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US Deep Underground Science and Engineering Laboratory

- Scientific Justification "S1 process"
  - DUSEL more than Physics
  - DUSEL Physics Justifications
    - Example of Dark Matter
  - Findings and recommendations
- Implementation
  - MREFC line item
  - Site selection "S3 process"

The scientific case in the US

2000 Bahcall/Lesko committee

Series of workshops

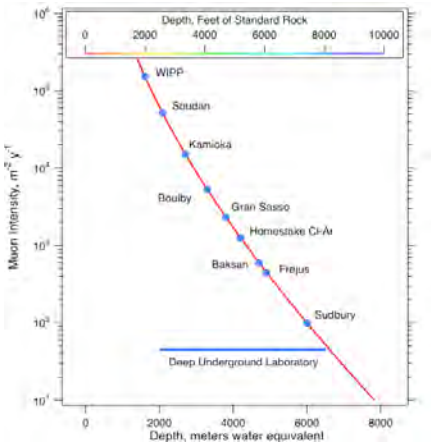
2004-2006 S1 workshops + report 30-50yrs

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

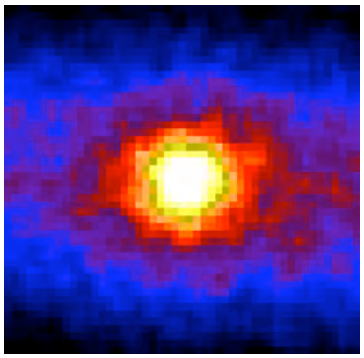
High Level Report directed at generalists
(government+funding agencies)
in the style of "Quantum Universe."
Web-based technical synthesis
directed at scientific community
Justifications and support the main report.
External review

www.dusel.org

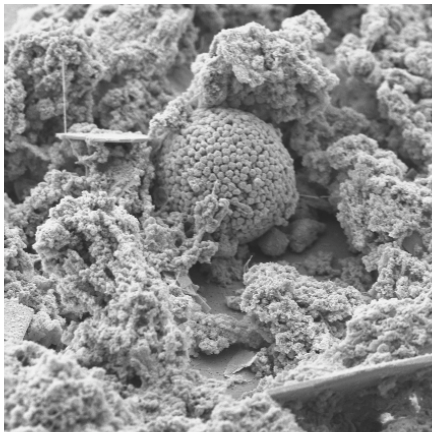
Why deep?



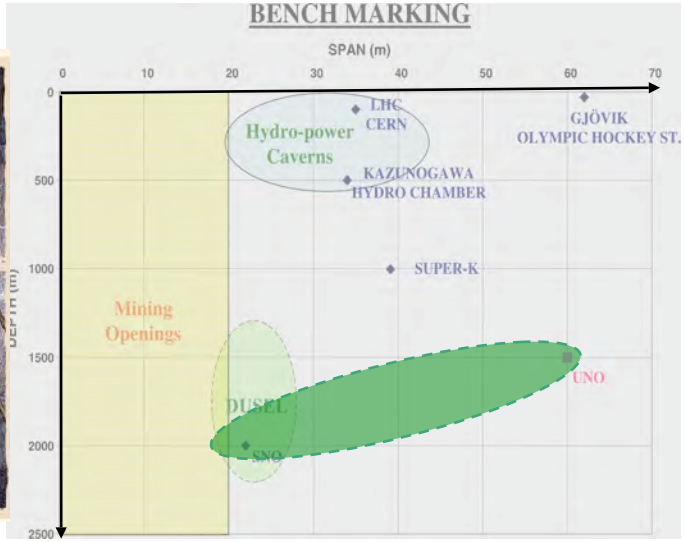
Neutrino picture of the Sun



Geo-microbes



Deep Science



Large Block Geo Experiment Coupled Processes

Size of cavity vs depth

Undergraduates in South Africa mine

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?

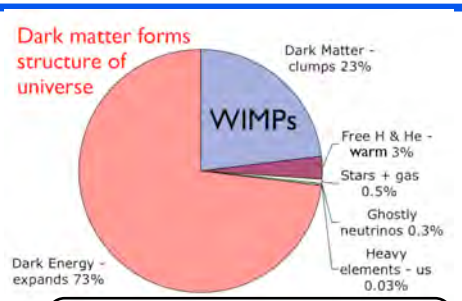
  Earth Sciences: Mechanisms behind the constant earth evolution

  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?



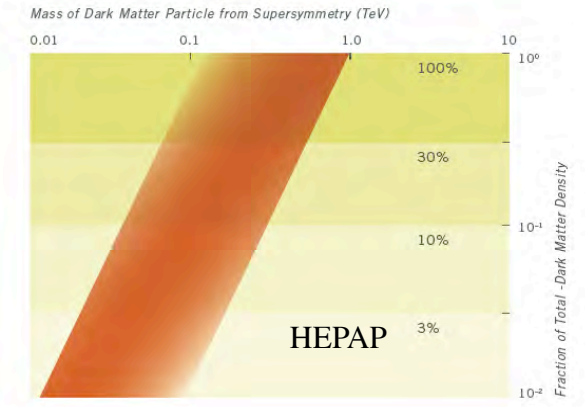
Generic

WIMPs

Particles in thermal equilibrium + decoupling when non-relativistic

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

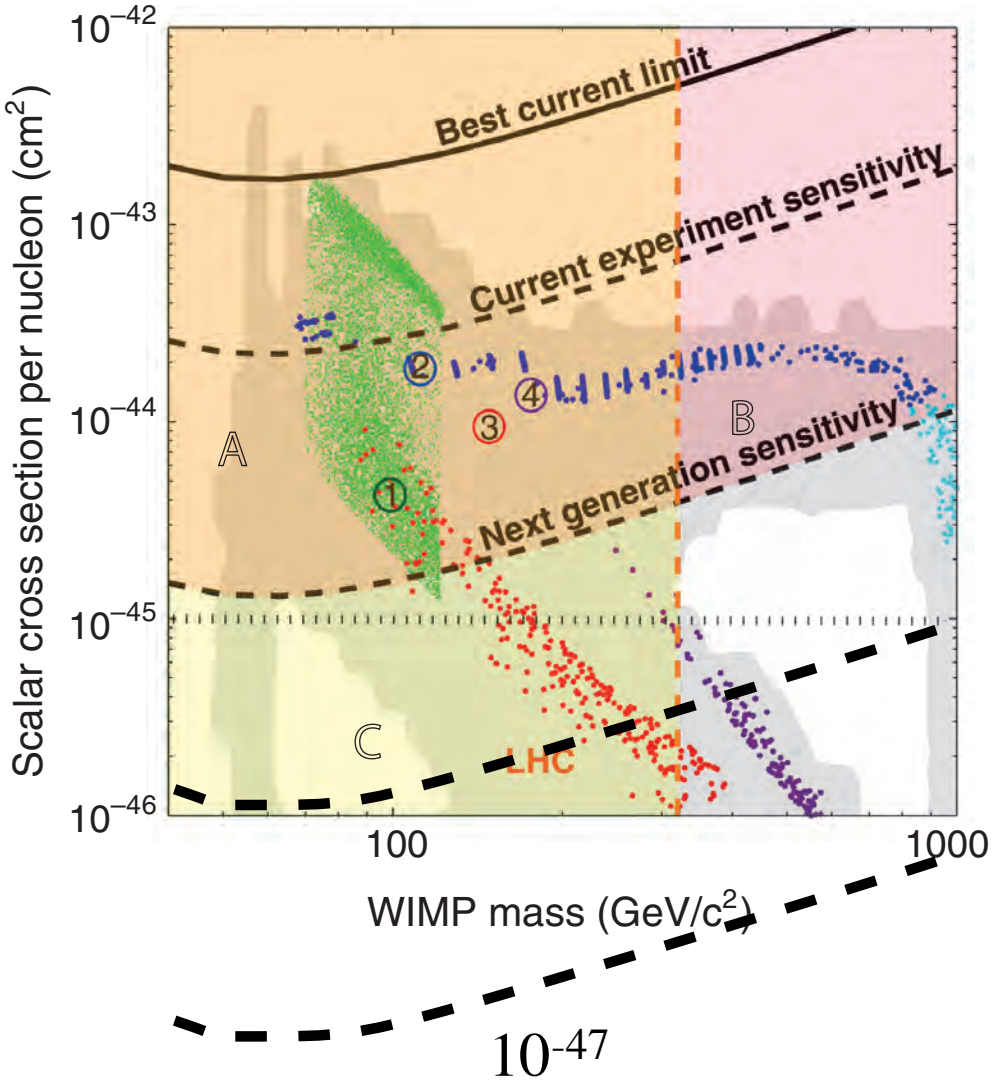
Push three frontiers (cf Sadoulet Science 315(07)61)

Astrophysical observations from ground and space

Colliders

Deep underground: Recognize nuclear recoil= WIMP interactions

WIMPs: At the brink of discovery?



10^{-45} cm^2 next step

Requires depth ≥ Gran Sasso

25-100kg

Ultimate 10^{-47} cm^2

2.5-10 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

The Frontier is at Large Depth!

Physics

Neutron and activation of materials

Neutrinoless double beta decay

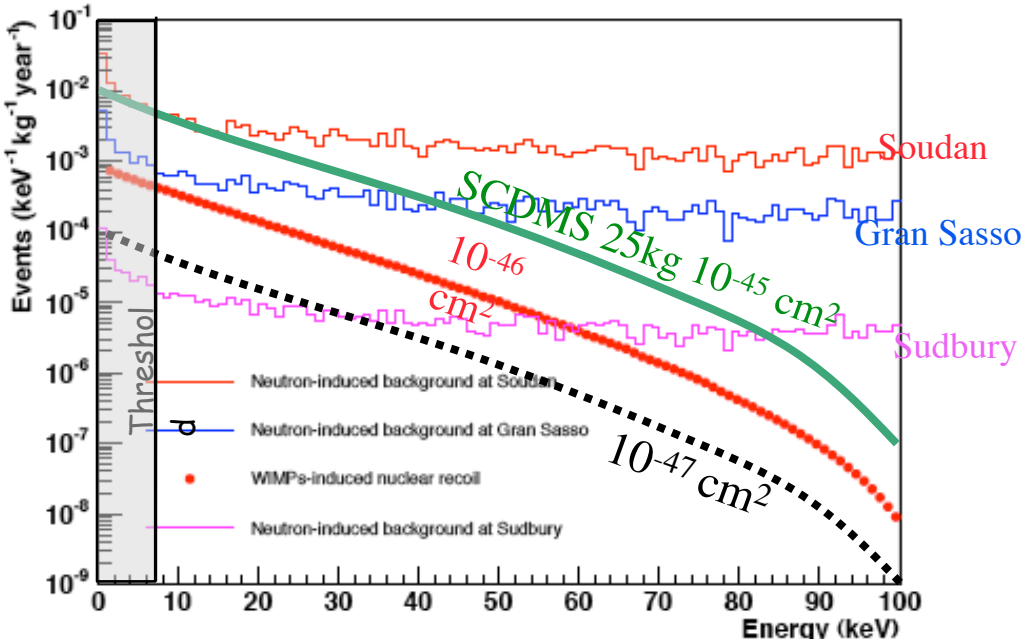
Dark Matter ← Example that I will take

Neutral current/ elastic scattering solar neutrino

New ideas

Frontier WIMP searches need depth

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



Raw neutron rates Mei/Hime 06

With good passive shield

μ veto

Rejection of multiples

WIMP Rate

M_{WIMP}=100GeV/c^2

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

Eventually cosmogenics

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

Complementary to other facilities

Need for New Underground Facilities

Chronic Oversubscription Worlwide

Increase in the community

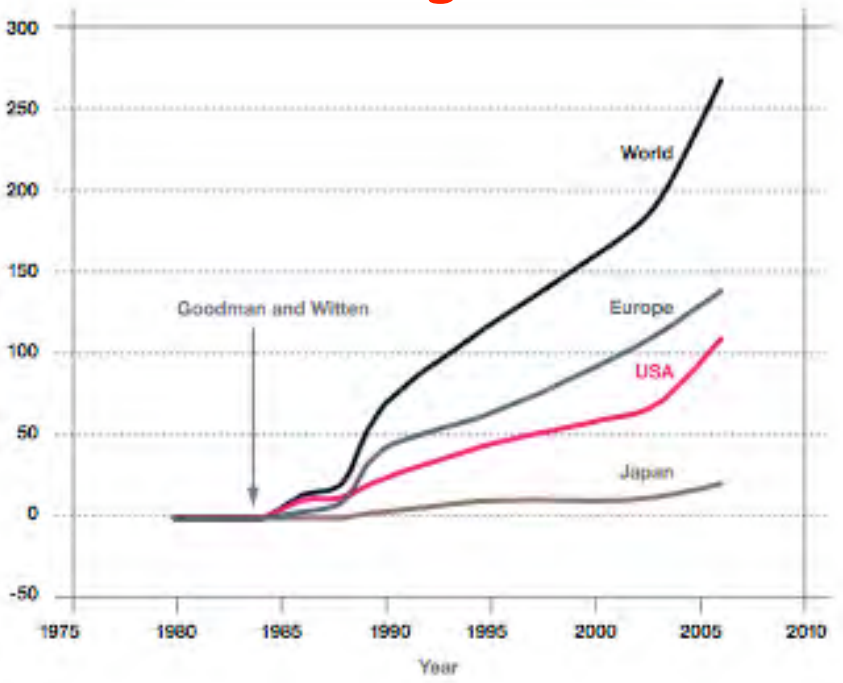
Importance/interest of the science: neutrinos, cosmology

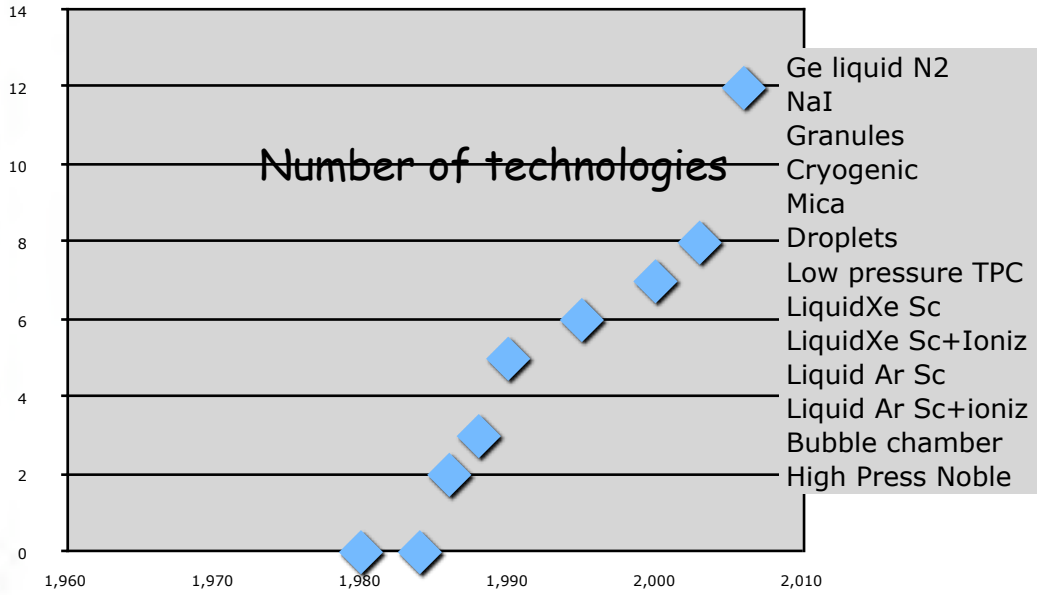
Shift from accelerator based experiments

Fast progress at boundaries between fields

Growth Example of WIMP searches

A blooming field





Need for New Underground Facilities

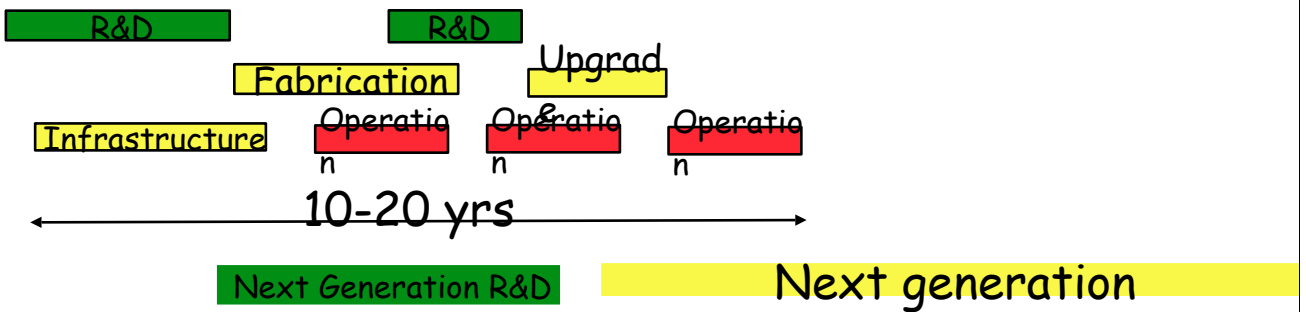
Chronic Oversubscription

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

Rec1:Strong Support for Deep Science

- Underground research is emerging as a unique and irreplaceable component of science, not only in physics and astrophysics, but also in biology, earth sciences and many disciplines of engineering.

- We recommend that the U.S. strengthen its research programs in subsurface sciences to become a world leader in the multidisciplinary exploration of this important new frontier.

- There can be little doubt that increased effort in this area will yield tremendous scientific dividends, including totally unexpected results.

Rec2:A US Cross-Agency Initiative

In order to broaden underground research and maximize its scientific impact, we recommend that the U.S. science agencies collaborate to launch a multidisciplinary Deep Science Initiative.

Focus on the most important scientific problems.
Optimize the use of existing or new underground facilities
Exploit the complementary aspects of a variety of rock formations.
Coordinate with other national initiatives and take full advantage of international collaboration opportunities.
Maximize synergies as strong foundation for discovery.

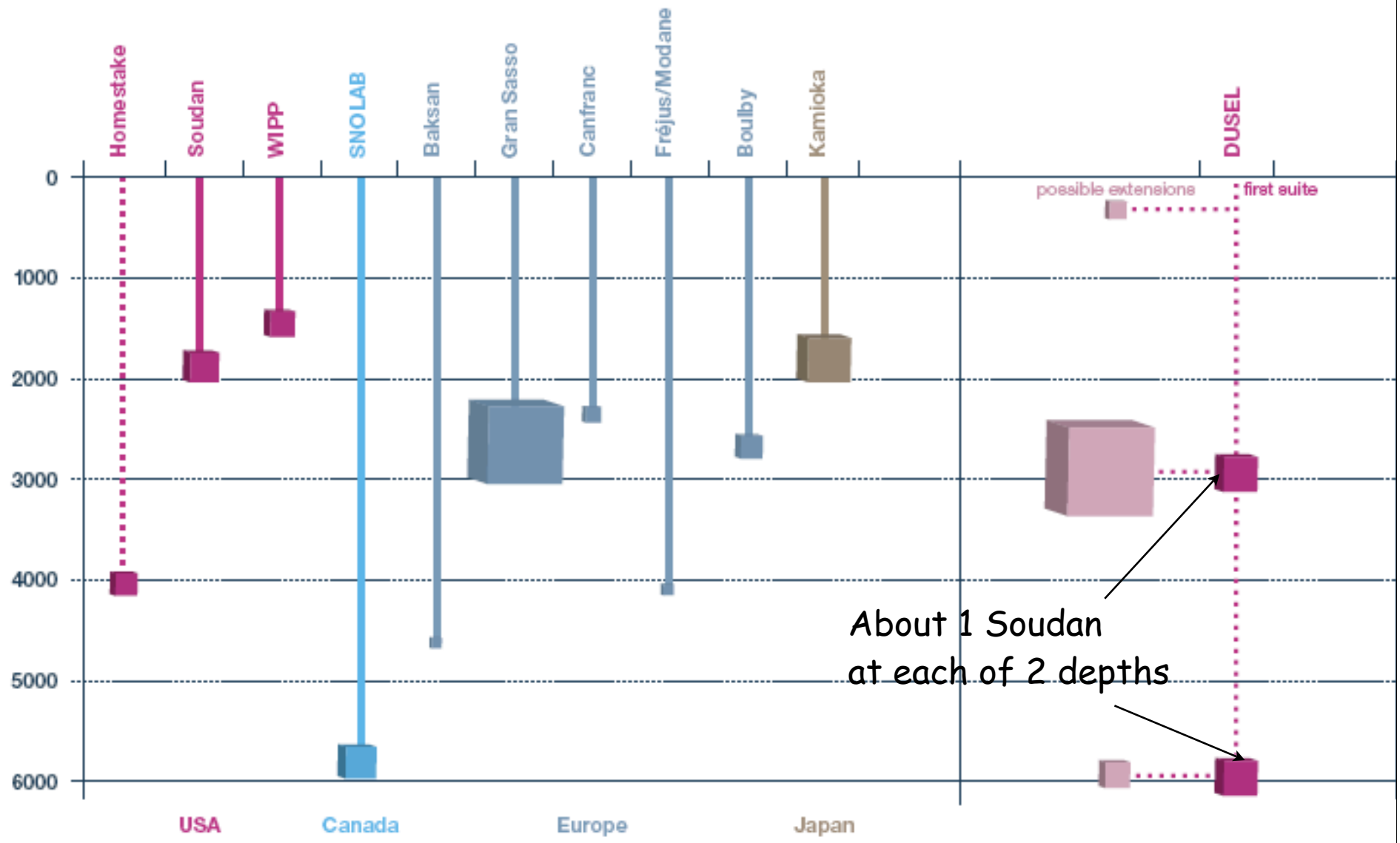
Rec3:A Deep Underground Science and Engineering Laboratory

- The U.S. should complement the nation's existing assets with a flagship world-class underground laboratory providing access to very great depth (≈ 6000 meters water equivalent) and ample facilities at intermediate depths (≈3000 m.w.e.) currently not available in the U.S. Superb access, cleanliness, environmental control, safety

- Such a Deep Underground Science and Engineering Laboratory (DUSEL) should be designed to allow evolution and expansion over the next 30 to 50 years.

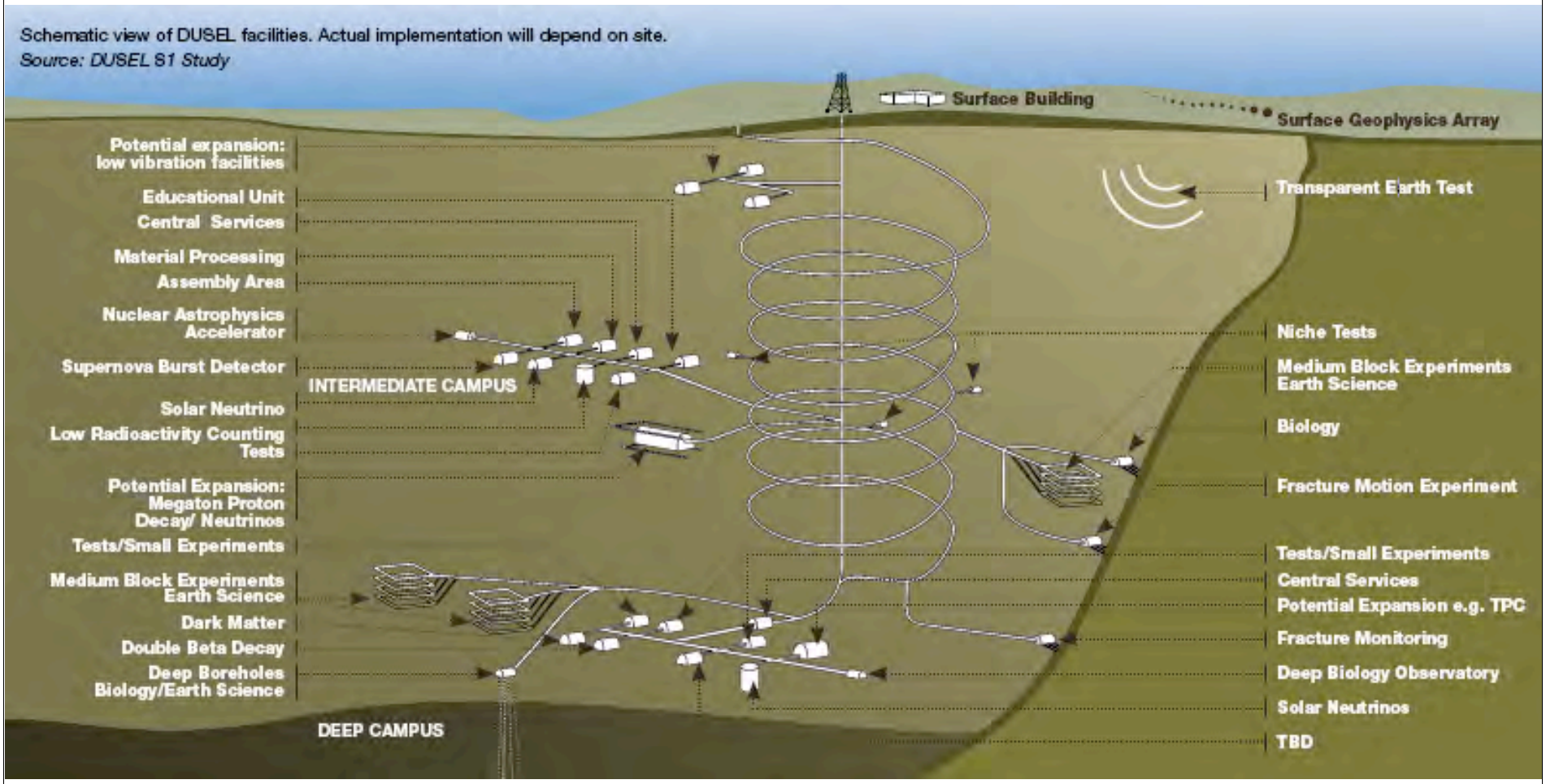
- Because of this long lifetime, the initial investment must be balanced with the operating costs.

Science Underground



First Suite of Experiments+ Extension

Note science before and during the excavation



Implementation and Site Selection

Possibility of a line item in NSF budget

MREFC to cover facility and NSF part of experiments.

S3 process

4 proposals

- Homestake
- Henderson
- Pioneer Tunnel
- Soudan

-> 1 site: Decision Spring 07

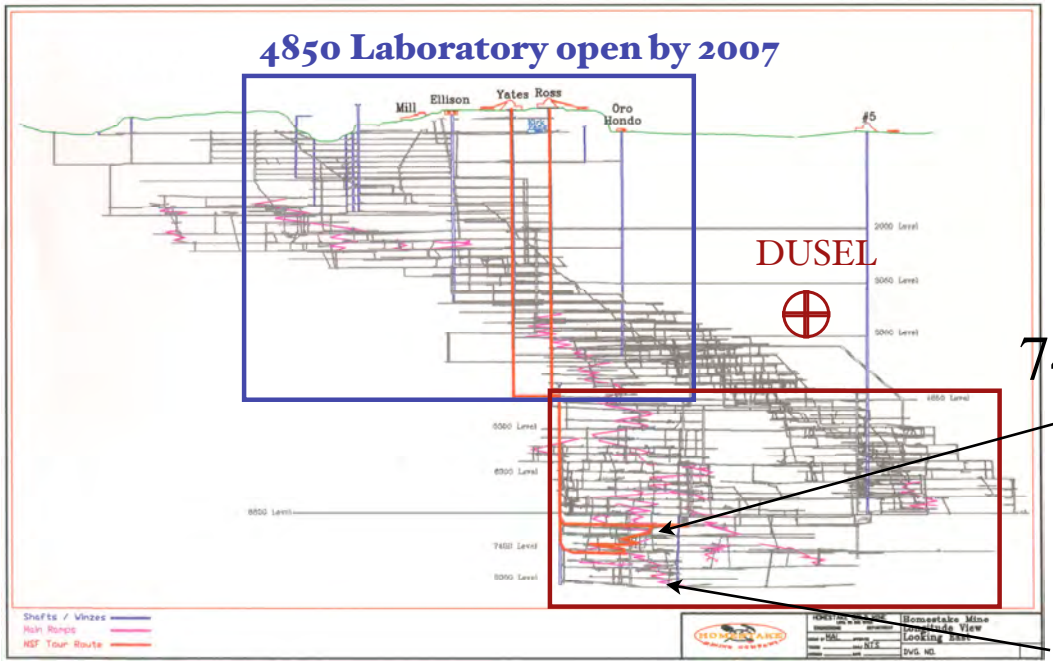
Technical design document End 07

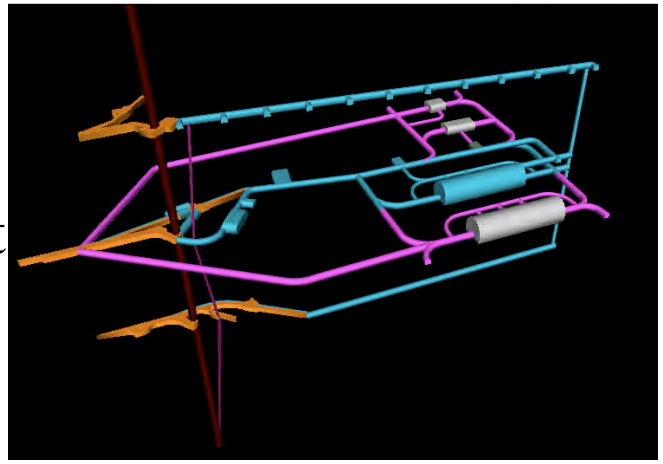
MREFC Panel early 08

Science board

In best scenario, start FY2010

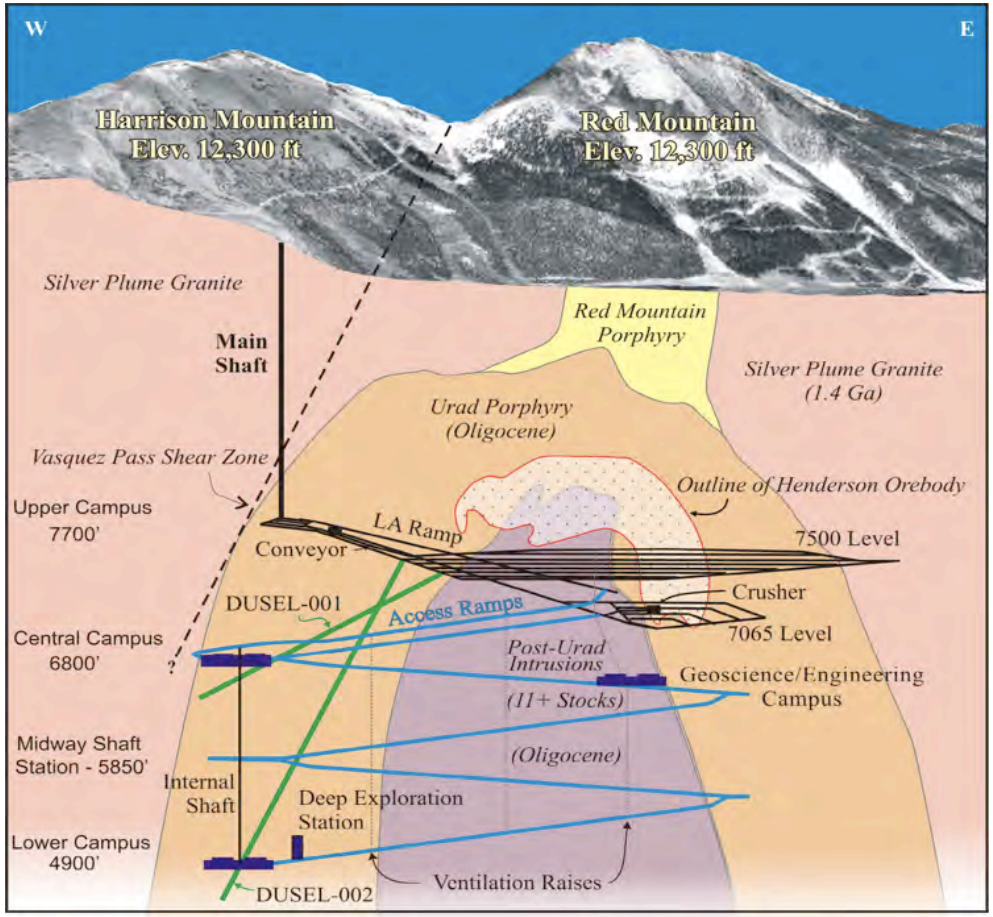
Homestake





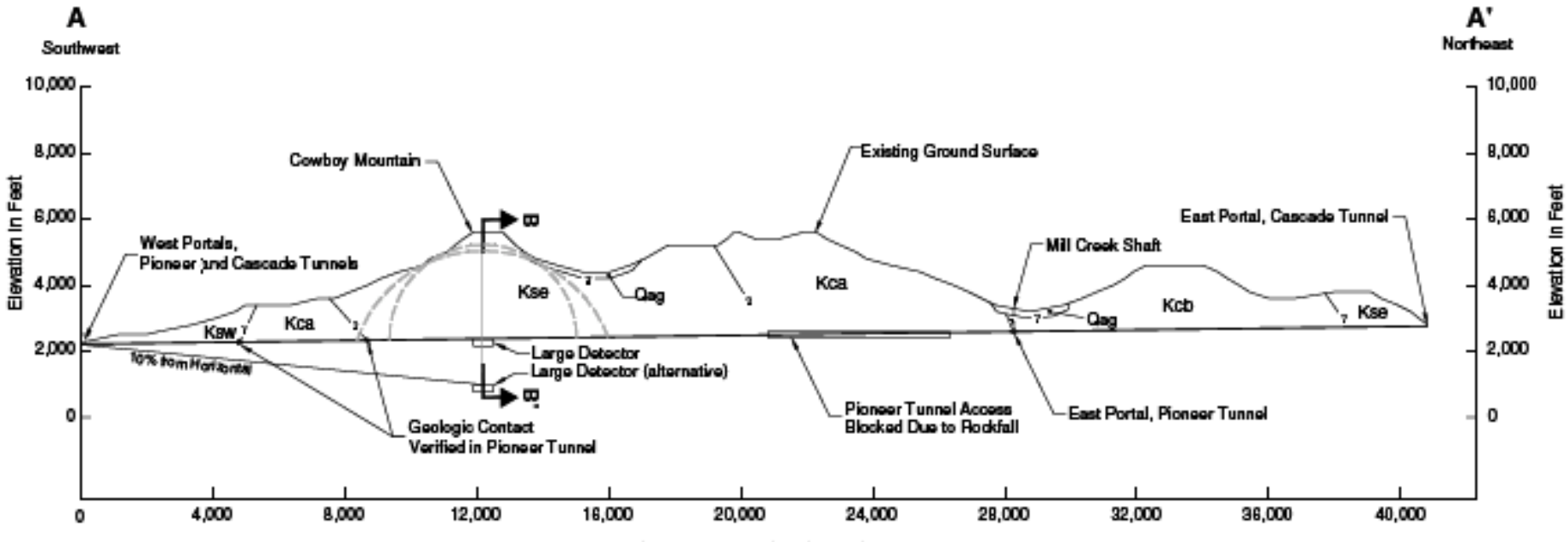
- Well-Characterized Site with miles of tunnels
  - Varied, Interesting, and Suitable Geology
  - Extensive Experience to > 8000 feet below ground. Low risk
- Phased Approach to Developing the Facility
  - Ability to host near-term R&D and Experimental Opportunities: interim lab
  - Phased entry into the Initial Suite of Experiments
- Success in Securing Independent Funding for Interim Lab
  - Exceptional Local and Regional Support for DUSEL Goals
- Dedicated Facility without Competition for Access,Resources, or Priorities

Henderson



- Modern mine
- Large shaft down to 7500 ft level
- Ramp to be built down to 2 science campuses
- Very large rock handling capability (+ permit 340Mt)
- Large water+sewage treatment, 2x24MW

Pioneer Tunnel



Unused existing tunnel

parallel to Grand Cascade tunnel: Cooperation of railway company
Horizontal access down to 2120 mwe at low cost

Arguments

all that is needed in the short run (Use SNOLAB for really deep needs)
put money in detectors
go down later when needs appears

Soudan

Multi-site => multidisciplinary, non traditional users

- Science => sites—not vice versa
- A neutrino beam towards Soudan. Cost of replacing or upgrading the NuMI beam.
- Geoscience (including geohydrology, geochemistry, geomicrobiology, etc.) is best served by multiple sites. Expensive instruments shared among multiple locations.
- There is a need **now** for low background counting. Soudan is available and can expand capacity quickly.
- No clear need for a new ultradeep facility for at least a decade. Investing a huge amount in a new facility will divert funds critically needed to initiate and develop new experiments. Decision when clear!

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

- MREFC≠ incremental approaches

DUSEL will benefit the International 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!
  - 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