The Oh-My-God Particle

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Editor's Note: *The calculations were redone to reflect the current ISO standard for length and time units.*

Disclaimer

The following calculations involve some elementary but easy to mess up algebra and some very demanding numerical calculations for which regular IEEE double precision is insufficient. If you'd like to double-check these results, be sure to use a multiple precision calculator with at least 30 significant digits of accuracy. I generally use Mathematica for symbolic work and Mark Hopkins' package C-BC for number crunching. It's entirely possible I've made one or more mistakes of order-of-magnitude or greater significance. But even so, (and please correct me!), this is, particle physics wise, a genuine Oh Wow event.

Fly's Eye

The University of Utah operates a cosmic ray detector called the Fly's Eye II, situated at the Dugway Proving Ground about an hour's drive from Salt Lake City. The Fly's Eye consists of an array of telescopes which stare into the night sky and record the blue flashes which result when very high energy cosmic rays slam into the atmosphere. From the height and intensity of the flash, one can calculate the nature of the particle and its energy.

On the night of 1991 October 15, the Fly's Eye detected a proton with an energy of 3×10^{20} electron volts.[1,2] By comparison, the recently-canceled Superconducting Super Collider (SSC) would have accelerated protons to an energy of $20TeV$, or 2×10^{13} electron volts – $10{,}000{,}000$ times less. The energy of the Oh My God particle seen by the Fly's Eye is equivalent to 48 joules – enough to light a 40 watt light bulb for more than a second – equivalent in the words of Utah physicist Pierre Sokolsky, to "a brick falling on your toe." The particle's energy is equivalent to an American baseball travelling fifty-five miles an hour.

All evidence points to these extremely high energy particles being protons – the nuclei of hydrogen atoms. Recalling that the rest mass of the proton is $938.28MeV \approx 1GeV = 10^9 eV$, all of the rest of the particle's energy results from the kinetic energy resulting from its motion, which we can calculate according to basic formulae of special relativity. So let's crunch a few numbers.

Microbial Mass

First of all, noting that mass and energy are equivalent, we can calculate the rest mass equivalent of a $3\times 10^{20} eV$ particle to be about 5×10^{13} grams. That doesn't sound like much until you recall that this is about 3×10^{11} daltons (chemists measure molecular mass in daltons, where 1 dalton is the mass of a hydrogen atom), just about the same as a single cell of the intestinal bacterium E. coli (5×10^{11} daltons). Thus this single subatomic particle had a mass-energy equivalent to a bacterium.

How Fast?

How fast was it going? Pretty fast. The total mass-energy of a particle is given in special relativity by the equation

$$m = \frac{m_0}{\sqrt{1 - v^2}} \tag{1}$$

where m_0 is the particle's rest mass, at speed 0, v is the particle's velocity, taken as a ratio to light speed, c. Okay, we know that the Oh My God proton has a rest mass of about $1GeV$, and a total kinetic energy of $3\times 10^{20} eV$, so let's solve equation (1) for v to obtain velocity as a fraction of the speed of light

$$v = c\frac{\sqrt{m^2 - m_0^{\,2}}}{m}$$

And thus, approximately:

$$v = 0.999{,}999{,}999{,}999{,}999{,}999{,}999{,}994{,}4c$$

or

$$v = (1 - 5.6 \times 10^{-24})c\ .$$

So taking $299{,}792{,}458$ metres per second as the speed of light (as is the ISO standard, used to calibrate the meter against seconds), we find that the particle was traveling $299{,}792{,}457.999{,}999{,}999{,}999{,}998{,}53$ metres per second, thus 1.67×10^{-15} metres per second slower than light – one and a half *femtometres per second* slower than light. If God's radar gun is slightly out of calibration, this puppy's gonna be doin' hard time for speeding. After traveling one light year, the particle would be only 0.18 femtoseconds – 53 nanometres – behind a photon that left at the same time.

Quicktime

Recall also that time passes more slowly in a moving reference frame, by the factor

$$t = \frac{t_0}{\sqrt{1 - v^2}}$$

Since we know v, we can immediately calculate

$$\frac{t}{t_0} = \frac{m}{m_0} = 3 \times 10^{11}$$

and thus, moving in the reference frame of the particle, time passes *300,000,000 times* slower than in a rest frame. Thus, given that the particle travels with essentially the speed of light, an observer traveling along with the particle would perceive the flight time from the following objects to the Earth.

Object	**Light Years[3]**	**Perceived Travel Time**
Alpha Centauri	4.36	0.43 milliseconds
Galactic nucleus	32,000	3.2 seconds
Andromeda galaxy	2,180,000	3.5 minutes
Virgo cluster	42,000,000	1.15 hours
Quasar 3C273	2,500,000,000	3 days
Edge of universe	17,000,000,000	19 days

Thus, if you could accelerate yourself to the speed at which the Oh My God particle was traveling, you'd be able to travel to the edge of the visible universe in a couple of weeks. Unfortunately, even assuming you found a source for the energy it would take and invented a means to accelerate yourself and Intergalactic Vessel Omega Point to this velocity, you wouldn't get far before being disrupted into subatomic goo due to interactions with photons in the ubiquitous cosmic microwave background radiation. Sokolsky has calculated that at $3 \times 10^{20}\,eV$, even a single proton could travel no farther than 10 megaparsecs, about the distance of the Virgo galaxy cluster, before losing energy in this manner.

Warp Factor Oh-My-God-Engage!

It is interesting to observe that a real particle, in our universe, subject to all the laws of physics we understand, is a rather better interstellar voyager than the best fielded in the 24th century by the United Federation of Planets. Their much-vaunted Galaxy Class starships are capable of speeds slightly in excess of Warp Factor 9, an apparent velocity of 1516 cochranes (or 1516 times the speed of light)[4]. At a velocity of 1516 c, traveling to the centre of the galaxy would take, as perceived by the life forms on board, a little more than 21 years. By contrast, an observer on board the Oh-My-God particle would arrive at the nucleus of the Milky Way, according to his clock, just about 3 seconds after leaving Starbase Terra. That's more than 9,700,000 times faster than the starship. In the time the starship spends vacuum-whooshing and rumbling its way to the nearby star Aldebaran, the particle could travel to the edge of the visible universe.

Go Fast – Grow Thin

Finally, let's consider the length contraction in the direction of motion which results from the Lorentz transformation--objects in the direction of travel are seen to contract in that direction by a factor of:

$$\frac{l}{l_0} = \sqrt{1 - v^2}\ .$$

And thus, paralleling the time dilation calculated above, in the frame of the particle, oncoming objects are seen as contracted by a factor of 3×10^{11}, three hundred billion times, in thickness. Thus, seen from the particle, the objects below will have the following thickness.

Object	Rest Frame Thickness	Particle Frame Thickness
Earth's diameter	12,756 km	0.0399 mm
Solar system	80 AU	37 metres
Sun/Alpha Centauri	4.3 light years	127 km (79 miles)
Milky Way galaxy	30 kiloparsecs	2,895,000 km, about ten times the distance

But How?

How was such an extraordinary particle created? What cosmic process accelerated a mundane proton to a brick-on-the-toe-energy?

Nobody knows. A particle with such energy would be deflected little by galactic magnetic fields, and so its impact track should point right back at the source. Astronomers see nothing unusual in that direction.

Nature remains rich in mysteries.

References

[1] *Physical Review Letters*, 1993 November 22

[2] G. Taubes, *Science* **262**, 1649 (1993).

[3] Ottewell, G. *The Astronomical Companion.* Greenville SC: Astronomical Workshop, 1979-1992. ISBN 0-93456-01-0.

[4] Sternbach, R. and M. Okuda. *Star Trek: The Next Generation Technical Manual.* New York: Pocket Books, 1991. ISBN 0-671-70427-3.