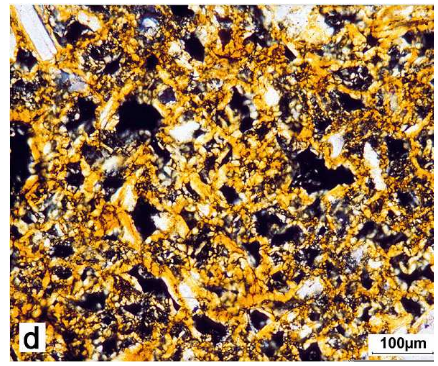
Why do we need bigger and bigger accelerators

To See Smaller and Smaller Structure?

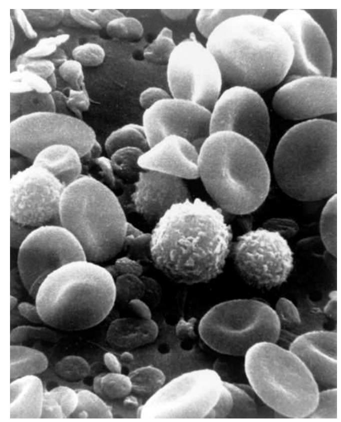
# Ordinary matter is made out of littler bits

$\Longrightarrow$

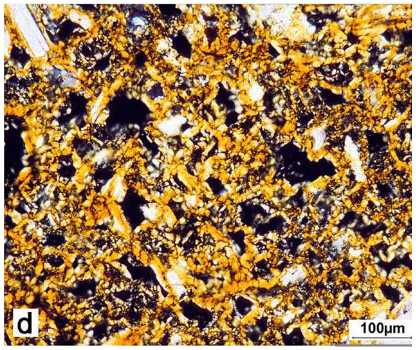




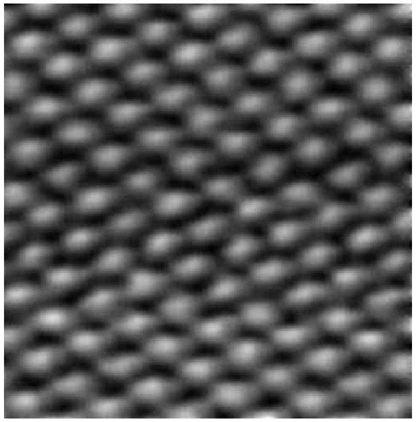
$\Longrightarrow$



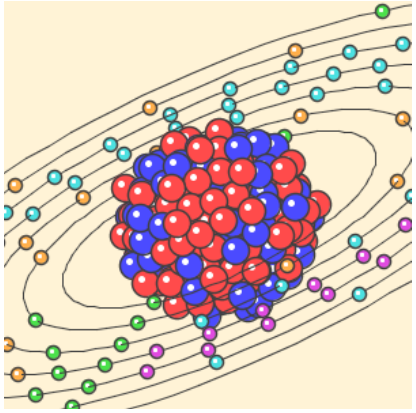
## Those are made of littler bits




$\Longrightarrow$



These blobs are atoms. But even they have substructure:



# What are those made out of?

## Does it go on forever like that?

These are the central questions of particle physics.

What are the littlest bits?

How do they "work" and what are the rules describing them?

With these rules you can figure out how all the bigger things work step by step and size by size At least in principle

# Compound objects and Smallest bits

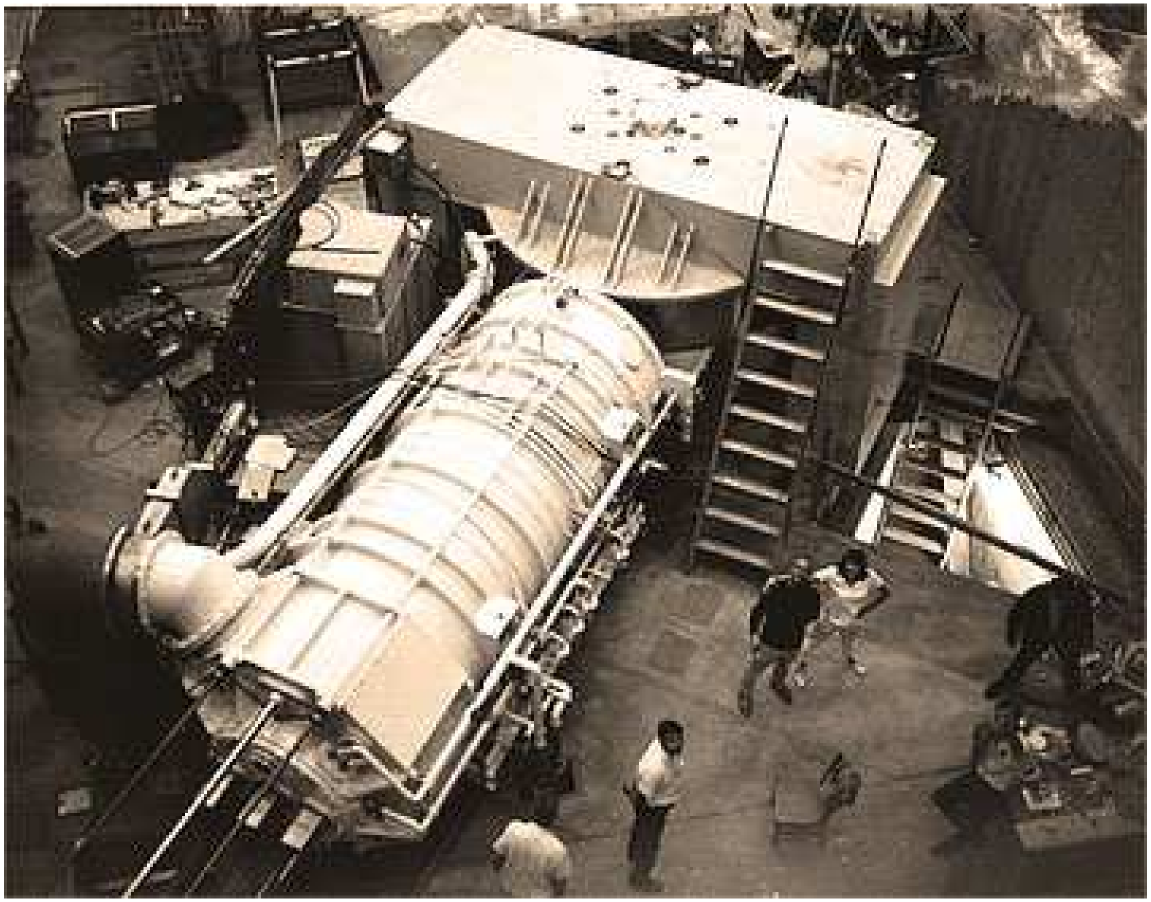
$$\begin{aligned} \text{Light} &= \text{photons} \\ \text{electricity} &= \text{electrons} \\ \text{atoms} &\longrightarrow \text{electrons} + \text{nucleus} \\ \text{nucleus} &\longrightarrow \text{neutrons, protons} \\ \text{neutron,proton} &\longrightarrow \text{quarks, gluons} \end{aligned}$$

So far we think those in red are "elementary"

# Experiments to see smaller

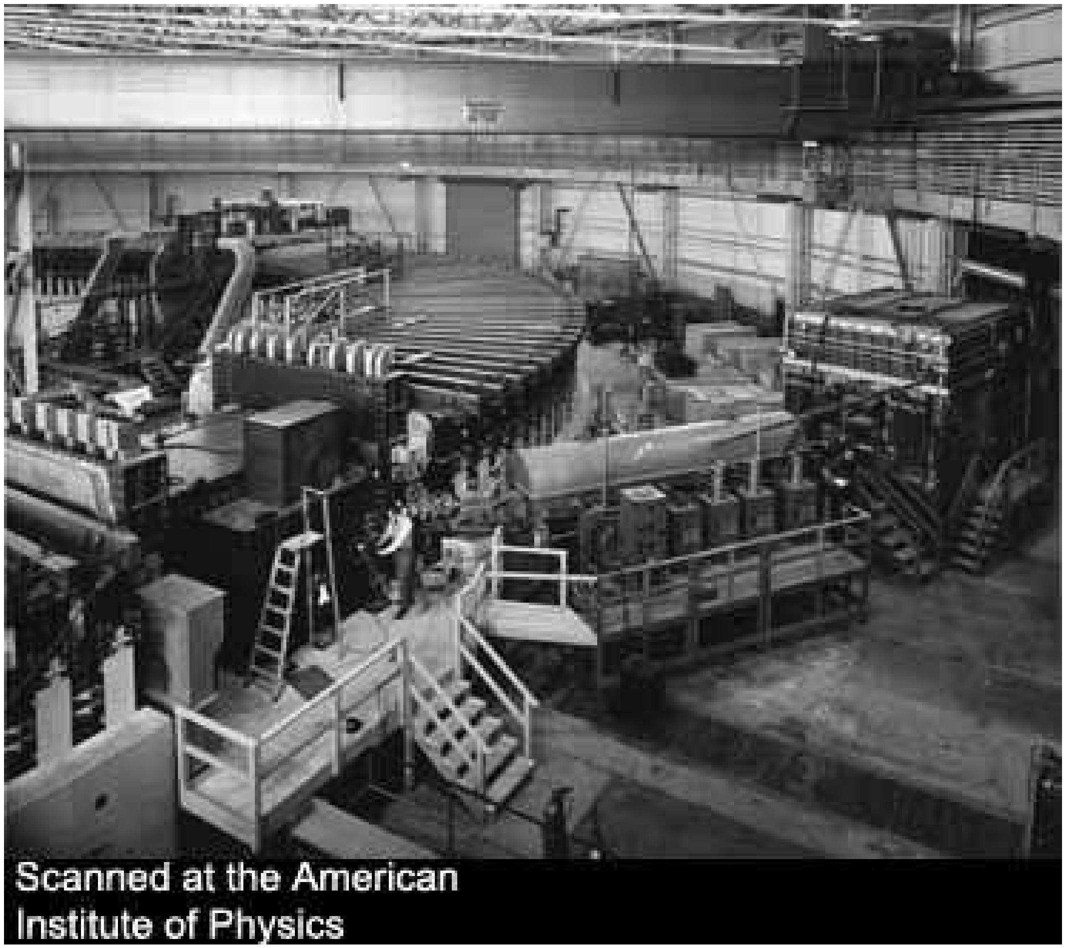
Cyclotron

# Experiments to see smaller



a better cyclotron

# Experiments to see smaller




Bevatron–even better resolution, inside nucleus

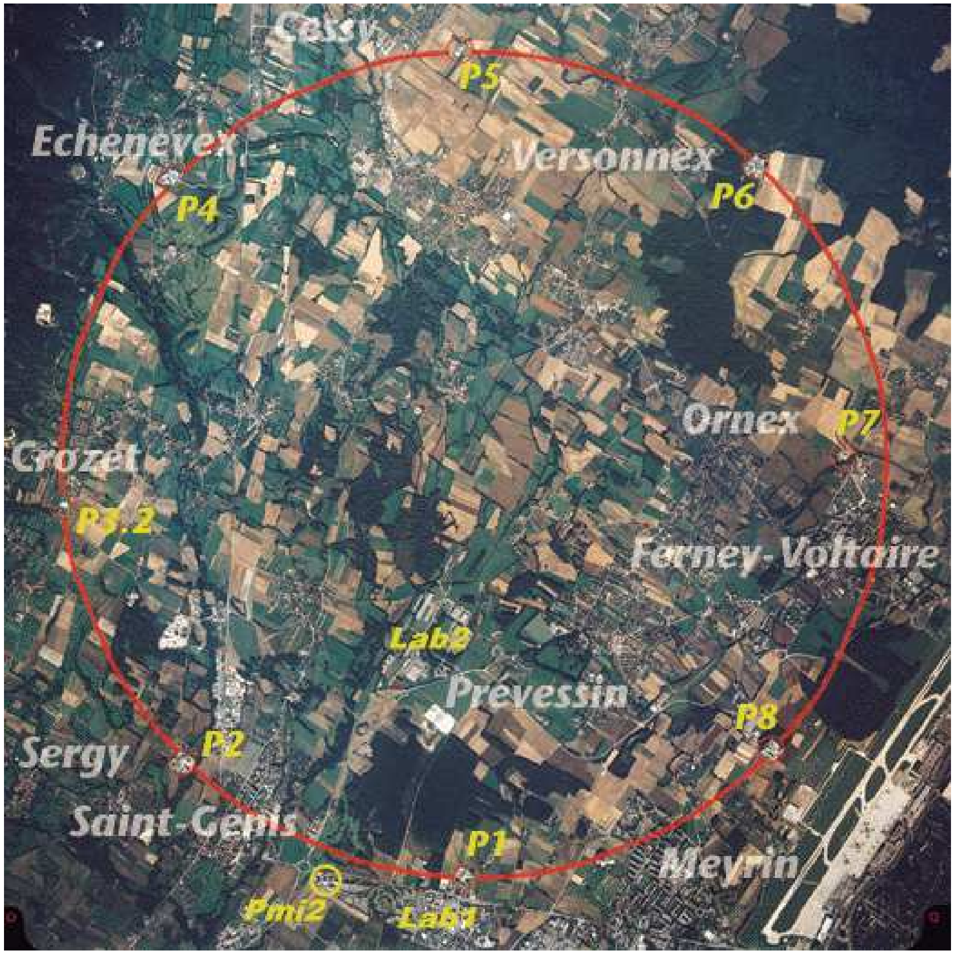
# Experiments to see smaller


AGS (14 times bevatron) and RHIC (500 times)

# Experiments to see smaller

Tevatron: best so far (2000 times bevatron)

# Experiments to see smaller




The LHC: the next big step (14 000 times bevatron)

If we want to see smaller and smaller

## WHY ARE THE EXPERIMENTS GETTING BIGGER AND BIGGER?

# Property of smallest bits:

# They "wiggle"

1 photon is not 

It is 

# Deep property

The harder a particle is flying ("more momentum")
the tighter the wiggles.

$\Longrightarrow$ is 

$\longrightarrow$ is 

## How do I tell if it's going right or left?

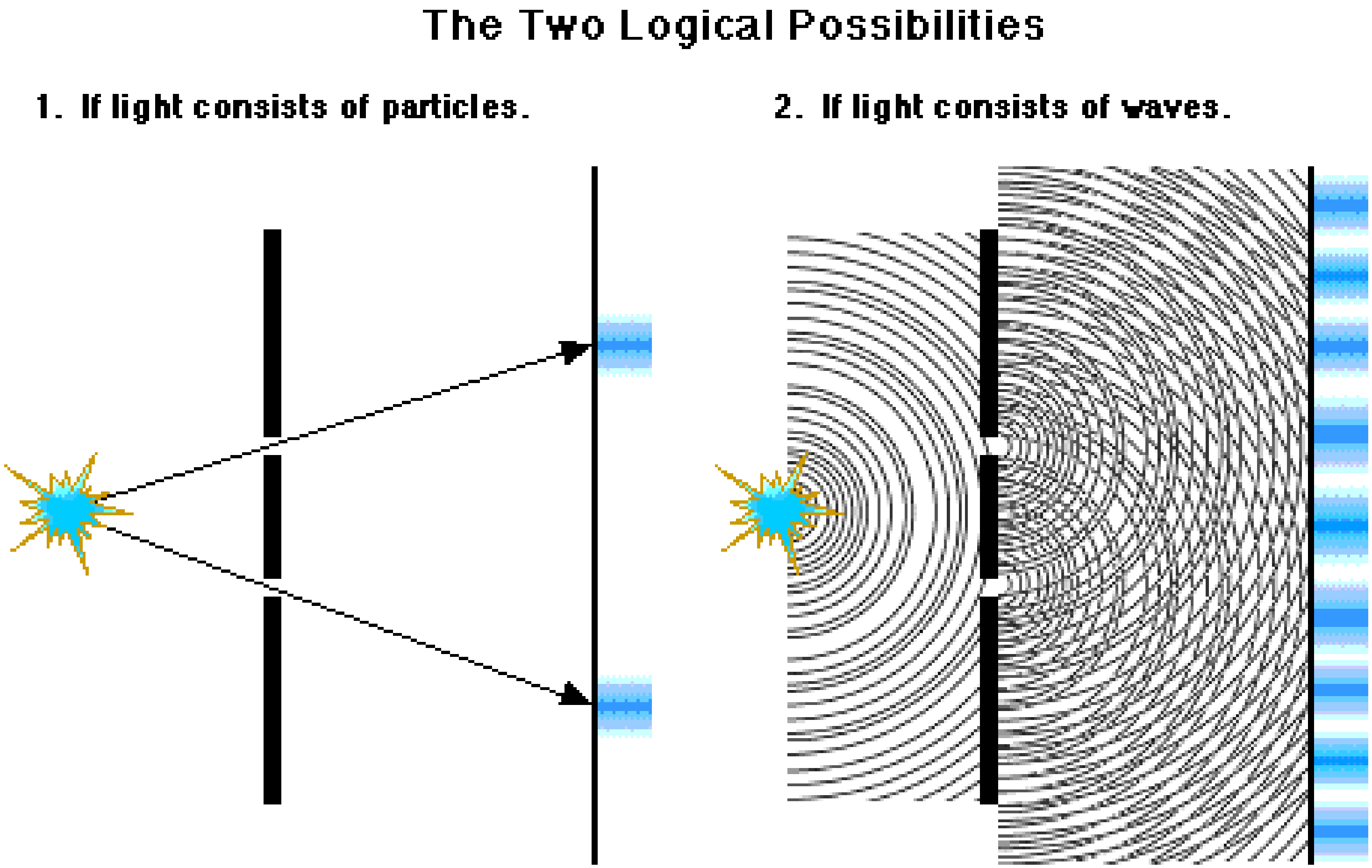
The wiggling is really corkscrew (in some sense)

$\Longrightarrow$ is 

$\Longleftarrow$ is 

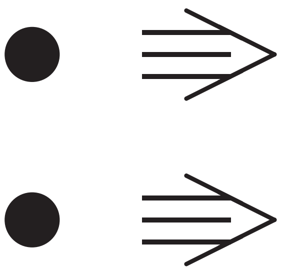
# How can we tell things are “wiggling”?

Experimental fact.

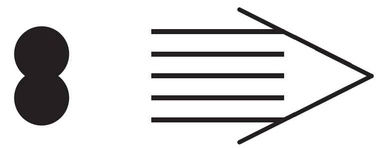


## Add two particles: add their momenta.

(How hard two things hit is how hard first hits plus how hard second hits.)



stuck together:



## Wiggles add too:

plus

becomes

# Example: light

The wavelength of light is from 400 nm to 700 nm (0.4 to 0.7 microns).

A human hair is about 50 microns across.

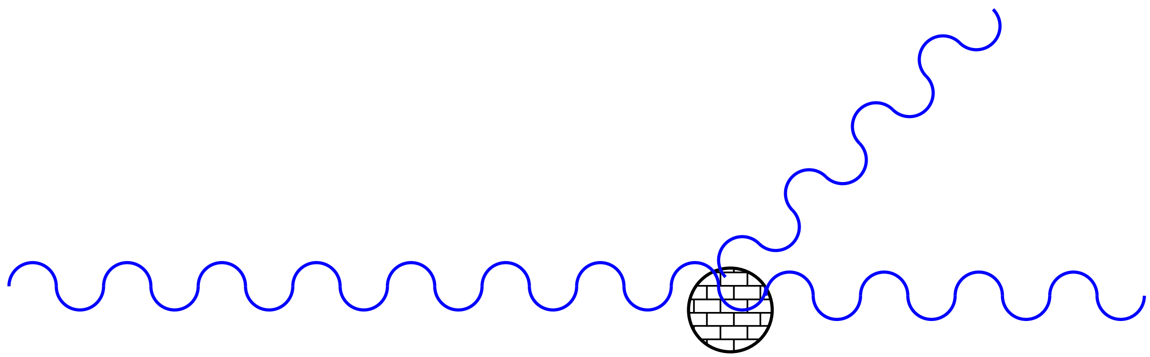
About 100 wavelengths of light fit across width of 1 hair.

Your eye can see features smaller than 50 microns, but not 1 micron.

Good microscopes can see down to about 0.5 micron.

# How microscopes work (roughly)

Light either bends or gets absorbed off irregularities.

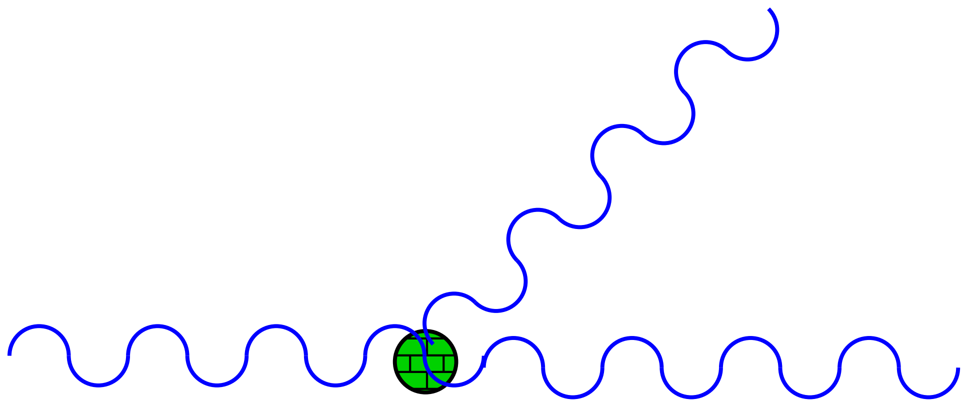


Roughly, angle = (wave length) / (size of irregularity).

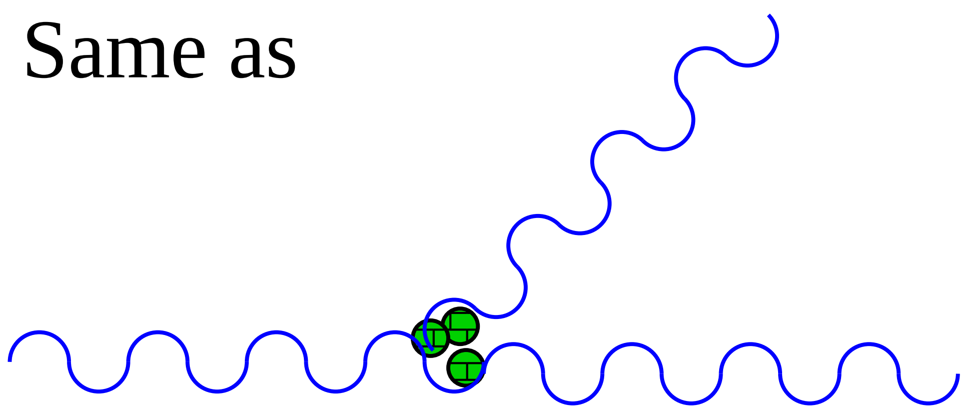
Information about bent and surviving light tells about objects.

# Why can microscopes only see to 0.5 micron?

Light doesn't resolve things smaller than 1 wiggle:



Same as



## Need tighter wiggles to see smaller!

Forget about light (visible photons).

Go with **X**-rays.

10,000 times harder hitting, see 10,000 times smaller.

Resolve atoms. (Ask Mark Sutton.)

# A problem:

The smaller I want to see, the harder hitting the probe must be.

Harder hitting–imparts more energy

Beyond some point:

Blows apart the thing you are looking at!

(**X**-ray destroys the atom it hits.) That's why they give you cancer

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# Solution:

Realize that you don't care.

# Problem

How do you get one elementary particle to fly so hard?

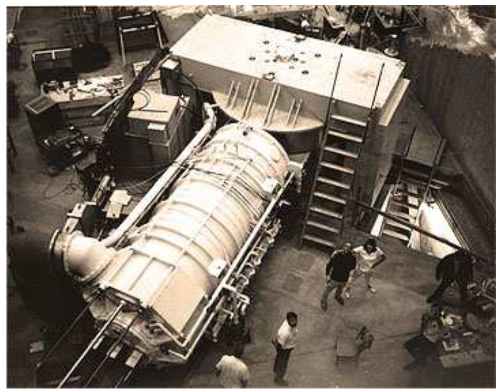
Similar to problem of a slingshot:

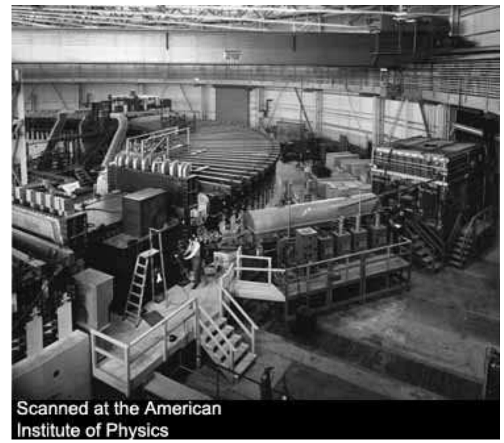
# How do I shoot something faster?

Either use thicker, stronger rubber OR


USE A BIGGER SLINGSHOT!

# Physicists need bigger and bigger slingshots



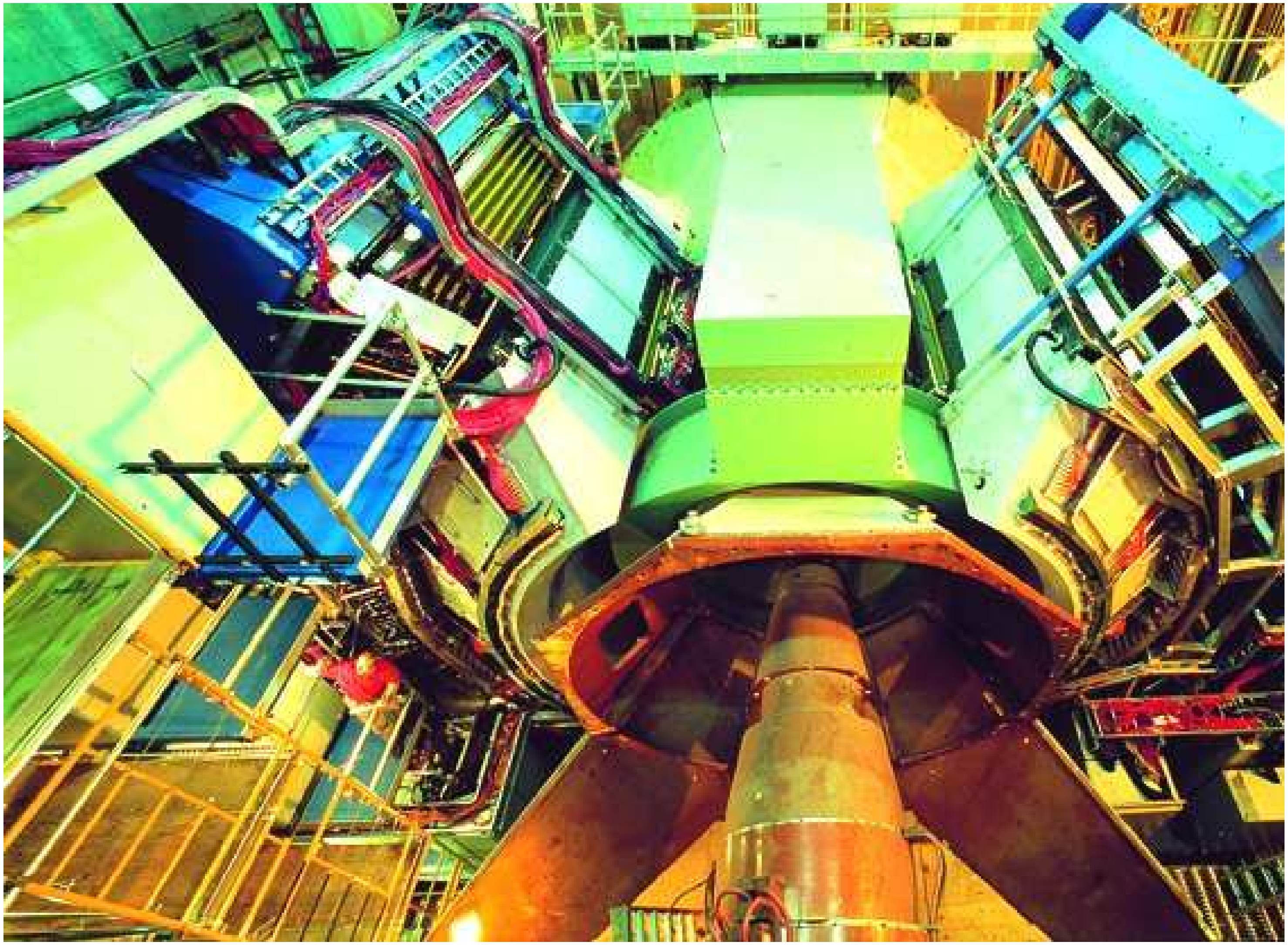




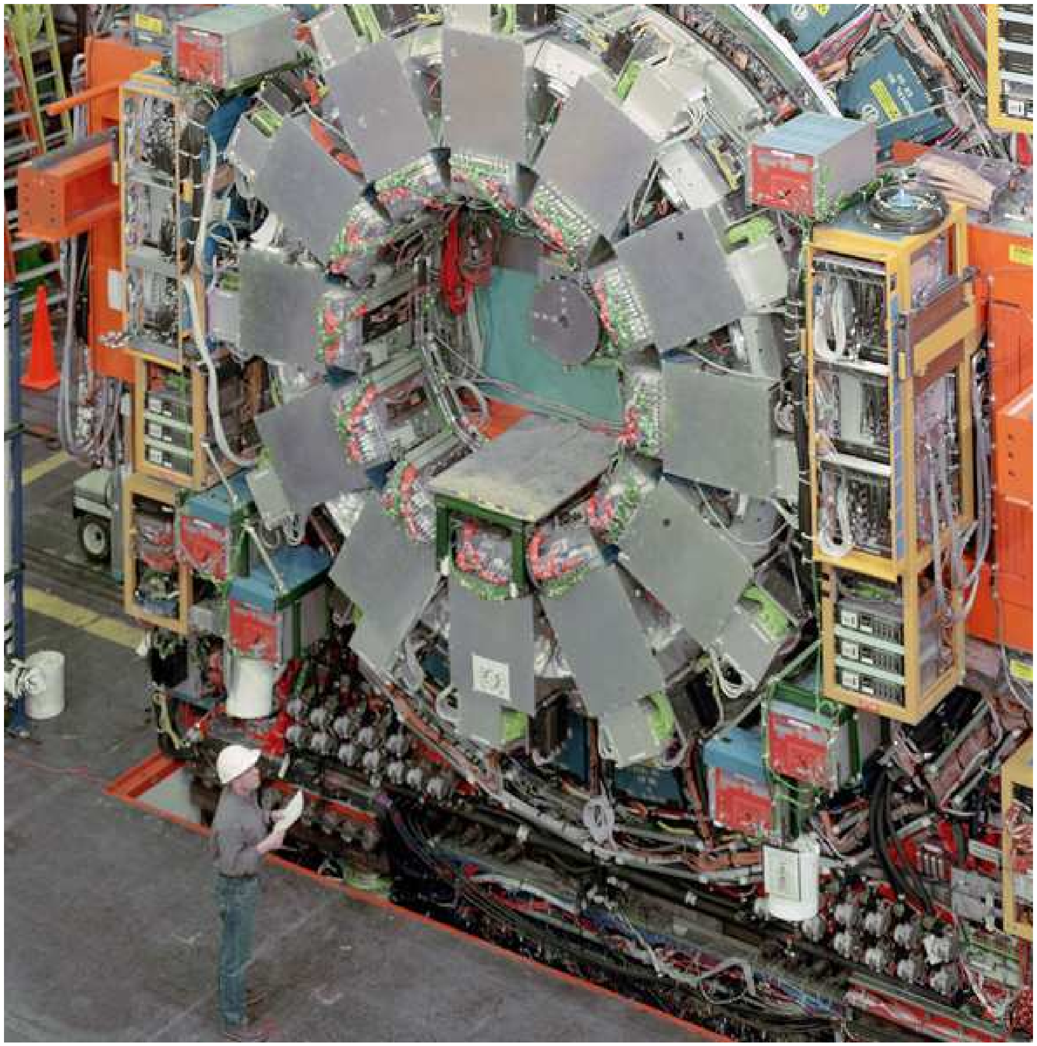
# The bits come flying out faster too

Which means you need a bigger detector to catch them.

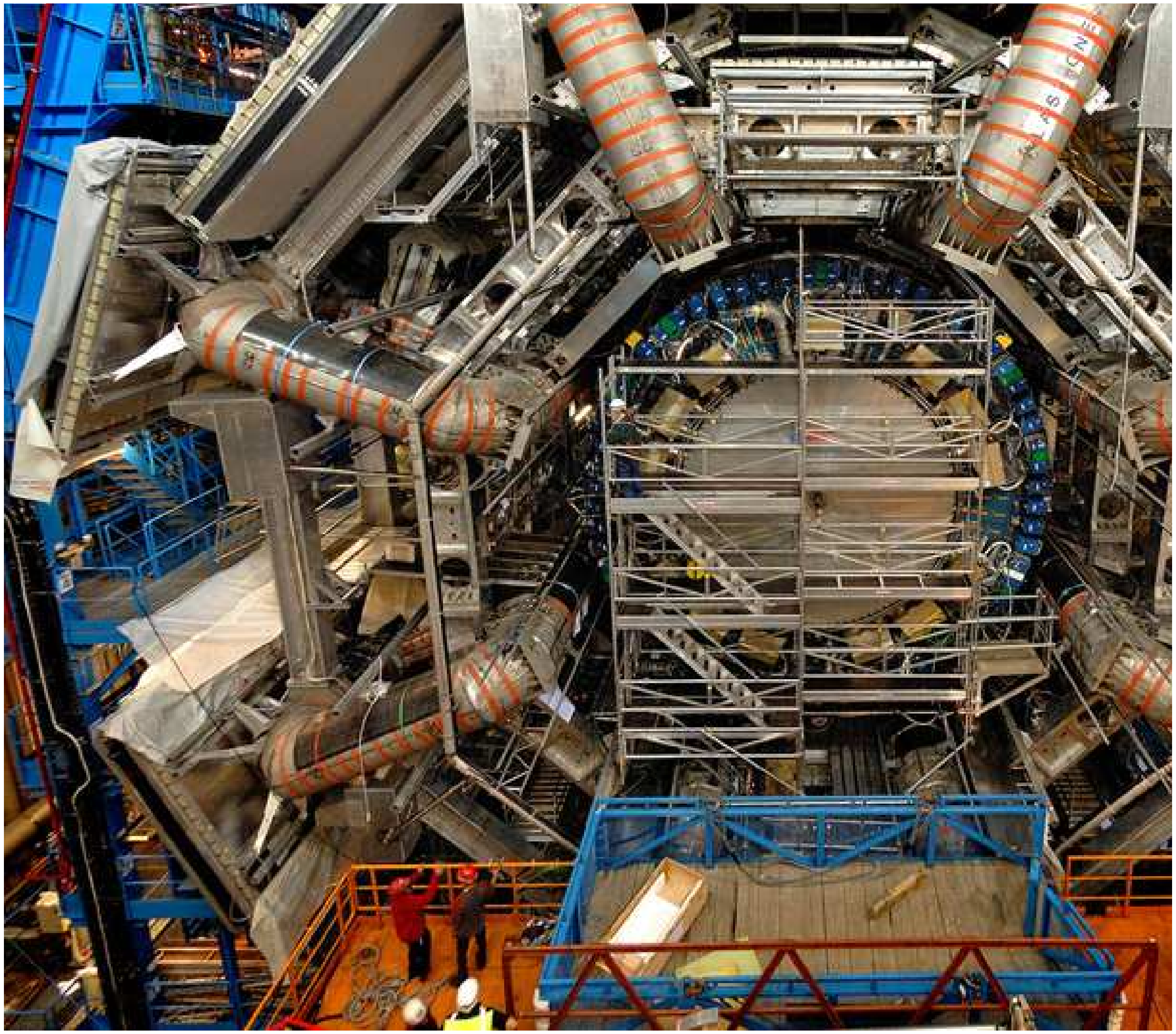
Cleo detector (10 GeV)



Phenix detector (500 GeV)



CDF detector (2000 GeV)



ATLAS detector (14 000 GeV)

# How small have we seen?

- Light: $\dfrac{1}{50}$ a hair

cells

- $\mathbf{X}$-rays: $\dfrac{1}{500\,000}$ a hair

atoms

- 200MeV $e^-$: $\dfrac{1}{50\,000\,000\,000}$ a hair

nucleus, $p, n$

- 200GeV $e^-$: $\dfrac{1}{50\,000\,000\,000\,000}$ a hair

quark, gluon, $W$,$Z$

# What's next?

LHC: will see $7\times$ smaller than we have gotten so far.

We "know" there *will* be new things to see

May be the last step we need

## Or we might need to go even smaller (bigger)!