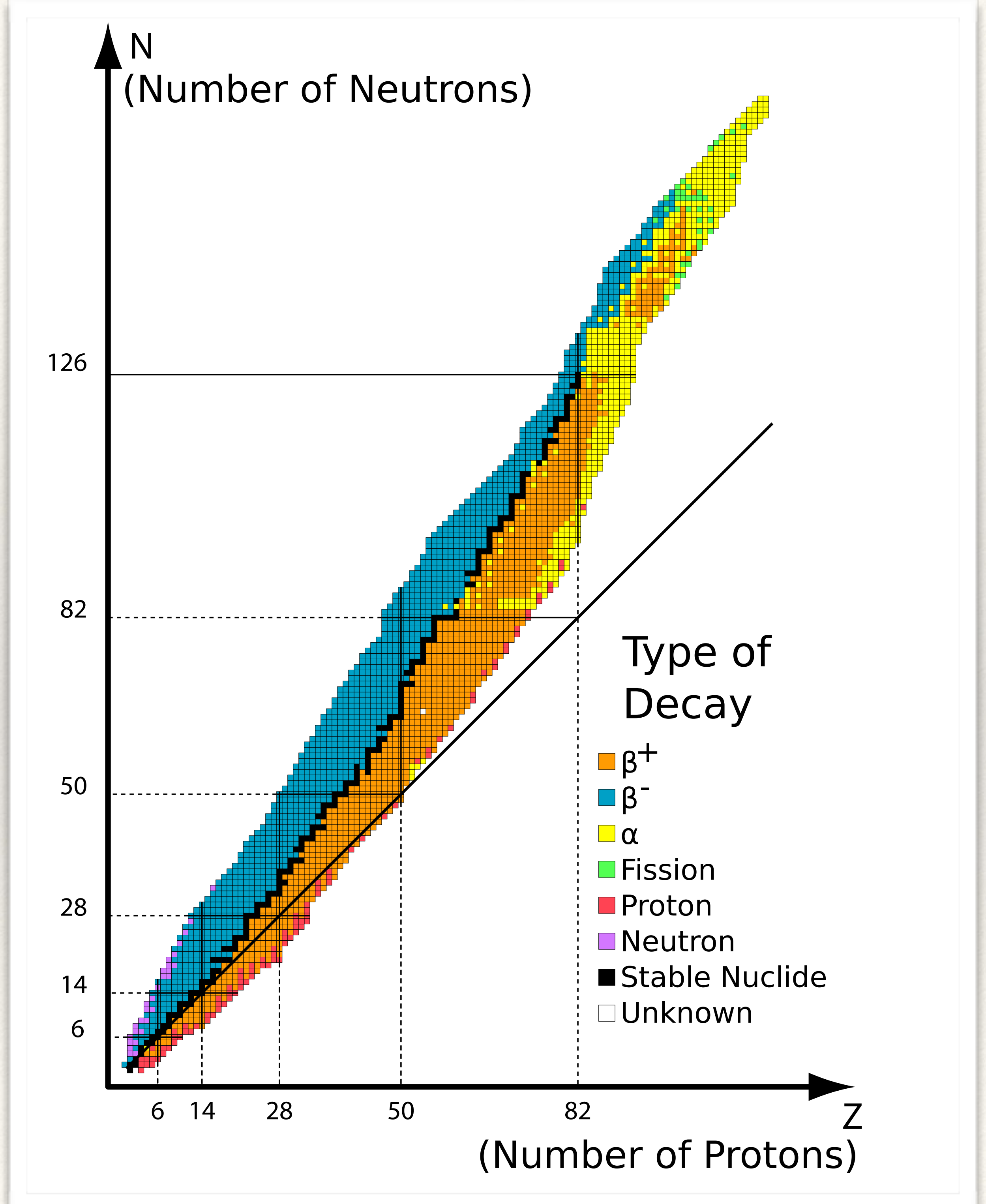
- initial condition for **Big-Bang nucleosynthesis**



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- ε is **important to determine light quark mass ratios**

Lattice QCD+QED

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- Lattice QCD simulation: **Monte-Carlo estimation of discretised QCD functional integrals**

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- **Extremely expensive**, but ***ab-initio***

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- Naively discretised **Maxwell action**:

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- No mass gap: **large finite volume effects expected**

Zero-mode subtraction

Finite volume: **momentum quantisation**

$$\alpha \int \frac{\mathrm{d}^4 k}{(2\pi)^4} \frac{1}{k^2} \cdots \quad \longmapsto \quad \frac{\alpha}{V} \sum_k \frac{1}{k^2} \cdots$$

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Contains a straight 1/0 !

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- Some more interesting that others

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- $\mathrm{QED}_{\mathrm{TL}}$ **does not have reflection positivity**

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- Example — 1-loop QED_{TL} [BMWc, 2014]:

$$m(T,L) \underset{T,L\to+\infty}{\sim} m\left\{1 - q^2\alpha\left[\frac{\kappa}{2mL}\left(1+\frac{2}{mL}\left[1-\frac{\pi}{2\kappa}\frac{T}{L}\right]\right) - \frac{3\pi}{(mL)^3}\left[1-\frac{\coth(mT)}{2}\right] - \frac{3\pi}{2(mL)^4}\frac{L}{T}\right]\right\}$$

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- Same behaviour independently discovered by MILC

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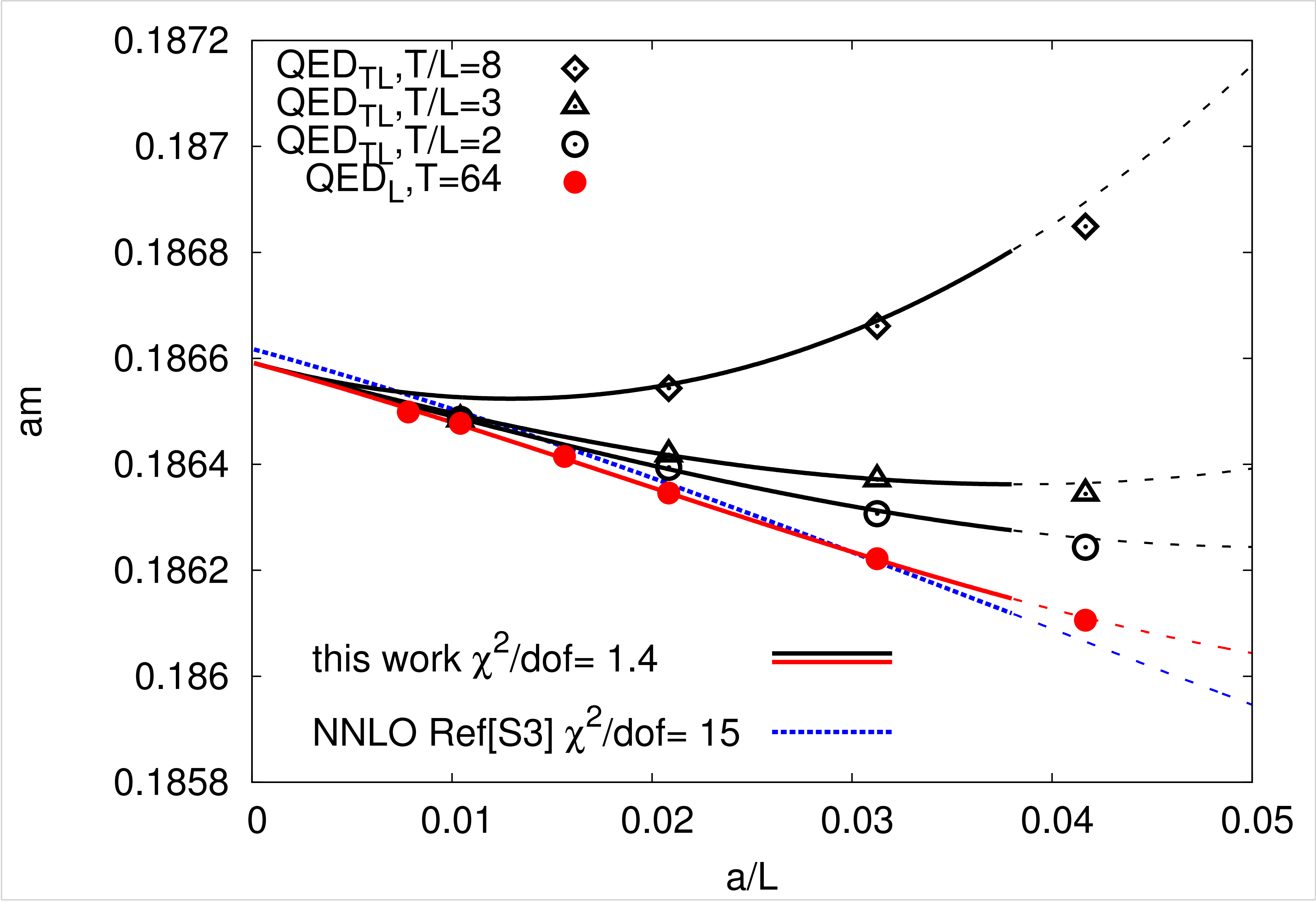
inverse powers of L, independent of T

Finite-volume effects



Pure QED simulations (quenched) from [BMWc, 2015a] — [S3]=[Davoudi & Savage, 2014]

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- [BMWc, 2015a]: Ward identities: **NLO is universal**

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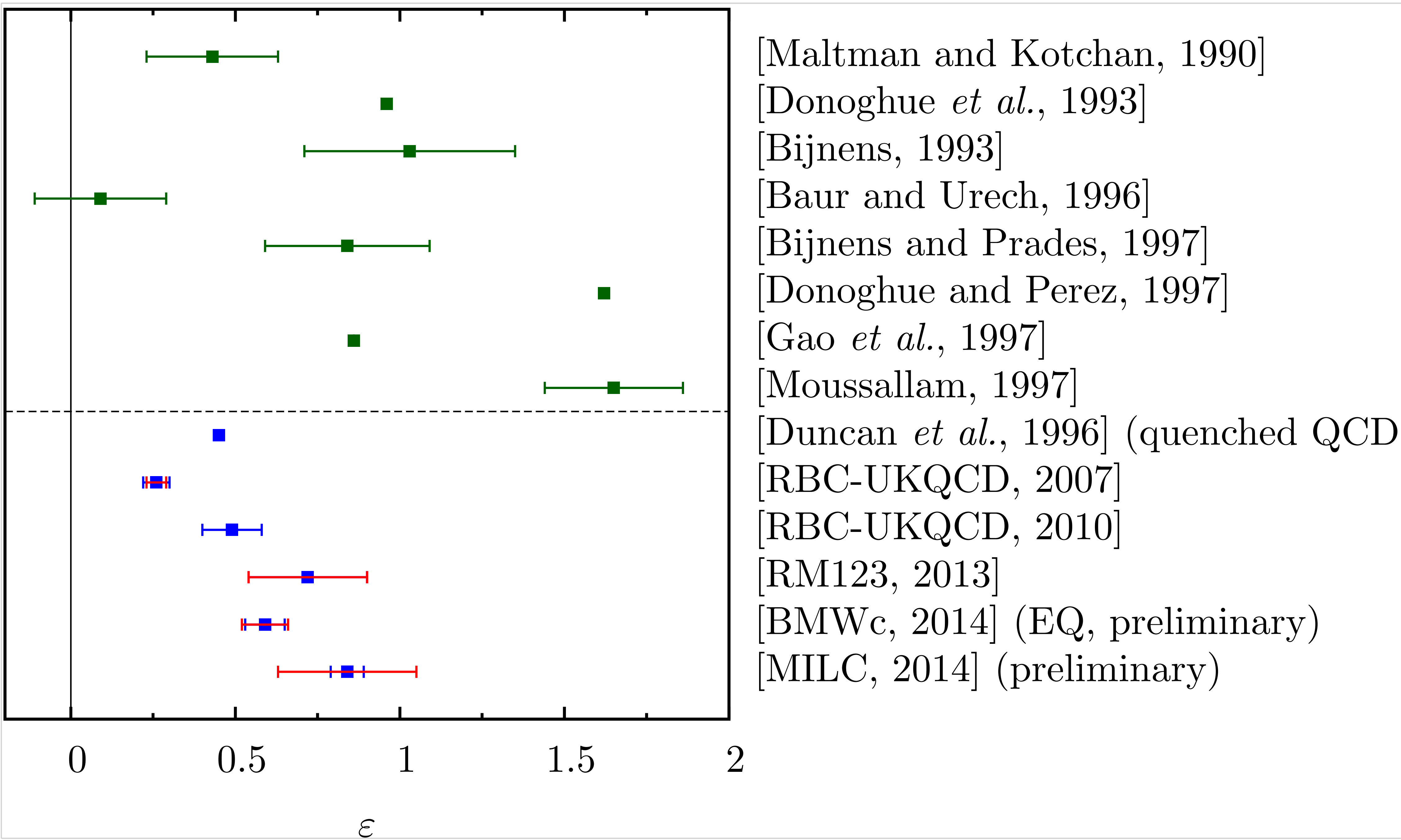
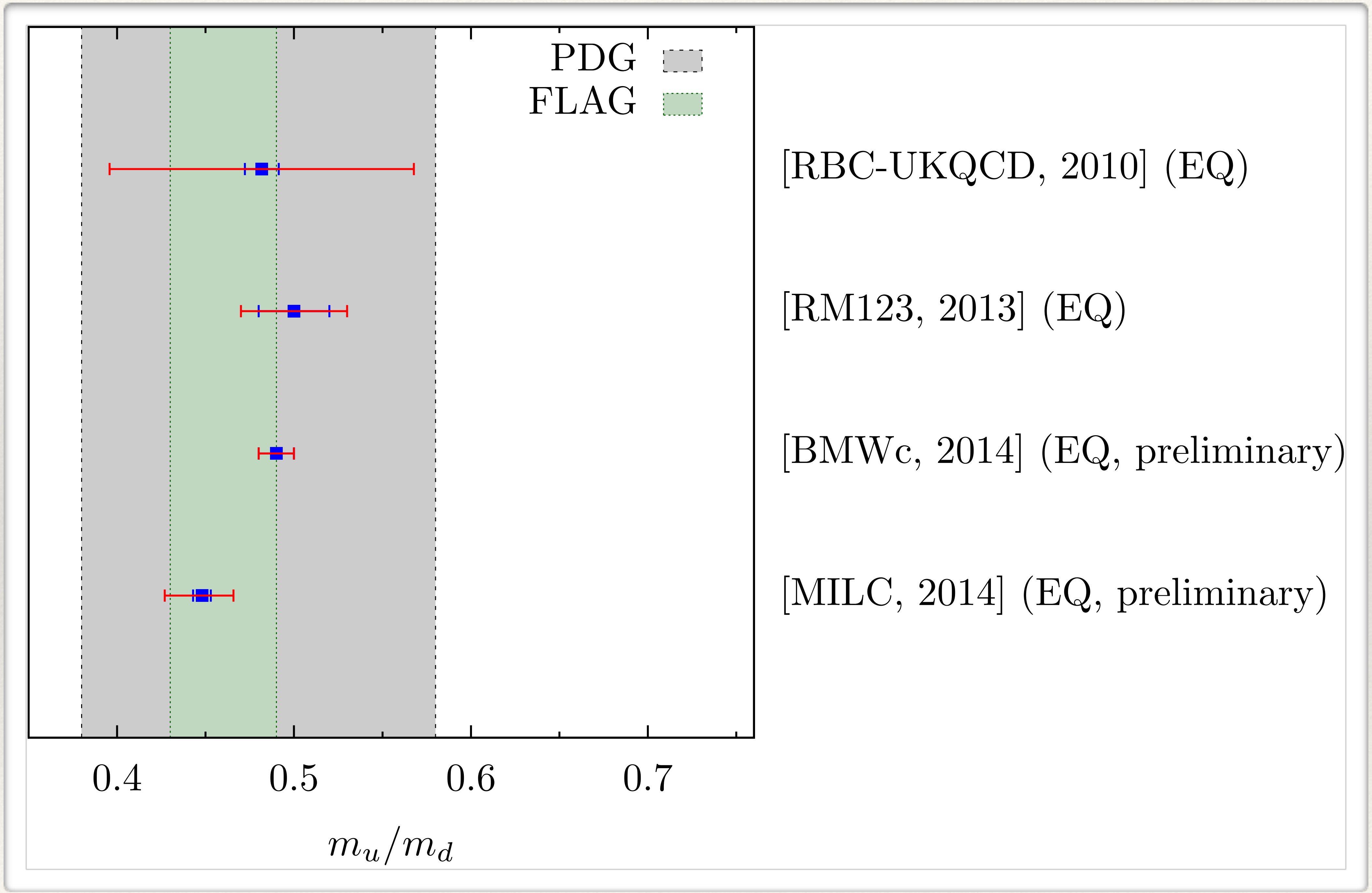
- In agreement with PQChPT estimates
  [J. Bijnens & N. Danielsson, PRD 75(1), p. 014505, 2007]

Update on electro-quenched results

EQ results for ε



EQ results for light quark masses



Isospin splittings in the hadron spectrum

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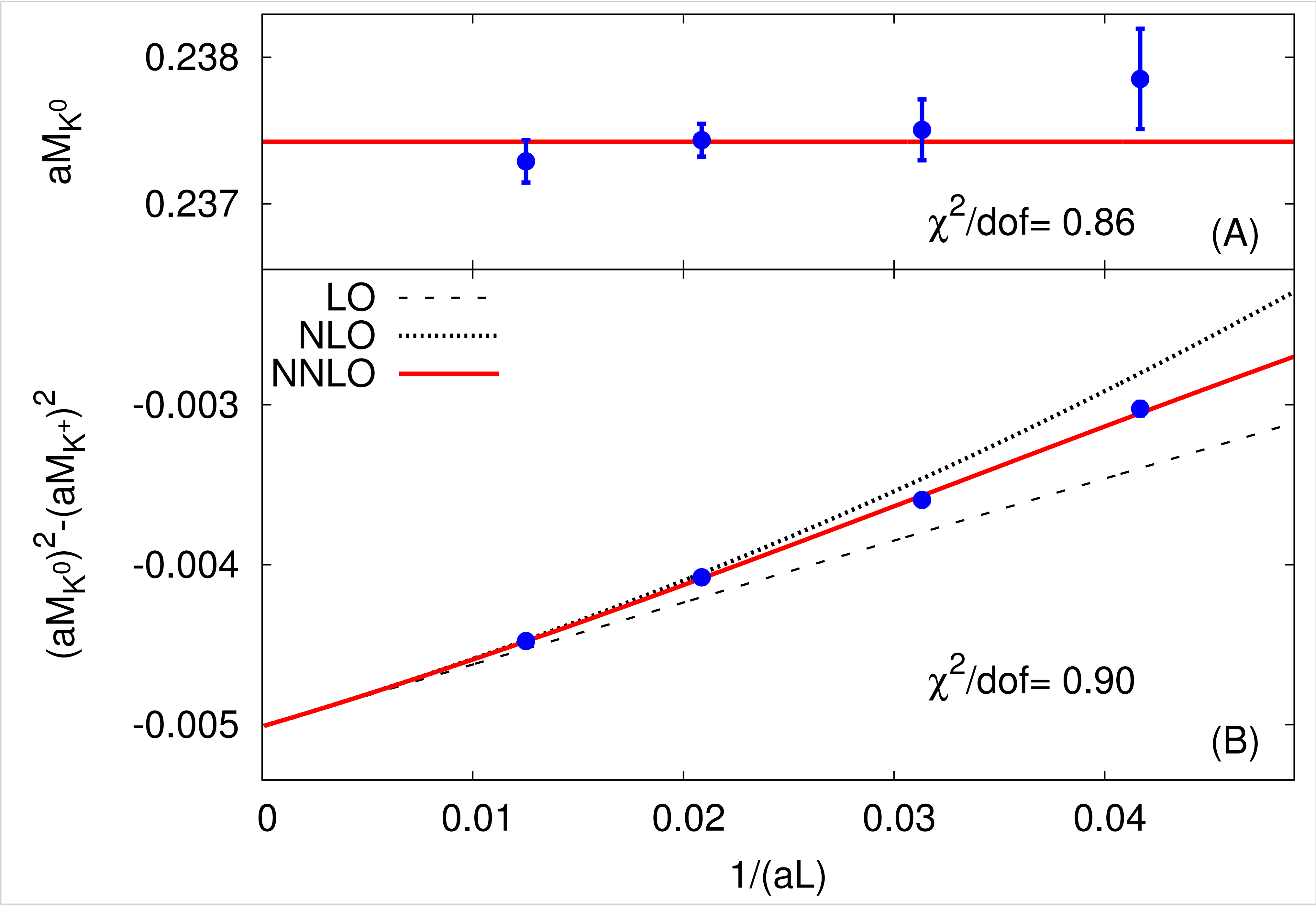
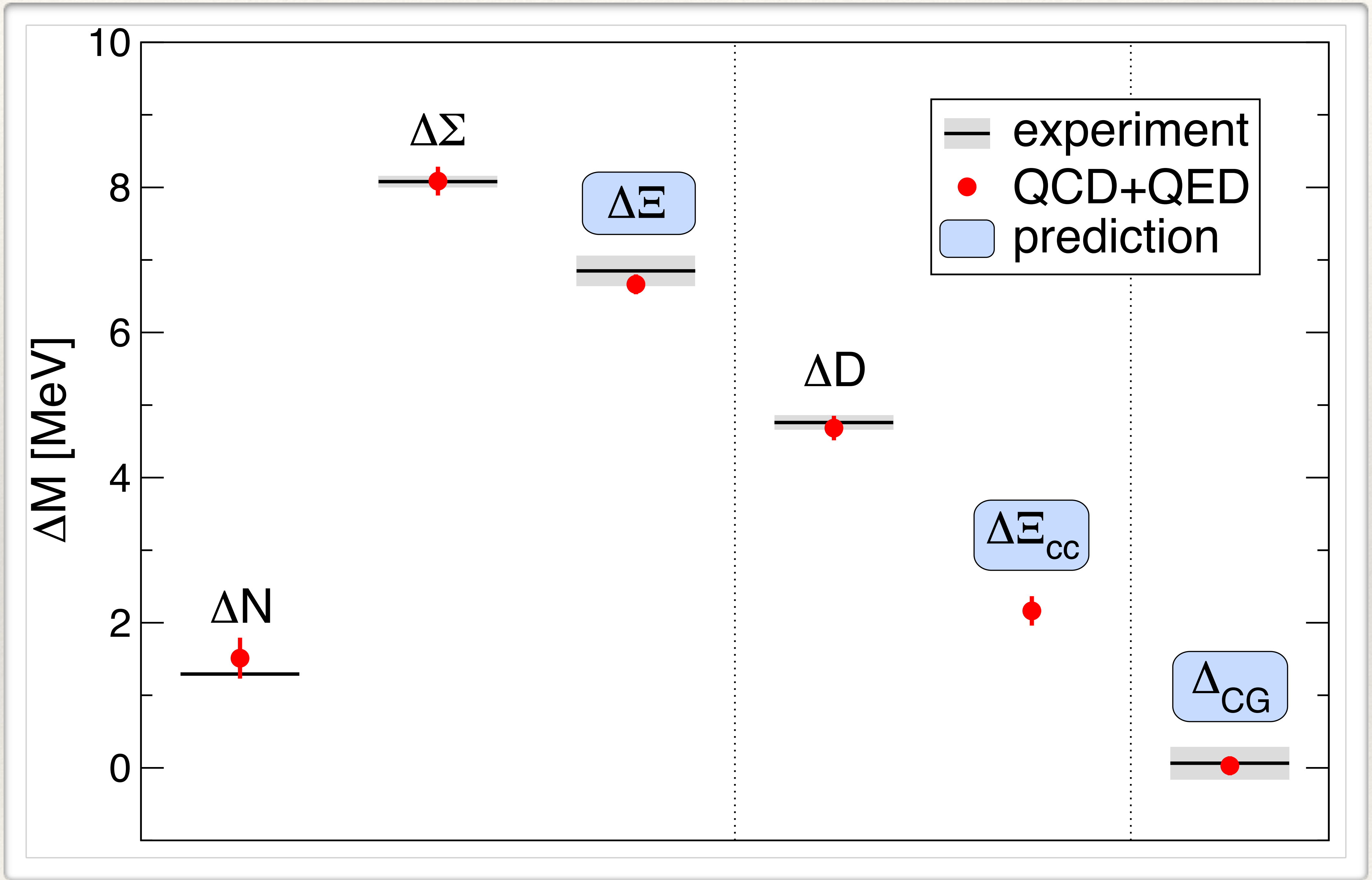
- **O(500) analyses per mass splitting**

[BMWc, 2015a]: finite-volume study



[BMWc, 2015a]: result summary



$\Delta_{\mathrm{CG}} = \Delta M_N - \Delta M_\Sigma + \Delta M_\Xi$ (Coleman-Glashow relation)

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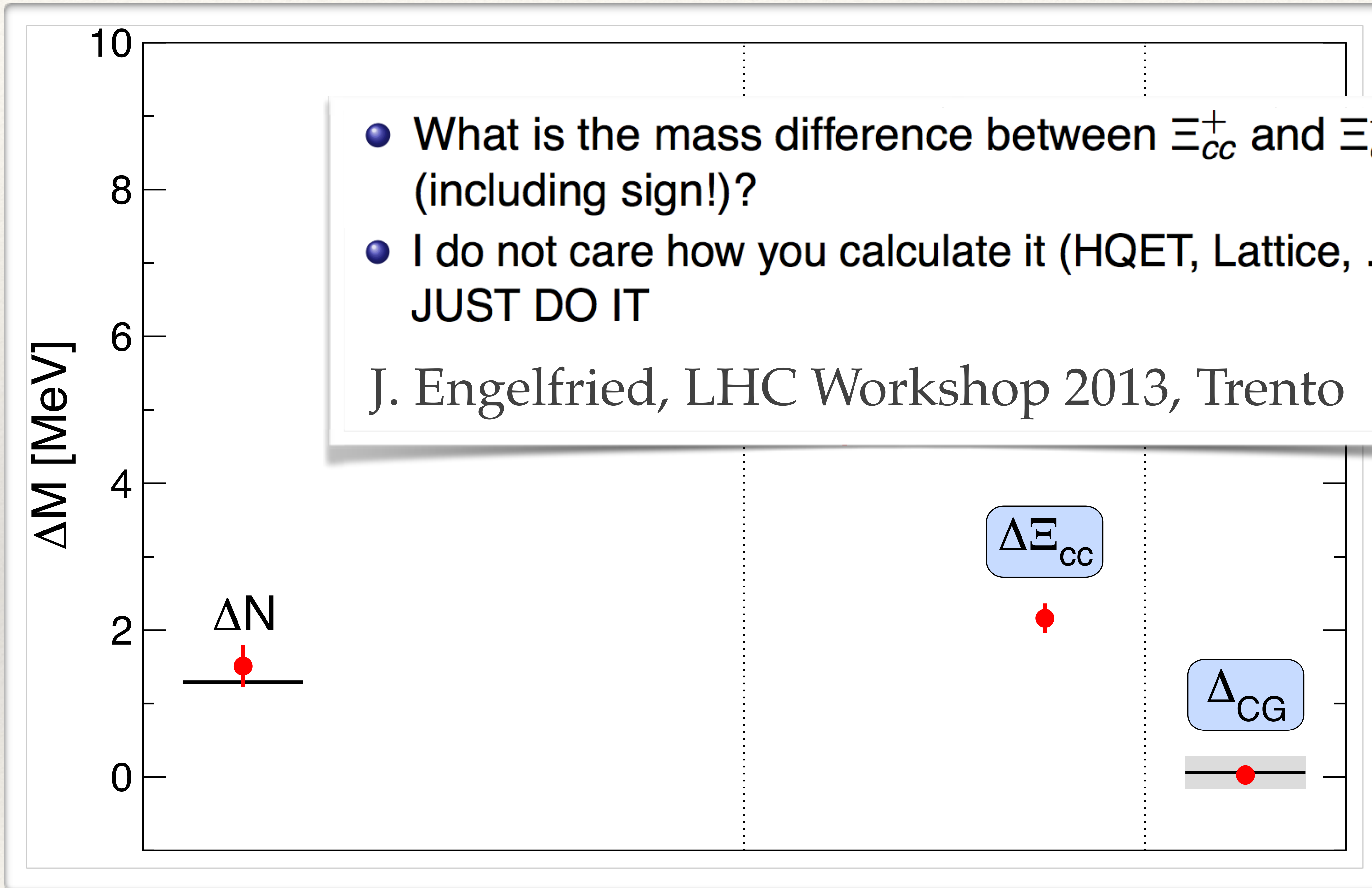

- What is the mass difference between Ξ_{cc}^{+} and Ξ_{cc}^{++} (including sign!)?
- I do not care how you calculate it (HQET, Lattice, ...), JUST DO IT

J. Engelfried, LHC Workshop 2013, Trento

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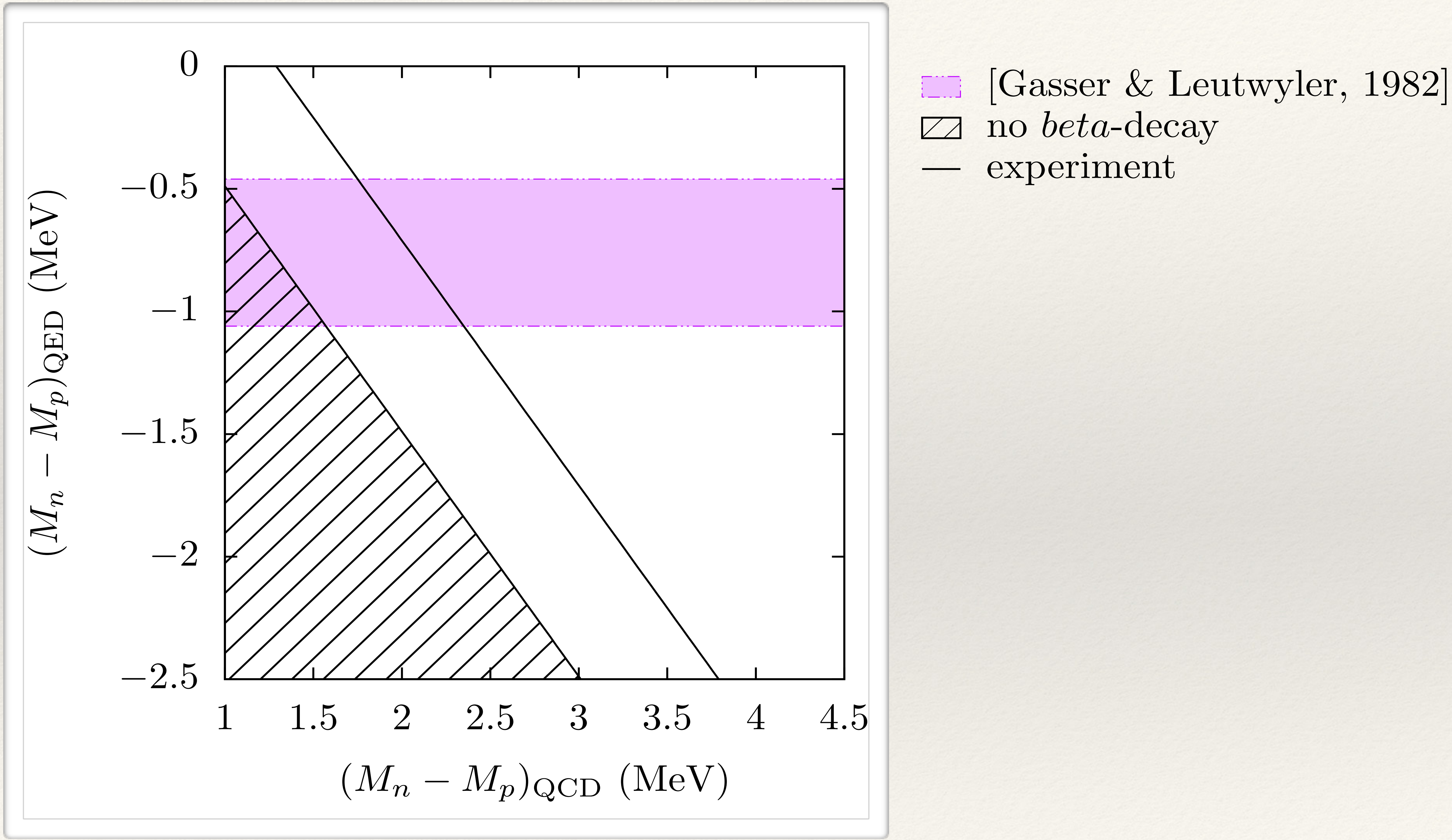
Results for the nucleon mass splitting



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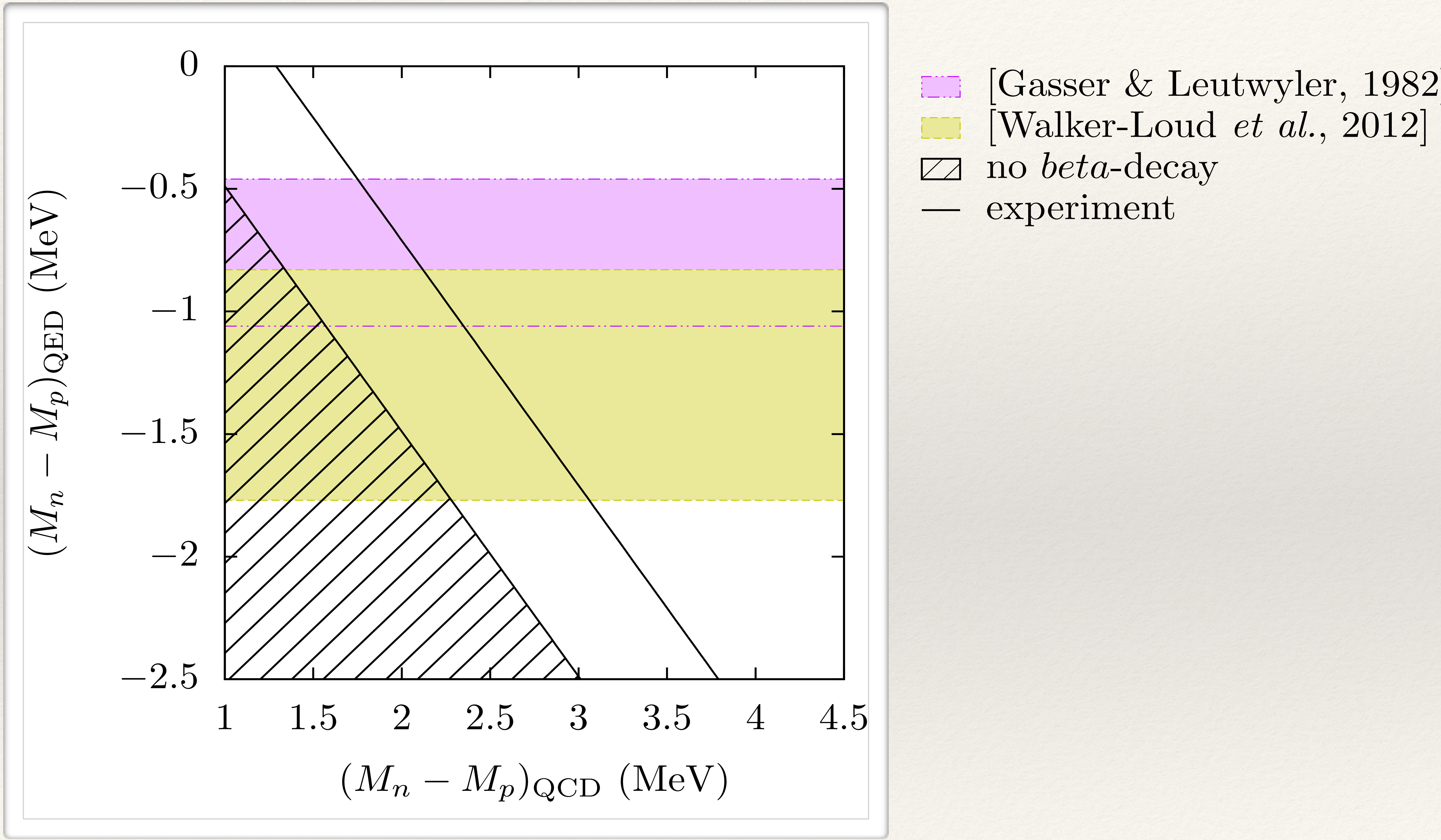

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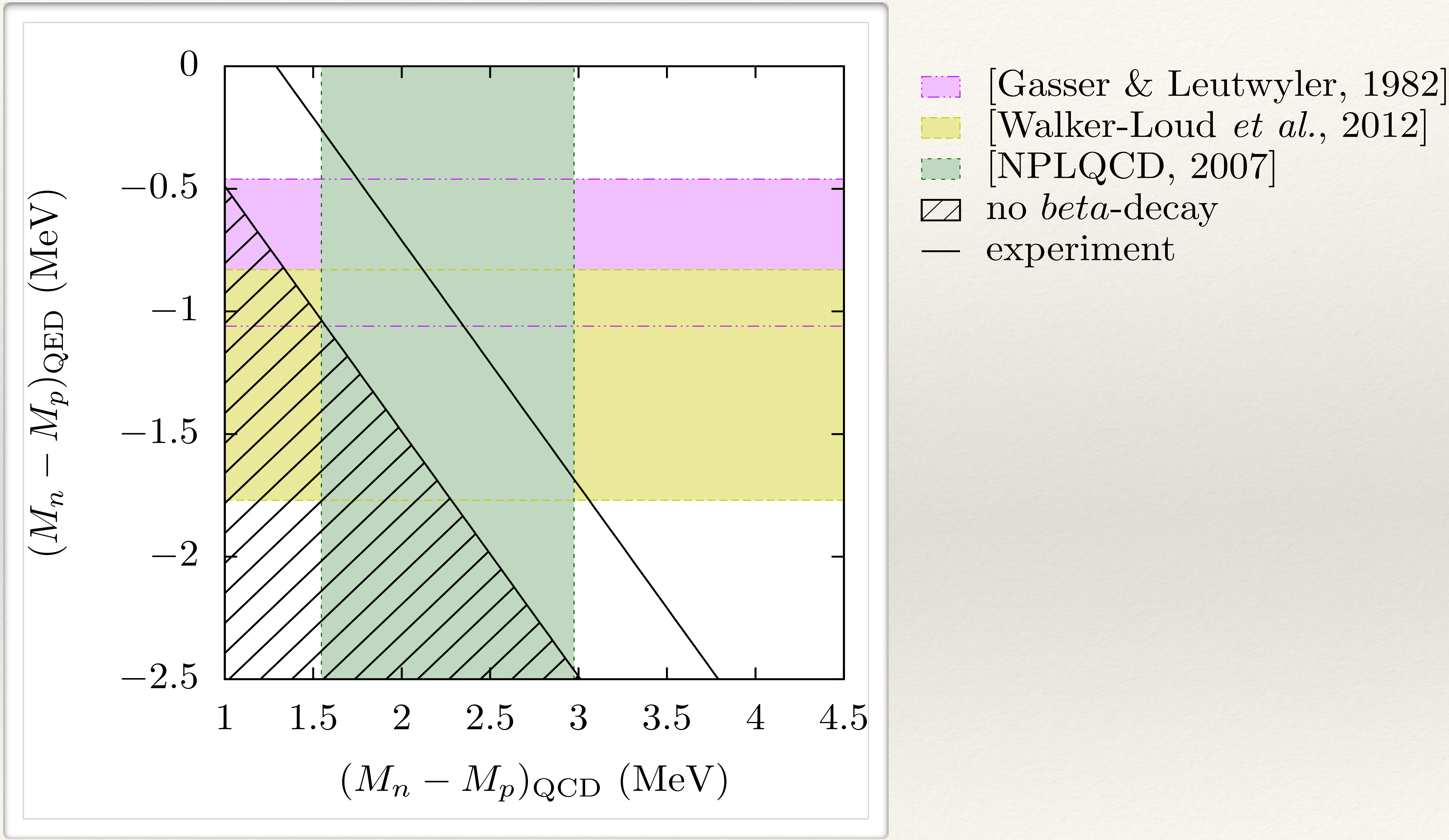

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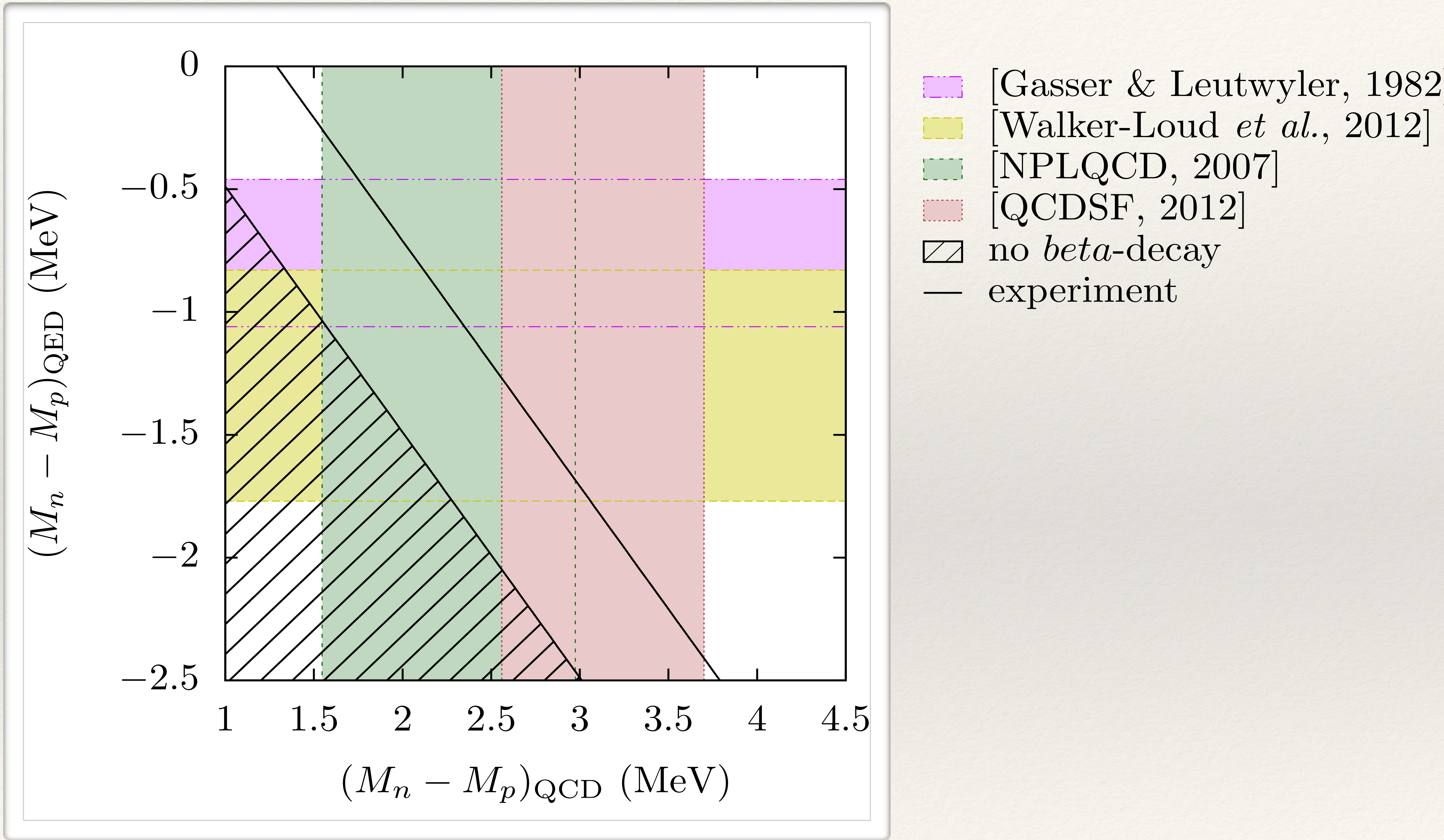

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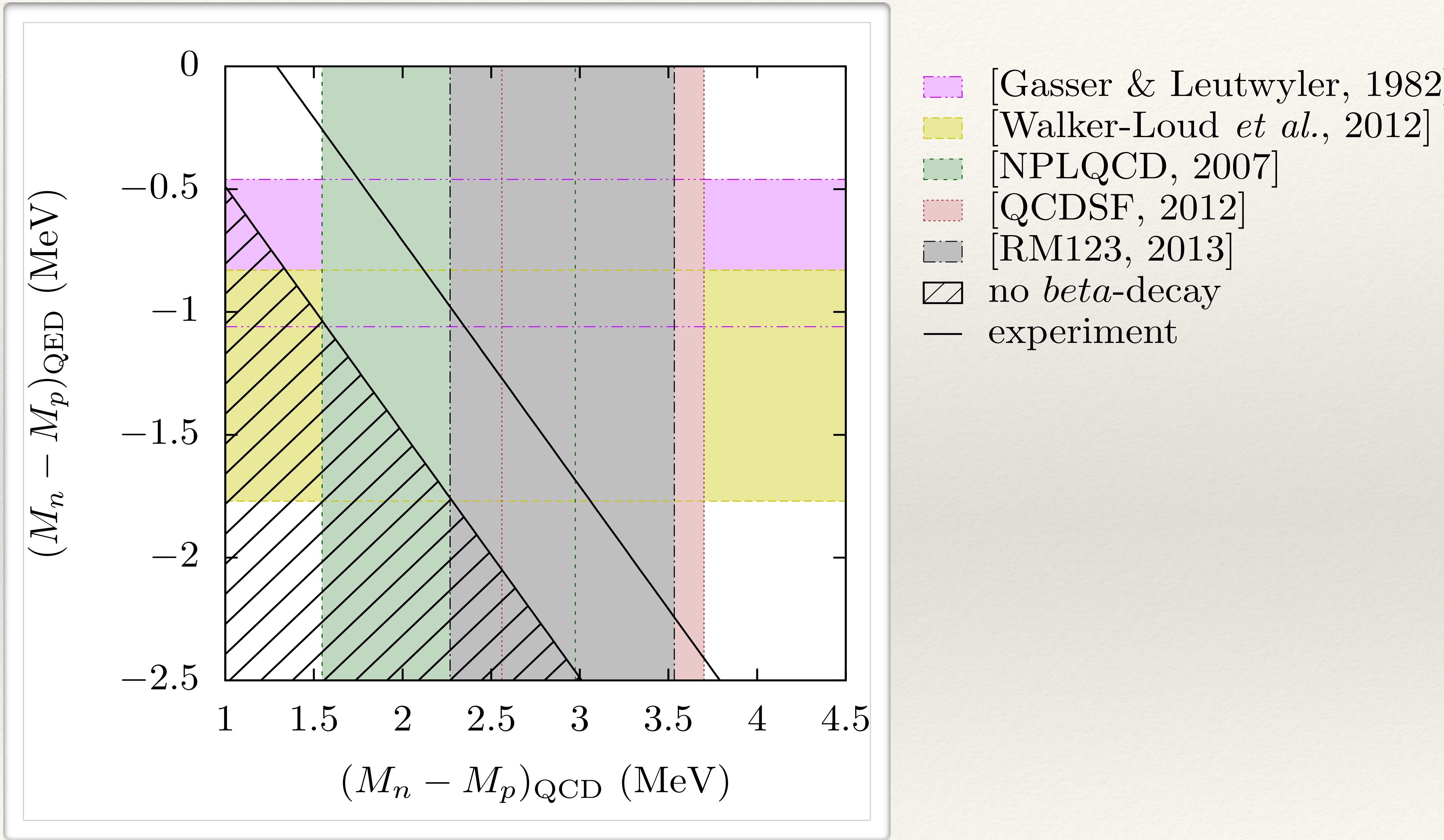

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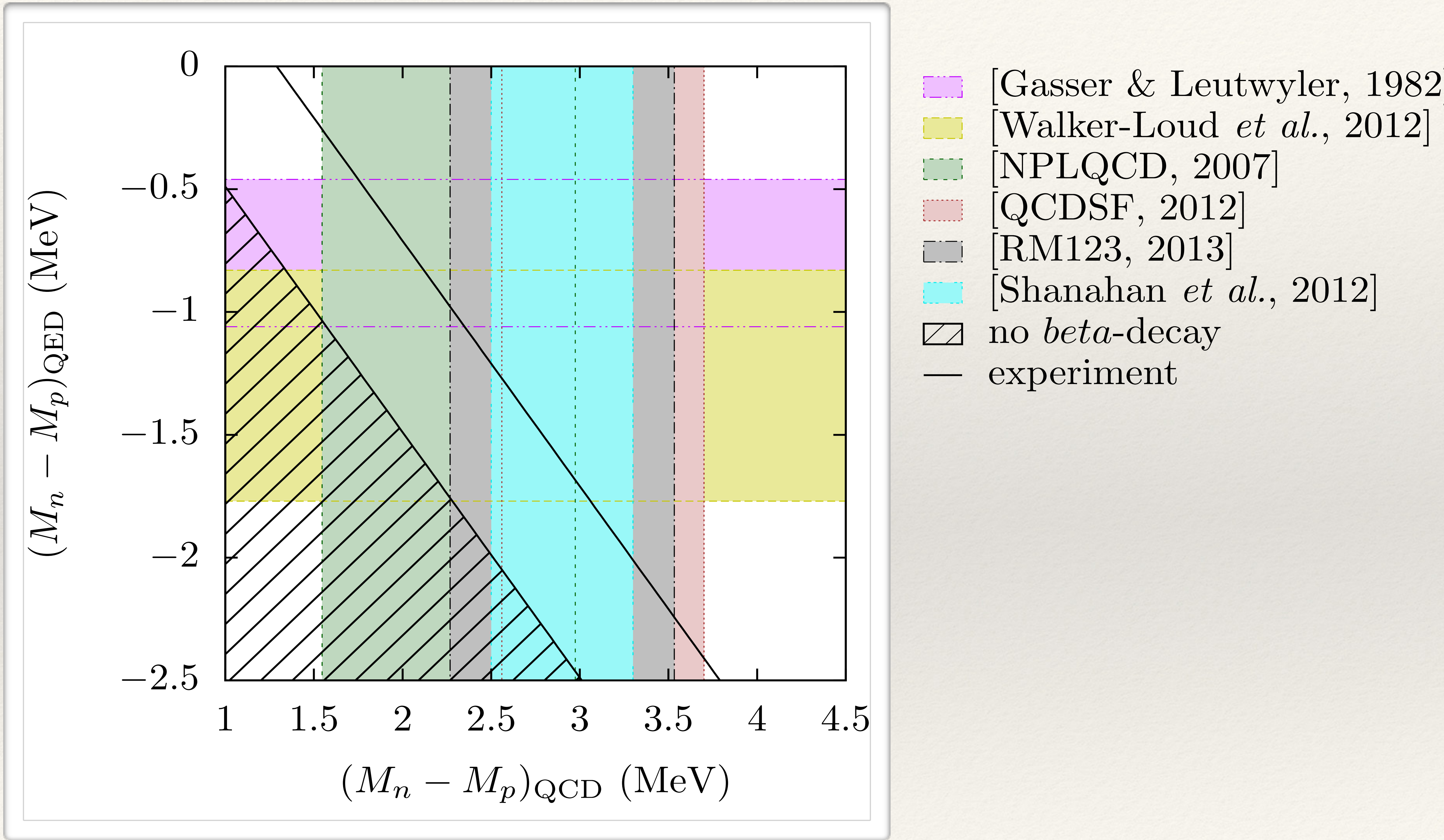

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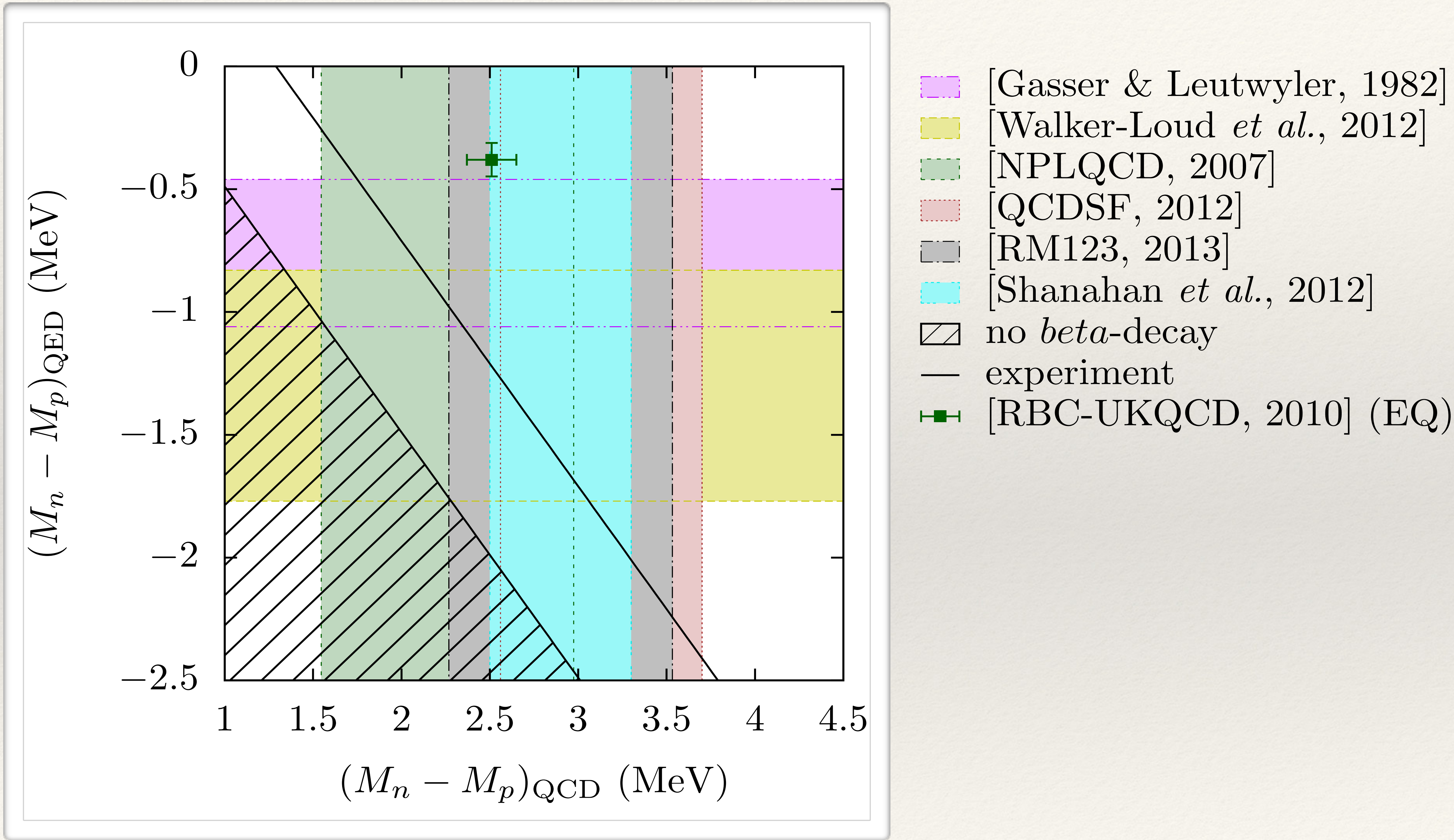

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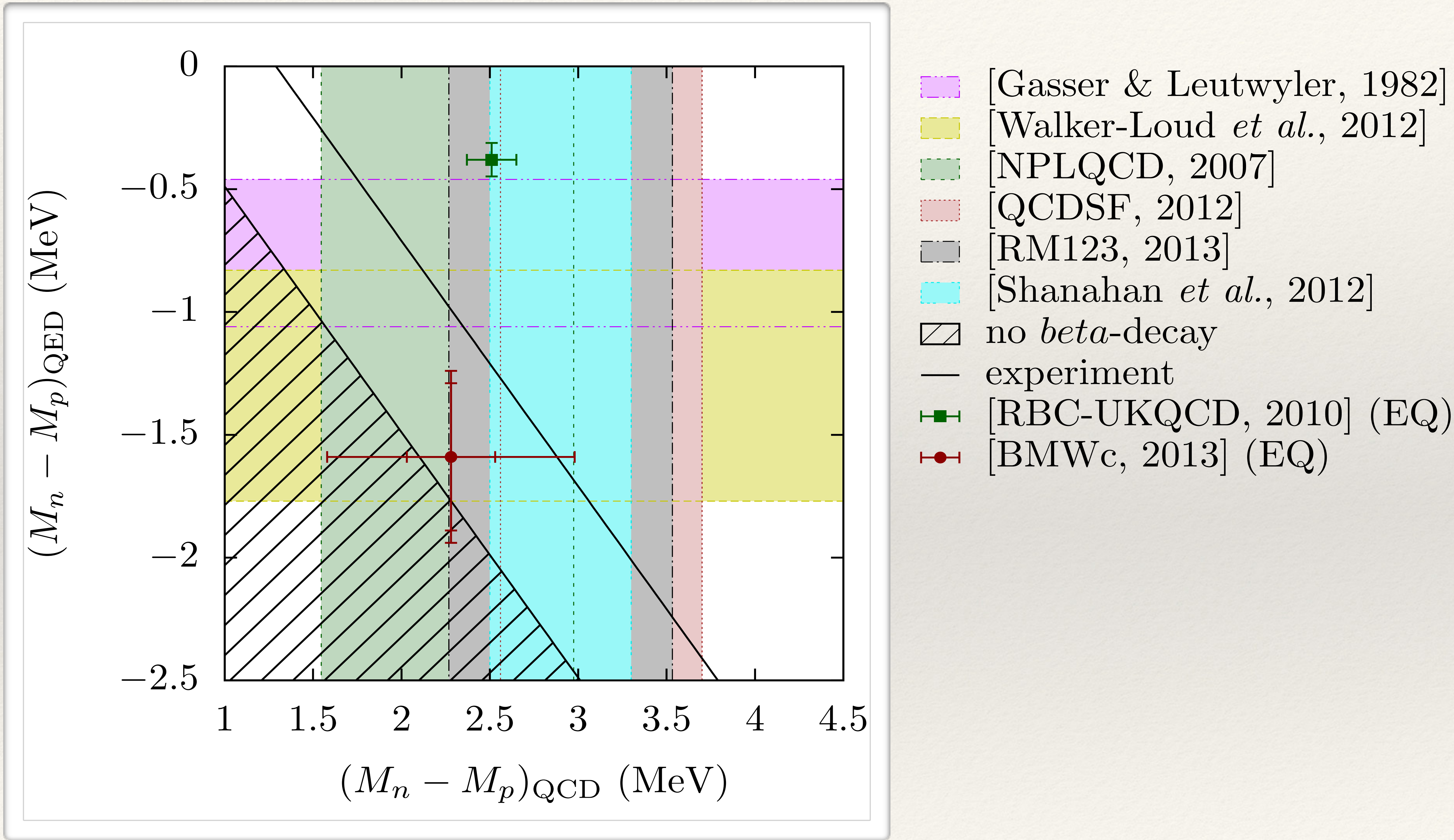

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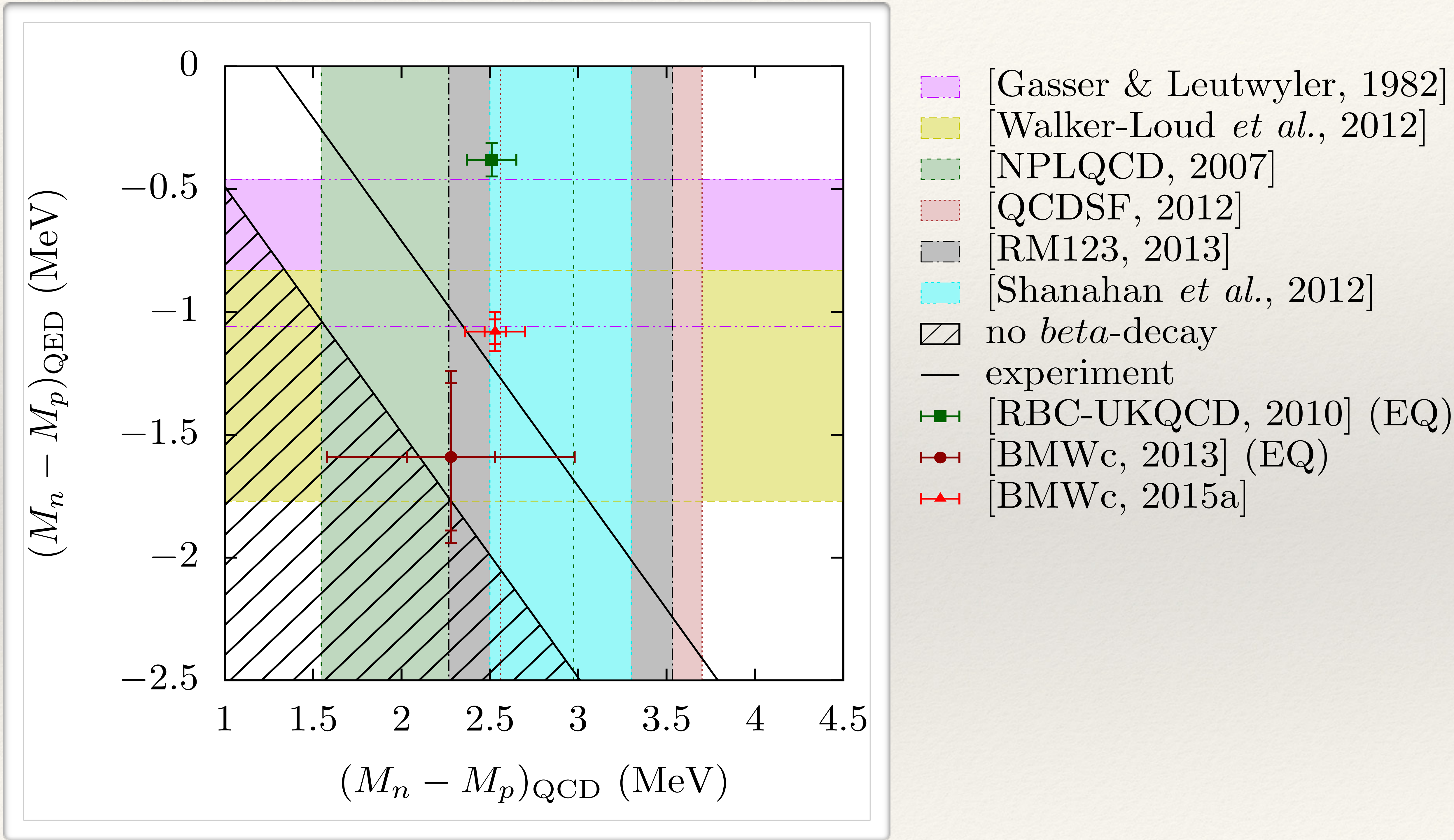

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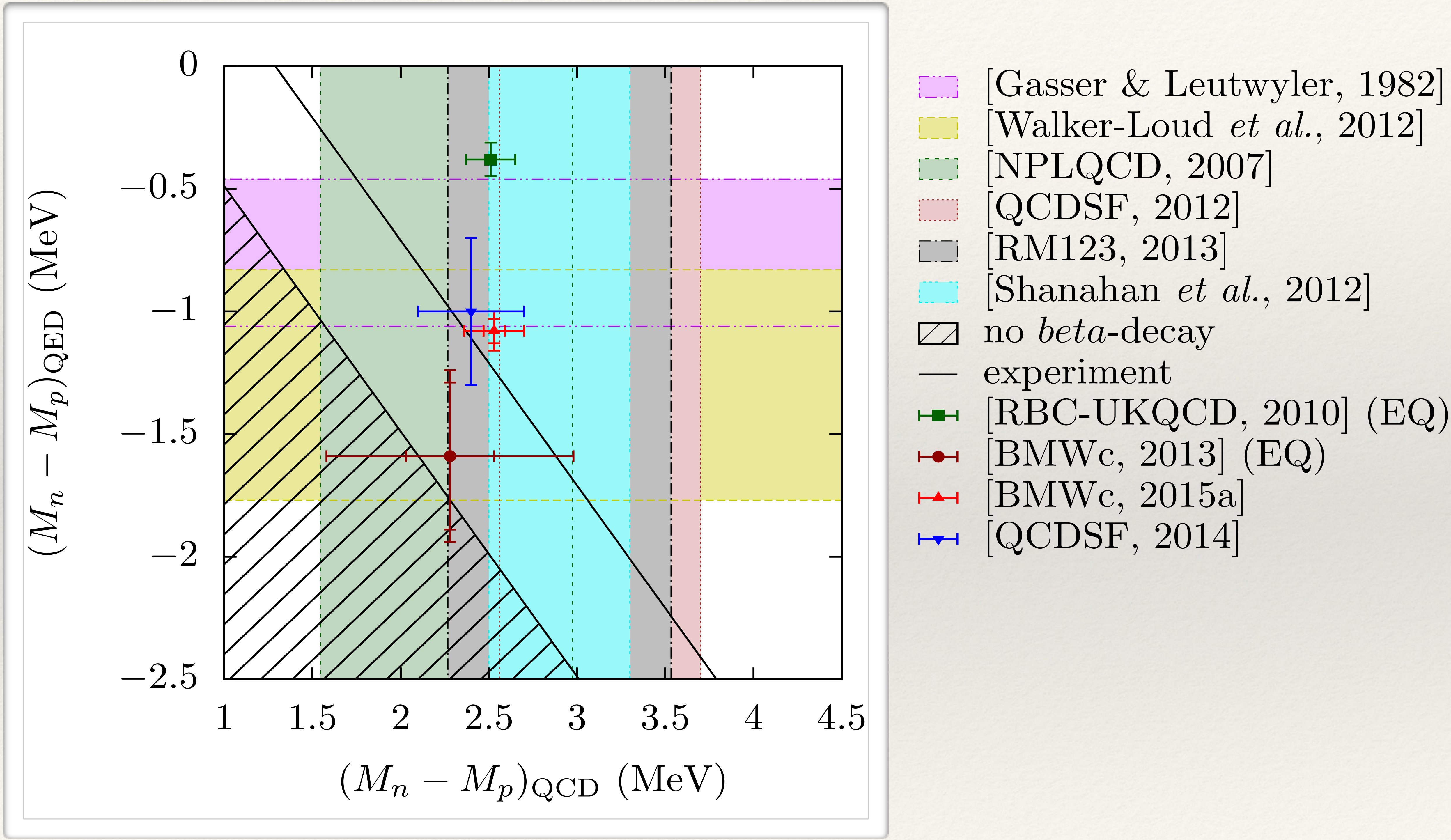

Summary & outlook

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- QCD+QED to compute hadronic corrections to anomalous magnetic moments.

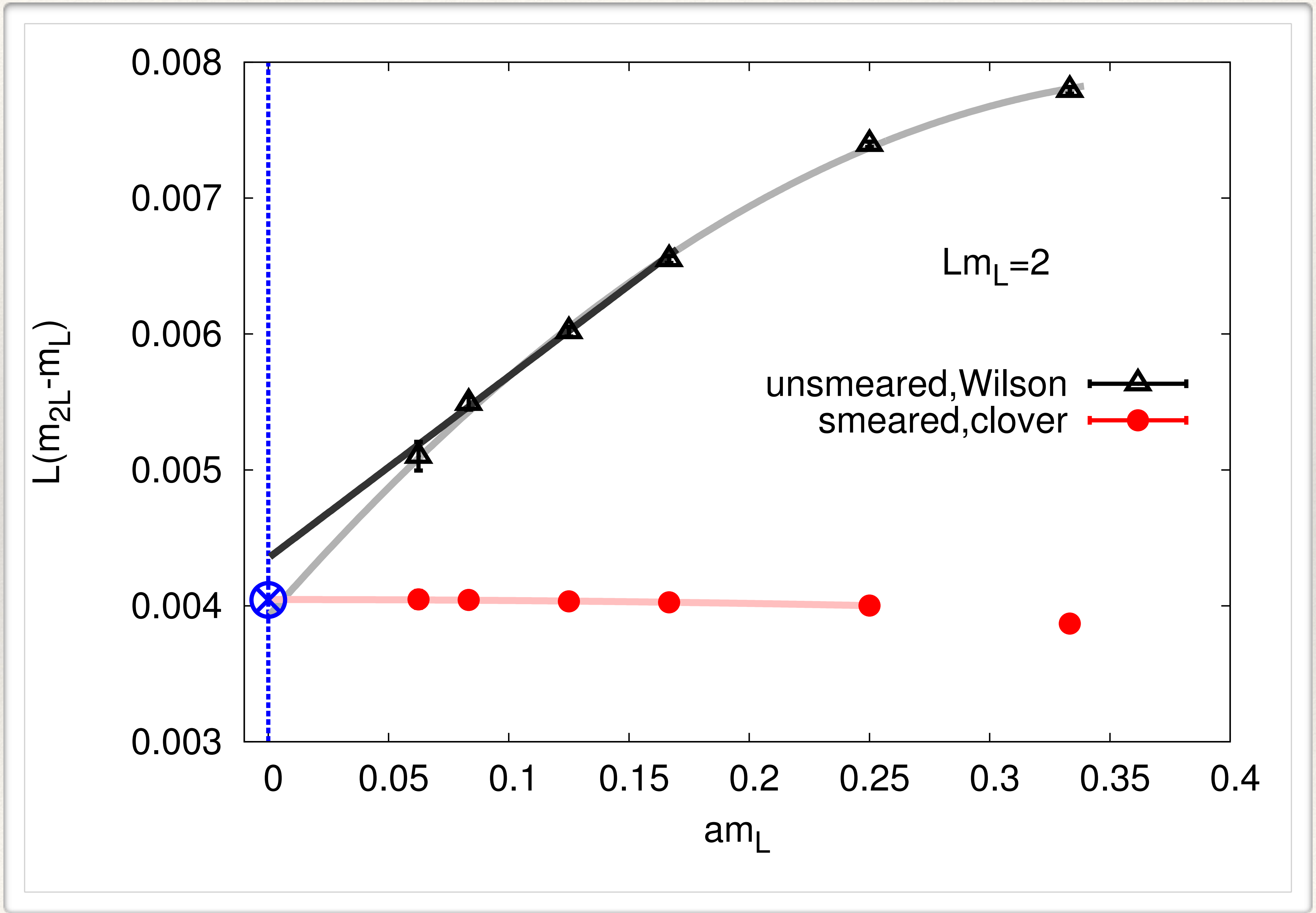
Thank you!

Backup

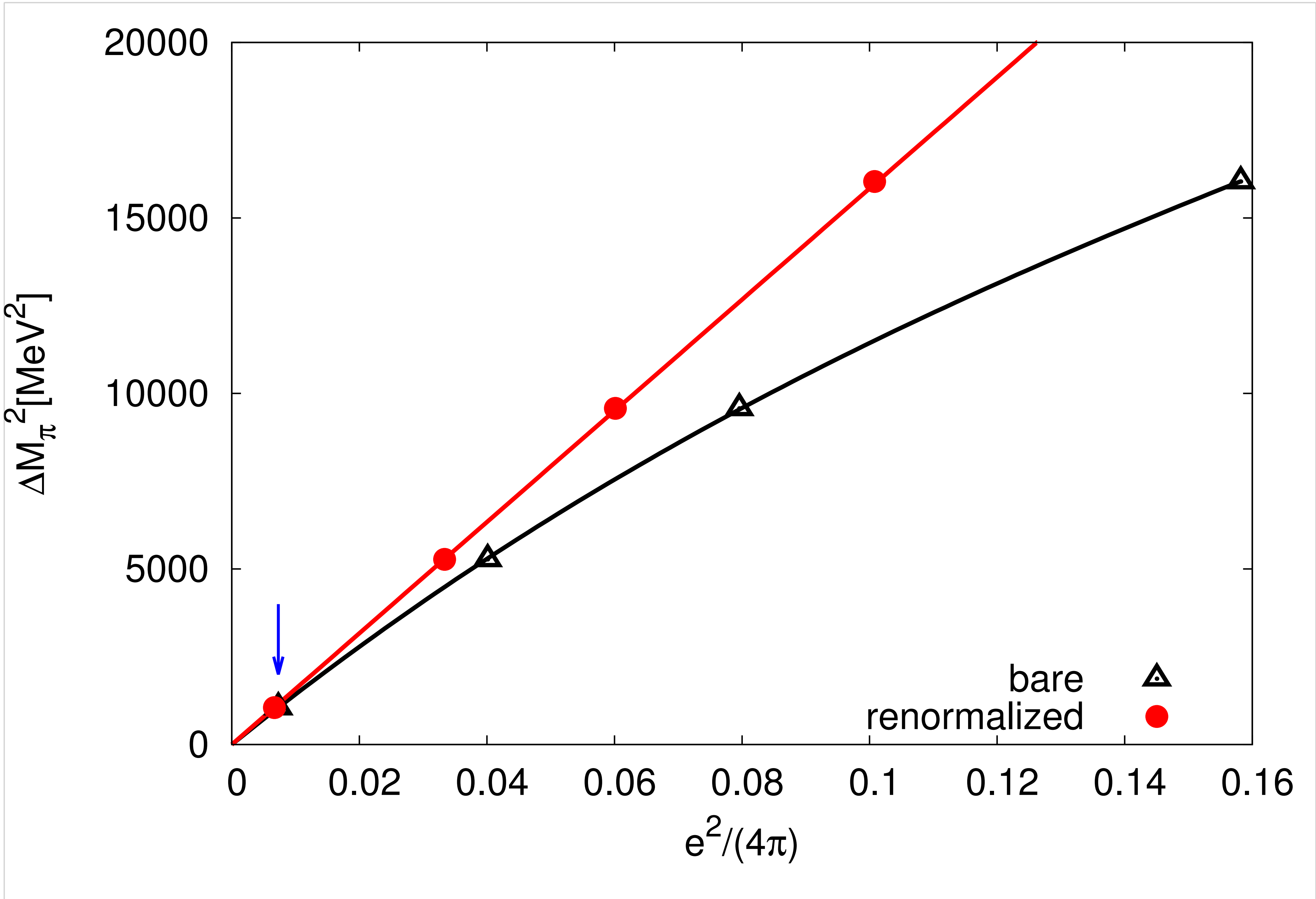
Full QCD + QED projects

	RBC-UKQCD	PACS-CS	QCDSF-UKQCD	BMWc
arXiv	1006.1311	1205.2961	**1311.4554 and Lat. 2014**	**1406.4088**
fermions	DWF	clover	**clover**	**clover**
N_f	2+1	1+1+1	**1+1+1**	**1+1+1+1**
method	reweighting	reweighting	**RHMC**	**RHMC**
min(M_π) (MeV)	420	135	**250**	**195**
a (fm)	0.11	0.09	**0.08**	**0.06 — 0.10**
$\# a$	1	1	**1**	**4**
L (fm)	1.8	2.9	**1.9 — 2.6**	**2.1 — 8.3**
$\# L$	1	1	**2**	**11**

[BMWc, 2015a]: QED simulations



[BMWc, 2015a]: charge renormalisation



[BMWc, 2015a]: charm discretisation effects