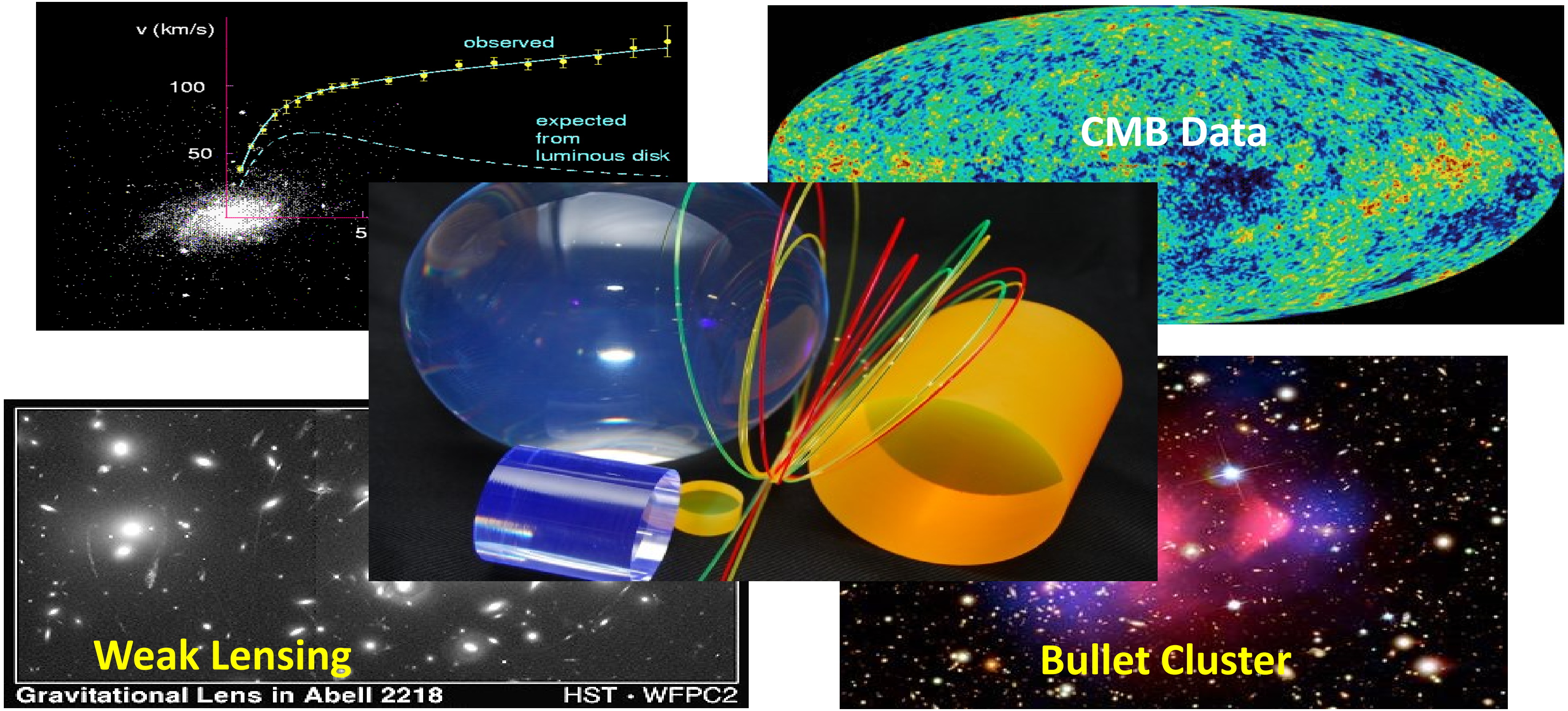
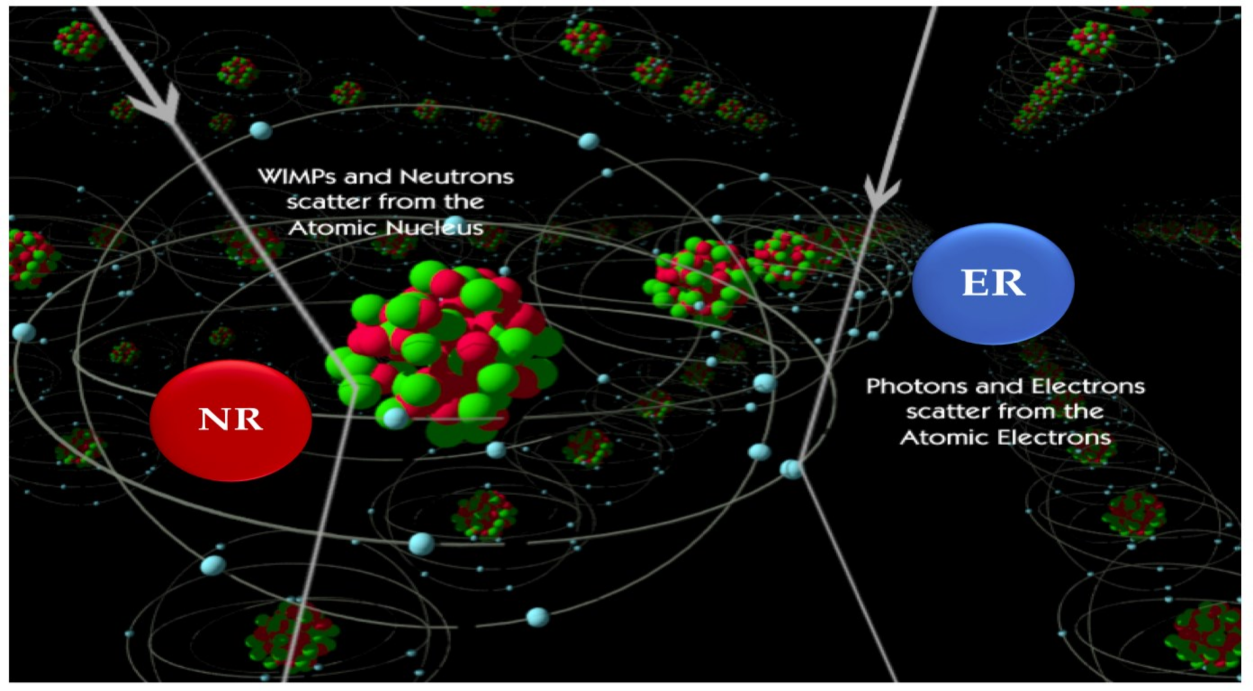
Dark Matter Search at INO: perspectives and possibilities

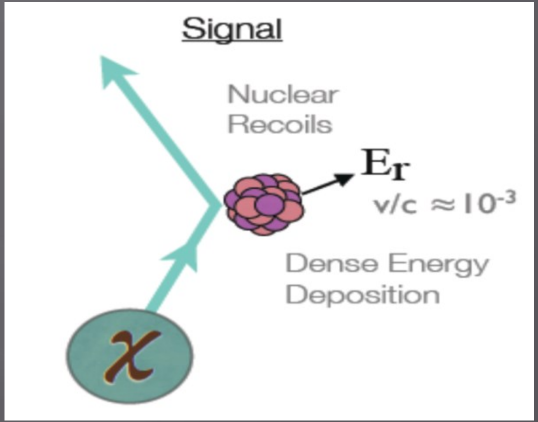


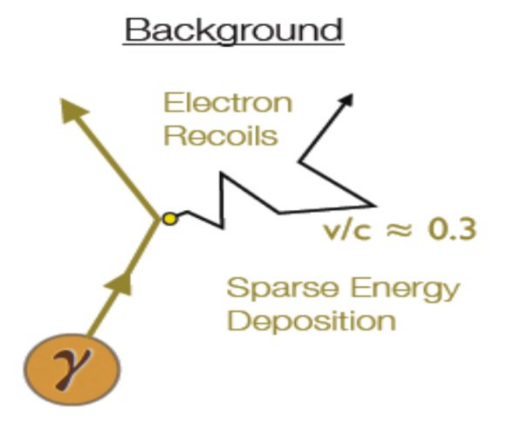
A new initiative for an underground facility in India,
TIFR August 6-7, 2022

Satyajit Saha SINP

A B C of Direct DM Search







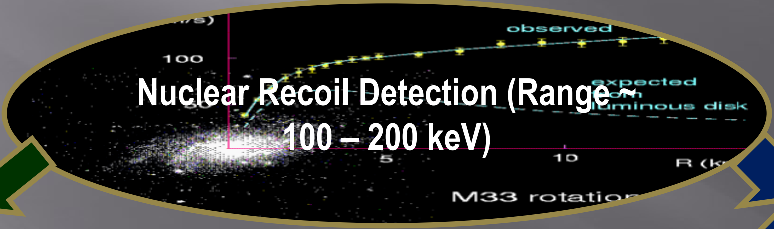
Classification of Direct detection experiments based on detection strategies with stress on discrimination

CDMS / SuperCDMS
EDELWEISS
CoGeNT

CRESST I COUPP
PICASSO / PICO
ROSEBUD
TOKYO (LiF)

CRESST-II & III
ROSEBUD
DINO

PHONON (Eff=100% / E ~ meV)



Nuclear Recoil Detection (Range ~ 100 – 200 keV)

IONIZATION (Eff ~ 10 - 30% E ~ eV)

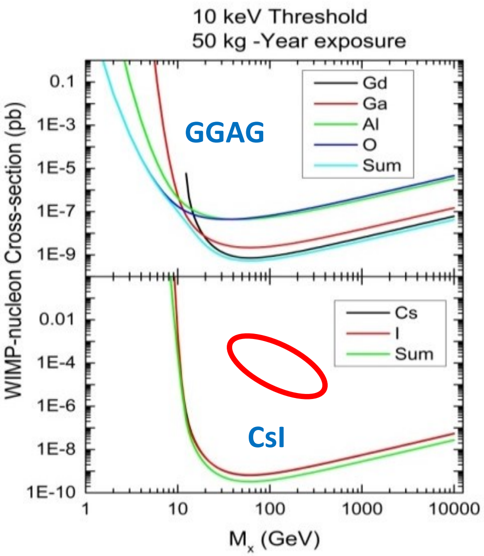
HDMS
GERDA
IGEX-DM
MAJORANA

LZ XENON1T /nT
DARWIN XMASS
CLEAN

SCINTILLATION (Eff ~ 1-10% E ~ keV)

DAMA / LIBRA ANAIS
ELEGANT ZEPLIN I NAIAD
DEAP 360 SABRE KIMS ….

DM search: why and how?

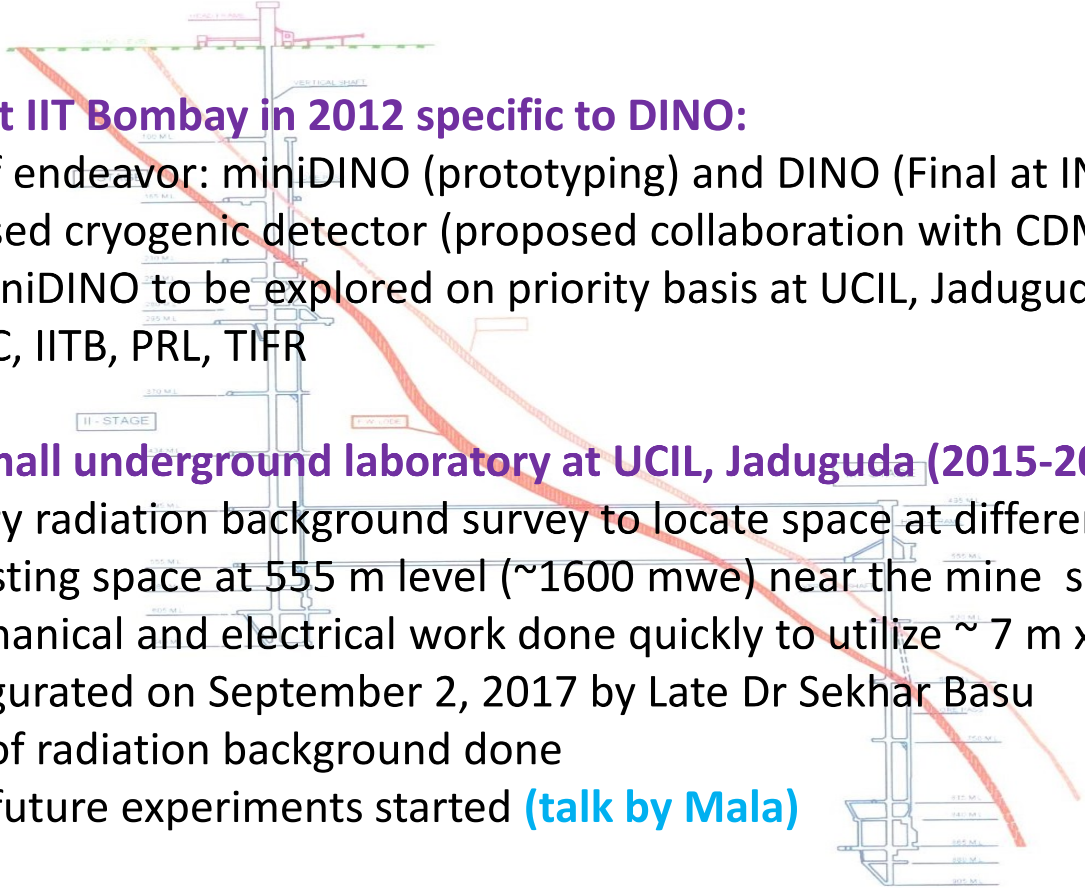


- Classification by Physics Issues: Where is the WIMP mass placed?
  - Target Mass (GeV)
  - Exposure (kg-days / kg-Years)
  - Energy threshold (eV - keV)
  - Positive Signal Contour

- Classification by detection techniques:
  WIMP recoil vs electron recoil
  Single channel vs 2 channel detection: discrimination

- Classification by Types and phases:
  Solid scintillators:
  NaI CsI CaWO4 CdWO4
  BGO GGAG (Gd+Ga+Al+O)
  Liquid Scintillators (single and multi-phases):
  Xe, Argon (Scintillation + TPC)
  Gas scintillators:
  Pressurized He, Ne, Ar, Xe ? (Scintillation + TPC)

Dark Matter Search at INO: historical perspectives



- **First meeting at IIT Bombay in 2012 specific to DINO:**
  - Phasing of endeavor: miniDINO (prototyping) and DINO (Final at INO site)
  - Silicon based cryogenic detector (proposed collaboration with CDMS / Texas A & M)
  - Site for miniDINO to be explored on priority basis at UCIL, Jaduguda
  - SINP, BARC, IITB, PRL, TIFR

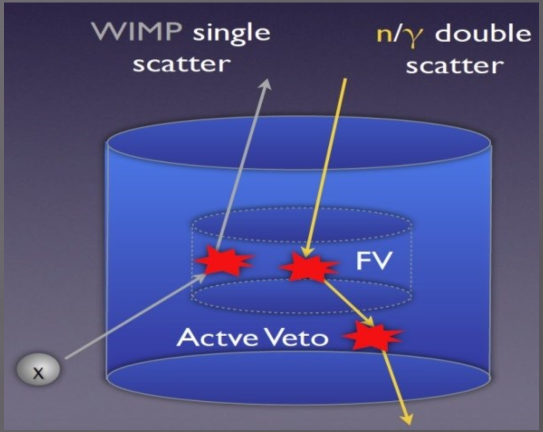
- **Proposal for small underground laboratory at UCIL, Jaduguda (2015-2017):**
  - Preliminary radiation background survey to locate space at different available levels
  - Utilize existing space at 555 m level (~1600 mwe) near the mine shaft (tub hold bay)
  - Civil, mechanical and electrical work done quickly to utilize ~ 7 m x 4.5 m x 2.2 m space
  - JUSL inaugurated on September 2, 2017 by Late Dr Sekhar Basu
  - Mapping of radiation background done
  - R & D for future experiments started **(talk by Mala)**

Proposed Scintillation detectors for DM search and related studies at JUSL (Phase I: miniDINO room temperature Phase II: miniDINO Cryogenic)

- CsI CdWO4 ZnWO4 GGAG
- Sensitivity to heavy WIMPs (W / Cs / I / Gd) ($\sigma_{coh} \sim A^2$) as well as to light WIMPs (Zn / Al / O).
- Increase in Light Yield at low temperature [CsI, GGAG(?)]
- Increase in decay time of principal comp. and emergence of long decay time comp at low temp.
- PSD for discrimination of response to

  (1) alpha and gamma, (2) neutron and gamma
- Passive and active shielding to reduce external radiation background (Cu, Polyethylene, Pb and Plastic scintillators)
- Reduce radioactivity background of the scintillators **(RADIOPURE)**
- Phonon and photon detection using SQUID / W-TES technology. **NEED DILUTION FRIDGE (~ 15 mK)**
- Exploration of neutron response at low temperature operation using SQUID / TES, discrimination of electron / photon signals from neutron signals.
- **Need extra space and height at the JUSL laboratory for the DF.**

Sources of external background



External gamma rays from radioactivity:

- Suppression by self-shielding of Target
- Materials screening and selection
- Rejection of multiple scatters
- Discrimination

External muons from cosmic rays:

- Go underground!
- Active shielding (veto detectors)

External neutrons from muon induced reactions [COSMOGENIC)]
(α, n) reaction on materials or fission (U, Th) [RADIOGENIC]

- Go underground to reduce cosmogenic!
- Use shield: passive (HDPE, water) or active (water / neutron scintillator veto)
- Judicious materials and site selection (low U / Th)
- Reduce / monitor Radon contamination at the underground site

Passive and Active Shield

Neutrinos from Sun, atmosphere and from supernovae explosion:

- Elastic neutrino-electron scattering
- Coherent neutrino-nucleus scattering

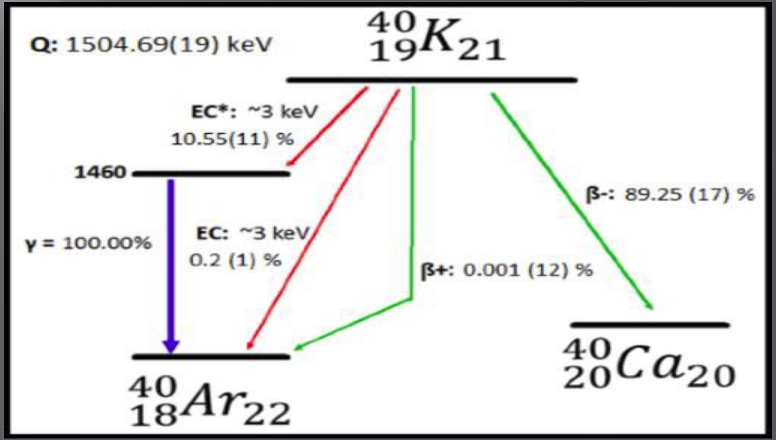
No hope to reduce, unless....

Sources of internal background

- **Internal contamination in liquids:**
  - Krypton: ^{85}**Kr** ($T_{1/2}$= 10.8 Y) remove by cryogenic distillation / centrifuges
  - **Rn:** remove by absorption in activated carbon
  - Argon: ^{39}**Ar** (E_β=565 keV, $T_{1/2}$ = 268 Y, cosmogenic production, 759 ± 128 atoms/kg/day, Phys. Rev. C 100, 024608)
    ^{42}**Ar** ((E_β=599 keV , $T_{1/2}$ = 32.9 Y, cosmogenic, nuclear weapons test)
  - Xenon: ^{136}**Xe** $\beta\beta$ decay ($T_{1/2} = 2.2 \times 10^{21}\ Y$) very long lifetime

- **Surface background in solids (from bulk and contaminations):**
  - Germanium or scintillators grown out of high purity materials / pay attention to the melts
    → lower intrinsic background
  - Cosmic activation
  - Surface events from α *or* β decays

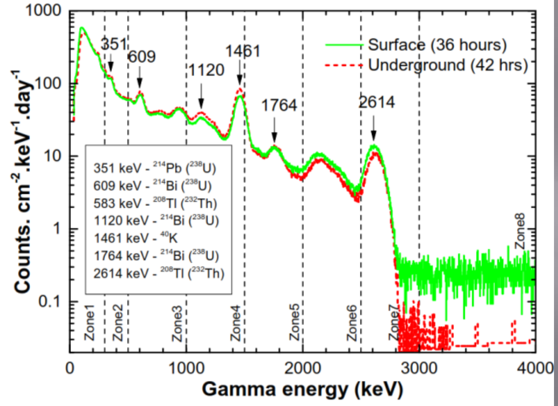
- **Natural / Intrinsic radioactivity**
  background: ^{40}K (1.25 x 10^9 Y
  E_γ 1460 keV, E_β 1311 keV)
  Uranium – Thorium

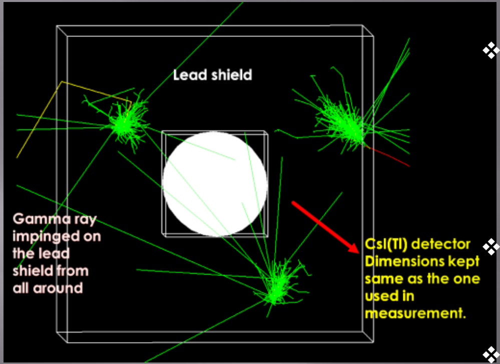


Important to select and procure radiopure materials

Gamma ray and cosmic muon background at JUSL

Gamma rays



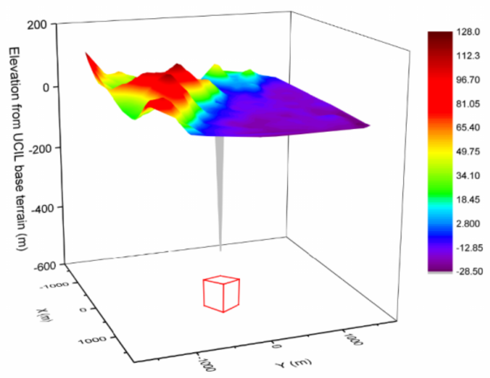


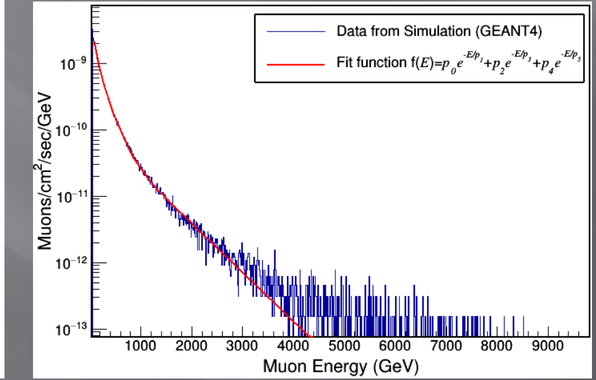
Gamma ray impinged on the lead shield from all around

CsI(Tl) detector Dimensions kept same as the one used in measurement.

- Gamma ray flux averaged over 0-3 MeV range (**including 30 cm Lead shield**): ~ 3 x 10^{-8} cm^2.sec^{-1}
- Average muon energy from simulation: $E_{\mu}^{\text{avg}} = 186.45 \pm 0.51$ GeV.
- Muon flux from **simulation**: $(2.051 \pm 0.142 \pm 0.009) \times 10^{-7}$ cm^{-2} sec^{-1}.
- **Measured** muon flux: $(2.257 \pm 0.261 \pm 0.042) \times 10^{-7}$ cm^{-2} sec^{-1}.
- Based on the muon flux, cosmogenic neutron spectral distribution and flux are estimated using GEANT4 simulation.

Cosmic muons

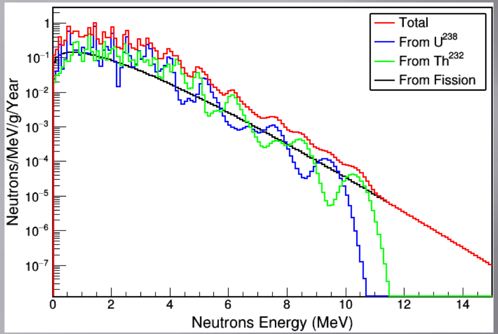




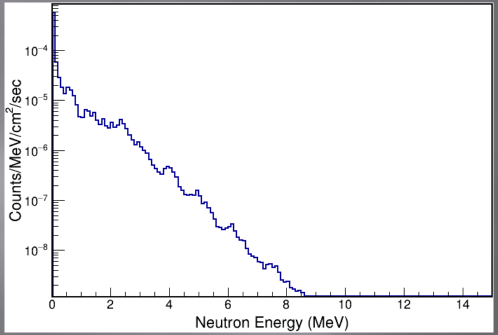
Sayan Ghosh, *et. al.*, Astropart. Phys. 139 102700 (2022) / Sayan Ghosh: Ph D Thesis 2022 HBNI

Neutron background at JUSL: Radiogenic neutron simulation

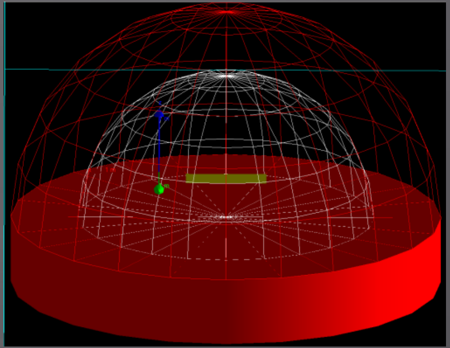
Input: rock composition and radioactivity



Output: Radiogenic n spectrum



GEANT4 model:



GEANT4 simulation:

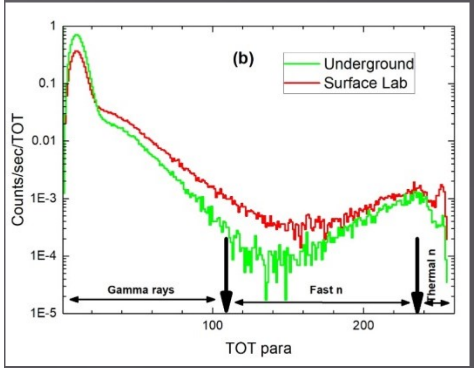
- Neutrons undergo elastic and inelastic collisions.
- Estimated neutron flux including backscattering:

$2.61 \pm 0.17 \times 10^{-4}$ cm^{-2} sec^{-1}.

Experiment:

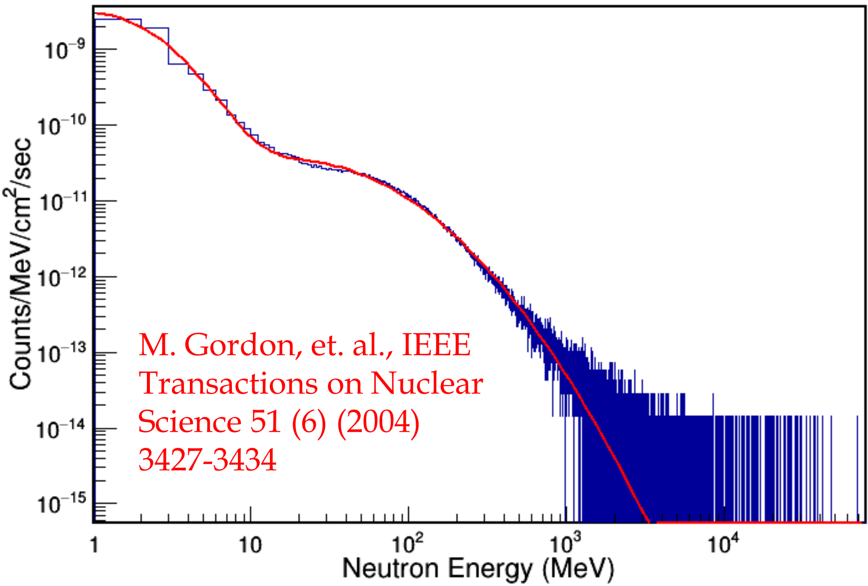
Flux of neutrons in the energy range $E_n \leq 10$ MeV was fo
to be **$1.63 \pm 0.03 \times 10^{-4}$** cm^{-2} sec^{-1}.

Pressurized Helium-4 neutron detector



Sayan Ghosh: Ph D Thesis 2022 HBNI

Simulation of cosmogenic neutrons at JUSL

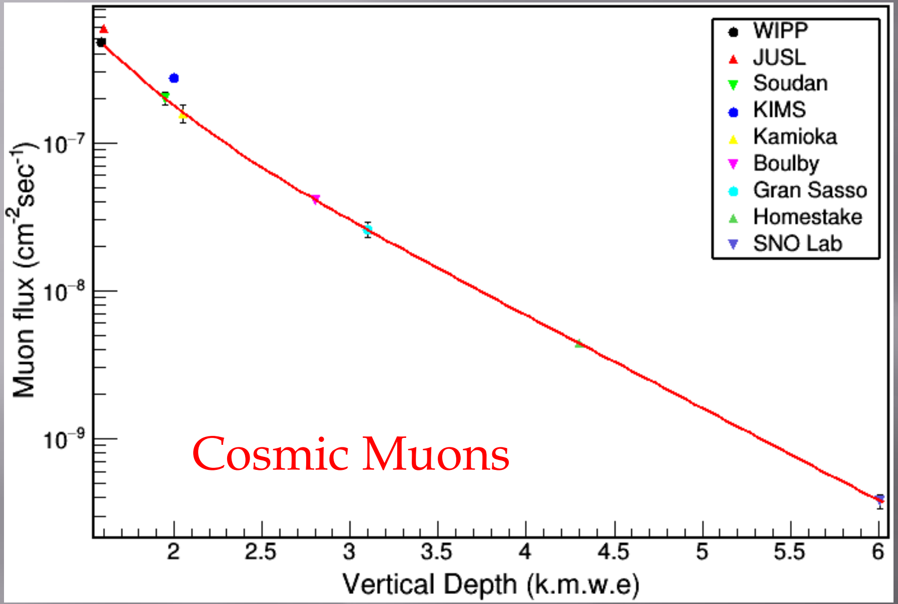


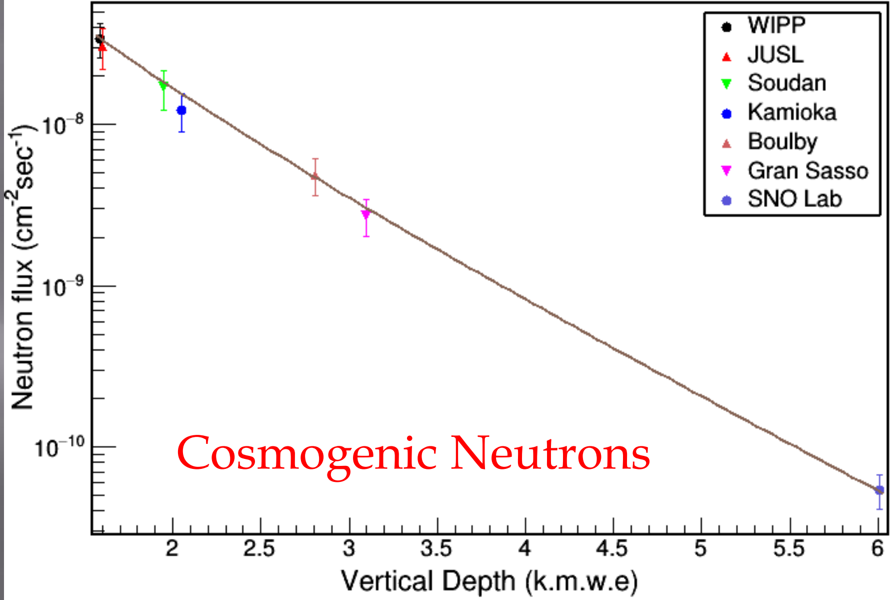
M. Gordon, et. al., IEEE Transactions on Nuclear Science 51 (6) (2004) 3427-3434

- 2 m of rock shell thickness found to be the optimum choice. Floor thickness 1 m not found to cause any difference in the cosmogenic neutron flux.
- Flux of cosmogenic neutrons at the detector: $\mathbf{5.661 \pm 0.103 \times 10^{-8}}$ **cm^{-2} sec^{-1}**.

Sayan Ghosh: Ph D Thesis 2022 HBNI

Comparison of JUSL fluxes with other underground laboratories





- Global Fit functions :- D. Mei, A. Hime, Phys. Rev. D 73 (2006) 053004.

Direct DM search: Future possibilities for Indian physicists

- Scintillator based (spans a large WIMP mass range)
- Superheated droplet / bubble chamber based (very low WIMP mass sensitivity)
- Solid state cryogenic detector (Si, Ge)
- Noble liquid or gas based (pressurized) TPC

Noble liquid or gas based (pressurized) TPC for direct DM search

Advantages:

Large to Huge: Scalable

Purity: Radiopure

Multiple physics goals can be targeted:

Neutrino Physics CEvNS DM search Neutrinoless DBD Supernova explosion

Long history of detector development spanning 4-5 decades

Natural discrimination between radiation quanta : 2 phase 2 signal channels.

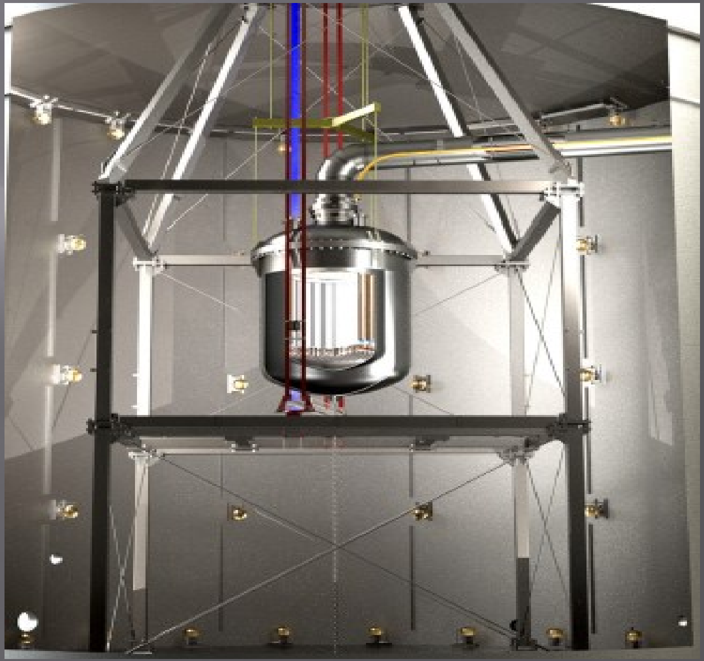
Liquids: Xenon: LZ Xenon1T XENONnT PANDA X III DARWIN (g5) XLZ?? (g6)
Argon LArTPC DUNE DEAP CLEAN

Noble liquid or gas based (pressurized) TPC for direct DM search

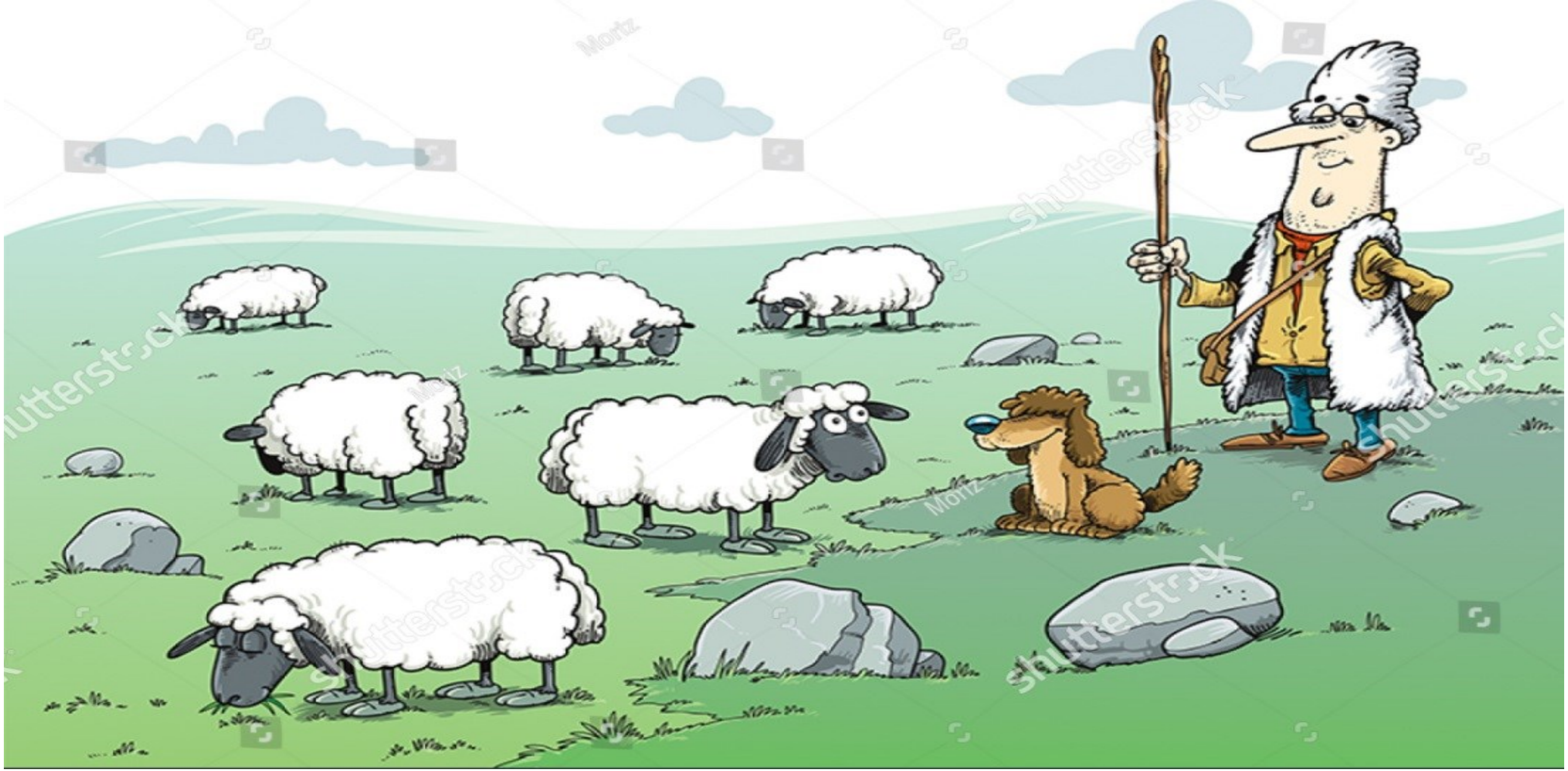
A few relevant physical properties:

Element	Phase	W_i (eV)	W_{SC} (eV)	λ_{em} (nm)
He	Gas	~ 42		70
Ar	Gas	26.4		127
Ar	Liquid	~23 (?)	19.5	
Kr	Gas	24.2	~30	148
Kr	Liquid	23.6	15	
Xe	Gas	22.1	28	~170
Xe	Liquid	15.6	13.8	~178

XENON1T experiment



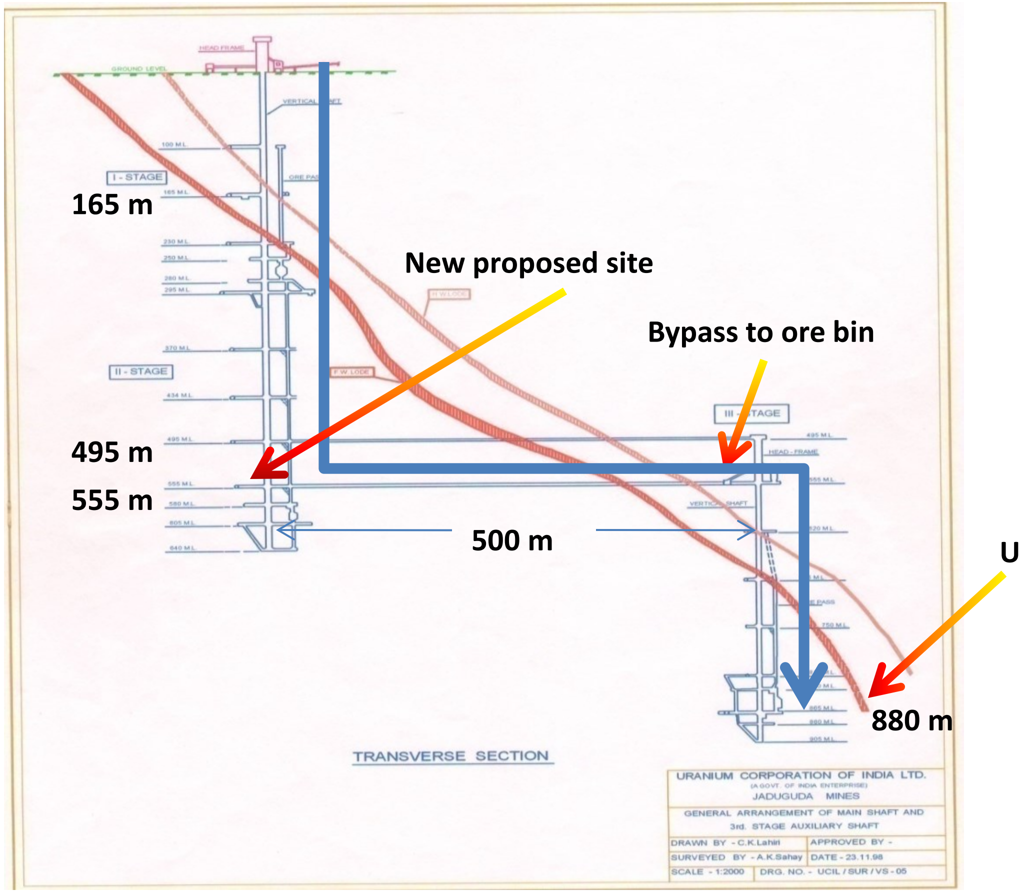
Summary



Thank you

Back up

JADUGUDA MINE ELEVATION DRAWING



165 m

New proposed site

Bypass to ore bin

495 m

555 m

500 m

Uranium mining on

880 m

URANIUM CORPORATION OF INDIA LTD.
(A GOVT. OF INDIA ENTERPRISE)
JADUGUDA MINES

GENERAL ARRANGEMENT OF MAIN SHAFT AND
3rd. STAGE AUXILIARY SHAFT

DRAWN BY - C.K.Lahiri
APPROVED BY -
SURVEYED BY - A.K.Sahay
DATE - 23.11.98
SCALE - 1:2000
DRG. NO. - UCIL / SUR / VS - 05