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

DUSEL
S1 study

DUSEL more than Physics
DUSEL Physics Justifications
- Example of Dark Matter

Findings and recommendations
Comparison with other strategies

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

Site Independent Study (S1)

Mission from the NSF

1) to organize a dialog inside the community
about a multidisciplinary, Deep Underground Science and Engineering Laboratory in the U.S..

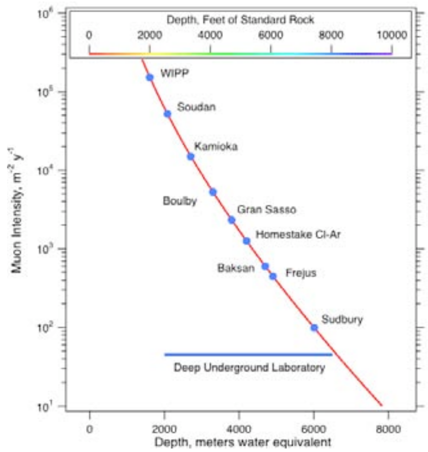
2) to discover whether there is a compelling scientific justification for such a laboratory, cutting across our many disciplines

3) If there is, to specify the infrastructure requirements
for such a laboratory that will address the needs of a broad cross section of science over the next 20-30 years and complement other facilities worldwide.

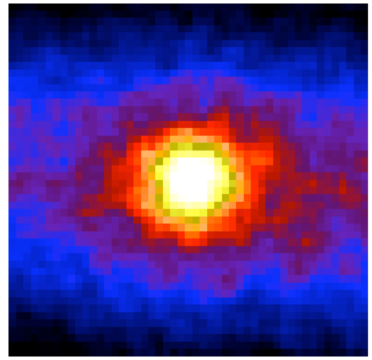
Deliverables (in coming weeks)

- High Level Report directed at generalists (government+funding agencies) in the style of "Quantum Universe."
- Web-based technical synthesis directed at scientific community Justifications and support the main report.
- External review

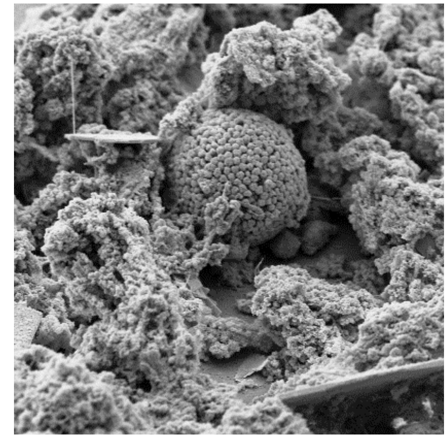
Why deep?



Neutrino picture of the Sun

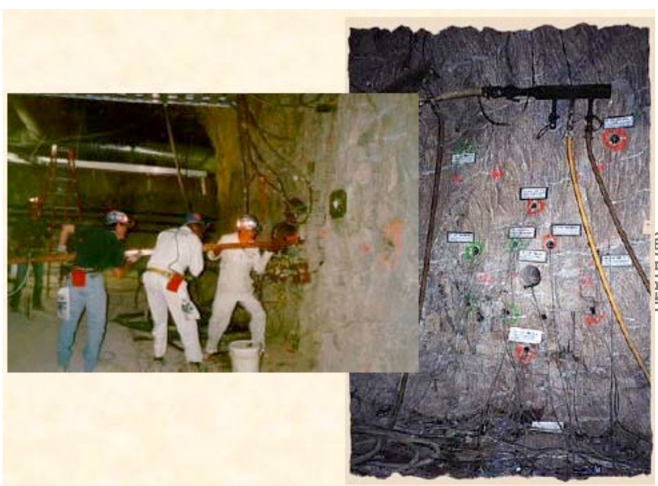


Geo-microbes

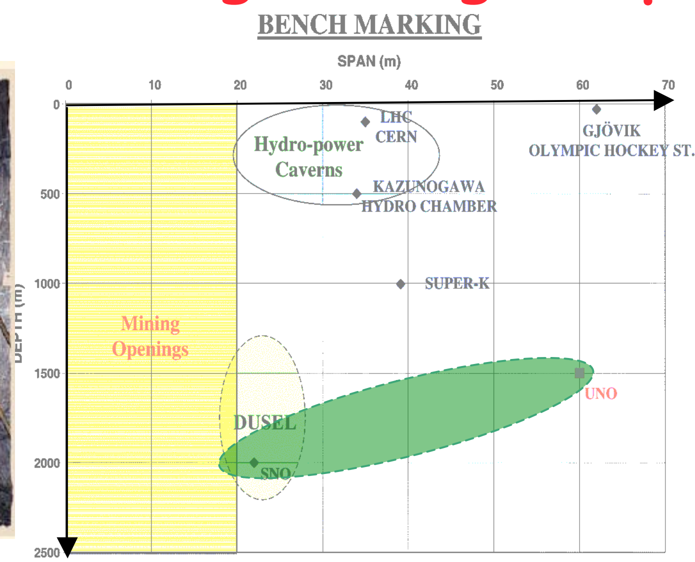


Ground Truth

Frontier Science and Engineering Deep Underground



Large Block Geo Experiment Coupled Processes



Size of cavity vs depth

Undergraduates in South Africa mine

Scientific Motivation

Extraordinary increase of interest in underground science and engineering

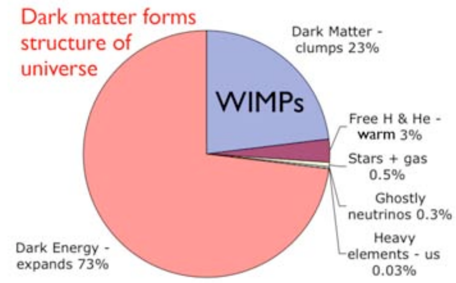
3 Fundamental Questions that uniquely require a deep laboratory

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

e.g. Dark Matter

A central puzzle of cosmology

What is the nature of ≈ 25% of stuff in the universe?



WIMPs

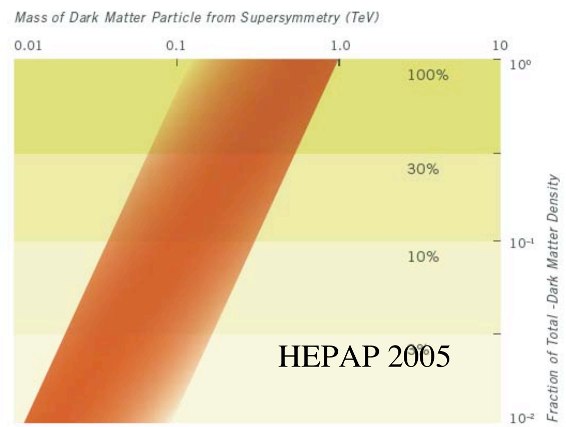
Particles in thermal equilibrium

+ decoupling when non-relativistic

Generic Class

Freeze out when annihilation rate ≈ expansion rate

$$\Rightarrow \Omega_x h^2 = \frac{3 \cdot 10^{-27} cm^3 / s}{\langle \sigma_A v \rangle} \Rightarrow \sigma_A \approx \frac{a^2}{M_{EW}^2}$$

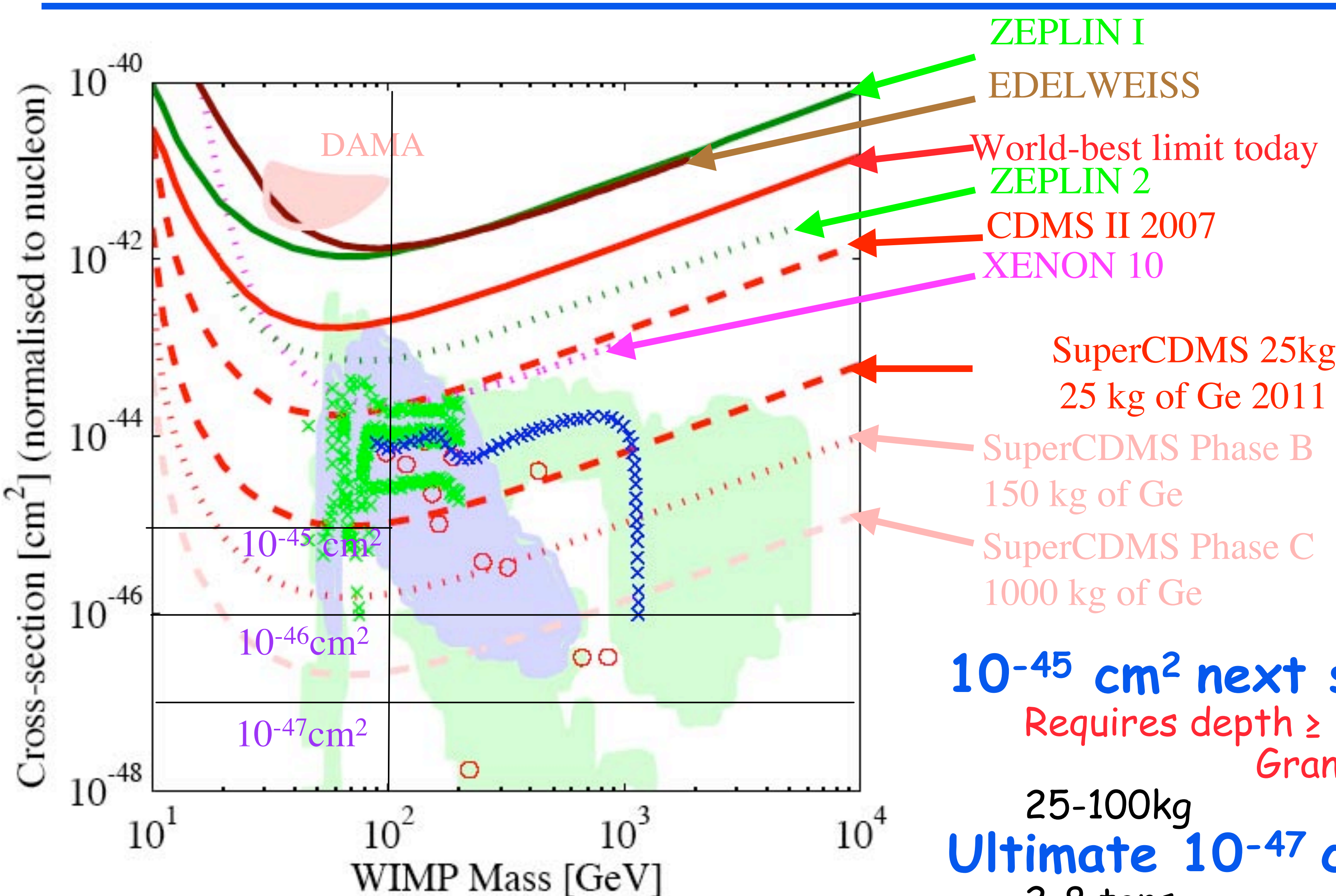


Cosmology points to W&Z scale
Inversely standard particle model requires new physics at this scale (e.g. supersymmetry or additional dimensions)
=> significant amount of dark matter

Push three frontiers

Astrophysical observations from ground and space
Colliders
Deep underground: Recognize nuclear recoil= WIMP interactions

An Example: WIMPs



10^{-45} cm^2 next step

Requires depth ≥ Gran Sasso

25-100kg

Ultimate 10^{-47} cm^2

2-8 tons

≈ No background!

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

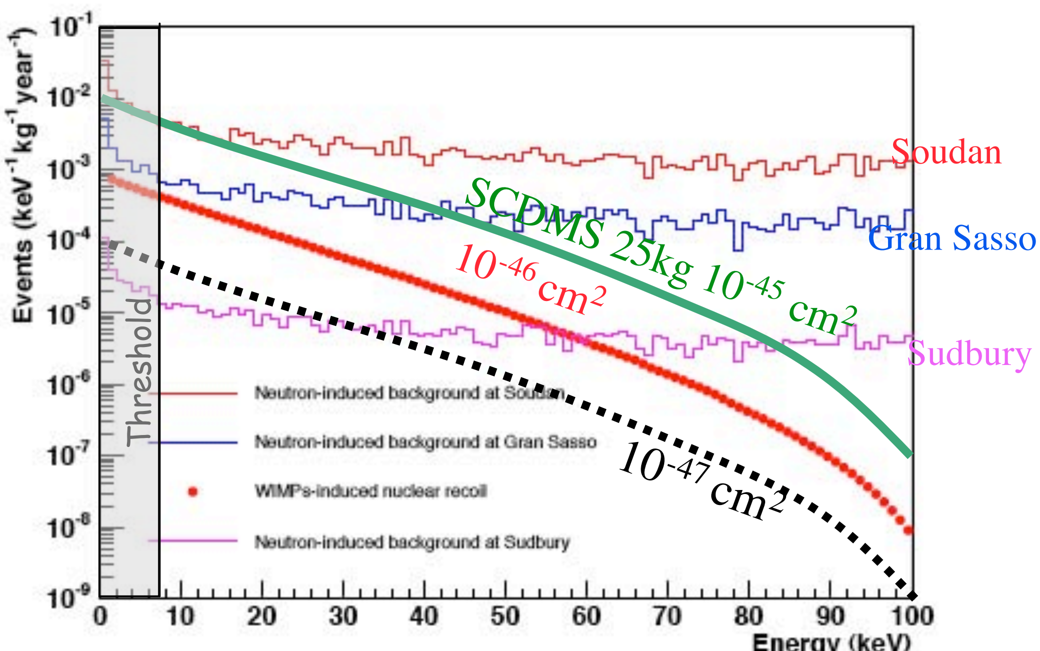
- **Underground construction:** the new frontier (urban, mining,fuel storage)
- **Resource extraction:** Critical need for recovery efficiency improvement
- Water resources:
- **Environmental stewardship**
  - Remediation (e.g. with micro-organisms)
  - Waste isolation and carbon dioxide sequestration.
- **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

Frontier WIMP searches need depth

$10^{-47}cm^2$ needs 6000mwe



Raw neutron rates

With good passive shield

μ veto

Rejection of multiples

WIMP Rate

M_{WIMP}=100GeV/c^2

Mei, Hime astro-ph0512125

Shallow+ active neutron veto?

e.g. 90% efficiency at Soudan would be OK for SCDMS 25kg

But: 300 MeV neutrons!

- Risky : shielding notoriously difficult
- No safety margin: rates known within factor 2?
- Have to fight two backgrounds instead of one
- No path to future

Loss of sensitivity hurts

- Discovery potential
- Complementarity to LHC

Eventually γ background from n and μ activation

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 (300MeV) 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

Motivations for a National Facility

Although

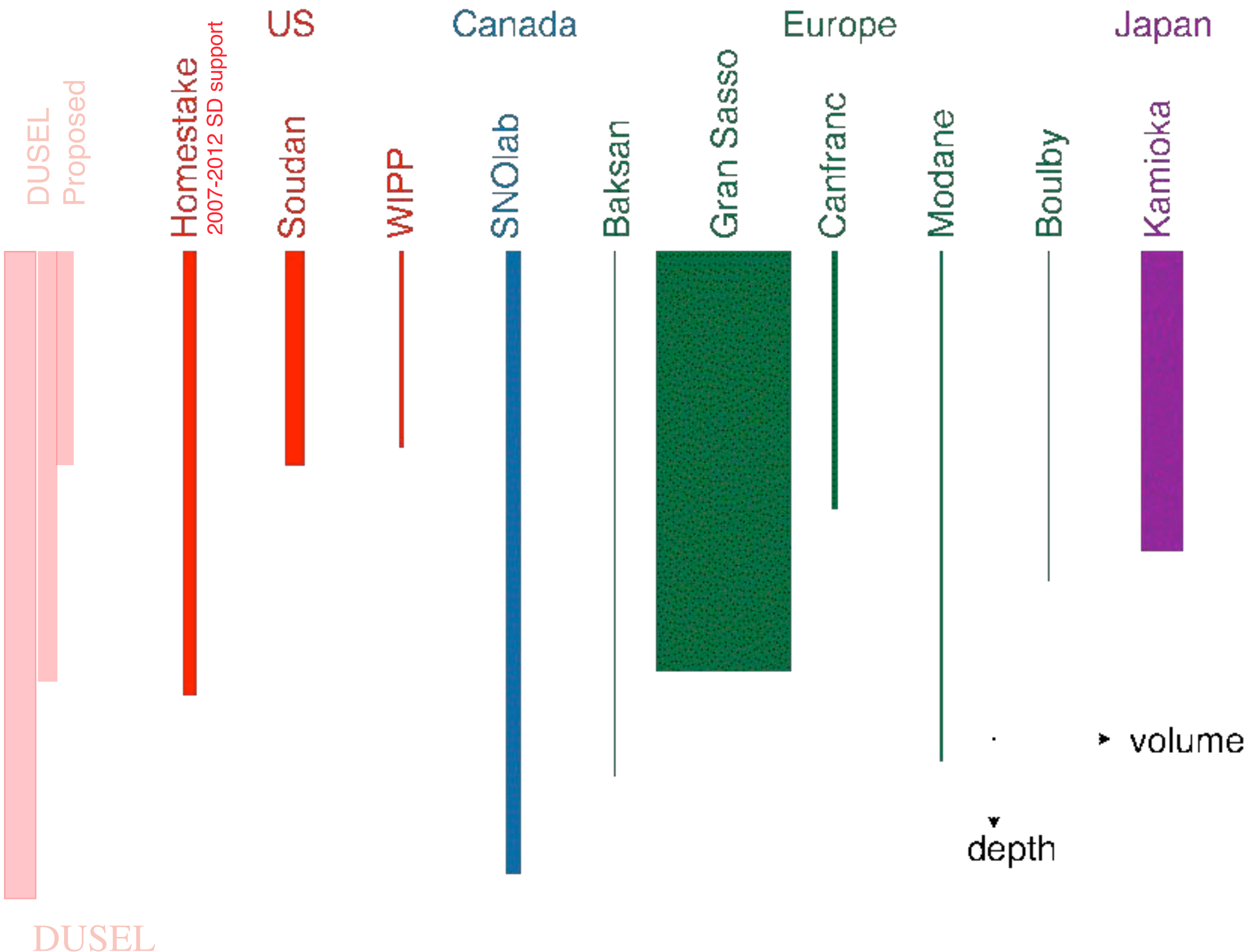
- Science is international in nature
- U.S. scientists and engineers managed to play a pioneering role without a dedicated U.S. deep underground laboratory

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

U.S. one of the only G8 nations without national facility

Science Underground



Need for New Underground Facilities

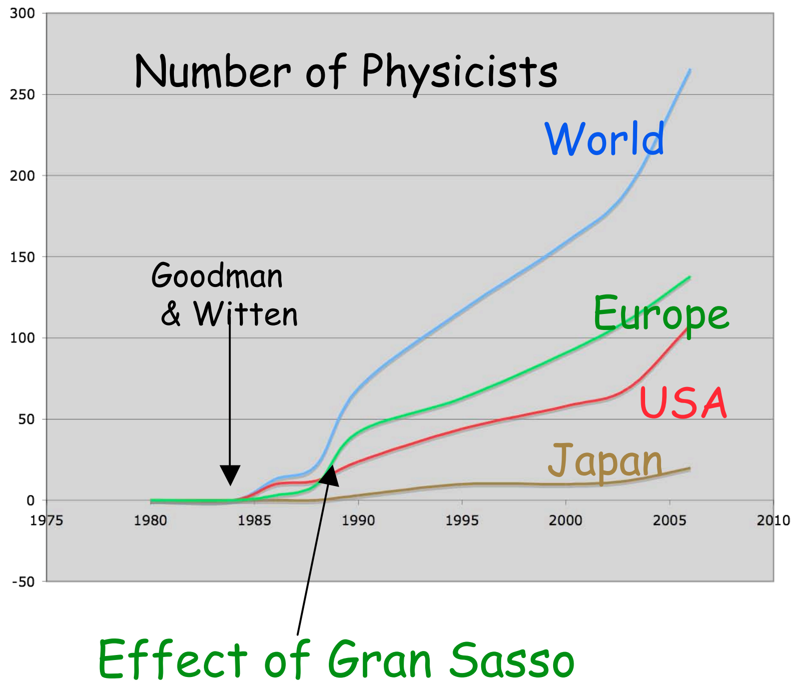
Chronic Oversubscription Worlwide

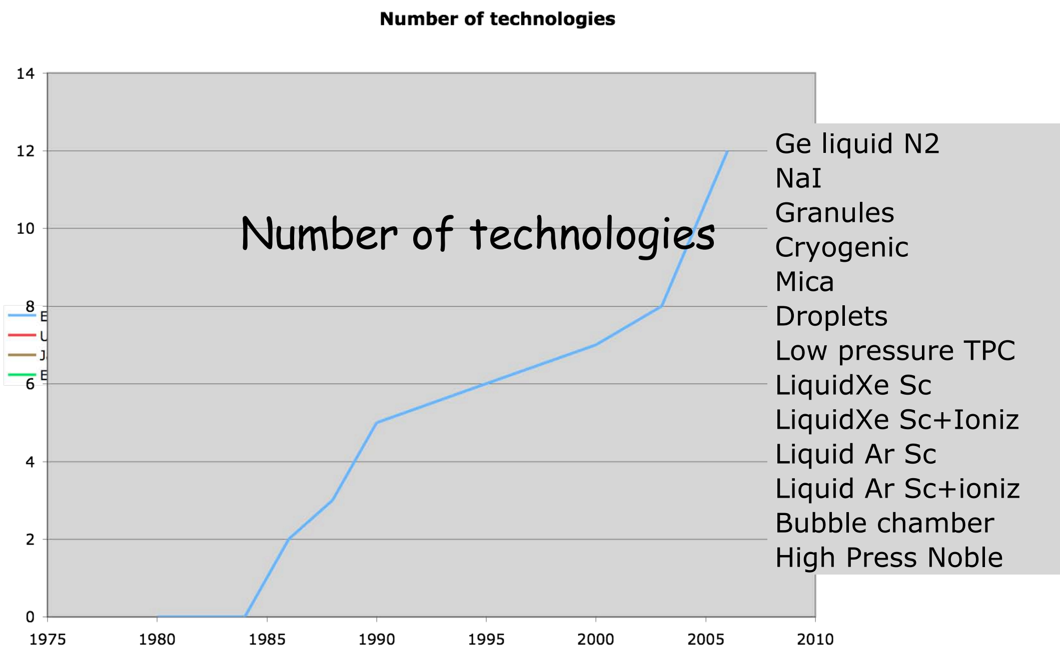
- Historically True!
  - Only exception: currently Gran Sasso as ICARUS won't be expanded above 600 tons

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 (preliminary)





SNOLab presumably SCDMS 25kg and Picasso -> > 2015
DUSEL next generation 150kg-1 ton (at least 1)

Need to start building infrastructure while SNOLab busy

Need for New Underground Facilities

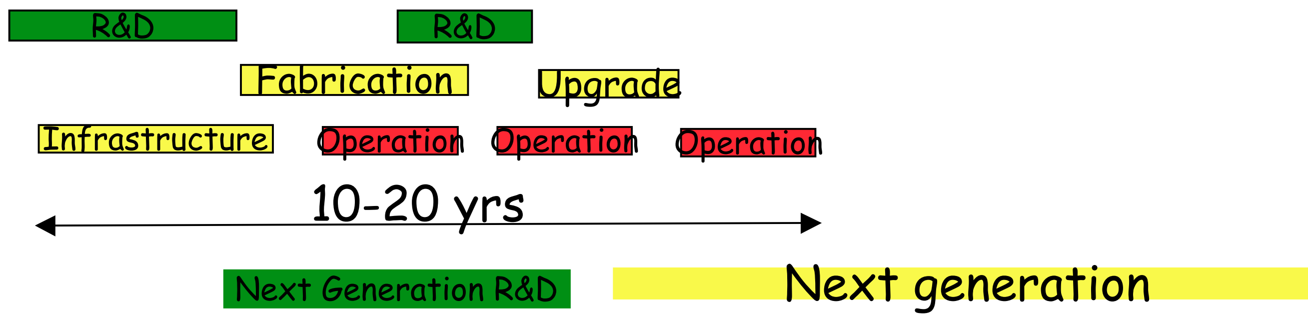
Chronic Oversubscription

Increase in the community

Importance/interest of the science: neutrinos, cosmology
Shift from accelerator based experiments
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 2ß , A^2 for WIMPs

But budgetary constraints ≠ sum of all dreams

Recommendations (Draft)

The U.S. should

1. **Seize the opportunity to strengthen its underground science and engineering program**
   - Scientific/Engineering frontier
   - Societal return on investment
2. **Initiate immediately the construction of DUSEL (≥2009)**
   - A premier facility with unique characteristics able to attract the best projects worlwide

   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.

Recommendations (Draft)

3. Concurrently establish a National Institute for Underground Science and Engineering (NIU)

Triple mission:

- Support technically and scientifically the U.S. research institutions engaged in underground science and engineering
  - Not only design and operate DUSEL but also:
  - Technical support
  - Long term R&D (instrumentation, low background, new approaches)
  - Theory, workshops -> vibrant interdisciplinary intellectual vitality
- Focus the national underground effort (critical mass, excellence)
  - + coordinate it with other national initiatives (accelerators, Earth Scope, SecureEarth)
  - and other underground labs nationally and internationally (e.g. SNOLab, Kamioka, Gran Sasso/Modane)
- Maximize societal benefits
  - Interagency, multidisciplinary collaborations
  - Involvement of industry
  - Education of the next generation of scientists and engineers
  - A better general understanding of frontier science by the public

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

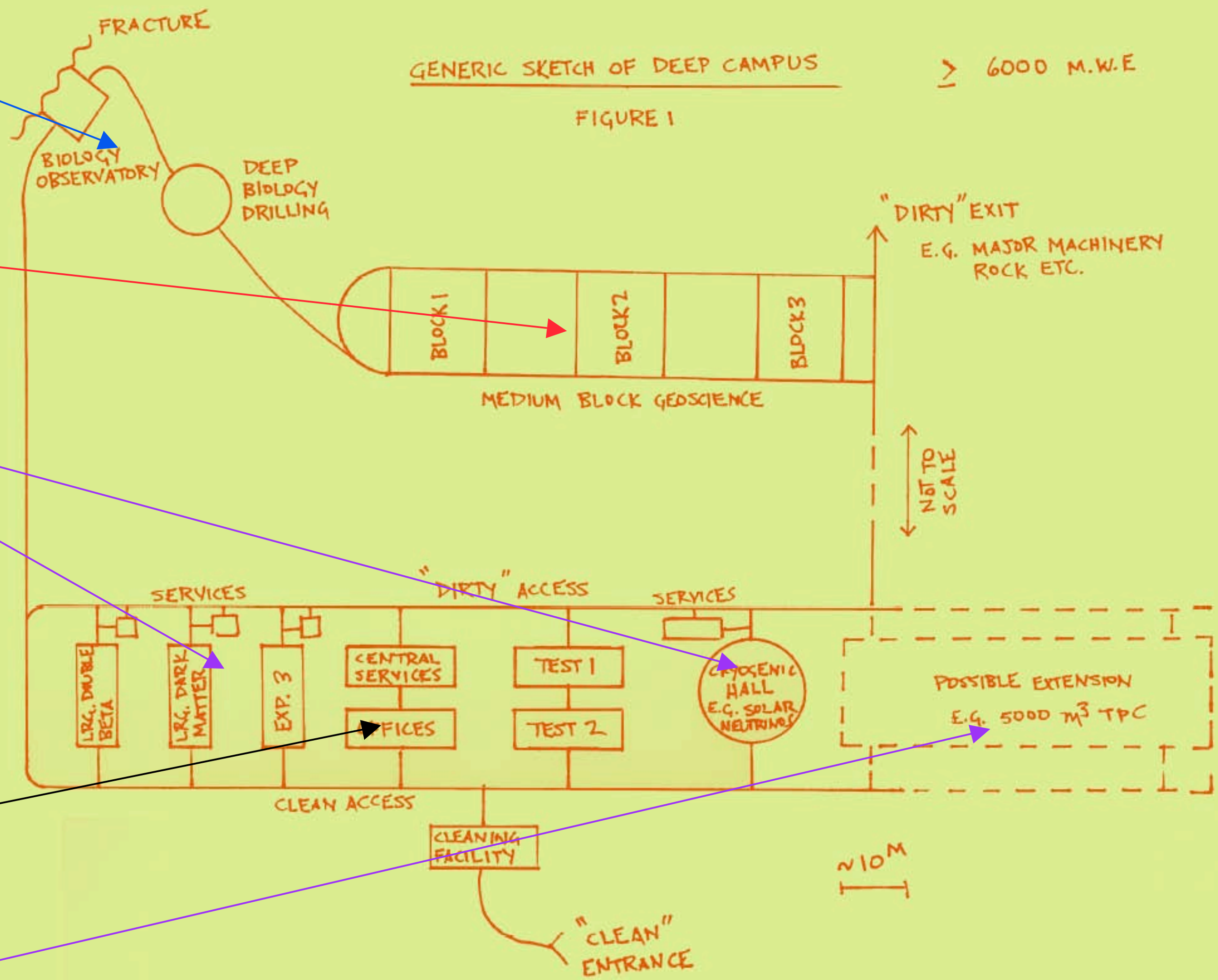
Biology observ.
Deep Biology
Drilling

Geo/Eng
3 Medium block
experiments

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

Central services
Offices etc.

Possible
extensions
large hall e.g
for TPC



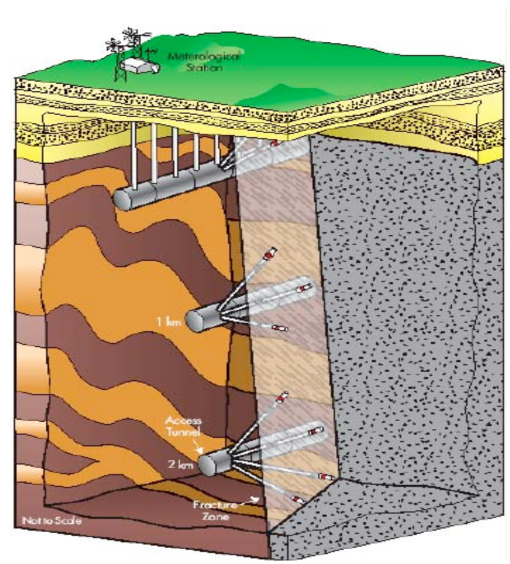
Initial Suite of Experiments (Draft)

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/Eng
- 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

Can we afford DUSEL?

MREFC line

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

=Line item

Strategy is to involve Geo/Bio/Eng to secure place in MRE queue

⇒Initially bring new resources to HEP/Nuclear community

Long term costs

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

- National Institute: a question of priority to the field
- 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

was context of horizontal /vertical access debate

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

Comparison with Other Strategies

Expansion of SNOLab

Limits of cooperation of INCO
Not everything needs to be deep
Not suitable for multidisciplinary enterprise
Strong reduction of benefits to U.S.

A shallow site + SNOLab + subsequent deepening

e.g. Soudan (existing ν beam) + SNOLab
Pioneer tunnel (already dug) + SNOLab

2000 m.w.e. indeed suitable for a number of experiments
(automatic in most facility)

But attempting to perform frontier experiments at lower depth with shielding because of lack of space is
risky (when given the choice teams choose depth)
only a temporary stop-gap

Lack of space may inhibit rapid exploration of new ideas

A subsequent extension is not well adapted to MREFC structure
Sequential approach delays a frontier facility

Conclusions

Frontier Science: we need the depth (and ≥30 yrs access)

DUSEL well justified from a global multidisciplinary perspective

- Alignment with many of NSF interests

Significant chance to obtain necessary resources

- ≠ incremental approaches

DUSEL will benefit the Physics Community

- Widens the underground frontier
  - Home for the most important experiments we foresee now
  - Flexible space for new unexpected ideas
- Multidisciplinary intellectual atmosphere, e.g. neutrino tomography!
- National Institute for Underground Science and Engineering:
  - Technical support
  - Long term R&D (instrumentation, low background)
  - Focus and coordination
  - E&O
- MREFC costs are initially not borne by community
  - But beware of large operating costs

Time scale is long: start now!