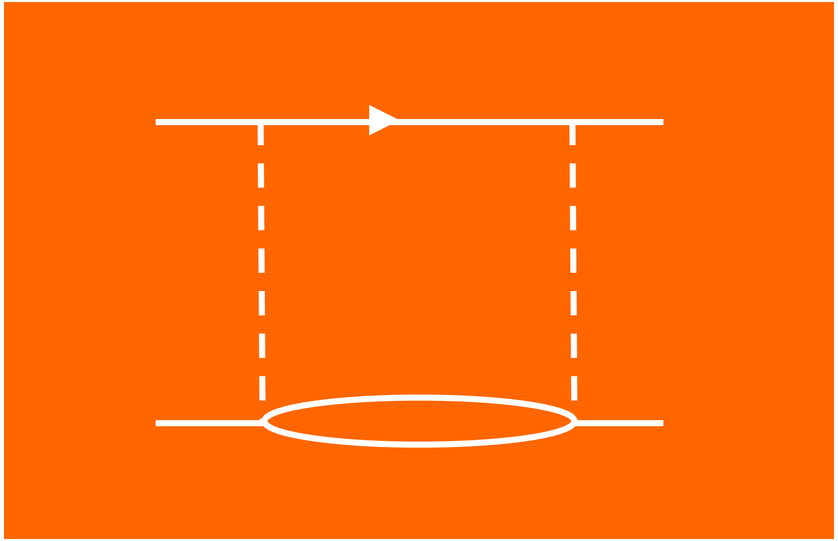
Understanding the Deuteron Radius Discrepancy: A systematic study of nuclear structure uncertainties



Presented by: Oscar Javier Hernandez

In collaboration with:

Andreas Ekström

Nir Nevo Dinur

Chen Ji

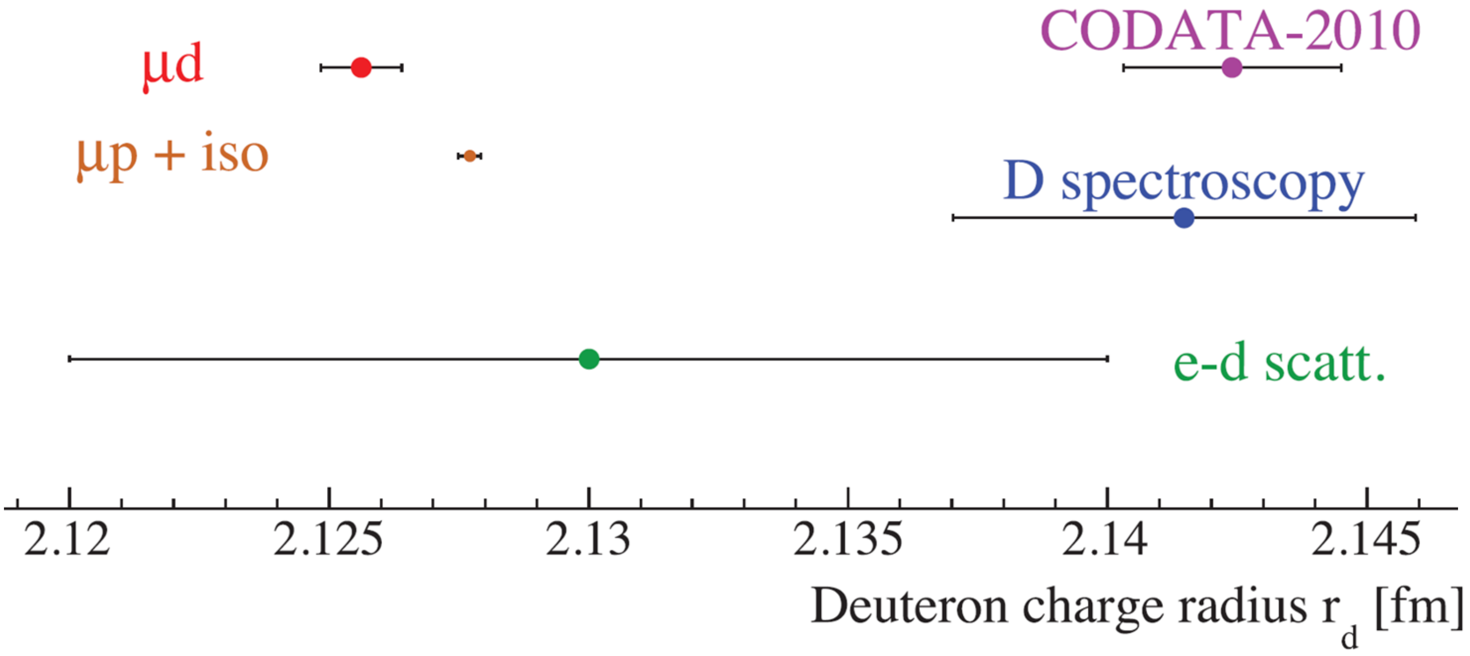
Sonia Bacca

Nir Barnea

THE UNIVERSITY OF BRITISH COLUMBIA

TRIUMF

There is a discrepancy between eD and μD data



[Pohl *et. al.* Science, Vol 353, 6300, 2016]

δ_{TPE} discrepancy between theory and experiment

$\langle r_{ch}^2 \rangle_d - \langle r_{ch}^2 \rangle_p$ =3.82007(65) fm^2

U.D. Jentschura, et al. Phys. Rev. A **83**, 042505 (2011)

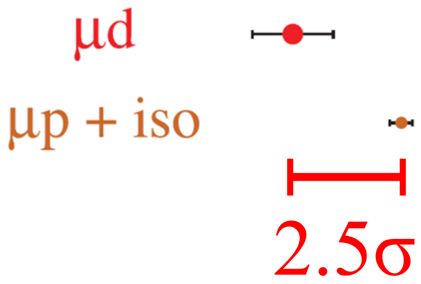
δ_{TPE} discrepancy between theory and experiment

$\delta_{TPE}(Our\ Work)$= -1.727(20) meV [Hernandez et. al, 2014]

$\delta_{TPE}(Pachucki)$ = -1.717(20) meV [Pachucki et. al, 2015]

$$\Delta E(2S-2P) = \delta_{QED} + \frac{m_r^3}{12}(Z\alpha)^4 \langle r_{ch}^2 \rangle_d + \delta_{TPE}$$

δ_{TPE} discrepancy between theory and experiment



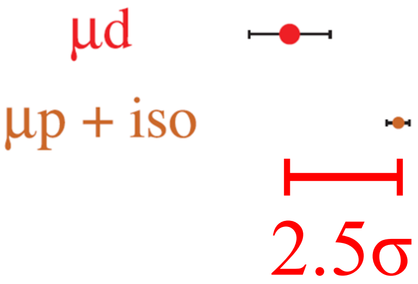
$\delta_{TPE}(Our\ Work)$= -1.727(20) meV [Hernandez et. al, 2014]

$\delta_{TPE}(Pachucki)$ = -1.717(20) meV [Pachucki et. al, 2015]

$\delta_{TPE}(Exp)$= -1.7638(68) meV [Pohl *et. al.* Science, 2016]

$$\Delta E(2S-2P) = \delta_{QED} + \frac{m_r^3}{12}(Z\alpha)^4\langle r_{ch}^2\rangle_d + \delta_{TPE}$$

δ_{TPE} discrepancy between theory and experiment



$\delta_{TPE}(Our\ Work)$= -1.727(20) meV [Hernandez et. al, 2014]

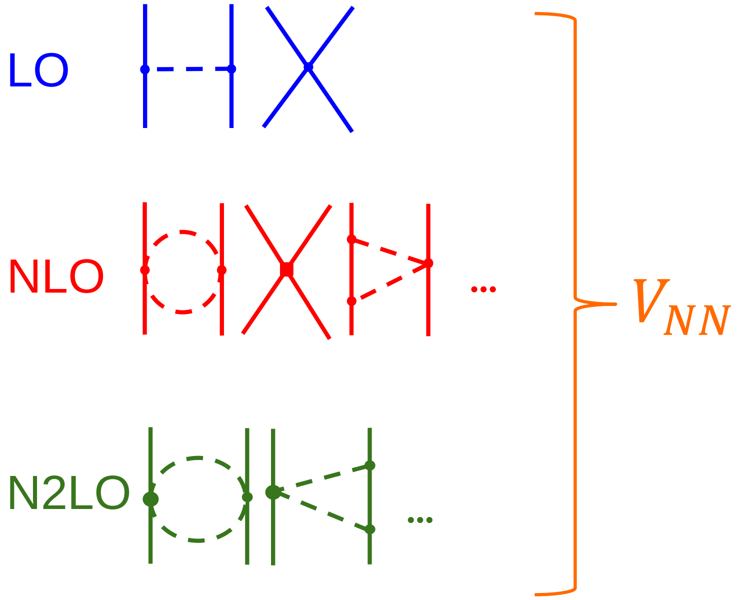
$\delta_{TPE}(Pachucki)$ = -1.717(20) meV [Pachucki et. al, 2015]

$\delta_{TPE}(Exp)$= -1.7638(68) meV [Pohl *et. al.* Science, 2016]

$$\Delta E(2S-2P) = \delta_{QED} + \frac{m_r^3}{12}(Z\alpha)^4\langle r_{ch}^2\rangle_d + \delta_{TPE}$$

- A thorough analysis may change our ~1% uncertainty and shed light on 2.5σ disagreement in δ_{TPE}

Road map to better assess the uncertainty

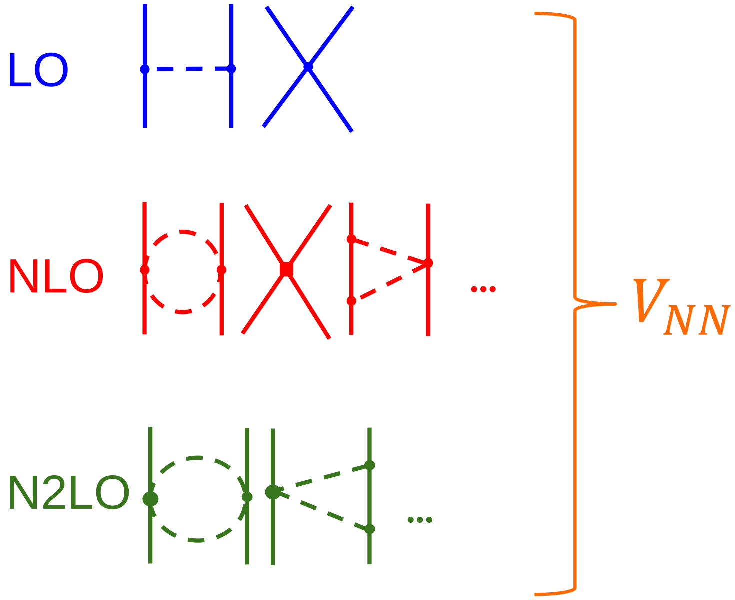


- Use N2LO potentials fit simulatenously to NN and πN data

$$A\ (T_{Lab}, \Lambda, \mathrm{c}_\nu)$$

Ekström et al., PRL (2013), JPG (2015), Carlsson et al., PRX (2016)

Road map to better assess the uncertainty



- Use N2LO potentials fit simulatenously to NN and πN data

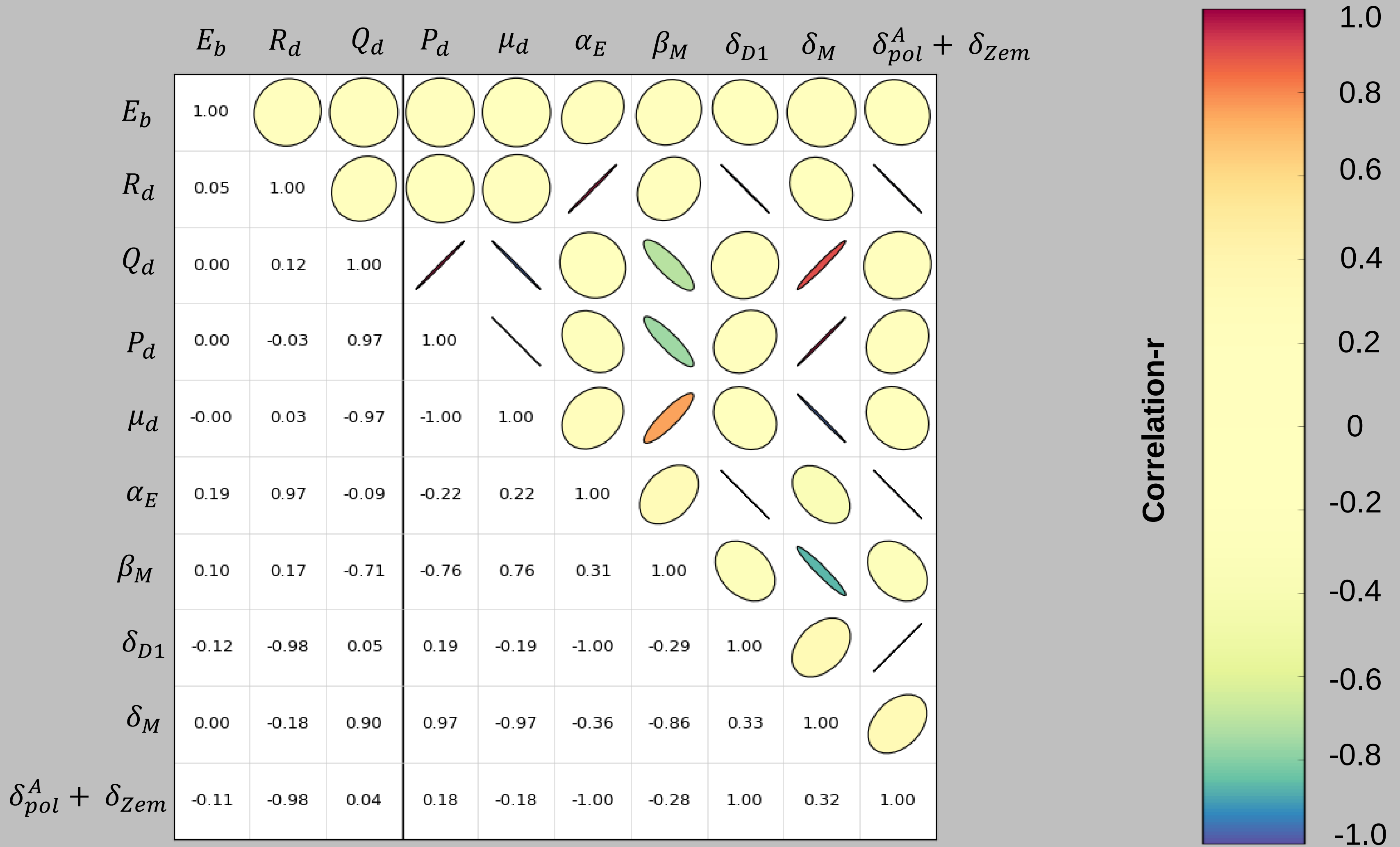
$$A\,(T_{Lab}, \Lambda, \mathrm{c}_{\nu})$$

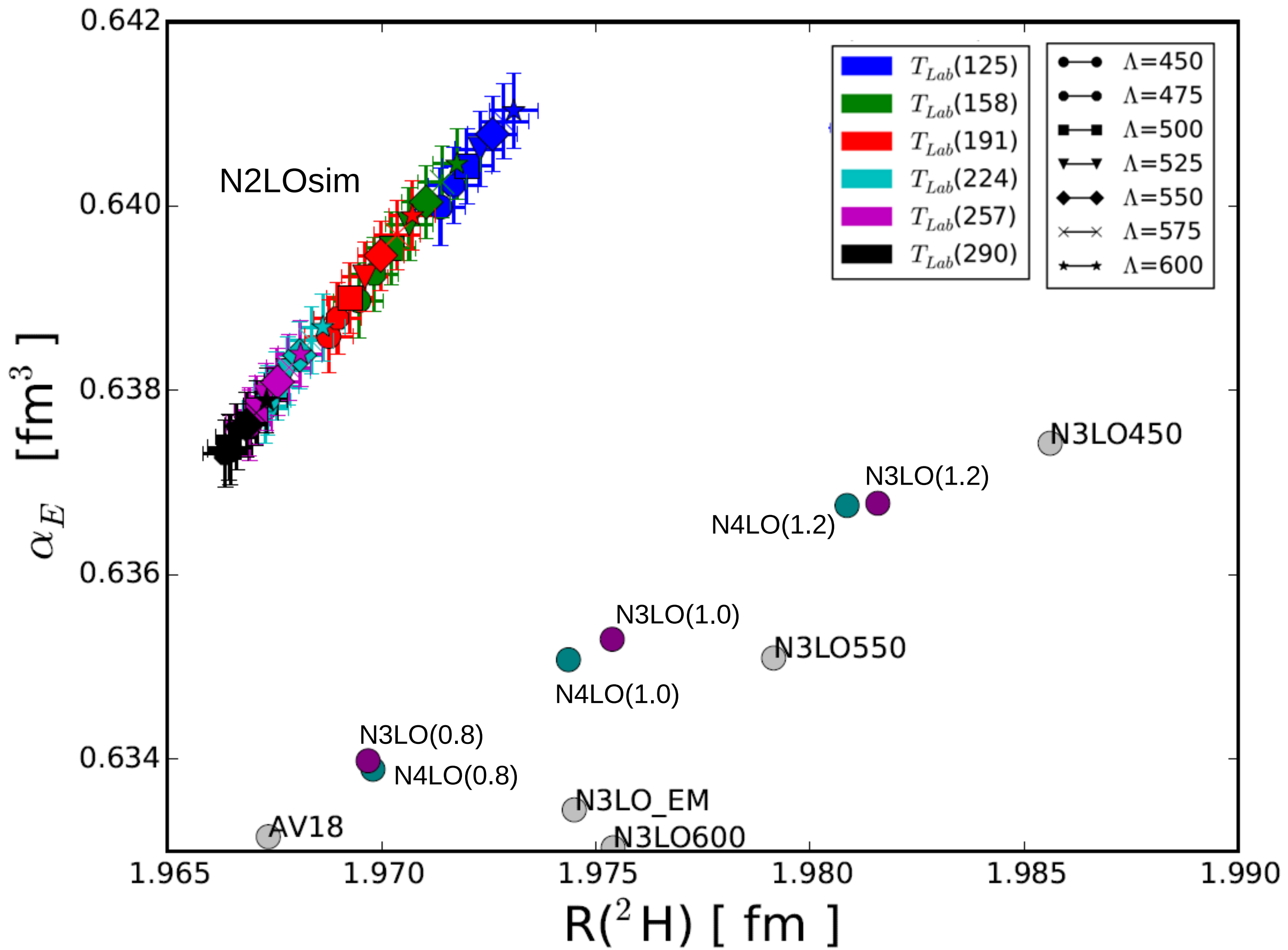
- Propagate errors using standard techniques

$$J_A^T = \frac{\partial A}{\partial c_{\nu}} \;, Cov(A,B) = J_A^T Cov(\mathrm{c}_{\nu}) J_B$$

$$\sigma_A = \sqrt{Cov(A,A)}$$

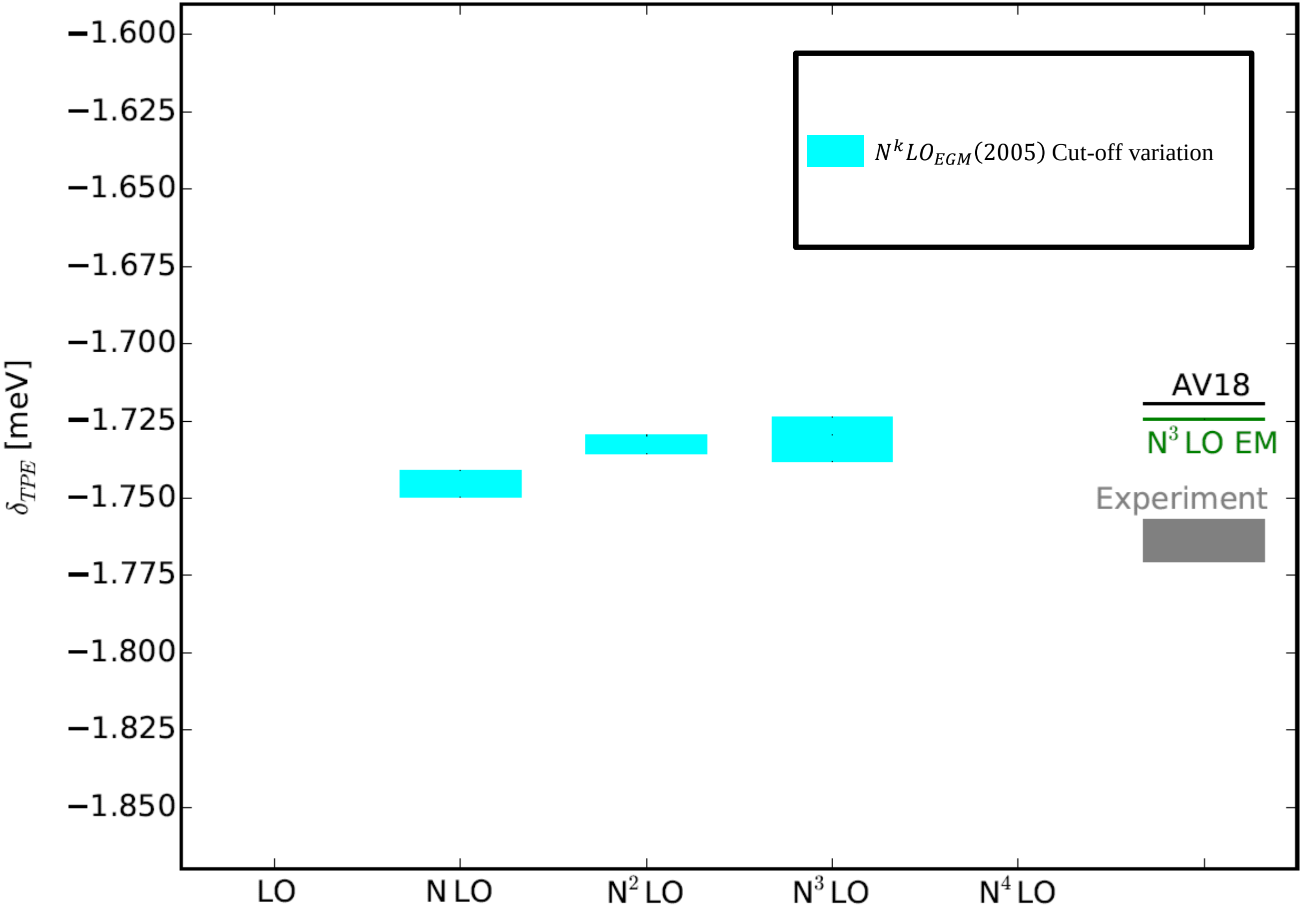
Ekström et al., PRL (2013), JPG (2015), Carlsson et al., PRX (2016)


E_b R_d Q_d P_d μ_d α_E β_M δ_{D1} δ_M $\delta^A_{pol} + \delta_{Zem}$
E_b 1.00
R_d 0.05 1.00
Q_d 0.00 0.12 1.00
P_d 0.00 -0.03 0.97 1.00
μ_d -0.00 0.03 -0.97 -1.00 1.00
α_E 0.19 0.97 -0.09 -0.22 0.22 1.00
β_M 0.10 0.17 -0.71 -0.76 0.76 0.31 1.00
δ_{D1} -0.12 -0.98 0.05 0.19 -0.19 -1.00 -0.29 1.00
δ_M 0.00 -0.18 0.90 0.97 -0.97 -0.36 -0.86 0.33 1.00
$\delta^A_{pol} + \delta_{Zem}$ -0.11 -0.98 0.04 0.18 -0.18 -1.00 -0.28 1.00 0.32 1.00
Correlation-r
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0

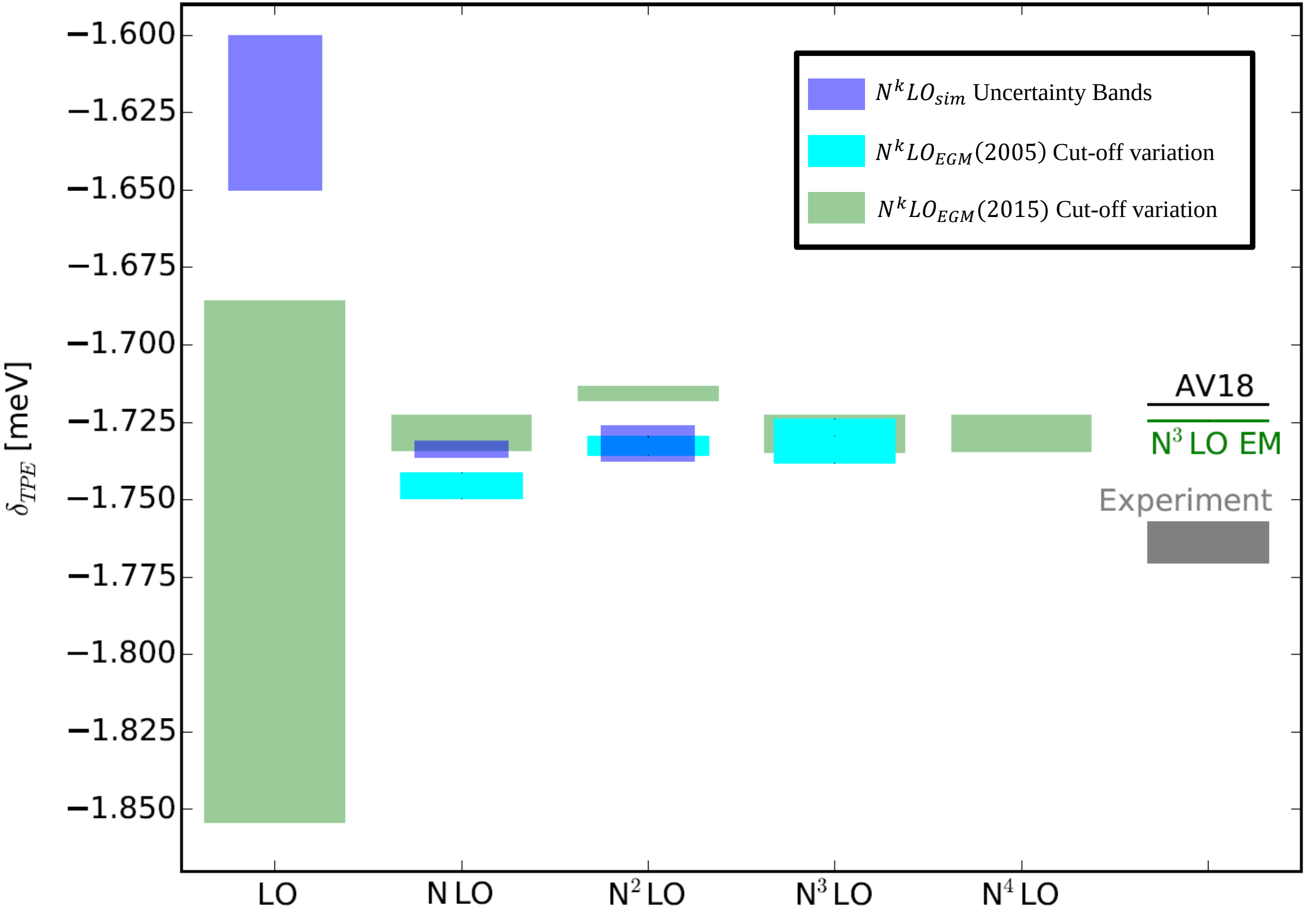


N2LOsim
$T_{Lab}(125)$
$T_{Lab}(158)$
$T_{Lab}(191)$
$T_{Lab}(224)$
$T_{Lab}(257)$
$T_{Lab}(290)$
Λ=450
Λ=475
Λ=500
Λ=525
Λ=550
Λ=575
Λ=600
N3LO450
N3LO(1.2)
N4LO(1.2)
N3LO(1.0)
N3LO550
N4LO(1.0)
N3LO(0.8)
N4LO(0.8)
N3LO_EM
AV18
N3LO600
0.642
0.640
0.638
0.636
0.634
1.965
1.970
1.975
1.980
1.985
1.990
α_E [fm^3]
R(^{2}H) [fm]

Preliminary Results



Preliminary Results

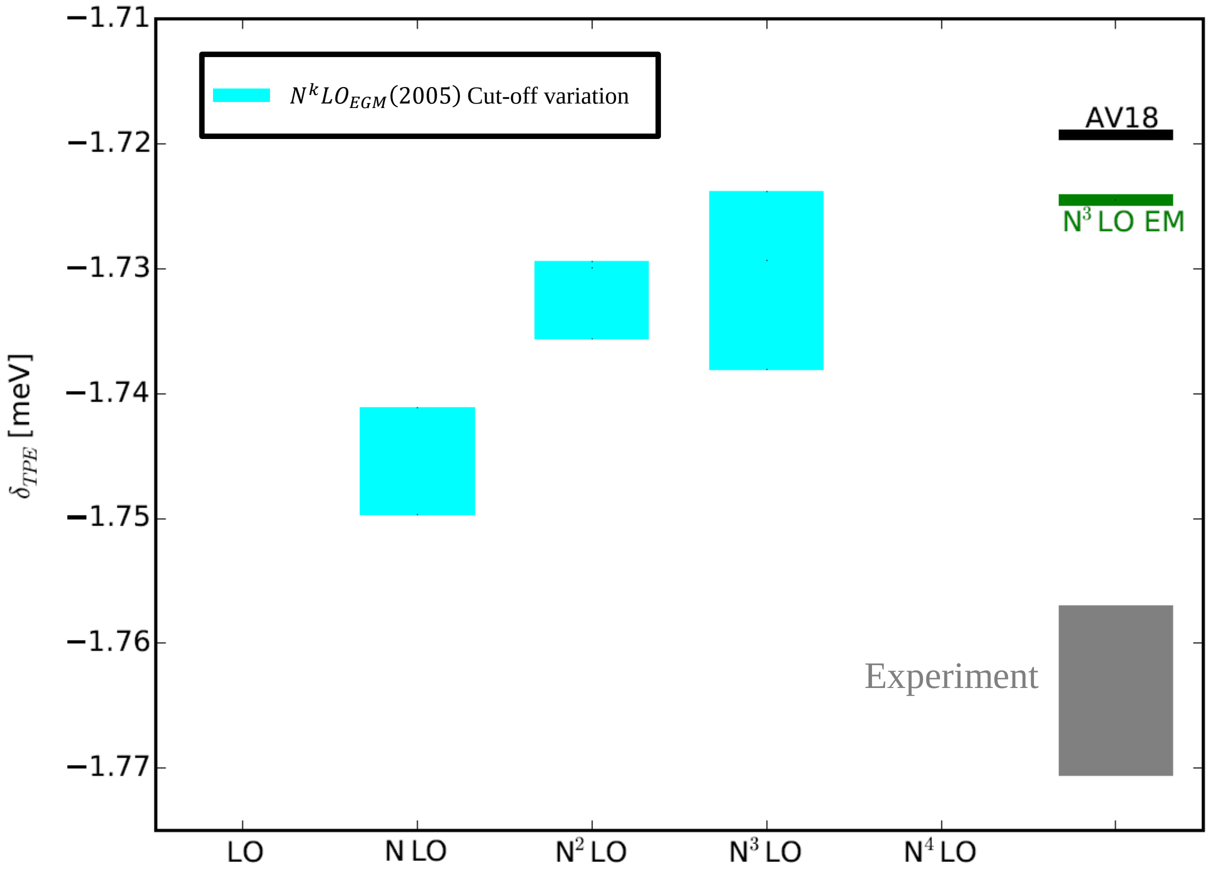


Outlook

- Solve 2.5σ discrepancy in μD to shed light on the puzzle(s)
- Develop an alternative derivation of δ_{TPE}
- Improve 1% atomic physics error estimate
- Apply (all of the above) to μHe where nuclear physics uncertainty dominates

Thank you!

Previous δ_{TPE} Results



	Error [%]
Nuclear Potential (1σ)	0.5
ChPT Convergence	0.3
Atomic Physics	1
Total	**1.16**

[Hernandez et. al, PLB, 2014]

The total Lamb shift error budget

$$\Delta E(2S-2P) = \delta_{QED} + \delta_{FS} + \delta_{TPE}$$

δ_{QED} 228.7766 (10) meV

δ_{FS} -6.1103 (3) r_d^2 meV/fm^2

δ_{TPE} 1.7096 (200) meV