GEORGES CHARPAK

Between Reality and Imagination

100 YEARS ANNIVERSARY

MPGD USTC HEFEI 2024

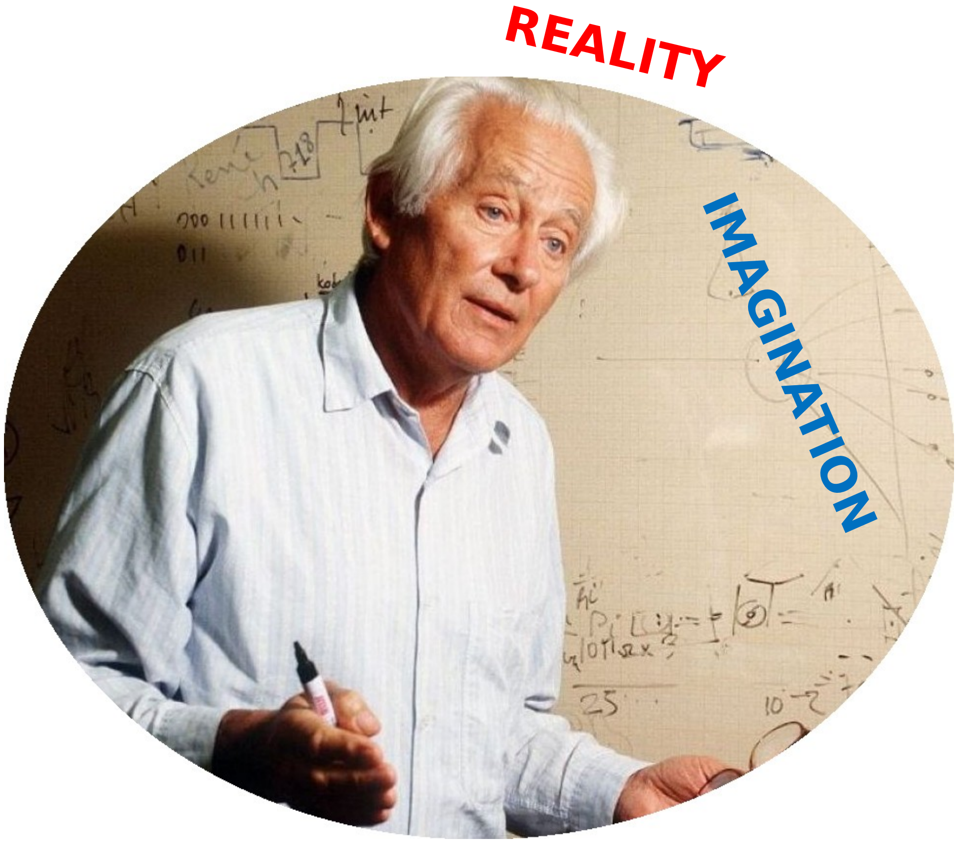
Fabio SAULI
CERN

CERN Delegation Visit to China HEP Institutes (October 1975)

At the National Peoples Congress Palace in Peking, Wu Lein-Fu(centre) between W. Weisskopf and W. Jentschke. Second from left Mrs Weisskopf. At the back (centre) L. Van Hove, Mrs Van Hove, G. Charpak*

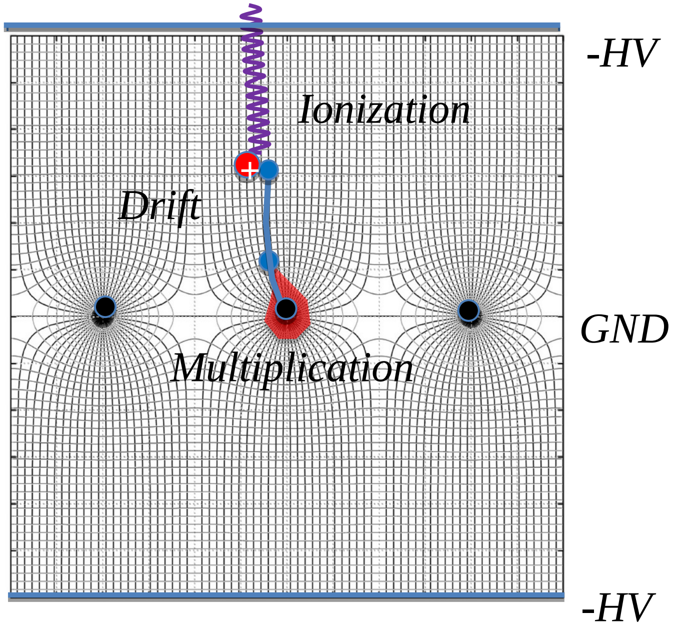
**Vice-Chairman of the Standing Committee of the National Peoples Congress.*

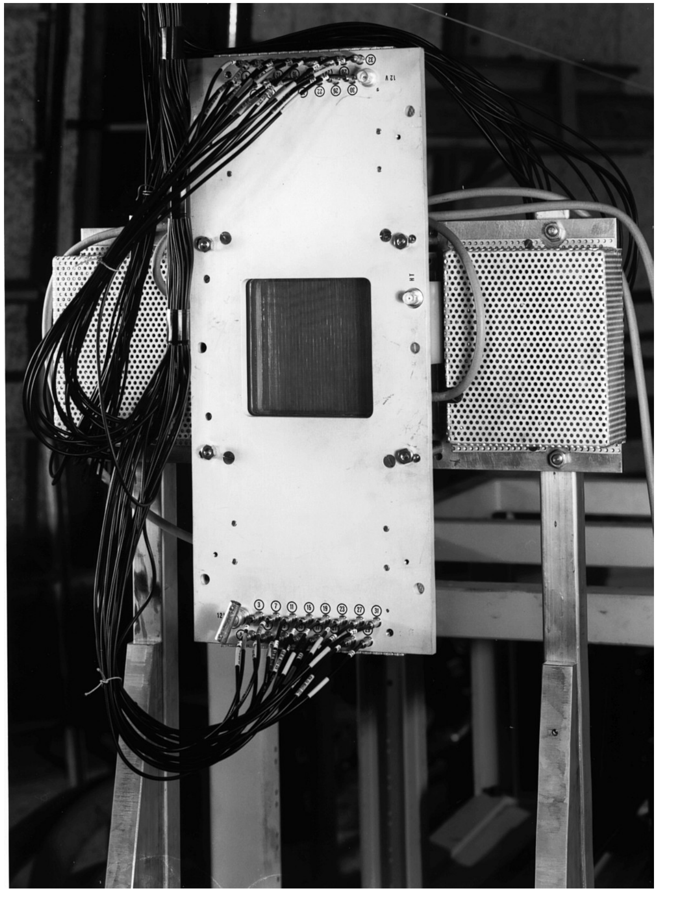
Georges Charpak
Yin and Yang of Research



REALITY

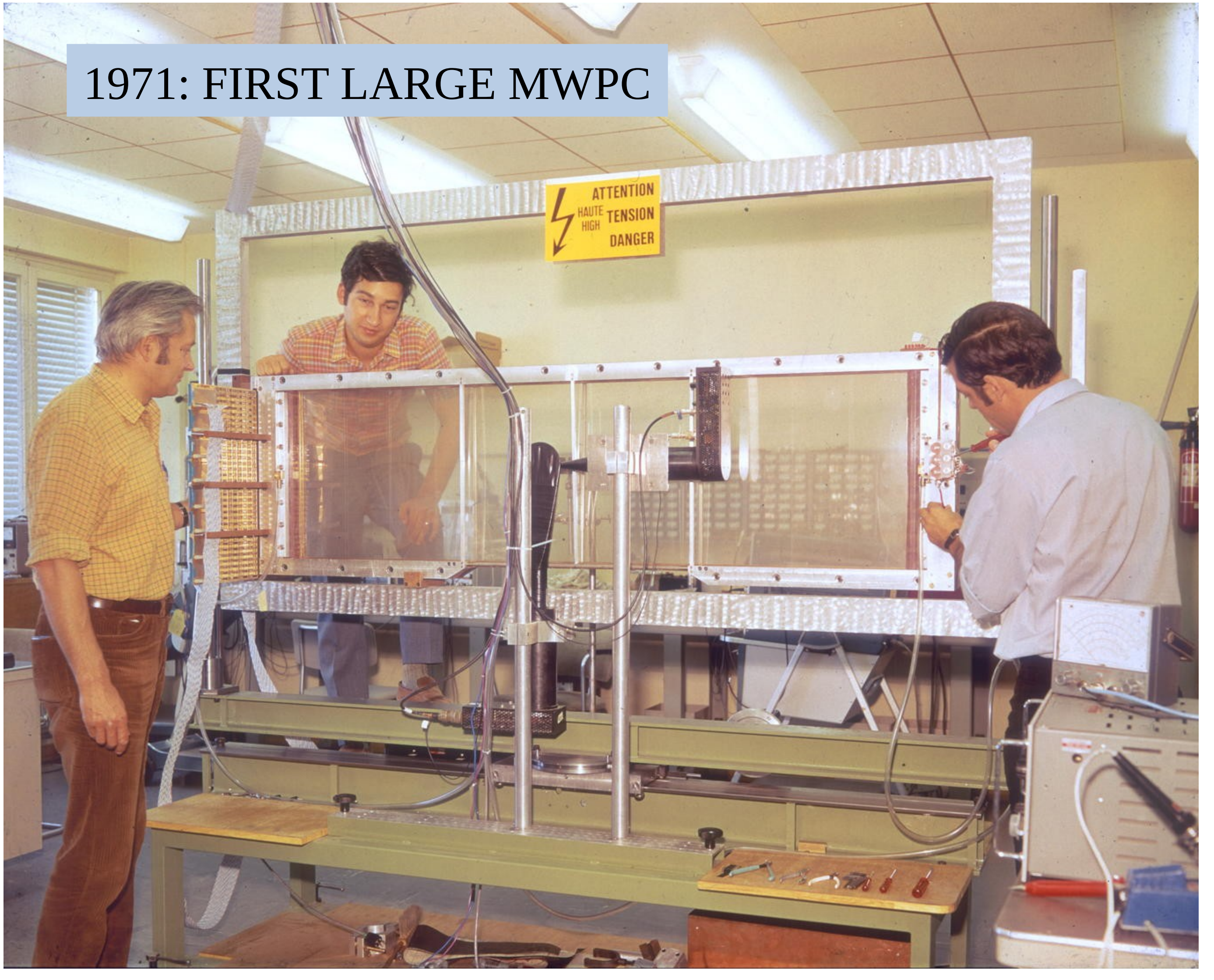
1968:MULTIWIRE PROPORTIONAL CHAMBER (MWPC)





- SUB-mm SPACE ACCURACY
- PROPORTIONAL GAIN 10^6
- SINGLE ELECTRON SENSITIVITY
- 10 ns TIME RESOLUTION
- 1 MHz / cm^2 RATE

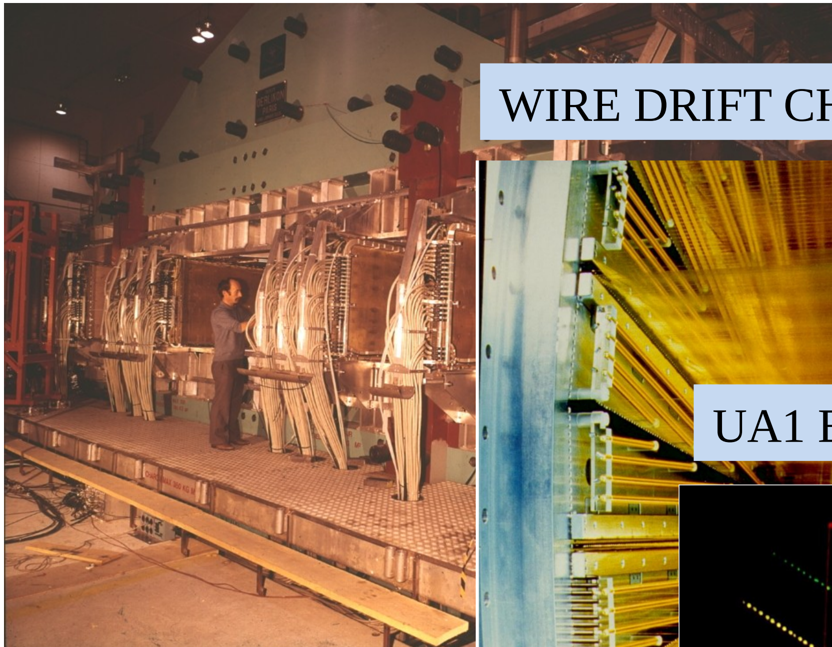
G. Charpak et al Nucl. Instr. Meth. 62 (1968) 262



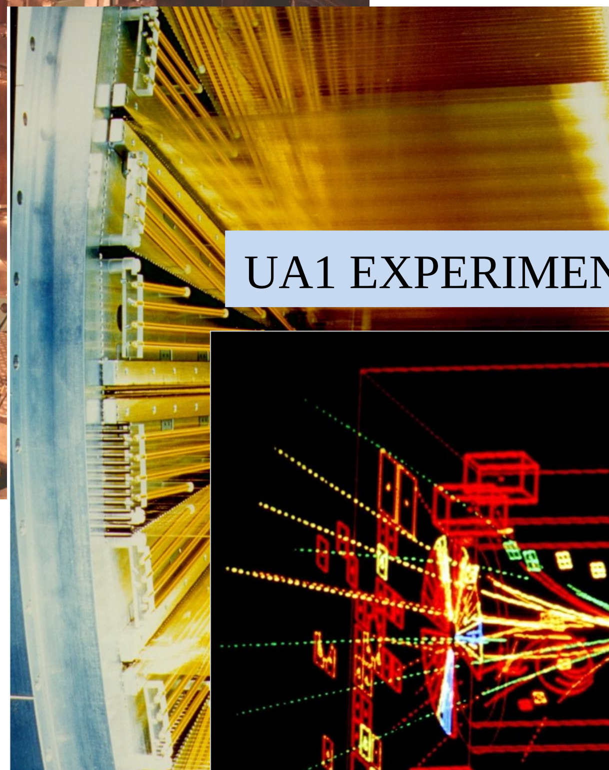
G. Charpak et al, Nucl. Instr. Meth. 97 (1971) 377

REALITY

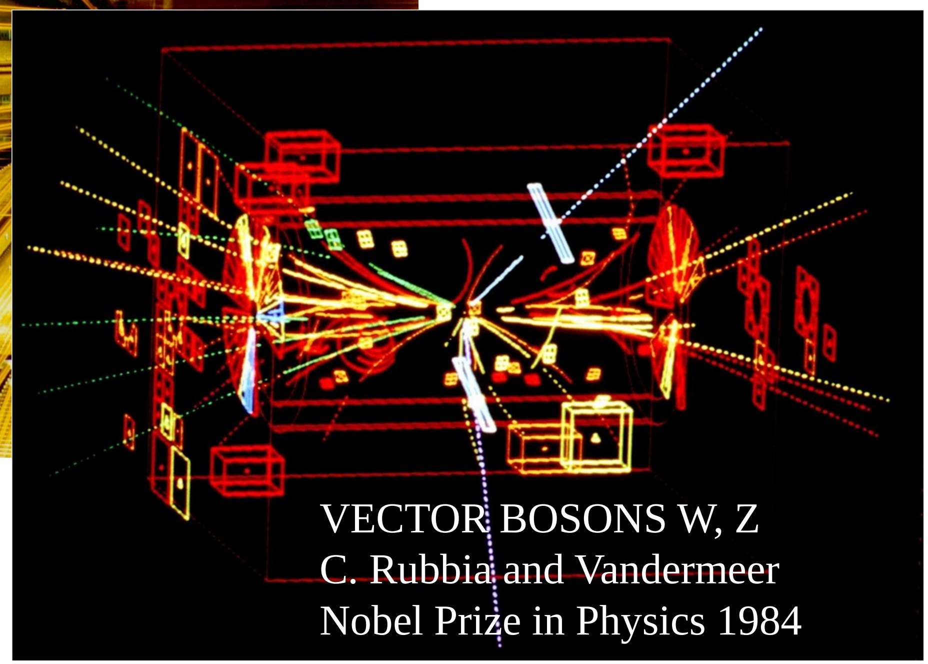
SPLIT FIELD MAGNET DETECTOR (CERN ~1972)



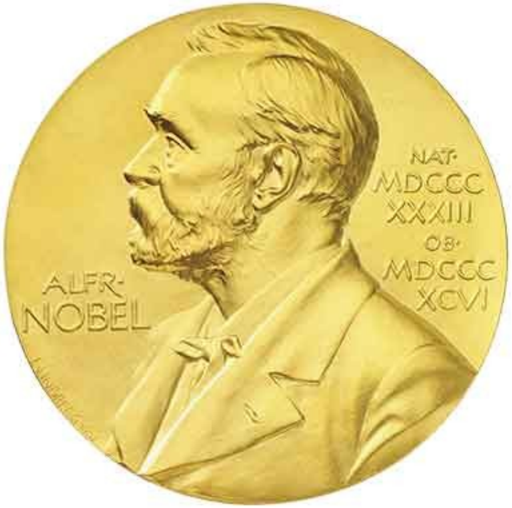
WIRE DRIFT CHAMBER (CERN ~1982)



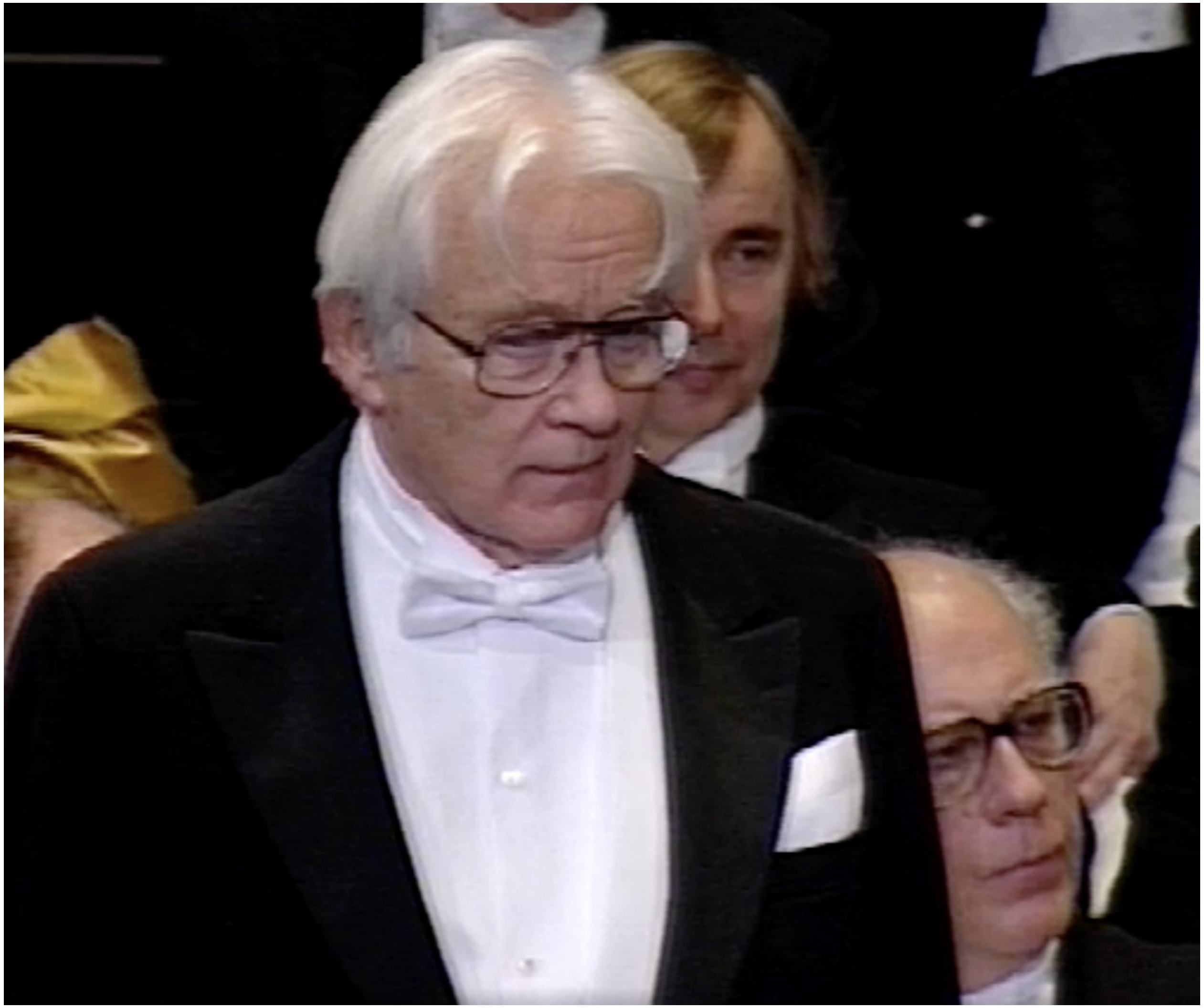
UA1 EXPERIMENT AT CERN (1987)



...AND MANY OTHERS...

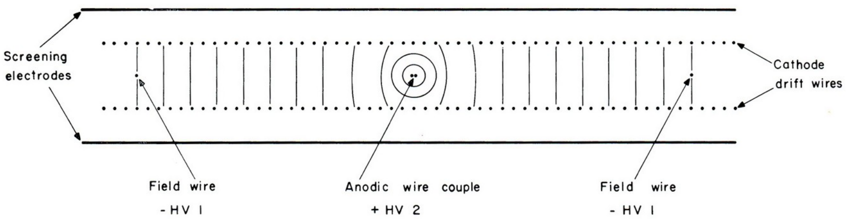


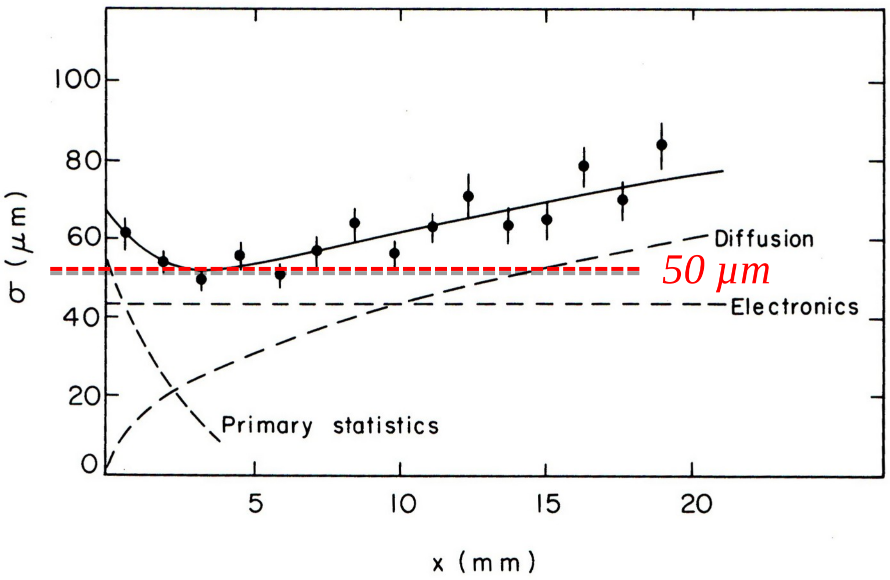
Nobel Prize 1992



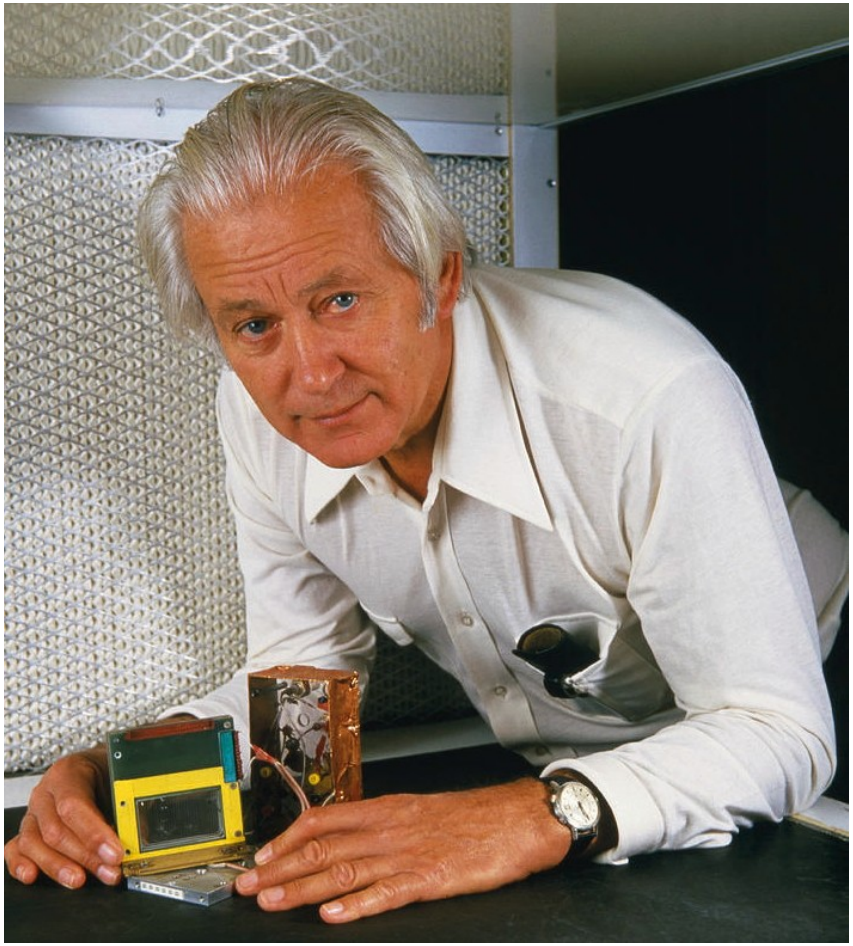
HIGH ACCURACY DRIFT CHAMBERS

REALITY





G. Charpak, F. Sauli and W. Duinker,
Nucl. Instr. Meth. 108(1973)108



NOT THE MWPC!

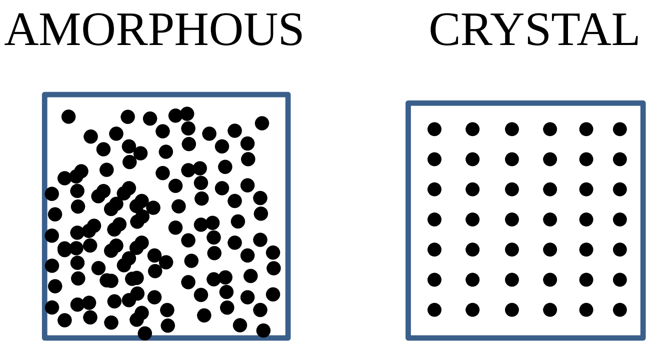
REALITY

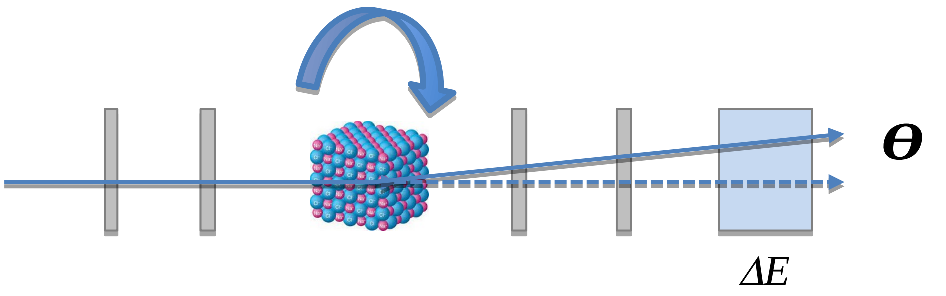
LARGE HIGH-ACCURACY DRIFT CHAMBER
FOR CERN OMEGA SPECTROMETER

$4 \times 2\ m^2$ DETECTOR

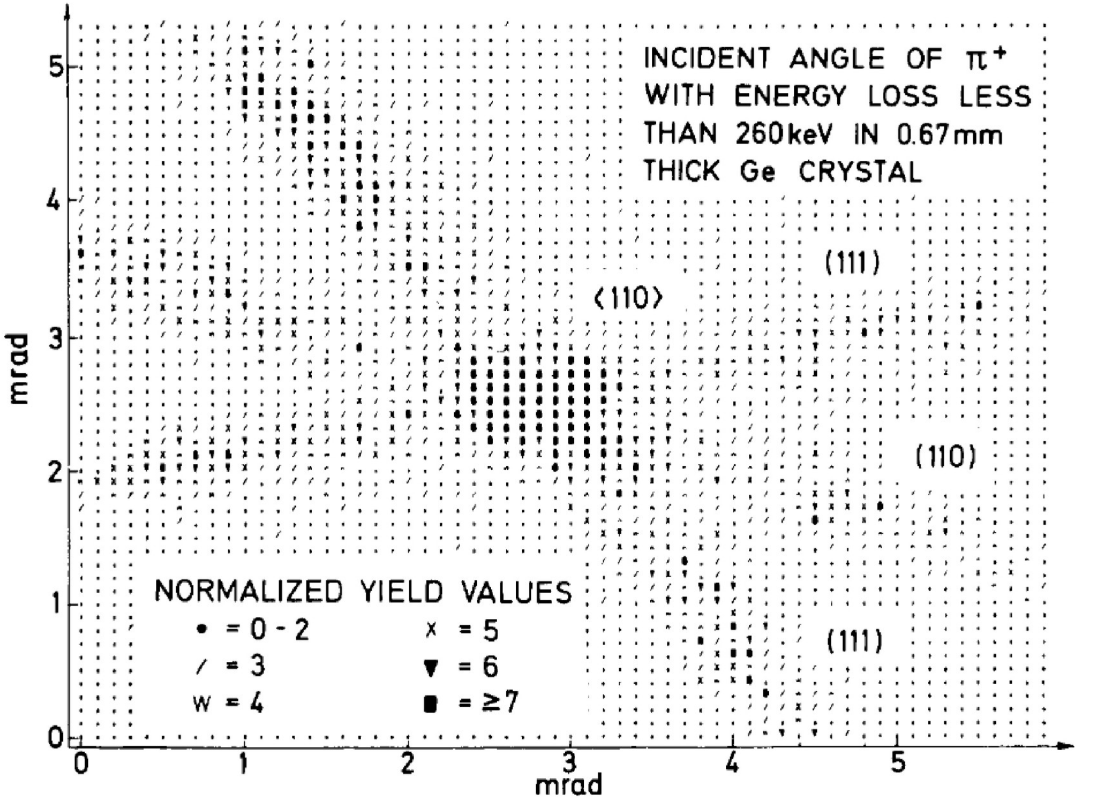
100 μm RESOLUTION

CHARGED PARTICLES CHANNELING



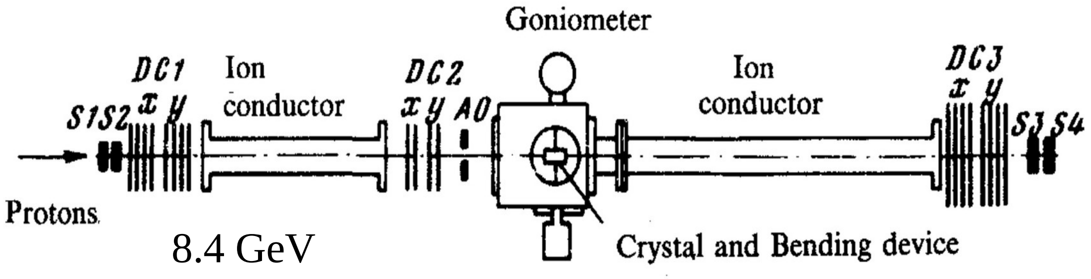


ANGULAR DISTRIBUTION OF PARTICLES WITH $\Delta E < 26$ 0 keV



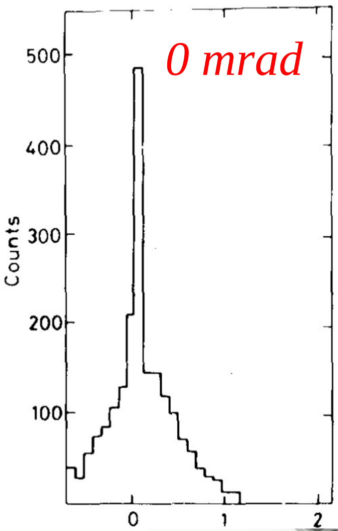
1976: HIGH ACCURACY DRIFT CHAMBERS
K-e SCATTERING EXPERIMENT AT FERMILAB

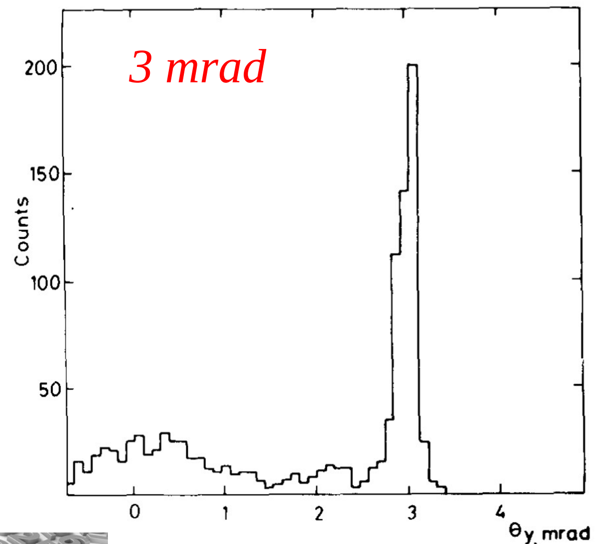
E. Tsyganov (Joint Institute for Nuclear Research, Dubna)

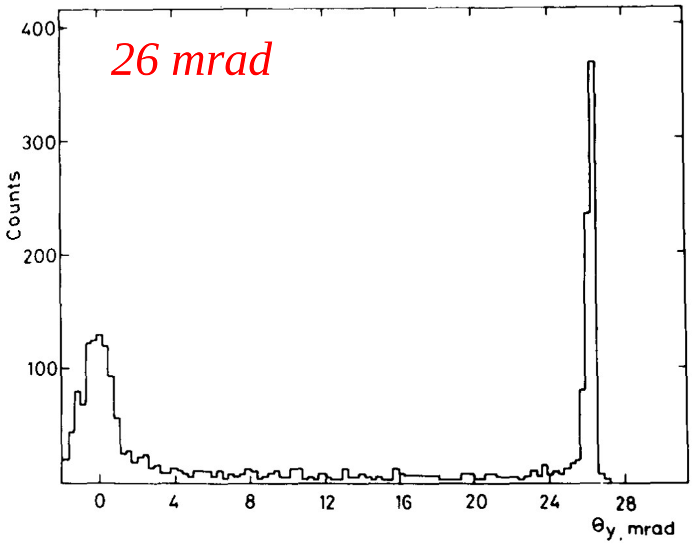


8.4 GeV

CRYSTAL BENDING ANGLE:







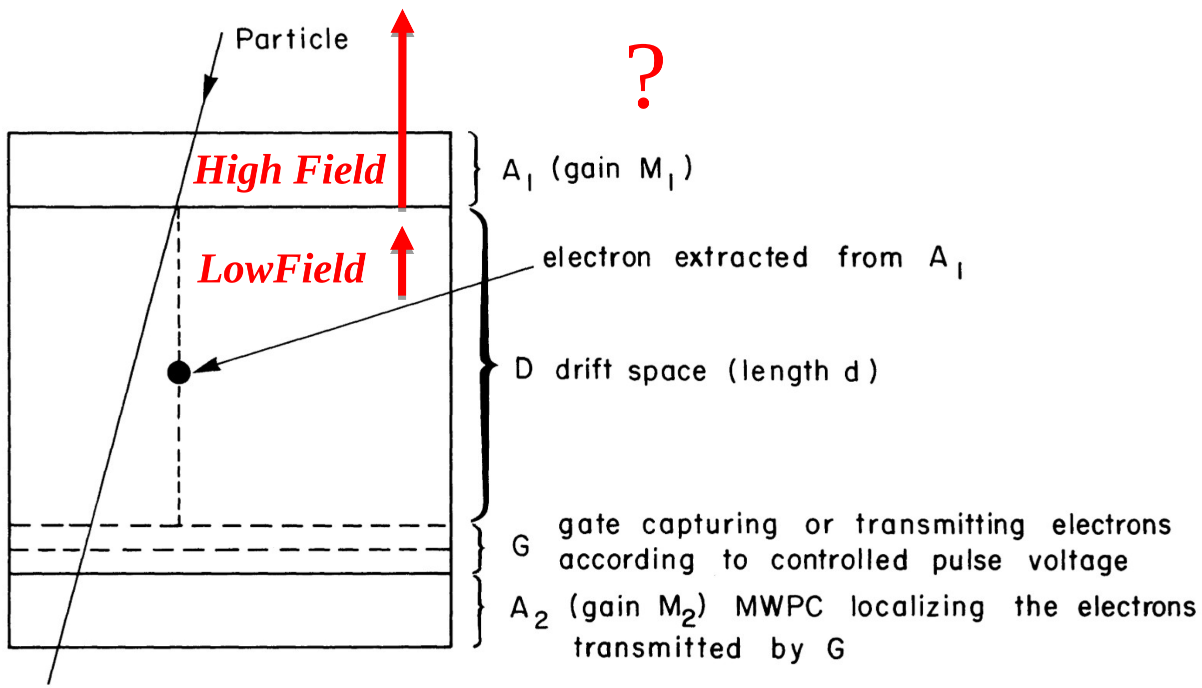
S. Redaelli et al, First observation of ion beam channeling in bent crystals at multi-TeV energies Eur. Phys. J. C (2021) 81

2 mm Crystal ≈ 100 Tesla!

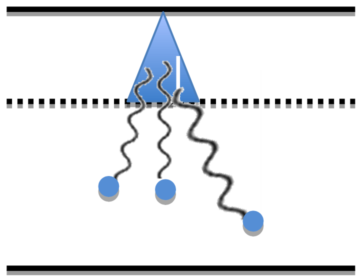
BETWEEN REALITY AND IMAGINATION

NEW APPROACHES TO HIGH-RATE PARTICLE DETECTORS
G. Charpak et al, CERN YELLOW REPORT 78-05
1 - THE GATED MULTISTEP CHAMBER
2 - ELECTRON ACCELERATION IN VACUUM

1 - GATED MULTISTEP CHAMBER



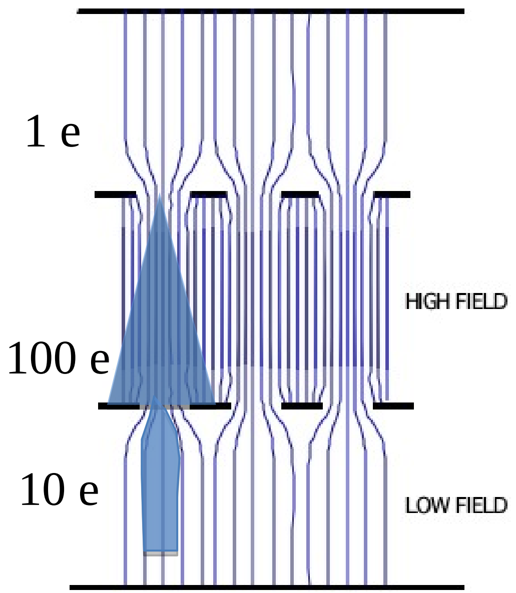
Photosensitive gas (TEA)
Photon-mediated

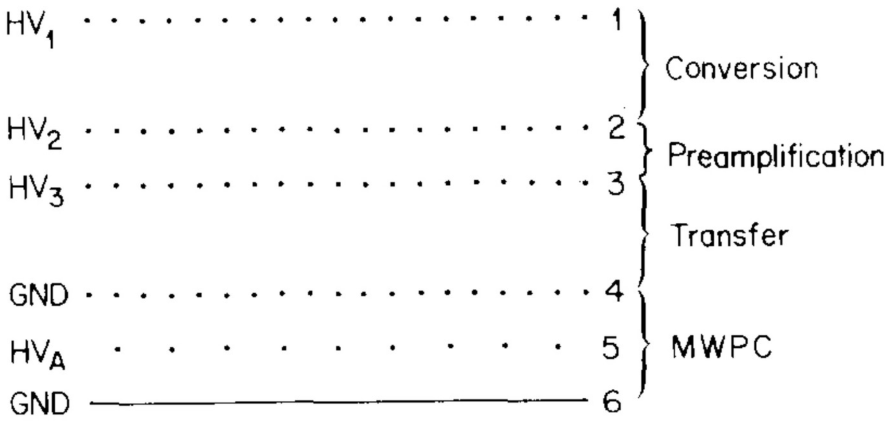


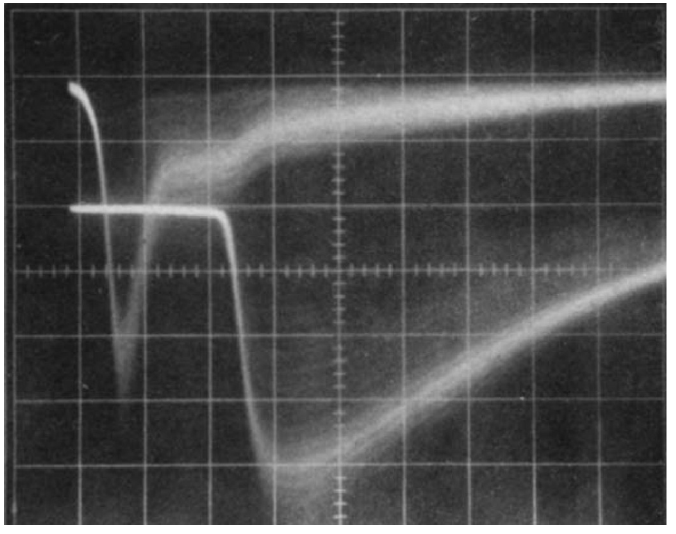
ELECTRONS PREAMPLIFICATION AND TRANSFER

MULTISTEP CHAMBER

Avalanche
Electron Diffusion



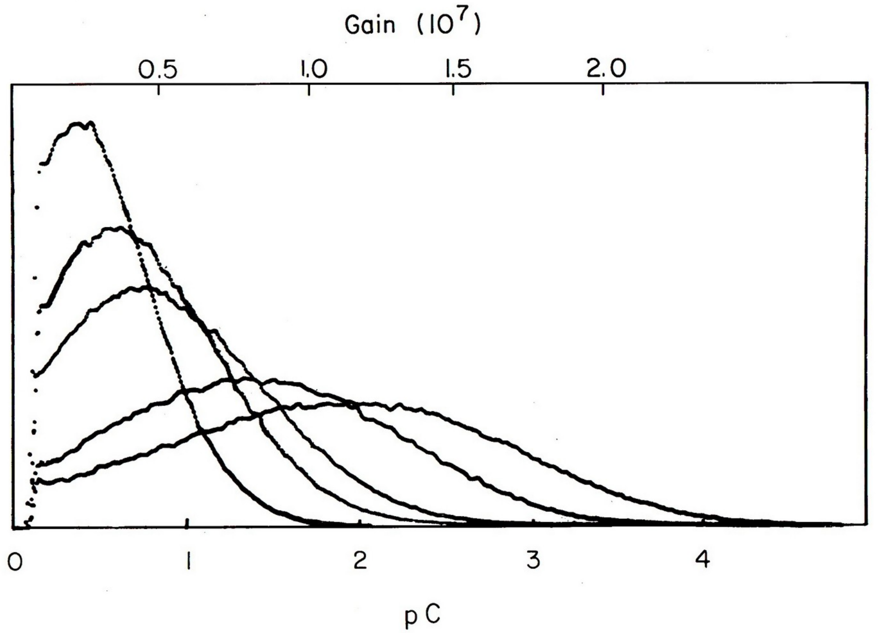




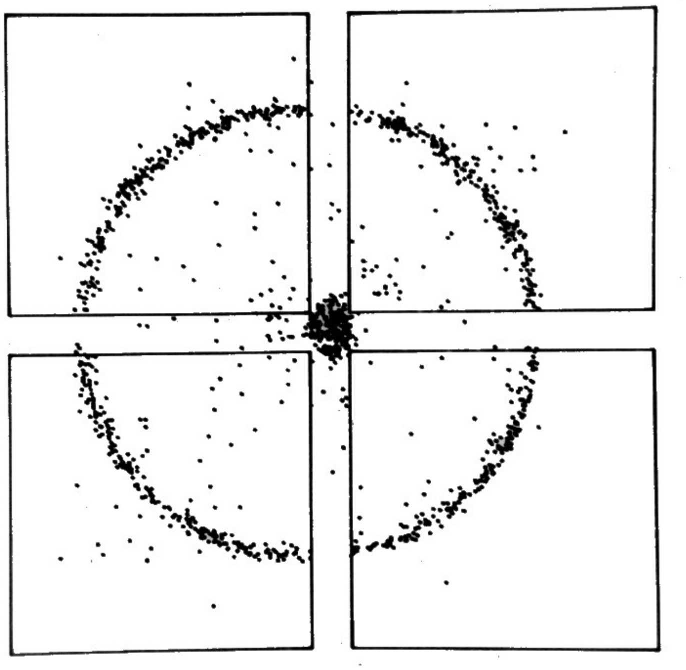
G. Charpak and F. Sauli, Phys. Letters 78B (1978) 523

THE MULTISTEP CHAMBER:
VERY HIGH GAINS IN PHOTOSENSITIVE GASES

SINGLE PHOTON PULSE HEIGHT SPECTRA

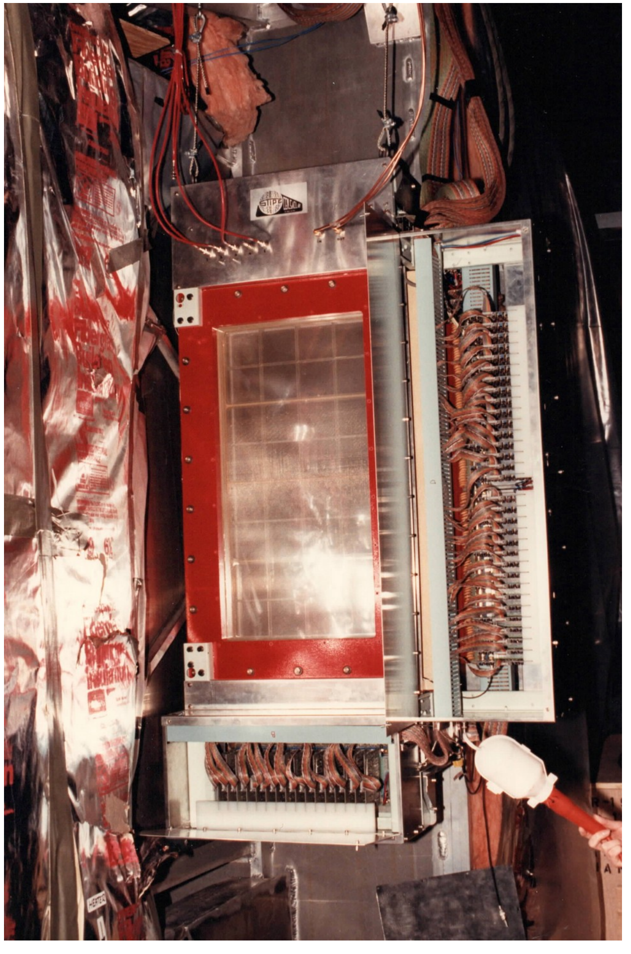


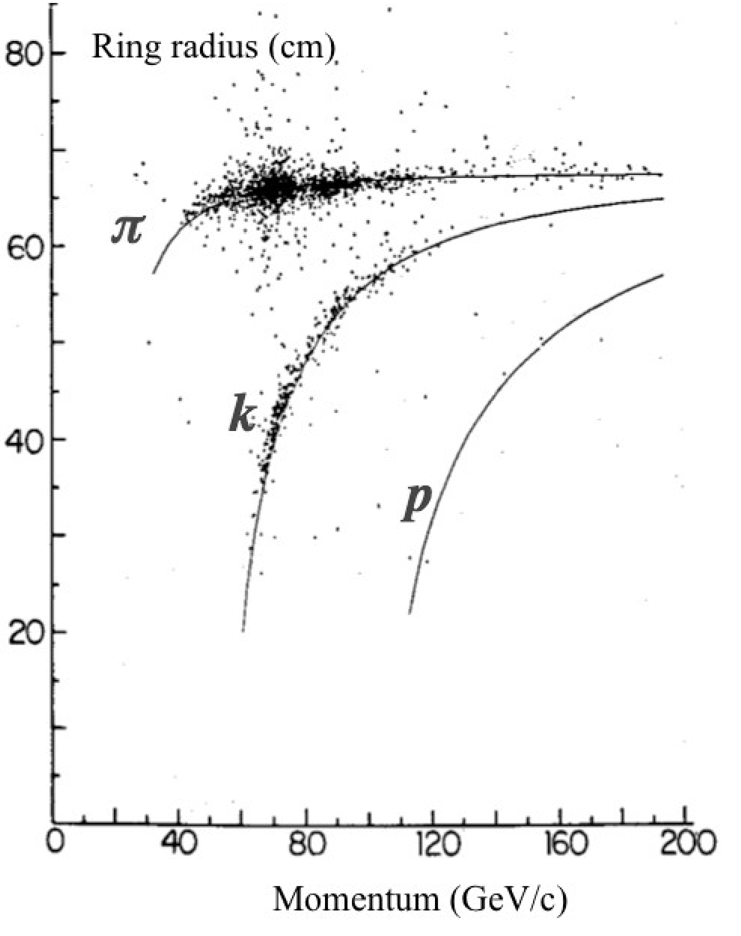
CHERENKOV RINGS IMAGING



G. Charpak, S. Majewski, G. Melchart, F. Sauli and T. Ypsilantis
Nucl. Instr. Meth. 164 (1979) 419

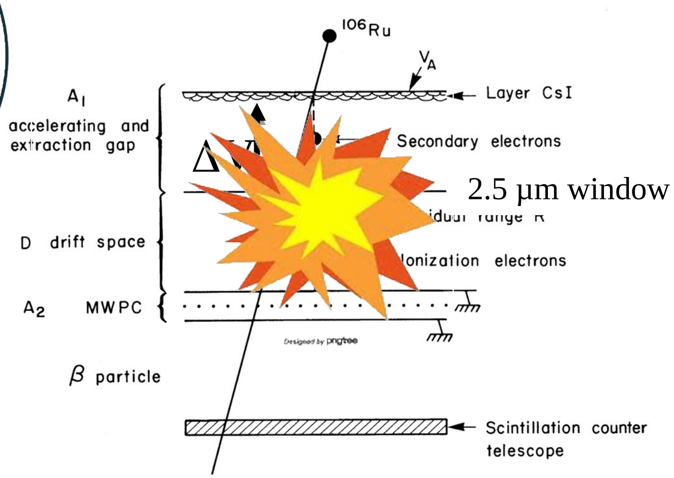
MULTISTEP CHAMBER WITH TEA FILLING
FERMILAB E605 RICH PARTICLE IDENTIFIER

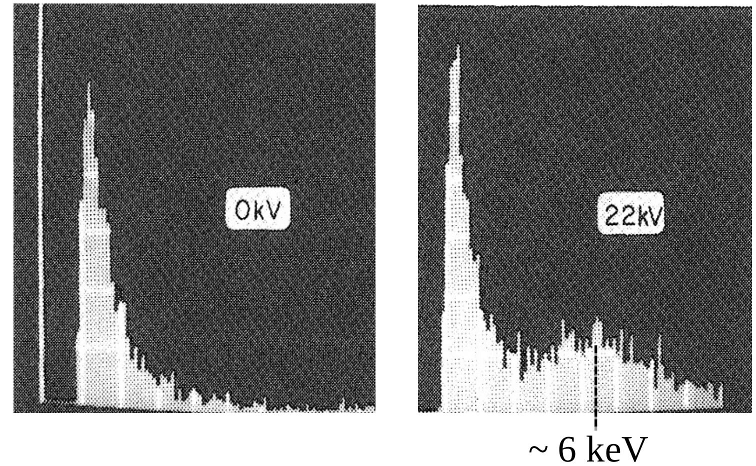




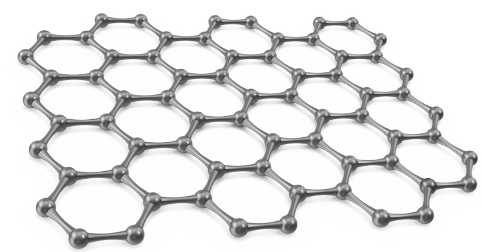
P. Mangeot et al, Nucl. Instr. Meth. 216 (1983) 79

2 - ELECTRON ACCELERATION IN VACUUM





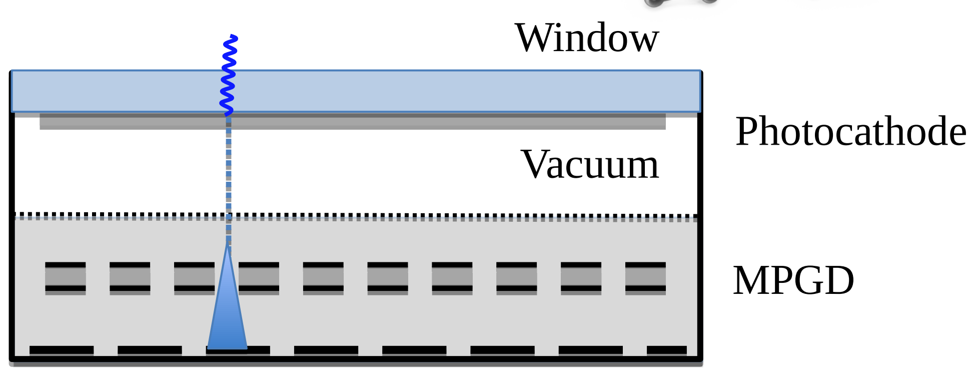
IMAGINATION ?



NEW DEVELOPMENTS: SUPER-STRONG GRAPHENE FOILS

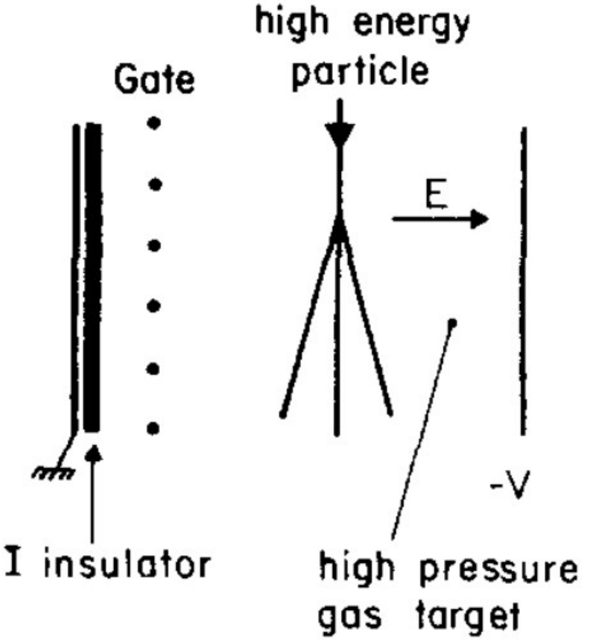
P. Sun et al: Gas Impermeabily of Graphene, Nature 579 (2020)229

VACUUM PHOTOCATHODE
+
GAS MPGD
?



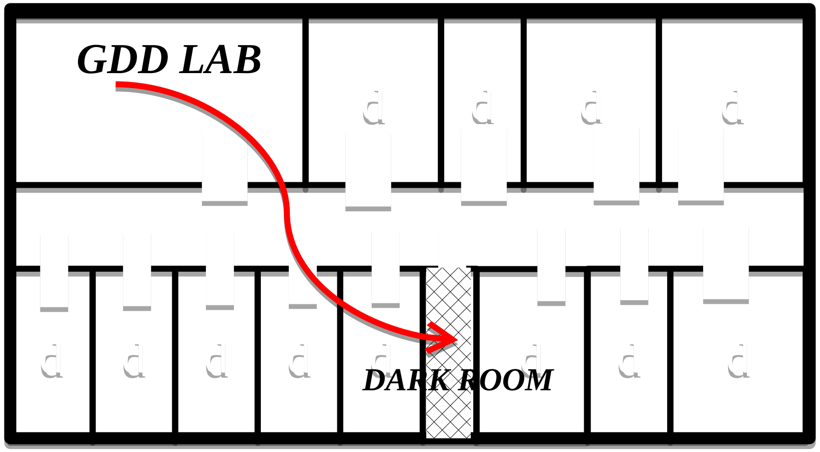
ELECTROSTATIC IMAGING
OF PARTICLE TRAJECTORIES

DETECTION OF
IONISATION COLLECTED
ON THE INSULATOR

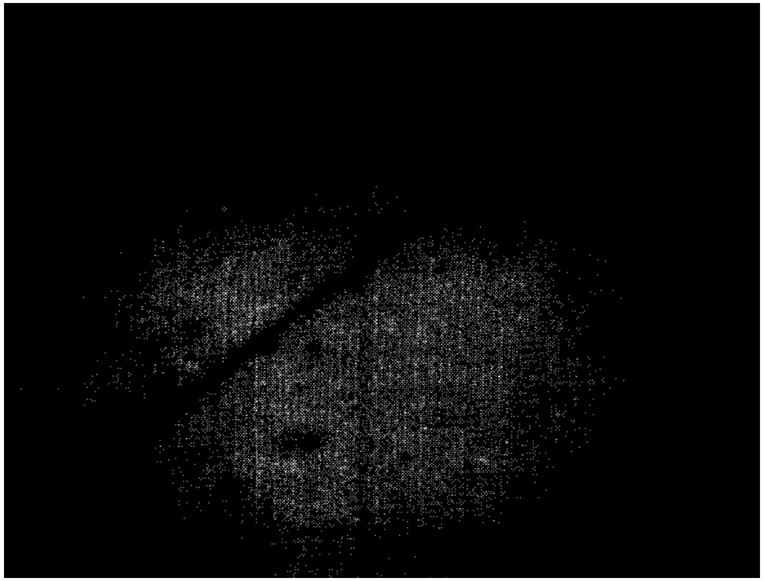


G. Charpak, R. Bouclier, A. Breskin, R. Chechik and J. Lewiner
Nucl. Instr. Meth. 192(1982)235

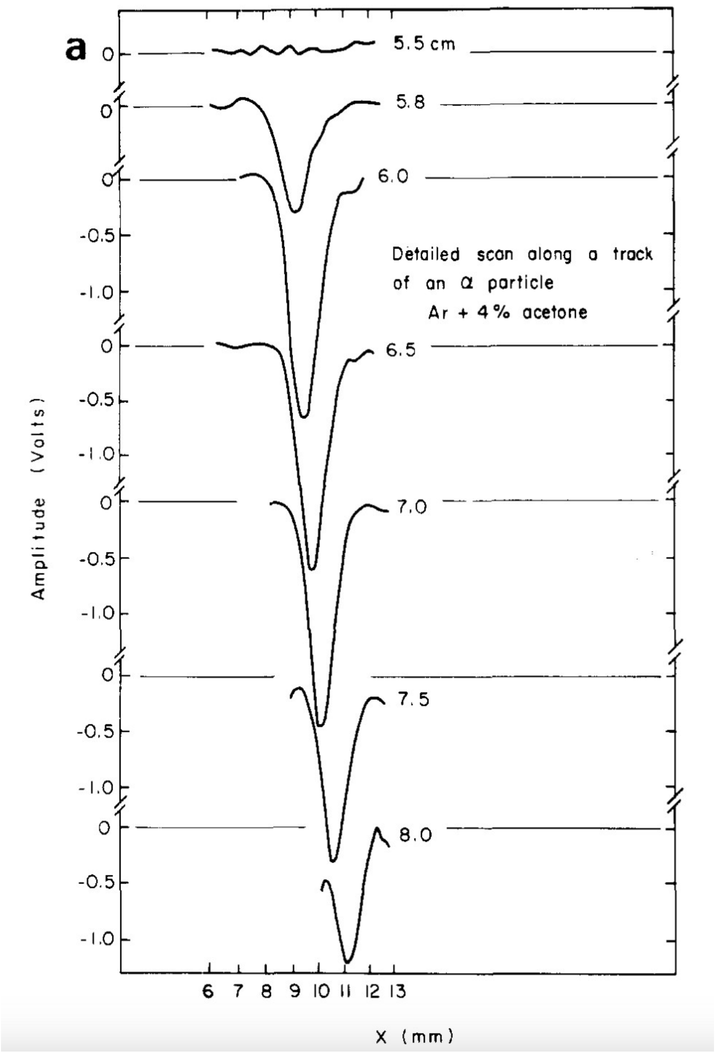
CARBON POWDER TONER FOR CHARGE VISUALIZATION



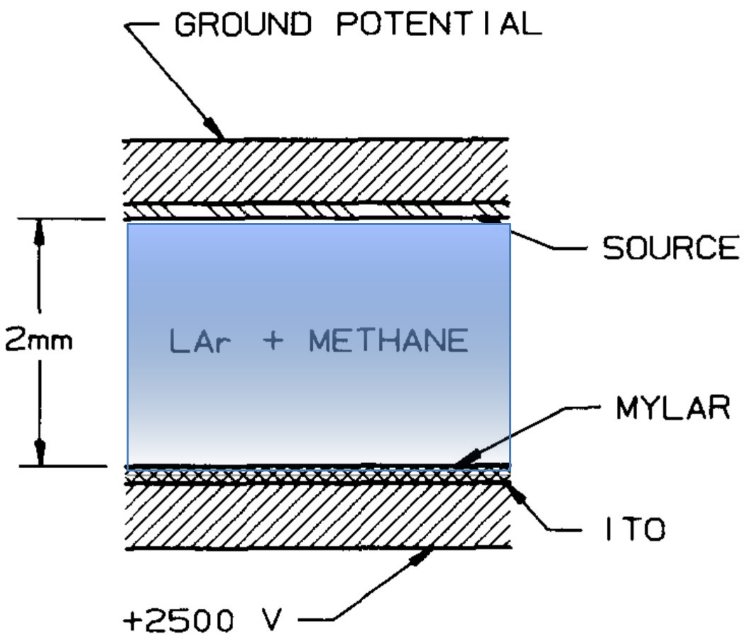
ALPHA PARTICLE TRACK + BACKGROUND



TRACK SCAN WITH ELECTROSTATIC MILLIVOLTMETER



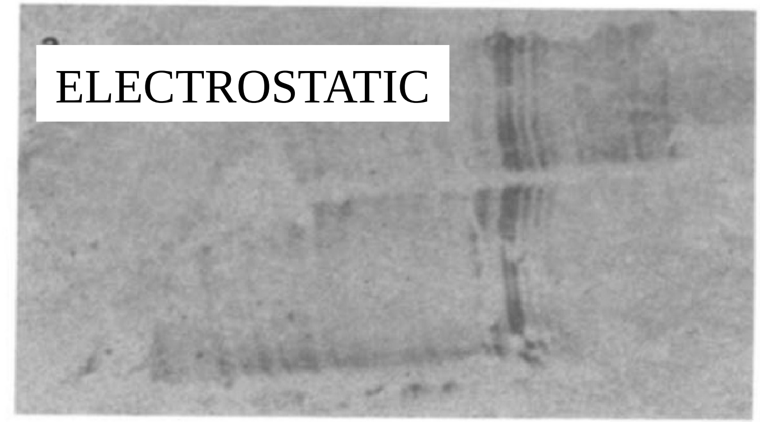
ELECTROSTATIC IMAGING IN LIQUID ARGON



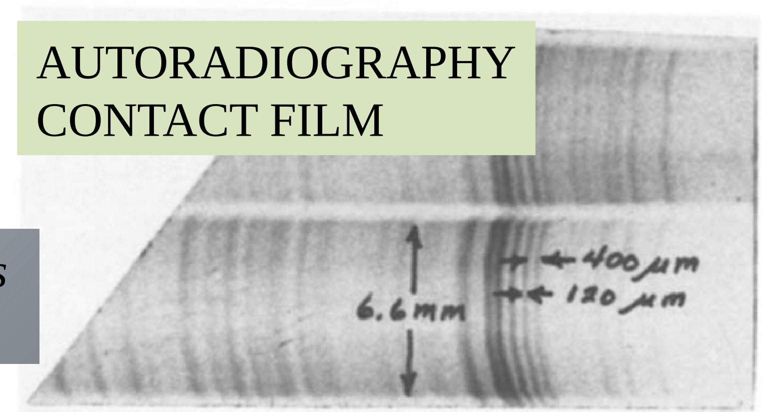
G. Charpak, D. F. Anderson and B. J. Kross
Nucl. Instr. Meth. 260 (1987) 365

RADIOCHROMATOGRAPHY OF BETA-EMITTING GEL

ELECTROSTATIC



AUTORADIOGRAPHY CONTACT FILM



ONLY IMAGINATION?
WIMPS AND DARK MATTER DETECTORS: MEGATONS LIQUID ARGON TPC
MILLIONS OF ELECTRONIC CHANNELS ➽ (ALMOST) NO EVENTS

PURE IMAGINATION

Physics Report 99 (1983) 341

NEUTRINO EXPLORATION OF THE EARTH*

A. De RÚJULA
CERN, Geneva, Switzerland

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R.R. WILSON
Physics Department, Columbia University, New York, NY 10027, U.S.A.

and

G. CHARPAK
CERN, Geneva, Switzerland

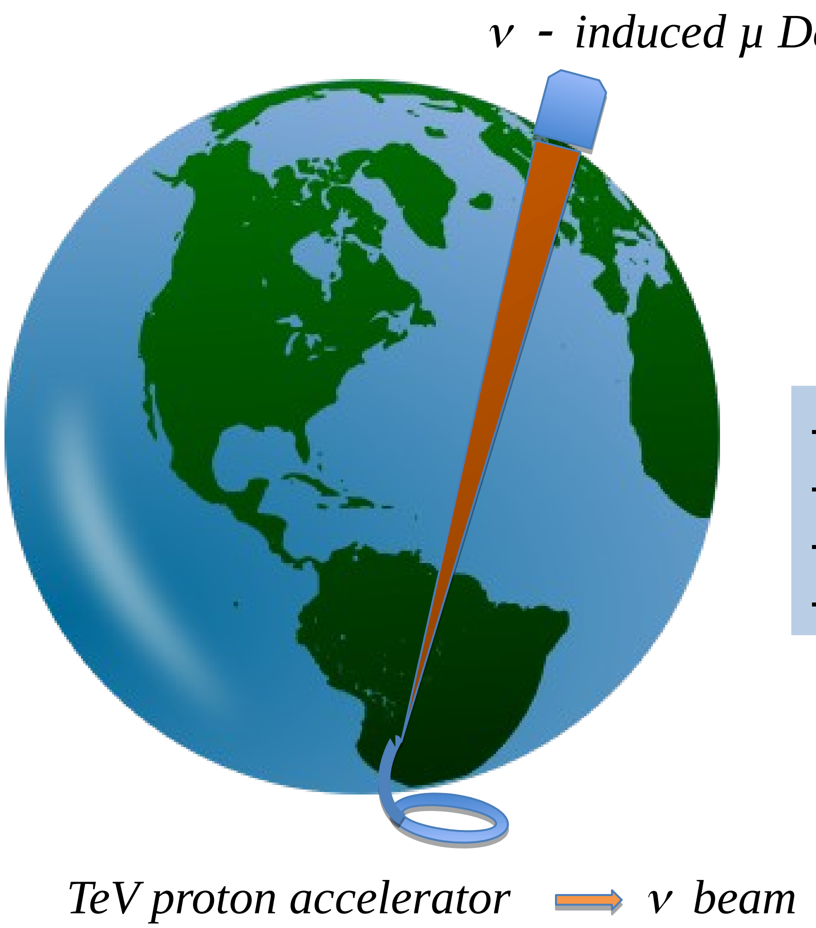
Received May 1983

CERN
Cosmology
Neutrino Physics

1979 Nobel
Laureate in Physics

First FERMILAB director
1967-1978

1992 Nobel Laureate in Physics



- Search for deep oil and gas deposits
- Search for High-Z ores
- 3-D map of Earth's core
- ……..

…NEUTRINO ENERGY SPECTRUM…

$$\frac{d^2N}{dx\, dE_\nu} \propto \frac{1}{E}\left\{\frac{m_\pi^2 - m_\mu^2}{EE_\nu} - \frac{m_\pi^2}{E^2} - \frac{x^2}{L^2}\right\}^{-1/2} \tag{3.14}$$

where L is the distance to the accelerator and x is the vertical distance to the center of the neutrino beam. This flux of neutrinos passing through the Earth produces the distribution of deposited energy

$$\frac{dW(E)}{dx} \propto \frac{1}{E}\int E_\nu^2\, dE_\nu \left\{\frac{m_\pi^2 - m_\mu^2}{EE_\nu} - \frac{m_\pi^2}{E^2} - \frac{x^2}{L^2}\right\}^{-1/2}, \tag{3.15}$$

where one factor of E_ν reflects the linear dependence of $\sigma_{\nu N}(E_\nu)$, and the other takes into account the energy deposition of each neutrino. The integration is carried out over the kinematically allowed range of neutrino energies to give

$$dW(E)/dx \propto E^{-4}(m_\pi^2/E^2 + x^2/L^2)^{-7/2}. \tag{3.16}$$

This is the energy deposition profile produced by a neutrino beam originating from a perfectly collimated beam of monochromatic pions.

Next, we determine the energy spectrum $f(E)$ of collimated pions which reproduces the shape of the observed neutrino energy spectrum (3.1). A beam of pions of energy E yields a normalized neutrino spectrum given by

$$S(E, E_\nu) = \frac{1}{E'}\,\theta(E' - E_\nu) \tag{3.17}$$

where $\theta(x) = 1$ for $x > 0$ and $\theta(x) = 0$ for $x \le 0$, and $E' = (m_\pi^2 - m_\mu^2)m_\pi^{-2}\,E$ is the maximal neutrino energy. We require that

$$\int_0^\infty f(E)\, S(E, E_\nu)\, dE \propto \exp(E_\nu/\langle E_\nu\rangle), \tag{3.18}$$

and find

$$f(E) \propto E \exp - (E/E_\pi) \tag{3.19}$$

$$E_\pi = m_\pi^2\langle E_\nu\rangle/(m_\pi^2 - m_\mu^2). \tag{3.20}$$

From (3.16) and (3.19) we deduce the energy deposition due to a neutrino beam with the correct energy distribution (3.1) generated by a well focused pion beam:

$$dW/dx \propto \int_0^\infty f(E)\frac{dW(E)}{dx}\, dE. \tag{3.21}$$

…SONIC NEUTRINO DETECTOR….

function of the frequency interval

$$d\langle a^2\rangle/df \quad \text{in cm}^2/\text{Hz} \tag{5.1}$$

as measured by Fix [23], at a very quiet location 130 m underground in Las Cruces, NM. The three curves labelled I, II, III are from data gathered by Bruce and Oliver [24]. They correspond, respectively, to noisy, average, or quiet surface situations. The quiet surface measurements of Bruce and Oliver agree with the Fix measurement at depth. We assume that these correspond to the true background noise, with surface waves subtracted, and we use this data for our signal-to-noise estimates. An "average" site is about one order of magnitude noisier in sonic amplitude than a "quiet" site. In fig. 5.1b we show again the Fix data, and a power-law fit at average and quiet surface sites. For the quiet location, the fit is

$$d\langle a^2\rangle/df = 10^{-14}(\text{Hz}/f)^{4.4}\ \text{cm}^2/\text{Hz}. \tag{5.2}$$

In fig. 5.1c, we show observations of noise levels at shallow depths in the sea [25]. These are of interest in view of possible applications of our methods to the geological exploration of off-shore sites, and because they extend to higher frequencies. The curves labelled I and II correspond to maximal and minimal prevailing noise levels. What is plotted is

$$(\text{noise level/Hz}) \text{ in ``decibels''} = 10\log_{10}\left\{\frac{d\langle p^2\rangle}{df}\,\frac{\text{Hz}}{[2\times 10^{-4}\ \text{dynes/cm}^2]}\right\} \tag{5.3}$$

where $d\langle p^2\rangle$ is the mean-squared sonic pressure in the frequency interval df. The dotted line is thermal noise. The dashed lines are the extrapolations of the fits of fig. 5.1b converted to units appropriate to eq. (5.3),

$$\frac{d\langle p^2\rangle}{df} = (2\pi\rho c)^2\,\frac{d}{df}[f^2\langle a^2\rangle], \tag{5.4}$$

where ρ and c are the density and sound velocity in water. The fall-off of the noise levels in the sea as a function of frequency is seen to follow approximately the same power behavior as in the ground, up to a few hundred Hz. Noise levels at sea decrease exponentially with depth and are 5–10 times smaller in amplitude at a depth of 3 km than at the sea surface in the relevant frequency domain [26].

We now estimate the signal-to-noise ratio for the acoustic signal produced by the neutrino beam at the Earth's surface. Since our signal is a wide band signal, we define a root-mean-square background noise in a frequency window $f_2 > f > f_1$:

$$p(f_1, f_2) = \left[\int_{f_1}^{f_2} \frac{d\langle p^2\rangle}{df}\, df\right]^{1/2}. \tag{5.5}$$

Using (5.2), (5.4) and (5.5), we obtain

$$p(f_1, f_2) = 3.4\times 10^{-2}\left(\frac{\rho}{\text{g/cm}^3}\right)\left(\frac{c}{\text{km/sec}}\right)\left(\frac{\text{Hz}}{f_1}\right)^{0.7}\left[1 - \left(\frac{f_1}{f_2}\right)^{1.4}\right]^{1/2} \tag{5.6}$$

THE PROBLEM: OUR EARTH IS ½ WATER

GROUND-BASED MOBILE MUON DETECTOR

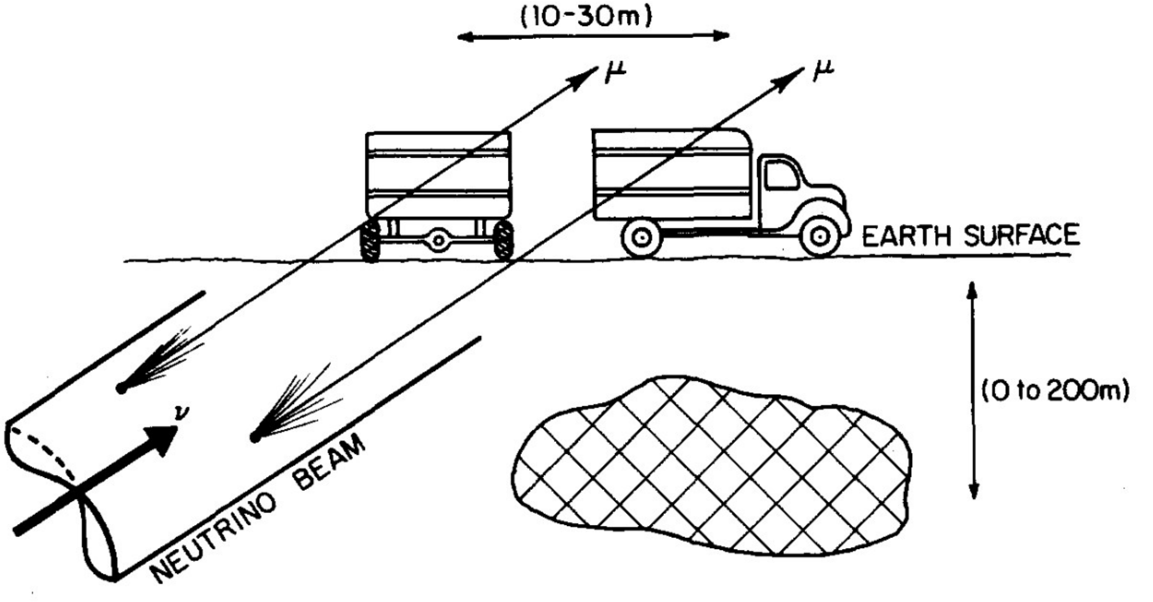


Fig. 7.1. GEMINI's truck-mounted muon detectors.

UNDERWATER 10 TeV ACCELERATOR SUSPENDED TO A SHIP:

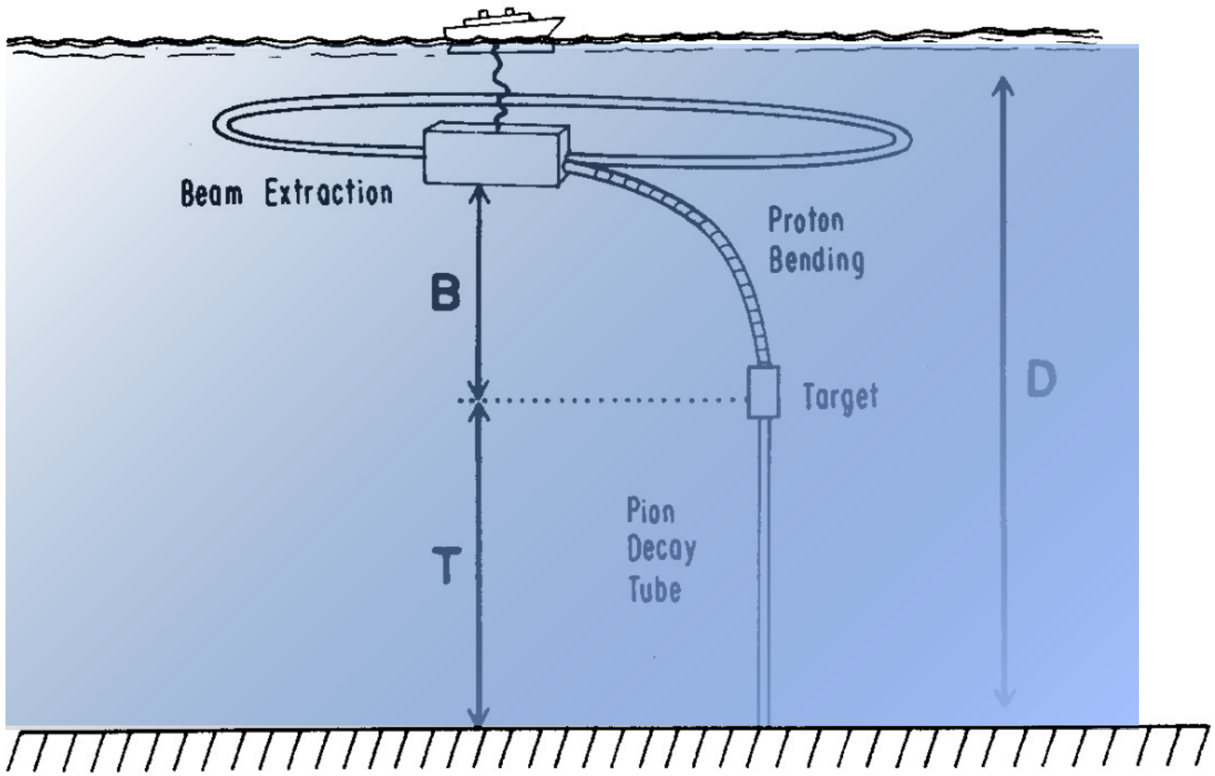


Fig. 8.3. Accelerator and beam deployment at sea, a possibility that suggests itself in a GEOSCAN Project.

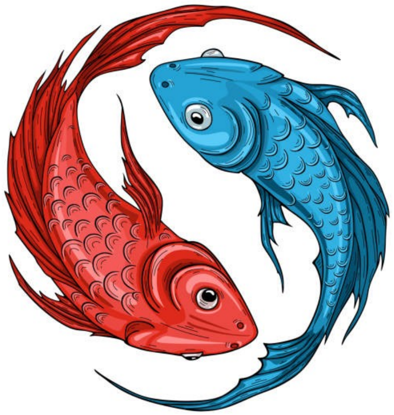
The project we imagine is one of the most ambitious ever conceived by our species. We are thinking of a mobile circular submarine accelerator with a circumference of 100 miles. It rivals the construction of the pyramids, the cathedrals, and the manned space program.

Costs, seemingly so prosaic, are in reality utterly romantic, and in every sense of the word. We have seen that the idiot's delight we started with might cost two billion dollars. With a better design, the Geotron as just described might cost about one billion dollars. By more ingenious people, it might cost less; but it might cost very much more if built under the loving supervision of present day bureaucrats.

WHEN WAS THIS PAPER SUBMITTED?

…… *Received May 1983*

COULD IT BE GEORGES' APRIL FOOL DAY?
FISH



THANKS FOR YOUR ATTENTION

THANKS FOR YOUR ATTENTION