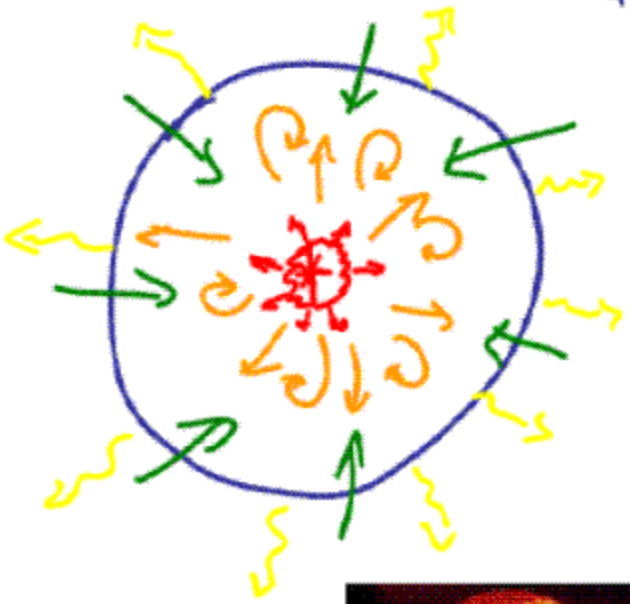
Physics 100 - March 30, 2009

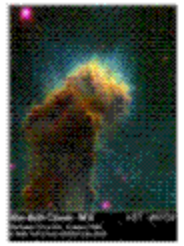
- Presentation groups ... Meet/plan to meet Soon

  http://doodle.com

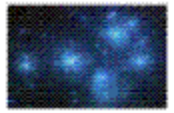
  Web utility I've found useful for setting up meetings with groups

Last time intimate relation between the large + small drive the stars and synthesize the elements

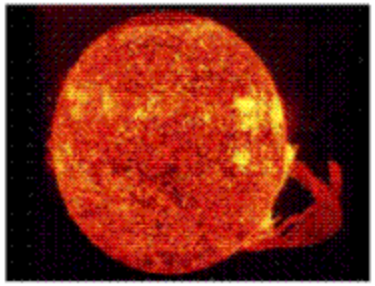




- gravity pulls in
- heat (radiation pressure) pushes out



- "Thermonuclear" fusion reactions in core

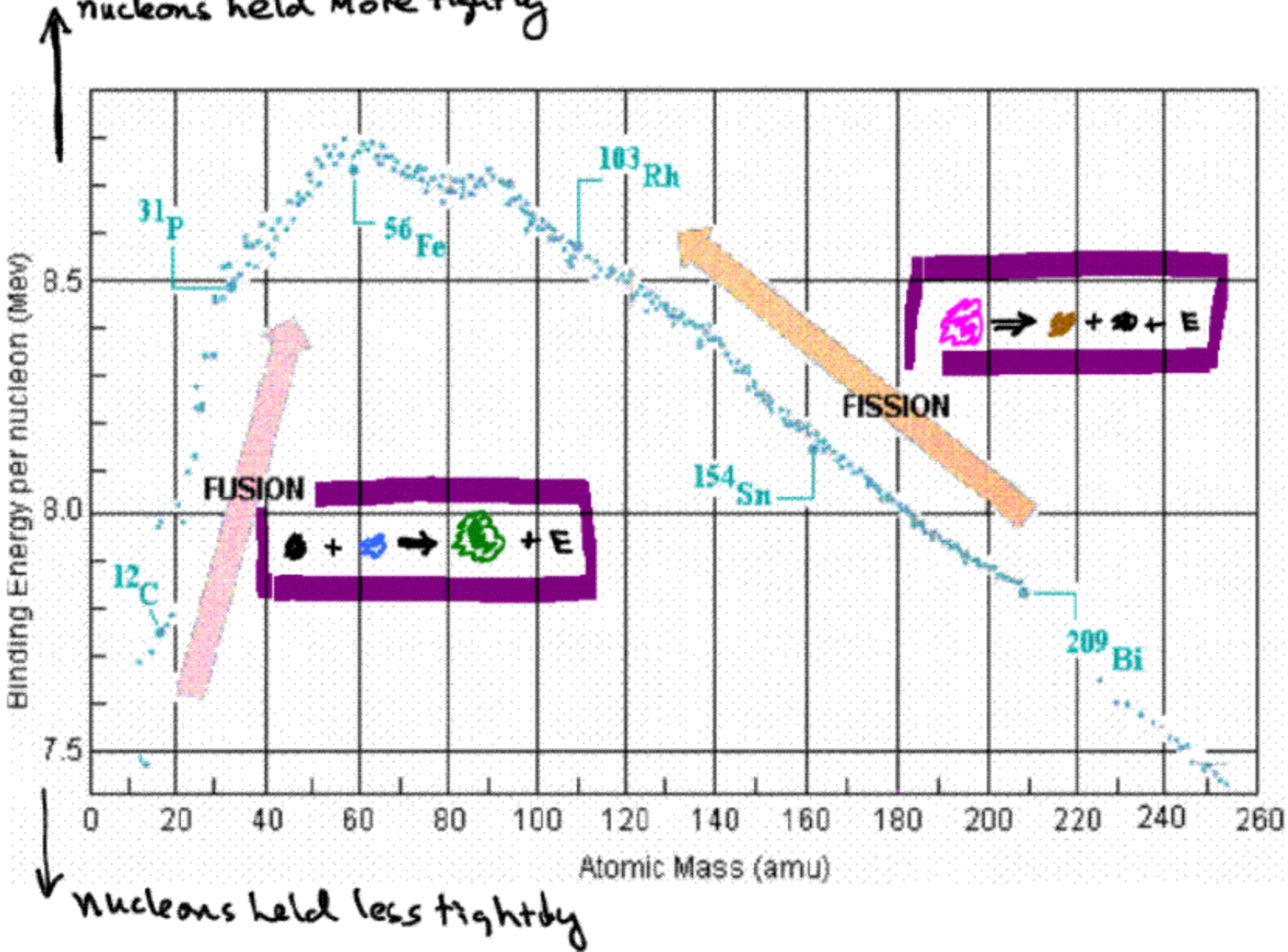


- stars w/ H → He but can work way up to ^{56}Fe

- Heavier elements formed in supernovae
- white dwarfs, neutron stars, Black Holes

Rotation comes from Conservation of "Angular Momentum"

Inherent Nuclear stability as function of nuclear size



Elements heavier than ^{56}Fe are synthesized in supernovae

$M < 8 M_\odot$ ⟶ planetary nebulae

↳ white dwarfs

$M > 8 M_\odot$ ⟶ neutron star (pulsar)

or

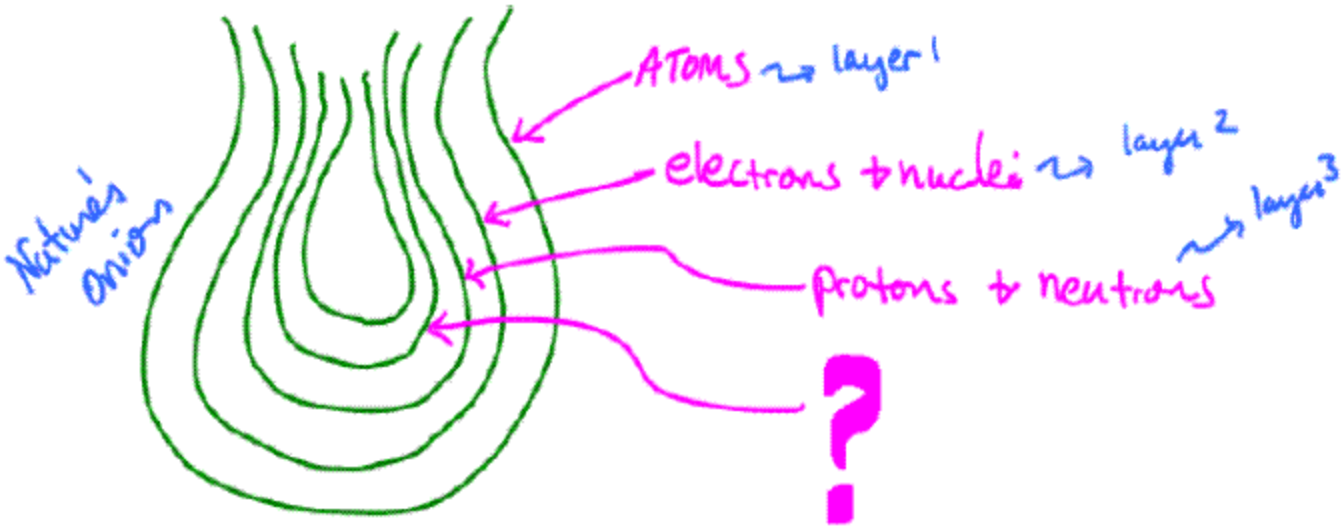
Black hole

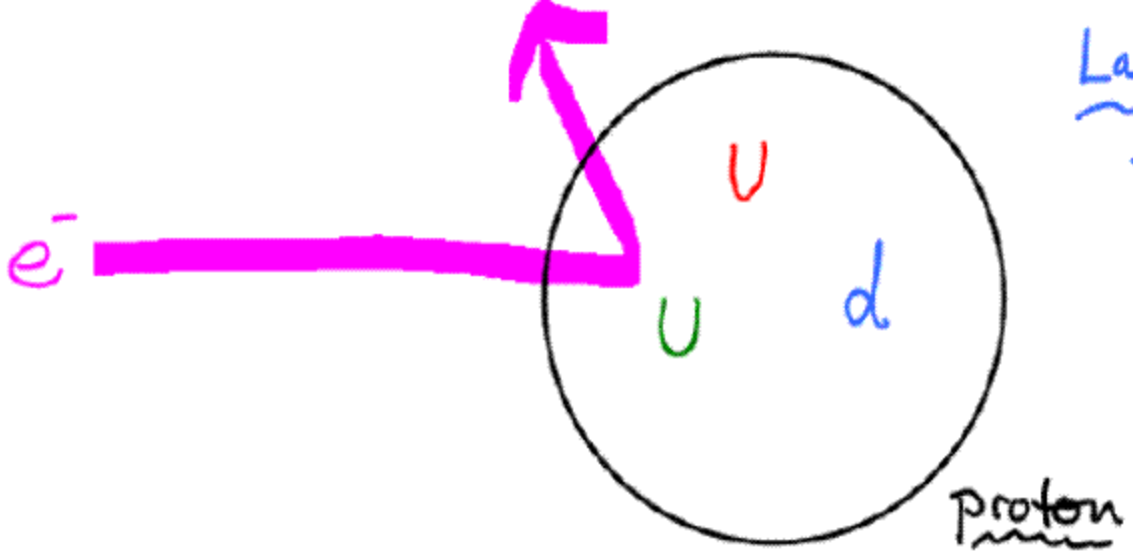
Dead shell of star held up by atomic shells

held up by neutrons

Black hole

Voyage into inner Space





Layer 4

The Subnuclear World

U ≡ up quark $q = +\frac{2}{3}|e|$

d ≡ down quark $q = -\frac{1}{3}|e|$

The STANDARD Model!

Particle (high energy) Physics

New Taxonomy of Particles
New way of looking at forces

a little overwhelming at 1st ...

Places to learn more:
Particle and nuclear physics links

http://pdg.lbl.gov

http://particleadventure.org

http://www.slac.stanford.edu/gen/edu/aboutslac.html

http://www.bnl.gov/bnlweb/sciindex.html

http://www.bnl.gov/rhic/

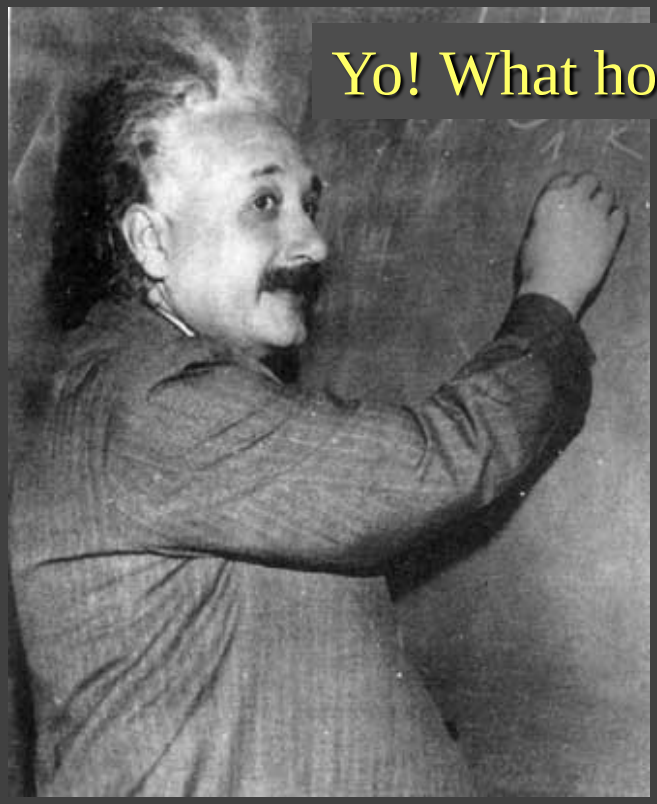
http://public.web.cern.ch/public/

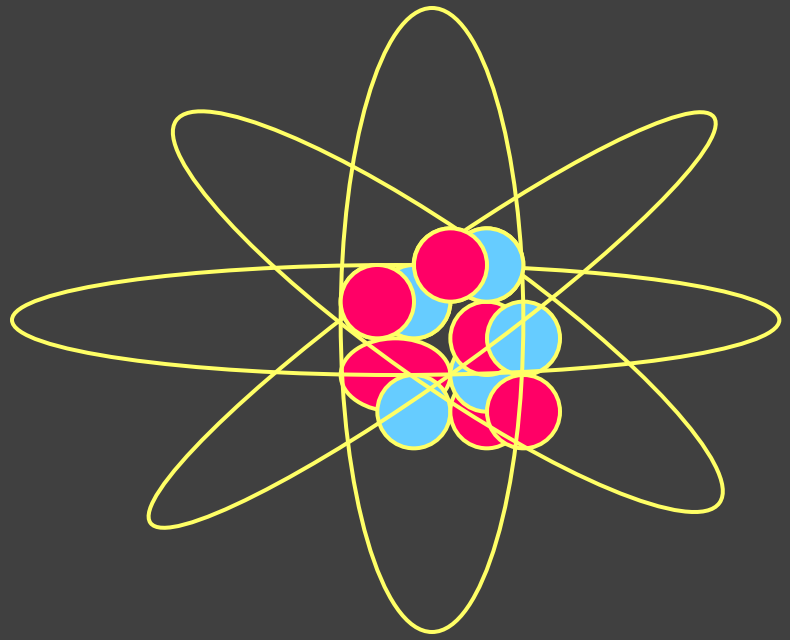
http://www.fnal.gov/

http://www.er.doe.gov/production/henp/np/index.html

http://www.science.doe.gov/hep/index.shtm

Inquiring minds want to know …

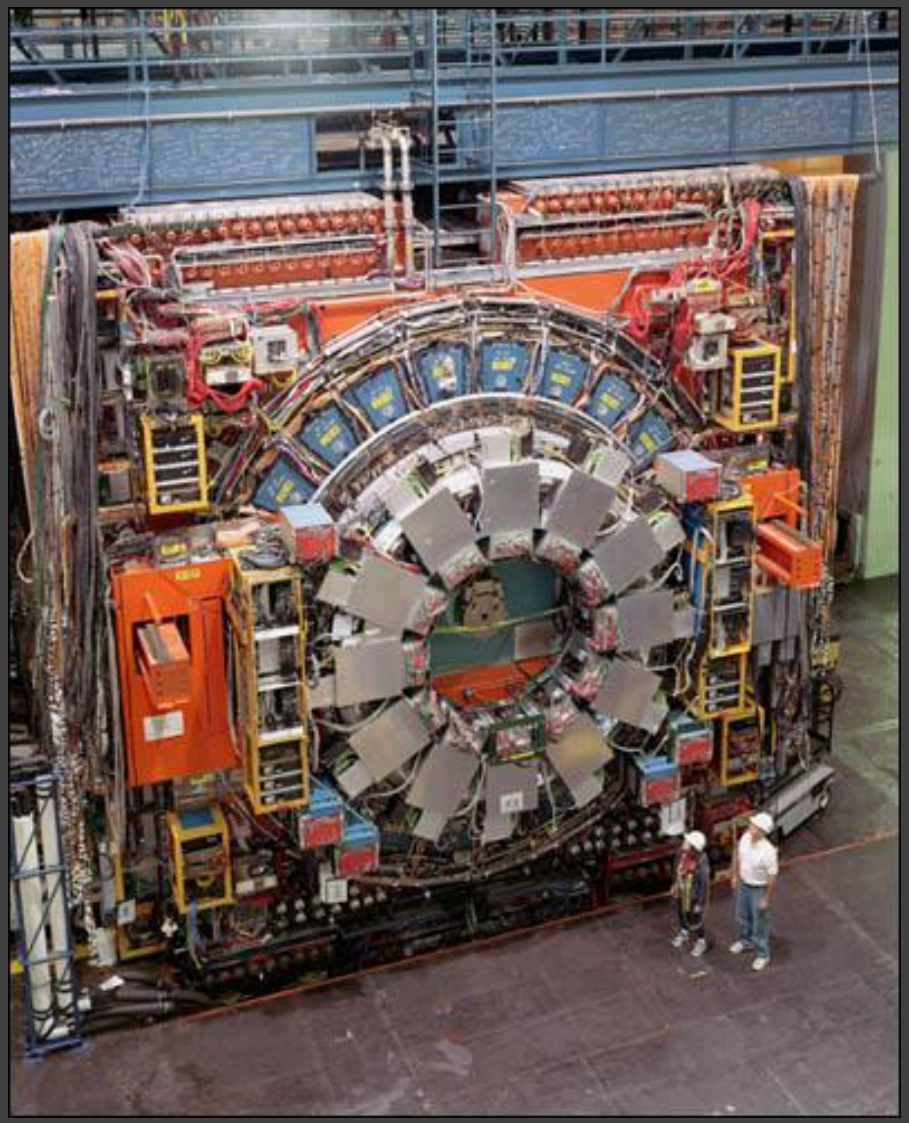




52
46
ACXIOM
27
HASTINGS

Fermi National Accelerator Laboratory (near Chicago)

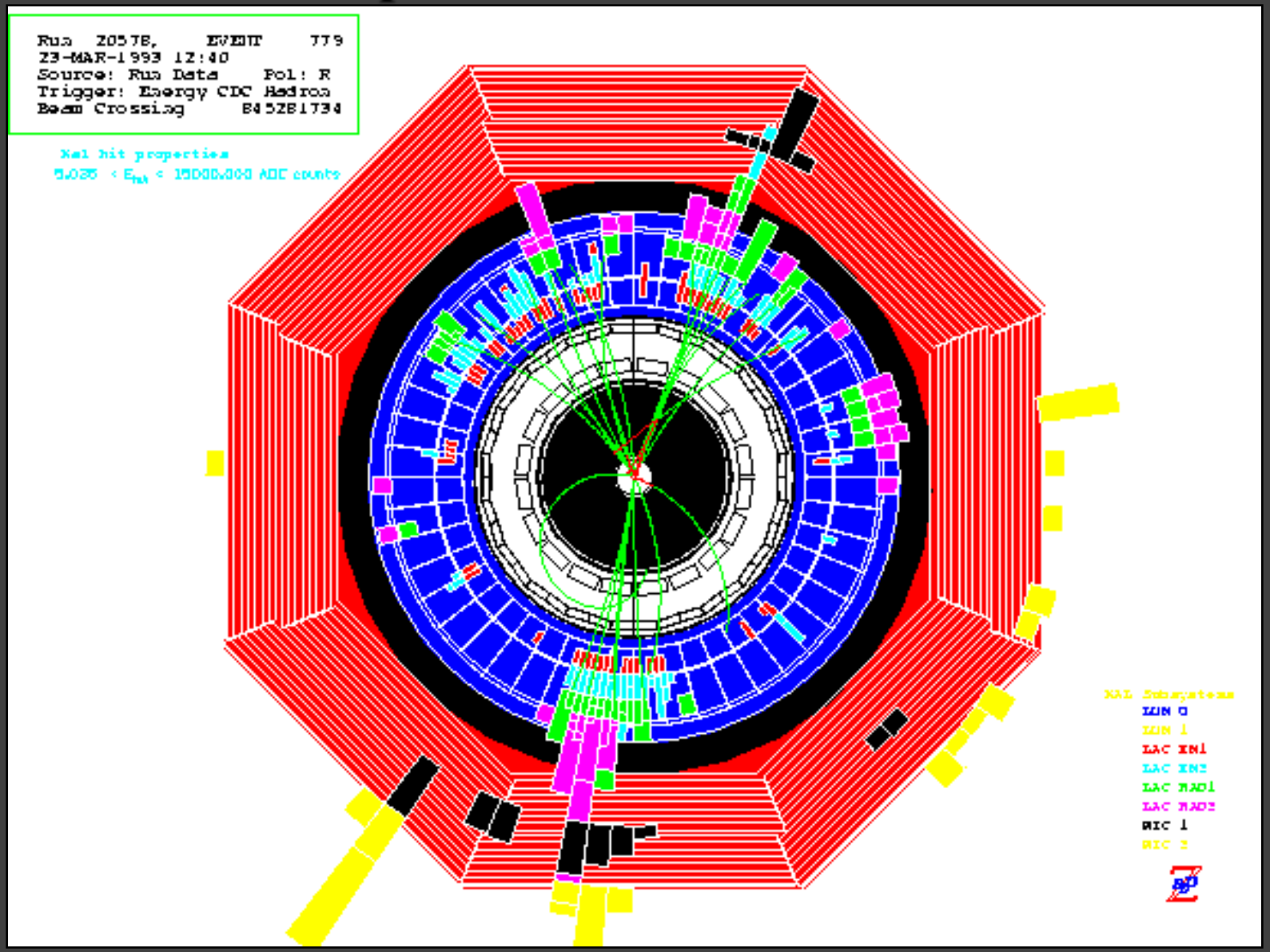
CDF



Minos

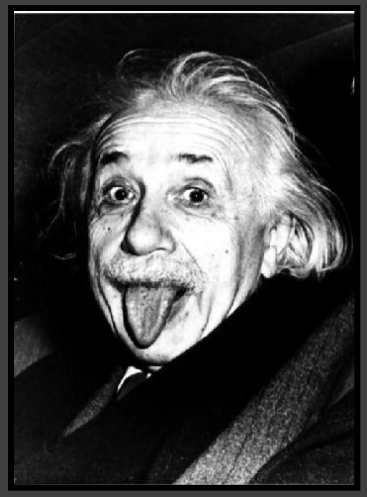
Stanford Linear Accelerator Center

Event display from the SLD experiment at SLAC



What forces exist in nature?

What is a force?



How do they interact?

How do forces change with energy or temperature?

How has the universe evolved?

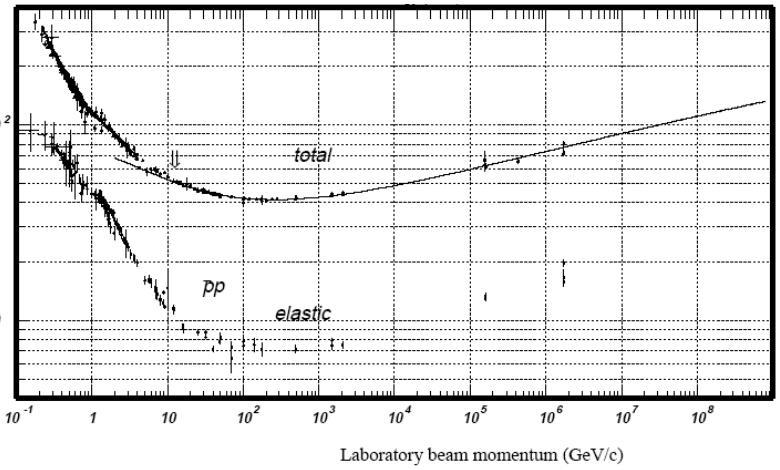
π^0

$I^G(J^{PC}) = 1^-(0^-+)$

Mass $m = 134.9766 \pm 0.0006$ MeV (S = 1.1)
$m_{\pi^\pm} - m_{\pi^0} = 4.5936 \pm 0.0005$ MeV
Mean life $\tau = (8.4 \pm 0.6) \times 10^{-17}$ s (S = 3.0)
$c\tau = 25.1$ nm

For decay limits to particles which are not established, see the appropriate Search sections (A^0 (axion), and Other Light Boson (X^0) Searches, etc.).

π^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
2γ		(98.798 ± 0.032) %	S=1.1	67
$e^+e^-\gamma$		(1.198 ± 0.032) %	S=1.1	67
γ positronium		(1.82 ± 0.29) × 10^{-9}		67
$e^+e^+e^-e^-$		(3.14 ± 0.30) × 10^{-5}		67
e^+e^-		(6.2 ± 0.5) × 10^{-8}		67
4γ		< 2 × 10^{-8}	CL=90%	67
$\nu\bar{\nu}$	[a]	< 8.3 × 10^{-7}	CL=90%	67
$\nu_e\bar{\nu}_e$		< 1.7 × 10^{-6}	CL=90%	67
$\nu_\mu\bar{\nu}_\mu$		< 3.1 × 10^{-6}	CL=90%	67
$\nu_\tau\bar{\nu}_\tau$		< 2.1 × 10^{-6}	CL=90%	67
$\gamma\nu\bar{\nu}$		< 6 × 10^{-4}	CL=90%	–
Charge conjugation (C) or Lepton Family number (LF) violating modes				
3γ	C	< 3.1 × 10^{-8}	CL=90%	67
μ^+e^-	LF	< 3.8 × 10^{-10}	CL=90%	26
μ^-e^+	LF	< 3.4 × 10^{-9}	CL=90%	–
$\mu^+e^- + \mu^-e^+$	LF	< 1.72 × 10^{-8}	CL=90%	26



week ending
4 JUNE 2004

→ $\omega Y(1S)$

E. Coan,[2] Y. S. Gao,[2] F. Liu,[2]
Dorjkhaidav,[3] R. Mountain,[3]
. Mahmood,[4] S. E. Csorna,[5]
pas,[7] A. Shapiro,[7] W. M. Sun,[7]

S 30 MARCH 1998

ass

mendolia,[27] D. Amidei,[20] J. Antos,[33]
[8] M. Atac,[7] P. Azzi-Bacchetta,[25]

1 MARCH 1999

ıe Measurement
miokande

Itow,[1] T. Kajita,[1] J. Kameda,[1]

26 MAY 1975

e $\psi(3095)$†

ischer, D. Fryberger, G. Hanson,
, D. Lyon, C. C. Morehouse,
R. F. Schwitters,

yford, California 94305

G. Golhaber, J. A. Kadyk,
Trilling, J. S. Whitaker,

lifornia, Berkeley, California 94720

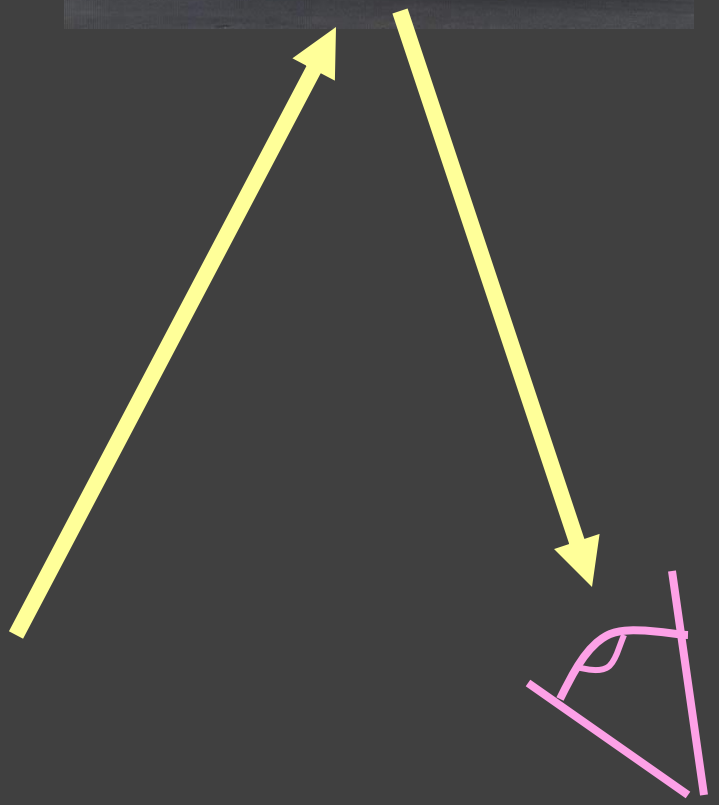
near 3095 MeV. The

Mini-Ph.D. – Quantum Mechanics 101

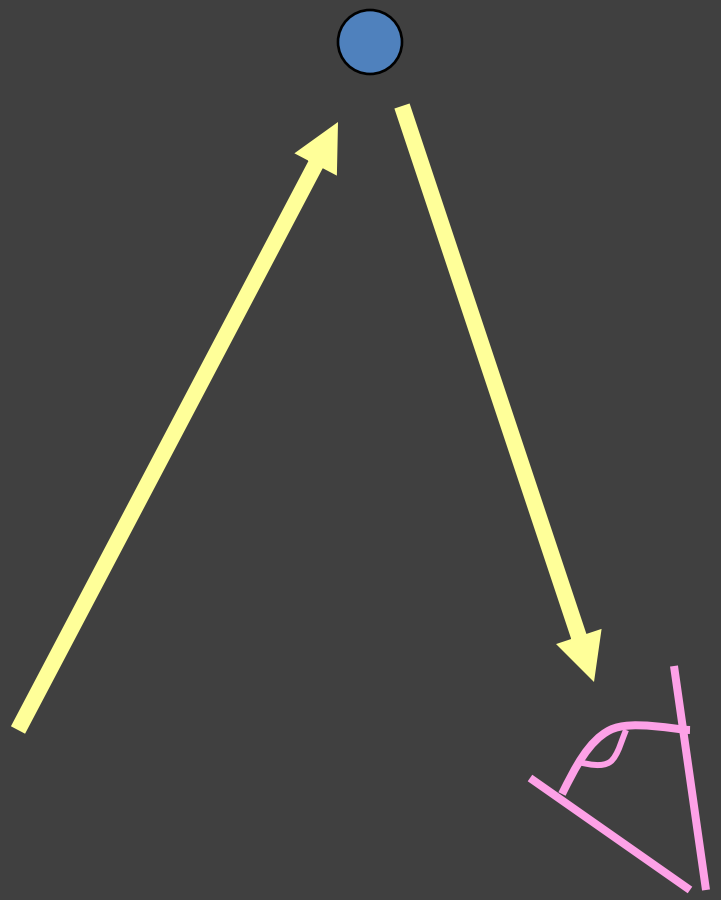
Lesson 1:

Size actually does matter.

Determine the postion and velocity of a car … no problem

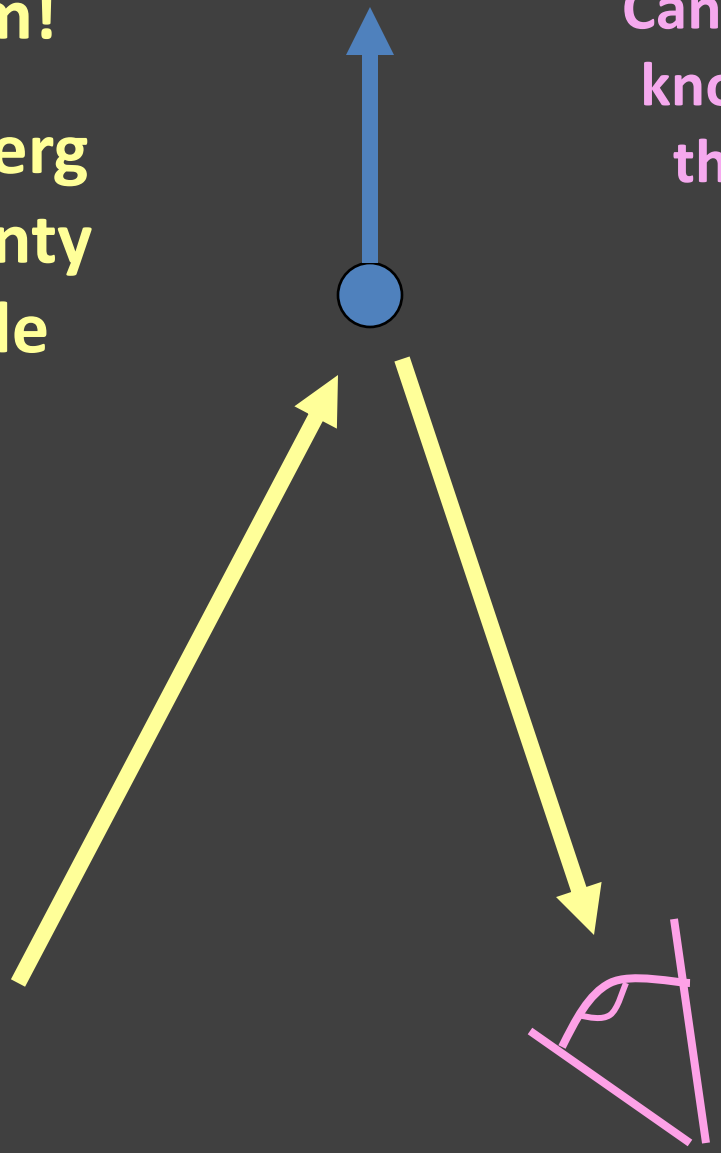


Determine the postion and velocity of a small particle … no problem



Problem!

Heisenberg uncertainty principle



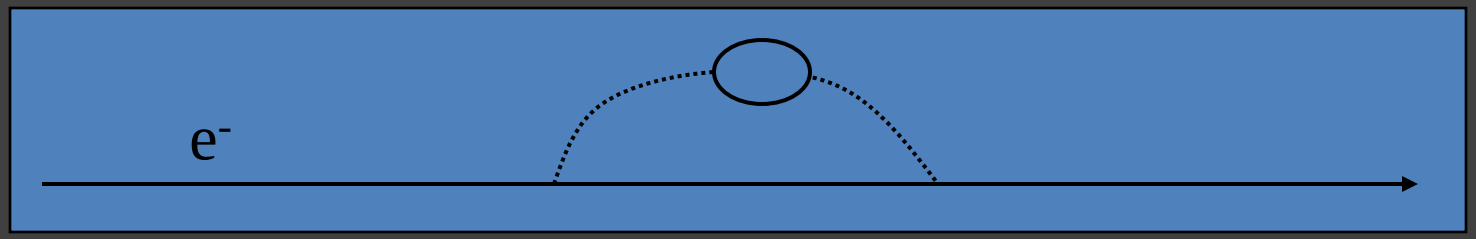
Cannot have perfect knowledge of both the position and velocity

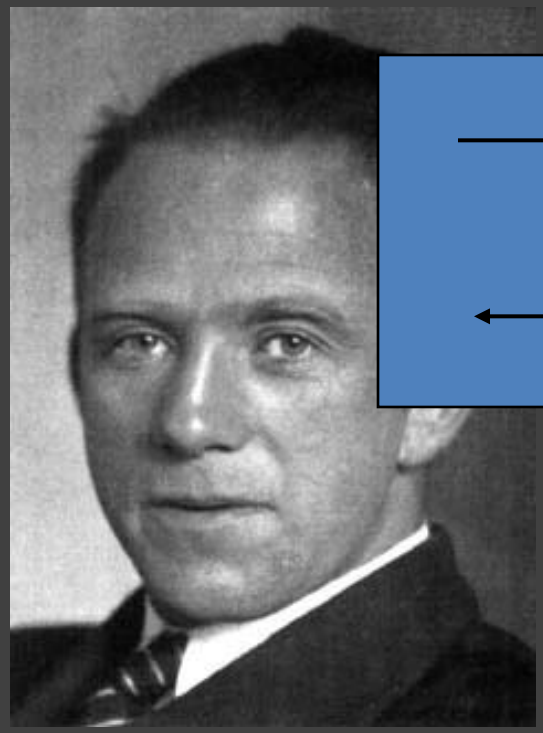
Heisenberg

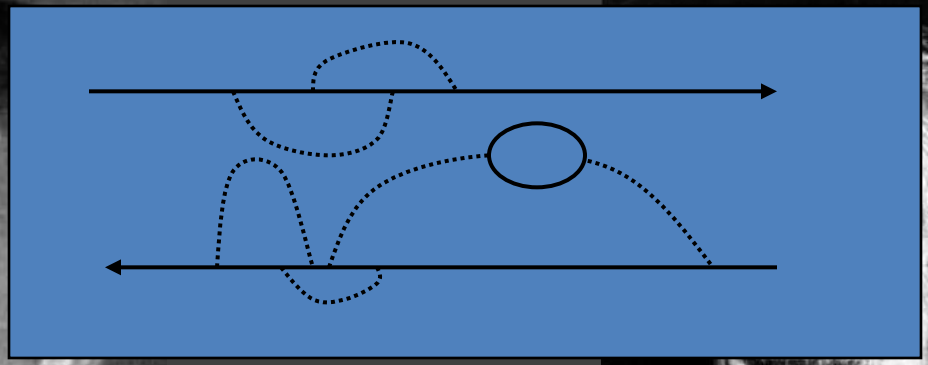
The fundamental nature of forces: virtual particles

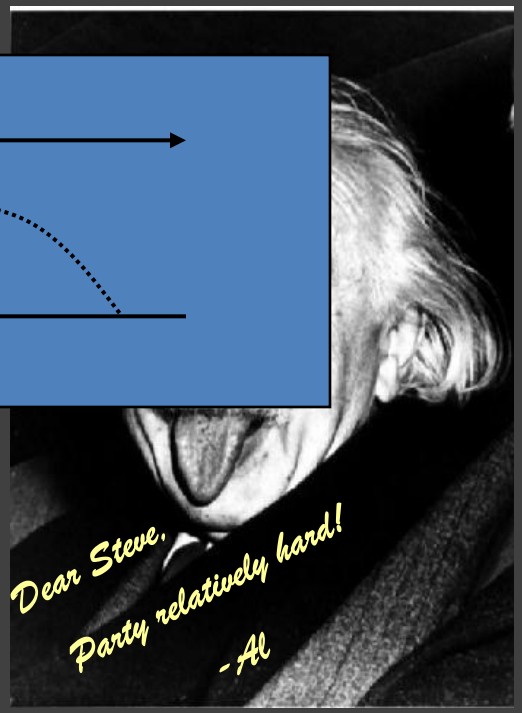
$\Delta E \Delta t \approx h$ Heisenberg

$E = mc^2$ Einstein





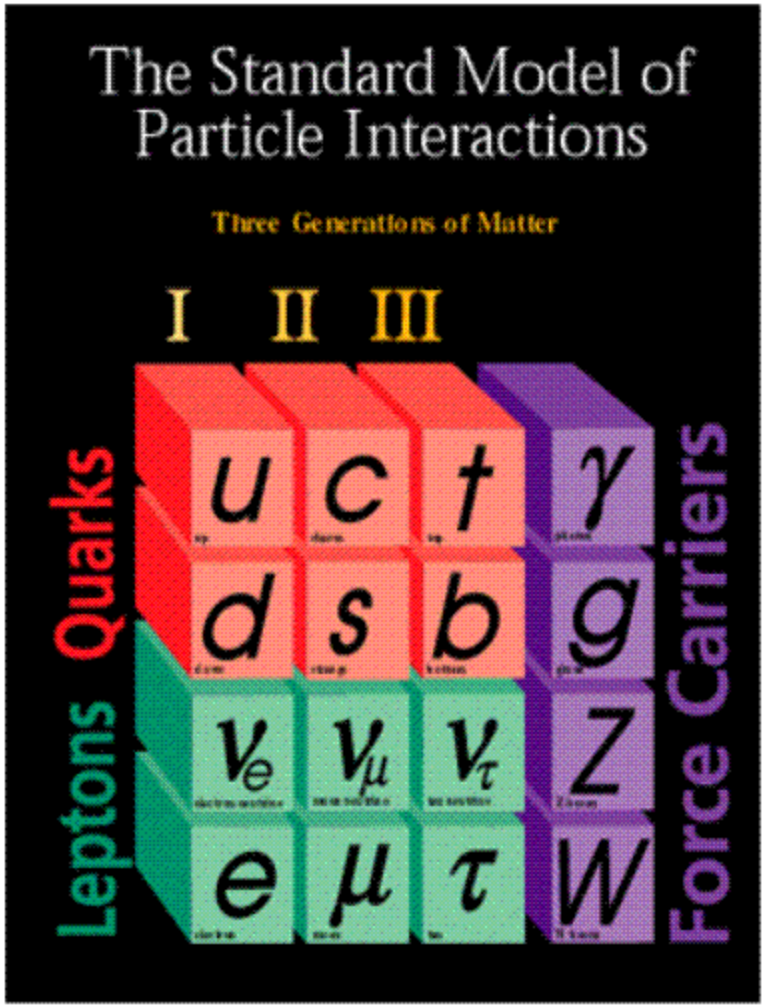




Quantum Field Theory → Exchange force

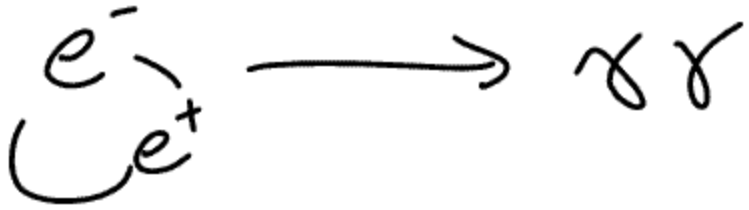
Force	*Source*	*Range*	*Strength*
Gravitation	mass	infinite	10^{-39}
Electromagnetism	Electric charge	infinite	10^{-2}
Strong nuclear	Color charge	10^{-15} m	1
Weak nuclear	Weak charge	10^{-18} m	10^{-5}

The "Fundamental" particles



Anti Matter

e^- ~ e^+ positron
Anti-electron



All particles have antiparticles

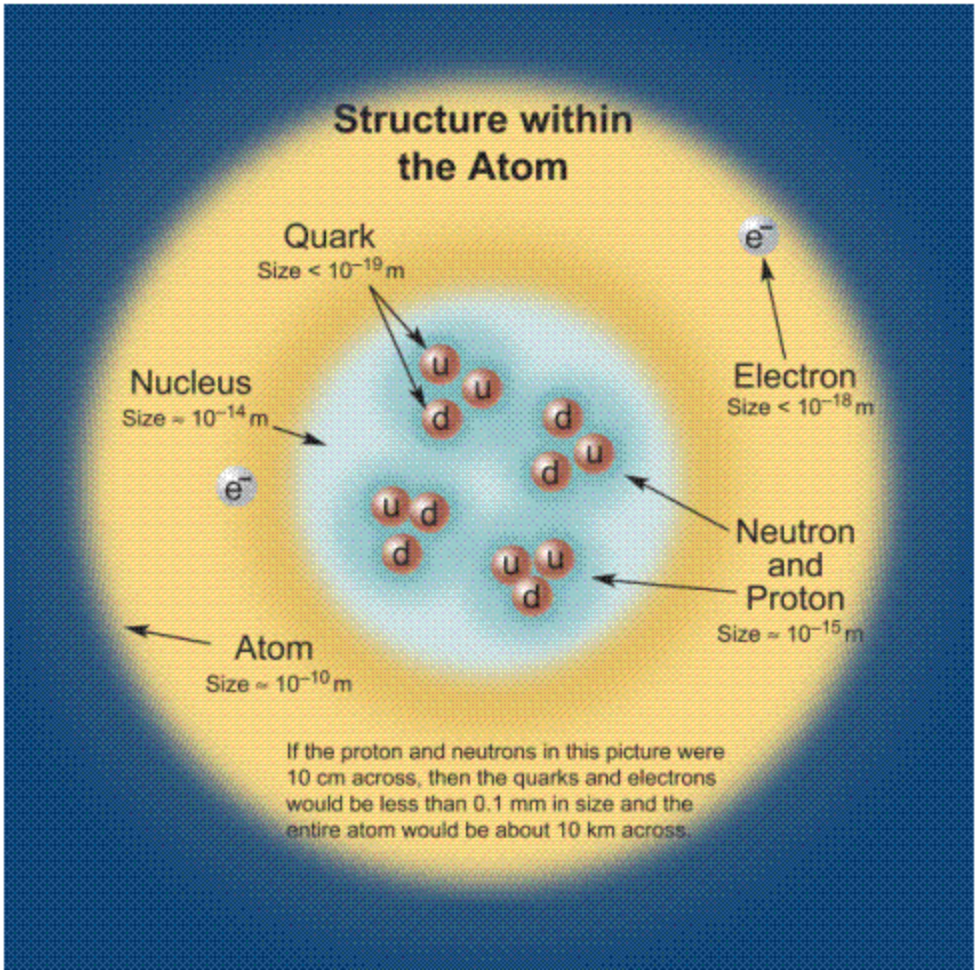
Why is universe made of matter rather than antimatter?
We don't know why this is true ... yet.
Active area of study ... believed it is probably due to a basic matter-antimatter asymmetry in one of the forces of nature.

→ Standard Model of Particle Physics

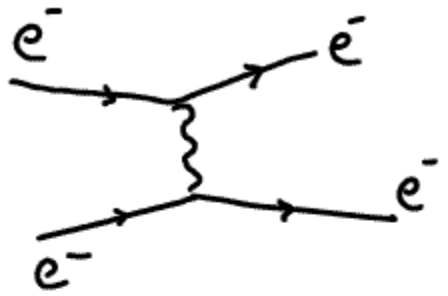
http://particleadventure.org/

http://hepwww.rl.ac.uk/Pub/Phil/ppintro/ppintro.html

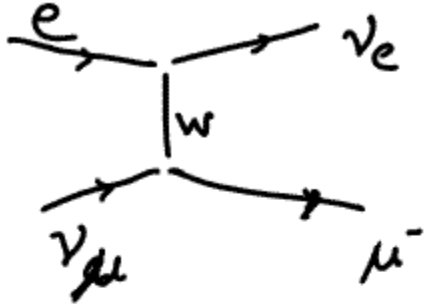
Decent online sources of information - please read



$\Delta E \Delta T \gtrsim \hbar$



Electromagnetism



weak interaction

Strong force

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.39	–1
W^+ W bosons	80.39	+1
Z^0 Z boson	91.188	0

Strong (color) spin =1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60

other particles

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
These are a few of the many types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	**uud**	1	0.938	1/2
$\bar{\mathbf{p}}$	antiproton	$\bar{\mathbf{u}}\bar{\mathbf{u}}\bar{\mathbf{d}}$	–1	0.938	1/2
n	neutron	**udd**	0	0.940	1/2
Λ	lambda	**uds**	0	1.116	1/2
Ω^-	omega	**sss**	–1	1.672	3/2

Mesons $q\bar{q}$

Mesons are bosonic hadrons
These are a few of the many types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$\mathbf{u\bar{d}}$	+1	0.140	0
$\mathbf{K^-}$	kaon	$\mathbf{s\bar{u}}$	–1	0.494	0
ρ^+	rho	$\mathbf{u\bar{d}}$	+1	0.776	1
B^0	B-zero	$\mathbf{d\bar{b}}$	0	5.279	0
η_c	eta-c	$\mathbf{c\bar{c}}$	0	2.980	0

quarks

u	c	t
d	s	b

leptons

e	μ	τ
ν_e	ν_μ	ν_τ

Gauge bosons

W, Z, g, γ, G

Strong interaction

Hadrons

Baryons qqq $q\bar{q}$ mesons

p = uud

n = udd

$K = u\bar{s}$ or $\bar{u}s$

$\pi = u\bar{d}$ or $\bar{u}d$

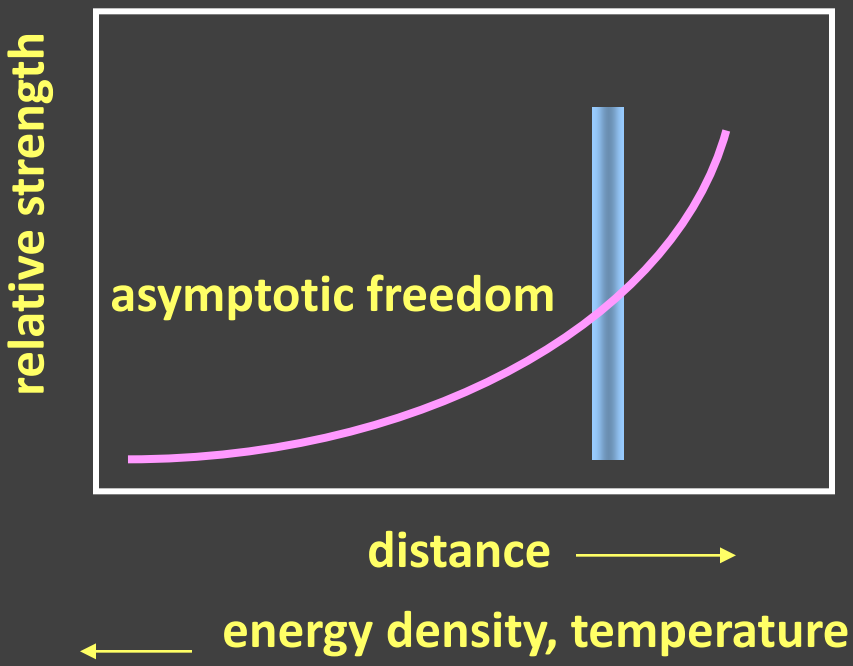
nuclei

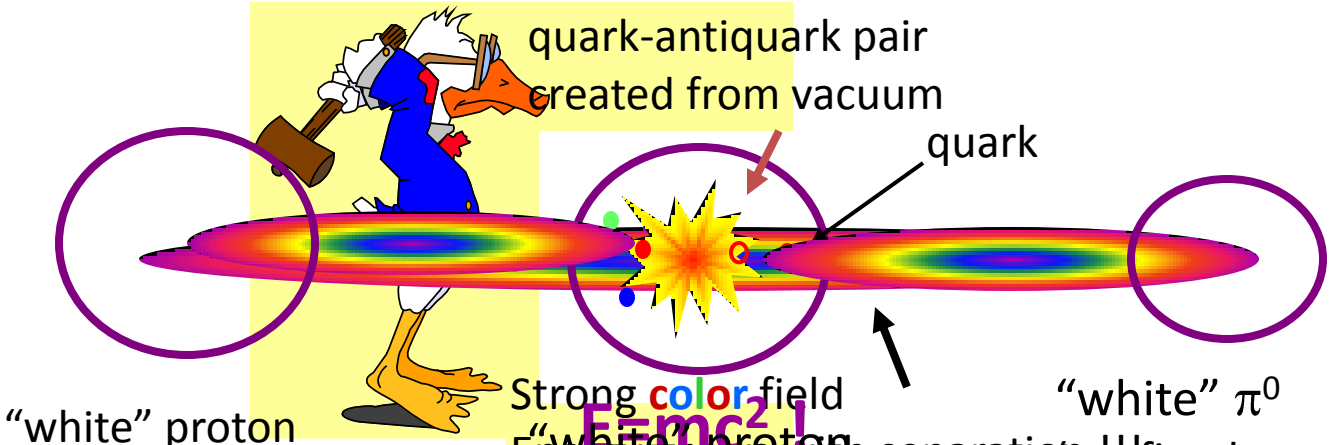
Electromagnetic interaction

atoms

Quantum Chromodynamics QCD

Why bare quarks have never been observed.



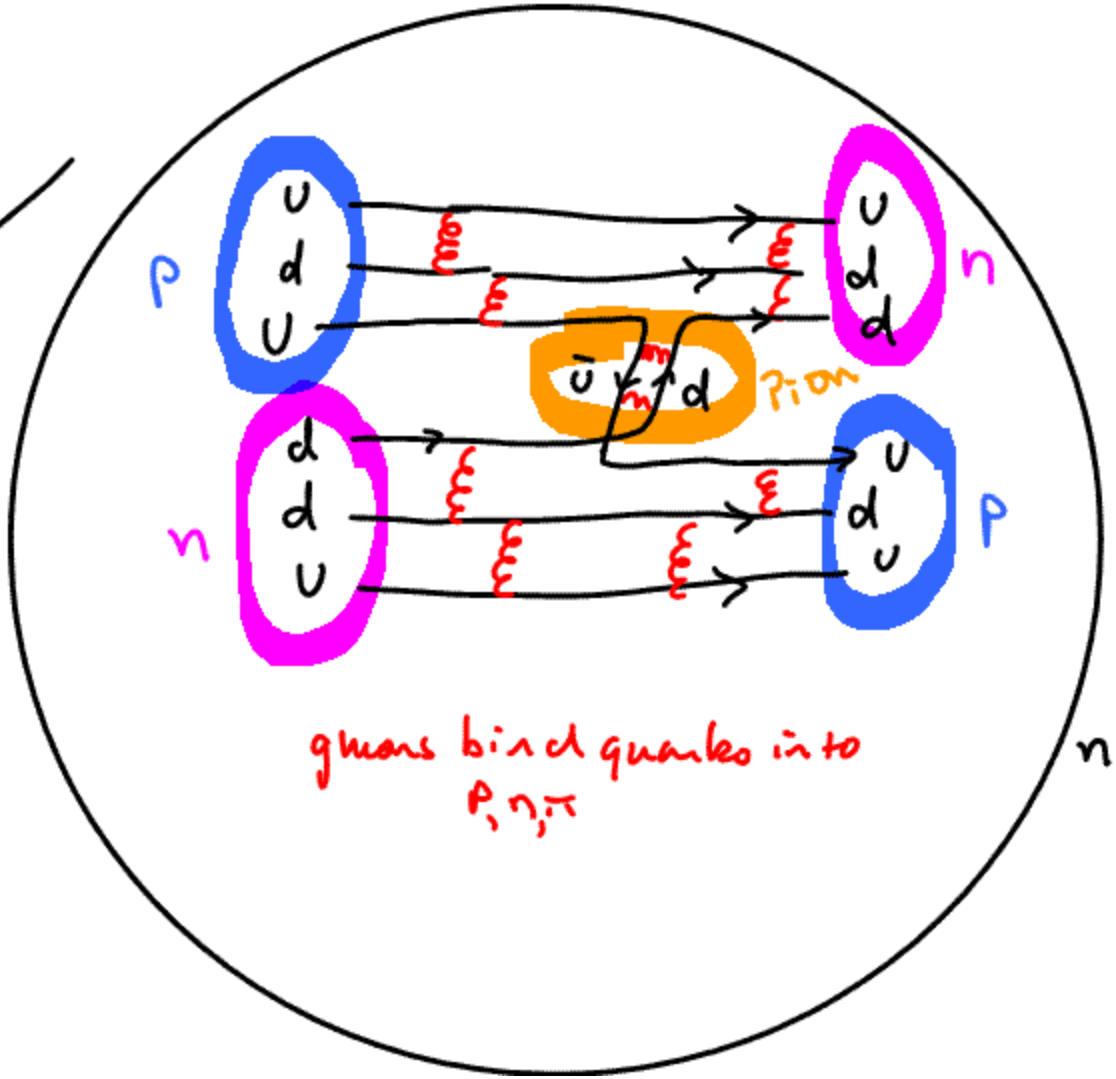


$E = mc^2$!

Thanks to Mike Lisa (OSU) for parts of this animation

nucleon-nucleon force – exchange of π (pion)

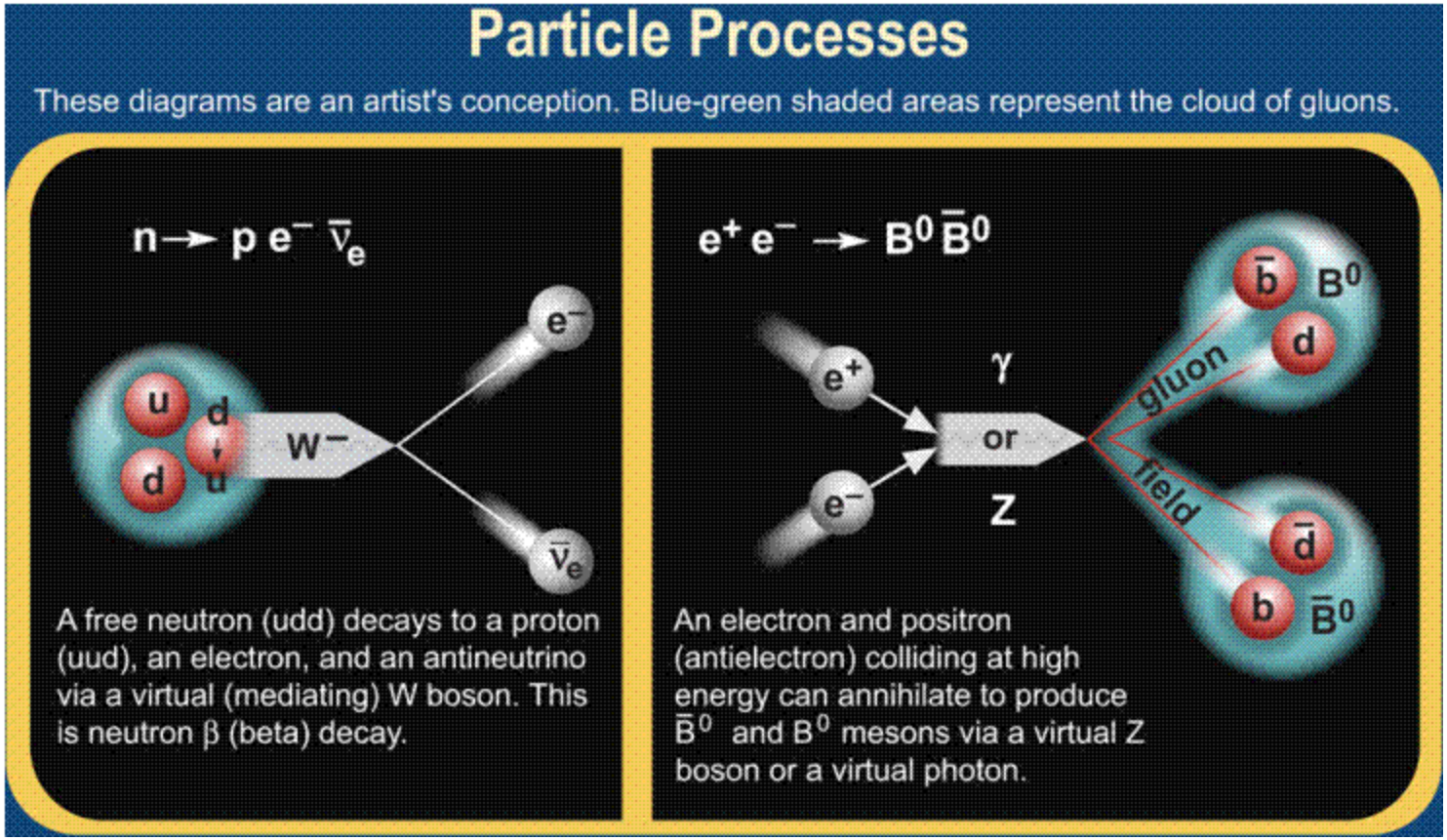
fine point for completeness



gluons bind quarks into p, n, π

nucleus

Example


Particle Processes
These diagrams are an artist's conception. Blue-green shaded areas represent the cloud of gluons.
n → p e⁻ ν̄e
u
d
d
u
W⁻
e⁻
ν̄e
A free neutron (udd) decays to a proton (uud), an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β (beta) decay.
e⁺ e⁻ → B⁰ B̄⁰
e⁺
e⁻
γ
or
Z
gluon field
b̄
B⁰
d
d̄
b
B̄⁰
An electron and positron (antielectron) colliding at high energy can annihilate to produce B̄⁰ and B⁰ mesons via a virtual Z boson or a virtual photon.

The Vacuum

-R. Kolb

Much ado about NOTHING:

Nothing is something

Nothing has energy

Nothing interacts with something