Mining for gravitational waves

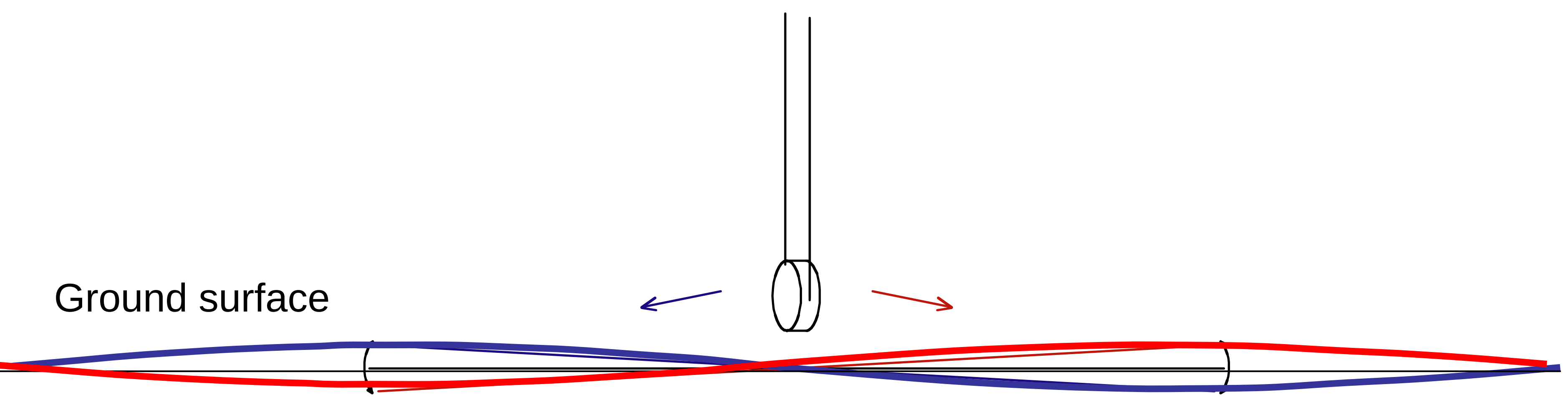
- How to mine out an GW facility
- discussion

Aspen January 17th 2005

LIGO-**G050049-00-R**

Causes of NN on the surface

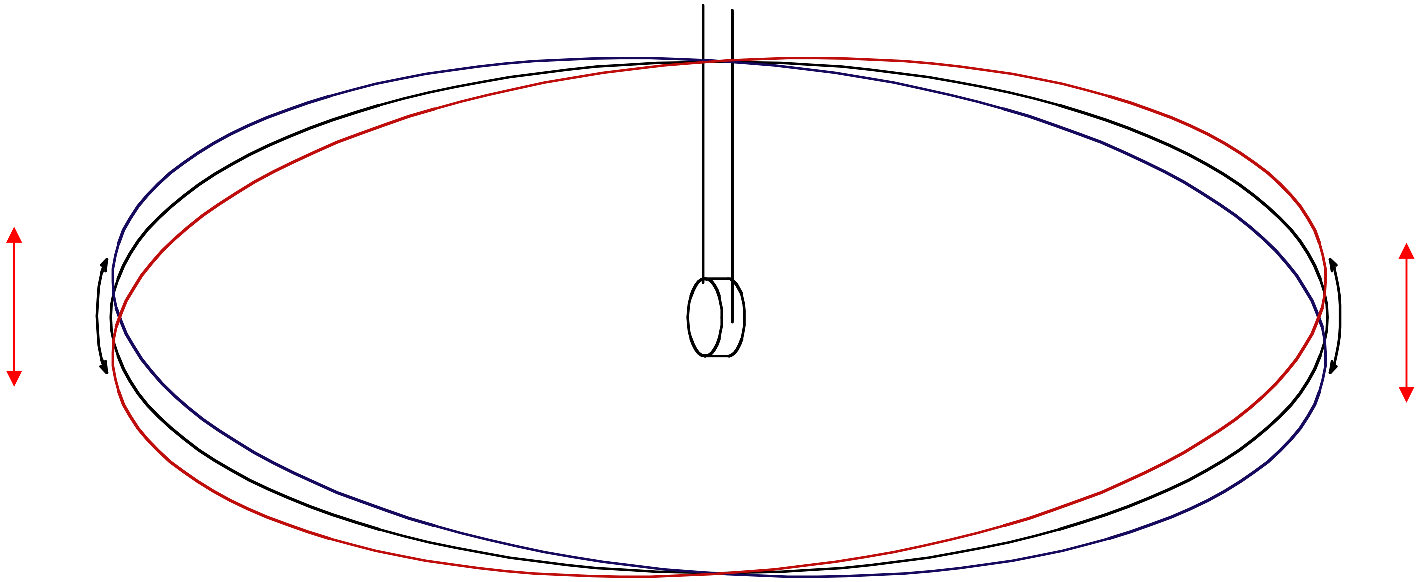
- The dominant term of NN is the rock-to-air interface movement



seismic motion **tilting ground** leads to **fluctuating attraction force**

NN reduction underground

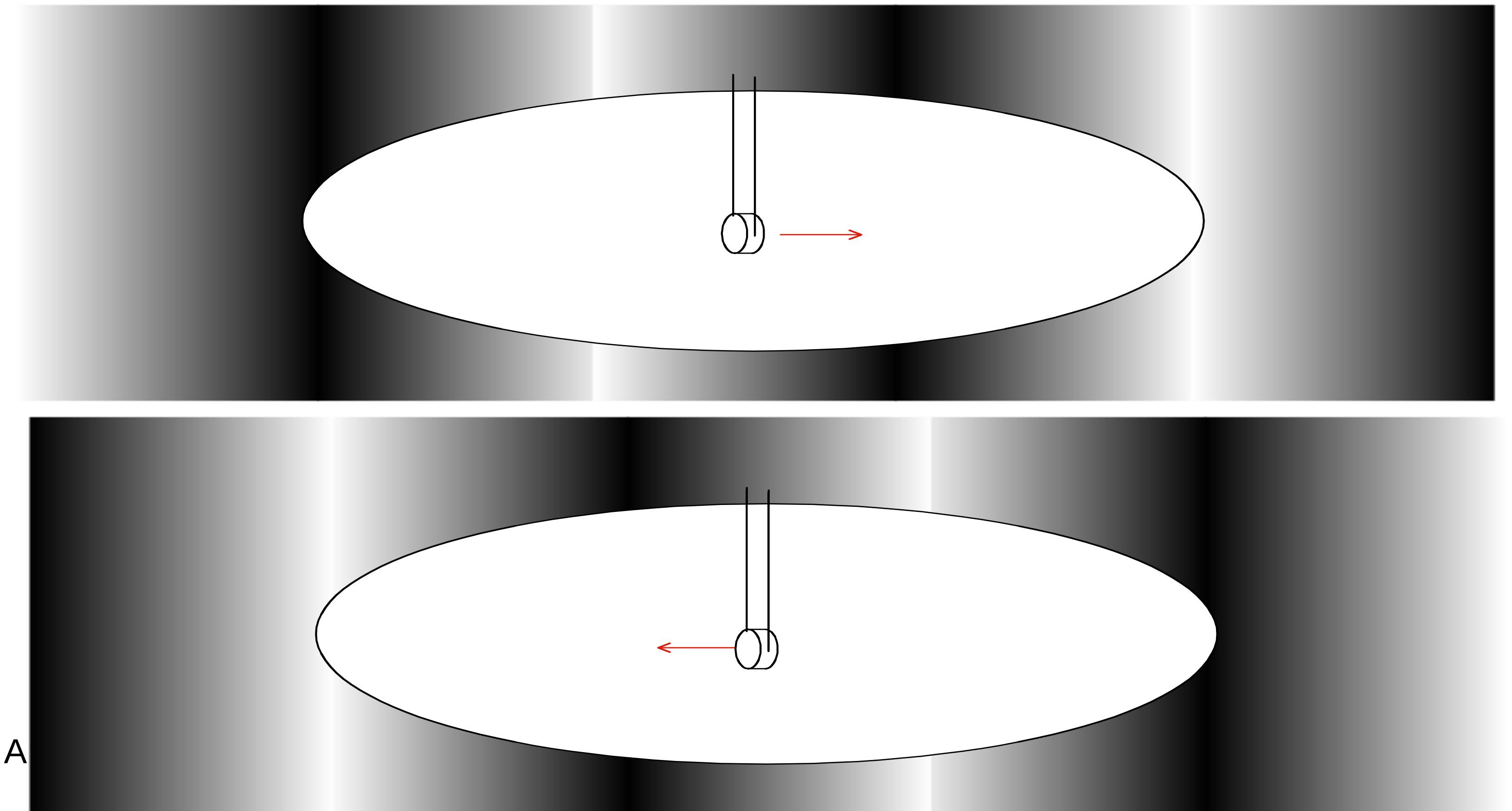
- If the cavern housing the suspended test mass is shaped symmetrically along the beam line and around the test mass tilting and surface deformations, the dominant terms of NN, cancel out
  - (with the exception of the longitudinal dipole moment, which can be measured and subtracted).



a tilting symmetrical cavern leads to NO fluctuating attraction force

NN reduction underground

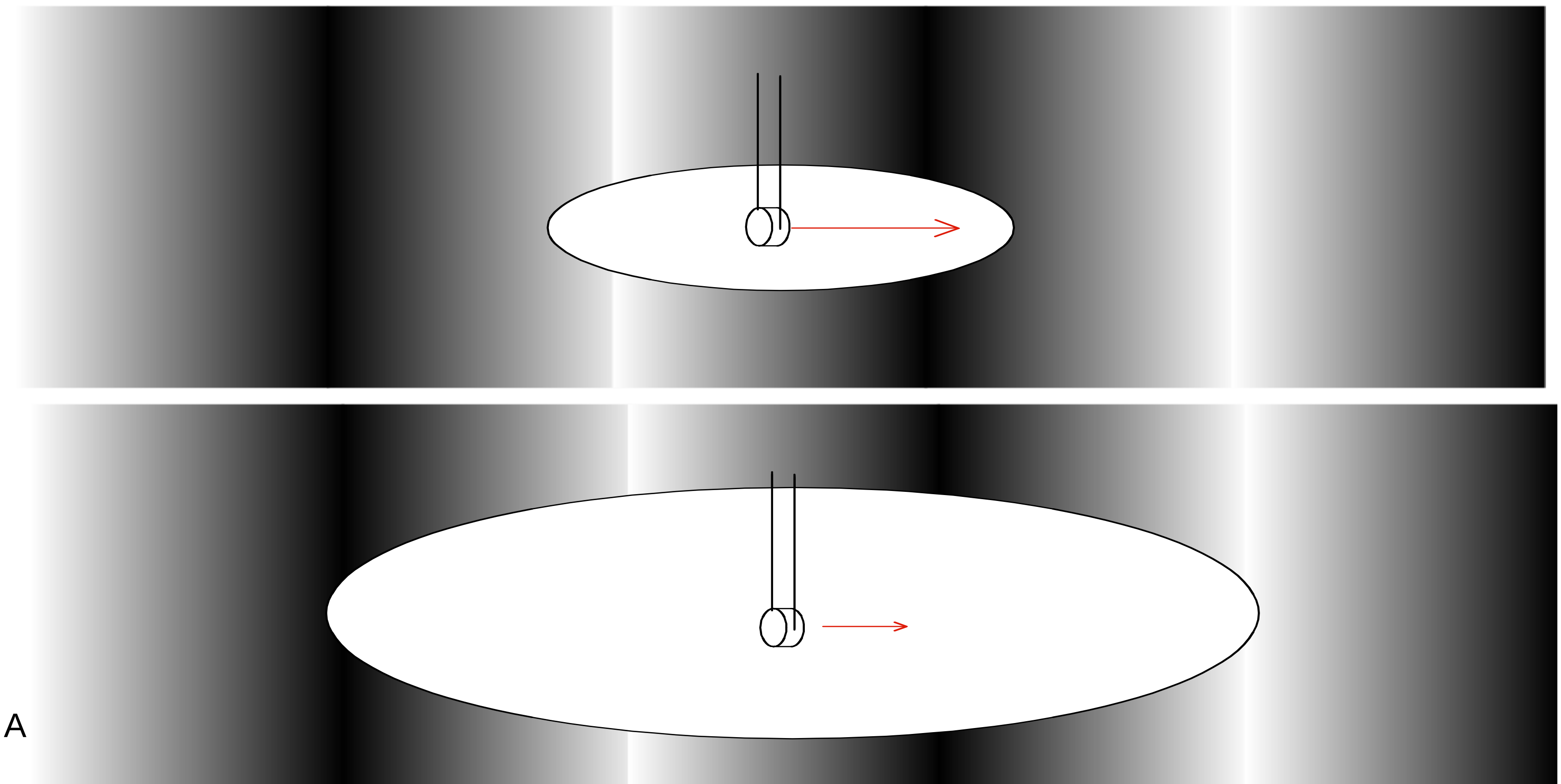
- Pressure seismic waves induce fluctuating rock density around the test mass
- The result is also fluctuating gravitational forces on the test mass



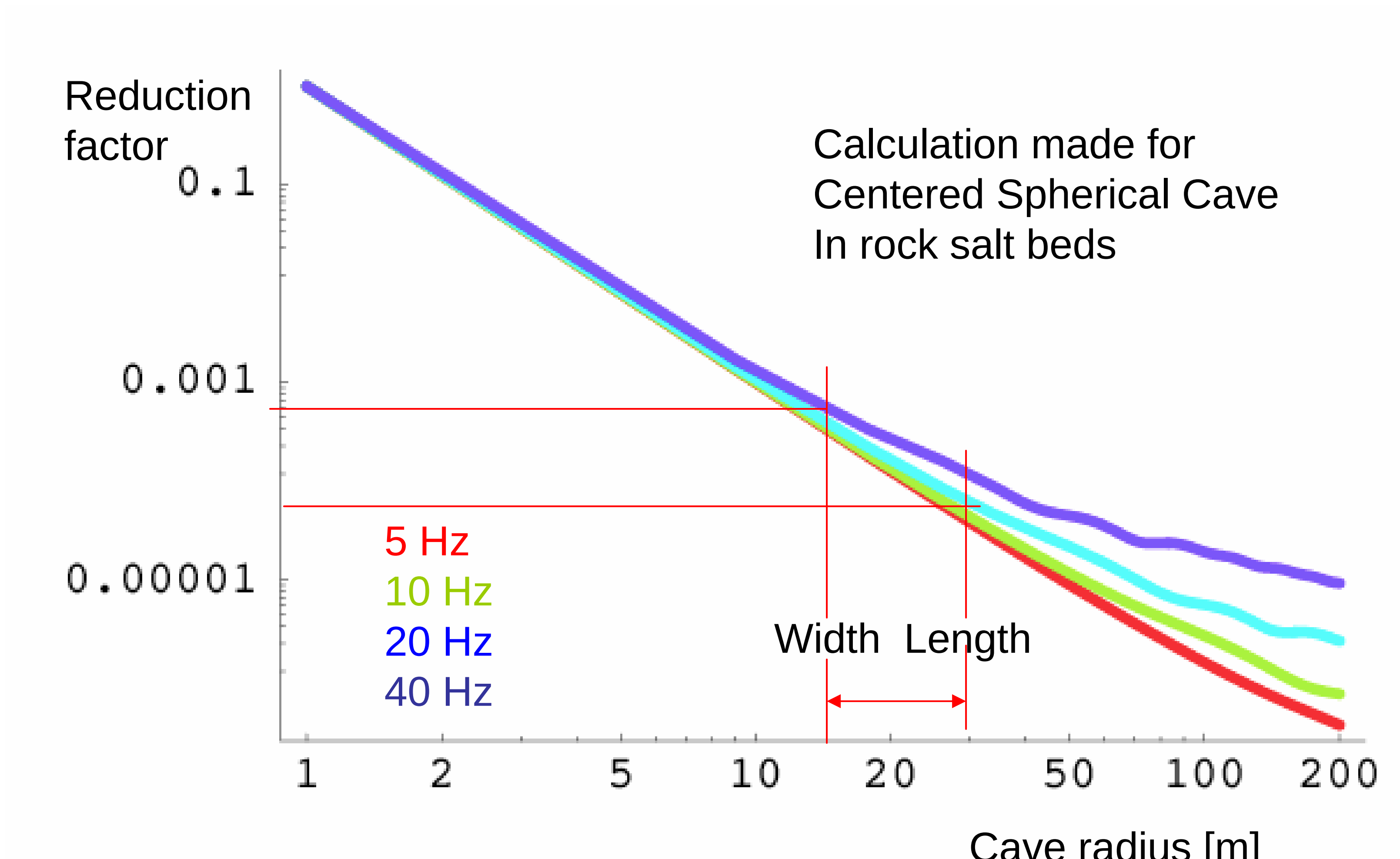
A

NN reduction underground

- Larger caves induce smaller test mass perturbations
- The noise reduction is proportional to $1/r^3$
- The longitudinal direction is more important =>elliptic cave



NN reduction from size



Why digging in salts

- For reasons of rock uniformity and stability evaporites (salts) are probably the best choice for GW underground Interferometers
- Long tunnels and large caves (for NN cancellation) will be necessary

Digging in salts is made by means of continuous mining machines like this one

Arbitrary cave shapes are possible within the rock stability limits (30-50-even 100 m depending on salt quality)

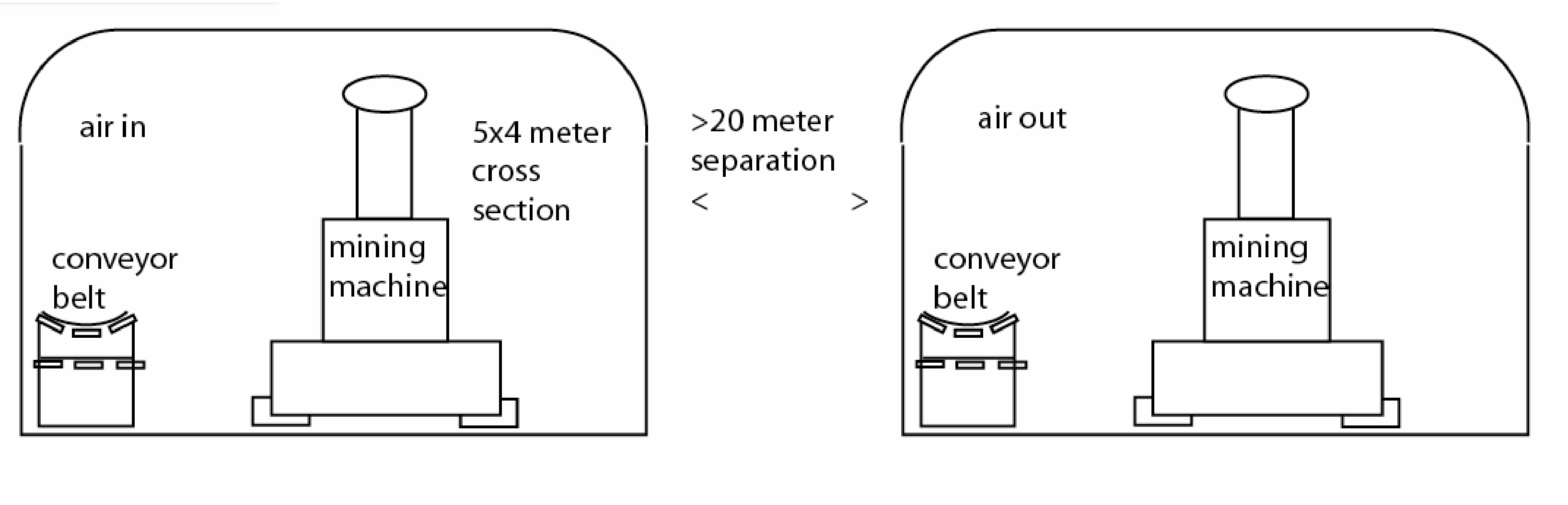
Realmonte mine in Sicily

Mining is often done in rectangular cross section to maximize extraction volume

For science better (ellipsoidal) shapes allow for larger cave dimensions and

Digging consideration

- A minimal cross section is required for rock evacuation and access, 5x4 or 4x3 meter
- for very long distances dual tunnels required for air circulation and safety (<500 m cross-overs)



Cost breakdown of an underground GW facility

- Costs per meter of tunnel and/or interferometer
  - Digging Cost per meter (see later)
  - Pipe Cost per meter
- Non recurring costs (for each additional tunnel or tunnel extension)
  - Cost of access (road, electricity and general facility)
  - Cost of surface plant (offices, housing, computing..)
  - Cost of continuous mining and other machines
  - Cost of conveyor belts and temporary air ducting (finished tunnel would be vented through a bore-hole at the end of the tunnel)
  - Cost of pipe manufacturing and treatment facility

Digging cost considerations

- Access will be a sizeable fraction of the facility cost, unless an existing facility is available
- Access is often difficult because of bad digging conditions, poor rock, fracturation, aquifers, etc.
- Well versus ramp tunnel (700 m depth)
  - Well 10-20 M$
  - Ramp tunnel, 6 times longer, cheaper/m, 3-4 times more expensive overall, 30-60 M$
  - Well more expensive to maintain(require operators), and worse access
  - Rock Evacuation:
  - 1.5$/ton on ramp vs. 5$/ton on well
  - With ramp 200$ savings per meter of dual tunnel
  - Savings do not pay for the difference but access, local rock configuration and maintenance cost may justify the ramp choice

Digging cost considerations

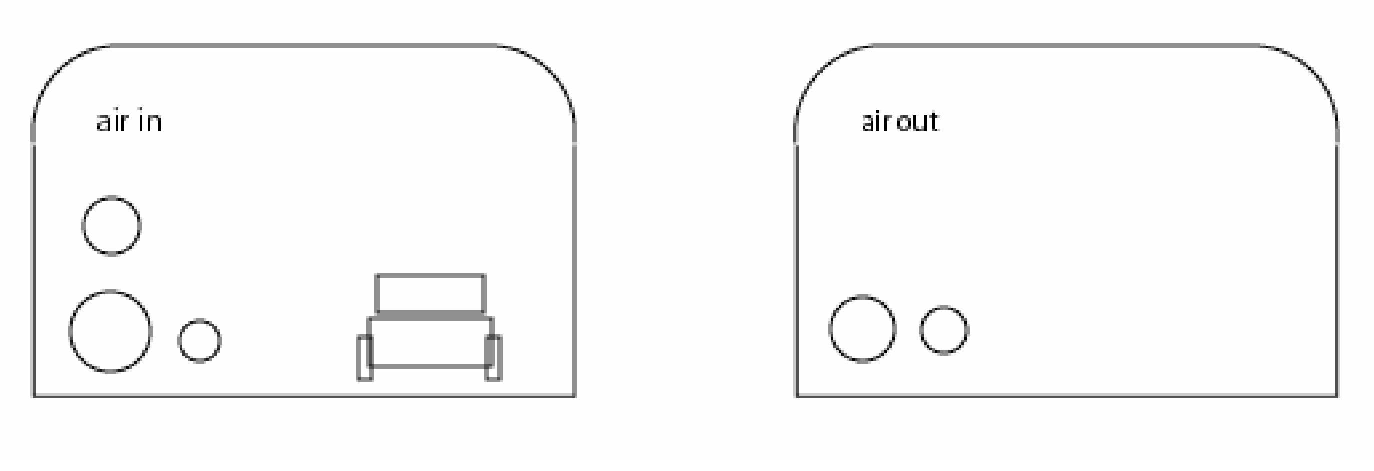
- Actual tunnel digging costs ~ 1500 $/meter for a dual bore tunnel

- Conveyor belts 2x1000 $/meter (also in ramp)
- Mining machines 1.5-2 M$ each (x 2 for dual)

- Equipment non recurring costs (and access costs) are a large fraction for just 2 tunnels

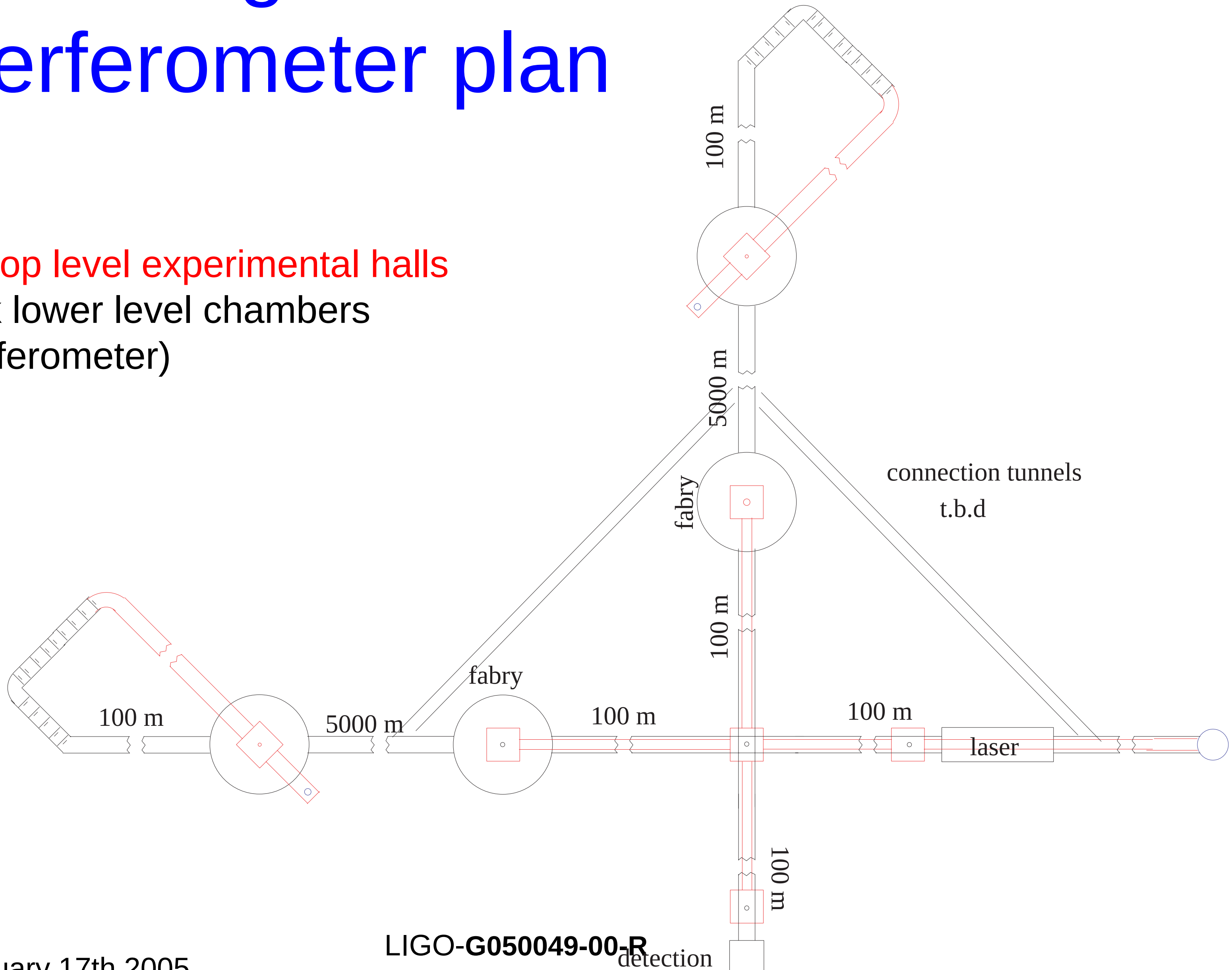
- Premium to make more tunnels to cover both polarizations
- Premium to make longer tunnels for increased sensitivity

- In any case plenty of space for multiple interferometer pipes



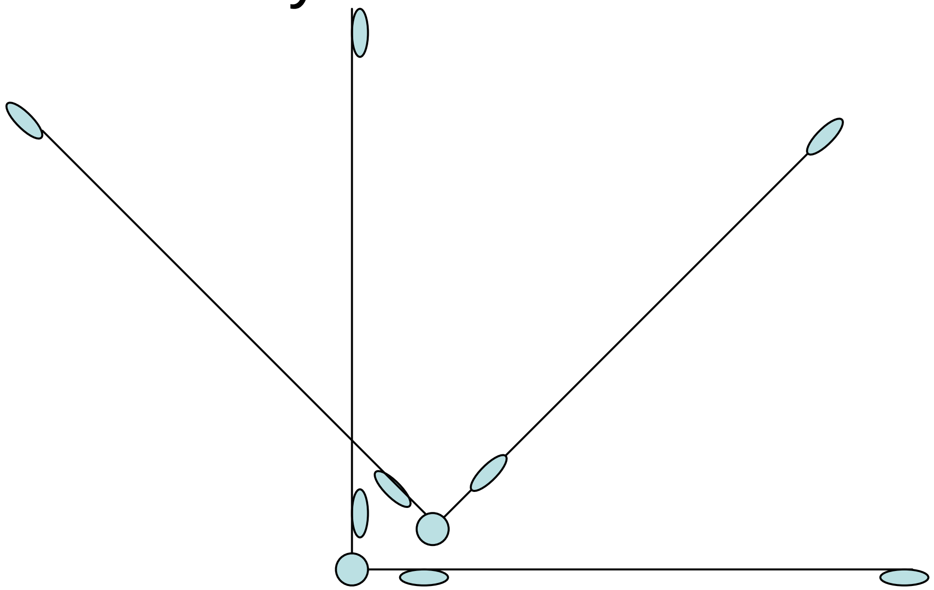
Underground interferometer plan

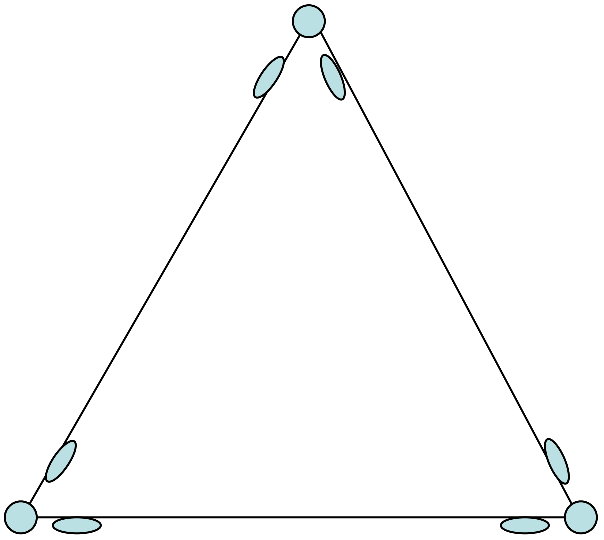
Red top level experimental halls
Black lower level chambers (interferometer)



Tunnel use considerations

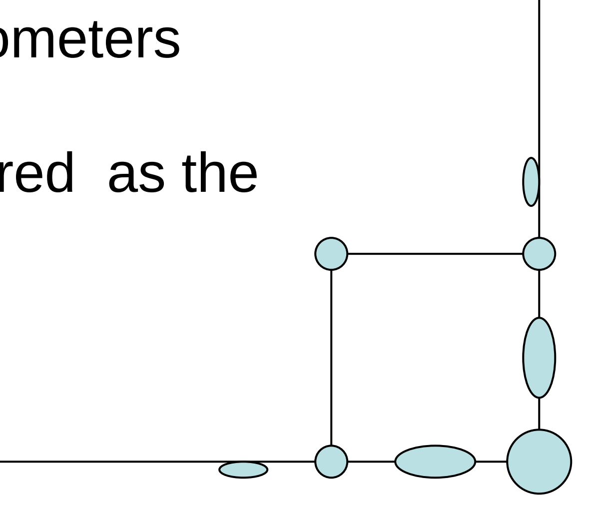
- There is no practical way to use an interferometer to cover more than so much in frequency
- Multiple interferometers in the same tunnel are a necessity





Tunnel use considerations

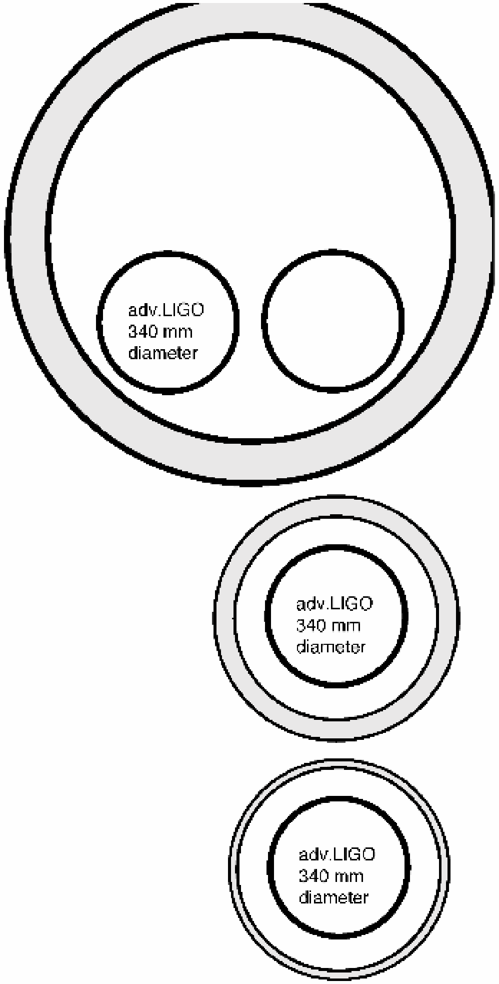
- Interferometers at higher frequency would be located with folding mirrors progressively farther from the lowest frequency interferometer BS, say at 100 m intervals.
- Higher frequency interferometers have in any case less need for length.
- Of course the flarings of the Nerwtonian Noise suppression caves for the different interferometers would be concentric to each beam line,
- Progressively smaller cave sizes are required as the sensitivity frequency goes up.



Vacuum pipe cost considerations

- An important consideration is that beam pipes does not need to be that much bigger than the beam as we did in LIGO or Ad-LIGO

- Half size means
- half surface,
- half thickness of material and weld
- => less than half the cost
  - Half size is not a quarter cost but almost!
- Additional diameter savings by replacing baffles with a spiral band saw welded in place during tube manufacturing



Vacuum pipe cost considerations

- The LIGO pipes cost 40 M$ including raw material (10%), manufacturing,cutting in sections for transport, transport, processing, installation and welding in place.
- Building the pipes in site will allow the construction of longer sections (cheaper)
  - In LIGO 2x20 m sections were first cut and then welded together between each sets of bellows
- The cleaner (dust, hydrocarbon and humidity free environment) environment will make for cheaper and easier handling
- The pipe factory (2-3 million dollar worth) is a non recurring cost that can be reused for additional interferometers

Vacuum pipe cost considerations

- There is a premium in making more separate vacuum pipes for separate interferometers
- Maintenance in one interferometer does not affect others
- If seismic isolation is good, can implement new interferometers while operating old ones

Where to find a good location?

- Many locations around the world
- Germany, New Mexico (WIPP), Saskatchewan, Sichuan etc.

Where to find a good location?

- Piggy-backing on existing mine may have advantages
  - Access
  - Expertise
  - Discharge of rock in old digs
- Disadvantages because of mining noise?
  - Continuous miners (small enough?)
  - Daily explosions (good calibrations?)

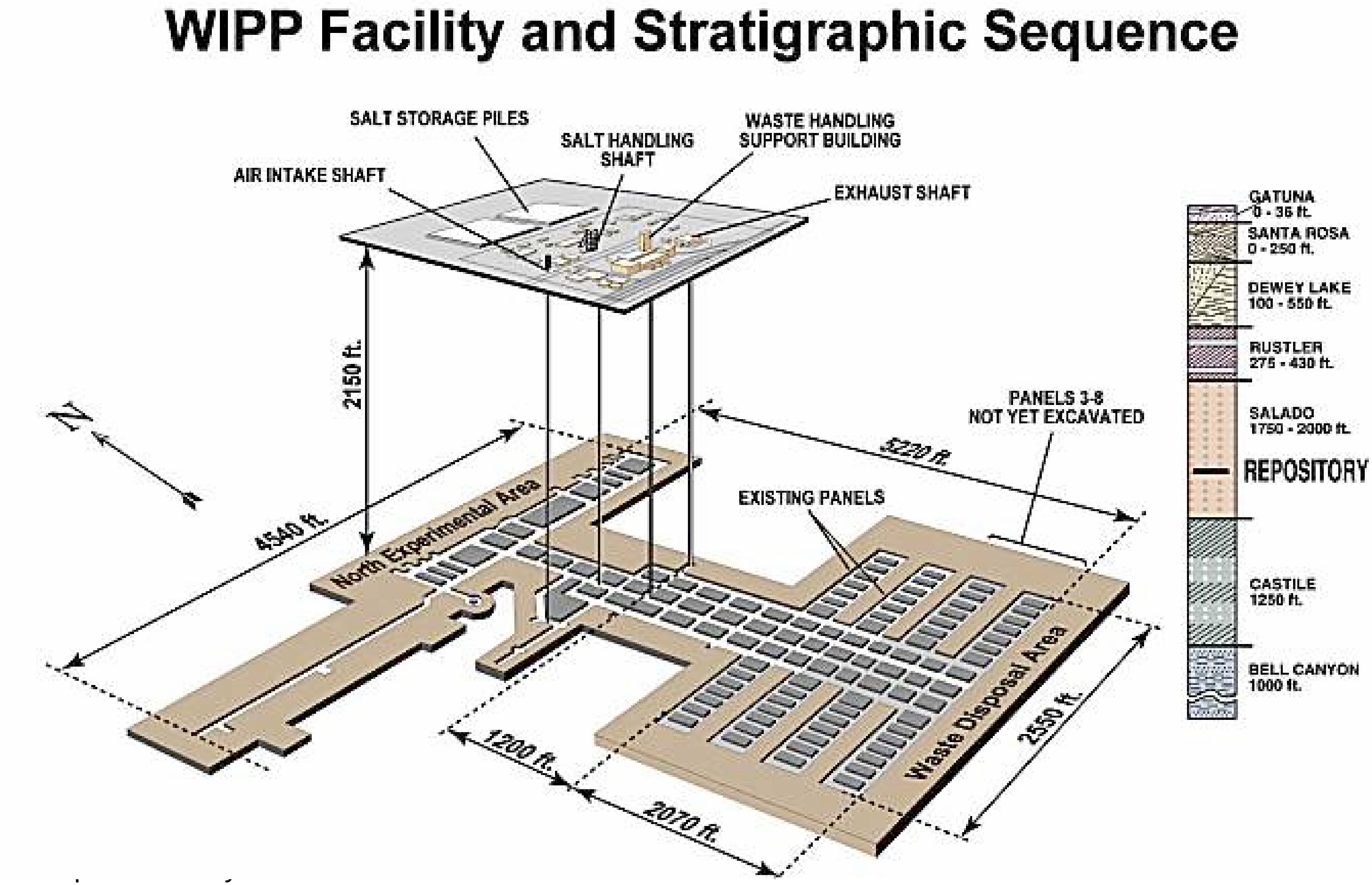
Where to find a good location?

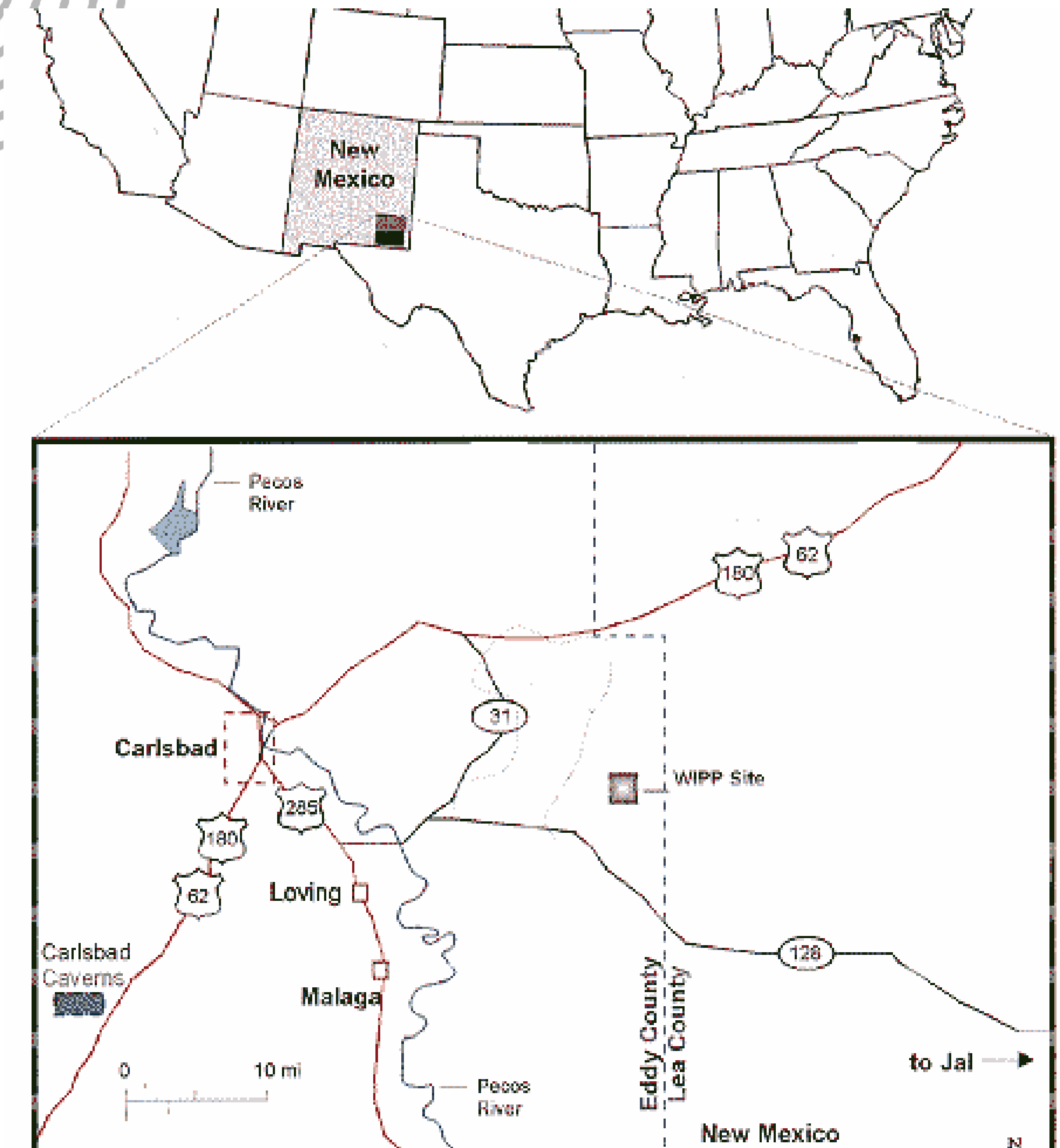
- Example: Kali und Saltz mines of Hattorf or Wintershall near the city of Kassel in Germany
- Mining a 700 m deep, 5 m thick layer of Potassium salts
- Below there is a 50-60 m thick layer of Sodium Salts and below that a Gypsum layer
- Access is already available
- The salt is particularly stable
- Ventilation and access may be available with little cost
- Evacuation costs reduced with discharge of material in numerous abandoned caves
- Large population of experienced personnel
- May be possible to use existing equipment (continuous miners, conveyor belts, trucks)

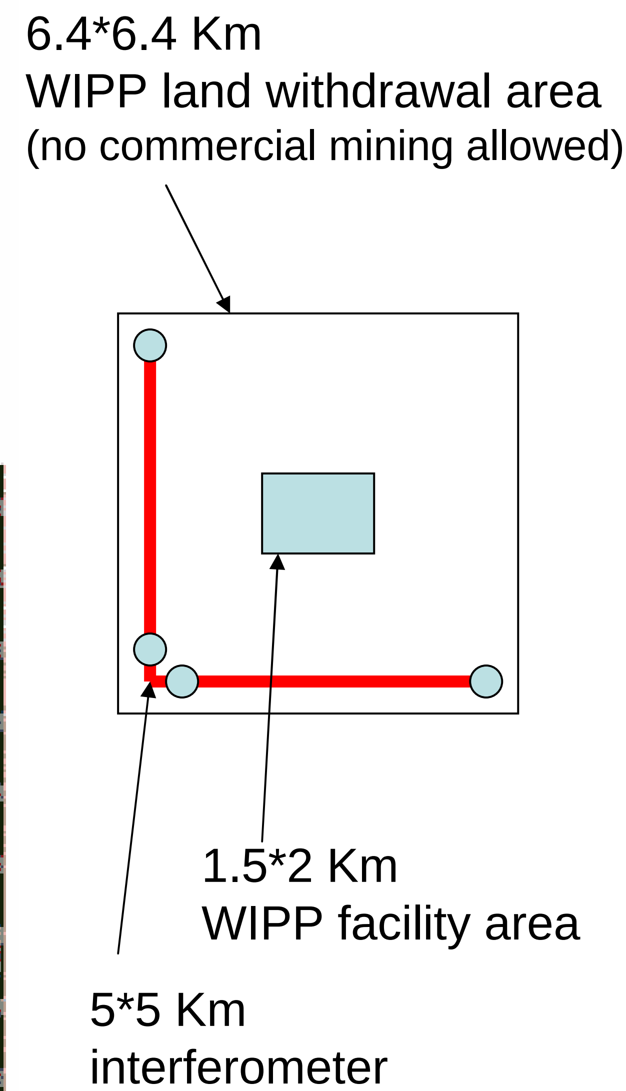
Where to find a good location?

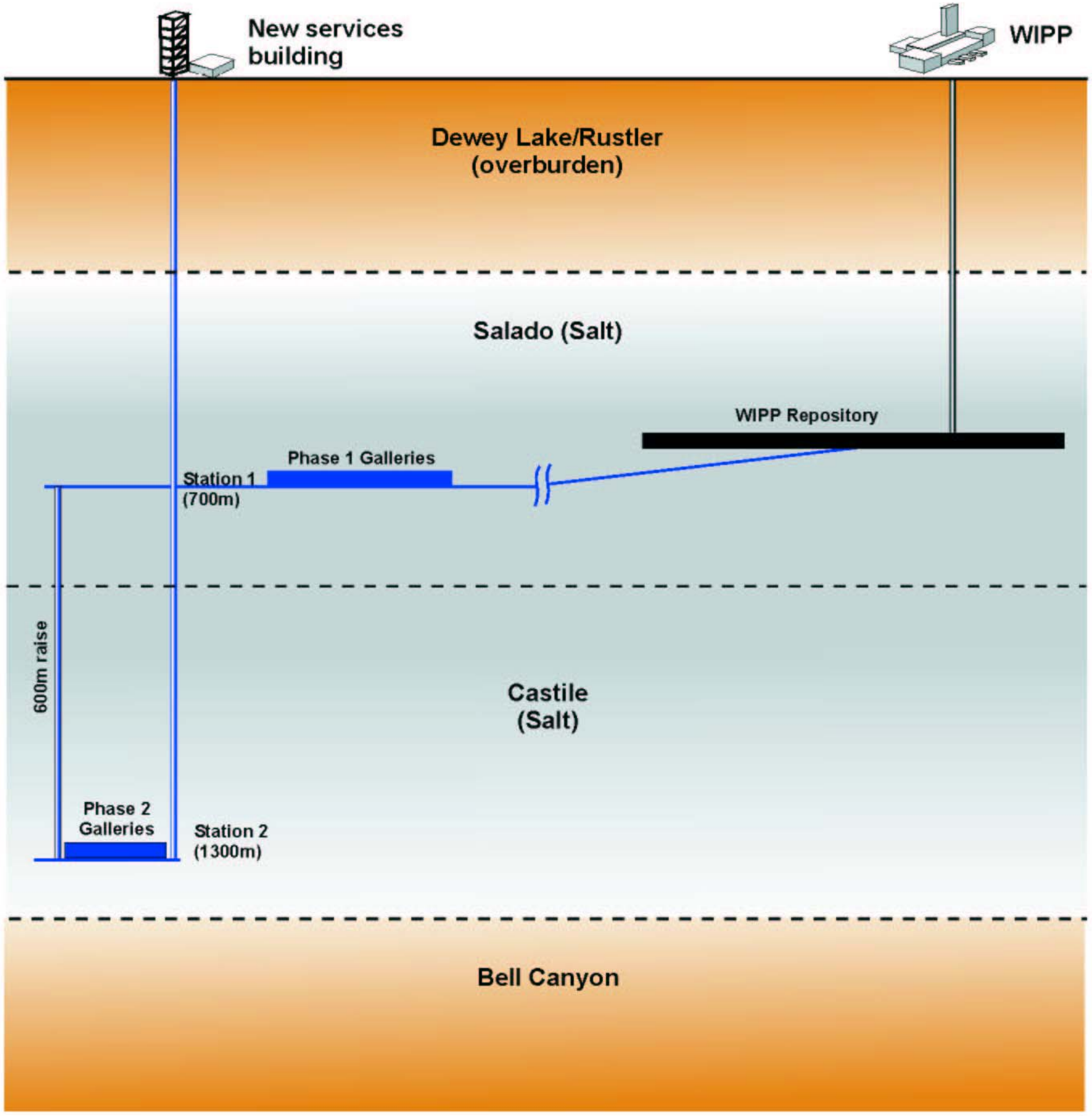
- Example: WIPP nuclear repository in New Mexico
- Mining forbidden in the reservation but allowed for scientific uses
- Below there are thick layers of various evaporites
- Access may be already available
- Some advantages as for the German site

A site example, The WIPP site




New Mexico
Pecos River
62
180
31
Carlsbad
WIPP Site
285
180
62
Loving
Carlsbad Caverns
Malaga
128
Eddy County
Lea County
0
10 mi
Pecos River
to Jal
New Mexico


6.4*6.4 Km
WIPP land withdrawal area
(no commercial mining allowed)
1.5*2 Km
WIPP facility area
5*5 Km
interferometer



Chlorides
Dens. 2.1
More conv.

Sulfides
Dens. 2.3
Less conv.

Conclusions

- There are many advantages for going underground
- The prices are not outrageous
- Fixed costs are an large fraction
- Premium for longer and multiple interferometer in the same facility
- Can detect GW as low as 1 Hz!
- Need to go down into deep black holes beneath earth to see the heavy black holes in the heavens.