Neutrino Production at the SNS
How well do we know it?

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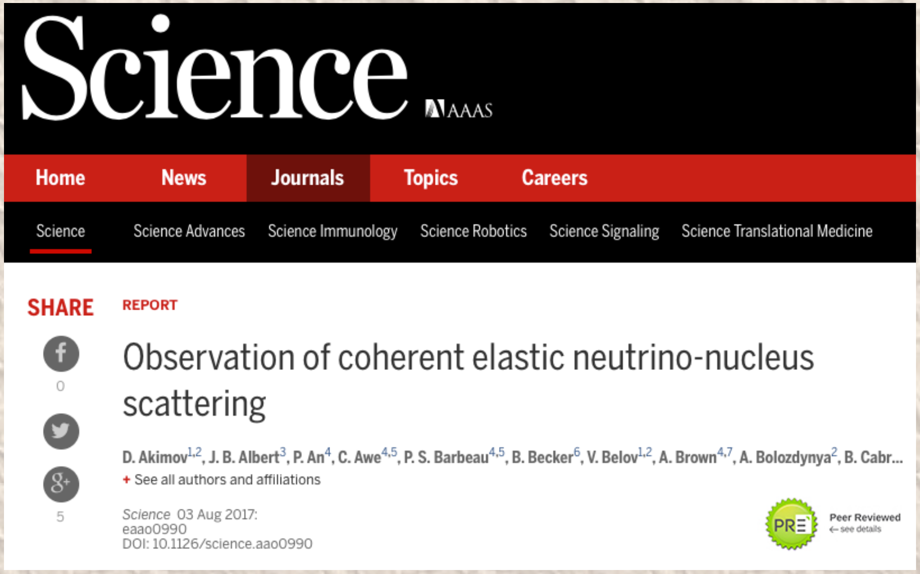
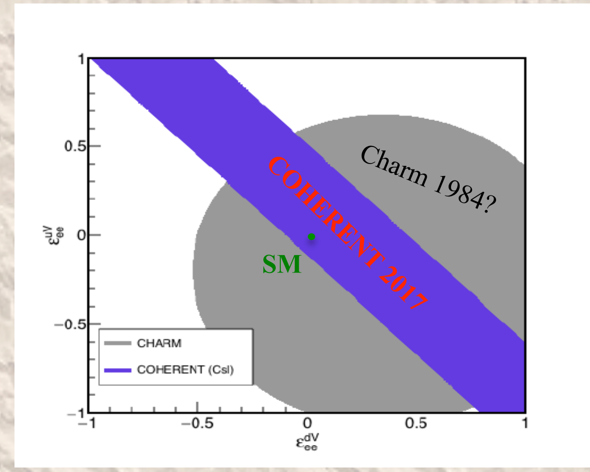
August 20 2017, Knoxville

CEvNS has been detected



So far our accuracy in measuring CEvNS cross section is limited by:

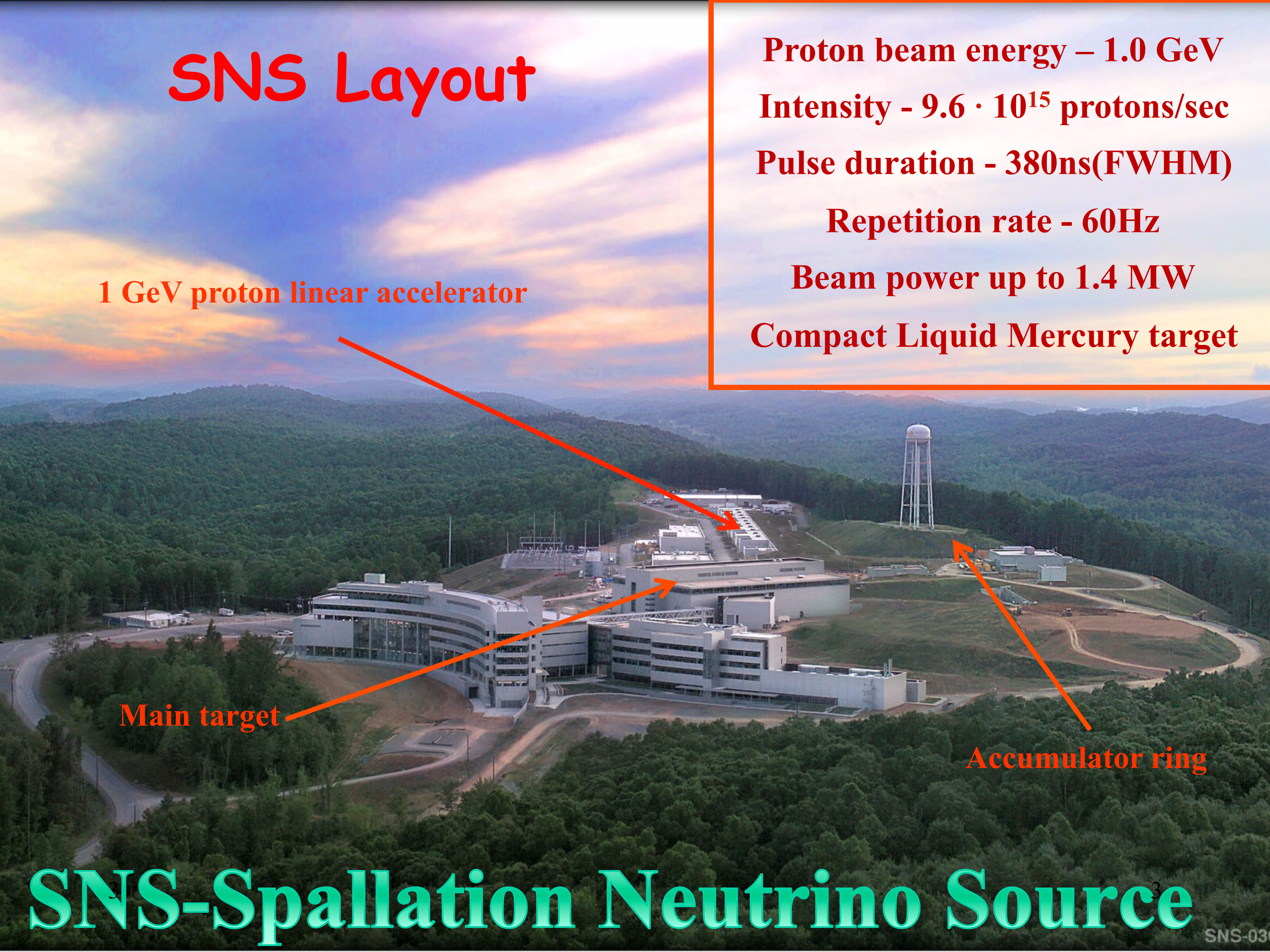
- **Statistics**
- **Calibration of detector (quenching)**
- **SNS neutrino flux**



At our publication, quoted accuracy of measured cross section is 27%

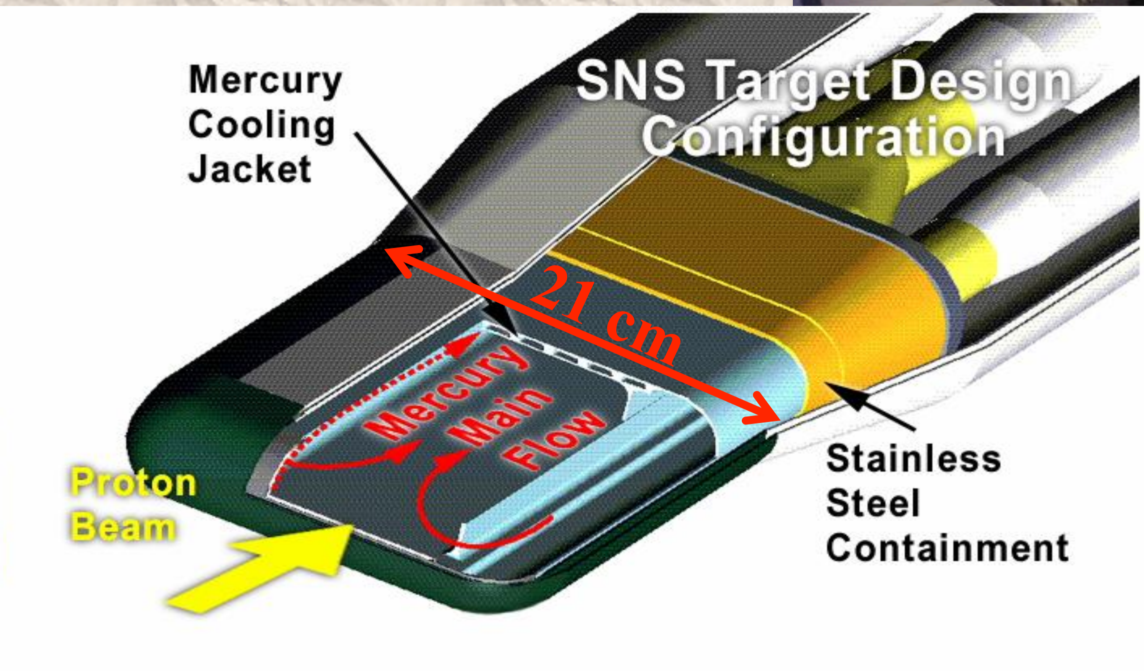
SNS Layout

Proton beam energy – 1.0 GeV
Intensity - 9.6 · 10^{15} protons/sec
Pulse duration - 380ns(FWHM)
Repetition rate - 60Hz
Beam power up to 1.4 MW
Compact Liquid Mercury target



SNS-Spallation Neutrino Source

Mercury target

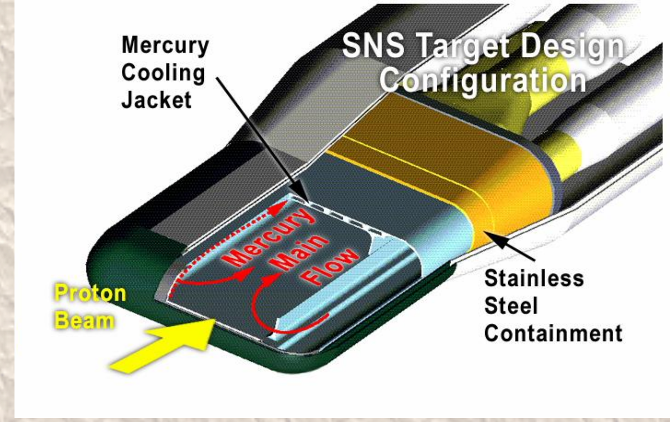


Mercury Inventory – 20 t
Flow rate 340 kg/sec
V_{max} 3.5 m/sec
T_{in} 60^0C
T_{out} 90^0C

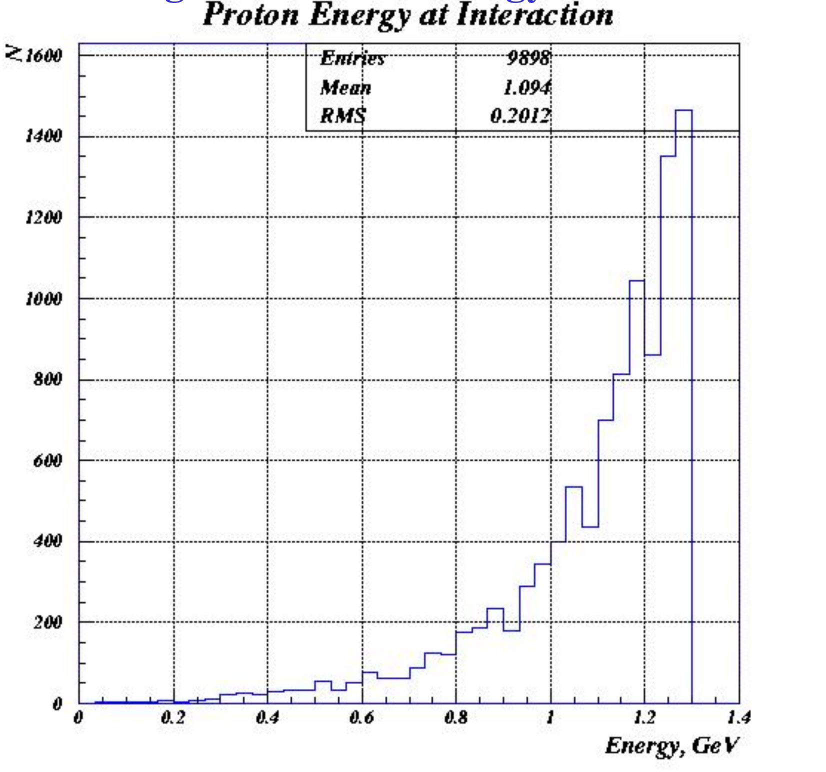
Mercury lasts the entire 40 year lifetime of SNS no change is required

Stainless steel vessel should be replaced periodically

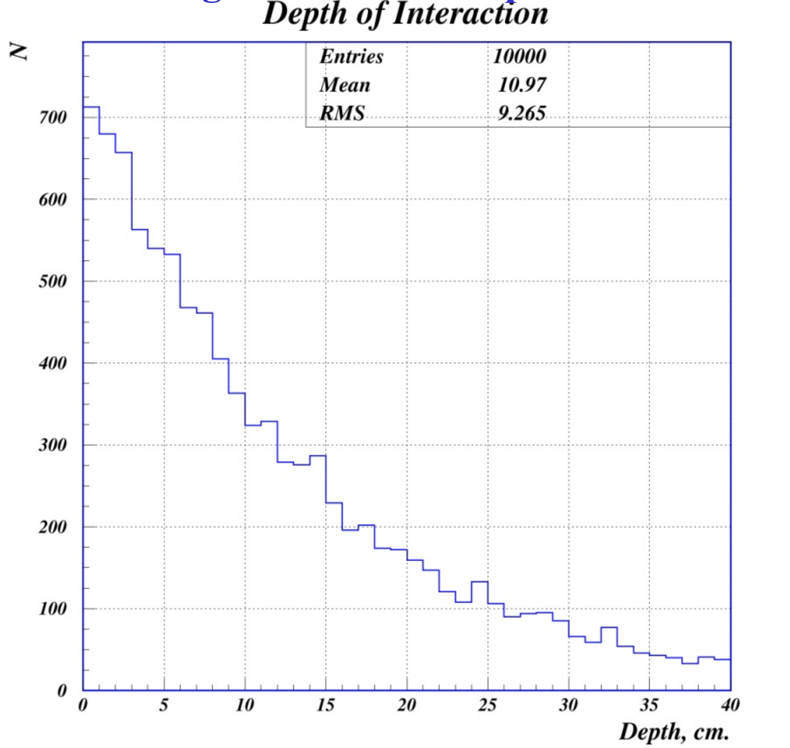
Some Details of Interaction in the Target for 1.3 GeV protons



Average interaction energy is ~1.1 GeV



Average interaction depth ~11 cm

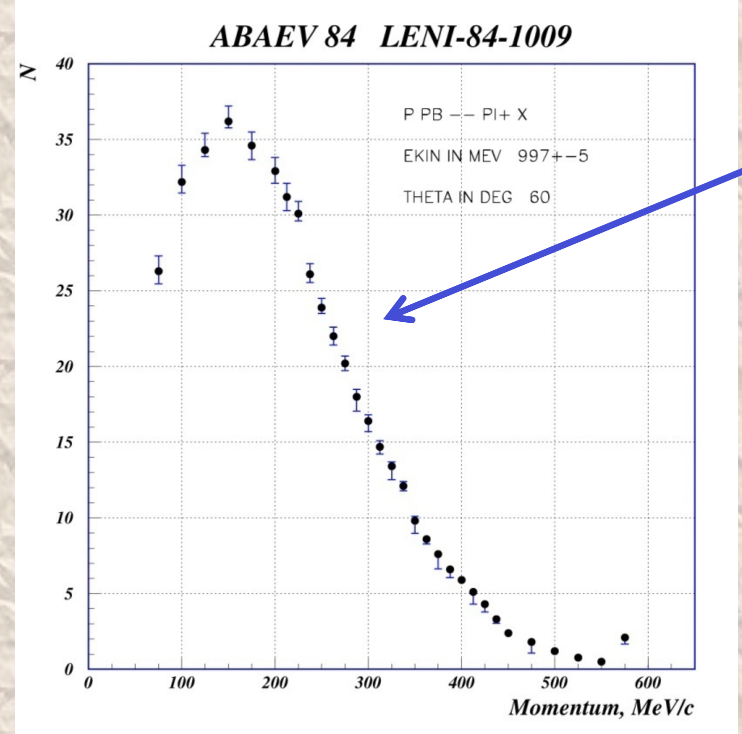


Proton interacts near the front part of the target

Neutrino sourse is very compact!!!!

DIF vs. DAR

Pion Spectra



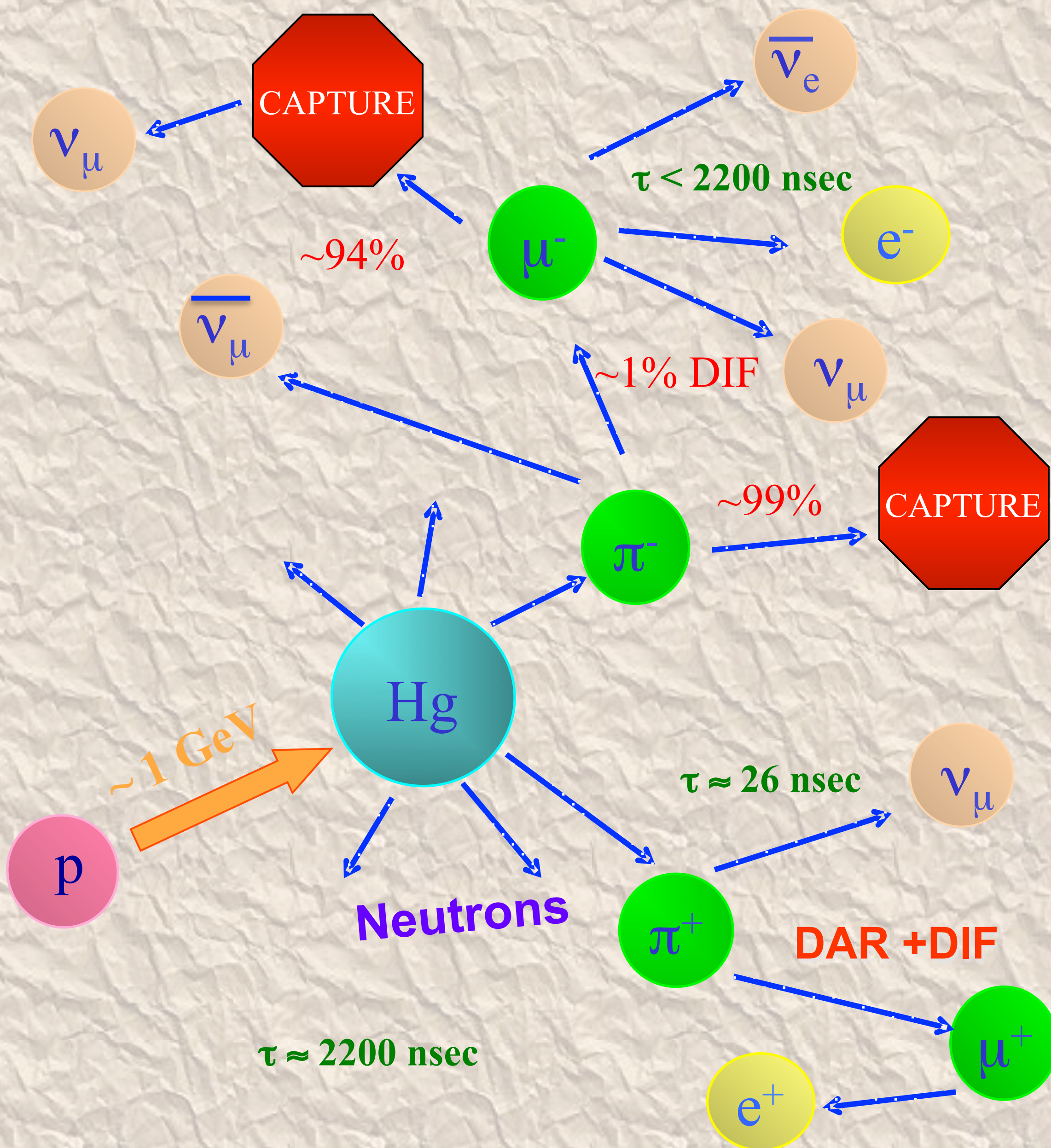
200 MeV/c pions range in mercury is ~ 5 cm

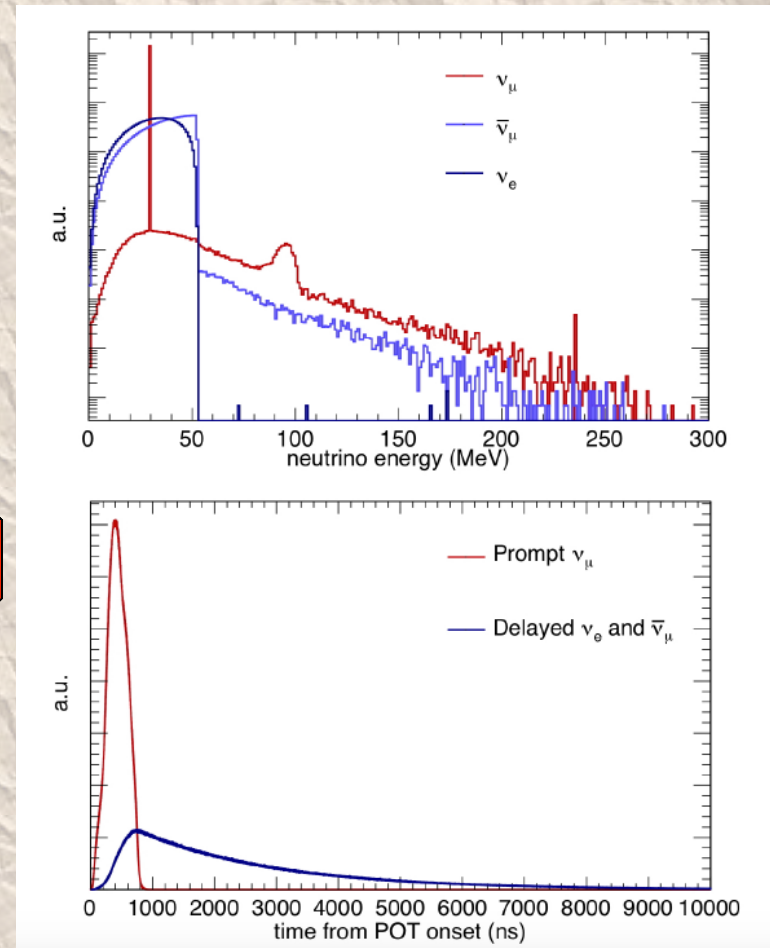
Very few pions have a chance to decay before coming to the rest

Because of the bulk Mercury target, SNS is mostly Decay At Rest (DAR) facility !!

DIF is on the level of a 1 present and it has an angular dependent

Neutrino Production at the SNS





CAVEAT

There is a larger, "constant" flux of low energy electron neutrinos from beta decays of radioactive isotopes produced in the SNS target

Nobody manage to calculate this flux so far.

Neutrino Production

Each π^+ generates:

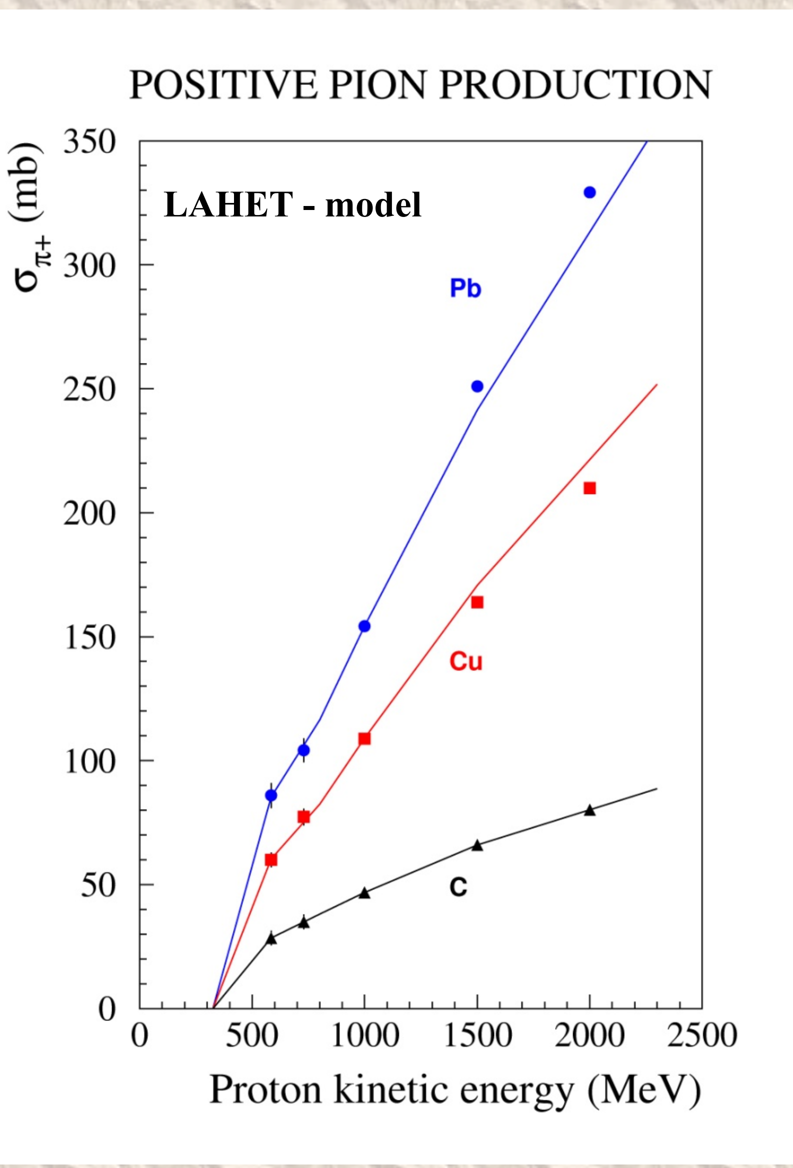
electron neutrino
muon neutrino
and muon antineutrino
With DAR spectra

For GEANT4 we tried two physics lists.
QGSP-BERT and QCSP-BIC

They gives predictions which different by a factor of two. Do not use QCSP-BIC

QGSP-BERT is based on the Bertini Phys.Rev 188(1969).

Same model was used in LAHET code for early calculations of neutrino fluxes at LANL(LSND) and ISIS(KARMEN).



Neutrino Flux Uncertainty

We adopted Bertini model. Average over SNS beam energy pion production is 0.084 pions per proton.

GENAT-3 is using Bertini as well, and gave very similar to GEANT-4 numbers.

Early calculation of Flux for SNS R.L. Burman(1997) used LAHET code with corrections based on D.R.F. Cochran(1972) and J.F. Crawford(1980)

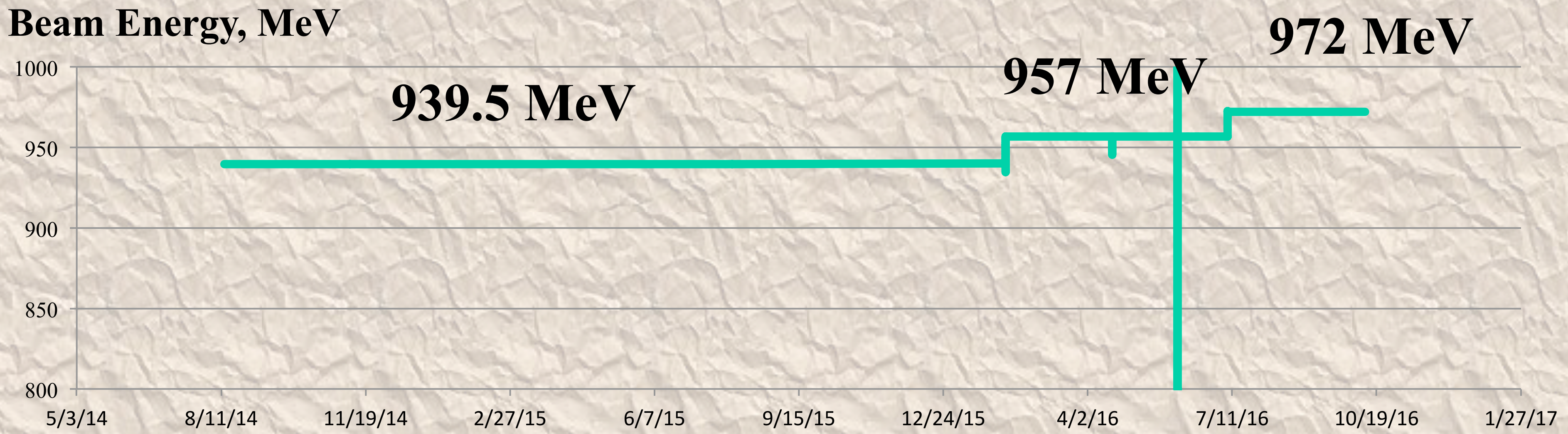
Predictions was ~ 0.075 pions/proton

Recent global parameterization of cross sections data by J.W.Norbury(2007) is in disagreement with implemented by Burman(1997) corrections to LAHET.

Therefore we adopted average rate of 0.08 pions/proton and conservatively assigned 10% systematic uncertainty on pion production

Ultimately we like to do better than that

SNS Beam Energy is Changing but Recorded



Beam Energy MeV	Number of pions per proton, GEANT4
939.5	0.082
957	0.084
972	0.086
990 (from July 2017)	0.088

SNS flux calibration

First way is to accurately measure pion production in Mercury for a few energy sets for protons below 1.2 GeV.
Need to measure pion spectra and angular distributions as well.

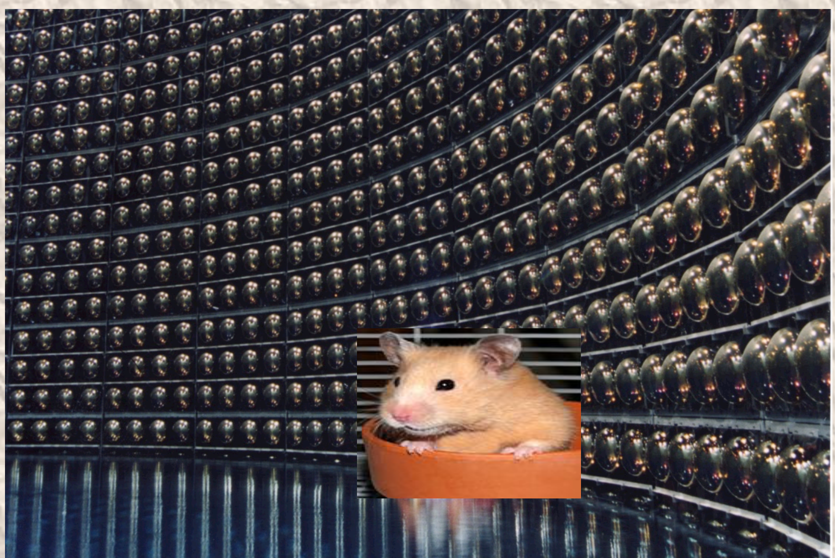
HARP experiment at CERN did measure pion production at low energy, but not low enough.

Second way is to measure neutrino flux at the SNS using reaction with well known neutrino interaction cross sections.

Remember that without big capital investment, we are limited in the size of a detector

Neutrino Electron scattering
Cross section are known well

Water Cherenkov Detector
Nano SNSokande



Integrated over DAR cross section:

$\nu_e + e^-$ → $3.0 * 10^{-43}$ cm^2
$\nu_\mu + e^-$ → $4.8 * 10^{-44}$ cm^2
$\nu_{\mu\text{-bar}} + e^-$ → $4.5 * 10^{-44}$ cm^2

For 1 t fiducial mass

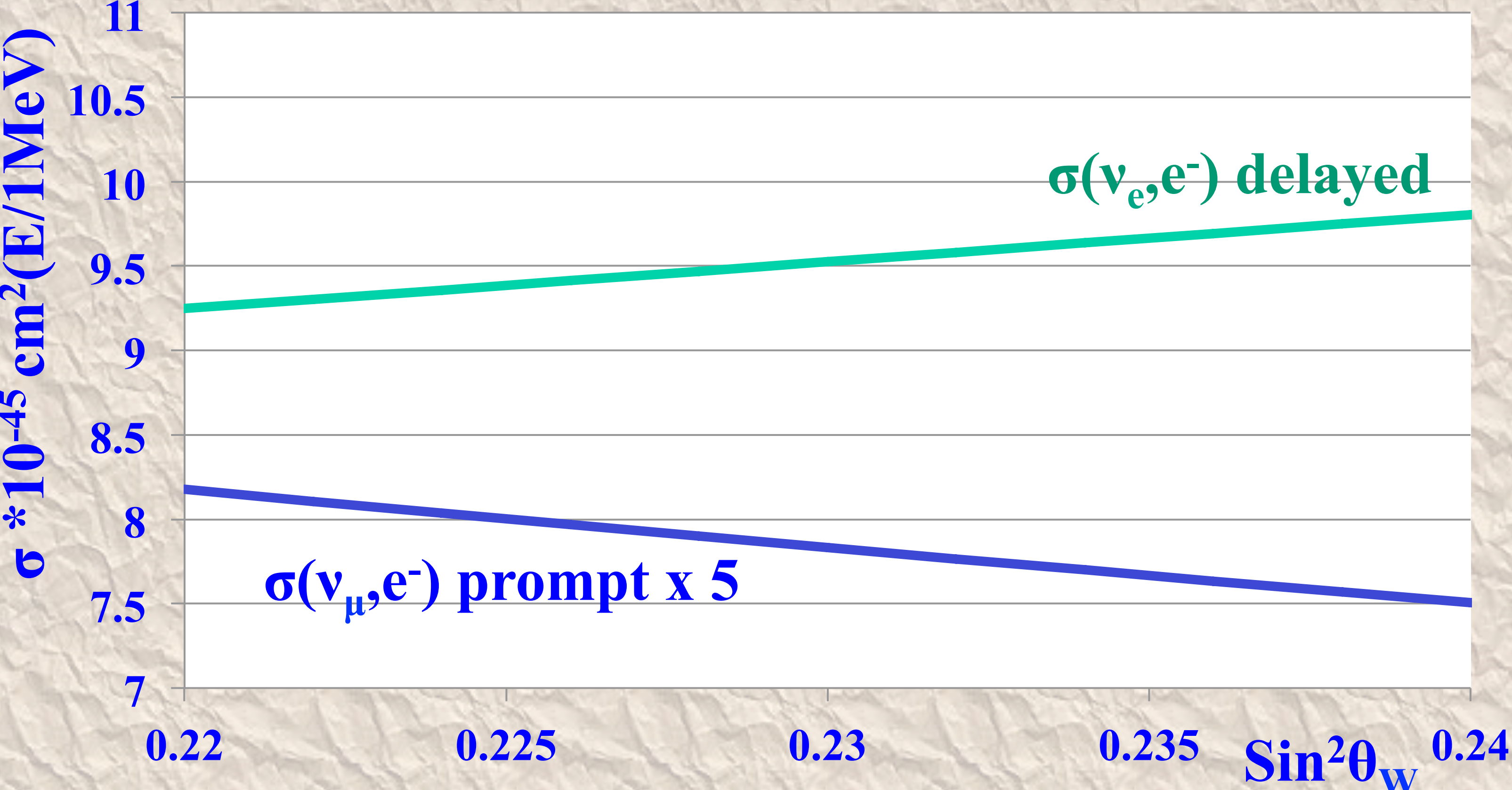
$\nu_e + e^-$ 20 interactions per year
$\nu_\mu + e^-$ 3 interactions per year
$\nu_{\mu\text{-bar}} + e^-$ 3 interactions per year

Need much larger detector to measure neutrino flux with a good accuracy

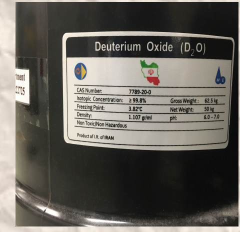
Neutrino Electron scattering II

Sensitivity to the electroweak angle

Electron and muon neutrinos have different trends

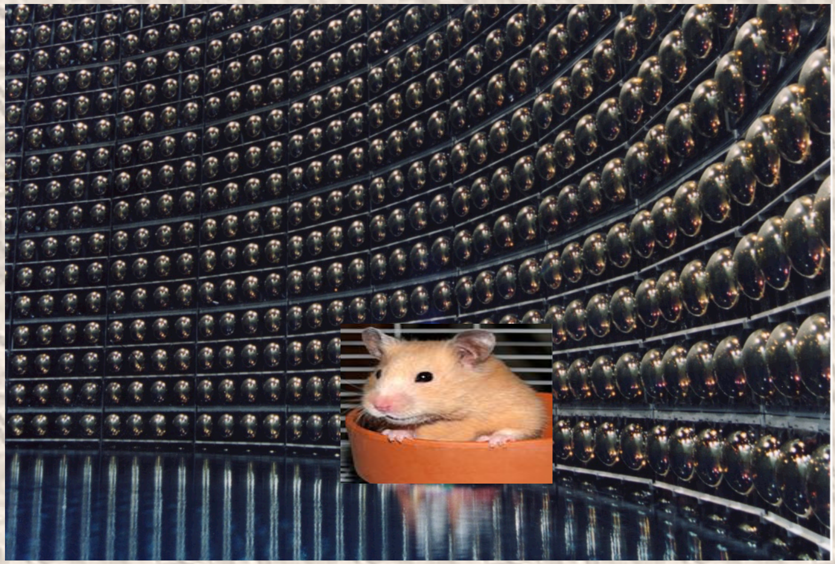


Neutrino Deuteron Interaction



Cross section is known with accuracy of 2-3%

Water Cherenkov Detector
Nano SNSokande heavy



Cross sections

S.Nakamura et. al. Nucl.Phys. A721(2003) 549

Prompt NC ν_{μ} +d → $1.8*10^{-41}$ cm^2

Delayed NC $\nu_{e\mu\text{-}bar}$+ d → $6.0*10^{-41}$ cm^2

Delayed CC ν_e + d → $5.5*10^{-41}$ cm^2

For 1 t fiducial mass detector

Prompt NC ν_{μ}+d → 220 interactions year^{-1}

Delayed NC $\nu_{e\mu\text{-}bar}$+d → 717 interactions year^{-1}

Delayed CC ν_e+d → 665 interactions year^{-1}

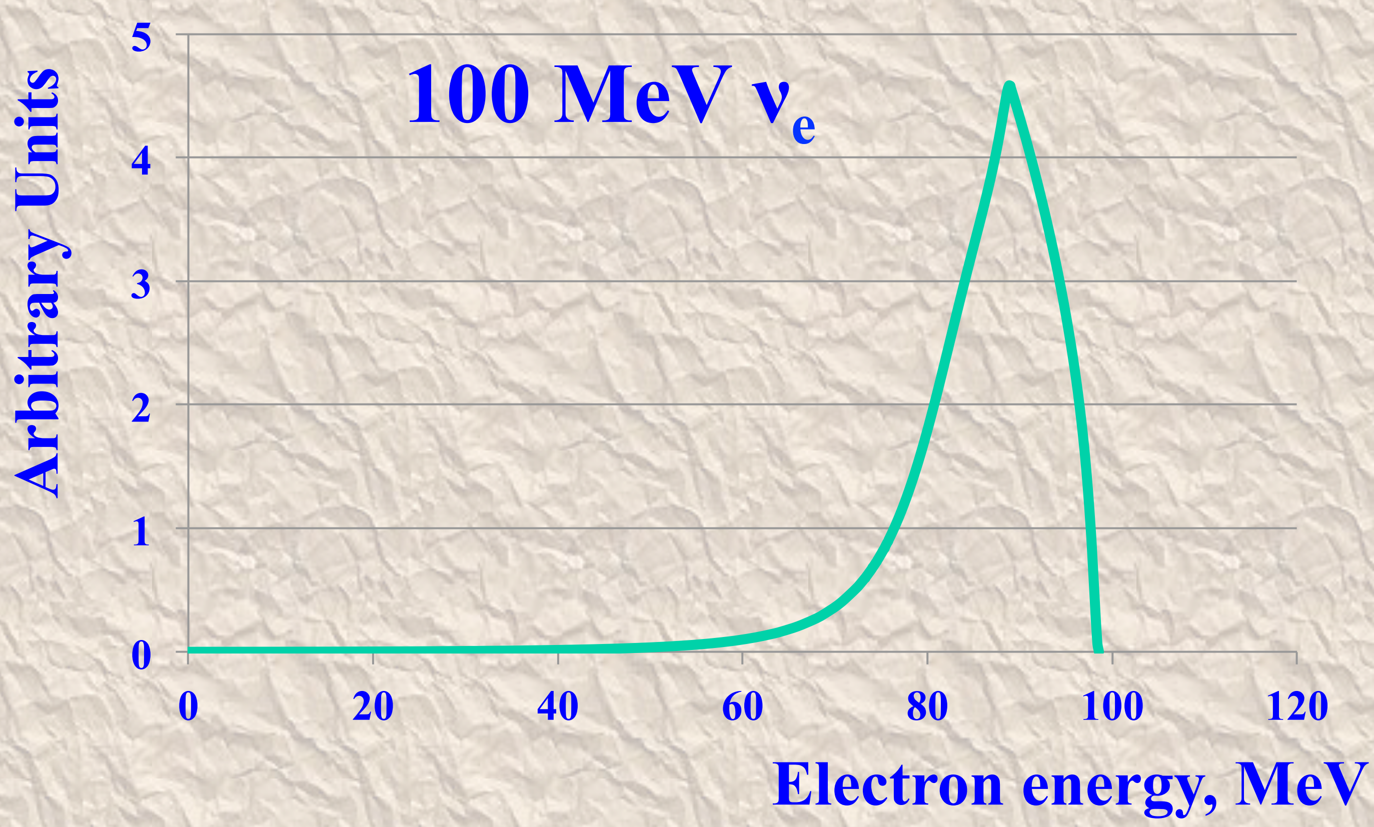
Looks Interesting !!!

This detector can benefit from resent progress in LAPPD development

ArXiv:1707.08222v2

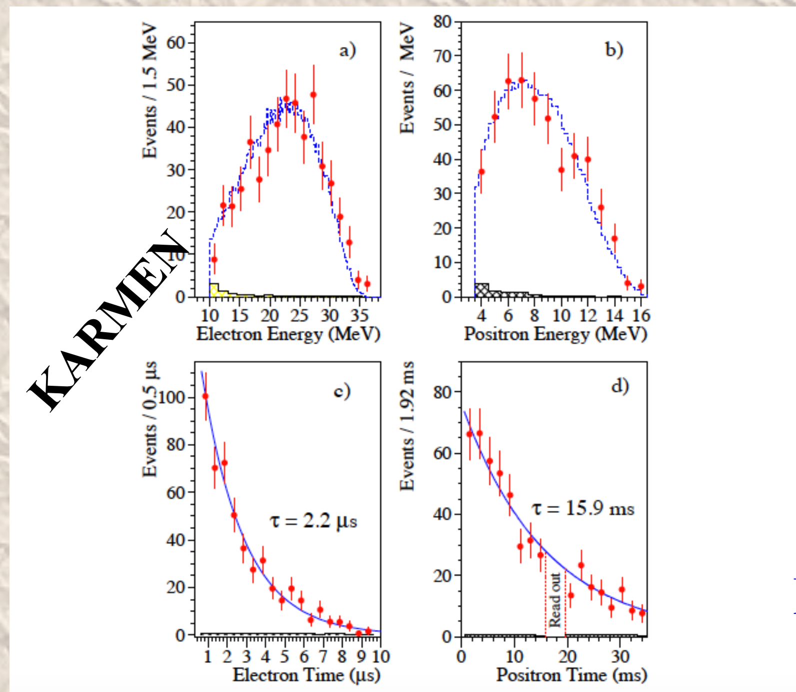
CC reaction on Deuterium can give a handle on DIF neutrino flux

$\nu_e + d \rightarrow e^- + p + p$



Charge Current on Carbon

$^{12}C(\nu_e,e^-)^{12}N_{gs}$ $\quad$ $^{12}N_{gs} \rightarrow {}^{12}C+e^+ + \nu_e(bar)$



Cross sections For DAR

Experimental

E225 $(9.3\pm0.4\pm0.8)\ 10^{-42}\ cm^2$

LSND $(9.1\pm0.4\pm0.9)\ 10^{-42}\ cm^2$

KARMEN $(9.3\pm0.4\pm0.8)\ 10^{-42}\ cm^2$

Theoretical

M.Fukugita et al. Phys Lett B212(1988) 139
$9.2*10^{-42}\ cm^2$

E.Kolbe et al., Phys RevC 49(1994) 1122
$9.3*10^{-42}\ cm^2$

T.W.Donnelly, private communications
$9.4*10^{-42}\ cm^2$

For 1 t fiducial mass detector (CH)

CC $\rightarrow$ 70 interactions year^{-1}

Conclusion

To do precision test of S.M. via CEvNS we need to calibrate SNS neutrino flux

Several options have been discussed

Any other suggestions are very welcome!!!!