Deepening Questions about Electron Deep Orbits of the Hydrogen Atom

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Electron deep orbits (EDOs)
Work in continuous progress

Prior papers

"Tunneling Beneath the $^4He*$ Fragmentation Energy," AM-KPS, 239th ACS Nat. Meeting *JCMNS* 4
"From the Naught Orbit to He4 Ground State" AM, ICCF-16, *JCMNS* 10
"Deep-electron orbits in Cold Fusion," AM-KPS, ICCF-16, *JCMNS* 13
"Deep-Orbit-Electron Radiation Emission in Decay from 4He* to 4He," AM-KPS, ICCF-16, *JCMNS* 13
"Femto-atoms and Transmutation," AM, ICCF-16, *JCMNS* 13
"Lochon and Extended-Lochon Models for LENR in a Lattice," AM-KPS, *Infinite Energy Magazine,* pp. 29-32, Issue 112, November/December 2013
"Femto-Atom and Femto-Molecule Models of Cold Fusion," *AM, Infinite Energy Magazine,* pp. 41-45, Issue 112, November/December 2013
"Femto-Helium and PdD Transmutation," AM, ICCF-18, *JCMNS* 15
"Deep-orbit-electron radiation absorption and emission," AM, ICCF-18, *JCMNS* 15

"Arguments for the Anomalous Solutions of the Dirac Equations". JLP-AM, *JCMNS 18*
"Basis for Electron Deep Orbits of the Hydrogen Atom". JLP-AM, *ICCF19, JCMNS 19*
"Nature of the Deep Dirac Levels". AM-JLP, *ICCF1, JCMNS 19*
"Basis for femto-molecules and -ions created from femto-atoms". AM-JLP, *ICCF19*. *JCMNS 19*
"Electron Deep Orbits of the Hydrogen Atom". JLP-AM, *11th Int. W., Airbus, Toulouse*. *JCMNS 23*
"Special Relativity, the Source of the Electron Deep Orbits". JLP-AM, *Found. of Phys. 47(2)*
"Relativity and Electron Deep Orbits of the Hydrogen Atom". JLP-AM *RNBE I, Avignon, JCMNS 21*
"Advance on Electron Deep Orbits of the Hydrogen Atom". JLP-AM, *Subm*. to ICCF20, Sendai.
"Implications of the electron deep orbits for cold fusion and physics". AM-JLP, *ICCF20*.
"Physical reasons for accepting the Deep-Dirac Levels". AM-JLP, *ICCF20*.

Note: All the computations are made with Maple software

EDO models as applied to CF predictions and experimental results

EDO model – electrons are Coulomb-bound in deep orbits about a nucleus

1. The existence of deep orbits is predicted by the **relativistic** Klein-Gordon and Dirac equations.
2. For H, the predicted orbits are in the femtometer range with a binding energy |BE| ≥ 507 keV.
3. Kinetic energy of DO electrons has been predicted to be in the

   KE = 1 MeV <u>and</u> 100 MeV ranges.
4. KE = 1 MeV DO electrons violate Heisenberg Uncertainty Relation. 100 MeV electrons do not.
5. H or ^{4}He with DO electrons are *femto-atoms*, which are near-nuclear-size neutral objects with properties to explain most of CF experimental results.

EDO model - was created to explain the D+D => ^{4}He results of CF:

1. It does so by transferring energy (mass) from a nucleus to a bound relativistic electron orbiting within femto-meters of the nucleus. *This occurs prior to, during, and after fusion*.

2. The DO electron, in forming a femto-atom, eliminates the Coulomb barrier of a hydrogen nucleus.

3. The extra kinetic energy of the DO electron lowers the mass defect Q of the fusing deuteron pair to below the ^{4}He* fragmentation or other excited-nucleon levels.

4. Fragmentation or gamma decay is not possible, thus other decay modes must lower ^{4}He* to ^{4}He.

5. Most, or all, other CF experimental results can be explained by application of this model and its consequences.

Example of such energy/mass transfer –

energy conservation in the atomic hydrogen system:

1. E_{total} = mass energy (E_m) + kinetic energy (KE) + potential energy (PE) + photon energy (E_γ); $E_{total} = E_m + KE + PE + E_\gamma$
2. Virial theorem for non-relativistic stable orbits (with v<<c) in a Coulomb (1/r) potential => $\langle KE \rangle = |\langle PE \rangle|/2$
3. Photo-transition of one orbit to a lower orbit requires $\Delta|\langle PE \rangle| = \Delta\langle KE \rangle + E_\gamma$, with binding energy $BE = E_{total} - E_m$
4. As a photon leaves the atom, it becomes the BE of the electron, reducing the atomic mass (for a H atom of proton + electron, $E_m = E_{mp} + E_{me}$) by the same amount.
5. Increase in KE of the electron in lower orbits means that its effective mass, $E_{me} = \gamma m_o c^2$, also increases. Therefore,
6. The actual mass of the proton must decrease.

EDO model predictions – How does the model fit with Cold Fusion models and experiment?

1. It is a natural extension of Sinha's Lochon Model that has published calculations of interaction probabilities for the D^+ - D^- fusion reaction in a solid state lattice.
2. It is a natural consequence of both the linear-H molecule model and Takahashi's Tetrahedral Symmetric Condensate
3. It works for both D-D and H-H cold fusion results and explains the observed differences.
4. It predicts transmutation results consistent with observed.
5. It predicts the CF results of nuclear energy transfer to the lattice without the energetic particles or gamma radiation of hot fusion and neutron activation experiments.
6. It predicts selective attraction of femto-atoms to radioactive isotopes for nuclear waste remediation

Quick recall on EDO's

- Dirac equation with external field $(i\gamma^{\mu}\partial_{\mu} - m)\psi = -e\gamma^{\mu}A_{\mu}\psi$

"Anomalous solutions" $E = mc^2\left[1 + \frac{\alpha^2}{\left(n' - \sqrt{(k^2 - \alpha^2)}\right)^2}\right]^{-1/2}$ n'= radial Q number
k = angular Q number

System of 1st order radial equations --> 2d order Kummer's equation -->

E satisfies $\frac{1}{2}\alpha\left\{\sqrt{\frac{mc^2+E}{mc^2-E}} - \sqrt{\frac{mc^2-E}{mc^2+E}}\right\} = (n'+s) = |k| - (k^2-\alpha^2)^{\frac{1}{2}} > 0$ *Positive Energy*

When $|k| = n'$ --> $E \sim mc^2\alpha/2$ --> $|BE| \sim mc^2(1 - \alpha/2|k|) >$ **509** keV $\approx mc^2$

- Features of EDO solutions

  (i) Very deep orbits: mean radius <*r*> of order fm

  (ii) Special relativity is essential to obtain EDO's

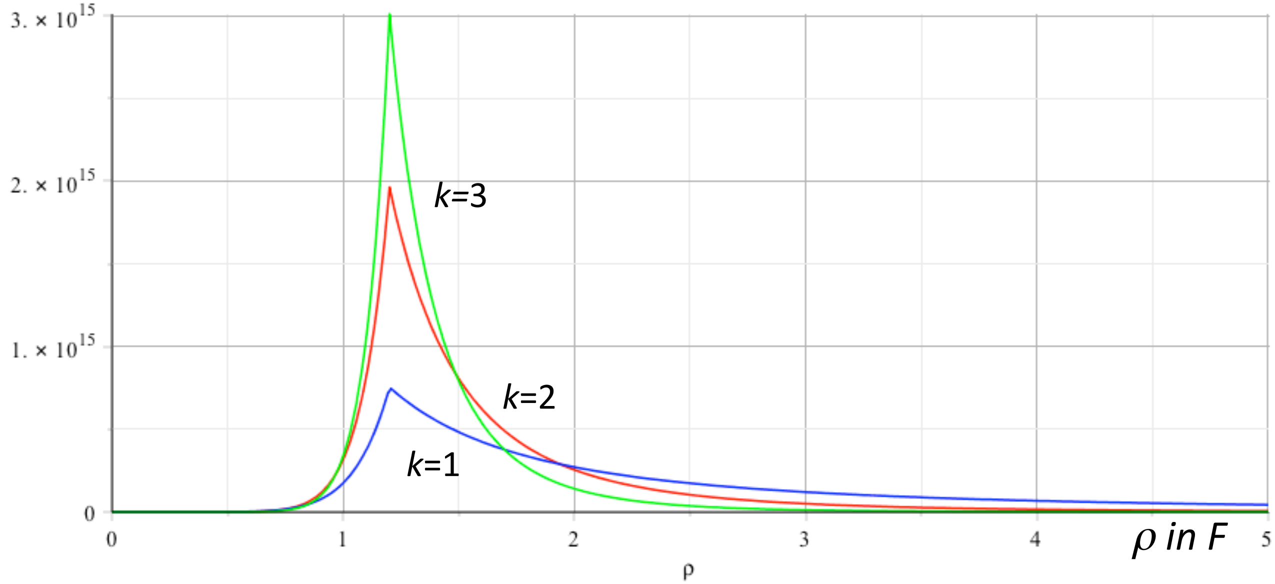
Quick recall on EDO's (cont'd)

Computations of the mean radius, including consideration of a finite potential inside the nucleus

Works: Maly & Va'vra, Deck, Amar, & Fralick

- Values obtained for $R_0 = 1.2$ F (from Maly & Va'vra)

k = 1 , <*r*> ~ 6.62 F
k = 2 , <*r*> ~ 1.65 F
k = 3 , <*r*> ~ 1.39 F
k = 10, <*r*> ~ 1.226 F
k = 20, <*r*> ~ 1.207 F



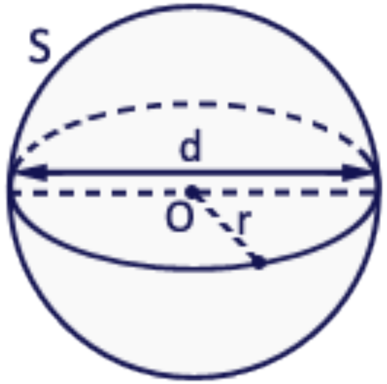
- Dependence

<*r*>(*k*) *depends essentially on the matching radius* R_0

HUR and Special Relativity

- HUR as *Starting Point*:

  for confined electron at distance *r* from the nucleus



$\Delta p \,.\, \Delta r \geq \hbar/2$ ---> $p \geq \hbar/2r$

one can put $p \sim \hbar/r$

Ex.: For $r = 2$ F , $p \sim 5.27 \times 10^{-20}$ SI

- With non-relativistic treatment: $E_{nR} = p^2/2m$ => $E_{nR} \sim$ 9.5 GeV
- With relativistic treatment: $mc^2 \sim 511$ keV << $p\,c \sim 98$ MeV

$E_R \sim [p^2c^2 + m^2c^4]^{1/2} \sim p\,c \sim 98$ MeV : *100 x smaller than* E_{nR} !

Remark : *Confinement is not unrealistic*; **but** ,

Question: *Can a potential be strong enough to confine an electron* ?

Answer: **Yes** (next diapos) !!!

HUR and Special Relativity (cont'd)

- Relativistic coefficient γ deduced from HUR

Where $\gamma = (1 - v^2/c^2)^{1/2}$

$$p = \gamma mv \geq \hbar/2r \quad \Rightarrow \quad \gamma^2 \geq 1 + \hbar^2/4(mcr)^2 = 1 + (\underline{\lambda}_c)^2/4r^2$$

where $\underline{\lambda}_c$ = "reduced" Compton wavelength = $\hbar/mc \sim 386$ F

For r of order a few F, one has $(\underline{\lambda}_c)^2/4r^2 >> 1 \Rightarrow$

$$\gamma \geq \underline{\lambda}_c/2r = \gamma_m$$

Example: $r = 2$ F $\Rightarrow$ $\gamma_m(r)$ close to 100 (~ 96.5),

which gives $\beta \sim 0.99995$ ...

HUR and Special Relativity (cont'd)

Relativistic correction of Cb potential -> "*effective" potential* V_{eff}

$$V_{eff} = V\,(E/mc^2) - V^2/2mc^2 = \gamma V + V^2/2mc^2$$

For $r \leq \underline{\lambda}_c/2 \sim 193$ F , one has $\gamma \geq \underline{\lambda}_c/2r$

Then one has $V_{eff} \leq (-e^2/2r^2)\,\underline{\lambda}_c\,(1-\alpha) \sim$ $-\underline{\lambda}_c\, e^2/2r^2 = \gamma_m V$

(i). V_{eff} is always attractive (*negative*)

(ii). $|V_{eff}| > |V|$: Strengthening of the static Coulomb potential

(iii). V_{eff} has behaviour in K/r^2 when r decreases

(iv). $|V_{eff}|$ *increases* with γ

Ex.: For $r = 2$ F,

if $\gamma \sim \gamma_m = 96.5$ one has $V_{eff} \sim -71$ MeV $\geq KE = (\gamma - 1)\, mc^2 \sim 50$ MeV

V_{eff} is *strong enough* to confine an energetic electron

- Relativity is the source of EDO's
- Relativity is the solution for HUR problem

Barut-Vigier model

Radial potential as a sum of inverse power terms

$$V(r) = A/r + B/r^2 + C/r^3 + D/r^4$$

Coulomb , (attractive)	Centrifugal, (repulsive)	Spin-Orbit, (v. attractive)	"Diamagnetic" term (repulsive)

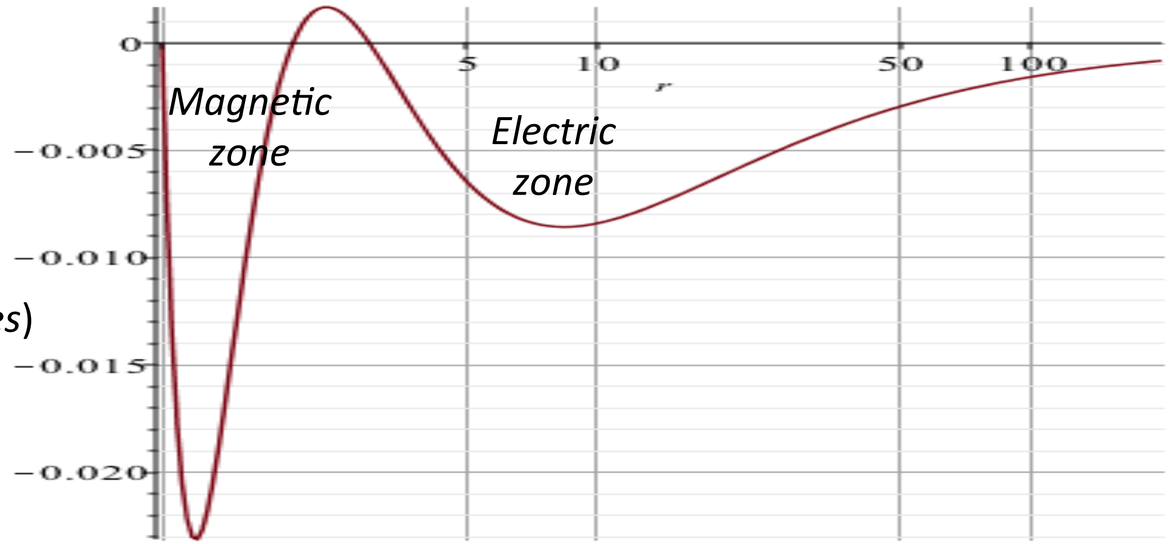
Prior work (in non relativistic context):

Vigier, Barut, Samsonenko et al., Dragi et al., Özçelik et al. , …

very little positive results about tight orbits

Fig 1. semi-log plot simulation of 2 wells

(*not significant values on axes*)



Works of Barut in *relativistic* context of Dirac equation with electron AMM:

Tight state for positronium at 0.02F, resonance of order 35 GeV

Magnetic interactions

I. Spin-Orbit

$$E_{SO}(r) = (k/r^3)\, L \bullet S$$

Fig 2. $S_{e\text{-}}O_p$

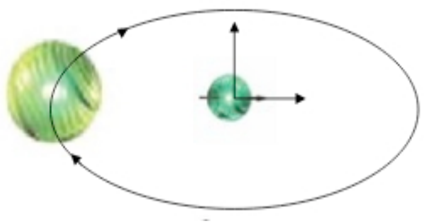
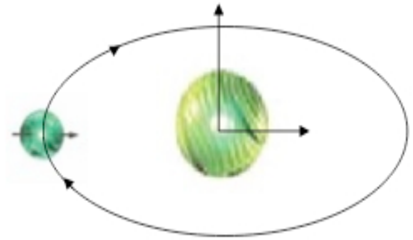


Fig 3. S_pO_e



$S_{e\text{-}}O_p$ attractive version: for $l = 1$, $L \bullet S = ½\,(J^2\text{-}L^2\text{-}S^2) = -\hbar^2$ --> $E_{SO}(r) \sim -10^{-34}/r^3$ eV

- Full relativistic expression :

$$\omega_{tot} = [\gamma/(\gamma+1)]\,\omega_{Larmor} \quad \text{if } \gamma >> 1 \Rightarrow \omega_{tot} \sim \omega_{Larmor}$$

(for atomic states $\omega_{tot} \sim \omega_{Larm}/2$)

- There is a S_pO_e interaction (*not included in Dirac equation*). But , it can be neglected: the proton magnetic moment $\mu_p \sim 660$ x smaller << μ_e

- Comparison: (*Source of* U^{91+} *data*: Working Group, GSI-Darmstadt)

  Heavy element : Fine Structure for U^{91+} *2p* level - 4.56 keV

  Atom H: Fine structure - 45 μeV ;

  at r = 2F , $E_{SO} \sim -13$ GeV, *unrealistic*

Magnetic interactions (cont'd)

II. Spin-Spin. $S_e \cdot S_p = ½ (S^2 - (S_e)^2 - (S_p)^2) = (\hbar^2/2) [s(s+1) - 3/2]$

$s = 0 \Rightarrow S_e \cdot S_p = -(¾) \hbar^2$ *singlet state* ----> *attractive* potential
$s = 1 \Rightarrow S_e \cdot S_p = +(¼) \hbar^2$ *triplet state* ----> *repulsive* potential

- Energy expression of $S{\cdot}S$ interactions in K/r^3, $K = -¾ A$ or $¼ A$

At $r =$ 53 pm (*Bohr radius*) *1s* level ,

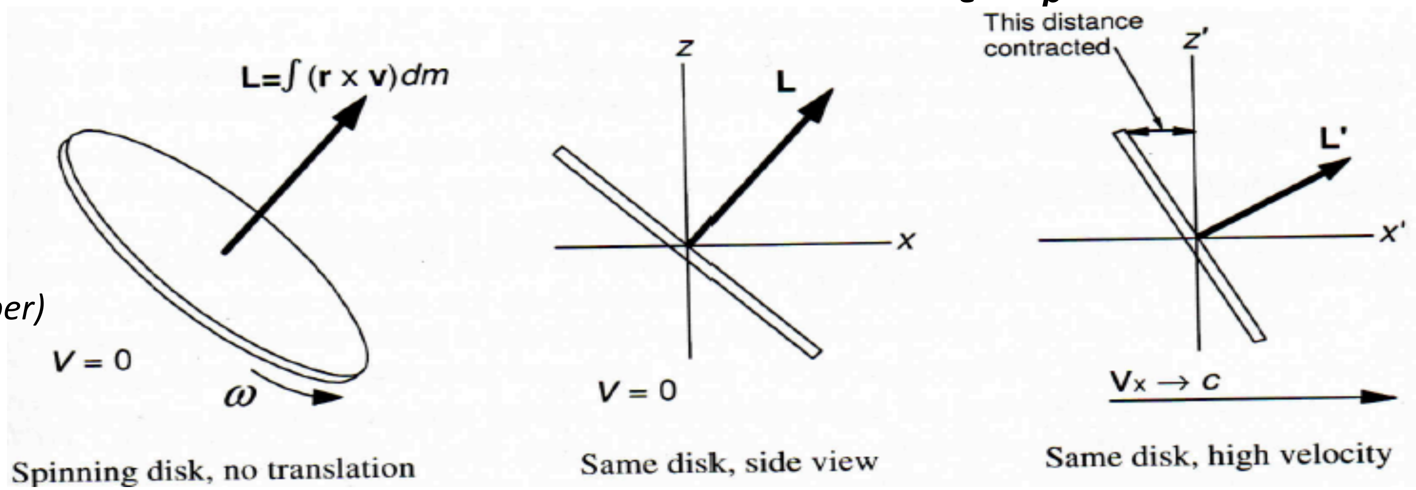
$A \sim 6\ \mu$eV ---> attractive $E_{SS}(r) \sim -6.4 \times 10^{-37}/r^3$ eV

At r = 2F, *attractive* $E_{SS} \sim -81$ MeV, *repulsive* $E_{SS} \sim 27$ MeV

- Possible *weakening* at relativistic velocity *v*

Spin axis "bending" in the direction of *v* reduces $\boldsymbol{S_e \cdot S_p}$

Fig 4. Classical spinning object translating at relativistic speed. *(from QFT, R.Klauber)*



Magnetic interactions (cont'd)

III. Diamagnetic term

From "moment term" $(\mathbf{P}_i \pm e_i \mathbf{A_j})^2$ --> $e_i^2\mathbf{A}_j^2 \geq 0$ --> *repulsive* potential

Interaction: electric charge e_1 in magnetic field with *vector potential*

$|\mathbf{A_j}| = K\,\mu\,/r^2$, μ : magnetic moment --> $e_i^2\mathbf{A}_j^2 \propto 1/r^4$

Two-body Pauli equation --> two terms $e_i^2\mathbf{A}_j^2$

1. with e_i for electron, $\mathbf{A}_j$ for proton (spin) magnetic dipole
2. with e_i for proton, $\mathbf{A}_j$ for electron (spin) magnetic dipole

But, the term #1 can be neglected since it is ~240 x smaller than the #2 term

This latter can be expressed by

$$E_D = (\mu_0/4\pi) \times [e^4\hbar^2/(4\,m_e^2 m_p)]\,/r^4 \sim 8.2 \times 10^{-53}/r^4 \text{ eV}$$

At "ground state" level: r = 53 pm --> $E_D \sim$ 10 peV

At "EDO" level: r = 2F, $E_D \sim$ 5 MeV

Radiative corrections (QED)

- Self-energy (*SE*)

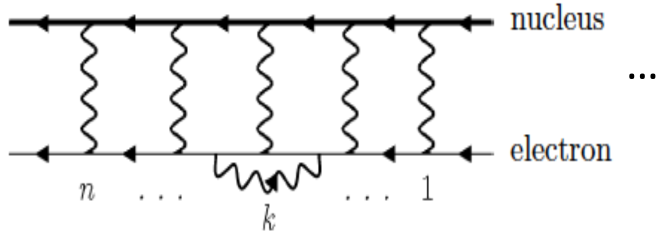
  Electron closed loops

  Repulsive effect

Bound electron

virtual photon

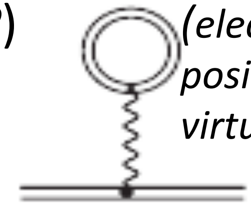
= Sum of



- Vacuum polarization (*VP*)

  Photon closed loops

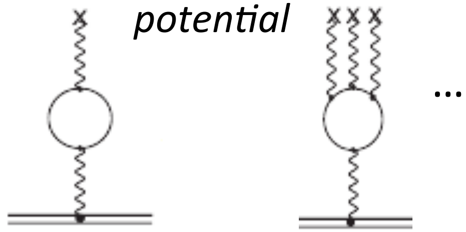
  Attractive effect



(electron, positron) virtual pair

= Sum of

potential



- Some values and comparisons

  For atom H : BE_H of 1s state ~ -13.6 eV, Lamb Shift E_H ~ $SE+VP$ ~ **35 μeV**

  Note: $|E_{SS}| < E_H < |E_{SO}|$

  For U^{91+} : BE_{U+} 1s state ~ - 132 keV, SE ~ 355 eV, VP ~ - 89 eV -> E_{U+} = $SE+VP$ ~ **266 eV**

  (Lamb Shift ~ SE + VP + Nucl. Size effect ~ 464 eV) $<r>_{1s\text{-}U}$ ~ 580 F ~ $\mathbf{r_{Bohr}}$ **/100**

  Ratios: $BE_{U+}/BE_H \sim 10^4$, $E_{U+}/E_H \sim 8\text{x}10^6$ **1000** *times higher than* BE_{U+}/BE_H

  QED effects increase with the strength of electric field =>

  for EDO's, one can expect *strong radiative corrections*

Looking for a resonance near the nucleus

- Classical recall:

  local minimal energy for the ground state at r_0 (Bohr)

  HUR --> $\Delta p \geq \hbar / r$ --> $KE = p^2/2m$ and $PE = - e^2/r$

  $E \geq (\hbar^2 / 2mr^2) - (e^2 / r)$ --> min(E) for $r_0 \sim 53$ pm

- Relativistic context:

$E = \sqrt{\mathbf{p}^2 c^2 + m^2 c^4}$ --> HUR --> $E_H = \left[\sqrt{\frac{\hbar^2 c^2}{r^2} + m^2 c^4} \right] + V$

Here V = sum of potentials

Question: can E_H have a Local Minimum (*LM*) near the nucleus ?

Looking for a resonance near the nucleus (cont'd)

- Simulations with V involving V_{eff} , E_{SO} , E_{SS} (attract/repuls) , E_{D} , $V_{\text{centrifug}}$

  Previous computations

  (i) E_{SO} excessive, even if combined with $V_{\text{centrifug}}$; so, we will take $l = 0$

  (ii) E_{SSA} (attractive) --> LM inside the nucleus, at $r \sim 0.17$ F

  (proton charge radius ~ 0.84F)

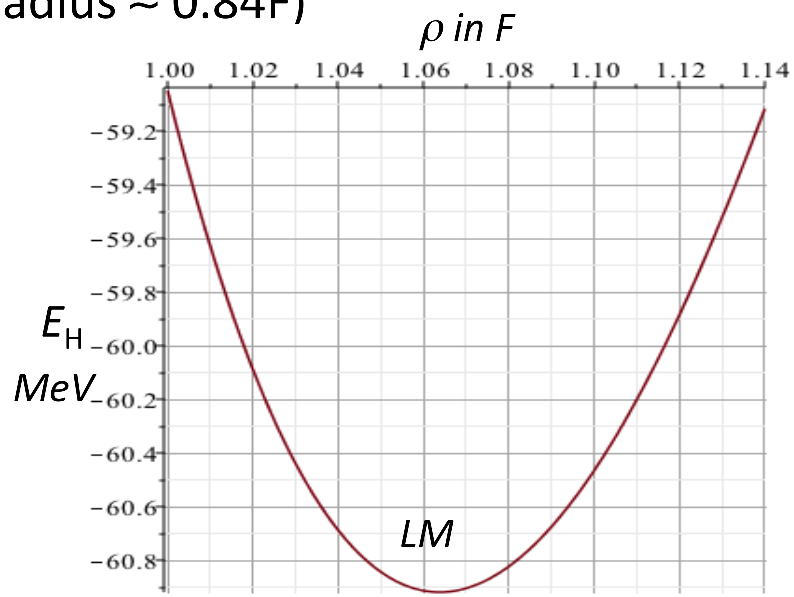
  New computations

  Fig 5.

  E_H with $V = V_{eff} + E_{\text{SSR}}$(repulsive) + E_{D}

  LM at $r \sim 1.06$ F, $E_{\text{H}} \sim -61$ MeV,

  $V \sim -246$ MeV, $\gamma \sim 360$



Looking for a resonance near the nucleus (cont'd)

Computations taking into account weakening of EM interactions

- V_{Cbw}: V_{Cb} with *linear weakening* of gradient K in region $[r_0, r_1]$ around the nucleus ($r_0 \sim 0.84$F)
- V_{effw}: V_{Cbw} --> $V_{effw} = \gamma V_{Cbw} + (V_{Cbw})^2/2mc^2$
- $V = V_{effw} + E_{SSR}/C + V_4/D$

Non-exhaustive simulations -->

LM's found in the interval [1F , 2.2F]

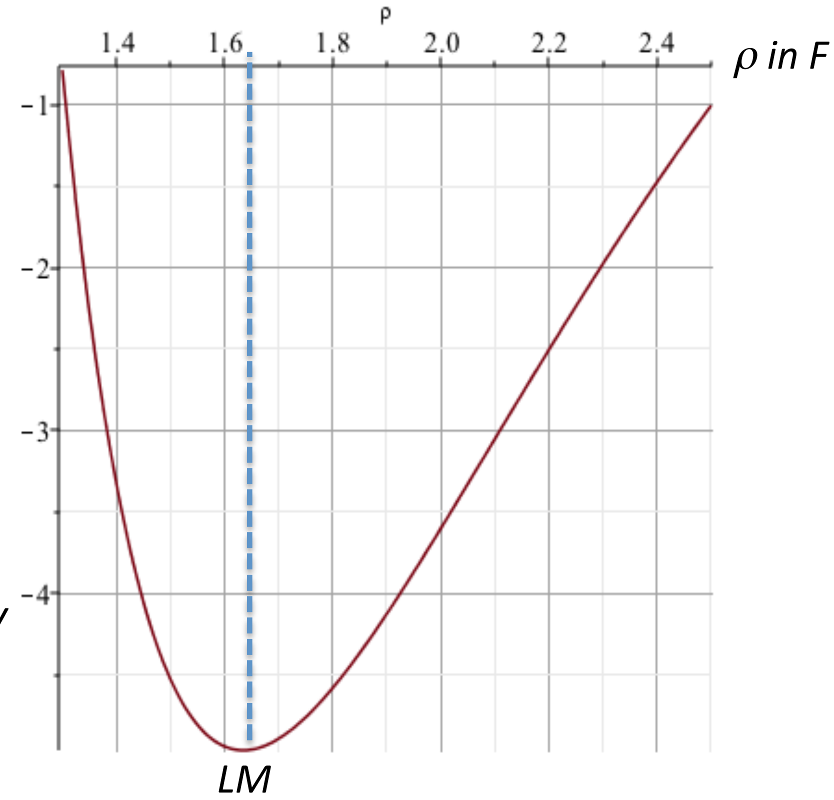
Example

Fig 6.

r_1 = 2.5 F, K = 0.55, C = 1.8, D = 2

LM at $r \sim$ 1.63 F, E_H ~ -5 MeV,

$V \sim$ -126 MeV, $\gamma \sim$ 235



Conclusion and Future work

The present study, despite coarse computation, shows

- EDO's can *respect the HUR*
- Possible *highly relativistic resonances* near the nucleus
- Need to consider *EM interactions not included* in the one particle Dirac equation: *Spin-Spin* interaction, *Diamagnetic* term, and QED corrections

But, 2-Body equations in highly relativistic context can lead to a "no-interactions problem" with potentials defined in a point

(because of action-at-a distance interactions) -->

To progress into the definition of precise deep resonances, we need *QFT-based full covariant* methods