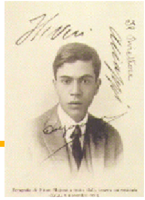
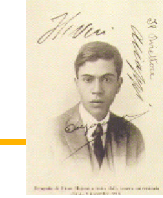


Simulation studies of muon-produced background events deep underground

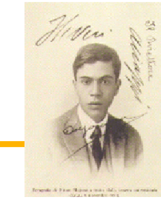
- a side for the next generation 0νββ experiment -

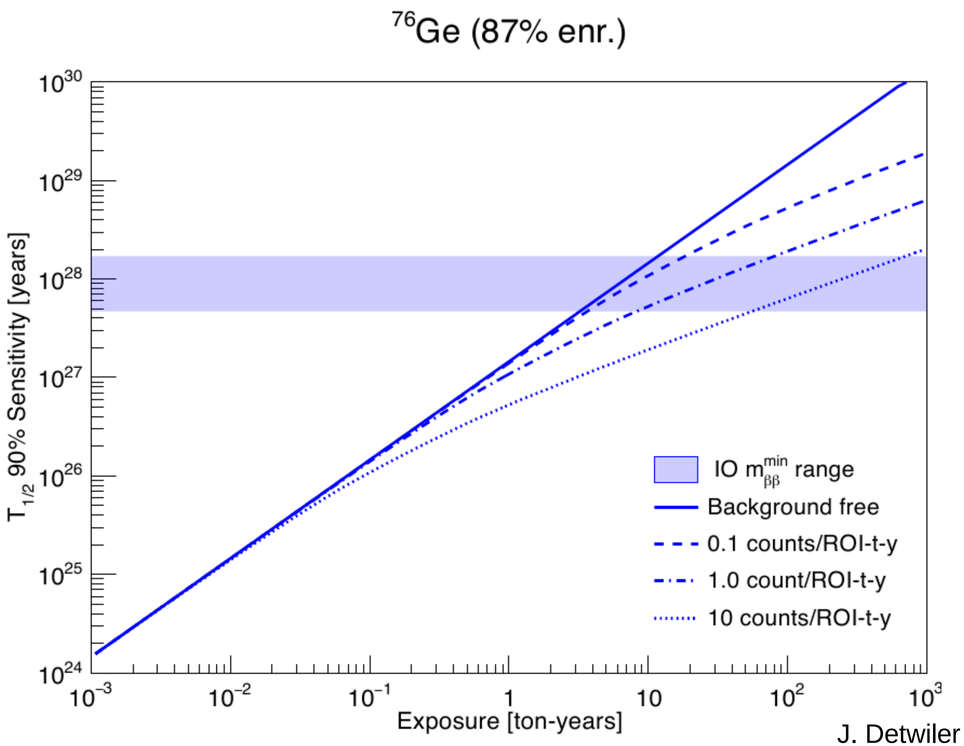
Ralph Massarczyk (LANL)

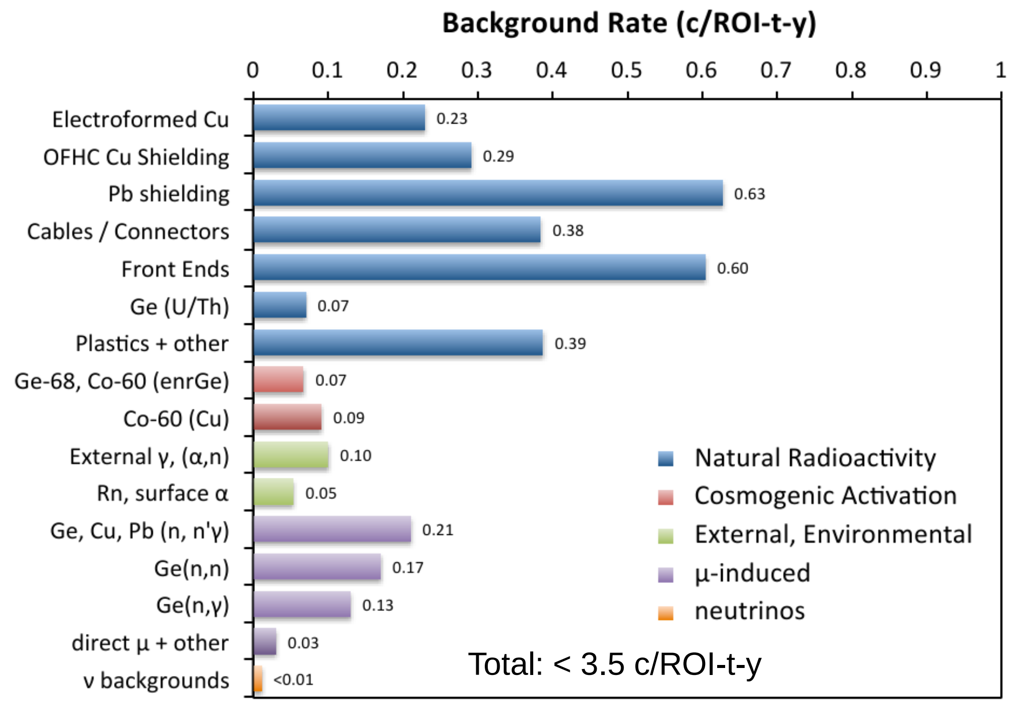


- Muon flux simulations
- Evidence of cosmogenic neutron

Sensitivity, Background and Exposure



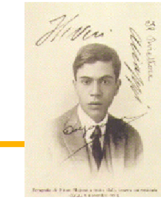


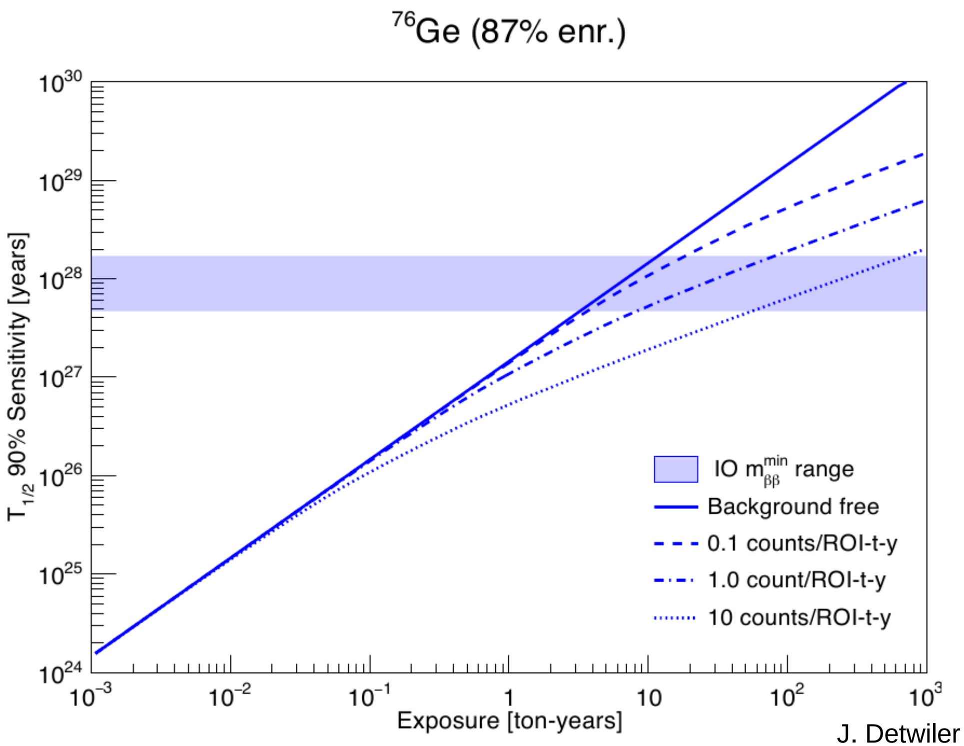


less background – higher discovery potential

current MAJORANA Demonstrator background budget

Sensitivity, Background and Exposure





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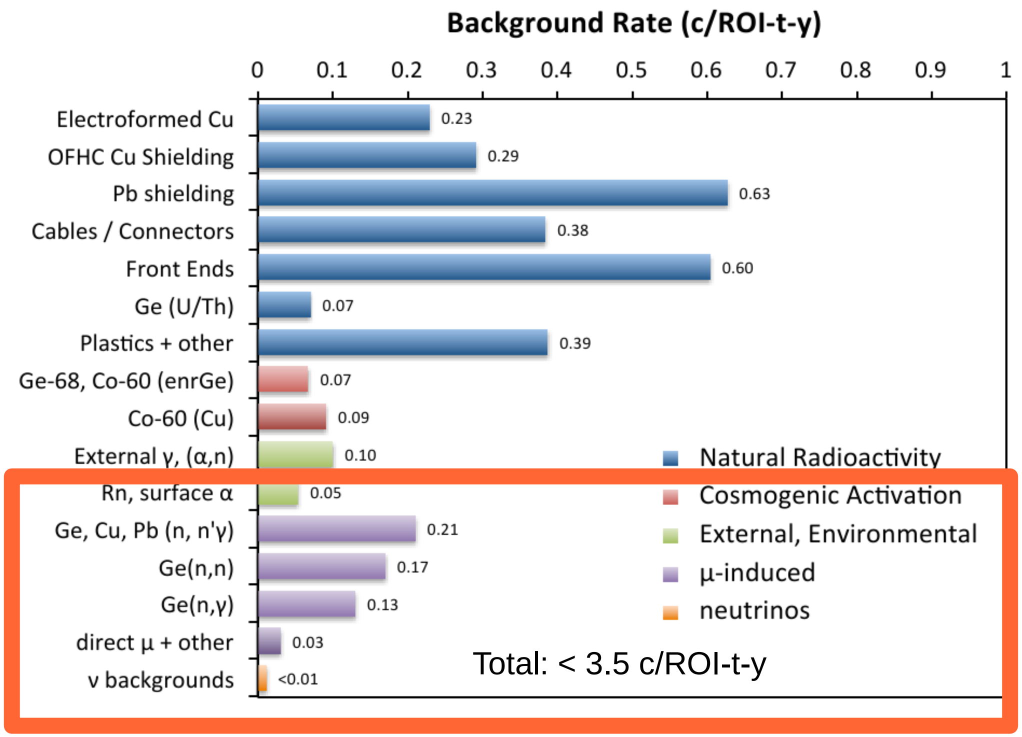
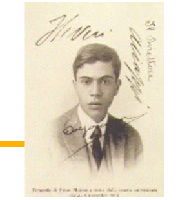


current MAJORANA Demonstrator
background budget

about 20 % from cosmogenics

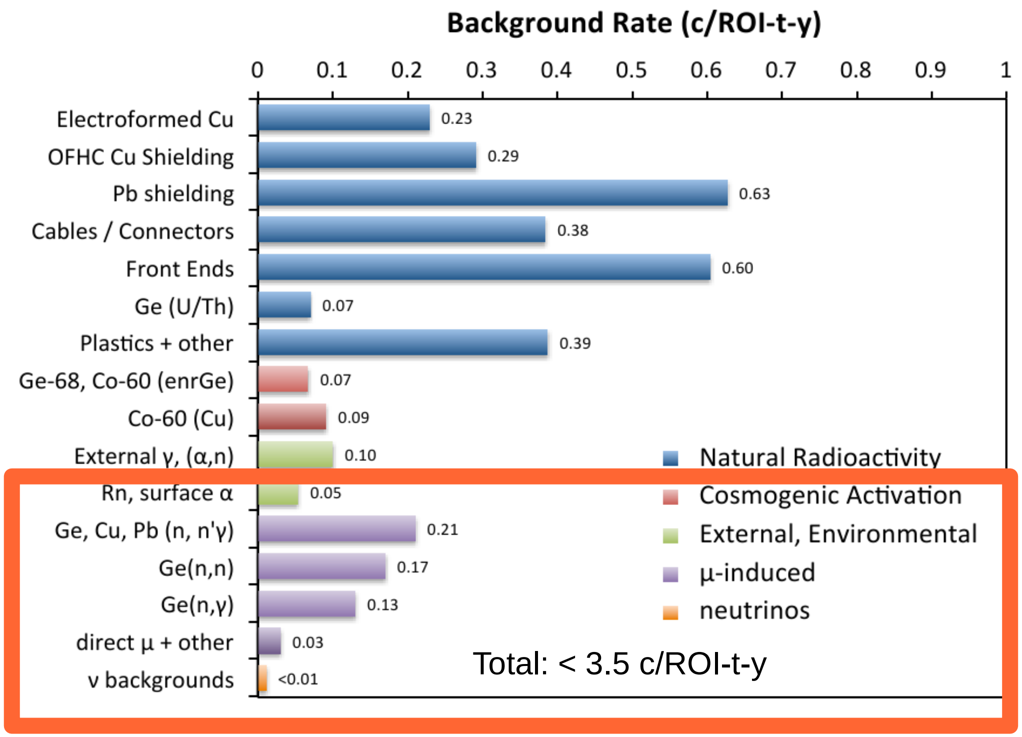
Sensitivity, Background and Exposure



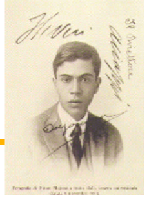
next generation experiment

reduced due to self shielding

proportional to the muon flux



current MAJORANA Demonstrator background budget



Previous studies

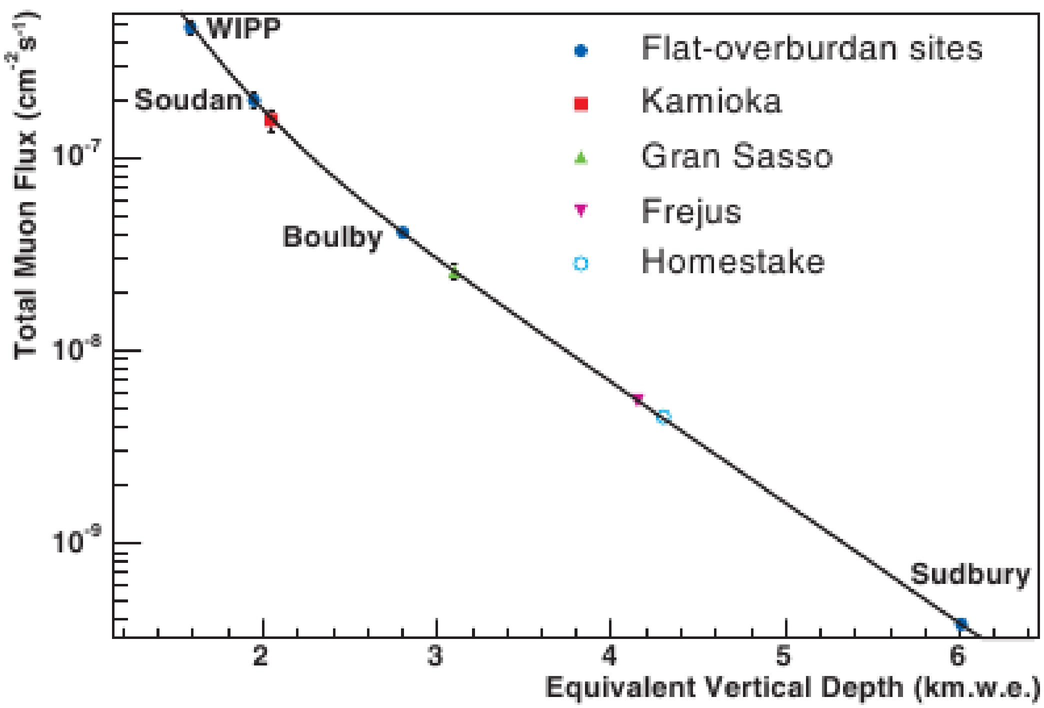
PHYSICAL REVIEW D **73,** 053004 (2006)

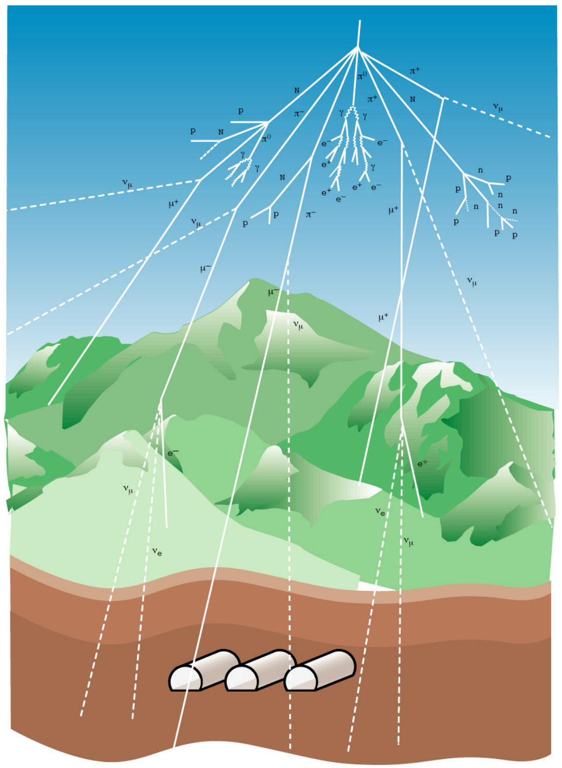
Muon-induced background study for underground laboratories

D.-M. Mei and A. Hime

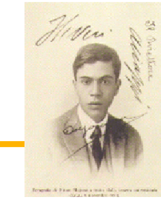
Physics Division, MS H803, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

(Received 5 December 2005; published 6 March 2006)





Previous studies



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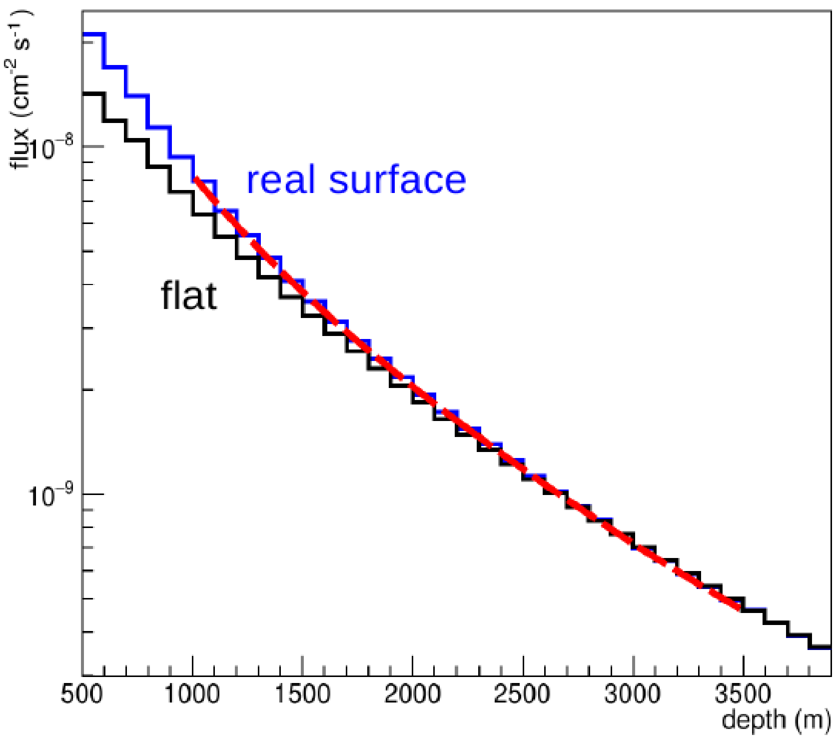


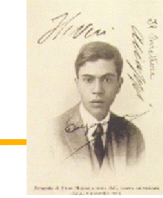
effect on the muon flux when using surface topography for Sanford Underground Research Facility (MAJORANA)

$$I_\mu(h_0) = 67.97 \times 10^{-6} \boxed{e^{-h_0/0.285}} + 2.071 \times 10^{-6} \boxed{e^{-h_0/0.698},}$$

need simulations, because:

- surface topography

Previous studies



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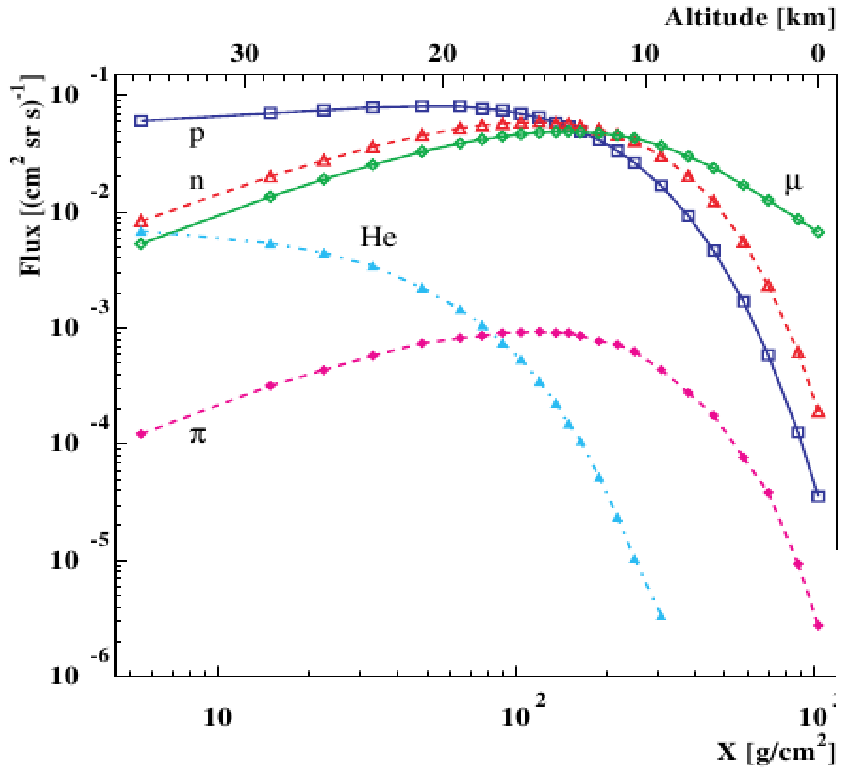


FIG. 2. (Color online) Total fluxes of muons, pions, protons, neutrons and helium nuclei as a function of atmospheric depth and altitude above sea level. The lines are drawn to guide the eye.

$$I_\mu(h_0) = \boxed{67.97\times 10^{-6}}\,\boxed{e^{-h_0/0.285}} + \boxed{2.071}\times\boxed{10^{-6}}\,\boxed{e^{-h_0/0.698}},$$

need simulations, because:

- surface topography
- surface muon flux at different altitudes

PHYSICAL REVIEW D **68**, 103001 (2003)

Flux of atmospheric muons: Comparison between AIRES simulations and CAPRICE98 data

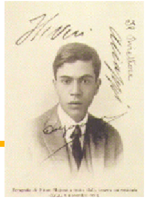
P. Hansen, P. Carlson, and E. Mocchiutti
Royal Institute of Technology (KTH), AlbaNova University Center, S-10691 Stockholm, Sweden

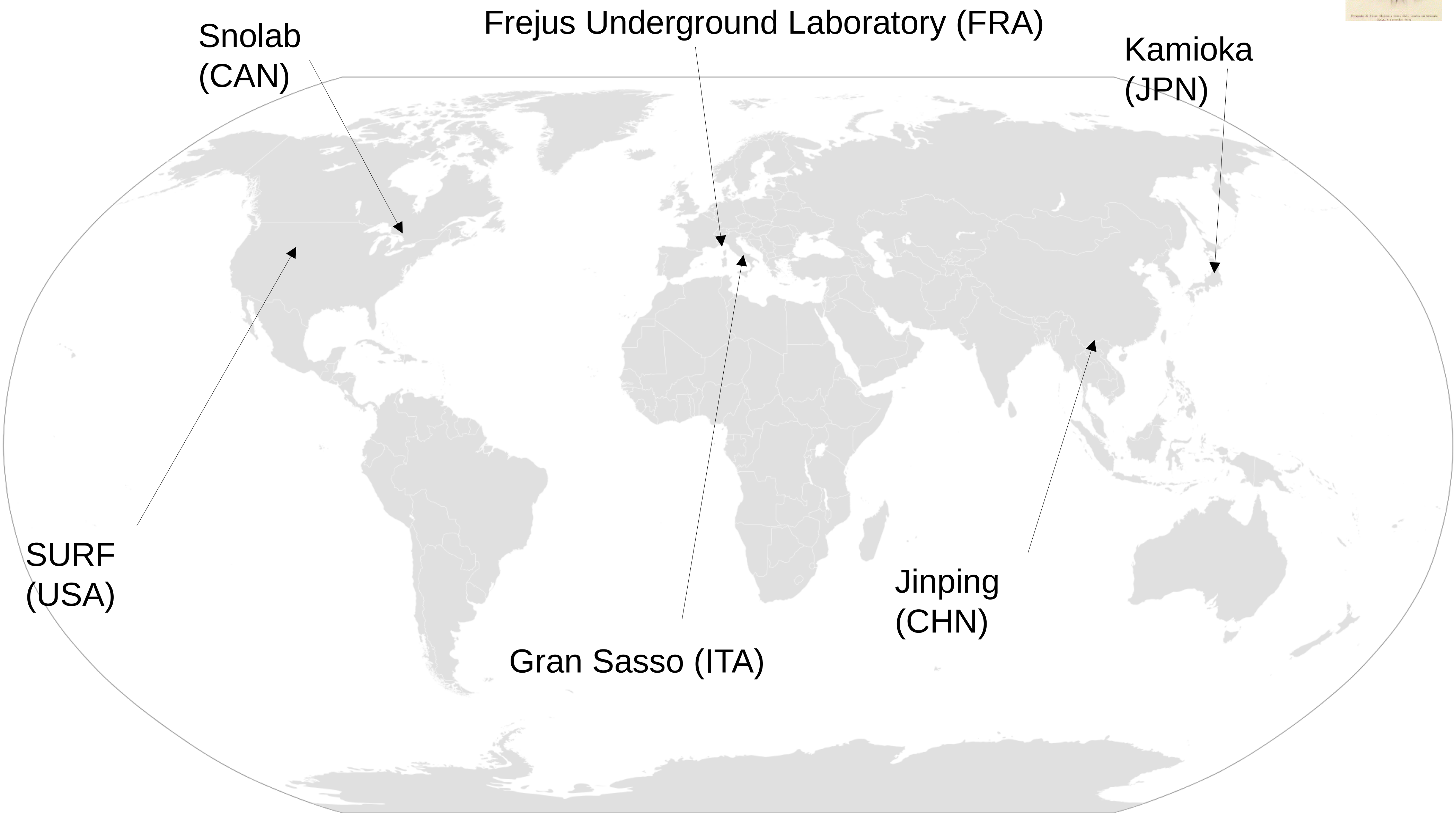
S. J. Sciutto
Departamento de Física, Universidad Nacional de La Plata, C. C. 67, 1900 La Plata, Argentina

M. Boezio
University of Trieste and Sezione INFN di Trieste, Via A. Valerio 2, I-34147 Trieste, Italy

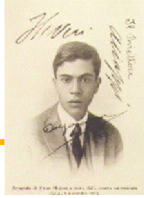
(Received 21 May 2003; published 17 November 2003)

Underground labs for this study

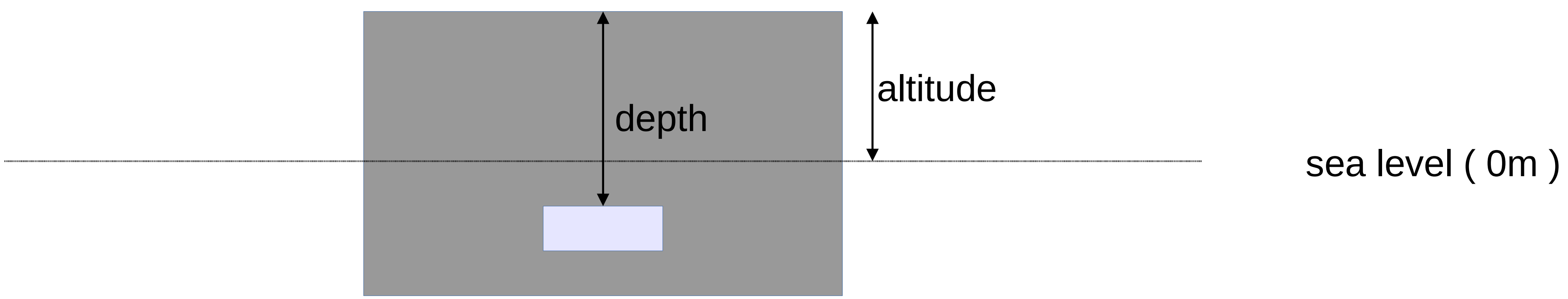




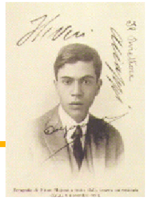
Underground labs for this study



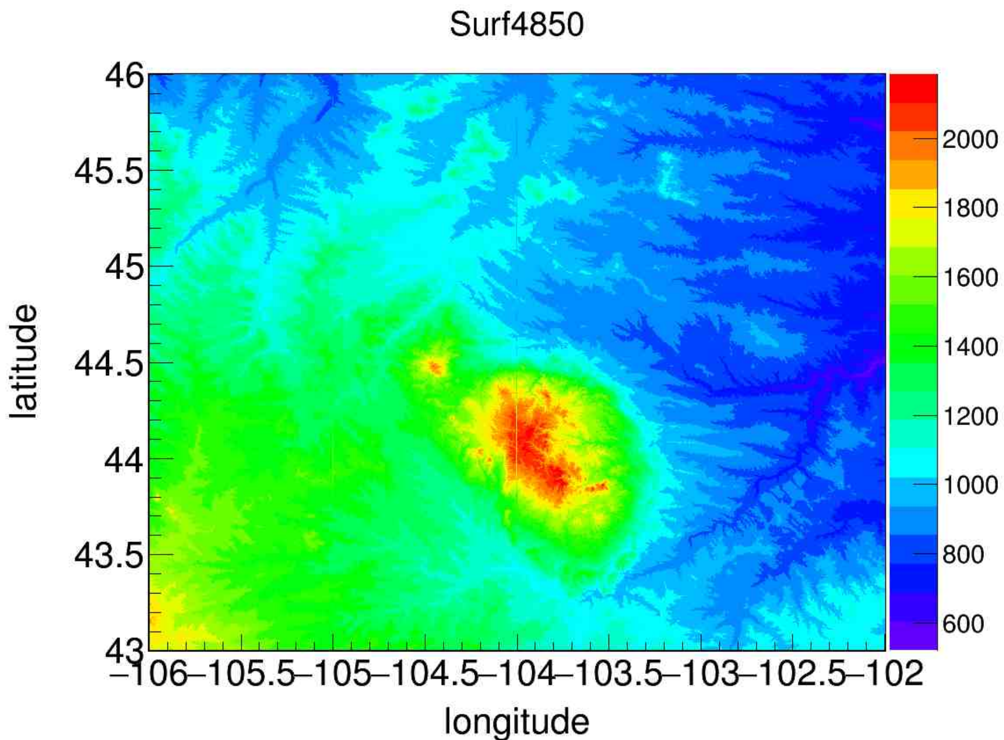
laboratory	depth	altitude (lab / surface)	experiments, e.g.
Frejus	1263m	1475m / 2738m	EDELWEISS
Gran Sasso	1400m	914m / 2314m	GERDA
Jinping	2400m	954m / 3354m	PandaX
Kamioka	1000m	324m / 1324m	Kamland, SuperK
SNOLAB	2070m	-1764m / 305m	SNO+, MiniClean
SURF4850	1478m	128m / 1606m	MAJORANA, LUX
SURF8000	2438m	-831m / 1606m	level in the mine, no lab

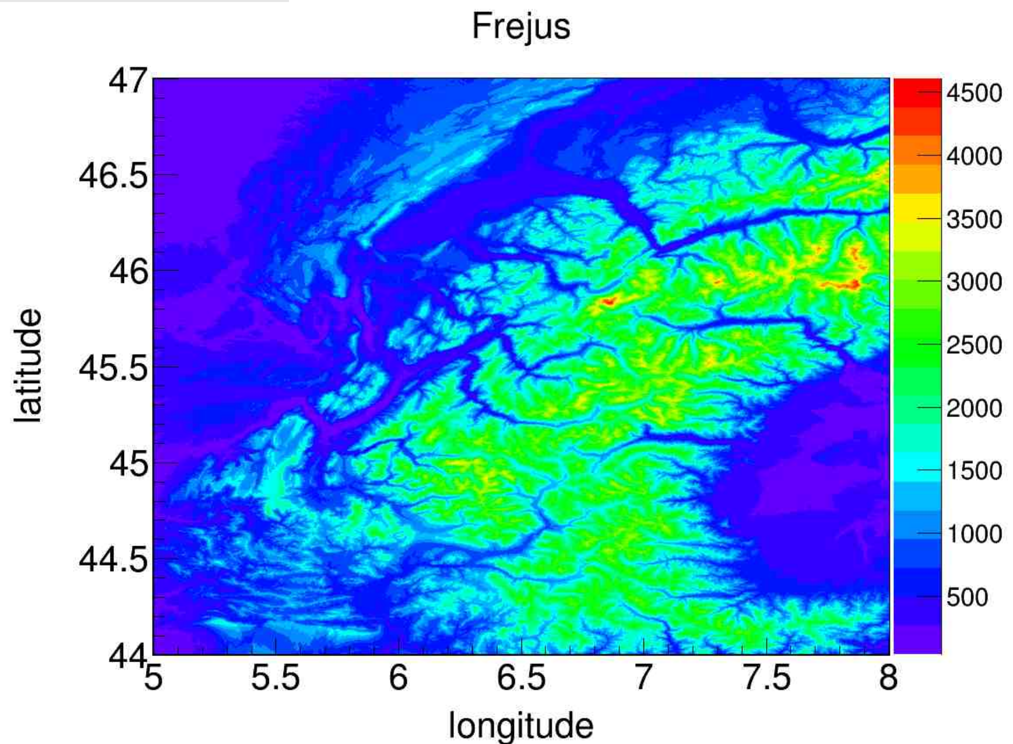


Data from space for underground research

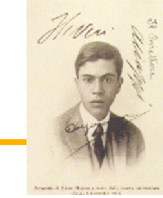


- use **SRTM3** (mission from 2000, data released 2014):
- resolution (x,y) : ~ 90m
- whole world, except polar areas
- http://www2.jpl.nasa.gov/srtm/





Data from space for underground research



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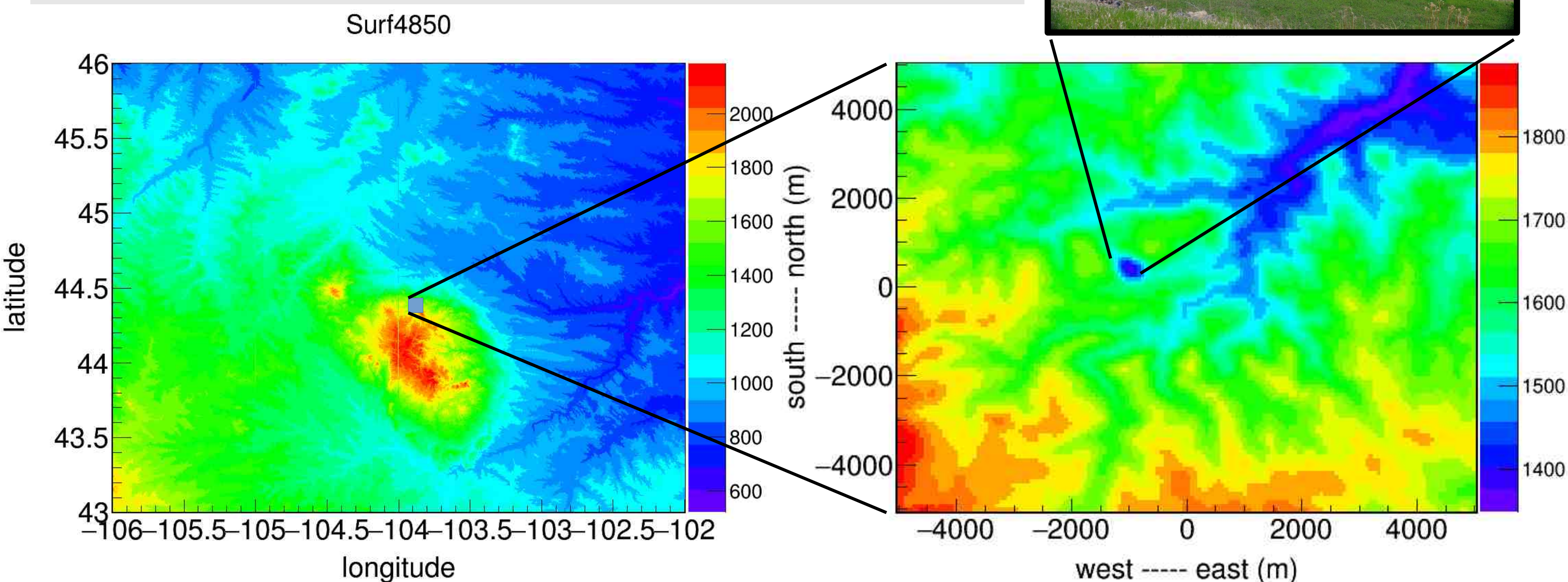
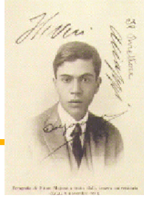
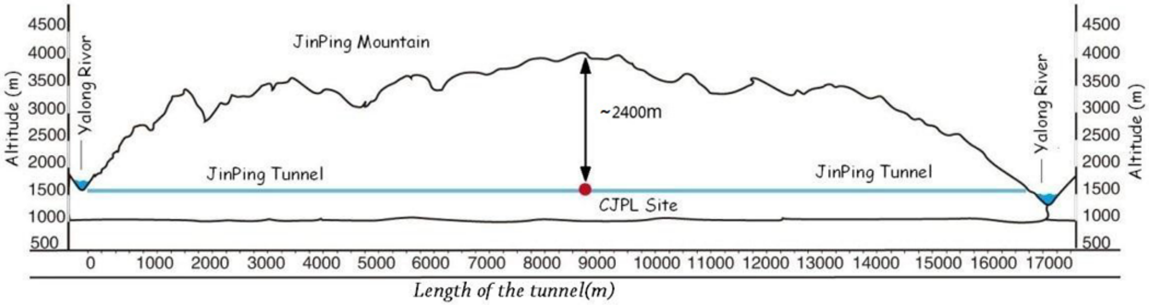


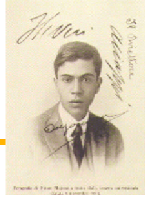
Compare the rock thickness of the different sites

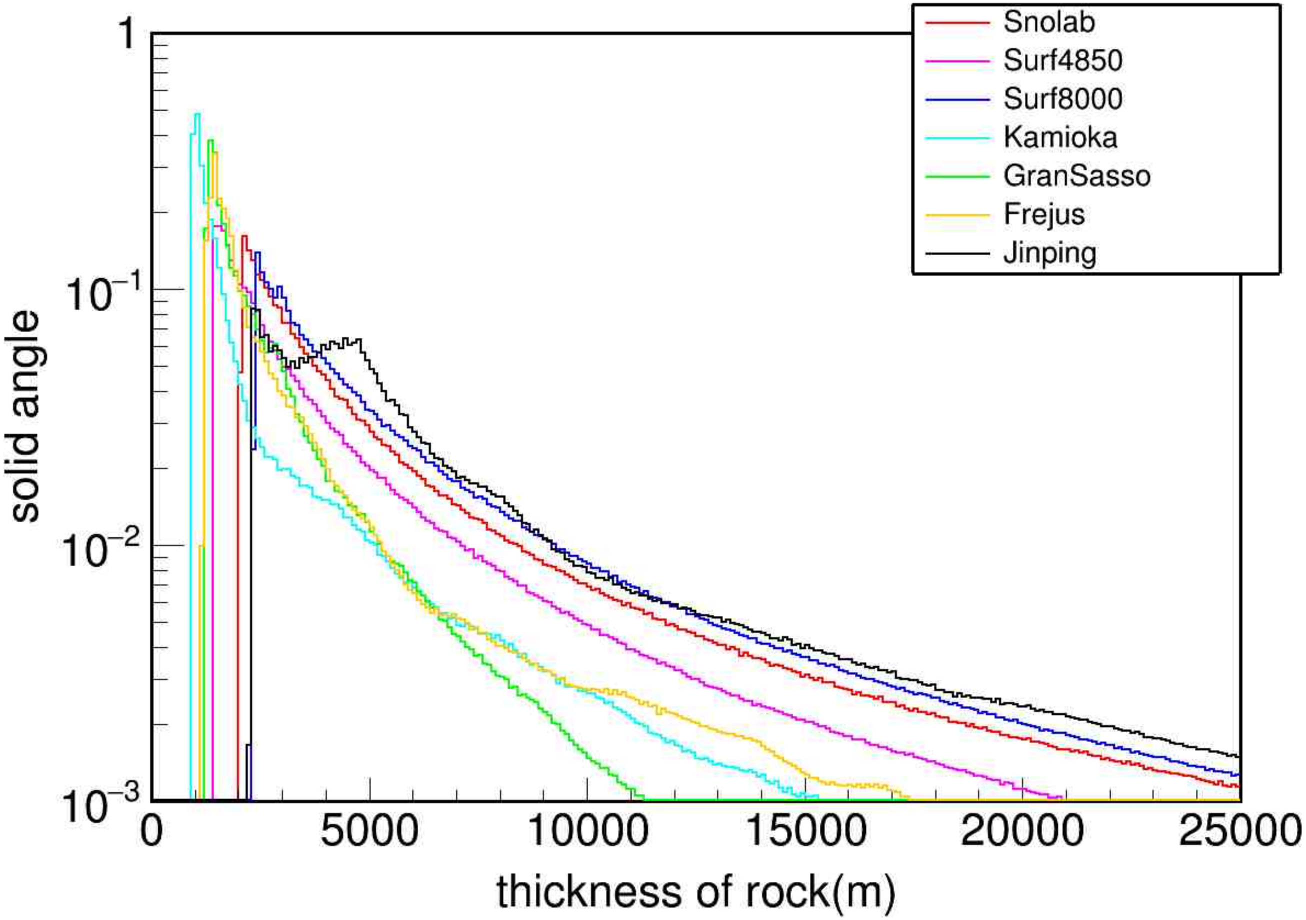


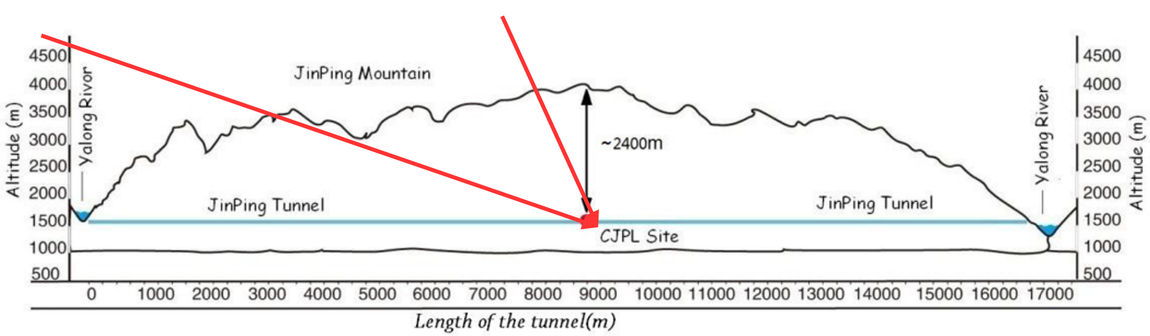


from http://hep.tsinghua.edu.cn/CJPLNE/

Compare the rock thickness of the different sites



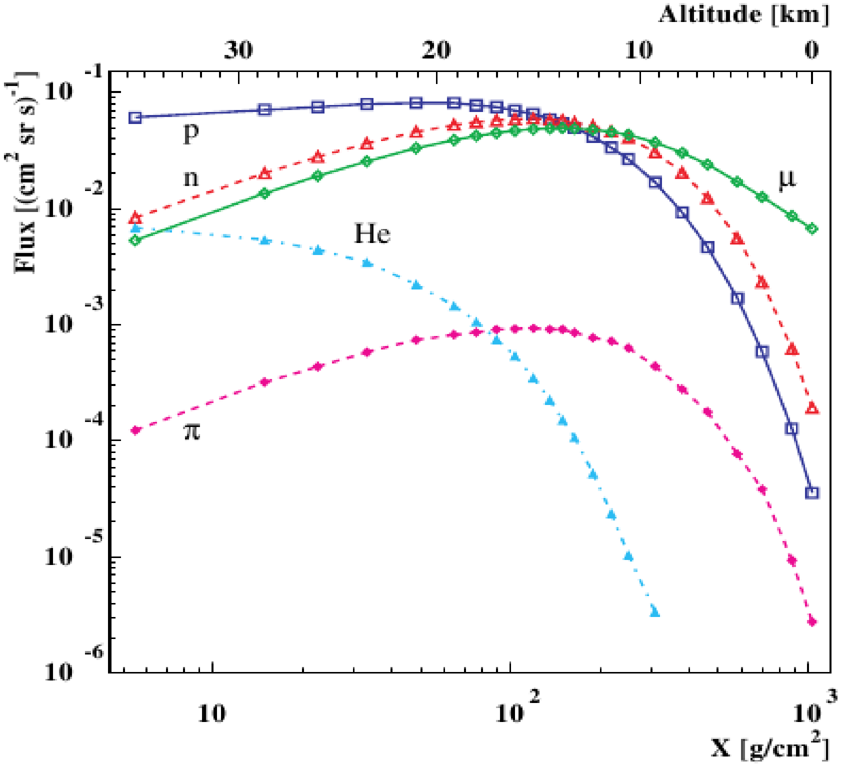




from http://hep.tsinghua.edu.cn/CJPLNE/

Muon flux – start with surface muon flux

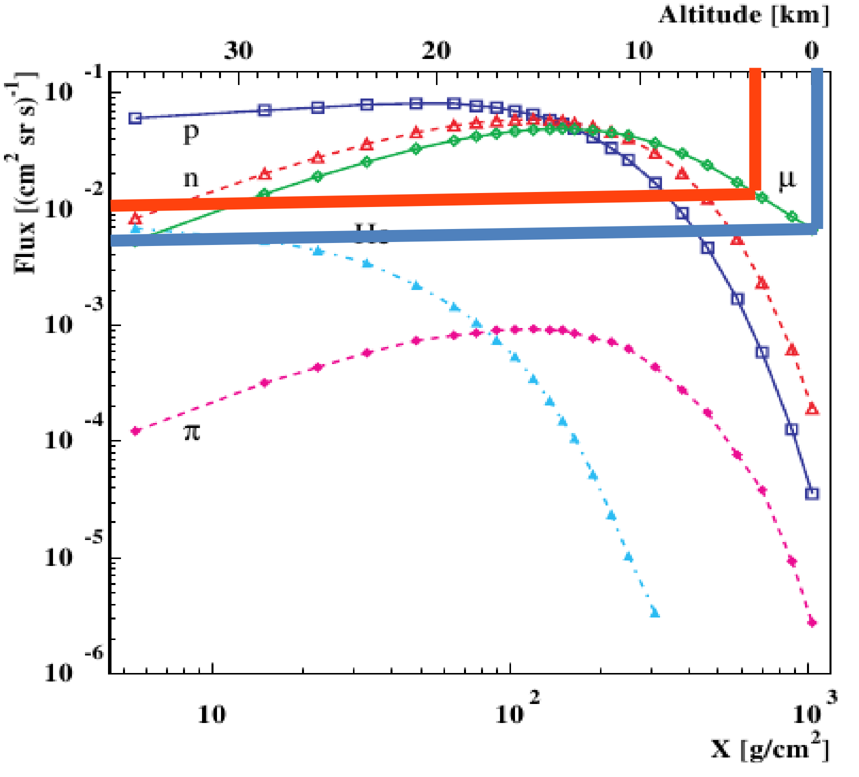
laboratory	depth	altitude (lab / surface)	
Frejus	1263m	1475m / 2738m	
Gran Sasso	1400m	914m / 2314m	
Jinping	2400m	954m / 3354m	
Kamioka	1000m	324m / 1324m	
SNOLAB	2070m	-1764m / 305m	
SURF4850	1478m	128m / 1606m	
SURF8000	2438m	-831m / 1606m	



Muon flux – start with surface muon flux

laboratory	depth	altitude (lab / surface)	Surface flux (μ sr^{-1} cm^{-2} s^{-1})
Frejus	1263m	1475m / 2738m	6.1
Gran Sasso	1400m	914m / 2314m	5.8
Jinping	2400m	954m / 3354m	6.4
Kamioka	1000m	324m / 1324m	4.8
SNOLAB	2070m	-1764m / 305m	3.6
SURF4850	1478m	128m / 1606m	5.1
SURF8000	2438m	-831m / 1606m	5.1

flux on surface can vary almost by a factor 2



Muon flux – results for simulation with GEANT4

laboratory	depth	flux (μ cm^{-2} s^{-1})	Mei-Hime
Frejus	1263m		
Gran Sasso	1400m		
Jinping	2400m		
Kamioka	1000m		
SNOLAB	2070m		
SURF4850	1478m		
SURF8000	2438m		

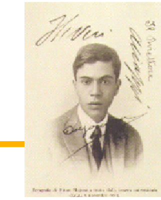
simulations:

- GEANT4 muon energies up to 500 TeV
- for radii of 20 km around lab location
- rock densities between 2.5 and 3.1 g/cm^{-3}

uncertainites:

- about 10% from surface flux
- density uncertainty

Muon flux – results for simulation with GEANT4



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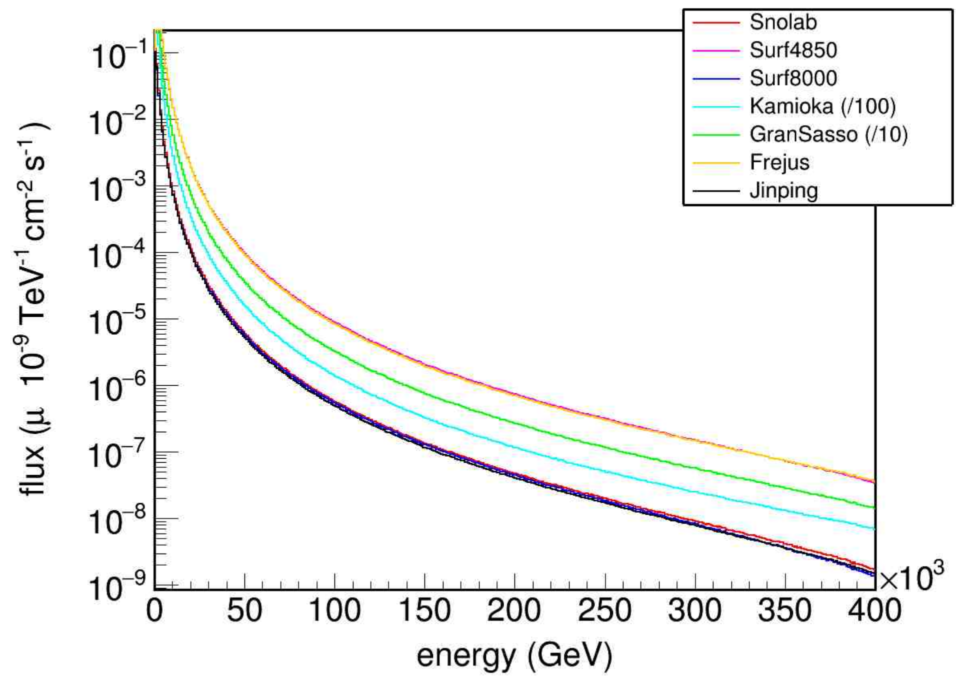
Jinping	2400m		
Kamioka	1000m		
SNOLAB	2070m		
SURF4850	1478m		
SURF8000	2438m		



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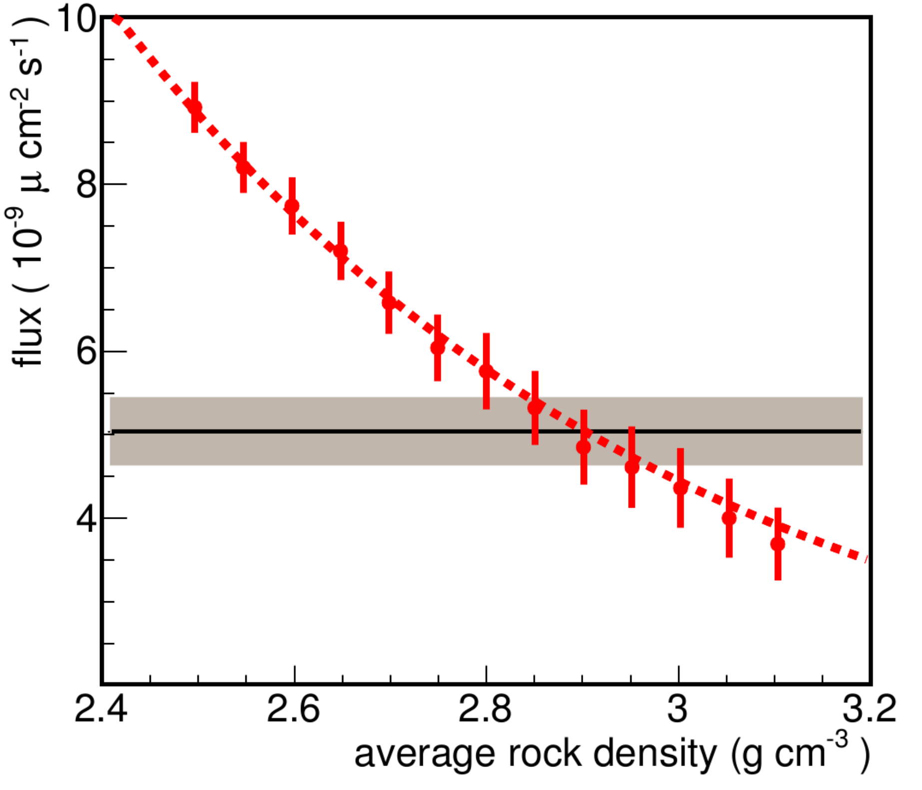
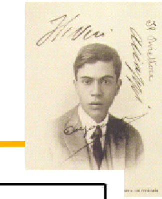
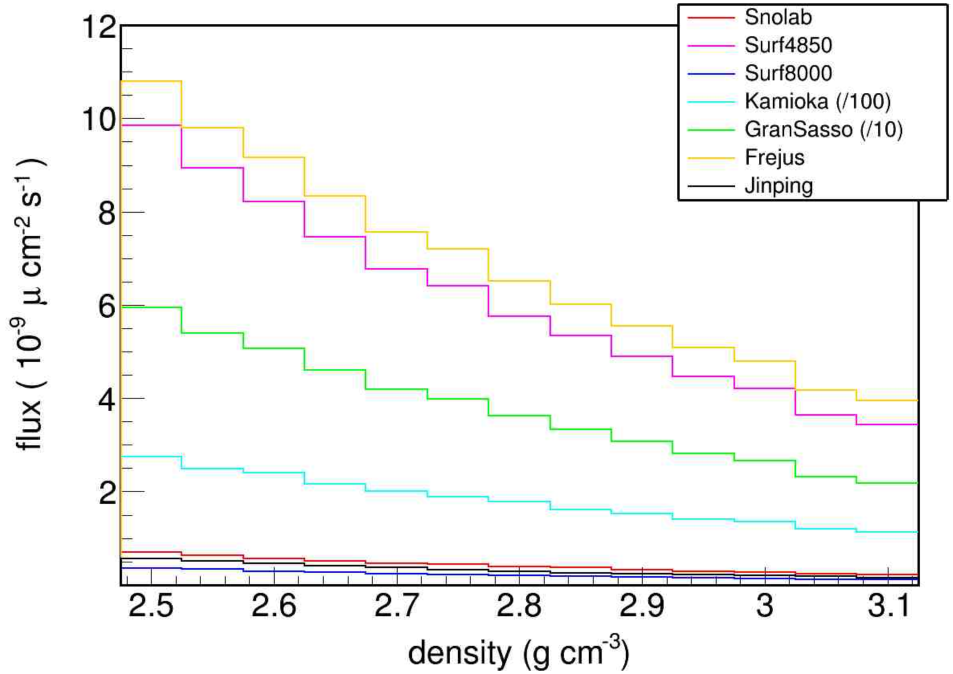
Kamioka	1000m		
SNOLAB	2070m		
SURF4850	1478m	**5.7**	**4.4**
SURF8000	2438m		

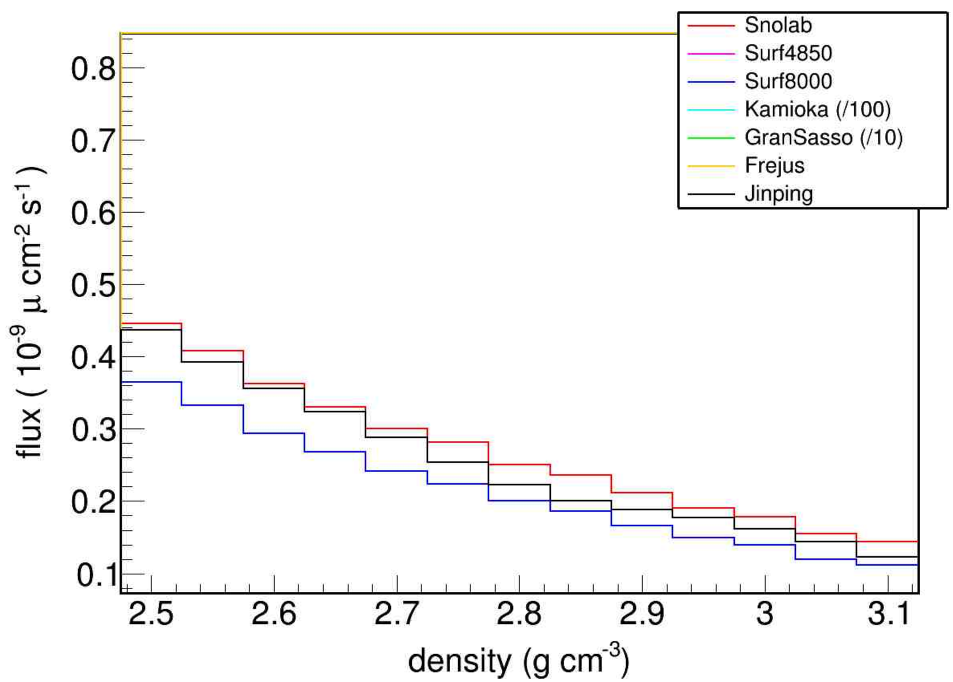


recent results for the muon flux at SURF including our measurement value

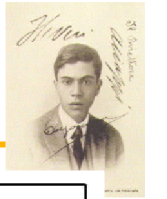
Muon flux – results for simulation with GEANT4

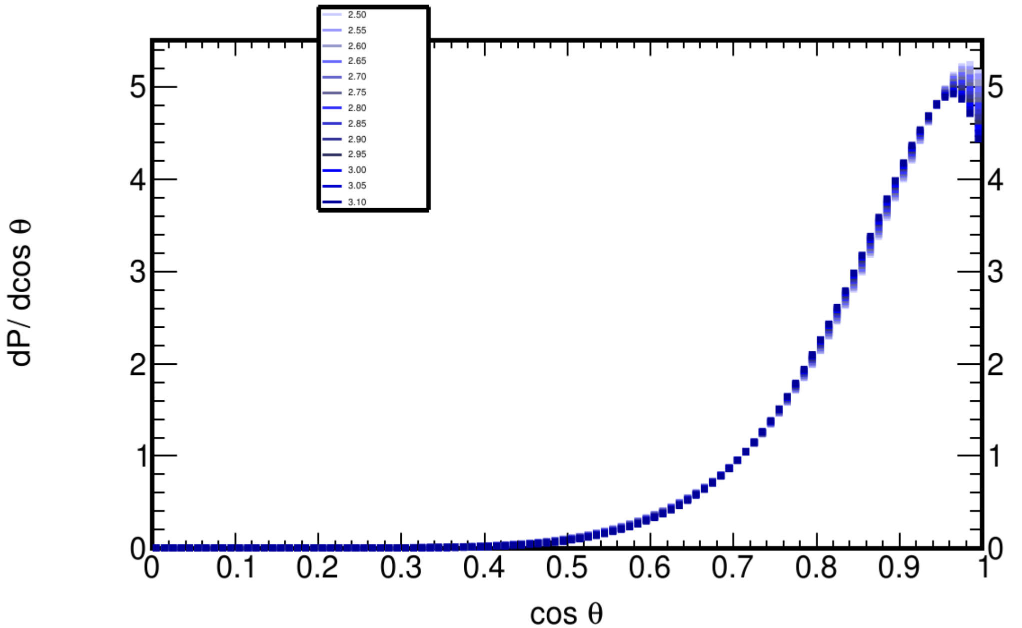


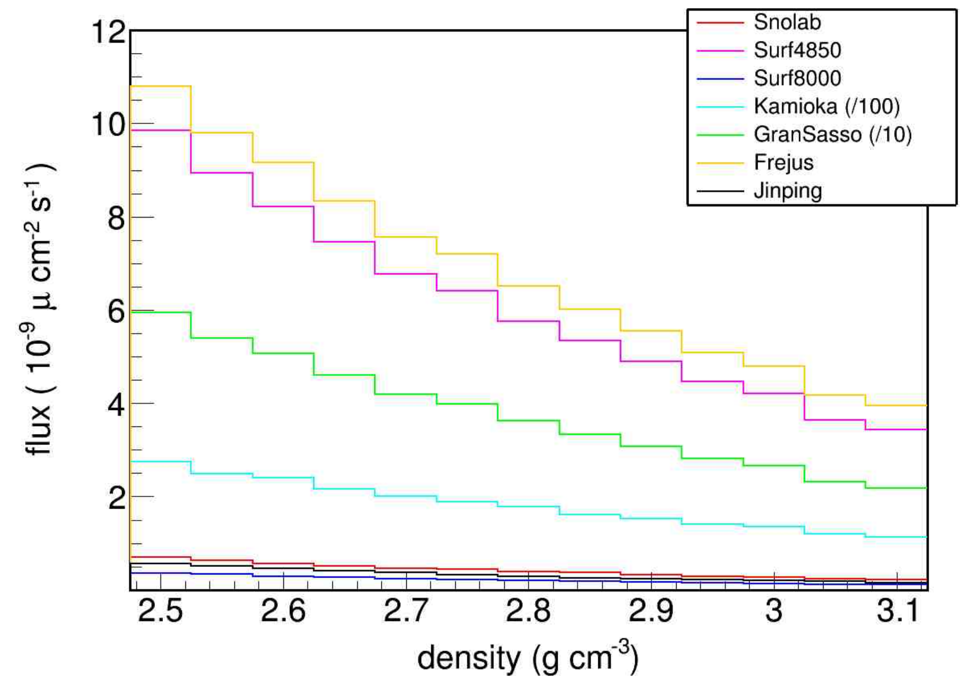


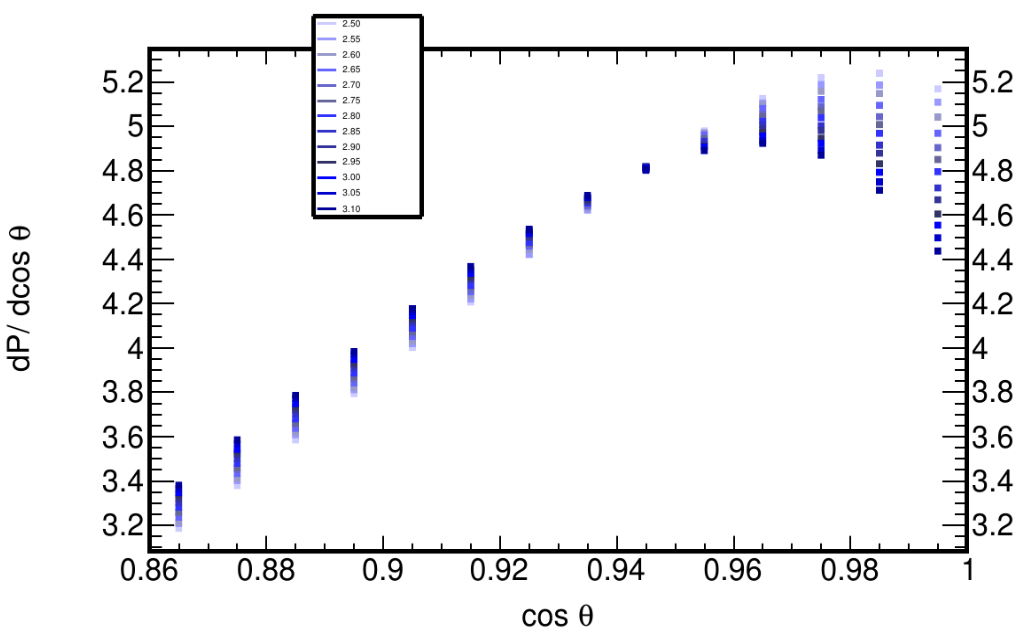


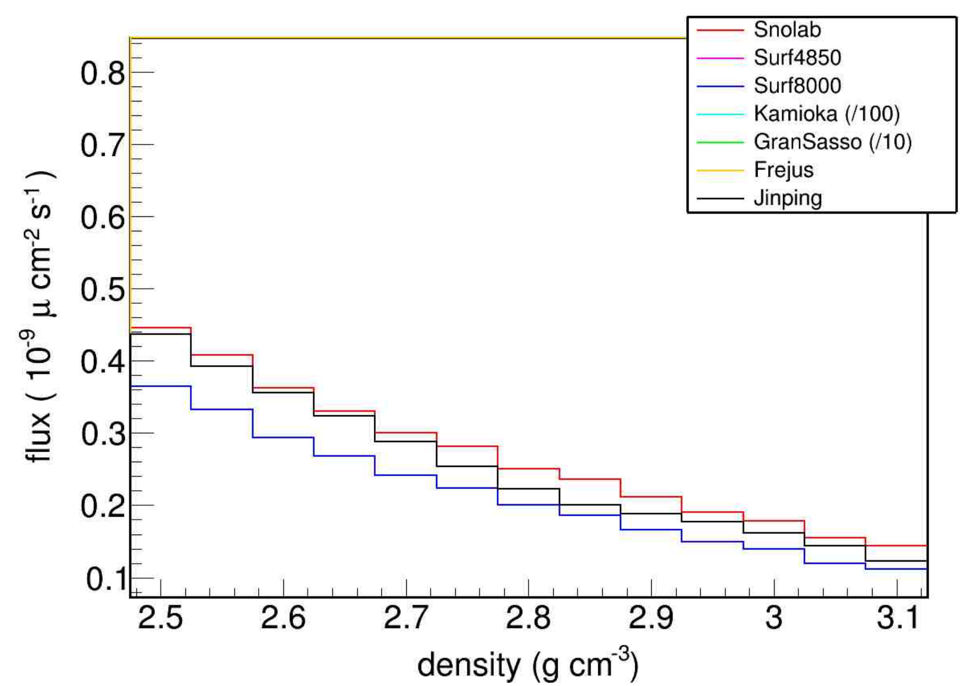
Muon flux – results for simulation with GEANT4



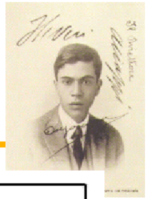


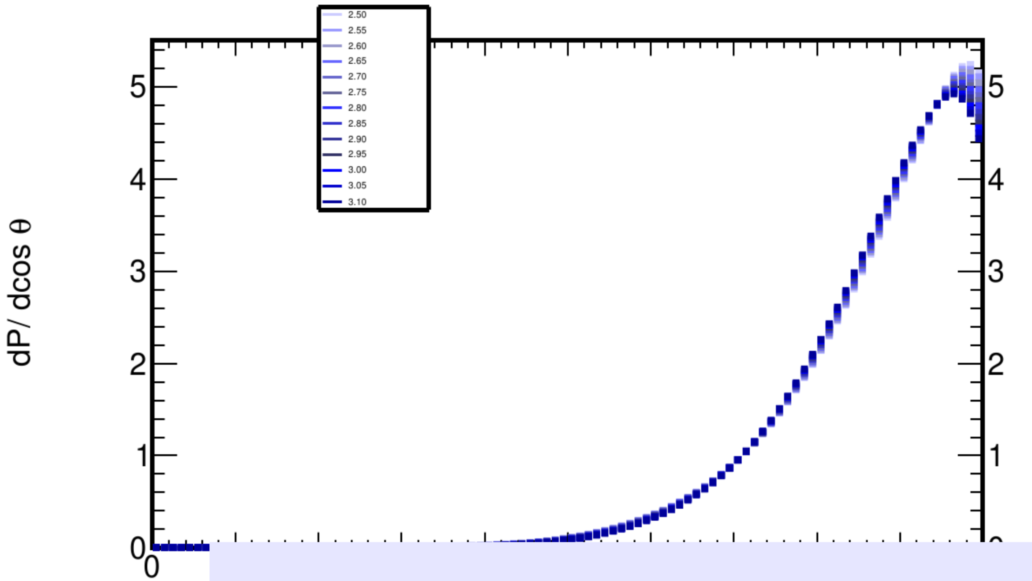


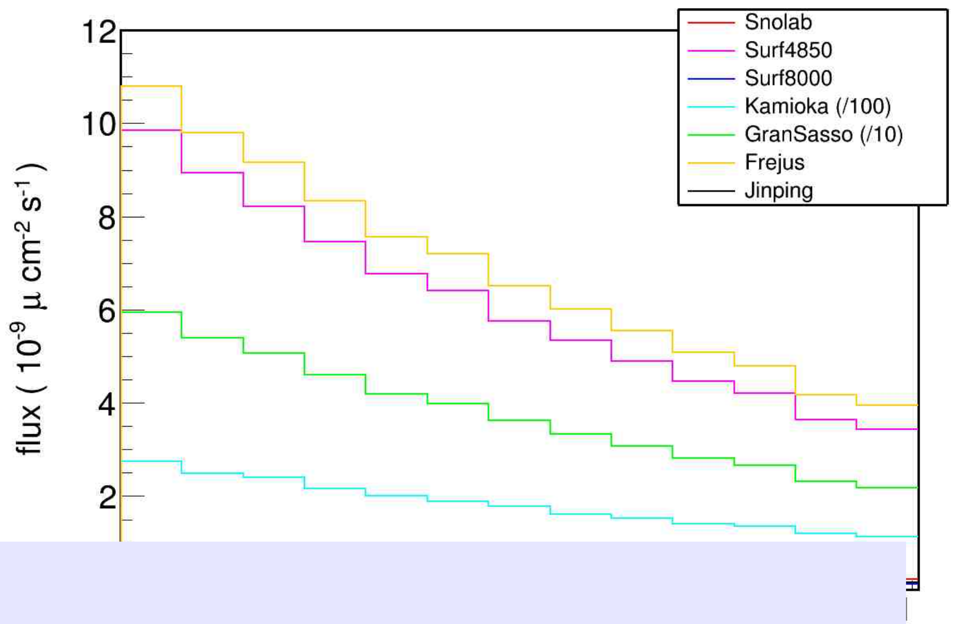




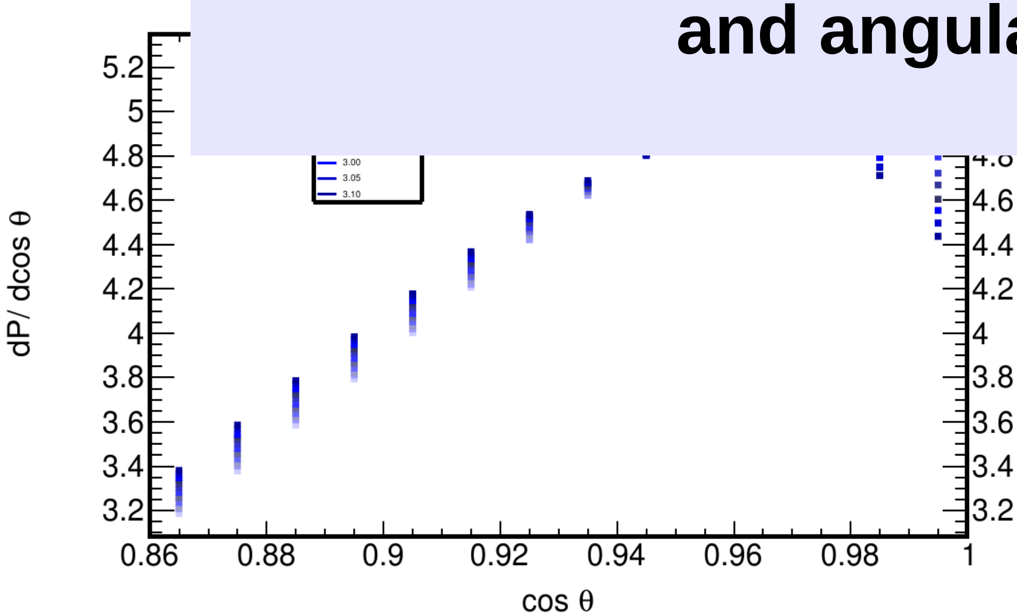
Muon flux – results for simulation with GEANT4

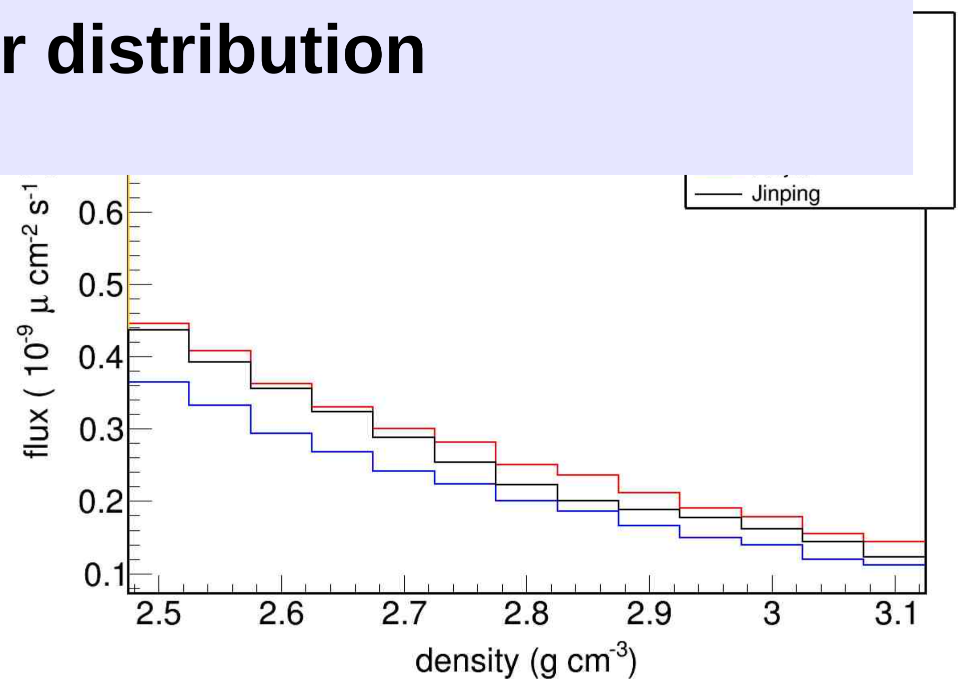




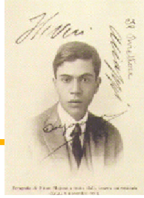


Density changes absolute flux and angular distribution



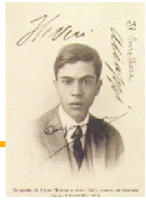


Muon flux – at the labs



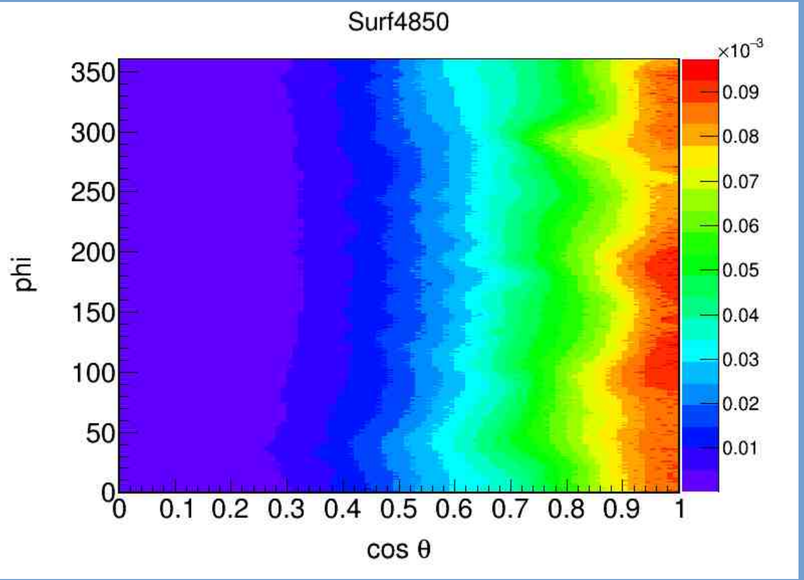
laboratory	depth	flux ($\mu\ cm^{-2}\ s^{-1}$) 2.8g/cm3	Mei-Hime	measured
Frejus	1263m	6.2	4.8	5.8
Gran Sasso	1400m	31	25.8	34.7
Jinping	2400m	0.27	--	0.21
Kamioka	1000m	161	158	148 or 170
SNOLAB	2070m	0.37	0.38	0.31
SURF4850	1478m	5.7	4.4	5.08
SURF8000	2438m	0.18	--	--

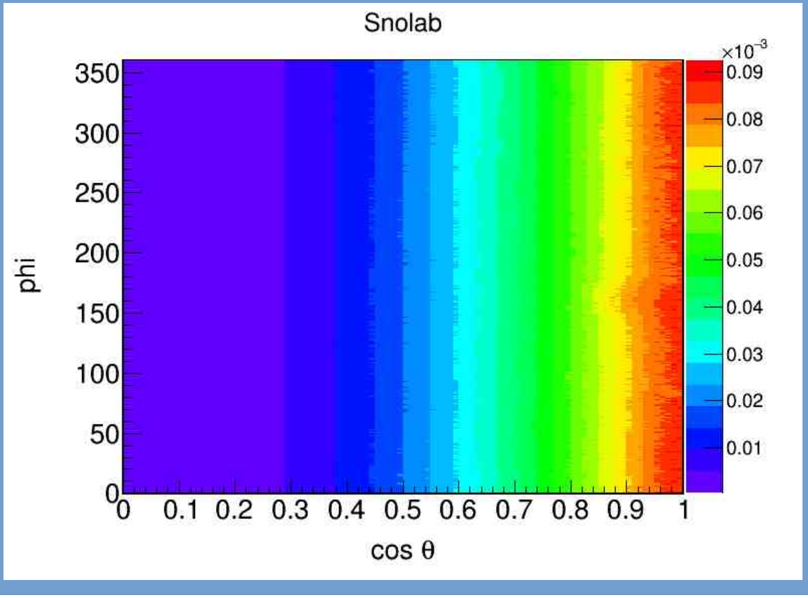
Muon – angular distribution at the lab



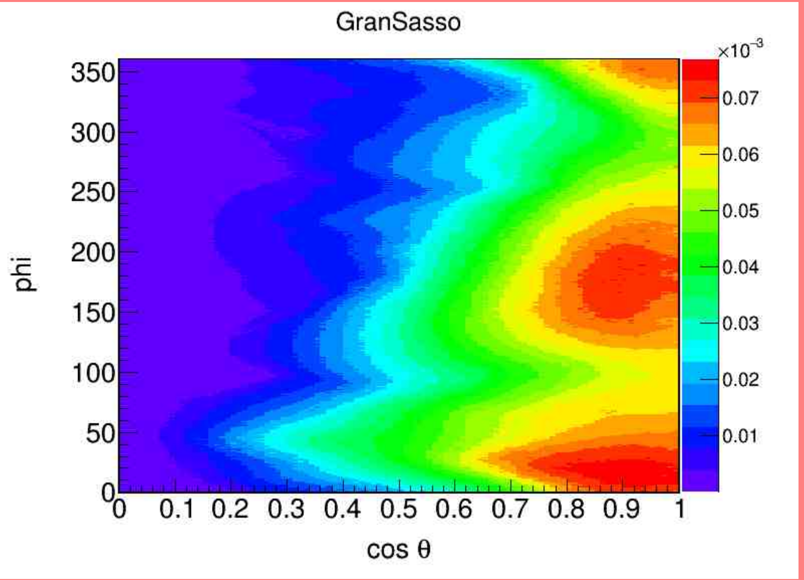
- relative contribution to the muon flux

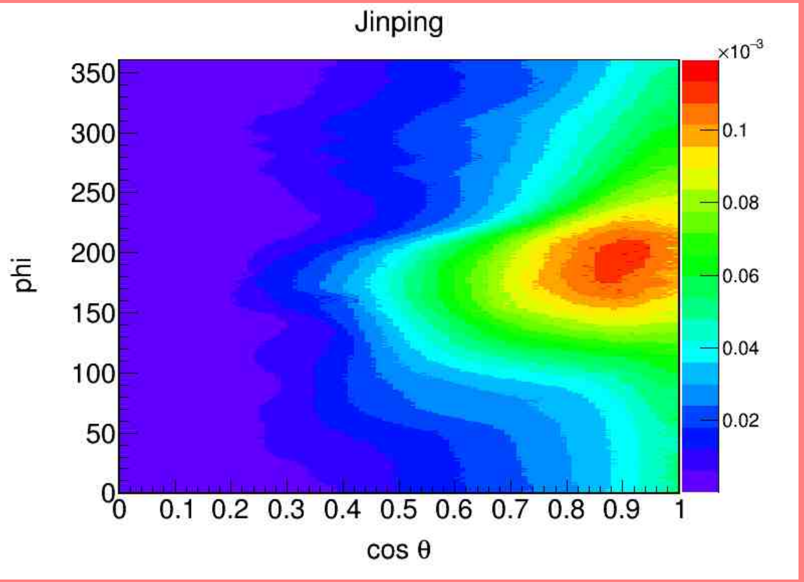
sides with “flat” surfaces topography



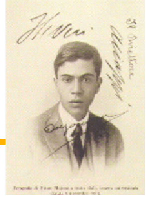


mountain sides





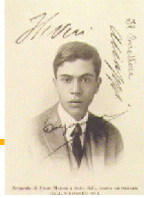
Results



- We can reduce the muon induced background by a factor ~15

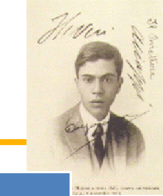
- Jinping is the deepest one of all the labs at the moment, but has some disadvantages related to surface topography and surface muon flux

- density of the rock can heavily influence the results for the muon flux



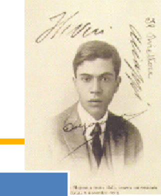
Detection of events produced by cosmogenics

Evidence of cosmogenic neutron (Pinghan Chu)



Isotope	Reaction	β Q value(MeV)	Signature
^{77}Ge	$^{76}Ge(n, \gamma)^{77}Ge$	2.7	Time-delayed coincidence
^{75}Ge	$^{74}Ge(n, \gamma)^{75}Ge$, $^{76}Ge(n, 2n)^{75}Ge$	1.1	Instantaneous coincidence
^{73}Ga	$^{73}Ge(n, p)^{73}Ga$, $^{74}Ge(n, d)^{73}Ga$, $^{76}Ge(n,2nt)^{73}Ga$, ($^{76}Ge(n, \alpha)^{73}Zn$, $^{73}Zn \rightarrow {}^{73}Ga+\beta+v$)	1.6	Time-delayed coincidence, two-level transition in single waveform

Evidence of cosmogenic neutron (Pinghan Chu)



Isotope	Reaction	β Q value(MeV)	Signature
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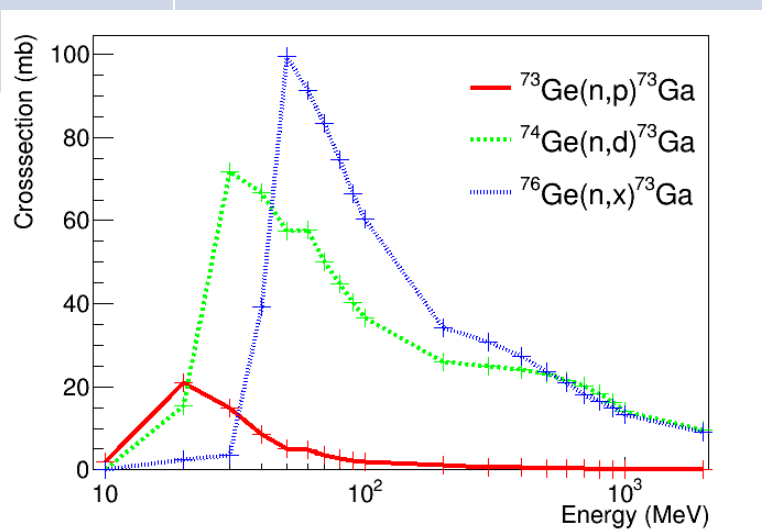
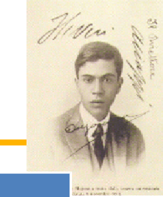
^{73}Ga	^{73}Ge(n, p)^{73}Ga, ^{74}Ge(n, d)^{73}Ga, ^{76}Ge(n,2nt)^{73}Ga, (^{76}Ge(n, α)^{73}Zn, ^{73}Zn→^{73}Ga+β+ν)	1.6	Time-delayed coincidence, two-level transition in single waveform



Evidence of cosmogenic neutron (Pinghan Chu)



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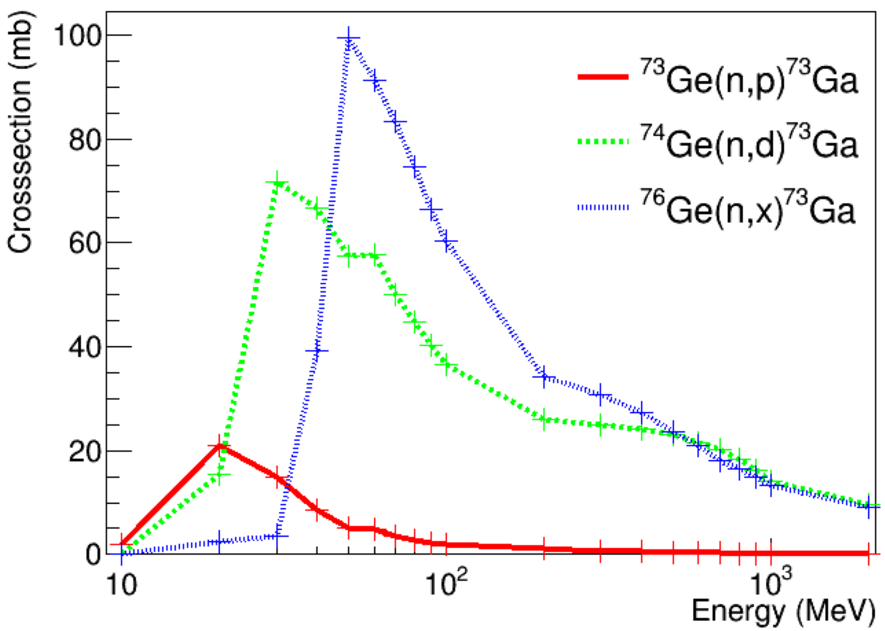
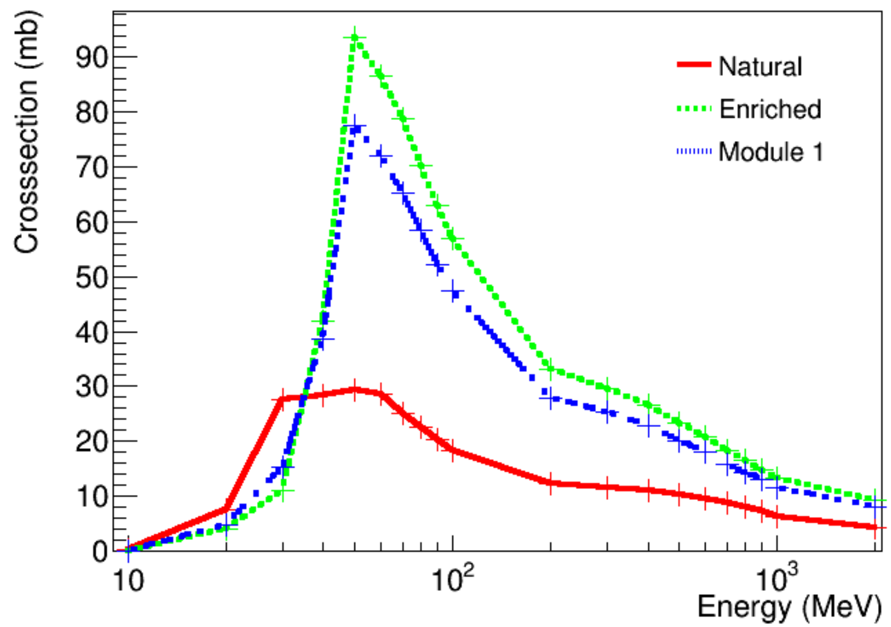
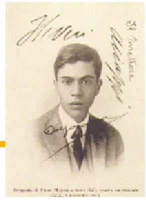




^{73}Ga Decay



^{73}Ga

$Q_{\beta-}$ = 1593 keV, $t_{1/2}$ = 4.9 h

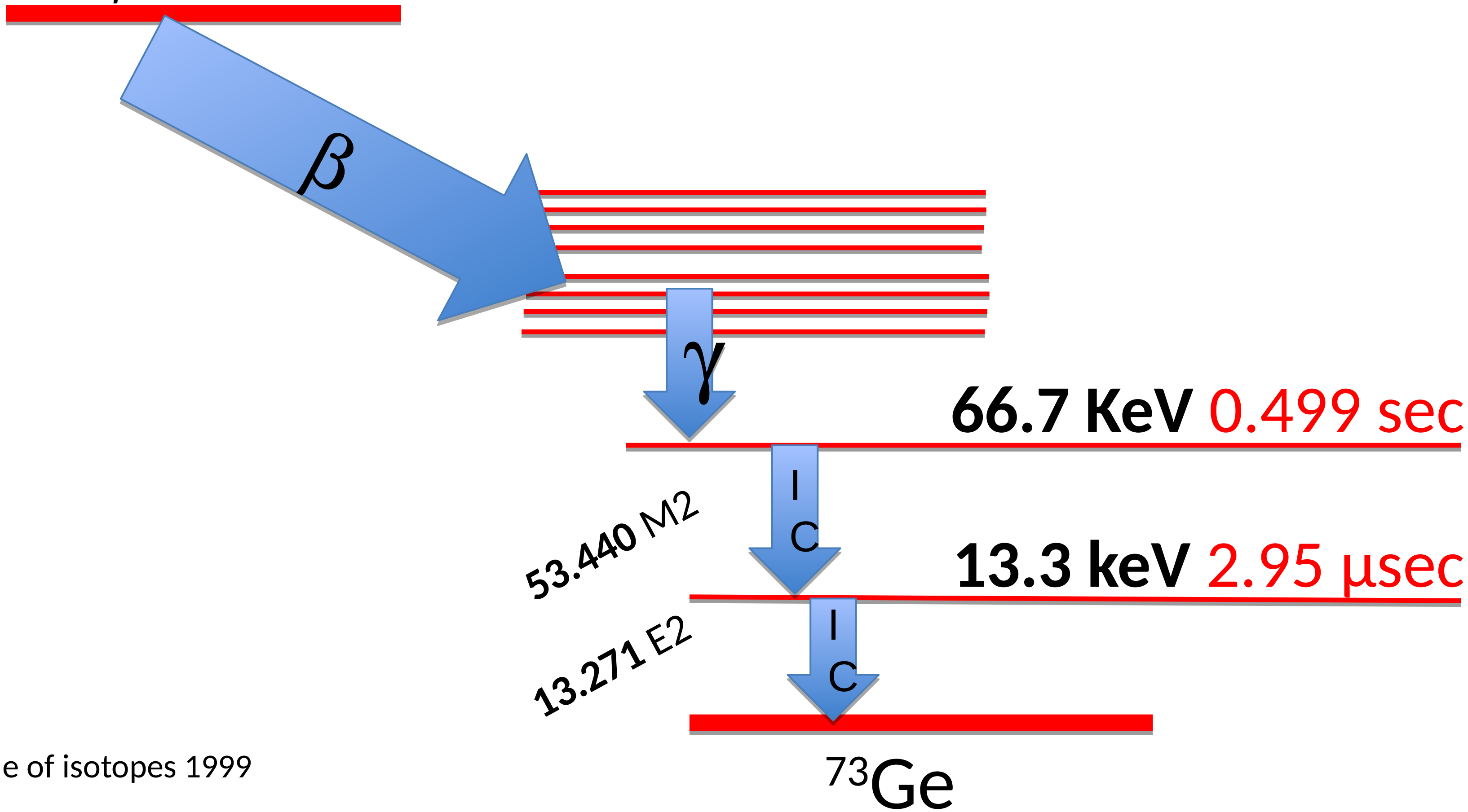
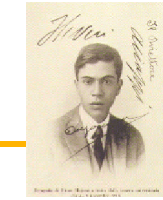


Table of isotopes 1999

Example of 4-Fold Correlated Event



P5D1

The top detector in string 5

β 328.4 keV

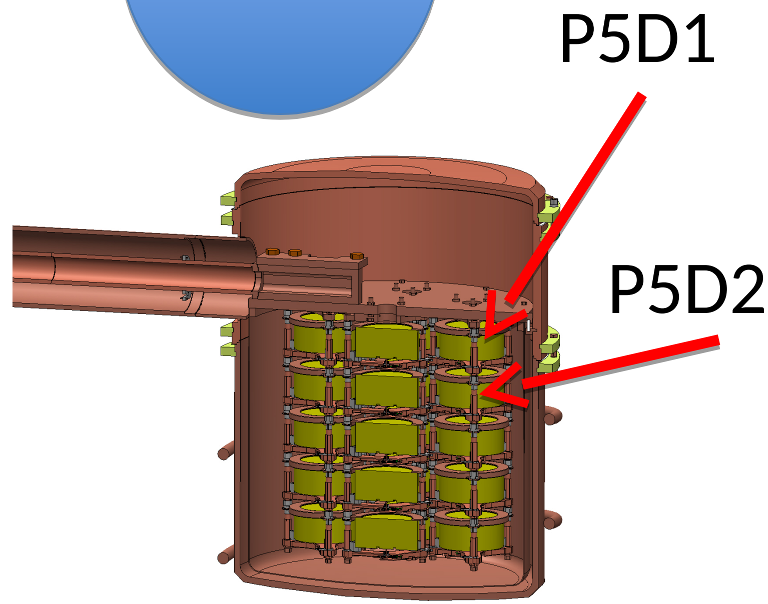
IC 53 keV

IC 13 keV

P5D2

The second detector in string 5

Compton γ 734.8 keV



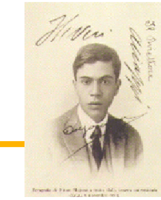
0

+84 ms

+0.92μs

Time

Example of 4-Fold Correlated Event



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The top detector in string 5

β 328.4 keV

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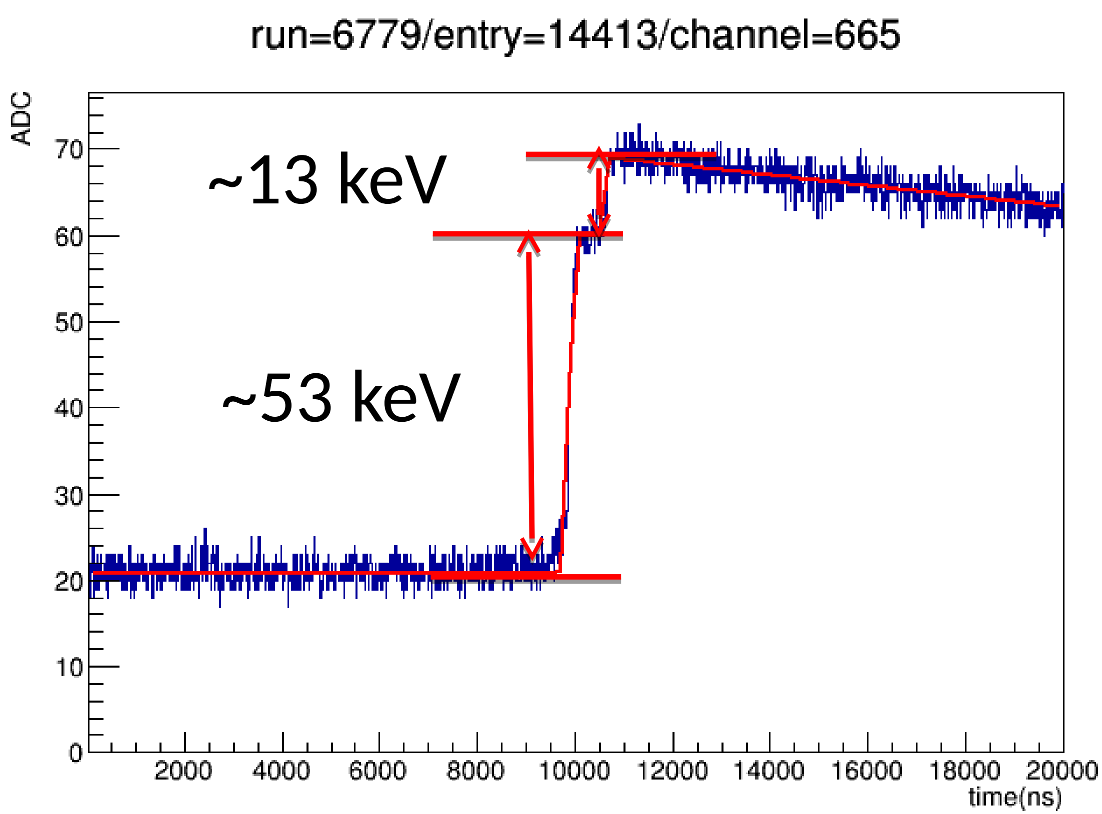
IC 13 keV

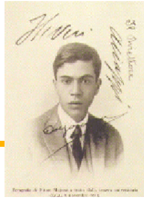
P5D2

The second detector in string 5

Compton γ 734.8 keV

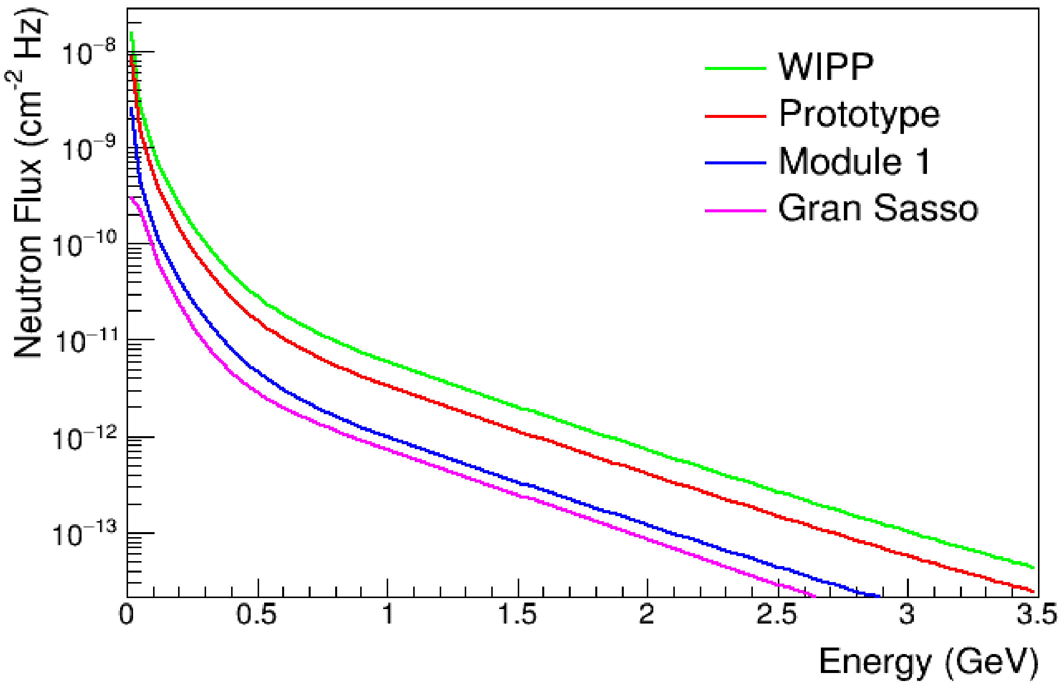


Results

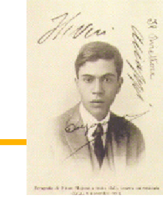


- in total 3 Events so far in different MJD runs (Prototype/Module 1)
- using MeiHime neutron flux distribution to estimate event rate

==== gives a rough number for the total neutron flux ====
(@30 MeV: ~1 10^{-7} n/cm^{-2}/s^{-1} @50 MeV: ~0.4 10^{-7} n/cm^{-2}/s^{-1})
(very preliminary, needs life time, active mass, efficiency)



Results



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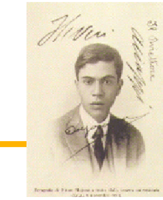
  (see Physics Review C 82, 054610)

- estimate background from these isotopes in ROI by a MC

==== 2 - 5 ct/t/yr ====

Results



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(see Physics Review C 82, 054610)

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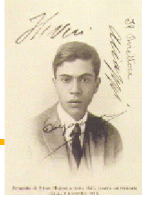
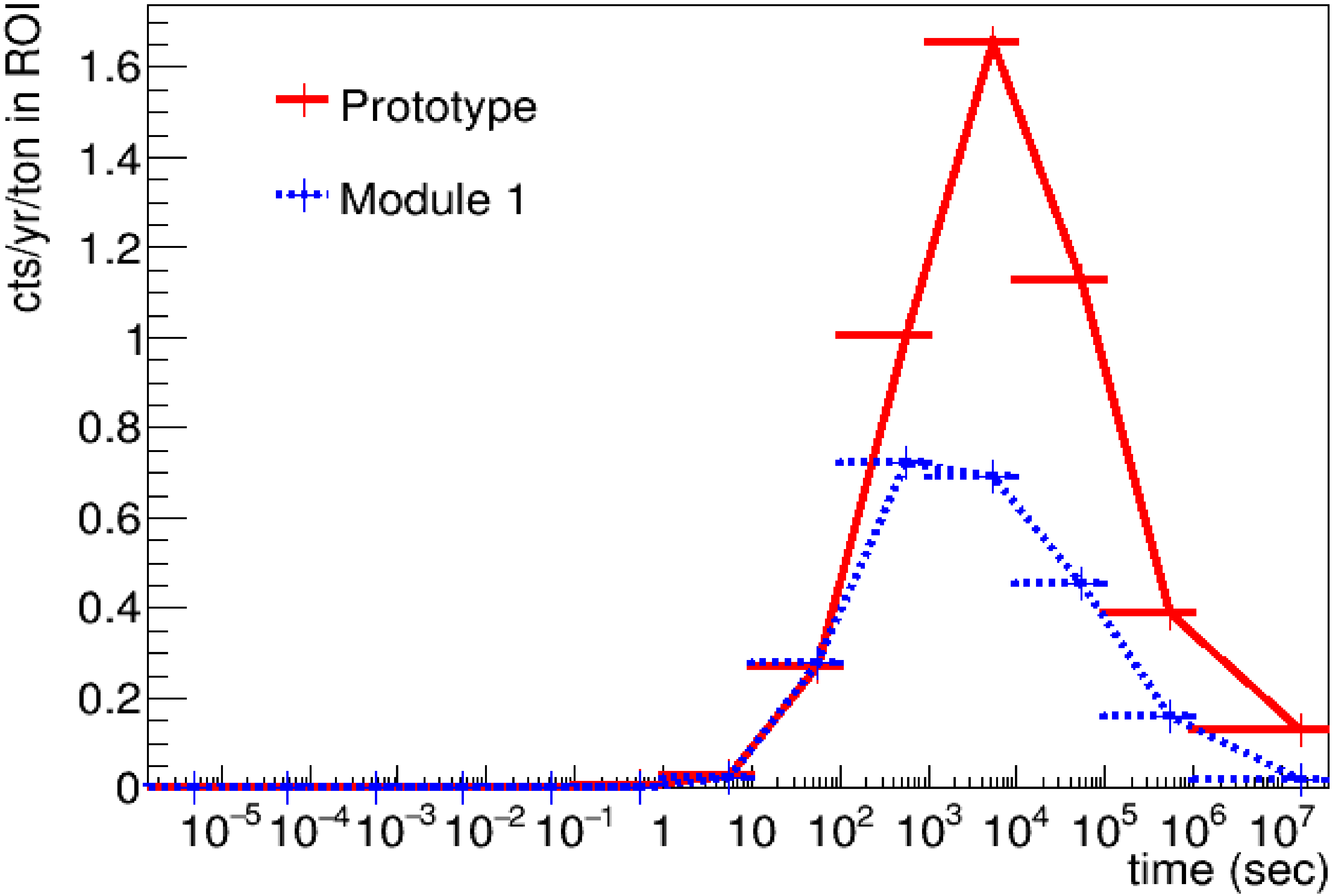
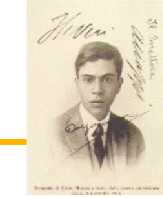
==== 2 - 5 ct/t/yr ====

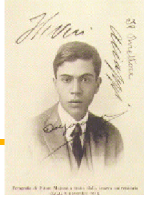
- **Can we veto these ?**

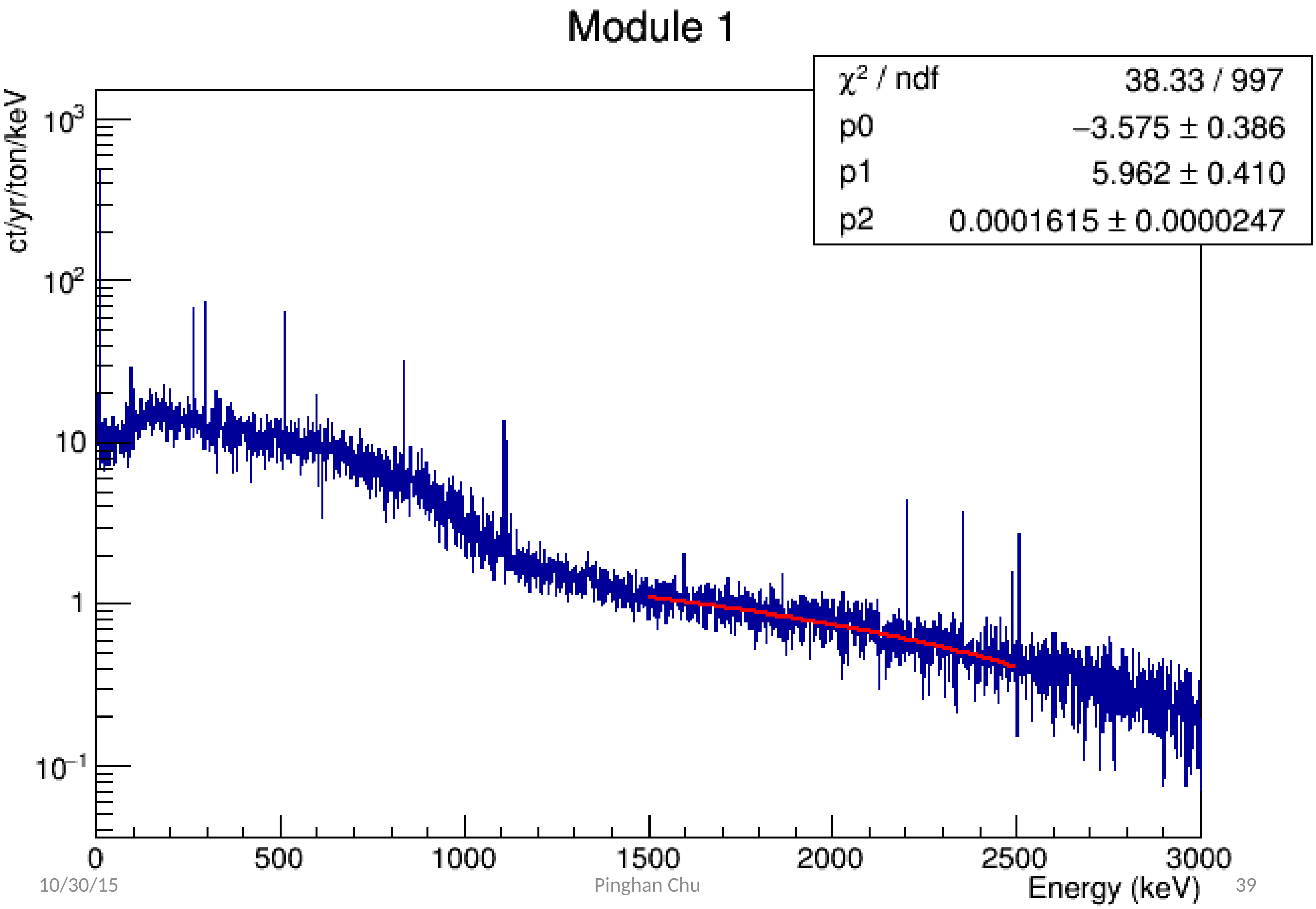
Time of beta delayed event in ROI (activation at t =0)

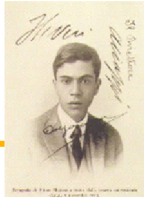









Module 1
χ² / ndf 38.33 / 997
p0 −3.575 ± 0.386
p1 5.962 ± 0.410
p2 0.0001615 ± 0.0000247
ct/yr/ton/keV
Energy (keV)
0
500
1000
1500
2000
2500
3000



laboratory	**depth**	**flux (μ 10-9 cm^{-2} s^{-1}) this work**	**Mei-Hime**	real	citation
Frejus	1263m	6.2	4.83	5.76	Berger, all n
Gran Sasso	1400m	31	25.8	34.7	GerdaArxiv
Jinping	2400m	0.27	--	0.20	jinpingArxiv
Kamioka	1000m	161	158	148 or 170	PHYSICAL REVIEW D 74, 053007 (2006)
SNOLAB	2070m	0.37	0.38	0.31	SnolabUserManual page 13
SURF4850	1478m	5.7	4.4	5.08	Majorana submitted
SURF8000	2438m	0.18	--		