IONIZATION CALORIMETRY

CONSISTS IN THE

EXPLOITATION OF ELECTRICAL

SIGNALS

INDUCED BY MOTION OF

FREE CHARGE

CARRIERS

GENERATED BY FAST PARTICLES

IN A SUITABLE

MEDIUM

WHEN THE PRIMARY PARTICLE

OR PHOTON

DEPOSITS ALL (OR A SIZABLE FRACTION)

OF ITS

ENERGY

IN THE ACTIVE MEDIUM

TO MEASURE THE ENERGY OF THE

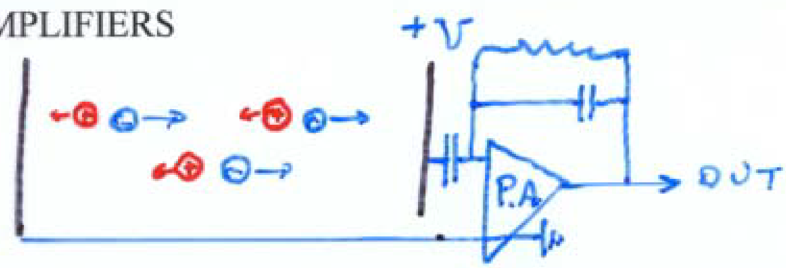
PRIMARY PARTICLE

CALOR 2000 LAPP 11/10/00 I. MANNELLI
SNS PISA

THE THREE BASIC STEPS

1. THE PASSAGE OF FAST CHARGED PARTICLES IN A SUITABLE MEDIUM RESULTS IN THE PRODUCTION OF FREE ELECTRON-ION OR, IN CASE OF SEMICONDUCTORS, OF FREE ELECTRON-HOLE PAIRS

2. FOR MEDIA IN WHICH THE LIFE TIME OF THESE CHARGE CARRIERS IS LONG ENOUGH, THEIR MOTION, UNDER THE INFLUENCE OF A DRIFT FIELD, INDUCES CURRENTS ON ELECTRODES WHICH ARE CONNECTED TO LOW NOISE PREAMPLIFIERS



3. THE INDUCED CURRENTS ARE RECORDED, AFTER APPROPRIATE SHAPING AND ANALOG-DIGITAL PROCESSING

THE PROPERTIES OF THE THREE STEPS, LINKING THE ENERGY LOST BY THE PRIMARY PARTICLE TO THE RECORDED SIGNAL, HAVE BEEN EXTENSIVELY STUDIED AND FOR MANY PRACTICAL CIRCUMSTANCES THEY ARE WELL UNDERSTOOD AND CAN BE ACCURATELY MODELLED IN REMARKABLE DETAIL

THIS IS TRUE IN PARTICULAR FOR ELECTROMAGNETIC CALORIMETRY AND IN SITUATIONS IN WHICH LIQUIDS OR SEMICONDUCTORS ARE USED AS ACTIVE MEDIA.

IN THESE CASES NO SECONDARY CHARGE MULTIPLICATION OCCURS

THE CURRENT I INDUCED ON A GIVEN ELECTRODE BY THE MOTION OF A CHARGE q IS

$$I = q\vec{v} \cdot \vec{E} / V$$

$\vec{v}$: IS THE VELOCITY OF THE CHARGE

$\vec{E}$: THE ELECTRIC FIELD WHICH WOULD BE GENERATED AT THE LOCATION OF THE CHARGE q BY BRINGING THE ELECTRODE IN QUESTION AT A POTENTIAL DIFFERENCE V, RELATIVE TO ALL OTHER ELECTRODES GROUNDED TOGETHER

FOR THE SIMPLEST CASE OF A SINGLE CHARGE WITH A CONSTANT VELOCITY PERPENDICULAR TO TWO PARALLEL PLANE ELECTRODES

THE CURRENT IS GIVEN BY:

$$I = q/T_D$$

T_D : IS THE DRIFT TIME THAT THE CHARGE WOULD TAKE TO COVER THE DISTANCE BETWEEN THE ELECTRODES

FOR A SUFFICENTLY HIGH APPLIED VOLTAGE THE DRIFT VELOCITY SATURATES TO A COSTANT VALUE V_D AND THE CURRENT DEPENDS ON THE GEOMETRY OF THE ELECTRODES, NOT ON THE POSITION OF THE CHARGE:

$$I = q \cdot v_D / W$$

W : IS THE DISTANCE BETWEEN THE ELECTRODES

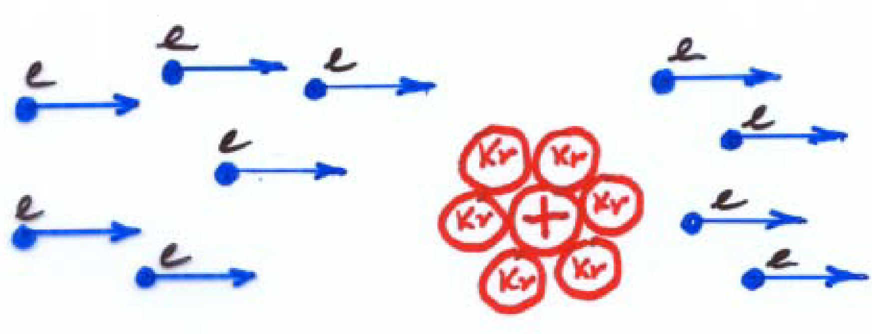
IN THE CASE OF SEMICONDUCTOR DETECTORS, BOTH ELECTRONS AND HOLES CONTRIBUTE A SIMILAR AMOUNT TO THE INDUCED SIGNAL

FOR INONIZATION DETECTORS THE MOBILITY OF IONS BEEING SEVERAL ORDER OF MAGNITUDES SMALLER THAN THE MOBILITY OF ELECTRONS, THE CONTRIBUTION OF THE IONS CAN BE GENERALLY NEGLECTED, EXCEPT FOR POSSIBLE SPACE CHARGE EFFECTS DISTORTING THE DRIFT FIELD

e.g. IN LKr at 122 K
3000 V/cm DRIFT FIELD

v_D for e^- 3.16 mm/μs

FOR "IONS" ~ 14 mm/s



"SOLID" KRYPTON
ICEBERGS
NOT JUST FREE IONS!

DEPENDING ON THE TYPE OF PARTICLES AND THE RANGE OF ENERGIES TO BE MEASURED CALORIMETERS CAN HAVE VERY DIFFERENT SIZE AND STRUCTURE.AT THE SMALL END OF THE SPECTRUM I WOULD LIKE TO QUOTE SEMICONDUCTOR DETECTOR, IN PARTICULAR THE SO CALLED

SEMICONDUCTOR DRIFT

CHAMBER

INTRODUCED IN 1984 BY E. GATTI AND P. REHAK WHICH, IN ADDITION TO BE CAPABLE OF REACHING SPACE RESOLUTION OF A FEW 10^{-6}m, AS THE NOW STANDARD MULTIELECTRODE SEMICONDUCTOR DEVICES USED IN VERTEX DETECTOR, HAS PROVEN ITSELF AS

CALORIMETER

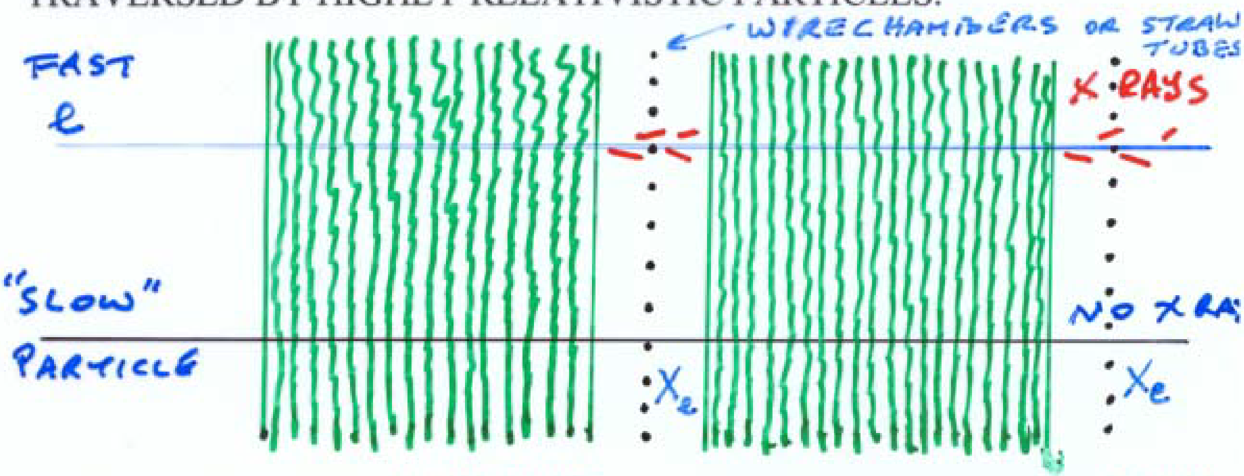
WITH EXCELLENT ENERGY RESOLUTION

FOR LOW-ENERGY X-RAY

SPECTROSCOPY

ESPECIALLY APPLIED TO ASTRONOMY, X-RAY FLUORESCENCE DETECTORS ETC.

ANOTHER APPLICATION, WHICH WOULD NOT BE NORMALLY REFERRED TO AS IONIZATION CALORIMETRY, IS THE MEASUREMENT OF THE LOW ENERGY X-RAYS COMPONENT EMERGING FROM MULTIFOIL TRANSITIONS RADIATORS TRAVERSED BY HIGHLY RELATIVISTIC PARTICLES.



FOR HIGH ENERGY HADRONIC CALORIMETRY TILL NOW, ONLY SAMPLING CALORIMETERS HAVE BEEN USED AND THE BEST RESOLUTION HAS BEEN ACHIEVED USING SCINTILLATION, RATHER THEN IONIZATION IN THE ACTIVE MEDIUM, WHICH ALLOWS A BETTER "COMPENSATION" FOR THE FLUCTUATION IN THE RATIO OF ELECTROMAGNETIC AND HADRONIC CASCADE COMPONENTS

LEAVING ASIDE THE CASE OF SEMICONDUCTOR DETECTORS, SAMPLING AND HOMOGENOUS IONIZATION CALORIMETER HAVE BEEN EXTENSIVELY USED FOR PHOTON AND ELECTRON DETECTION

RADEKA AND WILLIS FIRST DEMONSTRATED IN 1974 THAT PRACTICAL SAMPLING e.m. CALORIMETER COULD BE BUILT USING LIQUID ARGON AS SENSITIVE MEDIUM

THE BEST PERFORMANCE, WHEN SIZE AND COST HAS ALLOWED IT, HAS BEEN ACHIEVED BY USING (NEARLY) HOMOGENEOUS DEVICES WITH (NEARLY) FULL CONTAINMENT OF THE ELECTROMAGNETIC SHOWERS.

CALORIMETERS HAVE BEEN BUILT FOR MULTI GeV PHOTONS WITH ENERGY RESOLUTION BETTER THAN 1%, CAPABLE OF LOCALIZING THE TRAJECTORY OF SEVERAL INDIVIDUAL PHOTONS TO WITHIN ≤1mm AND WITH TIME RESOLUTION OF ≤500ps

COMPARABLE PERFORMANCE HAS BEEN OBTAINED USING SCINTILLATION FROM C_SI CRYSTALS AND WITH IONIZATION IN LIQUID KRYPTON OUTCLASSING IN SEVERAL ASPECTS THE ORIGINAL LEAD-GLASS CERENKOV DETECTORS.

EXAMPLE NA48 AT CERN

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- STRUCTURE & INITIAL CURRENT PRINCIPLE
- LINEARITY & RESOLUTION
- TIME RESOLUTION
- CALIBRATION IN PRINCIPLE
- AND IN HARDWARE, INCLUDING HV PROTECTION SWITCH

ATLAS

↓

- STRUCTURE

FOR IN DEPTH DESCRIPTION FOLLOW TALKS BY G. UNAL AND S. GIUDICI AND D. SAUVAGE C. CLEMENT, A. MINAENKO, R. ORR FOR ATLAS

NA 48

LKr electromagnetic calorimeter

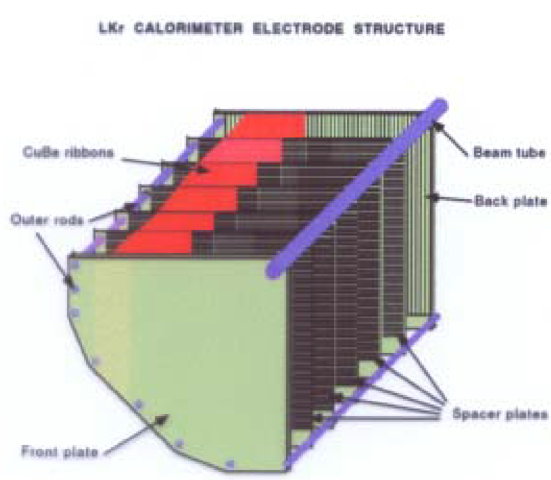
- Quasi-homogeneous detector

  $10\ m^3$ liquid krypton (120 K)
  ($X_0 = 4.7\ cm$, $R_M = 6.1\ cm$)

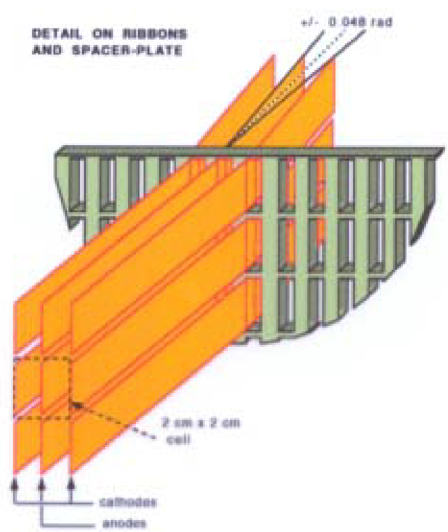
- 13212 cells
  - Granularity $2 \times 2\ cm^2$
  - Depth $1.25\ m$ ($\sim 27\ X_0$)

- Projective geometry pointing to decay region ($\sim$ 114 m upstream)

- Accordion geometry ($\pm 48\ mrad$) to diminish anode effects.



A quarter of calorimeter

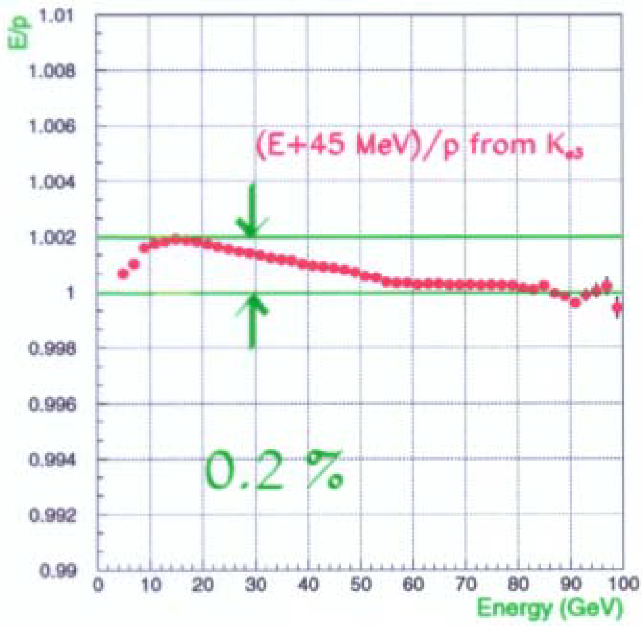


Ribbons and a spacer

- Initial current read-out technique.

Calorimeter performances

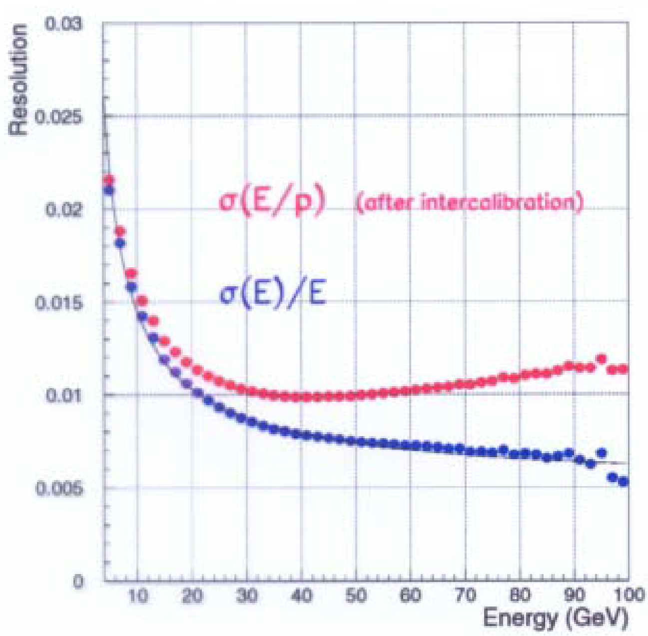
Using electrons from $\pi e \nu$ decay as a probe



- Linearity

$$\frac{Energy(LKR)}{Momentum(DCH)}$$

$\Rightarrow$ Linearity $< 0.2\%$
(from 5 to 100 GeV)



- Resolutions

E/P resolution

drift chamber deconvoluted

$$\frac{\sigma(E)}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{100\ MeV}{E} \oplus 0.5\%$$

$\pi^0 \rightarrow \gamma\gamma$ mass resolution : 1.1 MeV/c^2

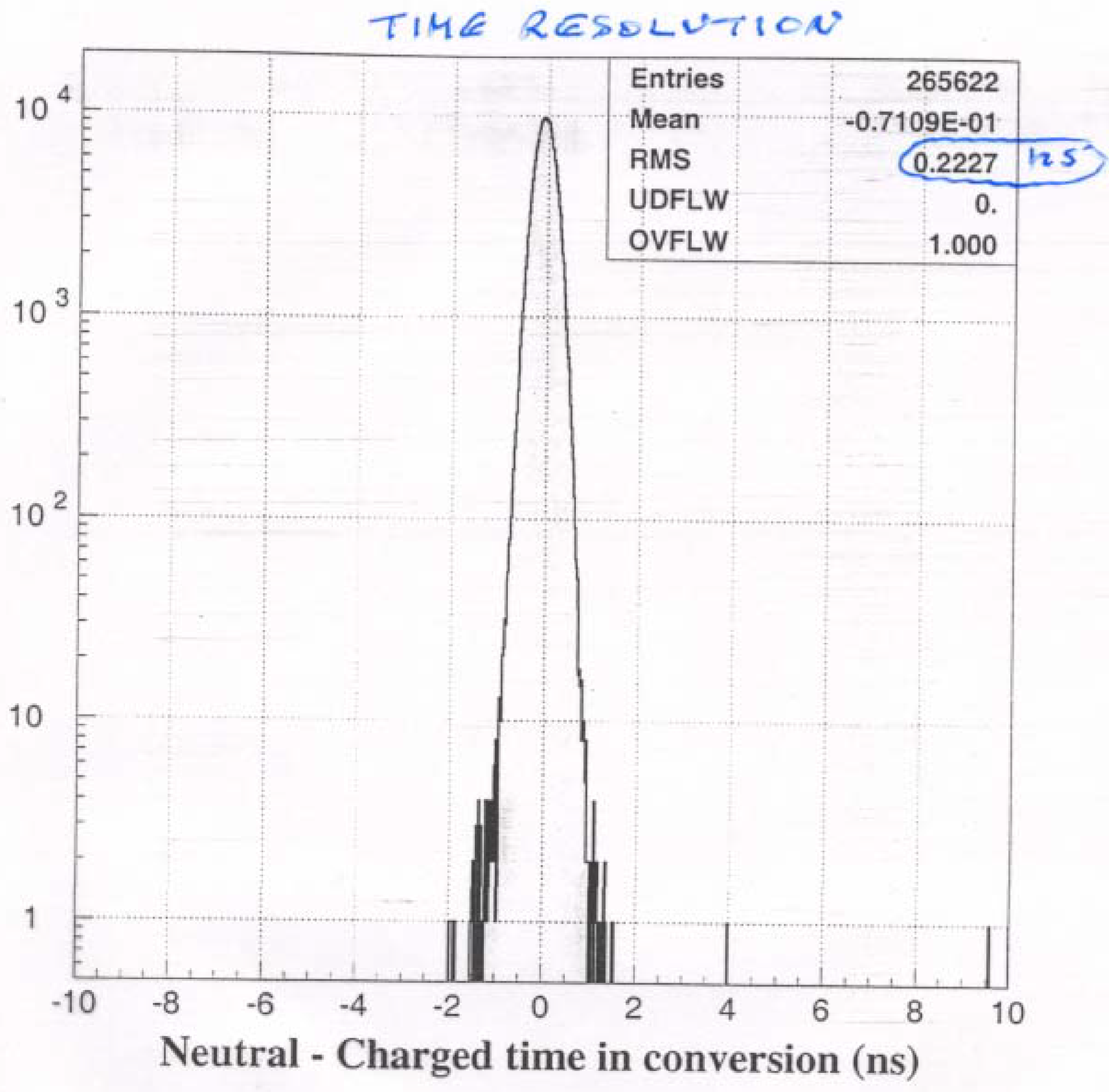
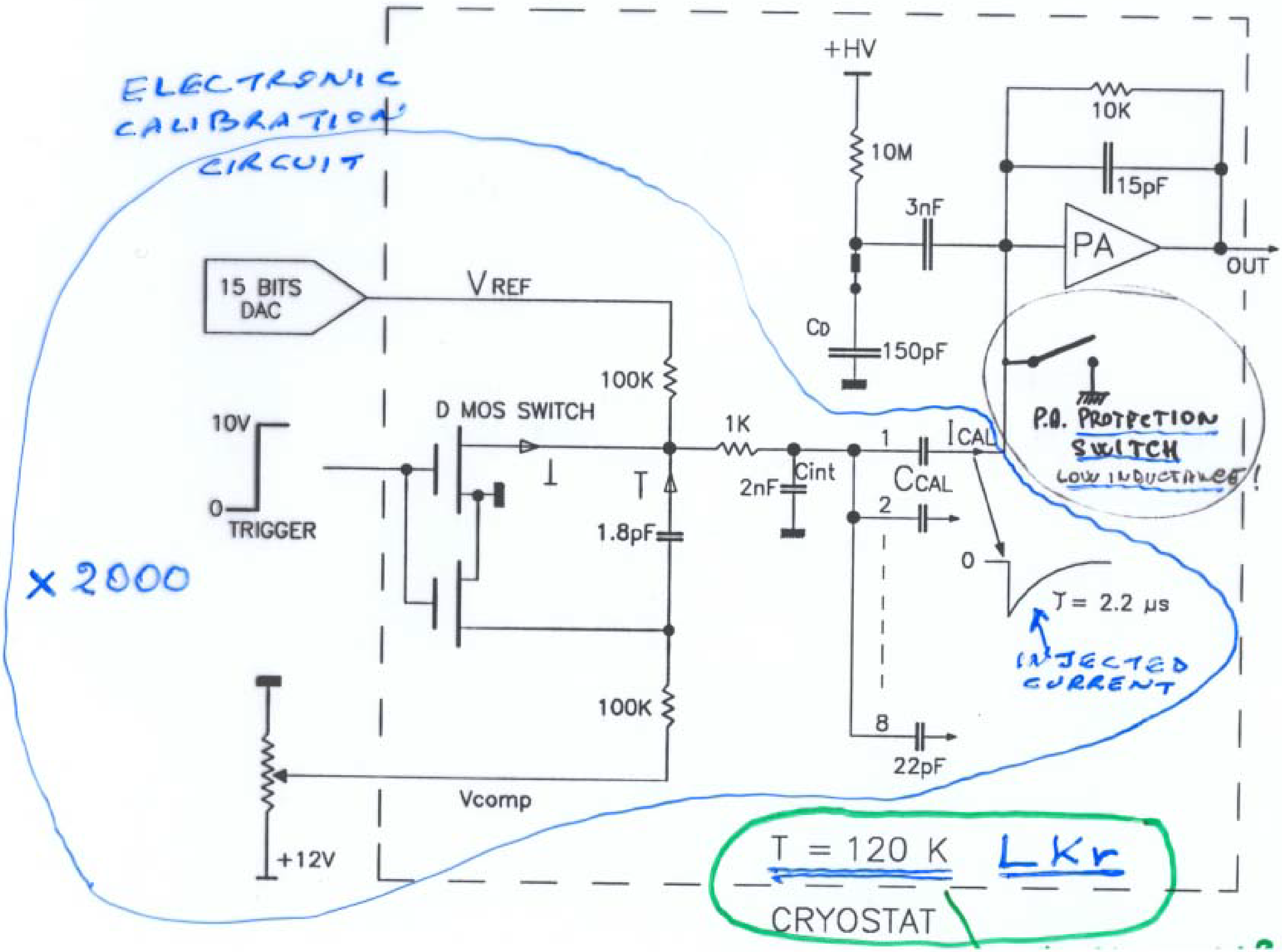
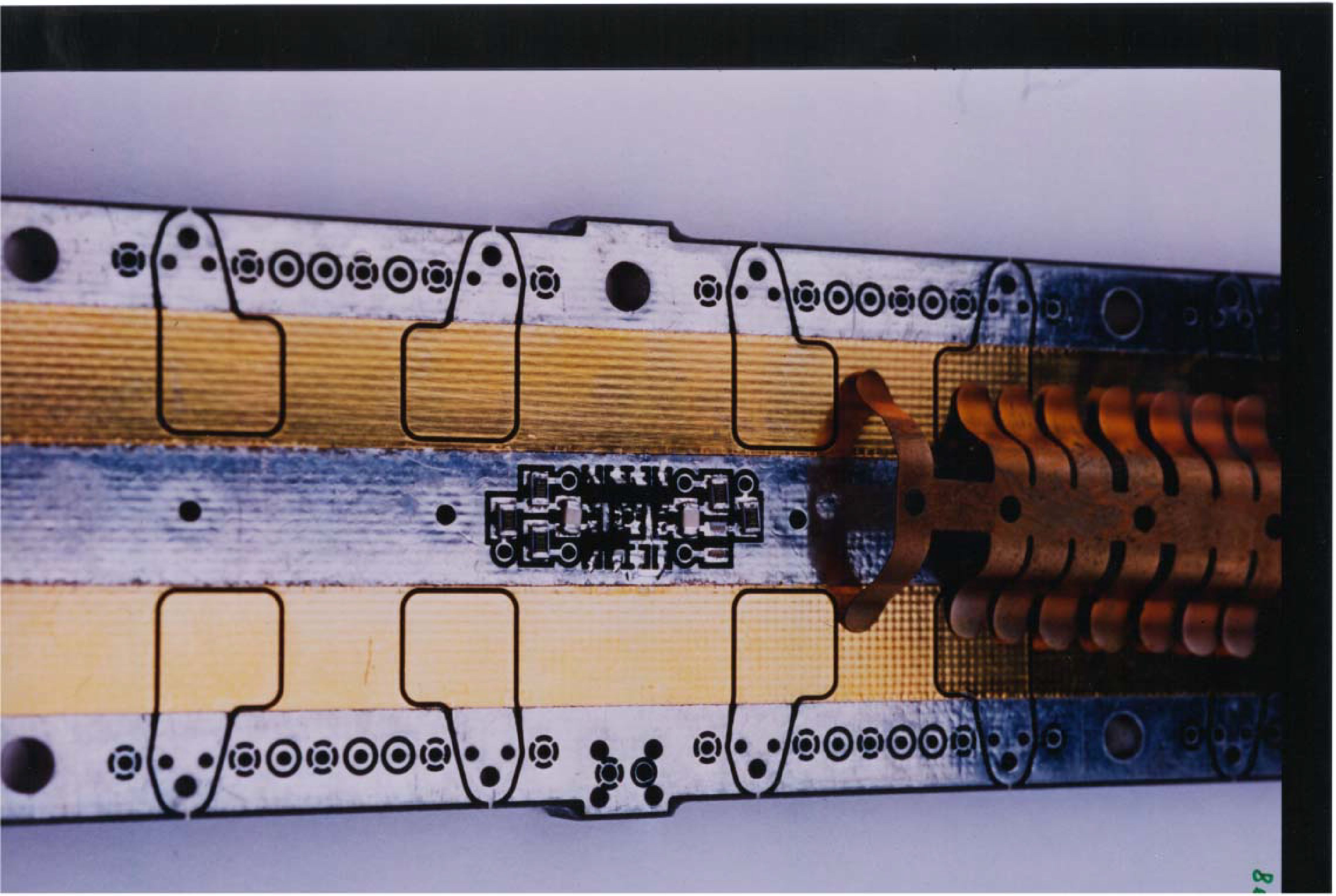


Figure 3: Time resolution for the NA48 LKr calorimeter


ELECTRONIC CALIBRATION CIRCUIT
+HV
10M
10K
15pF
3nF
PA
OUT
15 BITS DAC
VREF
CD
150pF
100K
D MOS SWITCH
10V
0
TRIGGER
1K
1
ICAL
T
1.8pF
2nF
Cint
CCAL
2
P.A. PROTECTION SWITCH
LOW INDUCTANCE!
0
τ = 2.2 μs
INJECTED CURRENT
× 2000
100K
8
22pF
Vcomp
+12V
T = 120 K
LKr
CRYOSTAT

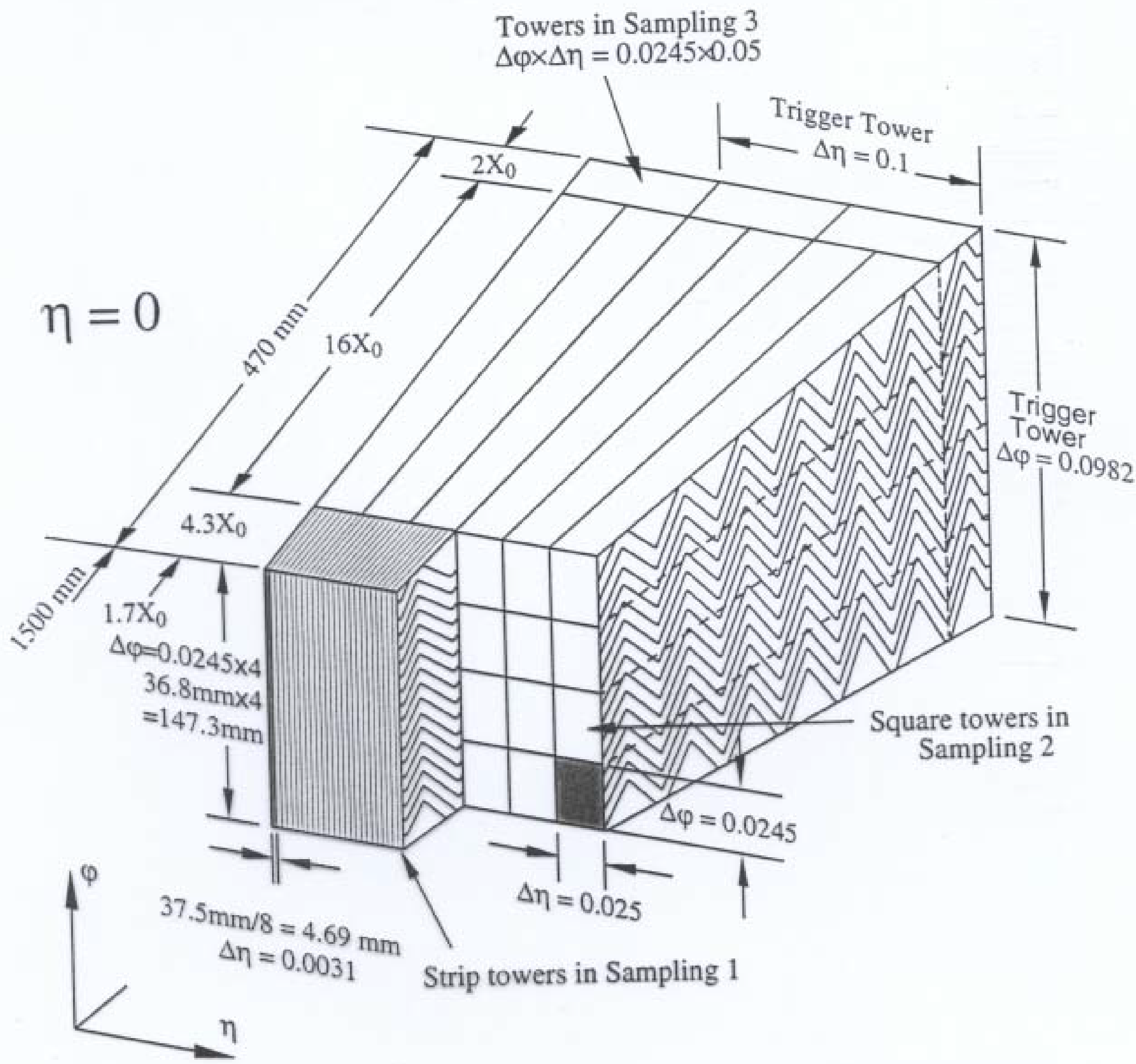


LAr *accordion*

- Main physics goal: $H \rightarrow \gamma\gamma$

113 $<(m_H < 150 GeV/c^2)$

- specs: $\frac{\sigma(E)}{E} = \frac{10\%}{\sqrt{E}} \oplus 0.7\% \oplus \frac{0.27}{E}$



- up to $\sim 3\ X_0$ of material in front of Barrel LAr $\rightarrow$ pre-sampler
- ~ 170 K channels in total

CERENKOV CALORIMETRY IS FAR FROM DEAD SINCE IT HAS EVOLVED INTO THE CONSTRUCTION OF SUPERKAMIOKANDE AND THE CONCEPTION OF EVEN MORE MASSIVE UNDER SEA AND UNDER ICE DETECTORS, NOT TO MENTION THE EXPLOITATION OF CERENKOV RADIATION IN THE ATMOSPHERE TO DETECT SUPER HIGH ENERGY COSMIC RAYS

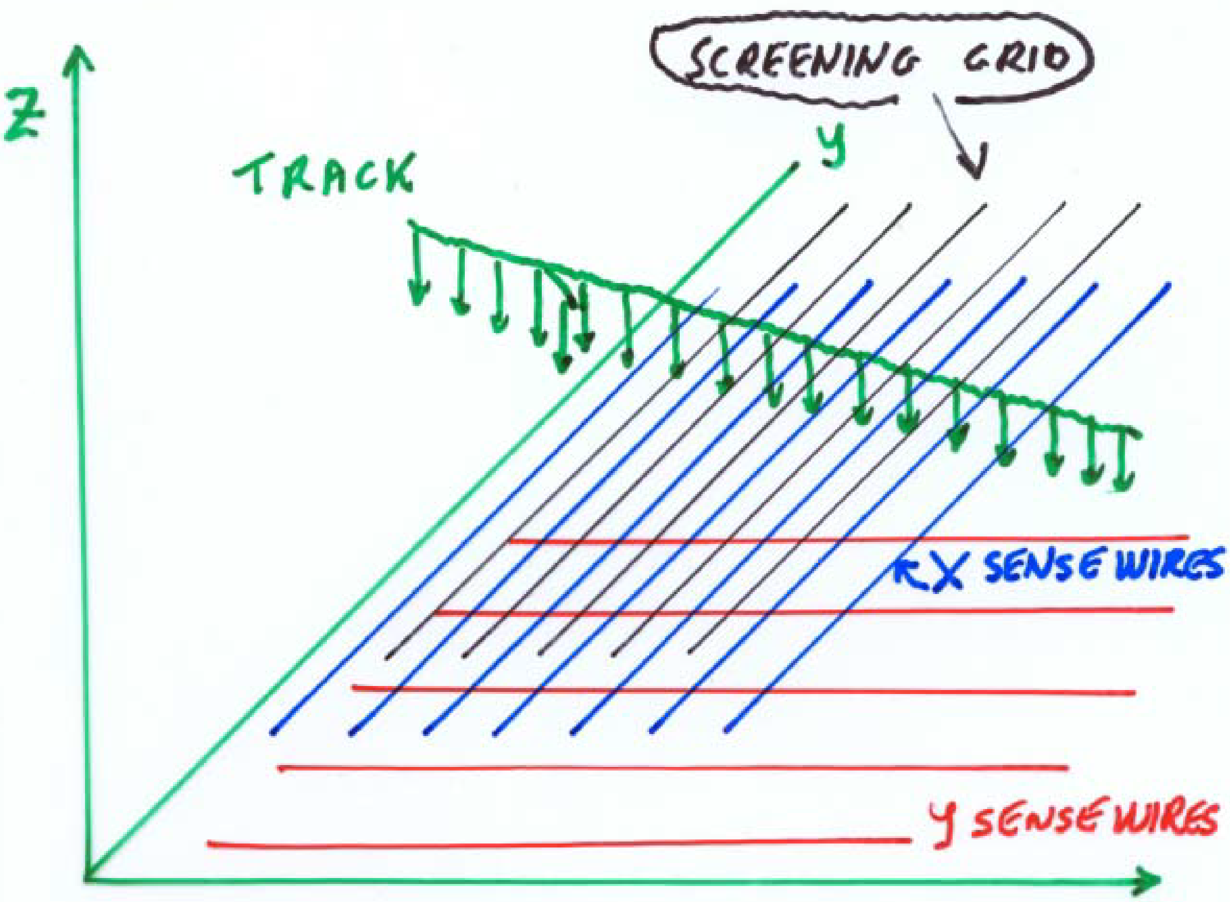
IT MUST BE KEPT IN MIND THAT

IN REAL CALORIMETERS, PRACTICAL REQUIREMENTS LIMIT THE PERFORMANCE TO VALUES TYPICALLY SOME ORDER OF MAGNITUDE INFERIOR TO THE THEORETICAL ONE. THIS MEANS THERE IS ROOM FOR IMPROVEMENT GIVING ENOUGH ATTENTION TO "DETAILS".

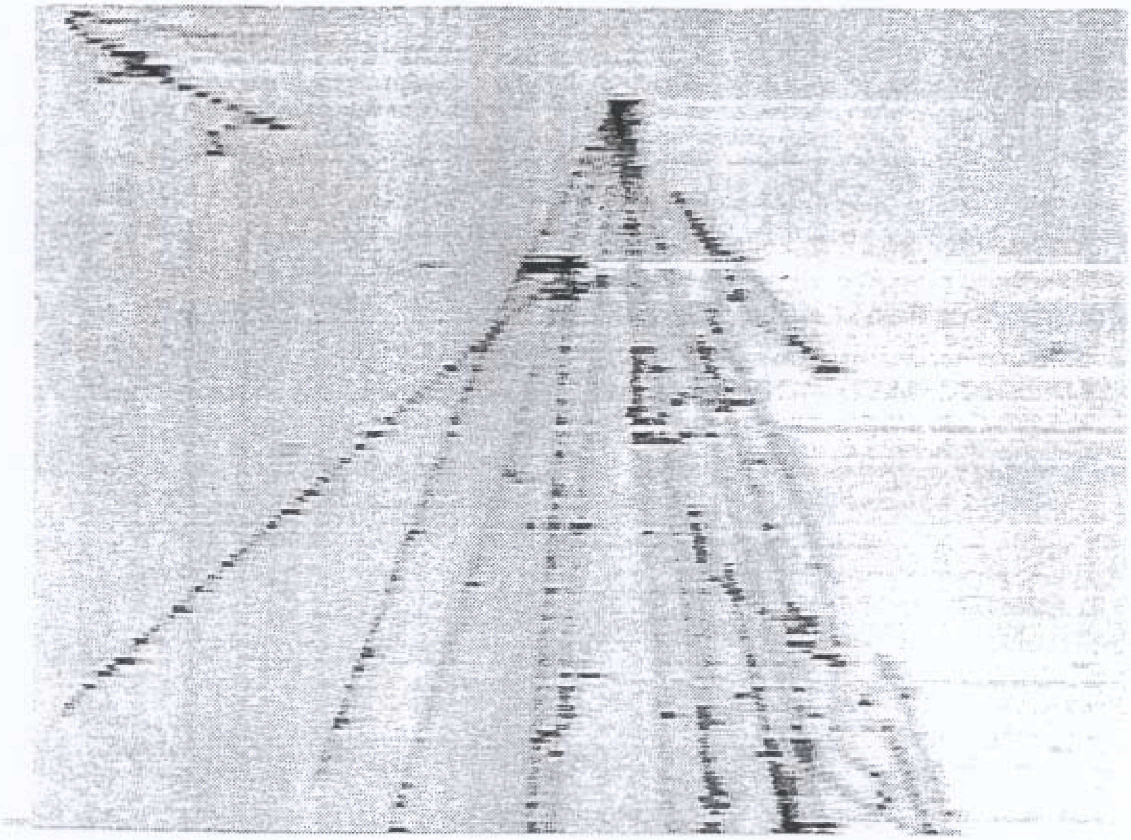
IN STRIVING TO SATISFY THE NEEDS OF FUTURE EXPERIMENTS, IONIZATION CALORIMETRY HAS THE ADVANTAGE THAT THE BASIC STEPS, LINKING THE RECORDED SIGNALS TO THE ENERGY AND OTHER PROPERTIES TO BE MEASURED (E.G. THE STATISTICAL PROPERTIES OF THE IONIZATION ITSELF, RECONBINATION AND ELECTRON CAPTURE, DRIFT VELOCITY, FEATURES OF E.M. SHOWER DEVELOPMENT, SIGNAL FORMATION, NOISE ETC.), HAVE BEEN WELL STUDIED. WITH THIS ACCUMULATED KNOWLEDGE, COUPLED TO THE INTRINSIC STABILITY OF THESE DEVICES, IT SHOULD BE POSSIBLE TO ENGINEER INCREASINGLY ACCURATE FEATURES FOR DIFFERENT APPLICATIONS

A REMARKABLE PROJECT HAS BEEN GOING ON FOR MORE THAN TWO DECADES, FOLLOWING AN IDEA OF CARLO RUBBIA, TO DEVELOP THE DETECTION OF IONIZATION IN ARGON INTO MULTI KILOTON ELECTRONIC BUBBLE CHAMBERS

THIS SO CALLED ICARUS PRINCIPLE HAS BEEN SHOWN TO WORK CLOSE TO EXPECTATION AND A BIG EFFORT IS CURRENTLY GOING ON TO EXTRAPOLATE IT TO THE VERY LARGE SIZE NEEDED FOR NEUTRINO DETECTION AND STUDY OF PROTON DECAY

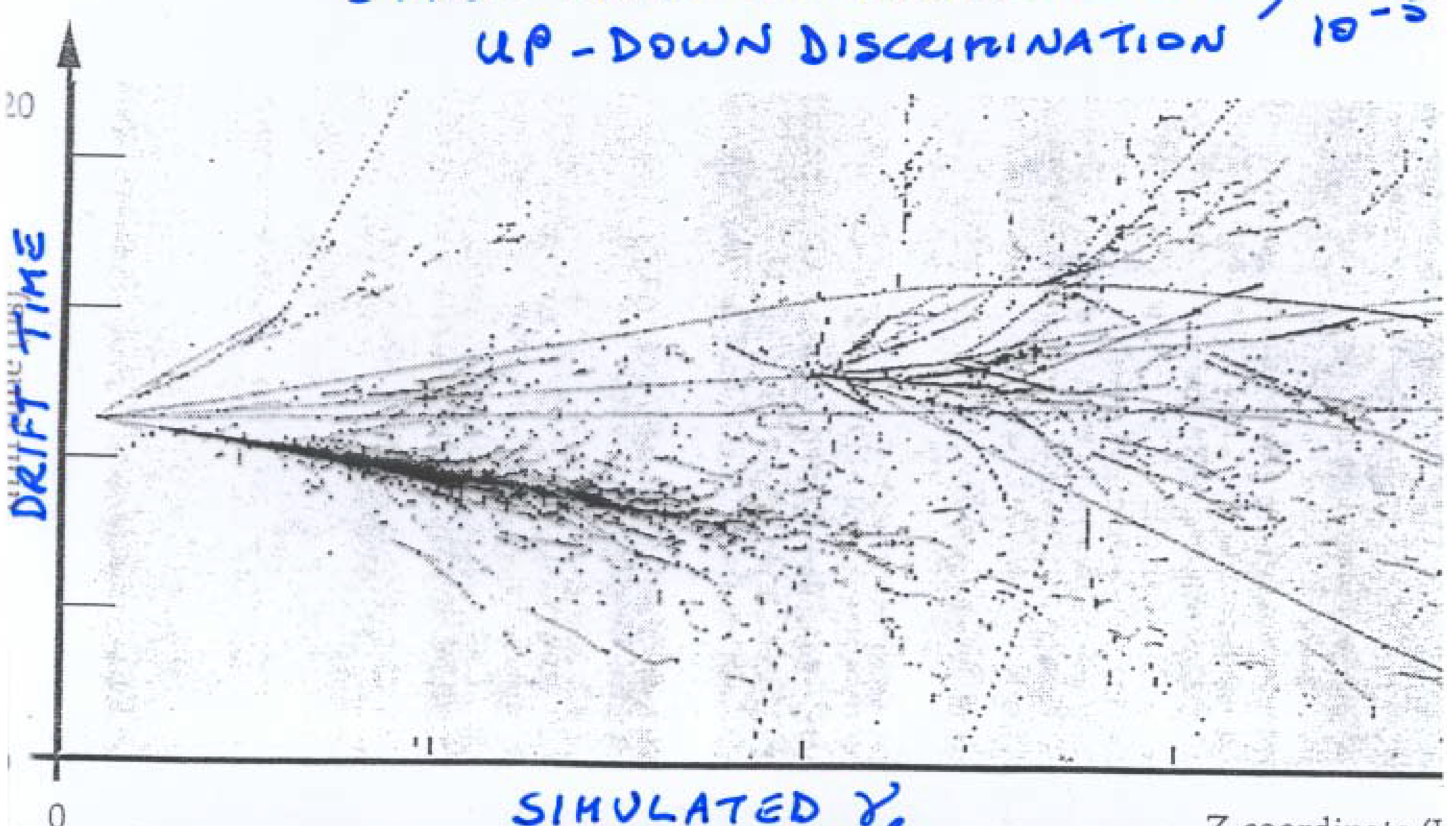


FOR EACH TRACK ELEMENT
UNAMBIGUOS X, Y, Z (TIME)
ASSOCIATION



REAL ν INTERACTION
IN 50ℓ PROTOTYPE

δ RAYS SEEN ON 140cm LONG μ TRA
UP-DOWN DISCRIMINATION 10^{-5}



SIMULATED ν_e
INTERACTION

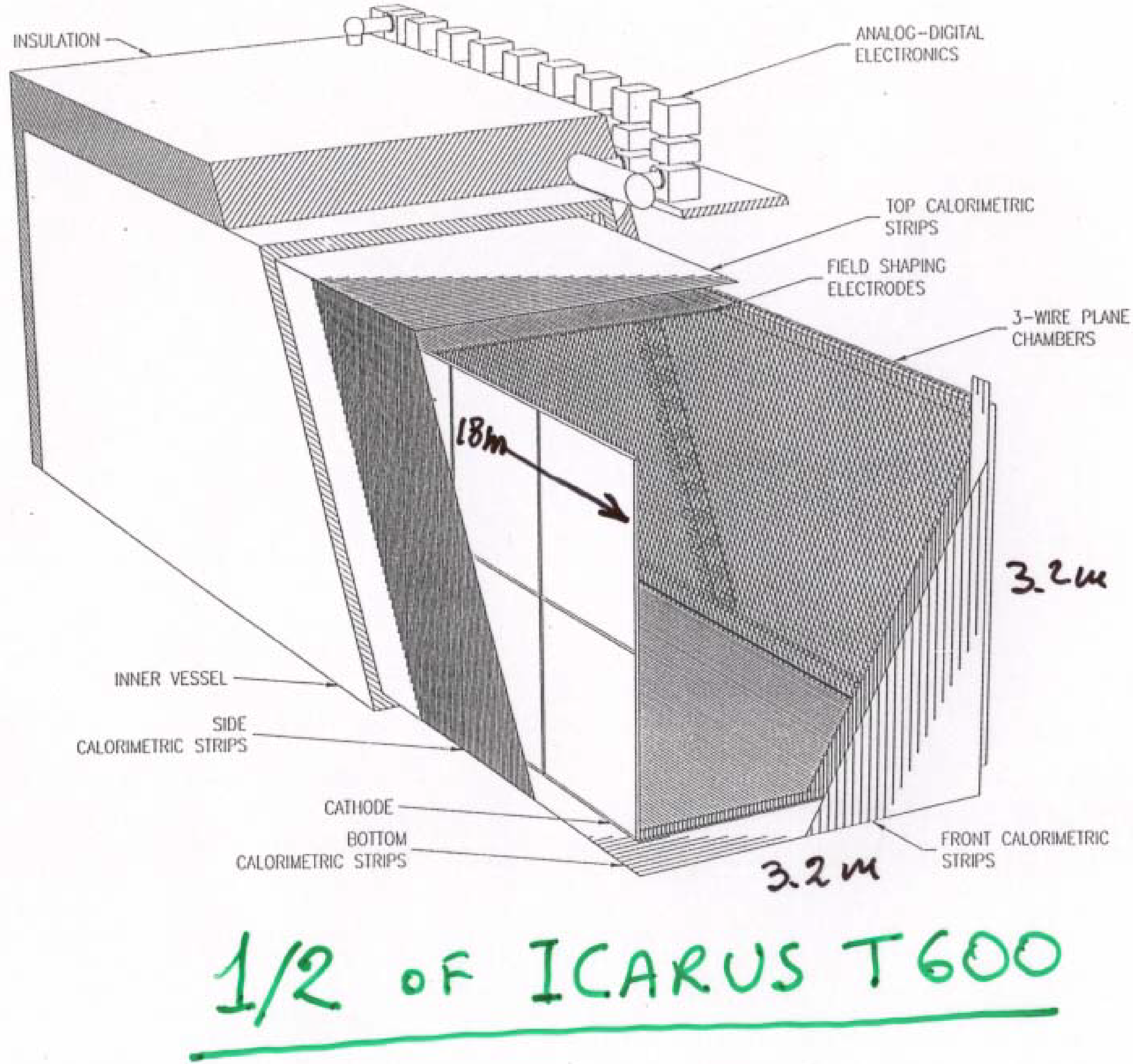


Figure 3.7: Layout of the calorimetric readout in the non imaging regions of each LA submodule.