An experimental proposal “The first observation of Neutrino Nucleus Coherent Scattering”

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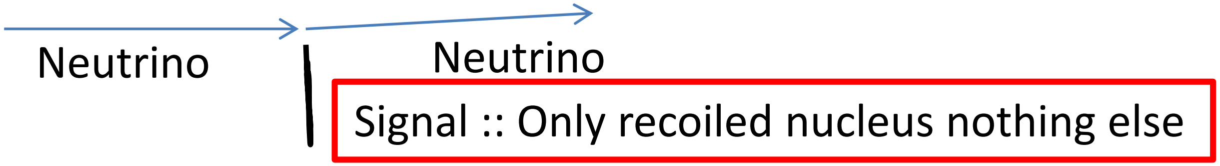
Motivation

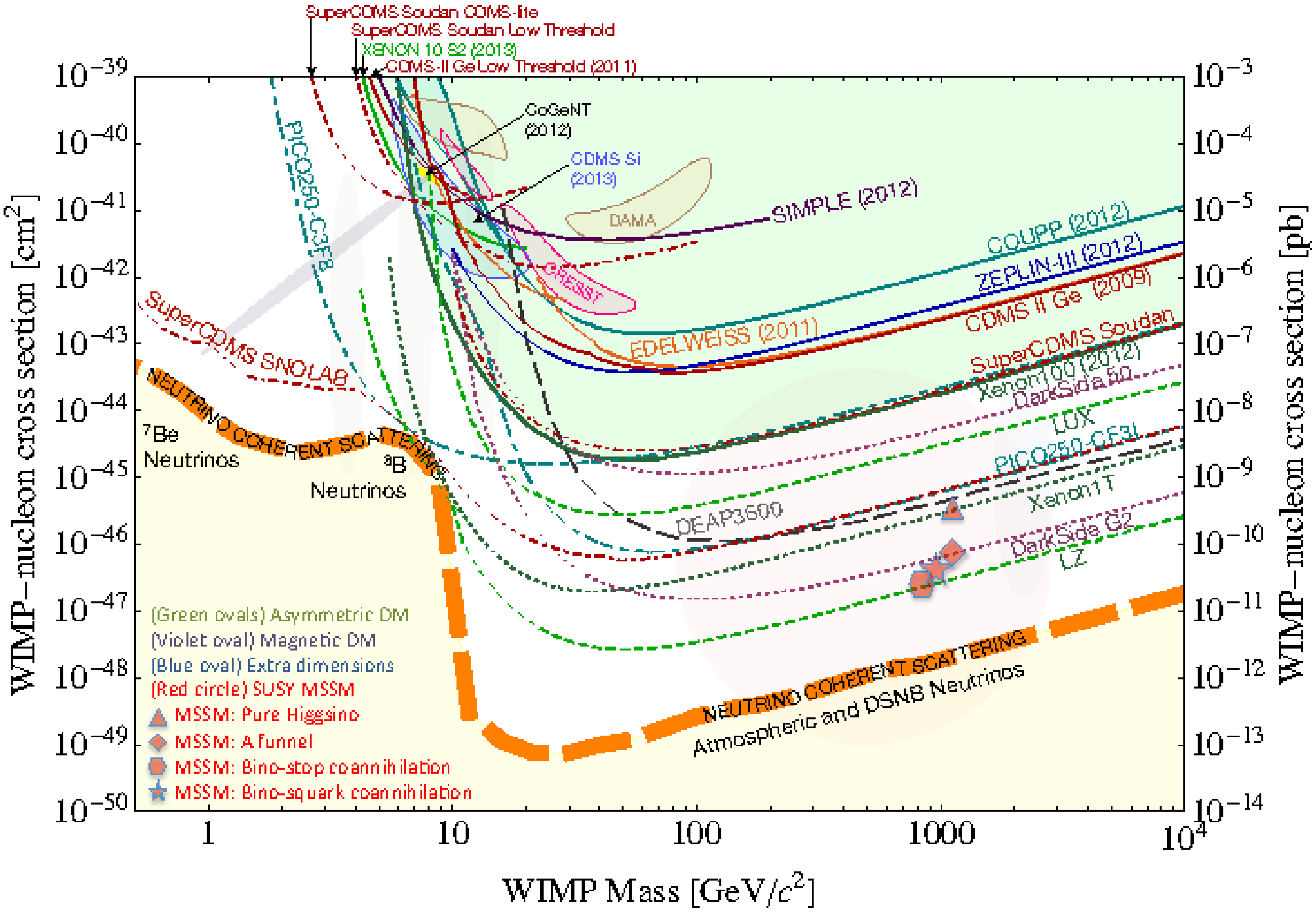
- Neutrino Nucleus Coherent Scattering (NNCS) is **not observed yet**!



Signal :: Only recoiled nucleus nothing else

- NNCS is known as a **background source for Dark Matter** search for near future.
- Sensitivity of many experiments detecting only Dark Matter energy deposit will be spoiled due to NNCS.
- It is need to be understood the detailed feature of NNCS int.

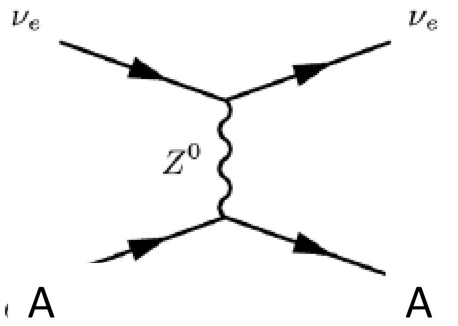
- Coherent Scattering is the key for relic 1.9K neutrino detection.
- Hints to understanding for the **Mirrors for relic neutrino**.
- Some day, we would like to **establishing neutrino optics using them.**
- Starting study on NNCS from higher energy then moving to lower energy toward 1.9K neutrino detection.

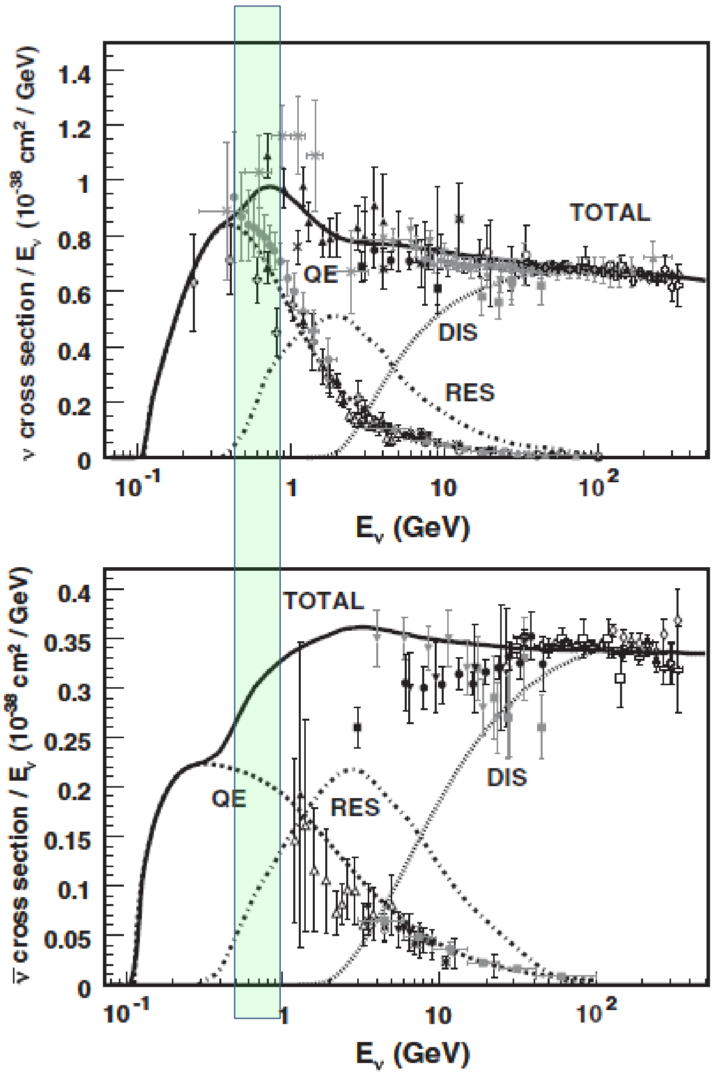


Snowmass 2013 : Cosmic Frontier Working Group Summary , arXiv:1401.6085

Neutrino coherent scattering

$$\nu + A_N^Z \to \nu + A_N^{*Z}.$$





Coherent scattering cross-section

$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M_A \left(1 - \frac{M_A T}{2E_\nu^2}\right) F(Q^2)^2,$$

$$Q_W = N - Z(1 - 4\sin^2\theta_W).$$

Differential cross section for angle

$$\frac{d\sigma}{d(\cos\theta)} = \frac{G_F^2}{8\pi} Q_W^2 \; E_\nu^2 \; (1 + \cos\theta) \; F(Q^2)^2 \; ,$$

P. Grothaus et al. arXiv: 1406.5047v1

What dose Coherent mean ?

- Defining the amplitude of scattering with a nucleon(i) as

  $W(\nu + N_i \rightarrow \nu + N_i) = W(N_i)$
- Interaction cross section can be calculated by

  $\sigma = \{W(N_1) + W(N_2) +.. W(N_n)\}^2$

- If phases of $W(N_i)$ were random, $\sigma = \mathbf{n}\, W(N_1)^2$
- If phases of $W(N_i)$ were the same, $\sigma = \mathbf{n}^2\, W(N_1)^2$

The same amplitude waves = Coherent !

Large σ, **n**(# of nucleons) times !

Typically **n** is written with limited a nucleus, maximum as Atomic number.
It is just due to treating larger momentum transfer than the scale (1/Atom).
But if momentum transfer was small enough than (1/Atom),
degree of freedom outside of an Atom like crystal will contribute.
n increase by $(1/\text{momentum transfer})^3$!

You can imagine what happen if n was large as Avogadro's number or more.

➔ Neutrino can be scattered easily. Mirror for neutrinos.

Nuclear Form Factor

$$F(q) = \int \rho(r) e^{iq\cdot r}\, d^3r = \frac{4\pi}{q} \int_0^\infty r \sin(qr)\, \rho(r) dr$$

Following Helm's Form factor well describe
Fermi distribution of nucleus density at edge

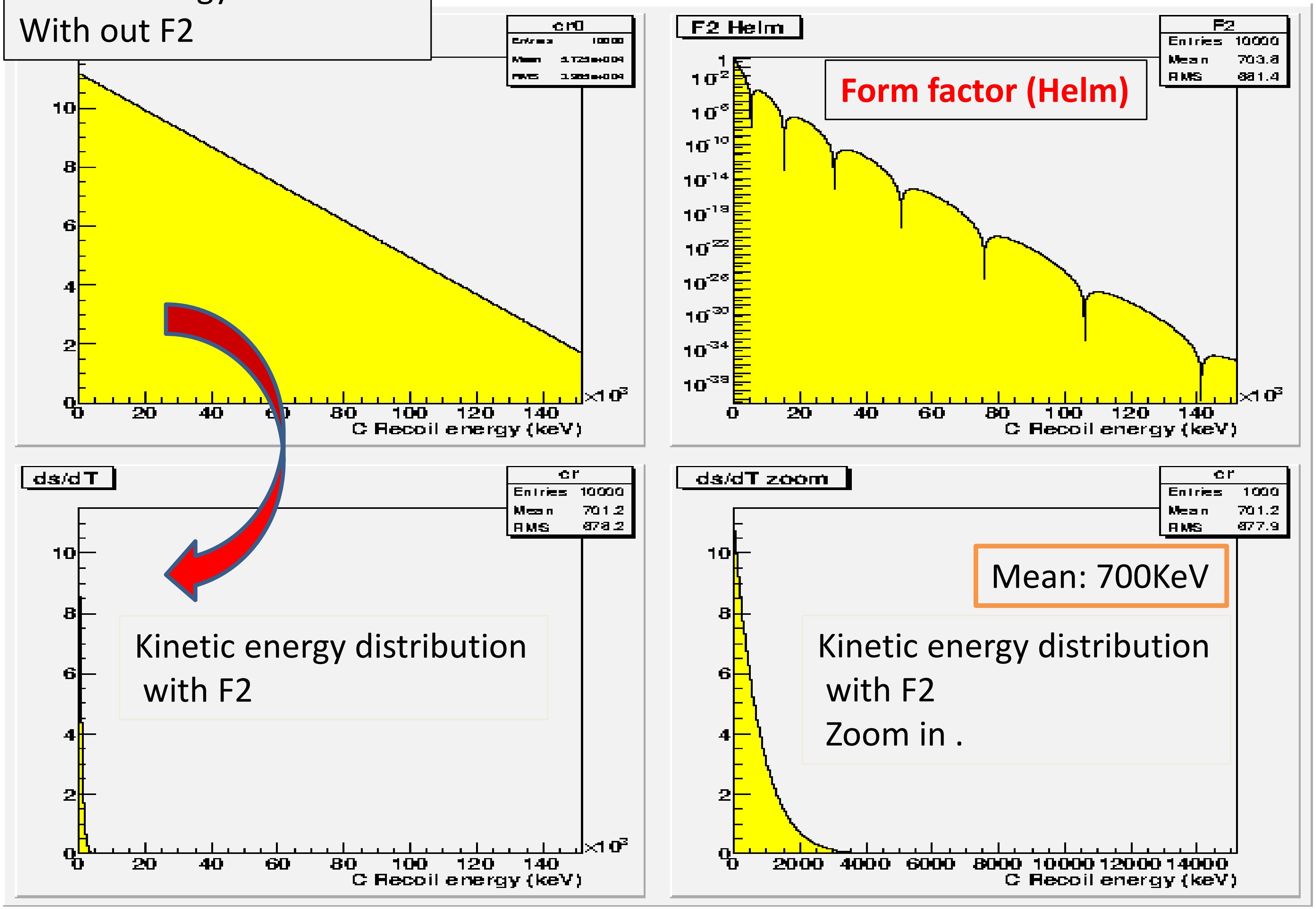
$$F(q) = 3\,\frac{j_1(qrn)}{qr_n}\; e^{-(qs)^2/2}$$

$$r_n = 1.14A^{1/3} fm,\ \ s = 0.9\ fm$$

Very roughly
Form factor become 1 if momentum transfer q is well smaller than the inverse size of the target object (nucleus) .
It become zero if momentum transfer q is well larger than the inverse size of the object.

Spatial size of about less than 1/q can be treated as a point like object even composite .

Carbon recoil (Eν=1GeV)



Kinetic energy distribution
With out F2

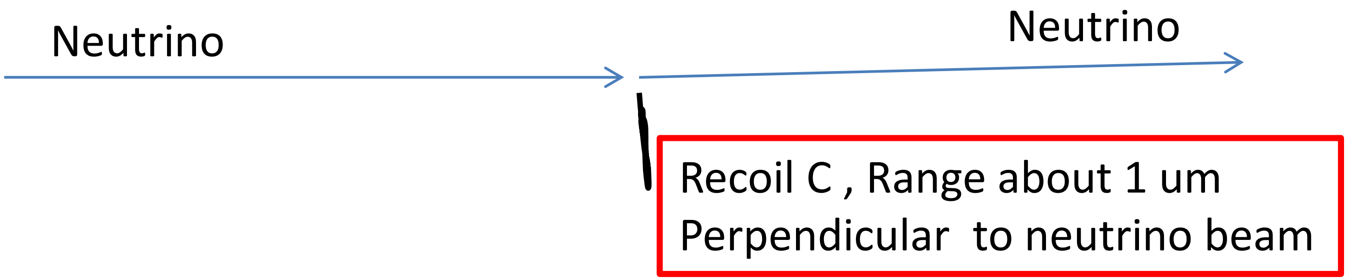
Form factor (Helm)

Kinetic energy distribution
with F2

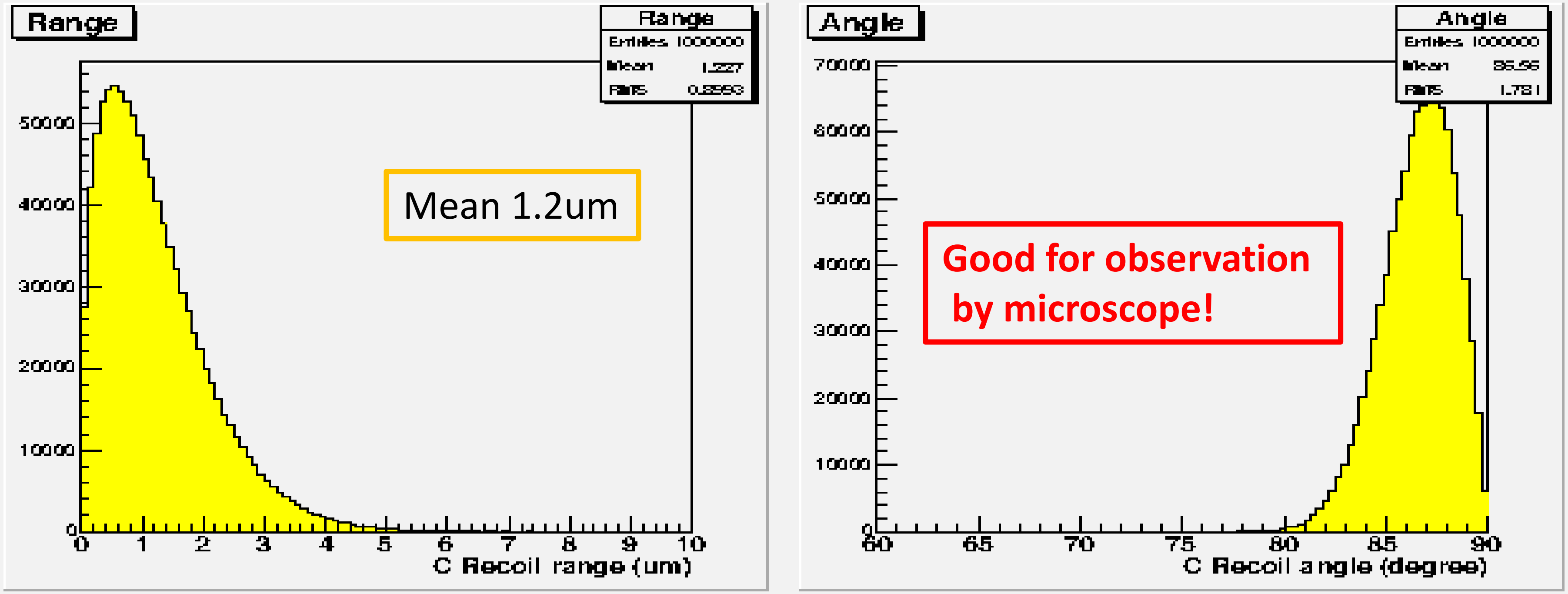
Mean: 700KeV

Kinetic energy distribution
with F2
Zoom in .

Carbon recoil (Eν=1GeV)



Recoil C , Range about 1 um
Perpendicular to neutrino beam



Mean 1.2um

Good for observation by microscope!

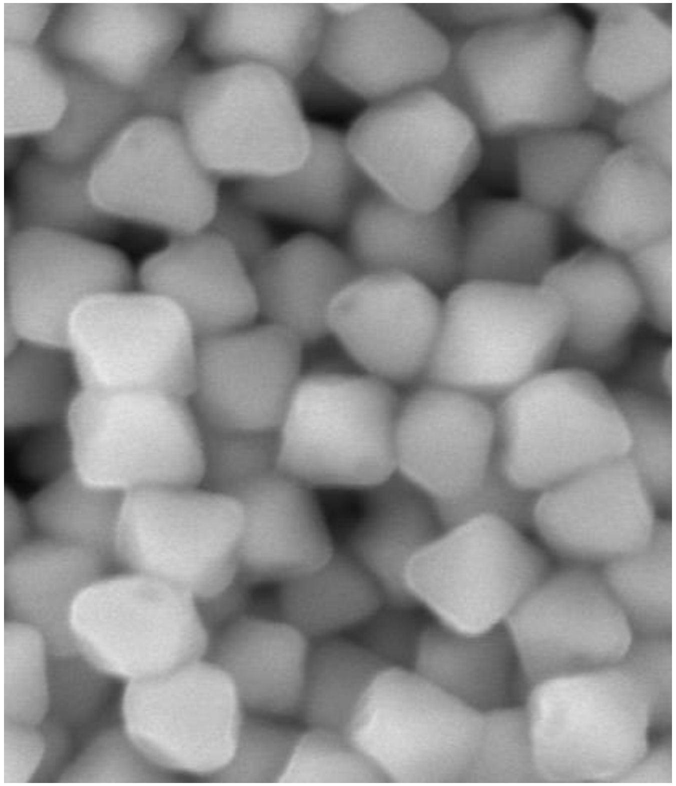
OPERA Emulsion vs. NIT

- Crystal size

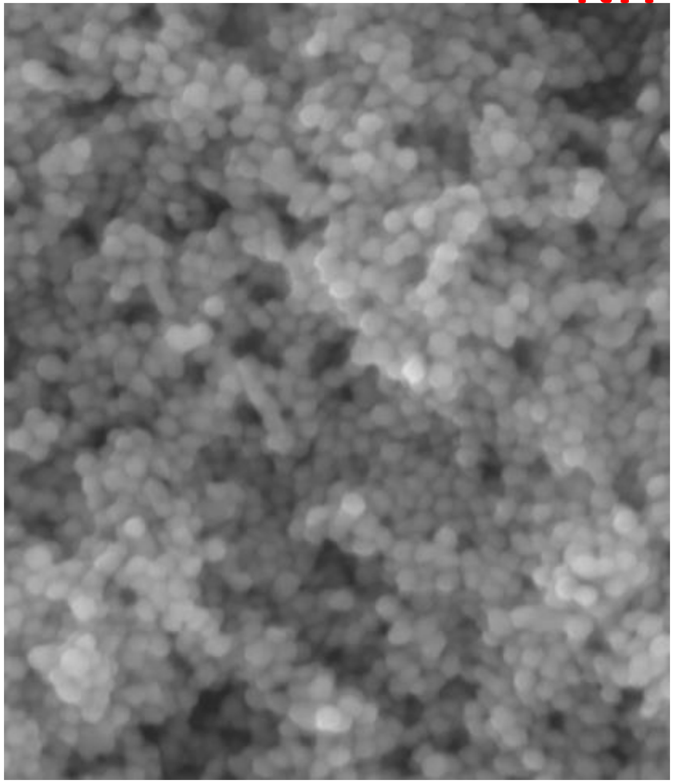
OPERA 200nm → 2.3 crystal / um

NIT 40nm → 13-14 Crystal/um → Tracking

OPERA

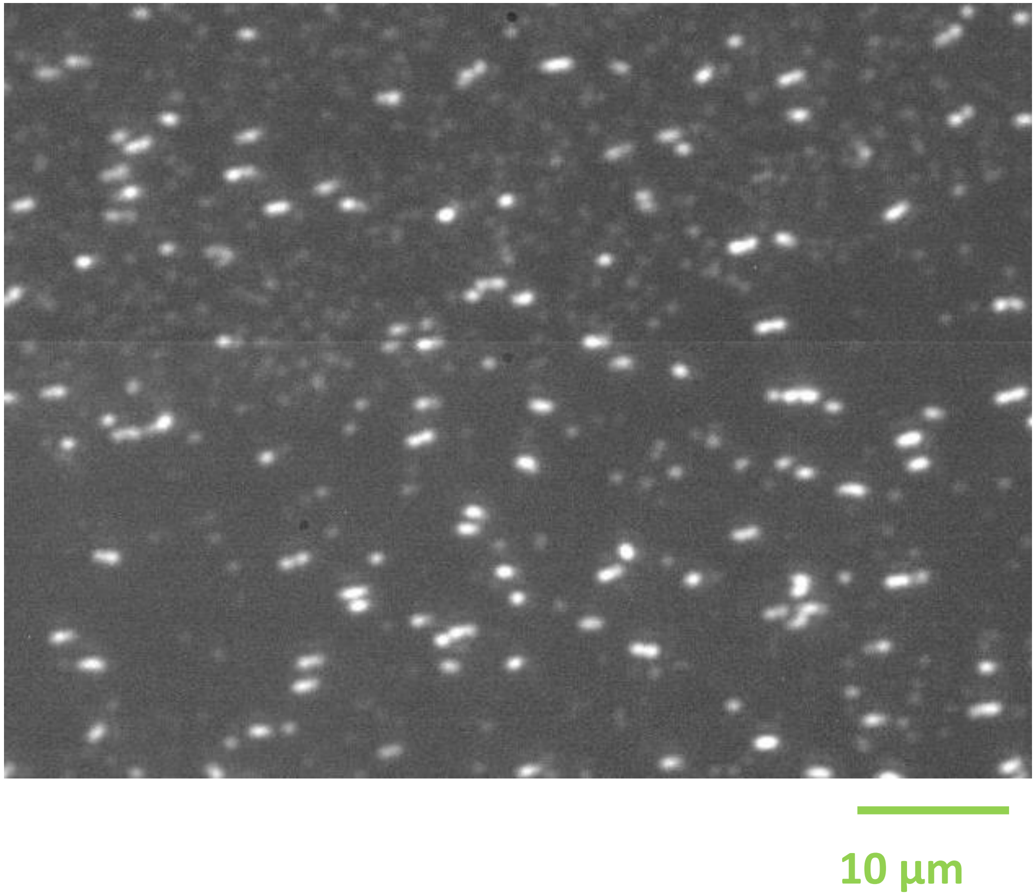


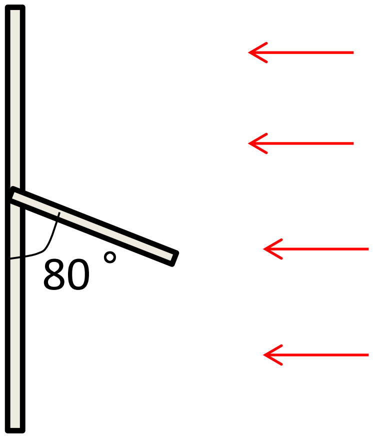
NIT



Expected signal

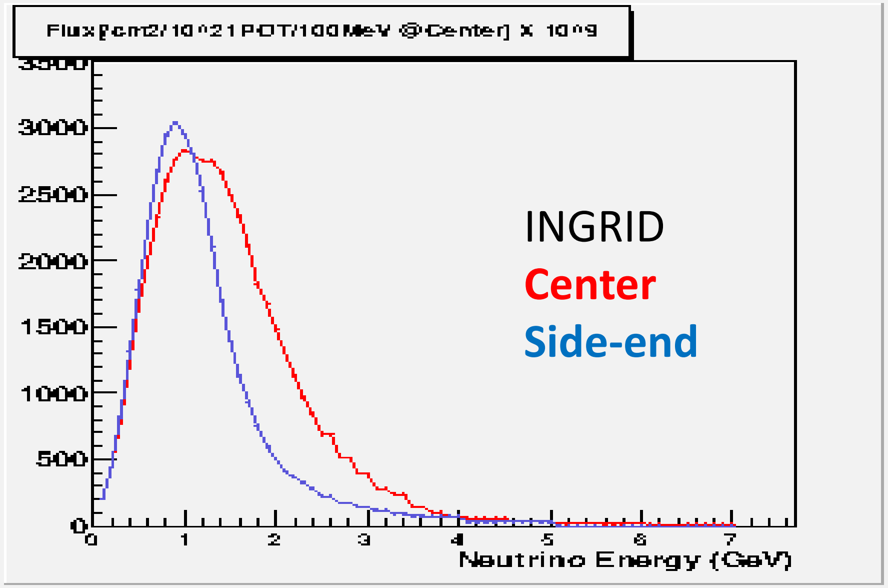
DATA:: Readout tracks by Carbon injected with **800KeV (about expected energy)** to fine grain (40nm crystal) emulsion

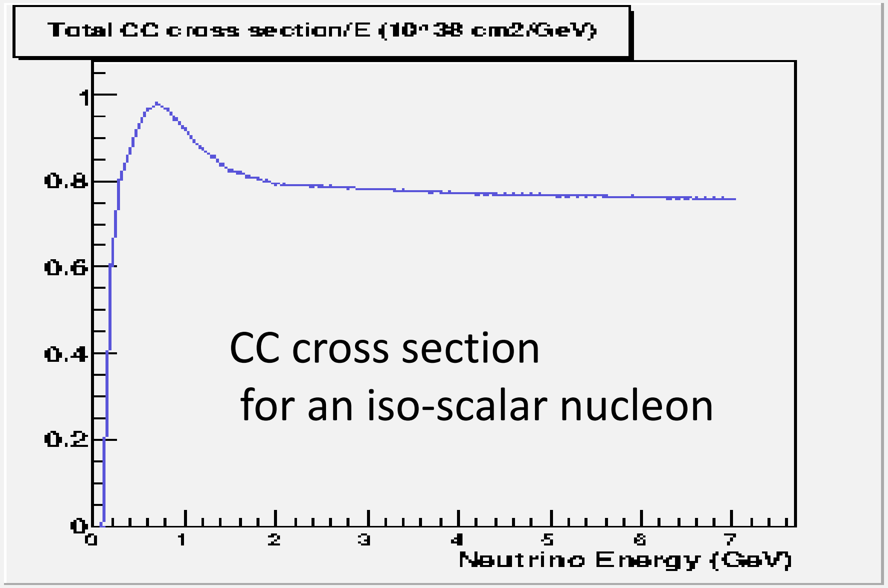




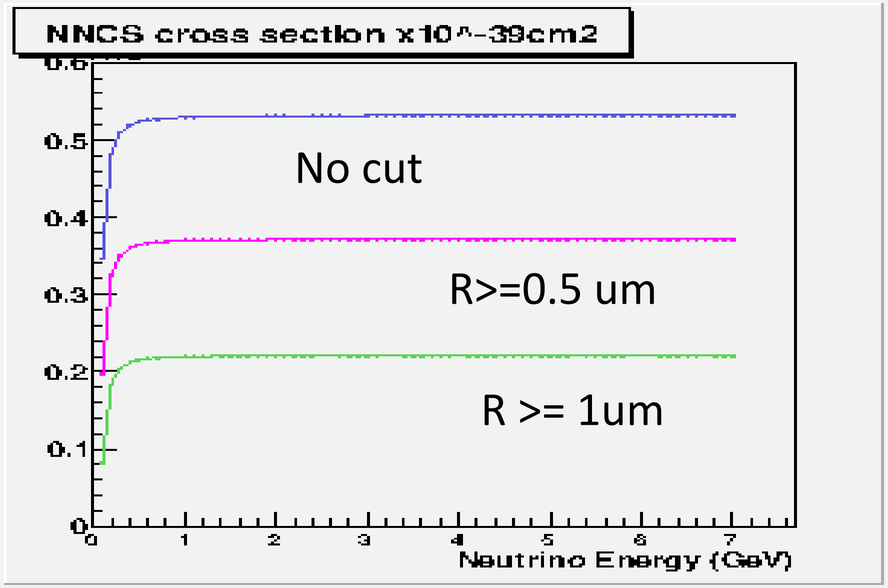
C ion : 800 keV
Exposure angle : 10 deg.
Light : Halogen (no filter)
Lens : NA of 1.25

Neutrino Flux & cross sections





CC cross section
for an iso-scalar nucleon



Number of interactions

$$N = \int_0^\infty \sigma(E)\frac{d\varphi}{dE}dE \cdot \kappa\left(\frac{mol}{gr}\right) \cdot NA\left(\frac{1}{mol}\right) \cdot w(g)$$

κ : number of nucleus in one gr.

NA : Avogadro number

Φ : neutrino flux

W : target mass

σ : cross section

(INGRID CENTER)	ev/10^21 POT/gr	CC events/ ev	Mass ･POT/ev (kg･10^21)
CC	$3.70\ 10^{-1}$	---	$2.70\ 10^{-3}$
NNCS(All)	$7.17\ 10^{-4}$	529	1.40
NNCS(0.5um)	$5.00\ 10^{-4}$	758	2.00
NNCS(1.0um)	$2.97\ 10^{-4}$	1277	3.37

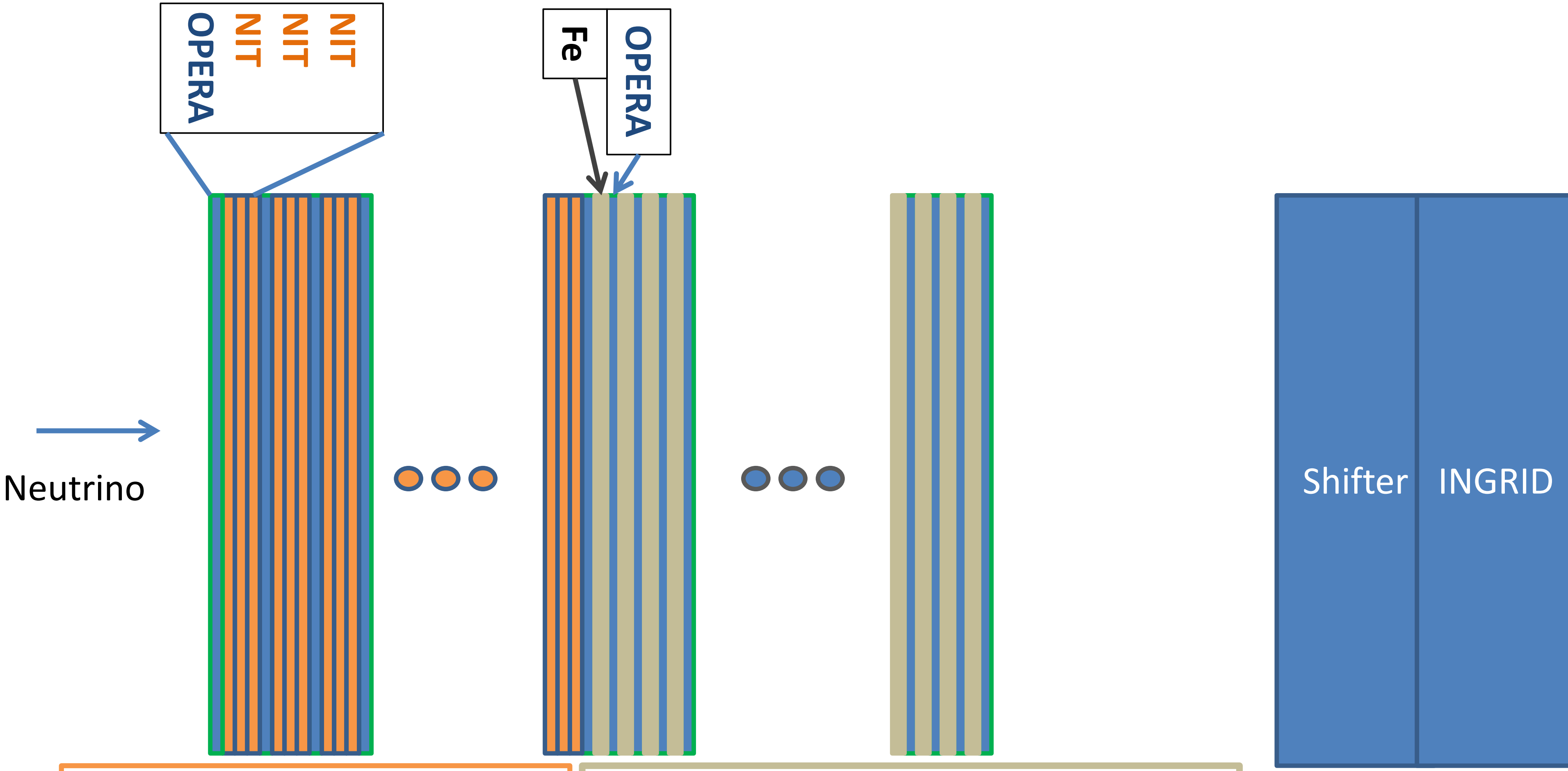
(INGRID SIDE)	ev/10^21 POT/gr	CC events/ ev	Mass ･POT/ev (kg･10^21)
CC	$2.26\ 10^{-1}$	---	$4.42\ 10^{-3}$
NNCS(All)	$5.26\ 10^{-4}$	440	1.90
NNCS(0.5um)	$3.67\ 10^{-4}$	631	2.73
NNCS(1.0um)	$2.17\ 10^{-4}$	1064	4.60

Target mass for 10 observed ev

(INGRID CENTER)	**Mass (kg) / 10 ev By 1year =0.7 10^21**	**Mass (kg) / 10 ev By 2year =1.4 10^21**
NNCS(0.5um)	**28.6**	**14.3**
NNCS(1.0um)	**48.1**	**24.1**

(INGRID SIDE)	**Mass (kg) / 10 ev By 1year =0.7 10^21**	**Mass (kg) / 10 ev By 2year =1.4 10^21**
NNCS(0.5um)	**39.0**	**19.5**
NNCS(1.0um)	**65.7**	**32.9**

Schematic view of an unit of brick 300g target



Target for NNCS
99NIT + 35OPERA(tracking)
200um base
+ 50um both sides

300g(NIT) @OPERA size

ECC :: detecting π^0
π,μ momentum measurement
500um Fe + OPERA sandwich structure
About 2 X_0 :: 40 plates

About 10 times weights of Target part

Number of NIT films @30Kg and readout

- 1Brick≒300g NIT 100 pl (10cmx10cm,50um both side)
- 100birck≒30kg **NIT 10,000 pl**

- HTS (Developing at Nagoya Univ.) can read emulsion by several min /plate and no problem for readout speed.
- While pixel size of HTS imaging sensor at object is 0.4um and not suit for detection of short range about 1um tracks with high efficiency.
- We are planning to develop HTS' for short range track with **pixel size 60nm with designed readout speed of 3-4kg /Year/1Sys**, and 5 systems can readout 30kg.

Main back ground sources

- 1 π^0 coherent production events

1) small number of π^0 production / 1 NC event
2) detecting π^0 → They will be another kind of signal !

- Inelastic NC interaction :: only broken pieces of nucleus

1) detecting multi short range tracks from a vertex
2) Shorter range for heavy nucleus

→ Probably they will not be background but detailed study is needed.

- **Neutrons about 1-10 MeV**

→ Recoil CNO give mimic signal

About a factor 10^6 reduction is needed assuming neutron flux at ground. It is needed to **measure the neutron energy spectrum, flux at the experimental places**. Probably the flux is smaller than that of at ground. Shield by 4 m thick water will provide 10^6 reduction.

Summary

- Observation of Neutrino Nucleus Coherent Scattering events
  is a nice challenge, with using fine spatial resolution emulsion.

- About **30 kg** of fine grain emulsion , NIT will provide **10 detected signal of CNO recoils** ranging about 1um, and direction perpendicular to neutrino beam
  by **1 or 2 year exposure @T2K**.

- Study on fading about NIT films (and also OPERA type films) for long period is needed.

- **Some further studies to be done** for

1) **Readout** of signals from 10,000 plates
   Similar Concept but fine pixel microscope will be developed.
2) **Neutron BG spectrum measurement** at experimental places, and **the shielding**
   Neutron shield by 4m water thickness will make 10^6 reduction .
   The Shield needed for also at film production, neutrino exposure, development
   Pouring emulsion and development at underground (or shielded room)
   at (or near) experimental cite would be the best.

Your comments and advises are very welcome ！

Back up

NNCS Cross section

The kinetic energy of recoiled Nucleus will distribute with

$d\sigma/dT = G_F^2/4\pi\ Q^2_w\ M_A\ (1 - M_A T/2E_\nu^2)\ F(Q^2)^2$ (eq.1)

$F(Q^2)^2$: Nuclear form factor

Q : momentum transfer

M_A : target nucleus mass

Q^2_w : NC Weak current term , $(N - Z(1 - 4\sin^2\theta_w))^2 = (N - 0.075 Z)^2$

T : Kinetic energy of recoiled nucleus

E_ν : neutrino energy

eq.1 decreasing linearly and close to zero at the maximum kinetic energy, T_max.

T_max= $E_\nu / (1 + M_A/2 E_\nu)$ can be re-written as T_max= $2E_\nu{}^2/ M_A$ if $M_A > E_\nu$.

One can integrate eq.1 and get total cross section

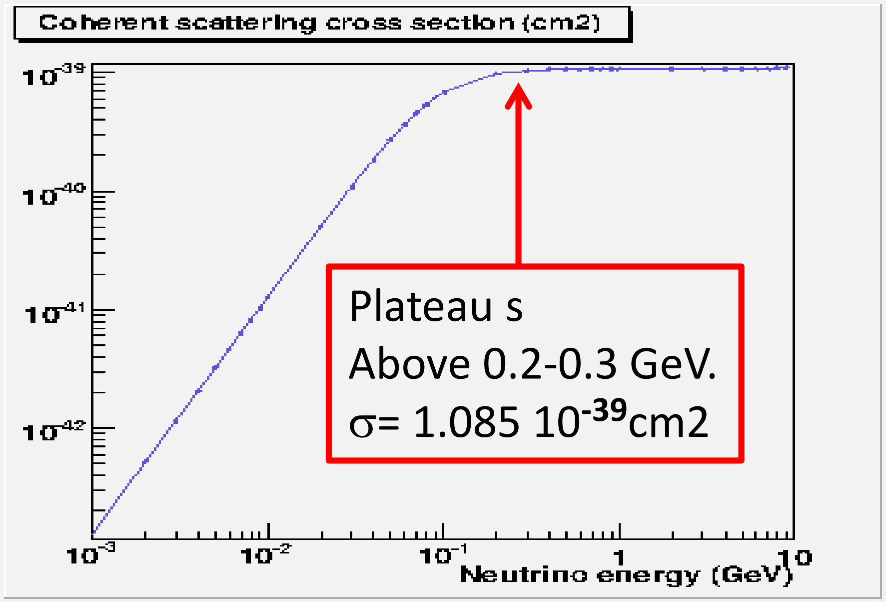
$d\sigma = G_F^2/4\pi\ Q^2_w\ E_\nu{}^2\ F(Q^2)^2$ (eq.2)

$= 0.42\ 10^{-44}\ Q^2_w\ (E_\nu(\mathrm{MeV}))^2\ F(Q^2)^2$ cm^2

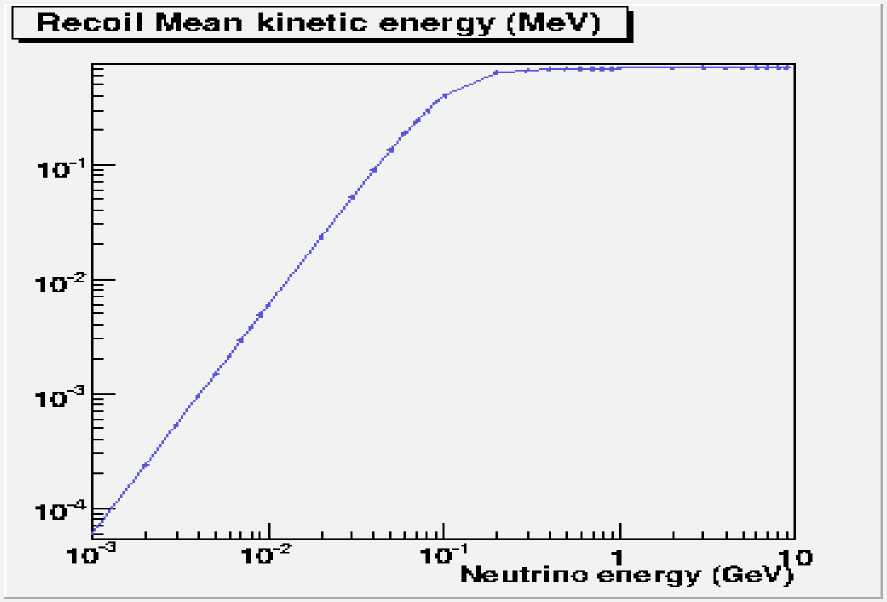
NNCS cross sections

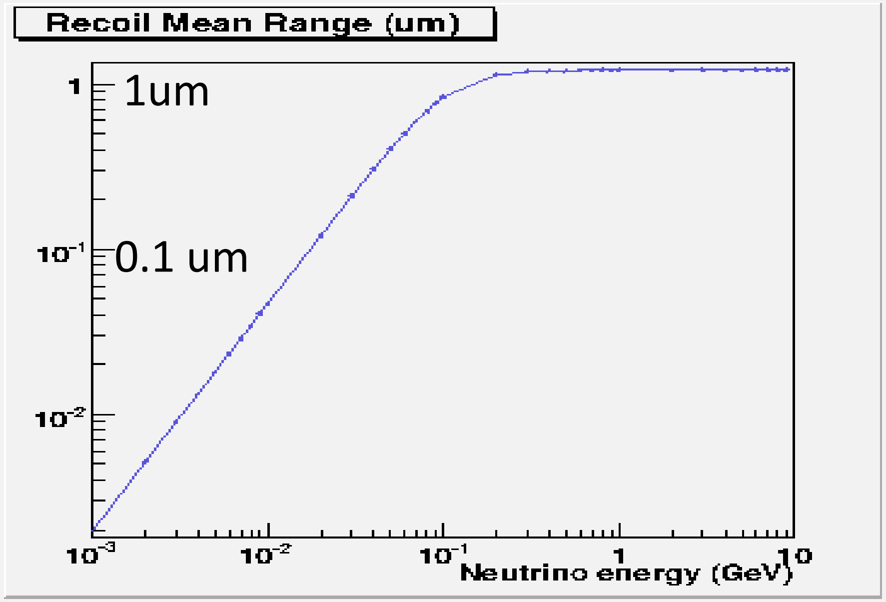
	Atom%	Mean Recoil enegy (keV)	Mean recoil range (um)	σ NNCS @1GeV 10-39cm2	σ NNCS @1GeV R>=1um 10-39cm2	σ NNCS @1GeV R>=0.5um 10-39cm2
Ag	**8.939**	**25.7**	**0.017**	**35.680**	**-**	**-**
Br	**7.842**	**40.7**	**0.028**	**23.070**	**-**	**-**
I	**0.184**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
C	**18.805**	**701.6**	**1.236**	**1.085**	**0.574**	**0.852**
O	**14.164**	**460.0**	**0.971**	**1.686**	**0.543**	**1.051**
N	**6.291**	**560.0**	**0.832**	**1.375**	**0.555**	**0.962**
H	**43.745**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
S	**0.030**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

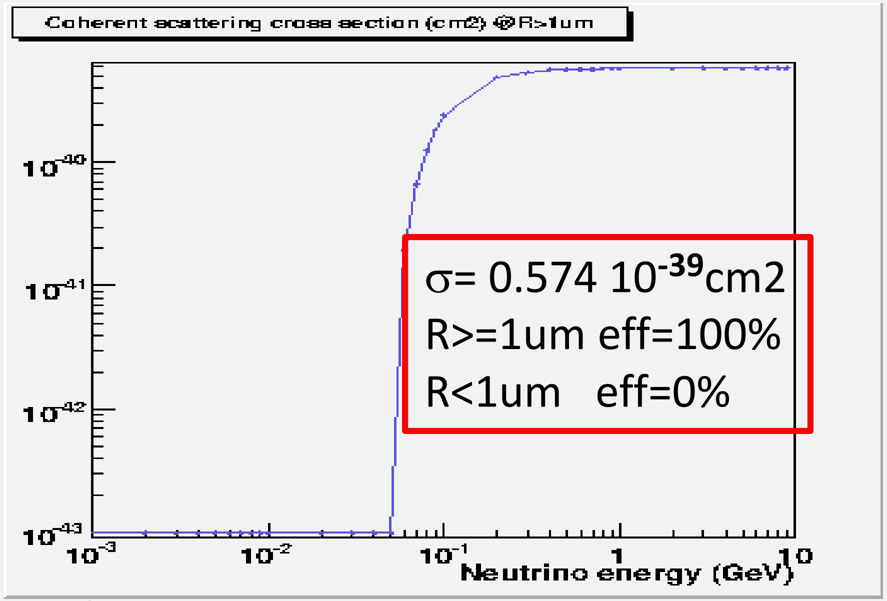
Neutrino energy dependence (C)



Plateau s
Above 0.2-0.3 GeV.
σ= 1.085 10^{-39}cm2







σ= 0.574 10^{-39}cm2
R>=1um eff=100%
R<1um eff=0%

Neutron back ground

- More than 1MeV neutron will kick CNO nucleus similar to signal.
- Flux at surface :: n=1.E(-3) /cm^2/s
- Target surface :: S=1E(2) cm^2 x 100 brick= 1E(4) cm^2
- Time :: T= 2 years = 6.3E(7) s
- Number of neutron :: N= nST = 6.3E(8) 個

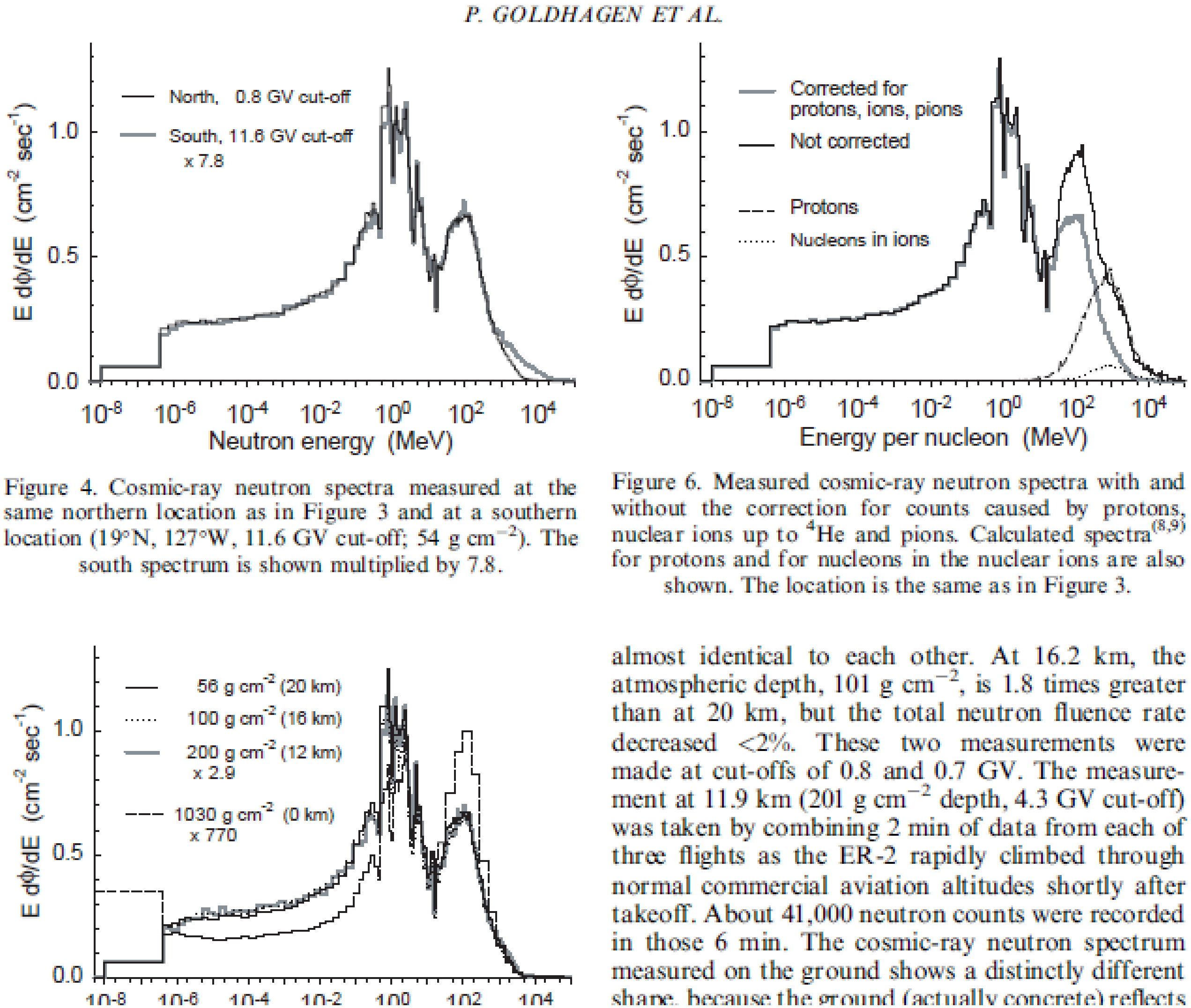
- Scattering probability in target part , CNO, 1cm depth : 2.5%
- Range cut efficiency : 50%
- Direction to neutrino (>=80°) : 17%
- Total acceptance, efficiency 2.5E(-2)*0.5*0.17= 2E(-3)

- **Detected background neutron :: N * 2E(-3) = 1.3E(6)**
- **Need to reduce at least factor 1.3E(6)**

- Underground 30m 80mwe would help some reduction .
  → Need to measure !
- How to reduce (shield) to the level of satisfy.
  → Need to study

Neutron spectrum @surface or atmosphere

Radiation Protection Dosimetry (2004), Vol.110,Nos 1-4, pp.387-392



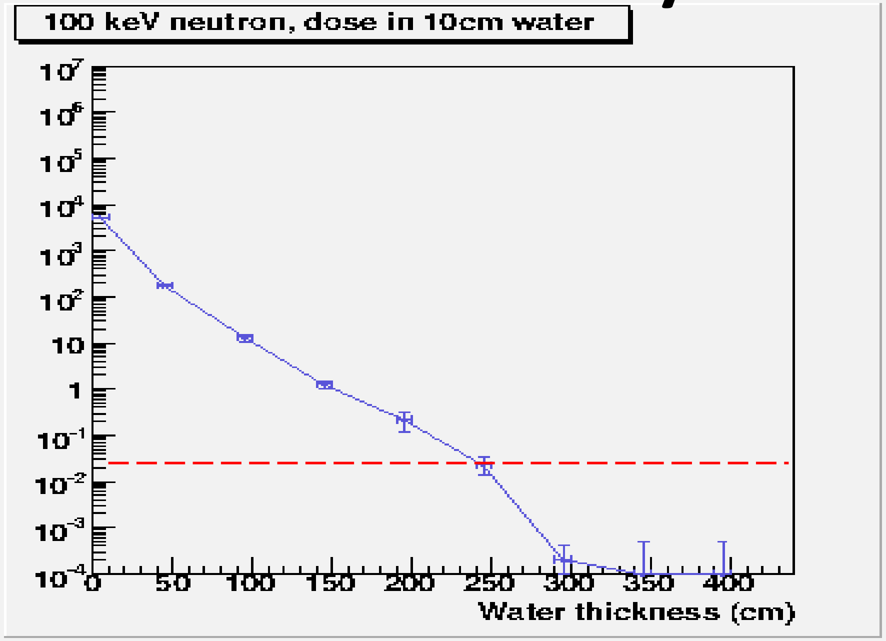
P. GOLDHAGEN ET AL.

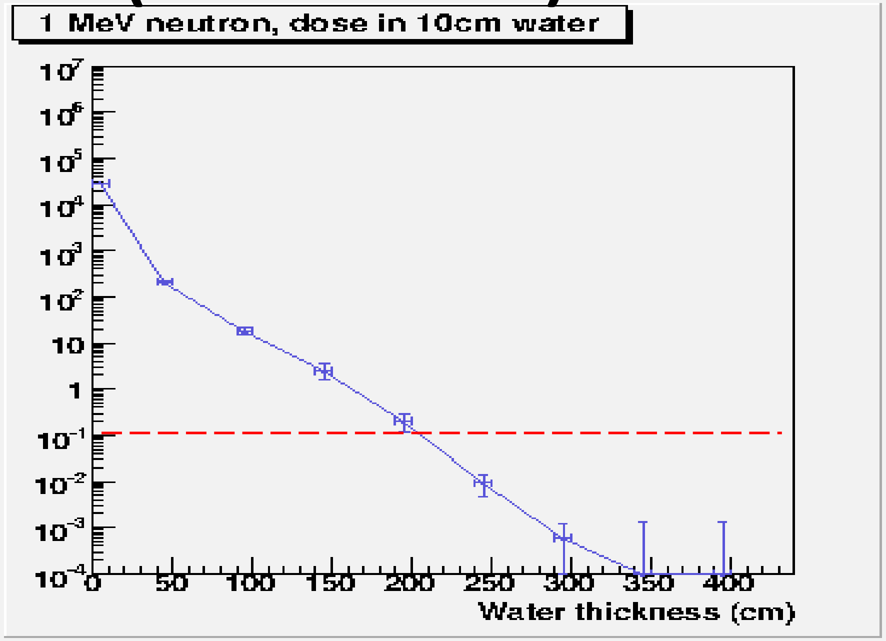
Figure 4. Cosmic-ray neutron spectra measured at the same northern location as in Figure 3 and at a southern location (19°N, 127°W, 11.6 GV cut-off; 54 g cm^{-2}). The south spectrum is shown multiplied by 7.8.

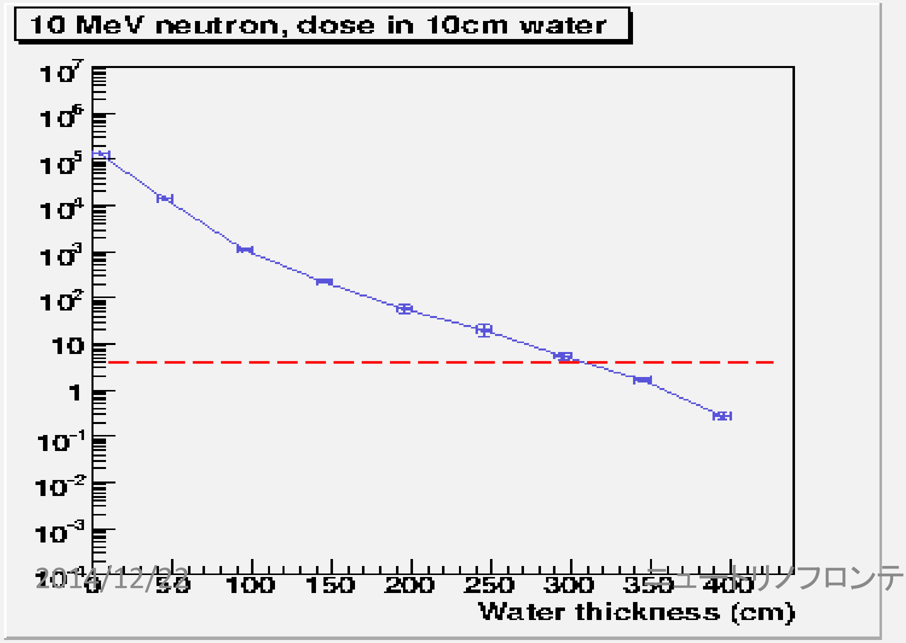
Figure 6. Measured cosmic-ray neutron spectra with and without the correction for counts caused by protons, nuclear ions up to ^{4}He and pions. Calculated spectra(8,9) for protons and for nucleons in the nuclear ions are also shown. The location is the same as in Figure 3.

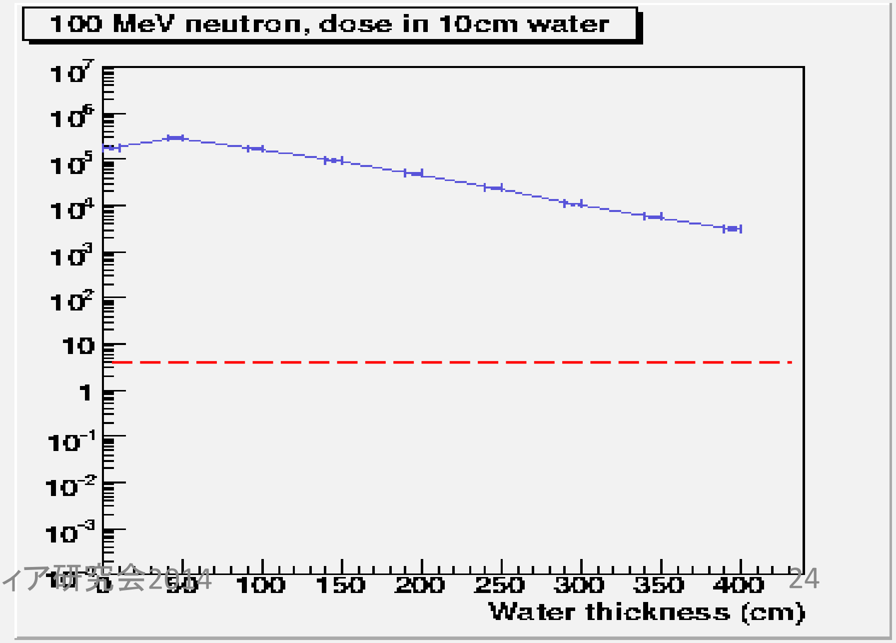
almost identical to each other. At 16.2 km, the atmospheric depth, 101 g cm^{-2}, is 1.8 times greater than at 20 km, but the total neutron fluence rate decreased <2%. These two measurements were made at cut-offs of 0.8 and 0.7 GV. The measurement at 11.9 km (201 g cm^{-2} depth, 4.3 GV cut-off) was taken by combining 2 min of data from each of three flights as the ER-2 rapidly climbed through normal commercial aviation altitudes shortly after takeoff. About 41,000 neutron counts were recorded in those 6 min. The cosmic-ray neutron spectrum measured on the ground shows a distinctly different shape, because the ground (actually concrete) reflects

Shield by water (GEANT4)



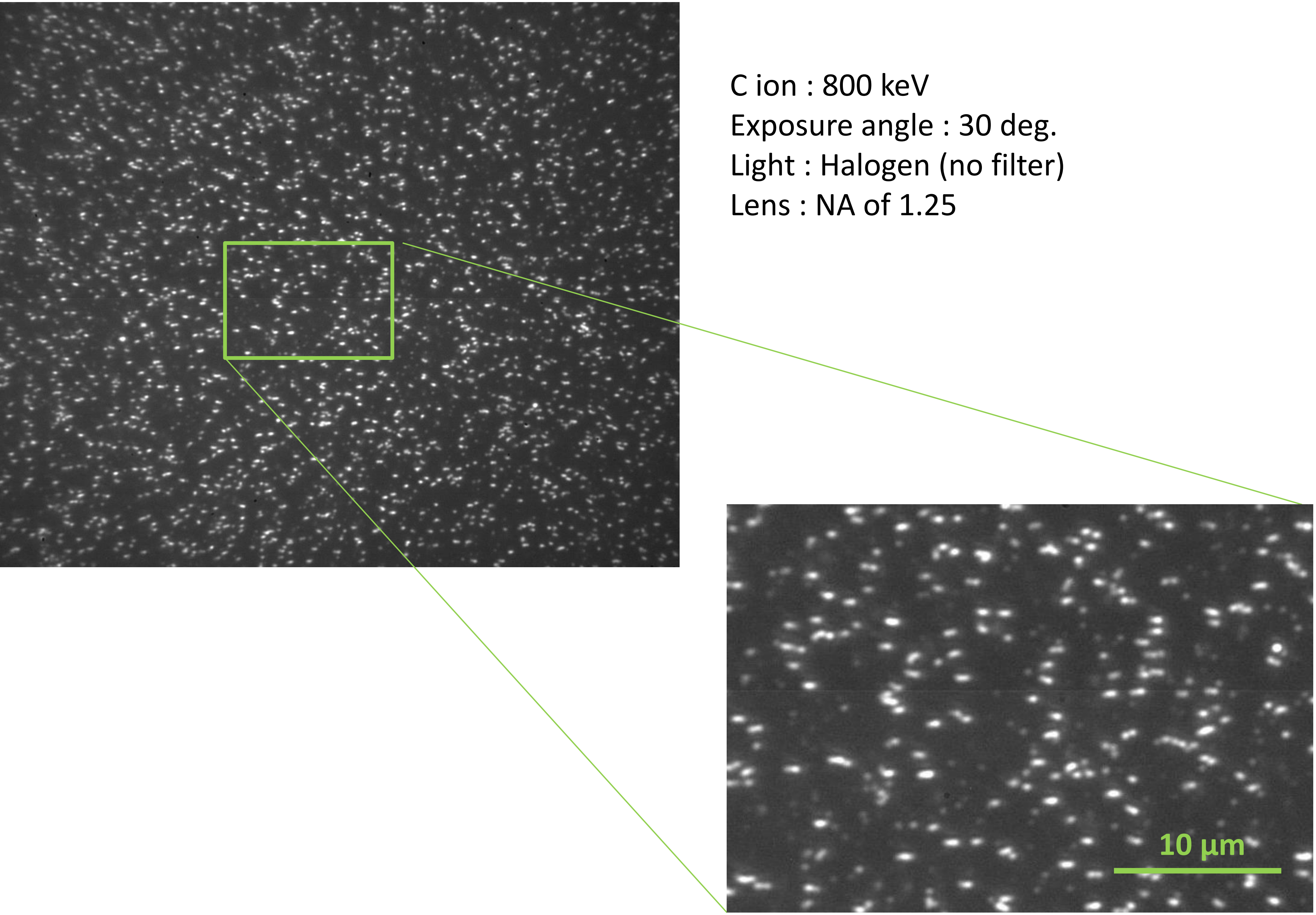


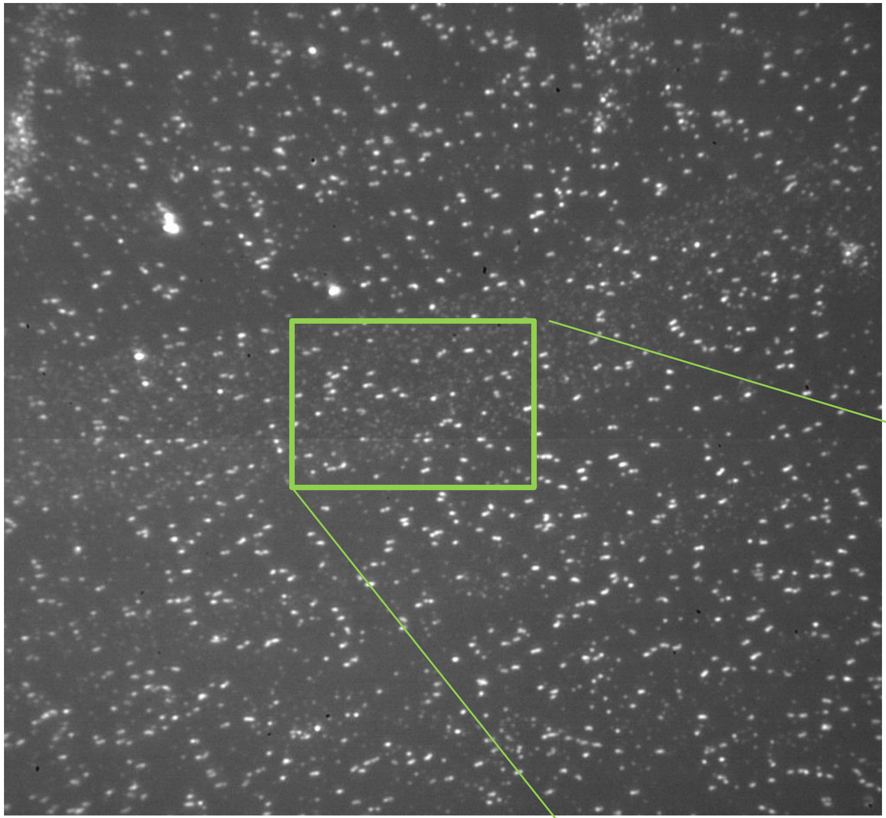




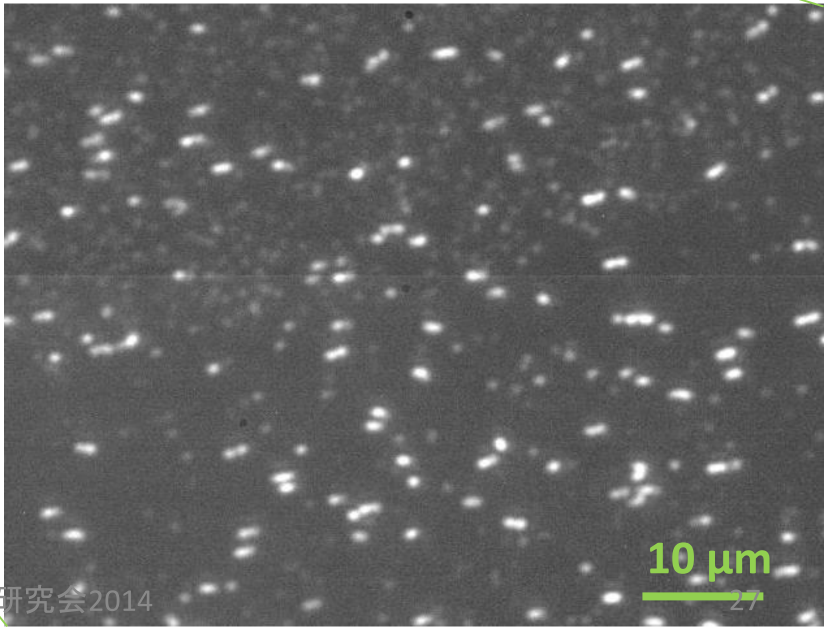
C 800 keV image

C ion : 800 keV
Exposure angle : 30 deg.
Light : Halogen (no filter)
Lens : NA of 1.25





C ion : 800 keV
Exposure angle : 10 deg.
Light : Halogen (no filter)
Lens : NA of 1.25

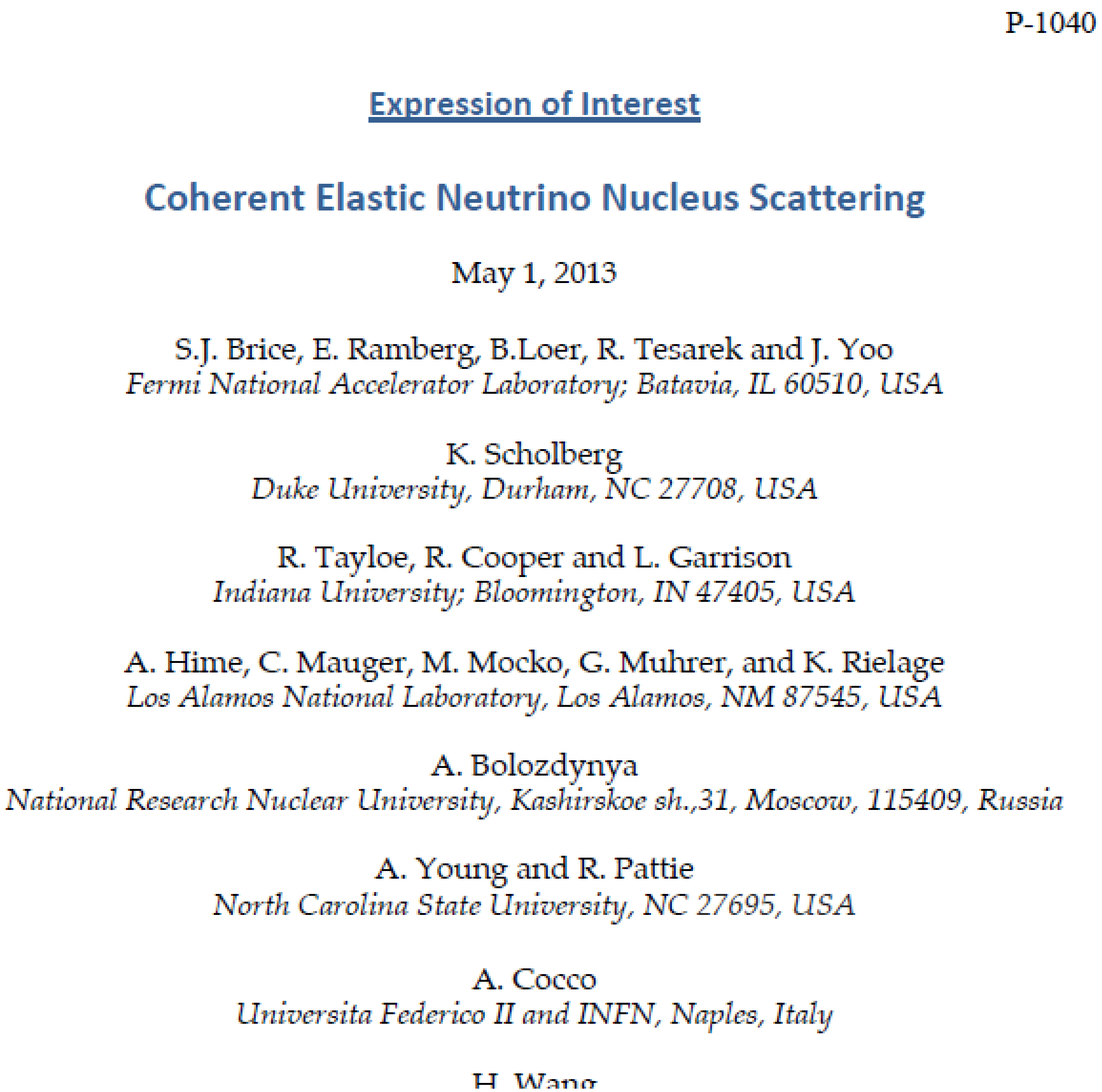


RAW(.bmp)
1 view(2352 x 1728, 58nm/pix)

FAN030HAC8001E7pl4
d60plateMAA5d10mPPD02
->
30deg. Exposer
@Carbon 800keV

After_analysis(.bmp_3ch)
With Contour line
-Red; Elli>=1.25&&Minor>=5

Some Competitors



P-1040

Expression of Interest

Coherent Elastic Neutrino Nucleus Scattering

May 1, 2013

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Some Competitors

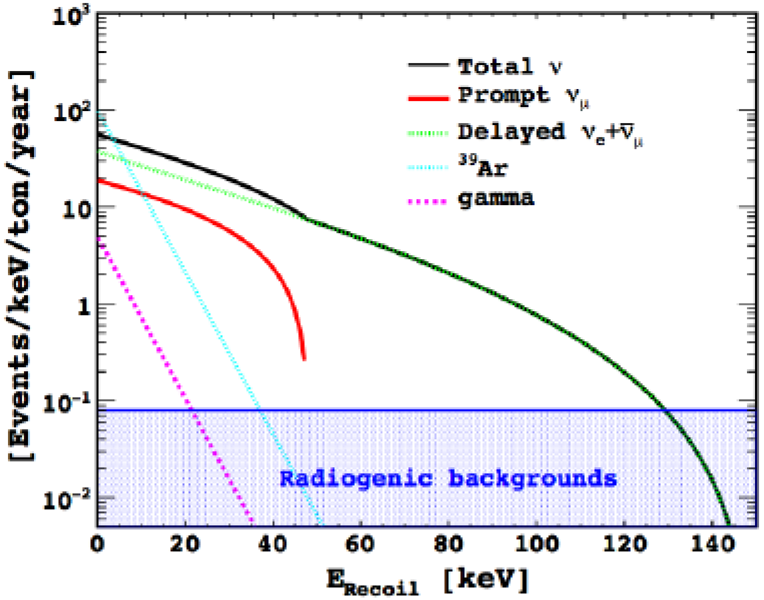
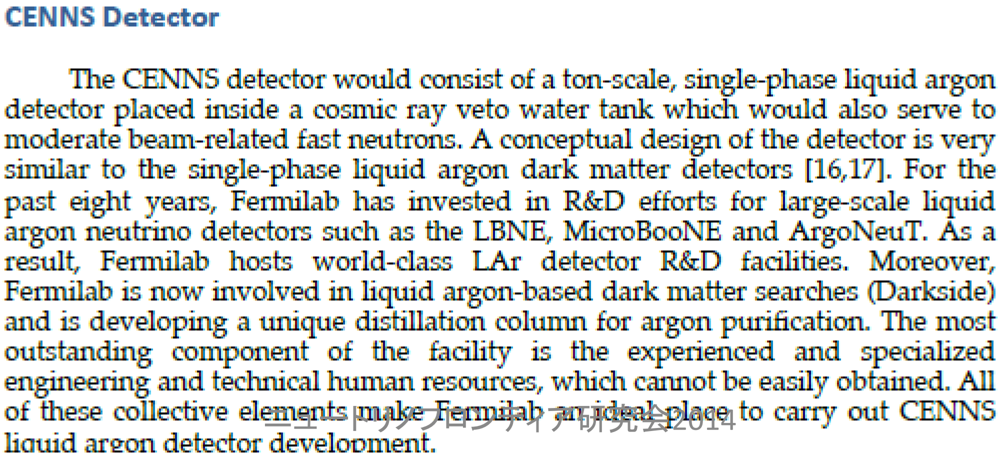


Figure 2: Number of expected CENNS events with far-off-axis BNB (32kW) neutrinos. The detector is located at 20m away from the target.



CENNS Detector

The CENNS detector would consist of a ton-scale, single-phase liquid argon detector placed inside a cosmic ray veto water tank which would also serve to moderate beam-related fast neutrons. A conceptual design of the detector is very similar to the single-phase liquid argon dark matter detectors [16,17]. For the past eight years, Fermilab has invested in R&D efforts for large-scale liquid argon neutrino detectors such as the LBNE, MicroBooNE and ArgoNeuT. As a result, Fermilab hosts world-class LAr detector R&D facilities. Moreover, Fermilab is now involved in liquid argon-based dark matter searches (Darkside) and is developing a unique distillation column for argon purification. The most outstanding component of the facility is the experienced and specialized engineering and technical human resources, which cannot be easily obtained. All of these collective elements make Fermilab an ideal place to carry out CENNS liquid argon detector development.