Cours/Lecture Series

1993 – 1994 ACADEMIC TRAINING PROGRAMME

LECTURE SERIES

SPEAKER : E. IAROCCI, Frascati, Italy
TITLE : New Detector Techniques
TIME : 14, 15, 16, 17 & 18 March, from 11.00 to 12.00 hrs
PLACE : Auditorium

ABSTRACT

The intense R&D effort being carried out in view of LHC, has given rise in a relatively short time to a wide spectrum of new detector concepts and technologies. Subject of the lectures will be some of the most interesting new ideas and developments, in the field of noble liquid, crystal and scintillating fiber calorimeters, and gas, solid state and scintillating fiber trackers. The emphasis will be on the basis aspects of detector operation.

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E. IAROCCI I LECT.

NEW DETECTOR DEVELOPMENTS

- mostly those related to LHC
- with discussion of basic principles

Outline:

- Detectors of ionization charge:
    - in Gases and Liquids
    - in Solids

GUIDELINE: DETECTOR ASPECTS

. MAINLY TRACKERS

- Calorimeters
    - with Noble Liquids
    - with Scintillators

GUIDELINE: SUBSYSTEM ASPECTS

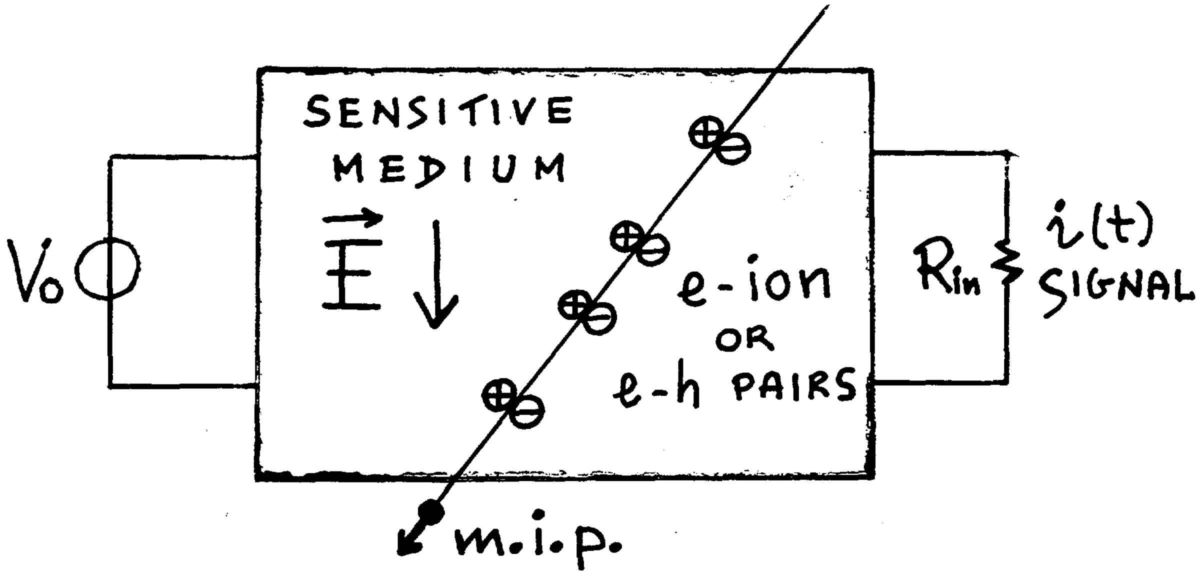
Detectors of ionization charge in Gases and Liquids

(~ 2 Lectures)

- Currents induced by the motion of charges
- LAr: the ACCORDION ionization chamber
  and ICARUS 3-dimensional imaging
- Avalanches and Streamers in Gas (PPC, RPC, Pestov)
- Proportional Tubes (RD6-TRT)
- Muon Chambers for LHC (RD5, JTC, HPT)
- TPC: from LEP to LHC-Heavy Ions

- GHSC: after Solid State Detectors

DETECTORS OF IONIZATION CHARGE



SENSITIVE MEDIUM :
ANY INSULATOR WHERE ELECTRONS(*) CAN MOVE FREE

- NON ELECTRONEGATIVE GASES (ELECTRON MULTIPLICATION NEEDED) OR LIQUIDS (e-ion PAIRS)
- *INSULATING CRYSTALS* (REVERSE BIASED SEMICONDUCTOR JUNCTIONS) (e-h PAIRS)

(*) THE ELECTRIC FORCE IS THE SAME ON ELECTRONS AND IONS BUT $\mu_e \gg \mu_{ion}$
→ MAXIMUM POWER TRANSFER TO ELECTRONS

SIGNAL

GENERATION

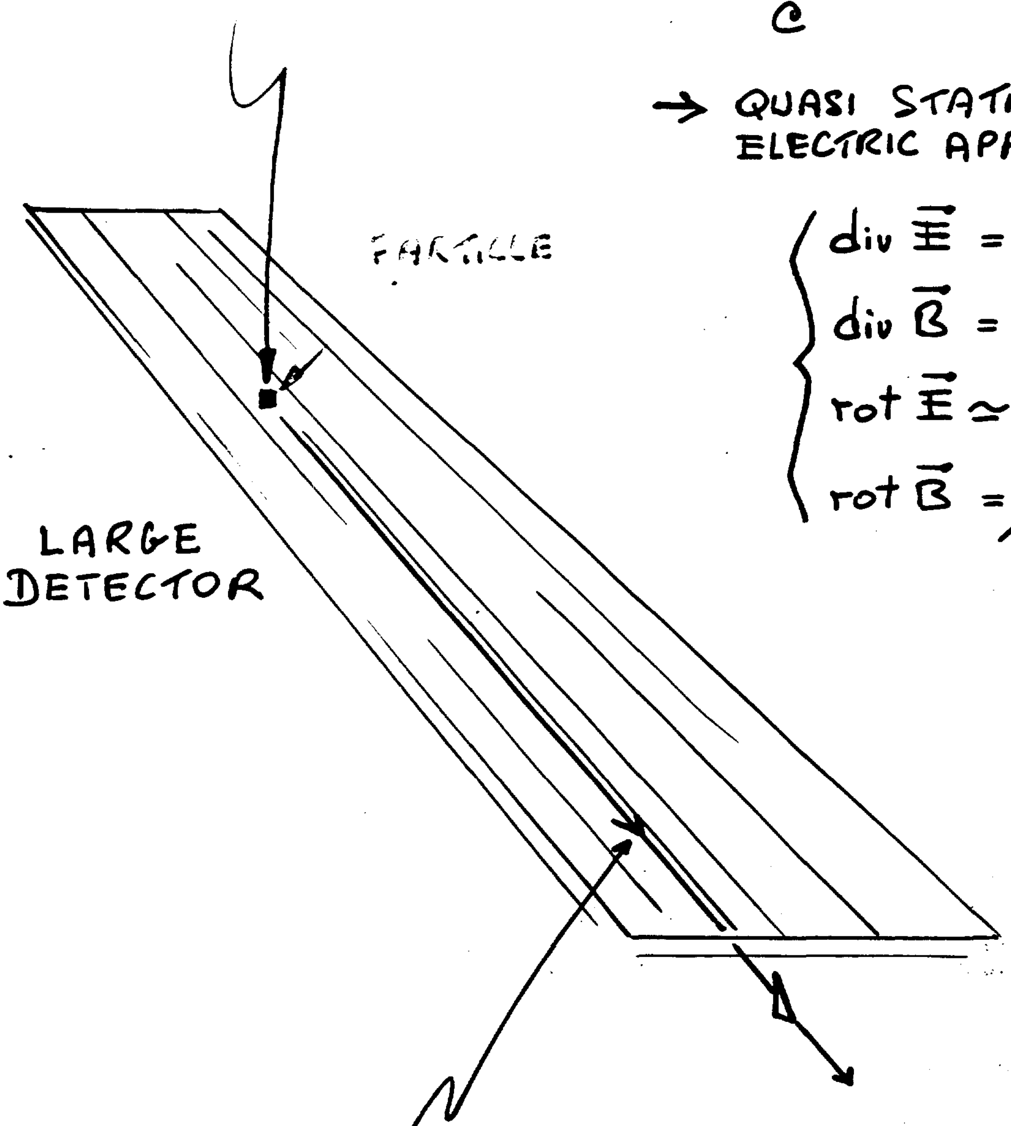
IS USUALLY LOCALIZED WITHIN

$\lesssim (1\,\mathrm{cm})^3$ CELL

$\frac{1\,\mathrm{cm}}{c} \sim 30\,\mathrm{ps}$

→ QUASI STATIONARY ELECTRIC APPROXIMATION

$$\begin{cases} \operatorname{div}\vec{E} = \rho/\varepsilon_0 \\ \operatorname{div}\vec{B} = 0 \\ \operatorname{rot}\vec{E} \simeq 0 \\ \operatorname{rot}\vec{B} = \mu_0\vec{J} + \mu_0\varepsilon_0\frac{\partial\vec{E}}{\partial t} \end{cases} \qquad \nabla^2 V = -\frac{\rho}{\varepsilon_0}$$



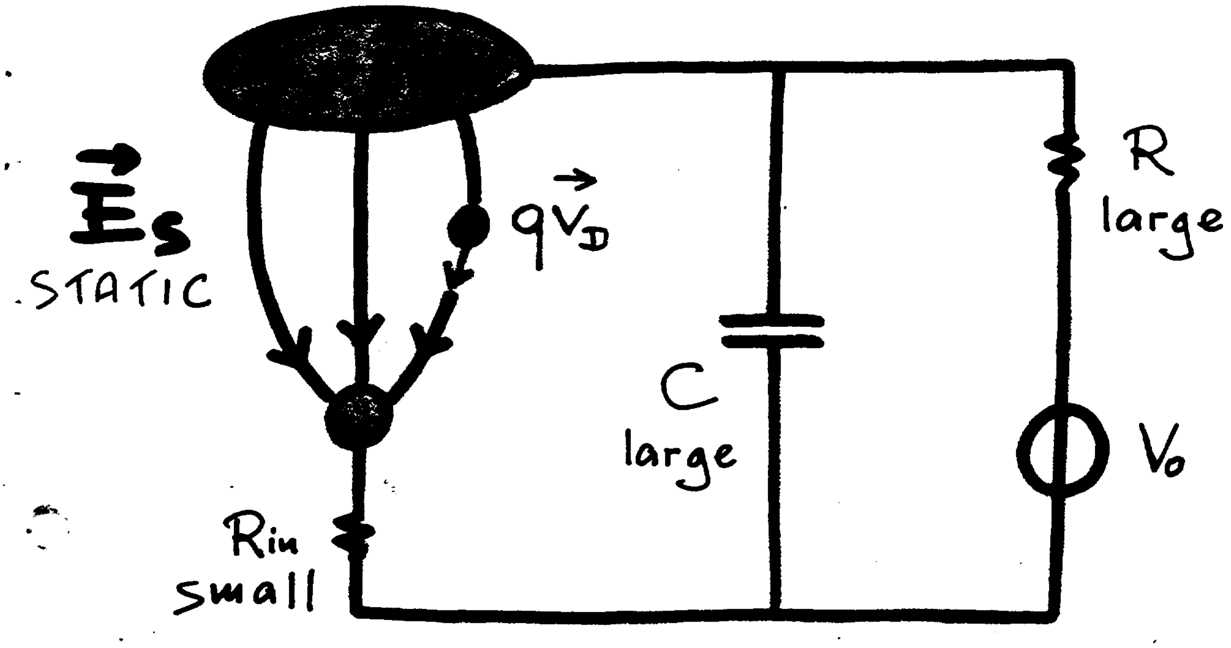
SIGNAL

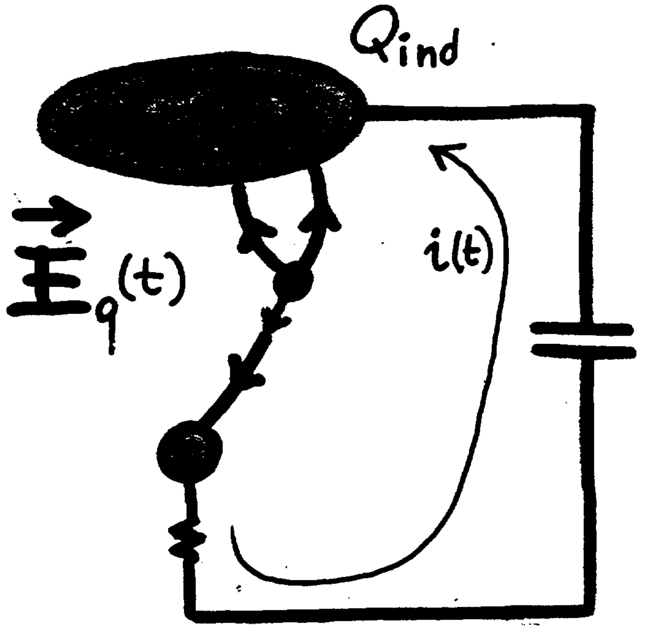
TRANSMISSION

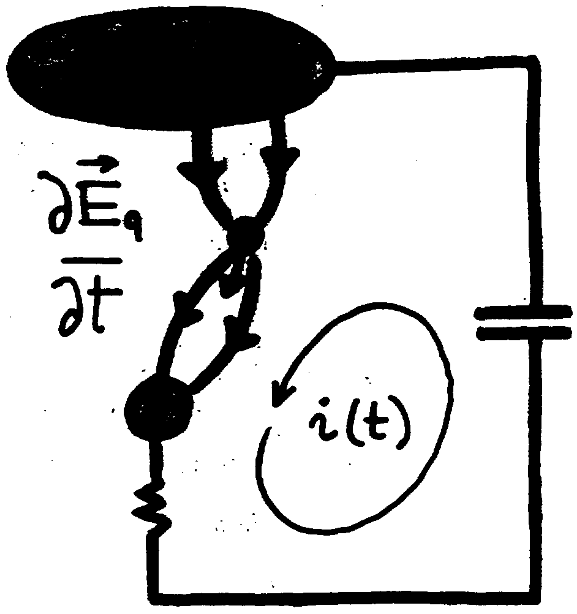
AT VELOCITY $c/\sqrt{\varepsilon_r}$

IF NOT SLOWED BY R, L, C

CURRENT ASSOCIATED TO A CHARGE DRIFTING IN A STATIC ELECTRIC FIELD BETWEEN TWO ELECTRODES





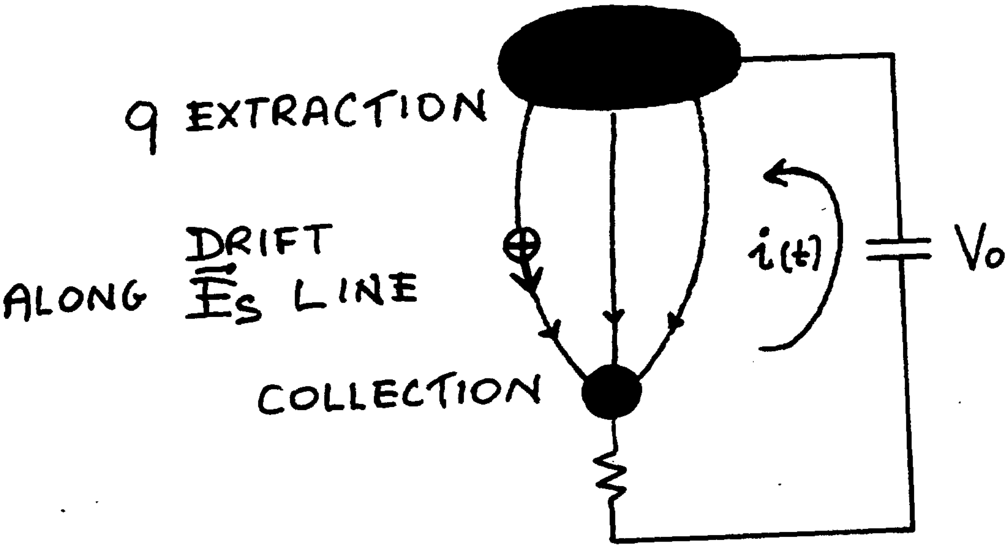


$$i(t) = \frac{dQ_{ind}}{dt} =$$

CURRENT INDUCED BY THE CHARGE IN MOTION

LOOP CLOSED BY DISPLACEMENT CURRENT

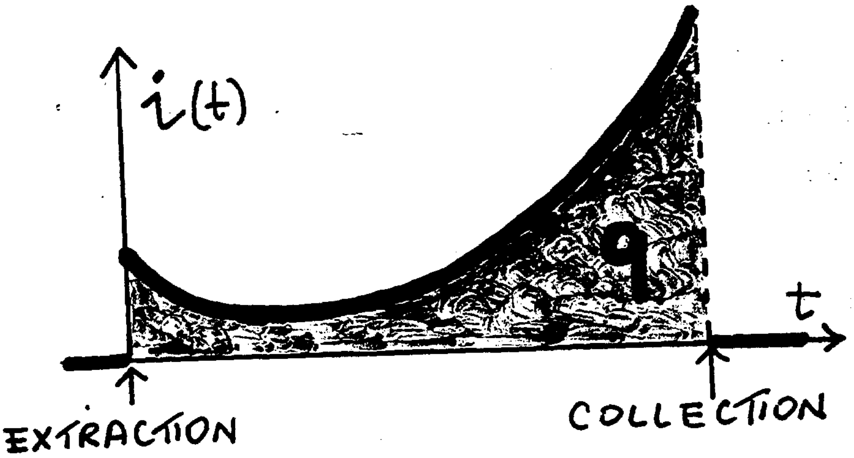
CALCULATION OF THE INDUCED CURRENT IN THE CASE OF ONLY TWO ELECTRODES



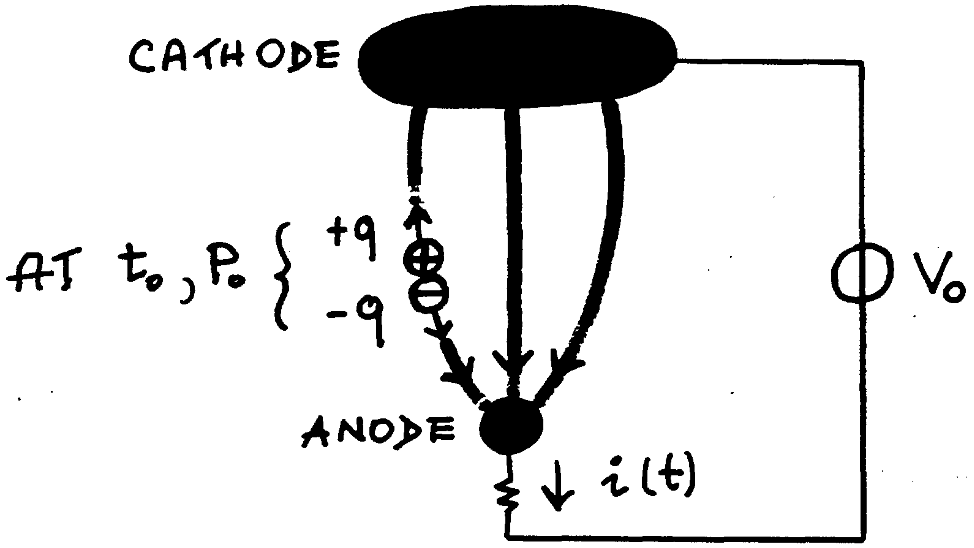
POWER BY V_0 ON $i(t)$ = POWER BY $\vec{E}_S$ ON $q\vec{v}_D$

$$V_0 \, i(t) = (q E_s) \, v_D$$

$$\rightarrow i(t) = q \, \frac{E_S(t)}{V_0} \, v_D(t)$$



IN GENERAL IN DETECTORS e-ion (e-h) PAIRS ARE PRODUCED AT SOME POSITION IN THE SENSITIVE VOLUME



$$i(t) = i_e + i_{ion} = q\,\frac{E_s^{(e)}}{V_0}\,v_e + q\,\frac{E_s^{(ion)}}{V_0}\,v_{ion} \quad \overset{v_e}{\widehat{\widehat{\;}}}$$

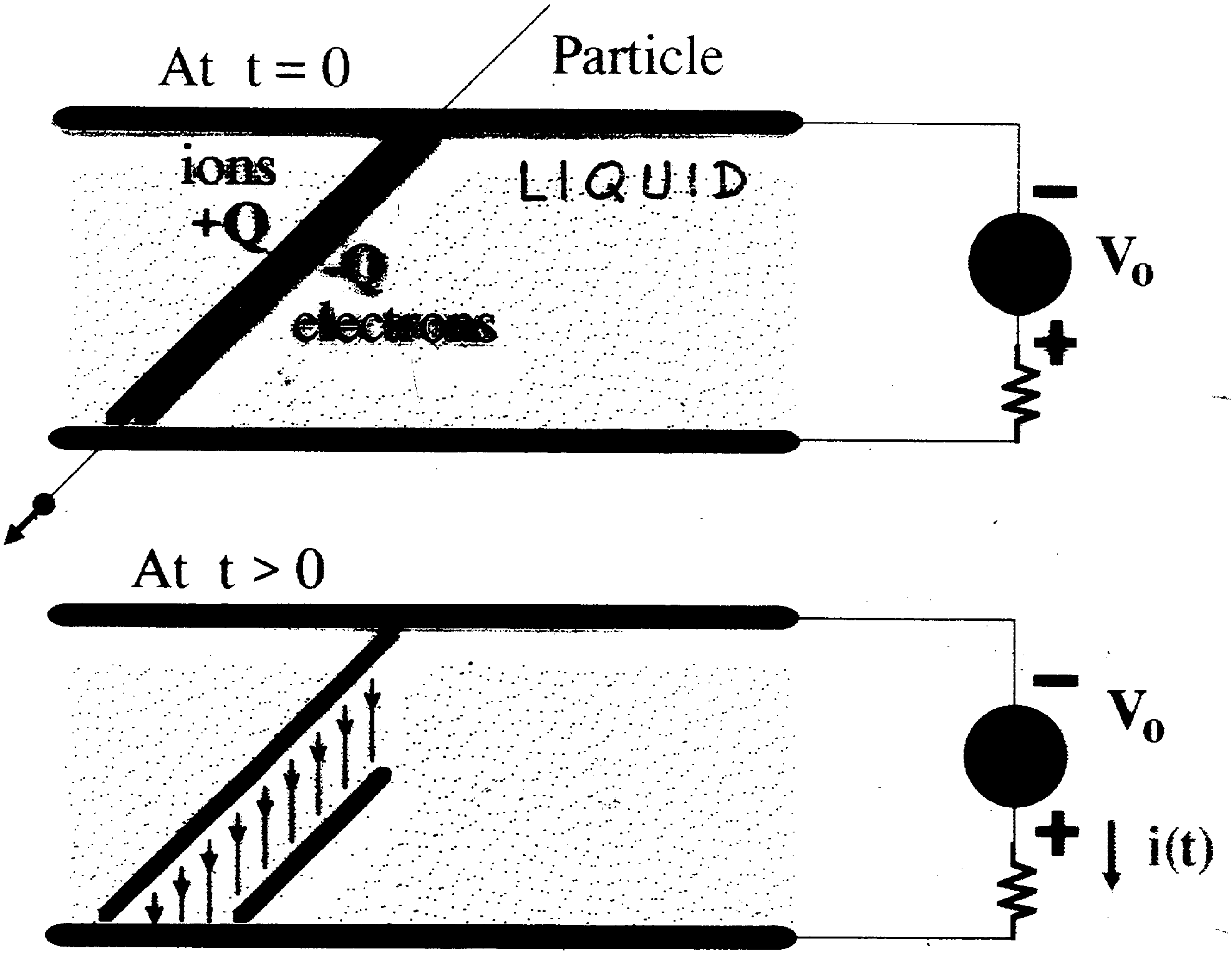
- ELECTRON CHARGE SIGNAL :

$$\underset{\swarrow\ \text{CHARGE FLOWN}}{Q_e} = \int_{t_0}^{\text{COLLECTION}} i_e(t)\,dt = \frac{q}{V_0}\int_{P_0}^{\text{ANODE}} E_s\,\frac{dl}{dt}\,dt =$$

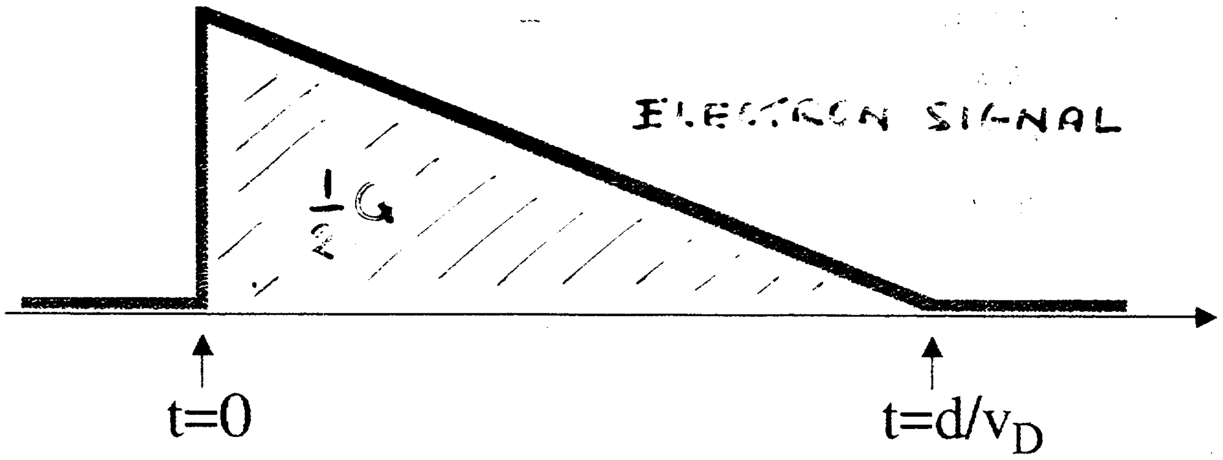
$$= \underbrace{\boxed{q\,\frac{\Delta V}{V_0}}}_{} \underset{\substack{\uparrow \\ \text{IF } E_s \text{ UNIFORM}}}{=} q\,\frac{\text{ELECTRON PATH}}{\text{ELECTRODE DISTANCE}}$$

- IONS : SIMILAR BUT MUCH SLOWER → $Q_e + Q_{ion} = q$

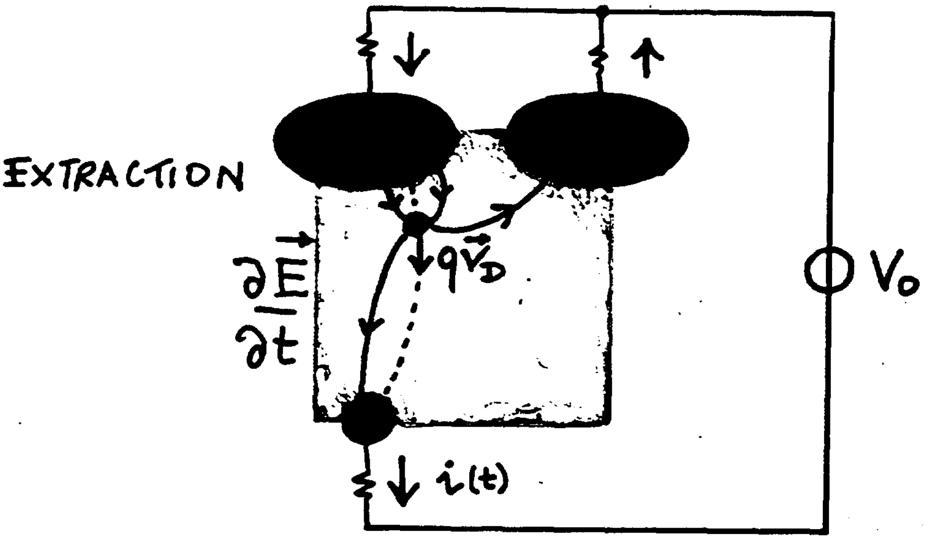
Current signal in a parallel plate ionization chamber

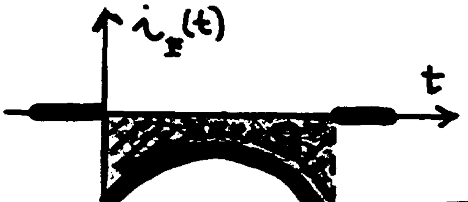


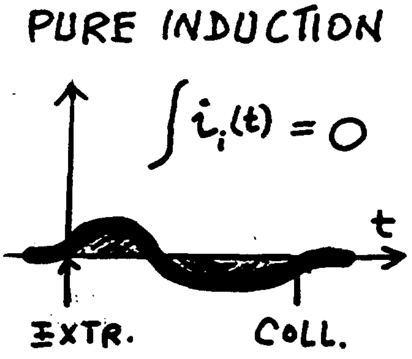
$$i(t) = \frac{E}{V_0}\, q(t)\, v_D = \frac{E}{V_0}\, Q \left(1 - \frac{v_D}{d}\, t\right) v_D$$

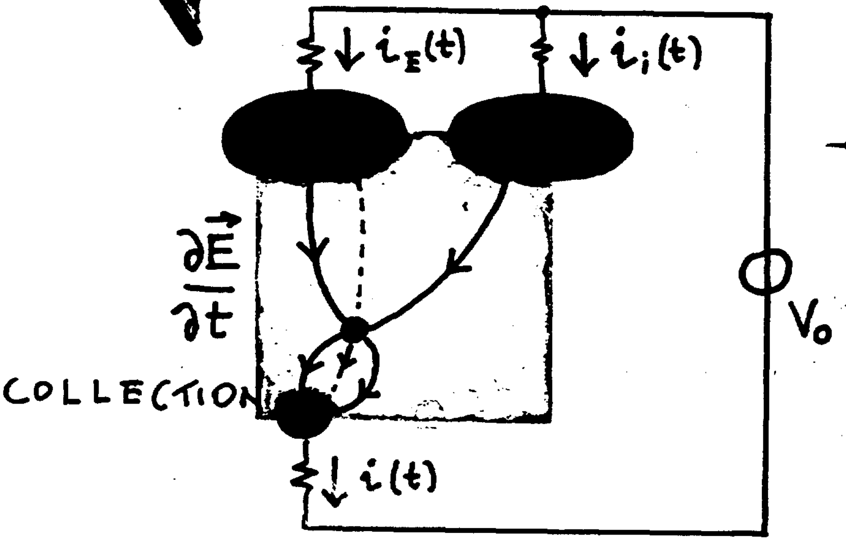


INDUCED CURRENT IN THE CASE OF MORE THAN TWO ELECTRODES

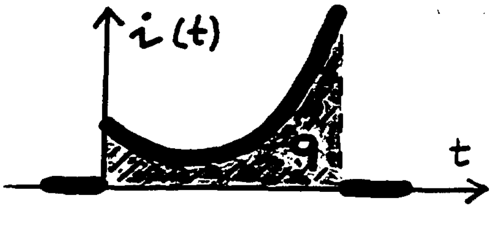






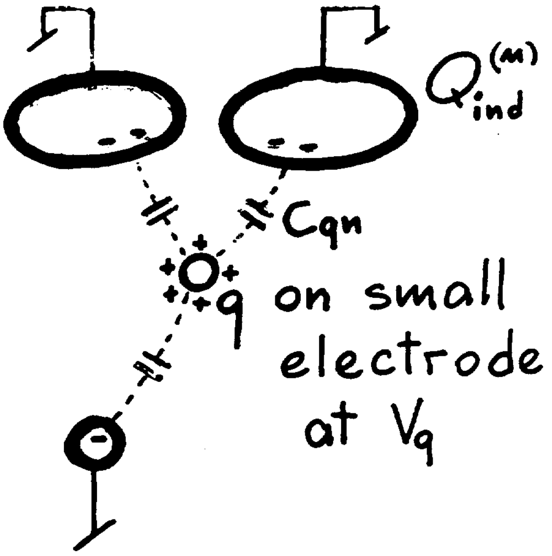


$$i(t) = q \frac{E_s}{V_0} v_D$$



CALCULATION OF INDUCED CURRENT ON ANY ELECTRODE BY THE WEIGHTING FIELD

(V. Radeka, Ann. Rev. Nucl. Part. Sci. 1988. 38: 217)



$$\frac{Q_{ind}^{(m)}}{q} = \frac{C_{qm}}{C_{tot}}$$

$$\rightarrow Q_{ind}^{(m)} = C_{qm}\frac{q}{C_{tot}} = C_{qm} V_q = \left(\frac{q}{V_m}\right) V_q$$

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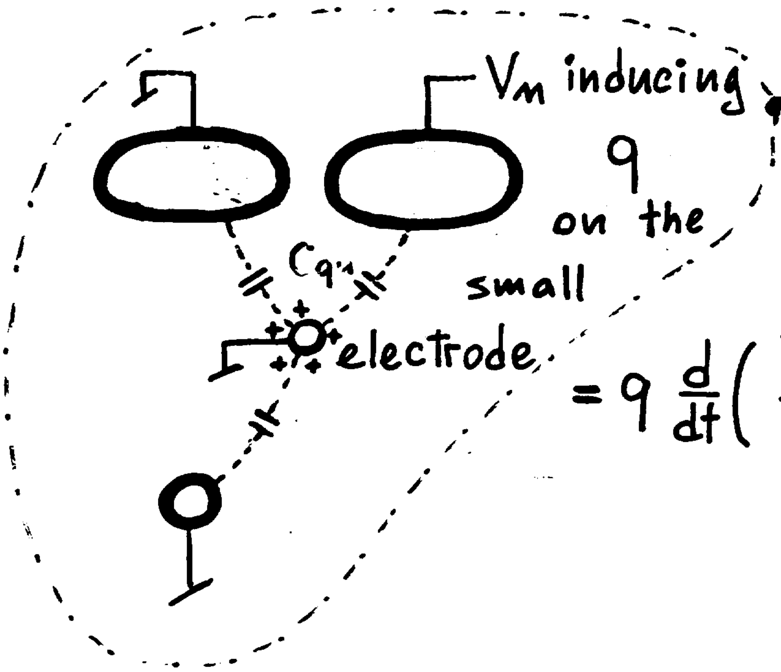


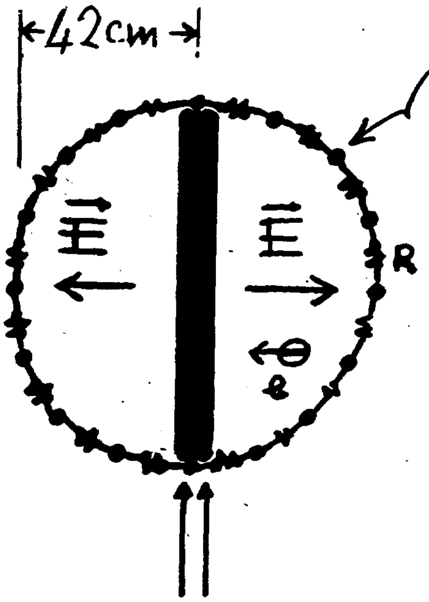
$$i_m(t) = \frac{dQ_{ind}^{(m)}}{dt} = q\frac{d}{dt}\left(\frac{V_q}{V_m}\right) = q\frac{d}{dl}\left(\underset{\substack{\parallel \\ \text{ADIMENSIONAL} \\ \text{SCALAR FIELD}}}{\frac{V_q}{V_m}}\right)\frac{dl}{dt} =$$

$$= q\vec{\nabla}U_w \cdot \vec{v}_D = -q\underset{\substack{\parallel \\ \text{WEIGHTING FIELD}}}{\vec{\mathcal{E}}} \cdot \vec{v}_D$$

NOTE: 2 ELECTRODES
→ $\mathcal{E}_w = E_s / V_0$

THE ICARUS 3 ton PROTOTYPE:
3-DIMENSIONAL FINE GRAIN TRACKING IN LAr

- ARRANGEMENT: LAr PURITY ALLOWING FREE e DRIFT [illegible]



CATHODE BARS WITH GRADED VOLTAGE TO ESTABLISH A UNIFORM DRIFT FIELD

TWO X-Y WIRE CHAMBERS TO MEASURE POSITION AND DRIFT TIME OF IONIZATION ELECTRONS

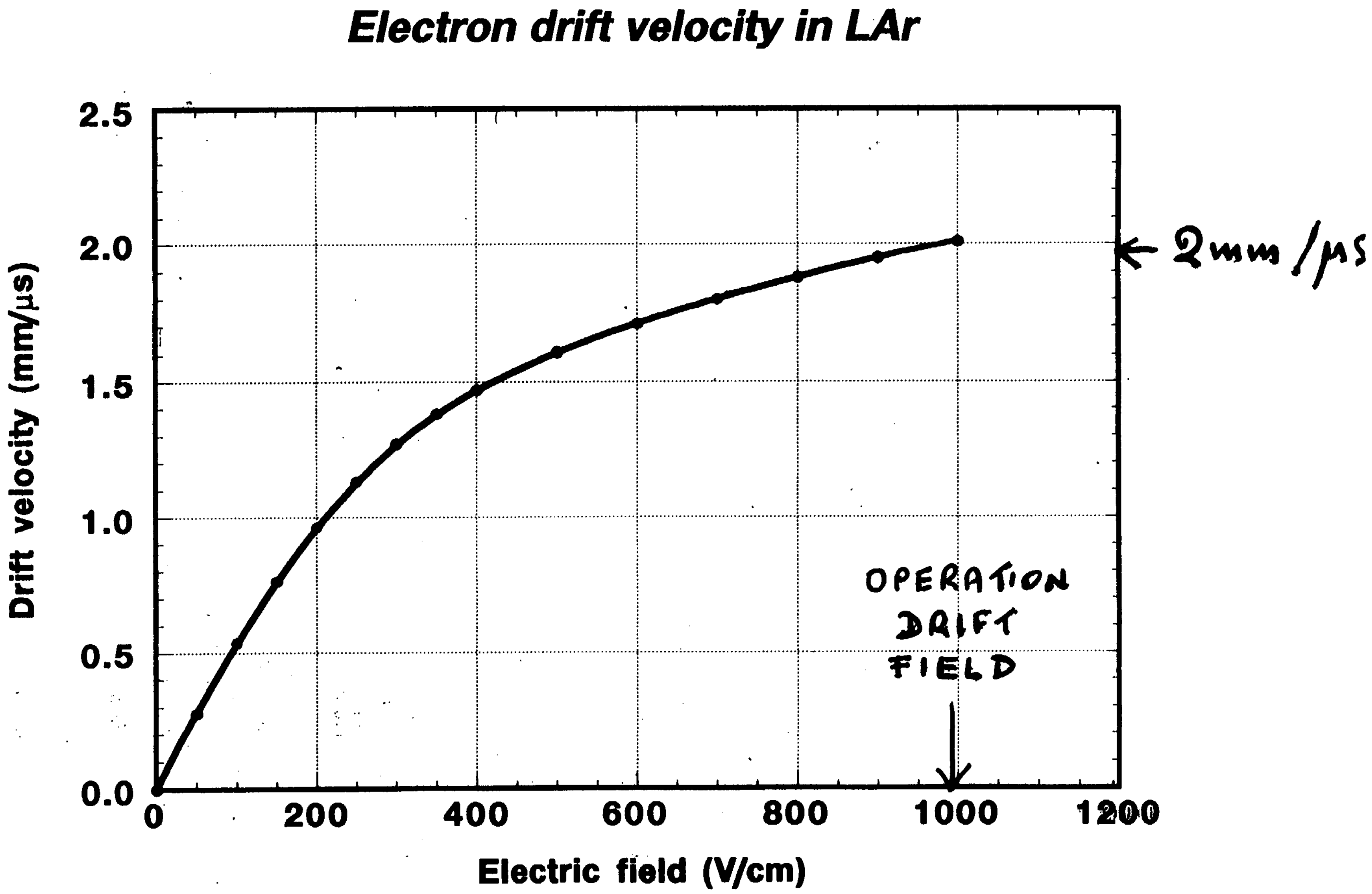
READOUT CELL:

2 mm × 2 mm × 0.6 mm

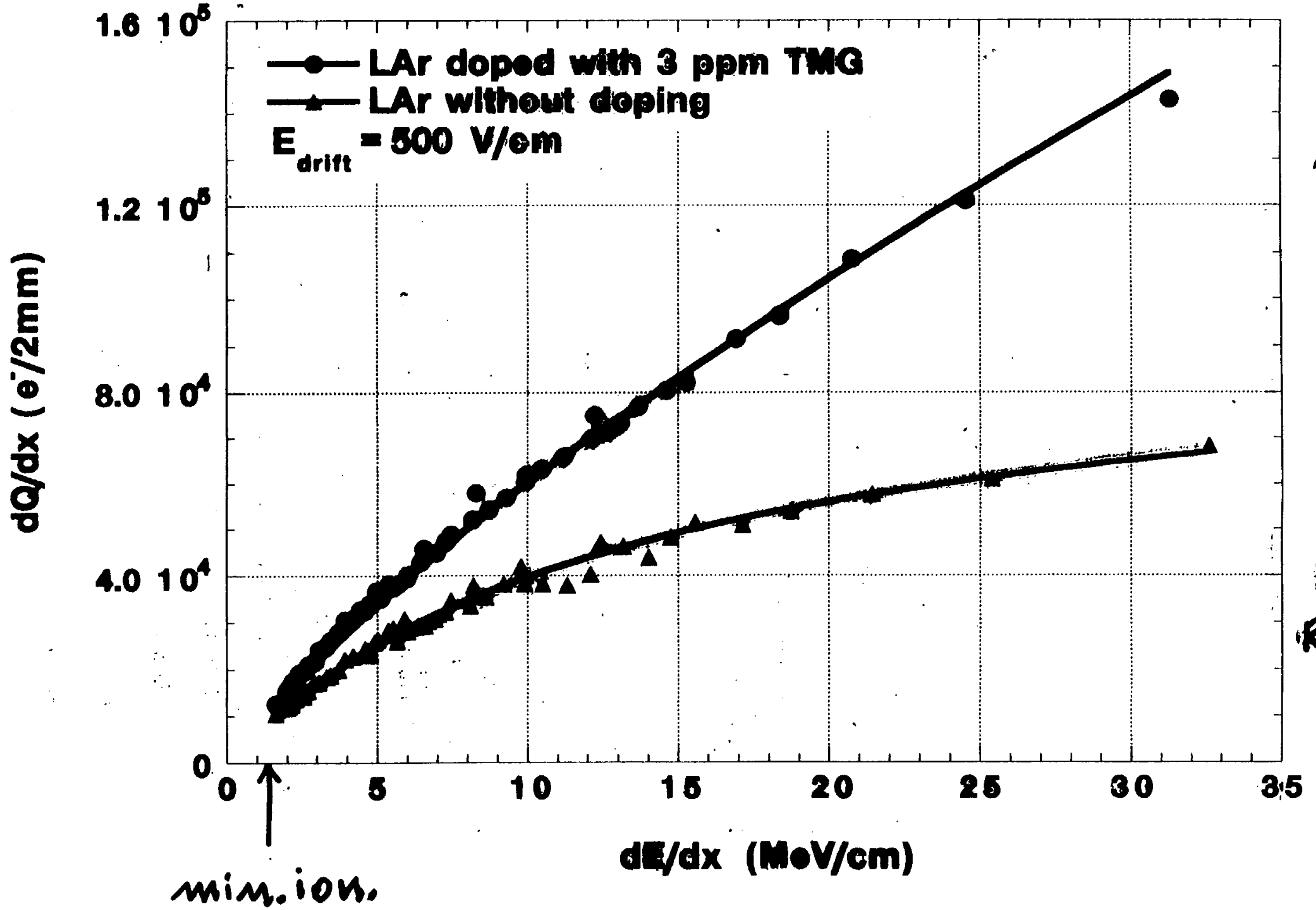
↓ COLLECTION WIRES

↓ INDUCTION WIRES

↓ DRIFT TIME

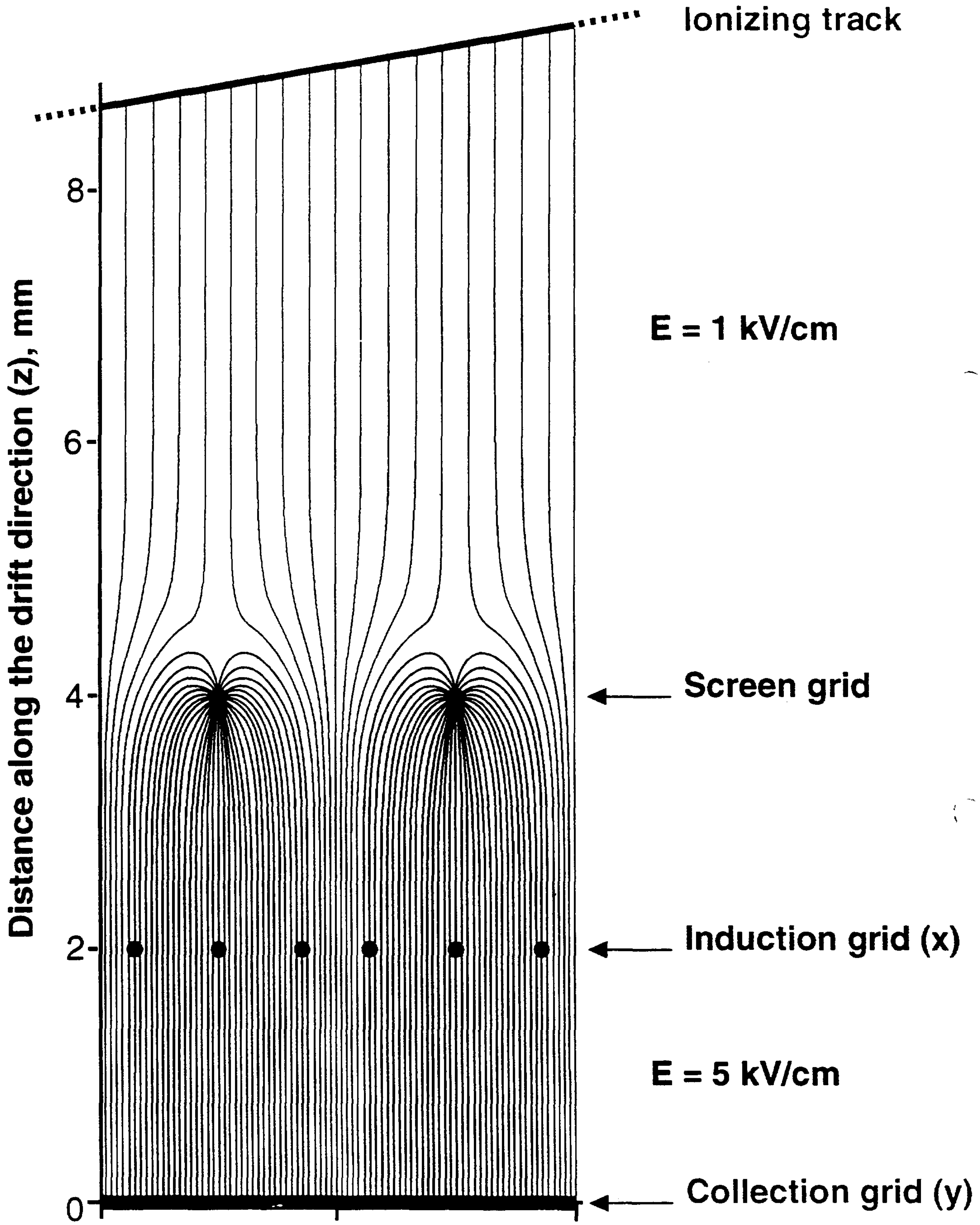

Electron drift velocity in LAr
Drift velocity (mm/µs)
2.5
2.0
1.5
1.0
0.5
0.0
0
200
400
600
800
1000
1200
Electric field (V/cm)
2mm/µs
OPERATION
DRIFT
FIELD

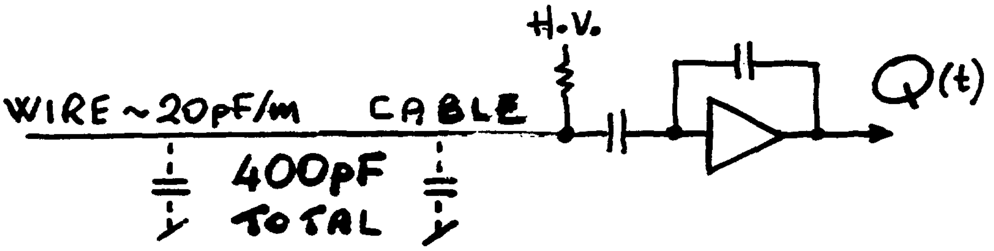
Charge collected vs energy deposited in LAr (electron-ion ricombination effect)



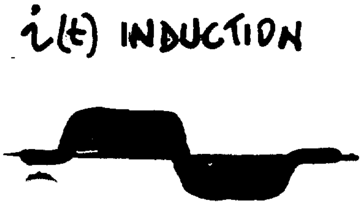
m.i.p. IN
2mm LAr
↓
16'000 e
↓
11'000 e
AFTER
RICOMBINATION
IN 1kV/cm
FIELD

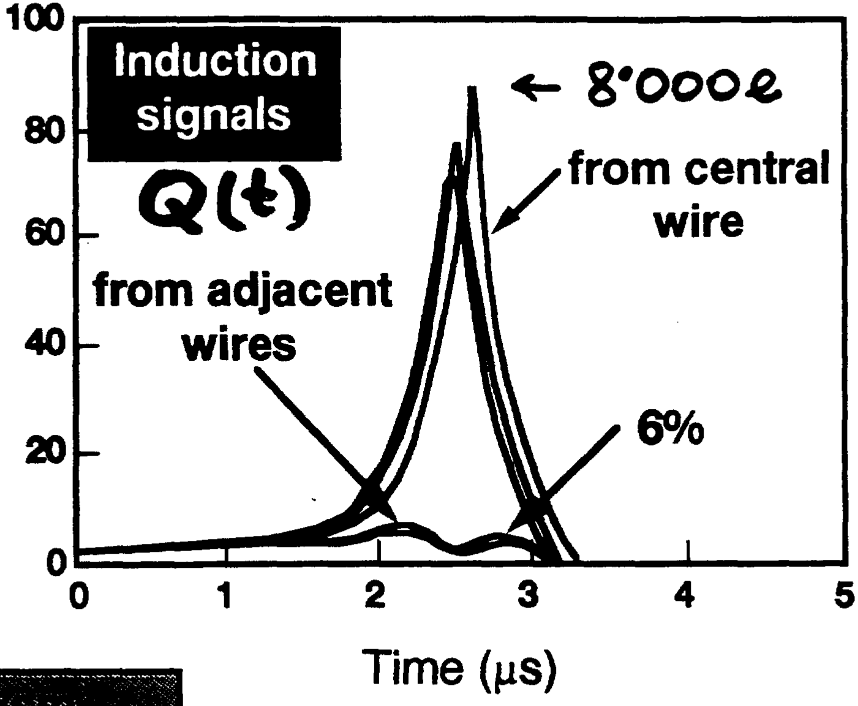
ICARUS 3-D non distructive imaging read-out





$$\mathrm{ENC} = \underset{300e}{\underset{\parallel}{a}} + \underset{\frac{2e}{pF}}{\underset{\parallel}{b}}\,C \approx 1'000e$$





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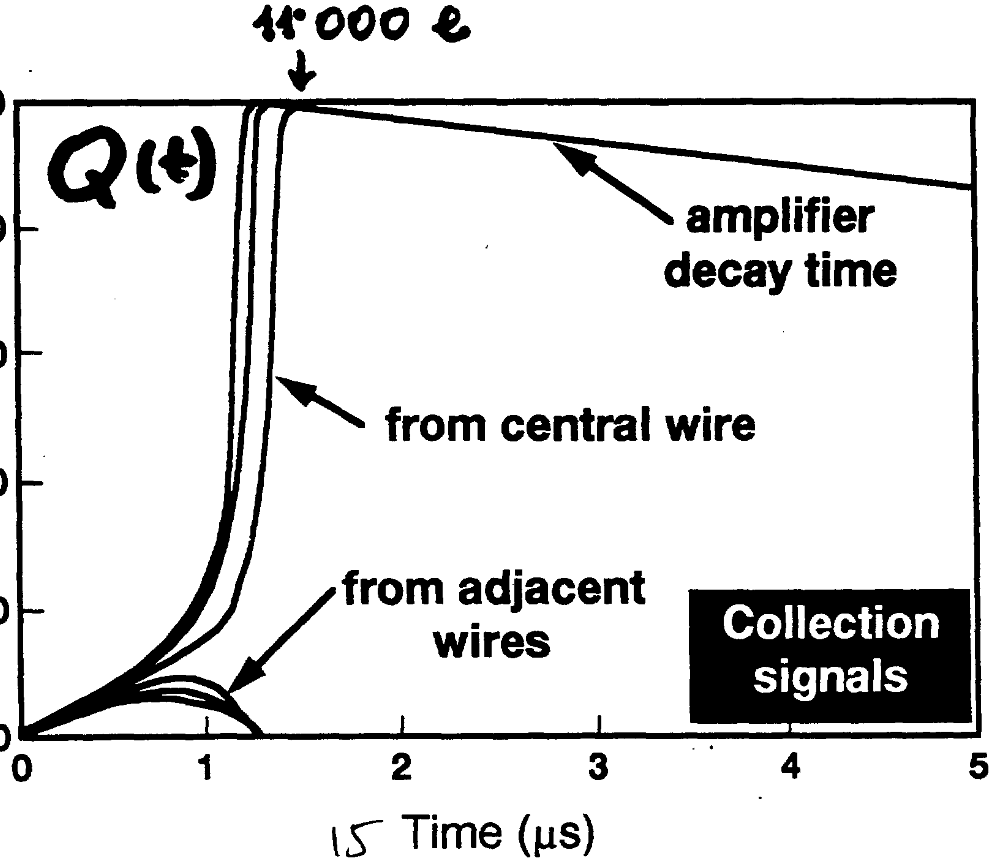
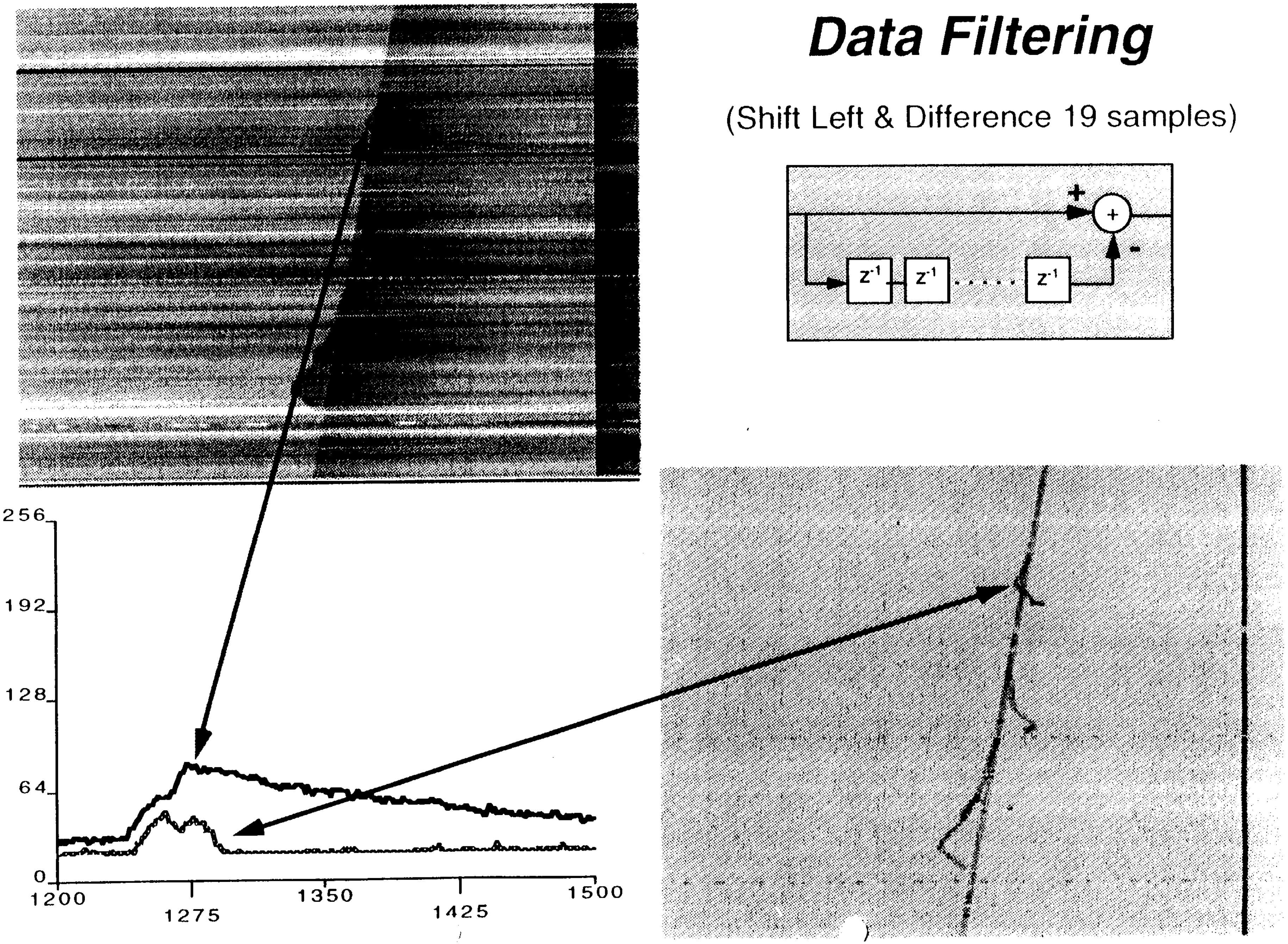


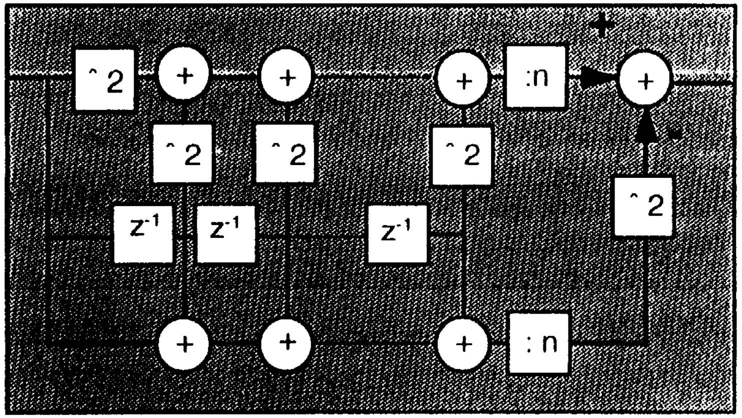
Data Filtering

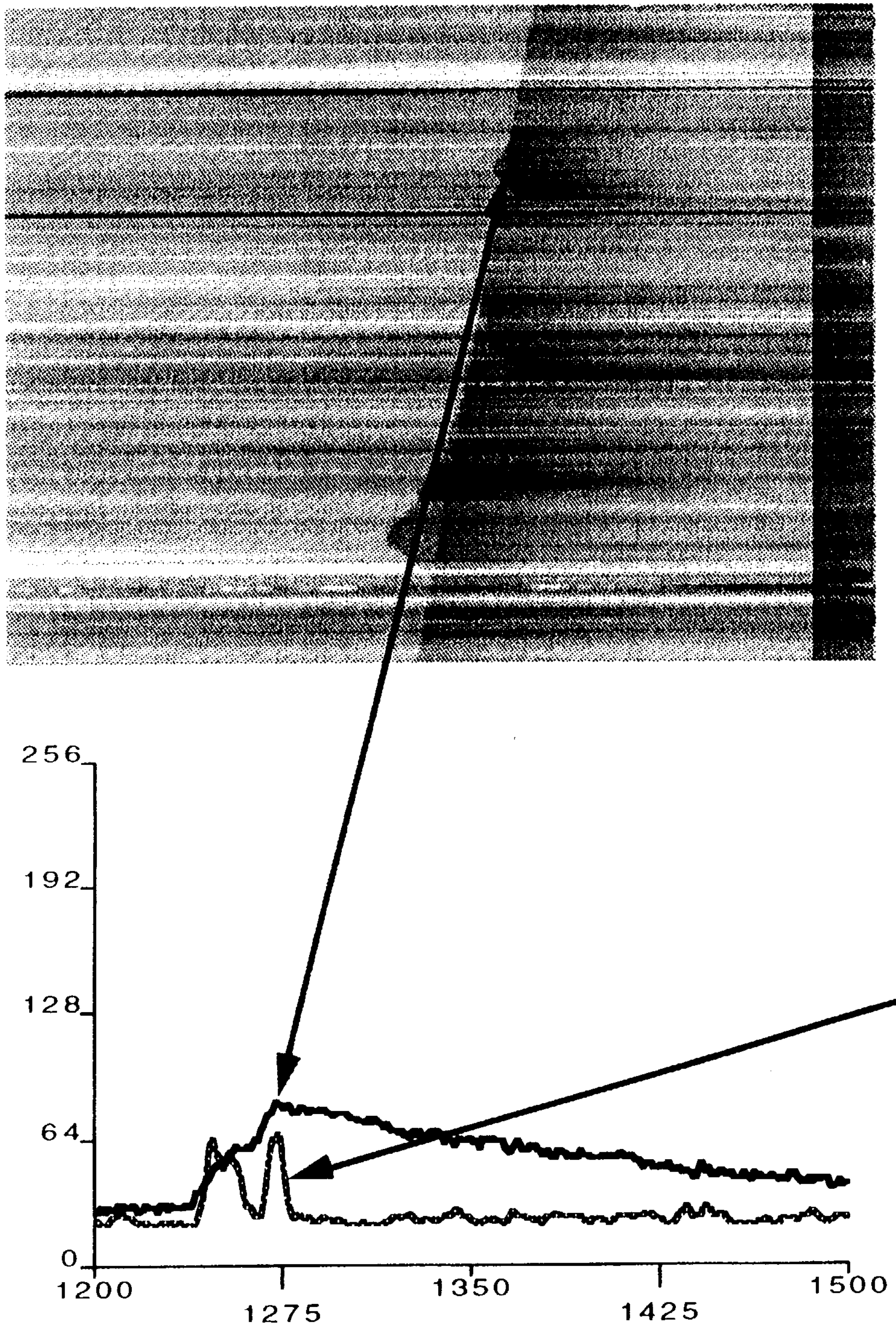
(Shift Left & Difference 19 samples)

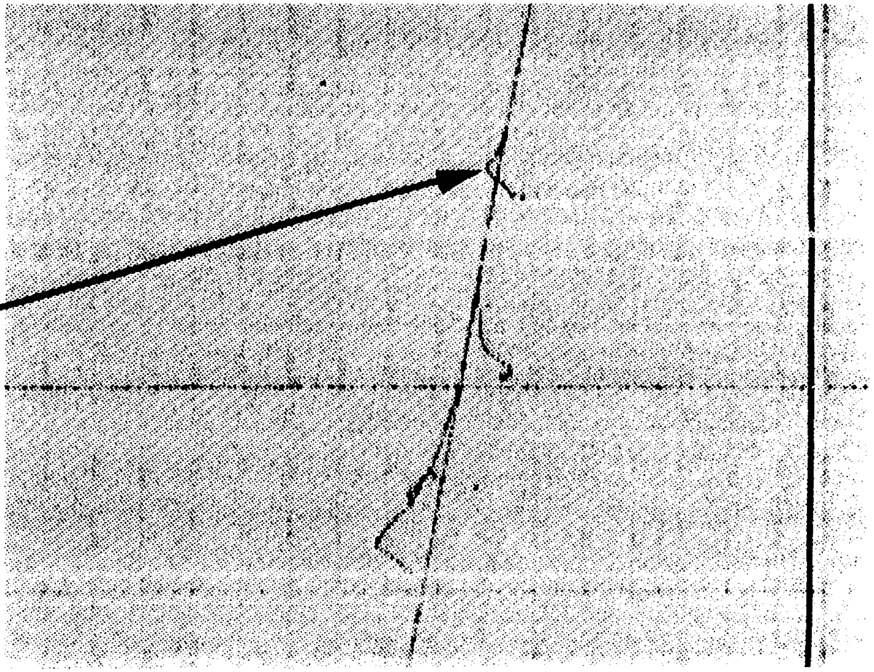


Data Filtering

(Signal Power on a 9 samples window)

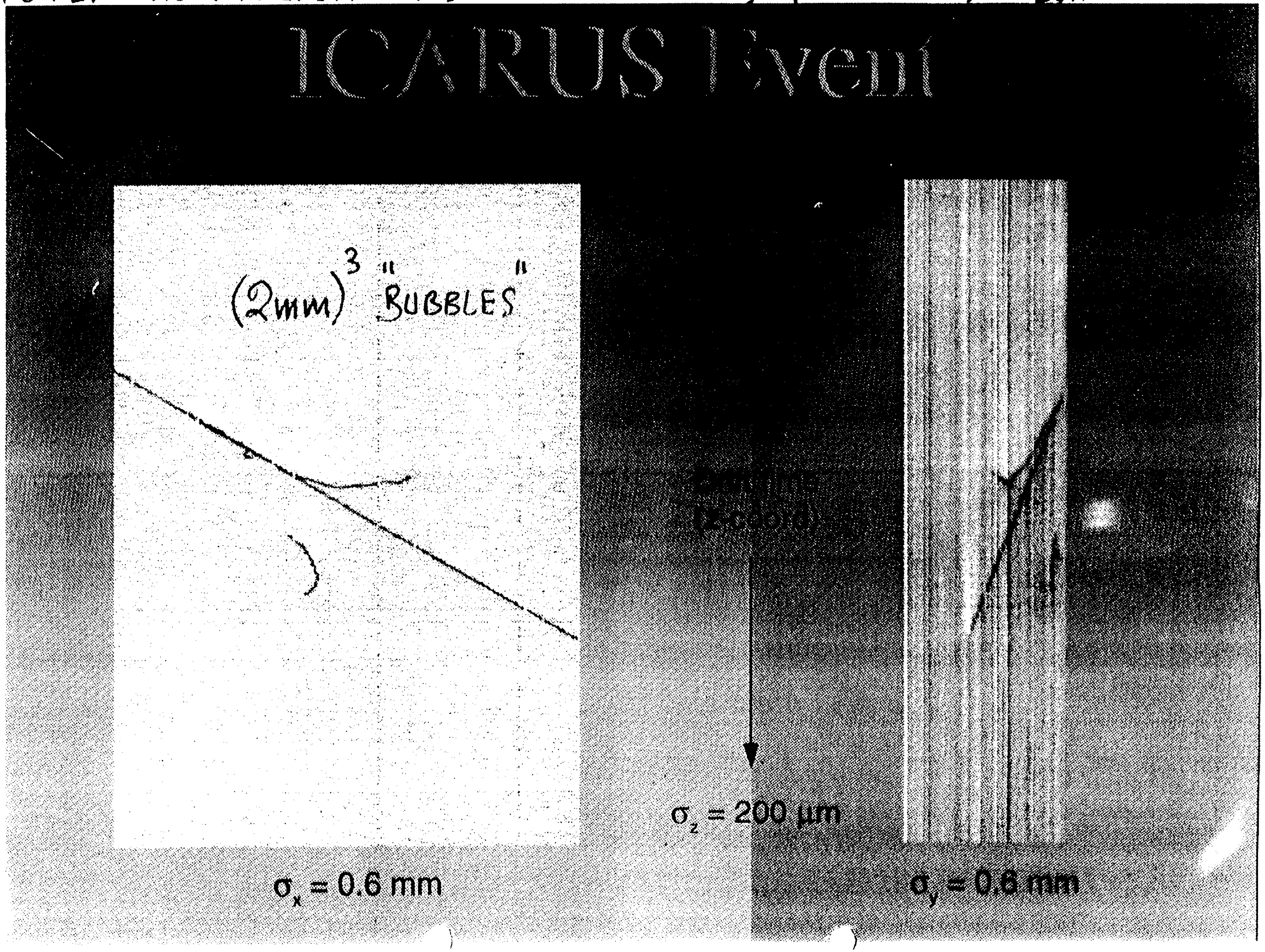




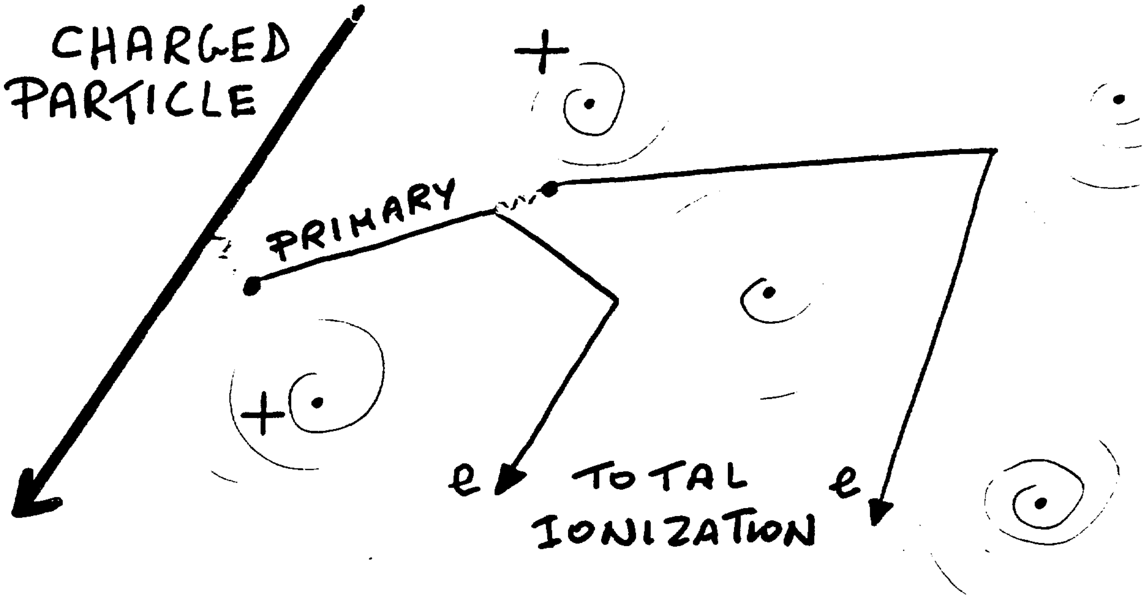


POTENTIAL APPLICATIONS : ν_τ AT LHC ; P-DECAY, ν_{SUN} AT GRAN SASS

ICARUS Event



THE IONIZATION PROCESS IN GASES AND LIQUIDS



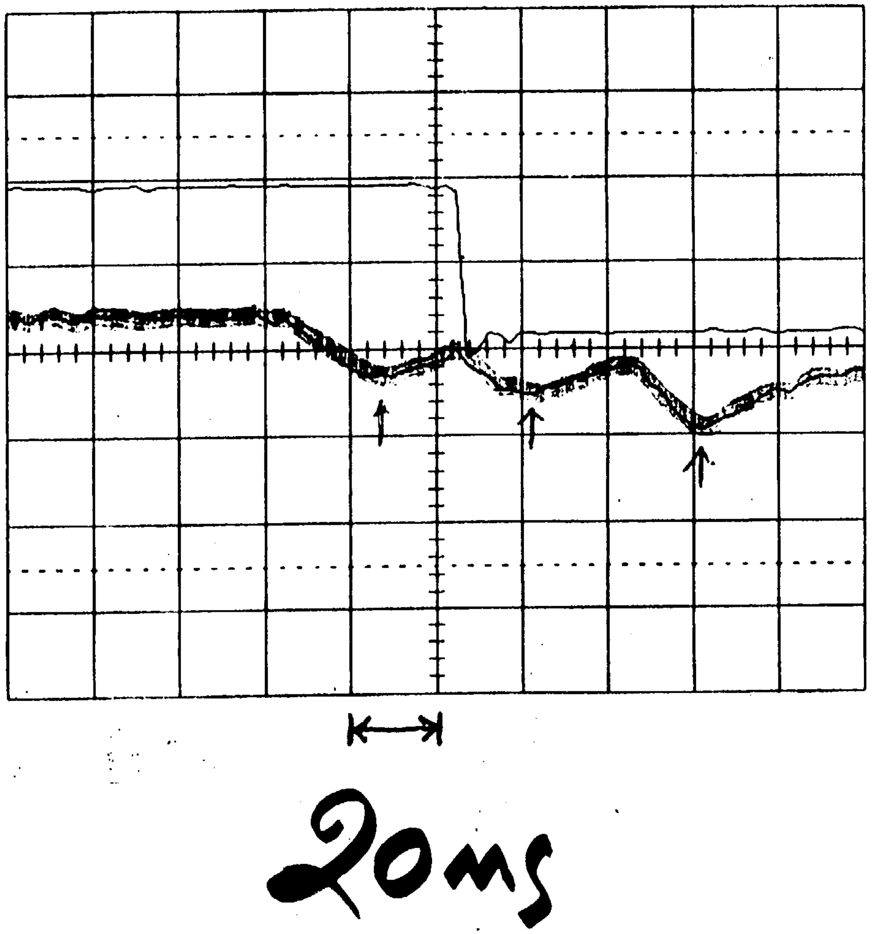
$\frac{\Delta N_{PRIMARY}}{\Delta x} \rightarrow$ GAUSSIAN $\frac{\Delta N_{TOTAL}}{\Delta x} \rightarrow$ LANDAU

SOME NON ELECTRONEGATIVE GASES

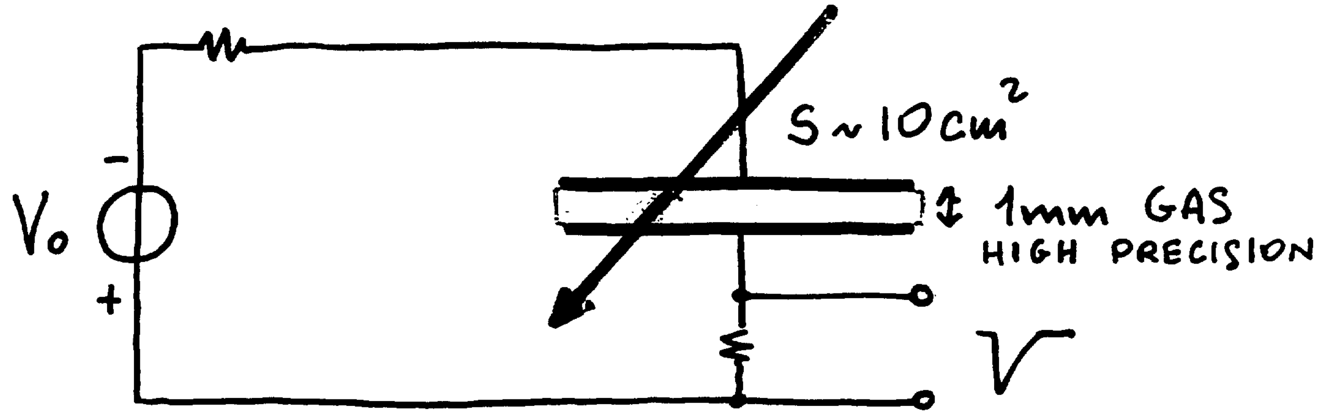
		$N_{PRIMARY}/cm$	N_{TOTAL}/cm
NOBLE	He	5	8
	Ar	24	94
	Xe	44	307
QUENCHING	CH_4	26	53
	C_4H_{10}	90	195
	CO_2	36	91

GAS DEVICES NEED e AVALANCHE MULTIPLICATION

SINGLE CLUSTERS IN He + FEW % QUENCHER
(KLOE DRIFT CHAMBER STUDIES)



Parallel Plate Chamber
(CMS R&D)



- GAS : CO_2, CF_4 alone or mixed with
  iC_4H_{10} → FEW IONIZATION CLUSTERS

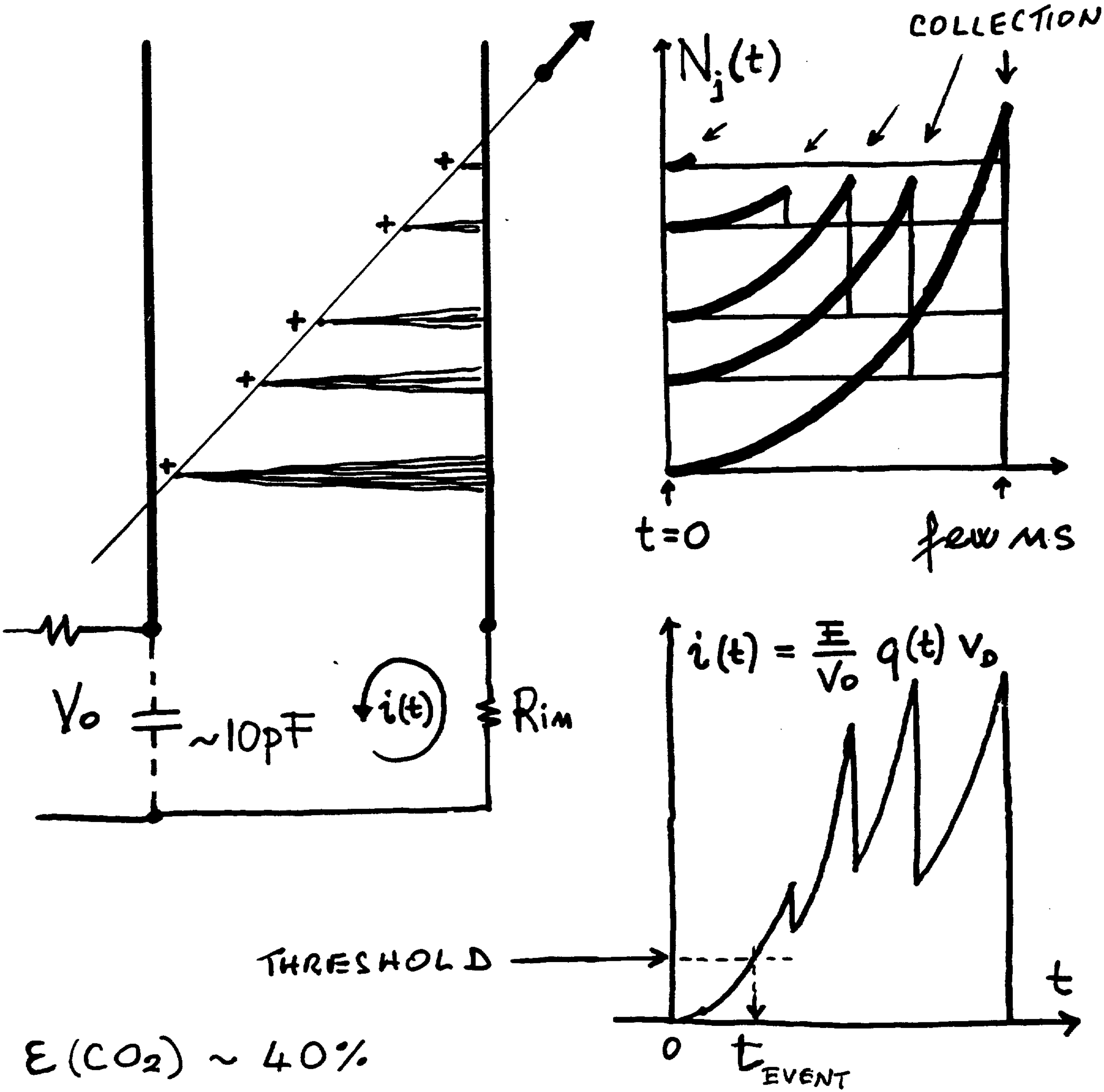
- electron avalanche in E_S = few 10^4 V/cm

→ high speed and high rate (> 10^6/cm²s)
for triggering
in very high radiation environment

PPC operation

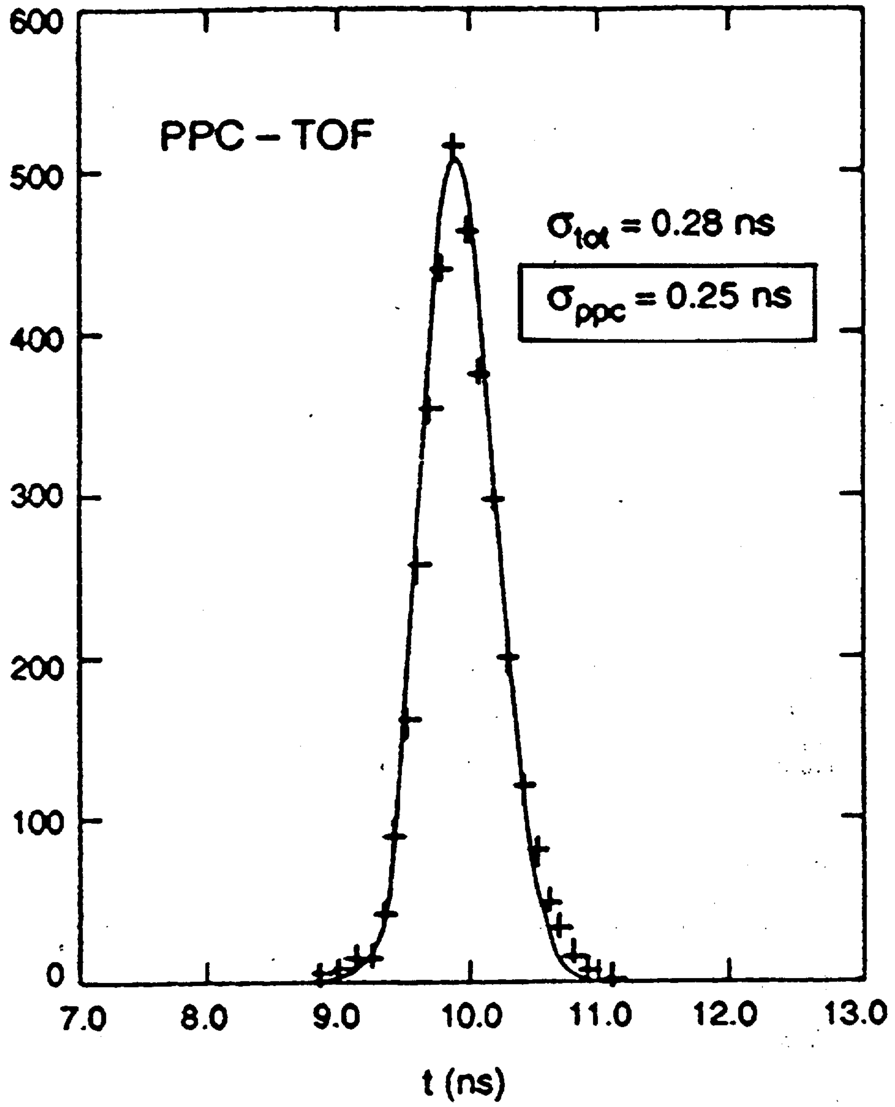
- electron avalanche in uniform $\vec{E}$
- single cluster avalanche :

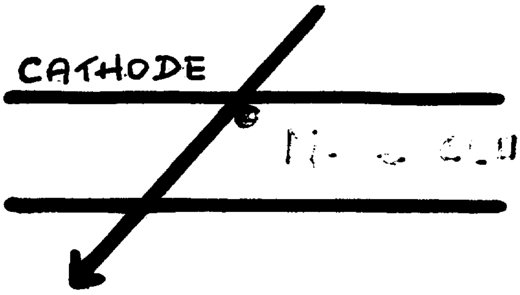
$$N = N_0 \exp(\alpha x) = N_0 \exp(\alpha v_D t)$$



$\varepsilon(CO_2) \sim 40\%$
$\varepsilon(iC_4H_{10}) \sim 90\%$

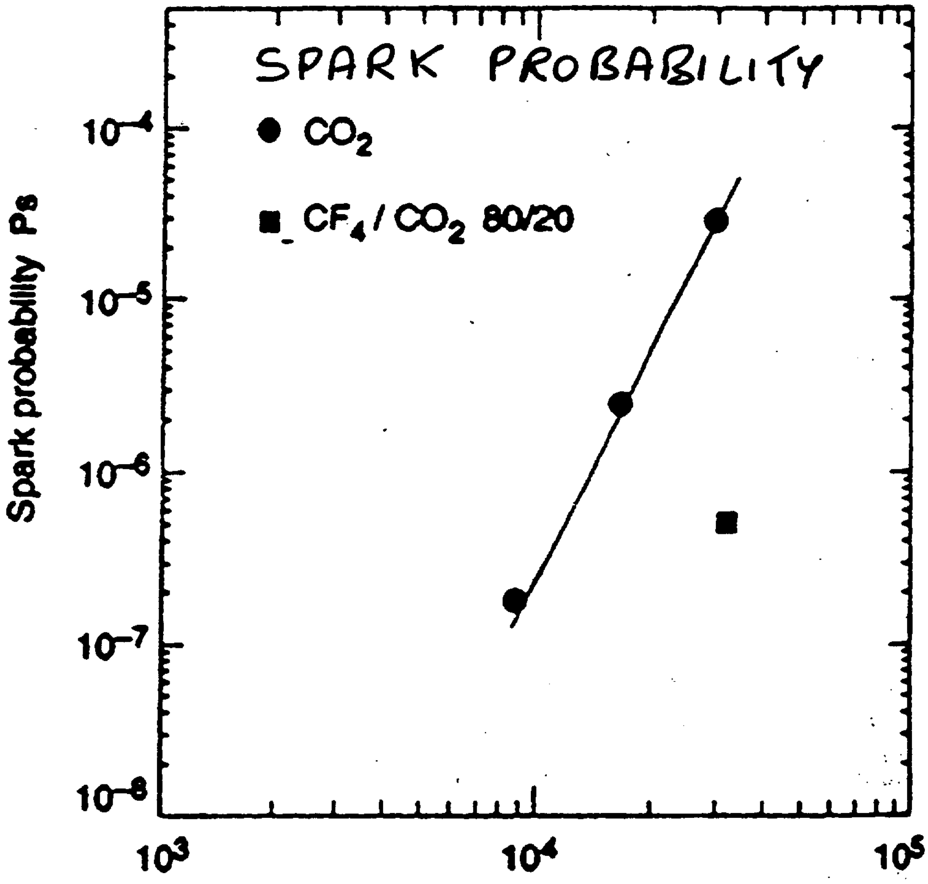
PPC TIME ACCURACY





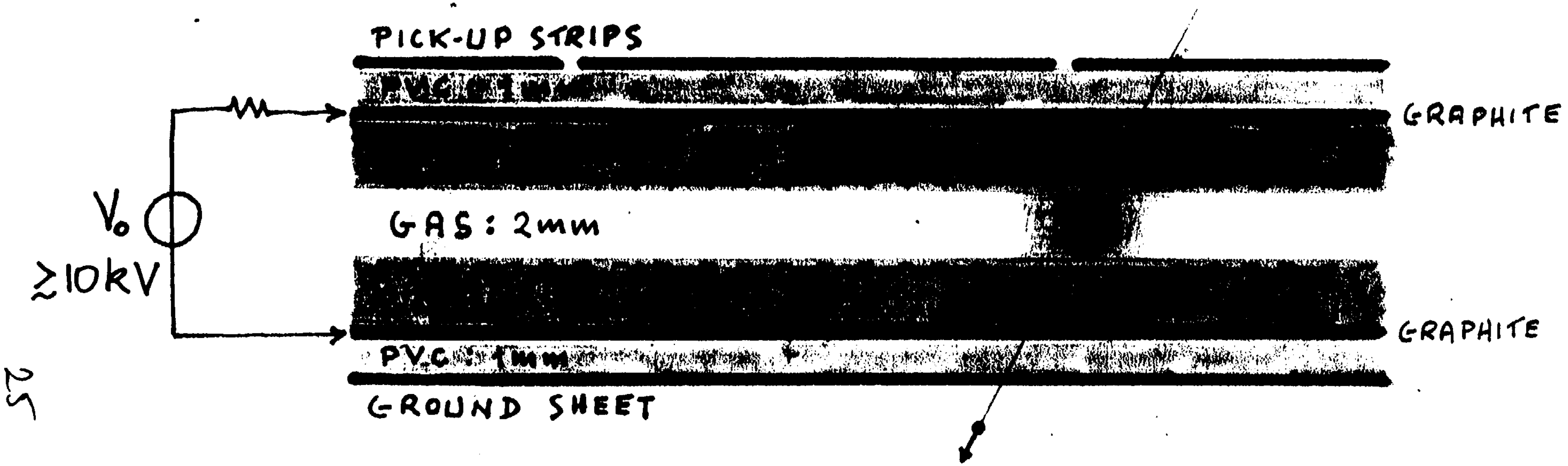
N. e CLUSTER = [illegible] RAY
OR HEAVILY IONIZING
NUCLEAR FRAGMENT

AVALANCHE CRITICAL CONDITION: $N \approx 10^8 e$ → STREAMER →
→ SPARK



RD 37: PPC FOR HADRON CALORIMETRY
IN THE VERY FORWARD AT LHC

RESISTIVE PLATE CHAMBERS (RD5)

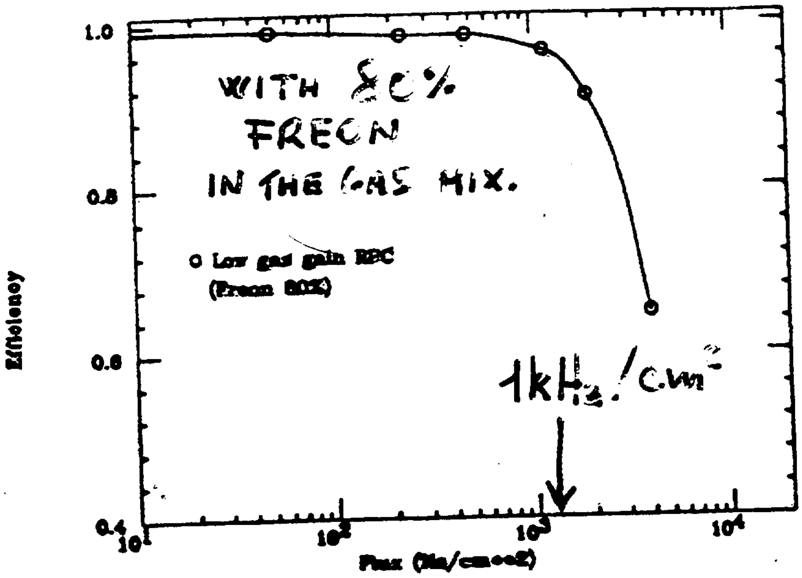


GAS : Ar + QUENCHER + FREON

STREAMER-SPARK CONFINED BY VOLTAGE DROP AND U.V. ABSORPTION

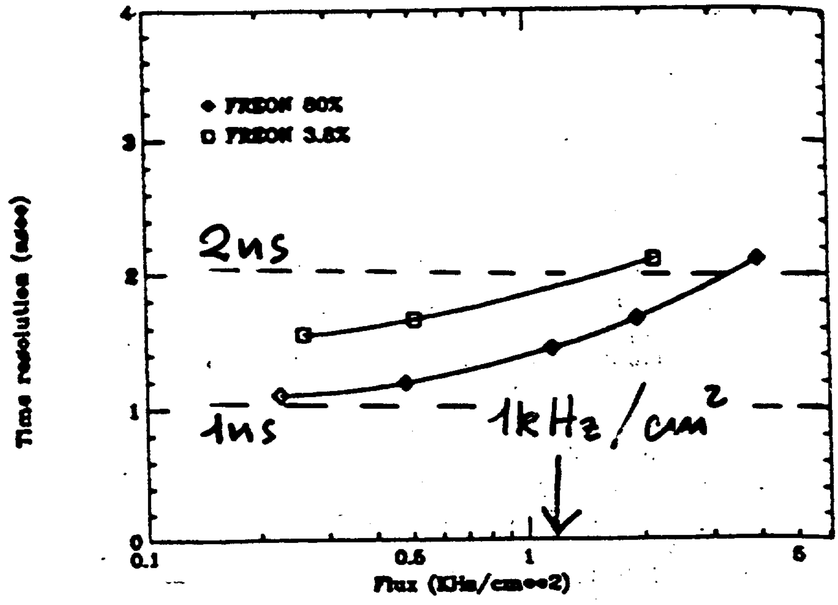
$\sigma_t \sim 1$ ns → μ TRIGGER WITH BEAM CROSSING IDENTIFICATION

RPC EFFICIENCY vs PARTICLE FLUX



RATE CAPABILITY SUFFICIENT FOR μ TRIGGER IN THE BARREL

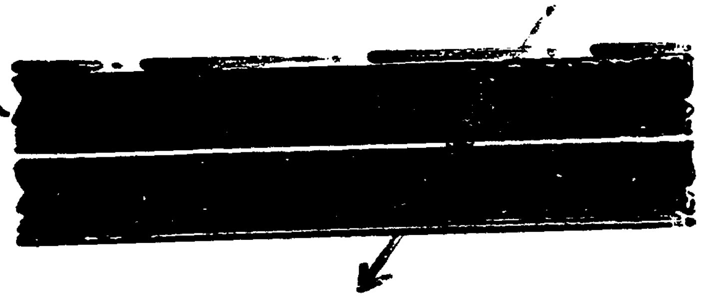
TIME RESOLUTION vs PARTICLE FLUX



SPACE ACCURACY BY CHARGE CENTROID OVER 1cm WIDE STRIPS :

$$\sigma_x \sim 200\mu m$$

PESTOV SPARK COUNTER (ALICE R&D)

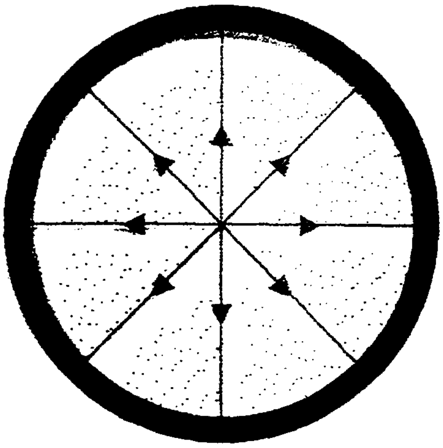


✳ $\sigma_t \sim 30\,ps$ → LOW MOMENTUM PARTICLE IDENTIFICATION BY TOF

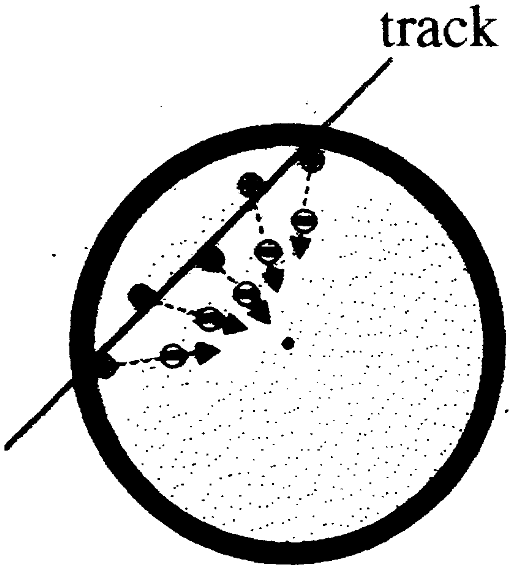
- MAX PARTICLE RATE ~ 20 kHz/cm^2
- $\sigma_x \lesssim 6\,mm$

ALICE OPTION : 4'000 COUNTERS

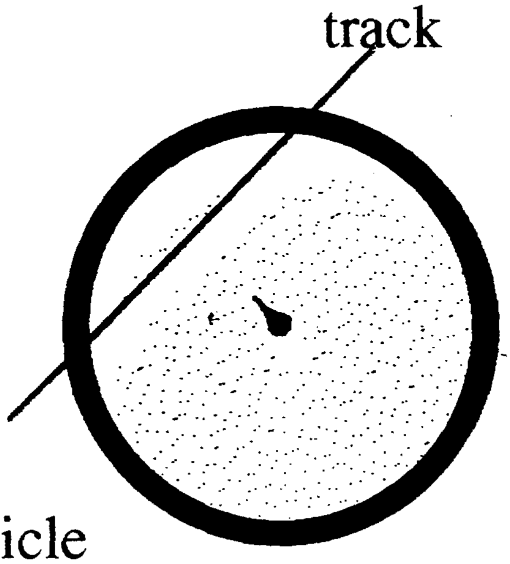
Proportional Tube



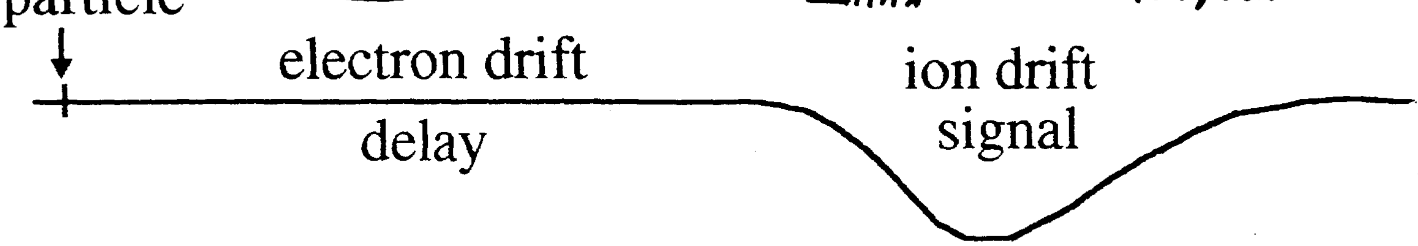
- cathode tube: 3÷100 mm
- anode wire: 20÷ 100 μm
- non electronegative gas
- E ∝ 1/r



- electronic drift ~ 1mm/20ns
- negligible ionic drift

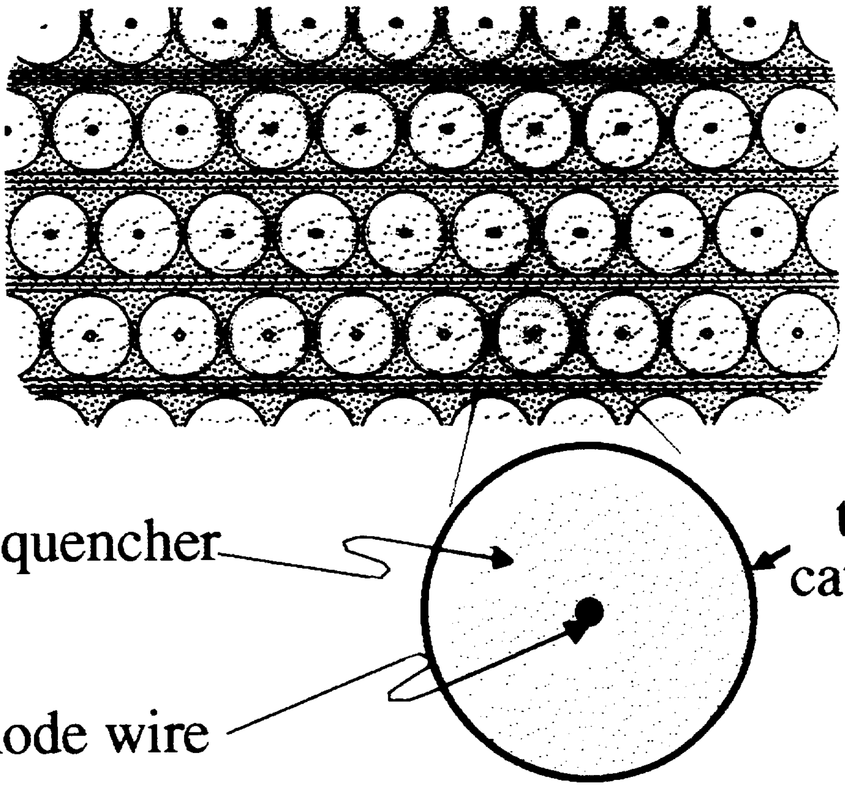


- electronic avalanche
- $N=N_0e^{\alpha(E)x}$
- $\alpha(E)\neq 0$ near the wire only
  - E_{MAX} ~ 200 kV/cm



RD6 -TRANSITION RADIATION TRACKER

ø 4 mm x 50 cm PROPORTIONAL STRAW TUBES



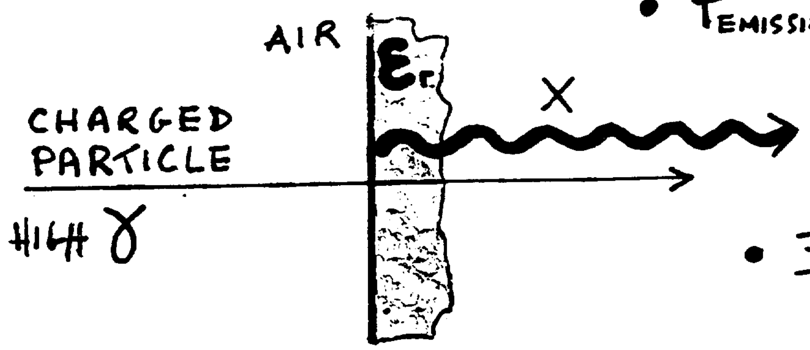
with
sheet
or foam
radiator

gas: Xe + quencher

thin
cathode

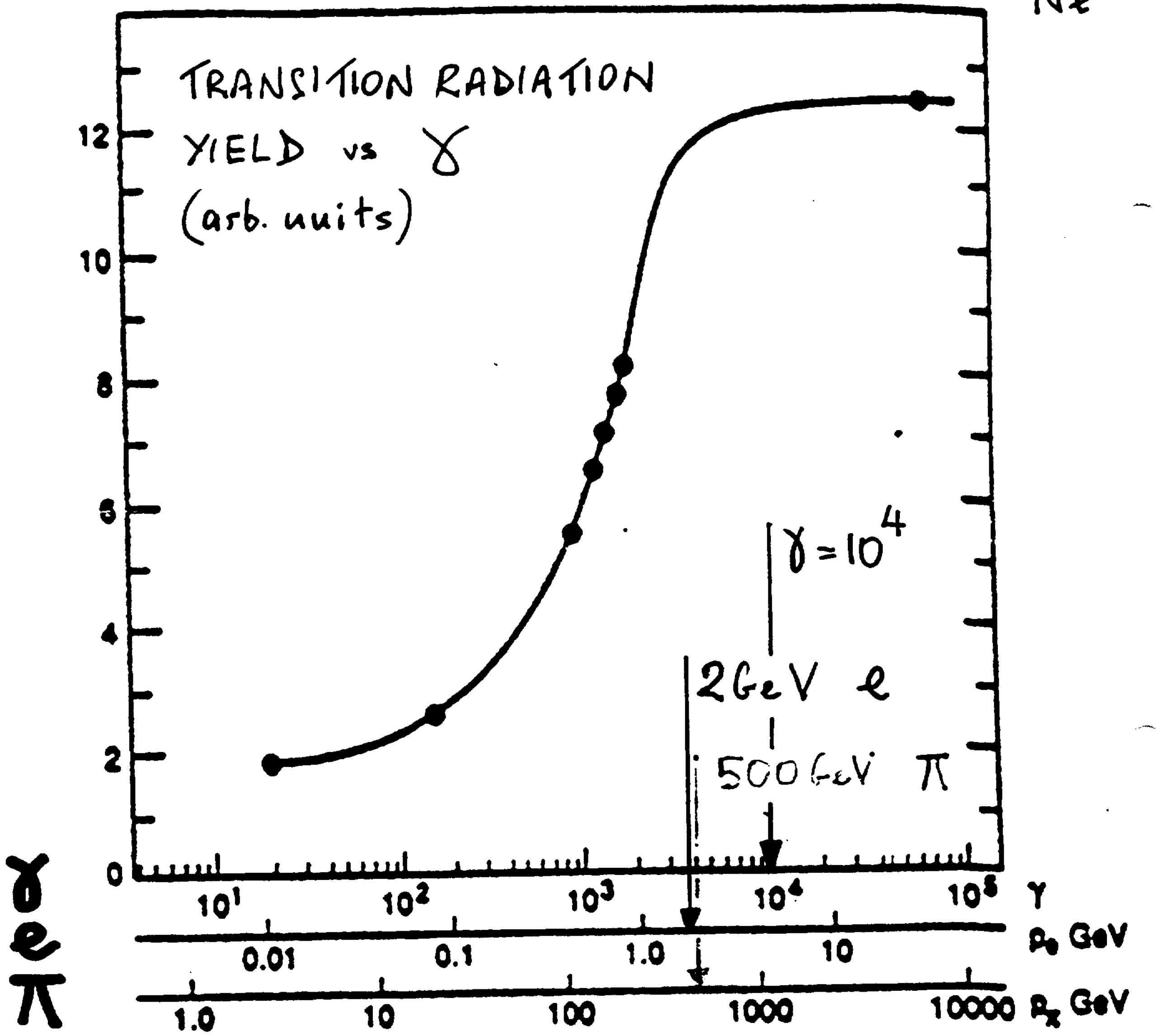
50 µm anode wire

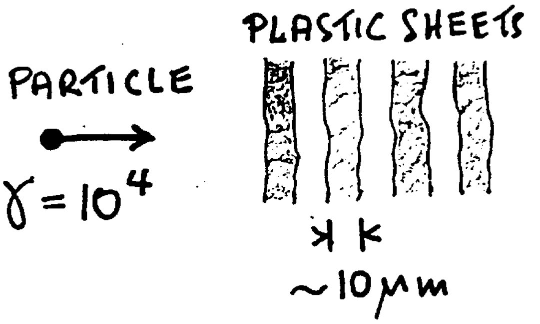
- Identification and tracking of high γ particles
  ≥ 10 GeV e, ≥ 100 µ

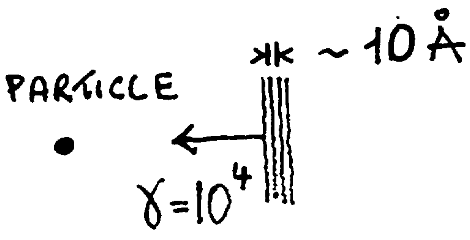


- $P_{EMISSION} = \alpha = \frac{1}{137}$

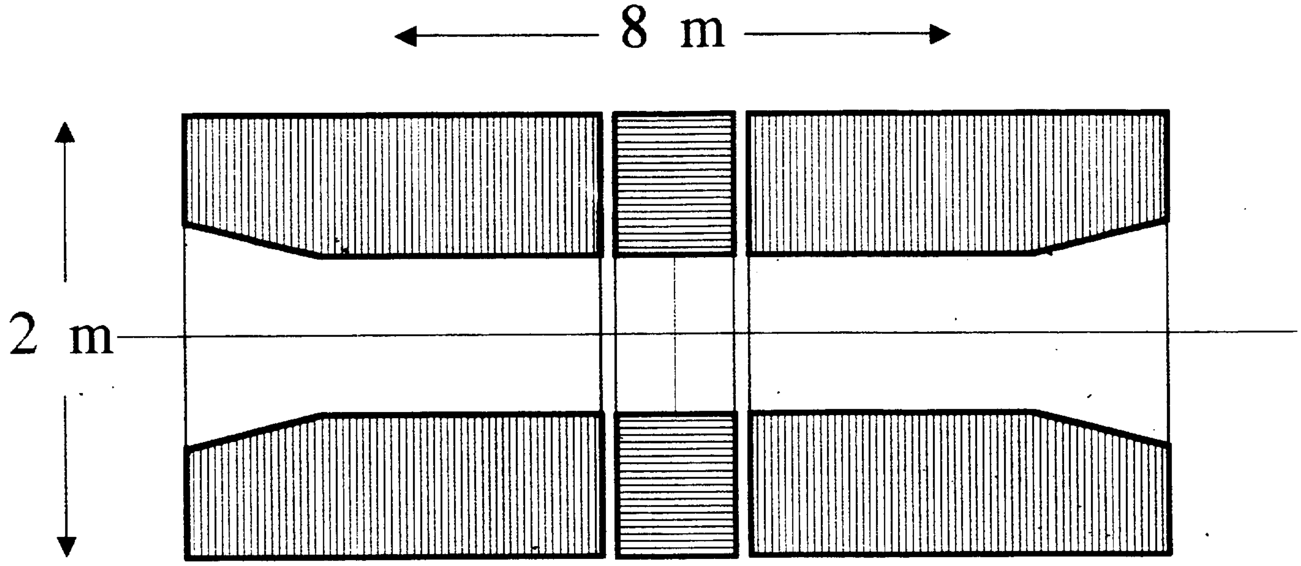
- $E_X \approx \frac{2}{3}\gamma\alpha\,\underset{\underset{N_e}{\propto}}{\omega_p}$



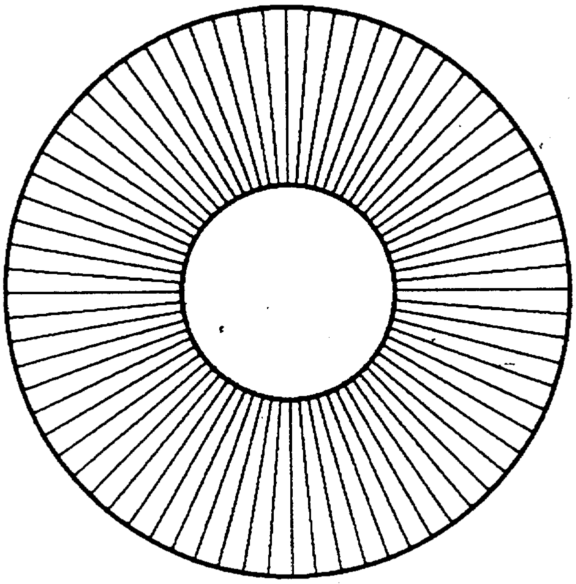




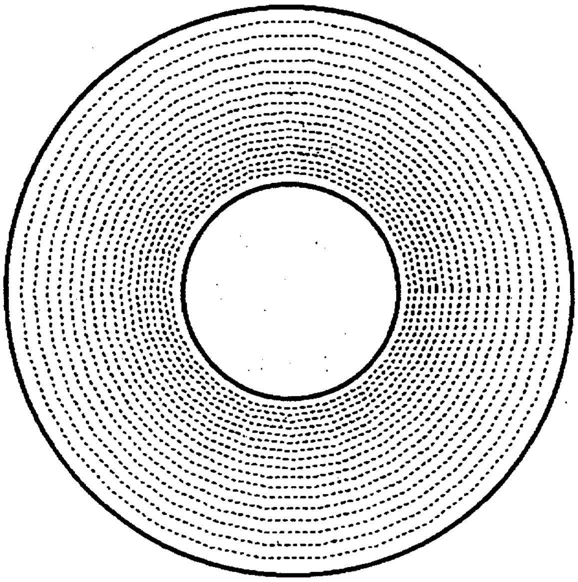
TRD tracker design



end parts



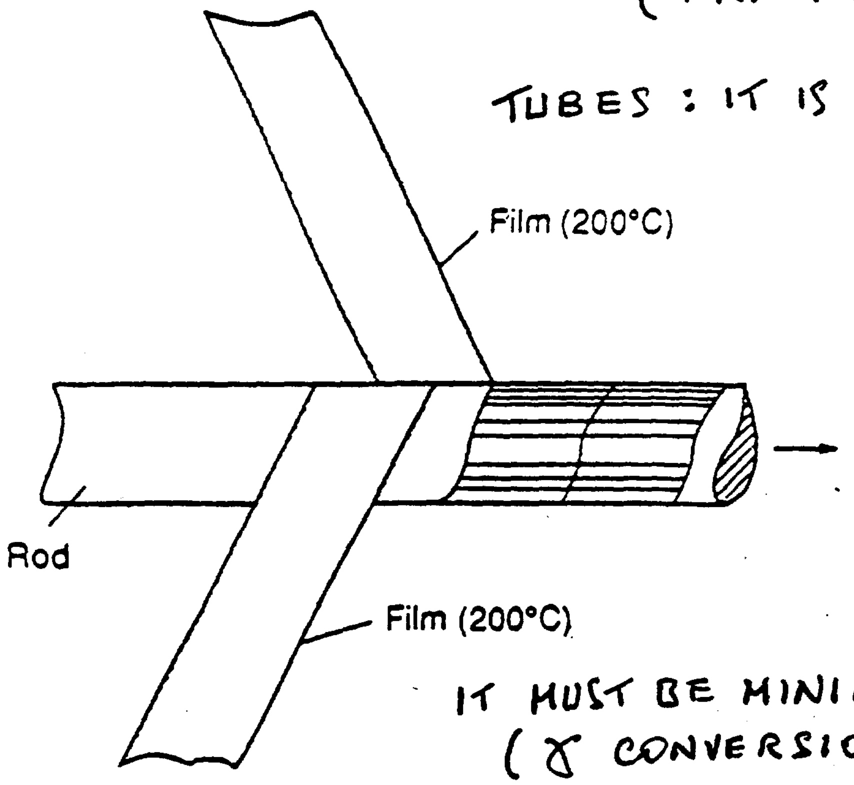
barrel



ATLAS DESIGN : FEW 10^5 STRAWS

CHAMBERS : THE SUPPORT MATERIAL IS CONCENTRATED (FRAMES)

TUBES : IT IS DISTRIBUTED



IT MUST BE MINIMIZED (γ CONVERSIONS)

Fig. 1 The straw manufacturing procedure.

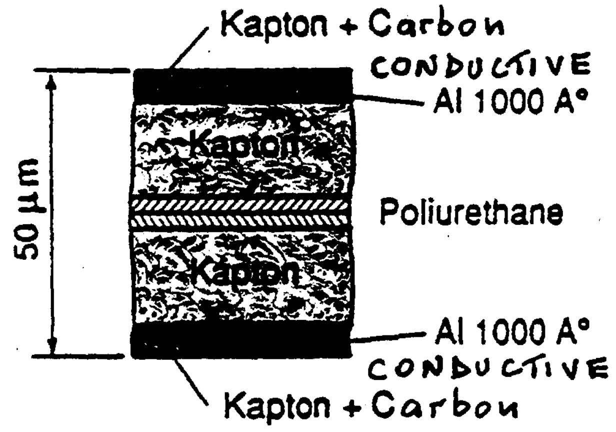
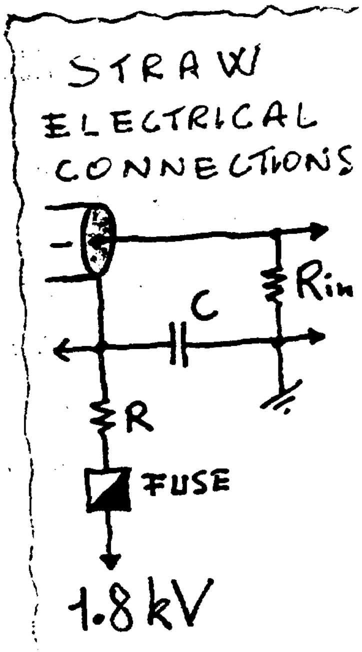


Fig. 2 Cut through the straw wall.



THE MECHANICS OF THE END PARTS

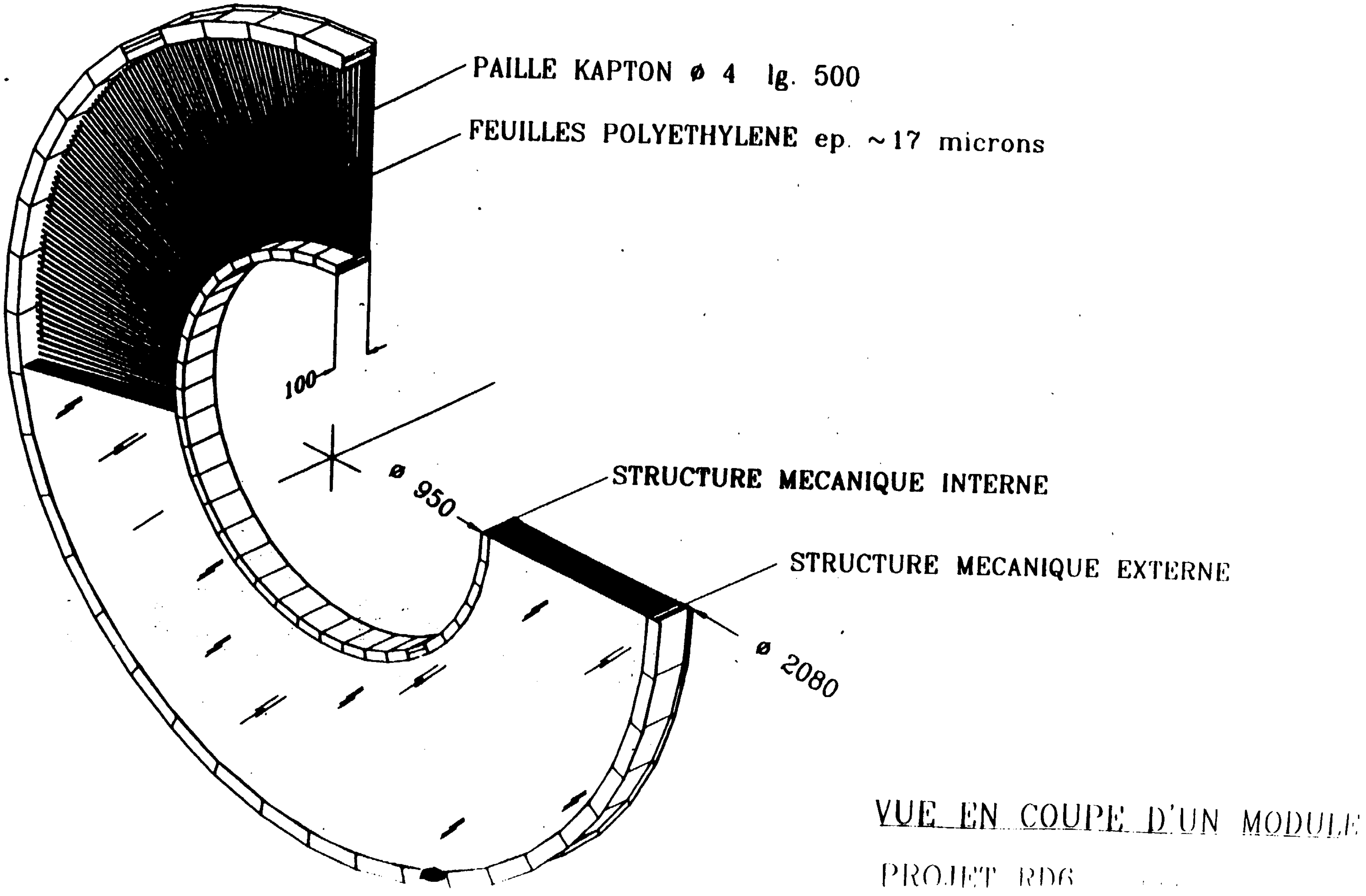
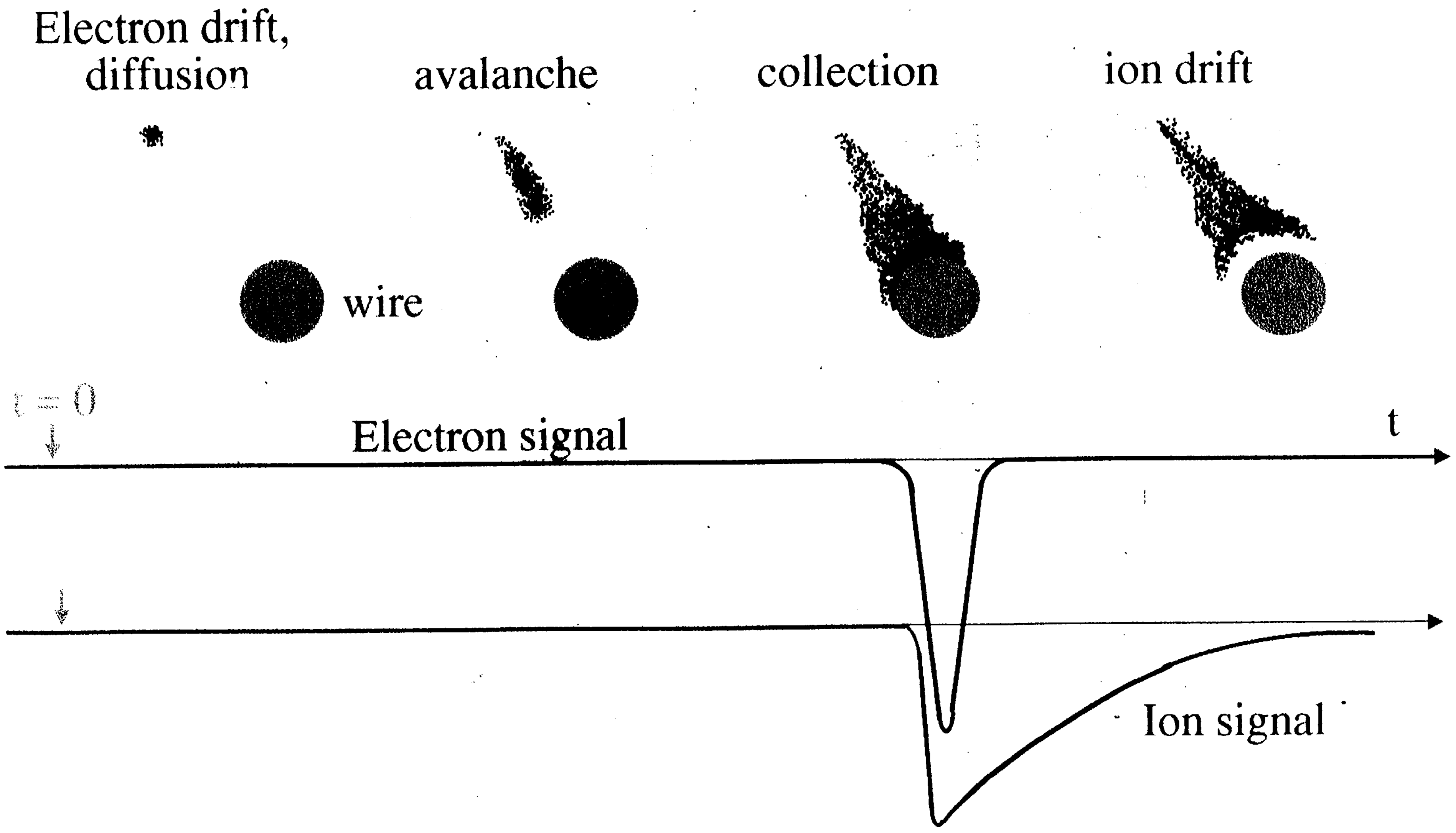


Figure 34


Electron drift,
diffusion
avalanche
collection
ion drift
wire
t = 0
Electron signal
t
Ion signal

WITH ^{55}Fe: 5,9 keV X RAYS

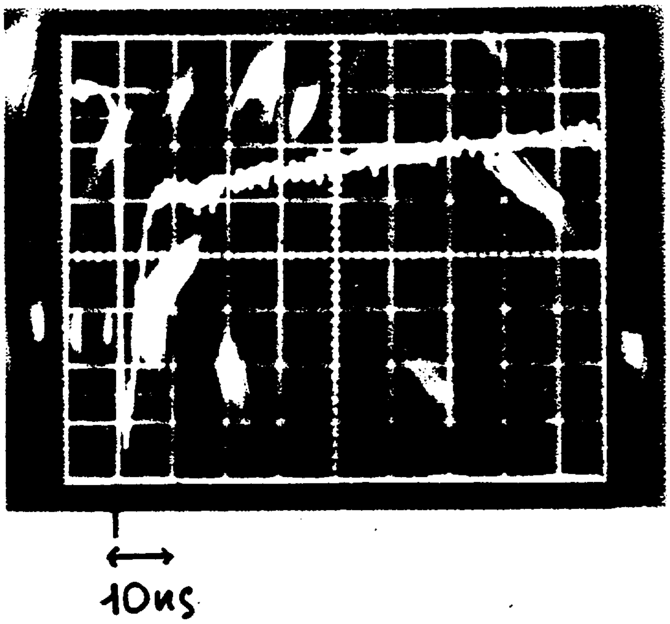
→ 200 e CLUSTER

CURRENT SIGNALS

$Xe + CF_4 + CO_2$

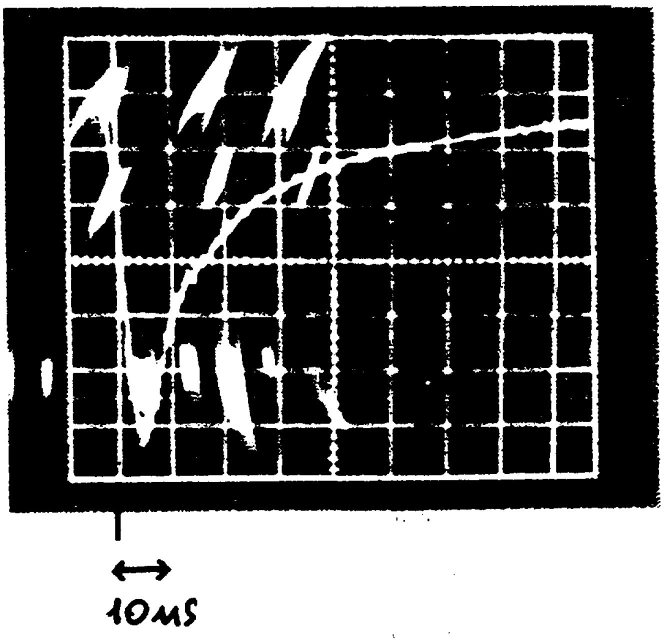
.7 .2 .1

- .7 → HIGH T.R. DETECTION EFFICIENCY
- .2 → HIGH DRIFT VELOCITY
- .1 → GAIN STABILIZER



$Ar + CH_4$

.8 .2



FROM $i(t) = q \frac{E_S}{V_0} v_D$, IN CYLINDRICAL GEO.

$$\rightarrow i_{ion}(t) = \frac{i_0}{1 + \frac{t}{t_0}}$$

$$t_0 = \frac{a^2 \ln(b/a)}{2 \mu_{ion} V_0}$$

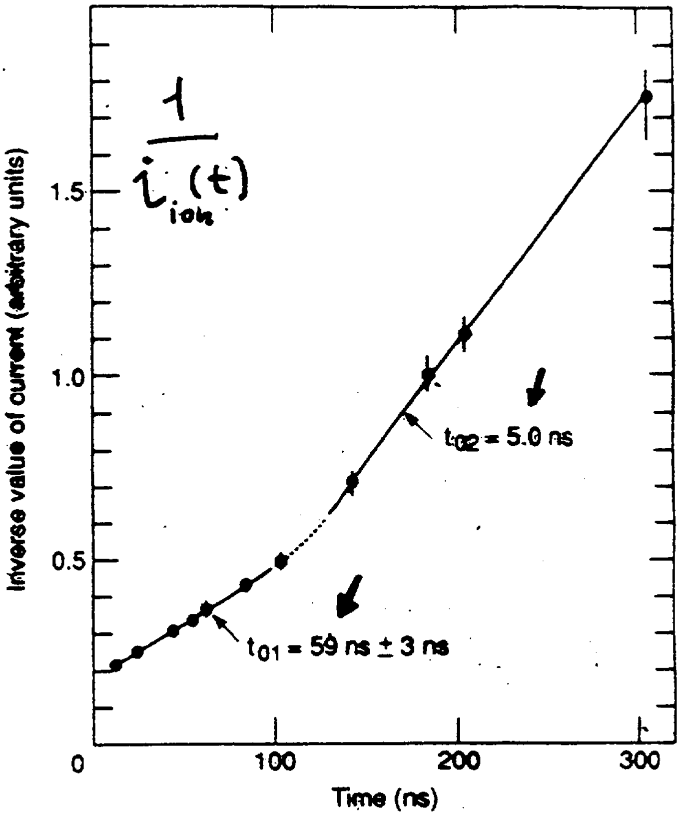
↑

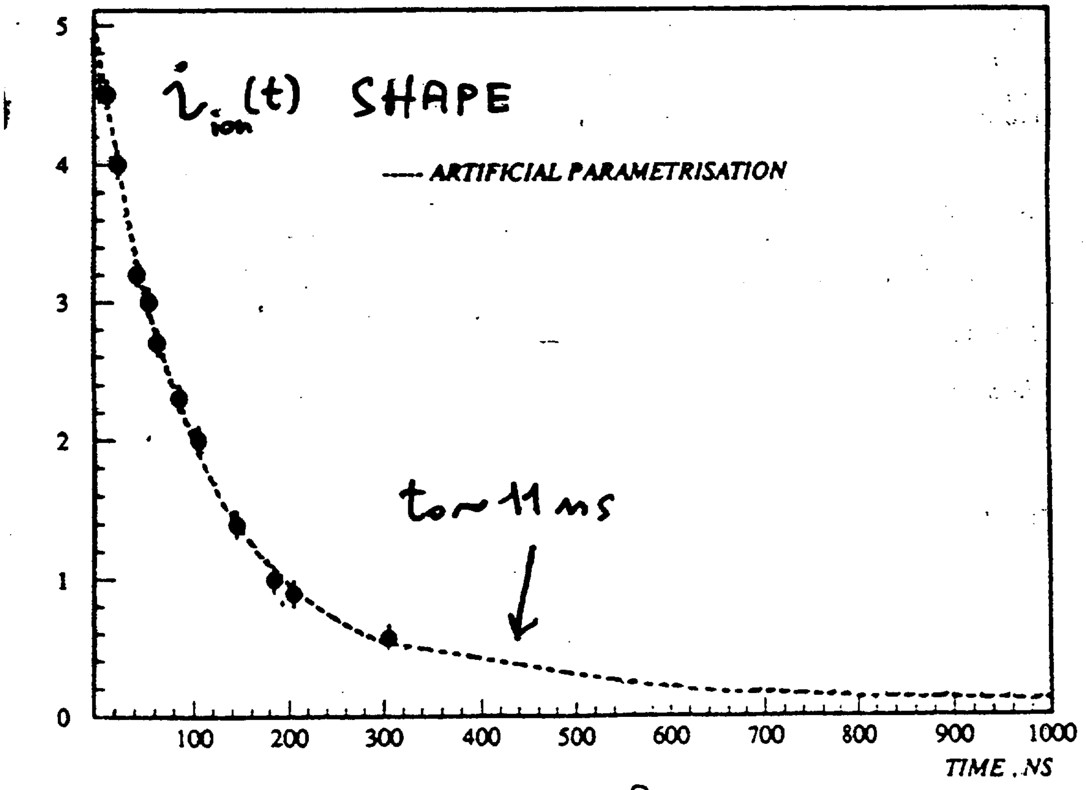
ASSUMED CONSTANT

(Radeka)

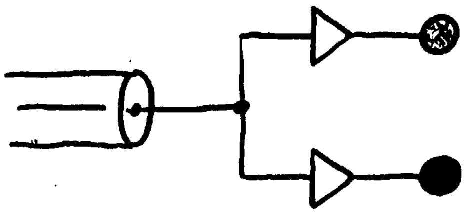
WITH KNOWN $\mu_{X_e^+}$:

$t_0 = 11.4$ ns





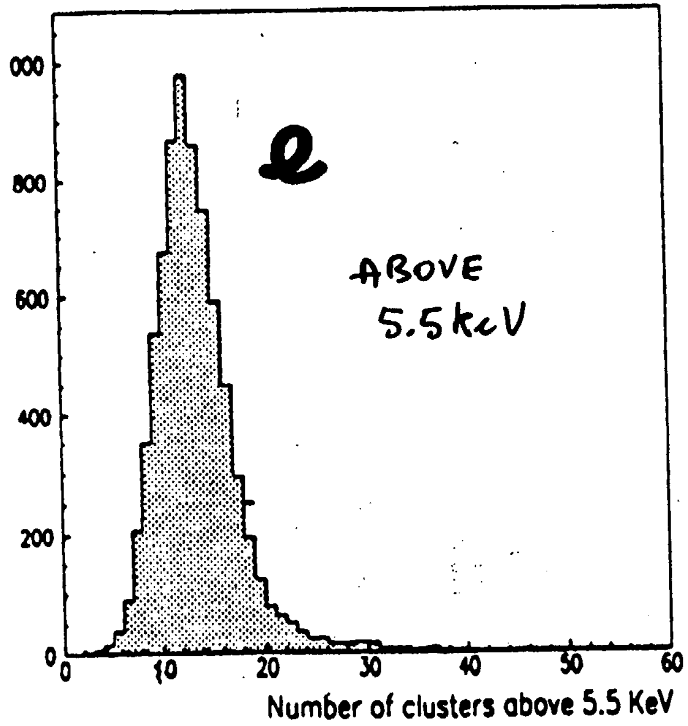
EACH TRT STRAW : 2-FOLD DIGITAL READOUT

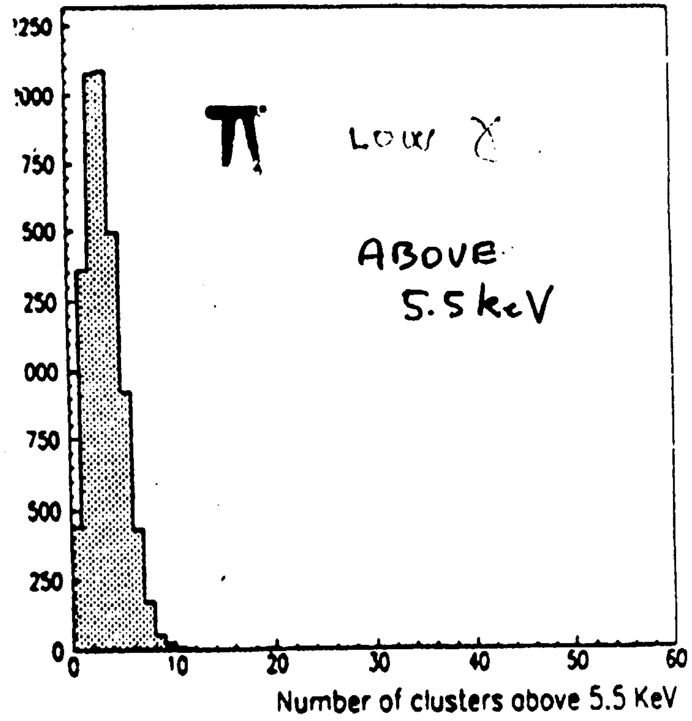


LOW THRESHOLD, 0.2 keV : ALL TRACKS

HIGH THRESHOLD, 5.5 keV :
EFFICIENT ONLY FOR TR HITS, DOUBLE TRACKS,...

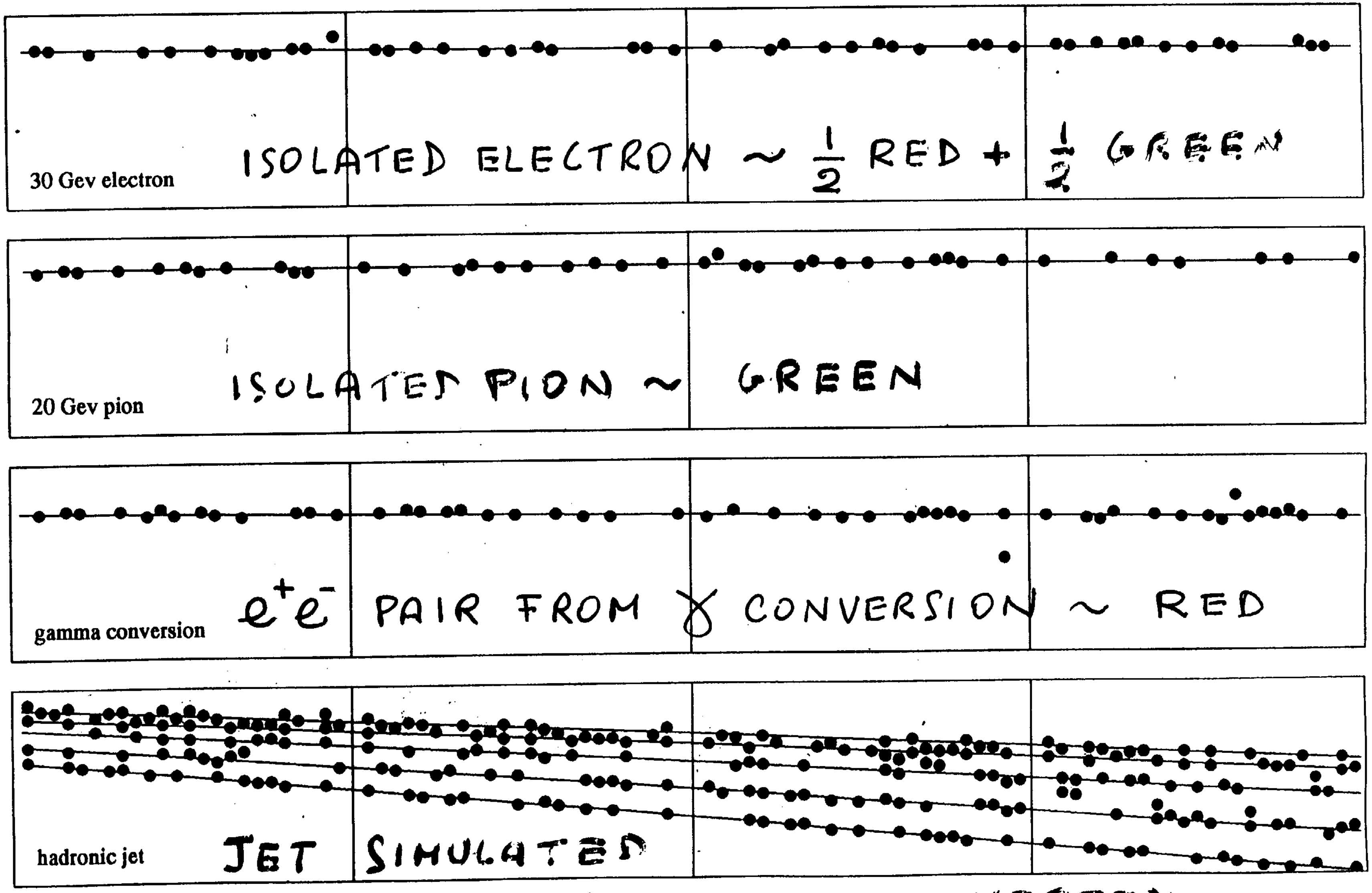
GAIN ~ 10^4





PRINCIPLE DEMONSTRATED IN 1991

TRD Event Display



ISOLATED ELECTRON ~ $\frac{1}{2}$ RED + $\frac{1}{2}$ GREEN

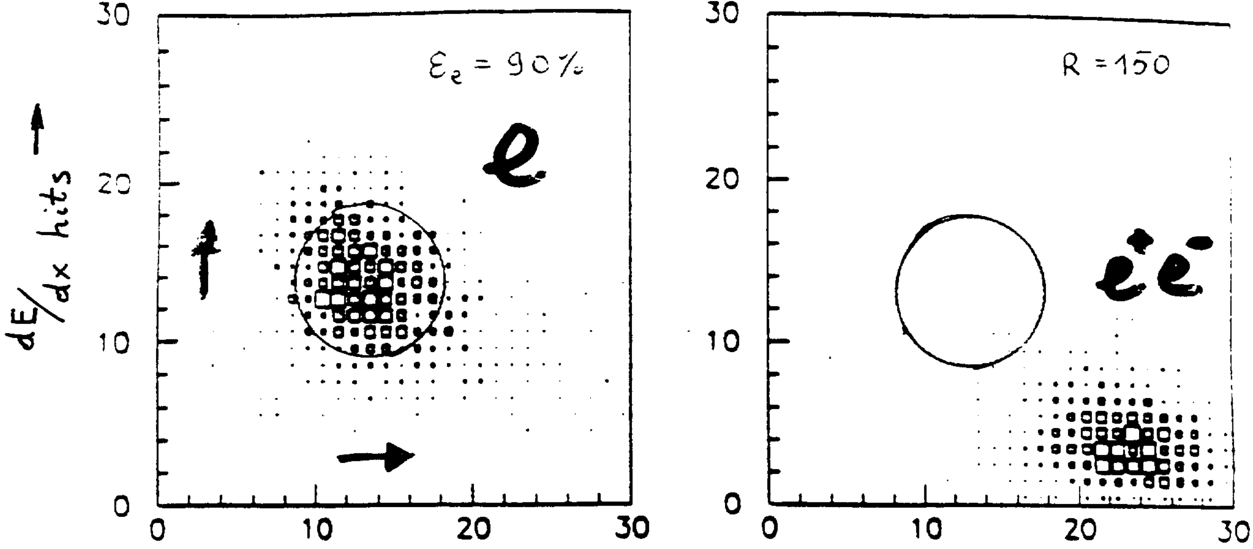
ISOLATED PION ~ GREEN

e^+e^- PAIR FROM γ CONVERSION ~ RED

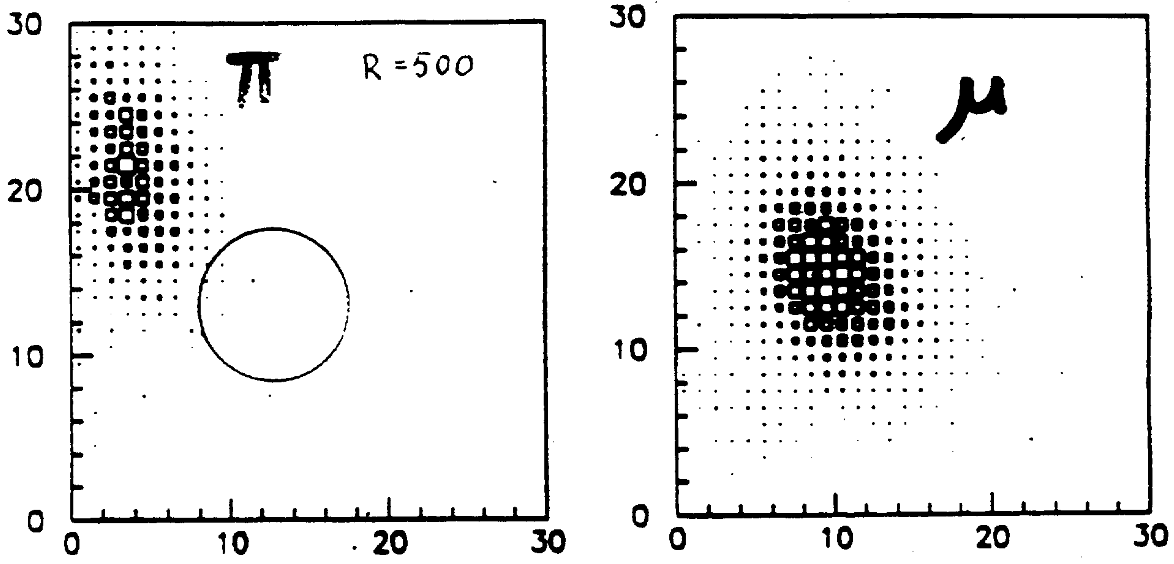
JET SIMULATED BY HADRONIC SHOWER FAR FROM VERTEX:

THE MAIN SOURCE OF FAKE ELECTRONS

TRD-91 data



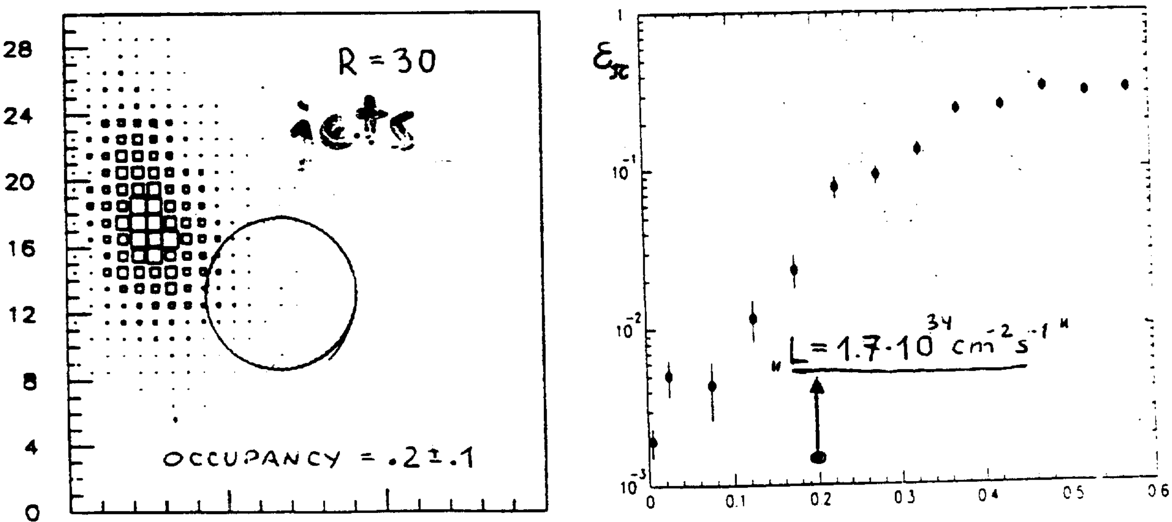
Electrons, 30 Gev **External conversions**



Pions, 20 Gev **Muons, 200 Gev**

Pions 20 GeV

Straw TRD 1991 run

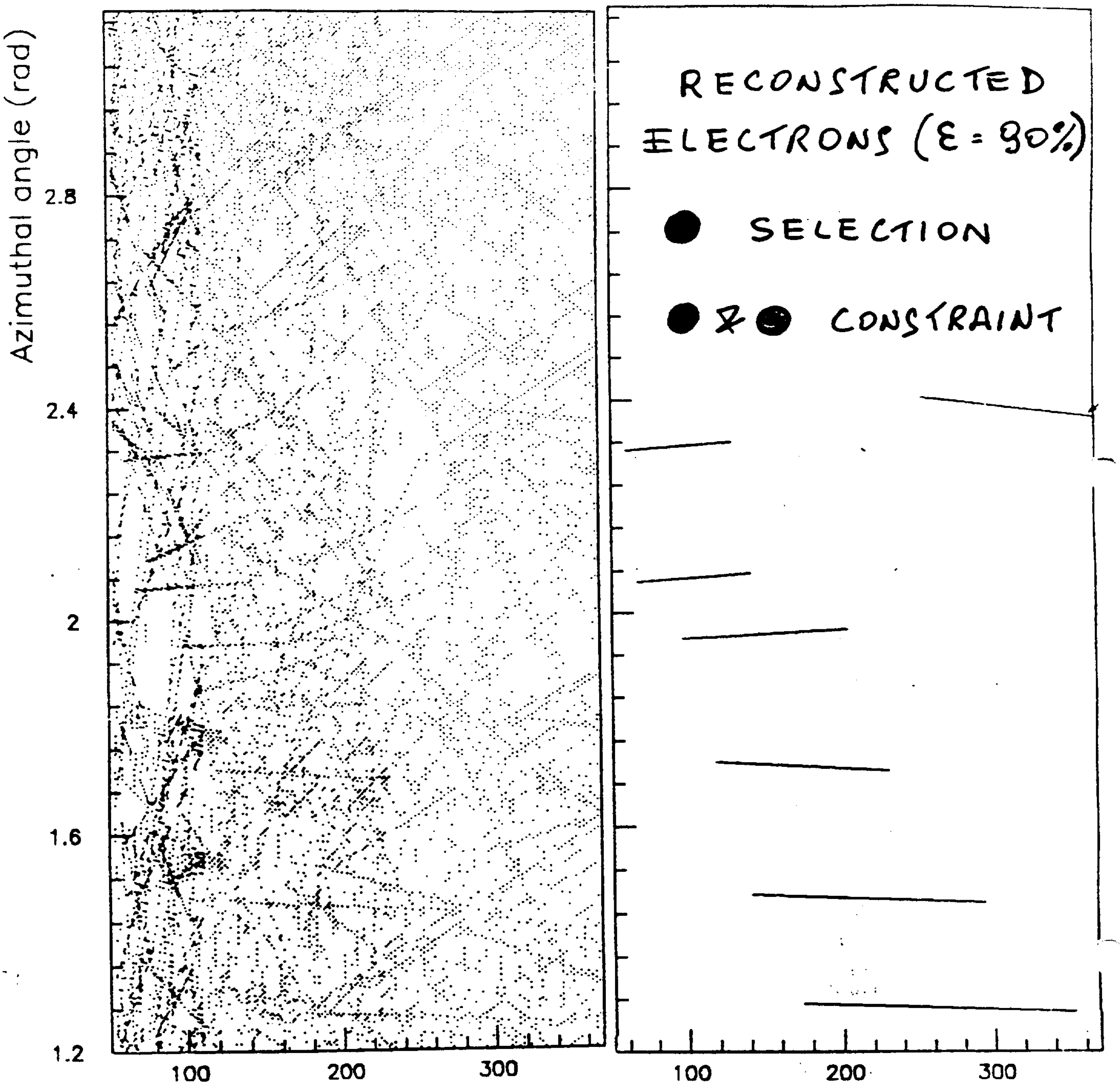


Pion rejection vs occupancy

TARGET RUN

SIMULATION AT $\mathcal{L}_{MAX}$ WITH
TEST BEAM PERFORMANCE

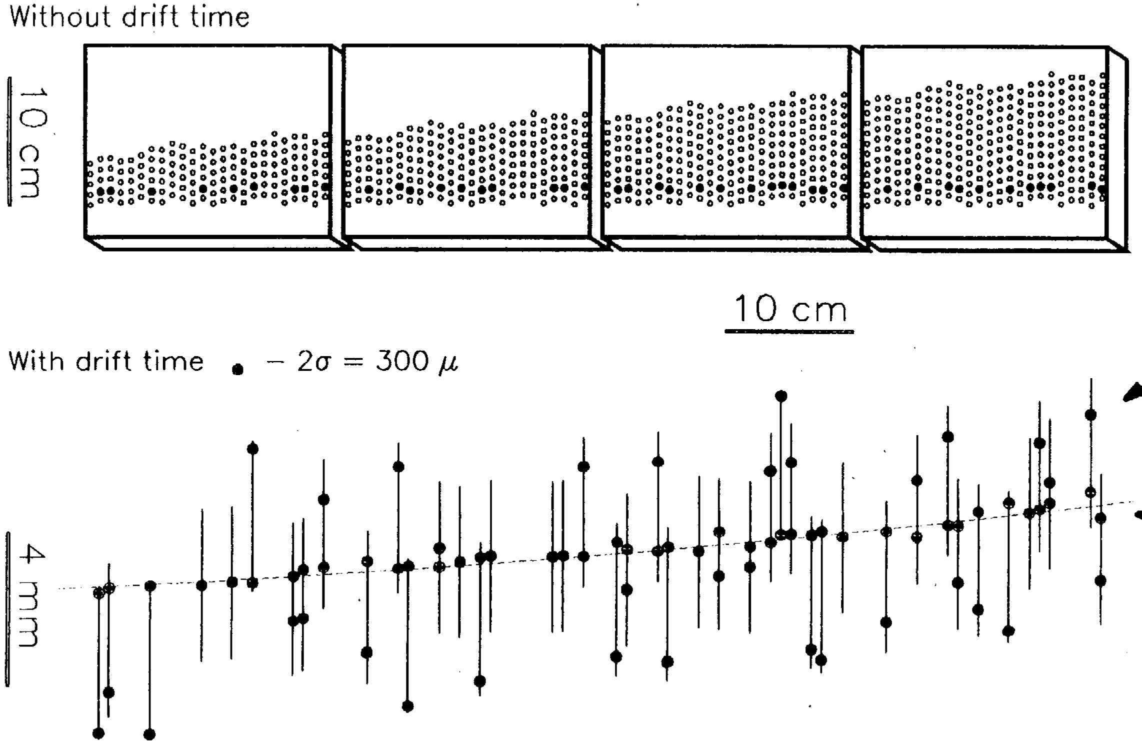
⊚ ALL TRACKS



TRD–tracker (end cap)

TRD–event display

π^-(20 GeV/c)+ B=0.232 T



Test beam → $\Delta p/p = 4.2\times10^{-3} P_T$ for BL = 0.3 T.m

● TRD at LHC → $\Delta p/p = 8\times10^{-4} P_T$ for BL = 2 T.m

RD6 WITH 2-THRESHOLD
DIGITAL READOUT:

- ● ALL TRACKS: 20% OCCUPANCY
- ● T.R. HITS : 1% OCCUPANCY

→ GOOD PARTICLE IDENTIFIER
BUT MODERATE TRACKER

● $\sigma_x \sim 0.6$ mm

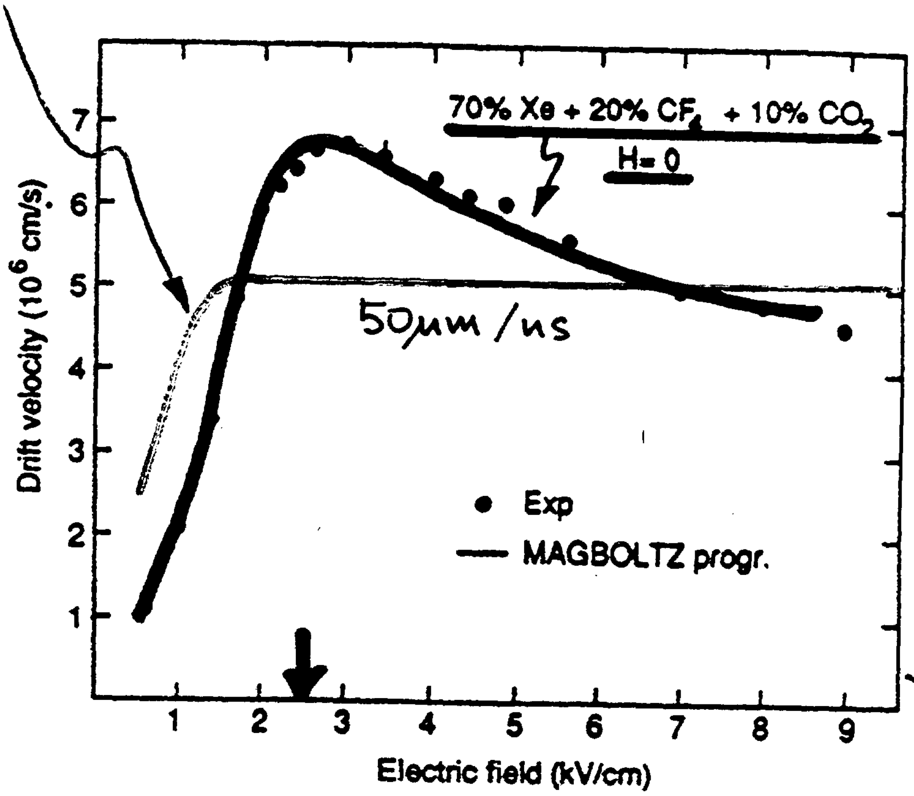
WITH DRIFT TIME READOUT

● $\sigma_x = 150\ \mu$m

→ IMPROVED GRANULARITY

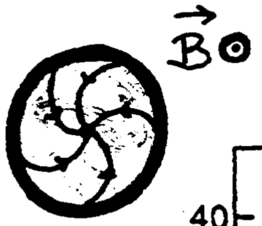
→ HIGH ACCURACY
CONTINUOUS
TRACKER

TYPICAL SATURATED DRIFT VELOCITY CURVE
(Ar + Ethane: 50+50, etc.)

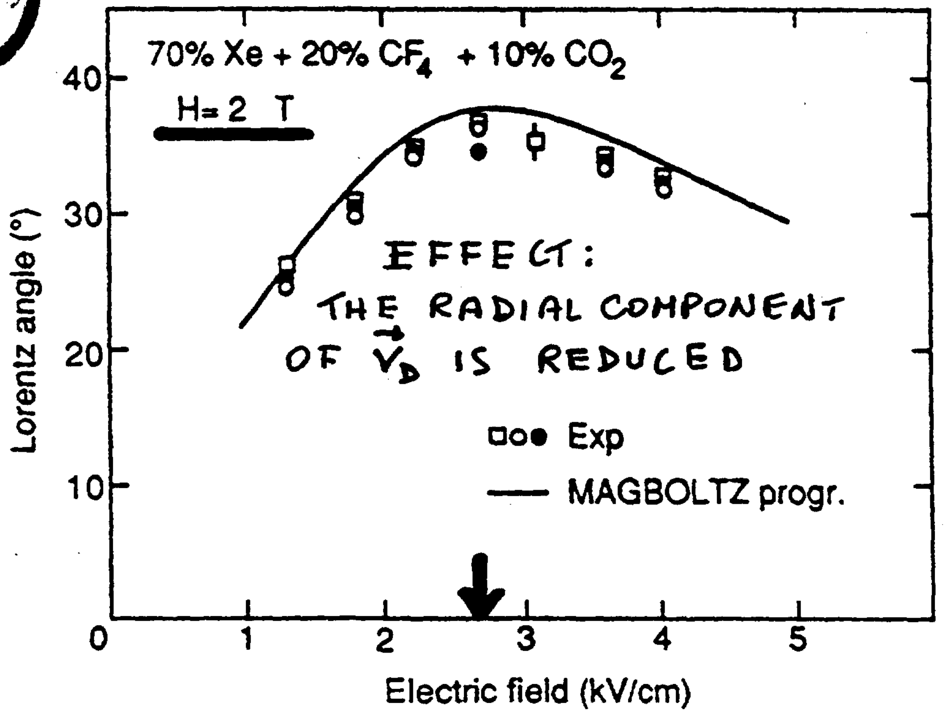


DRIFT VELOCITY vs $\vec{E}$

NO $\vec{B}$ FIELD

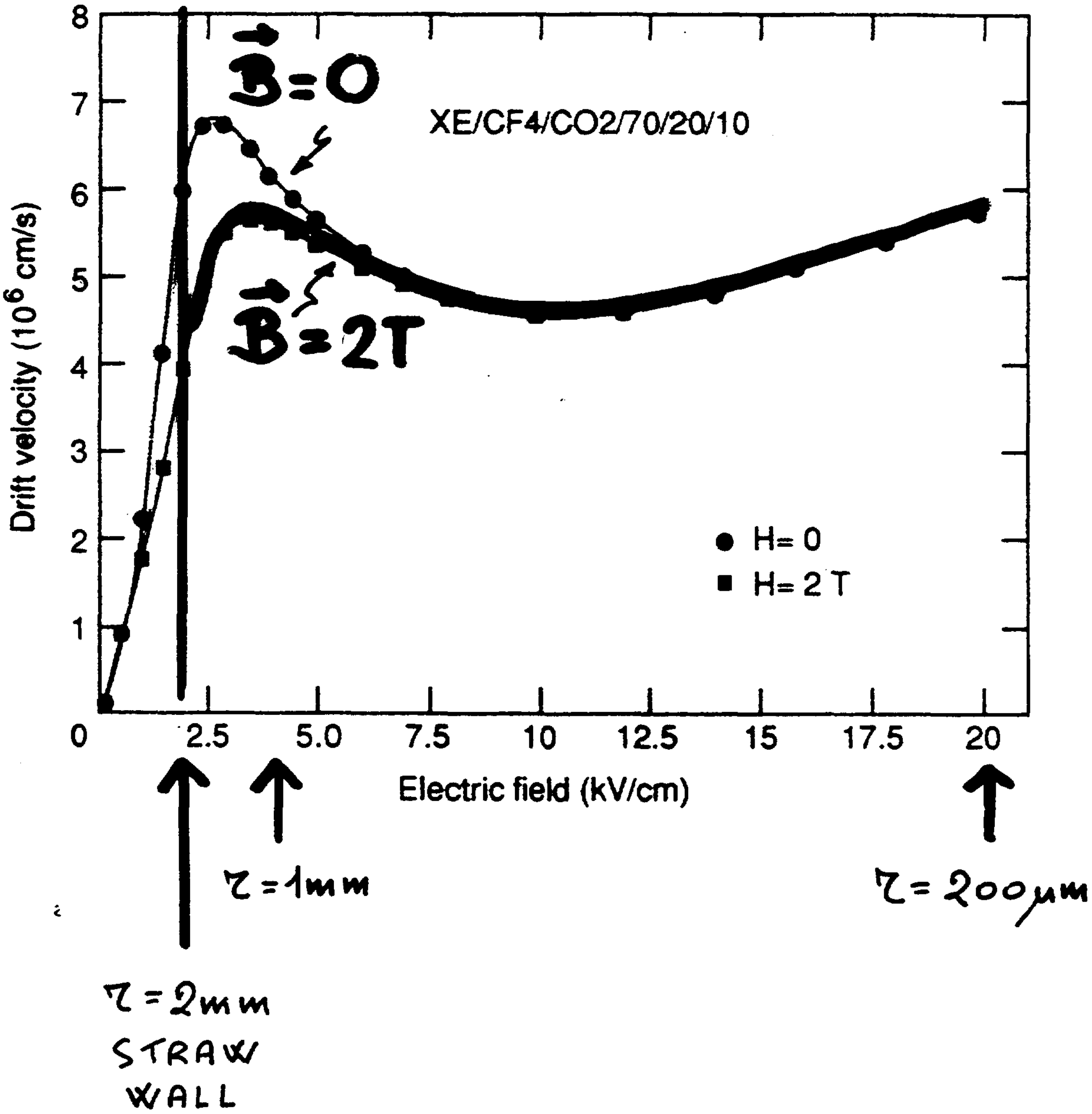


LORENTZ ANGLE vs $\vec{E}$

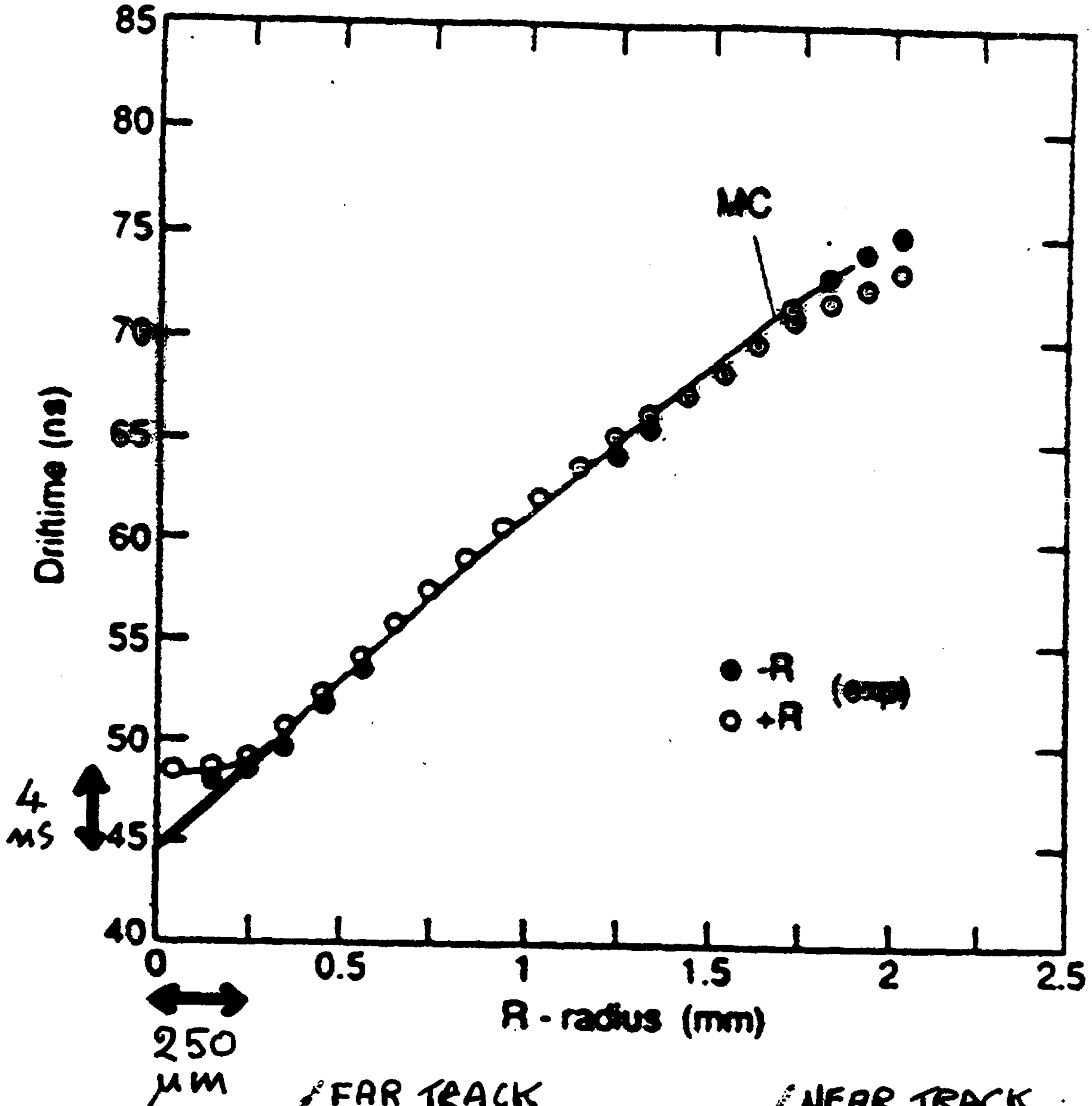


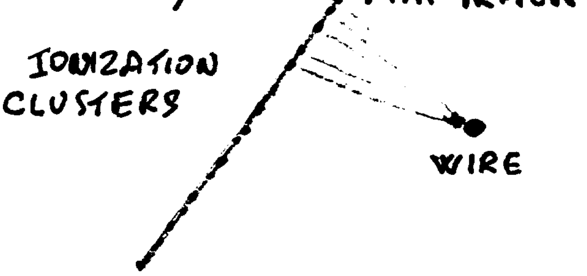
EFFECT:
THE RADIAL COMPONENT OF $\vec{V}_D$ IS REDUCED

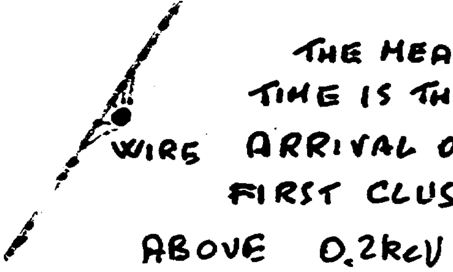
ELECTRON DRIFT VELOCITY IN THE STRAW TUBE
VS ELECTRIC FIELD AND DISTANCE FROM AXIS
WITH Xe + CF4 + CO2 (70 + 20 + 10)
WITH AND WITHOUT 2T MAGNETIC FIELD



DRIFT TIME TO DISTANCE RELATION

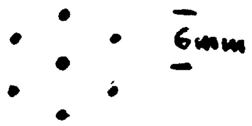




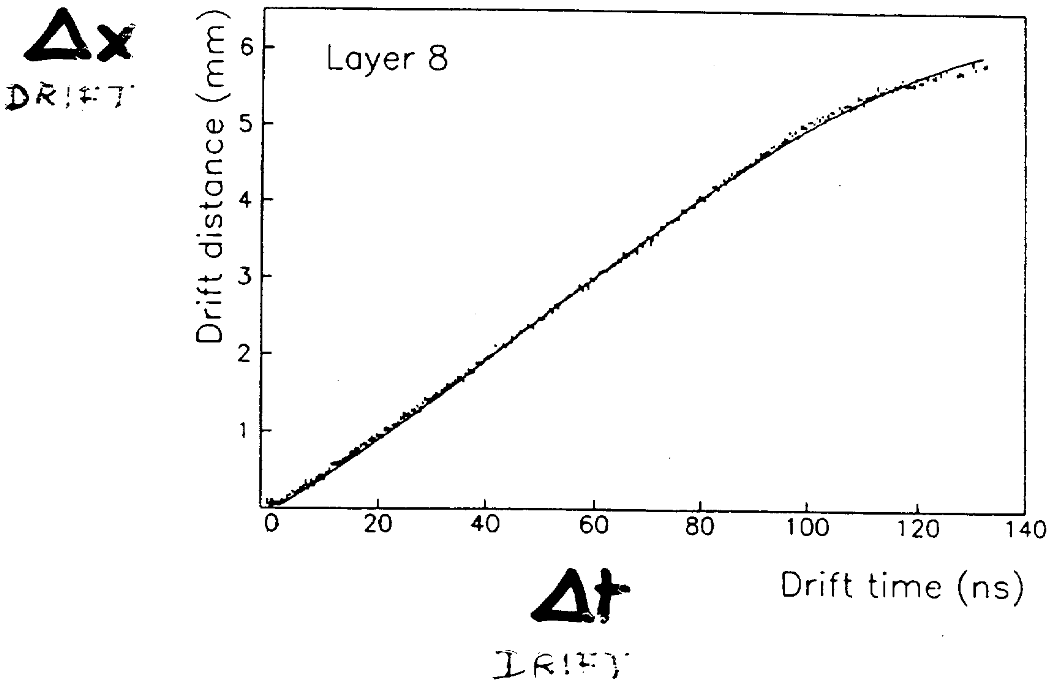


THE MEASURED TIME IS THAT OF ARRIVAL OF THE FIRST CLUSTER ABOVE 0.2keV THRESH.

FOR COMPARISON : ALEPH ITC



DRIFT DISTANCE vs TIME RELATION



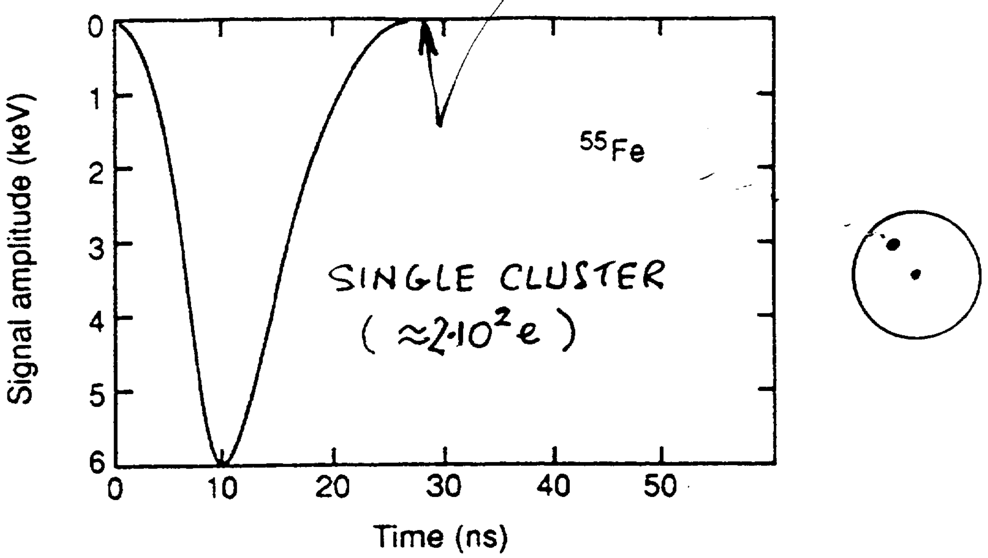
$$v_{DRIFT} \simeq \frac{1\,mm}{20\,ns}$$

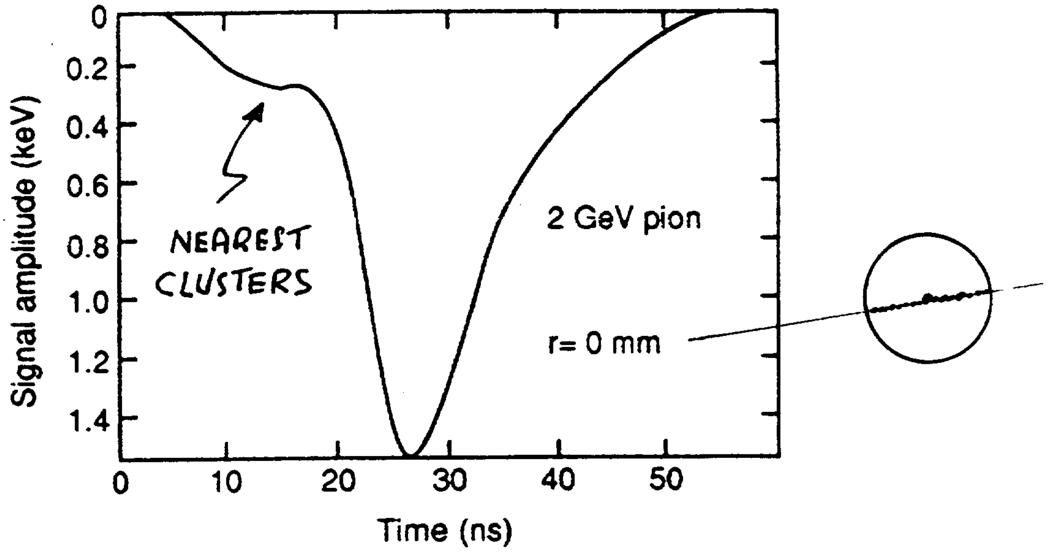
$$\langle \sigma_x \rangle \sim 100\mu m$$

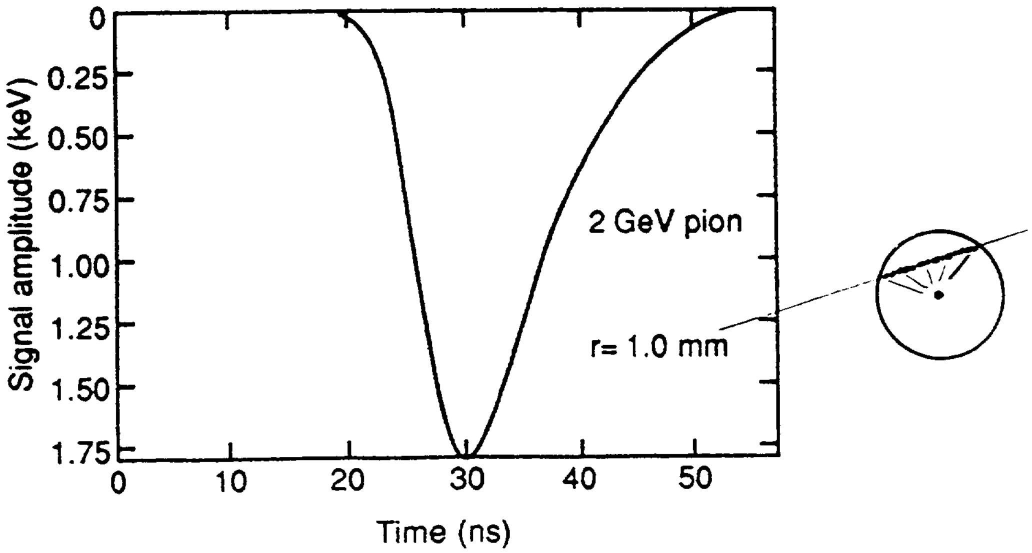
TRT STRAWS:

PREDICTED STRAW SIGNAL SHAPES AFTER PREAMPLIFIER AND SHAPER (TAIL SUPPRESSION)

10 ns
SHAPING
TIME
↓
25ns
AT THE
BASE





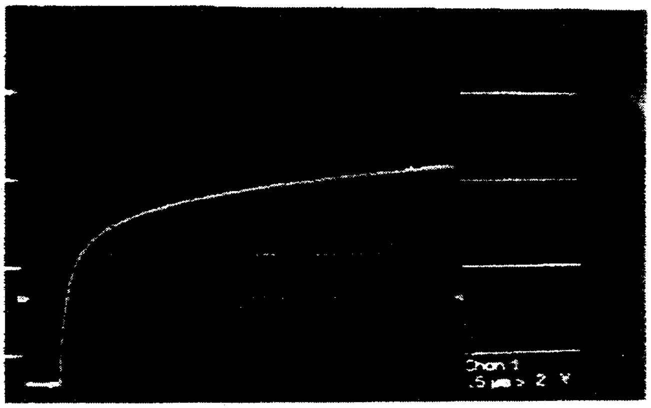


CHARGE
COLLECTION
TIME
≳ 25ns
LHC
BUNCH
CROSSING
PERIOD

STRAW
TUBE
CHARGE
SIGNAL

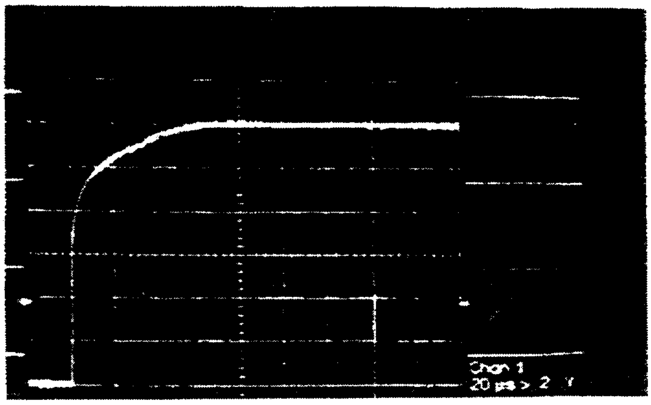
$$Q(t) = \int_0^t i(t')\,dt'$$

← 1µs →



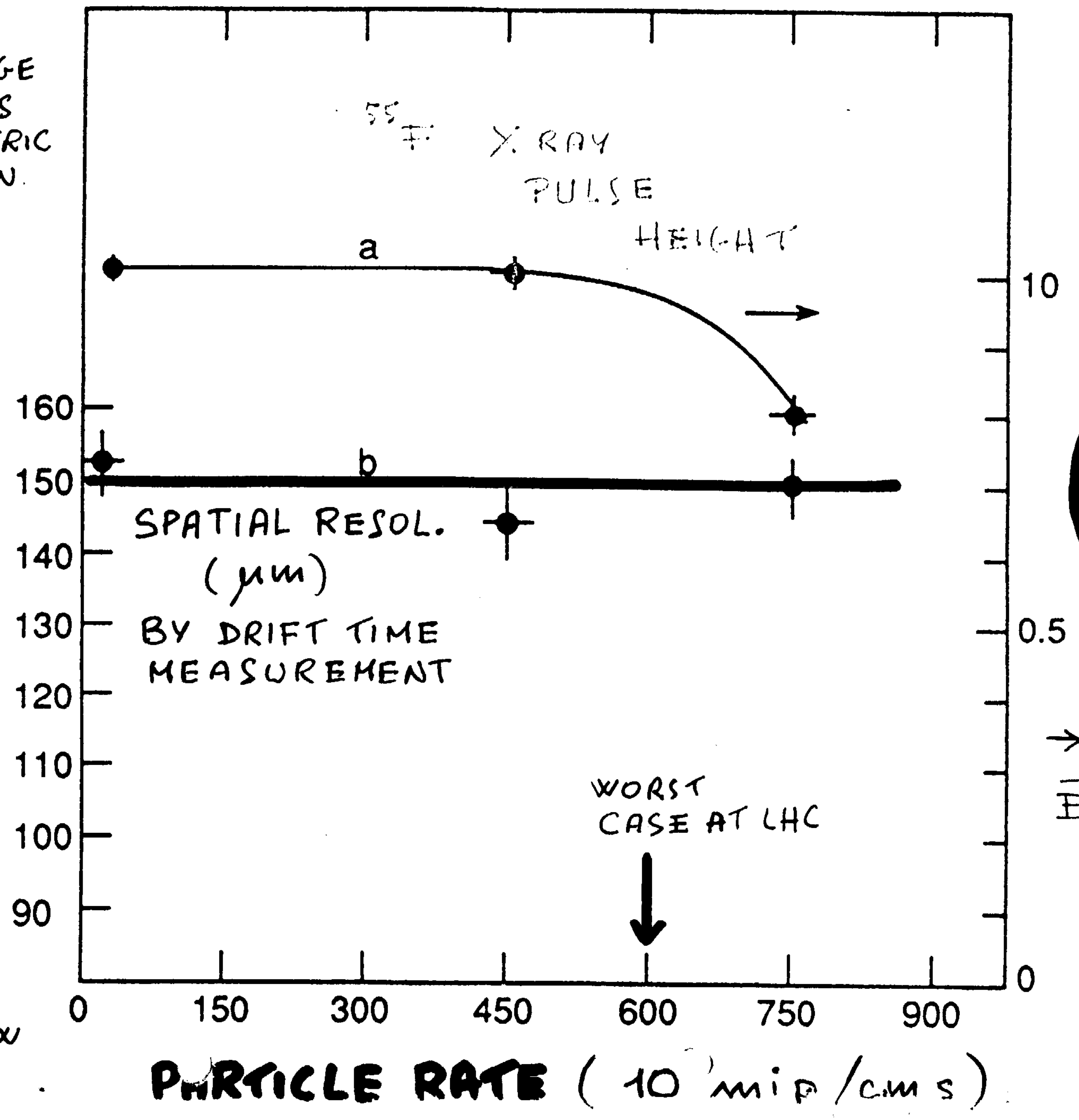
← 5 µs →

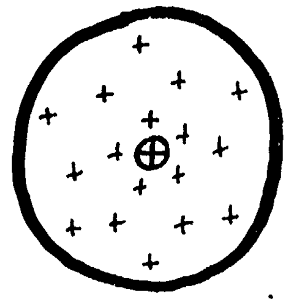
TOTAL CHARGE
COLLECTION TIME
WITH Xe : 60µs
(WITH Ar : 28µs)



← 200 µs →

AT HIGH RATE
THE SPACE CHARGE
OF DRIFTING IONS
AFFECTS THE ELECTRIC
FIELD DISTRIBUTION.





V_0 = const

→ $\langle E(r) \rangle$ = const

$\vec{E}$ WEAKER NEAR THE WIRE

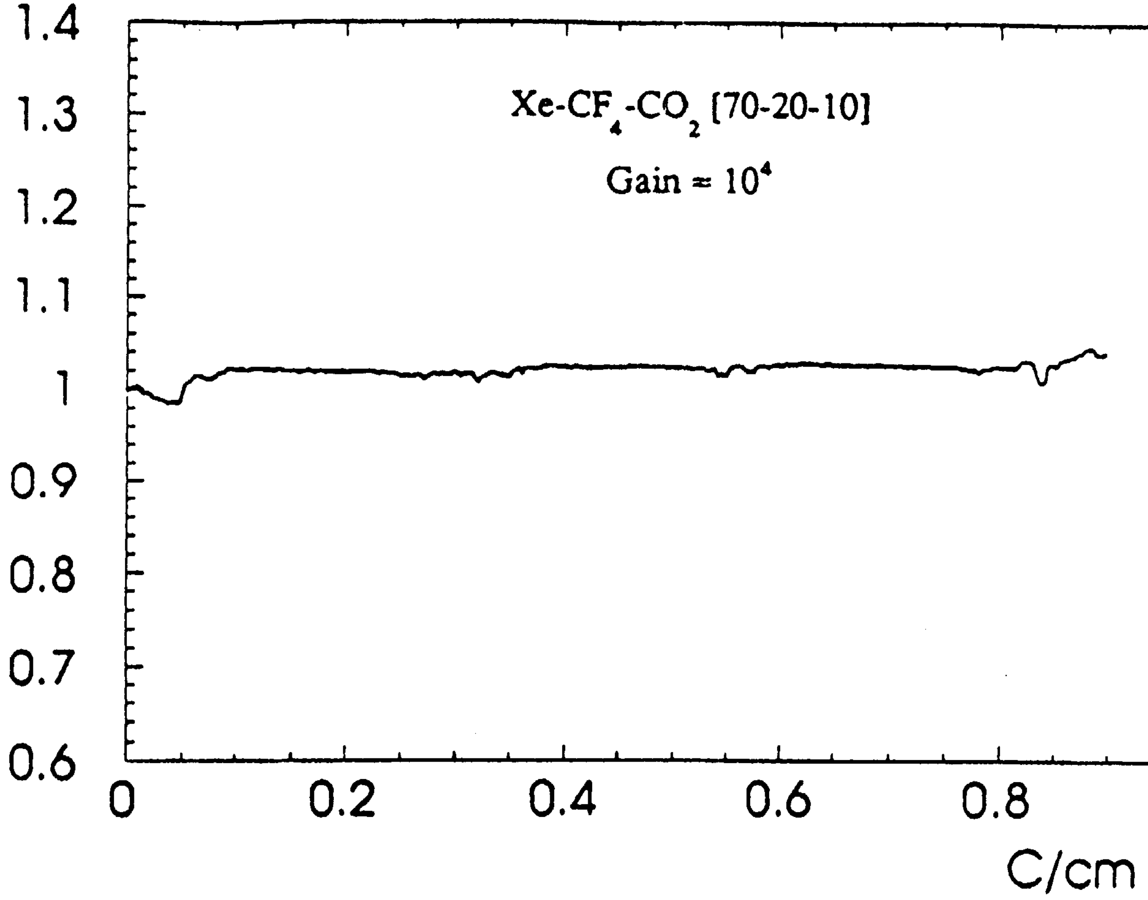
$\langle I \rangle_{MAX} = 7 \mu A$

$V_0 I = 13 mW$

COOLING BY
GAS FLOW:
260 cm^3/min. × straw

GAS AGEING : NO EFFECT OBSERVED FOR A TOTAL INTEGRATED CHARGE UP TO

5C/cm ~ 8 years AT LHC



- IT IS A TRICKY ISSUE (ppm POLLUTANTS)
- RD 10 : PROJECT TO STUDY AND IMPROVE RAD. HARDNESS OF GASEOUS DET.

↓

- AVAILABLE TEST FACILITY

THE RD6-Transition Radiation Tracker

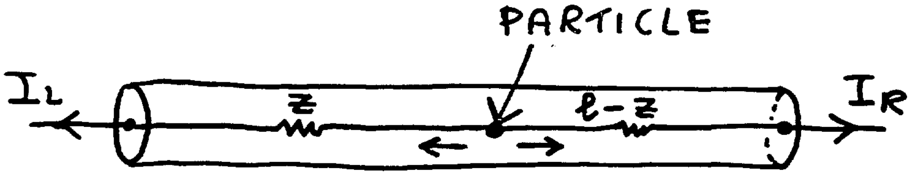
BEYOND BEING A PARTICLE IDENTIFIER IS
A HIGH PRECISION CONTINUOUS TRACKER

HOWEVER IT IS NOT 3-DIMENSIONAL

(THAT IS LEFT TO INNER AND OUTER SYSTEMS)

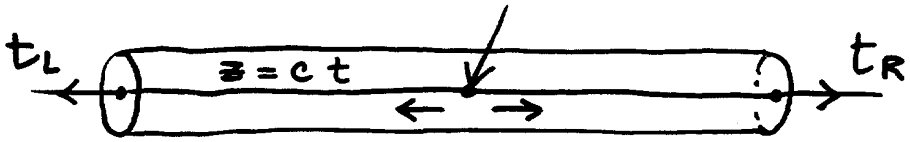
HOW COULD ONE MEASURE PARTICLE POSITION ALONG THE WIRE OF A STRAW TUBE?

① CURRENT DIVISION (LEFT-RIGHT)



$\rightarrow \sigma_z \sim 10^{-2}\ell$ (LIMITED BY NOISE)

② TIME DIFFERENCE, LEFT-RIGHT (ALEPH ITC)



$\rightarrow \sigma_z \sim 3$ cm ($\leftarrow$ 0.1 ms)

- BOTH METHODS ARE UNAMBIGUOUS BUT EXPENSIVE

MUON DETECTION AT LHC (pp)

- A SUBSTANTIAL FRACTION OF THE PYSICS POTENTIAL IS BASED ON HIGH PRECISION MUON DETECTION (MOMENTUM MEASUREMENT)

- DUE TO MAGNETIC FIELD AND CALORIMETER FILTERING RATES ARE NOT AS CHALLENGING AS INSIDE:

  $\lesssim 1 \mathrm{kHz}/\mathrm{cm}^2$ IN THE BARREL

→ CONVENTIONAL GAS DETECTORS CAN BE USED: DRIFT TUBES OR CHAMBERS WITH $\sigma_x \approx 100 \mu m$

- THE PROMPT IDENTIFICATION OF BUNCH CROSSING IS DESIRABLE, i.e. $\sigma_t \ll 25 ns$

  OBVIOUS SOLUTION: USE DEDICATED DETECTORS

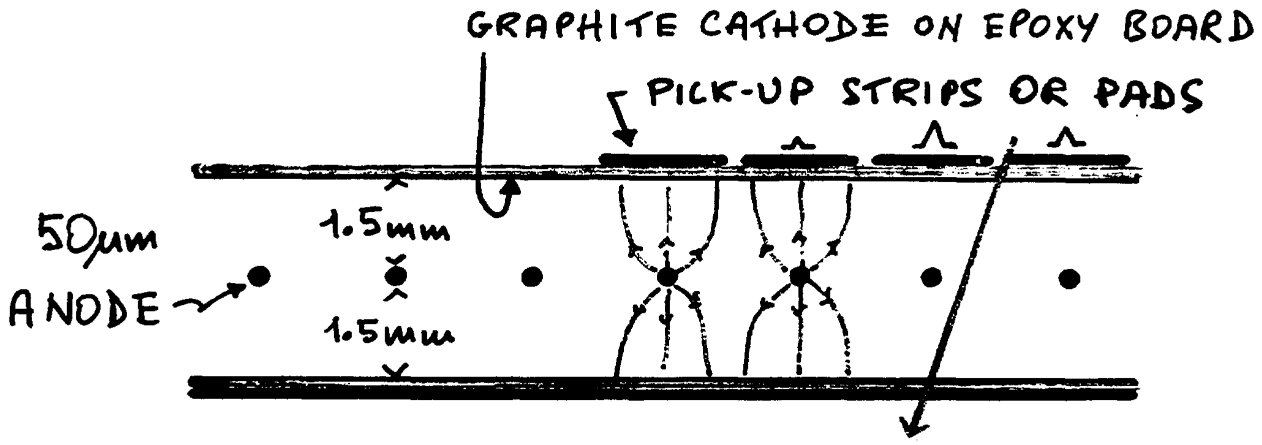
  ALREADY DISCUSSED:

  PPC : $\sigma_t = 0.25 ns$
  RPC : $\sigma_t \sim 1 ns$
  } FAST AVALANCHE OR STREAMER IN UNIFORM $\vec{E}$

  ANOTHER POSSIBILITY:
  THE THIN GAP WIRE CHAMBER

THE THIN GAP WIRE CHAMBER

(~400 m^2 IN OPAL HAD. CAL., ATLAS R&D)



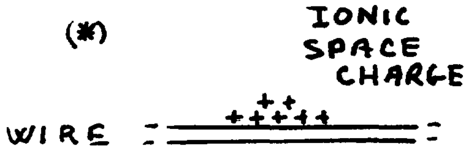
- OPERATED IN SATURATED MODE(*): GAIN > 10^5
  - → SMALL LANDAU TAILS
  - → LOW SENSITIVITY TO MECH. DEFORMATION
- FULLY EFFICIENT

* RATE CAPABILITY ~ 0.3 MHz/cm^2

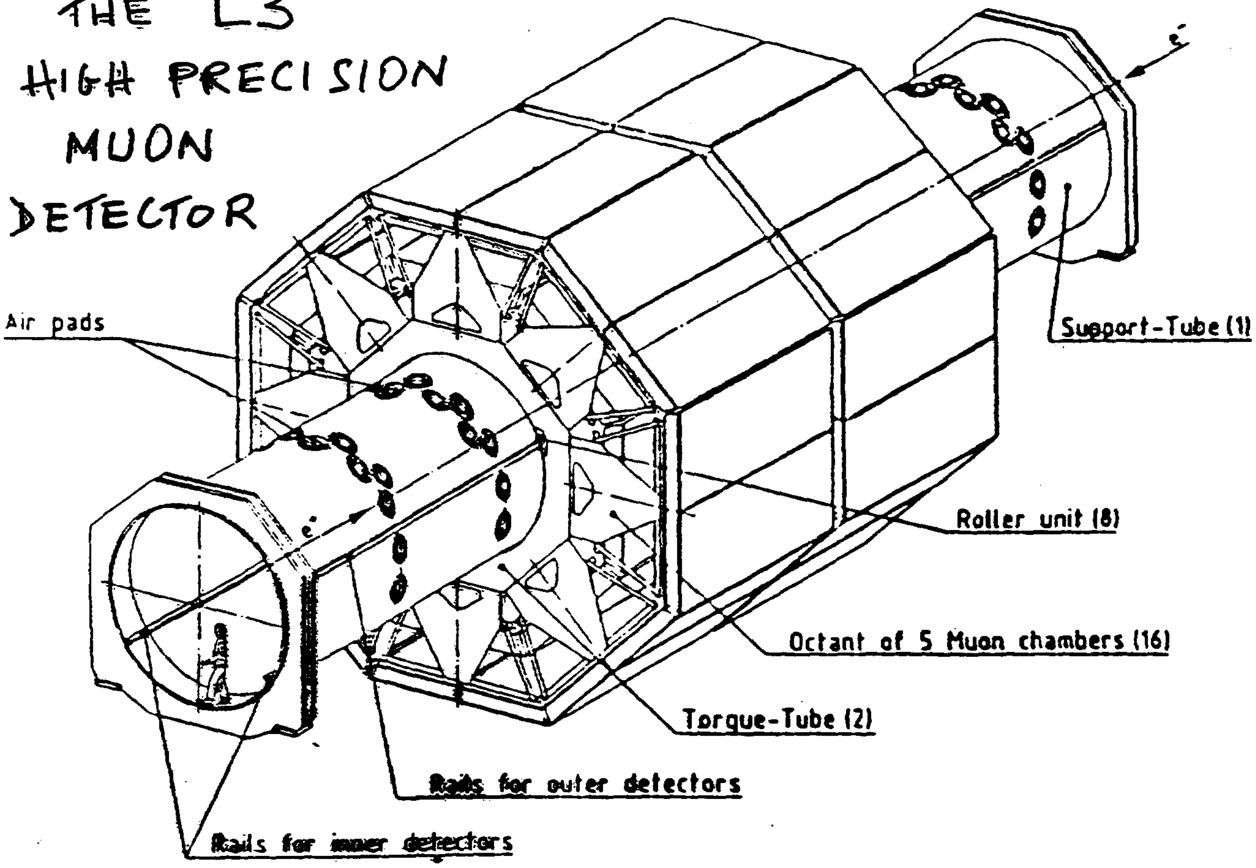
* TIME ACCURACY: $\sigma_t \sim 5$ ns
→ DISTRIBUTION CONTAINED IN 20ns

- WITH 2mm WIDE READOUT STRIPS, BY MEASURING THE INDUCED CHARGE AND TAKING THE CENTROID
  → $\sigma_x \sim 150 \mu m$

(*)



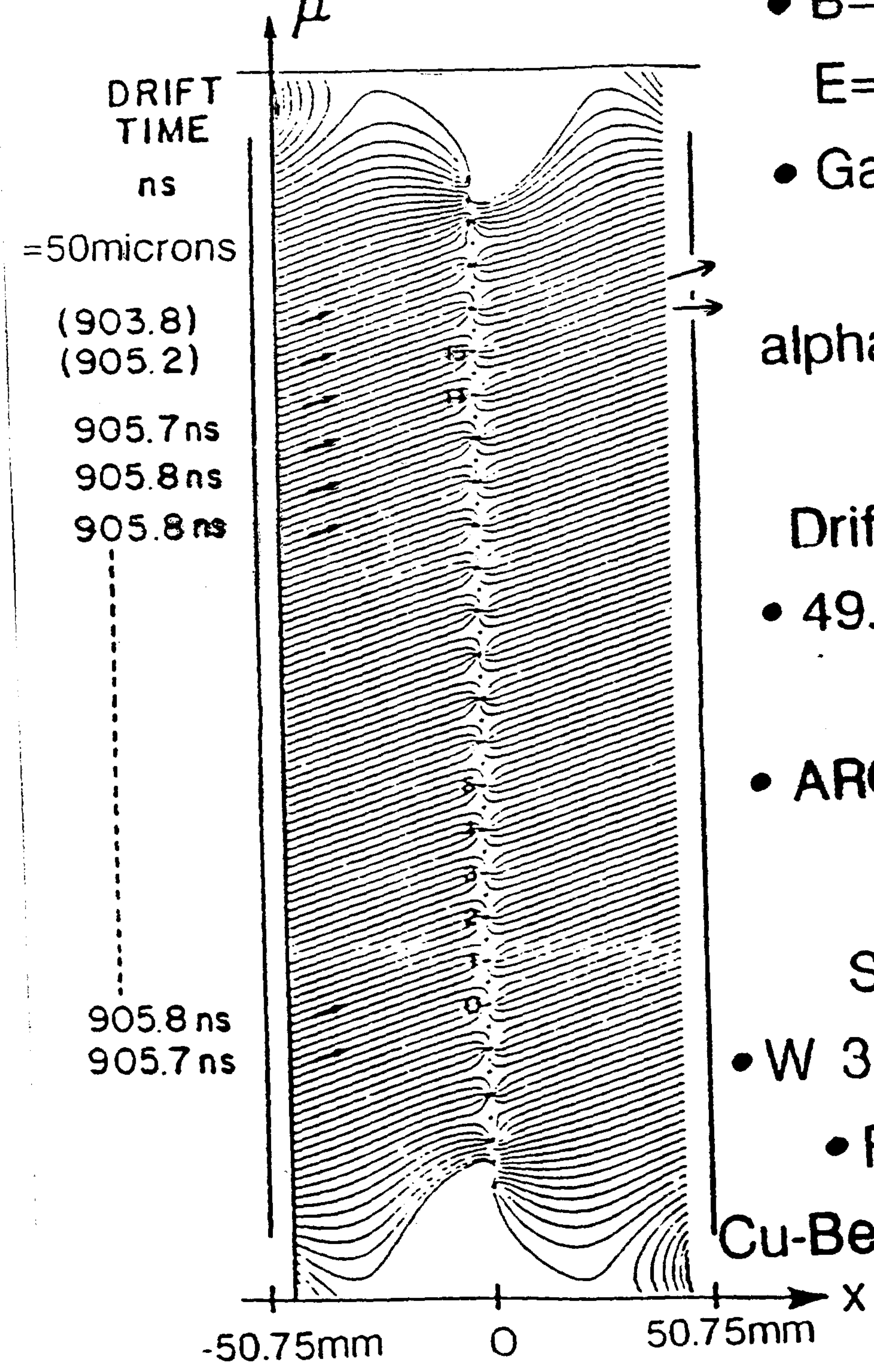
THE L3 HIGH PRECISION MUON DETECTOR



TOTAL

Volume	:	→ 1000 m^3
Weight	:	190 ton
Area of Chambers	:	→ 900 m^2
Wires, all	:	250 000
in Bending Plane	:	16 000
along Beam	:	8 000
Gas volume	:	250 m^3
Amplifiers		
TDC 500 Mc	:	24 000

L3: CHAMBER PARAMETERS



- B=5.1kGauss
  E=1200V/cm
- Gain=50'000

alpha=19degrees

Drift velocity:

- 49.8microns/ns

- ARGON/ETHANE
  62.38%

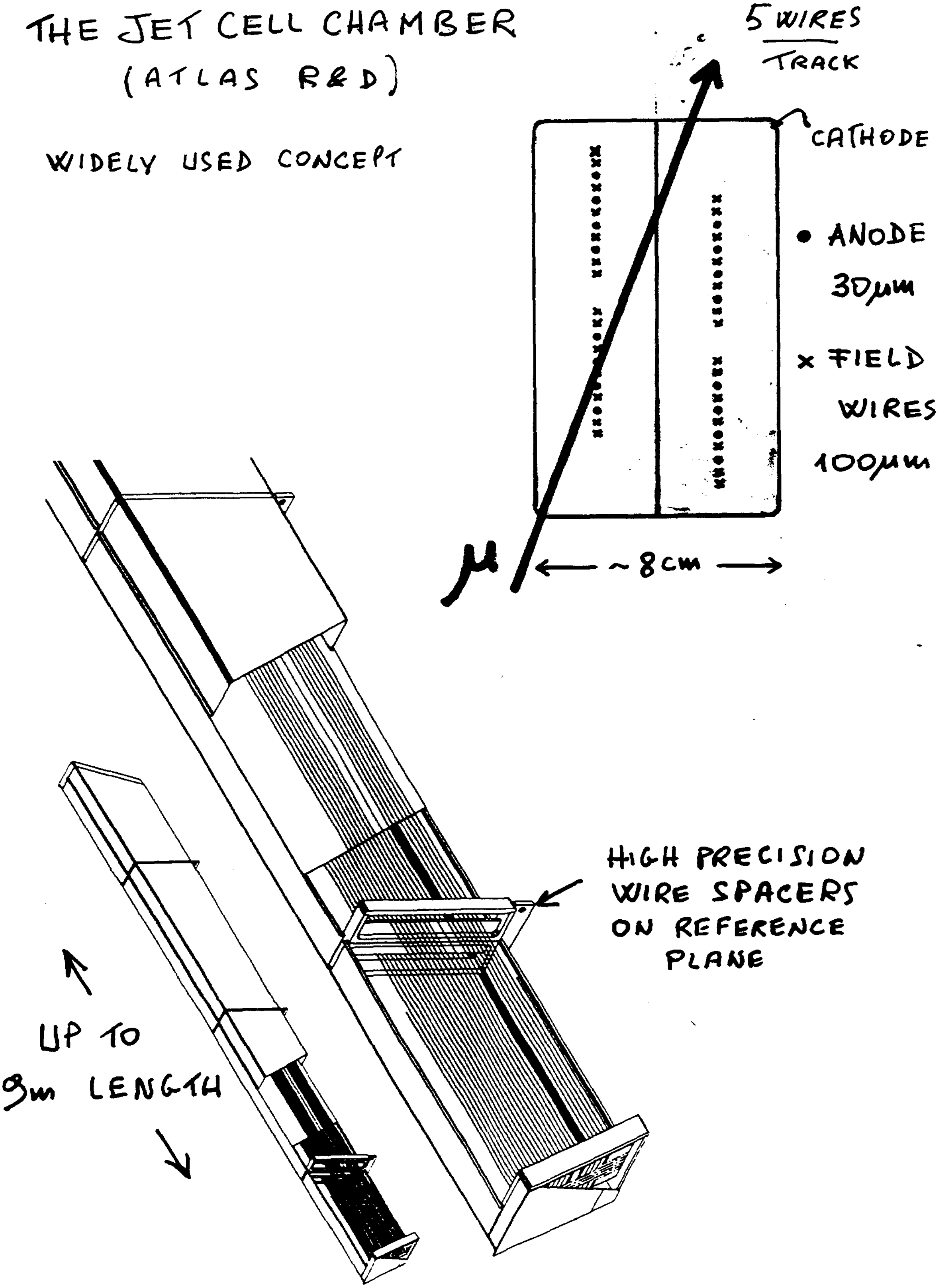
Signal wires:

- W 30microns,130g
- Field wires:

Cu-Be 75microns,385g
9mm spacing

THE JET CELL CHAMBER
(ATLAS R&D)

WIDELY USED CONCEPT



THE CHALLENGING ASPECT OF A
HIGH PRECISION MUON SPECTROMETER AT LHC
IS THE ABSOLUTE SPACE ACCURACY GOAL (~L3):

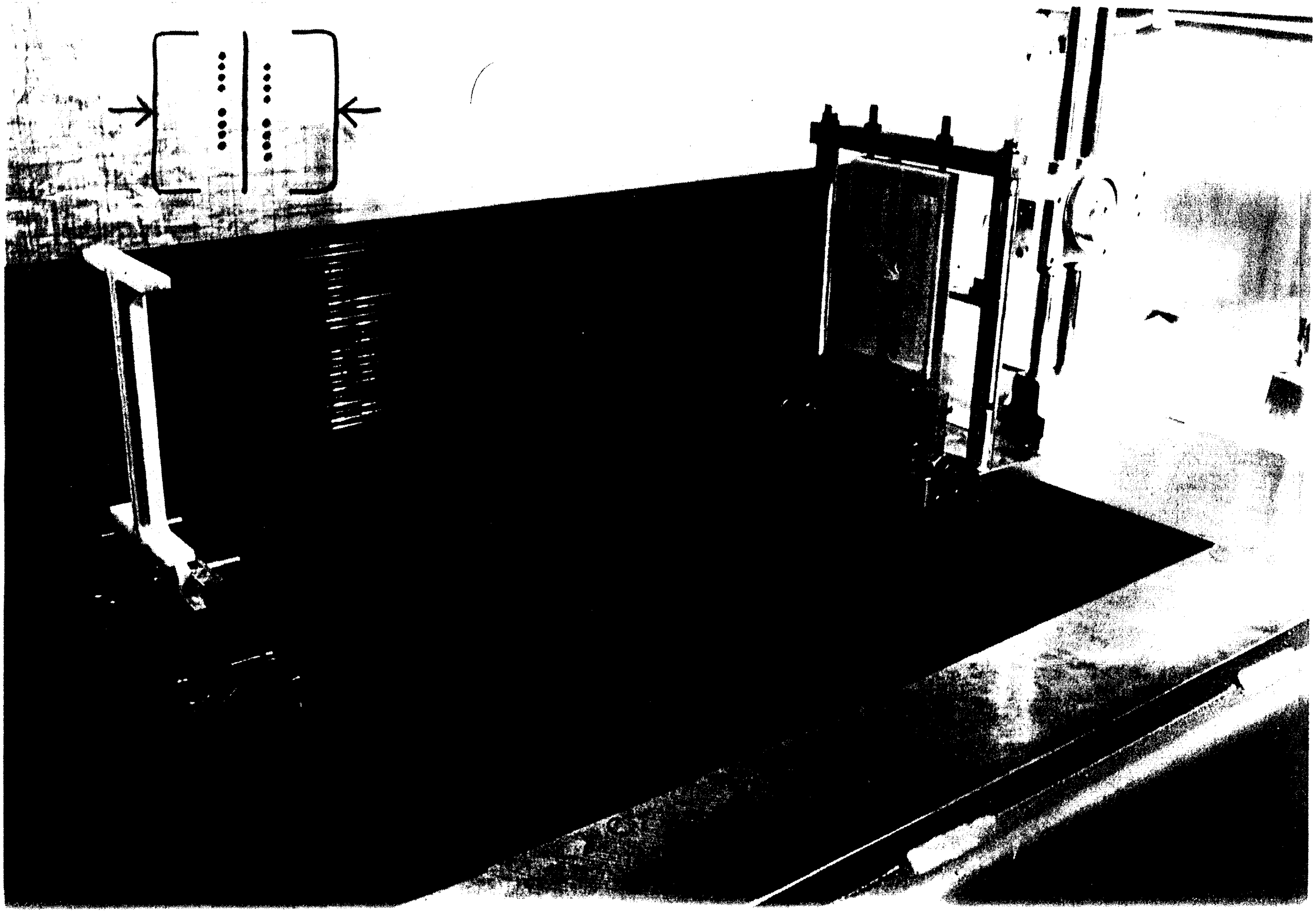
$\approx 70\,\mu m$ / CH. STATION (INCLUDING ALIGNMENT)

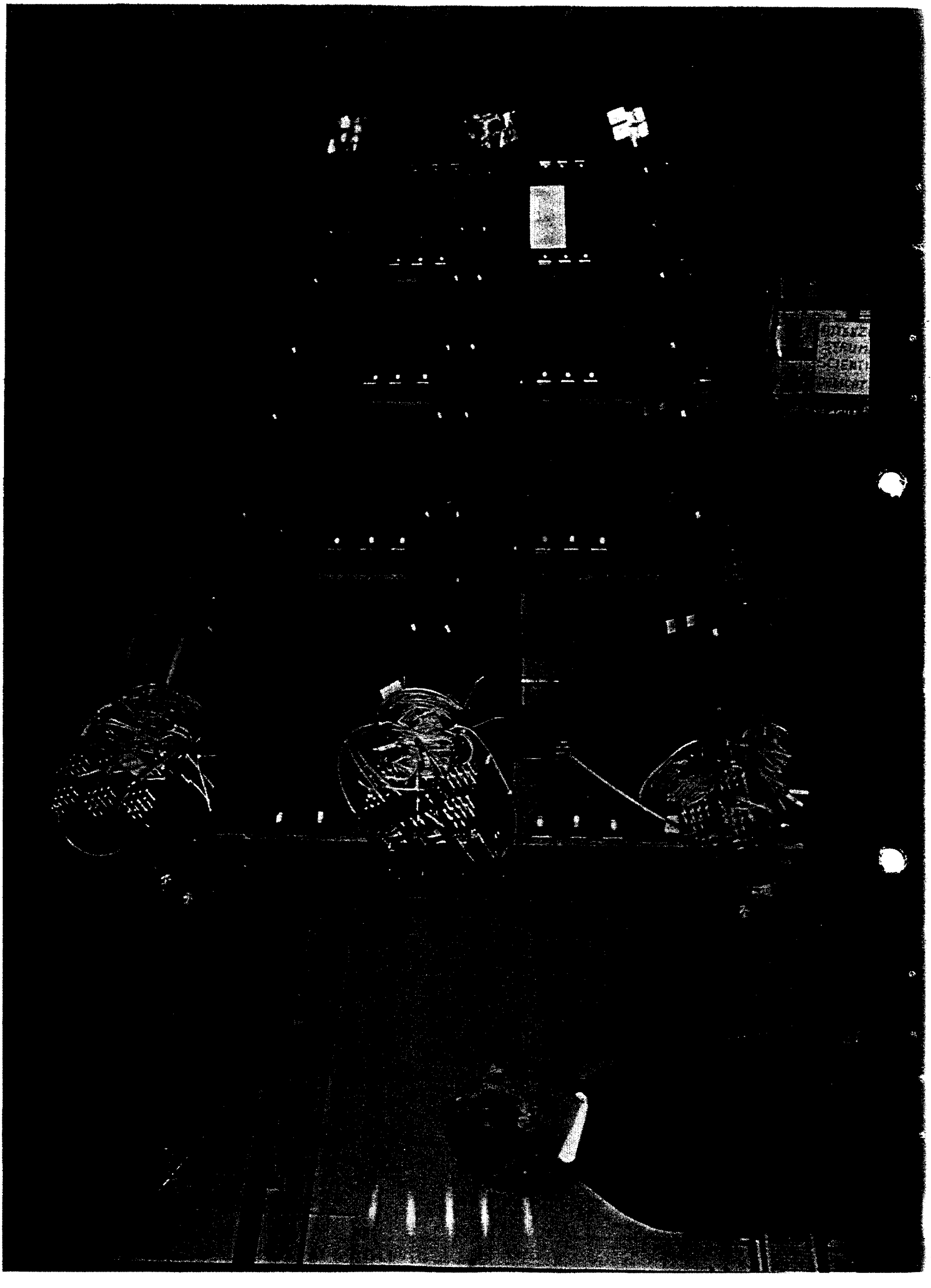
- WITH TOTAL CHAMBER AREA $\approx$ SEVERAL $10^3\,m^2$
- DISTRIBUTED OVER $\approx$ $\varnothing\,20m \times 20m$
- WITH NON COMFORTABLE PARTICLE RATES

MANY WIRE CHAMBER CONFIGURATIONS
HAVE THE ADEQUATE NOMINAL PERFORMANCE

HOWEVER THE CONSTRUCTION AND OPERATION
DETAILS CAN HAVE AN IMPORTANT IMPACT
ON FINAL PERFORMANCE AND COST

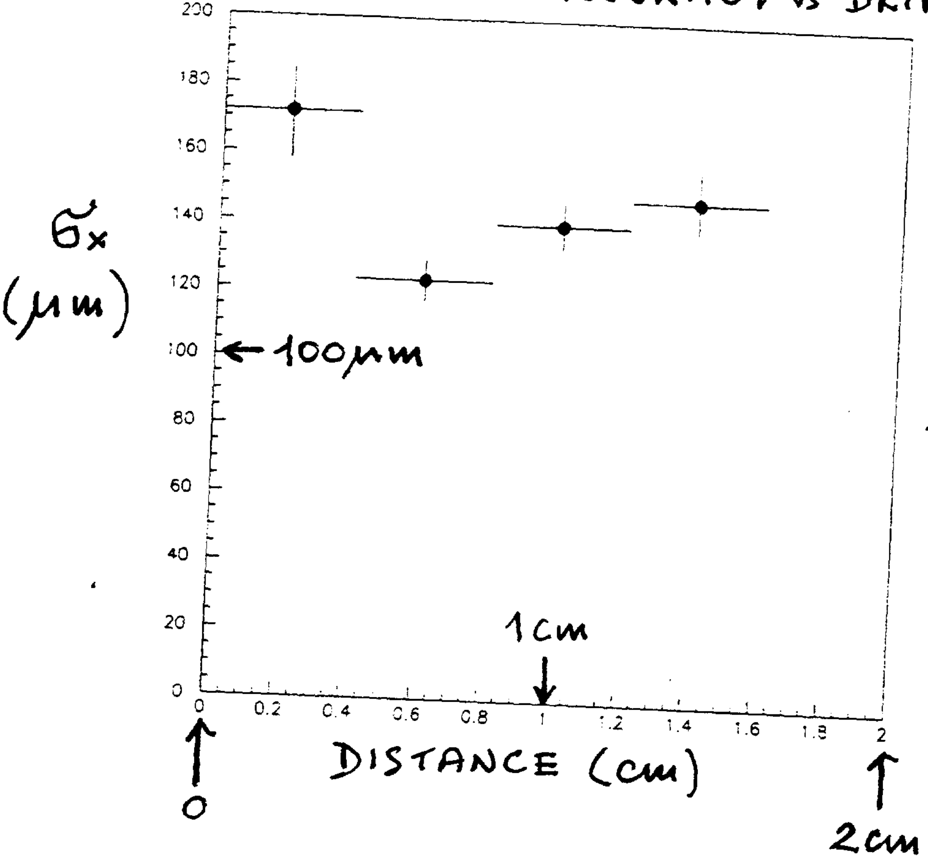
THE CHOICE IS DIFFICULT





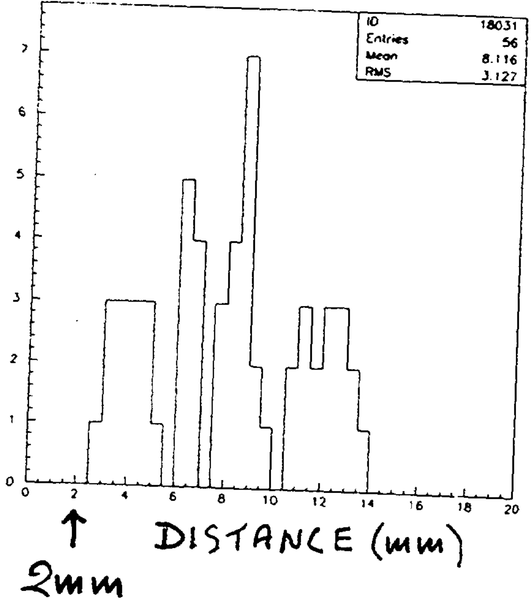
JCC

SINGLE WIRE ACCURACY vs DRIFT DISTANCE



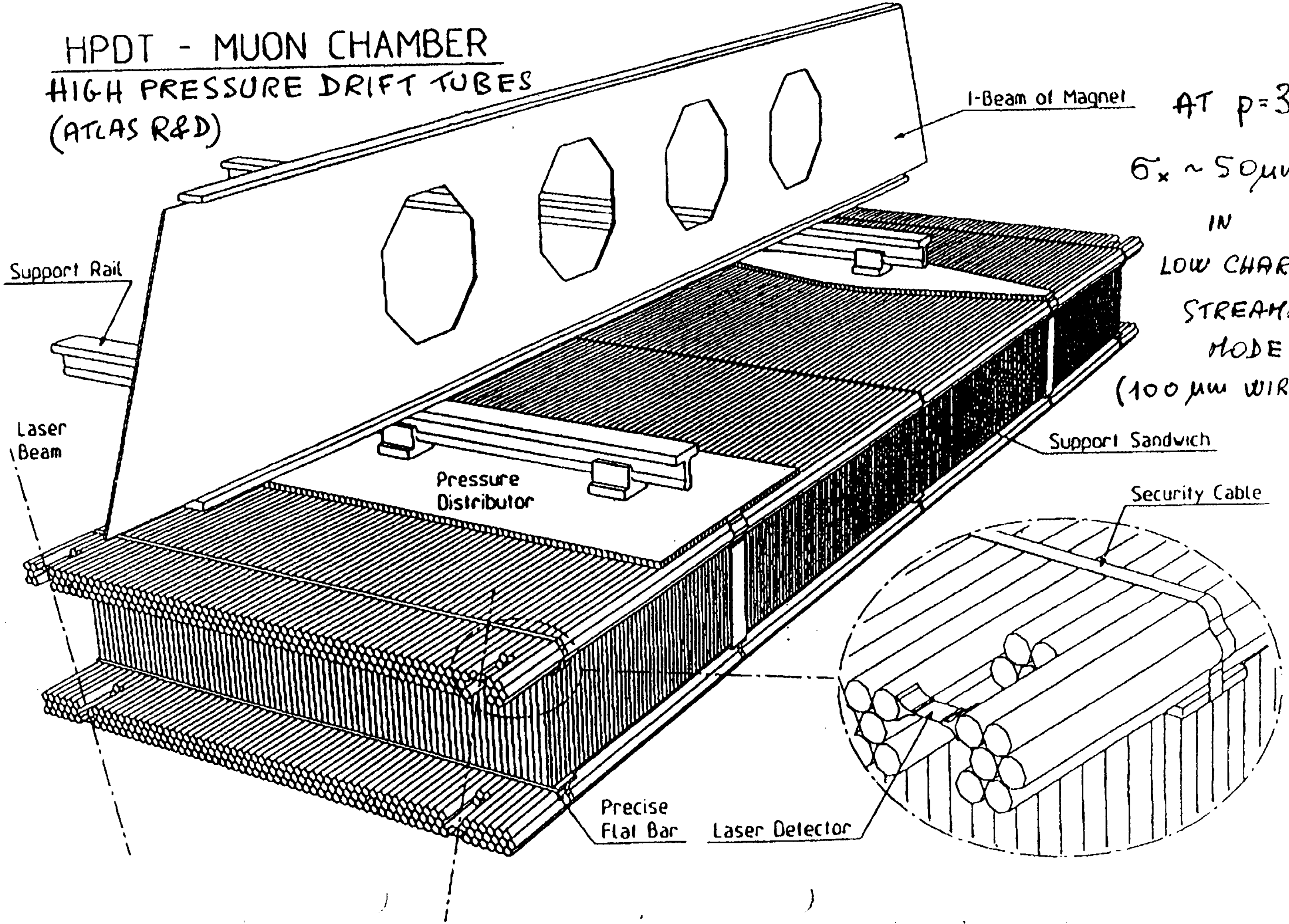
FEW IONIZ.
ELECTRON
THRESHOLD

2 TRACK SEPARATION



HPDT - MUON CHAMBER

HIGH PRESSURE DRIFT TUBES
(ATLAS R&D)



AT $p = 3$ bar

$\sigma_x \sim 50 \mu m$

IN

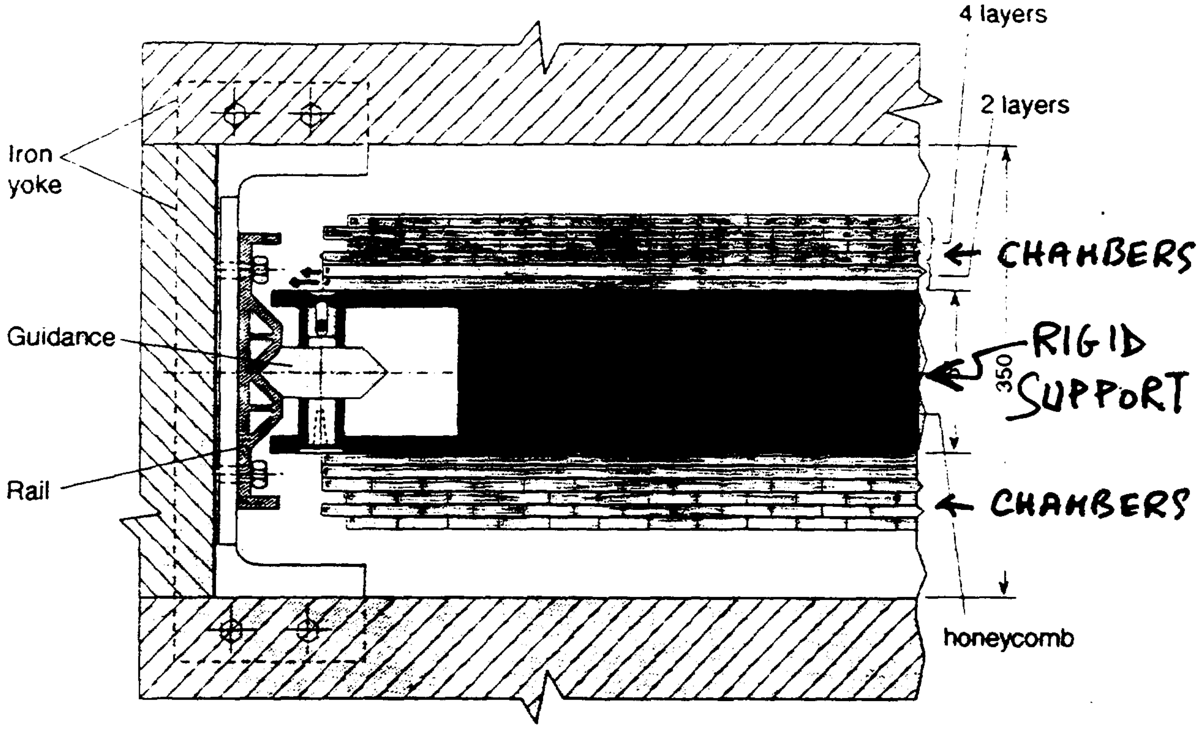
LOW CHARGE

STREAMER

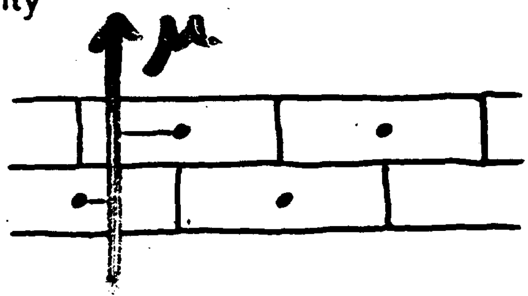
MODE

(100 μm WIRE)

DTBX Performance (CMS R&D)

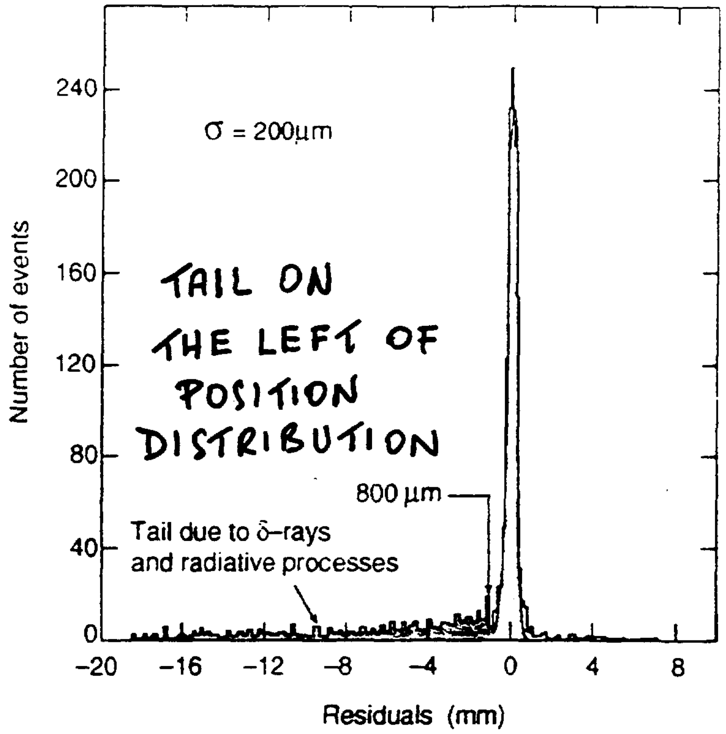


- Plastic drift cells 38 x 10 mm^2
  2 x 4 layers for the coordinate in bending plane
  2 x 2 layers transverse to bending plane
  5" honeycomb structure for rigidity
  50 µm anode wires
  Gas mixture: Ar-CO$_2$ (88-12)
- Mean timer technique readout

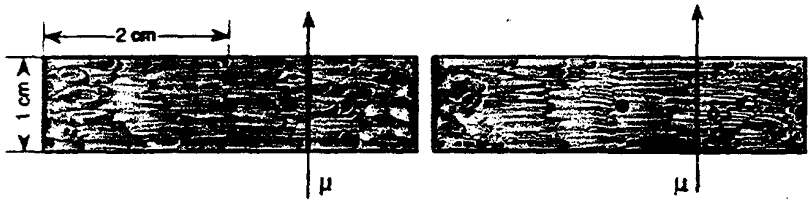


Spatial resolution: • $\sigma_x \approx 200\ \mu m$
Mean Timer resolution: • $\sigma_t \approx 3$ ns
Bunch Crossing identification efficiency
on isolated tracks in each 4 layer system: • $\varepsilon \approx 94\ \%$

DTBX Inefficiencies due to δ-rays



TAIL ON THE LEFT OF POSITION DISTRIBUTION



detected δ **undetected δ**

Momentum [GeV]	• δ's per layer [%]	• δ's confined in one layer [%]
100	5.7 ± 0.02	79 ± 4
200	5.5 ± 0.02	77 ± 4
300	5.9 ± 0.02	78 ± 5

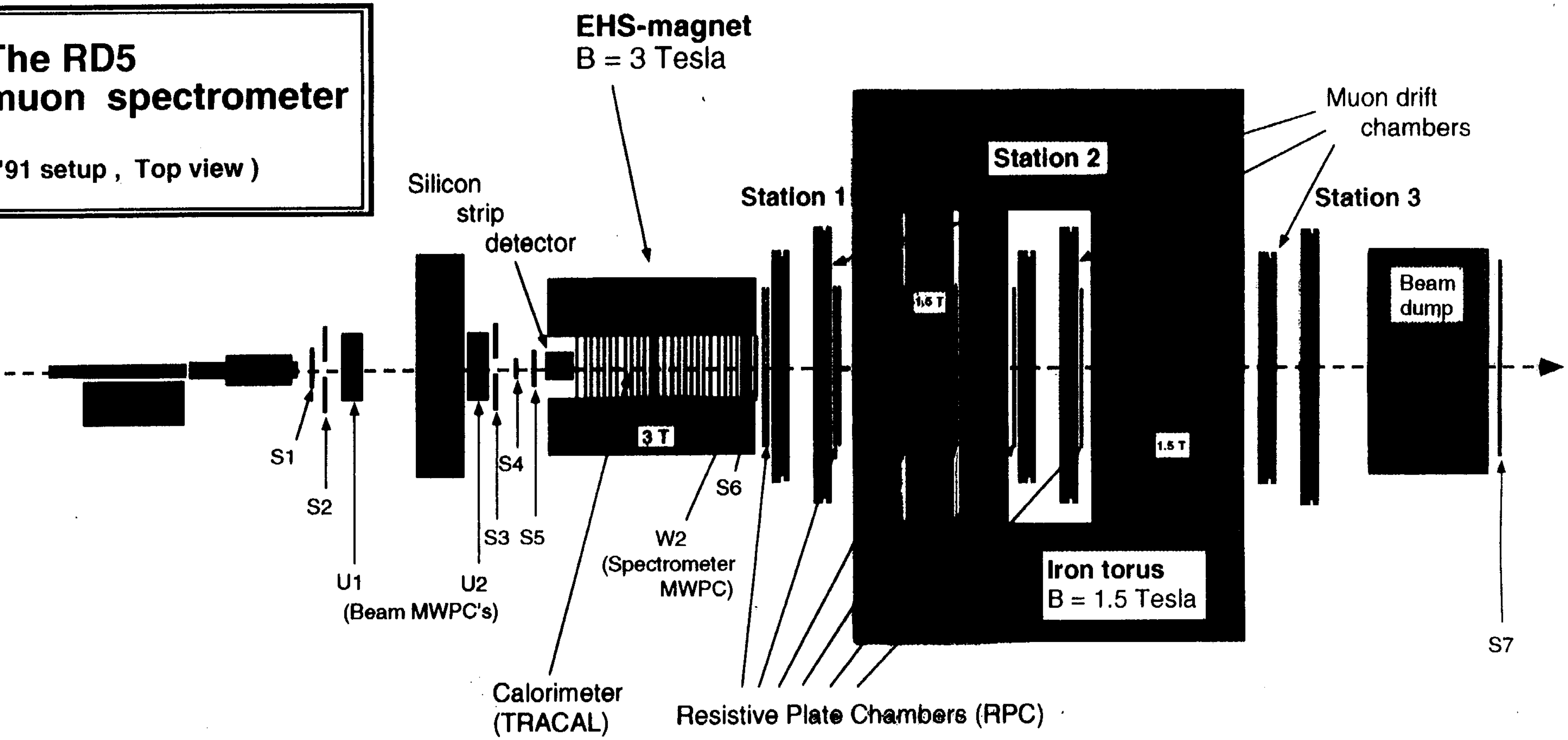
- Probability to have ≥ 3 clean layers out of 4:

$$P = (1-P_1)^4 + (1-P_1)^3 P_1 + 3P_1 P_2 (1-P_1)^3 = 95.2\ \%$$

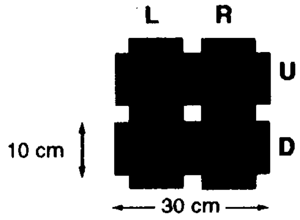
$$P_1 = 5.5\ \% \qquad P_2 = 78\ \%$$

The RD5 muon spectrometer

('91 setup , Top view)



S2, S3 - counters



Scintillation counters

S1:	10 cm	x	15	cm
S5:	15 cm	x	15	cm
S4:	4 cm	x	4	cm
S6:	70 cm	x	100	cm
S7:	100 cm	x	250	cm

Trigger

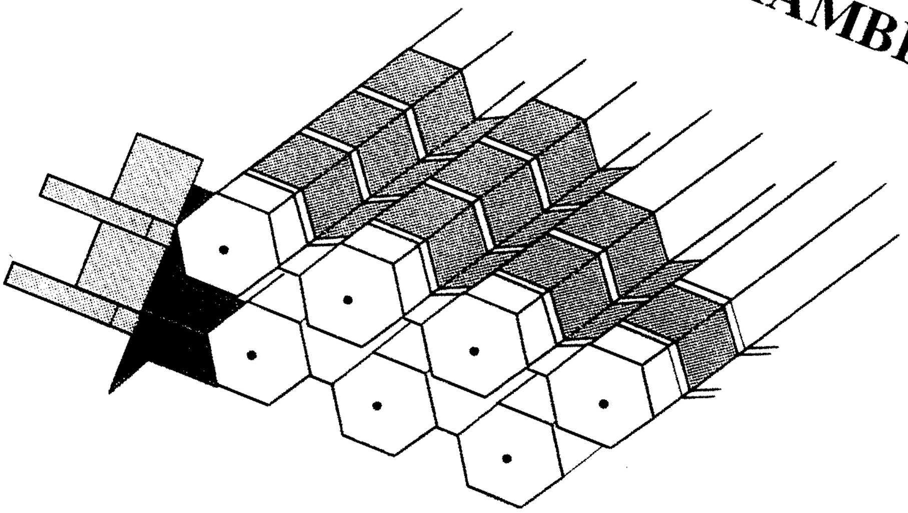
π (minimum bias) : **S1 x S4 x S5**

π (punch through > 10 λ) : **S1 x S4 x S5 x S6**

μ (muons) : **S1 x (S4) x S5 x S6**

Hans Tuchscherer
RWTH Aachen

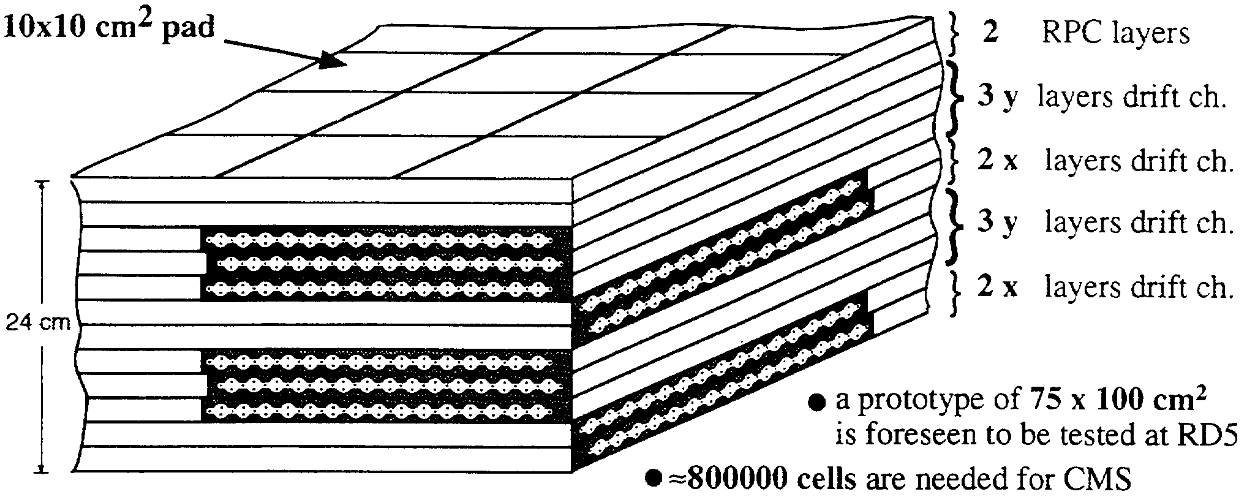
HONEYCOMB STRIP CHAMBERS



- Folded mylar foil with copper strips
- Central gold plated tungsten wire (20 μm)
- 2 coordinates from the same detector
  Wire pitch: 13 mm
  Strip pitch: 5 mm
- 2 – track separation 15 mm (strips)
  13 mm (wires)
- CMS muon station : 8 planes
  efficiency of a muon station inside absorber
  to be measured in RD5 (dirty measurements
  due to radiated soft electrons)
- Strip resolution 80 μm at normal incidence
  (measured in RD5)

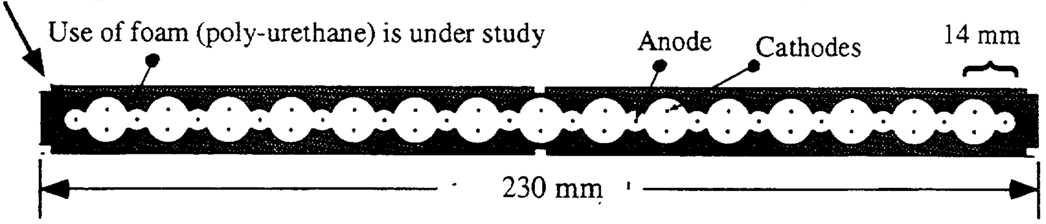
Wall-less Drift Chamber (WLDC) + RPC

CERN 16. Sep.'1992
Aachen μ- group



- a prototype of **$75 \times 100\ cm^2$** is foreseen to be tested at RD5
- **≈800000 cells** are needed for CMS

One single multi-cell (16 cells, each 14 mm wide) unit



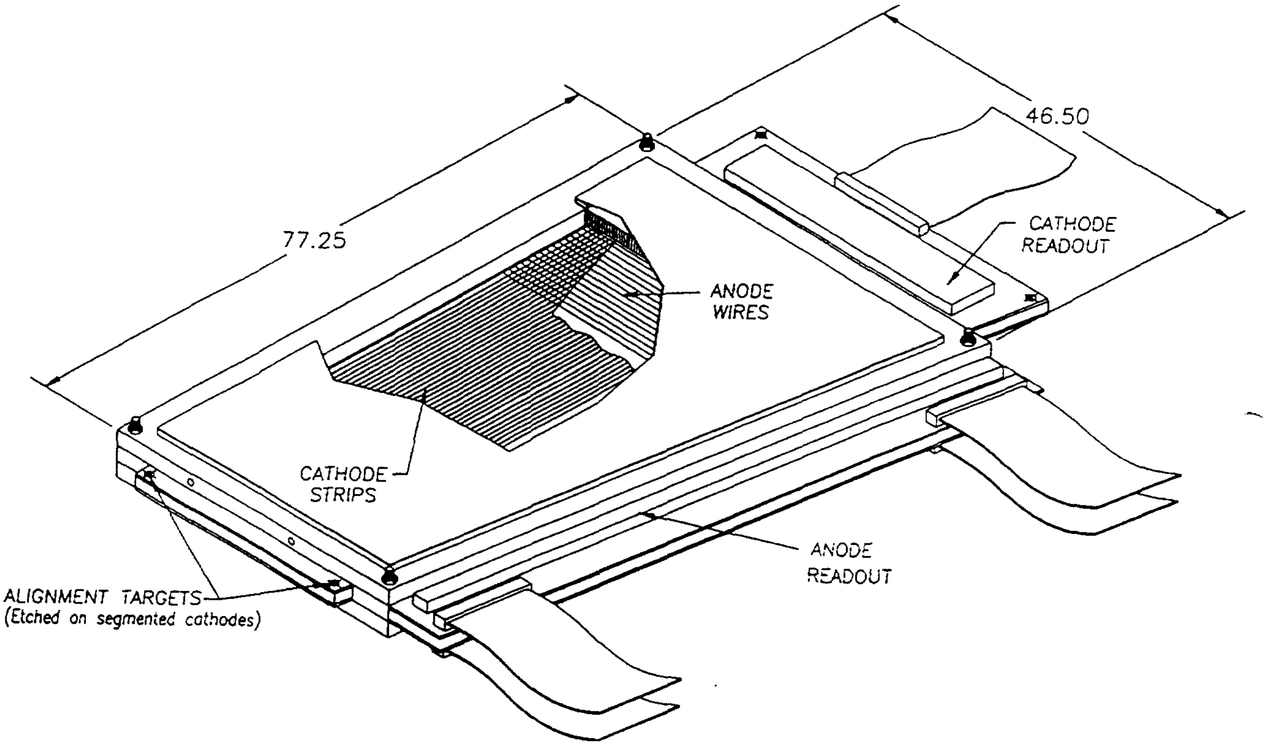
Driftchamber:
(by Aachen group)
- measure the particle's track position and angle
- maximum drift time t_{max} (for Ar/Ethane) **≈150 ns**
- maximum drift time t_{max} (for Ar/CO_2) **≈ 300 ns**
- residuals measured in a smaller prototype ≈ **250 μm**

RPC:
(by ROME group)
- measure the time reference for the particle's arrival
- help resolve both temporal and spacial ambiguities, which tracks of the projections to combine, when more than 1 track in the chamber

Output of the detector:
- Resolution for track segment ≈ **100 μm, ≤ 3 mr**
- Efficiency > **99.2 %**
- 4-6 hits in bending plane, 3-4 hits in other plane
- Bunch crossing number measured locally by RPC

Test of prototypes:
- two small prototypes were successfully studies in Aachen and delivered the above results
- the prototype K2 having 6+5+6+5+6+5+6+5 = 44 cells in 8 layers for only one projection is used in the RD5 ' 92 runs. Results are under study

CATHODE STRIP CHAMBERS (CSC)
FOR FORWARD MUON DETECTION



- Easy cathode segmentation to optimize rates.
- Chamber used for precision momentum measurement, transverse coordinate measurement, bunch crossing assignment and first level (and higher) trigger ability.
- Insensitivity to variations in gas gain, wire positioning, gas pressure and temperature.

Forward Muon Detector:

- Endcap modules of trapezoidal shape.
- Sandwich of 2.5 cm thick paper honeycomb with 2 layers of copper-clad glass-epoxy laminates, 1.25 mm thick.
- Radial strips of 5 mm average pitch.
- Two anode planes with 30 μm wires spaced at 2.5 mm at a distance of 2.5 mm from either strip cathode.
- Maximum drift time 25 ns for CF_4 - CO_2 at a field of 6 kV/cm.

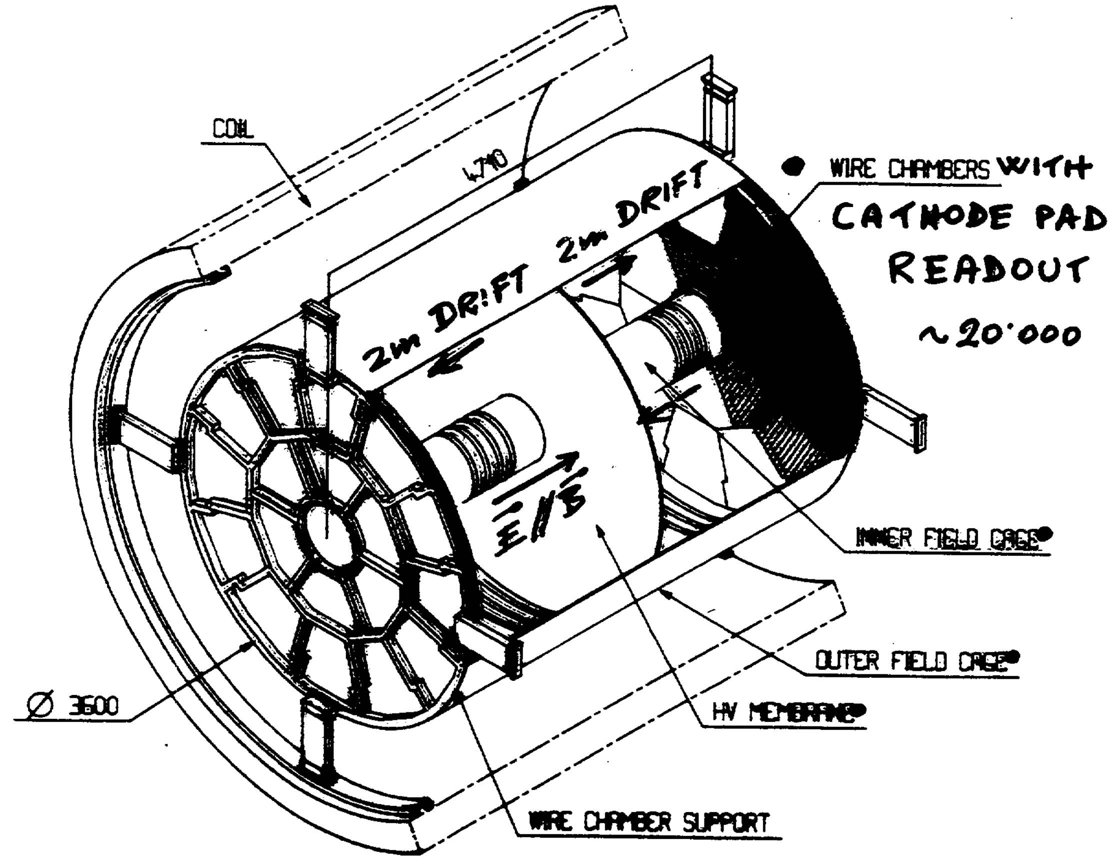
TPC : ALEPH

THE SYNTHESIS OF

- DRIFT TIME READOUT METHOD
- CHARGE CENTROID METHOD

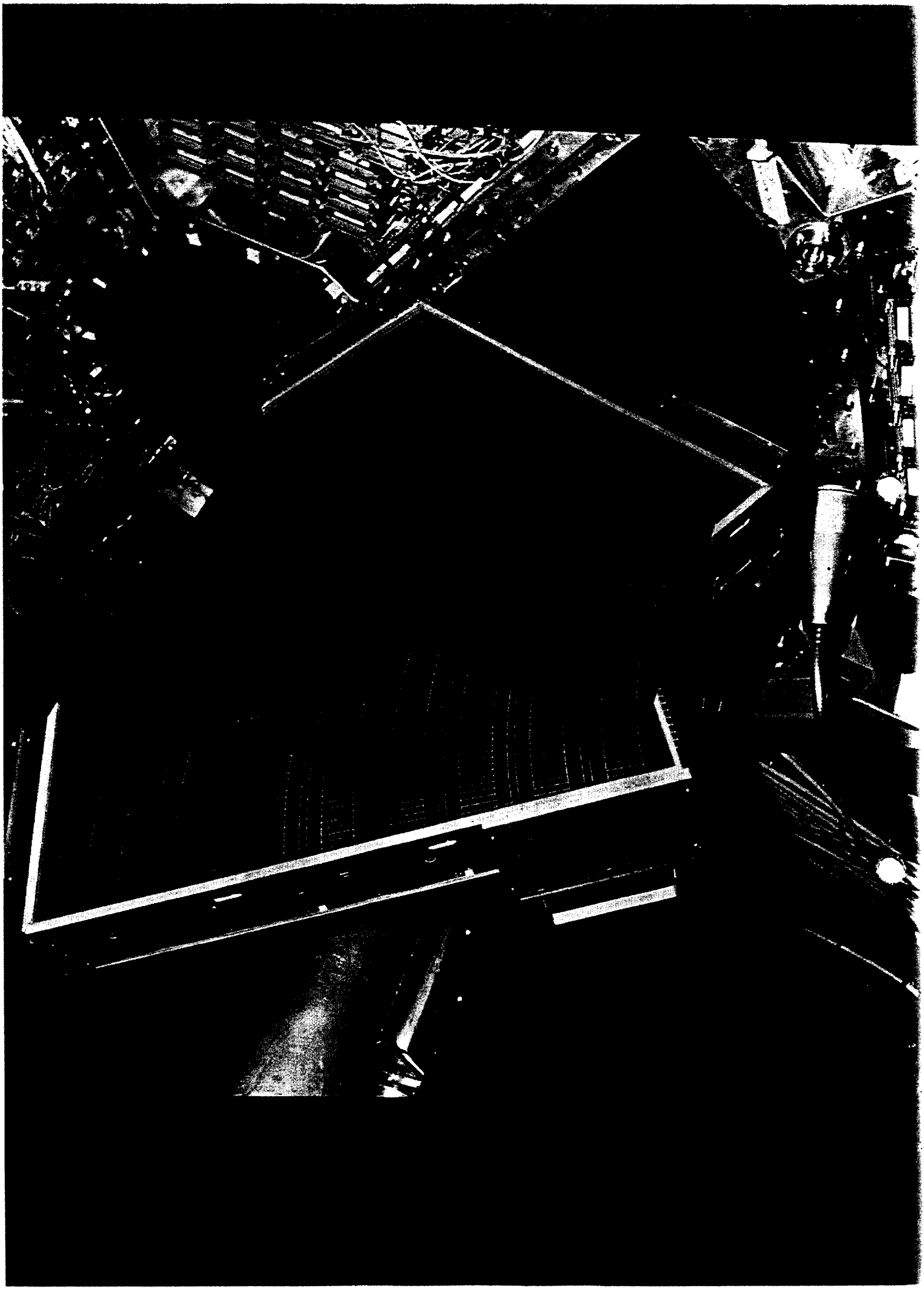
DIFFUSION:

- $\tau_D \propto \sqrt{d}$
- $\overline{E}$: 



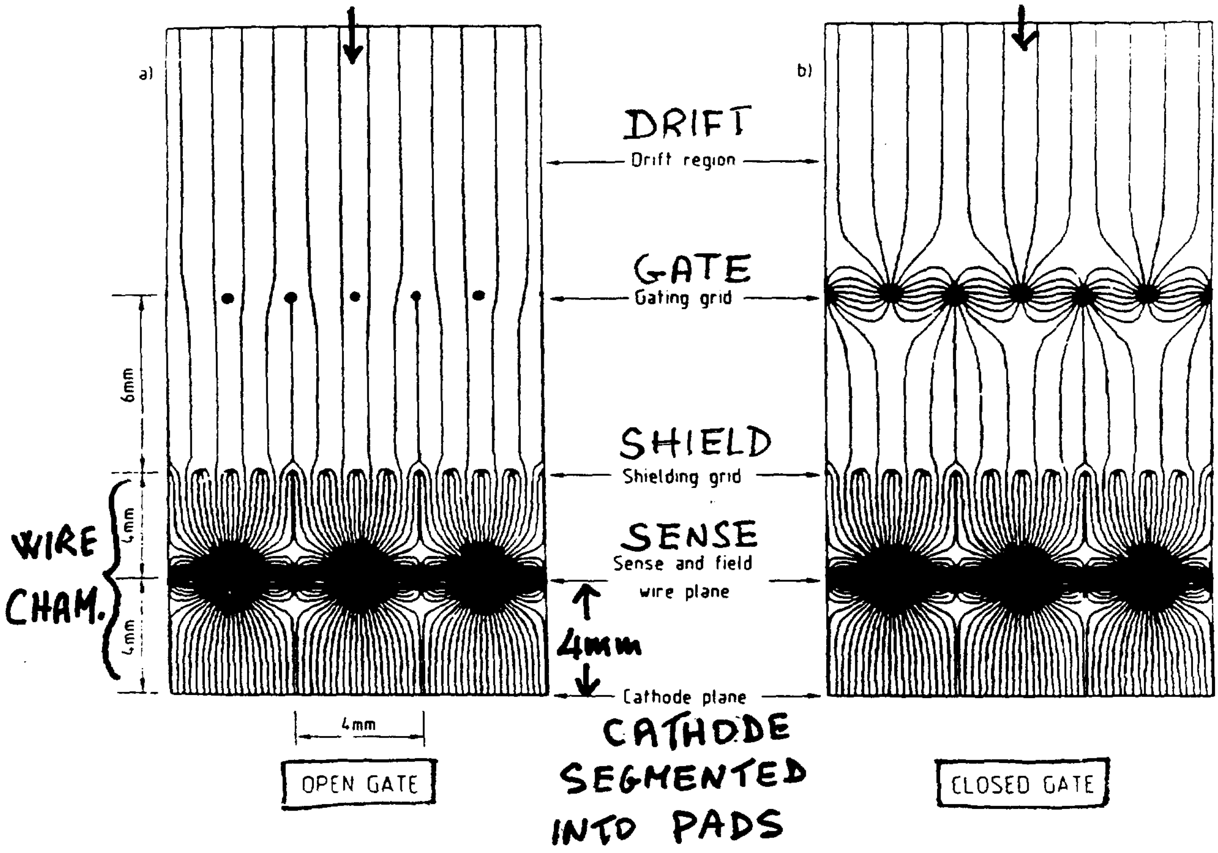
- $\sigma_T = 170\,\mu m$ (CHARGE CENTROID OVER PADS)
- $\sigma_L = 0.7\,mm$ (BY DRIFT TIME)
- 2 TRACK SEPARATION = 1,5 ÷ 2 cm

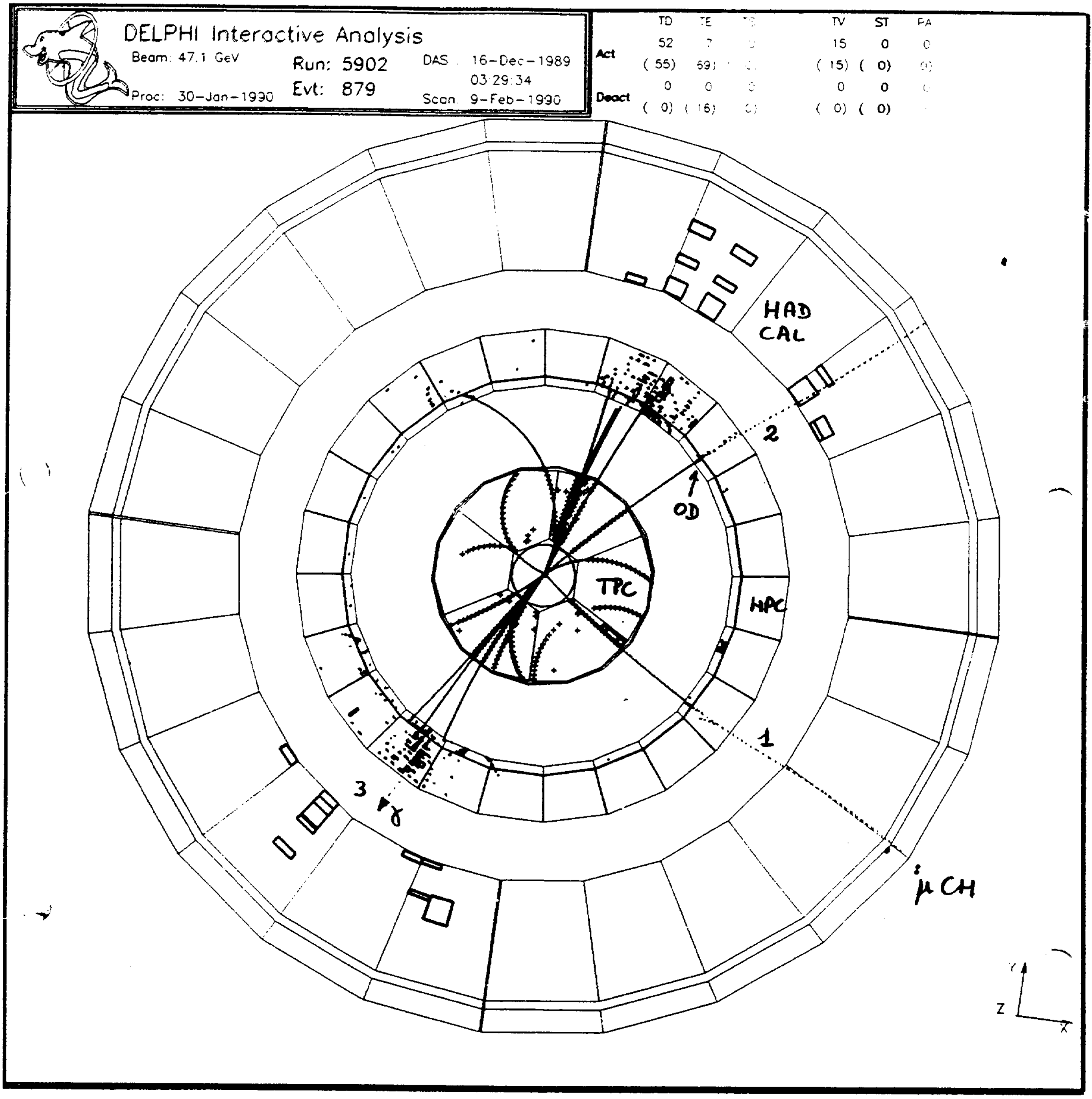
- $\delta p_T / p_T = 1.2 \cdot 10^{-3}\, p_T$ (GeV/c)
- $dE/dx = 4.5\%$ (~300 MEASUREMENTS/TRACK)



TPC

GATING AND SHIELDING WIRE PLANES BEFORE THE ANODE WIRES





DELPHI Interactive Analysis

Beam: 47.1 GeV
Run: 5902
Evt: 879
DAS: 16-Dec-1989
03:29:34
Proc: 30-Jan-1990
Scan: 9-Feb-1990

	TD	TE	[illegible]	TV	ST	PA
Act	52	7	0	15	0	0
	(55)	69)	[illegible]	(15)	(0)	(0)
Deact	0	0	0	0	0	0
	(0)	(16)	0)	(0)	(0)	