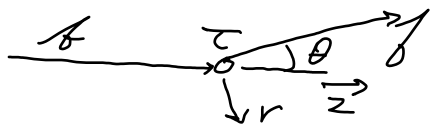
Momentum transfer to forward scattered particle

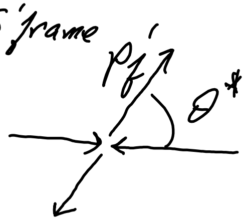
$$\tau = (\tilde{p}_b - \tilde{p}_f)^2$$
$$= m_b^2 + m_f^2 - 2(E_b E_f - \vec{p}_b \cdot \vec{p}_f)$$

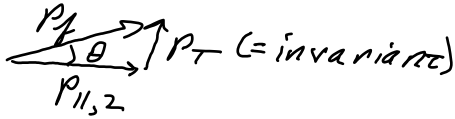
Relation between polar scattering angles in CM and LAB frames:

S frame



S' frame



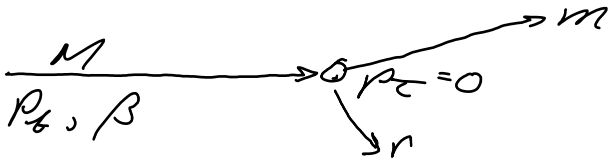


β_0 is velocity of S relative to S'

$$\tan\theta_{LAB} = \frac{p_T}{p_z}$$
$$= \frac{p_T'}{\gamma_0(p_z' + \beta_0 E'/c)} \left(\frac{1/p_f'}{1/p_f'}\right)$$
$$= \boxed{\frac{\sin\theta^*}{\gamma_0(\cos\theta^* + \beta_0/\beta^*)}}$$

Maximum Energy Transfer

Consider beam particle with mass $M \gg m$, where m is target mass.



In CM frame

$$p_r^* = mc\beta_0\gamma_0$$
$$E_r^* = mc^2\gamma_0$$

β_0 is target velocity CM

Since m is very small

(Be careful of approximations!)

$$\beta_0 \simeq \frac{p_b c}{(p_b^2 c^2 + M^2 c^4)^{1/2}} = \beta$$

Transforming from CM → LAB

$$E_r \simeq \gamma c\left(\frac{E_r^*}{c} + \beta p_r^*\right)$$
$$= \gamma c\,(mc\gamma_0 + \beta mc\beta_0\gamma_0)$$

E_t was just mc^2, so

$$\boxed{\Delta E_{max} \simeq 2mc^2\beta^2\gamma^2}$$

Particle Physics Experiments

Extreme extensions of our senses
- → eyes: intensity, λ
- → ears: heat, acoustic

this information arises in these organs + must be mapped and calibrated to world observed

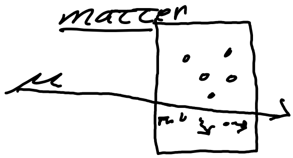
No different with our detectors

But first there are some earlier steps:

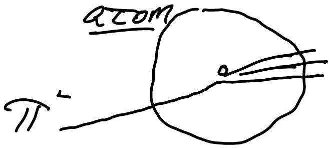
- generally, we must extract relatively low energy particles of mundane type, such as e^-, p, π
- → accelerate them
  - astrophysical means (e.g. cosmic rays)
  - manipulation of electric + magnetic fields ⇐ particle accelerator
- → collide them (an 'event')
  - produce interaction with some probability of exhibiting process for study

Fixed target	collider

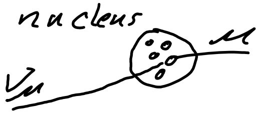
Detect resulting particles



Electromagnetic interactions



Strong nuclear Interactions



Weak interactions

Detectors designed and built by precise knowledge of these

Immediate result: charge, light, phonons

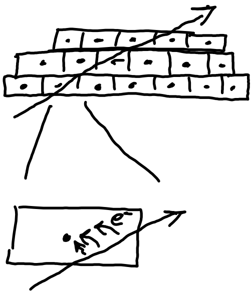
From these we obtain measures of

- kinematics ($\vec{p}$, E)
- particle properties (q, m, γ, spin, τ)

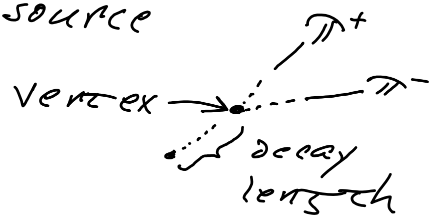
Tracking Detectors

very sensitive to the spatial coordinates of a ~~detector~~ particle

minimize interaction with particle so as not to modify its trajectory

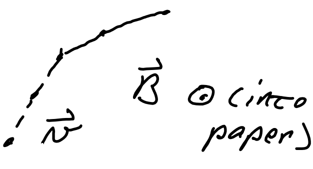


- measure direction
- multiple tracks from a common source



If in a magnetic field
- ability to measure curvature

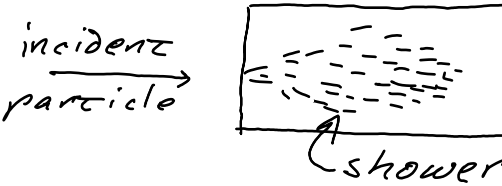
Gives momentum



Calorimeters

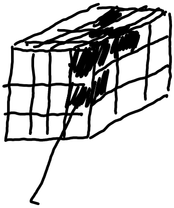
Charged and neutral particle energy measurement

Want to stop particles: loose all energy + measure while doing it



Position measurement by transverse segmentation

→ much less precise than a tracker



longitudinal segmentation for particle identification

<u>shallow</u> (EM): $e, \gamma, \pi^0 (2\gamma)$

→ <u>Deep</u> (hadronic): $\pi^\pm, p, n$

shower characteristics

Detectors for
Particle Identification

many types:
rely on sensitivity to:
charge, mass, β/γ, decay

Example 1: transition radiation
Light particle (e.g. e^-), high γ
emits above some threshold
→ massive particle: no emission

Example 2: combination of detectors
→ calorimeter: little energy
+
→ tracker: track after
= a muon

Critical properties
→ efficiency for desired object
very high
→ mis-identification or
'false positive' rate: very low

Triggering and Data Acquisition

Raw data obtained via electronics
- Analog signals (eg. current) ultimately converted to digital format
  → stability and noise level important
  → calibration

Rate of interactions may be higher than rate can take data
- triggering selects events with qualities most likely to be interesting
  - energy/momentum threshold
  - particle identification criteria
- hardware and software triggers
- may have to buffer (store) analog signal
  - wait for trigger decision before digitize

important parameters: efficiency, rejection, 'dead time'

Reconstruction

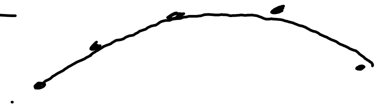
raw data: voltages, currents, ADC counts

Need to operate on to reveal experimental observables: momentum, θ, energy, charge, time

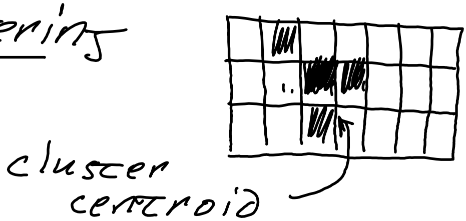
Many types of operation

Two most common types:

- Tracking



- Clustering



Calibration
→ correct for several effects
- detector
- electronics

Analysis

Ascertain sensitivity to desired processes

- efficiencies ($= \frac{\#\text{observed}}{\#\text{actual}}$): detector, trigger, reconstruction
- resolutions ($= \frac{x_{meas} - \langle x \rangle}{\langle x \rangle}$): momentum, position, angle

Monte Carlo techniques to model random processes governed by known rules
e.g. detector simulation
pseudoexperiments

Statistical knowledge and techniques important
- distributions (e.g. Gaussian, binomial)
- maximum likelihood

Discrimination techniques
- cuts, neural networks, decision trees...