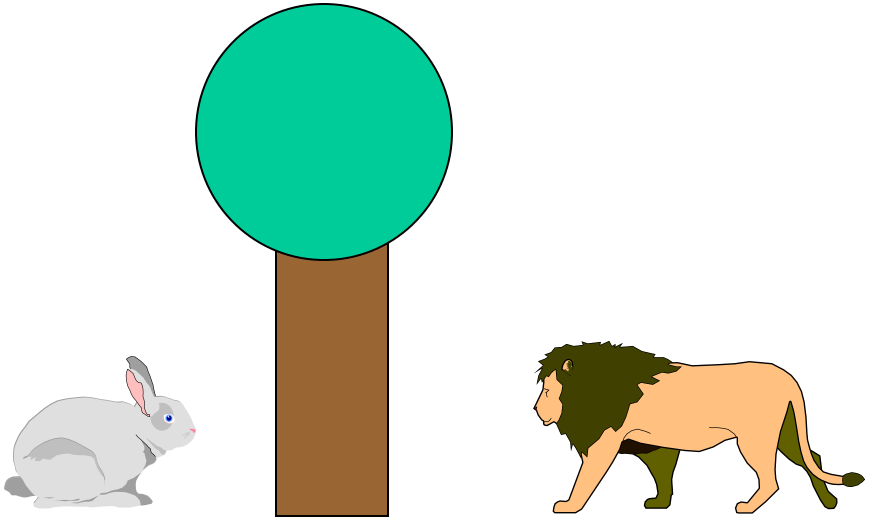
Introduction To Particle Physics

Or Everything you wanted to know about the Higgs particle … but were afraid to ask

- **Why do we need accelerators and detectors?**
- **Particle Detectors with examples.**
- **Standard Model of Particle Physics**
- **Introduction to the Higgs**
- **The future**

Why do we need Accelerators(1)

- Why can’t the lion see the rabbit but it can hear it?



Why do we need Accelerators(2)

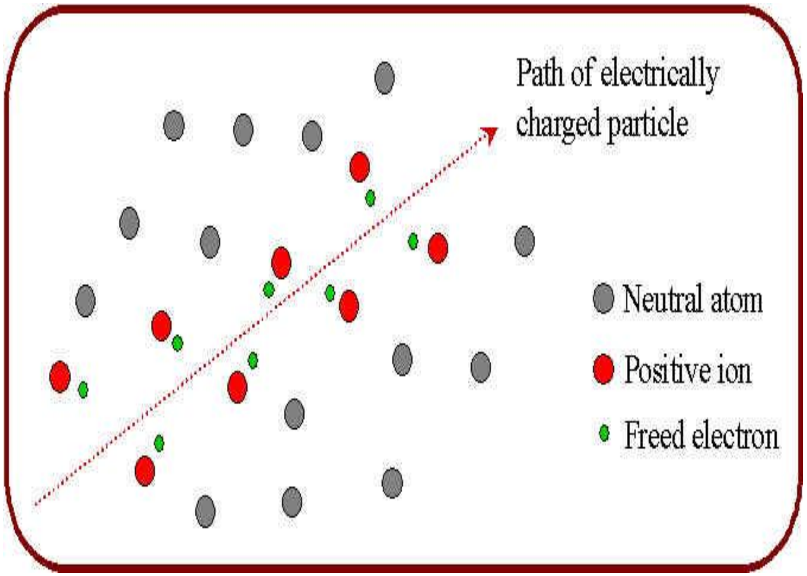
- To study an object of size R, need resolution much better than R ➔ wavelength of probe λ <R.
- ➔Optical microscopes resolution limited ~ μm but we need resolution of ~10^{-15} m to study quarks.
- Quantum mechanics says λ=h/p (h =Plank's constant, p=momentum).
- ➔ High energy/momentum particles to study structure of matter at smallest scales.

Particle Detectors

- **Everybody has examples of particle detectors at home**
- **Examples are …**

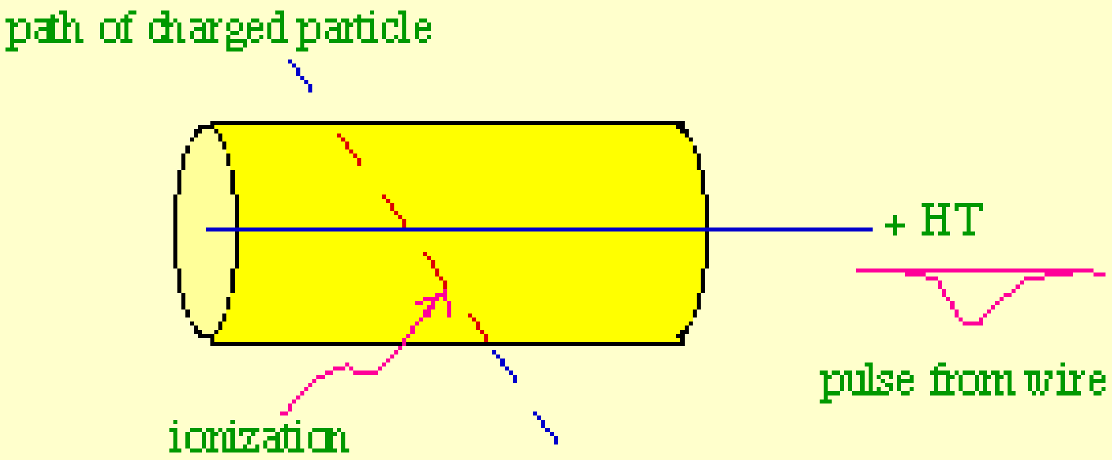
Particle Detectors

- To detect high energy particles we can use ionisation.
- High energy particle knocks electrons out of atoms ➔ electrons and positive ions.
- Detect resulting electrons.



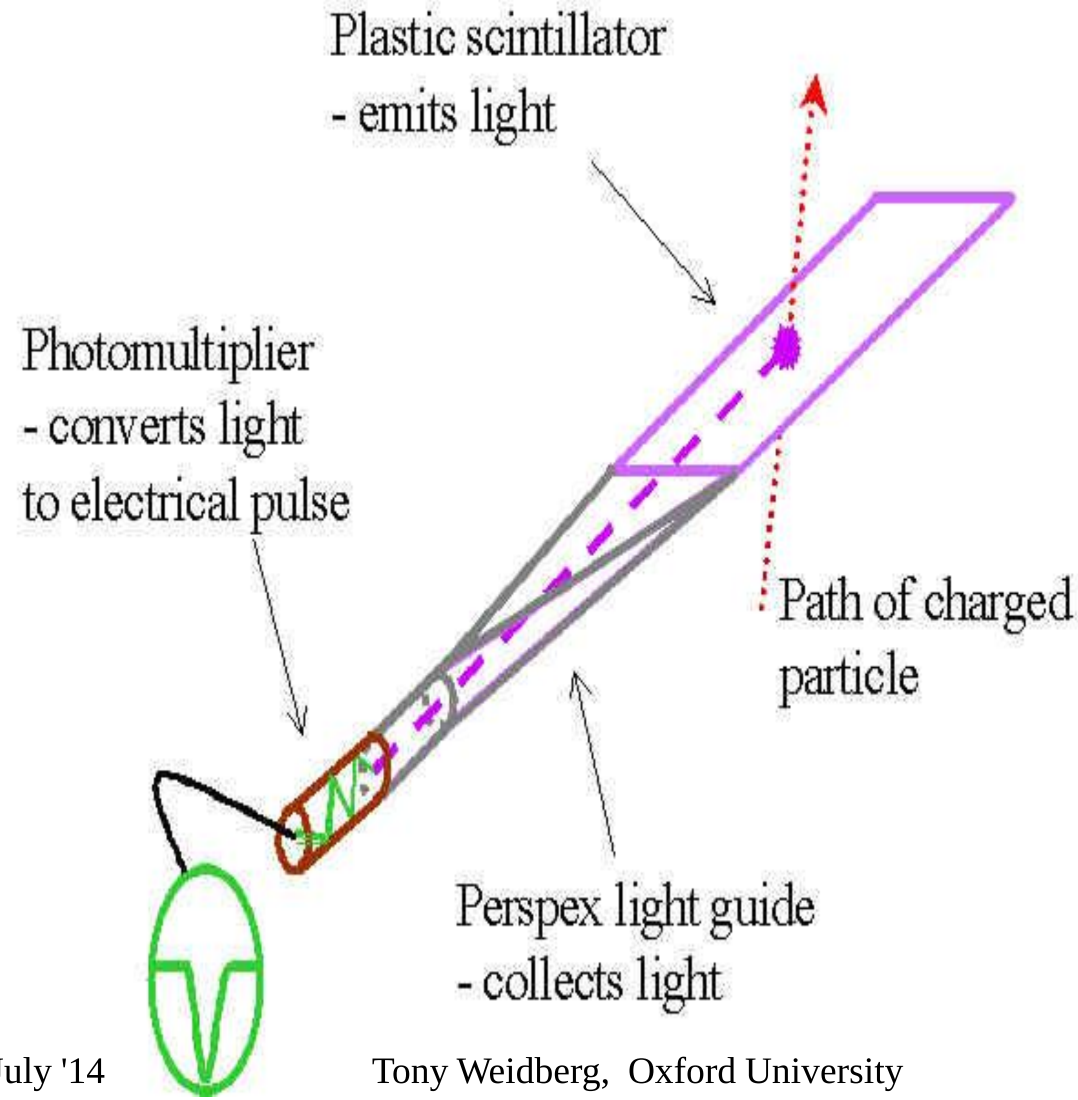
Wire Chambers

Principles of a Gaseous Detector



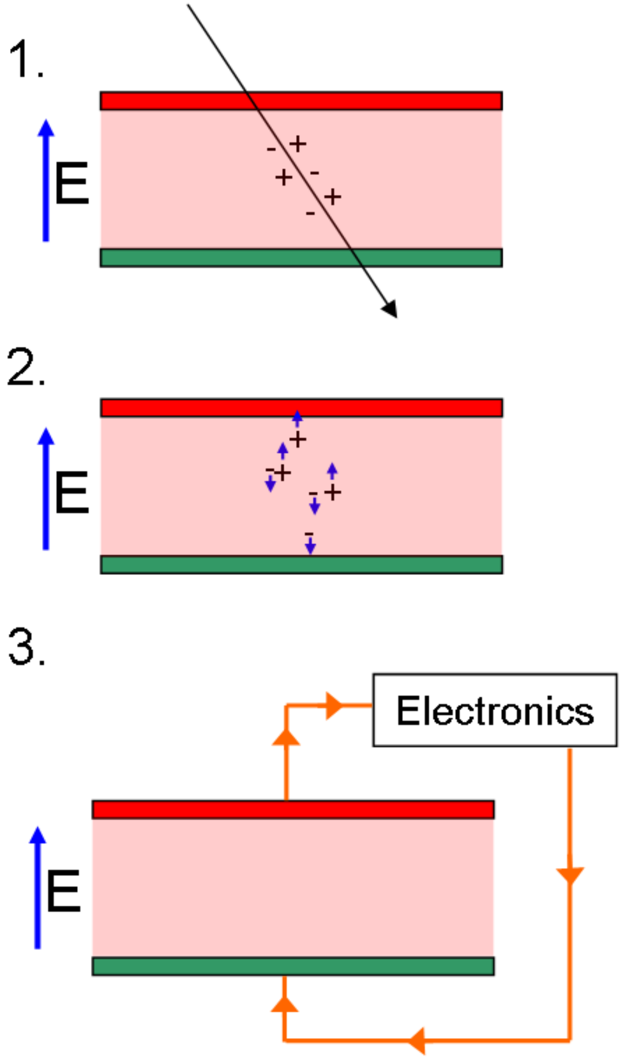
- charged particle ionizes gas in tube
- ionization (electrons) drifts to central wire
- further ionization near wire as electrons gain energy
- electronic pulse obtained from wire

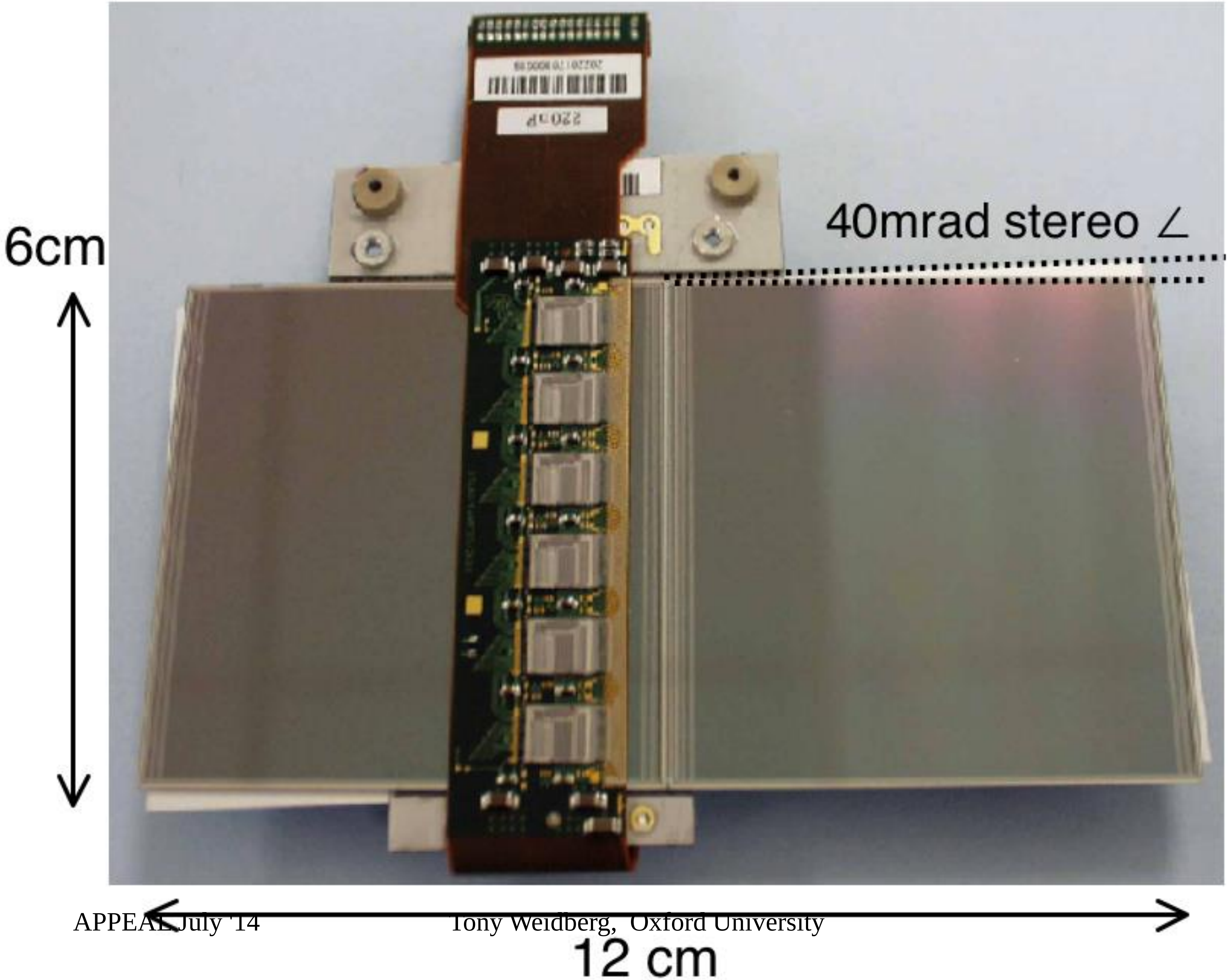
Scintillation Counters



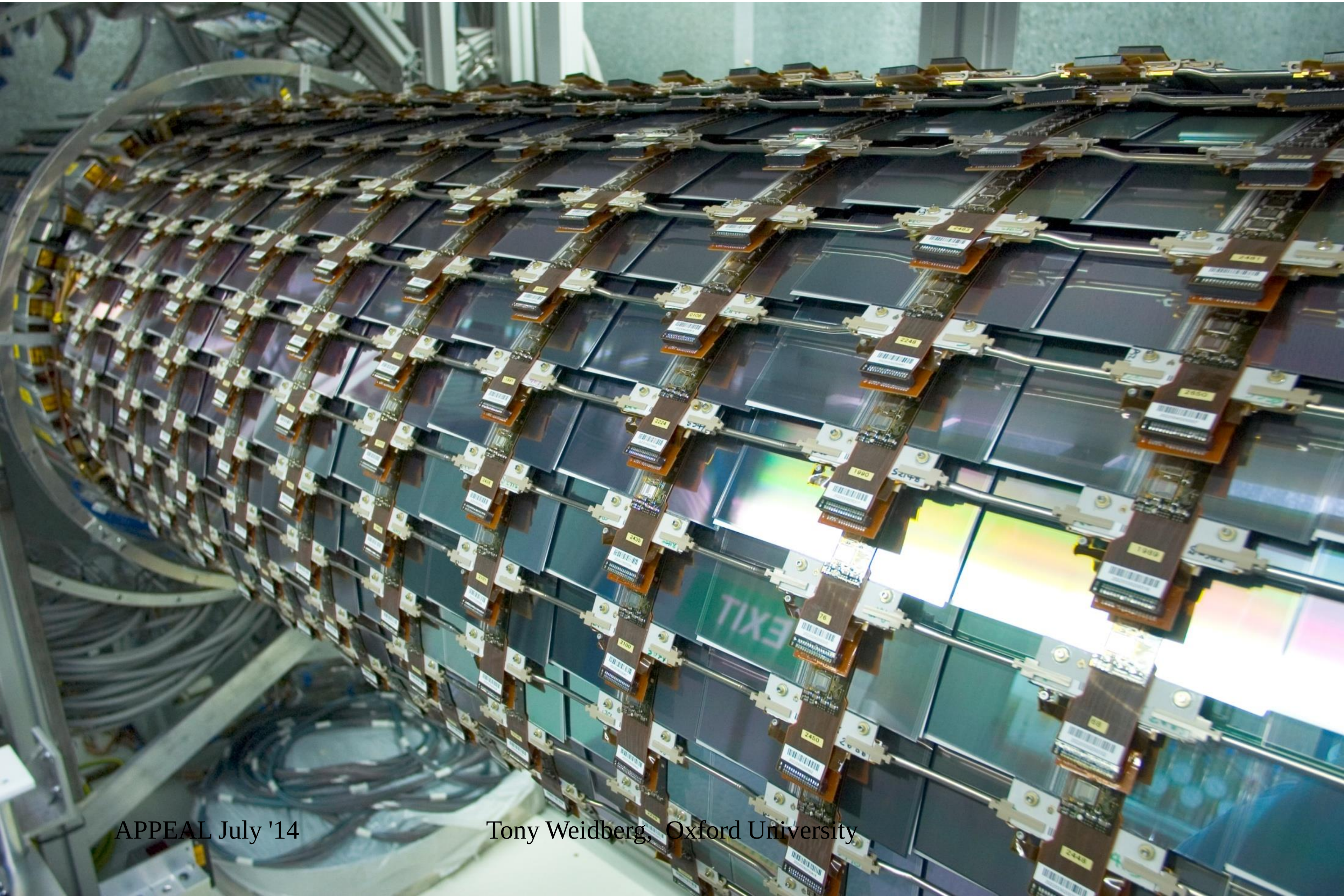
Example: Silicon Detector

- **High energy charged particle knocks out electrons (-ive)**
- **+ive and –ive charges move in opposite directions because of applied electric field.**
- **Resulting current measured by electronics.**
- **This is the principle behind the camera on your phone**

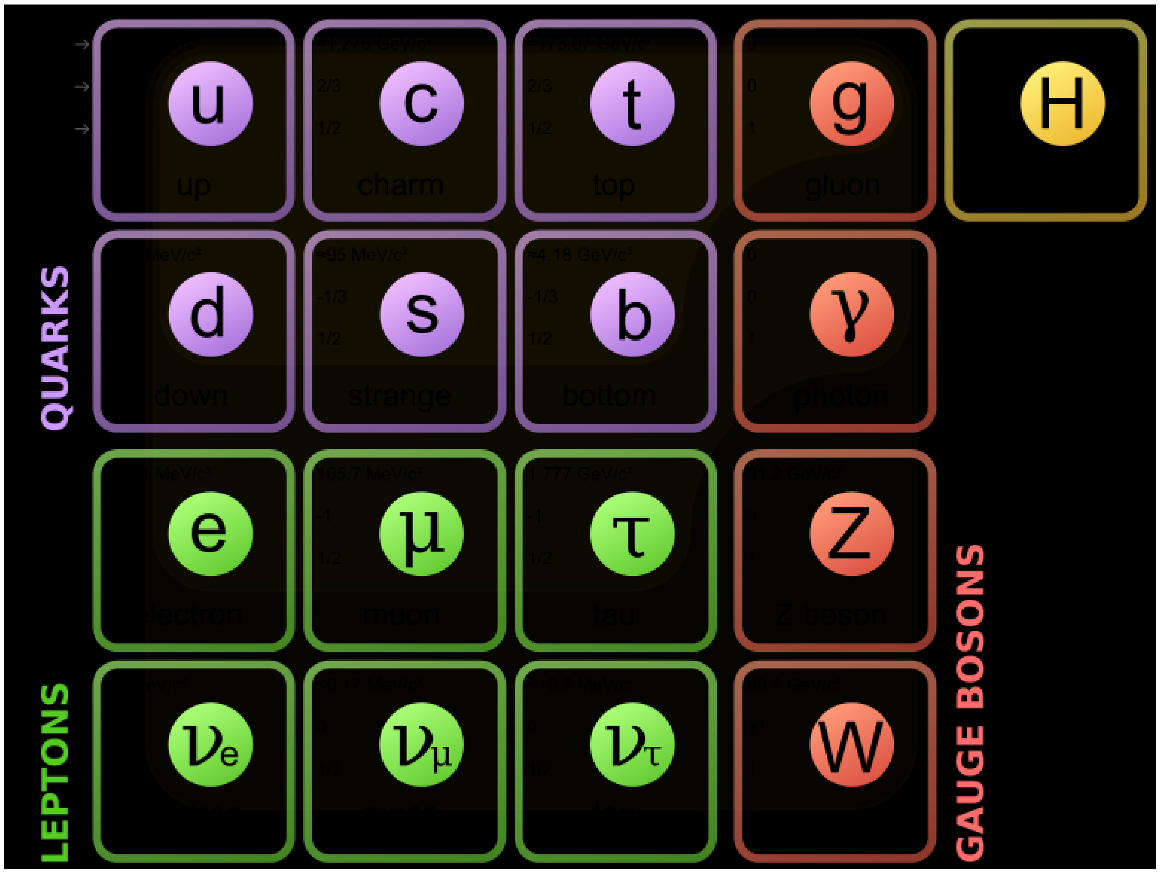



40mrad stereo ∠
6cm
12 cm

ATLAS Si detector barrel @ Oxford



Standard Model Particle Physics

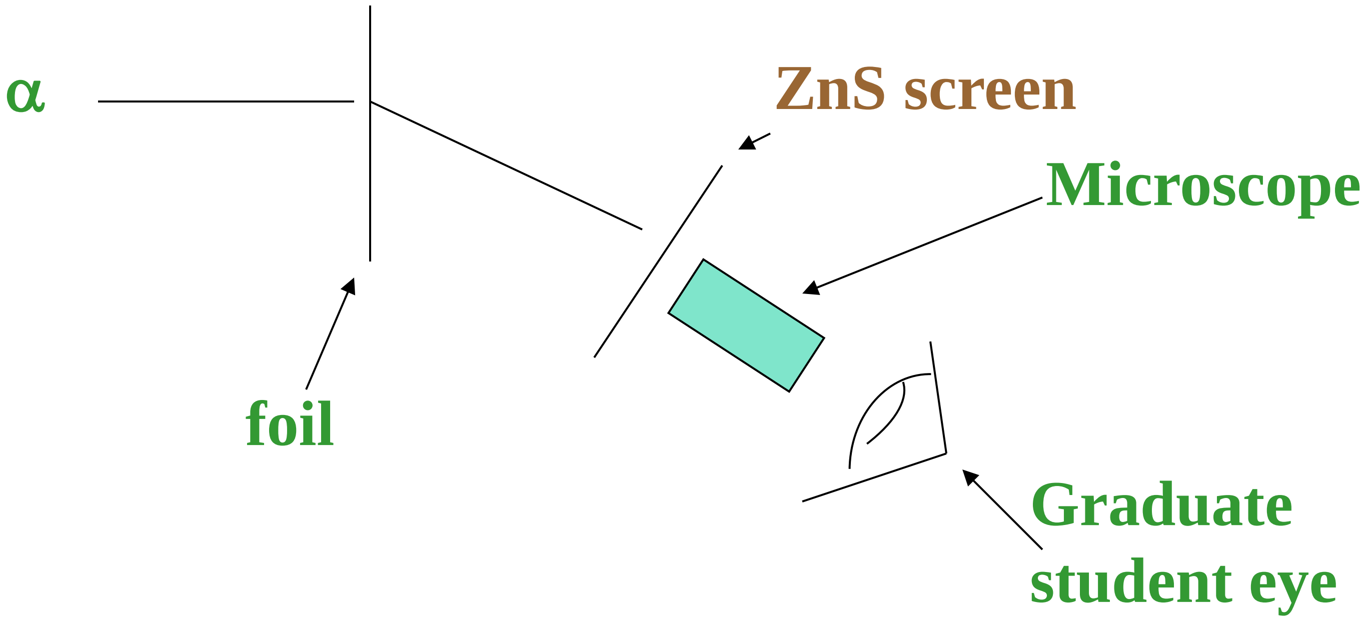


How do we know all these particles exist ?

- Experiments !
- Electron is easy measure e/m
- Quarks confined in hadrons ➔ more difficult.
- How about unstable particles?
  - Take Z^0 as an example t~ 10^{-24} s.

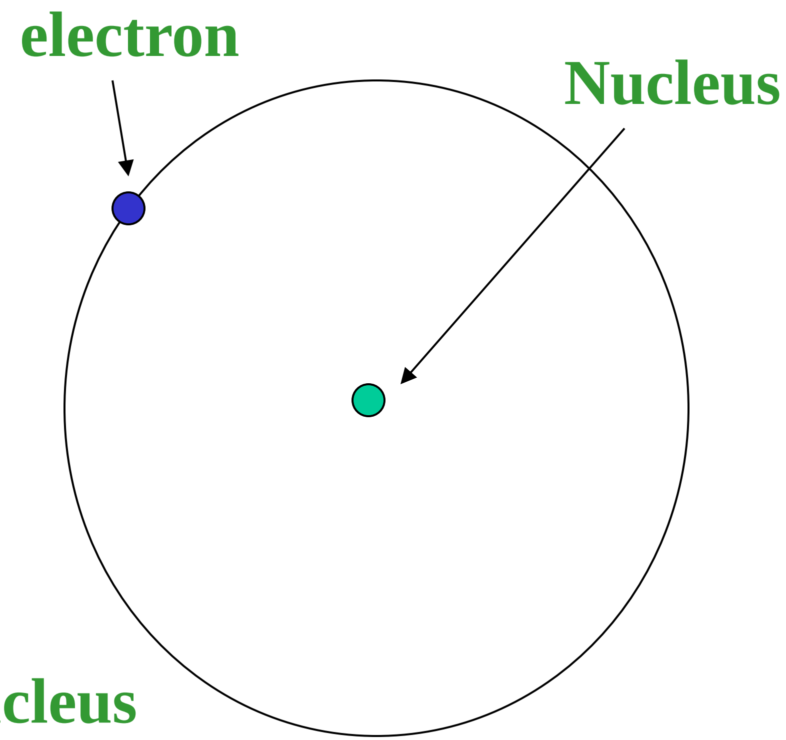
Discovery of Nucleus Experiment

- **Fire alpha particles at thin foils and look at angle of scattering.**



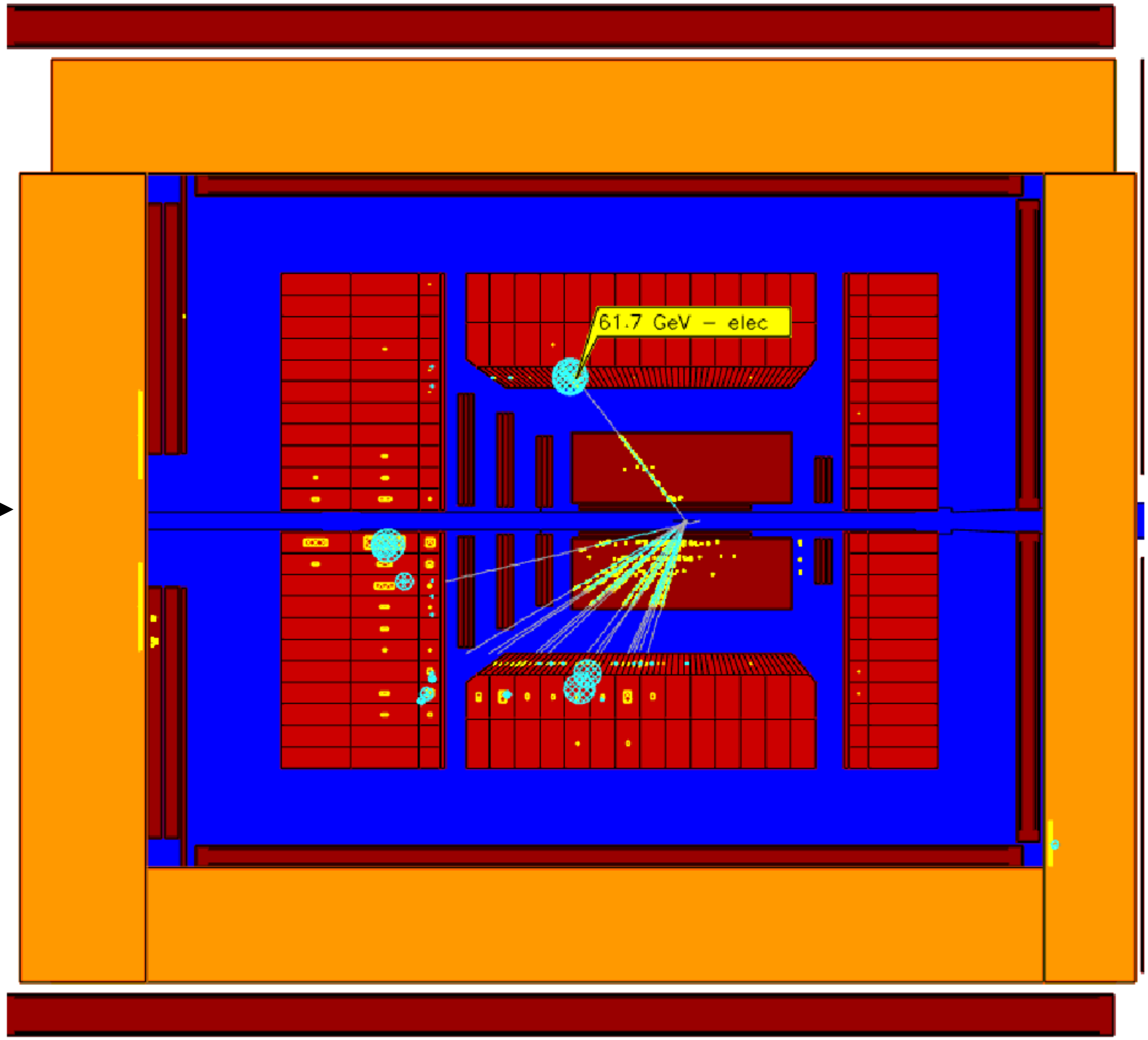
Discovery of Nucleus Theory

- Rutherford found that most collisions were at small angles but occasionally the α particles would bounce back.
- "it was as if you fired 15" shells at tissue paper and they bounced back and hit you"



Positive charge all inside small nucleus
➔ large angle scatters.

Large angle e⁻ scattering event in ZEUS



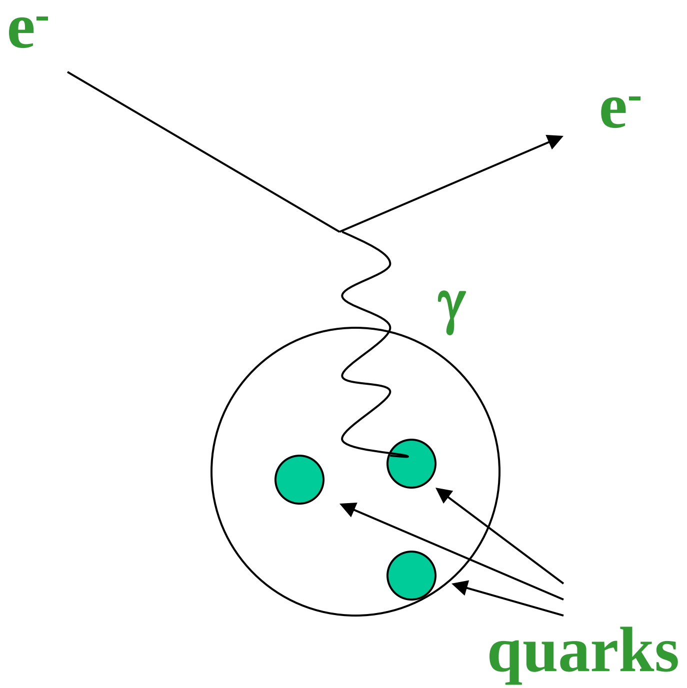
30 GeV
e⁻ in

820 GeV
p in

ZR

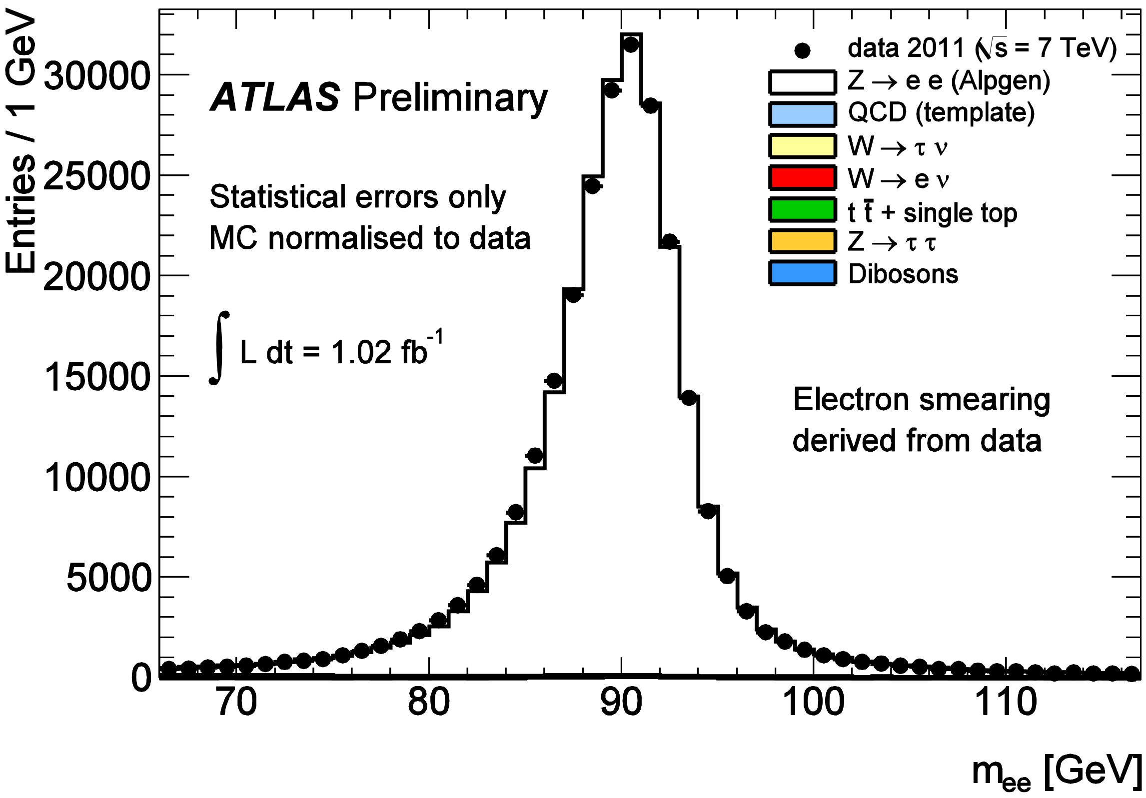
Structure of the proton

- Proton R ~ 10^{-15} m ➔ high energy probes e.g. electrons
- Proton appears to be made up of point like constituents: quarks
- Electromagnetic interaction = exchange of virtual photons.



Z^0 decays

- **Reconstruct decay products e.g. $Z \rightarrow e^+e^-$**
- **Boost to CMS**
- **Use $E=mc^2$**



Origin of Mass

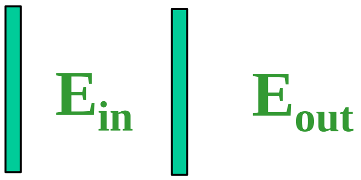
- Consider Feynman’s wheelbarrow experiment:
  - Put ball in wheelbarrow, push it forward and stop suddenly.
  - The ball continues to move forward and rolls out.
- Why ???

Origin of Mass(2)

- **So classical mechanics doesn’t explain origin of mass.**
- **Quantum theory predicts masses of all particles should be 0 !**
- **Need to understand quantum vacuum**
  - **What is left in a bottle after I remove all the molecules?**
  - **Remember Heisenberg $\Delta E \, \Delta t > h$**
  - **Why does this matter?**

Quantum Vacuum

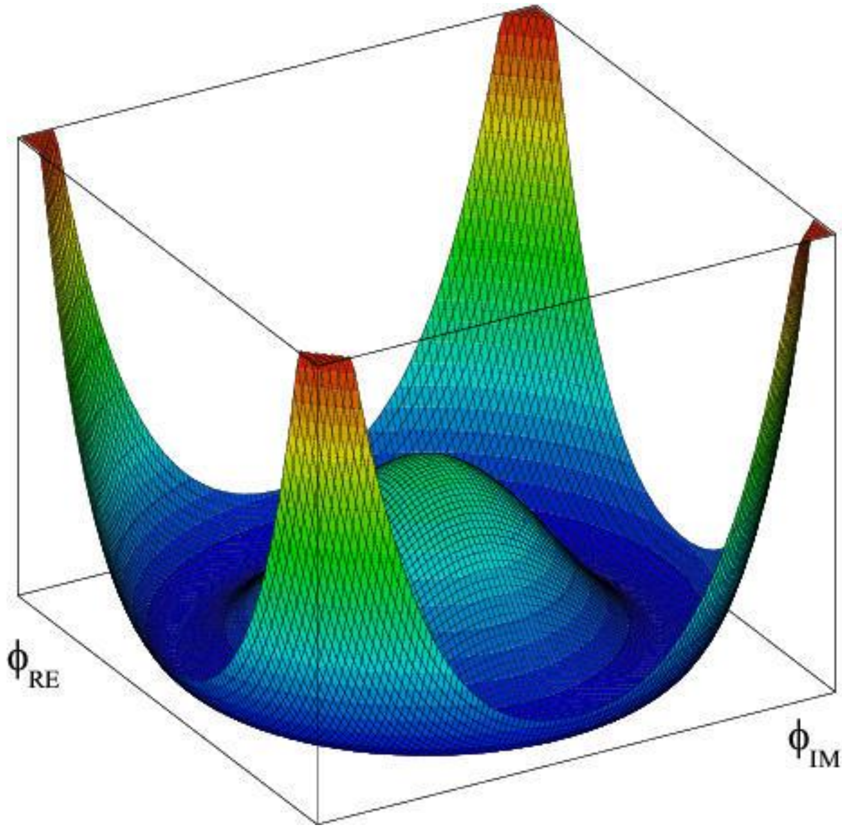
- **Can measure small changes in atomic energy levels, magnetic moments etc. ➔ agree with theory.**
- **Macroscopic example: Casimir force**



- **$E_{in} < E_{out}$ why? Creates inward pressure.**

Higgs Vacuum

- Vacuum is lowest energy state of fields
- Average value of Higgs field non-zero.
- Particles interact with this field acquire mass.
- Can we test this theory? Yes we can
- Put enough energy in to create a Higgs boson.

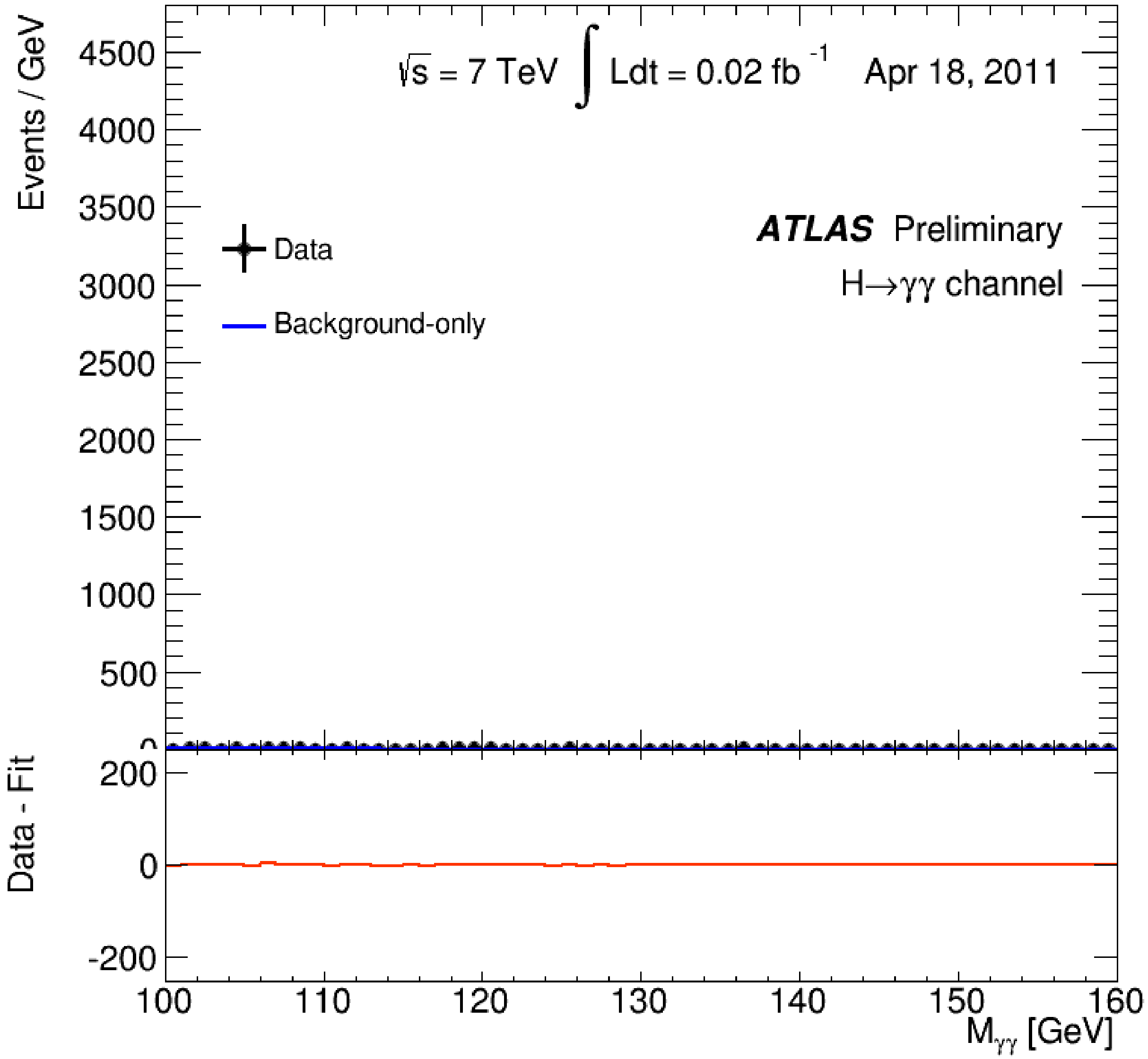


Higgs hunting

- **How would we know if we made a Higgs boson?**
- **Use good old $E=mc^2$**
- **Measure energies of decay products ➔ reconstruct m_H .**

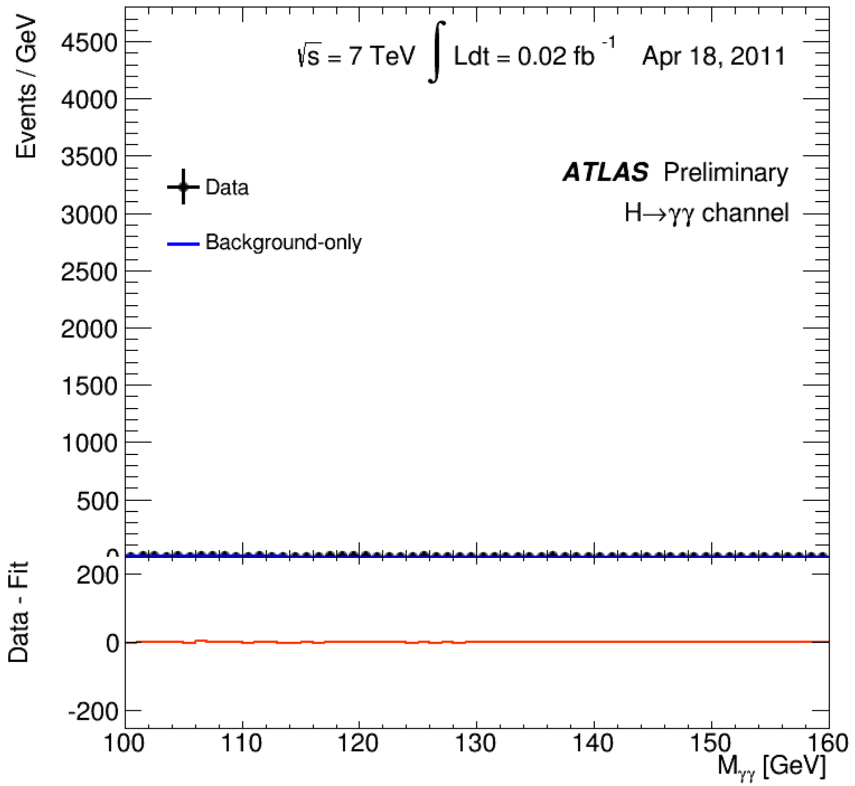
Higgs Hunting

- **Look for Higgs decaying to two photons and reconstruct Higgs mass $E=mc^2$**
- **Evidence for Higgs boson also seen in other decay modes (ZZ and WW).**
- **How do we know the signal is real and not just a statistical fluctuation?**
- **Calculate probability of a fluctuation producing a larger signal**

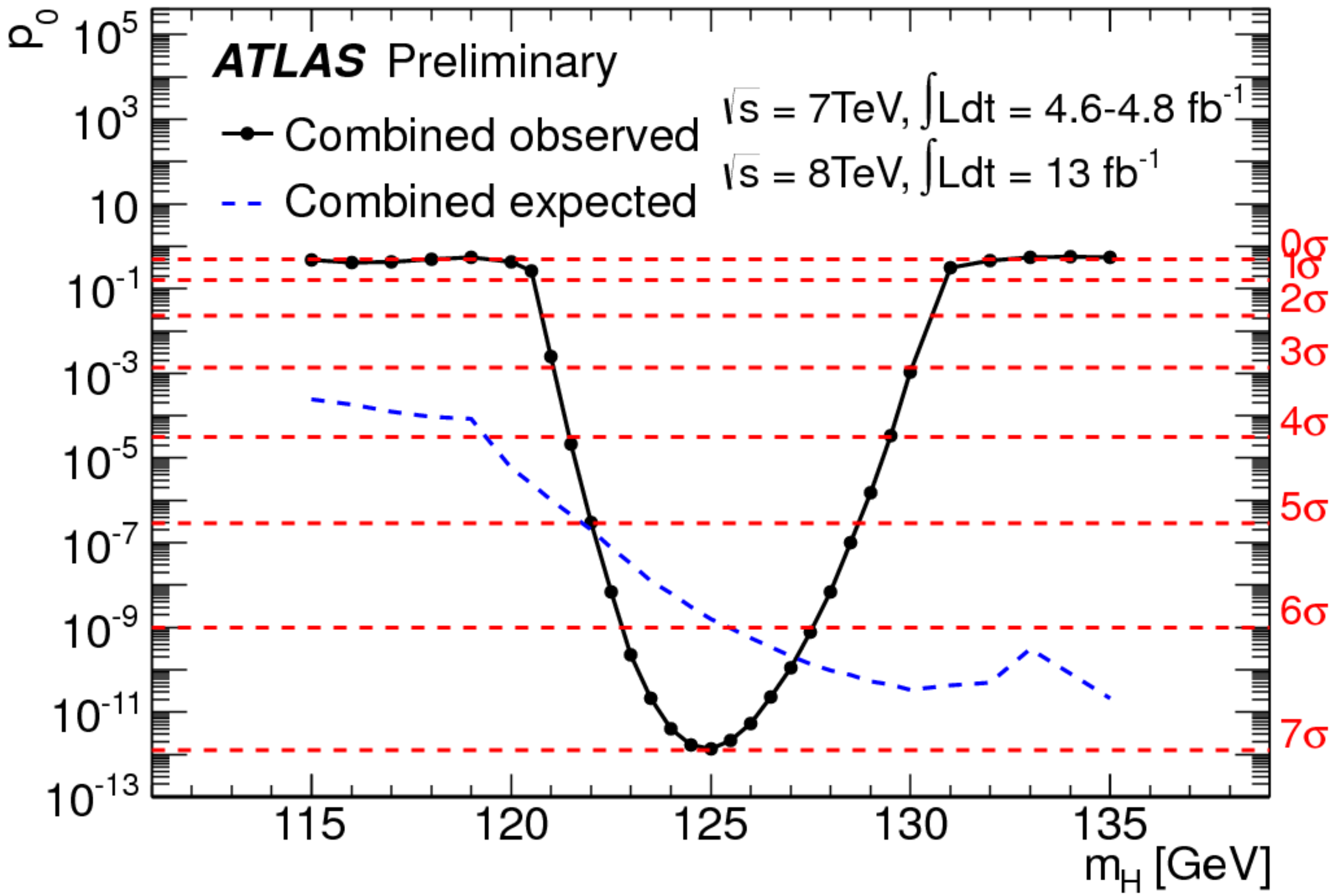


$\sqrt{s}$ = 7 TeV $\int$ Ldt = 0.02 fb^{-1} Apr 18, 2011
ATLAS Preliminary
H→γγ channel
Data
Background-only
Events / GeV
Data - Fit
$M_{\gamma\gamma}$ [GeV]

Higgs Signal γγ



Statistical Evidence



Outlook

- **We have definitely discovered a new boson but is it the Standard Model Higgs?**
- **Measurements of spin=0 suggest it is a Higgs boson but is it SM or exotic?**
- **Need much more data …**

Q. Why do Particle Physics?

- **Answer: because it is interesting !**
- **fundamental questions of what the Universe is made of and how it interacts.**
- **Towards a T.O.E.**
- **Also help to explain how the Universe evolved.**
- **Dark Matter**

Other Benefits of Particle Physics

- **Many important applications of technology developed for Particle Physics are used.**
- **Ion beam accelerators required in semiconductor industry.**
- **Synchrotron radiation**
  - **By-product of particle accelerators.**
- **Accelerators used in hospitals to produce radio-isotopes.**
- **Medical imaging (e.g. PET).**
- **Safe transformation of nuclear waste.**
- **World Wide Web invented at CERN (by Oxford Physics graduate).**

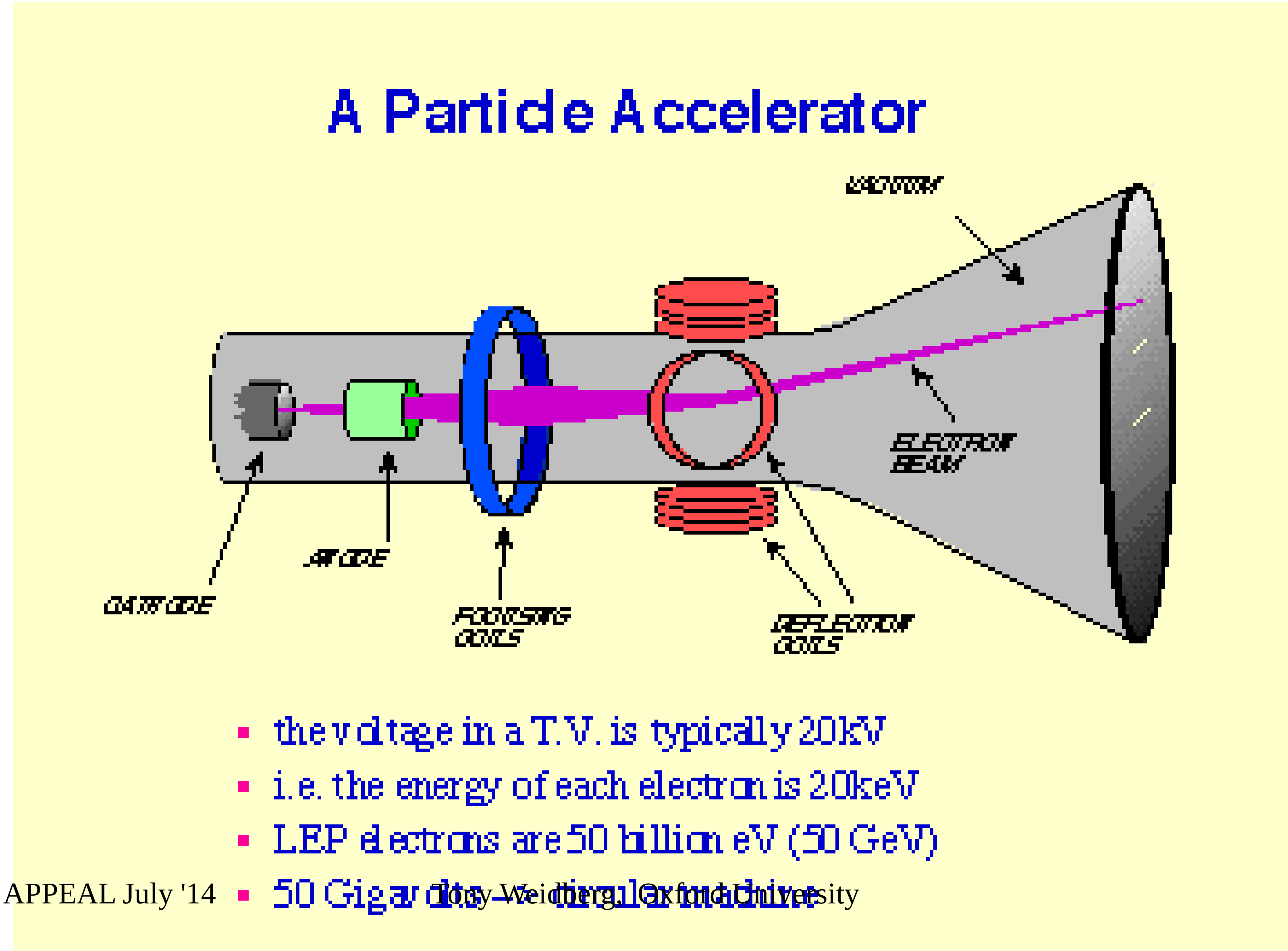
Accelerators

- Use $E=mc^2$ What does this mean?
- We know Higgs mass m_H>115 GeV/c^2
- Need very high energy particle accelerator:
  - LHC centre of mass proton – proton collisions 7 to 8 TeV (upgrade to 14 TeV).
  - 1 TeV = 10^{12} eV: 1 eV is energy given to an electron by a 1V battery

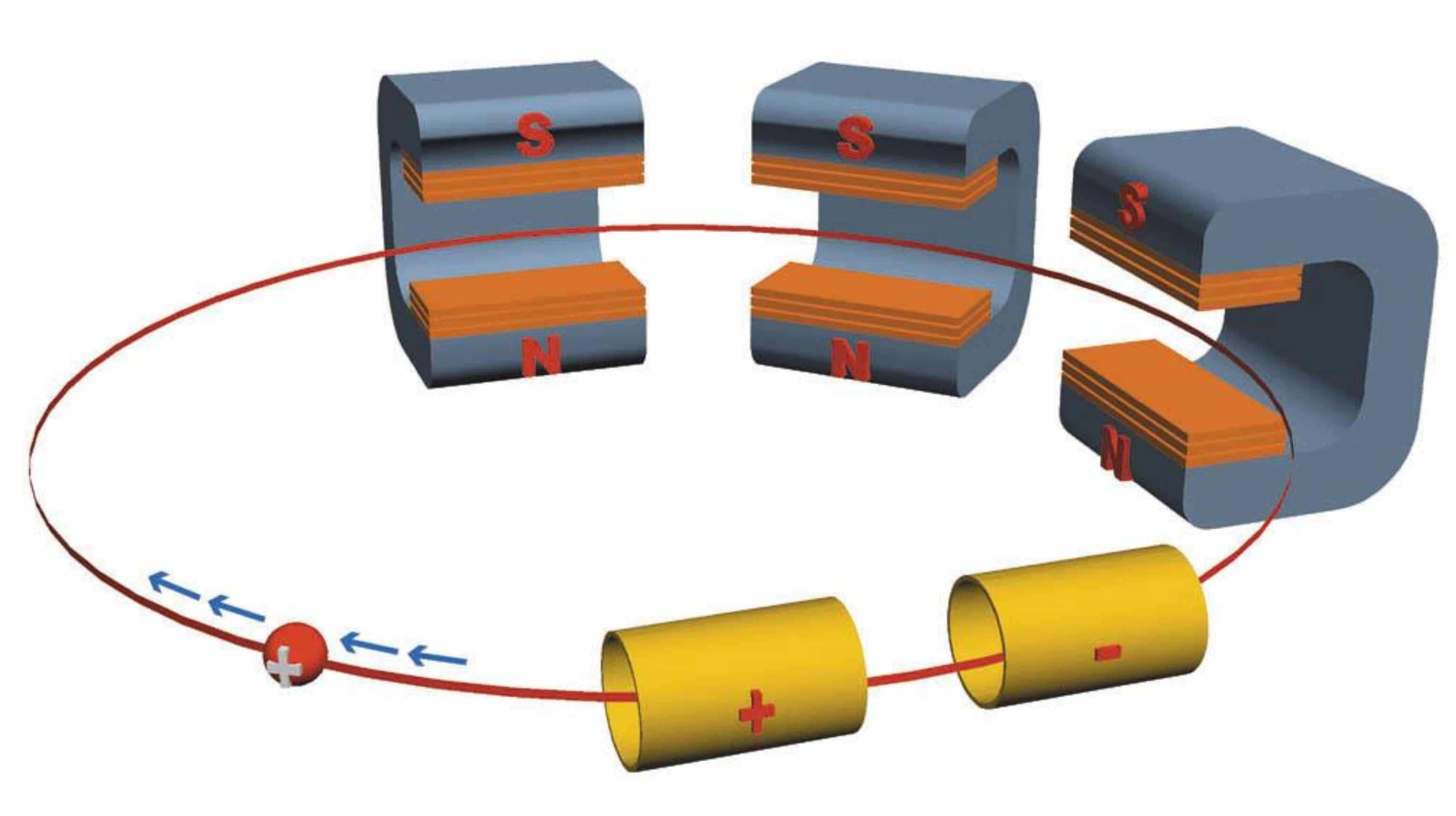
Particle Accelerators

- **Everybody has a particle accelerator at home.**
- **It is called a …**

TV = Electron Accelerators



Circular Accelerators

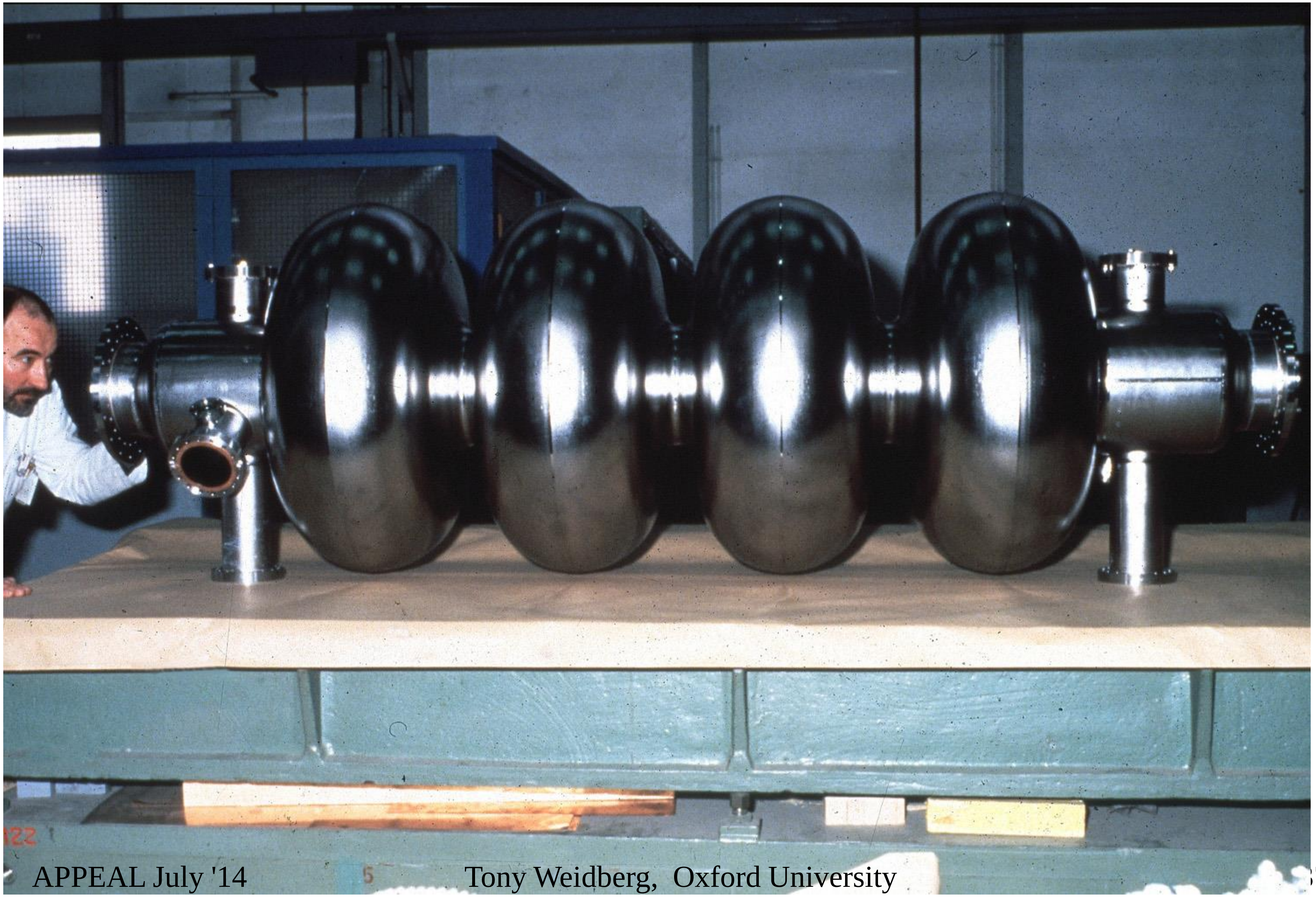



MB 231

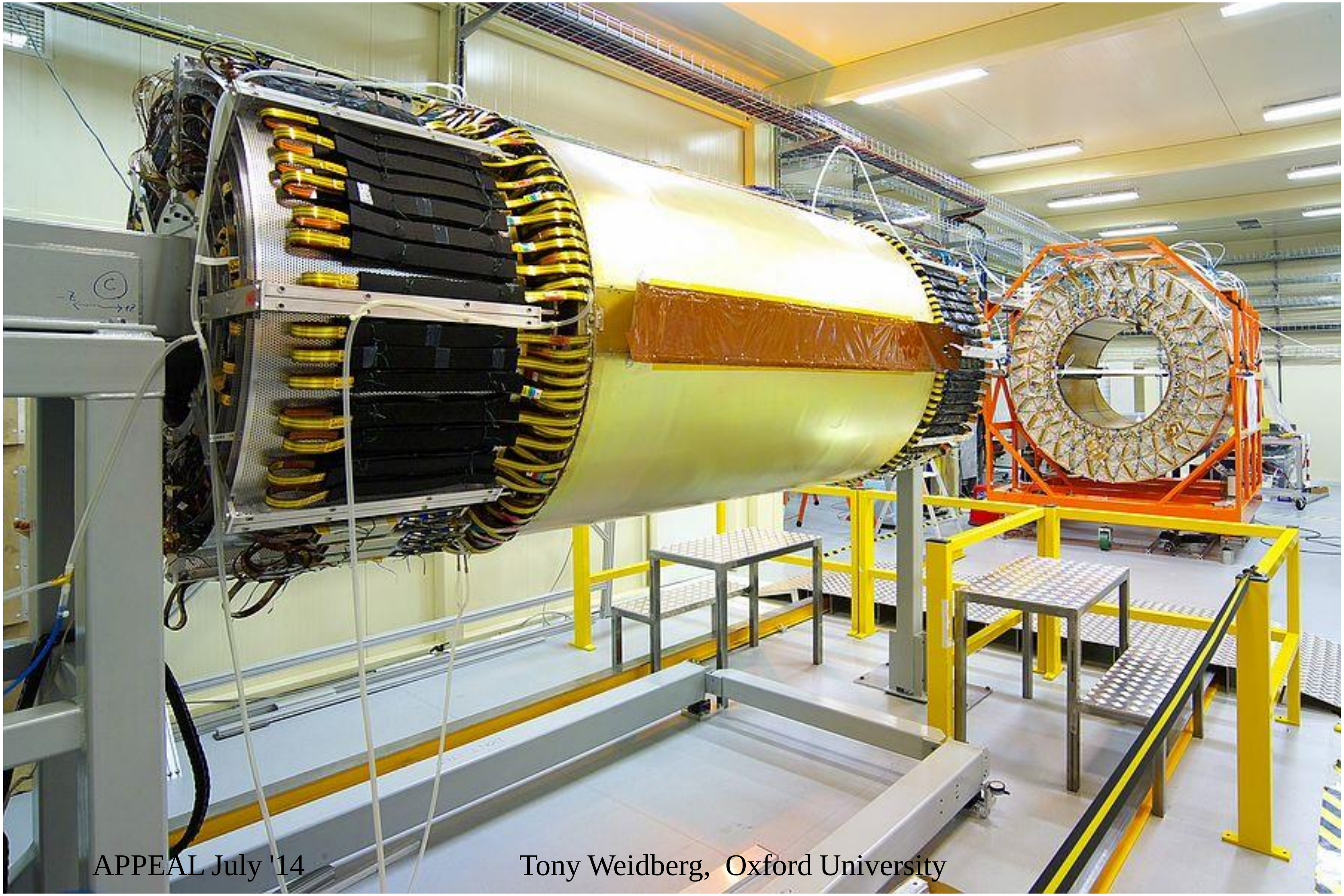

PR752

1200 Superconducting Magnets 9T for the LHC

Superconducting RF Cavity

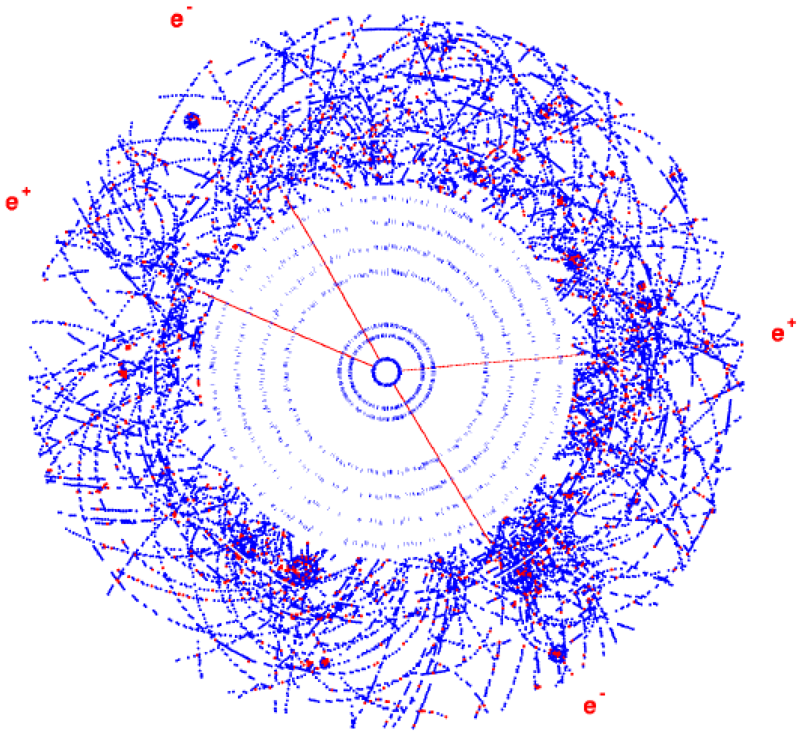


4 Si Barrels Assembled



Detector Challenges

- 10^9 interactions/second
- Select ~10^3 interesting events from background of 10^{16}
- Makes finding finding a needle in a haytsack look like a piece of cake.



ATLAS Torroid Magnets