

Fermilab

January 2010

**FAUST IN COPENHAGEN**

A Struggle for the Soul of Physics





**FAUST IN COPENHAGEN**  
A STRUGGLE FOR THE SOUL OF PHYSICS

**GINO SEGRÈ**

*Author of A Matter of Degrees*



"In 1932, the year the neutron was discovered, the greatest names of what was arguably the greatest age in physics met in Copenhagen to talk shop, among them Niels Bohr, Werner Heisenberg, Paul Dirac, and Wolfgang Pauli. . . . This is the stuff of which cracking good narrative history is made." —*Time*

**FAUST IN COPENHAGEN**  
A STRUGGLE FOR THE SOUL OF PHYSICS

**GINO SEGRÉ**



BOHR  
EHRENFEST  
DIRAC  
MEITNER  
HEISENBERG  
DELBRÜCK  
PAULI



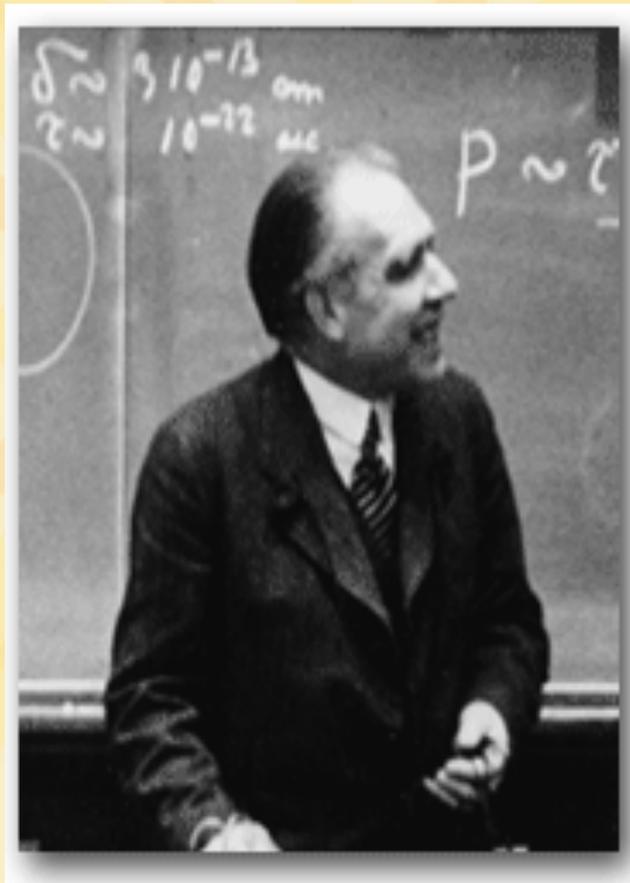
# Faust IN COPENHAGEN

The Struggle for the Soul of Physics  
and the Birth of the Nuclear Age



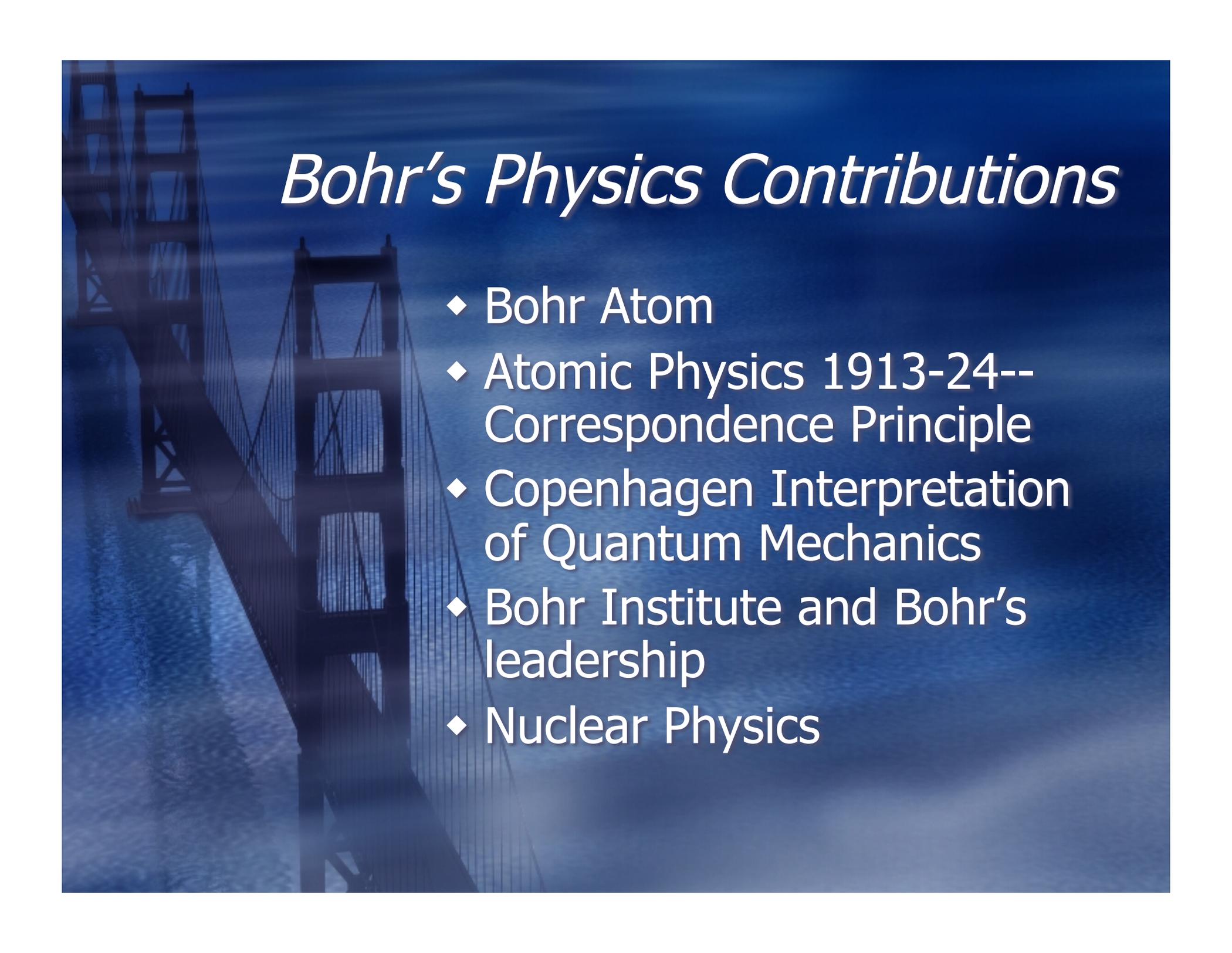
GINO SEGRÈ

# Niels Bohr



# Goethe





# *Bohr's Physics Contributions*

- ◆ Bohr Atom
- ◆ Atomic Physics 1913-24--  
Correspondence Principle
- ◆ Copenhagen Interpretation  
of Quantum Mechanics
- ◆ Bohr Institute and Bohr's  
leadership
- ◆ Nuclear Physics

# Bohr's Influence

---

- *“Bohr’s Influence on science is only partially expressed in his published work. . . . . But quite apart from their unbounded admiration for his achievements, the scientists of all nations felt for him an affection which has perhaps never been equaled.”*
- Sir George Thomson

# Bohr-Atomic Physics

- ✧ *“This walk (Göttingen June 1922) was to have profound repercussions on my scientific career, or perhaps it is more correct to say that my real scientific career only began that afternoon”.*
- ✧ *“Bohr’s influence on the physics and physicists of our century was greater than that of anyone else, even than that of Albert Einstein.”*
- ✧ Werner Heisenberg

# Bohr-Nuclear Physics

---

- Nothing has done more to convince me that there once existed friends of mankind with the human wisdom of Confucius and Buddha, Jesus and Pericles, Erasmus and Lincoln than walks and talks under the beech trees of Klampenborg Forest with Niels Bohr.
- John Wheeler

# *1921-Bohr in Berlin*



*Physics Institute 1921--  
Another kind of Bohr  
Contribution*

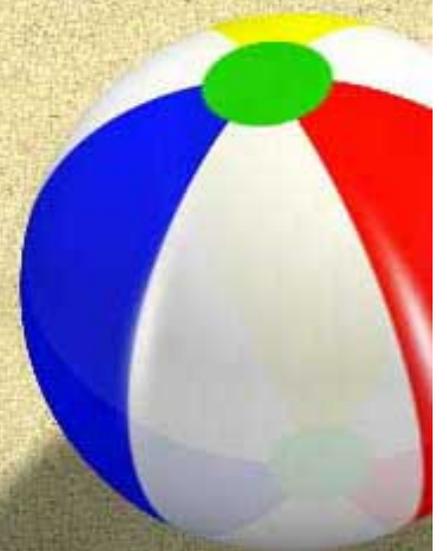


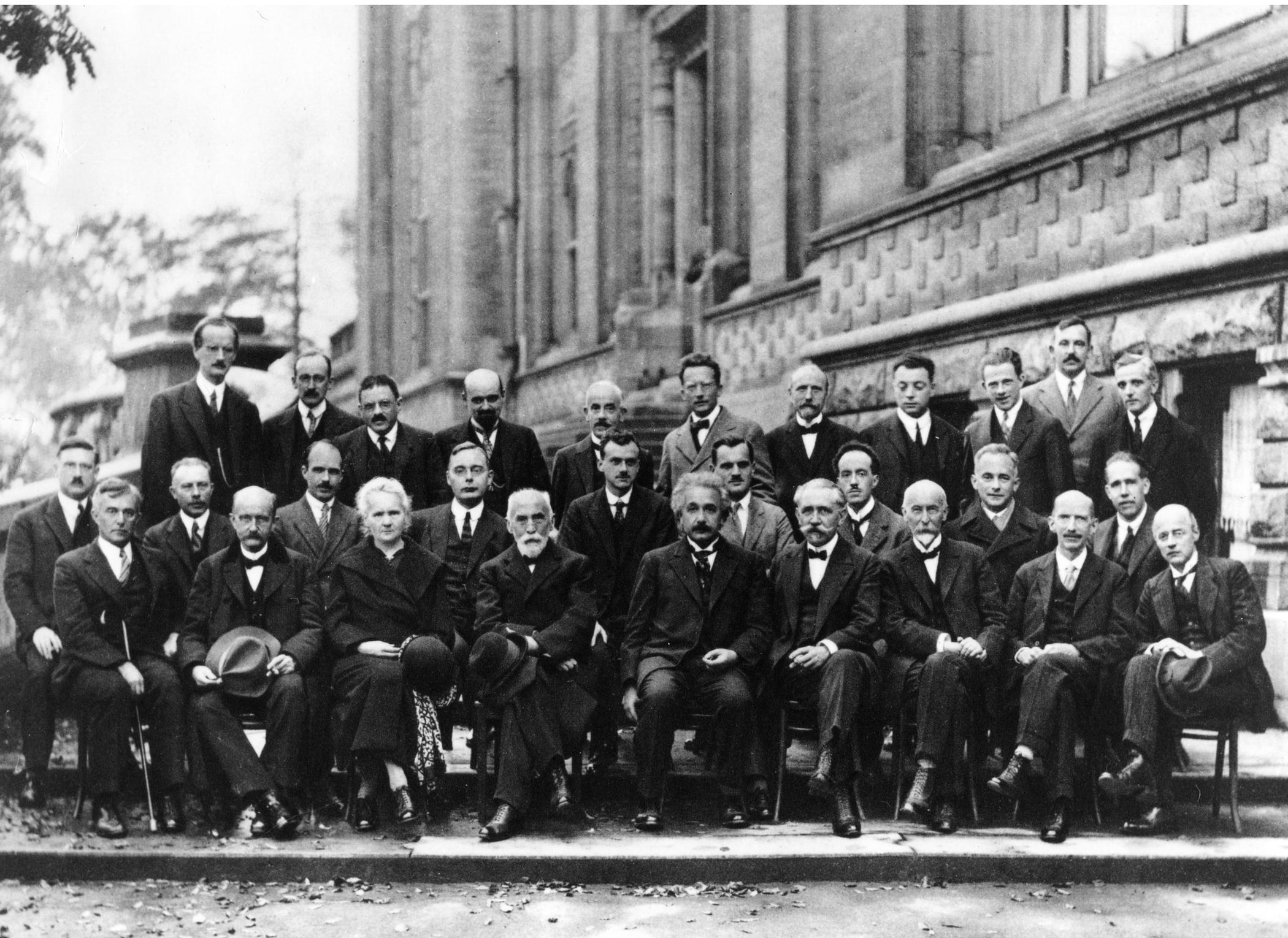
# Q.M. is born

- 1924-Pauli Exclusion Principle
- Summer 1925---Heisenberg's Matrix Mechanics
- January- June 1926---Schrodinger's Wave Mechanics
- 1927 -Copenhagen Interpretation with Uncertainty Principle-- Complementarity

# Puzzling Features of Q.M

- ✱ 1) Probabilistic Interpretation  
(what does the  $\psi$  function represent?)
- ✱ 2) Particle-Wave Duality
- ✱ 3) Uncertainty Principle





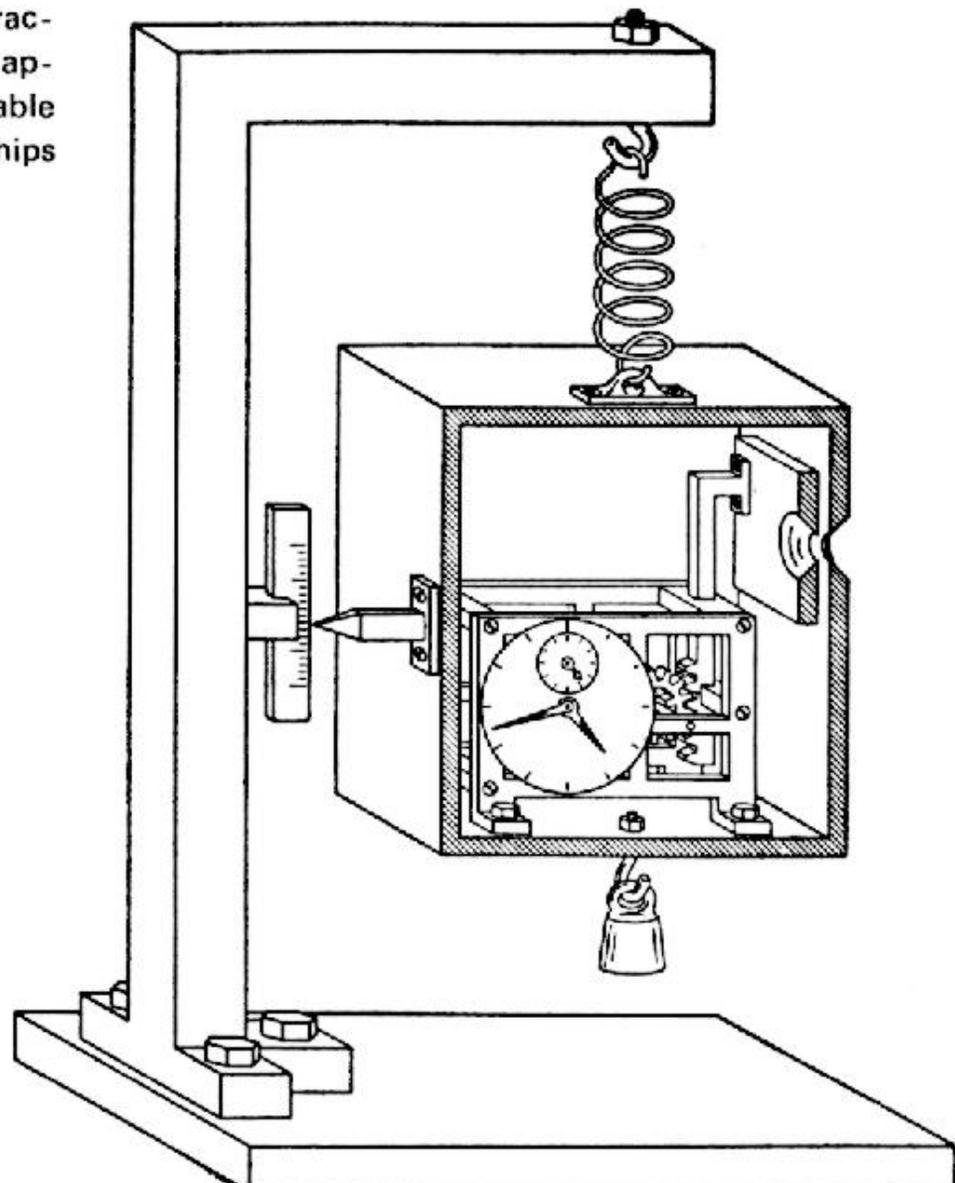
# 1930 Solvay-Bohr and Einstein

---



- I shall never forget the sight of the two antagonists leaving the conference, Einstein, a tall majestic figure walking quietly with a somewhat ironic smile and Bohr trotting near him, very excited. The next morning came Bohr's triumph." Bohr had refuted Einstein's paradox.

Illustration of a thought experiment which played an important part in the discussions between Bohr and Einstein on the interpretation of quantum mechanics (1930). With the many "technical" details in the drawing Niels Bohr wanted to stress that, in measurements of atomic quantities, the whole experimental arrangement must be taken into account. Thus, it is indicated that an accurate time measurement requires a solid system of gears and that a determination of position assumes the existence of a properly fixed measuring rod. The apparatus has become so elaborate because, during the discussions, Einstein proposed new measurements to control the interaction of the atomic object with the original apparatus now enclosed in a box. Bohr was able to show how the complementary relationships appear also in the new experiment.



# Testing $\Delta E \Delta T$

- Measuring scale with accuracy  $\Delta q$  implies uncertainty  $\Delta p$  such that
  - $\Delta p \Delta q > h$
- During time  $T$  of balancing procedure, there is an uncertainty  $\Delta m$  of box's mass and hence an uncertainty in its momentum of  $\Delta m v = \Delta m g T$  where  $g =$  gravitational constant. We want  $\Delta p$ , uncertainty due to measuring, to be smaller than this. In other words we should have
- $\Delta m g T > h / \Delta q$ ----the more precise the position, the longer the time needed to measure it

# BOHR'S REFUTATION II

- Because of the gravitational redshift, an uncertainty  $\Delta q$  in the clock's position implies an uncertainty  $\Delta T$  in its measurement of time
- $\Delta T/T = \Delta f/f = v/c = g \Delta q/c^2$
- Using  $\Delta mgT > h/\Delta q$ , (previous page)
- And  $1/\Delta q = gT/\Delta T$  we find  
 $\Delta mgT > h gT/\Delta T$  or  $\Delta T > h/\Delta m c^2$   
implying  $\Delta E \Delta T > h$  QED



# Pilgrimages

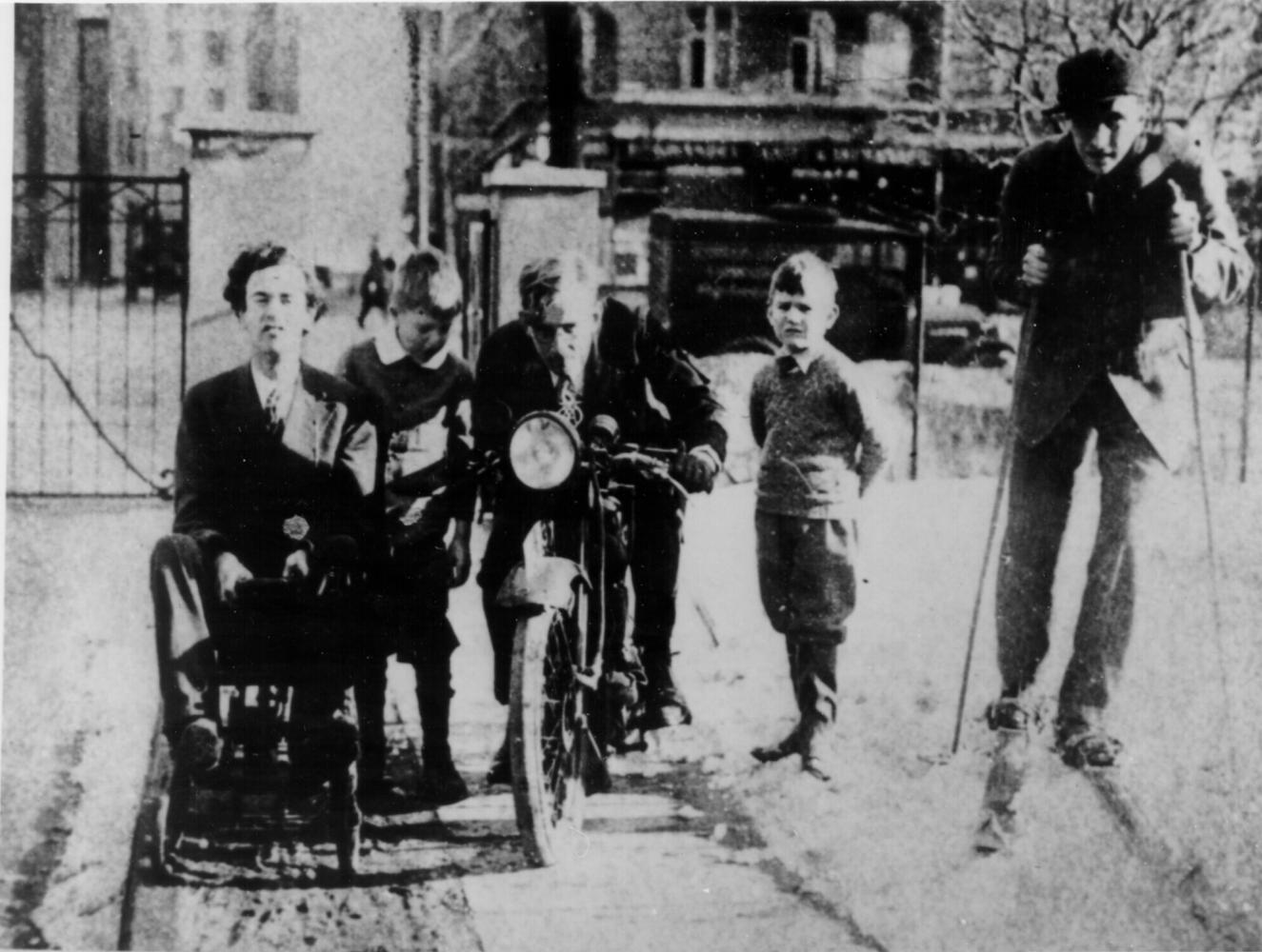


- On the Road to Santiago de Compostela



- On the Road to Lhasa

# On the Road to Copenhagen



# Meetings--1930 Front Row



# 1932 DISCUSSIONS

- QUANTUM MECHANICS DID NOT EXPLAIN THE BEHAVIOR OF THE ATOMIC NUCLEUS
- THERE WAS ALSO AN APPARENT VIOLATION OF ENERGY CONSERVATION

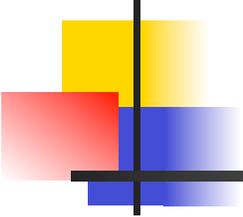
# Bohr proposes E non conservation in nucleus

- Dirac: *I should prefer to keep rigorous conservation at all costs*
- Pauli ( letter to Bohr): *Do you intend to mistreat the poor energy further?*
- Rutherford: *I have heard you are on the warpath and wanting to upset the Conservation of Energy. I will wait and see before expressing an opinion but I always feel “ there are more things in Heaven and Earth than are dreamt of in our philosophy”*

# Reasons for Proposal and Later Solutions to 4 Puzzles

---

- 1) Klein Paradox --apparent violation of unitarity (solution:positron existence- pair production possible)
- 2) Wrong Statistics in Nuclei--N-14 nucleus appeared to be bosonic--(solution: neutron not a proton-electron bound state)
- 3) Beta Ray Emission-apparent Energy non conservation (solution:neutrino)
- 4) Energy Generation in Stars (solution: nuclear forces, pep chain, carbon cycle etc.----pion)



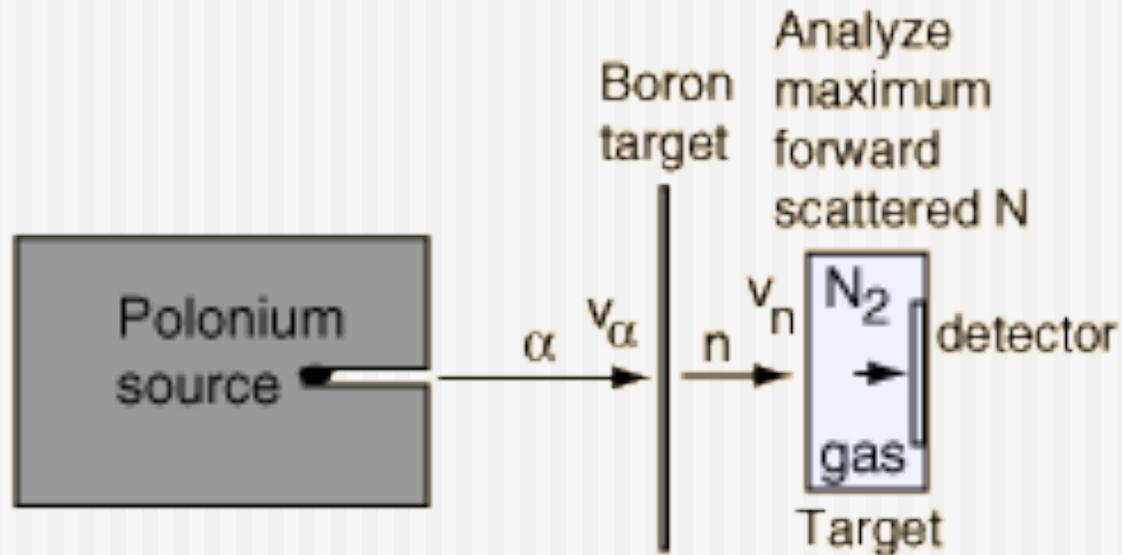
# 1932--Experiment comes to the rescue

---

- 1) Discovery of Neutron (beginning of nuclear physics)
- 2) First Nuclear Disintegration
- 3) First Cyclotron--the move to BIG physics
- 4) Discovery of anti- matter ( positive electron or positron)
- 5) Discovery of deuterium
- 6) Proton Magnetic Moment Measurement

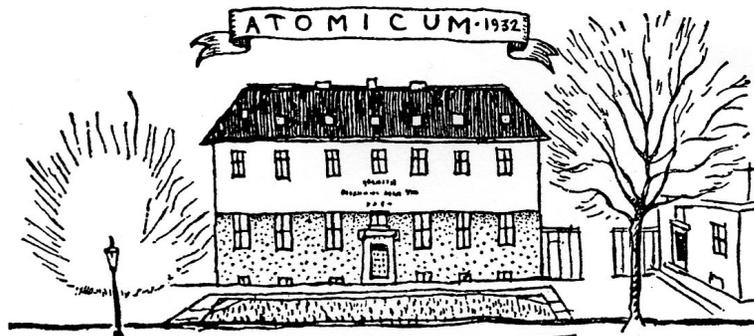
# Chadwick ( February 1932) discovery of n

---



# The 1932 Copenhagen Skit

- ✦ 1932 was 100th anniversary of Goethe's Death
- ✦ 1932 was 10th anniversary of Institute's Founding
- ✦ Skit was part of meeting ( young make fun of their elders--very much unlike Solvay
- ✦ 1932 skit was parody of Faust adapted to world of physics



# FAUST

E I N E   H I S T O R I E

MANUSCRIPT AFTER: J. W. von Goethe

PRODUCED BY: The Task Force of the  
"Institute for Theoretical Physics,"  
Copenhagen



*Motto:*

Not to criticize . . .

N. Bohr



Mephi : Pourquoi tout ce vacarme ? que demande Monsieur ? qu'a-t'il pour son service ?



# FIRST PART

## Faust's Study



Important tidings to foretell.

At heat of 10 to 7th power  
The gas degenerates in flame,  
Permitting us our shining hour  
Of freest flight in *Fermi's* name.<sup>5</sup>

#### THE THREE

This vision fills us with elation  
(Though none of us can understand).  
As on the Day of Publication  
The brilliant Works are strange and grand.

#### MEPHISTO

(*springing forward*)



Since you, O *Lord*, yourself have now seen fit  
To visit us and learn how each behaves,



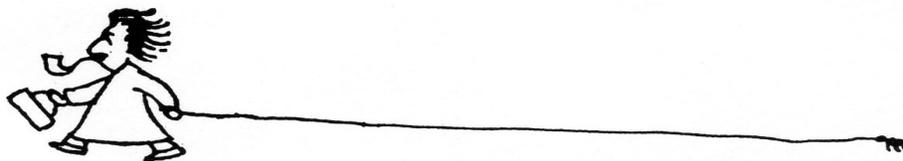
221

192

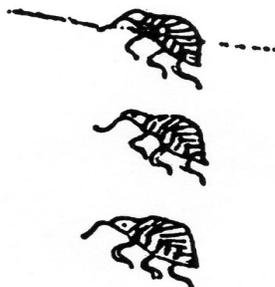
THIRTY YEARS THAT SHOOK PHYSICS

A *Monarch* cherished dearly  
A *Flea*, just as a son,<sup>19</sup>  
And quite as much—or nearly—  
As *Gra-vee-táy-shee-un*.

The *Monarch* summoned *Mayer*,<sup>20</sup>  
Said *Mayer*: “To be sure!  
I’ll make him tensors, *Sire*,<sup>21</sup>  
With junker curvature.”



Attired as a dandy,  
The *Flea* was then displayed.  
Folks ate him up like candy  
So sweetly was he made.



The *Flea* grew up, and later  
His *Son* was born. The son<sup>22</sup>  
Kept challenging his pater  
But never got to run.

131

36

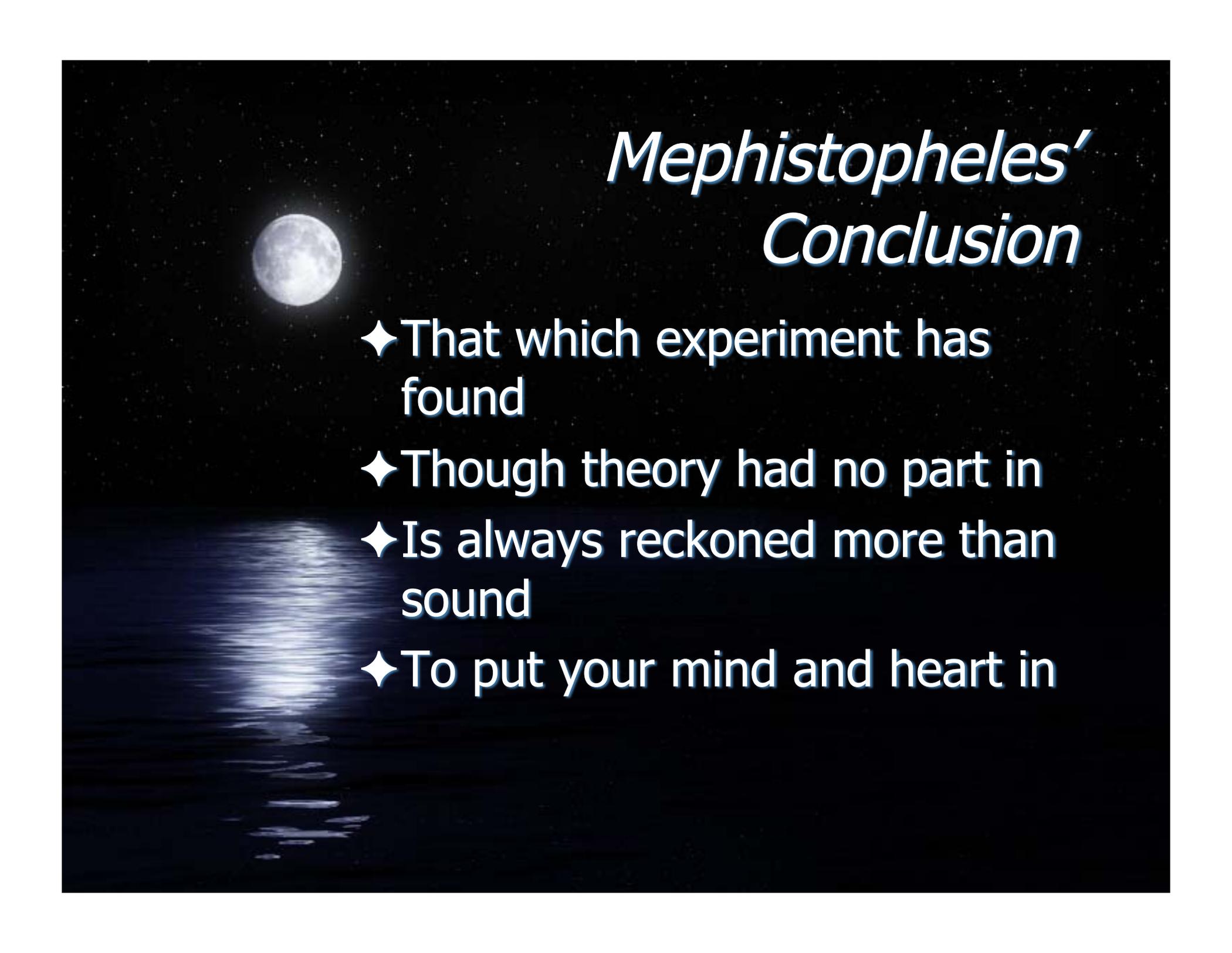
WAGNER<sup>41</sup>

*(appears, as the personification of the ideal experimentalist, balancing a black ball on his finger, and says, with pride)*



The *Neutron* has come to be.  
Loaded with Mass is he.  
Of Charge, forever free.  
Pauli, do you agree?



A full moon is visible in the upper left quadrant of a dark, starry sky. Below the moon, a body of water reflects the moon's light, creating a shimmering path that extends towards the bottom center of the frame. The overall scene is serene and atmospheric.

## *Mephistopheles' Conclusion*

- ◆ That which experiment has found
- ◆ Though theory had no part in
- ◆ Is always reckoned more than sound
- ◆ To put your mind and heart in

# OLD AGE

♦ *Old age is a cold fever, it's an ague that freezes, fancies that torment and plague . Once over thirty you're as good as dead.*

♦ Faust, Act II

♦ *Certainly old age is a cold fever that every physicist suffers with! When one is past thirty, he is as good as dead!*

♦ Skit

Um! Um-um! Um-um! Um-um!

THE LORD

Don't interrupt this colloquy!  
*I'll* do the talking. Dau, you see,  
The only proper rule of thumb  
Is

LANDAU

Um! Um-um! Um-um! Um-um!

*(At the other side of the stage, to the back, appears  
the face of GAMOW, through bars)*



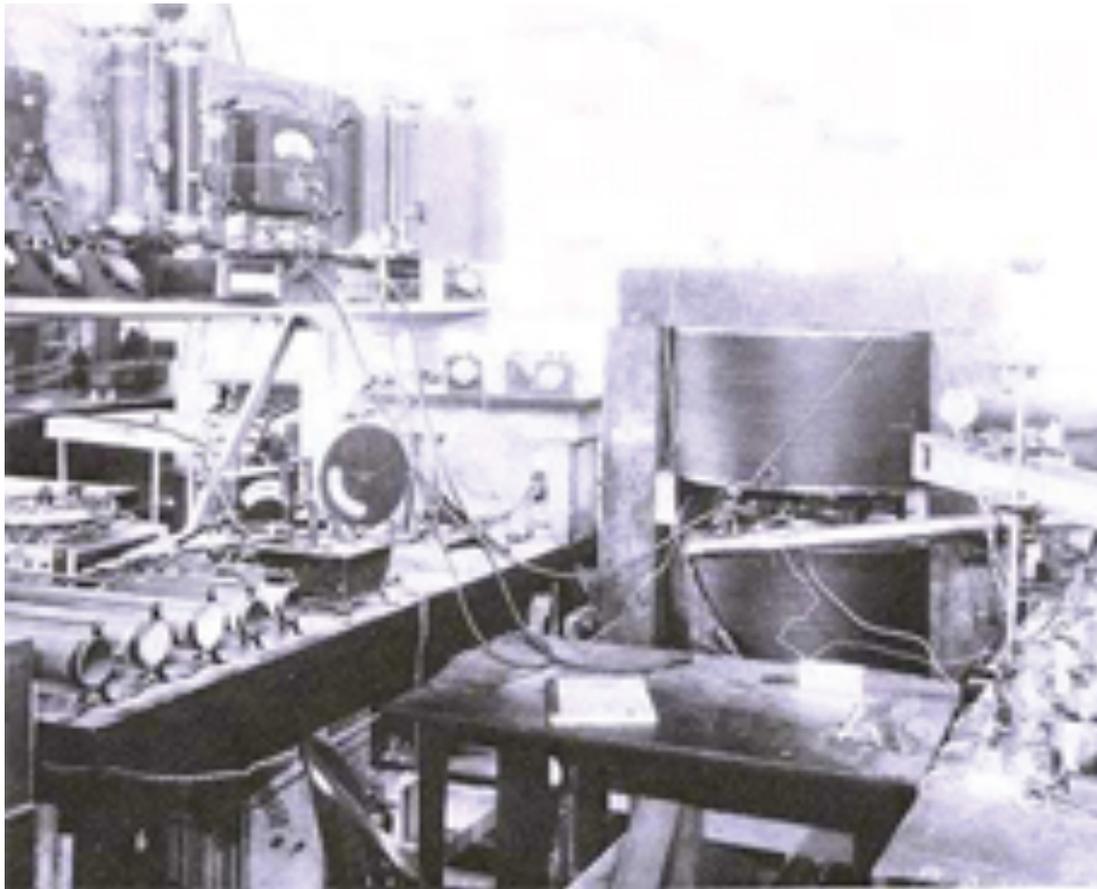
# Other 1932 discoveries

- ✦ 2) First Nuclear Disintegration
- ✦ 3) First Cyclotron--the move to BIG physics
- ✦ 4) Discovery of anti- matter (positive electron or positron)
- ✦ 5) Discovery of deuterium
- ✦ 6) Proton Magnetic Moment Measurement

# Anderson and his cloud chamber 1932

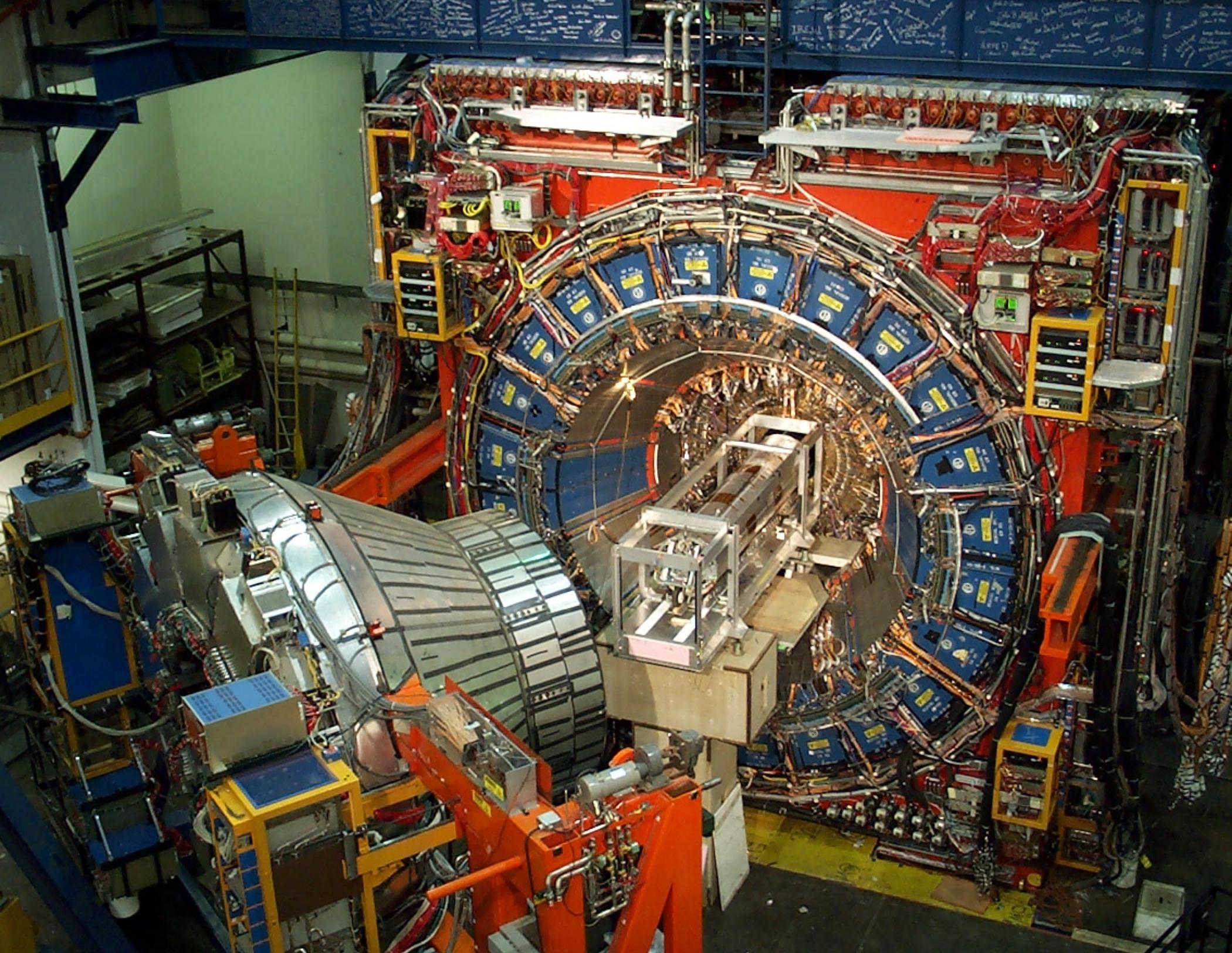


# Lawrence's Tabletop Cyclotron



# Cockroft Walton Accelerator (1932)







# Josef Stalin (man of steel) Iosif Dzughashvlii



ADOLF (SCHICKELGRUBER)  
HITLER



# ***Burning of Reichstag (February 1933)***



# Copenhagen 1933

