# Average CsI Neutron Density Distribution from COHERENT Data

**Based on Cadeddu, Giunti, YFL, Zhang, Phys. Rev. Lett. 120 (2018) 072501**

**Yu-Feng Li***
**Institute of High Energy Physics, Beijing, China**
*corresponding author: liyufeng@ihep.ac.cn

## Abstract

**Using the coherent elastic neutrino-nucleus scattering data of the COHERENT experiment, we determine for the first time the average neutron rms radius of 133Cs and 127I. We obtain the practically model-independent value Rn=5.5$^{+0.9}_{-1.1}$ fm using the symmetrized Fermi and Helm form factors. We also point out that the COHERENT data show a 2.3σ evidence of the nuclear structure suppression of the full coherence.**

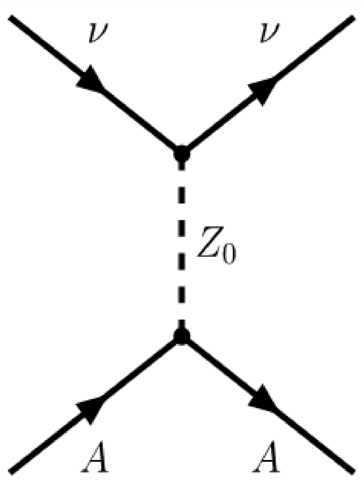
## Introduction

### Theoretical Prediction:

**(1) Coherent effect of a weak neutral current:**

- (a) In analogy to the coherent behavior of electron-nucleus scattering
- (b) "an act of hubris" [1] : Daniel Z. Freedman (1974)

**(2) Coherent neutrino-nucleus scattering (CEvNS)**

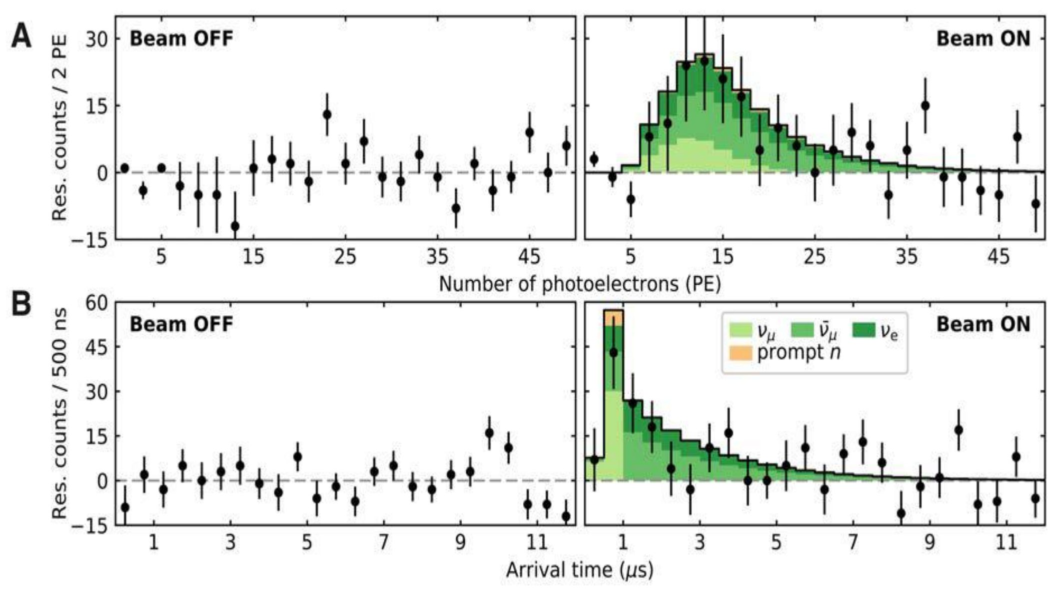



- (a) Conceptually important
- (b) Useful method to test new physics
- (c) Importance of astrophysics and cosmology

### Experimental Observation:

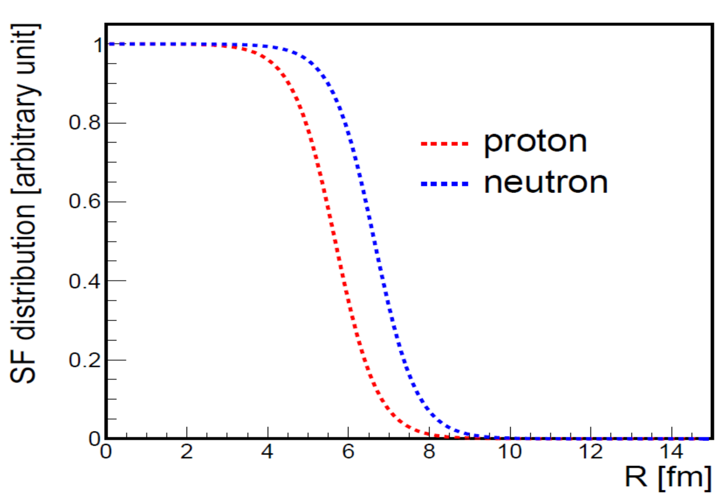
**(3) 43 years later, it was finally observed by the COHERENT collaboration [2] :**

- (a) **Using pion decay-at-rest flux** from Spallation Neutron Source at Oak Ridge National Laboratory
- (b) **Using CsI[Na]** Scintillating crystal detector
- (c) Low threshold and good background control
- (d) Using both energy and time information




### Neutron Weak Density Distribution[3]:

**(4) Neutrons and protons are finite-sized in the weak interactions:**




(a) **Root mean square (rms) radius**

(b) **Form factor** is the **Fourier transform** of the density distribution

(c) Difference of the neutron and proton radii is defined as the **neutron skin**

(d) Proton radius is **accurately measured** (4.8 fm Cs/I)

## Method

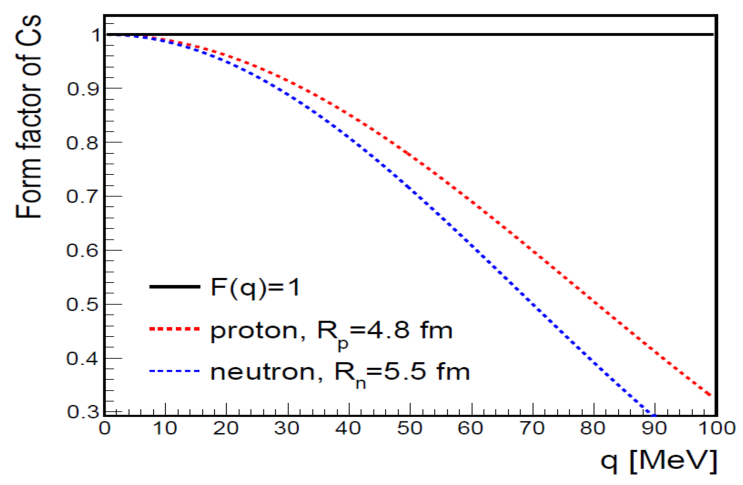
### CEvNS Cross Section [4,5]:

$$\epsilon = 1 - 4\sin^2\vartheta_W$$

$$\frac{d\sigma_{\nu\text{-}\mathcal{N}}}{dT}(E,T) \simeq \frac{G_F^2 M}{4\pi}\left(1-\frac{MT}{2E^2}\right) \times \left[N F_N(q^2) - \epsilon Z F_Z(q^2)\right]^2$$

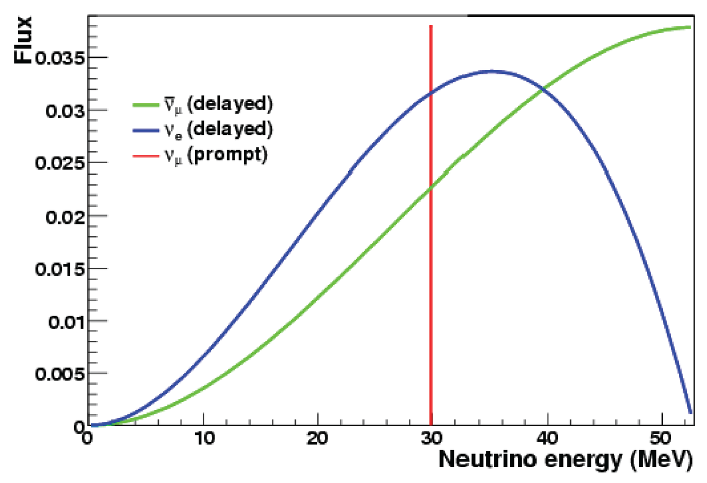
- (a) **As the function of N²**

**Form factors as functions of the momentum transfer**




- (a) Form factors contribute to **suppression of full coherency**

### Pion Decay-at-rest Flux [2]:



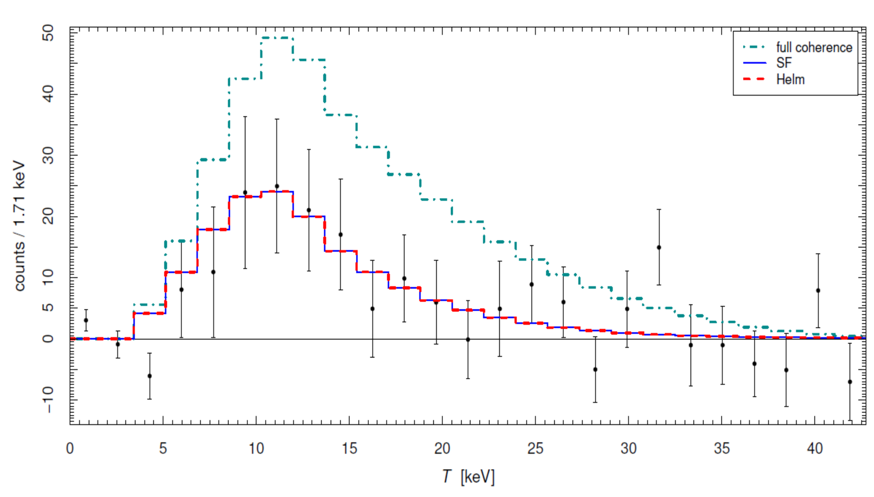

### Least Squares Function [6]:

$$\chi^2 = \sum_{i=4}^{15}\left(\frac{N_i^{\text{exp}} - (1+\alpha)N_i^{\text{th}} - (1+\beta)B_i}{\sigma_i}\right)^2 + \left(\frac{\alpha}{\sigma_\alpha}\right)^2 + \left(\frac{\beta}{\sigma_\beta}\right)^2.$$

- (a) Systematics: 28% (signal) and 25% (background)

## Result-1

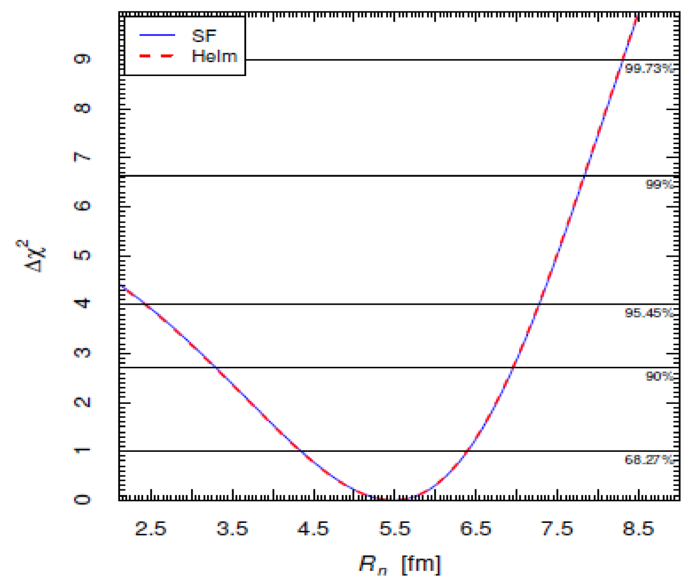
### Suppression of Full Coherency [6]:



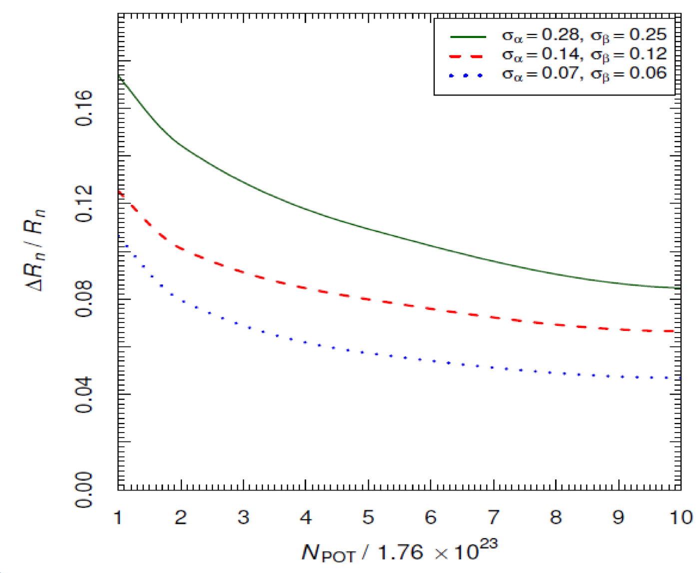

- (a) For both cases with **the symmetrized Fermi and Helm** form factors, we obtained a minimum $\chi^2$ which is smaller than the $\chi^2$ of full coherence **by 5.5**.
- (b) Therefore, there is a **2.3 σ** evidence of **the nuclear structure suppression of the coherence**.

## Result-2

### Measurement of the Neutron Radius [6]:




- (a) **Average neutron radius** of 133Cs and 127I: $R_n = 5.5^{+0.9}_{-1.1}$ fm.
- (b) **Neutron skin**: $\Delta R_{np} \simeq 0.7^{+0.9}_{-1.1}$ fm.
- (d) Future prospect: **towards the accuracy of 0.3 fm and better**




## Implications

### Importance of the Neutron Radius:

- (a) The neutron radius and neutron skin are correlated to **the nuclear Equation of State (EOS), the slope of bulk symmetry energy**, and other nuclear quantities.
- (b) A larger neutron skin would suggest **a stiffer EOS and imply a larger neutron star radius**, which is related to the gravitational binding energy of core collapse supernovae.
- (c) **With the first observation of binary neutron star inspiral** at Advanced LIGO and Advanced Virgo [7], one can infer **the tidal deformability parameter**, which is related to the neutron star EOS and to the neutron skin [8].
- (d) Information on the nuclear neutron density radius is also important for **a precise determination of the background due to coherent elastic neutrino-nucleus scattering in dark matter detectors** [9] (e.g., 133Cs and 127I have similar atomic and mass numbers to that of Xenon).

## References

[1] D. Z. Freedman, Phys. Rev. D9, 1389 (1974).
[2] D. Akimov *et al.* (COHERENT), Science 357, 1123 (2017).
[3] K. Patton, J. Engel, G. C. McLaughlin, and N. Schunck, Phys. Rev. C86, 024612 (2012)
[4] A. Drukier and L. Stodolsky, Phys. Rev. D30, 2295 (1984).
[5] J. Barranco, O. G. Miranda, and T. I. Rashba, JHEP 0512, 021 (2005).
[6] M. Cadeddu, C. Giunti, Y. F. Li and Y. Y. Zhang, Phys. Rev. Lett. 120, 072501 (2018).
[7] B. P. Abbott *et al.* (Virgo, LIGO Scientic), Phys. Rev. Lett. 119, 161101 (2017).
[8] F. J. Fattoyev, J. Piekarewicz, and C. J. Horowitz, Phys. Rev. Lett. 120, 172702 (2018).
[9] J. Billard, L. Strigari, and E. Figueroa-Feliciano, Phys. Rev. D89, 023524 (2014).

NEUTRINO 2018 Heidelberg 4–9 June

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences