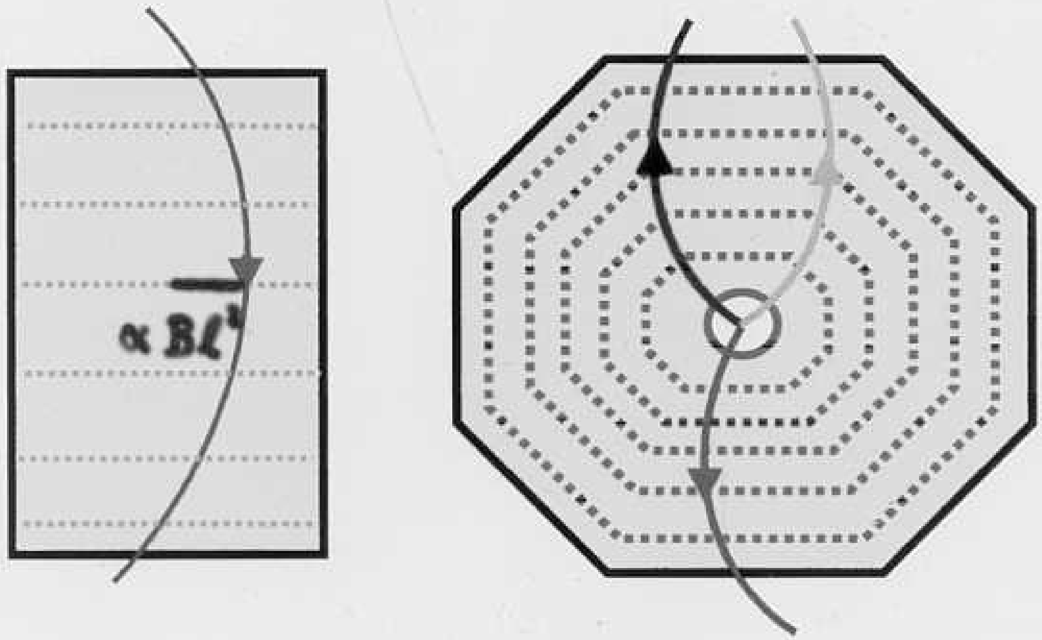

AVAL

Large Tracking Detectors

Yet with some accuracy



Principle of measurement
Drift chambers in general
Drift detectors Past
Present
Future

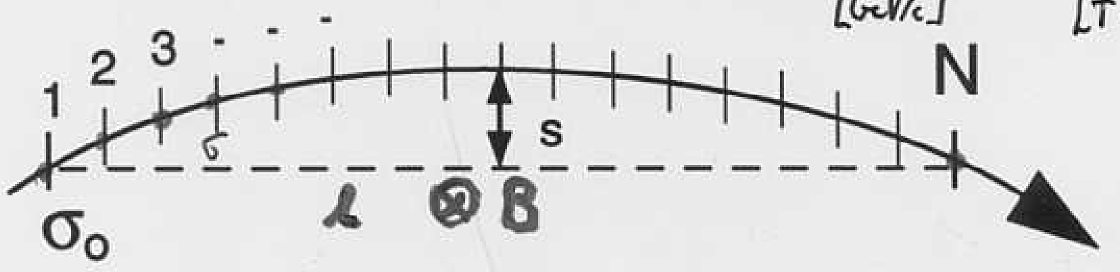
Ulrich Becker, MIT

New England Particle Physics Student Retreat
North Woodstock, New Hampshire
Aug. 18-23, 2002

WHY? $\vec{p}$ from curvature ρ in $\vec{B}_\perp$

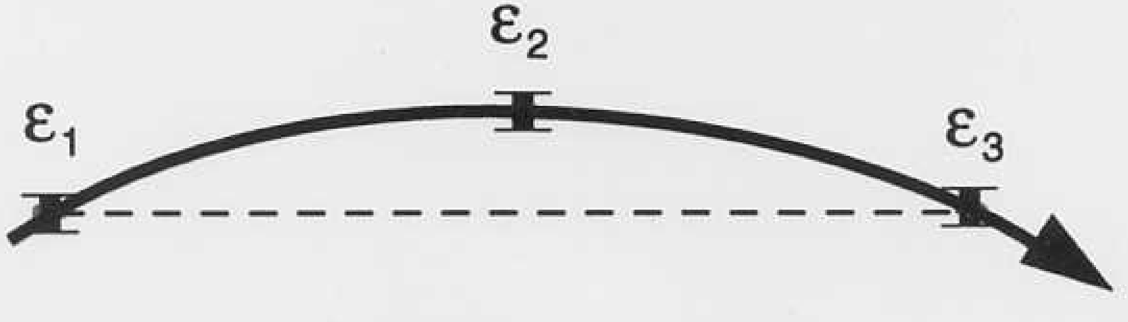
$$p_{[\mathrm{GeV/c}]} \sin\lambda = 0.3\, B \cdot \rho_{[\mathrm{T \cdot m}]}$$

a)



$$\frac{\Delta p_\perp}{p_\perp} = \frac{\Delta s}{s} = \frac{p_\perp \sigma}{.3 B l^2} \sqrt{\frac{720}{N+5}}$$

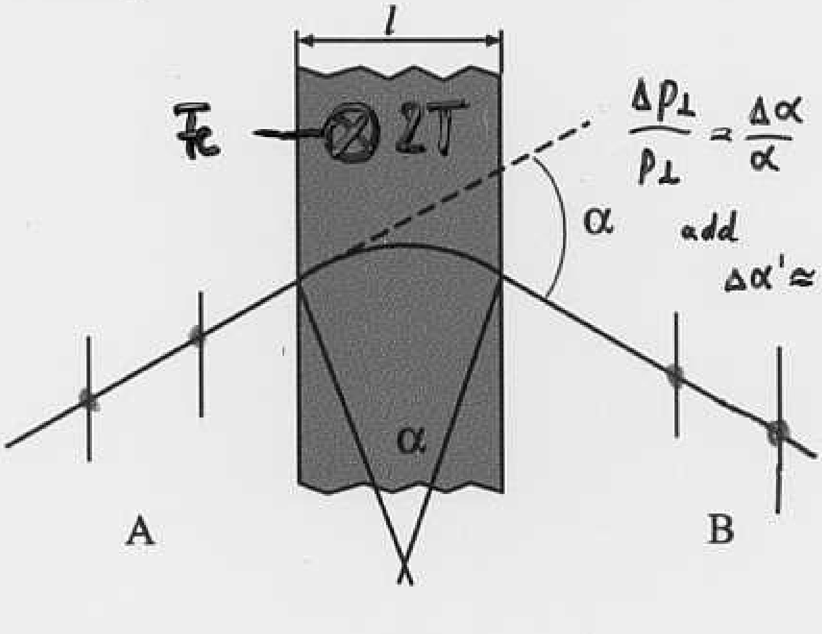
b)



$$\frac{\Delta p_\perp}{p_\perp} = \frac{p_\perp}{.3 B l^2} \sqrt{\left(\frac{\varepsilon_1}{2}\right)^2 + \varepsilon_2^2 + \left(\frac{\varepsilon_3}{2}\right)^2}$$

$l^2 \rightarrow$ large detectors
many channels

c)



$$\frac{\Delta p_\perp}{p_\perp} = \frac{\Delta \alpha}{\alpha}$$

add $\Delta\alpha' \approx \frac{.016}{p X} \sqrt{\frac{X}{X_0}}$

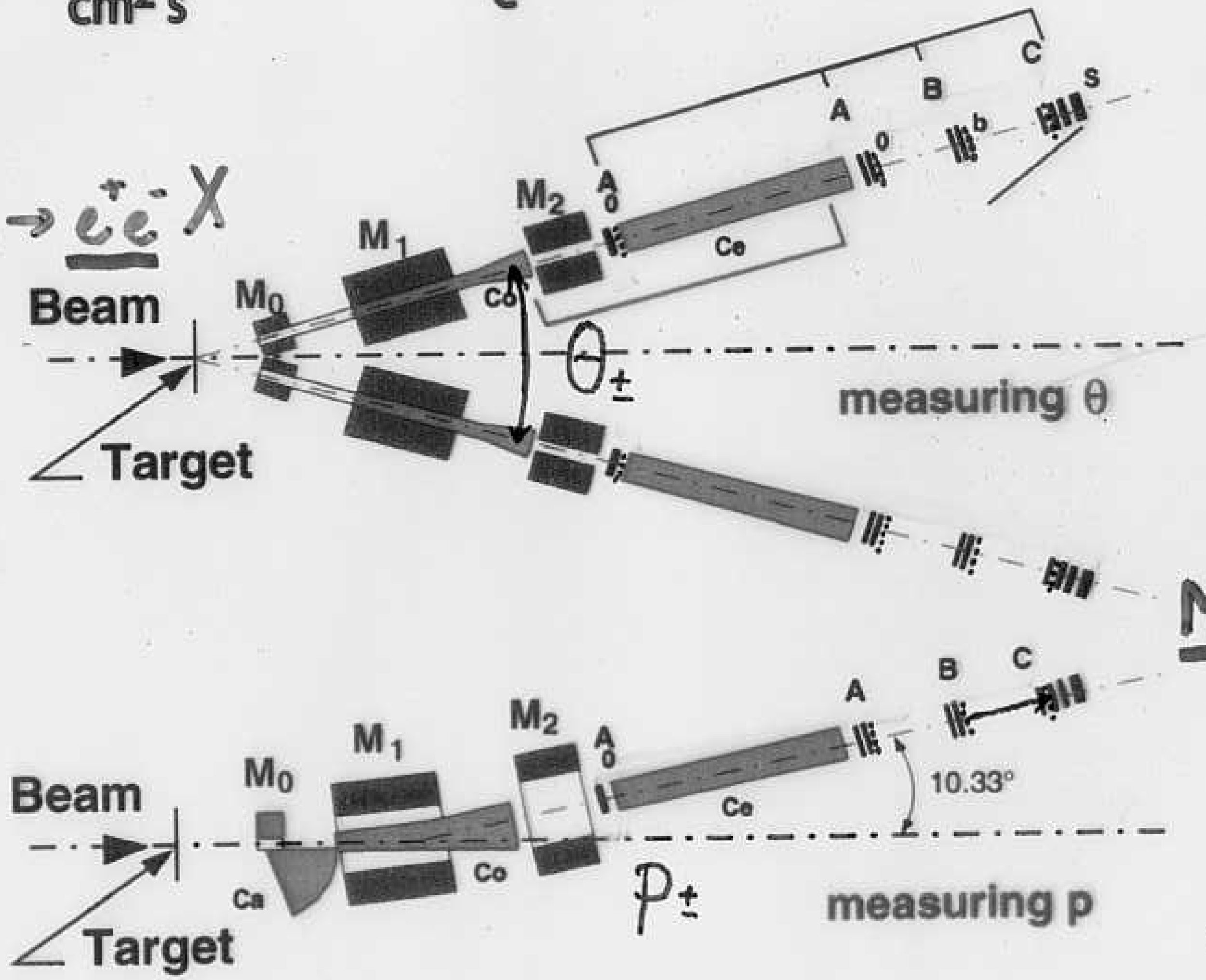
for Mult. Scatt.

* Instrumentation in HEP World Scientific Vol 9 (1992) U. Becker, p 532...

J/ψ particle Spectrometer

$L \cong 10^{36} \frac{1}{cm^2 s}$ $\frac{p}{e} = 10^{10}$

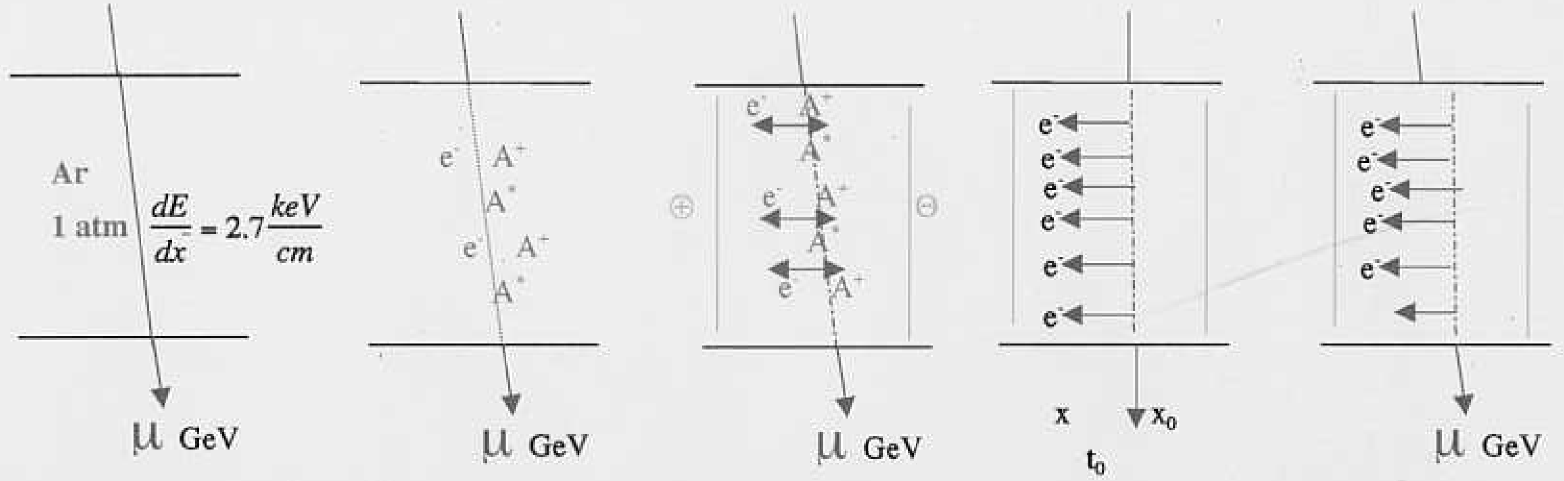
$p + Be \rightarrow e^+e^- X$



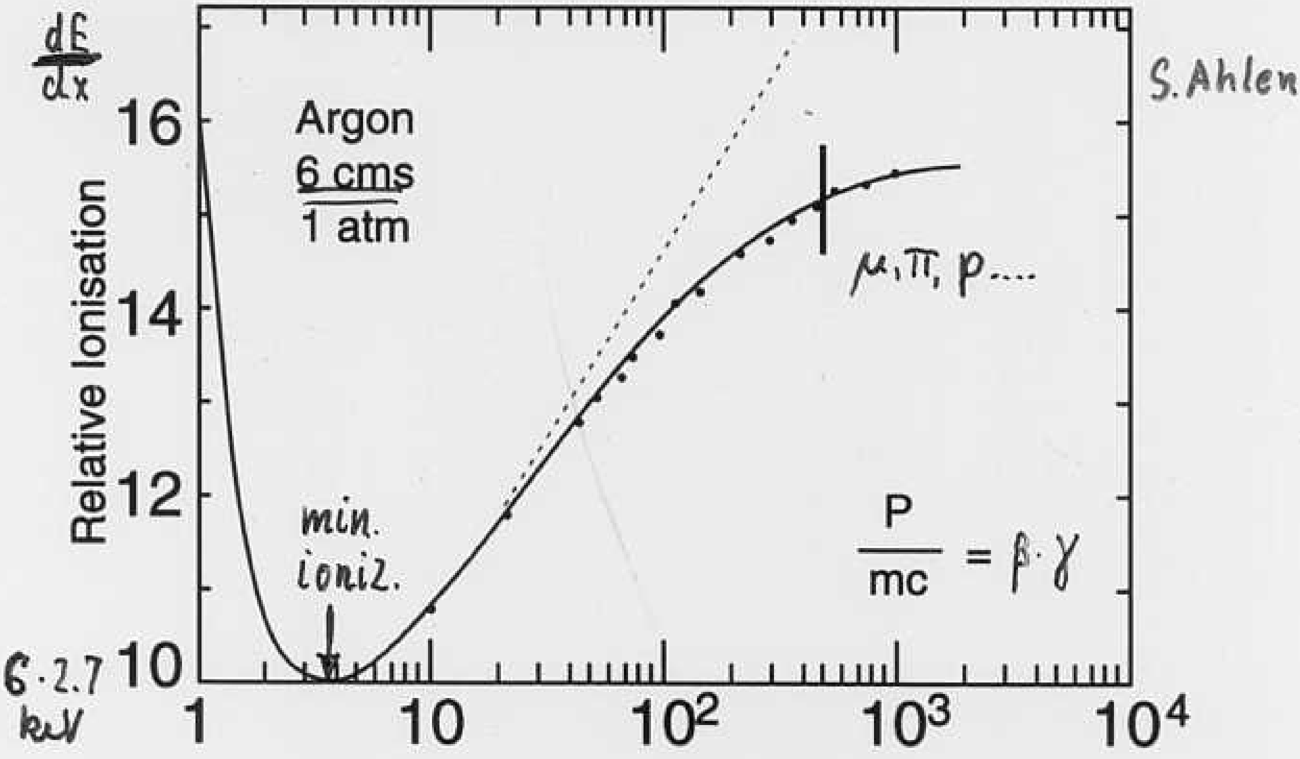
$m^2_{ee} = p_+ p_- (1 - \cos\theta_{+-})$

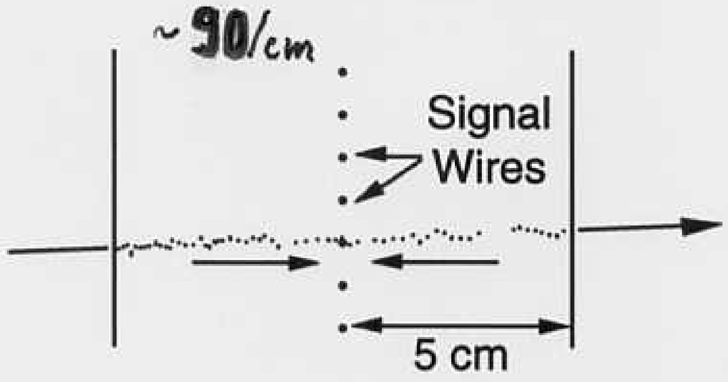
Ionizing tracks in Drift Chambers: **How does it work?**

Let a min.ionizing Particle traverse gas

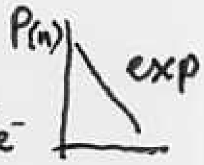


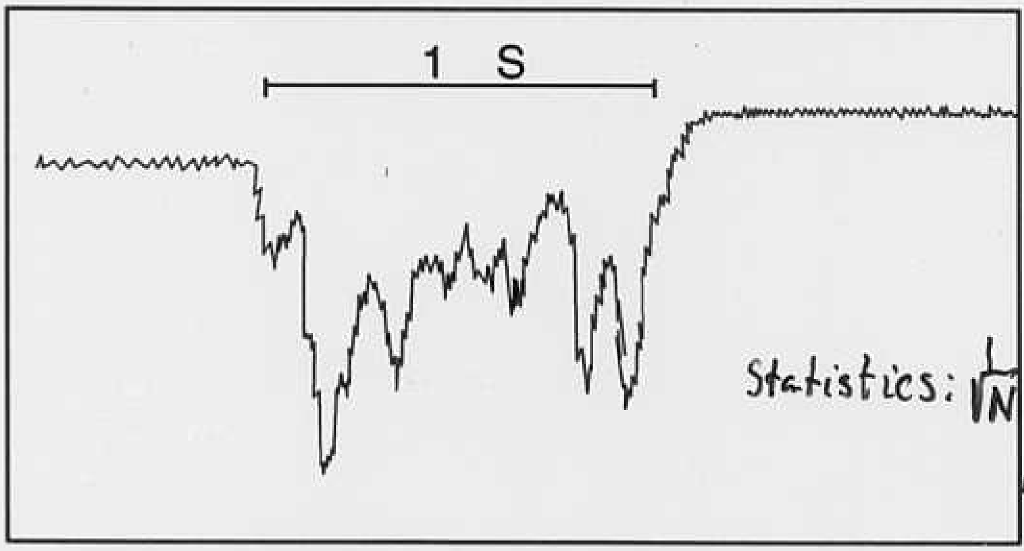
Noble Gas so that e^- are NOT attached To gas molec.	$E_{ion}(Ar)$=15.8eV + inel.collisions E_{eff} = 33 eV	~80 e^-/cm separated by E-field A^+ slow	$x-x_0=v_D(t-t_0)$ t known pos.meas. ~150 μm	diffusion smears $\sigma=200\mu\sqrt{x(cm)}$ 1 atm





but ~25 clusters of 1,2,..15e^-





Statistics: $\frac{1}{\sqrt{N}}$ ≈ 25 not 90!

Drift Velocity

$V(e^-) \gg V_D$ "Drift velocity"

e^- suffer dn random collisions in dx: $$dn = \frac{1}{v\tau}dx$$

Note: $v\tau$ = meanfree path

Collision rate $1/\tau$ α to gas density N: $$\frac{1}{\tau} = N\sigma v$$

$\vec{E}$ accelerates between collisions: $$eE = m\frac{dv}{dt}$$

Causing a displacement of: $$x(t) = \frac{1}{2}\frac{e}{m}Et^2$$

Prob. for time intervals between coll. $$dP = \frac{1}{\tau}e^{-t/\tau}dt$$

Average path: $$\langle x \rangle = \int_0^\infty \frac{1}{2}\frac{e}{m}Et^2\frac{1}{\tau}e^{-t/\tau}dt = \frac{e}{m}E\tau^2$$

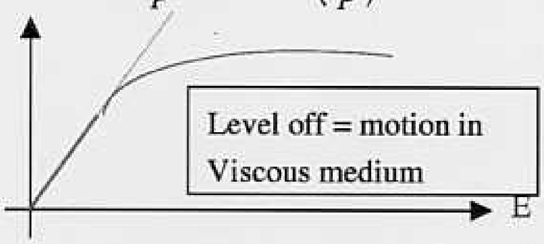
Average drift Velocity: $\langle v \rangle = v_D = \frac{\langle x \rangle}{\tau} = \frac{e}{m}\tau E =_{def} \mu E$

μ is called the 'mobility'

But τ depends on density: $$v_D = \mu E\frac{p_0}{p} = \mu \cdot p_0\left(\frac{E}{p}\right),$$

"E/p Scaling"

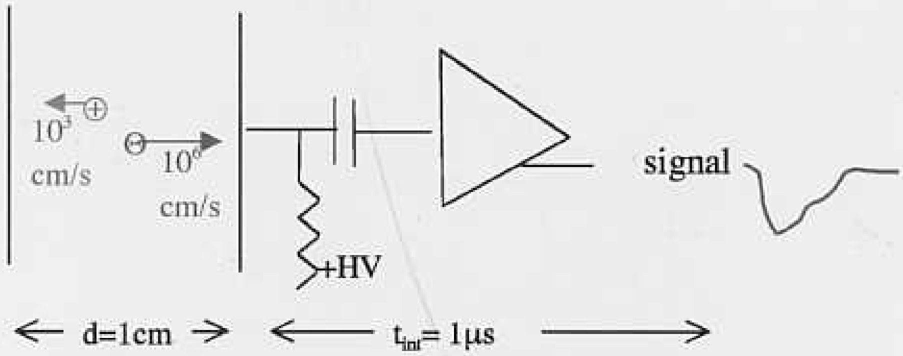
So far:



But σ and there fore τ depend on the energy of the electron:

important for drift chambers

Signal Basic Example I

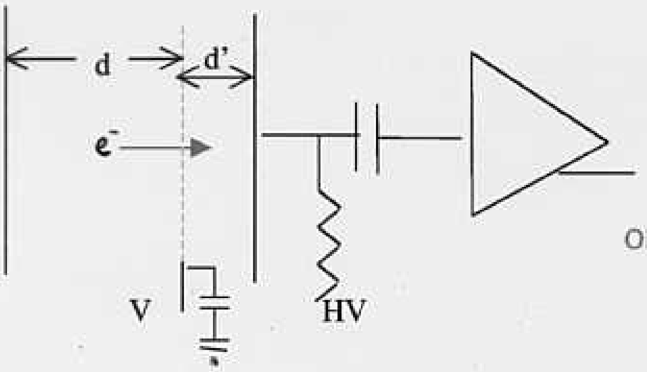


During the integration time charges move: $\Delta x = v\, t_{int}$ = { 1cm for e^-

{10^{-3} cm for A^+

…the moving A^+ induce: $\Delta Q = n\, \Delta x/d = 10^{-3}\, n$

but the induced charges q depend on the position: $0 < q < Ne$,
which can be avoided by introducing a (Frisch) grid



2 volumes, 2 circuits:

1.Cathode- Grid:

$\Delta Q' = Ne\Delta x/d \neq 0$

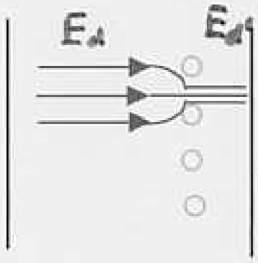
on the grid, AC grounded $= 0$

2. Grid- Anode:

$\Delta Q = Ned'/d' = Ne$

which is the full charge.

Can the grid be very transparent??



YES!

if $E_{d'} \geq 3\, E_d$ 98% get through

Program: Maxwell
Garfield…

Drift Velocity of IONS

$$v^+ = \mu^+ E\, p/p_0$$

Ions are heavy, have large σ → the mobility $\mu^+ \approx$const., small

He^+	in He	10.2 $cm^2/(Vs)$
A^+	in A	1.7
$iC_4H_{10}^+$	in $iC_4H_{10}^+$	0.61
CO_2^+	in A	1.1
CH_4^+	in A	1.87

multiply by a typical drift field of 1KV/cm to get a typical ion velocity

$$v^+ \approx 10^3 \text{ cm/s},$$

small compared to electrons $v = v_D \approx 5\ 10^6$ cm/s = 5 cm/μs

The slow drifting ions can be neglected for signal formation in the integration time of 1 μs. However, they will affect the rate capability by charging up the gas volume. Worst; TPC's. Best are straws of 4mm diameter; still ok at rates $>10^7$/s..

Attachment (R.Dinner, MIT BS thesis 2001) converts fast electrons to slow ions, useless for signals in 1 μs.

$e^- + O_2 \rightarrow O_2^-$ 1% -> $e^{-x/\lambda}$ $\lambda \approx 3$ cm

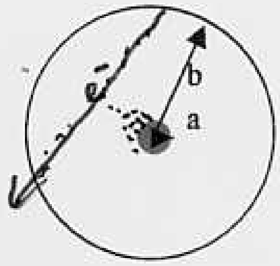
$e^- + Cl_2 \rightarrow Cl_2^-$

$e^- + H_{2O} \rightarrow H_2O^-$

Air (O_2 not N_2) is bad for you!

Signal Example II

induced on the Wire



Potential $\phi \propto \ln(r)/\ln(b/a)$

electrons $\phi_{elec} = -Ne(\phi(a)-\phi(r)) = -Ne \ln(r/a)/\ln(b/a)$

ions $\phi_{ion} = Ne(\phi(b)-\phi(r)) = Ne \ln(b/r)/\ln(b/a)$

The electron avalanche starts, when the field is high enough:

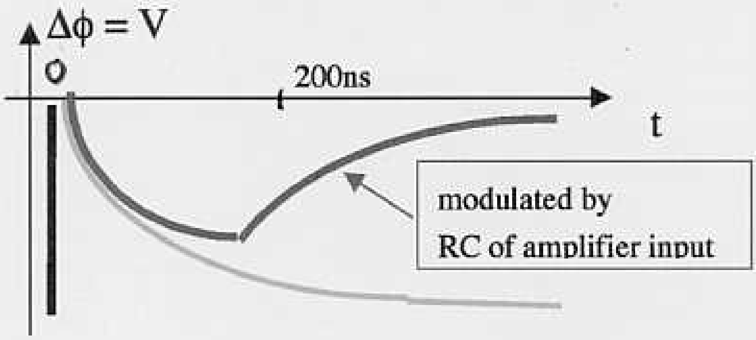
e $E_{crit}\lambda$ > 30 eV. then $r \approx 3a$, $\ln(r/a)= 1.1$

For the A^{+}ions $b/r \approx 1000$ $\ln(b/r)= 7$

SURPRISE !! The signal comes from the mirror charges of the ions

Of course the e^- current is much higher (peaked), but only lasts

50 μm/50mm/μs = 1ns, which normal amplifiers cannot follow. So the electronic voltage signal is dominated by the avalanche ions (not ionization) slowly drifting away.



Basic Example III Prop Tubes&Chambers

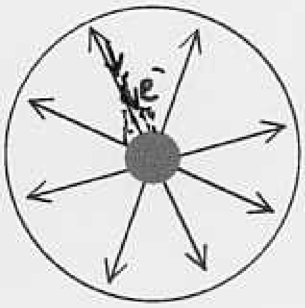
At high $\vec{E}$, N electrons drifting along x ionize secondaries off the gas molecules. These amplify the signal causing a "Gas Gain" G.

Townsend coeff.: secondaries in dx: $dN = \alpha(E)\, N\, dx$

and consequently $G = N/N_0 = e^{\alpha(E)\Delta x}$

For a 'Geiger Geometry'

$$E(r) = \frac{V}{\ln(b/a)}\frac{1}{r}$$



The avalanche starts, when

$eE\lambda \approx 33\text{eV}$ or $E_{crit} \approx 40$ KV/cm

This is close to the wire: $r_{crit} = \frac{V}{\ln(b/a)\, E_{crit}} \approx 3a$ typically

No grid is needed, since Amplif. volume = 10^{-6} gas volume

Gain = N/N_0 $\qquad \int dN = N_0 \int_{r_{crit}}^{a} \alpha(r)\, dr$

But α depends on $\vec{E}$ $\qquad \ln G = \int_{r_{crit}}^{a} \alpha(r)\, dr = \int_{E_{crit}}^{E(a)} \alpha(E) \frac{dr}{dE}\, dE$

Diethorn approximation: $\alpha \approx \beta * |\vec{E}|\, p/p_0 = \ln 2/\Delta V * E\, p/p_0$

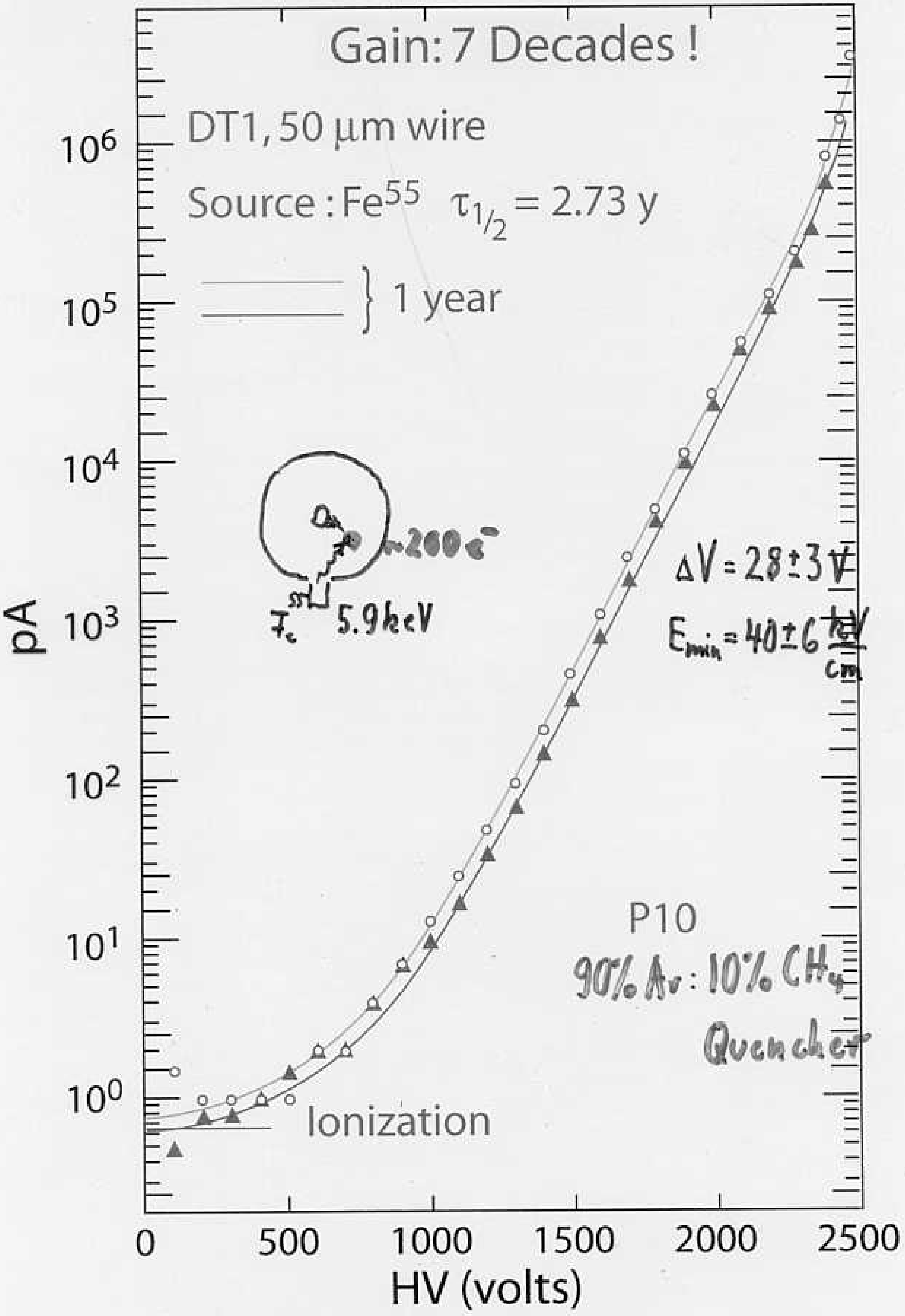
SOLUTION	$\ln G = \frac{\ln 2}{\Delta V}\frac{V}{\ln b/a} \ln\left\{\frac{V}{\ln b/a\, E_{crit}(r_{crit}, p)\cdot a \cdot (p/p_0)}\right\}$

where $\Delta V \approx 33$V is the effective ionization potential

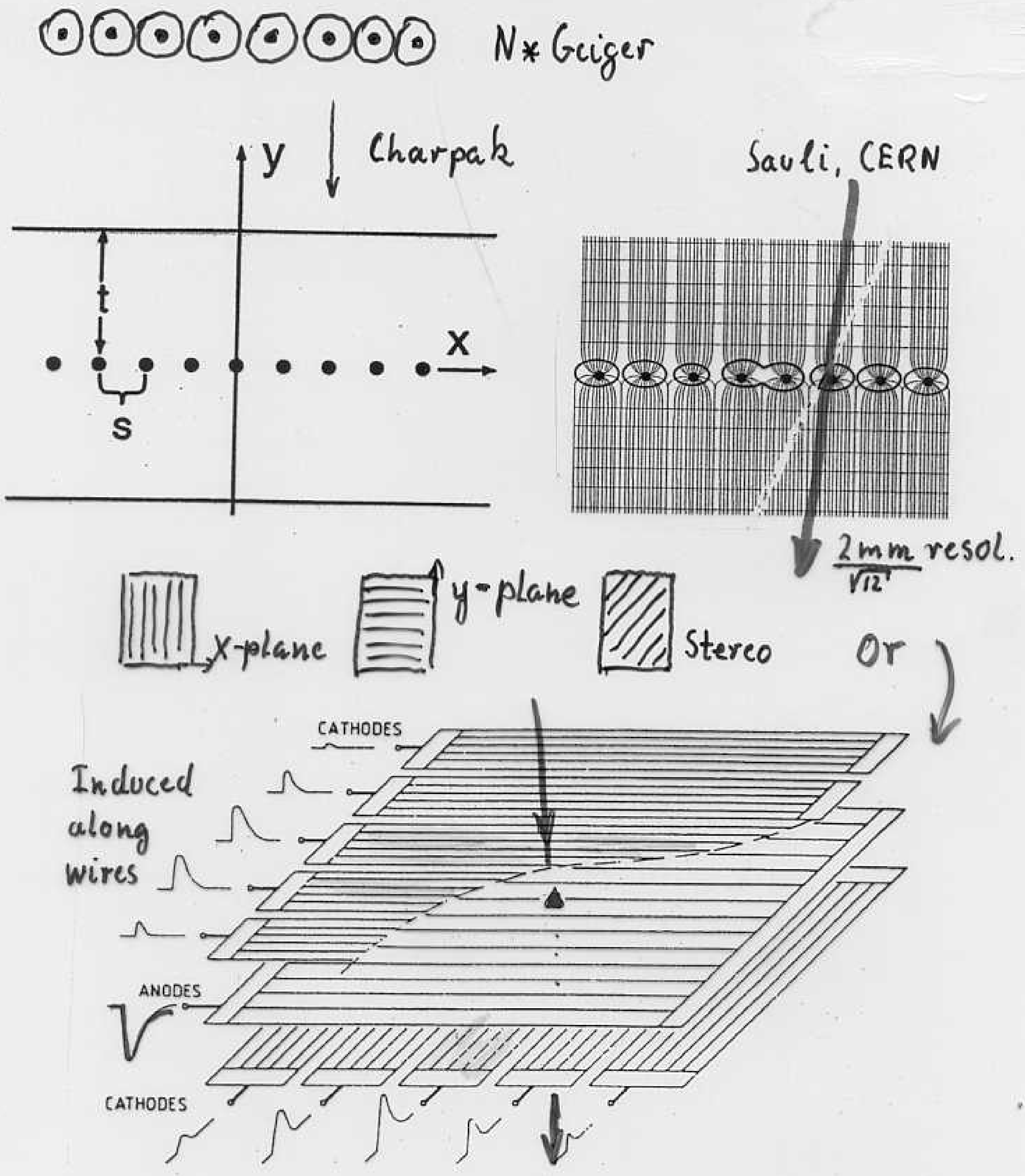
V the applied voltage, p_0 the reference pressure,

$E_{crit}(r, p)$ field where avalanche starts

World record



PROPORTIONAL CHAMBERS

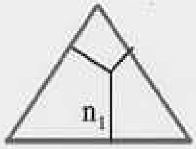


X-Y Cathode Strip Readout (from Charpak)

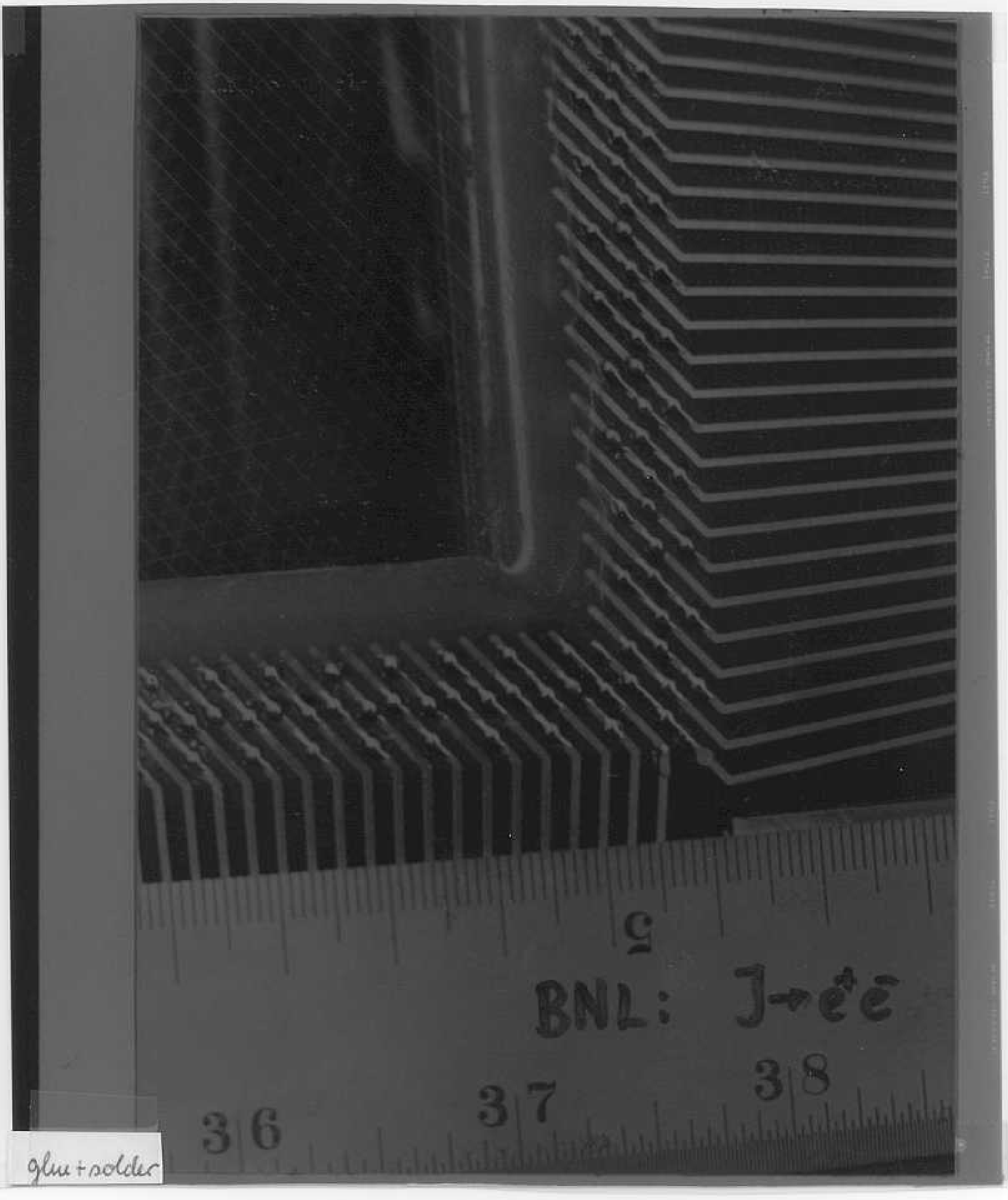
MultiWireProp.Chambers - BNL 598 J-Exp.

3 planes:

2mm

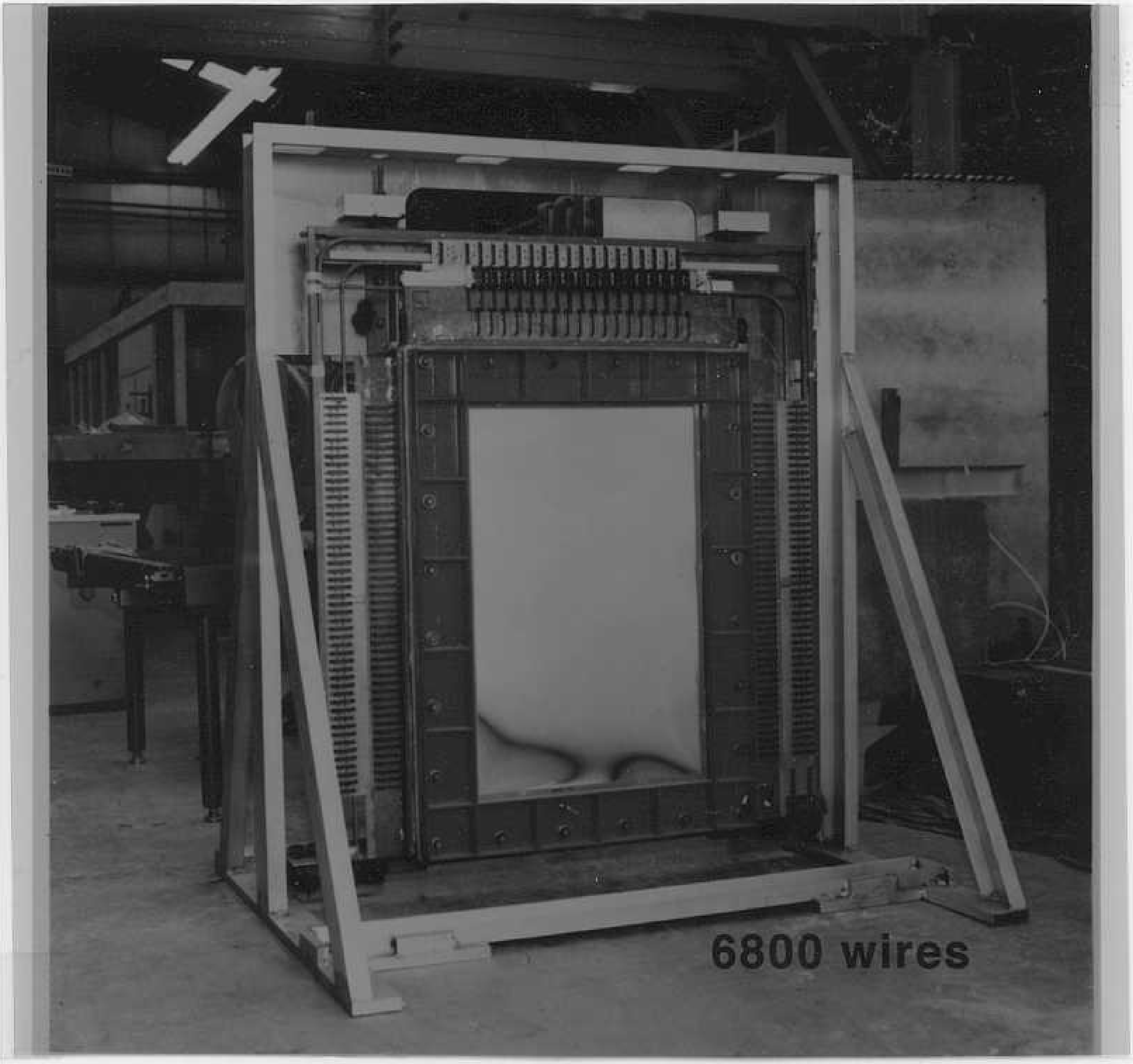


$n_1 + n_2 + n_3 = \text{const}$



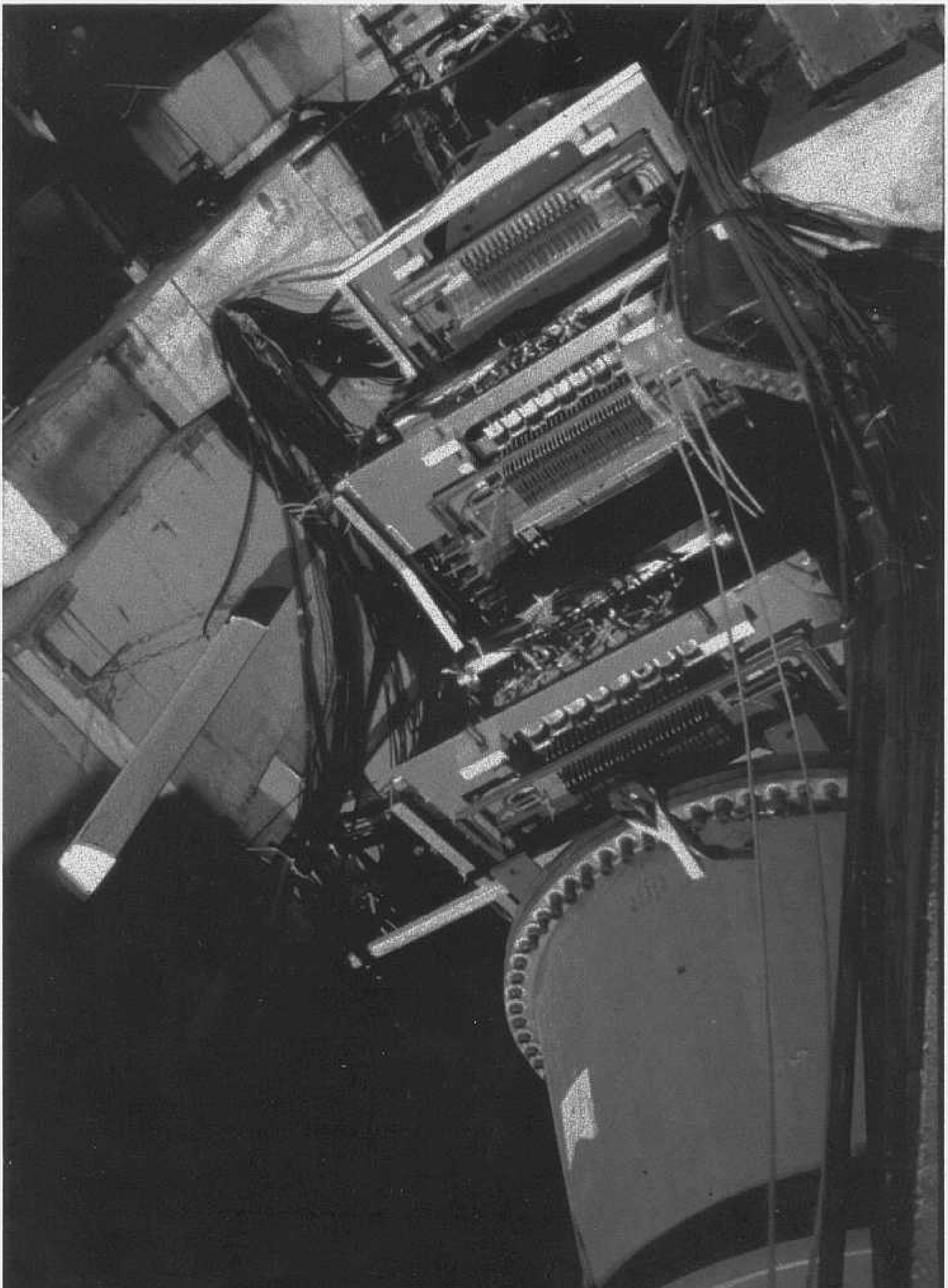
but AGS... $L = 10^{36}$ cm^{-2} s^{-1} Ageing!

Argon-Methylal -> No Ageing!

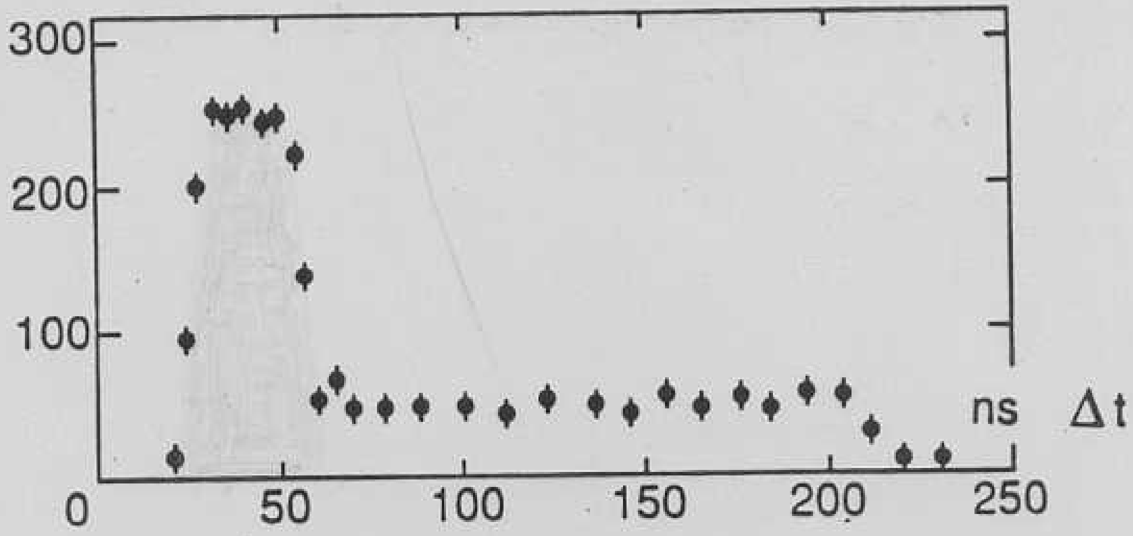


2 Chambers-> Υ - FNAL

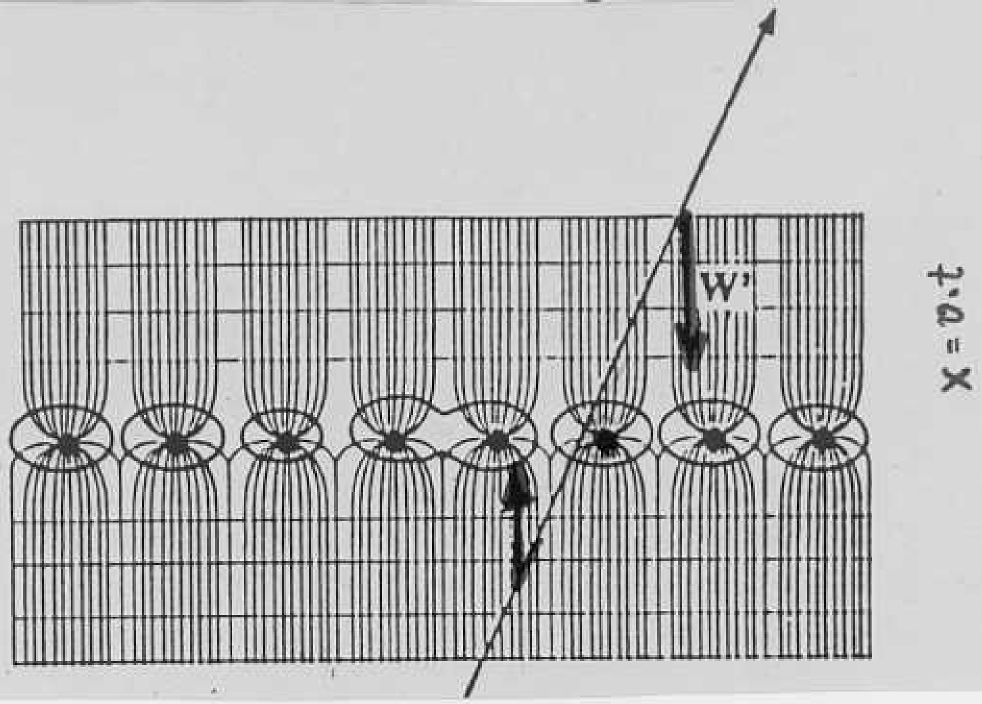
1 Chamber -> Smithsonian



100% eff. But why a tail?



Neighbour wires fire, too, but later
Ionization 'drifts' along E- lines



⇒missed invention of Drift Chamber

A Word on Wirology

See U.Becker "large Area and Muon Detectors" in World Scientific Instrumentation in High Energy Physics (1992),p513-

Mechanical stuff

Parallel to earth all wires sag:

$$z = \frac{\mu g}{T}\frac{x^2}{2}$$

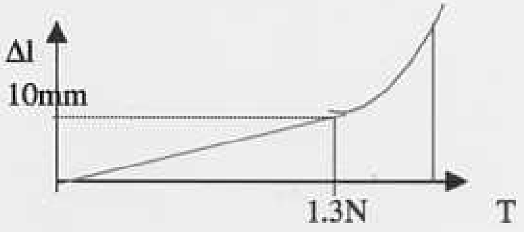
A Tungsten-Rhenium wire of 30 μm dia. (4% Au plated) has 0,138 mg/cm and can be elasticly stretched to 1.3N. For l=3m the sag is:

z_{max} = 117 μm

Sag or tension is easily verified by the resonance frequency. Putting AC between wire and a plate

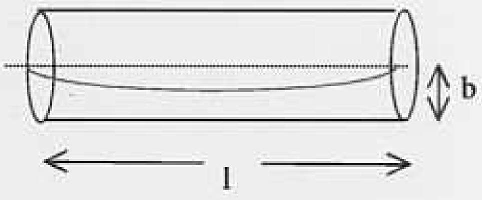
$$\nu = \frac{1}{2l}\sqrt{\frac{T}{\mu}} = \frac{1}{4}\sqrt{\frac{g}{2z_{max}}}$$

Tungsten-Rhenium is the best wire material: ϕ 30 μm



Electrostatic Stability

Putting a Voltage on ~~the~~ a 'sagged' wire in a coaxial Arrangement, makes ~~it~~ worse. It will touch The wall at $U_{max} = 1.43\left[\frac{V^2}{gr}\right]\sqrt{T}\frac{b}{l}\ln\frac{b}{a}$



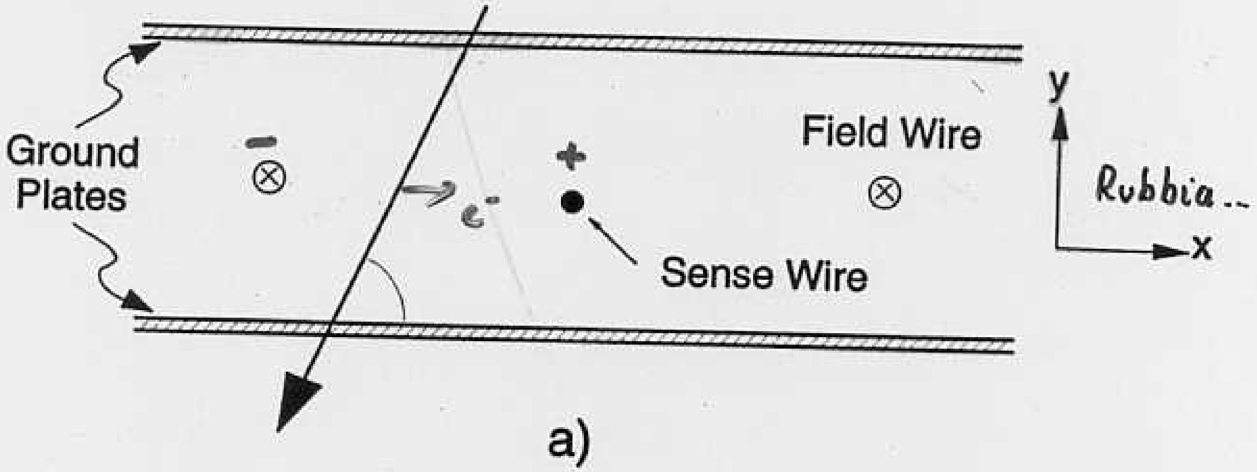
The elstat.displacement grows with init.δ^2!

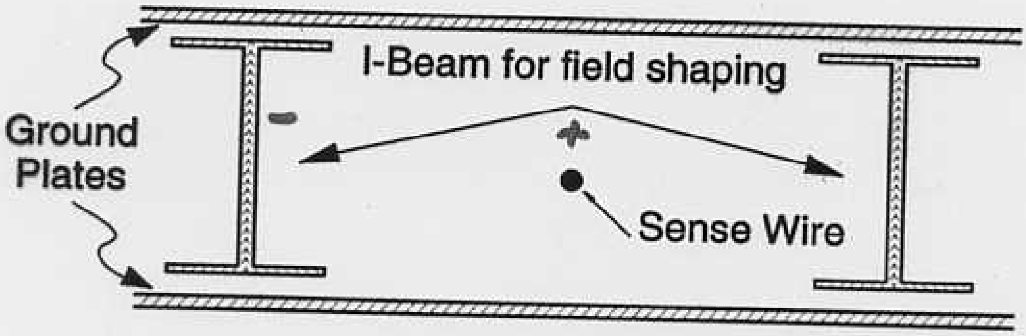
Wire planes get unstable by the degeneracy: Typically for dia.=20μm wires at 60 g and 2.4kV

$l \leq 80$ cm

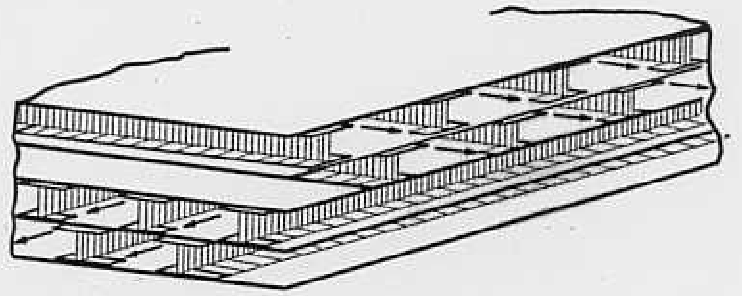
DRIFT CHAMBERS

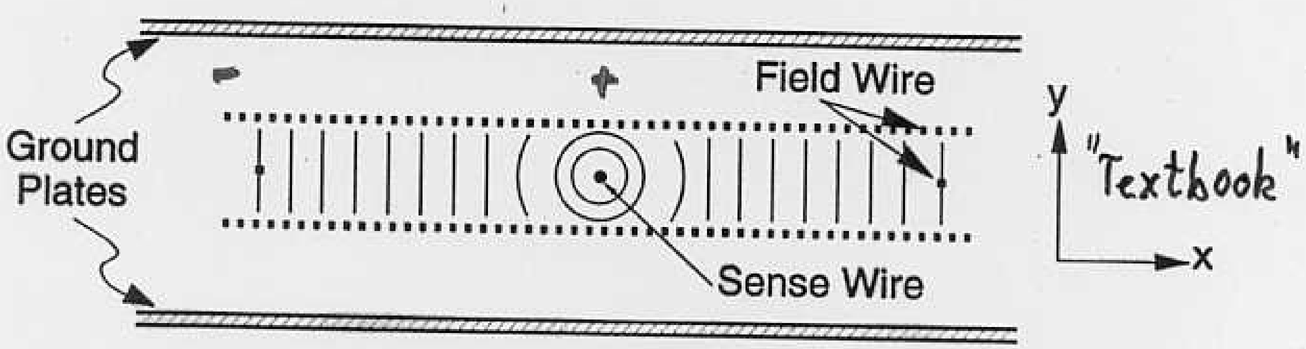
Instead 1 wire / 2 mm → 1 wire / 10 cm → large coverage!





Becher 75
CDF 85
CMS 00

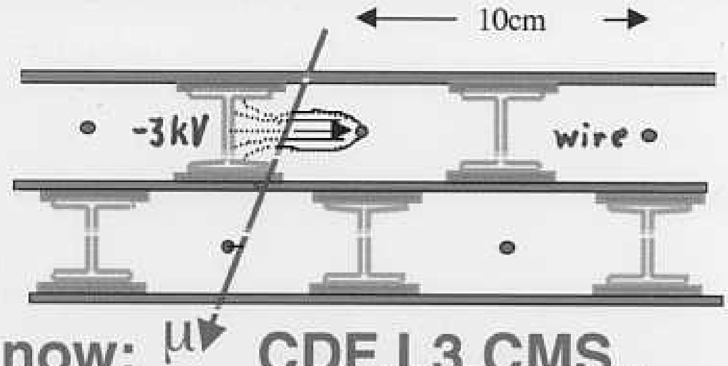




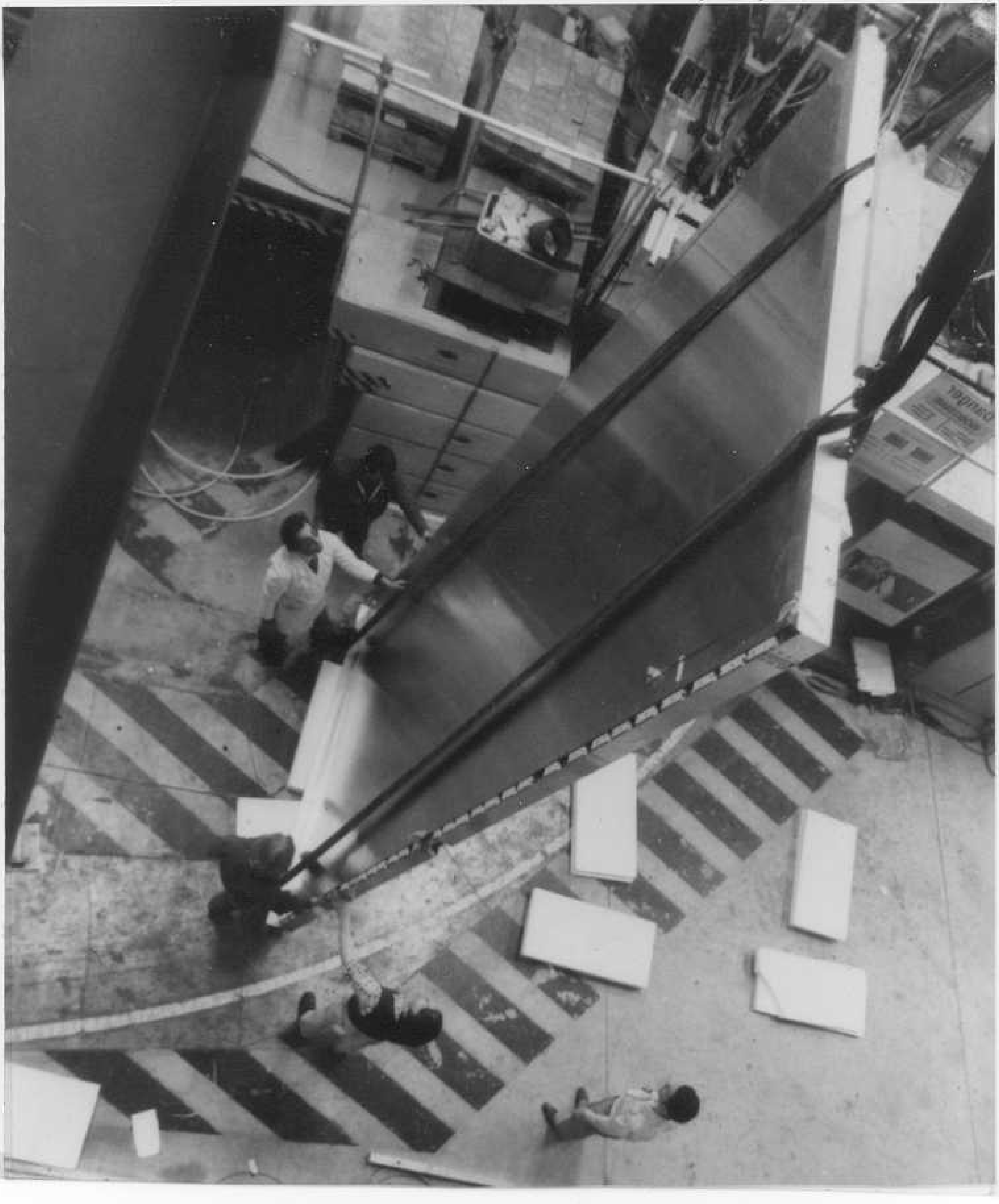
New Design

I - Chamber

6m mechanical
& Fieldshaping
ISR,PETRA



now: CDF,L3,CMS..

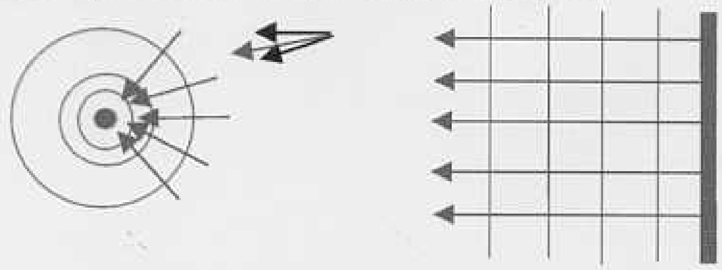


Recall E & M

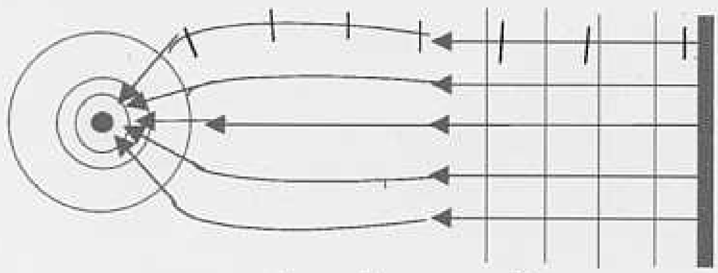
Charges (e) follow field line of E

- Metals are equipotentials ϕ= const
-
-

- E = - grad ϕ
- Superposition valid at all points



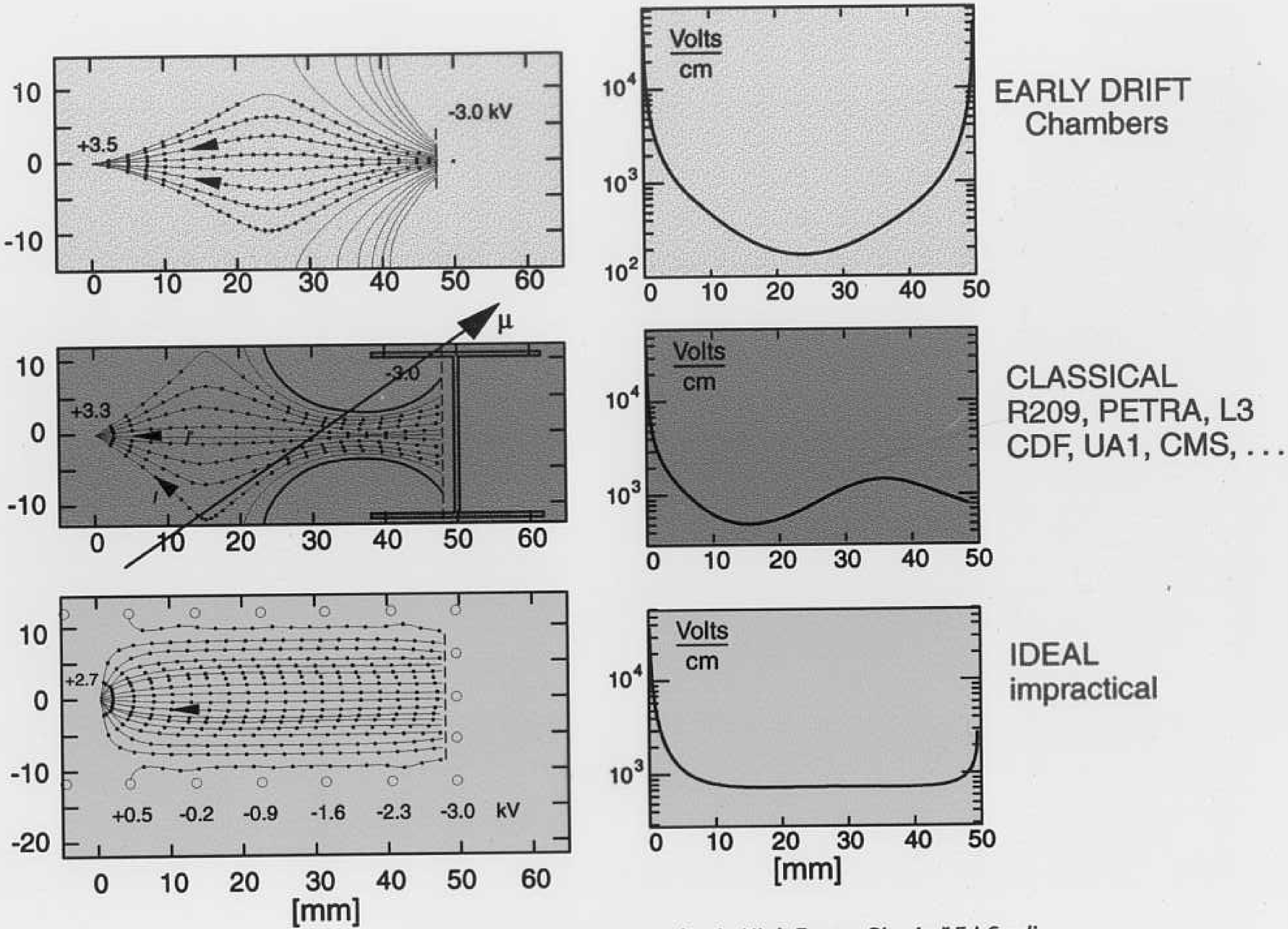
Continuous functions



Laplace - Poisson

$$\nabla^2 \phi = 0, 4\pi\rho$$

Programs: Maxwell Garfield ....



U. Becker in "Instrumentation in High Energy Physics" Ed. Sauli
World Scientific, Adv. Series, Vol.9, (1998) 513

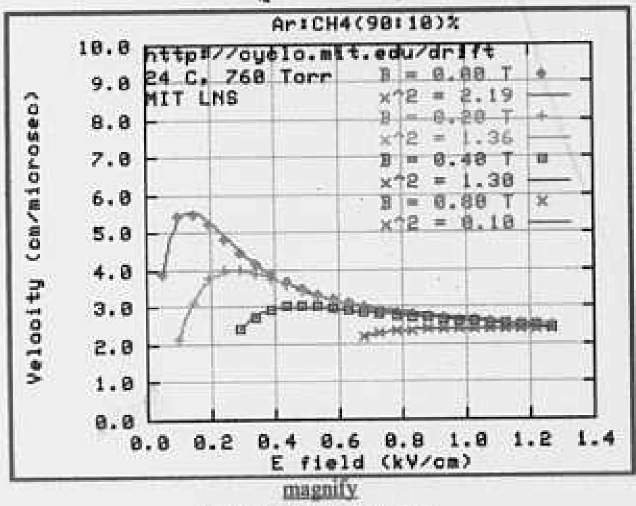
Becker 17_16 Col

Data you requested from Drift Gas R&D Home Page

If used, please reference: "U. Becker et. al. Gas R&D Home Page (http://cyclotron.mit.edu/drift)"

Ar

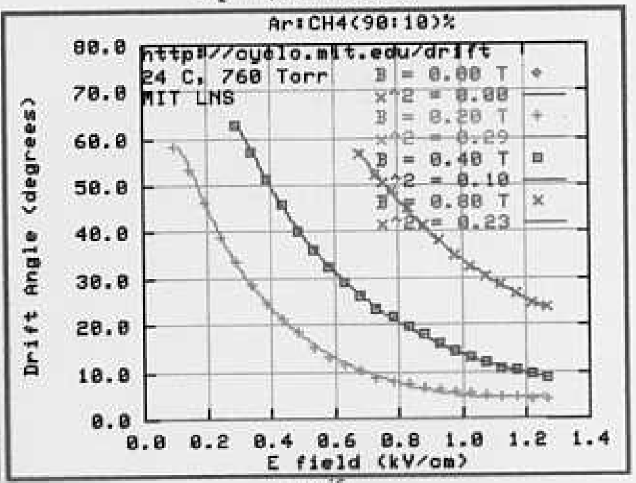
V (parallel to E)



magnify

Postscript Velocity graph

alpha (relative to E)



magnify

Postscript Angle grapha

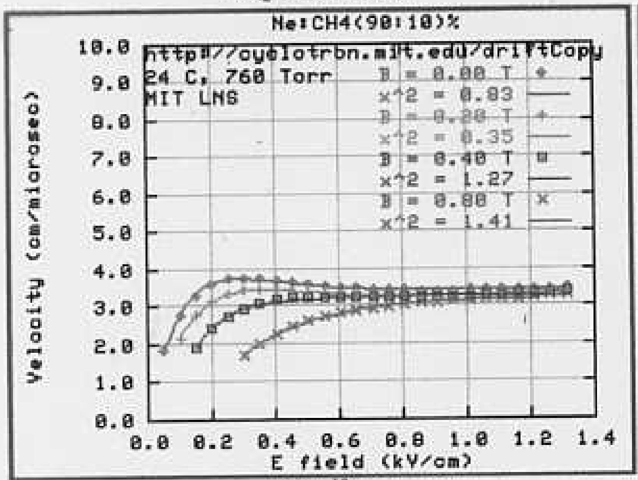
$V_{||}=U_1(1-e^{-(E-a_1)/E_1})+U_2(E-a_1)e^{-(E-a_1+a_2)*E_2}+W(E-a_1)$

$\sin(alpha)=V_{||}B/(10*E)+P_1+P_2*E+P_3*E^2$

B(T)	U_1	E_1	U_2	E_2	W	a_1	a_2	X^2/dof	P_1	P_2	P_3	X^2/dof
0	3.523	0.10	85.932	9.80	-0.834	0.000	0.000	2.19	0.000	0.000	0.000	0.000
0.2	2.532	0.17	35.640	5.91	0.000	0.041	0.000	1.36	0.487	-0.841	0.388	0.290
0.4	3.236	0.06	0.000	0.00	-0.752	0.203	0.000	1.30	0.855	-1.124	0.400	0.101
0.8	2.411	0.07	0.000	0.00	0.000	0.499	0.000	0.10	1.287	-1.293	0.372	0.235

Ne

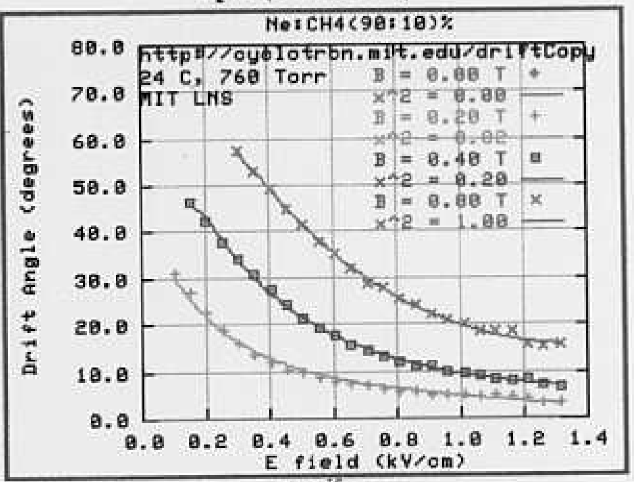
V (parallel to E)



magnify

Postscript Velocity graph

alpha (relative to E)



magnify

Postscript Angle grapha

→ better

Detector R&D at MIT

U. Becker, P. Fisher, K. Ensslin, J. Thompson*,
T. Fazio*, R. Henning, B. Demirköz, J. Lue, M. Sekora,
E. Rhode, S. Yue, J. Pate, B. Stacey
*graduated, 2002

Drift MWPC

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drift gas

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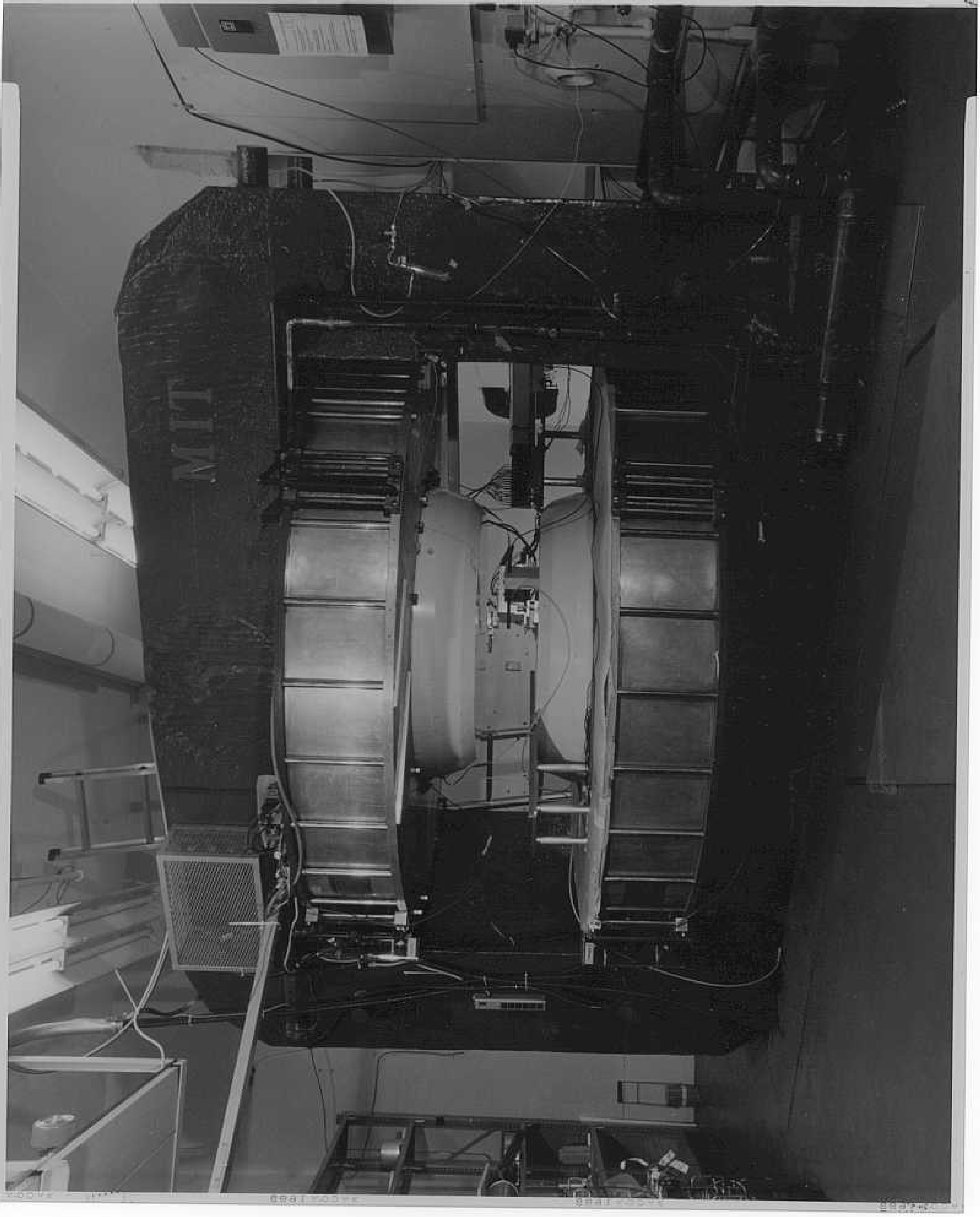
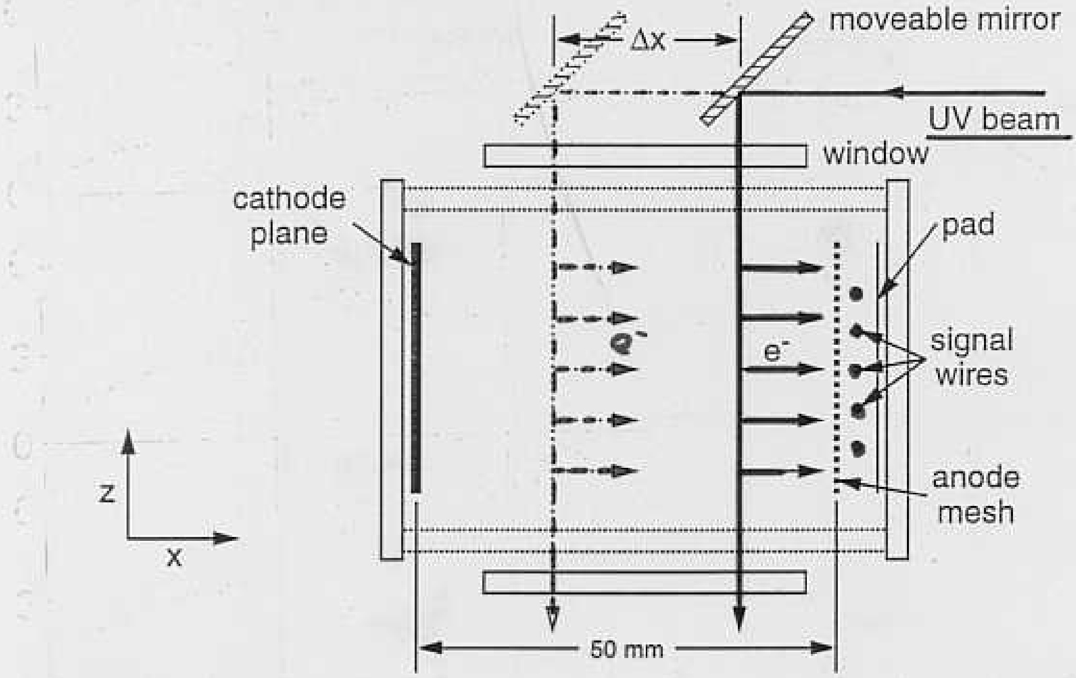
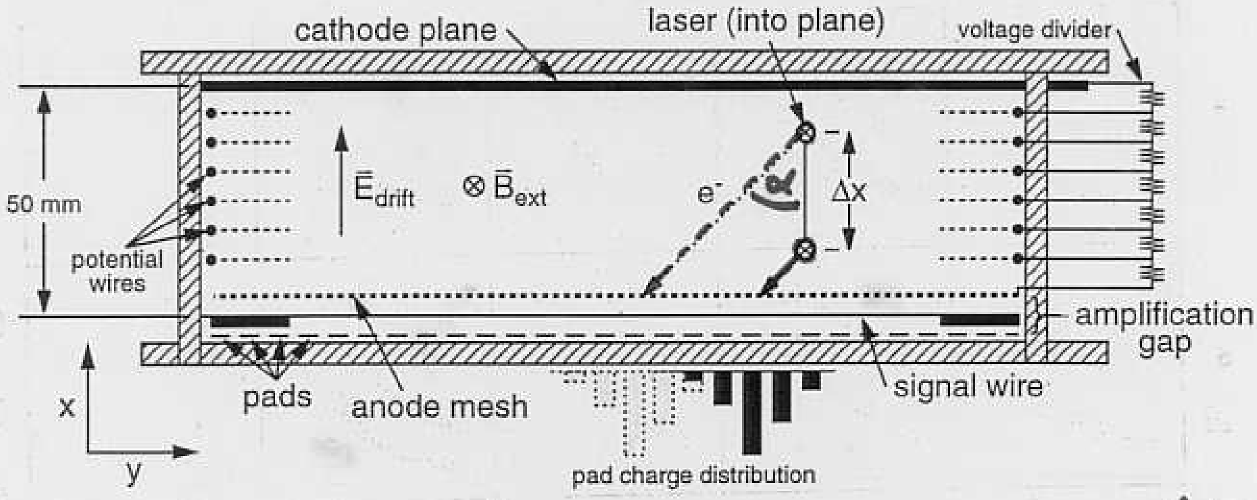
⟶ 773+ drift gas mixtures on the web


MIT

$v_\parallel - \alpha$ Measurement



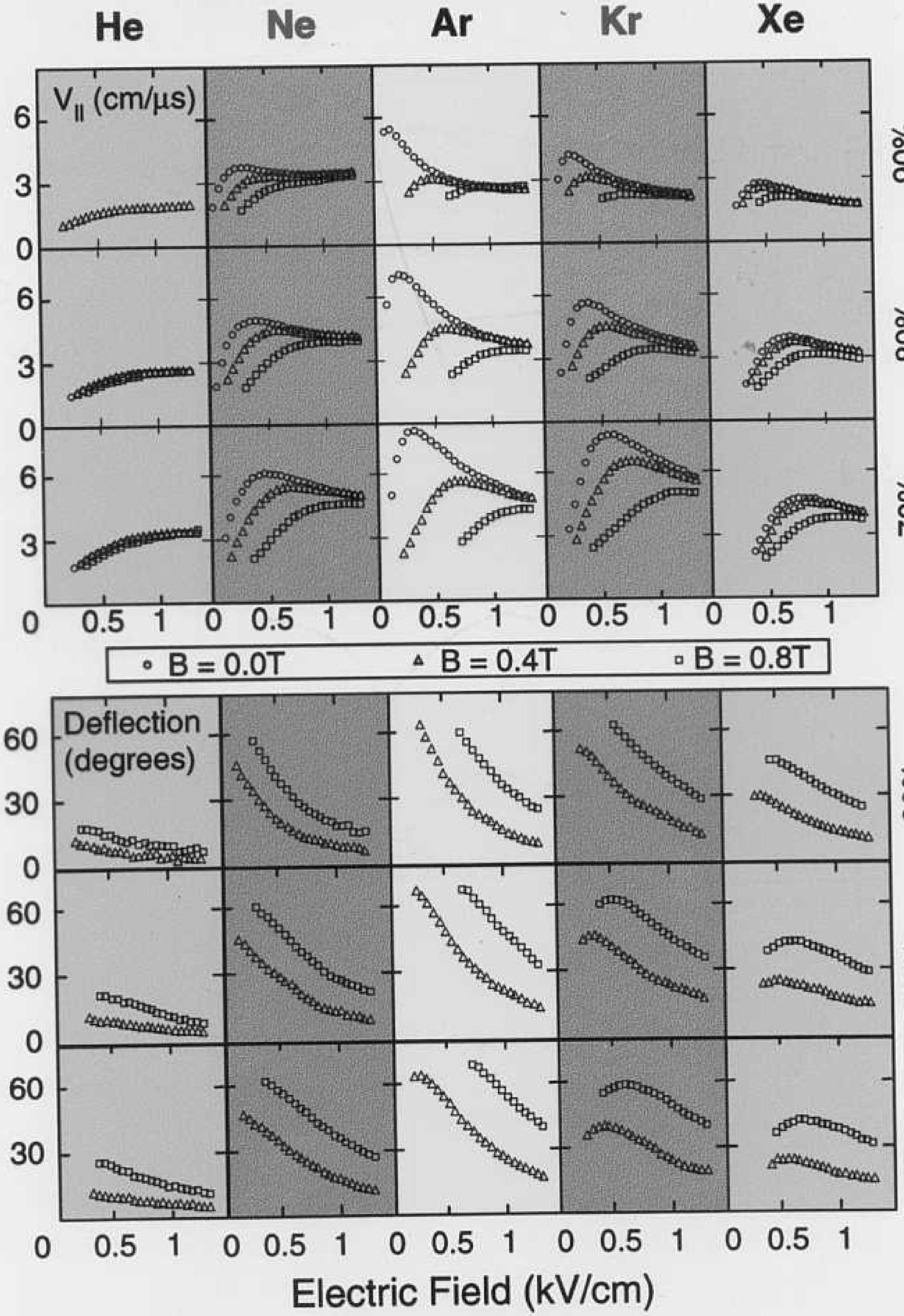
$$v_\parallel = \frac{\Delta x}{\Delta t}$$



$$\tan\alpha = \frac{\Delta y}{\Delta x}$$

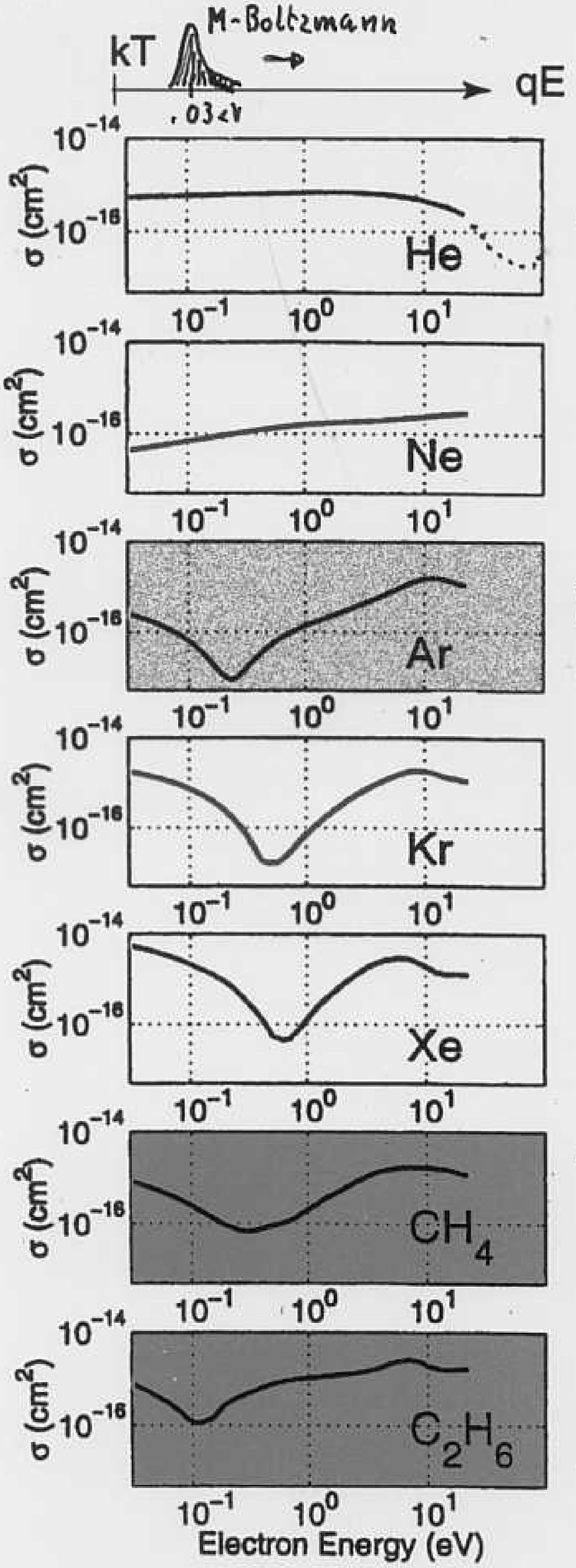
Differential → ACCURATE

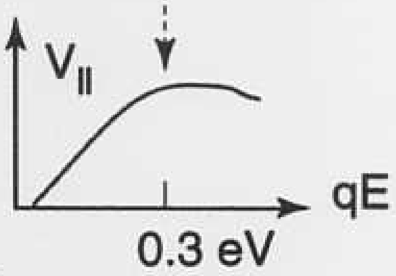
Noble Gases: V (B), α (B)



y2K190Becker

Use	Cross Section	Effect
		V_D ≈
Low X_0	He	σ large -> slow
TPC Expensive	Ne	odd medium
Cheap	Ar	Ramsauer fast
Calorimeter	Kr	Minimum
TRD	Xe	
	CH_4, C_2H_6	Quencher absorbs UV STOP





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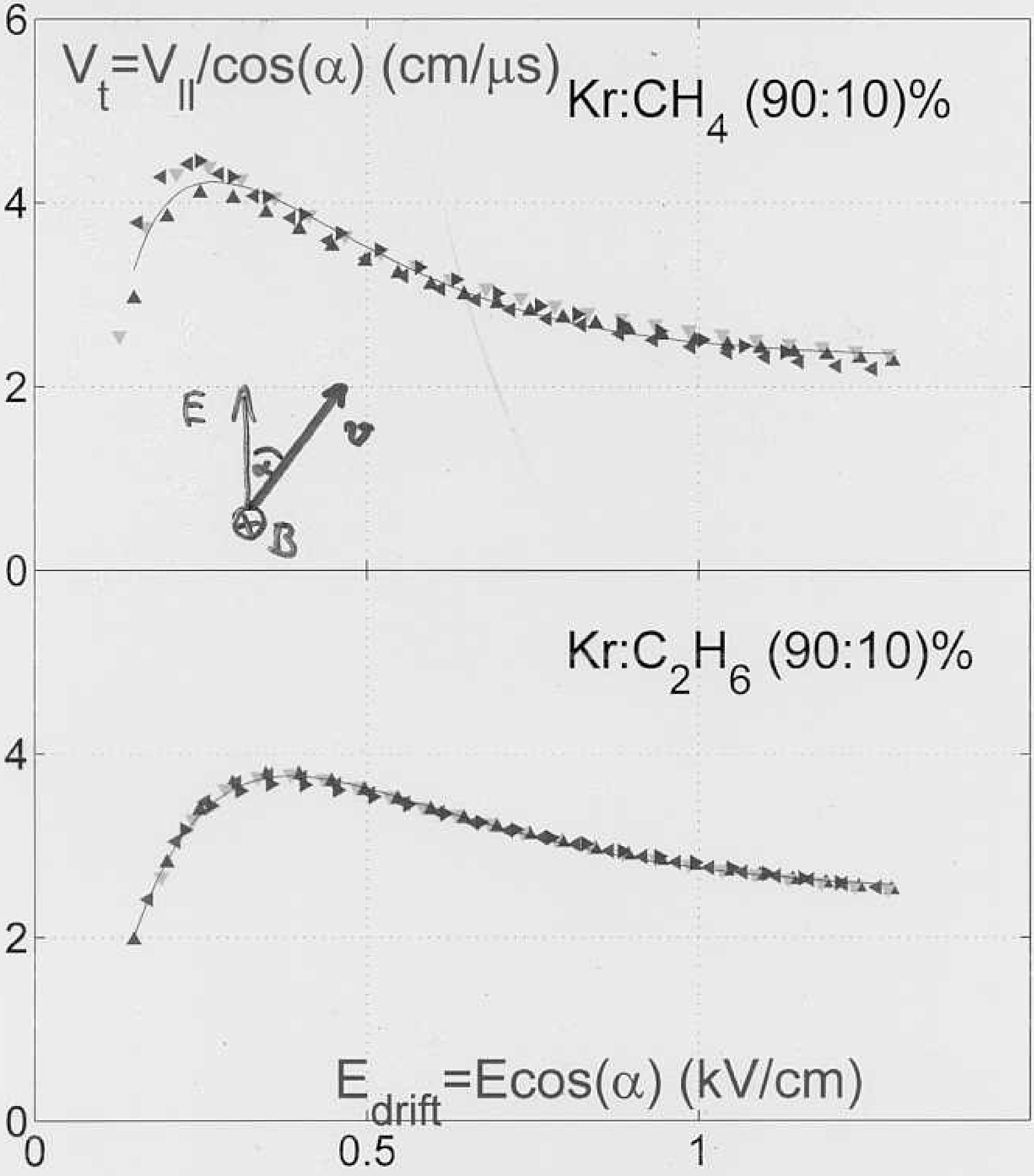
"Universal Curve" describes all $\vec{B}$ data



Universal Fit Information

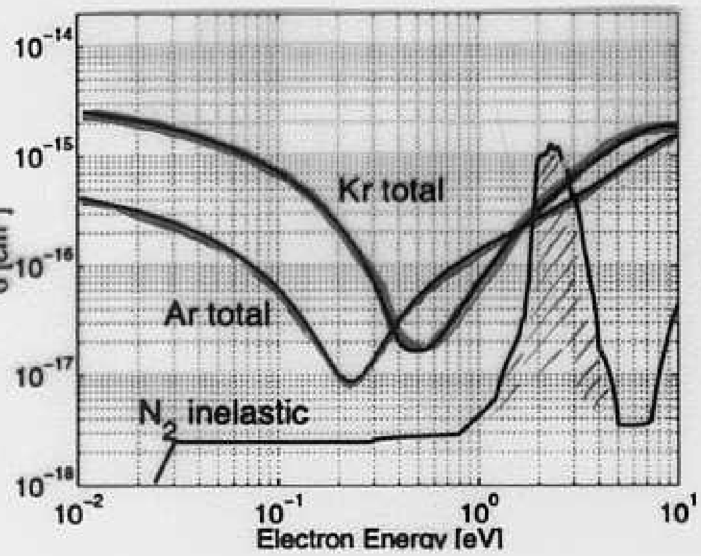
$$V_t=U_1(1-e^{-(E_d-\varepsilon)/E_1})+U_2(E_d-\varepsilon)e^{-(E_d-\varepsilon+\varepsilon_2)^{*}E_2}+W(E_d-\varepsilon)$$

B(T)								
0.0 ▲								
0.2 ▼	1st:	U_1= 2.3	E_1= 0.033	U_2= 29	E_2= 5.6	W= 0	ε= 0.086	ε_2= 0
0.4 ◀								
0.8 ▶	2nd:	U_1= 2.5	E_1= 0.21	U_2= 26	E_2= 4.8	W= 0	ε= 0.079	ε_2= 0

Reduce Data and Interpolate!!!

Understanding the Influence of Cross Sections

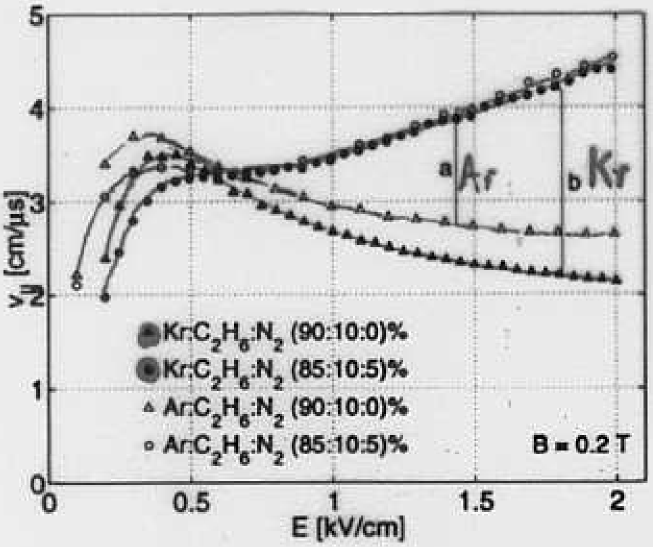
Example:



N_2 moderates e^- energy into minima

⟶ increase of $v_{\|}$

Proof of Understanding:



Kr has larger effect.

Ref: E. Fortunato, U. Becker, R. Dinner. Understanding the impact of additives with large inelastic cross-sections on drift chamber performance. NIM A421 (1999), 278-283.

⟶ Tailor Features of Drift Gas

4. Consider a normal drift tube working in proportional mode. at G = 10^3. You increase the voltage (gain) on the wire.

a) What will limit the Gain eventually√

b) What is the function of the quencher?

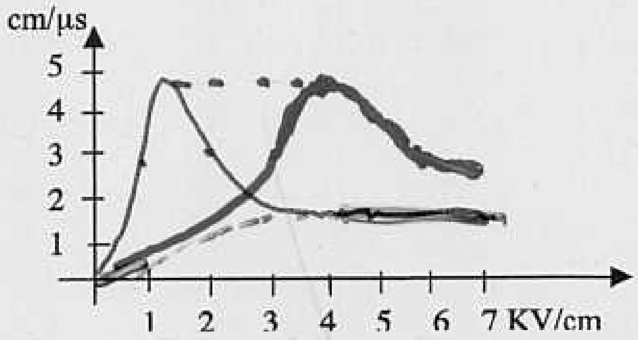
a) 

Backward propagation of UV from the avalanche

- proportional region
- streamer mode
- Geiger mode
- Spark ↯

b) Supress UV.

2.You are given the drift velocity in a gas at 1 atm as shown below.



a) Sketch the expectation for 3 atm.
b) A magnetic field of 0.5T is turned on and the electrons by the Lorentz force are deflected by tanα = .77 (vxB)/E. Roughly how would the curve look then√

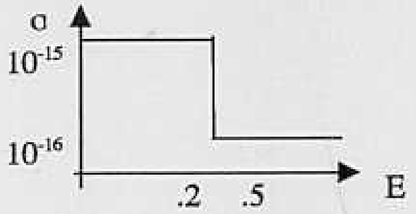
a) E/p scaling → $E' = 3E_0$

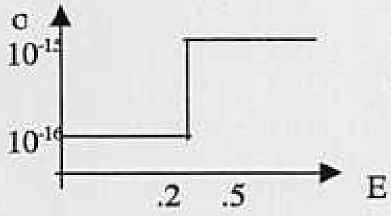
b) $E \to \infty$ $\tan\alpha \to 0$ $E\cos\alpha \sim E$

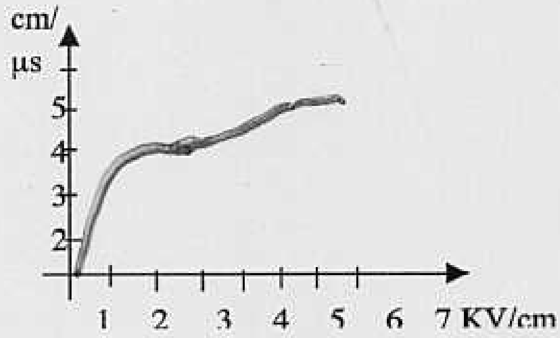
$E \to 0$ $\tan\alpha \to \infty$ $E\cos\alpha \to 0$

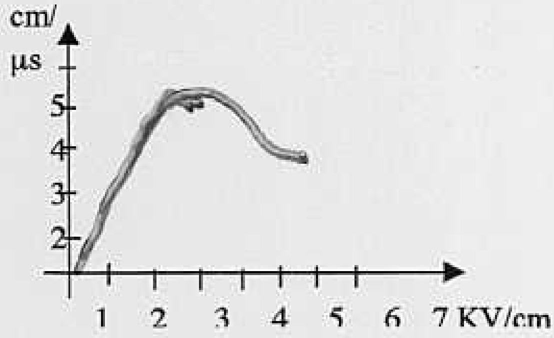
$K \cdot \frac{v \times B}{E}$

3.Given the following cross sections for electrons in a hypothetical gas, sketch
Your guess of a drift velocity vs e (orE/p).









Quick Check

1. If a minimum ionizing particle leaves in Argon at 1 atm 90 e^-/cm in 20 clusters behind as a "track memory", a) what would expect in Helium?
b) Estimate the efficiency of a 0.5 cm parallel plate counter.

a) Bethe-Bloch

$$-\frac{dE}{dx} = k z^2 \left(\frac{Z}{A}\right) \frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2 m_e c^2 T_{max} \beta^2 \gamma^2}{I^2} - \beta^2 - \frac{\delta}{2}\right]$$

$$\frac{Z_{He}}{Z_{Ar}} = \frac{2}{18} \rightarrow \quad N_e \sim 90/9 = 10 \quad (16)$$

$$N_{cl} \sim 20/9 = 2.2 \quad (5)$$

b) Relevant: clusters

Probability to have <u>no</u> cluster in 0.5 cm

$$P(0,\mu) = e^{-\mu d} = e^{-\frac{2.2}{2}} \approx ~~67~~\ 37\%$$

(91%)

$$E_{ff} \quad 1 - e^{-\frac{2.2}{2}} \approx 67\%$$