A set of isotopically enriched detectors as a tool for precise CEvNS measurements

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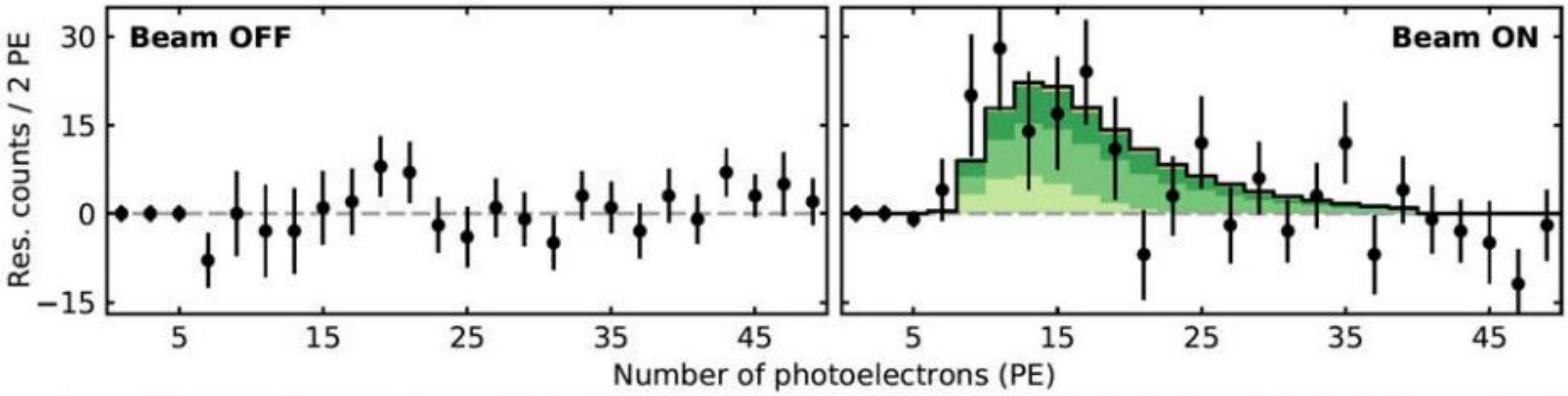
Outline:

1. Motivation
2. Using isotopically enriched detectors to measure CEvNS
3. Test case: N^2 dependence
4. Expectations for π-DAR neutrinos
5. Expectations for Reactor neutrinos
6. Summary

Status of CEvNS measurements:

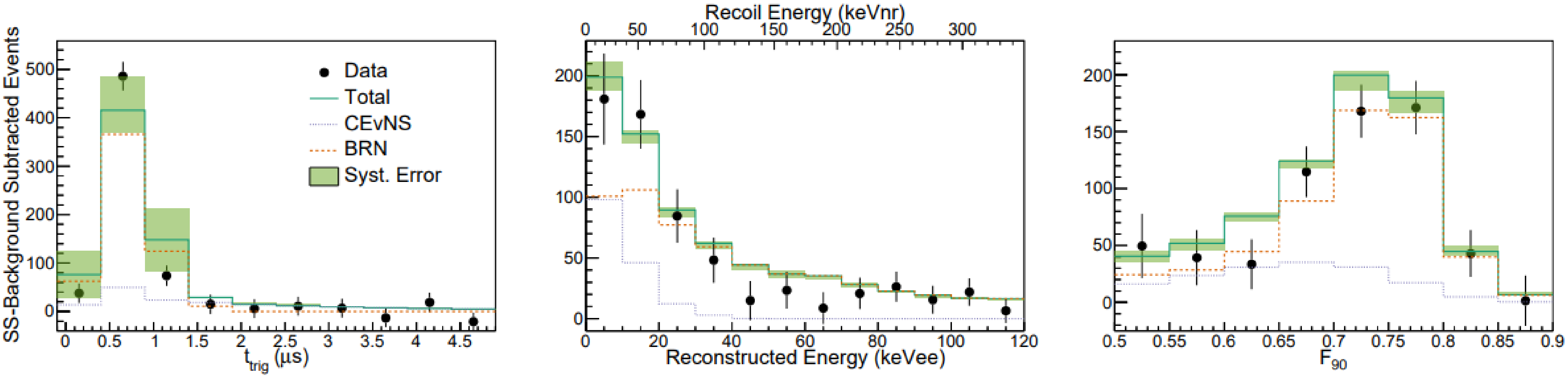
- First detection by the COHERENT collaboration in 2017 using a π-DAR source and a CsI detector.



134 ± 22 reported events with 2017 dataset.

D. Akimov et al., "Observation of Coherent Elastic Neutrino-Nucleus Scattering," Science 357 (2017) 1123–1126

- Second observation by the COHERENT collaboration in 2020 using a LAr detector:



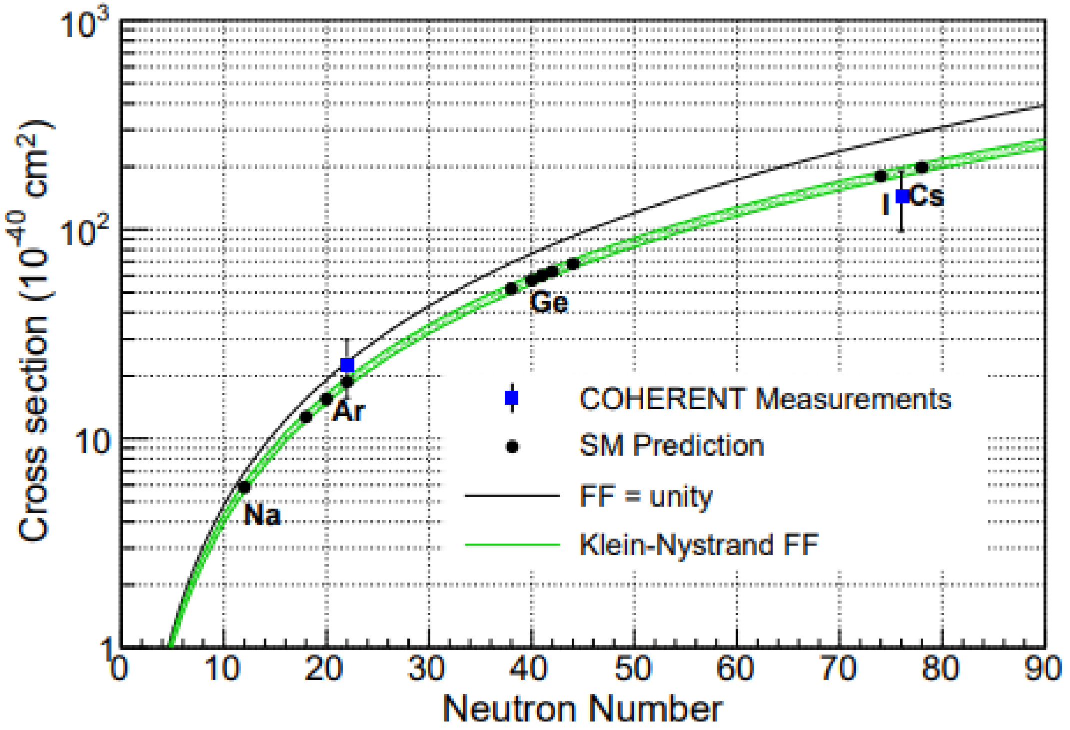
159 ± 43 ± 14 reported events. (Analysis A)

D. Akimov et al., "First Detection of Coherent Elastic Neutrino-Nucleus Scattering on Argon," arXiv:2003.10630

Towards precision measurements

- Precision measurements need to be done; this will lead to **a better understanding of the cross section.**
- Additional experiments would be desirable to elucidate, for instance, the quadratic dependence in the neutron number.
- Precision measurements and mitigation of systematic errors are needed in order to study new Physics:
    - Non-Standard Interactions (NSI)
    - Light Mediators
    - Neutrino Magnetic Moment
    - Sterile Neutrinos

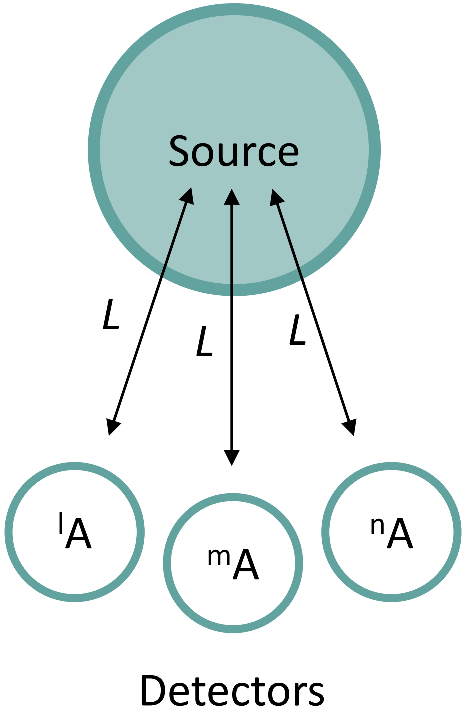
$$\left(\frac{d\sigma}{dT}\right)^{\text{coh}}_{\text{SM}} = \frac{G_F^2 M}{\pi}\left[1 - \frac{MT}{2E_\nu^2}\right]\left[Z g_V^p F_Z(q^2) + N g_V^n F_N(q^2)\right]^2$$



D. Akimov et al., "Observation of Coherent Elastic Neutrino-Nucleus Scattering," Science 357 (2017) 1123–1126

A novel approach to measure CEvNS

- We propose an array of detectors of **different isotopes**[1] to make a simultaneous measurement.
- Systematic effects will be *common to all the detectors*.
- Nuclei of different isotopes only differ by the number of neutrons, *leading to a correlation of* systematic uncertainties of form factors and quenching factors.
- The idea is applicable to different elements.



A = Element (Ge, Si, Ni)

l, m, n = Number of neutrons

Z fixed

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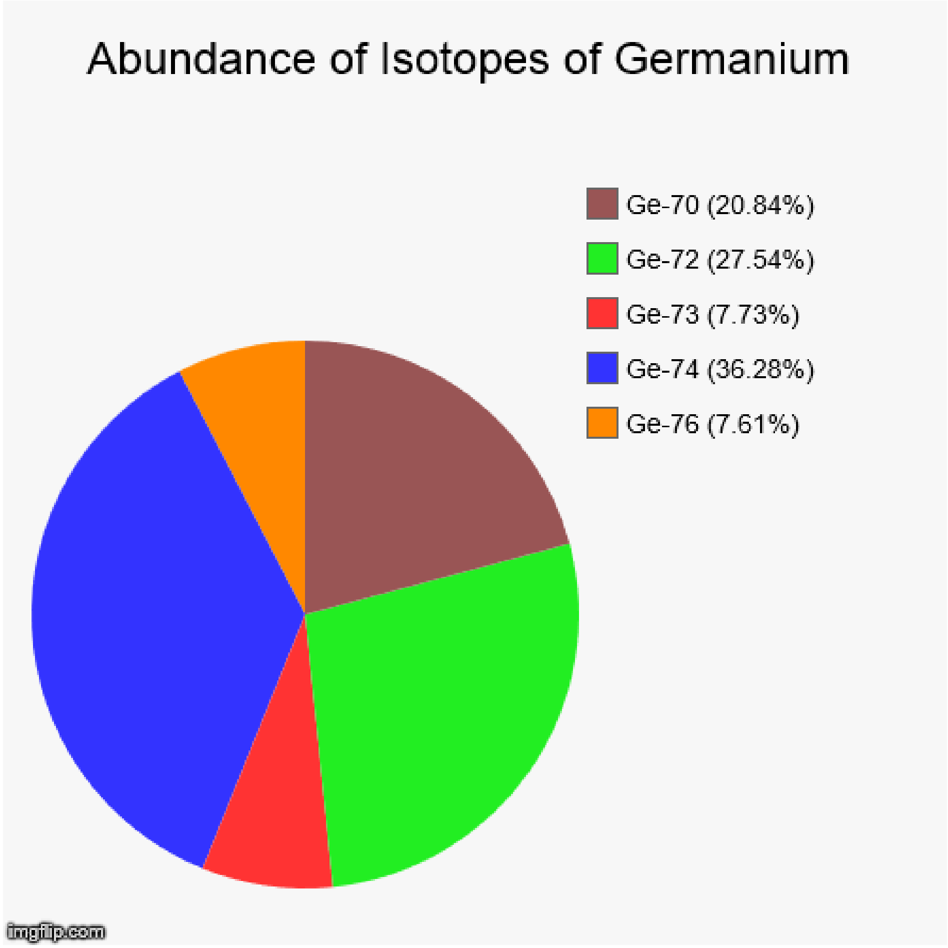
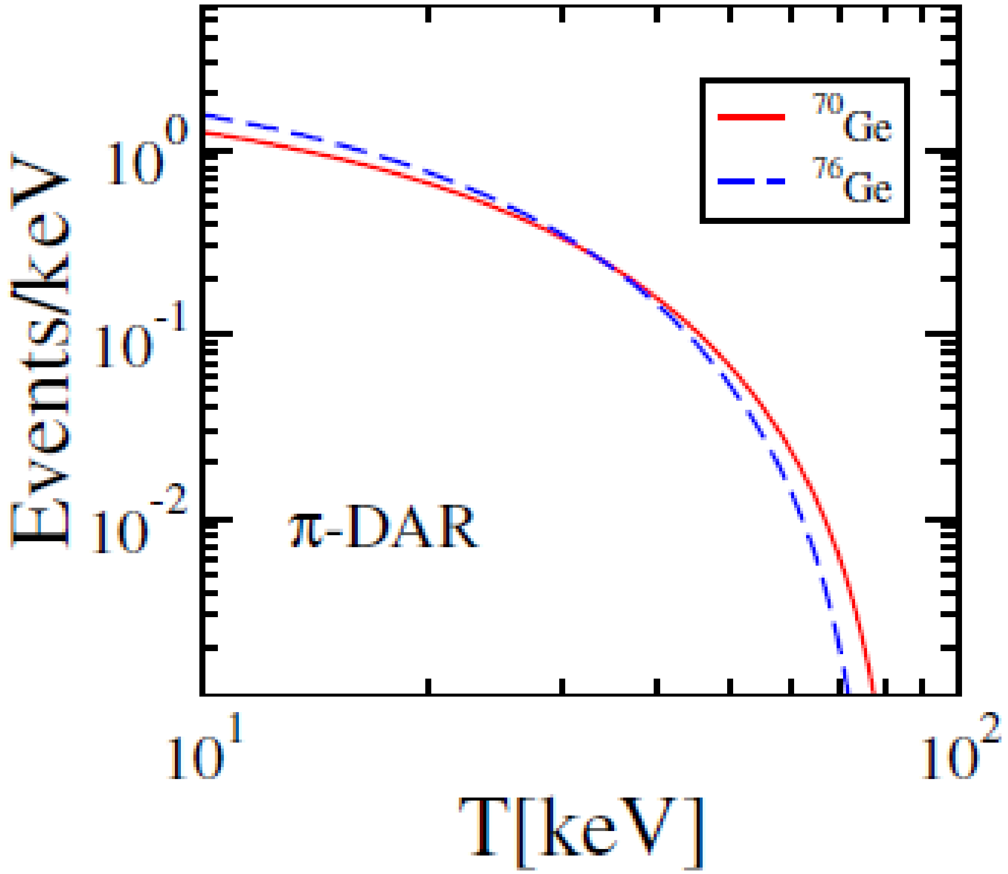
[1] *Galindo-Uribarri, A. (2019). Differential measurement of coherent-elastic neutrino-nucleus scattering using isotopically enriched Ge detectors. Bulletin of the American Physical Society, 64.*

The Germanium example:

- HPGe detectors are currently being used in the search of CEvNS.
- Natural Ge has five different stable isotopes.
- Highly enriched ^{76}Ge detectors are being used for the search of 0νββ.
- Detectors depleted in ^{76}Ge show an identical performance as those from natural germanium material.



Differential rate for the SNS:



$$N^{th} = N_D \int_T A(T)dT \int_{E_{min}}^{E_{Max}} dE\phi(E)\frac{\mathrm{d}\sigma}{\mathrm{d}T}$$

- One-year data taking for the characteristics of the Spallation Neutron Source.
- Crossover at the tail of the spectrum due to kinematic effects.
- Expected quadratic dependence if we cover the whole recoil energy spectrum.

How can we take advantage of the correlation effects?

- Let’s say we want to test the theoretical prediction about the quadratic dependence of the cross section.

$$\left(\frac{d\sigma}{dT}\right)^{\mathrm{coh}}_{\mathrm{SM}} = \frac{G_F^2 M}{\pi}\left[1-\frac{MT}{2E_\nu^2}\right]\left[Z g_V^p F_Z(q^2) + N g_V^n F_N(q^2)\right]^2$$

- **First step:** We introduce a parameter *N′* to quantify the deviation in the number of events.

$$\begin{aligned}\mathcal{N}^{theo} = {} & N'^2\left(g_V^{n^2} N_D \frac{G_F^2 M}{\pi}\int_T A(T)dT\int_{E_{min}}^{E_{Max}} dE\left[1-\frac{MT}{2E_\nu^2}\right]\phi(E)F_N^2(q^2)\right)\\ & + N'\left(Z g_V^p g_V^n N_D \frac{G_F^2 M}{\pi}\int_T A(T)dT\int_{E_{min}}^{E_{Max}} dE\left[1-\frac{MT}{2E_\nu^2}\right]\phi(E)F_Z(q^2)F_N(q^2)\right)\\ & + Z^2 g_V^{p^2} N_D \frac{G_F^2 M}{\pi}\int_T A(T)dT\int_{E_{min}}^{E_{Max}} dE\left[1-\frac{MT}{2E_\nu^2}\right]\phi(E)F_Z^2(q^2)\end{aligned}$$

- We introduce a correlation matrix to minimize the function:

$$\chi^2 = \sum_{ij} (\mathcal{N}_i^{theo} - \mathcal{N}_i^{exp}) [\sigma_{ij}^2]^{-1} (\mathcal{N}_j^{theo} - \mathcal{N}_j^{exp})$$

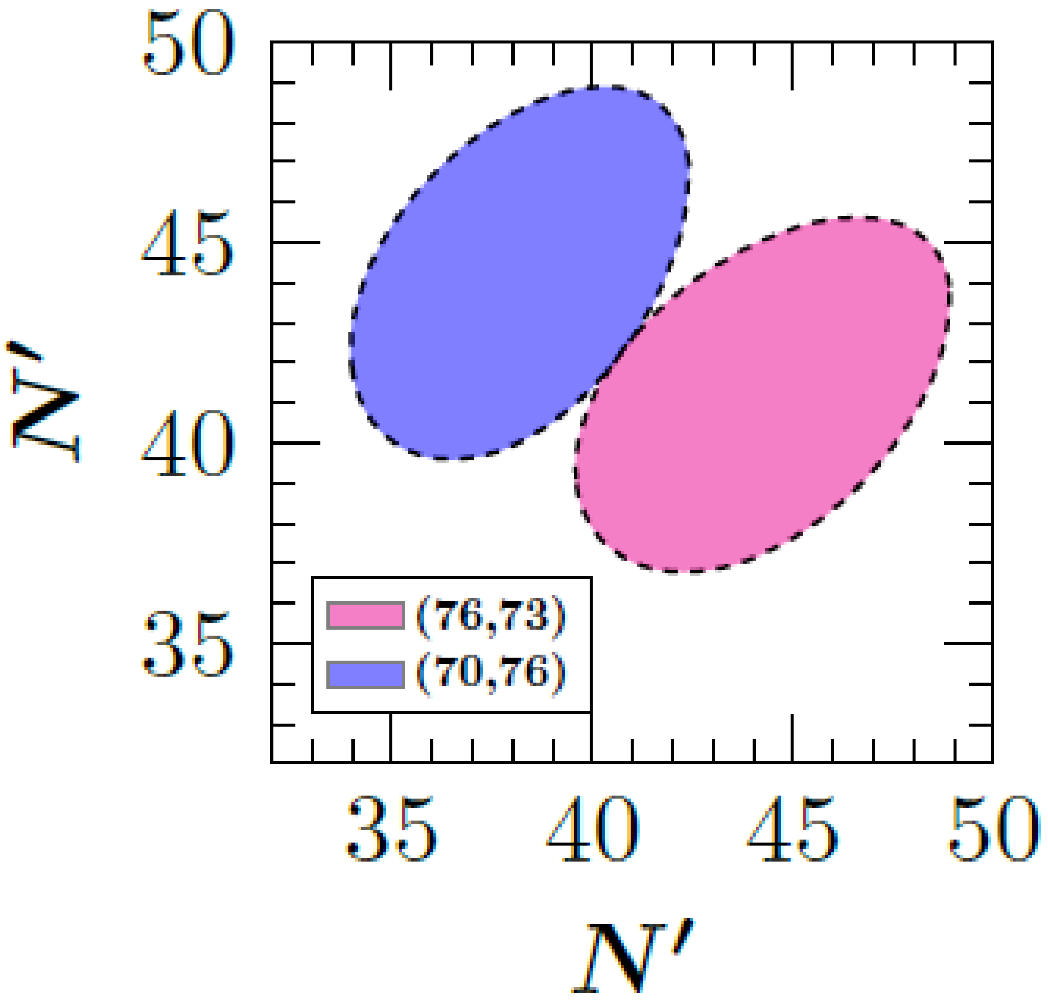
- If we consider three different detectors like ^{70}Ge, ^{73}Ge and ^{76}Ge the correlation matrix reads:

$$\sigma^2 = \begin{pmatrix} {\sigma_{70}^{stat}}^2 + {\sigma_{70}^{A}}^2 + {\sigma_{70}^{B}}^2 & \sigma_{70}^{A}\sigma_{73}^{A} + \sigma_{70}^{B}\sigma_{73}^{B} & \sigma_{70}^{A}\sigma_{76}^{A} + \sigma_{70}^{B}\sigma_{76}^{B} \\ \sigma_{70}^{A}\sigma_{73}^{A} + \sigma_{70}^{B}\sigma_{73}^{B} & {\sigma_{73}^{stat}}^2 + {\sigma_{73}^{A}}^2 + {\sigma_{73}^{B}}^2 & \sigma_{73}^{A}\sigma_{76}^{A} + \sigma_{73}^{B}\sigma_{76}^{B} \\ \sigma_{70}^{A}\sigma_{76}^{A} + \sigma_{70}^{B}\sigma_{76}^{B} & \sigma_{73}^{A}\sigma_{76}^{A} + \sigma_{73}^{B}\sigma_{76}^{B} & {\sigma_{76}^{stat}}^2 + {\sigma_{76}^{A}}^2 + {\sigma_{76}^{B}}^2 \end{pmatrix}$$

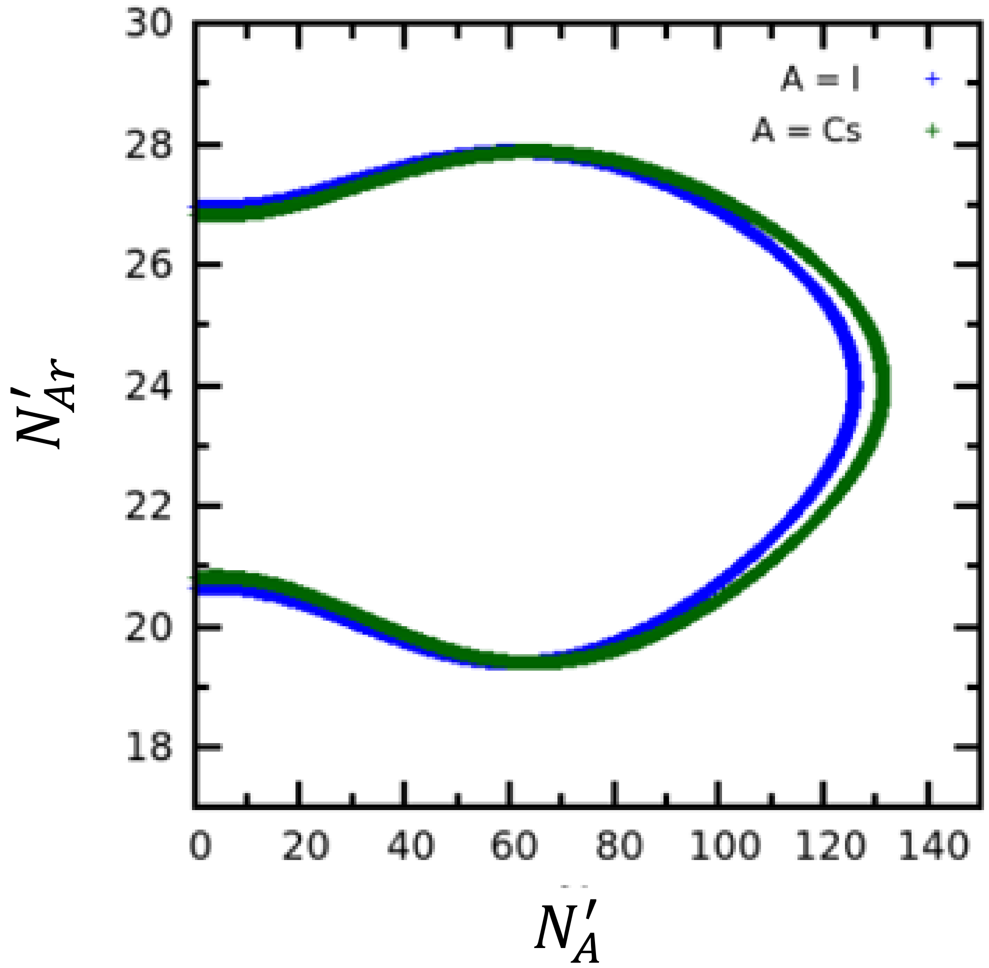
- The indices *A* and *B* stand for the most significant sources of systematic errors.
- For the SNS we consider ***σ^A = quenching factor*** and ***σ^B = form factor*** contributions.

Expected results for the SNS:

- We consider a set of 3 different isotopes: ^{70}Ge, ^{73}Ge and ^{76}Ge
- Expectation for the allowed values of the N’ parameter consistent with theory at a 90% C.L.
- We chose a convenient recoil energy range from 5 to 30 keV.
- Clearly separated regions as a result of the correlations between experiments.



Comparison with current CsI and LAr measurements.

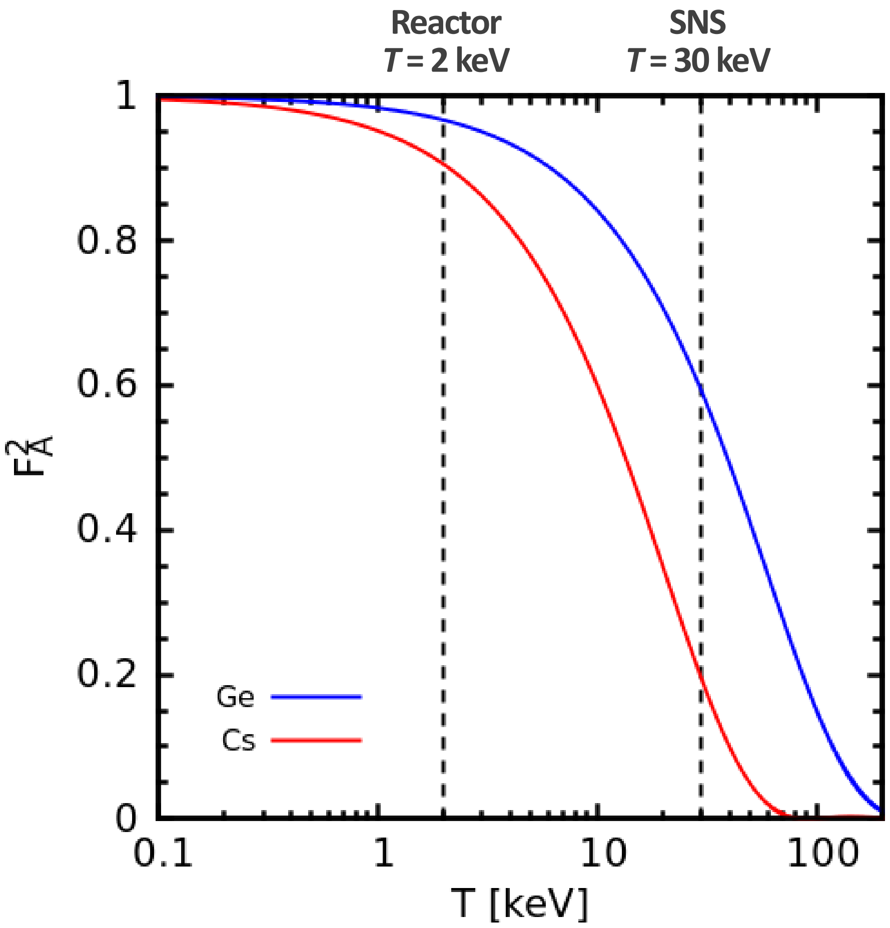


- No correlations for a combined analysis with CsI and LAr measurements.
- Unbounded region at a 90% C.L.
- Either Cs or I fixed for the analysis in each region.

CEvNS with reactor neutrinos

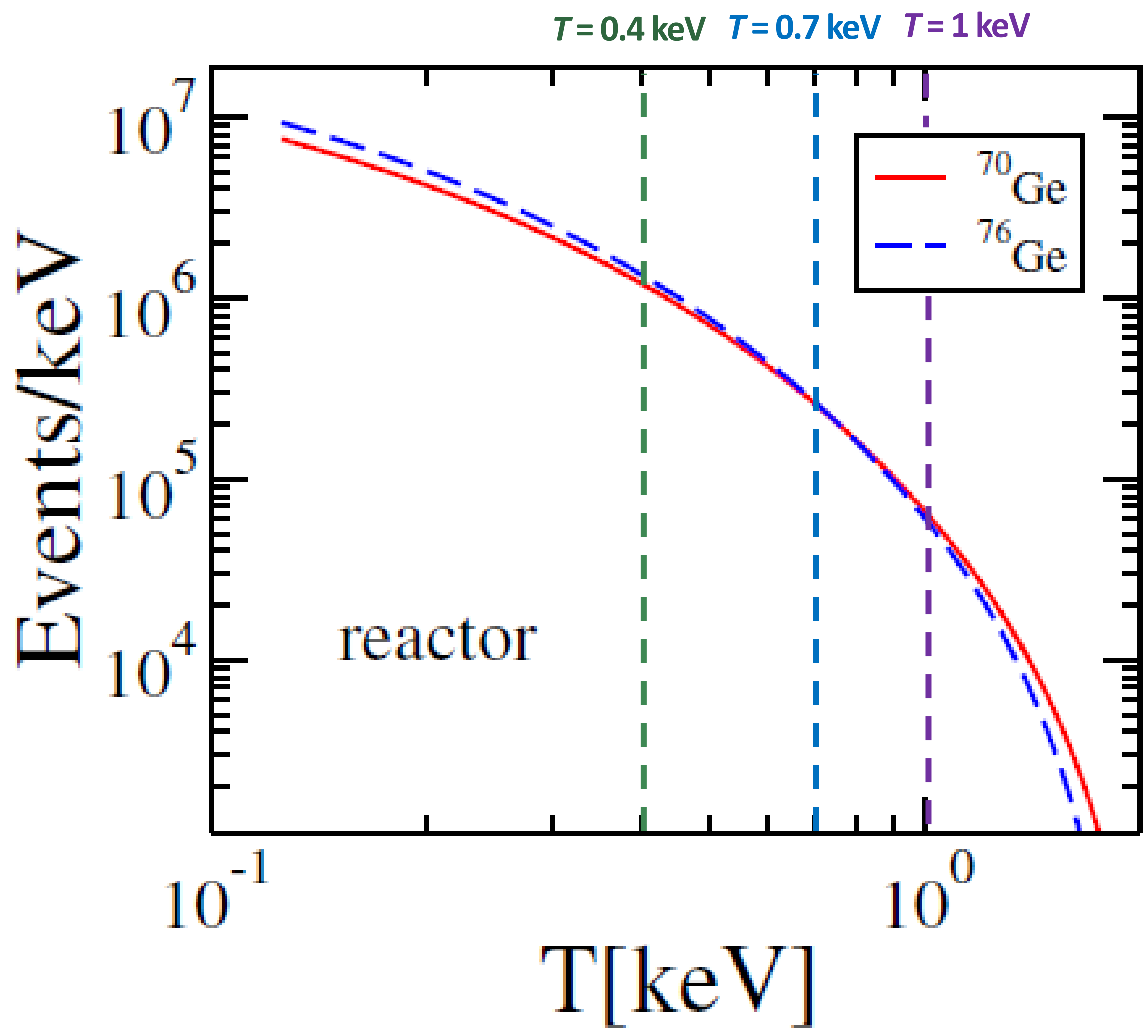
CEvNS with reactor neutrinos

- Many experiments are working to get the first CEvNS signal from reactor neutrinos.
- **Advantages:**
- Better statistics.
- Form factor effects do not play a significant role due to the low energy regime.
- **Disadvantages:**
- Lower energy detection thresholds needed.

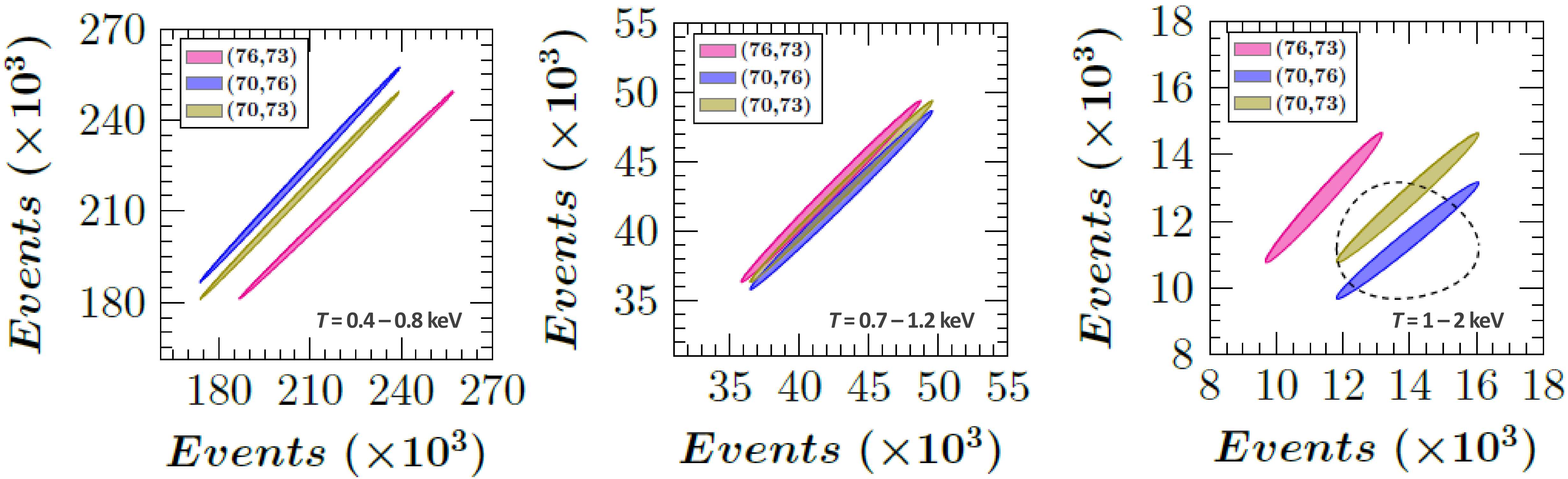


Differential rate for reactor experiments.

- Very low recoil energy threshold needed.
- Possibility to explore different recoil energy regions.
- Significant sources of systematic errors are *A = quenching factor* and *B = neutrino flux.*



Expected number of events at 90% C.L.:



- Different behavior of the allowed regions depending on the recoil energy interval under study.

Summary:

- Studying CEvNS with several isotopically enriched detectors under the same conditions can be a reliable way to improve the accuracy of the measurements.
- Germanium isotopes are convenient to perform these measurements, although with current technologies, the idea can be applied to other nuclei as Si and Ni.
- Precision measurements are needed in order to use this process to study new physics scenarios as well as to get information about nuclear parameters.
- This method can be generalized to the study of other parameters that include the effects of new physics.
- *Arxiv* paper has been submitted.

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