Fermilab

PBAR NOTE #462

Transparencies of Talk given at the 2nd Topical Seminar on Perspectives for Experimental Apparatus at Furture High Energy Machines

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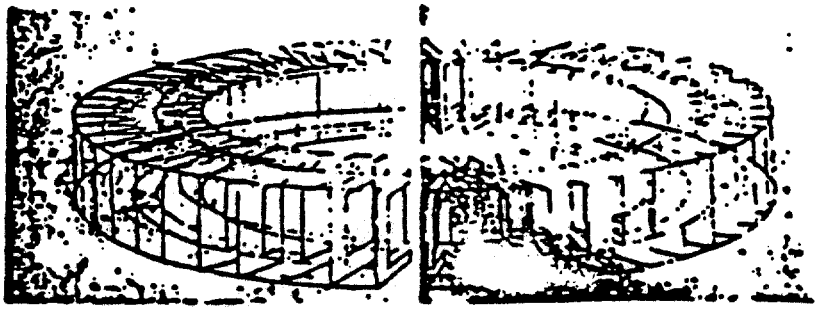
5/23/86

Institut de Physique Nucléaire
Université de Lausanne

SEMINAIRE DE PHYSIQUE NUCLEAIRE

23 Mai 1986 à 16h00
Salle BSP 626

Compte rendu de la conférence de Miniato 1986



2ND TOPICAL SEMINAR on PERSPECTIVES for EXPERIMENTAL APPARATUS at FUTURE HIGH ENERGY MACHINES

Prof. Ernest Malamud
Université de Lausanne

E. Malamud
May 23, 1986

2nd TOPICAL SEMINAR on

PERSPECTIVES for EXPERIMENTAL APPARATUS at FUTURE HIGH ENERGY MACHINES

San Miniato, Italy May 5-9, 1986

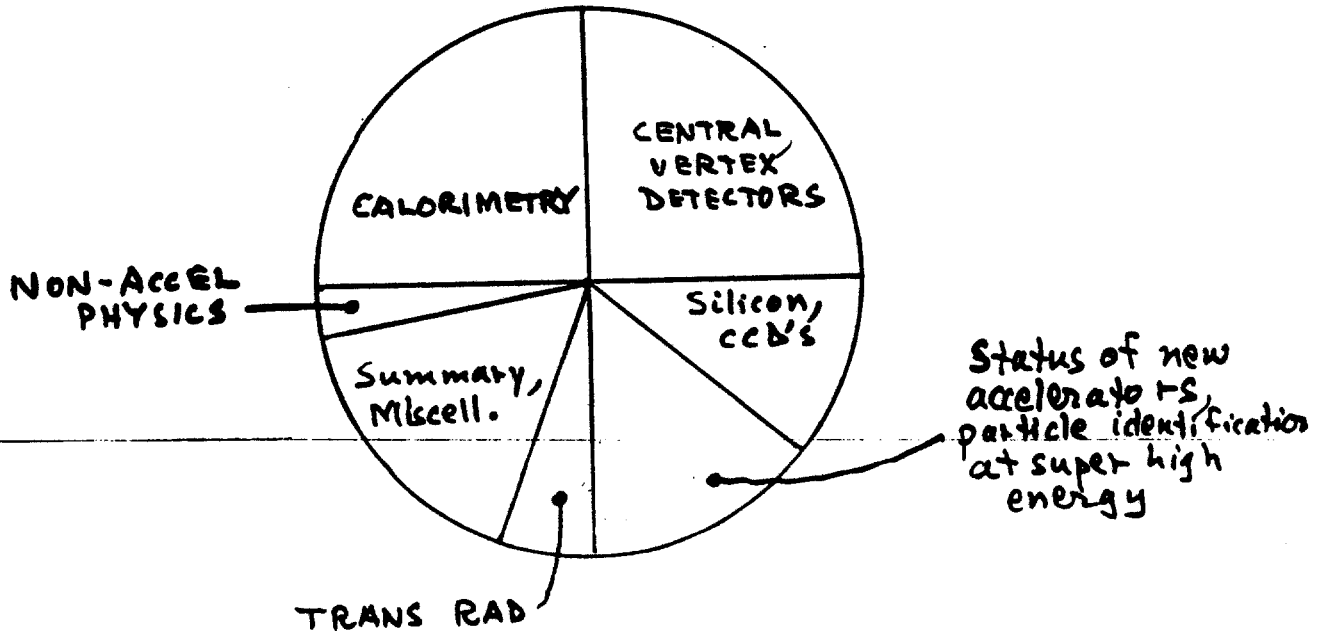
≲ 75 physicists / 10 countries
≲ 25 industry representatives / 16 companies

~ 100 participants

48 talks
2 round table discussions
- calorimetry
- HEP ↔ Industry

1 parallel session

} ≲ ≈ 30 h.

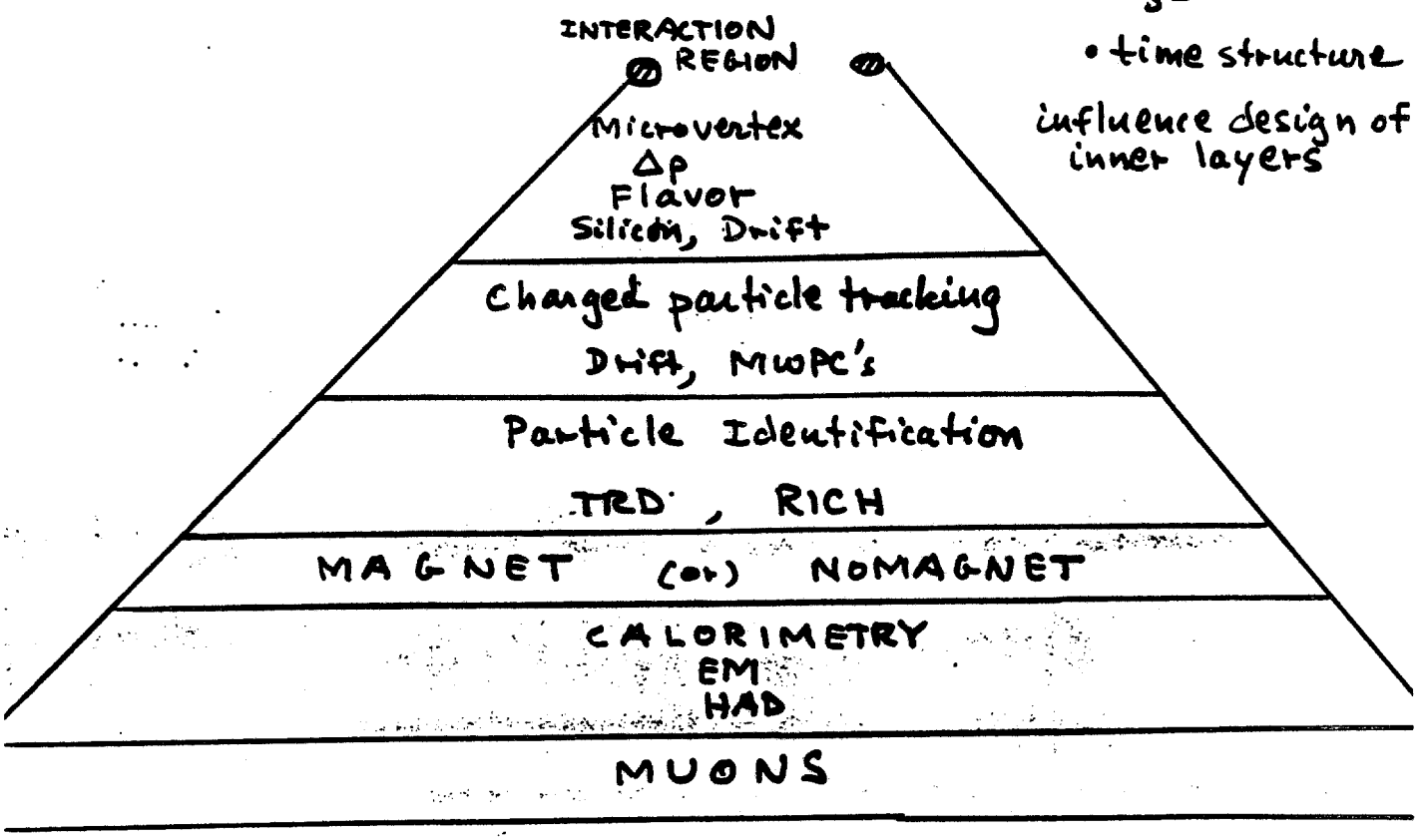


- At the conference various applications were discussed:
  - Non-accelerator (e.g. ICARUS)
  - Fixed target (e.g. HELIOS)
  - Colliders

- Detectors for colliders all have a similar configuration:

Important parameters
- size
- time structure

influence design of inner layers



- For most of the major collider detectors there was a report on at least one portion of the detector.

- Copies of transparencies from a few talks and some commercial brochures available.

86 87 88 89 90 91 92 93 94 95 96

SPS Collider $p \rightarrow \leftarrow \bar{p}$ 315 315 — 3×10^{29} — 3×10^{30} (ACOL)

UA1

UA2

Tevatron I $p \rightarrow \leftarrow \bar{p}$ 800 800 (1000) (1000) — H TEST — $\gtrsim 10^{30}$

CDF

DØ

SLC $e^- \rightarrow \leftarrow e^+$ 50 50 — 5x 10^{28}, 6x 10^{29}, 6x 10^{30}, polarized beams

Mark II

SLD

LEP $e^- \rightarrow \leftarrow e^+$ 50 50 — 10^{31}

L3

DELPHI

OPAL

ALEPH

HERA $p \rightarrow \leftarrow e^-$ 820 30 (38) — 1.5×10^{31}

H1

ZEUS

? SSC $p \rightarrow \leftarrow p$ 20000 20000 — 10^{32}–10^{33}

($250×10^6)

? LHC $p \rightarrow \leftarrow p$ 6000 6000

? COLLIDING LINACS $e^- \rightarrow \leftarrow e^+$ 1000 1000

PLAN FOR SEMINAR.

1- CALORIMETRY

Rather general remarks

2- VERTEX / CENTRAL DETECTORS

3 - SILICON STRIP DETECTORS

(based on excellent review talk by R. Horisberger, CERN)

4- PARTICLE IDENTIFICATION AT SSC ENERGIES

5- NON-ACCELERATOR PHYSICS

"Review of review talks"

- J. Ernwein, Saclay
- E. Fiorini, Milan

1. CALORIMETRY

Some obvious remarks on the importance of calorimetry:

① Energy (momentum) measurement.

Magnet + Chambers [gives sign] $\frac{\Delta p}{p} = k_1 p$

Calorimeter $\Delta E/E = k_2 / E^{1/2}$

These are equal at $p = E = \left(\frac{k_2}{k_1}\right)^{2/3}$

Generally 50 - 100 GeV

② Calorimeters dominate all of the new large detectors and generally represent > 50% of cost

③ There are 5 "elementary" particles to detect at very high energy:

γ
e
ν → missing P_t
quarks → Jets → $e/\pi = 1.000$
μ

} CALORIMETRY

- In general, a calorimeter consists of alternating layers of

  Passive material
  Active material – readout medium

- In separate talks various calorimeters were described having different combinations:

Passive	Active (sampling)	Combined Passive, active
Lead	Scintillator – PM	BGO
Copper	Scintillator – PD	Lead-glass tubes
Uranium	SILICON	(Liquid Ar (SSC)
	Liquid:	
	Argon	
	Room temp –	
	TMS, TMP	
	(Plastic / Glass fibers	

- and their relative advantages and disadvantges were discussed in terms of:
  - Performance. Energy, spatial resolution (t, L)
  - Compactness, Hermeticity (ν's)
  - Cost, ease of construction
  - Control of systematic errors
  - Radiation resistance

Silicon calorimetry

Application : EM calorimetry

- low noise → can use for low E
- E linearity 47 MeV/GeV
- Fast $\lesssim$ 10 ns for 300 μ. thick
- Compact, geometry flexible
- Low voltage
- active layer thin → poor E-resolution $.17 - .20 / \sqrt{E}$
- expensive

		t(active) μ	A (cm²)
W	CERN-SICAPO	70, 200 PD	25
?	ICRR Tokyo	1000 (Li-dr) FD	38
U	ICR - Hamburg ZEUS	200 Surf.barr. FD	8 → 530
Pb	Hamburg H1 plug		

Physics aspects of high resolution calorimetry

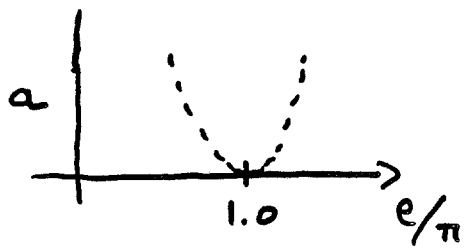
Talk by R. Wigams, CERN.

In general $\sigma\left(\frac{\Delta E}{E}\right) = a + \frac{b}{E^{1/2}}$

OFFSET TERM DOMINATES AT HIGH ENERGY.
($b = .3$ to $.5$)

$a = 0$ if $e/\pi = 1.000$

This can be demonstrated by looking in detail at the equations for longtitudinal shower developement.



In a general calorimeter $e/\pi \neq 1$.

How to make $e/\pi = 1$?

Passive material - Uranium - fission
Lead - spallation products
$\longrightarrow$ neutrons

Active material - if there are free p's
$\rightarrow$ np elastic scattering
large σ at low E

(1) less n-induced fission
(2) n captured close to point of production
} non-sampling

Type protons
① scintillator
② in TMS, TMP
③ add CH_4 to Ar

Wigams has studied shower processes (especially the crucial part < 1 MeV) by neutron activation -

He cuts up his calorimeter in pieces and determines the t, L distribution of different isotopes.

For any given combination of passive / active (free p) he can "tune" e/π to 1.000 by adjusting t_p, t_a

<u>Round table discussion</u>

What is the <u>ultimate</u> achievable resolution?

Passive. U.

Intrinsic spread in binding E $\sim .18/\sqrt{E}$
Sampling $\sim .18/\sqrt{E}$ } $\frac{.35}{\sqrt{E}}$

DØ
$e/\pi = 1.0 - 1.1$
add CH_4

Active. Free p $\rightarrow e/\pi = 1.000$.

Suppose $E > 1$ TeV ?

$\sigma(\Delta E/E) \lesssim 1\%$.

Systematics may limit any further gain

$\Delta t = \frac{21}{n}$ $n \geq 6$

- Stability - ion chamber better, (but slower)
- Radiation damage
- Calibration, monitoring in a large system

2. VERTEX / CENTRAL DETECTORS

SOME FACTORS INFLUENCING DESIGN:

(1) Size of interaction region

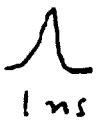
	$\sigma_x \sim \sigma_y$	σ_z
SLC	1-2 μ	
SSC	5 μ	7 cm.
Tevatron I	≥ 60 μ	40 cm.

(2) Accelerator time structure

several 10^4 analog channels → power dissipation in readout electronics

	time between crossings	
SLC	5556 μsec.	(180 pps)
LEP	22 → 11 μsec.	
Tevatron I	6.9 → 1.2 (?)	
SPS-ACOL	3.8 usec.	
SSC	> 13 nsec	

(3) Beam pickup:

e.g. Tev I $\xrightarrow{10^{12} \text{ protons}}$  $I_{pk} = 160$ a.

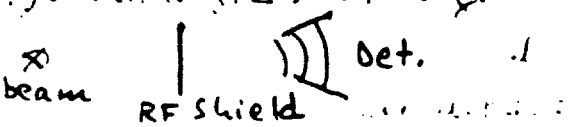
1 ns bunch

UA1 $\xrightarrow{10^{11} \text{ protons}}$ p.u 4 mv, signal 5 mv

carbon fibre vac tube, Aluminized

successful operation of Si-strip detectors in vacuum

~~Tev I (PTA) small angle scattering~~



(4) Total $\mathcal{L}$. At 3×10^{30} (ACOL) 2×10^6 chg part./sec.

Selections from 3 interesting talks:

① The UA1 Central Detector at Present and Future Luminosities. V. Vuillemin, CERN.

- An "old" detector running into trouble as $\mathcal{L}$ is raised.

② The Spiral Projection Chamber. U. Gastaldi

- "ASTERIX" at LEAR
- "OBELIX" at LEAR
- $\bar{p}p$ GAS JET EXPERIMENT IN FERMILAB ACCUMULATOR

Talk at IPN-Lausanne
by
John Peoples, E-760
(Tevatron I project manager)
JUNE 4 (Wednesday)

- Similar geometry at DØ, SLD (?) --- etc.

③ High Resolution Particle Tracking in Scintillating Glass Fiber Trackers. J. Kirkby CERN

- compare to Plastic Fibers (UA2 upgrade)
- besides application as trackers, fibers might be used in calorimetry

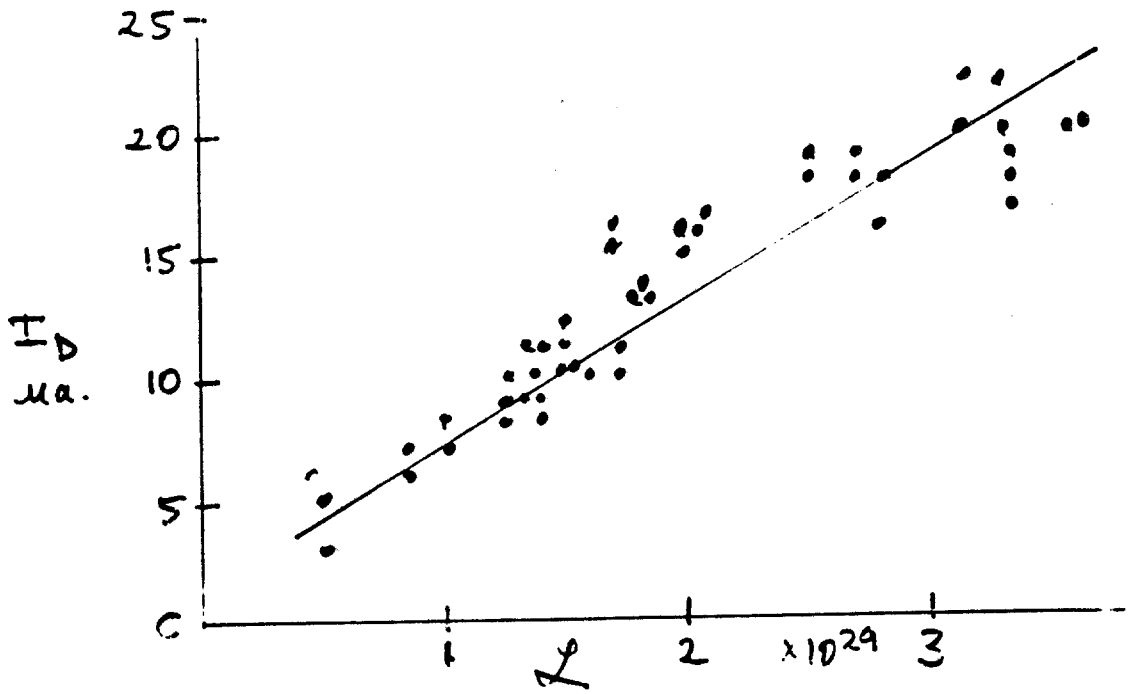
① UA1 Central Tracker (V. Vuillemin)

Record $\mathcal{L}$ 5.6×10^{29} $cm^{-2} sec^{-1}$

ACOL $\sim 3 \times 10^{30}$

Due to long electron drift paths and high gas gain (10^5) UA1 will face 2 major problems:

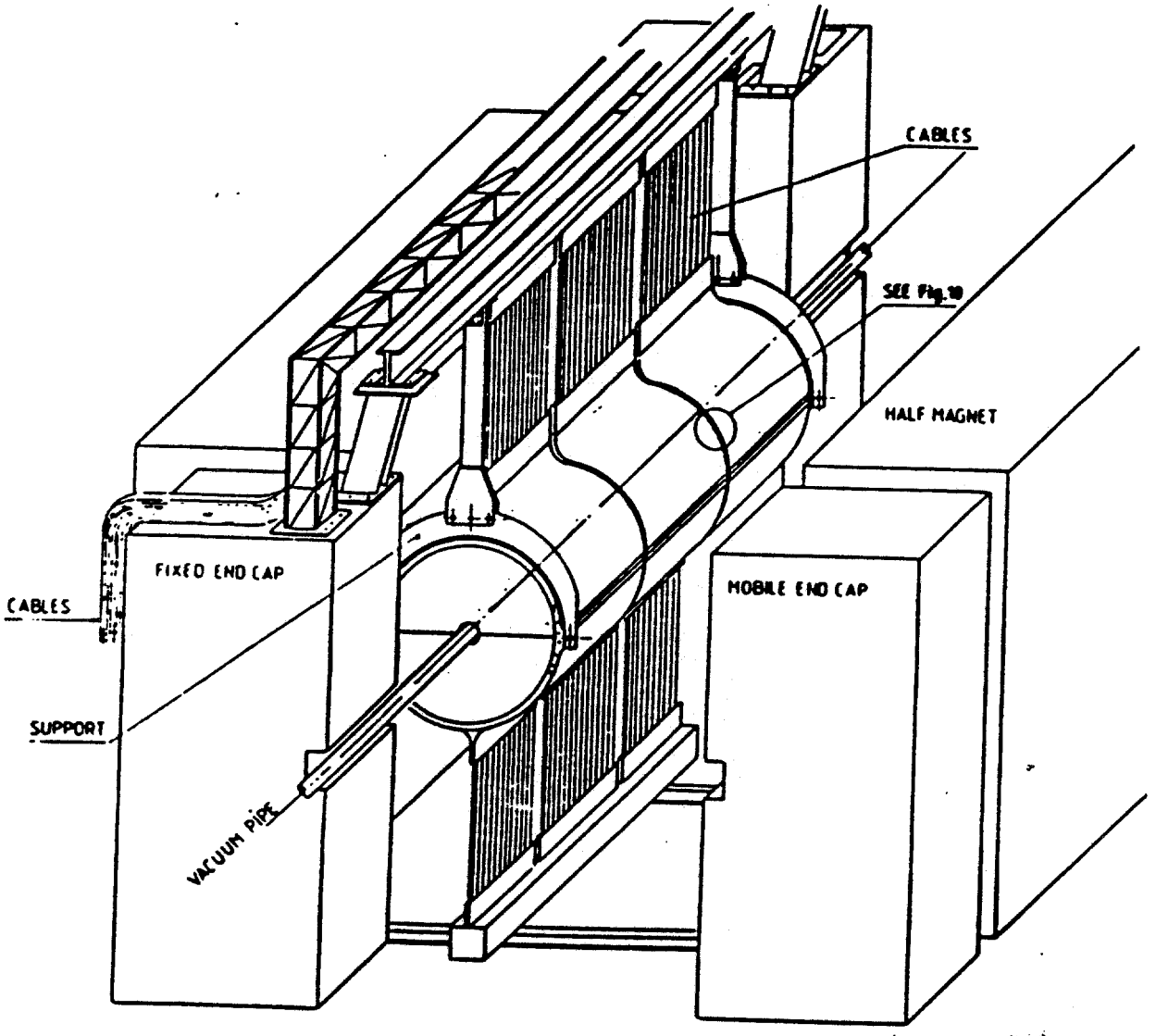
(1) Track distortions due to space charge caused by +'ve ions. Main problem is in large horizontal gaps near the beam.



Extrapolate: $I_D = 200$ ua, $I_C = 70$ ua } ACOL

Track distortions can be parameterized as a function of I_D, but become unacceptably large ($> 500\ \mu$) at these currents.

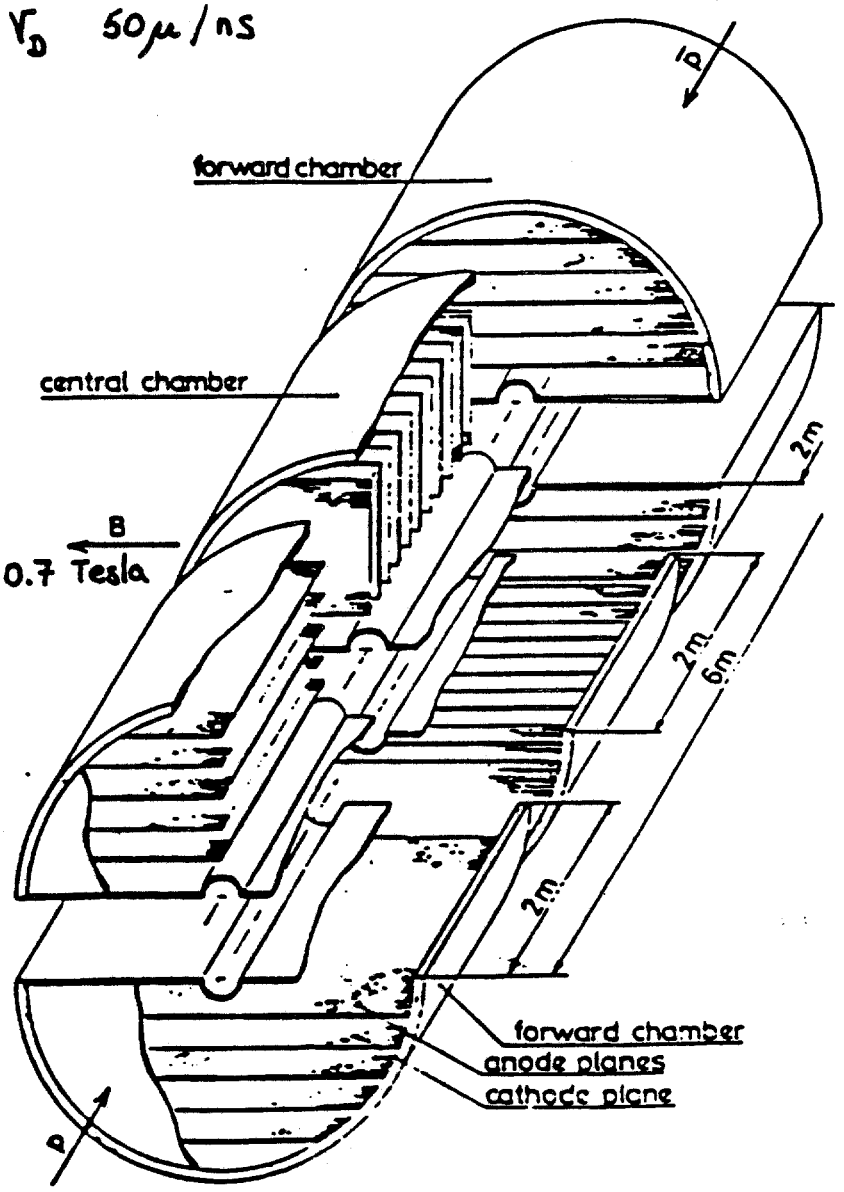
UA1 CENTRAL DETECTOR



L = 6 meters

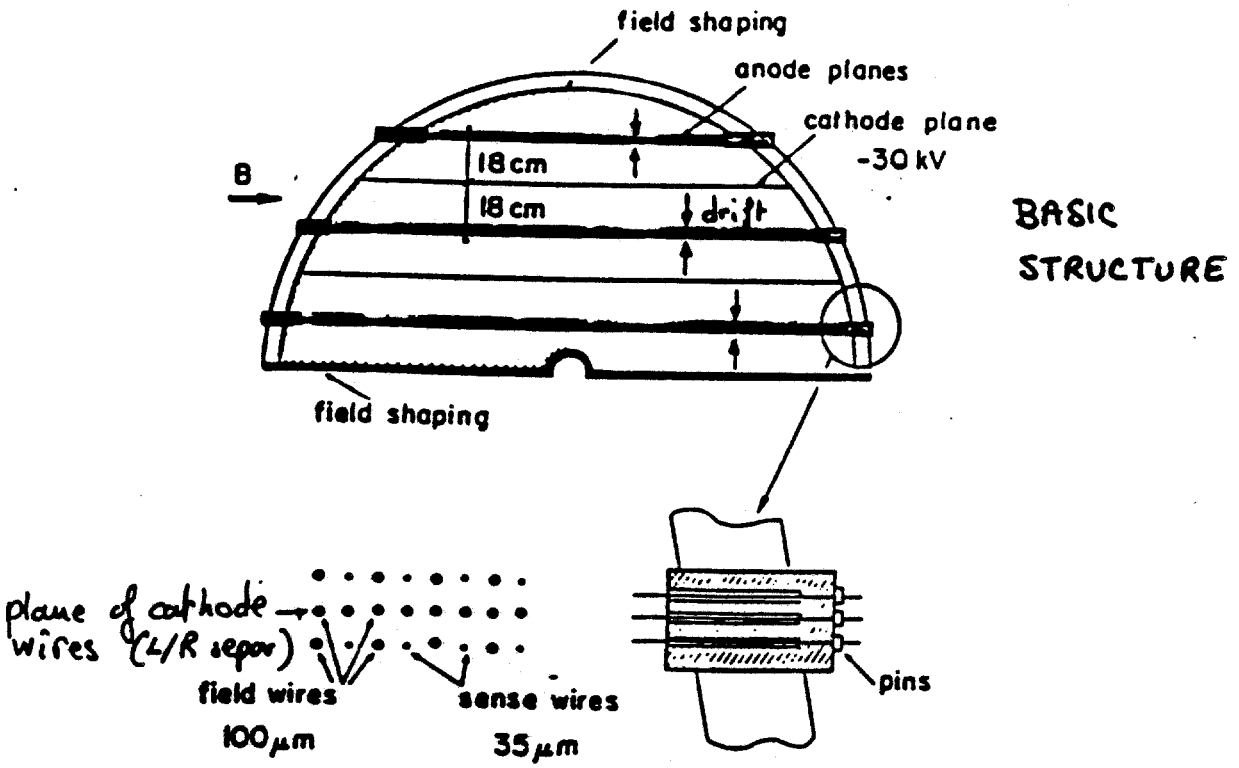
6 half-cylinders
All wires horizontal

GAS Ar-Ethane 40/60 (V: 25 m^3)
GAIN $\sim 10^5$
v_D 50 μ/ns

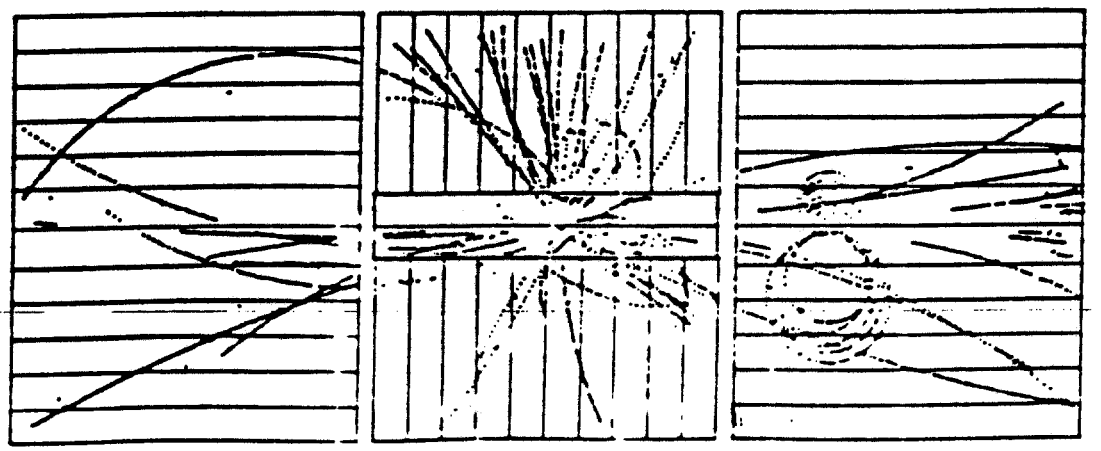


- wires along magnetic field
- planes of wires arranged to optimize N (hits) / track
- measurement of 3 coordinates + dE/dx

FORWARD CHAMBER



Typical hits recorded for a UA1 event
(Megatek display)



General characteristics of the detector

Type	Drift chamber with charge division readout of the second coordinate
Gas mixture	Argon (40%) + ethane (60%)
Drift field and gap length	1.5 kV/cm, 18cm
Drift velocity	5.3 cm/microsec
Drift angle	23^0 at B = 0.7 T
Anode plan arrangement	
a) Distance between sense wires	10 mm
b) Wire length	80 cm min., 220 cm max.
c) Sense wire charac.	35 microns Ni-Cr streched at 80 g
d) Field wire charac.	100 microns gold-plated Cu-Be streched at 200 g
Cathode plane structure	
a) Distance between wires	5 mm
b) Wire characteristics	150 microns gold-plated Cu-Be ,streched at 200 g
Total number of wires	22800
Total number of sense wires	6110

Working voltages:

V_D = 26 kV

V_C = 2.7 kV

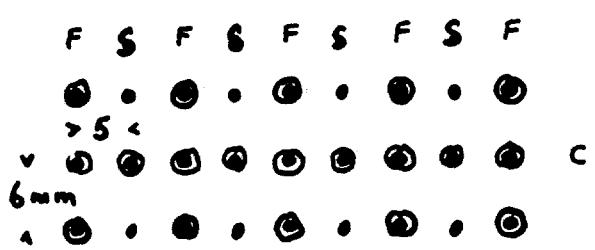
V_F = 2.0 kV

E field at surface of wires

E_S = 210 kV/cm

E_C = 33 kV/cm

E_f = 2.7 kV/cm



$\frac{1}{5}$ An obvious way to solve these problems is to <u>lower</u> the gas gain.

- $\Delta z/z$ becomes worse (charge div.) $\times 5$ (prop. charge)
- Need to modify electronics

$\mathcal{L}$	gain	I_D	dist. (worst)	σ_z
3×10^{29}	10^5	20	190 μ	1.5 % * l → 3.3 cm max.
3×10^{30}	10^5	200		
3×10^{30}	2×10^4	40	380 μ	10 % → 20 cm.

(2) Detector Aging

Comparison of Sept. '83 and Dec. '85 data shows no aging effect even in "hottest" region. $\int Q\,dt = 1$ coul/meter.

Using source and small test chamber they observed degradation in chamber characteristics for $\int Q\,dt > 7$ coul/m.

By adding 0.8% Ethanol leakage current stopped

<u>Present R&D</u>

Use laser induced ionization (∞ p) to map long range distortions repeatedly.
Problem is to find a suitable "doping seed".

② SPIRAL PROJECTION CHAMBER (Gestaldi)

COATED WITH UNIFORM HIGH RESIS CONDUCTIVE LAYER
- Field shaping end caps
- Internal, external cylinders

$\vec{E}$ radial

$E \propto \frac{1}{r}$ (Like a cylindrical capacitor)

Inner cylinder can be conical.

<u>Characteristics</u>

(1) Magnification (for tracks near inner radius)

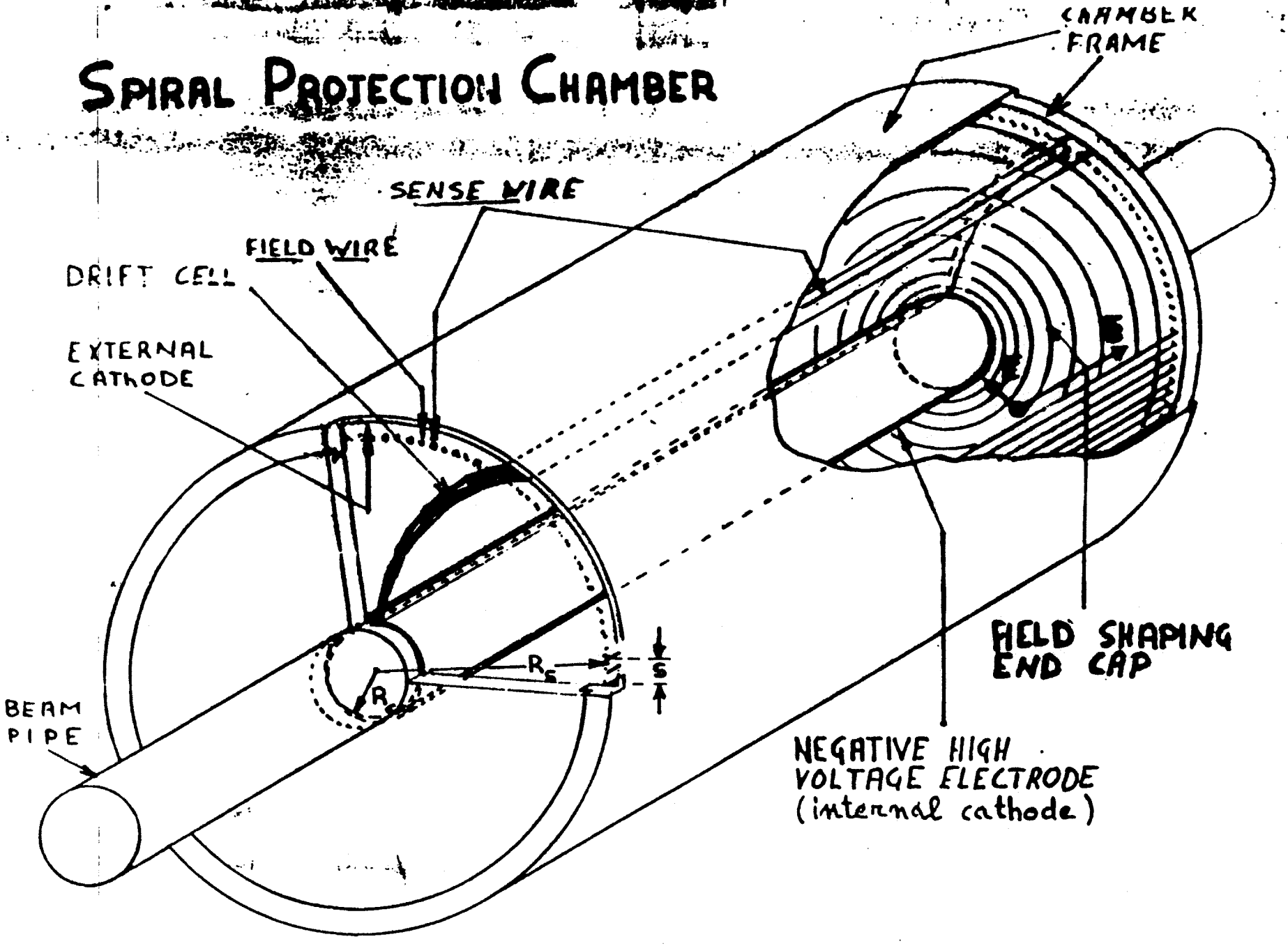
(2) Cylindrical symmetry
Equal $\Delta\phi$, towers

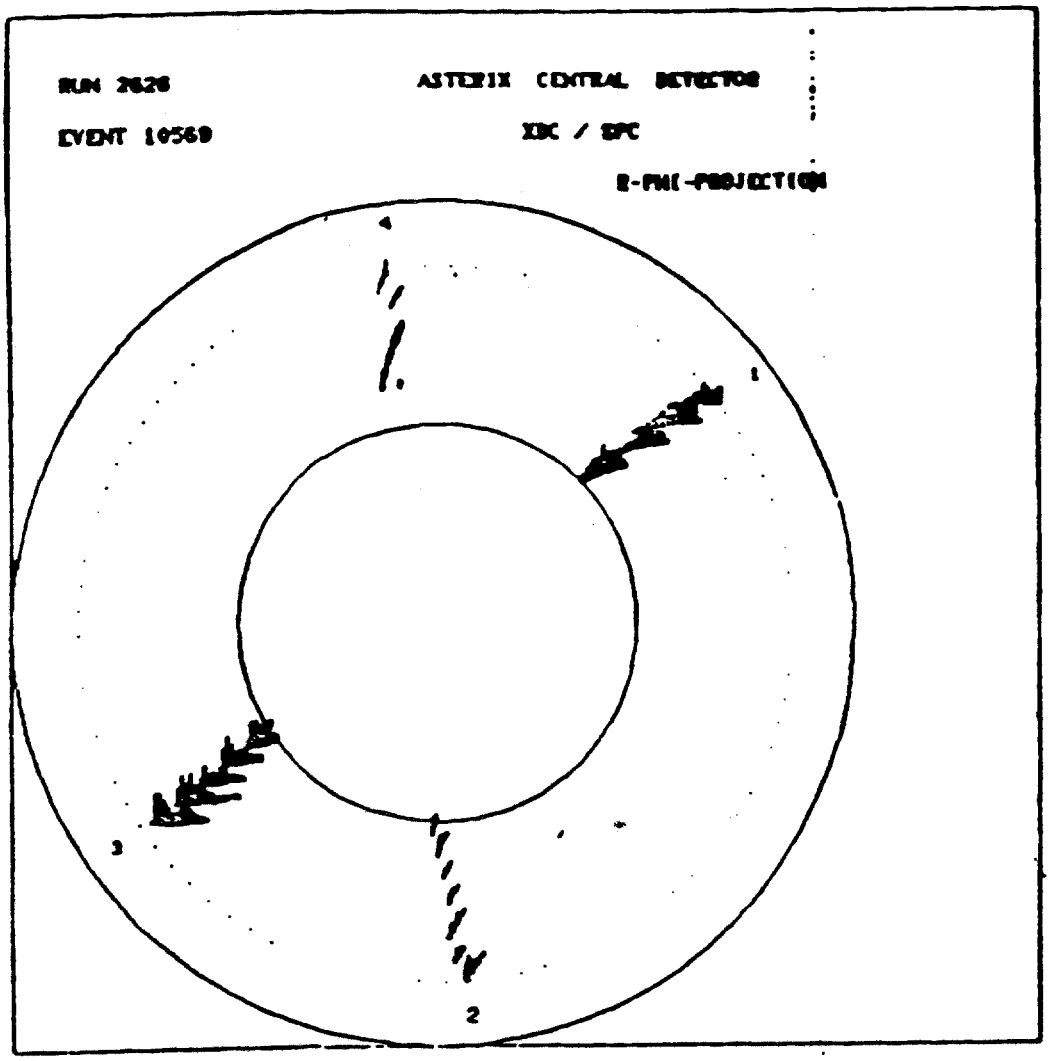
(3) Can be very long

(4) Wires, mechanics, electronics at outside radius (away from radiation)

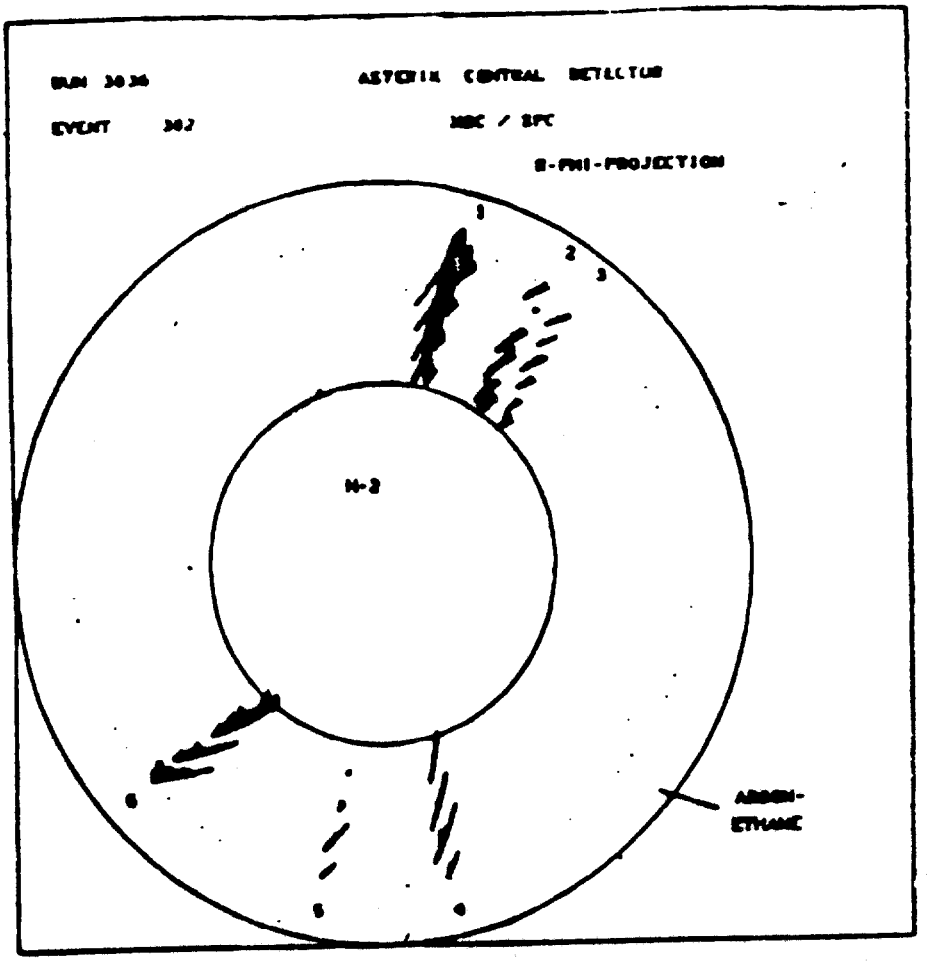
(5) Interesting option:
HIGH DENSITY RADIAL PROJECTION CHAMBER

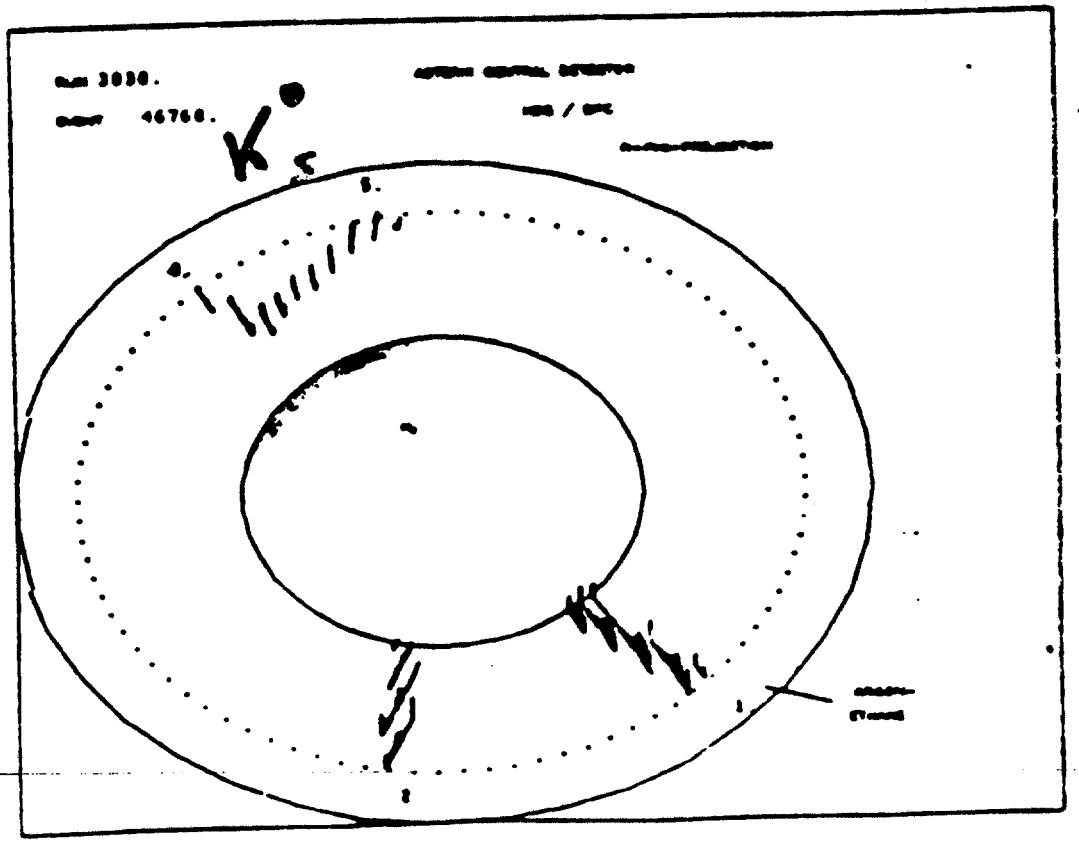
SPIRAL PROJECTION CHAMBER

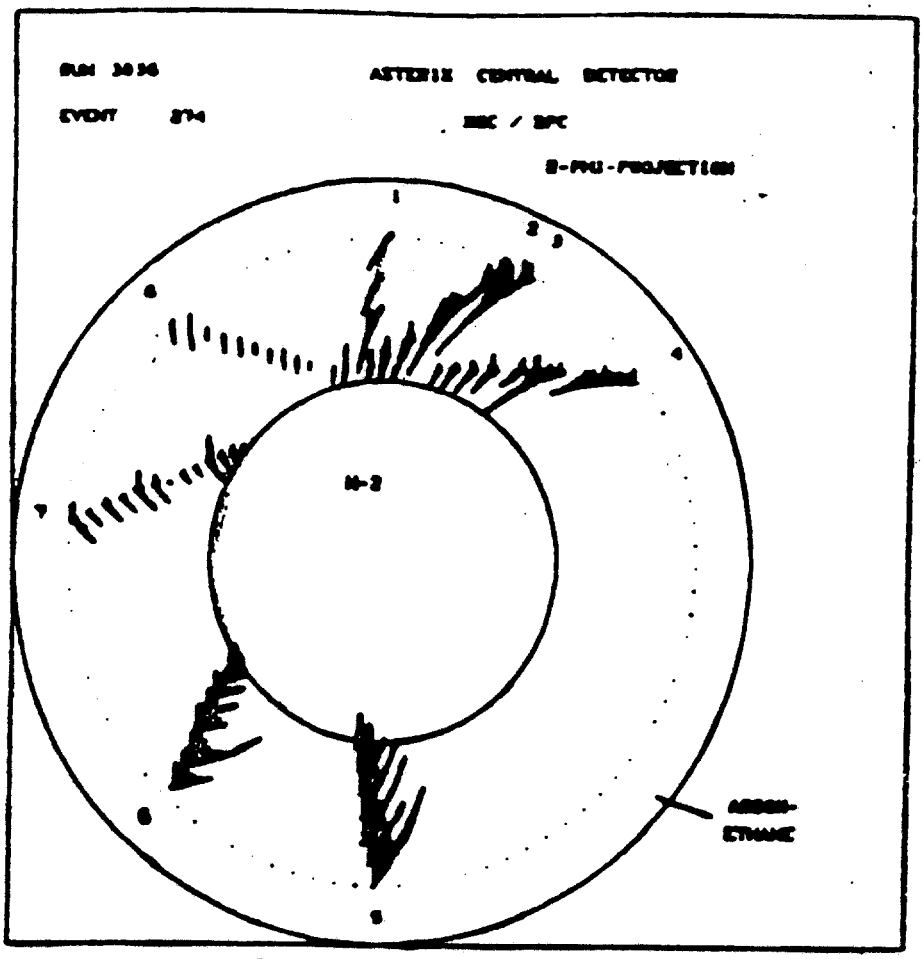


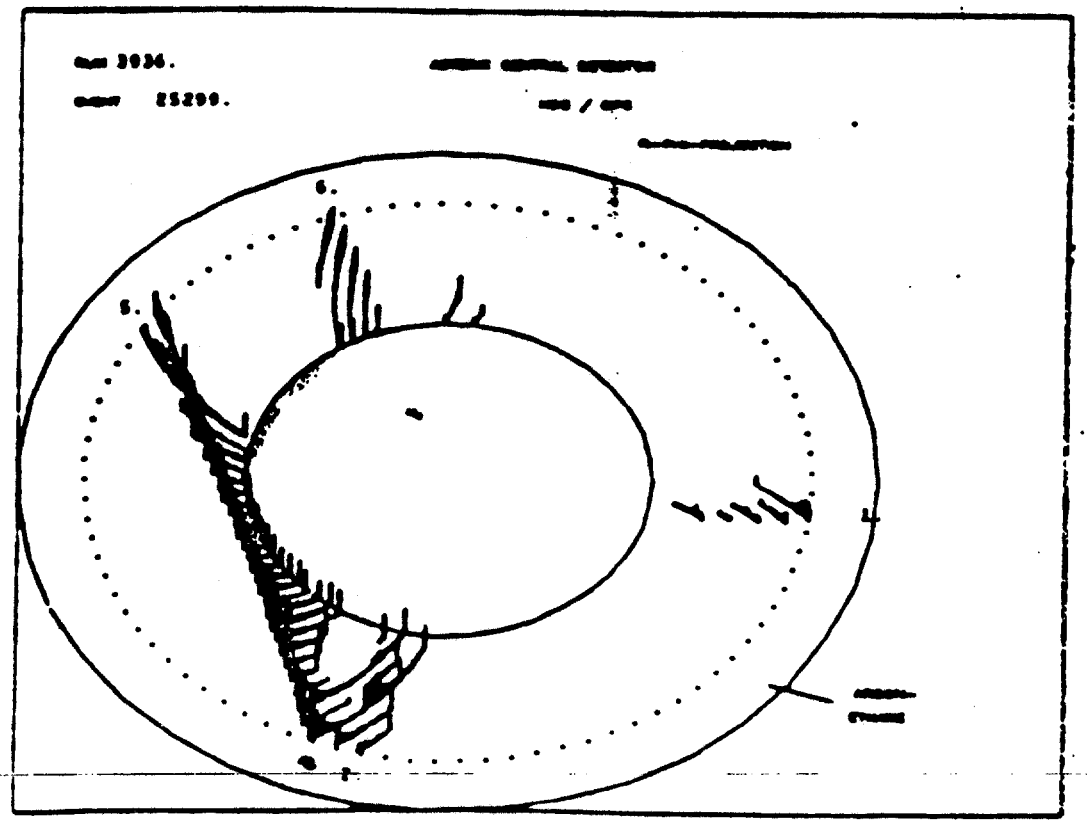


$K^+ K^- \pi^+ \pi^-$ event


RUN 3036
ASTERIX CENTRAL DETECTOR
EVENT 302
MBC / SPC
R-PHI-PROJECTION
1
2
3
N-2
6
5
4
ARGON-
ETHANE


RUN 3030.
EVENT 46768.
K
5.
4.
1
2


RUN 3036
ASTERIX CENTRAL DETECTOR
EVENT 274
N-2
ARGON-
ETHANE

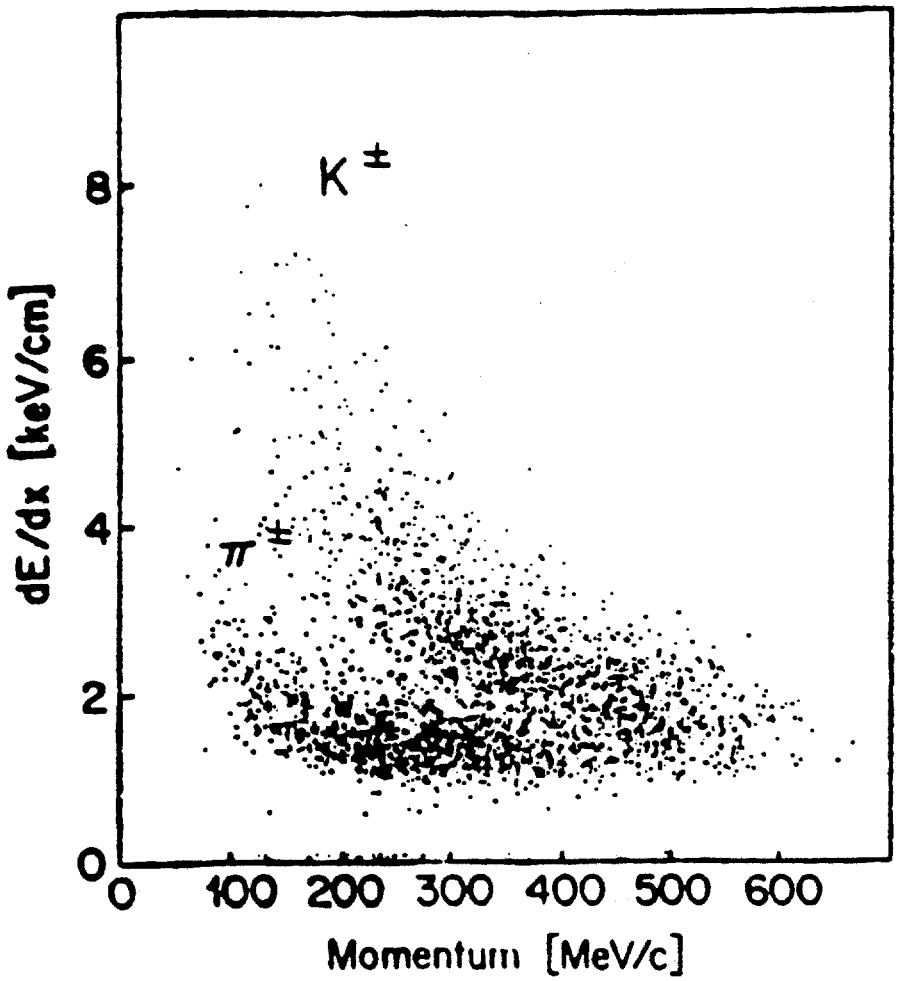

RUN 3036.
EVENT 25299.

ASTERIX PS 141

$K^{\pm}/\pi^{\pm}$ identification by dE/dx

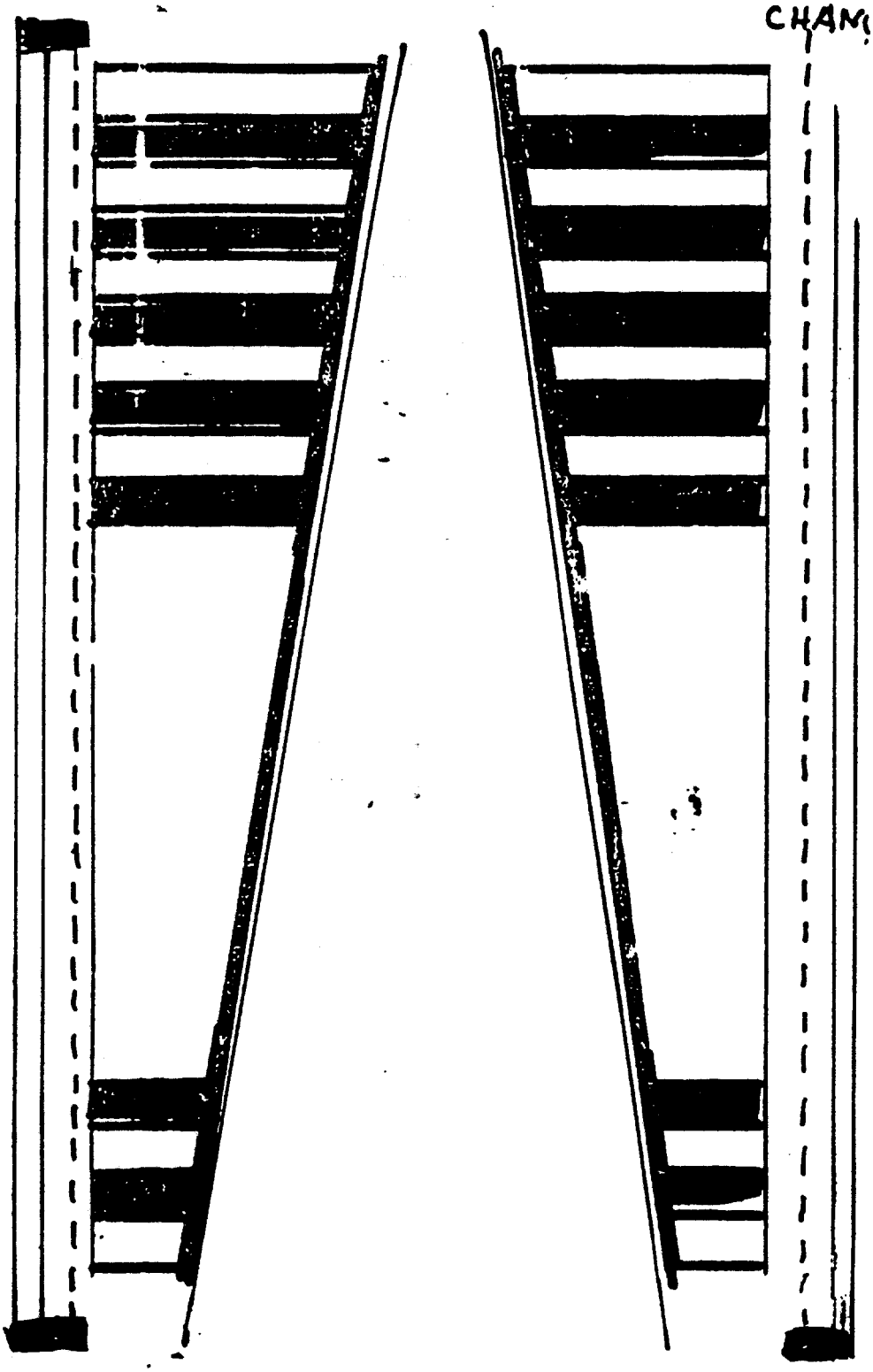
in the ASTERIX SPC up to ~350 MeV/c

Pi Rol Projection Number



dE/dx w/K separation in the ASTERIX experiment.

HIGH DENSITY RADIAL SPIRAL PROJECTION CHAMBER



(3) FIBERS FOR TRACKING (Kirkby)

APPLICATIONS

(1) Live targets. Direct observation of τ, c, b, ... decay.

10^{-13} sec. → impact parameters ~30 μ

(2) Precise tracking.
Small size can reduce overall detector size.

CHARACTERISTICS and CRITERIA

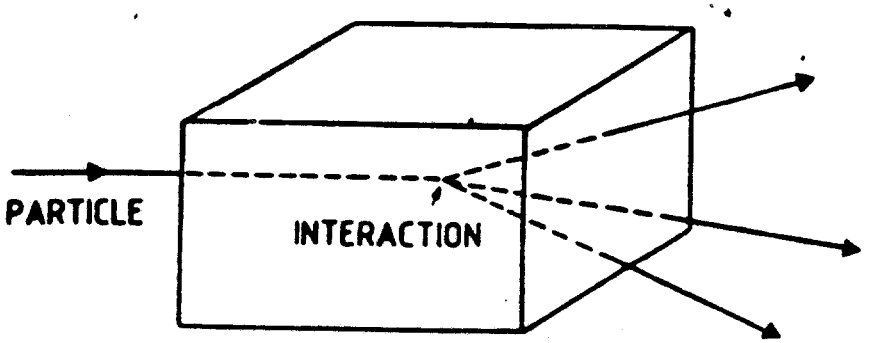
(1) Single track resolution. $\sigma \sim 10\ \mu$.
(2) $\sigma_{2\text{-hit}} \sim 100\ \mu$.
(3) Rate. $1 - 10 \times 10^6$
(4) Radiation resistance
(5) Low mass
~~(6) Radiation resistance~~

PLASTIC	GLASS
Light yield	poor light yield }
Long λ_{att}	short λ_{attn} }
min D ~ 1000 μ	D ~ 30 μ !
	Radiation resistant
low mass $X_0 = 44$ cm	High mass $X_0 = 9.8$ cm

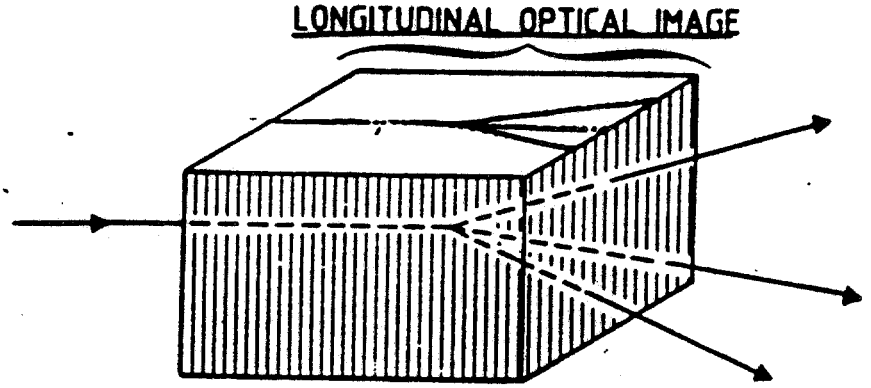
important to try and reduce

PRINCIPLE OF OPERATION

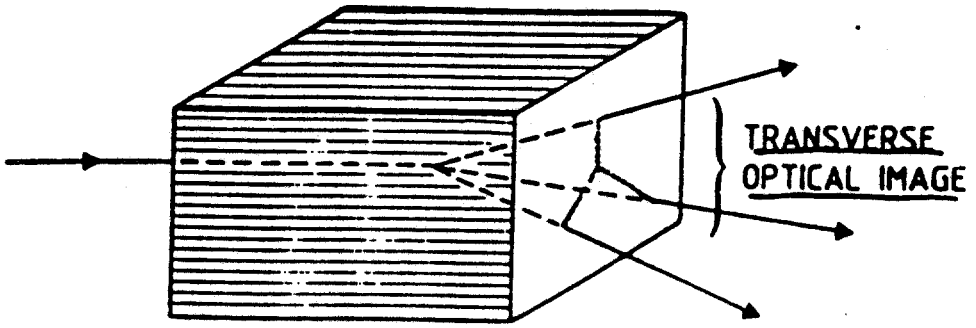
a) SOLID SCINTILLATOR



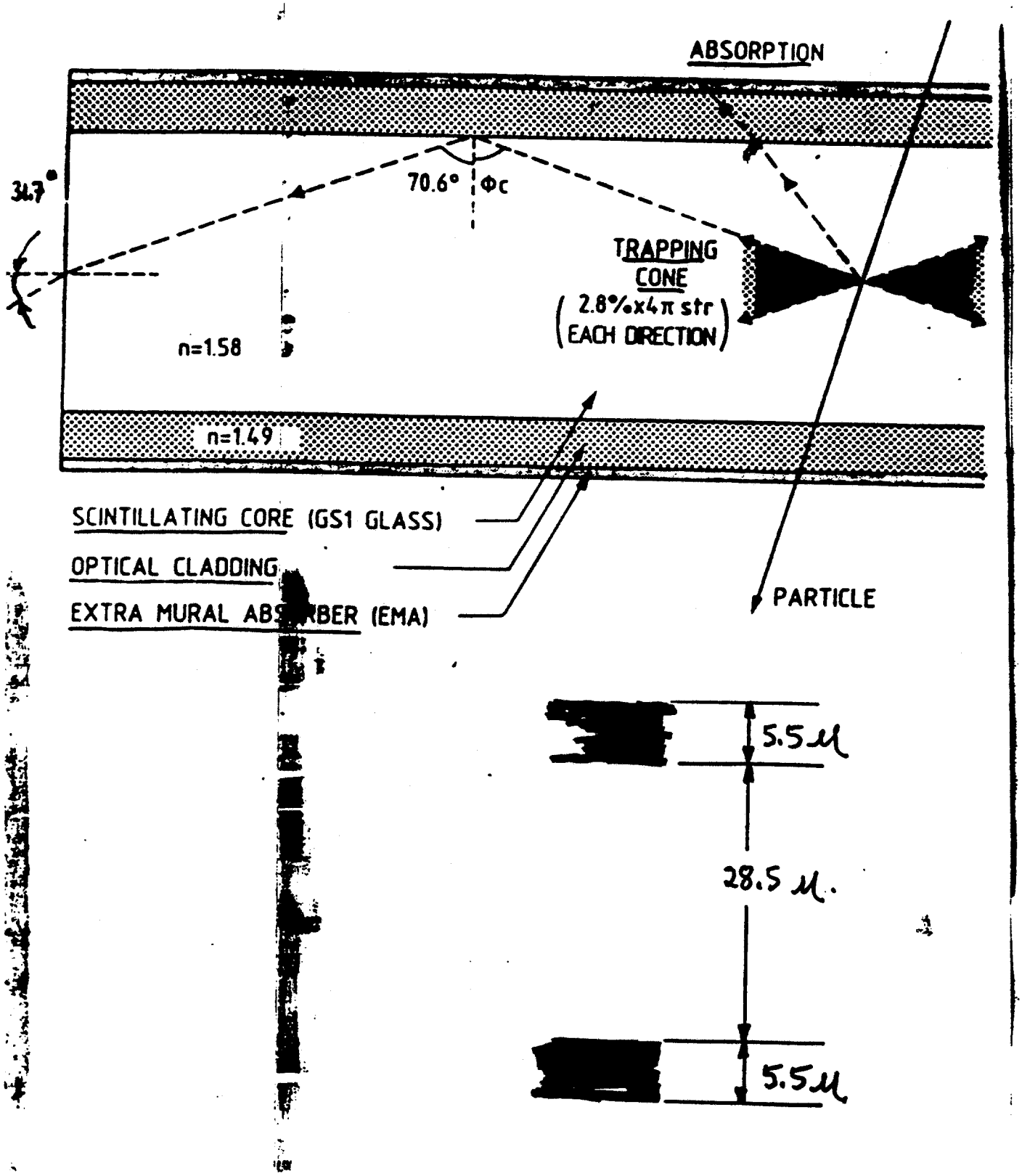
b) SCINTILLATING FIBRE BUNDLE (FIBRES PERPENDICULAR TO TRACK)



c) SCINTILLATING FIBRE BUNDLE (FIBRES PARALLEL TO TRACK)



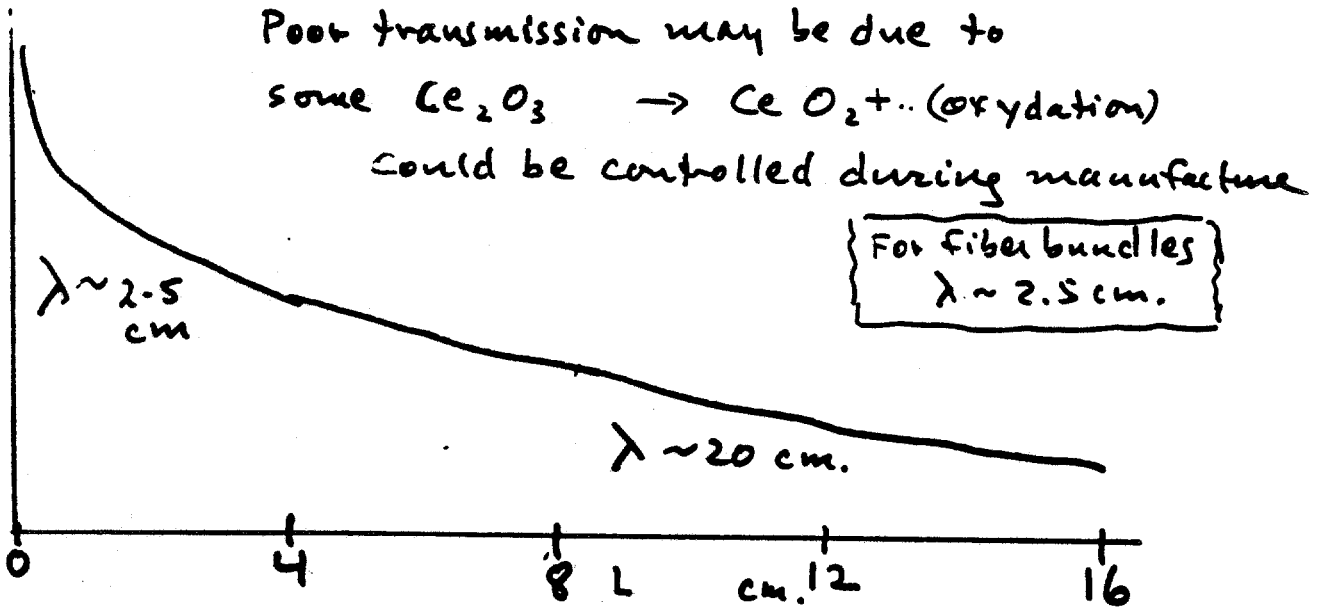
INDIVIDUAL FIBRE



Current measurements and R & D.

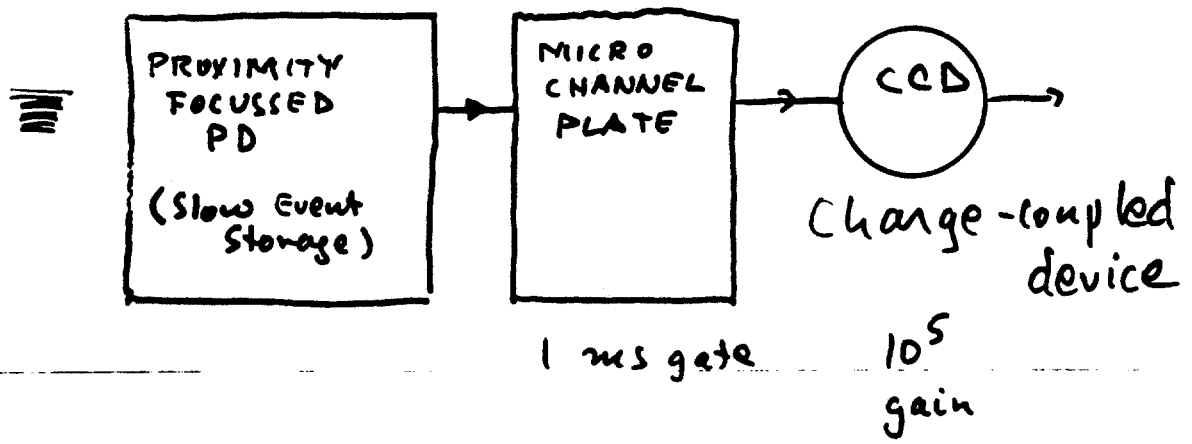
(1) GSI Scintillating glass.
Cerium doped. Has Ce_2O_3 (4%) (scintillator)

(2) Attenuation length



(3) Radiation test: 10^8 rad. ($\equiv$ 100 years 10 cm. from SSC interaction point)
"weak" yellow
Followed by temperature annealing (not possible with plastic)

(4) Read out (oversimplified)

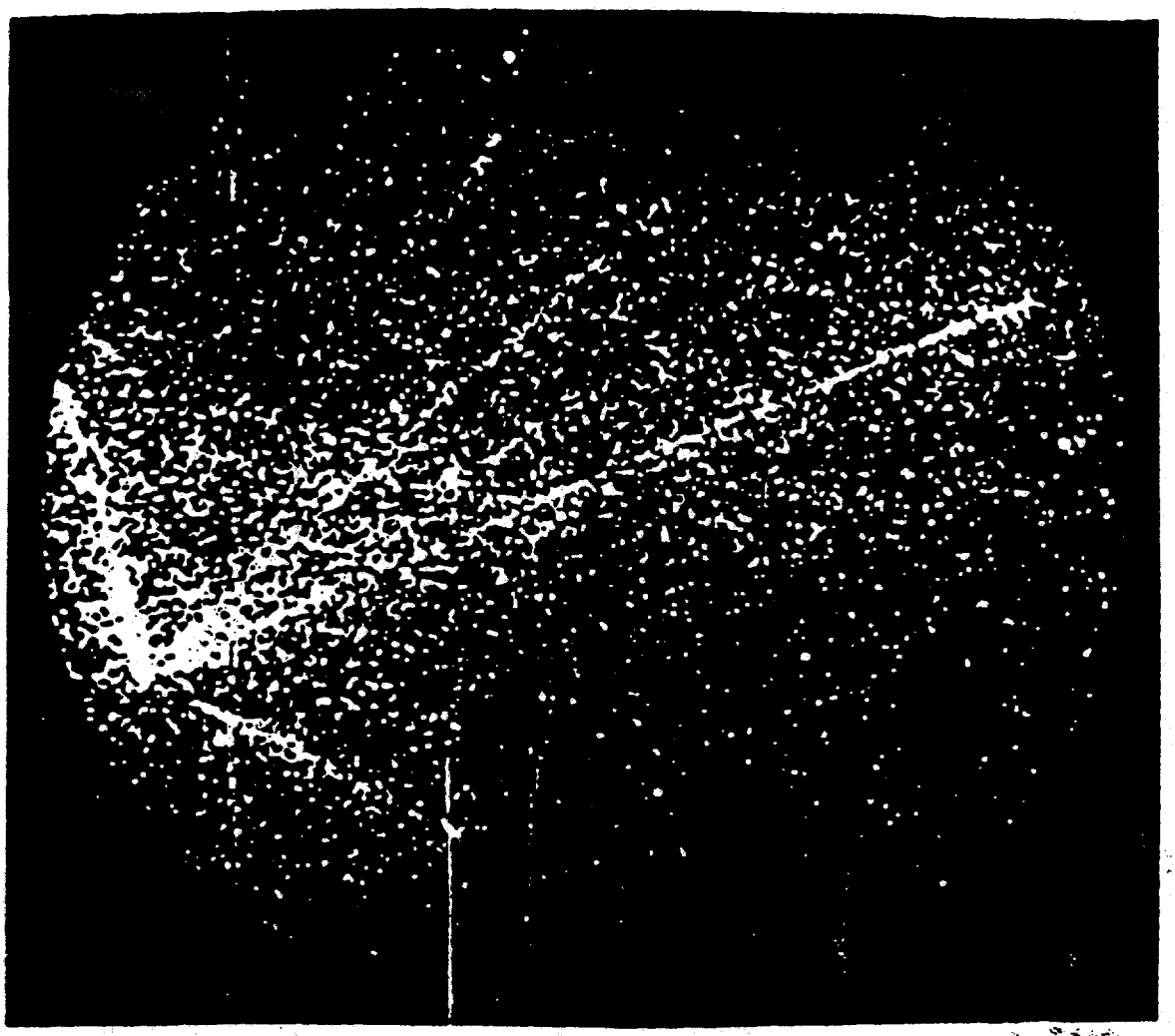


(5) Track residuals $\sigma = 25\mu$ (−30). 2-tr. res. 80μ.

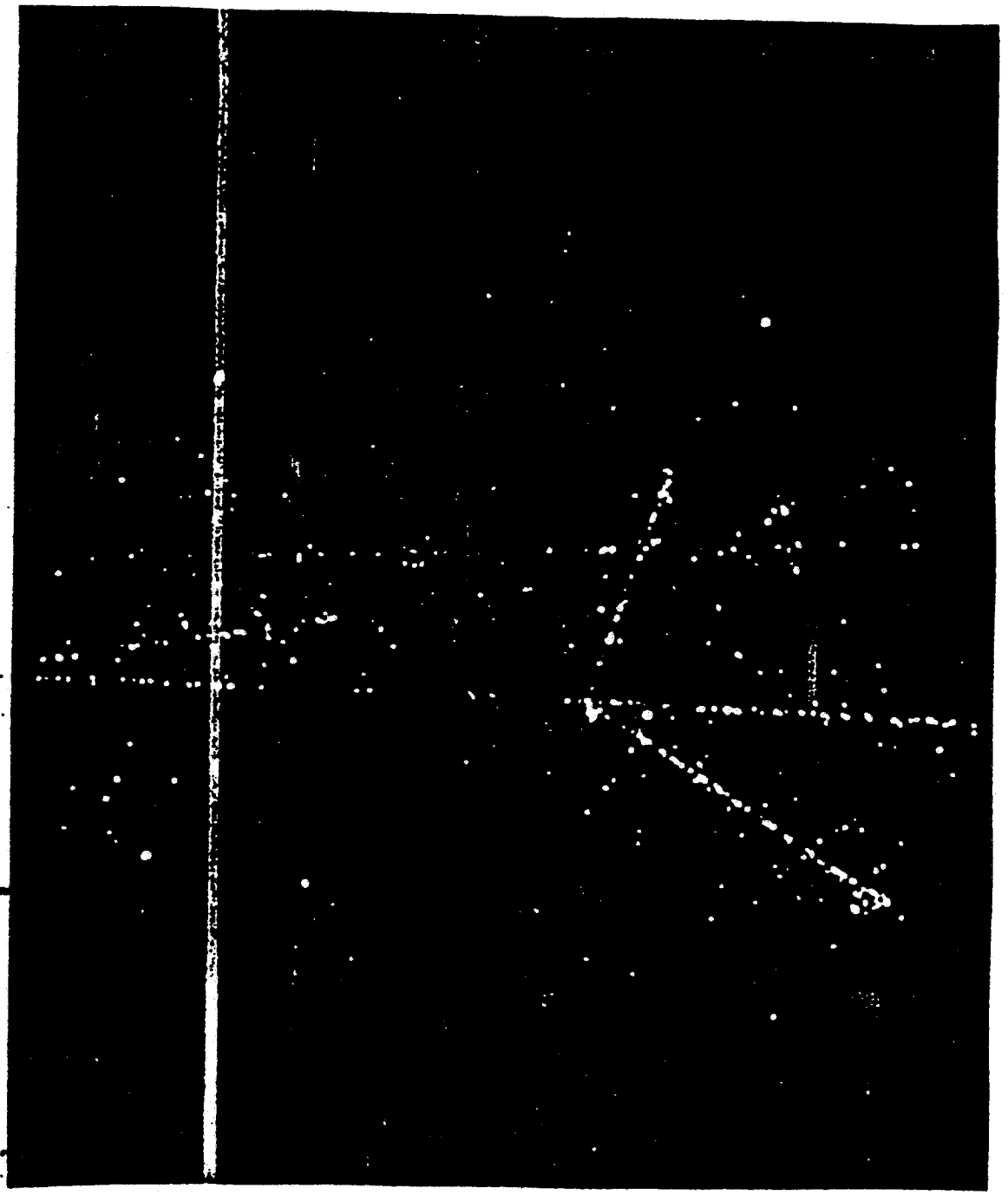
Some examples

5 GeV/c π^- beam

18 mm



no EMA → noise



EMA, → less noise

2 hits/mm

3. SILICON STRIP DETECTORS

- Another rapidly evolving technology
- The main challenge lies in the area of electronics FIXED TARG → COLLIDER more chans
- Motivation: same as for fiber tracking
  - Secondary vertices
  - Improve $\Delta p/p$ → reduce size of detector
- Other advantages of silicon:
  - Primary ionization localized
    δ rays < 1 μ (cf. gas several mm.)
  - Precise structure using well developed IC technology
  - $\Delta E = 3.6$ eV/eh pair → large charge statistics
  - signal collection ~20 nsec. (holes)
  - electrical signals can be directly interfaced and processed
- Size limited by largest round silicon rods

  2" 50 mm

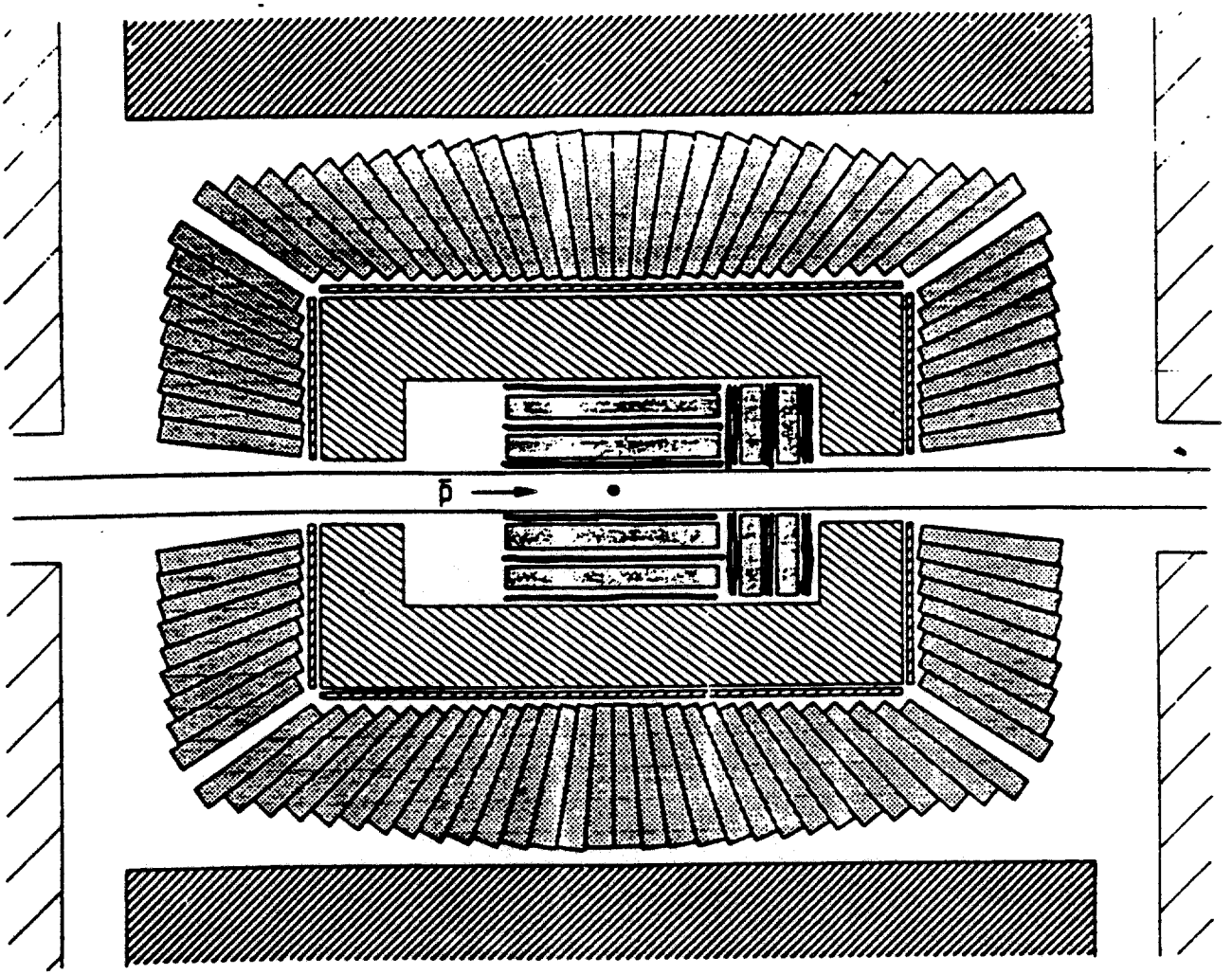
  3" 75 mm

  ⋮

  4" 100 mm

JETSET - PROPOSAL LEAR

PSCC 86-23



$$\left(\frac{\Delta p}{p}\right)^2 = \left(0.4\%\ p\,(\mathrm{GeV}/c)\right)^2 + (1\%)^2$$

0 10 20cm

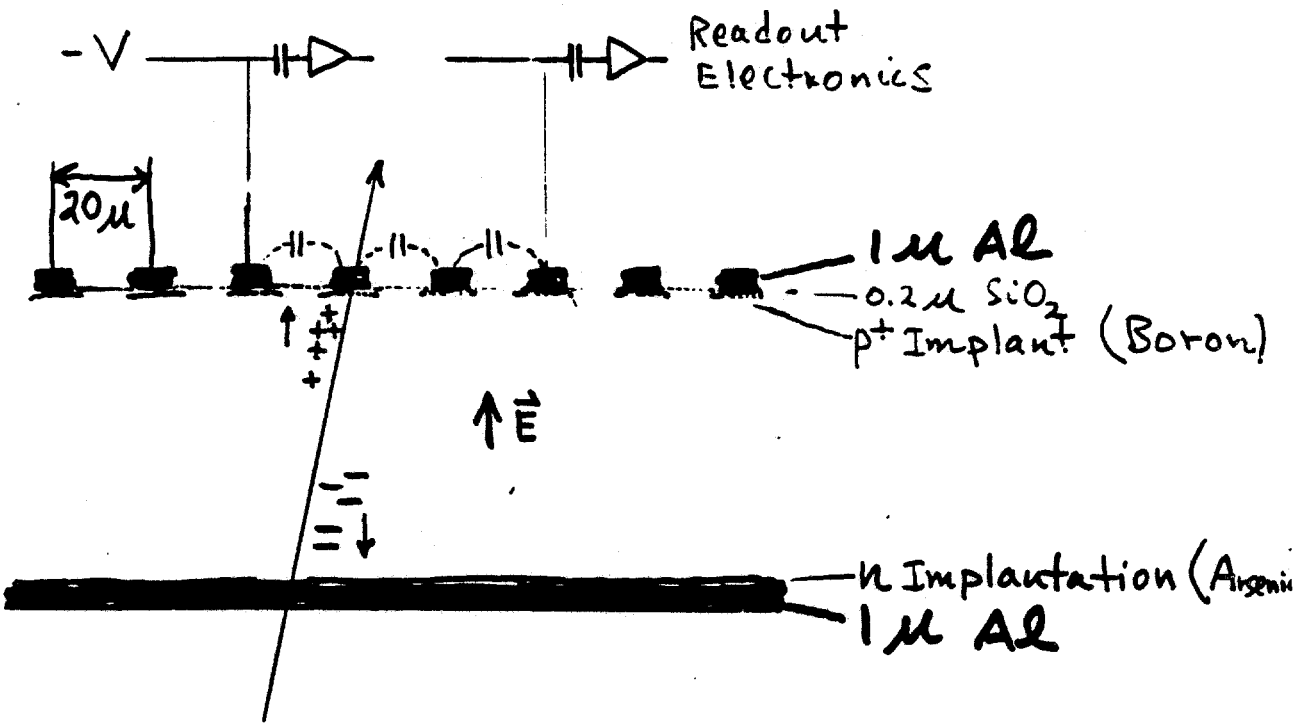
NOTE COMPACTNESS OF DETECTOR

- GAS JET (direction into paper)
- SILICON MICRO-STRIP TRACKER (barrel: 3 z layers; end-cap: 3 x+y layers) R_{outer} = 13 cm.
- STRAW CHAMBER (barrel: 8 z layers; end-cap: 4 x+y layers)
- FAST RICH (liquid C_6F_{14} radiator)
- BGO ELECTROMAGNETIC CALORIMETER (photodiode readout)
- SUPERCONDUCTING SOLENOID (6 Tesla)
- FLUX RETURN (restricted to top and bottom sides of detector)

Diode Strip Structure

Silicon planar process

- Start with $\gtrsim 10\ k\Omega\,cm$ n-doped
- Ion implant
- Metallization etc.



Typical thickness 300μ. (0.3% L_{RAD})

Resolution determined by

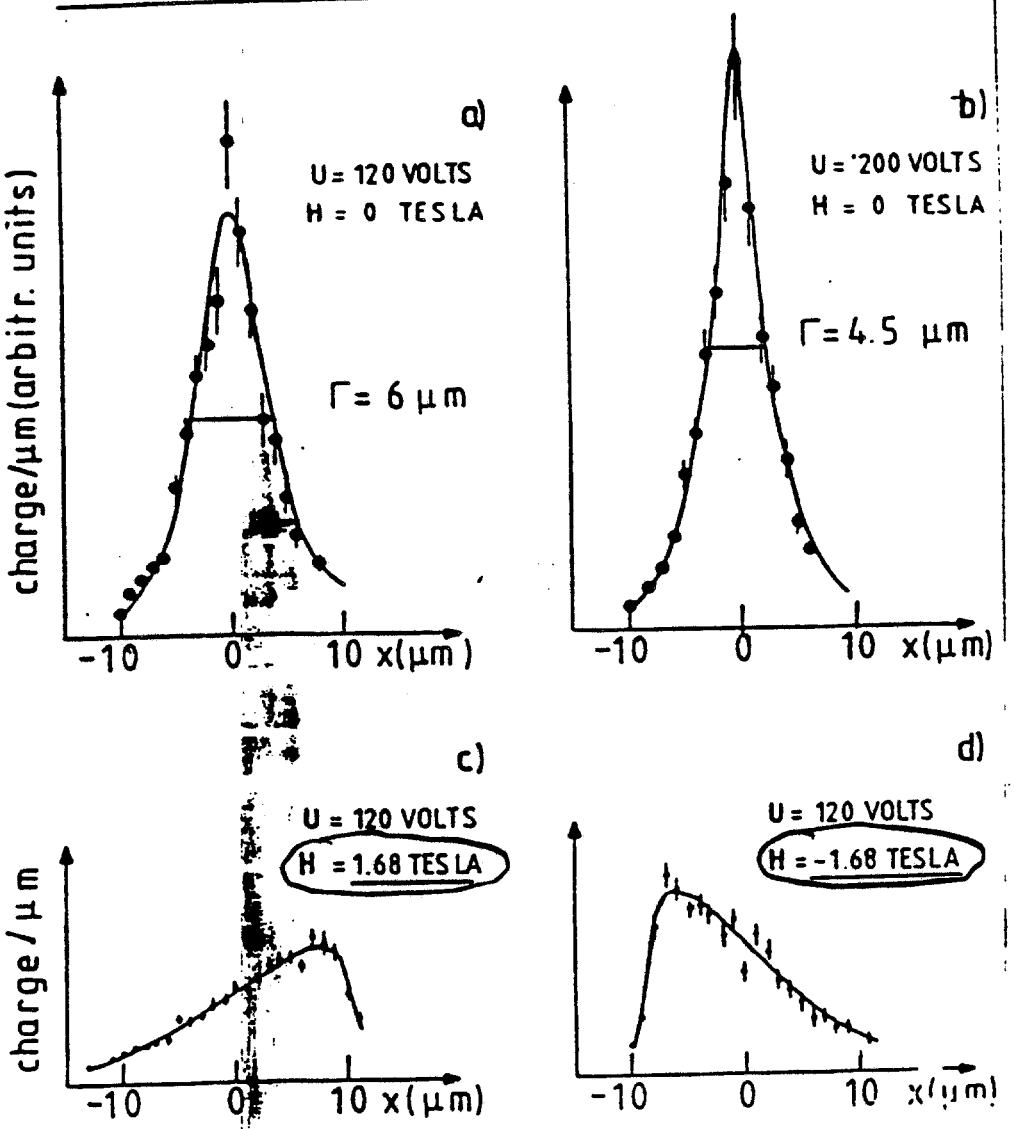
- Landau fluctuations, δ-rays, inclined tracks, $\vec{B}$
- Strip pitch, readout (inter-strip capacity, charge division)

Too wide: charge interpolation not possible

Too narrow: Electronic noise

OBSERVED CHARGE DISTRIBUTION

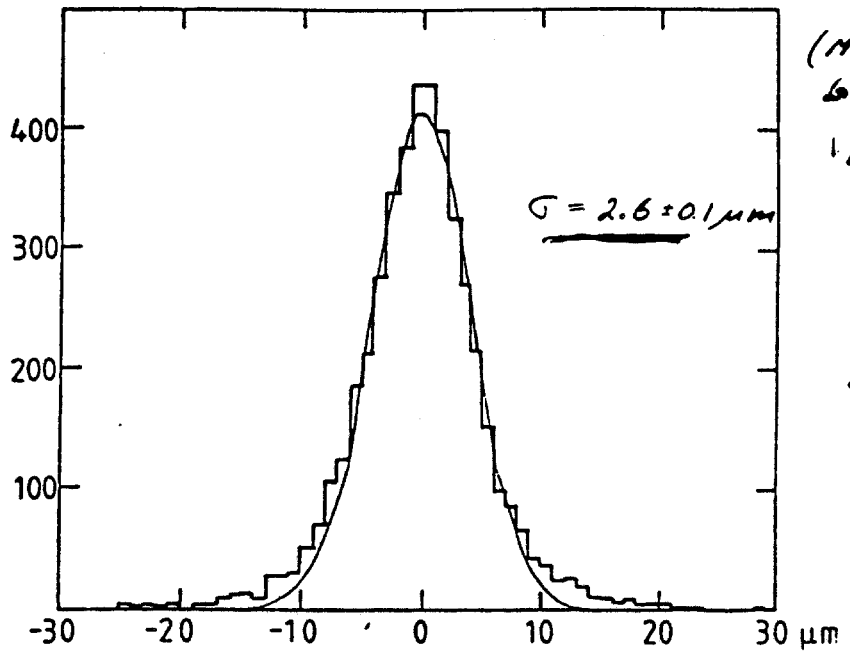
OF MICROSTRIP COUNTERS (KEMMER)



E. BELAU et al.
NIM 214 (1983) 253.

NA32. 200 GeV/c π^-

25μ PITCH EVERY STRIP READ OUT

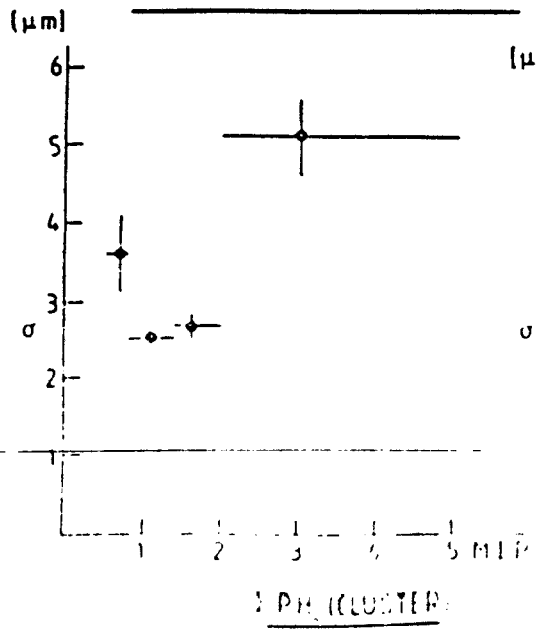


(MICRON)
64mm × 60mm
V_{bias} ~ 50V

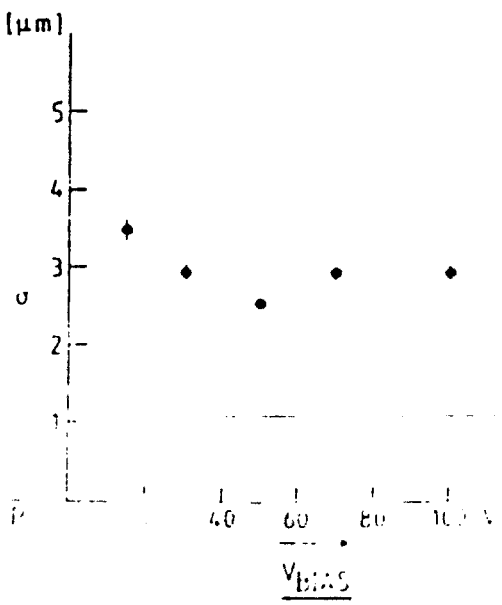
CHARGE DISTRIB.
Γ = 8μm

PREDICTED − MEASURED COORDINATE

σ .VS. PULSEHEIGHT



σ .VS. BIAS VOLTAGE



Evolution of electronics

	# chan.		cost/ch. (incl. ADC)
DISCRETE COMPONENTS PC BOARD	100 - 1000	Fixed target	
HYBRIDS	1 - 10 K	Fixed target Collider	35 - 75 SF
VLSI (Microplex)	100 K	Collider	1.3 - 2.3 SF

Application to collider experiments

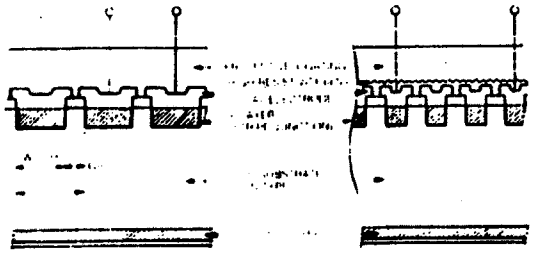
Several important differences:

- # of channels 10 - 100 X more
- mechanical structure holding the detectors must be light
- ----- but also precise! survey difficult

DETECTOR STRUCTURES

Basically, all types have the same structure. Only the S2457 has a high resistivity layer of amorphous silicon formed between the detector surface and protective coating. This layer is for capacitive charge division readout via electrodes provided at every strip junction. With this readout method, the S2457 achieves a spatial resolution of better than 10 μm.

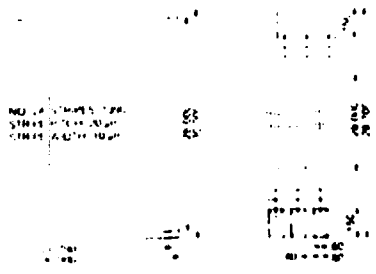
For the S2458, S2459, S2460 and S2461 detectors, an electrode is provided for each stripe for direct readout of all stripes. Spatial resolution is mainly determined by the stripe pitch.



S2458, S2459, S2460, S2461
(Direct Readout)

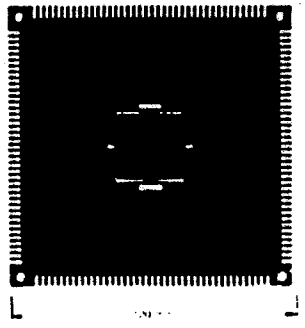
S2457
(Capacitive Charge-Division Readout)

S2457



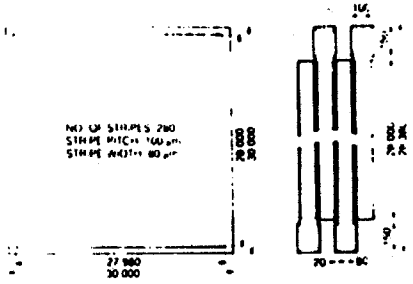
Details of elements

Evaluation Board for S2457



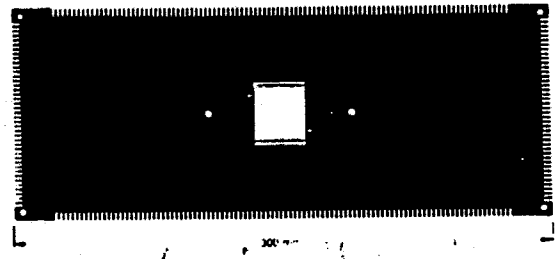
Bonding connection

S2458

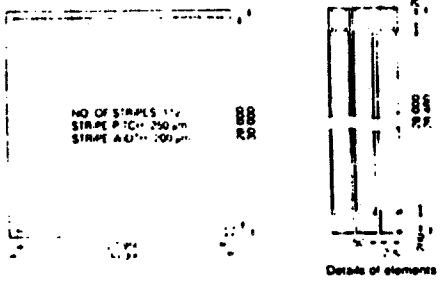


Details of elements

Evaluation Board for S2458

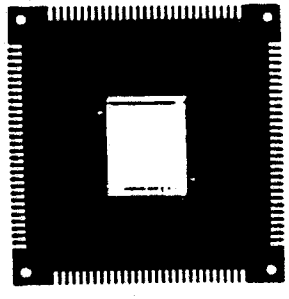


S2459



Details of elements

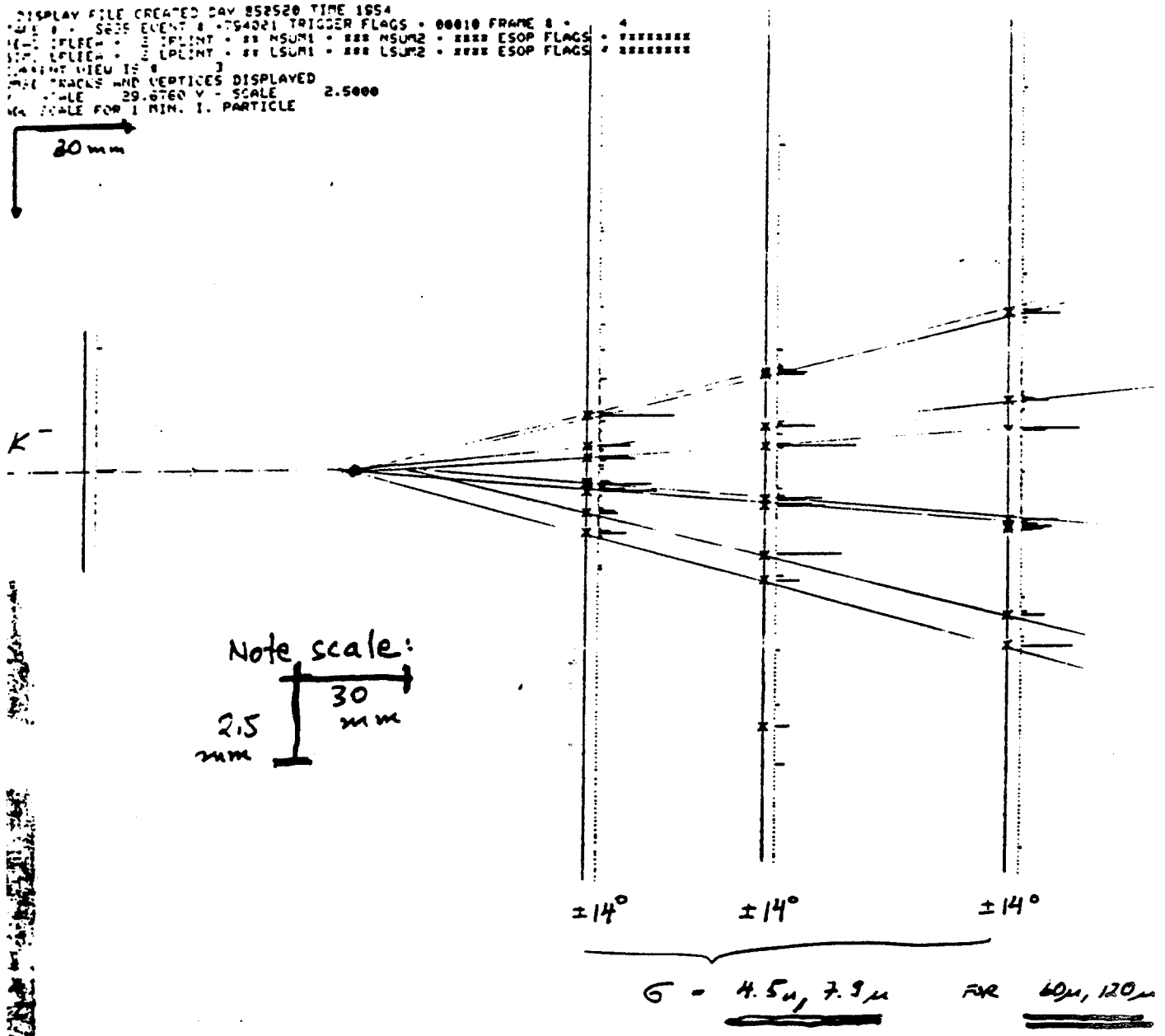
Evaluation Board for S2459



Also MICRO SEMICONDUCTOR LTD.
Small company - only HEP

FIXED TARGET APPLICATION

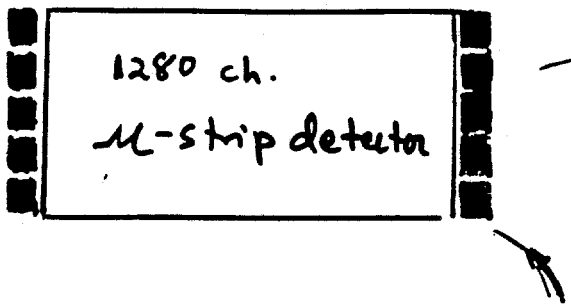
Heavy flavor search



Secondary vertex resolution
for 30-40 GeV $D^0 \to K^-\pi^+$ etc. (⟨ℓ⟩ 3-4 mm)
$\sigma_\ell = 130\ \mu$

What is Microplex? (CERN, SLAC)

example (DELPHI)



10 μplex VLSI chips Soldered directly to detector

128 chs. Low noise amps.

Read out serially. (few MHz) (shift register)

1280 chs → 1 twisted pair

SLAC - pulsed analog power → reduce total P.
(×10/μsec)

amp. rise time 20 nsec

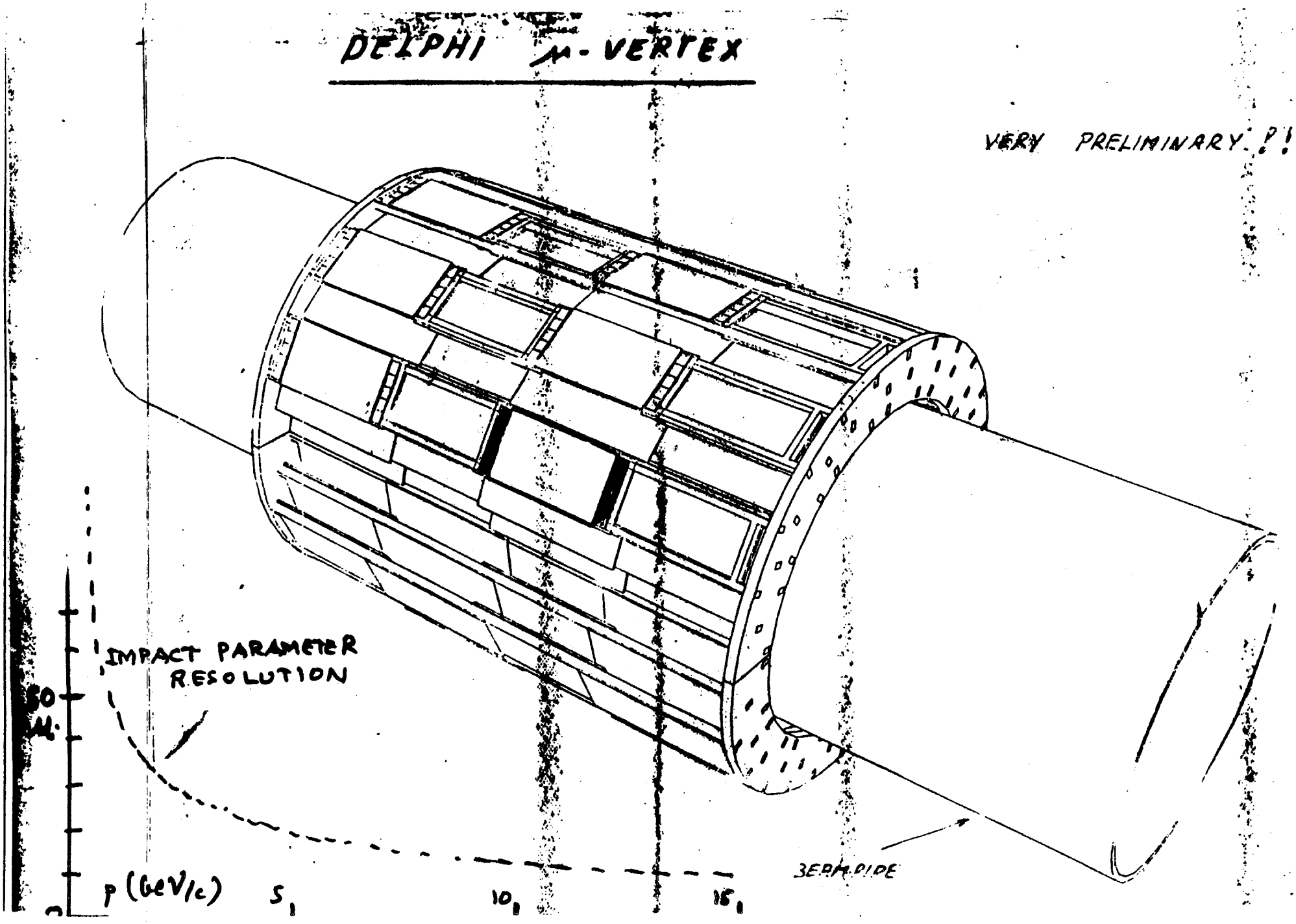
storage cap memory time > 50 msec.

Future directions:

- reduce power
- circuit protect (large detector capac. ≈ 100's of pF)
- more preprocessing on chip

DELPHI μ-VERTEX

VERY PRELIMINARY ?!



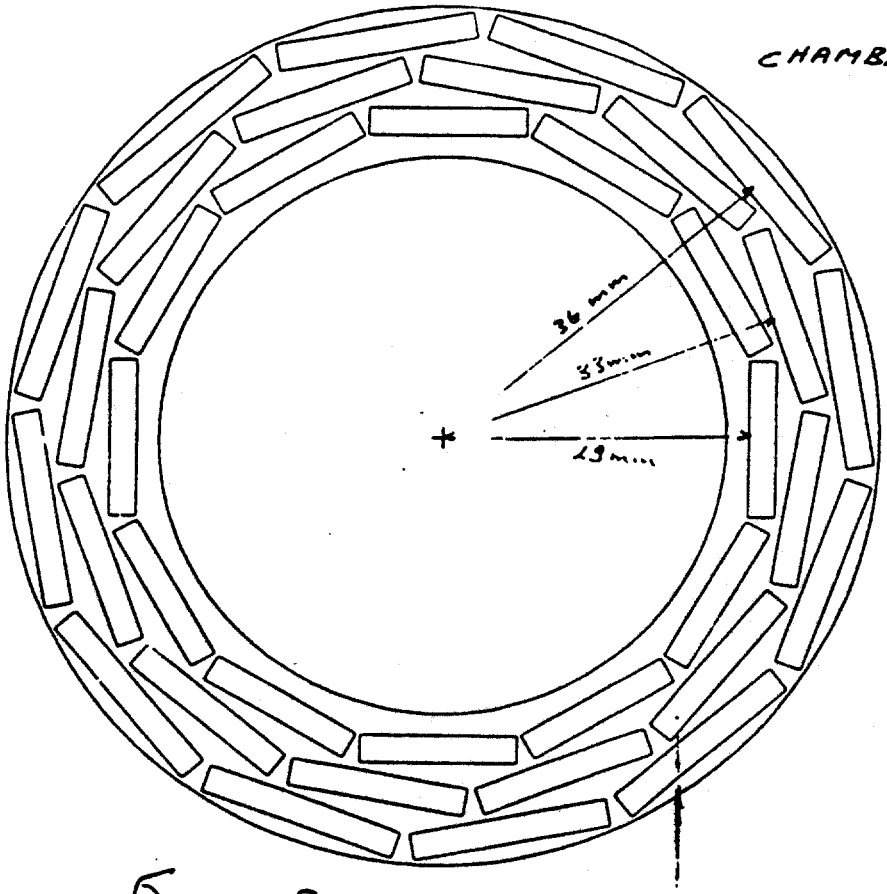
MARK II - MICROVERTEX DETECTOR

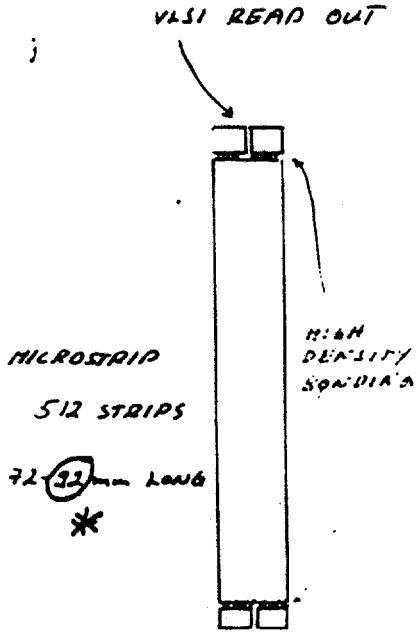
UNIV. OF HAWAII, UC SANTA CRUZ, SLAC

(COMBINED R+D WITH CERN ON VLSI READ OUT CHIP)

MICROPLEX

SILICON MICROSTRIP DETECTOR INSIDE PRECISE GASEOUS DRIFT CHAMBER.





$\sigma_{rd} \sim 3\mu$. 25 μ readout pitch

* Detectors will be cut from 4" wafers (under development)

ALEPH (MPI, Duisberg, PISA)

Double sided readout for r-φ and r-z

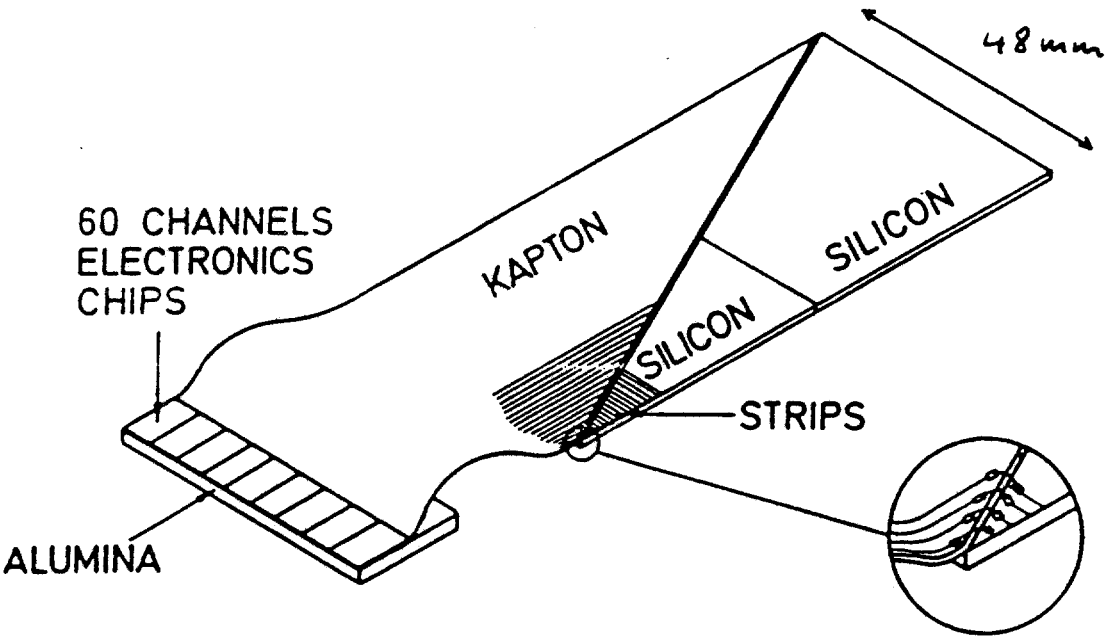
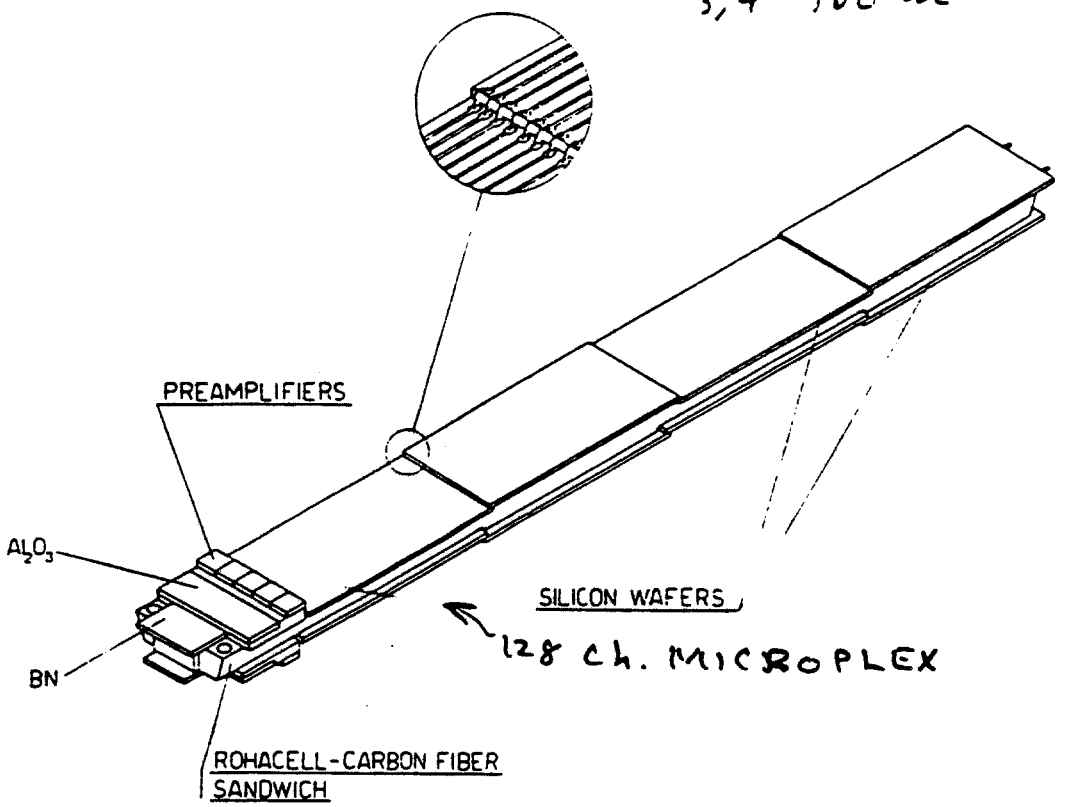


FIG. 6 r - z READ - OUT

CDF (Fermilab)

(PISA)

- 4 layers (will use 4" wafers)
- pitch 25 μ
- readout pitch: layers 1,2 50 μ.
  3,4 100 μ.



Performance:

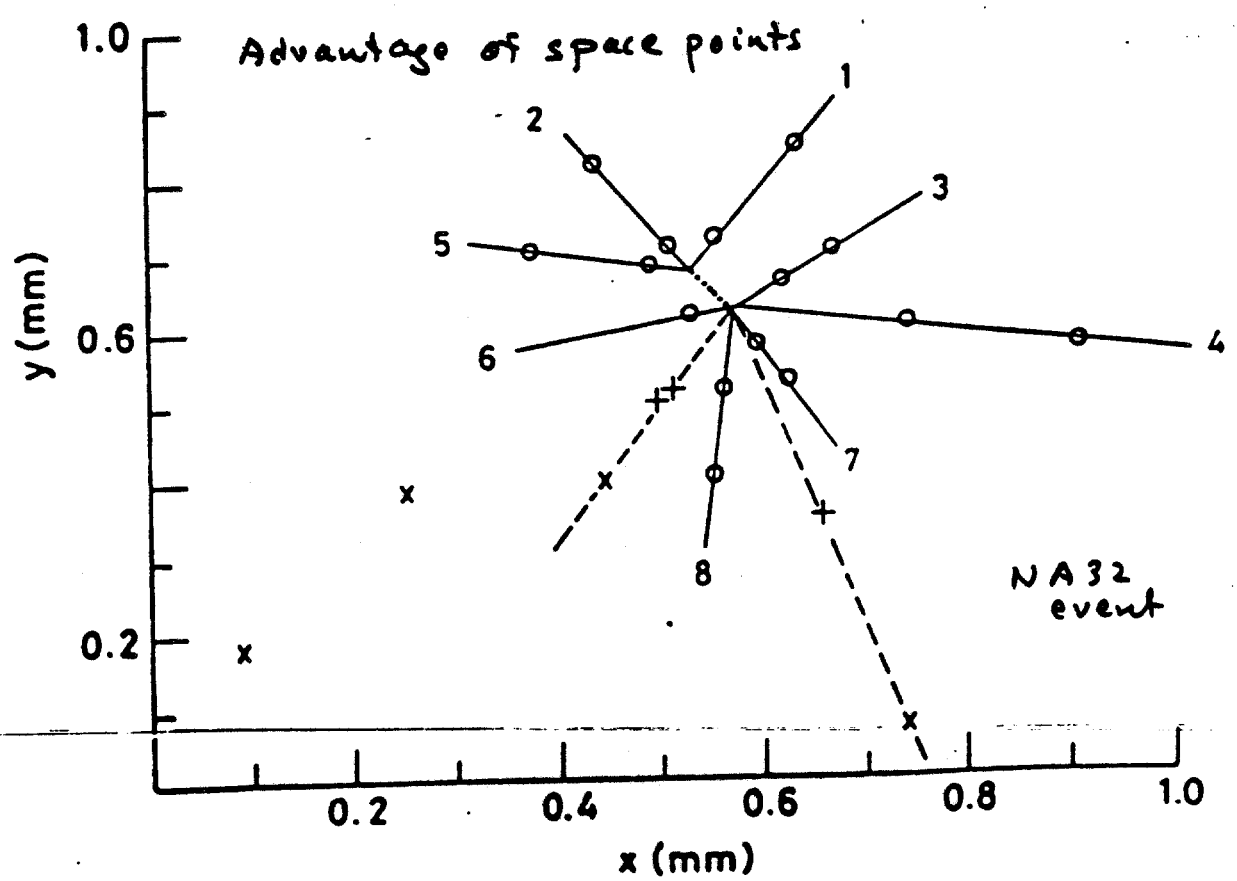
1. Short-lived particles. At 10 GeV/c $\sigma_{ip} < 20\,\mu$.
2. Improved $\frac{\Delta p}{p}$ .001 p at 10 GeV/c
   .0005 p " with vertex detector

Charge Coupled Devices

① Read out device for high data rates (delay line)

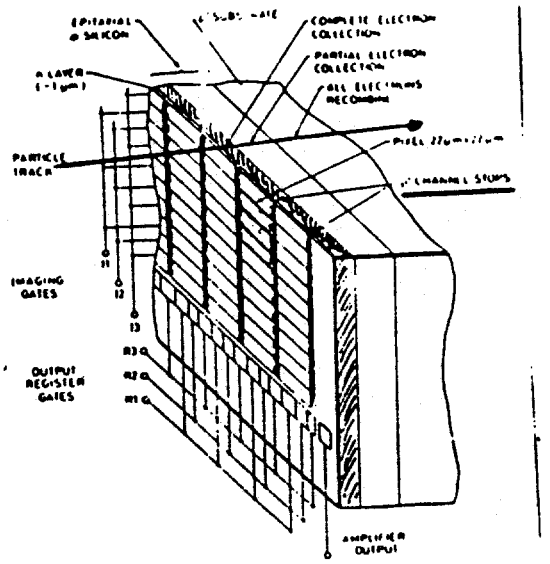
② Directly as a detector.

- 2 dimensional → space points
- Typical pixel size: 22 μ × 22 μ
- t ~ 15 μ (so signal is $\frac{1}{20}$ Micro Strip det)
- For low noise needs cooling (liq. N_2)
- MAJOR PROBLEMS:
  No fast clear
  Stays sensitive during ~20 msec readout.



Single track σ
5μ × 5μ

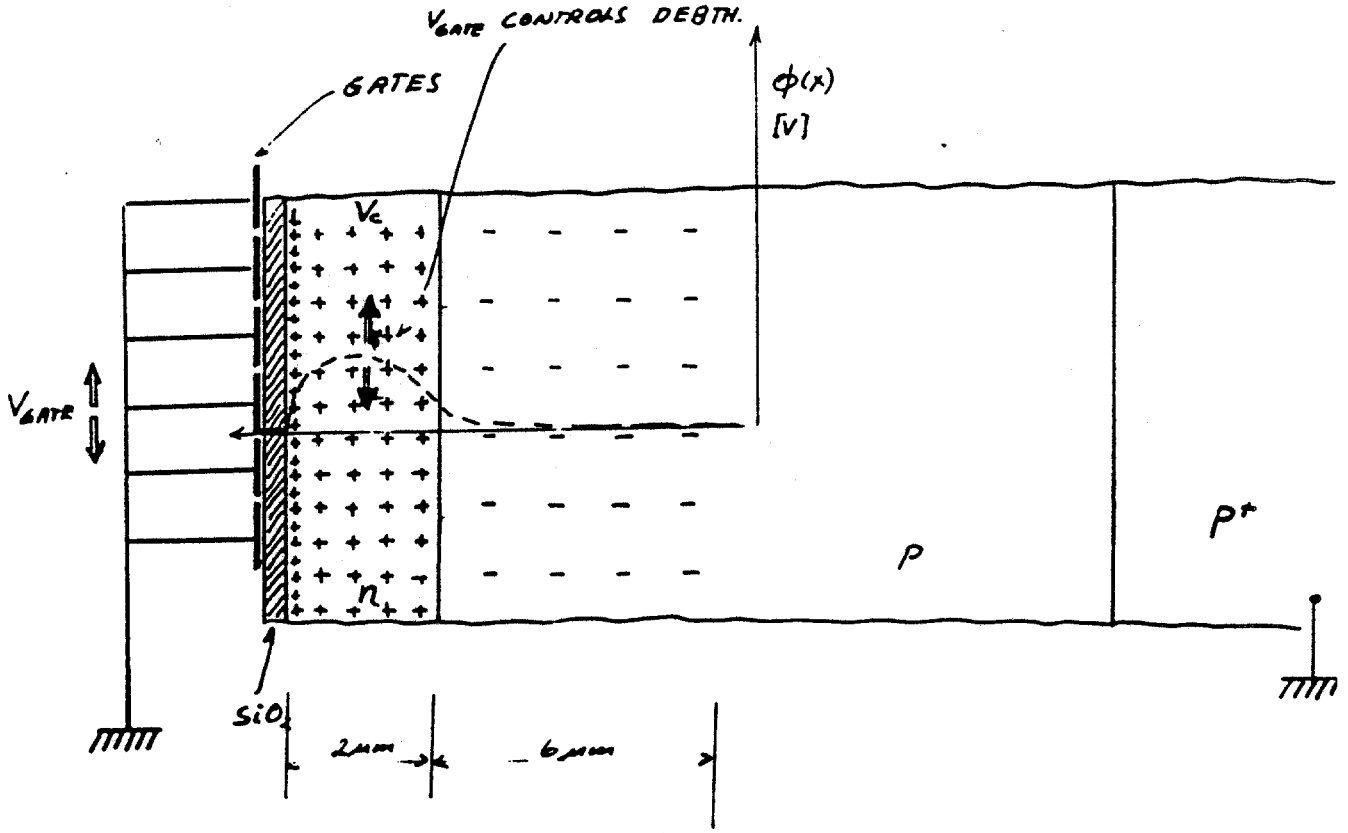
Double track separation in space
40μ



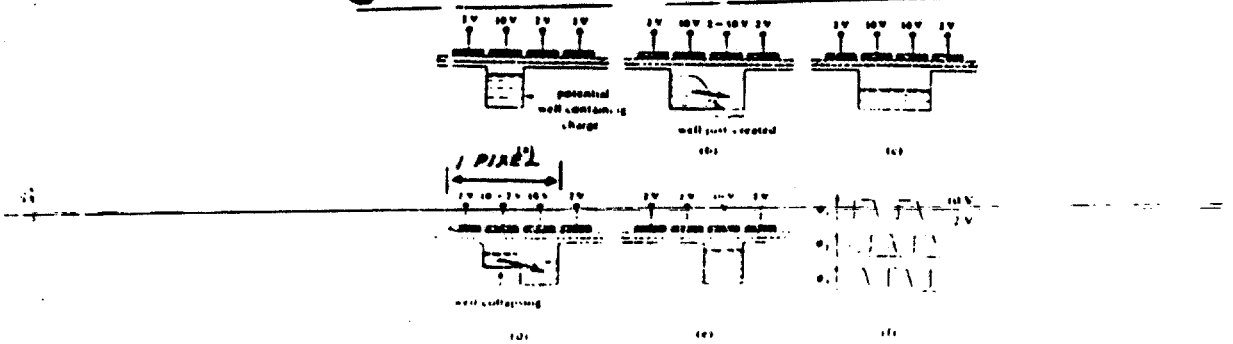
98±2% EFFICIENT FOR MINIIONIZING PARTICLES.

High information density allows spurious hits

POTENTIAL BUCKET
V_{GATE} CONTROLS DEPTH.



3 PHASE CHARGE TRANSPORT IN CCD's



CCD MICROVERTEX DETECTOR FOR SLD

(L. VAMERELL et al.)

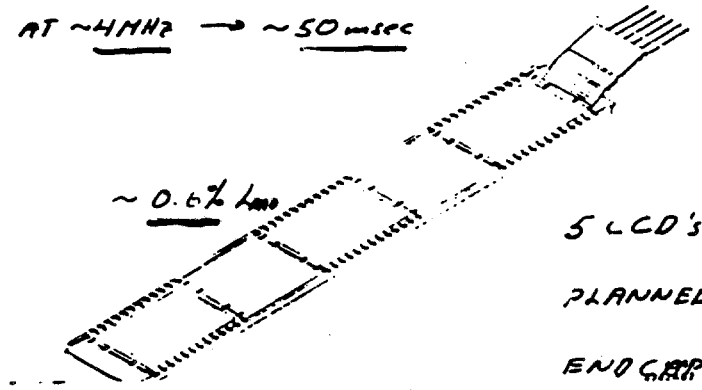
OPERATION OF CCD'S AND THEIR READ OUT CONSTRAINTS

MATCH NICELY WITH SLC OPERATION — small int. region, 180 pps

USE CCD'S WITH : 22 μm × 22 μm PIXEL SIZE

385 × 576 PIXELS → 8.5 mm × 12.7 mm SIZE

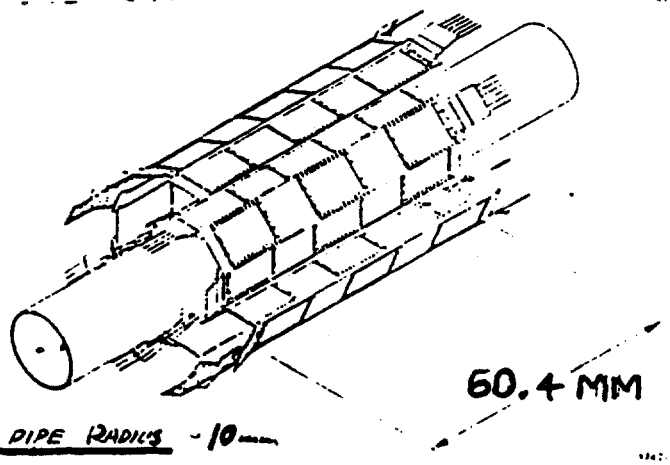
READ OUT AT ~4 MHz → ~50 msec



5 CCD'S PER LADDER

PLANNED INITIALLY WITH

END CAPS.



$|\cos\theta| > .25$ 1 HIT

$|\cos\theta| > .30$ 2 HITS

CCD'S GASCOOLED (He)

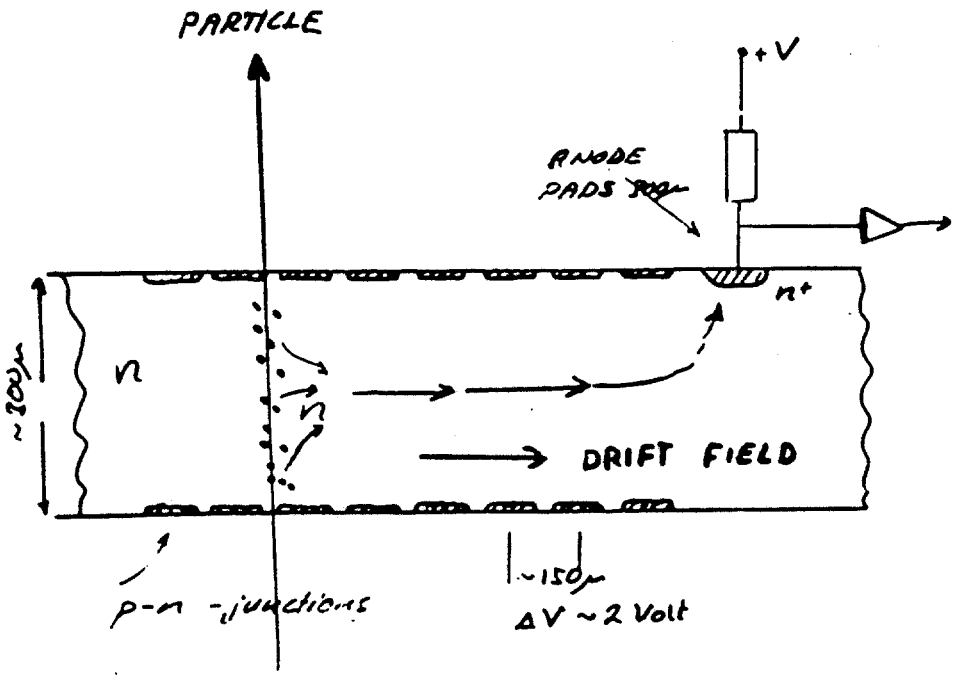
BEAM PIPE RADIUS ~10 mm

.... one last Silicon device ----

SILICON DRIFT CHAMBER

GATTI, REHAK
NIM 225, 226

KEMMER MPI



characteristics

- Drift velocity 2 μ/ns
  E: 150 V/cm
- Requires very uniform doping (sensitive to radiation damage ?)
- 1 coord. from drift time ~20μ
- 1 coord from pad interpol. ~20μ
- Double track separation 500μ in space

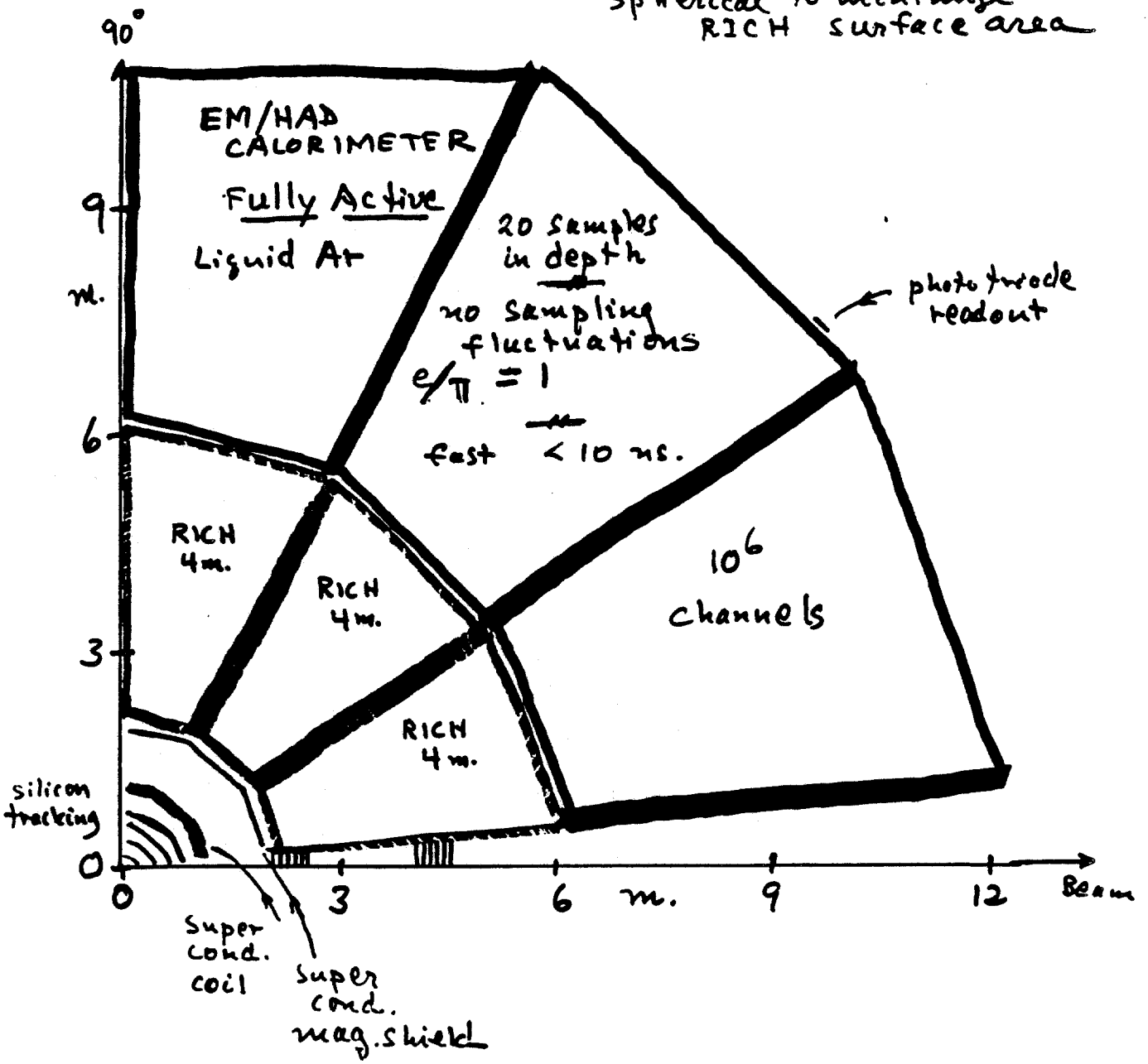
Proposed for UA6 upgrade.
2 measuring stations in front of magnet

4. PARTICLE IDENTIFICATION AT SSC ENERGIES

Very abbreviated version of talk by T. Ypsilantis.

SSC Detector concept (non-conventional)

Spherical to minimise RICH surface area



Ring Imaging Čerenkov Counter <u>RICH</u>

(1) Resolution obtained with DELPHI prototypes for both liquid/gas radiators agrees with predictions.

(2) After some algebra he derives:

$$p^2 = \frac{100\, N_0 L}{n_\sigma \sqrt{N}} \left(m_K^2 - m_\pi^2 \right)$$

$N_0 = 150\ \mathrm{cm}^{-1}$ for TMAE radiator, best possible mirrors, and best quartz window.

Suppose we choose $n_\sigma = 4.2$ SD

This $\Rightarrow$ that 1% of the time π/K misidentification will occur.

Next choose desired # of p.e.

e.g. $N = 25$.

with this choice a <u>4 meter long counter</u> will separate π/K (99% prob) up to 257 GeV.

(3) The RICH counter can also be thought of as a γ measuring device.

$$\frac{\Delta\gamma}{\gamma^3} = \frac{5\times10^{-3}}{\sqrt{N}}\frac{1}{\gamma_T^2} \qquad \gamma_T = \frac{n}{\sqrt{n^2-1}}$$

For present design, $N = 25$ p.e.

$\gamma_T = 50 \qquad n-1 = 200\times10^{-6}$ (e.g. He/Ne)

$\frac{\Delta\gamma}{\gamma} = 4\%$ at $\gamma = 316$ (44 GeV π)

(4) Particle <u>direction</u> measured with precision.

For $N = 25$, $\gamma_T = 50 \qquad \Delta\theta = 20\ \mu$ radians.

Use $\vec{\gamma}$ to help tracking (modulo mass)

(5) Readout requirements:

$A = 50\ m^2 \qquad 50\times10^6$ pixels $(1\ mm^2)$

at 10 pixels/pad $\rightarrow 5\times10^6$ pads !

5. NON-ACCELERATOR PHYSICS

Important questions discussed in 2 excellent review talks by Fiorini and Ernwein:

(1) Why is the solar ν flux as measured by Davis low?

(2) Are there ν oscillations?

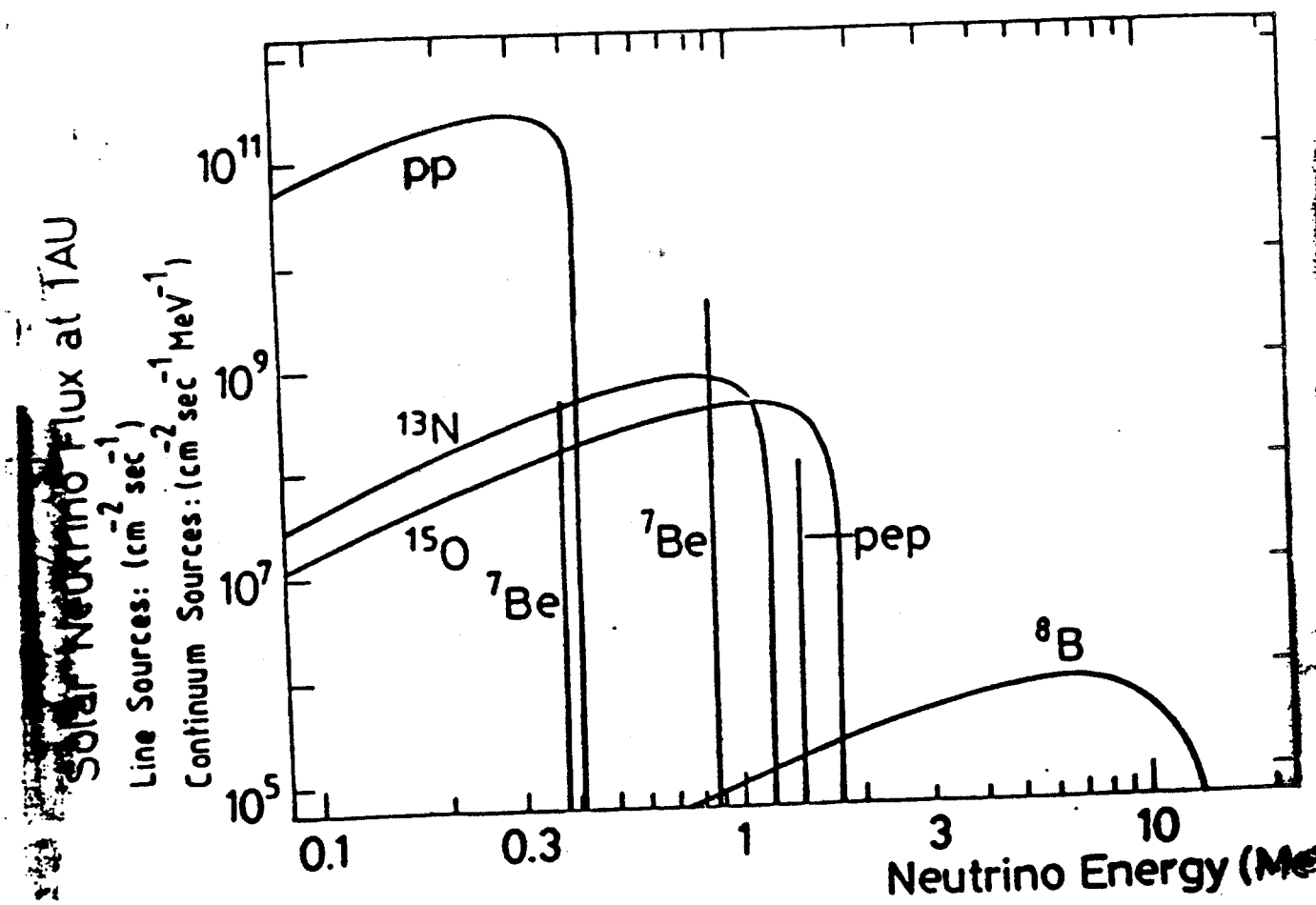
(3) Is the ν-mass $\neq 0$?

(4) Are nucleons stable?

(5) Is there some new, unexplained particle coming from the X-ray source Cygnus-X?

There is only time to repeat their main conclusions.

SOLAR ν-FLUX


Solar Neutrino Flux at TAU
Line Sources: (cm^{-2} sec^{-1})
Continuum Sources: (cm^{-2} sec^{-1} MeV^{-1})
10^{11}
10^{9}
10^{7}
10^{5}
pp
^{13}N
^{15}O
^{7}Be
^{7}Be
pep
^{8}B
0.1
0.3
1
3
10
Neutrino Energy (MeV)

Davis (BNL) experiment.

$E_\nu > 1$ MeV

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

$\hookrightarrow$ 35 day τ

Theory / Exp = 3 !

Why ?

- SOLAR MODEL WRONG
- ν- Oscillations

  $\nu_e \rightarrow \nu_\mu$ on way from $\odot$ to $\oplus$

<u>However</u>, most $\odot$ ν's below E detectable by Davis.

New experiments being prepared (no results yet)

(1) GALLIUM. $\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e^-$

$\hookrightarrow$ 11.4 days

$E_\nu > 233$ keV, collect 70% of ν's from solar pp cycle.

3 experiments:

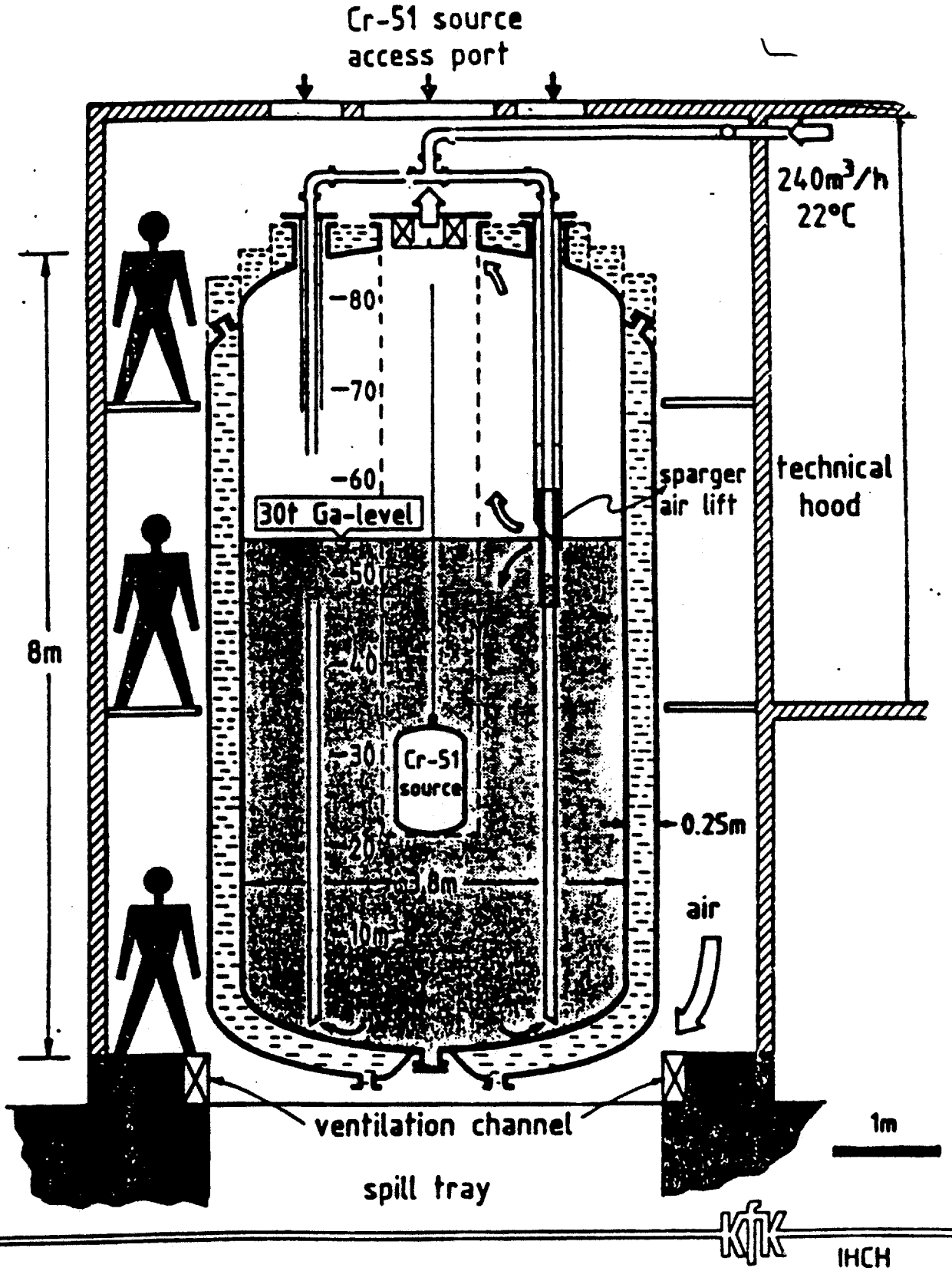
- GALLEX. Gran Sasso tunnel.

  GaCl in HCl $\rightarrow$ GeH^4 gas
- <u>GA</u>llium <u>US</u> <u>CAN</u>adian
- BAKSAM (USSR)

  must remain metallic!

  melt $\rightarrow$ blow gas through it

MAJOR ADVANTAGE : Calibration source



GALLEX TARGET TANK

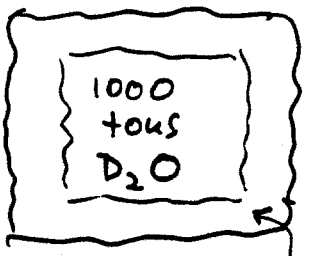
(2) Look for Tc (Technicium) τ = Megayr.
in Mo (Molybdenum) bearing rock

$E_{th} > 1.7$ MeV

$\nu_e + {}^{98}_{97}Mo \rightarrow {}^{98}_{97}Tc + e^-$

Need to look at 100's of tons to be sensitive

(3) Sunbury Mine



Direct reactions

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

$\nu_e + (pn) \rightarrow$ cc
nc

Surrounded by PM's.

(4) ICARUS - Liquid-A
TPC type detector
Gran Sasso tunnel

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

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

Neutrino oscillations

e.g. $\nu_e = \nu_1 \cos\alpha + \nu_2 \sin\alpha$

$\nu_\mu = -\nu_1 \sin\alpha + \nu_2 \cos\alpha$

Experiments have been done at

- ACCELERATORS (incl. π- factories)
- Underground.
  Byproduct of solar ν, p-decay
- Reactors $\bar{\nu}_e$

NO EVIDENCE FOR OSCILLATIONS

Neutrino Masses

$m_{\nu_\mu} < 270$ keV

$m_{\nu_\tau} < 56$ MeV

m_{ν_e} ?

$^3H \rightarrow {}^3He + e^- + \bar{\nu}_e$ Use Kurie-plot to measure end point.

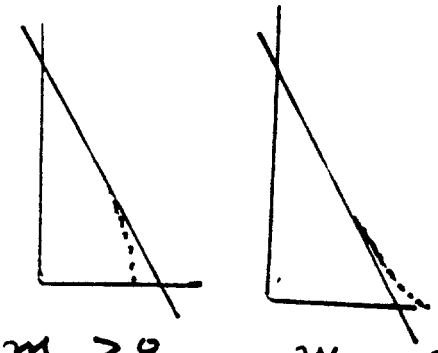
3 experiments have been done at ITEP (Moscow) Lubimov et al

(1980) $14 \leq m_\nu \leq 46$ eV 99% CL

(1983) $m_\nu \geq 20$ 95% CL

(1984) $m_\nu > 9$

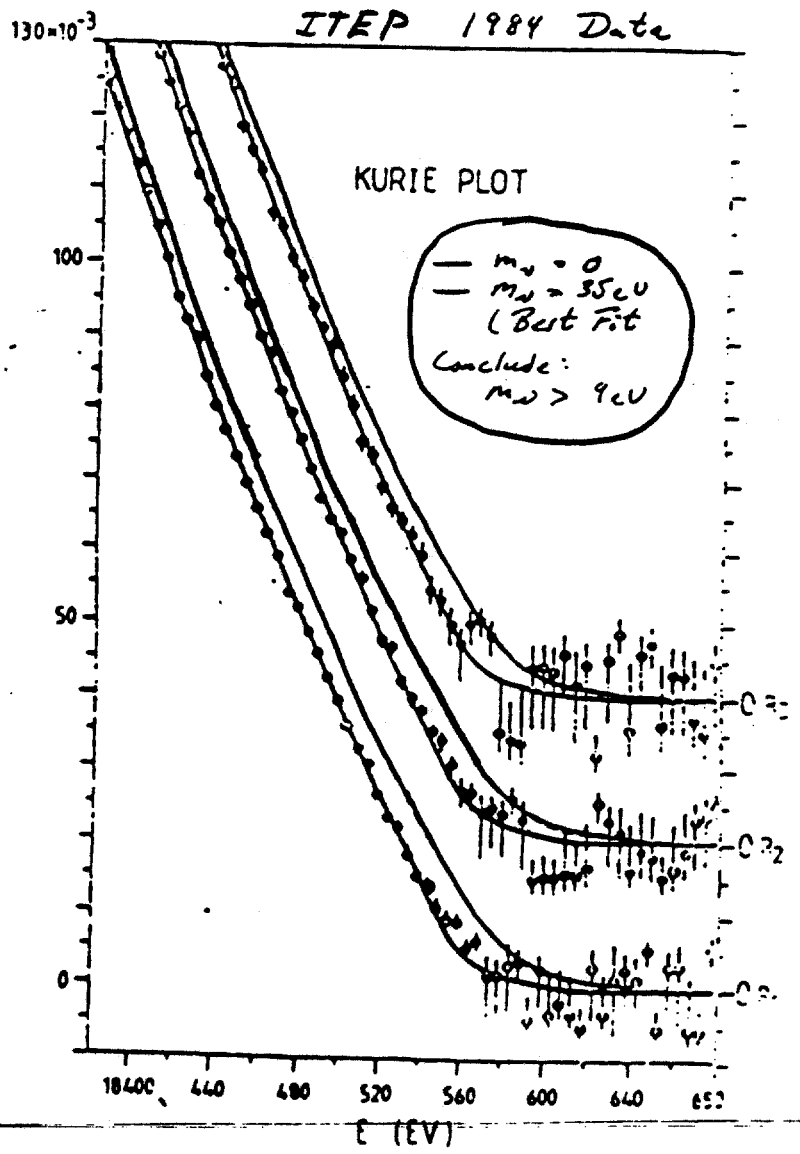
Experimental difficulties



$m_\nu > 0$
resolution
prefect

$m_\nu = 0$
finite
resolution

- molecular effects
- low counting rates in crucial region

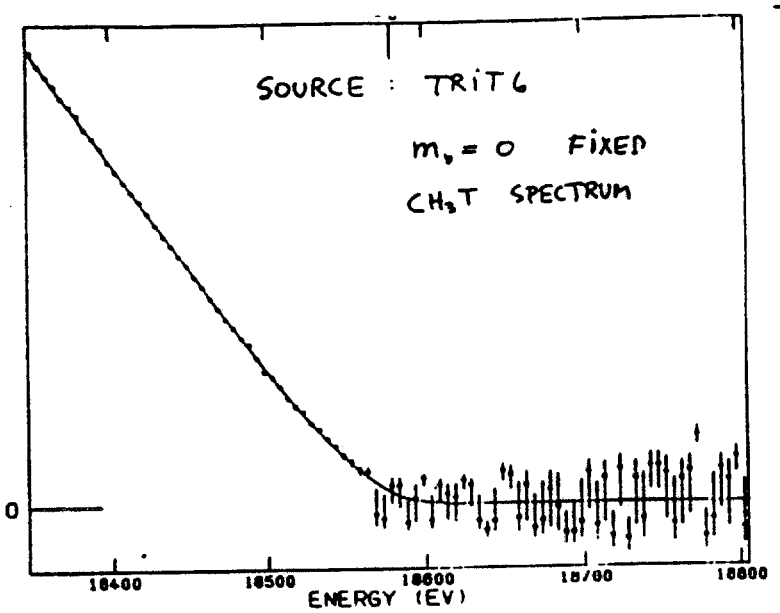


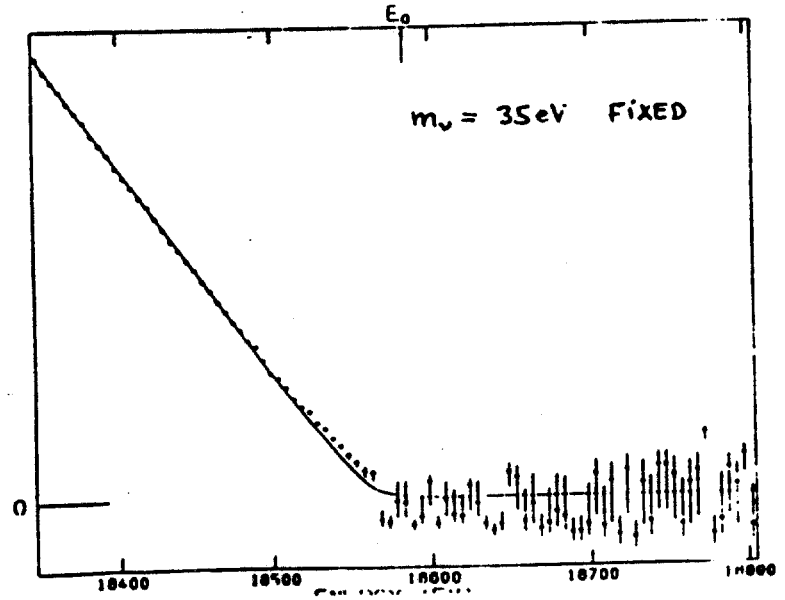
New experiments cast doubt on ITEP result

① LOS ALAMOS

$m_{\nu_e} < 36$ eV (95% CL)

② SIN $m_\nu < 9$ eV (95% CL)





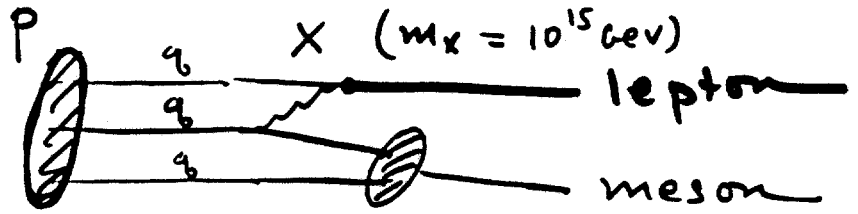
Nucleon Decay

Is the proton stable?

Age of universe $\gtrsim 10^{10}$ years

Radio/geochemical $\gtrsim 10^{27}$ years
(Th^{232} ..)

Minimal SU_5 GUT $10^{29 \pm 1.4}$ years



$p \to e^+ \pi^0$
$n \to e^+ \pi^-$

Best limit today $\tau > 3.6 \times 10^{32}$
for $p \to e^+ \pi^0$

So minimal SU_5 ruled out.

Theory: Other symmetry groups predict other decay modes and longer life times.

Experiments: More complex decay modes being studied and sensitivity being improved

Two techiques:

(1) Water Cerenkov.

(2) Fine grained tracking calorimeters (Iron, Gas readout)

WATER CERENKOV

- $\beta_{th} > 0.75$
- homogenous
- good timing (directionality)
- good $\Delta E/E$ for showers
- 11 % free protons
- low cost → large mass
- ideal for $p \to e^+ \pi^0$
- $\sigma_{vertex} \sim 75$ cm.

Fe - gas Sampling Calorimetry

- get "pictures" good for complex topology
- DENSE → SMALL → DEEP
- sensitive to slow particles
- nuclear effects larger
- $\sigma_{vertex} \lesssim 1$ cm

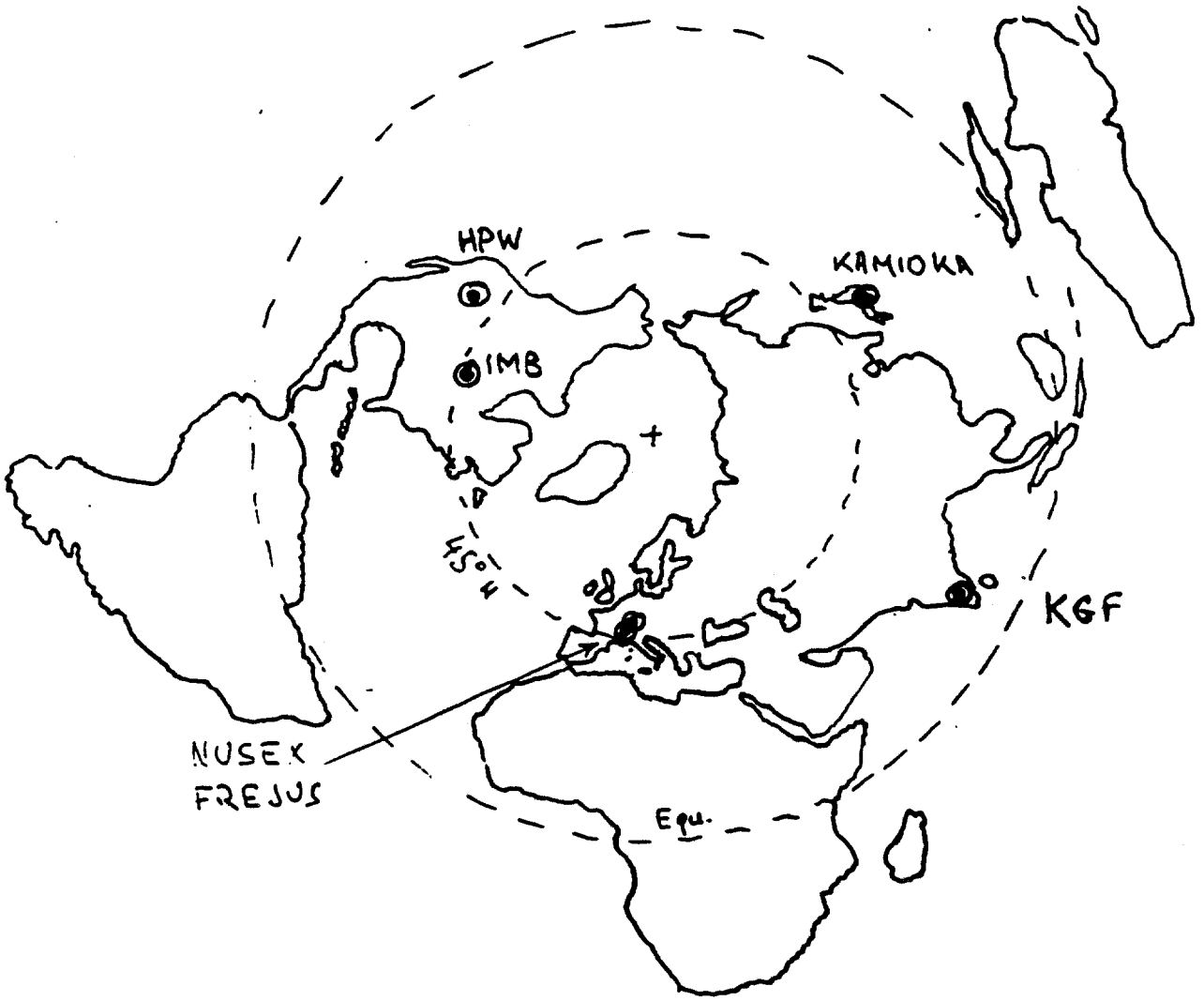
	(HPW [a])	IMB	KAMIOKA	KGF	NUSEX	FREJUS
	←	Water C.	→	←	Iron cal	→
First Operation	1982	1982	1983	1980	1982	1984
Overburden(hg/cm2)	1500	1600	2700	7600	5000	4850
Total/Fiducial Mass(TONS)	700/180	8000/3300	3000/880	140/65	150/130	900/600
Sensitivity (kiloton.year)	0.13	3.8	1.5	0.25	0.35	0.61
# of contained events	0 [a]	401	181	19	37	65
# of candidates (background)	0(0.7)	21(20)	5(3)	4(≥1)	3(1.6)	1(≈1)

[a] : events with multiple muon decay only

under construction : SOUDAN 2 (1987-88)

under design : Super-Kamioka, Icarus } 1990's.

UNDERGROUND DETECTORS



Conclusions

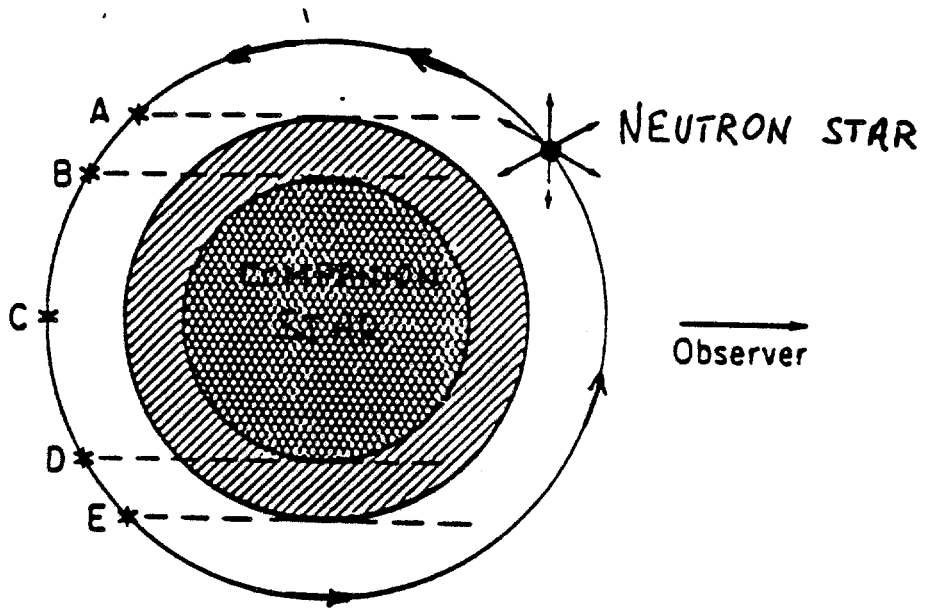
1. ~ 10 candidates, have possible ν background interpretations

2. Present experiments may reach 10^{32} yr. limit after thorough ν background studies

3. Projects for 1990's may reach $> 10^{33}$

CYGNUS X-3

$d = 35{,}000$ L.Y.



- Variable X-ray and radio source (1000 : 1)
- $E_\gamma \rightarrow 10^{15}$ eV
- $P = 4.8$ hours
- NUSSEX, SOUDAN } 1981-84 observed an excess of μ's coming from direction of Cygnus X-3 when 4.8 hour periodicity used.
- If true these must be secondaries due to some new neutral particle.
- NUSSEX, FREJUS, BAKSAN, HOMESTAKE, KAMIOKA, HPW, IMB } 1983-86 fail to confirm effect.