

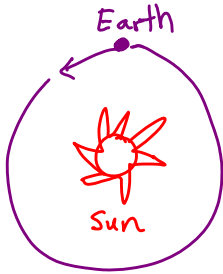
Space-Time, Quantum Mechanics

+

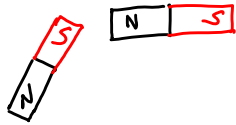
The Large Hadron Collider

4 Basic Interactions

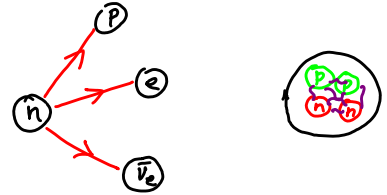
Gravity

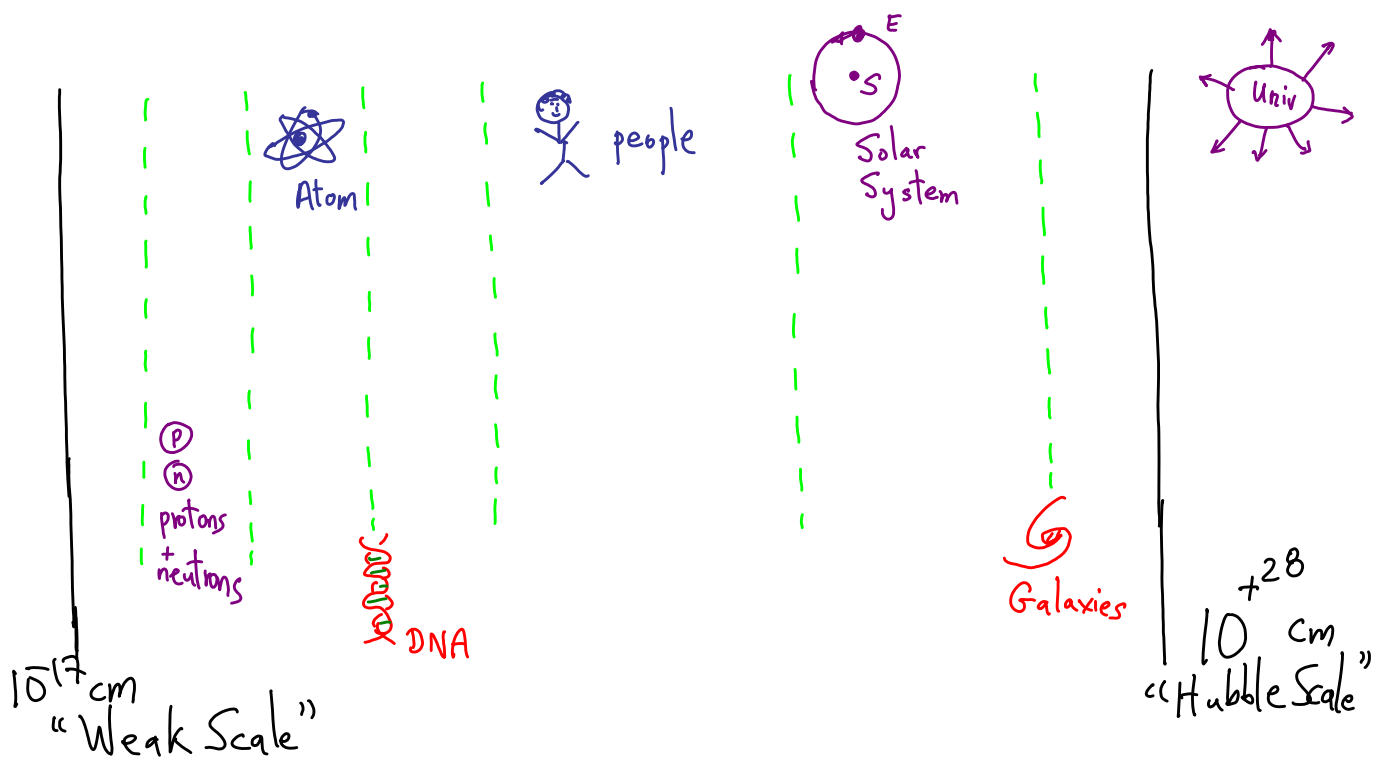


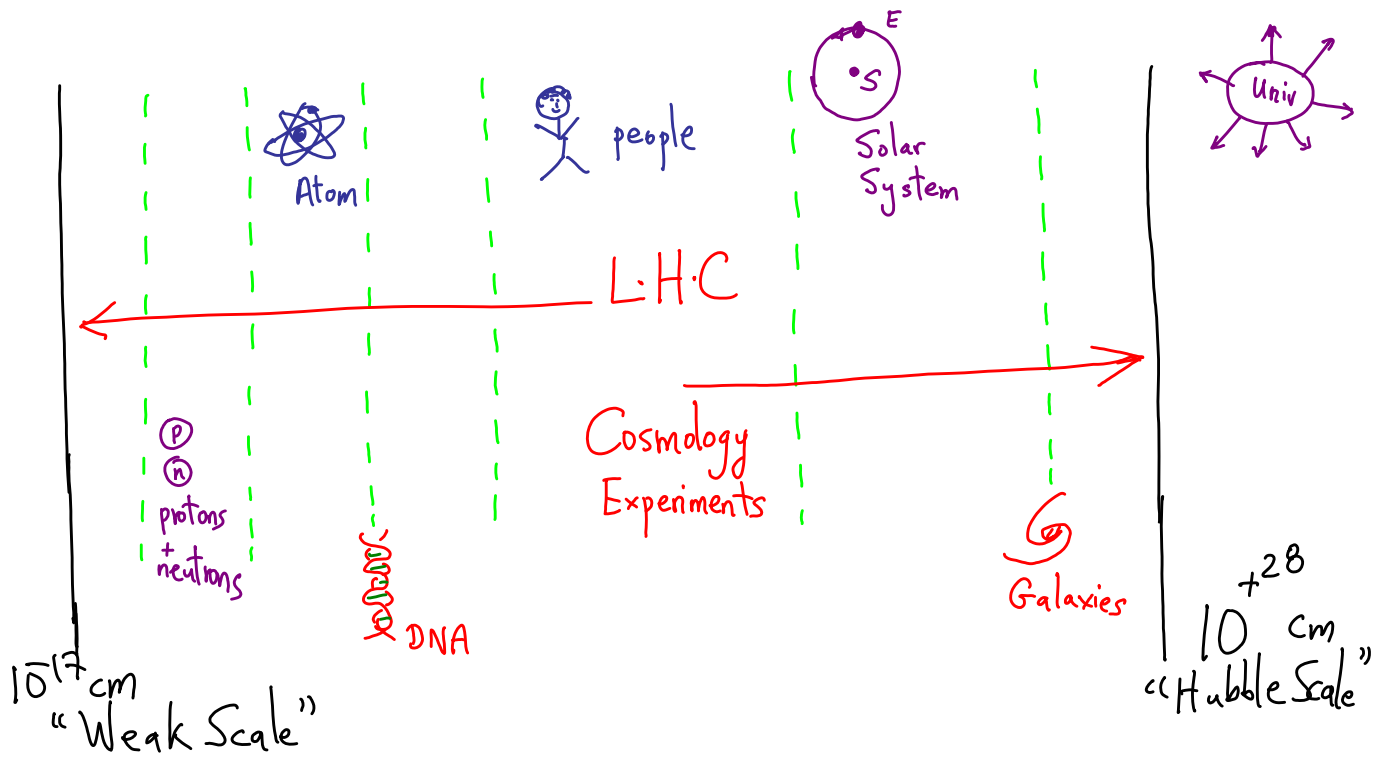
Electromagnetism



Weak + Strong







10^{-33} cm

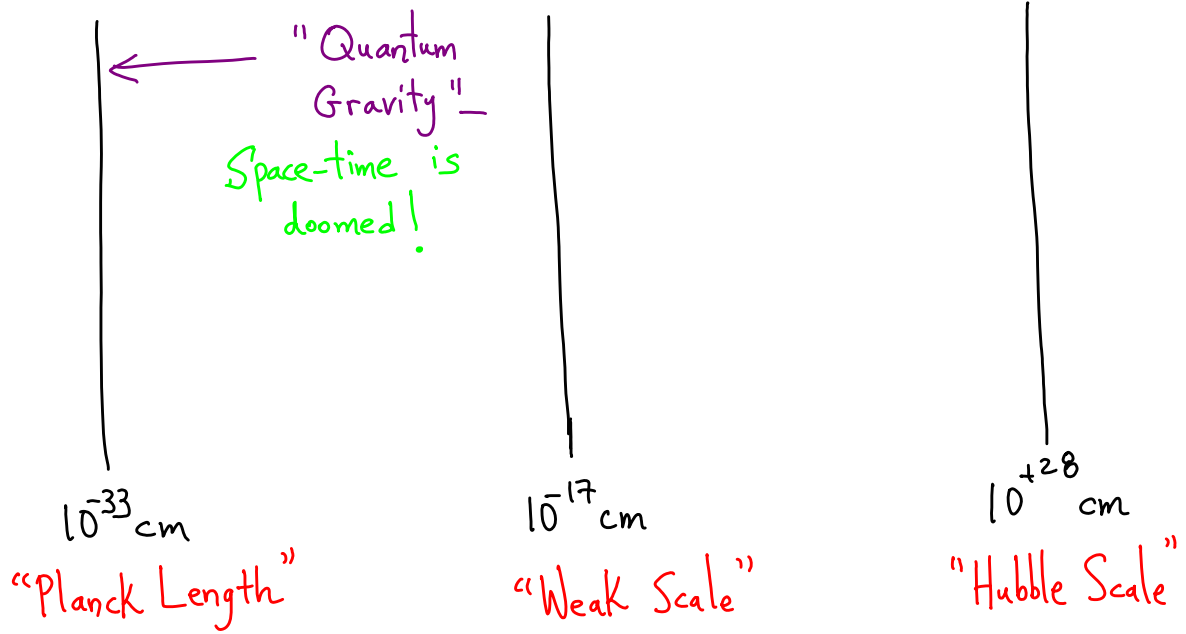
"Planck Length"

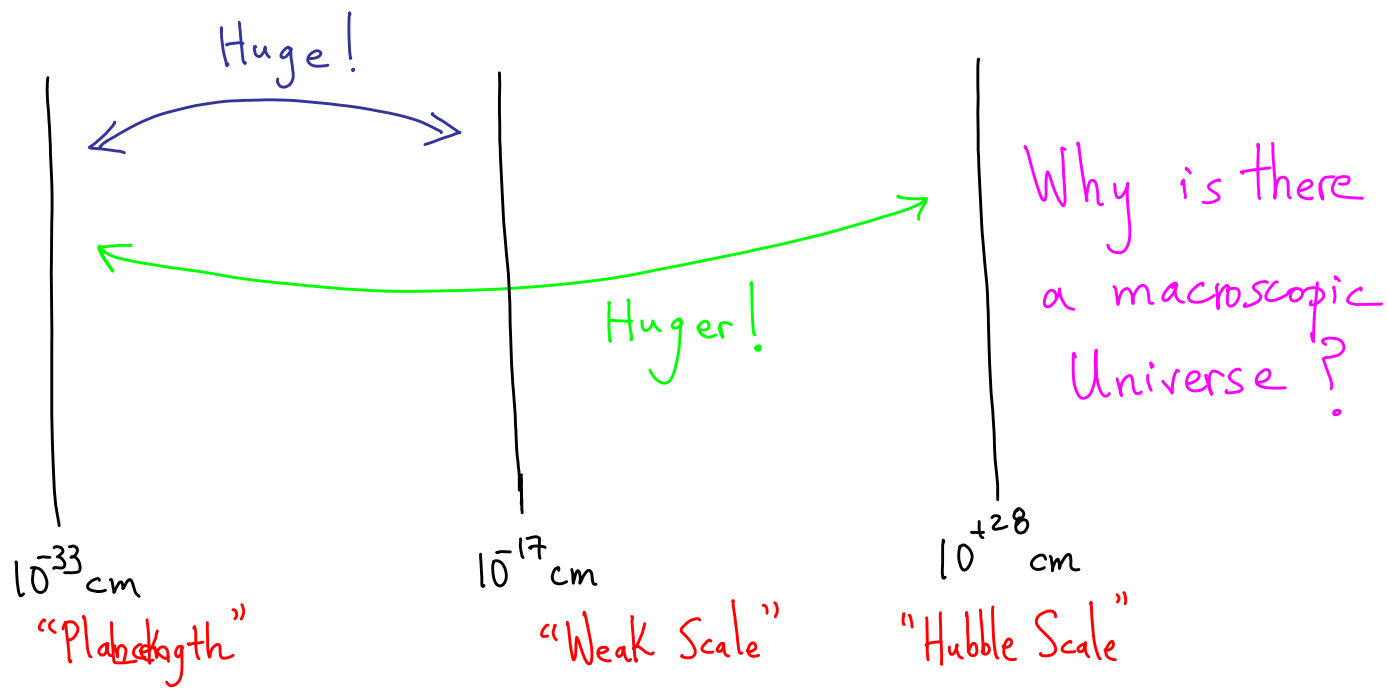
10^{-17} cm

"Weak Scale"

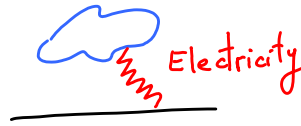
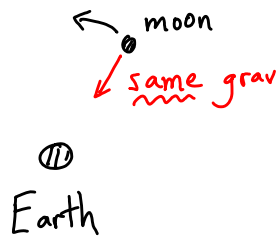
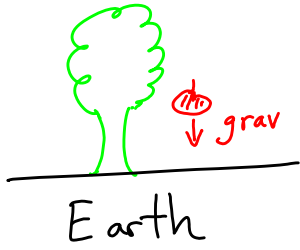
10^{+28} cm

"Hubble Scale"



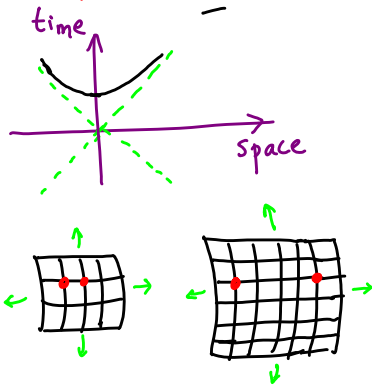


Unification



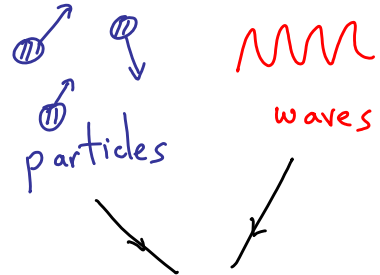
Different Aspects of Same Thing!

Relativity

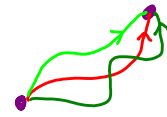


Space-Time

Quantum Mechanics



Quantum
Particles



Synthesis of QM + Relativity:

"Quantum Field Theory"

→ Forces existence of anti-particles

• e^-

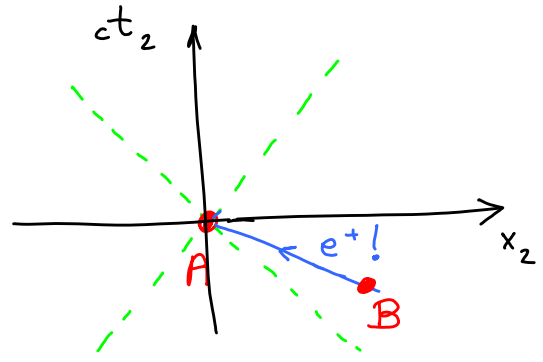
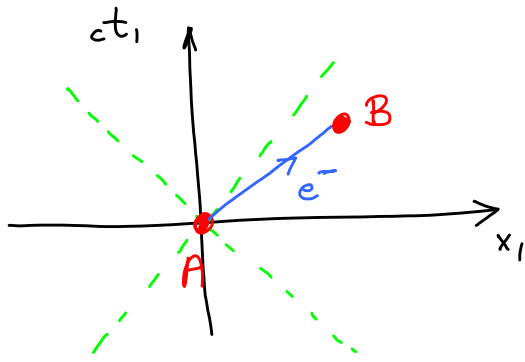
• e^+

• p^+

• p^-

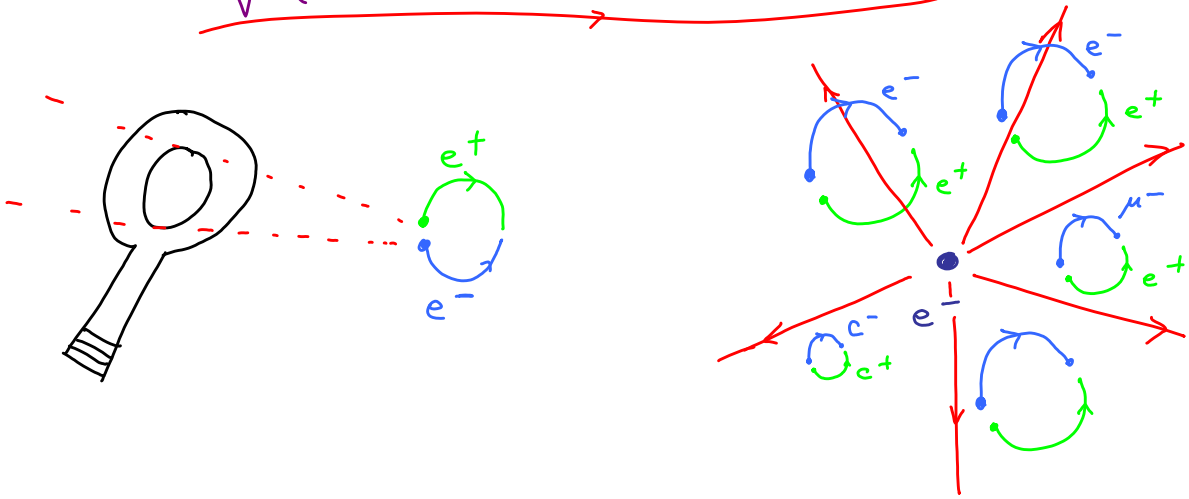
}

Amazing: Unification of
Space-time + Quantum Mechanics
doubled the world!

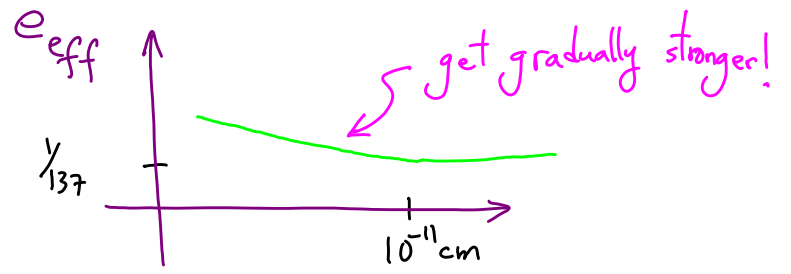
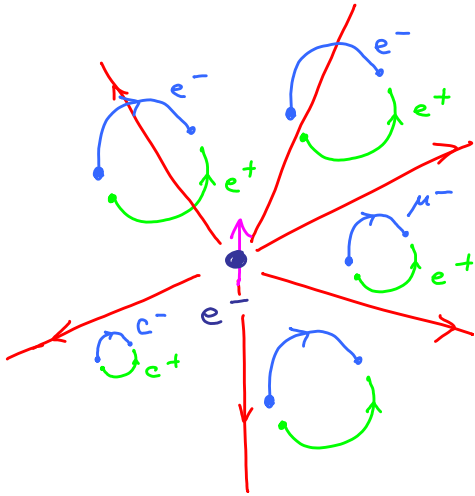


Causality \longrightarrow Antiparticles

"Vacuum" is Exciting!

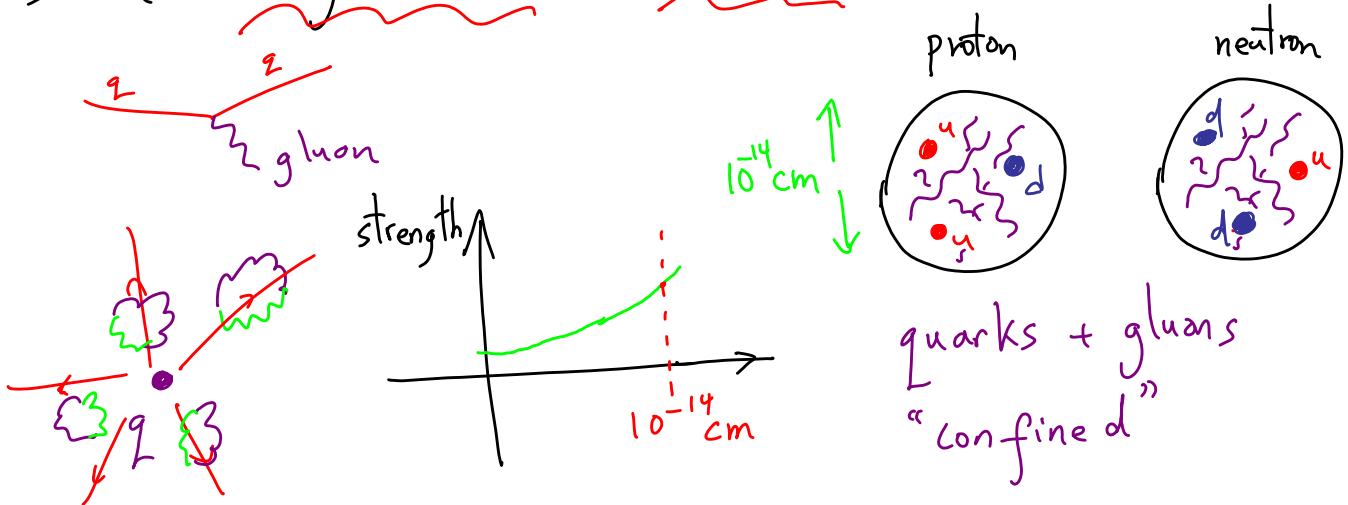


These developments culminated in the
1970's with the invention of a specific
Q.F.T describing all known interactions
down to at least 10^{-16} cm.... spectacularly
successful!

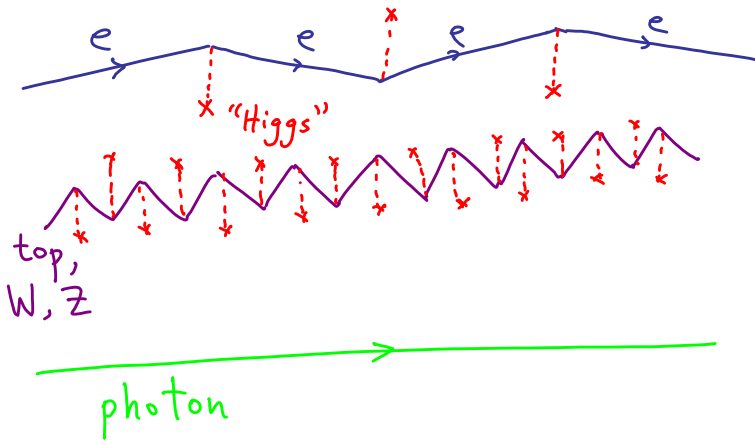


$$\frac{g-2}{2} = .001159652181 \dots$$

The apparent huge disparity between forces is a long-distance illusion:



Origin of Mass

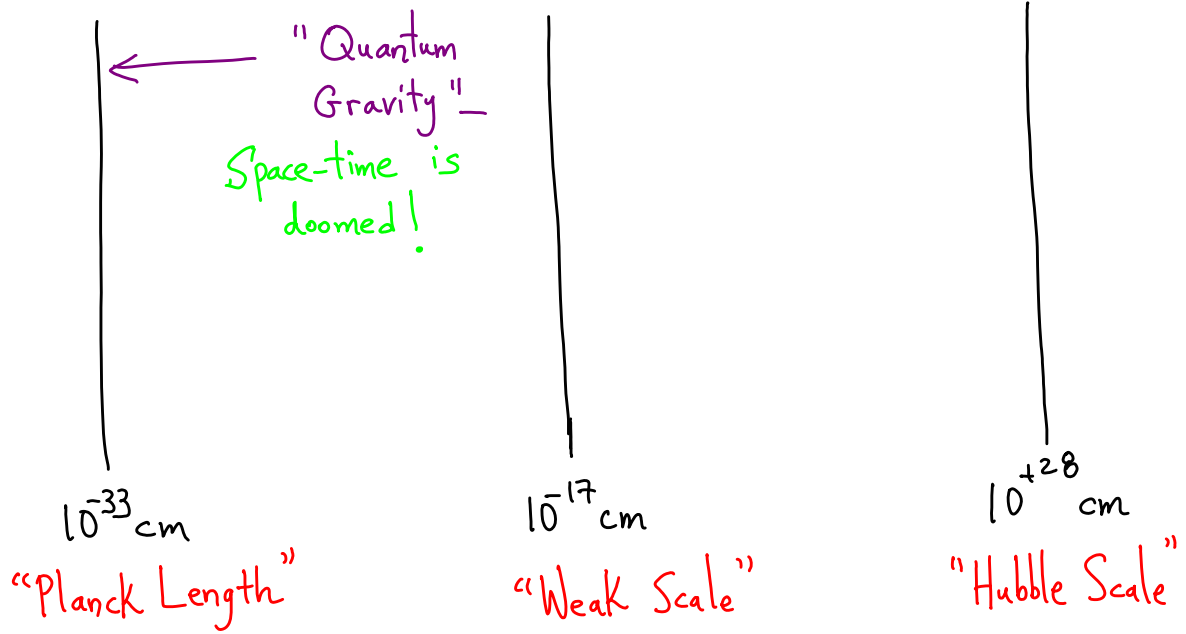


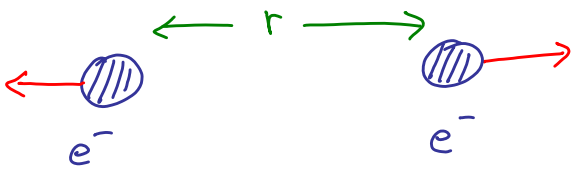
Typical length between collisions $\sim 10^{-17}$ cm.

L.H.C. must excite "Higgs Particle"!

Space-Time is Doomed -

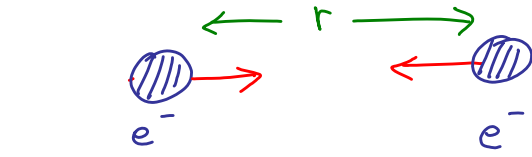
What Replaces It?





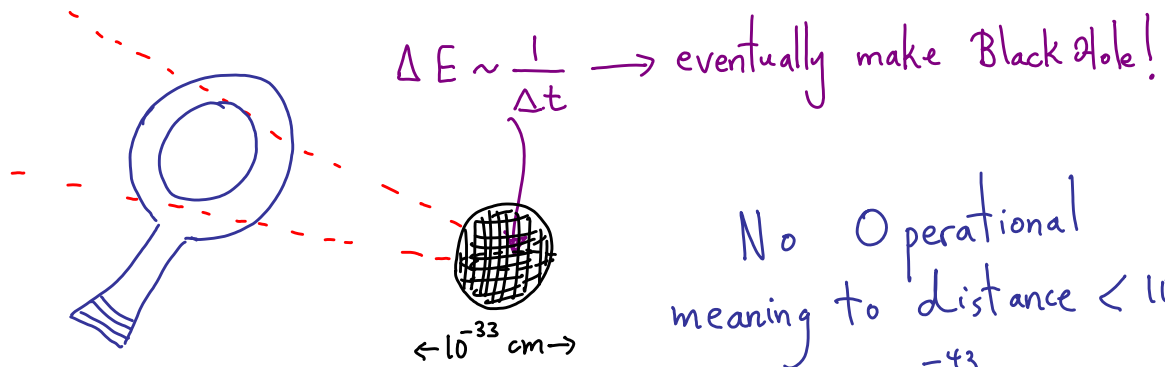
$$E^{\text{electric}} \sim \left(\frac{e^2}{4\pi} \right) \frac{1}{r}$$

strength $\sim \frac{1}{137}$ (a pure number!)



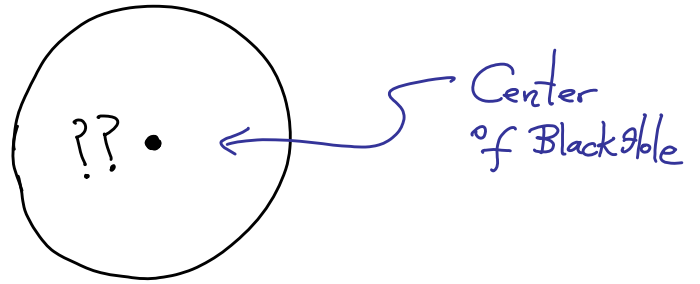
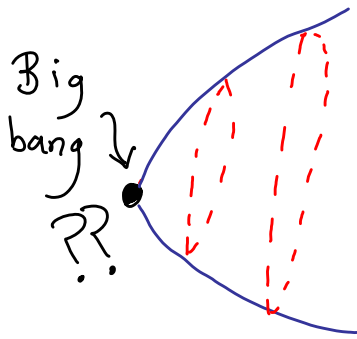
$$E^{\text{grav}} \sim -G_N \frac{m_e^2}{r}$$

$$\sim (10^{-33} \text{ cm})^2 \sim (\ell_{\text{Planck}})^2$$



No Operational
meaning to distance $< 10^{-33}$ cm,
times $< 10^{-43}$ s,

End of Space-Time

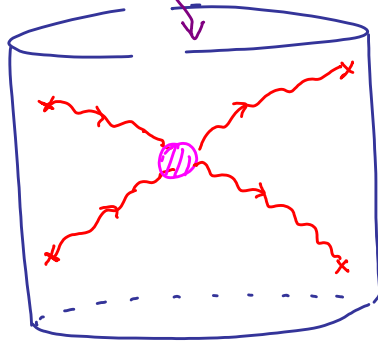


Our theories just break down when gravity is strong and quantum gravity effects are dominant.

$$(\text{Quantum Gravity})_{D+1} = (\text{Quantum Field Theory})_D (!)$$

Emergent
Space, Gravity,
Strings ...

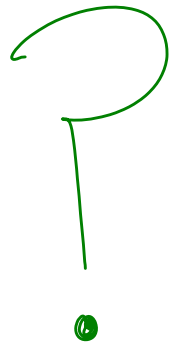
↑
time



“Anti-de Sitter
Space”

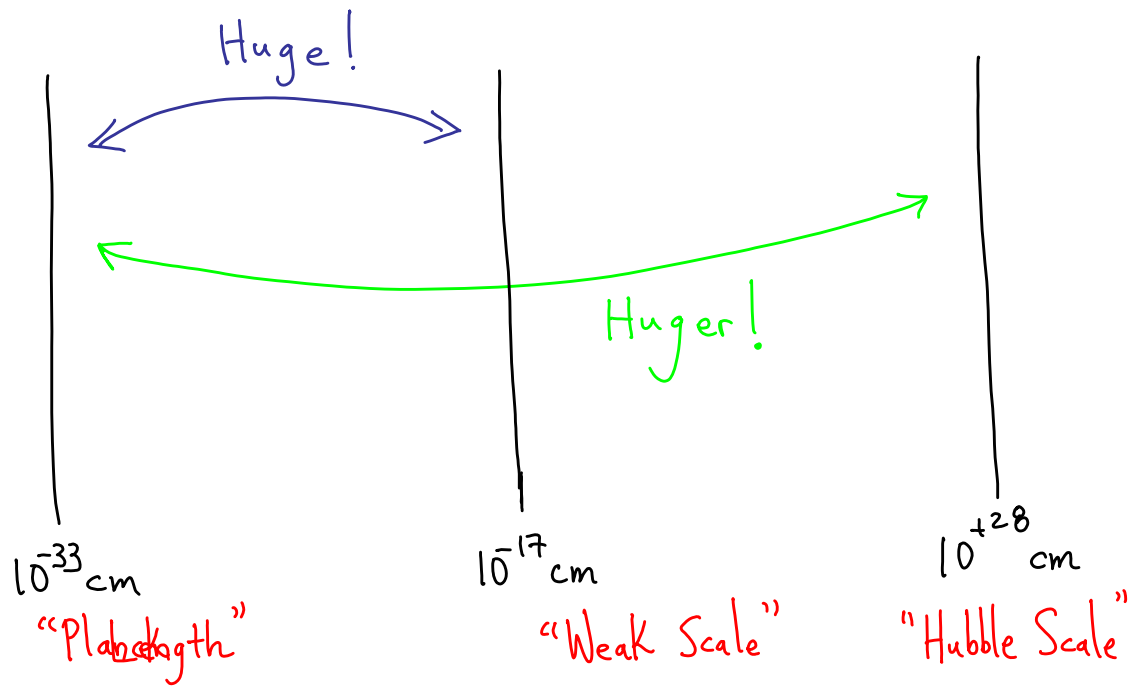
$$\text{String Theory (weak)} = \text{Particle Physics (strong)}$$

More generally, we must come
to grips with Emergent Time.

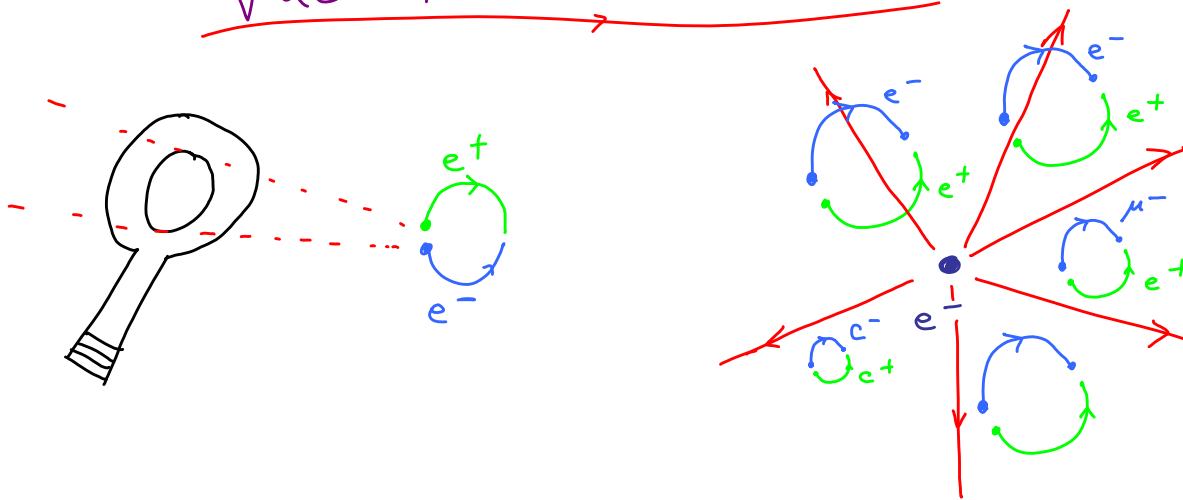


Why is there a

Macroscopic Universe?

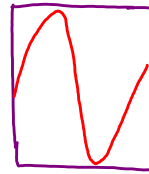
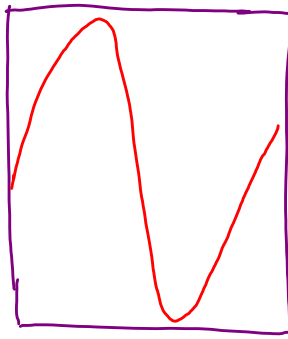
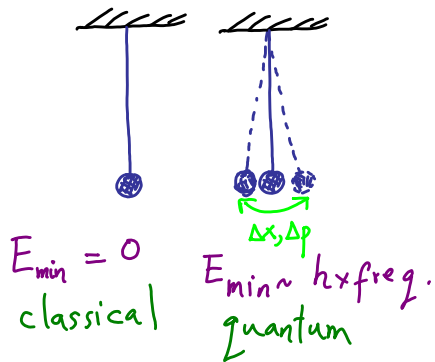


"Vacuum" is Exciting!



Too Exciting!

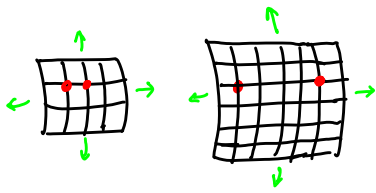
Even Vacuum has energy!



Bigger Fluctuations at Shorter Distances

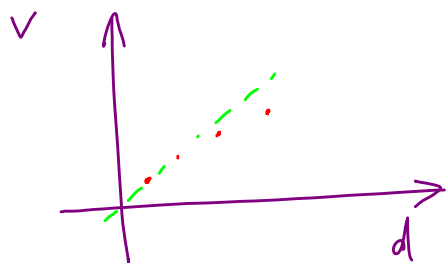
Estimating Λ

$$\text{"Vacuum Energy Density"} \sim \frac{\text{Energy}}{\text{Volume}} \sim \left[\frac{\text{Planck}}{\text{Planck Volume}} \right]$$



Explosive Acceleration -
Doubling size every 10^{-43} s !

Universe is Accelerating



but doubles in size every 10^{10} yrs!

$$\Delta_{\text{observed}} \sim 10^{-120} \Delta_{\text{estimate}}$$

Biggest Error in History of Physics
Science

What We Do

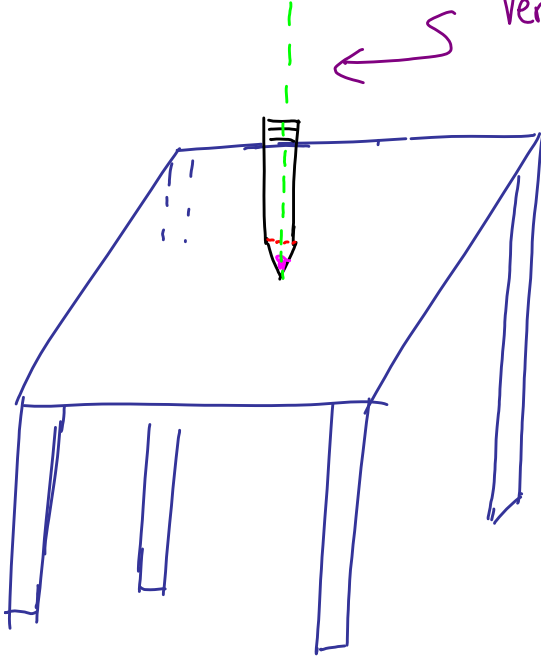
$$\Delta_{\text{observed}} = \Delta_{\text{classical}} + \Delta_{\text{Quantum}}$$

$$\begin{array}{ccc} \nearrow & & \nearrow \\ -2.6493781 \dots 526 \dots & + & 2.6493781 \dots 534 \dots \\ \underbrace{\hspace{10em}}_{120 \text{ decimals}} & & \underbrace{\hspace{10em}}_{120 \text{ decimals}} \end{array}$$

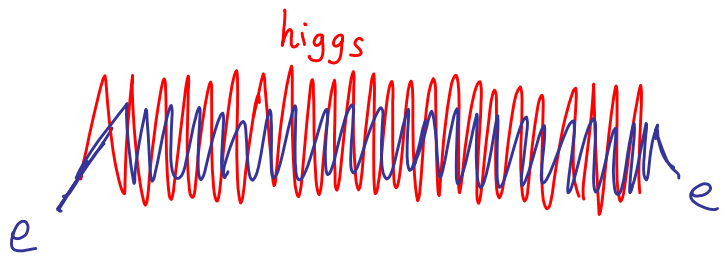
LUDICROUS!

"Fine Tuning"

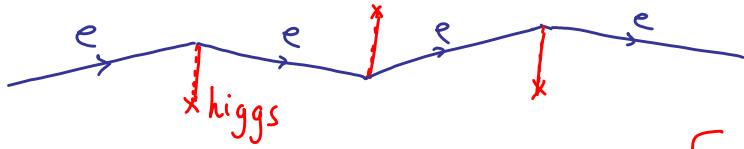
Vertical to accuracy 10^{-120} degrees!



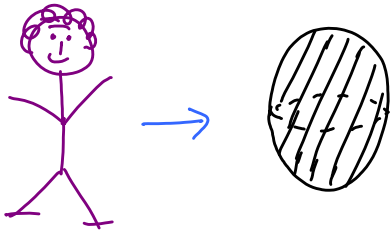
[Why is the Universe Big?]



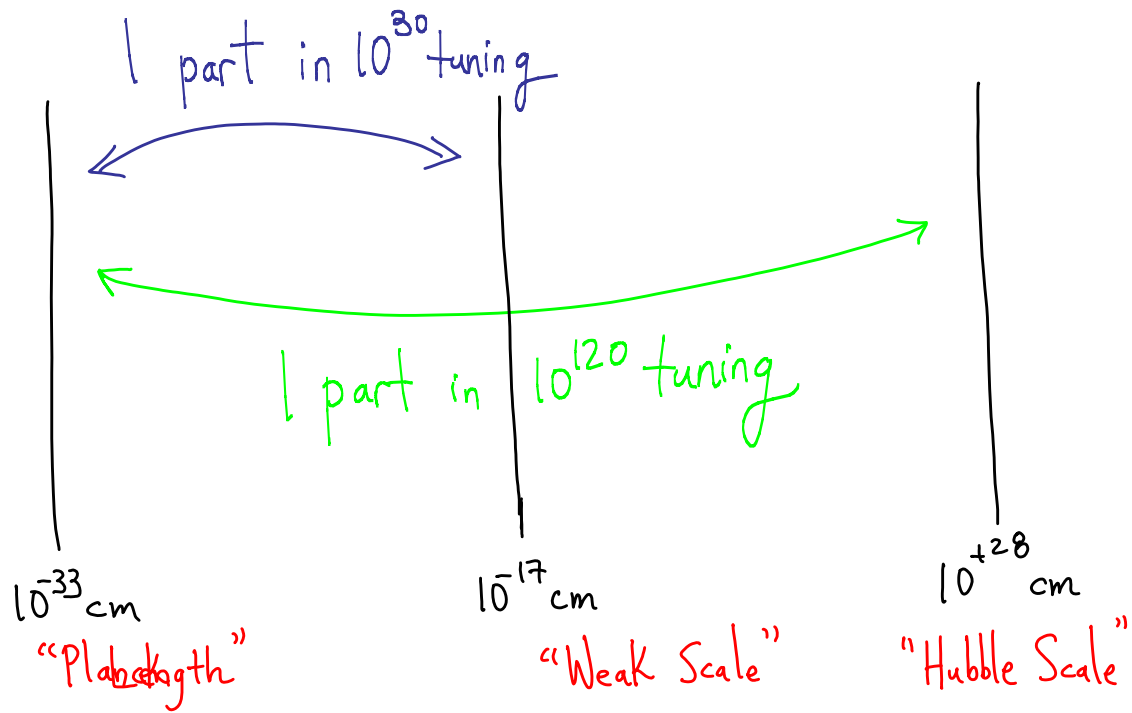
← Estimated distance between collisions $\sim 10^{-33}$ cm, vs

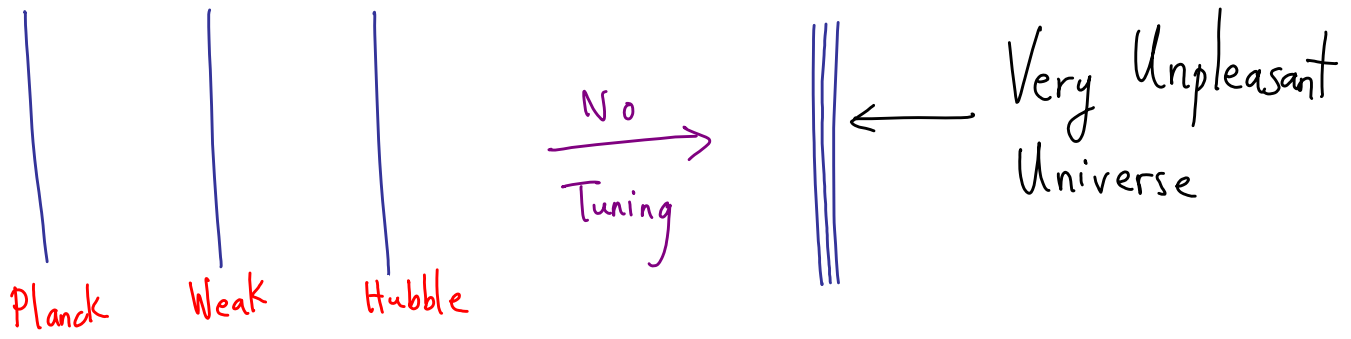


← Observed 10^{-17} cm



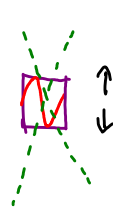
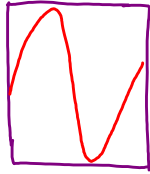
[Why is Gravity Weak?]





What Controls Violent Fluctuations of the Vacuum?
Why is There a Macroscopic Universe?

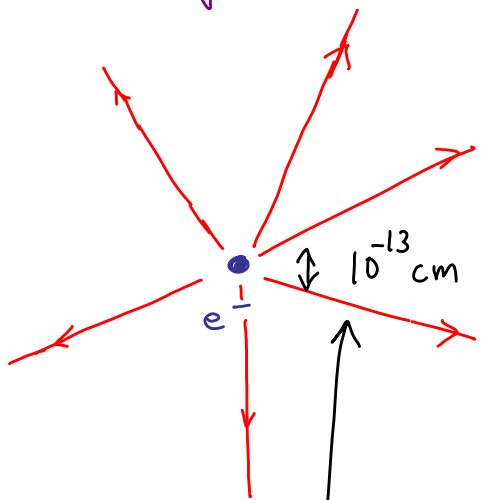
New Physics around the Corner?



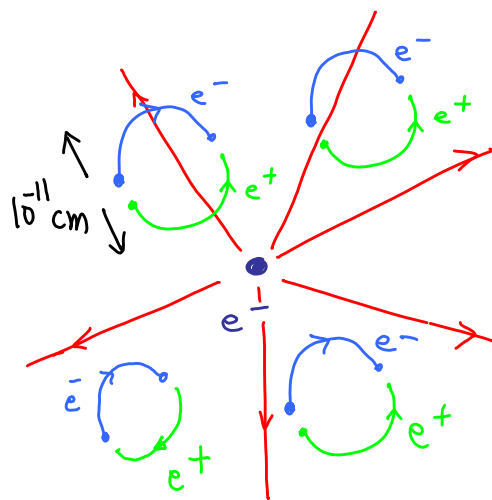
10^{-17} cm

Something new needs to happen here!

Infinite Energy In Electric Field

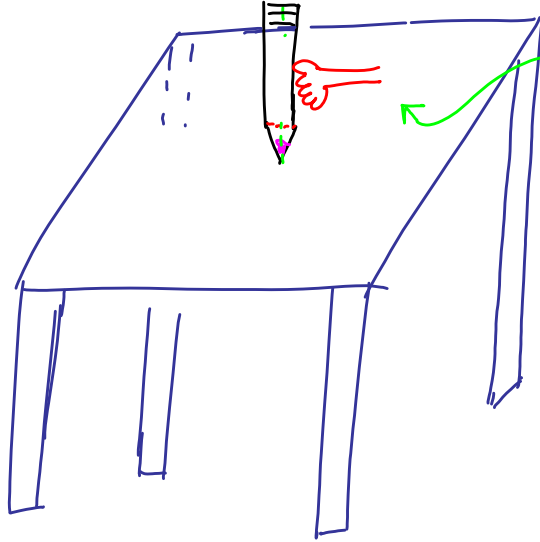


Q.M.
Rel.



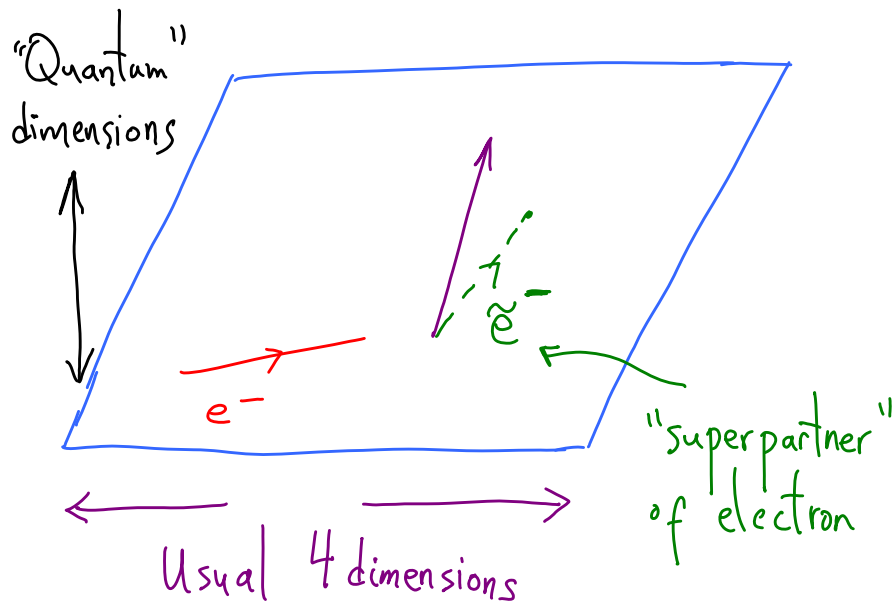
Something new by this scale

What Could It Be?



Extensions to our
notion of spacetime
can remove the
violent quantum
fluctuations

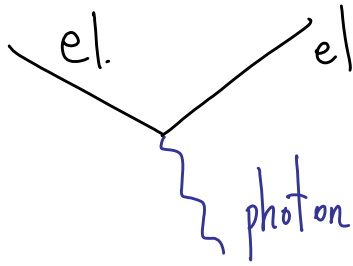
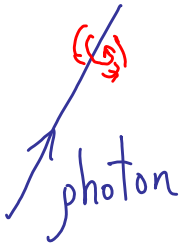
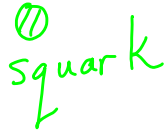
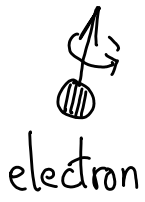
Supersymmetry



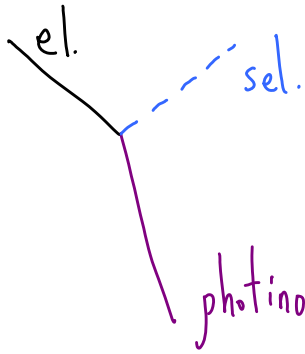
$d_x^{\text{Quantum}}, d_y^{\text{Quantum}}, \dots$

$$d_x^Q d_y^Q = -d_y^Q d_x^Q$$

$$(d_{xy}^Q)^2 = 0$$



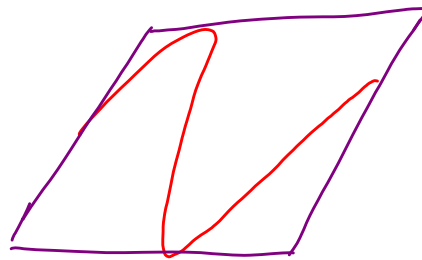
||



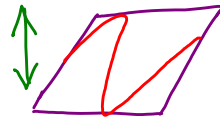
Symmetry
between
Ordinary +
Quantum
Dimensions

Violent
Quantum
Fluctuations

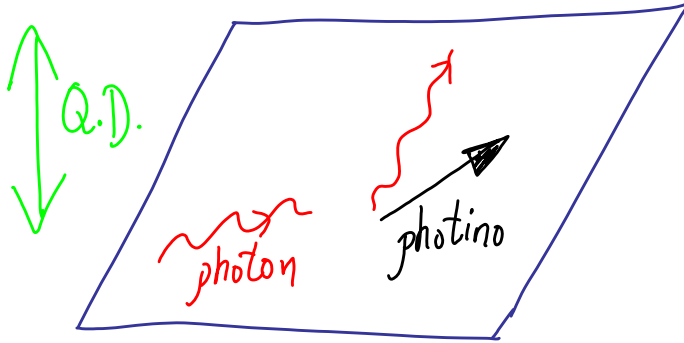
Gone
wmmm



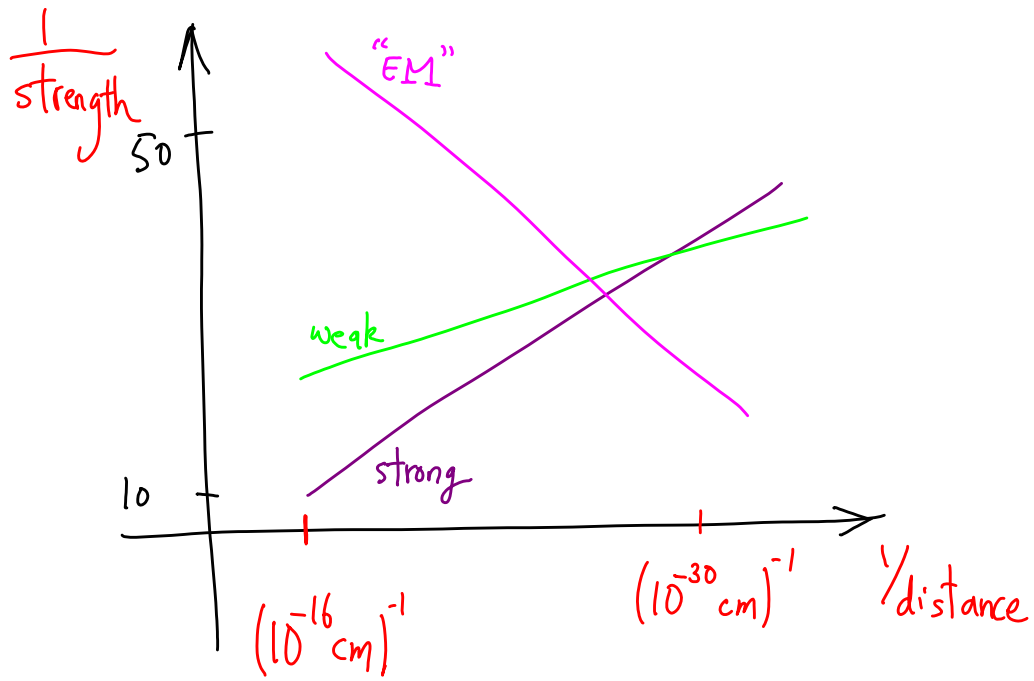
See Quant
dim.

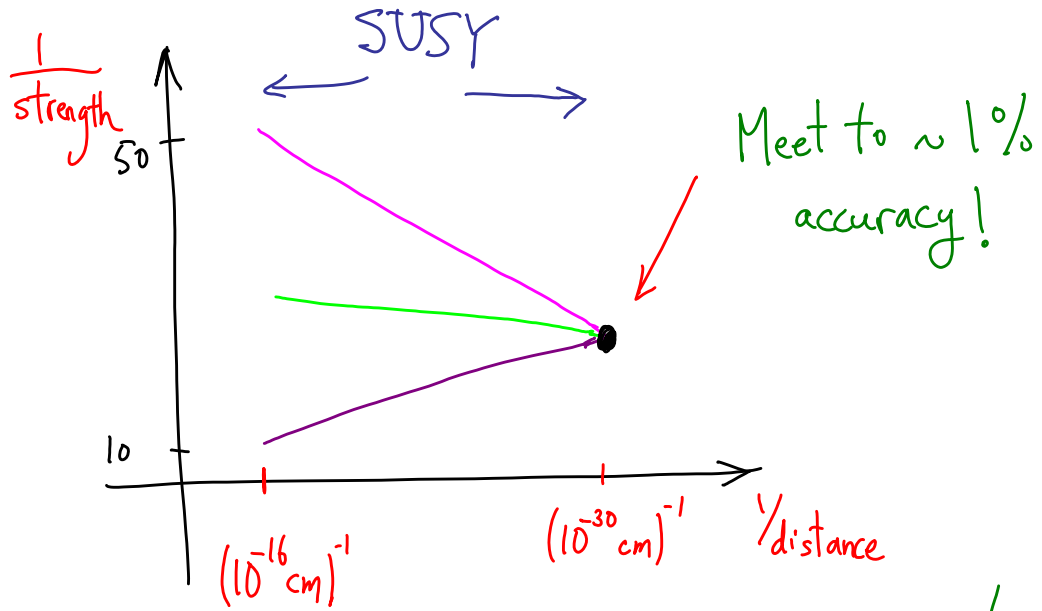


$\leftarrow 10^{-17} \text{ cm} \rightarrow$



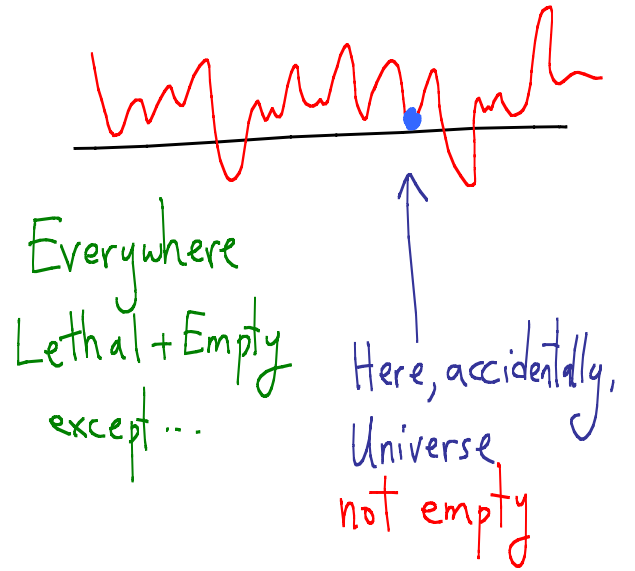
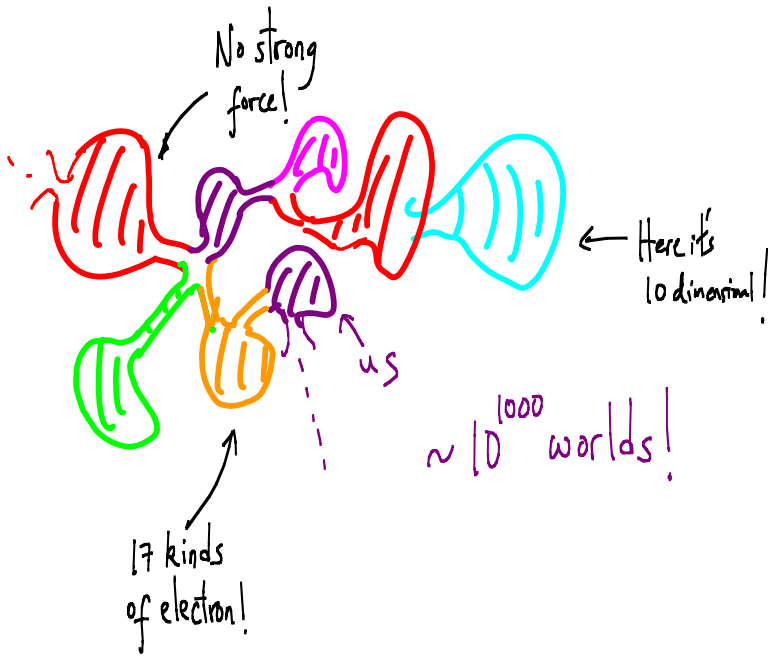
Dark Matter
Might be *Light*,
Moving in the new
Quantum Dimensions!





Unification of the Forces - Gravity not far behind!

Mr?




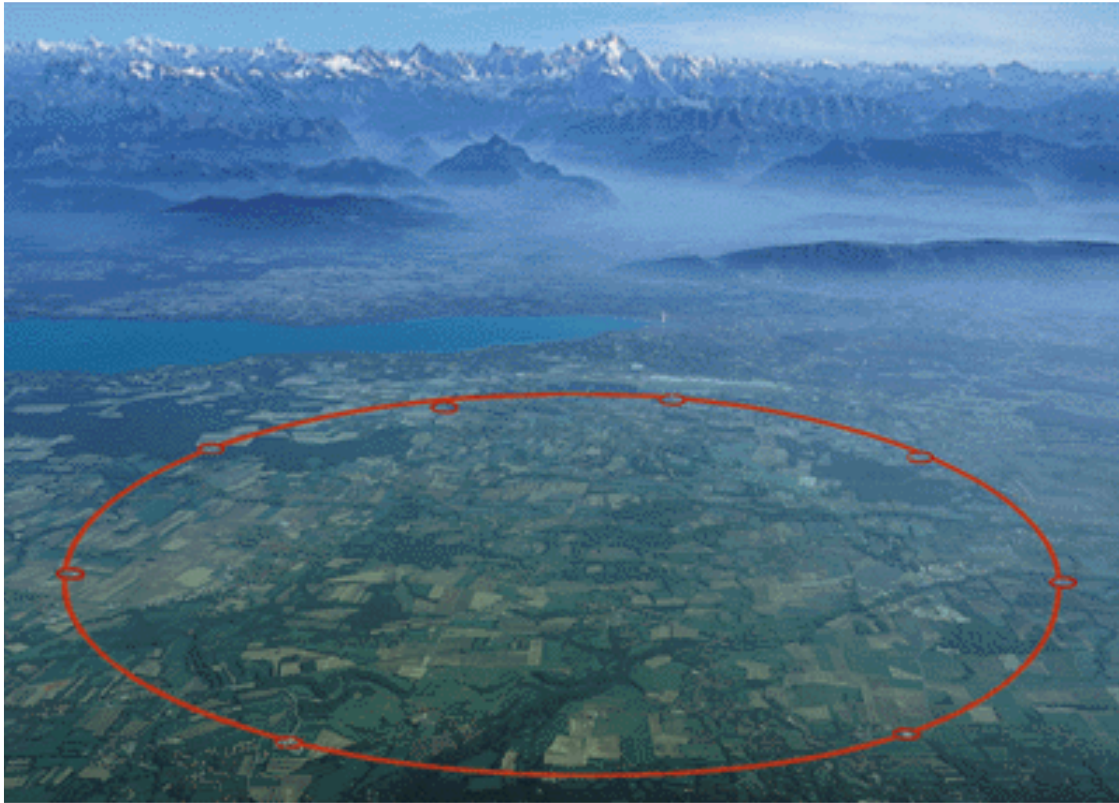
Are we tiny part of a Vast Multiverse?

• If true - modern Copernican Revolution!

• Conceptual Problem - how can we
"see" other universes - how can we
know that they're there?

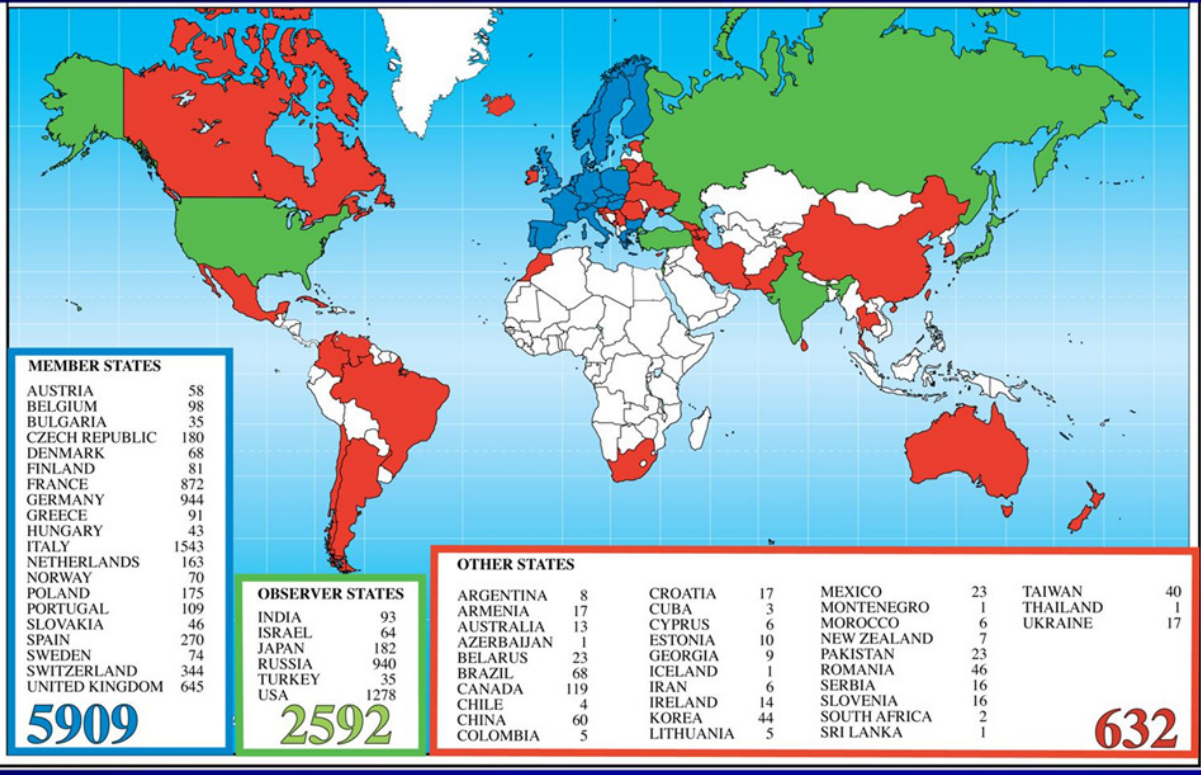
Large Hadron Collider

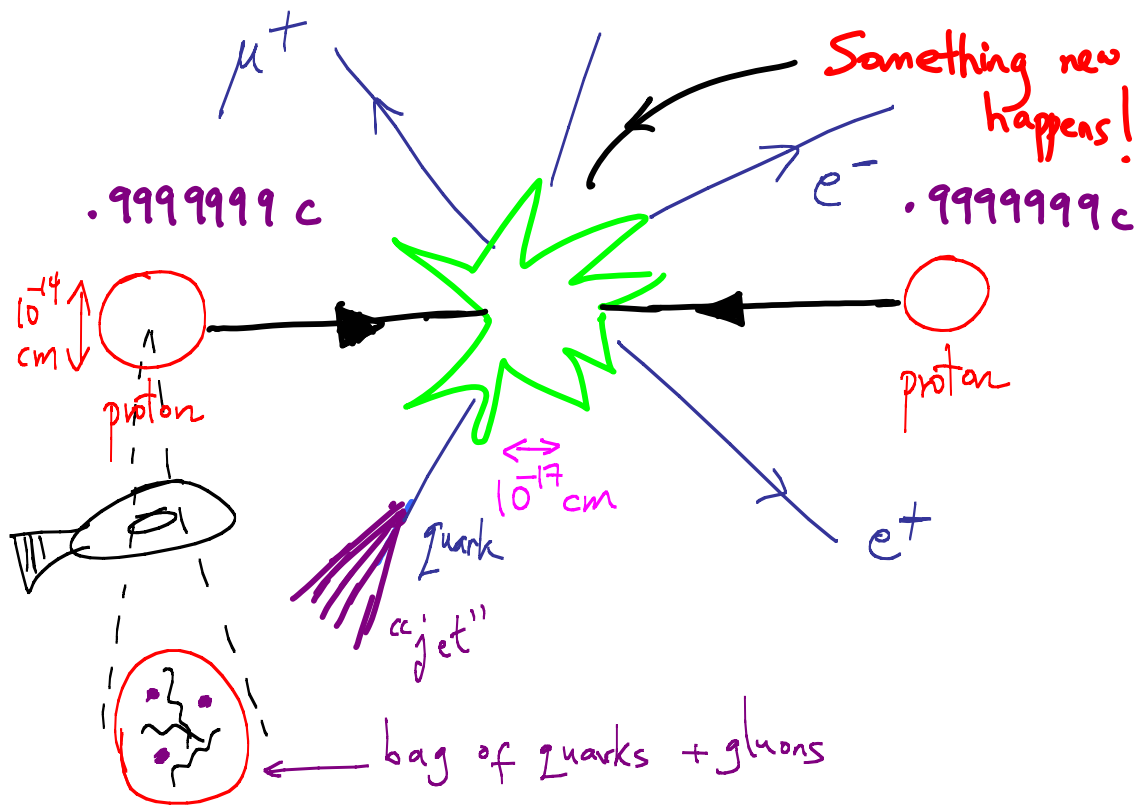






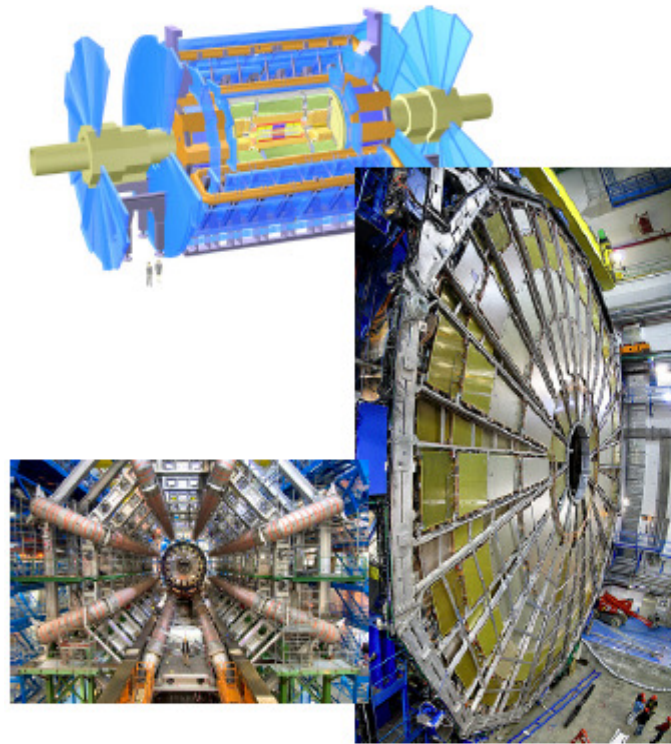
Distribution of All CERN Users by Nation of Institute on 5 February 2008



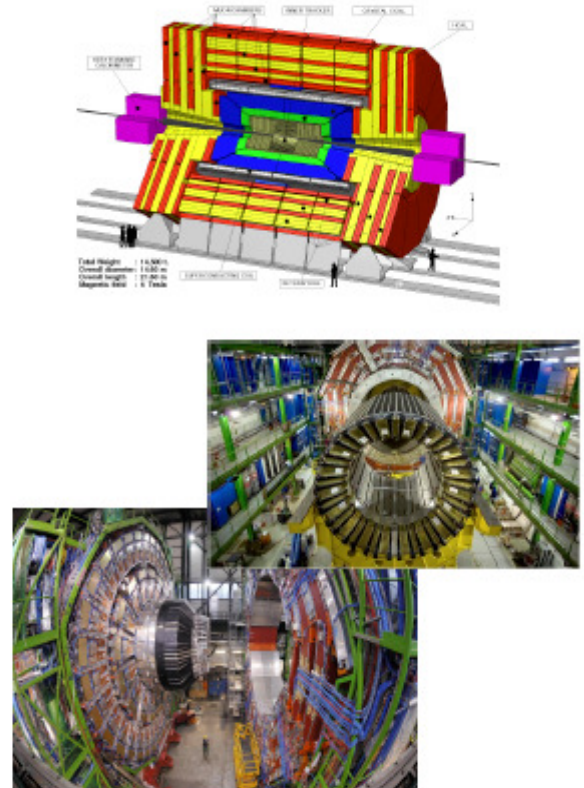


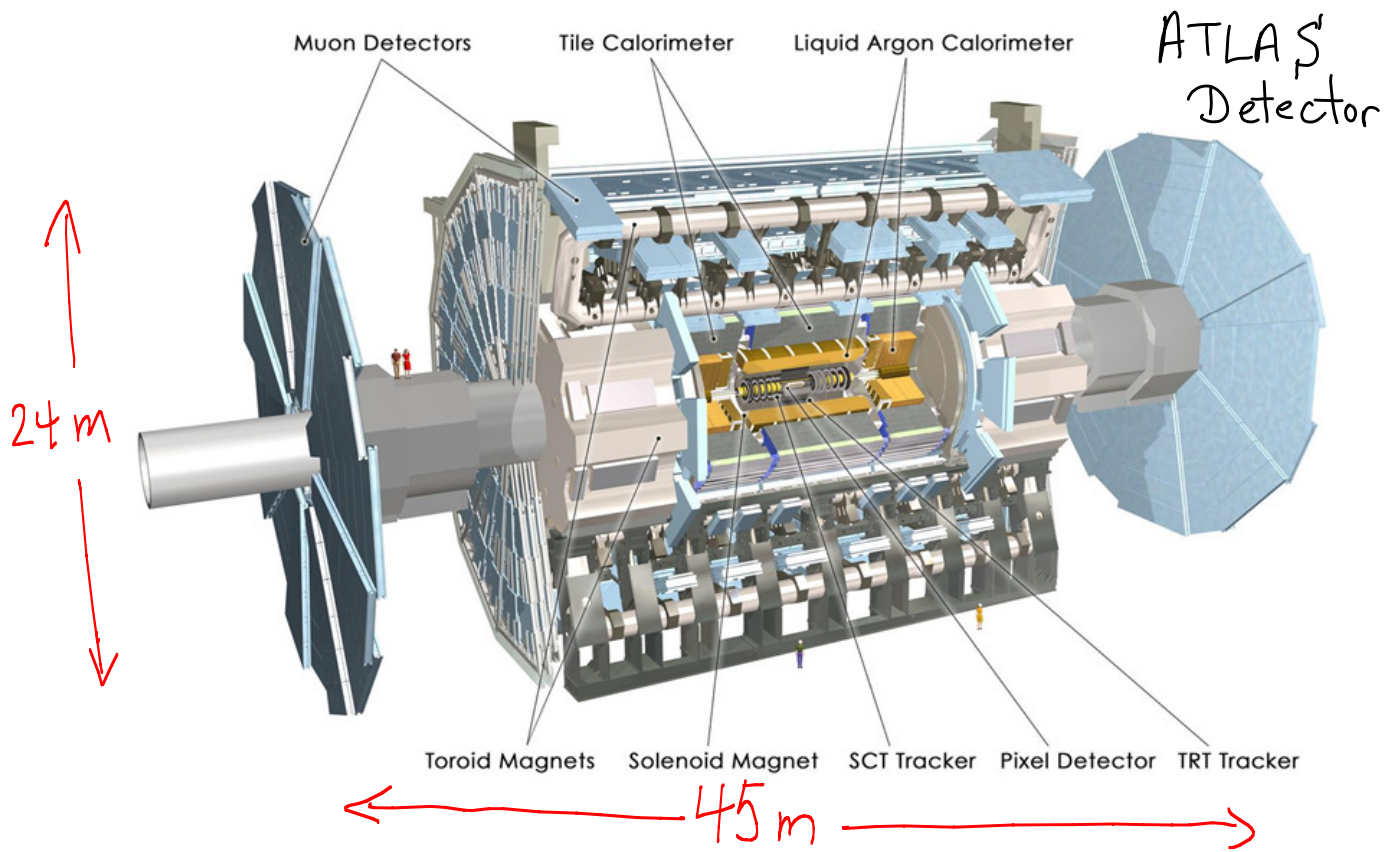
Particle Detectors

ATLAS



CMS





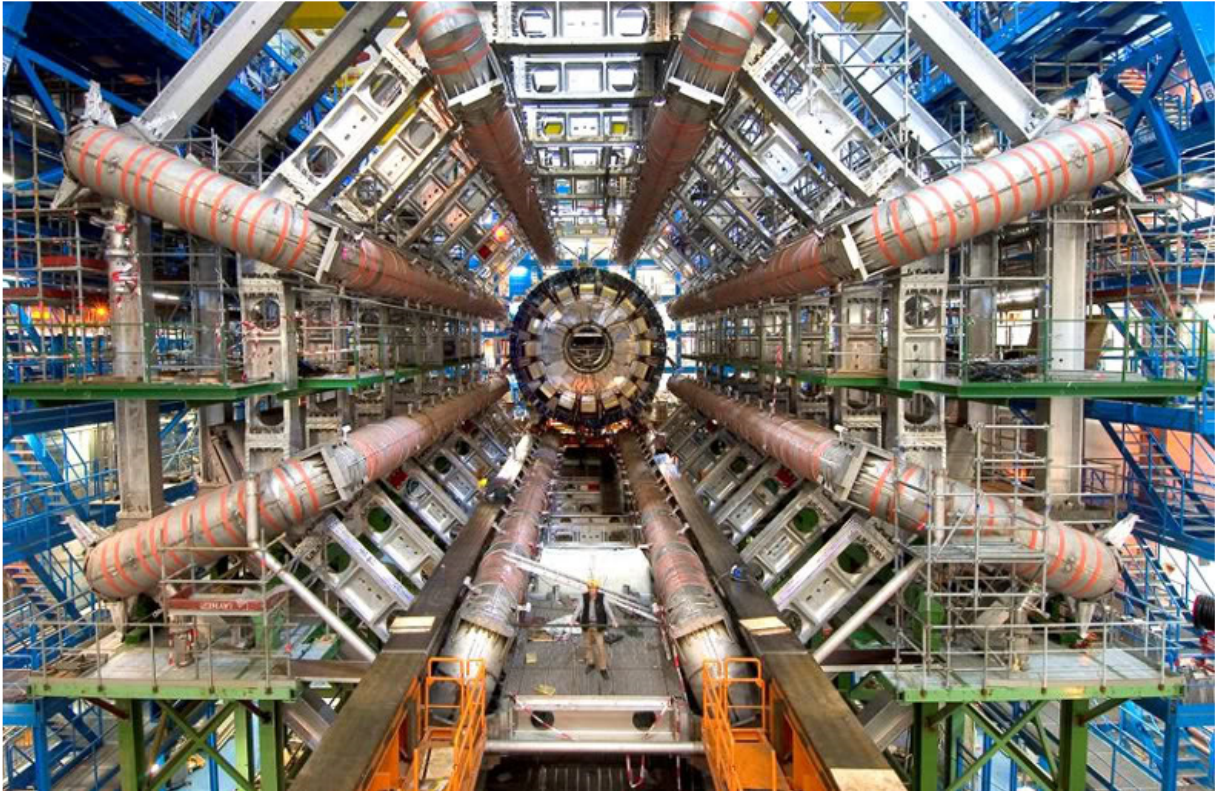
Collision Event at 7 TeV

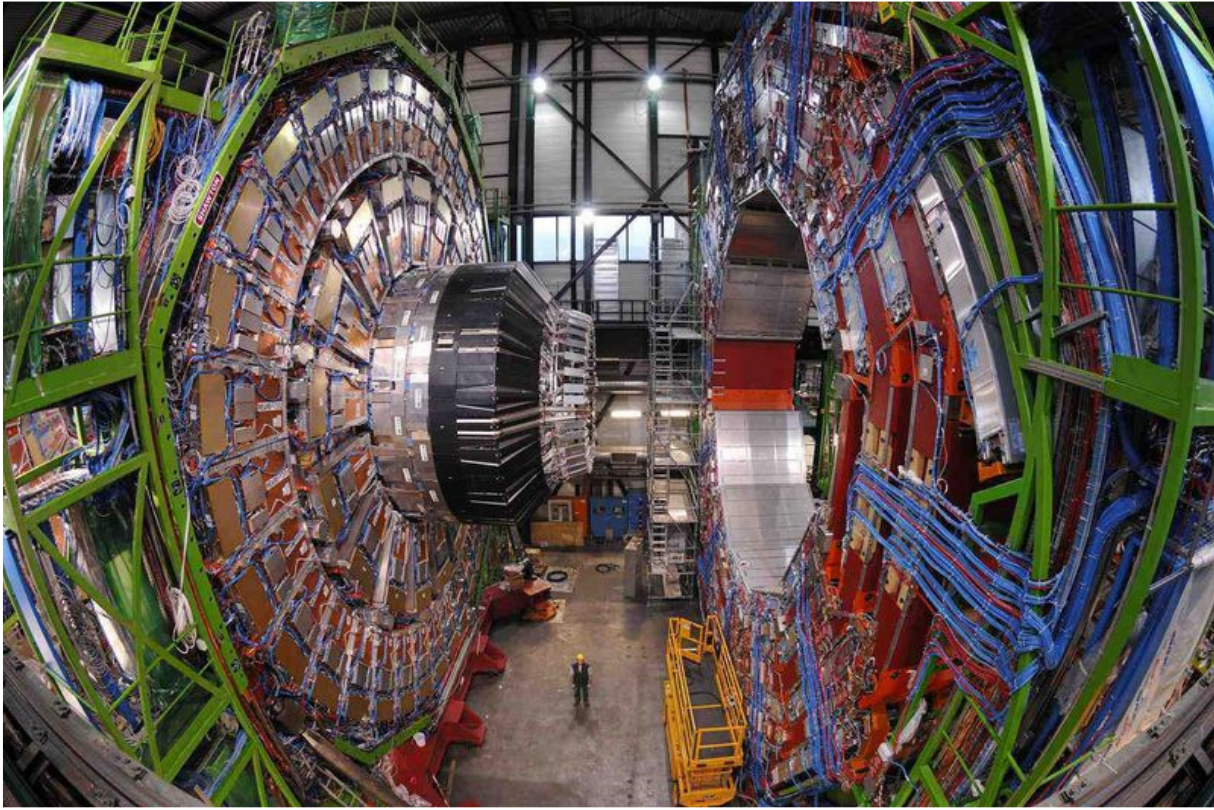


 **ATLAS**
EXPERIMENT

2010-03-30, 12:58 CEST
Run 152166, Event 316199

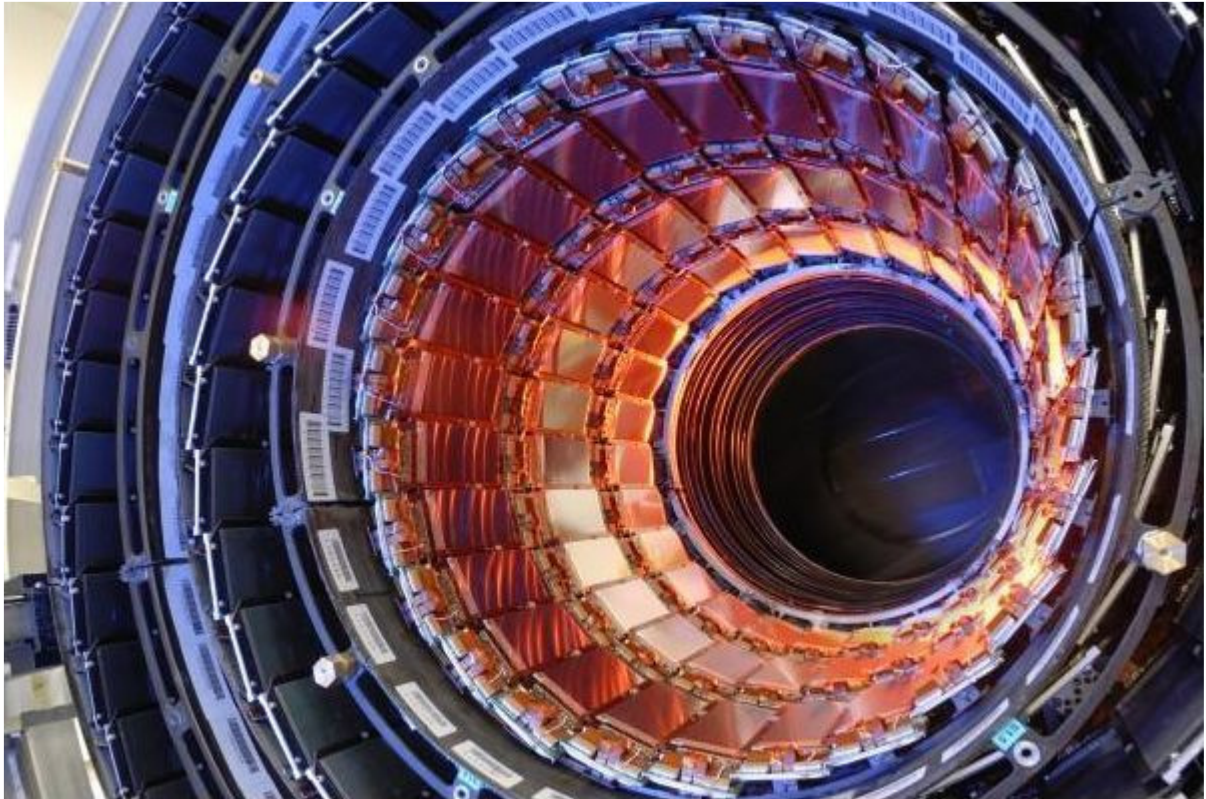
<http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html>





CMS
Detector

VERY FANCY DIGITAL CAMERA!



Underground Experiment Cavern



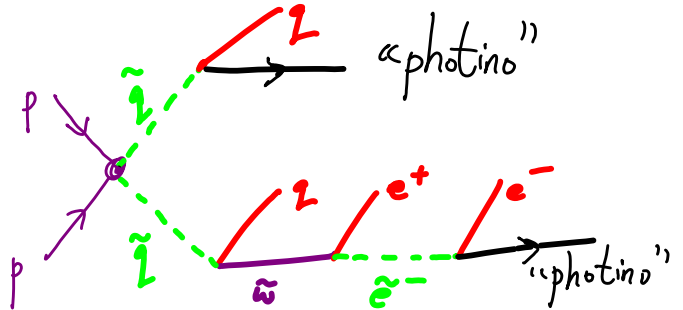
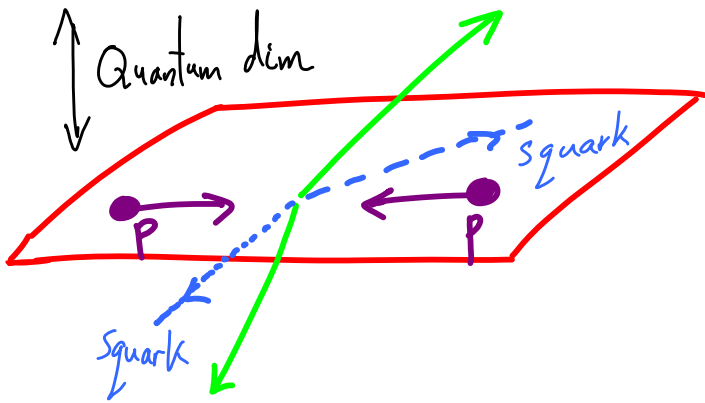
L.H.C. operations are now in
full swing - machine + detector
performance is spectacular!

Massive amount of information:

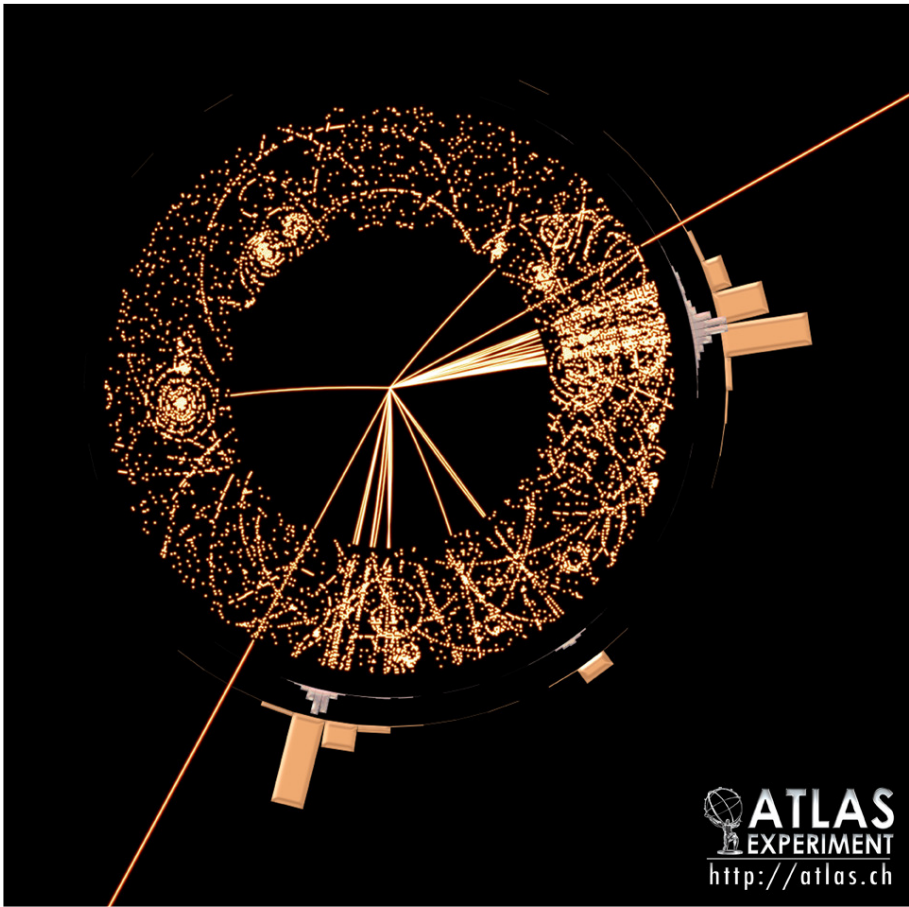
\sim Tbyte/s \rightarrow 10 Zetabytes/yr!

[Total other info on the planet ~ 10 Zb/yr].

SUSY at the LHC

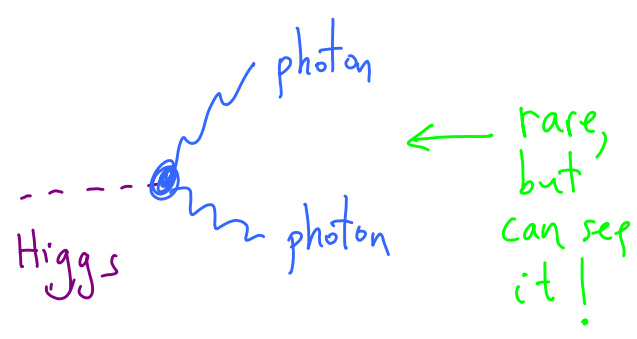
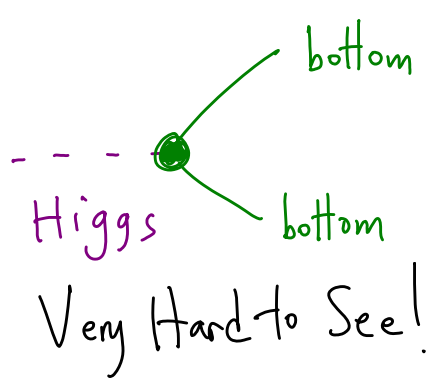
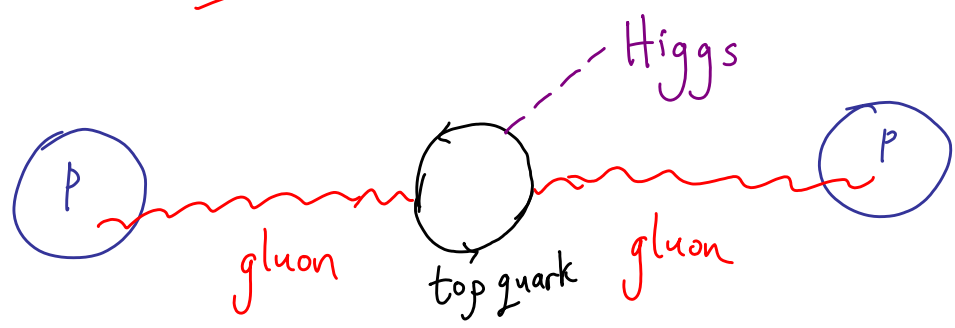


«Missing» Energy

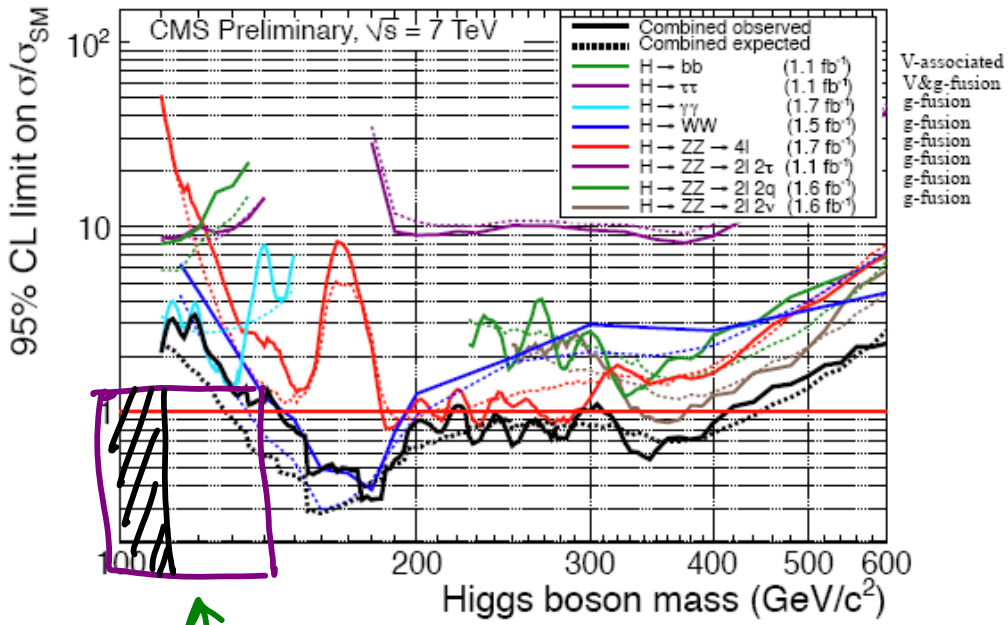


 **ATLAS**
EXPERIMENT
<http://atlas.ch>

Higgs at the LHC



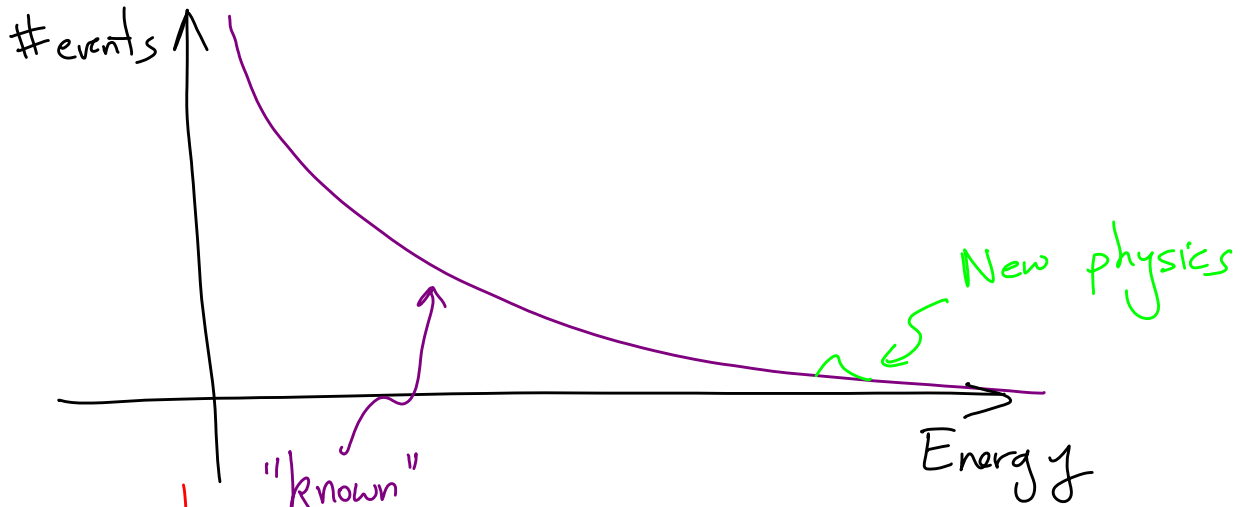
CMS Higgs Results



It's here somewhere!

- Big Story of 2011 -

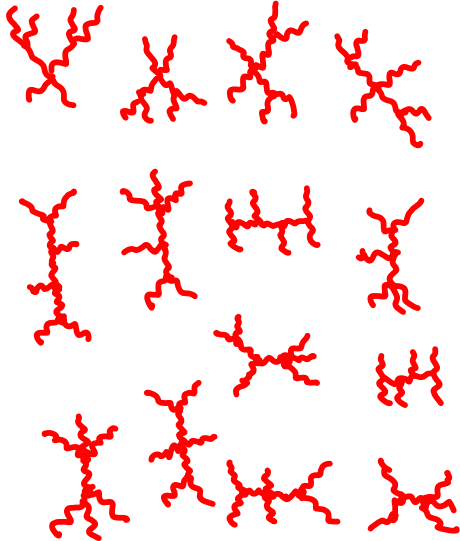
We are in the endgame
of the search for the Higgs!



Rates:

- ~ 1 billion collisions/sec
- ~ 10 top quarks/sec
- ~ 1 squark minute.

Feynman Gets Hard

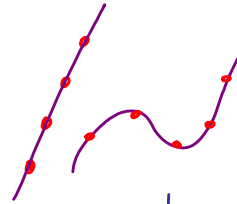
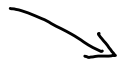
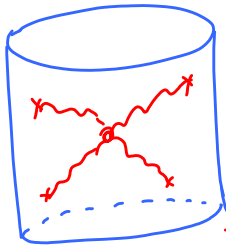


+ ...

220 Diagrams

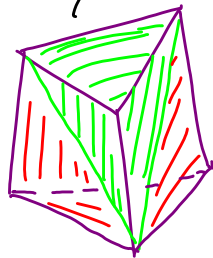
10's of thousands
of terms ...

Sitting Under our Noses for 60 yrs



Scattering Without Spacetime?

Twistor Theory



Algebraic Geometry

What Might We Know By

2020?

See "Nothing"?



"Impossible"!

See SUSY - Euphoria! First
extension of spacetime since Einstein.

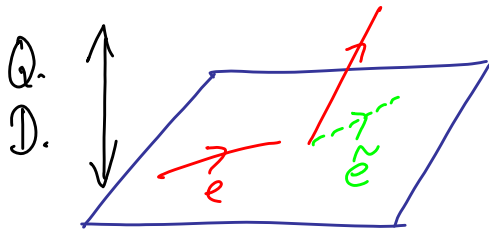
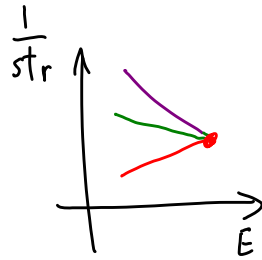
No "fine-tuning" for "why is gravity weak"?

[What about Λ ?]

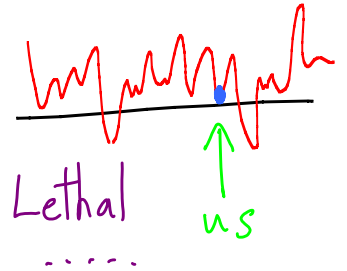
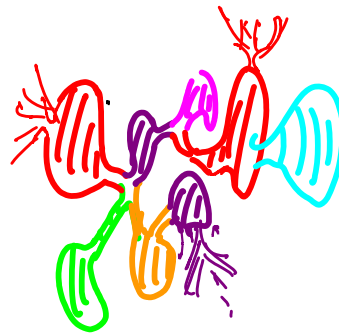
• Only Higgs + nothing else?

Very ~~confusing~~ Confusing. Evidence for
fine-tuning → just like  

Order



Chaos



Λ + weakness of gravity?

STAY TUNED

The Best Is Yet To Come!