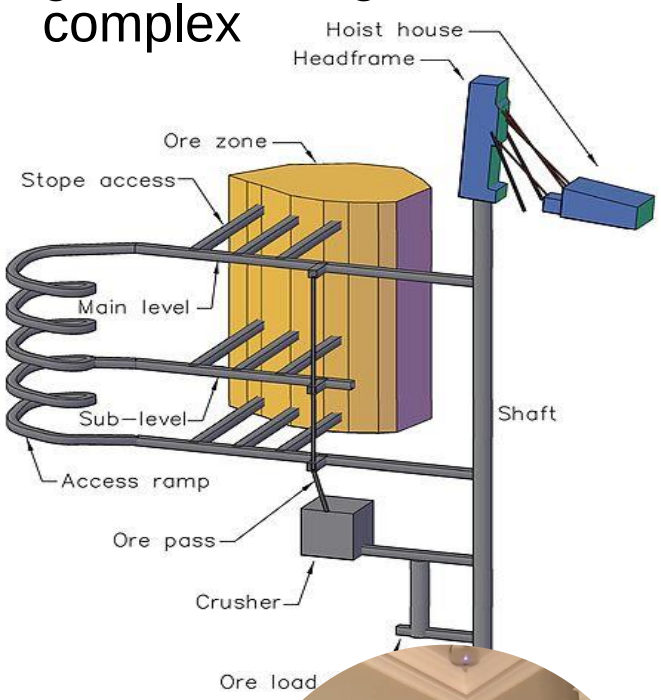
# From South African Underground Laboratory (SAUL) to PAUL

- Historical Introduction & context
- Underground Physics in SA
- Current activities
  - Huguenot Tunnel Survey
  - Geophysical due diligence
- Intended projects and strategy

3D image of an underground mining complex




ZEBLON Z. VILAKAZI
UNIVERSITY OF WITWATERSRAND (WITS)

# Early Nuclear Physics Research in SA

The first Universities were established in mid- to late late 1800's.

The Council for Scientific and Industrial Research established in 1945

The Atomic Energy Board (now Necsa) was established in 1950 – Nuclear weapons programme.

**The South African Institute of Physics was established in 1955**.


Significant former nuclear weapons related faciliti
Complex, near Pretoria, South Africa. December 1
www.terraserver.com.

# Context and South Africa's history of HEP

Some prominent physicists/cosmologists who were educated in RSA

- Stanley Mandelstam (Dirac medal); B. Sc. Hons (Witwatersrand)
- Jonathan Dorfan [ex SLAC director]; B. Sc. (Cape Town)
- Werner Israel [Cosmologist]; B. Sc (Cape Town)
- Saul Teuklosky (Dirac medal) [Astrophysics] B. Sc Hons (Witwatersrand)
- Alan Cormack (Nobel Prize [CT-scan]); B. Sc. (Cape Town)

All the above were based abroad.

PHYSICAL REVIEW VOLUME 96, NUMBER 3 NOVEMBER 1, 1954

**Direct Quantitative Observation of the Three-Photon Annihilation of a Positron-Negatron Pair***

J. K. Basson
*National Physical Laboratory, Council for Scientific and Industrial Research, Pretoria, Union of South Africa*
(Received January 11, 1954)

Three-photon annihilation of the positron with a negatron has been determined quantitatively as well as qualitatively by the simultaneous observation of the emitted photons with scintillation counters. The ratio of the reaction cross sections for two- and three-photon annihilation has been determined as $\sigma_{2\gamma}/\sigma_{3\gamma}=402 \pm 50$. This is in agreement with the theory of Ore and Powell but definitely differs from the theoretical values obtained by Lifshitz and by Ivanenko and Sokolov.

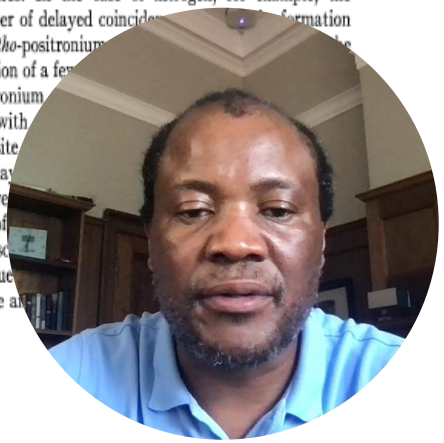
INTRODUCTION

THE possibility that an appreciable part of positron-negatron reactions might result in annihilation with the radiation of three photons, was first theoretically postulated by Lifshitz[1] and by Ivanenko and Sokolov[2] and a short while later by Ore and Powell.[3] They all used the time-independent perturbation theory to compute the cross section for three-photon annihilation. The influence of Coulomb binding was neglected and plane wave functions were assumed for the initial and final states of the positron-negatron system. Similar results were obtained but with different numerical values.

When the positron and negatron meet in free space they can be considered to form a bound system similar to that of the hydrogen atom, as suggested by Wheeler.[4] The triplet or singlet state is formed depending on whether the spins of the positron and negatron are parallel or antiparallel. These states are called respectively *ortho-* and *para*-positronium. Transitions between the two are strictly forbidden.[5]

The singlet state is annihilated with the emission

$10^{12}$ per second. This may result in the de-excitation of the triplet state to the singlet state, with resulting two- instead of three-photon annihilation, in a gas (such as NO) where electron exchange takes place easily. The number of delayed ($\sim 10^{-7}$ sec) coincidences between the emission of the gamma quantum from the decay of the $Na^{22}$ nucleus and the appearance of an annihilation quantum when the positron is brought to rest in the gas, has been measured by Deutsch in different gas mixtures. In the case of nitrogen, for example, the number of delayed coinci… formation of *ortho*-positroniu… addition of a fe… positronium… sion with… opposite… of delay… (where… tion of… Deutsc… a valu… of Ore a…



# Historical context

In 2011: a letter from Steven Adler [IAS] to the DD-G of science & technology that was routed to the director of iThemba LABS

**-----Original Message-----**

**From: adler@ias.edu [mailto:adler@ias.edu]**

**Sent: Thursday, January 20, 2011 7:13 PM**

**To: Thomas Auf der Heyde**

**Cc: rturrell@gmail.com; hastings@ias.edu**

**Subject:**

**Dear Professor AufderHeyde,**

**Although I missed talking to you at the meeting in Trieste, Arlen Hastings kindly gave my your email. There follows a brief memo on the case for a Southern Hemisphere underground lab that I am sending t people I met at th conference.**

**With best wishes,**

**Steve Adler**

Having a Southern Hemisphere analogue of the DAMA/LIBRA experiment would give a control against many such artefacts, since seasonal fluctuations would be 6 months out of phase with those in the Northern Hemisphere.

Another place where a Southern Hemisphere experiment would be valuable would be in the study of possible annual modulation effects in certain radioactive decays,

These possible effects are culled from experiments in Northern Hemisphere laboratories, and may be due to seasonal variations. Again, having a Southern Hemisphere facility in which to repeat the experiments, with good shielding, would be important in seeing whether these effects are indications of new physics. If radioactive decay rates did show an annual modulation, they could also be an additional potential background for dark matter searches that look for annual modulation effects.

In addition to the above experiments, an underground labor
Southern Hemisphere could mount all the other types of exp
currently underway in the Northern Hemisphere, such as sola
neutrino detection experiments and searches for rare beta decay

## Cosmic radiation and underground laboratories

Primaries

- Protons
- Nuclei
  - (Helium... Oxygen... Iron)
- Neutrons
- Gammas

Secondaries

- muons
- electrons/positrons
- gammas
- neutrons
- neutrinos

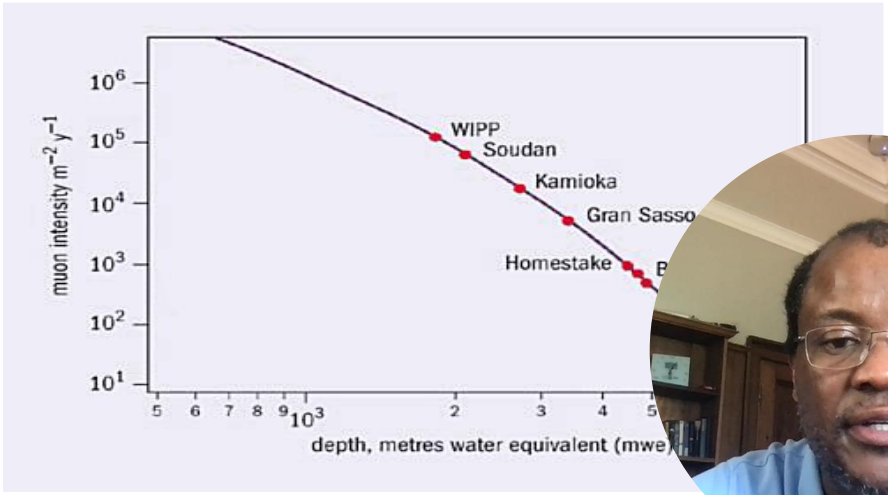
…

# Cosmic rays background:

In a cubic meter of detector at ground level, one typically detects the following events per every day:

- $10^8$ muons
- $10^8$ gammas/electrons/positrons
- $10^6$ neutrons
- $10^3$ neutrinos
- $10^7$ supernova neutrinos
- maybe 100s of dark matter pa

Muon flux at ground level: a few $100 m^2 s^{-1}$




Muon flux at 5000 m.w.e. underground: $1 m^2$ d

# Response from the SA community

On 2/14/2011 8:53 AM, Director wrote:
Dear Professor Adler,

I was forwarded your e-mail by Dr. Auf der Heyde regarding the matter in the subject field above.

**We have thought that we would advance the discussion to a wider South African physics community (and other interested parties) in order to allow us to arrive at a better informed position regarding the way forward. In that regard we would kindly request some more time to follow wider consultation and soon thereafter we will revert. We anticipate that the process could take no more than 2 months.**

**All can say, at this stage though is that the community has – thus far – responded quite positively.**

Yours Sincerely,
Zeblon VILAKAZI

Dear Professor Vilkazi,

Thanks for the update; I'm glad there is interest. I look forward to hearing what happens. It would be great if a project can be developed in Africa.

In the meantime, quite independent of my email, I learned that people in South America have been thinking about adding an underground lab to a proposed tunnel under the Andes. See the link http://particulas.cnea.gov.ar/andes/ which was sent me by Xavier Bertou from Argentina.

Best Wishes
Steven

**in SA, uranium and gold are co-genetic.**

**One expects radon buildup, the U and Th series of isotopes leading to alphas and gammas.**

**This should rule things out without a more detailed comparative study for a properly secondary-shielded enclosure.**

**not withstanding the above: that for astrophysical considerations, the strategic advantage of Southern Hemisphere observation should be weighed very heavily.**

**The SA mines are also the world's deepest, in addition, the overburden would be more dense.**

**The effective depth or shielding factor would be an important additional advantage.**

SA

# EVIDENCE FOR HIGH-ENERGY COSMIC-RAY NEUTRINO INTERACTIONS*

F. Reines, M. F. Crouch, T. L. Jenkins, W. R. Kropp, H. S. Gurr, and G. R. Smith

Case Institute of Technology, Cleveland, Ohio

and

J. P. F. Sellschop and B. Meyer

University of the Witwatersrand, Johannesburg, Republic of South Africa

(Received 26 July 1965)

are favored over the $3\pi$ and $\eta+2\pi$ modes, although it probably is still insufficient to account for the vast differences in decay rates between these two types of processes without introducing symmetry-breaking effects. The $\rho+2\pi$ and $\omega+2\pi$ modes are found to be comparable. For a detailed list of branching ratios, see reference 2.

[7]H. Harari, H. J. Lipkin, and S. Meshkov, Phys.

other way with equal amounts. Therefore, the statistical average of the $\rho+3\pi$ processes should not be greatly perturbed.

[8]See reference 1 for a summary of the experimental data.

[9]R. Armenteros et al., Phys. Letters 17, 170 (1465); N. Barash et al., "Antiproton Annihilation in Hydrogen at Rest I, Reaction $\bar{p}+p\to K+\bar{K}+\pi^0$ (to be published).

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The flux of high-energy neutrinos from the decay of $K$, $\pi$, and $\mu$ mesons produced in the earth's atmosphere by the interaction of primary cosmic rays has been calculated by many authors.[1] In addition, there has been some conjecture[1] as to the much rarer primary flux of high-energy neutrinos originating outside the earth's atmosphere. We present here evidence[3] for the interactions of "natural" high-energy neutrinos obtained with a large area liquid scintillation detector (110 $m^2$) located at a depth of 3200 m (8800 meters of water equivalent, average $Z^2/A \simeq 5.0$) in a South African gold mine.

The essential idea of the present experiment[3] is to detect the energetic muons produced in neutrino interactions in a mass of rock by means of a large area detector array imbedded in it. Backgrounds are reduced by the large overburden and by utilizing the fact that the angular distribution of the residual muons from the earth's atmosphere is strongly peaked in the vertical direction at this depth. The angular distribution of the muons produced by neutrino interactions should show a slight peaking in the horizontal direction.[1]

The detector array, shown schematically in Fig. 1, consists of two parallel vertical walls made up of 36 detector elements. The array is grouped into 6 "bays" of 6 elements each. Each detector element, Fig. 2, is a rectangular box of Lucite of wall area 3.07 $m^2$ containing 380 liters of a mineral-oil based liquid scintillator,[4] and is viewed at each end by two 5-in. photomultiplier tubes. The array constitutes a hodoscope which gives a rough measurement of the zenith angle of a charged particle passing through it. In addition, the event is located along the detector axis by the ratio of the photomultiplier responses at the two ends. The sum of the responses then pro-

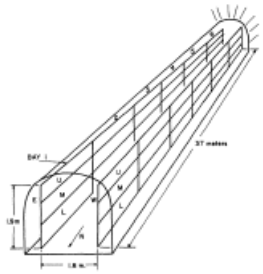
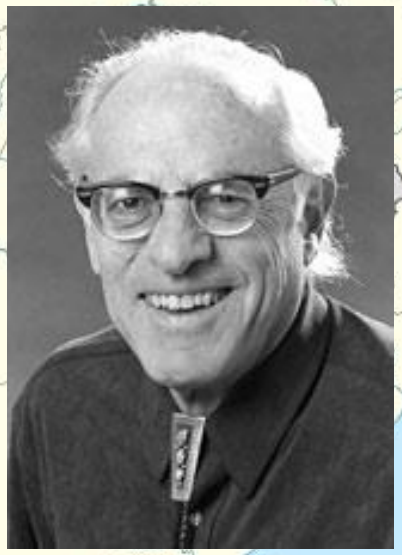
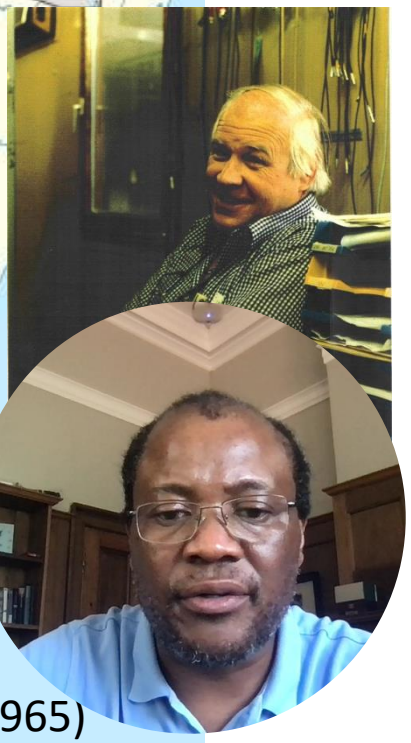


FIG. 1. Schematic of detector array.





Frederick Reines



Phys Rev Lett, 15, 429 (1965)

# How Can South Africa Play a role in underground physics research?

- **South Africa was active in this area of research in the 1960's through pioneering experiments done at ERPM gold mine the where the late Nobel Laureate F. Reines (including the late JPF Sellschop )**
  - **observed (in 1965) the first natural neutrinos** along with the Indian team led by Goku Menon and colleagues in Kolar Gold fields in India, **setting first astrophysical limits**!
- Some of the World's deepest mines are in SA:
  - Tau Tona 3,900 m (12,800 ft) – 50 C
  - Plans to extend Mponeng mine, a sister mine to TauTona, down to 4,500 m (14,800 ft) in the coming years
  - World Leading Mining engir
    seismology schools

# Initial studies in the Huguenot Tunnel Mountains, in the Western Cape.

## Characterisation of radioactivity:

- ✓ Radon in air: measurements in the northern bore and connecting sections using Electret Ion Chambers (EIC) and a RAD7 continuous radon monitor. The EIC measurements will involve

  **deployment of EIC for a period of about a week when using SST electrets. The RAD7 measurements will involve sniff measurements over a period of about 1 hour**.

- ✓ Gamma ray: measurements along the length of the northern bore and outside the tunnel by

  **means of a mobile MEDUSA scintillator detector. These data will be complementary to the radon measurements in the sense in that we will also be sensitive to thorium series radionuclides, potassium 40 and other uranium series radionuclides.**

- ✓ Long (~one month) : stationary gamma ray measurements outside the tunnel and inside the northern bore.

- ✓ Measurements of cosmic ray background using organic scintillators inside and outside the tunnel.

**peak Height** 1,995 m/6,545 ft)

# Intended project and strategy

**Following the current feasibility study a small workshop (Stellenbosch ~March 2014) was held with the South African Department of Science, South African Roads Agency Limited (SANREL), potential role players (SA Universities, iThemba LABS and International community) :**

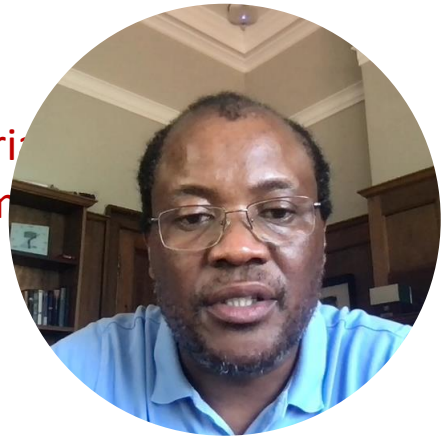
**Kai Zuber was a guest speaker/participant and he offered invaluable input**

- **Enter discussions to have a permanent facility in place within the tunnel (request letters of support).**

- **Develop established programs in the studies of double beta decay, geoneutrinos, dark matter, etc**

✓ might need a ULB Ge-detector and/or scintillators for materi
screening and physics measurements [W Trzaska (priv. comm

**Exchange of knowledge, skills and the training of young people.**



# 2014

- Formal constitution of ZA underground physics collaboration
- Approach SANRAL for Tunnel access to at least 2016
- Approach DST/SANRAL about vision of establishing a Physics cavern off the Hu Tunnel +10 years

# 2015 (draft)

- Jan.- Feb. – Symposium on Underground Science in Western Cape
- Formalize the ZA Science Case for a long term underground science facility.
- Start HPGe measurements inside tunnel

2016

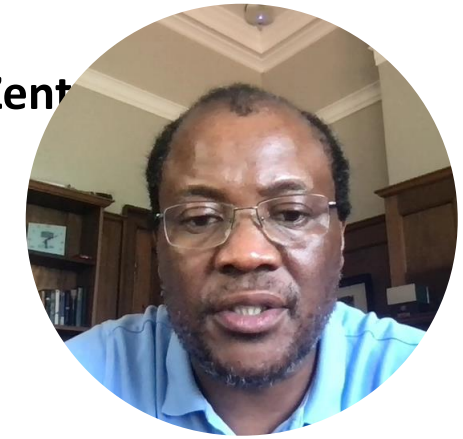
•Involvement of Geo-scientists from WITS to lo
suitability (Geo-seismicity , Geology (rock form
safety

# Geo Seismology tests

*Semi-controlled earthquake-generation experiments at deep gold mines, 1995-2008 (after Ogasawara et al 2009a)*


# SA-JPN Geo-Seismology (2)

- **JAGUARS (2007-2008)**
- The JAGUARS team (**JApanese-German Underground Acoustic emission Research in South Africa)** **deployed a network of eight acoustic emission (AE) sensors 3.3 km below surface in the Mponeng gold mine to measure seismic events (Nakatani, Yabe, Philipp et al 2008).**
  - **Participating Japanese institutions :**
    - **Kyoto and Ritsumeikan Universities,**
    - **the Earthquake Research Institute at Tokyo University,**
    - **Research Centre for Prediction of Earthquakes and Volcanic Eruptions at Tohoku University.**
    - **German organisations included the GeoForschungsZent the Helmholtz Centre,**



# Outlook

Strong case established

- Need a champion expert to drive the project
  - Raise interest locally and internationally
  - Help build expertise and co-ordination among various players (iThemba, Necsa etc)
  - Liaise with Mining companies who will “donate” a working mine that will have appropriate depth and meets safety requirements
- Get Understanding of background in mi
- Complete a thorough Geo-seimicity stu