The COHERENT Collaboration

Observation of CEvNS at SNS

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Contents

- CEvNS
- Neutrinos at SNS
- CsI[Na] detector
- Backgrounds
- Analysis and results
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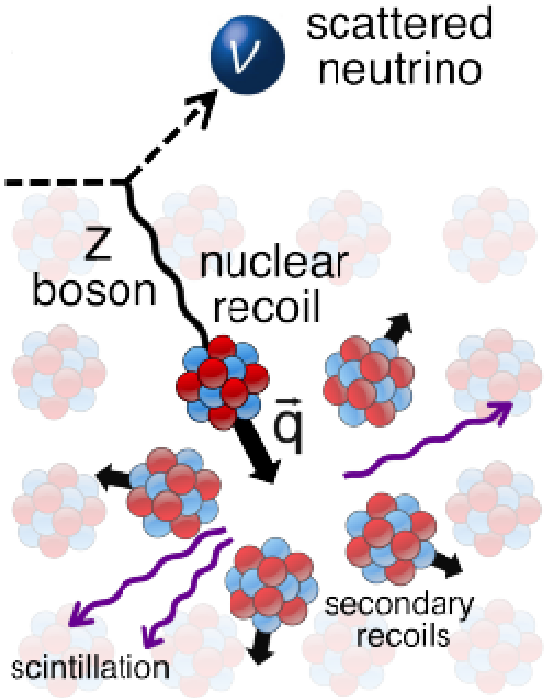
Collaboration

THE UNIVERSITY OF CHICAGO
Duke UNIVERSITY
UF UNIVERSITY of FLORIDA
KAIST
Laurentian University Université Laurentienne
Los Alamos NATIONAL LABORATORY EST. 1943
BERKELEY LAB
MEPhI
NORTH CAROLINA CENTRAL UNIVERSITY
NC STATE UNIVERSITY
NM STATE UNIVERSITY
OAK RIDGE National Laboratory
Carnegie Mellon University
Sandia National Laboratories
THE UNIVERSITY of TENNESSEE UT KNOXVILLE
TUNL
W UNIVERSITY of WASHINGTON

Coherent elastic neutrino-nucleus scattering



- Neutral weak current process
- Low momentum transfer, $\lambda_z = 1/q < R_N$
- Identical initial and final states

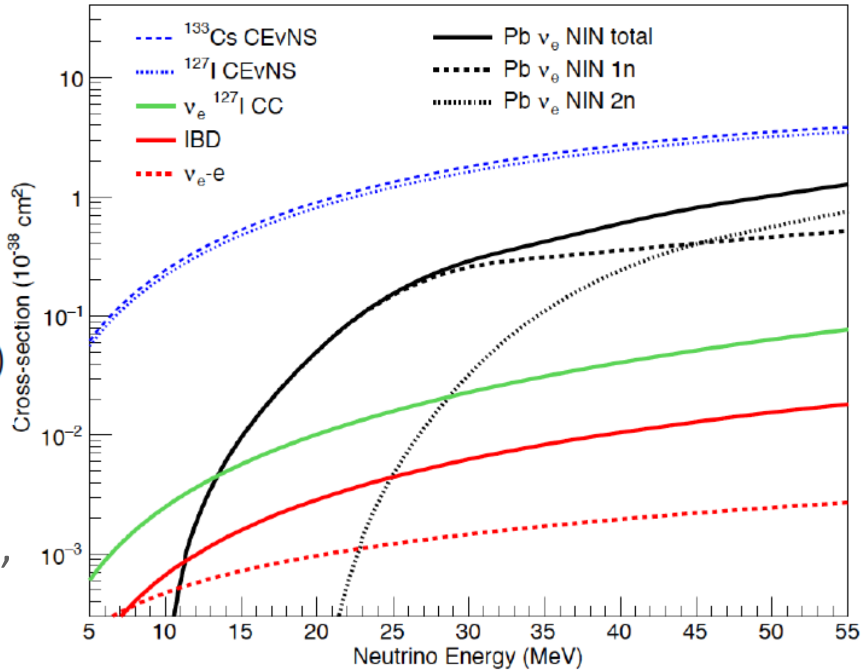
The process was predicted about four decades ago:

D. Z. Freedman, “Coherent effects of a weak neutral current”, Phys. Rev. D9, 1389 (1974)

Largest of all Standard Model low-energy neutrino interactions cross-section

$$\frac{d\sigma}{d\Omega} = \frac{G^2}{4\pi^2} k^2 (1+\cos\theta) \frac{(N-(1-4\sin^2\theta_W)Z)^2}{4} F^2(Q^2)$$

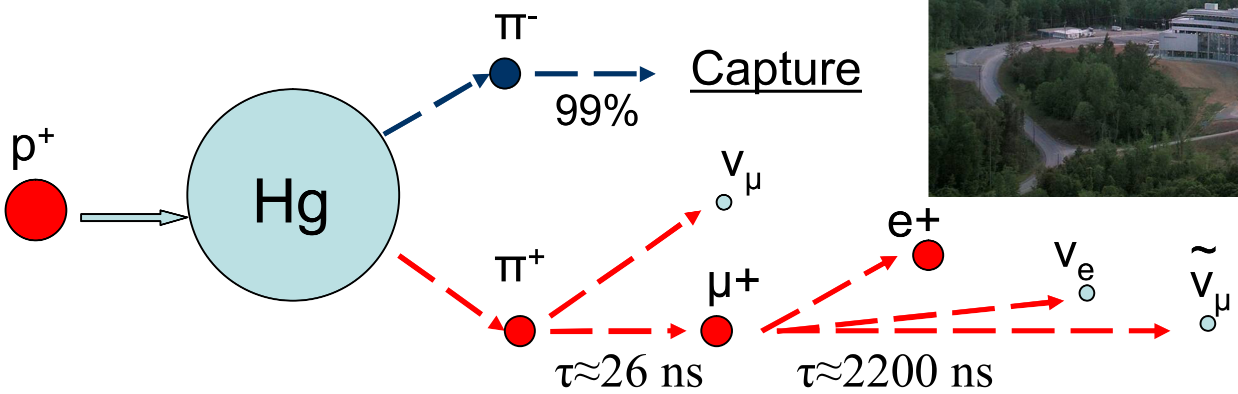
where G – Fermi constant, Z – number of protons, N – number of neutrons, F(Q²) – nuclear form factor, Q – momentum transfer, k – neutrino energy



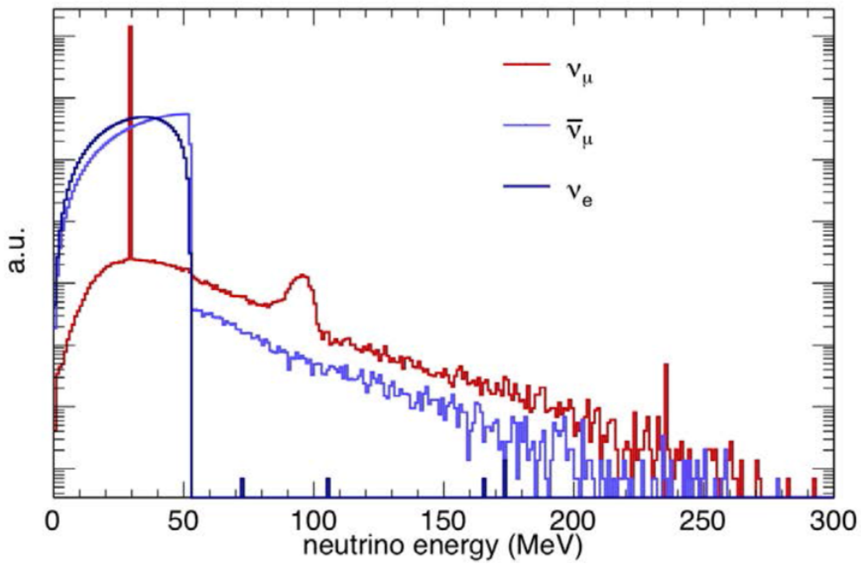
Spallation Neutron Source (SNS) accelerator at ORNL

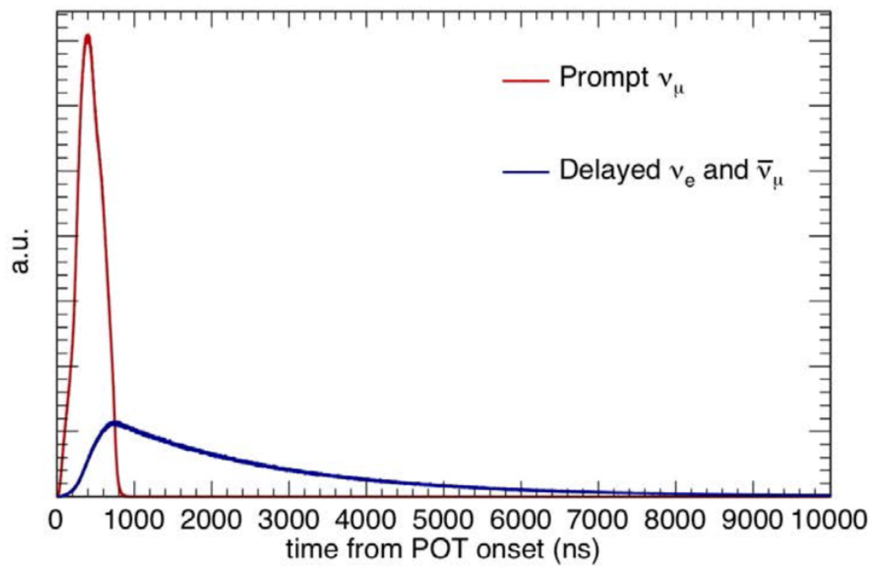
Dumping bunches of ~1 GeV protons on the Hg target with 60 Hz frequency

Full width of a bunch time profile ~800 ns



Total neutrino flux $4.3 \cdot 10^{7}$ cm^{-2}*s^{-1} at 20m





The CsI[Na] detector

CsI[Na] cylindrical crystal manufactured by Amcrys-H, Ukraine

Crystal dimensions:

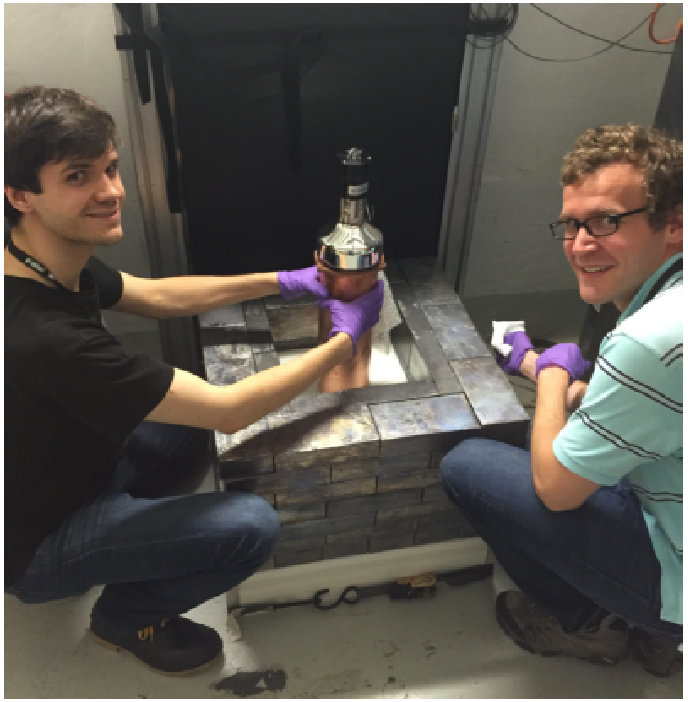
diameter – 11 cm,

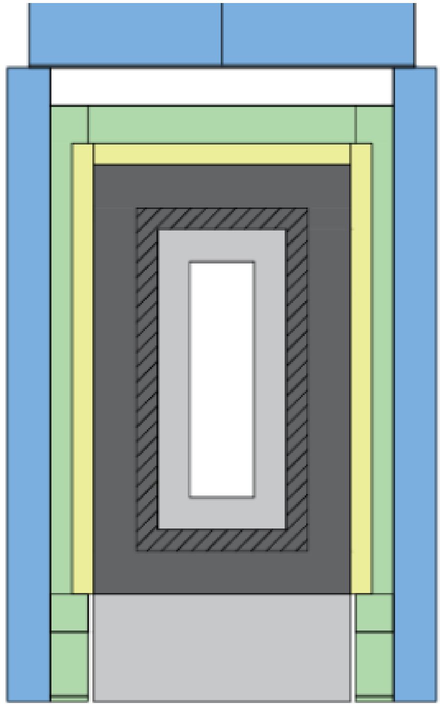
length - 34 cm,

weight – 14.5 kg

Light collection by R877-100 PMT

Light yield of 13.35 PE/keV





J. Collar et al., "Coherent neutrino-nucleus scattering detection with a CsI[Na]…",NIM A773, 56 (2015)

Shielding design:

Layer	HDPE*	Low backg. lead	Lead	Muon veto	Water
Thickness	3''	2''	4''	2''	4''
Colour					

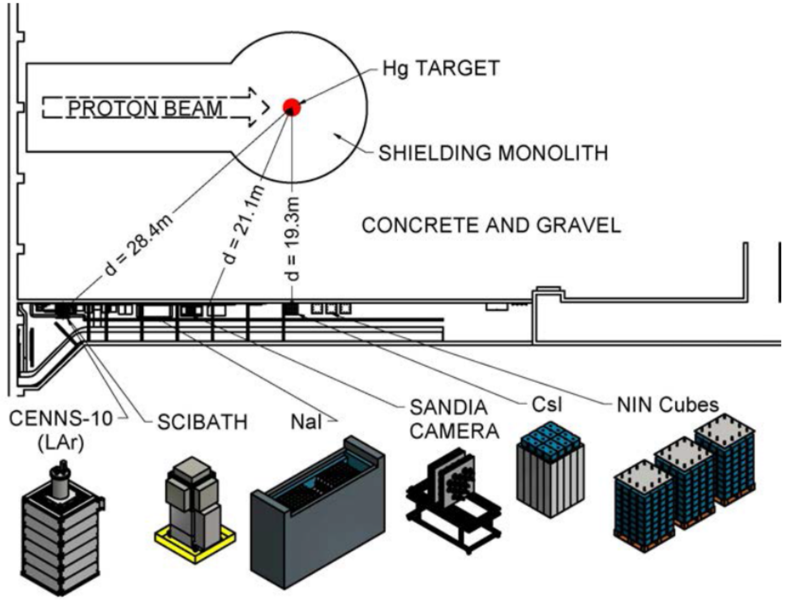
Neutron backgrounds

"Neutrino alley":

SNS basement with 8 m.w.e. overburden
-> reduction of CR background

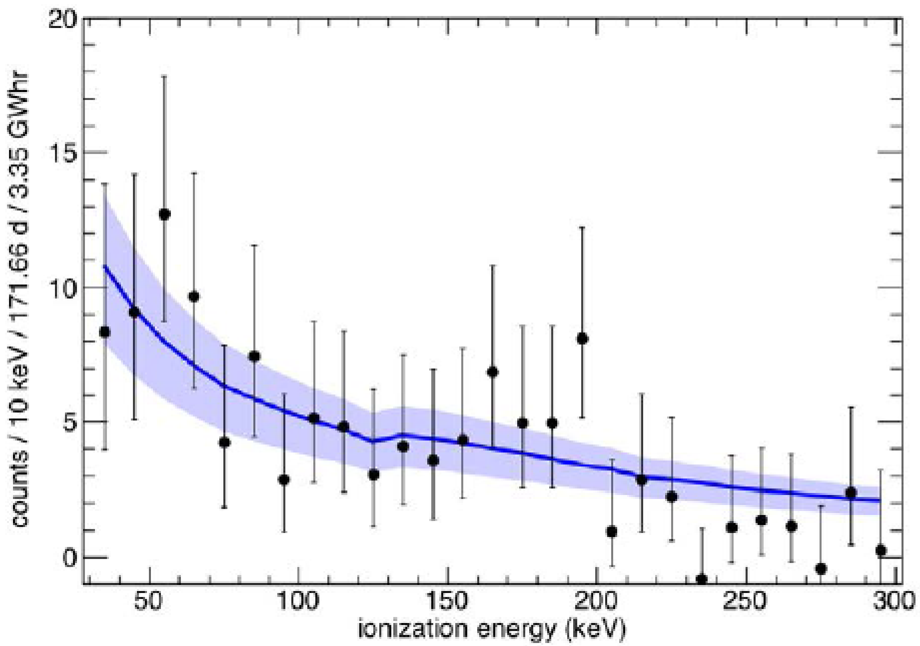
20 m of concrete and gravel to the SNS target
-> reduction of prompt neutron flux

Steady state background reduction (pulsed source): ~10^3 (for CsI[Na])



Prompt neutron flux measurements:

- Measurements with Scibath and Sandia Camera
- In situ measurements within the CsI[Na] shielding prior to installation (Liquid Scint.)
- Limits coming from the absence of peak from the ^{127}I(n,n'γ) reaction in the CEvNS search data



Neutrino induced neutrons (NINs)

In situ measurement with LS was also used to constrain NINs rate

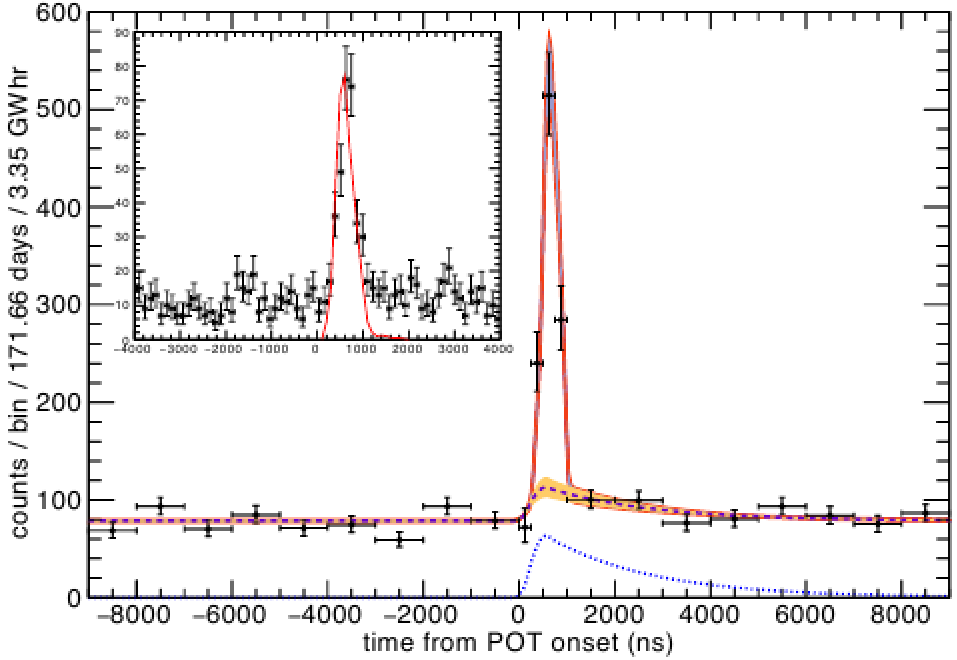
$$\nu_e +^{208} Pb \Rightarrow {}^{208}Bi^* + e^- \quad (CC)$$
$$\Downarrow$$
$$^{208-y}Bi + x\gamma + yn$$

$$\nu_x +^{208} Pb \Rightarrow {}^{208}Pb^* + \nu_x' \quad (NC)$$
$$\Downarrow$$
$$^{208-y}Pb + x\gamma + yn.$$

Fitting of the arrival times of neutron-like signals

First indication of NINs detection

(1.7 times below theory prediction)



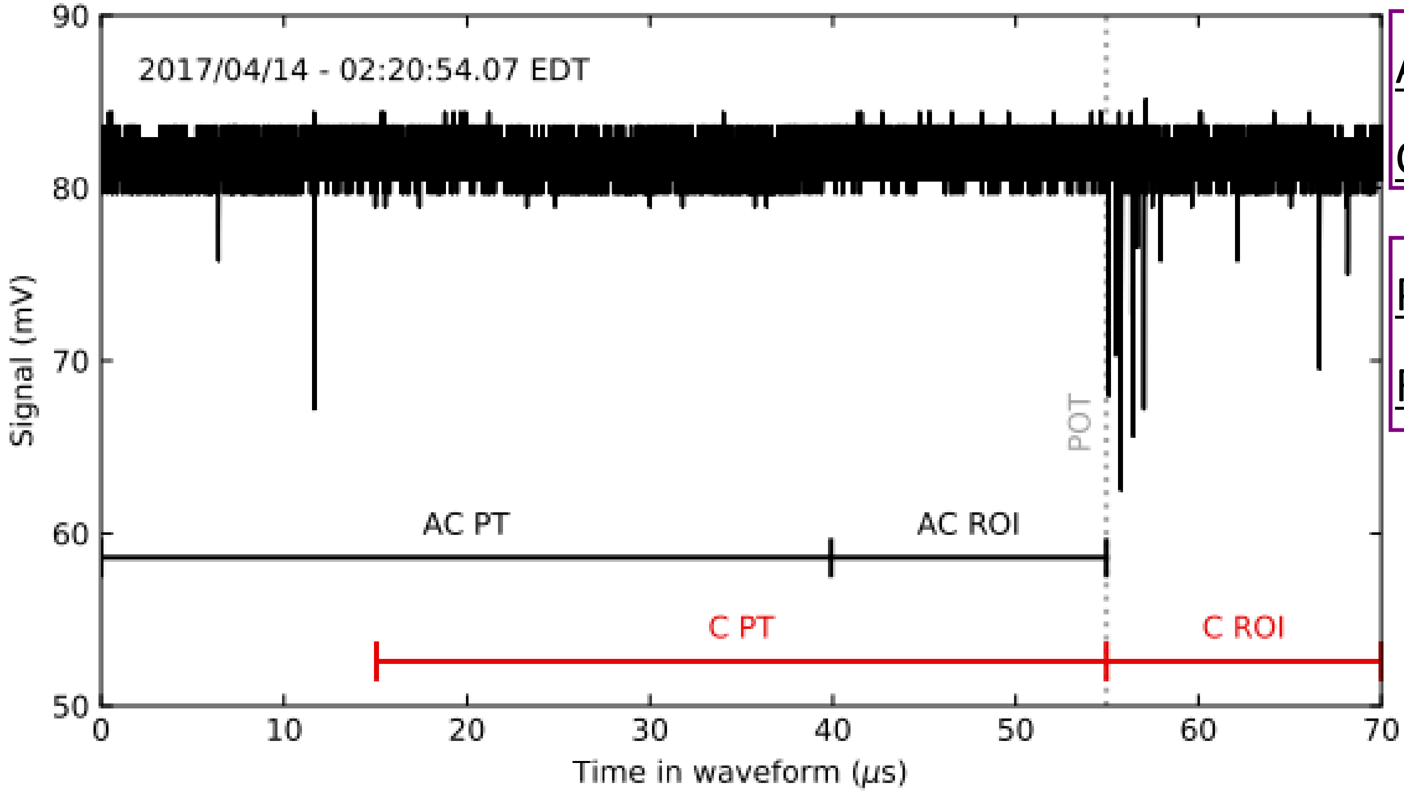
Prompt neutron and NINs rates estimates were used in the final analysis

This process can be important in many stellar environments

E. Kolbe, E. Langanke, "Role of v-induced reactions on lead and iron…", Phys. Rev. C63 (2001)

DAQ and analysis approach

Recording of 70 µs waveforms with 500 MHz sampling of CsI and veto channels



AC – anti-coincidence;

C – coincidence

PT – pretrace;

ROI – region of interest

Around 2 billions of waveforms were recorded!

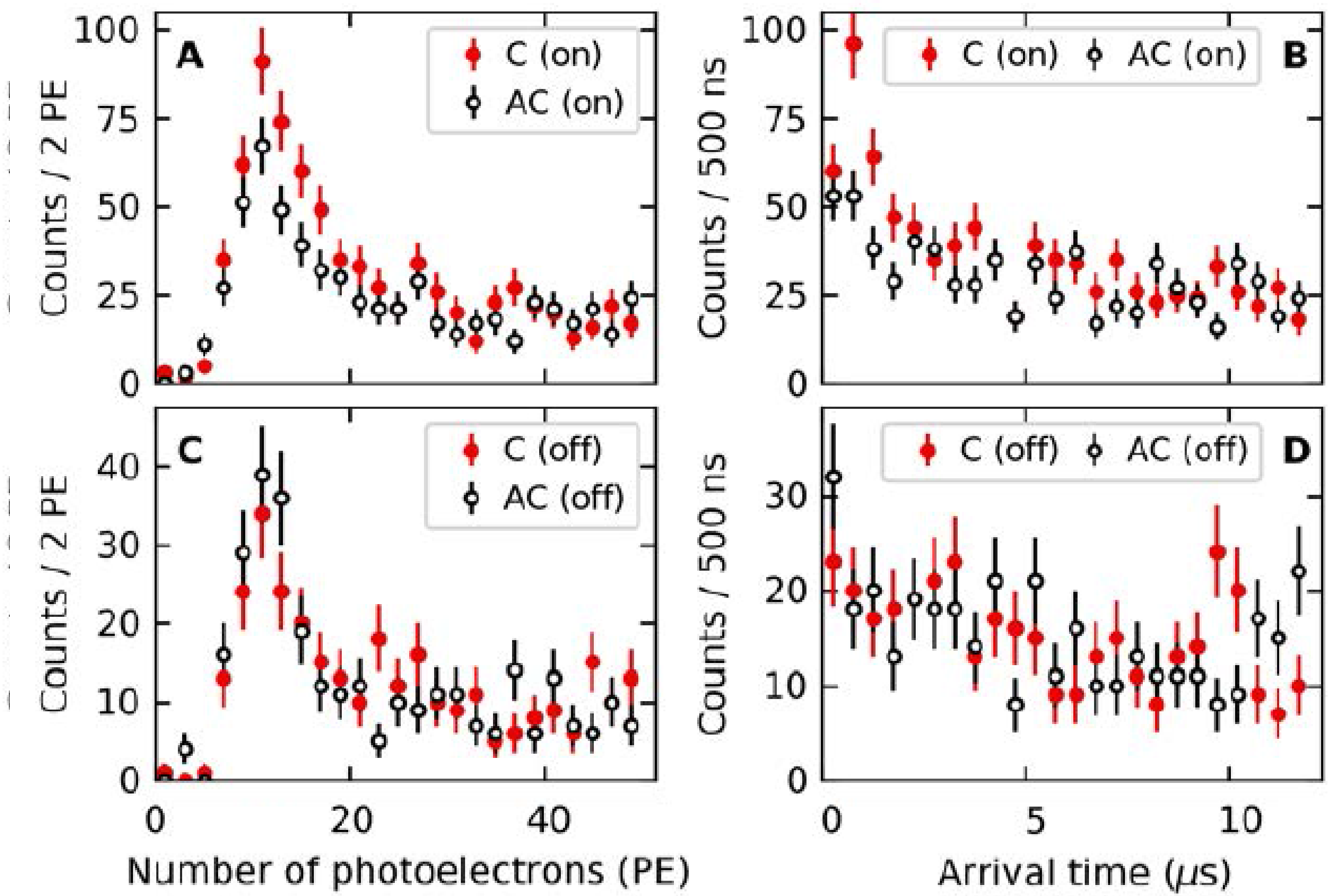
Scheme: look into ROI → find the first pulse → integrate for 3 µsec

C ROI (after trigger) – AC ROI (before trigger) =

CEvNS + Beam correlated background + Fluctuations of steady state background

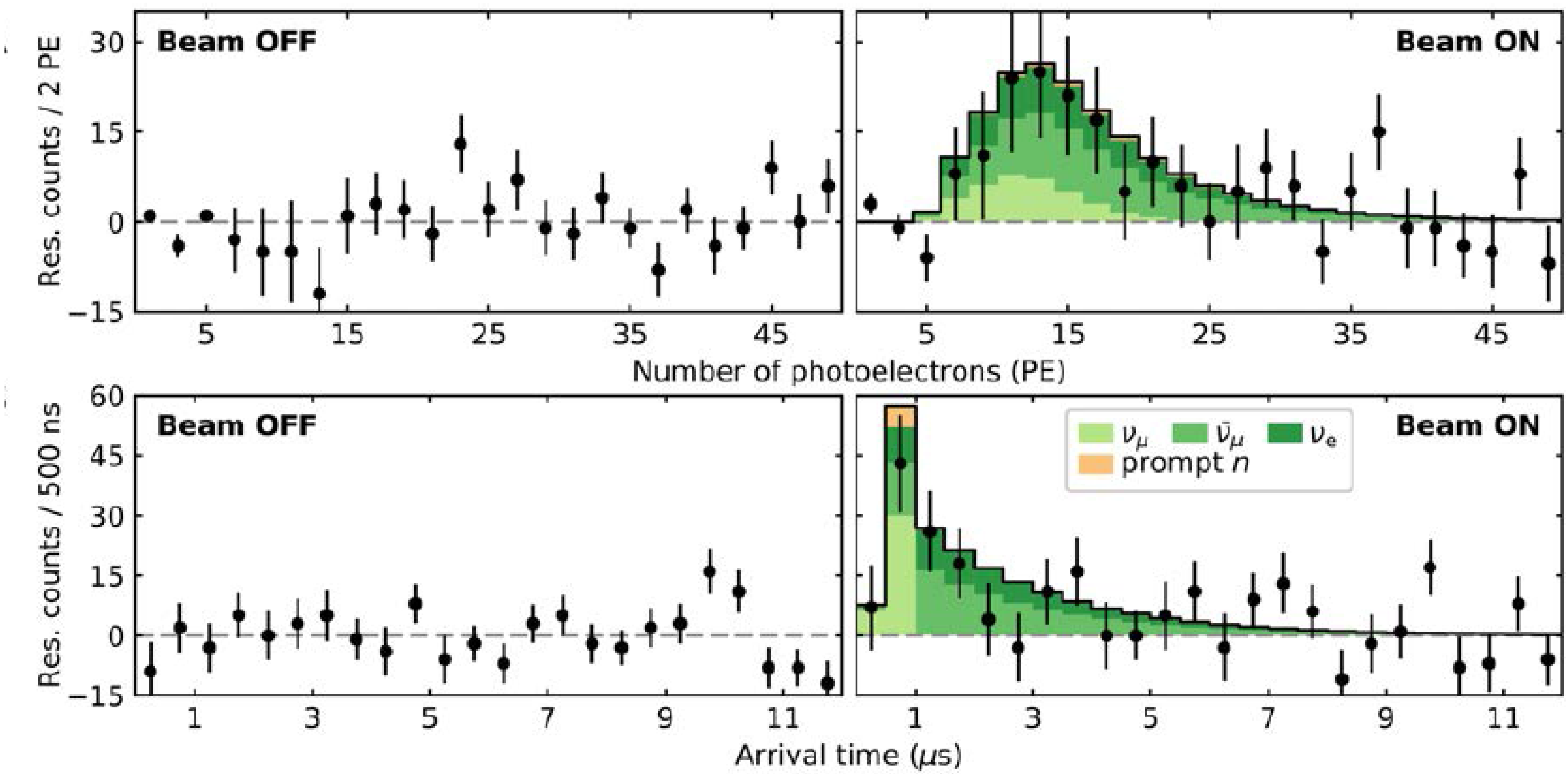
Results

Spectra of integrals and arrival times of signals appearing in ROI



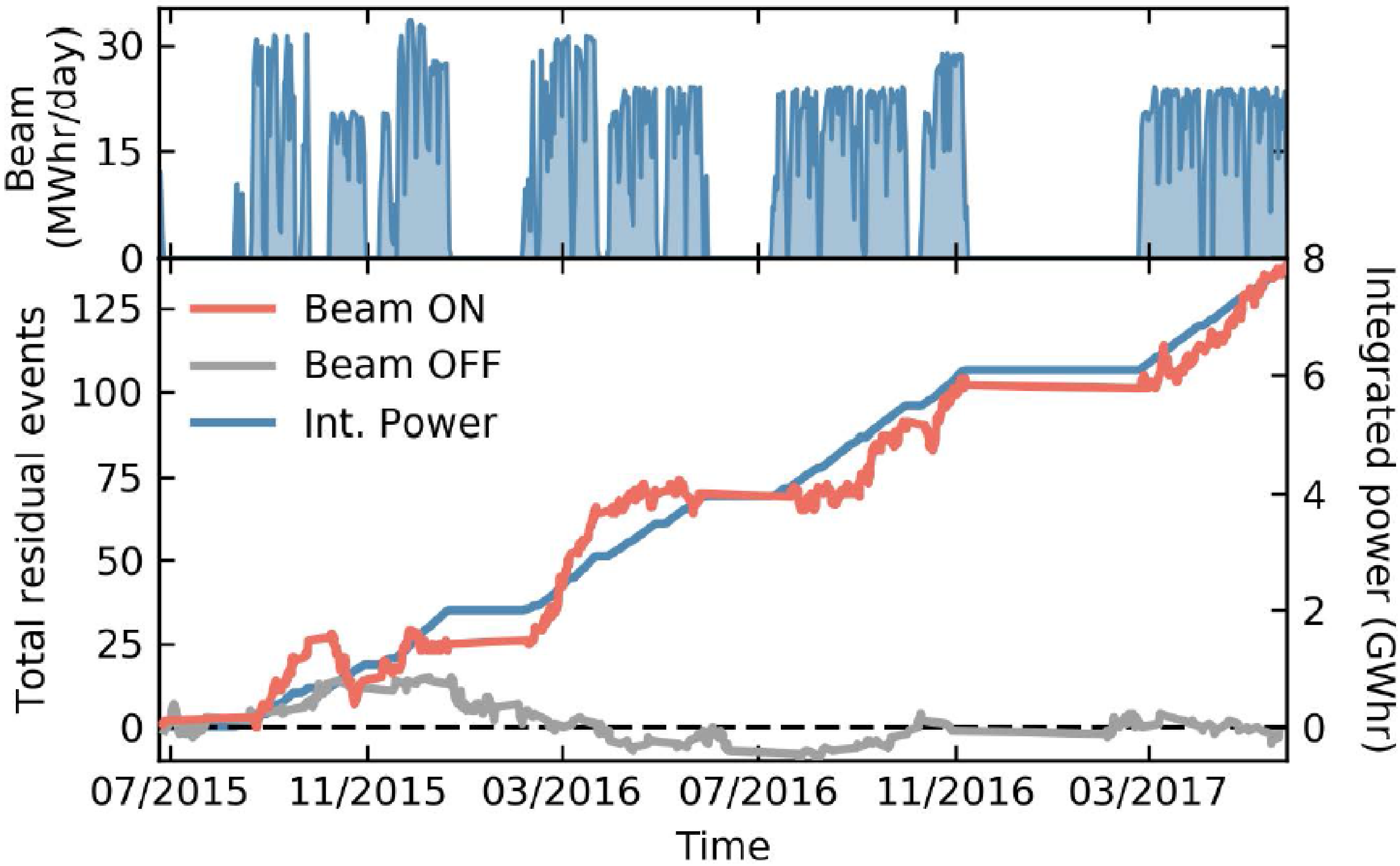
Results: residual spectra

Residual spectra of integrals and arrival times of signals appearing in ROI



The significant excess in both spectra for BEAM ON only periods is observed

Results: accumulated residuals vs. Beam Power



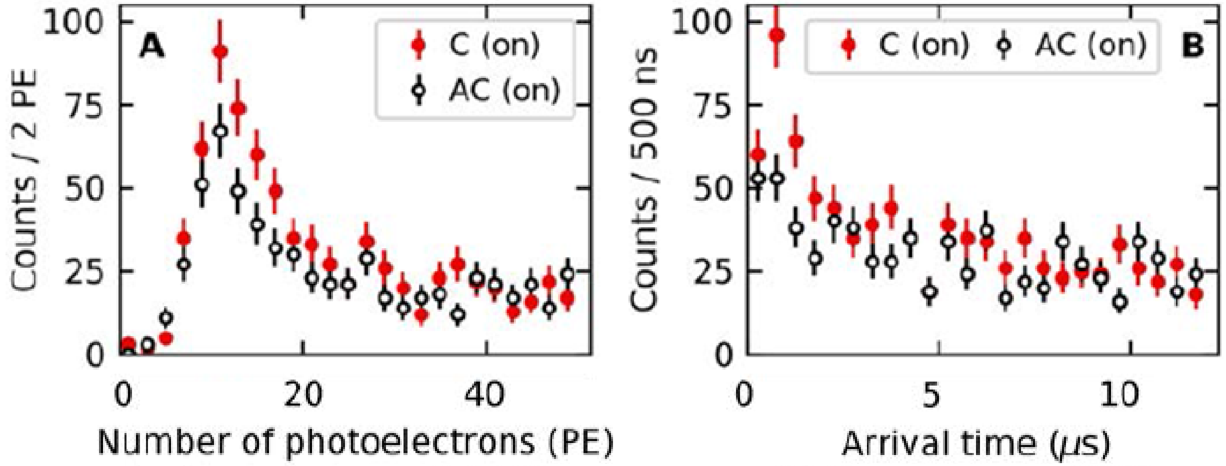
The formation of excess is strongly correlated with the accumulated Beam Power

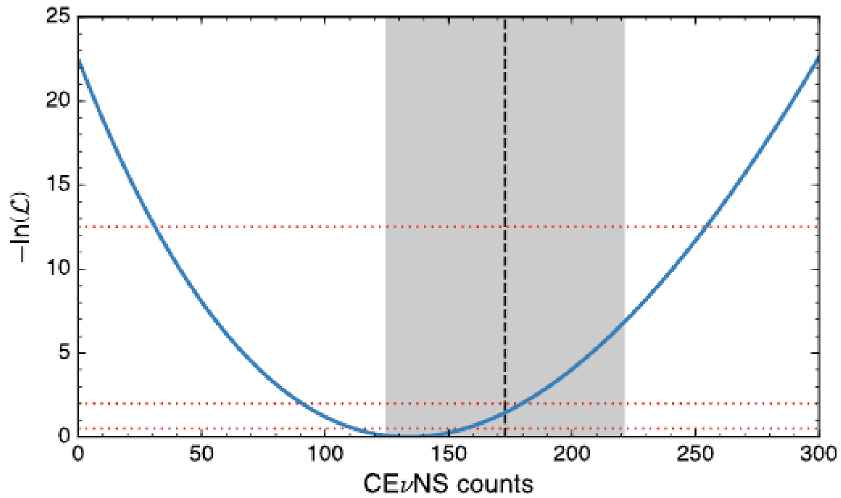
Results: significance

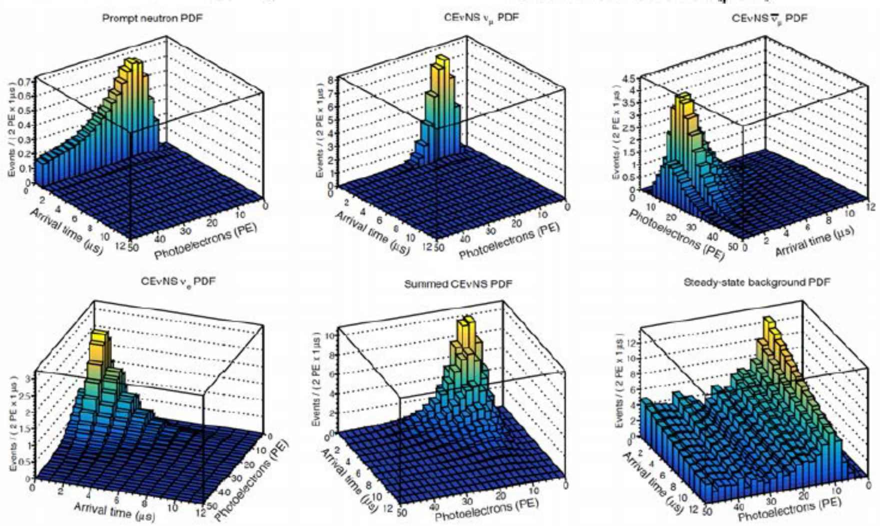
The ML fit for the CEvNS signal including contributions from the prompt neutrons and the steady state backgrounds taken from the anti-coincidence window

6.7σ significance!

Agreement with the SM prediction to within 1σ





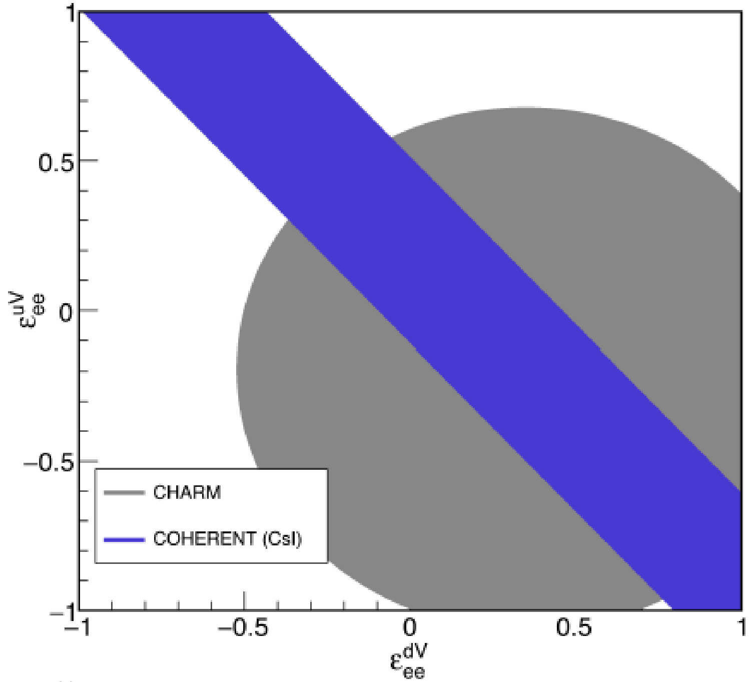


D. Akimov et al., “Observation of Coherent Elastic Neutrino-Nucleus Scattering”, Science (2017) , arXiv[1708.01294]

CEvNS and NSI

Model independent parameterization of NS contributions to neutrino-quark interactions

Considering only $\varepsilon_{ee}^{uV}, \varepsilon_{ee}^{dV}$ to have non-zero values

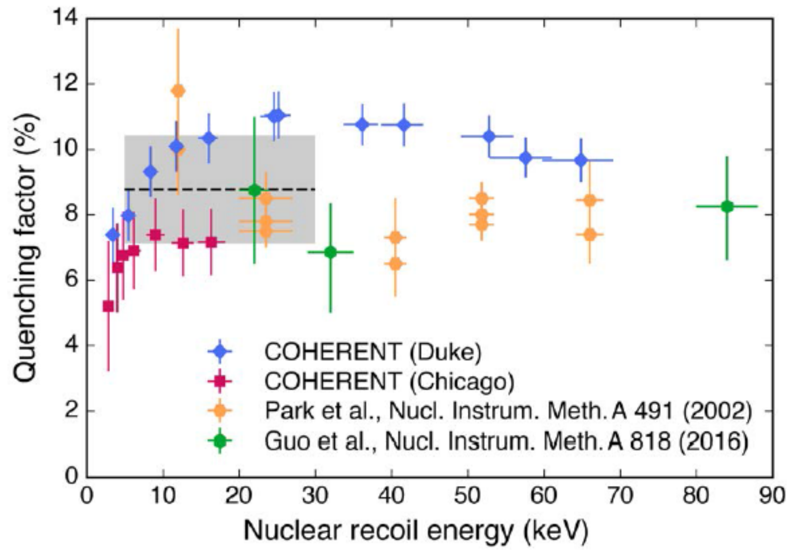


First result can improve constraints on non-universal interactions

Systematics

- Uncertainty in the CsI[Na] QF (~25%)
- SNS neutrino flux (~10%)
- Signal acceptance (~5%)
- Form-factor uncertainty (~5%)

Total: 28%



Activities and perspectives

- CENNS-10 LAr detector (single phase, 22 kg) aiming for CEvNS
- “NIN cubes” to measure NINs production on lead, iron and copper
- NaIve (NaI[Tl], 185 kg → 2T) to measure CC and NC on ^{127}I, CEvNS on Na
- P-Type Point Contact HPGE detector to be deployed soon to hunt for CEvNS
- Scibath, Sandia Camera and MARS to measure neutron backgrounds
- Small CsI[Na] crystal to repeat the QF measurements at TUNL
- CsI[Na] continues acquiring statistics

Hope to see new exciting results soon!

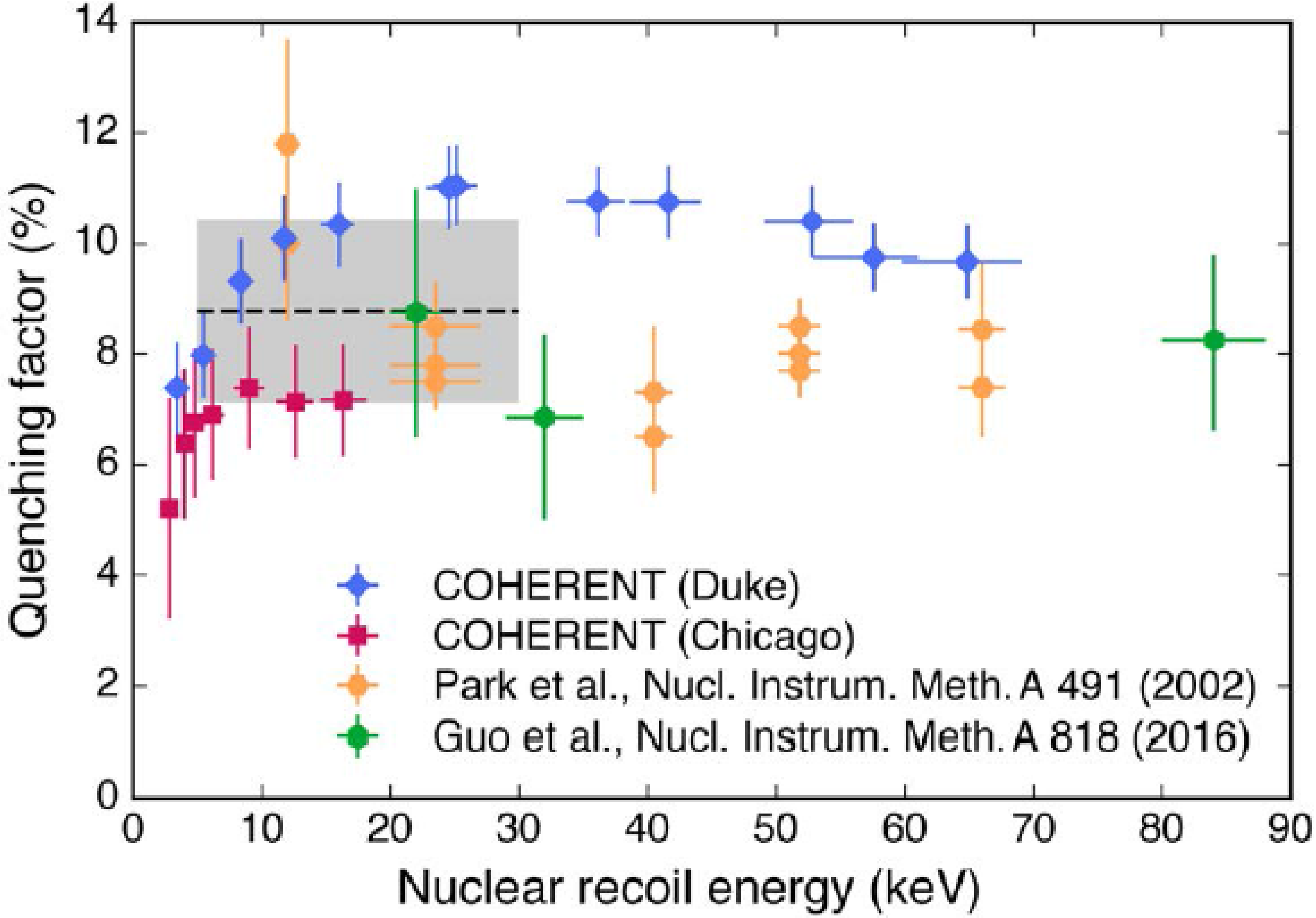
Backup 1: QF measurements at TUNL

- D(D,n) generator (3.8 MeV)
- shield to attenuate off-axis neutrons
- scatterer under investigation (not shown)
- twelve backing detectors
- zero-degree beam monitor

Two independent measurements with the ~100 g CsI[Na] crystal from the same manufacturer as 14.5 kg one

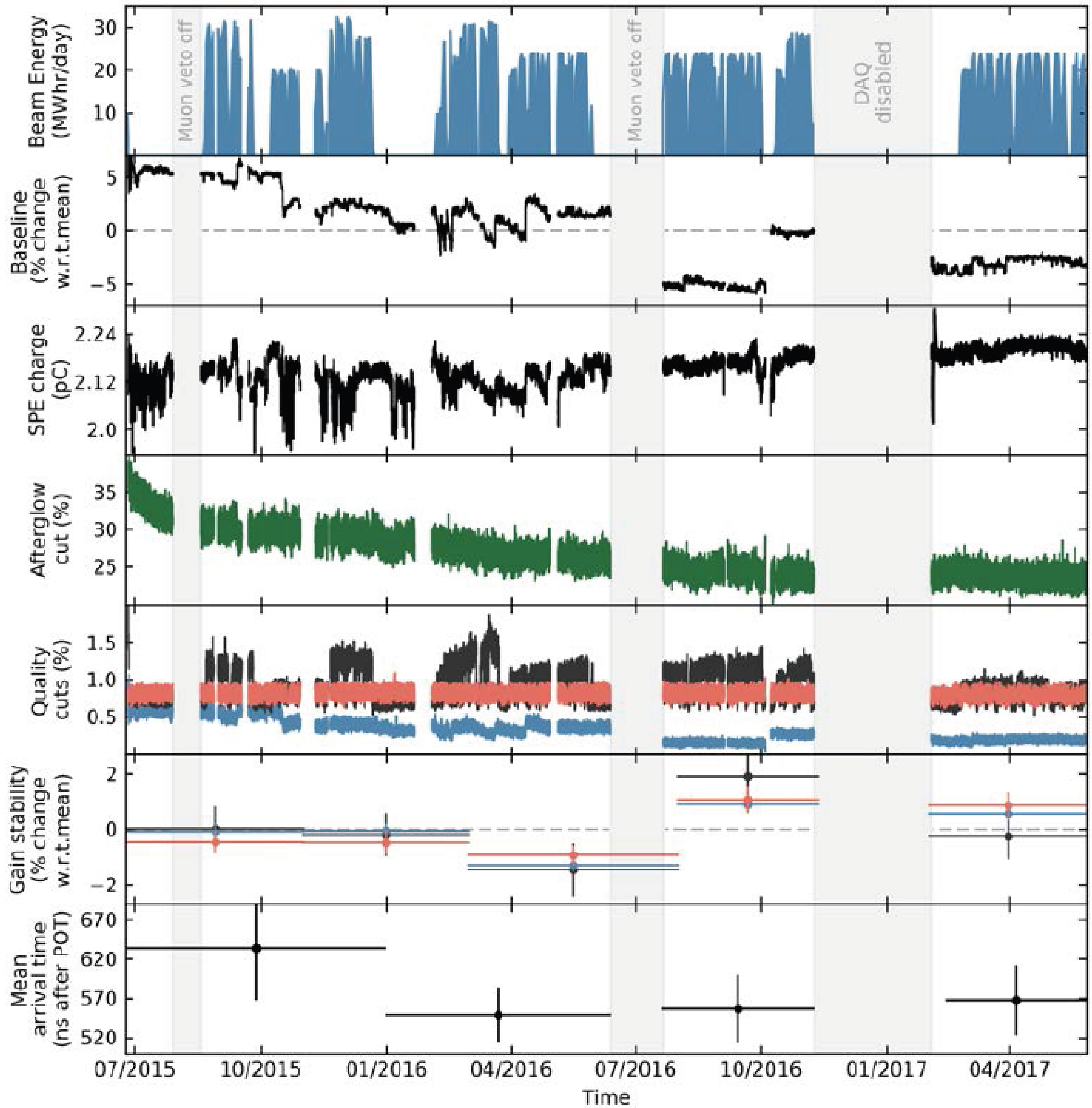
The Na concentration is the same for both crystals

Backup 2: QF

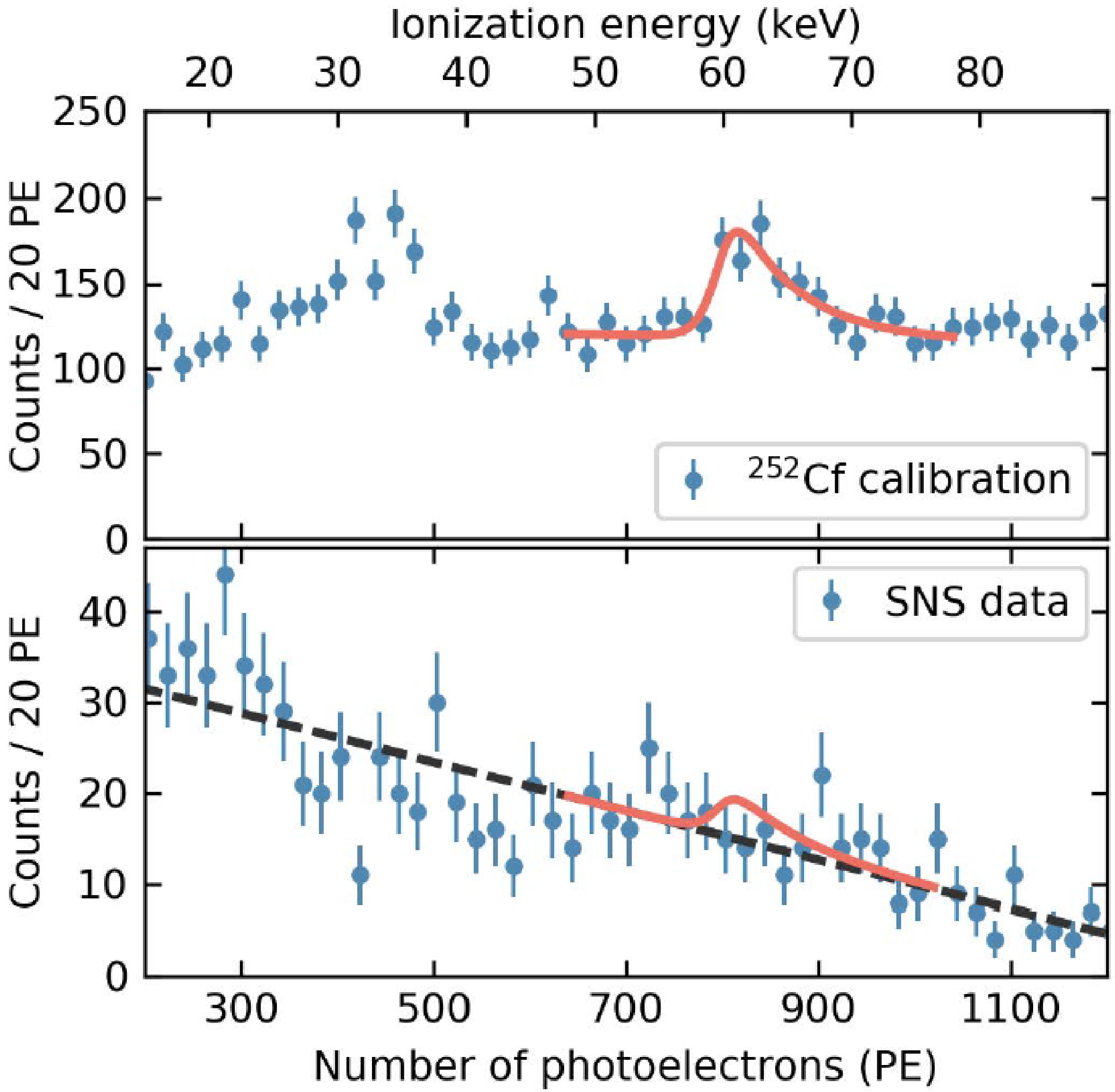


Quenching factor (%)
Nuclear recoil energy (keV)
COHERENT (Duke)
COHERENT (Chicago)
Park et al., Nucl. Instrum. Meth. A 491 (2002)
Guo et al., Nucl. Instrum. Meth. A 818 (2016)

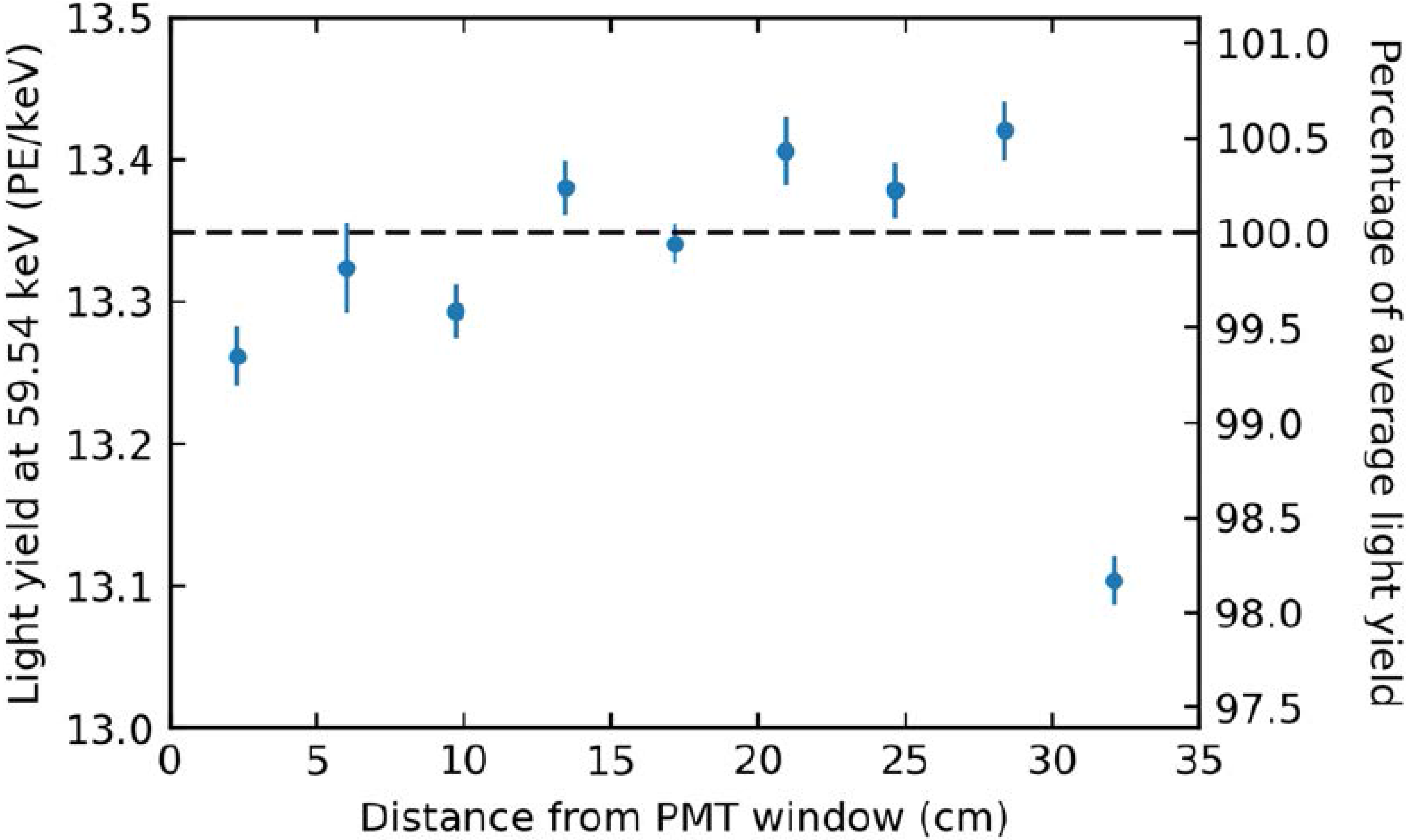
Backup 3: CsI[Na] stability



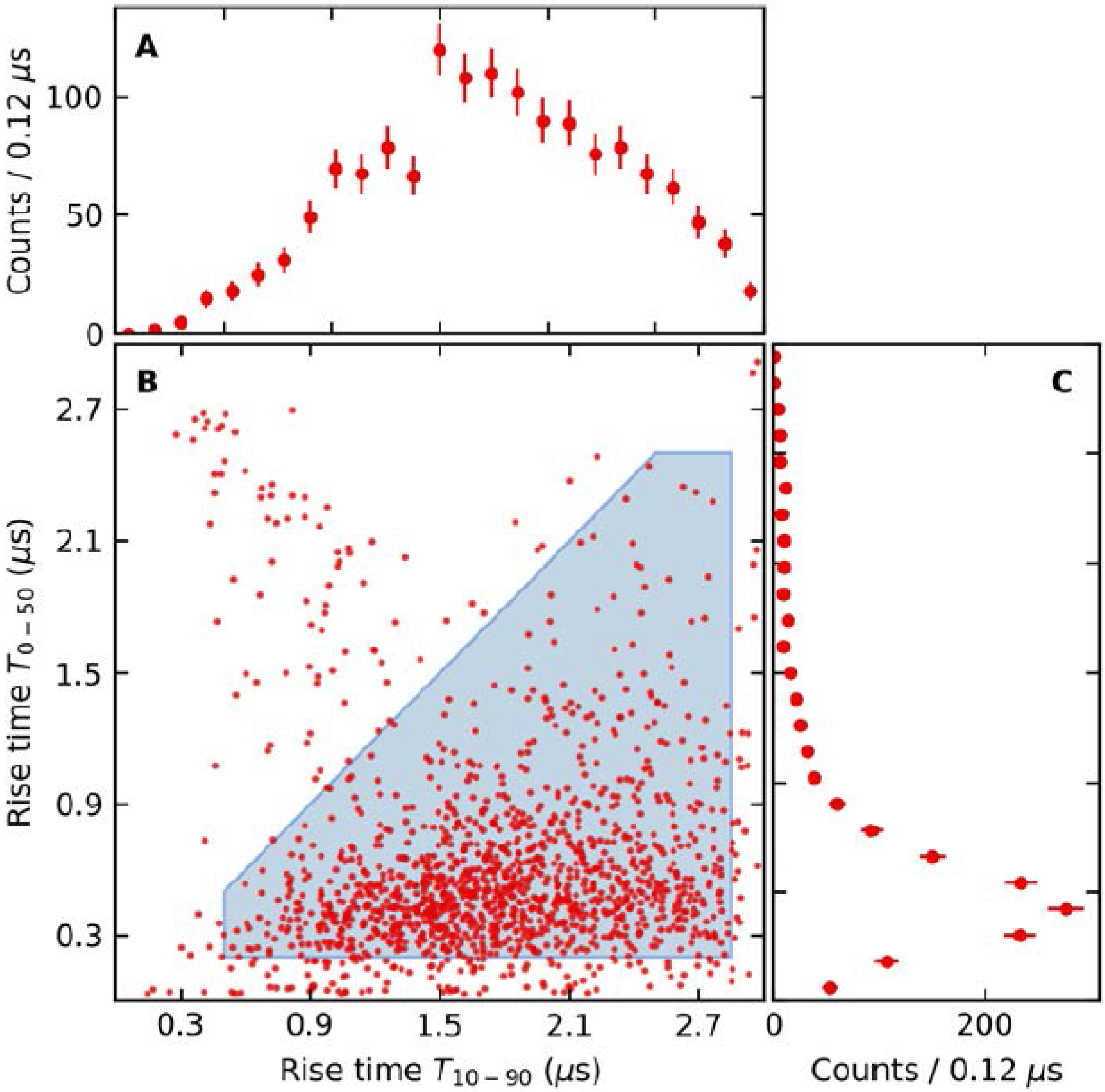
Backup 4: ^{252}Cf calibration and ^{127}I(n,n'γ)



Backup 5: light yield ^{241}Am calibration

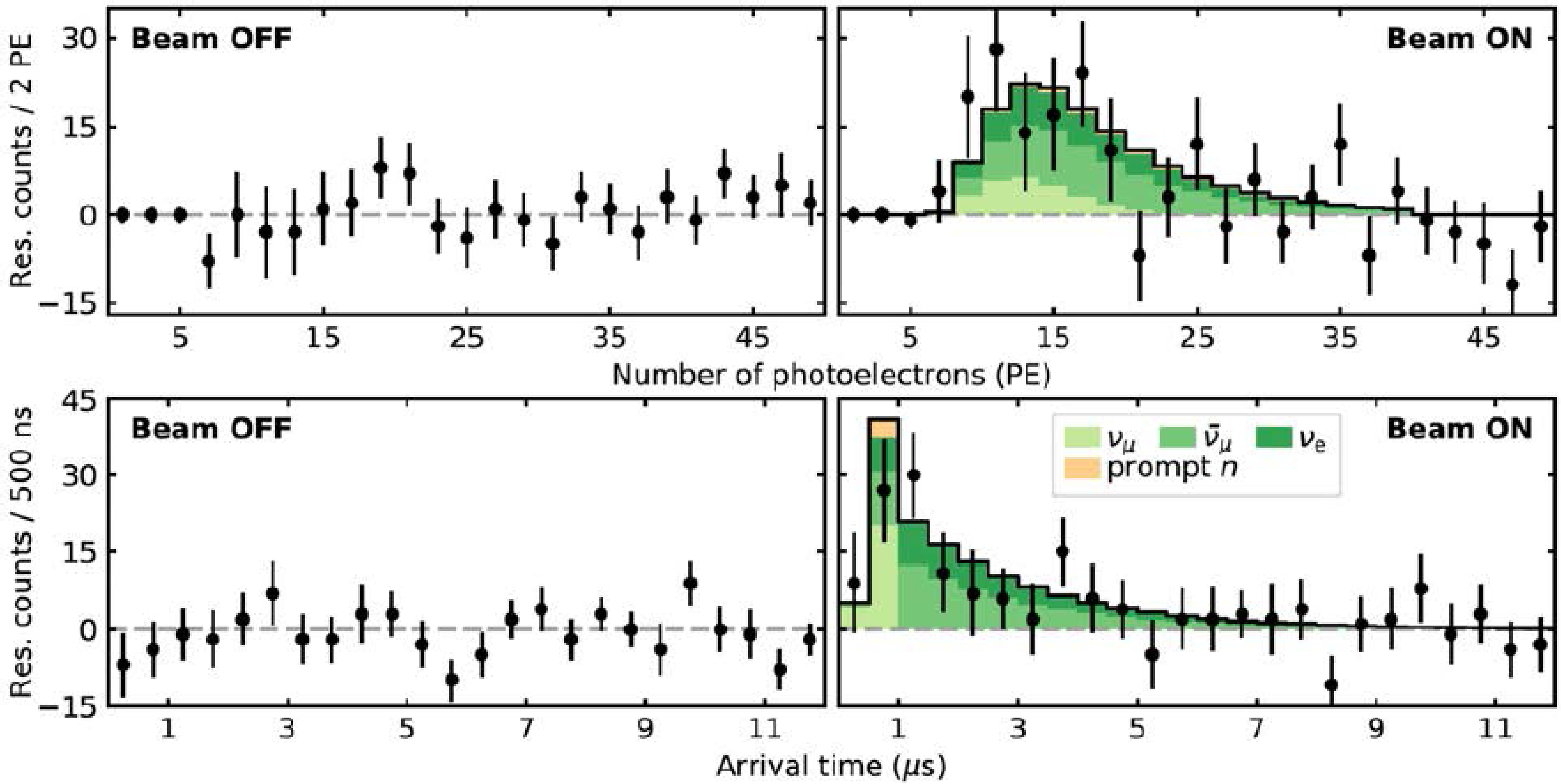


Backup 6: risetimes cut



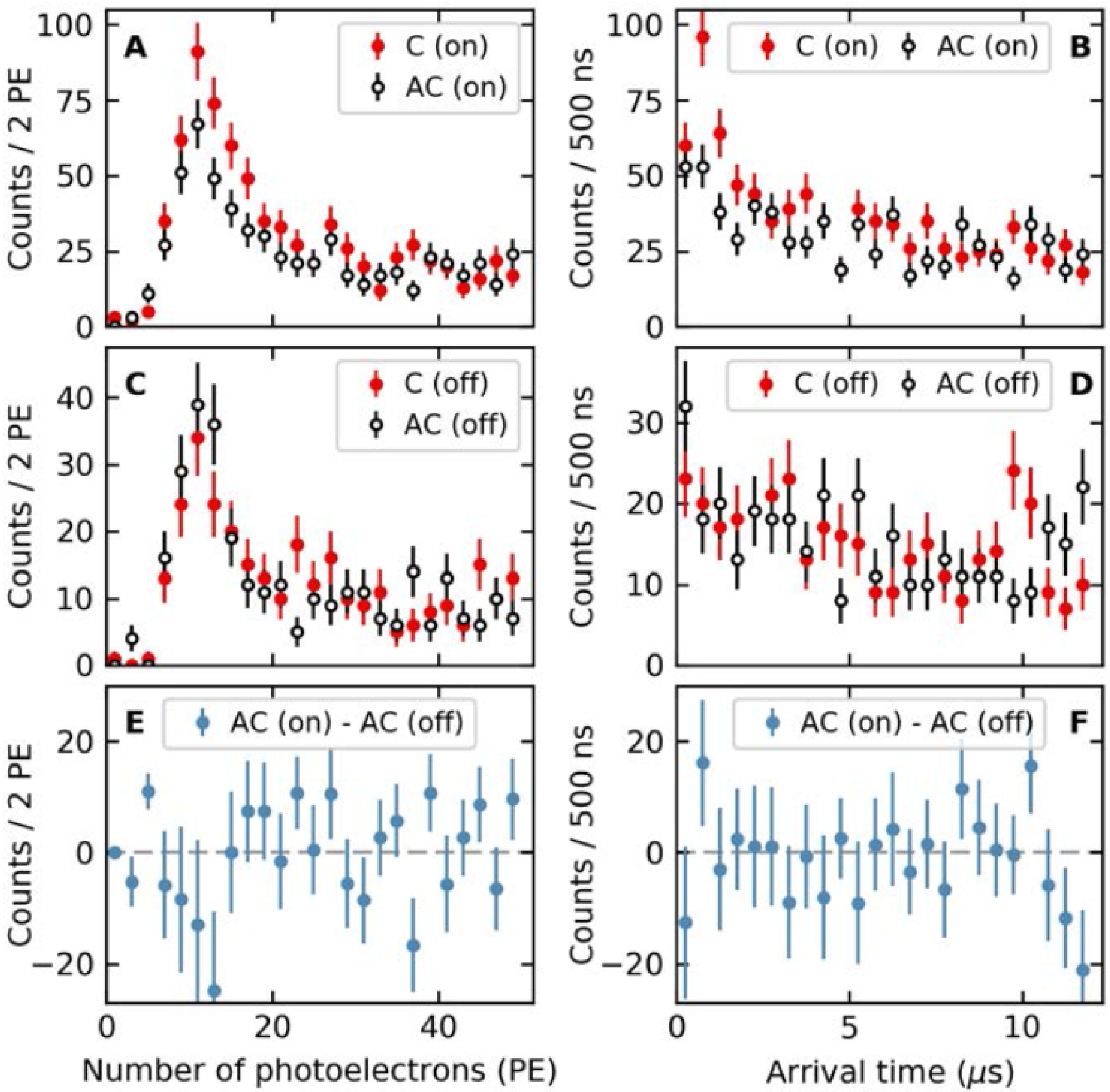
Backup 7: the parallel analysis results

Separately dealing with the data already at the digitized trace level

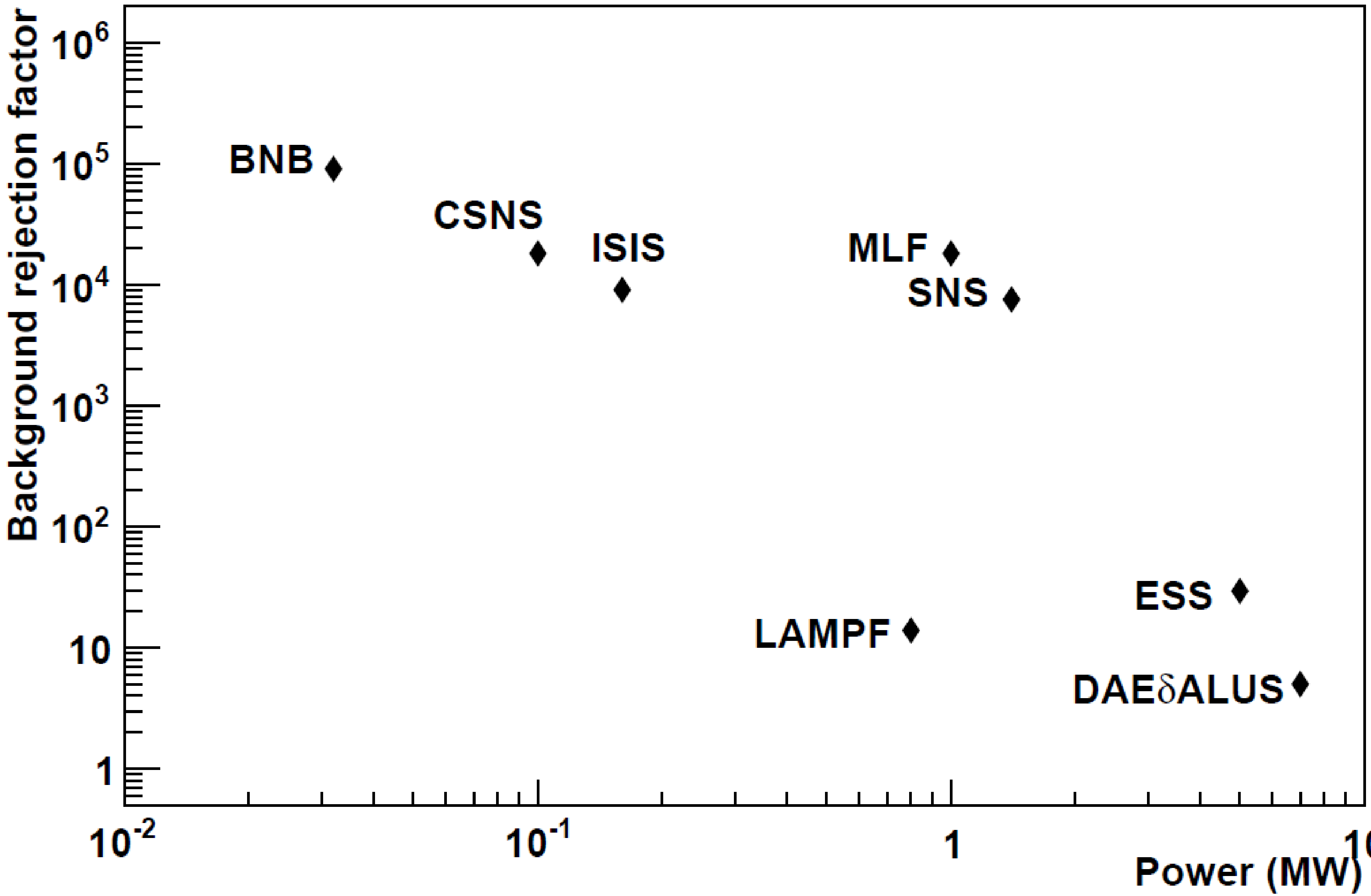


The results are consistent with the first analysis and the prediction of the Standard Model

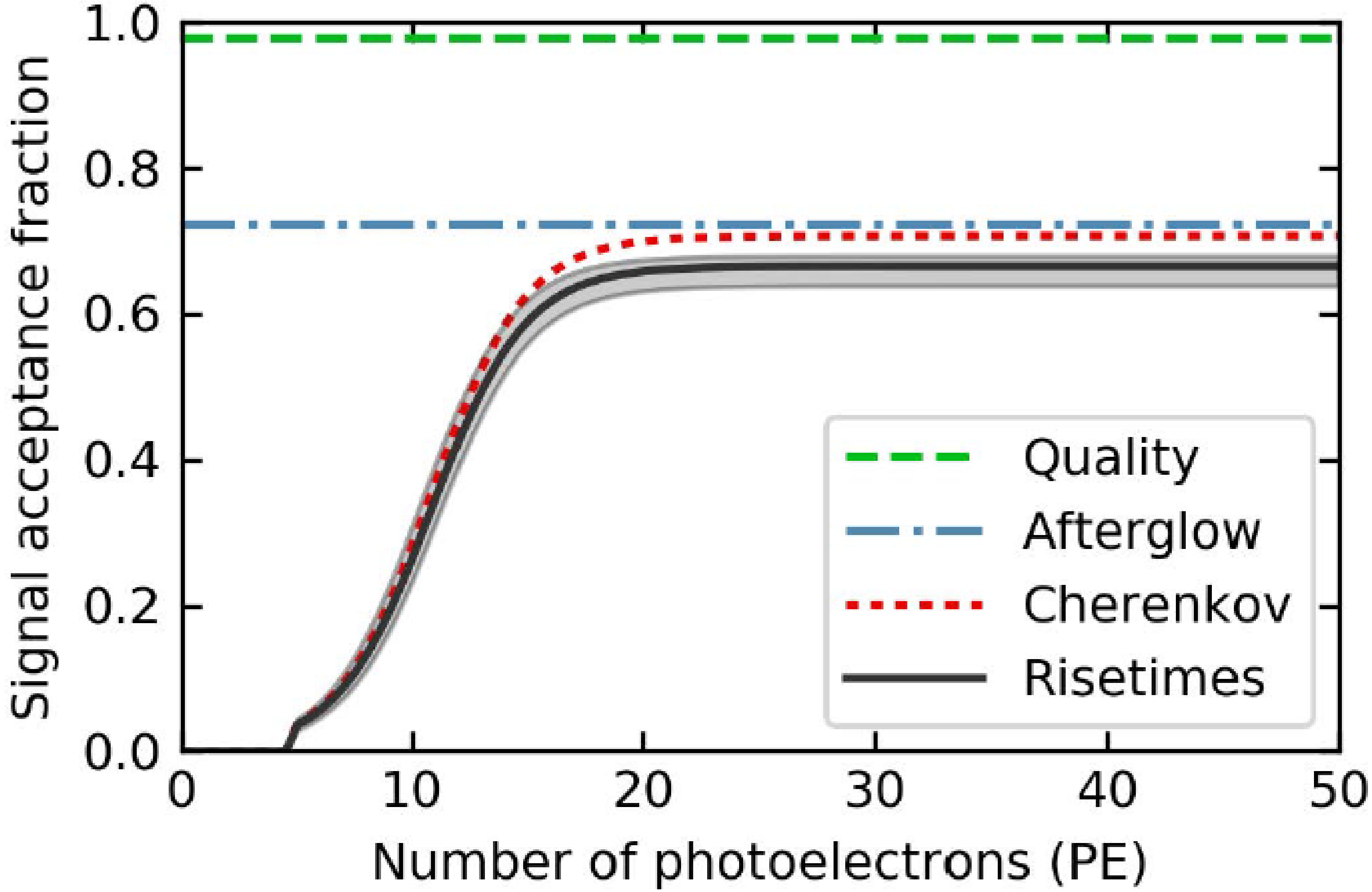
Backup 8: AC (on) –AC (off) residuals



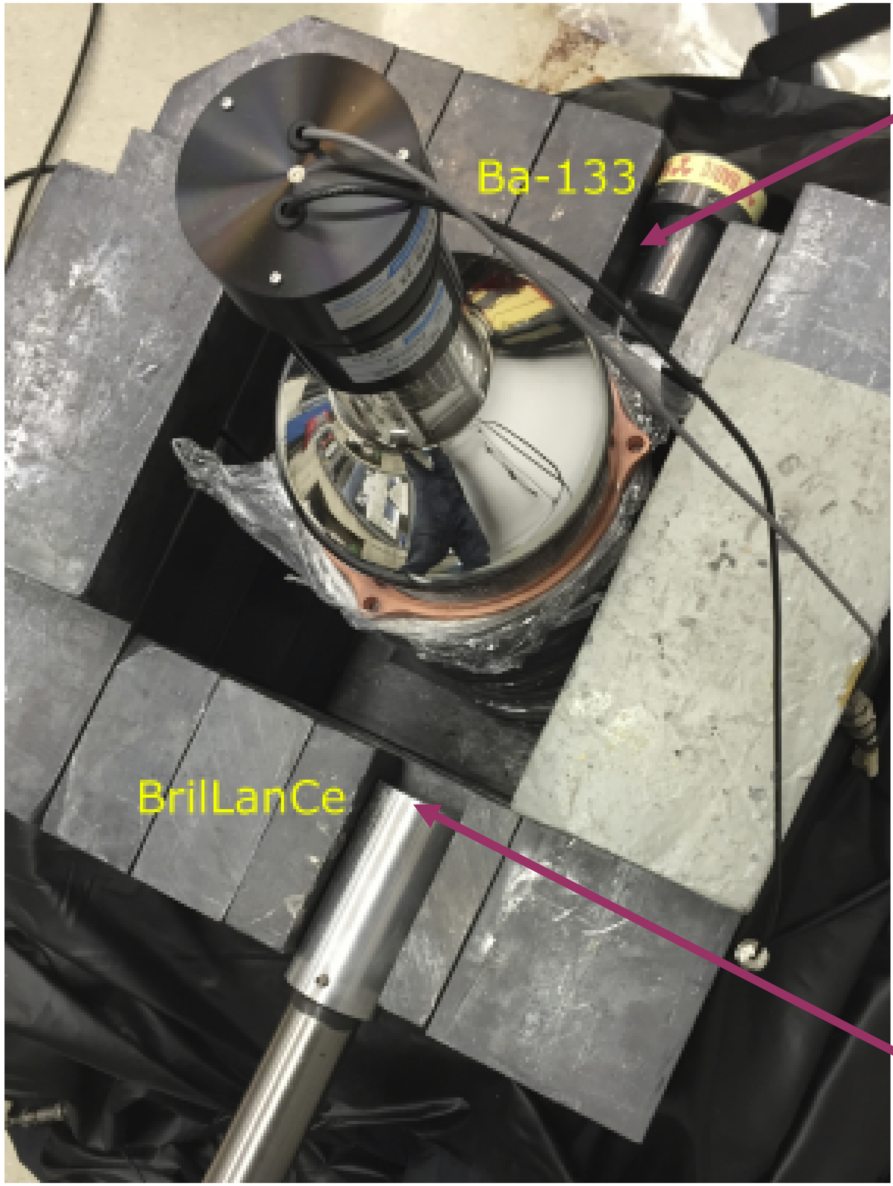
Backup 9: why SNS



Backup 10: cuts efficiency



Backup 11: ^{133}Ba calibration



collimated pencil beam of ^{133}Ba gammas

The maximum single scattering angle for a coincidence signal is θ ~ 12°

Corresponding energy – up to 6.2 keV

<u>Goal:</u>

to have a dataset with few to few tens phe events to “train” cuts on

BrilLanCe crystal to trigger on forward scattered gammas

Backup 12: Motivation

CEvNS can be used as a tool to investigate :

- Sterile neutrino existence

  A.J. Anderson et al., PRD 86 013004 (2012)
  A. Drukier & L. Stodolsky, PRD 30 2295 (1984)

- Neutron distribution functions

  K. Patton et al., PRC 86, 024216 (2012)

- Weak mixing angle at tens MeV scale

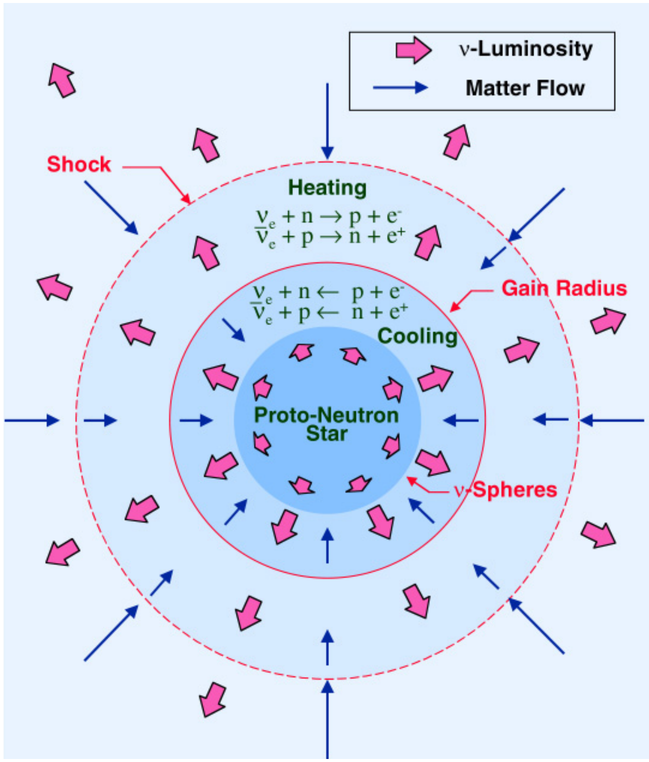
  L. M. Krauss, Phys. Lett. B 269 407 (1991)

- NSI interactions relevant for LBL CP violation experiments

  P. Coloma et al., JHEP 12 021 (2005)
  K. Scholberg, PRD 73 033005 (2006)
  J. Barranco et al., PRD 76 073008 (2007)
  P. Coloma, T. Schwetz, PRD 94 055005 (2016)
  M. Masud, P. Mehta, arxiv:1603.01389 (2016)

CEvNS also plays major role in the supernovae dynamics

J.R. Wilson, PRL 34 113 (1974)
D.N. Schramm, W.D. Arnett, PRL 34, 113 (1975)



<u>Potential application</u>: nuclear power plant monitoring!

Y. Kim, Nucl. Eng. Tech. 48, 285 (2016)