Charged Particle Detectors

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- Interactions of charged particles and photons with matter
- Gas detectors
- Cherenkov Detectors
- Silicon detectors

Interactions of charged particles with matter

Charge particles traversing matter produce electromagnetic fields that can remove electrons from atoms.

The energy loss per unit length is called

$$\frac{dE}{dx}$$

The energy loss depends on z^2 where z is the charge of the particle, i.e. and its velocity $\beta = \frac{v}{c}$

$$\frac{dE}{dx} = z^2 f(\beta)$$

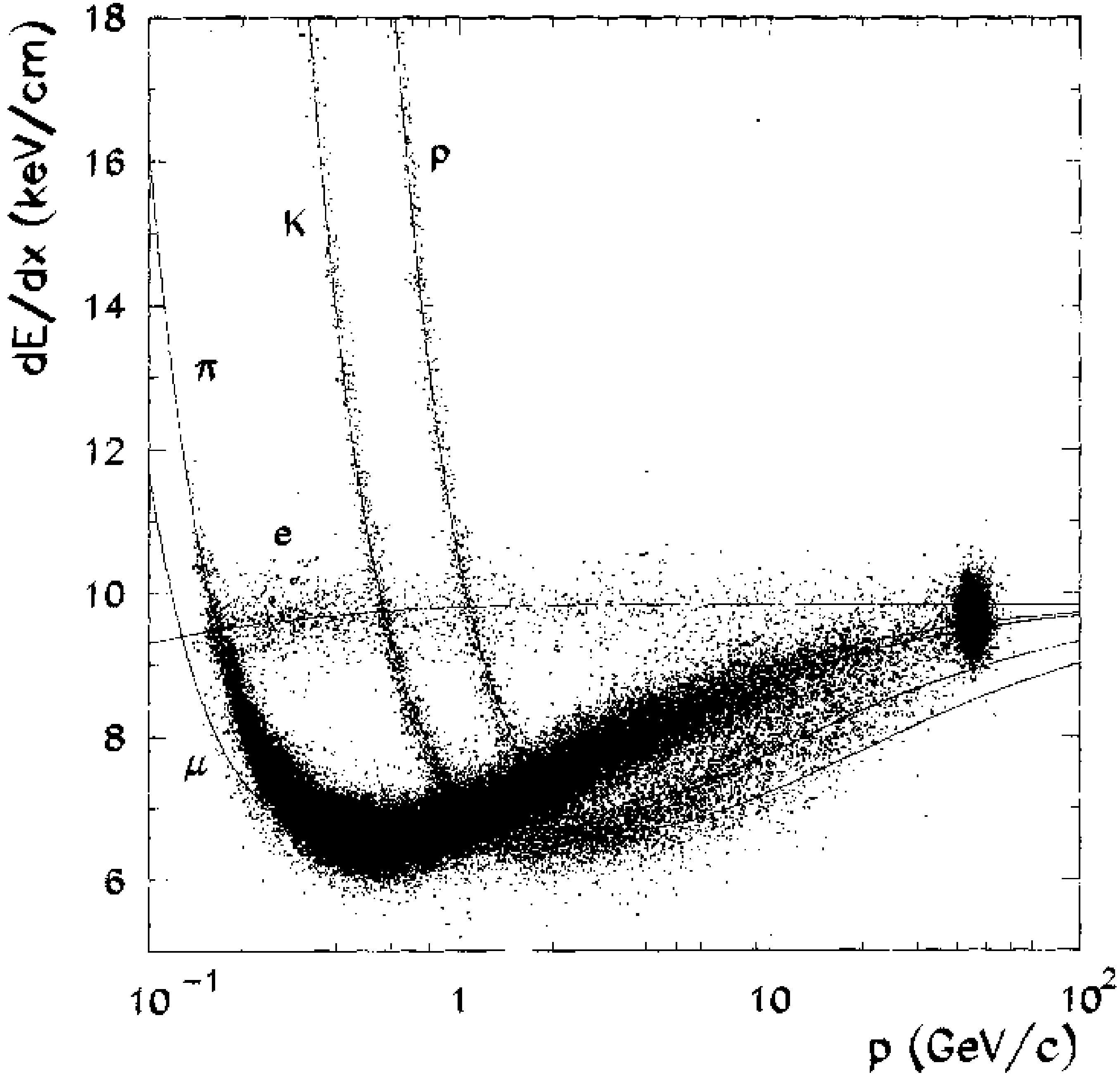
or in detail

$$\frac{dE}{dx} = \frac{z^2 4\pi r_e^2 m_e c^2}{\beta^2}\left[\log\frac{2m_e v^2}{I(1-\beta^2)} - \beta^2\right]\frac{N_0 Z\rho}{A}$$

$$\begin{array}{lcl}
r_e & = & \text{classical radius of the electron } (\frac{e^2}{m_e c^2}) \\
m_e & = & \text{electron mass} \\
I & = & \text{effective ionization potential} \\
v & = & \text{particles velocity} \\
c & = & \text{speed of light} \\
\beta & = & \frac{v}{c} \\
N_0 & = & \text{Avogadro's number} \\
Z & = & \text{atomic number of medium} \\
A & = & \text{atomic mass number of medium} \\
\rho & = & \text{medium density}
\end{array}$$

If we can measure $\frac{dE}{dx}$ we can find β

This formula is called the Bethe-Bloch formula



Energy loss as a function of momentum (OPAL NIM A314 (1992) 74)

- Minimum ionizing particle = MIP
- Cosmic ray muons will usually have energies close to a MIP (rise above $\sim$ 500MeV is small)
- Stopping particles lose most of their energy near the end of their range
- Can be used to our advantage in cancer therapy
- The machine at right is called a “Mevatron”

Mevatron the band

Genre(s)

Death Metal

Origin	Formed in	Current label	Status
Germany	2002	Unsigned	Active

Current line-up

Marita - Guitars/Vocals
Daniela - Bass, Keyboards, Backing Vocals
Mario - drums

Additional notes

Formed by (former?) members of Sacralis. They are currently looking for a drummer so they can commence performing live. They expect their first album to be recorded somewhere in 2003.

Submitted by	On
Egregius	September 2nd, 2003

Last modified by	On
HEADTHRASHER	January 11th, 2006

Member options

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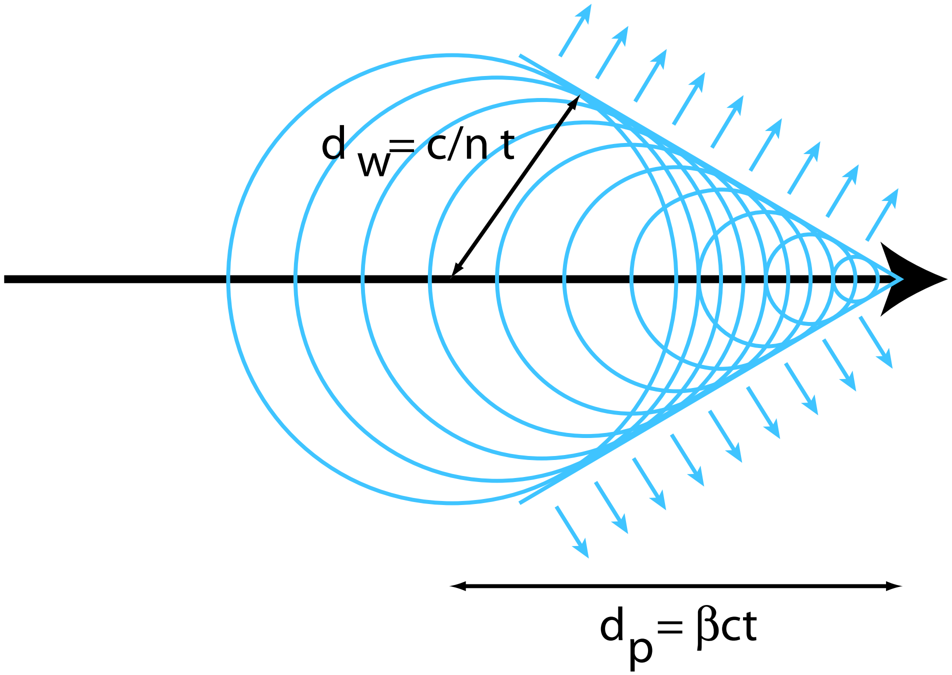
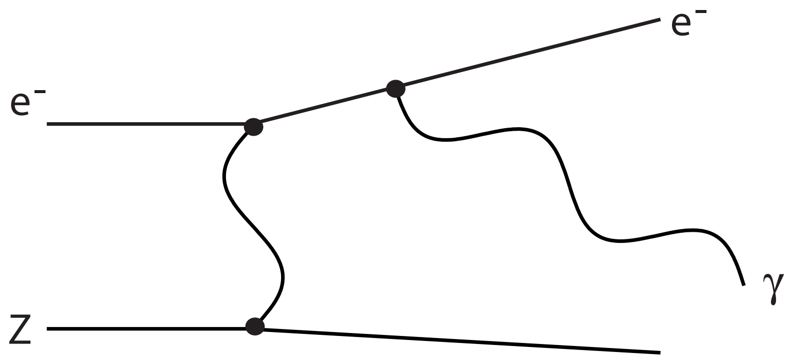
Other energy loss mechanisms for charged particles:

- Chenekov Radiation:



Can measure cone size (or threshold in materials with various n's) to get β

- Radiative losses or "bremsstrahlung" for electrons

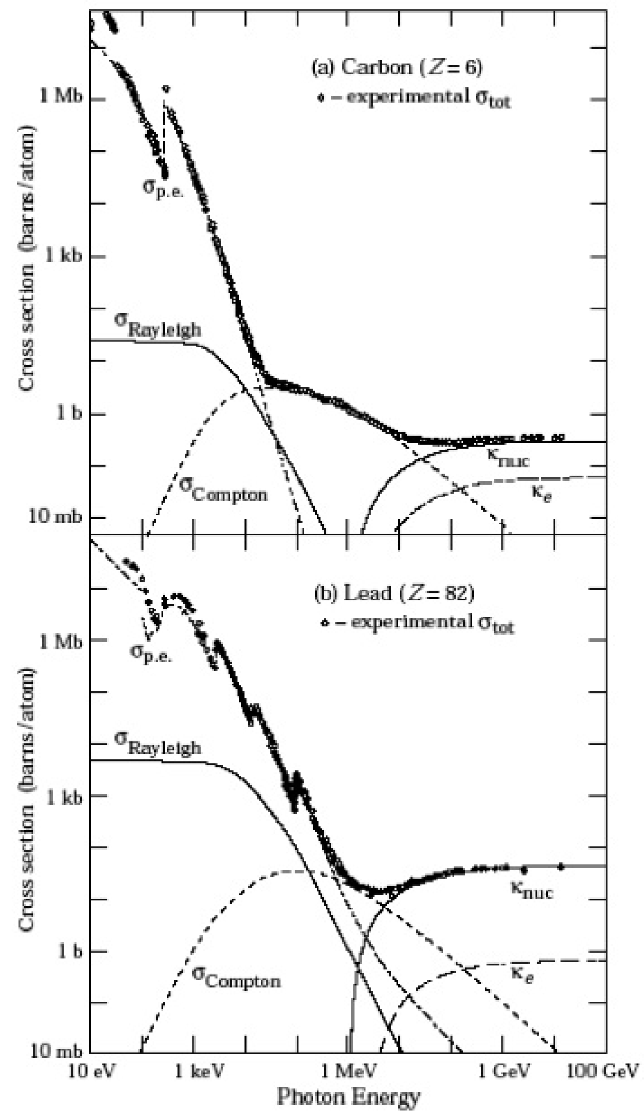


$$\frac{1}{E}\frac{dE}{dx} \simeq 4\alpha Z^2 r_e^2 \log\left(\frac{183}{Z^{\frac{1}{3}}}\right)\frac{N_0\rho}{A}$$

r_e	$=$	classical radius of the electron ($\frac{e^2}{m_e c^2}$)
α	$=$	fine structure constant
N_0	$=$	Avogadro's number
Z	$=$	atomic number of medium
A	$=$	atomic mass number of medium
ρ	$=$	medium density

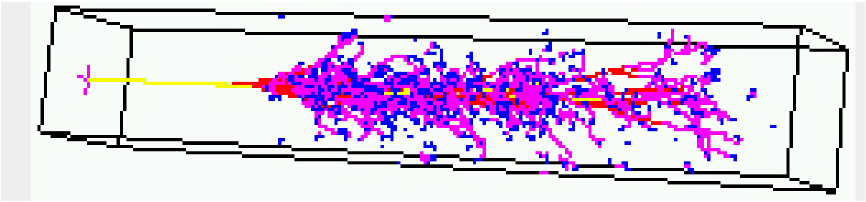
Absorption of γ-rays

- Photoelectric absorption ($\gamma + A \to A^{+} + e^{-}$)
- Compton scattering ($\gamma + e \to e + \gamma$)
- Pair production ($\gamma + Z \to e^{+}e^{-} + Z$)



Energetic γ rays and electrons produce electromagnetic showers

- Radiated photons pair convert or Compton scatter
- Electrons and positrons radiate more photons
- Etc.



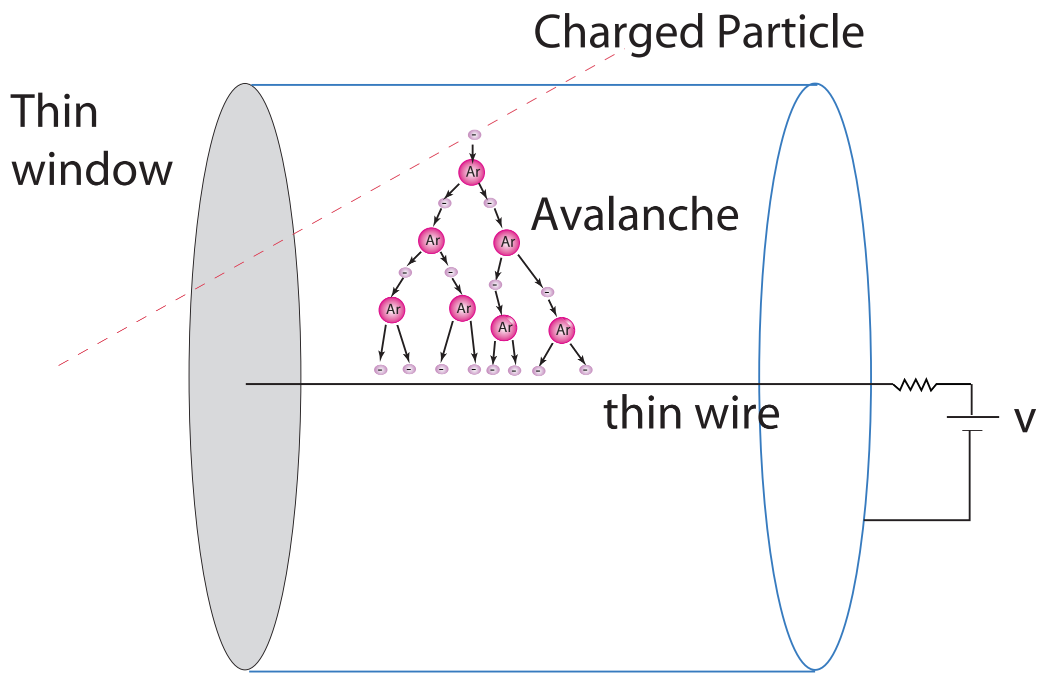
For an animation see http://www.mppmu.mpg.de/~menke/elss/home.shtml

Sampling calorimeters have layers of inactive material and active detectors

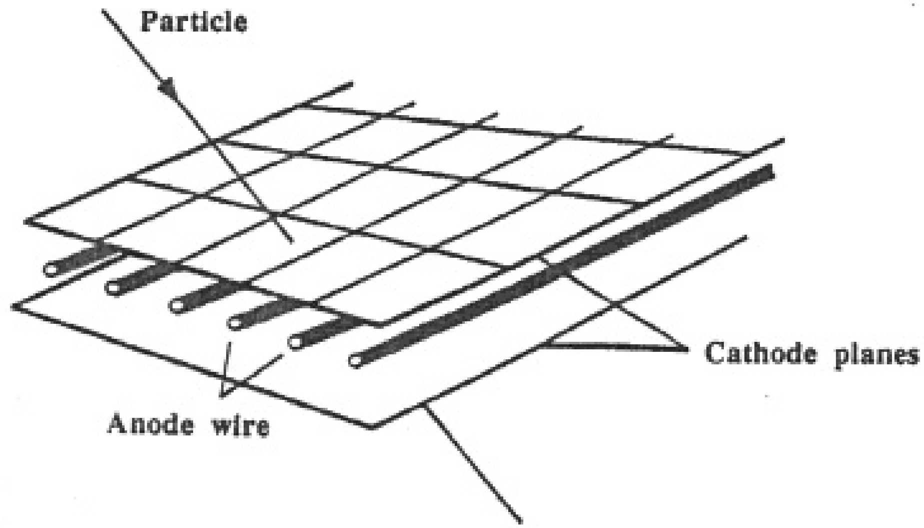
Crystal calorimeters collect Chernkov and/or scintillation light from the electrons and positrons

Gas Detectors

- Geiger counters
- Proportional chambers
- Drift chambers
- Time Projection Chambers TPCs
- Resistive Plate Chambers RPCs

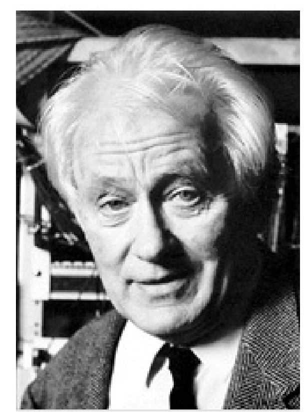


- A charged (or neutral particle) ionizes the gas in the counter
- An electron avalanche develops in the large E field near the wire
- A conducting path in the gas discharges the capacitor formed by the wire and case of the counter
- Counting rate of Gieger counters limited by the speed of charging up the detector after a hit



• Proportional chambers have limited gain ($< 10^6$)and signals that are proportional to the original ionization event
• Gas gain occurs close to wires, signal independent of position

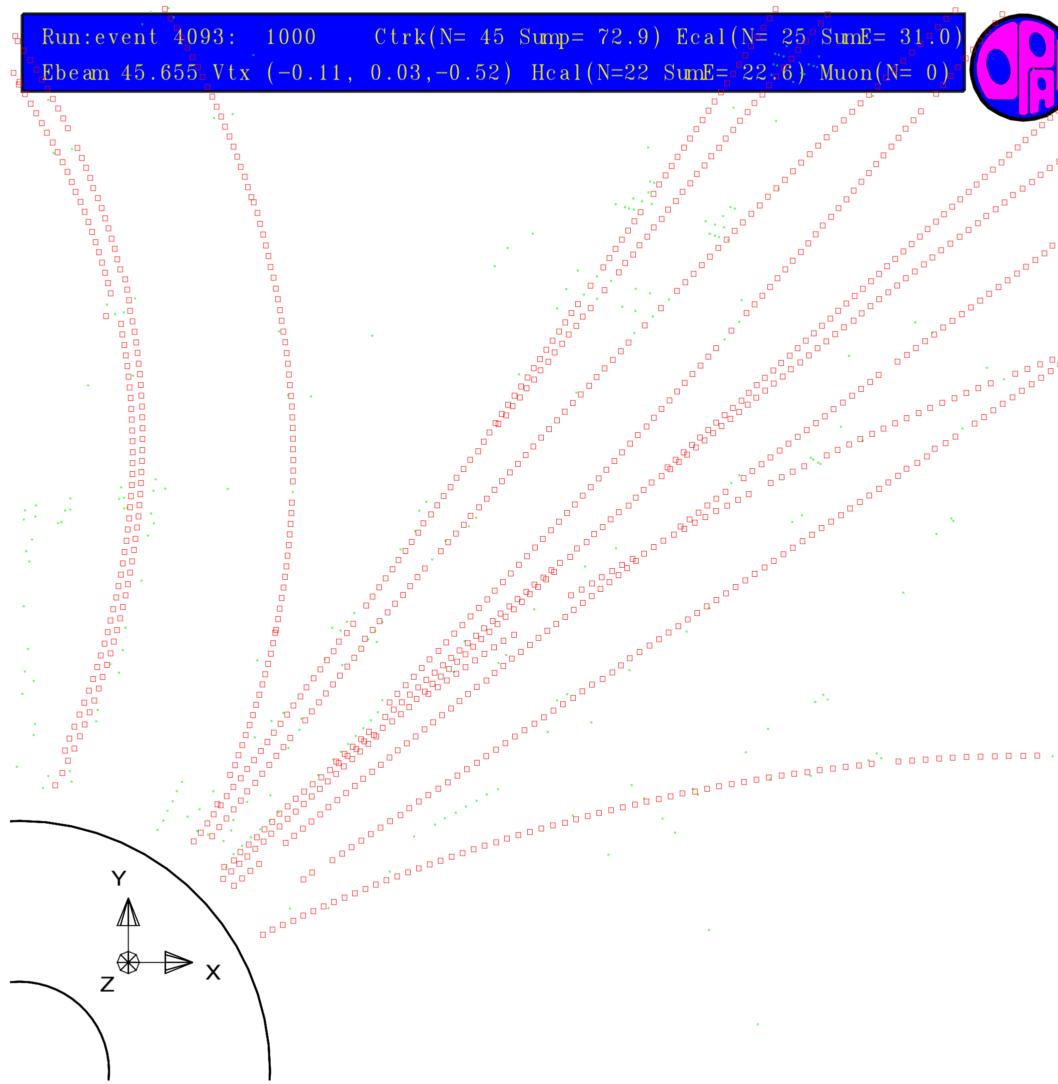
• Georges Charpak received the 1992 noble prize for his work on these chambers.



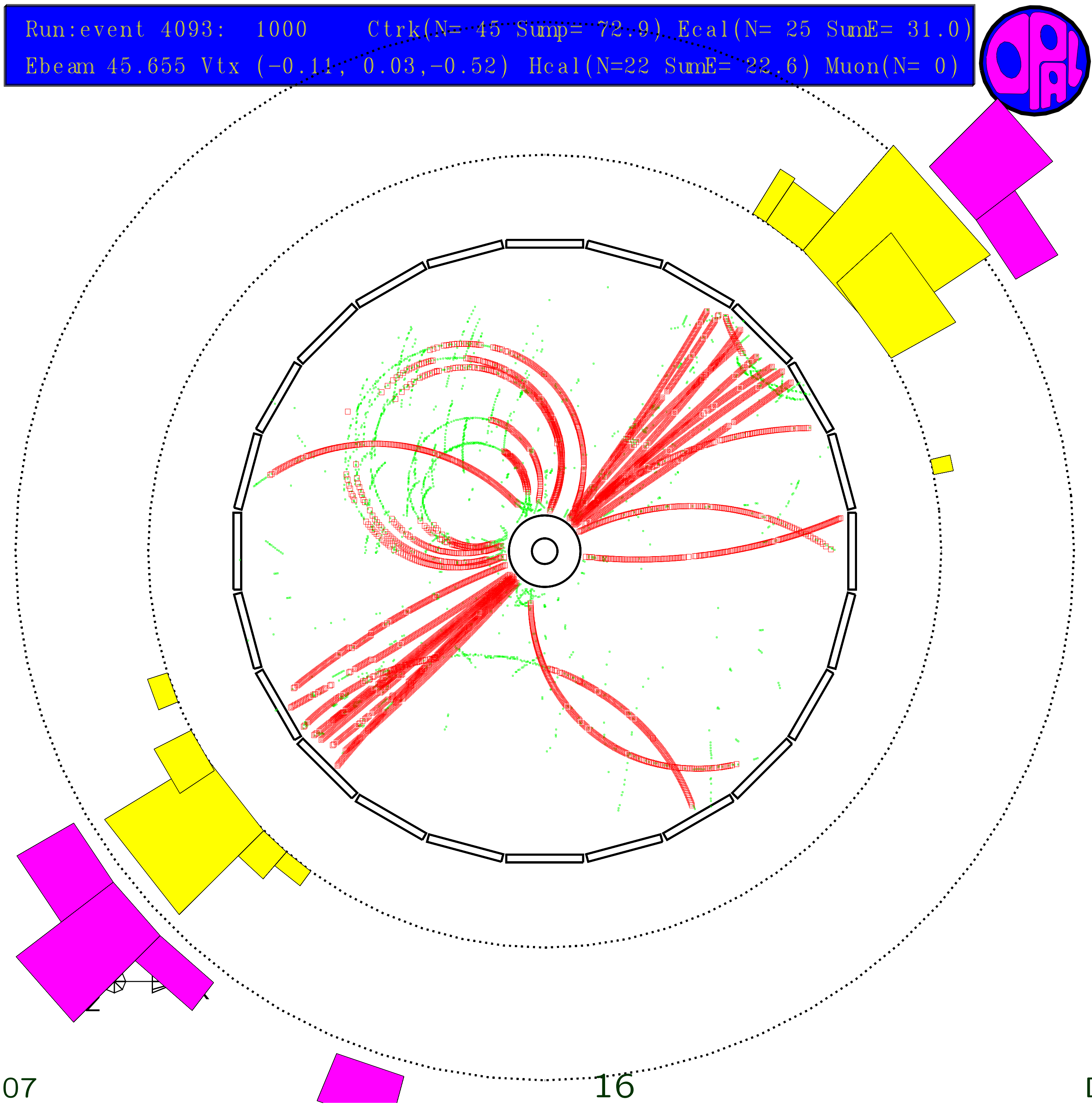
Sector of OPAL jet chamber:

Drift Chambers

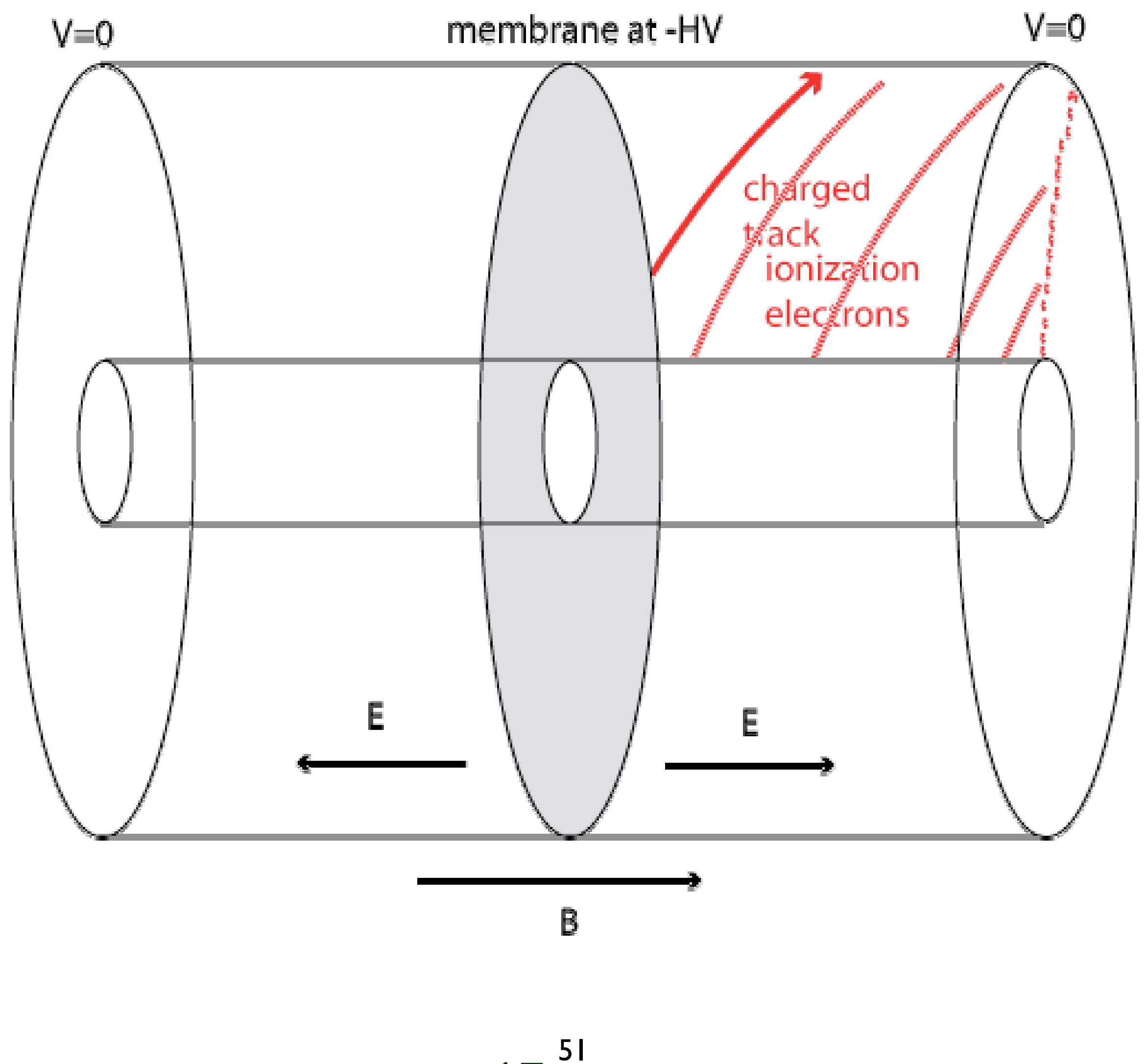
- Position is reconstructed by measuring the time needed for the ionization to drift in a near constant E field.
- Accuracies of 100 -200 μm are possible
- Momentum can be determined by the track curveture
- Some information of the particle mass comes from $\frac{dE}{dx}$
- Main challenge is to measure longitudinal coordinate



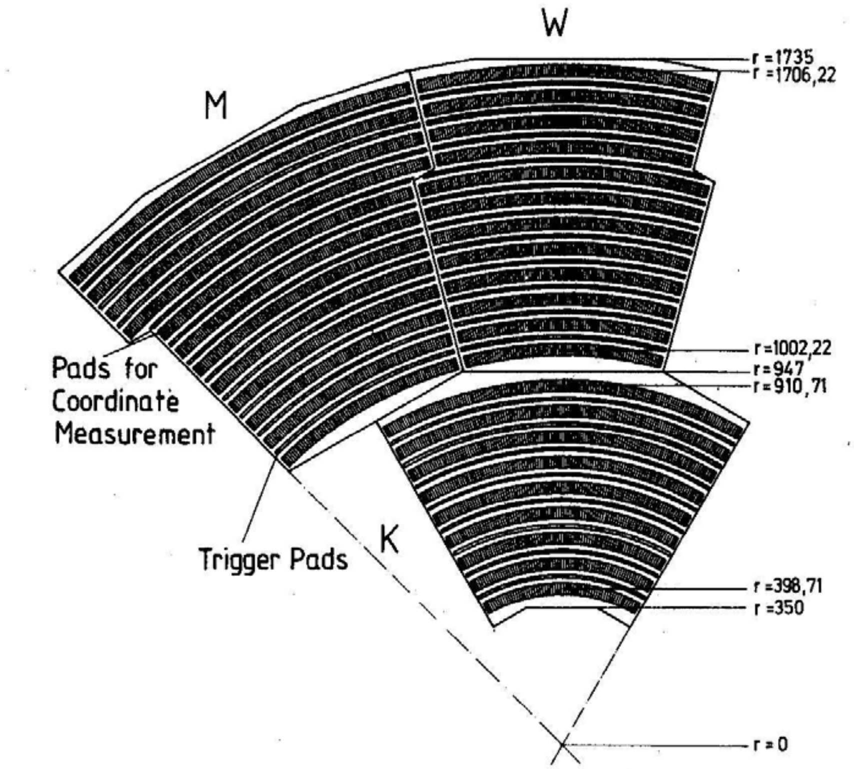
A fully reconstructed event:

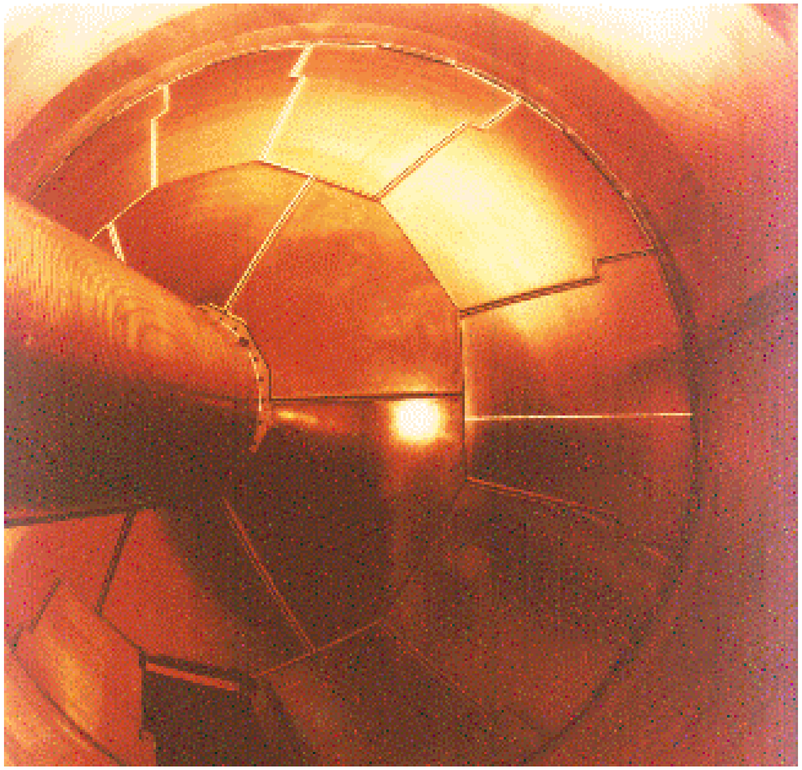


Time Projection Chambers

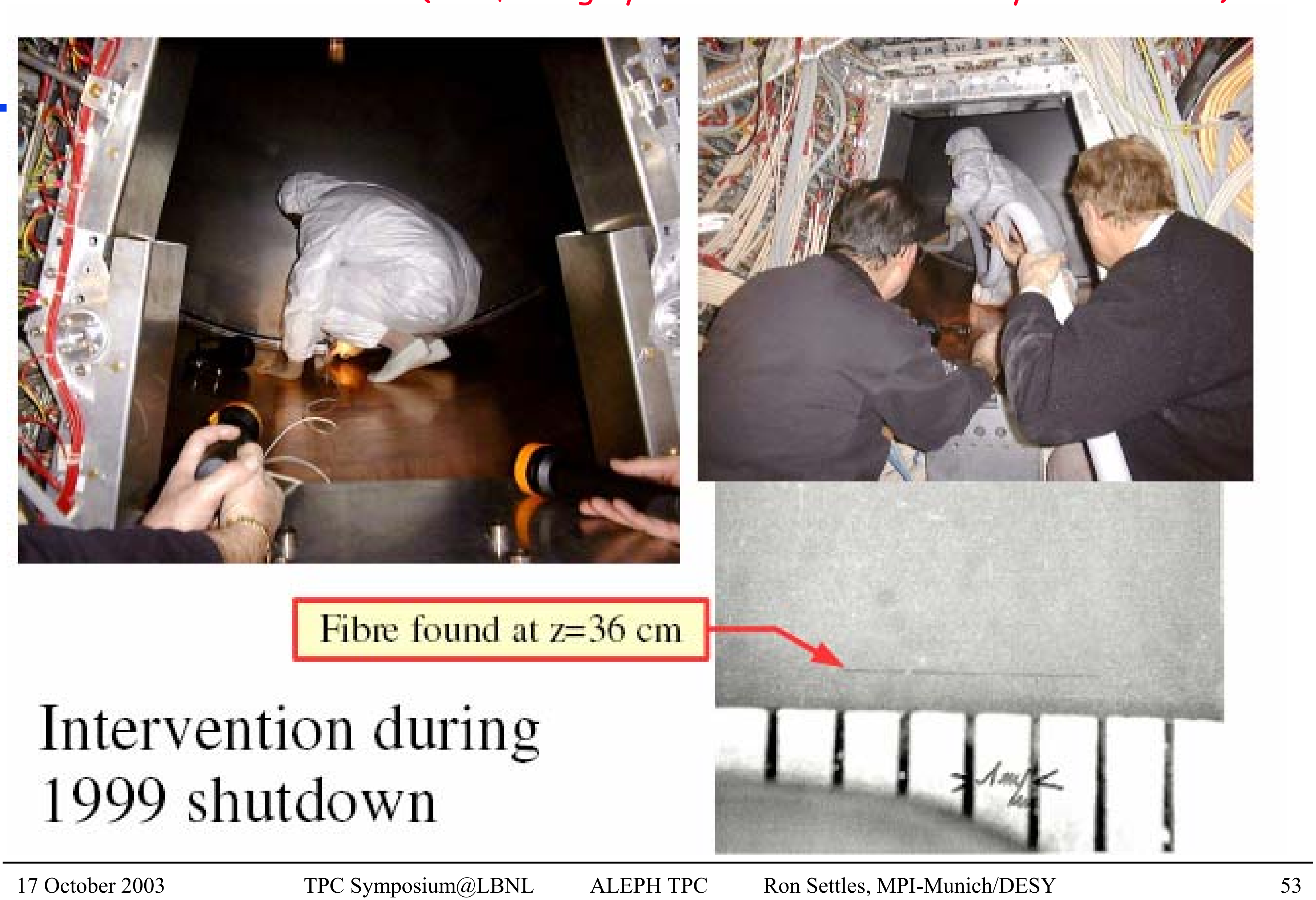


From the drawing board to the gadget...

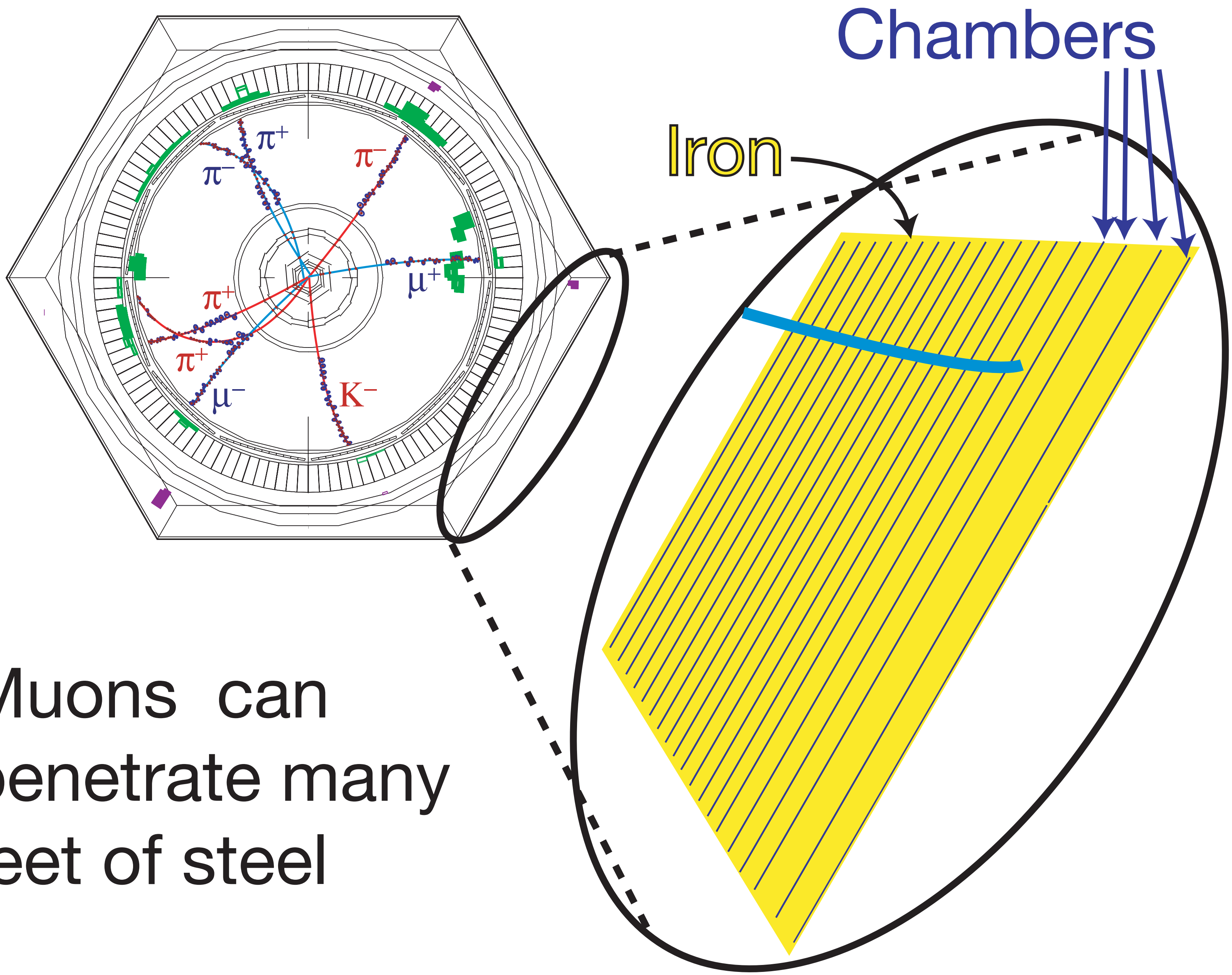




(N.B., design your detector to be easily accessible...)

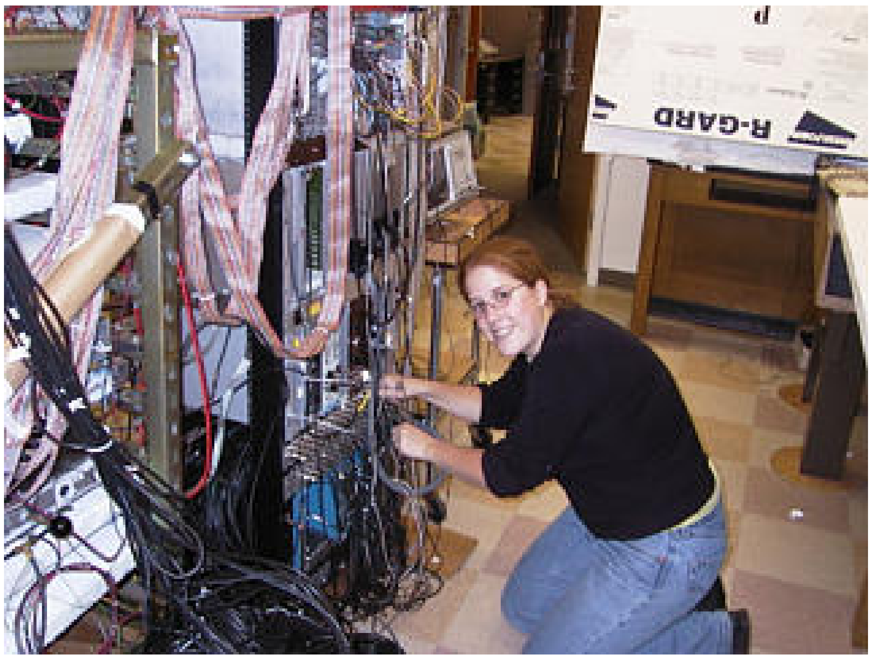


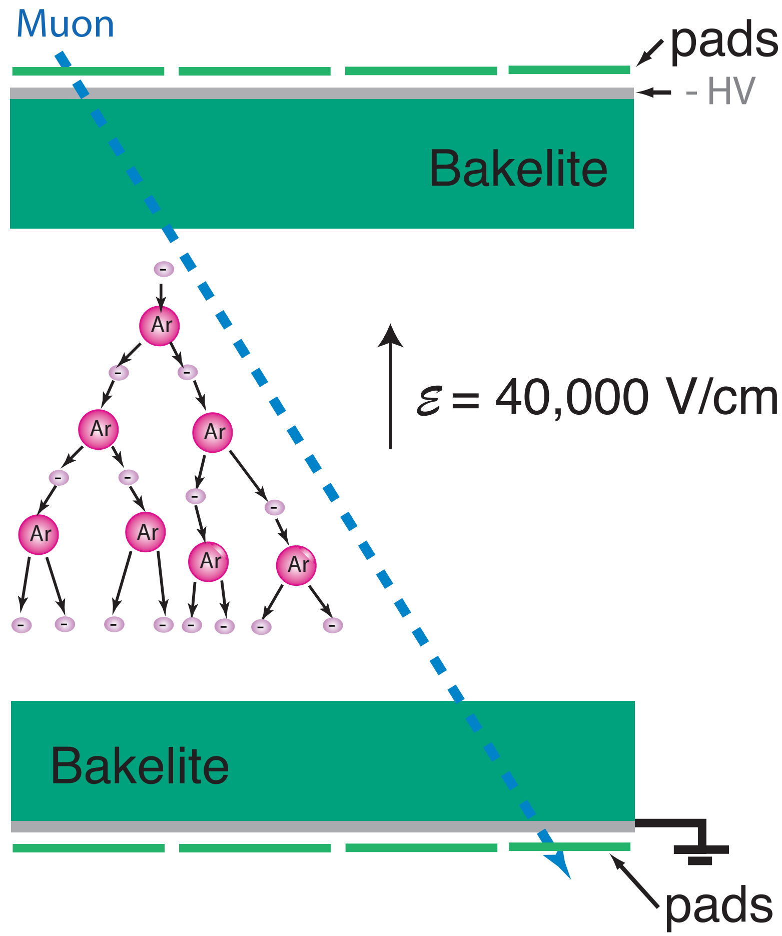
Babar instrumented flux return (used as a mainly as a muon detector)

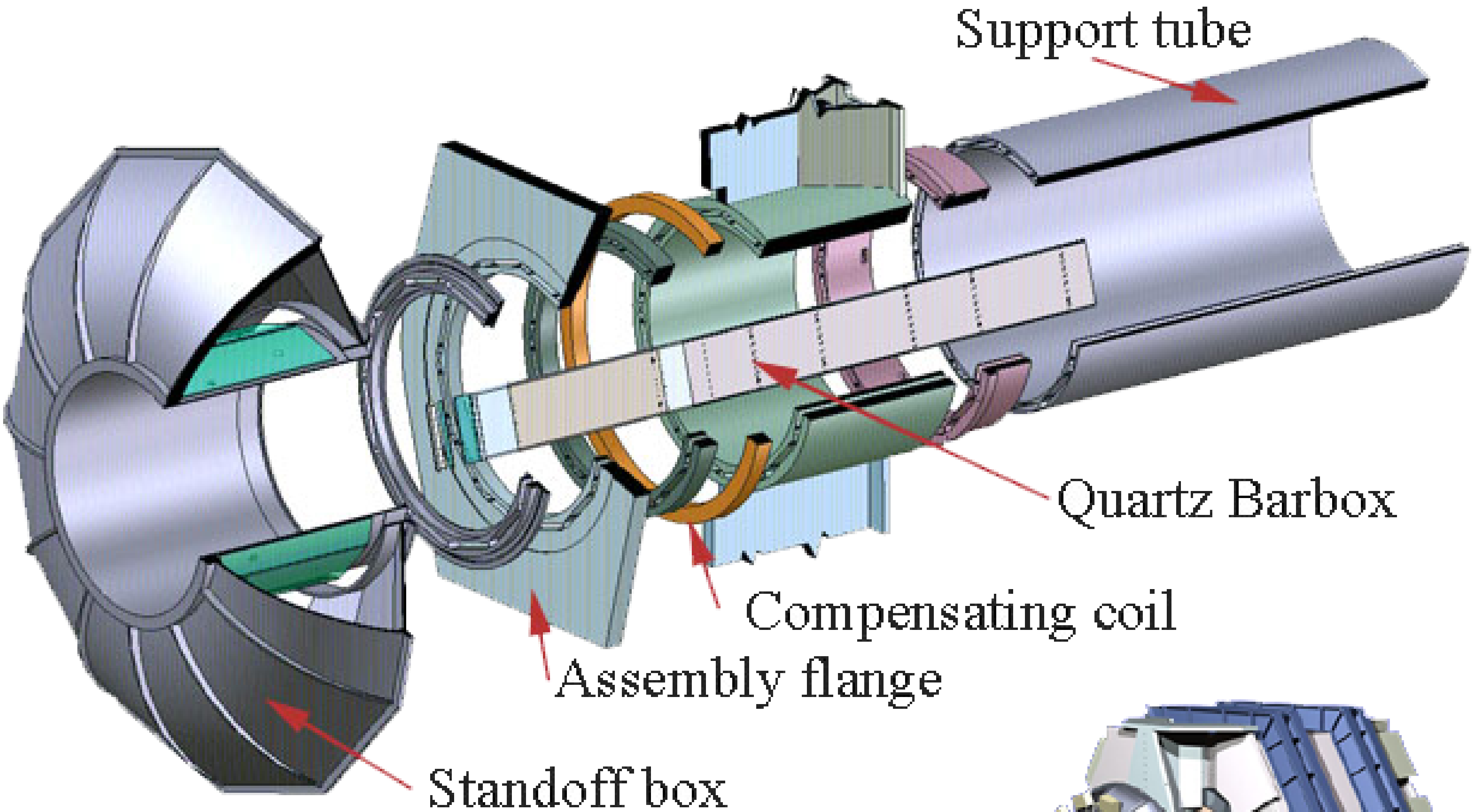


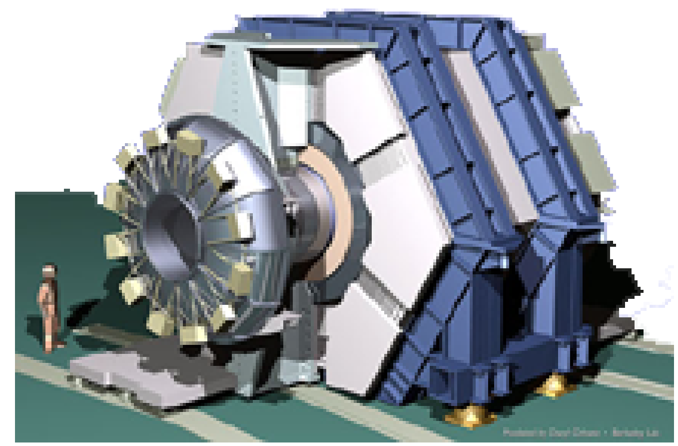
Muons can penetrate many feet of steel

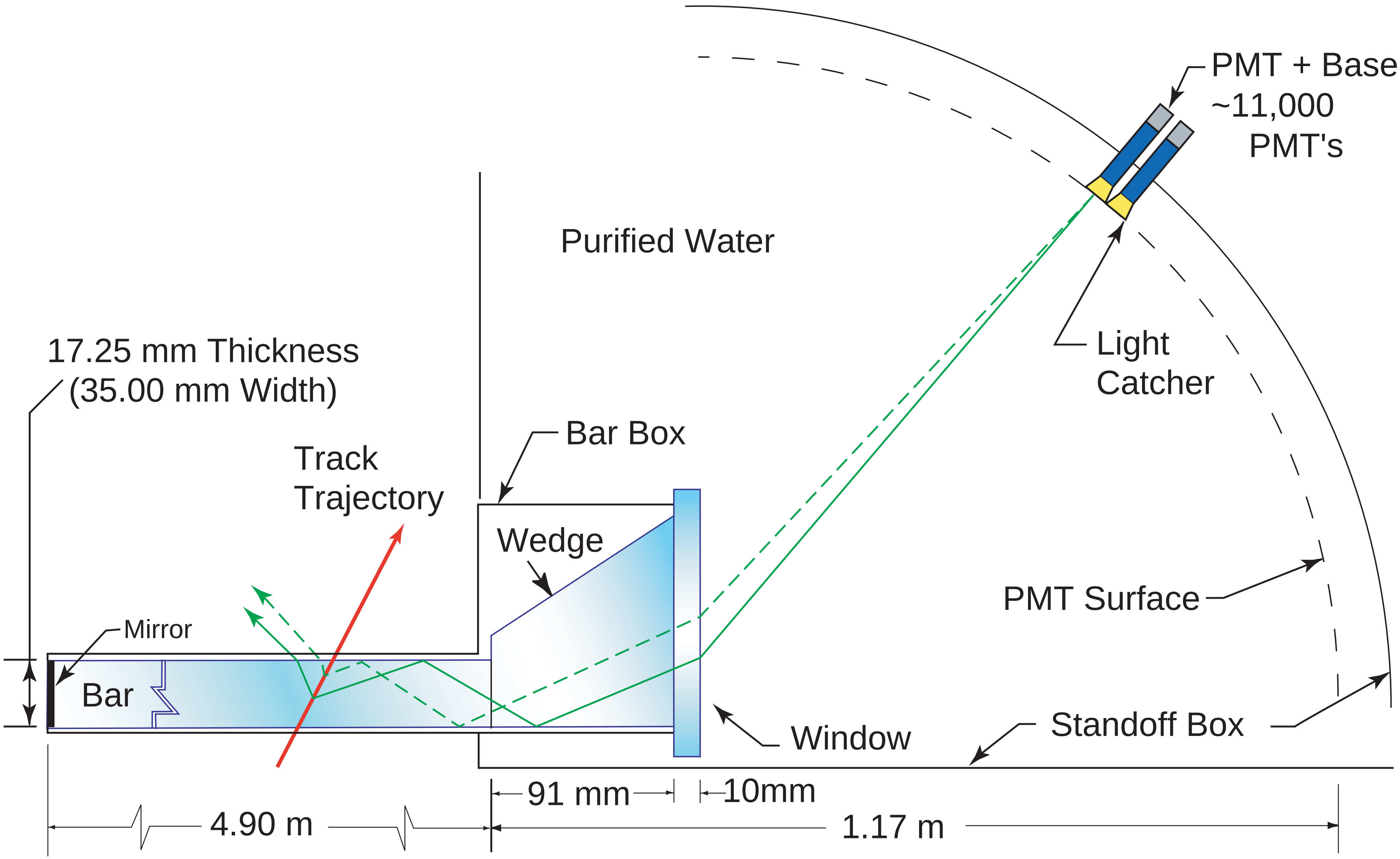
UO undergrad working to understand BaBar Resistive Plate Chambers (RPCs)






Support tube
Quartz Barbox
Compensating coil
Assembly flange
Standoff box

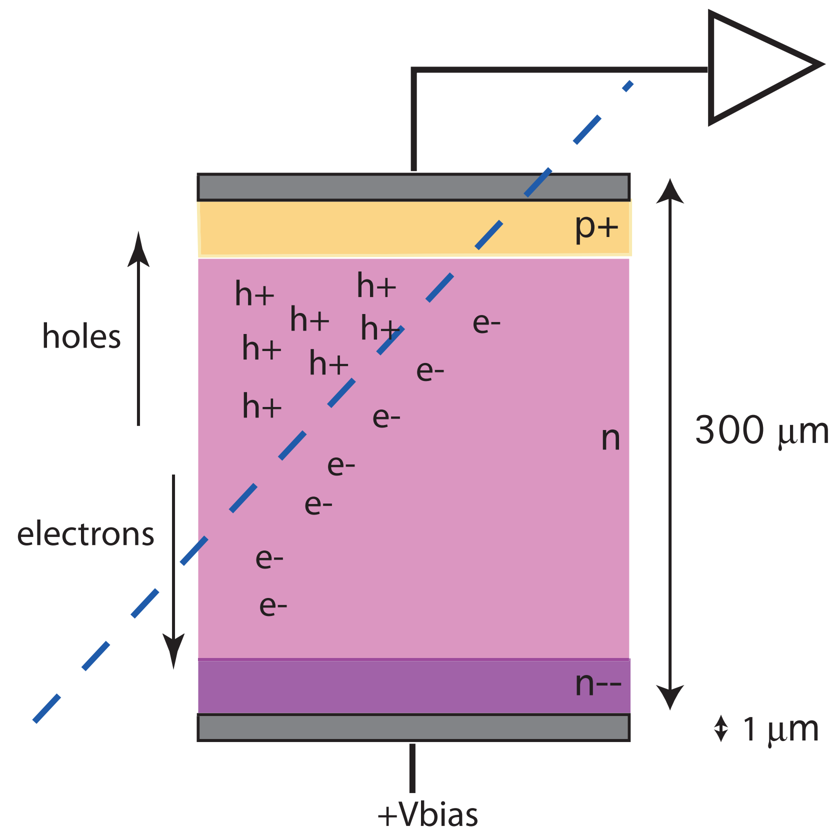




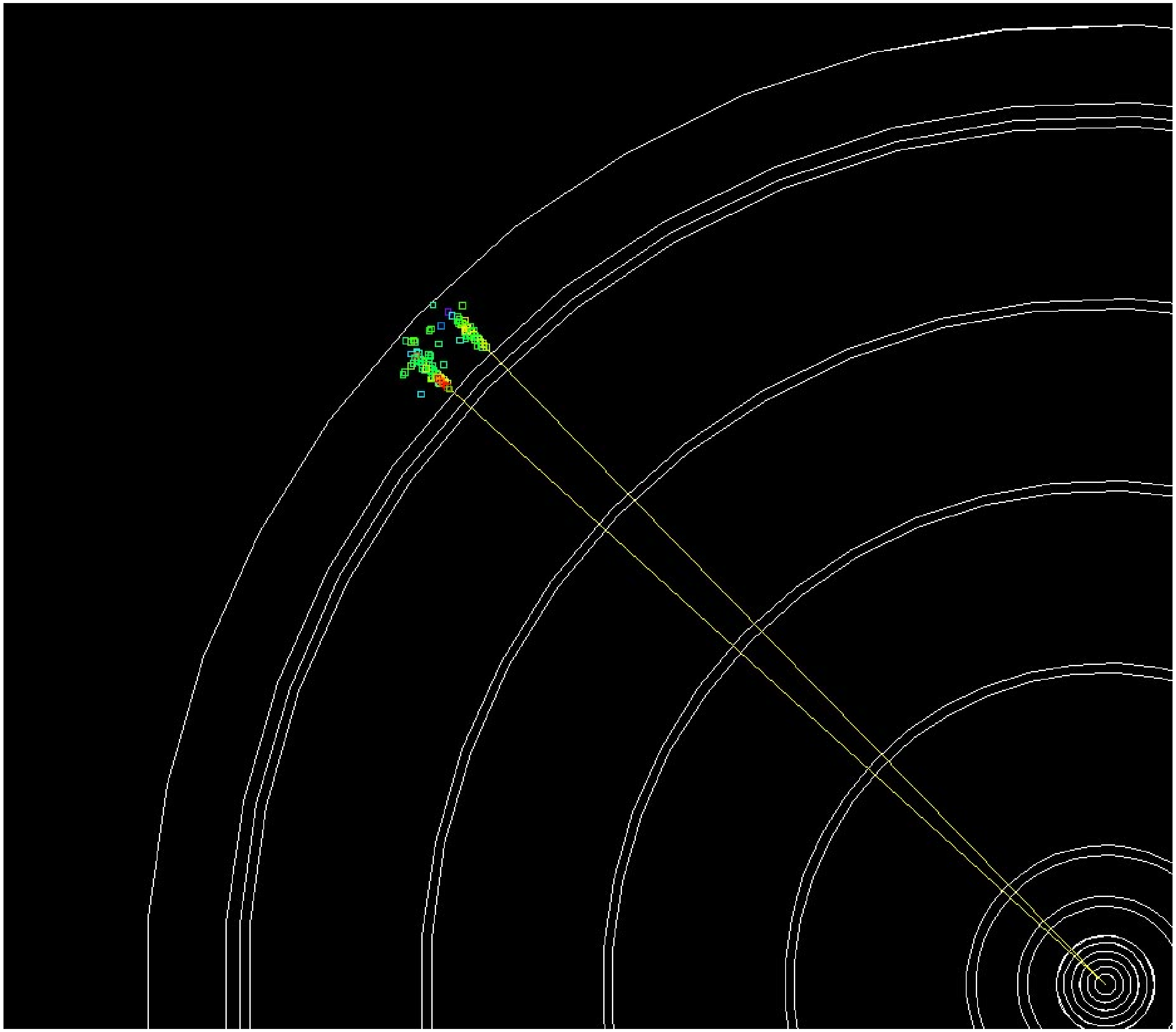
4 x 1.225 m
Synthetic Fused Silica
Bars glued end-to-end

Silicon Detectors

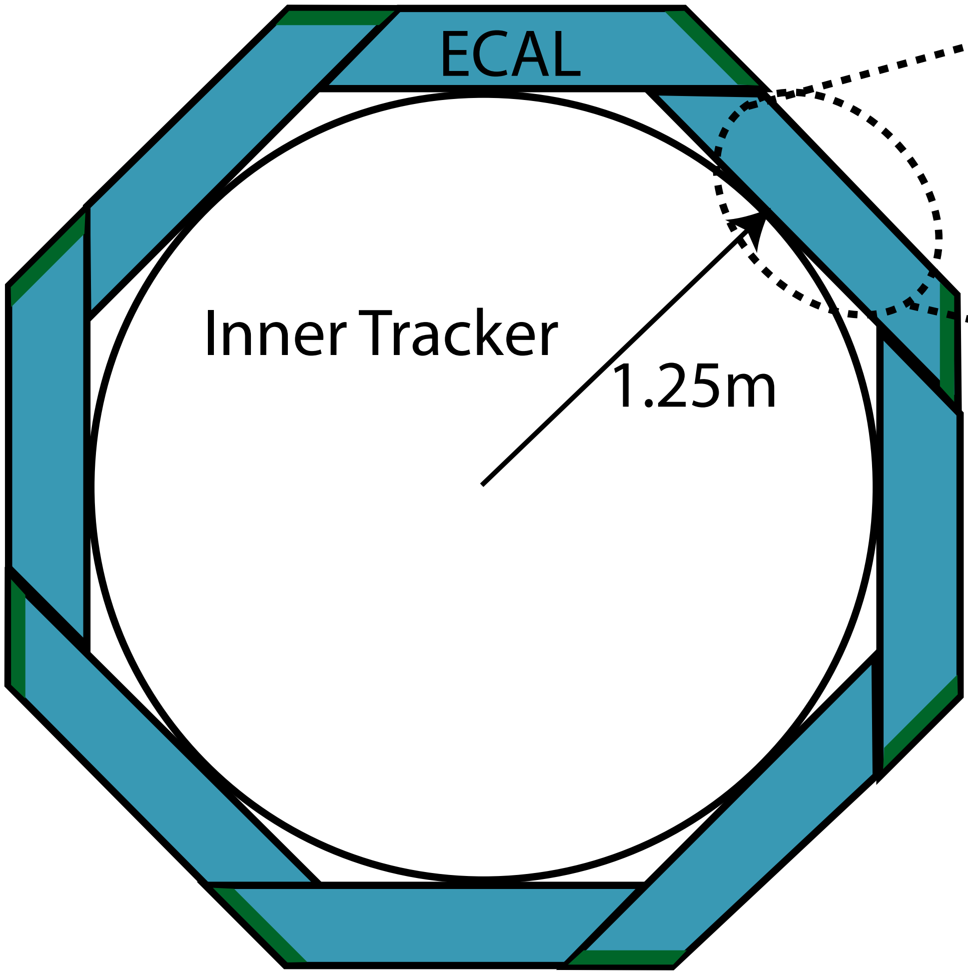
- Detectors are based on reversed bias detectors
- In silicon charge particles produce electron-hole pairs instead of ion-electron pairs
- 3.67 eV of energy is needed to release one hole-pair (c.f. Si bandgap = 1.12 eV)
- For 300 μm thick devices about 25,000 electrons (4fC) are produced
- Main challenge is to see the small signals
- Silicon detectors can be used for both sampling calorimetry and tracking

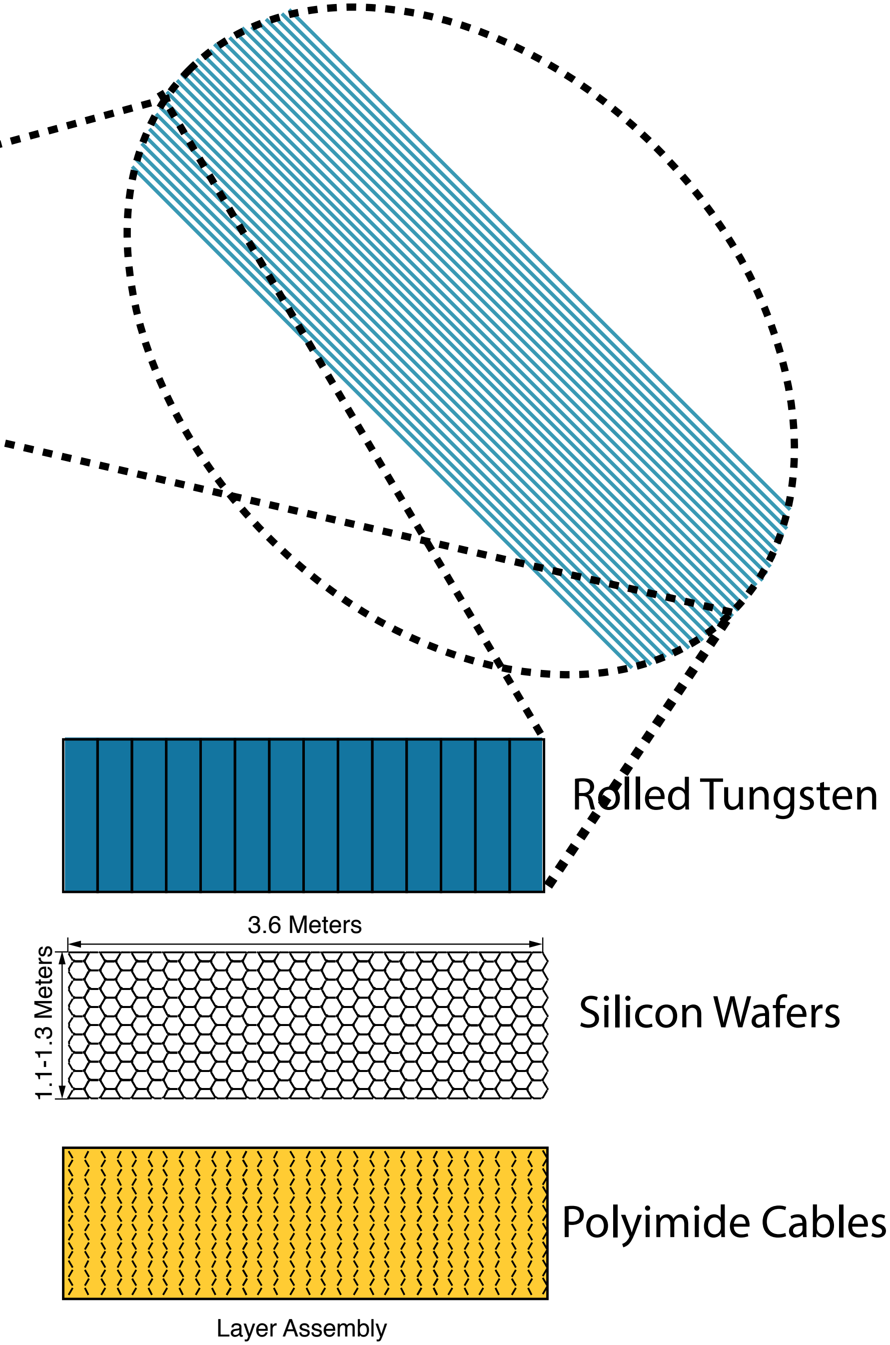


At a linear collider it is important to be able to resolve closely spaced photons:



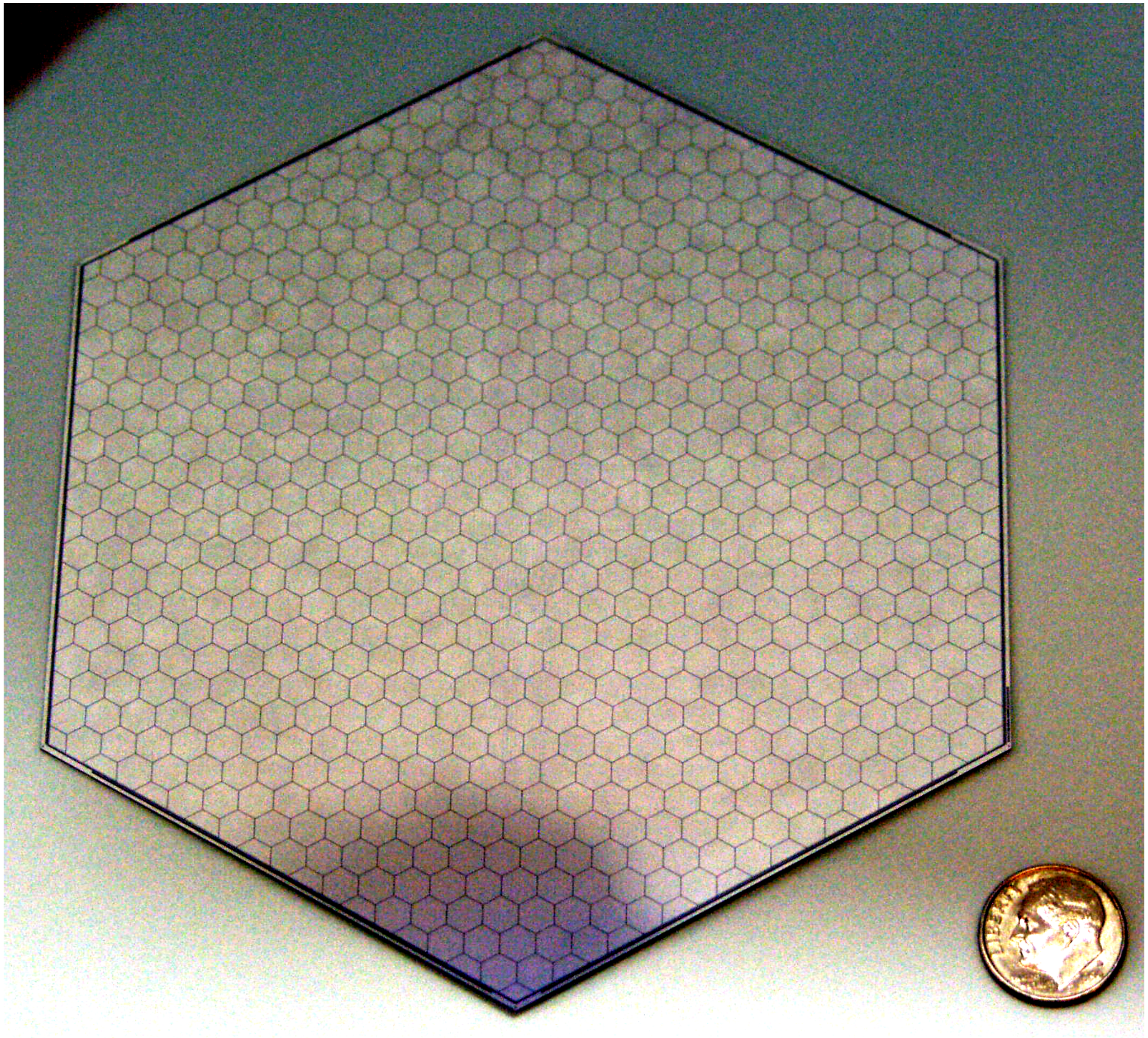
Si-W Calorimeter Concept



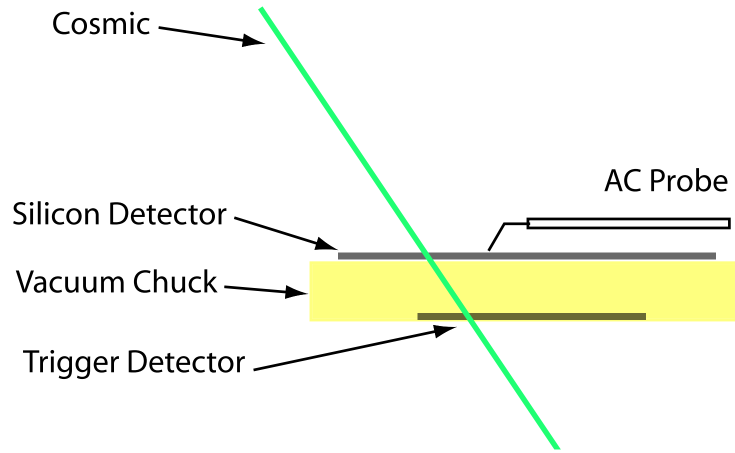


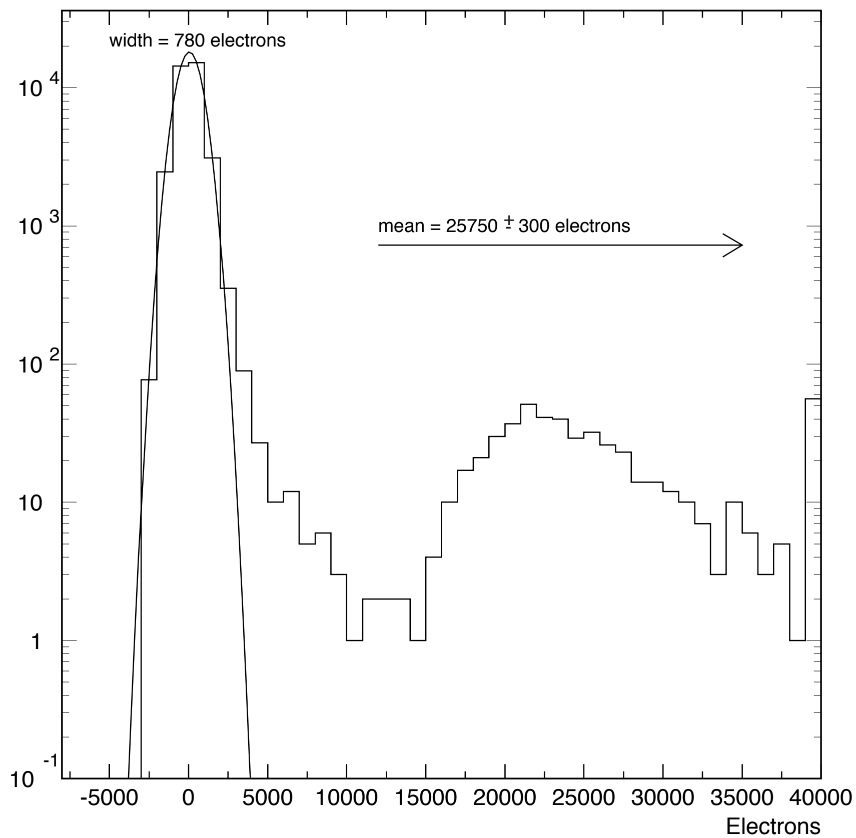
Transverse Segmentation ~5mm
30 Longitudinal Samples
Energy Resolution ~15%/$E^{1/2}$

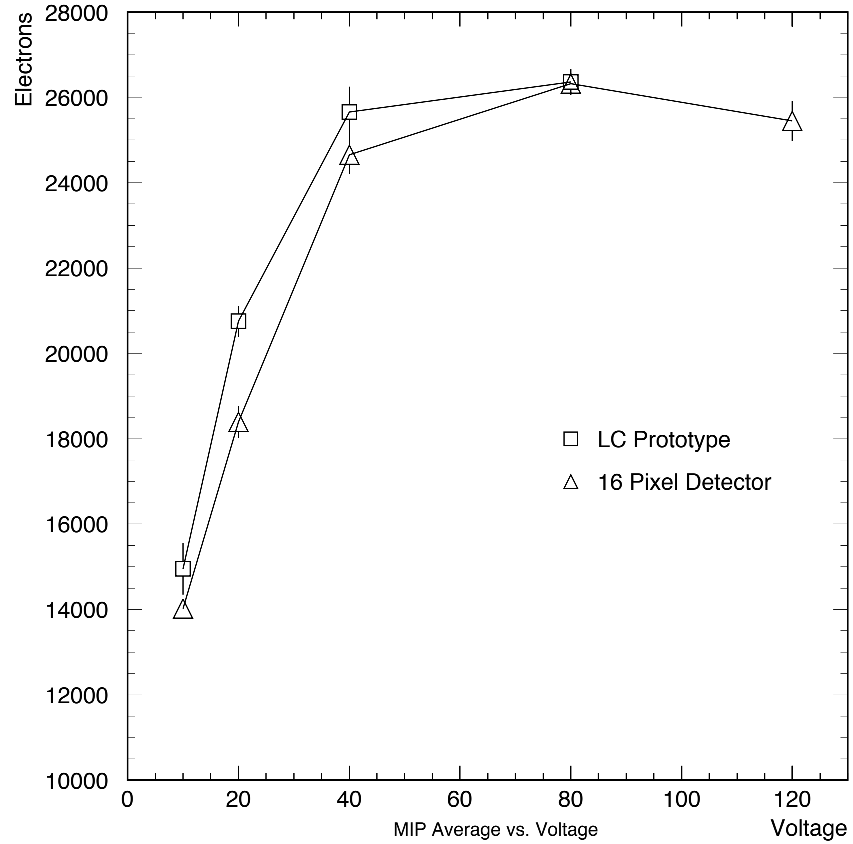
Silicon Pad Detectors



Response of detectors to Cosmics
(Single 5mm pixel)
Simulate LC electronics
(noise somewhat better)

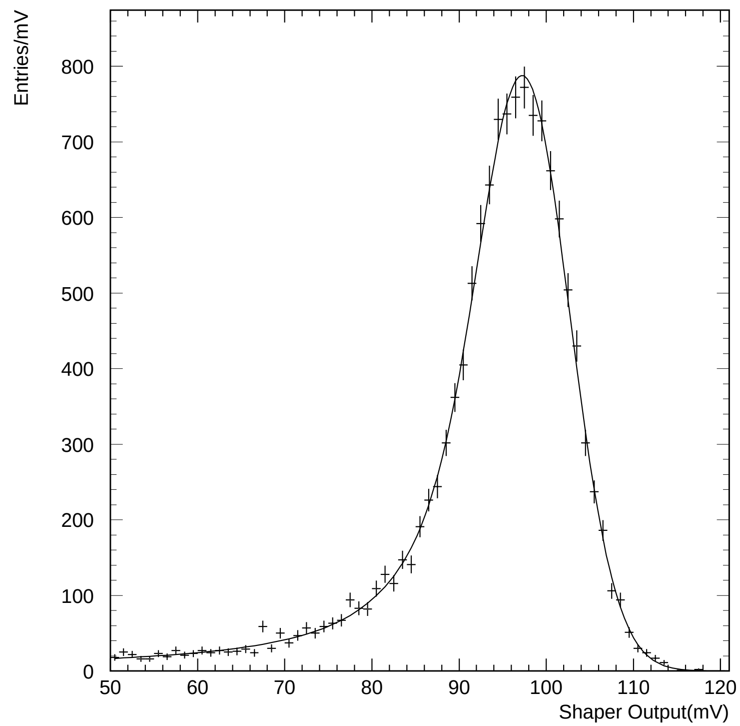






Errors do not include ∼ 10% calibration uncertainty (no source calibration)

Response of Detectors to 60KeV Gamma's from Am^{241}

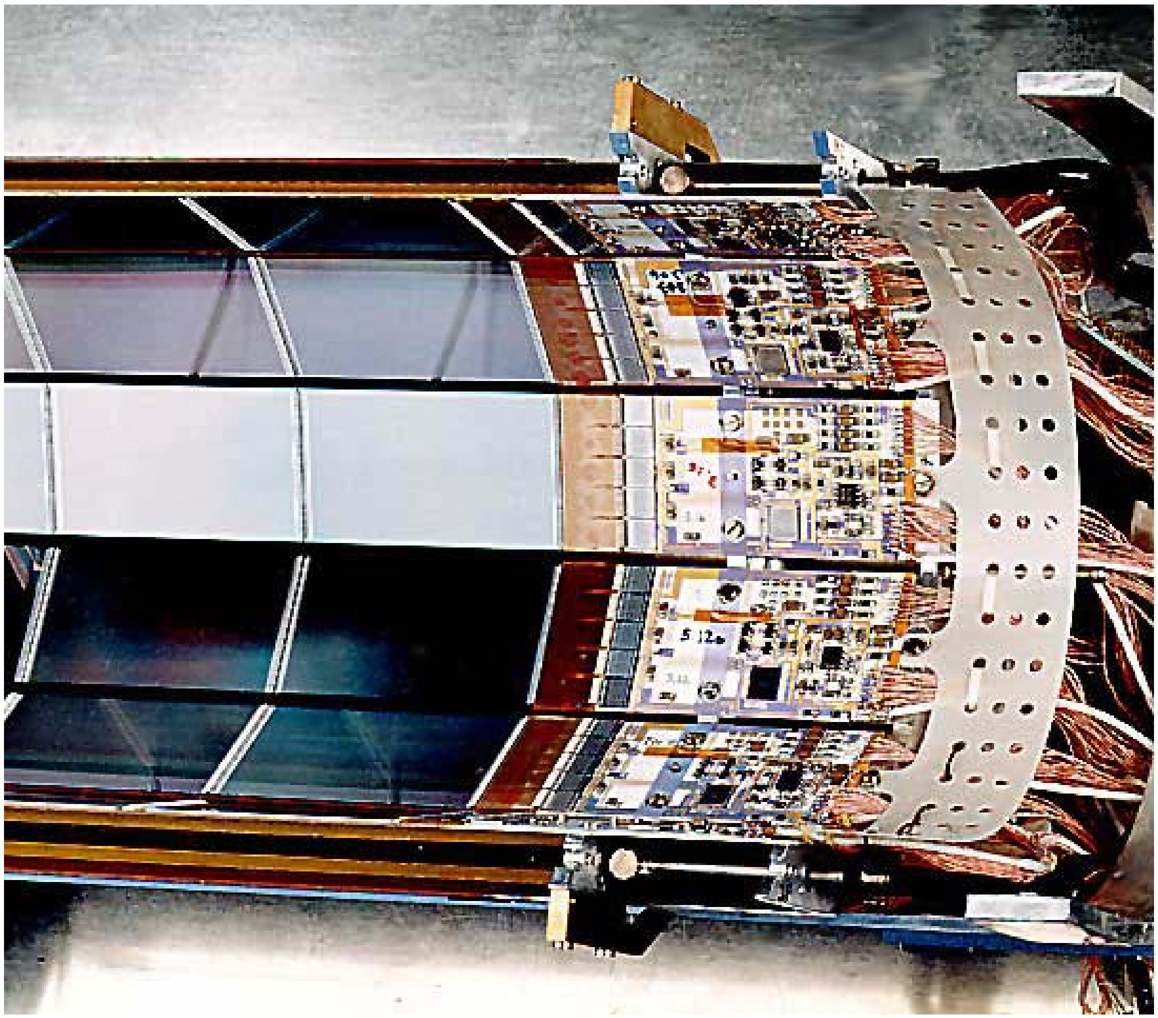


Possible $\sim$ 1% wafer-wafer calibration?

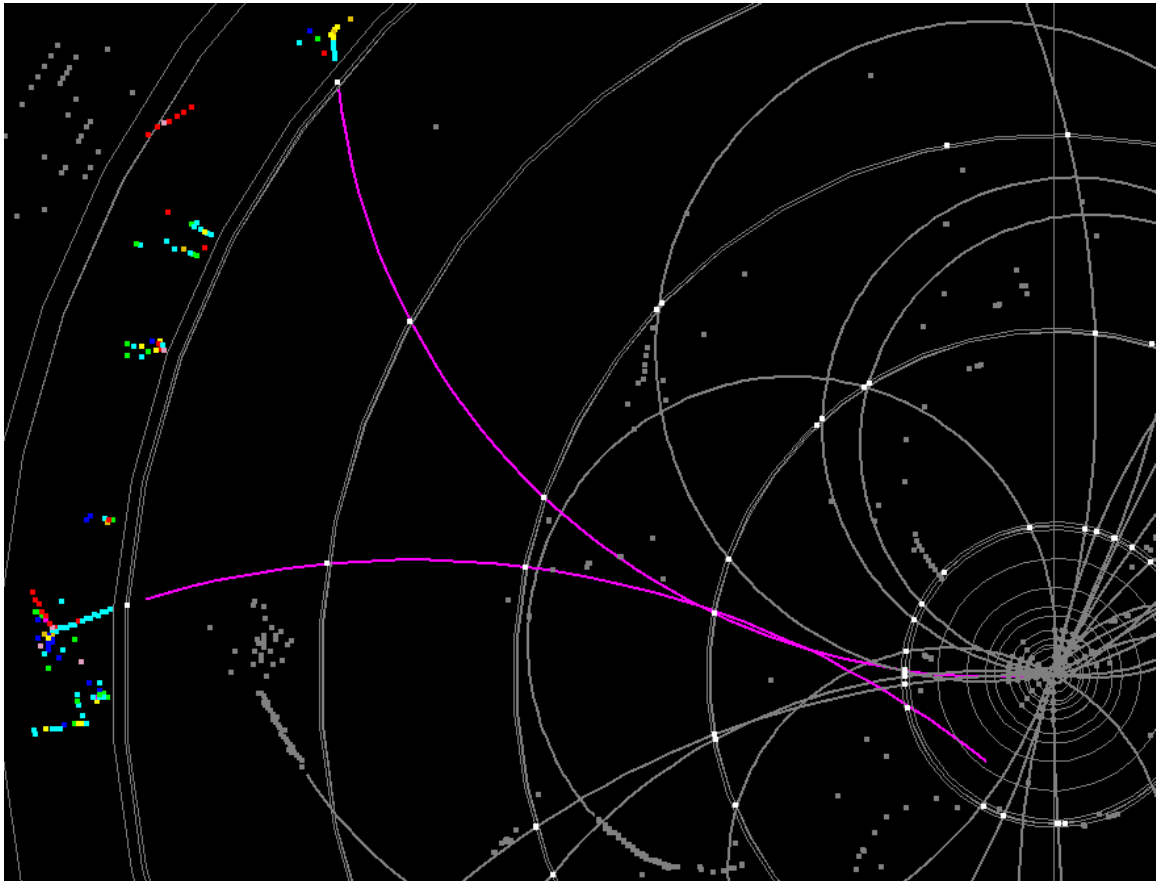
Width of distributions corresponds to $\sim$ 1000 electrons noise. Pixels under test are on outer edge of wafer – includes larger series resistance contribution than cosmic data.

Silicon detectors can also be in a strip geometry (usually 50μm pitch) for tracking:

The OPAL microvertex detector



A simulated linear collider event reconstructed in the silicon tracking detector



Eckhard von Toerne, LCWS05

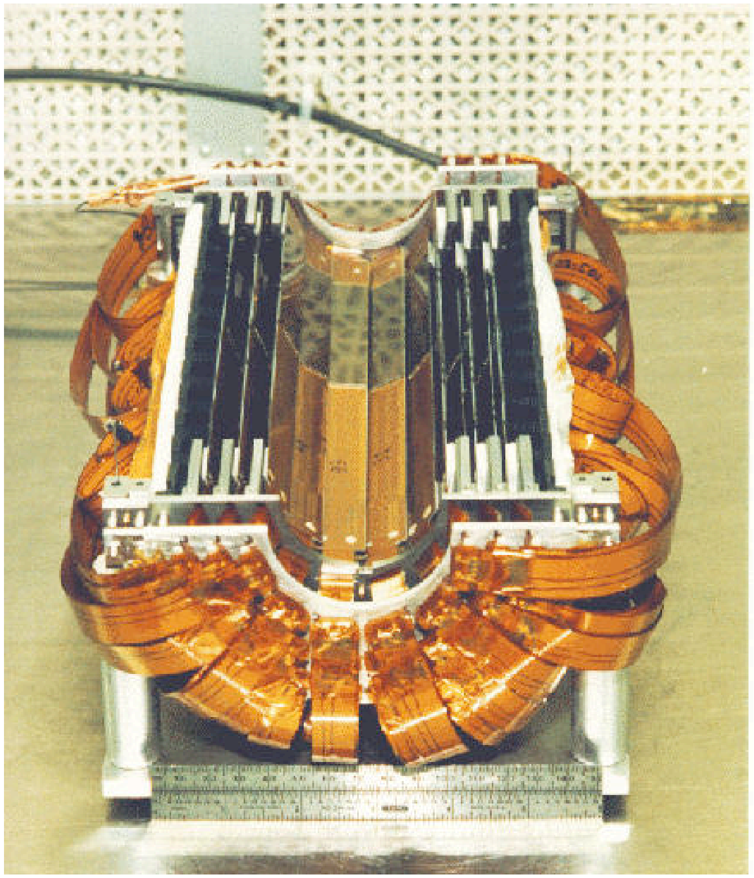
At the smallest radii it is possible to use $20\mu\text{m} \times 20\mu\text{m}$ rather than strips

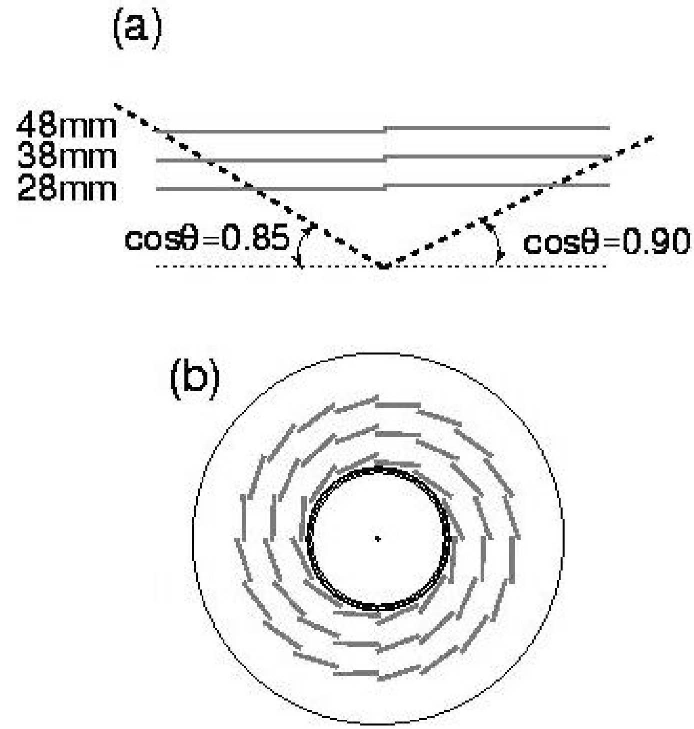
- In previous experiments CCD detectors were used (similar to digital camera)

- In future experiments "active pixels" or CMOS sensors will be used.

VXD3 at SLD

CCD Vertex Detectors





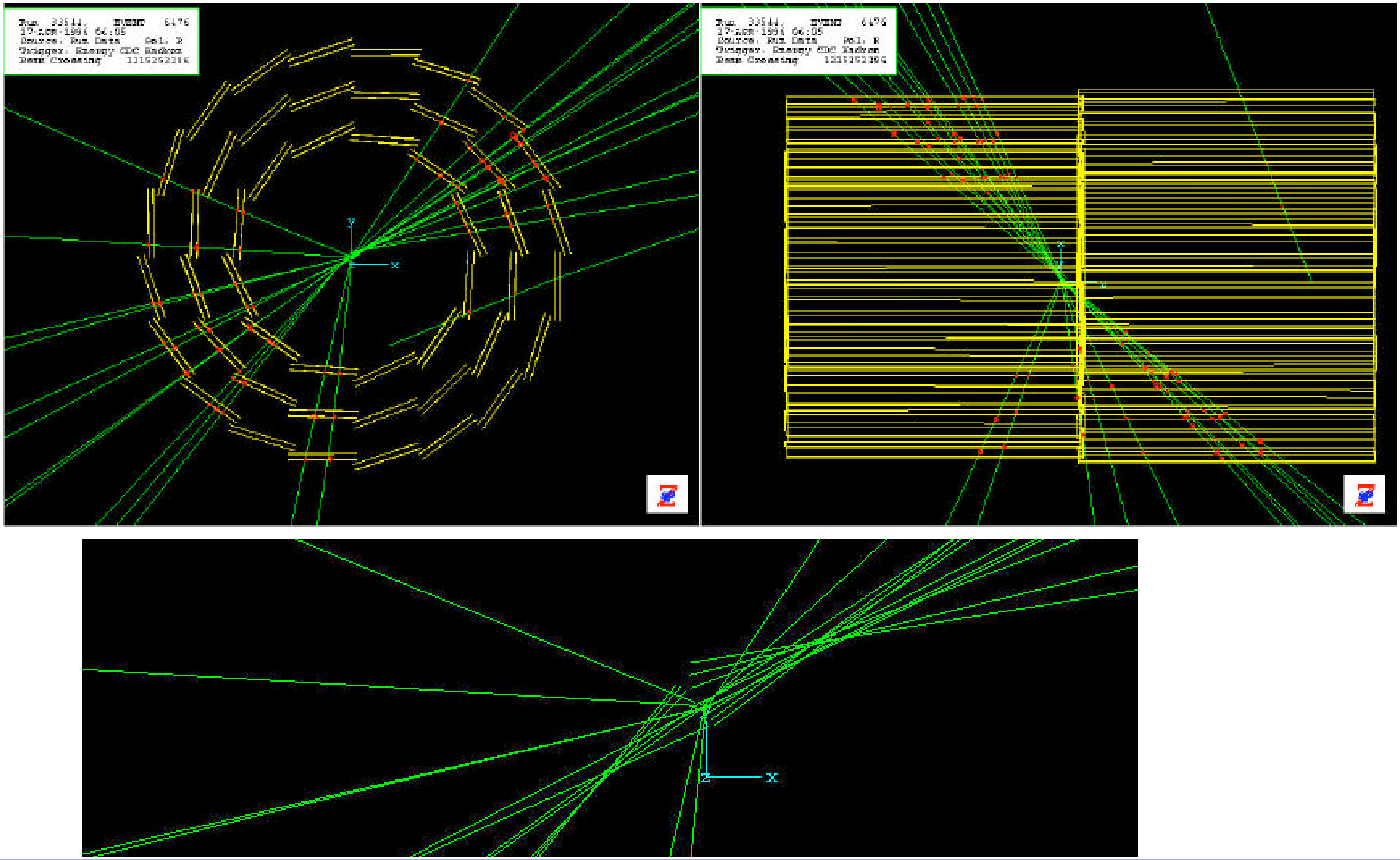
SLD Collab., NIM A400, 287-343 (1997)

307,000,000 pixels
3.8 μm point resolution
Excellent b/c tagging

J. Brau, Snowmass, July 11, 2001 13

VXD3 Event Reconstruction

CCD Vertex Detectors



J. Brau, Snowmass, July 11, 2001

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Thanks to Jim Brau, John Conway, Ron Settles, Eckhard von Toerne for useful slides...