Coherent NC Elastic Scattering Measurement at Fermilab

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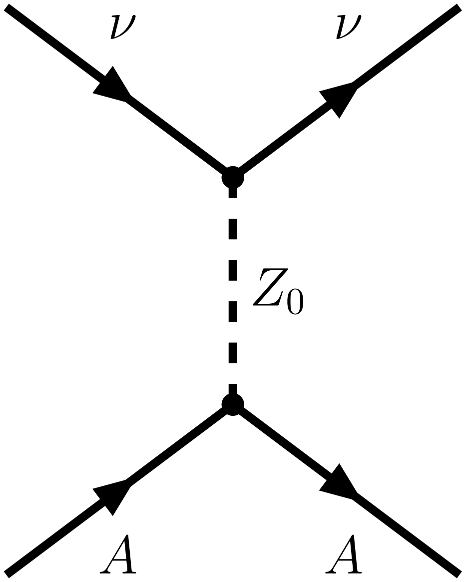
Future Short-Baseline Neutrino Experiments

Coherent-NCvAS has never been observed!

$$\mathcal{L}_{eff} = \frac{G_F}{\sqrt{2}} l^{\mu} j_{\mu}$$



Cross section for zero-momentum transfer limit

$$\sigma_{\nu N} \simeq \frac{4}{\pi} E_{\nu}^2 \left[Z\omega_p + (A - Z)\omega_n \right]^2$$

$$g(Z_0 u) = \frac{1}{4} - \frac{2}{3}\sin^2\theta_W, \qquad g(Z_0 d) = -\frac{1}{4} + \frac{1}{3}\sin^2\theta_W$$

$$\omega_p = \frac{G_F}{4}(4\sin^2\theta_W - 1), \qquad \omega_n = \frac{G_F}{4}$$

Differential cross section for finite momentum transfer

$$\frac{d\sigma}{dE} = \frac{G_F^2}{4\pi}[(1 - 4\sin^2\theta_w)Z - (A - Z)]^2 M \left(1 - \frac{ME}{2E_{\nu}^2}\right) F(Q^2)^2$$

Requirements of the coherent-NCvAS

For most of the detector target nucleus, the coherence condition is fulfilled by neutrino energy of

$$E_\nu < \frac{1}{R_N} \simeq 50 \text{ MeV}$$

$$E_{max} \simeq \frac{2E_\nu^2}{M} \simeq \mathcal{O}(100) \text{ keV}$$

Coherent-NCvAS cross section at these energy (~50MeV)

$$\sigma_{\nu N} \simeq 10^{-39} cm^2$$

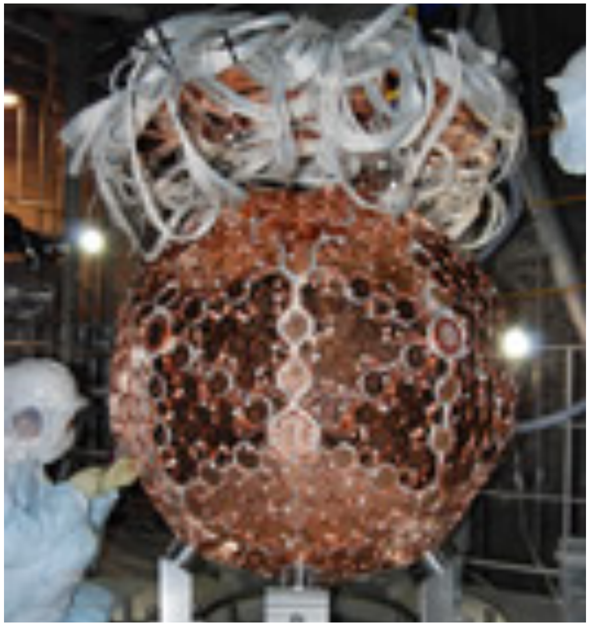
cf) v-N charged current : 10^{-40}cm^2
v-e elastic scattering : 10^{-43}cm^2

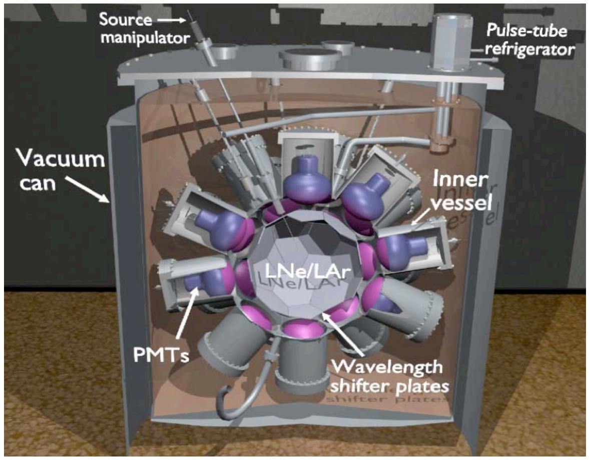
Requires a ton-scale detector with ~10 keV energy threshold

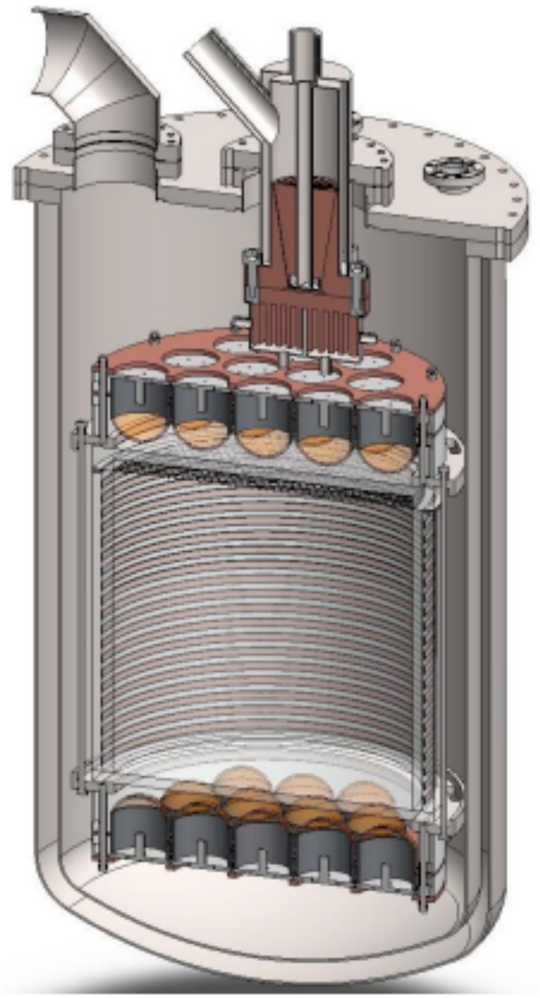
$$R \simeq \mathcal{O}(10^3) \left(\frac{\sigma}{10^{-39} cm^2}\right) \times \left(\frac{\Phi}{10^{13} \nu/year/cm^2}\right) \times \left(\frac{M}{ton}\right) events/year$$

Measuring Coherent-NCvAS

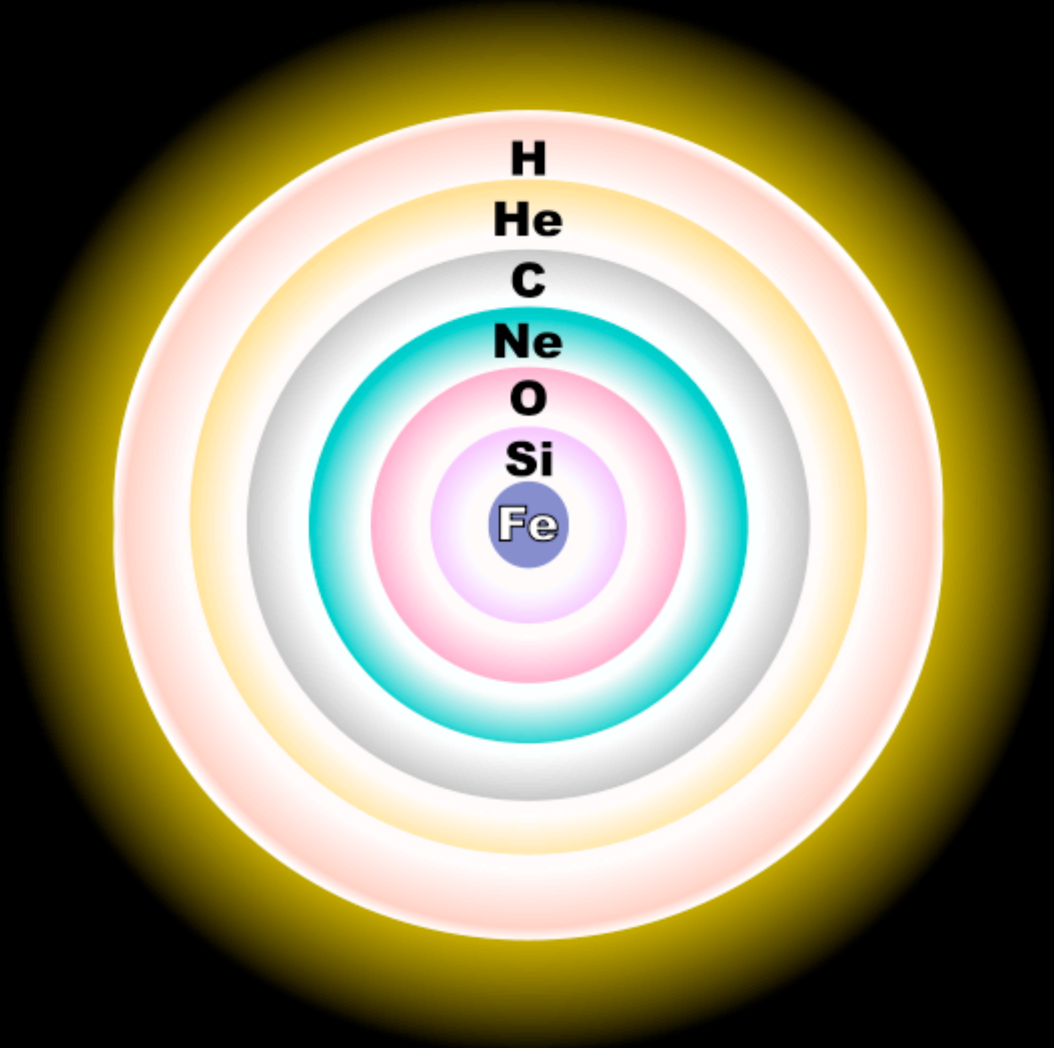
Recent innovation of Dark Matter detector technology makes it possible to access coherent-NCvAS







Supernova Explosion



Type-II supernova (Core collapse supernova)

We know that type-II supernova is exploding - hence "supernova".

However, we do not know how and why it's exploding.

It is NOT understood how the burst of neutrinos transfers its energy to the rest of the star producing the shock wave which causes the star to explode.

Neutrinos and coherent-NCvAS may play an important role in the supernova explosion.

Beyond the Standard Model?

Note again, coherent-NCνAS has never been measured!

- Test Standard Model weak mixing angle
  - K.Scholberg, PRD73 (2006)

- Non-standard interaction of neutrinos
  - J.Barranco et al, hep-ph/0702175

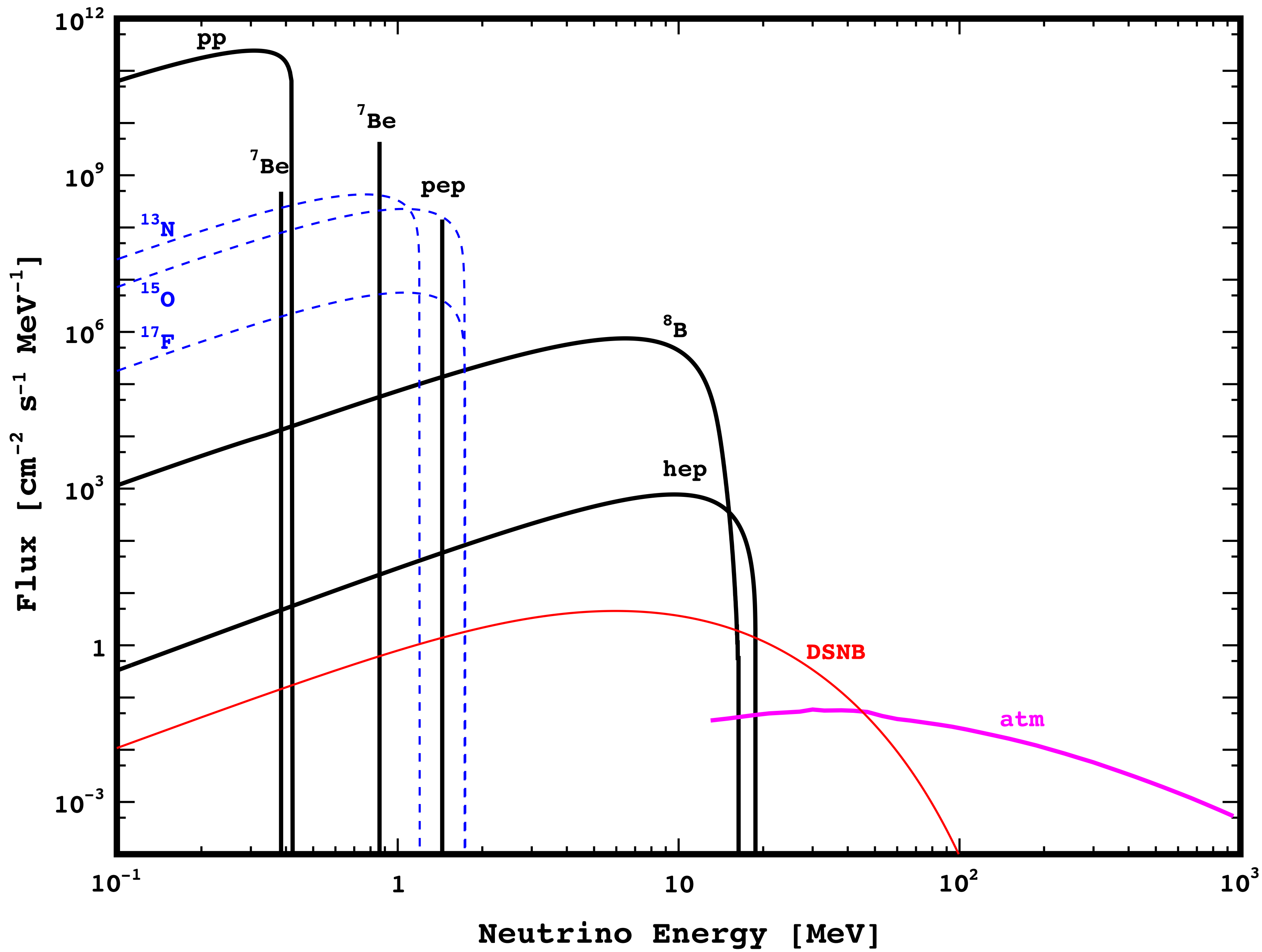
- Neutrino magnetic moment
  - Conclusive measurement requires intensive neutrino flux (Project-XI ?)

- Neutron form factor from coherent-NCνAS
  - P.S.Amanik et al, hep-ph/0707.4191

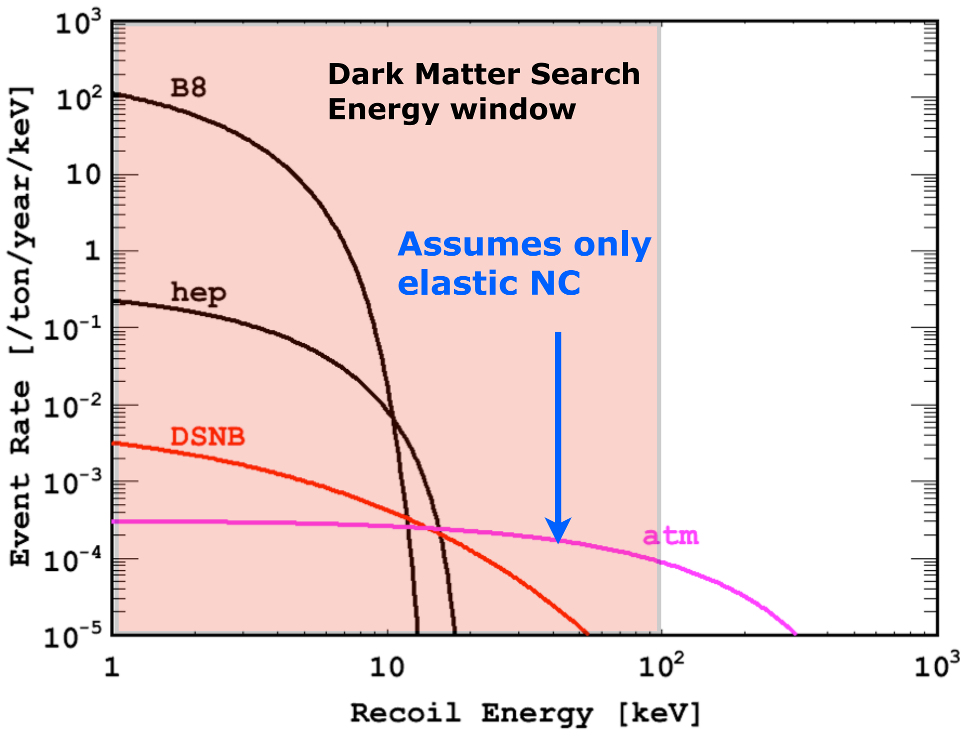
→ **Neutrinos always provided us with the physics Beyond the *then-Standard Model* !**

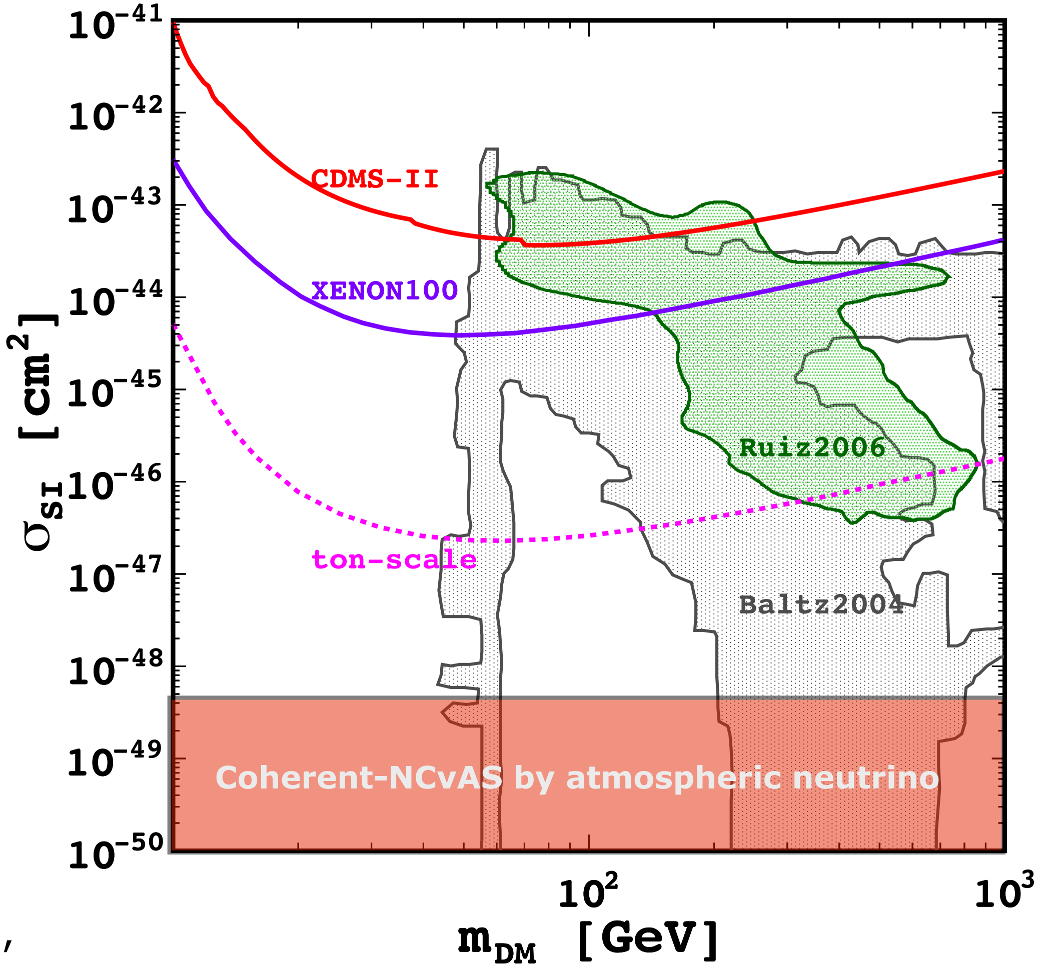
Irreducible Backgrounds for Dark Matter Search

Neutrinos from astrophysical origin



Irreducible Backgrounds



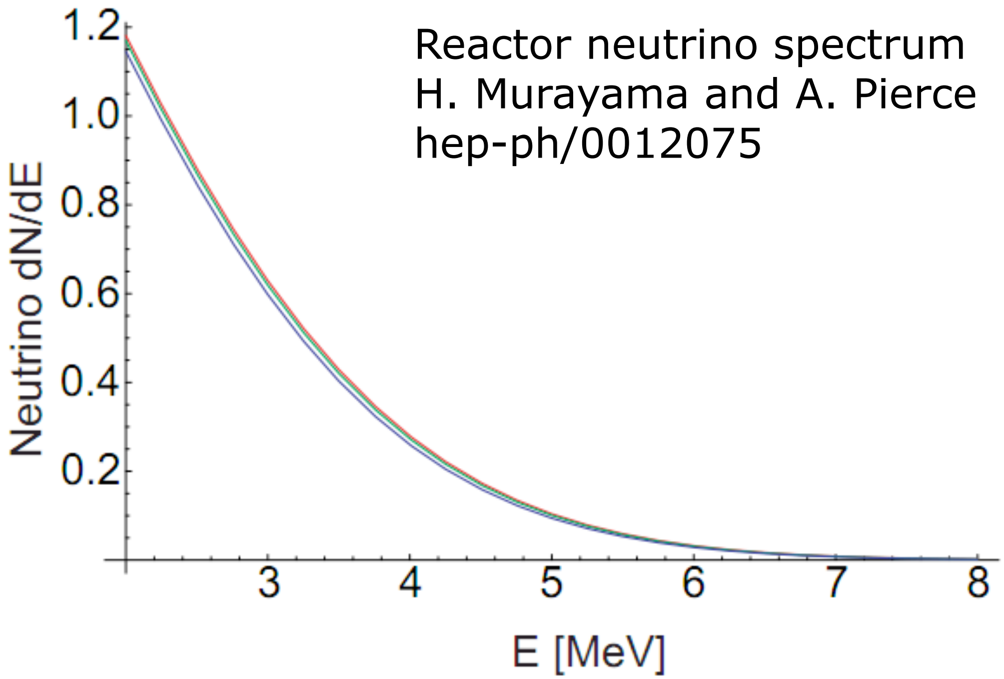


- Coherent scattering of atmospheric neutrino is an irreducible background in the future *O*(10 ton) scale dark matter experiments (see Strigari, arXiv:0903.3630)

- What about the inelastic interaction tail by high energy neutrinos?

Sensitivity of Dark Matter detectors will be saturated out by irreducible neutrino backgrounds

Reactor Neutrinos



Reactor neutrino spectrum
H. Murayama and A. Pierce
hep-ph/0012075

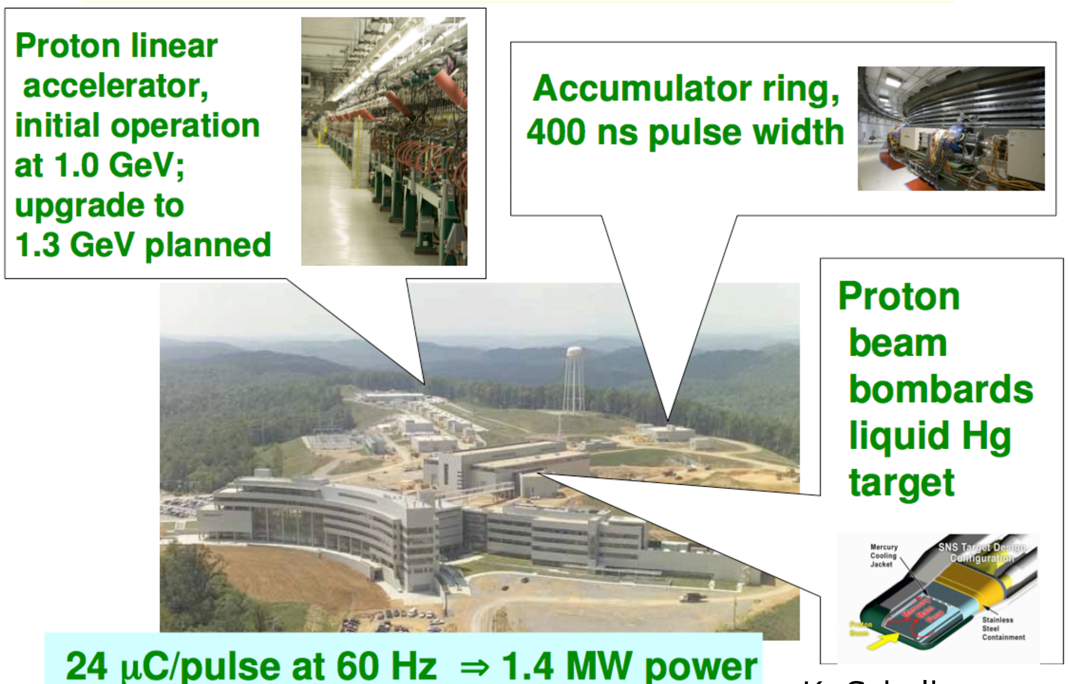
$$E_{max} \simeq \frac{2E_\nu^2}{M} < \mathrm{keV}$$

$$\Phi = 10^{20} \bar{\nu}_e / sec / 4\pi R^2 \qquad (\Phi = 10^{12} \bar{\nu}_e / sec / cm^2 @ \ 20 \ \mathrm{m})$$

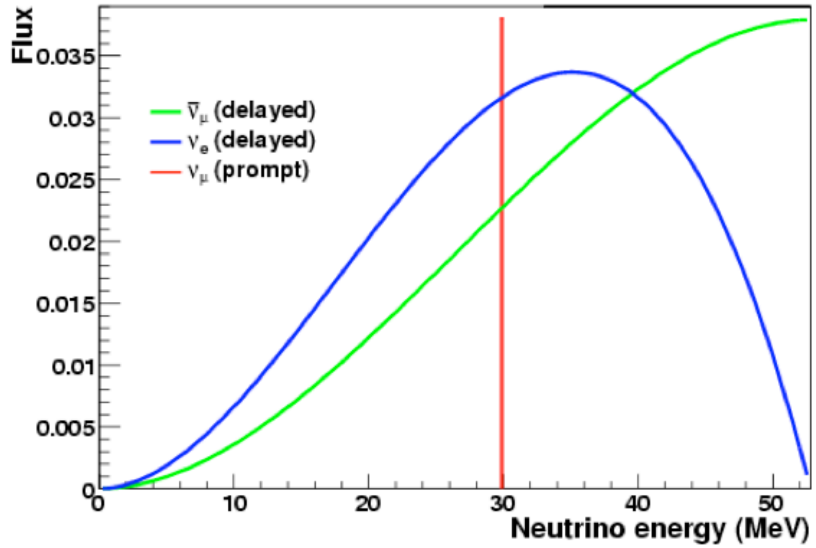
- Ultra-clean, kg-size, ~10 eV threshold detector
- Need to overcome steady state backgrounds and detector noise
- Reactor off-time can be used for background subtraction
- Detector development is challenging for a realistic experiment

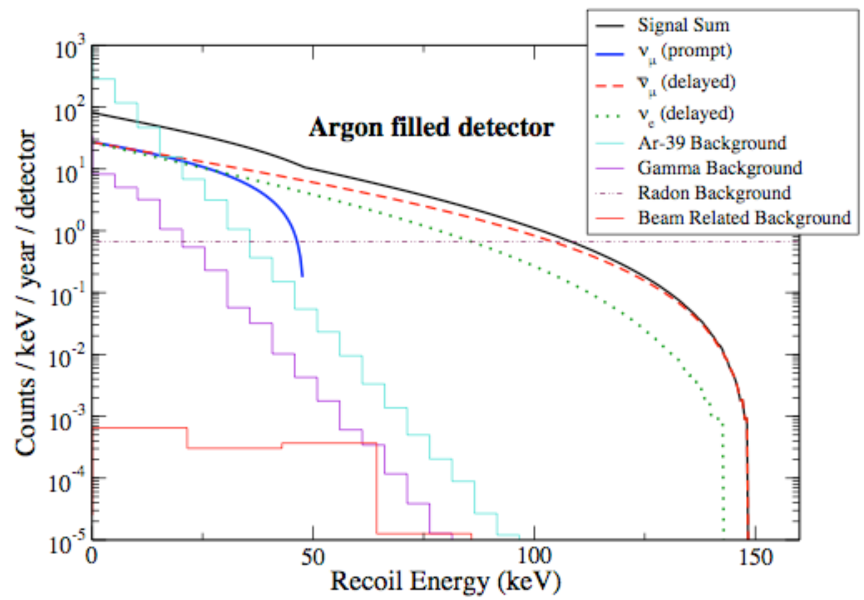
Neutrino Source from Stopping Pions

- See **CLEAR** proposal : K. Scholberg *et al.*, hep-ex:0910.1989
- Spallation Neutron Source (SNS) at Oak Ridge National Lab
  F. Avignone and Y. Efremenko, J. Phys. G, 29 (2003) 2615-2628



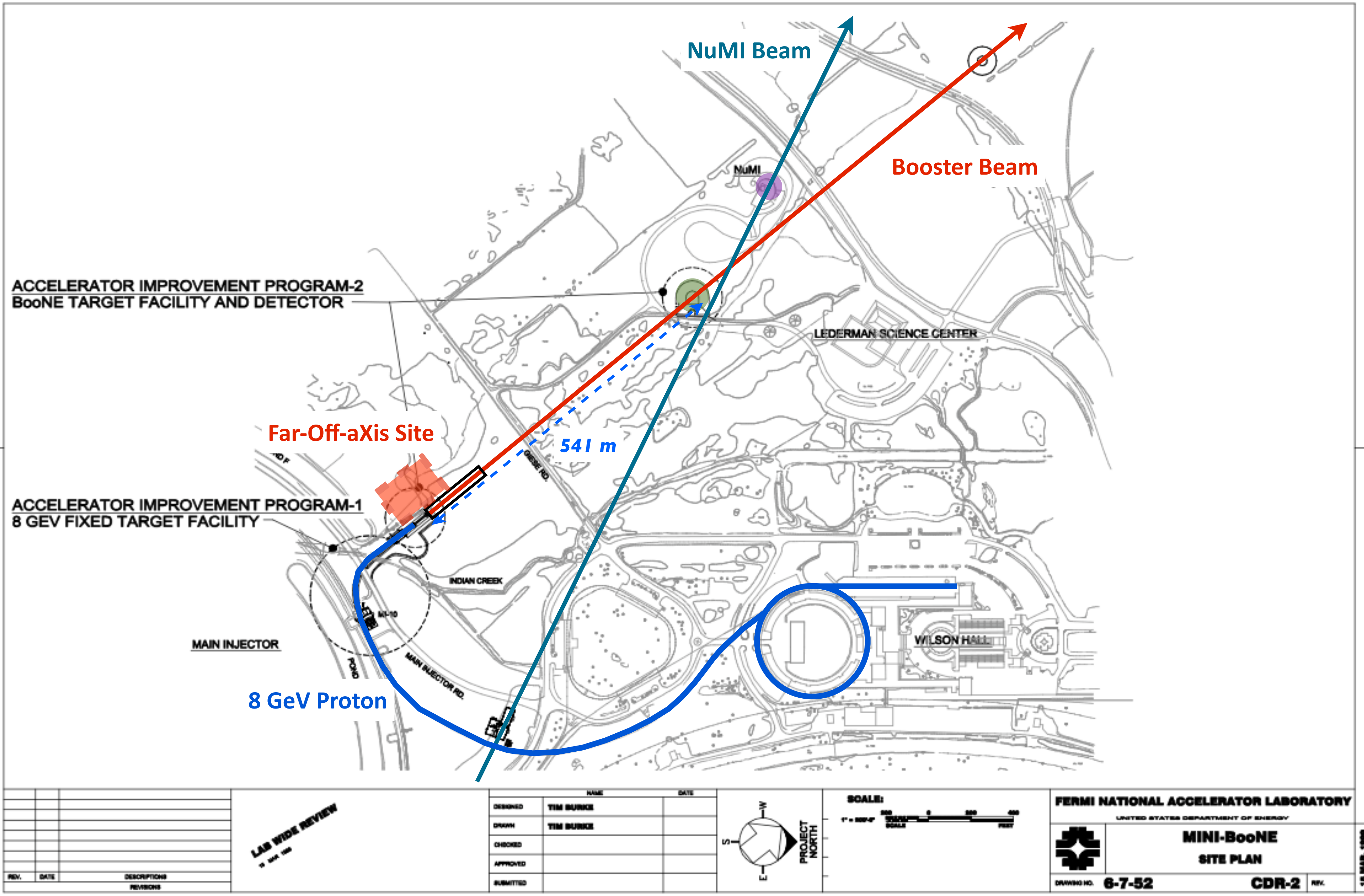
K. Scholberg





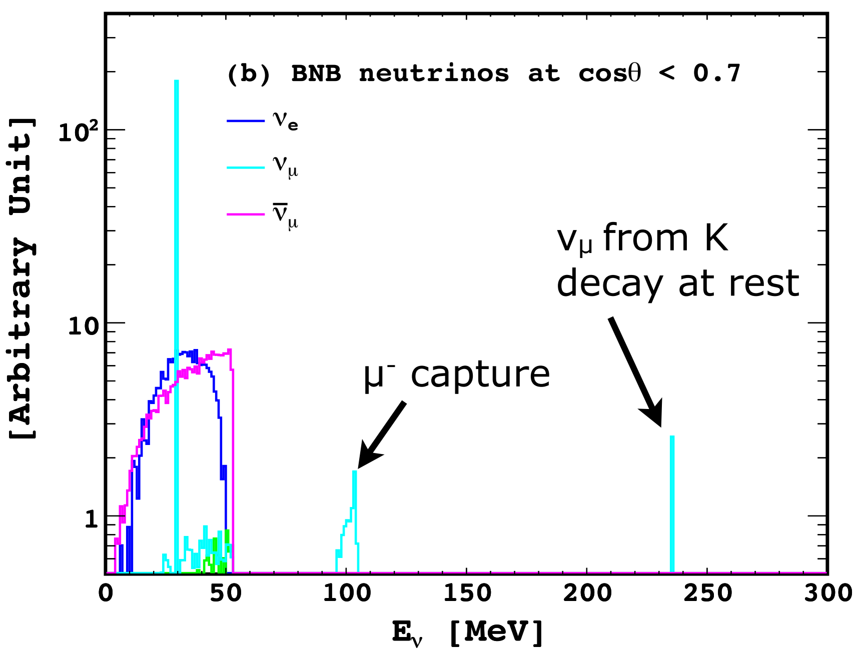
- Flux ~ 10^7/sec/cm^2 at 20m from the target
- 60 Hz pulsed source
- Steady state background rejection factor ~10^{-4}
- Expected event rate in a single-phase 500kg LAr detector: ~890 events/year of detection (E_{th}>20 keV) at the proposed experiment site (46m from SNS target)

Fermilab Neutrino Beams



Far-Off-aXis (FOX) Neutrinos at BNB

From Booster Beam MC (S. Brice)



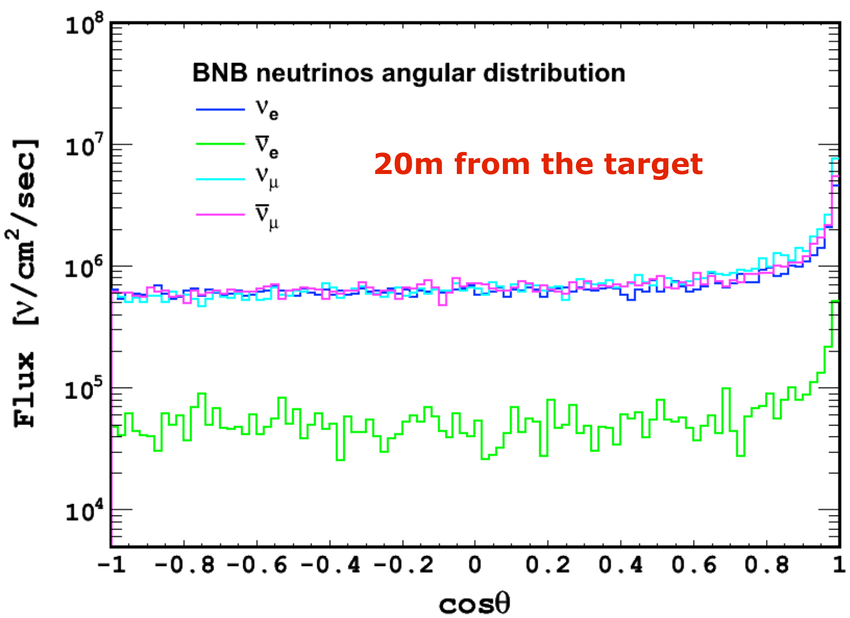
Beam MC Configuration

- Use standard Booster Beam MC
  - release stopping pion cuts in the original MC
- 8 GeV, 5Hz 5×10^{12} Protons on Be target
  - 32 kW max power (NUMI beam on 8 kW)
- 173 kA horn current neutrino mode

Dominant neutrino production process at the Far-Off-aXis is pion decay at rest

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \qquad E(\nu_\mu) = 29.9 \text{ MeV}$$

$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e \qquad \text{delay} = 2.2\ \mu\text{s}$$

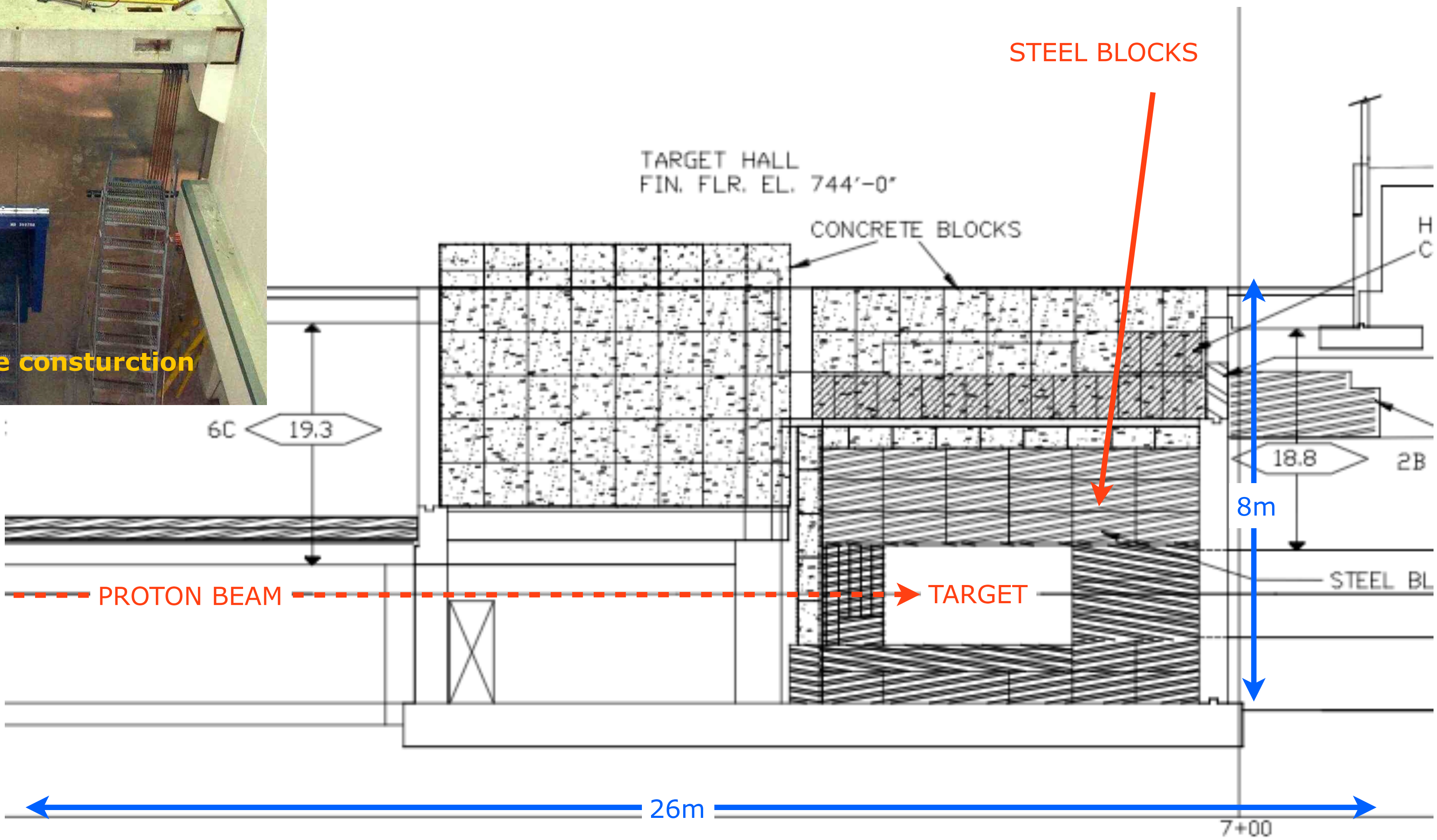


⇨ $\phi \sim 5 \times 10^5\ \nu/\text{cm}^2/\text{s}$ (@20m, $\cos\theta < 0.5$)

- Systematic uncertainties of the neutrino flux estimation should be checked in detail
- Beam correlated muons and neutrons at the detector site should be evaluated

Target Building (MI-12)

- Very impressive shielding at BNB target
  total ~2.5m-thick steel blocks + ~2.5m-thick concrete
  (Thanks to Fermilab Safety Regulations)
- Ballpark estimation of beam induced neutron flux at 10m seem to be OK → need to measure the background



Beam Induced Background Study at BNB Tareget Building

Initial Survey : Feb 2012

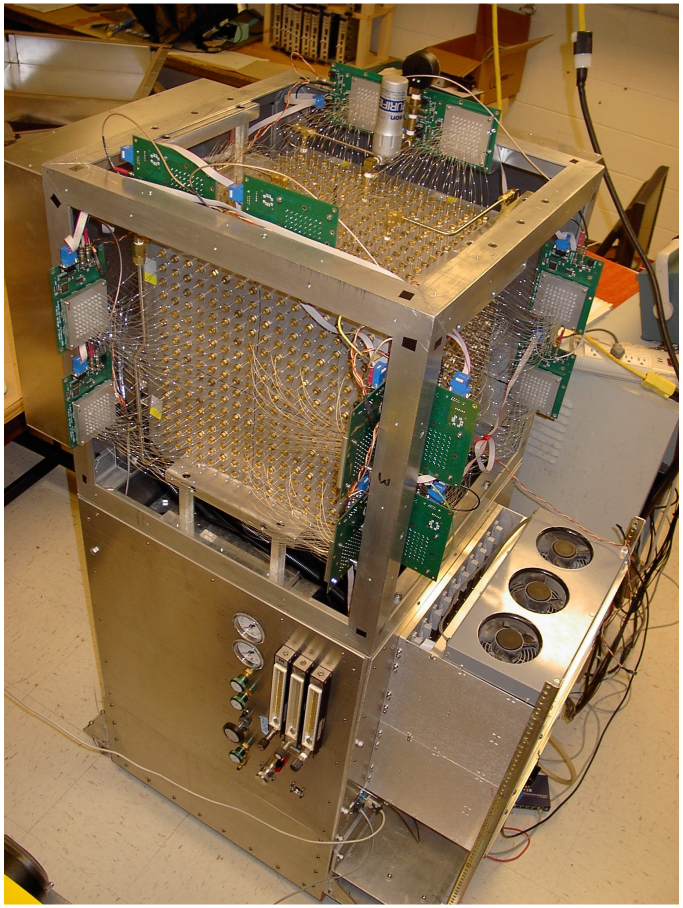
- Commercial 5"D EJ-301 neutron detector
- Establish logistics of data taking procedure at the target building
- Measure potential beam induced event rate

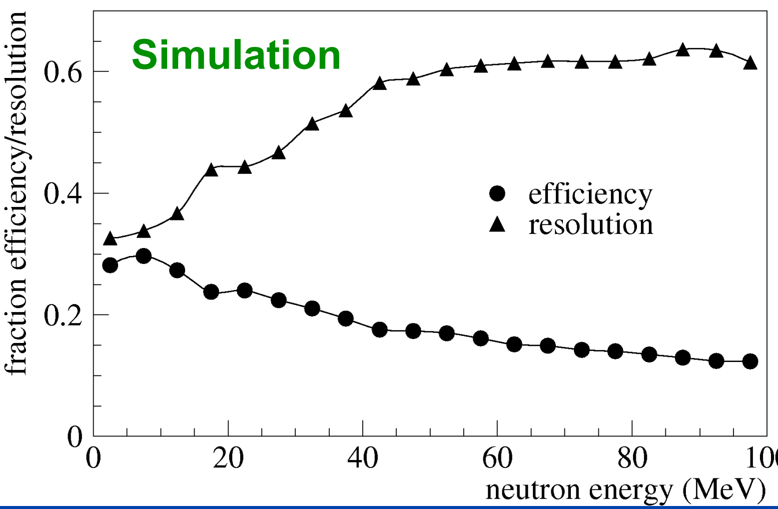
Background study in BNB target building: Mar 2012
SciBath (Indiana University, R.Tayloe)

- $(45\text{cm})^3$ volume containing...
- 82 liters (70kg) of liquid scintillator: mineral oil, 11% pseudocumene, + PPO
- 3 16x16 grids, in x,y,z (768 total), 2.5cm spacing, 1.5mm wavelength-shifting (WLS) fibers (UV->blue)
- coupled to clear plastic fibers, routed to readout:
- 12 Hamamatsu 64-anode PMTs
- custom-built readout system
- Detector test completed at NuMI tunnel

Plans

- Beam induced background measurement
- cosmic-induced fast neutron flux measurement

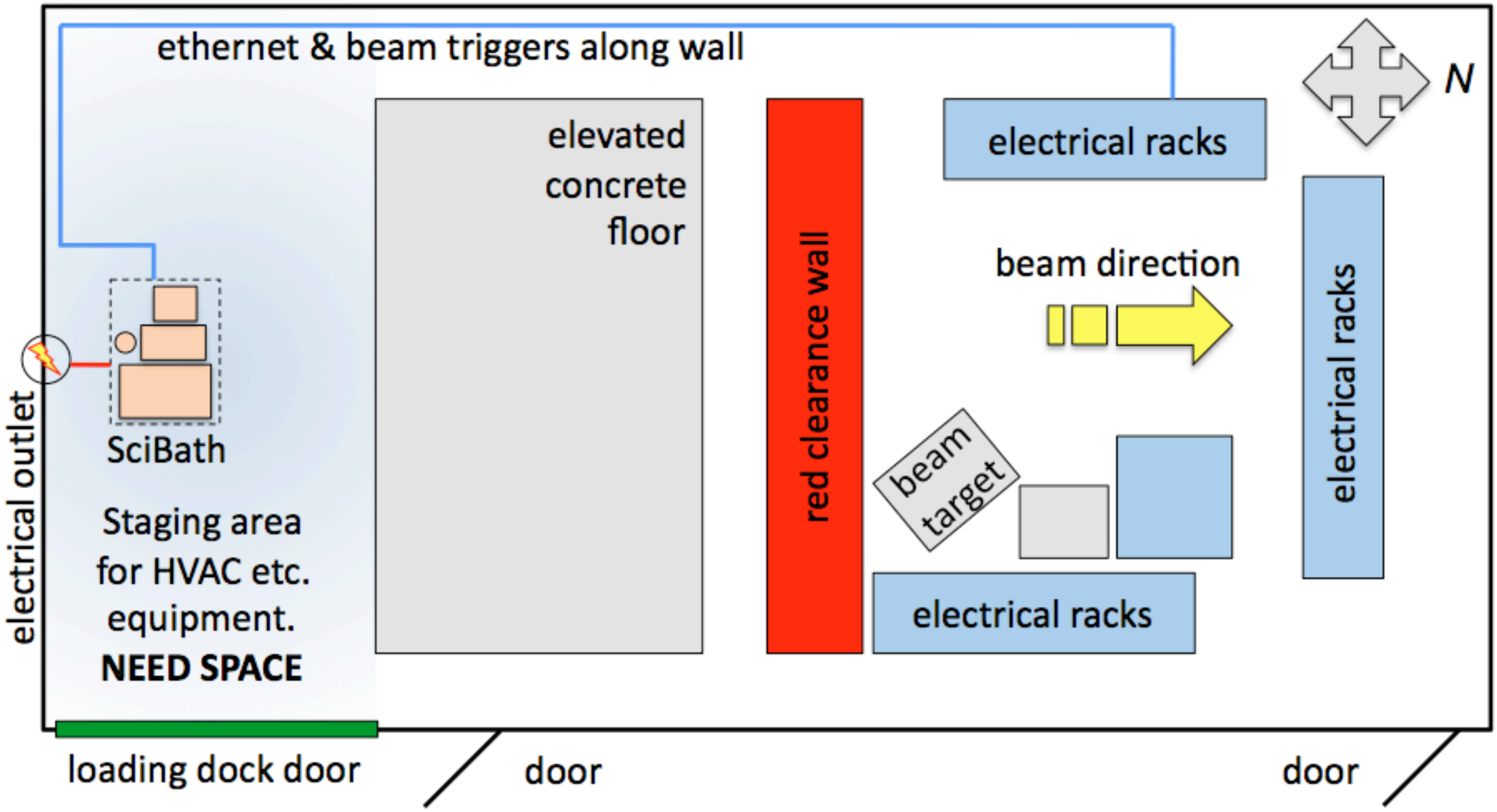




SciBath at MI-12 (Tareget Building)

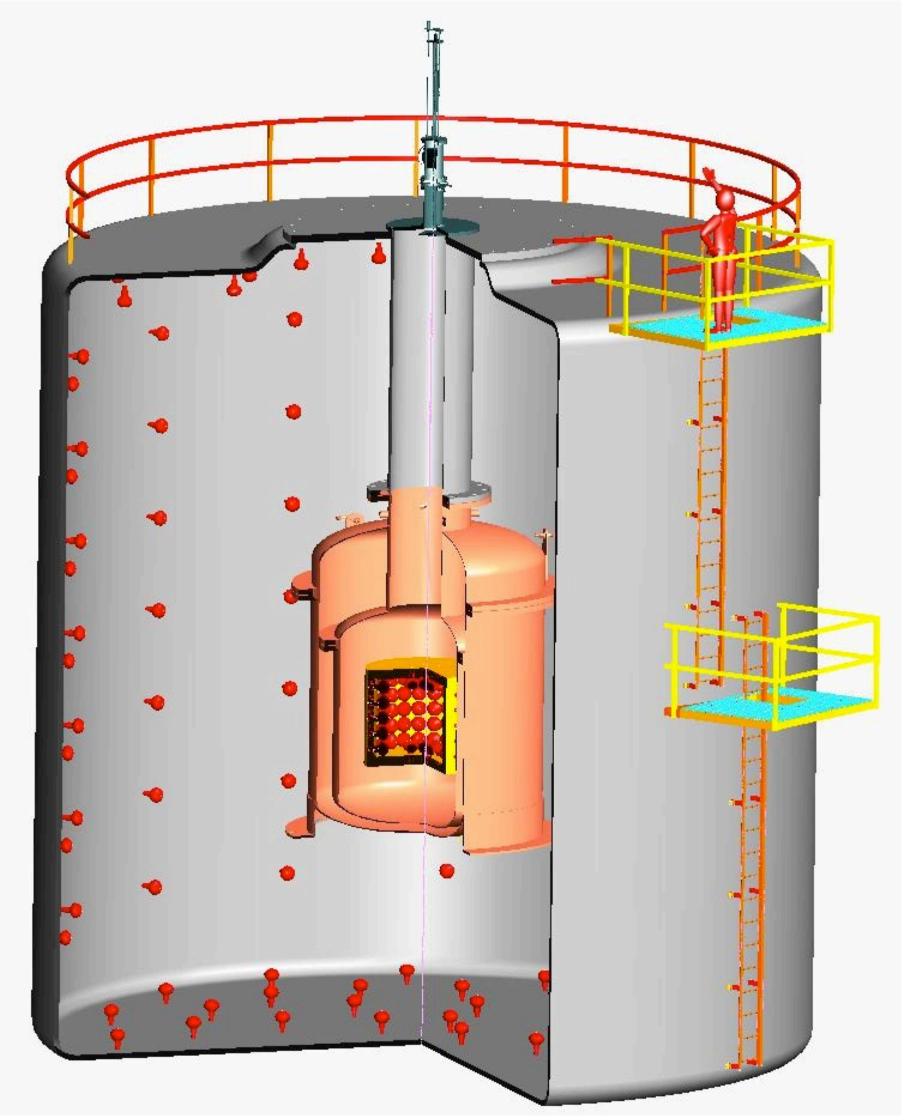
SciBath Operation at MI-12 : Feb ~ Apr 2012
- Understand beam induced background
- Understand cosmic ray induced background

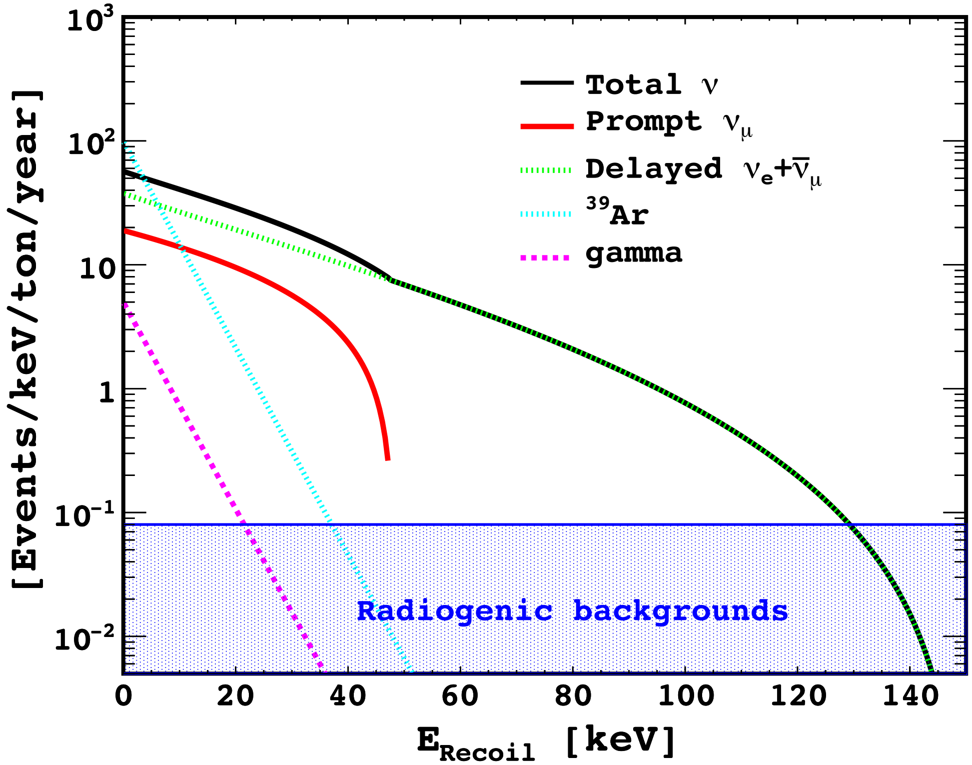
R.Cooper



Expected Coherent-NCνAS Event Rates at FOX

A ton-scale single phase LAr detector may perform the first ever observation of the coherent-NCνAS at Fermilab





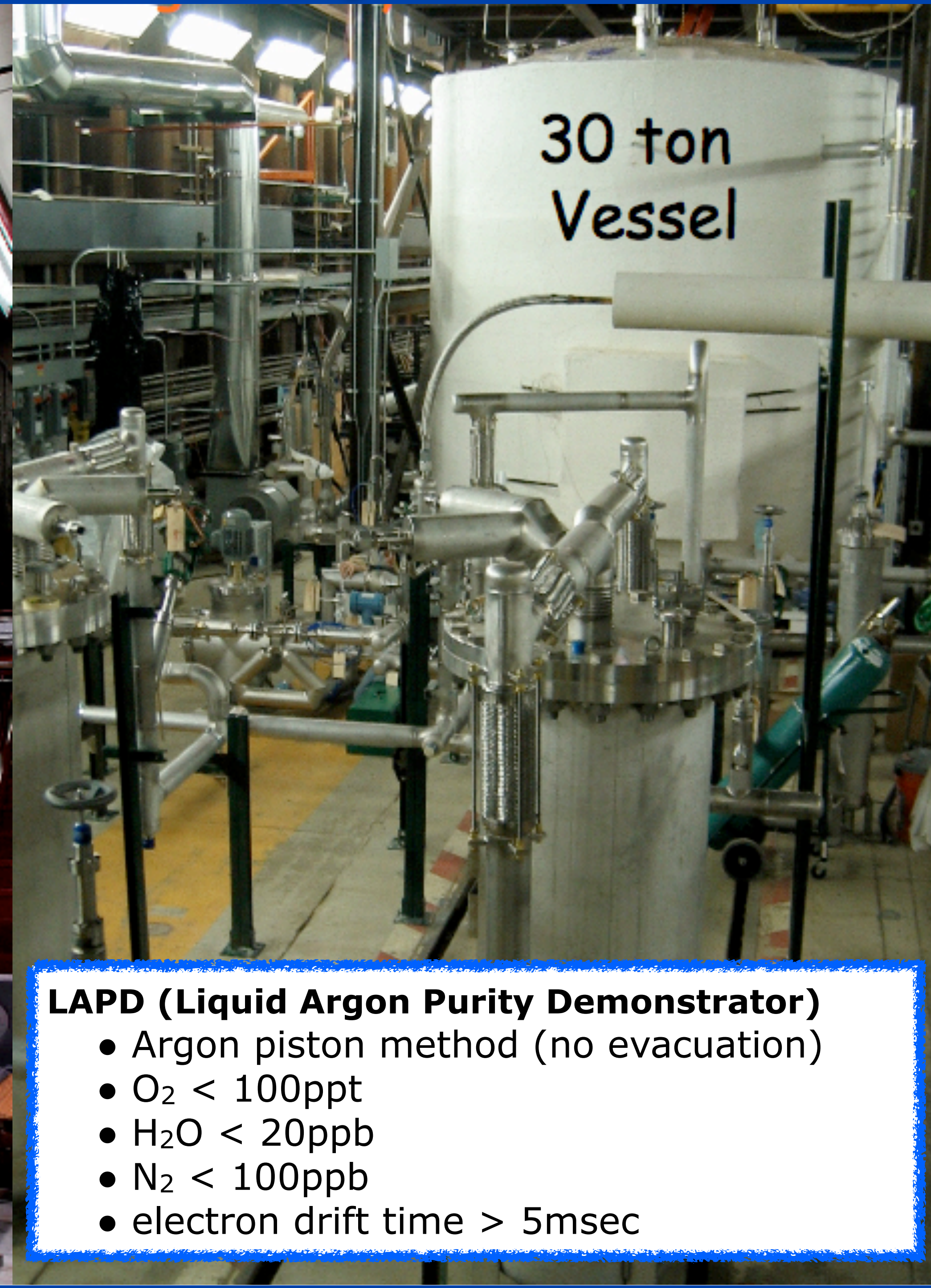
- 20m from the target
- Steady state background rejection factor ~10^{-5}
- Use pulse shape discrimination of nuclear recoil (fast) and electron recoil (slow) signal in LAr (see Boulay and Hime: astro-ph/0411358)
- Well known detector technology (DEAP/CLEAN)
- Expected Event Rate in a single-phase 1-ton LAr detector: ~200evt/year (E_{th}> 30 keV) w/ full-power operation (w/ NUMI: ~50 evt/year)

Fermilab Noble Gas Detector R&D Facility

LArTPC R&D Setup (@PAB)

Fermilab Noble Gas Detector R&D Facility

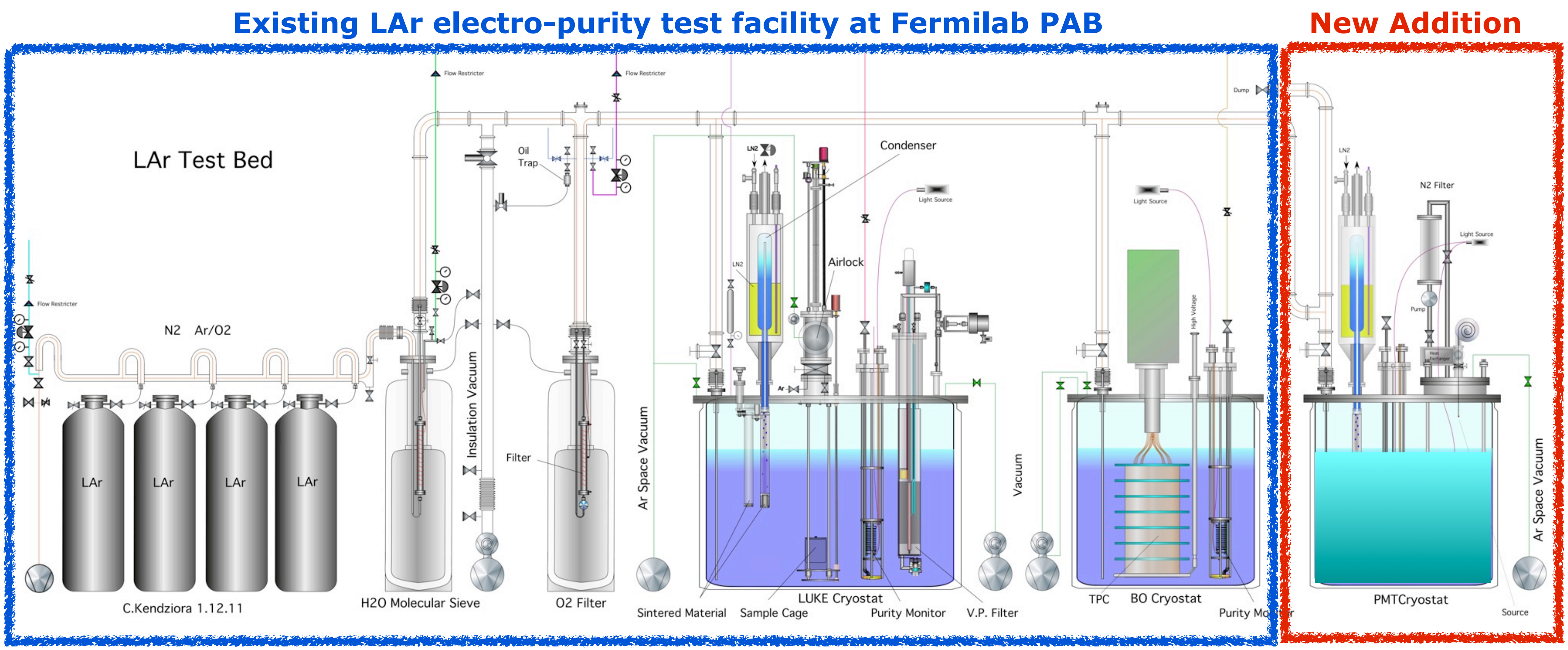
Noble Gas Purification Tower (Darkside Collab)



LAPD (Liquid Argon Purity Demonstrator)

- Argon piston method (no evacuation)
- O_2 < 100ppt
- H_2O < 20ppb
- N_2 < 100ppb
- electron drift time > 5msec

Prototype Detector Test Chamber



- Existing LAr test chamber system demonstrated 20ppt level of purity on electronegative elements (H_2O and O_2)
- N_2 contamination above ~ppm in LAr is known to affect pulse shape discrimination of nuclear recoil events (see 2010 JINST 5 P06003 by WArP collaboration)
- The new chamber can be designed as a prototype detector

Summary

- Coherent-NCνAS has never been observed since its first prediction in 1974.

- Dark Matter Search experiments will face irreducible coherent-NCνAS neutrino backgrounds in next decade.

- There is a well defined low energy (<50MeV) neutrino source at Fermilab which might be useful for coherent-NCνAS experiment.
  → Beam induced background study is just started.

- Further R&D within Project-X neutrino program (8GeV~0.3MW proton beam) can open up new endeavors and opportunities of future short baseline projects.

- Current Collaboration:
  - Fermilab: S.Brice, F.DeJongh, B.Loer, S.Pordes, E.Ramberg, R.Tesarek, J.Yoo
  - Duke: K.Scholberg
  - Indiana: R.Cooper, L.Garrison, R.Tayloe
  - UCLA: H.Wang

Future of FOX neutrinos?

Short Baseline Neutrinos at Project X

Exploring 3 GeV and 8 GeV programs
This workshop

• 8GeV, 0.3MW pulsed beam will provide intensive high energy (~GeV) neutrinos at on-axis. Low energy scattering of ~GeV on-axis neutrinos is very interesting. (study DM backgrounds)

• The same beam will provide very precious byproduct - low energy neutrinos with 4π coverage.

• Characterizing the neutrino sources will be extremely useful for the future short baseline experiments.