CEvNS at Jefferson Lab

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On behalf νBDX collaboration

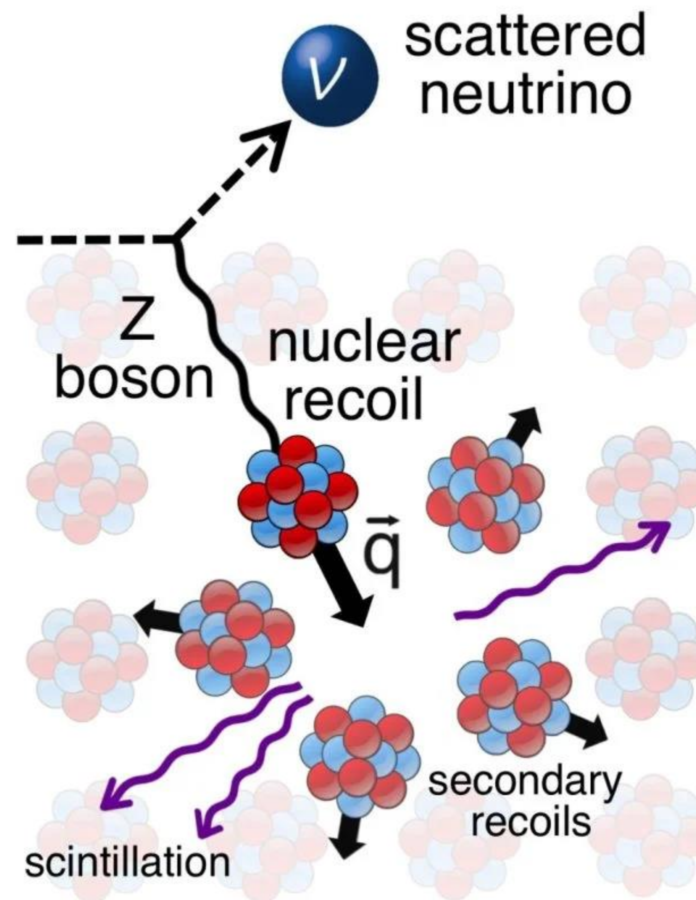
Summary

- CEvNS
- Physics Interest
- Detection Method
- Neutrino at Jlab
- Background
- Result

CEvNS

- Coherent elastic neutrino-nucleus scattering, or **CEvNS** is the process of a low energy neutrino scattering on a nucleus. In the process is exchange a Z_0 boson
- Is **coherent** because the neutrino interacts with the **nucleus as a whole**, not with individual nucleons
- **Recoil** nucleus have small energy, **few keV**.

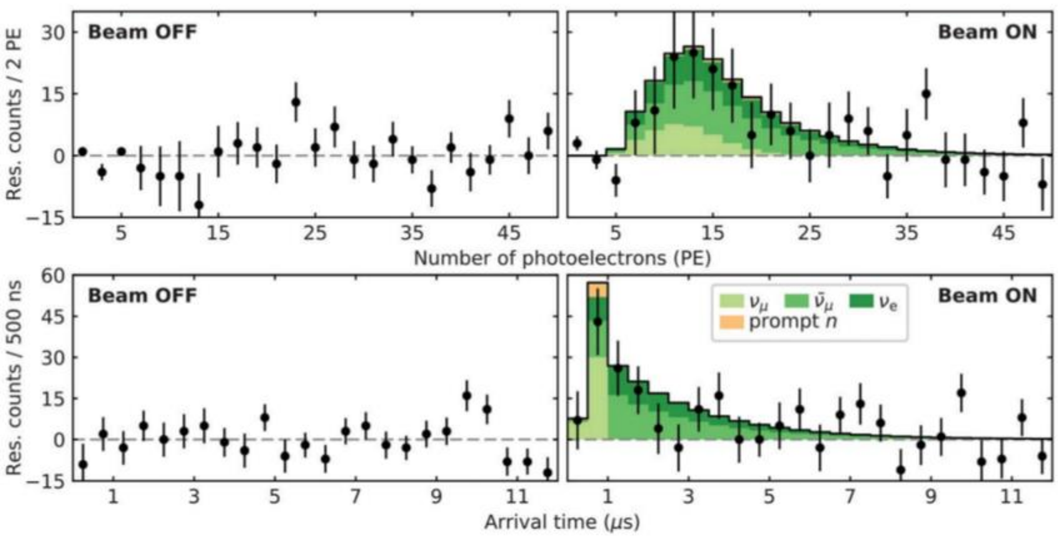
  ->That's not easy to detect

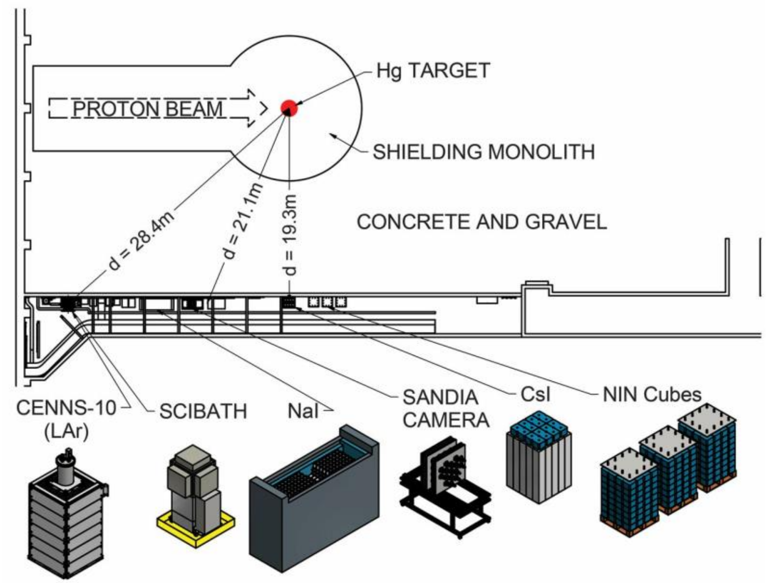


Coherent Experiment

In 2017, the COHERENT collaboration announced the observation in a CsI[Na] scintillator exposed to the neutrino emissions from the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory.

Proton beam of 10^{20} p/day and a neutrino flux of 10^{11} ν/cm^{2}/s





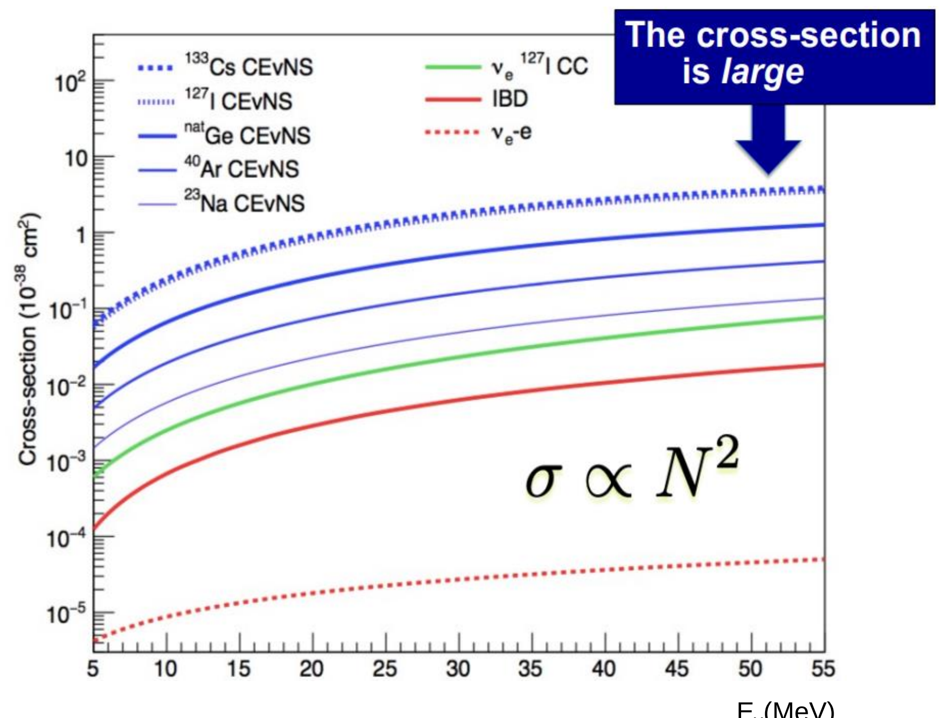
D. Akimov et al. (COHERENT), Science 357, 1123 (2017), 1708.01294.

CEvNS Cross-Section

- CEvNS cross section is quite large, around 10^{-39} cm^2.
- It is proportional to coherent weak nuclear charge Qw that quantifies the Z-nucleus vector coupling

$$Q_W^2 = \left[N g_V^n F_N(q) + Z g_V^p F_Z(q)\right]^2$$

$$\frac{d\sigma}{dE_r} = \frac{m_N G_F^2}{2\pi}\left(2 - \frac{E_r m_N}{E_\nu^2}\right) Q_W^2$$



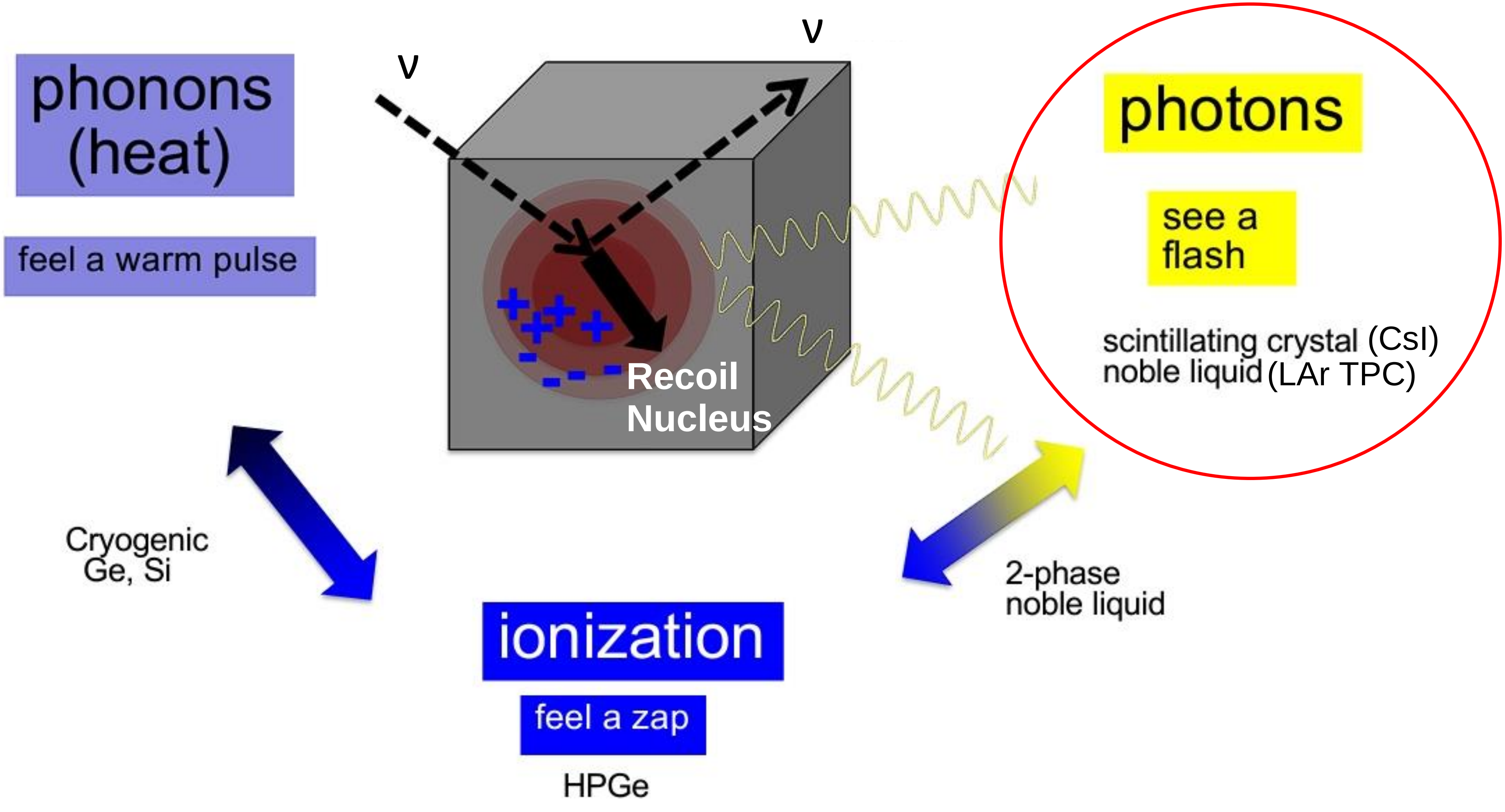
- Proton and neutron charges are define as g^p_v=1/2 − 2 $\sin^2\theta_W$ (Weinberg angle), g^n_v=-1/2
- $g^p_v \sim 0$

-> cross-section proportional to N^2

Physics Interest I

- CevNS is a process sensitive to the **weak mixing angle**
  - θ_W appear in cross-section at tree-level
- RMS radius of the neutron distribution.
  - neutron skin thickness of a nucleus, $\Delta r_{np}(\text{nucleus}) = r^n_{rms} - r^p_{rms}$.
- Neutrino NSI
- Dark Matter
  - CEvNS background for DM search

Detection Methods



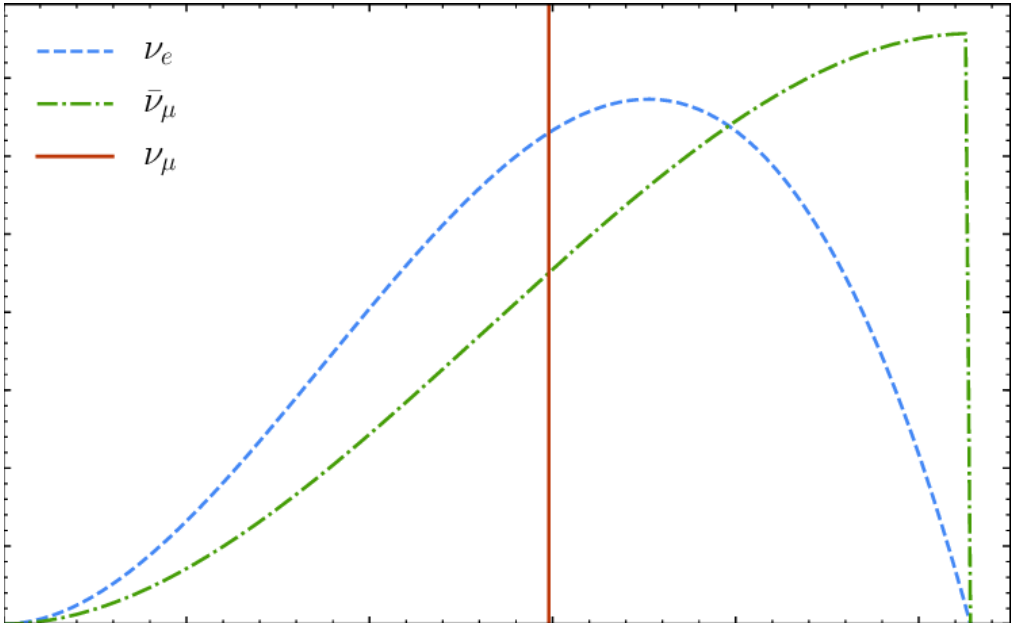
Neutrino at Jlab

- Neutrino production at Jefferson Lab
  - e-beam on Hall A Beam Dump can produces an intense ν-beam
  - Electron interact with dump generating π

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \qquad E_\nu \approx 30 \text{ MeV}$$
$$\mu^+ \rightarrow e^+ + \bar{\nu}_e + \nu_\mu \qquad 0 < E_\nu < 50 \text{ MeV}$$

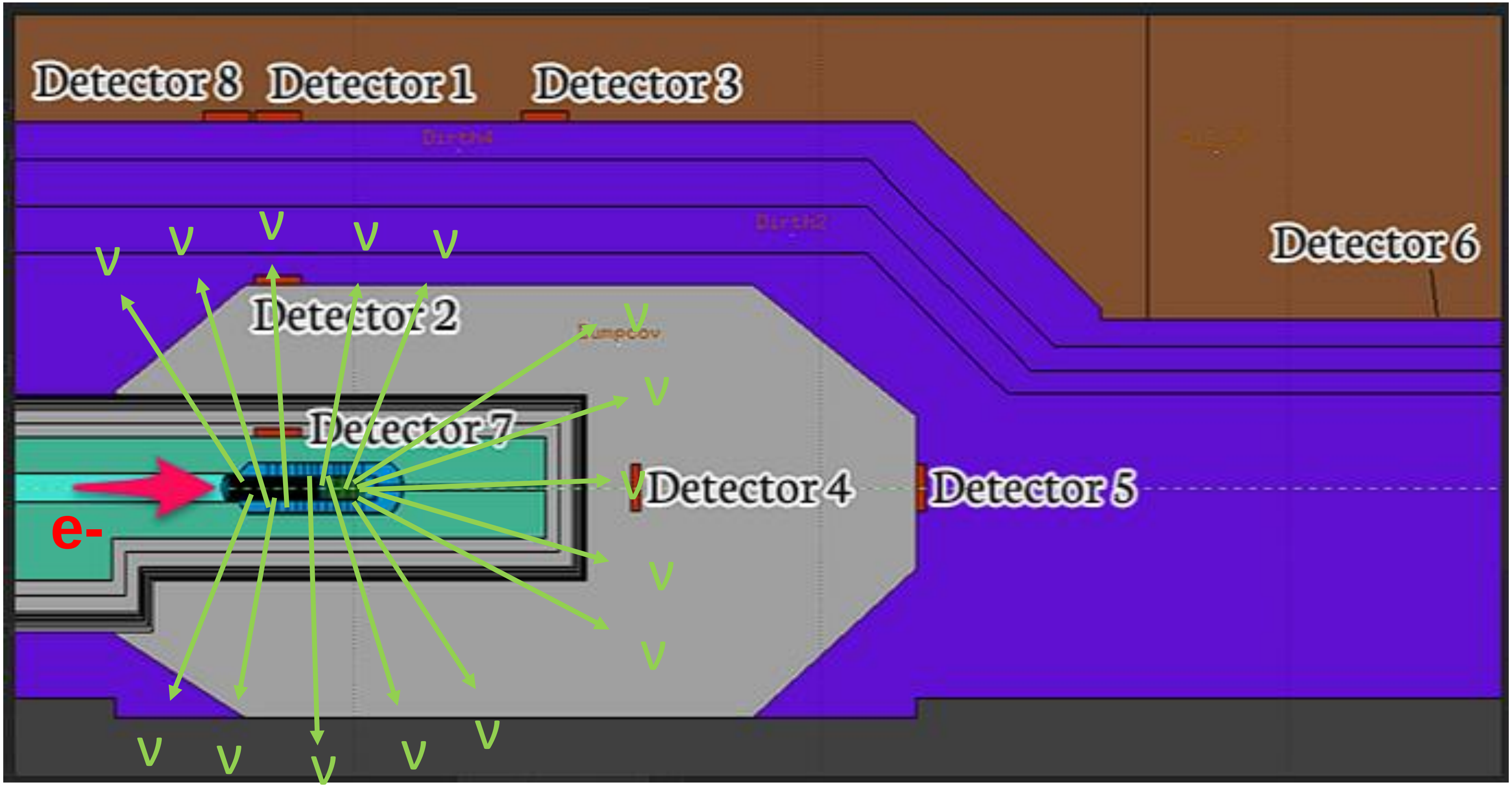
  - π mainly decay (isotropically) at rest (DAR) in μ and ν
  - μ decay in 2 ν

  - π decay on flight produce a small tail of higher energy neutrino



Hall A BD DAR ν Energy Spectrum

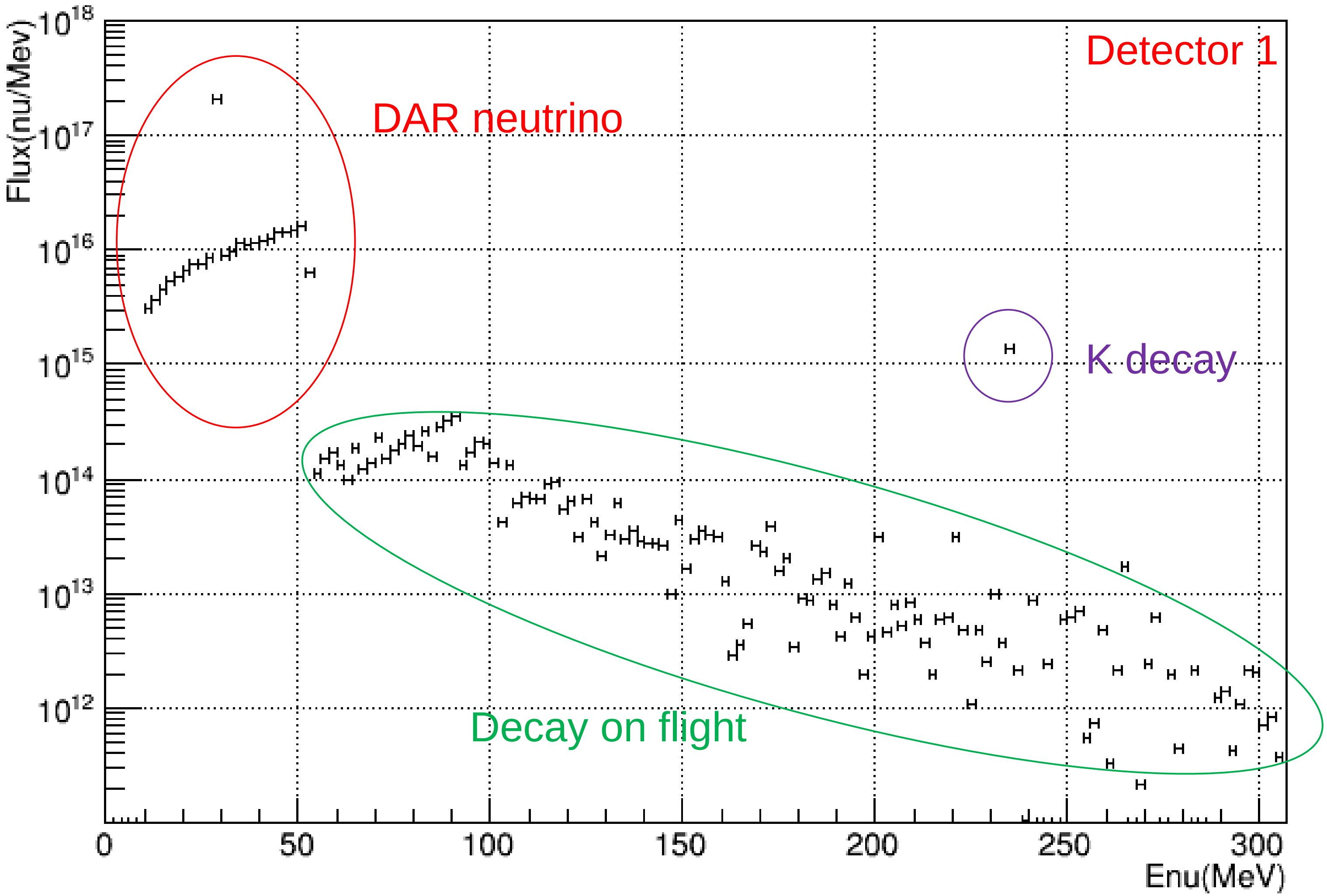
- Simulation of neutrino fluxes at different positions to identify a suitable place for an detector



Hall A BD DAR ν Energy Spectrum

- e-Beam of about 10^{22} EOT/y can produce 10^{18} ν/year/m^2 (mainly DAR)

Integrated neutrino Flux as function of neutrino energy in 1y/m^2



Signal Yield at JLab

- Yield calculation need to rewrite CEvNS cross-section introducing the nucleus kinetic energy T_A and three-momentum transfer |q|

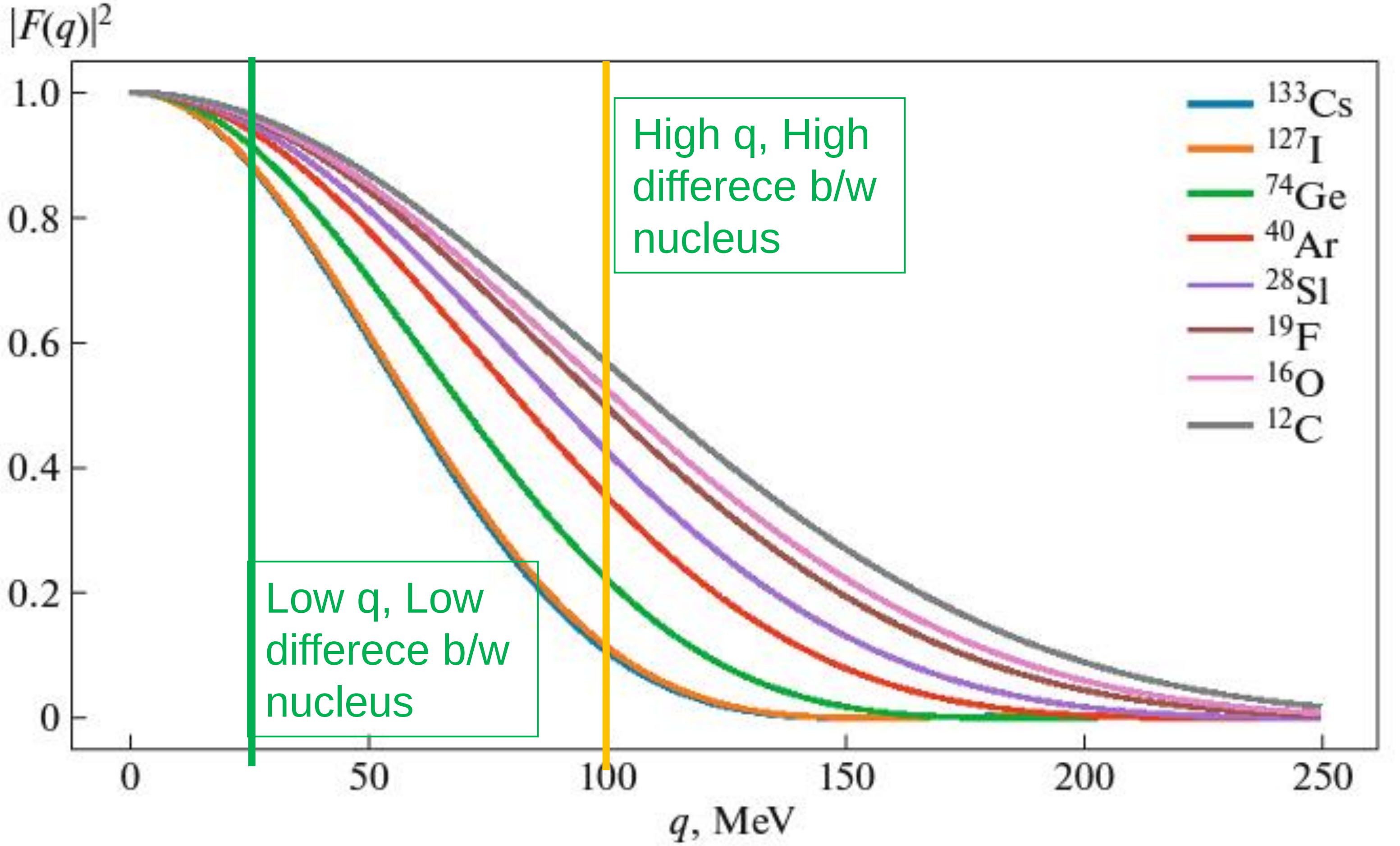
$$\frac{d\sigma_{\text{coh}}}{dT_A} \approx \frac{G_F^2 m_A}{\pi}\left(1 - \frac{T_A}{T_A^{\max}}\right)|F(q)|^2 \left(g_V^n\right)^2 N^2,$$

$$|\boldsymbol{q}| = \left(E_\nu^2 + E_\nu'^2 - 2E_\nu E_\nu' \cos\theta\right)^{1/2} \simeq (2m_A T_A)^{1/2} \qquad T_A^{\max} = \lim_{\cos\theta\to -1} T_A \approx \frac{(2E_\nu - \Delta\varepsilon_{mn})^2}{2m_A},$$

- Last important term is the nucleus form factor |F(q)|

Signal Yield at JLab

- $|F(q)|^2$ depends on q and change with nucleus



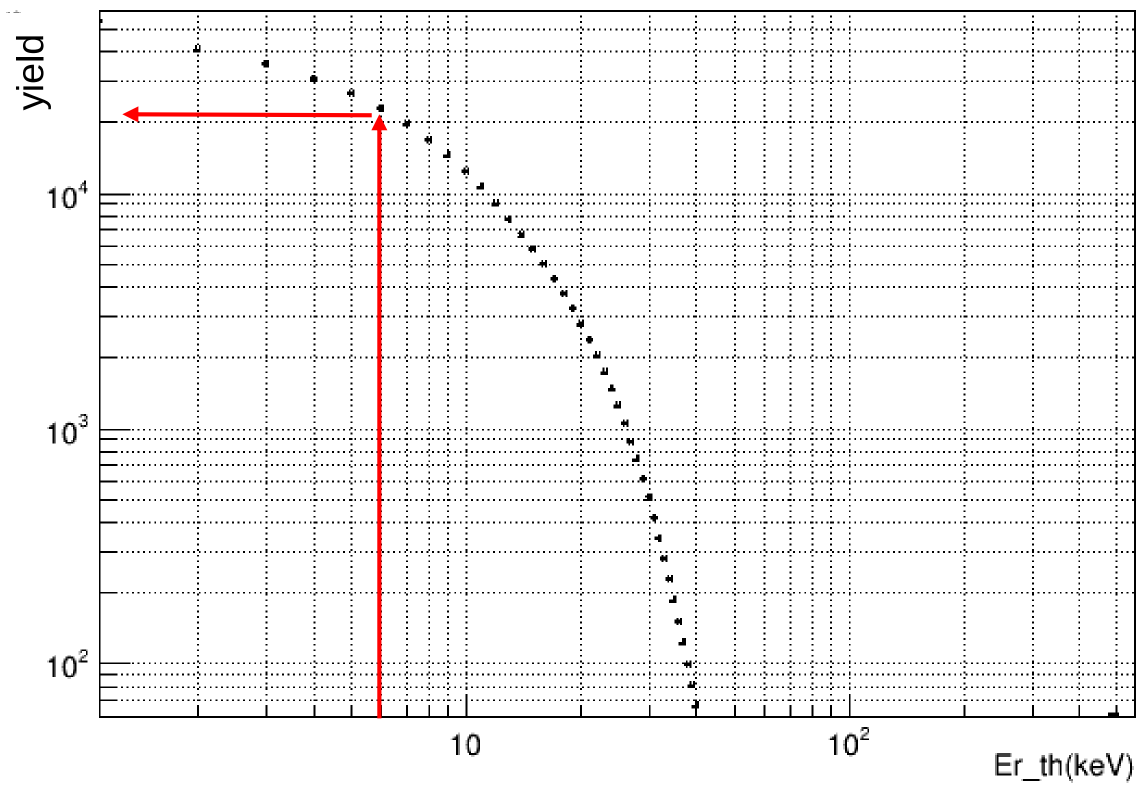
Heavy nuclei form factor drops rapidily but N^2 dependence still dominates

Signal Yield at JLab

- Deploying a 1 m^3 CsI crystal detector (nuBDX experiment)

$$\frac{dR}{dE_r} = V_{\mathrm{det}}\,\rho(P)\,\frac{N_A}{m_{\mathrm{molar}}}\int_{E_\nu^{\mathrm{min}}}^{E_\nu^{\mathrm{max}}}\frac{d\sigma}{dT_A}\,\frac{d\Phi}{dE_\nu}\,dE_\nu$$

- The yield depends on the mininum detectable recoil energy E_r
- With 5 KeV treshold 10^4 CEvNS interactions/y



Background

- Neutron scattering with nuclei is the main Background

- Main neutron source:
  - Cosmic
  - Intrinsic radioactivity
  - Beam related background

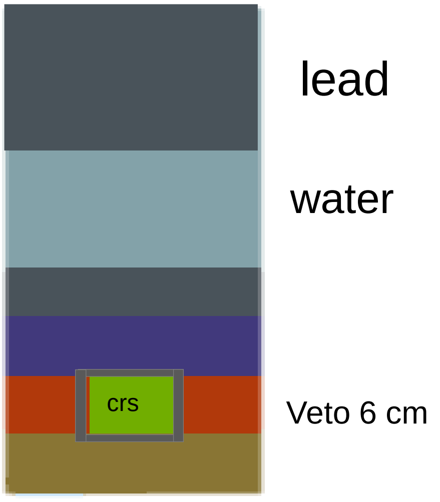
Cosmic neutron Shileding

- Cosmic Neutron have wide energy range
  - ➢ need Multi-layer shield and veto surrounding the detector.

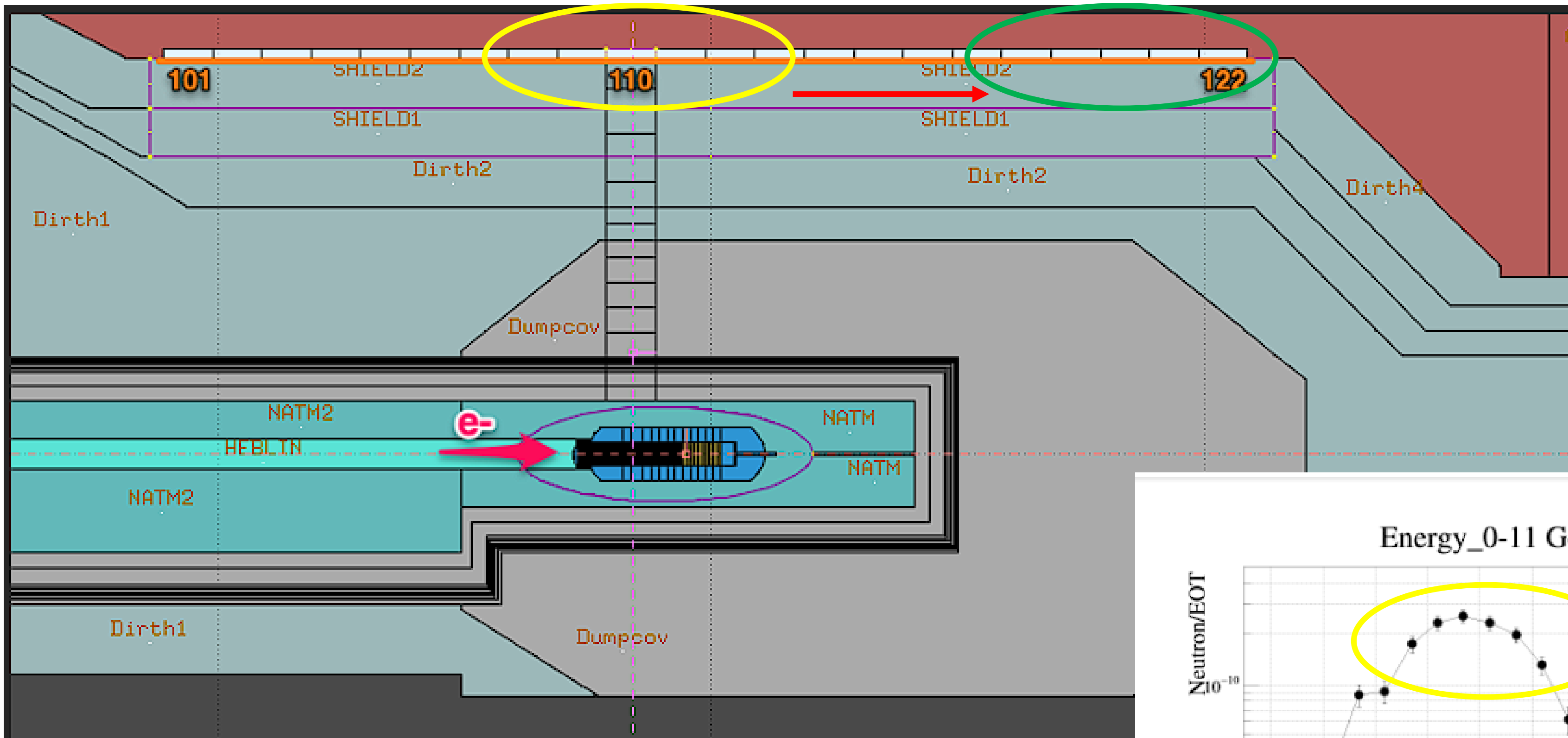
- Possible to measure cosmic neutron contribution with beam off and subtract it.

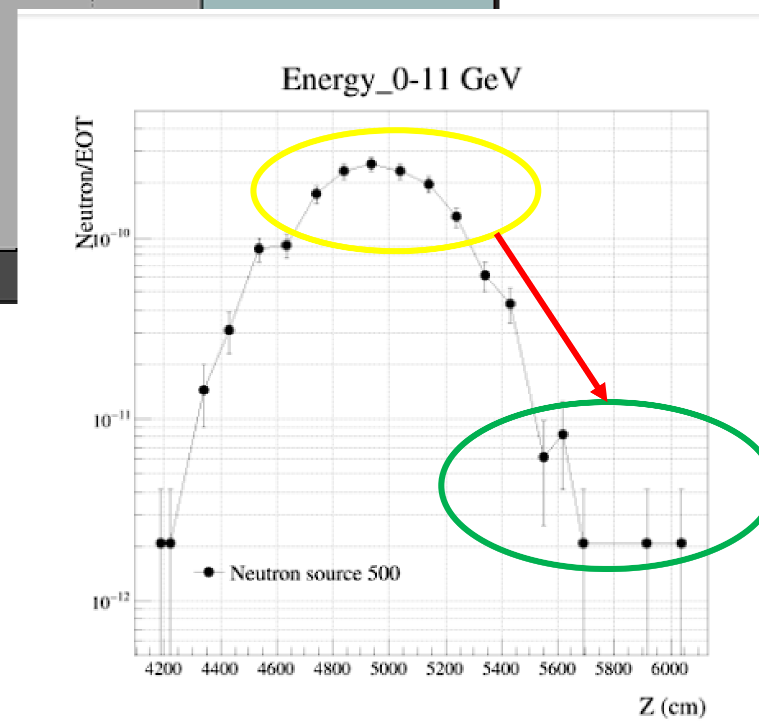
- With the an optimized cosmic shield/veto setup

  -> 1.7 10^5 n/y (cosmic)



(Unshielded) Beam-On Background





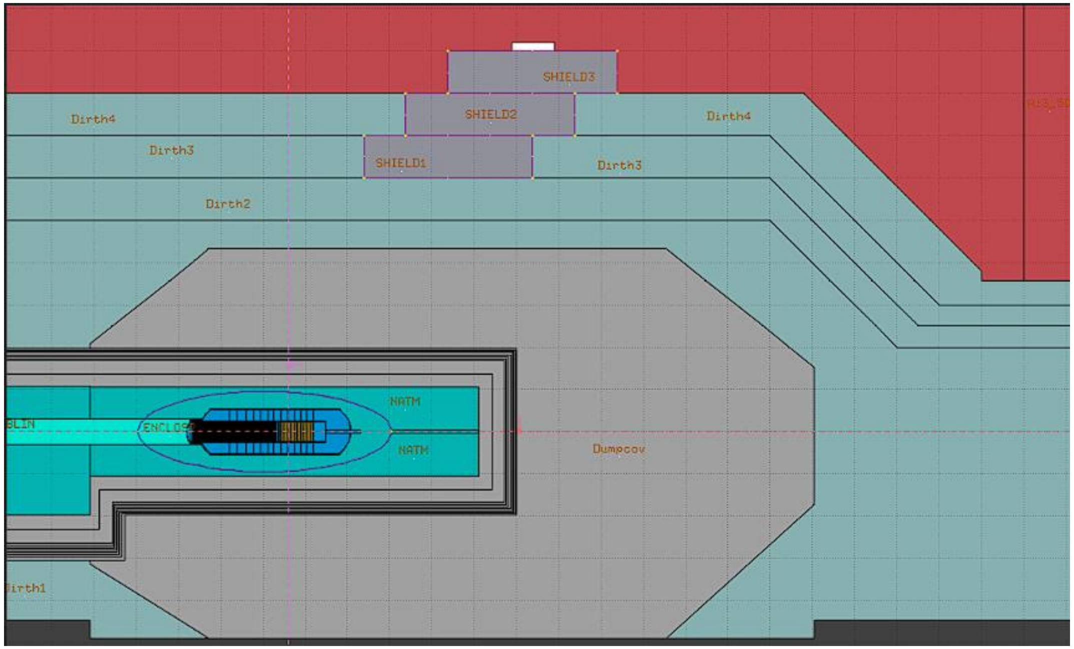
Relocate the detector to reduce the neutron background

-> 2 order of magnitude less n-yield

-> only a factor of 2 reduction for ν

Beam-On neutron Shielding

- Continuous Beam -> no time correlation
- Multi-Layer shield and veto below the main detector and detector position optimization
- Sensitive area of the detector (1m3) will be divided into a matrix of smaller crystals -> by studying the multiplicity of hits in the matrix it is possible to filter the neutron events



Optimized Beam-On shield/veto setup -> $2*10^5$ n/y (beam)

Theta Weinberg Reach

- Simple single-bin chi-square analysis used to determinate the sensitivity to theta weinberg

$$\chi^2 = \left(\frac{N_{\text{Exp}} - (1+\alpha)N_{\text{Theo}}(p)}{\sigma}\right)^2 + \left(\frac{\alpha}{\sigma_\alpha}\right)^2 ,$$

- N_{Exp} = experimental events

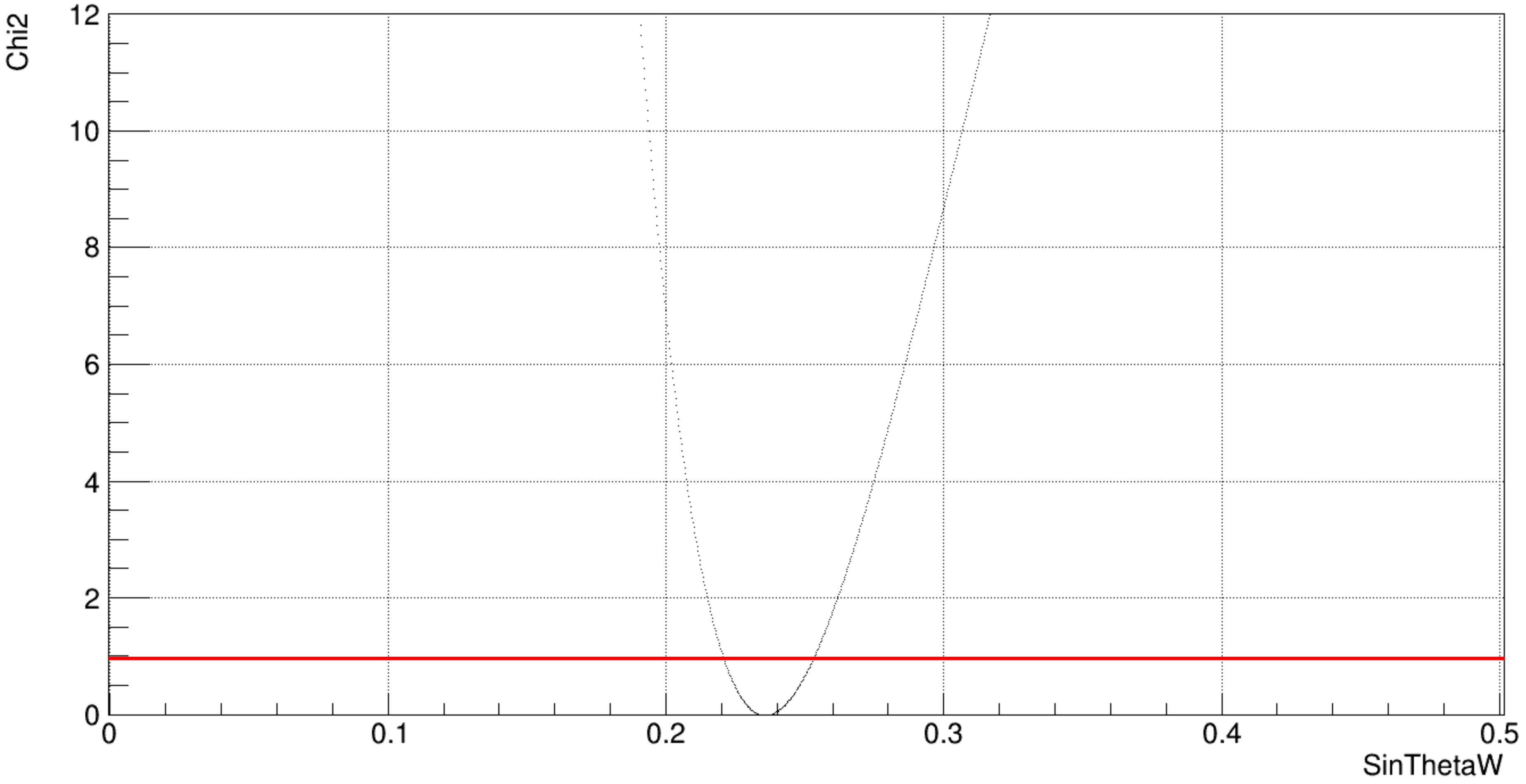
  N_{theo} = prediction of underlying hypothesis

  $\sigma = \sqrt{N_{Exp} + B}$ statistical uncertainty

  B = Nexp * f background define as a certain fraction of signal

  $\frac{\alpha}{\sigma_\alpha}$ = systematic uncertainty, mainly from Quenching factor

Theta Weinberg Reach



Plot Chi2:

- $1m^3$ CsI detector and 1 y data taking
- Background/signal ~ 35
- QF ~ 13%
- Detector efficiency = 100%

$Sin^2\theta_W = 0.2351^{+0.016}{}_{-0.0143}$

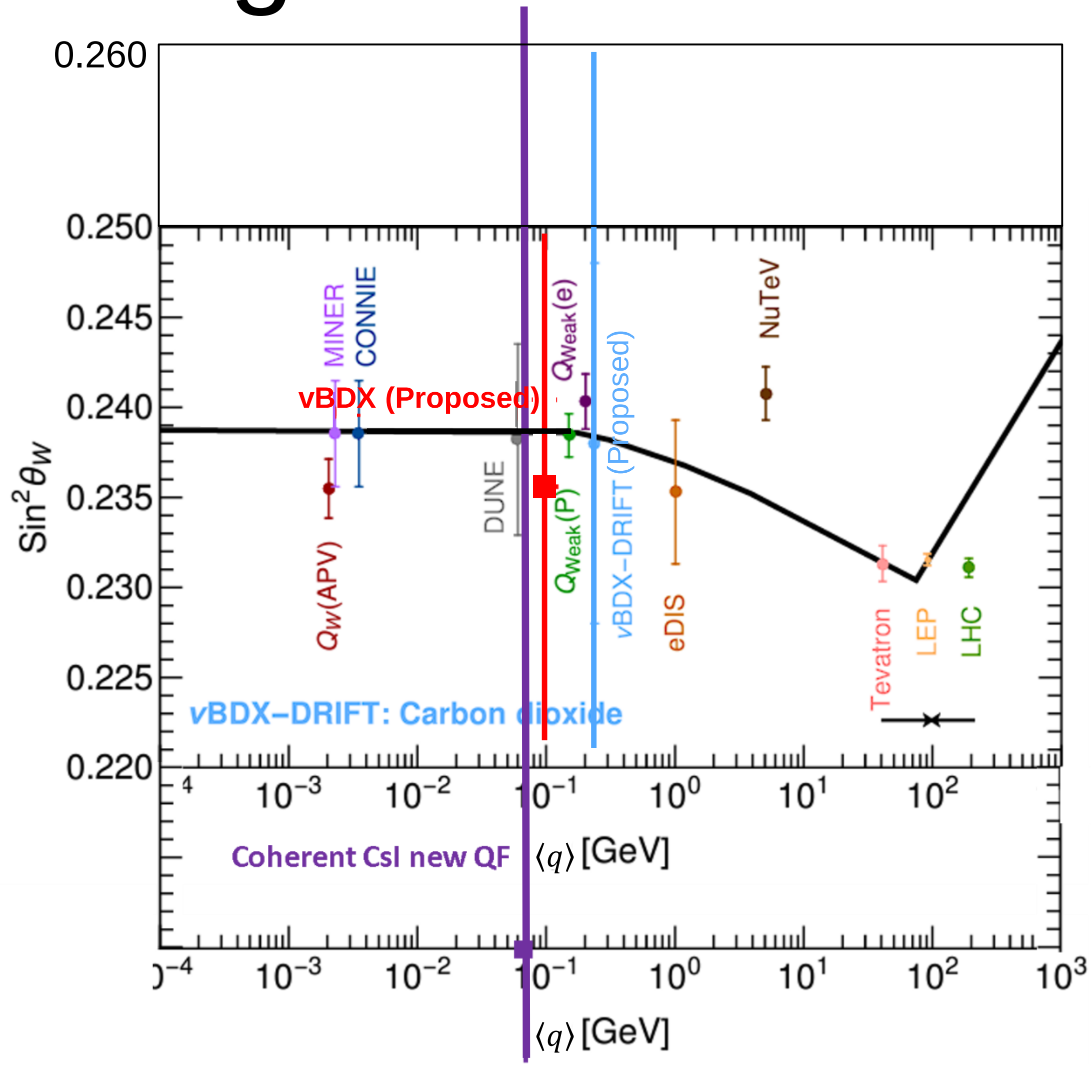
Theta Weinberg Reach

$\sin^2\theta_W = 0.2351^{+0.016}_{-0.0143}$

The uncertain obtain are mainly influenced by QF as already note in Coherent collaboration analysis

Respect to Coherent, νBDX can achieve a precision that is 4 times better

-> $\sin^2\theta_W = 0.209^{+0.072}_{-0.069}$



PHYSICAL REVIEW D102, 113004 (2020)

Comparison with other experiments shows that νBDX can be competitive

Conclusion

- The intense neutrino beam generrated by JLab electron beam and Hall-A beam-dump can be used to study CEvNS

- Weak Mixing angle can be measured with good precision
  - 4 times better that Coherent

- Neutron Background reduction is currently under study and close to optimized veto/shield configuration
- ν-BDX reach is competitive respect to other CEvNS experiments