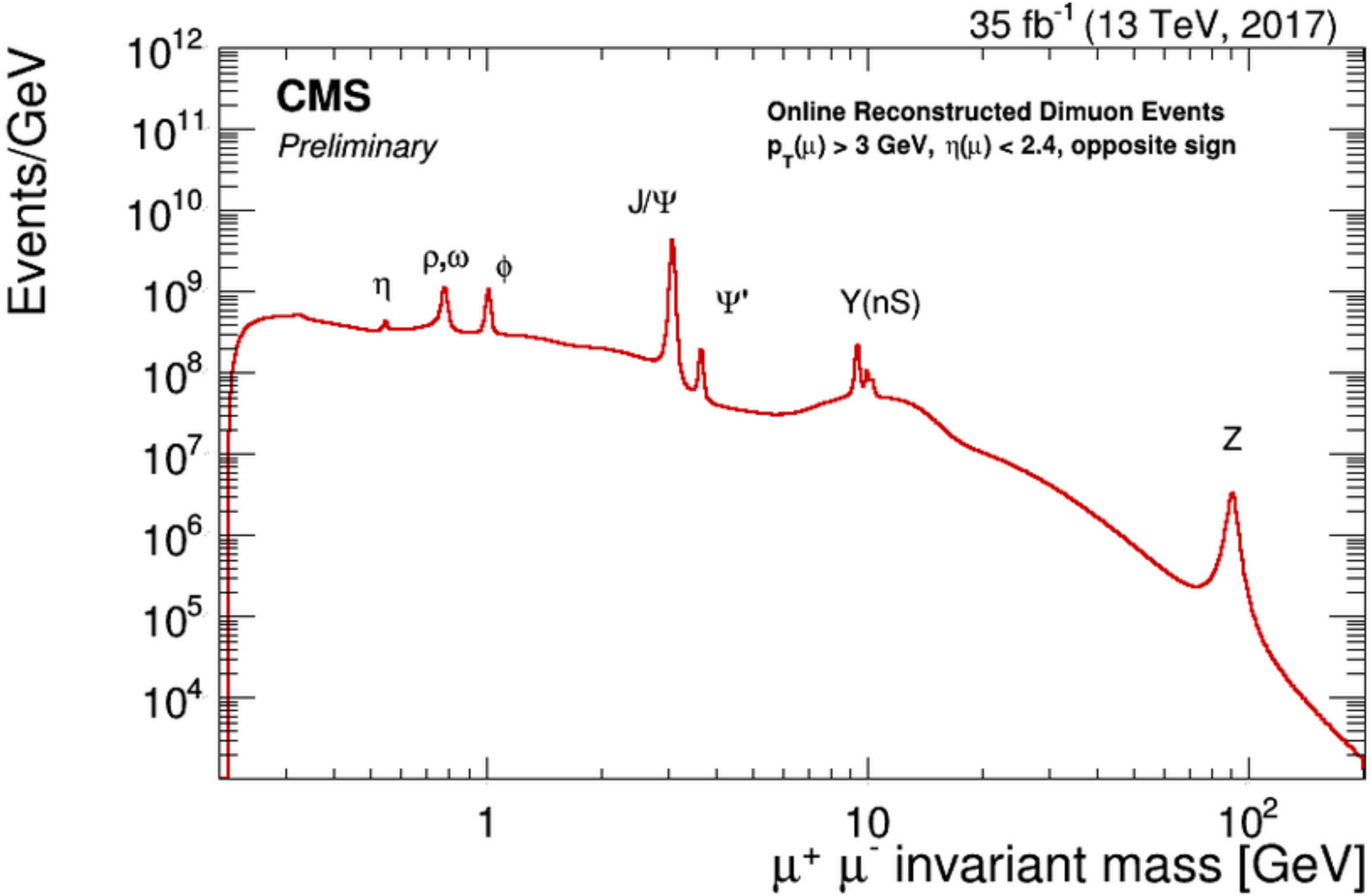
Detectors 1

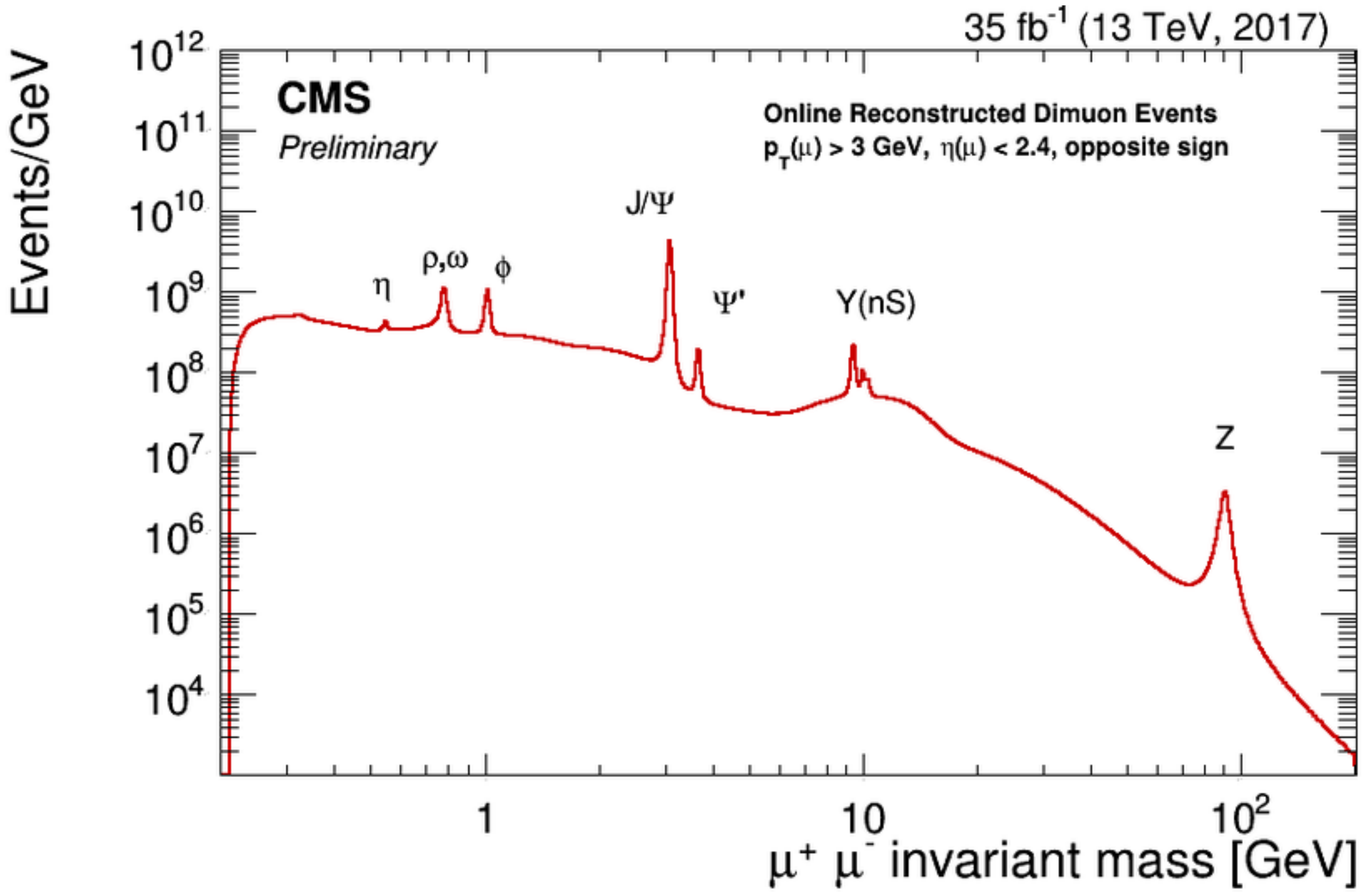
Outline

- Goal - discuss how we actually produce plots like the one we saw yesterday?
-



Outline

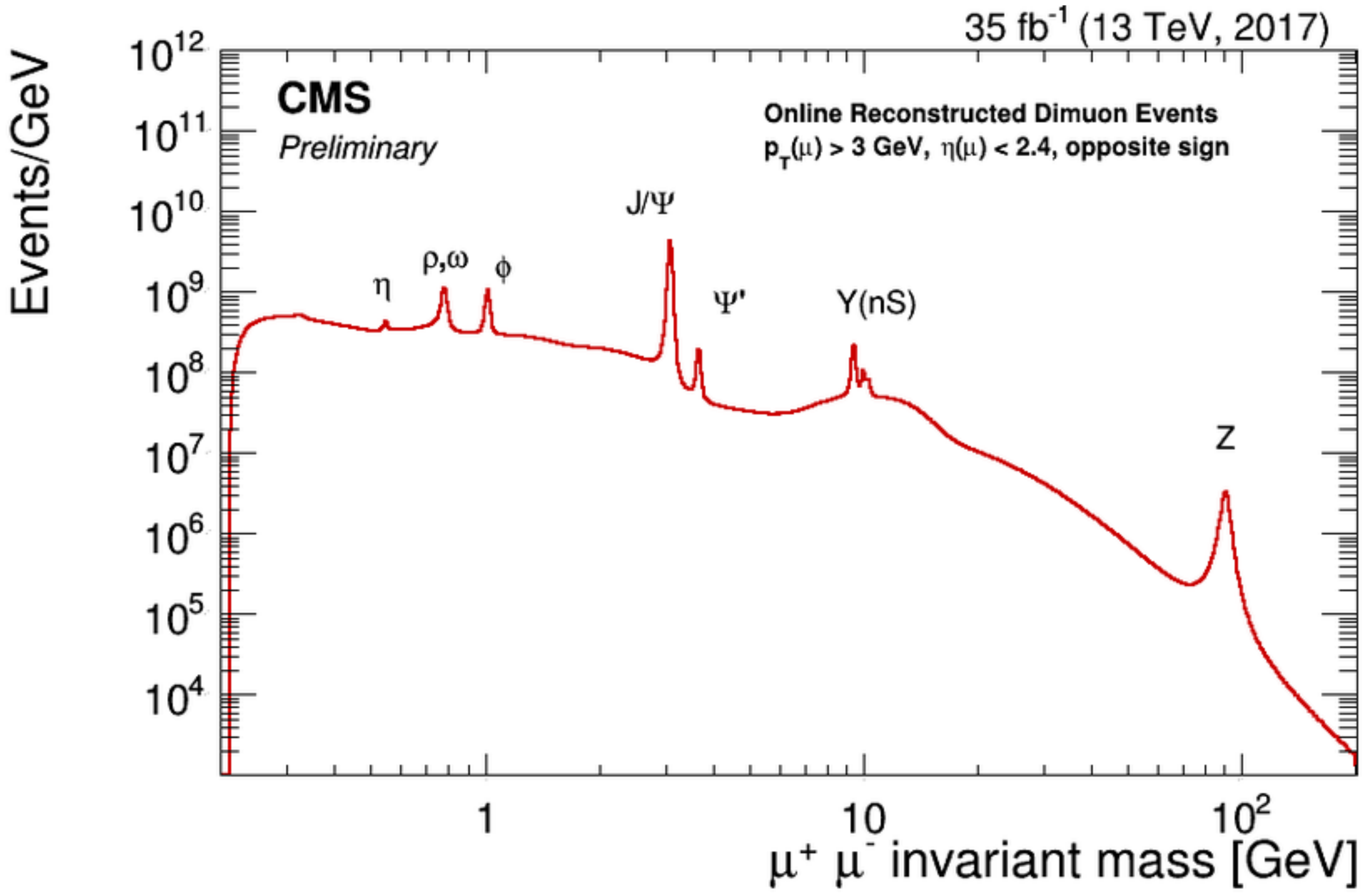
- Goal - to discuss how we actually produce plots like the one we saw yesterday?



- Why measuring momentum is so important

Outline

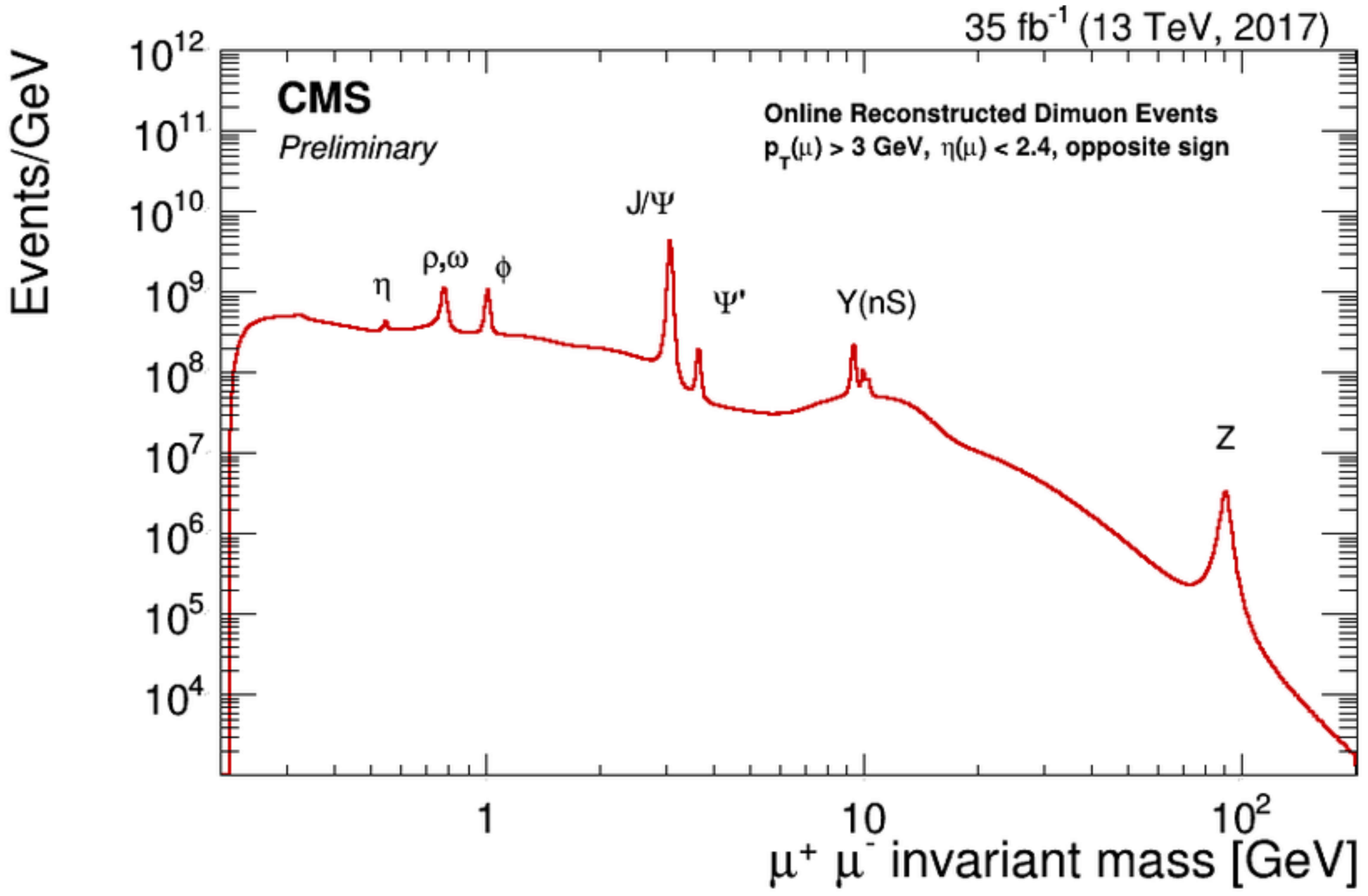
- Goal - to discuss how we actually produce plots like the one we saw yesterday?



- Why measuring momentum is so important
- Why are particle detectors so big?

Outline

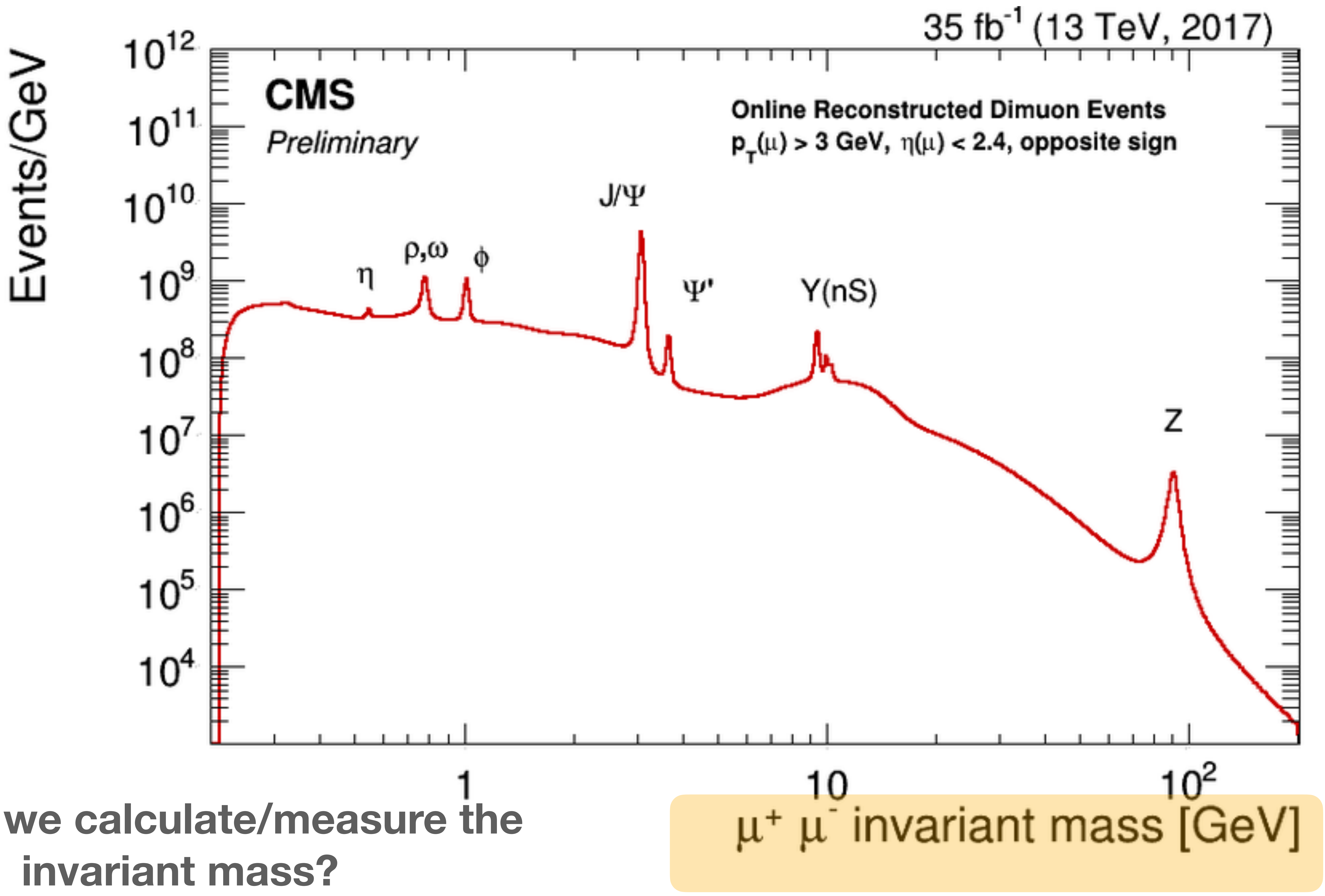
- Goal - to discuss how we actually produce plots like the one we saw yesterday?



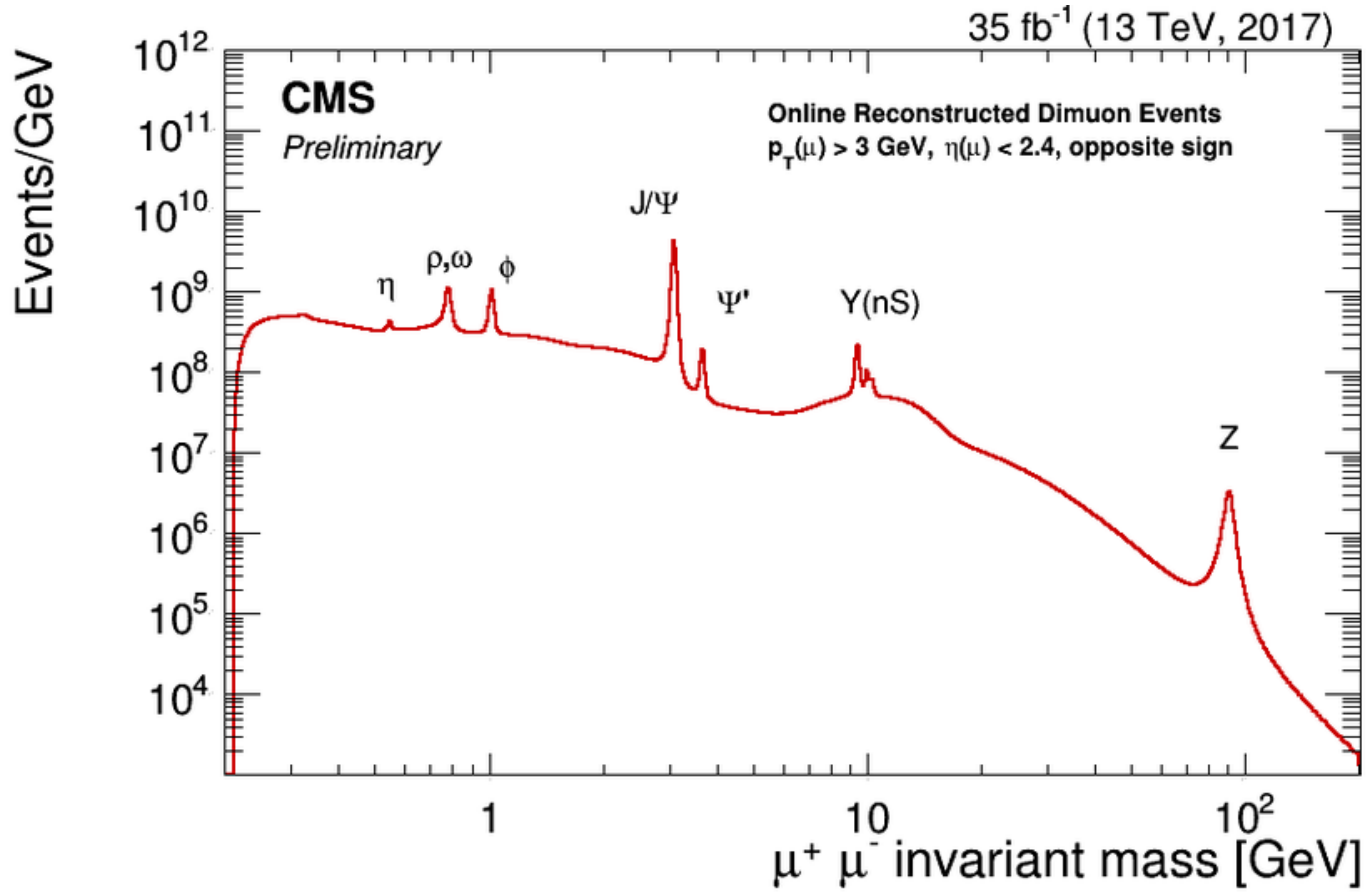
- Why measuring momentum is so important
- Why are particle detectors so big?
- Brief introduction to tracking and measuring momentum


LHCb
YCMM01
UX85


BIG!!!!
LHCb
YCMM01
UX85

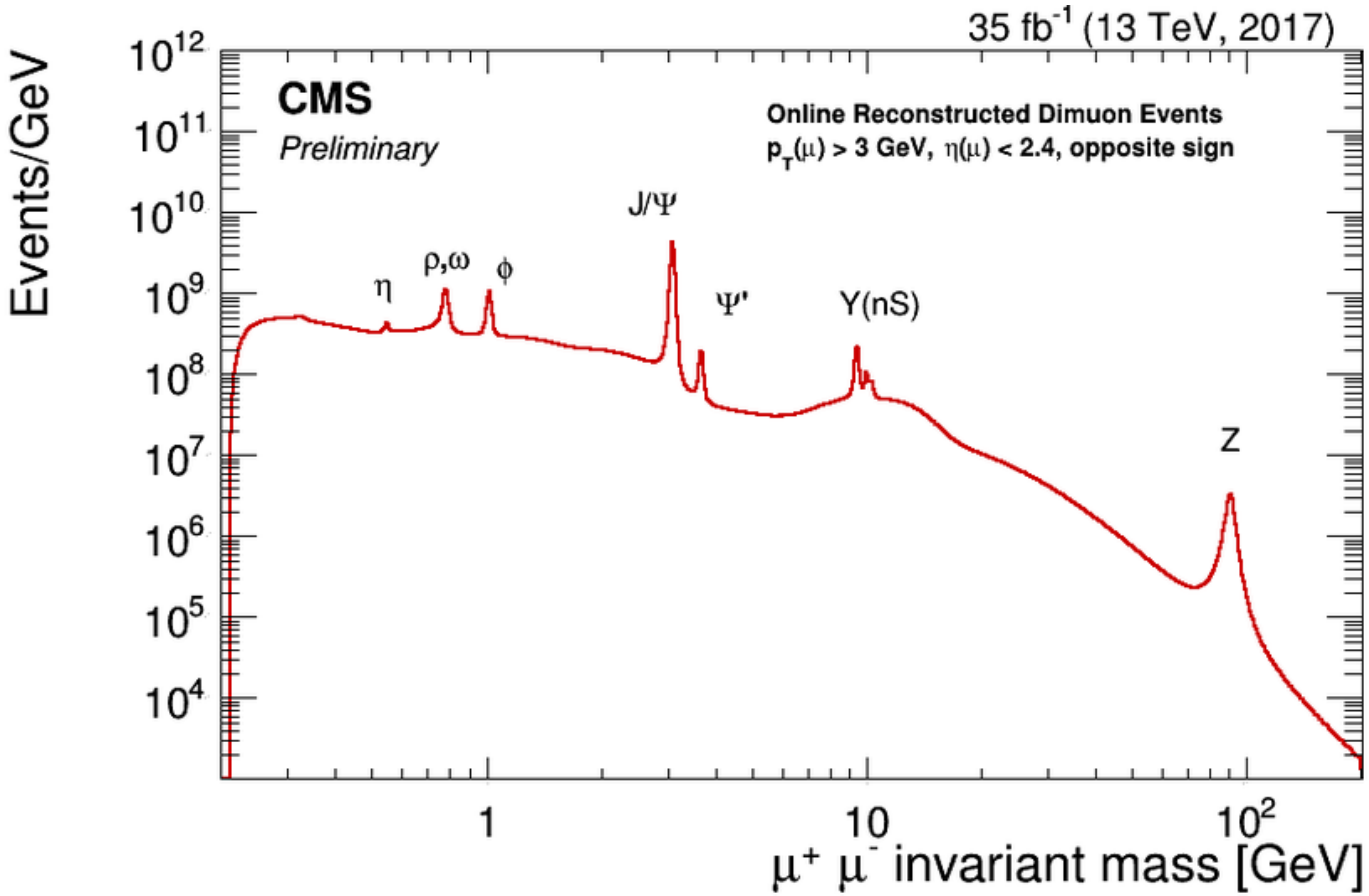


How do we calculate/measure the invariant mass?



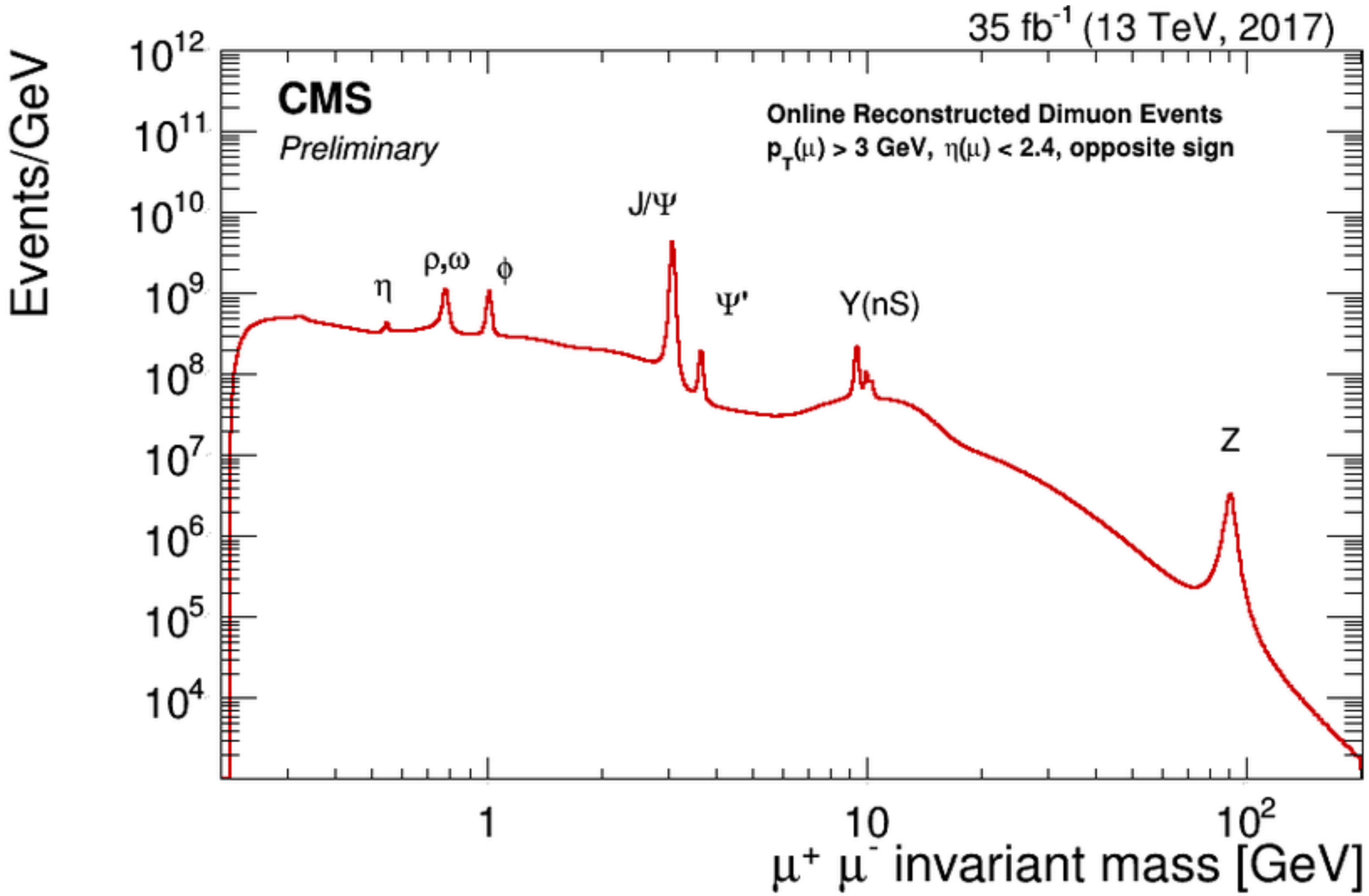
$$E^2 = p^2 + m^2$$

Energy of particle



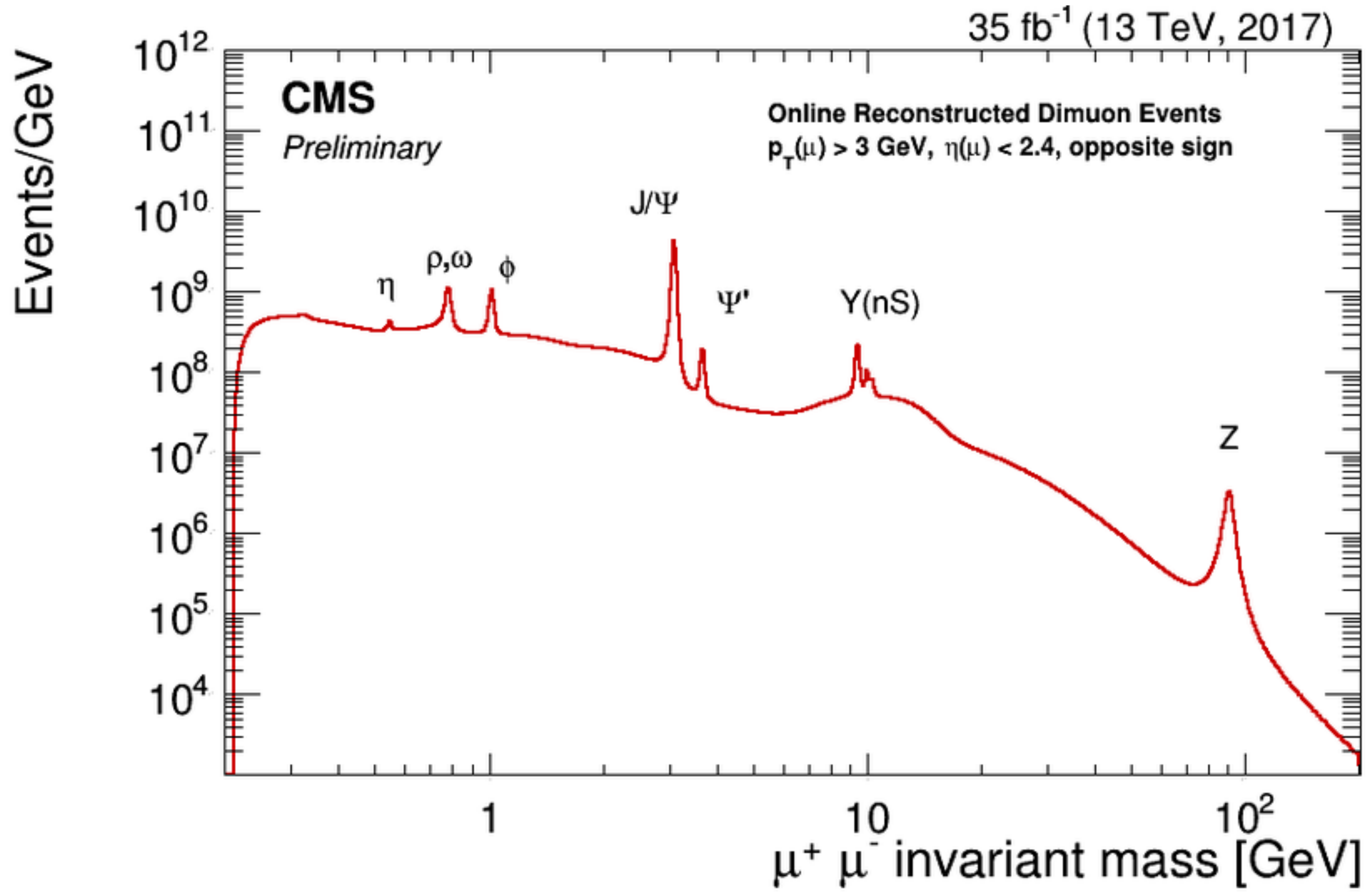
$$E^2 = p^2 + m^2$$

Momentum of particle



$$E^2 = p^2 + m^2$$

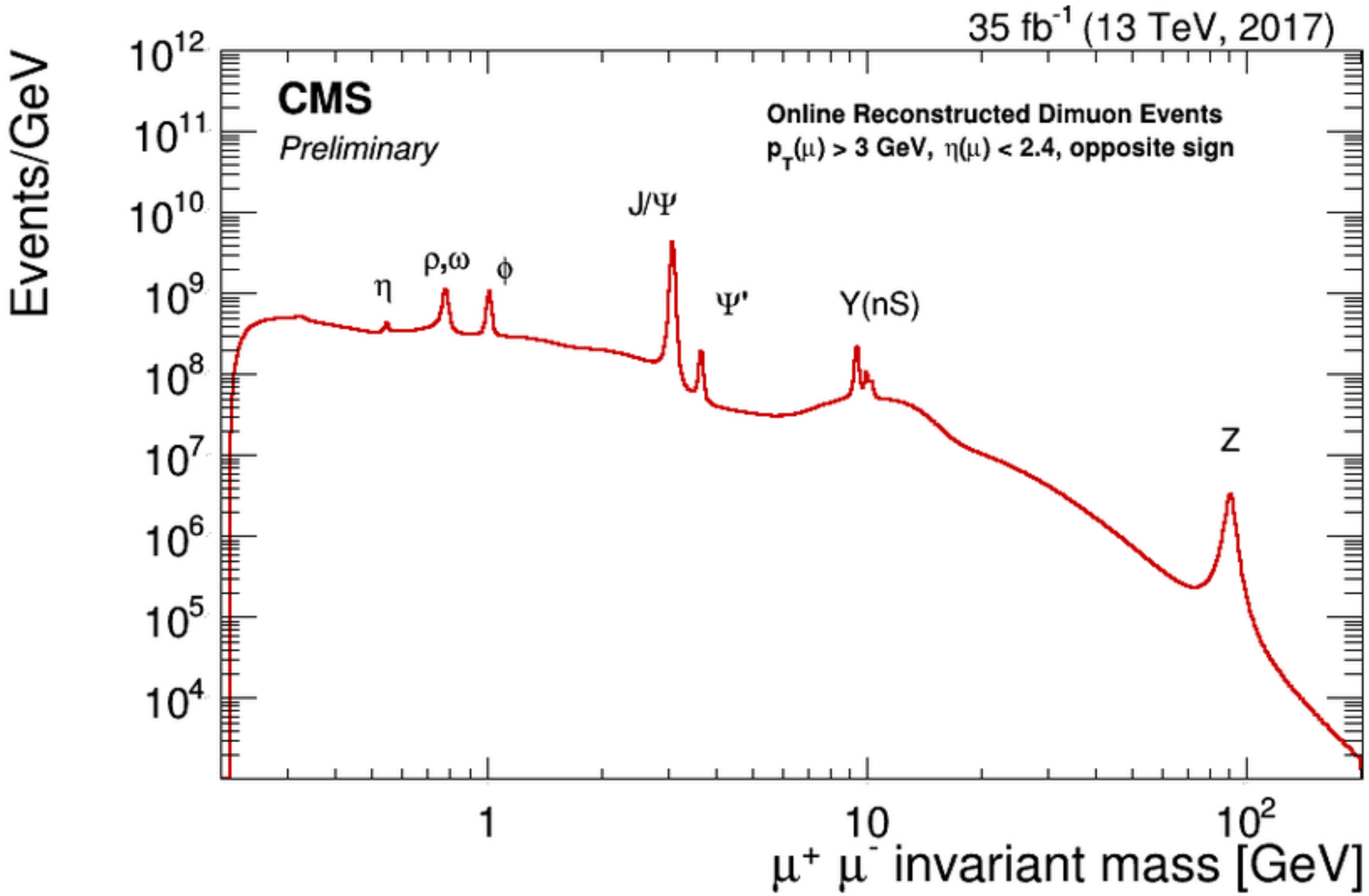
(Invariant) mass of particle



$$E^2 = p^2 + m^2$$

(Invariant) mass of particle

$$m^2 = E^2 - p^2$$

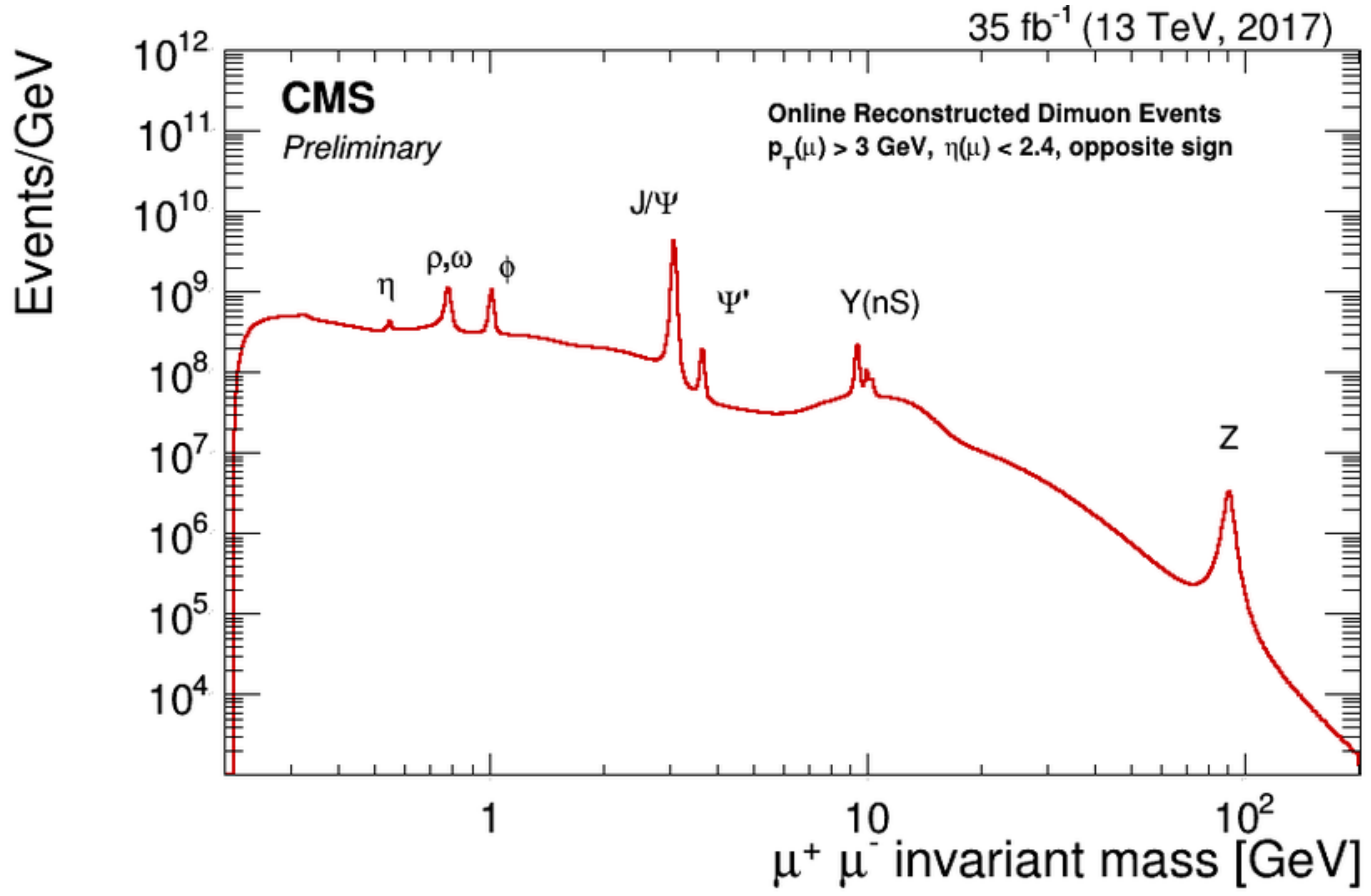


$$E^2 = p^2 + m^2$$

(Invariant) mass of particle

$$m^2 = E^2 - p^2$$

Lets look at concrete example of $Z \rightarrow \mu^+\mu^-$

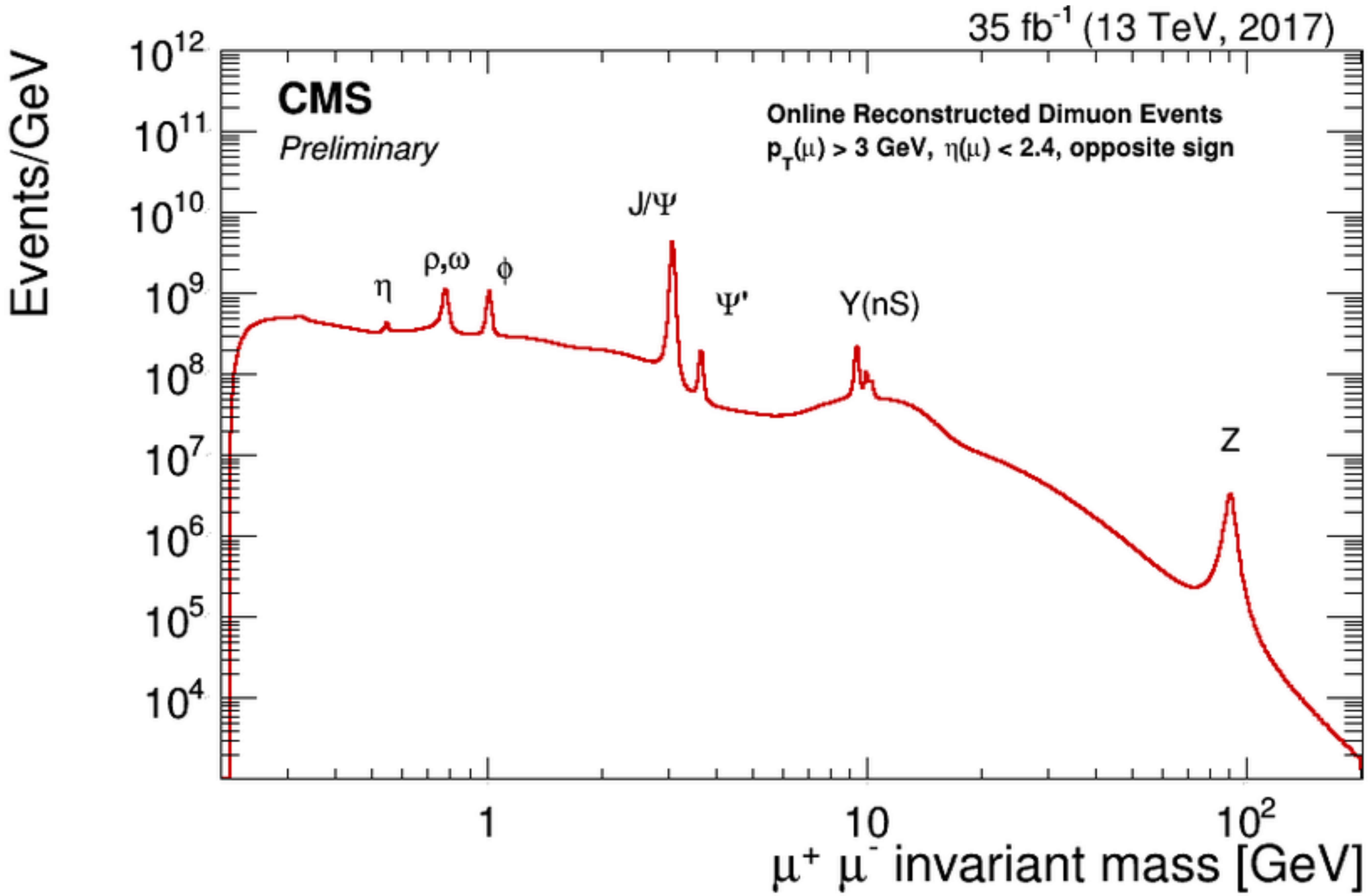


$$E^2 = p^2 + m^2$$

(Invariant) mass of particle

$$m^2 = E^2 - p^2$$

$$m_{\mu^+\mu^-}^2 = (E_1 + E_2)^2 - (p_{1,x} + p_{2,x})^2 - (p_{1,y} + p_{2,y})^2 - (p_{1,z} + p_{2,z})^2$$



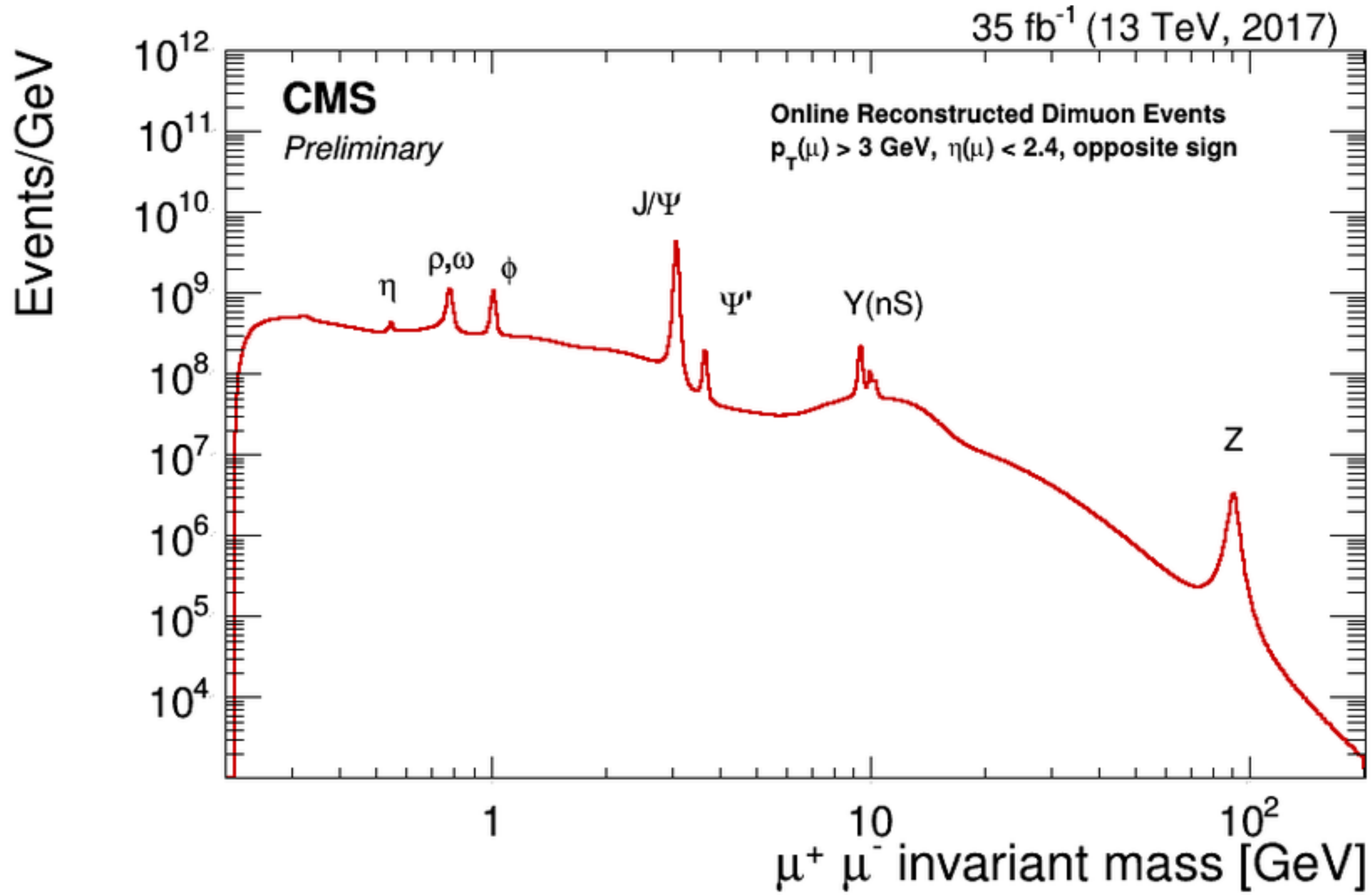
$$E^2 = p^2 + m^2$$

(Invariant) mass of particle

$$m^2 = E^2 - p^2$$

No direct energy measurement for muons, instead *assume* mass = m_μ and use $E = \sqrt{(|p|^2 + m_\mu^2)}$

$$m^2_{\mu^+\mu^-} = (E_1 + E_2)^2 - (p_{1,x} + p_{2,x})^2 - (p_{1,y} + p_{2,y})^2 - (p_{1,z} + p_{2,z})^2$$



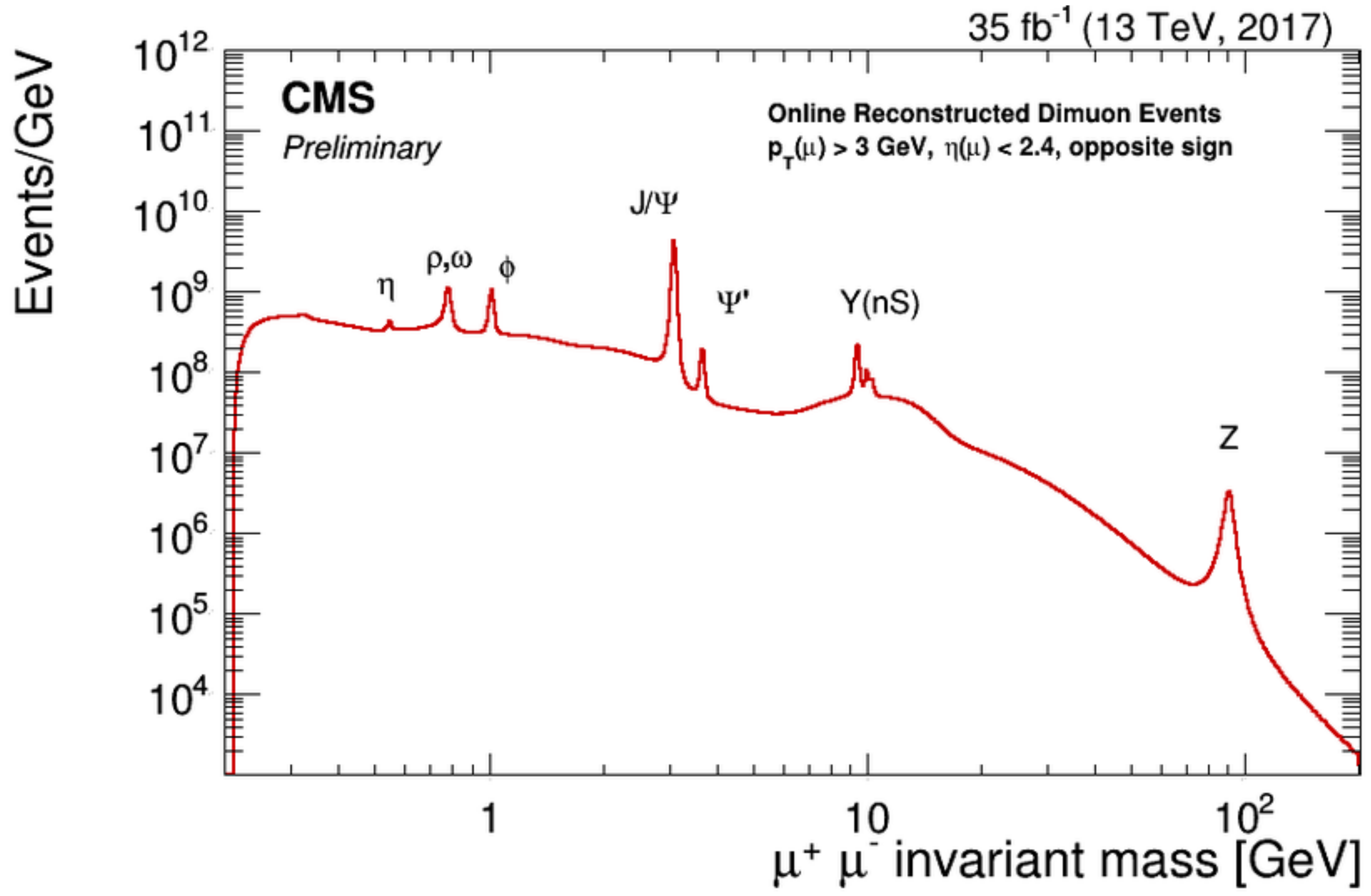
$$E^2 = p^2 + m^2$$

(Invariant) mass of particle

$$m^2 = E^2 - p^2$$

$$m^2_{\mu^+\mu^-} = (E_1 + E_2)^2 - (p_{1,x} + p_{2,x})^2 - (p_{1,y} + p_{2,y})^2 - (p_{1,z} + p_{2,z})^2$$

$$m^2_{\mu^+\mu^-} = \left[\sqrt{(m^2_\mu + |p_1|^2)} + \sqrt{(m^2_\mu + |p_2|^2)}\right]^2 - (p_{1,x} + p_{2,x})^2 - (p_{1,y} + p_{2,y})^2 - (p_{1,z} + p_{2,z})$$



$$E^2 = p^2 + m^2$$

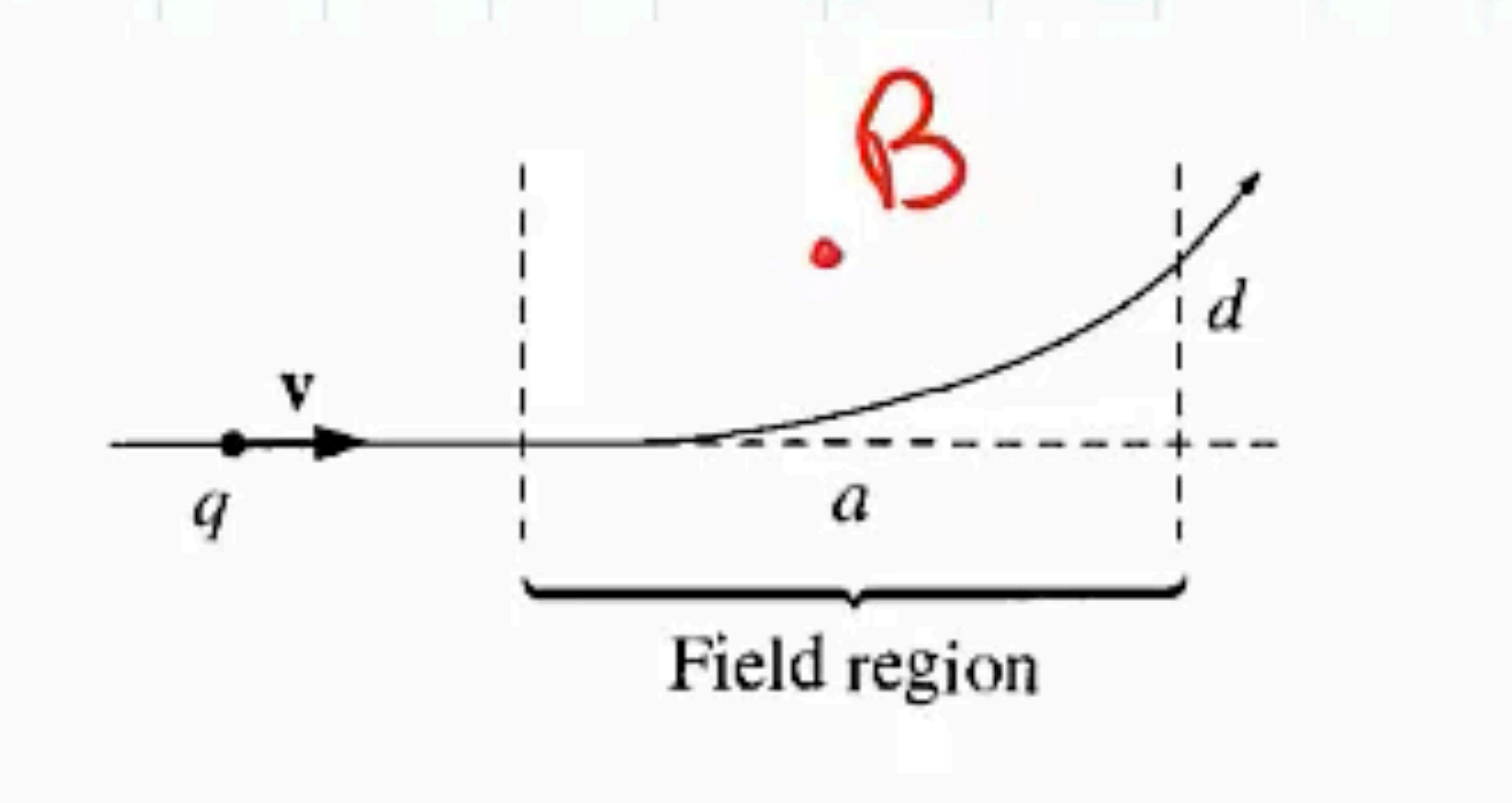
(Invariant) mass of particle

$$m^2 = E^2 - p^2$$

Summary : If we know the momentum of a track, and can have a good guess at the mass of the particle, we have enough information to make this plot

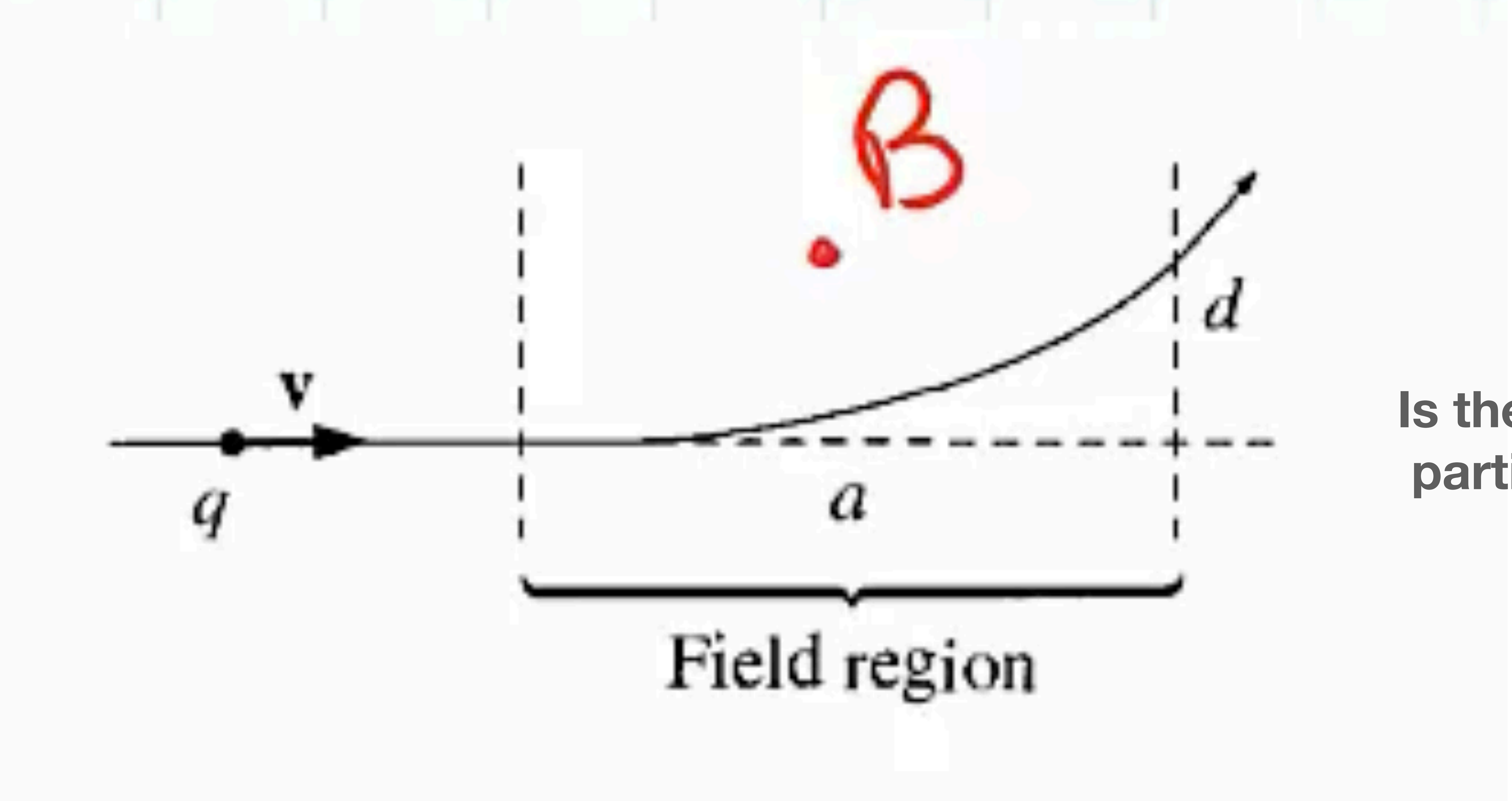
$$m^2_{\mu^+\mu^-} = \left[\sqrt{(m_\mu^2 + |p_1|^2)} + \sqrt{(m_\mu^2 + |p_2|^2)}\right]^2 - (p_{1,x} + p_{2,x})^2 - (p_{1,y} + p_{2,y})^2 - (p_{1,z} + p_{2,z})$$

How to measure particle momentum ?



$$F = q\overrightarrow{v} \times \overrightarrow{B}$$

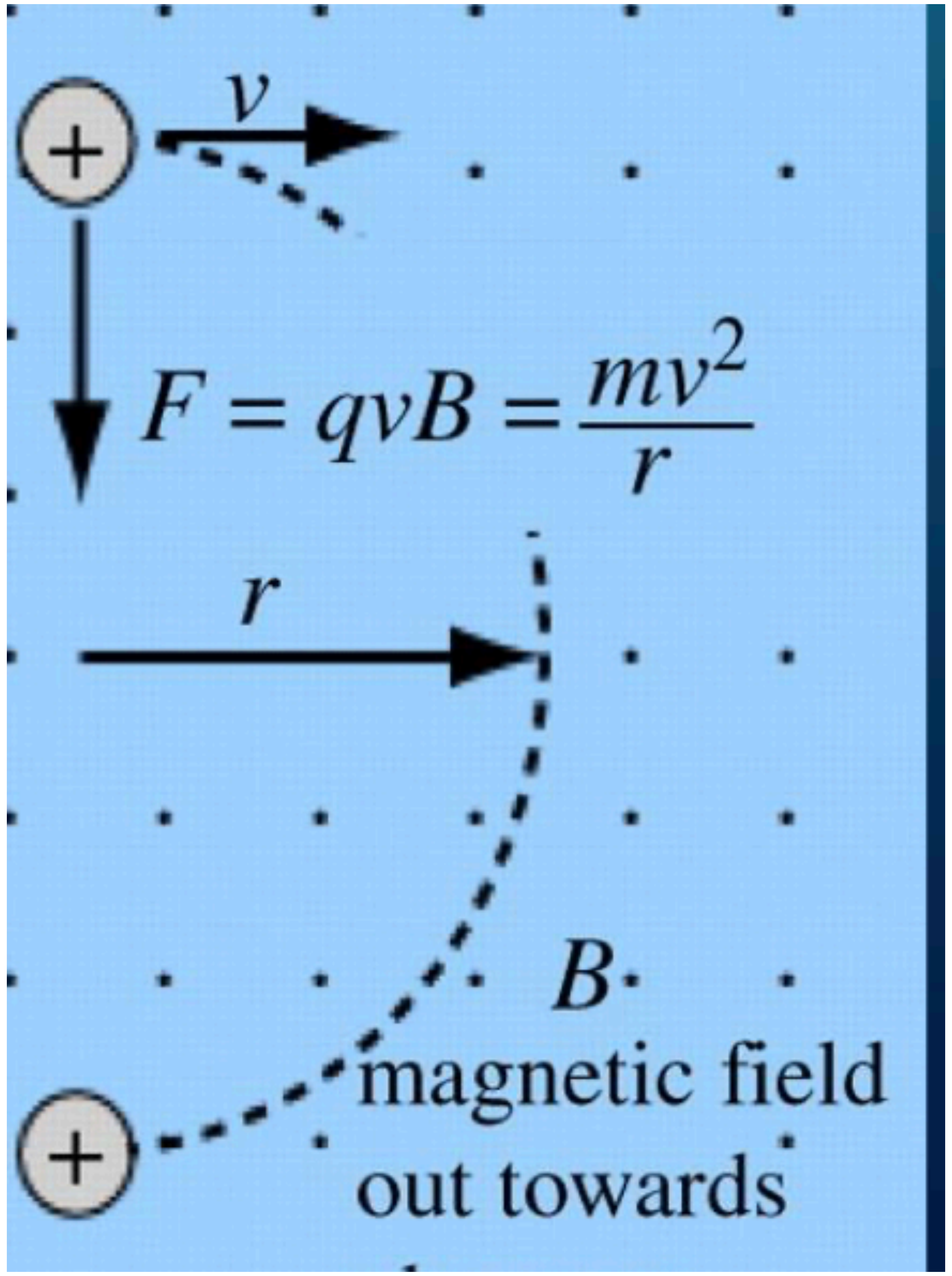
How to measure particle momentum ?



Is the charge of this particle positive or negative?

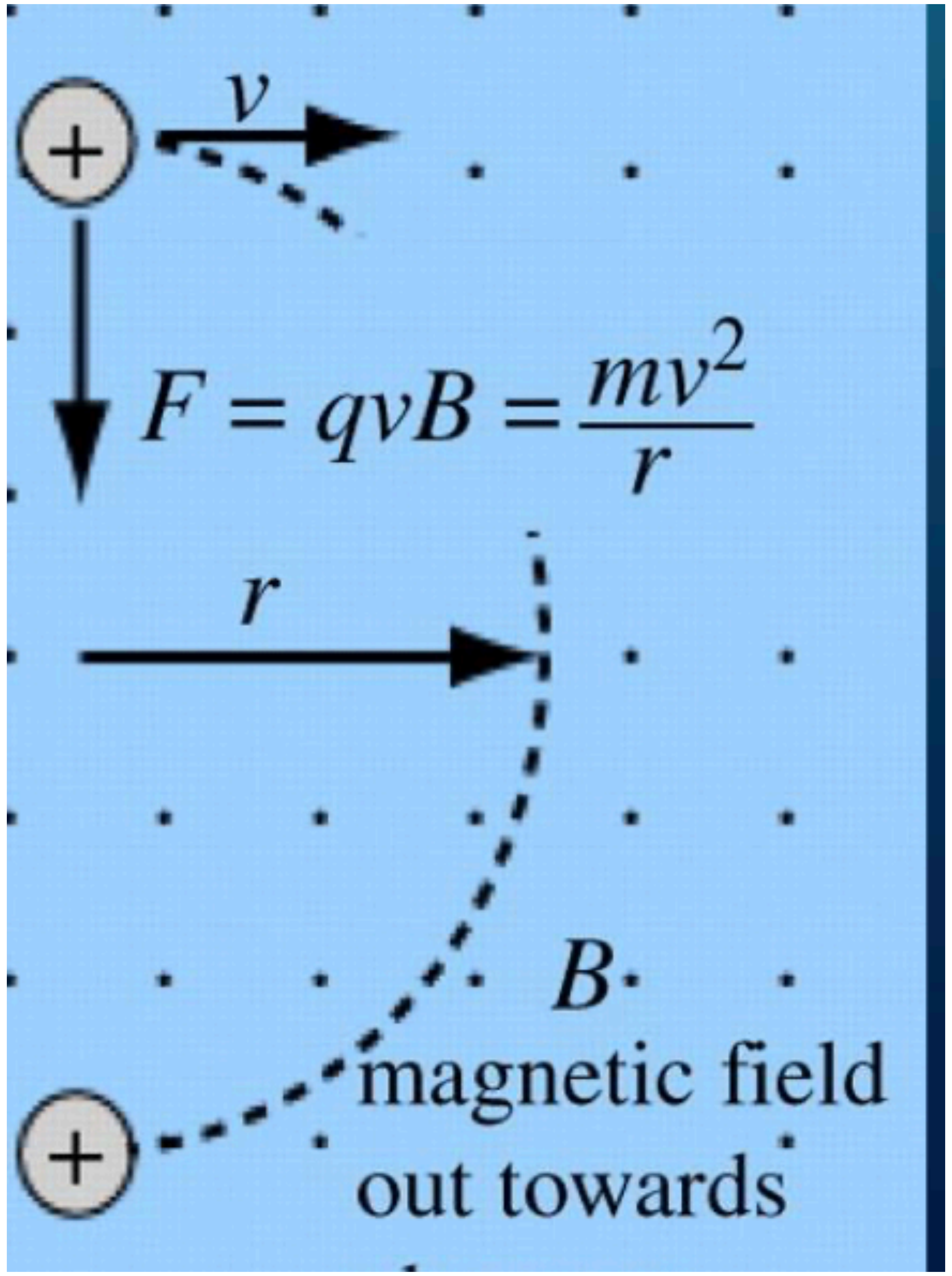
$$F = q\overrightarrow{v} \times \overrightarrow{B}$$

How to measure particle momentum ?



$$mv = p = qBr$$

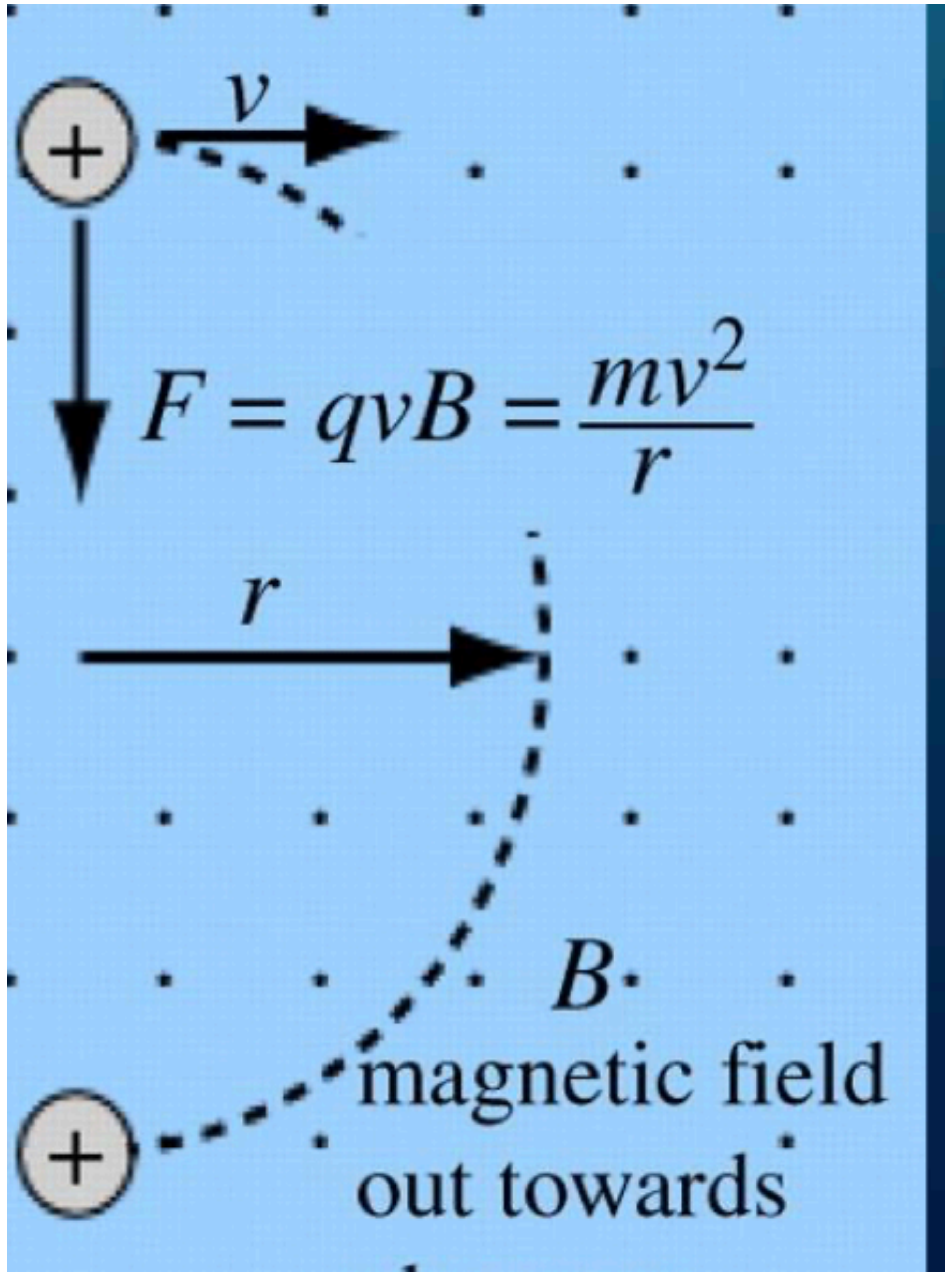
How to measure particle momentum ?



$$mv = p = qBr$$

If we know B, assume q, and measure r, we get momentum

How to measure particle momentum ?



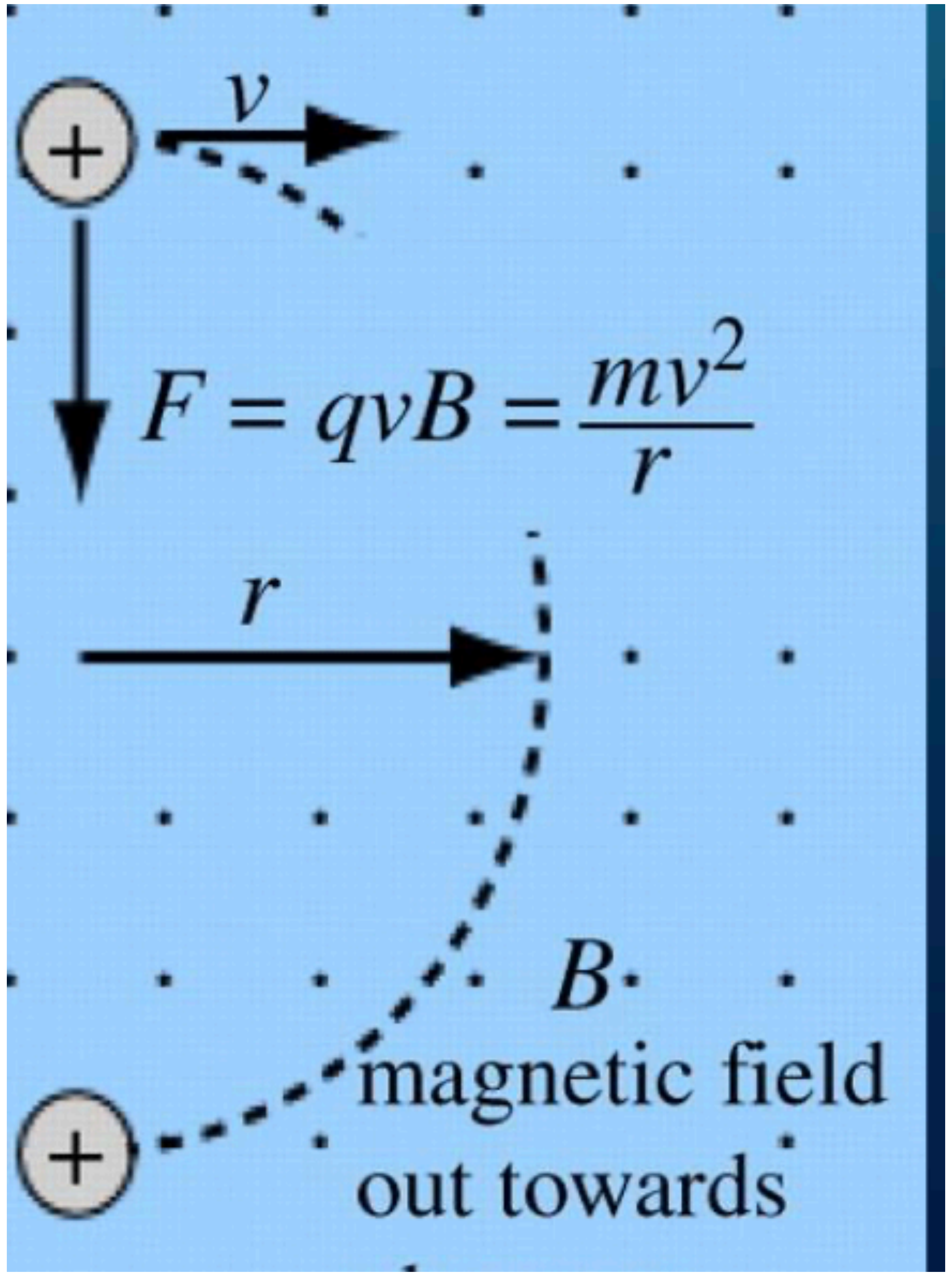
$$p = qBr$$

If we know B, assume q, and measure r, we get momentum

We generally assume $q = 1$

$$r = mv/B$$

How to measure particle momentum ?

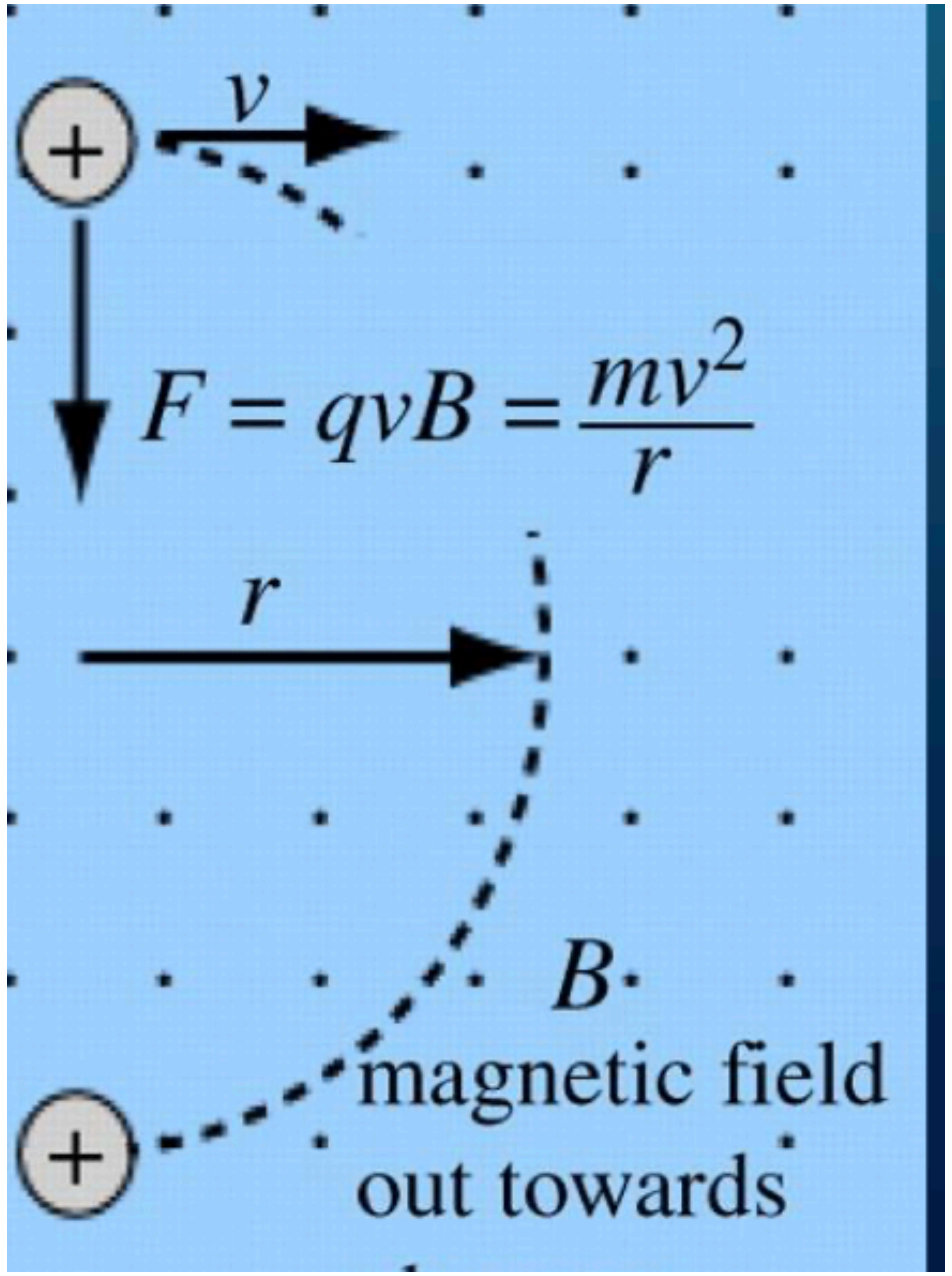


$$p = qBr$$

If we know B, assume q, and measure r,
we get momentum

$$r = mv/B$$

How to measure particle momentum ?



$$p = qBr$$

If we know B, assume q, and measure r,
we get momentum

$$r = mv/B$$

What type of speeds are we dealing with ??

How to measure particle momentum ?

$$r = mv/B$$

Take example of $Z \to \mu^+\mu^-$

$$m_Z \sim 90\text{GeV}$$

$$m_\mu \sim 0.1\text{GeV}$$

How to measure particle momentum ?

$$r = mv/B$$

Take example of $Z \to \mu^+\mu^-$

$$m_Z \sim 90\text{GeV}$$

$$m_\mu \sim 0.1\text{GeV}$$

Assume each muon gets half this momentum

How to measure particle momentum ?

$$r = mv/B$$

Take example of $Z \rightarrow \mu^+\mu^-$

$$m_Z \sim 90\text{GeV}$$

$$m_\mu \sim 0.1\text{GeV}$$

$$\frac{v}{c} = \frac{E}{p} = \sqrt{p^2 + m^2}/p = (\sqrt{(90/2)^2 + 0.1^2})/(90/2) \sim 1$$

How to measure particle momentum ?

$$r = mv/B$$

Take example of $Z \to \mu^+\mu^-$

$$m_Z \sim 90\text{GeV}$$

$$m_\mu \sim 0.1\text{GeV}$$

$$\frac{v}{c} = \frac{E}{p} = \sqrt{p^2 + m^2}/p = (\sqrt{(90/2)^2 + 0.1^2})/(90/2) \sim 1$$

When things are going at the speed of light, very small curve radius

How to measure particle momentum ?

$$r = mv/B$$

Take example of $Z \to \mu^+\mu^-$

$$m_Z \sim 90\text{GeV}$$

$$m_\mu \sim 0.1\text{GeV}$$

This is why particle detectors are so big!!!

$$\frac{v}{c} = \frac{E}{p} = \sqrt{p^2 + m^2}/p = (\sqrt{(90/2)^2 + 0.1^2})/(90/2) \sim 1$$

When things are going at the speed of light, very small curve radius

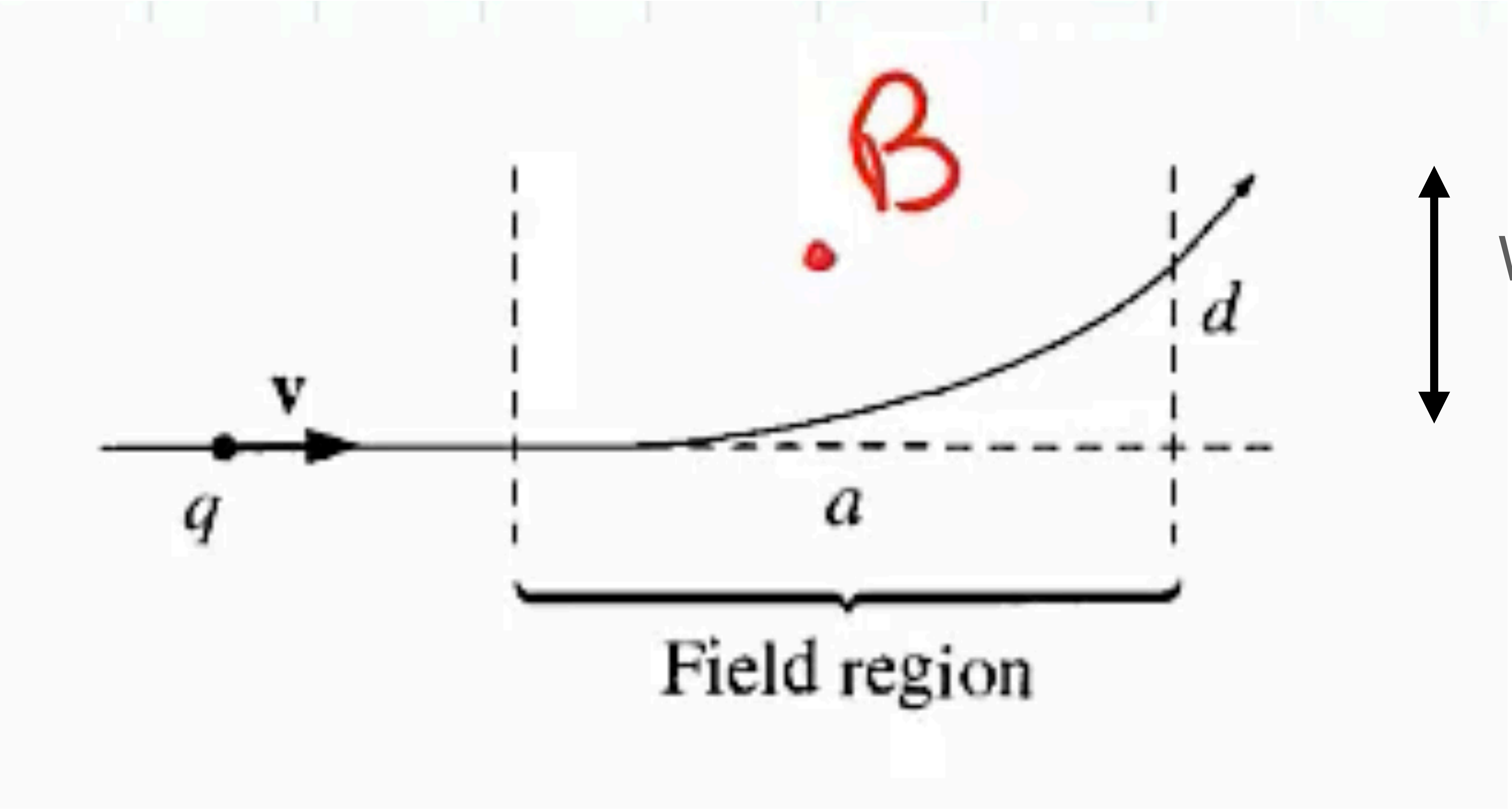
How to measure particle momentum ?

How to measure particle momentum ?

= how to measure the curvature of tracks in a magnetic field ?

How to measure particle momentum ?

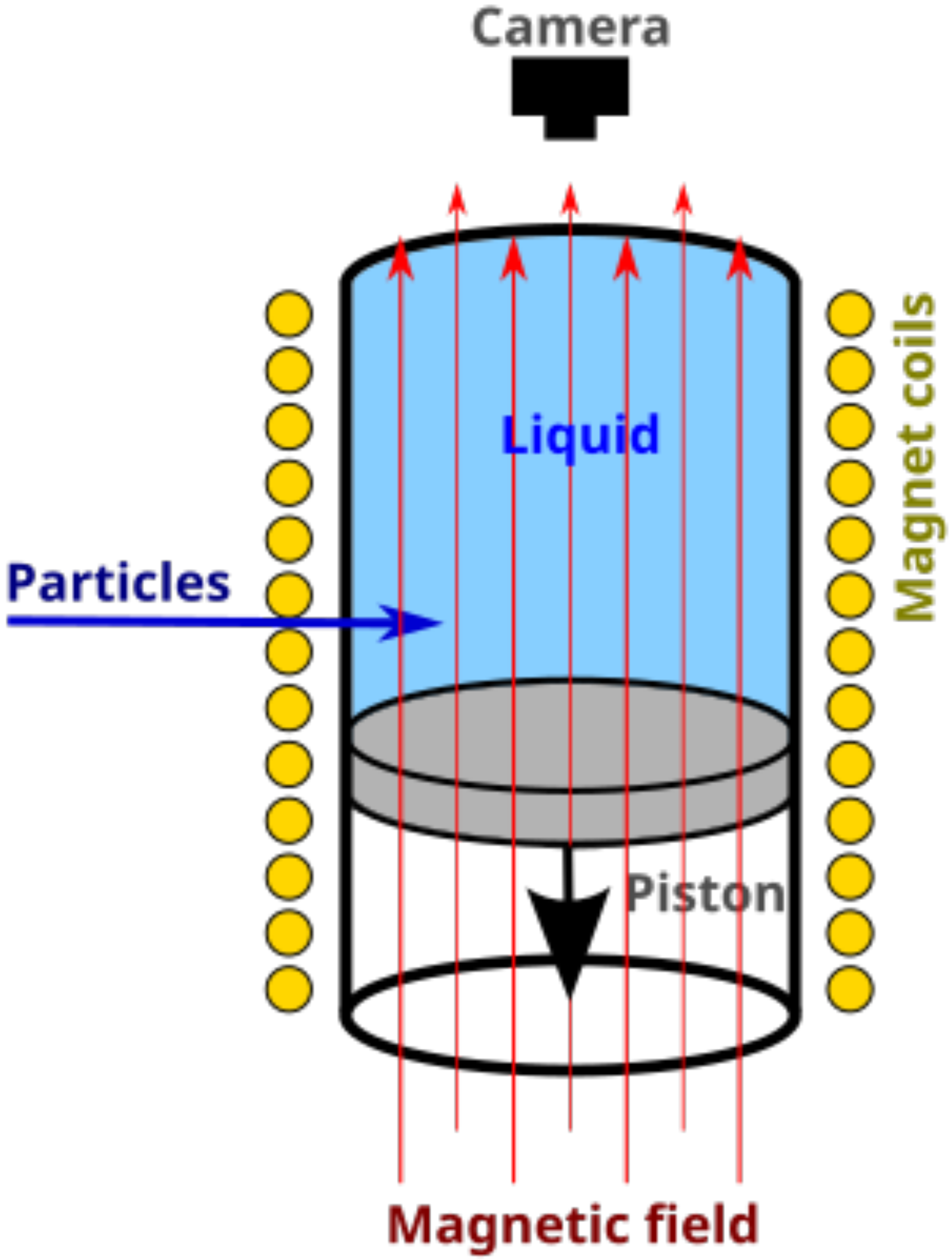
= how to measure the curvature of tracks in a magnetic field ?

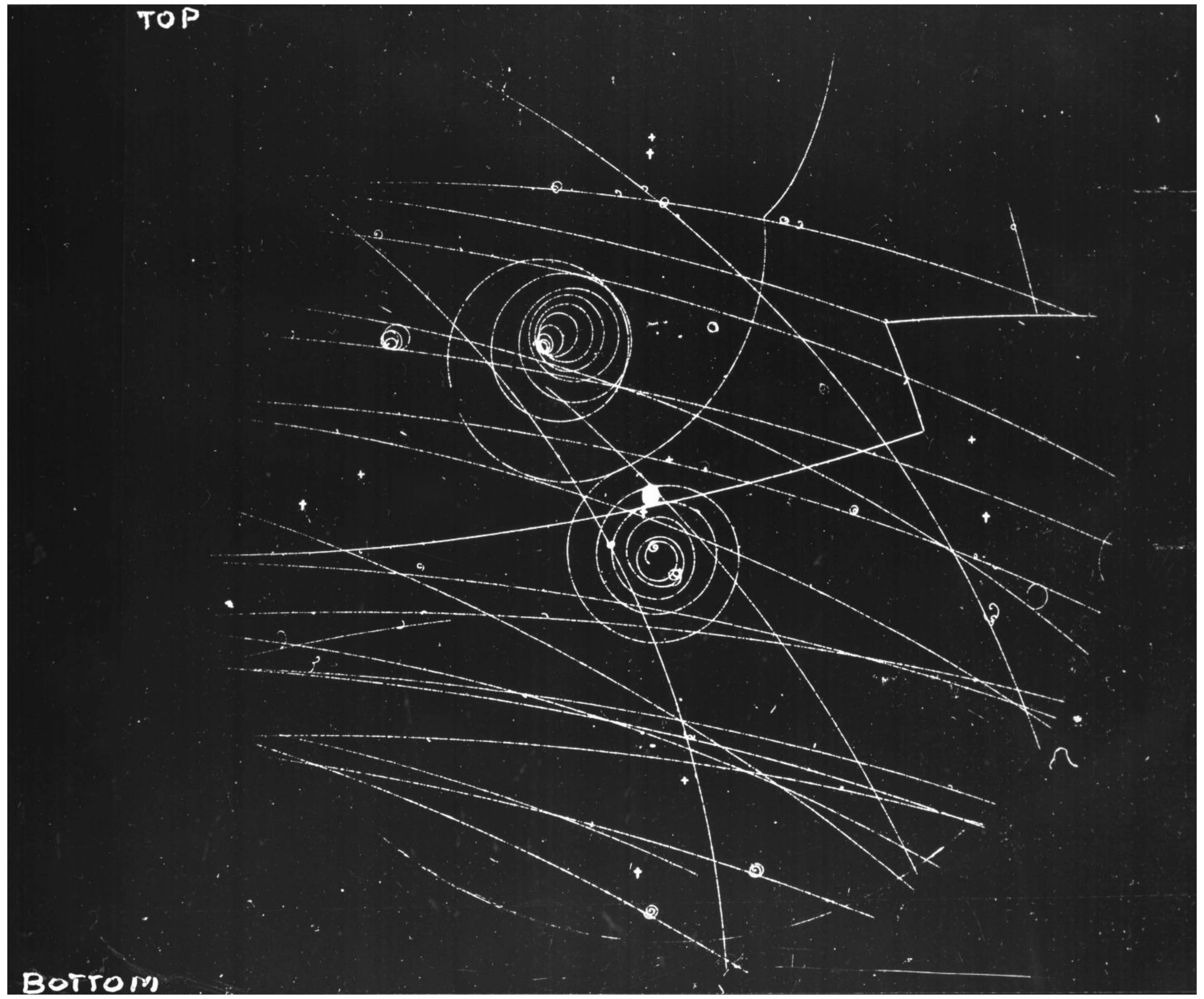


We want to measure this deflection

So - how do we track particles ?

Starting in the 1950's.. the bubble chamber

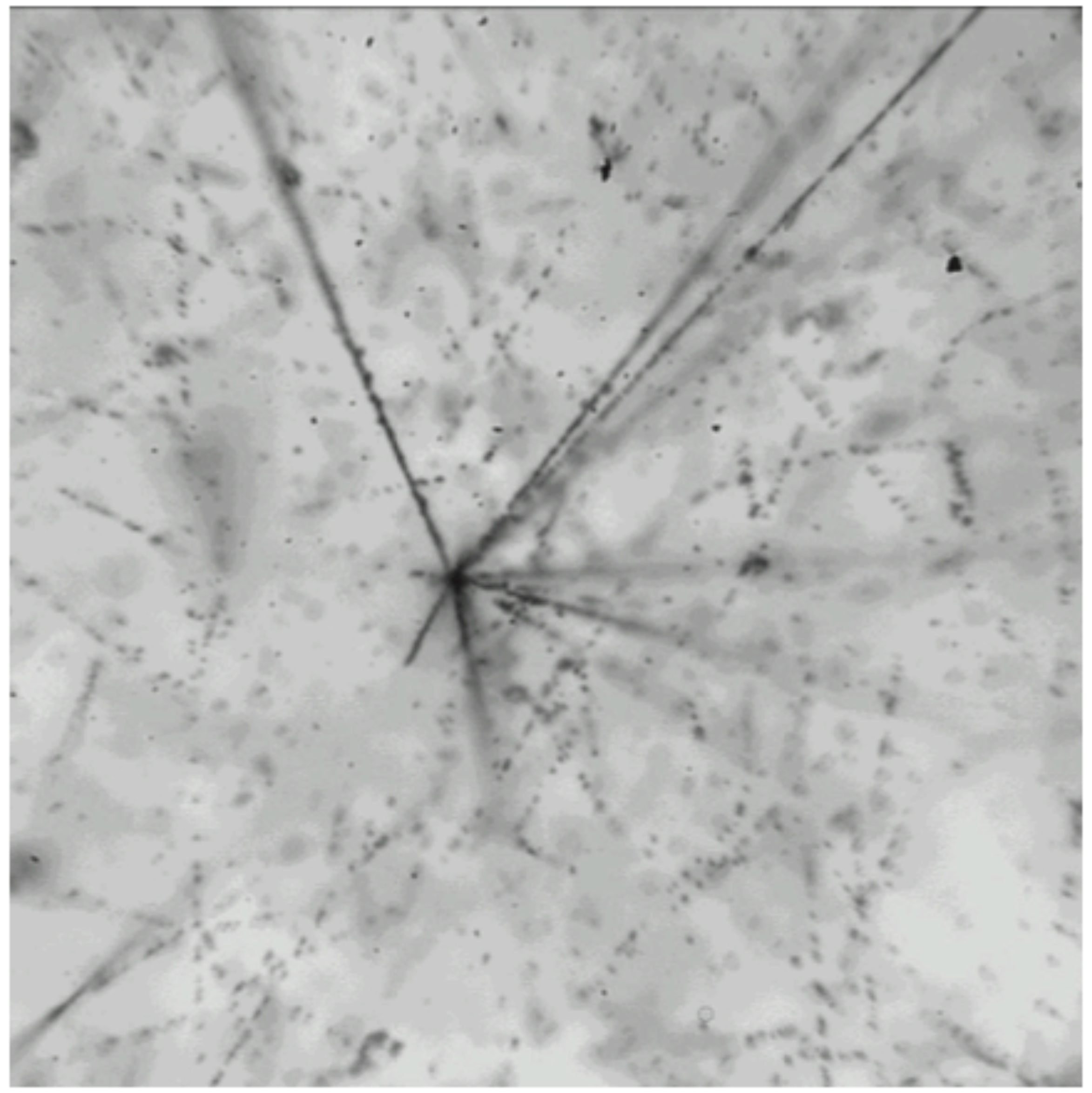




Emulsion - similar idea - a photograph

- Emulsion detectors
  - Essentially traditional photographs
  - Passing particle makes local change to *molecular structure*

100 μm

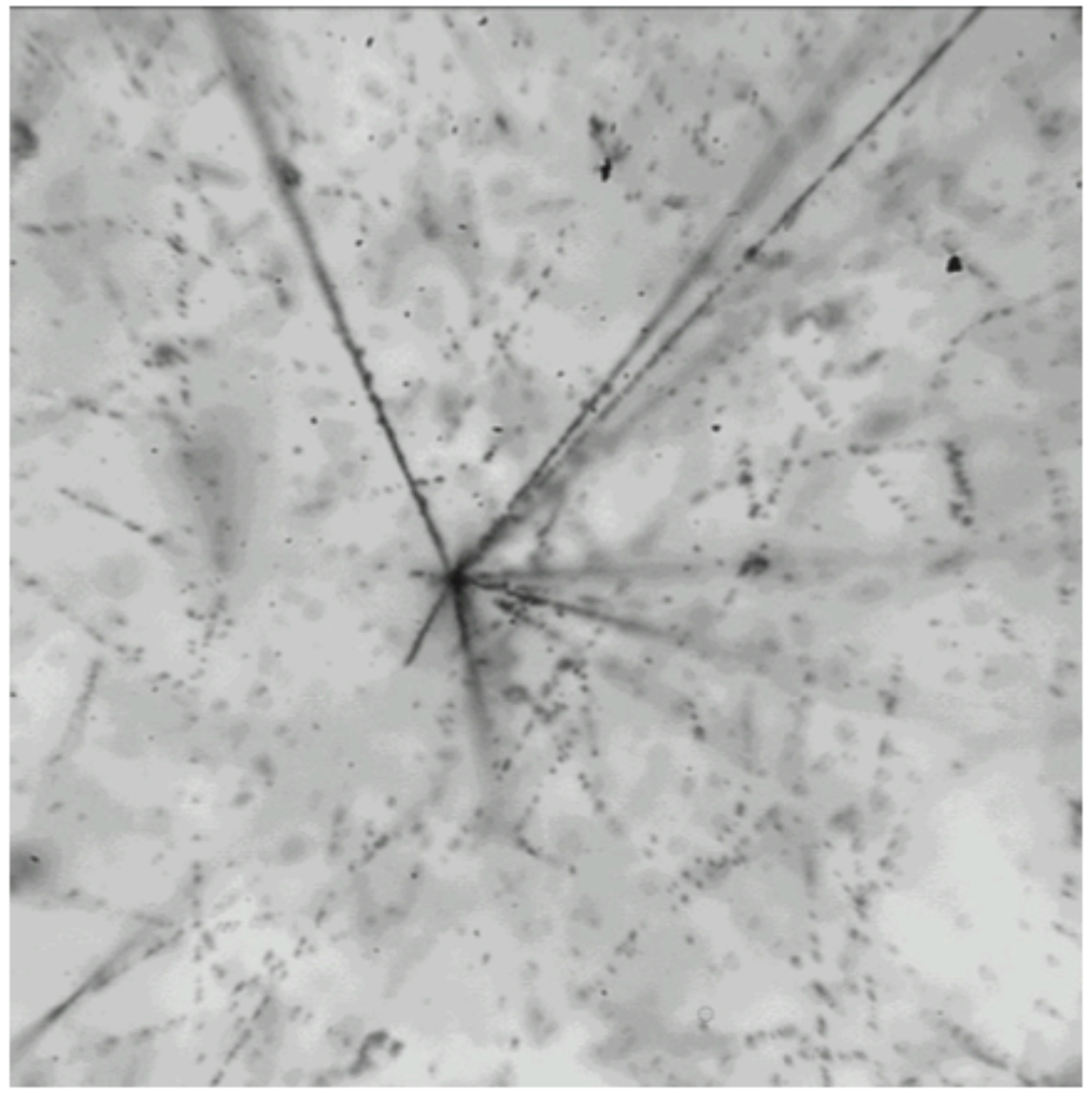


- This give a much higher resolution on a particle track then e.g. the silicon detectors used in high energy physics /FCC

Emulsion - similar idea - a photograph

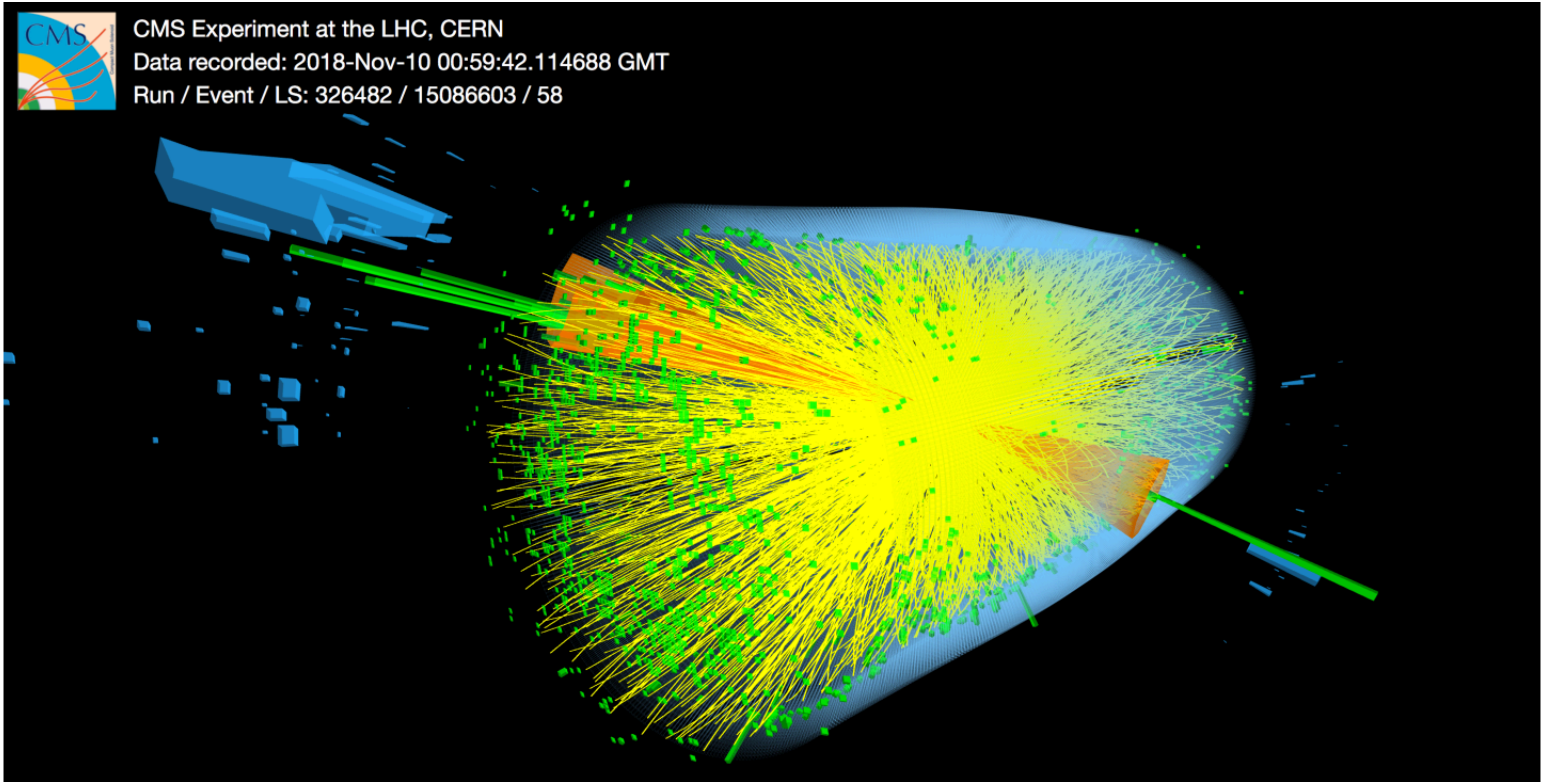
- Emulsion detectors
    - Essentially traditional photographs
    - Passing particle makes local change to *molecular structure*

100 μm



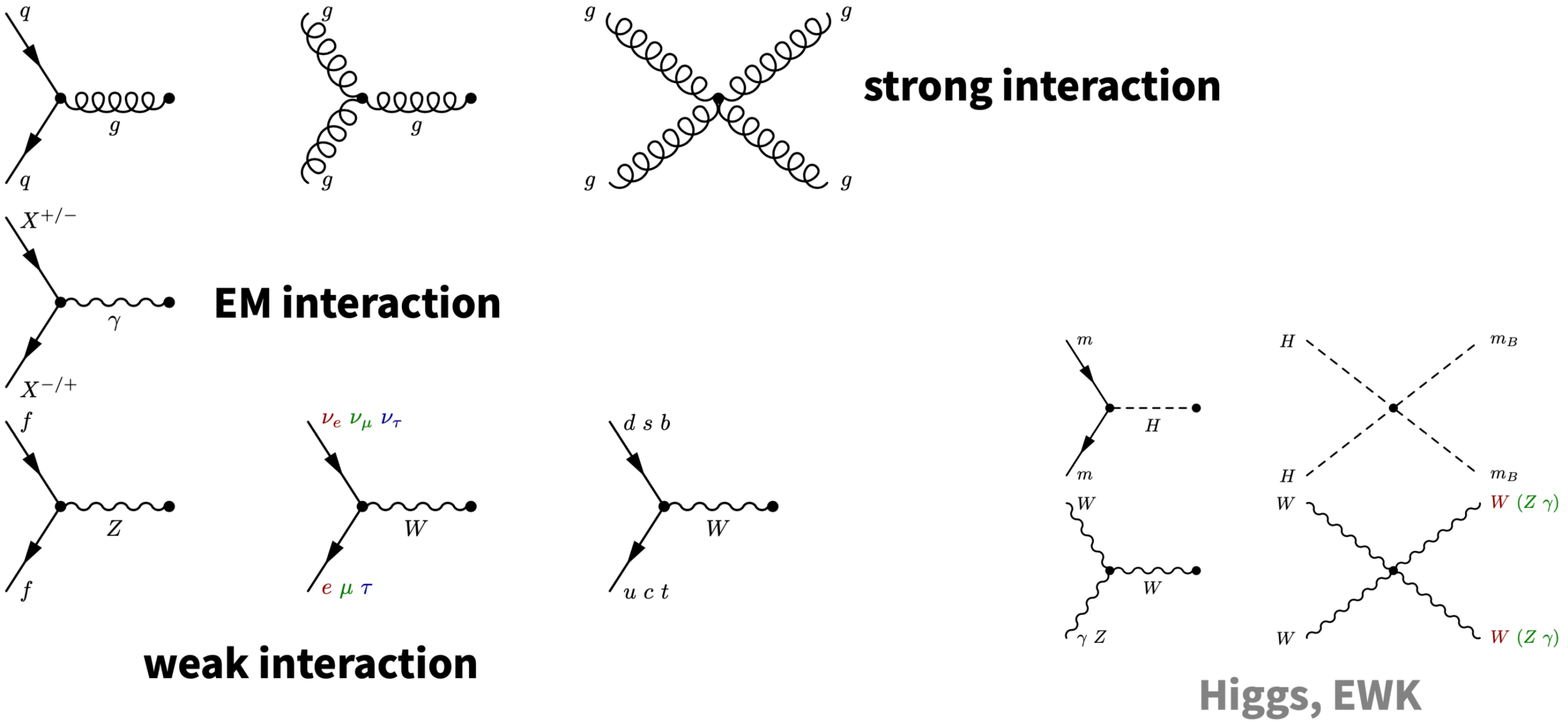
- This give a much higher resolution on a particle track then e.g. the silicon detectors used in high energy physics /FCC

- What is the major draw back of taking photographs to measure tracks?


CMS Experiment at the LHC, CERN
Data recorded: 2018-Nov-10 00:59:42.114688 GMT
Run / Event / LS: 326482 / 15086603 / 58

Interaction of particles with matter

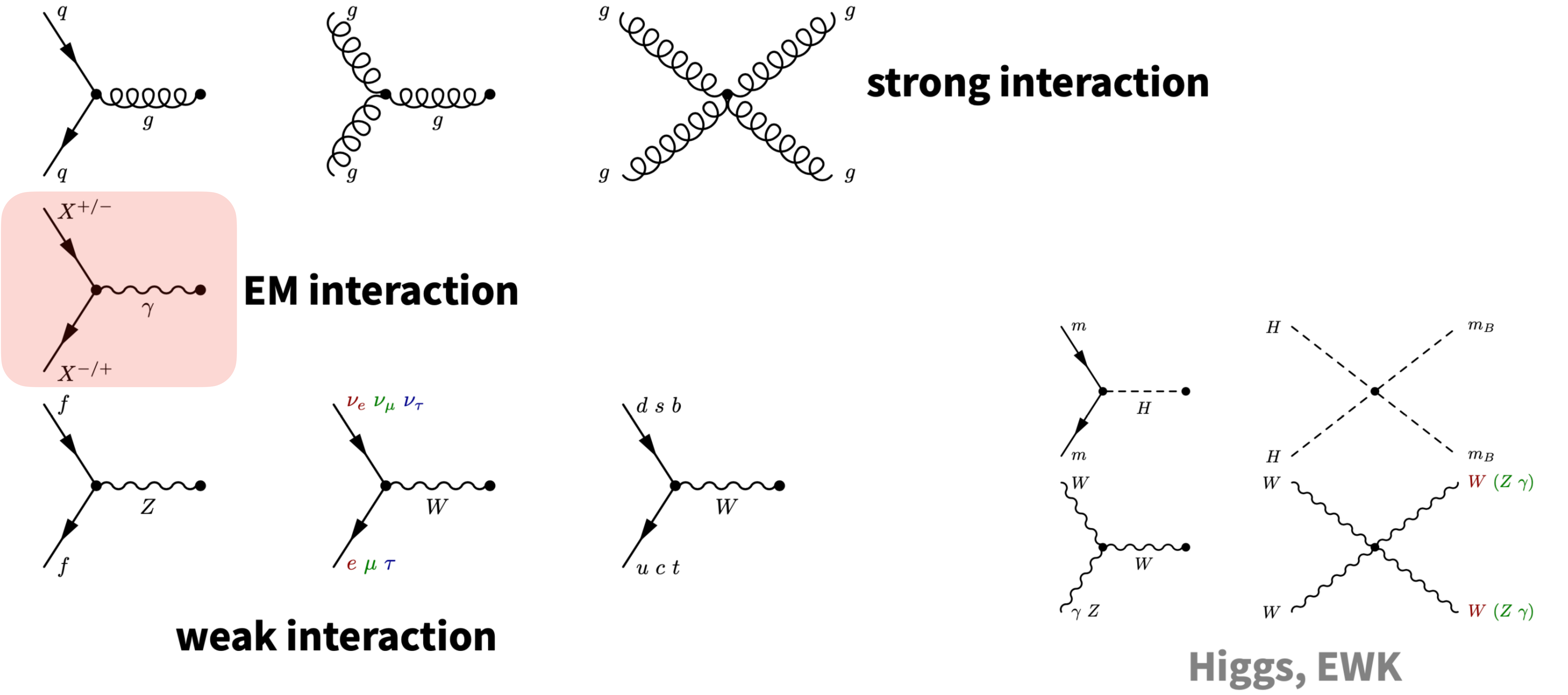
Reminder - all the interaction vertices in the SM



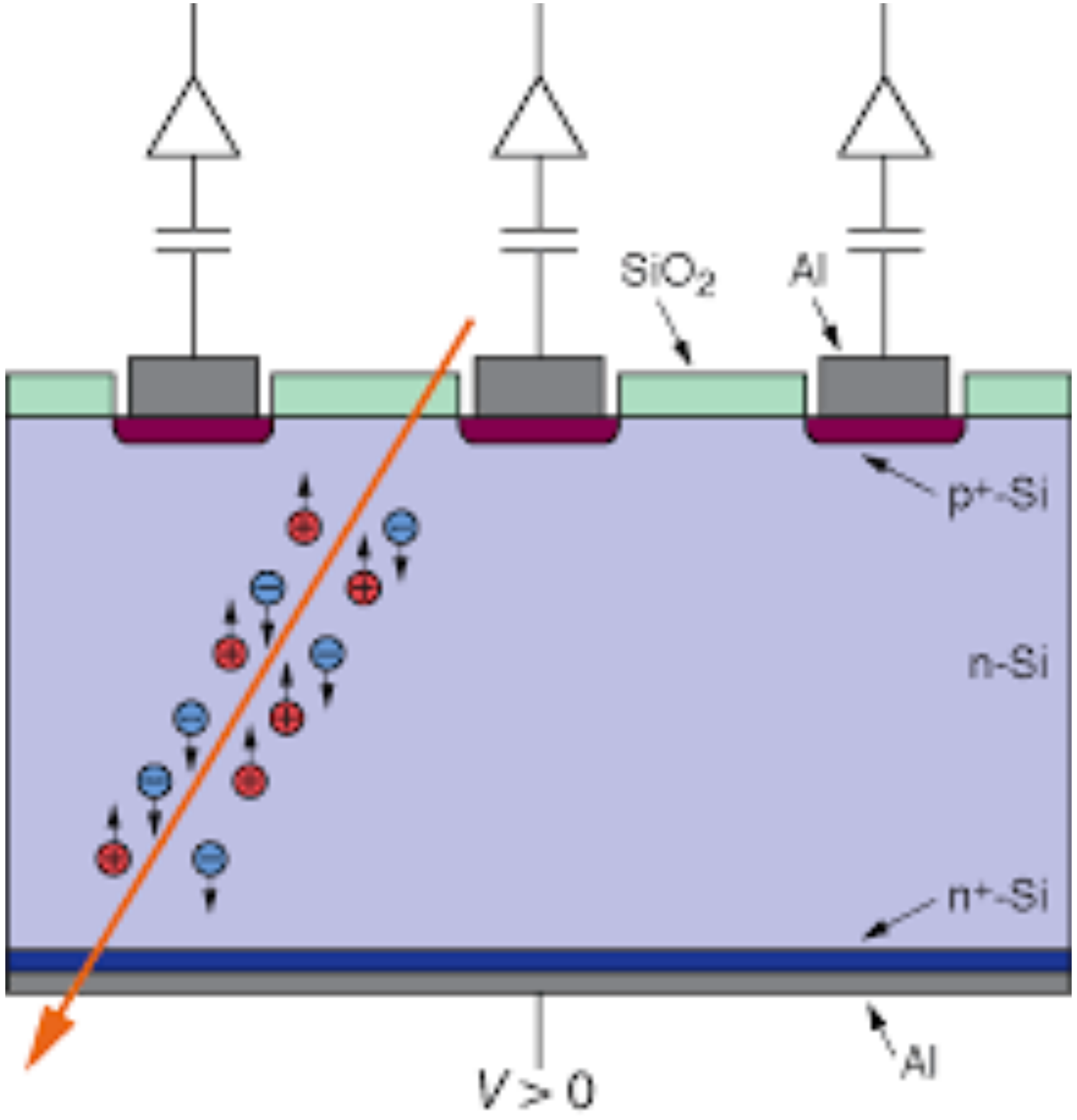
Interaction of particles with matter

Reminder - all the interaction vertices in the SM

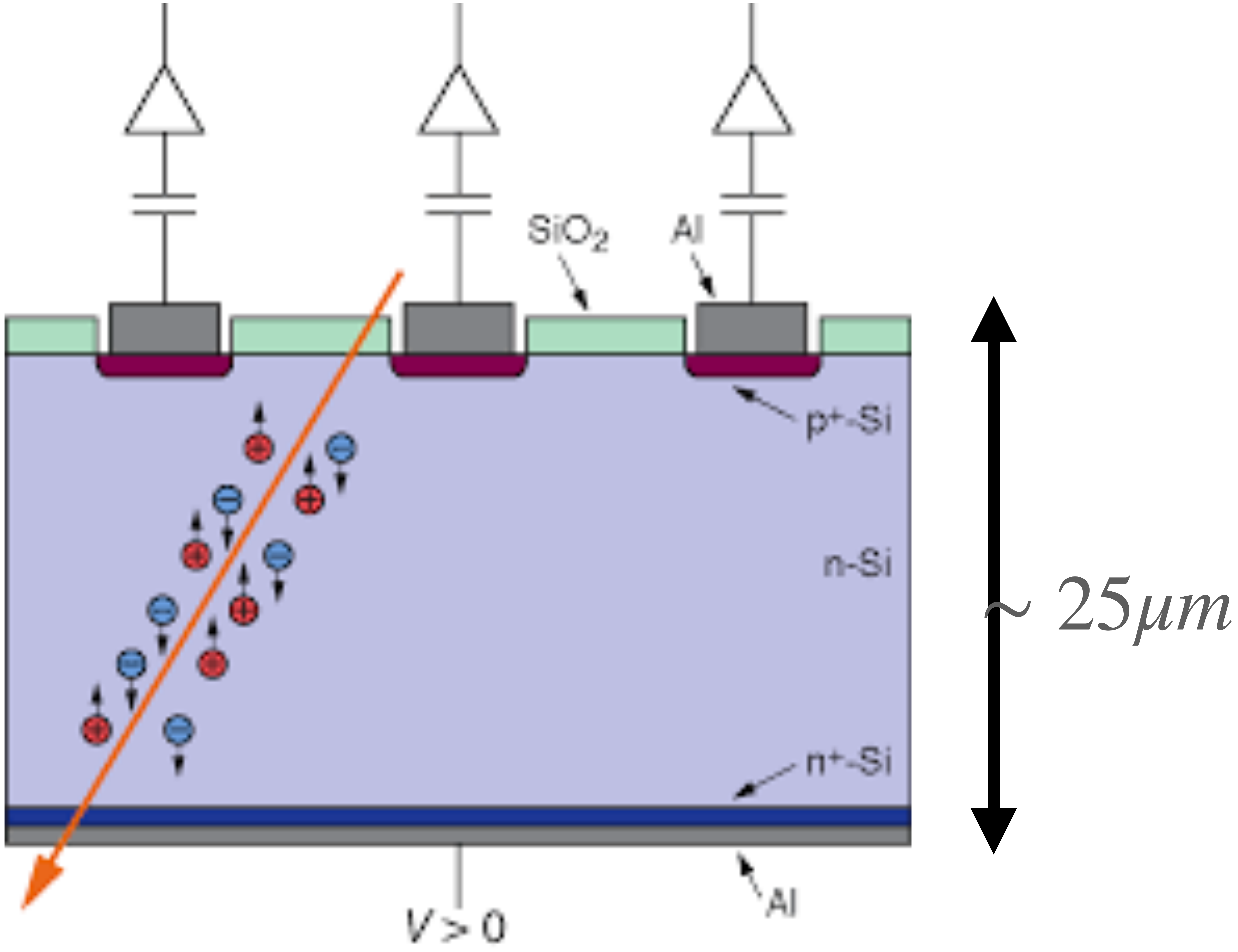
Most common way to detect particles



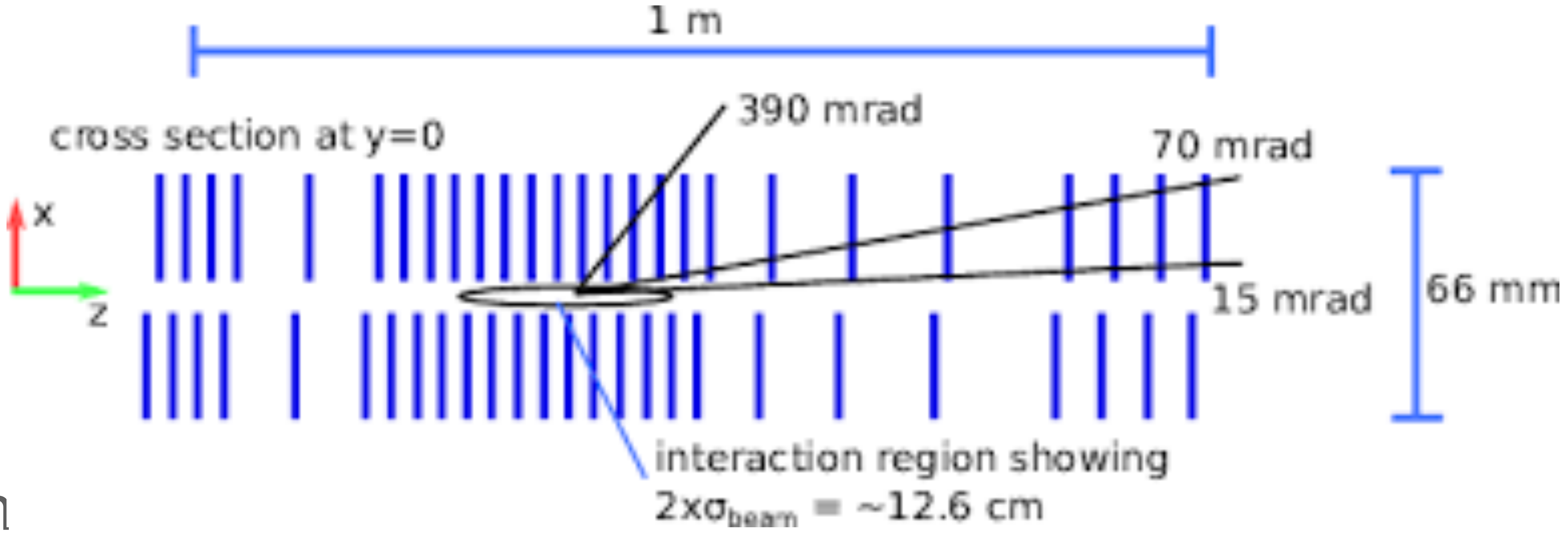
Modern particle tracking, use ionisation



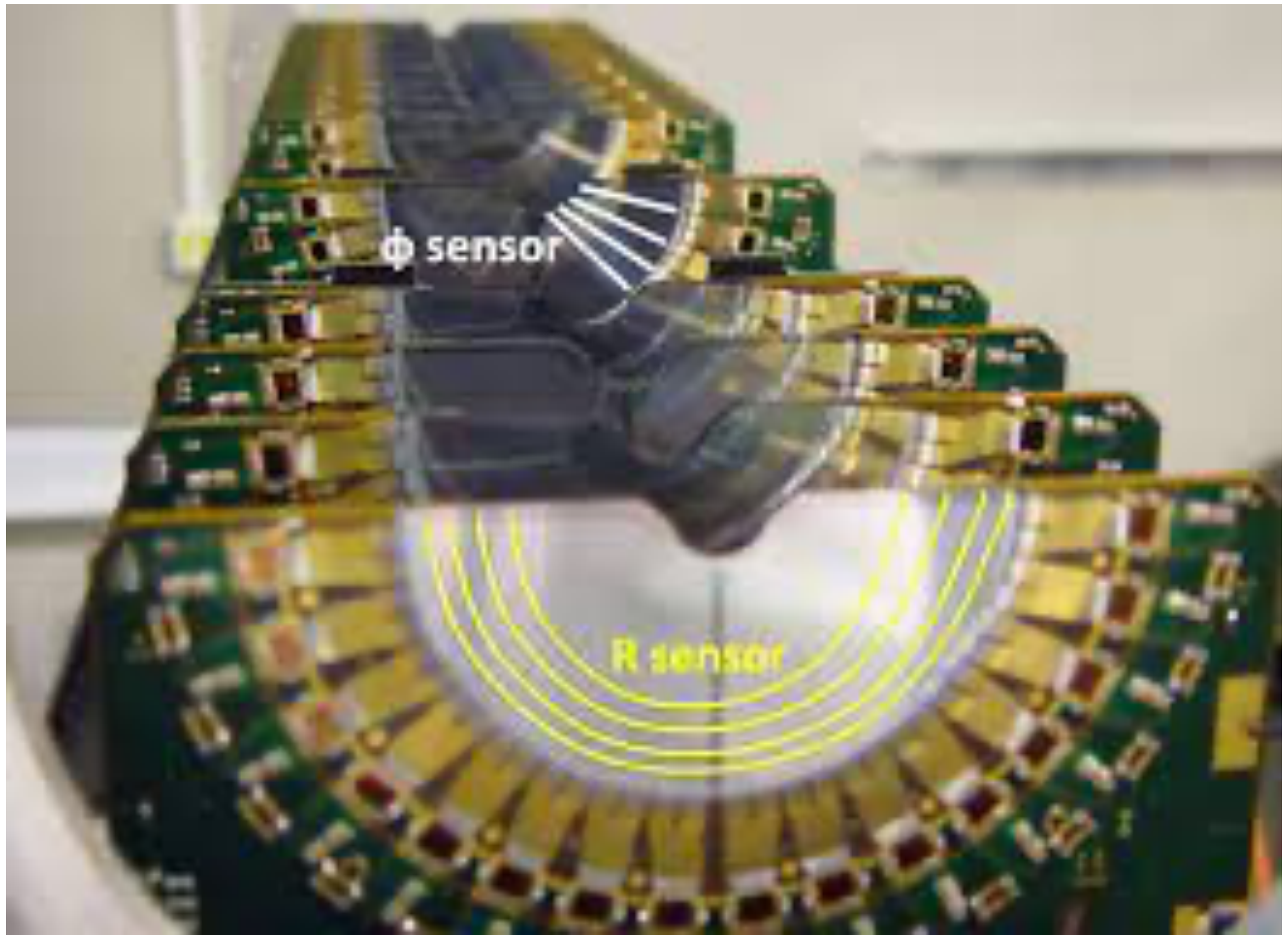
Modern particle tracking, use ionisation



- For example, silicon (semi-conductor)
  - Correct doping means particle passing through releases a lot of electrons/ holes ($\mathcal{O}(10{,}000)$) even over very small region
  - Precise and fast
  - Downside - expensive / radiation hardness



Example of silicon strip detector



Spatial resolution of the hit made by a particle going through each sensor is $\mathcal{O}(10\mu m)$

Summary

- Why measuring momentum is so important
    - *Is the key way we reconstruct the invariant mass of particles, which in turn tells us which particle we are actually looking at!*

Summary

- Why measuring momentum is so important
  - *Is the key way we reconstruct the invariant mass of particles, which in turn tells us which particle we are actually looking at!*
- Why are particle detectors so big?
  - *Particles bend in magnetic fields, which tells us the momentum, but they are such high energy these can be really small deflections, need a long lever arm to see it!*

Summary

- Why measuring momentum is so important
  - *Is the key way we reconstruct the invariant mass of particles, which in turn tells us which particle we are actually looking at!*
- Why are particle detectors so big?
  - *Particles bend in magnetic fields, which tells us the momentum, but they are such high energy these can be really small deflections, need a long lever arm to see it!*
- Brief introduction to tracking and measuring momentum
  - *Modern detectors rely on charged particles ionising material as they pass though, semi conductors give you a lot of charge over small area so are very precise, but expense*