Introduction to the SALSA experiment (SALt-dome Shower Array)

Probing astrophyics and elementary particles using a teraton (500 km^3-sr) UHE cosmic neutrino detector

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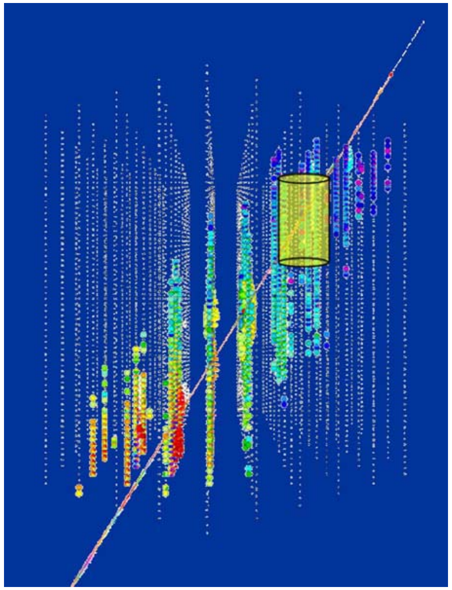
for the SALSA Collaboration

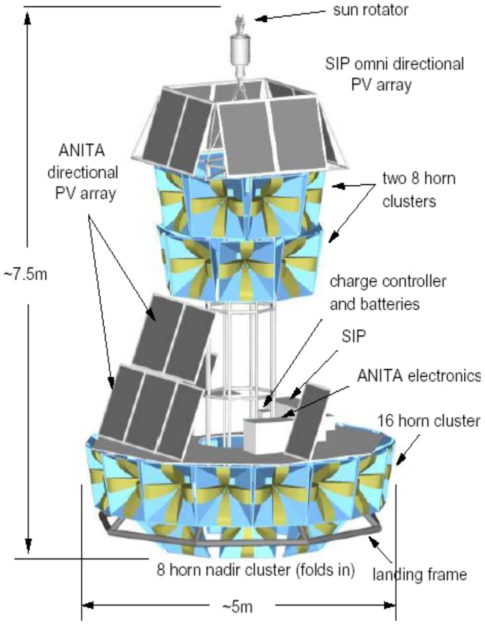
ARENA meeting
DESY-Zeuthen
May 19, 2005

- More info at http://www.physics.ucla.edu/astroparticle/salsa/slacfeb05/talks_feb05.html (SLAC meeting, Feb. 2005)

Where we might be in just 5 years…

- IceCube
  - Discovery of bottom-up sources
  - Discovery of a few GZK neutrinos
- ANITA:
  Discovery of up to 30 GZK neutrinos
- Auger
  - Discovery of a few GZK neutrinos

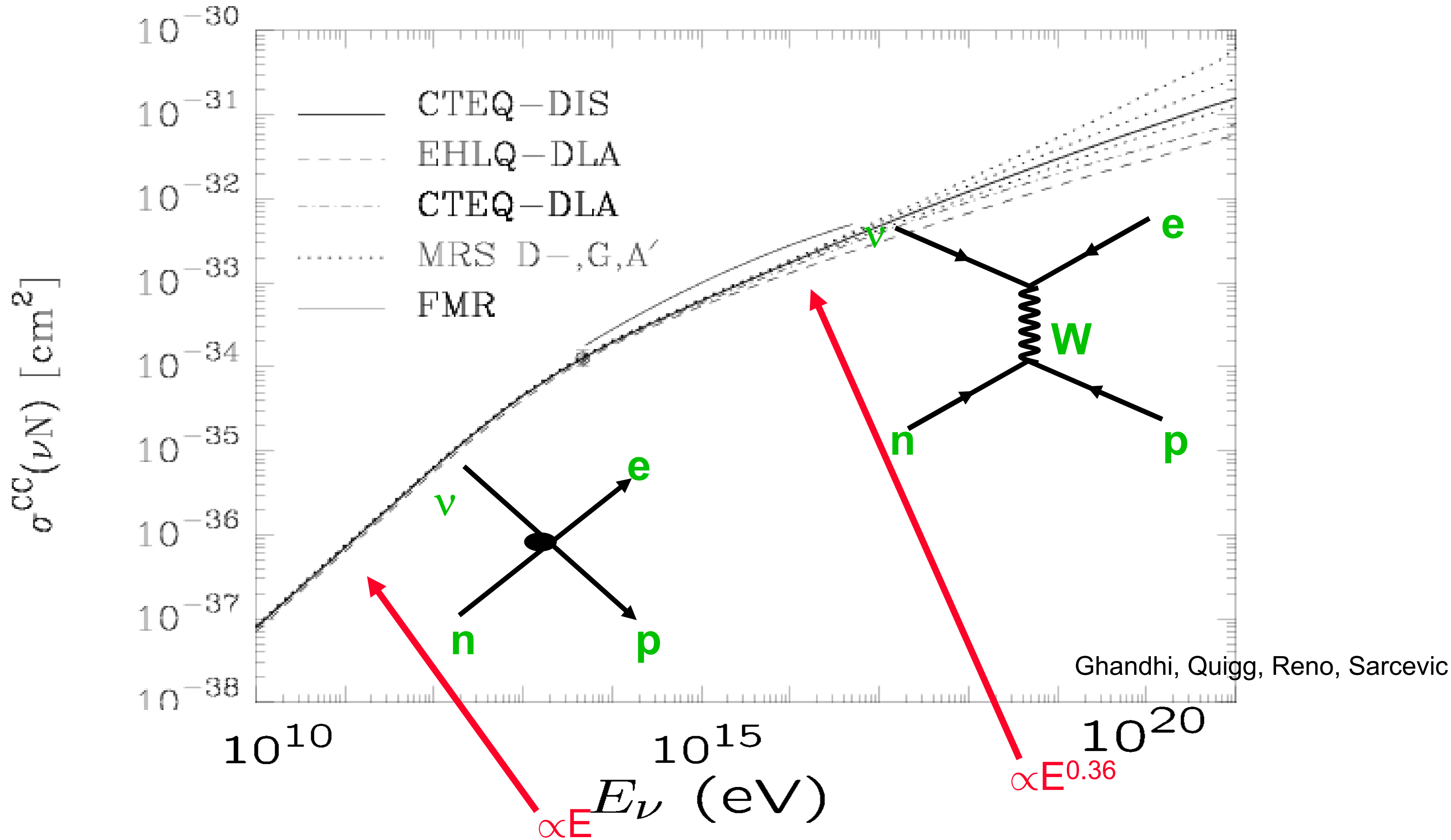




What will we want to know about the GZK neutrinos?

- Astrophysics:
  - Every neutrino points back to its source
    - Are they isotropic?
    - What is energy spectrum?
    - No flaring?
- Particle Physics:
  - What is the ν cross section?
  - What are the flavor ratios of the detected neutrinos?
  - Are the interactions what we expect?
- We'll need more than just a few GZK events

Neutrino interactions in the Standard Model



UHE Neutrino Cross Section and low-scale Quantum Gravity

- Probing interactions at high CM
  - $E_{cm} = (2\, m_p\, E_\nu)^{1/2}$ ➔ 150 TeV for $E_\nu = 10^{19}$ eV
  - $\sigma_{SM}(\nu+N) \sim 10^{-7} \times \sigma_{SM}(p+N)$
- Large extra dimension models could enhance ν cross section
  - Gravity could become strong at $E_{CM}=M_D$
  - Non-perturbative effects could produce KK-exitations, string excitation, pea-branes, micro-BH above E_{CM}

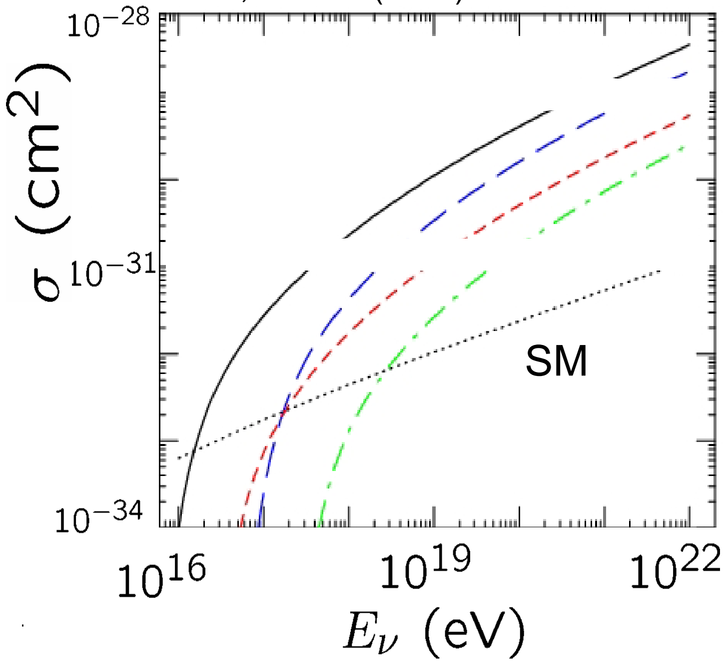
$$M_D = [\frac{M_{pl}^2}{8\pi r_c^n}]^{\frac{1}{2+n}} \text{ where } M_{pl} \equiv 10^{28}\text{eV}$$

- Astrophysics and laboratory limits still allow
  - $n=4$, $M_D > 10$ TeV
  - $n \geq 5$ $M_D > 1$ TeV

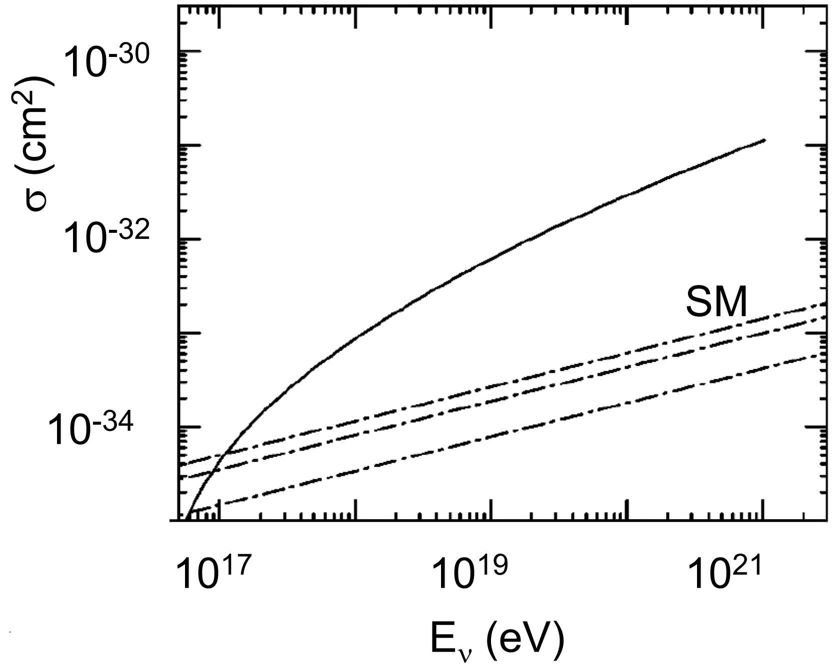
Enhancement of UHE Neutrino Cross Section

Sample predictions for M_D~1 TeV, n~6-7:

Alvarez-Muniz,Feng,Halzen,Han,Hooper
PRD65, 124015 (2002)



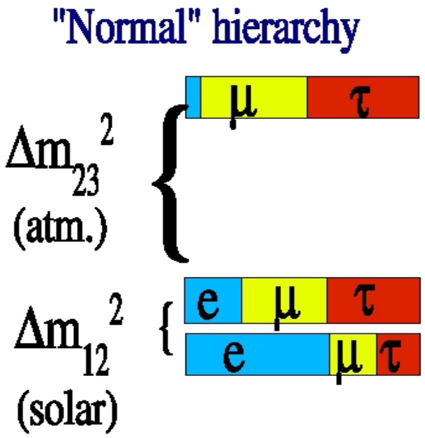
Anchordoqui,Feng,Goldberg,Shapere,
PRD65, 103002 (2002)



- Caveat: not all energy goes into BH or excitation, and need minimum energy for classical BH formation.
- UHE ν cross sections could be up to ~100$\times$ Standard Model
  - * would be invisible to UHECR interactions

Neutrino Decay imprint on Neutrino flavors

- Critical parameter for neutrino oscillations and decay is proper time, L/E
  - Solar neutrinos: 150,000 km/5x10^6 eV = 30 m/eV
  - GZK neutrinos @ SALSA from 4 Gpc/10^{17} eV = 10^9 m/eV



$\nu_e : \nu_\mu : \nu_\tau$

$(1:1:1) \rightarrow (5\text{-}6):1:1$

- Neutrino decay leaves a strong imprint on flavor ratios at Earth (e.g. Pakvasa et al.)

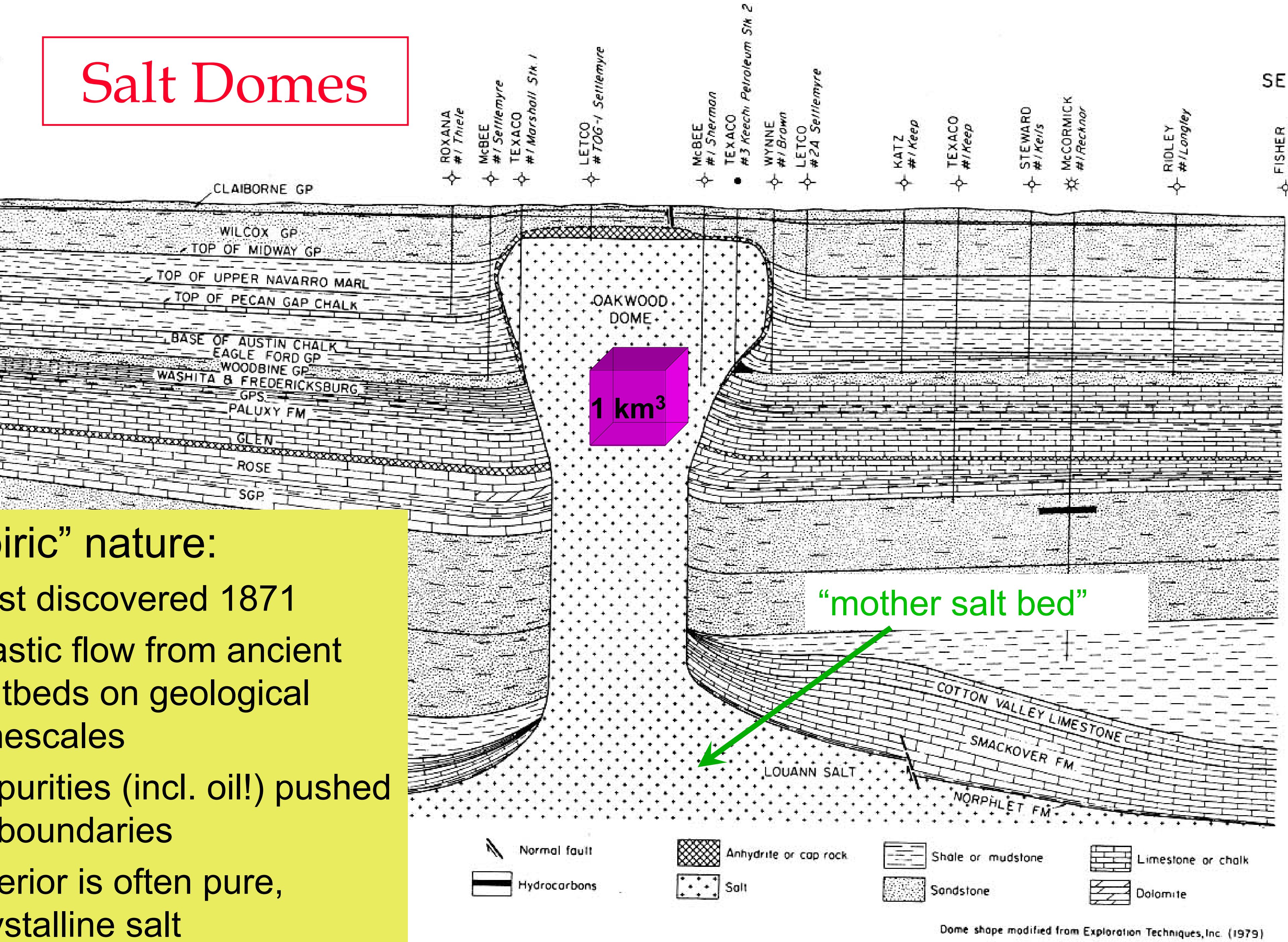
What is needed?

- Need a 500 km^3-sr detector with a 100% duty cycle.

- Need attenuation lengths of scale O(1 km w.e.)
  - ➔ radio and acoustic detection

- Large natural salt formations (domes) offer excellent candidates….

Salt Domes



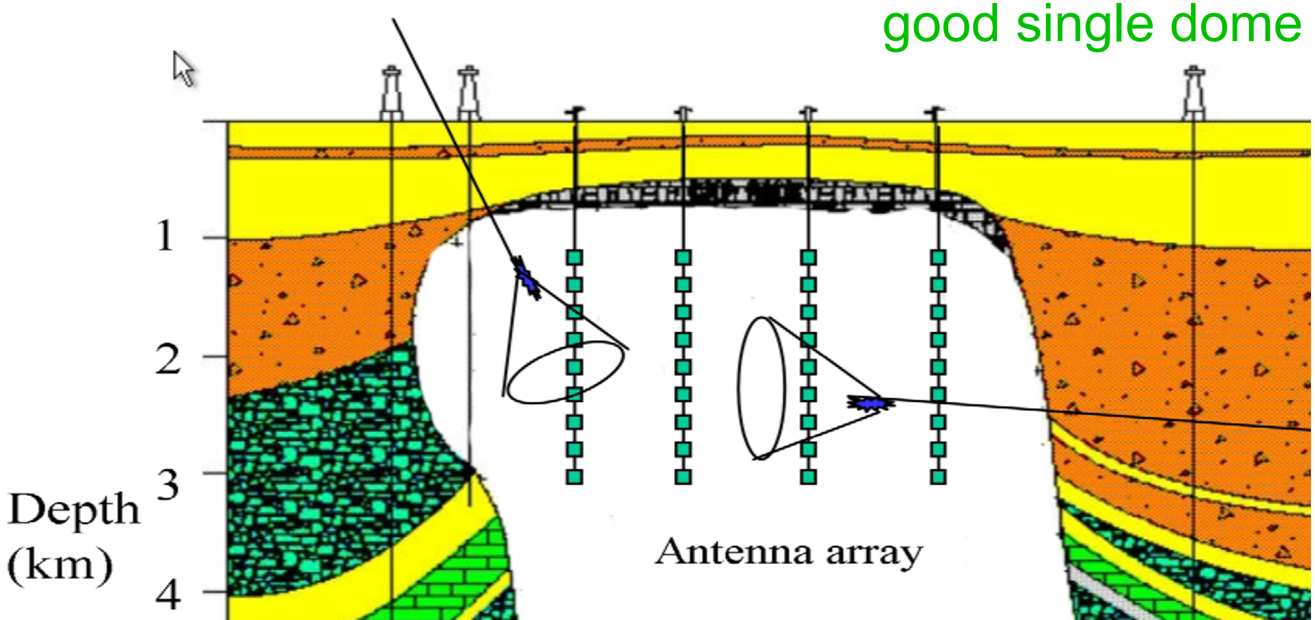
…piric" nature:

- …st discovered 1871
- …astic flow from ancient …tbeds on geological …nescales
- …purities (incl. oil!) pushed … boundaries
- …erior is often pure, …ystalline salt

Standard Imbedded array design, with some differences…

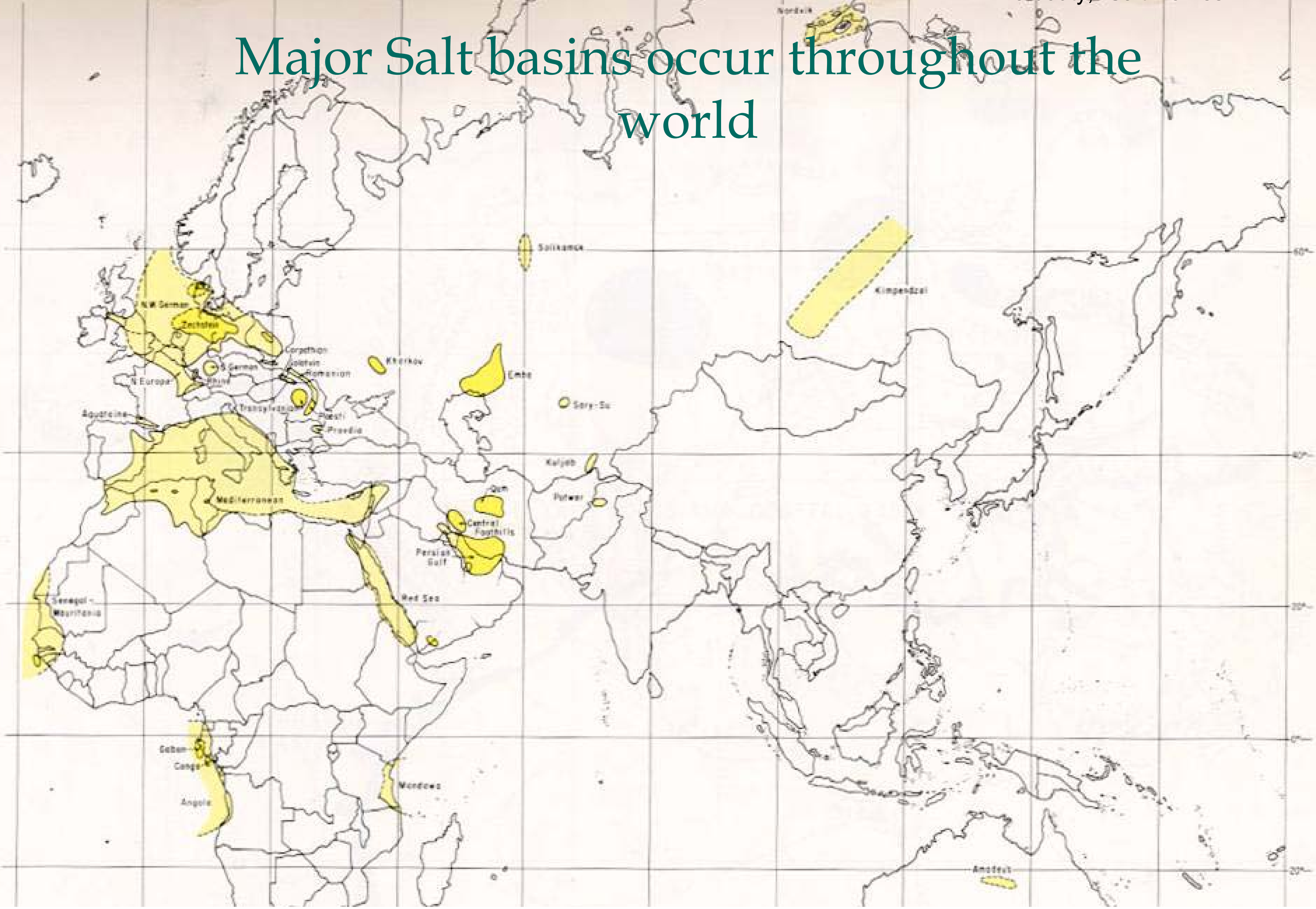
- Spacing: $\sim$ 1 attenuation length
- Filling volume ➔ contained events
- View $\Delta\,\Omega$ ~ 2π (zenith to >horizon)
- Vertex with timing (to a few meters)
- Angular and energy measurements from
  - amplitude
  - *polarization*

- For RF, as clear as Antarctic ice (Acoustic under study)
- But nucleons packed 2.4 times tighter
- typical good domes 50-100km^3 in upper 3 km
- 500 km^3-sr w.eq. achievable in a good single dome



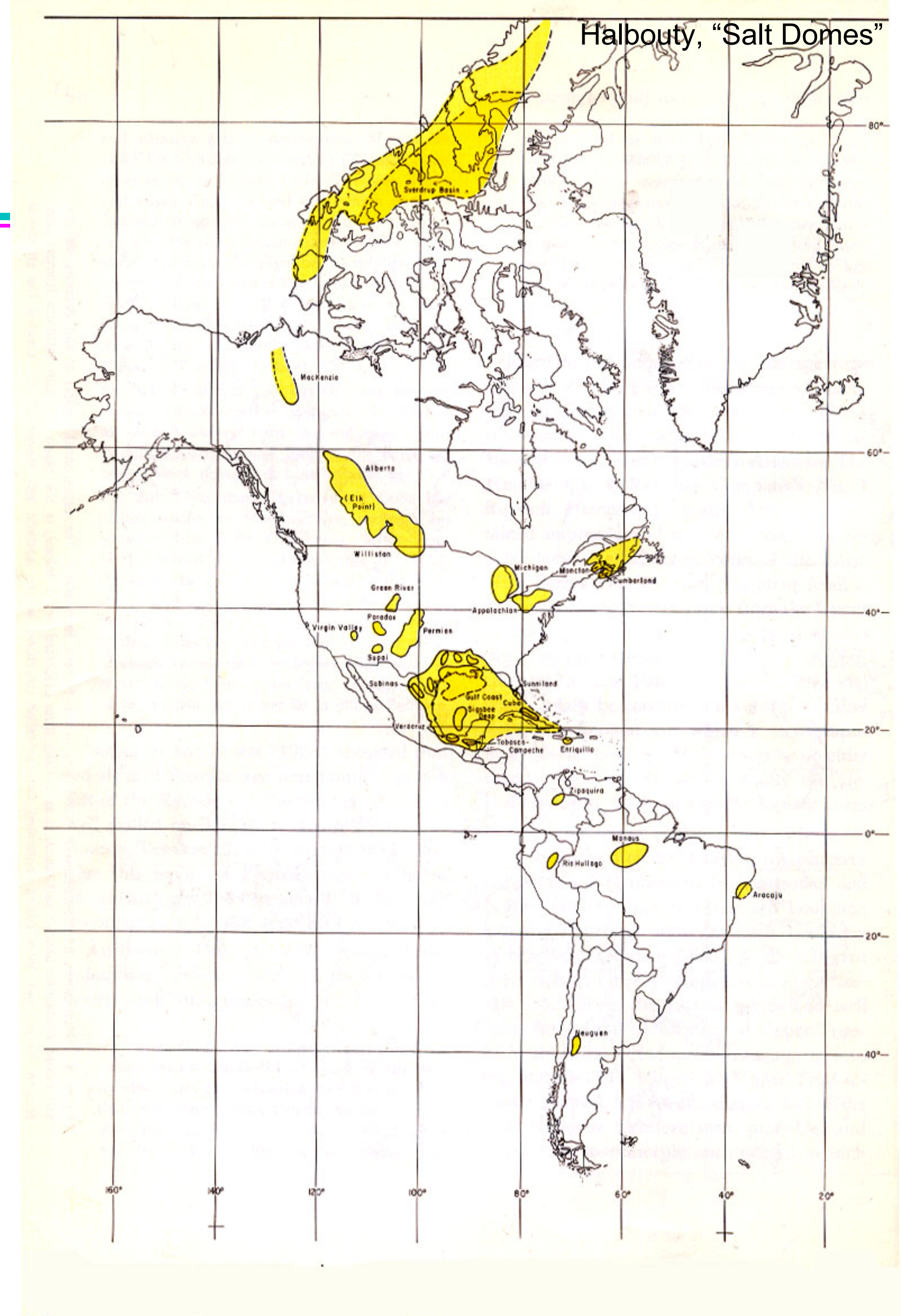
P. Gorham

Major Salt basins occur throughout the world



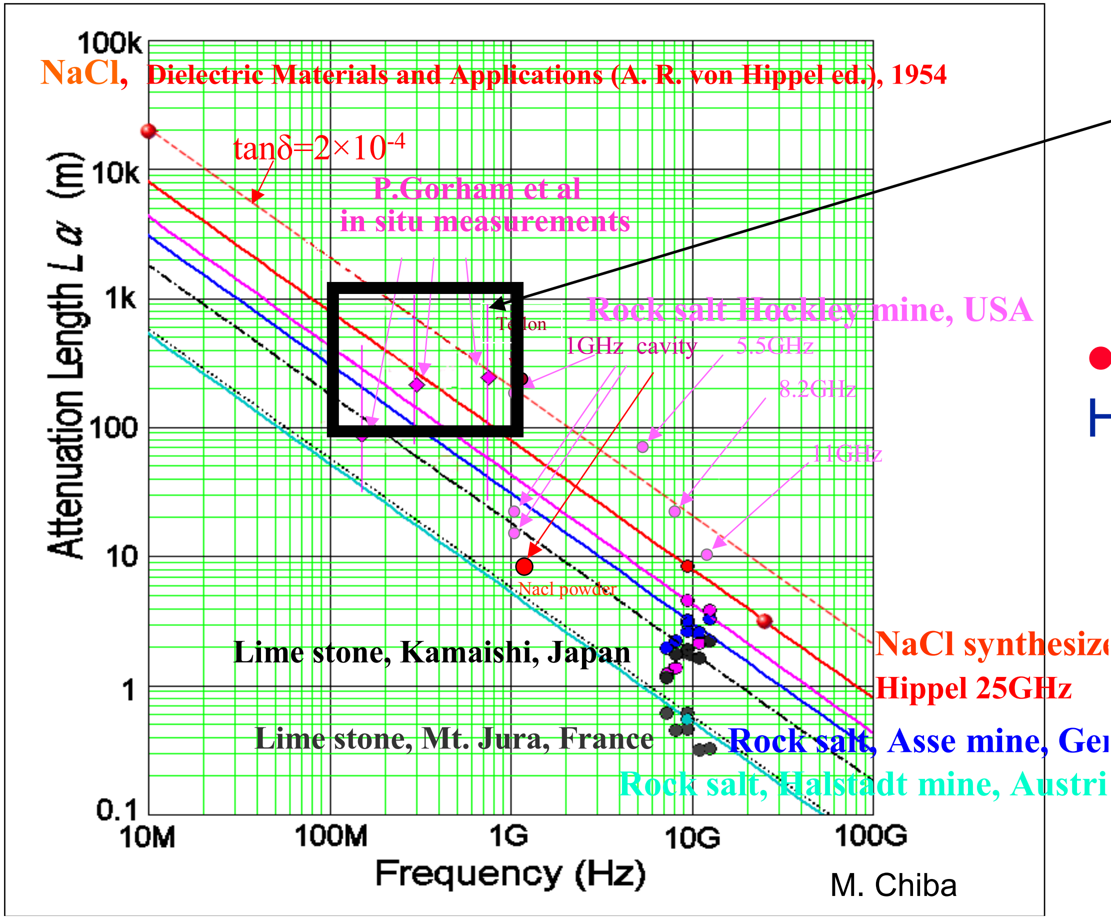
- Many are more accessible than the South Pole

Major Salt basins occur throughout the world…



- Many are more accessible than the South Pole

What we need for realistic design & full proposal: Radio Detection (RF)

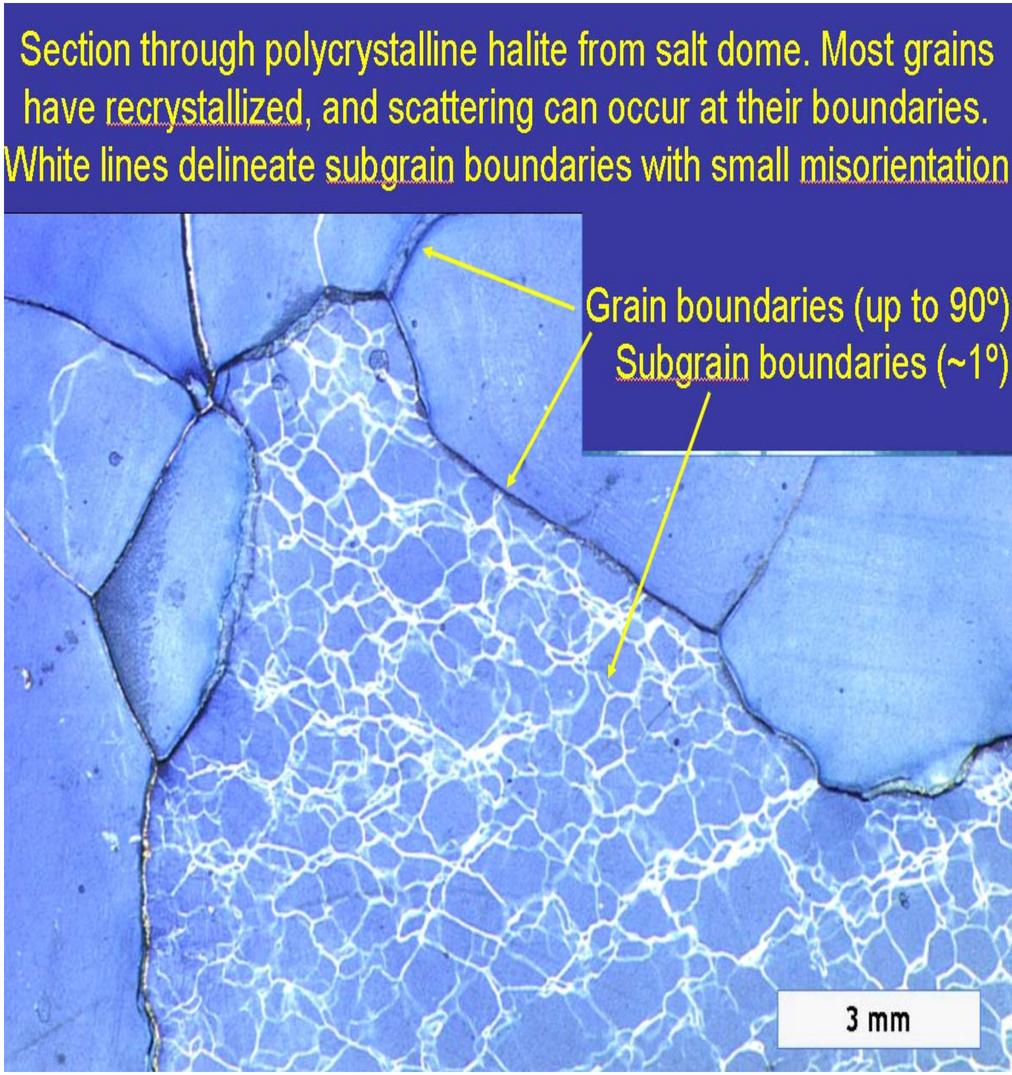


- In situ measurements at Hockley:
  - * L_{atten}>~250 m
  - * no observed birefringence
  - * no observed multipath
  - * 300-350 K noise

- Attenuation looks >250m, but need better measurements for a full proposal
- Will also be dome-specific.

Status of Acoustic Detection

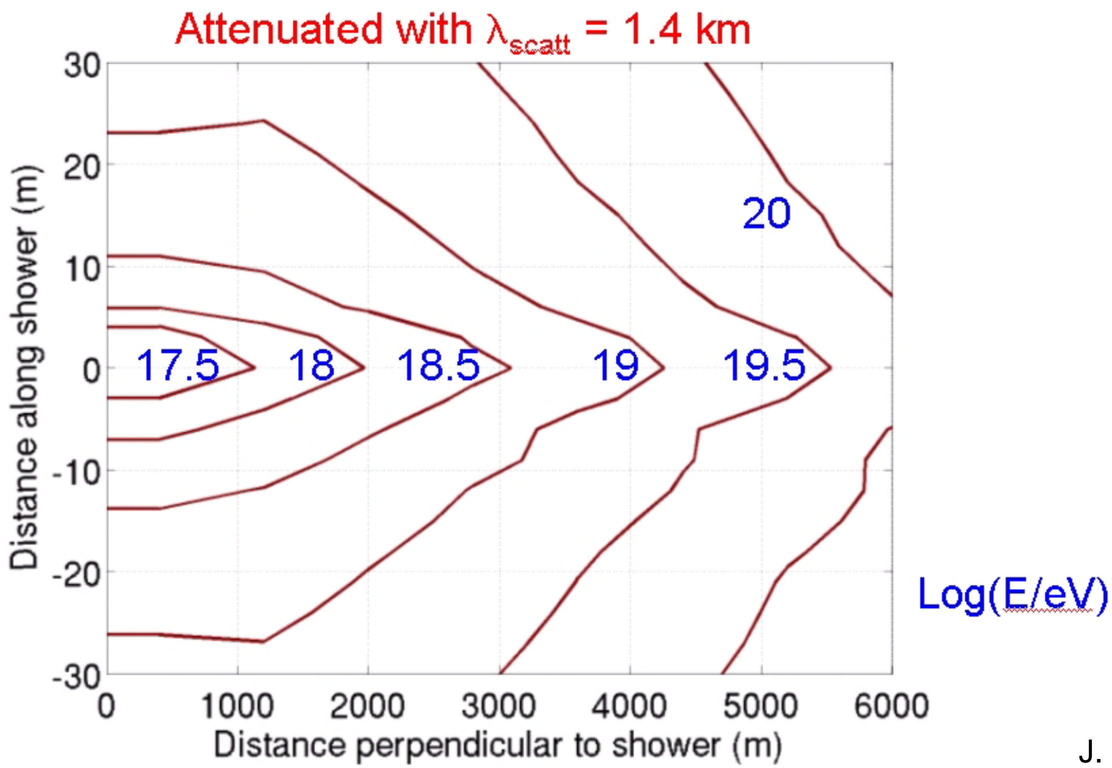
- Acoustic is complementary to radio
  - low speed of propagaton
  - no polarization
- Need now:
  - in-situ measurements of salt attenuation 10-100 kHz
  - in-situ noise levels at these frequencies.
  - understand basic emission (beam test?)
- Also requires further development of sensors and couplers to salt



B. Price

Preliminary Acoustic MC work

Receivers within the contour for each energy would trigger.



J. Vandenbrouke

- Adding acoustic detection to existing Radio Monte Carlos

Roadmap to SALSA

- Phase A: (Ongoing)
  - preliminary site inventory
  - mineral and land rights investigation
  - simulations
  - Instrumentation prototyping (building on ANITA & RICE experience)
  - propose Phase B
- Phase B:
  - Drill ~ 3 holes in ~3 best domes
  - Attenuation and Noise measurements
  - for both Radio and Acoustic
  - 4-string mini array
- Phase C
  - full array(s)

Phase A: preliminary site selection

- Based on literature and discussion with geologists
- Begin with east Texas, Louisiana, Mississippi (examples):

Dome	State	Volume in upper 3km	min caprock	Notes	follow-up so far
Richton	MS	39.6 km^3	220 m	flat cap	
Hainesville	TX	36.3	336	circular flat cap, low population	X
Brooks	TX	37.5	100	under wasser	
Chacahoula	LA	29.0	370	low population	
Keechi	TX	19.8	91		X
Cypress Cr.	MS	13.3	396		
Napoleonville	LA	11.6	200		
Oakwood	TX	15	250		X
Venice Field	LA	9.5	500		

G. Varner/ P. Gorham

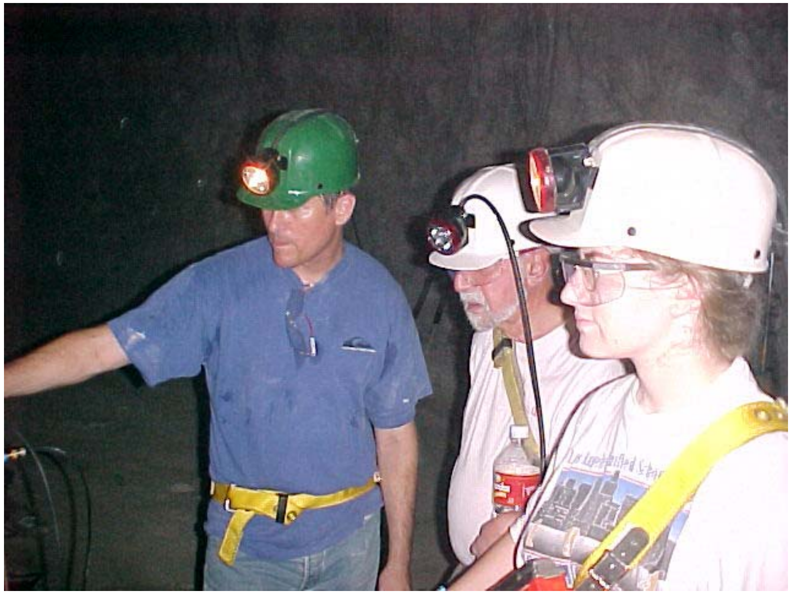
- Further study of No. Louisiana and Mississippi underway
- Utah, Newfoundland, Mexico also possible
- European site searches…

Phase A – preliminary site selection

- Site specific land-leasing and mineral-rights reports
  - (professionals in the field)
- Results:
  - Hainesville. One exploration company dominates land and mineral contracts
    - have contacted the major stakeholder
  - Oakwood & Keechi: Patchwork of many owners
  - Other sites under investigation.

Phase A:
attenuation length

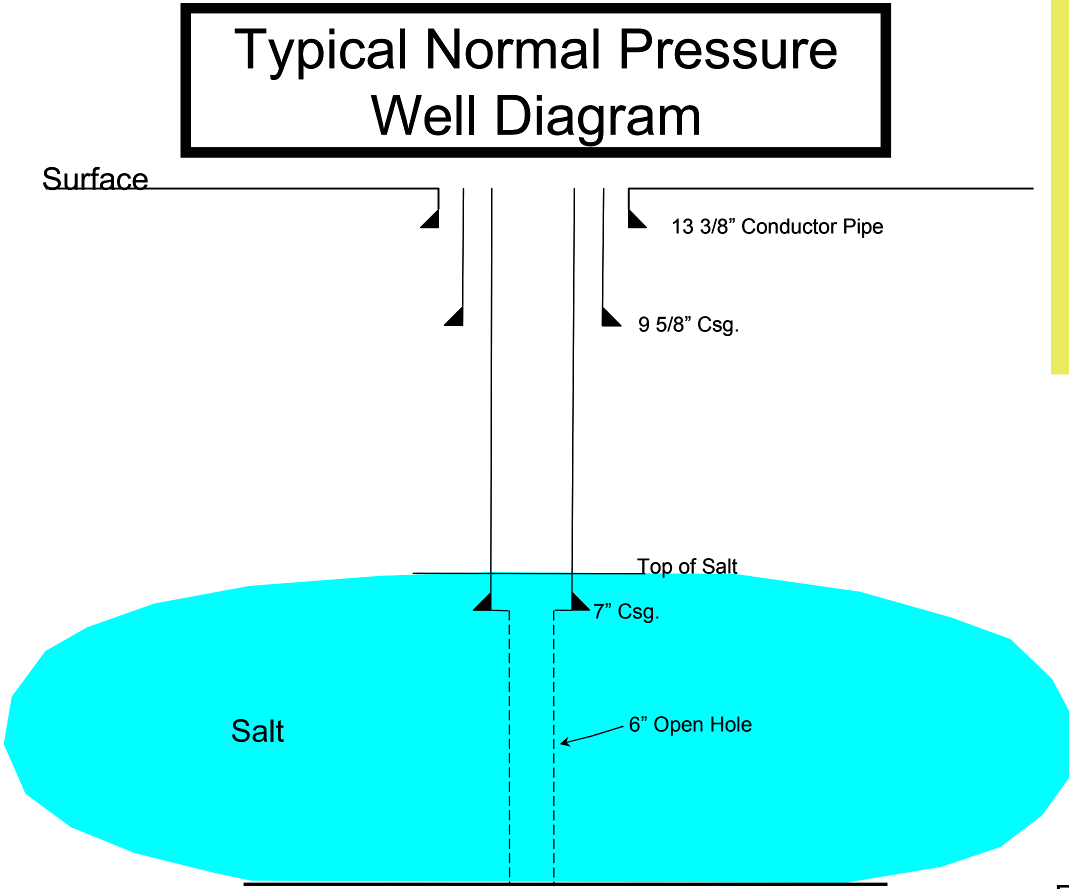
- While arranging for long boreholes:
  - still could improve Hockley measurements:
    - 5m boreholes from mine drifts now available
    - Power amps and pulsers available
    - planning trip for this summer
  - Developing instrumentation (later slides)



Phase B – measure properties

- Desire >=3 boreholes/dome in about 3 different domes
- Measure attenuation length and T_{sys} down to about 3km
- Test instrumentation; iterate
- Forms the beginning of an array:
  - 4-string “SALSA-4” study

Drilling considerations



- Required casing to protect ground water
- Advantage for domes near surface

R. Bain

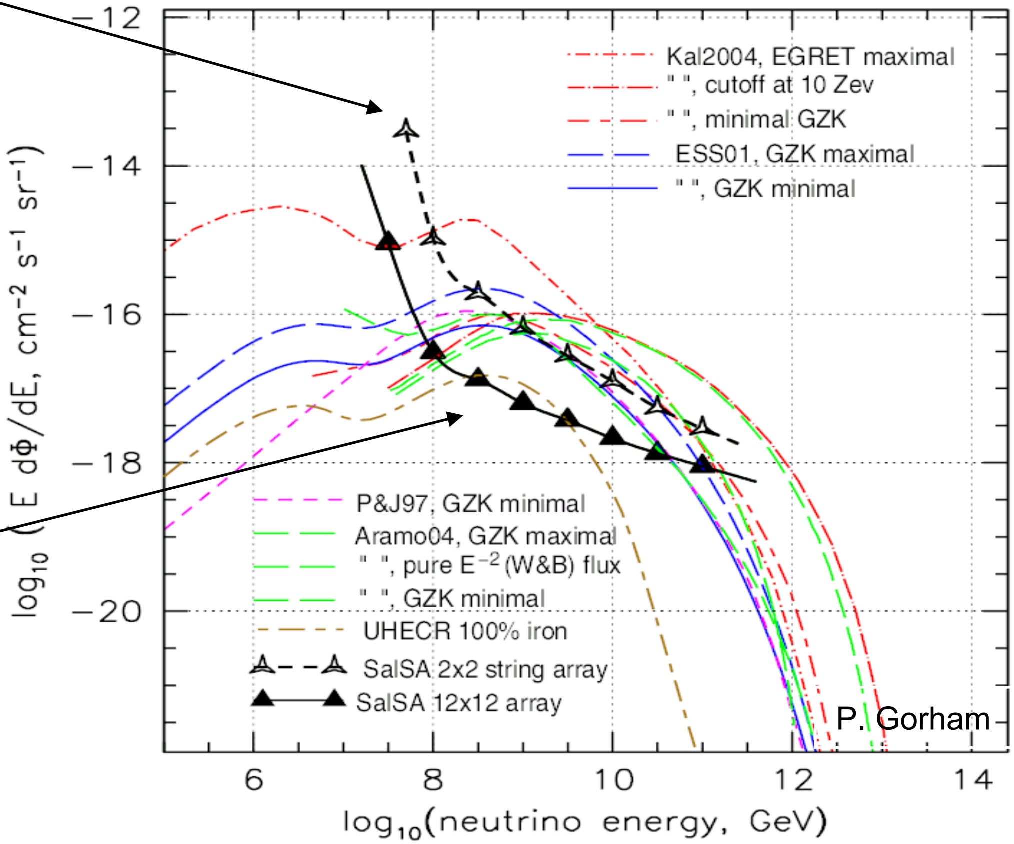
Install roads, make drillsite, install flowline, mix mud, drill surface hole, drill intermediate hole, casings, drill salt, diesel, secure

end of Phase B: Salsa-4

- Monte Carlo sensitivity studies for 4-string array
- Predicts 2-3 GZK events per year even for “minimal” models
- Allows for two-phase construction
- Phase C

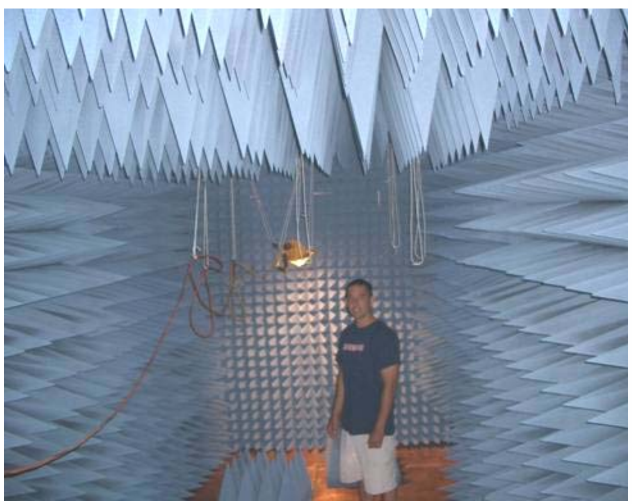
ν flux and

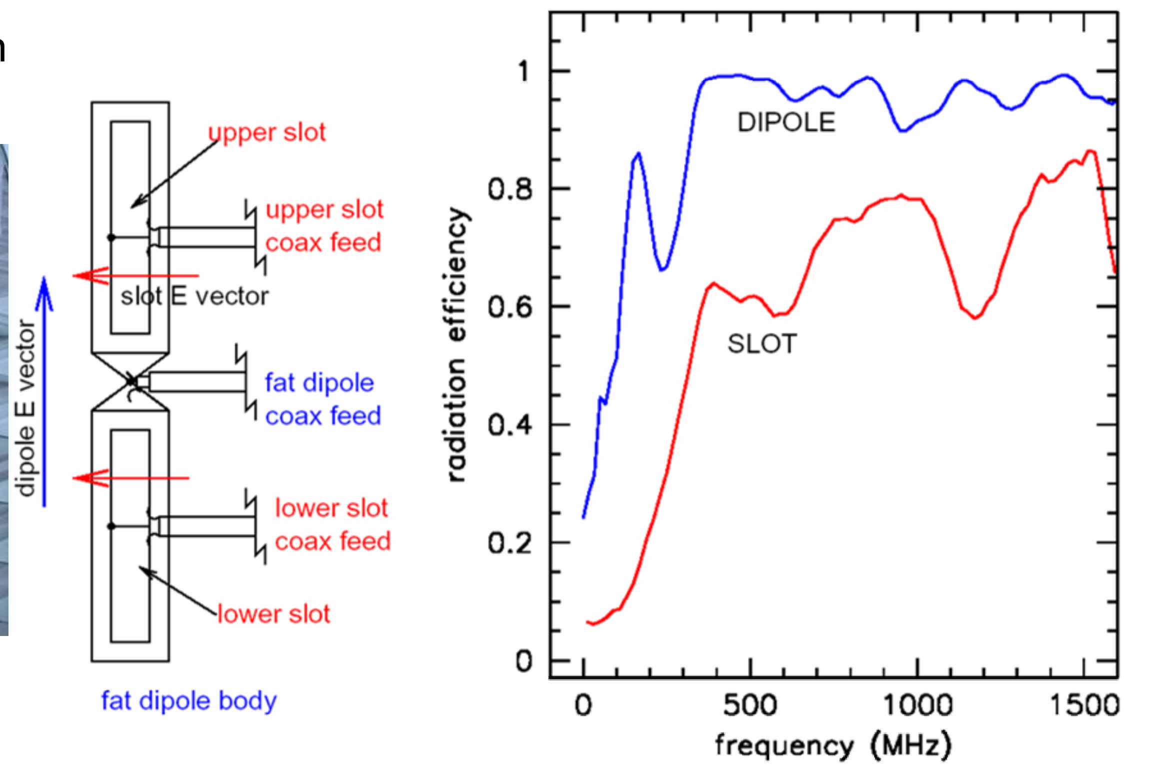
90% CL with 2.3 events per decade of energy over 1 year



Phase C:
Architecture and Antennas

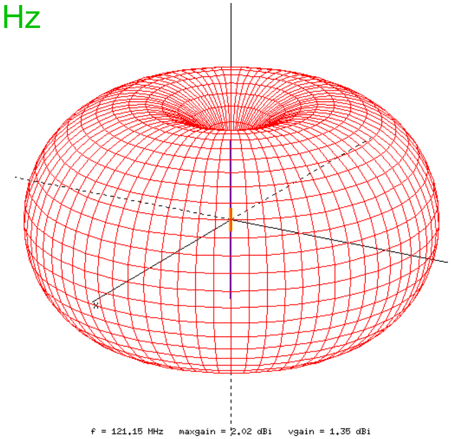
- Several architectures under consideration:
  - Generally build up out of nodes (clusters ~12) dipole antennas
  - Separate nodes by ~ 1 attenuation length
  - Want both polarizations
    - but in narrow hole: con



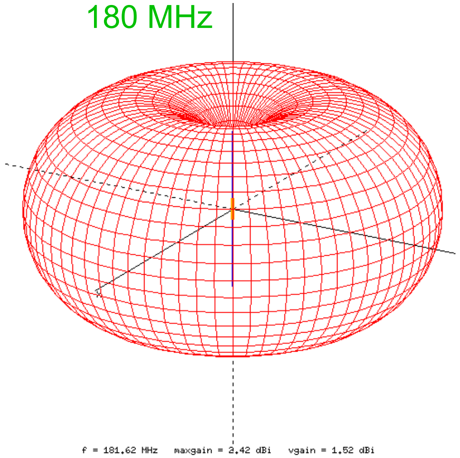


Dipole patterns in Salt (NEC2)

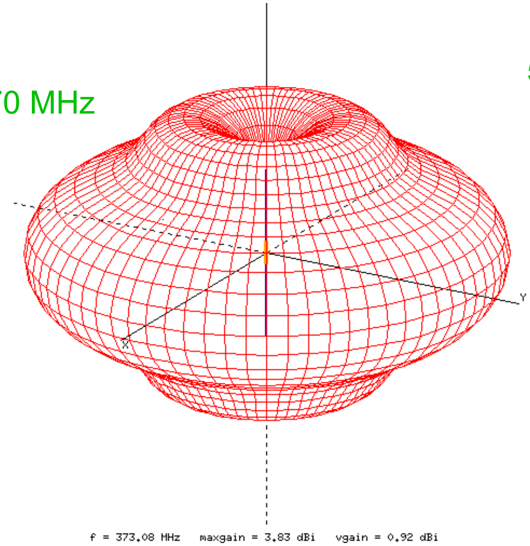
120 MHz



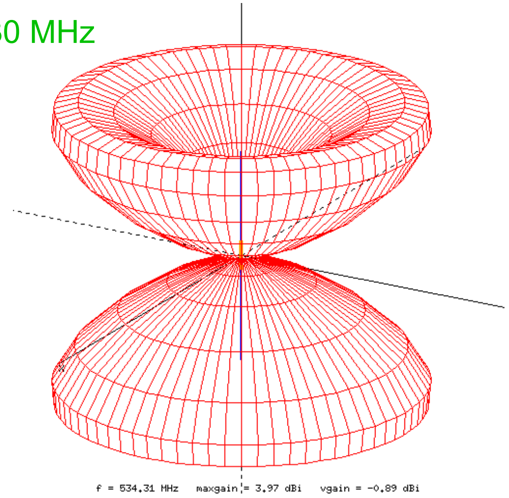
180 MHz



370 MHz



530 MHz



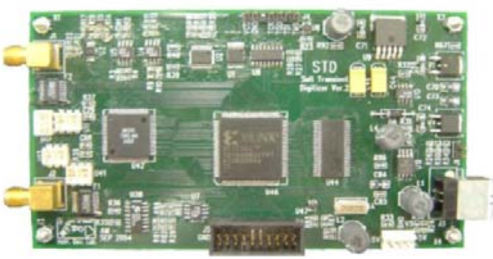
Gives 50Ω at feedpoint

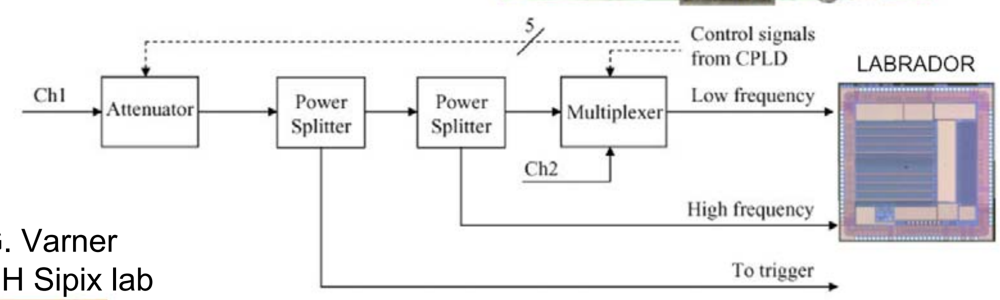
Architecture & DAQ

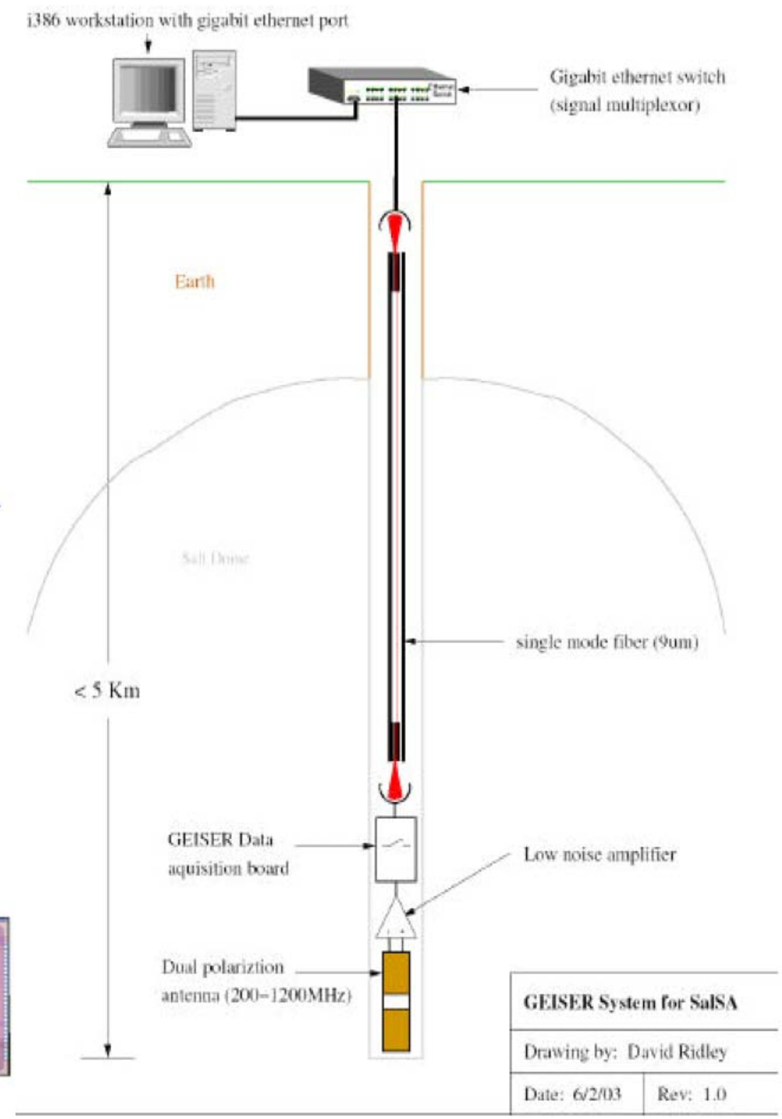
- Several architectures under consideration:
  - Generally build up out of nodes (clusters ~12) dipole antennas.
  - Some examples:
    - amplify & digitize near antenna upon local trigger. Push up bits. Higher level trigger at surface
    - Push up analog over fiber using commercial links

Salt Transient Digitizer (STD)

- 2 Channels
- Changing the voltage level in software changes the attenuation on board



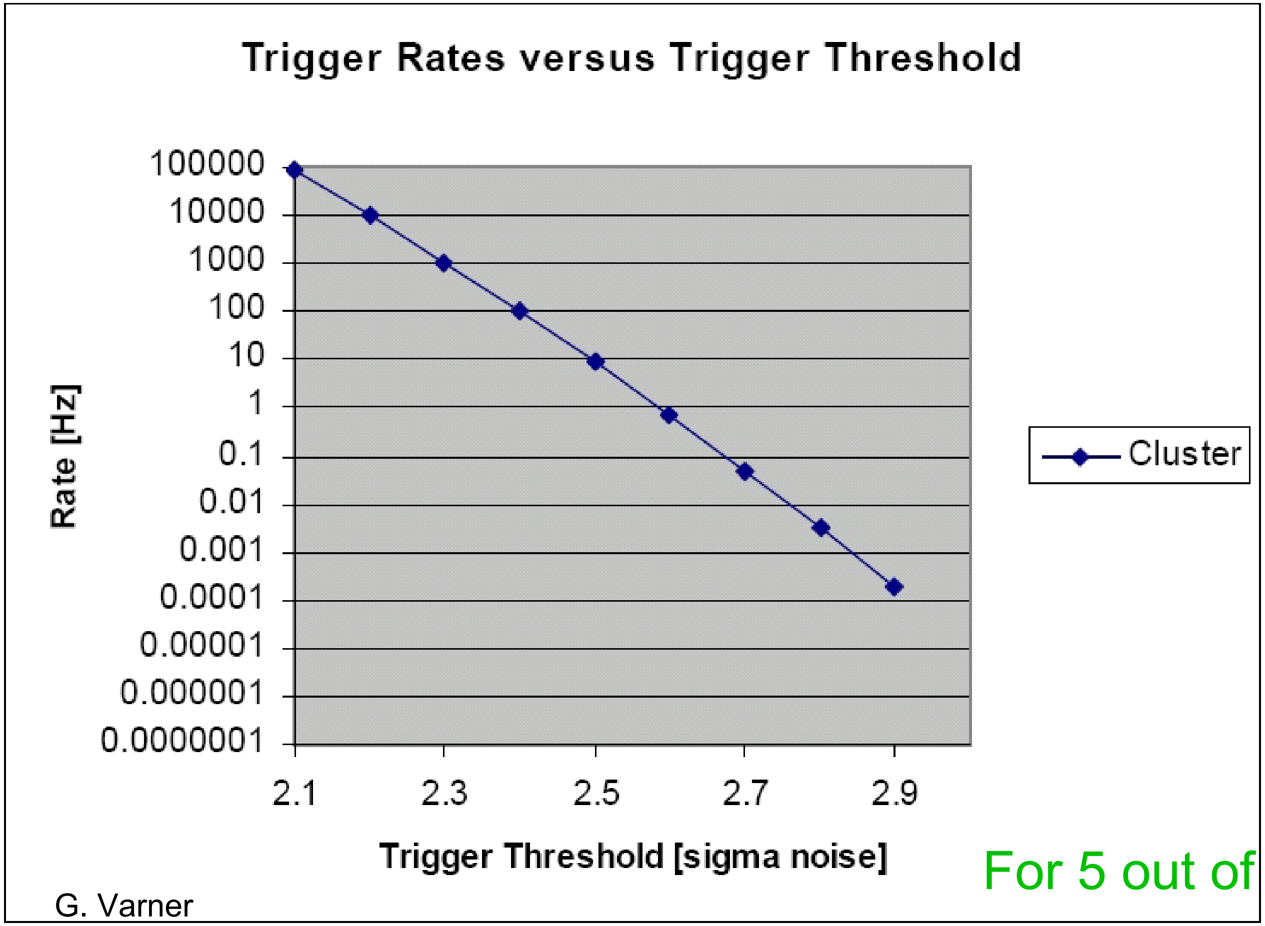




G. Varner
UH Sipix lab

Trigger

- Local trigger for pushing data to surface:

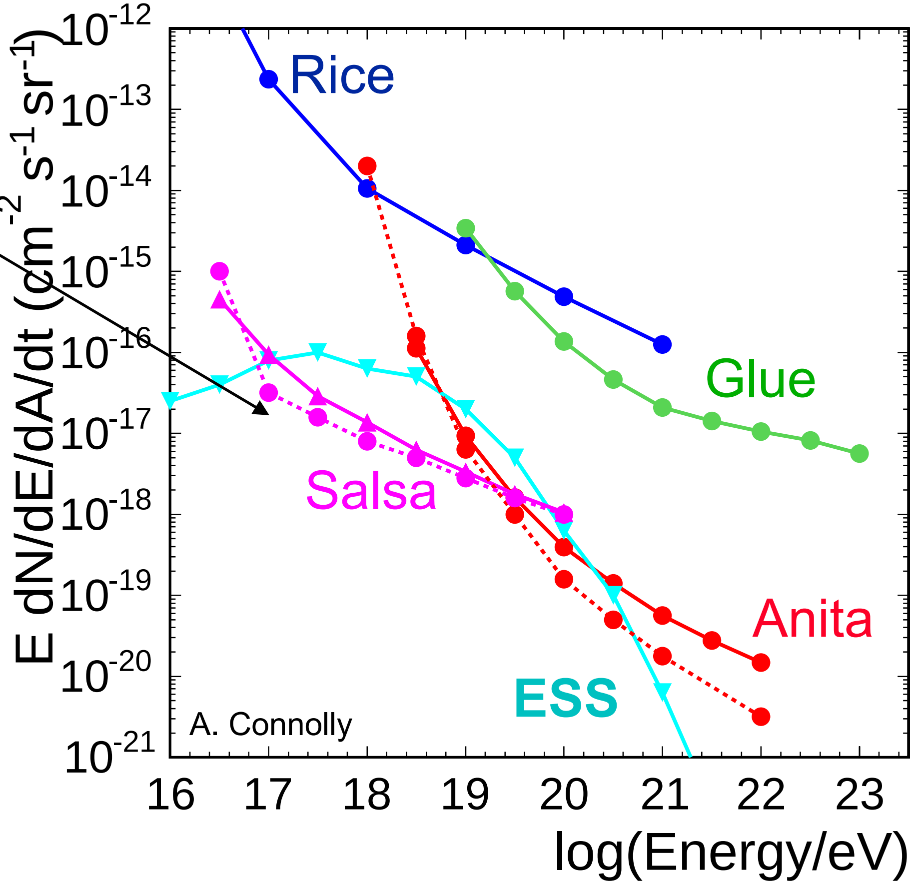


For 5 out of 8

Phase C : SALSA-100 (Sensitivity)

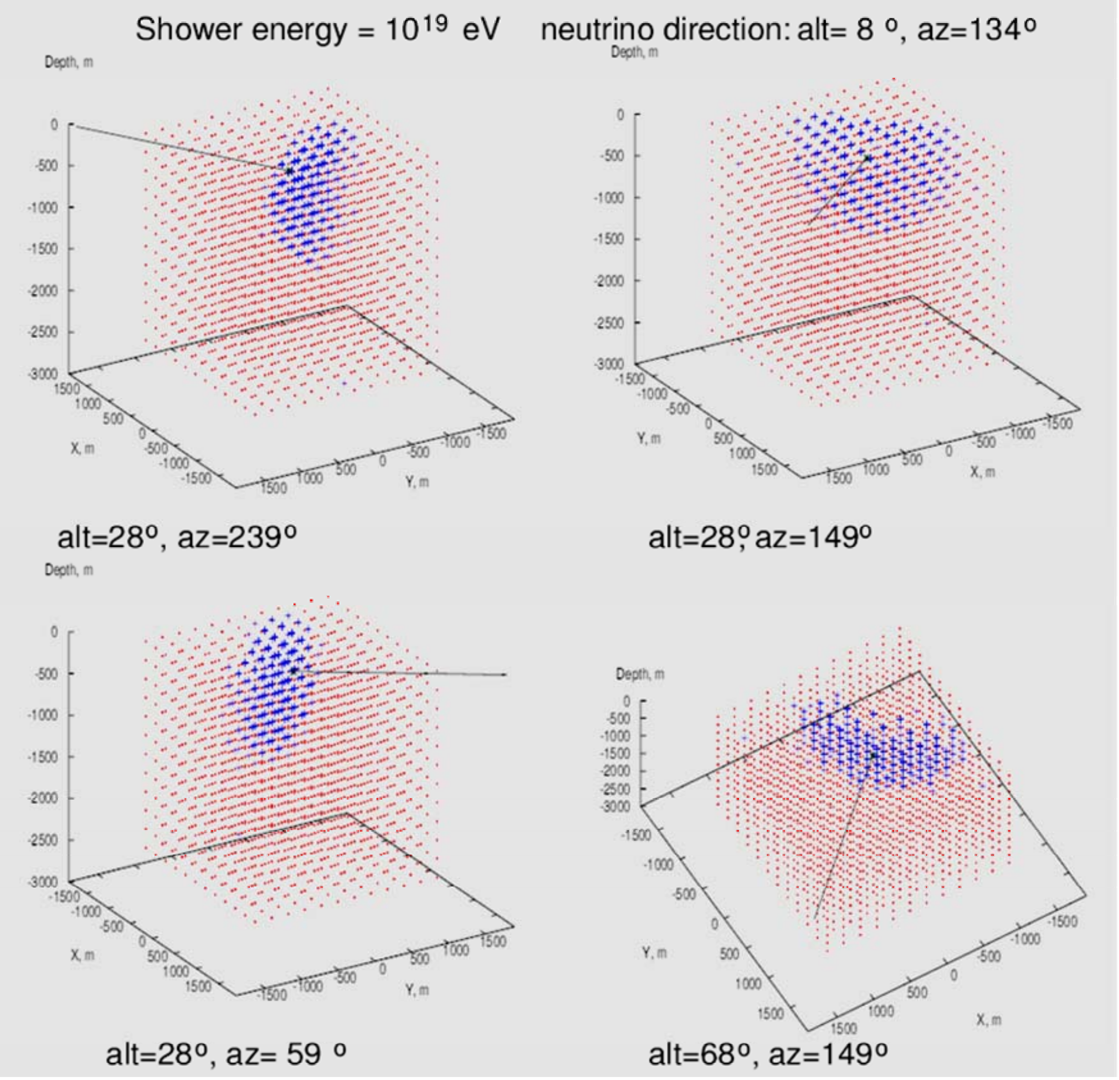
- solid points:
  ∼10x10 "straw" arrays
  2 independent MCs
- (caveat: not exactly same thing plotted here within factor of two, but agree within ~20% on event rates).
- 20-90 GZK events per year
- "Conservative" parameters for "straw" study.
  - 250m atten. length
  - 100-300 MHz
  - Secondary interactions not included yet

ν flux vs.
~1/(aperture*1year)



Phase C:
Event Displays

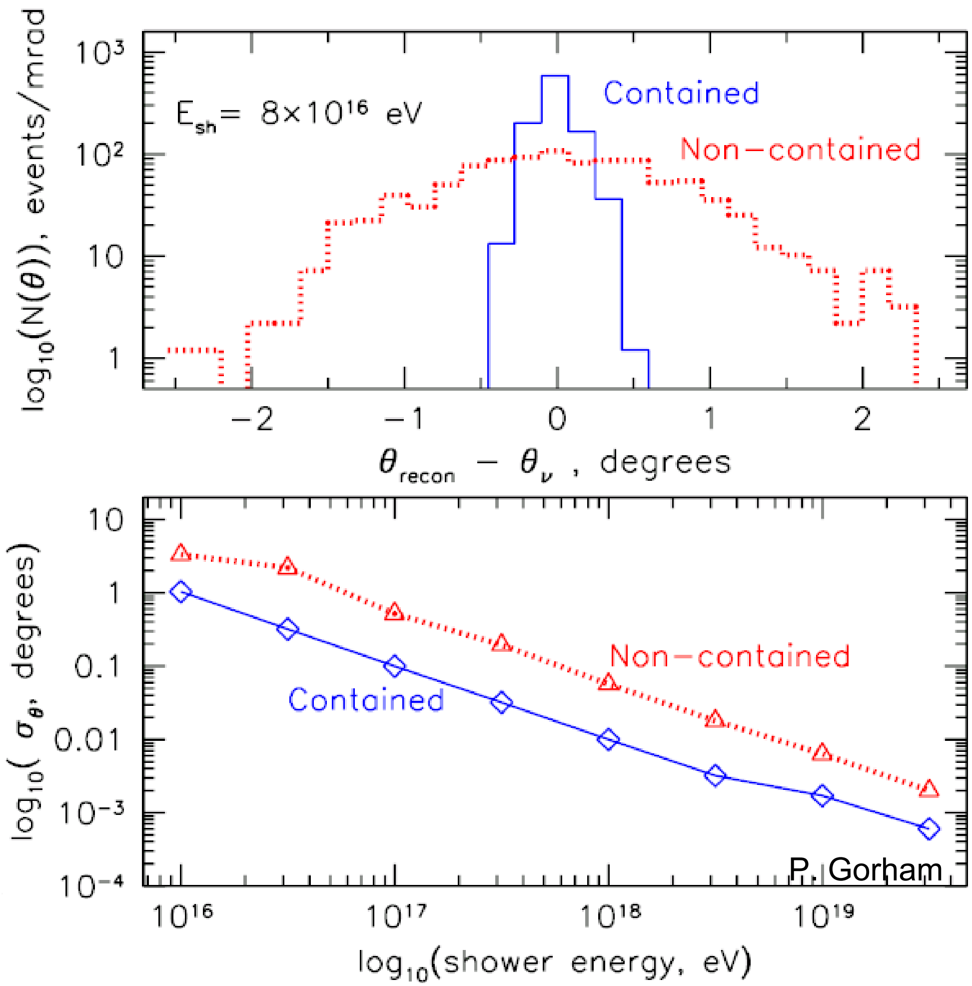
- Goal is to measure events well. This has to be more than just a counting experiment.
  - Flavor ID
  - CC vs. NC
  - Energy
  - Direction
- Need many hits per event.



P. Gorham

Phase C:
SALSA-100 Angular Resolution

- ~10 arcminute angular resolution for contained events
- ~ 1 degree for non-contained
- Improves for higher energy

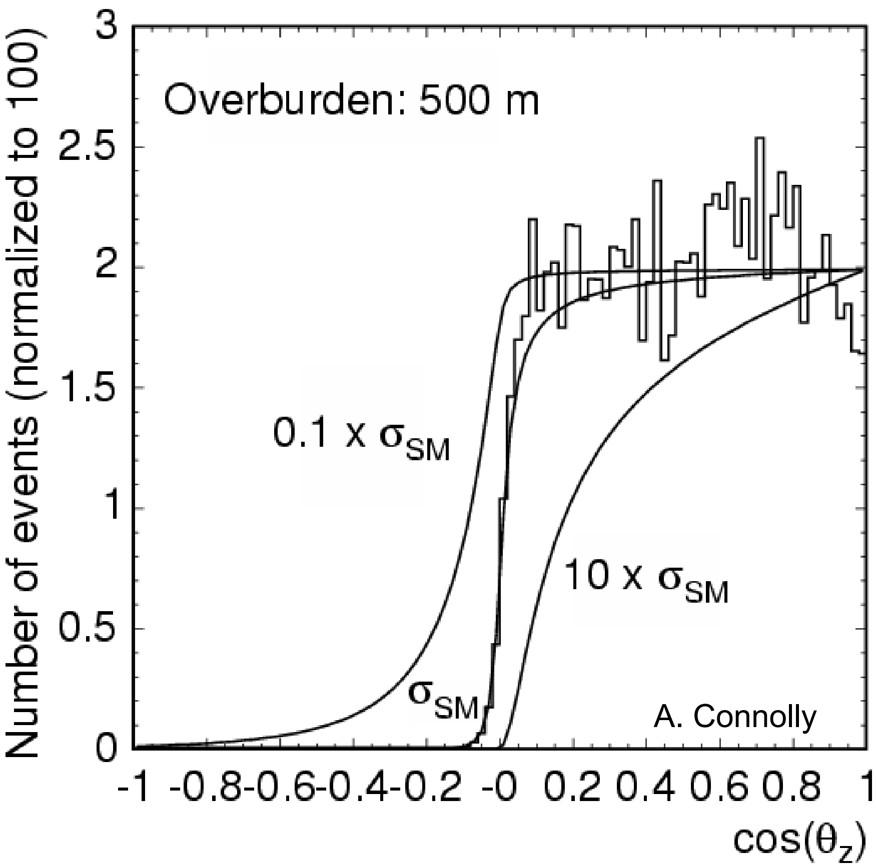


SALSA-100
Flavor and CC/NC ID

- See next talk by Ped Miocinovic
  - General idea: Secondary interaction or decay of charged lepton will produce a secondary vertex. SALSA can separate vertices more than a tens of meters apart.
  - Flavor ID is critical for neutrino decay scenarios
  - Can check NC/CC for consistency

SALSA-100
measuring ν cross section

- Measurement easily achievable using Earth as a filter near horizon
- Angular resolution even for non-contained events is sufficient.
- 30% measurement of SM cross section with 100 events.
- Anomalously large cross section would be clearly visible.



Conclusions

- Need to be ready for the GZK discovery in about 5 years
- Next generation:
  - Science beyond the discovery
  - Need to measure events well, not just count
  - will require information we don't have yet about radio attenuation and propagation in ice & salt.
  - will require information we don't have yet about acoustic production, attenuation and propagation in ice & salt
- *In-situ* results from real boreholes required for full proposals
- *In-situ* results require serious drilling from the surface and instrumentation infrastructure
- GZK neutrinos from the 4-string Phase-B would help push the case
- For salt, SALSA collaboration forming. Phase-B proposal to U.S. DOE in the works.