PHYS101

Week 5

Momentum

- Trick Question: If you sit in your car at rest at a red light, what would you "prefer" to rear-end you:
  - A Mini-Cooper going at 10 miles/hour?
  - A Hummer going at 10 miles/hour?
  - A Mini-Cooper going at 60 miles/hour?
  - A Hummer going at 60 miles/hour?
- A new way to characterize the "impact": **momentum** and **impulse**.
- Momentum of an object: $\vec{\mathbf{p}} = m\,\vec{\mathbf{v}}$
- Impulse transferred in a collision: $\vec{\mathbf{J}} = \Delta\vec{\mathbf{p}}$
  (change in momentum)

Newton's 2nd Law - again

- If mass doesn't change:
  $\Sigma \mathbf{F} = m\,\mathbf{a} = m\,\Delta\mathbf{v} / \Delta t = \Delta(m\,\mathbf{v})/ \Delta t = \Delta\mathbf{p} / \Delta t$ =>
- Any change in momentum must be due to a force acting on object
- Change is proportional to amount of force and duration of its presence:
  - Constant force =>
    $\Delta\,\mathbf{p} = \mathbf{p}_2 - \mathbf{p}_1 = \Sigma\,\mathbf{F} \cdot \Delta t$
  - Average Force:
    $\Sigma\,\mathbf{F}_{ave} = \Delta\,\mathbf{p} / \Delta t$
  - Change of momentum = Impulse **J**
    $\mathbf{J} = \Delta\,\mathbf{p} = \Sigma\,\mathbf{F}_{ave}\ \Delta t$
  - LARGE FORCE x short time = small force x LLLOOOONNNNG TIME
  - Examples: Hammer hitting nail, foot hitting soccer ball, car crashing into wall, egg hitting sheet, ball bouncing, collision with a moving object, shuttle docking to space station, gravitational sling shot…

Newton's 3rd Law - again

- If object A transfers an impulse **J** to object B, then object B transfers impulse -**J** to object A
- Bouncing collision => LARGER Impulse (greater change in momentum) than "sticking collision"

Conservation of momentum

- Define system of objects (particles)
  - Example: System made of 2 particles with masses m_1 and m_2
- Internal forces: Acting only **between** particles in the system (one particle acting on another)
  - Example: Particle 1 bouncing off Particle 2
- **No** other (**external**) forces (all forces are due to interactions between particles **in** the system)
- => Total momentum $\Sigma \mathbf{p} = \mathbf{p}_1 + \mathbf{p}_2 + \ldots$
  of the system is conserved (impulse is just passed around)
  - Example: $m_1 \mathbf{v}_1 + m_2 \mathbf{v}_2$ = const.; even if velocities change size and direction after each bounce. **Why? Newton's 3rd Law!**

Momentum conservation

Examples:

- Ice skaters giving each other “ high five”
- Rifle recoil
- Rocket propulsion
- Ball hitting brick wall vs. styrofoam
- Cars crashing into each other:
  - Elastically
  - Inelastically
  - At right angles

Collisions

- Two bodies colliding => force between them may be
  - conservative (total energy conserved) => **elastic** collision
  - dissipative (energy lost to thermal motion or internal excitation) => **inelastic** collision
- Either way, total momentum is conserved (as long as no **external** force is present)
- Motion along straight line: once we know both initial velocities and **one** final one, we can calculate the other:

  $m_1 v_{1\,\mathrm{i}} + m_2 v_{2\,\mathrm{i}} = m_1 v_{1\,\mathrm{f}} + m_2 v_{2\,\mathrm{f}}$ =>

  $v_{2\,\mathrm{f}} = (-m_1 v_{1\,\mathrm{f}} + m_1 v_{1\,\mathrm{i}} + m_2 v_{2\,\mathrm{i}}) / m_2$

Completely Inelastic Collisions

- Inelastic collision: some energy is lost (dissipated). Examples: Traffic accidents, “flat” ball, putty… really ALL collisions (bouncing ball looses height)
- **Completely** inelastic collisions: Both partners “stick together” afterwards
  - Gives one more equation to be satisfied: $v_{2\,f} = v_{1\,f}$
  - Can predict outcome even if only **initial** momenta are known. =>
  - $m_1 v_{1\,i} + m_2 v_{2\,i} = (m_1 + m_2)\, v_f$
  - Example 1: Moving glider bumps into glider at rest
  - Example 2: SUV bumps into compact car with equal speed but at right angle
  - Example 3: Coal dropping into rail car

Completely Elastic Collisions

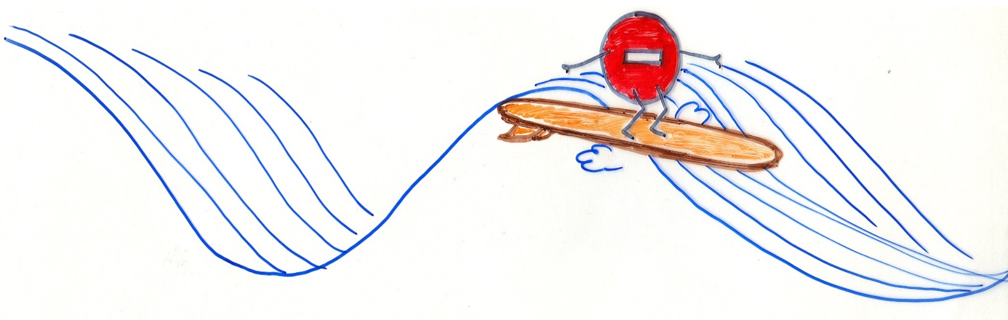
- Total energy (K.E.) is conserved during collision (hard spheres, springs, …)

  Eliminates **one** unkn…

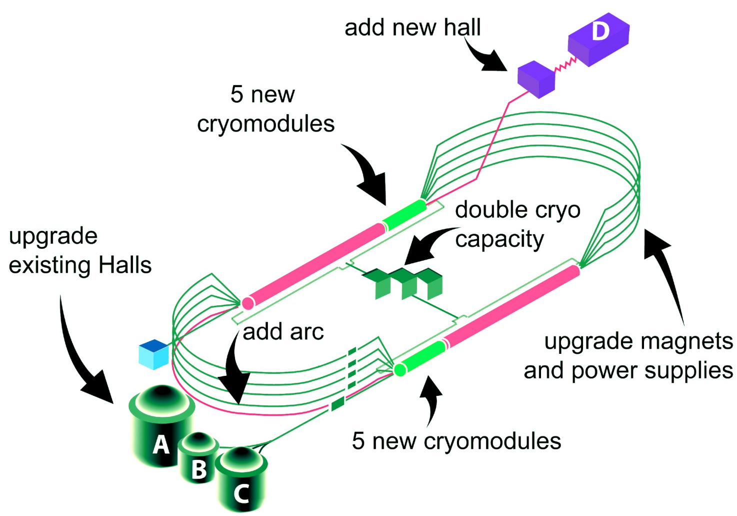
  See next chapter

  - Purely linear motion: … initial momenta ($p_{\text{tot i}} = p_{1\text{ i}} + p_{2\text{ i}}$):
    $p^2 = 2m$ K.E. => p_2 … K.E.$_{\text{i}}$ - $p_{1\text{f}}^{\,2} / 2m_1$ = K.E.$_{\text{i}}$ - $(p_{\text{tot i}} - p_{2\text{f}})^2 / 2m_1$
  - Motion in a plane: need to know initial momenta and one angle of final velocities
  - 3D motion: Can always reduce to motion in a plane!
- Examples: Moving glider bouncing off second one; Newton's cradle; "stack of balls" bounce; billiards.
- If initial 2 momenta add up to zero (Center-of-Mass system):
  - inelastic collision -> particles are at rest
  - elastic collision -> particles continue with same speed, but different direction

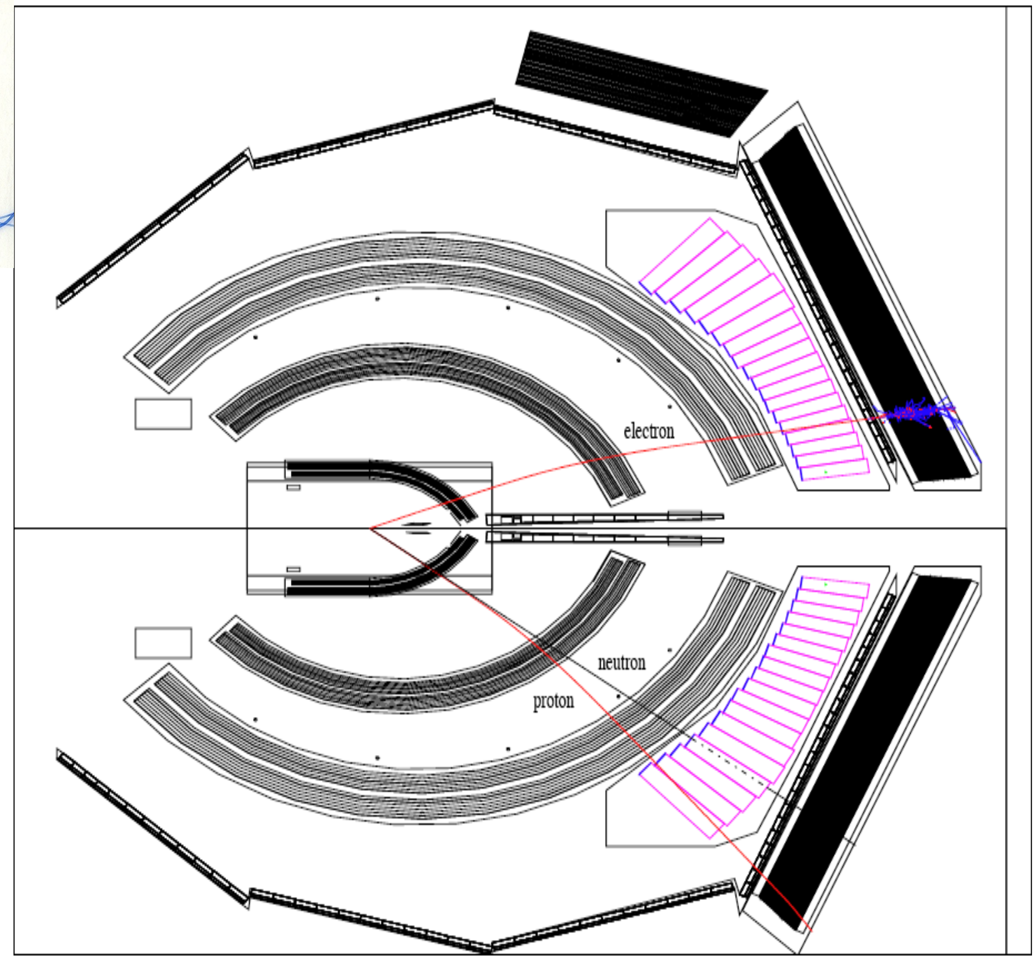
Electron scattering from nuclear target



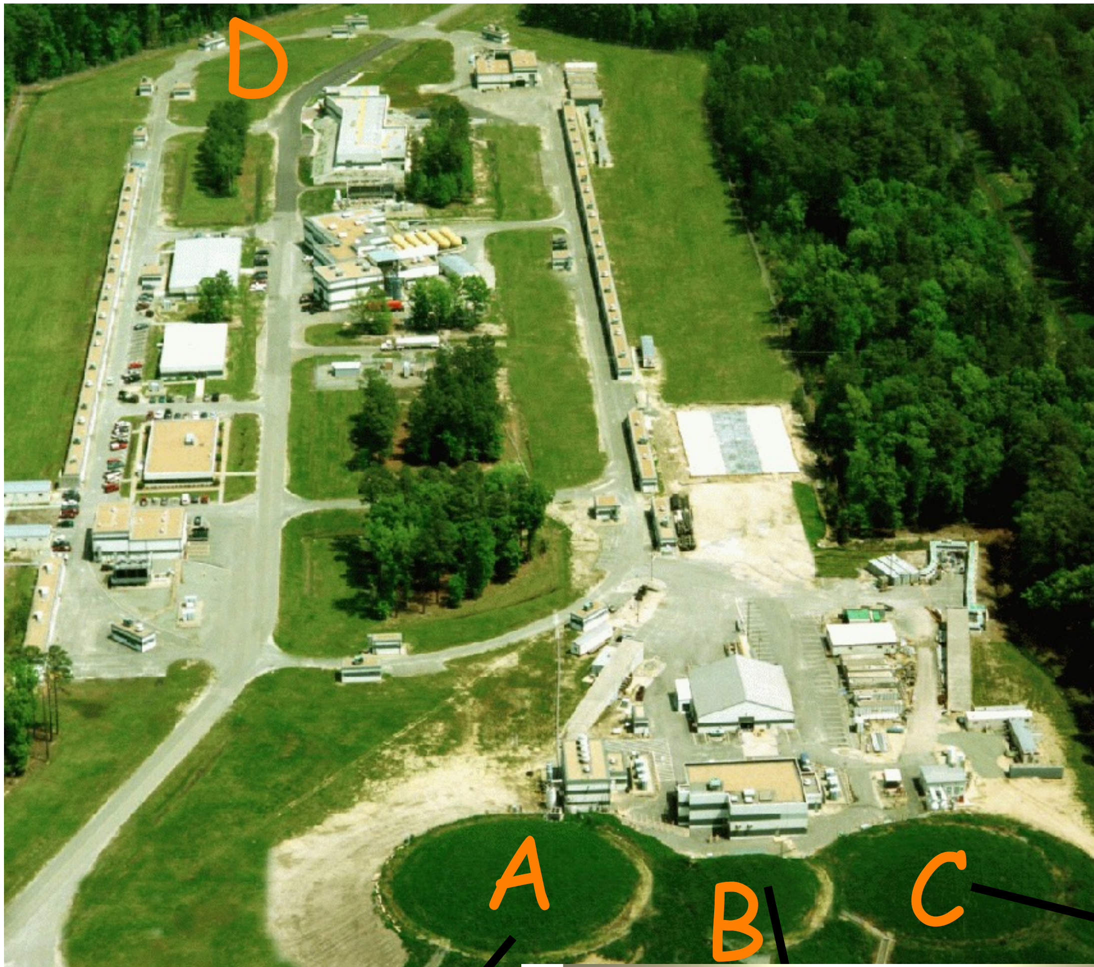
High-energy Accelerators…



…smash electrons into a target…



…and detectors measure the outgoing particles.

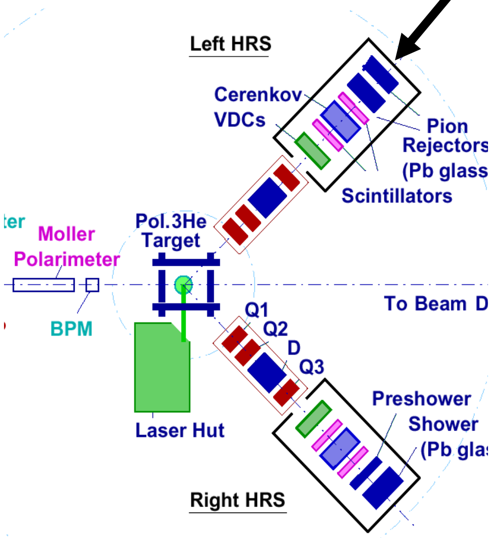


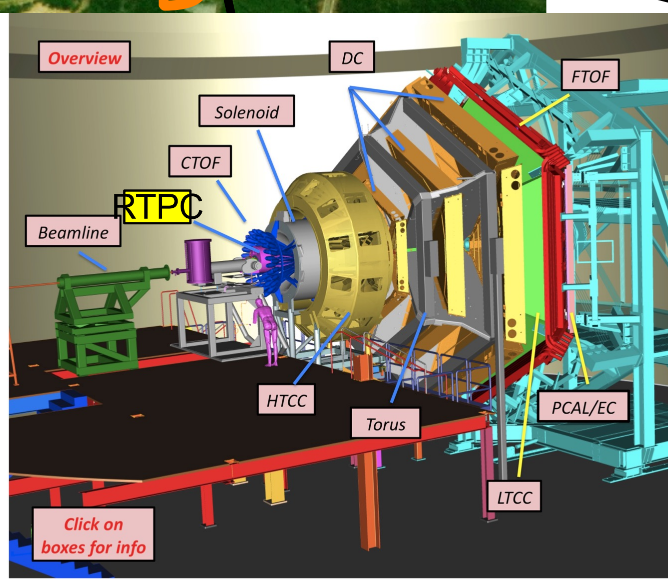
Jefferson Lab

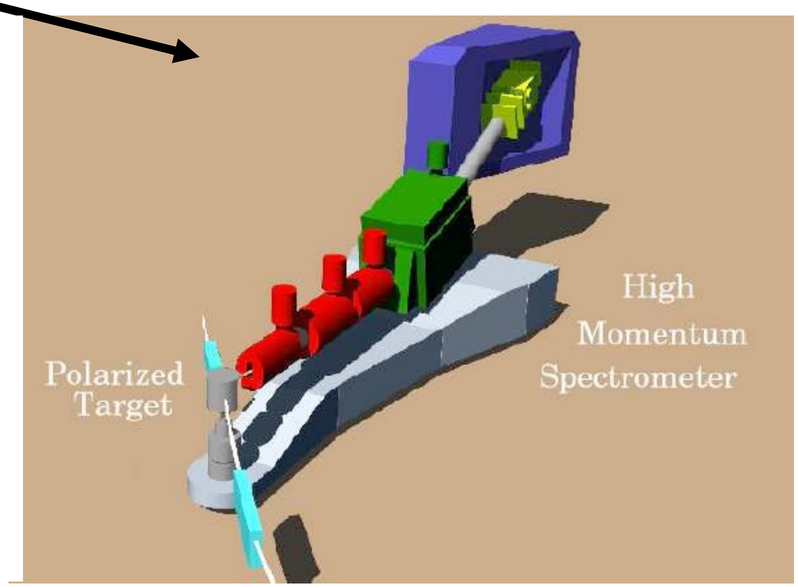
≤12 GeV electron beam

Longitudinal polarization up to 85%

Beam current from <1nA to >50μA



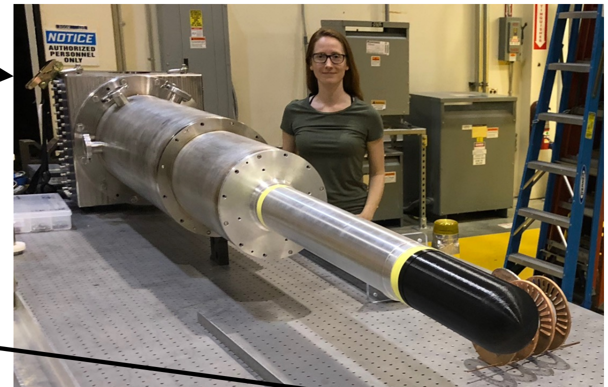


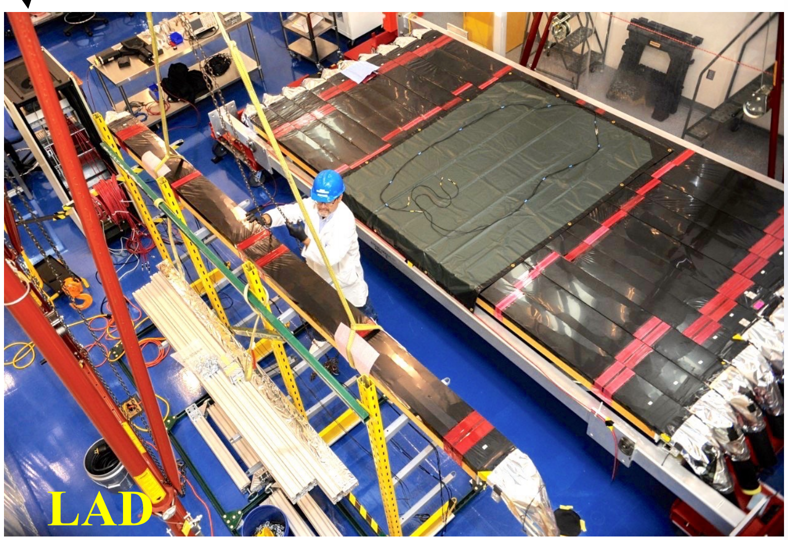


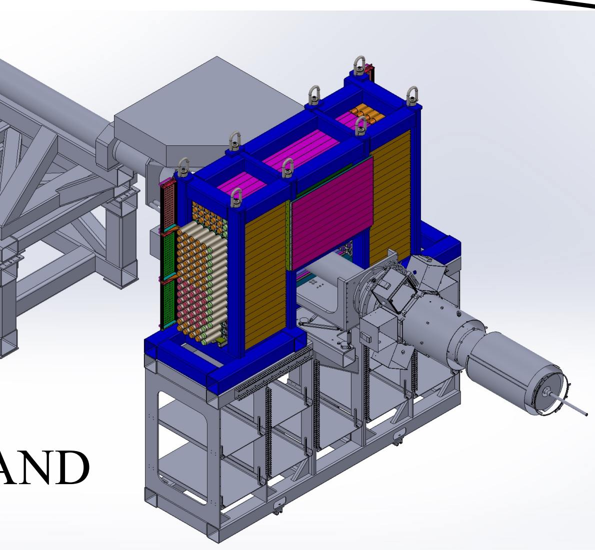
We build some of this equipment at ODU:

- Bonus (small radial TPC)
- Polarized H and D frozen ammonia targets
- BAND
- LAD
- CLAS12 Region 2 Drift Chambers

BoNuS RTPC detector







BAND