老師：張嘉泓　　　　　物理系

Office: A213   Phone #: 7749-6038

手機：0922-492150

E-mail: chvchang@hotmail.com

FB: https://www.facebook.com/CHVincentChang

個人網址：http://phy.ntnu.edu.tw/~chchang

課程網址：http://phy.ntnu.edu.tw/~chchang/MP.htm

鏡好聽 MIRROR VOICE　發現　節目　有聲書　課程　節目主持人/有聲書主播　立即訂閱

【物理好好玩S1EP07】電子的劈腿問題，它是一種波嗎？

曾幾何時，我們的生命已一天都離不開電。電就是電子的流動，因此我們得認識電子。在四月的節目〈玩骰子的上帝——從放射性原子核談起〉中，我們已經介紹了，電子與原子核組合成了原子，而原子就組成所有的物質。但電子究竟是什麼？最自然的想像，我們都覺得電子是像撞球一樣的粒子。這樣的圖像很有用，因為電子的首要特徵，就是它如撞球一樣，完全不能分割。當然如果能量用得大一點，撞球還是可以被切碎的。但物理學家就算用極大的能量，到今天為止，還是無法將電子切開。換言之，我們從沒有看到過半個電子，而且無論你是在何處找到它，每一個電子都是一模一樣的。它的性質完全無法微調，輕一點、重一點都不可能，每一個都貨真價實。

撞球還有一個特點，每一個時刻它只有一個特定的位置，在這裏，就不能同時在那裡，在位置這件事上，它是不能劈腿的。二十世紀初的物理學家竟然發現，電子不完全是這樣。

電子如果是波，劈腿就名正言順了

最早提出電子有劈腿嫌疑的是一位法國的王子，德布羅意。德布羅意家族從十六世紀起就是法國的公爵，德布羅意是家中的老二，所以是王子，後來哥哥過世了，他才繼承了爵位。原本德布羅意是學歷史的，但受到哥哥的影響，改學物理。他的博士論文提出了一個駭人聽聞的想法，電子應該是一個波。請聽眾注意，這時沒有任何實驗證據顯

收錄於

節目

物理好好玩【第二季】

★★★★★

5 (2)

同專輯的其他音檔

【物理好好玩S2EP00】科學不是保存於...

【物理好好玩S2EP01】為微中子寫的一...

【物理好好玩S2EP02】生命的算計——...

【物理好好玩S2EP03】遍地開花的科學...

https://www.mirrorvoice.com.tw/podcasts/78

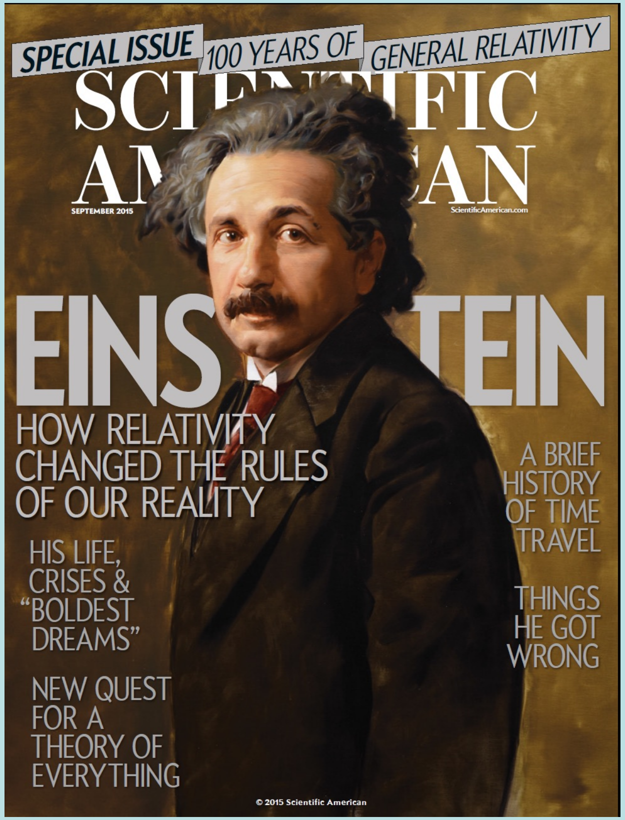
https://www.mirrorvoice.com.tw/podcasts/140

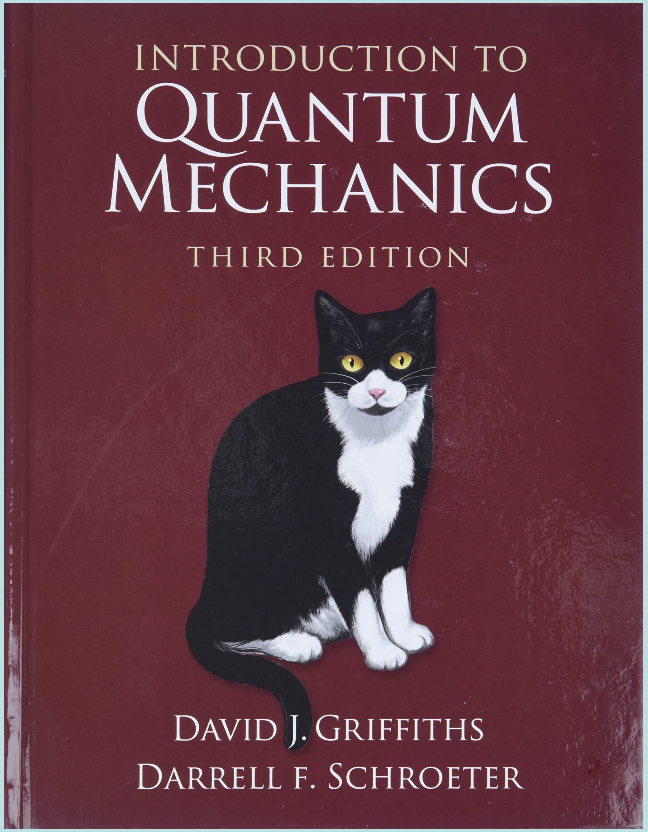
近代物理＝不是古典的物理學！

近代物理＝相對論＋量子論

＝速度接近光速的物理＋大小小於原子的物理

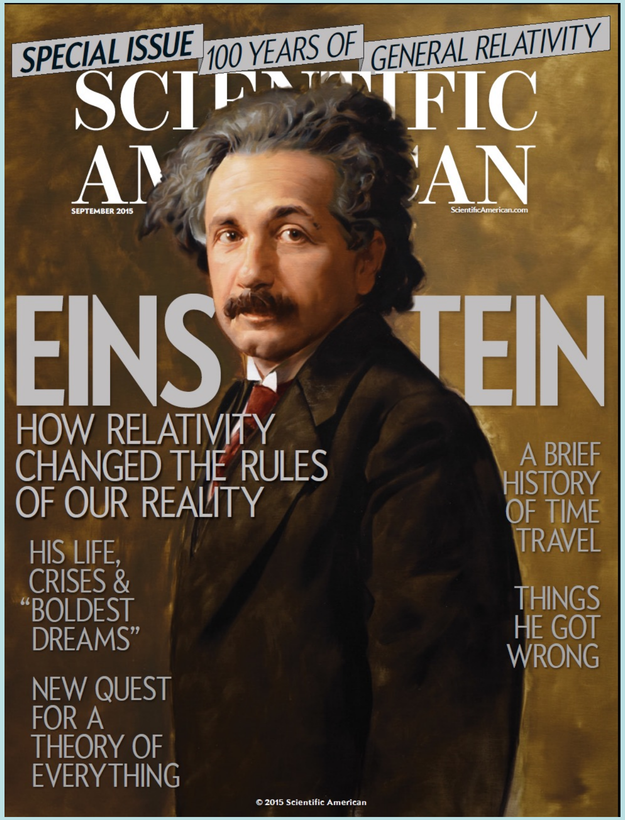
但量子力學其實是非相對論性量子力學！

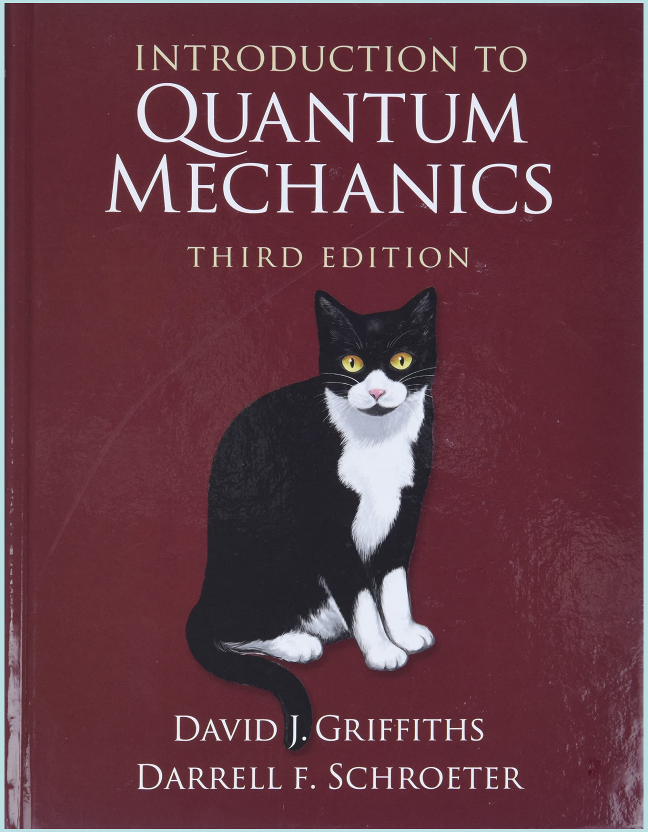




但相對論篇幅<<量子力學

近代物理≈量子力學





近代物理≈量子力學：微觀世界的物理！

微觀的世界的物理定律竟然與巨觀世界有截然的差異！

在近代物理學課，我們將幾乎從基礎開始，重新學習物理！

這個微觀的世界是物理學家的私人後花園。在大眾文化中沒有太多痕跡！

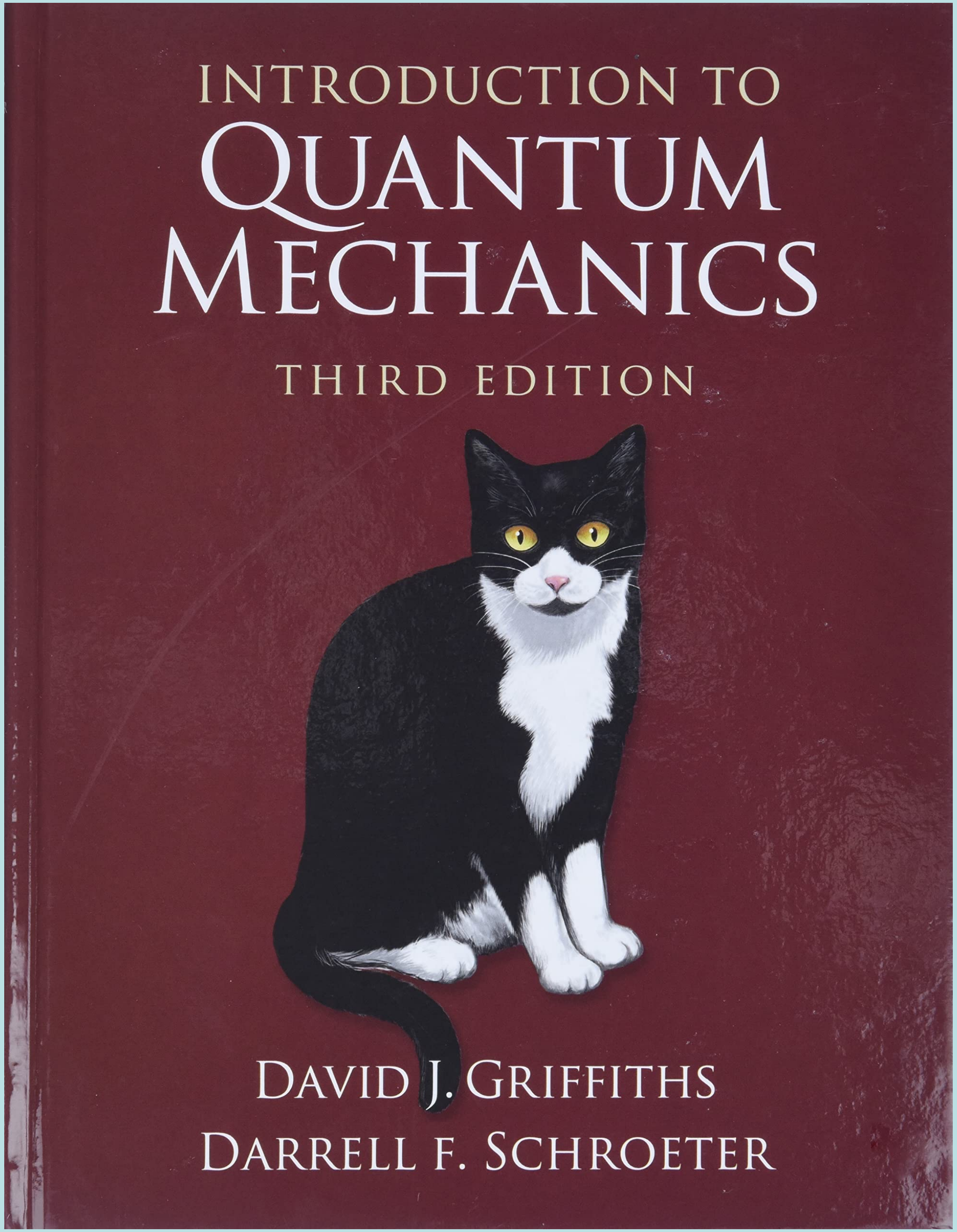
拋棄牛頓力學，粒子竟然要用波來了解！簡言之這是：波動力學。

量子力學 ≈ 波動力學！

近代物理課程主要以波動力學的角度介紹微觀世界的物理定律，但不只....

量子力學

物理的成年禮！


INTRODUCTION TO
QUANTUM
MECHANICS
THIRD EDITION
DAVID J. GRIFFITHS
DARRELL F. SCHROETER

1.1 The Schrödinger Equation

Imagine a particle of mass *m*, constrained to move along the *x* axis, subject to some specified force $F(x,t)$ (Figure 1.1). The program of *classical* mechanics is to determine the position of the particle at any given time: $x(t)$. Once we know that, we can figure out the velocity ($v = dx/dt$), the momentum ($p = mv$), the kinetic energy ($T = (1/2)mv^2$), or any other dynamical variable of interest. And how do we go about determining $x(t)$? We apply Newton's second law: $F = ma$. (For *conservative* systems—the only kind we shall consider, and, fortunately, the only kind that *occur* at the microscopic level—the force can be expressed as the derivative of a potential energy function,[1] $F = -\partial V/\partial x$, and Newton's law reads $m\, d^2x/dt^2 = -\partial V/\partial x$.) This, together with appropriate initial conditions (typically the position and velocity at $t = 0$), determines $x(t)$.

這是古典牛頓力學Newtonian Mechanics的基本思考方式！

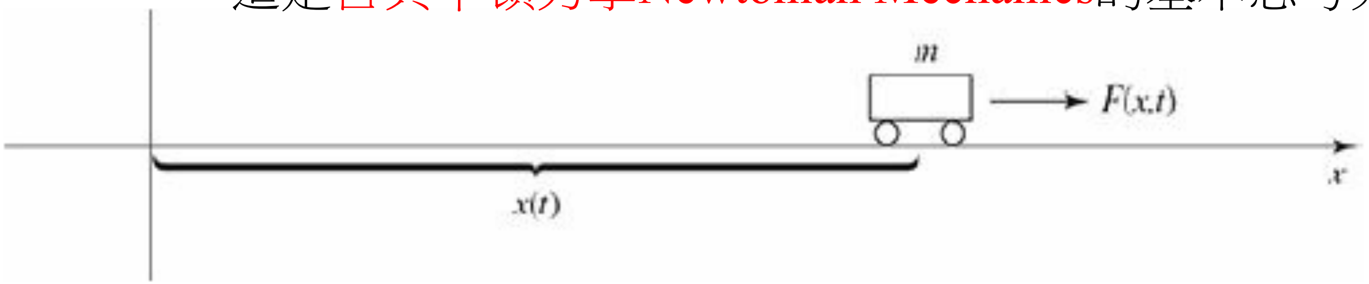


Figure 1.1: A "particle" constrained to move in one dimension under the influence of a specified force.

Quantum mechanics approaches this same problem quite differently. In this case what we're looking for is the particle's **wave function,** $\Psi(x, t)$, and we get it by solving the **Schrödinger equation:**

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V\Psi. \tag{1.1}$$

量子力學Quantum Mechanics的基本思考方式！

It is the wavefunction 波函數 we use to describe electron.

Here i is the square root of -1, and $\hbar$ is Planck's constant—or rather, his *original* constant (h) divided by 2π:

$$\hbar = \frac{h}{2\pi} = 1.054573 \times 10^{-34} \text{ J s}. \tag{1.2}$$

The Schrödinger equation plays a role logically analogous to Newton's second law: Given suitable initial conditions (typically, $\Psi(x, 0)$), the Schrödinger equation determines $\Psi(x, t)$ for all future time, just as, in classical mechanics, Newton's law determines $x(t)$ for all future time.[2]

$$x(t)$$

$$m\frac{d^2x}{dt^2} = -\frac{\partial V}{\partial x}$$

$$\psi(x,t)$$

$$-\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V(x)\Psi = i\hbar\frac{\partial\Psi}{\partial t}$$

這是一個嶄新的時代開始！描述微觀世界的方法不同了！

物理測量的方式、可以問的問題也都必須改變！

而這才是物理的未來。

電子的真面目

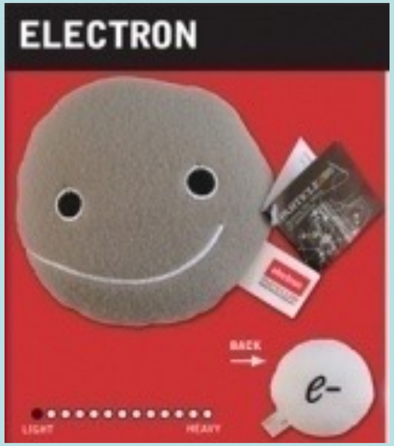
波的強度等於若觀察時在該處發現此粒子的機率！

狀態的變化是以波方程式來計算
(未觀察時）

觀察時電荷及位置總是顆粒狀

由波函數$\psi(x,t)$來描述的粒子

（而不是位置函數$x(t)$）



波函數無法觀察，所以只是一個數學語言！

波的語言可以以抽象的向量空間來取代！

電子的真面目

波的語言可以以抽象的無限維向量空間來取代！

向量的長度等於若觀察時在該處發現此粒子的機率！

狀態向量的變化可以向量的演化方程式來計算
(未觀察時）

觀察時電荷及位置總是顆粒狀

狀態由無限維向量空間的向量來描述的粒子

（而不是位置函數）

而物理量是由無限維向量空間的算子來描述的粒子

波也是一個等價的數學語言！但不是一定必要的！

波性只是反映出電子粒子狀態是一個滿足疊加定理的無限維向量空間的向量！

這是一個補習班！

1. [20 points] Consider the electron radiation process

$$e(p) \to e(p') + \gamma(q)$$

where p, p' and q are their 4-momenta and all these particles are on shell.

(a) [10] Use appropriate equations to explain why this process cannot happen *in vacuum*.

(b) [10] Use appropriate equations to explain why this process can possibly happen *in a detector* (*e.g.*, the Cerenkov radiation). Specify under what condition does that happen.

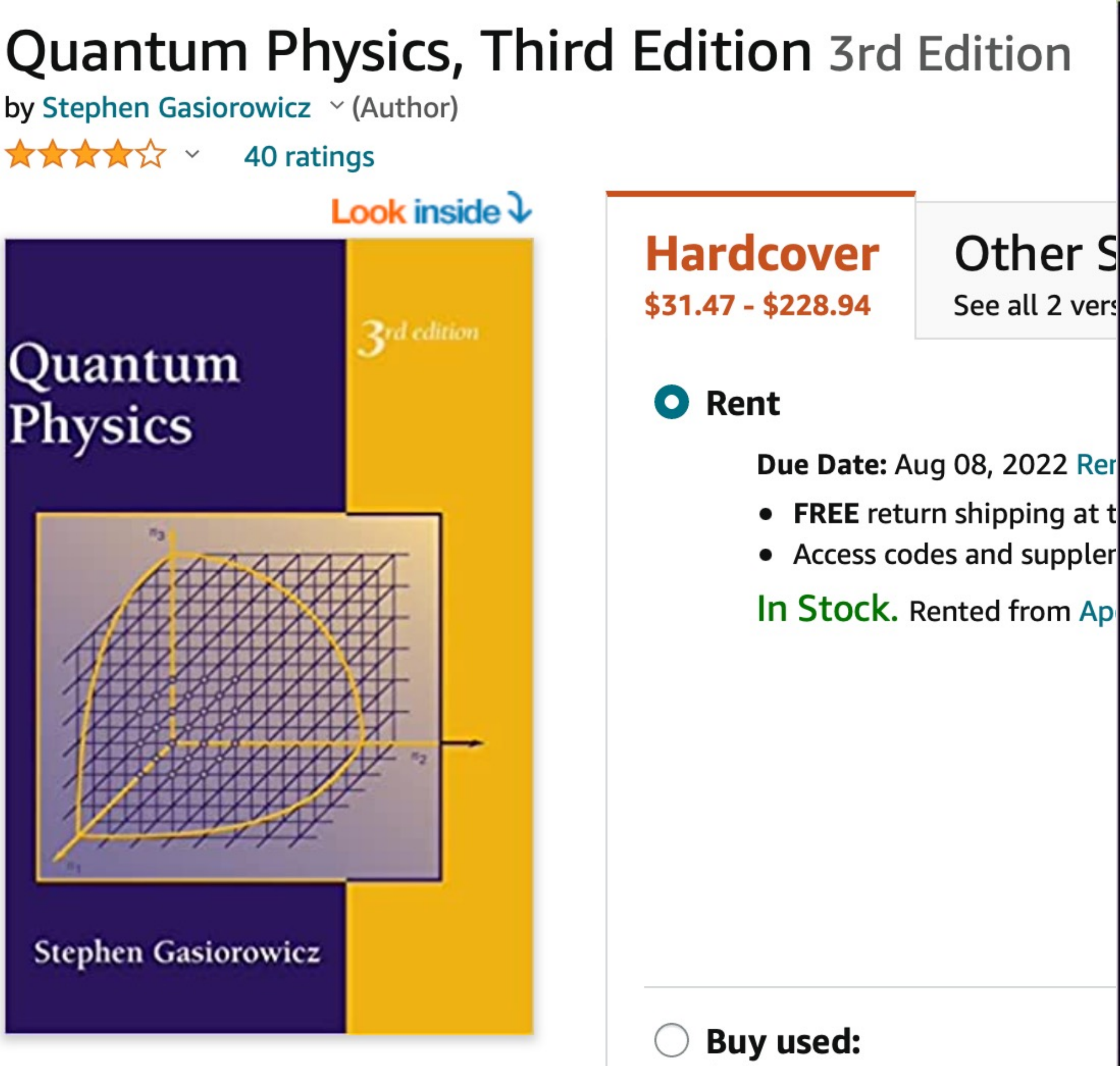
2. [30 points] A box containing a particle is divided into a left compartment and a right compartment by a thin partition. If the particle is known to be on the left (right) side with certainty, the state is represented by the position eigenket $|L\rangle$ ($|R\rangle$). A general state vector can be expressed as

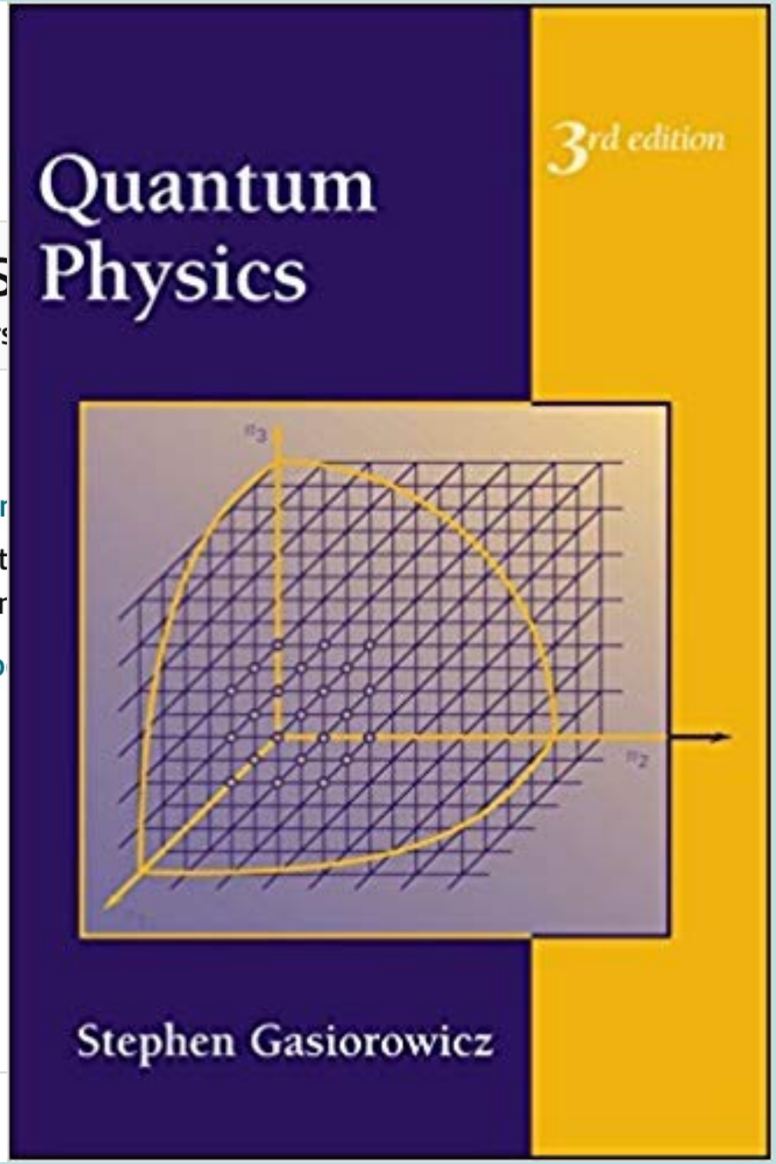
$$|\alpha\rangle = |L\rangle\langle L|\alpha\rangle + |R\rangle\langle R|\alpha\rangle \ .$$

Suppose it is possible for the particle to tunnel through the partition or remain in the original partition, as characterized by the Hamiltonian

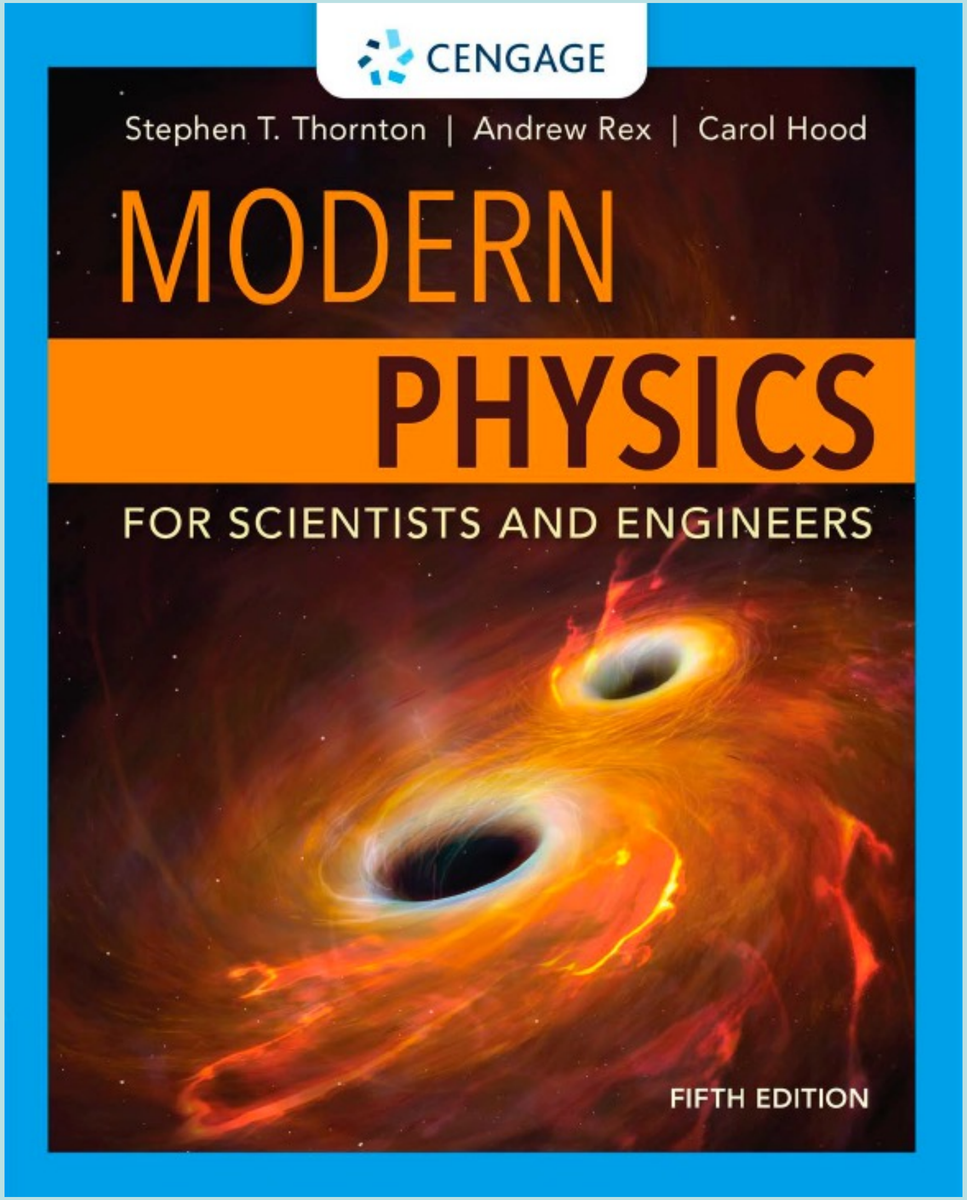
$$\mathcal{H} = \Delta\left(|L\rangle\langle L| + |L\rangle\langle R| + |R\rangle\langle L| + |R\rangle\langle R|\right) \qquad \text{with } \Delta \in \mathbb{R} \ .$$

(a) [10] Find the normalized energy e the corresponding energy eigenvalues.

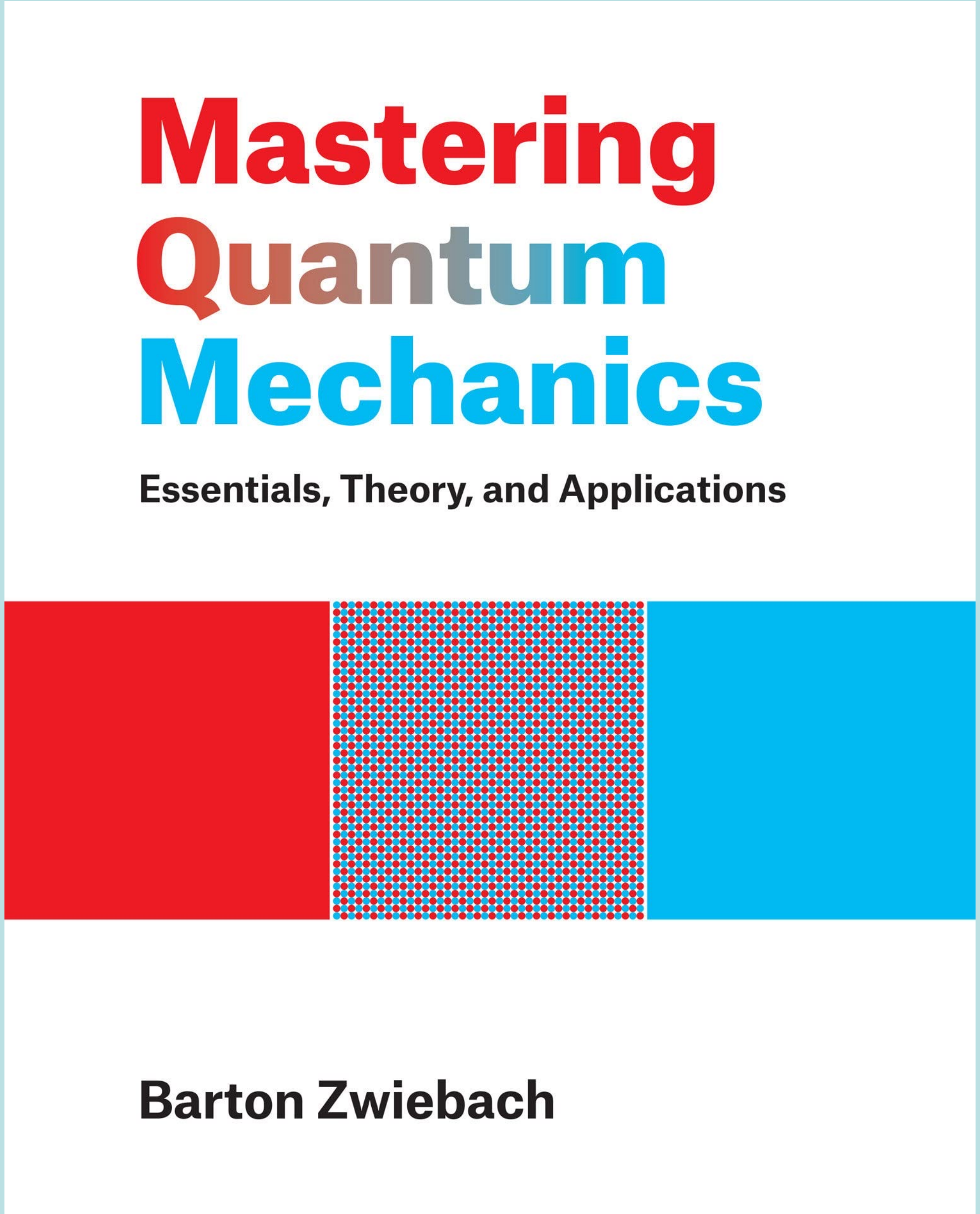




課本：**Quantum Physics 3/E, S. Gasiorowicz**



電機系用的，對物理系有點太簡單了！但實驗的討論很多，非常值得參考。


Mastering
Quantum
Mechanics
Essentials, Theory, and Applications
Barton Zwiebach

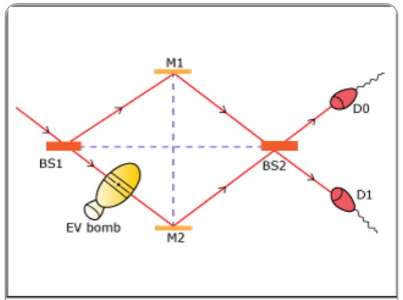
我會偷偷置入…….

MITOPENCOURSEWARE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

GIVE NOW ABOUT OCW HELP & FAQS CONTACT U

QUANTUM PHYSICS I

- SYLLABUS
- CALENDAR
- LECTURE NOTES
- VIDEO LECTURES +
- ASSIGNMENTS
- EXAMS



A Mach-Zehnder interferometer, with two beam splitters, two mirrors, and two detectors, is used to test if an

Screenshot

COURSE DESCRIPTION

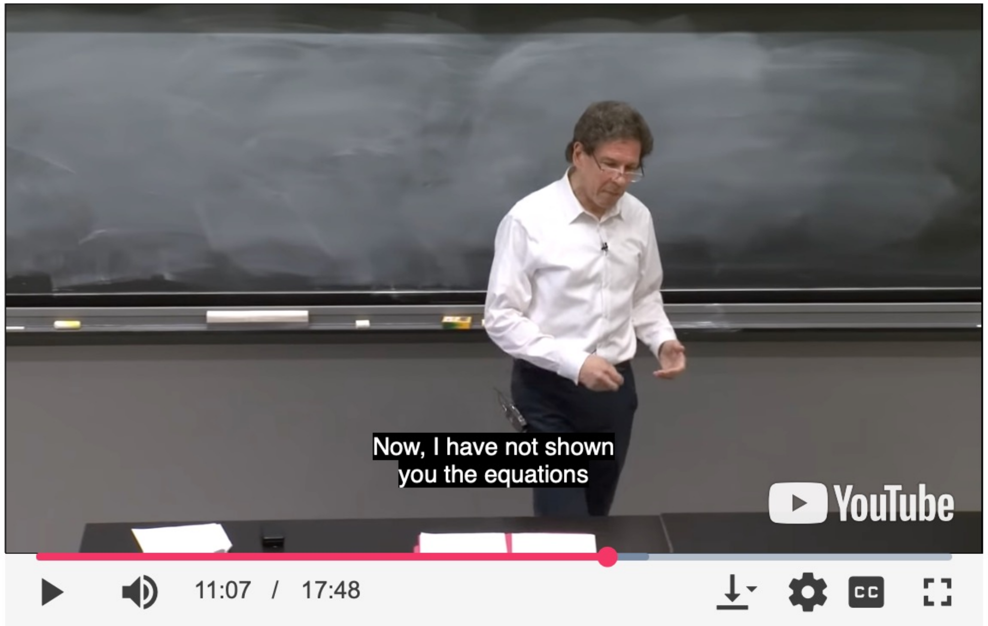
This is the first course in the undergraduate Quantum Physics sequence. It introduces the basic features of quantum mechanics. It covers the experimental basis of quantum physics, introduces wave mechanics, Schrödinger's equation in a single

COURSE INFO

Instructor:	Prof. Barton Zwiebach
Course Number:	8.04
Departments:	Physics
Topics:	Science > Physics > Quantum Mechanics
As Taught In:	Spring 2016

Part 1: Basic Concepts

QUANTUM MECHANICS AS A FRAMEWORK. DEFINING LINEARITY



Transcript

Screenshot

HIDE COURSE INFO

COURSE INFO

Instructor: Prof. Barton Zwiebach

Course Number: 8.04

Departments: Physics

As Taught In: Spring 2016

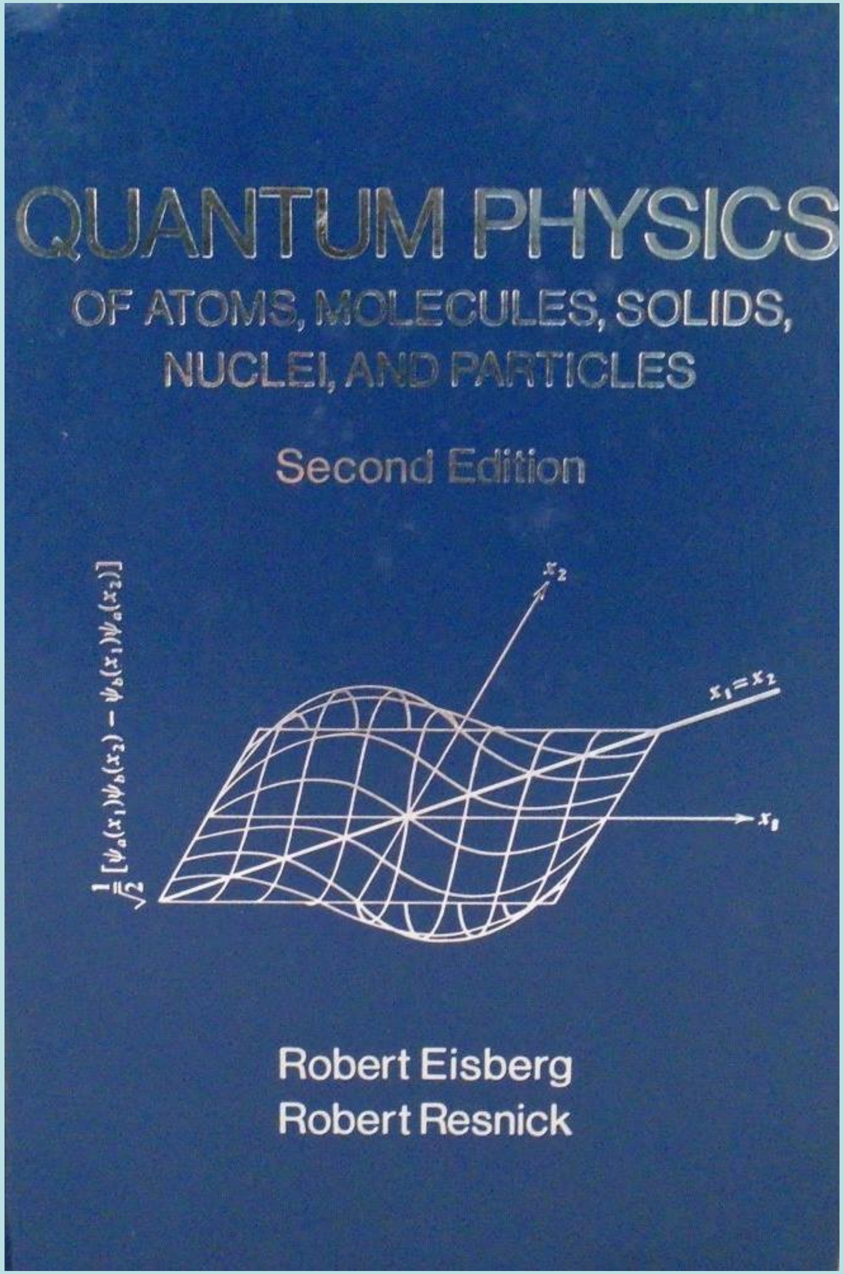
Level: Undergraduate

TOPICS

- Science
  - Physics
    - Quantum Mechanics

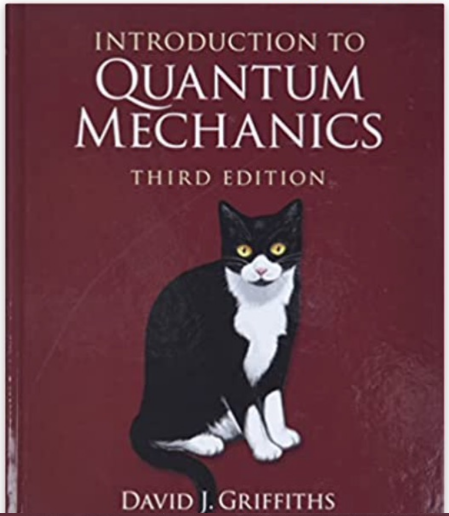
LEARNING RESOURCE TYPES

- **Lecture Videos**
- **Problem Sets**
- **Exams**
- **Lecture Notes**


QUANTUM PHYSICS
OF ATOMS, MOLECULES, SOLIDS, NUCLEI, AND PARTICLES
Second Edition
Robert Eisberg
Robert Resnick

標準教科書，可以參考。

Look inside



Introduction to Quantum Mechanics 3rd Edition

by David J. Griffiths (Author), Darrell F. Schroeter (Author)

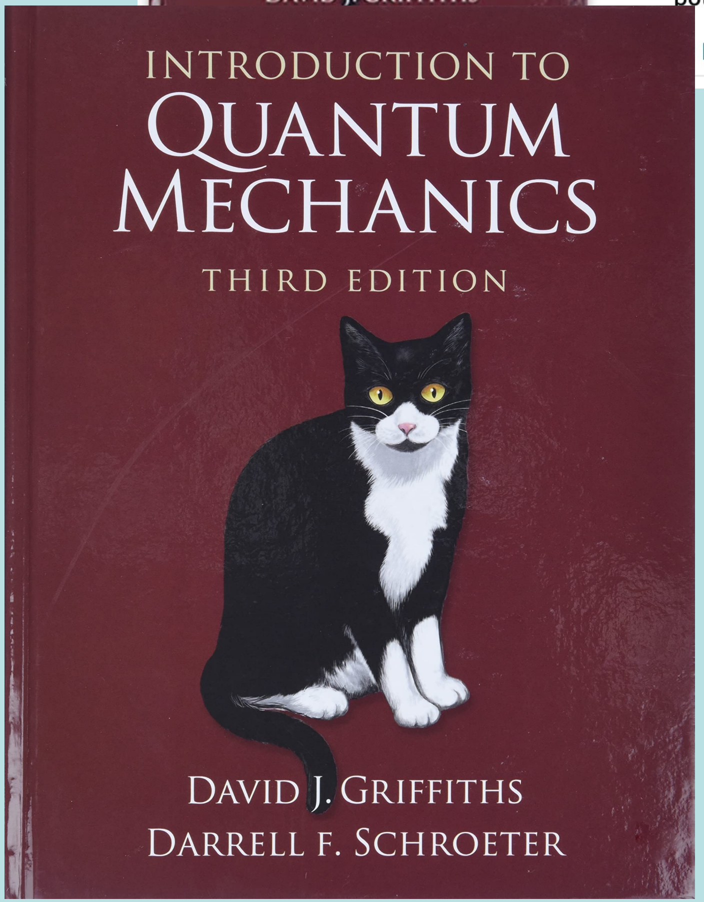
1,182 ratings

See all formats and editions

eTextbook	Hardcover
$48.29	$18.14 - $60.98
Read with Our Free App	8 Used from $60.92 13 New from $55.40 3 Rentals from $18.14

Changes and additions to the new edition of this classic textbook include a new chapter on symmetries, new problems and examples, improved explanations, more numerical problems to be worked on a computer, new applications to solid state physics, and consolidated treatment of time-dependent potentials.

Report incorrect product information.

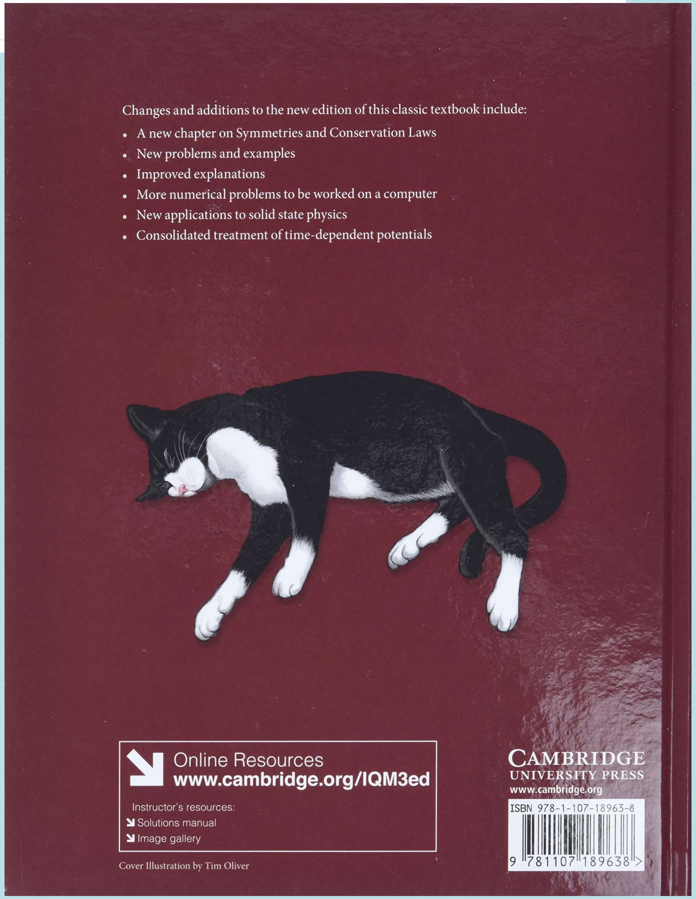


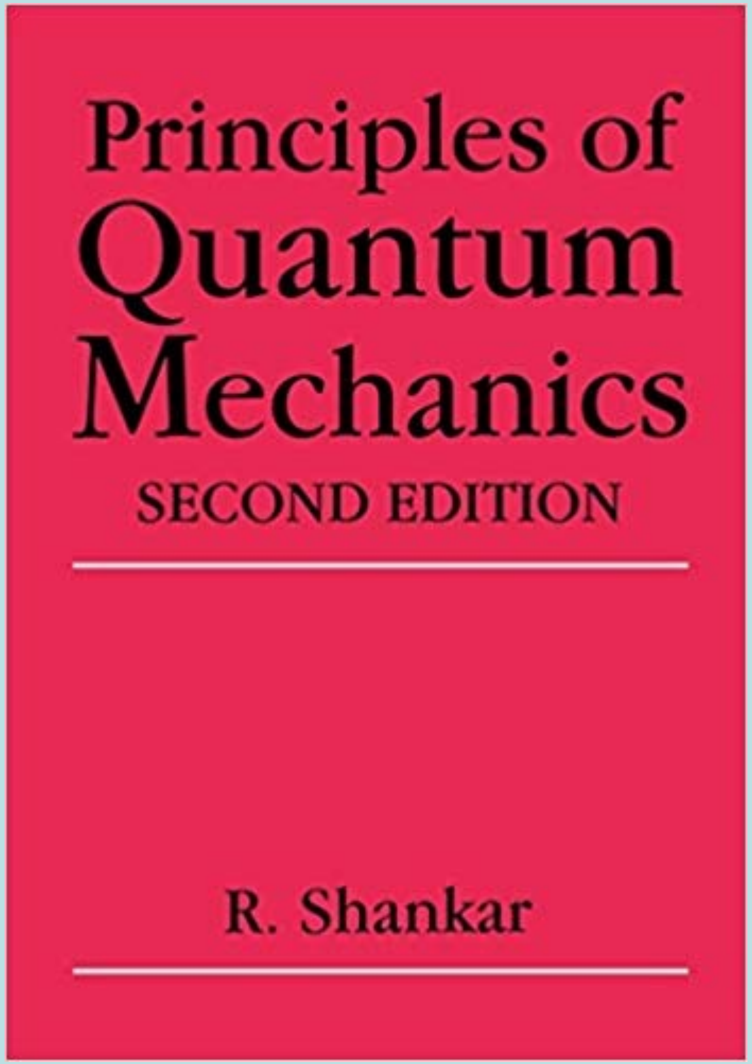
大四 量子力學導論

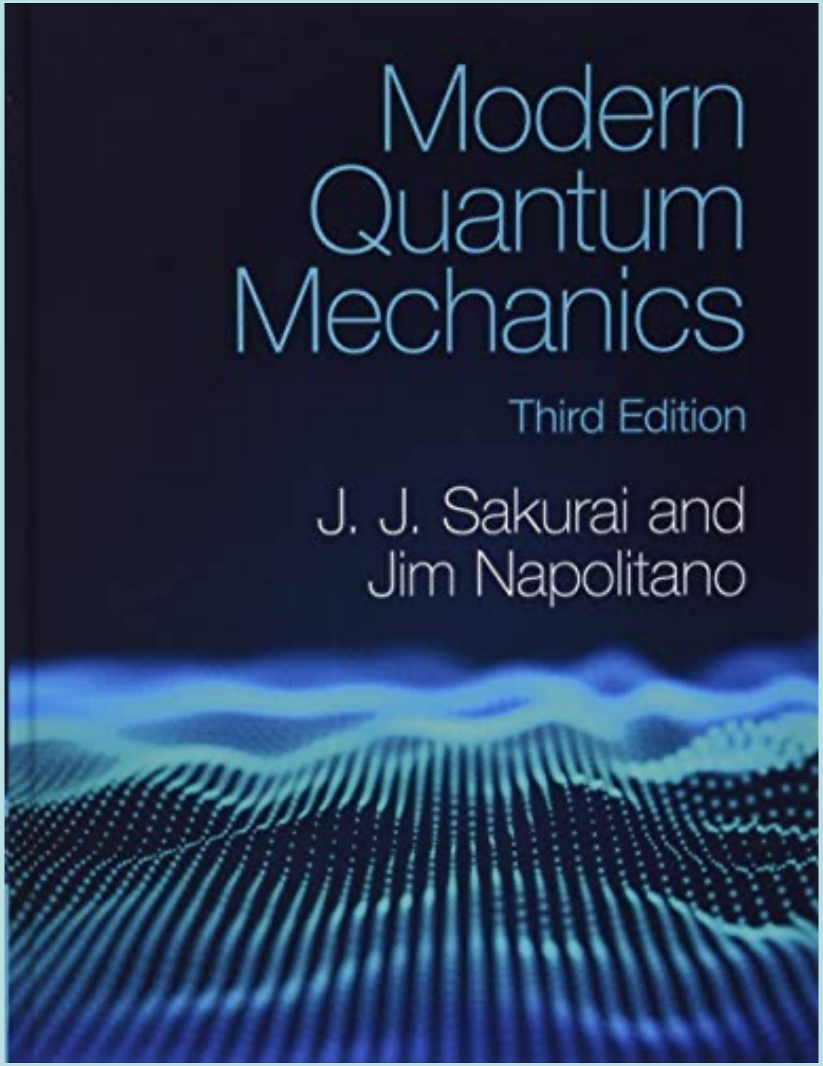
清晰好懂，

又有貓……

大推……也會置入。







研一量子力學，很棒，但再說吧.....

week 1,2 Special Relativity (Oppenheimer and Einstein)

week 1,2 簡介Particle and Waves, Probability interpretation, Quantum Mechanics

week 3 Photoelectric Effects, Photons, Borh's Model of The Atom, Matter Wave (Where Quantum Mechanics was from)

week 4 Wave function and Schrodinger's equations

week 5 Wave Packet, Expectation Values

week 6 Stationary State, Eigenvalues, Eigenfunctions (QM as Wave Mechanics)

week 7 Eigenvalues, Eigenfunctions (QM as Wave Mechanics)

week 8 One-dimensional Potentials, Energy Quantization, Scattering

week 9 Mid-term exam

week 10,11 Simple Harmonic Motion, Operator Methods,

week 12,13 General Structures of Wave Mechanics   (Examples of Wave Mechanics)

week 14-15 Schrodinger's equations in 3D, Angular Momentum,

week 16 Final exam

2nd Semester

Week 1,2 Hydrogen (Schrodinger's equations in 3D)

Week 3,4 Electron Spin, Matrix Formulation, Dynamics of QM, Resonance

Week 5,6 Time-Independent Perturbation,

Week 7 Stark Effect, Perturbation with degeneracy

Week 8 Periodic Potential

Week 9 Mid-term exam

Week 10 Real Hydrogen Atom

Week 11 Identical Particles, Many Particle System

Week 12 Bloch Equation, Solid State Physics, Semiconductor (Application of QM)

Week 13 Molecules

Week 14 Semiconductor again

Nuclear Physics

Time-dependent Perturbation, Interaction of electron with EM Field, Radiation (Laser)

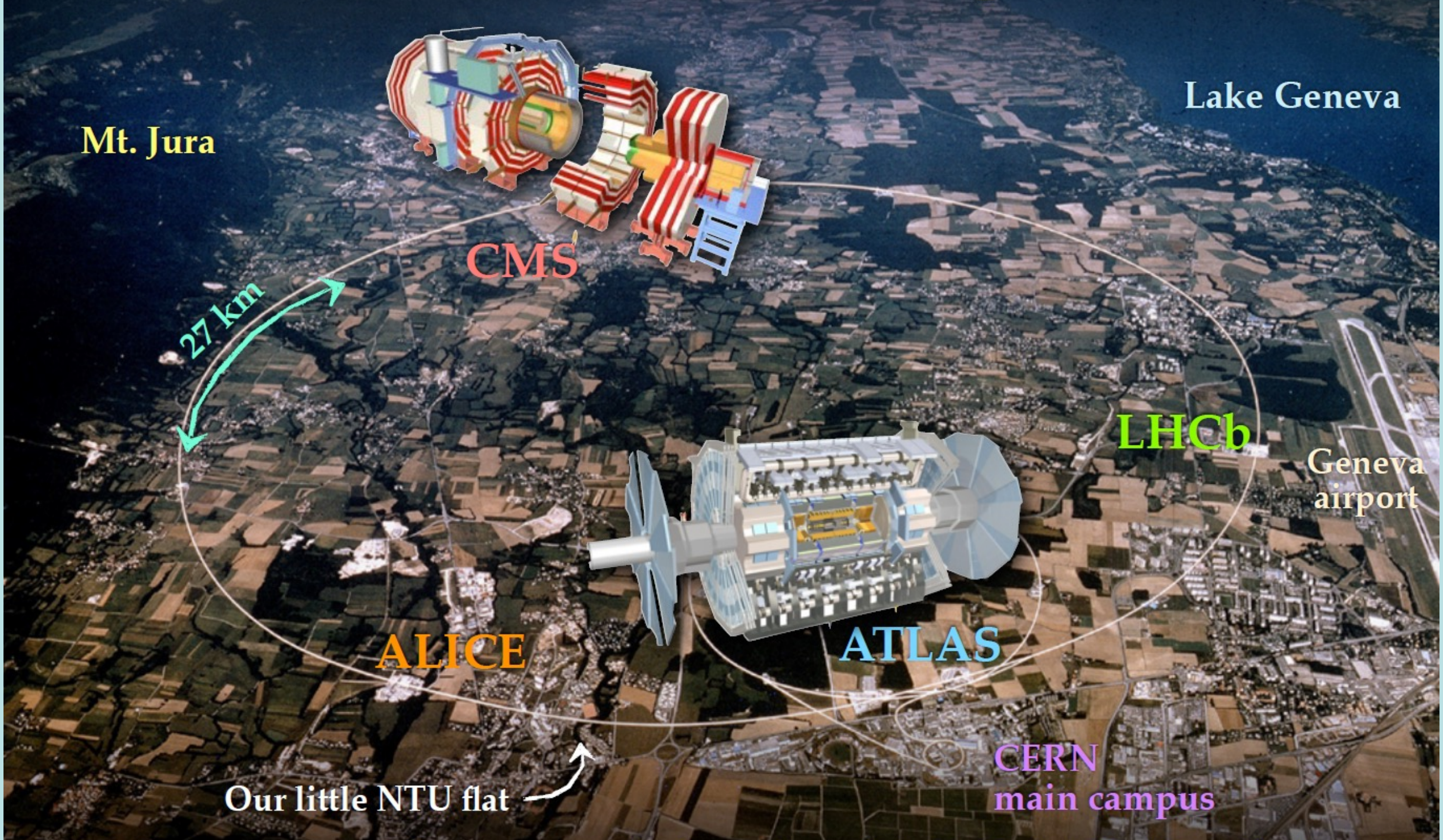
It is an exciting time to be a scientist!

做科學很令人興奮!

Webb Space Telescope 韋伯太空望遠鏡

第一張韋伯深空區照片，包含上千個星系，每個星系又有上億顆恆星，是宇宙至今最深、最清晰的紅外線影像。照片前景中，大部分星系是屬於星系團SMACS 0723，距離我們大約50億光年。而更顯眼、正要緊的是許多後方更加極度遙遠的星系，它們發出的光先經過SMACS 0723才到地球。被SMACS 0723極大的重力影響，光是彎著走的，所以它們影像好像經過了透鏡，被扭曲、放大成奇怪的形狀，有的看似毛筆隨意的一筆，有的像一段圓弧，有的甚至像是被壓扁了的麵疙瘩。這是典型的重力透鏡效應，

A Friendly Reminder – LHC & Experiments

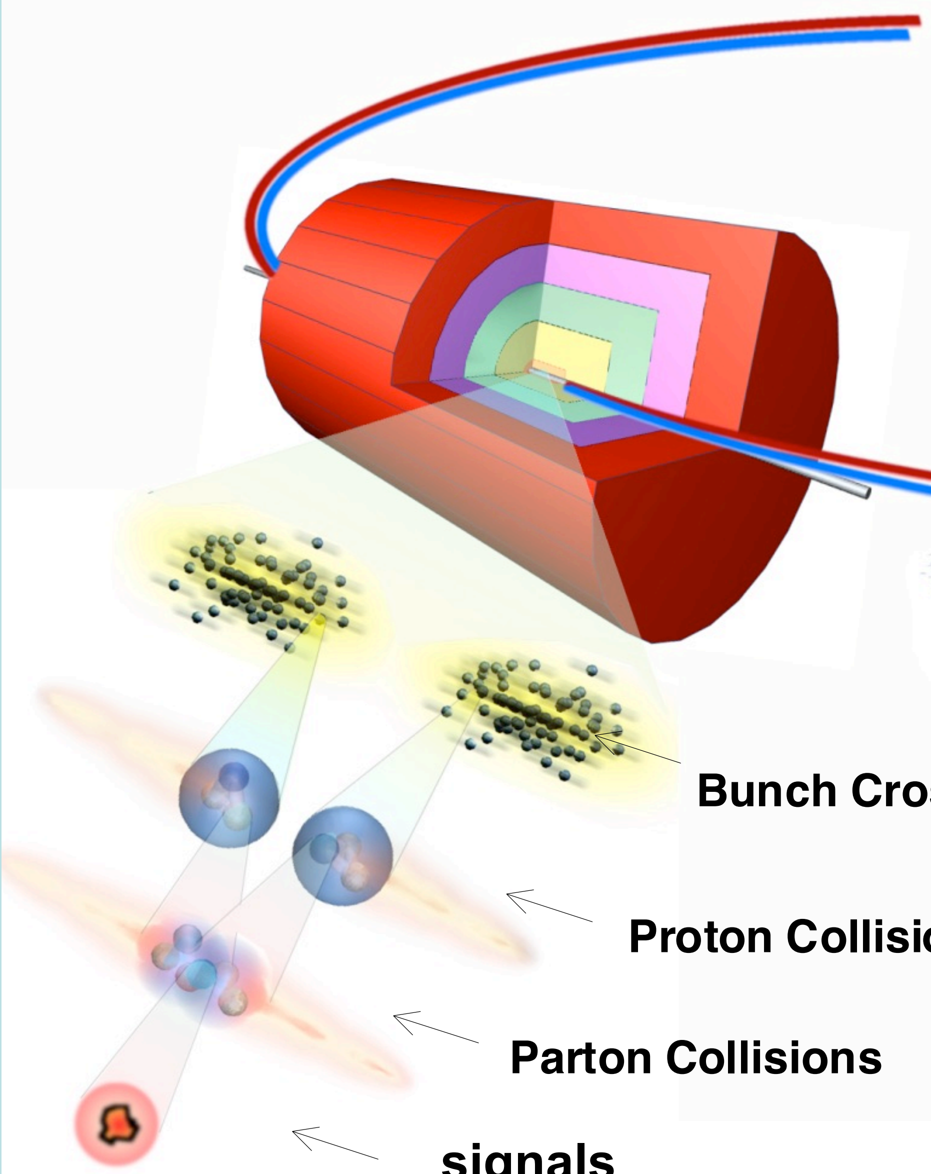


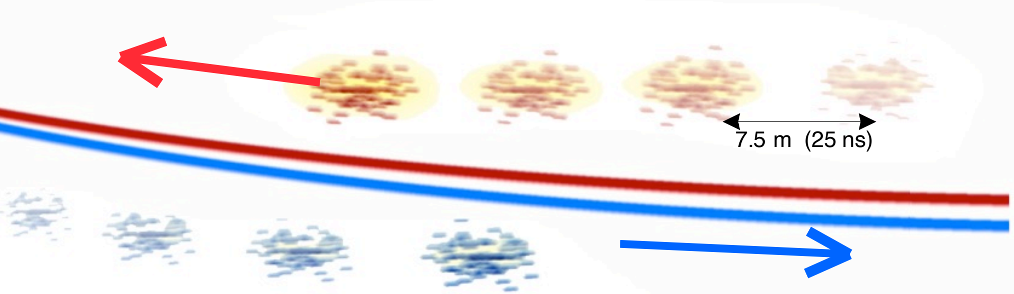
Going to cover the new results from (mostly) CMS & ATLAS today!

質心能量14TeV，台灣光子源的5000倍。

美國的Tevatron的14倍。

$7\text{x}10^{12}$ eV	Beam Energy
10^{34} cm^{-2} s^{-1}	Luminosity
2835	Bunches/Beam
10^{11}	Protons/Bunch





7 TeV Proton Proton colliding beams

Bunch Crossing **$4\ 10^{7}$ Hz**

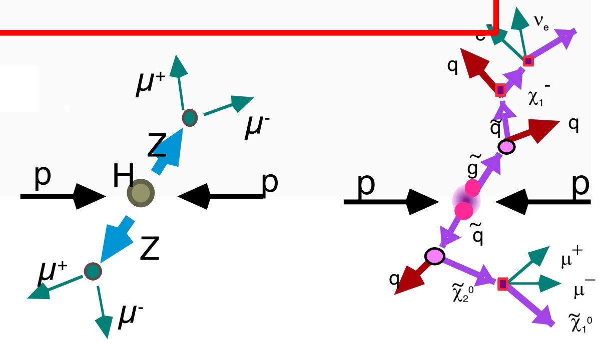
Proton Collisions **10^{9} Hz**

NUMBER OF HIGGS PARTICLES:
1 every 2.5 seconds

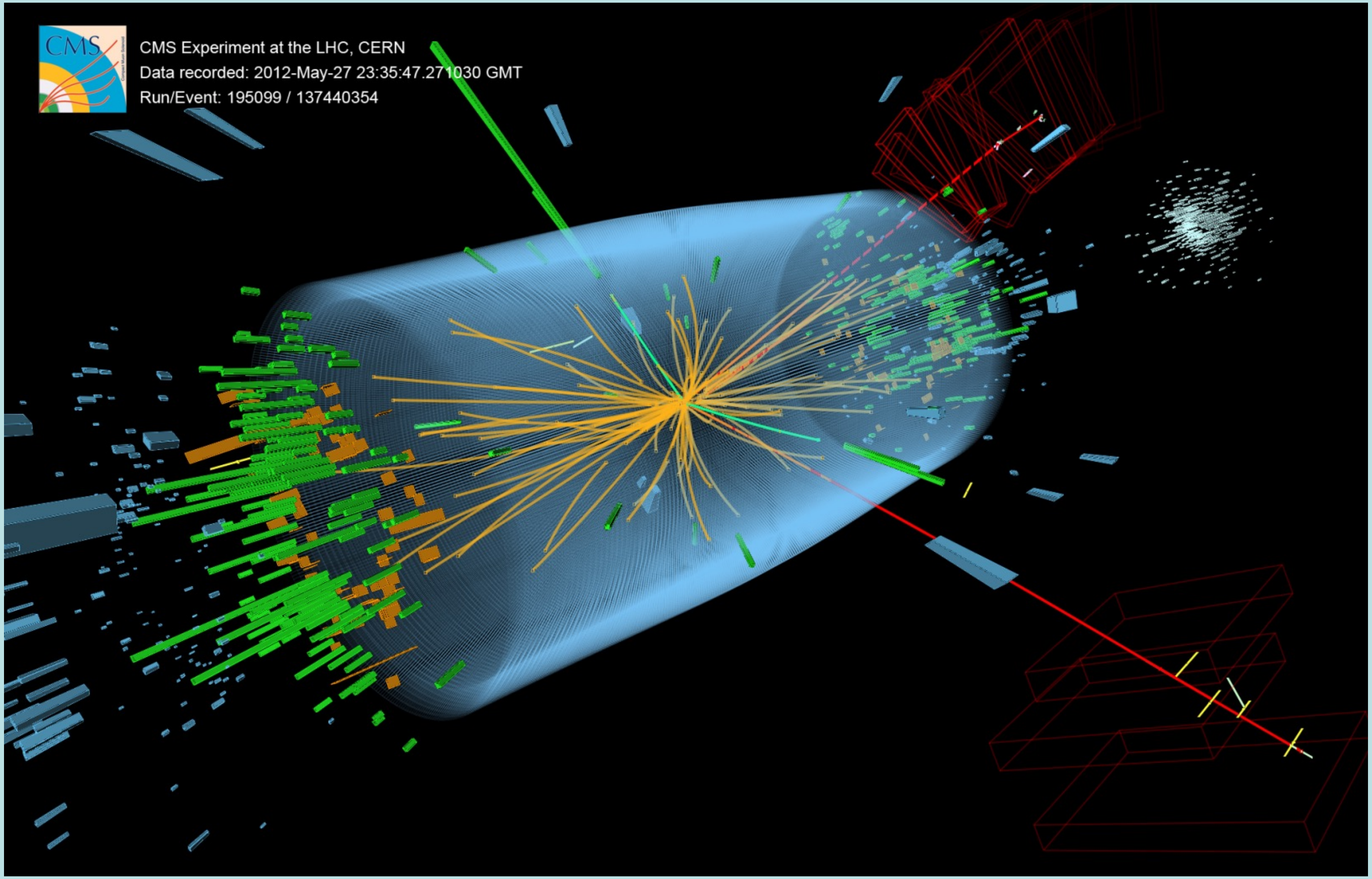
Parton Collisions

signals **10^{-5} Hz**

(Higgs, SUSY, ...)



Selection of 1 event in 10,000,000,000,000



For one event, we record the tracks of charged partciles, the energy deposited in a certain direction at two layers and the tracks of muons!

Event recorded with the CMS detector in 2012 at a proton-proton centre-of-mass energy of 8 TeV. The event shows characteristics expected from the decay of the SM Higgs boson to a pair of Z bosons, one of which subsequently decays to a pair of electrons (green lines and green towers) and the other Z decays to a pair of muons (red lines).

希格斯粒子很難產生，但撞擊的次數夠多，產生的數量也不算少！

It is not difficult to produce Higgs Boson if you have large enough number of collisions.

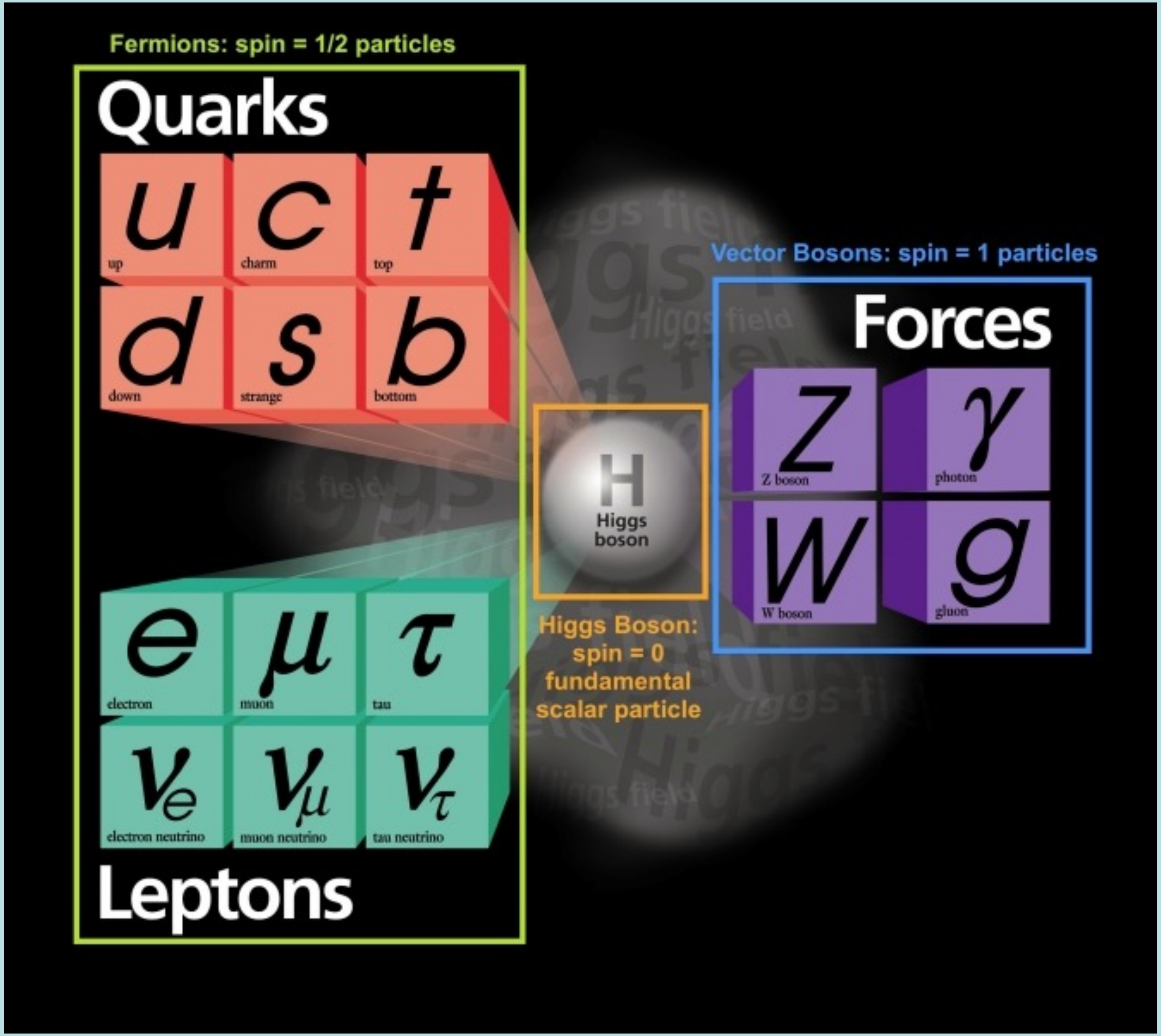
Proton Collisions 10^9 Hz

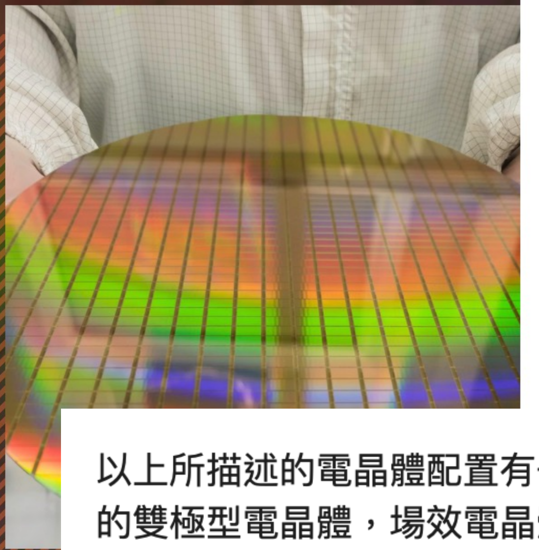
NUMBER OF HIGGS PARTICLES:
1 every 2.5 seconds

難的是如何識別出產生出來的希格斯粒子。

What is difficult is to identify a Higgs Boson.

LHC confirmed Standard Model and Standard Model only!





節目 知識好好玩

EP08｜台灣這美麗的矽島——聊一聊半導體物理

查看節目資訊

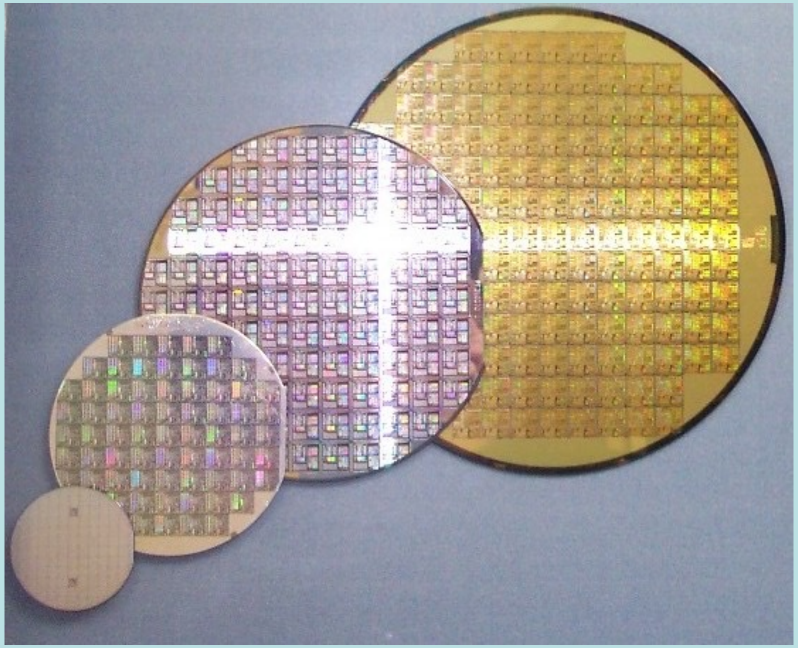
開始播放

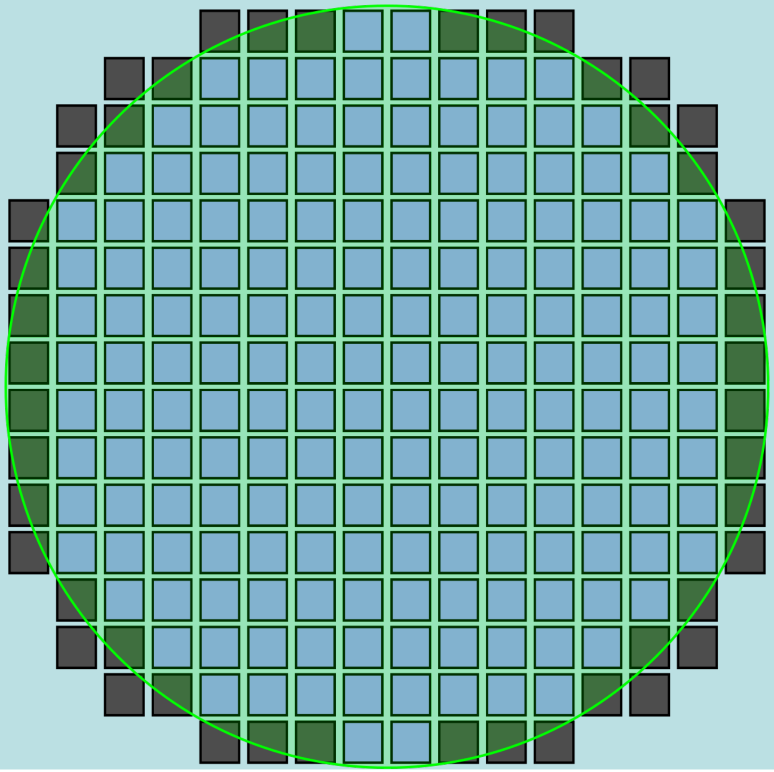
主持人｜張嘉泓

單曲長度｜00:25:46 發布時間｜2021-08-03

以上所描述的電晶體配置有一個很長的名字：金屬氧化物半導體、場效型電晶體 MOSFET，比起傳統的雙極型電晶體，場效電晶體更適合於平面的半導體大量製造，而且體積可以極度縮小。如上所述，場效電晶體的主體是由p型與n型半導體分布組成，這個分布可以規劃在二維平面上，於是由電晶體所組成的電路就可以在一片平板上展開。製作時會以矽為晶片基板，第一步先全部摻雜為p型半導體。接著先設計好藍圖，在平面上安排出n型半導體的位置。第三步，在基板上塗一層感光的光阻劑，然後將設計畫在一片光罩上，當光罩放置於基板上時，光罩的圖案會遮蓋規劃為p型半導體的區域。接著以紫外線曝照，消除掉光罩圖案未遮蓋處的光阻劑，於是規劃為n型半導體區域的基板就曝露在外。最後，將此曝露的部分滲進適當雜質，就得到所設計的n型半導體分布，而光阻劑覆蓋的部分則維持原來的p型。利用這樣的製程就可以在晶片上建構出你所設計的分布，其他如絕緣層、導電線路與電極也可以用類似的方式往上堆疊建構。

上一段描述是不是讓你感覺很枯燥、很機械化？那就對了，一個接著一個的步驟，有條不紊，如此，就可以大量機械化生產。而且平面化的設計，可以將電路非常節省空間地集中在一塊小晶片上，這就稱為積體電路。它的最大好處在於，只要你的藍圖光罩夠精細，電晶體的大小幾乎可以無限地縮小。如此我們才能把驚人的計算能力，置於一個日常生活能夠輕鬆攜帶的裝置。積體電路在1960年代出現，大概從

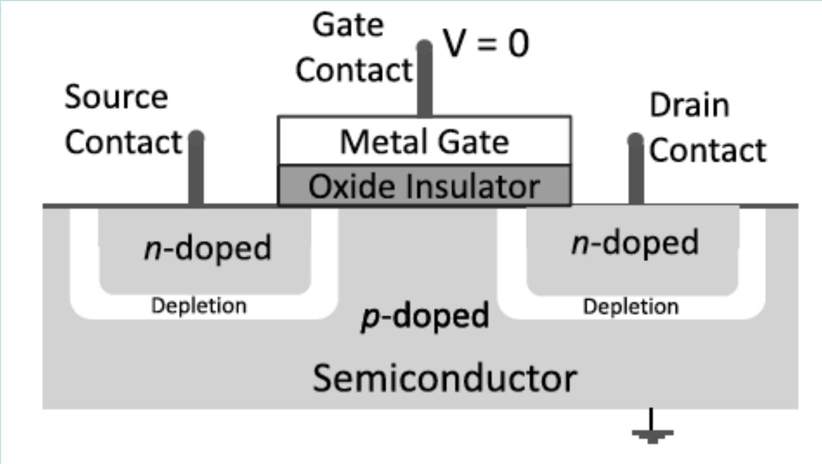




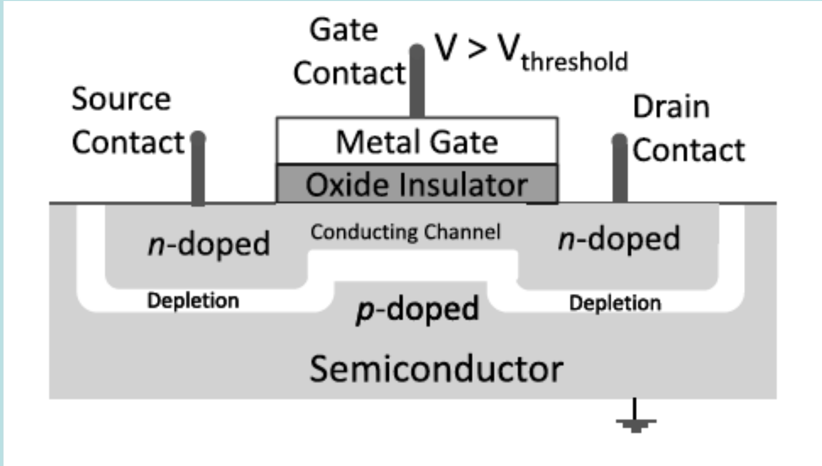

tsmc


RELIEF WRENCH
LOCATED BEHIND
THIS PANEL

EUV stands for extreme ultraviolet light, which produces the circuitry.

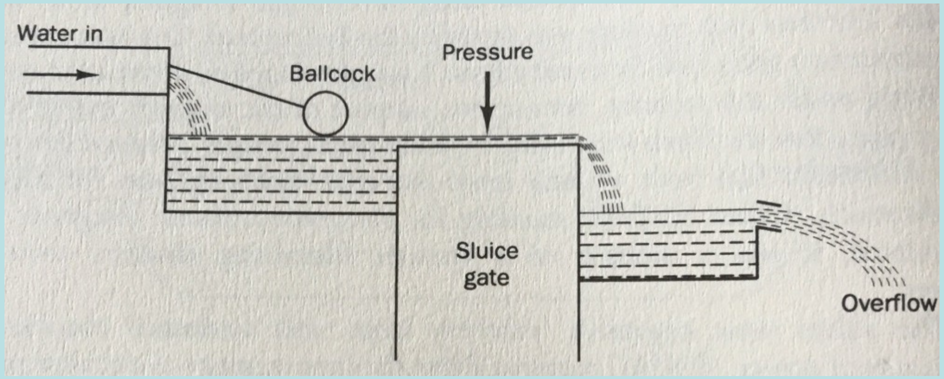


V_G



如此以閘電壓V_G做為條件，來控制電壓V_S是否能產生I_S。

如果電壓V_G很小而且有訊號，電壓V_S很大，所產生的大I_S就會攜帶訊號。



V_G