Simulation of Ge Detector

- Brief introduction of Nankai HEP experimental Group
- Main task in CDEX-TEXONO
- Simulation of Ge Detector: two tasks
- Result and Conclusion
- Next plan

Chunxu Yu, yucx@nankai.edu.cn

CDEX - TEXONO Collaboration

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Nankai HEP Experimental Group

- BESIII (τ-charm physics):
  - M.G. Zhao, and me
  - Students: A.Q. Guo, Y.P. Guo, Z.Y. He and Q.P. Ji (? New) T.R. Liang, Y.M. Zhu
  - We've made achievements focusing on Charm and Charmonium Physics since I came back in 2006 Oct.;
  - A brief introduction is shown on next page.
- TEXONO – CDEX: Y. Xu, and me (my talk)
  - Students: W. Wu (? New), P. Yang, Y.F. Liu and X.H. Hu
  - ≥ one new Ma.Sc students will join us, also one from other major such as Optics.
  - At moment, we focus on its simulation and hope to make achievements the way on BESIII

BESIII: a brief description

- More than 10 subjects and topics (My team's activities)
- Papers to be published in 2011 (4):
  - Measuring h_c resonance parameters and the product BR of $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$ and $\eta_c \to$ exclusive decay **(A.Q. Guo, 1/2)**
  - Measuring η_c resonance parameter thru η_c exclusive decay **(Y.P. Guo, 1/3)**
  - Search for LFV thru $J/\psi \to \mu e$ process **(Z.Y. He, 1/1)**
  - Search for χ_{cJ} hadronic transition $\chi_{cJ} \to \pi^+\pi^-\eta$ **(Y.P. Guo, 1/2)**
- Mature topics (6):
  - D semi-lepton decay of $D^+ \to \pi^0(\eta)\, e^+ \nu_e$ (M.G. Zhao, Z.Y. He, 1/1)
  - Observing pΛ-bar enhancement in $\psi(3770)$ decay (M.G. Zhao, A.Q. Guo, 1/1)
  - D single-tag software package development (M.G. Zhao, 1/1)
  - Experimental study of χ_{cJ} inclusive decay (M.G. Zhao, Y.M. Zhu, 1/1)
  - $\eta_c \to \omega\omega$, $K^{*+}K^{*-}$ (Q.P. Ji, 1/2)
  - $\psi(4040) \to \omega\eta_c$, $\omega \to \pi^+\pi^-\pi^0$ (Y.P. Guo, 1/2)

TEXONO - CDEX: introduction

DM and Neutrino: the direct detect of DM flux is one of 11 challenges in 21st Century. Probing DM's evidence is one of most important subjects of fundamental Physics:

- What is the dark matter?
- What are the masses of neutrinos, and how have they shaped the evolution of universe?
- Are there additional space time dimension?
- What is the nature of the dark energy?
- Are protons unstable?
- How did the universe begin?
- Did Einstein have the last word on gravity?
- How do cosmic accelerators work and what are they accelerating?
- Are there new state of matter at exceedingly high density and temperature?
- Is a new theory of matter and light needed at the highest energy?
- How were the elements from iron to uranium made?

TEXONO - CDEX: introduction

- It'll be much more important than (1) the discovery of J/ψ to prove the exist of charm; (2) the observatory of W, Z particle to verify the Weinberg's theory; (3) the Micro-Wave Radio to support Universe Big-Bang theory, so on.

✓ More coming experiments for it. Nature looks at key findings and events that could emerge from the research world in 2011, Richard V. Noorden, H. Ledford and A. Mann: Dark Matter's moment of truth (6^{th}/13): "A number of Underground expt.s, such as XENON100 at Italy's Gran Sasso National Lab near L'Aquila, and the Cryogenic DM Search (CDMSII) in northern Minnesota's Soudan Mine, are hunting for DM particles and expect to release results in 2011".

✓ Turned back China, CJPL - CDEX has built since Dec. 2010.

✓ For the expt.s, extremely low B.G. detectors and low B.G. environments required, its B.G. study is very key.

TEXONO - CDEX: Data Analysis Sketch

WWW.NANKAI.EDU.CN

Detector: DAQ

Energy, time information ...

Challenges

Probing DM and Neutrino

➔B.G. profile and understanding

➔B.G. subtracted becoming very important

neu

o

I. Background Understanding at KSNL-TEXONO thru Simulation Studies

Yanfang Liu, Yin Xu, Henry Wong and me

TEXONO: Taiwan Experiment On NeutrinO

It is at the Taiwan Kuo-Sheng Nuclear Power Station at a distance of 28m from the 2.9GW reactor core, its lab, KSNL, locating at a depth of 12m below sea-level and with about 25m water equivalence of overburden.

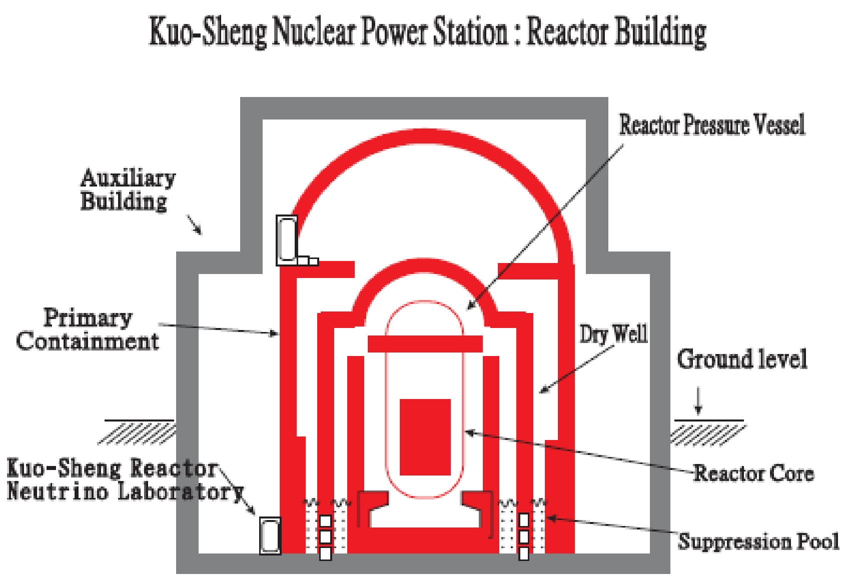


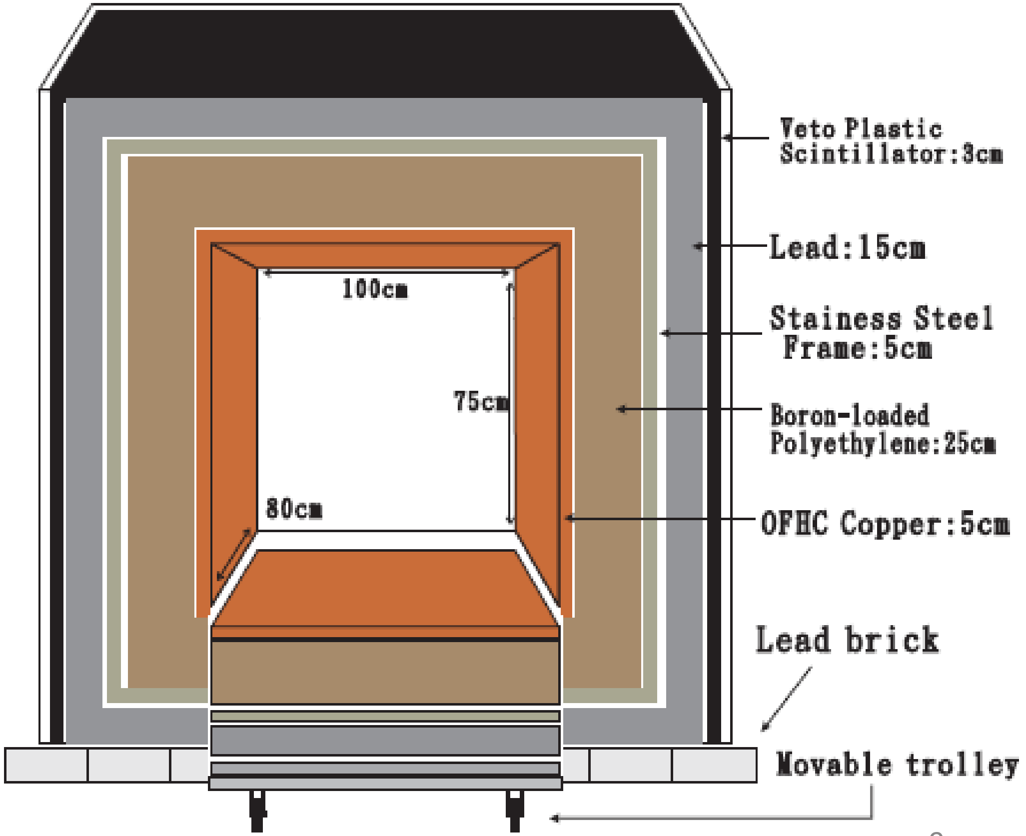
FIG. 3: Schematic layout of the Kuo-Sheng Neutrino Laboratory in relation to the core of the power reactor.

KSNL

Environments Condition

1. Ambient γ- B.G. at the reactor site is about 10 times higher in the MeV range than that of a typical lab.
2. ^{60}Co and ^{54}Mn are present as dust in the environment, they could get settled on the exposed surfaces within hours and are difficult to be removed.

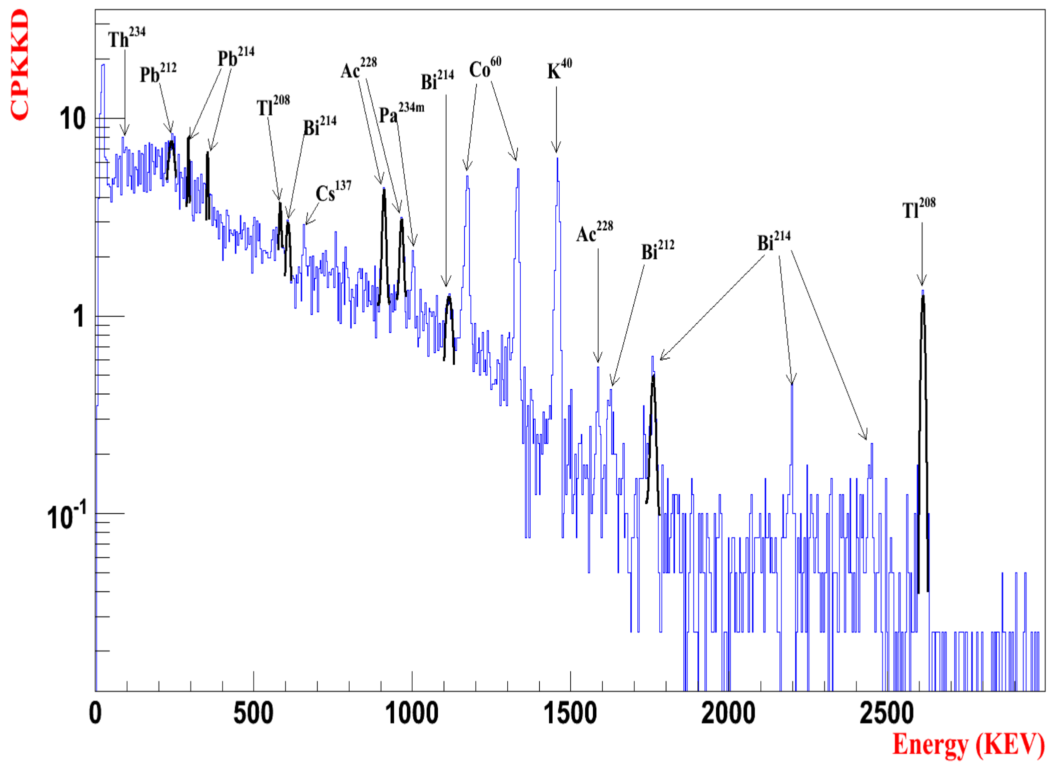
As indicated in the picture is the shielding of TEXONO. Our purpose is to understand the B.G. (mainly γ) inside the setup.



Dominative gamma B.G. source in KSNL

Source	Energy (KeV)
^{238}U	1764.5, 351.9, 609.3, …
^{232}Th	2614.4, 238.6, 582.6, …
^{60}Co	1332.5 1173.2
^{40}K	1460.8

Real data measured

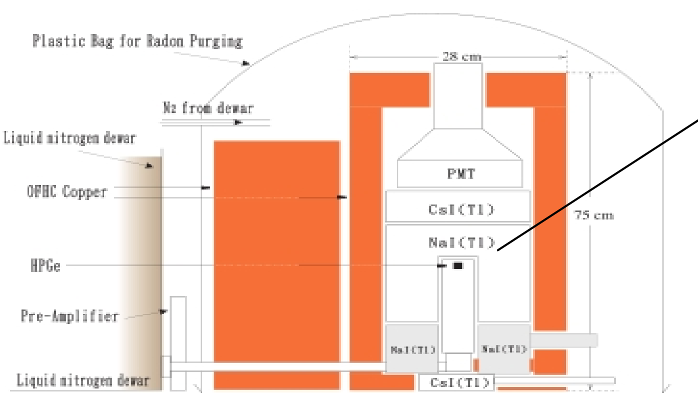


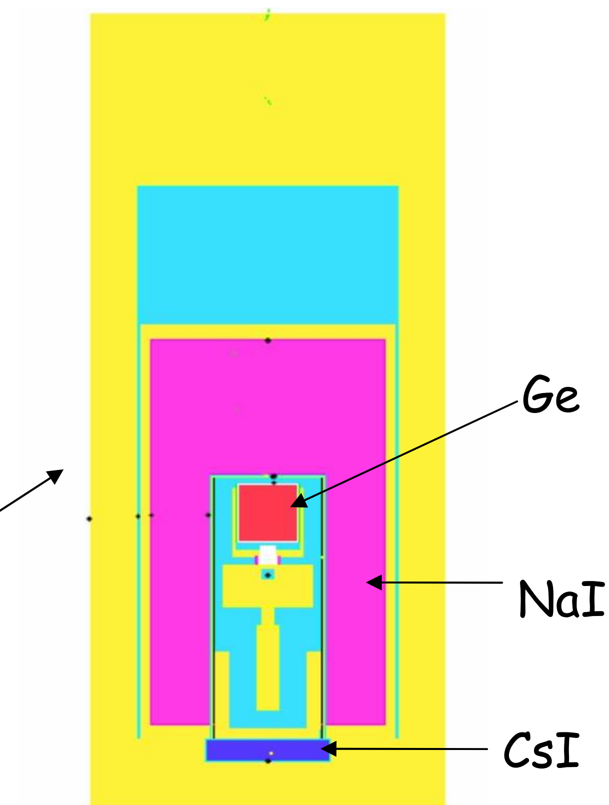
Geant4 Simulation

- To simulate the neutron B.G. is done by Y.T. Shen (IoP), with a close relationship with us. We simulate the gamma B.G..
- Main idea: the ratios between each energy peak are different from different positions of sources, thus
  - Getting the counts of peaks (strengths) due to each position of source, calculating the ratio between the MC data
  - Finding the reasonable positions thru comparing the ratio between MC and real data
  - Confirming the proportion of each B.G. source and extrapolating to the low energy to obtained each B.G. contribution
- Next only show you the previous result.

TEXONO Geometry

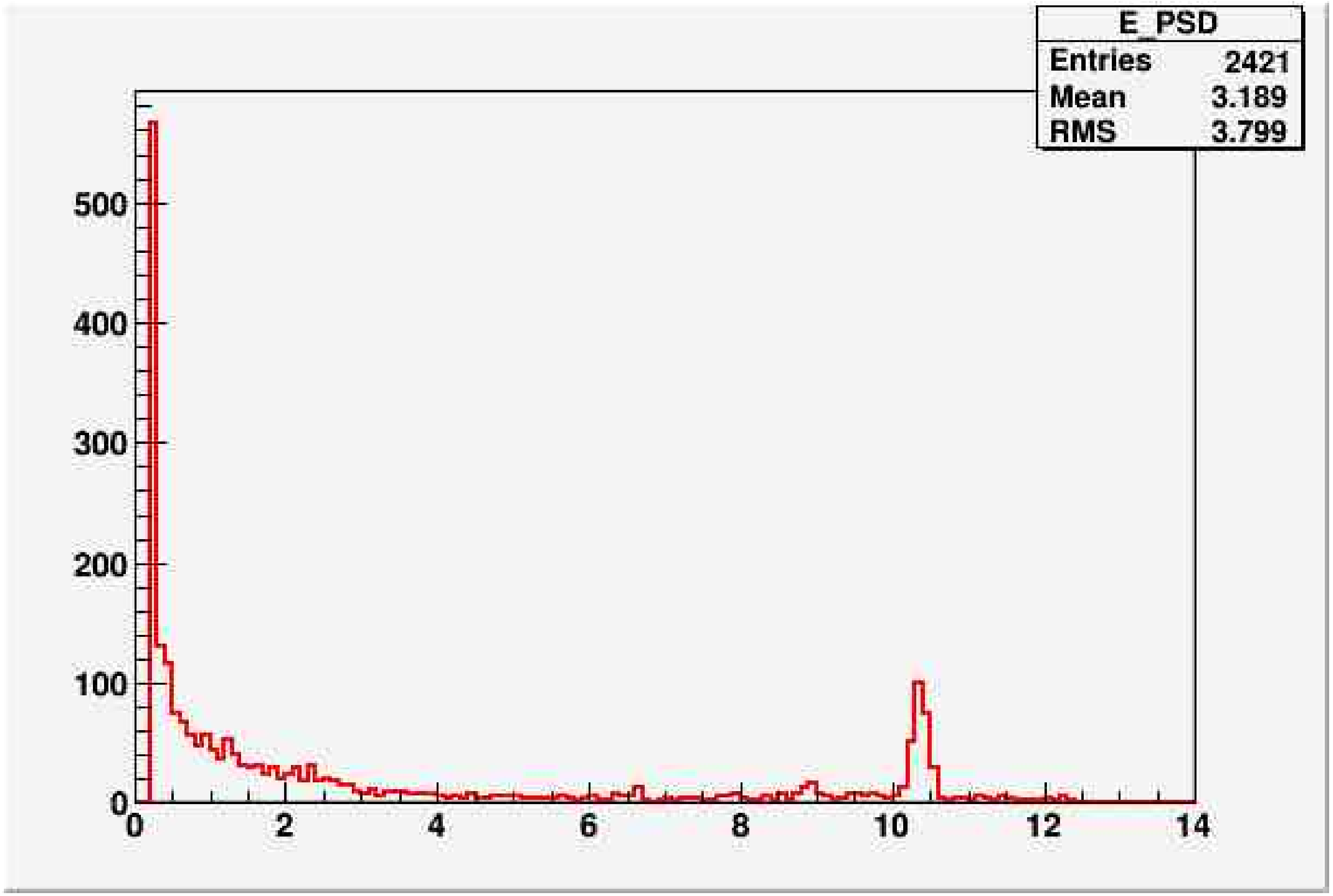
- Main detector: A high purity germanium detector, with the weight of about 500g
- Anti-Compton veto detector system: A scintillating NaI crystal
- A CsI Box at the bottom
- Shielding materials: Cu , Al…





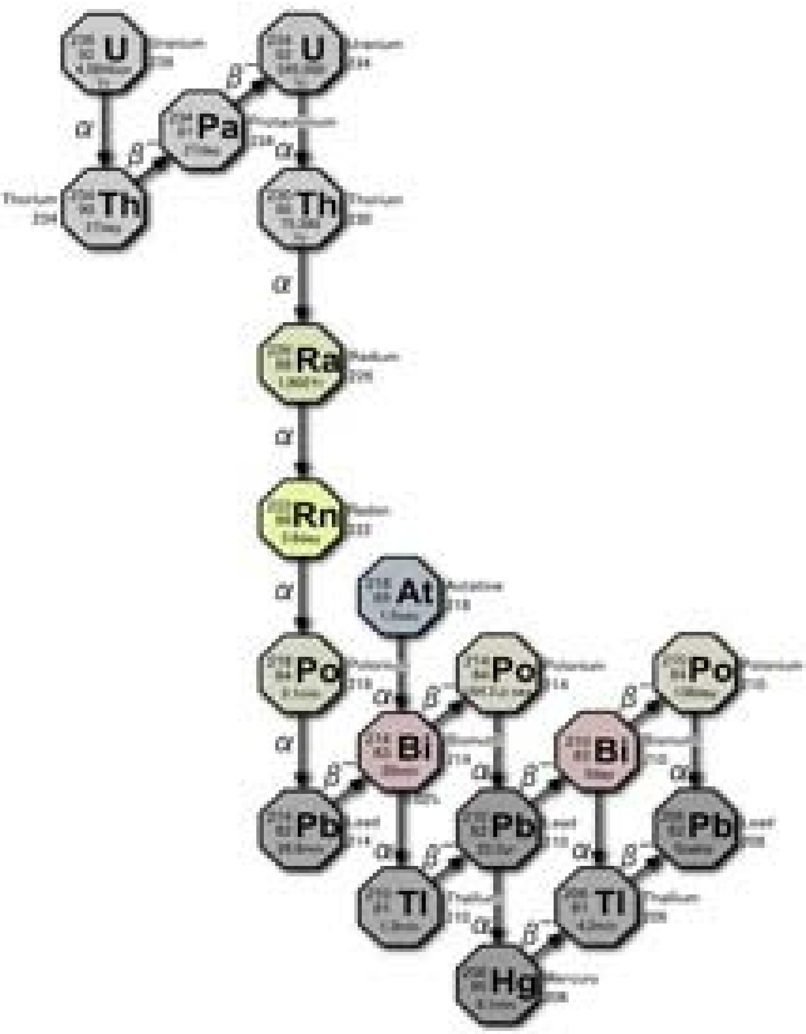
Real Data used

- The actual measurement used is the date from Feb. 10, 2010, and their live time is 11.91 days, their B.G level is about 10.56 CPKKD (4 - 8keV).

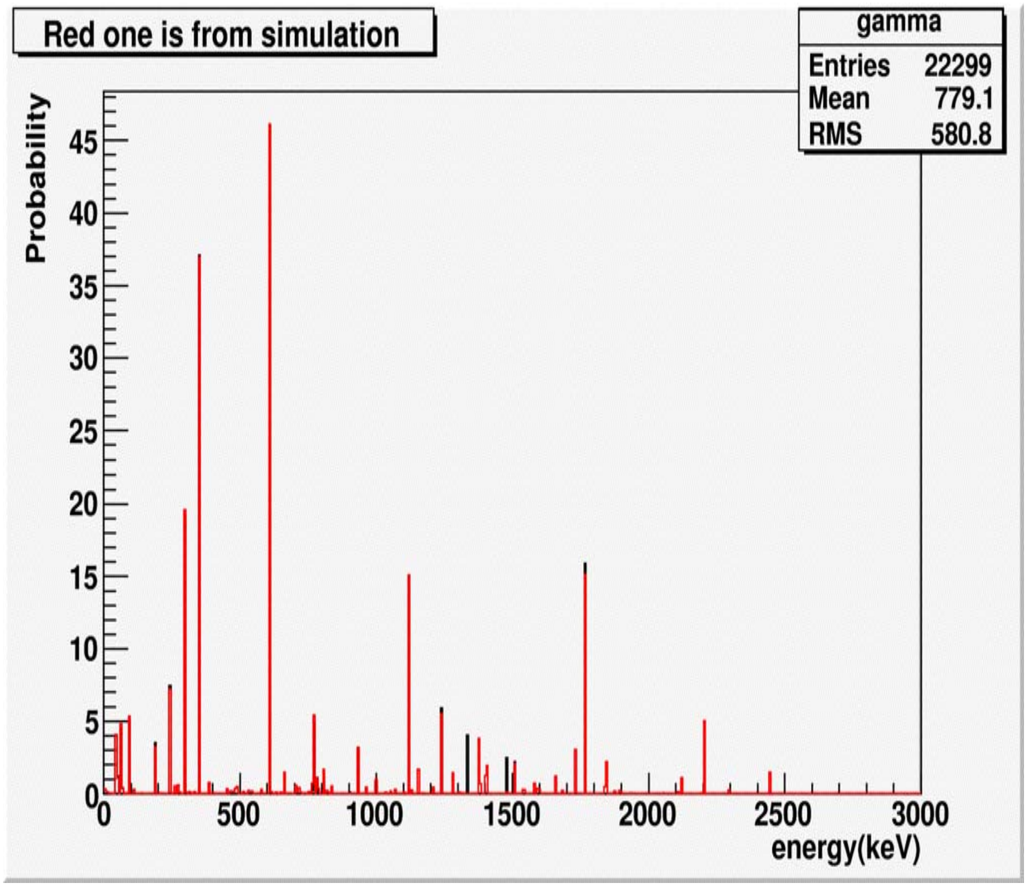


Finding the position of ^{238}U

U-238 Decay Chain



The energy spectrum of the gamma rays (keV) used: 295, 352, 609, 1120, 1764, …



Finding the position of ^{238}U

Getting the counts of the peaks from each position of source

	Side2	Top4	Bot1	Side4	Bot3	Top3	Side3	Top2	Side0	Side1	Top_NaI	Side_NaI	real_data
1764.5	12	2728.5	0	0	5744.5	16881.5	11523.5	21	6	223.5	0	0	7.17
1120.3	1	188	0	0	5297	1498	1784.5	13	1	147.5	0	0	9.66
609.3	1	1167.5	1	0	13775.5	9643	6795	4	0	141	0	0	10.48
351.9	0	30210	-0.5	0	13926.5	186911	41464	0	1	22	0	0	0

Calculating the ratios

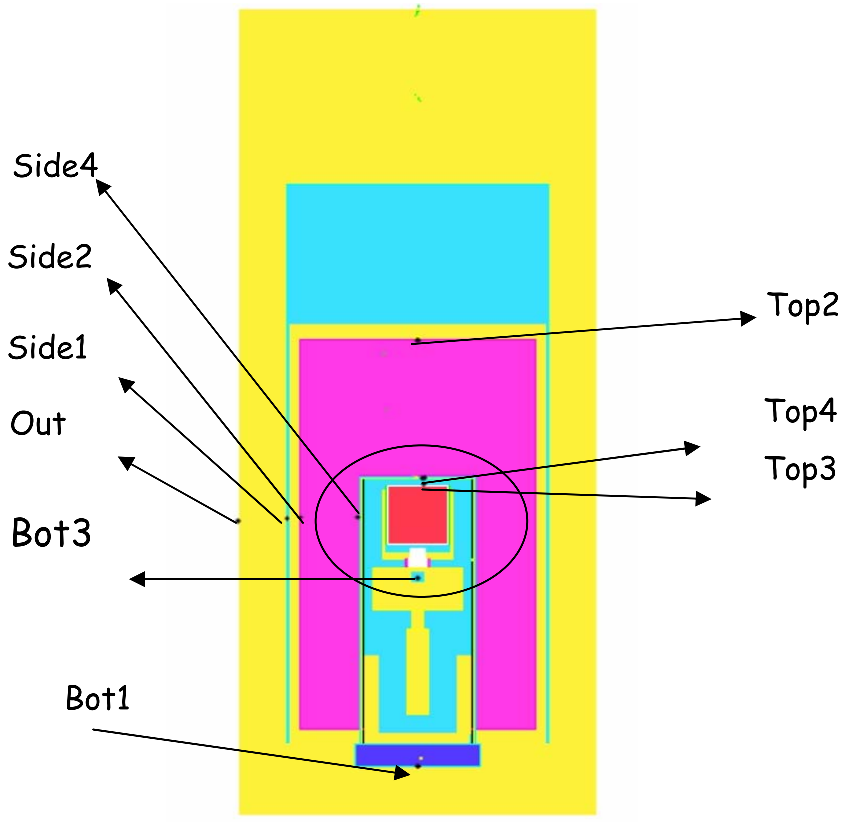
ratio	ACV part							
1764.5/1120.3	12	14.51	1.08	11.27	6.46	1.62	1.52	0.74
1764.5/609.3	12	2.34	0.42	1.75	1.7	5.25	1.59	0.68
1120/609	1	0.16	0.38	0.16	0.26	3.25	1.05	0.92

Finding the most reasonable position: Bot3

	Side2	Top4	Bot3	Top3	Side3	Top2	Side1	real_data
1764.5/1120.3	-11.26	-13.77	-0.34	-10.53	-5.72	-0.88	-0.78	0
1764.5/609.3	-11.32	-1.66	0.26	-1.07	-1.02	-4.57	-0.91	0
1120/609	-0.08	0.76	0.54	0.76	0.66	-2.33	-0.13	0

Finding the position of ^{238}U

Conclusion: Bot3 is the most possible position, closest to the bottom of Ge.

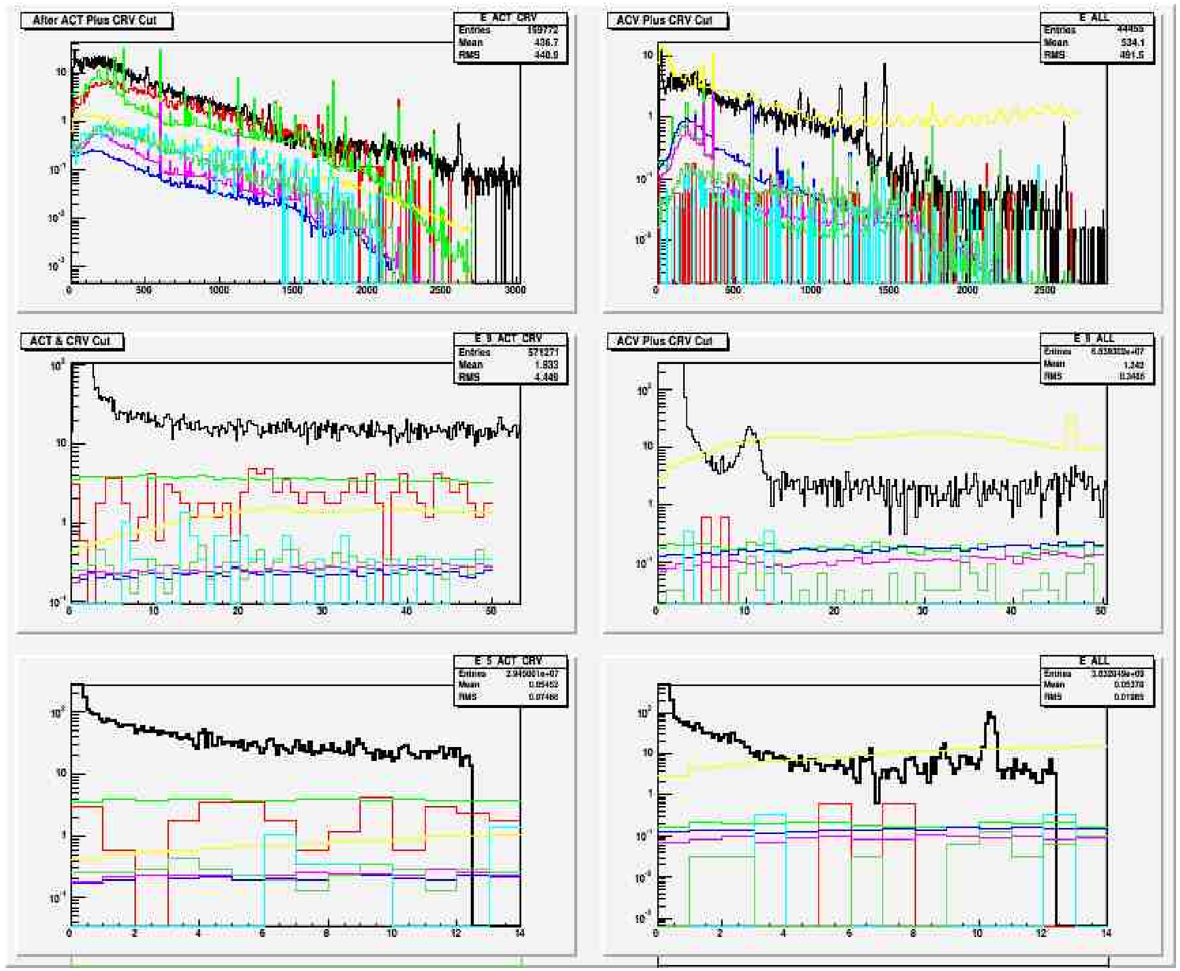


Gamma B.G. from ^{238}U

Scaled by the peak of 1.76MeV

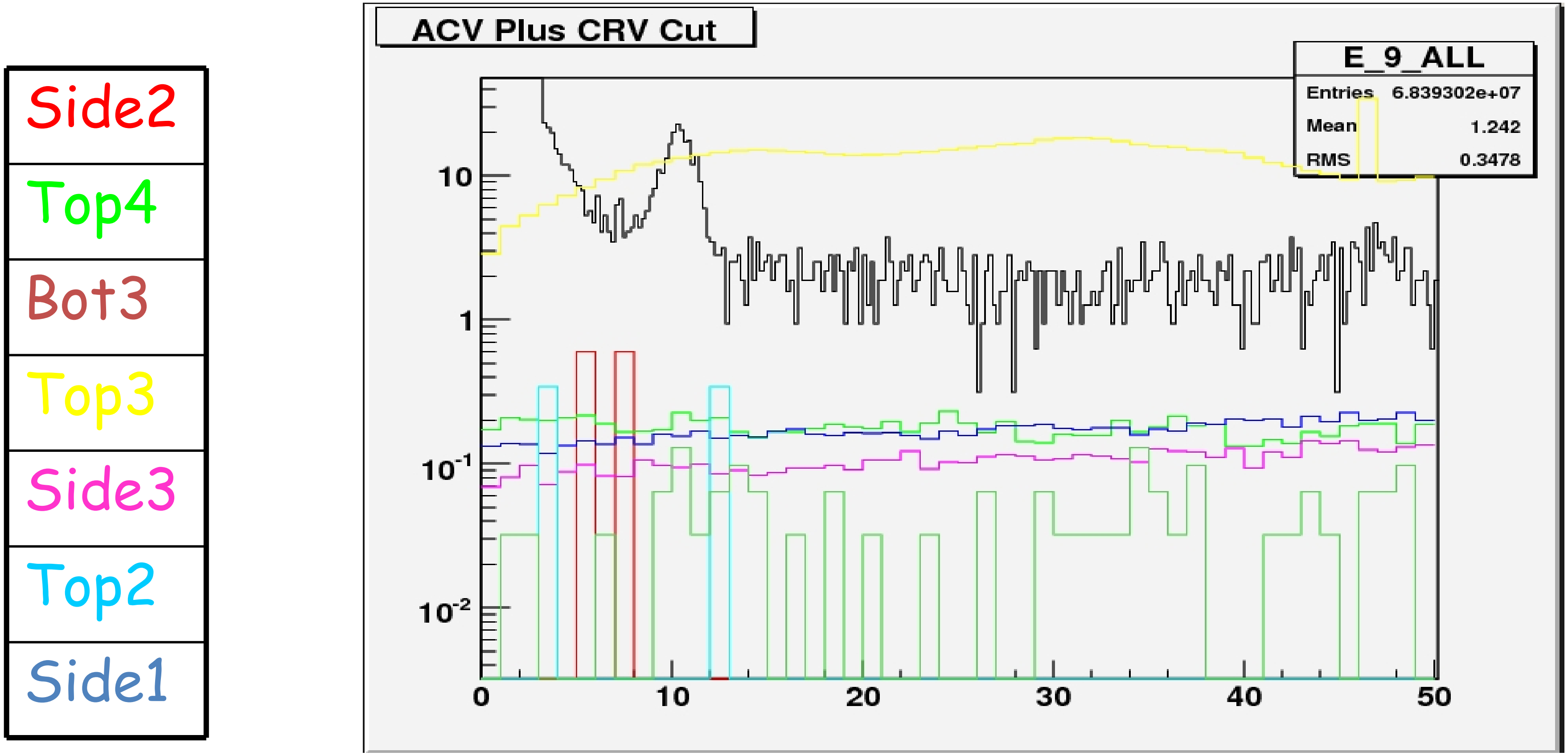
ACT_HE (0-3MeV)	ACV_HE (0-3MeV)
ACT_ME (0-50keV)	ACV_ME (0-50keV)
ACT_LE (0-14keV)	ACV_LE (0-14keV)

Side2
Top4
Bot3
Top3
Side3
Top2
Side1



Proportion of Gamma B.G. from ^{238}U

0 - 50keV



The B.G. from ^{238}U is about: 0.17cpkkd (Bot3).

Finding the position of ^{232}Th

Getting the counts of the peaks in each position

	Side2	Top4	Bot1	Side4	Bot3	Top3	Side3	Top2	Side0	Side1	Top_NaI	Side_NaI	real_data
2614.5	13	316.5	1	0	9555.5	2328.5	2286.5	28	27	463	0	0	12.5
238.6	0	46248	-0.5	0	13074	312068	46050.5	0	0	-1.5	0	0	44.1
538.2	0.5	814	-0.5	0	7042.5	6266	2862.5	3	0	71	0	0	22.99
911.2	6	4638	0	0	10166	40949.5	19825	5	0	205	0	0	32.15
964.8	1	630.5	0	0	2018	5786.5	2896.5	1	0	47.5	0	0	
969	5	5903	0	0	6114	32986	11829	1	0	130	0	0	
964.8+969	6	6533.5	0	0	8132	38772.5	14725.5	2	0	177.5	0	0	22.58

Calculating the ratios

ratio	ACV part							
	Side2	Top4	Bot3	Top3	Side3	Top2	Side1	real_data
2414/238.6	#DIV/0!	0.01	0.73	0.01	0.05	#DIV/0!	-308.67	0.28
2614/960	2.17	0.05	1.18	0.06	0.16	14	2.61	0.55
2614/911.2	2.17	0.07	0.94	0.06	0.12	5.6	2.26	0.39
238/538	0	56.82	1.86	49.8	16.09	0	-0.02	1.92

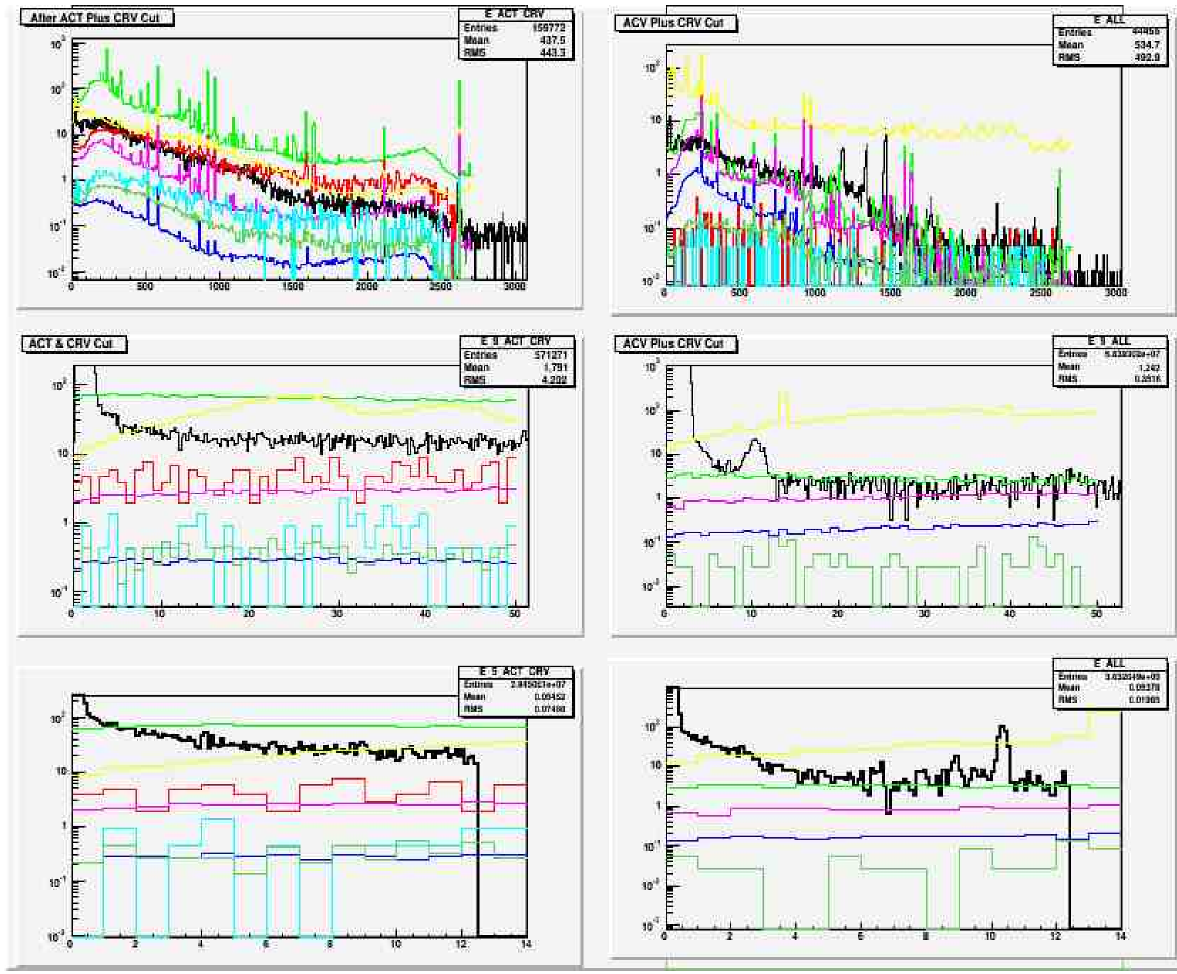
Finding the best fit position: Bot3 (closest the bottom of Ge)

	Side2	Top4	Bot3	Top3	Side3	Top2	Side1	real_data
2414/238.6	#DIV/0!	0.27	-0.45	0.27	0.23	#DIV/0!	308.95	0
2614/960	-1.62	0.5	-0.63	0.49	0.39	-13.45	-2.06	0
2614/911.2	-1.78	0.32	-0.55	0.33	0.27	-5.21	-1.87	0
238/538	1.92	-54.9	0.06	-47.88	-14.17	1.92	1.94	0

Gamma B.G. from ^{232}Th

Scaled by the peak of 2.61MeV

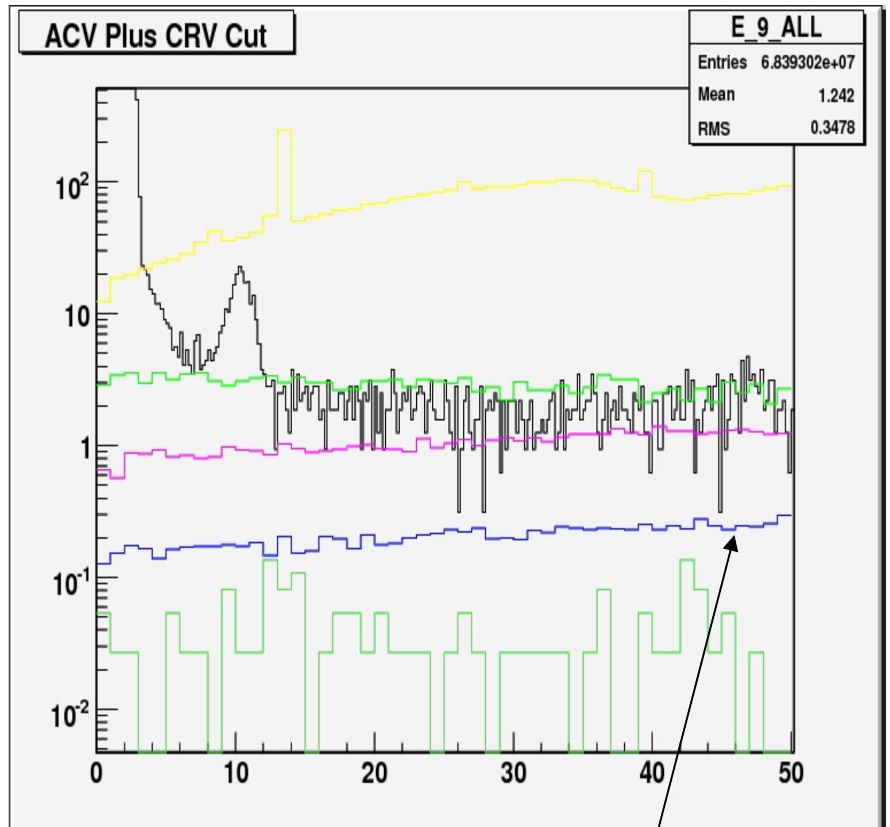
Side1
Top4
Bot3
Top3
Side3
Top2
Side2



Proportion of Gamma B.G. from ^{232}Th

0 - 50keV

Side1
Top4
Bot3
Top3
Side3
Top2
Side2



The B.G. from ^{232}Th is about: 0.20cpkkd (Bot3).

Finding the position of ^{60}Co

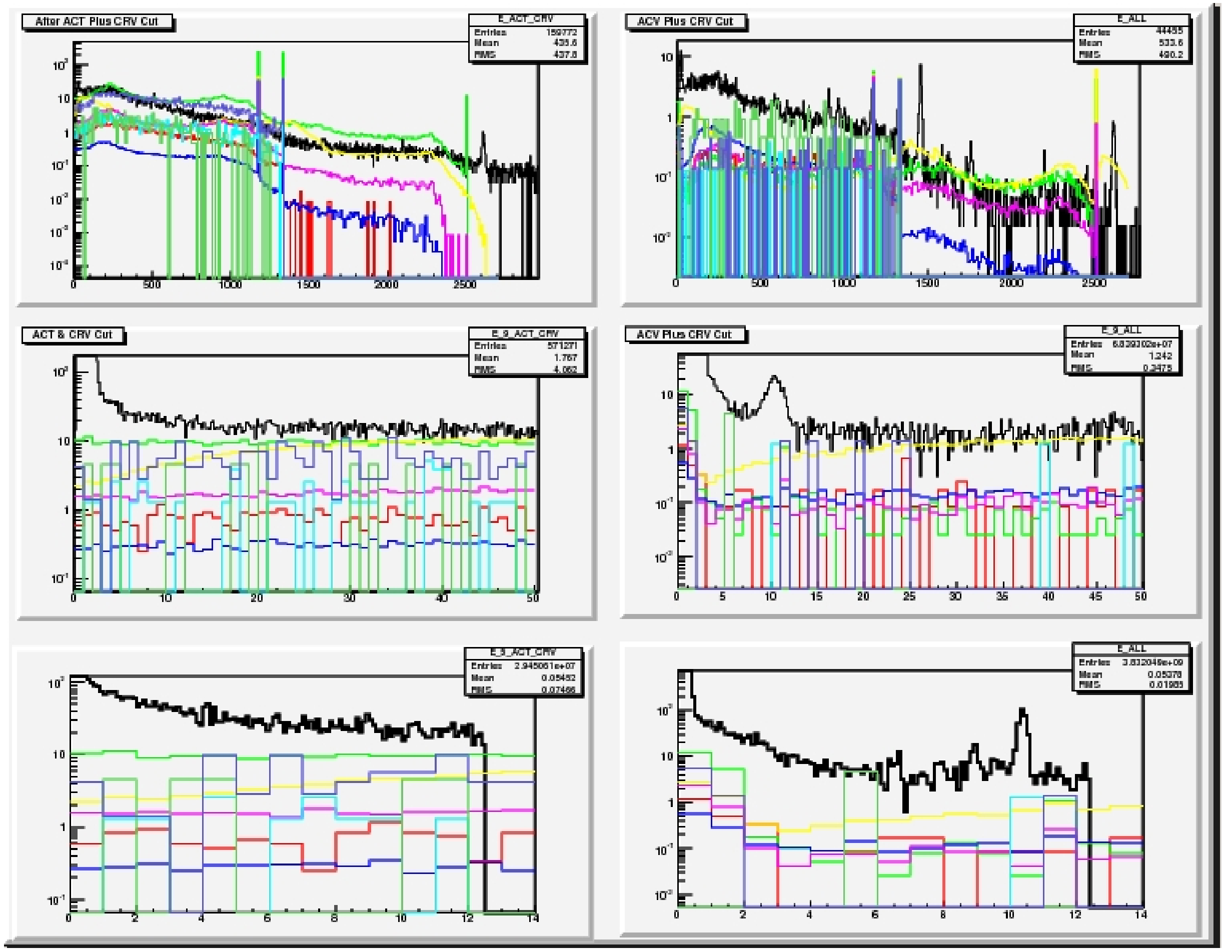
- Best fit position is: Side1 (between the NaI and Cu)

	Side2	Top4	Side4	Bot3	Top3	Side3	Top2	Side1	Side_NaI	real_data
1.17/1.33_ACV	0.17	-0.24	#DIV/0!	0.12	-0.08	0.02	0.32	0.17	#DIV/0!	0
2.5/1.33_ACV	0	0	0	0	0	0	0	0	0	0
1.17/1.33_ACT	0.05	-0.18	-0.14	-0.22	-0.2	-0.15	-0.06	0.03	-0.13	0
2.5/1.33_ACT	0	-0.05	-0.02	0	0	0	0	0	-0.01	0
1.17_ACV/1.17_ACT	2.94	3.04	3.05	0.23	2.94	2.91	1.81	-0.15	3.06	0
1.17_ ACV/1.33_ACT	2.64	2.72	2.73	-0.41	2.61	2.59	1.55	-0.02	2.74	0

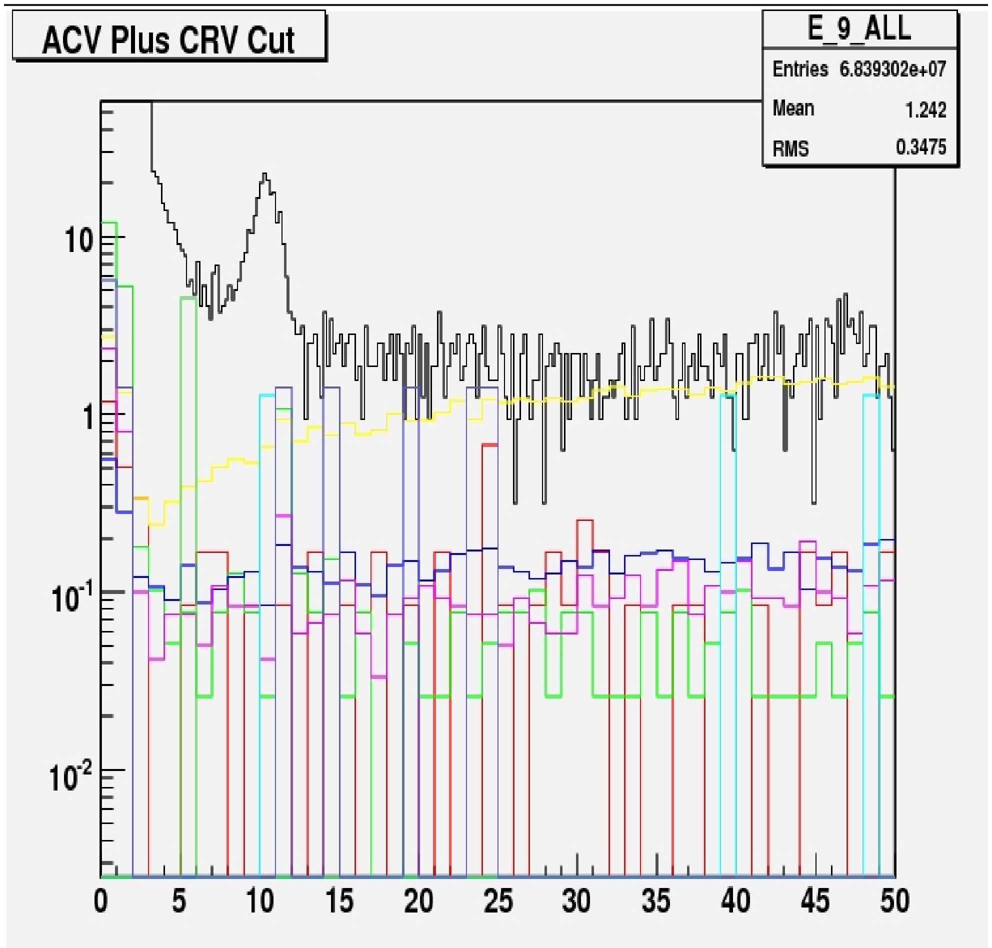
Gamma B.G. from ^{60}Co

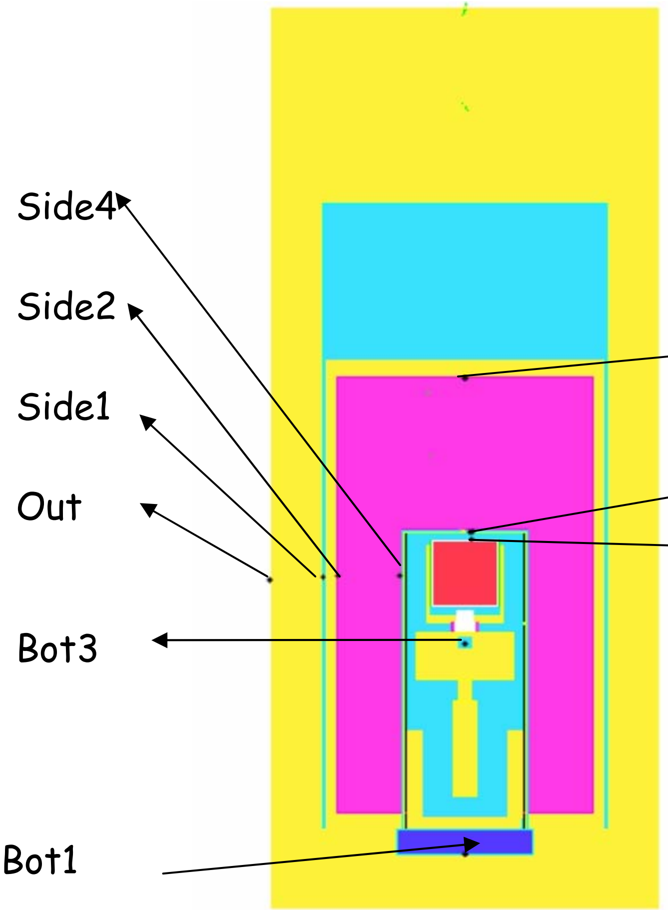
Scaled by the peak of 1.33MeV

- Side1
- Top4
- Bot3
- Top3
- Side3
- Top2
- Side0
- Side2



Gamma B.G. from ^{60}Co





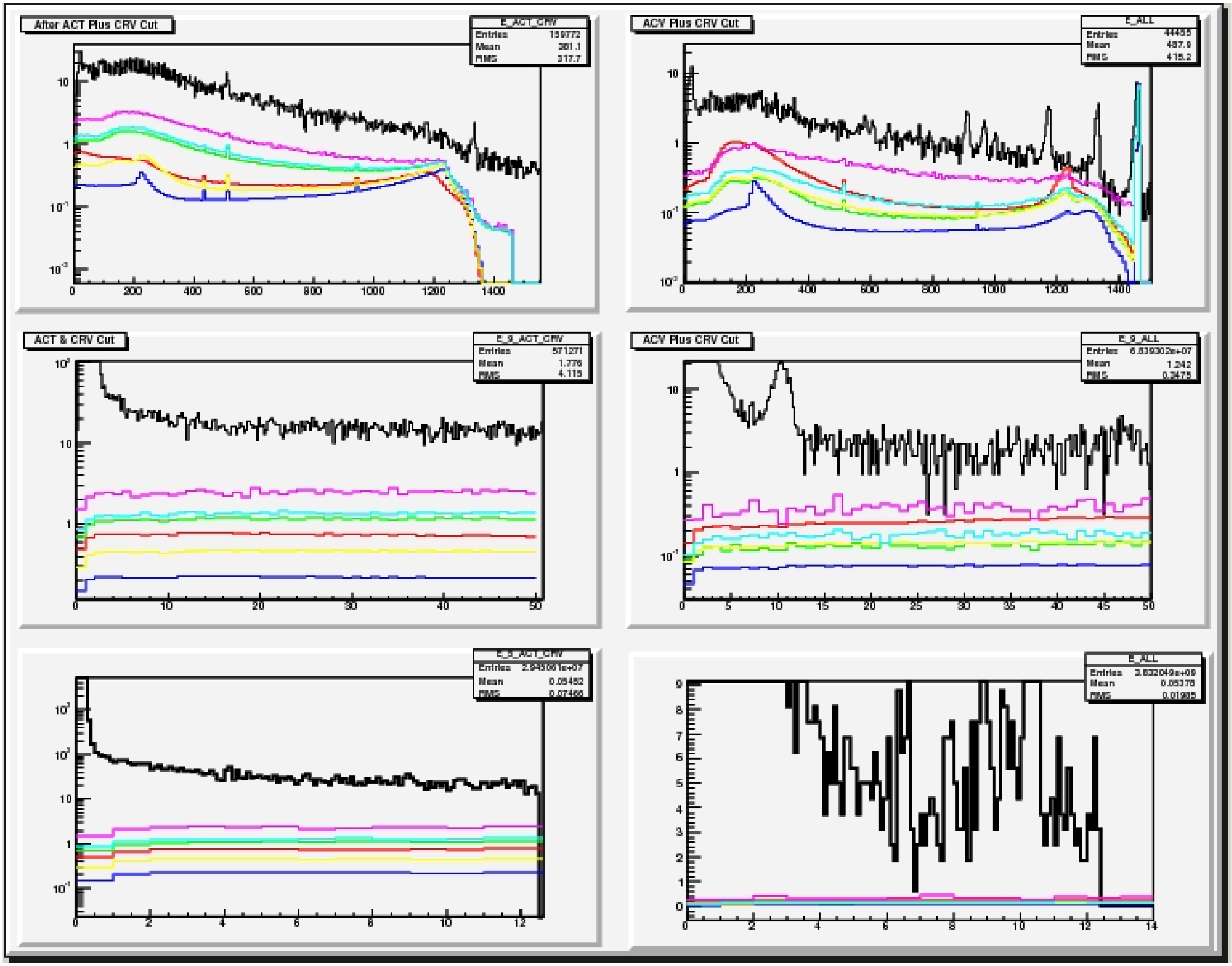
Not inside

The B.G. from ^{60}Co is about: 0.18cpkkd (Side1).

Gamma B.G. from ^{40}K

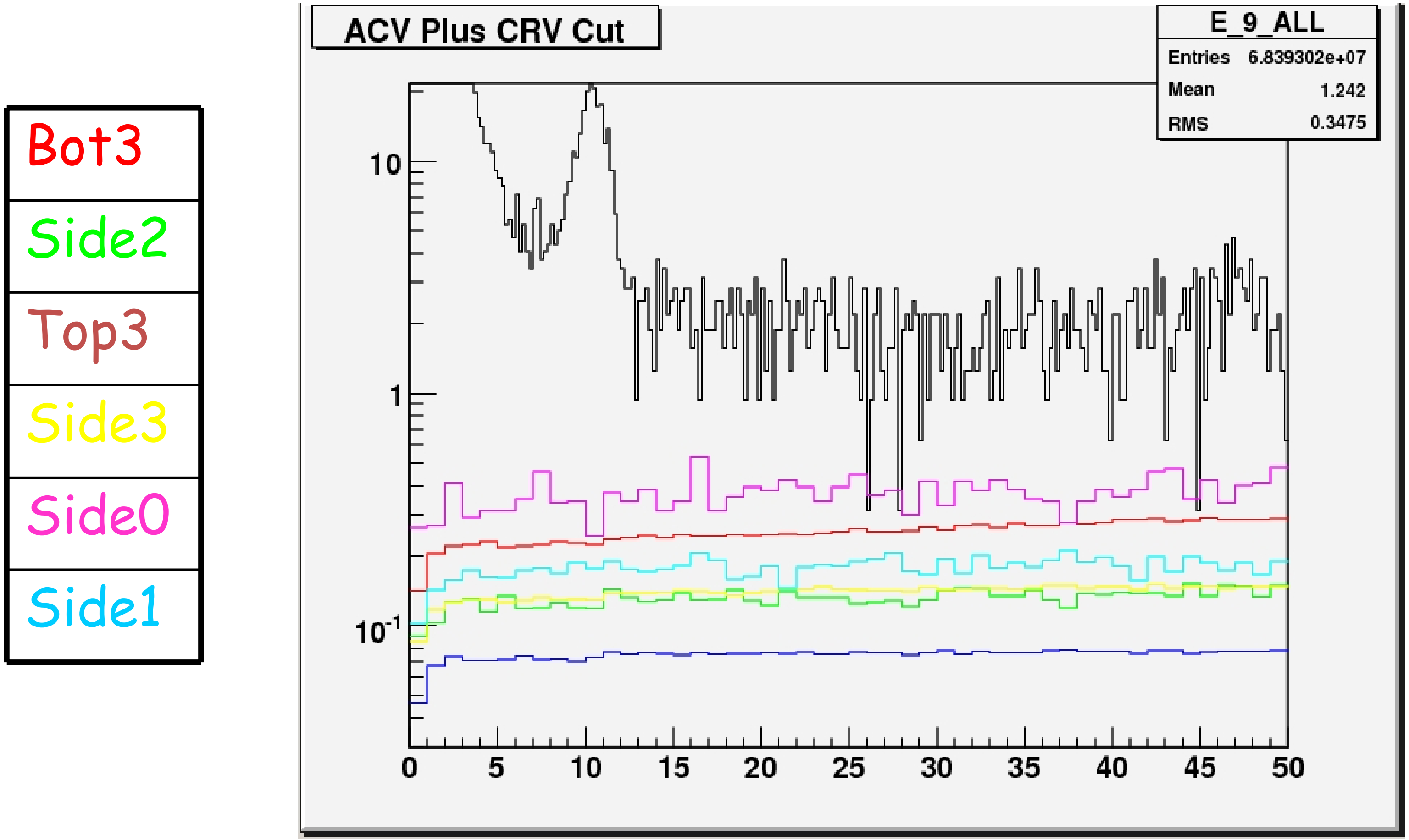
Scaled by the peak of 1.46MeV

Bot3
Side2
Top3
Side3
Side0
Side1



Gamma B.G. from ^{40}K

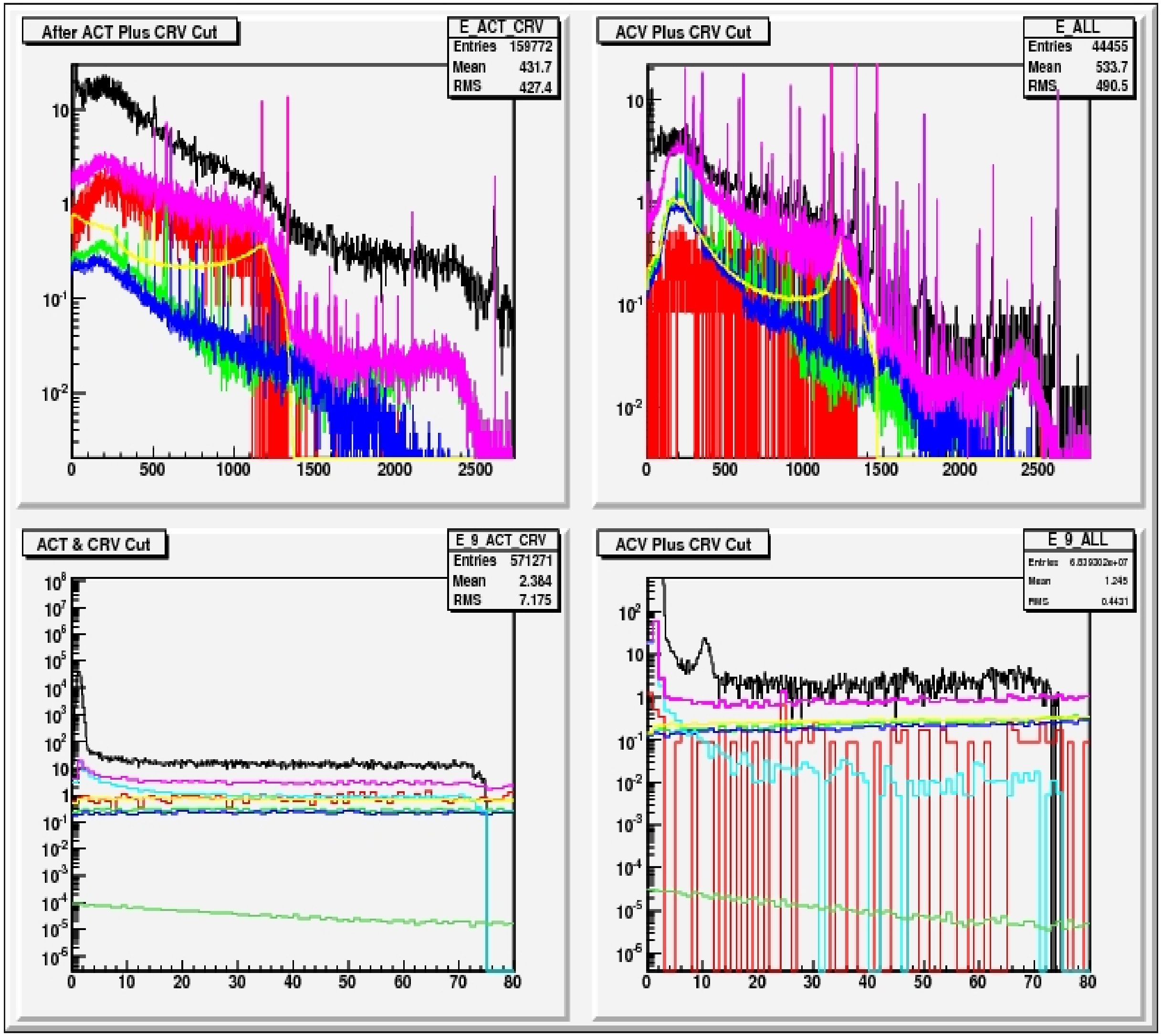
Scaled by the peak of 1.46MeV



The B.G. from ^{40}K is about: 0.23cpkkd (Bot3).

Result

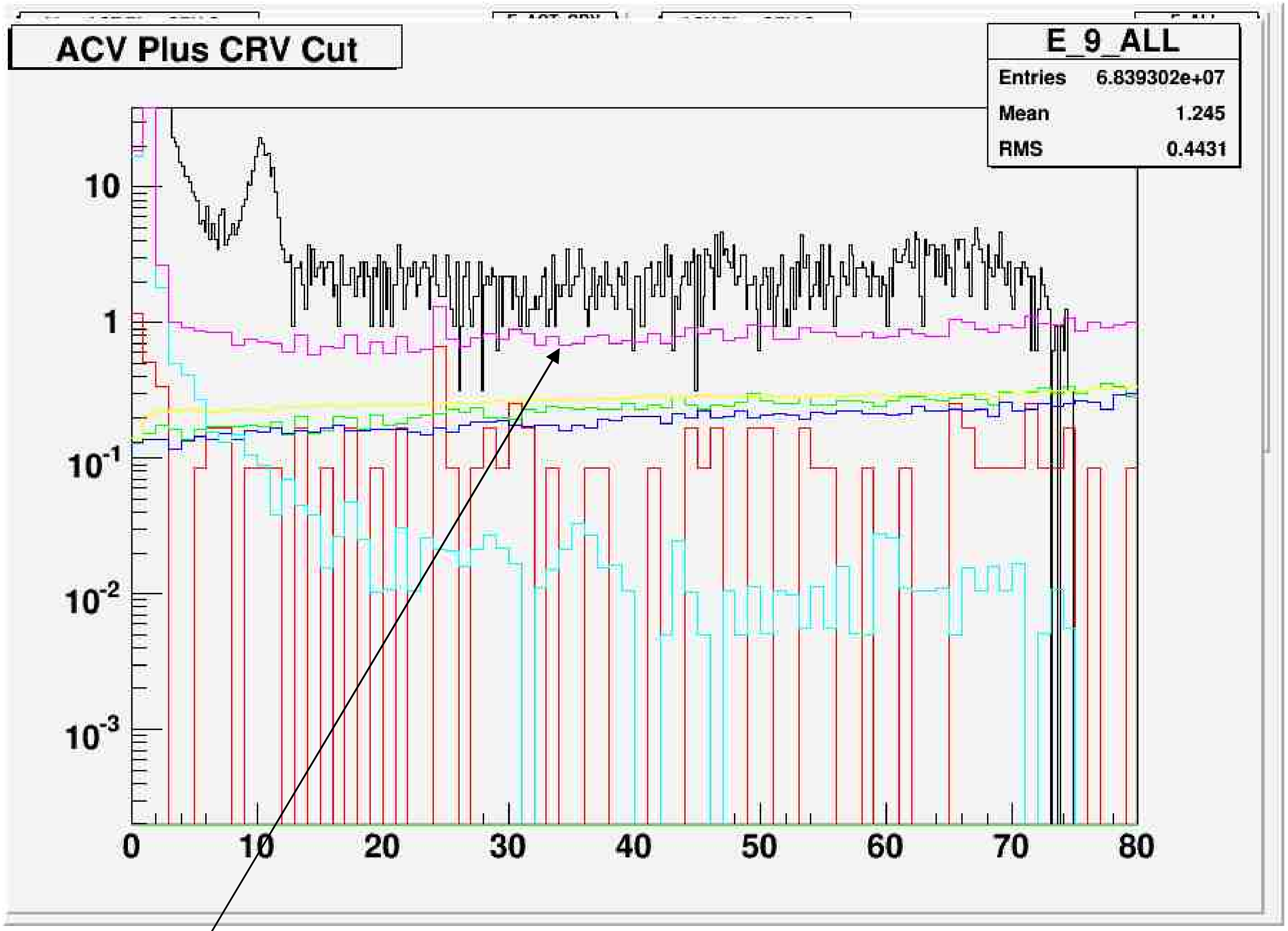
Those lines from all sources have been normalized.



Source: gamma
^{60}Co : Red line
^{40}K : Yellow line
^{238}U : Green line
^{232}Th: Blue line
All: purple line

Source: neutron
Cosmic ray
U,Th

Result



Adding all in one, we've explained the B.G. profiles below the purple line (~ 65% between 0 ~ 50keV), any uncertainties?

Conclusion

- At moment, from the M.C. simulation and real-data analysis, we could get the results: ^{232}Th, ^{238}U are closest to HPGe, most probably originating from the front-end pre-amplifier components located in the vicinity of HPGe;
- The line shapes are similar, so the results for ^{232}Th and ^{238}U are reasonable.
- About ^{60}Co's behavior, it comes most possibly from side part between NaI and copper shielding, it presents as dust in the environment, should be outside of HPGe. And the result for ^{60}Co is also fine and reasonable.
- We've explained ~ 65% of its B.G. at the low energy, from the above 4 main gamma B.G. sources. Next we will further refine this study, with the actual measurement and move to CDEX.

II. Simulation of neutron background induced by radionuclide for CDEX

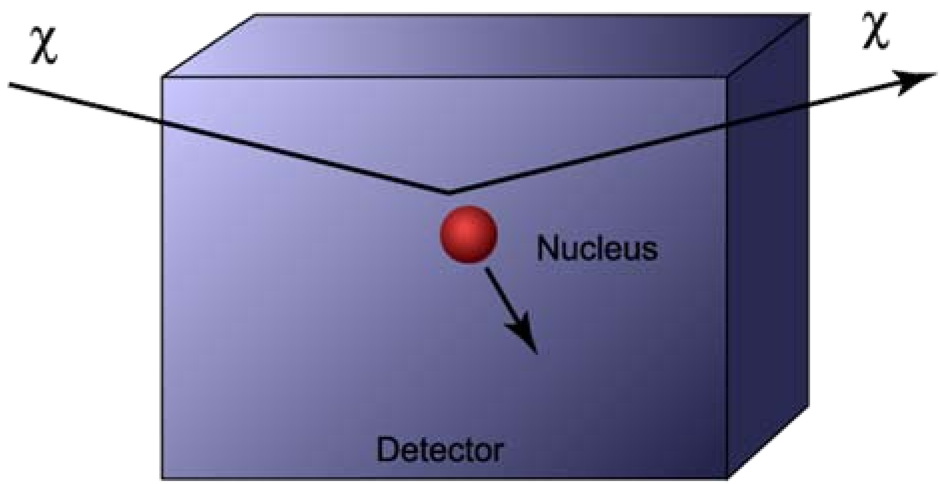
Pu Yang, Yin Xu, Qian Yue and me

Xinhui Hu joins us already.

1. Introduction

- As we know, CDEX Collaboration aims at searching for WIMP directly by using ULE-HPGe detector.
- CJPL is located in the tunnel of JinPing Mountain with a vertical depth more than 2400m overburden of Rock, $CaCo_3$, which can strongly reduce cosmic rays.
- Such kinds of experiment are rare-event and work at a very low energy threshold.
- These extremely rare events are difficult to be distinguished from other more ordinary signals which come from cosmic rays and natural radioactivity.
- So to suppress B.G. as lower as possible is absolutely needed, and a complex shielding system has been designed for it.

Motivation



- WIMP + nucleus WIMP + nucleus, measuring the nuclear recoil energy

- neutron is known to be one of most important B.G. sources to CDEX.
- Neutron induces low-energy single nuclear recoil in the detectors indistinguishable from the expected WIMP signal.
- Its B.G. level needs to be understood.

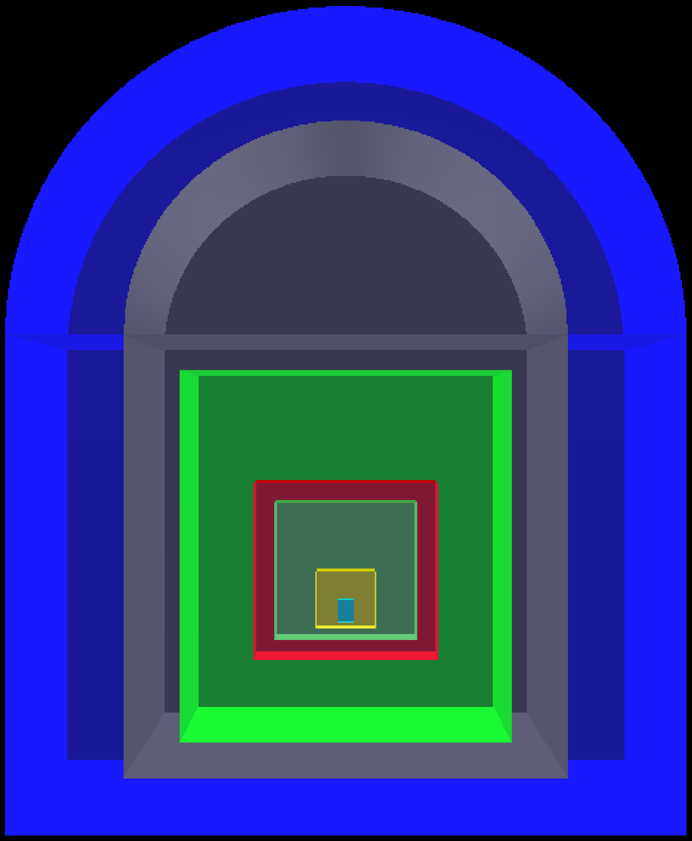
2. Shielding system designed for CDEX

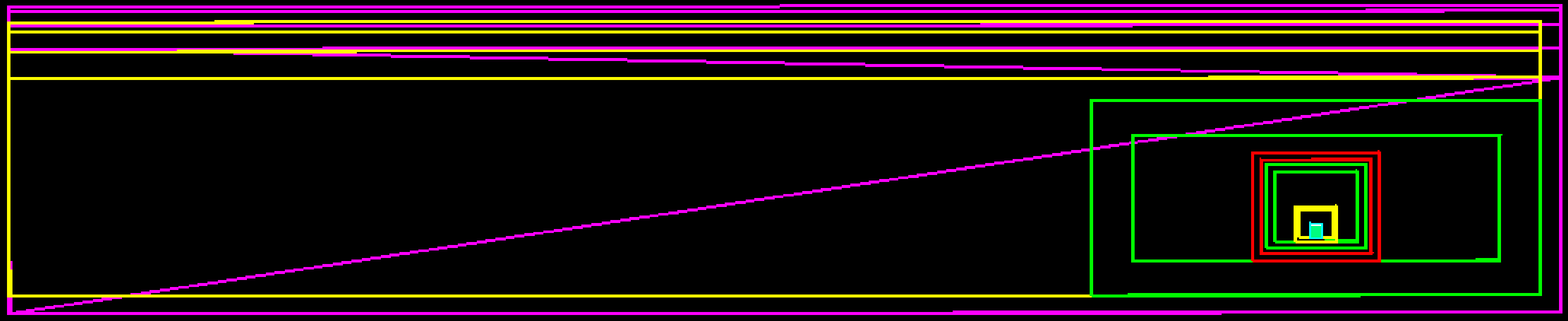
- Dimension of CJPL: $7.5 \times 8.5 \times 40 m^3$
- Depth of rock: 2m
- Depth of concrete: 50cm
- Dimension of Shielding system: $6.5 \times 5.6 \times 11 m^3$ from outer to inner orderly: Polythene, Pb, Support, Boron-doped-Polythene and Cu
- ULE-HPGe detector space

We also implement the code and method for it based on Geant4.

Geant4 Geometry

	Thickness (cm)	Outer Size (cm)			Density (g/cm^3)
		Width	Length	Height	
Rock	200	1150	4000	1250	2.7
Concrete	50	750	3800	850	2.162
Polythene	100	650	1100	560	0.96
Lead	20	310	310	310	11.35
Support	15	270	270	270	0.13
Boron-doped-Polythene	20	240	240	240	0.99
Copper	10	100	100	100	8.96
HPGe space		80	80	80	





3. Sources of neutron

- The neutron B.G. mainly arises from two sources:
  - Cosmic-rays muon
  - Local radioactivity

- CDEX is located 2400m overburden, and cosmic-rays have been reduced so much. We mainly discuss the neutrons from the second source here.

Local Radioactivity

- The radioactive nuclide produces neutrons via:
  - Spontaneous fission
  - (α, n) reactions

- The (α, n) reactions are initiated by alpha from radioactive decays of Uranium and Thorium embedded in all materials of CJPL, we mainly considered four different places: the surrounding rock ($CaCO_3$), concrete layer, lead layer and copper layer.

1. Introduction

- The radioactivity of rock and concrete samples at CJPL have been measured by Tsinghua University:

	Nuclides	
	232Th	238U
Rock ($CaCO_3$)	< 66.3ppb	147.3 ± 16.4ppb
Concrete	< 992.8ppb	< 798.2ppb

4. Monte Carlo simulation and result

(1) Neutron yields and energy spectra from (alpha, n)

- The Ref as follow and http://neutronyield.usd.edu calculated the neutron yields and energy spectra, which are via interactions of alphas in uranium or thorium decay chains with different nuclei such as: H, C, O, Al, Si, Fe, Ca, Mg and Cu

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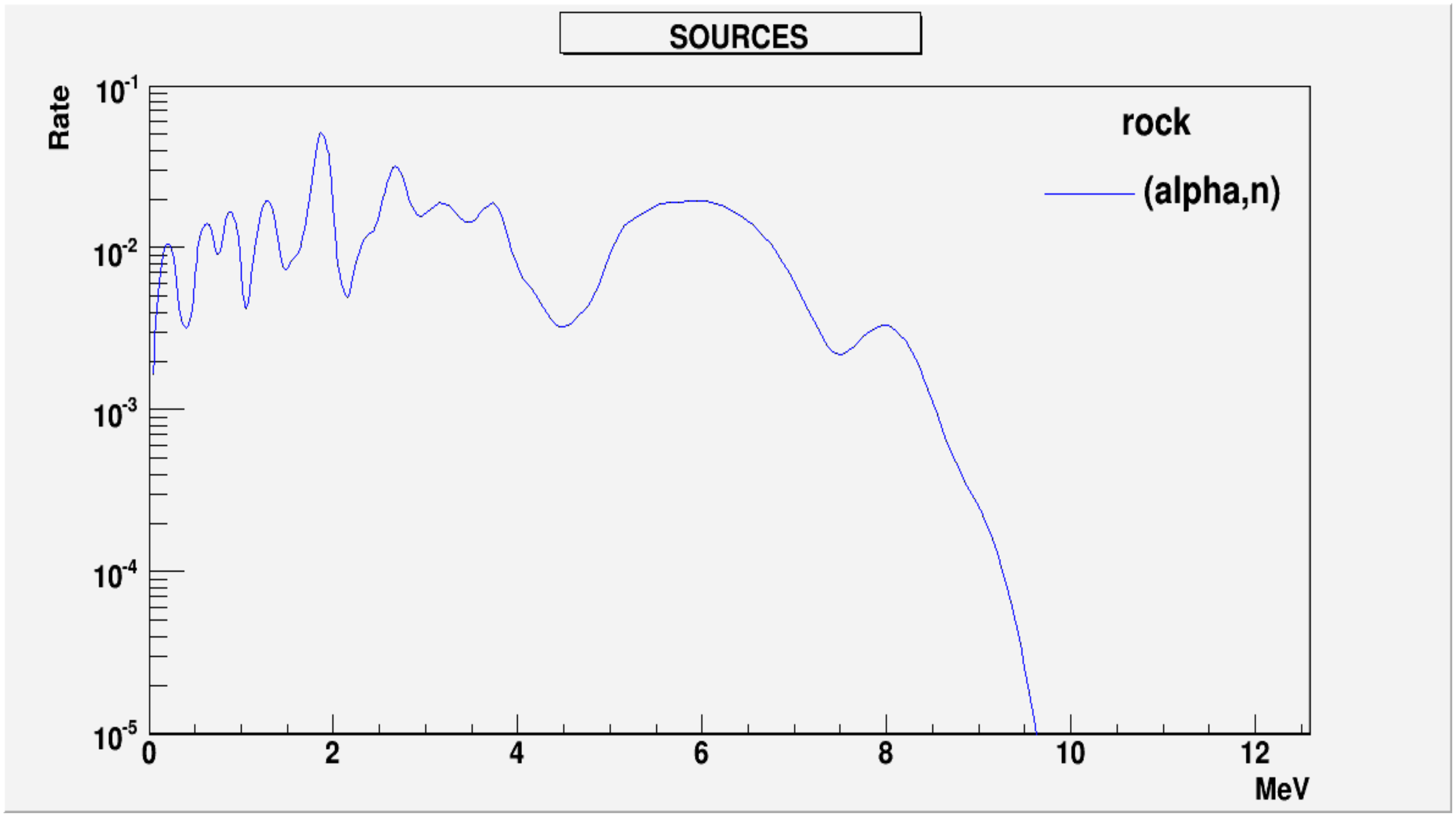
Evaluation of (α, n) induced neutrons as a background for dark matter experiments

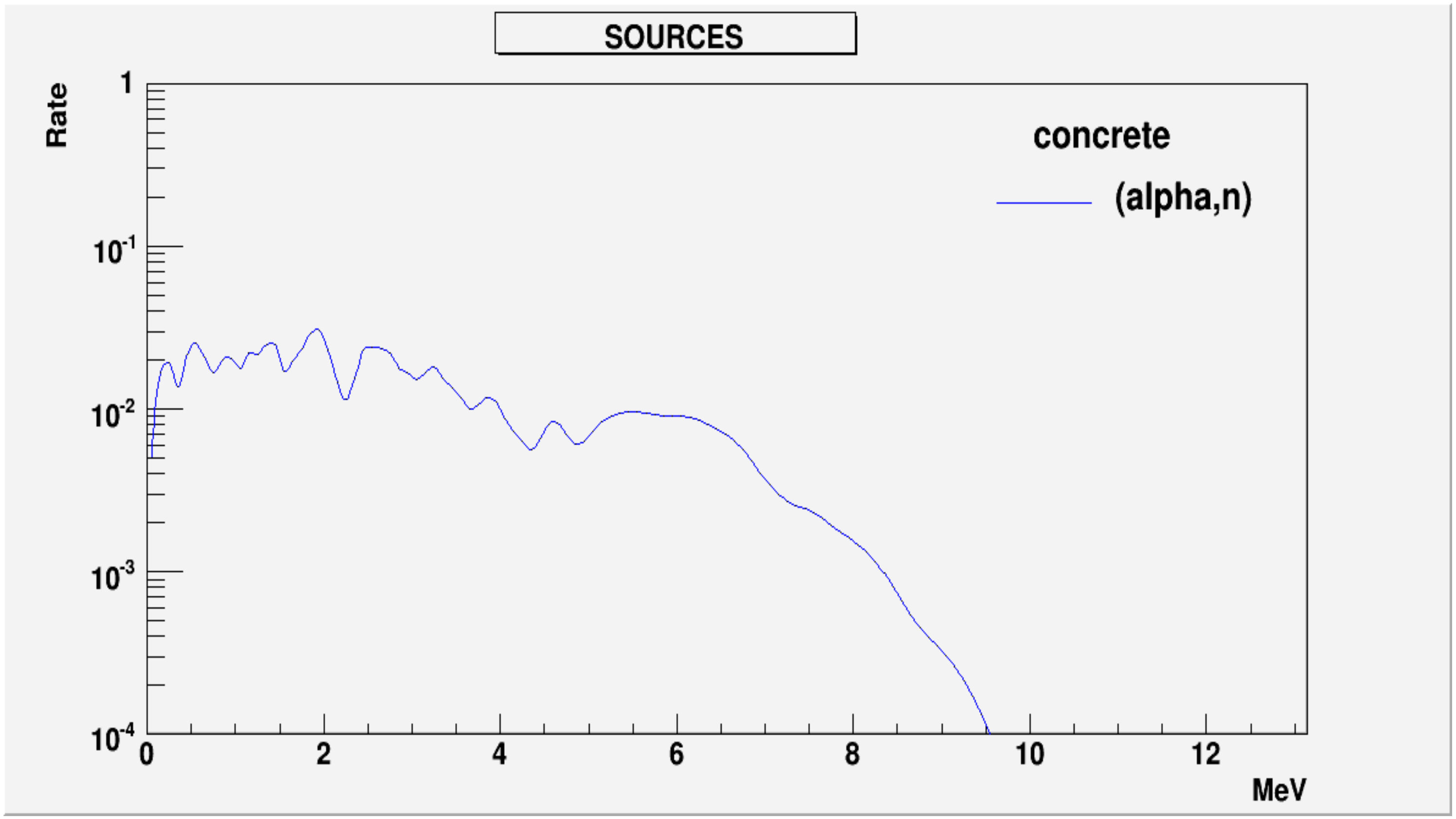
D.-M. Mei [a,*], C. Zhang [a,b], A. Hime [c]

[a] Department of Physics, The University of South Dakota, Vermillion, SD 57069, USA
[b] College of Sciences, China Three Gorges University, Yichang 443002, China
[c] P-23, H803, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

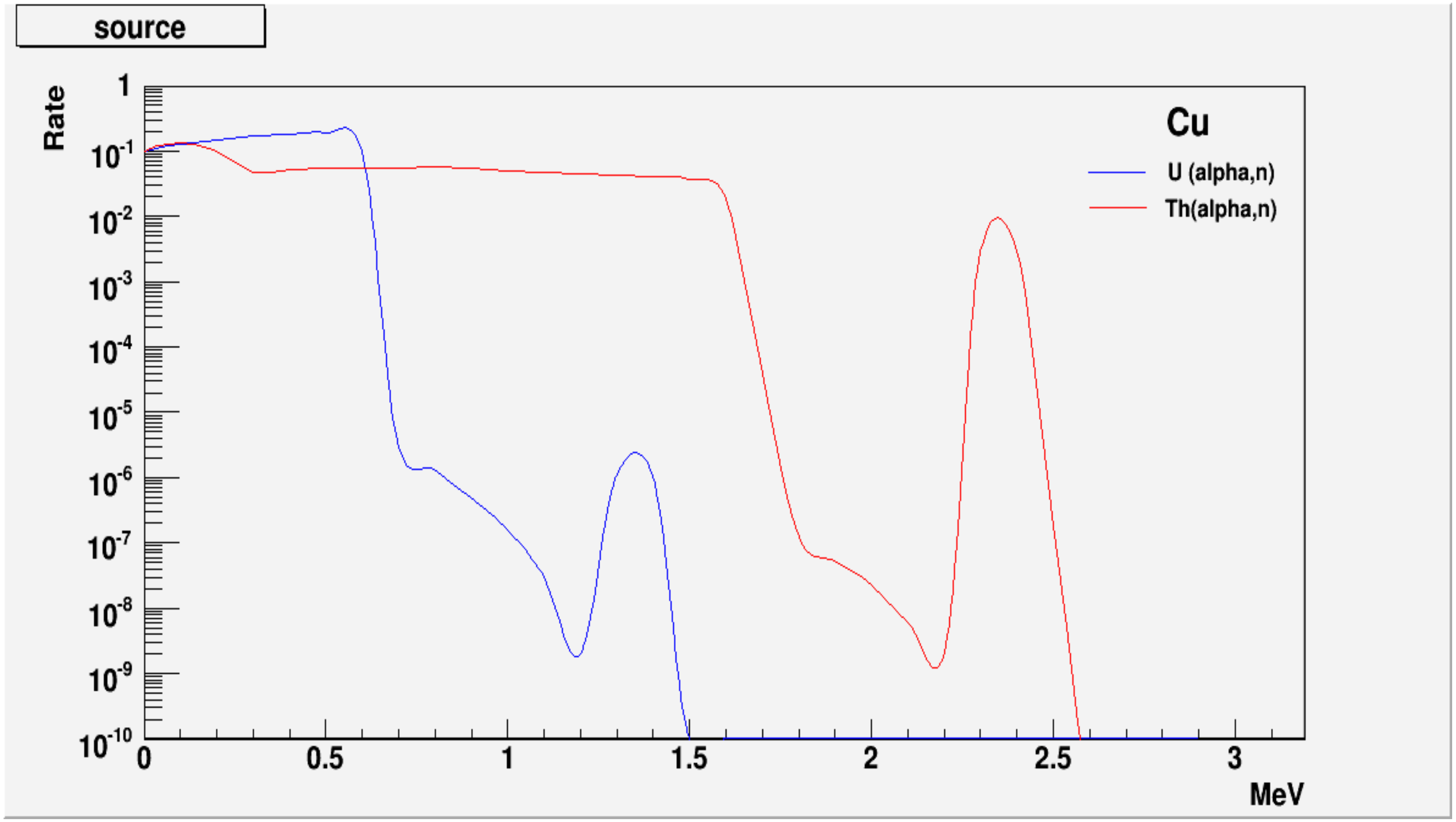
- Neutron energy spectrum yielded (alpha, n) in rock: Ra-226, 0.27Bq/kg; Th-232, 1.8Bq/kg



- Neutron energy spectrum yielded from (alpha, n) in concrete
  Ra-226, 9.914Bq/kg; Th-232, 4.016Bq/kg



- Neutron energy spectrum yielded from (alpha, n) in Cu

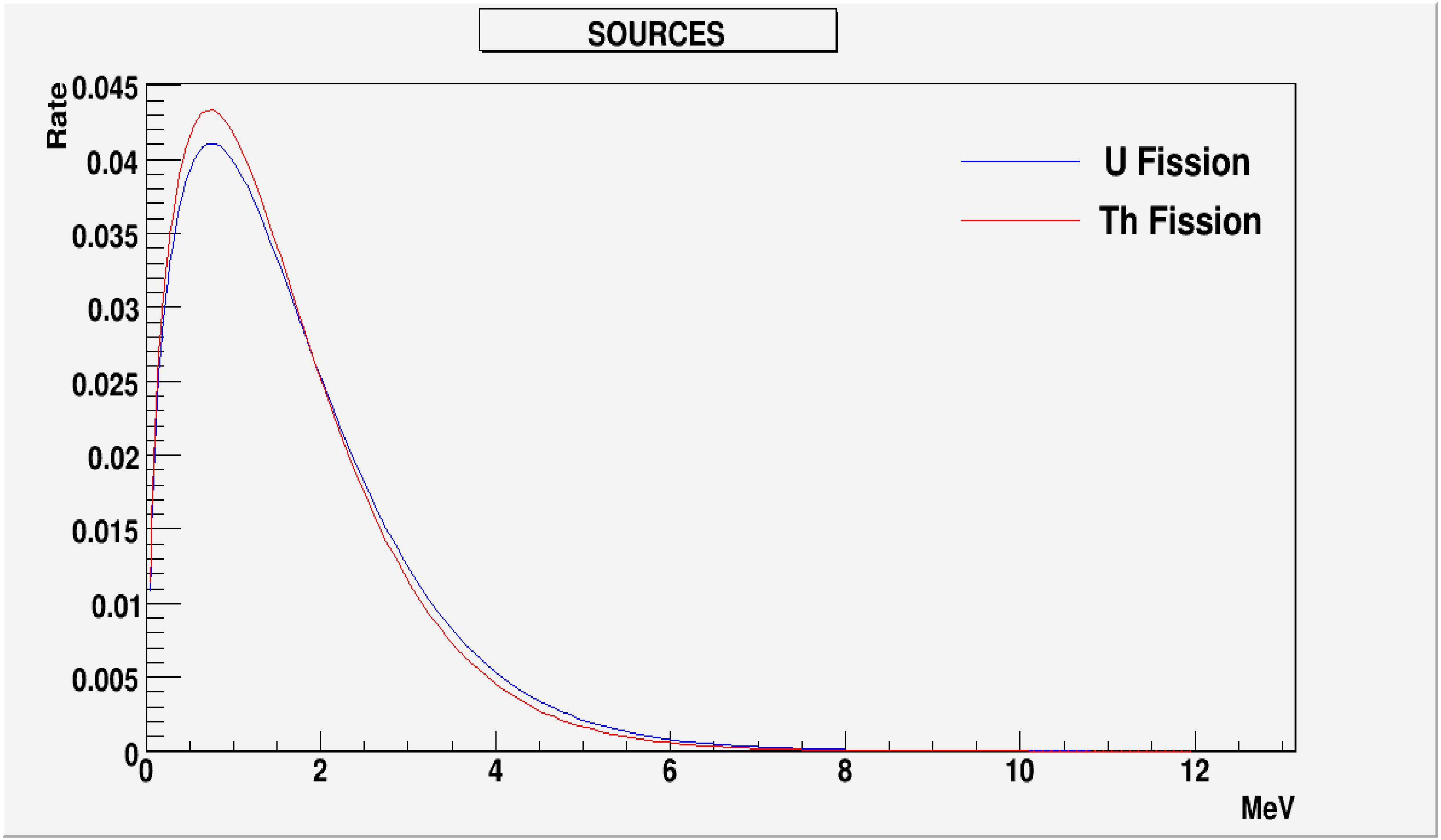


(2) Spontaneous fission neutron spectrum

- Watt spectrum is used as the spontaneous fission neutron spectrum:
  - $f(E) = C\exp(-E/A) \times sh(BE)^{\frac{1}{2}}$, $E_{min} \leq E \leq E_{max}$, where A, B, C, E_{min} and E_{max} are related to the different isotopes.

Isotope	Parameters of Fission Spectrum	
	A	B
^{232}Th	0.5934	8.030
^{238}U	0.6483	6.811
^{235}U	0.965	2.290
^{234}U	0.7712	4.924
^{230}Th	0.6620	6.528

Neutron Spectrum from U and Th Spontaneous fission

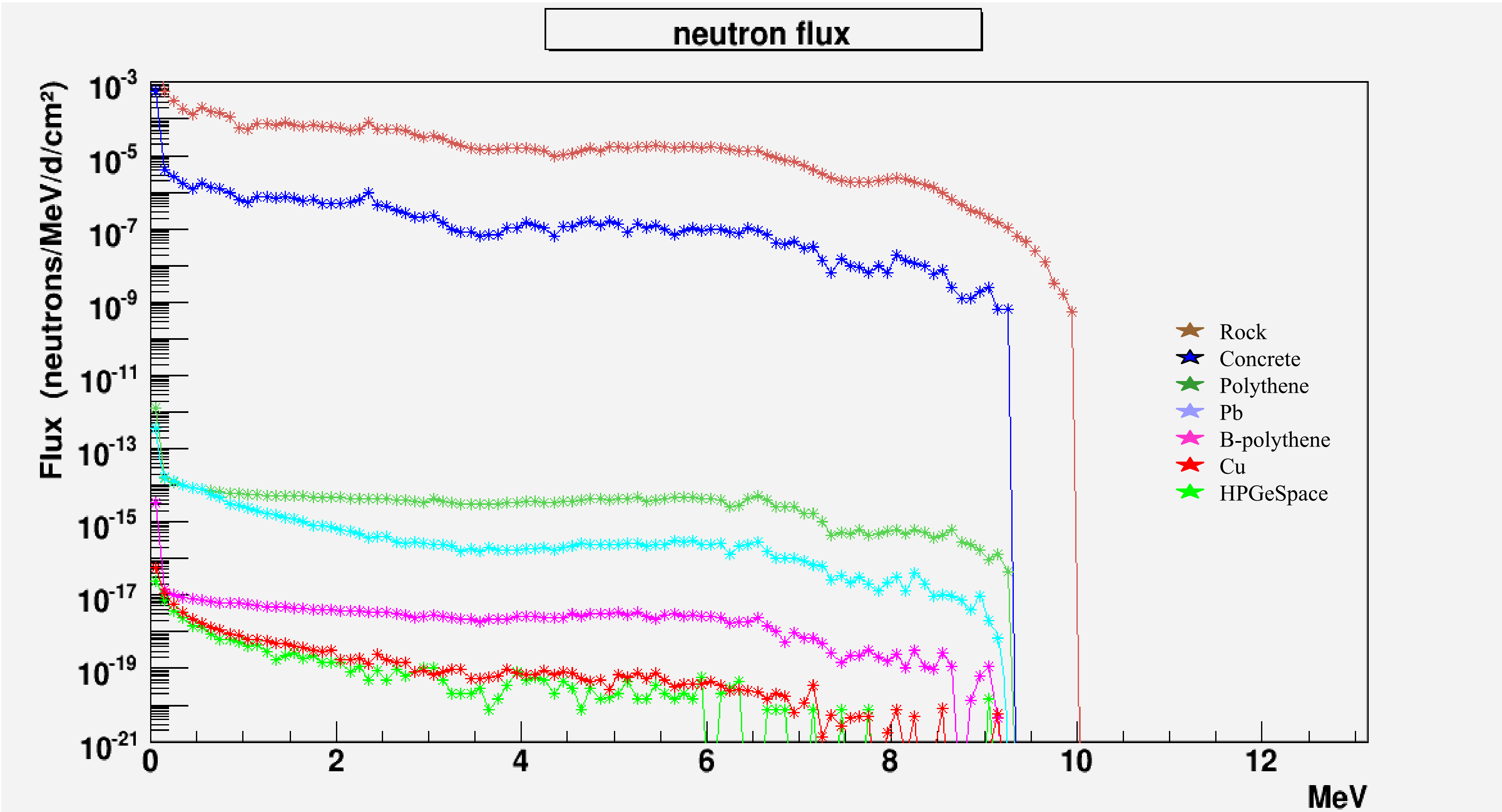


(3) Result

- Neutron energy was sampled according to its energy spectra from two above sources.
- Set the neutron located in different fields: rock, concrete, Pb and Cu;
- Set the direction of initial momentum isotropicly.

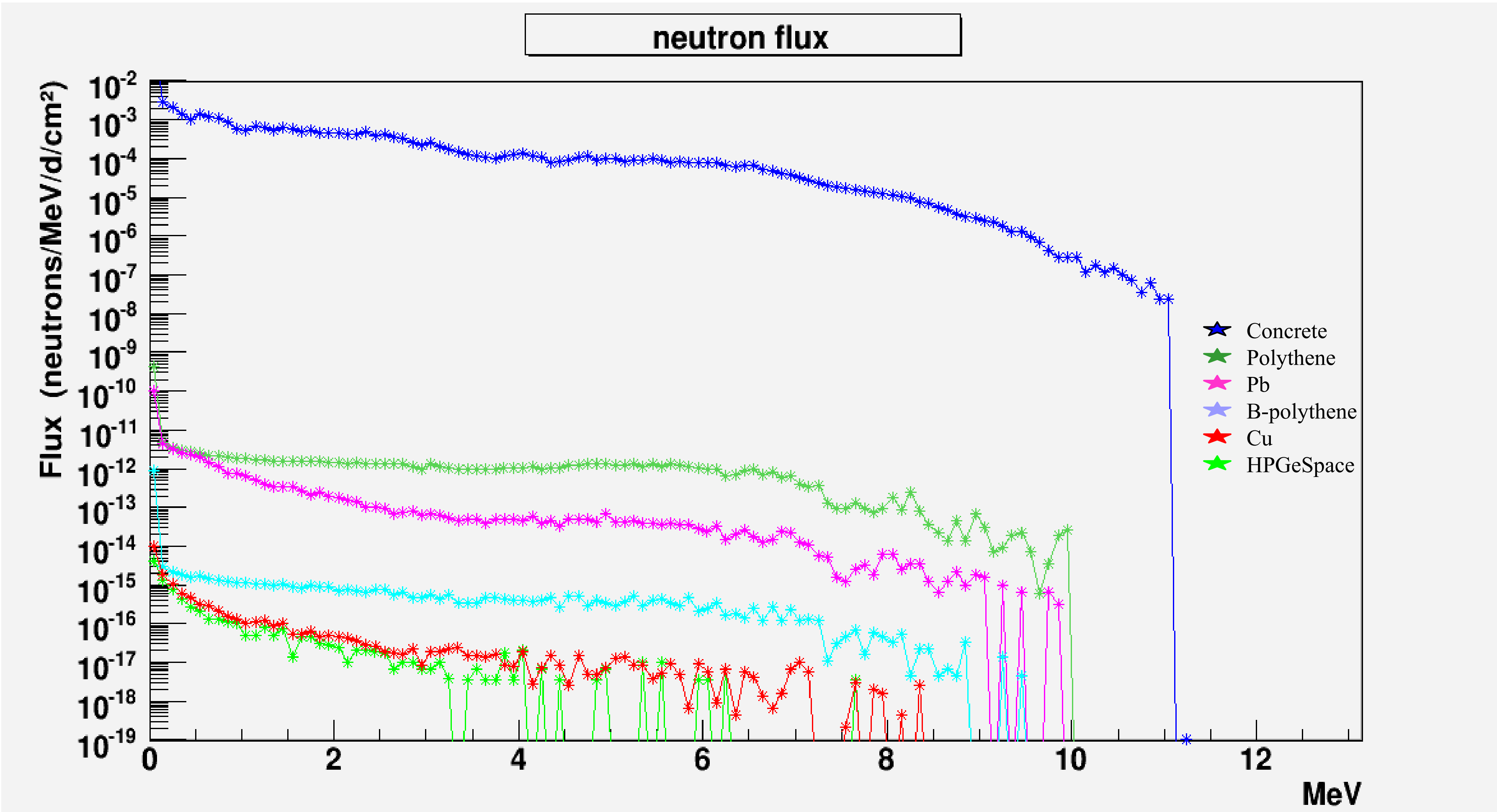
- Finally simulate the neutron behaviors.

Rock (^{226}Ra: 0.27Bq/kg; ^{232}Th: 1.8Bq/kg)



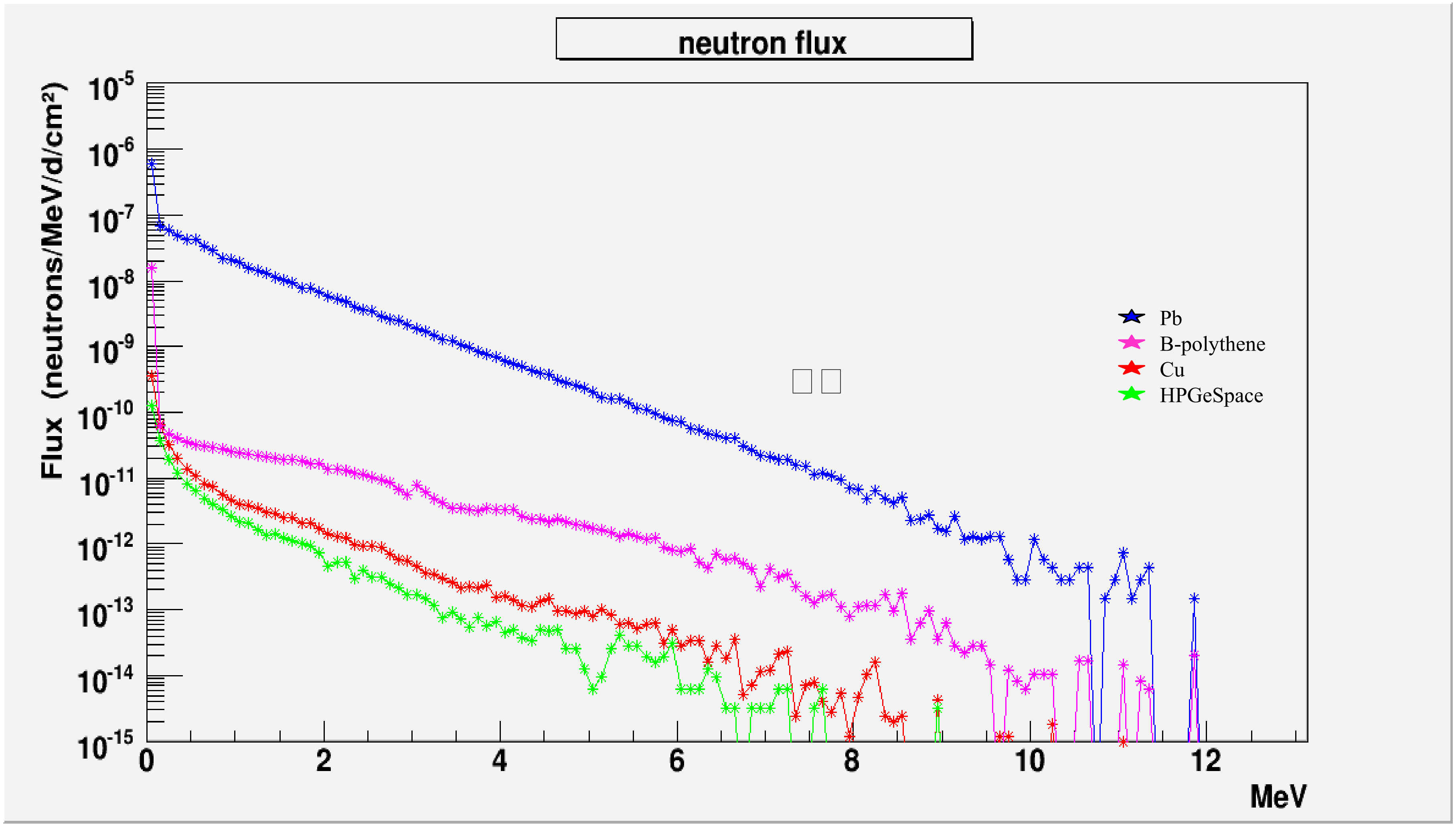
Layers	Flux (neutrons * cm^{-2} * day^{-1})
Rock	1.734e-2
Concrete	5.952e-4
Polythene	1.583e-12
Pb	4.483e-13
B-Polythene	3.656e-15
Cu	9.029e-17
HPGe-Space	4.681e-17

Concrete (^{226}Ra: 9.914Bq/kg; ^{232}Th: 4.016Bq/kg)

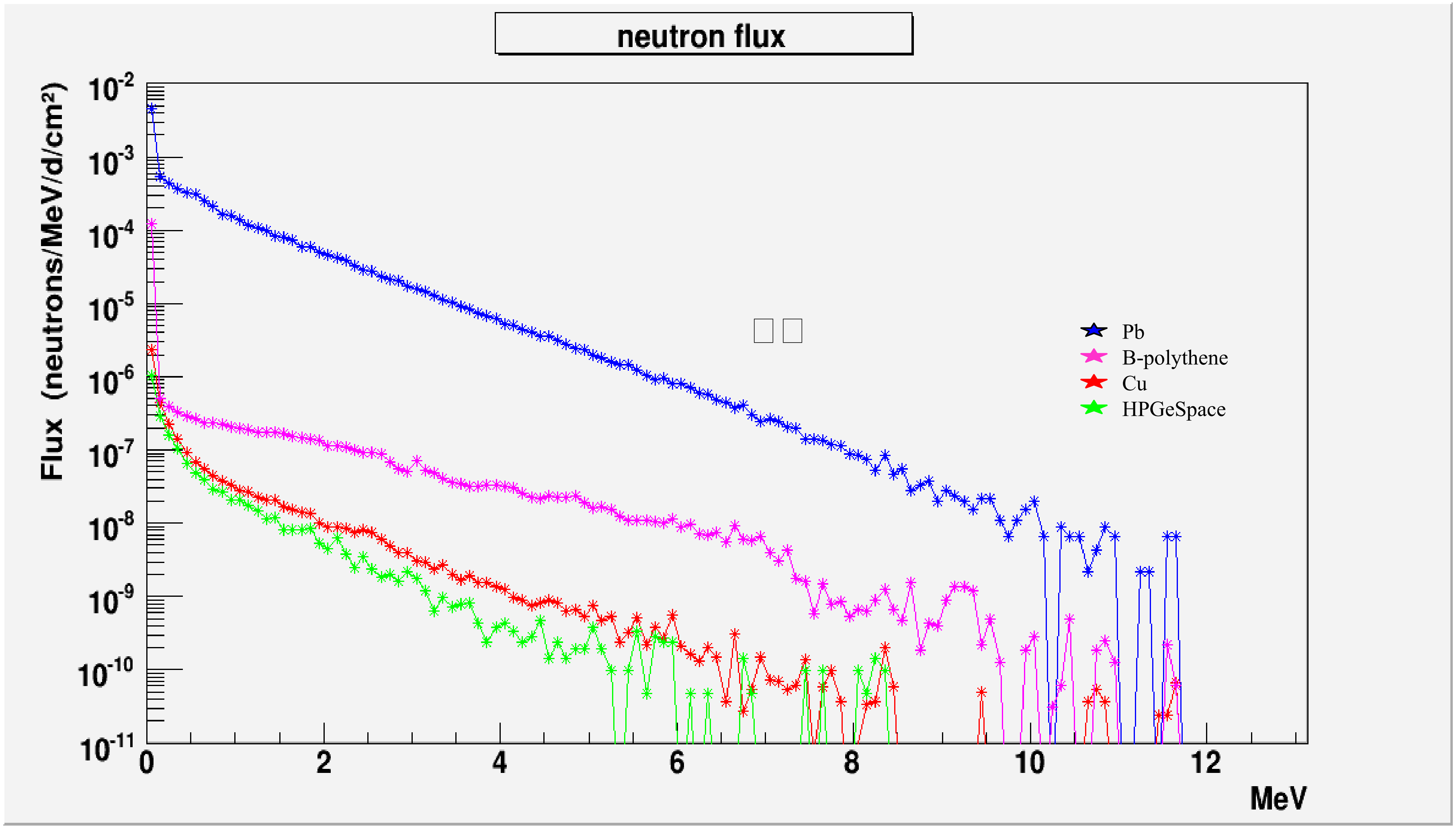


Layers	Flux (neutrons * cm^{-2} * day^{-1})
Concrete	9.438e-2
Polythene	5.150e-10
Pb	1.295e-10
B-Polythene	9.114e-13
Cu	1.690e-14
HPGe-Space	8.505e-15

Pb (^{238}U 1 ppm, ^{232}Th 1 ppm, estimated higher)



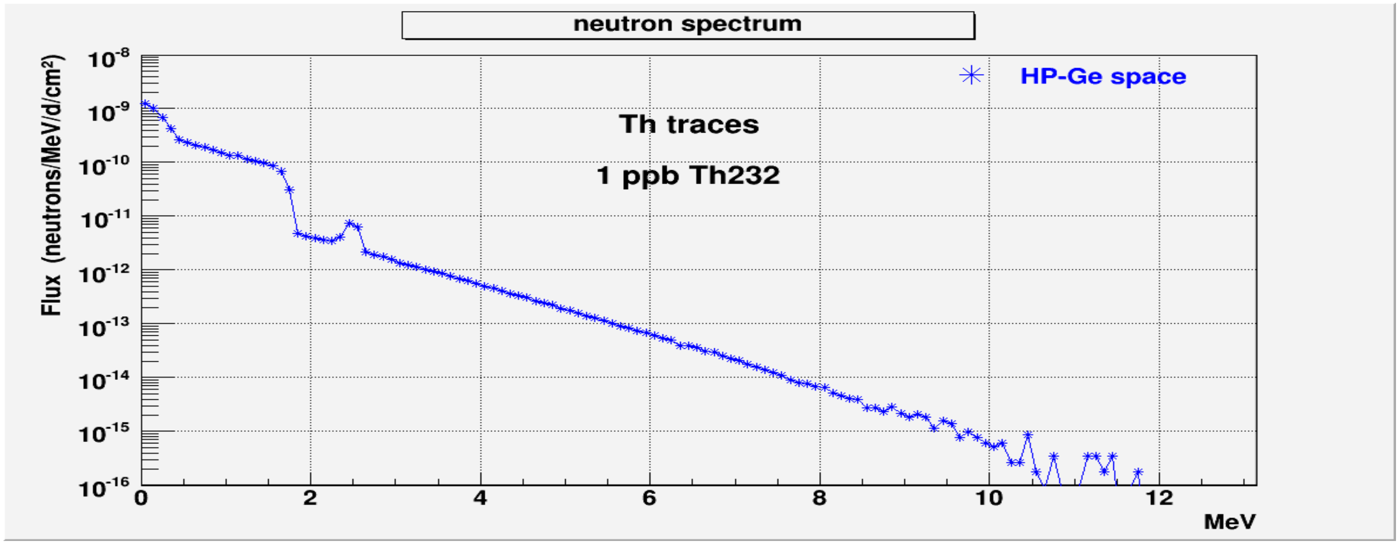
Pb (^{238}U 1 ppm, ^{232}Th 1 ppm, estimated higher)

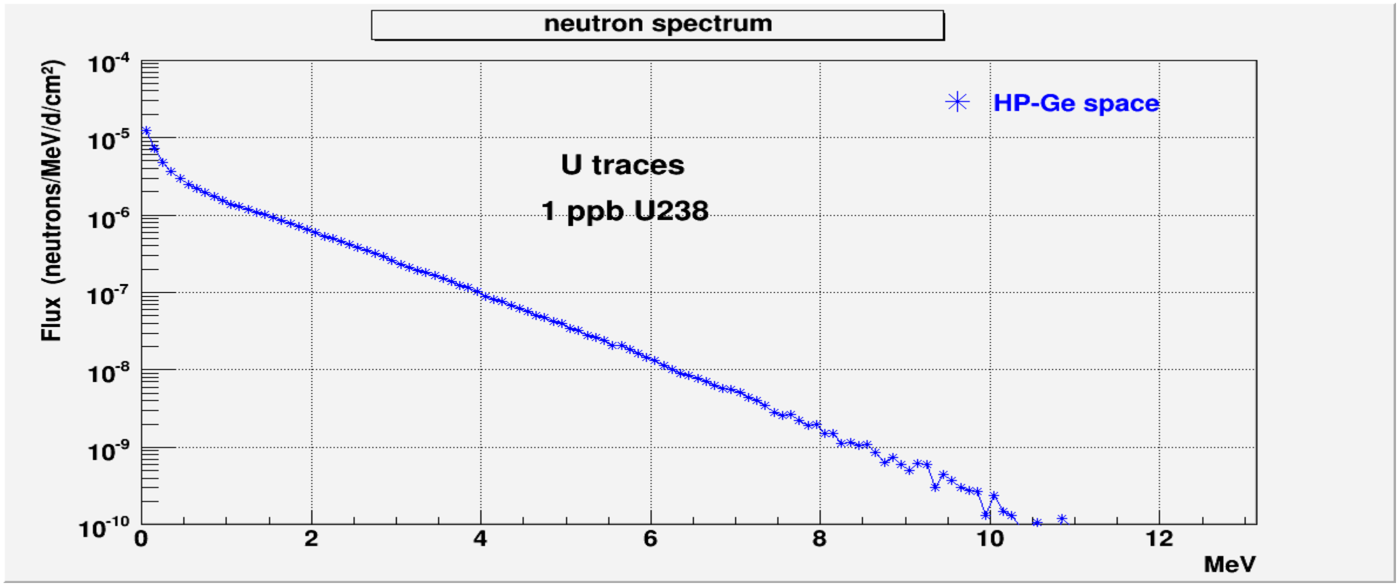


Layers	Flux (neutrons * cm^{-2} * day^{-1})		
	U	Th	Total
Pb	8.648e-3	1.136e-6	8.648e-3
B-Polythene	1.290e-4	1.664e-8	1.290e-4
Cu	3.802e-6	5.625e-10	3.082e-6
HPGe-Space	2.012e-6	2.441e-10	2.012e-6

Cu (^{238}U 1 ppb, ^{232}Th 1 ppb, estimated higher)

- The results are as follows:





Neutron Flux entering HPGe

Layers	Flux (neutrons * cm^{-2} * day^{-1})		
	U	Th	Total
HPGe-Space	5.744e-5	5.414e-9	5.745e-5

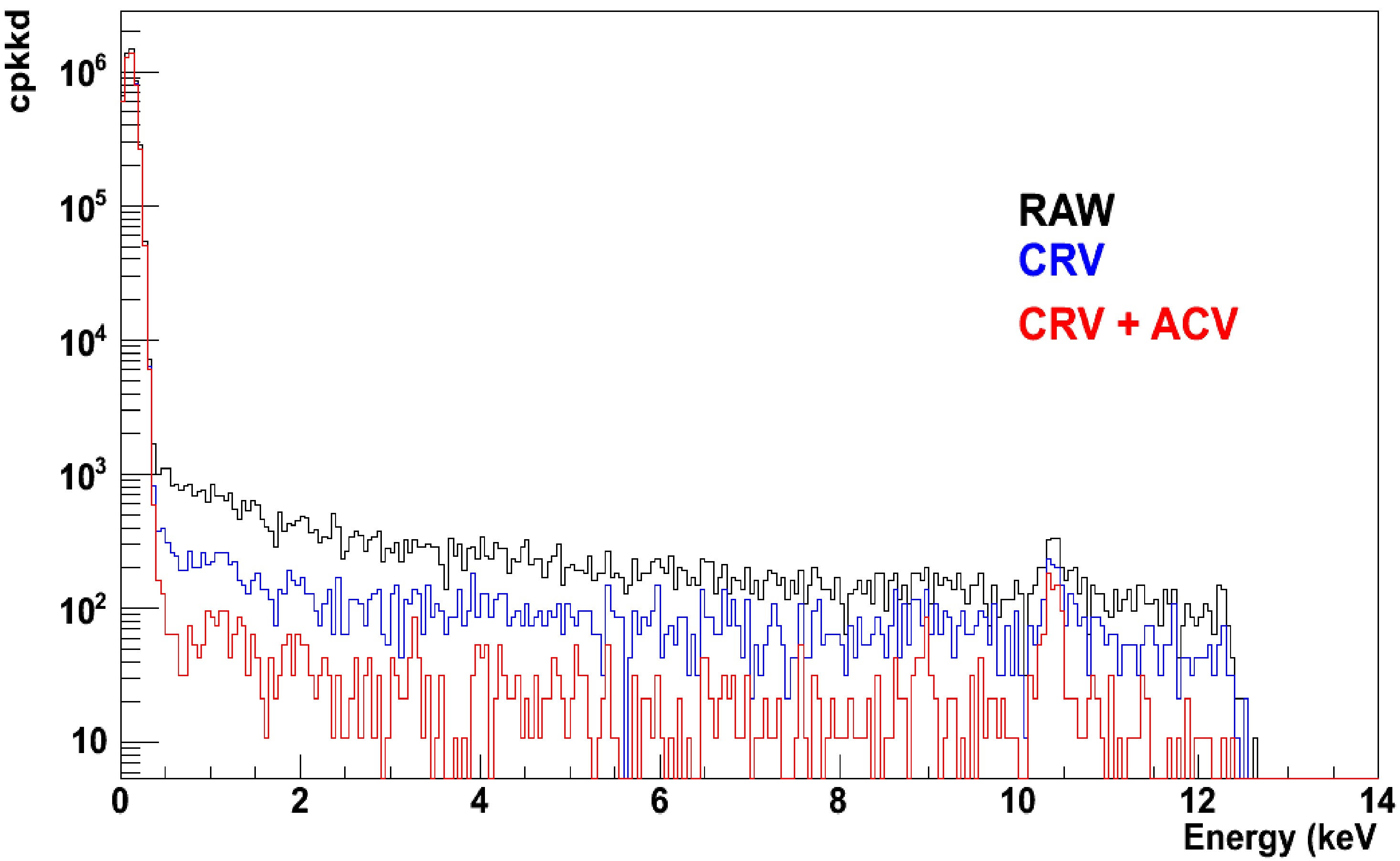
5. Conclusion

- The neutrons produced from local radioactivity in different places through our design proposal of shielding system are simulated. The neutron B.G.s are reduced effectively by shielding system.
- The neutron flux, induced from the surrounding rock, concrete layer, lead layer and copper layer, to HPGe space, are: 4.68e-17, 8.50e-15, 2.01e-6 and 5.74e-5 ($cm^{-2} \times day^{-1}$), respectively. So the main contaminations of neutron are from Pb and Cu.
- Next plan: we'll continue to tune the MC parameters with a comparison with the actual data measured in-situ and we're planing to send student there.

III. Data analysis

- Because CDEX ~ 0.5Tera - byte of data will be taken per week in the future, a huge database, it needs more manpower with all best efforts.
- Nankai is going to build a pc-farm for both its data analysis and simulation, each member of us being able to login on it.
- At moment, several new manpower's will, promisingly, join with us and come for it.
- Here show you a brief result of TEXONO, having not more meaning. Sooner, we will show you CDEX data analysis, to understand each phase such as how to calibrate its energy, how to calculate live-time and dead-time so on.

Data analysis: TEXONO data



Data base: 2009/02/20 (provided by us)

Conclusion

- We've simulated
  - the B.G. Gamma source affect on TEXONO detector
  - and the neutron B.G. source from Rock around CJPL influence on CDEX detector
  - obtained a preliminary and reasonable result.
- We'll continue the above works, trying to find a method for verifying the results:
  - Environment B.G. affect to CDEX
  - Both Gamma and neutron B.G. source around Detector affect to CDEX
  - We'll do the CDEX data analysis too.
  - Fortunately several students will promisingly join us in the next semester.
- We'll hold a CDEX workshop in May or later this year.

We are at a very exciting era of DM physics.
Stay tuned ...

Thanks a lot! Danke!