Connecting Nuclear Physics to QCD with the lattice

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Dubna International Advanced School of Theoretical Physics
Helmholtz International Summer School

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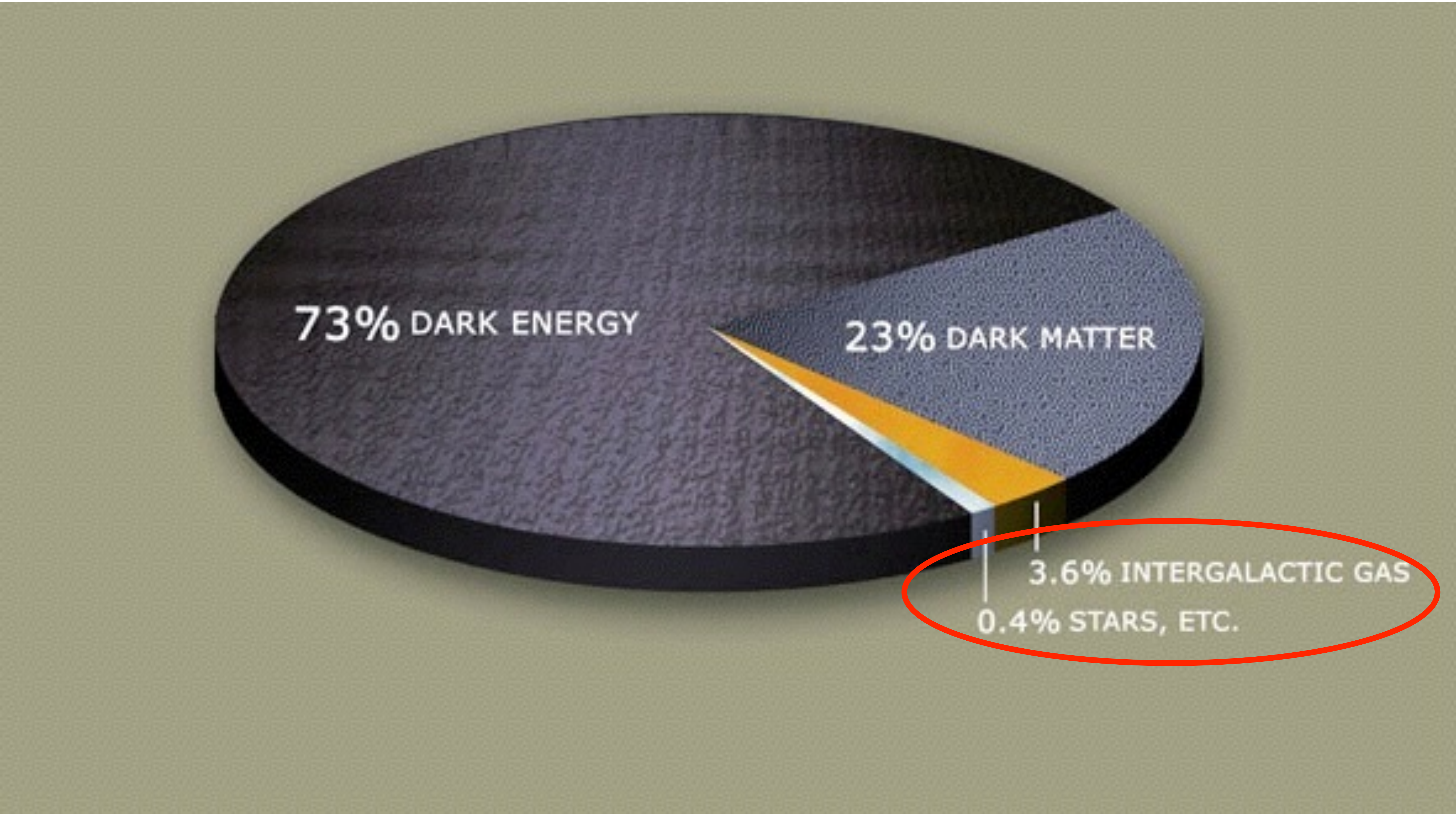
Lattice QCD, Hadron Structure and Hadronic Matter

Energy Budget of the Universe



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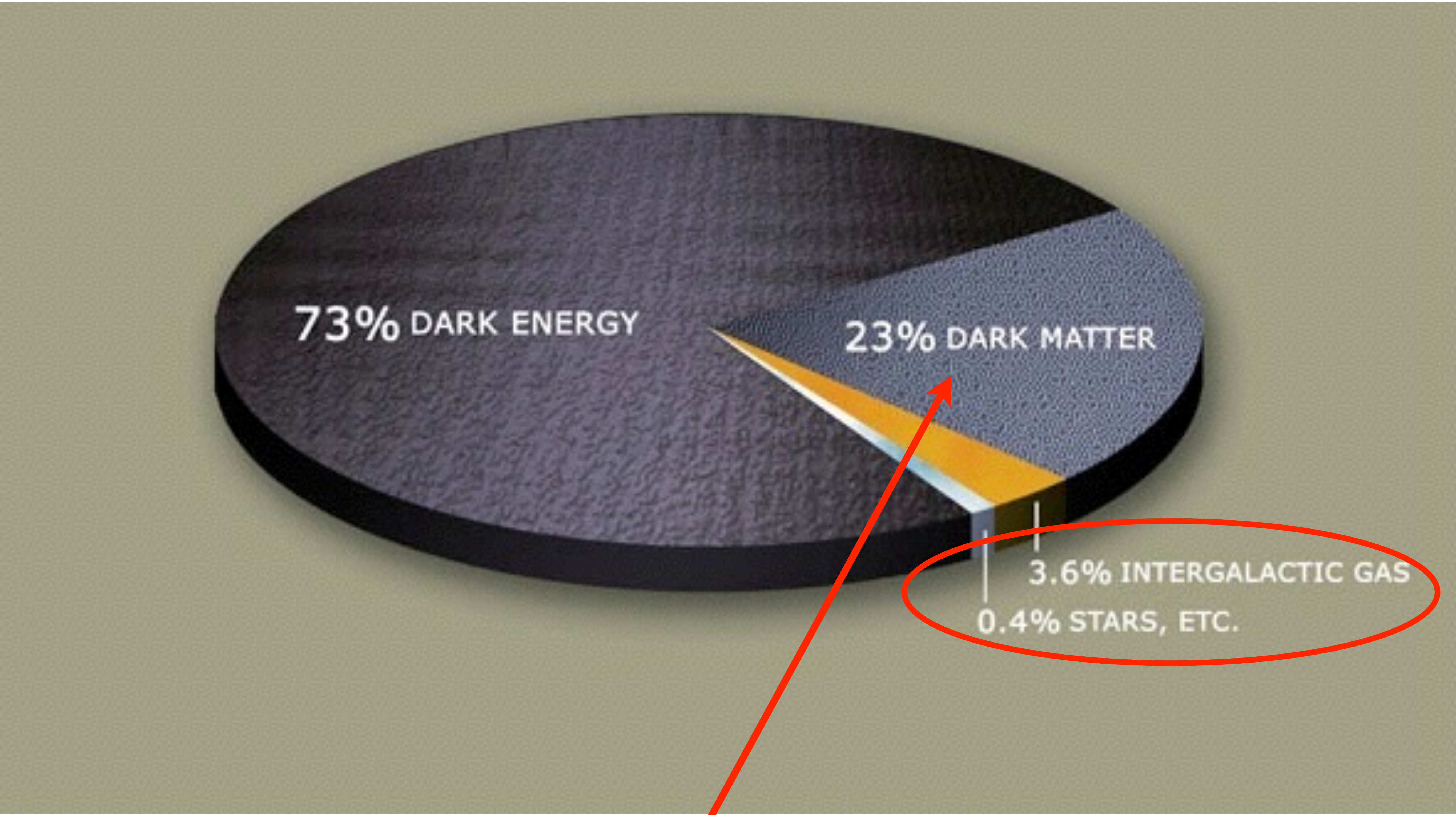
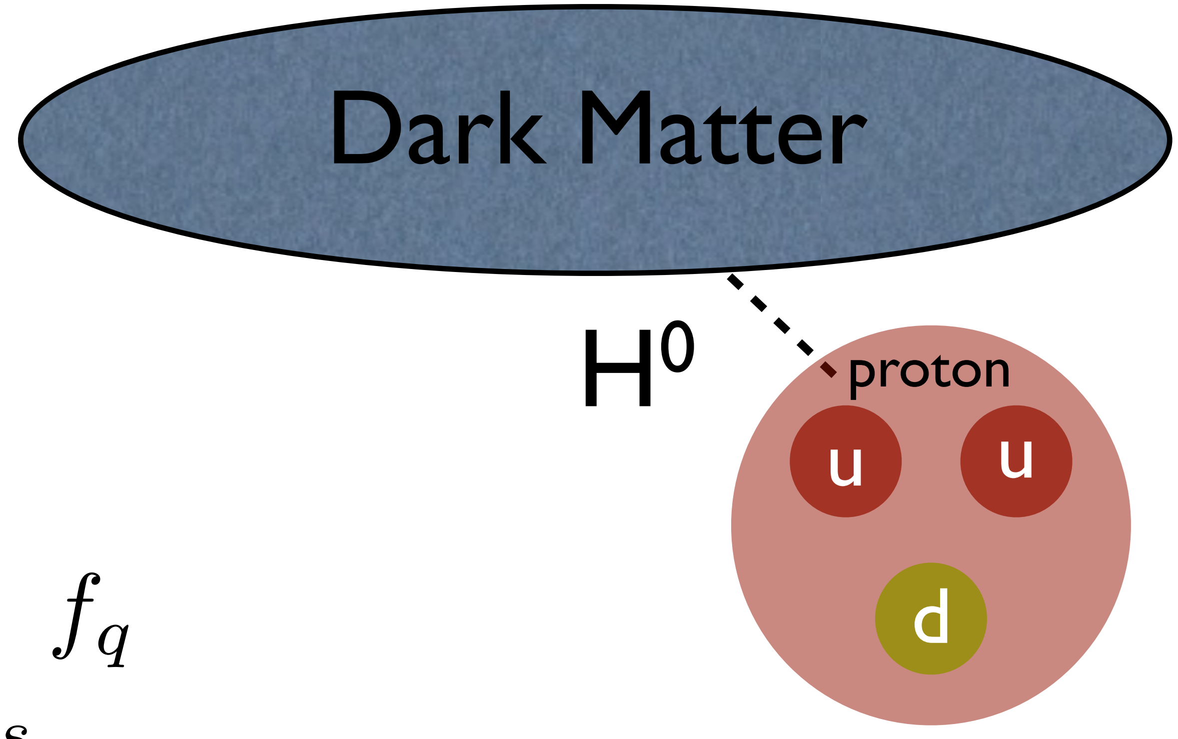


quark mass dependence of nucleon mass helps us understand sensitivities of direct dark matter detection

If Dark Matter couples to the scalar current of the nucleon (eg via Higgs) Spin Independent cross section



$$\sigma \propto |f|^2 \qquad f = \frac{2}{9} + \frac{7}{9} \sum_{q=u,d,s} f_q$$

$$f_q \equiv \frac{\langle N | m_q \bar{q} q | N \rangle}{m_N}$$

see eg. Cheung, Hall, Pinner, Ruderman arXiv:1211.4873

with enhancement of A^2 for nucleus (Xenon)

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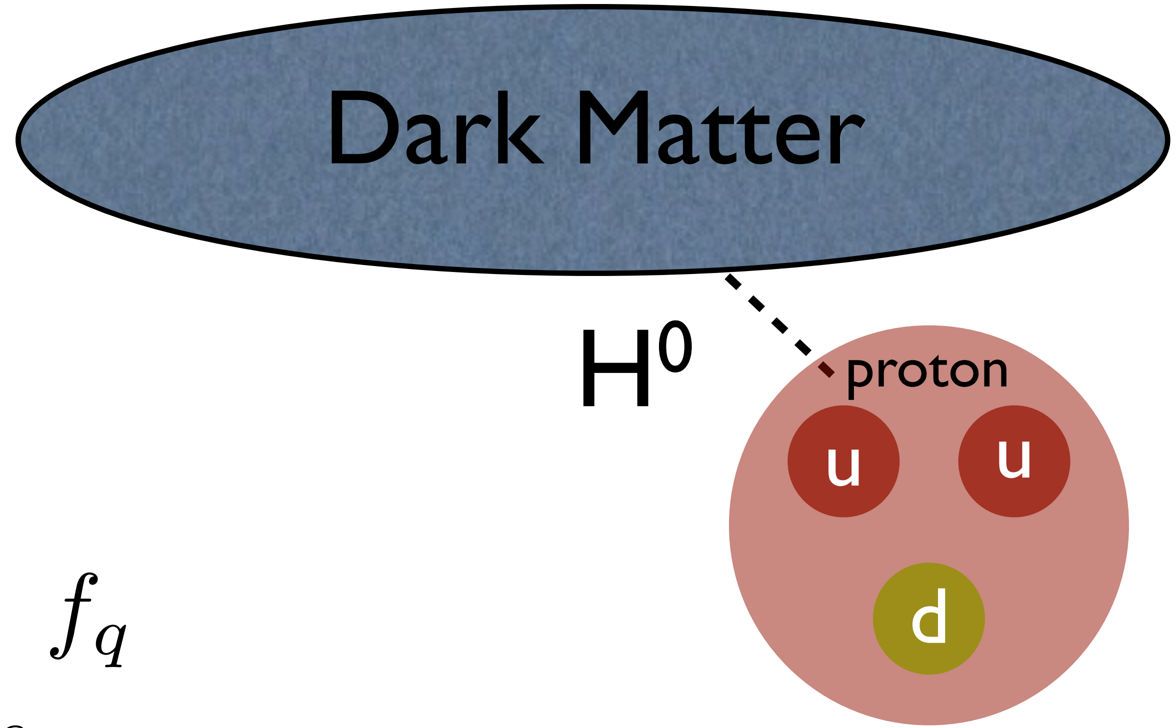

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scalar current difficult to measure experimentally

$f_{u,d}$ estimated from pion-nucleon scattering

f_s uncertainty dominates estimates of cross section

Ellis, Olive, Savage
Phys.Rev. D77 (2008)

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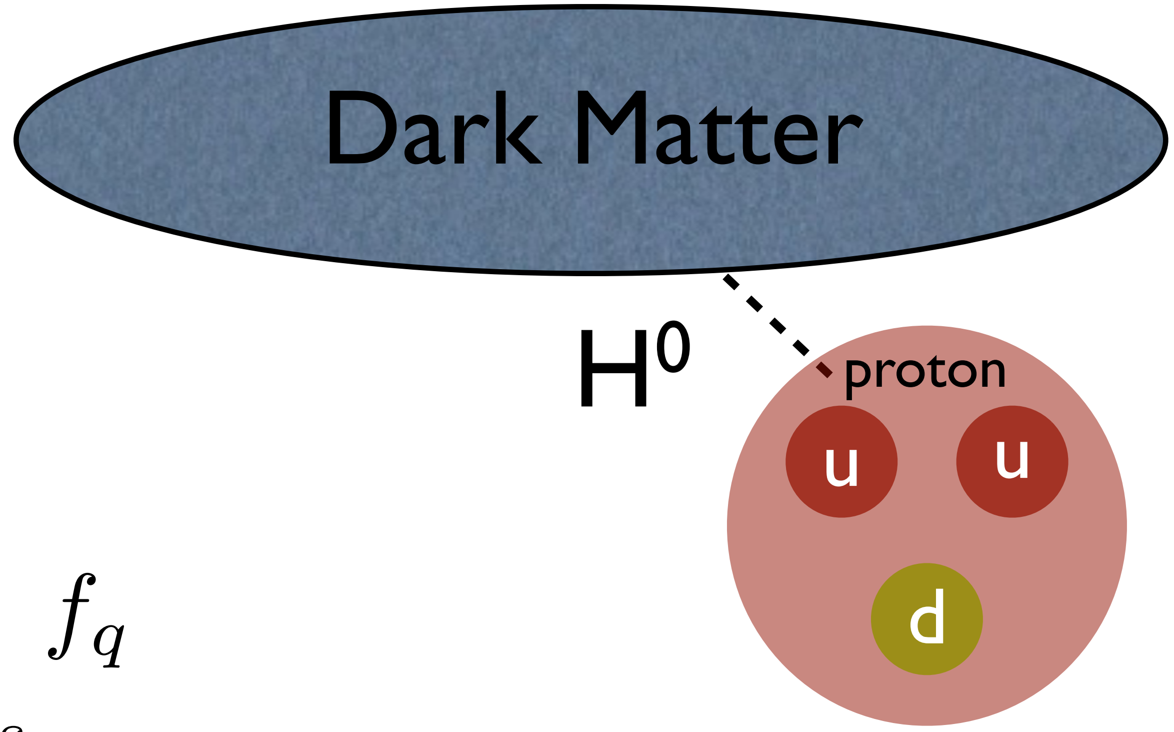

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figure adapted from arXiv:1211.4873
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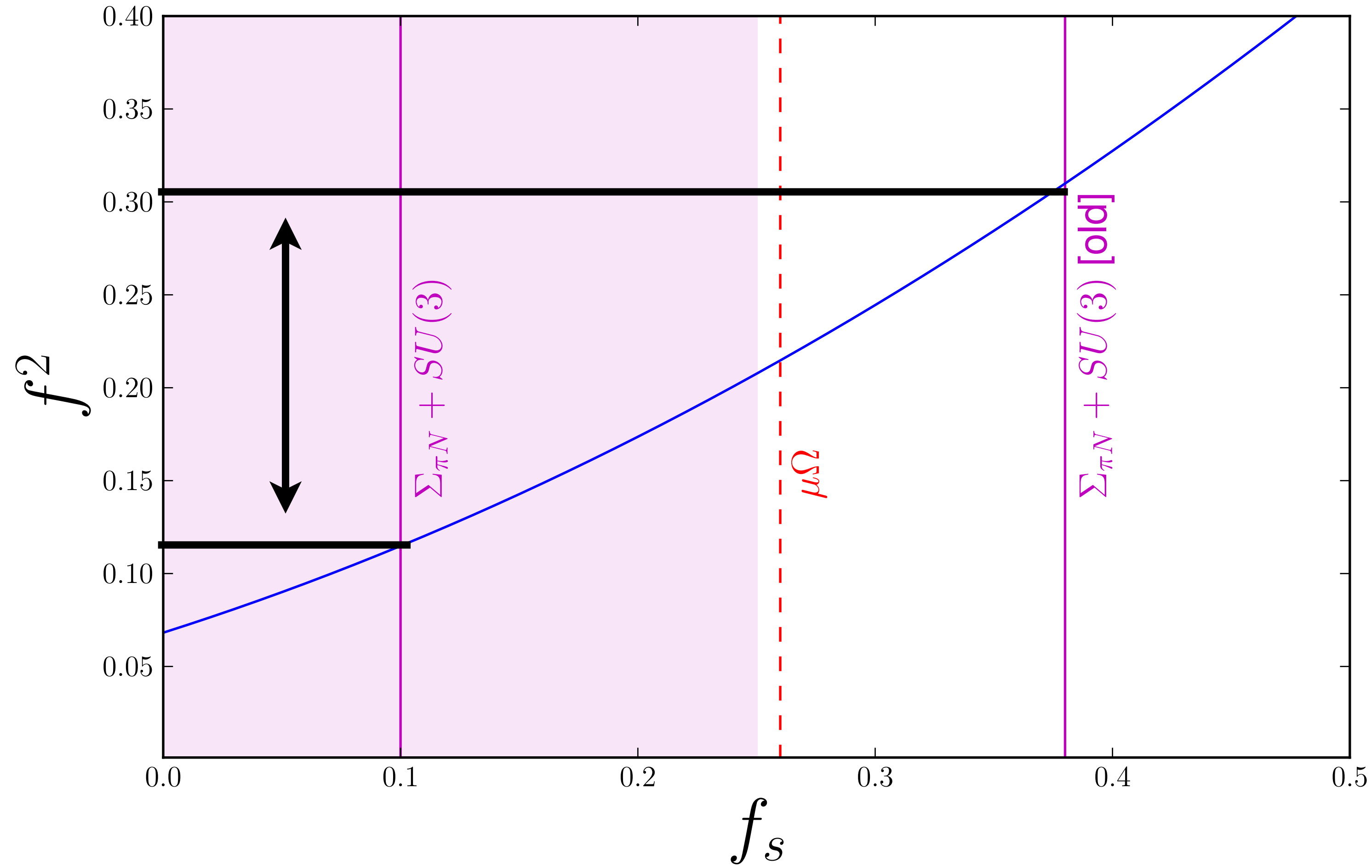


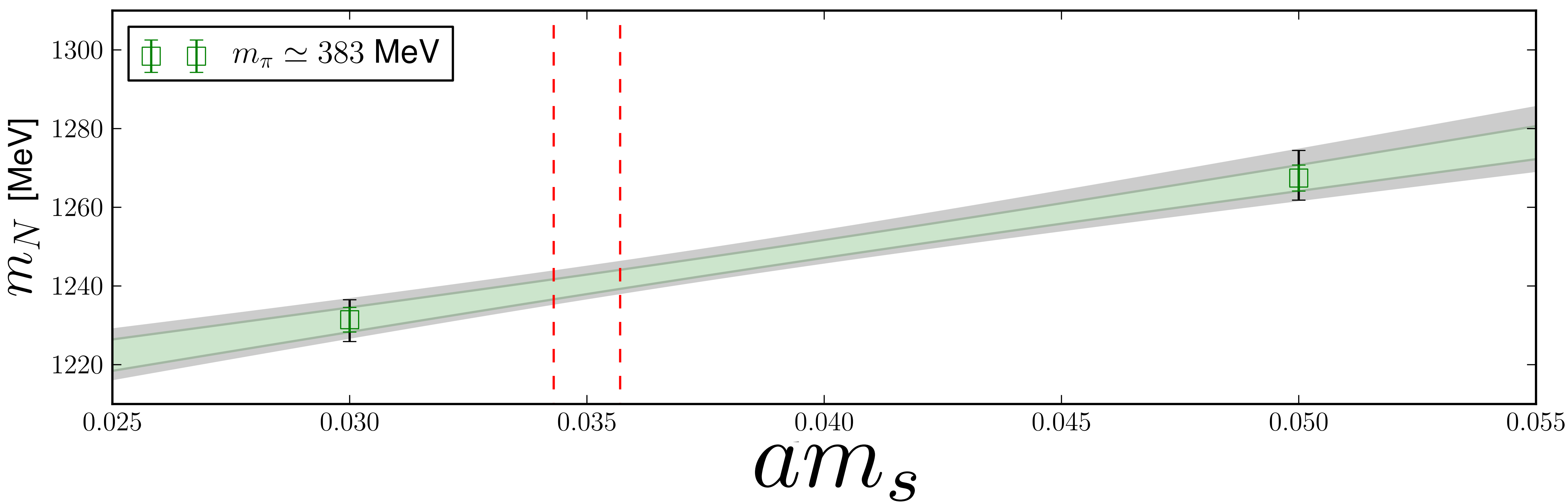
strange content of the nucleon

P. Junnarkar and AWL
arXiv:1301.1114

Lattice QCD perfect tool to compute strange content of nucleon $m_s\langle N|\bar{s}s|N\rangle$

Feynman-Hellmann Theorem $$m_q\langle N|\bar{q}q|N\rangle = m_q \frac{\partial}{\partial m_q} m_N$$

am_s^{phys}



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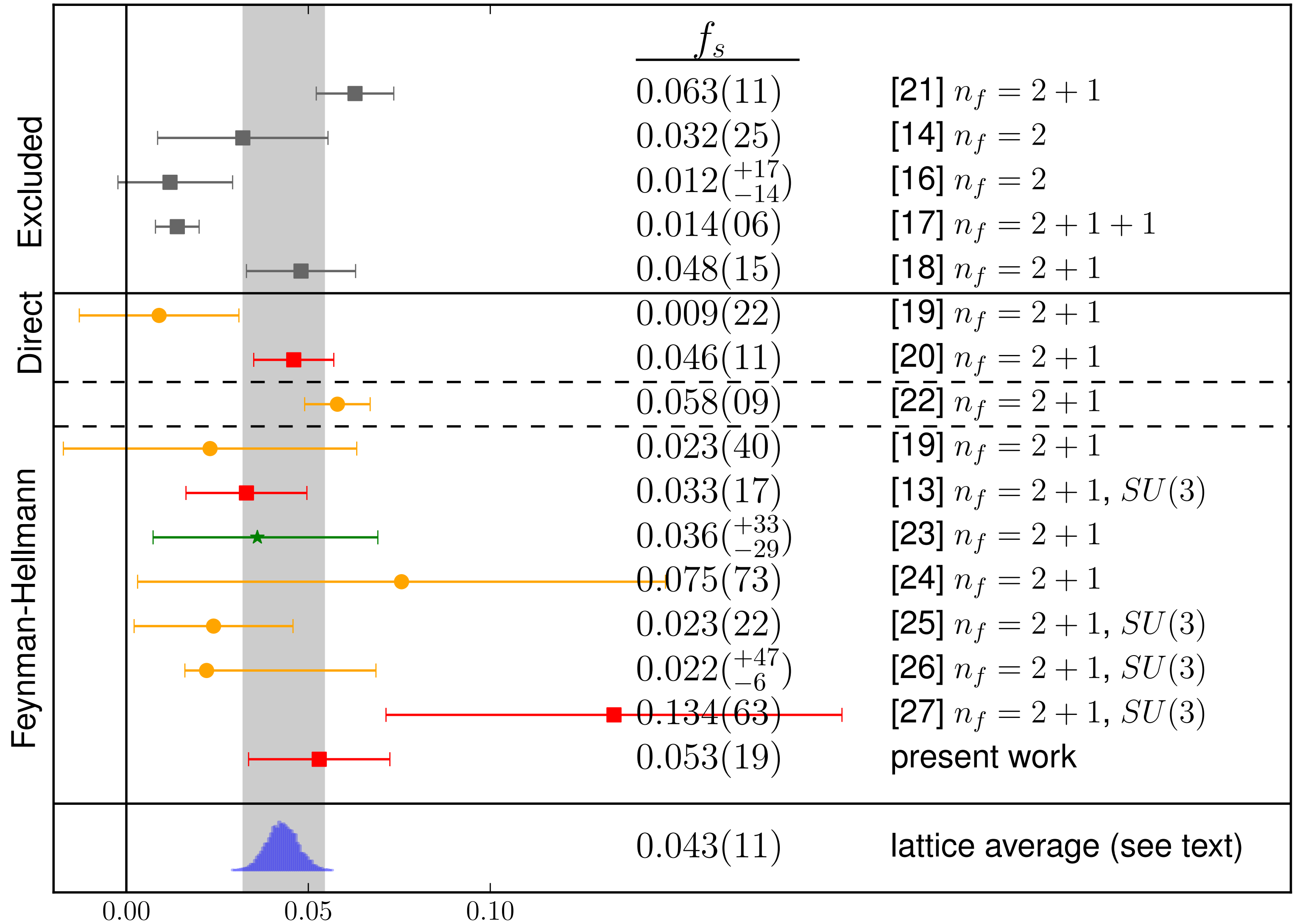

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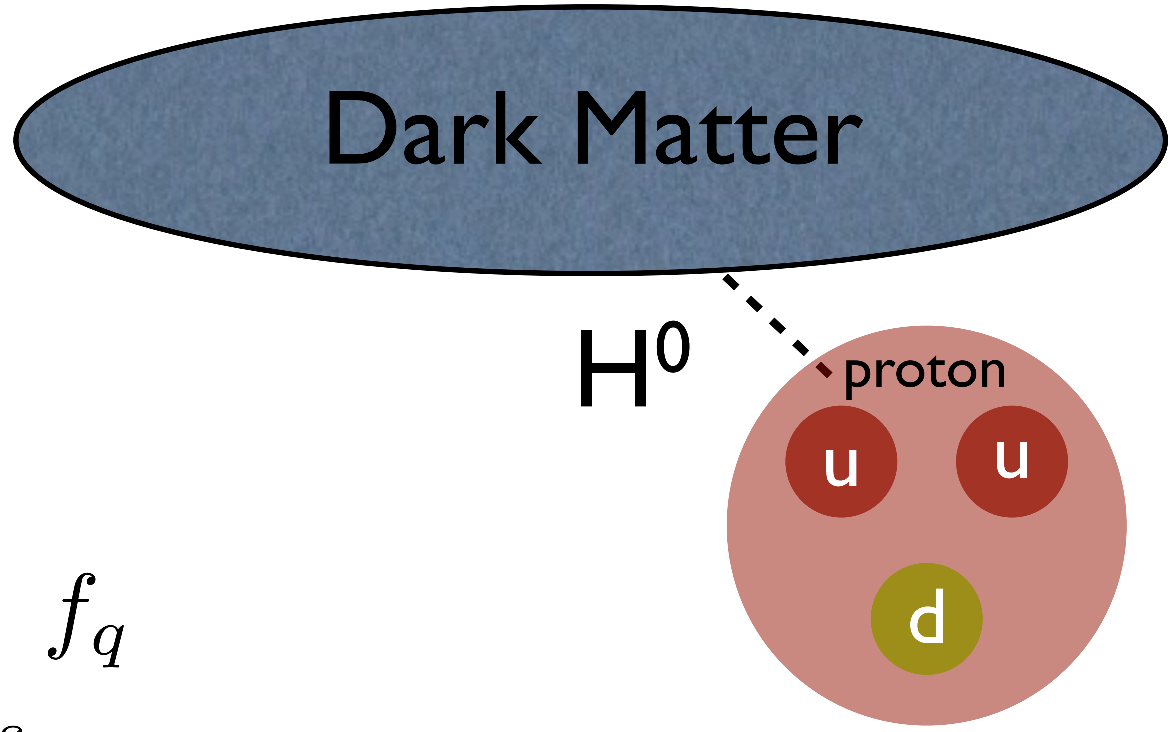

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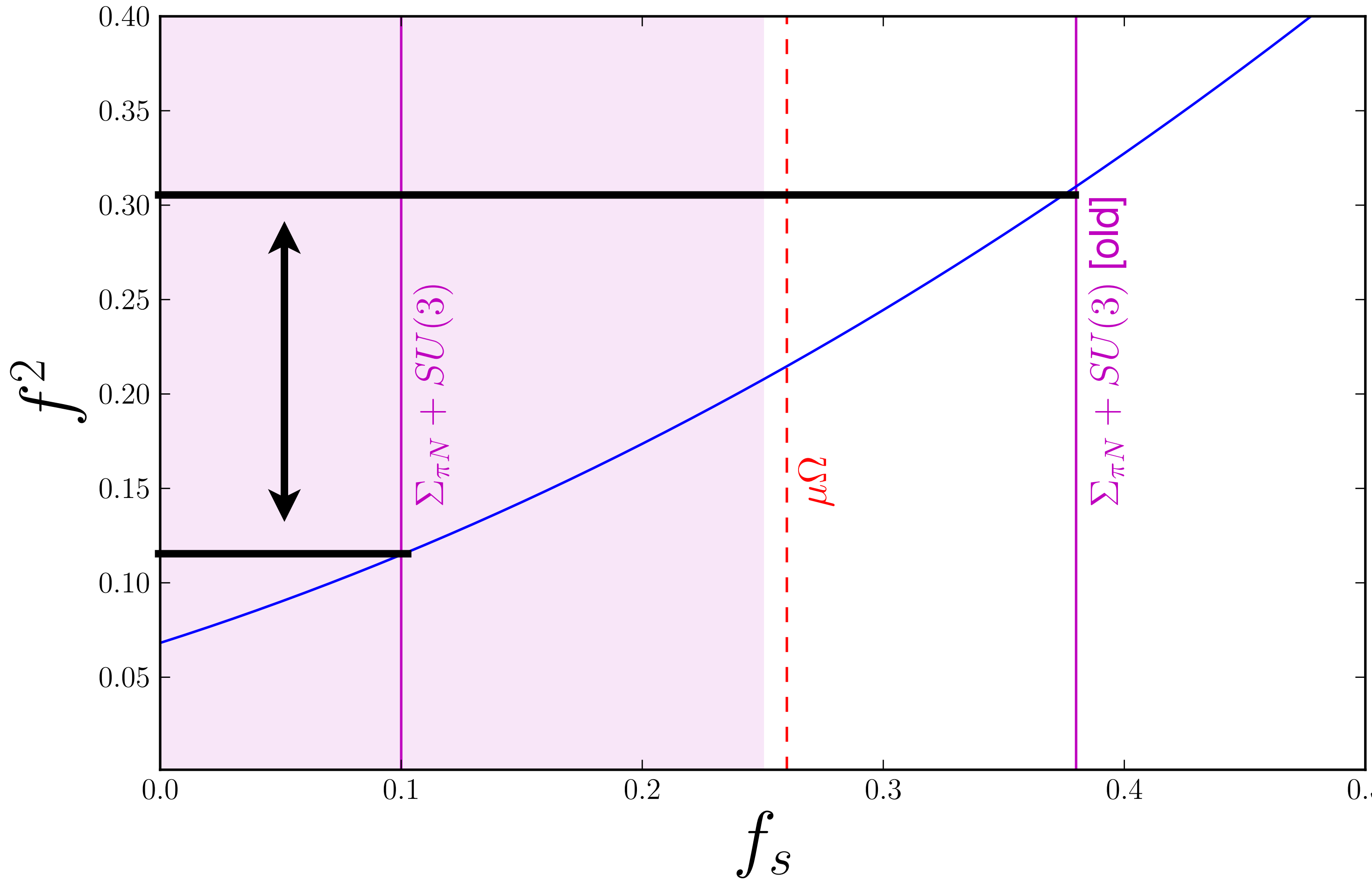

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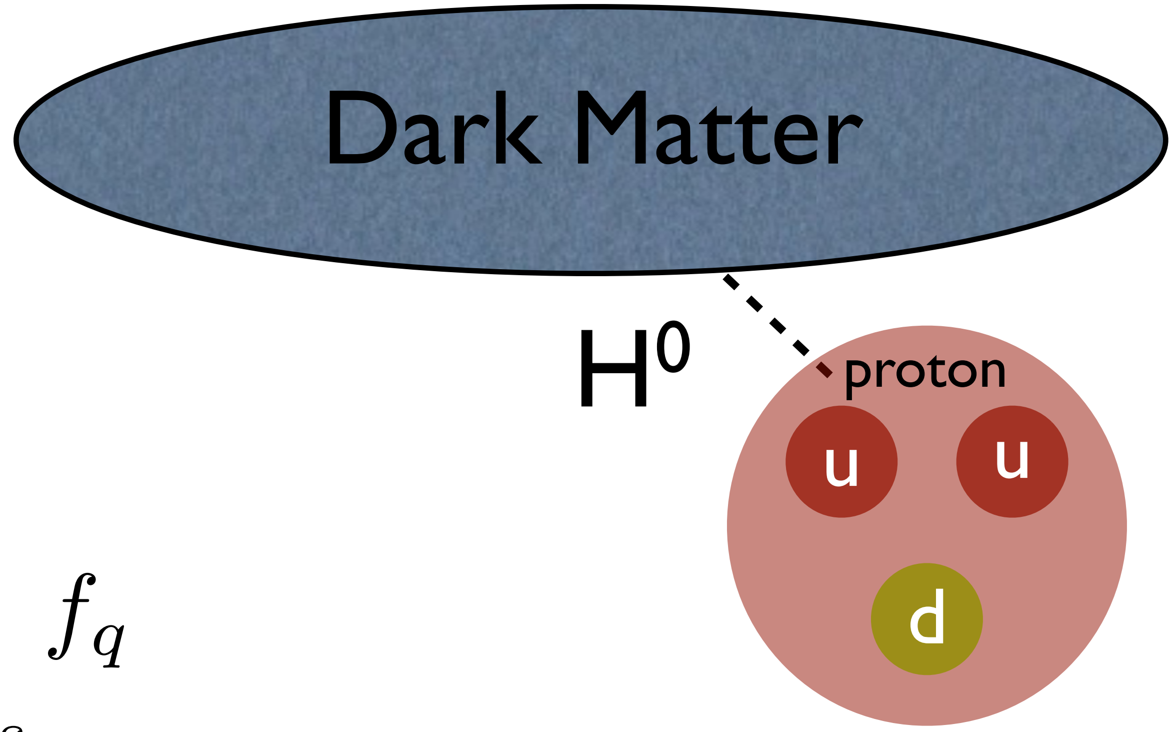

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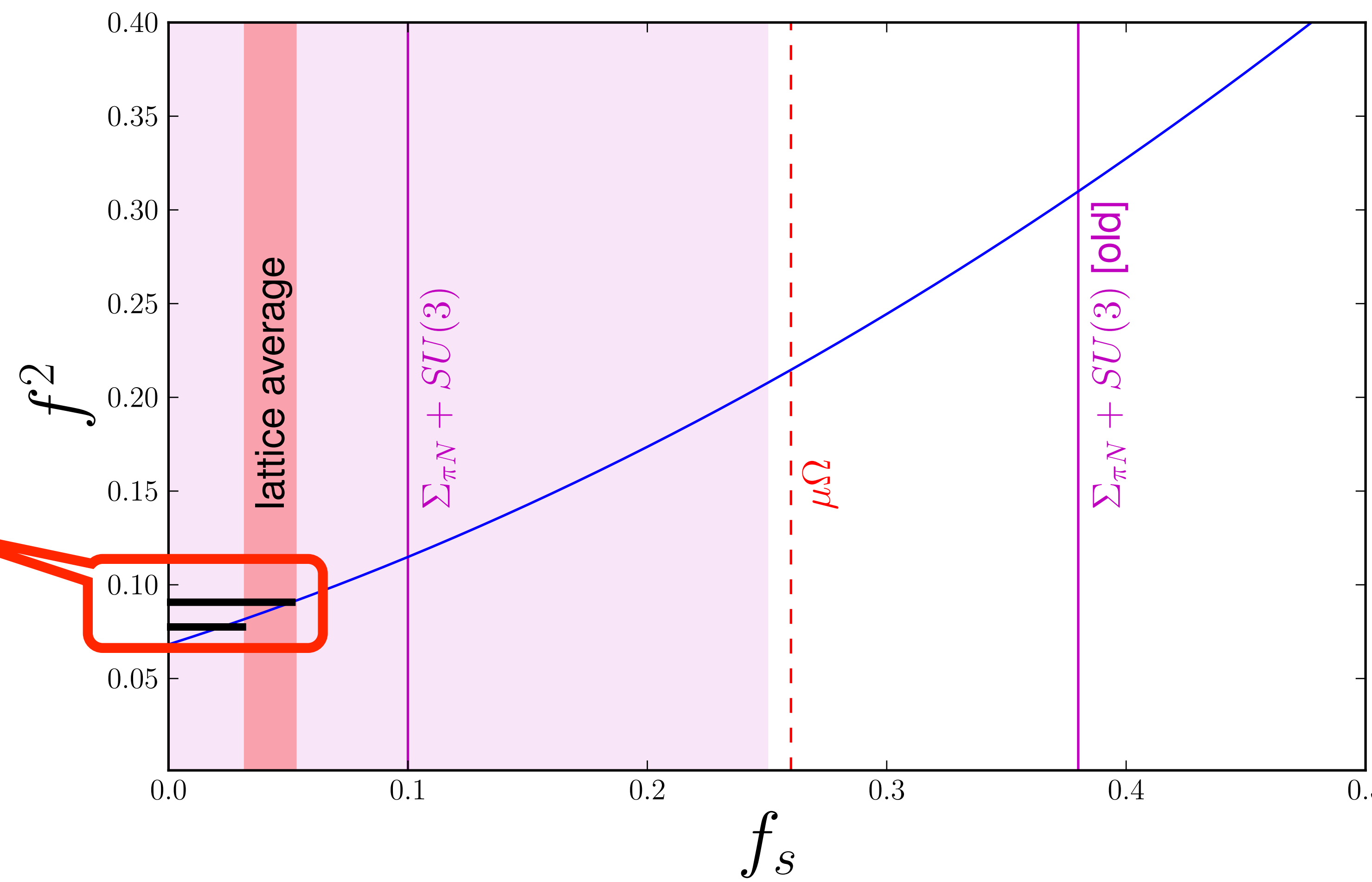
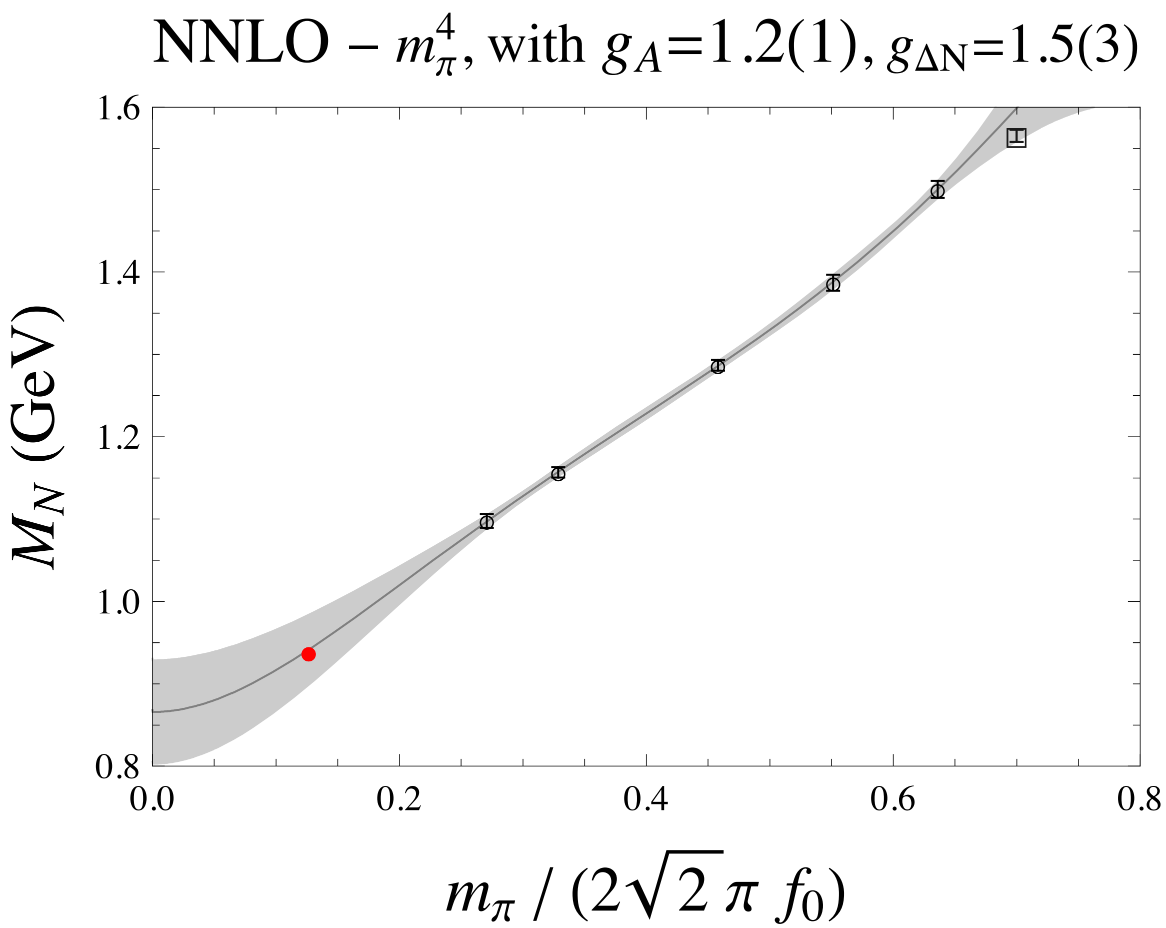
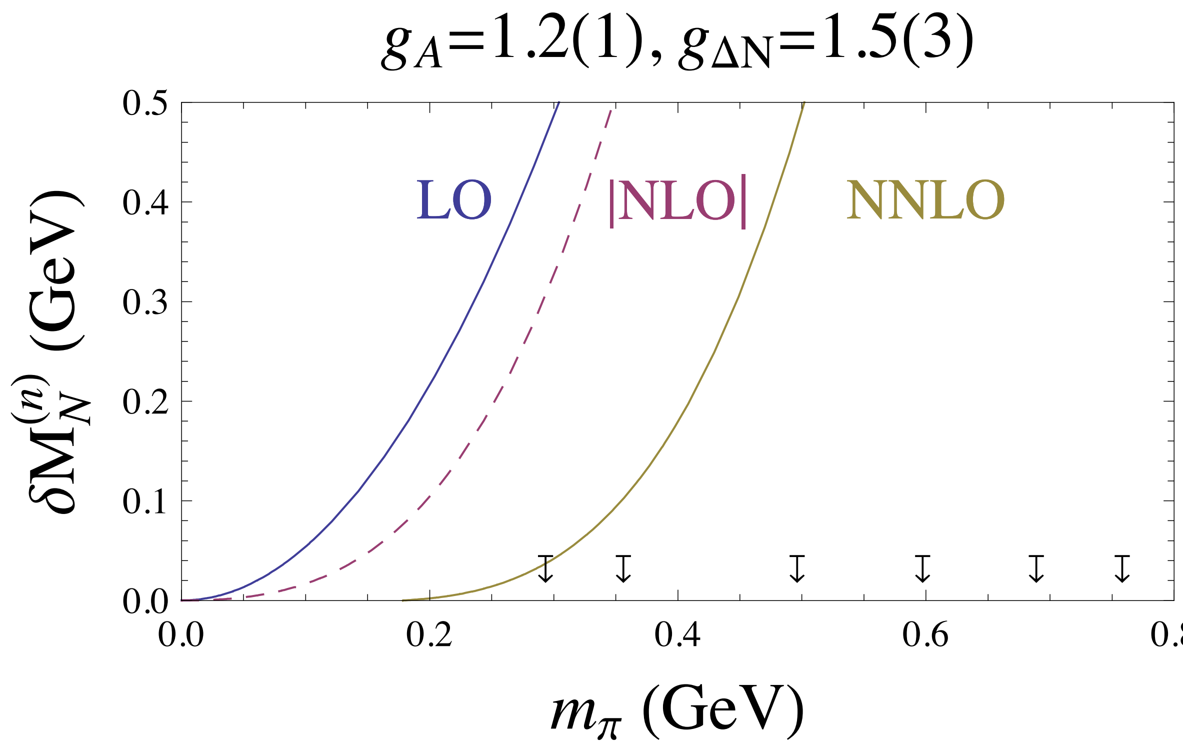


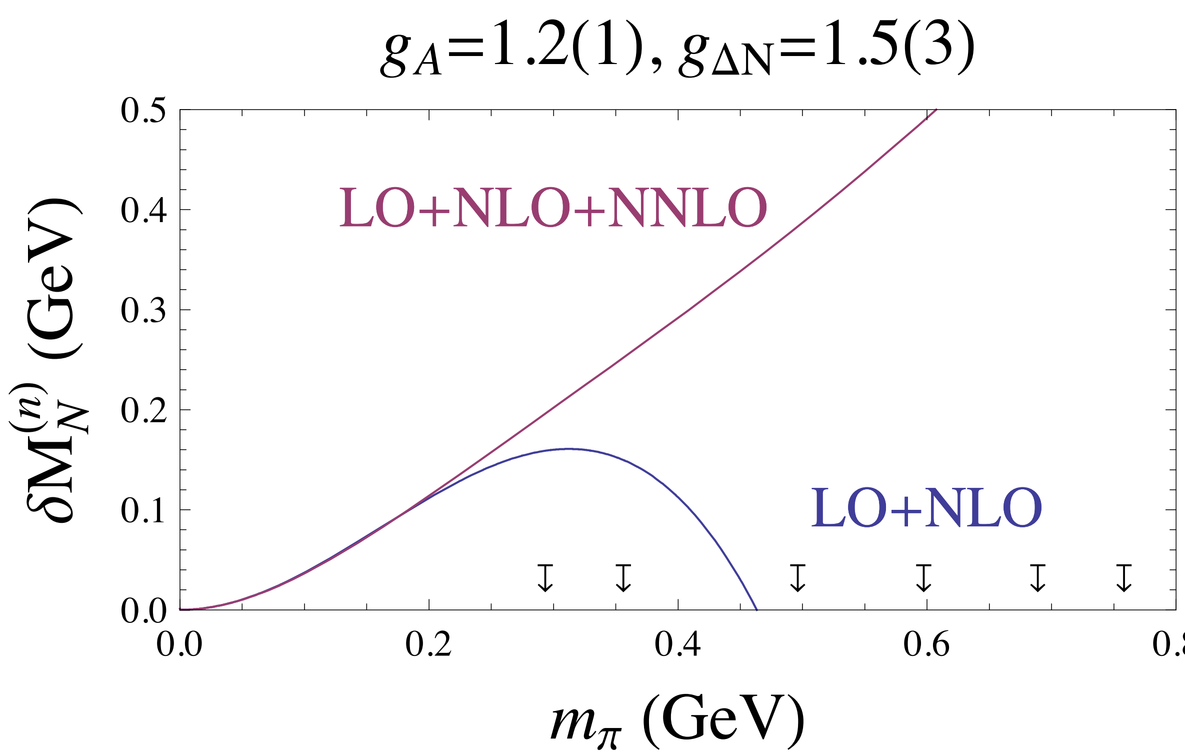
dramatic reduction in uncertainty of cross section

now $f_{u,d}$ gives larger uncertainty - but harder

Baryons in lattice QCD   Light quark mass dependence of M_N







NNLO Heavy Baryon Fit

$$M_N = 954 \pm 42 \pm 20 \text{ MeV}$$

statistical

varying inputs

LHP Collaboration arXiv:0806.4549

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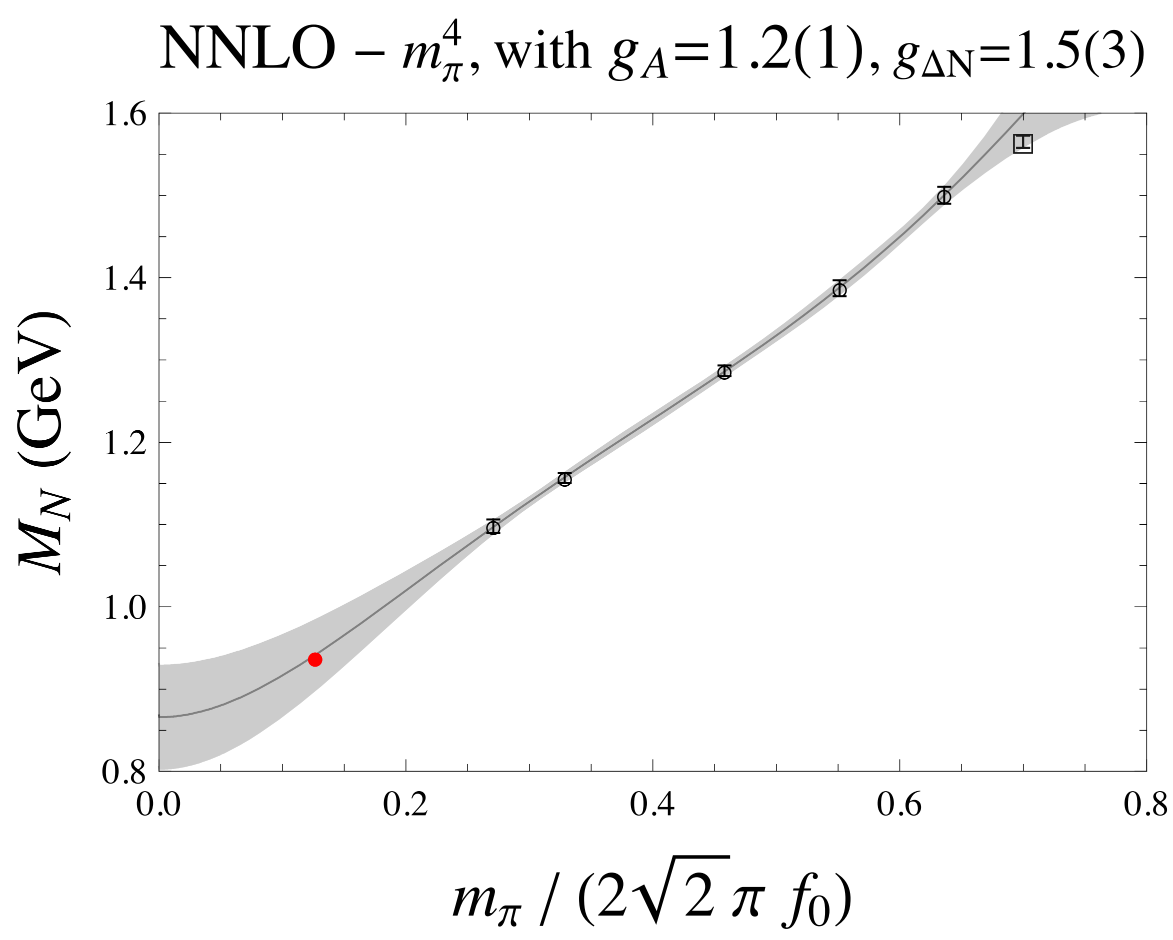

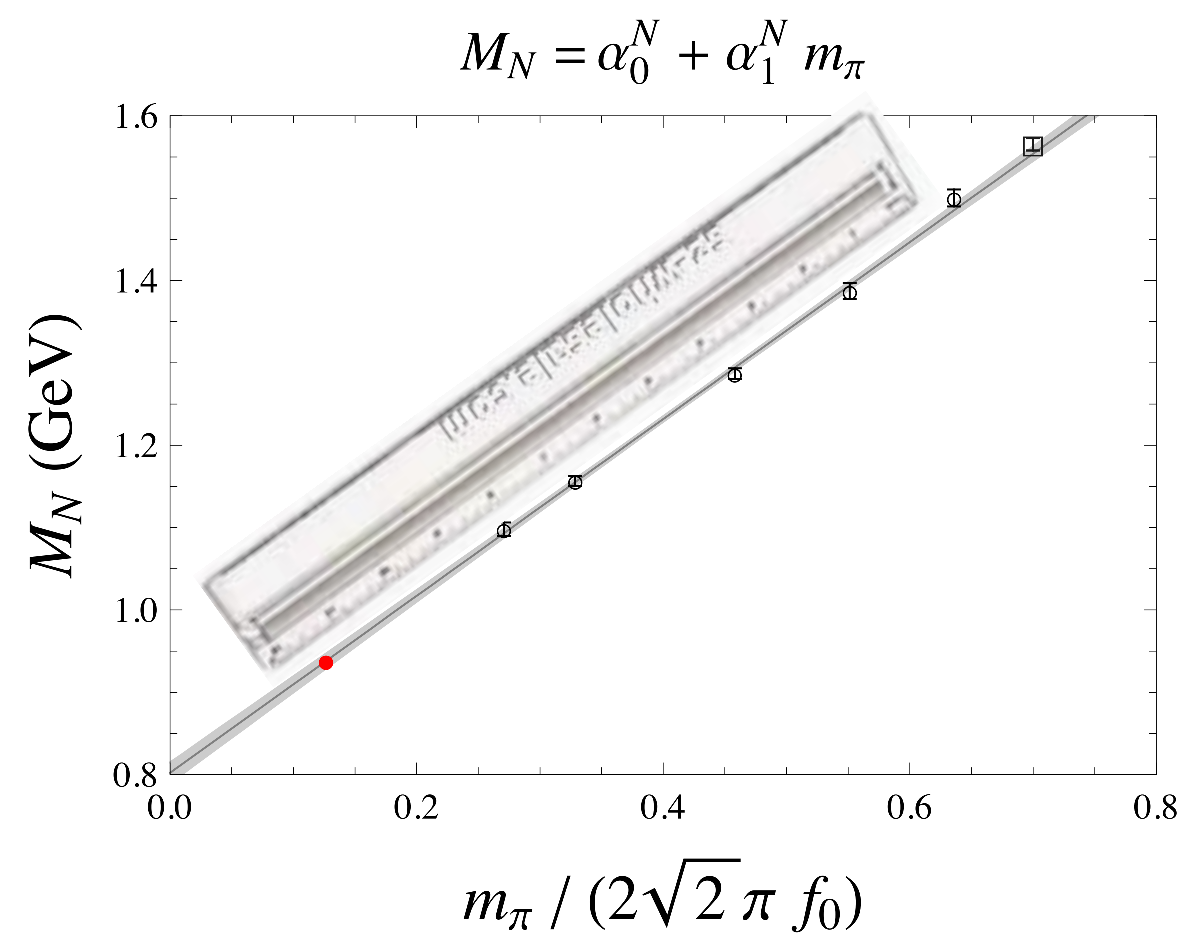

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Ruler Approximation

$M_N = \alpha_0^N + \alpha_1^N m_\pi$

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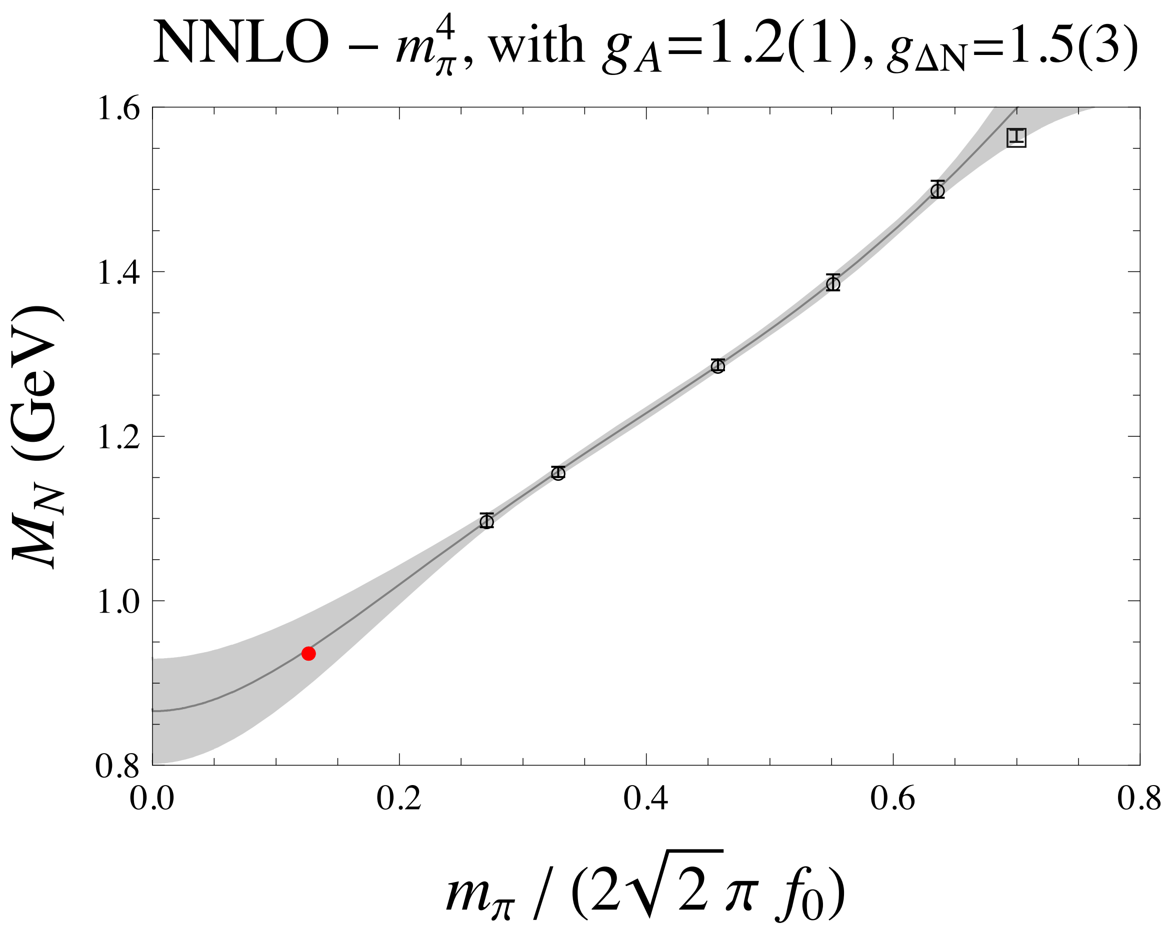

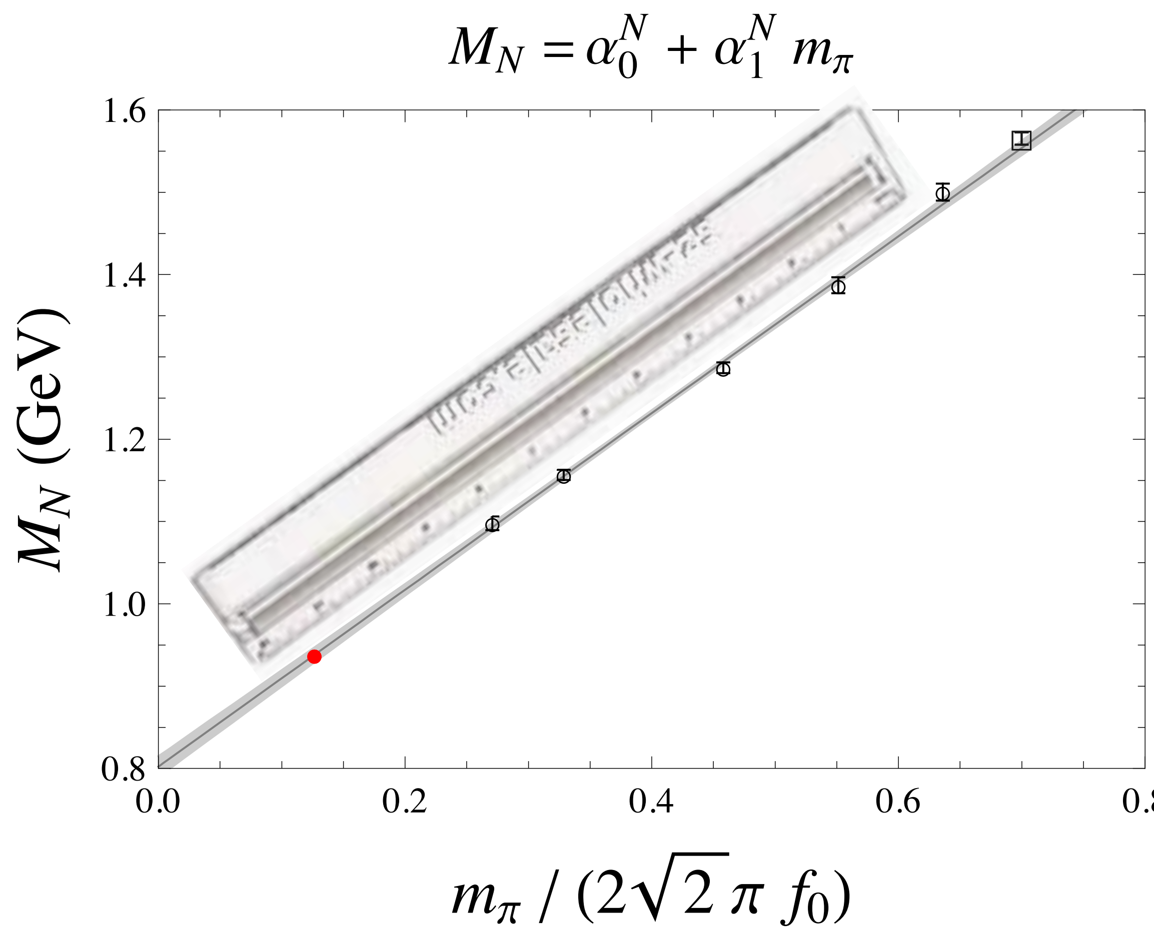

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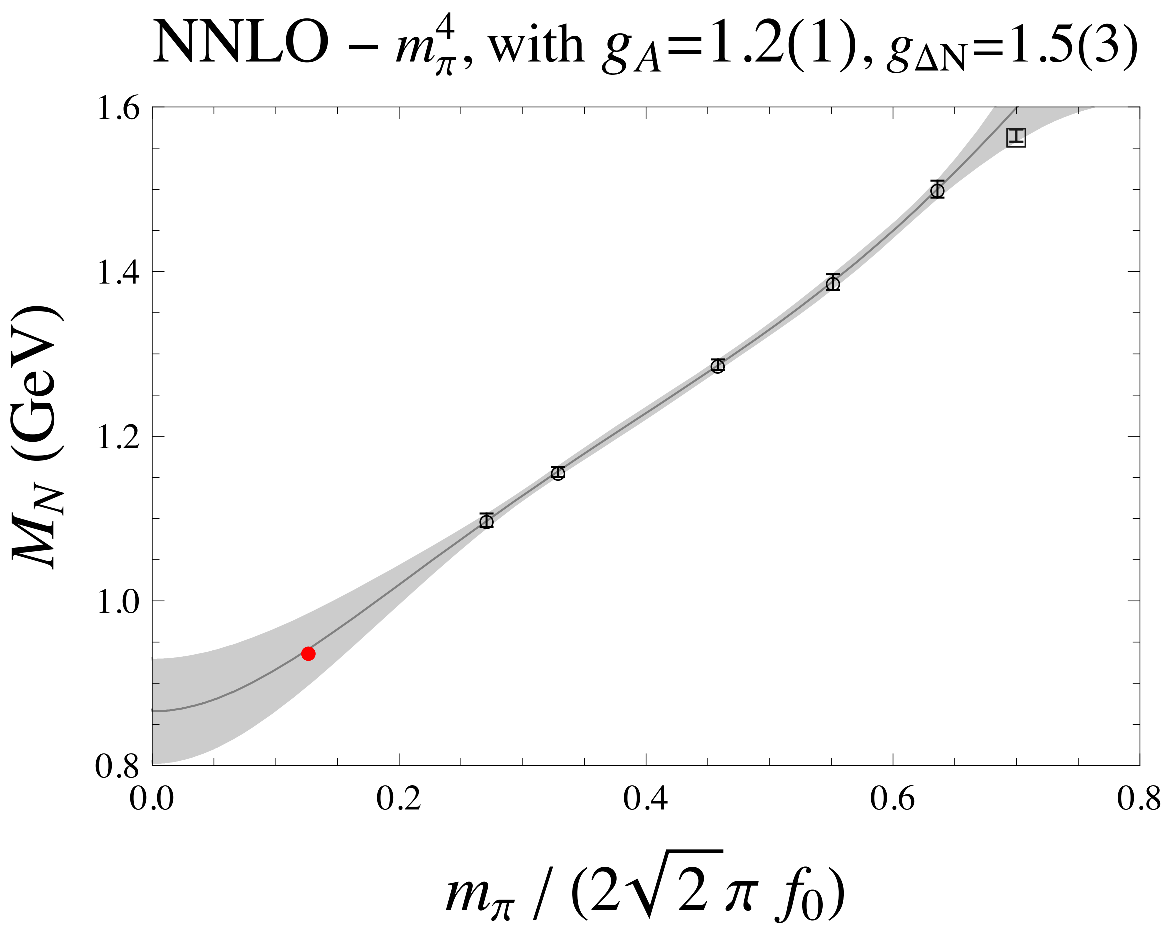

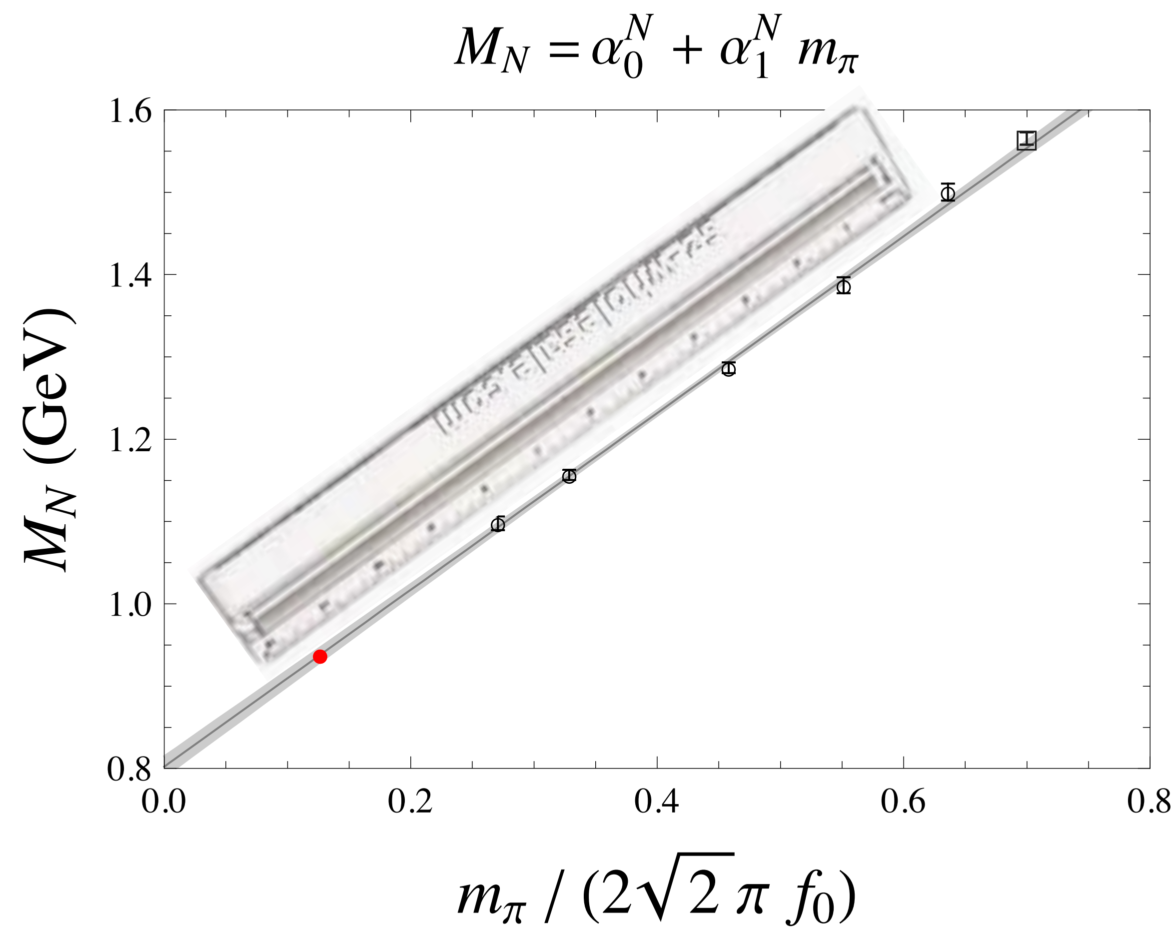

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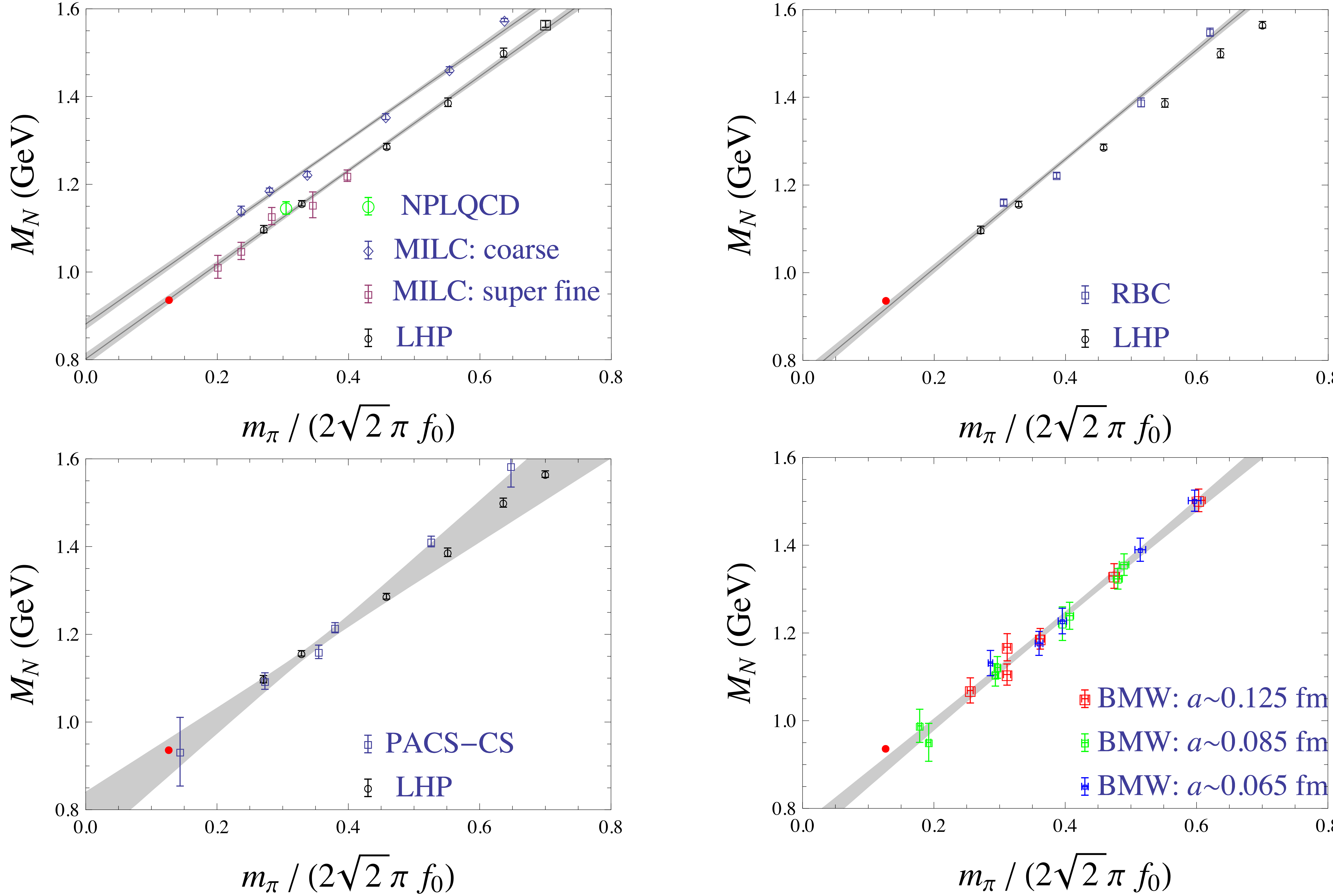
MILC: $M_N = \alpha_0^N + \alpha_1^N m_\pi$ Latt 2008, arXiv:0810.0663 $M_N = \alpha_0^N + \alpha_1^N m_\pi$



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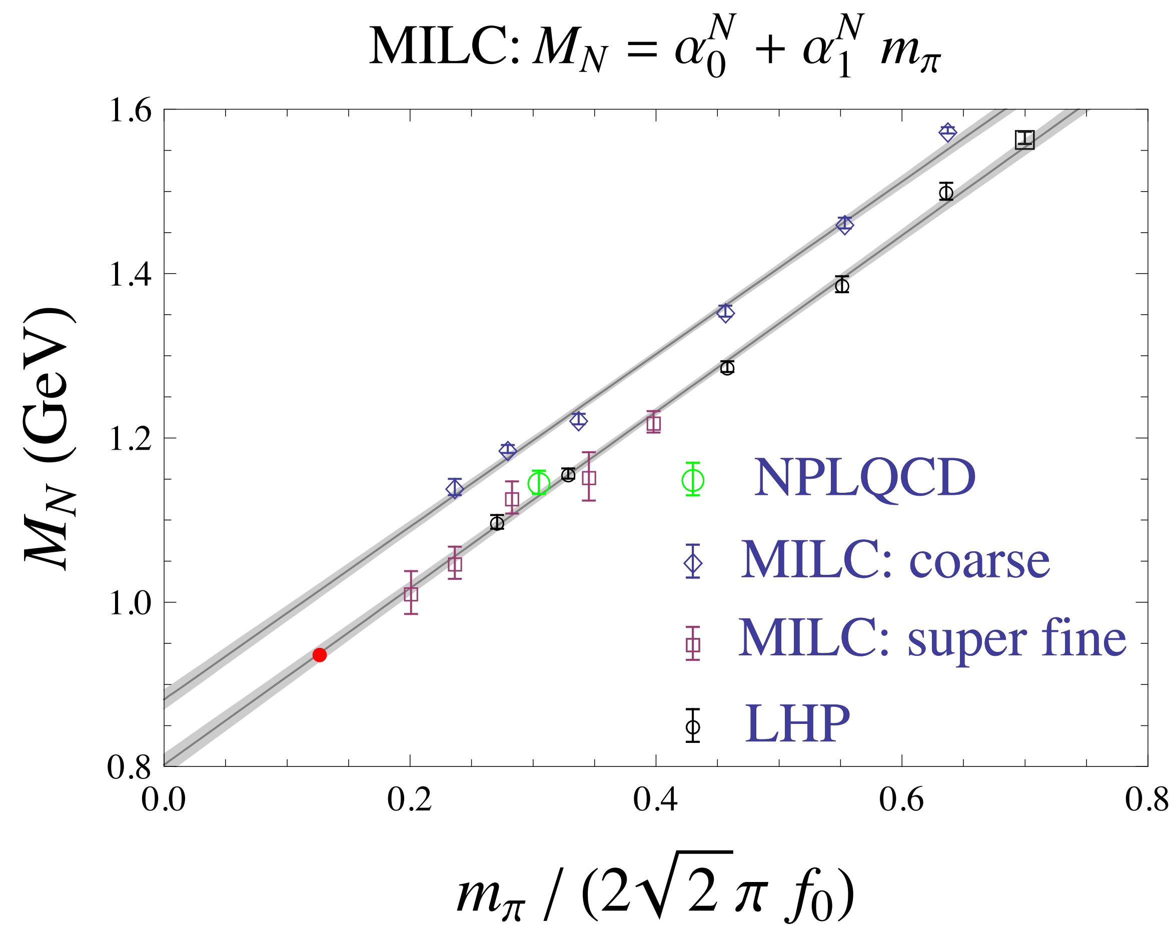
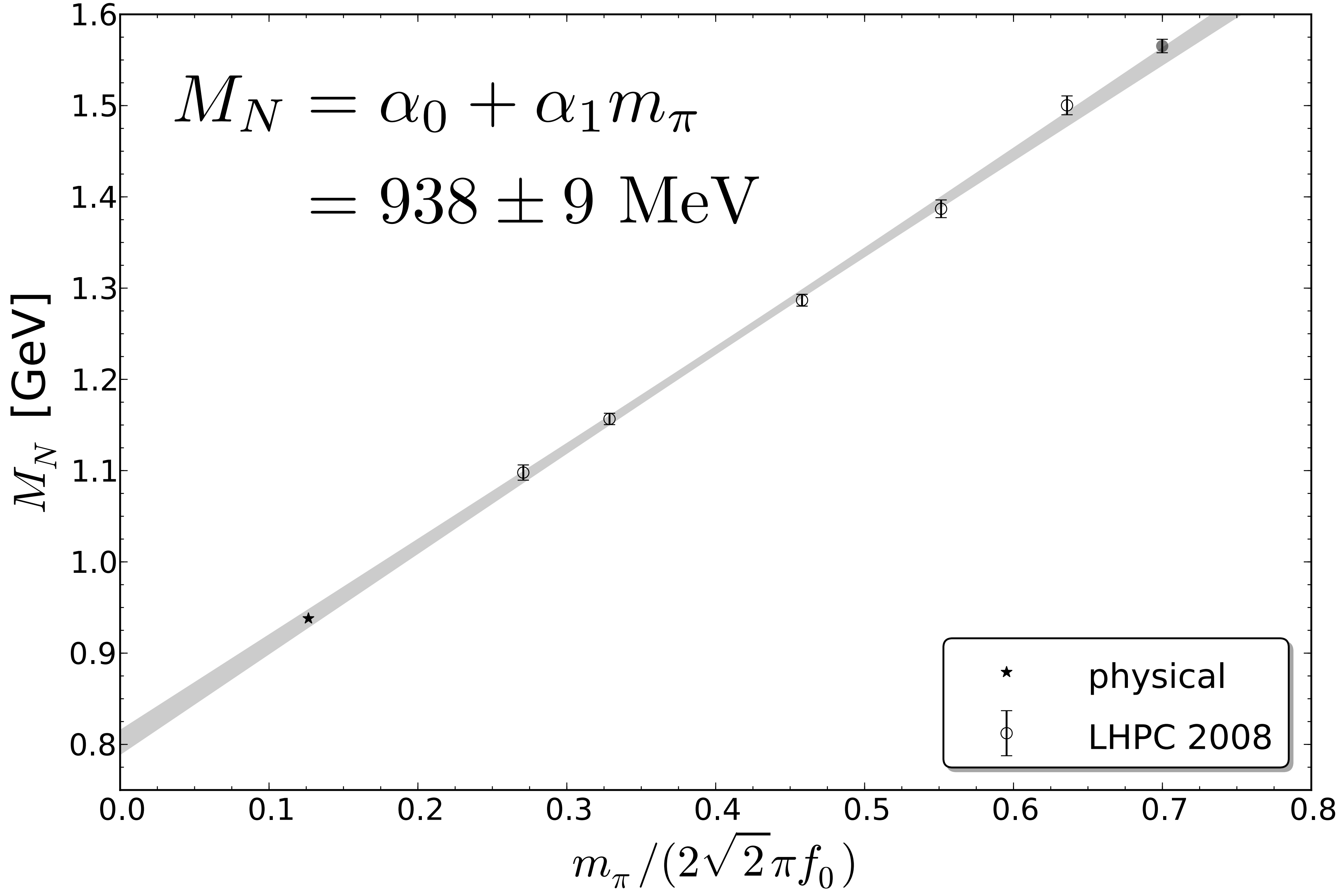


What does this teach us?

For these pion masses, there is a strong cancelation between LO, NLO and NNLO $\chi\mathrm{PT}$ contributions

perhaps should have been expected given poor convergence (but just not a straight line!!!)

What is the status now (2012)?



Physical point NOT included in fit

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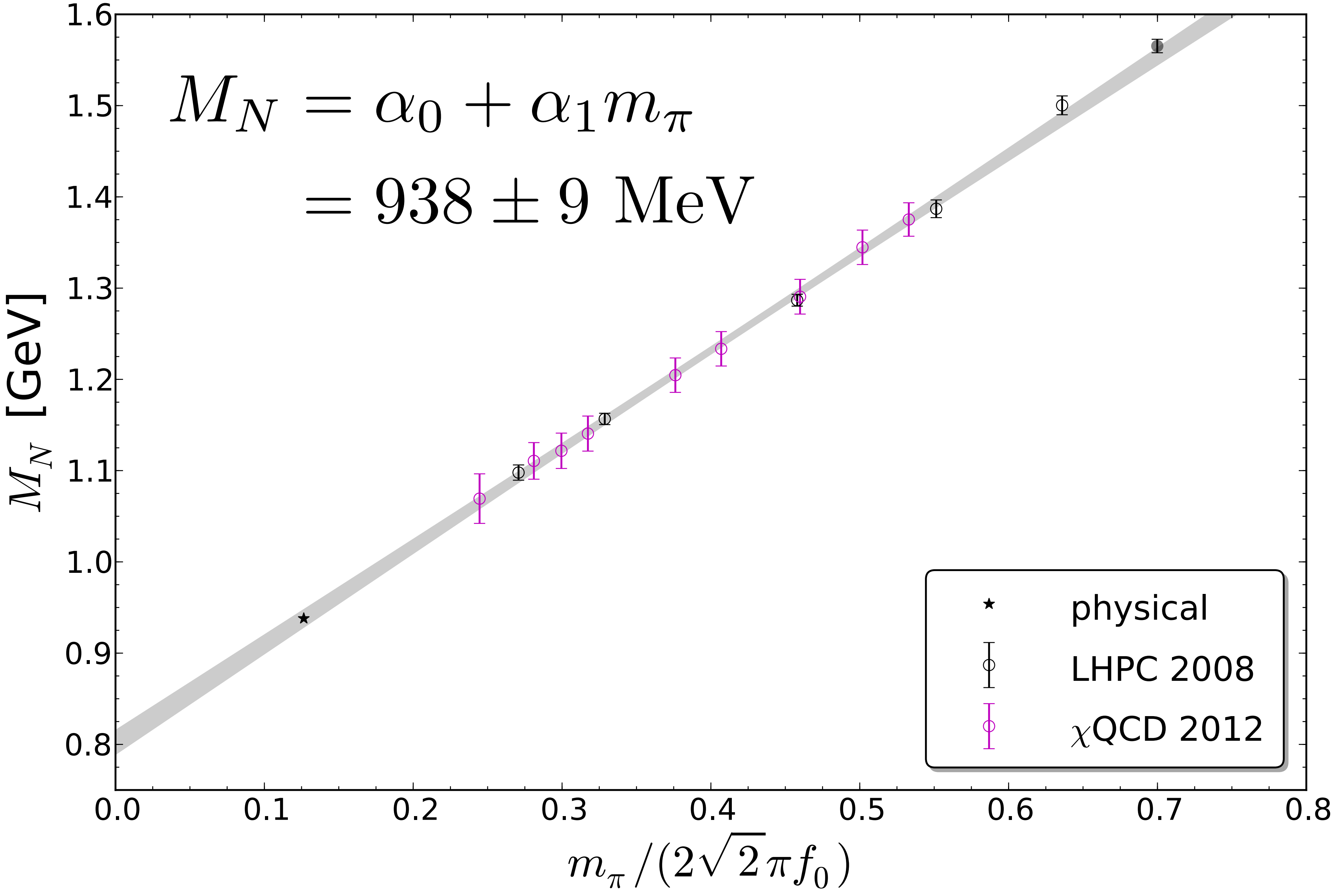

χQCD Collaboration uses Overlap Valence fermions on Domain-Wall (RBC-UKQCD) sea fermions

Light quark mass dependence of M_N

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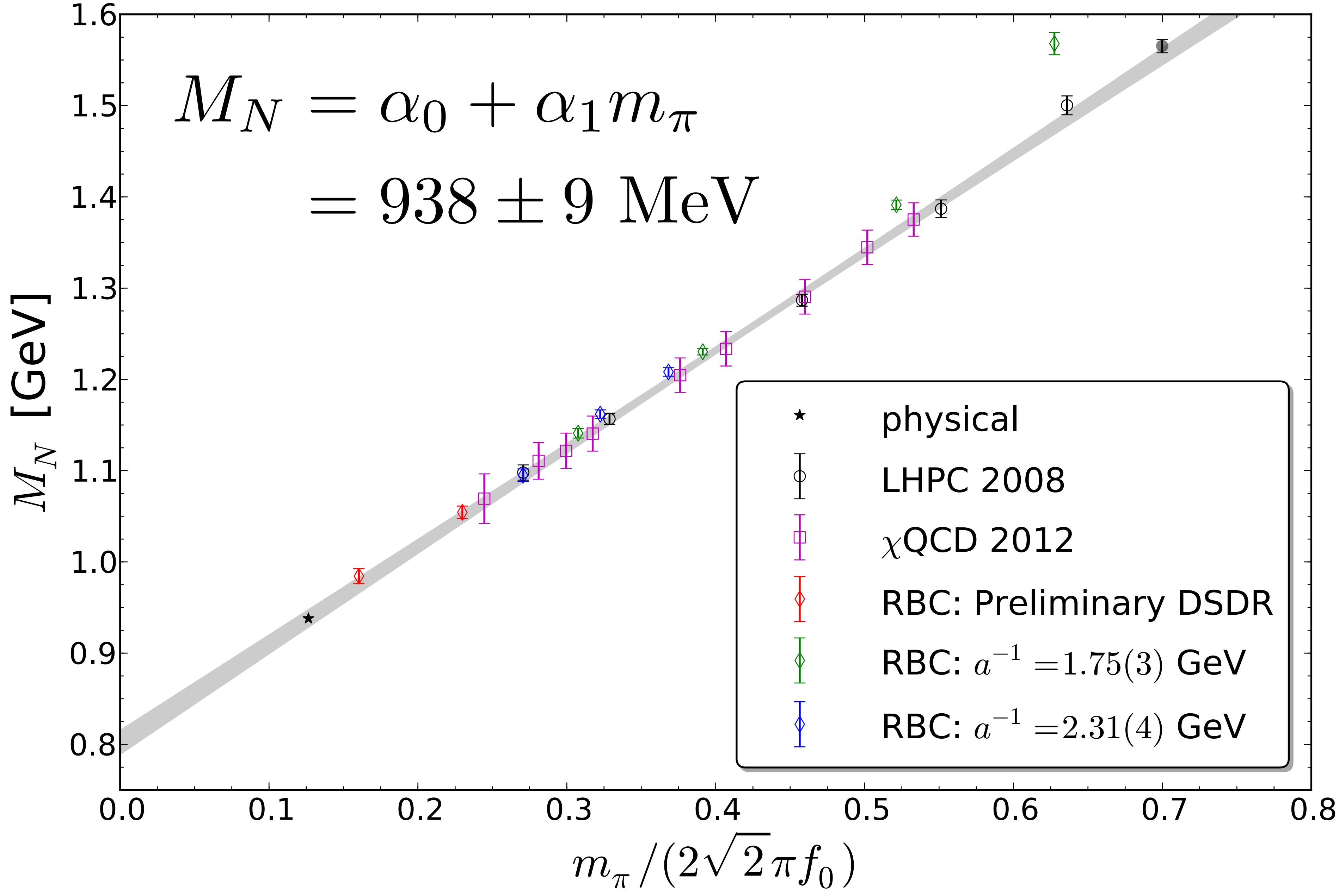

RBC-UKQCD Collaboration uses Domain-Wall valence and sea fermions

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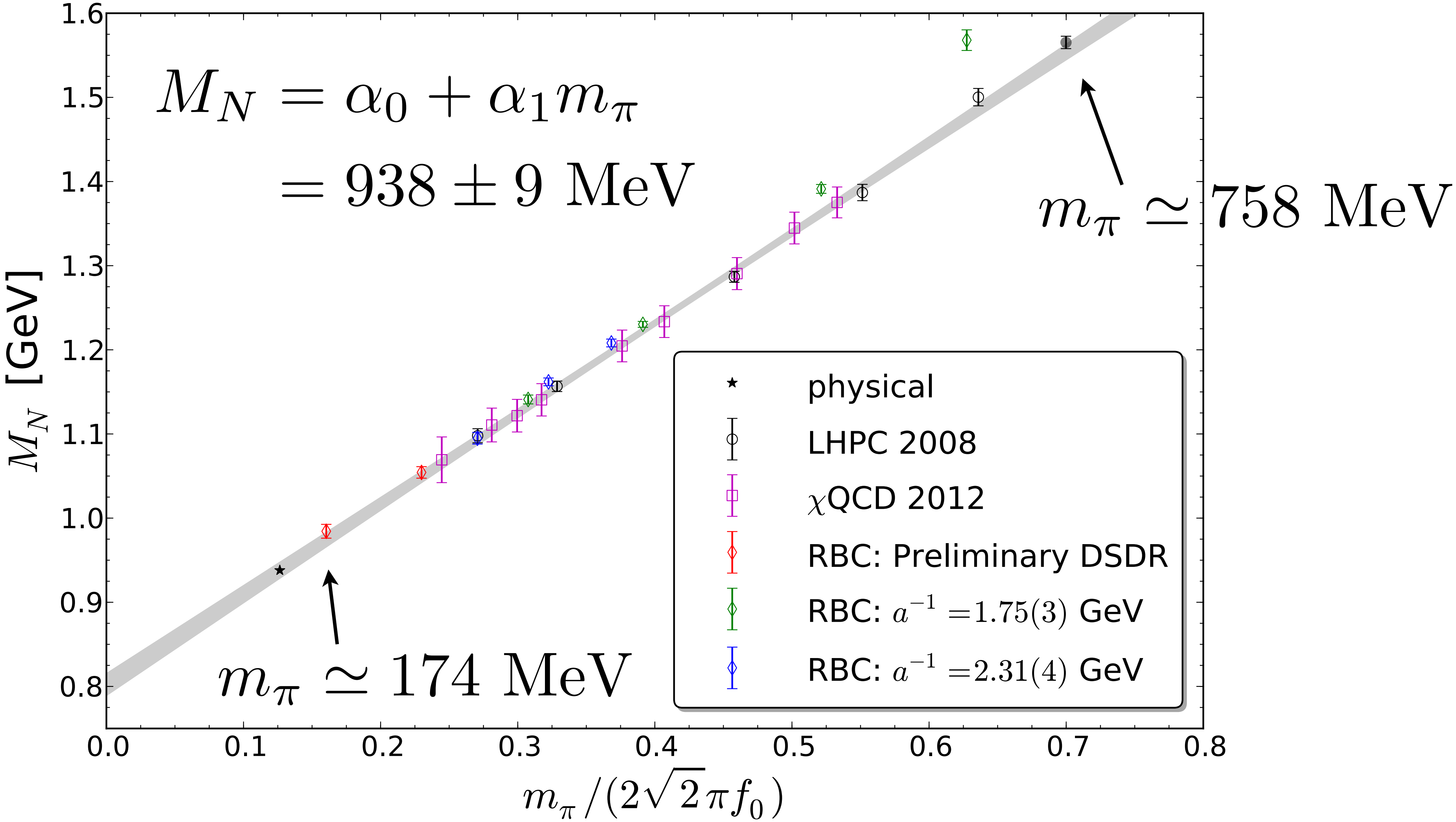

Taking this seriously yields

$$\sigma_{\pi N} = 67 \pm 4 \text{ MeV}$$

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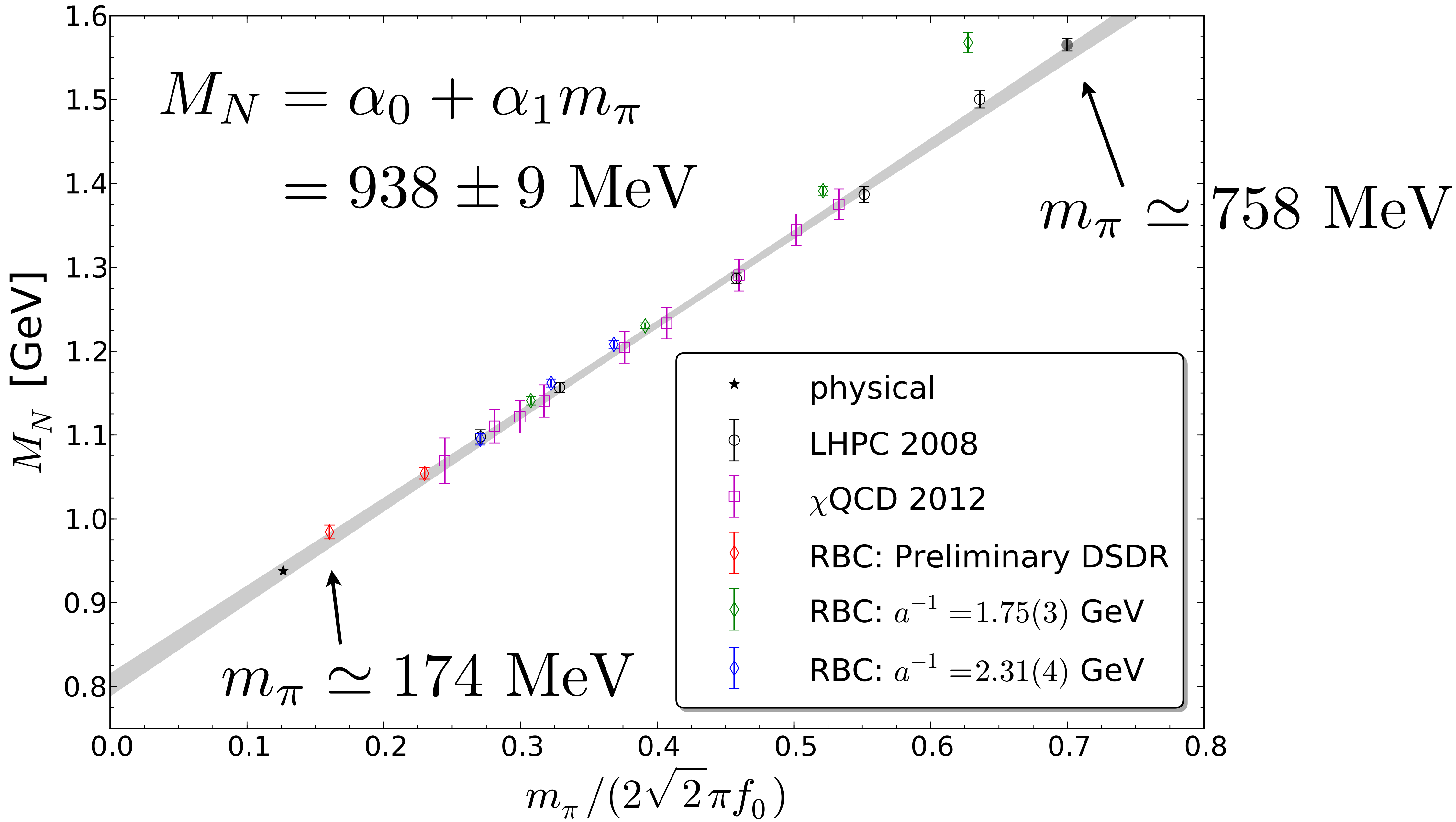

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