Bernard Sadoulet
Dept. of Physics /LBNL UC Berkeley
UC Institute for Nuclear and Particle Astrophysics and Cosmology (INPAC)

A U.S. Deep Science Initiative

Historical context and process
The Deep Scientific frontier
Multidisciplinary

Site independent study
recommendations

"Quantum Universe" style brochure

History

Many attempts to establish an underground laboratory in the US

1980's Yucca Mountain
San Jacinto
2000 Homestake - various worshops NUSL
2004 New Deep Underground Science and Engineering Laboratory
DUSEL

Restart process with 2 simultaneous process
A community wide site independent study

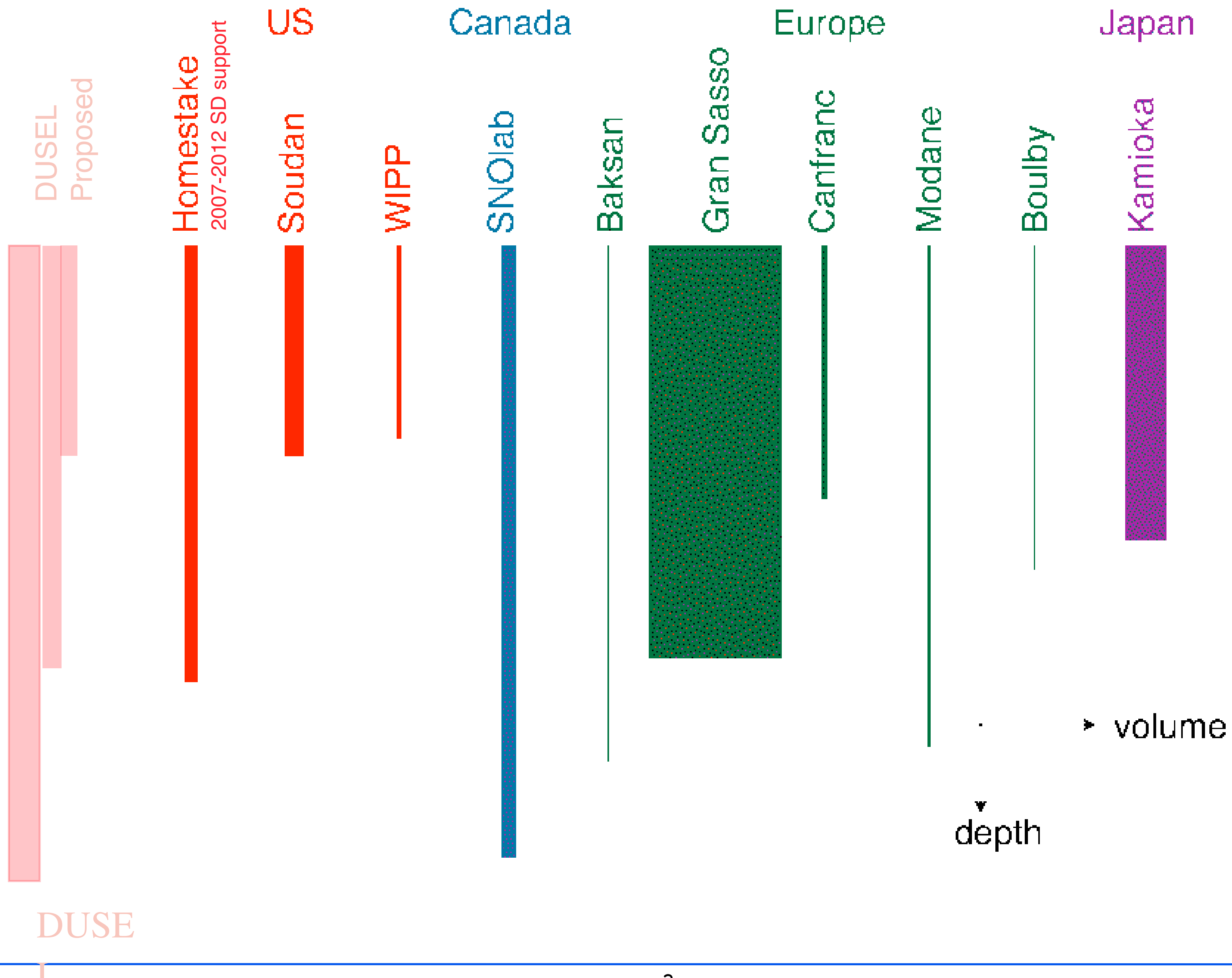
Bernard Sadoulet, UC Berkeley, Astrophysics/Cosmology
Eugene Beier, U. of Pennsylvania, Particle Physics
Charles Fairhurst, U. of Minnesota, geology/engineering
Tullis Onstott, Princeton, geomicrobiology
Hamish Robertson, U. Washington, Nuclear Physics
James Tiedje, Michigan State, microbiology

Multidisciplinary!

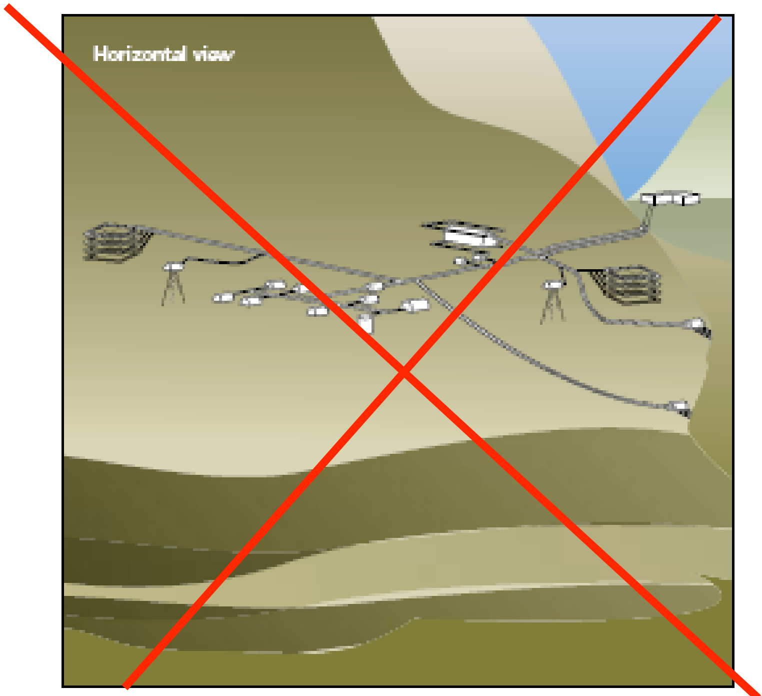
A preselection of the site(s)
August 2005 Henderson and Homestake preselected

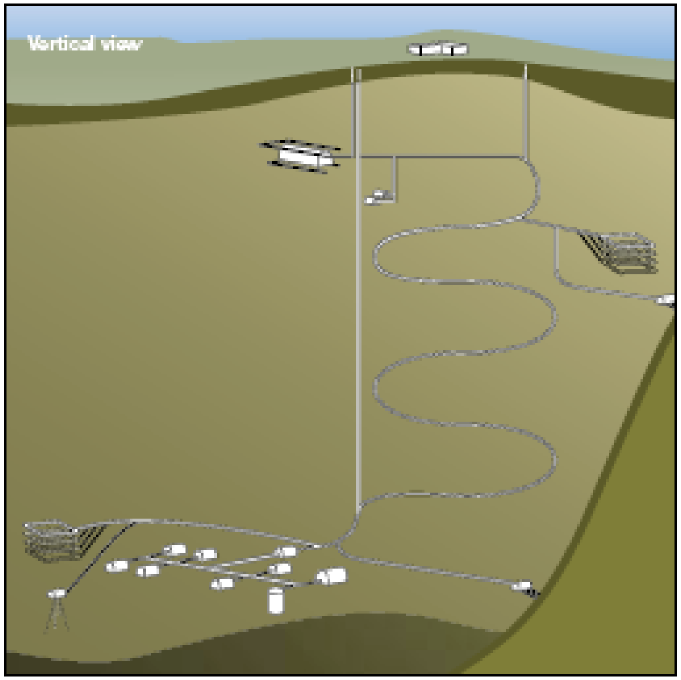
June 2006 Conceptual Design Reports
Dec 2006 S3 proposals-> down select
Dec 2007 Technical design Report-> MREFC -> ≥FY 2010 budget

Science Underground



Debate within the community





Horizontal Access vs Vertical Access

Easiness of access
Initial investment vs operation costs

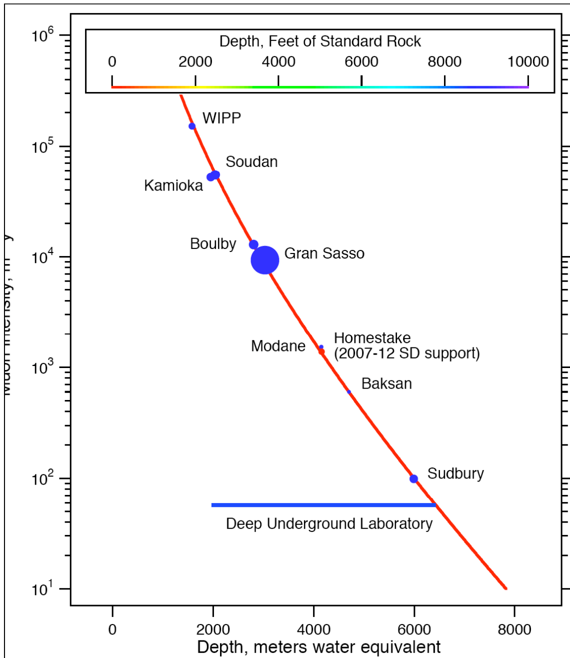
Green site vs old mine

Operation costs
Pristine rock
Risk in permitting

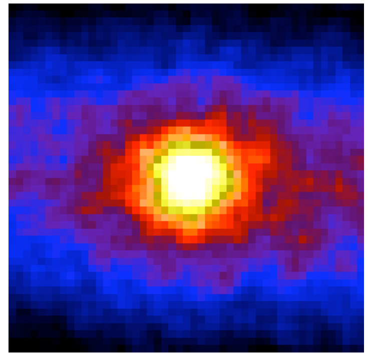
Sedimentary vs Hard Rock

Some unhappiness about criteria used by NSF

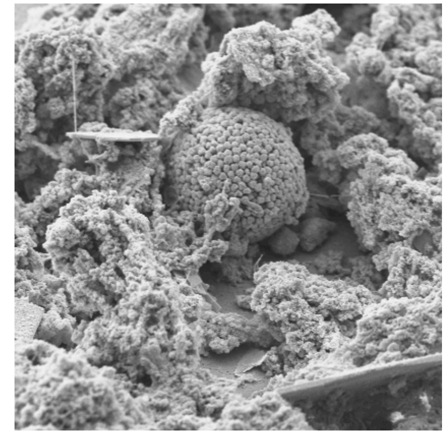
Legal challenge granted
Clumsy handling
Back on track



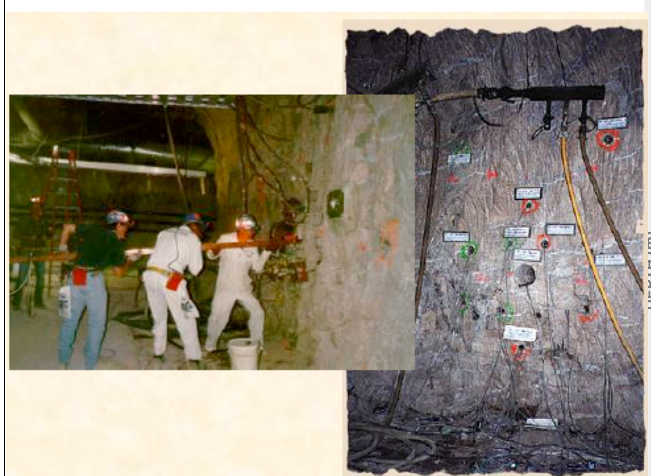
Neutrino picture of the Sun



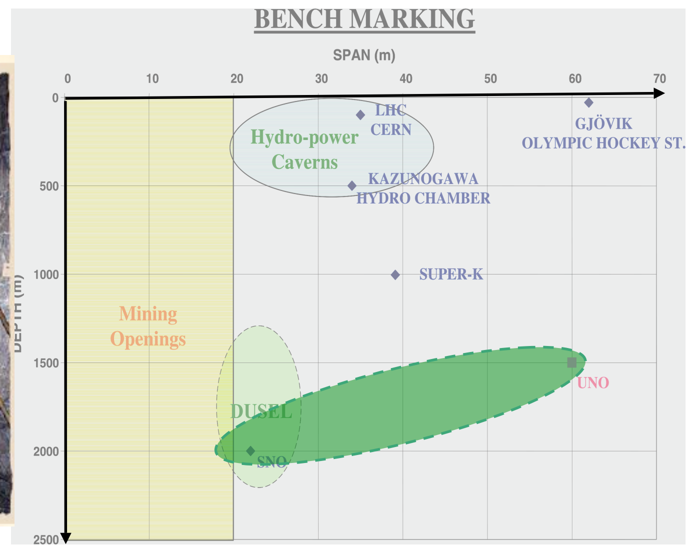
Geo-microbes



Deep Science



Large Block Geo Experiment Coupled Processes



Size of cavity vs depth

Undergraduates in South Africa mine

Deep Science

Extraordinary increase of interest in underground science and engineering

3 Fundamental Questions that uniquely require a deep laboratory

- What is the universe made of? What is the nature of dark matter? What happened to the antimatter? What are neutrinos telling us?
  - Particle/Nuclear Physics: Neutrinos, Proton decay
  - Astrophysics: Dark Matter, Solar/Supernovae neutrinos

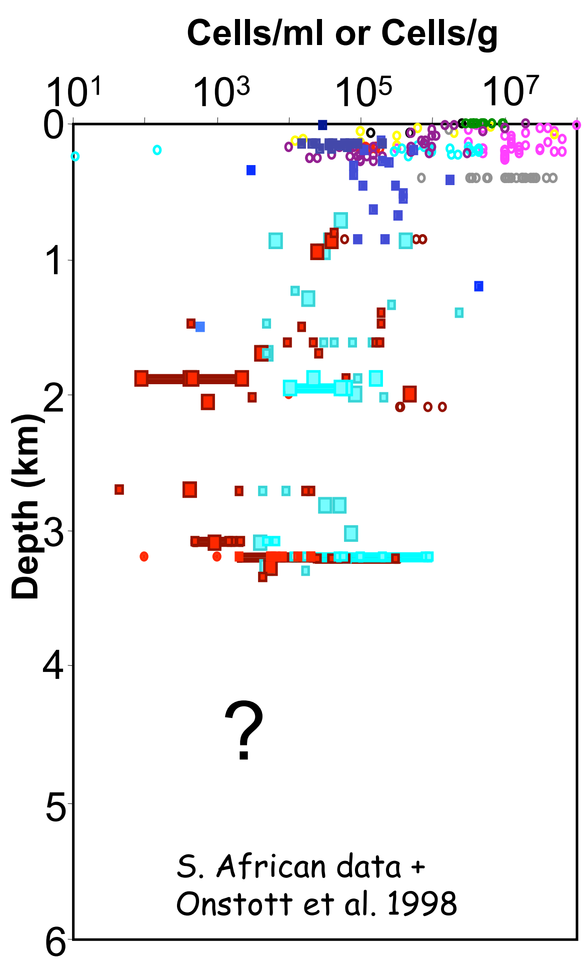
Push three frontiers

Astrophysical observations from ground and spa
Colliders
Deep underground

- How deeply in the earth does life extend? What makes life successful at extreme depth and temperature? What can life underground teach us about how life evolved on earth and about life on other planets?
  - Unprecedented opportunity for long term **in situ** observations
- How rock mass strength depends on length and time scales? Can we understand slippage mechanisms in high stress environment, in conditions as close as possible to tectonic faults/earthquakes?
  - Earth Sciences: Mechanisms behind the constant earth evolution
  - Engineering: rock mechanics at large scales, interplay with hydrology/chemistry/

Geomicrobiology

A recent breakthrough



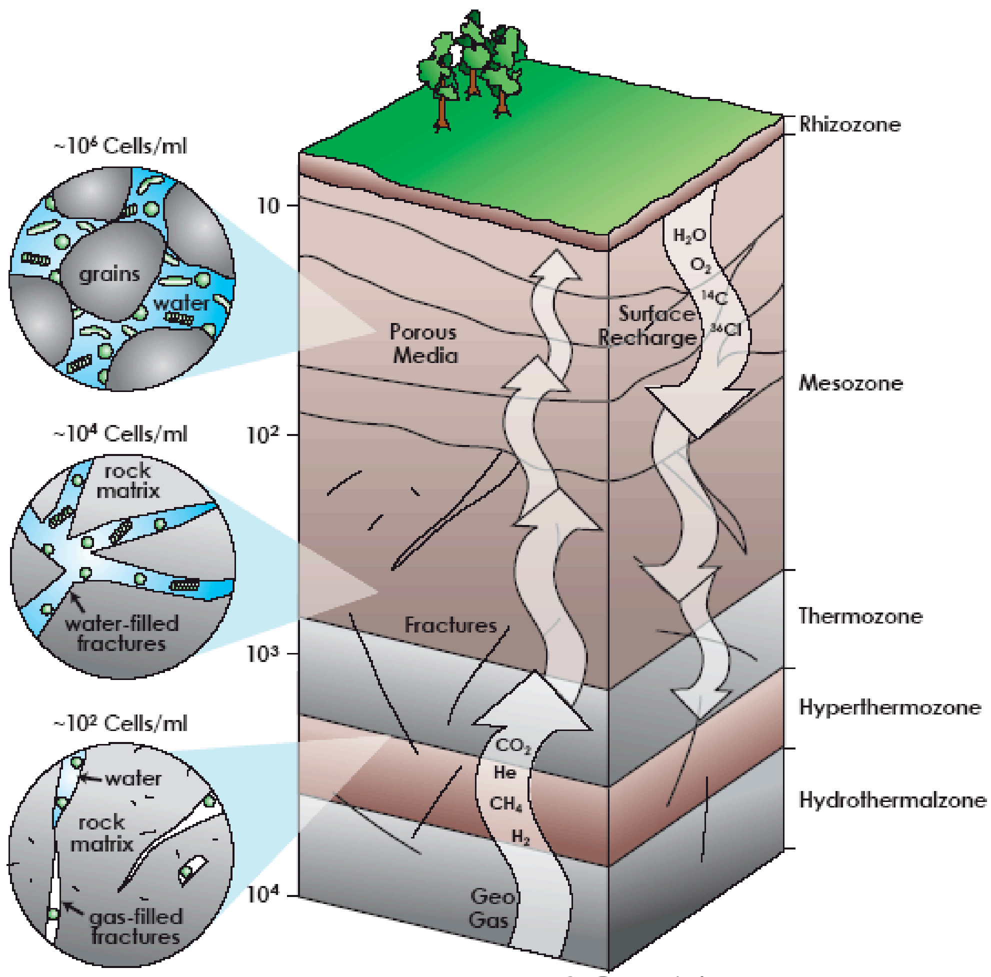


Fig. 2 of Earthlab report

Rock Mechanics

Failure of Malpasset Dam, 1958

Remains of the Malpasset Dam;
Reproduced courtesy of Structurae;
photographer Jean-François Perréard

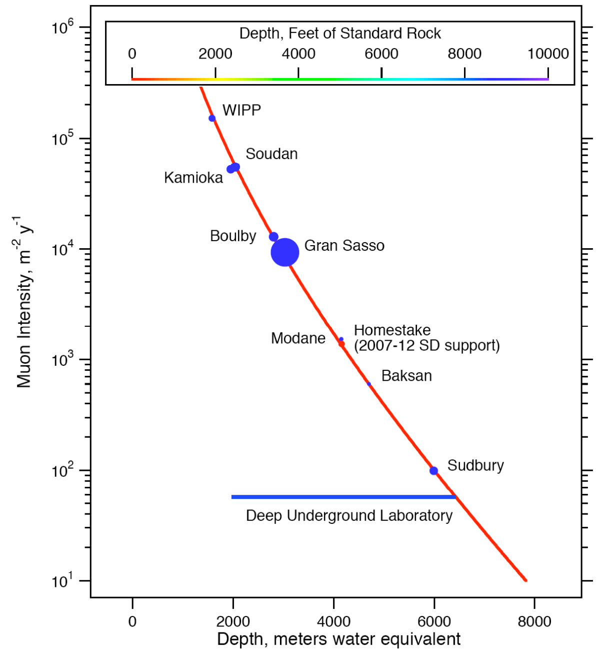
Malpasset Dam Remains.
Reproduced courtesy of Structurae;
photographer Alain Pasquet

The tragedy killed 424 people and led to the realization that geoscience and engineering required new directions.

The Frontier is at Large Depth!

Physics

- Neutron and activation of materials
  - Neutrinoless double beta decay
  - Dark Matter
  - Neutral current/ elastic scattering solar neutrino
  - New ideas (e.g. related to dark energy)
- Neutron active shielding is difficult and risky
- Rejection of cosmogenic activity is challenging



Biology

- DUSEL = aseptic environment at depth
- Study microbes in situ (at constant pressure, microbial activity at low respiration rate)
- Deep campus: Platform to drill deeper -> 12000ft (120°C)

Earth science/ Engineering

- Get closer to conditions of earthquakes
- Scale/stress f
- Complementary to other facilities

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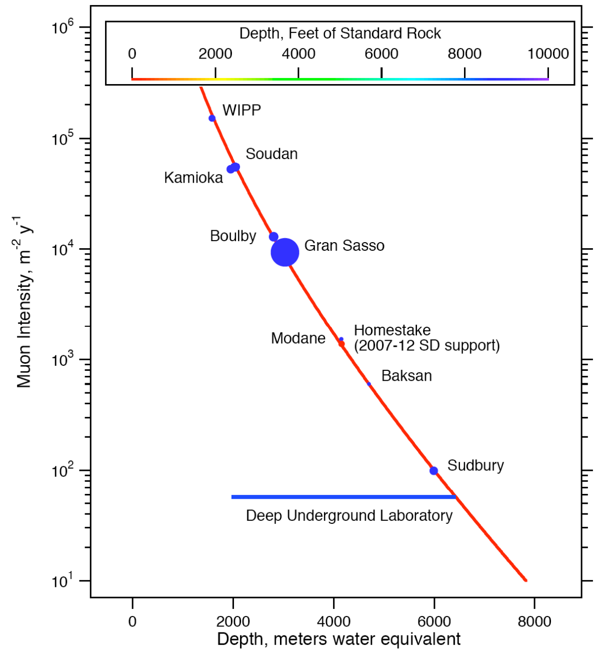

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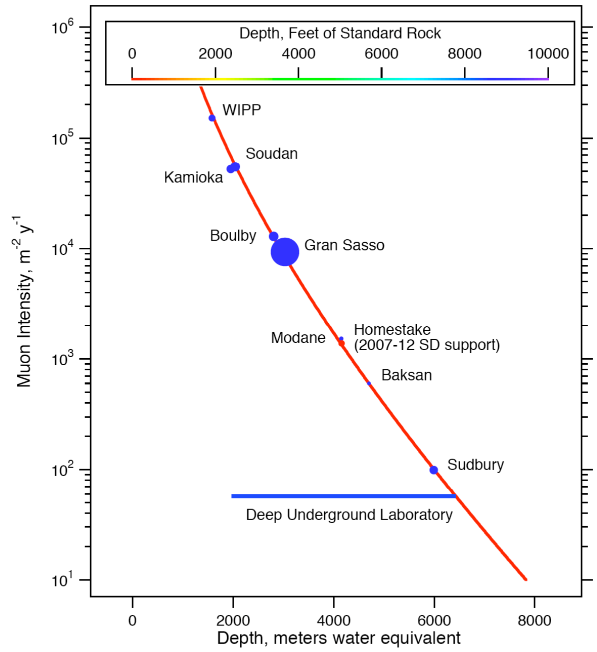

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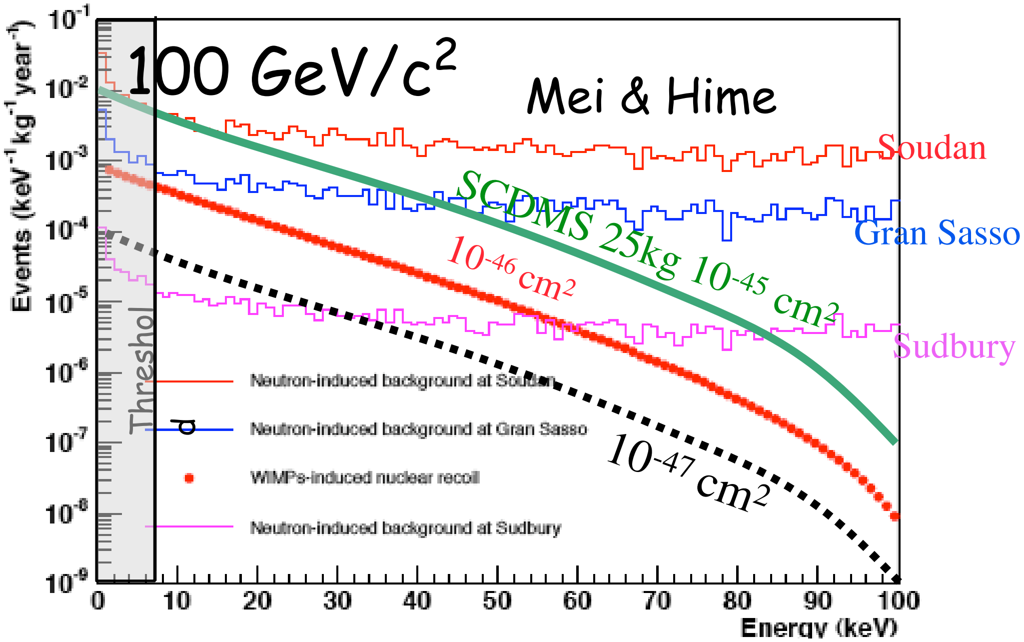
Frontier WIMP searches need depth



Raw neutron rates

With good passive shield
μ veto but no shower rejection
Rejection of multiples
Mei, Hime astro-ph0512125

10^{-47}cm² needs 6000mwe

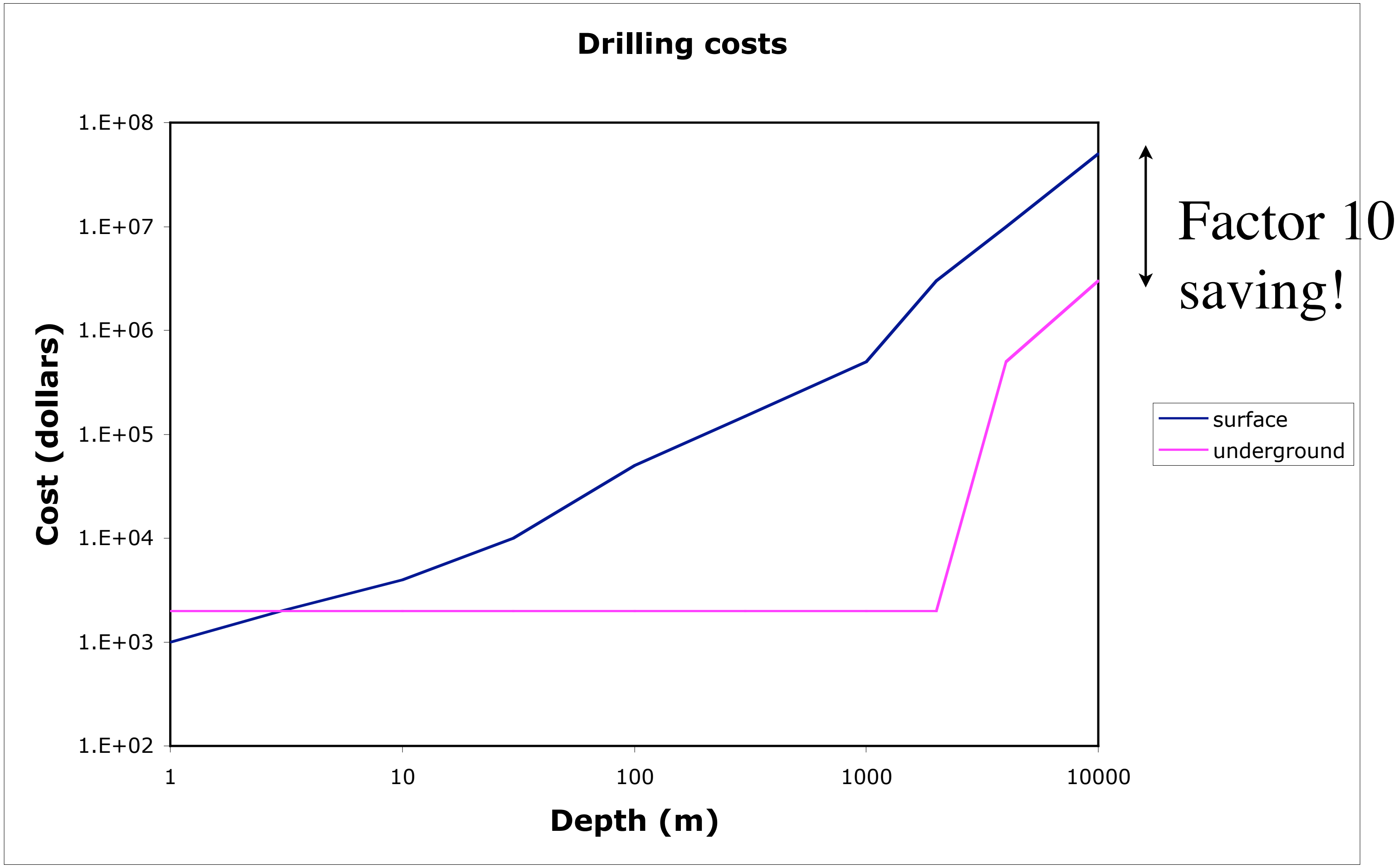
Some factor gained by shower rejection × 5-10?

Shallow+ active neutron veto?

But: 300 MeV neutrons!
Risky : shielding notoriously difficult

Eventually γ background from n and μ activation

Deep Drilling



Other Motivations

Exciting potential for cross disciplinary synergies

Pushing the rock mechanics envelope <-> physicists needs for large span cavities at great depth

"Transparent earth" Improvement of standard methods + new technologies

Neutrino tomography of the earth?

Sensors, low radioactivity, education etc...

Relevance to Society

- **Underground construction:** the new frontier (urban, mining,fuel storage)
- **Resource extraction:** Critical need for recovery efficiency improvement
- Water resources:
- **Environmental stewardship**
  - Remediation (e.g. with micro-organisms)
  - Waste isolation and carbon dioxide sequestration.
- **Risk prevention and safety**
  - Making progress in understanding rock failure in structures and earthquakes
- **National security**
  - Ultra sensitive detection methods based on radioactivity

Training next generation of scientists and engineers

+ public outreach: better understanding of science

3 Important Questions

What is the likely demand for deep underground space?

Can't we survive with SNOLAB and maybe extension of Modane?

Is there a danger of having too much space?

Why a U.S. facility in an international context?

Isn't outdated parochialism?

Priority vs other national/international initiatives?

e.g. International Linear Collider

Need for New Underground Facilities

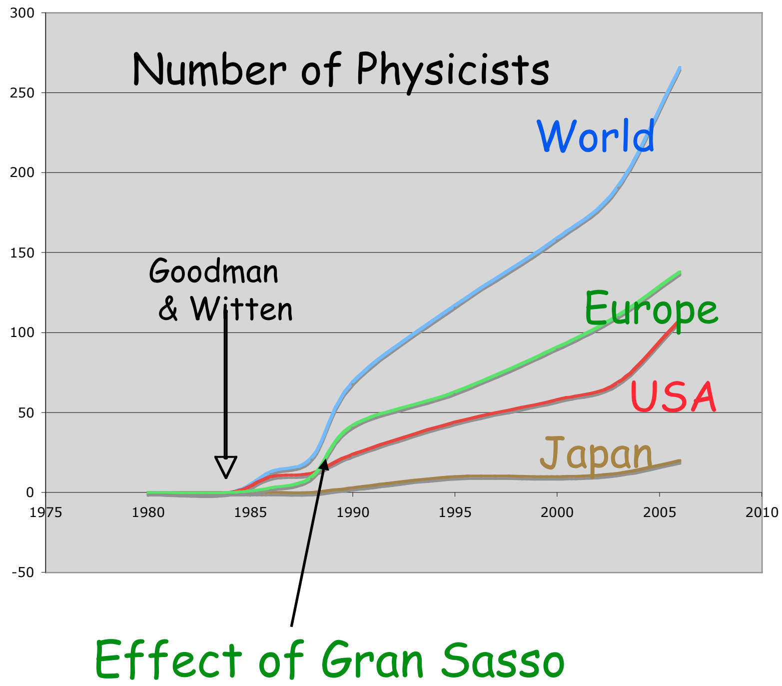
Chronic Oversubscription Worldwide

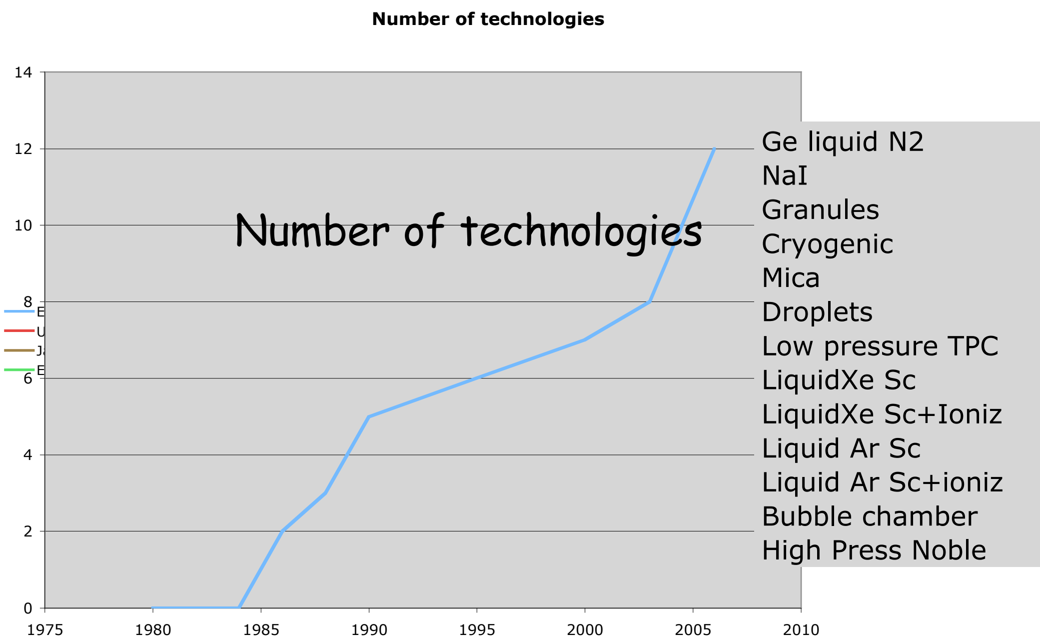
Historically True!

Increase in the community

Importance/interest of the science: neutrinos, cosmology
Shift from accelerator based experiments
Fast progress at boundaries between fields

Growth Example of WIMP searches





Need for New Underground Facilities

Chronic Oversubscription

Increase in the community

- Importance/interest of the science: neutrinos, cosmology
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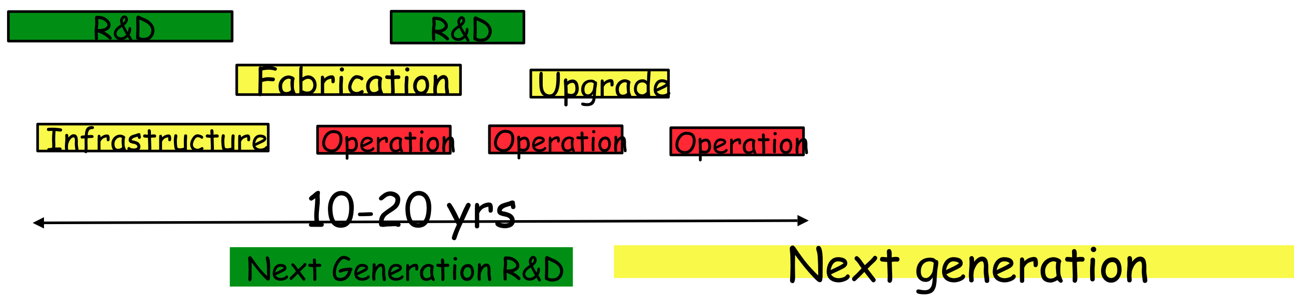
- Fast progress at boundaries between fields

Life cycle of experiments

- Getting longer



- Overlap between running of previous generation and construction of next

For important questions, need for several experiments

- Decrease risk: several technologies => R&D at nearly full scale
- Dependence on target: e.g matrix element for 2β , A^2 for WIMPs

But budgetary constraints ≠ sum of all dreams

Motivations for a National Facility

Although

- Science is international in nature
- U.S. scientists and engineers managed to play a pioneering role without a dedicated U.S. deep underground laboratory

There is no substitute for a premier national facility with unique characteristics

- Push frontier science
- Strategic advantage for U.S. scientists and engineers in the :
  - Rapid exploration of new ideas, and unexpected phenomena
  - Full exploitation of existing national assets, such as accelerators.
  - Maximization of the program's impact on our society

Can we afford DUSEL?

MREFC line New Money

Covers Facility + NSF contribution to first suite of experiments
(NSF-DOE working group)

⇒Initially bring new resources to HEP/Nuclear community

Long term costs

Cost of operation will be eventually borne in part by Physics community

- Facility operation and safety: potentially important discriminant
  Water pumping, hoist operation, maintenance
- Easiness of access
  Installation (e.g. 100-200 man-yrs of SNO, small experiments)
  Emergency interventions, maintenance

Impact on future projects:

Although multidisciplinary, MRE would be seen as Physics possibly impacting other NSF initiatives

But: different scale from ILC
enabling possible extensions
e.g. Proton Decay/Long Baseline neutrino detector

S1 Recommendations (Draft)

1 A cross-agency Deep Science Initiative.

Given

- the importance of deep underground science and engineering
- its high potential for revolutionary discoveries
- the promise of synergy among currently unrelated disciplines
- and its broad impact on society

The U.S. science agencies should collaborate to launch an initiative in deep underground science and engineering.

National Science Foundation (Mathematics and Physical Sciences,Geology, Biology and Engineering),
DOE (High Energy Physics, Nuclear Physics, Basic Energy Sciences, Biological and Environmental Research),
US Geological Survey,
NASA (for astrobiology)
potentially NIH (for some genome studies and medical applications)

Focus existing +new resources on a few key scientific problems +R&D
Coordinate U.S. underground researchers at universities, national laboratories and centers funded by a variety of agencies + synergy
Optimize the use of existing infrastructure
Take full advantage of international collaborative opportunities
Use of complementary national assets (e.g. accelerators)

Recommendations (Draft)

2. To fully support frontier underground science, the U.S. should complement the nation's existing assets with the construction of a world-class underground laboratory

Unique characteristics able to attract the best projects worldwide

Depth (>6000 m.w.e.≈ 6000ft -> 12000 ft biologists)
Long term access (≥ 30 years)

Easiness of access 24h/day 365 days/yr
- Highly desirable: Small trailer or ISO 1/2 container (2.4 x 6.1 x2.6 m^3)
- Dust, radon control, low vibration, electromagnetic noise
- Local technical support, information infrastructure

Access to pristine rock
Evolutionary: Additional cavities (e.g. Proton Decay/ Neutrino long base line)
Proactive Safety
Capability to address unconventional requirements (e.g. challenging safety issues: large cryogenic liquid experiment, fracture motion experiments)

Unique combination with accelerators (L≥1000km)
Multidisciplinary synergies, intellectual atmosphere.

3. A program broader than DUSEL.

Although DUSEL would be the central element of a new Deep Science Initiative, the initiative not be limited to DUSEL.

- Other U.S. or international facilities may be better suited
- Some explorations, such as research in sedimentary rock, may not immediately require a dedicated facility.
- As future needs arise, existing underground laboratories and DUSEL could be supplemented by additional underground facilities in different rock or with different characteristics.

Initial Program (Draft)

4 phases

1) **Before the excavation**

Physics: R&D and low background counting facility.

Earth Sciences/Engineering: Full characterization of the site with a number of instrumented bore holes and imaging.

Biology: Use of bore holes for sampling

2) **During excavation**

Earth Sciences/Engineering: Monitoring of rock motion, modification of stress during construction

Tests of imaging methods

Biology: sampling ahead

3) **First suite of experiments**

See next two slides

4) **Design potential extensions in the first ten years**

Initial Suite of Experiments (Draft)

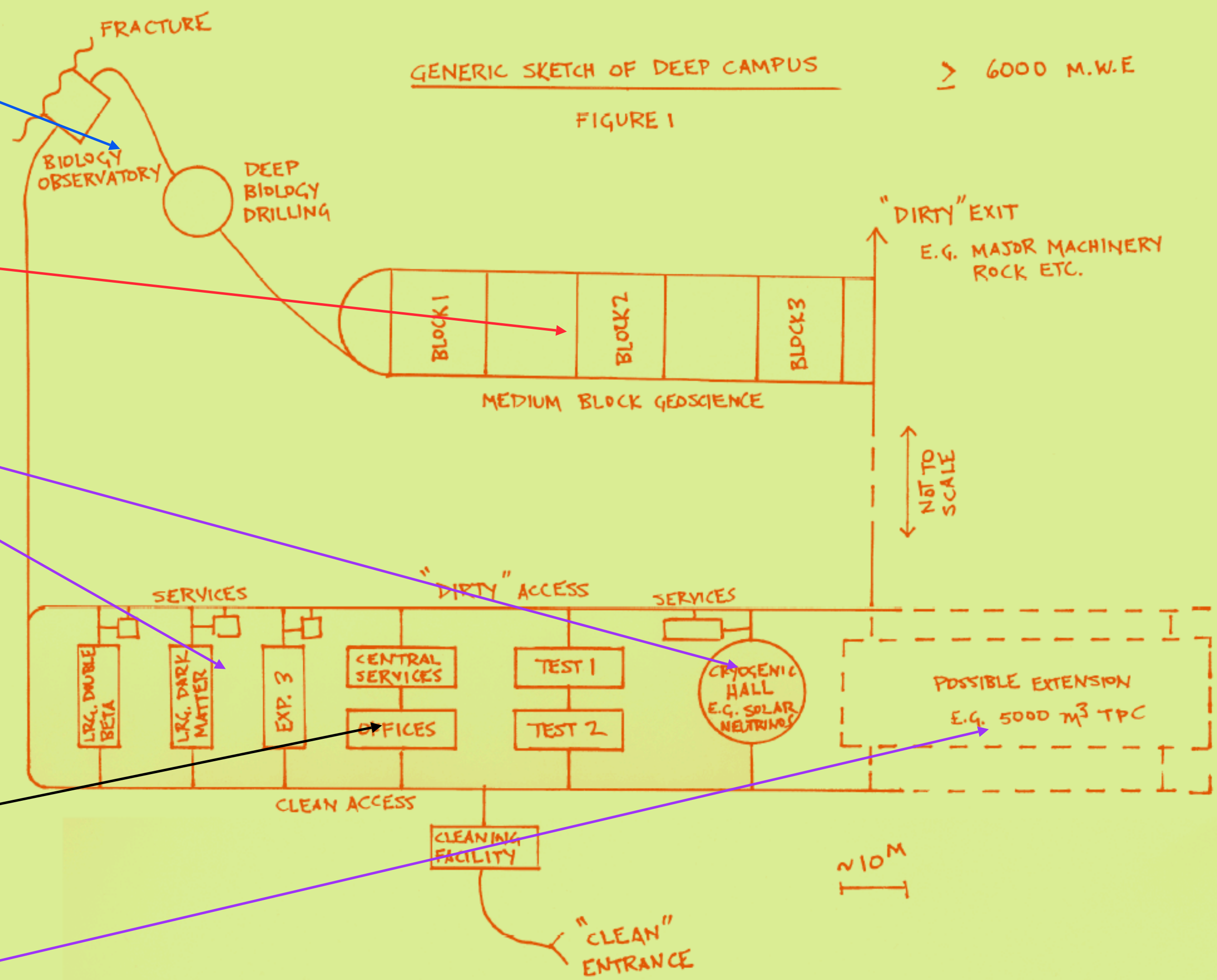
Deep Campus

Biology observ.
Deep Biology
Drilling

Geo/Eng
3 Medium block
experiments

Dark Matter
Double beta
Exp. 3 TBD
Solar
neutrino
2 test/small
expt areas

Central services
Offices etc.

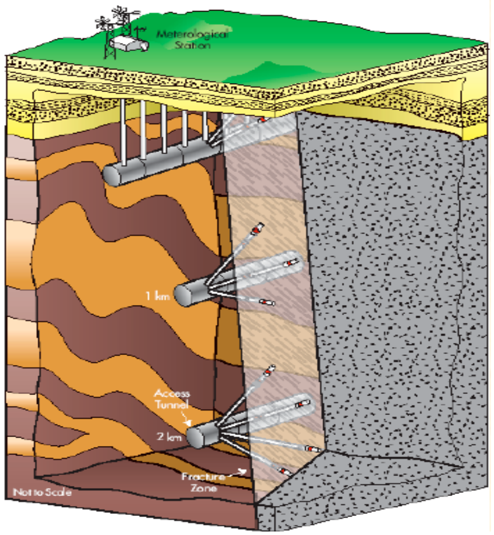


Initial Suite of Experiments (Draft)

Intermediate levels

- Low background counting
- Underground fabrication facilities, Ge & Cu refining
- Potentially: Low vibration facilities for Atomic Molecular and Optical Gravitational research
- Outreach module

- Nuclear Astrophysics Accelerator
- SN burst detectors



Geo/Engineering

- Intermediate level block experiments
  coordinated to lower level
- Fracture motion experiment:
  Far from rest of of laboratory!

- Intermediate biology observatories (coordinated to lower level)

- Potential expansions: Megaton neutrino/proton decay

Conclusions

A Deep Science Initiative

+ engineering

Scientific importance for Physics /Astrophysics
Biology
Earth sciences
Engineering

Frontier is at depth: likely long term need for deep space

As part of this initiative: DUSEL

Complement to existing facilities (nationally and internationally)

Multidisciplinary approach from the start + synergy

Significant chance to obtain new resources

DUSEL will benefit the Physics/Astro Community

Widens the underground frontier

- Home for the most important experiments we foresee now
- Flexible space for new unexpected ideas

Synergies (e.g. Neutrino tomography)

MREFC costs are initially not borne by community

But beware of large operating costs

Time scale is long: start now!