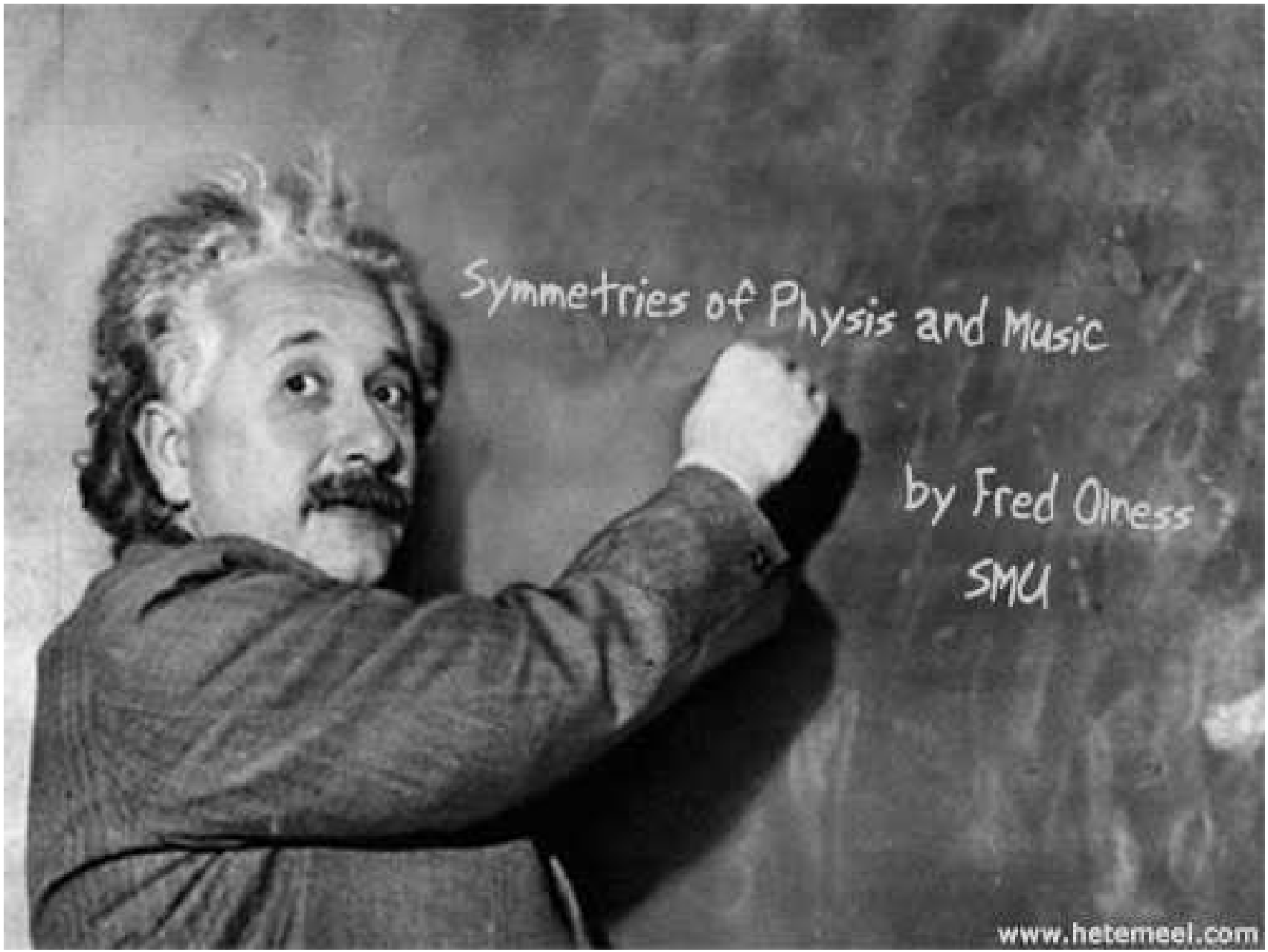
"Symmetries of Physics and of Music

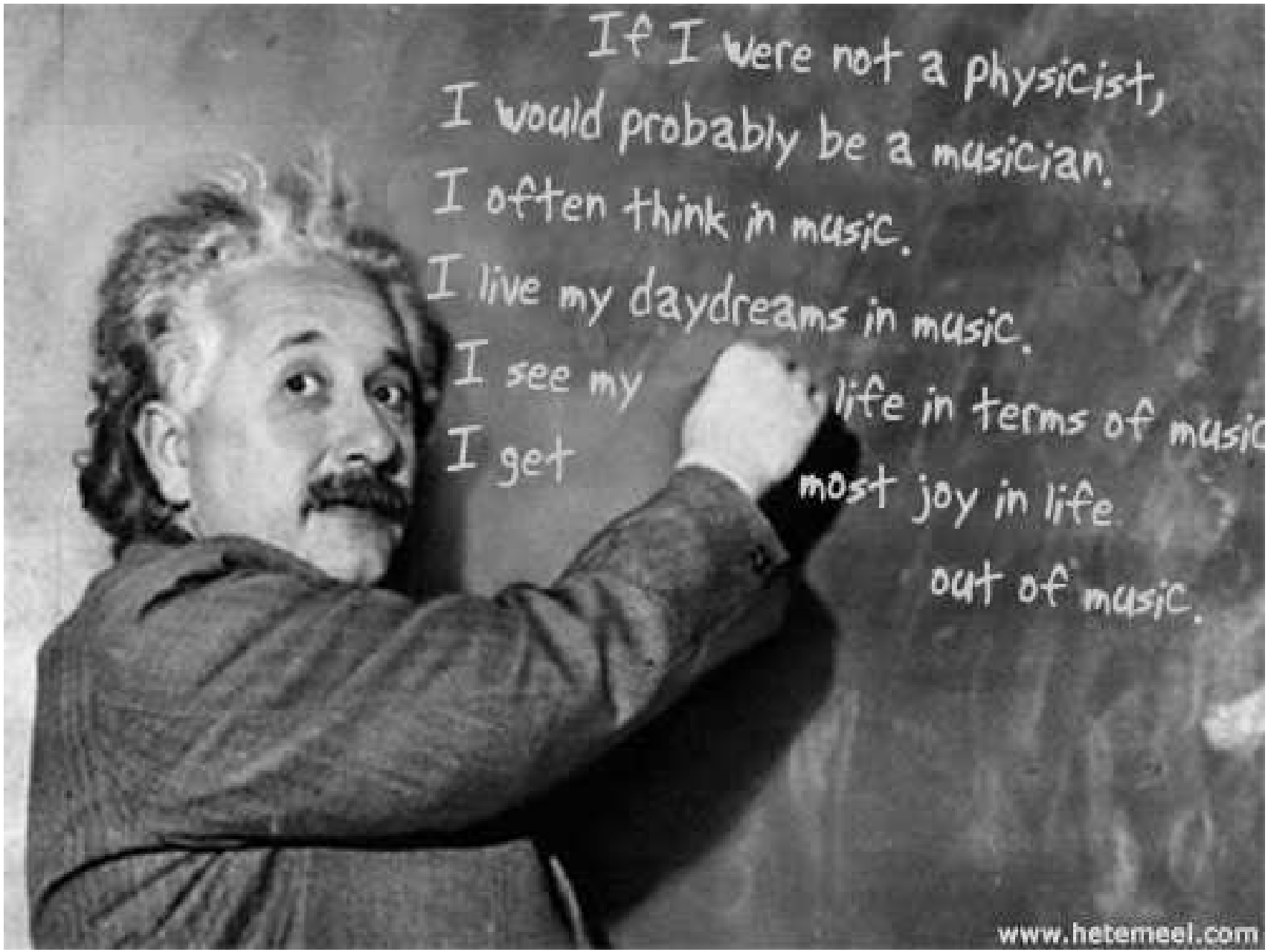
What are we trying to discover at the LHC

Fred Olness

SMU

SMU QuarkNet Program
June 2006


Symmetries of Physis and Music
by Fred Olness
SMU
www.hetemeel.com


If I were not a physicist,
I would probably be a musician.
I often think in music.
I live my daydreams in music.
I see my life in terms of music
I get most joy in life
out of music.
www.hetemeel.com

“If I were not a physicist, I would probably be a musician. I often think in music. I live my daydreams in music. I see my life in terms of music. ... I get most joy in life out of music.”

When Albert Einstein was asked if his interest in music helped with the development of the theory of relativity, he responded: “It occurred to me by intuition, and music was the driving force behind that intuition. My discovery was the result of musical perception.”


TRANS-ELECTRONIC MUSIC PRODUCTIONS, INC. PRESENTS
SWITCHED-ON BACH
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BRANDENBURG CONCERTO NO. 3/"AIR ON A G STRING"
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PRELUDES AND FUGUES FROM "THE WELL-TEMPERED CLAVIER"
WENDY CARLOS PERFORMING
ON THE MOOG SYNTHESIZER

Age-Old Questions Physicsts Ask

What are the fundamental constitutients which comprise the universe?

How do they interact?

What holds them together?

Who will win the NBA Championship?

Periodic Table
Circa 400 BC

Sidney Harris

"The periodic table."

Compact

Easy to remember

Fits on a T-Shirt

The Periodic Table of the Elements

Periodic Table
Circa 1900 AD

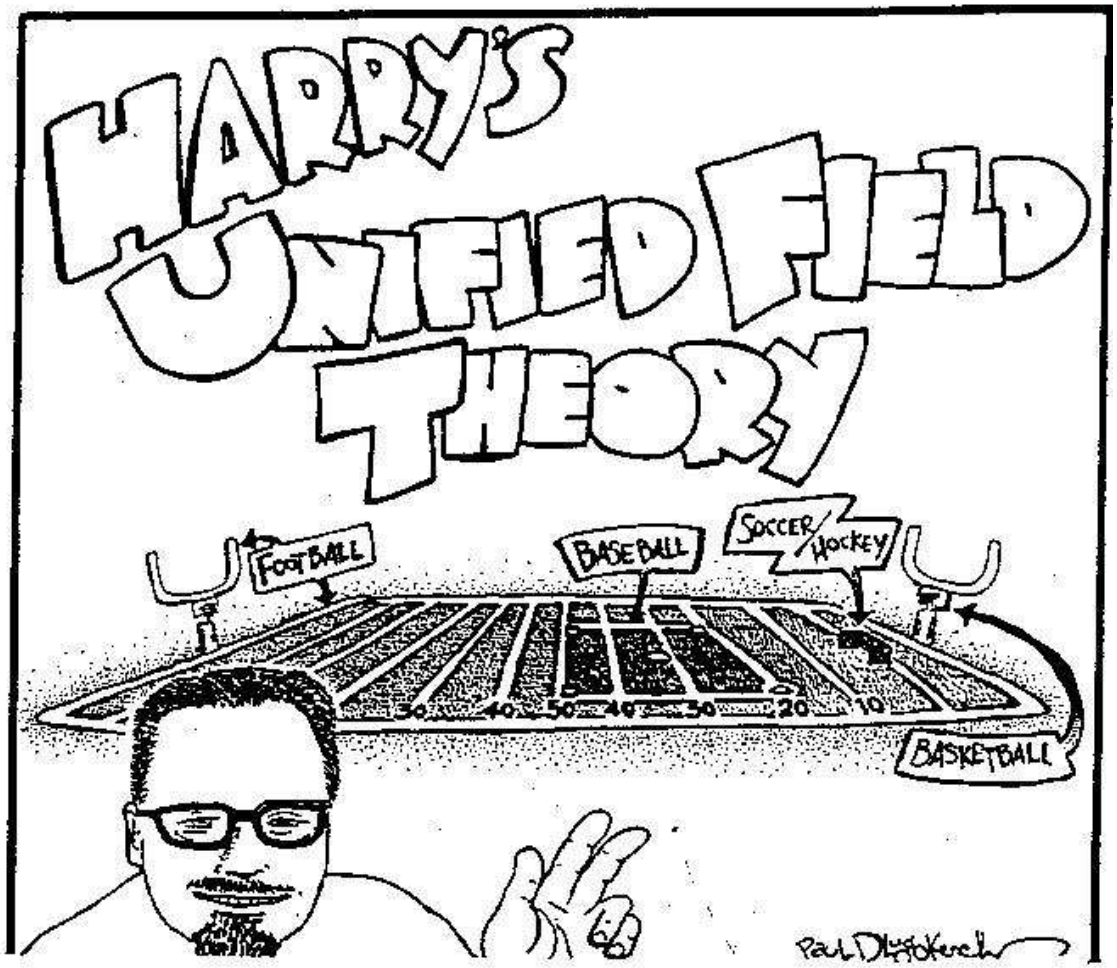
1 H Hydrogen 1.00794																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

1995 IUPAC masses and Approved Names from http://www.chem.qmw.ac.uk/iupac/AtWt/
masses for 107-111 from C&EN, March 13, 1995, p. 35
112 from http://www.gsi.de/~l12e.html

Complex
Difficult to remember
Hard to fit on a T-Shirt

There are a variety of Grand Unified Theories



Others predict the existence of:*

SUSY
Higgs Bosons
SuperStrings
...

How will we find these???

We need higher energies to access these proposed particles

Compare these machines:

LEP	e^+e^-	$\sqrt{s} = 200$ GeV
HERA	ep	$\sqrt{s} = 314$ GeV
RHIC	NN	$\sqrt{s} = N \times 100$ GeV
Tevatron	p - p-bar	$\sqrt{s} = 2000$ GeV
LHC	pp	$\sqrt{s} = 14{,}000$ GeV

Hadron beams provide the highest energy

The world: Pre-Columbus

LHC: The High Energy Frontier (2007)

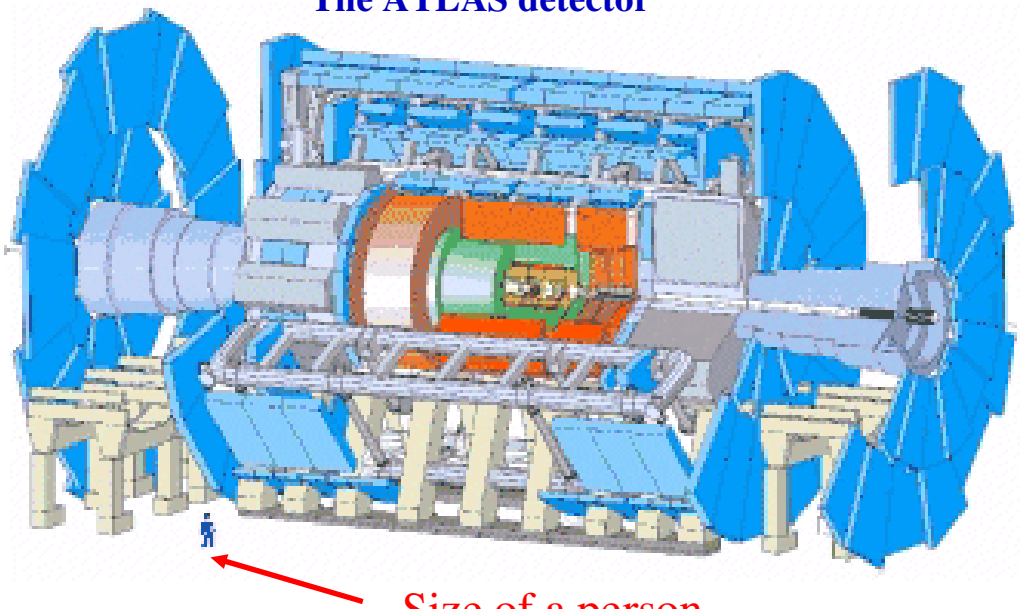
P P collisions

$\sqrt{s}$ = 14,000 GeV

Note: 5 GeV ~ 1 Fermi

$\therefore$ 14,000 GeV ~ 3×10^{-19}m

The ATLAS detector



Size of a person

The LHC is poised to open up one of the largest kinematic frontiers in many decades

You need big detectors to study small stuff!!!

An Example: The Higgs Boson

Scientists glimpse elusive particle

Los Angeles Times

GENEVA — For more than 20 years, scientists around the world have been searching for an invisible particle that determines the basic properties of matter. The particle, called a "Higgs boson," is thought to be a vibrating chunk of the unseen vacuum that underlies everything in the universe.

Friday, physicists at the European laboratory CERN are set to announce what they believe is the first glimpse of the Higgs boson.

The evidence is by no means conclusive. But the discovery of the Higgs boson is considered critical to physics — not only concluding one chapter but also opening the door to another undiscovered realm.

Once physicists understand this pervasive, unseen influence, they will be able to answer a question so fundamental that ancient thinkers probably never even dared to ask it: "Why does matter have mass?"

Collider experiments reveal 'Higgs boson'

Said Chris Tully of Princeton: "I think it will eventually be hailed as one of the greatest achievements you can make in science."

Possible traces of the particle were detected in experiments in the 17-mile-around Large Electron Positron collider, or LEP, by crashing atomic particles at high speeds.

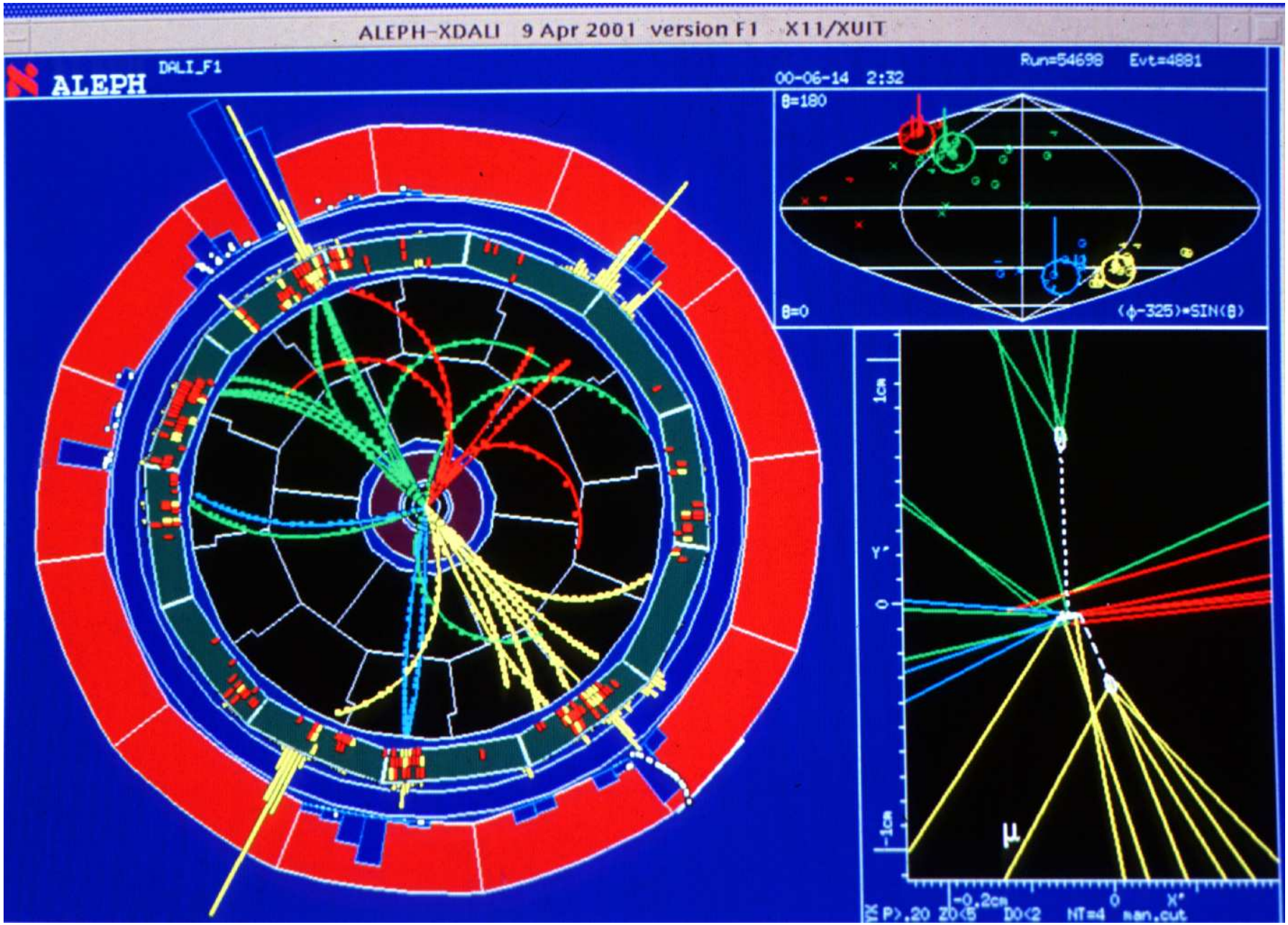
Tracks suggesting the possible presence of the so-far unseen particle have teased CERN physicists with a frustrating succession of appearances and disappearances over the past month. But evidence accumulated last week convinced them to request an emergency resuscitation of the aging accelerator. CERN officials had previously decided to tear down the collider.

Skeptics have been saying for weeks that the hints that surfaced at CERN last month were only wishful thinking.

But in a dizzying series of events, two detectors at the collider spied what scientists feel are solid Higgs tracks.

"Among physicists, we believe we have them. But we don't believe we have enough of them" to claim a discovery, said Jason Nielsen, a graduate student from the University of Wisconsin.

Is this a Higgs Boson??? $e^+e^- \rightarrow Z \rightarrow ZH \rightarrow$ bbjj



How do we know what to look for???

Symmetries: A brief history

Einstein's Special Relativity: 1905

- All inertial reference frames are created equal
- Light travels with speed *c* in all frames

Gauge Symmetry (and Gauge Invariance) 1954

- Physics is independent of gauge (~ coordinate system)
- Higgs Boson respects gauge invariance

SUSY: SuperSymmetry 1976 *(6453 Theory Papers; 0 Data)*

- There exists a symmetry between Fermions and Bosons
- Previously:
  - Fermions (s=1/2: building blocks)
  - Bosons (s=0,1, ... : forces)

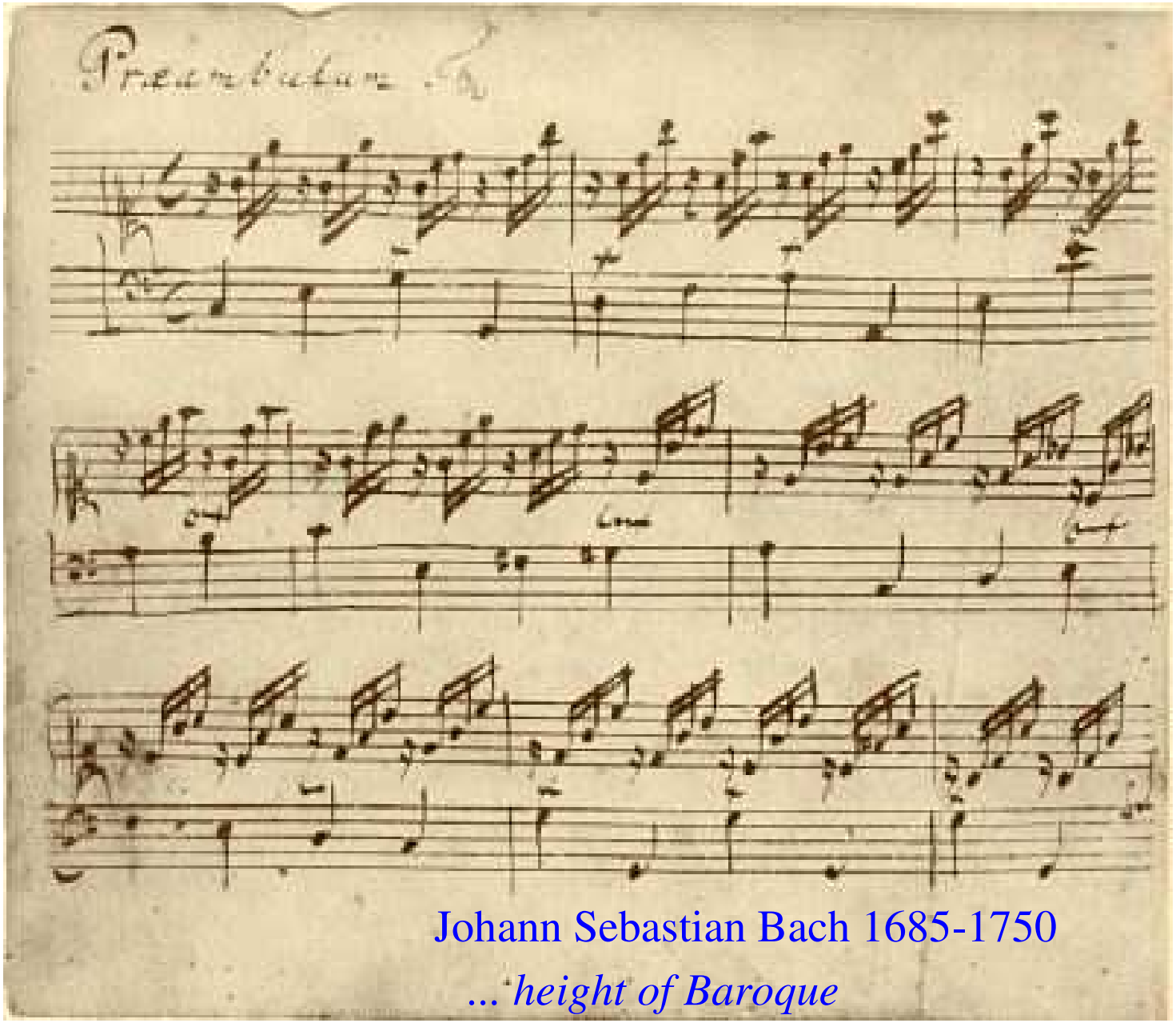
Mathematical String Theology: 1974 *(4870 Theory Papers; 0 Data)*

Things are simple in 11 dimensions

Symmetries play a central role in physics

... and in music

Symmetries in music:



Johann Sebastian Bach 1685-1750

... height of Baroque

Fugue: A type of Baroque composition similar to a crossword puzzle, but with fewer clues. The greatest fugue composer was J.S. Bach, who died before completing his seminal work, The Art of Fugue. Many musicians since have died trying to play it. *(One misguided musicologist who thought that the Fugue was actually an 18th century portrait painter was unceremoniously drummed out of the profession, and has since made a fortune writing record-liner notes.)* Stolen from: *A Musician's Dictionary*, by David W. Barber

Counterpoint: A musical device similar to needlepoint, although not designed to be hung on the wall or used on seat covers. Said to be a musical conversation, it more often resembles an argument. A favorite device of many Baroque composers, all of whom are now dead---although a direct connection between these two has never been conclusively established. Although no longer in practice by modern composers, it's still taught in schools, as a form of punishment.

Stolen from: *A Musician's Dictionary*, by David W. Barber

GENERAL RULES FOR COUNTERPOINT

(Numbers in brackets refer to Rules as listed in the Palestrina computer program.)

The Cantus Firmus (which means fixed or pre-existing voice or part, and is usually abbreviated as CF) will be provided by me.

Your counterpoint:

conjunct movement wherever possible (2, 6, 13)

permitted leaps are the octave, perfect 4th, perfect 5th, major and minor 3rds, minor 6th (ascending only). You cannot use augmented or diminished leaps, 7ths of any kind, leaps greater than an octave (1)

avoid outlining augmented or diminished leaps (i.e. having them within about 3 or 4 notes of each other (see below, under 'leaps'). Therefore two consecutive leaps in the same direction are forbidden (12)

a leap is usually followed by a step back within the leap; occasionally by a step in the same direction (i.e. a little further). If you wish a leap to be followed by a leap back within the interval (which is certainly permissible) you will have to be careful that the notes follow the harmonic rules (see below) (10)

Your harmony:

until allowed to do otherwise, you must make all intervals concordant. Concords are of two types:

perfect concords: octaves and fifths;

imperfect concords: major and minor 3rd, major and minor 6th (15)

Two consecutive perfect concords are forbidden (22, 23, 24). This covers not only consecutive 5ths and 8ves, but a 5th moving to an octave. The only exception to this is a 5th moving down to an 8ve, especially at a cadence.

Discords are forbidden. These are 2nds, 7ths, diminished and augmented intervals, and, most important, perfect 4ths (15)

Moving in parallel upwards to a perfect concord is also forbidden, even from an imperfect concord (21)

In two parts spacing should not exceed a 12th (an octave and a fifth) (28)

Exercises should start on a unison or fifth (or their octaves) and finish on a unison or octave (19)

Actual unisons (i.e. the same note) may appear only at the beginning and end (18)

The harmony should be written in such a way that the melodic lines are so smooth that they are easily singable (14)

Check for careless errors, such as additional beats or half-beats (20)

Note: these are not my rules; they come from observing what happens in real music. If in doubt, look at the music yourself; the works of Palestrina make a good starting-point.

Clefs:

We shall sometimes use C-clefs. The C indicated by a C-clef is always middle C. For nomenclature count up from the bottom line (e.g. the tenor C-clef is C4). More often we shall use the transposed G-clef for the tenor, the subscript 8 indicating down an octave.

Wagner's music is
better than it sounds.

Mark Twain

What makes Good vs. Bad music???

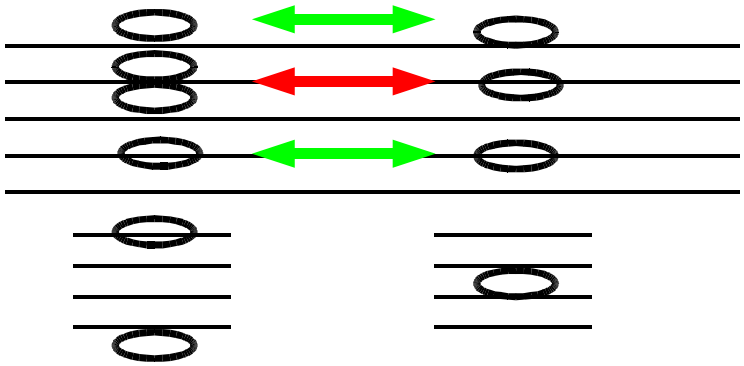
Where do the rules of Counterpoint come from???

Is there a symmetry underlying the music???

Harmony: Over-simplified

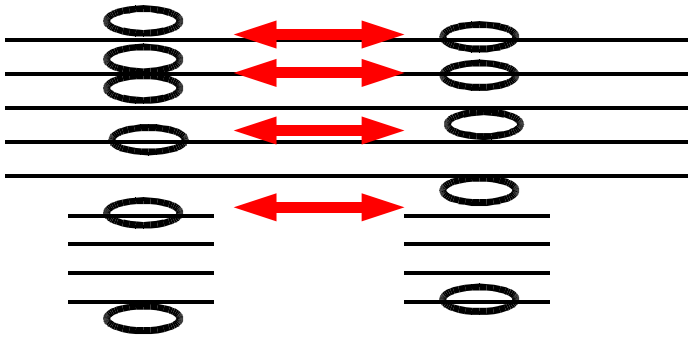
$$f_{beats} = \Delta f$$

Harmony



C G

Cacophony



C D

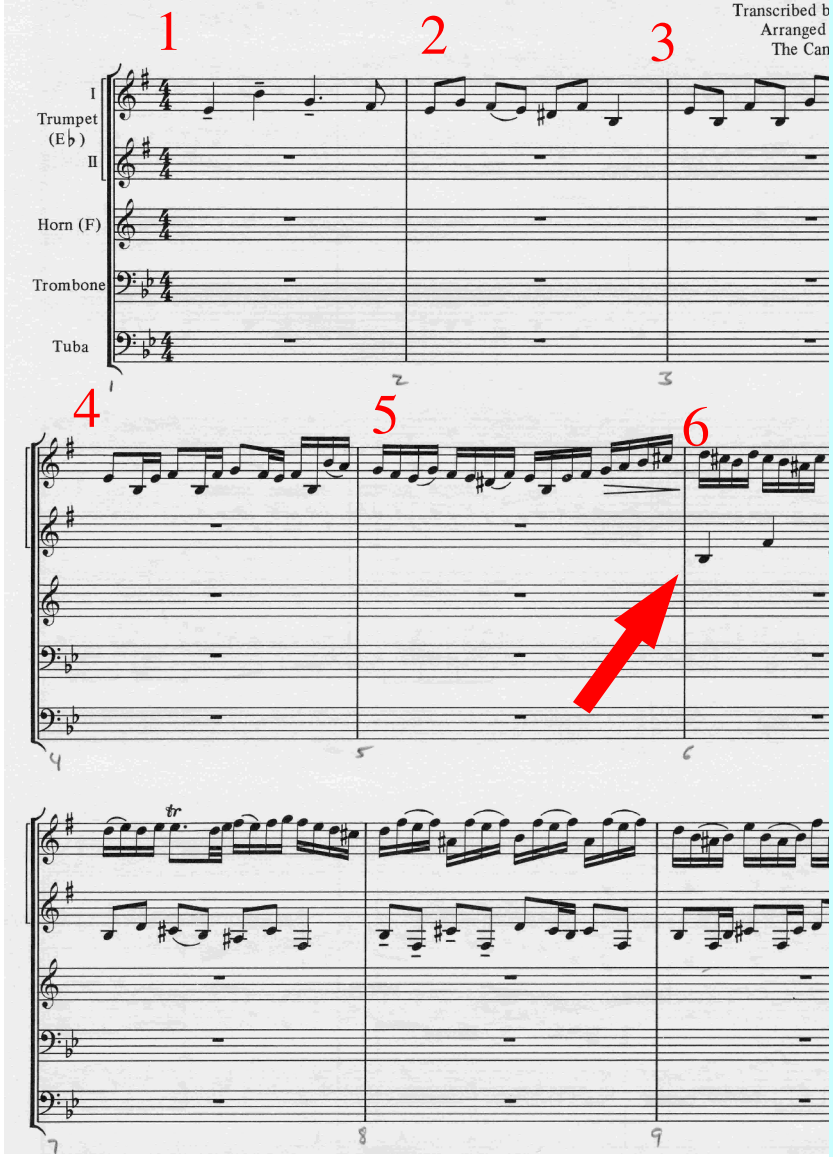
Note: Parallel 5th's are a no-no!!!

Canadian Brass Series

FUGUE IN G MINOR

(THE LITTLE)

J. S.
Transcribed b
Arranged
The Can



FREDRICK OLNESS

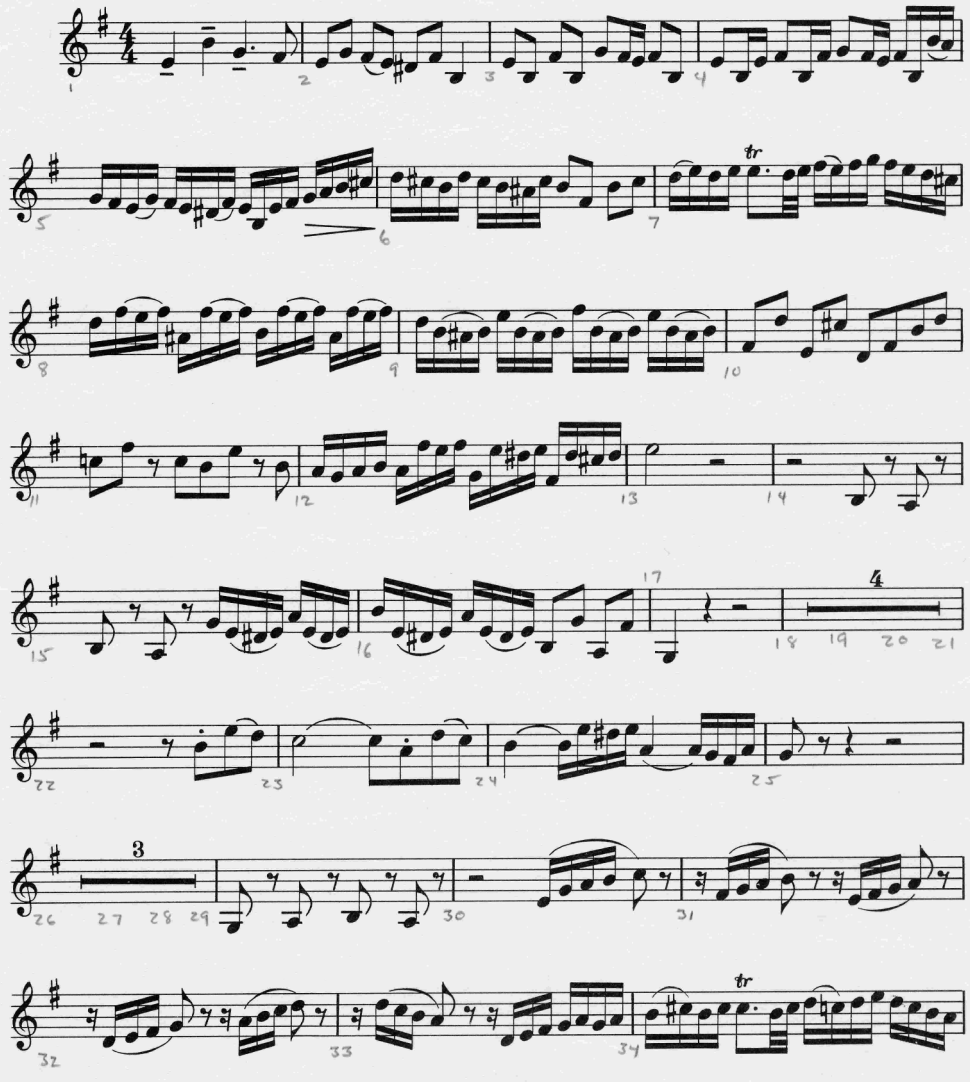
Canadian Brass Series

FUGUE IN G MINOR

(THE LITTLE)

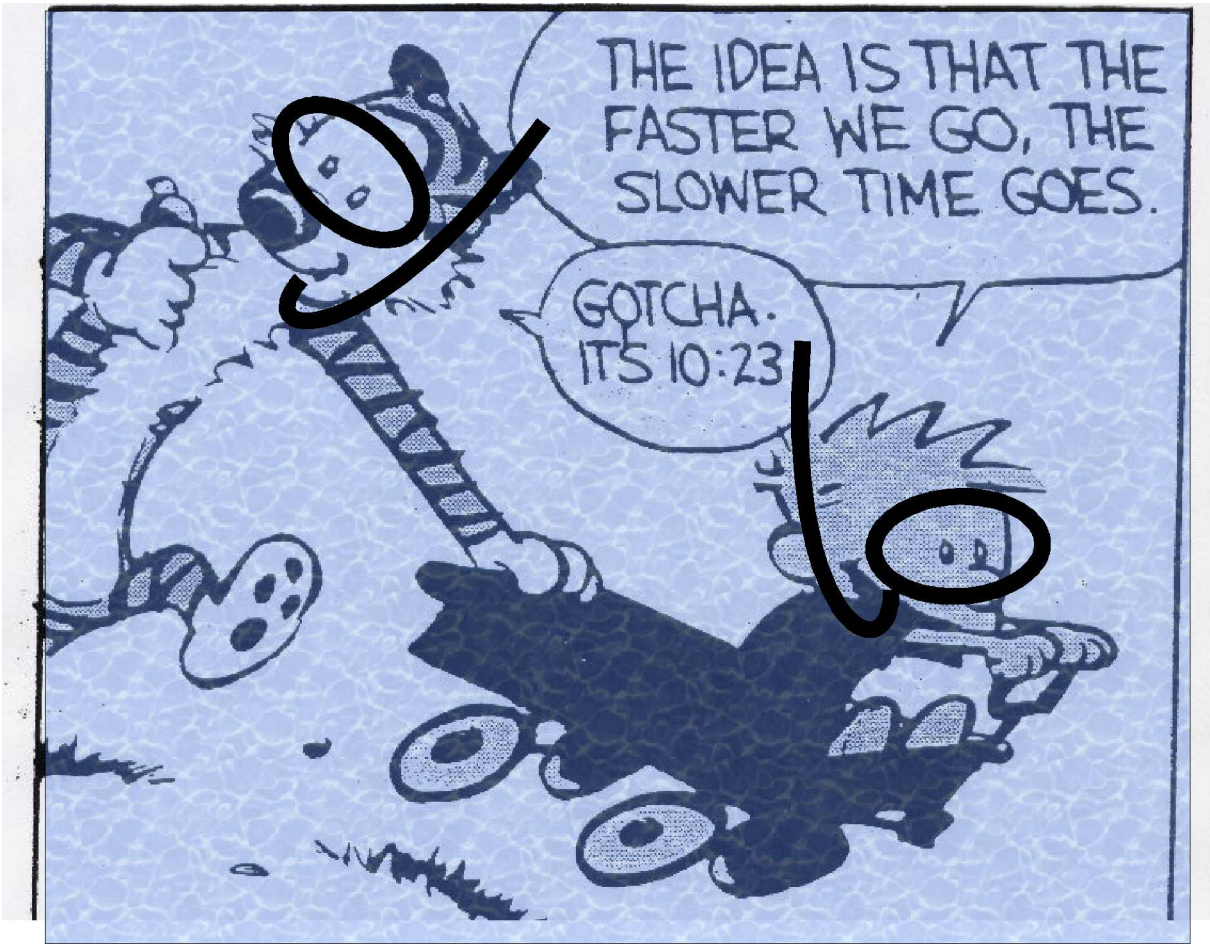
Trumpet I (in E♭)
(Alternate)

J. S. BACH
Transcribed by Ronald Romm
Arranged and edited by
The Canadian Brass



Higgs Bosons Really Simplified ...

Underwater!!!

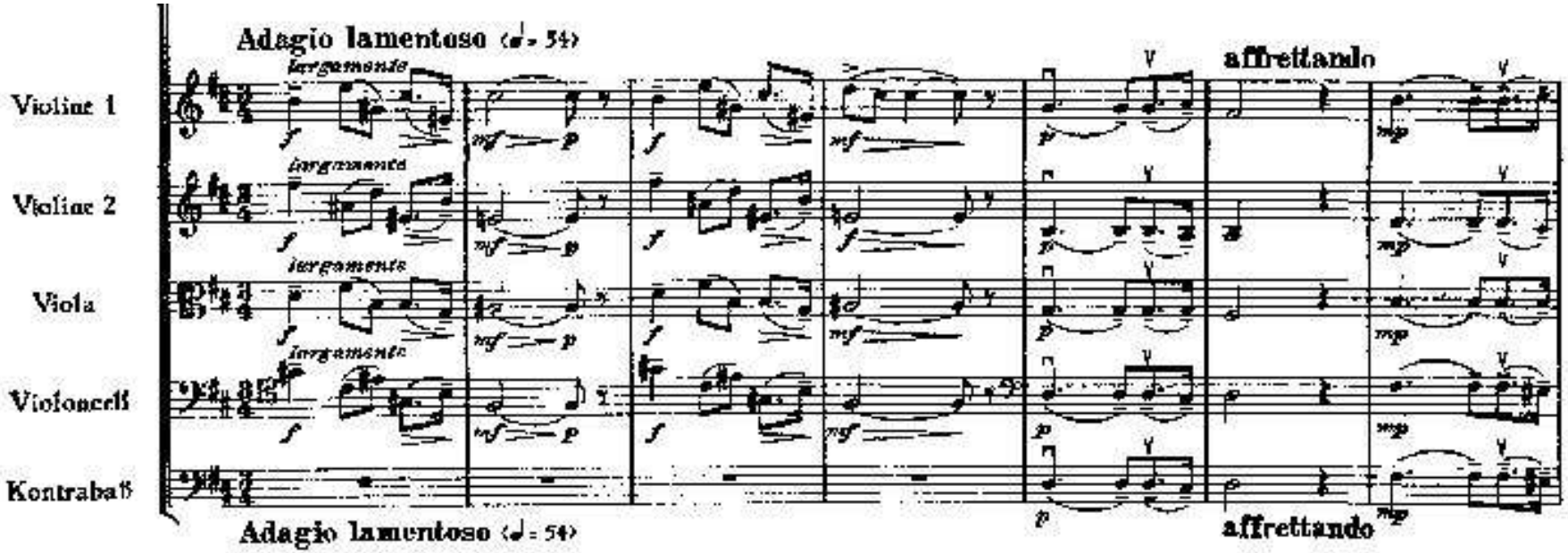


$$F = m\,a$$

$$m = F/a$$

Enables the theory to have a mass term AND respect gauge invariance

Symphony No.6 (Tchaikovsky, Pyotr Ilyich) 4th Movement



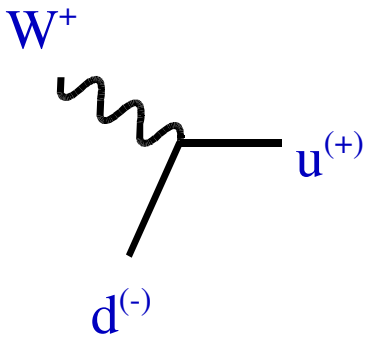
Hidden Symmetry

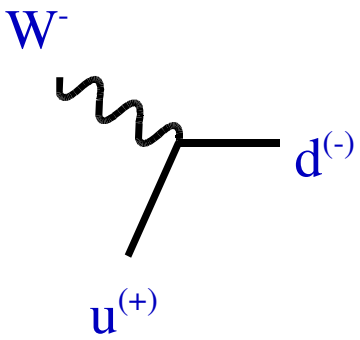
Wolfgang Amadeus Mozart 1756-1791

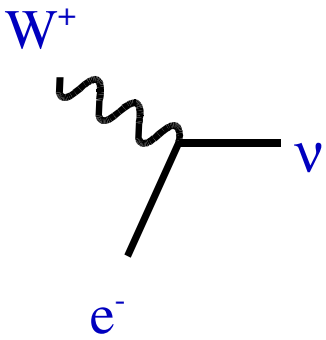
That which is not expressly forbidden is allowed

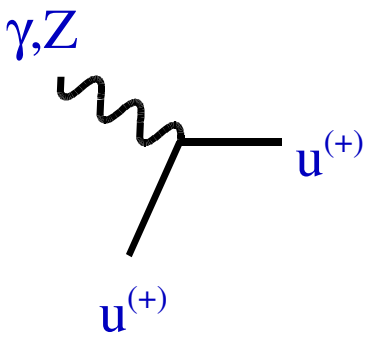
common folklore

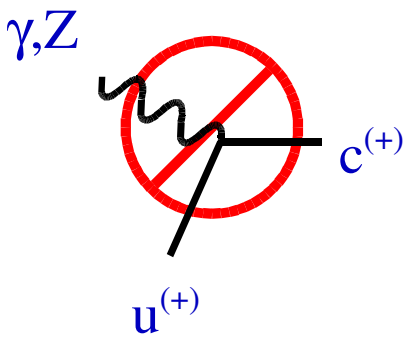
Flavor Changing Neutral Currents

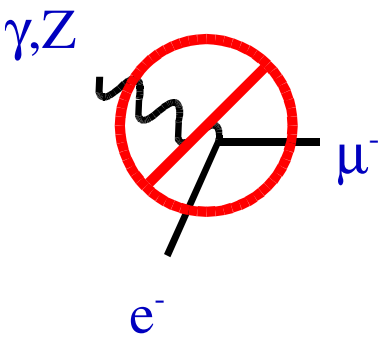








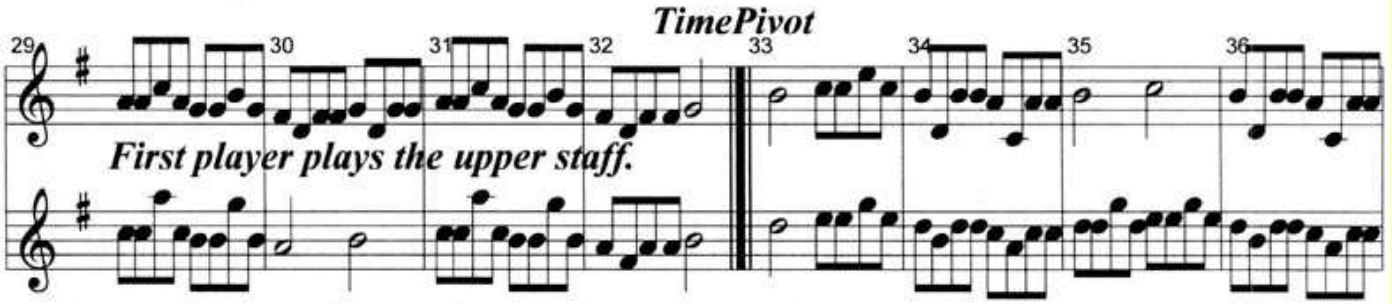




Why are these not observed even though they are allowed????

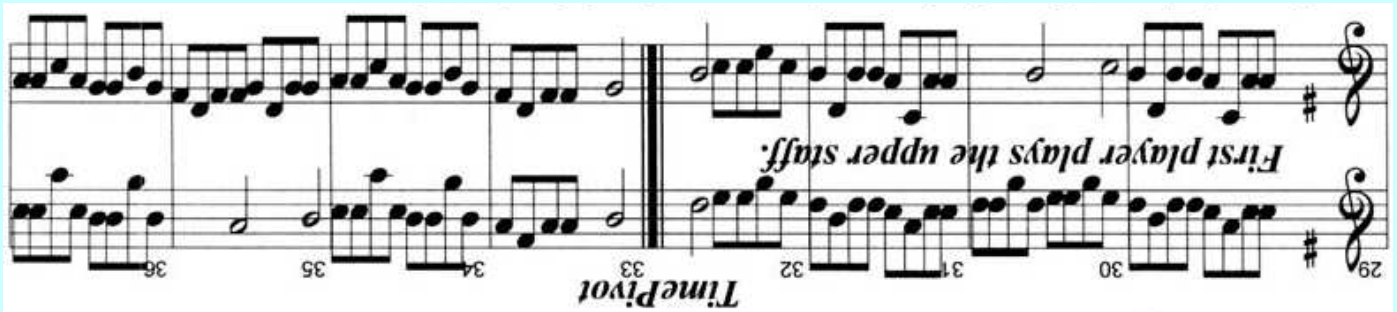
Mozart: Inverted retrograde canon in G

64 measures, pivoting in the center measures shown here.



Second player plays the inverted retrograde of the first player.
If you read the first staff with the sheet upside down, you get the second staff.

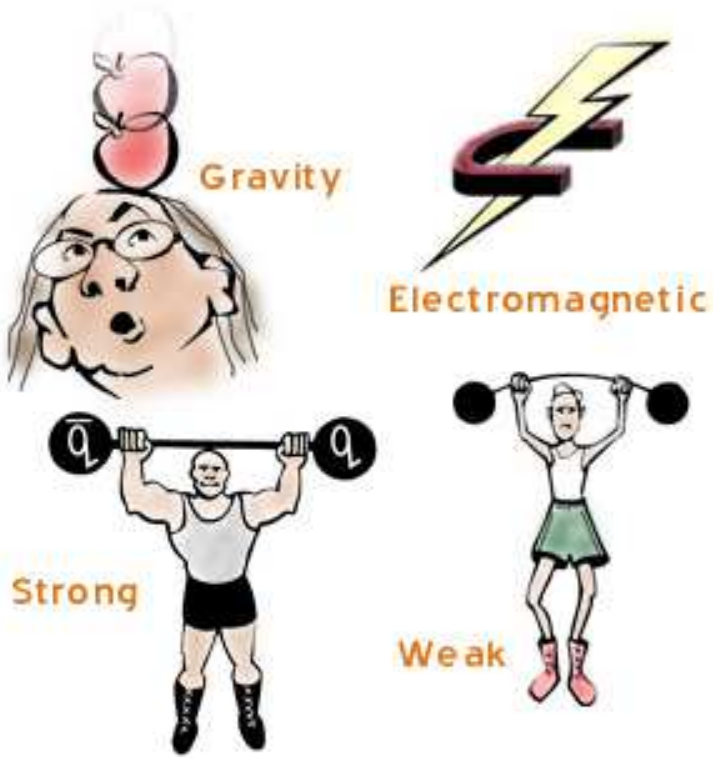
(In G Major, the G chord is pivoting around the central B, third note of that scale, as explained in the inversion paper.)



Mozart: Inverted retrograde canon in G

64 measures, pivoting in the center measures shown here.

Periodic Table

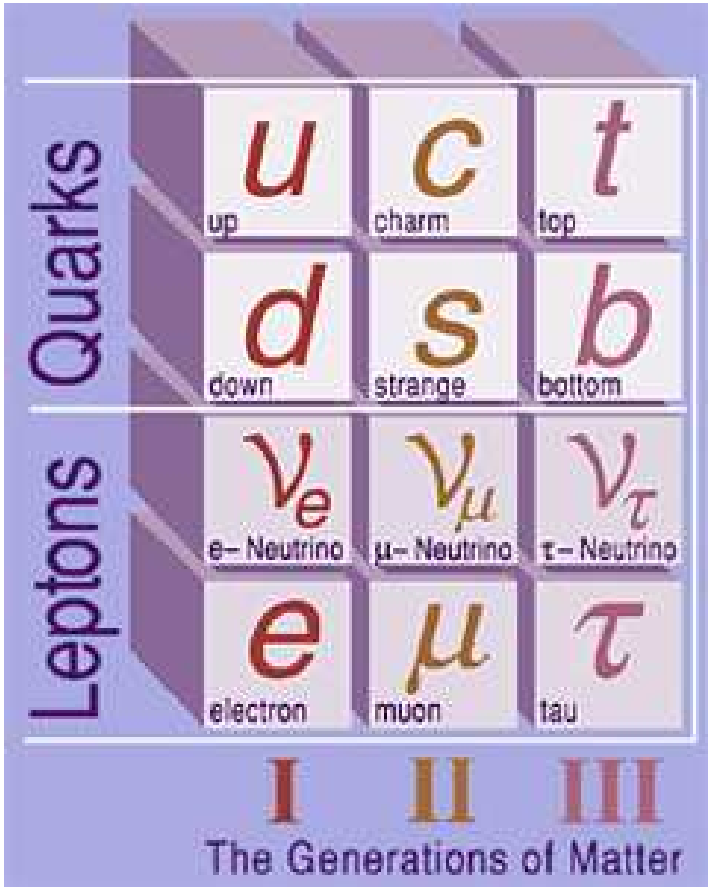


Compact

Easy to remember

Fits on a T-Shirt

Circa 2000 AD



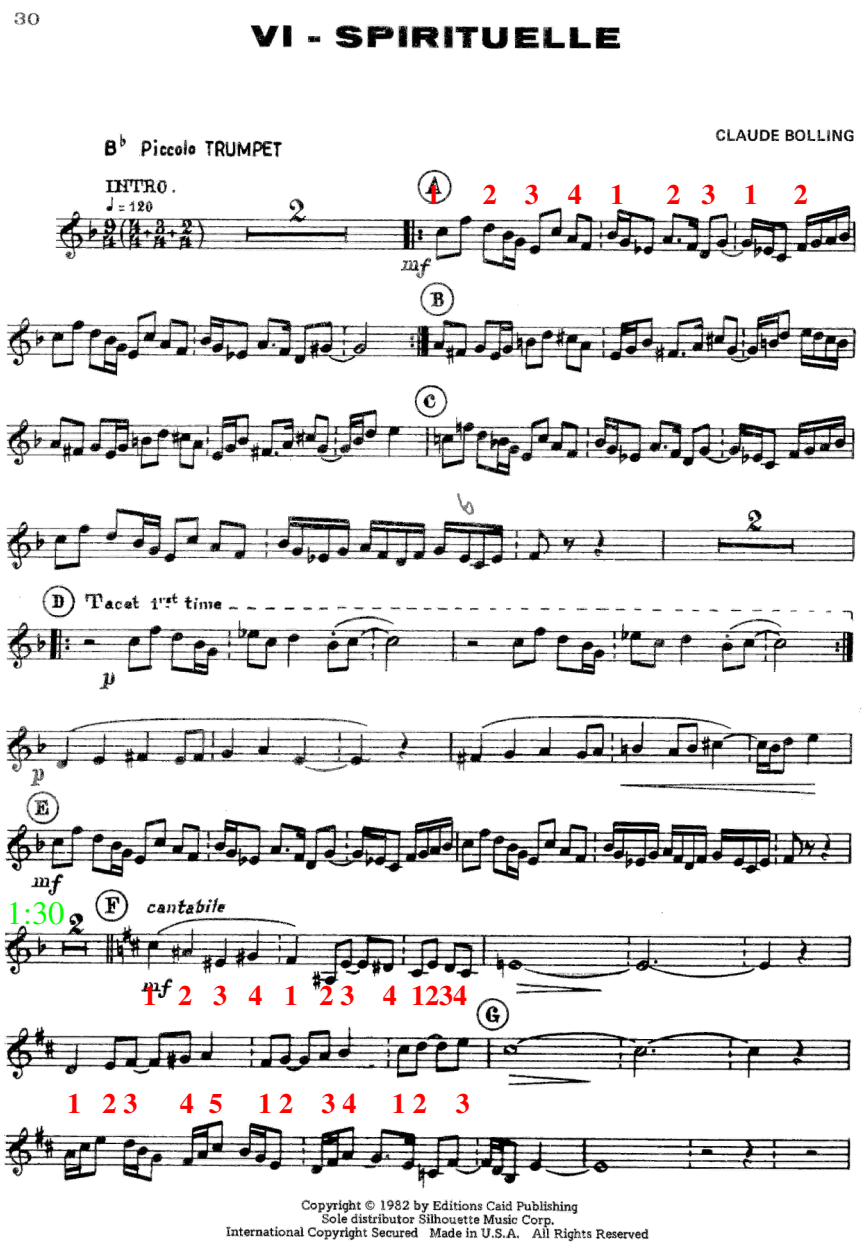
Why duplication of generations????

Signal of underlying structure???

Can we unify these 4 forces???

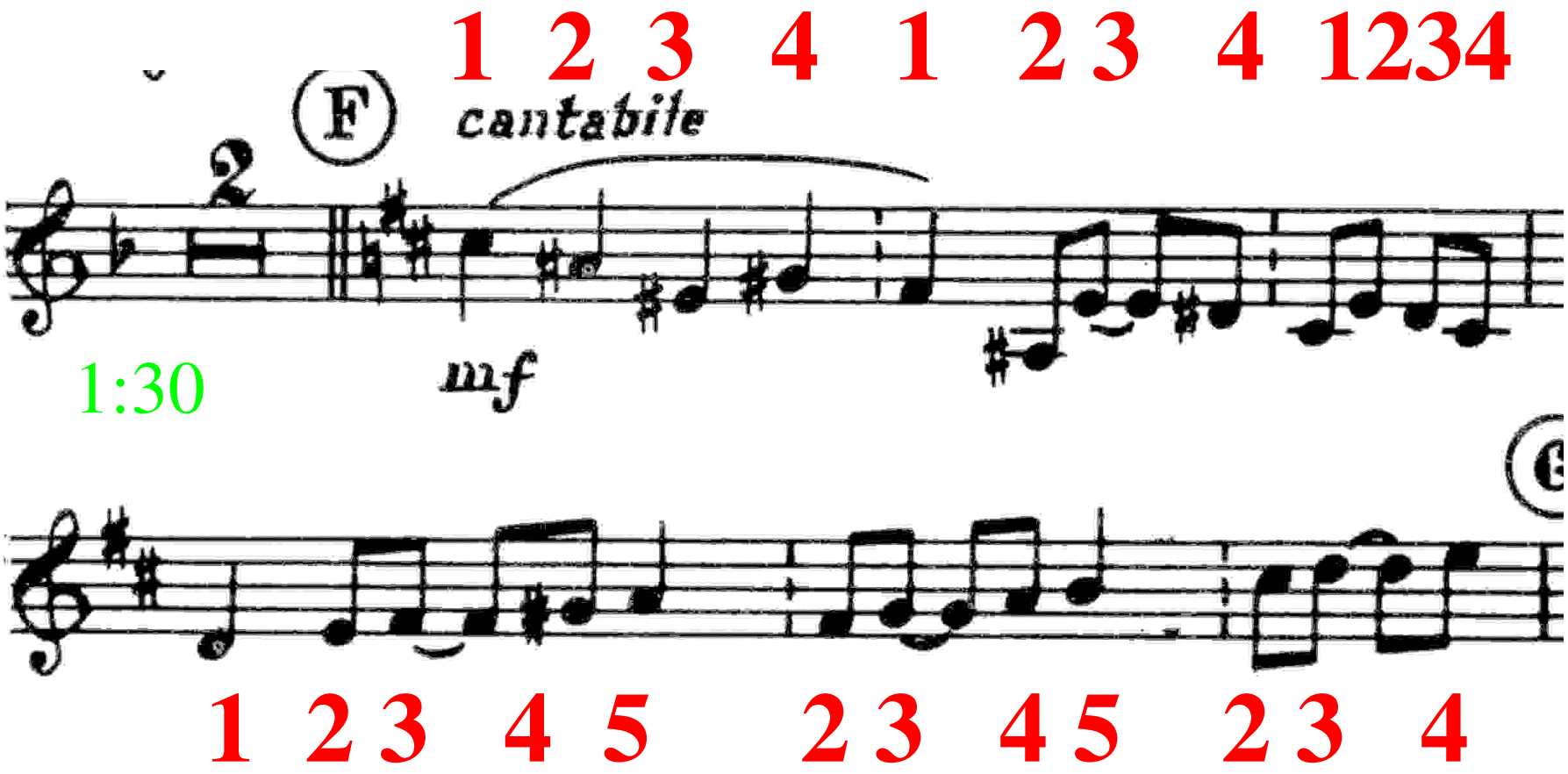
Let’s look for more patterns:

What is the time-signature of this piece???

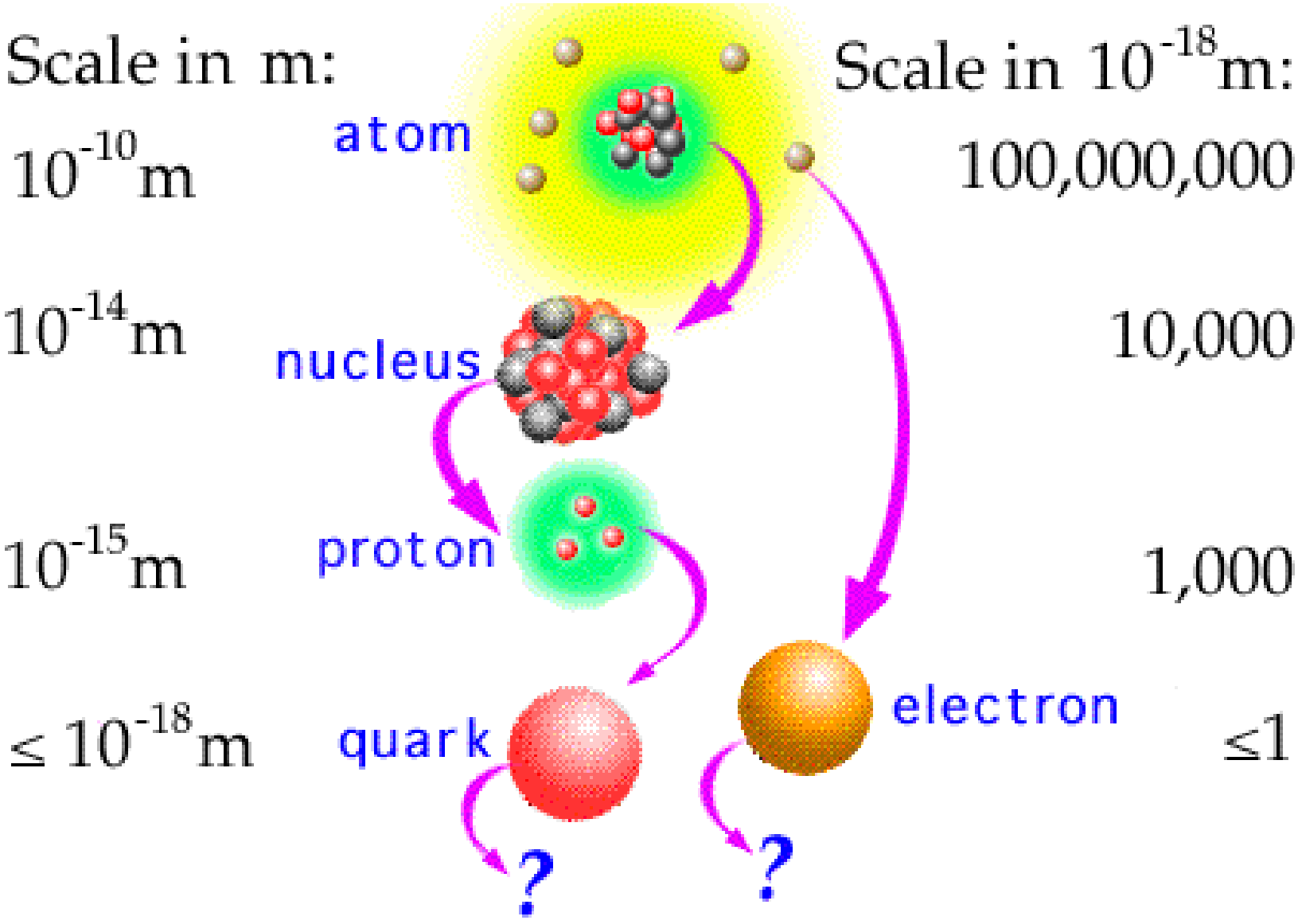


Looking for Patterns

Looking for Patterns

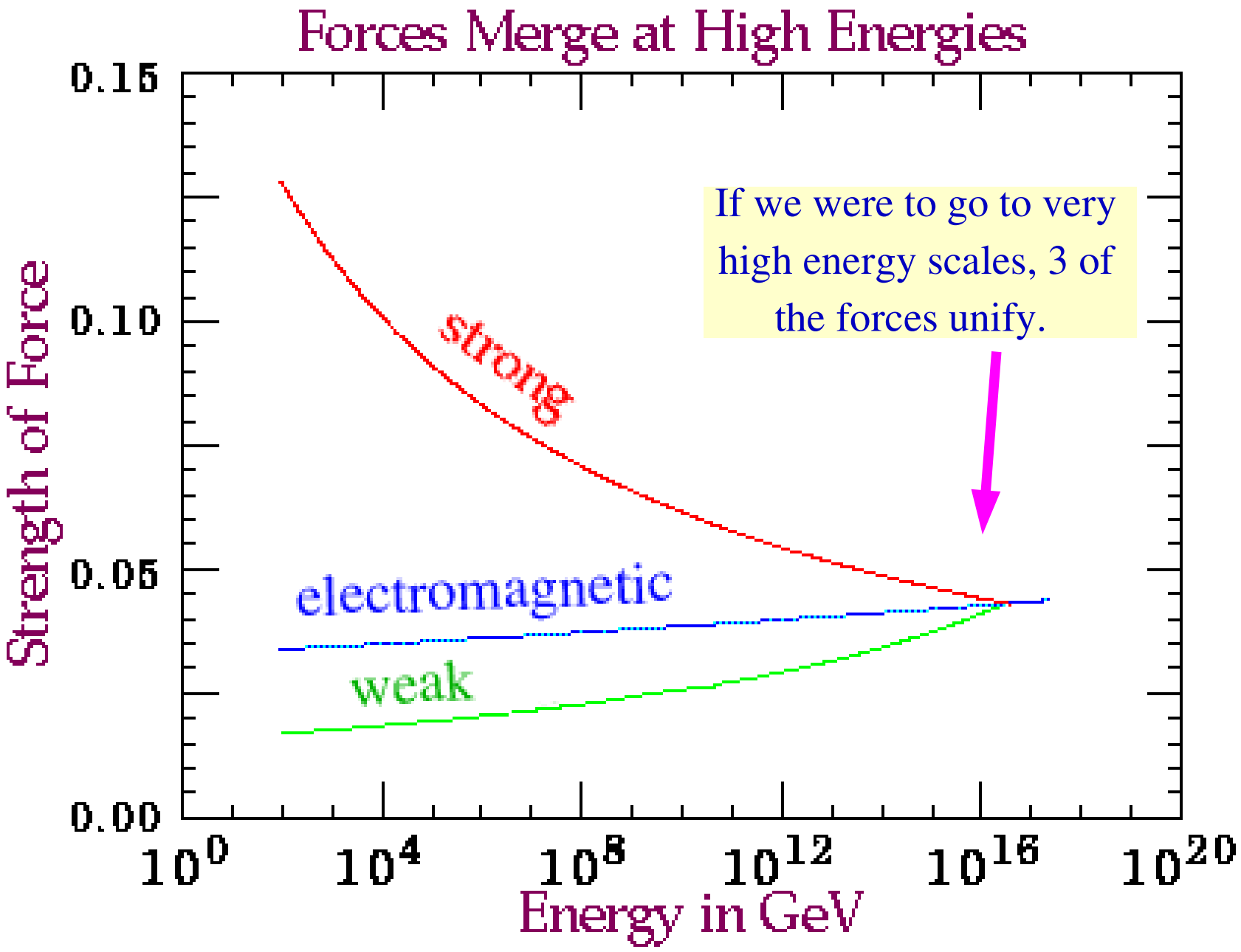


Small distance ~ High Energy



Going to smaller scale, we get to simpler, more fundamental objects

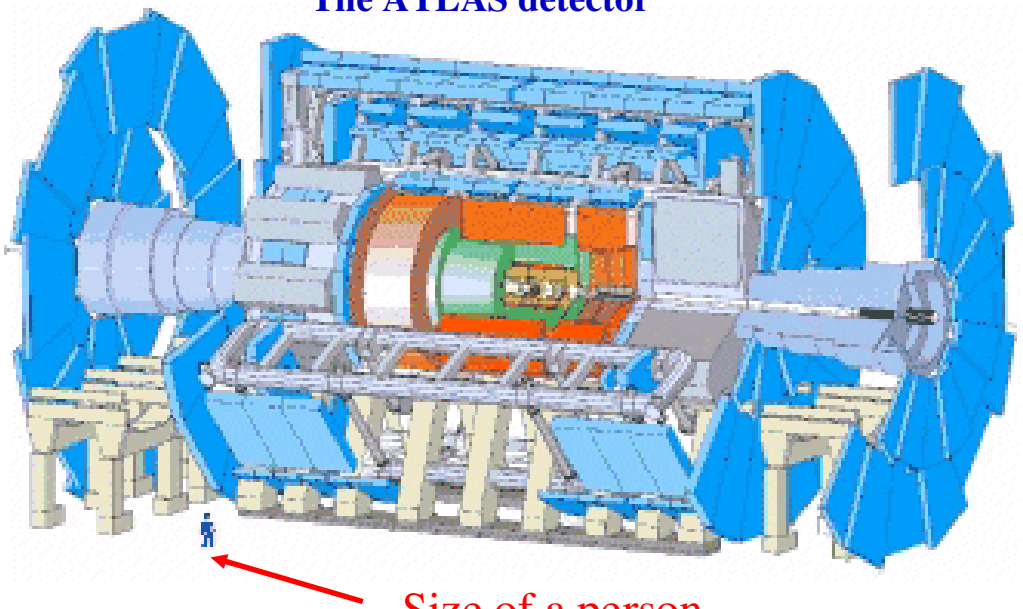
The Unification Scale



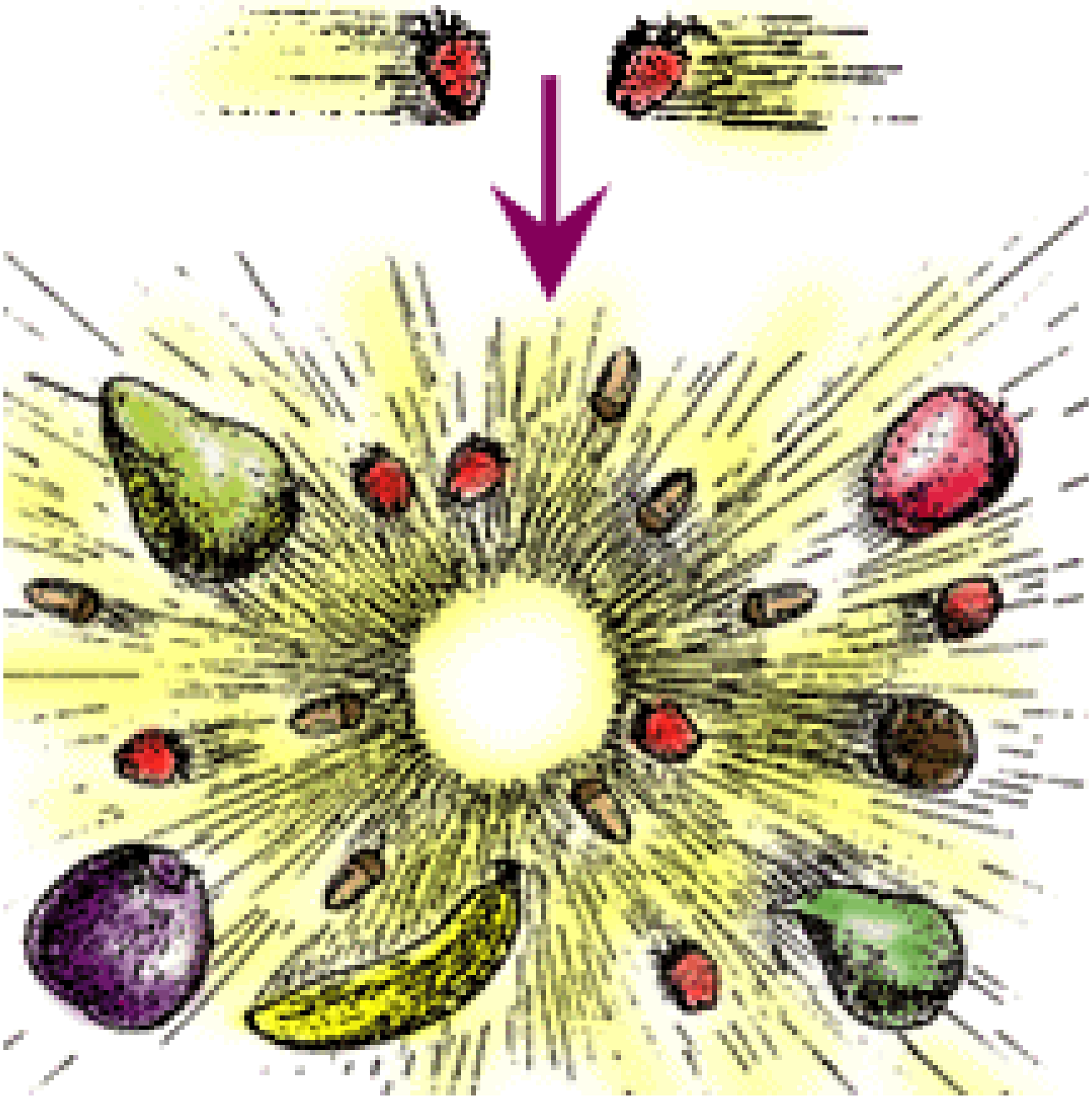
Stay tuned: Coming next year to a news stand near you (2007)

Caveat: Physics is data driven while music is subjective

The ATLAS detector



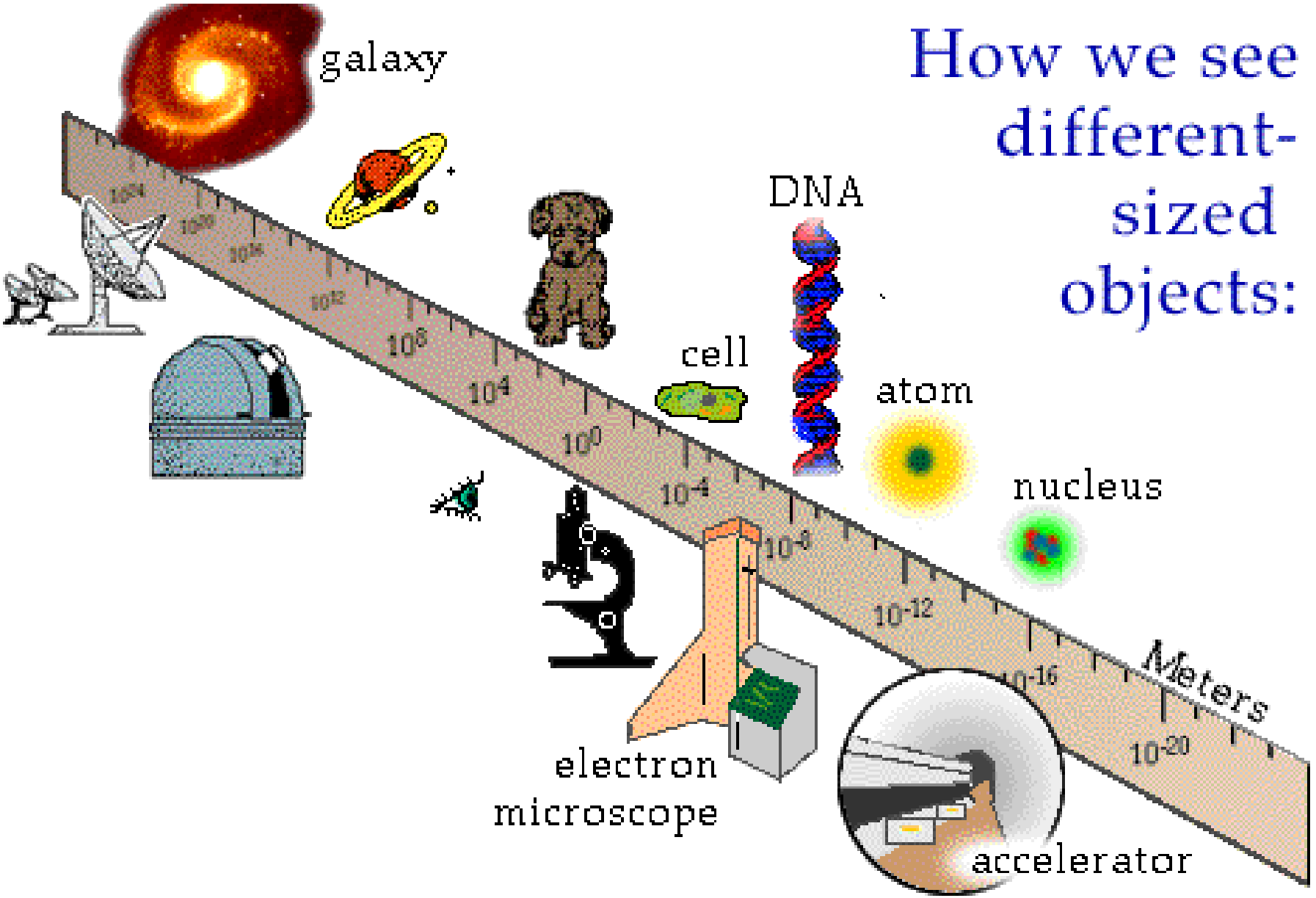
One interpretation of a hadron-hadron collision

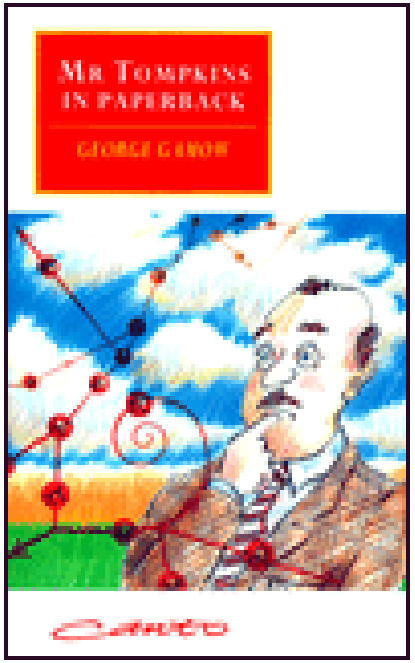


Musicians Compose

Physicists must decompose???

How we see different-sized objects:



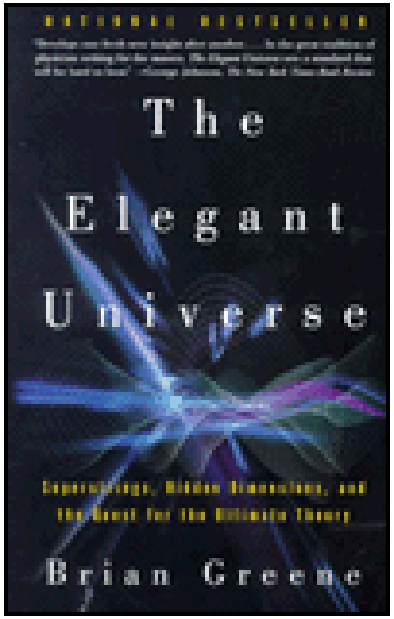


Mr. Tompkinks

George Gamow

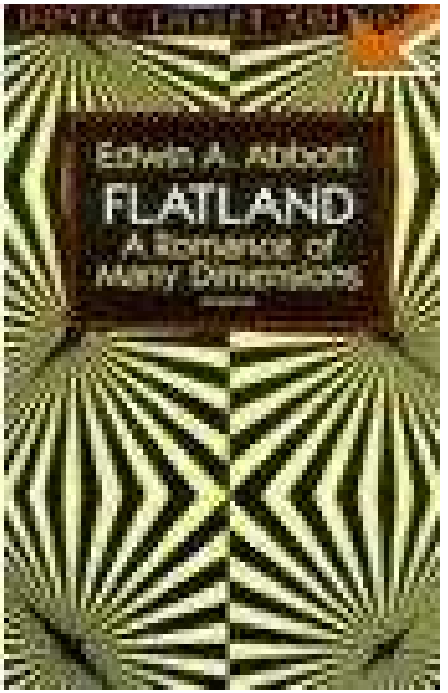
One, Two, Three, Infinity

George Gamow



The Elegant Universe

Brian Greene



Flatland

Edwin Abbot