

# NEW INSIGHTS INTO NUCLEAR PHYSICS AND WEAK MIXING ANGLE USING ELECTROWEAK PROBES

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ATOMIC PARITY VIOLATION IN CESIUM



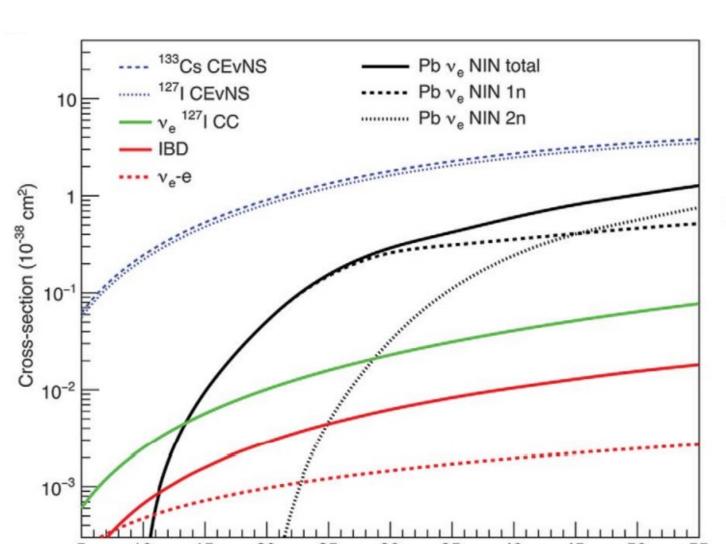
#### **ABSTRACT**

In this poster we will present the first measurement of the neutron skin of cesium and iodine using electroweak probes, coherent elastic neutrino-nucleus scattering and atomic parity violation. This measurement, differently from hadronic probes, is model-independent and suggests a preference for nuclear models which predict large neutron skin values, with implications that range from neutron stars to heavy ion collisions.

Moreover, we will show a new determination of the low-energy weak mixing angle, with a percent uncertainty, fully determined from electroweak processes and independent of the neutron radius of cesium, allowed to vary in the fit. This will permit to put reliable constraints to theories beyond the standard model.

### COHERENT ELASTIC NEUTRINO NUCLEUS SCATTERING The Coherent Elastic Neutrino Neutrino

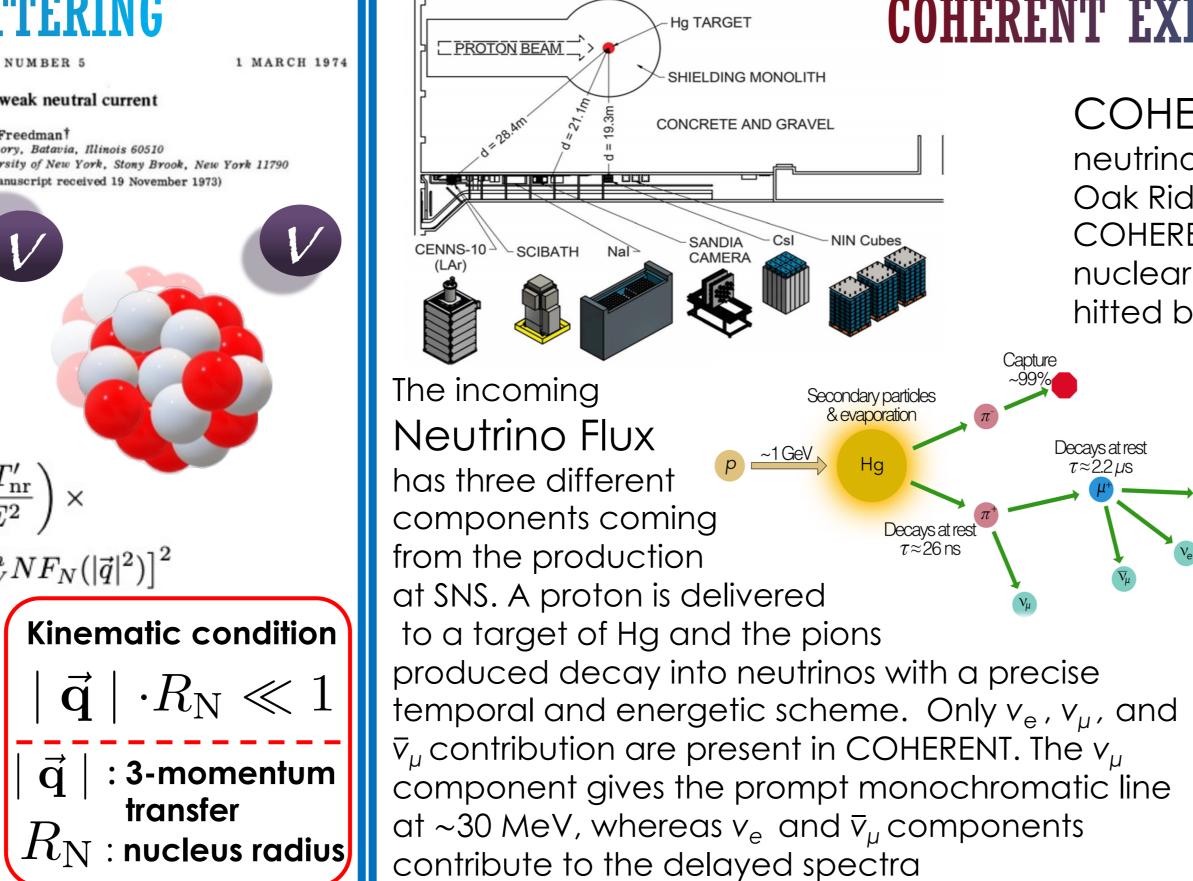
Scattering (CEVNS) process is well described in the Standard Model (SM) framework. It was predicted by Freedman in 1974 as a neutral current interaction of neutrinos with the target nucleus.

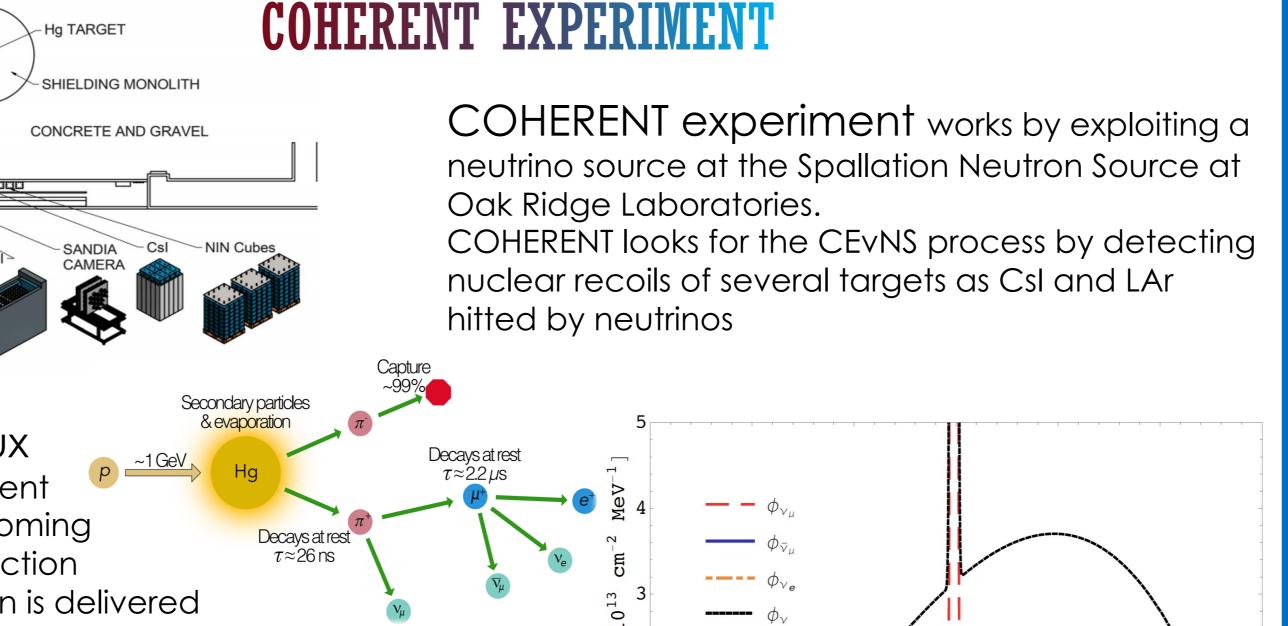


Phys. Rev. D 9, 1389 CEVNS has the largest cross-section among neutrino processes roughly proportional to N<sup>2</sup>...  $\frac{d\sigma_{\nu_\ell\text{-}\mathcal{N}}}{dT_{\rm nr}'}(E,T_{\rm nr}') = \frac{G_{\rm F}^2M}{\pi} \left(1 - \frac{MT_{\rm nr}'}{2E^2}\right) \times$  $\left[g_V^p Z F_Z(|\vec{q}|^2) + g_V^n N F_N(|\vec{q}|^2)\right]^2$ 

..but, given the kinematic Kinematic condition condition, it is really hard to  $\vec{\mathbf{q}} \mid \cdot R_{\mathrm{N}} \ll 1$ detect the signature of this process.

A very low energy threshold is needed to detect the nuclear recoil!





#### Parity Non-Conserving (PNC) interaction mixes S states with P states. In cesium, this feature allows for the transition 6S→7S between Zeeman sub-levels. By measuring the transition amplitude E<sub>PNC</sub> induced by PNC interaction it is

possible to test the

Phys. Rev. Lett. 55, 2680

Phys. Rev. D 101, 033004

electroweak charge

extracted by measuring the parity violating amplitude,  $E_{PNC}$ , and the Stark vector transition polarizability, β

Experimentally, the weak charge of a nucleus is

$$Q_W = N \left( \frac{\operatorname{Im} E_{\text{PNC}}}{\beta} \right)_{\text{exp.}} \left( \frac{Q_W}{N \operatorname{Im} E_{\text{PNC}}} \right)_{\text{th.}} \beta_{\text{exp.+th}}$$

The **neutron skin**, encased in the parity violating amplitude, takes into account the difference between  $R_n$  and  $R_p$  that has to be considered for the atomic theory derivation.

$$Q_W^{\text{n.s.}}(R_n) = N \left( \frac{\text{Im} E_{\text{PNC}}}{\beta} \right)_{\text{exp.}} \left( \frac{Q_W}{N \text{ Im} \left( E_{\text{PNC}}^{\text{w.n.s.}} + \delta E_{\text{PNC}}^{\text{n.s.}}(R_n) \right)} \right)_{\text{th.}} \beta_{\text{exp.+th.}}$$

The APV result depends on the

neutron distribution radius!

# $\delta E_{\text{PNC}}^{\text{n.s.}}(R_n) = [(N/Q_W) (1 - (q_n(R_n)/q_p)) E_{\text{PNC}}^{\text{w.n.s.}}]$

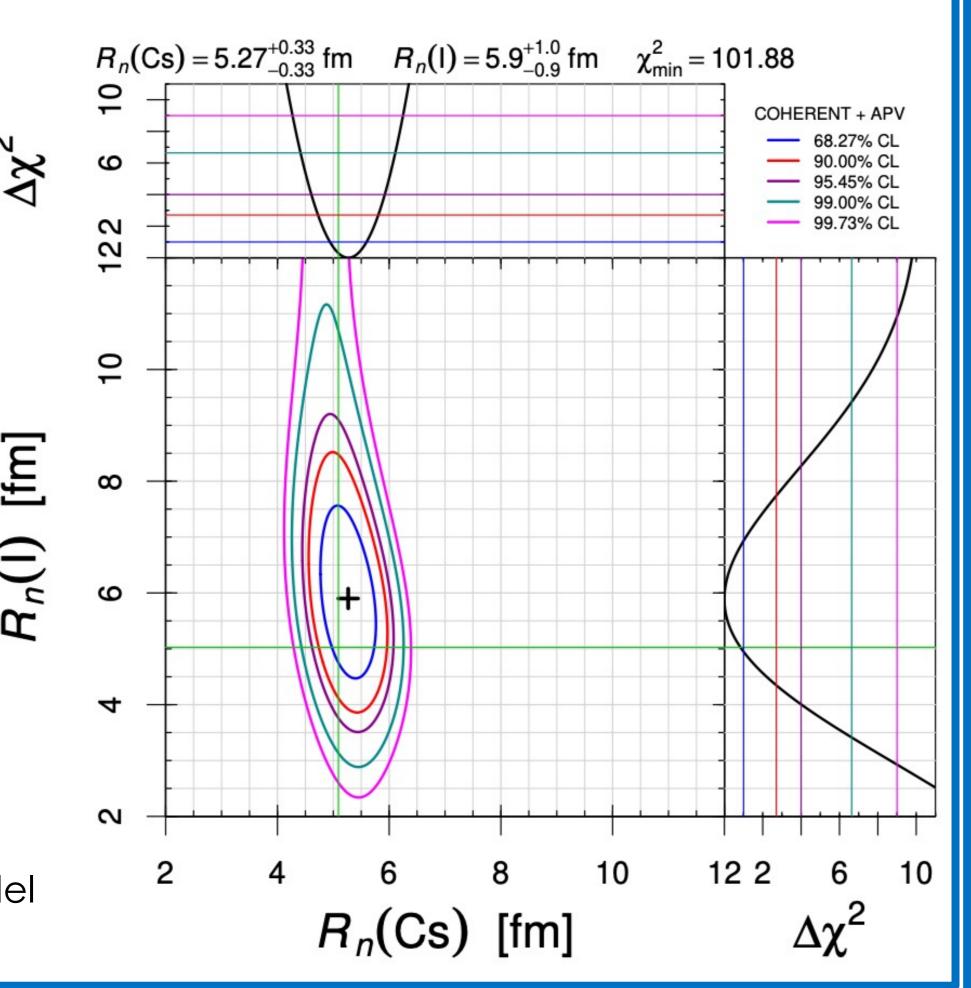
## FIRST DETERMINATION OF I AND CS NEUTRON RADIUS

We fitted the 2020 COHERENT dataset obtained with a 14.6 kg CsI detector and 3.2×10<sup>23</sup> protons delivered to the Hg target at 19.3 m of distance from the detector.

By using the dependence of the distribution radius in the neutron form factor  $F_N(q^2)$  in CEVNS crosssection and the one in the determination of the APV weak-charge it has been possible to with

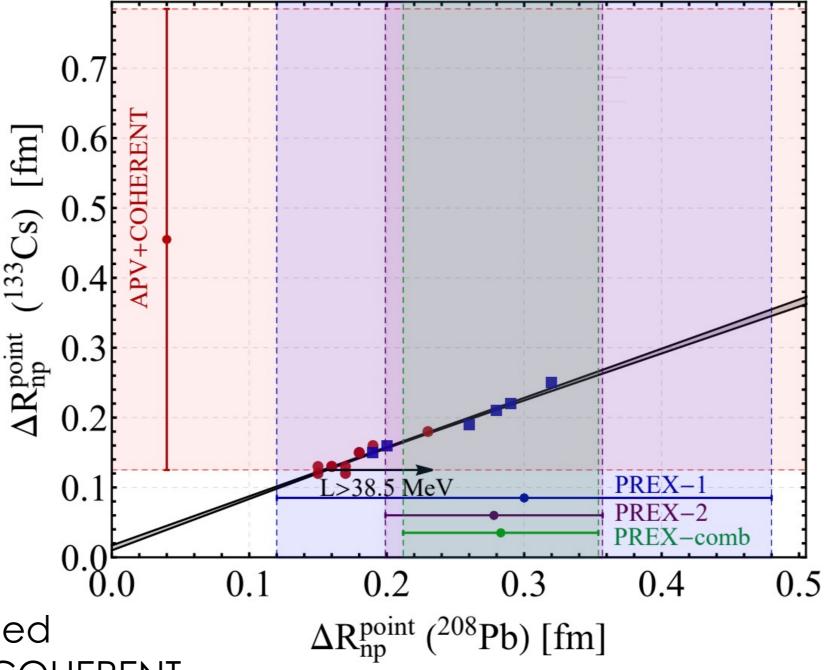
disentangle for the first time the neutron distribution radii of both Cs and I, a good precision for Cs.

The results are obtained by leaving  $R_n$  (Cs) and  $R_n$ (I) free to vary and by fixing the value of the sin<sup>2</sup> $\vartheta_{w}$  at the Standard Model value of 0.23857.



# THE IMPORTANCE OF THE NEUTRON SKIN

The neutron skin of a neutron-rich nucleus is the result of the competition between the Coulomb repulsion between the protons, the surface tension, that decreases when the excess neutrons are pushed to the surface, and the symmetry energy.



Phys. Rev. Lett. 86, 5647

Neutrino energy [MeV]

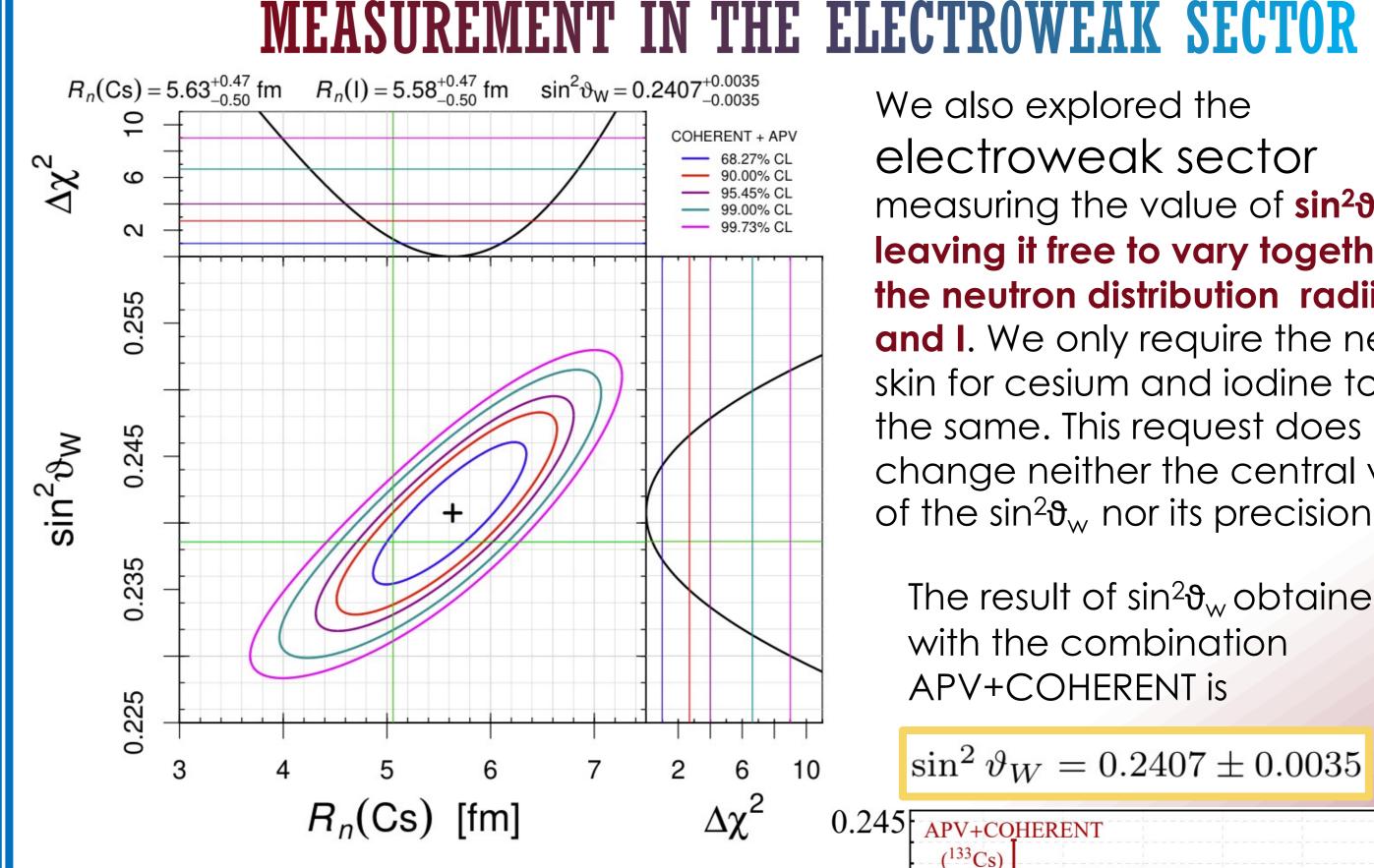
Our result of Cs neutron skin obtained through the combination of APV+COHERENT

can test nuclear models. Together with the measurement of Pb neutron skin performed by PREX experiment it is possible to prefer relativistic nuclear models, leading to larger neutron skin values Phys. Rev. Lett. 126, 172502

$$\Delta R_{np}(^{133}\text{Cs}) = R_n(^{133}\text{Cs}) - R_p(^{133}\text{Cs}) = 0.45^{+0.33}_{-0.33} \text{ fm}$$

Information on neutron skin would greatly improve the modeling of matter inside the cores of **neutron stars** 

For the **Equation of State** it is important to link the binding energy to the density. This connection is represented by the slope parameter L, suggested to be >38.5 MeV according to our result, implying a fairly stiff EOS at typical atomic density

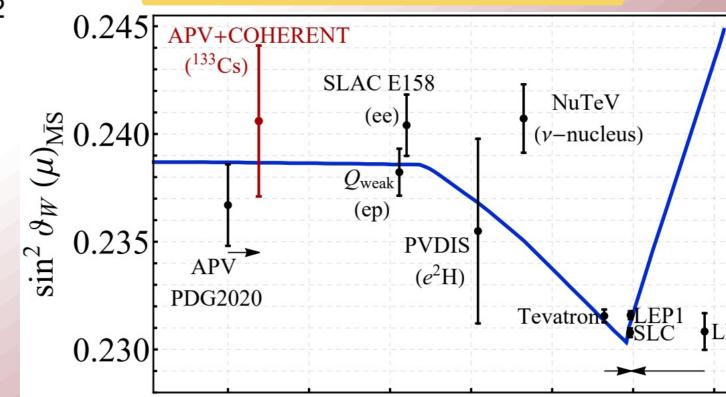


The value of  $\sin^2 \vartheta_w$  depends on the scale, identified by the momentum transfer of the process

We provided for the first time a fully data-driven measureament of the Weinber

We also explored the electroweak sector measuring the value of sin<sup>2</sup>0<sub>w</sub>, by leaving it free to vary together with the neutron distribution radii of Cs and I. We only require the neutron skin for cesium and iodine to be the same. This request does not change neither the central value of the  $\sin^2\theta_w$  nor its precision.

The result of sin<sup>2</sup> obtained with the combination APV+COHERENT is



 $10^{-3} \ 10^{-2} \ 10^{-1}$ angle at lowest scale  $\mu$  [GeV]

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