Kinematics; 2

Invariant mass

Follows from energy-momentum 4 vector.

Eg. Single particle.

invariant $= E^2 - c^2p^2$ (general case: all frames)

$= m^2c^4$ (rest frame; $p^2=0$)

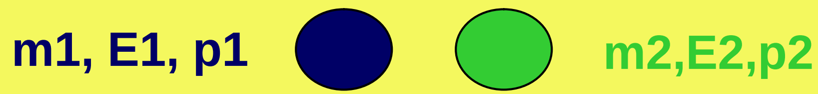
For single particle invariant mass = rest mass

- characteristic of particle type

Invariant mass/ CM energy

Eg.(2) System of > 1 particle.

invariant $=(\Sigma E)^2 - c^2(\Sigma p)^2$ (combined 4 vector)



General solution: $(E1 + E2)^2 - c^2(p1 + p2)^2$

$$= E1^2 + E2^2 + 2.E1E2 - c^2p1^2 - c^2p2^2 - 2c^2p1.p2$$

$$= m1^2c^4 + m2^2c^4 + 2E1E2 - 2c^2p1.p2$$

…. Valid for any frame … but horrible maths!

Often easier to consider rest frame: $= \Sigma E^2$ (rest frame; $\Sigma p^2=0$)

Special case if both particles at rest $= (m1 + m2)^2c^4$

If > 1 particle, invariant mass called CENTRE-OF-MASS ENERGY

Overview

- **Reminder:**
  - Centre of mass frame, lab frame
  - Invariant mass
  - CM energy
- **How do we detect/identify particles?**
  - Distance probes of matter
  - Fixed target vs collider experiments
  - Discovering resonances

How do we find particles?

- We now have all the tools we need
- Resolving structure of matter is dependent on energy
- Observing new particles is dependent on energy

Can only interact with particle if energy sufficient to "see" it

Can only observe particle of mass X if X GeV CM energy available to produce it

Fixed target?

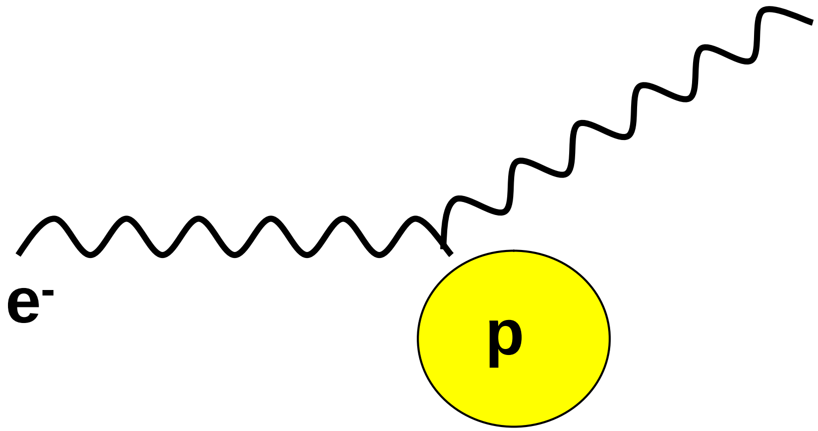
How do we reach CM energy most efficiently?

Collide particle beams?

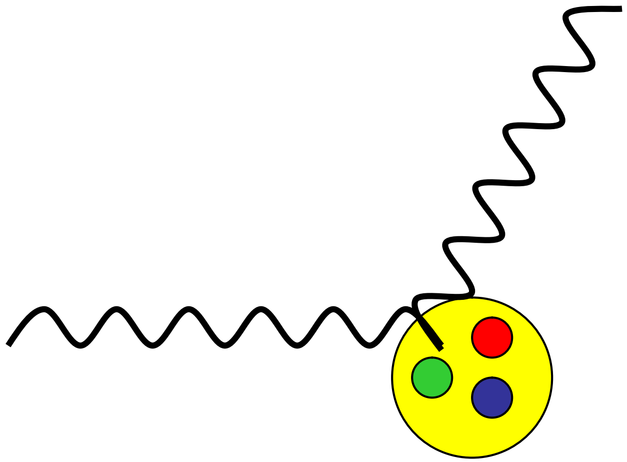
Resolving structure of matter

Energy/distance scale of particle probe:

- Relativistic particle: $E^2 = p^2c^2 + m^2c^4$
- De Broglie relation:



Resolving structure of matter



Increase energy

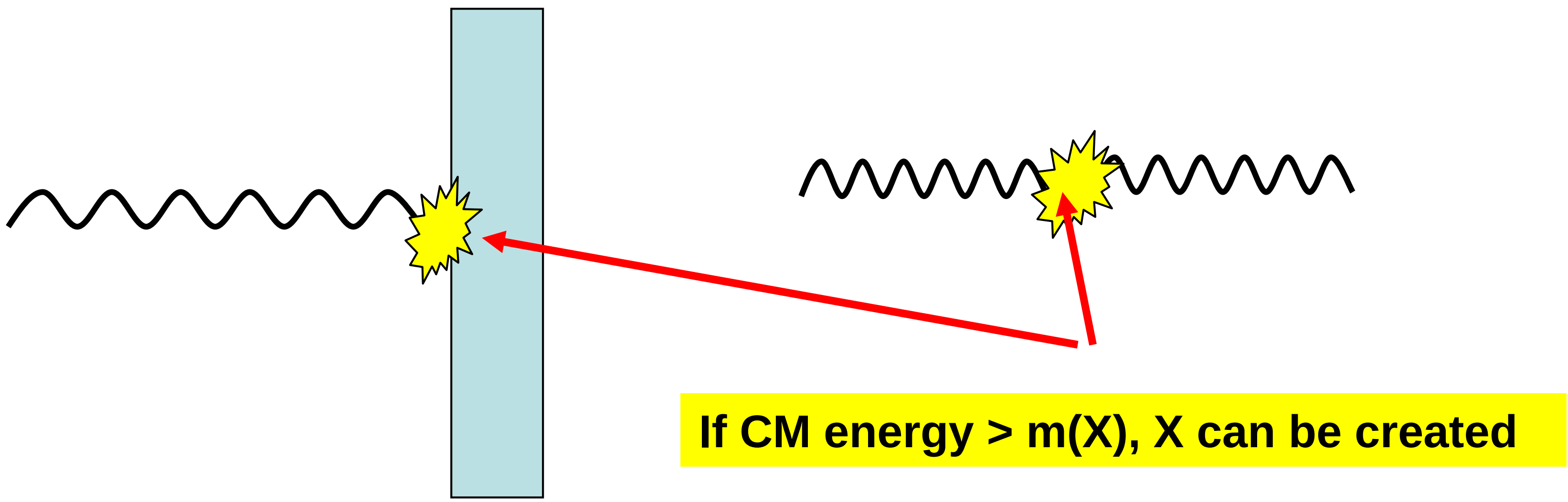
Decrease probing distance

=> Probe/interact with smallest constituents of matter

How to probe smallest distance?

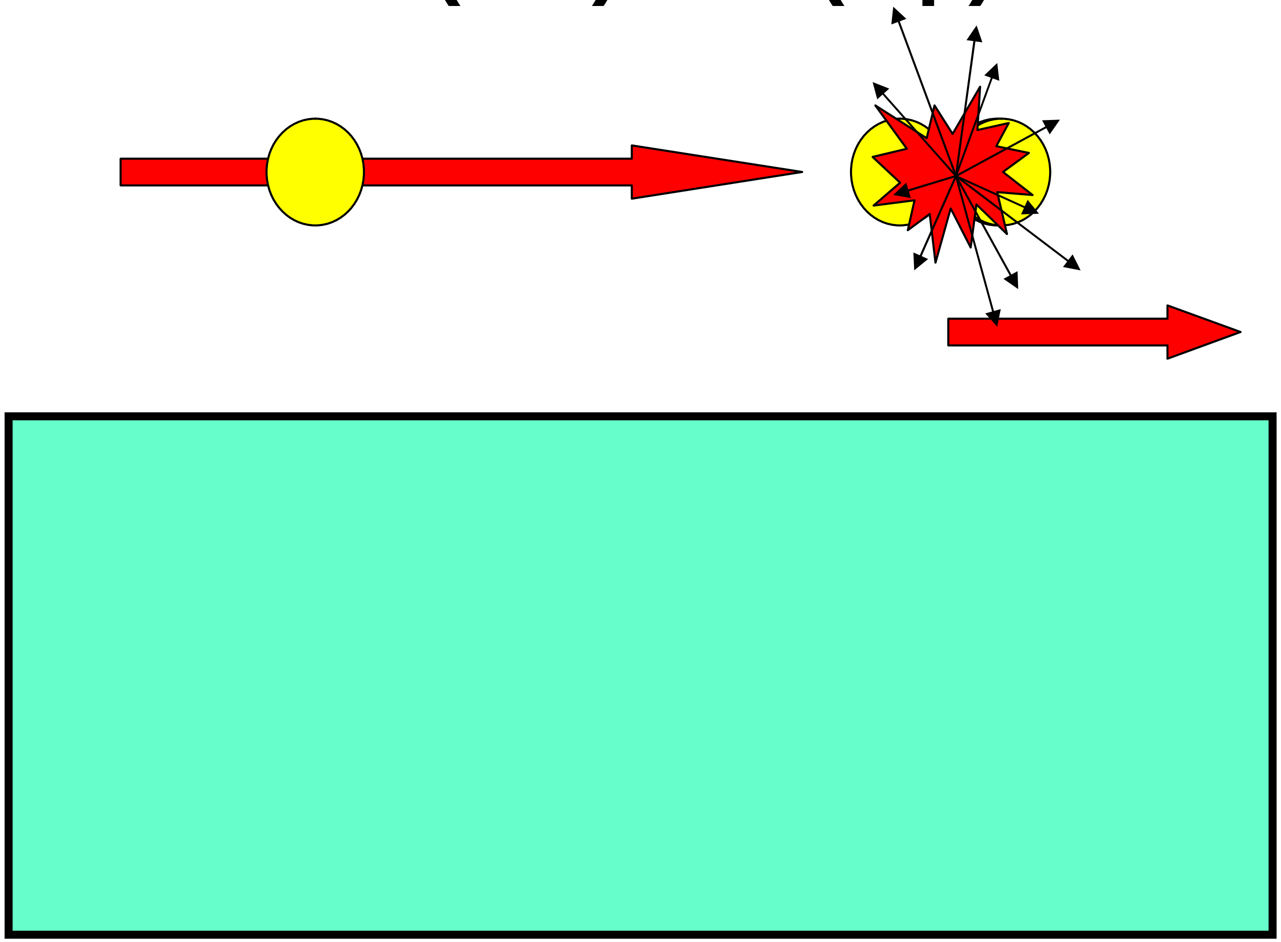
Smallest distance $\Rightarrow$ highest energy
($\Rightarrow$ most massive particles)
Two methods can be considered:

1) Beam on fixed target **2) 2 beams colliding**



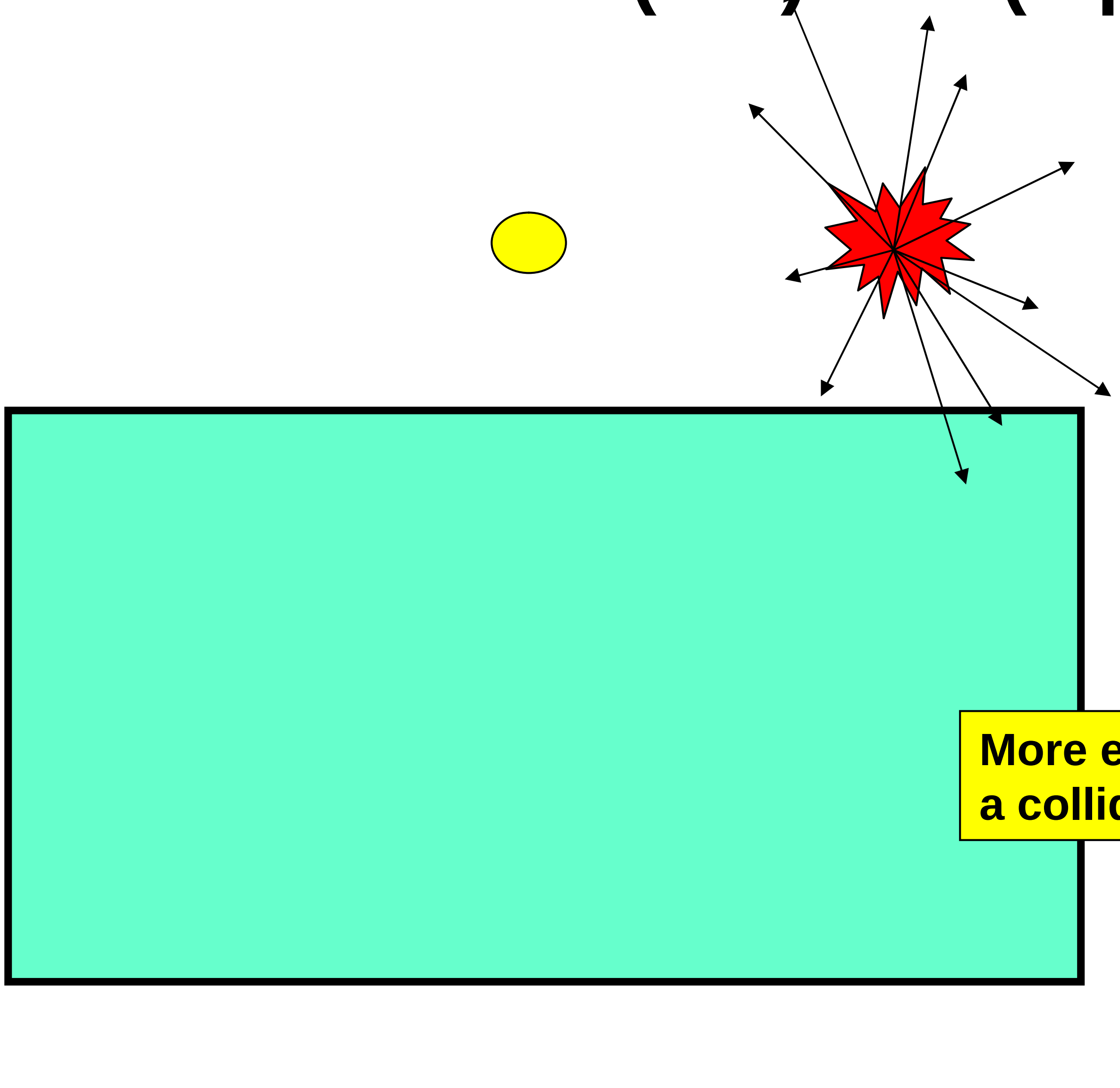
(1) Fixed target expt.

$$E^{*2} = (\Sigma E)^2 - c^2(\Sigma p)^2$$



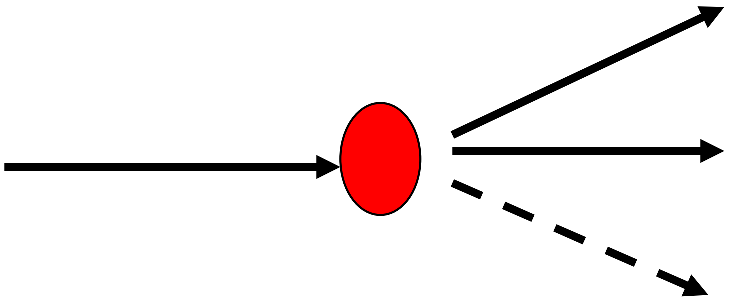
(2) Colliding beams expt.

$$E^{*2} = (\Sigma E)^2 - c^2(\Sigma p)^2$$



More energy reach with a collider! Better probe.

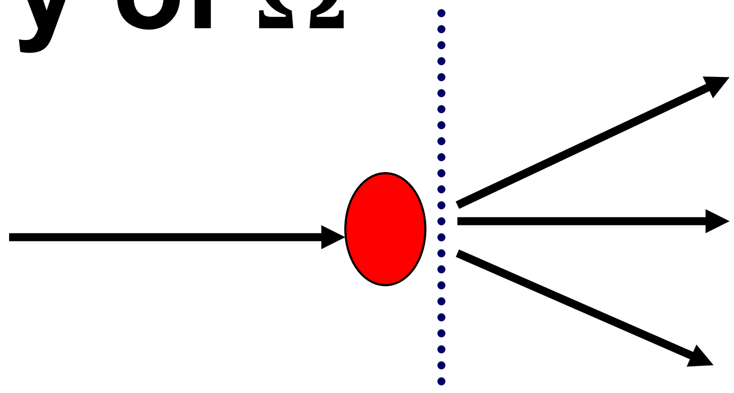
Exercise: discovery of Ω^-(sss)



$K^- + p \rightarrow \Omega^- + K^+ + K^0$

What is the minimum energy of the kaon needed to produce the omega?

Discovery of Ω^-



$M(K^+) = 0.494\ GeV/c^2$
$M(K^0) = 0.498\ GeV/c^2$
$M(p) = 0.938\ GeV/c^2$
$M(\Omega^-) = 1.672\ GeV/c^2$

Assumptions:

1. Let proton target be at rest
2. Consider minimum energy needed to make system
3. With minimum energy ("at threshold"), products produced at rest

Review

- Reminder of special relativity
  - Fundamental particles in particle physics are usually relativistic (or at rest!)
- What have we learnt?
  - Time dilation can make particles live long enough for us to detect
  - More energetic particles can interact with smaller objects
  - Energy conservation implies we create CM energies more efficiently with colliding beam experiments