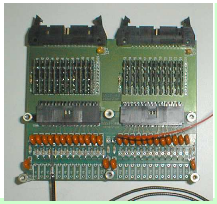
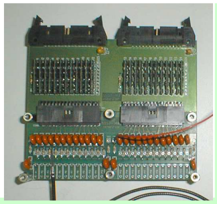


The Drift Chamber,
D. Peterson

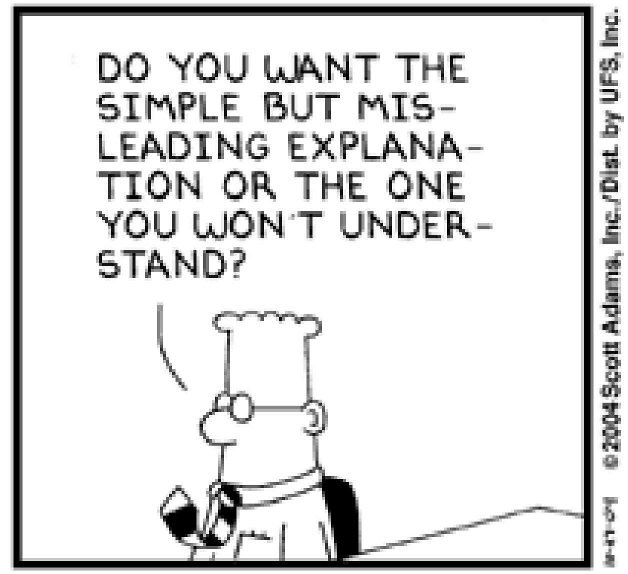
topics
- physical description
  - container, wires, cell, gas, electric field, magnetic field
- track momentum measurement
  - measurement error, scattering error,
  - z measurements with stereo wires
- basic signal generation
  - ionization,
  - electric field, drift, gasses,
  - avalanche
- observable signal
  - electron motion, ion motion,
  - Sauli, amplifiers,
  - discriminator basics,
  - time measurement basics,
- resolution limit in the inner third (at the wire)
  - ion statistics,
  - noise, amplification,
  - discrimator threshold,

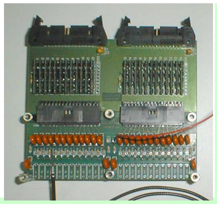


advanced and/or tangential topics

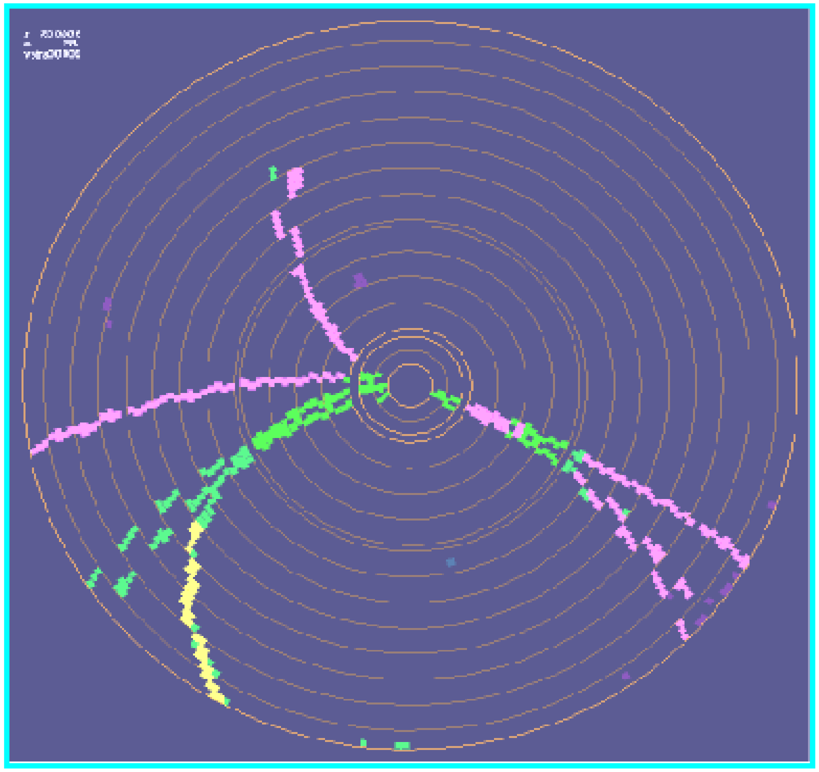
I am not going to talk about…

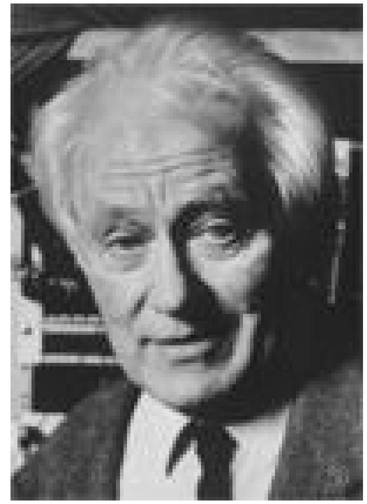
- other topics in signal generation/measurement
  - secondary ionization,
  - diffusion,
  - charge division,
  - Lorentz angle
- other limits on the resolution
  - calibration,
  - construction techniques,
  - alignment,
  - electric field asymmetry,
  - cell distortion in the magnetic field,
  - wire sag, creep, electromechanical instability
  - bunch finding and coordination with the trigger
- alternative chamber designs
  - jet chambers,
    - with and without multi-hit electronics (CDF vs BES)
  - straw tube chambers





Why? Who?

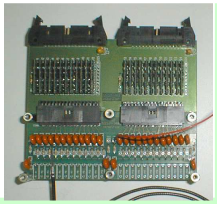




Georges Charpak
Nobel Prize 1992
Invention of the
Multi-wire Proportional Chamber (MWPC)

A "drift chamber" is an adaptation of a "multi-wire proportional chamber" in which the fast timing information is measured to derive precision position information.

In CLEO, we measure the momentum vector (x,y,z) of "all" charged particles in an event.



track measurement

$R^2 = (R-s)^2 + L^2/4$

$R^2 - 2Rs + s^2 + L^2/4$

$s = L^2/8R$

at 1 GeV, P_t=150MeV * (2 R /meter)

$1/(2R)$ = 150MeV / P_t /meter

$s = L^2/4$ * 150MeV/P_t /meter

$\delta P_t/P_t = -\delta s/s$

mult scat : θ=13.6MeV/βcP $(x/X_0)^{1/2}$

$\delta s \sim \theta$, so $\delta P_t/P_t = const/(P_t s) = const_2$

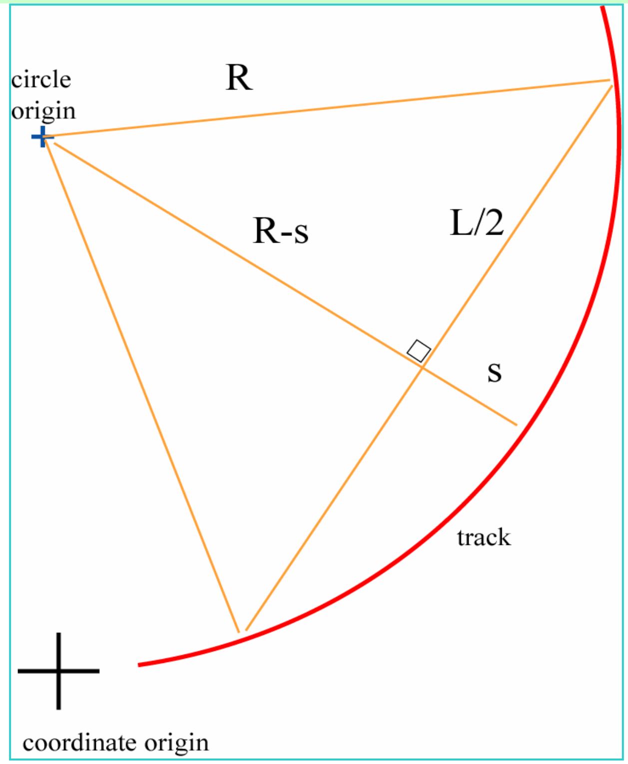
measurement error:

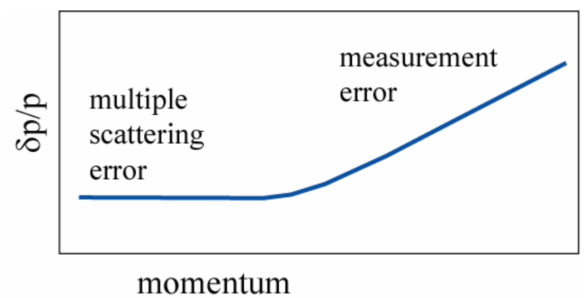
δs is a constant; s^{-1} is proportional to P_t

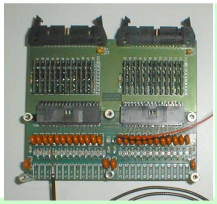
so $\delta P_t/P_t$ is proportional to P_t

and it is proportional to

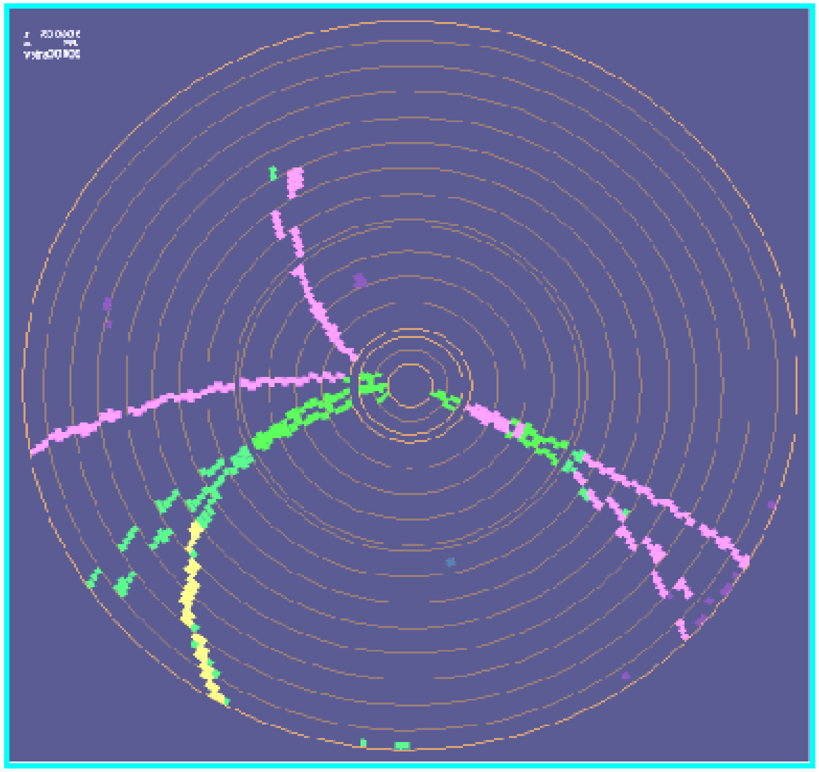
ε, the single measurement error

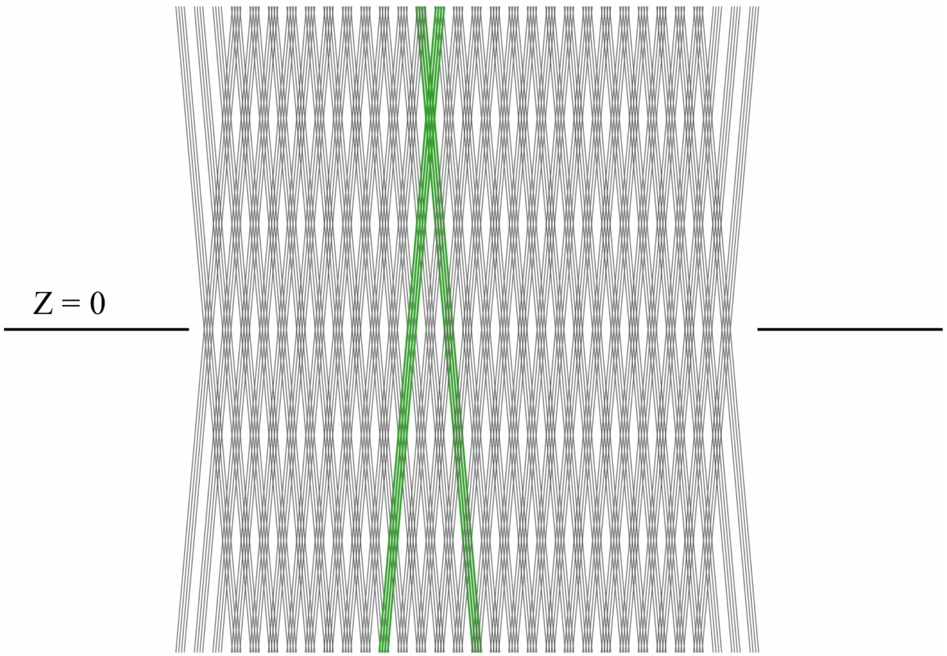




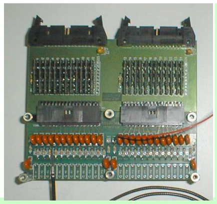


Stereo measurements

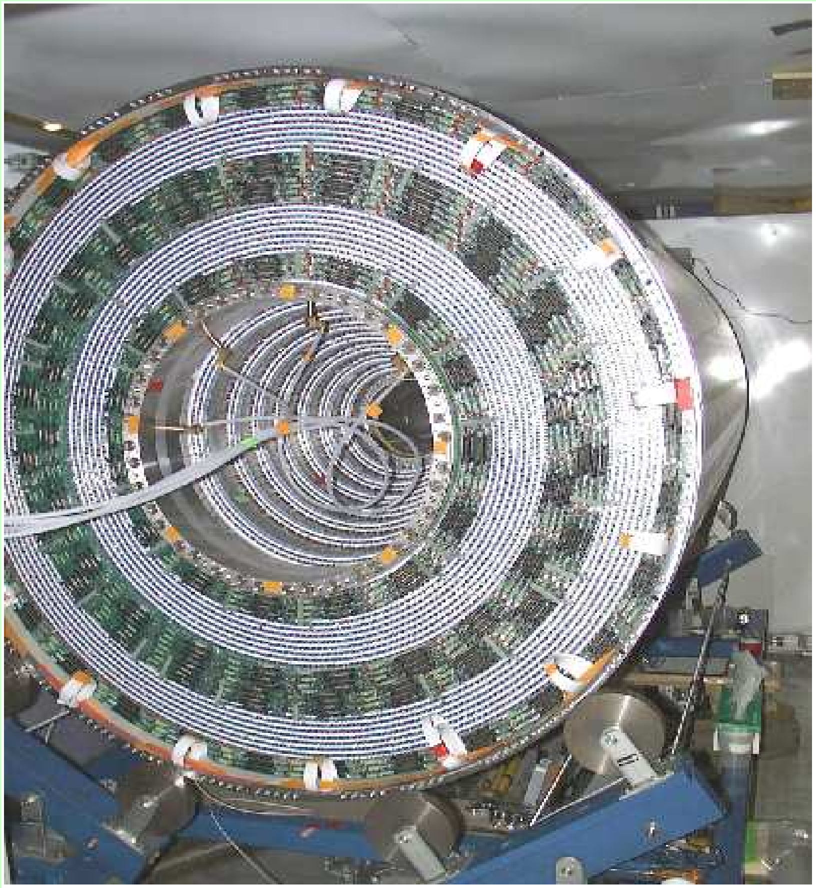




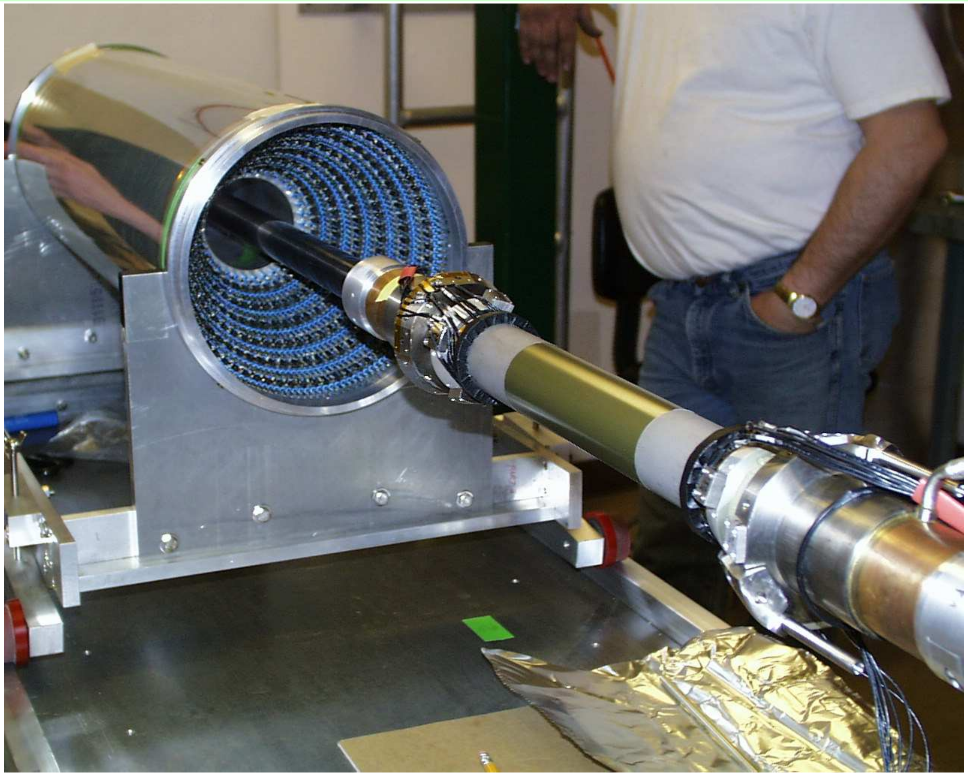
The electronics read-out looks like at 2-dimensional measurement.
The CLEO chambers use stereo wires to measure the z coordinate.
The event displays show you the wire position at z=0.



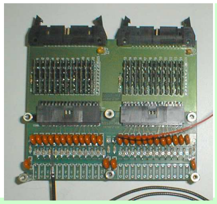
Basic Chamber Construction



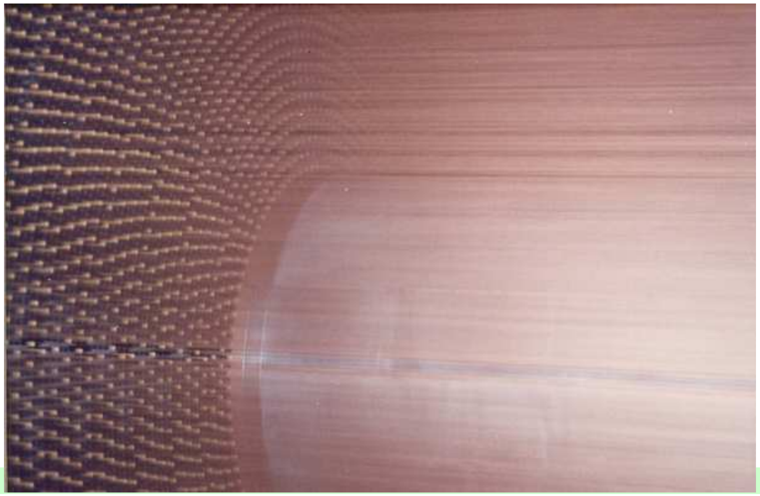
CLEO III/c drift chamber
1999 – present
Design/Construction: 1992 - 1999



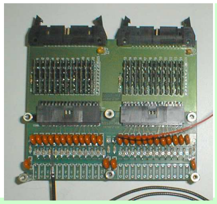
CLEO c inner drift chamber
2003 – present
Design/Construction: 2001 - 2003



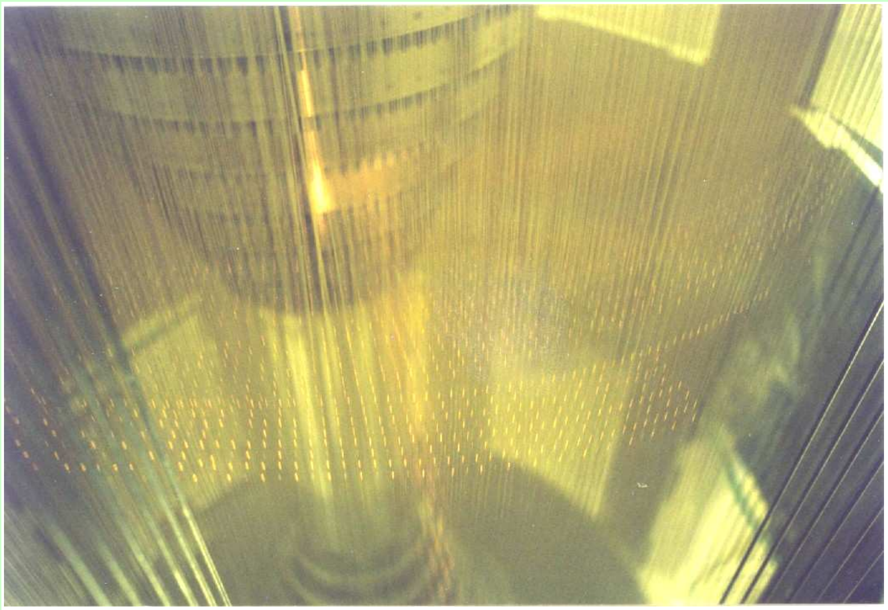
Inside the chambers (DR2)



Wires:
- field wires, .0043 inch aluminum
  110 μm
- sense wires, .0008 inch tungsten
  20 μm



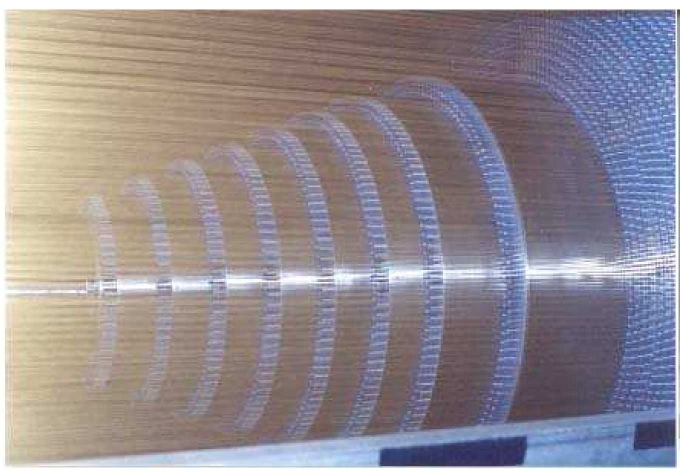
Inside DR3



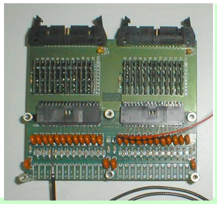
9796 sense wires
29693 field wires (about 3:1)

"wedding cake" structure
individual rings and bands
1696 sense wires

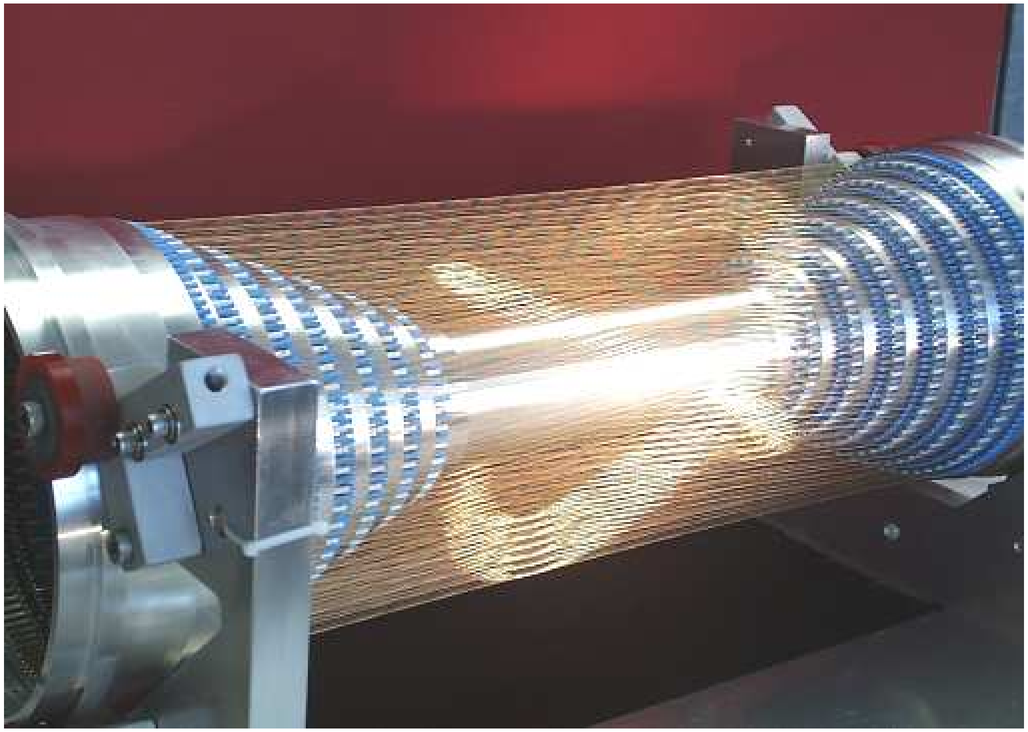
conical "big" end plate
8100 sense wires



outer cathode



Inside the ZD



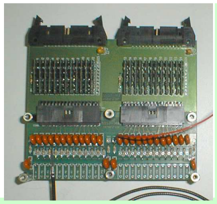
The light patterns show the stereo angle.

300 cells
about 1000 field wires

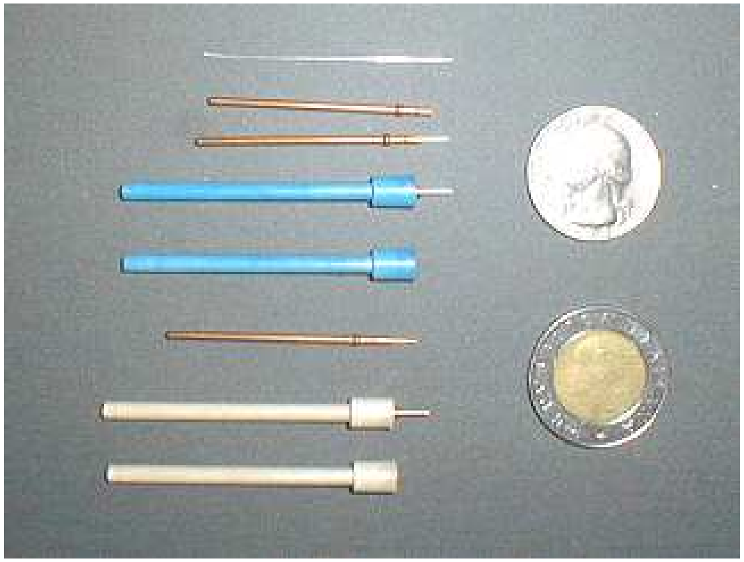
uses the same wires pins
and bushings as DR3

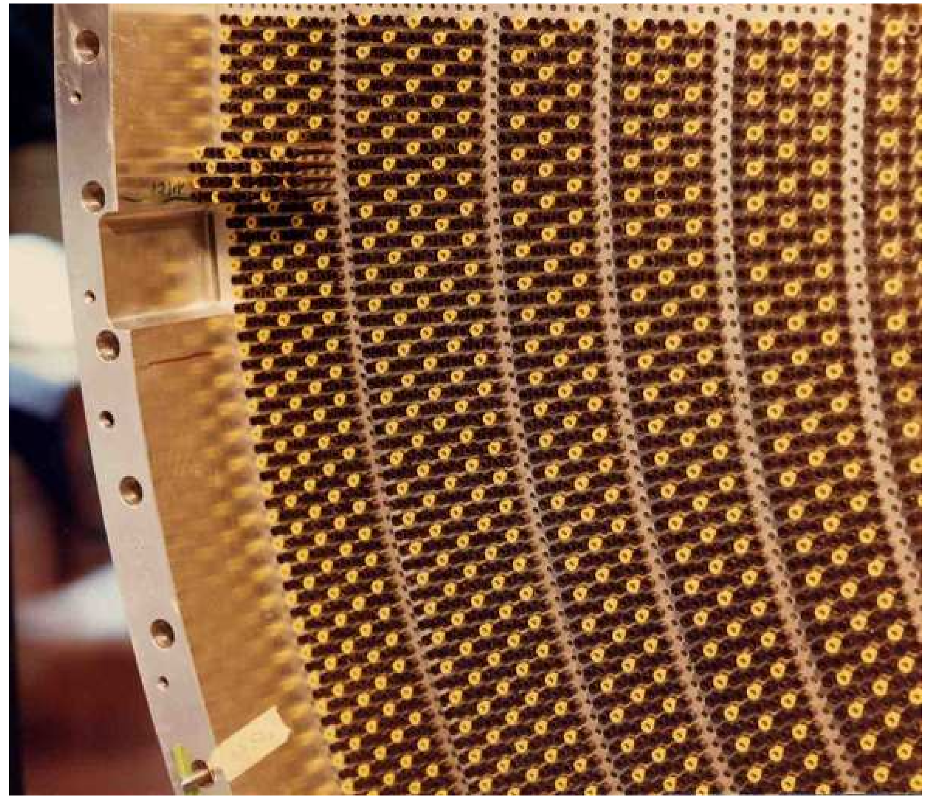
all stereo
this chamber was made to provide
sufficient z measurements
at small radius

the stereo angle is very large,
$d\phi/dz = .1$

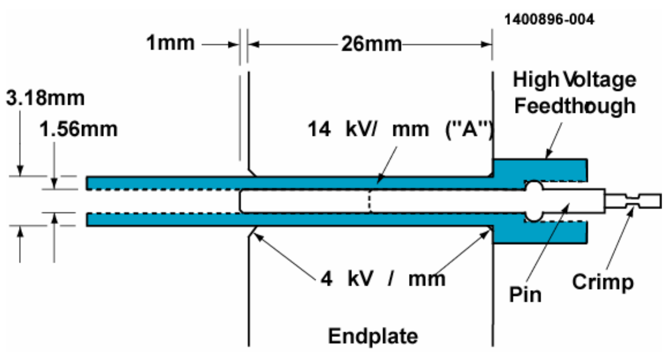


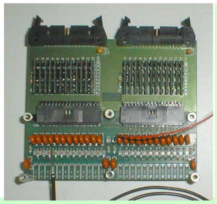
The Cell (visually)



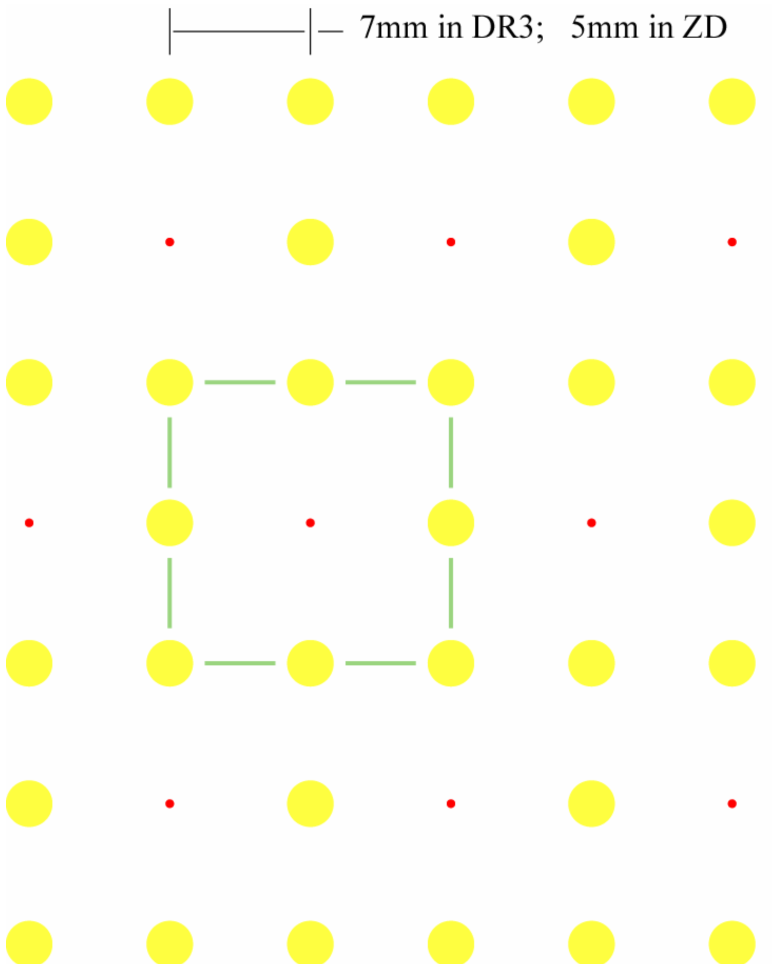


insulating bushings, showing the cell design





The Cell (schematic)



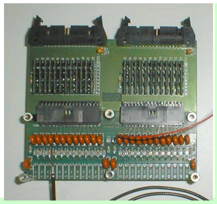
note: wires are shown 21 times actual relative (DR3) size

This is a 3:1 square cell.
Although there are 8 field wires surrounding each sense wire,
the pattern can be build from a basic block with 3 field wires and 1 sense.

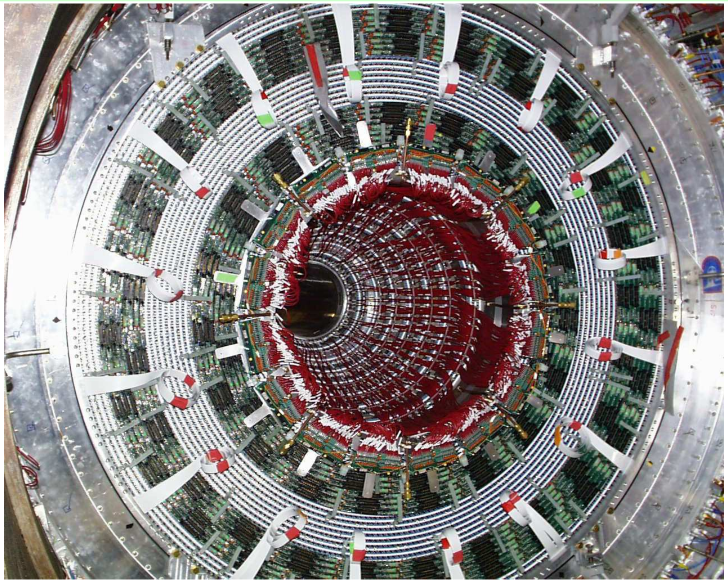
DR3 half cell size: 7mm

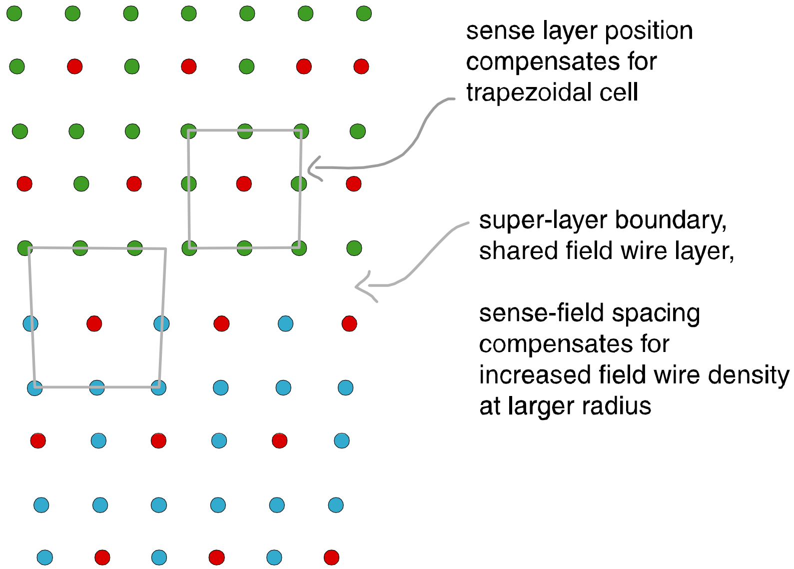
The ZD uses a variation of this wire pattern, 3:1 hex, achieved by shifting the field wire layers by ¼ cell.

CLEO studies in 1994 showed that this modification did not change the response.



Super layers

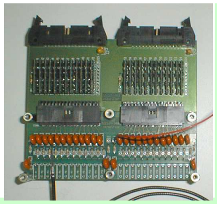




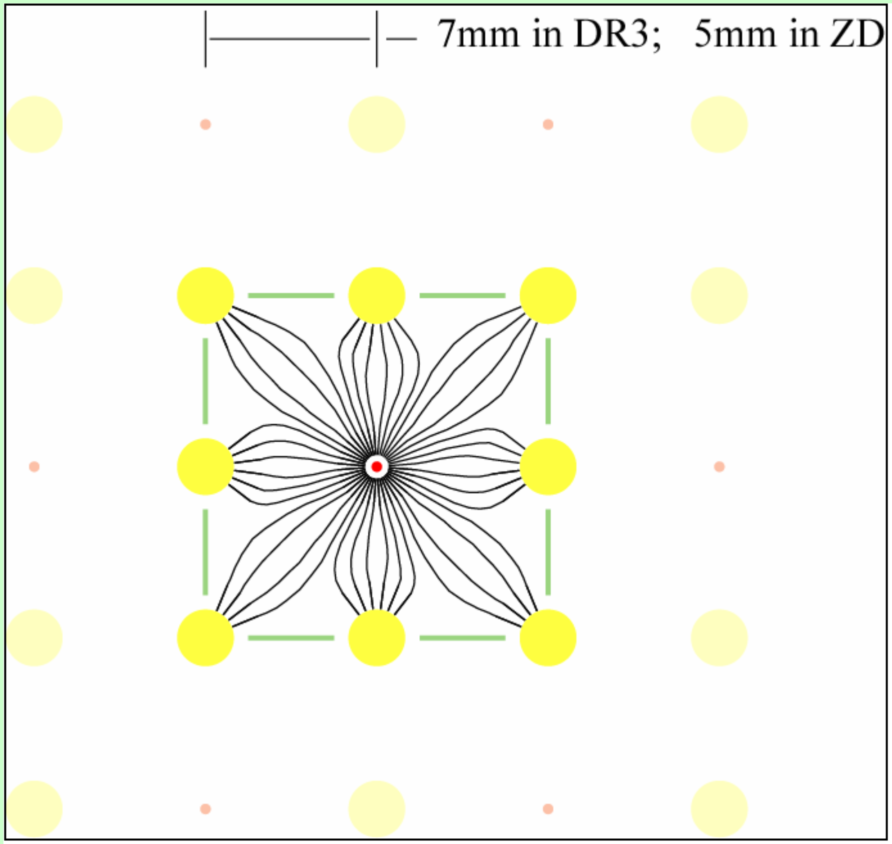
In DR3, the layers are arranged in super layers, with 4 layers/superlayer.
Within the superlayer, there are the same number of wires per layer , half cell stagger.

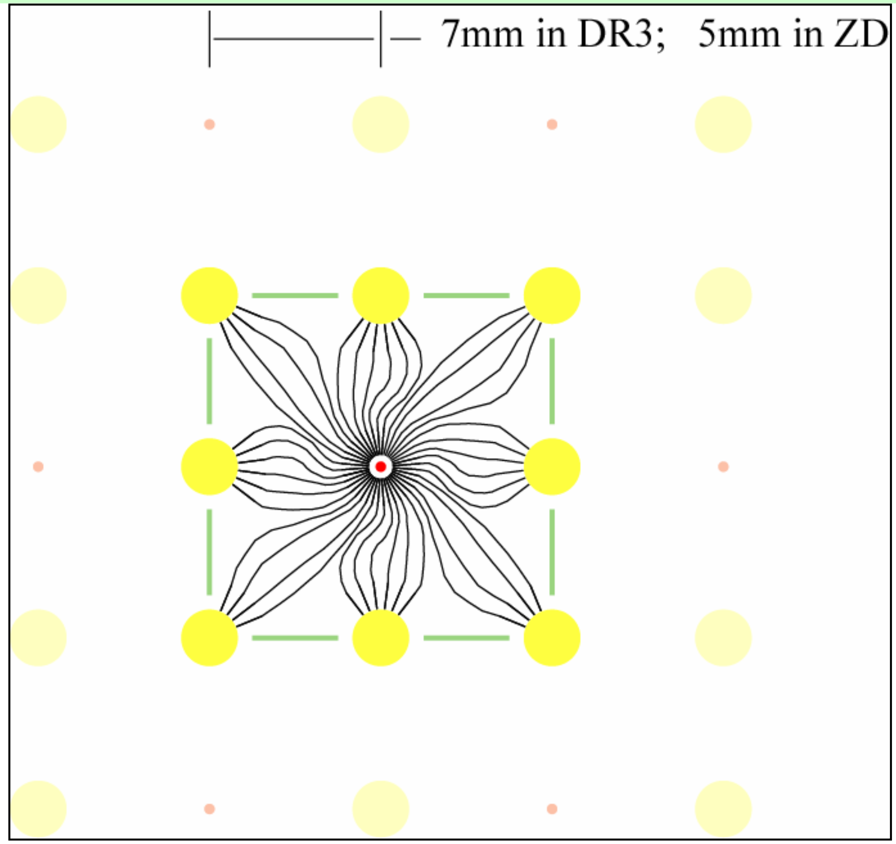
To save space at superlayer boundaries,
the first field wire layer of the larger radius super layer
is also used as the last field wire layer of the smaller radius super layer.

The details won't be discussed here.



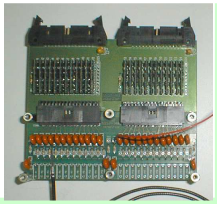
The field cage with electric and magnetic fields





The sense wire is a a potential of
2100V (1900V) in the DR3 (ZD)
Field wires are at ground,
for noise suppression.

Field lines are twisted in a magnetic field.
This leads to many design considerations
and corrections that will not be discussed.



Primary ionization: first step of the signal

A track goes through the gas and ionizes some of the molecules.
How many? Bethe-Bloch isn't very useful.

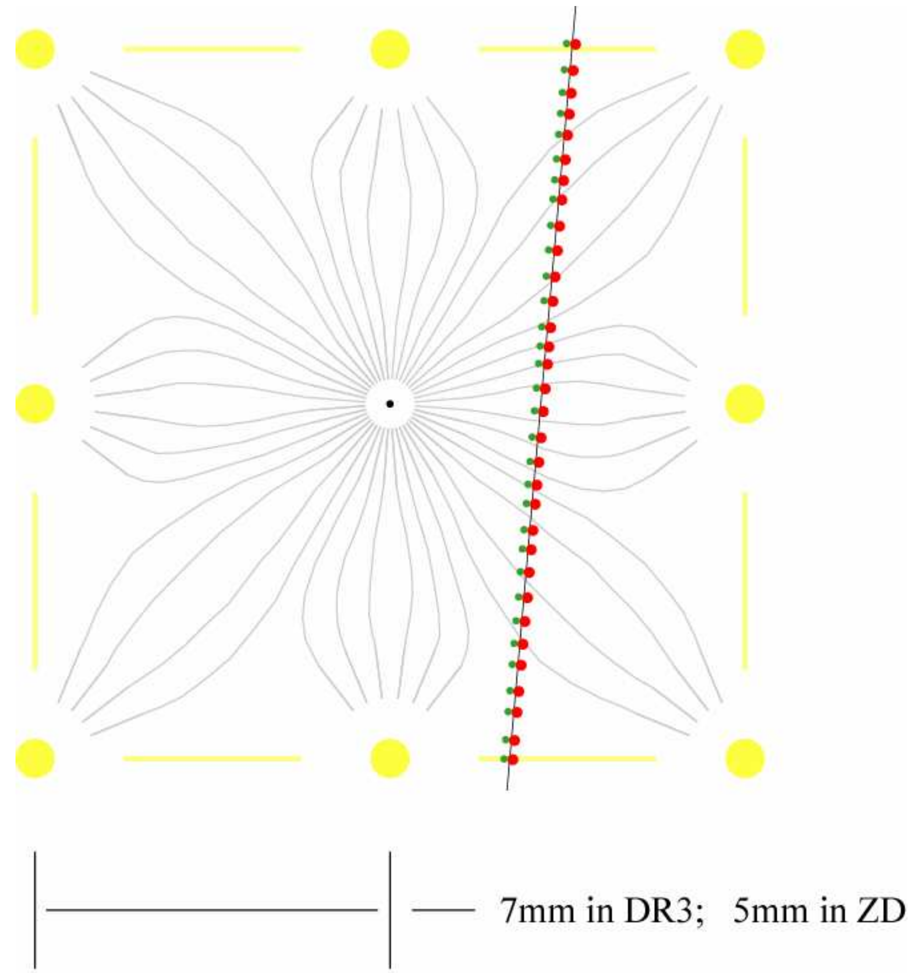
$dE/dx = .307\ (MeV/(g/cm2))\ Z/A\ \rho\ 1/\beta^2\ z^2\ (\ln(2mc^2\beta^2\gamma^2/I) - \beta^2)$

It gives the total energy loss; we want the number of ion pairs.

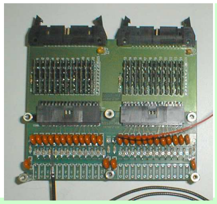
There are measurements of the primary ionization cross section at min. ion.

	σ_p (10^{-20} cm^2)	λ (cm)
He	18.6	1/ 3
Ar	90.3	1/ 24
C_2H_6	161	1/ 43
C_3H_8	269	1/ 72

where λ is the interaction length:
$\lambda = 22.4\text{cm}^3/(6.023\times10^{23}\ \ \sigma_p)$
In 1.4 cm of He-prop 60:40, ~43 prim. ions



note: wires are shown 7 times actual relative (DR3) size

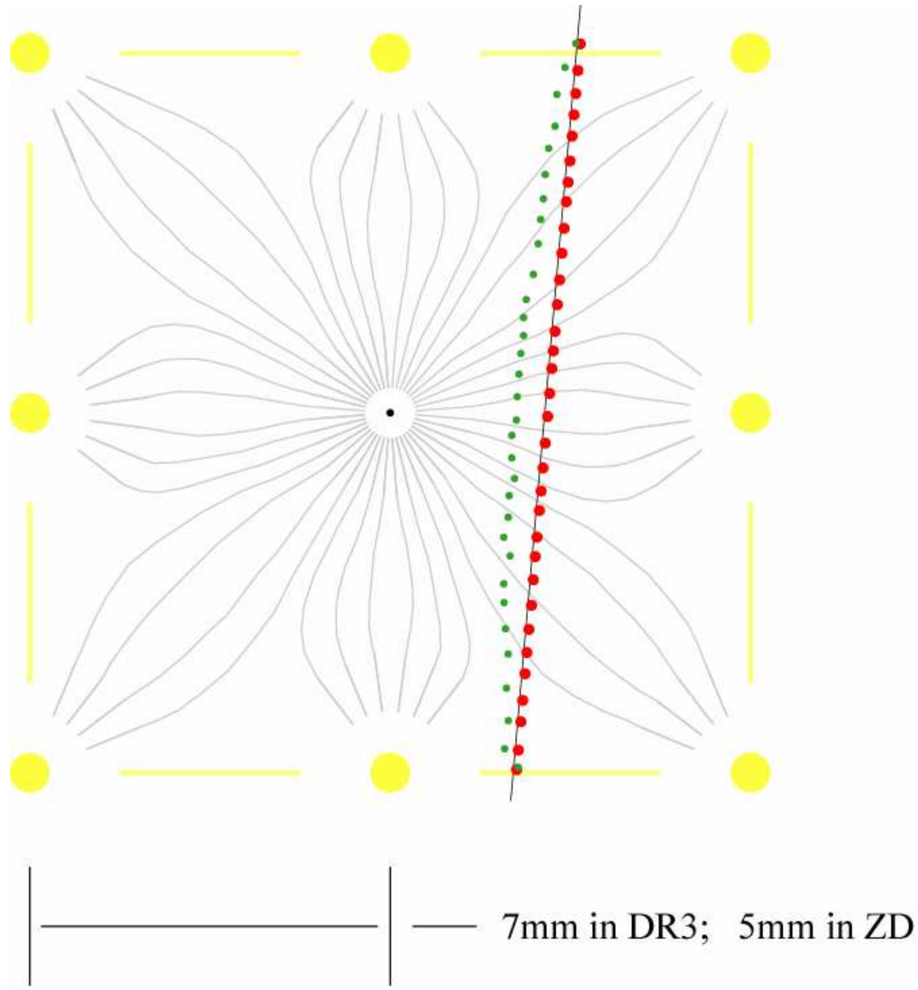


drift

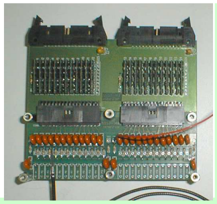
There is secondary ionization.
This occurs when a product of the primary ionization has energy greater than the ionization energy. However, this does not change the discreteness of the primary ion distribution.

The electrons drift to the anode.
They follow the field lines
Drift velocity is on the next slide.

Diffusion disrupts the drift.
Re-combination,
or attachment to oxygen,
could destroy the electrons.



note: wires are shown 7 times actual relative (DR3) size



Drift velocity

Drift velocity depends on
acceleration in the electric field
mean free path.

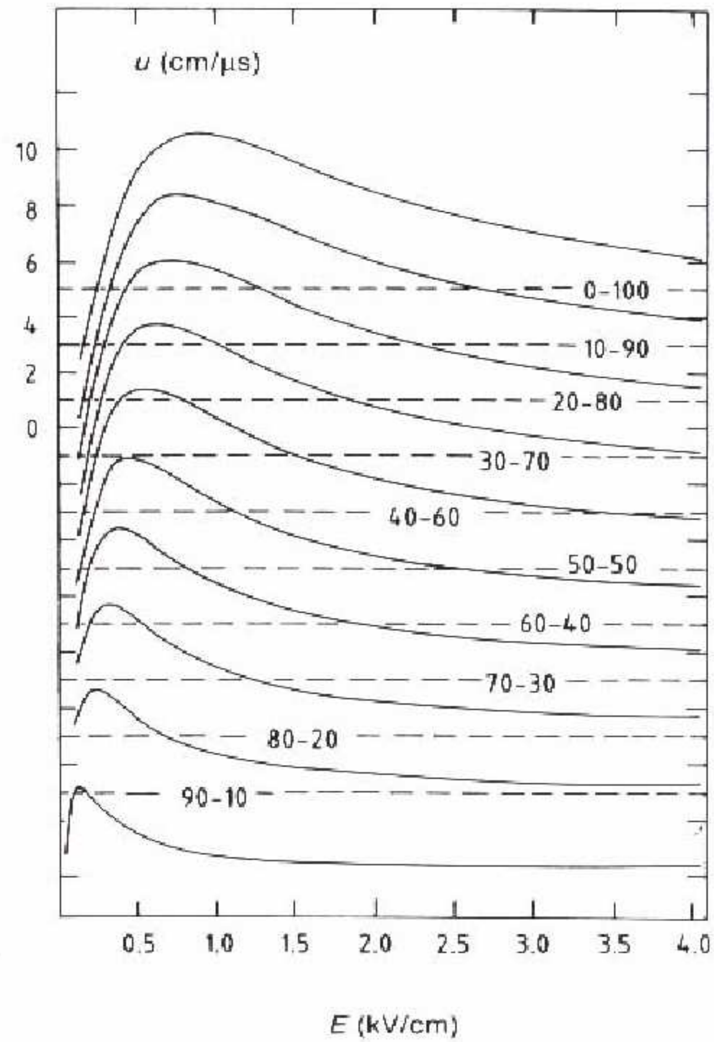
Drift velocity for Ar-methane mixtures

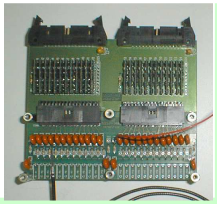
CLEO operates at
3 kV/cm (average)

note: velocity is saturated

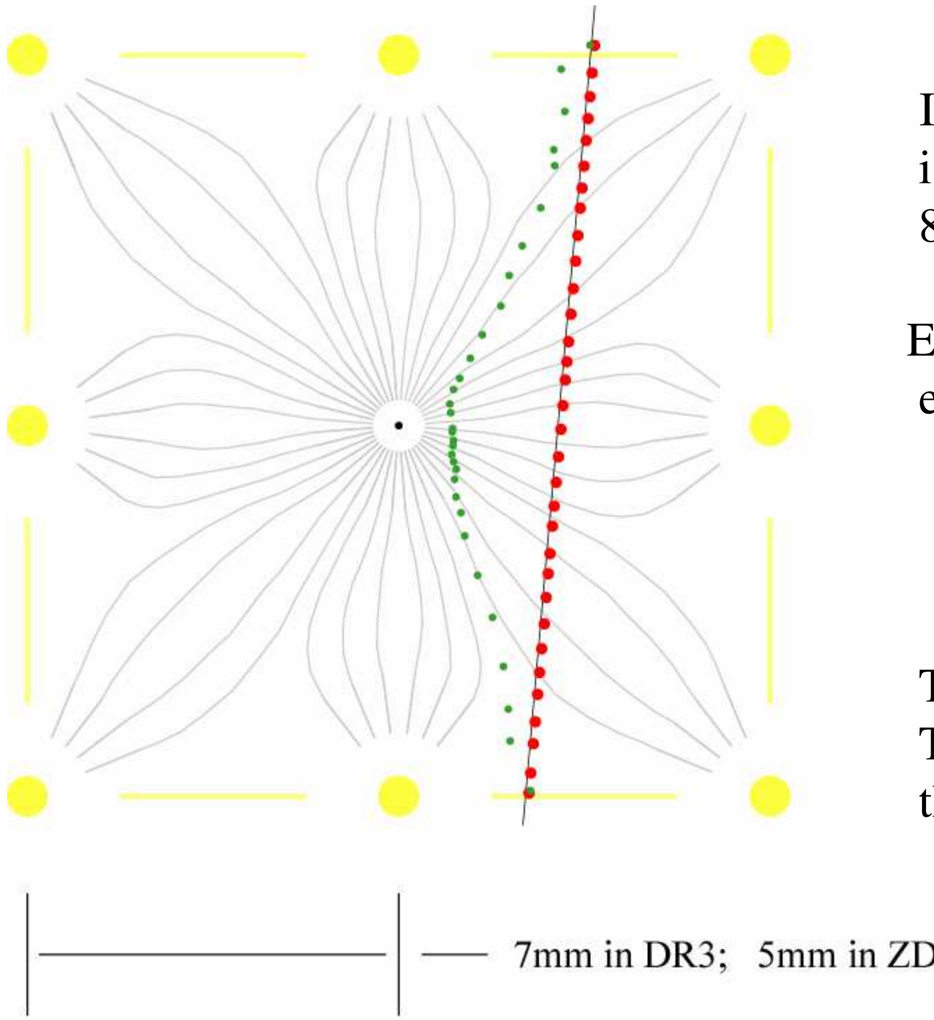
also note:
those dashed lines
at a vertical value of 5 cm/µs
are all on top of each other

5 cm/µs = 50 µm/ns





Drift more

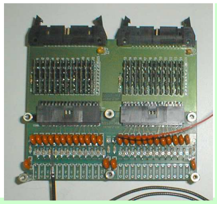


note: wires are shown 7 times actual relative (DR3) size

I am amazed that the drift mechanism is accurate enough to provide 85 μm resolution. But it does.

Electrons in the low field region will either
- recombine,
- drift in much later,
- find their way to another sense wire.

The positive ions do relatively little. The mass is 2000+ times that of the electrons.



Radius of Avalanche

$E=Q/r$ where "Q" is $\lambda/(2\pi\varepsilon_0)$;
and λ is the charge density

Integrate…
$V=Q \ln(b/a)$ where b is the cell "radius"
a is the wire radius
V is the applied voltage
$E = (V/r) / (\ln(b/a))$

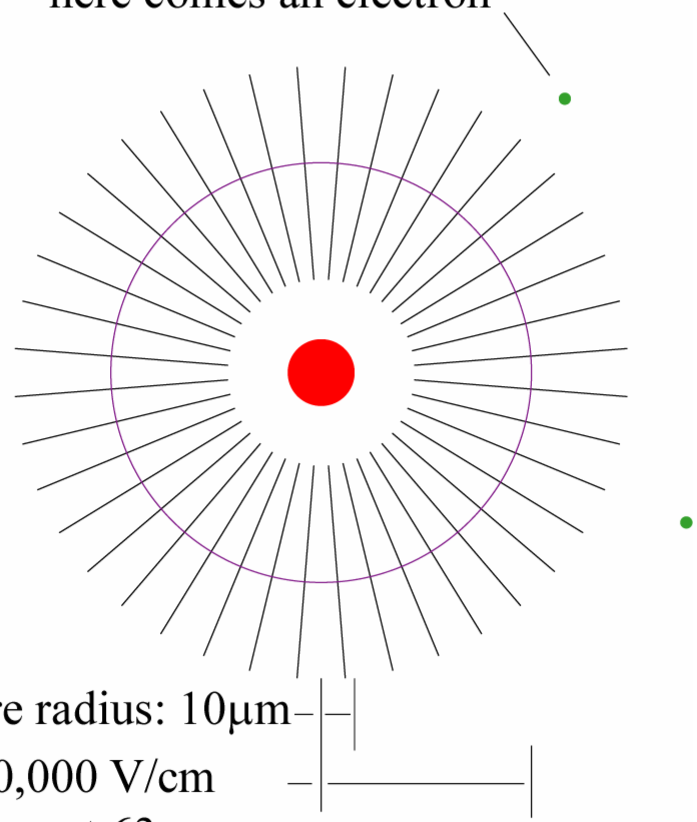
DR3, b=7000µm, a=10µm
$1/\ln(b/a)=0.15$

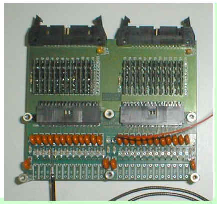
V/a=2100V / 10µm

At the wire surface: $E = 31.5 \times 10^4$ V/cm

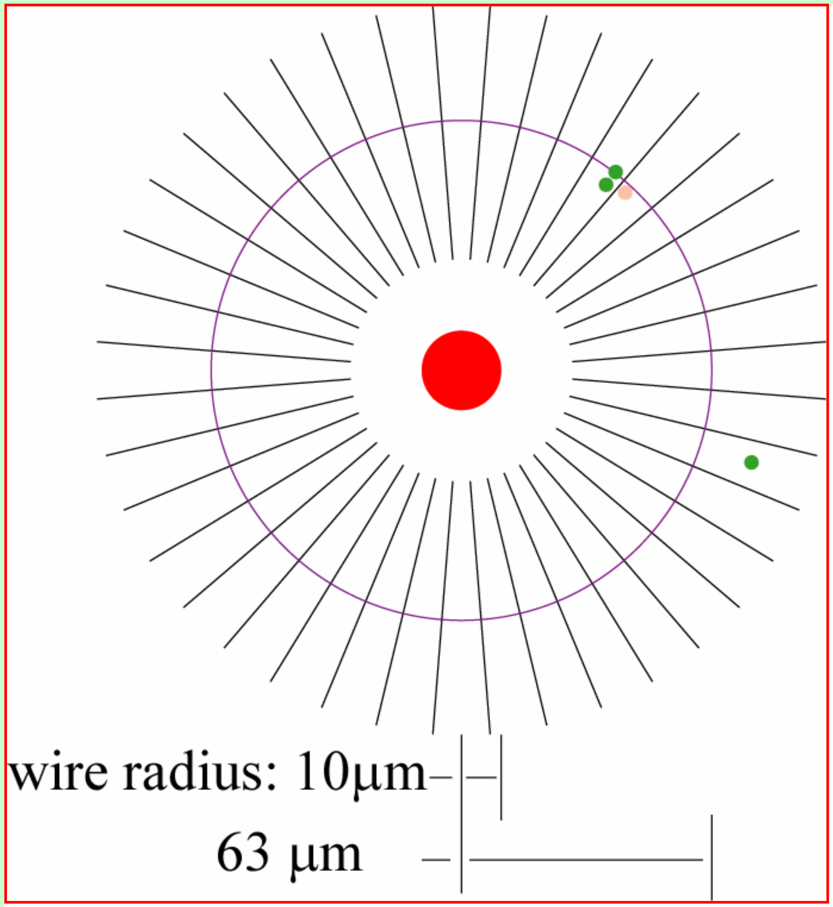
and at t r=63mm: $E= 5 \times 10^4$ V/cm

This significance is described on the next slide.





Onset of avalanche



$22.4 \times 10^3\ cm^3$ mole volume
$/\ 6.023 \times 10^{23}$ atoms per mole
$/\ (\sim 10^{-8}\ cm)^2$ atom cross section *
$= 4\ \mu m$ collision length

the field strength (previous page)
at 63 mm radius
5×10^4 V/cm or 5 V/µm

The energy at the collision length is
5 V/µm x 4µm = 20 V

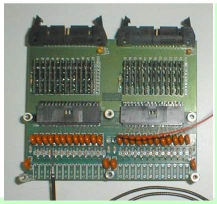
Average energy to create one ionization electron

Ar	16 eV	He	25 eV
methane	13 eV		
ethane	12 eV		
propane	??		

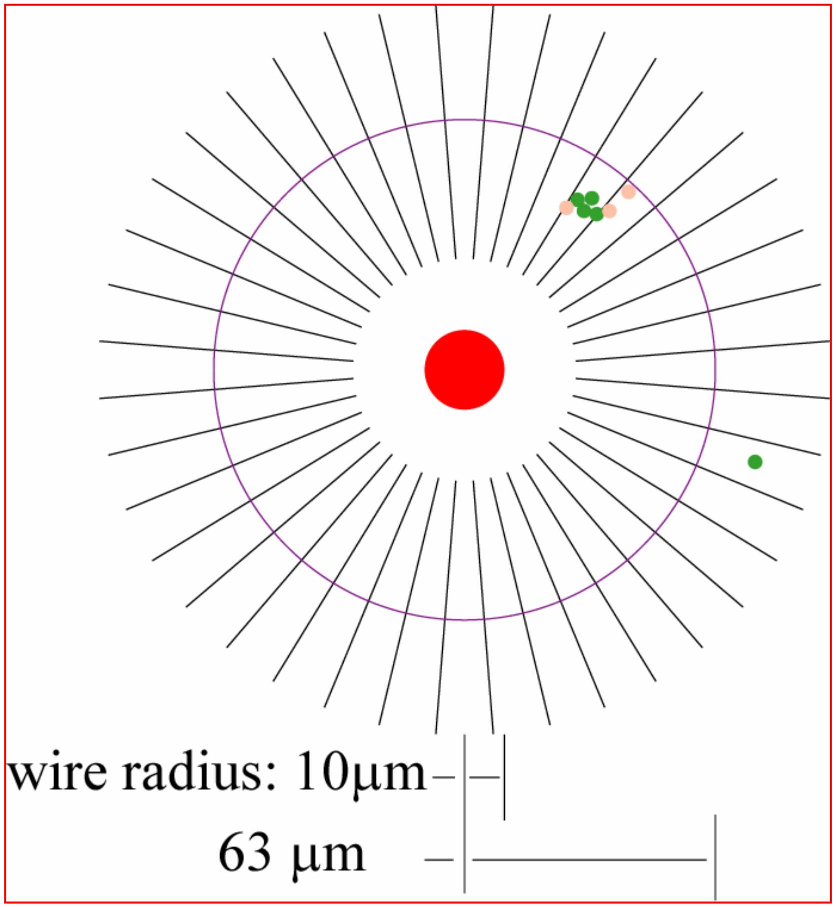
(*Blum and Rolandi*, p 6)

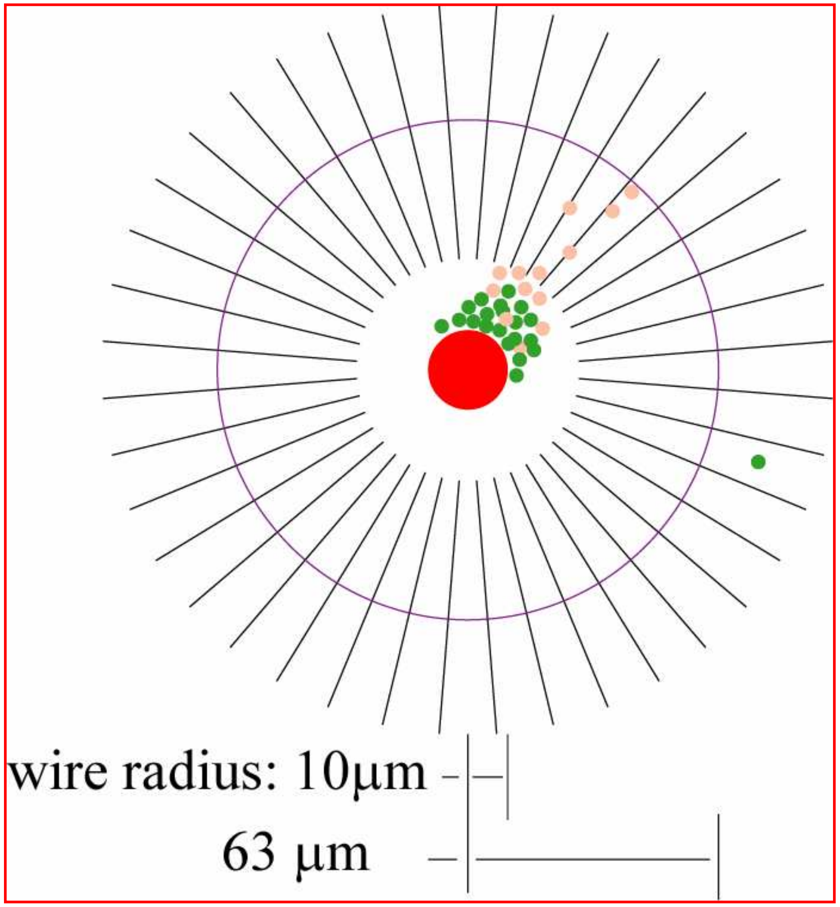
* This is very "hand-waving".
I am using the order-of-magnitude size of an atom.
Of course, the hydro-carbon atoms are even bigger.

Why are field wires bigger than sense wires?

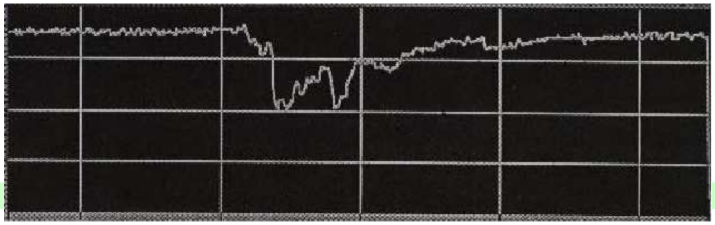


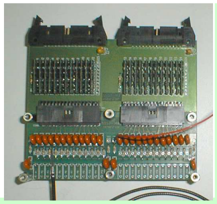
The avalanche





Multiplication continues with a 4 µm length.
When the electron cloud reaches the wire,
we see a pulse.





Spatial Resolution

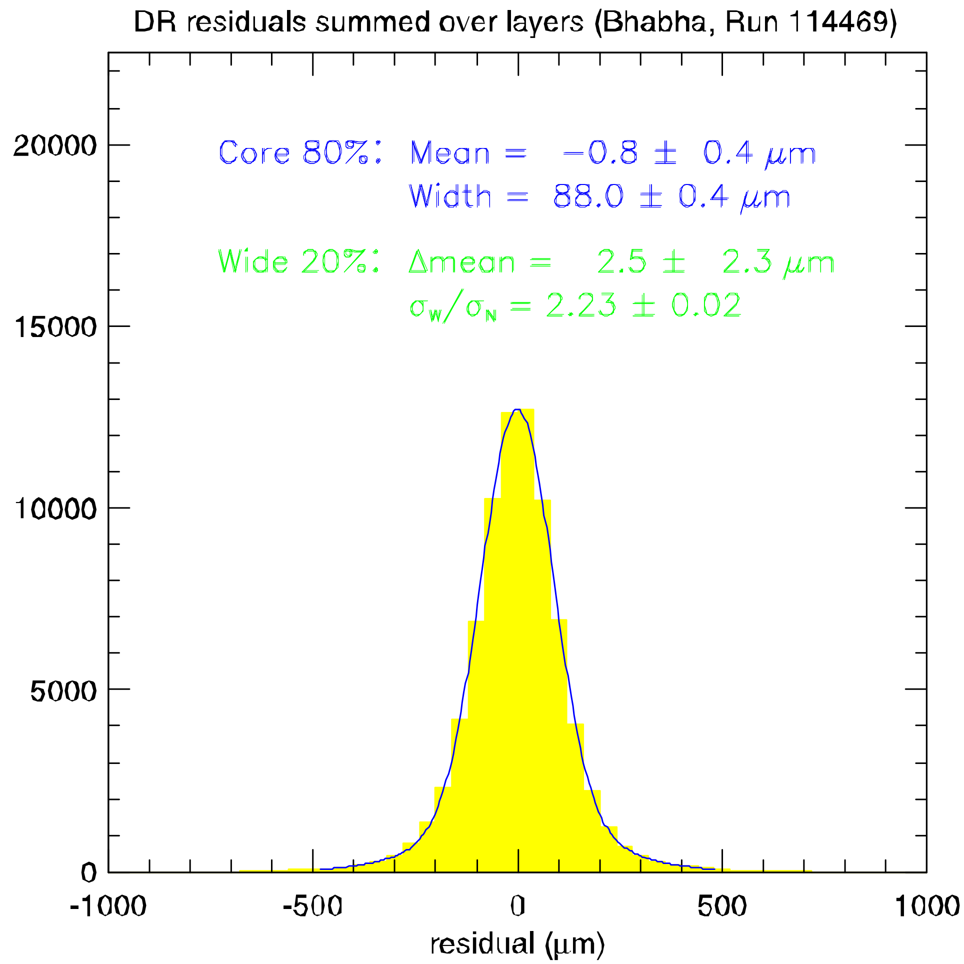
Residuals: time-measured hit position are compared to the fitted position.

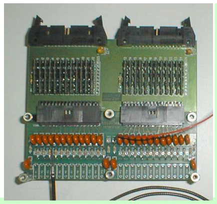
Parameterized as double gaussian with fixed 80% fraction in narrow component.

Narrow component:
(average over entire cell)
σ=88 µm

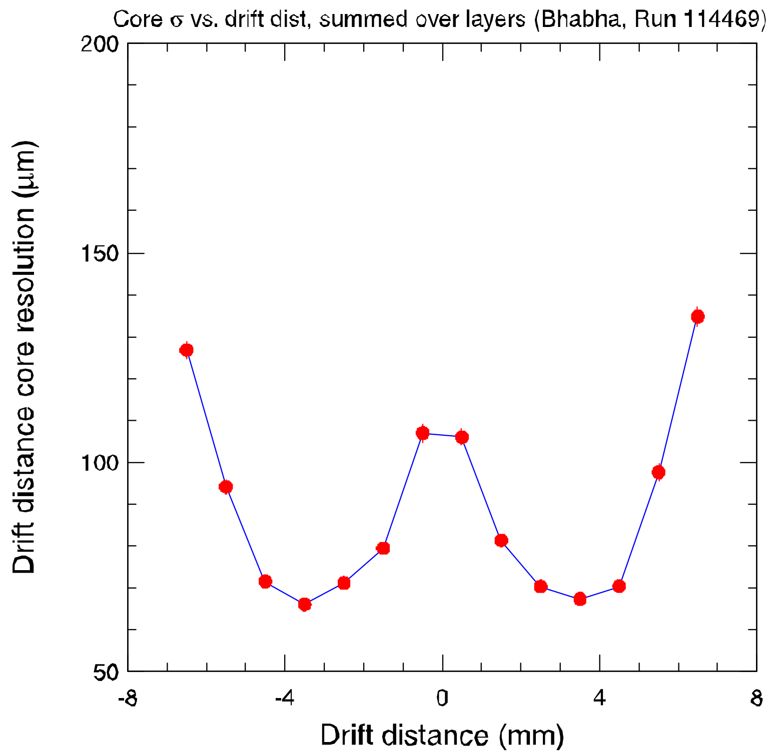
Wide component: 200 µm
Average, full cell, all hits : 110 µm

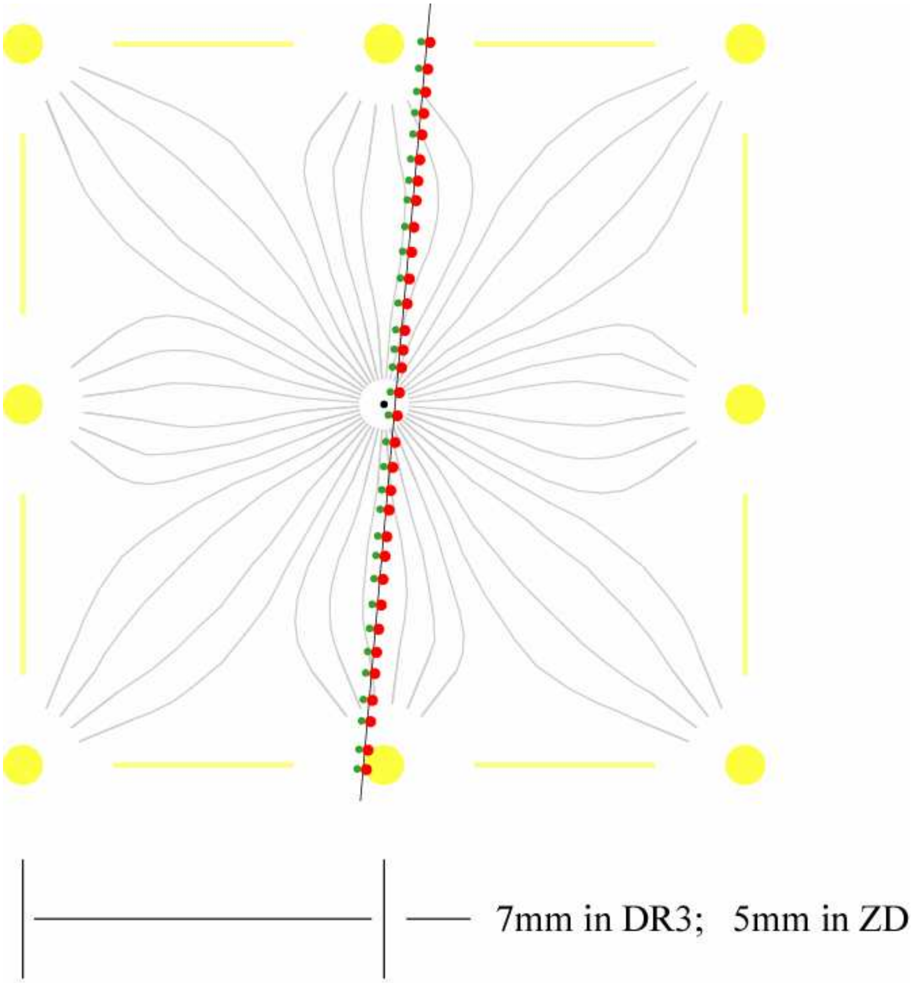
(CLEO-III TDR Goal: 150 µm)



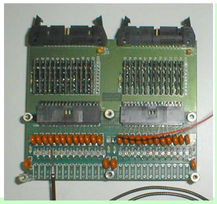


Resolution at the wire

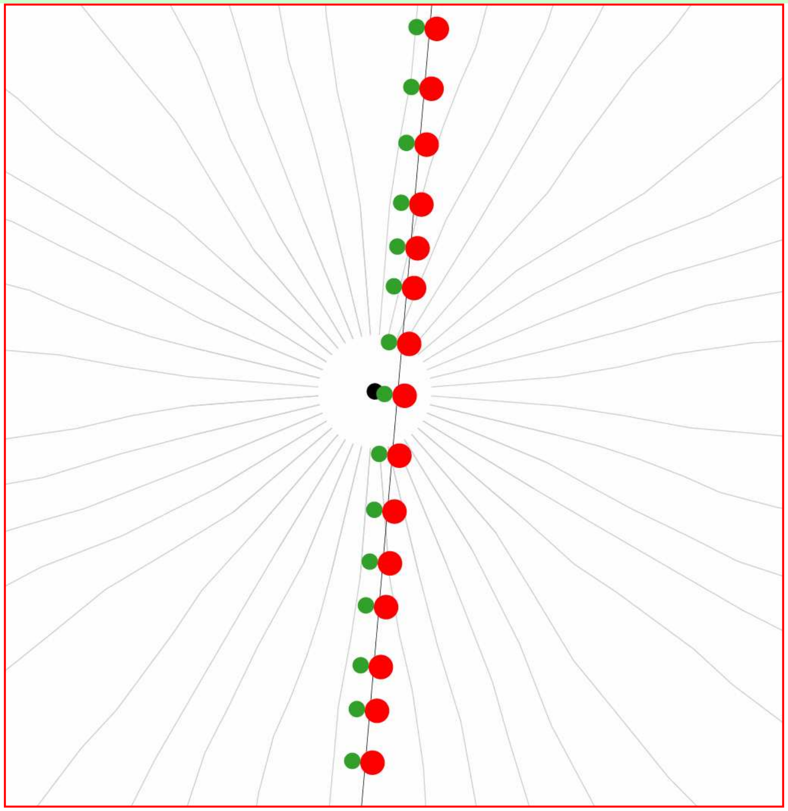


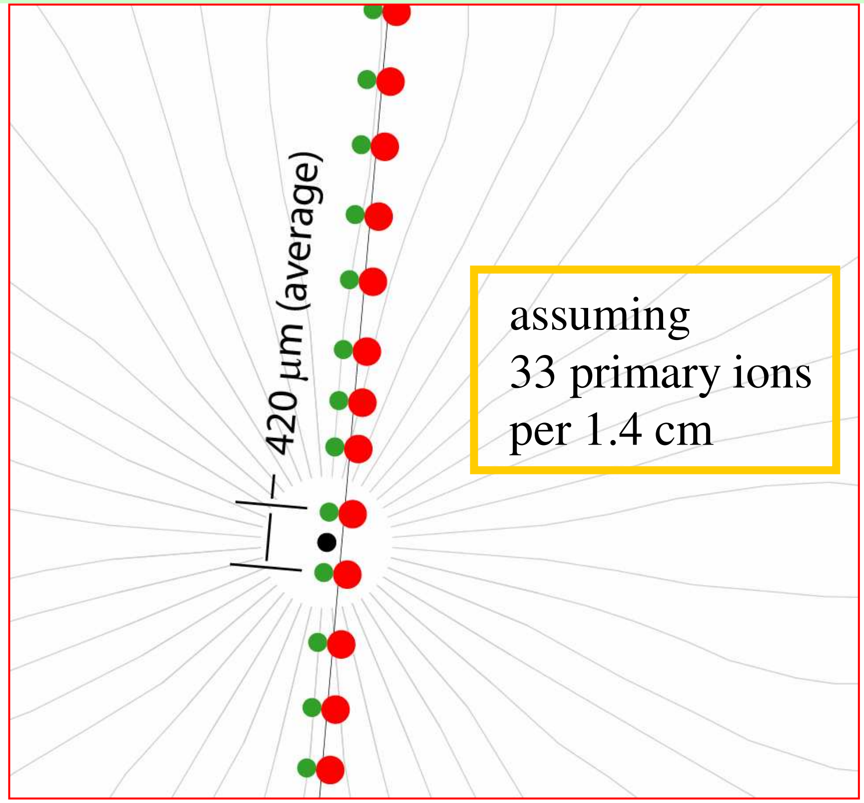


note: wires are shown 7 times actual relative (DR3) size



The track at low drift distance





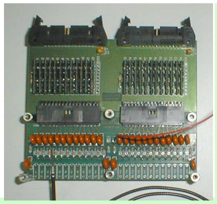
assuming
33 primary ions
per 1.4 cm

Ion spacing is a contribution to the resolution at low drift distance.

The drift distance for the first electron is 0 to 210 μm adding a contribution of 60 μm to σ.

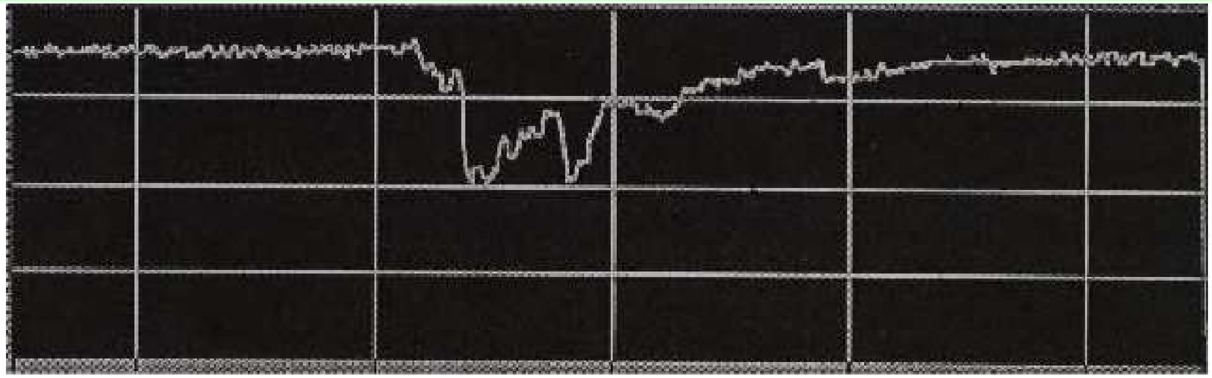
What would happen if the discriminator threshold is equivalent to 3 primary electron?

At zero impact, the drift distance for the 3rd electron would be {420 – 630} μm. **At 500 μm impact,** the drift distance for the 3rd electron would be {652 – 804} μm, *i.e.* **increasing by only 200 μm.**



The Signal

pulse height
20 mV /division



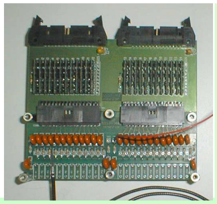
time, 200ns / division

I introduced the pulse 4 slides back. How is this signal developed?
Understanding more about the signal will help in understanding the electronics design.

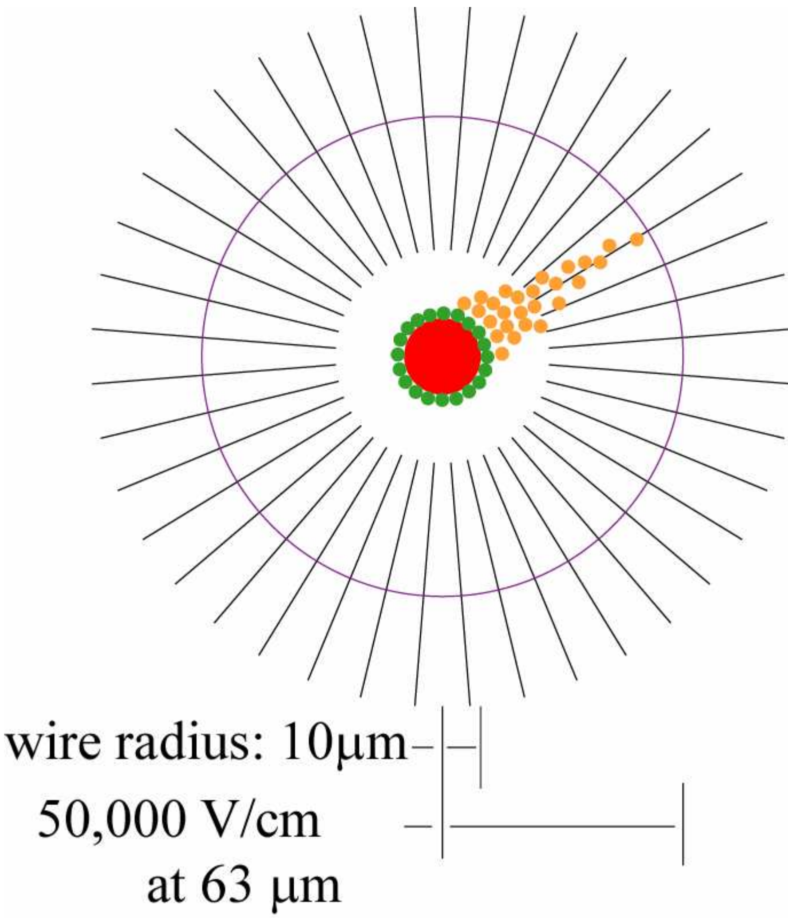
Note: we are making σ=100µm distance measurements.
The gas velocity is 28µm/ns (He-propane 60:40).
Thus, the time measurement must have precision: σ=3.5 ns.
The resolution tells us that leading edge must be defined to 3.5 ns.

The signal shown has significant voltage over about 150ns.
(Note: the total drift time in our cell is 250ns.)

Some of the substructure is individual ions, some is electronic noise.



The signal and the lies (well, misunderstandings)



"almost all the energy and all the signal in a proportional counter are due to the motion of the positive ions."
Blum and Rolandi, p155

"The signal is due to the motion of the positive ions" *various unnamed*

"it is an energy argument" *ibid*

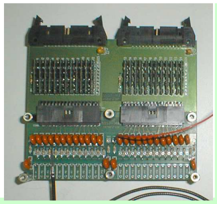
" it says so in Sauli" *ibid*

The ions move about 10,000 times slower than the electrons.

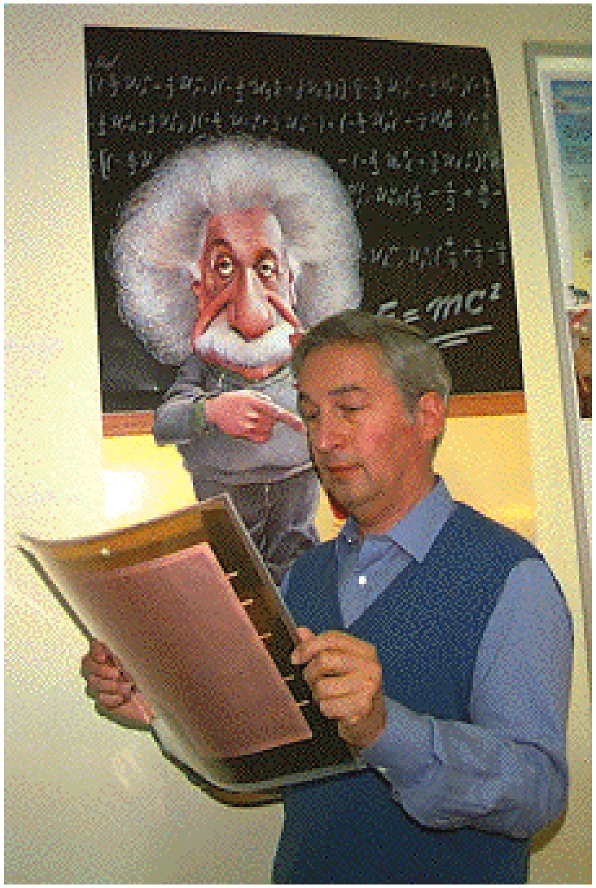
Therefore, the time across the cell is ~2.5 ms and this is inconsistent with the observed signal.

One will never get 100μm resolution with the time dependence on the ion motion.

And, who is Sauli?



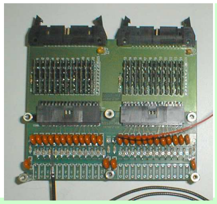
Sauli



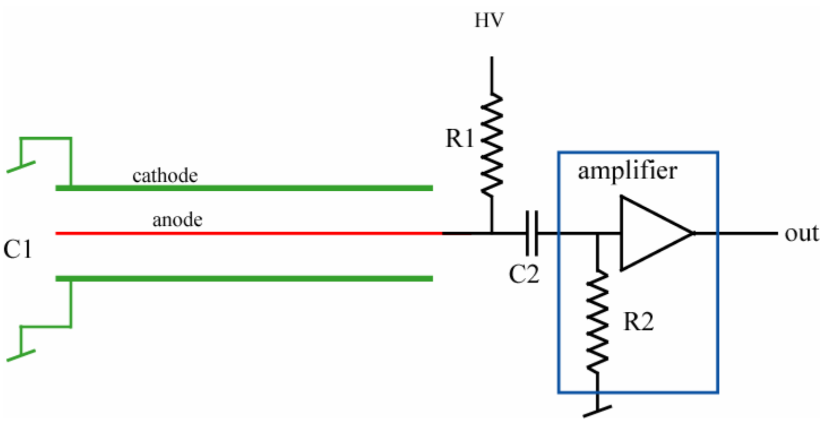
"The detected signal, negative on the anode and positive on the cathode, is a consequence of the change in energy of the system due to the movement of the charges."
Fabio Sauli, CERN 77-09, p 44.

read on…
" It is therefore normal practice to terminate the counter with a resistor such that the **signal is differentiated** with a time constant τ=RC."
ibid, p 46.

in CLEO, C=330 x 10^{-12} F
termination resistance =0



The truth about the signal.



Notice, they didn't say anything about R_1 ; that is 1 MΩ but does not determine the time characteristics.

R_2 is the amplifier input impedance, which is =0, so the condition holds.

KME will describe the amplifiers.

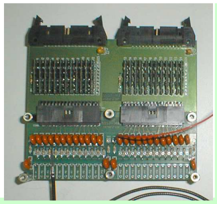
"In the case where R_2C_2 and R_2C_1 are small compared to the pulse rise time,..

…the potential of the wire is re-established during the development of the pulse…
…the counter then acts as a current source…

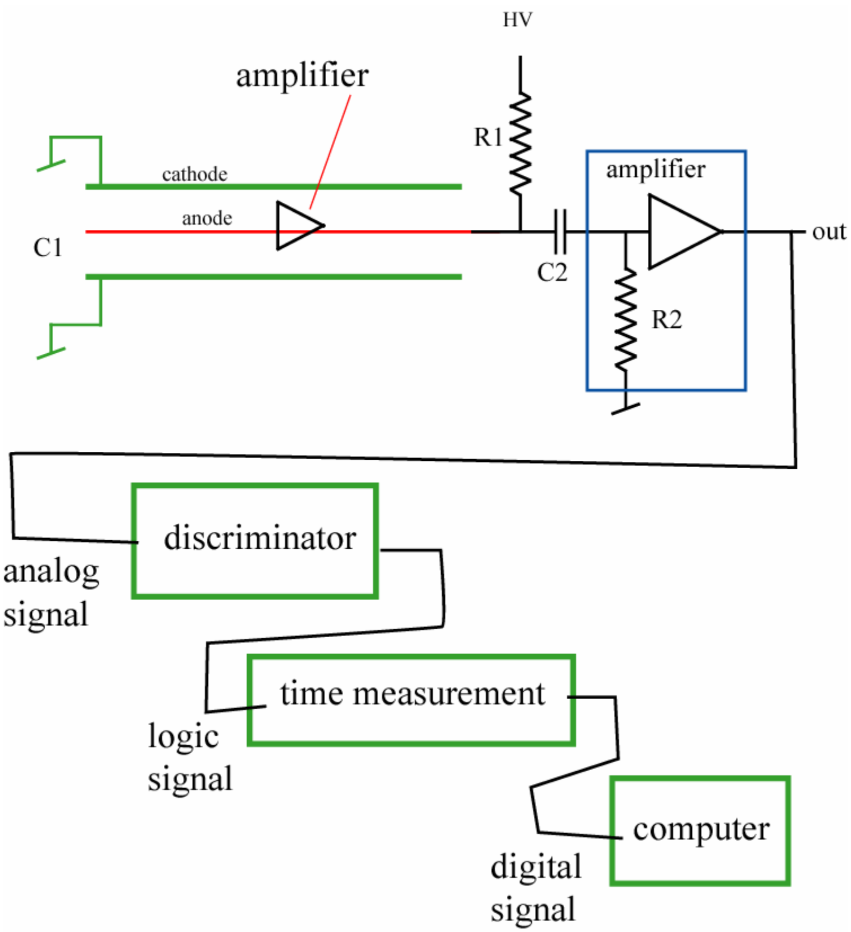
… and **the signal is**
the current that flows through $\mathbf{R_2}$.

… The current signal involves the **derivative** of (the energy time dependence)."

Blum and Rolandi, p156,157,158



The circuit and noise



Matt will describe the discriminators (TQT).

Noise can be injected at several places in the system.

Radiation noise can lead to real ionization which will amplified by the avalanche and the electronics amplifier.

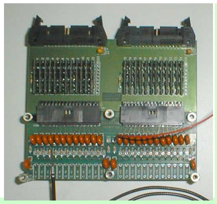
The wire is a big antenna. RF noise can be amplified by the electronics amplifier.

Electronics noise can be on either side of the electronics amplifier.

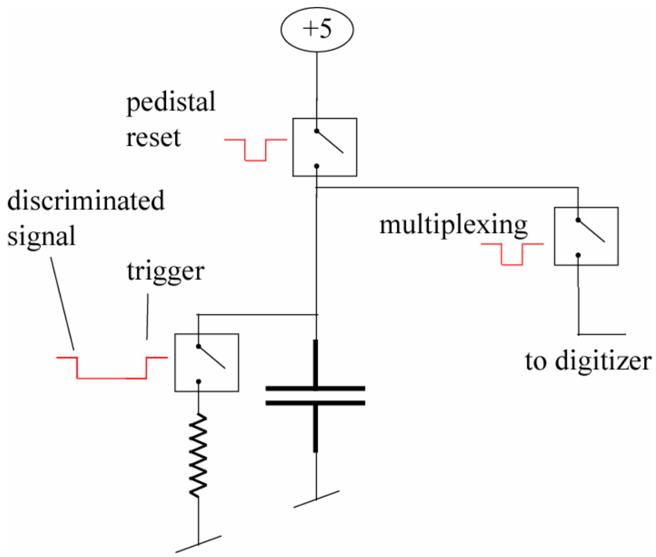
We have several ways of changing the "threshold" to reject noise.

change the HV
change the electronics amplifier gain
change the discriminator threshold.

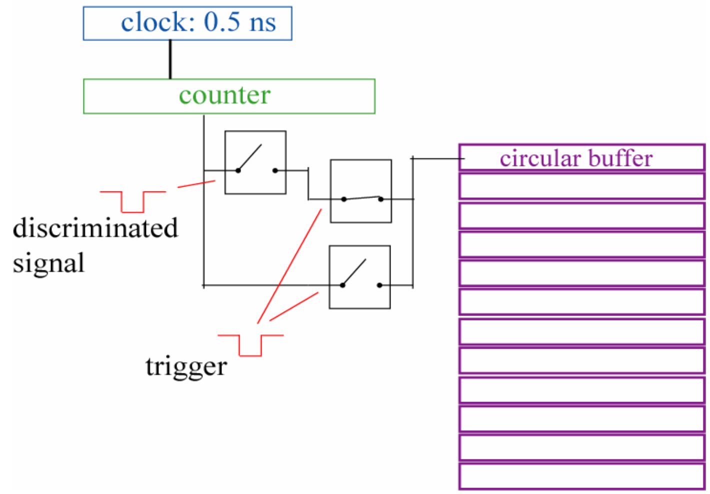
The most effective method is to increase the HV and increase the discriminator threshold.
But, this could damage the chamber so we must find a balance.



Time measurement, basics



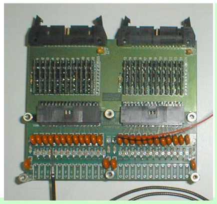
Capacitor ramp-down timing



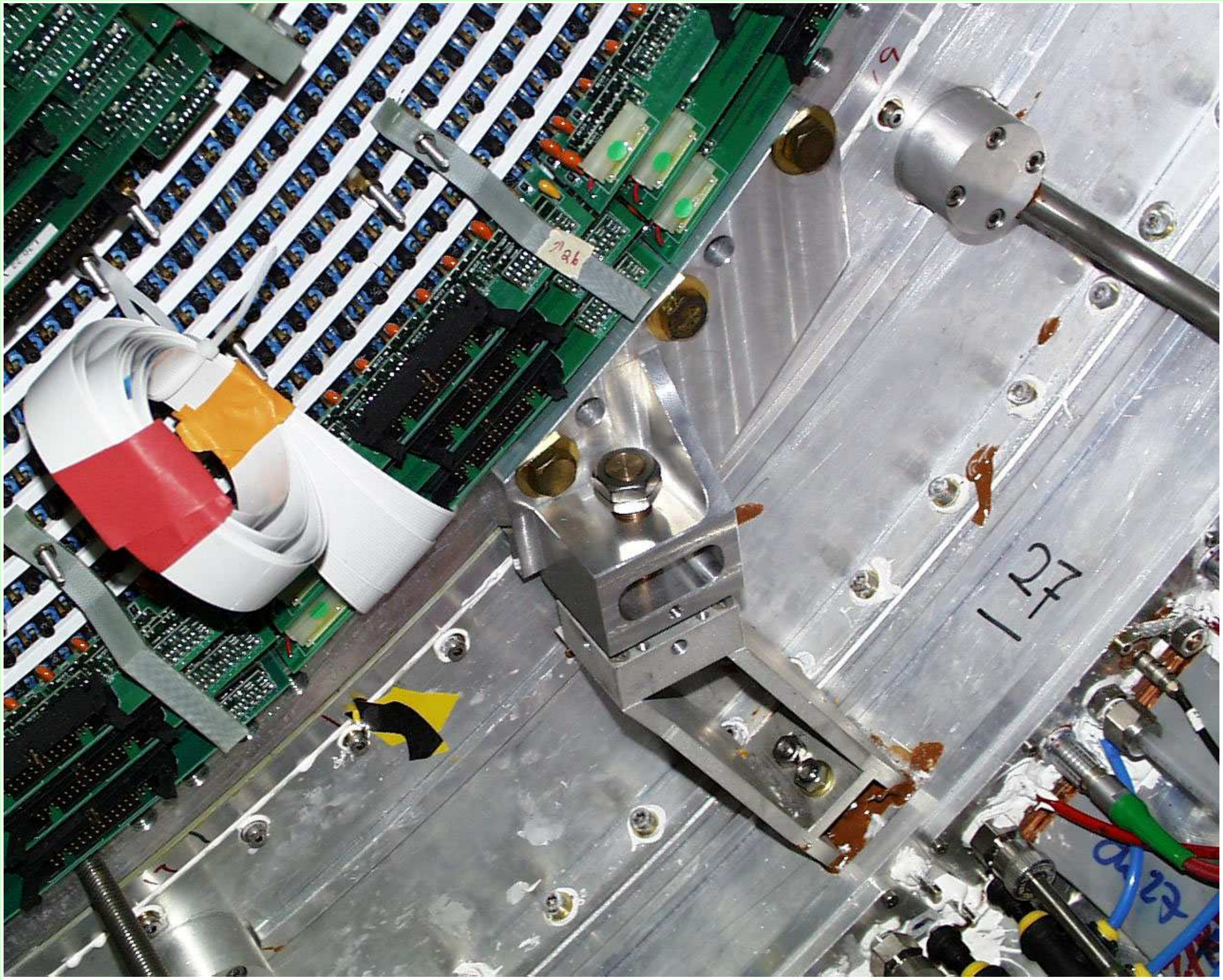
Clock timing

Matt will describe the TDCs

We have used two types of timing devices in CLEO.
The capacitor timing was used in CLEO I and II. It was designed in-house.
There were many problems: non-linear response on the RC circuit,
channel-to-channel variations that required another layer of calibration,
and (most significant) the need for a pedestal reset during live time.
The clock timing circuits are used in CLEO III/c. This design solves the above issues.
They are commercial. We bought the French ones, probably because we could not afford the Italian product. We gripe a lot, but we would not survive with the capacitor circuits.



DR3 at the outer radius



super layer 8

ground strips

crimp pin ends

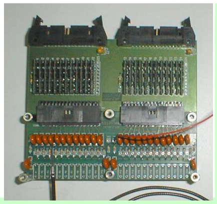
HV connections

signal connections

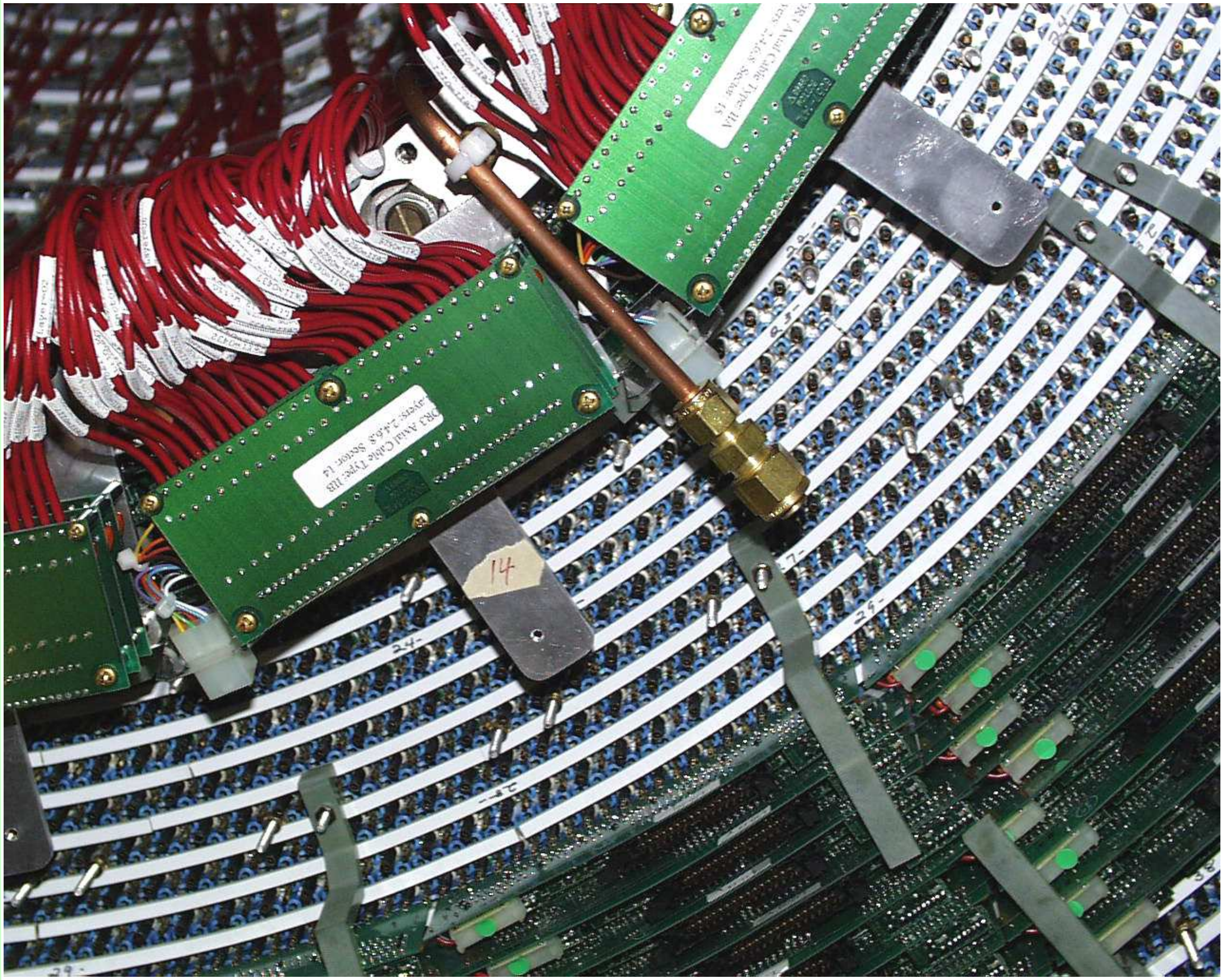
cathodes

chamber support

RICH gas (run!)



DR3 at medium radius



super layer 1 3,4

ground strips

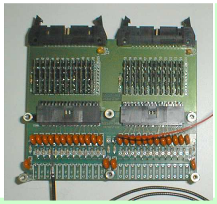
crimp pin ends

HV connections

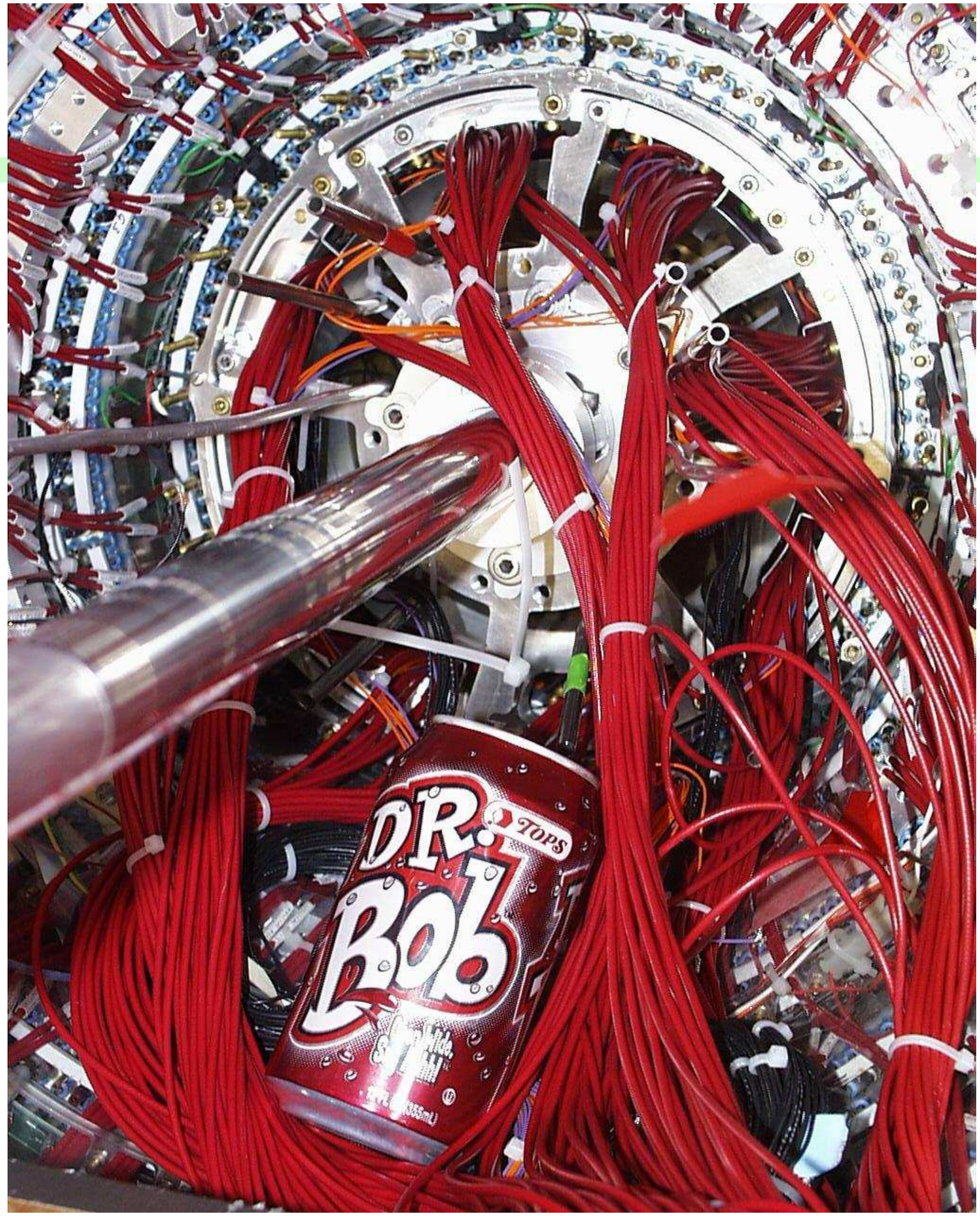
signal connections

axial HV distribution

DR3 gas pipe



ZD and DR3 ring 1



We will not see this again
if we are lucky.

DR3 axial ring 1,
layer 2 connected, this is west.

DR3 axial signal coax

DR3 ground strips

DR3 F1- voltage distribution

ZD cables

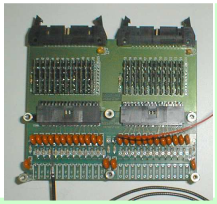
ZD gas

ZD support

beam pipe cooling

permanent magnet support ring

beverage



It’s FUN