“전하 주제에 의한 변주곡”

권 영 준

연세대 물리학과

전하(charge)가 들려주는 신기한 이야기!

NAVER 사전 영어/영영 **국어** 한자 일본어 중국어 프랑스어 스페인어 독일어 베트남어 더보기 지식백과

국어사전

전체 | 전하 | 검색 | 옛한글 입력기 | 상세검색

◉ **전체** ○ 단어 ○ 속담/관용구 ○ 예문 ○ 본문 ○ 맞춤법/표기법

'**전하**' 에 대한 검색 결과입니다.

단어 (29)

전하1 (殿下) [전: 하]

[명사]

1. <역사>조선 시대에, 왕을 높여 이르거나 부르던 말.

2. <가톨릭>'추기경(로마 가톨릭교회에서, 교황 다음가는 성직)'을 높여 이르는 말.

유의어 : 각하5

전하2 (電荷) [전: 하]

(electric) charge

[명사] <물리> 물체가 띠고 있는 정전기의 양. 같은 부호의 **전하** 사이에는 미는 힘이, 다른 부호의 **전하** 사이에는 끄는 힘이 작용한다. 한 점에 집중되어 있는 것을 점**전하**라고 하며, 이것이 ...

전하3 (轉下) [전: 하]

[명사] 굴러 내려감. 또는 굴러떨어짐.

Program

- 서주 Adagio Sostenuto

- 1악장 Quantization 주제에 의한 변주곡
  - 제1변주 Moderato, "Magnetic Monopole"
  - 제2변주 Allegro ma non troppo, "Fractional Charge"

- 2악장 Conservation 주제에 의한 변주곡
  - 제1변주 Allegro con brio, "보존법칙과 대칭성"
  - 제2변주 Andante ma non tanto, "Anti-particle, anti-matter"

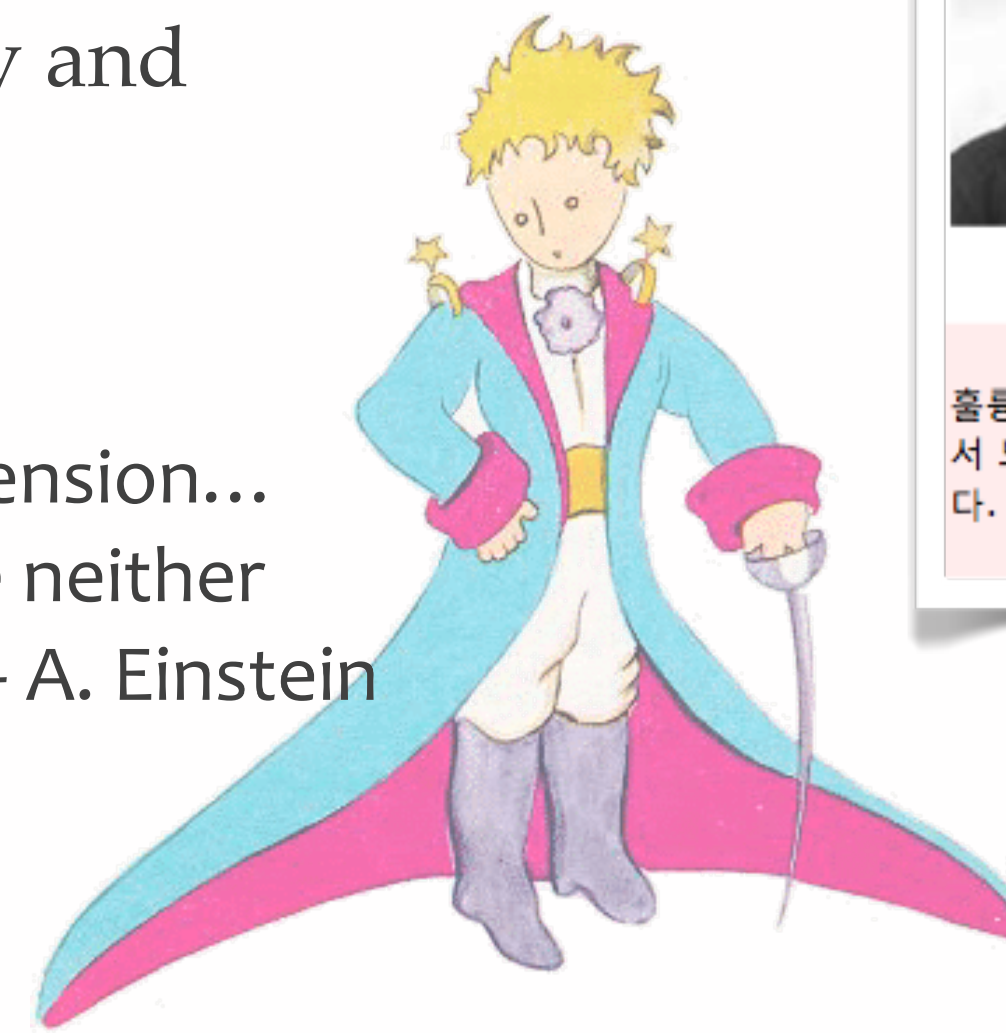
- Coda, Maestoso con spirito

물리학 – 떠오르는 이미지?

- 꿈
- 아름다움
- 정열
- 괴물
- 어려움
- 지겨움

"Nature has a great simplicity and therefore a great beauty."
- R. Feynman

"There exists a passion for comprehension… Without this passion, there would be neither mathematics nor natural science." - A. Einstein



재물포, 물망초, 진도개 …

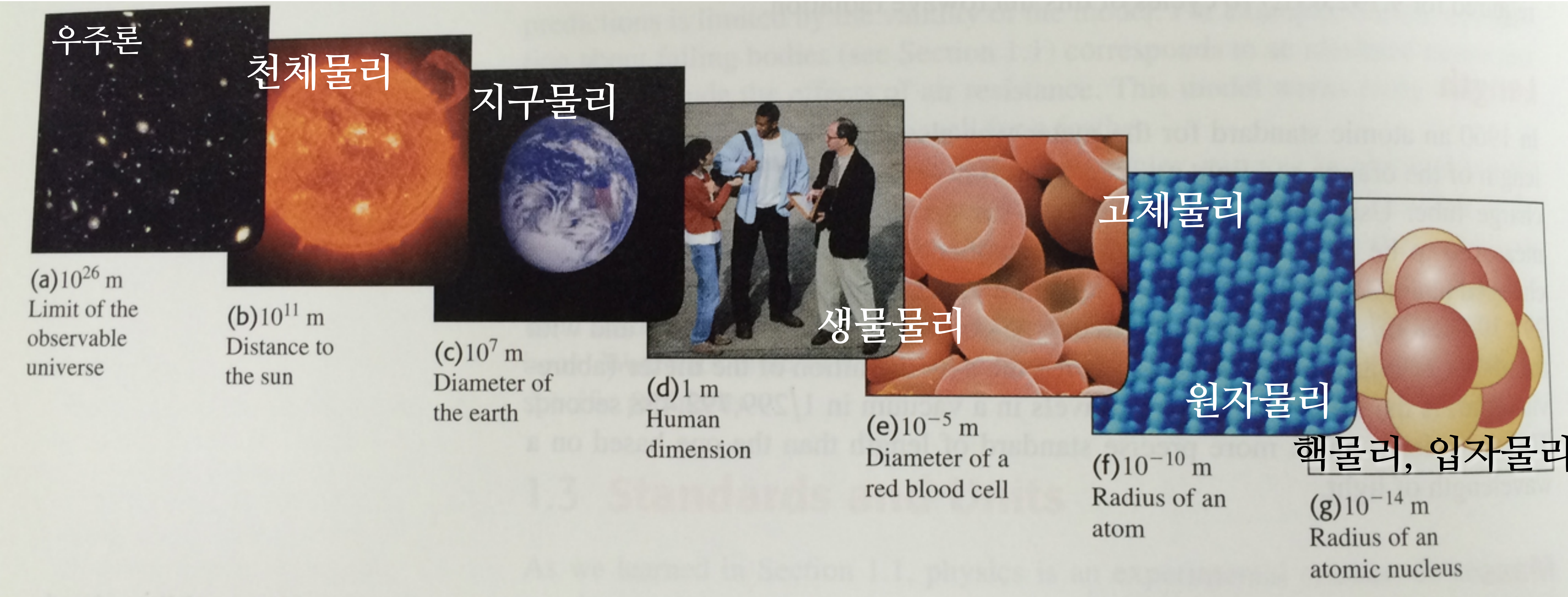
물리학 – 무엇을 연구 하는가?

- 물질(物質)의 이치(理致)를 연구하는 학문

- 물질이란? – 무생물 (기존 물리학의 연구 대상)
  - 기본입자 (elementary particles) ➔ 입자물리, 핵물리
  - 원자, 분자 ➔ 원자물리, 분자물리
  - 고체, 액체 ➔ 고체물리, 응집물질 물리
  - 플라즈마 ➔ 플라즈마 물리
  - 빛, 소리 ➔ 광학, 음향학
  - 다체계 (many-particle systems) ➔ 통계물리

but, 자연계에는 무생물만 있는 것이 아니다!

물리학이 다루는



우주론
천체물리
지구물리
생물물리
고체물리
원자물리
핵물리, 입자물리
(a) 10^{26} m
Limit of the observable universe
(b) 10^{11} m
Distance to the sun
(c) 10^{7} m
Diameter of the earth
(d) 1 m
Human dimension
(e) 10^{-5} m
Diameter of a red blood cell
(f) 10^{-10} m
Radius of an atom
(g) 10^{-14} m
Radius of an atomic nucleus

물리학 – 무엇을 연구 하는가?

but, 자연계에는 무생물만 있는 것이 아니다!

- 생명 시스템
  - 생물물리 (biophysics)
  - 의학물리 (medical physics)
- 경제, 사회 시스템
  - 경제물리 (econophysics)
  - 사회물리 (sociophysics)
  - 복잡계 및 혼돈(chaos)의 연구, 비선형 물리
- …

} 물리학의 새로운 연구분야들

그렇다면 물리는 만병통치인가?

- No, not at all!
- 그런데 왜 (주제넘게) 물리학자들은 생명, 경제, 사회 등의 분야까지도 연구하려 드는가?
  - 생명, 경제, 사회 현상 등에도 (왠지는 모르나…) 물리학에서 쓰이는 법칙이 성립되는 부분이 있음을 알게 됨
  - 컴퓨터의 발달로 계산 능력이 현저히 향상되어 복합계, 비선형계 등에 대한 연구 능력이 생김
  - *So, why not?*

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Nobel Prizes and Laureates

Prize in Economic Sci | 1997

- ▾ About the Prize in Economic Sciences 1997
  - Summary
  - Press Release
  - Advanced Information
  - Award Ceremony Speech
- ▸ Robert C. Merton
- ▸ Myron S. Scholes

All Prizes in Economic Sciences
All Nobel Prizes in 1997

The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 1997
Robert C. Merton, Myron S. Scholes

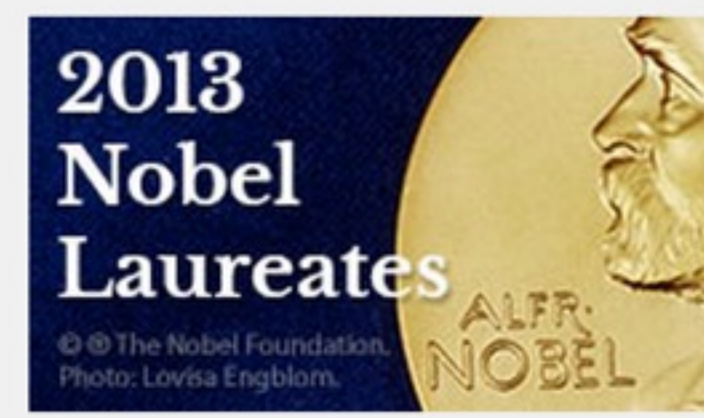
Share this: 3

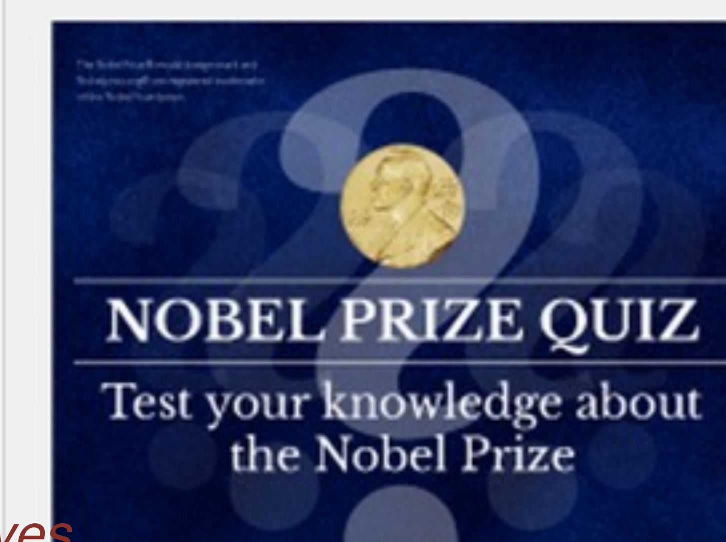
The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 1997

Robert C. Merton
Prize share: 1/2

Myron S. Scholes
Prize share: 1/2

The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 1997 was awarded jointly to Robert C. Merton and Myron S. Scholes *"for a new method to determine the value of* derivatives





uation hea | Heat equation - Wikipedia,

.wikipedia.org/wiki/Heat_equation

Statement of the equation [edit]

Note: $u(x, y, z, t)$ *is not velocity. It is an arbitrary function being considered; often it is temperature.*

For a function $u(x,y,z,t)$ of three spatial variables (x,y,z) (see cartesian coordinates) and the time variable t, the **heat equation** is

$$\frac{\partial u}{\partial t} - \alpha \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) = 0$$

More generally in any coordinate system:

$$\frac{\partial u}{\partial t} - \alpha \nabla^2 u = 0$$

where α is a positive constant, and Δ or ∇^2 denotes the Laplace operator. In the physical problem of temperature variation, $u(x,y,z,t)$ is the temperature and α is the thermal diffusivity. For the mathematical treatment it is sufficient to consider the case $\alpha = 1$.

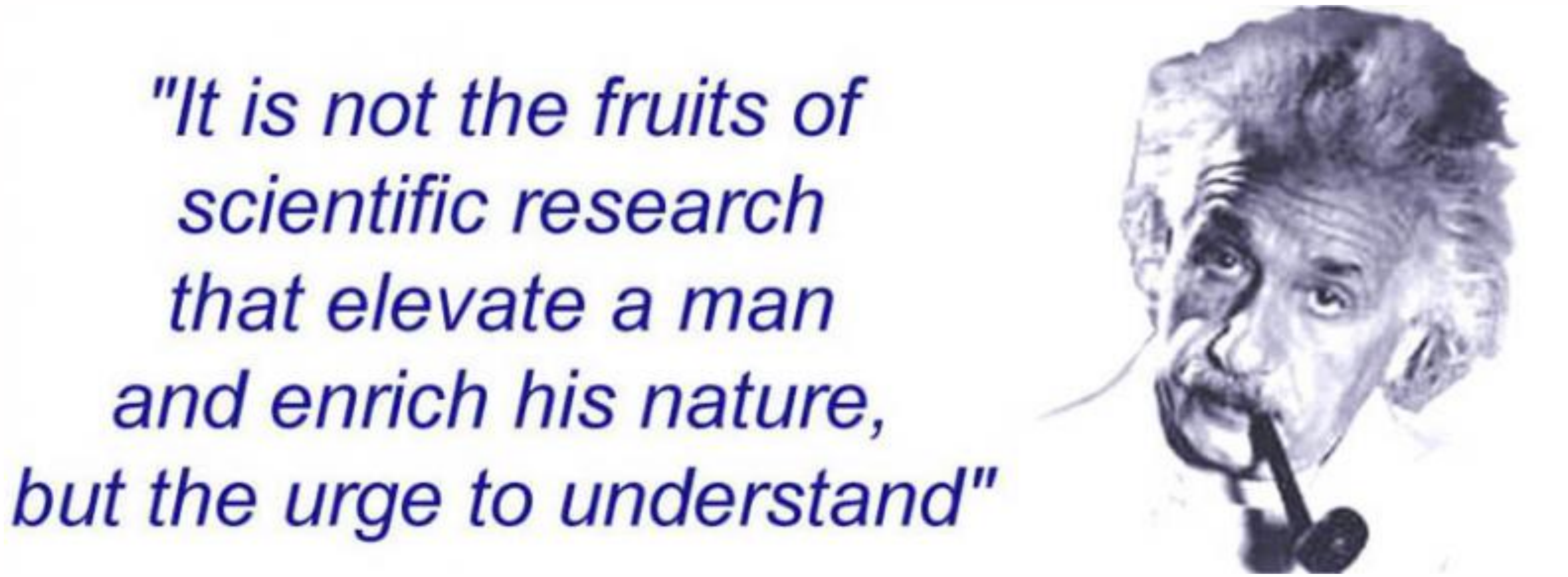
The heat equation is of fundamental importance in diverse scientific fields. In mathematics, it is the prototypical parabolic partial differential equation. In probability theory, the heat equation is connected with the study of Brownian motion via the Fokker–Planck equation. In financial mathematics it is used to solve the Black–Scholes partial differential equation. The diffusion equation, a more general version of the heat equation, arises in connection with the study of chemical diffusion and other related processes.

물리학 – 왜 하는가?

- 심심해서 & 호기심 때문에 (O)
- 아름다움에 대한 갈망 때문에 (O)
- 삶에서 부딪히는 문제를 해결하기 위해서 (O, X) – 실용성
  - 왕관은 순금으로 만들어졌는가? (O) - Archimedes' Principle
  - 나일강 홍수에 대비하자 (X) - 이건 공학에 더 가까움!
- 배가 고파서 (X)
  - 다른 길을 알아보세요!

> Science is a wonderful thing if one does not have to earn one's living at it.
>
> \- Albert Einstein

물리학 – 호기심을 위해

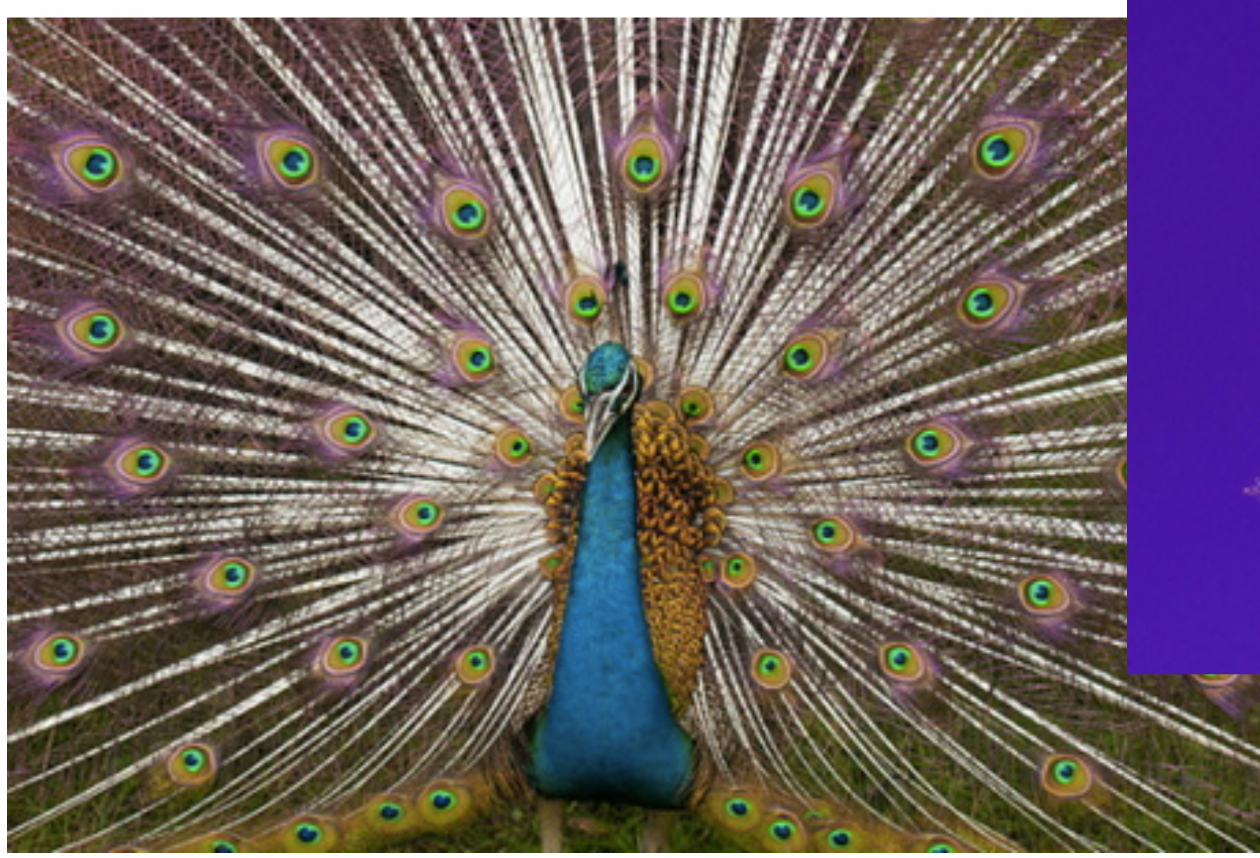

"It is not the fruits of
scientific research
that elevate a man
and enrich his nature,
but the urge to understand"

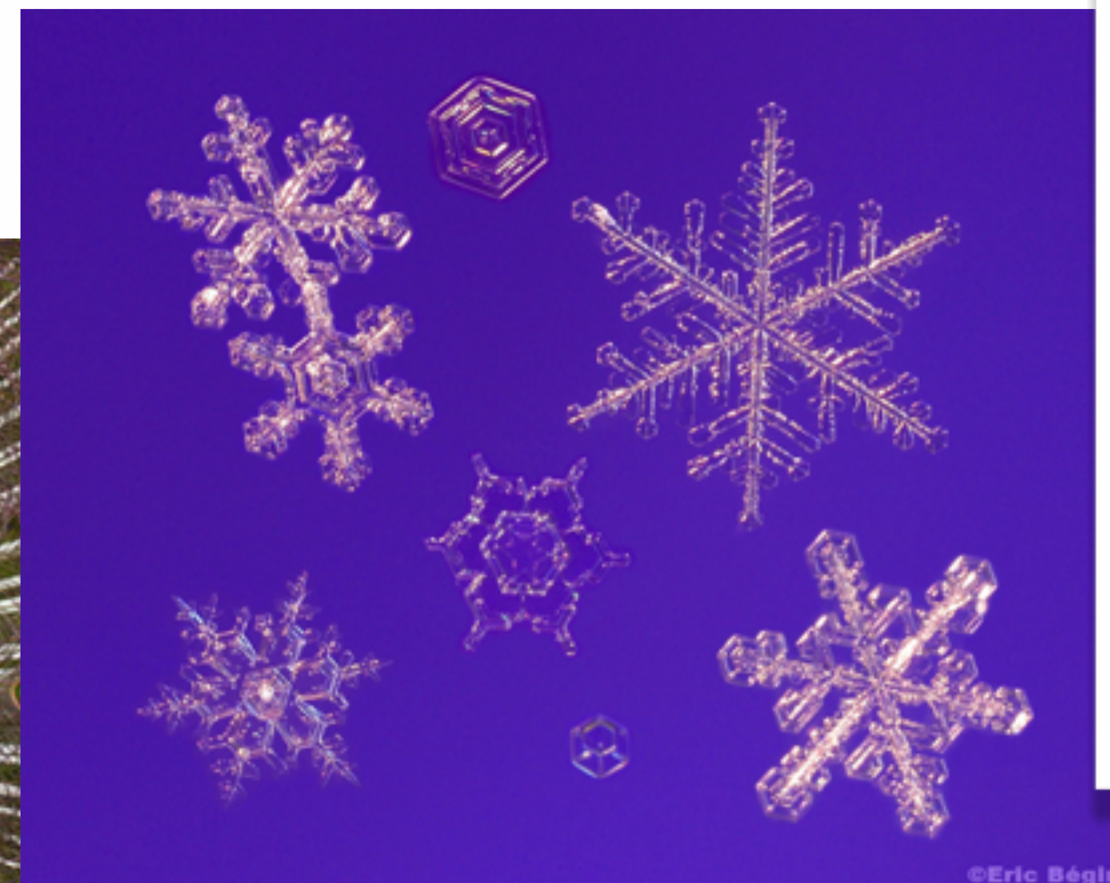
물리학 – 아름다움을 위해

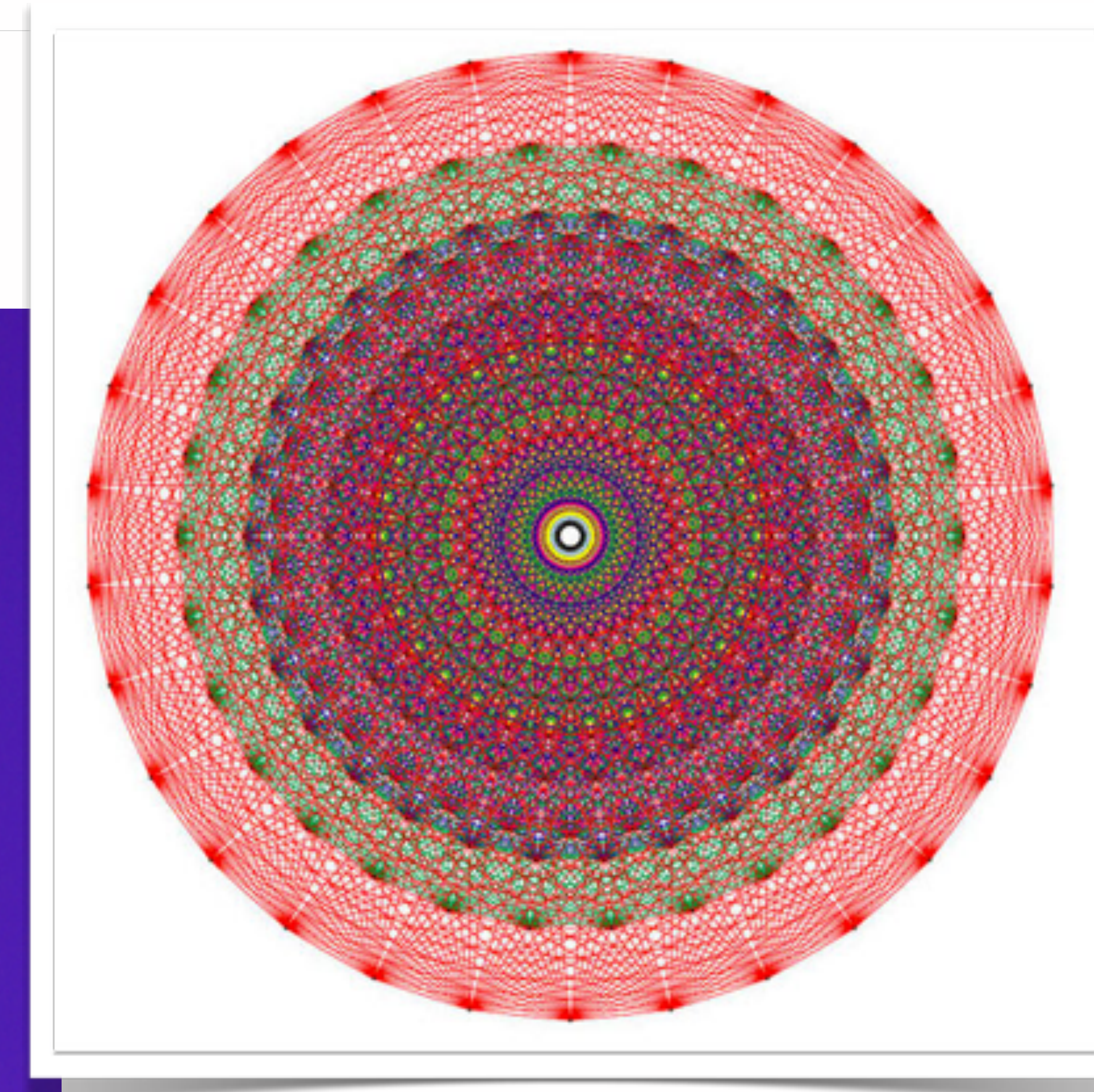
- 물리학자들이 가진 고집(신념)
  - 물리학의 기본 법칙은 아름답고 간단해야 한다
- 도대체 그들이 말하는 아름다움이란 무엇인가?
  - 대칭성의 아름다움
  - 가능한 한 많은 현상을 동시에 설명할 수 있는 강력한 이론체계
    - (예) 뉴턴의 운동 법칙 + 중력 법칙으로 사과의 떨어짐과 행성의 궤도 운동을 동시에 설명함.
    - (예) 맥스웰의 전자기 이론으로 전기 현상과 자기 현상을 하나의 이론으로 설명함.
  - 통일장 이론?!

대칭성의 아름다움

- some beautiful examples of symmetry





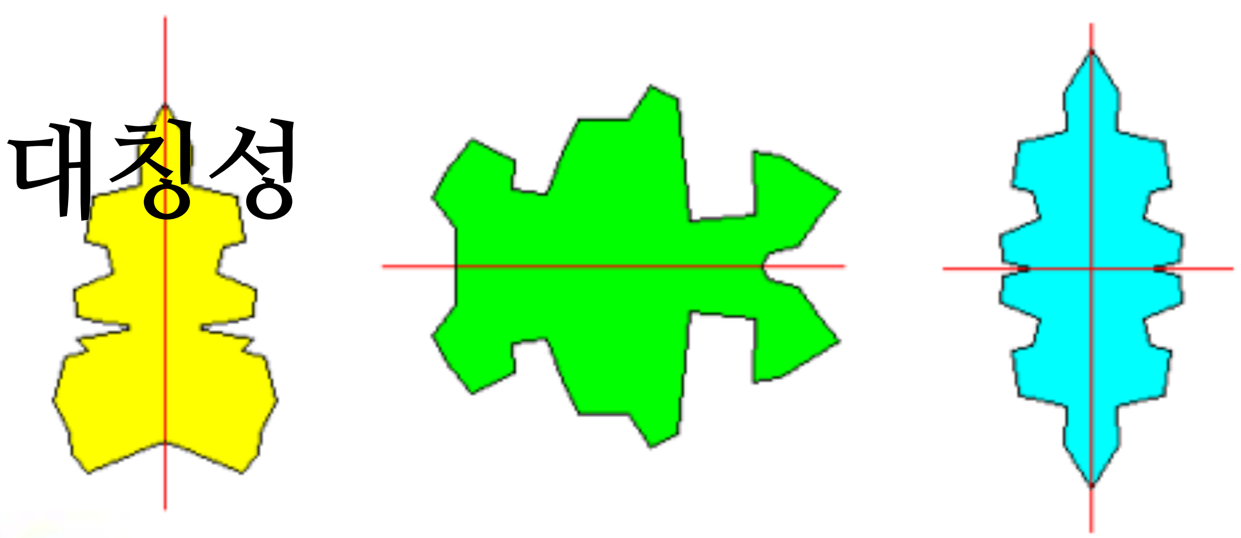


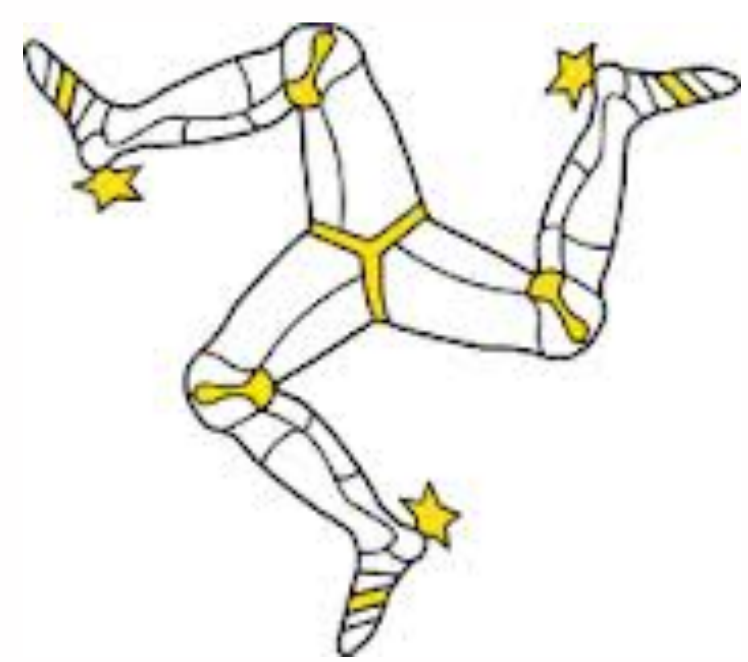
Beauty is truth, truth beauty — that is all
Ye know on earth, and all ye need to know.
- John Keats

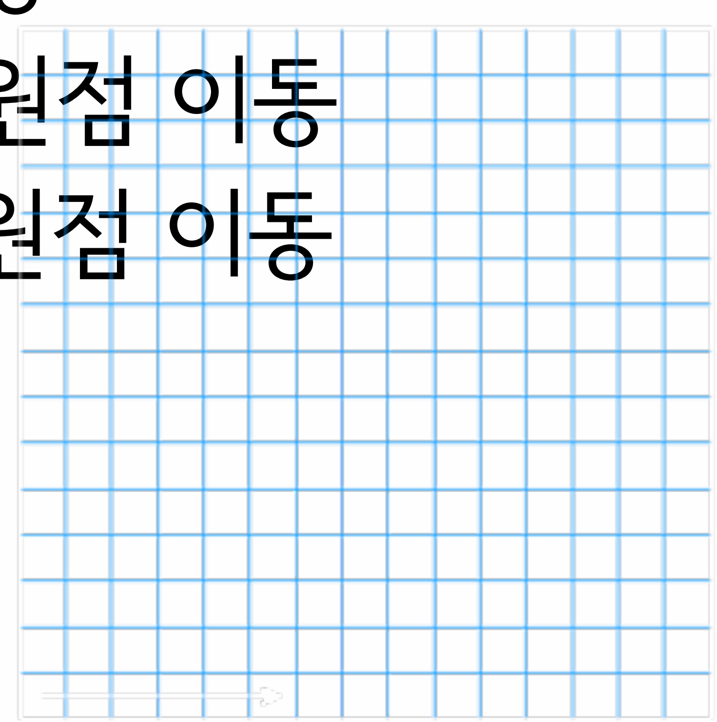
- 물리학에서 보는 대칭성은 어떤 것인가?

물리학의 대칭성

- 물리 법칙을 기술하는 독립변수에 변화를 주어도 (예: 시간, 공간 등의 입력정보를 변화) 그 법칙이 변하지 않을 때 '대칭적'이라고 한다.
  - 대칭성(symmetry) = "불변성(invariance)"
- 우리 우주가 지니고 있다고 여겨지는(?) 대칭성
  - 좌우 대칭(?)
  - 회전 대칭
  - 공간의 원점 이동
  - 시간의 원점 이동

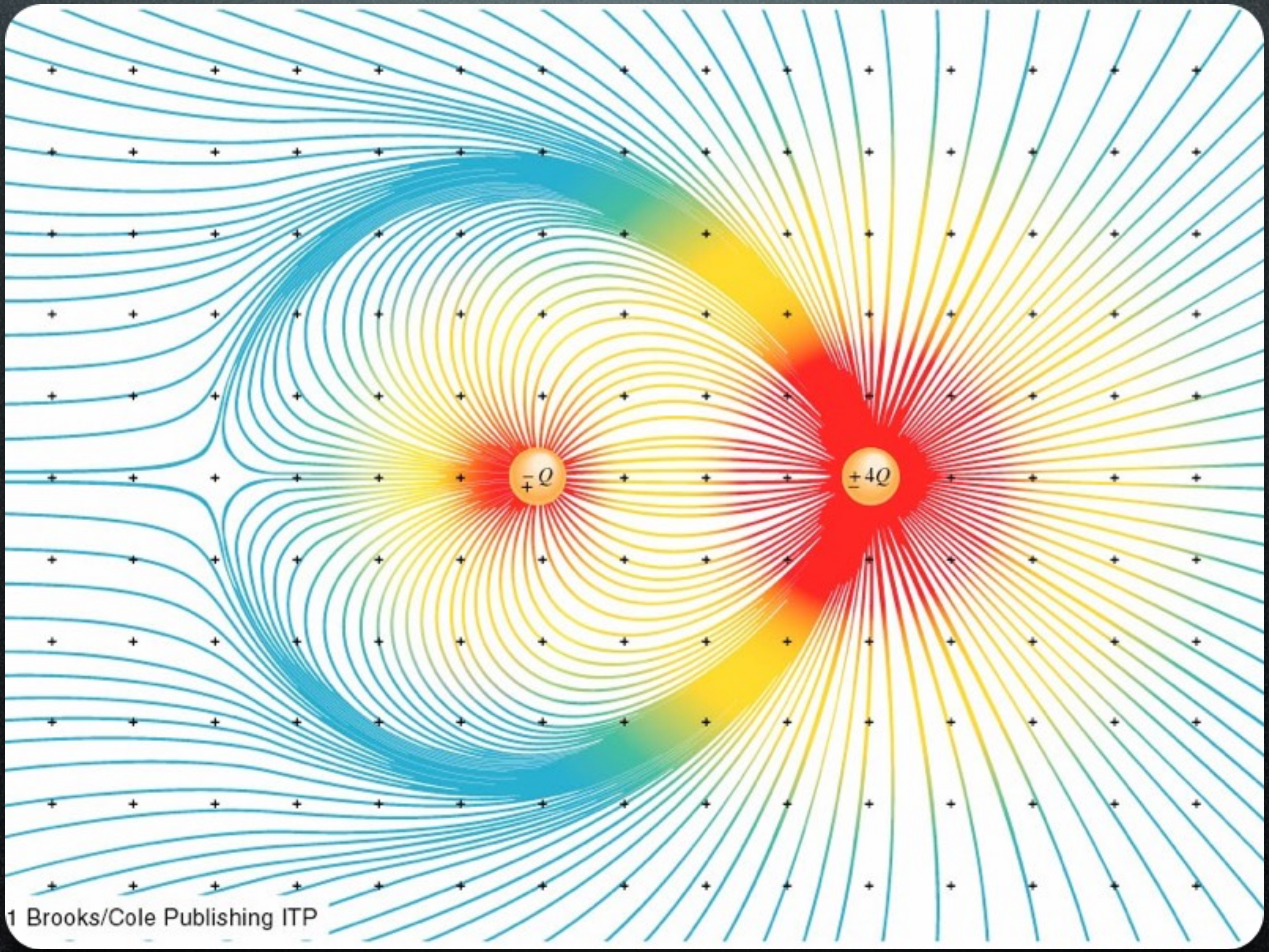






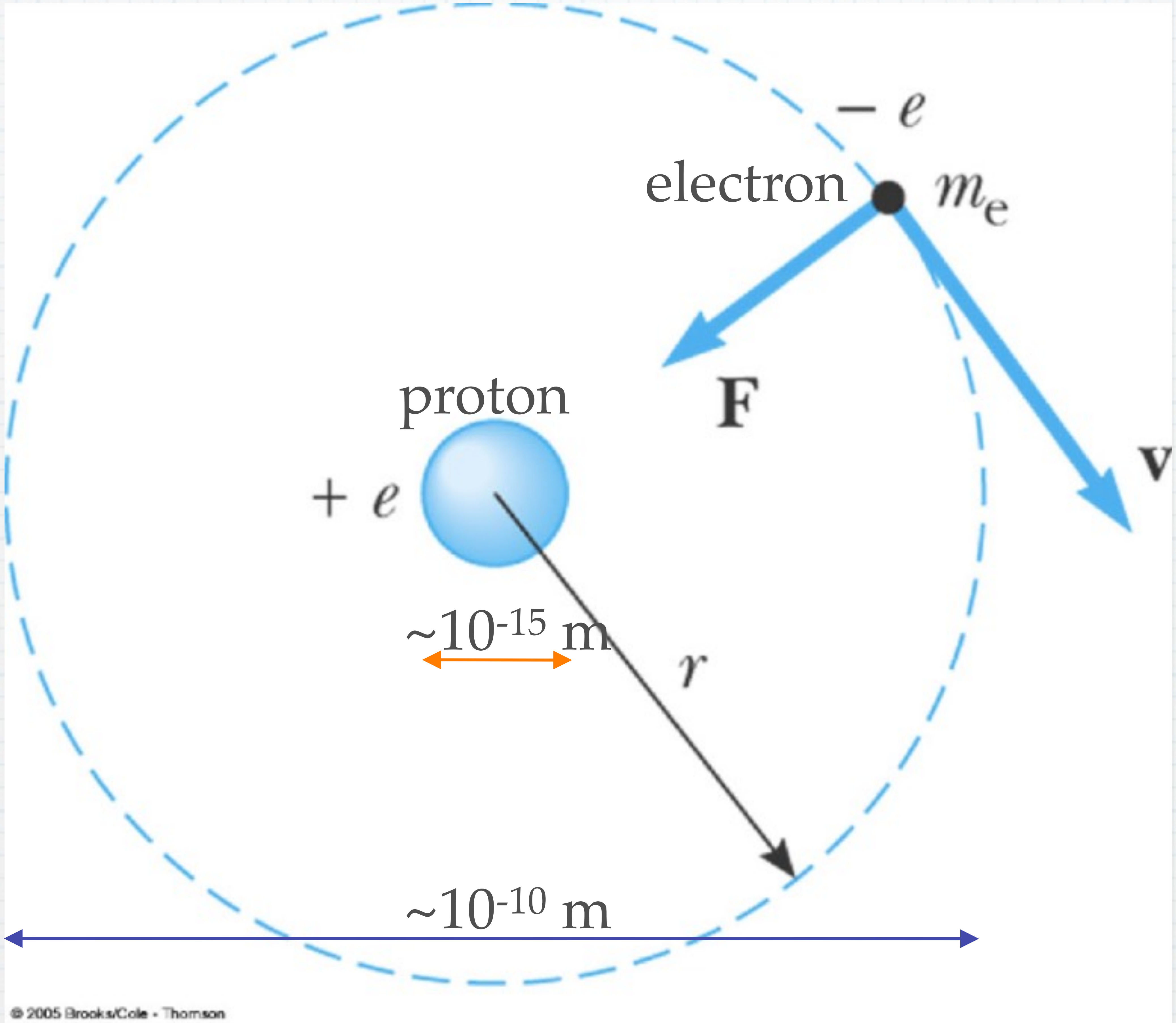
시간과 공간의 원점 이동에 대해 대칭인가?

- 시간의 원점 이동, 공간의 원점 이동에 대한 대칭성을 생각해 보자.
- 자연의 기본법칙(물리법칙)이 측정한 시간, 장소에 따라 달라진다면
  - 전세계 과학자들 혹은 물리학자들 간의 의사 소통이 가능할까?
    - 이 대칭성(=불변성)은 과학자들 간의 협력 연구를 가능케 하는 매우 기본적인 성질이므로 너무나 당연하게 여겨지고 있다.
  - 그런데.. 과연 그럴까?
    - 지구에서 한 물리 실험과 100억광년 떨어진 천체에서 한 물리 실험은 과연 같은 자연법칙을 따를까?
    - 오늘 지구에서 한 물리 실험과 10억년 전 지구에서 한 물리 실험은 과연 같은 자연법칙을 따를까?
    - 아직까지는 실험적으로 이 대칭성이 틀렸다는 증거는 없다.
    - **Enjoy (*the symmetries*) while you can!**



What is charge?

가장 간단한 원자: 수소



− e
electron
m_e
F
proton
v
+ e
~10-15 m
r
~10-10 m
© 2005 Brooks/Cole - Thomson

원자 안에 들어있는 전하

✦ 원자를 만드는 기본 요소들

- Electron (전자)
  - "electric" + "on"
  - 물질의 전기적, 화학적 성질은 대부분 전자에 의해서 결정됨
  - $Q = -e = -1.6 \times 10^{-19}$ C
- Nucleus (원자핵)
  - Proton (양성자): ("proto-" + "on"), Q = +e
  - Neutron (중성자): ("neutral" + "on"), Q = 0

- $e = 1.6 \times 10^{-19}$ Coulomb : basic unit of electric charge
- "proto-" : first, original (ex) protocol, prototype

우리가 가진 작은 지식들...

- 전하 $\propto$ 전자기력의 세기

- Some "elementary" objects have charge
  - electron (e^-), proton (p)
  - But, we don't know WHY...

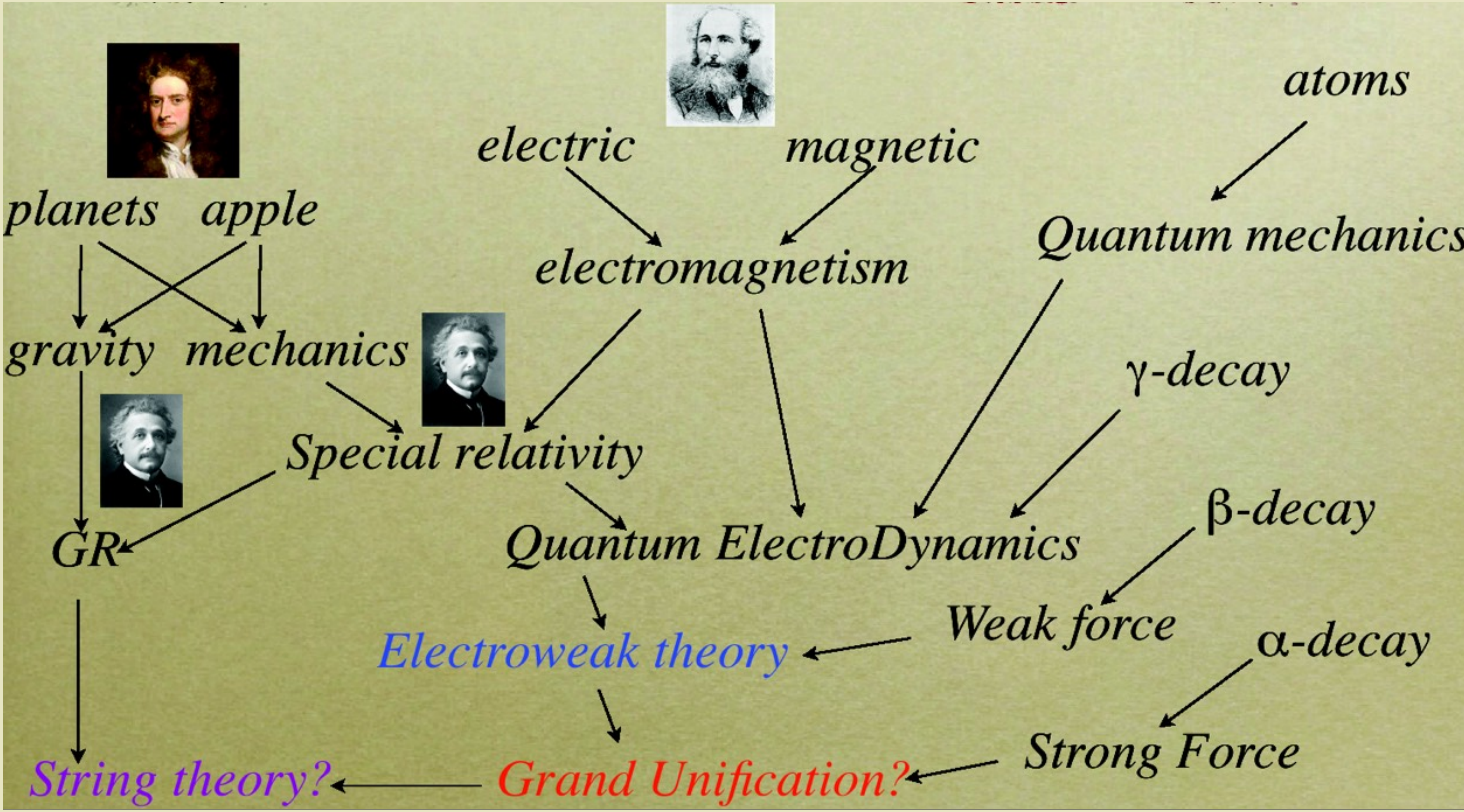
- 두가지 아주 중요한 성질들
  - Quantized (기본전하의 정수배)
  - Conserved (전하량 보존법칙)

전하가 만드는 힘

- For each fundamental interaction, there is a parameter that determines the coupling strength

$$\vec{F}_g = -G\frac{mM}{r^2}\hat{r} \qquad \vec{F}_E = \frac{1}{4\pi\epsilon_0}\frac{qQ}{r^2}\hat{r}$$

- Examples
  - electric charge for EM interaction
  - weak charge for weak int.
  - "color" charge for strong int.
  - gravtational charge??

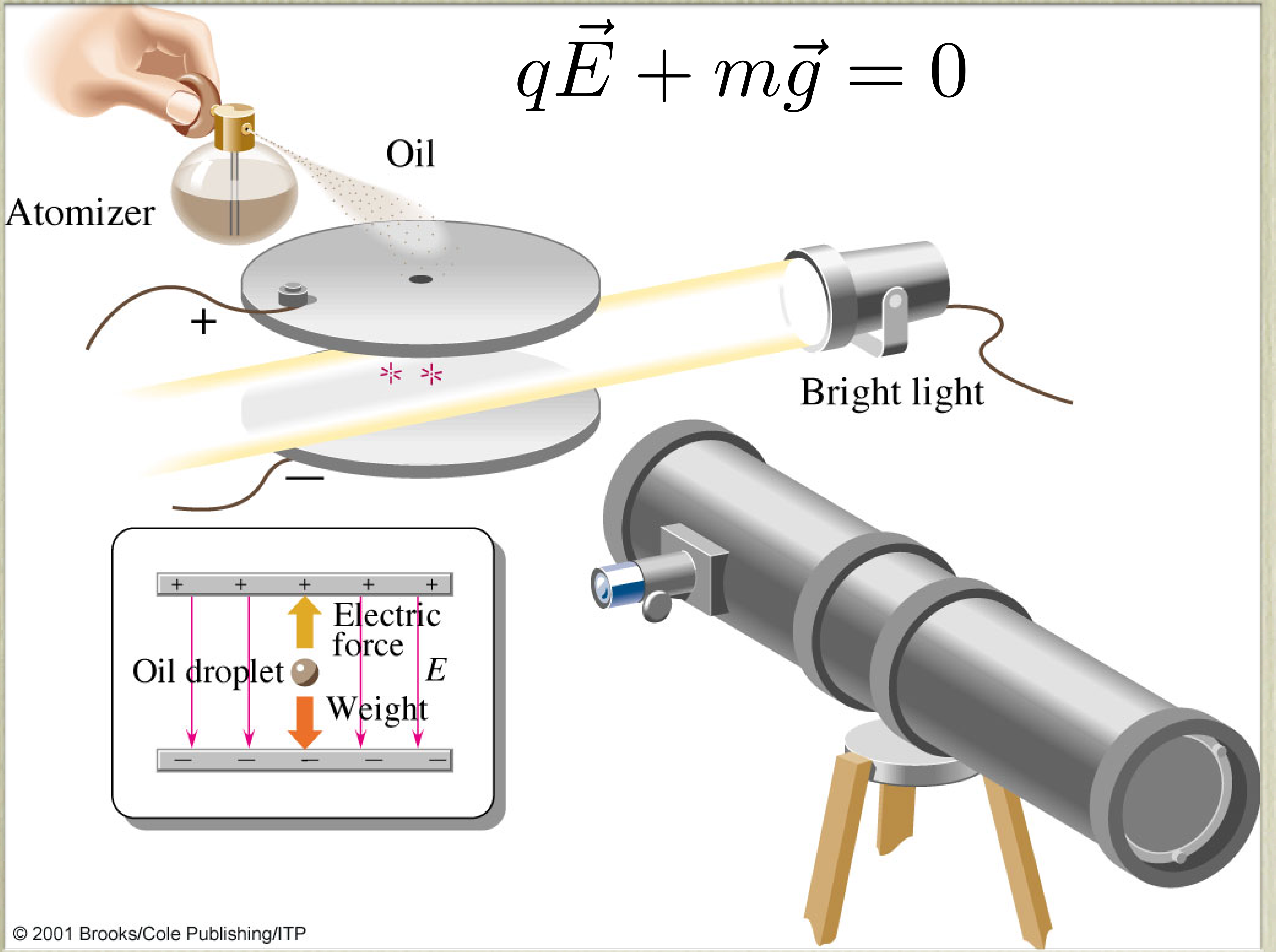


from H. Murayama's summary talk at LP 2003

Themes & Variations

- Variations on a theme of Quantization
- Variations on a theme of Conservation

Variations on a theme of Quantization

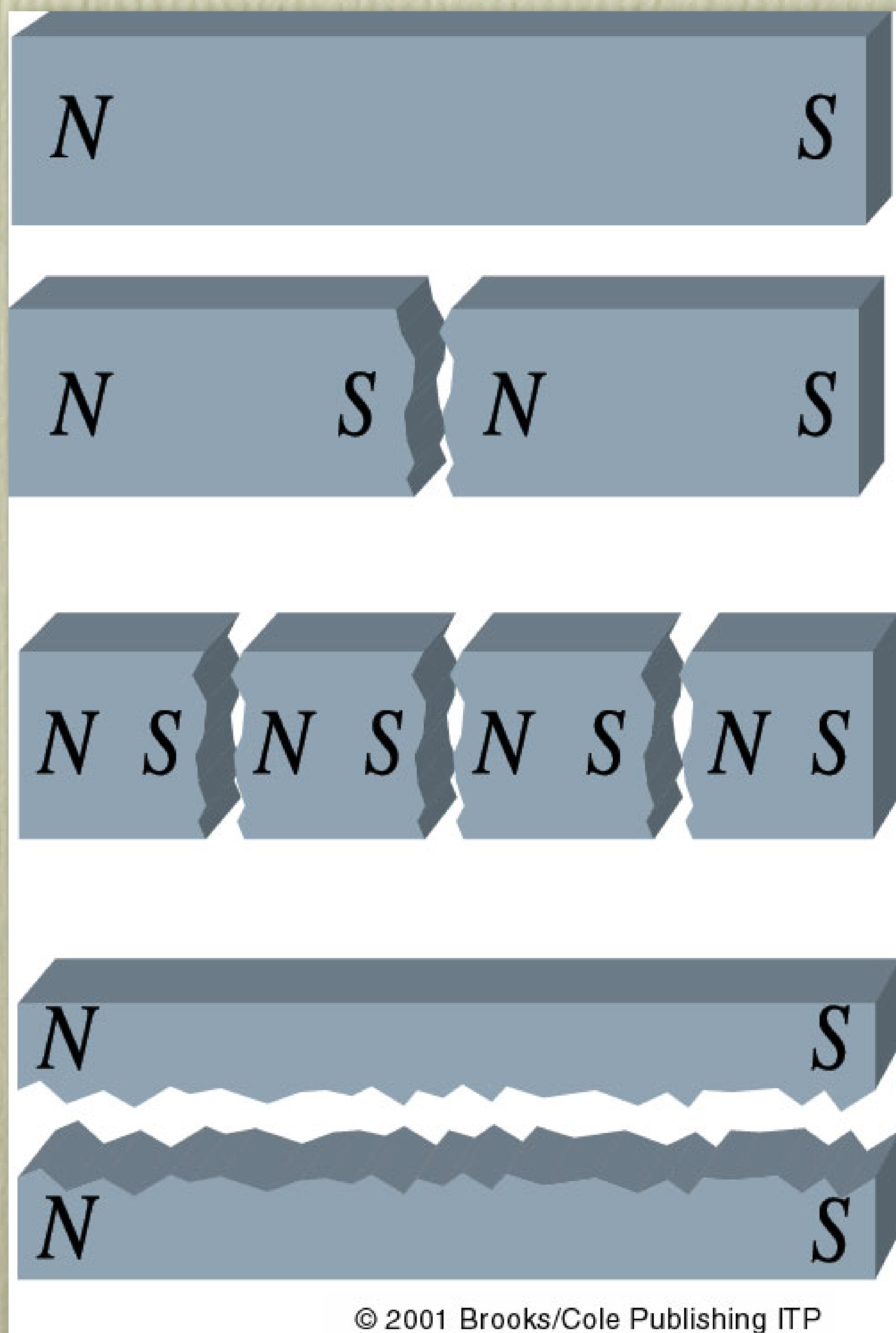


R. Millikan (1911)

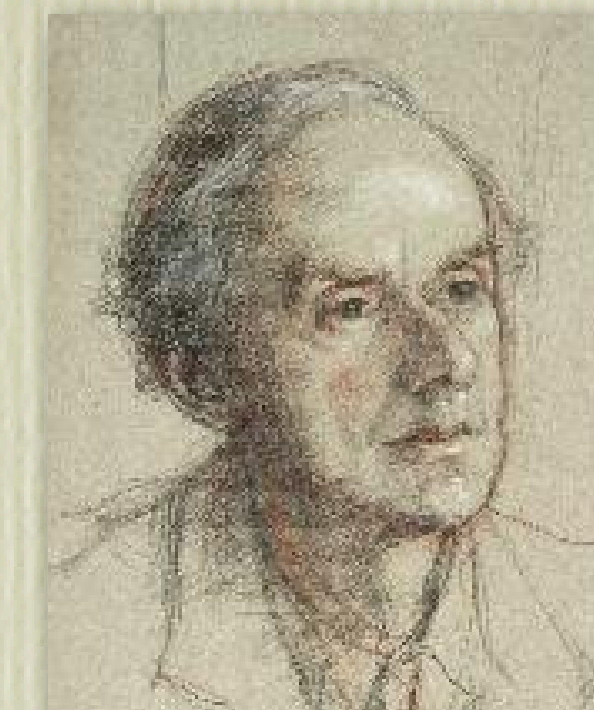
Nobel Prize(1923)

"… if these researches of Millikan had given a different result, the law of Einstein would have been without value, and the theory of Bohr without support. After Millikan's results both were awarded a Nobel Prize for Physics last year."

Quantization Variation I
Moderato, "Magnetic Monopole"

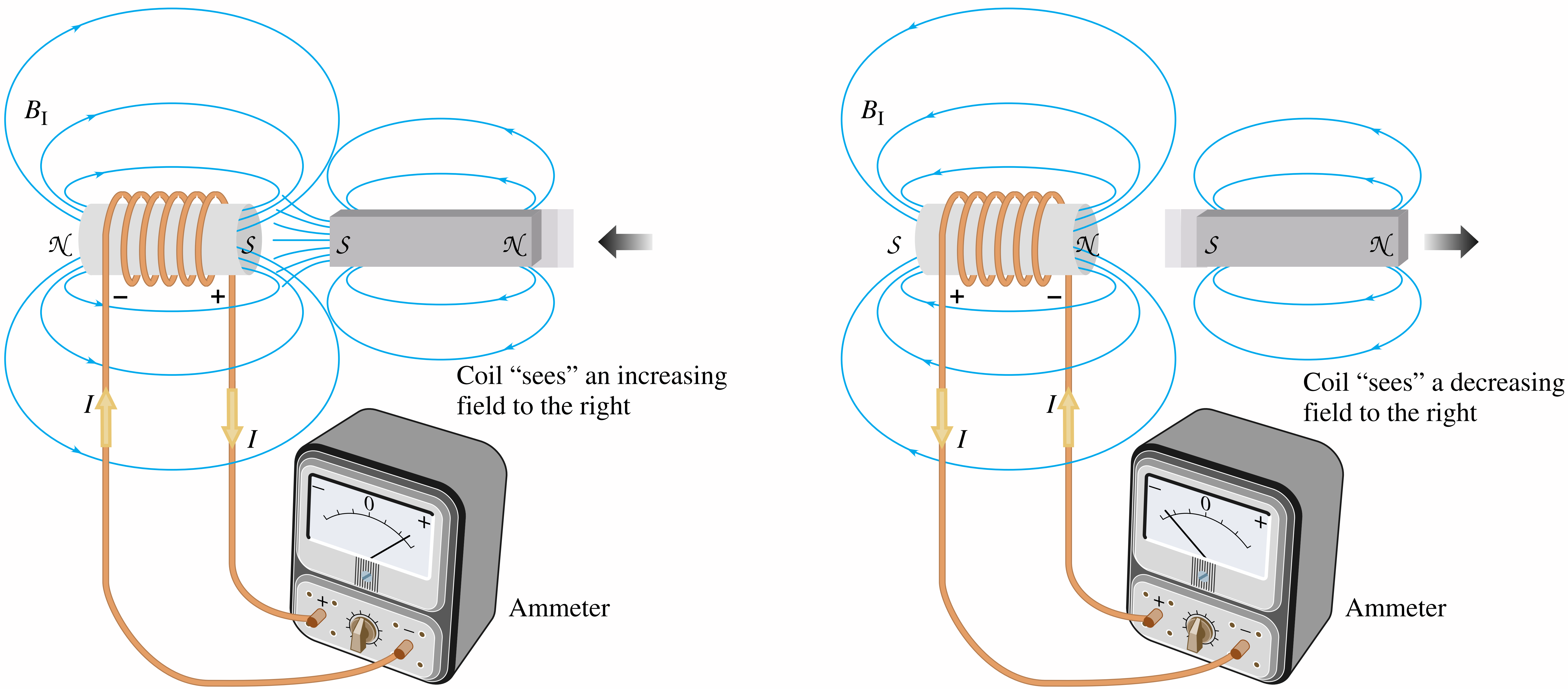


$$\frac{eg}{h} = n$$



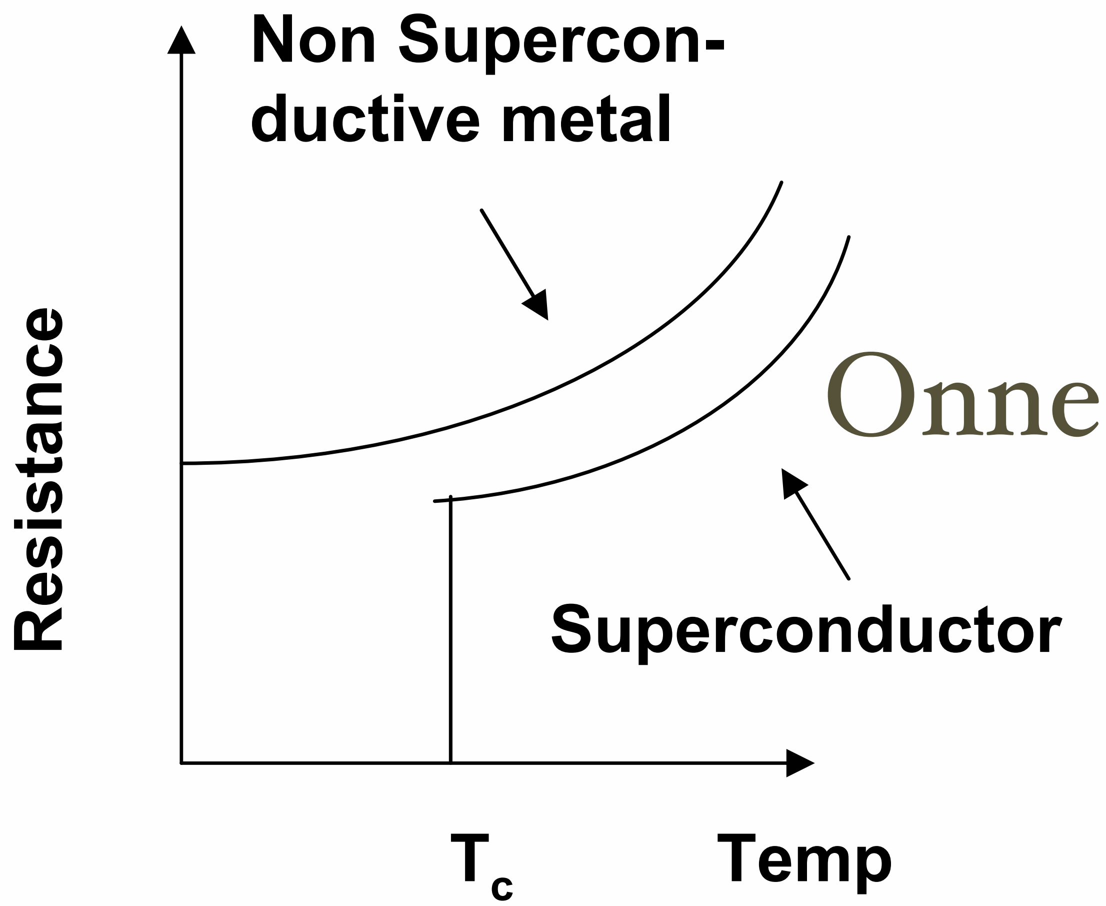
P.A.M. Dirac (1931)
- magnetic monopole 도입

Faraday's law

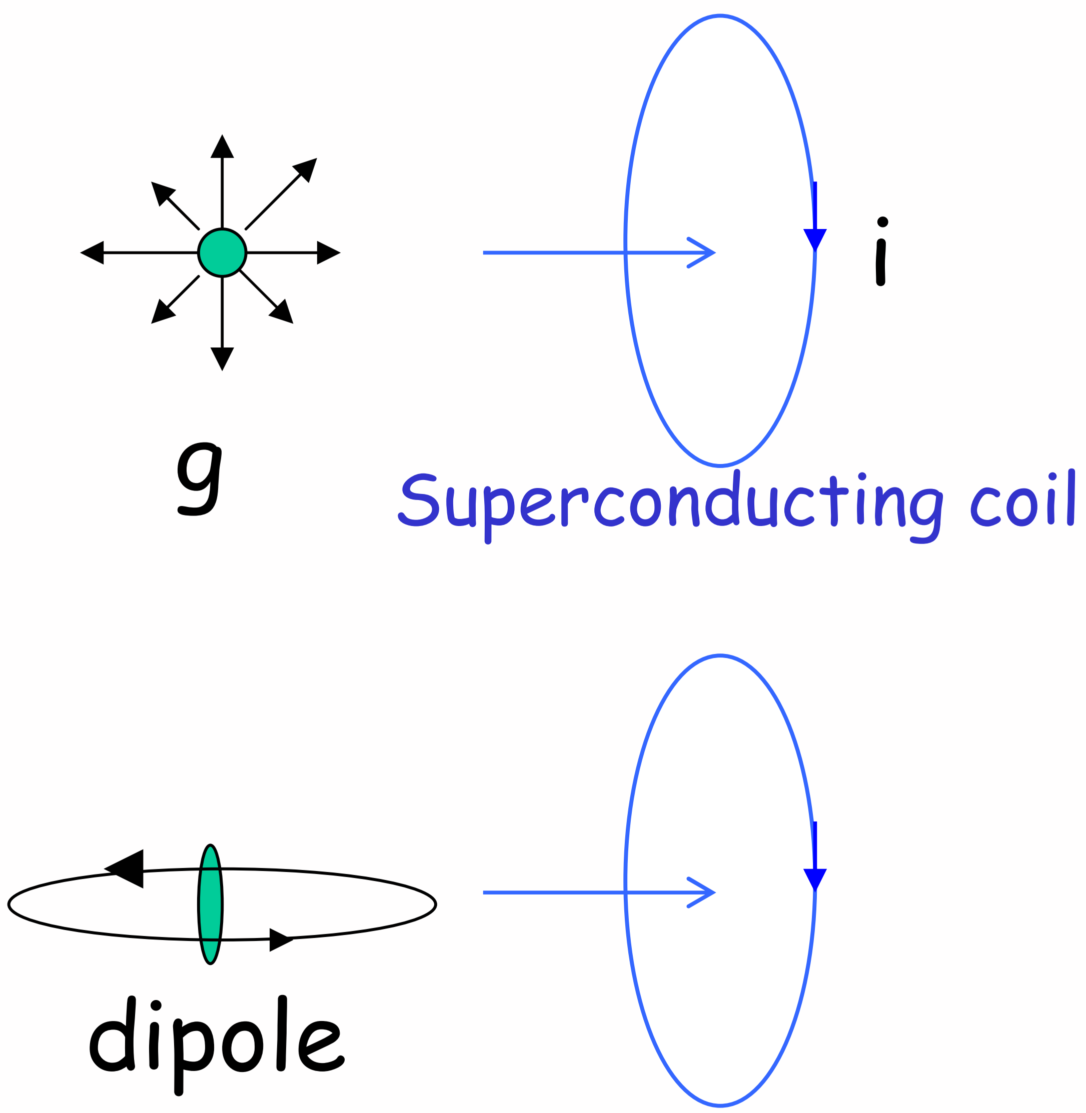


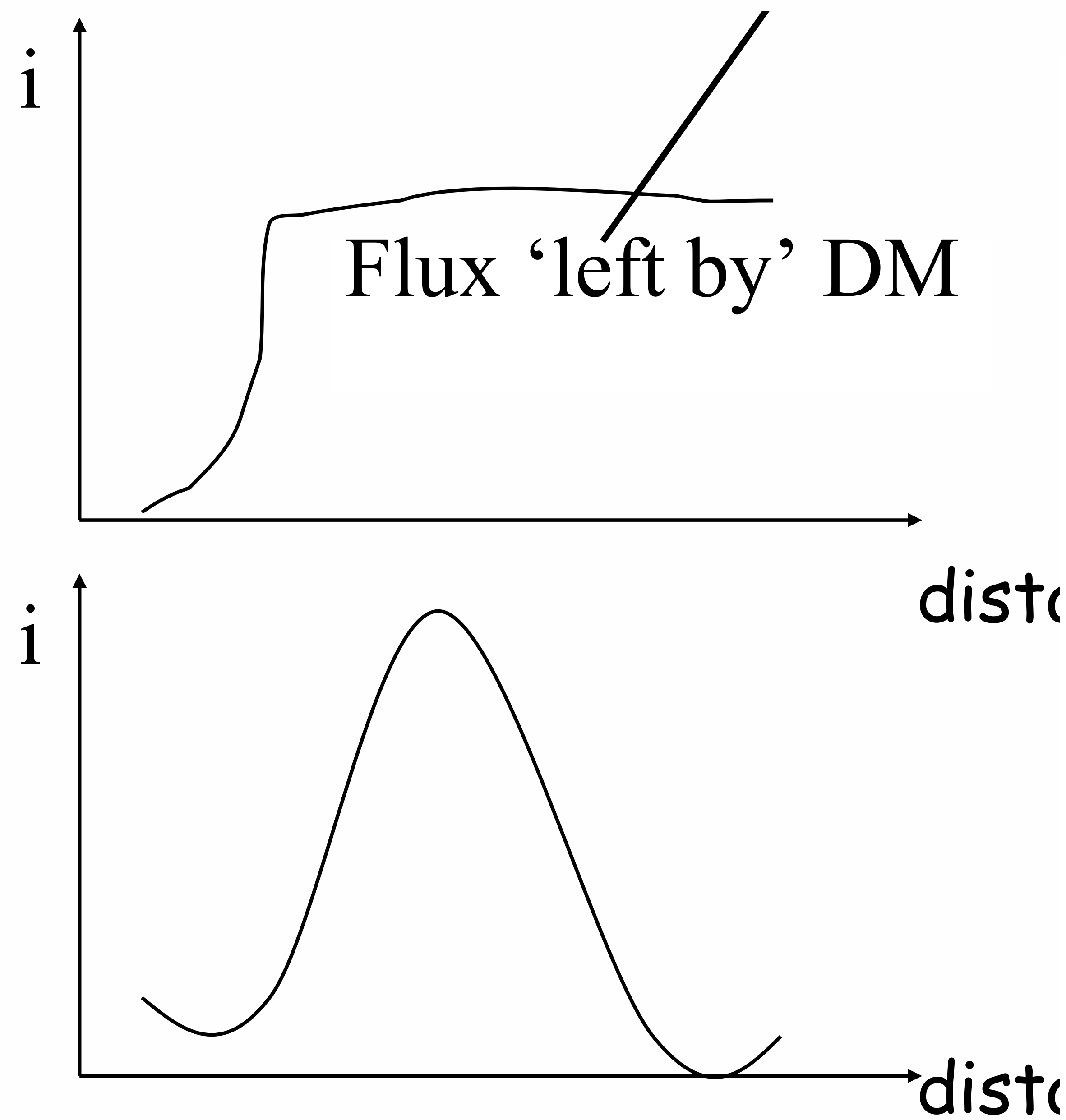
자석의 움직임 방향과 전류의 방향을 눈여겨 보시라!

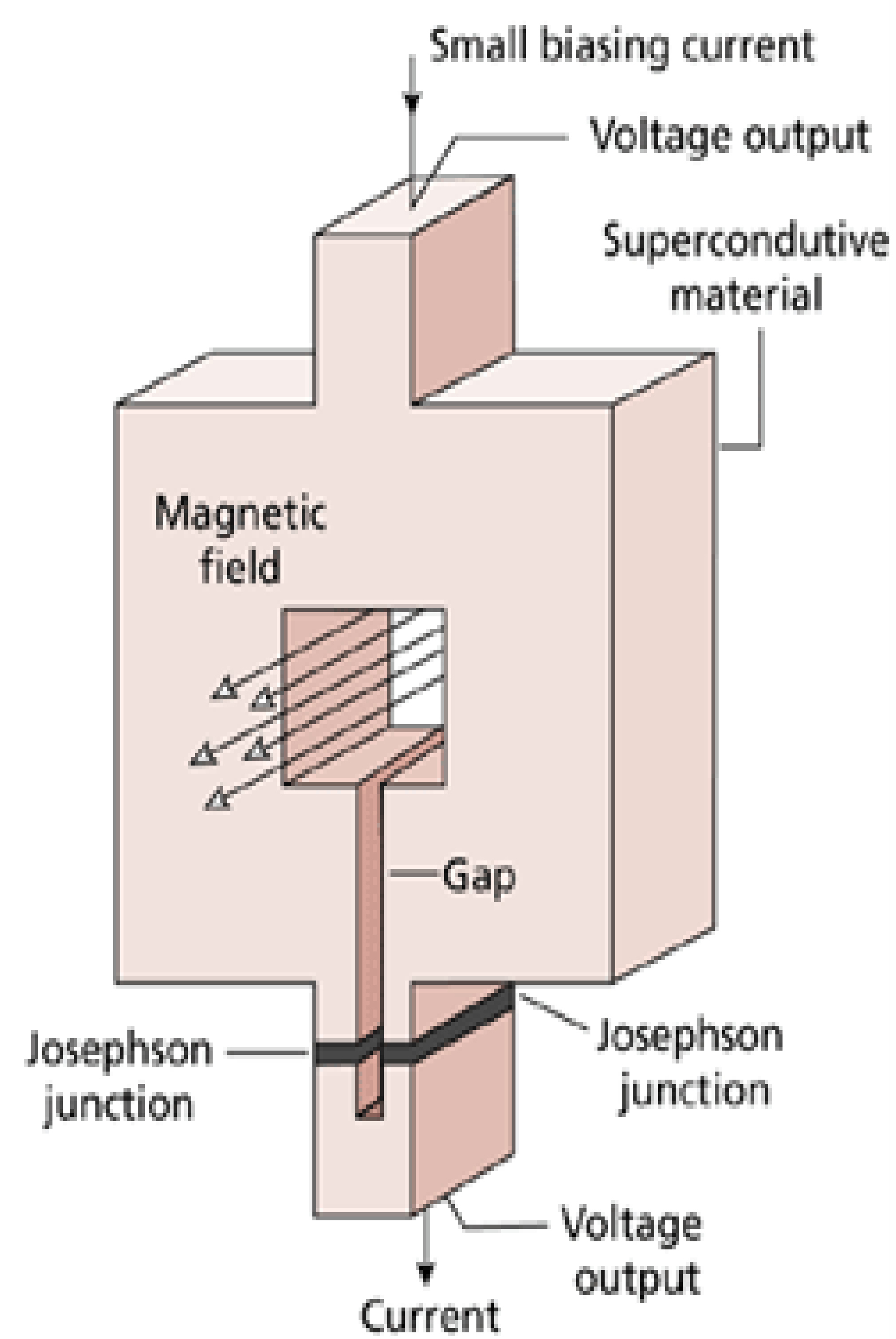
Quantization Variation I
Moderato, "Magnetic Monopole"



Onnes (1911)

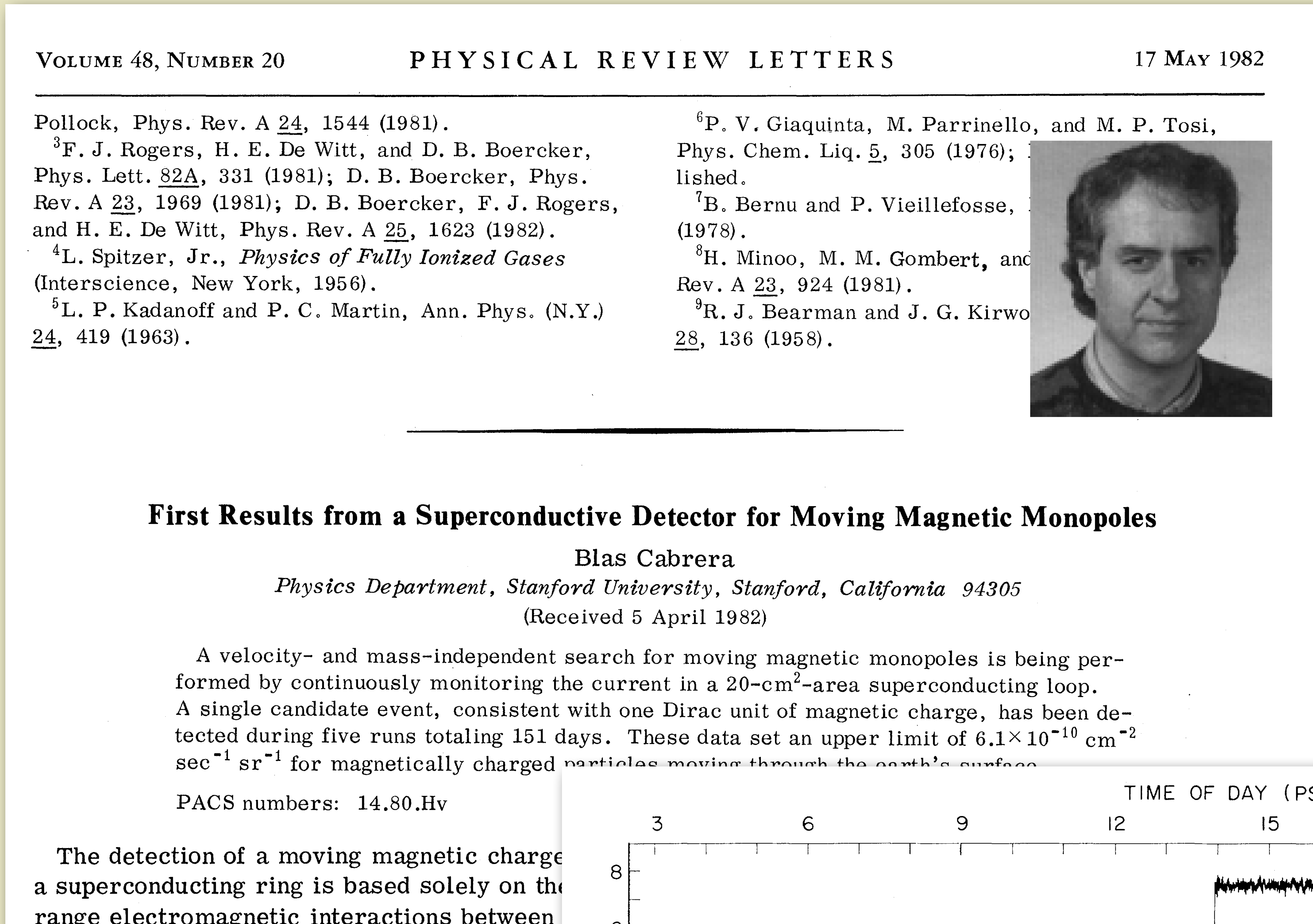






Monopole detection with SQUID

Quantization Variation I
Moderato, “Magnetic Monopole”



VOLUME 48, NUMBER 20 PHYSICAL REVIEW LETTERS 17 MAY 1982

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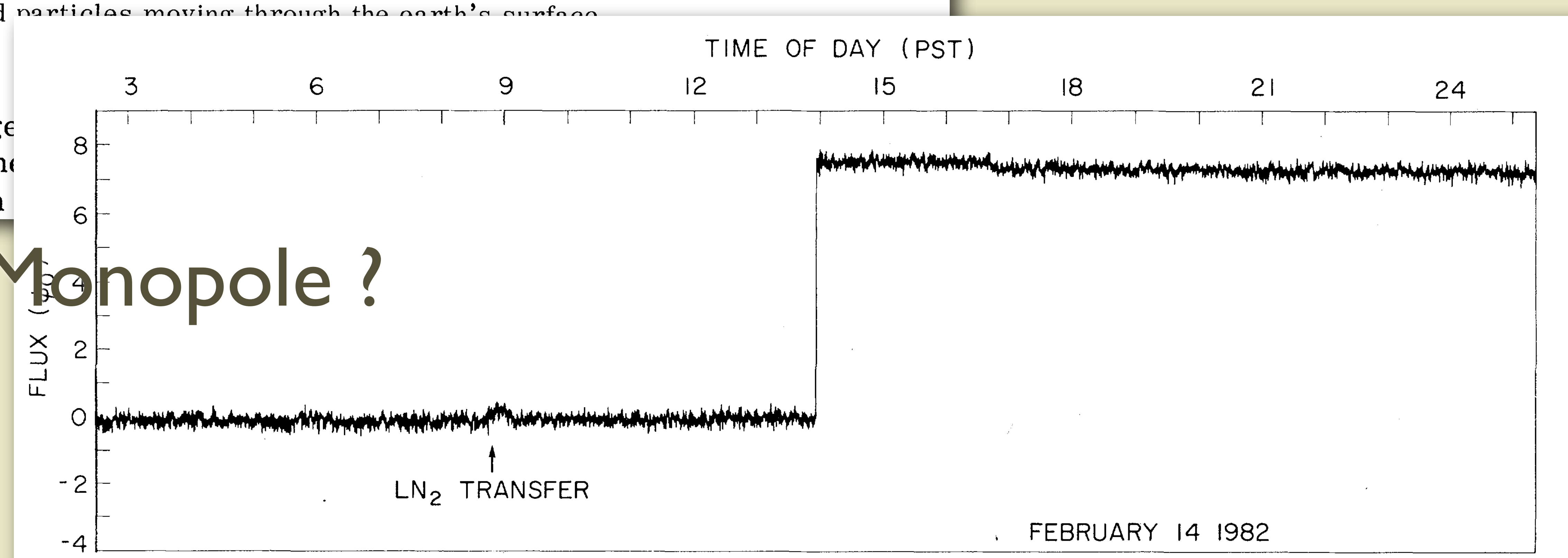
First Results from a Superconductive Detector for Moving Magnetic Monopoles

Blas Cabrera
Physics Department, Stanford University, Stanford, California 94305
(Received 5 April 1982)

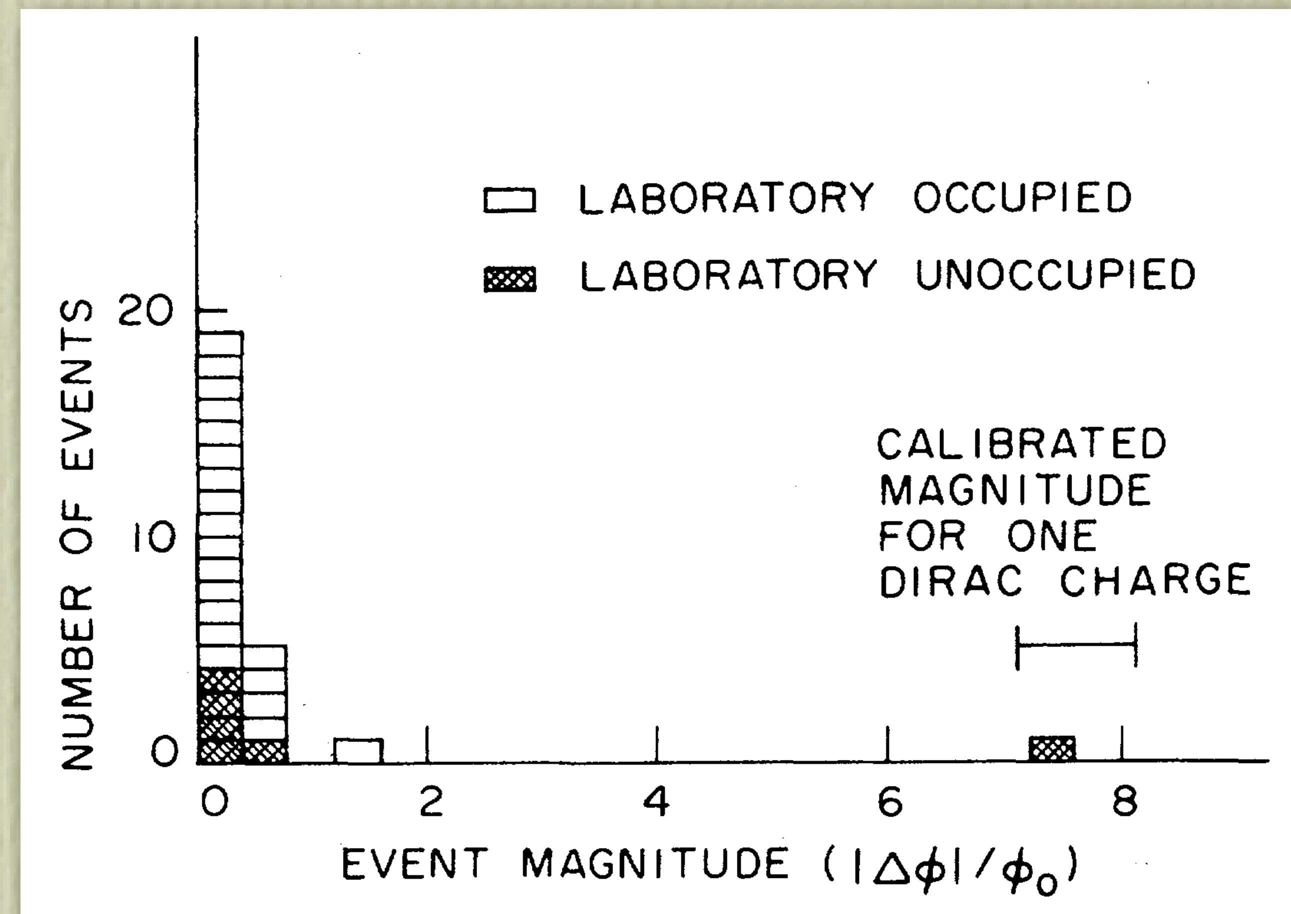
A velocity- and mass-independent search for moving magnetic monopoles is being performed by continuously monitoring the current in a 20-cm^2-area superconducting loop. A single candidate event, consistent with one Dirac unit of magnetic charge, has been detected during five runs totaling 151 days. These data set an upper limit of 6.1×10^{-10} cm^{-2} sec^{-1} sr^{-1} for magnetically charged

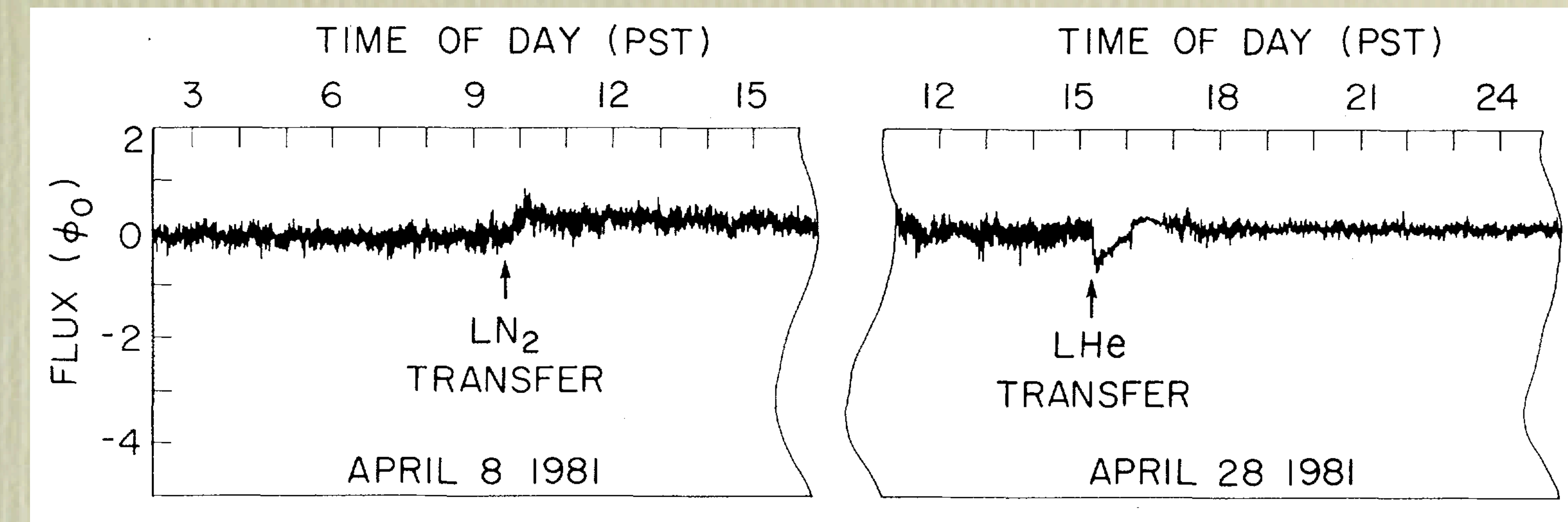
PACS numbers: 14.80.Hv

The detection of a moving magnetic charge
a superconducting ring is based solely on the
range electromagnetic interactions between



Valentine’s Day Monopole ?





In this experiment a four-turn, 5-cm-diam loop, positioned with its axis vertical, is connected to the superconducting input coil of a SQUID (superconducting quantum interference device) magnetometer.[3] The passage of a single Dirac charge through the loop would result in an $8\varphi_0$ change in the flux through the superconducting circuit, comprised of the detection loop and the SQUID input coil (a factor of 2 from $4\pi g = 2\varphi_0$ and of 4 from the turns in the pickup loop). The SQUID and loop are inside a 20-cm-diam, 1-m-long cylindrical superconducting shield closed at the bottom, and these are mounted inside a single Mumetal cylinder. The combined shielding provides 180-

(e) *The critical current* of the loop is not reached for currents a thousand times greater than $8\varphi_0/L$ and is typically 10^8 times greater.

(f) *Mechanically induced offsets* have been intentionally generated and are probably caused by shifts of the four-turn loop-wire geometry which produce inductance changes. Sharp raps with a screwdriver handle against the detector assembly cause such offsets. On two occasions out of 25 attempts these have exceeded $6\varphi_0$ (75% of the shift expected from one Dirac charge); however, drifts in the level were seen during the next hour.

(g) *No seismic disturbance* occurred on 14 February 1982.

(h) *Energetic cosmic rays* depositing $\lesssim 1$ GeV/

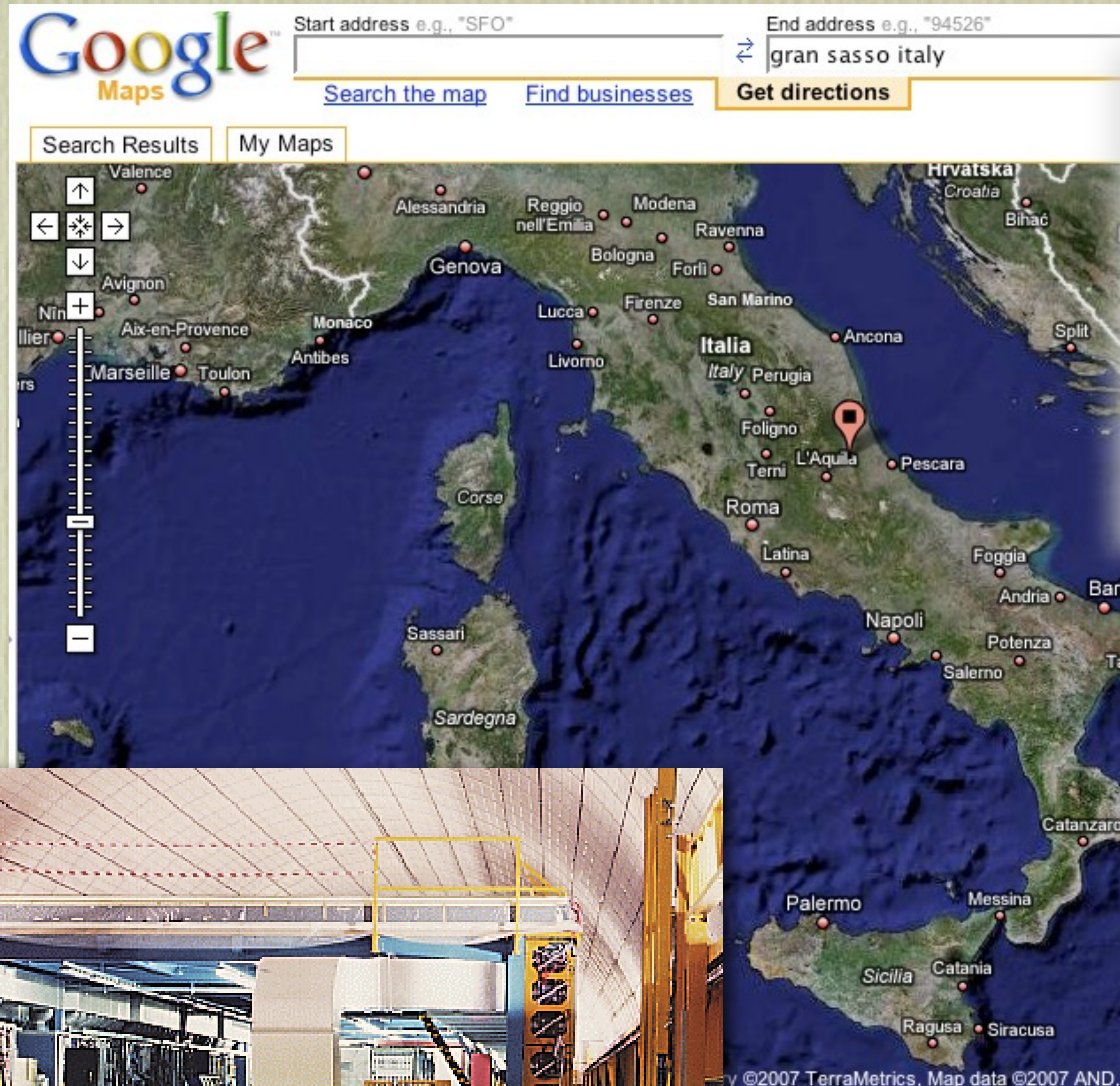
http://pdg.lbl.gov

Monopole Flux — Cosmic Ray Searches

"Caty" in the charge column indicates a search for monopole-catalyzed nucleon decay.
The absense of an entry usually means a track-etch experiment.

FLUX ($cm^{-2}sr^{-1}s^{-1}$)	MASS (GeV)	CHG (g)	COMMENTS ($\beta = v/c$)	EVTS	DOCUMENT ID		TECN
<1.4E−16		1	1.1E−4 < β <1	0	[10] AMBROSIO	02B	MCRO
<3E−16		Caty	1.1E−4 < β <5E−3	0	[11] AMBROSIO	02C	MCRO
<1.5E−15		1	5E−3 < β < 0.99	0	[12] AMBROSIO	02D	MCRO
<1E−15		1	1.1×10^{-4}–0.1	0	[13] AMBROSIO	97	MCRO
<5.6E−15		1	(0.18–3.0)E−3	0	[14] AHLEN	94	MCRO
<2.7E−15		Caty	$\beta \sim 1 \times 10^{-3}$	0	[15] BECKER-SZ...	94	IMB
<8.7E−15		1	>2.E−3	0	THRON	92	SOUD
<4.4E−12		1	all β	0	GARDNER	91	INDU
<7.2E−13		1	all β	0	HUBER	91	INDU
<4.E−11		1		0	CABRERA	83	INDU
<2.E−12		1	7.E−3 < β <6.E−1	0	BONARELLI	82	CNTR
6.E−10		1	all β	1	[22] CABRERA	82	INDU

Cosmis Ray 사용 monopole 검출 실험 현황



Monopole search w/ particle detector

Quantization Variation 2

Allegro ma non troppo, "Fractional Charge"

박첨지네 밭있어 그래그래서
그 밭에 오리가 있거든 그래그래서
예서 꽥 꽥 꽥, 제서 꽥 꽥 꽥 ...
(외국동요)

Old Macdonald had a farm, E-I-E-I-O
And on his farm he had a duck, E-I-E-I-O
With a "quack, quack" here and a "quack, quack" there
Here a "quack" there a "quack"
Everywhere a "quack, quack"
Old Macdonald had a farm, E-I-E-I-O

"물과 돌"

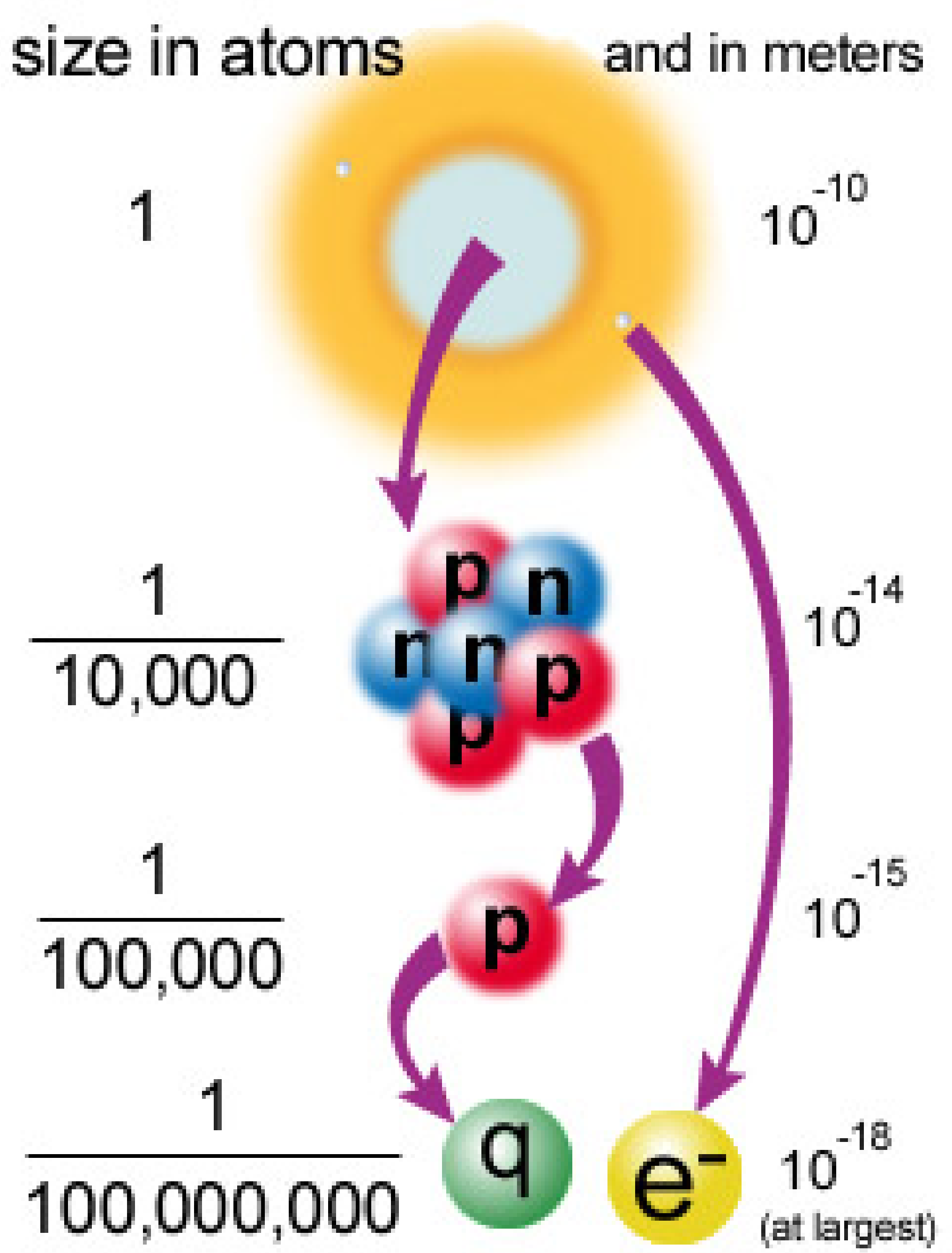
바윗돌 깨뜨려 돌덩이 / 돌덩이 깨뜨려 돌멩이
돌멩이 깨뜨려 자갈돌 / 자갈돌 깨뜨려 모래알
라라라라라 ~~~ (외국곡, 윤석중 작사)

모래알 깨뜨려 원자들 / 원자들 깨뜨려 원자핵
원자핵 깨뜨려 양성자 / 양성자 깨뜨려 쿼크알
라라라라라 ~~~ (U. Chicago, 김영기 교수 note에서)

"Fundamental Particles & Interactions?"

What is the world made of?

- is atom truly fundamental?



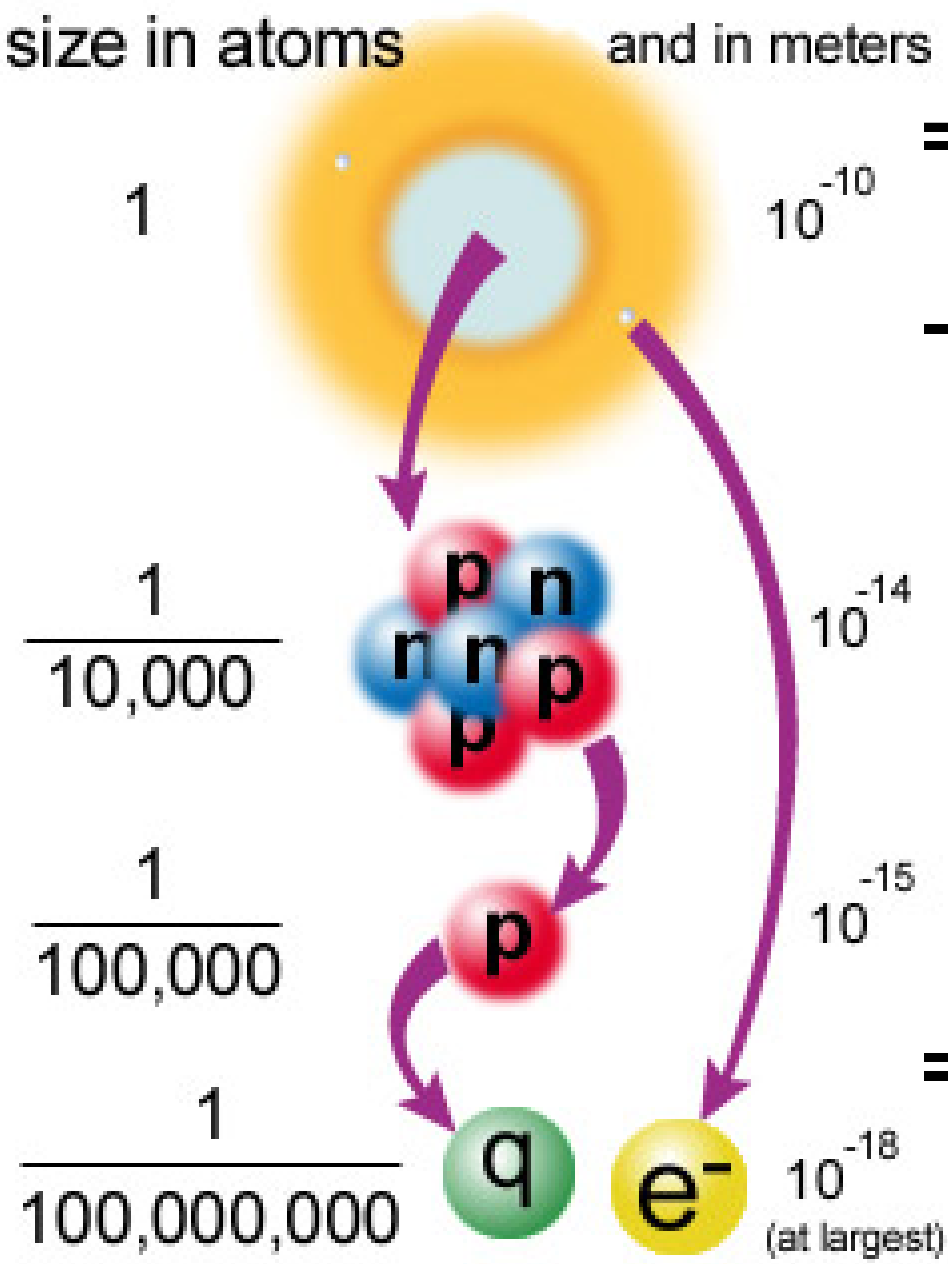
- The nucleus is ten thousand times smaller than the atom and the quarks and electrons are at least ten thousand times smaller than that.
- We don't know exactly how small quarks and electrons are; they are definitely smaller than 10-18 meters, and they might literally be points, but we do not know.

- It is also possible that quarks and electrons are not fundamental after all, and will turn out to be made up of other, more fundamental particles.
- (*Oh, will this madness ever end?*)
- 一尺之錘 日取其半 萬世不竭

Quantization Variation 2

Allegro ma non troppo, “Fractional Charge”

The fundamental fermions



Particle	Flavor			$Q/\lvert e\rvert$
leptons	ν_e	ν_μ	ν_τ	0
	e	μ	τ	–1
quarks	u	c	t	+2/3
	d	s	b	–1/3
	1st	2nd	3rd	

generations

??

Proton Structure

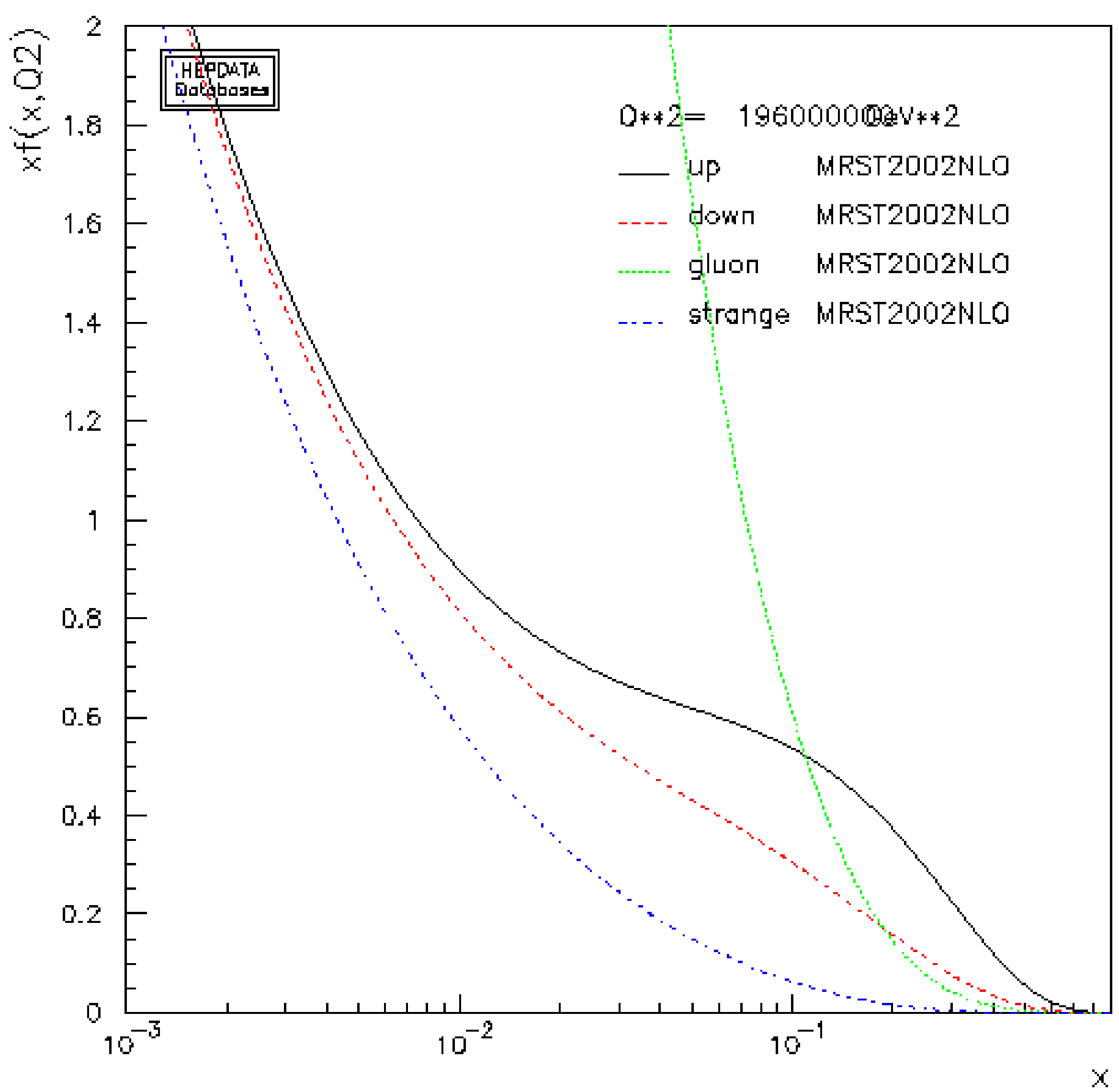
Partons

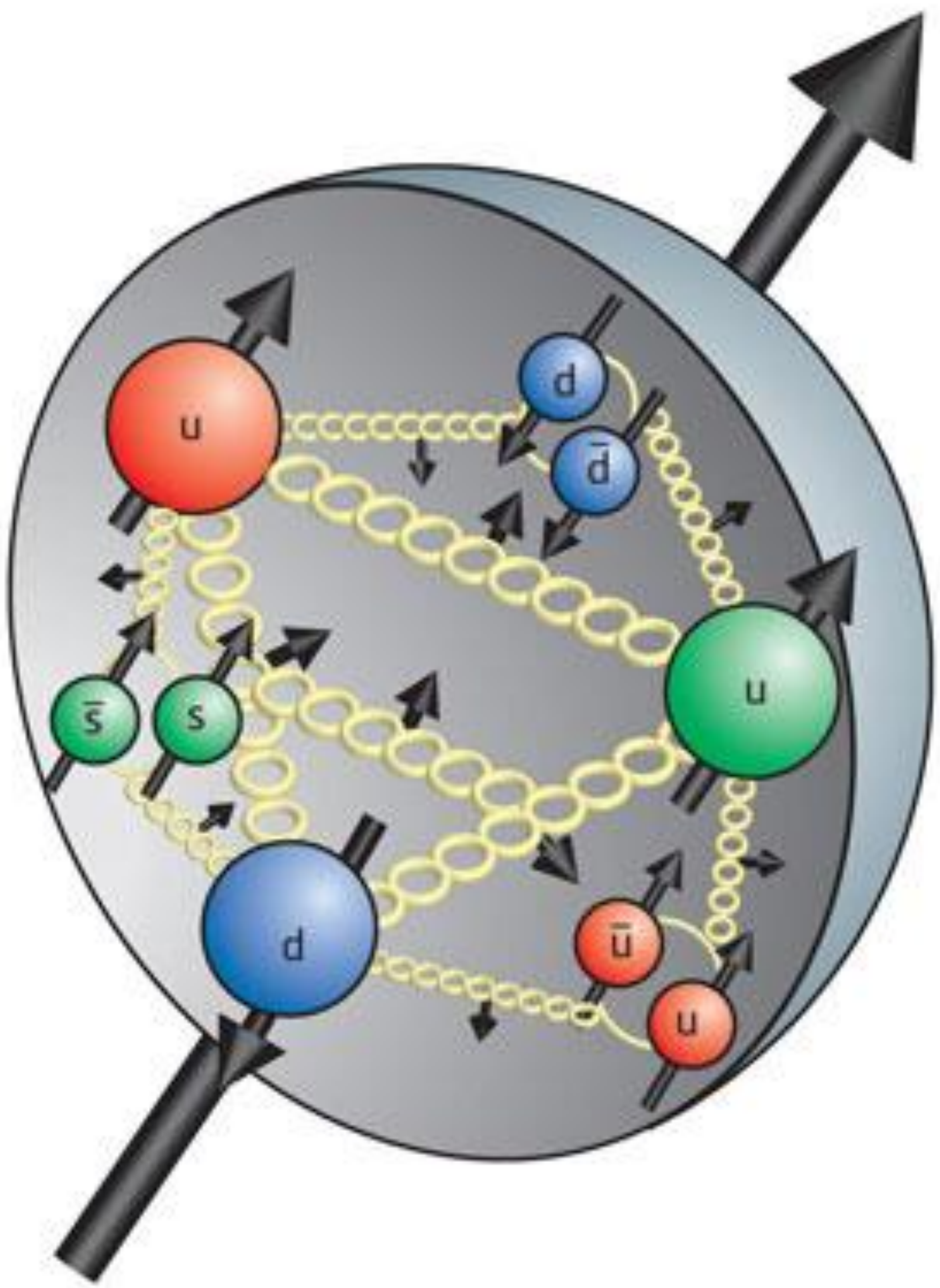
valence quark : u u d

sea quark : all quarks and antiquarks

gluons

Parton Distribution Function





Quantization Variation 2

Allegro ma non troppo, “Fractional Charge”

VOLUME 38, NUMBER 18 PHYSICAL REVIEW LETTERS 2 MAY 1977

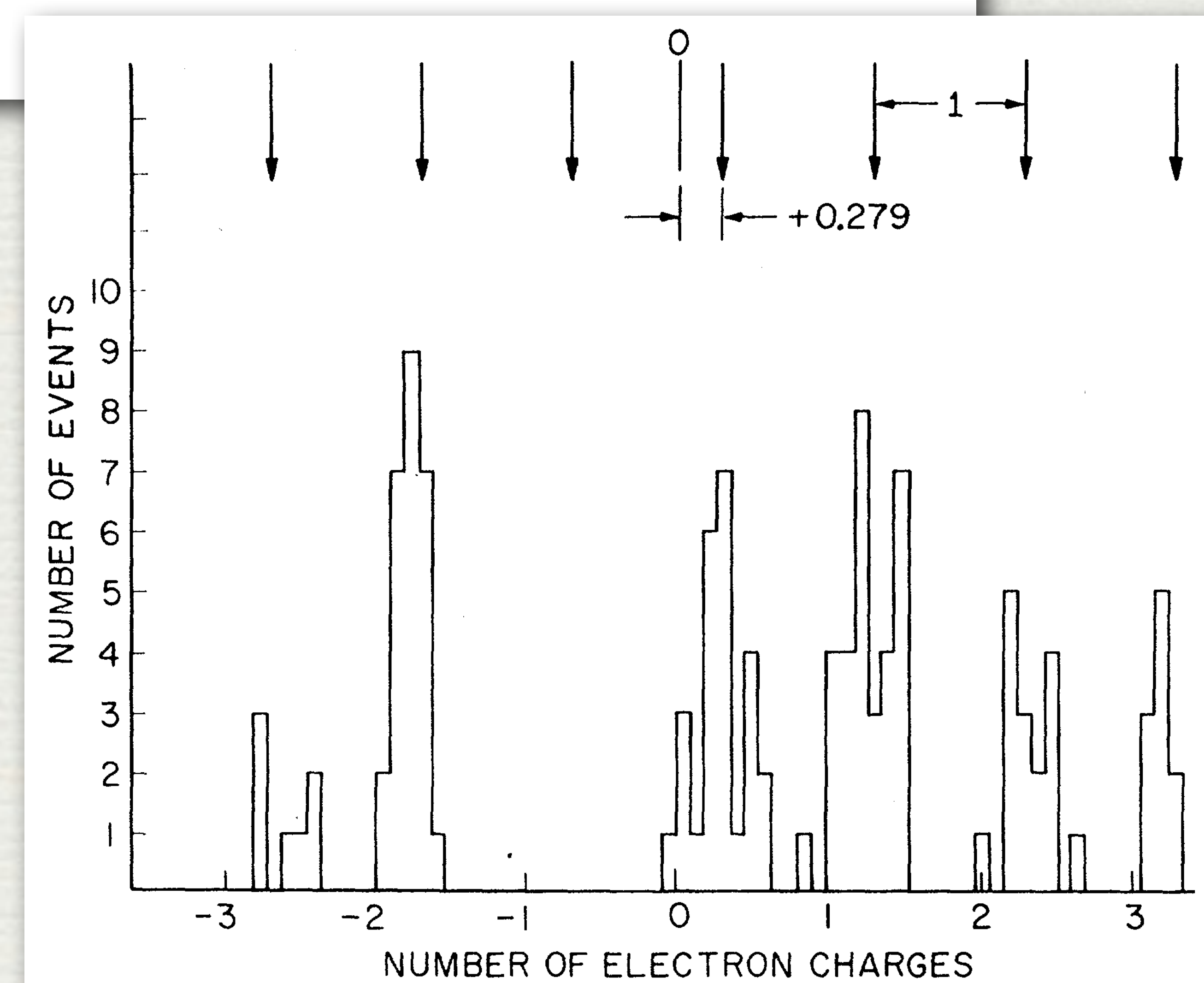
Evidence for the Existence of Fractional Charge on Matter*

George S. LaRue, William M. Fairbank,† and Arthur F. Hebard‡
Department of Physics, Stanford University, Stanford, California 94305
(Received 8 April 1977)

Accepted without review at the request of Walter E. Meyerhof under policy announced 26 April 1976

We present results of a superconducting magnetic levitation experiment which provide evidence for the existence of fractional charge on matter. Three niobium balls heat-treated on a tungsten substrate were found to have residual charges of $(+0.337 \pm 0.009)e$, $(-0.001 \pm 0.025)e$, and $(-0.331 \pm 0.070)e$. All five niobium balls heat-treated on a niobium substrate had residual charges near zero.

Superconducting magnetic levitation -- example



Quantization Variation 2

Allegro ma non troppo, "Fractional Charge"

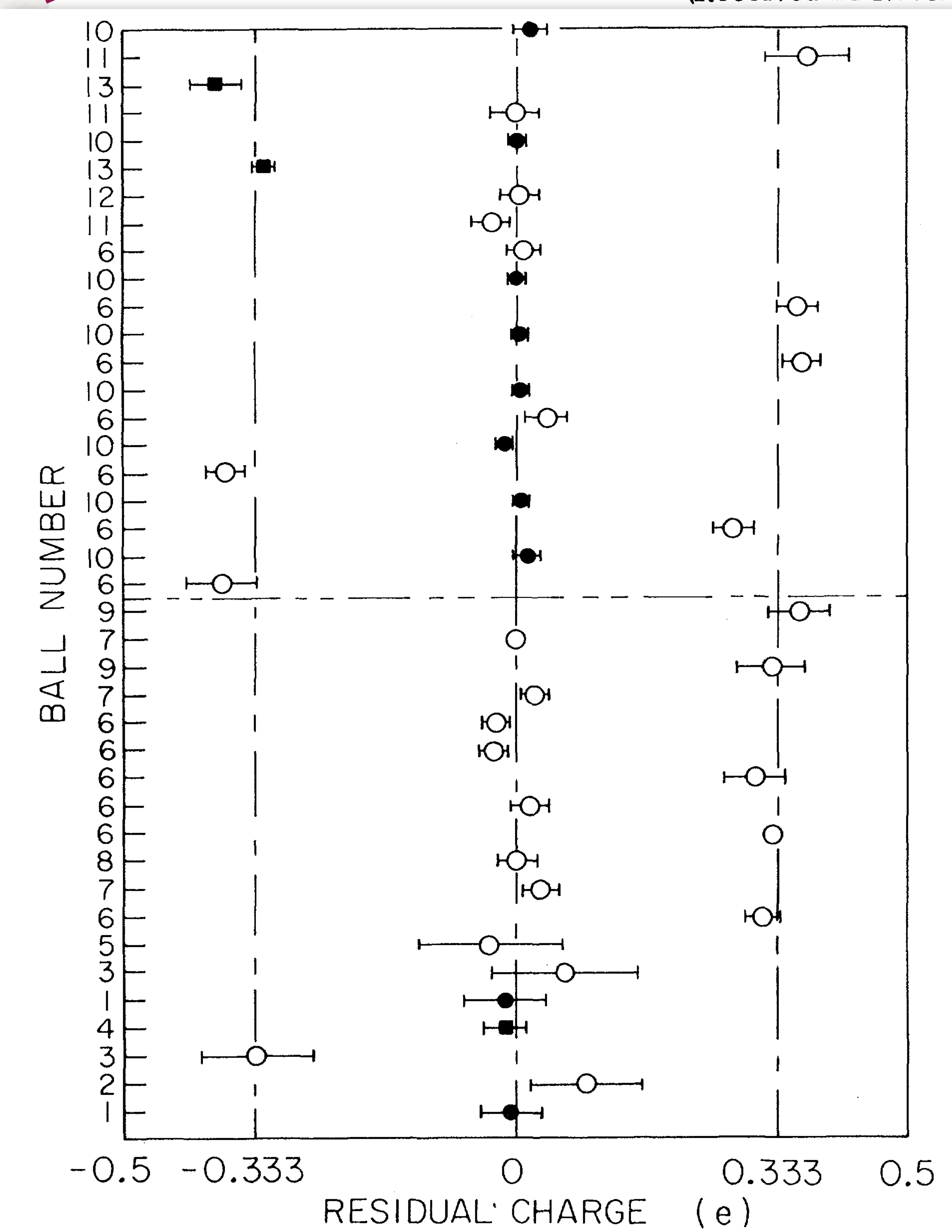
VOLUME 46, NUMBER 15 PHYSICAL REVIEW LETTERS 13 APRIL 1981

Mr. LaRue, again?

Observation of Fractional Charge of (1/3)e on Matter

George S. LaRue, James D. Phillips, and William M. Fairbank
Stanford University, Stanford, California 94035
(Received 24 November 1980)

nambiguously the existence of fractional
on particular spheres when they con-
21 new measurements, four charges of
Extensive measurements and critical
es are either negligible or have been



The apparatus is kept at 4.2 K and consists of a superconducting niobium ball (mass $\leq 9\times10^{-5}$ g) suspended magnetically between two horizontal capacitor plates. The ball's position is sensed by a SQUID (superconducting quantum interference device) magnetometer and its charge can be changed at will with movable β^+ and β^- emitters.

the vertical z direction is given by

$$F_A = (q_r + ne)E_A + \vec{P}_A \cdot \nabla E_F + \vec{P}_F \cdot \nabla E_A + F_M + F_Q,$$

Quantization Variation 2

Allegro ma non troppo, “Fractional Charge”

Citation: W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006) and 2007 partial update for edition 2008 (URL: http://pdg.lbl.gov)

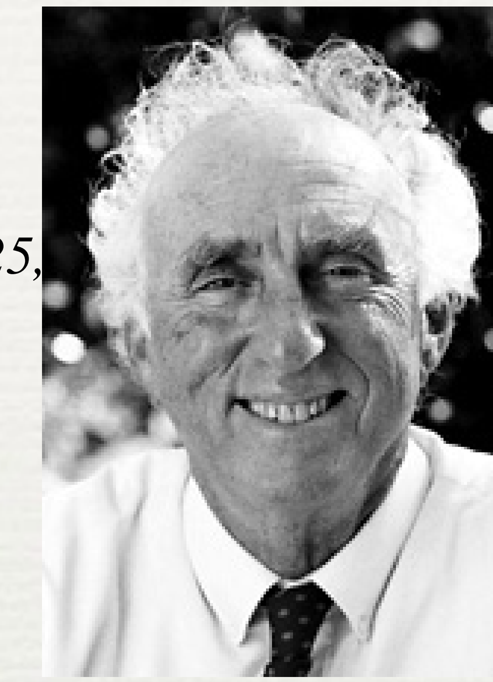
Quark Density — Matter Searches

QUARKS/ NUCLEON	CHG (e/3)	MASS (GeV)	MATERIAL/METHOD	EVTS	DOCUMENT ID	
<1.17E−22			silicone oil drops	0	[32] LEE	02
<4.71E−22			silicone oil drops	1	[33] HALYO	00
<4.7E−21	±1,2		silicone oil drops	0	MAR	96
<8.E−22	+2		Si/infrared photoionization	0	PERERA	93
<5.E−27	±1,2		sea water/levitation	0	HOMER	92
<4.E−20	±1,2		meteorites/mag. levitation	0	JONES	89
<1.E−19	±1,2		various/spectrometer	0	MILNER	87
<5.E−22	±1,2		W/levitation	0	SMITH	87
<3.E−20	+1,2		org liq/droplet tower	0	VANPOLEN	87
<6.E−20	−1,2		org liq/droplet tower	0	VANPOLEN	87
<3.E−21	±1		Hg drops-untreated	0	SAVAGE	86
<3.E−22	±1,2		levitated niobium	0	SMITH	86
<2.E−26	±1,2		^{4}He/levitation	0	SMITH	86B
<2.E−20	>±1	0.2–250	niobium+tungs/ion	0	MILNER	85
<1.E−21	±1		levitated niobium	0	SMITH	85
	+1,2	<100	niobium/mass spec	0	KUTSCHERA	84
<5.E−22			levitated steel	0	MARINELLI	84
<9.E−20	± <13		water/oil drop	0	JOYCE	83
<2.E−21	> | ± 1/2|		levitated steel	0	LIEBOWITZ	83
<1.E−19	±1,2		photo ion spec	0	VANDESTEEG	83
<2.E−20			mercury/oil drop	0	[34] HODGES	81
1.E−20	+1		levitated niobium	4	[35] LARUE	81
1.E−20	−1		levitated niobium	4	[35] LARUE	81
<1.E−21			levitated steel	0	MARINELLI	80B
<6.E−16			helium/mass spec	0	BOYD	79

Millikan's experiment in the digital era

PRL **99,** 161804 (2007) PHYSICAL REVIEW LETTERS week ending 19 OCTOBER 2007

Search for Fractional-Charge Particles in Meteoritic Material



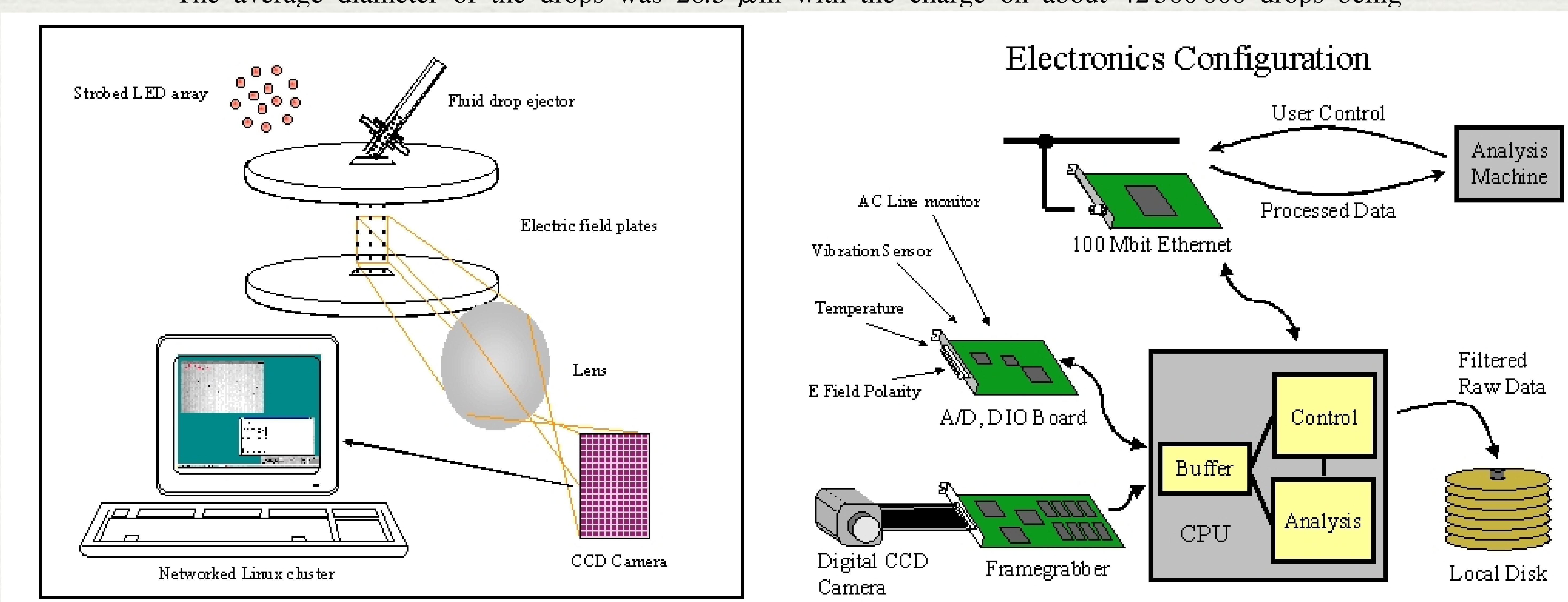
Peter C. Kim, Eric R. Lee, Irwin T. Lee, and Martin L. Perl*
Stanford Linear Accelerator Center, Stanford University, 2575 Sand Hill Road, Menlo Park, California 94025,

Valerie Halyo
Department of Physics, Princeton University, Princeton, New Jersey 08544, USA

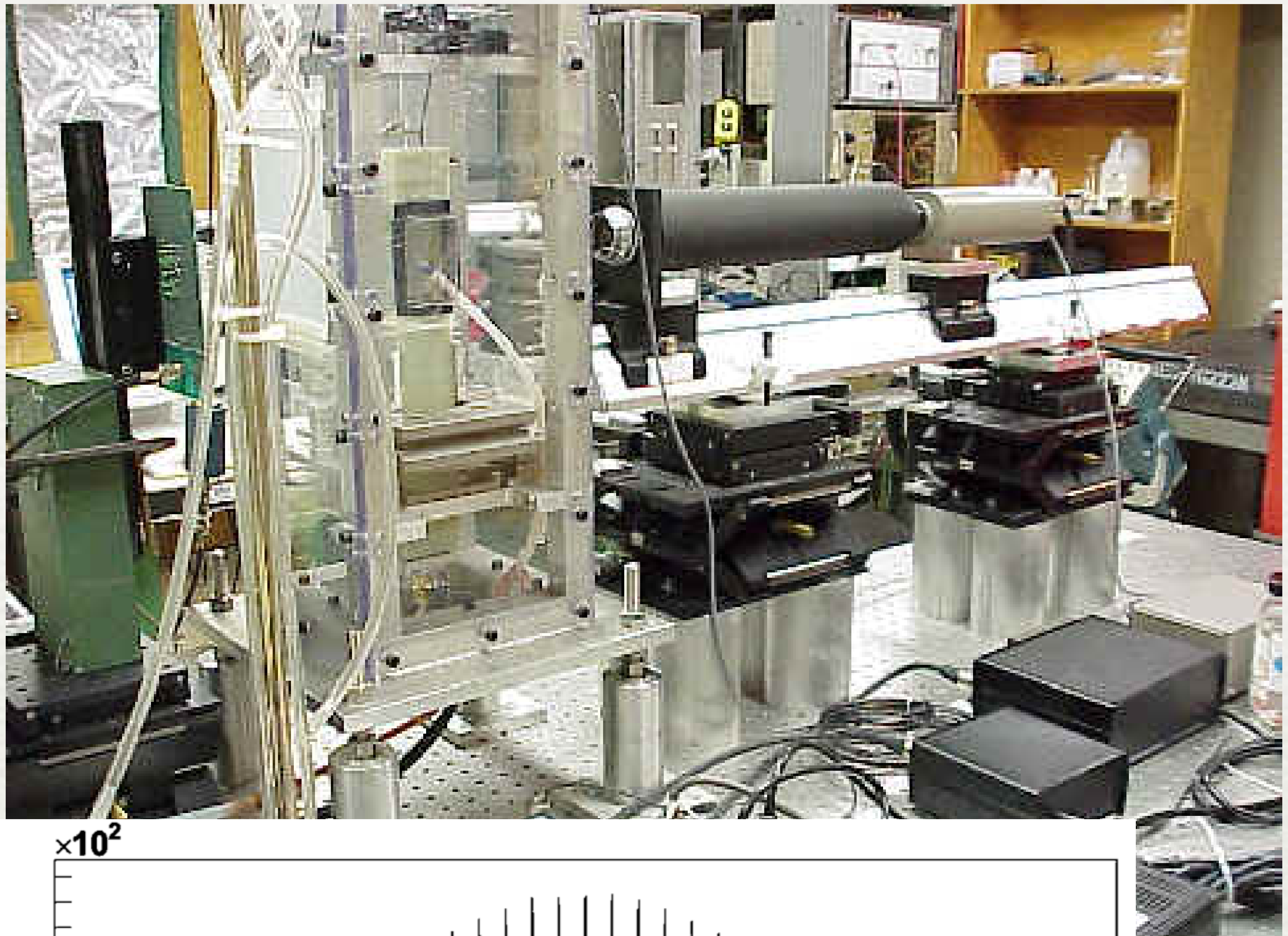
Dinesh Loomba
*Department of Physics, University of New Mexico, Albuquerque, New Mexico 87131, USA**

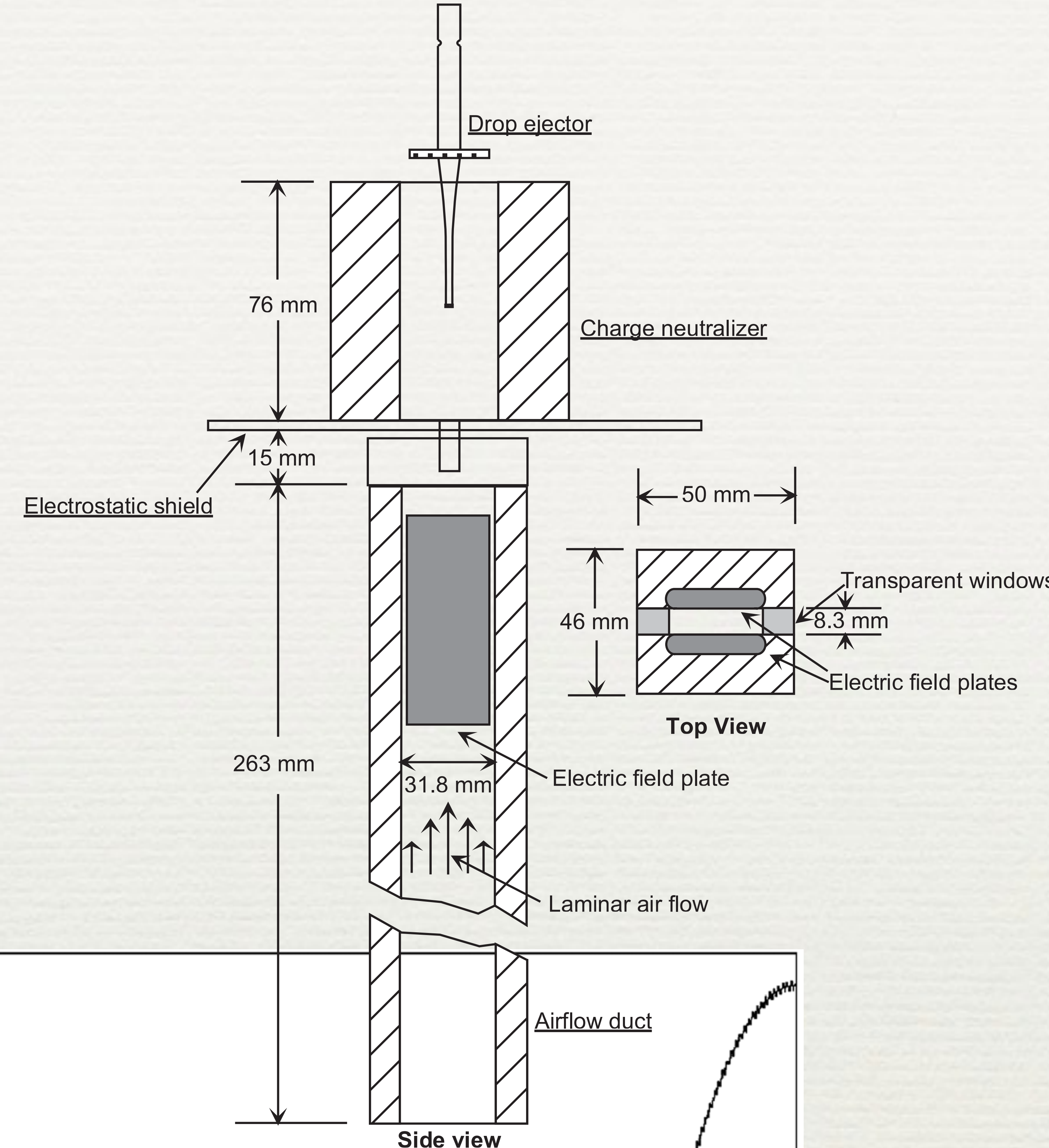
(Received 24 July 2007; published 19 October 2007)

We have used an automated Millikan oil drop method to search for free fractional-charge particles in a sample containing in total 3.9 mg of pulverized Allende meteorite suspended in 259 mg of mineral oil. The average diameter of the drops was 26.5 μm with the charge on about 42 500 000 drops being



Perl's last experiment





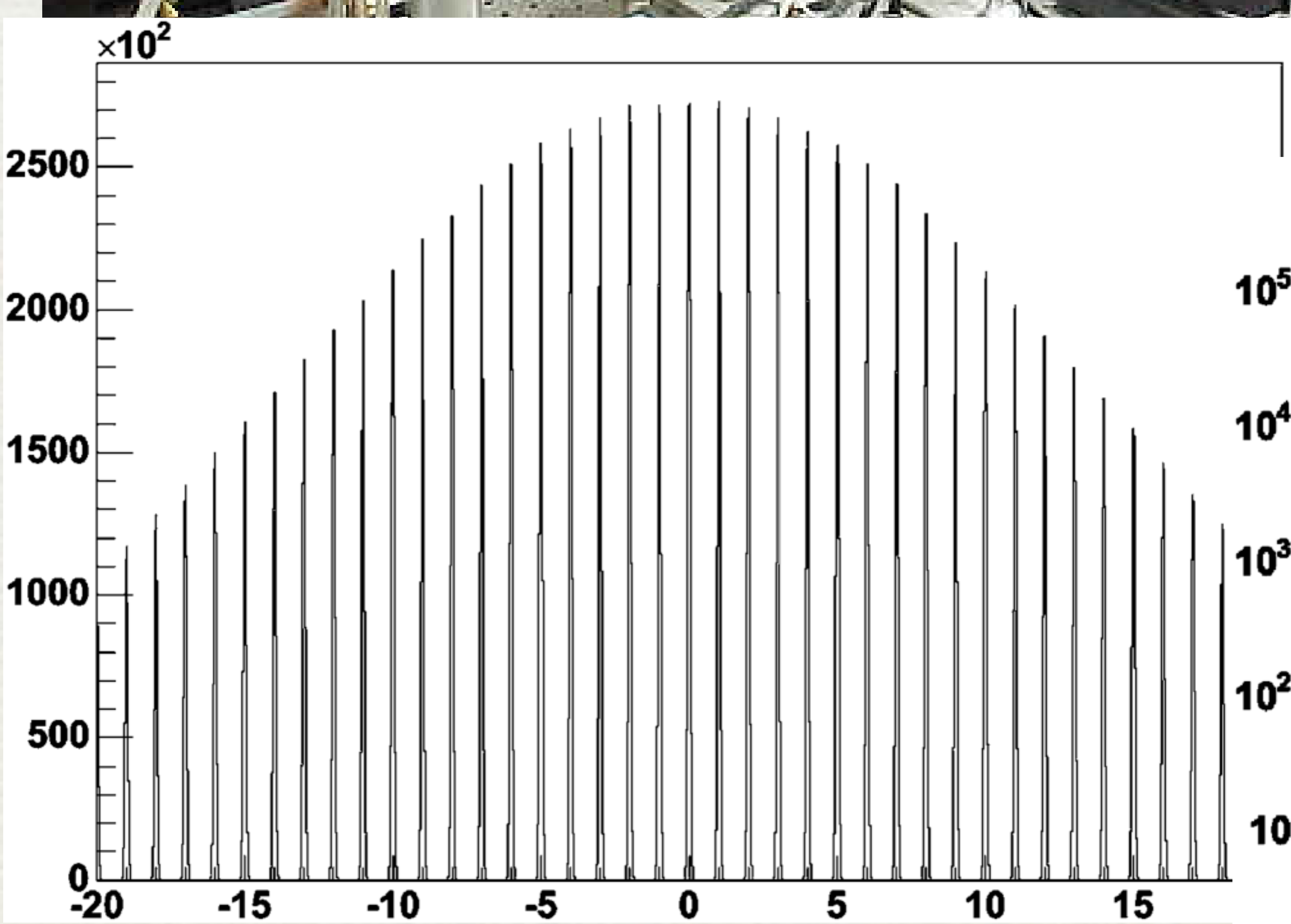


FIG. 2. The q charge distribution in units of e.

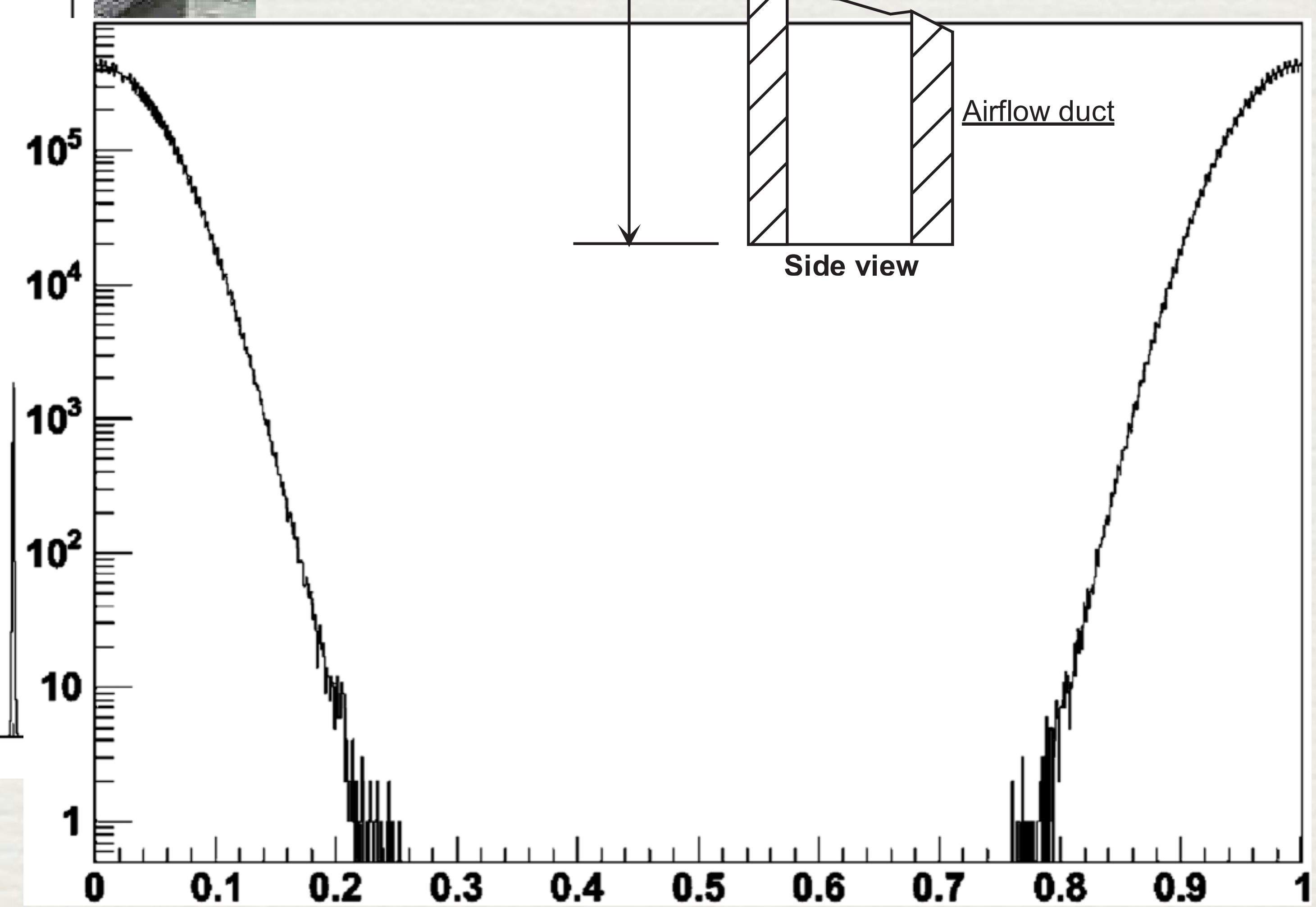


FIG. 4. The q_c residual charge distribution in units of e.

Stanford Report, October 1, 2014

Stanford's Martin L. Perl, winner of 1995 Nobel Prize for discovery of tau lepton, dead at 87

Physicist Martin Perl was part of SLAC and Stanford communities for half a century. "He was so excited to come to the lab," his son said. "It was the one place in the whole world to be, to do what he wanted to do."

BY GLENNDA CHUI

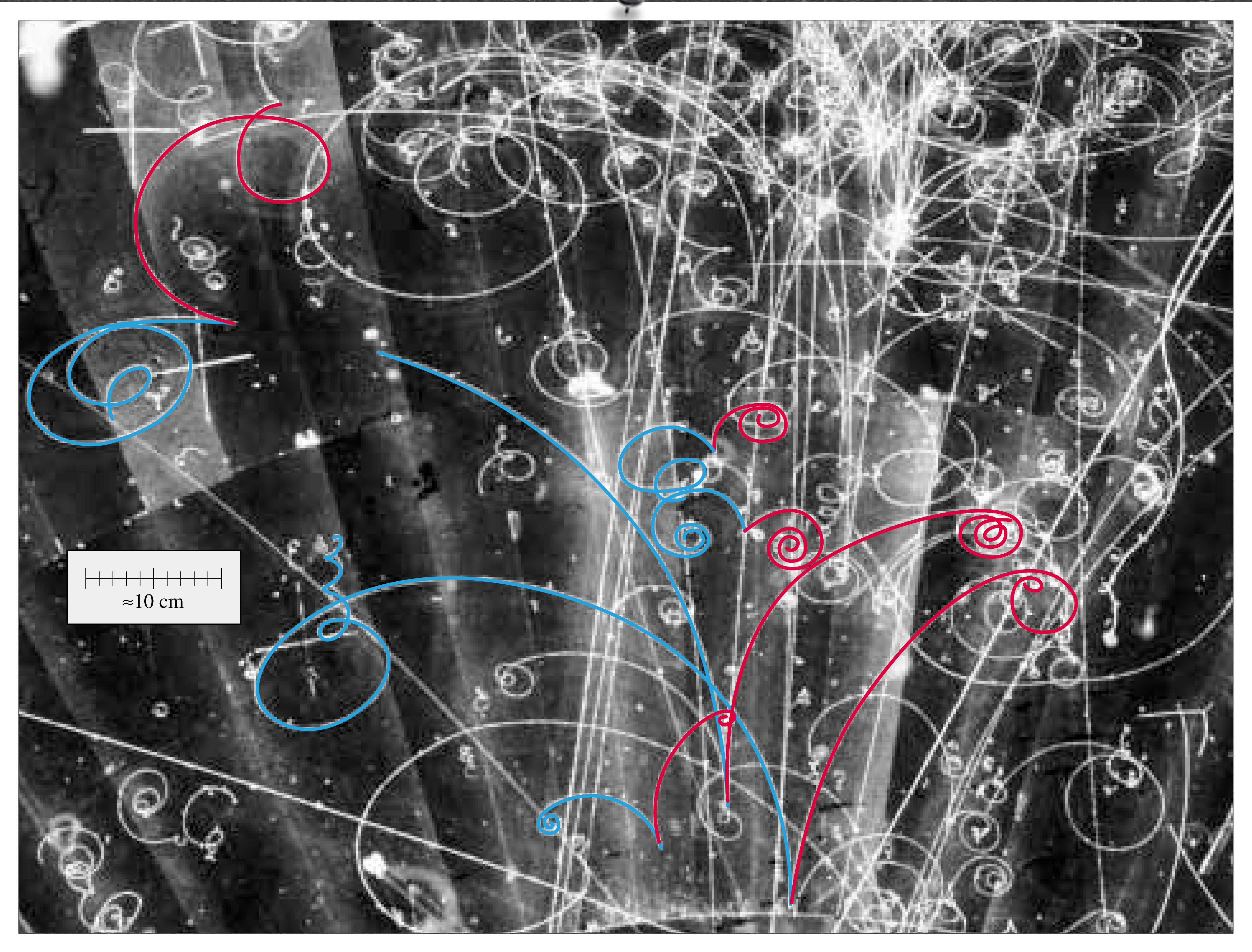
Martin L. Perl, a professor emeritus of physics at Stanford University and SLAC National Accelerator Laboratory who won the 1995 Nobel Prize in physics for discovery of the tau lepton, died Sept. 30 at Stanford Hospital in Palo Alto at the age of 87.

An elementary particle physicist, Perl was widely admired for his persistence and fortitude as a scientist. When he began the series of experiments that would lead to the Nobel Prize, the Standard Model that describes the fundamental particles and forces of nature seemed to be complete, with matter divided into two classes: quarks and leptons.

L.A. Cicero

An elementary particle physicist, Perl was widely admired for his persistence and fortitude as a scientist. He won the Nobel Prize in physics in 1995.

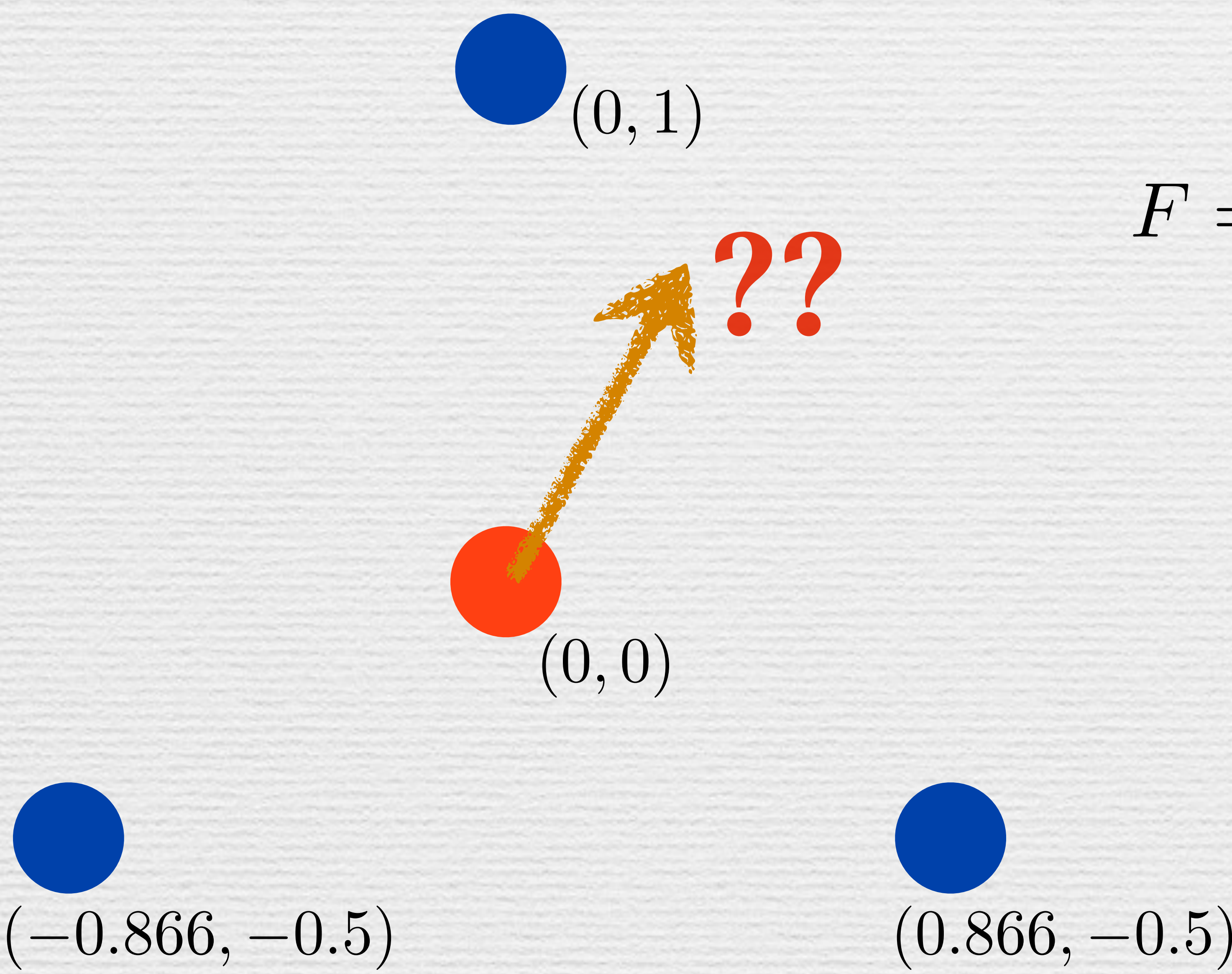
Variations on a theme of Conservation



Variation 1 : Allegro con brio
대칭성원리와 뇌테르의 정리

왜 (물리학은) 대칭성에 열광하는가?

- 많은 경우에 물리문제 해결을 쉽게, 즐겁게, 아름답게 만들어준다!
  - 주변의 세 물체(파란 점들)들이 원점에 있는 물체(빨간 점)에 작용하는 중력의 합은 얼마인가? 힘의 크기와 방향을 계산하시오.



$$F = \sqrt{F_x^2 + F_y^2} \text{ due to each blue mass}$$

$$F_x = G\frac{M_r M_b}{(x^2+y^2)}\frac{x}{\sqrt{x^2+y^2}}$$

$$F_y = G\frac{M_r M_b}{(x^2+y^2)}\frac{y}{\sqrt{x^2+y^2}}$$

왜 (물리학은) 대칭성에 열광하는가?

- 많은 경우에 물리문제 해결을 쉽게, 즐겁게, 아름답게 만들어준다!

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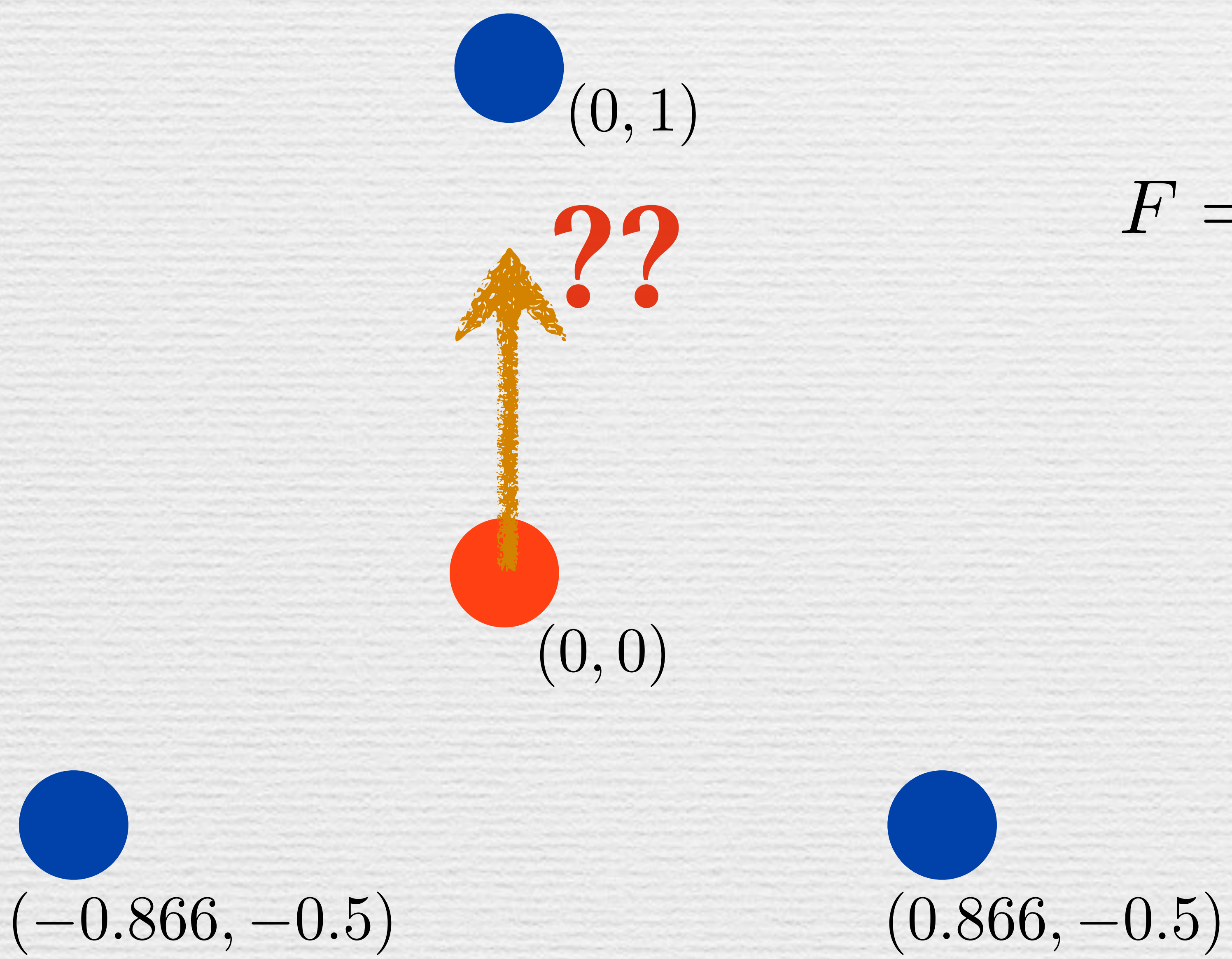


$$F = \sqrt{F_x^2 + F_y^2} \text{ due to each blue mass}$$

$$F_x = G\frac{M_r M_b}{(x^2+y^2)}\frac{x}{\sqrt{x^2+y^2}}$$

$$F_y = G\frac{M_r M_b}{(x^2+y^2)}\frac{y}{\sqrt{x^2+y^2}}$$

Emmy Nöther (1882 ~ 1935)

- 독일의 수학자, 물리학자
- 뇌테르의 정리를 증명함 (1918)
  - "대칭성이 있으면 그에 해당하는 보존법칙이 있다"
- 여성이라는 이유로 차별을 많이 받았음
  - "여기는 대학교이지 목욕탕이 아닙니다"
    - 스승 Hilbert가 뇌테르의 무보수 강사 임용조차 반대하는 동료교수에게 화를 내며
  - "막스 뇌테르는 에미 뇌테르의 아버지입니다"
    - 역시 수학자였던 아버지 막스 뇌테르의 장례식에서 에미 뇌테르가 막스의 딸이라는 얘기를 듣고 아인슈타인이 한 대꾸

To the Editor of The New York Times:

The efforts of most human-beings are consumed in the struggle for their daily bread, but most of those who are, either through fortune or some special gift, relieved of this struggle are largely absorbed in further improving their worldly lot. Beneath the effort directed toward the accumulation of worldly goods lies all too frequently the illusion that this is the most substantial and desirable end to be achieved; but there is, fortunately, a minority composed of those who recognize early in their lives that the most beautiful and satisfying experiences open to humankind are not derived from the outside, but are bound up with the development of the individual's own feeling, thinking and acting. The genuine artists, investigators and thinkers have always been persons of this kind. However inconspicuously the life of these individuals runs its course, none the less the fruits of their endeavors are the most valuable contributions which one generation can make to its successors.

Within the past few days a distinguished mathematician, Professor Emmy Noether, formerly connected with the University of Göttingen and for the past two years at Bryn Mawr College, died in her fifty-third year. In the judgment of the most competent living mathematicians, Fräulein Noether was the most significant creative mathematical genius thus far produced since the higher education of women began. In the realm of algebra, in which the most gifted mathematicians have been busy for centuries, she discovered methods which have proved of enormous importance in the development of the present-day younger generation of mathematicians. Pure mathematics is, in its way, the poetry of logical ideas. One seeks the most general ideas of operation which will bring together in simple, logical and unified form the largest possible circle of formal relationships. In this effort toward logical beauty spiritual formulas are discovered necessary for the deeper penetration into the laws of nature.

Born in a Jewish family distinguished for the love of learning, Emmy Noether, who, in spite of the efforts of the great Göttingen mathematician, Hilbert, never reached the academic standing due her in her own country, none the less surrounded herself with a group of students and investigators at Göttingen, who have already become distinguished as teachers and investigators. Her unselfish, significant work over a period of many years was rewarded by the new rulers of Germany with a dismissal, which cost her the means of maintaining her simple life and the opportunity to carry on her mathematical studies. Farsighted friends of science in this country were fortunately able to make such arrangements at Bryn Mawr College and at Princeton that she found in America up to the day of her death not only colleagues who esteemed her friendship but grateful pupils whose enthusiasm made her last years the happiest and perhaps the most fruitful of her entire career.

ALBERT EINSTEIN.
Princeton University, May 1, 1935.

[New York Times May 5, 1935]

Within the past few days a distinguished mathematician, Professor Emmy Noether, ... , died in her fifty-third year.

In the judgment of the most competent living mathematicians, Fräulein Noether was the most significant creative mathematical genius thus far produced since the higher education of women began.

In the realm of algebra, in which the most gifted mathematicians have been busy for centuries, she discovered methods which have proved of enormous importance in the development of the present-day younger generation of mathematicians.

Pure mathematics is, in its way, the poetry of logical ideas. One seeks the most general ideas of operation which will bring together in simple, logical and unified form the largest possible circle of formal relationships. In this effort toward logical beauty spiritual formulas are discovered necessary for the deeper penetration into the laws of nature.

A. Einstein, in a letter of obituary for E. Noether to NYT

뇌테르의 정리

Invariant Variation Problems

Emmy Noether

M. A. Tavel's English translation of "Invariante Variationsprobleme," *Nachr. d. König. Gesellsc d. Wiss. zu Göttingen, Math-phys. Klasse*, 235–257 (1918), which originally appeared in *Transpor Theory and Statistical Physics*, **1** (3), 183–207 (1971).[0]

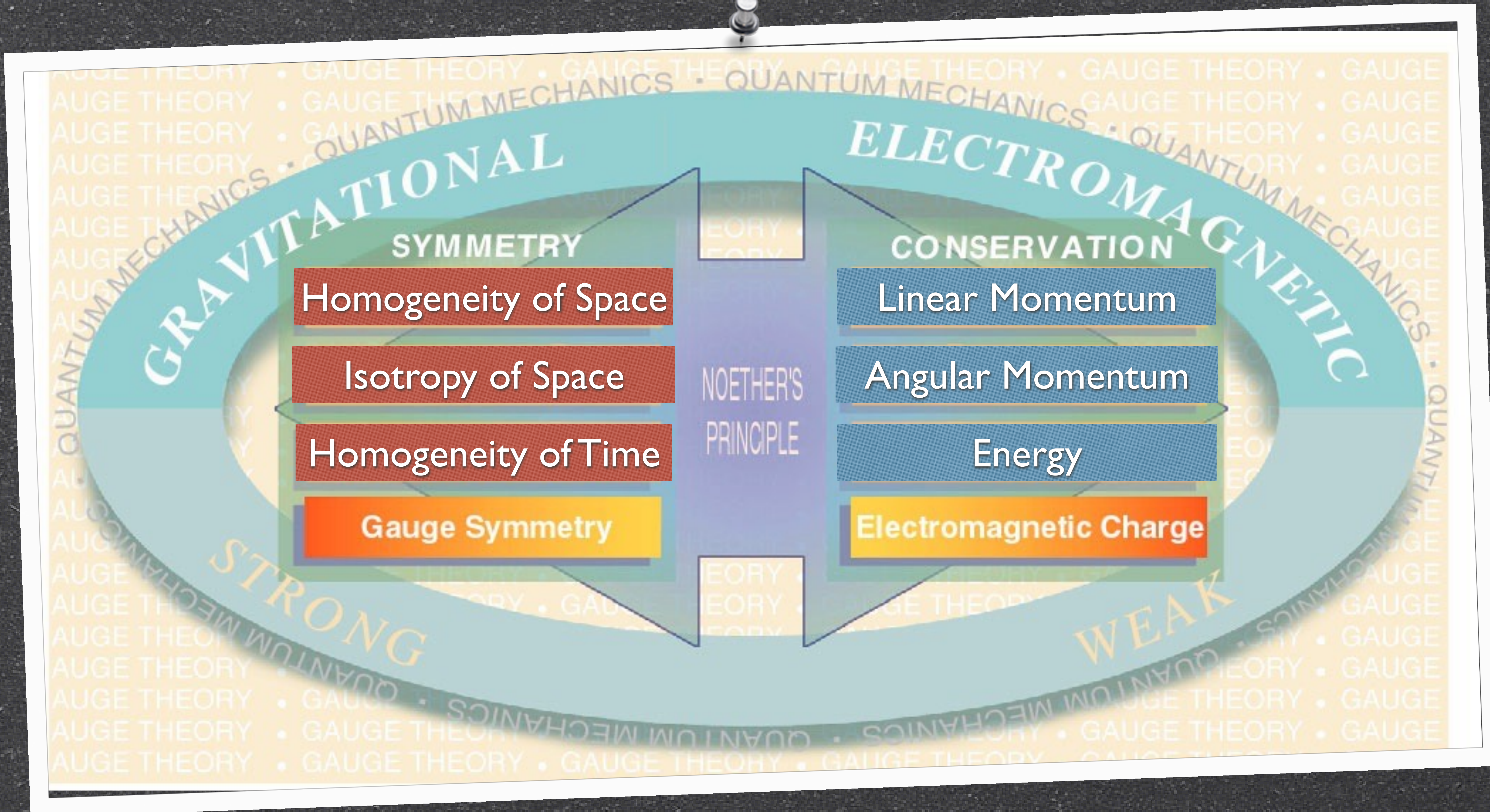
Abstract

The problems in variation here concerned are such as to admit a continuous group (in Lie's sense); the conclusions that emerge from the corresponding differential equations find their most general expression in the theorems formulated in Section 1 and proved in following sections. Concerning these differential equations that arise from problems of variation, far more precise statements can be made than about arbitrary differential equations admitting of a group, which are the subject of Lie's researches. What is to follow, therefore, represents a combination of the methods of the formal calculus of variations with those of Lie's group theory. For special groups and problems in variation, this combination of methods is not new; I may cite Hamel and Herglotz for special finite groups, Lorentz and his pupils (for instance Fokker), Weyl and Klein for special infinite groups.[1] Especially Klein's second Note and the present developments have been mutually influenced by each other, in which regard I may refer to the concluding remarks of Klein's Note.

§ 1. Preliminary Remarks and Formulation of Theorems

All functions occurring in the sequel are to be assumed analytic, or at least continuous and contin uously differentiable a definite number of times, and unique in the interval considered.

By a "group of transformation," familiarly, is meant a system of transformations such that fo

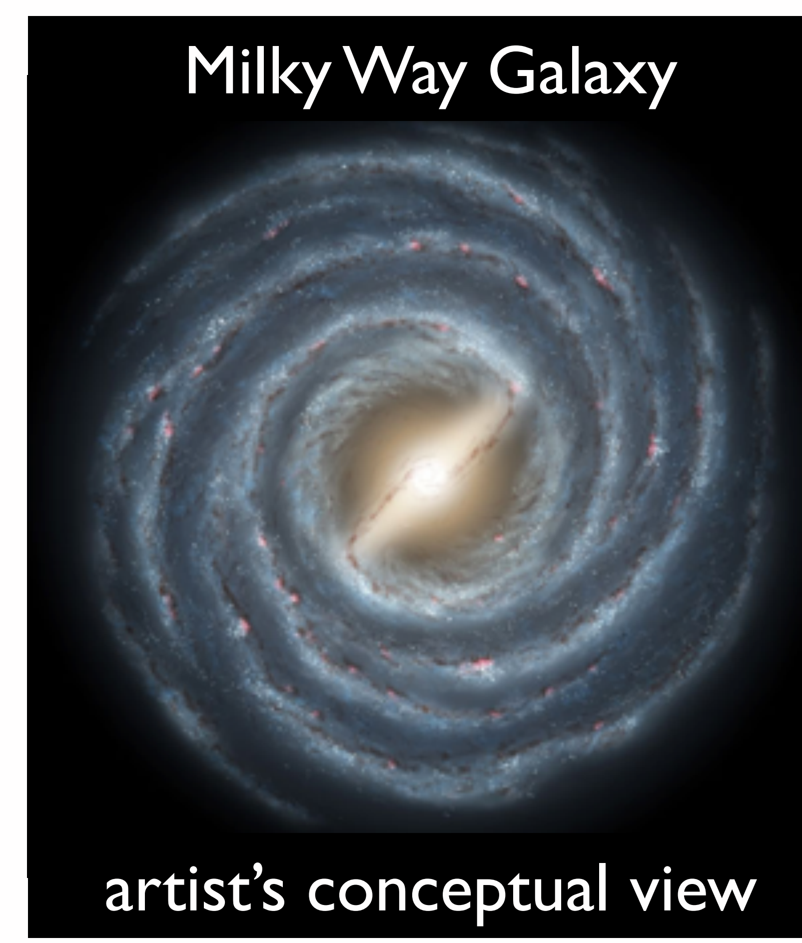


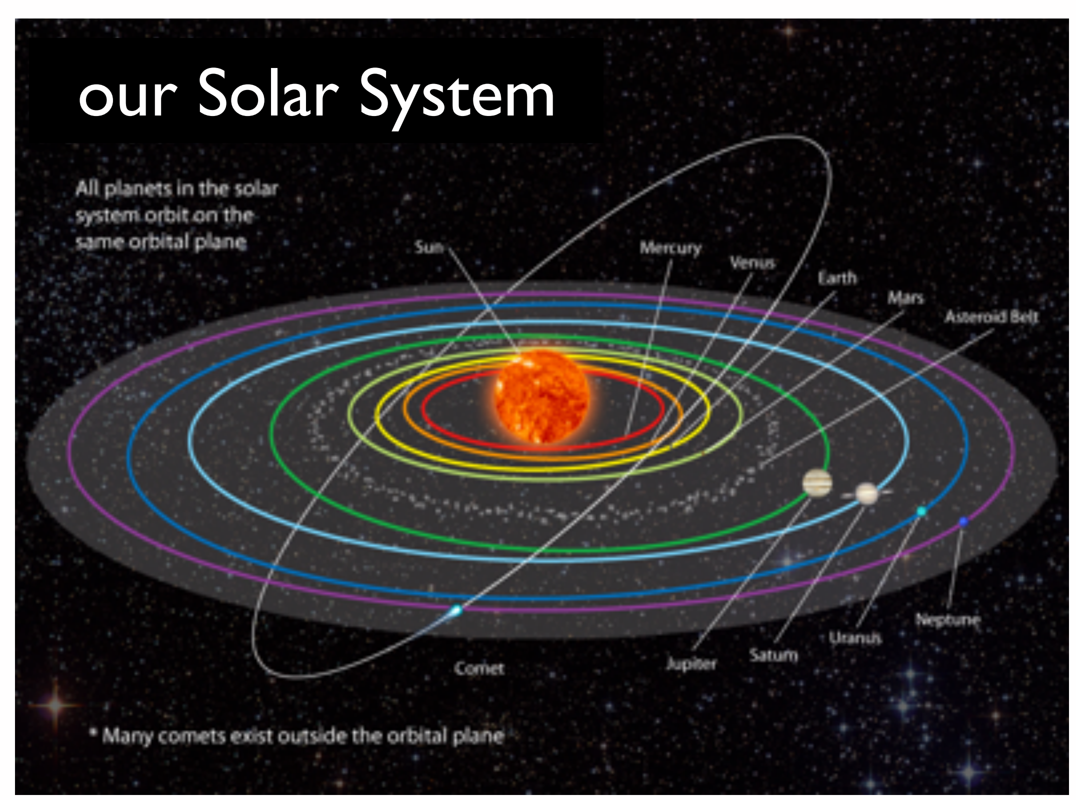
Symmetry & Conservation

방향(회전) 대칭성 isotropy

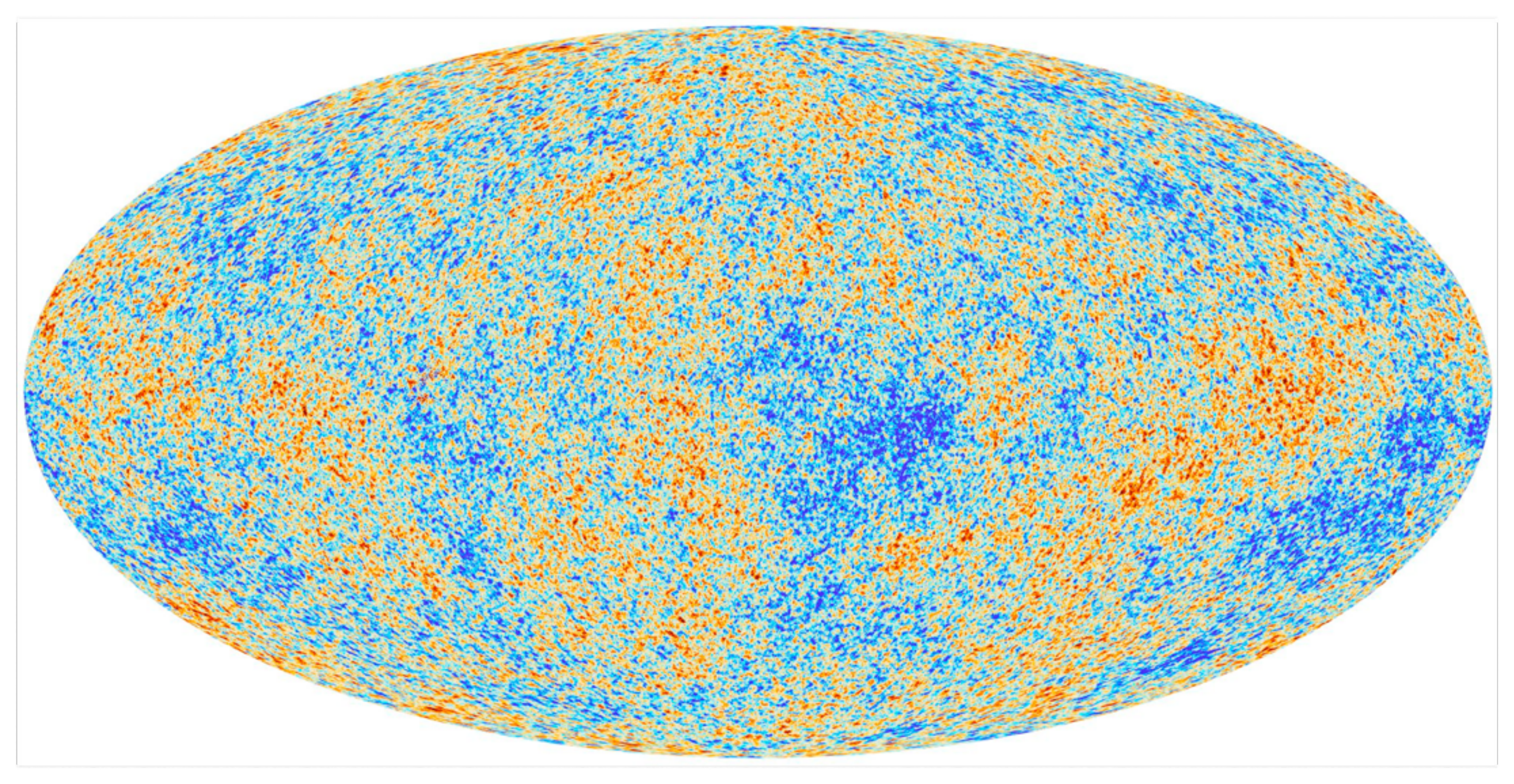
- 자연의 기본 법칙이 방향에 따라 다르다면?
  - 동쪽을 향해서 실험 장치를 설치하고 실험한 결과와 남쪽을 향해 설치하고 얻은 결과가 다르게 된다?
  - 우주에 동/서/남/북의 구별이 있을까?
    - 동서남북은 지구상에서나 존재하는 것!

- 아직까지 어느 실험에서도 공간이 회전대칭성을 만족하지 않는다는 증거는 찾지 못함
  - *Again, enjoy the symmetry while you can!*





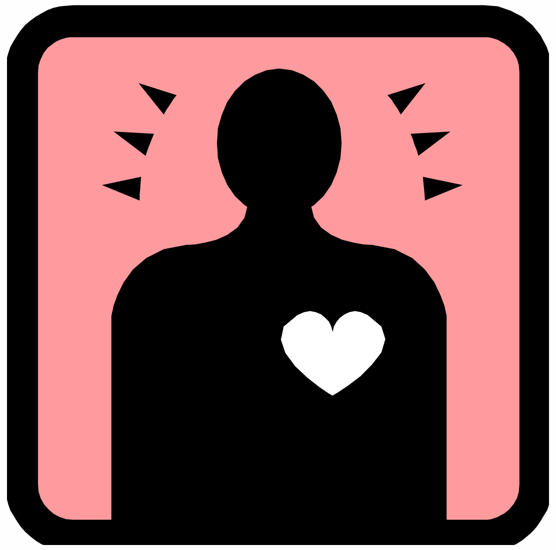
방향(회전) 대칭성 isotropy



Planck 실험에서 관측한 CMB 분포
거의 isotropic한 분포를 보여줌
(평균온도 2.7K를 기준으로 빨간색과 파란색의 차이는 약 10^{-5} K)

거울 대칭성 (=좌우 대칭성) parity

- 자연의 기본 법칙은 좌우변환에 대해 대칭적인가?
  - 실제 장면을 찍은 영화와 거울에 비친 모습을 찍은 영화를 구별할 수 있는가?
  - 자연의 근본법칙이 왼쪽과 오른쪽을 차별할까?
  - 사람은 좌우대칭일까?
    - 왜 심장은 왼쪽에 있을까?
    - 왜 사람은 오른손잡이가 많을까?



[Note] 놀랍게도(?!) 자연법칙 중 약한 핵력 (방사능 섭-붕괴의 원인) 현상은 좌우대칭이 완전히 깨져 있다.

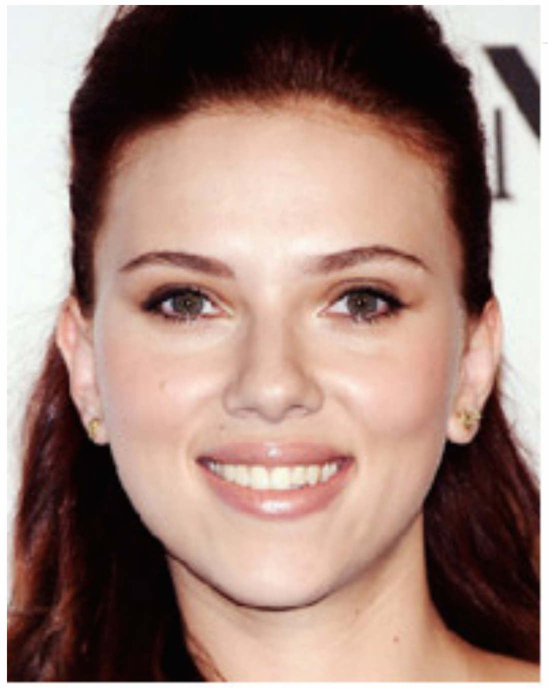
I cannot believe that God is a weak left hander.

- W. Pauli

그밖에 물리학에서 다루는 대칭성

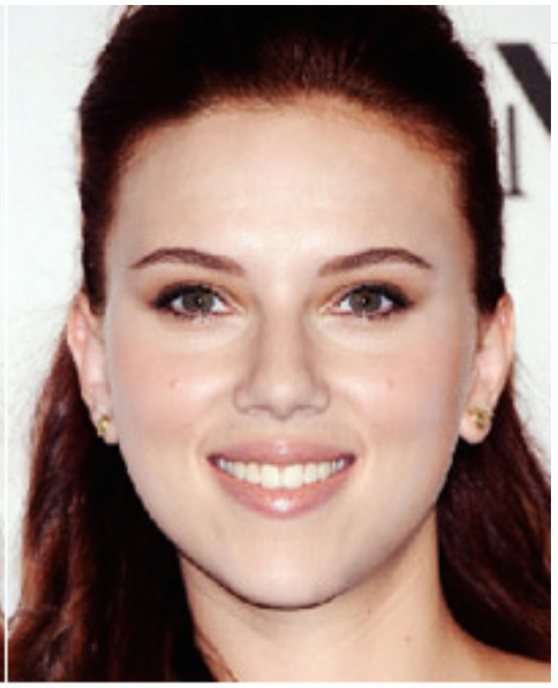
- 게이지 대칭성
- 물질-반물질 대칭성
- 시간 반전 대칭성
- 초대칭성
- 기타 ...

완벽한 대칭성? 불완전한 대칭성?



Original

Left Symmetry



Right Symmetry

… 덕수궁(德壽宮) 박물관에 청자 연적이 하나 있었다. 내가 본 그 연적(硯滴)은 연꽃 모양으로 된 것으로, 똑같이 생긴 꽃잎들이 정연(整然)히 달려 있었는데, 다만 그 중에 꽃잎 하나만이 약간 옆으로 꼬부라졌었다. 이 균형(均衡) 속에 있는, 눈에 거슬리지 않는 파격(破格)이 수필인가 한다. 한 조각 연꽃 잎을 옆으로 꼬부라지게 하기에는 마음의 여유(餘裕)를 필요로 한다. …

– 피천득 '수필'에서

완벽한 대칭성? 불완전한 대칭성?

- 자연계에 존재하는 상호작용(~힘)마다 각각에 해당하는 게이지 대칭성이 있다. 상호작용의 종류에 따라서 게이지 대칭성이 완벽하게 유지된 것도 있고 (자발적으로) 깨진 것도 있다.
- 각각의 게이지 대칭성에는 그에 해당하는 게이지 입자가 있다. 이 게이지 입자가 그 상호작용을 매개하는 역할을 한다.
- 완벽한 게이지 대칭성은 그에 해당하는 '전하량 보존법칙'을 가지고 있다. 이 경우 게이지 입자는 질량이 0이다.
- 깨어진 게이지 대칭성은 게이지 입자의 질량을 0보다 커지게 만든다.
- 게이지 대칭성이 자발적으로 깨지지 않으면 물리 이론을 쓸모 없게 만드는 괴상한 현상들이 생긴다.
- 게이지 대칭성을 자발적으로 깨지도록 만드는 역할을 하는 입자가 바로 힉스(Higgs) 입자이다.

대칭성의 자발적 깨짐

- (예) "좌빵 우물"

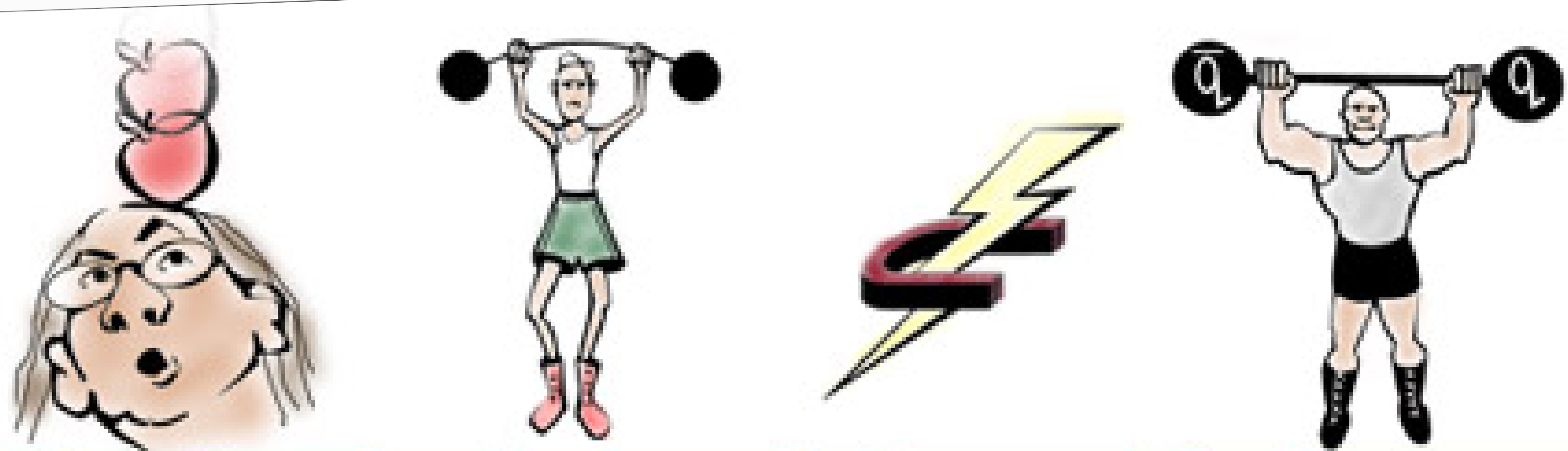
식탁에 빵과 물은 대칭적으로 놓여 있었다. 오른쪽 물컵과 왼쪽 물컵이 내 자리에서 정확히 같은 거리에 있다면 어느 쪽 물컵이 내 것인가?

누군가 우연히 오른쪽 컵을 잡으면 다른 사람들 모두 오른쪽 컵을 잡게 된다.

→ 좌우 대칭성이 자발적으로 깨진다.

“빛이 있으라!”

- 게이지 대칭성 -- 소립자 상호작용의 기본법칙
  - 양자역학적 대칭성
  - 게이지 대칭성을 유지하려면 새로운 입자 (게이지 입자)가 필요함
- Photon (particle of light) - 전자기력을 위한 게이지 입자
- 게이지 대칭성 --> 전하량 보존법칙!



	Gravity	Weak (Electroweak)	Electromagnetic	Strong
Carried By	Graviton (not yet observed)	W^+ W^- Z^0	Photon	Gluon
Acts on	All	Quarks and Leptons	Quarks and Charged Leptons and W^+ W^-	Quarks and Gluons

Fundamental Interactions & Gauge Bosons

The Nobel Prize in Physics 1979

"for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, inter alia, the prediction of the weak neutral current"

Sheldon Lee Glashow

Abdus Salam

Steven Weinberg

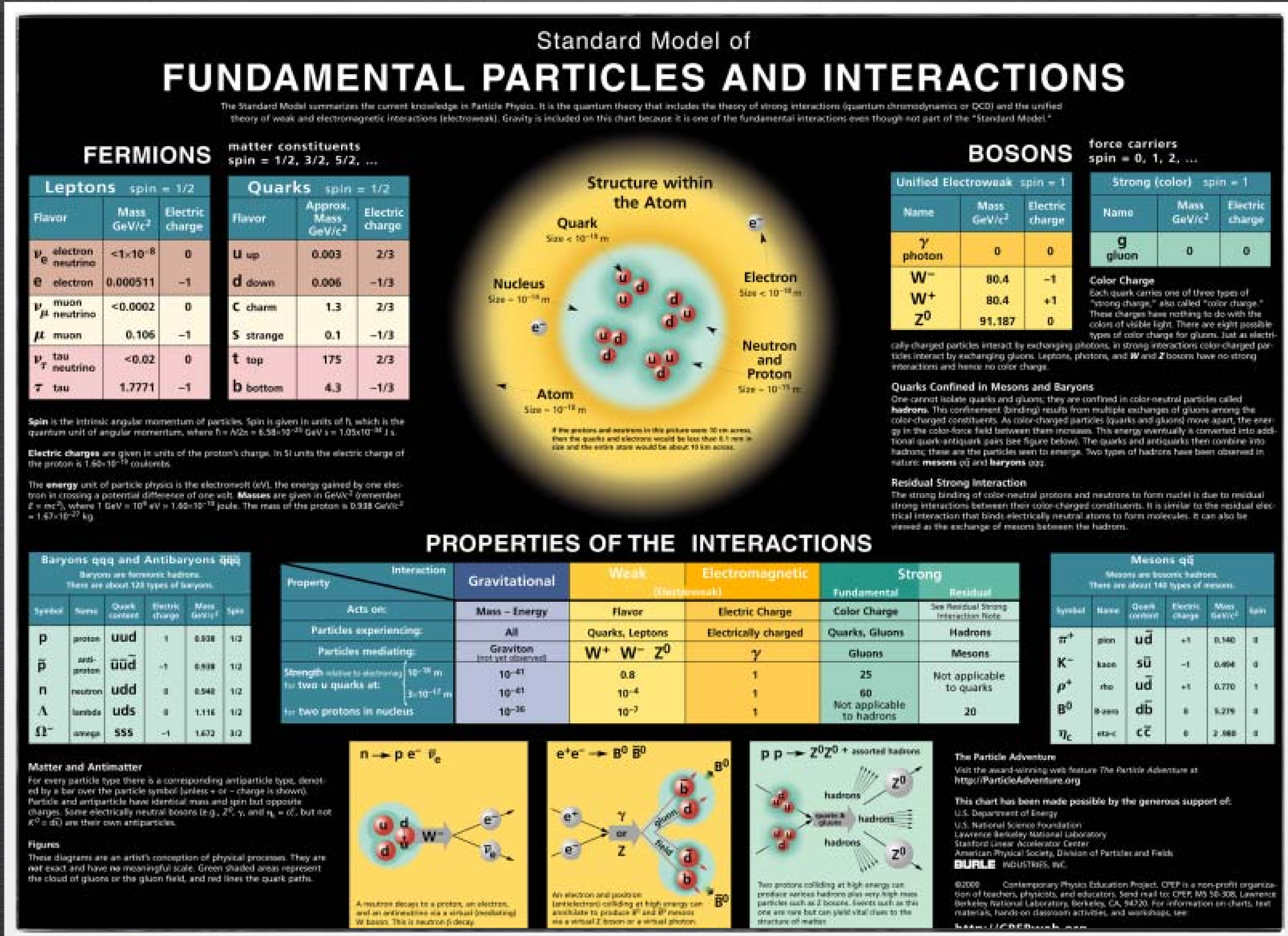
[보충설명 1] 표준이론 (**the Standard Model**)

표준이론은 **1960**년대 중반 **Sheldon Glashow, Steven Weinberg, Abdus Salam** 등에 의해서 당시에 존재하던 핵자들 간의 반응을 기본적인 물리적 원리에 의해서 체계적으로 설명을 시도한 이론으로, 중성미자의 질량에 관한 최근의 실험결과 외에는 어떤 물리학 실험에 의해서도 전혀 문제점을 찾아낼 수 없었던 이론이다.

이 이론을 만든 공로로 **Glashow, Weinberg, Salam**은 **1979**년 노벨 물리학상을 수상하였다. 또한 표준이론의 이론적 구조를 완성한 공로로 **Veltman**과 **'t Hooft**가 **1999**년 노벨 물리학상을 수상하였으며, 작고한 한국출신 물리학자 이휘소 박사도 표준이론의 이론적 구조 정립에 큰 공헌을 한 바 있다.

- The most powerful and successful theory which explains almost all of the experimental results in particle and nuclear physics
- Based on (**relativity**) + (**quantum theory**)

A culmination of Modern Physics!



Particle Physics in one page

입자물리 분야 노벨물리학상

For the last 40 years

1965 Feynman, Schwinger & Tomonaga	QED (양자전자기학) 이론 확립
1969 Gell-Mann	Quark model 확립
1976 Richter & Ting	J/ψ 입자 발견
1979 Glashow, Salam & Weinberg	Standard Model 이론 확립
1980 Cronin & Fitch	CP 대칭성 깨어짐 발견
1984 Rubia & Van der Meer	W, Z 입자 발견
1988 Lederman, Schwarz & Steinberger	중성미자의 flavor 구조 발견
1990 Friedman, Kendall & Taylor	양성자의 쿼크 구조 규명
1992 Charpak	MWPC 발명 (하전입자검출기)
1995 Perl & Reines	τ 경입자 / 중성미자 발견
1999 't Hooft & Veltman	Standard Model의 Renormalization
2002 Davis, Coshiba & Giaconni	宇宙線에서의 중성미자/천체물리
2004 Gross, Politzer & Wilczek	Asymptotic freedom in QCD
2008 Nambu, Kobayashi, Maskawa	대칭성 깨짐 이론
2013 Higgs, Englert	힉스 입자 예측

Variation 2 : Andante ma non tanto

Anti-particle, anti-matter & C̸P

- ***Special Relativity***: the framework for describing the physics of objects moving at speeds close to the speed of light.
- ***General Relativity***: the extension of this theory to include gravity.

- ***Quantum Mechanics***: the framework for studying the physics of very short distances

These are almost inconsistent with each other!

20세기 물리학의 두 기둥

The equations

Newton $$\vec{F} = m\frac{d^2\vec{r}}{dt^2}$$

Schrödinger $$i\hbar\frac{d}{dt}\psi = \left(-\frac{\hbar^2}{2m}\nabla^2 + V(\vec{r})\right)\psi$$

Dirac $$(i\gamma^\mu\partial_\mu - m)\psi = 0$$

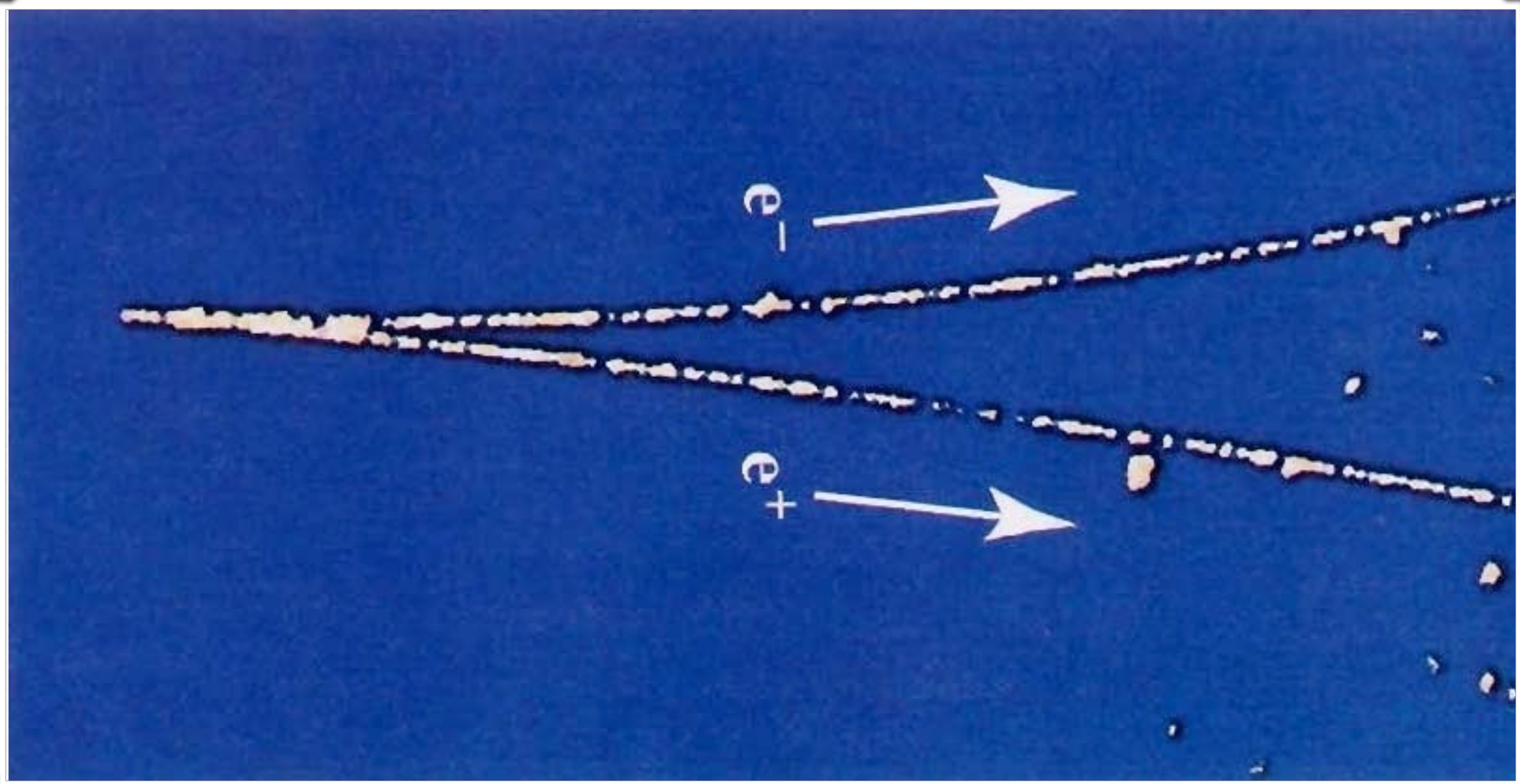
[보충설명 2] 반입자(反粒子, **antiparticle)**

주어진 입자와 질량은 같지만 電磁氣적 성질이 정 반대인 입자를 反粒子라고 부른다. 反粒子는 1928년에 Paul Dirac(1933년 노벨 물리학상 수상)에 의해서 현대물리학의 중요한 두 축인 양자역학과 상대성이론을 결합한 새로운 이론을 창시하는 과정에서 그 존재가 예언되었으며 1932년 Carl Anderson(1936년 노벨 물리학상 수상)에 의해서 처음 발견되었다.

모든 입자에 대해서 반입자가 있어야 한다는 것은 상대성이론 및 양자역학으로부터 나오는 피할 수 없는 결론인데 우리의 주위를 둘러보면 입자로 이루어진 보통의 물질에 비해서 반입자로 이루어진 反物質이 훨씬 적게 존재한다.

만일 우리 주위에 물질과 반물질이 같은 양으로 존재한다면 반입자들이 우리 몸을 이루는 입자들과 만나 쌍소멸을 일으켜서 빛 등으로 변화하기 때문에 우리는 더 이상 존재할 수가 없게 된다. 이와 같이 입자—반입자 간의 불균형이야말로 우리가 사는 세계가 존재할 수 있는 물리적 근거를 이룬다.

입자-반입자 쌍생성 (pair creation)



How can we exist?

- Big bang cosmology --> balanced production of matter & antimatter,
- 현재의 우주: 물질 >> 반물질
- Sakharov가 제시한 3가지 조건
  - baryon number non-conservation
  - C and CP violation
  - not in thermal equilibrium
- But, can CP violation happen in Nature?
- If it does, do we understand the mechanism?

노벨평화상을 받은 어느 물리학자

VIOLATION OF CP INVARIANCE, C ASYMMETRY, AND BARYON ASYMMETRY OF THE UNIVERSE

A. D. Sakharov
Submitted 23 September 1966
ZhETF Pis'ma 5, No. 1, 32-35, 1 January 1967

The theory of the expanding Universe, which presupposes a superdense initial state of matter, apparently excludes the possibility of macroscopic separation of matter from antimatter; it must therefore be assumed that there are no antimatter bodies in nature, i.e., the Universe is asymmetrical with respect to the number of particles and antiparticles (C asymmetry). In particular, the absence of antibaryons and the proposed absence of baryonic neutrinos implies a non-zero baryon charge (baryonic asymmetry). We wish to point out a possible explanation of C asymmetry in the hot model of the expanding Universe (see [1]) by making use of effects of CP invariance violation (see [2]). To explain baryon asymmetry, we propose in addition an approximate character for the baryon conservation law.

We assume that the baryon and muon conservation laws are not absolute and should be unified into a "combined" baryon-muon charge $n_c = 3n_B - n_\mu$. We put:

$$n_\mu = -1,\ n_K = +1 \text{ for antimuons } \mu_+ \text{ and } \nu_\mu = \mu_0,$$

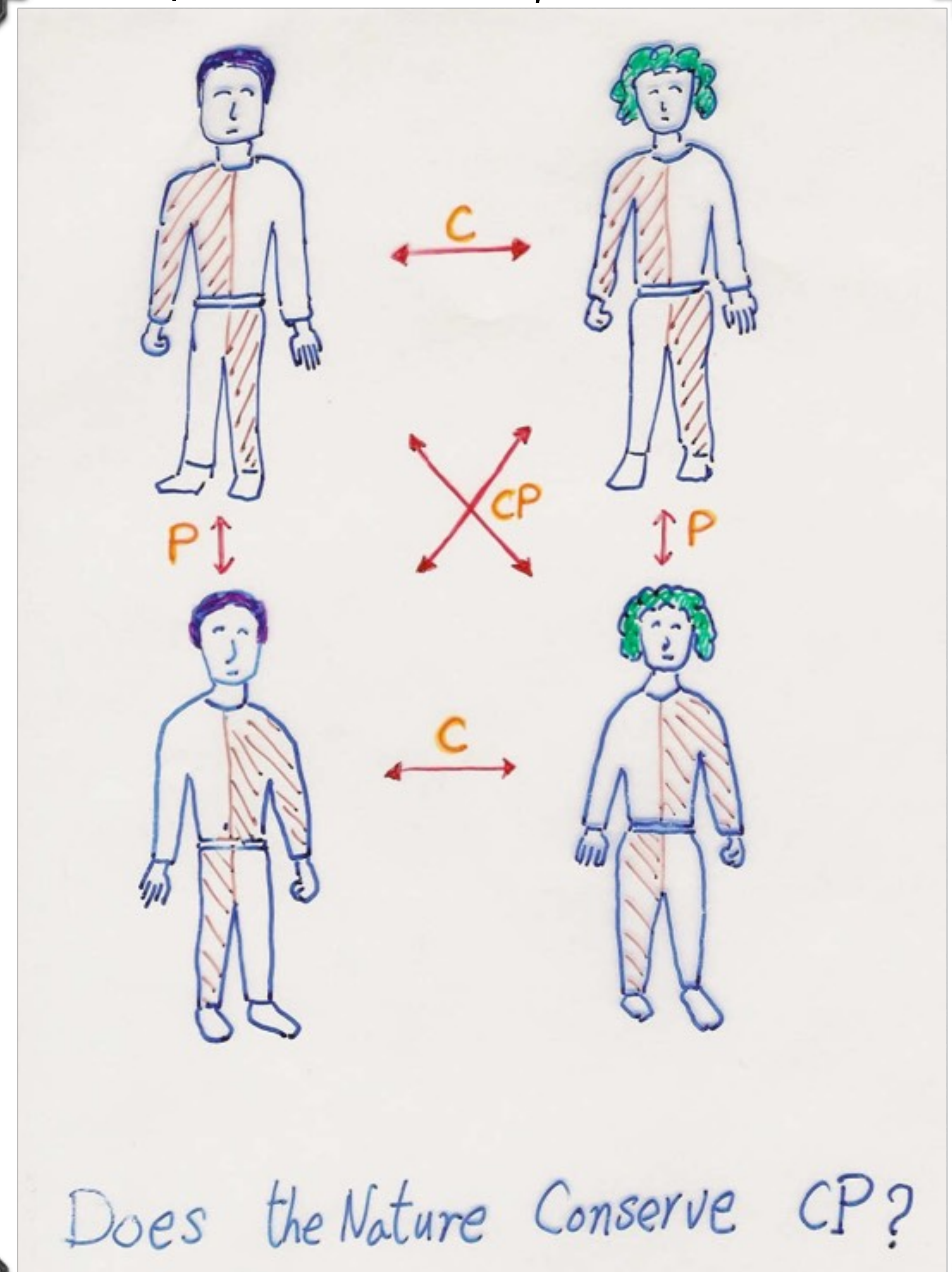
[보충설명 3] **C, P and T**

C (charge conjugation) : particle → anti-particle

P (parity) : $(x, y, z) \to (-x, -y, -z)$

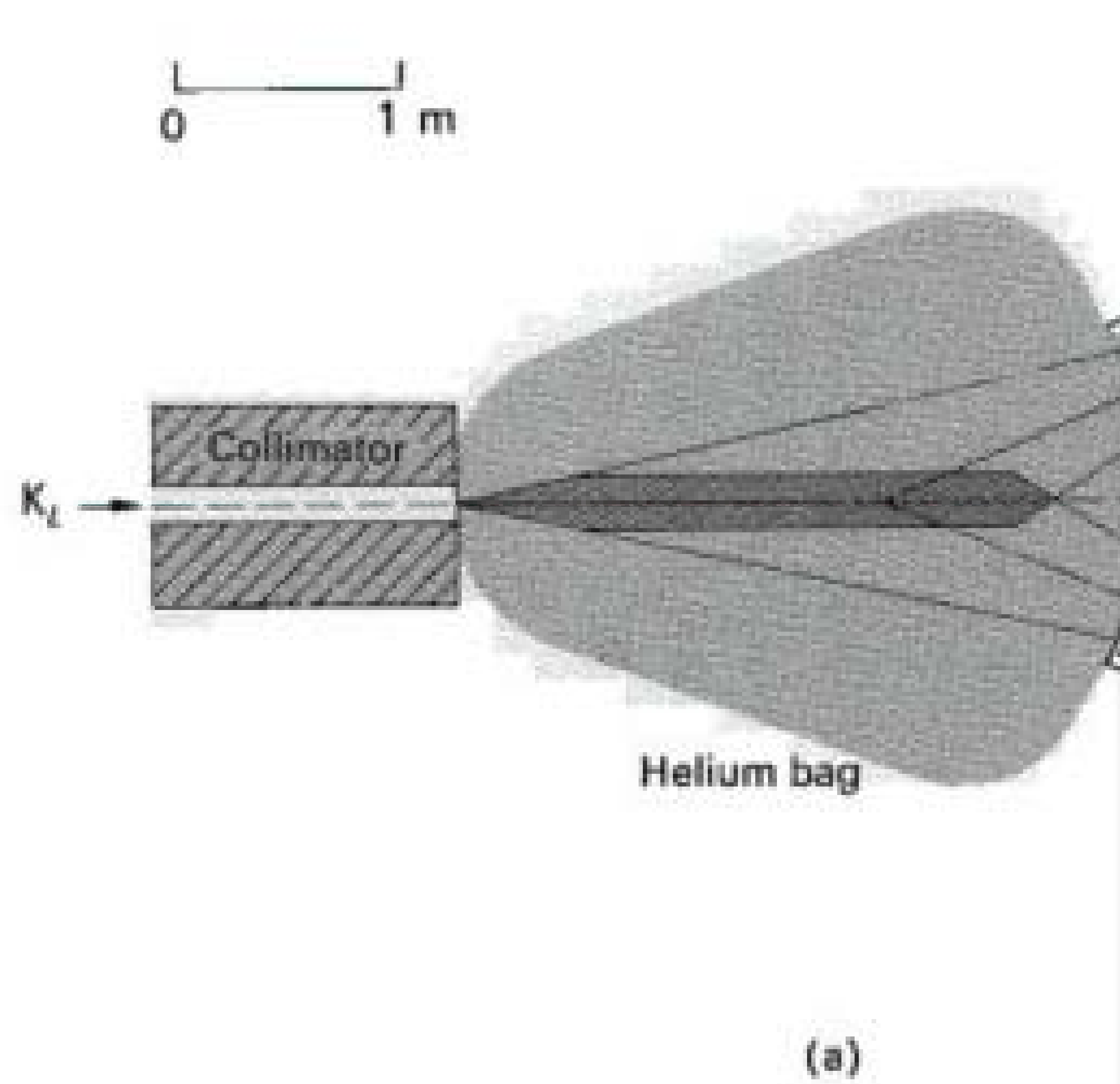
T (time reversal) : $t \to -t$

from 김충선 교수 colloquium at Yonsei



CP violation !

Cronin, Fitch, et al. (1964)

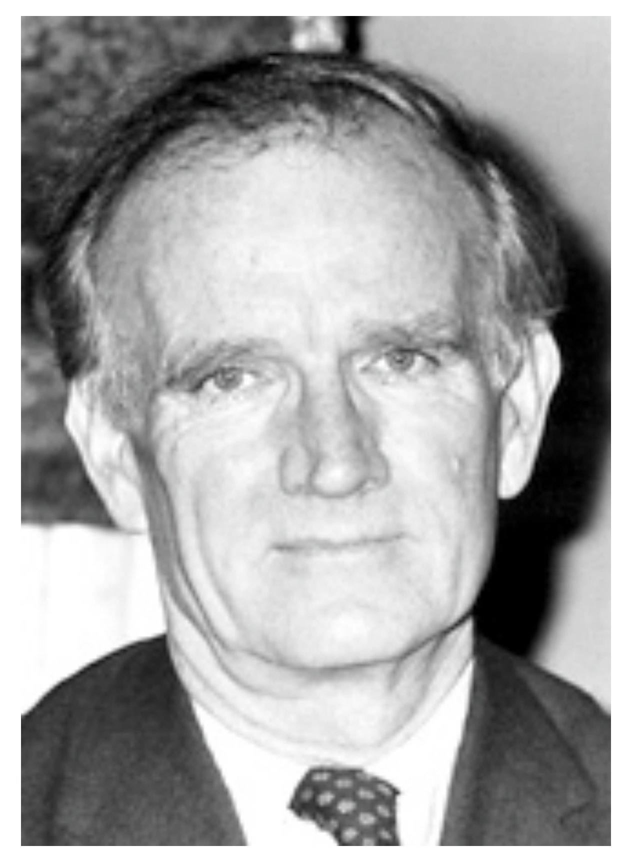


$$\begin{pmatrix} K_S \\ K_L \end{pmatrix} = \begin{pmatrix} & \end{pmatrix} \begin{pmatrix} K^0 \\ \overline{K}^0 \end{pmatrix}$$

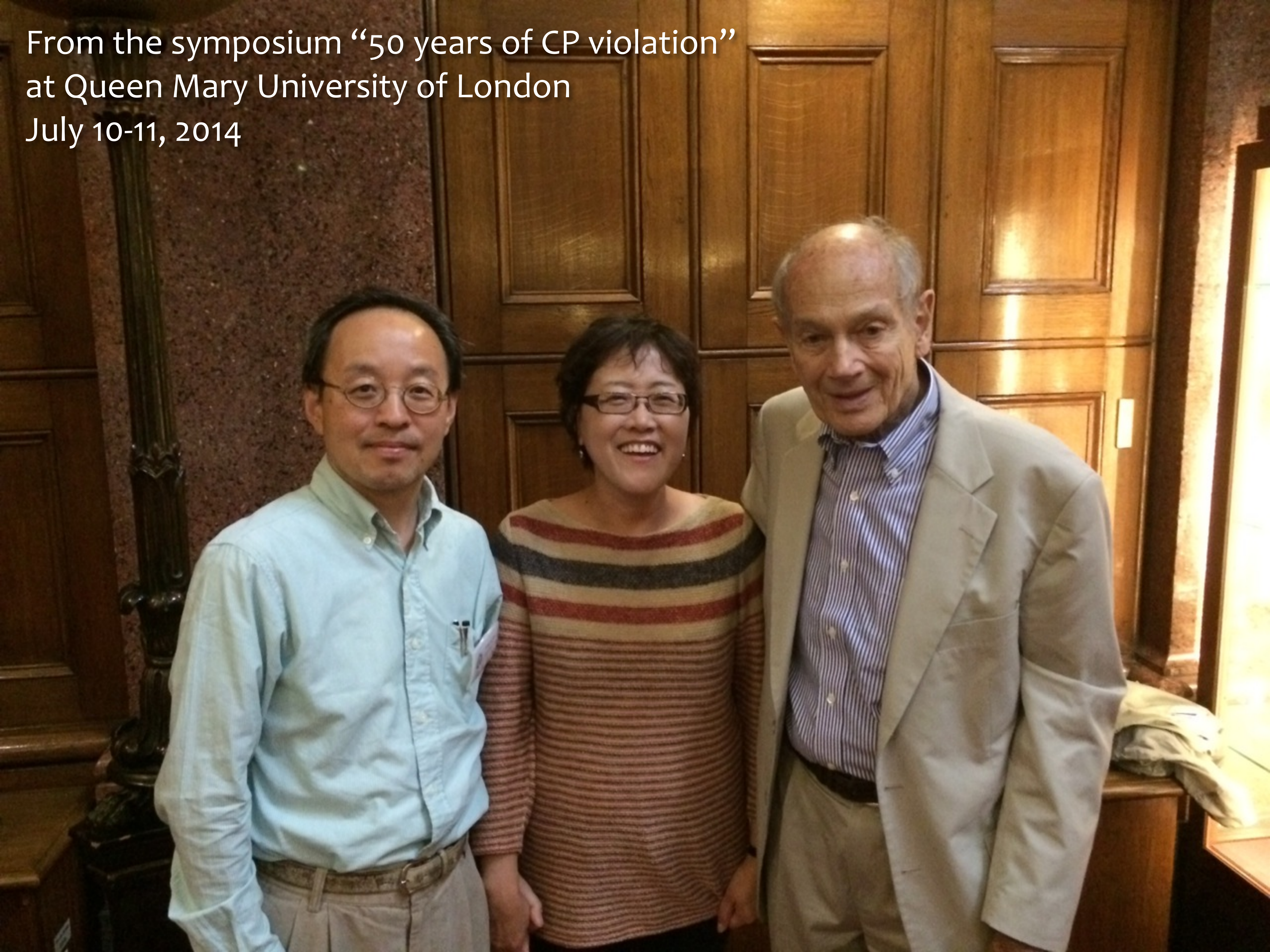
The Nobel Prize in Physics 1980

"for the discovery of violations of fundamental symmetry principles in the decay of neutral K-mesons"

James Watson Cronin



Val Logsdon Fitch



From the symposium "50 years of CP violation"
at Queen Mary University of London
July 10-11, 2014

Kobayashi-Maskawa (KM) 가설

"CPV is due to an irreducible phase in the quark mixing matrix in 3 generations"

; of Theoretical Physics, Vol. 49, No. 2, February 1973

CP-Violation in the Renormalizable Theory of Weak Interaction

Makoto KOBAYASHI and Toshihide MASKAWA

Department of Physics, Kyoto University, Kyoto

(Received September 1, 1972)

In a framework of the renormalizable theory of weak interaction, problems of *CP*-violation are studied. It is concluded that no realistic models of *CP*-violation exist in the quartet scheme without introducing any other new fields. Some possible models of *CP*-violation are also discussed.

When we apply the renormalizable theory of weak interaction[1] to the hadron system, we have some limitations on the hadron model. It is well known that there exists, in the case of the triplet model, a difficulty of the strangeness changing neutral current and that the quartet model is free from this difficulty. Fur-

First 3rd-gen. particle (τ) seen in 1975

From the symposium “50 years of CP violation”
at Queen Mary University of London
July 10-11, 2014

The "Beauty" Contest

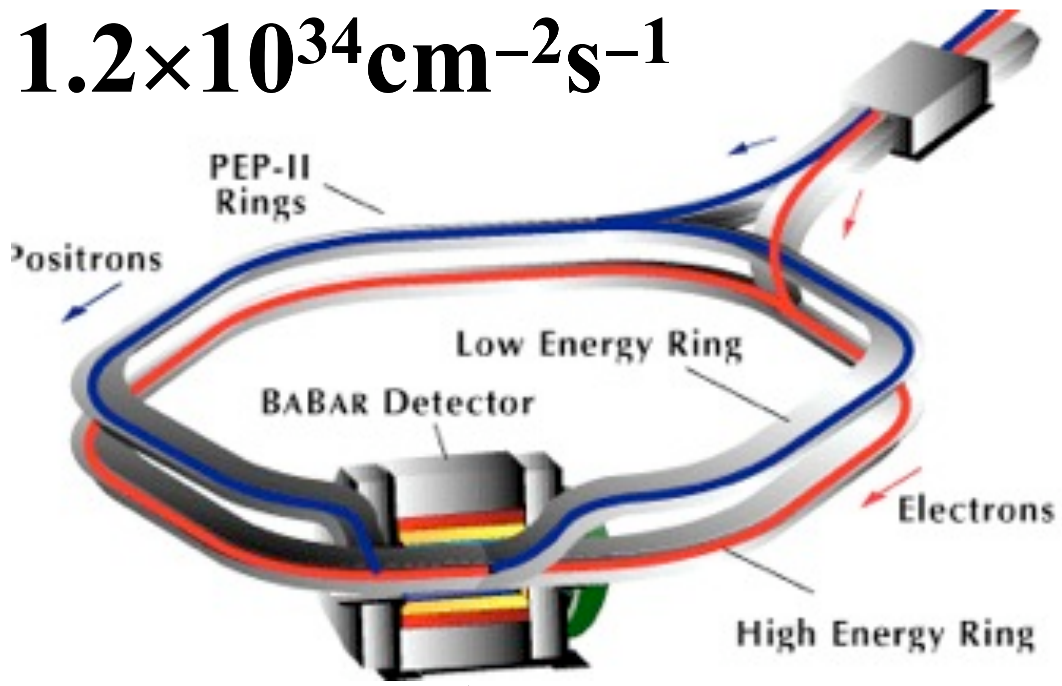
$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$$

Beauty and the B...

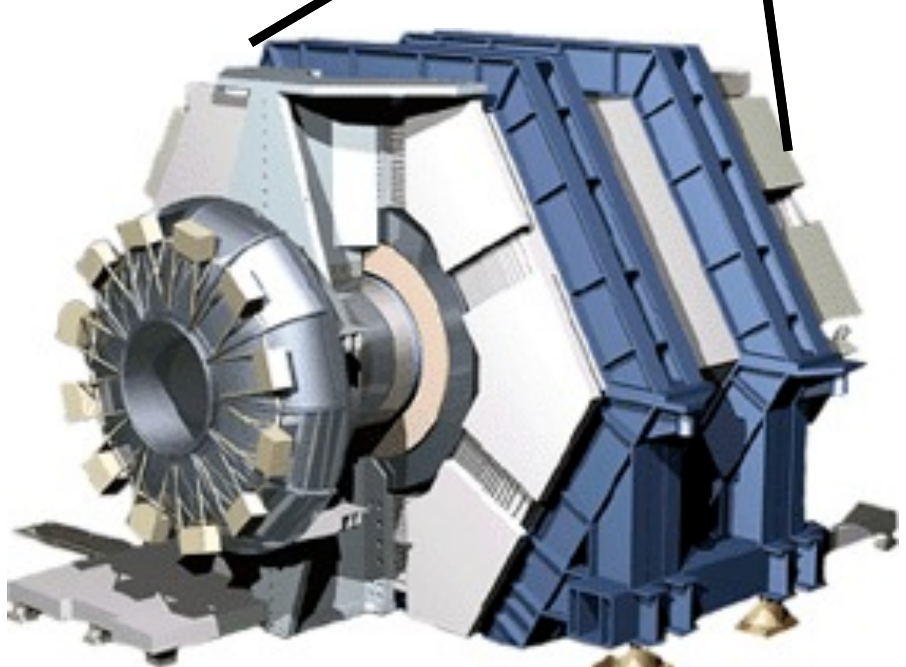
Two asymmetric B-factories

PEP-II at SLAC

9GeV (e^-) × 3.1GeV (e^+)
peak luminosity:
$1.2\times10^{34}cm^{-2}s^{-1}$

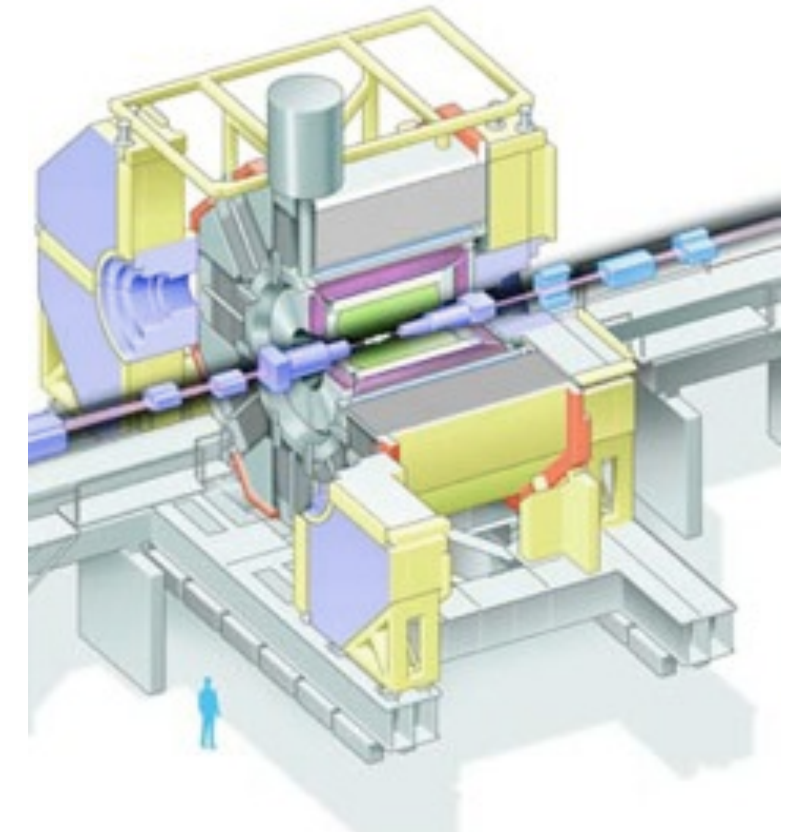


BaBar

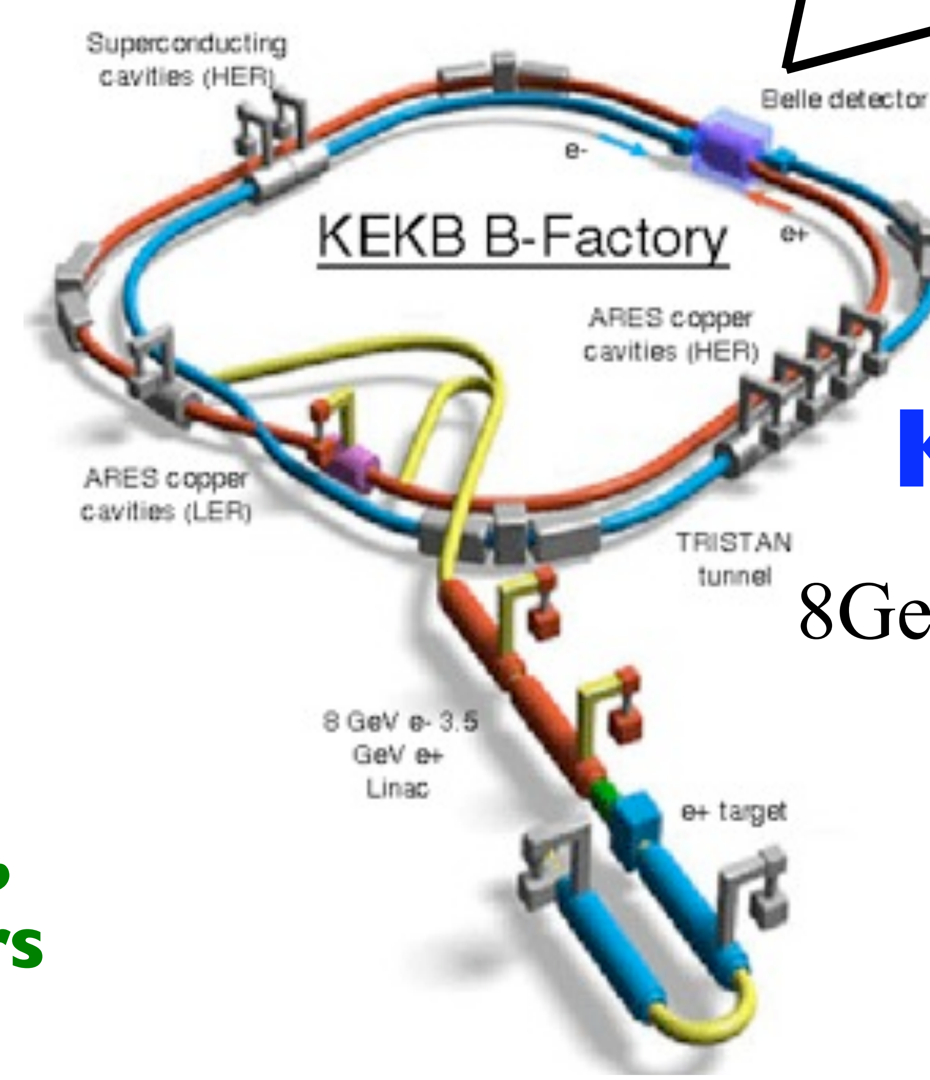


11 nations,
80 institutes,
~600 members

13 countries,
57 institutes,
~400 members

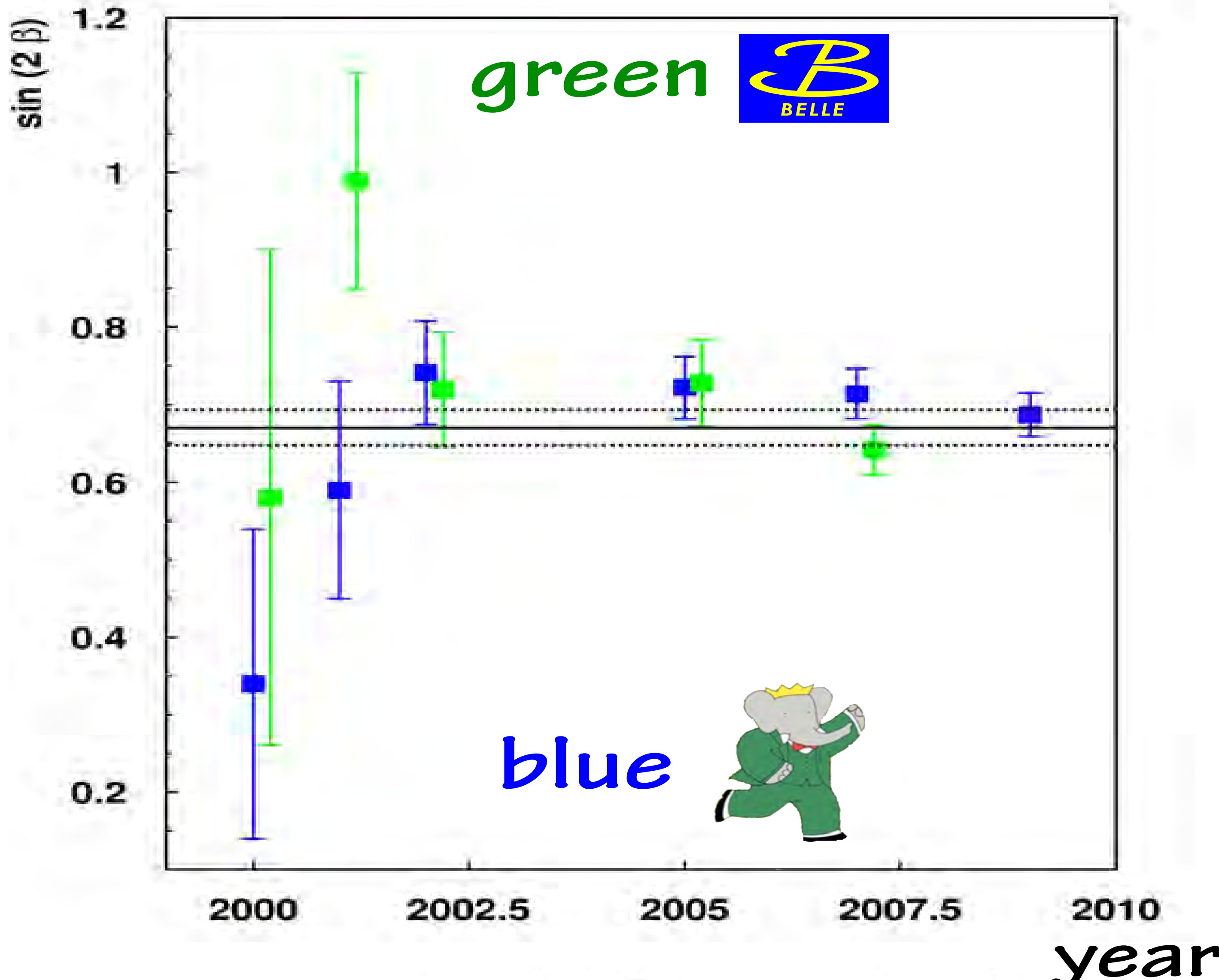


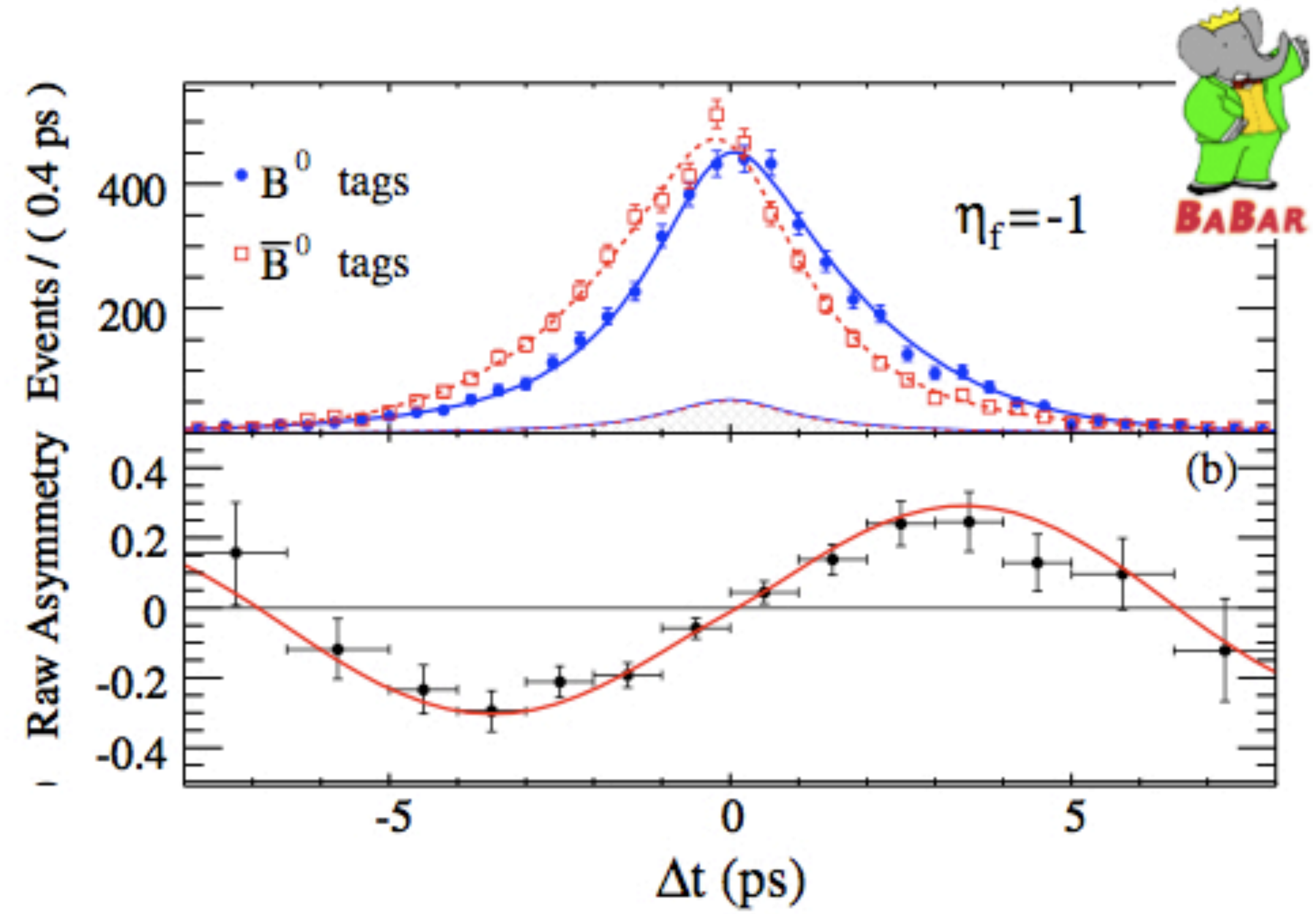
Belle



KEKB at KEK

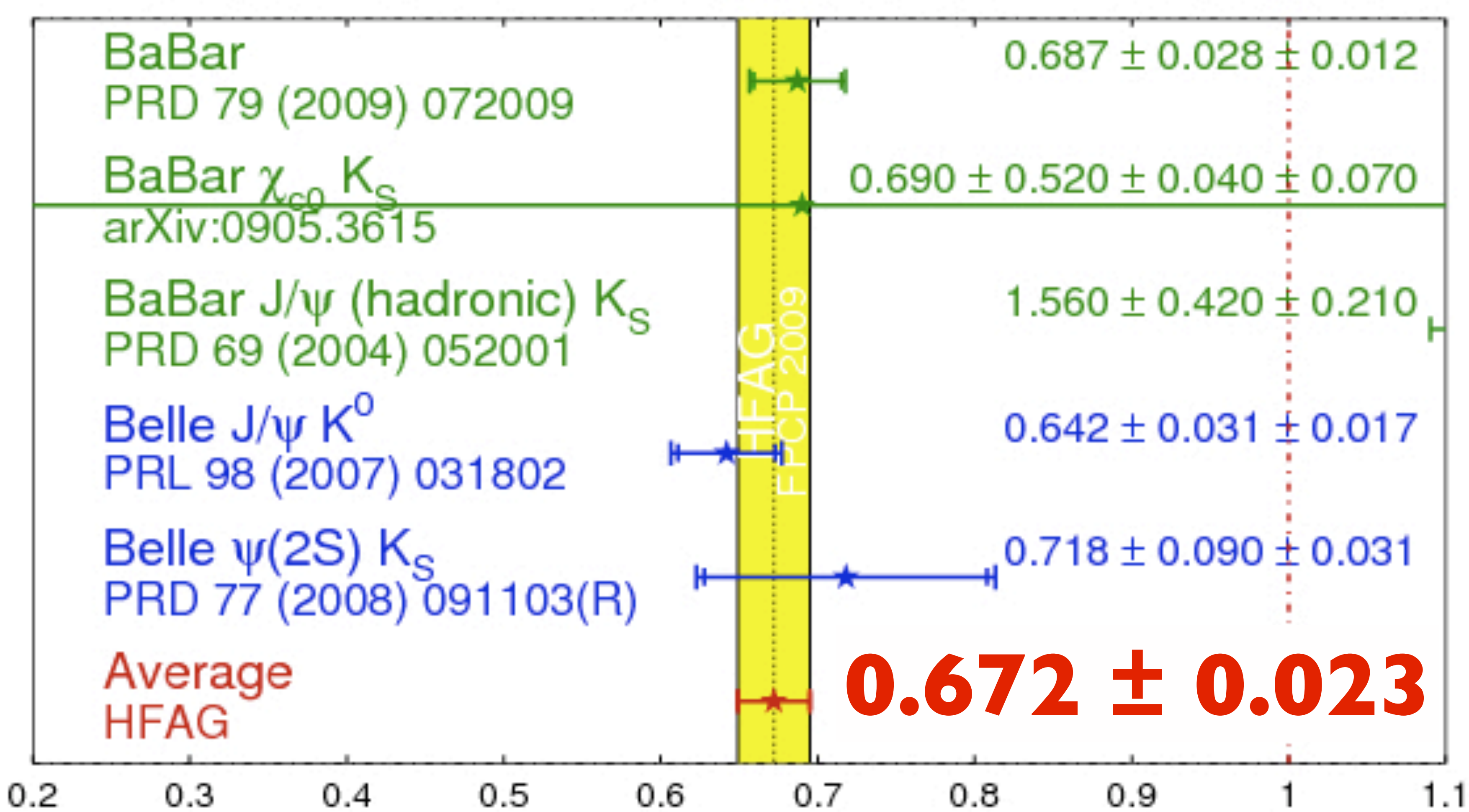
8GeV (e^-) × 3.5GeV (e^+)
peak luminosity:
$2.1\times10^{34}cm^{-2}s^{-1}$
world record

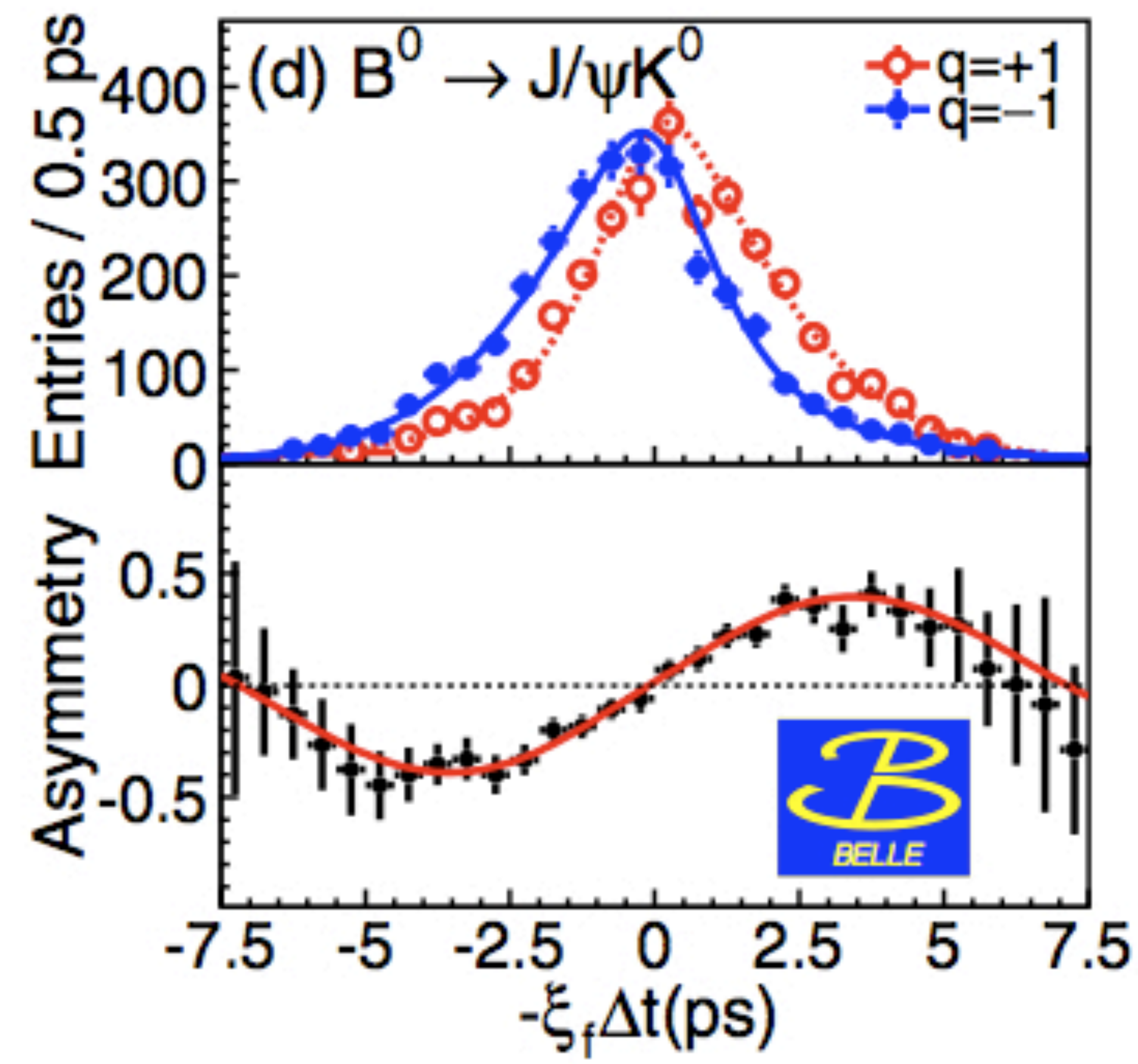




$\sin(2\beta) \equiv \sin(2\phi_1)$

HFAG
FPCP 2009
PRELIMINARY





Precise Measurement of the CP Violation Parameter $\sin 2\phi_1$ in $B^0 \to (c\bar{c})K^0$ Decays

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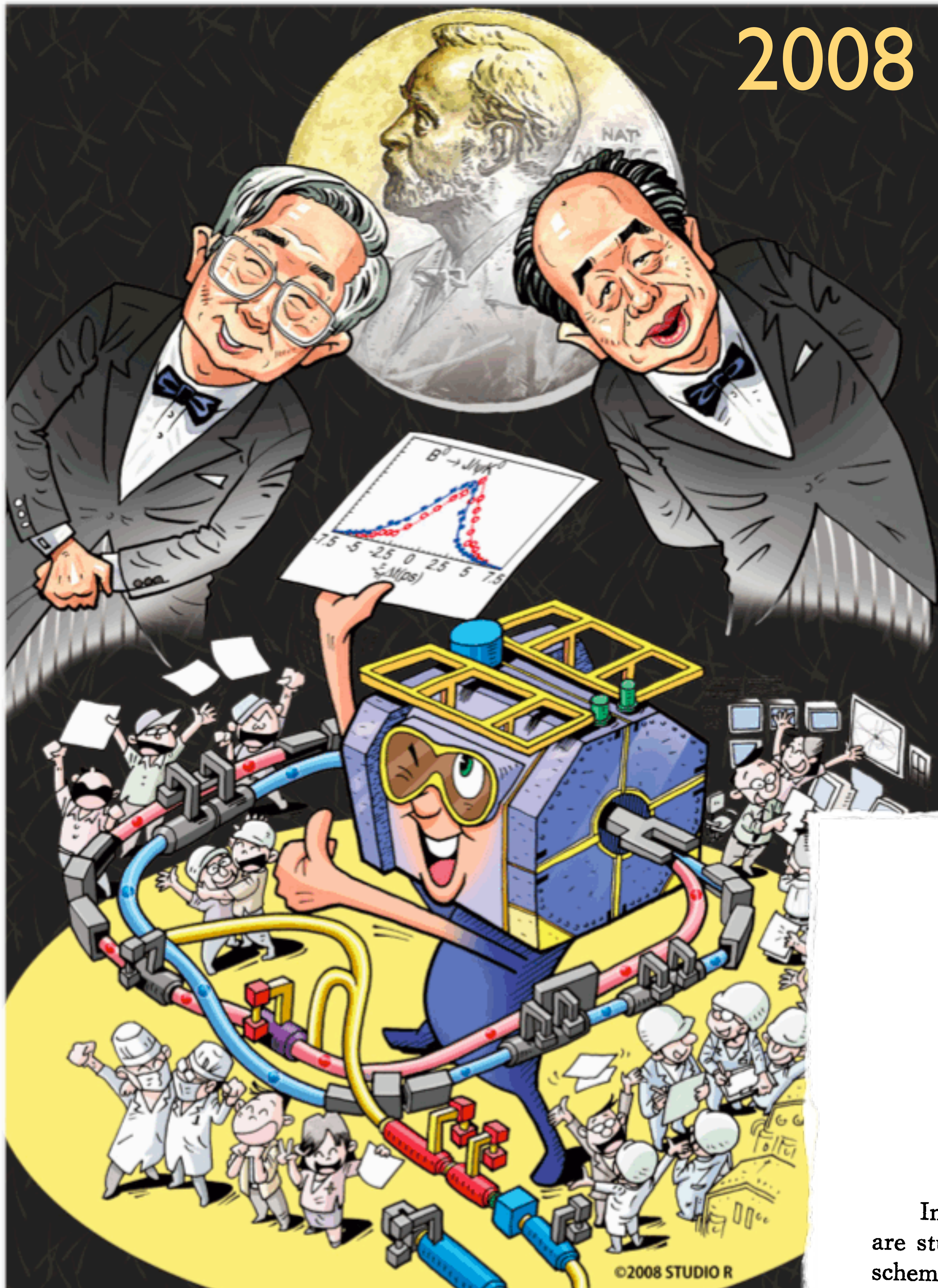
(The Belle Collaboration)

한국 참여기관

경북대, 경상대, 고려대, 서울대, 숭실대, 연세대, 전남대, 한양대, KISTI

CPV is due to an irreducible phase in the unitary quark mixing matrix in 3 generations



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CP-Violation in the Renormalizable Theory of Weak Interaction

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(Received September 1, 1972)

In a framework of the renormalizable theory of weak interaction, problems of CP-violation are studied. It is concluded that no realistic models of CP-violation exist in the quartet scheme without introducing any other new fields. Some possible models of CP-violation are also discussed.

When we apply the renormalizable theory of weak interaction[1)] to the hadron system, we have some limitations on the hadron

Coda

Maestoso con spirito

from 이강영 교수 (경상대) seminar at Yonsei, 2011

로버트 윌슨 Robert Rathbun Wilson

Robert Rathbun Wilson
(1914 –2000)

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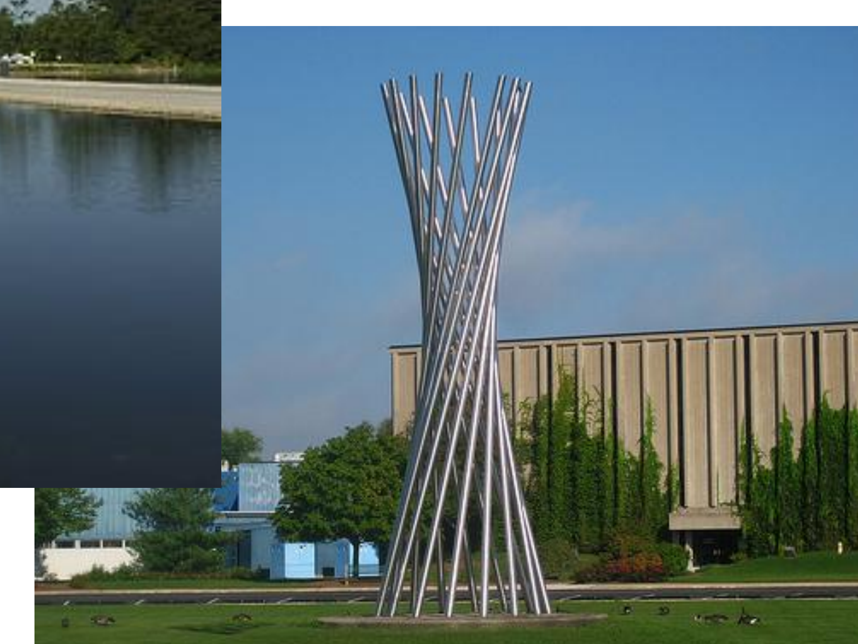
(1967–1978)

윌슨 홀



Pastore: Is there anything connected with the hopes of this accelerator that in any way involves the security of this country?

Wilson: No sir, I don't believe so.

Pastore: Nothing at all?

Wilson: Nothing at all.

Pastore: It has no value in that respect?

John Orlando Pastore
(1907 –2000)

Wilson: It has only to do with the respect with which we regard one another, the dignity of men, our love of culture. It has to do with whether we are good painters, good sculptors, great poets. I mean all the things we really venerate in our country and are patriotic about.
It has nothing to do directly with defending the country except to make it worth defending.

1969. 4. 17. 미국 의회 에너지 위원회에서

"가속기가 관계 있는 것은 인간의 존엄, 문화에 대한 사랑, 그러니까 훌륭한 화가나 조각가, 위대한 시인 같은 것입니다. 가속기는 나라를 지키는데 관계 있는 것이 아니라 나라가 지킬만한 가치가 있도록 하는 데 관계가 있습니다."

감사합니다!