The First Century of Cosmic Rays, an Historical Overview

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Outline

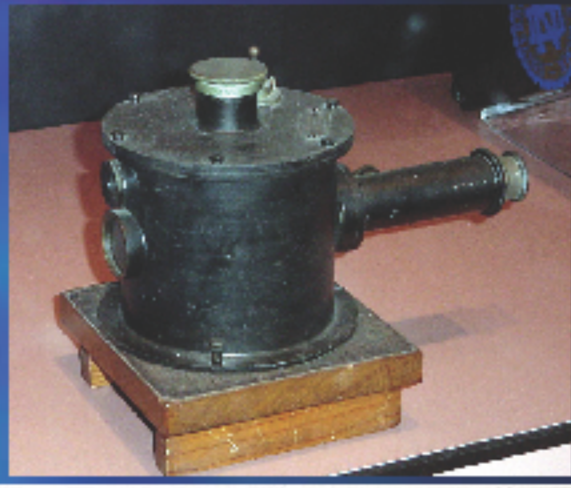
- 1912 Discovery and early observations
- Discovery of air-showers, primary charge, etc.
- Early discoveries of elementary particles
- Post WWII advent of accelerators
- Echo Lake and Mount Evans program
- The turn from particle physics to astrophysics
- Recent programs and discoveries

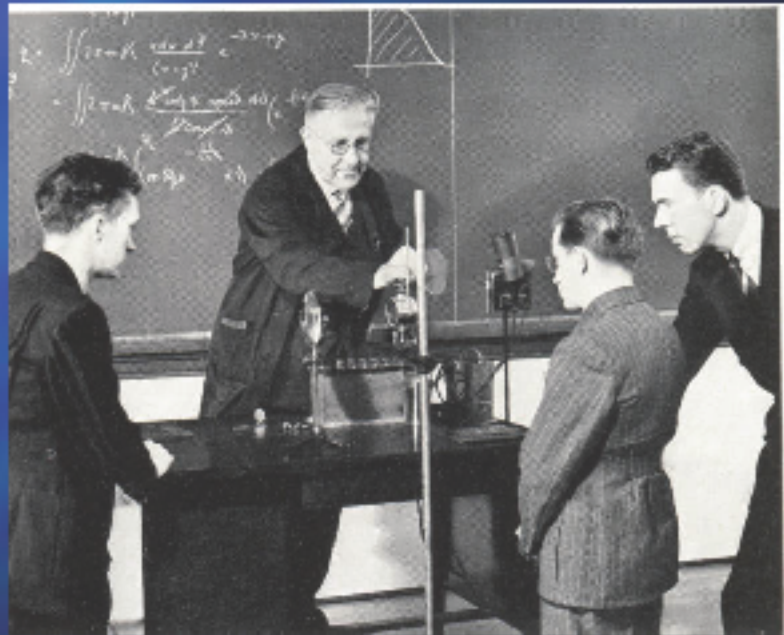
Victor Hess 1912

Victor Hess Discovers Cosmic Rays

Hydrogen balloon flights up to 17,500 ft

Detector: Wulff electroscope





Discharges faster if more radiation is present.

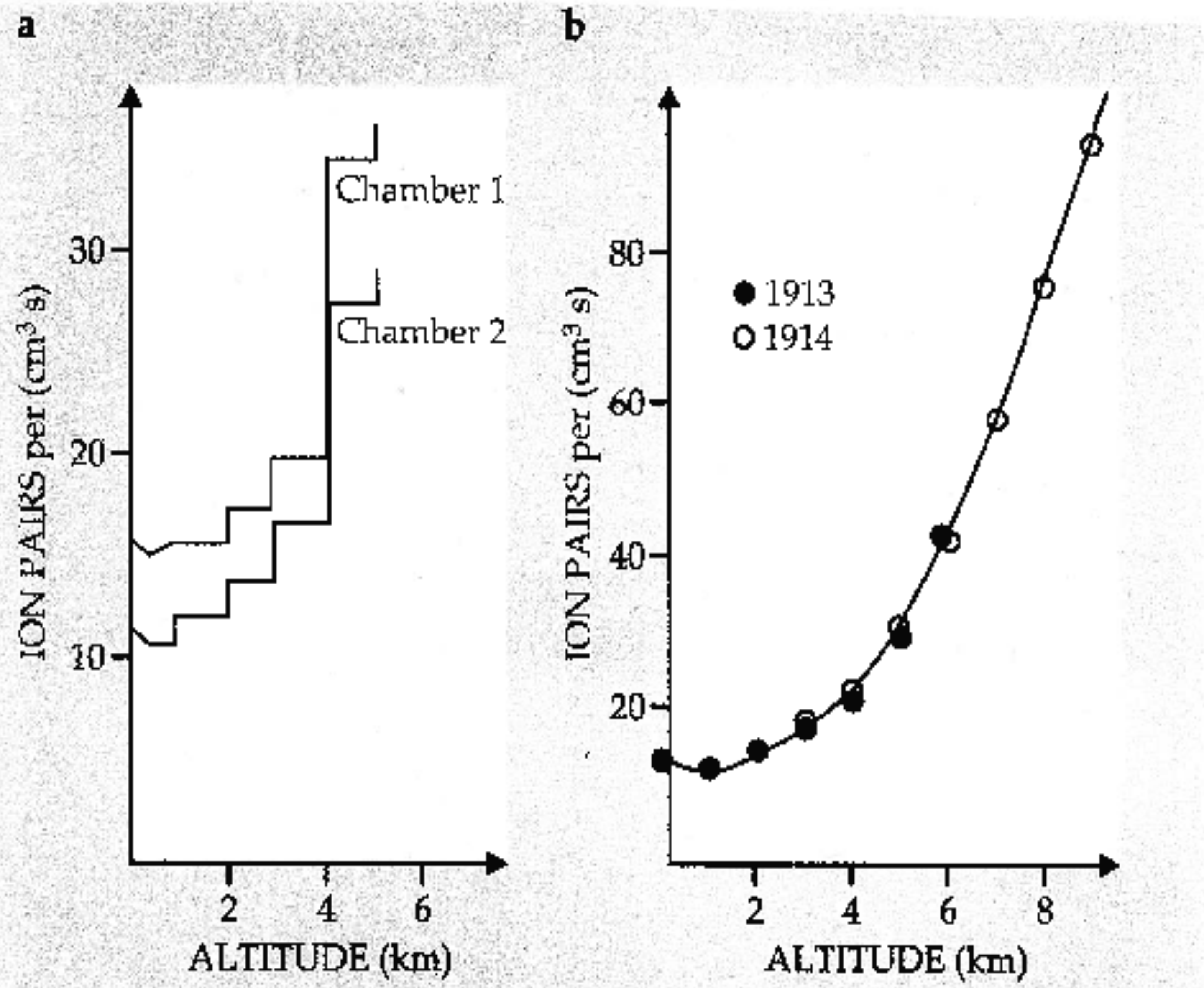
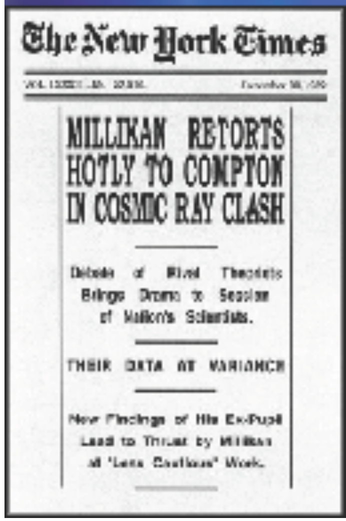


Figure 3. The rate of atmospheric ionization as a function of altitude, as measured **(a)** by Victor Hess on 7 August 1912, and **(b)** by Werner Kohlhörster

What Hess found

- Radiation rate *increases* with altitude! Not from the ground…
- Must be from a *cosmic* source!
- Not from the Sun: still present when flying during an eclipse in April, 1912;
- Confirmed by Kohlhörster 1913-1919, up to *28,000 ft.*

- Millikan disagreed at first, but eventually came around;
- coined *"cosmic rays".*



The New York Times

MILLIKAN RETORTS HOTLY TO COMPTON IN COSMIC RAY CLASH

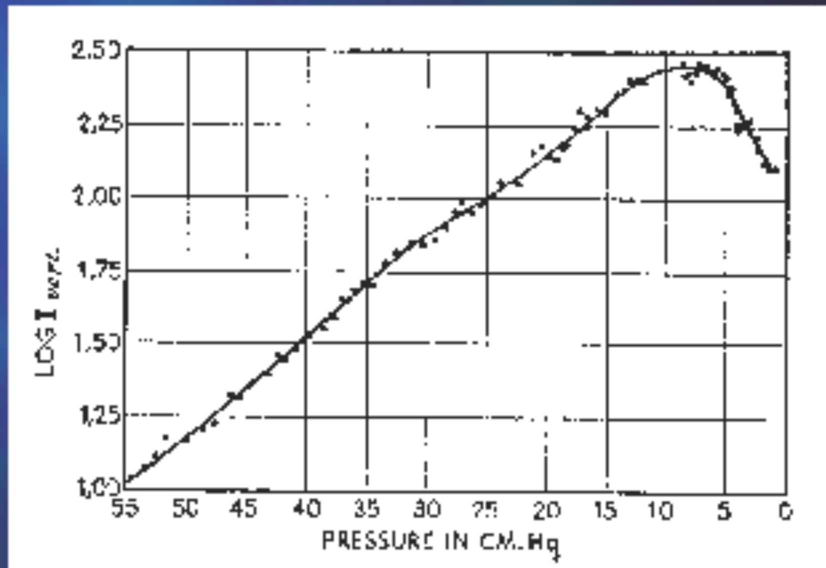
Debate of Rival Theorists Brings Drama to Session of Nation's Scientists.

THEIR DATA AT VARIANCE

New Findings of His Ex-Pupil Lead to Thrust by Millikan at 'Less Cautious' Work.

⇒ Hess: Nobel 1936
"a radiation of very high penetrating power enters our atmosphere from above."

radiation rate ↑



altitude →
← barometric pressure

Early Discoveries

- 1927 Jacob Clay, using an ionization chamber, sailed between Java and the Netherlands, and observed a significant latitude effect.
- 1927 Dmitri Skobeltsyn took a cloud chamber photo of cosmic ray tracks.
- 1929 Kolhörster and Walter Bothe, and (in 1930) Bruno Rossi, using G-M counters and coincidence circuits, found a fraction of the cosmic rays traversed 25 cm of Pb.
- 1933 Rossi, Compton, and Alvarez observed the East-West asymmetry, showing that the primaries were positive (e.g. protons).

- 1940 Marcel Schein showed, from balloon flights that the primaries were mostly protons.
- 1933 Rossi and (later) Pierre Auger observed the coincidence of cosmic ray particle counts between separated counters, and discovered air showers.
- 1947 A balloon experiment at 30 km altitude verified that, in addition to protons, primary cosmic rays included He plus a small fraction of heavier nuclei.

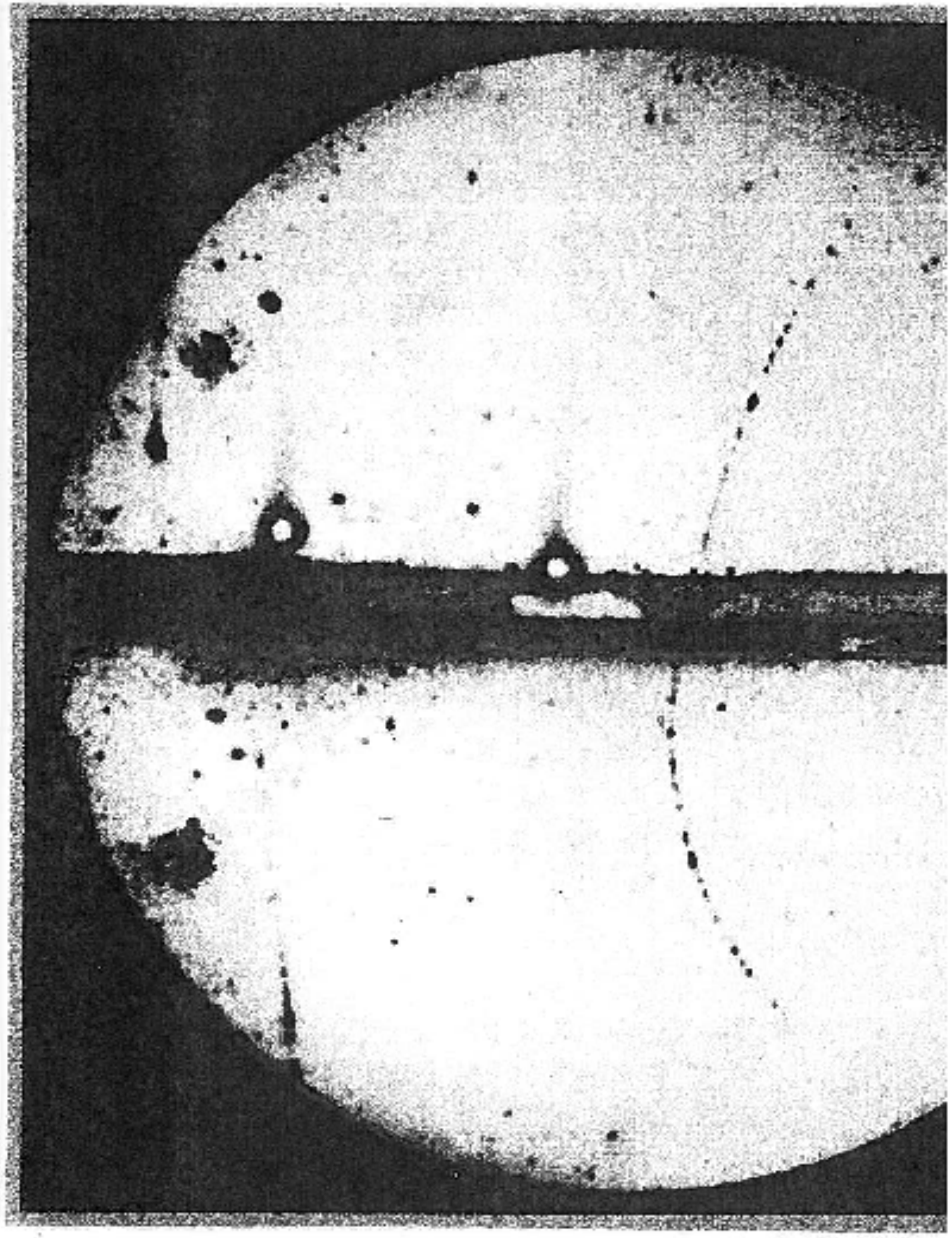
These and many other observations uncovered the nature of cosmic rays incident on the Earth from space.

In the first half of the century, elementary particles were discovered in cosmic rays.

- 1932: e^+ Carl Anderson (cloud chamber).
- 1936-37: μ Anderson, Neddermeyer, Street, and Stevenson, the Yukawa particle? "meson".
- 1947: π Lattes, Ochialini, and Powell.
- 1947 – 53: k Rochester, Butler, and Powell
- 1951: Λ
- 1952: Ξ
- 1953: Σ

Pic du Midi, cloud chamber studies.

Carl Anderson's 1932 cloud chamber photograph of a positron.



onference participants viewing the Hyperon Discovery Monument in the village squa
in Bagneres-de-Bigorre.

- The first accelerator to achieve an energy of over 1 GeV was named the “Cosmotron”, the 3 GeV proton synchrotron at Brookhaven, comissioned in 1952.
- And the Berkeley “Bevatron”, 6 GeV protons ~1955,
- The CERN “PS”, 28 GeV p rotons ~1959,
- The Brookhaven “AGS”, 31 GeV protons ~1962,
- The Dubna “Synchro-Phasatron”, 10 GeV protons ~1965.

Of course, there were also electron accelerators completed and operating during these years. Hence most of the studies of elementary particle physics moved away from cosmic rays during these years

Particle Physics Research above 100 GeV

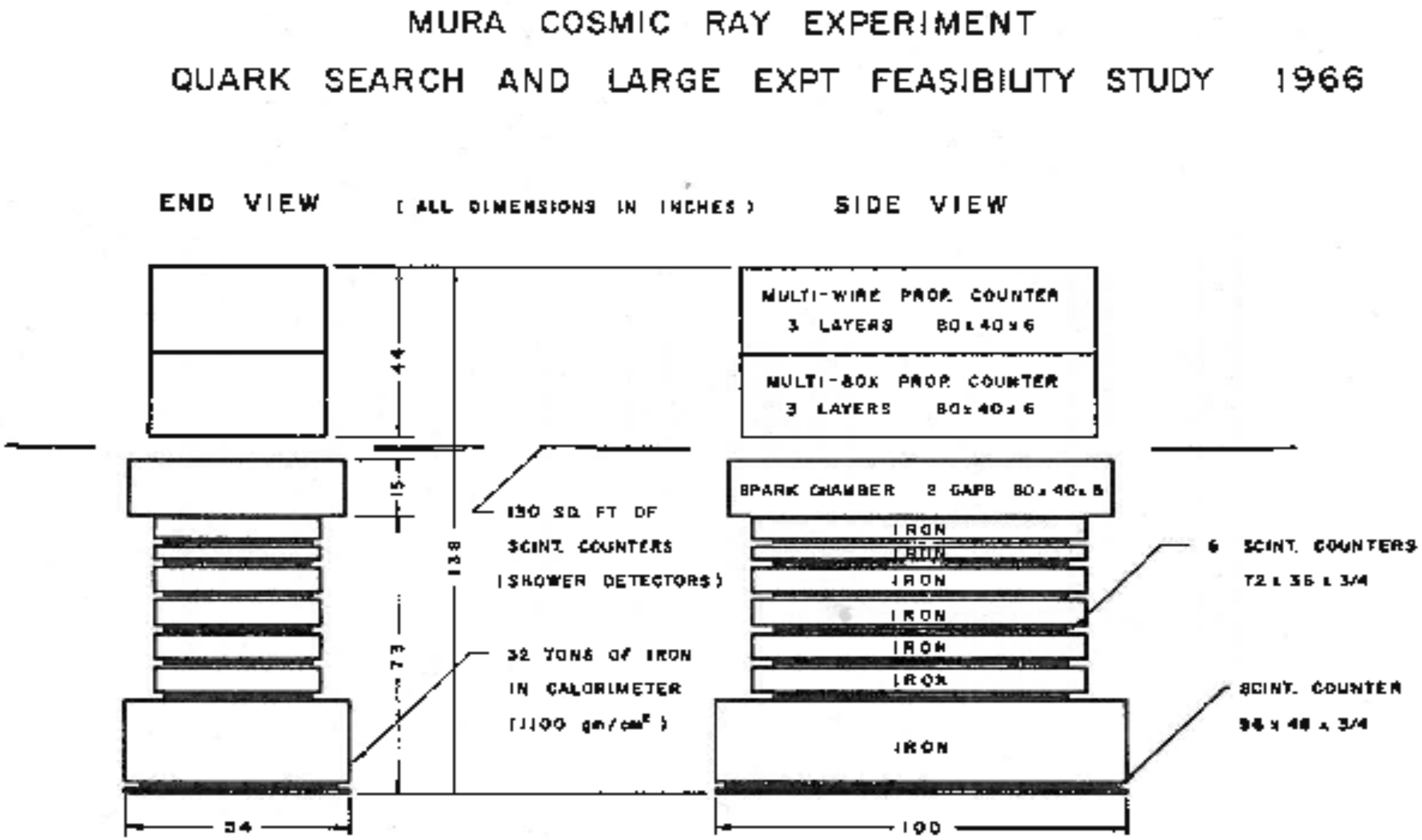
- In the early 1960s, there were extensive discussions in Europe and America about building the "next generation" (> 100 GeV) accelerators. There was confusion and political arguments concerning where to build such facilities, on both continents.
- In discussions with Giuseppi Cocconi and others, I learned that the flux of cosmic ray protons of energies above 100 GeV, at mountain altitudes, was sufficient to do serious particle physics experiments.

The Michigan-Wisconsin programs at Mt. Evans and Echo Lake, Colorado

- With colleagues at Wisconsin and elsewhere, in 1964 I initiated a cosmic ray program at Mt. Evans (4300 m) and Echo Lake (3260 m) in Colorado, U.S.A
- This Colorado site had hosted many outstanding cosmic ray physicists, including Bruno Rossi, Giuseppi Cocconi, John Wheeler, Marcel Schein, Ken Greisen, Wayne Hazen, Arthur Compton, and others.

Quark Search

- In 1966 we initiated a search for free quarks, among the incident cosmic ray particle flux.
- C.B.A. McCusker claimed evidence for a free quark in a cosmic ray cloud chamber; a track with 1/3 the ionization density of other c.r. tracks (e.g. muons).
- Our quark search result was negative, to a high precision; thus proving McCusker wrong.
- Many subsequent experiments, with cosmic rays, accelerators, and in stable matter, all also gave no evidence for free (q = 1/3 e or 2/3 e) quarks.



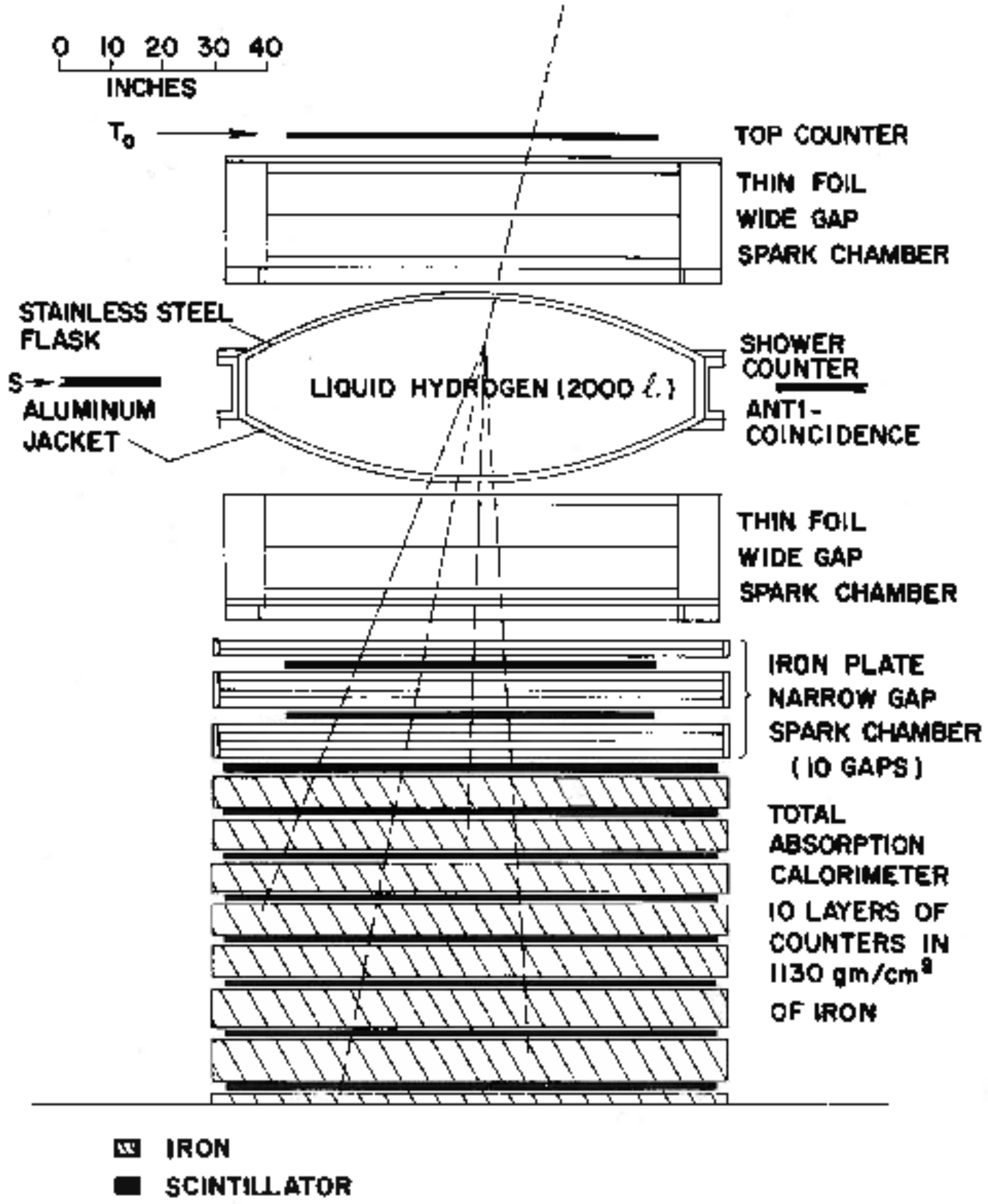
2. Configuration of quark search and large experiment feasibility study, Mt. Evans and Echo Lake, 1966-1967.

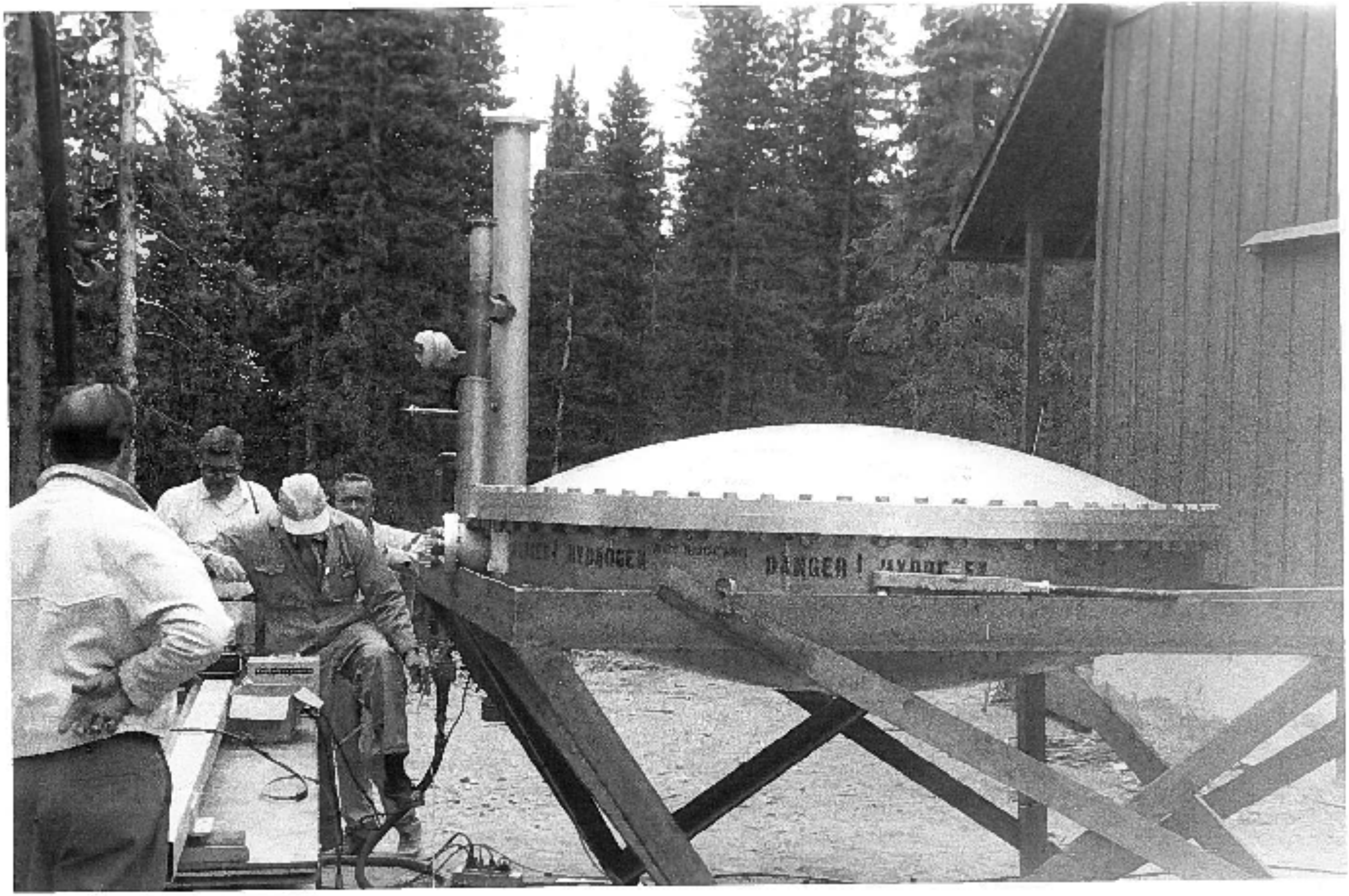
Proton-proton physics above 100 GeV

- At the 1967 International Cosmic Ray Conference in Calgary, Grigorov and his Russian colleagues reported results from the "Proton" Russian satellites; in particular, the p-p inelastic cross section (deduced from interactions in a graphite and a polyethylene target) was reported to be 22% greater at 500 GeV than at 20 GeV.
- This stimulated our group to pursue the direct study of p-p interactions at Echo Lake, where we had begun to build a large detector. Bruce Cork (from Berkeley) arranged for a 2000 liter liquid hydrogen target to incorporate into our detector, which included spark chambers and a large hadron calorimeter.

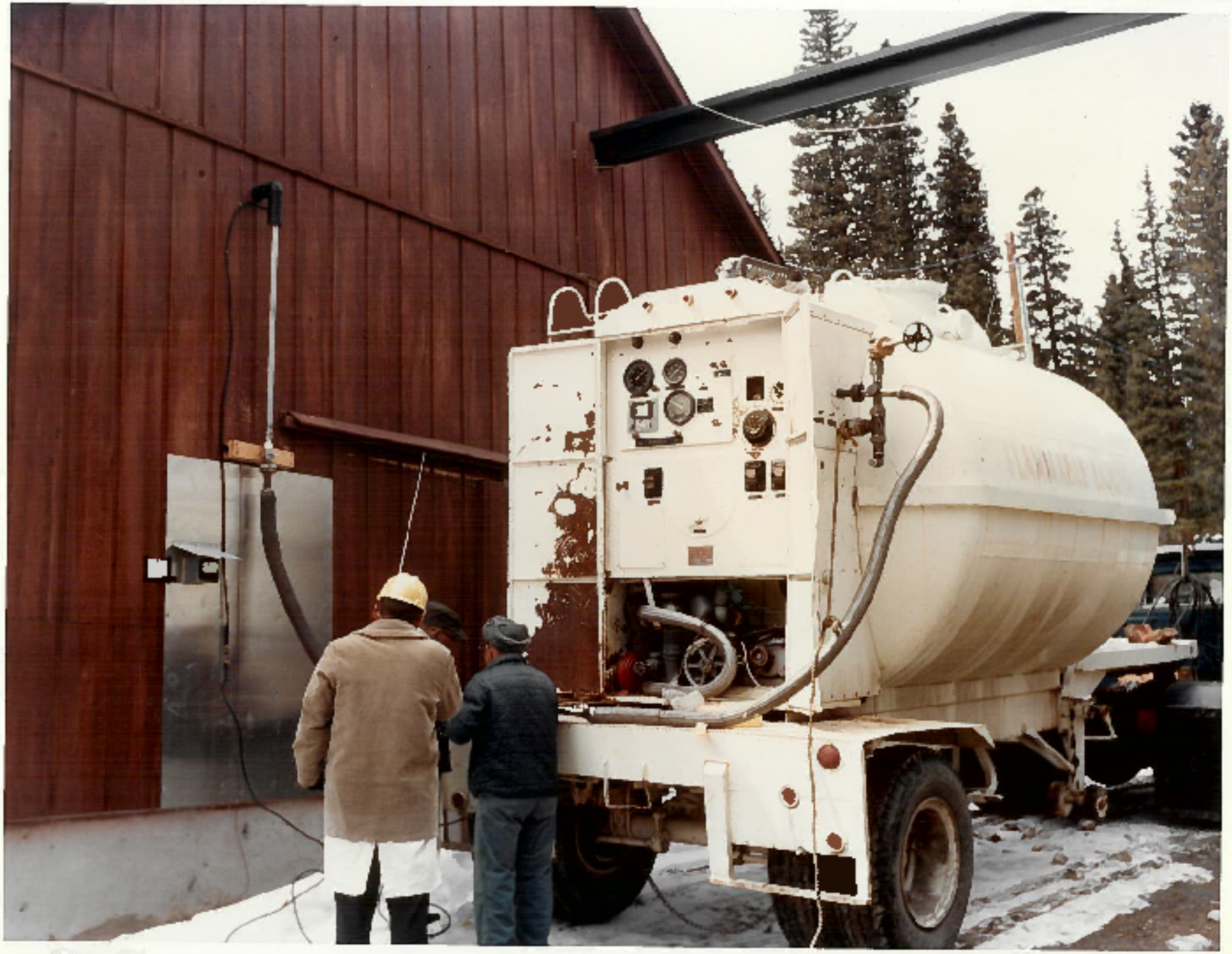
EXPERIMENTAL ARRANGEMENT

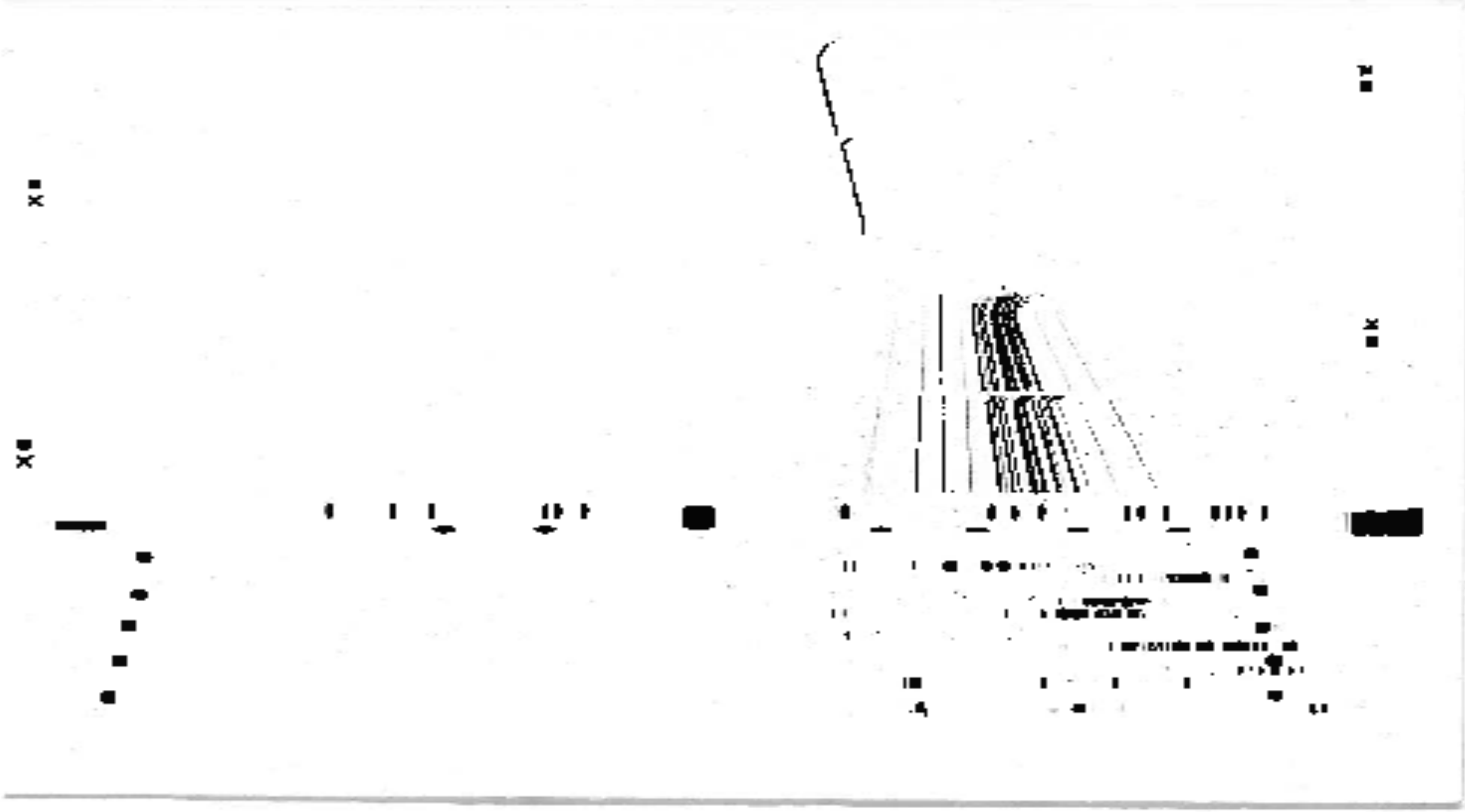
FRONT VIEW

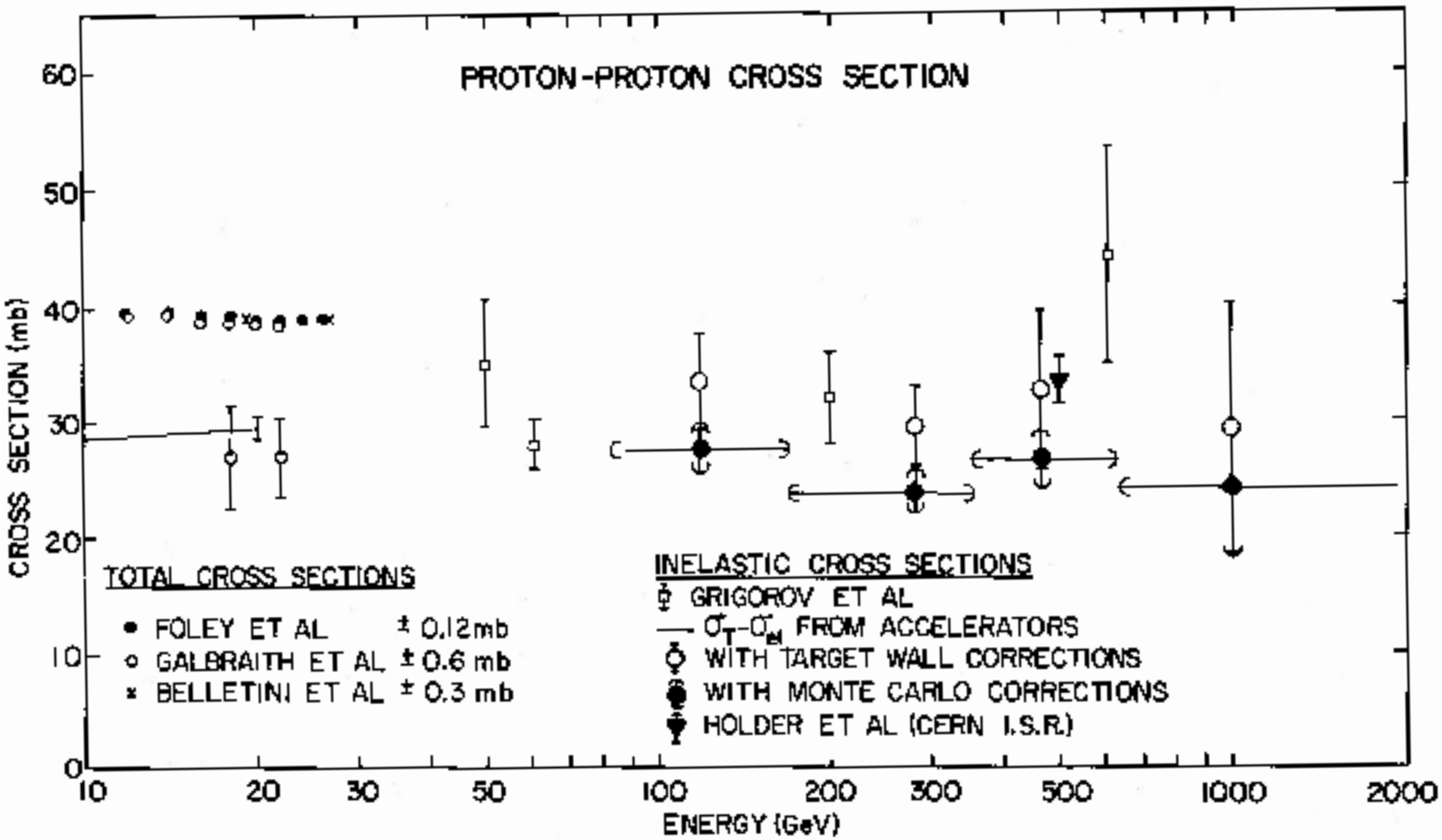




1967-68, 2000 liter liquid hydrogen target tank delivered, to be installed at the Echo Lake laboratory site, ~10,600 ft.. L–R: unidentified man (back to camera), Fred Mills, Orman Haas, and William Winter. The Echo Lake Laboratory building to the right of the tank.

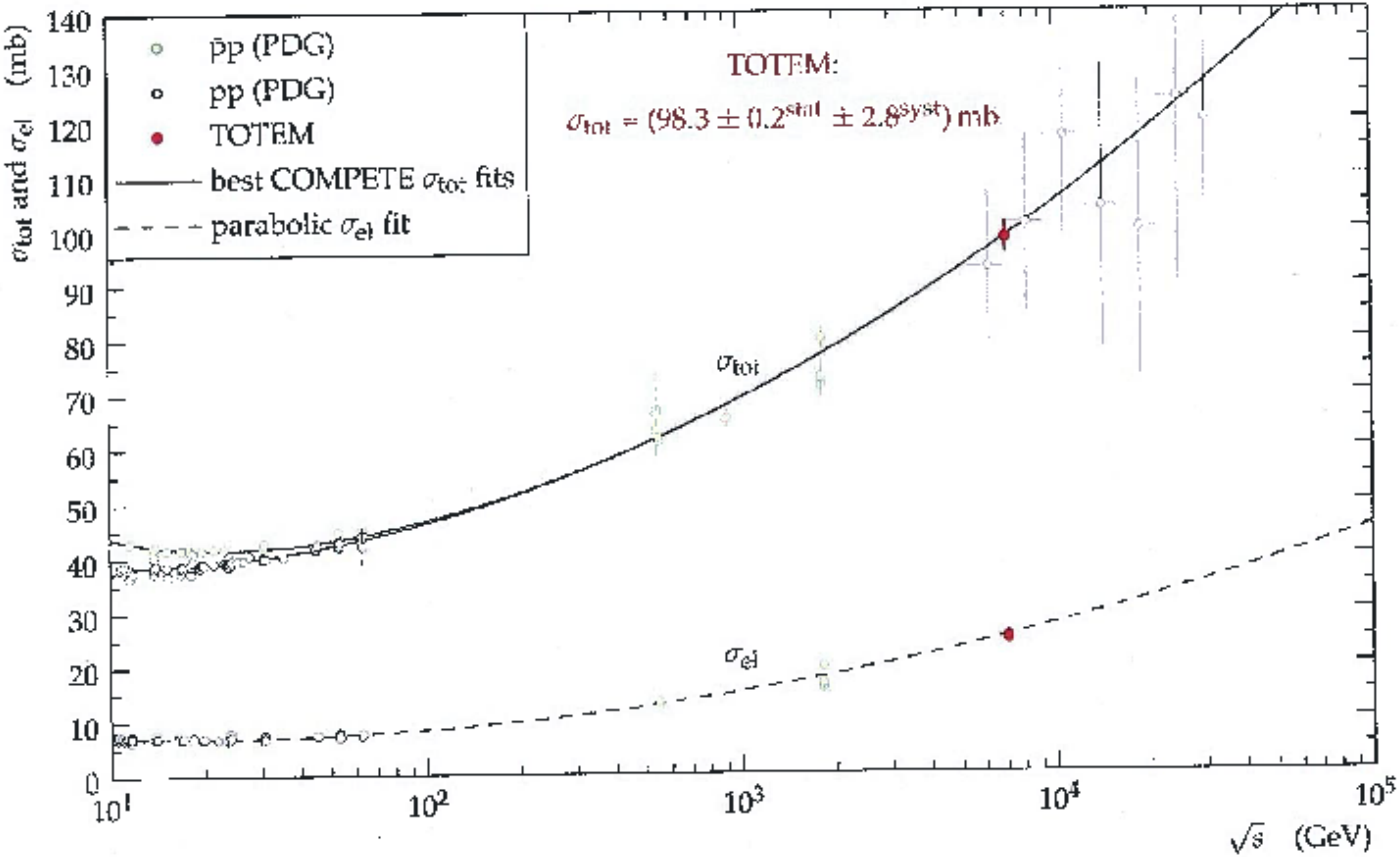






PROTON-PROTON CROSS SECTION
CROSS SECTION (mb)
ENERGY (GeV)
0
10
20
30
40
50
60
10
20
30
50
100
200
300
500
1000
2000
TOTAL CROSS SECTIONS
FOLEY ET AL ± 0.12mb
GALBRAITH ET AL ± 0.6 mb
BELLETINI ET AL ± 0.3 mb
INELASTIC CROSS SECTIONS
GRIGOROV ET AL
$\sigma_T - \sigma_{el}$ FROM ACCELERATORS
WITH TARGET WALL CORRECTIONS
WITH MONTE CARLO CORRECTIONS
HOLDER ET AL (CERN I.S.R.)

- Of course we now know that, at higher energies, the proton-proton cross section increases significantly.



σ_{tot} and σ_{el} (mb)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
$\bar{p}p$ (PDG)
pp (PDG)
TOTEM
best COMPETE σ_{tot} fits
parabolic σ_{el} fit
TOTEM:
$\sigma_{tot} = (98.3 \pm 0.2^{stat} \pm 2.8^{syst})$ mb
σ_{tot}
σ_{el}
10^1
10^2
10^3
10^4
10^5
$\sqrt{s}$ (GeV)

Some of the mountain-elevation sites

Mt. Aragatz (Armenia)	3250 m
Chacaltaya (Bolivia)	5230 m
EAS-TOP (Italy)	2005 m
Echo Lake (U.S.)	3260 m
Mt. Evans (U.S.)	4300 m
Mt. Norikura (Japan)	2770 m
Ootacamund (India)	2200 m
Pamir (Tadzhikistan)	4380 m
Pic du Midi (France)	2855 m
SPASE (South Pole)	2834 m
Tien Shan (Kazakhstan)	3340 m
Yangbajing (Tibet)	4370 m

Cosmic Rays during the recent half-century

- Since ~1962, the major emphasis of cosmic ray research has been directed towards questions in astro-physics and cosmology; for example:
- Studies of the primary spectrum and composition (with balloon- and satellite-borne detectors up to ~ TeV) and air-shower arrays; e.g. Auger.
- Studies of primary x-rays, gammas, γ-bursts, etc.
- Neutrino astronomy.
- Searches for anti-matter, e.g. Pamela's positrons.

- Since these and other astrophysics studies will all be discussed extensively at the Workshop, I will not take time here to review them and their recent history.

Emulsion Chambers

- An area of particle physics / cosmic ray research which is still active is the use of emulsion chambers. They are stacks of nuclear emulsions and/or X-ray film, separated by sheets of metal (or, sometimes, graphite) in which the tracks of particles from cosmic ray interactions may be observed and studied.
- Most of this activity is currently carried out by Russian, Japanese, and Brazilian physicists, with emulsion chamber arrays on mountains in Kazakhstan, Bolivia, and Tibet.
- An interesting Workshop, where recent results were reported, was in 2010 at Plock, Poland.

Central European Journal of Physics

Emulsion Chamber Observations of Centauros, Aligned Events and the Long–Flying Component

Review Article

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Abstract: The cosmic ray emulsion chamber community has reported several unusual phenomena which are also relevant to experiments at the current high energy accelerators, in particular, the Fermilab Tevatron Collider and the CERN Large Hadron Collider (LHC). A summary of a workshop "Cosmic rays at mountain altitude" held at Plock, Poland in September 2010 is given.

I confess that I do not believe that the phenomena described and discussed by the emulsion chamber groups represents new physics; but I support their efforts.

I look forward to the discussions at this Workshop of the current studies and latest results of cosmic ray physics and their contributions to the understanding of our Universe.

Thank you!