“SalSA”

The Saltdome Shower Array:
A Teraton UHE Neutrino Detector

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UHE Neutrinos: A Quick Review

- GZK mechanism ($p^+ + \gamma \rightarrow \Delta + \pi$) **guarantees** UHE neutrinos (standard model).
  - $p^+ + \gamma \rightarrow \Delta + \pi \rightarrow \nu + \ldots$
  - In addition to interaction location, additional neutrinos likely produced at acceleration site.
- Neutrinos unattenuated from source and maintain pointing direction back to source.

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Detecting UHE Neutrinos: Moving from Detection to Physics

Why SalSA?

- <1 event per year per km^3 of water or ice…
- Statistics via a teraton scale target (~1000 km^3 sr).
- Exploit Askaryan effect as in ANITA.
- Utilize coherent radio Cherenkov emission from neutrino induced showers.
- Combination of polarization, signal amplitude and timing provide excellent pointing resolution.
- Large salt deposits provide shower medium.

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Physics of SalSA

- Astrophysics
  - Find source(s) of UHECRs.
  - Anisotropy of sources.
  - Other UHE neutrino producers.
- Particle physics – Cross section measurement.
  - Look for standard model deviations.
  - Measurement at ~10 times center of mass energy of LHC.
- Neutrino oscillations
  - Very long L/E for oscillation studies.
  - Flavor ID possible for contained events.

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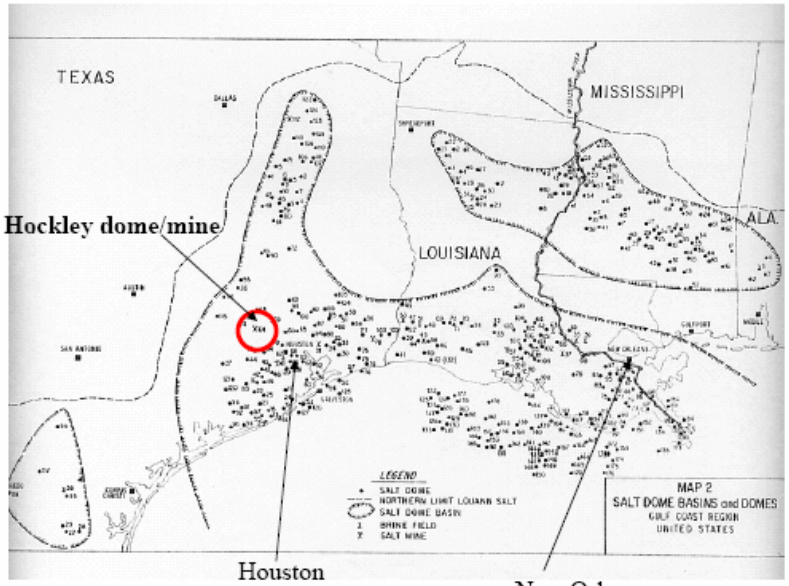
Saltdomes

- Saltdomes being investigated are (mostly) located along gulf coast.
  - Strong candidates:
    - Richdon (MS), Vacherie (LA), Keechie (TX)



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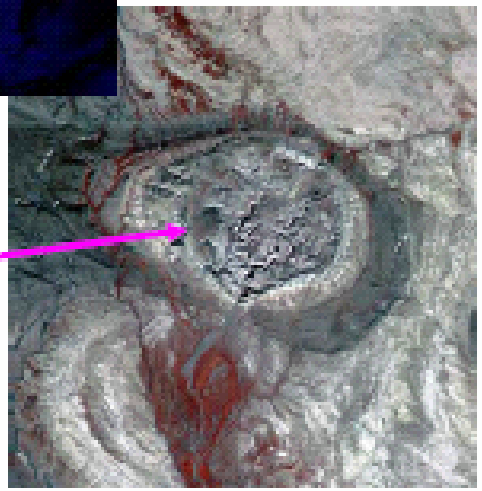
Salt domes: found throughout the world

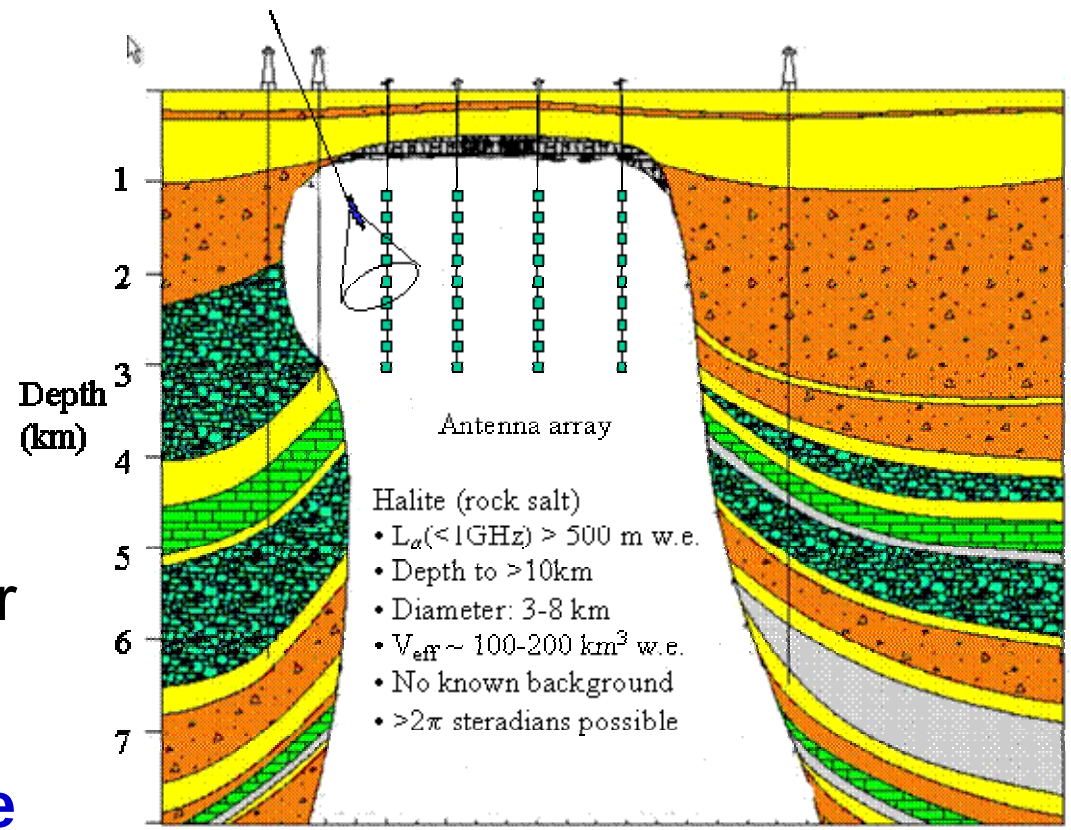
Qeshm Island, Hormuz strait, Iran, 7km diameter



Isacksen salt dome, Ellef Ringnes Island, Nunavut Territory, Canada 8x5 km

Saltdome Shower Array SalSA

- Deploy an array of antennas within a salt dome.
- Salt domes found everywhere in the world!
- As **radio clear as Antarctic ice** AND **2.4 times more dense**.
- typical: **50-100 km^3** water equivalent in top ~3km
- **300-500 km^3 sr possible**



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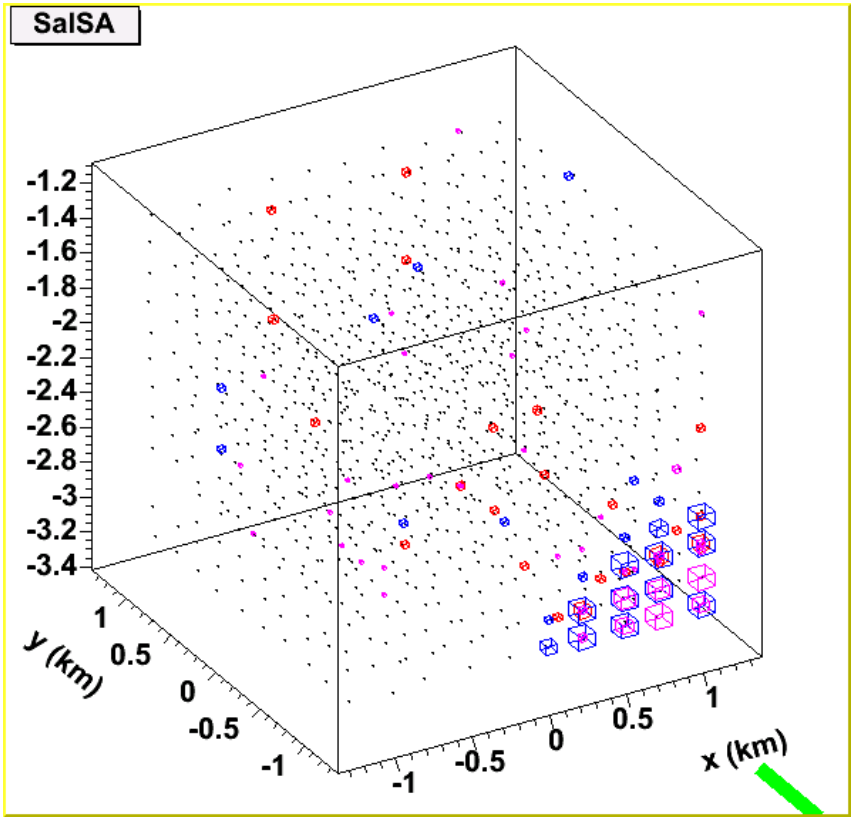
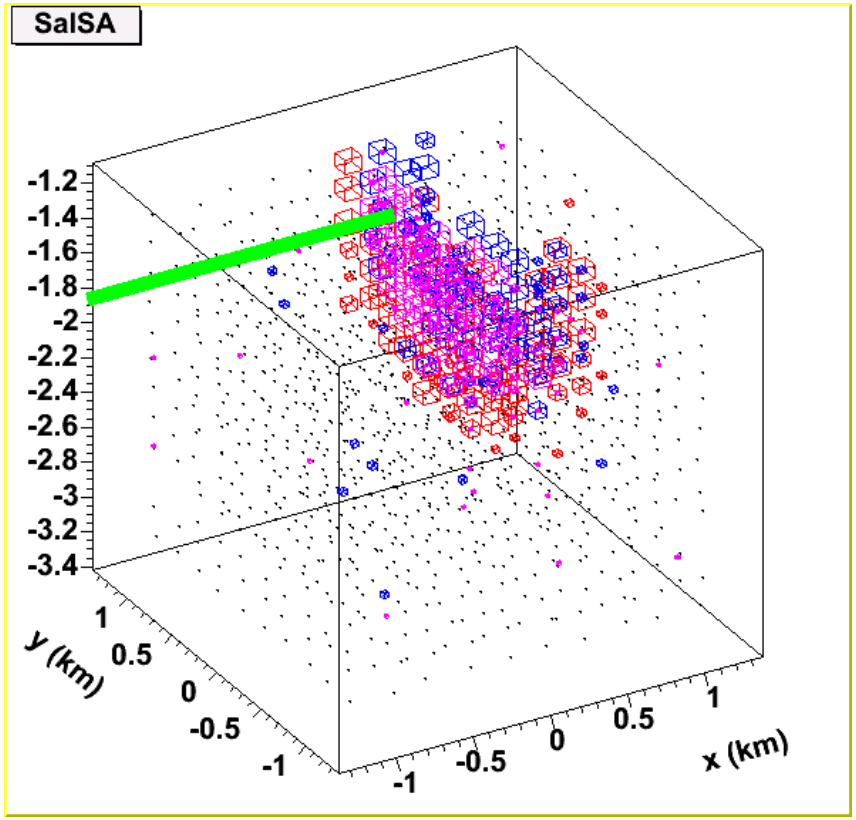
What will you see?

SalSA Events





$SalSA_{100}$ $E=10^{18.5}eV$

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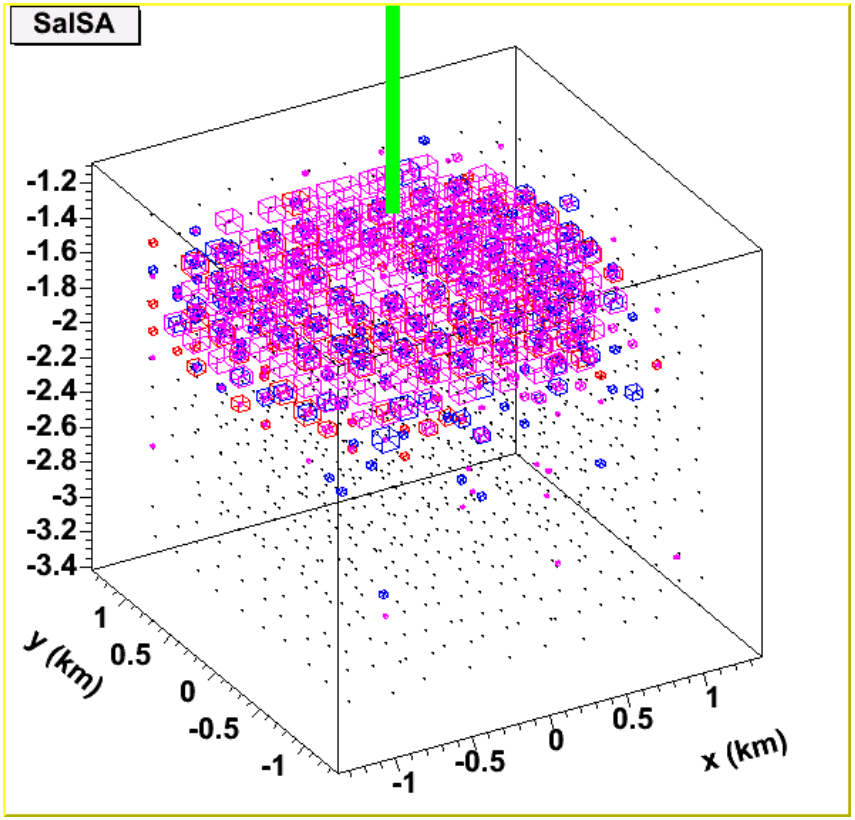
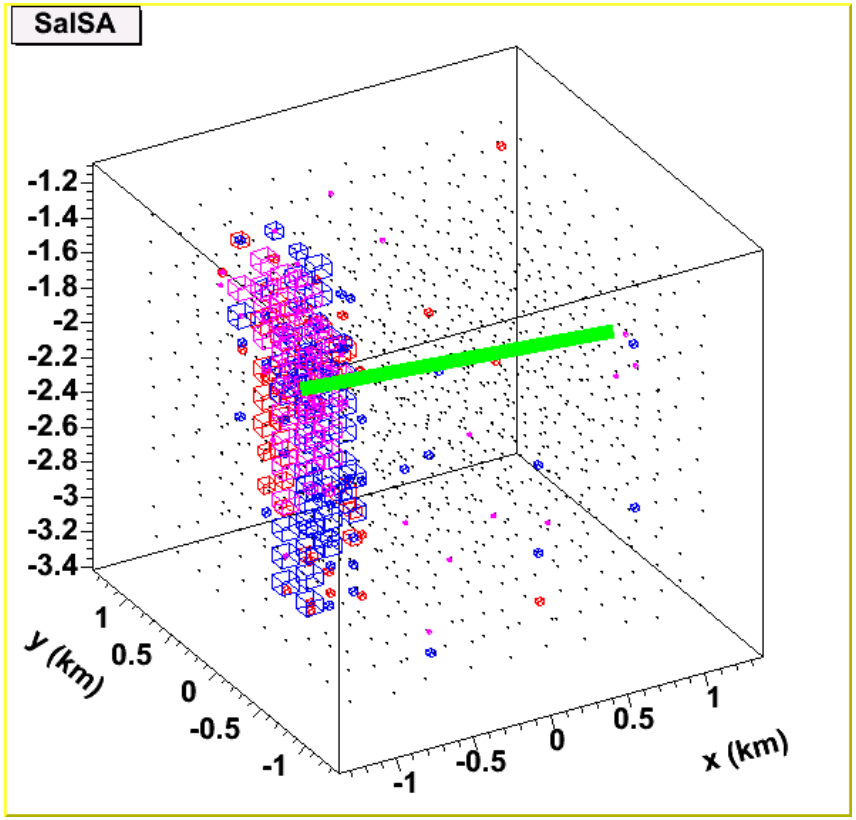
SalSA Events





$SalSA_{100}$ $E=10^{18.5}eV$

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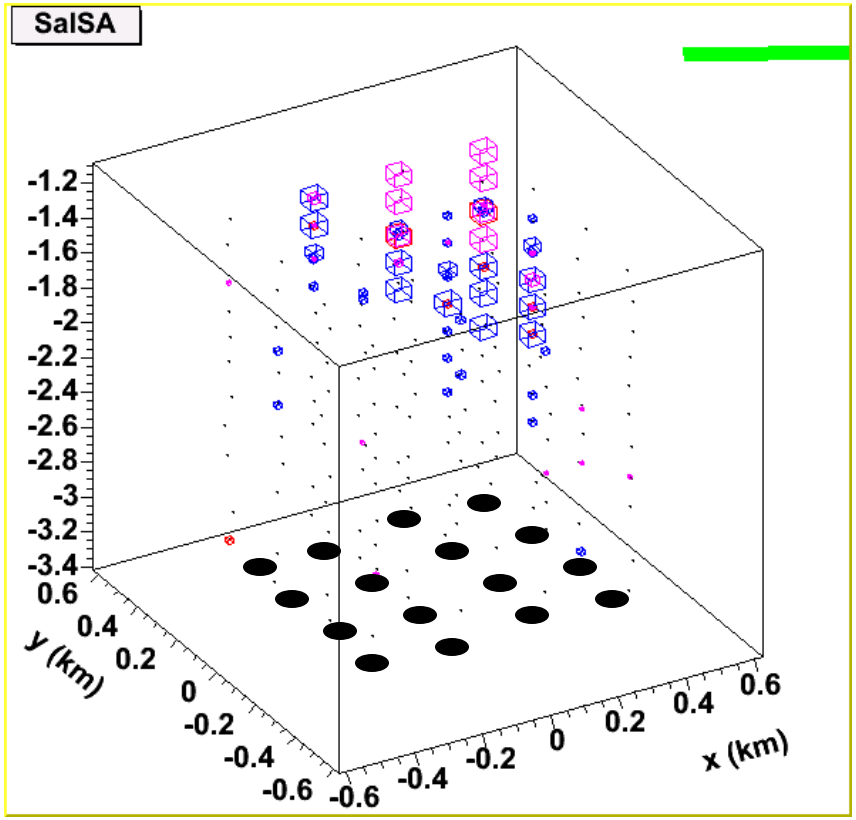
SalSA Configurations

- **$SalSA_{100}$ (10x10 grid)**
  - **Statistics AND Event Containment**
- **$SalSA_{16}$ (4x4 grid)**
- **$SalSA_{4}$ (2x2 grid) -** Prototype
- Antenna strings 2 km depth.
  - 250 m inter-string spacing.
  - 12 antenna nodes per string.
  - 12 antennas per node.
- Triggers:
  - 5 antennas trigger node
  - 5 nodes trigger detector.
- Vertical and horizontal polarizations to provide pointing accuracy.



$SalSA_{16}$ $E=10^{18.5}eV$

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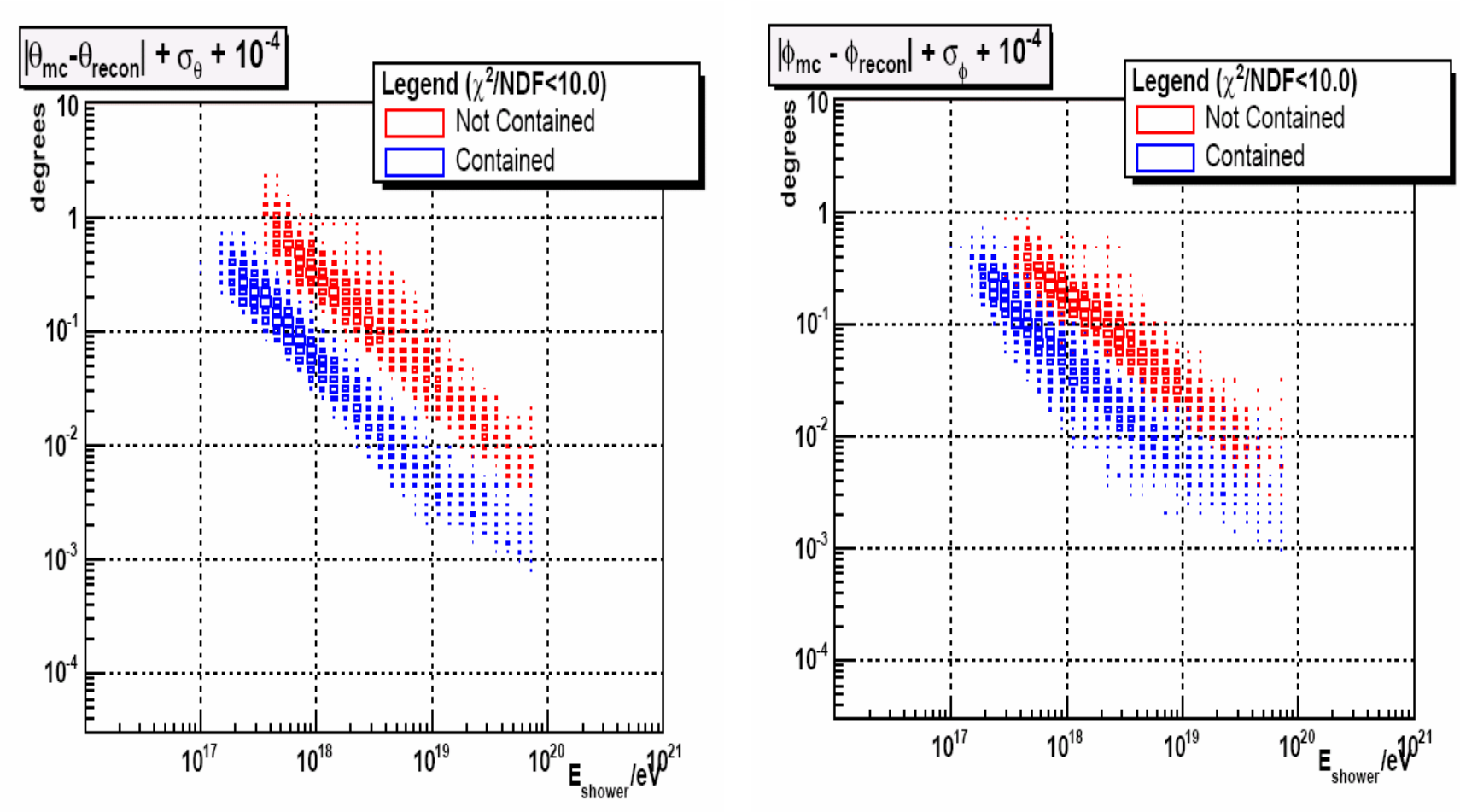
SalSA Detector Resolution



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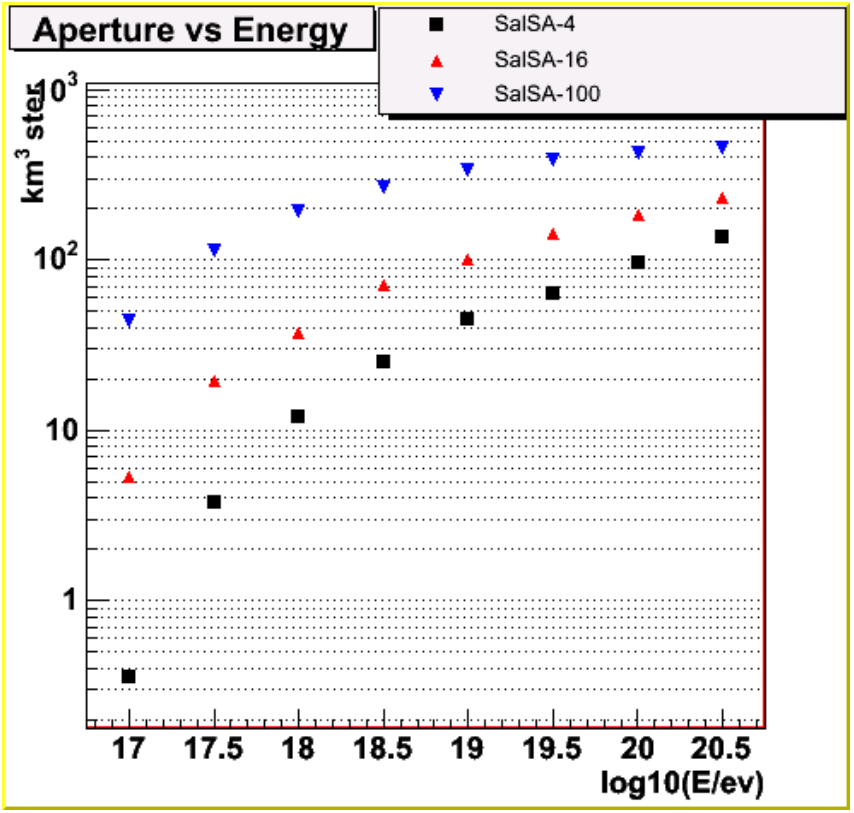
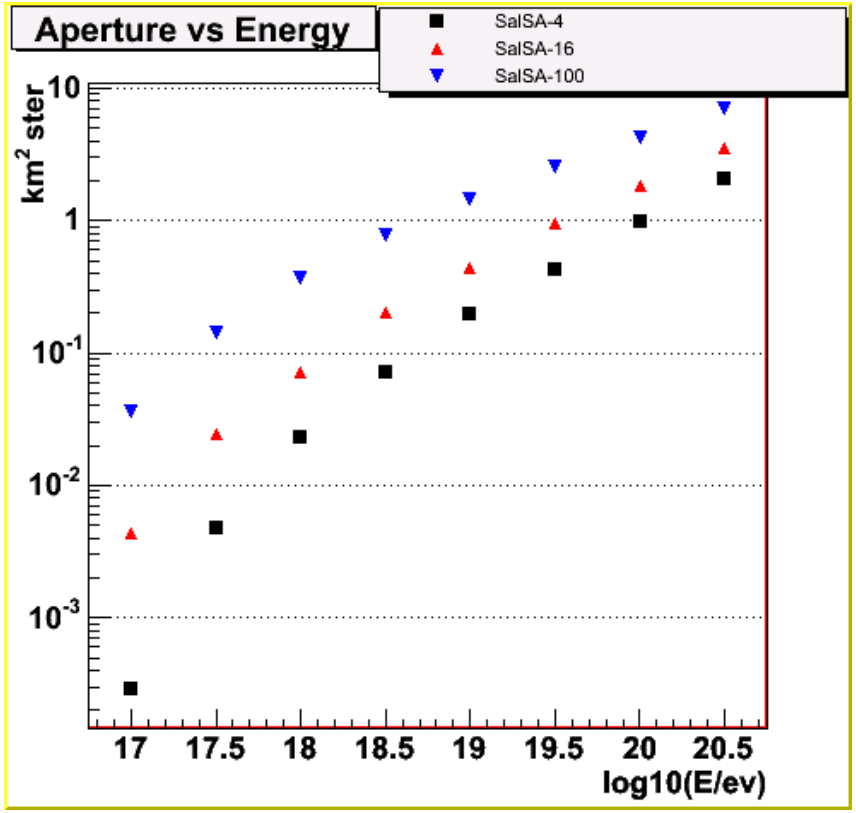
Sub-degree pointing resolution due to polarization!

SalSA Aperture

~500 km^3 sr at highest energies.





Effective area. (km^3 sr/$L_{interaction}$)

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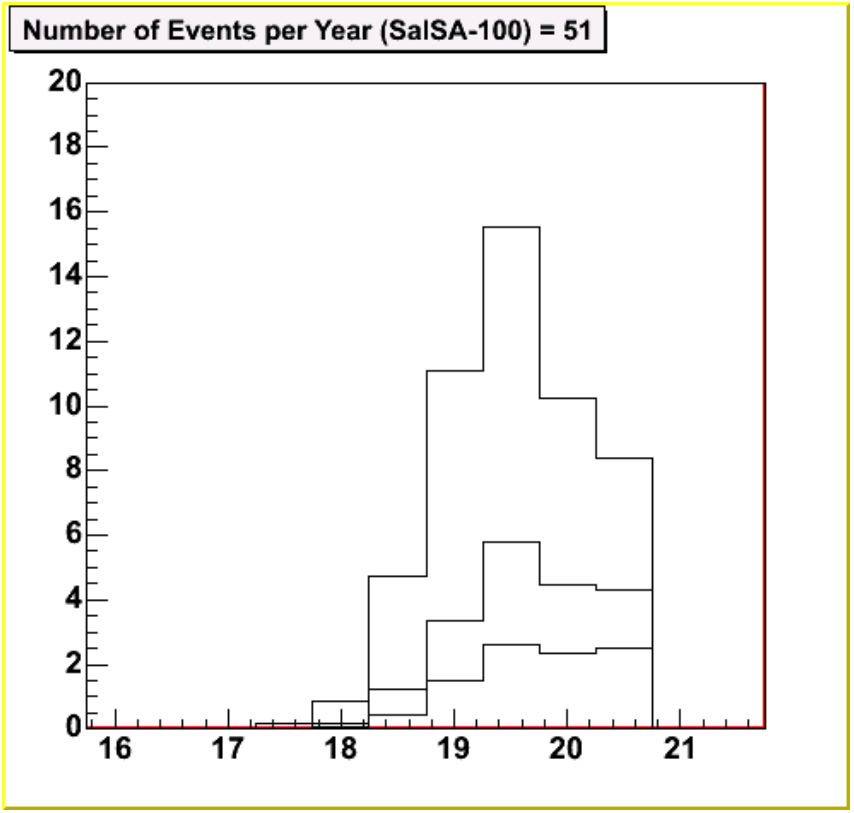
SalSA Event Rate



- $SalSA_{100}$
  - nominal GZK neutrino flux
  - 51 events/year.
- $SalSA_{16}$
  - 19 events/year.
- $SalSA_{4}$
  - 10 events/year.
- Larger volumes allow for higher percent of "contained" events which provide flavor ID.

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Current Efforts

1) **Measure radio attenuation length over large distances at Hockley salt mine.**

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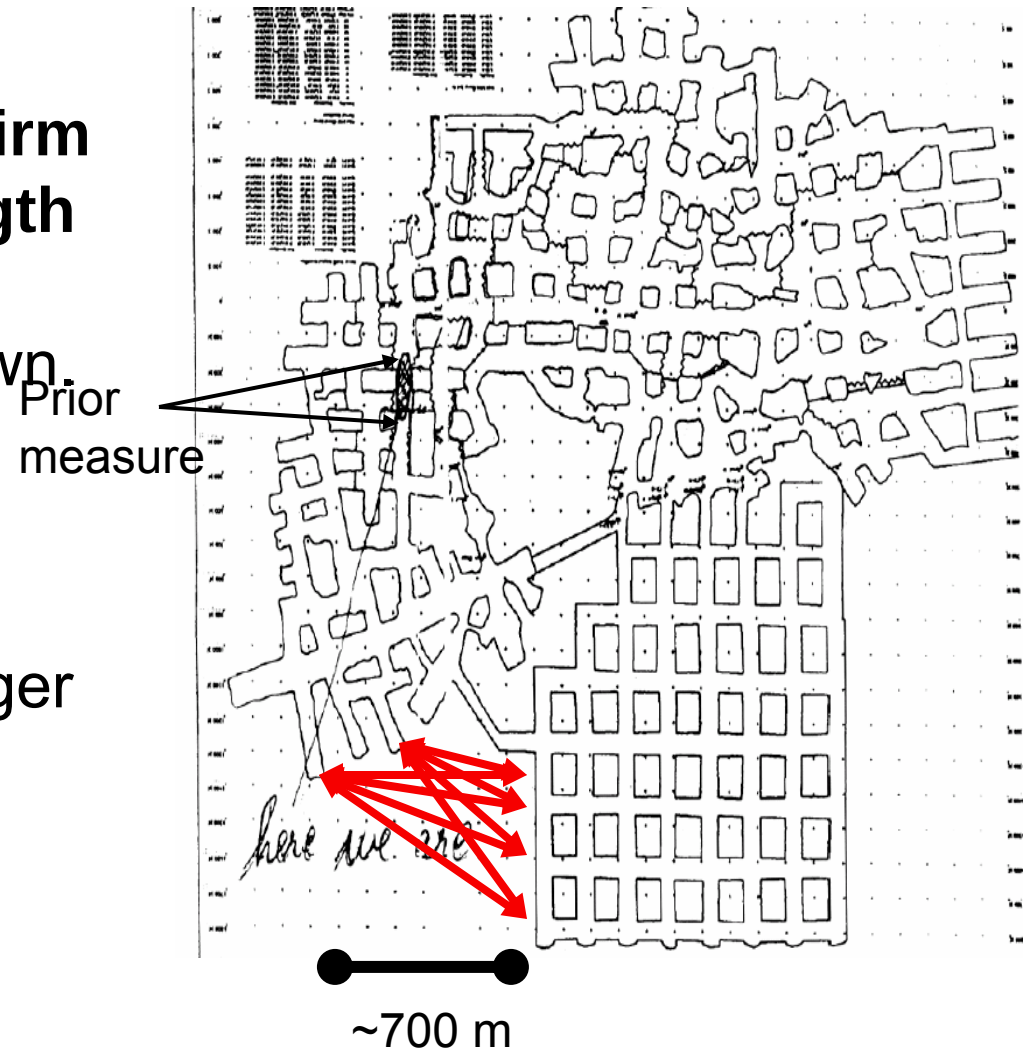
Attenuation Length Measurements

- **Previous measurements confirm that attenuation length is long** (>200 m) but actual length not known.
- We plan to **return to Hockley mine** and measure attenuation length over much longer distances.



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Current Efforts

1) Measure radio attenuation length over large distances at Hockley salt mine.
2) **Further develop SalSA Monte Carlo and reconstruction routines.**
   - Species identification via multi vertex interactions (ν_μ,ν_τ).
   - More realistic saltdome geometry, etc.
   - Improve reconstruction algorithms.
   - Optimize detector for highest physics yield.

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Current Efforts

1) Measure radio attenuation length over large distances at Hockley salt mine.
2) Further develop SalSA Monte Carlo and reconstruction routines.
3) **Ongoing R&D on antenna design and detector electronics.**
4) **Seeking support for prototype array ($SalSA_4$).**

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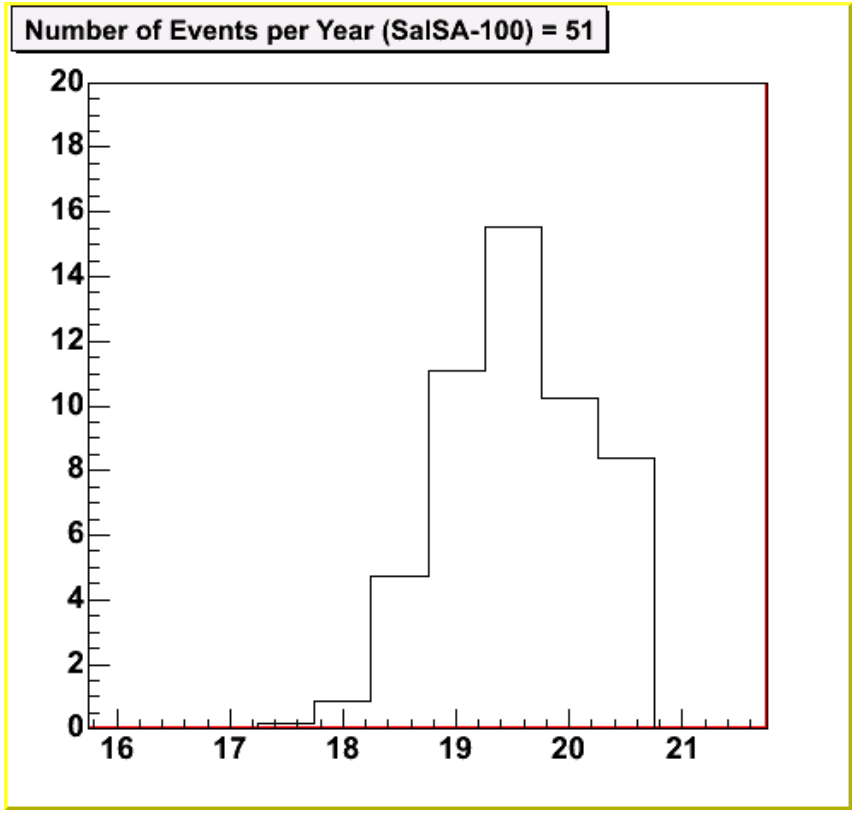
Summary: SalSA Physics

1) **SalSA offers "high" statistics measurements of UHE neutrinos.**



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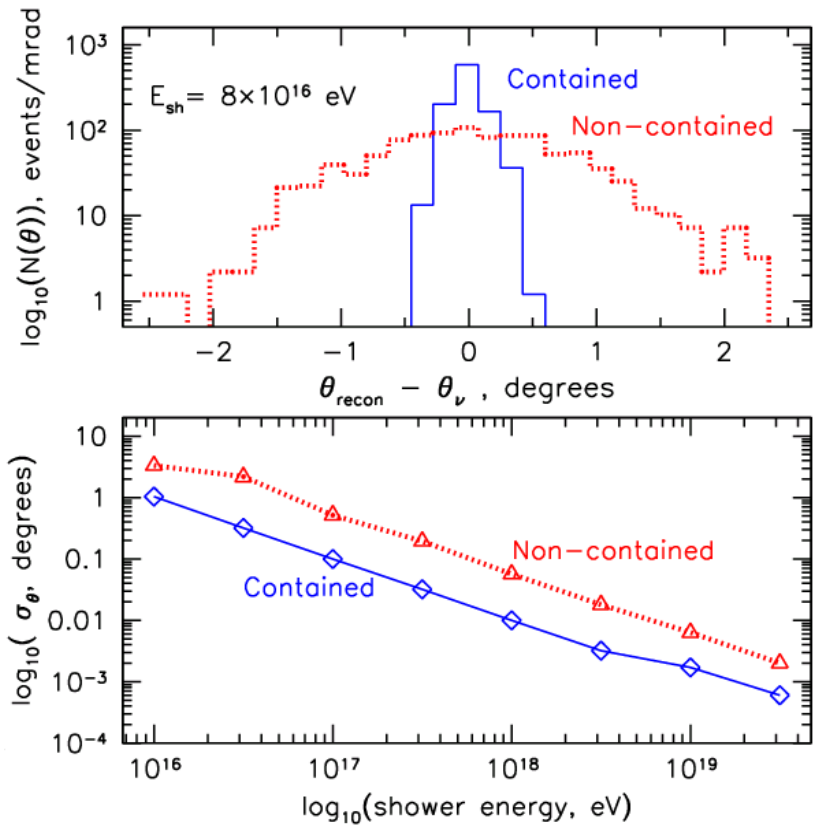
Summary: SalSA Physics

1) SalSA offers "high" statistics measurements of UHE neutrinos.
2) **Excellent angular resolution provides pointing direction to UHE neutrino source(s).**



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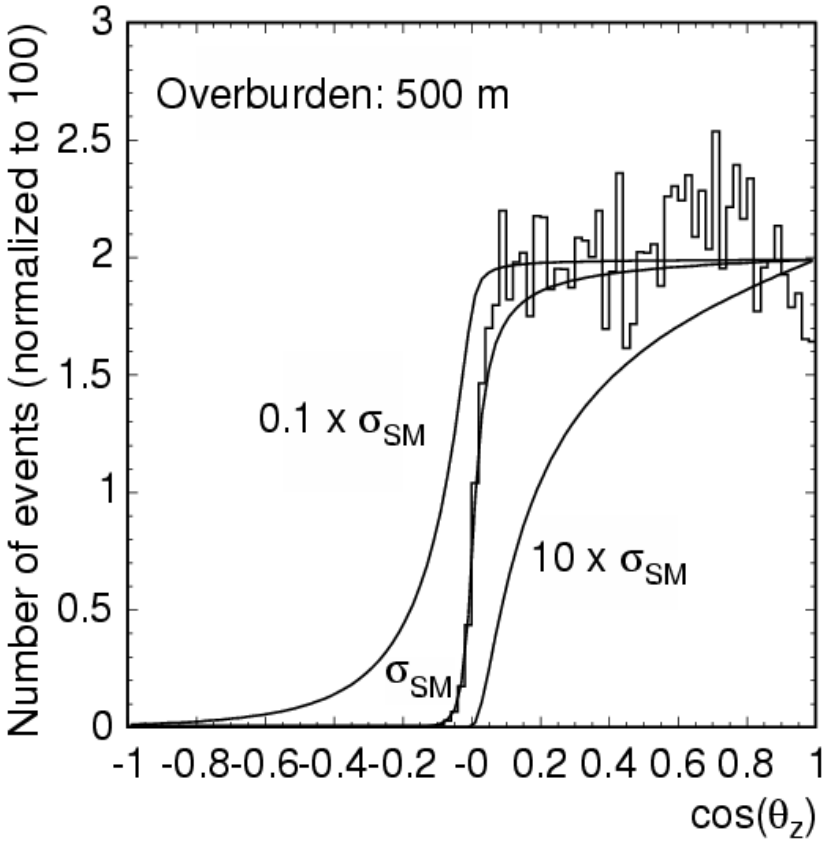
Summary: SalSA Physics

1) SalSA offers “high” statistics measurements of UHE neutrinos.
2) Excellent angular resolution provides pointing direction to UHE neutrino source(s).
3) **Measurement of neutrino cross sections.**



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Conclusion

1) SalSA offers “high” statistics measurements of UHE neutrinos.
2) Excellent angular resolution provides pointing direction to UHE neutrino source(s).
3) Measurement of neutrino cross sections.
4) **Extremely long L/E neutrino oscillation measurement with flavor ID.**
5) **New physics?**

- SalSA is the premiere UHE neutrino observatory!

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Extra's

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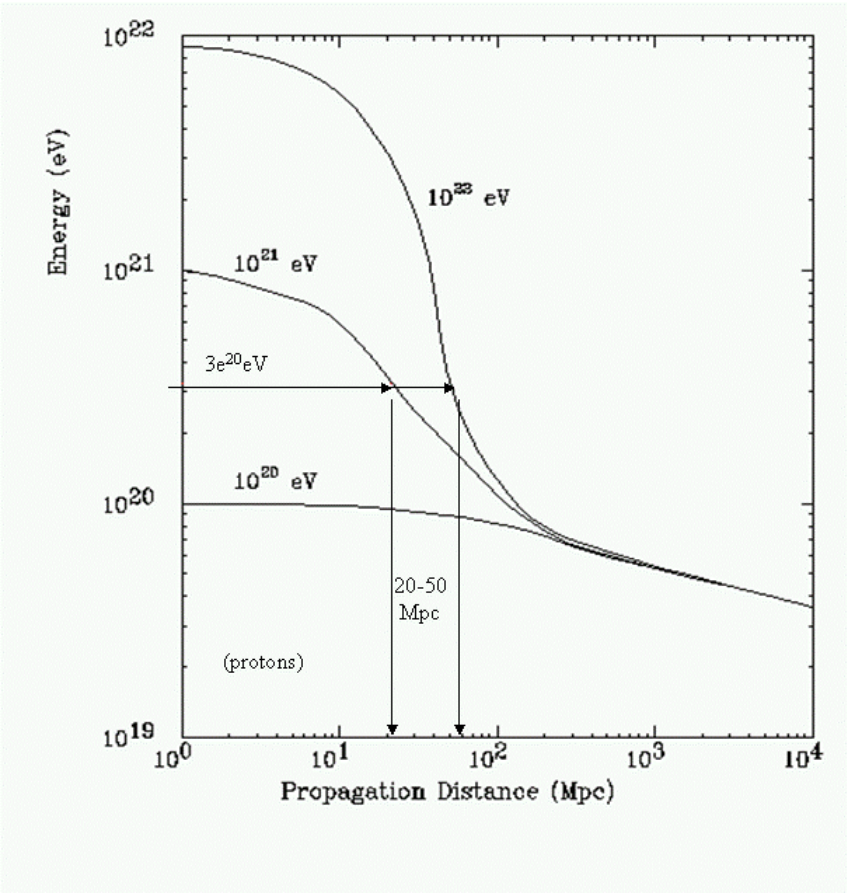
GZK Cutoff



- Cosmic Ray (p^+) with energy > ~ 5×10^{19} eV interact with CMB photons via the Δ resonance.
- $p^+ + \gamma \rightarrow \Delta + \pi$
- Within ~100 Mpc energy reduced to GZK limit.
- Super GZK events seen but no (required) local source identified.

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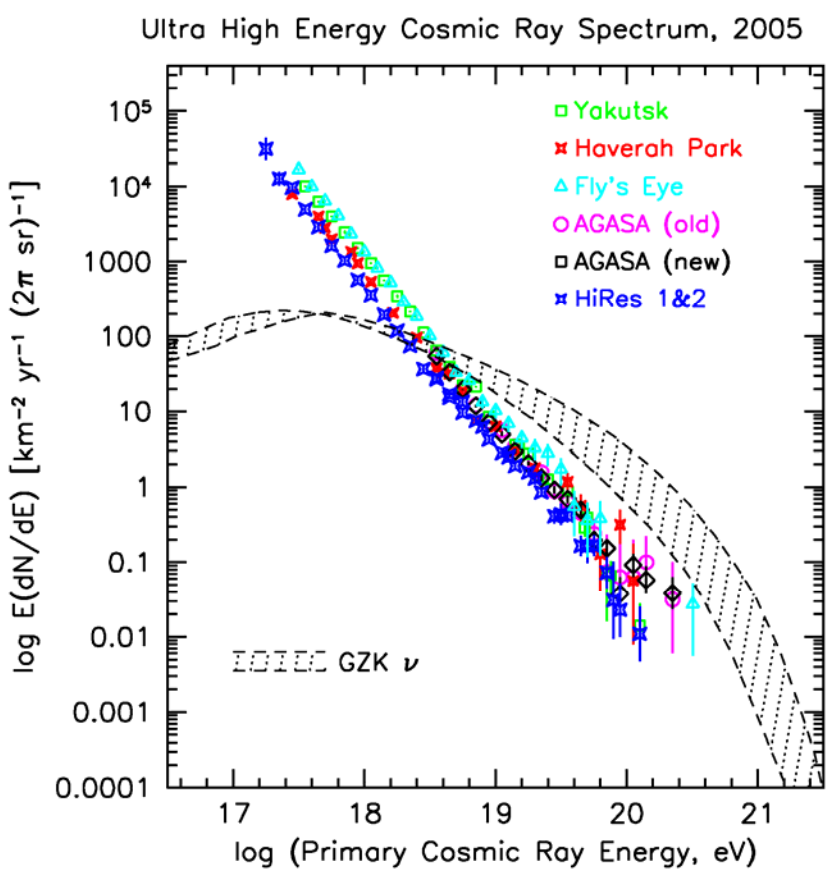
UHE Neutrinos



- GZK mechanism **requires** (standard model) neutrinos in range of 10^{17}-10^{19} eV.
- $p^+ + \gamma \rightarrow \Delta + \pi \rightarrow$ neutrino
- Additional neutrinos produced at UHECR acceleration site.

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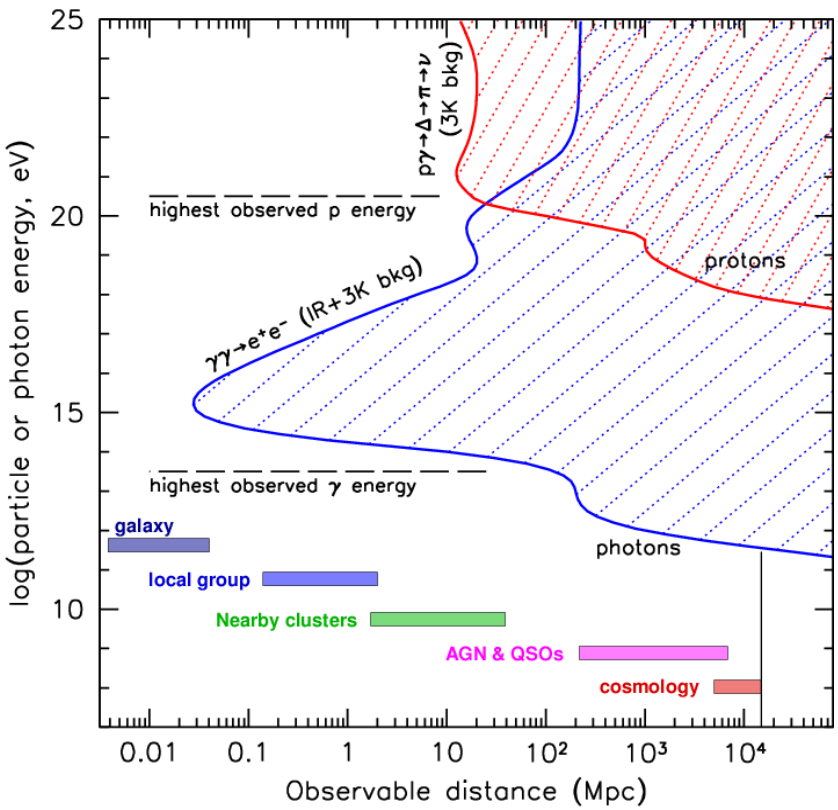
UHE Neutrinos



- Source of cosmic rays (in UHE range) is unknown.
- At highest energies **only neutrinos** can arrive from beyond the local supercluster.
- Provide **pointing back to source** of super GZK proton accelerators.

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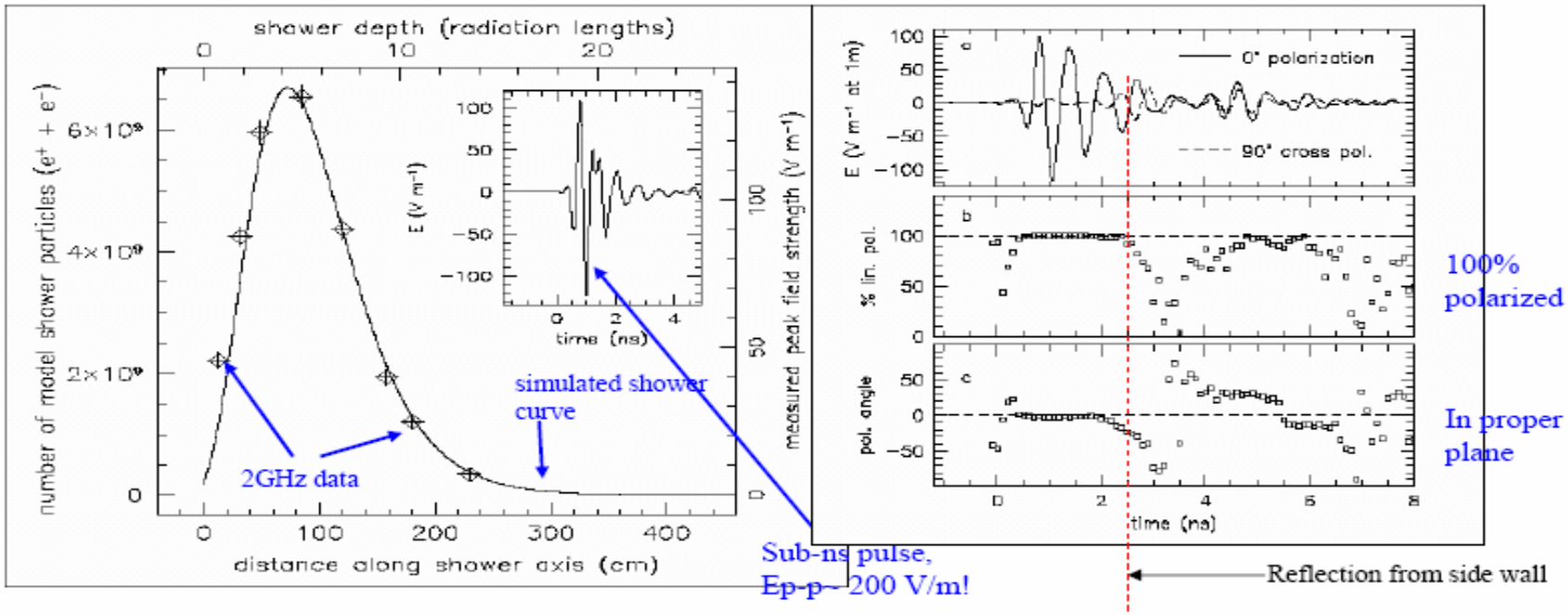
Exploit the Askaryan Effect



- Test beam T444 at SLAC confirms Askaryan effect.
- Measured radio emission from photon induced shower in silica sand.

NIM A490 (2002) 476
astro-ph/0412128

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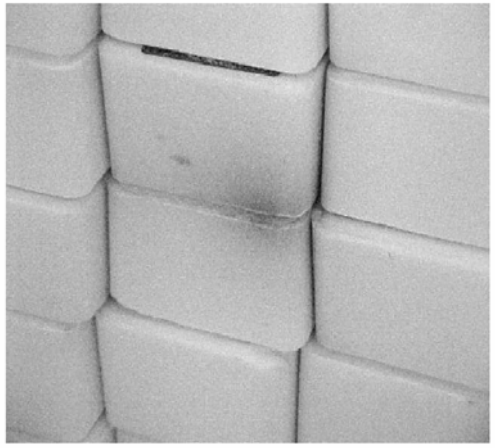
T-460



Measure polarization of radio Cherenkov using tons of salt.

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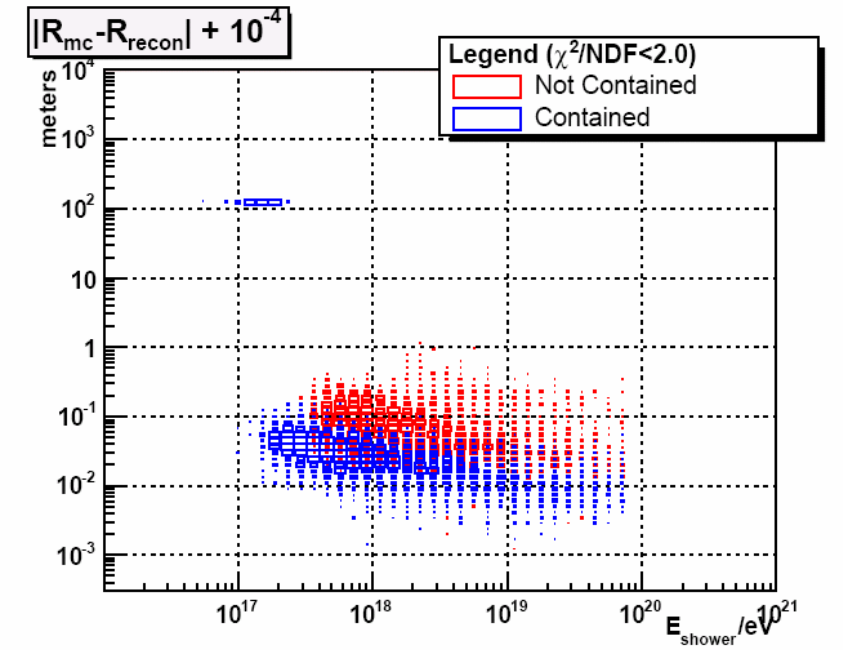
T460 test beam used to measure polarization of radio Cherenkov.

SalSA Resolution



- 0.1 μsec timing allows vertex reconstruction at sub-meter levels.
- Excellent shower vertex provides starting point for angular resolution.

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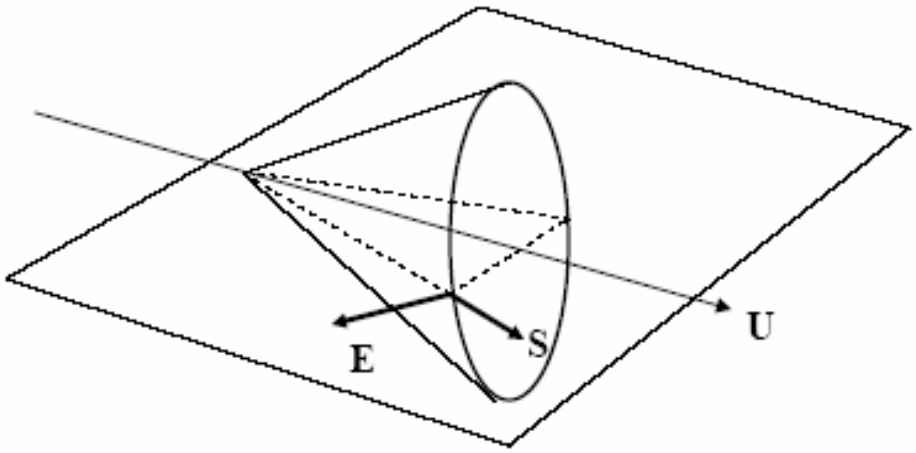
Cherenkov polarization tracking



Cherenkov radiation predictions:

- 100% linearly polarized
- plane of polarization aligned with plane containing Poynting vector **S** and particle/cascade velocity **U**

- Radio Cherenkov: polarization measurements are straightforward
- Two antennas at different parts of cone:
  - Will measure different projected plane of E, S
  - Intersection of these planes defines shower track

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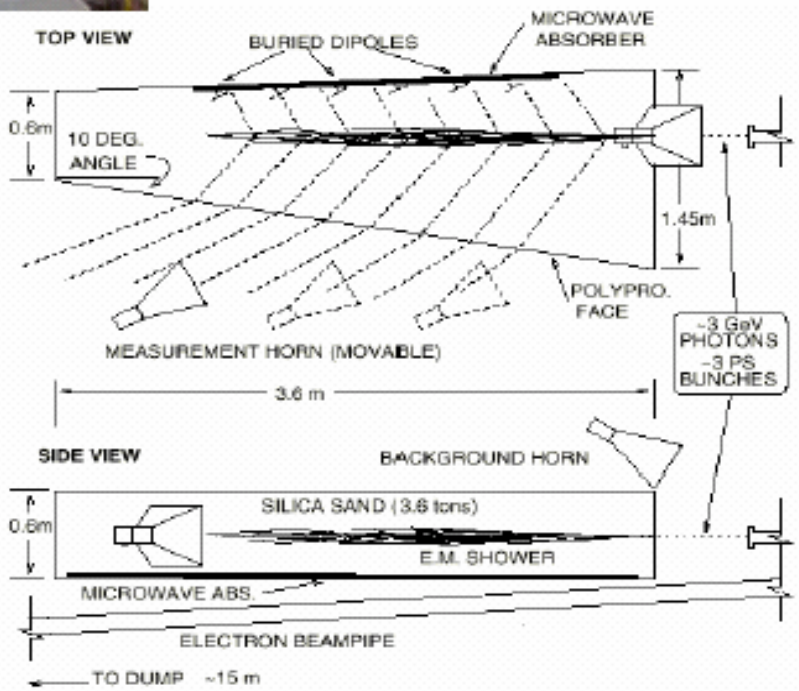
Askaryan Confirmation: SLAC T444 (2000)



From Saltzberg, Gorham, Walz et al PRL 2001

- Use 3.6 tons of silica sand, brem photons to avoid any charge entering target
  ==> no transition radiation
- Monitor all backgrounds carefully
  - but signals were much stronger!

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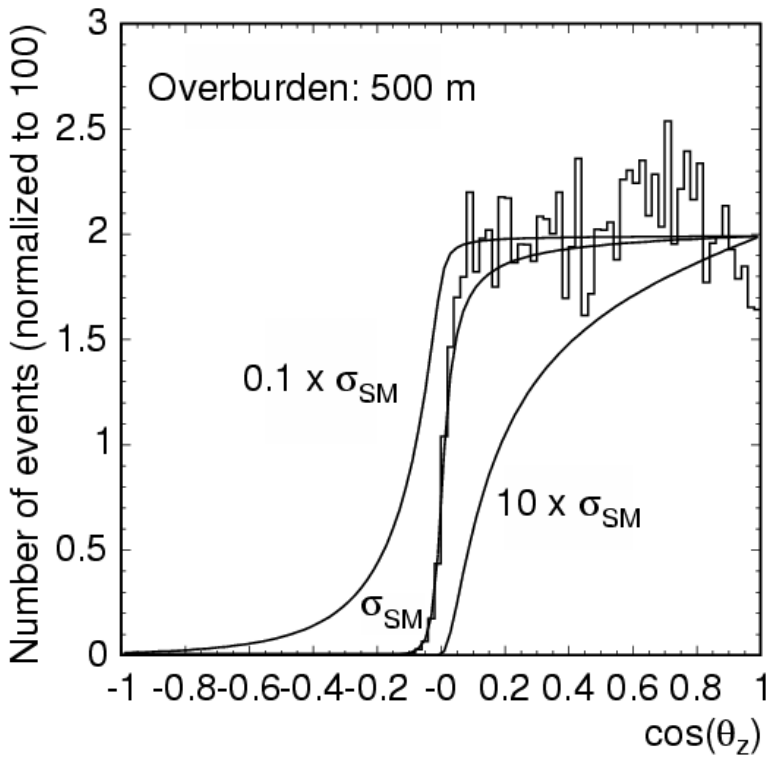
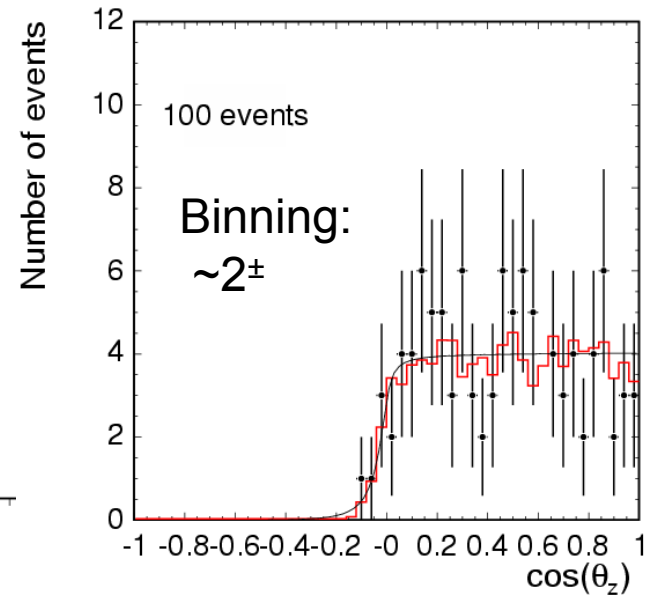
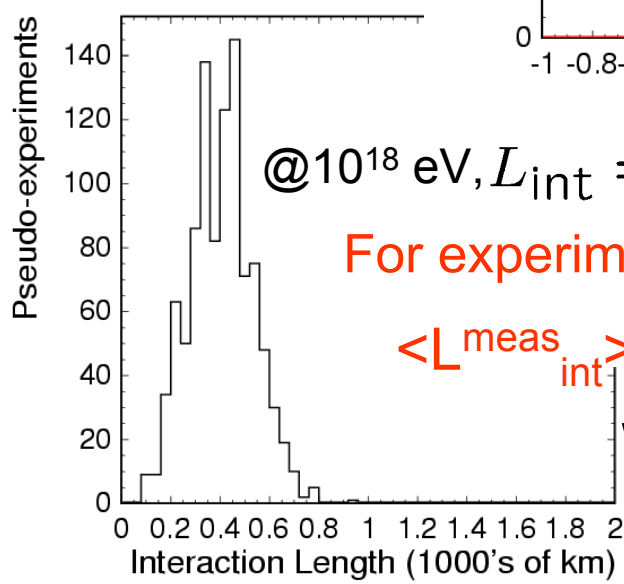
SalSA Cross Section Measurement

ν N cross section can be measured from cos θ_ν distribution



Generate cos θ_ν distribution from simulation and throw dice for many pseudo-experiments





@10^{18} eV, $L_{\rm int} = 395$ km(rock)

For experiments w/ 100 events

$\langle L^{meas}_{int} \rangle$=400 § 130 km

With 300 events

$\longrightarrow 410 \pm 80$ km

Use Poisson likelihood

At SM σ , only 10% of events in sensitive region

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SalSA: Benchmark Detector Parameters

- Overburden: 500 m
- Detector
  - Array starts at 750 m below surface
  - 10 x 10 string square array, 250 m horiz. separation
  - 2000 m deep, 12 “nodes”/string, 182 m vert. separation
  - 12 antennas/node
- Salt extends many atten. lengths from detector walls
- Attenuation length: 250 m
- Alternating vert., horiz. polarization antennas
- Bandwidth: 100-300 MHz
- Trigger requires 5/12 antennas on node, 5 nodes to fire: $V_{signal} > 2.8\ \sigma$ £ V_{RMS}
- Index of refraction=2.45
- Syst. Temp=450K=300K (salt) + 150K (receiver)

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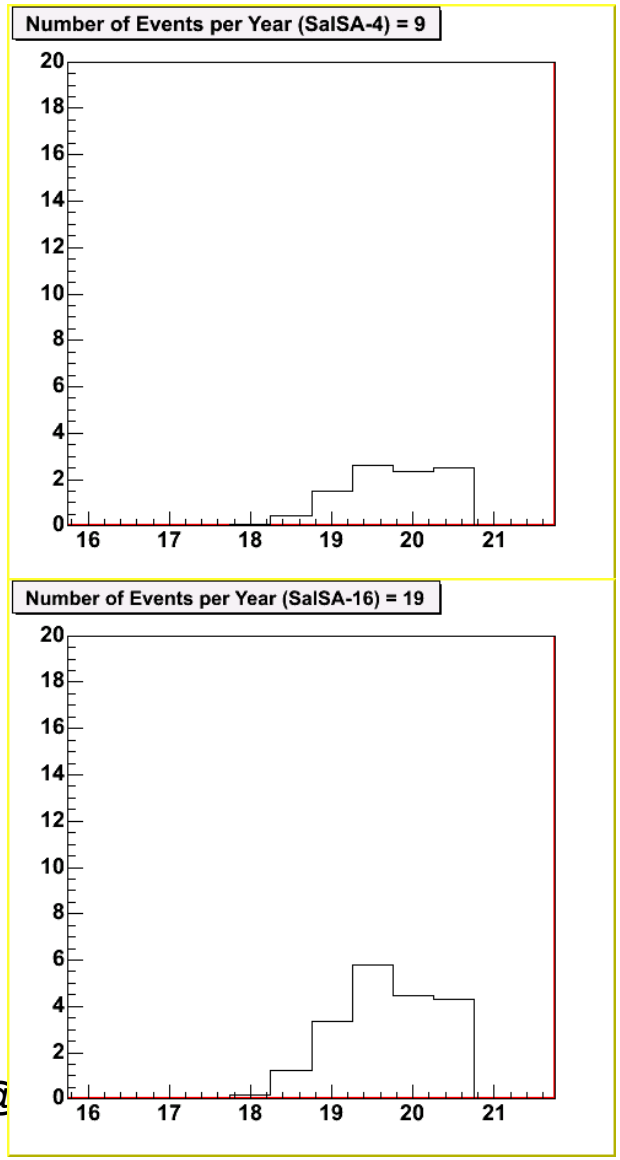
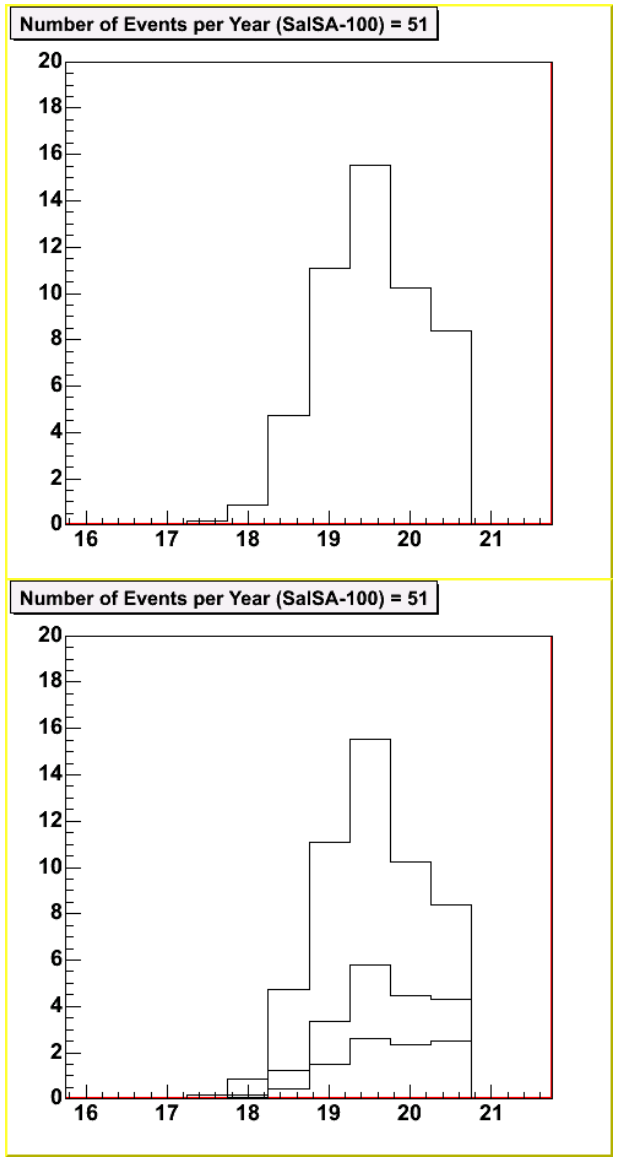
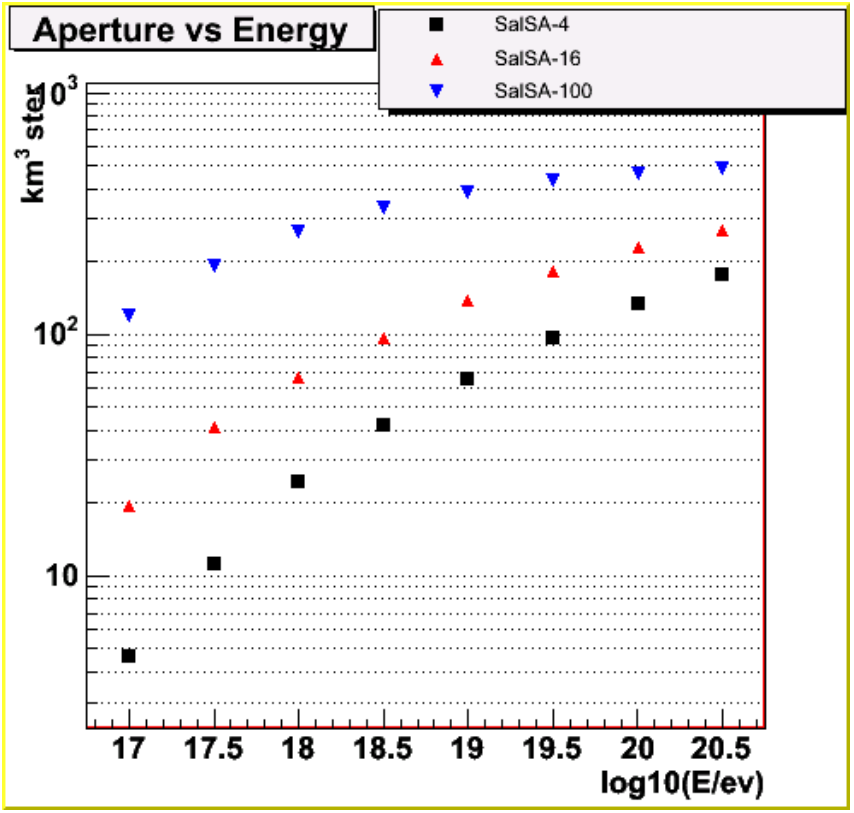
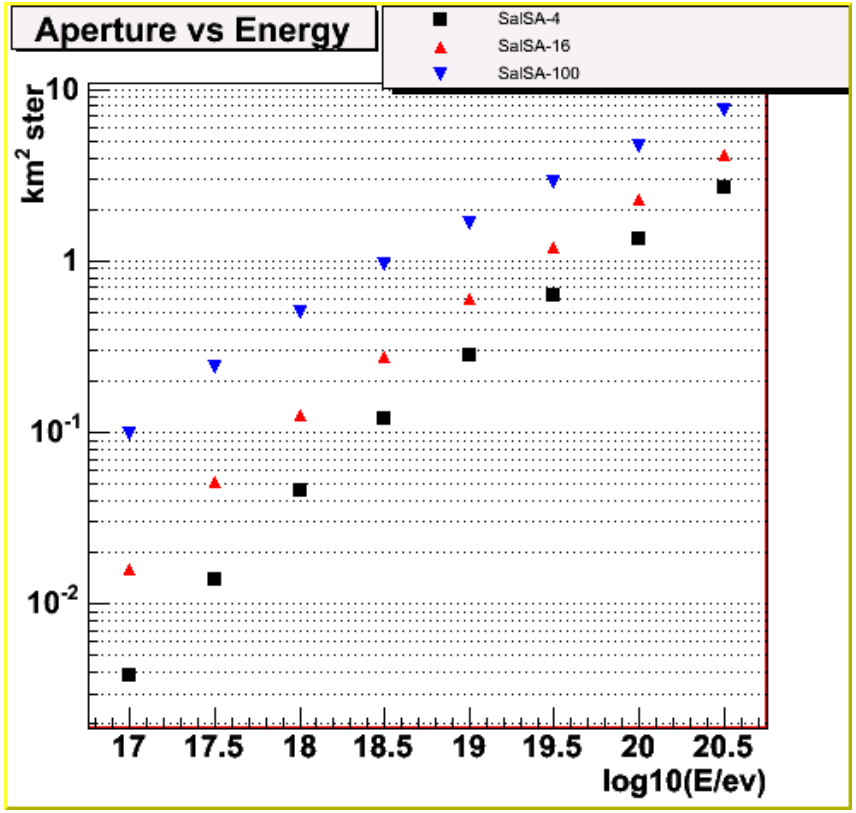
SalSA Event Rate





Aperture 2





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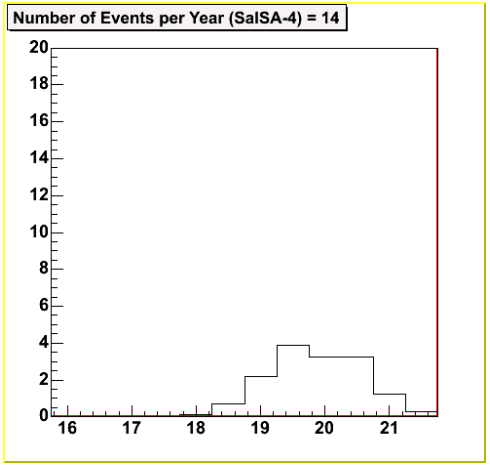
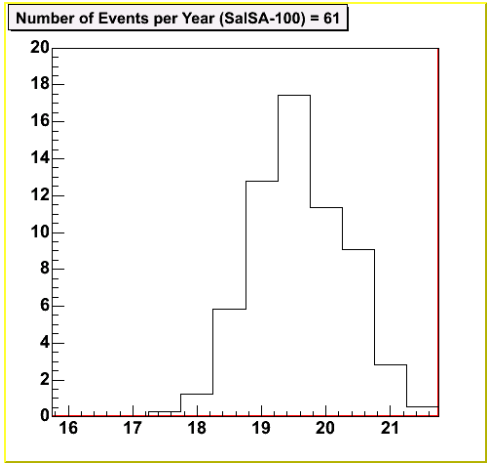
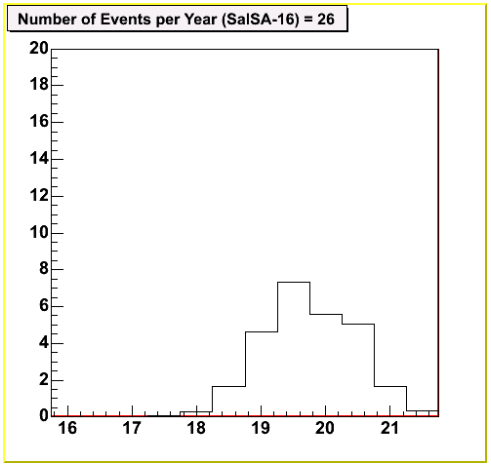
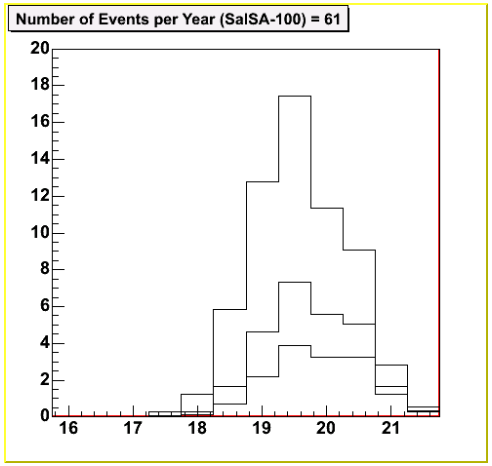
Event Rate 2









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