# COHERENT ELASTIC $\nu$-NUCLEUS SCATTERING AT THE SPALLATION NEUTRON SOURCE

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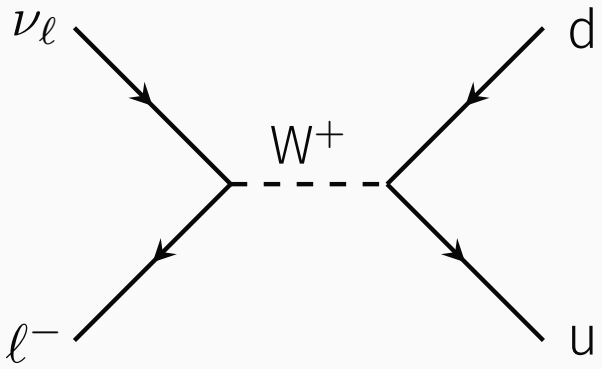
On behalf of the COHERENT collaboration

THE UNIVERSITY OF CHICAGO

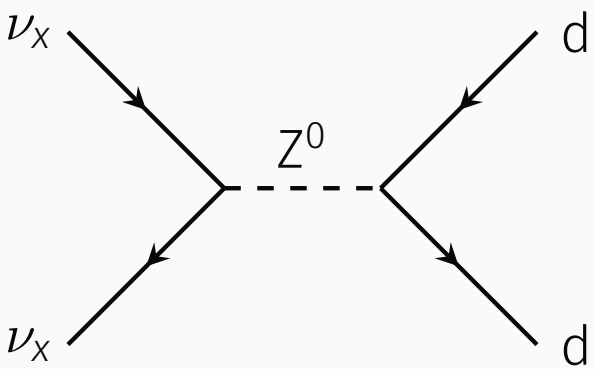
August 14, 2015

## Charged Current (CC)




Produces charged lepton

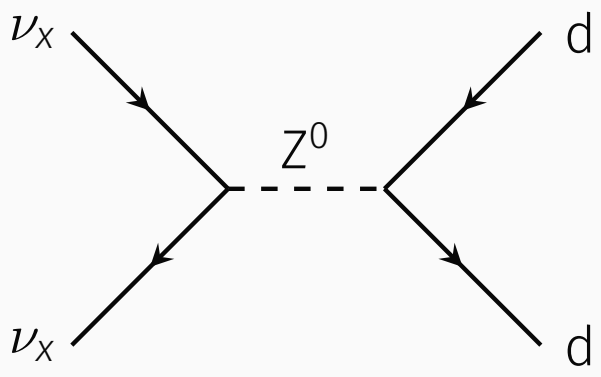
## Neutral Current (NC)




Flavor blind

## Standard Model cross section

(A.Drukier & L.Stodolsky, *PRD*30 (1984),2295)




$$\frac{d\sigma}{d\cos\theta} = \frac{G^2}{4\pi^2} E^2 (1+\cos\theta) \frac{\left[N - \left(1 - 4\sin^2\theta_W\right) Z\right]^2}{4} F^2(Q^2)$$

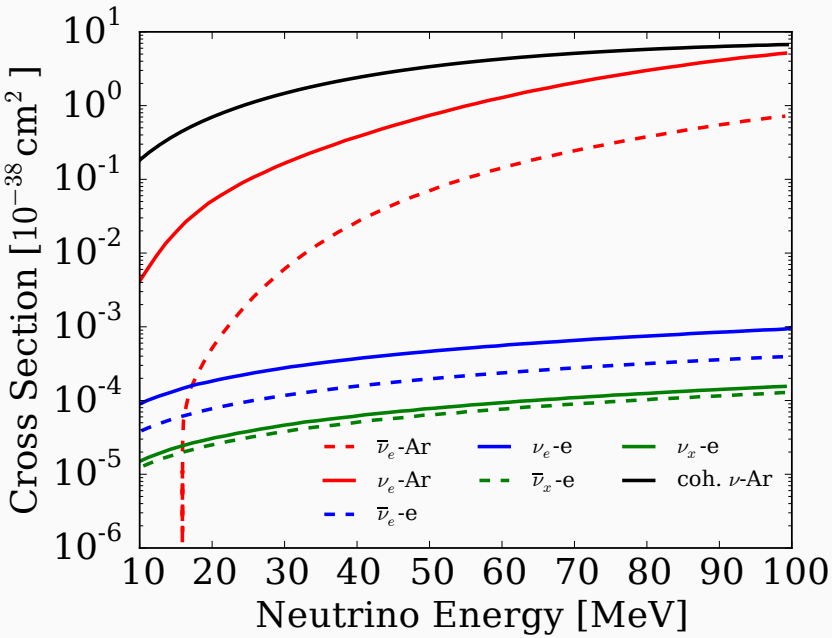
| | | | |
|---|---|---|---|
| G | Fermi constant | E | Neutrino energy |
| $\theta$ | Scattering angle | $\theta_W$ | Weinberg angle |
| N | # of neutrons | Z | # of protons |
| Q | 4-momentum transfer | F | Form factor |

# COHERENT ELASTIC NEUTRINO-NUCLEUS SCATTERING (CE$\nu$NS)

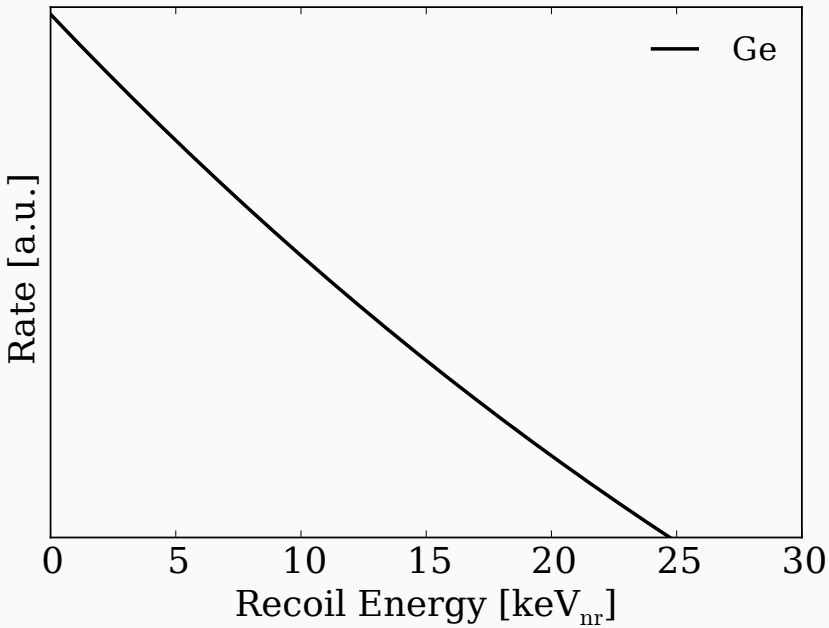
Coherent interaction for $Q \lesssim R_A^{-1} \approx 50\,\mathrm{MeV}$

## Cross Section

adapted from S. J. Brice *et al*, PRD89 (2014), 072004




## Recoil Energy

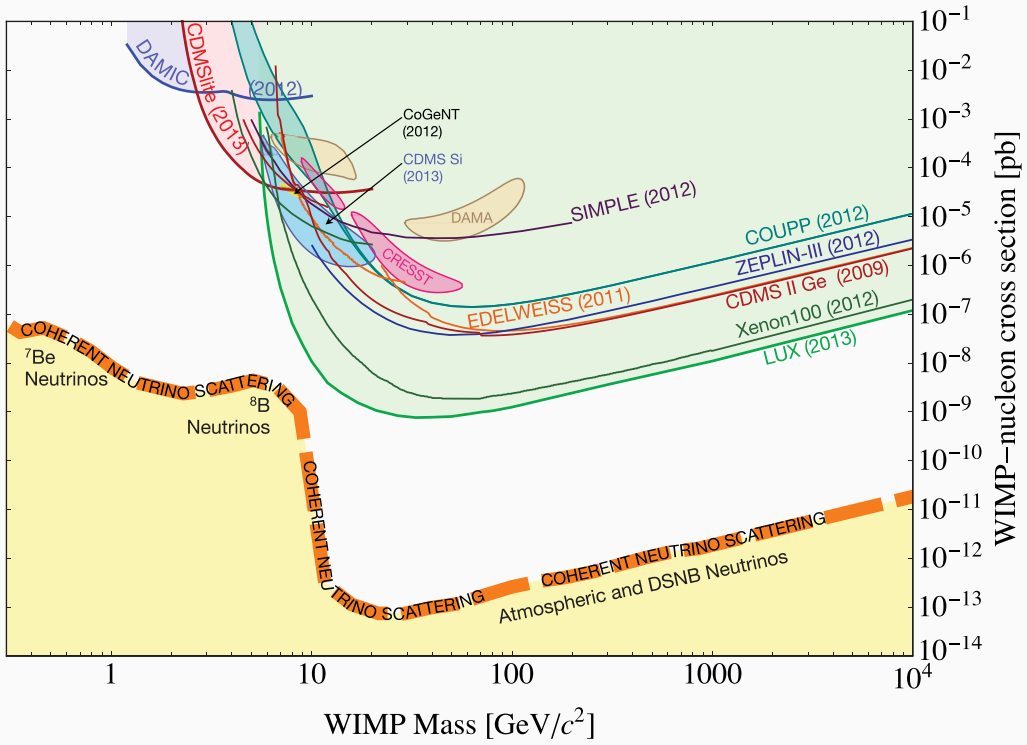



$$\sigma \propto \frac{G^2}{4\pi} E^2 \left[ N - \left(1 - 4\sin^2\theta_W\right) Z \right]^2$$

$$E_{\mathrm{NR,max}} = \frac{2E^2}{M}$$

# PHYSICS GOALS OF MEASURING CE$\nu$NS

- Excellent test of SM prediction
- Importance in stellar core-collapse
- Supernova $\nu$ detection
- Irreducible background for WIMP detection
- Weak mixing angle
- Neutron form factor
- Long reach:
  - $\nu$ magnetic moment
  - Sterile $\nu$ oscillations




J. Billard *et al*, PRD89 (2014), 023524

# THE COHERENT COLLABORATION

| | |
|---|---|
| UC Berkeley | U of Chicago |
| Duke | U of Florida |
| Indiana U | ITEP |
| LANL | LBNL |
| MEPHI | NCCU |
| NCSU | NMSU |
| ORNL | PNNL |
| Sandia NL | U of Tennessee |
| TUNL | U of Washington |

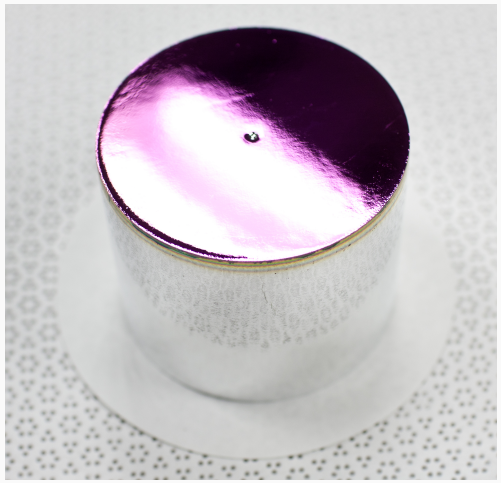
# THE COHERENT COLLABORATION

- **Goal**: Observe CE$\nu$NS at the Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory, Tennessee
- Combined experience from multiple different areas including rare event searches such as Dark Matter, CE$\nu$NS, $0\nu\beta\beta$-decay, . . ..

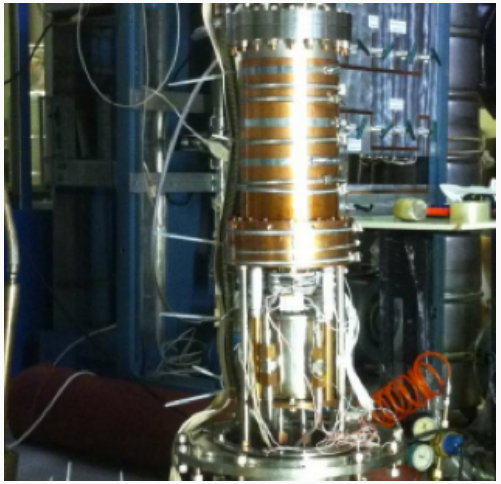
  (CoGeNT, LUX, Zeplin, CAST, IGEX, Majorana Demonstrator, EXO, Double Chooz, SK, SNO, T2K, PICO, . . .)
- Various targets at different scales suitable for CE$\nu$NS detection
  $\rightarrow$ Three technologies ready for prompt deployment (Phase I):

CsI

Ge



Xe



# THE SPALLATION NEUTRON SOURCE

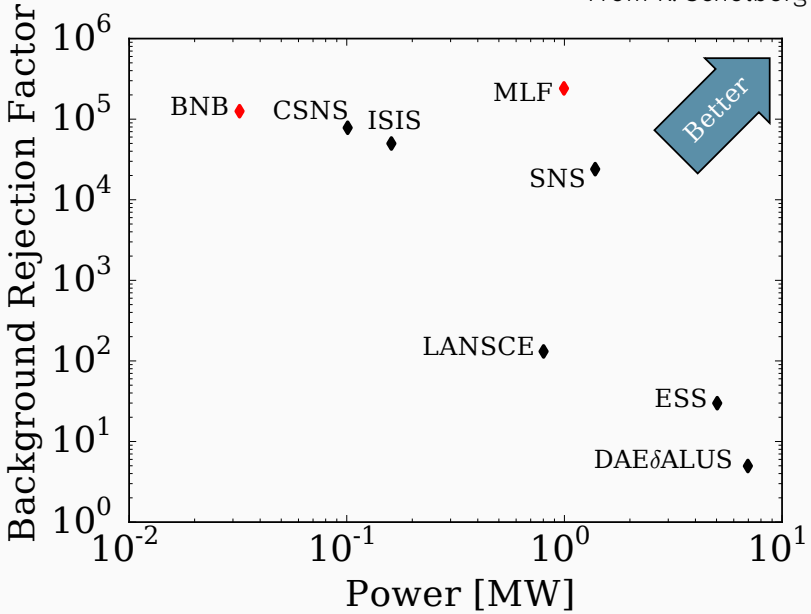
Image taken from *http://neutrons.ornl.gov/sns*

# THE SNS - A STOPPED $\pi$ NEUTRINO SOURCE

## What we want

- High $\nu$ flux
- Well understood $\nu$ spectrum
- Pulsed beam for BG rejection
- Multiple flavors

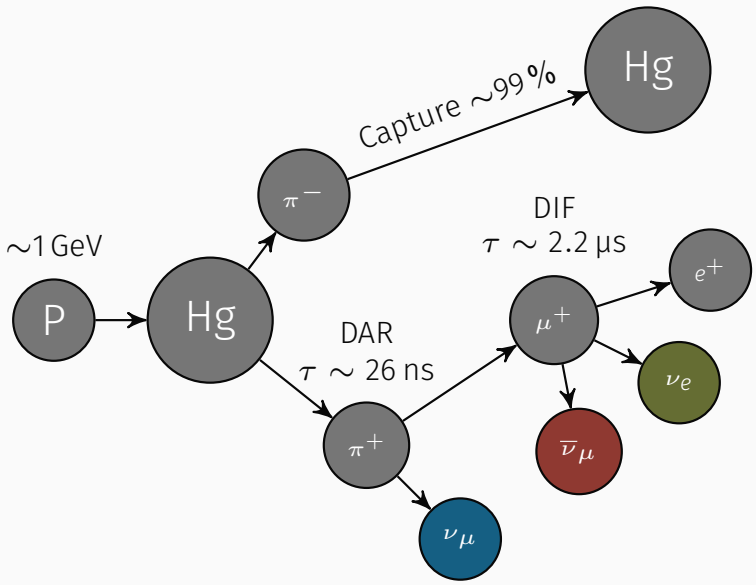
From K. Scholberg



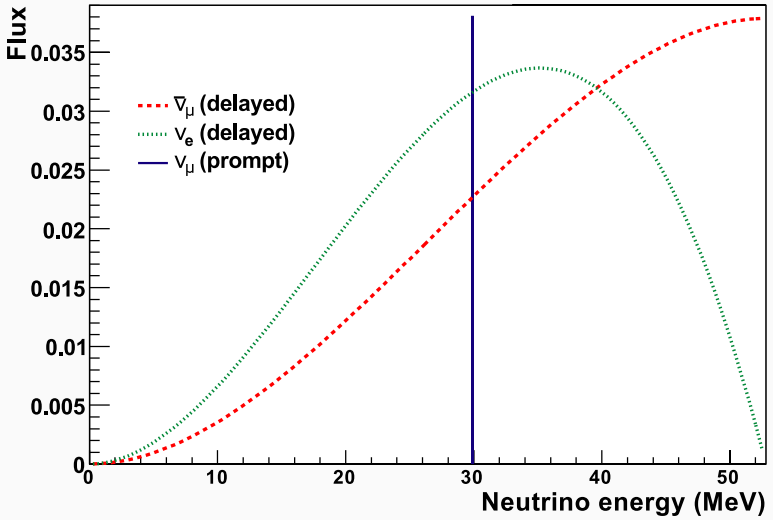

## SNS offers

- Proton energy ~1 GeV
- Intensity $\sim 10^{15}$ protons/s
- Pulse duration 380 ns (FWHM)
- Repetition rate 60 Hz
- Total power ~1 MW
- $\nu_x$ flux $\sim 2 \times 10^7 \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ at 20 m

# THE SNS - NEUTRINO PRODUCTION MECHANISM




K. Scholberg, PRD73 (2006), 033005




$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

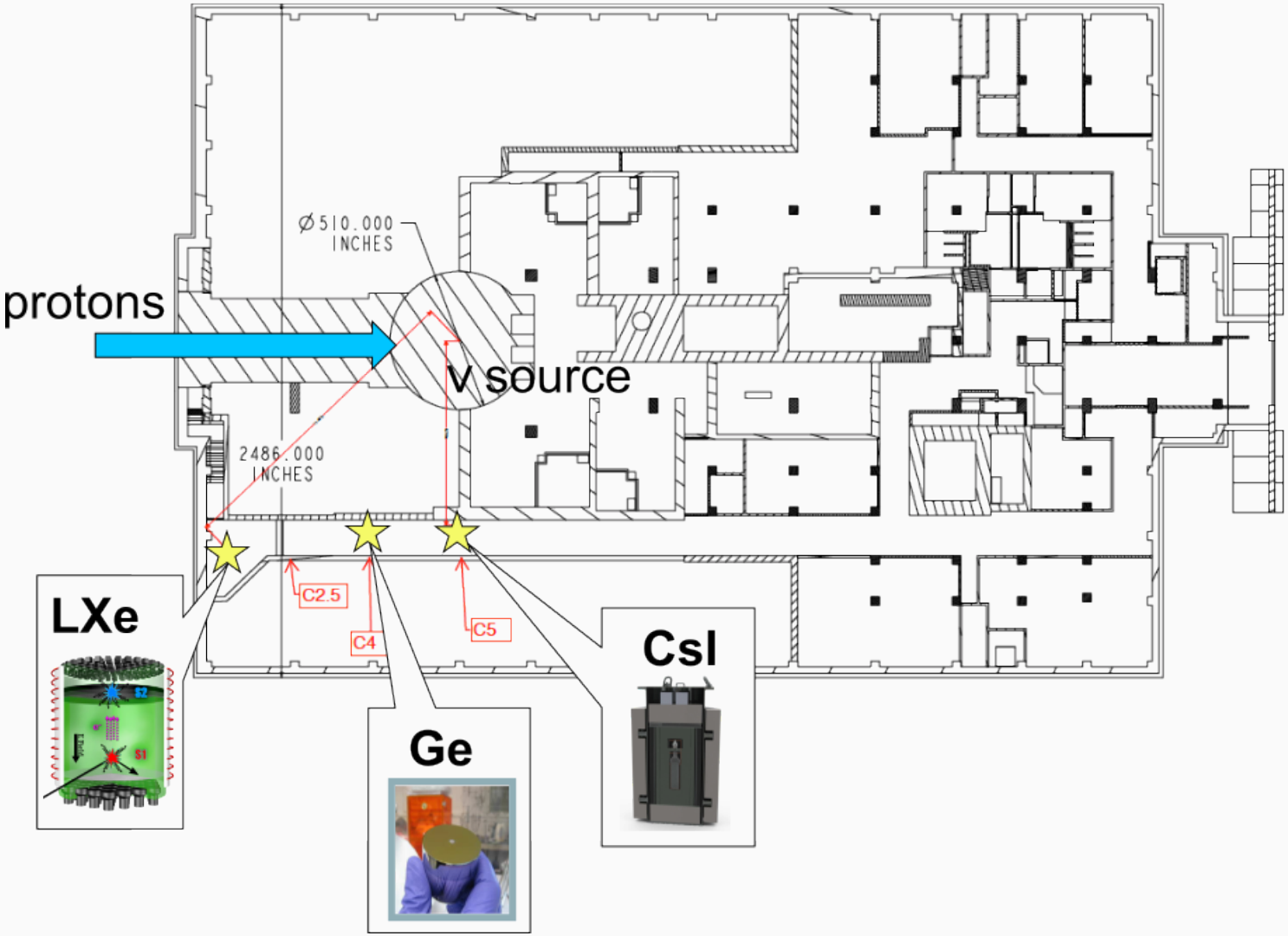
2-body decay - monochromatic 29.9 MeV - prompt

$$\downarrow$$

$$\mu^+ \rightarrow e^+ + \overline{\nu}_\mu + \nu_e$$

3-body decay - energies up to 52.6 MeV - delayed

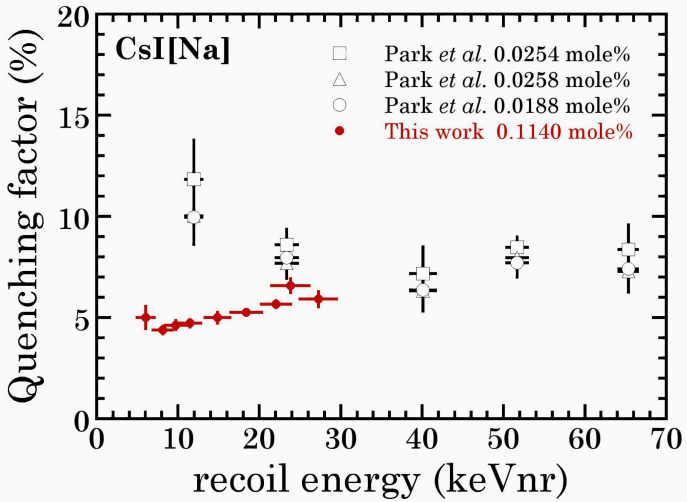
# THE SNS - DETECTOR LOCATIONS

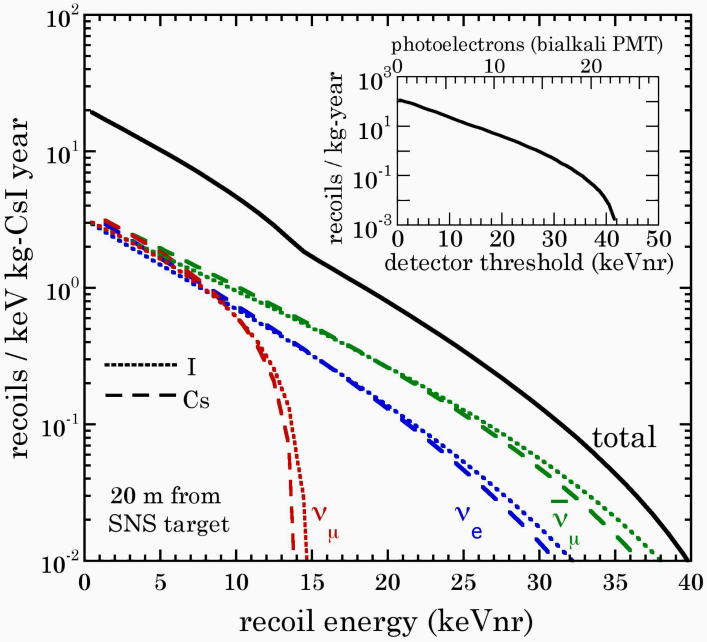


# DETECTOR TECHNOLOGIES - CSI[NA]

| | |
|---|---|
| Mass | 14.5 kg |
| Distance | 20 m |
| Threshold | 6.5 $keV_{nr}$ |

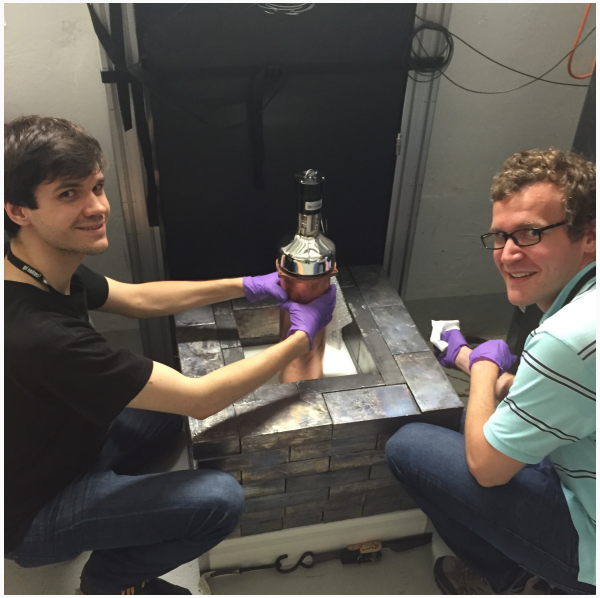
- Low background CsI[Na]
- Well-measured quenching factor
- High light yield (∼64 PE/keV)
- Emission well matched to SBA PMT QE.
- Cs (N = 78) and I (N=74) show very similar recoil spectrum
- Expect ∼ 800 recoils per year.
- Already taking data




Top & bottom: J. I. Collar *et al*, NIMA 773 (2015), 56 - 65

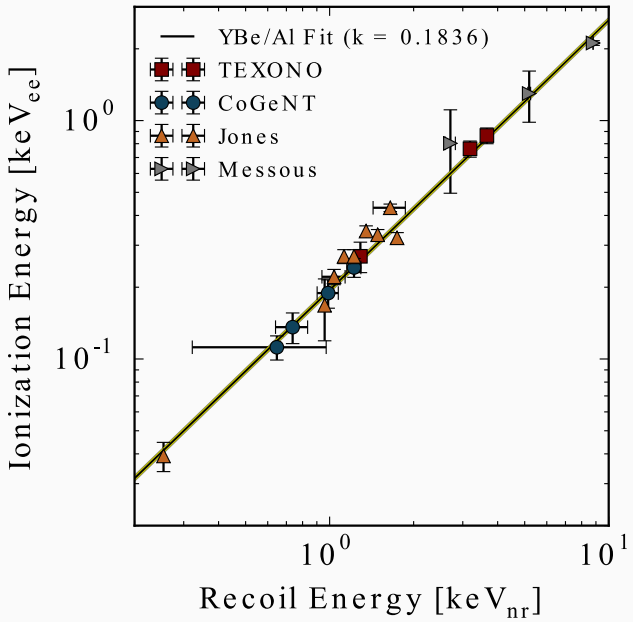
# DETECTOR TECHNOLOGIES - CSI[NA]

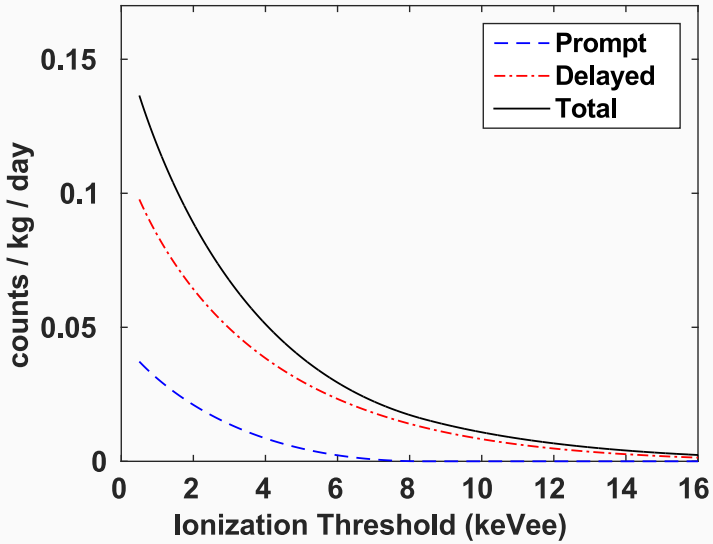


# DETECTOR TECHNOLOGIES - HPGE PPC

| | |
|---|---|
| Mass | 10-20 kg |
| Distance | 20 m |
| Threshold | 5 $keV_{nr}$ |

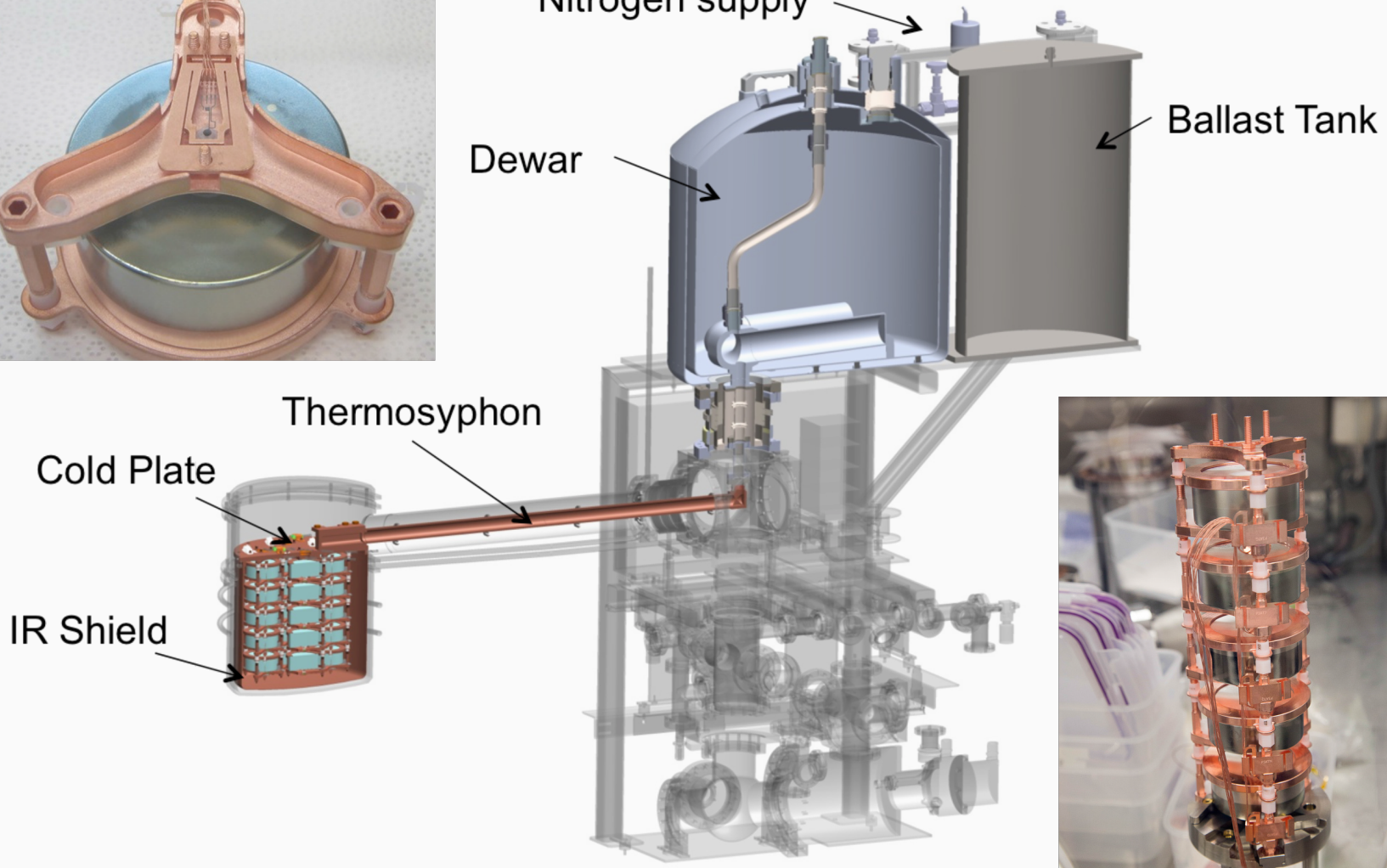
- Low noise & background PPC
- Well-measured quenching factor
- Excellent energy resolution
- Threshold 1 $keV_{ee}$
- Drift time ~1 µs
- Installation depends on decommissioning of Majorana Demonstrator

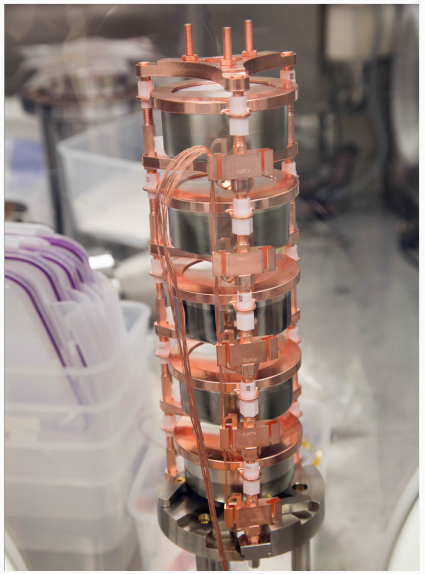



Bottom: M. Green/Ge Working Group

# DETECTOR TECHNOLOGIES - HPGE PPC



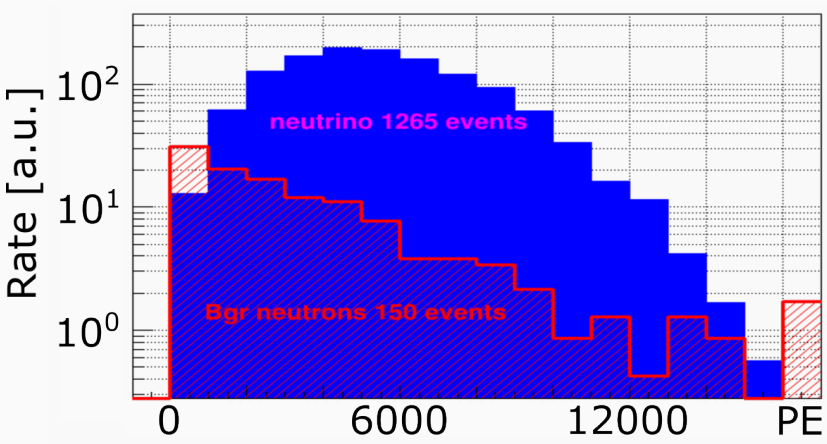



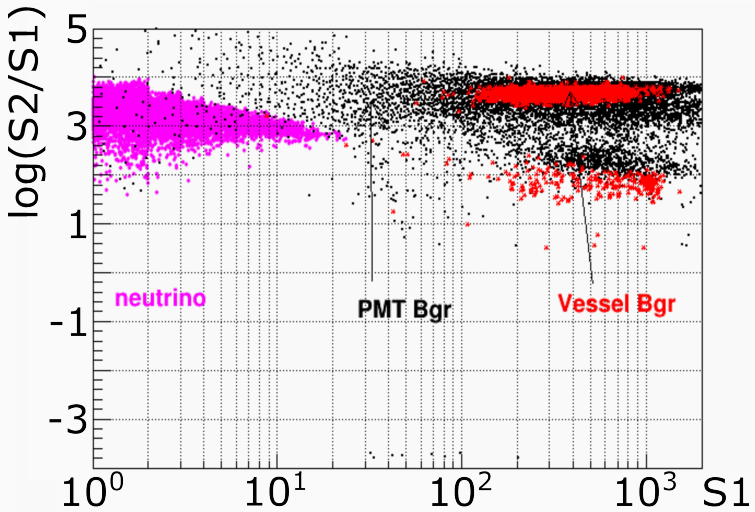
M. Green/Ge Working Group

# DETECTOR TECHNOLOGIES - 2-PHASE XENON (RED 100)

| | |
|---|---|
| Mass | 100 kg (FV) |
| Distance | 32 m |
| Threshold | 4 $keV_{nr}$ |

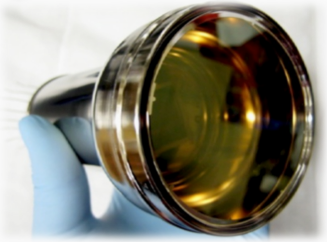
- Low background, self shielding
- Large mass
- Good nuclear/electronic recoil discrimination
- Vessel assembly finishing this month
- Physics run planned to start Q4'16/Q1'17



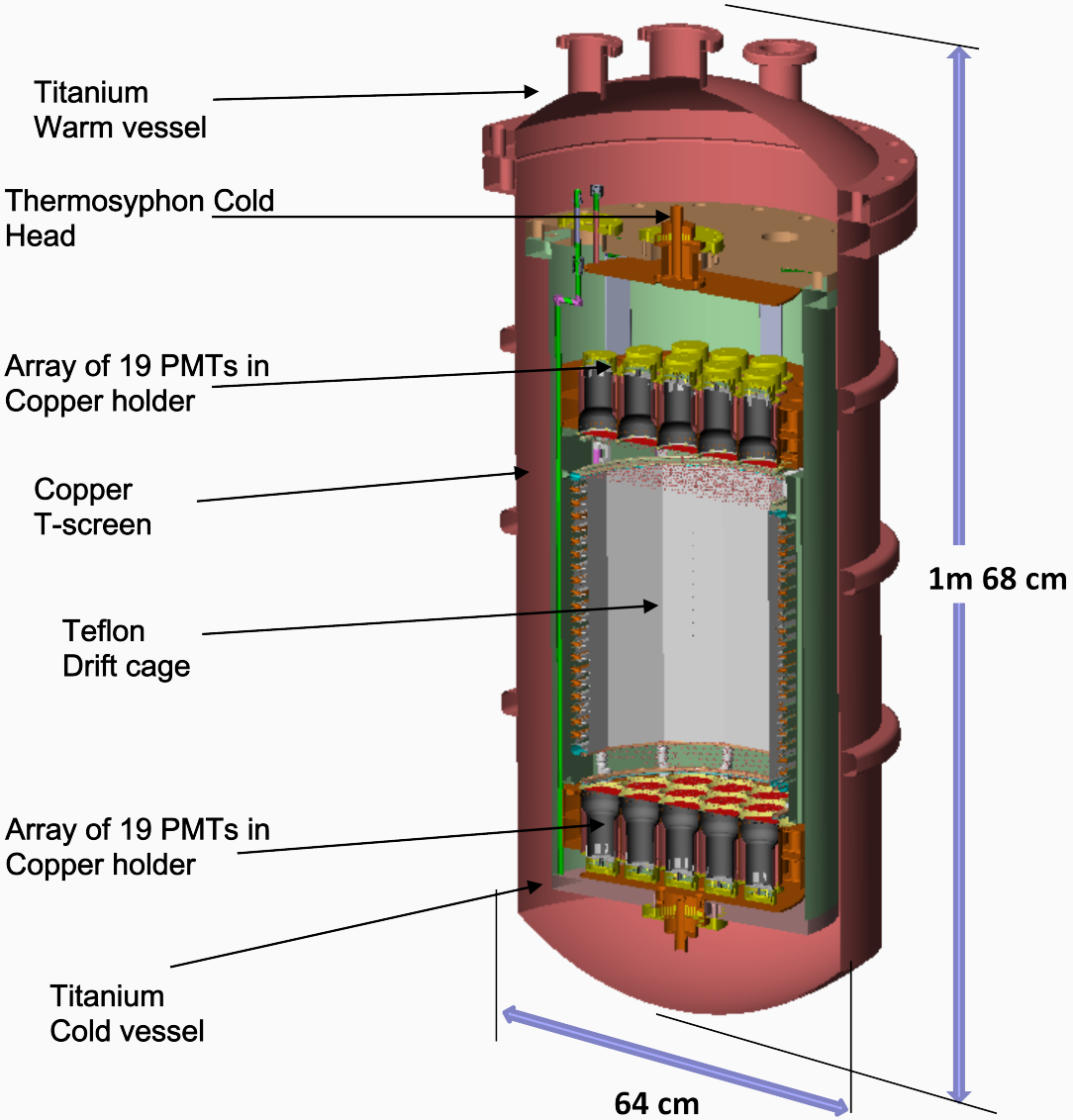




Top & bottom: A. Bolozdynya/Xe Working Group

# DETECTOR TECHNOLOGIES - 2-PHASE XENON (RED 100)



Hamamatsu R11410-20



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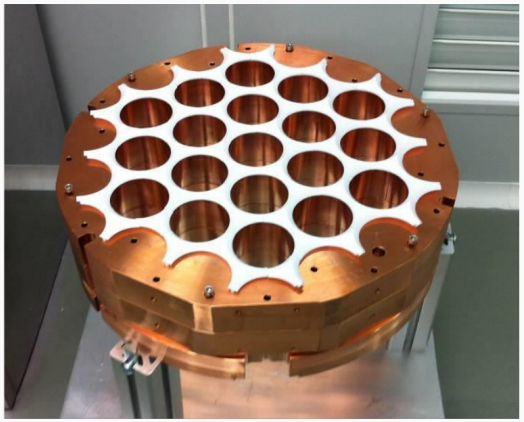
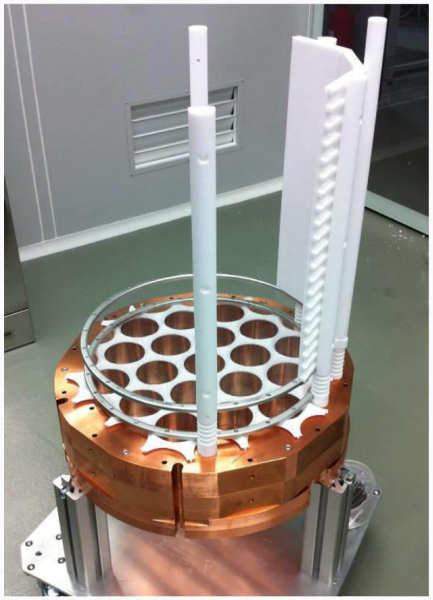
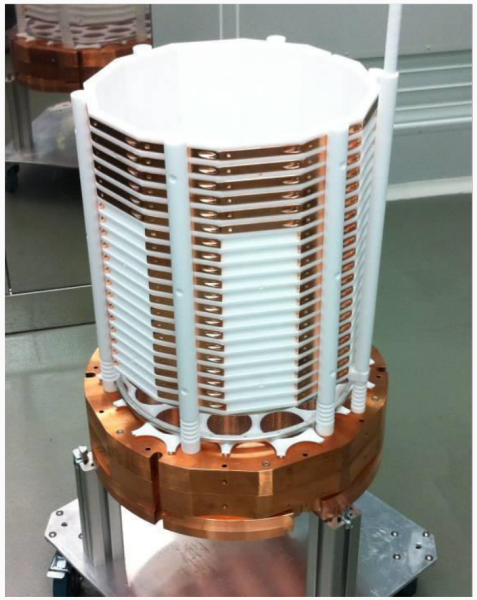
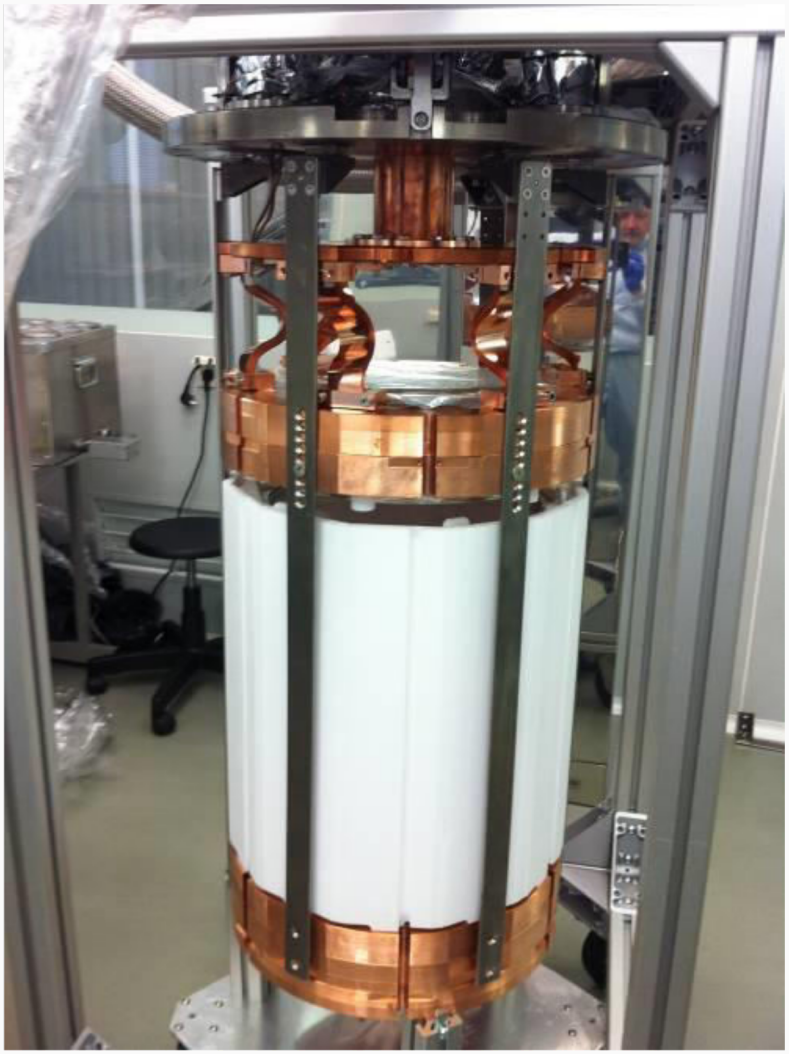








D. Akimov/Xe Working Group

# ADDITIONAL EFFORTS

- Ongoing neutron background measurements to confirm neutron quiet locations
- Additional quenching factor measurements for all detector materials
  - Tagged neutron scattering at TUNL
  - $^{88}$Y/Be photoneutron source
- Neutron transport simulations
- Neutrino induced neutron measurements

$$\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{208}\mathrm{Bi}^* + e^-$$
$$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{208}\mathrm{Pb}^* + \nu_x$$

# SUMMARY AND OUTLOOK

- COHERENT is an international collaboration aiming to observe CE$\nu$NS for the first time
- The SNS is one of the premier stopped $\pi$ neutrino source in the world
- Three detector technologies are available for short term deployment, one of them taking data right now
- Current multi-target detector generation will be able to test $\sigma_{\mathrm{SM}}$ and look for non-standard interactions

Future Prospects:

- Scalability of technologies allows larger detector masses in the future (Phase II and III)
  - Form factor measurements
  - Sterile neutrino searches
  - Neutrino magnetic moments
- Other target options, e.g. NaI, LAr

# THE COHERENT COLLABORATION

| | |
|---|---|
| UC Berkeley | U of Chicago |
| Duke | U of Florida |
| Indiana U | ITEP |
| LANL | LBNL |
| MEPHI | NCCU |
| NCSU | NMSU |
| ORNL | PNNL |
| Sandia NL | U of Tennessee |
| TUNL | U of Washington |

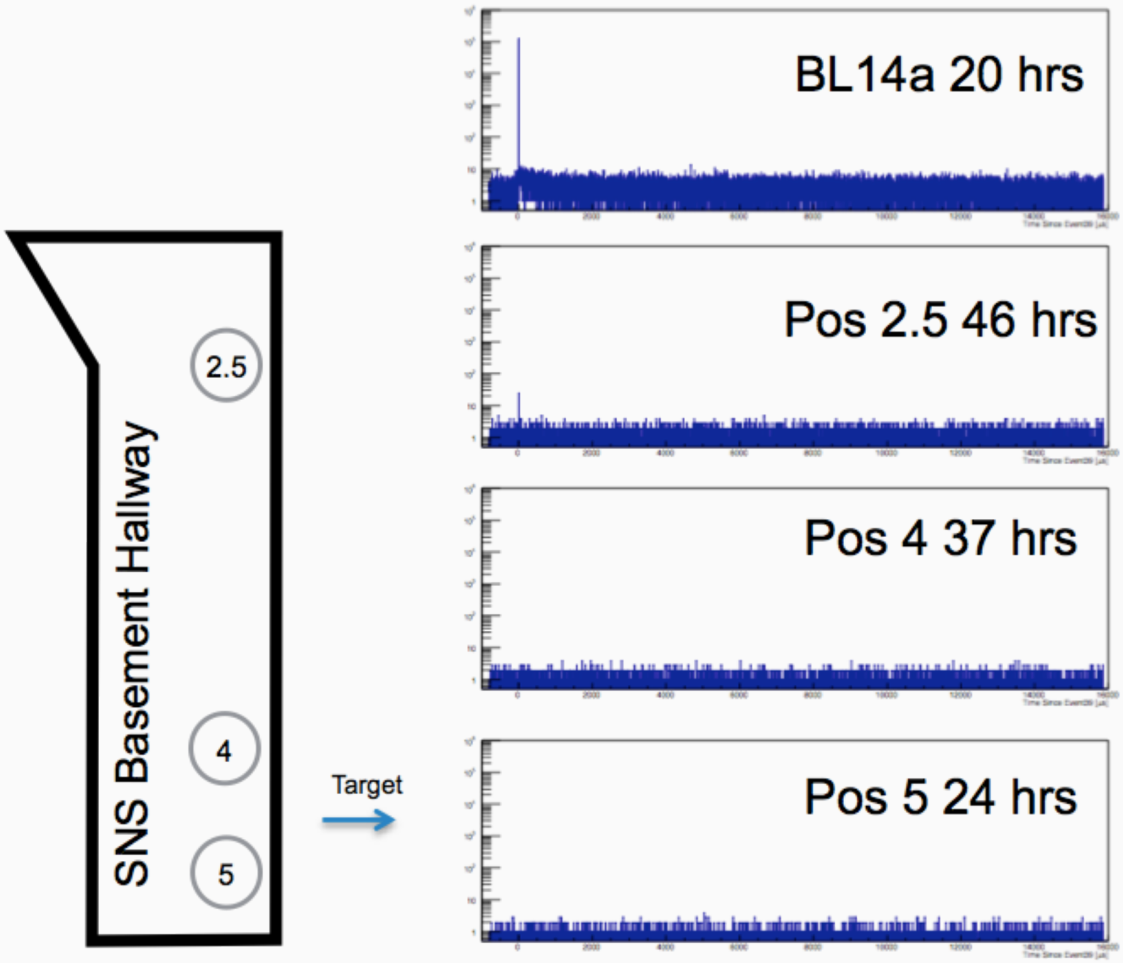
# BACKUP

# COMPARISON OF STOPPED $\pi$ FACILITIES

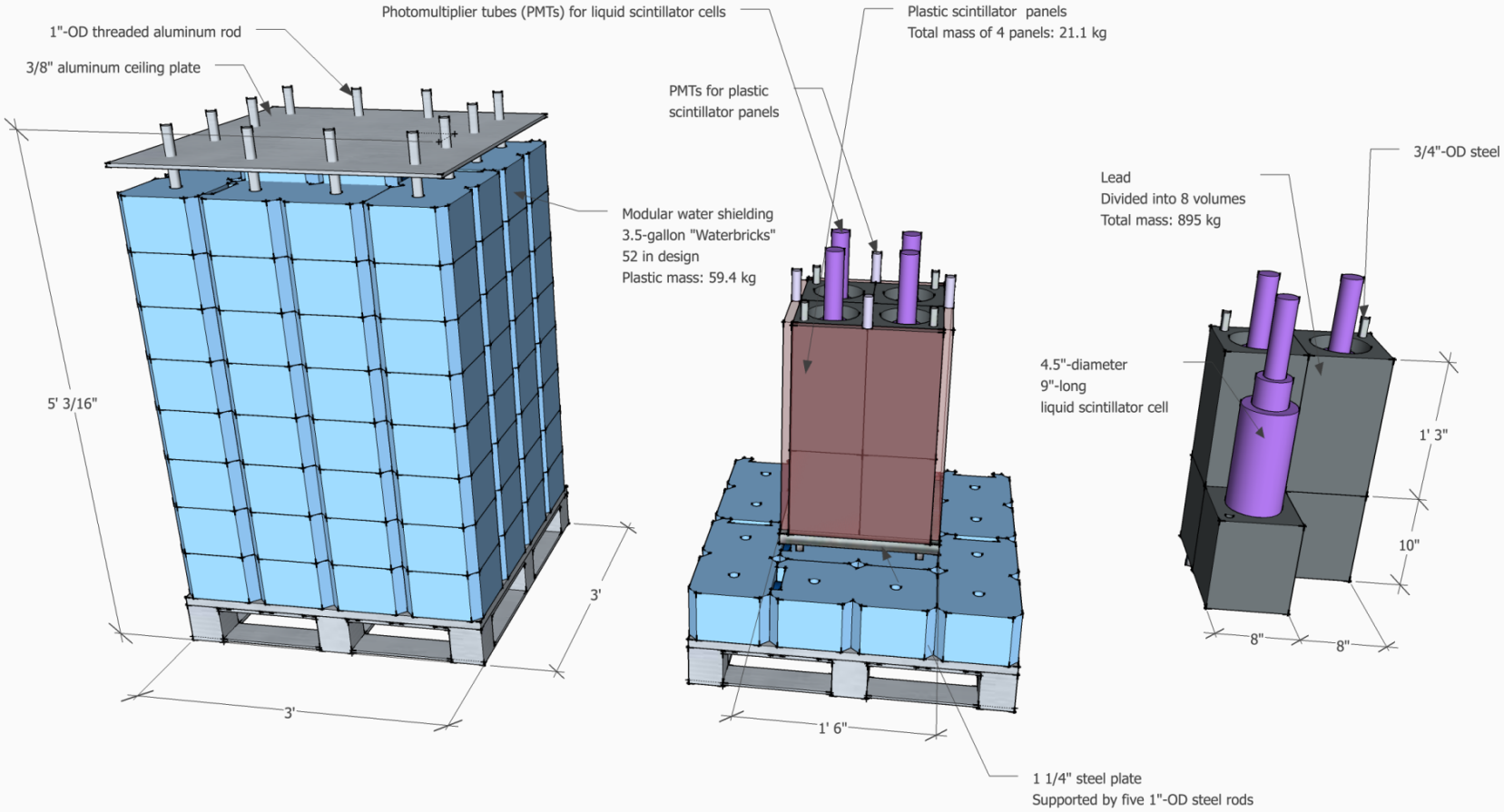
| Facility | Location | Proton Energy (GeV) | Power (MW) | Bunch Structure | Rate | Target |
|---|---|---|---|---|---|---|
| LANSCE | USA (LANL) | 0.8 | 0.056 | 600 μs | 120 Hz | Various |
| ISIS | UK (RAL) | 0.8 | 0.16 | 2 × 200 ns | 50 Hz | Water-cooled tantalum |
| BNB | USA (FNAL) | 8 | 0.032 | 1.6 μs | 5-11 Hz | Beryllium |
| SNS | USA (ORNL) | 1.3 | 1 | 700 ns | 60 Hz | Mercury |
| MLF | Japan (J-PARC) | 3 | 1 | 2 × 60-100 ns | 25 Hz | Mercury |
| ESS | Sweden (planned) | 1.3 | 5 | 2 ms | 17 Hz | Mercury |
| DAEδALUS | TBD (planned) | 0.7 | ∼ 7 × 1 | 100 ms | 2 Hz | Mercury |

A. Bolozdynya *et al.*, arXiv:1211.5199 (2012)

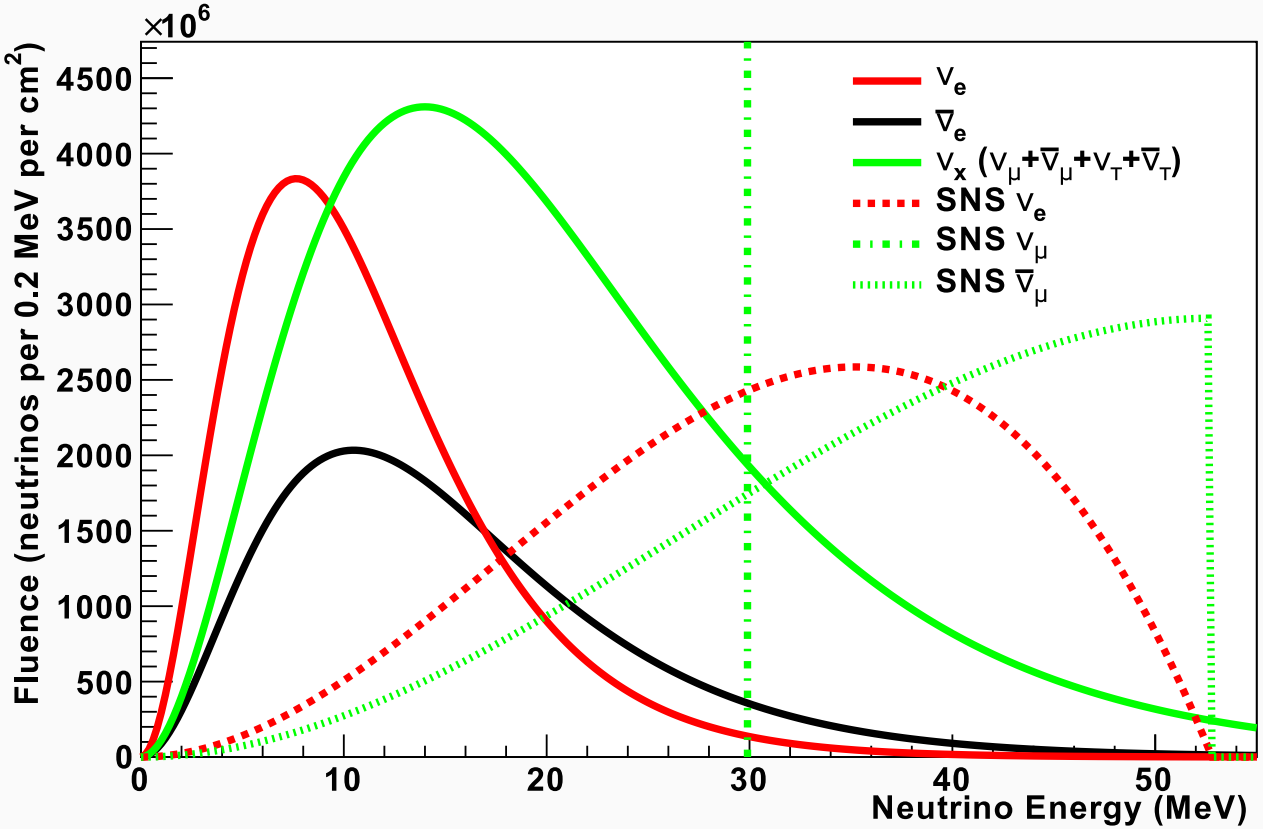
# NEUTRON BACKGROUND MEASUREMENTS



# NEUTRINO INDUCED NEUTRONS

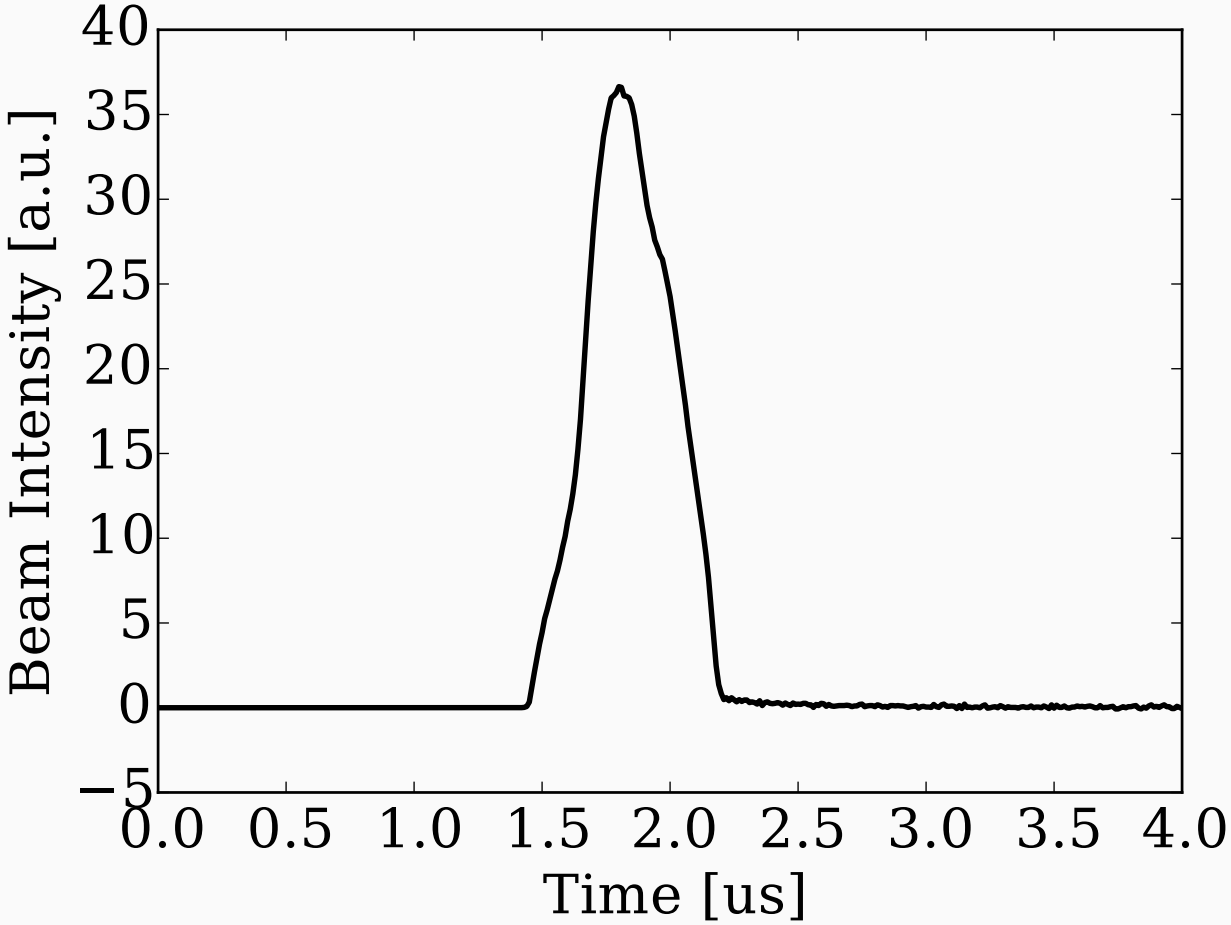


# SUPERNOVA SPECTRUM

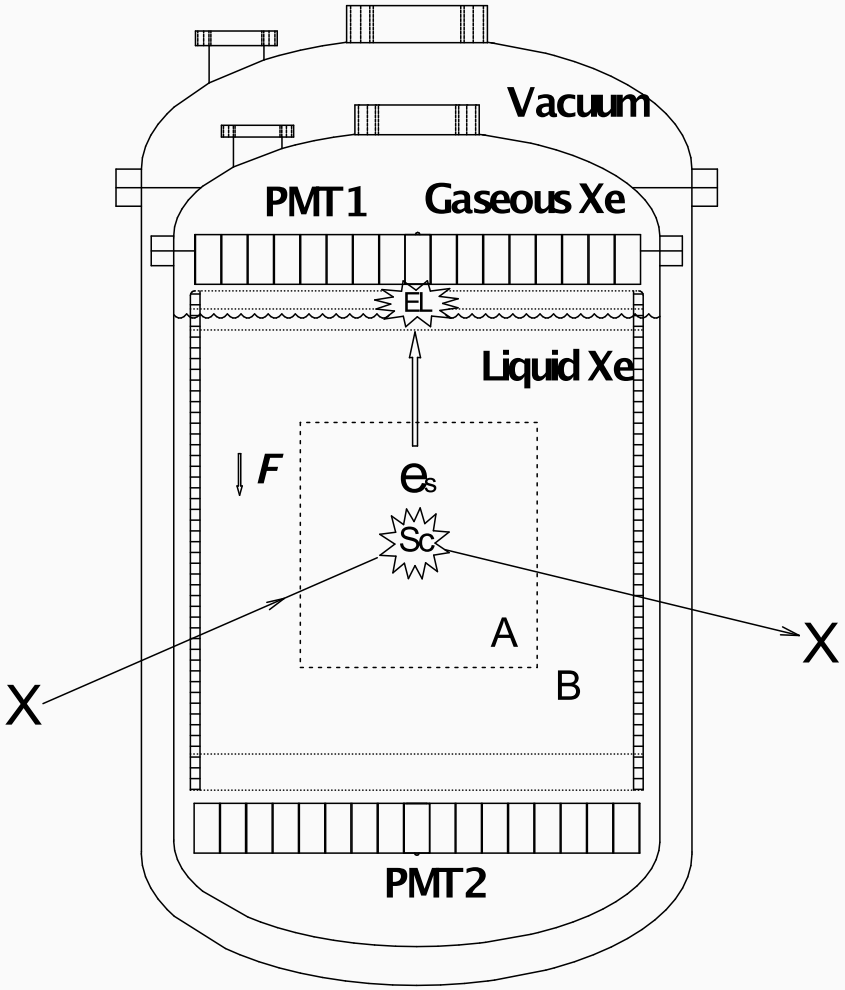


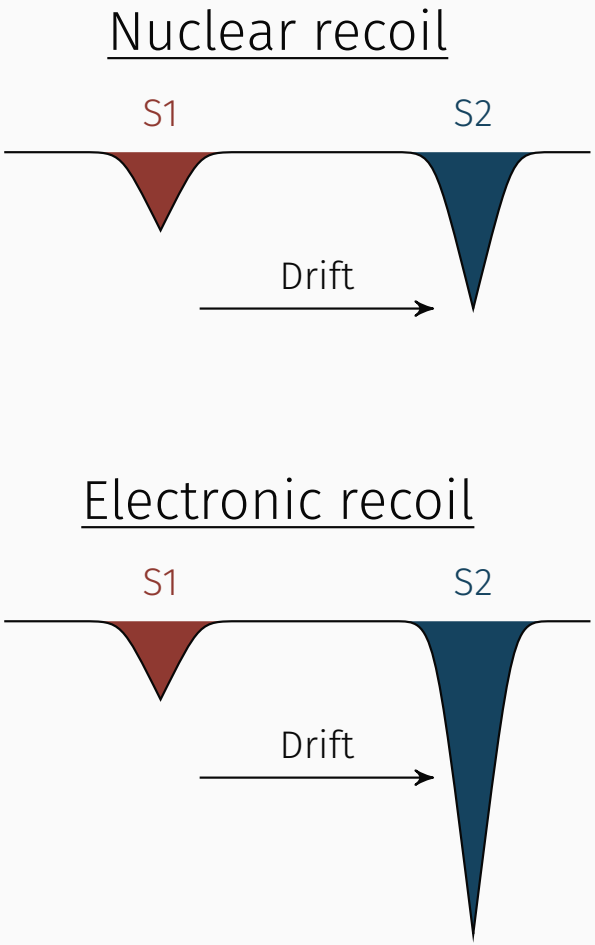

A. Bolozdynya *et al.*, arXiv:1211.5199 (2012)

# SNS BEAM TIME PROFILE



# 2-PHASE XENON - S1 AND S2 SIGNAL




D. Yu. Akimov *et al.*, JINST8 (2003), P10023