INTERNATIONAL ATOMIC ENERGY AGENCY
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SCHOOL ON NON-ACCELERATOR PHYSICS
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LARGE EXISTING UNDERGROUND DETECTORS

BY

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LARGE EXISTING UNDERGROUND DETECTORS.

INTRODUCTION

WHY UNDERGROUND EXPERIMENTS ?

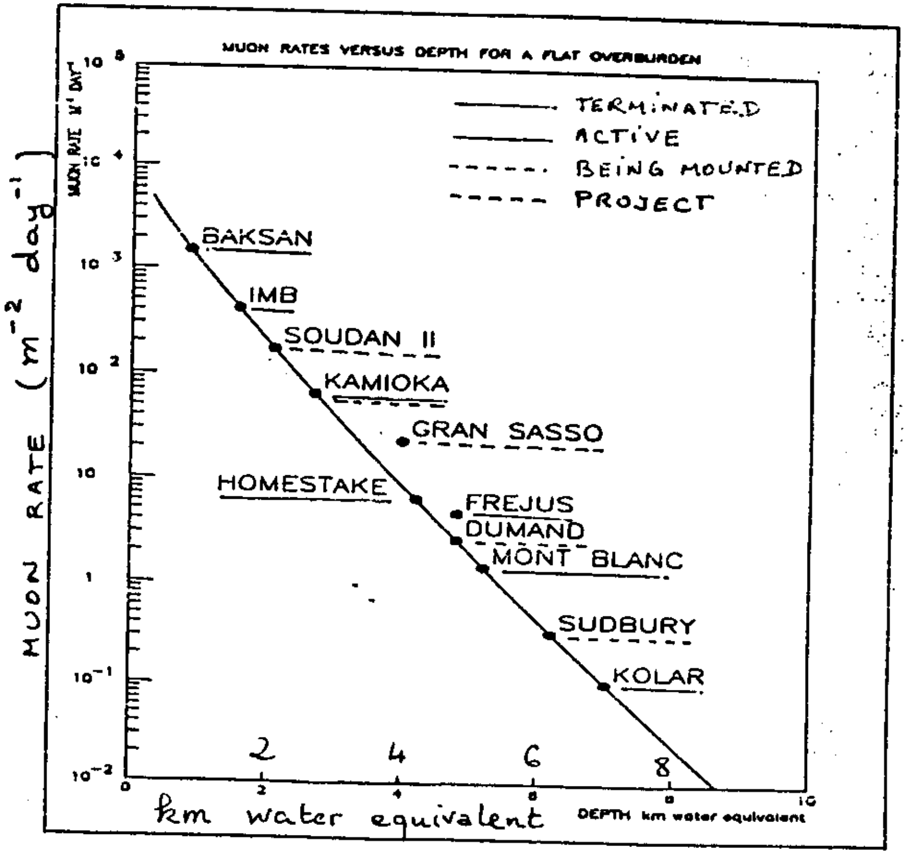
- PHYSICAL MOTIVATIONS
  (Particle Physics & Astrophysics)
- THE DIFFERENT KINDS OF STUDIES COVERED BY LARGE UNDERGROUND DETECTORS

SCHOOL OF NON-ACCELERATOR PHYSICS - TRIESTE 1988

B. Degrange

WHY UNDERGROUND EXPERIMENTS ?

10 years ago : Mainly small experiments ;
few underground labs .



NOW : LARGE UNDERGROUND EXP^L HALLS
DETECTORS WITH MASSES $\gtrsim$ 1000 tonnes
AREAS $\gtrsim$ 100 m^2

NEXT FUTURE : INCREASE MASS (SUPERKAMIOKA 32 000 tonnes)
AREA (MACRO 1000 m^2)

PARTICLE PHYSICS

BARYON NUMBER Violation

LEPTON NUMBER Violation

- ν Flavour Mixing
- ν Oscillations or decay
- ν masses
- WHY $m_\nu \ll m_{\ell, q}$
- Majorana ν $\Delta L = 2$

NEW PARTICLES

- SUSY
- Axion
- Majoron
- Monopoles

BEYOND PRESENT ACCELERATORS

Cosmic-ray phenomena

ASTROPHYSICS

COSMOLOGY: needs Baryon number violation (photon / nucleon ratio)

STANDARD SOLAR MODEL

Contradiction with ^{37}Cl experiment (Davis et al)

SUPERNOVA THEORY

Does the released energy go into ν's ?

DARK MATTER

Differential rotation of galaxies.

May be non baryonic

ORIGIN OF COSMIC RAYS

Localize γ-ray sources

Localize ν sources

Find chemical composition of very high energy C.R.

UNDERGROUND STUDIES:

STABILITY OF MATTER

- NUCLEON DECAY
- DOUBLE BETA DECAY

NEUTRINOS

- SOLAR NEUTRINOS
- SUPER-NOVA ν's
- ATMOSPHERIC ν's
- EXTRA-TERRESTRIAL ν's

MUONS

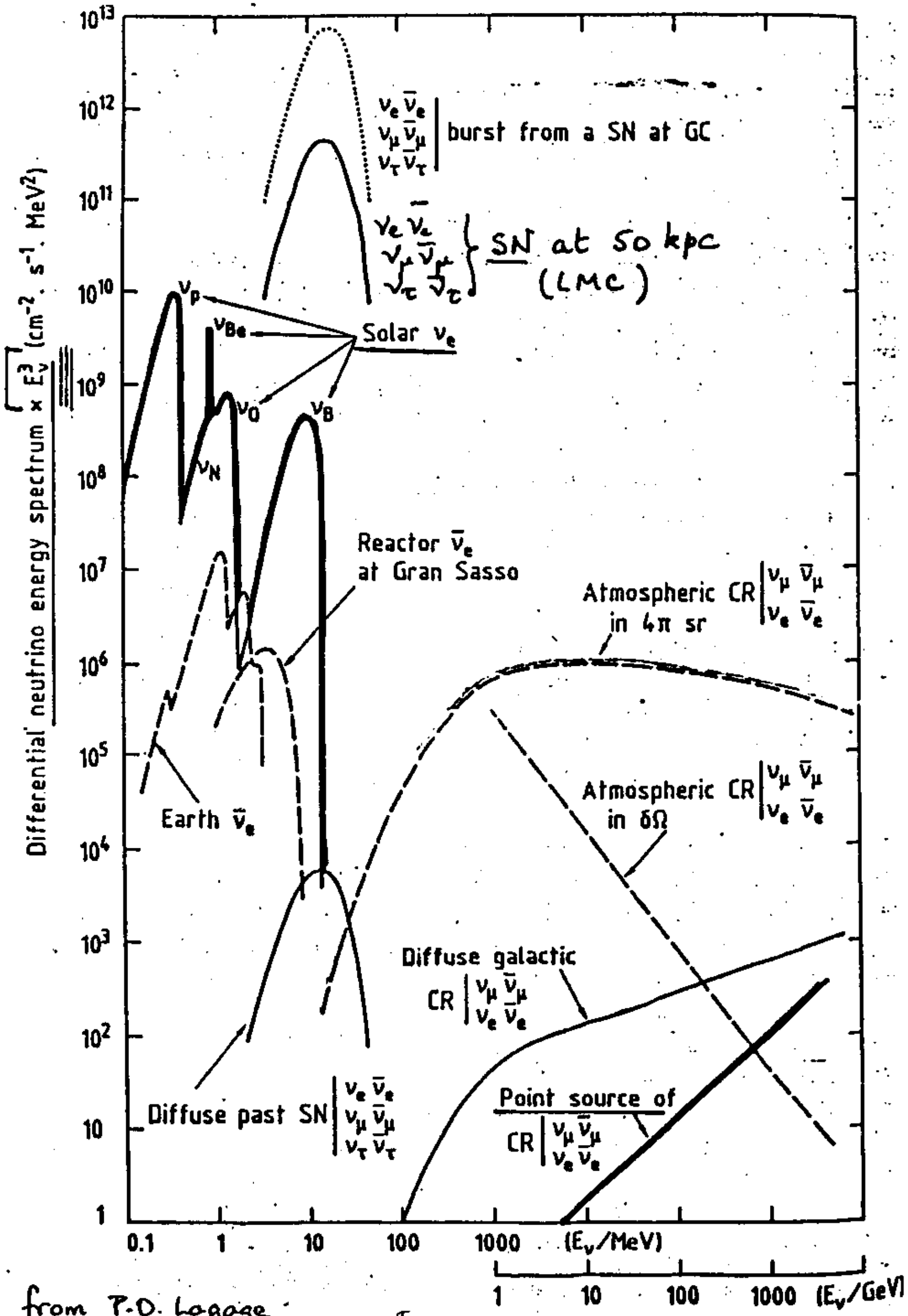
FROM

- EXTENSIVE AIR SHOWERS
- ν INTERACTIONS IN ROCK
- γ-RAYS ? OTHERS ?

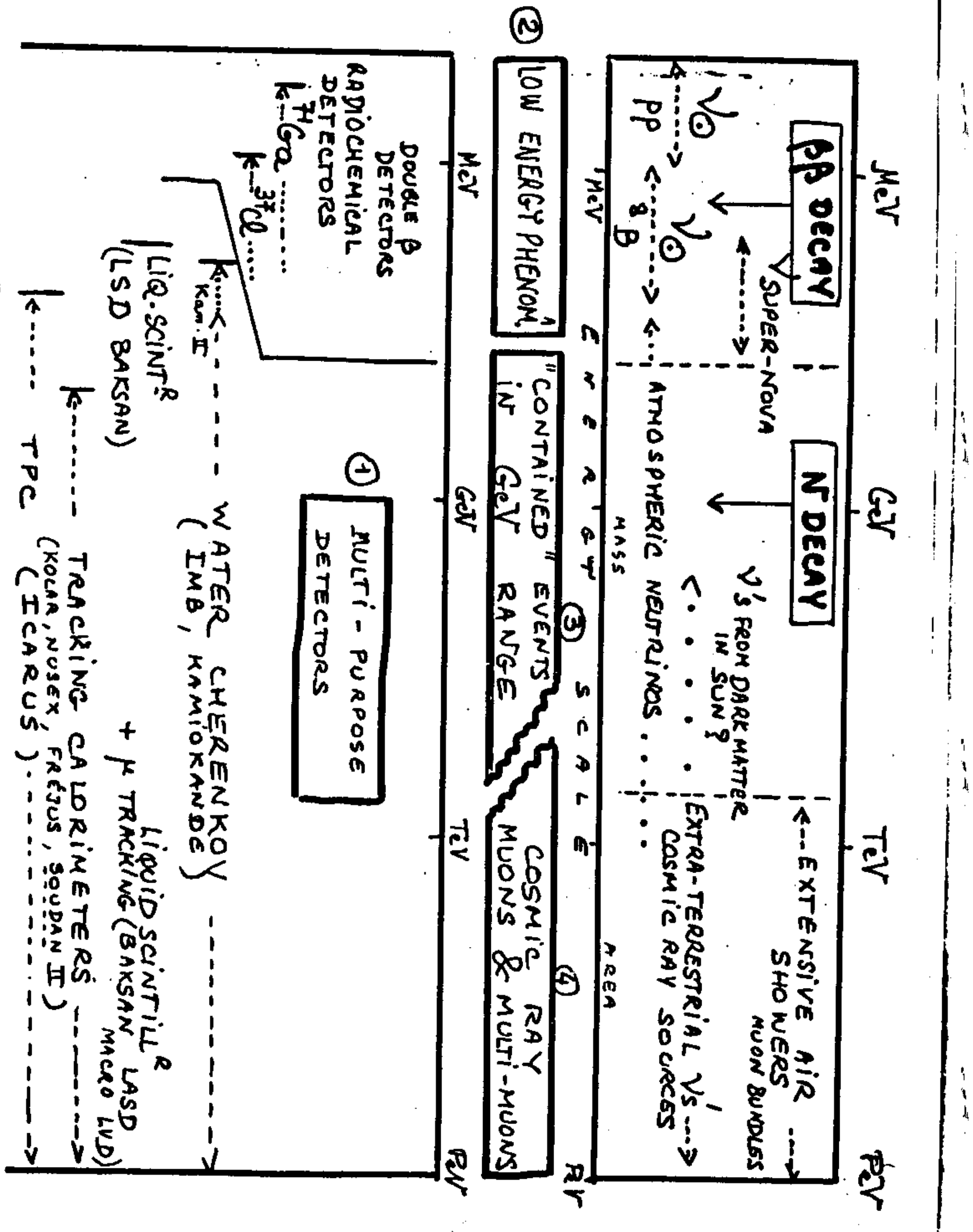
EXOTICS

- MONOPOLES

...



from P.D. Lagage



LARGE EXISTING UNDERGROUND DETECTORS

GENERAL LAY-OUT

- INTRODUCTION

(1)
- MAIN CHARACTERISTICS OF LARGE UNDERGROUND DETECTORS
- LOW ENERGY NEUTRINOS (5 MeV → 100 MeV)
  $\nu_\odot$ FROM ^8B, SUPERNOVAE BURSTS

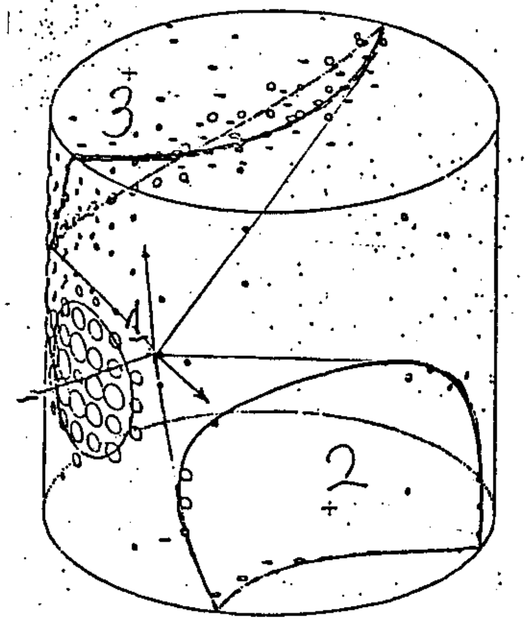
(2)
- "CONTAINED" EVENTS IN THE GeV ENERGY RANGE
  NUCLEON DECAY
  ATMOSPHERIC ν's
  "HIGH ENERGY" SOLAR ν's

(3)
- UNDERGROUND MUONS & MULTIMUONS
  COSMIC RAY SOURCES (ν's)
  COSMIC RAY COMPOSITION IN THE PeV ENERGY RANGE

- CONCLUSIONS & PERSPECTIVES

MAIN CHARACTERISTICS OF LARGE EXISTING UNDERGROUND DETECTORS

- WATER CHERENKOV DETECTORS.
  (e.g. KAMIOKANDE II)
- FINE GRAIN TRACKING CALORIMETERS.
  (e.g. FRÉJUS)
- LIQUID SCINTILLATOR DETECTORS.
  (e.g. BAKSAN)
- GENERAL OVERVIEW



KAMIOKANDE II

WATER CHERENKOV DETECTOR

CHERENKOV LIGHT IN WATER : 42° CONES

948 PHOTO-MULTIPLIER TUBES ON THE WALLS

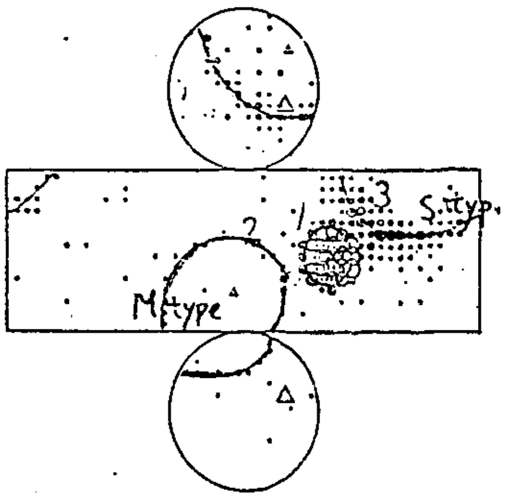
→ RING PATTERNS

SENSE OF TRACK DIRECTION

DISTINGUISH

S-TYPE : SHOWERING PARTICLES ($e\ \gamma$)

M-TYPE : NON SHOWERING PARTICLES (μ, π)

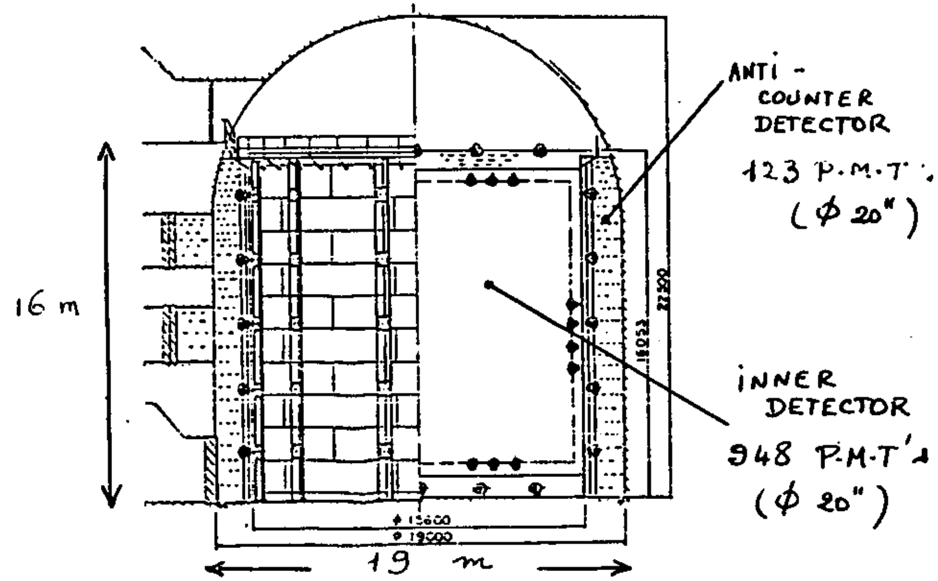


TWO LARGE WATER CHERENKO EXPERIMENTS :

- I.M.B. Morton salt Mine, Ohio, USA
  8000 tonnes 1570 m.w.e.
- KAMIOKANDE : Kamioka Mine, Japan
  3000 tonnes 2700 m.w.e.

KAMIOKANDE II CHERENKOV DETECTOR

(KAMIOKA MINE, JAPAN 2700 m.w.e.)



TOTAL MASS : 3000 tonnes of water

FIDUCIAL MASS (NUCLEON DECAY) : 780 tonnes

FIDUCIAL MASS (LOW ENERGY ν's) : 680 tonnes

~ 20% LIGHT COLLECTED

PHYSICS :

- LOW ENERGY ν's
  - ^8B SOLAR ν's
  - ν BURST FROM SN 1987 A
- NUCLEON DECAY & ATMOSPHERIC ν's
- COSMIC-RAY SOURCES
  - SINGLE μ's (Cyg. X3)
  - UPWARD-GOING μ's (SN 1987 A)

KAMIOKANDE II CHERENKOV DETECTOR

- **TRIGGER** :
  20 P.M.T's WITHIN 100 ns
  (LOW ENERGY ELECTRONS :
  THRESHOLD ~ 7.5 MeV)
  FOR MUONS : THRESH. ~ 165 MeV/c

- **MEASURED QUANTITIES** :
  - CHARGE COLLECTED BY EACH P.M.T.
    CHERENKOV RING PATTERN
    SHOWERING VS. NON SHOWERING
    e, γ μ π $p_{(> 1 GeV)}$
  - TIMES OF P.M.T. SIGNALS
    IMPROVES VERTEX RECONSTRUCT^{N}
    Δx : 1m $\longrightarrow$ 20 TO 50 cm
    MULTI-RING EVENT   IF TIMING AVAILABLE

- **DELAYED SIGNALS** :
  UP TO 10 μs AFTER TRIGGER
  ELECTRONS FROM μ DECAY
  EFFICIENCY ($\mu \to e$ DECAY) 80% in KAMIOKANDE II   (OR $\pi \to \mu \to e$ DECAYS)

- **ENERGY RESOLUTION** :
  $\Delta E / E \sim \frac{3.5\%}{\sqrt{E_{GeV}}}$ 22% AT 10 MeV

CALIBRATION : fast pulsed light sources.
At low energy : Cf-Ni γ source.

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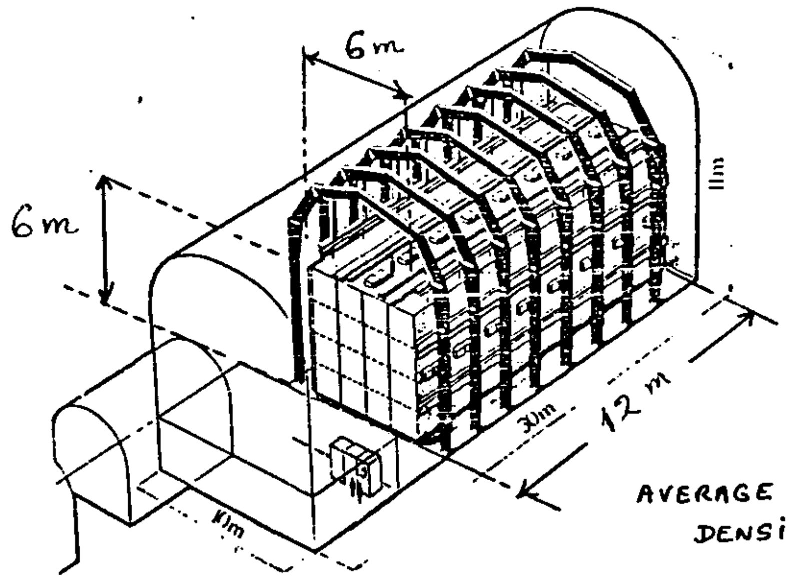
FRÉJUS TRACKING CALORIMETER

(FRÉJUS ALPINE ROAD TUNNEL, MODANE, FRANCE)
4800 m.w.e.



AVERAGE DENSITY : 2

FINE GRAIN DETECTOR ...
Flash tubes 5mm x 5mm
(6 m long)   Gas : Ne(70%) He([illegible]%)
0.9 10^{6} CHANNELS / 2 VIEWS

... TRIGGERED BY 113 GEIGER PLANES   Gas Ar (98%)
1 PLANE EVERY 11 cm

TOTAL MASS : 912 tonnes
FIDUCIAL MASS : 550 tonnes

PHYSICS :
- NUCLEON DECAY & ATMOSPHERIC ν's
- COSMIC RAY SOURCES
  Cyg X3 , SN 1987 A
- MUON BUNDLES

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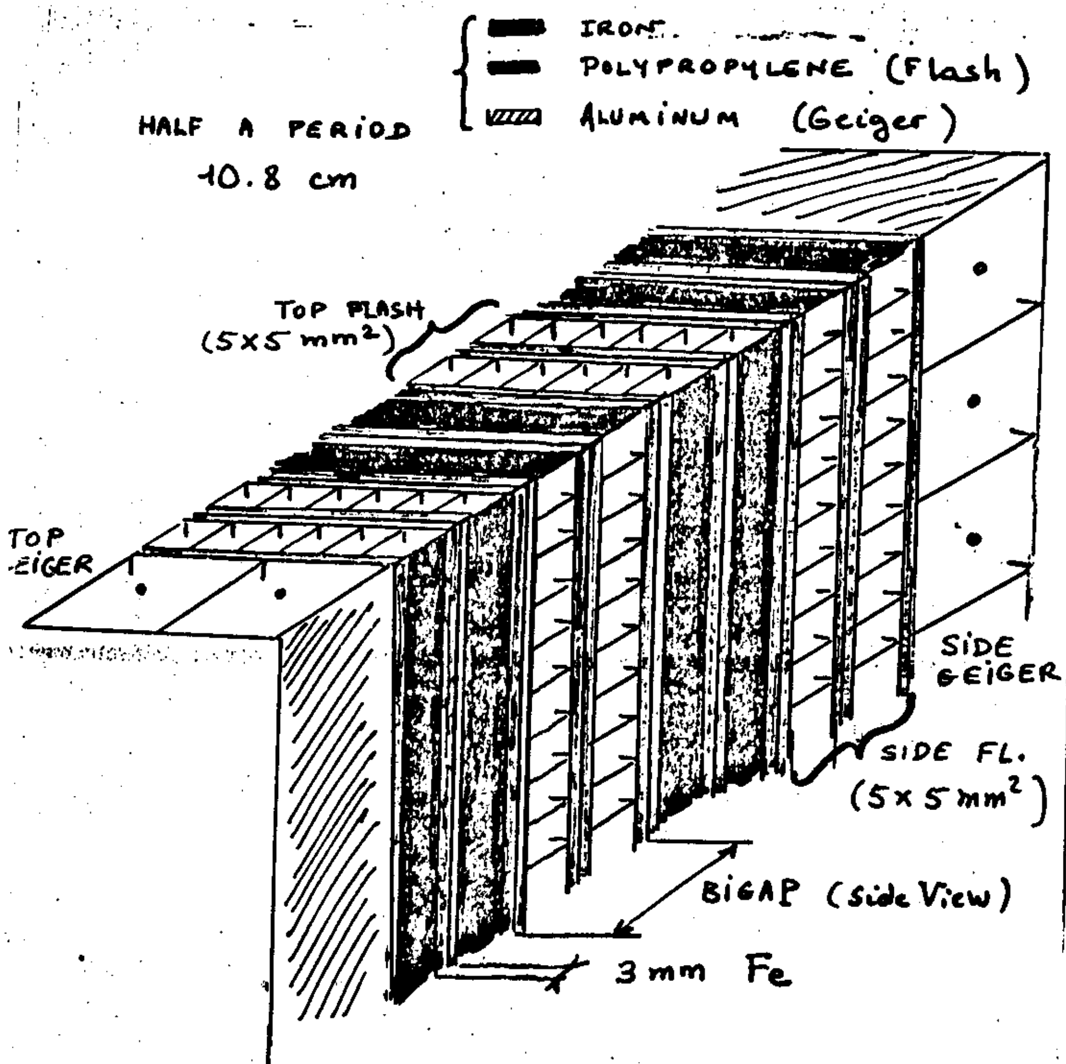
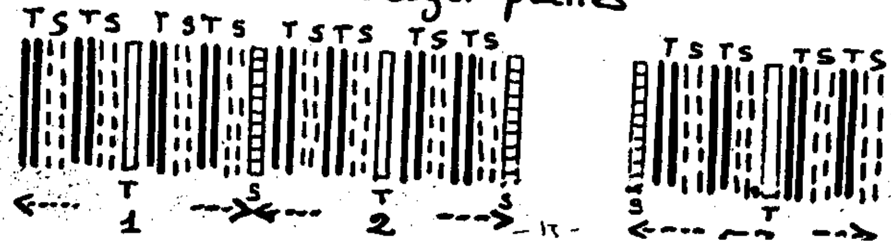
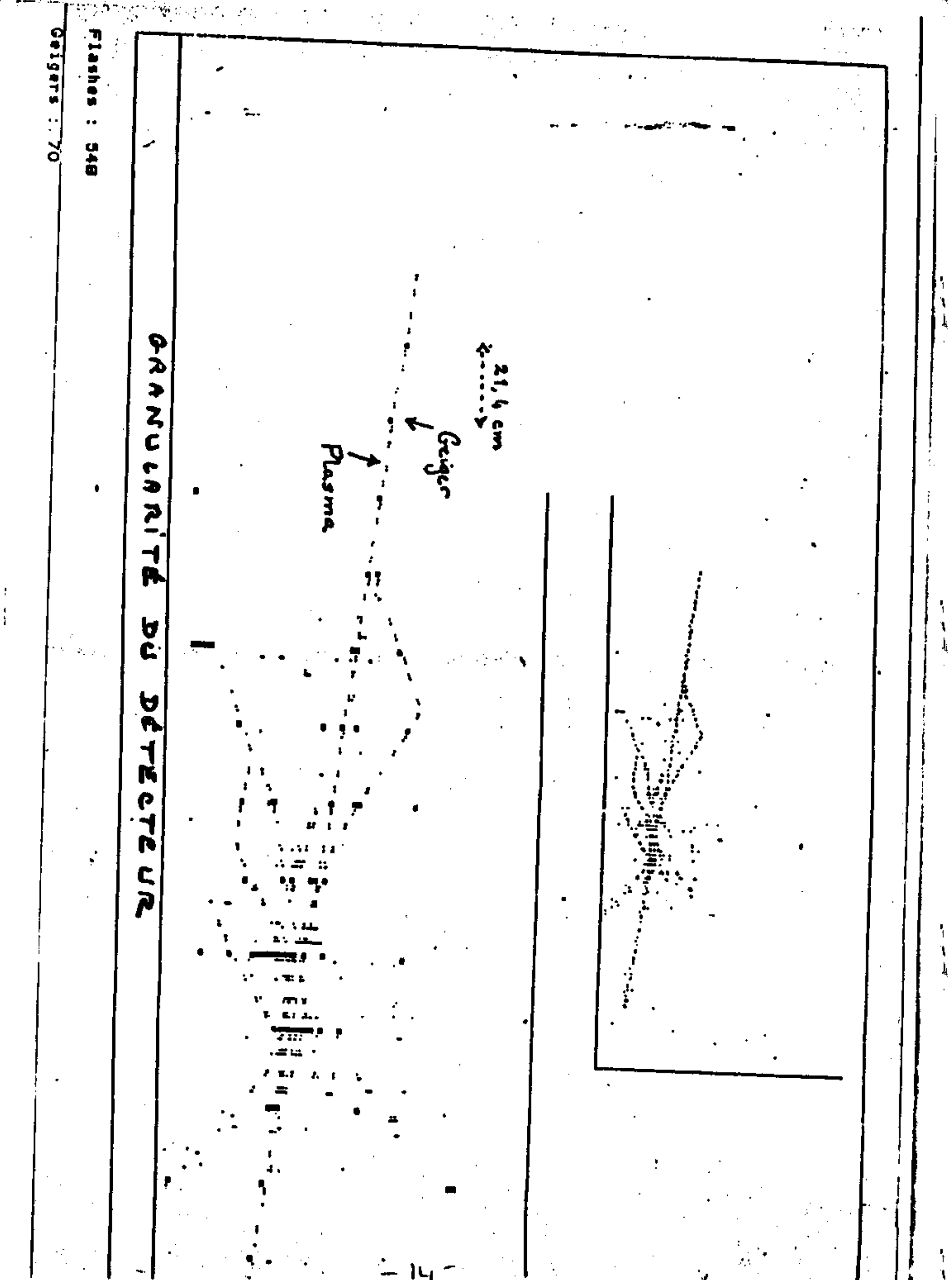
GENERAL STRUCTURE



456 = 8 × 57 Flash Ch. GAPS

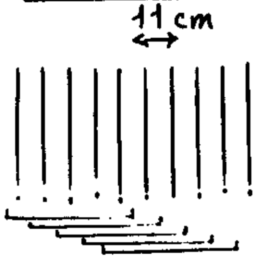
113 Geiger planes





FRÉJUS FINE GRAIN TRACKING CALORIMETER

• **TRIGGER** : (GEIGER PLANES)



- SUM UP CONTRIBUTIONS OF 5 CONSECUTIVE GEIGER PLANES : $N = \Sigma(C)$
- "CONTRIBUTION" = NUMBER OF FIRED TUBES, LIMITED TO 3. MORE THAN 3 HITS COUNT FOR 3.
- REQUIRE $N \geq 5$ WITHIN 300 ns

RATES : 20 COSMIC-RAY MUONS / h
20 RANDOM COINCIDENCES / h
(Radioactivity 2400 Hz / plane) + electronic noise)

* Flash chamber dead time (4 s) not critical with these rates (4 % of the time)

• **ENERGY RESOLUTION / THRESHOLDS**

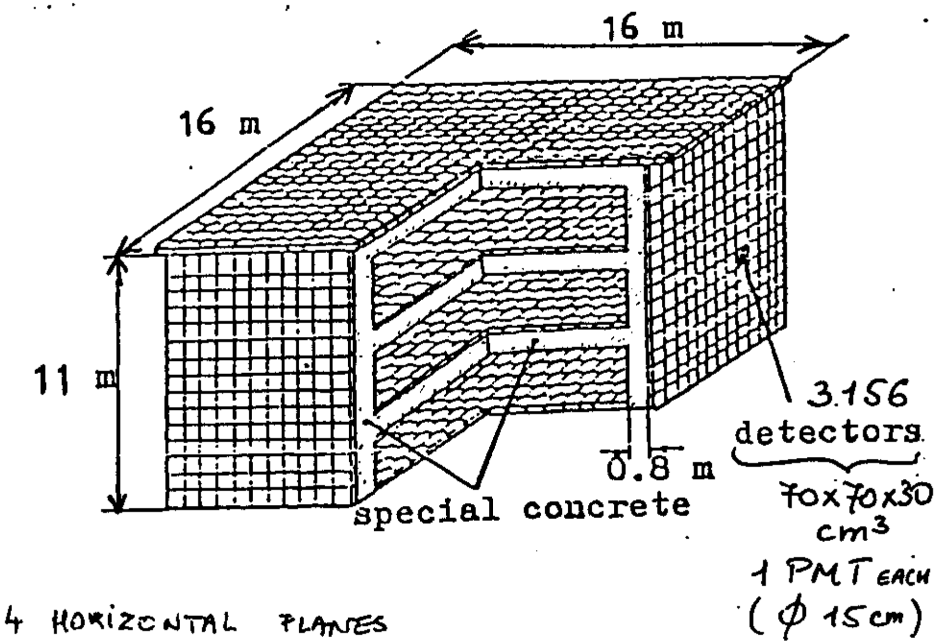
$\frac{\Delta E}{E} \sim 11\%$ AT 1 GeV
Calibration : Structure exposed to e beam (DESY), π & μ beams (BONN)

Trigger threshold : $\nu_e \; \nu_\mu \sim 200$ MeV

Visibility threshold : $\left\{ \begin{array}{ll} \text{electrons} & 40 \text{ MeV} \\ \mu / \pi & 150 \text{ MeV/c} \\ \text{protons} & 500 \text{ MeV/c} \end{array} \right.$

BAKSAN LIQUID SCINTILL^R DETECTOR

(BAKSAN TUNNEL, CAUCASUS, USSR, 850 m.w.e.)



4 HORIZONTAL PLANES
4 VERTICAL PLANES
TOTAL SCINTILLATOR MASS : 330 tonnes

PHYSICS :

- LOW ENERGY NEUTRINO BURSTS
- MUON BUNDLES
- COSMIC RAY SOURCES
- MONOPOLES

BAKSAN LIQUID SCINTILLATOR DETECTOR

- **TRIGGER** :

  MUON TRIGGER : ANY 2 PLANES 0.5 Hz

  "SINGLE DETECTOR" MODE :

  ONE SINGLE DETECTOR IN THE 3 INTERNAL HORIZ^{L} PLANES

  0.043 Hz → 0.013 Hz
  in 1979 in 1987
  (REMOVE NOISY PMT's)

- **UPWARD - GOING MUONS BY TIME-OF-FLIGHT** :

  TIME RESOLUTION ! 5 ns
  4 PLANES

  ANGULAR RESOLUTION : 2°

- **ENERGY THRESHOLD & RESOLUTION** :

  THRESHOLD : 12.5 MeV
  (1/4 MINIMUM-IONIZING)

  RESOLUTION : 20%

			LOW ENERGY ν's	GeV range e.g. N Decay					COSMIC RAY MUONS & MULTI-MUONS		
TECHNIQUE	DETECTOR	TOTAL MASS tonnes	E (e⁻) THRESH. MeV	FIDUC^{L} MASS tonnes	% LIGHT COLLECTED	Fe SAMPL^{G} DIST. cm	dE/dx	SPATIAL RESOL^{N} cm	AREA m^2	UPW^{D} GOING μ	DEPTH mwe
WATER CHERENKOV	IMB I / III	8000	50 / 20	3300	2% / 8%			~ 100	550	YES	1570
	KAMIOKA I / II	3000	30 / 7.5	880 / 780 + ACTIVE SHIELD	20%			~ 100 → 20	320	YES	2700
LIQUID SCINTILL^{R}	LSD M^{t} Blanc	90	5 - 7					~ 50	50	NO	5200
	LASD Homestake	~ 100	5					15	160	YES (TOF)	4200
	BAKSAN	330	12.5					15 - 35	300	YES (TOF)	850
TRACKING DETECTORS (Fe/Detect^{r} planes sandwich)	KOLAR Gold Fields I / II	140 / 260	Prop^{l} tubes	60 / 160		1.2 / 0.6	YES	10	30 / 60	NO	7000 / 6045
	NUSEX	150	Streamer Tubes	113		1	NO	1	20	NO	5200
	FRÉJUS	912	Flash T. (+ Geigers)	550		0.3	NO	0.5	100	NO	4800
	SOUDAN II	(1000) ~ 166 now	Drift Tubes	~ 600		0.3	YES	~ 0.5	130	NO	2100

LOW-ENERGY NEUTRINOS

~ 5 MeV TO ~ 100 MeV

- DETECTION OF LOW-ENERGY NEUTRINOS
- SOLAR NEUTRINOS FROM ^8B DECAY (UP TO 14 MeV)
- NEUTRINO BURSTS FROM SUPERNOVAE.

DETECTION OF LOW-ENERGY NEUTRINOS

(5 MeV TO ~ 50 ÷ 100 MeV)

- INTRINSIC LIMITATIONS
  - NATURAL RADIOACTIVITY

    $\left.\begin{array}{l}\gamma\text{-RAYS (e.g. } {}^{208}Tl) \\ \beta\text{-RAYS (e.g. } {}^{214}Bi)\end{array}\right\}$ UP TO ~ 4 MeV
  - NEUTRONS (SPONTAN.^{s} FISSION + COSMIC RAY MUONS INTERACTIONS IN THE ROCK)

    → UNSTABLE NUCLEI → β-RAYS UP TO ~ 8 MeV
  - LIMITED SPATIAL RESOLUTION (1.7 m in KAMIOKA II)
  - LIMITED ENERGY RESOLUTION (22 % at 10 MeV in KAMIOKA II)

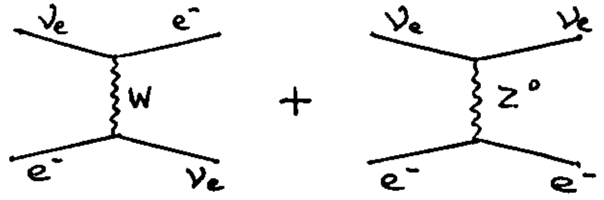
  THRESHOLDS : 5 TO 7 MeV (L.S.D. M^t Blanc)
  7.5 MeV (KAMIOKANDE II)

- TWO CATEGORIES OF REACTIONS
  - $\nu(\bar{\nu}) + e^- \longrightarrow \nu(\bar{\nu}) + e^-$

    ALL FLAVOURS
    - CONSTRAINT ON $\nu(\bar{\nu})$ DIRECTION
    - ONLY A LOWER BOUND ON $\nu(\bar{\nu})$ ENERGY
  - $\nu_e(\bar{\nu}_e) + \text{Nucleus} \longrightarrow e^{\mp} + N'$
    - NEUTRINO ENERGY CAN BE RECONSTRUCTED
    - (ALMOST) NO DIRECTIONALITY CONSTRAINT
    - THRESHOLD

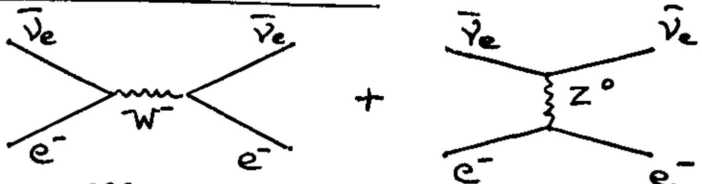
$\nu\ (\bar{\nu})$ + e^- REACTIONS

$$\nu_e + e^- \rightarrow \nu_e + e^-$$



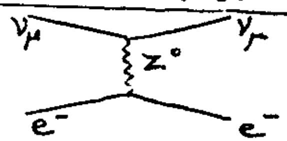
CHARGED CURRENT NEUTRAL CURRENT

$$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$$



CHARGED CURRENT NEUTRAL CURRENT

$$\begin{matrix}\nu_\mu\ (\bar{\nu}_\mu) \\ \nu_\tau\ (\bar{\nu}_\tau)\end{matrix} + e^- \rightarrow \begin{matrix}\nu_\mu\ (\bar{\nu}_\mu) \\ \nu_\tau\ (\bar{\nu}_\tau)\end{matrix} + e^-$$



NEUTRAL CURRENT ONLY

$$\sigma(\nu_e) = 0.94\ 10^{-43}\ cm^2 \times \left(\frac{E}{10\ MeV}\right)$$

$$\sigma(\bar{\nu}_e) = 0.39\ 10^{-43}\ cm^2 \times \left(\frac{E}{10\ MeV}\right)$$

$$\sigma(\nu_\mu \text{ OR } \nu_\tau) \simeq \frac{1}{6}\,\sigma(\nu_e)$$

KINEMATICAL CONSTRAINT ON ν DIRECTION

$$\sin^2\left((\nu, e^-)\text{ ANGLE}\right) \leq \frac{1}{1 + T_e/2m_e}$$

$T_e = e^-$ KINETIC ENERGY

ANGLE $< 24°$ AT 5 MeV
$< 13°$ AT 20 MeV ?? - EXP^L ERRORS NOT ... (+28° in Kam.)

$\nu_e\ (\bar{\nu}_e)$ + NUCLEUS REACTIONS

(INVERSE BETA PROCESSES)

NEUTRINO ENERGY IS MEASURED :

$$\nu_e(\bar{\nu}_e) + \underbrace{N}_{M} \rightarrow e^\mp + \underbrace{N'}_{M' = M+Q}$$

$$E_\nu = T_e + m_e + Q$$

BUT NO CONSTRAINT ON ν DIRECTION,
AND THRESHOLD = $m_e + Q$

- LOW THRESHOLD ON FREE PROTONS FOR ANTINEUTRINOS (1.8 MeV)

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

$$\boxed{\sigma(\bar{\nu}_e + p) = 0.89 \left(\frac{E_\nu}{10\ MeV}\right)^2 10^{-41}\ cm^2}$$

IDEAL FOR DETECTING SUPERNOVAE BURSTS.

$$\left[\frac{N(\bar{\nu}_e + p)}{N(\nu_e + e^-) + N(\bar{\nu}_e + e^-)}\right]_{H_2O} \simeq 10 \cdot \left(\frac{E_\nu}{10\ MeV}\right)$$

FREE PROTONS : H_2O, SCINTILL^R (e.g. C_nH_{2n+2})

- $\underbrace{\nu_e + {}^{16}O}_{13\ MeV}$ OR $\nu_e + {}^{12}C$ HAVE HIGHER THRESHOLDS IN THE 10 MeV - 50 MeV RANGE

$$\sigma(\nu_e + {}^{16}O) \sim 10^{-2} \cdot \sigma(\bar{\nu}_e + \text{free } p)$$

- LOWER THRESHOLDS FOR ν_e's.

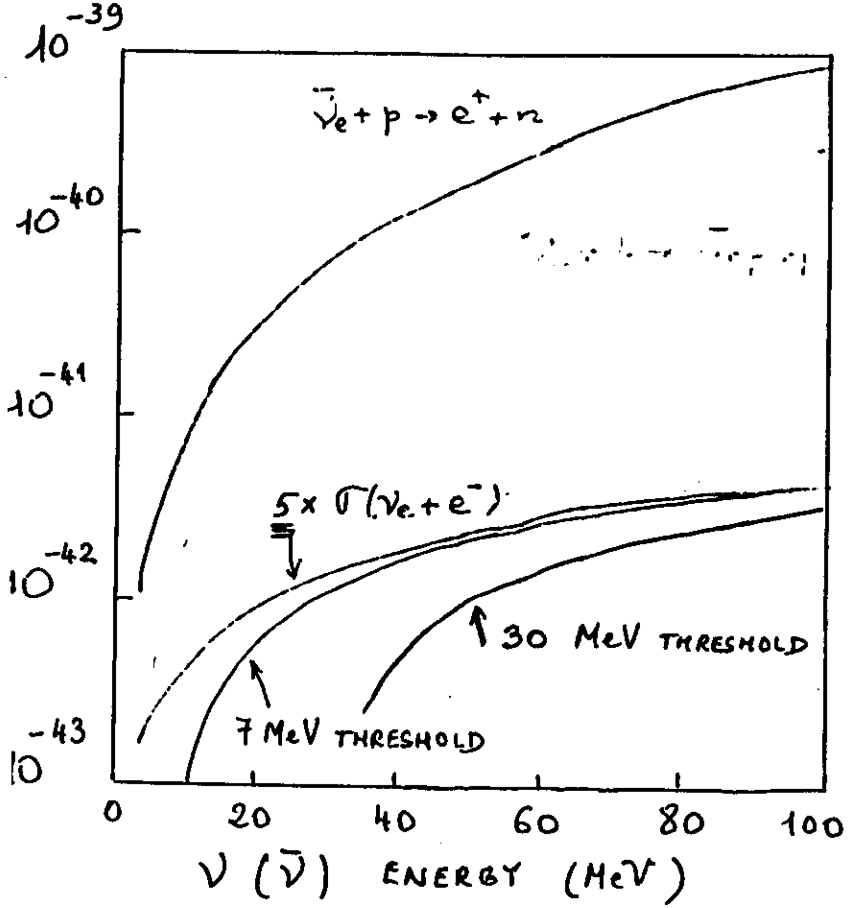
DEUTERIUM (HEAVY WATER CHERENKOV / SUDBURY PROJECT)

$$\nu_e + d \rightarrow e^- + p + p \quad (2.7\ MeV)$$

ARGON (^{40}Ar) (LIQUID ARGON DRIFT CHAMBER / ICARUS)

$$\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^-$$

NEUTRINO CROSS SECTIONS AT LOW ENERGIES



SOLAR NEUTRINOS FROM ^8B DECAY

THE SOLAR NEUTRINO PUZZLE

- THE TOTAL NEUTRINO FLUX is CONSTRAINED BY SOLAR LUMINOSITY

  ANY CYCLE : $4p + 2e^- \to {}^4He + \text{photons} + 2\nu_e$

  THUS : $\Phi_\nu = \underbrace{2}_{2\nu\text{'s per cycle}} \dfrac{L_\odot}{Q} \dfrac{1}{4\pi D^2}$

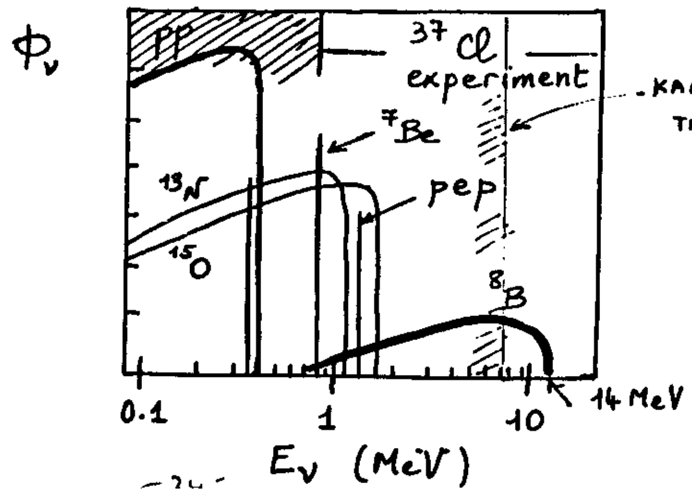
  $L_\odot$ SOLAR LUMINOSITY : $3.86\ 10^{33}$ ergs/s

  Q RELEASED ENERGY / CYCLE : 19 MeV TO 26.2 MeV

  D SUN - EARTH DIST$^{\underline{ce}}$: $1.5\ 10^{13}$ cm

  $\Phi_\nu \sim 6.5$ TO $9\ 10^{10}\ cm^{-2}s^{-1}$

- THE FORMER EXP$^{\underline{T}}$ OF DAVIS et al is ONLY SENSITIVE TO THE HIGHEST PART OF THE SPECTRUM



THE SOLAR NEUTRINO PUZZLE

- THE RADIO-CHEMICAL EXP^T OF DAVIS et al.

$(\nu_e + {}^{37}Cl \rightarrow {}^{37}Ar + e^-)$

$E_{\nu_e} > 0.814$ MeV

FINDS A LACK OF SOLAR NEUTRINOS

CAPTURE RATES in $(\underbrace{10^{-36} \text{ CAPTURES/Atom/s}}_{\text{SNU = SOLAR NEUTRINO UNIT}})$

EXPERIMENT	2.1 ± 0.3	
THEORY	5 TO 12	

THE EXPERIMENTAL RESULT IS EVEN COMPATIBLE WITH A TOTAL ABSENCE OF ^8B NEUTRINOS.

- BULK OF $\nu_\odot$'s COME FROM pp CYCLE. ONLY THOSE ONES ARE CONSTRAINED BY $L_\odot$

- $\nu_\odot$'s FROM ^8B ARE VERY SENSITIVE TO CORE TEMPERATURE IN THE SUN.

- NOW, TWO EXPERIMENTAL DIRECTIONS
  1) RADIOCHEMICAL EXP^{TS} WITH LOW THRESH.
     $\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e^- \quad (E_\nu > 0.236 \text{ MeV})$
     CHECK $\phi(\nu \text{ FROM } pp)$ VS. $L_\odot$
  2) DIRECT COUNTING EXP^{TS} ON ^8B ν's
     e.g. KAMIOKANDE II $E_e > 10$ MeV
     WHAT HAPPENS TO ^8B ν's ?
     (OSCILLATIONS ?)

DIRECT COUNTING EXPERIMENTS ON SOLAR NEUTRINOS

(e.g. KAMIOKANDE II)

- CONSTRAINTS
  - Radioactivity backgrounds sets a threshold in the 5-10 MeV range
    $E_e > 9$ MeV for KAMIOKANDE II
  - Experiment is sensitive to a part of ^8B neutrinos → small flux

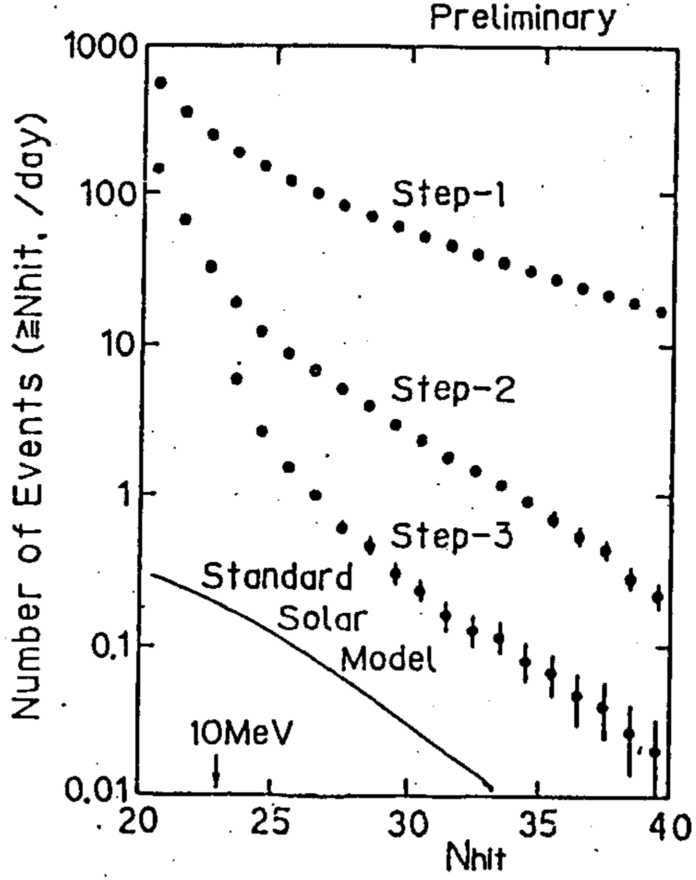
$$\begin{cases} \nu \text{ FLUX } (E_e > 10 \text{ MeV}) \simeq 4 \cdot 10^6 \text{ cm}^{-2}\text{s}^{-1} \text{ (expected)} \\ \text{TOTAL } \nu \text{ FLUX FROM SUN} \sim 7 \cdot 10^{10} \text{ cm}^{-2}\text{s}^{-1} \end{cases}$$

  - Mass $\gtrsim$ 1000 tonnes for rates of $\sim$ 1 ev^t/day.

- ADVANTAGES
  - DIRECTIONALITY CONSTRAINT
    $\overset{(-)}{\nu} + e^- \rightarrow \overset{(-)}{\nu} + e^-$
  - e^- SPECTRUM MEASUREMENT
    SPECTRUM IS MODIFIED IN CASE OF OSCILLATIONS; ν_μ FROM $\nu_e \rightarrow \nu_\mu$ POSSIBLE CONVERSION INTERACT WITH e^- (LOWER RATE)
  - ν ARRIVAL TIME IS KNOWN
    ($\neq$ Radiochemical exp^{ts} : 1 extract^n/2 weeks)
    eg. NIGHT/DAY EFFECT IF ν's OSCILLATE IN THE EARTH

^{8}B SOLAR NEUTRINOS

KAMIOKANDE II (1987)



KAMIOKANDE II EXPERIMENT

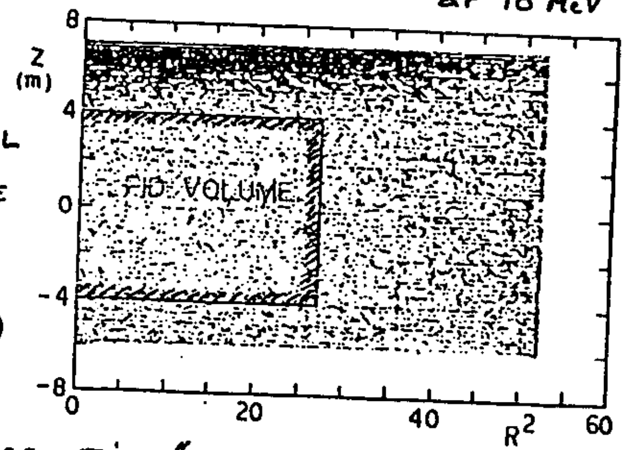
& ^{8}B SOLAR NEUTRINOS (E < 14 MeV)

{ EXPECTED RATE 0.2 events / day / 680 tonnes
{ TOTAL TRIGGER RATE 0.6 events / s in 1987

STEP 1 :
- N (photoelectrons inner detect.) < 100 (30 MeV)
- N (" Anticounter) < 30
- Δt with previous ev^t > 100 μs (remove e from μ decay)

STEP 2 : RECONSTRUCT VERTEX $\Delta x \sim 1.7$ m at 10 MeV

FIDUCIAL VOLUME CUT (680 tonnes)



STEP 3 : - "SPACE - TIME" CUT TO REMOVE MUON-INDUCED EVENTS

$\mu + {}^{16}O \rightarrow$ Radioactive Nuclei

$\tau_{1/2}$: 10 ms ÷ 10 s

$E_\beta \sim 10$ MeV

- ANGULAR DISTRIBUTION :
DIRECTION ANGLE WITH RESPECT TO THE SUN $\theta(\nu_e e^-) \sim 20°$ +
ANGULAR RESOL^N $\sim$ 20°

KAMIOKANDE II EXPERIMENT

^8B SOLAR NEUTRINOS

LATEST RESULTS

(Y. Totsuka, Aix-les-Bains WORKSHOP April '88)

330 DAYS OF DATA (Jan '87 - Jan '88)

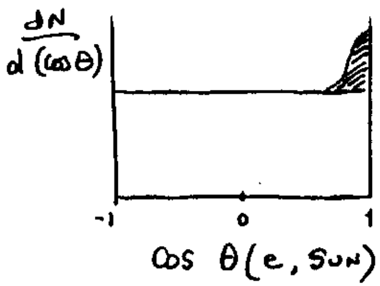
THRESHOLD : 9.1 MeV

$$\Phi_{^8B} < \underbrace{3.6\ 10^6}_{62\%\text{ of stand}^d\text{ solar model prediction}}\ cm^{-2}s^{-1} \quad (90\%\ c.l.)$$

VERY PRELIMINARY :

382 DAYS OF DATA (Jan '87 - March '88)

DATA SEEM TO INDICATE A SIGNAL FROM THE SUN.



WORK TO BE FINALIZED FOR NEXT SUMMER ...

NEUTRINO BURST FROM SN 1987 A

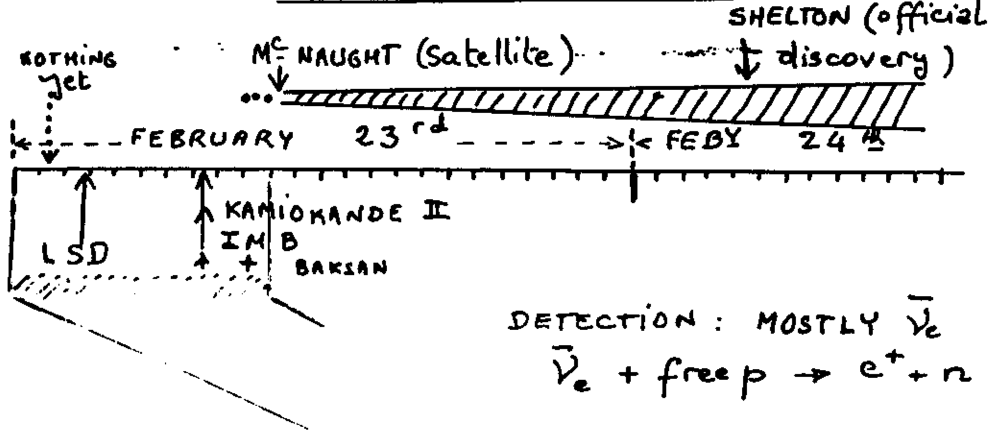
February 23^{rd} 1987 : FIRST NEARBY SUPERNOVA SINCE KEPLER.

LARGE MAGELLANIC CLOUD : 50 kiloparsecs

MANY INTERESTS FOR PARTICLE PHYSICS :

- MOST ENERGETIC PHENOMENON IN NATURE
  ENERGY RELEASED $\sim 10^{53}$ ergs
  (Gravitat^l binding energy of collapsed star)
  * LIGHT & KINETIC ENERGY OF FRAGMENTS : 10^{51} ergs only
- INVOLVES WEAK INTERACTIONS & NUCLEAR MATTER ON MACROSCOPIC SCALES.
  ν_e FROM NEUTRONIZATION ($e^- p \to \nu_e n$)
  $\nu \bar{\nu}$ ALL FLAVOURS (THERMAL)
  10^{57} $\nu\bar{\nu}$ PAIRS $E \sim 10$ MeV
  DO THEY ACCOUNT FOR THE MAIN PART OF THE ENERGY RELEASED IN THE EXPLOSION?
  * Number of ν flavours
- REMOTE SOURCE OF ν's : ν MASS ? STABILITY ?
  TRAVEL TIME $\sim$ 160 000 years
- MAY BE RELATED TO COSMIC RAY ACCELERATIO
  SHOCK WAVE ? PULSAR ?

SUPERNOVA SN 1987 A



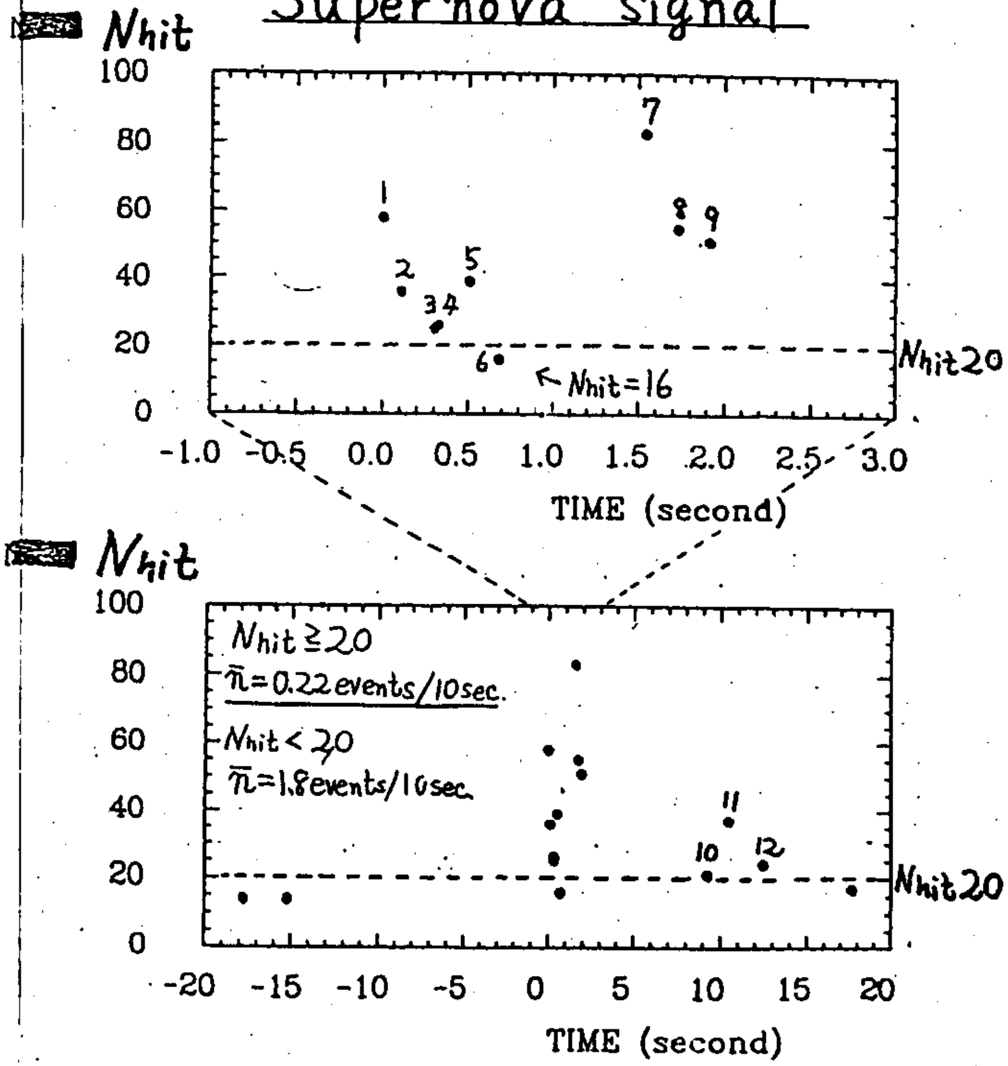
DETECTION : MOSTLY $\bar{\nu}_e$

$$\bar{\nu}_e + \text{free } p \rightarrow e^+ + n$$

DETECTOR	FIDL. MASS tonnes	E ($e^{\pm}$) THRESHOLD MeV	SIGNAL: UNIVL. TIME H:Mn:S	SIGNAL: EVENTS/DURATION	EXPECTED BACKGROUND in 10 s	PROBABILITY OF A BACKGROUND FLUCTUATION in 10 H
L.S.D. (Mt Blanc)	90	5 ÷ 7	2:52:36	5 EVTS. / 7 s	0.12	$0.8\ 10^{-3}$
KAMIOKA II	2140	7.5	7:35:35	11 EVTS. / 12.4 s 8 EVTS. / 1.92 s	0.22	$4.\ 10^{-10}$ $3.\ 10^{-11}$
I.M.B. III	5000	20	7:35:40	8 EVTS. / 6 s.	0.77	$2.\ 10^{-3}$
BAKSAN	200	12.5	7:36:06	5 EVTS. / 9 s	0.33	0.29

KAMIOKANDE II

Supernova signal



SN . 1987 A / CONCLUSIONS

- KAMIOKA - IMB BURST at 7:36
  - HIGH STATISTICAL SIGNIFICANCE
  - THE ENERGY OF $\nu\bar{\nu}$ PAIRS APPROXIMATELY MATCHES THE GRAVITAT^{L} BINDING ENERGY OF THE COLLAPSED STAR. ($\sim 3 \cdot 10^{53}$ ergs)
  - $\bar{\nu}_e$ LIFETIME $> 5 \cdot 10^{12} \left(\frac{m_\nu c^2}{E_\nu}\right)$ s
  - OTHER LIMITS (number of ν flavours, ν mass) cf. J. Ellis '87 Uppsala Conf^{ce} but not more constraining than laboratory limits.

* MAY BE A PROBLEM WITH ANGULAR DISTRIB^{N} WITH RESPECT TO SN DIRECTION.

$\bar{\nu}_e + p \to e^+ + n$: FLAT DISTRIB^{N} EXPECTED FOR cos (SN, e)

ADD KAMIOKANDE II + IMB III STATISTICS

15 "FORWARD" VS. 5 "BACKWARD"

BUT STATISTICS ARE POOR ...

- A BURST AT 2:52 (LSD) ?

FREE p RATIO $\frac{\text{KAMIOKANDE II}}{\text{LSD}} \simeq 17$

CAN THE RATIO OF EFFICIENCIES CANCEL THIS FACTOR? POSSIBLE WITH AN "ad hoc" $\bar{\nu}_e$ SPECTRUM, WITH LOWER ENERGIES THAN FOR 7:36 BURST BUT $\sigma(\bar{\nu}_e + p) \propto E^2 \Rightarrow$ LUMINOSITY 2 ORDERS OF MAGNITUDE $> 3\ 10^{53}$ ERGS !

LOW ENERGY NEUTRINOS. SUMMARY & PERSPECTIVES

- SOLAR NEUTRINOS FROM ^8B :
  - KAMIOKANDE II FIRST DIRECT COUNTING EXP^{T} ON $\nu_\odot$. E. > 9.1 MeV

$$\Phi_{\nu\,(^8B)} < \underbrace{3.6}_{68\%\ \text{OF STAND}^{D}\ \text{SOLAR MODEL}}\ 10^6\ cm^{-2} s^{-1} \quad (90\% CL)$$

* MAY BE A SIGNAL FROM THE SUN.

- IN THE FUTURE : LARGE DETECTORS IN THE KILOTONNE RANGE (RATES ~ 1 EVENT / DAY)
  - SUDBURY (D_2O CHERENKOV)
    $\nu + e^-$ BUT ALSO $\begin{cases} \nu_e + d \to e^- + p + p \\ \nu + d \to \nu + n + p \end{cases}$
  - ICARUS (Liq. Argon drift chamber)
    $\nu + e^-$ BUT ALSO $\nu_e + {}^{40}Ar \to e^- + {}^{40}K^*$

- SUPERNOVAE BURSTS :

MULTI - KILOTONNE DETECTORS

SUPERKAMIOKA		20 000 tonnes H_2O
LVD	(GRAN SASSO)	1 800 tonnes } LIQUID SCINTILL^{R}
MACRO	(GRAN SASSO)	1000 tonnes } LIQUID SCINTILL^{R}
SUDBURY		1000 tonnes D_2O (also sensitive to ν_e as well as $\bar{\nu}_e$)