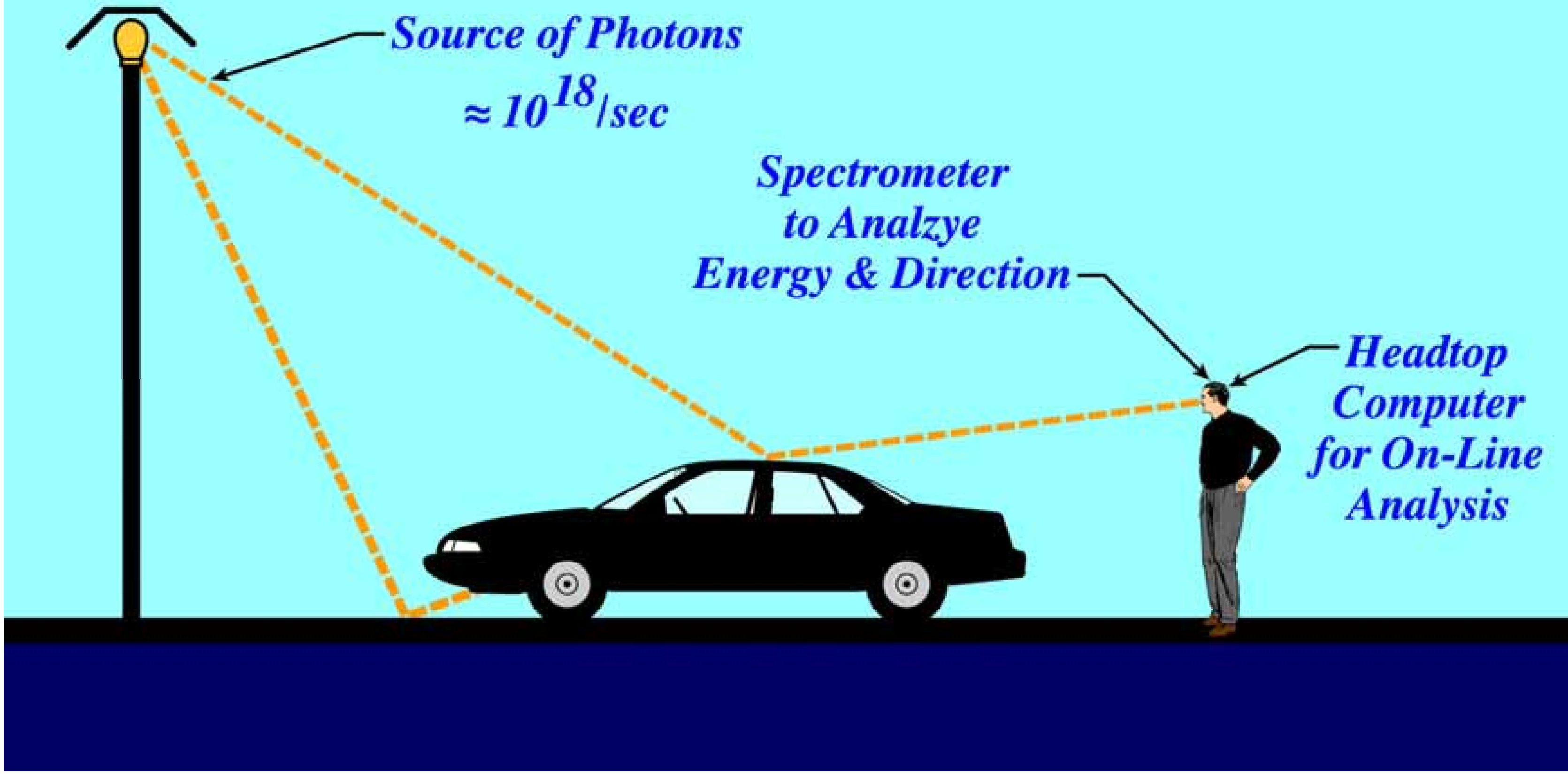
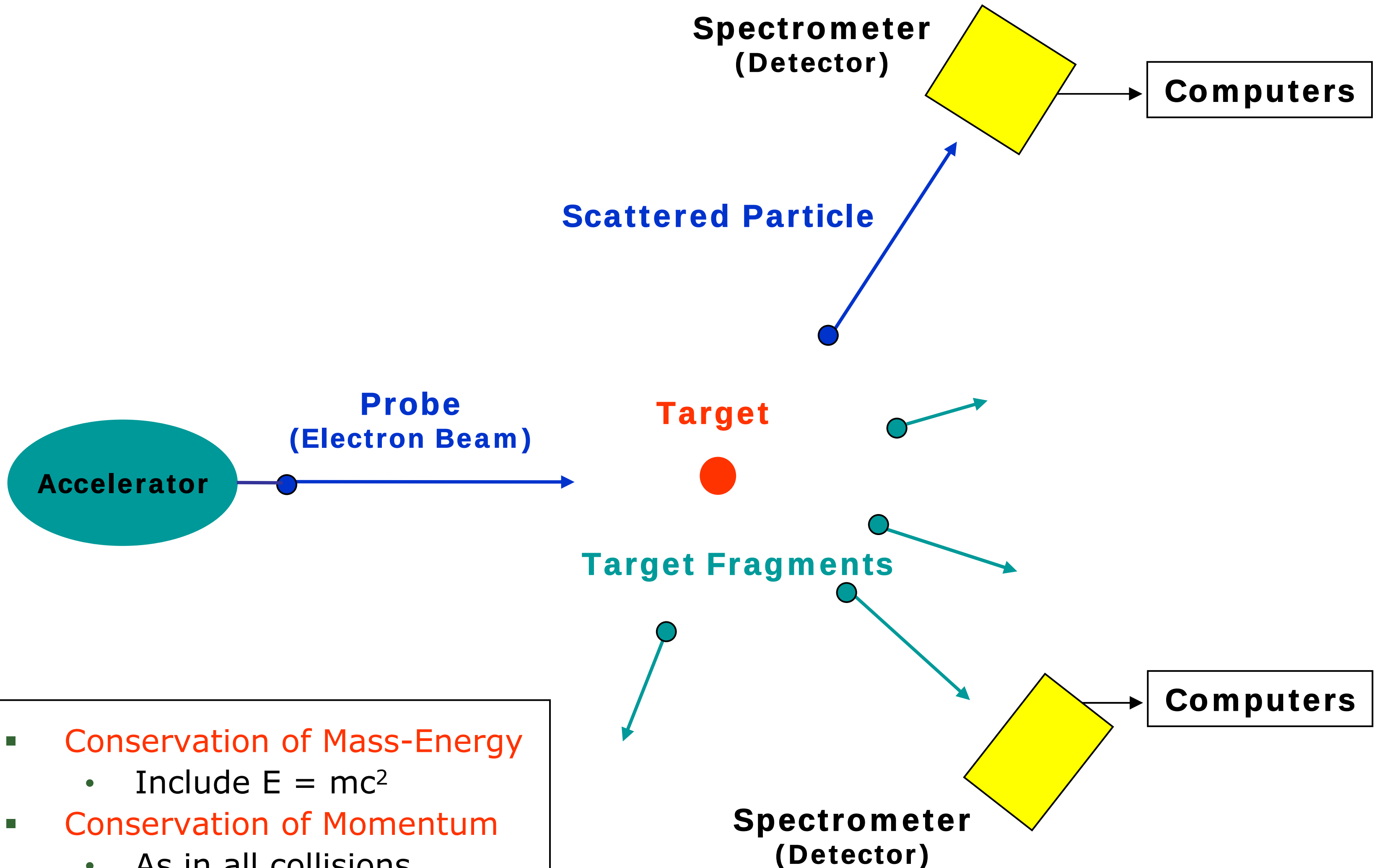
A Scattering Experiment in Hall A

Basic Equipment

Every-Day-Life Similarities to NP Experiments

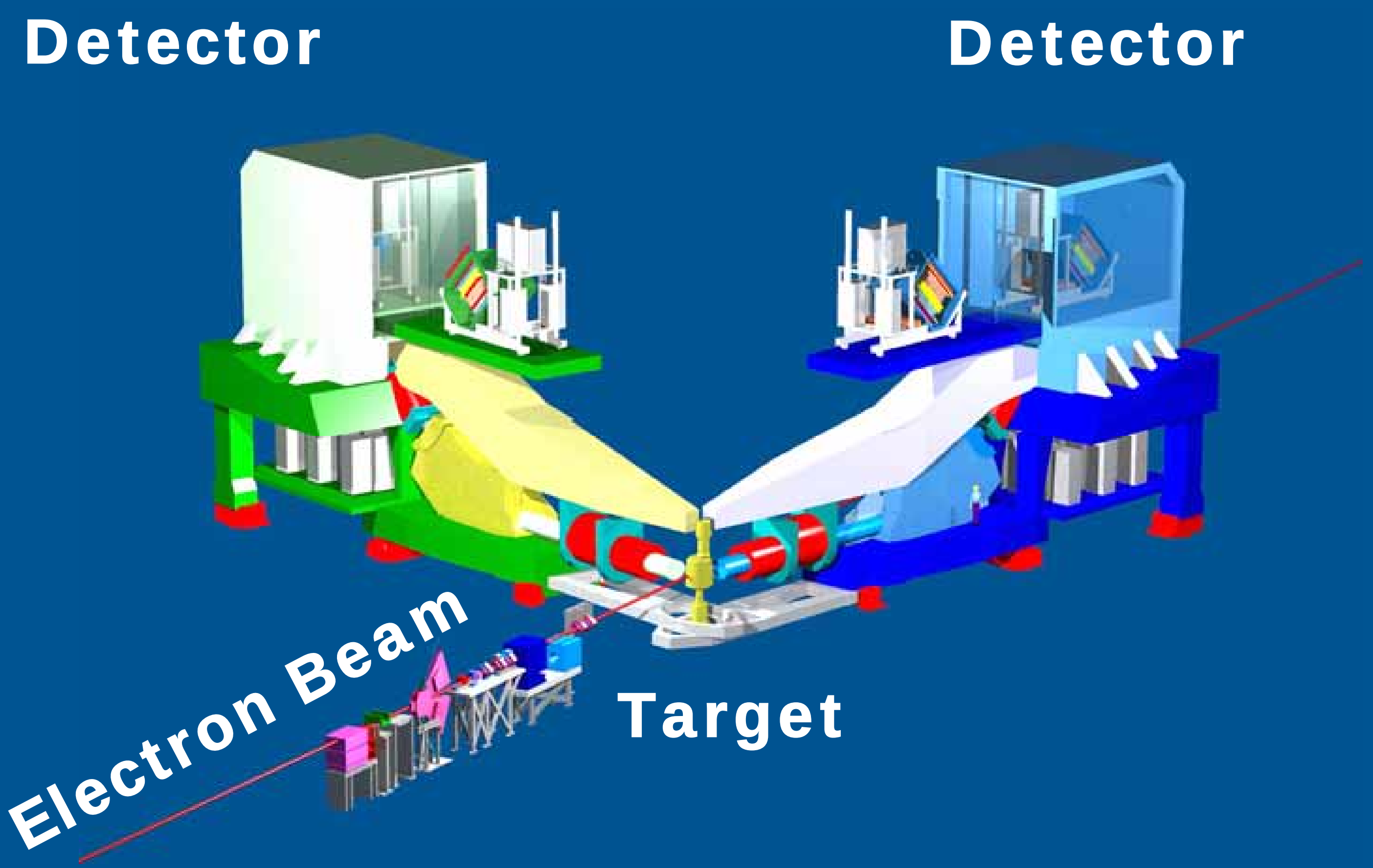


Typical Scattering Experiment

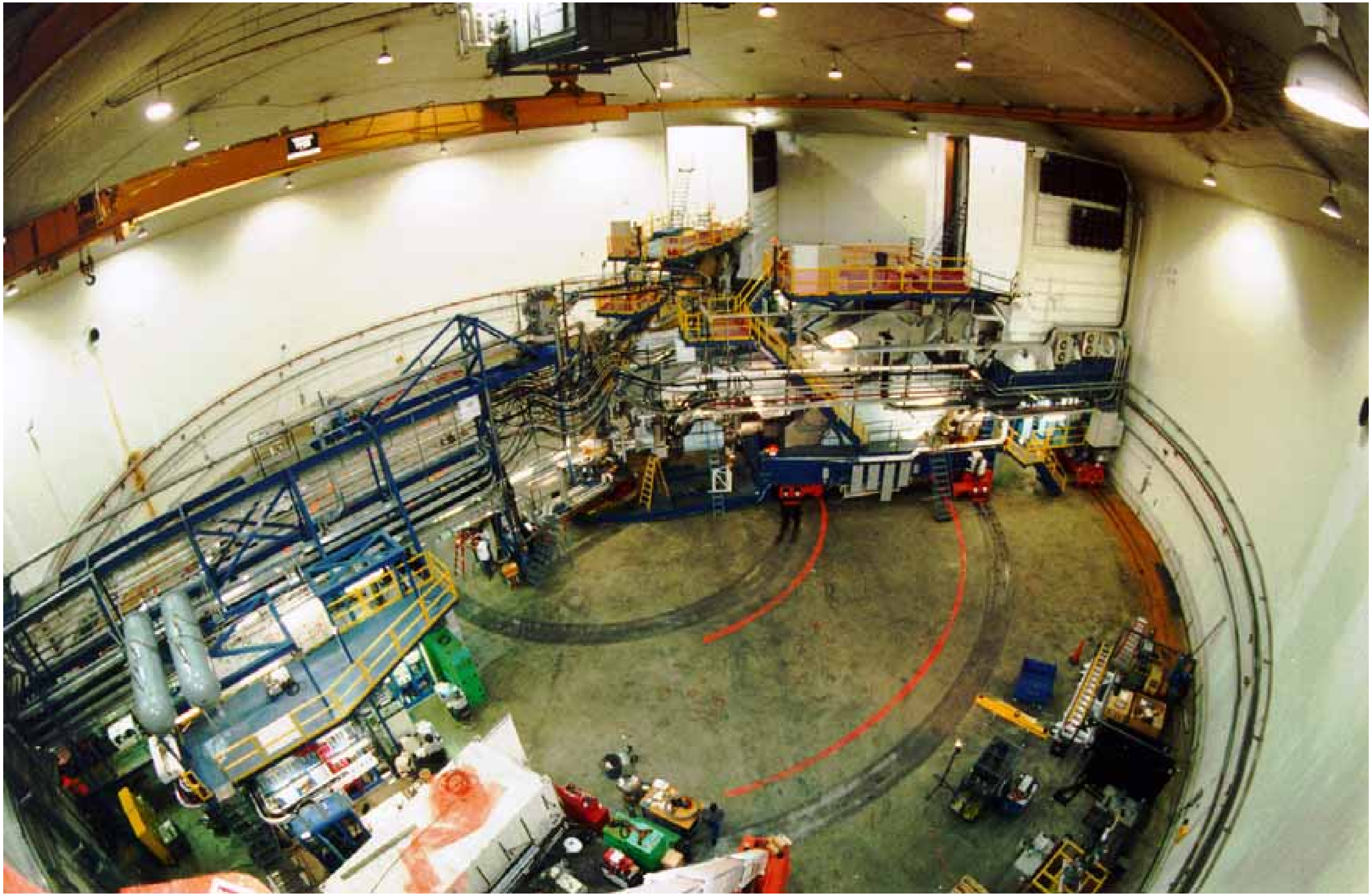


- Conservation of Mass-Energy
  - Include $E = mc^2$
- Conservation of Momentum
  - As in all collisions

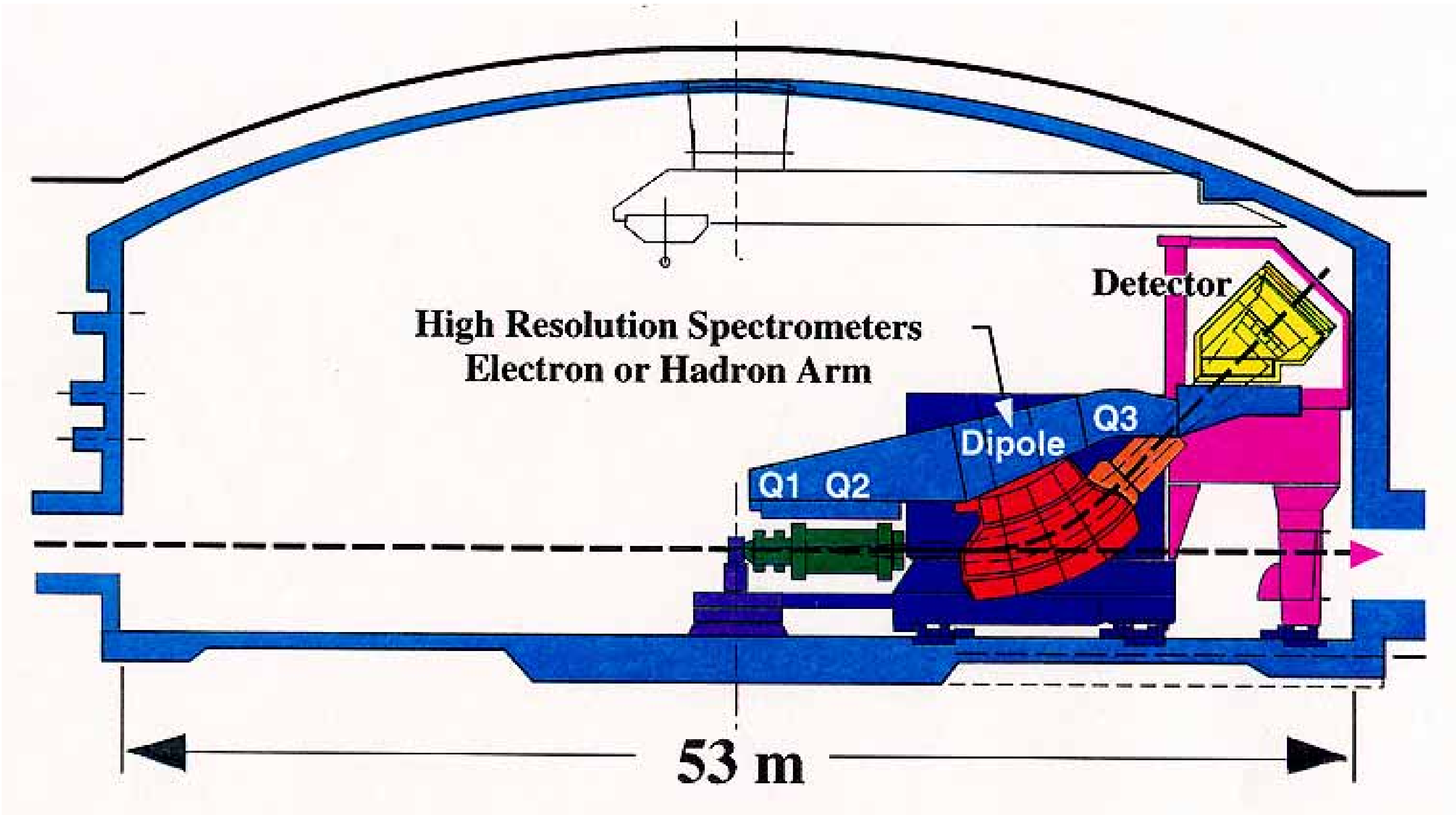
Experiment Layout



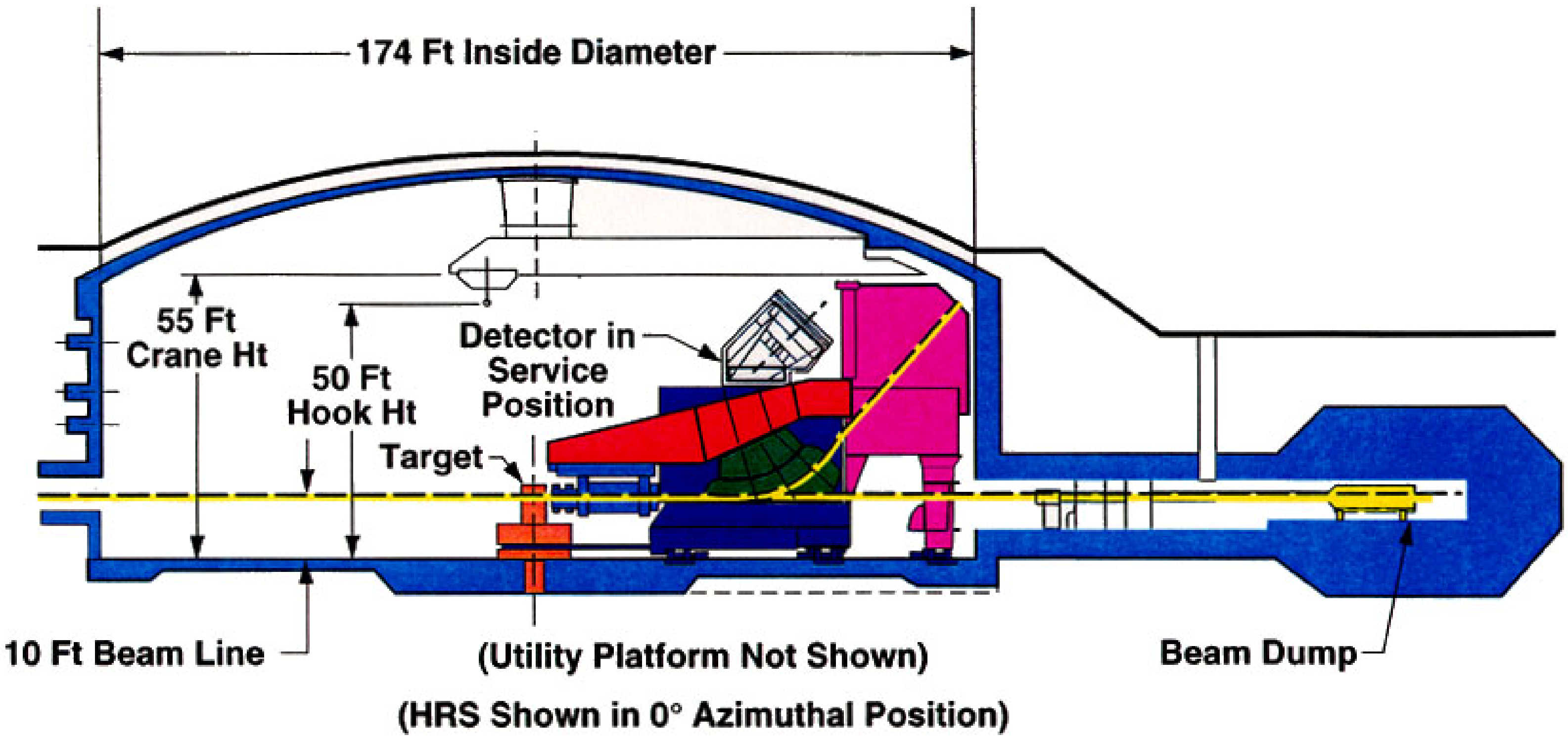
Hall A, Jefferson Lab

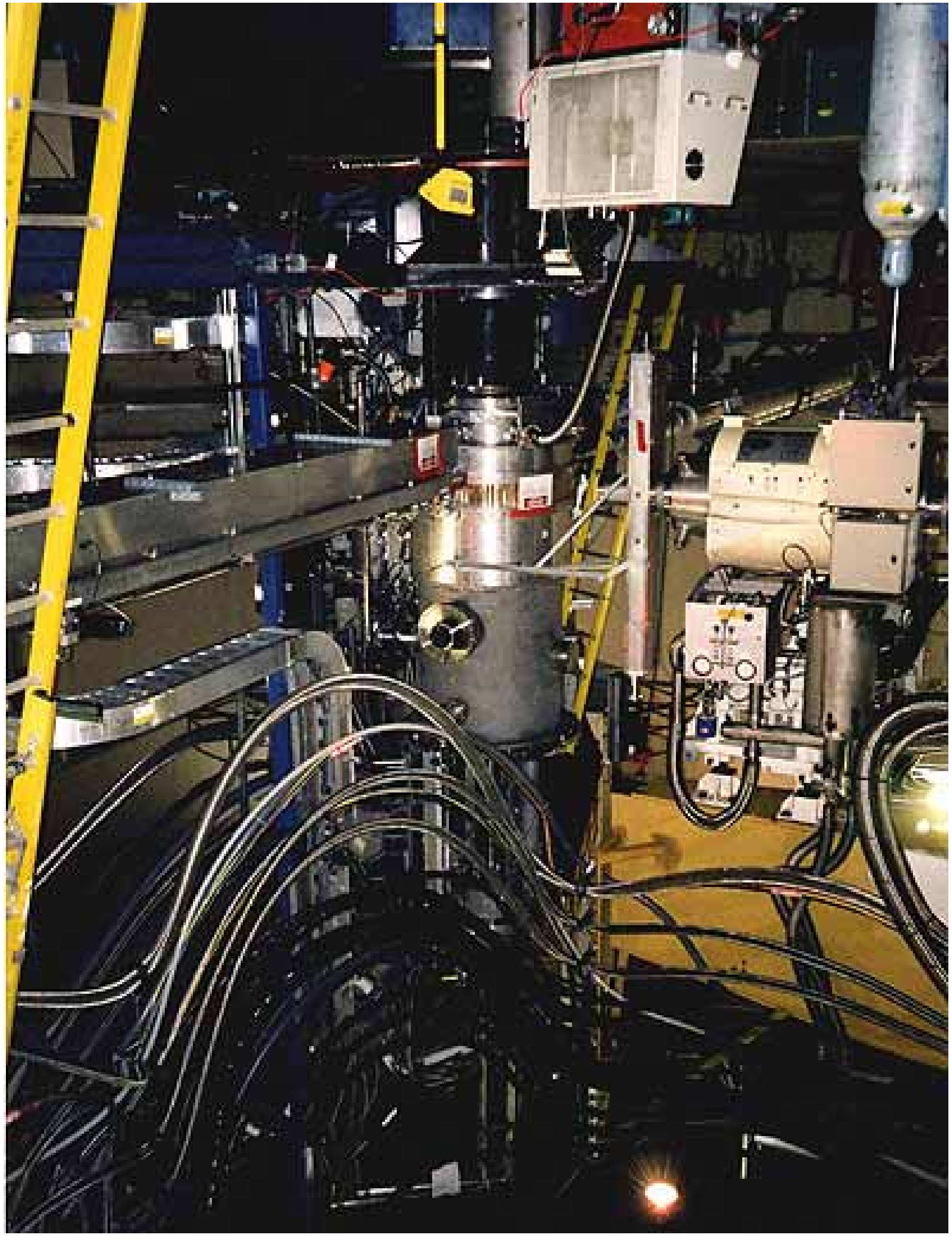


Hall A - Elevation Schematic



Hall A with Beam Dump





Scattering Chamber

Hall A Cryotarget

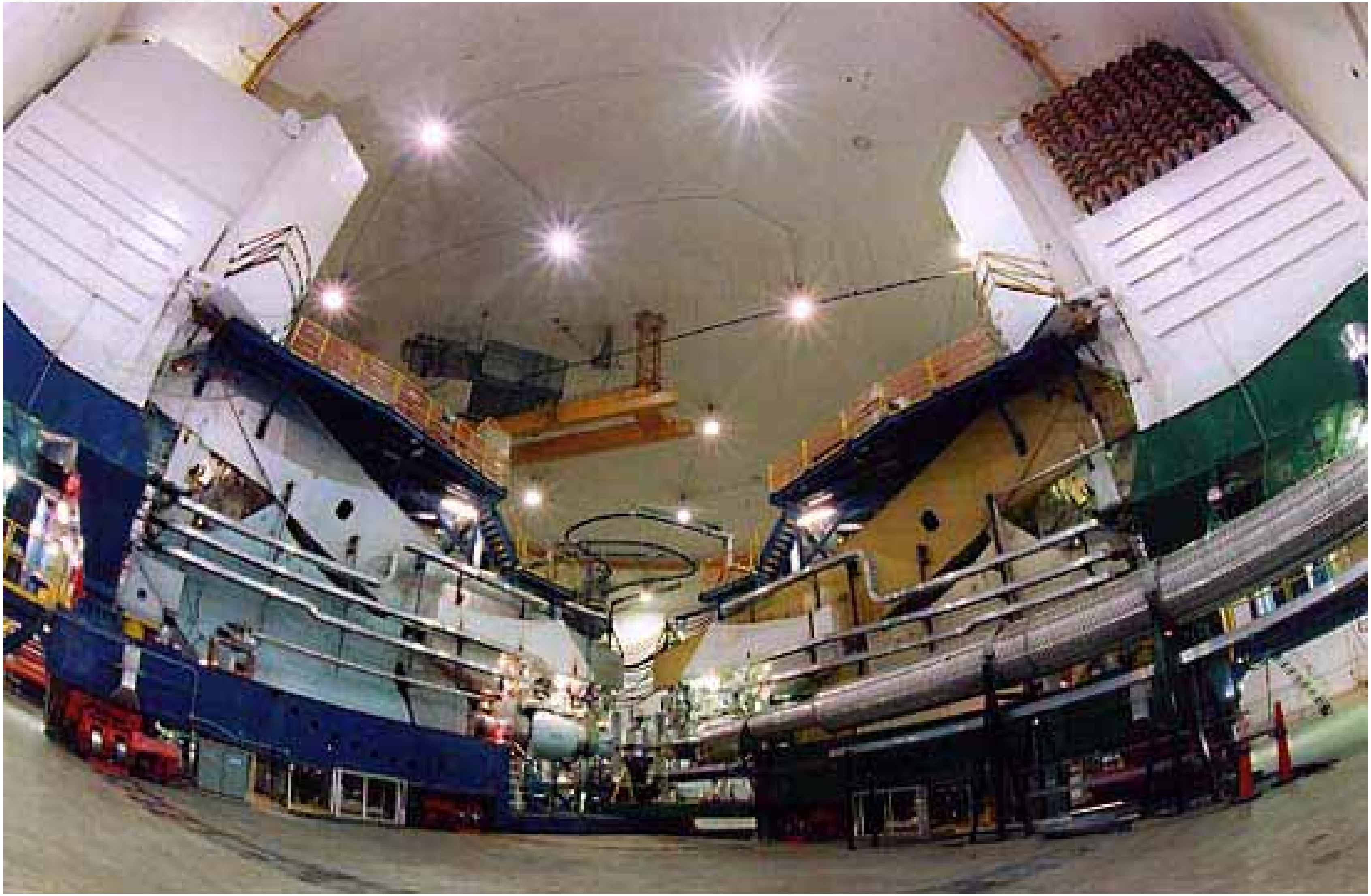
Targets for Hall A Experiments

- If target material exists in solid form (e.g. C, Al, Fe), prepare “thin” foil (usually 1” x 1”) to use directly in beam at room T.
- If target material exists in gaseous form (H, He), first transform it in a denser state (to increase the number of nuclei/cm^3 and thus improve nuclear reaction rate) using cryogenic cooling and/ or high pressures, then “package” it appropriately before presenting it to the electron beam.
  1. Compress the gas and simultaneously lower its temperature
     - ^{3}He or ^{4}He at 6 K and 10 -15 atm (150 – 220 psi)
  2. Liquify the gas and place it in special vessels (cells) of appropriate length (10 – 20 cm) at ~ 2 atm (30 psi) pressure and temperature (1-2 K below boiling point)
     - Liquid ^{1}H at 19 K
     - Liquid ^{2}H (D) at 22 K
- Special cases, e.g. ^{16}O
  - use recirculating H_20 at room T flowing in thin sheets (waterfall target).

Hall A Cryotarget

Cryotarget He, LH_2, LD_2 Loops

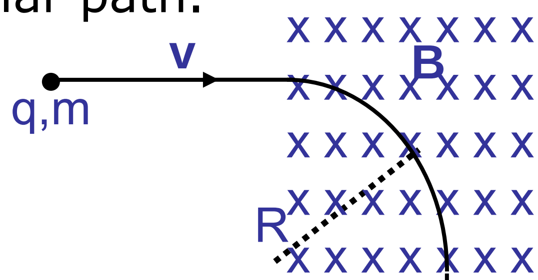
Hall A - Upstream View



Hall A High Resolution Spectrometer

Magnetic Spectrometer Operation

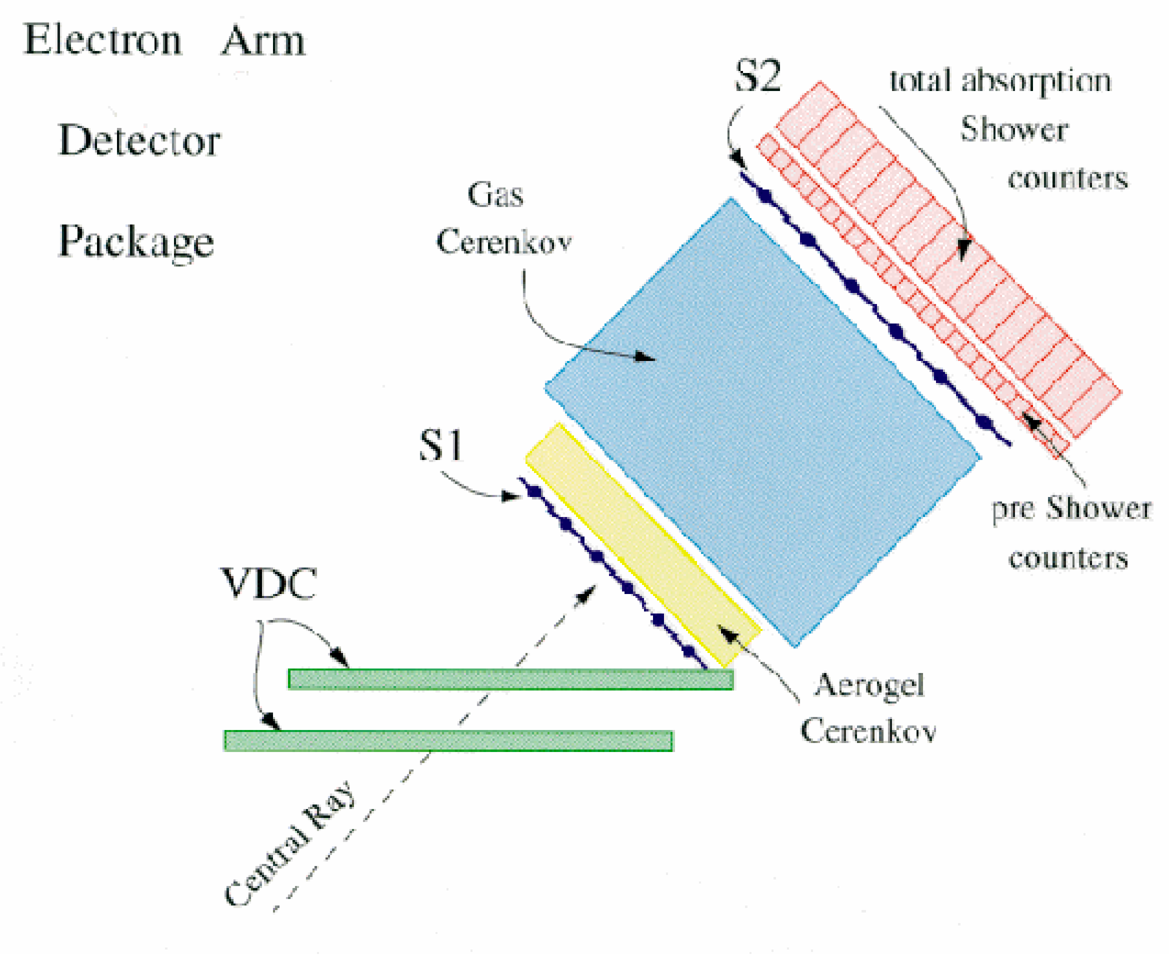
- A magnetic field **B** exerts a force on an electrically charged particle (mass m, charge q) moving with speed **v**. The force is in a direction perpendicular to the (**B**, **v**) plane (**F** = q**v** x **B**), causing the particle to move on a circular path.



- Using Newton's 2nd Law (**F** = m**a**) can compute the particle momentum: p = BqR
- That is, a uniform **B** will cause a particle of momentum **p** to move in a circular arc of radius R whose plane is perpendicular to **B**
- Heart of a spectrometer is a "dipole" magnet (adjustable **B**)
  - A specified **B** selects particles of corresponding momentum **p**
- Additional "quadrupole" magnets focus particles of same p at a point
- Particles of a limited range of **p** are focused at separate points (focal plane) upon exiting the dipole magnet.
- Hall A HRS design: QQDQ

Electron & Hadron High Resolution Spectrometers

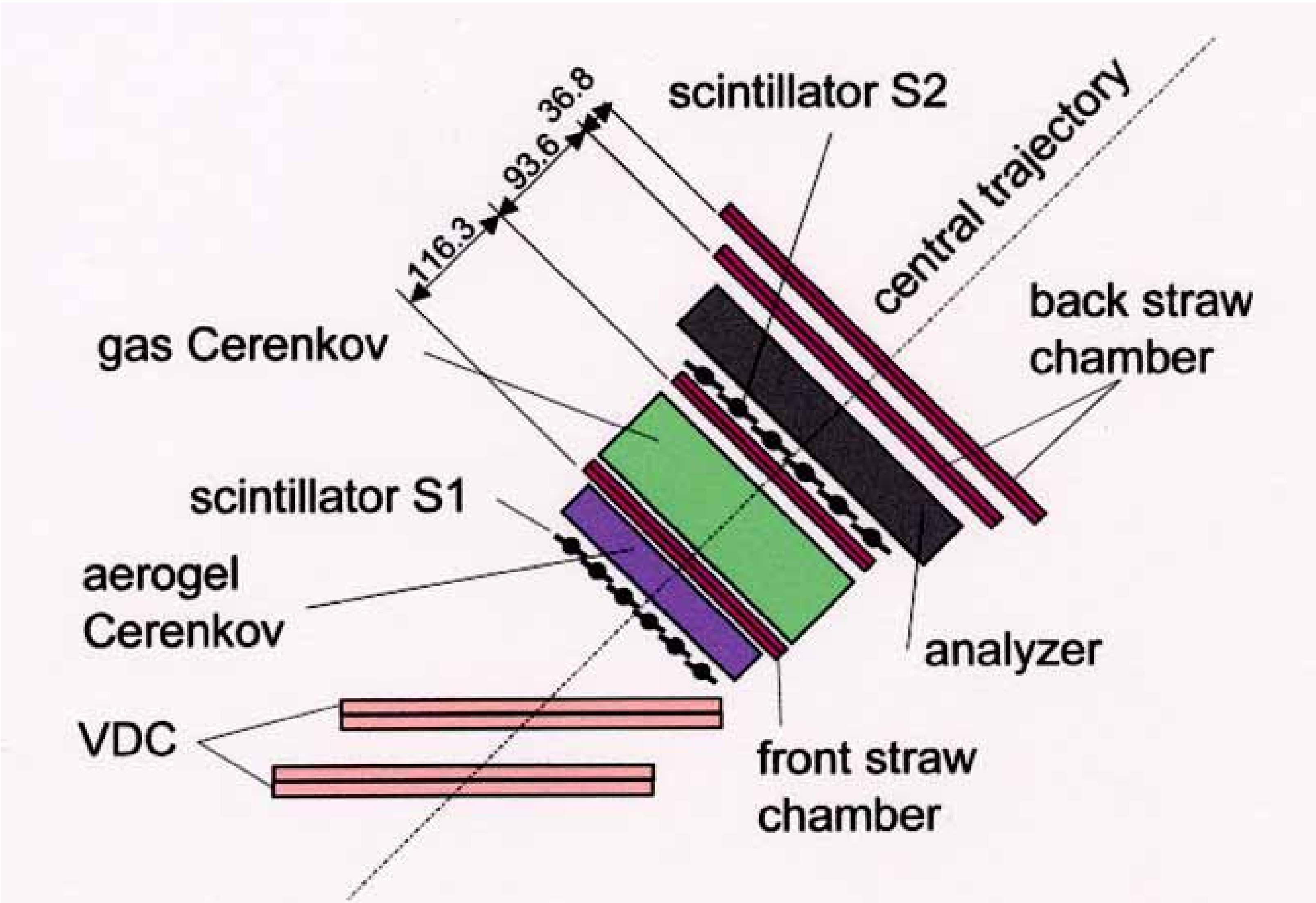
HRS Electron Detector Package



HRS Detector Package

- Vertical Drift Chambers (multi-wire proportional counters)
  - provide position and angular coordinates of particle tracks. May trace back location of nuclear reaction in the target (vertex reconstruction).
  - Lower VDC placed near focal plane.
- Scintillators (scintillation counters)
  - provide time, particle ID information and singles or coincidence trigger signals (planes are $\perp$ to central ray).
- Aerogel $(2SiO_2)(H_2O)$ Cherenkov detector ($n = 1.025$)
  - Aerogel detector NOT used in E89-044
- Gas Cherenkov detectors
  - Provide particle ID info, by separating particles of different masses with similar momenta (select e^- which radiate from π^- which do not (choice of n)
  - $c_n = c/n$; if $v > c_n = c/n$ or $\beta > 1/n \rightarrow$ CR emitted at $\cos\theta = 1/\beta n$
  - Dependence of θ of CR on $v_{threshold}$ can be used to distinguish particles
  - n is chosen so particle m radiates but m′ (m′>m) does not yet radiate
  - CO_2 at p=1 atm, n = 1.00041, p_{min} electron 17 MeV/c (emit CR); p_{min} pion 4.8 GeV/c (does not emit CR)
- Lead glass pre-shower and shower detectors.
  - Lead glass detectors NOT used in E89-044

HRS Hadron Detector Package with FPP



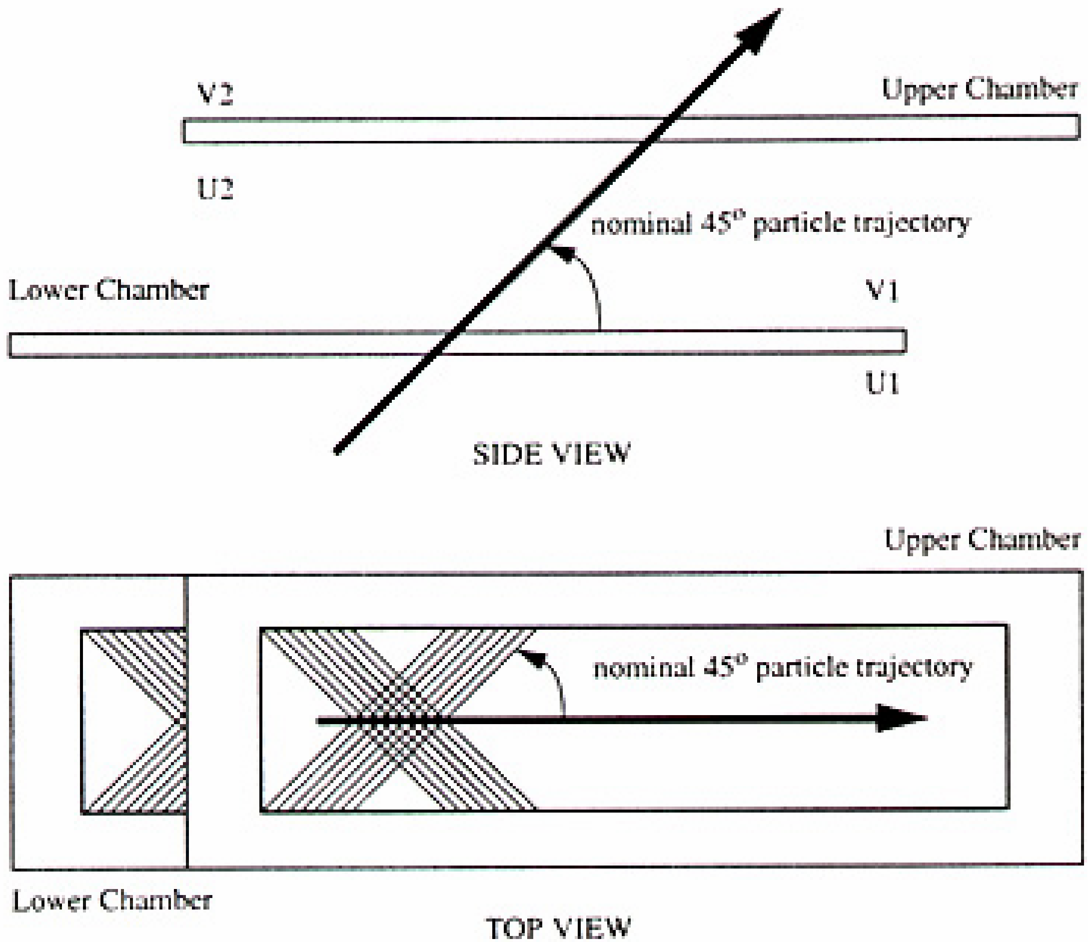
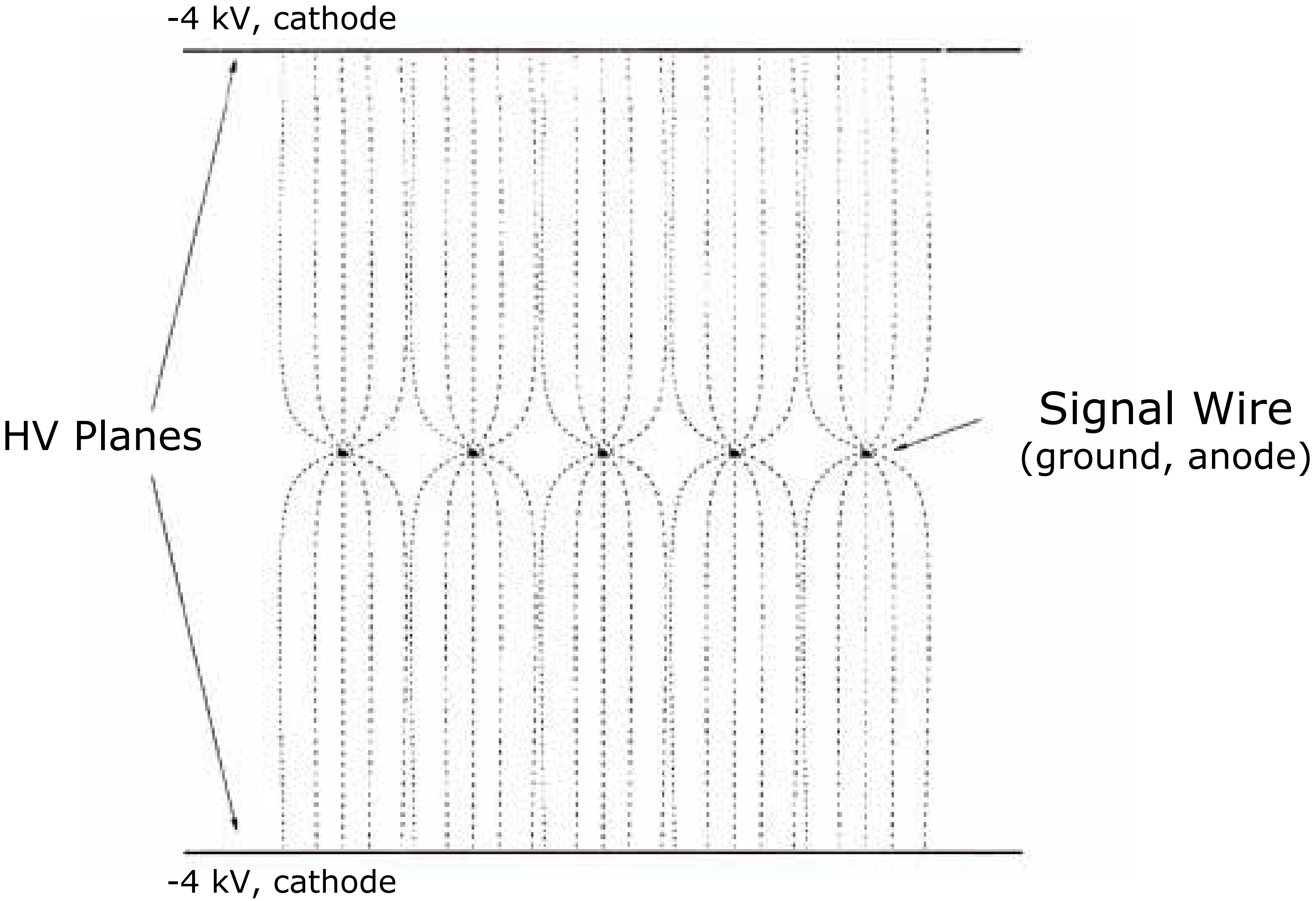


Figure 2-9: Side view and top view of VDC pair (not to scale).

VDC Operation

- VDC used to determine particle trajectories. Consists of a plane of equally spaced parallel wires centered between two parallel HV planes. Each wire behaves as an independent proportional counter and is connected to its own electronics.
- Fast, efficient, good timing and spatial resolution
- Two chambers, parallel to each other, 35 cm apart. Top 50 cm off.
- Each chamber 240 x 40 x 10 cm.
- Central ray within 0.5 cm of center of bottom VDC at 45º.
- Bottom VDC nearer HRS focal plane
- Each VDC: two wire planes (u,v) at 45º to dispersive direction.
- Each wire plane (grounded) between 2 HV planes (-2 kV)
- Each wire plane 386 wires (2 x 16 grounded for shaping E-field), 20 μm diameter gold-plated tungsten wire. Wires are 4.243 mm apart
- Each HV plane 6 μm Mylar, Au coated for good conductivity
- Planes are 2.6 cm apart.
- Gas mixture of Argon-Ethane (62%-38% by volume) flows at 5 l/h.
- Gas mixture provides high gain of signal (Argon) and good quenching of photons (ethane)
- Position resolution 100 μm per plane, angular resolution 0.5 mr

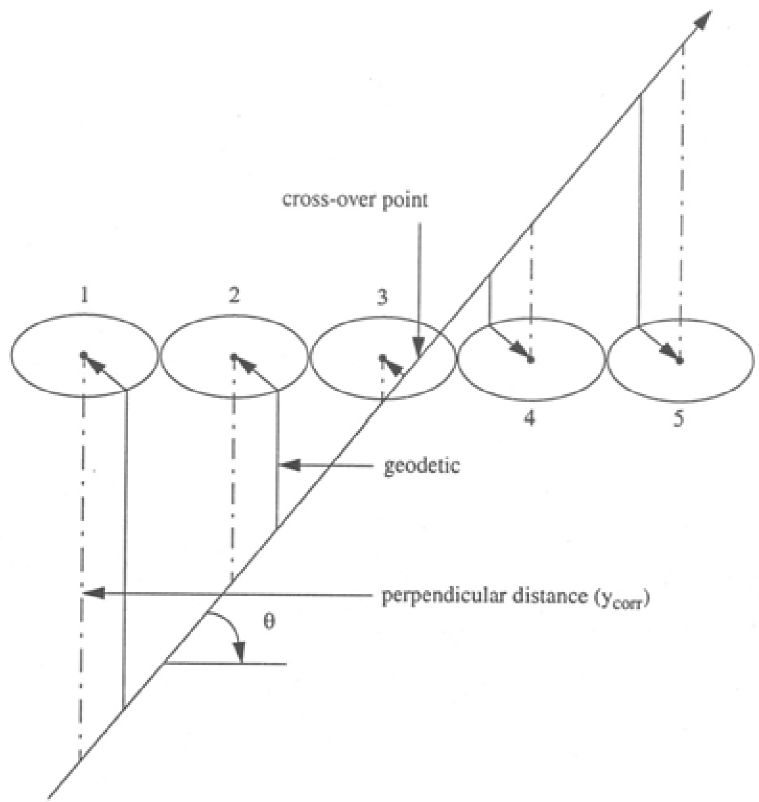
VDC Electric Field Lines



Particle Trajectory Information

- When charged particle passes through VDC gas atoms are ionized along trajectory. Electrons drift toward signal (anode) wires, along E-field lines. Near wire E-field ~1/r, electrons gain enough energy to cause successive additional ionizations (avalanche). As avalanche approaches wire, the positive ions (produced in the avalanche) INDUCE a negative signal on the anode wires.
- Signals are saturated at high gain, therefore independent of particle energy
- TCD measures time between initial ionization and induction of signal on wire.
- Four wire planes (2 per chamber) are used for (for improved resolution) provide 2 x,y coordinates, sufficient to determine position and direction of the charged particle through the HRS focal plane.
- Ethane is used as a quenching gas, it absorb photons emitted when energetic electrons strike a wire, or when electrons recombine with positive ions. These photons can travel long distances and interact with gas atoms to produce ion pairs at other locations.

Particle Trajectory Through VDC



Knowledge of electron drift velocity in gas and TDC time allows the perpendicular distance between particle trajectory and wire to be deduced. For a trajectory, 5-6 adjacent wires fire. From (perpendicular rather than geodetic, hence VDC) distances between trajectory and wires, the intersection point between trajectory and wire plane is determined, and this provides one set of x,y coordinates for the charged particle.

Coordinate Systems

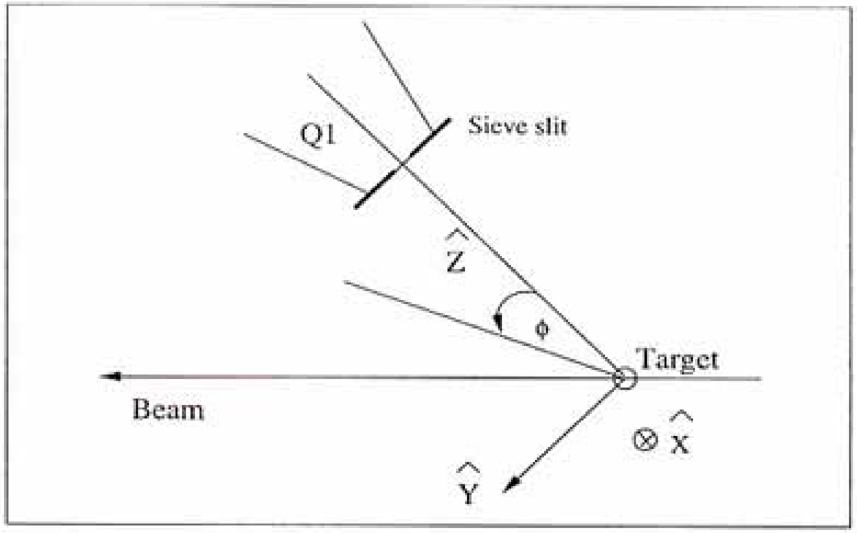


Figure 3-8: Target Coordinate System.

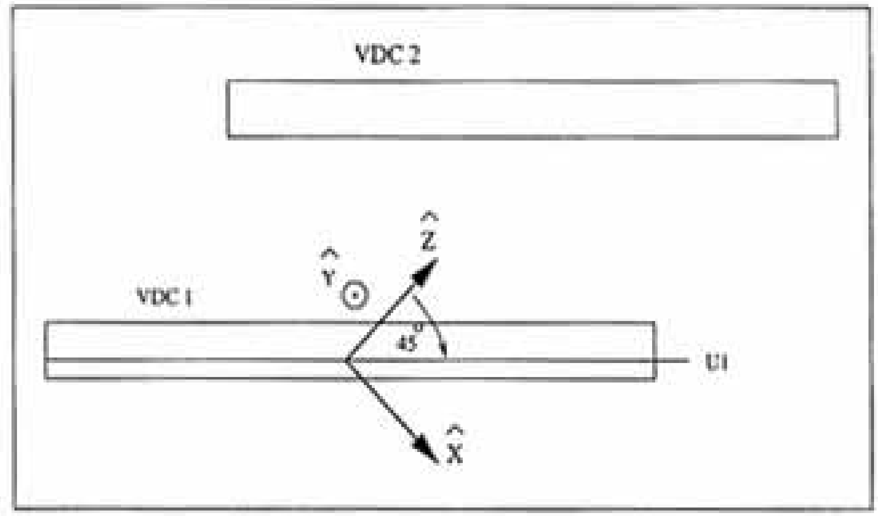


Figure 3-9: Transport Coordinate System.

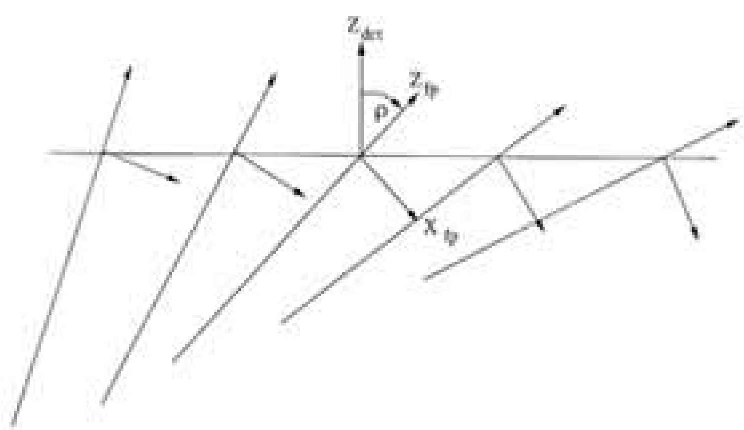


Figure 3-10: Focal Plane Coordinate System.