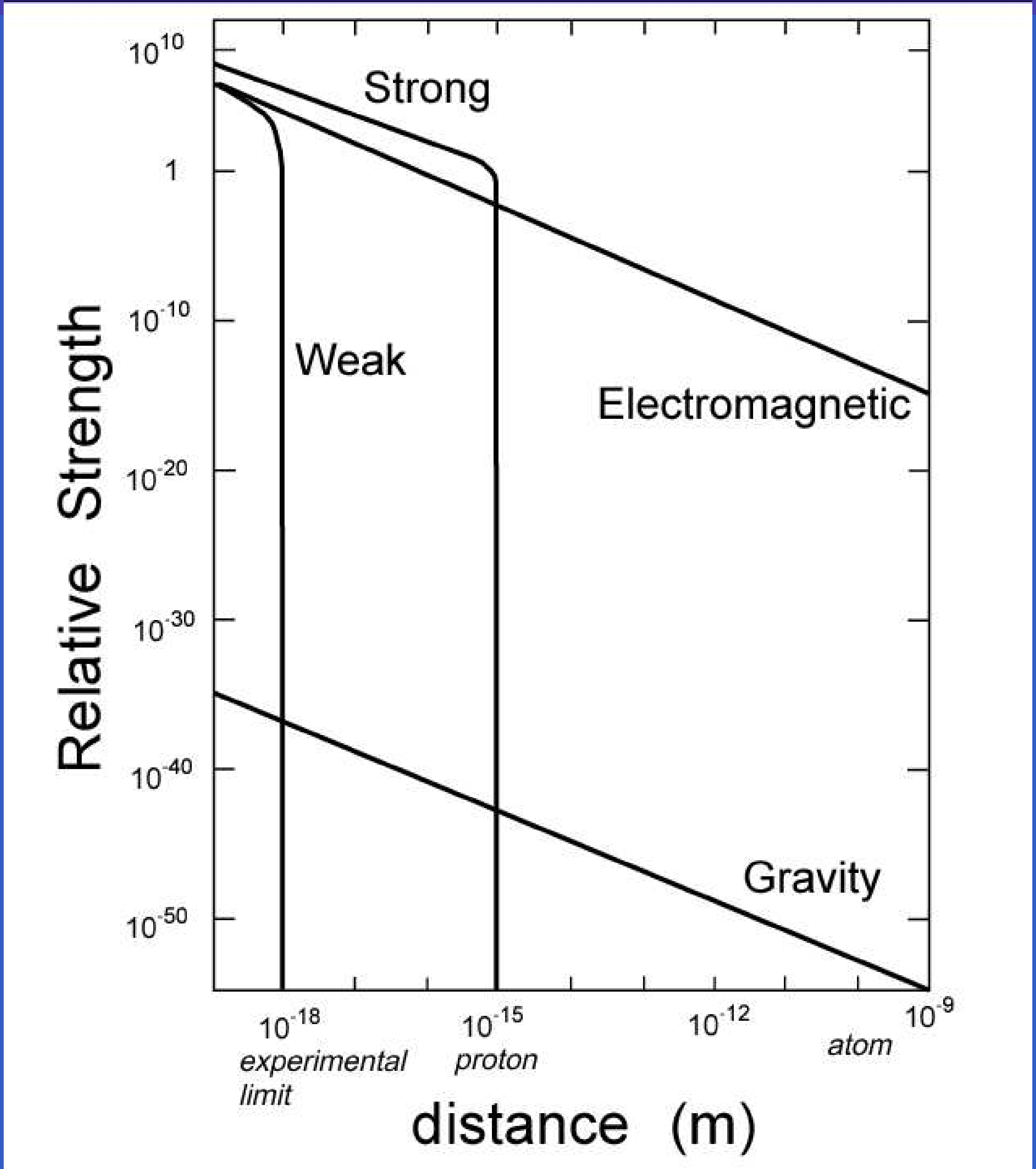
Institute for Theoretical and Experimental Physics, Moscow, 3 December 2003

The Quest for 10^{-20} Meters

James W. Rohlf

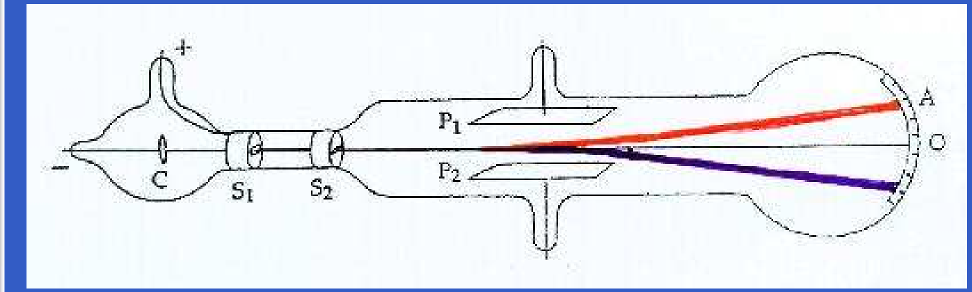
Boston University

ITEP **Forces and Distance**



ITEP Discovery of the electron 1897

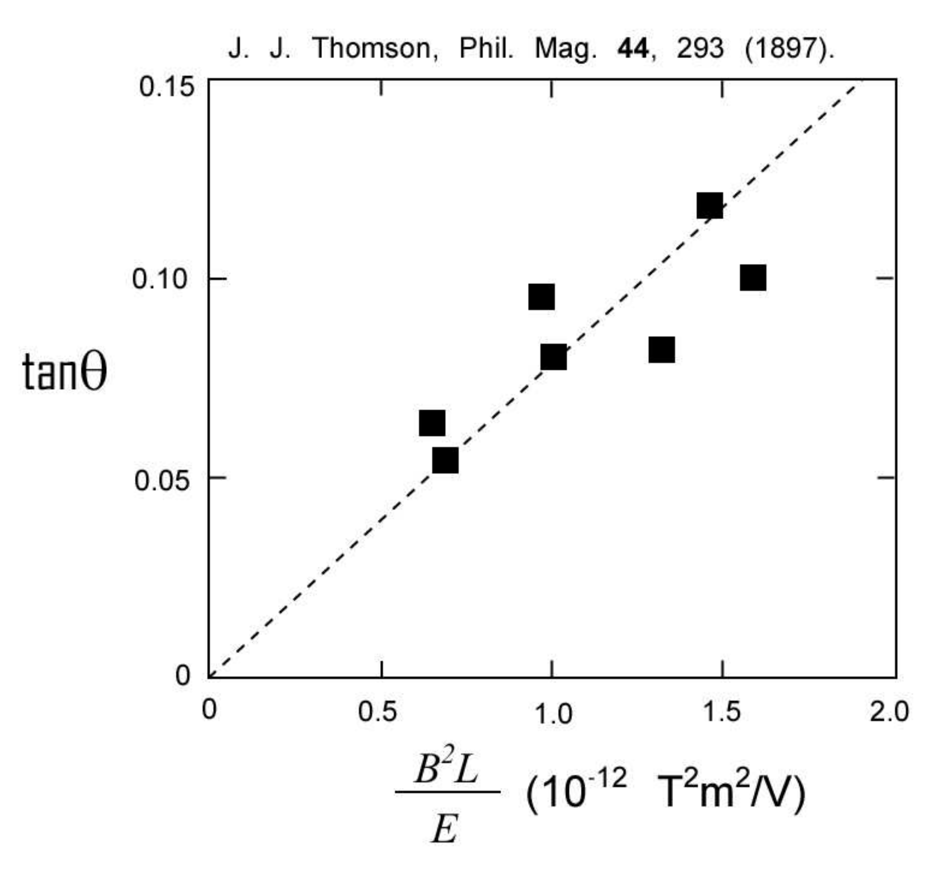
J. J. Thompson



...birth of the spectrometer!

Note: The charge to mass depends on the speed, which is hard to measure! The ingenuity of the experiment was to add a magnetic field to cancel the electric deflection.

ITEP Electron e/m J.J. Thomson



The electron gets acceleration

$$a = \frac{v_y}{t} = \frac{v_y v_x}{L} = \frac{v_x^2 \tan\theta}{L}$$

with B field on and no deflection,

$$v_x = \frac{E}{B}$$

$$\frac{e}{m} = \frac{a}{E} = \frac{E tan\theta}{LB^2}$$

E is field that produces deflection θ

B is field that produces no deflection.

ITEP Classical electron radius

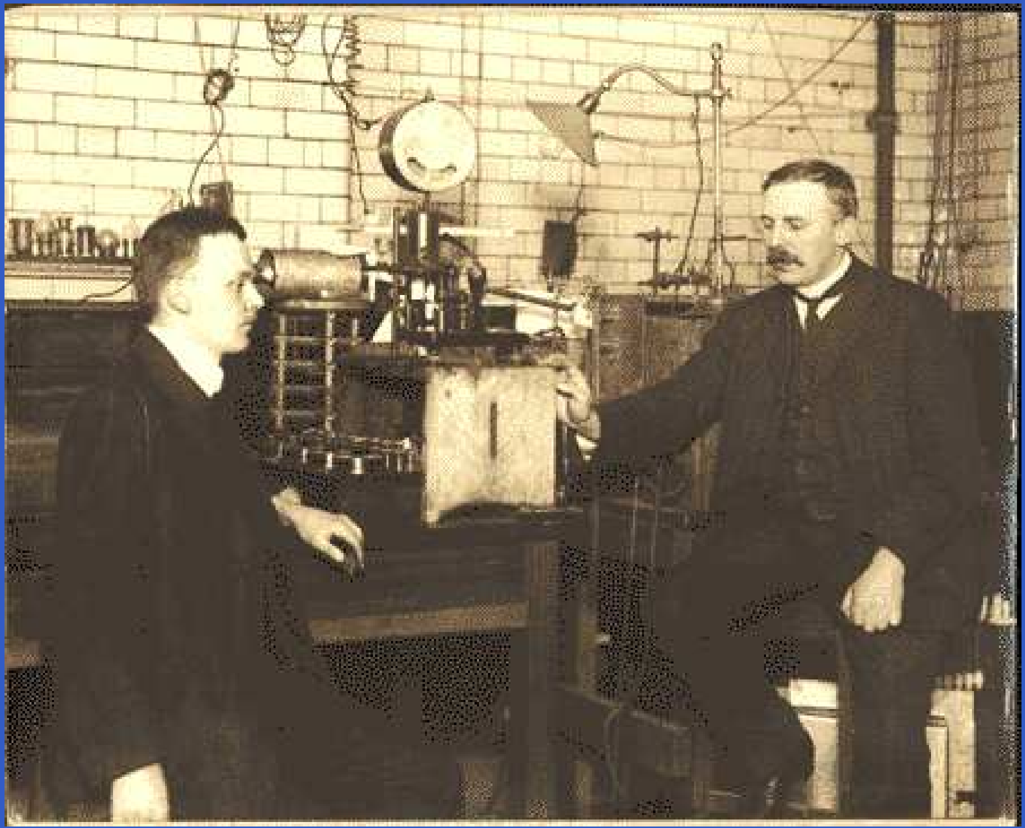
Big trouble at a distance where electrostatic potential energy exceeds electron mass energy:

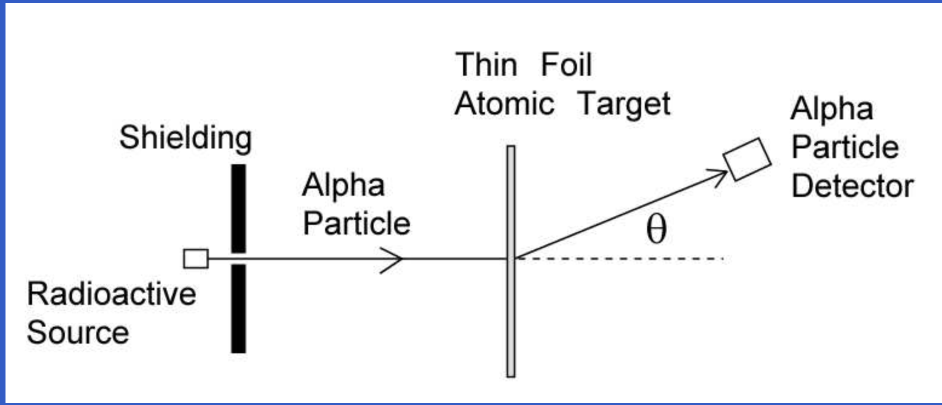
$$\frac{ke^2}{r} > mc^2$$

This occurs when

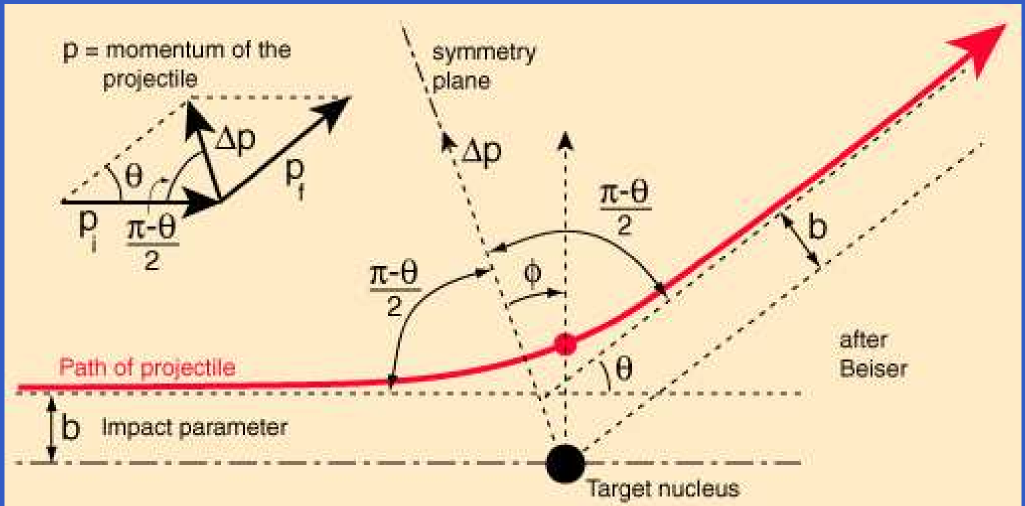
$$r < \frac{ke^2}{mc^2} = \frac{1.44\ \mathrm{eV\cdot nm}}{0.511\ \mathrm{MeV}} \simeq 3 \times 10^{-15}\ \mathrm{m}$$

ITEP Rutherford scattering 1909

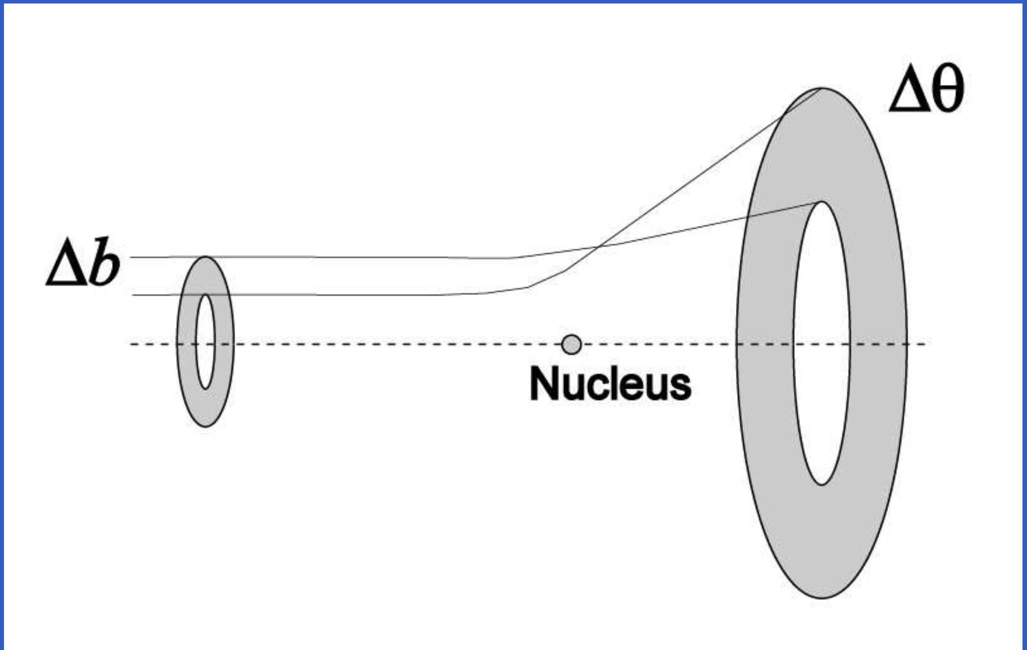


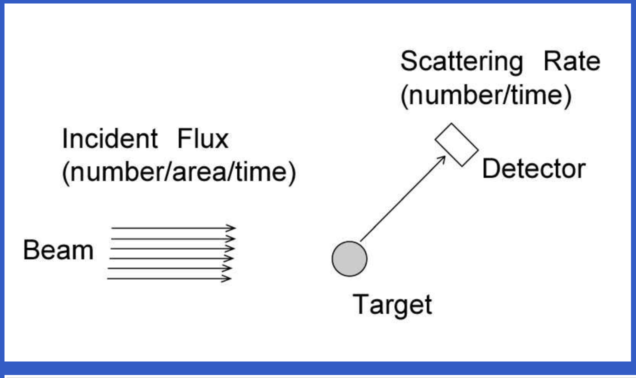


The detector consisted of a fluorescent screen and Hans Geiger looking through a microscope for light flashes. This experience is, no doubt, what motivated him to invent the Geiger counter!



ITEP Cross section definition





$$\sigma = \frac{\text{transition rate}}{\text{incident flux}}$$

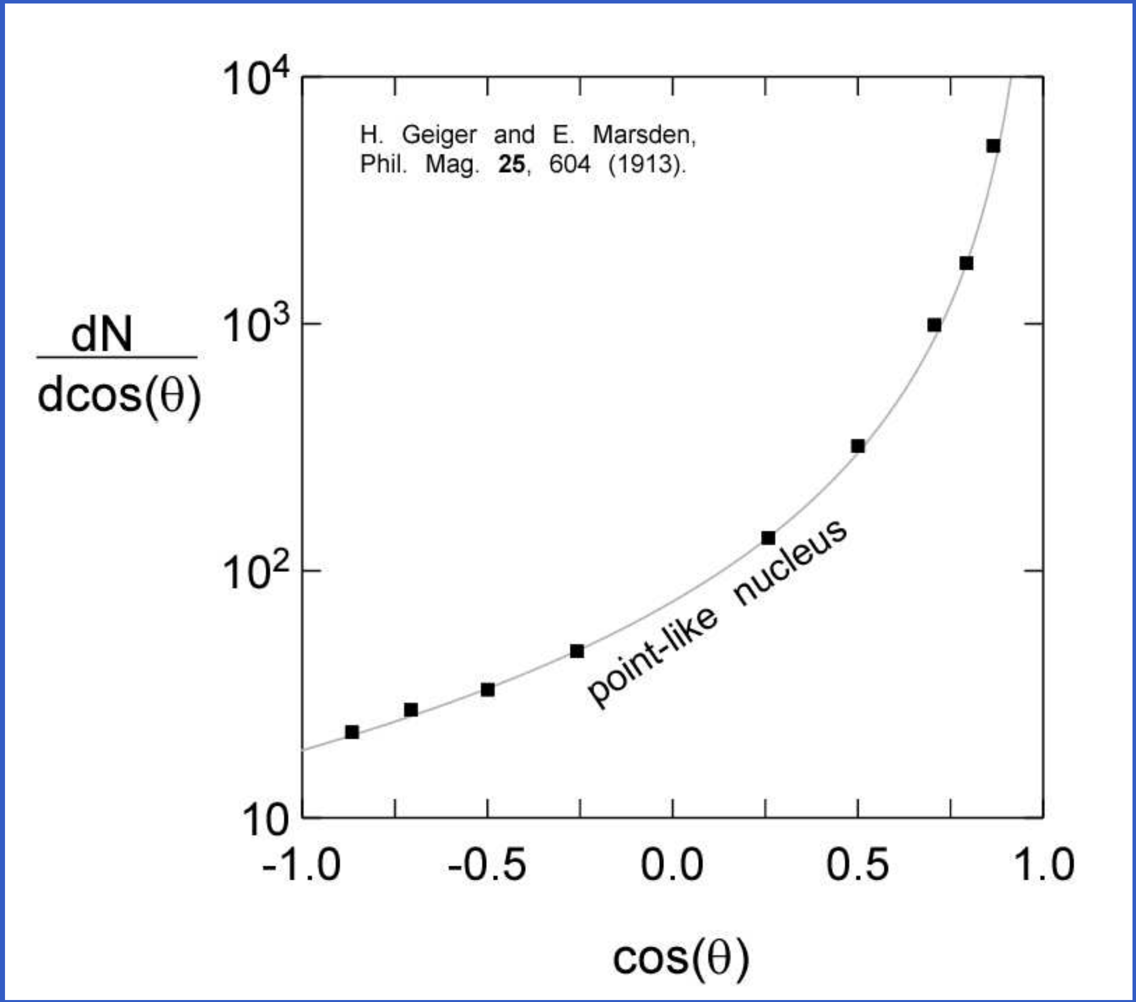
effective area of target

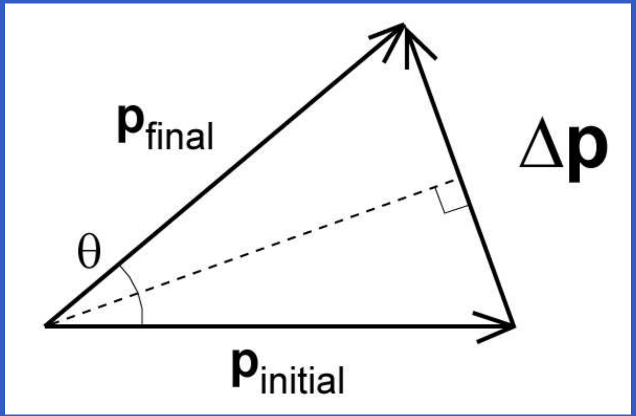
Examples:

nuclear	$\sim$ barn (b) = 10^{-28} m^2
pp (high energy)	$\sim$ 50 mb
W/Z^0 discovery at SPS	$\sim$ nb
rare processes at LHC	$\sim$ fb

ITEP Rutherford scattering

$$\frac{d\sigma}{d\cos\theta} \sim \alpha^2 \left(\frac{\hbar c}{E_\mathrm{k}}\right)^2 \frac{1}{(1-\cos\theta)^2}$$





$$(\Delta p)^2 = 2(mv)^2(1-\cos\theta)$$

$$d\sigma = 2\pi b db$$

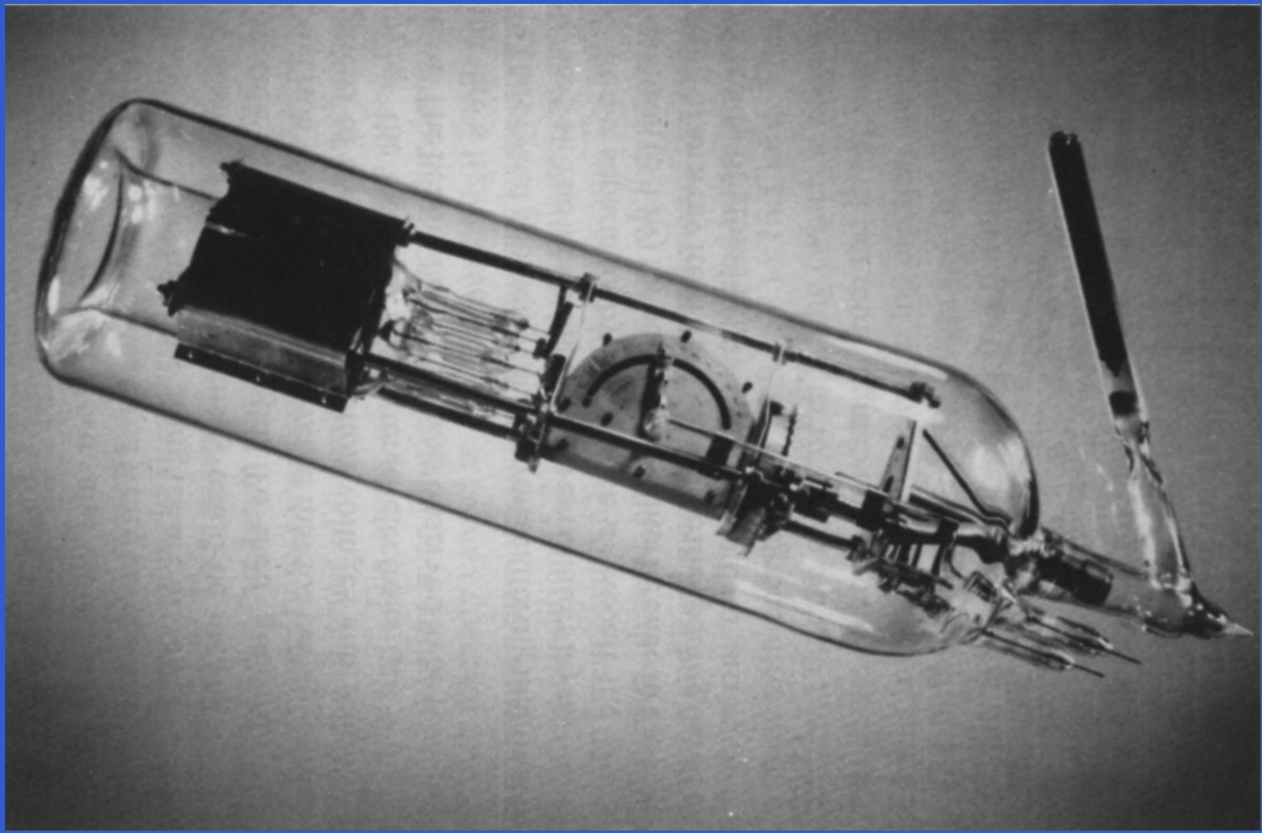
Can only happen if:

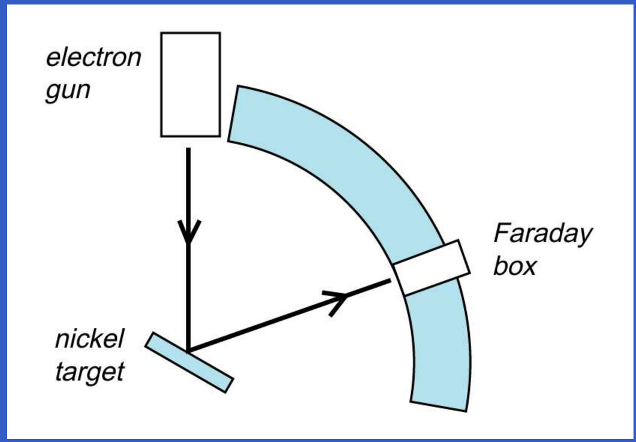
- force is $1/r^2$
- nucleus is pointlike
- J=1, m=0 photon

ITEP **Davisson-Germer** discovering electron waves

"We have become accustomed to think of the atom as rather like a solar system... There is a certain small probability, or at least there might seem to be, that the electron will strike into the atom in or near the surface of the metal, be swung about cometwise and sent flying out of the metal without loss of energy. The direction taken by such an electron as it leaves the metal should be a matter of private treaty between the electron and the individual atom. One does not see how neighboring atoms can have any voice in the matter."

ITEP Davisson-Germer discovering electron waves





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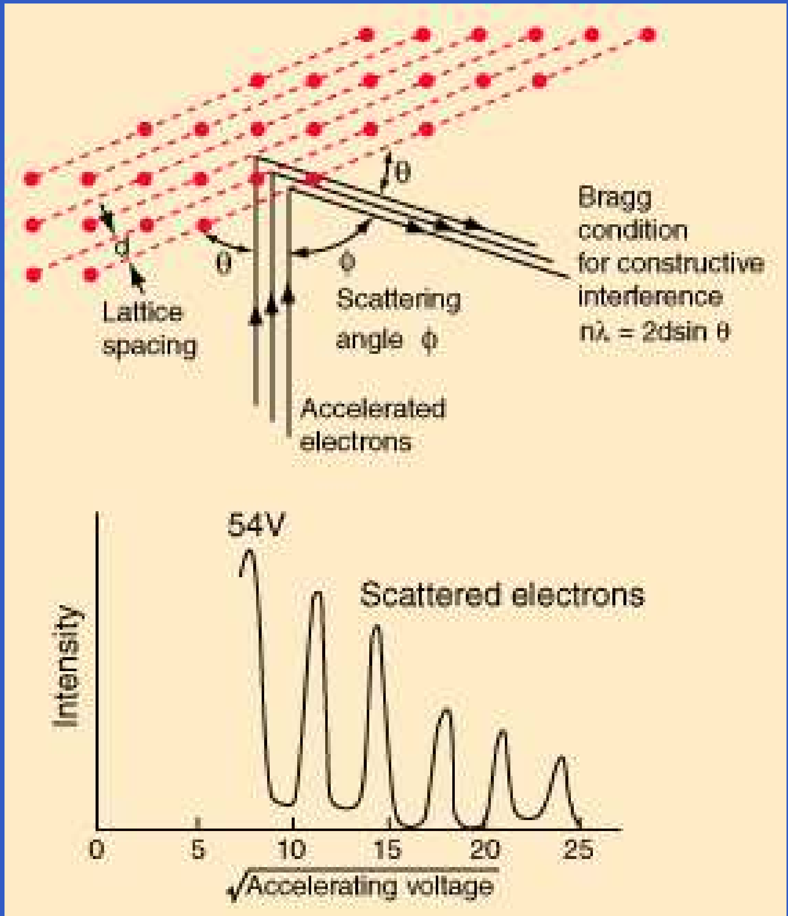
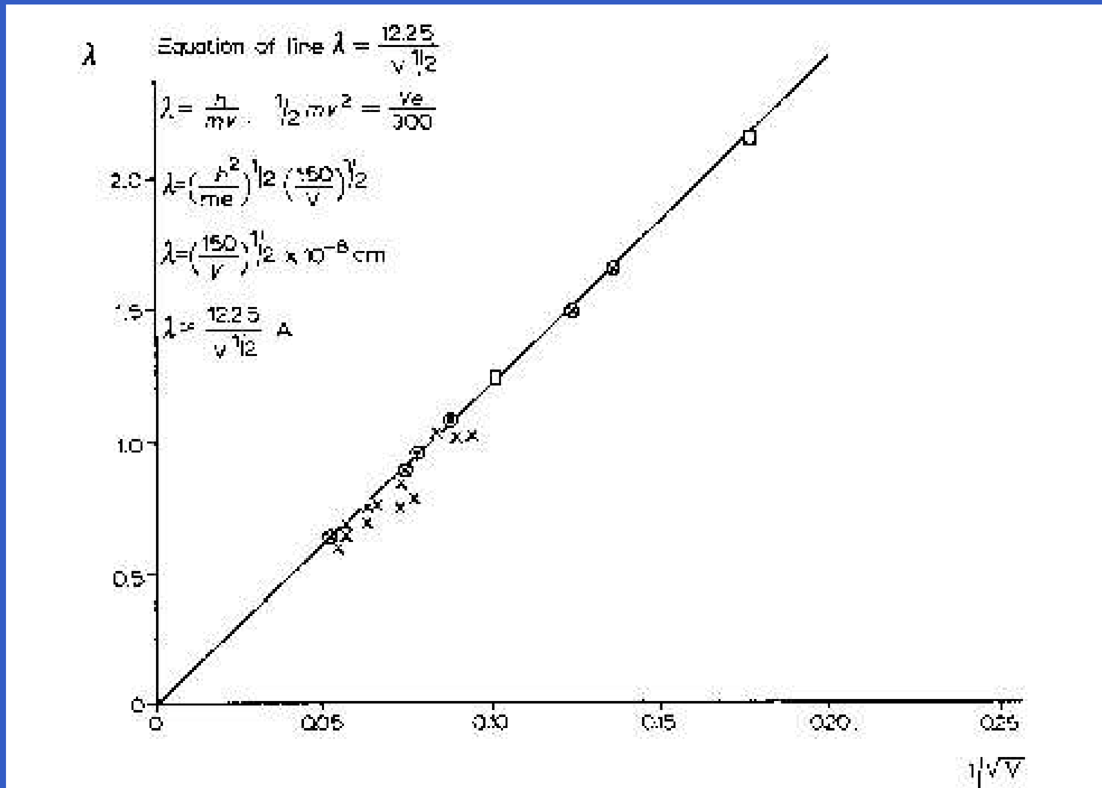




$$\lambda = \frac{h}{p} = \frac{hc}{\sqrt{2mc^2eV}} = \frac{1.23\ \mathrm{nm}\cdot\mathrm{V}^{1/2}}{\sqrt{V}}$$

ITEP Electron crisis solution

How to picture an atomic electron:
The electron is SLOW.

$$v \simeq \alpha c = \frac{c}{137}$$

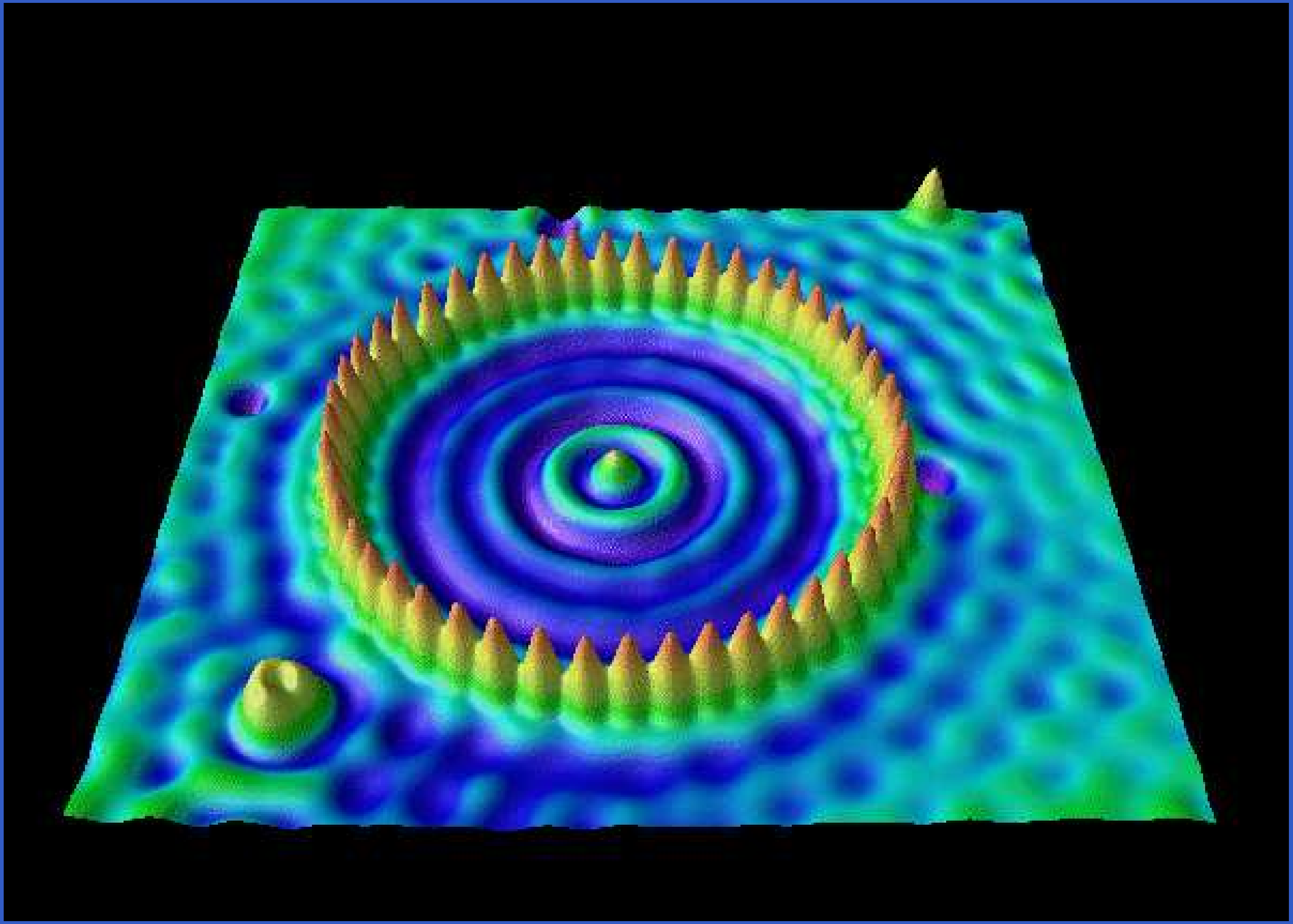
Slow means BIG thanks to *quantum mechanics!*
The electron has no structure at atomic scales, but it has a size given by its wavelength:

$$\lambda = \frac{h}{p}$$

$$\lambda = \frac{h}{p} = \frac{hc}{pc} = \frac{hc}{\alpha mc^2} \simeq \frac{1240 \text{ eV}\cdot\text{nm}}{(\frac{1}{137})(5.11 \times 10^{-5} \text{ eV})} \simeq 0.3 \text{ nm}$$

ITEP Electron waves iron atoms

scanning tunneling microscope



ITEP **Rutherford's α** wavelength

Rutherford's alpha particles had a kinetic energy of 5.5 MeV, corresponding to a momentum of

$$p \simeq \sqrt{2mE_{\rm k}}$$

The alpha particle wavelength is

$$\lambda \simeq \frac{h}{p} = \frac{hc}{\sqrt{2mc^2E_{\rm k}}} = \frac{1240\ \mathrm{eV{\cdot}nm}}{\sqrt{(2)(3730\ \mathrm{MeV})(5.5\ \mathrm{MeV})}} \simeq 6\ \mathrm{fm}$$

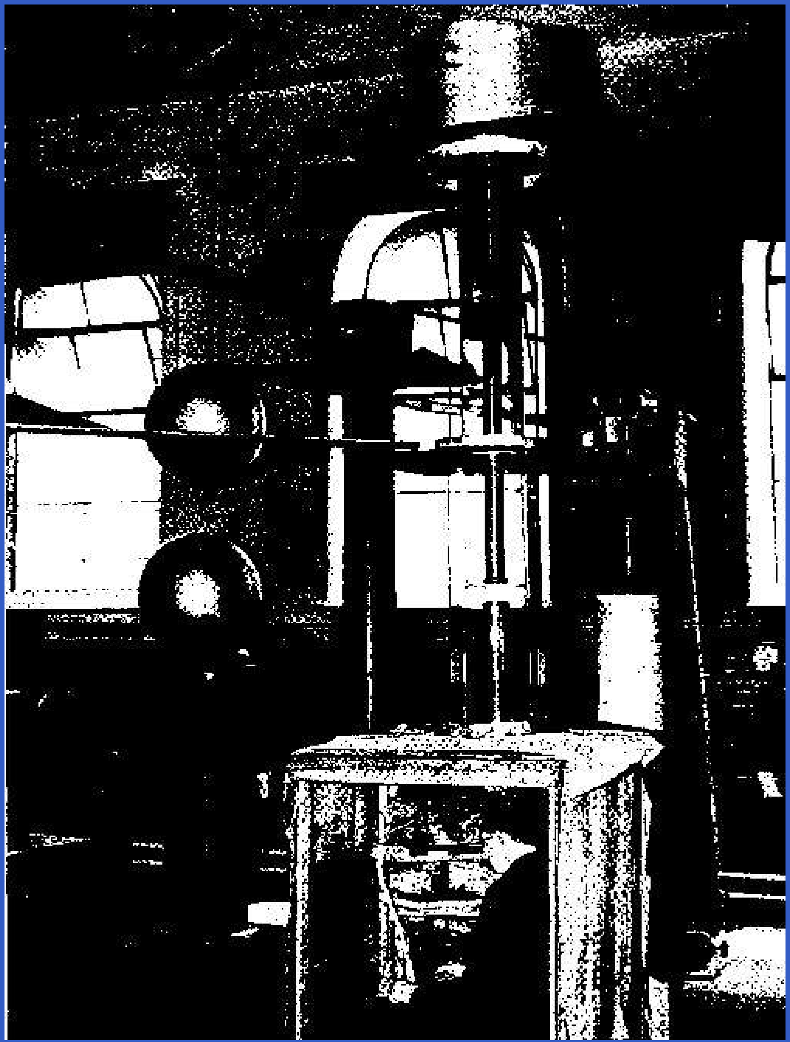
The size of the alpha corresponds to the resolution limit obtainable using it as a probe,

$$r \sim \frac{\hbar}{p} = \frac{\lambda}{2\pi} \simeq 1\ \mathrm{fm}$$

Luckily, the alpha particles of Rutherford were up to the task because they originated from nuclei.

ITEP **Cracking the nucleus** p + ^{7}Li $\rightarrow \alpha + \alpha$

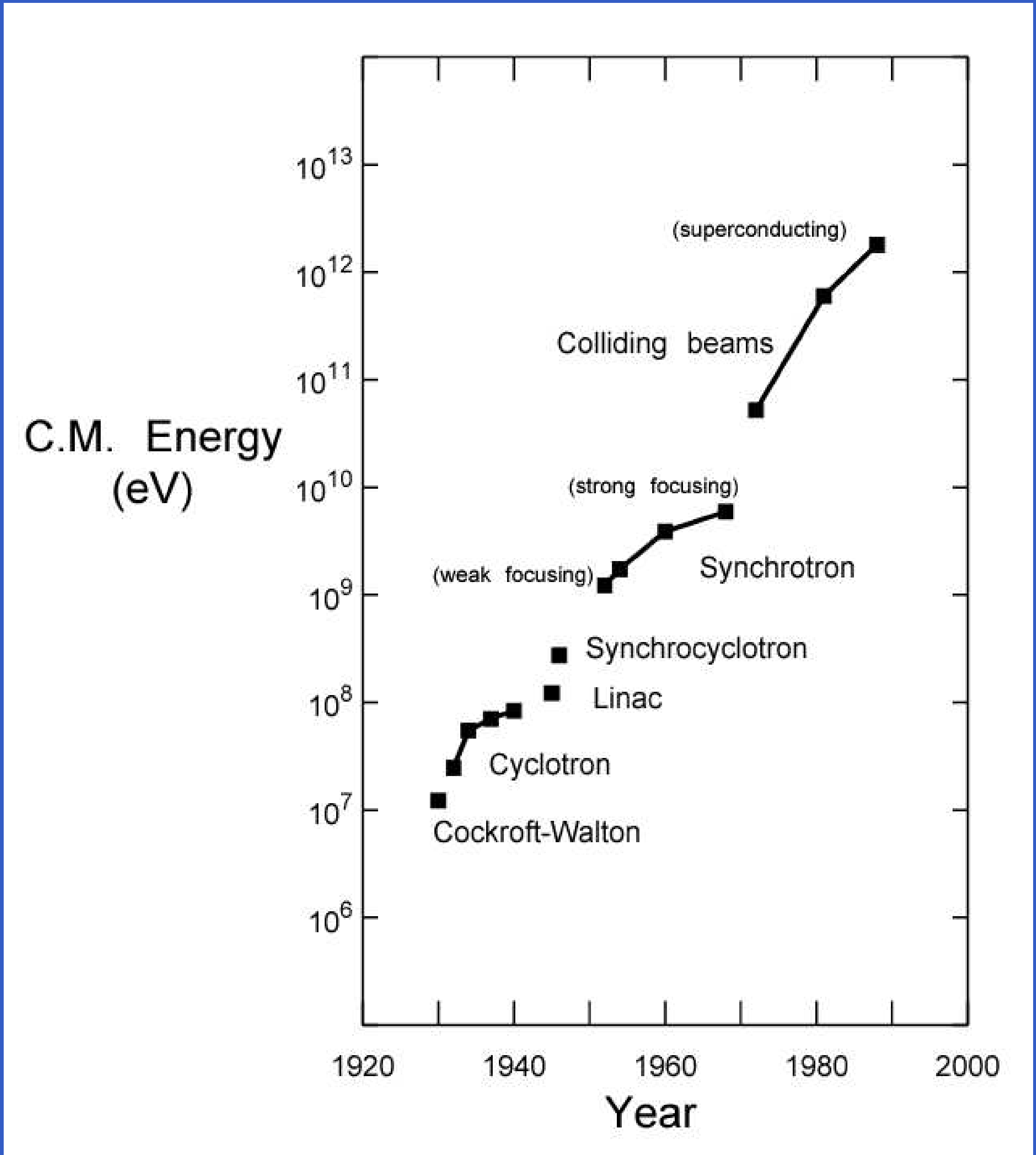
Cockroft and Walton, 1932



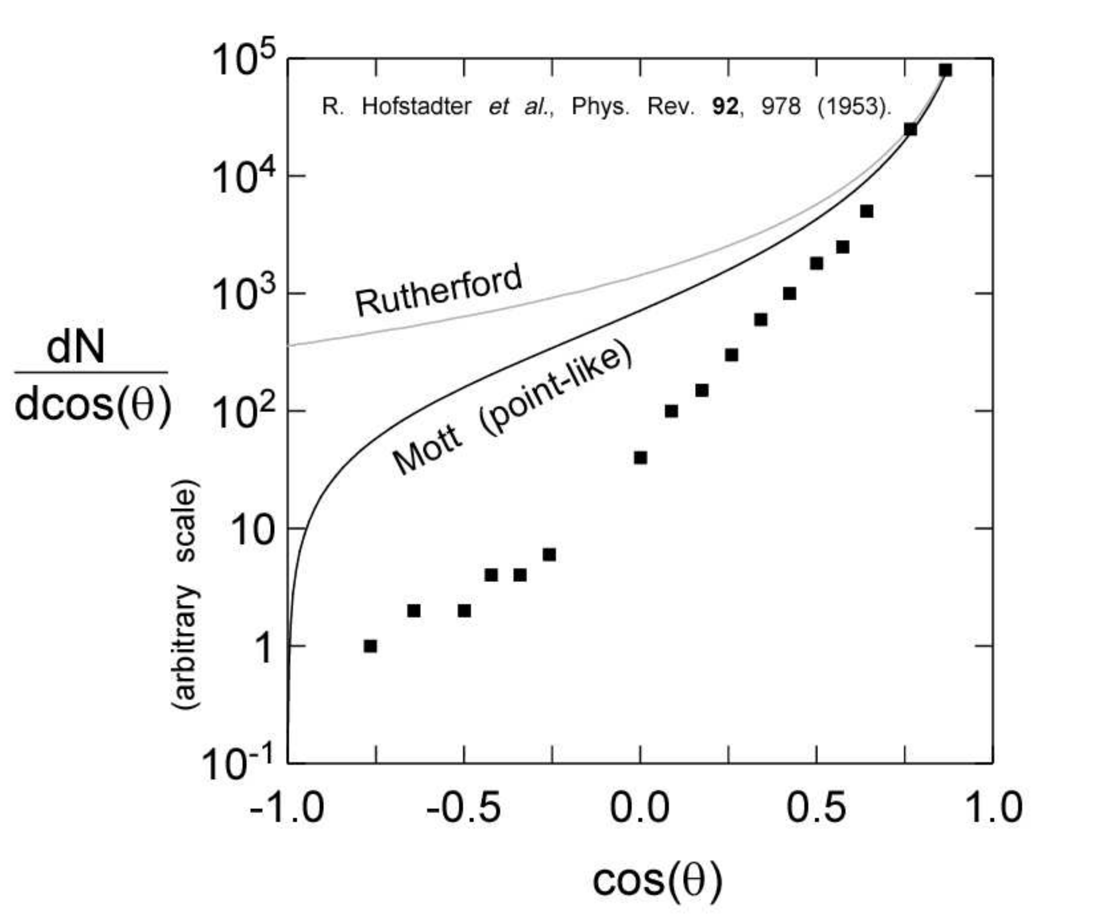
"Almost at once at an energy of 125 kilovolts, Dr. Walton saw the bright scintillations characteristic of α particles... We then confirmed by a primitive coincidence experiment carried out with two zinc sulphide screens and two observers tapping keys, that the α particles were emitted in pairs. Our resolving time was asecond or so- somewhat longer than the resolving time of modern coincidence circuits which operate in units of millimicroseconds."

J. D. Cockroft, Nobel Lecture (1951)

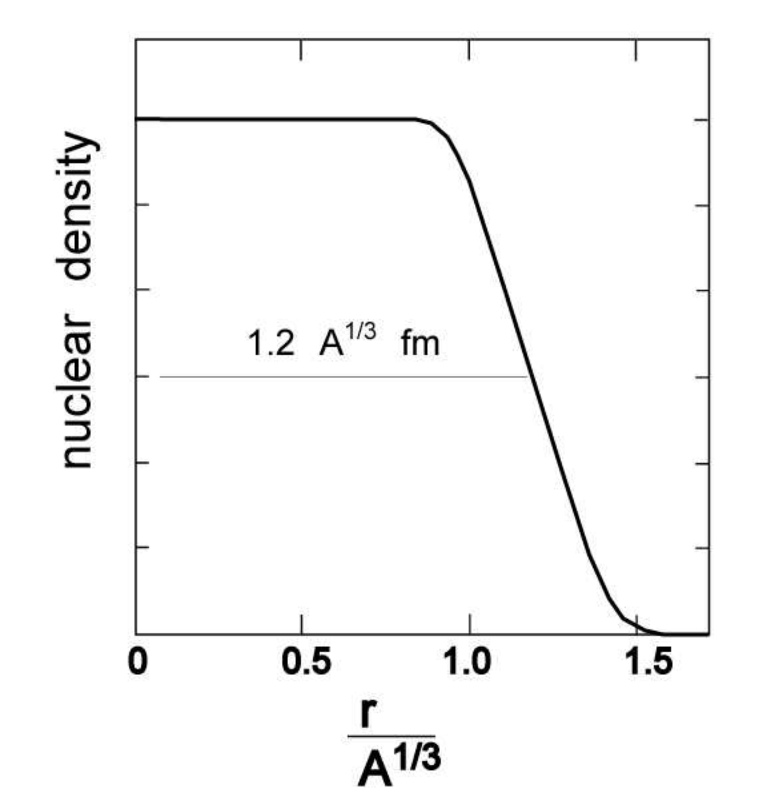
ITEP **Livingston plot** accelerator technology



ITEP Inside the nucleus eN → eN



125 MeV electrons + gold



$$\left[\frac{d\sigma}{d\cos\theta}\right]_{\mathrm{Mott}} = \left[\frac{d\sigma}{d\cos\theta}\right]_{\mathrm{R}} \frac{1+\cos\theta}{2[1+(1-\cos\theta)E_{\mathrm{k}}/Mc^2]}$$

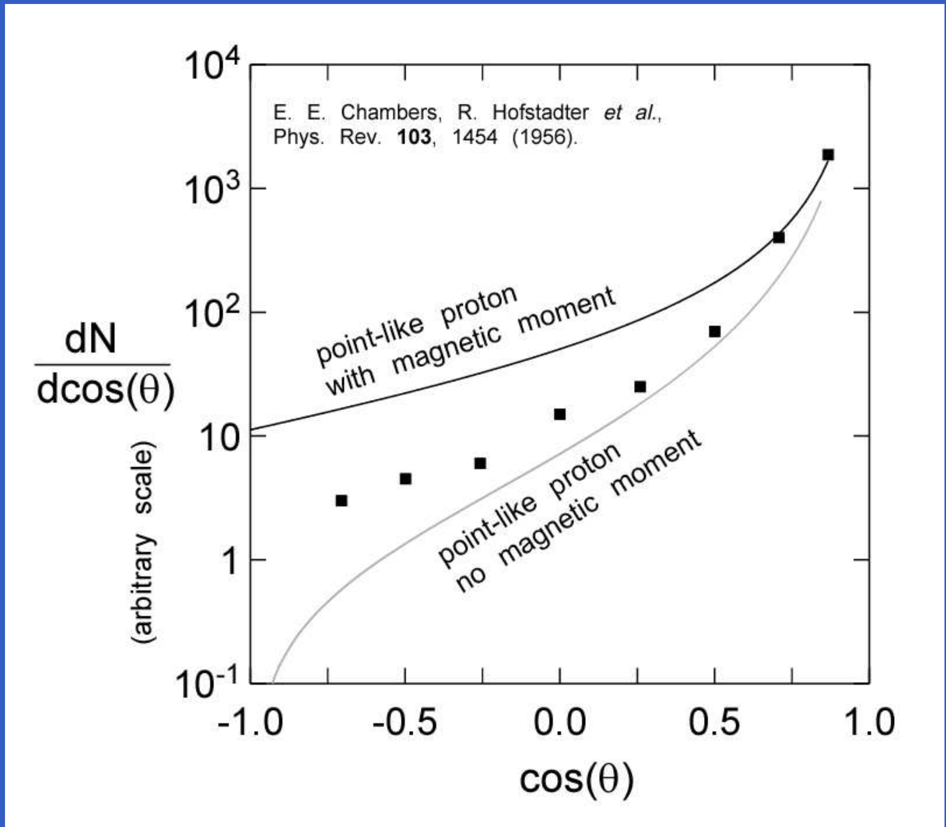
Pointlike cross section is modified by electron magnetic moment and nuclear recoil.

"I was more thrilled by seeing the structure in the alpha particle than by almost anything else, because Rutherford used the alpha particle in figuring out the scheme of construction of the atom."

Robert Hofstadter

$$\alpha \rightarrow \mathrm{p} \rightarrow \mathrm{q} \rightarrow ?$$

Inside the proton ep → ep



550 MeV electrons

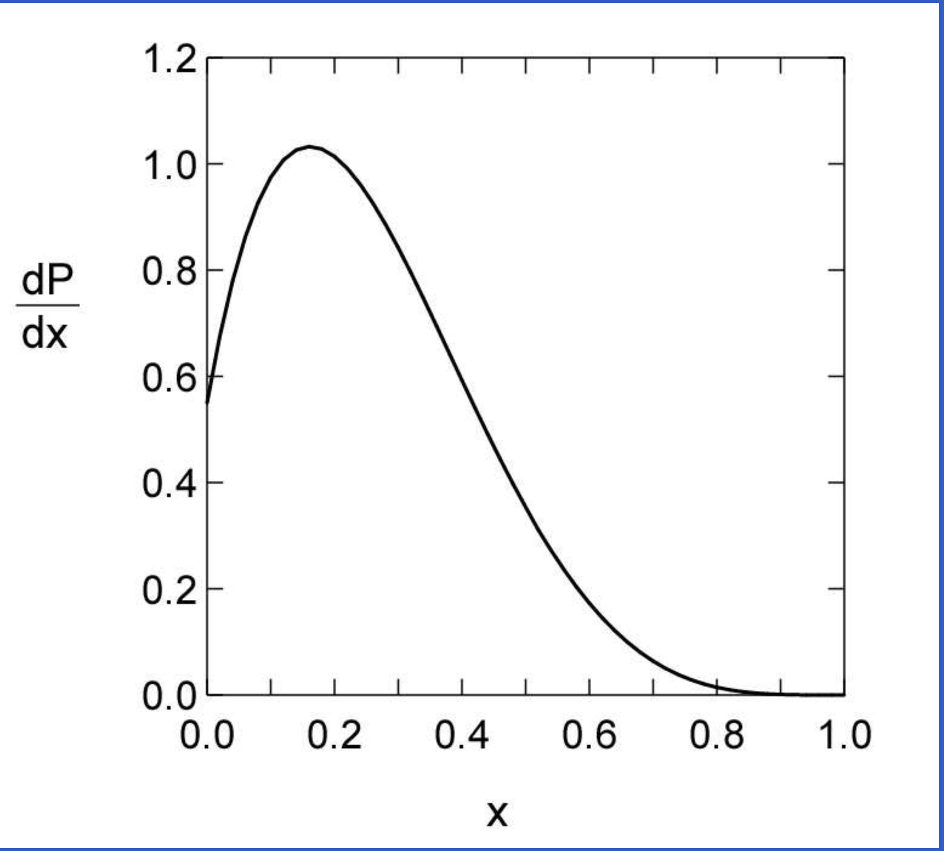
$$\left[\frac{d\sigma}{d\cos\theta}\right]_{\text{proton}} = \left[\frac{d\sigma}{d\cos\theta}\right]_{\text{Mott}} \left|F(\theta)\right|^2$$

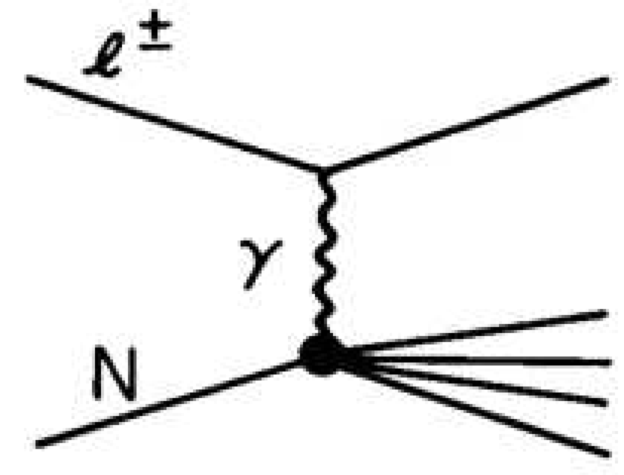
The function F is called the form factor; it contains the information on how the charge distribution inside the proton differs from a "point."

ITEP Deep inelastic $ep \to e + X$

10 GeV electrons

End Station A at SLAC





Kendall/Friedman/Taylor

"I am more sure of the conclusions than of any single argument which suggested them to me for they have an internal consistency which surprises me and exceeds the consistency of my deductive arguments which hinted at their existence."

Richard Feynman, “Very High Energy Collisions of Hadrons,” *Phys. Rev. Lett.* **24**, 1415 (1969)

Feynman x momentum fraction

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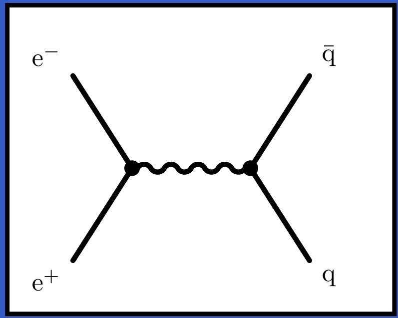
Sound confusing? Things were a mess!

ITEP **Predicting R** London conference (July 1974)

$$R = \frac{\sigma_{e^+e^- \to \mathrm{hadrons}}}{\sigma_{e^+e^- \to \mu^+\mu^-}} = \Sigma q_i^2$$

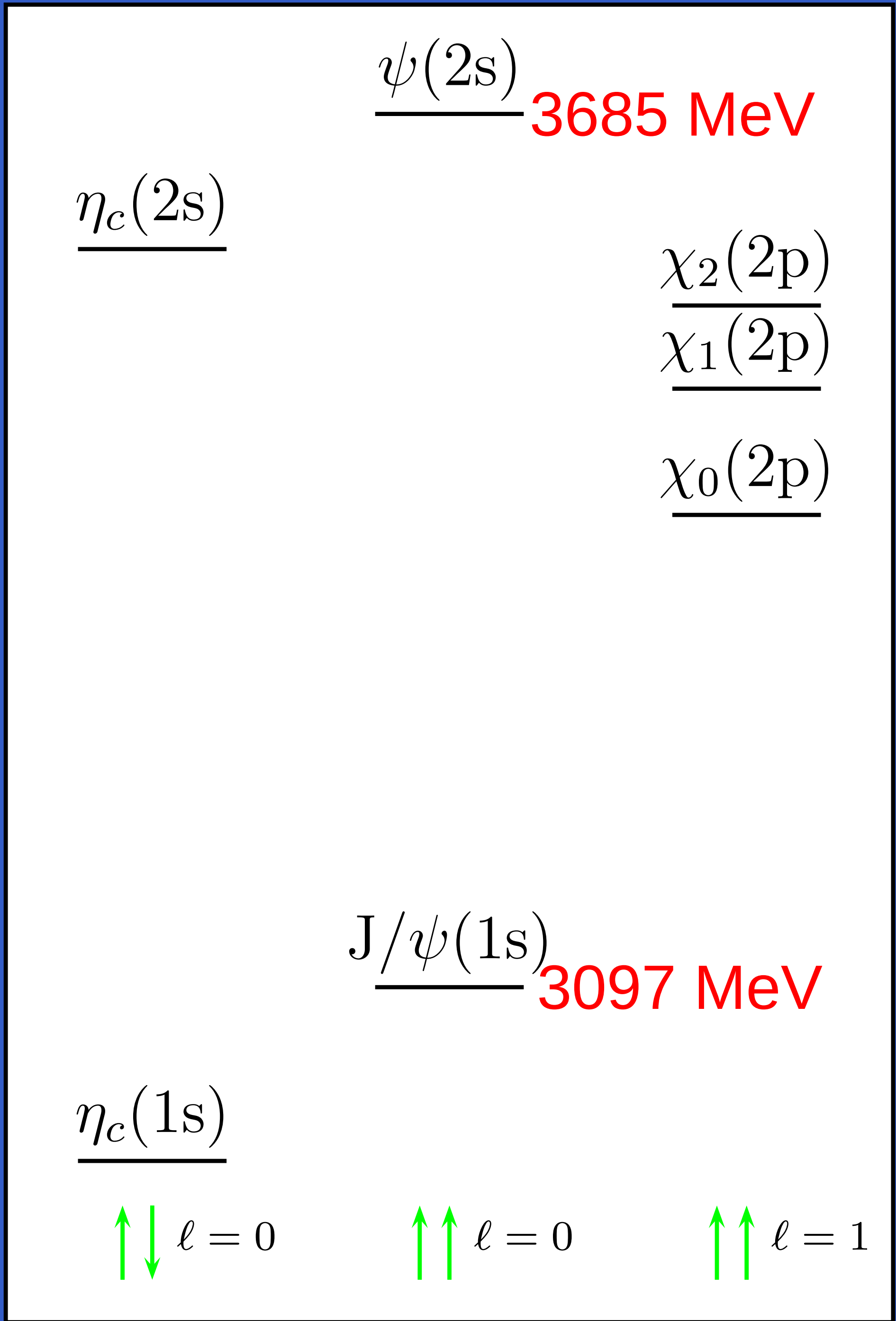


0.36	Bethe-Salpeter bound quarks
2/3	Gell-Mann Zweig quarks
0.69	vector meson dominance I
1	composite quarks
10/9	Gell-Mann Zweig with charm
2	colored quarks
2.5-3	vector meson dominance II
2-5	vector meson dominance III
3 1/3	colored charmed quarks
4	Han-Nambu quarks
5.7	trace anomaly

6	Han-Nambu with charm
6.69 - 7.77	Broken scale invariance
8	Tati quarks
8	trace anomaly II
9	gravitational cut-off
9	broken scale invariance
16	$SU_{12} \times SU_2$
35 1/3	rm $SU_{16} \times SU_1 6$
5000	high-Z quarks
70,383	Schwinger's quarks
∞	∞ partons

Reported by John Ellis

ITEP **Charm** believing in quarks and QCD



November Revolution (1974)

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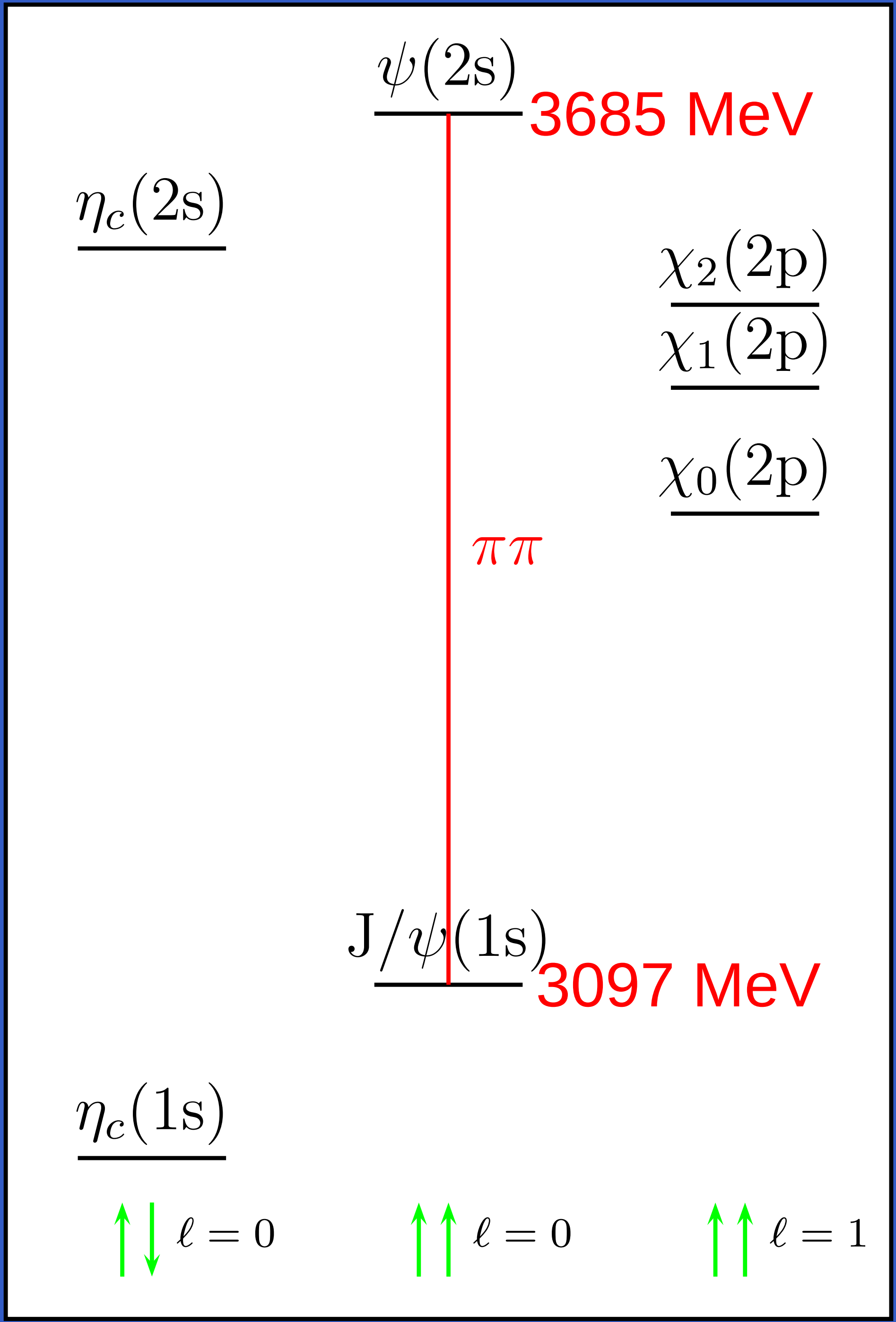

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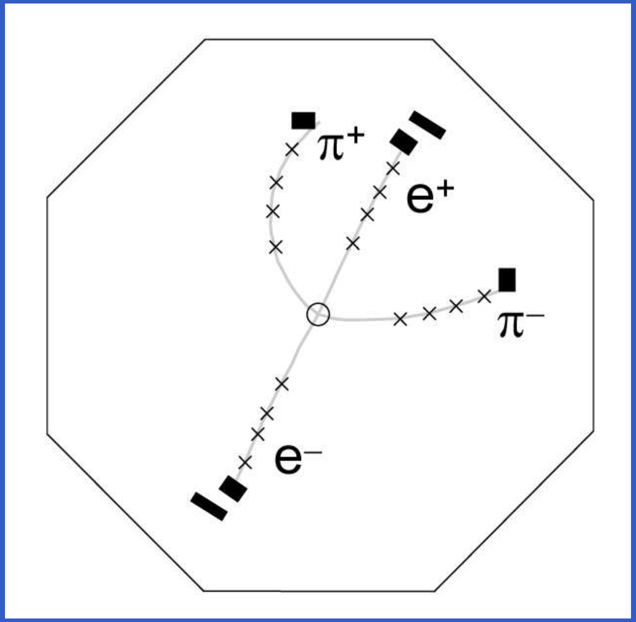
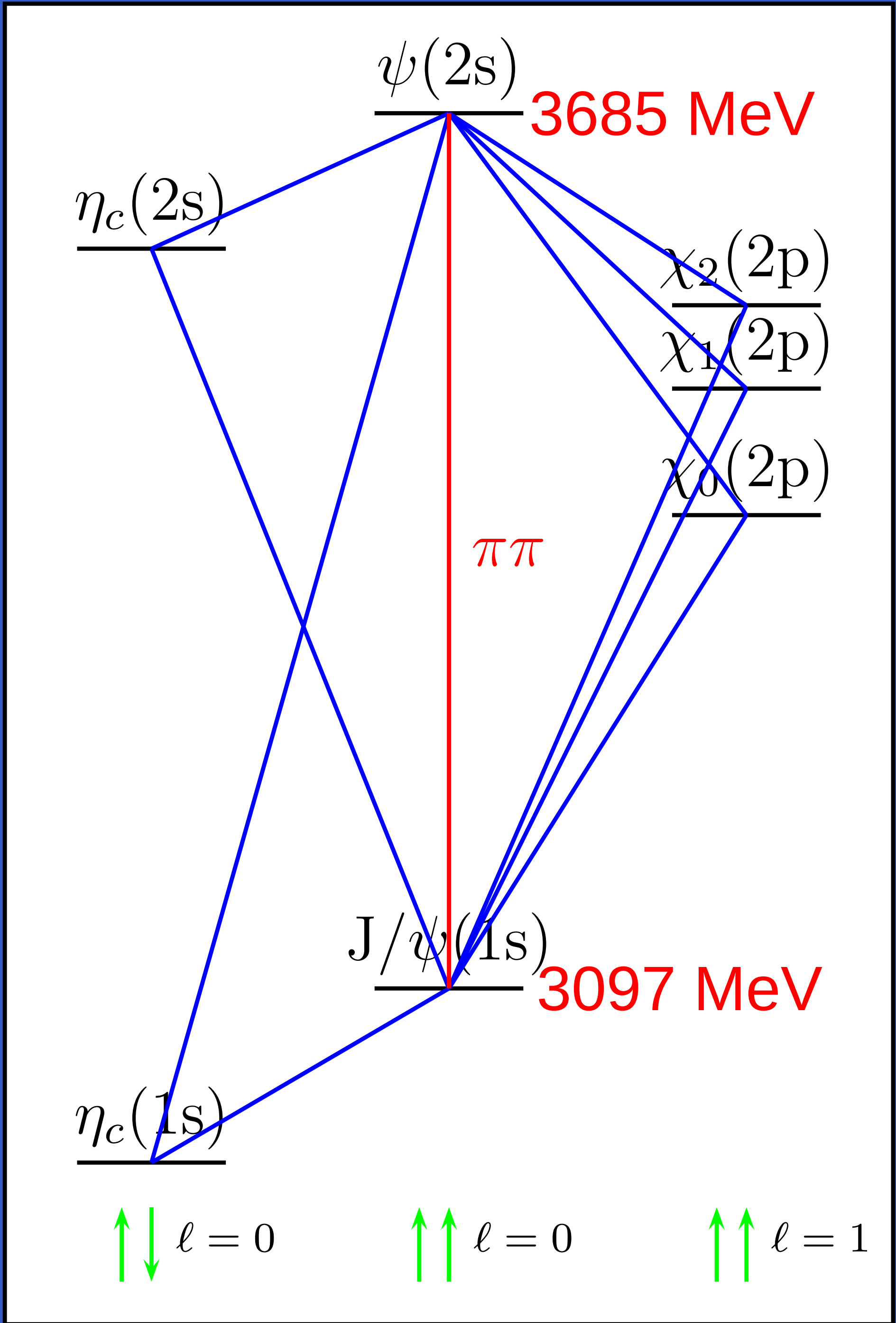


believing in quarks and QCD



November Revolution (1974)

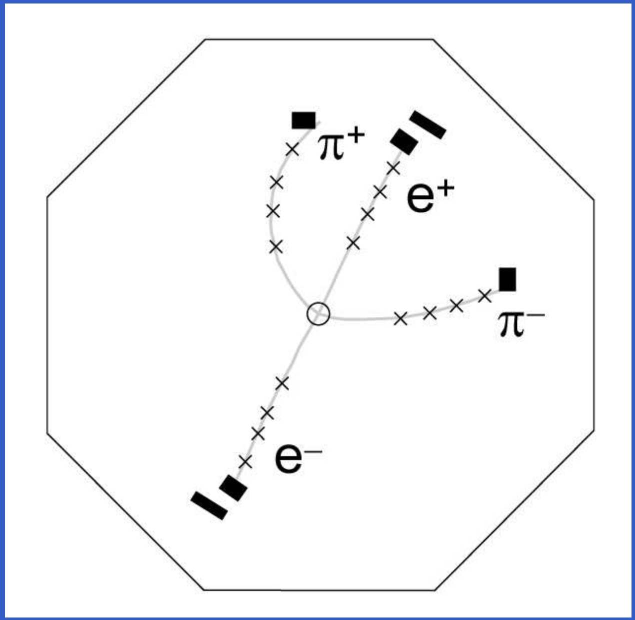
Charmonium:

Quantum mechanics of two spin 1/2 particles.

$$\vec{s} = 1/2 \oplus 1/2$$

$$\vec{j} = \vec{\ell} \oplus \vec{s}$$

n = radial QN.



ITEP **Strong interaction** potential

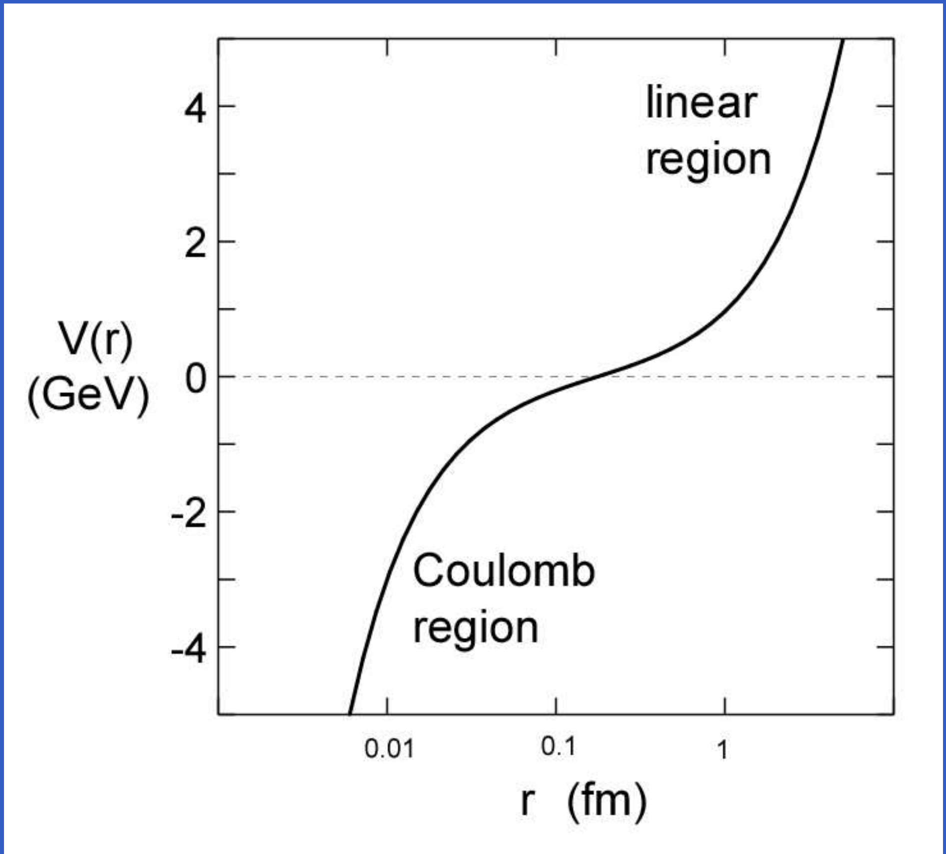
Speed of the quarks:

$$\lambda \simeq 2 \text{ fm}$$

$$pc = \frac{hc}{\lambda} = \frac{1.24 \text{ Gev}\cdot\text{fm}}{2 \text{ fm}} = 0.6 \text{ GeV}$$

$$E = \sqrt{(mc^2)^2 + (pc)^2} = \sqrt{(1.5 \text{ Gev})^2 + (0.6 \text{ GeV})^2} = 1.6 \text{ GeV}$$

$$v/c = \frac{pc}{E} = \frac{0.6 \text{ GeV}}{1.6 \text{ GeV}} \simeq 0.4$$

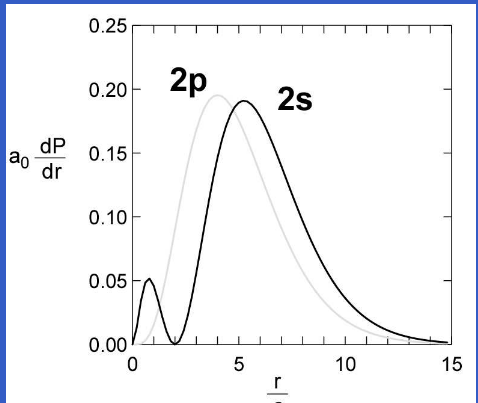


Potential:

$$V = -\frac{\kappa_1}{r} + \kappa_2 r$$

$$\kappa_1 \simeq 0.05 \text{ GeV} \cdot \text{fm}$$

$$\kappa_2 \simeq 1 \text{ GeV/fm}$$



hydrogen

my first publication

Observation of the production of jets of particles at high transverse momentum and comparison with inclusive single particle reactions,
Mar 1977. Phys. Rev. Lett. **38**, 1447 (1977)

my thesis

Experimental tests of quantum chromodynamics in high p_T jet production in 200 GeV/c hadron-proton collisions,
May 1979. Phys. Rev. Lett. **43**, 565 (1979).

ITEP The next step

"An even more fundamental set of questions which I find more interesting than the number of quarks... have to do with the possiblility of a unified picture of forces in nature... Weinberg and Salam have made the first models of a unified weak and electromagnetic interaction theory... The experimental information required to establish these unified pictures will almost certainly require still higher energies: several hundred GeV in the center-of-mass and again, I believe, in the e^+e^- system."

Burt Richter, Nobel Lecture (1976).

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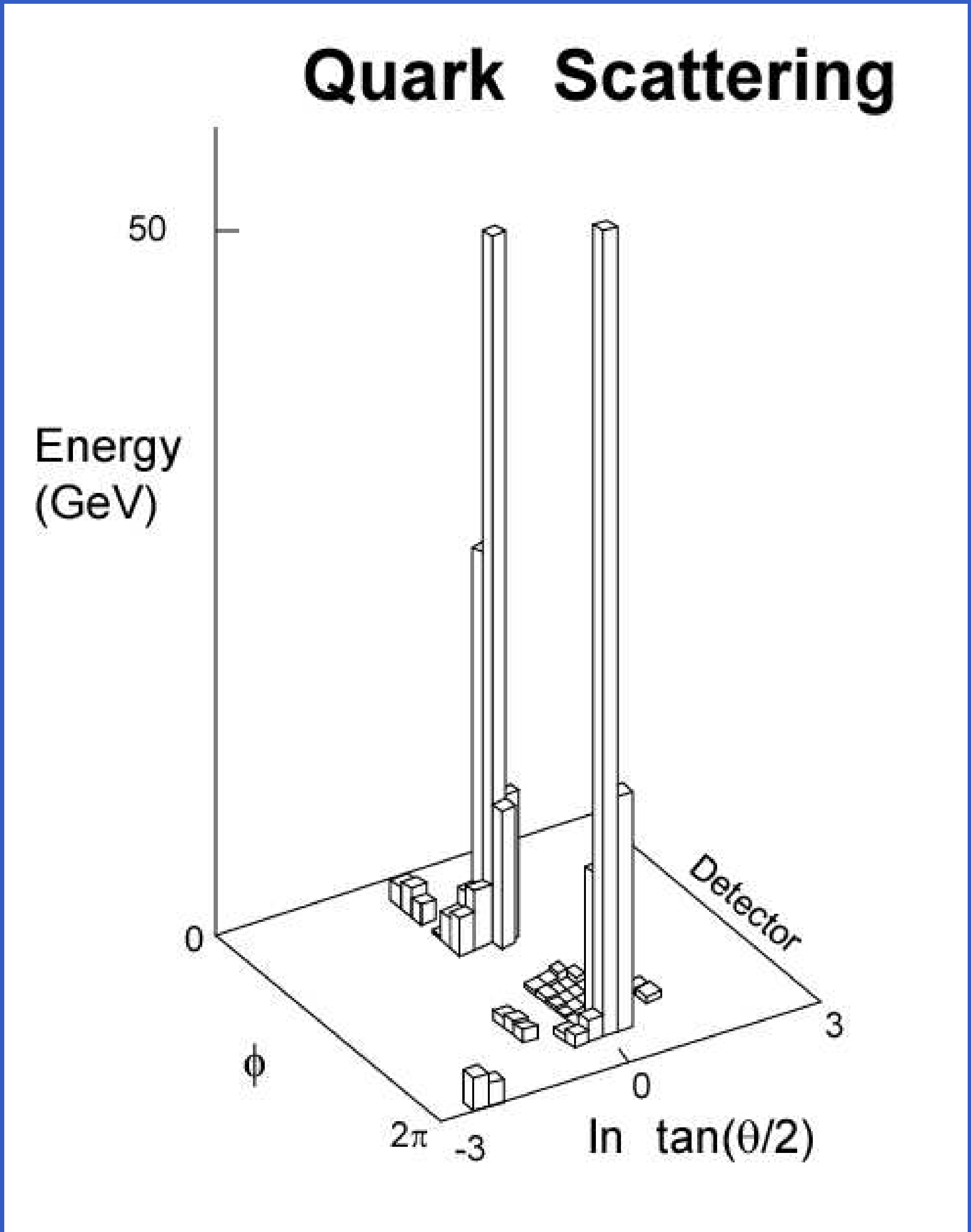
Letter from Richter to Carlo Rubbia on $\bar{p}p$:

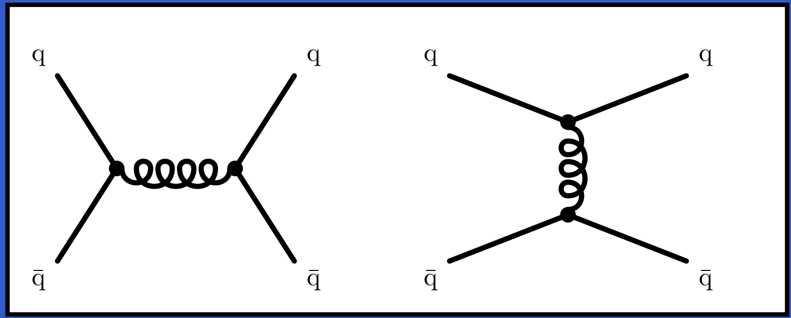
Z^0 maybe (IF machine works), W never!

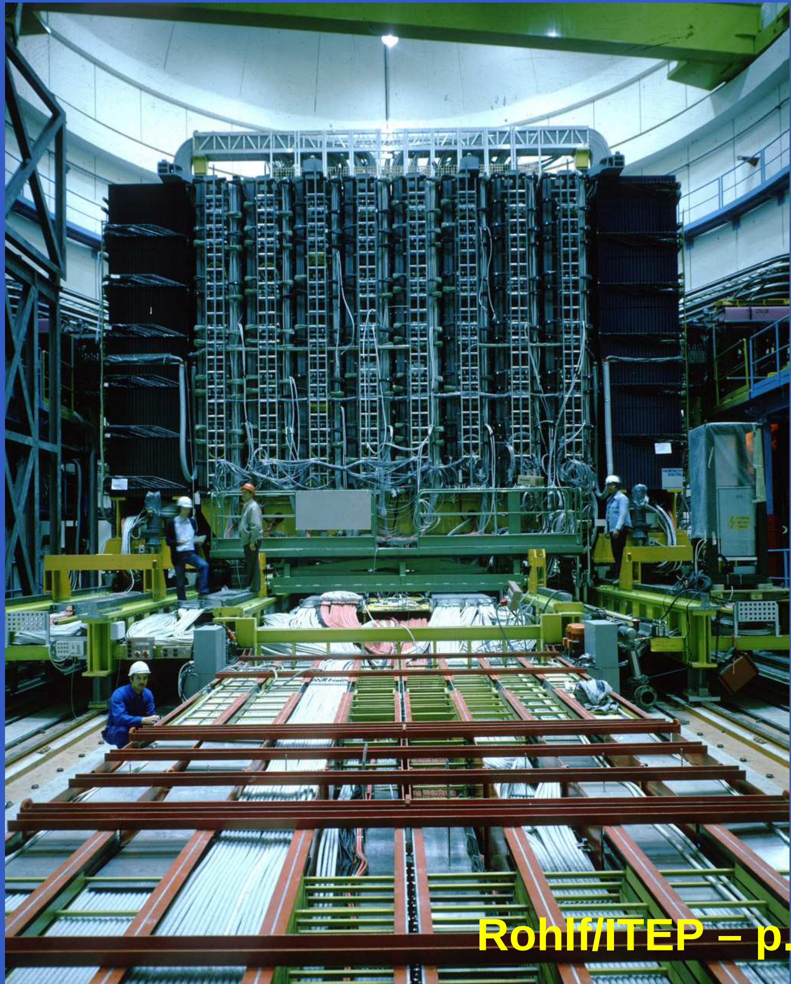
ITEP **Antiproton** stochastic cooling

ITEP Asymptotic freedom jets

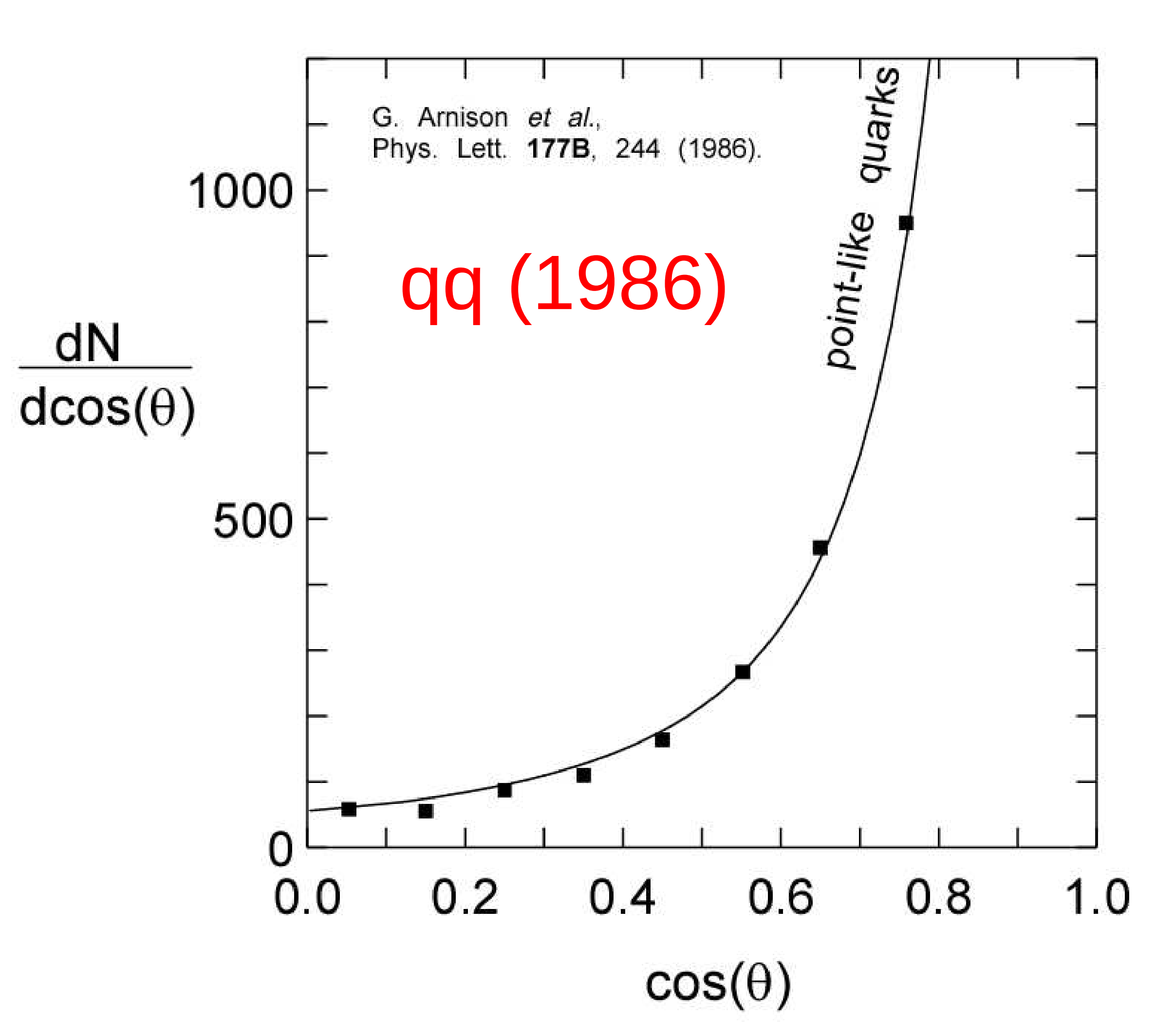


UA1





ITEP Scattering quarks 1986

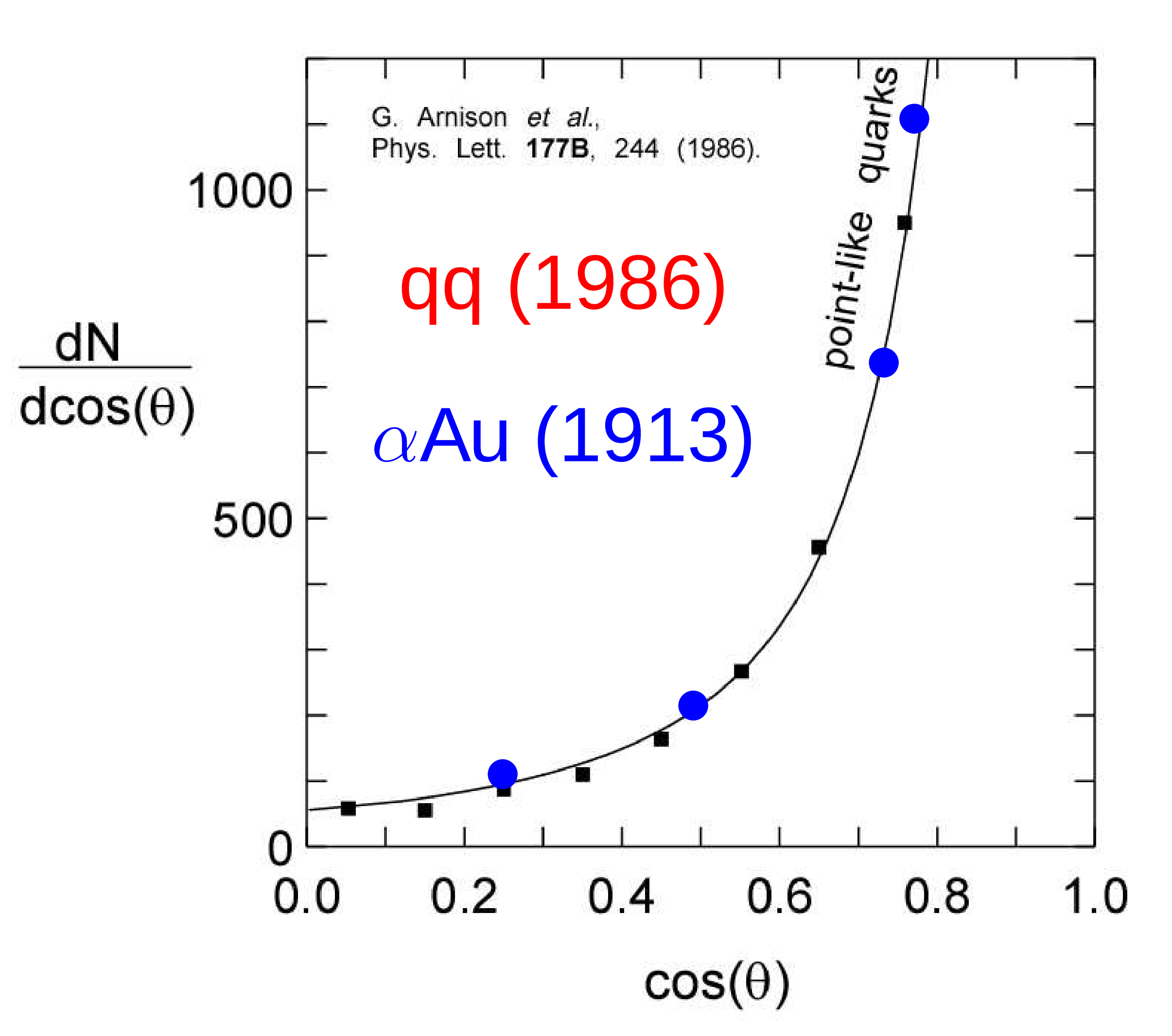


$$\frac{d\sigma}{d\cos\theta} \sim \alpha_s^2 \left(\frac{\hbar c}{E_{\mathrm{CM}}}\right)^2 \frac{1}{(1-\cos\theta)^2}$$

demonstrating:

- $1/r^2$ strong force
- spin 1 gluon
- pointlike quarks

Scattering quarks 1986



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demonstrating:

- $1/r^2$ strong force
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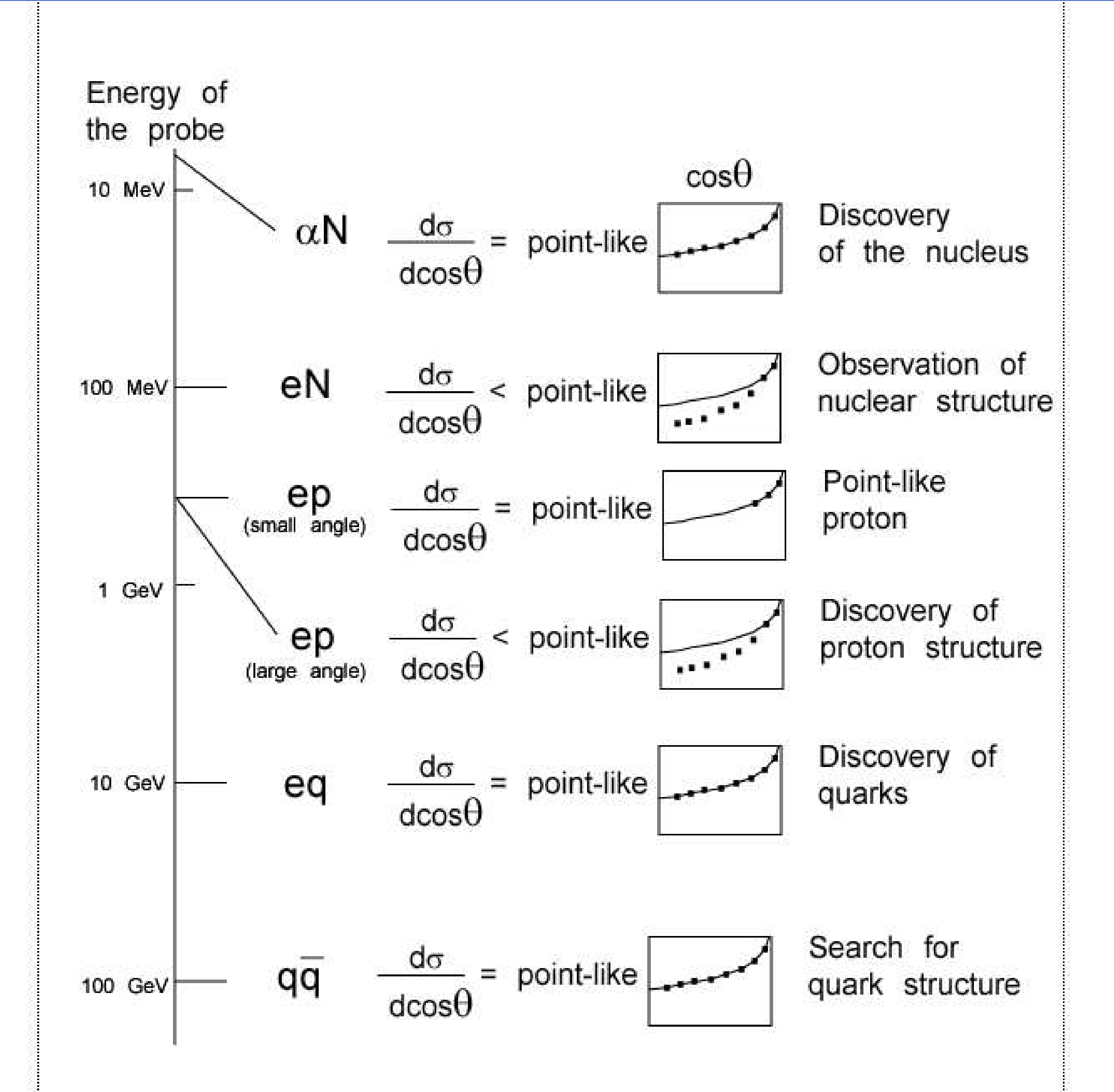
Summary scattering experiments



ITEP Producing the W and Z^0

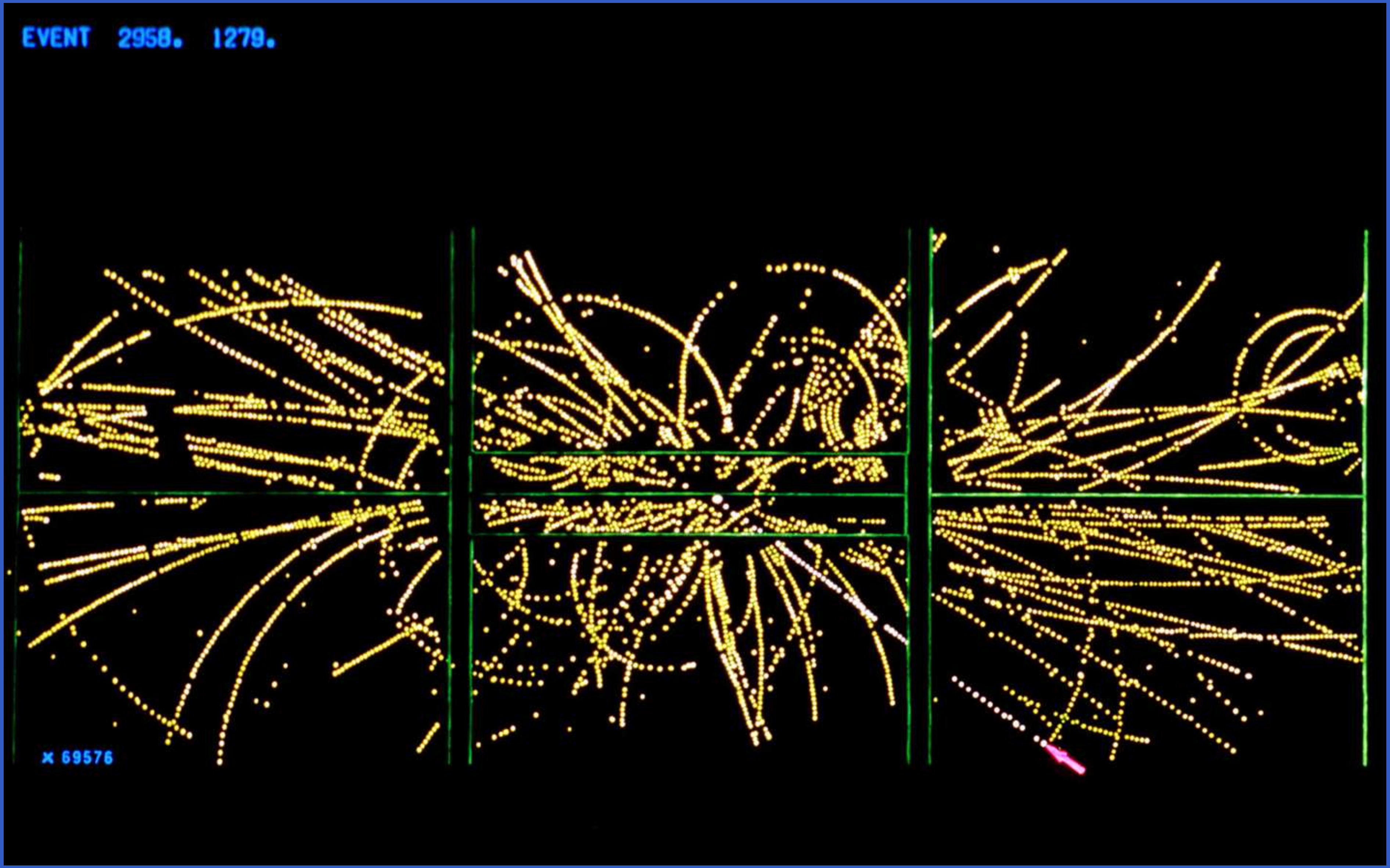
With constituent collisions at 100 GeV, we have probed nature to distances of

$$d \simeq \frac{\hbar}{p} = \frac{0.2 \ \text{GeV}\cdot\text{fm}}{100 \ \text{GeV}} = 2 \times 10^{-18} \ \text{m}$$

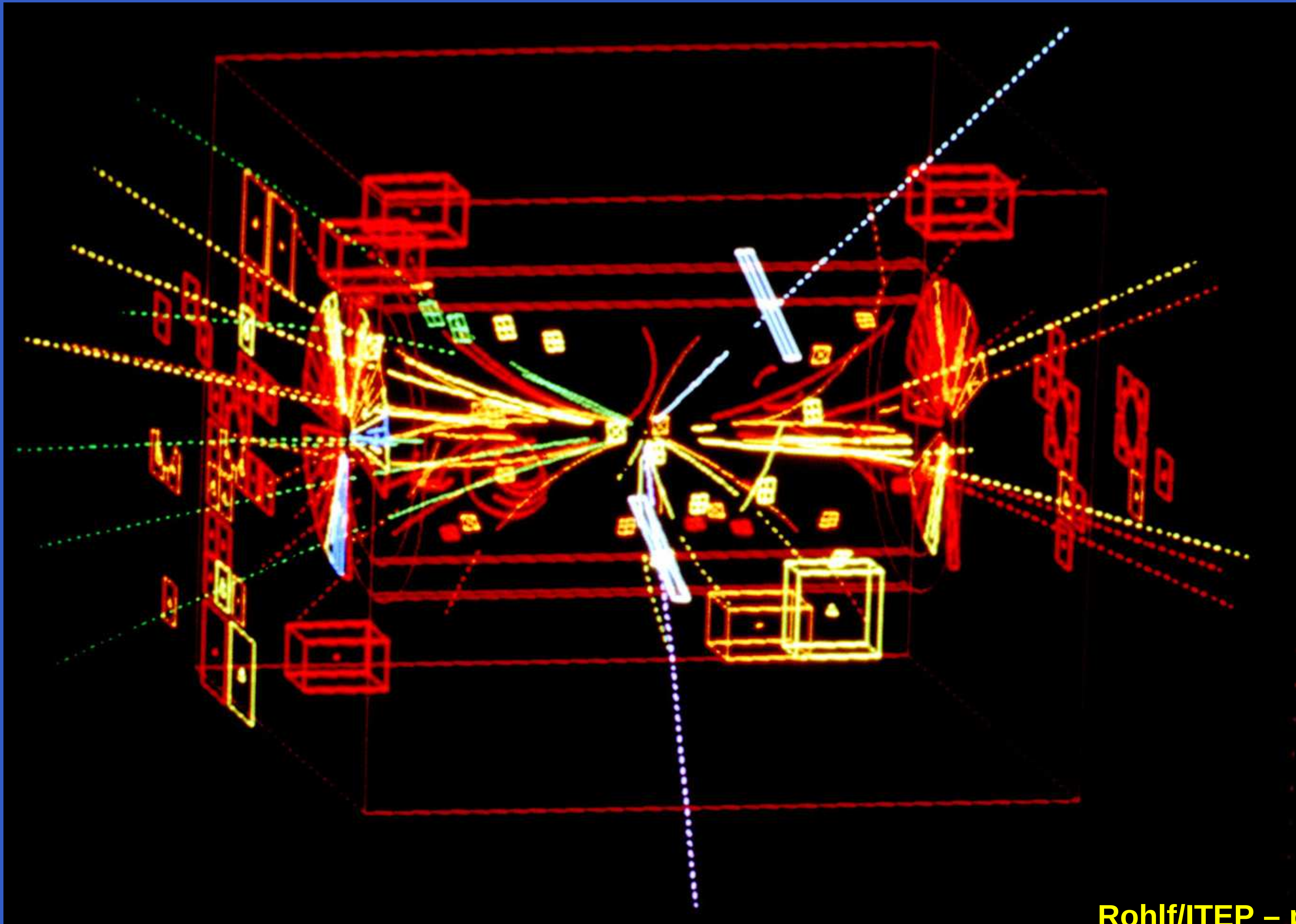
At this energy, the W and Z^0 are produced as free particles.

Tracking the W boson

UA1



ITEP Observing the Z^0 UA1



ITEP Electroweak symmetry breaking

Recall the crisis of the classical electron radius, the failure of electromagnetics at a distance of 1 fm... the solution of which appeared at a much larger distance scale (0.1 nm). Now we come to the current version...

$$\alpha_{\mathrm{W}} \simeq \alpha\left(\frac{E}{m_{\mathrm{W}}c^2}\right)^2$$

Our understanding of the weak force fails when

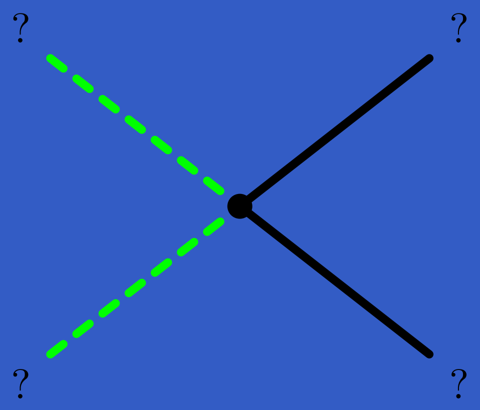
$$\alpha_{\mathrm{W}} \simeq 1.7\ \mathrm{TeV}$$

Our current understanding of the weak force is analogous to the understanding of electrodynamics in 1920... Some new physics must (!) appear on the TeV scale (or below), corresponding to 10^{-19} m.

This argument has been eloquently made by Lev Okun... more later.

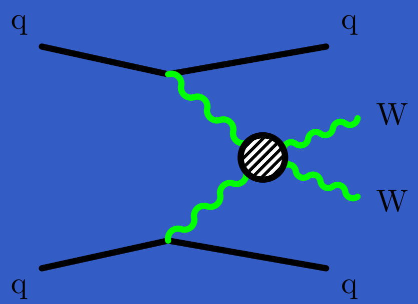
Big Picture

FIRST look at the TeV/c^2 mass scale to find a clue to the hierarchy problem... *What lies between the weak scale and the Planck mass?*



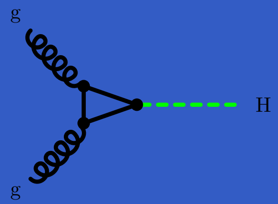
Medium Picture

EXPLORE the mechanism for electroweak symmetry breaking... *How do the* W/Z^0 *interact at high energies?*

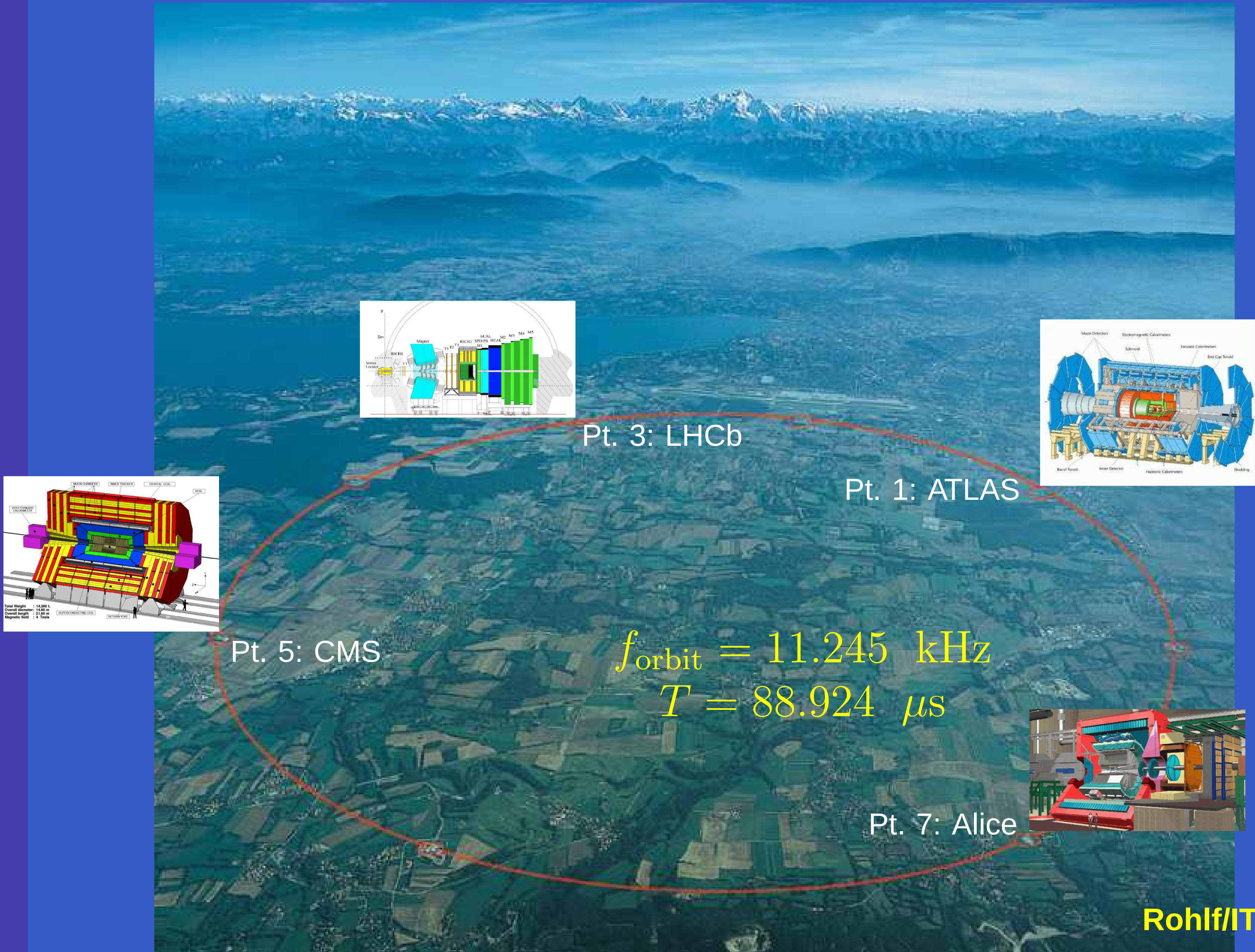


Small Picture

NAIL down the elusive Higgs boson...



ITEP LHC orbit



$$f_{\text{orbit}} = 11.245 \ \text{kHz}$$
$$T = 88.924 \ \mu\text{s}$$

The famous work of Vitaly Ginzburg and Landau brings the language of quantum mechanics to the description of superconductivity. In one-dimension:

$$\frac{d^2\psi}{dx^2} = \frac{2ma}{\hbar^2}\psi$$

m = Cooper pair mass
a = constant (T)

where the wave function squared represents the Cooper pair density. The solution is

$$\psi = e^{-x/\xi}$$

where

$$\xi = \frac{\hbar}{\sqrt{2ma}}$$

ξ, the coherence length is the distance scale for Cooper pair correlation.

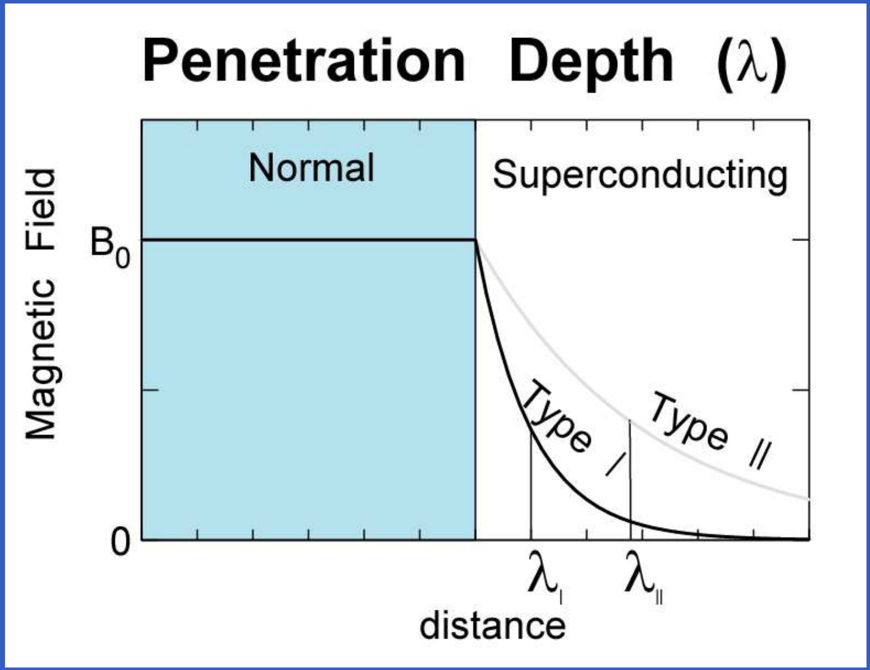
ITEP Superconductivity Type-II

The ratio of penetration depth to coherence length

$$\kappa = \frac{\lambda}{\xi}$$

is typically much smaller than unity.

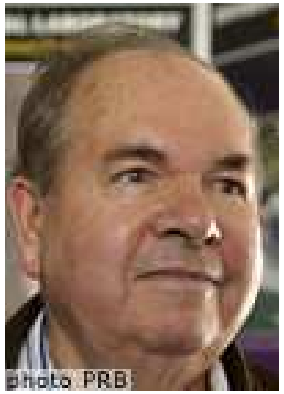
Alexei Abrikosov investigated what would happen if κ was large instead of small. He called these materials Type-II superconductors.



The discovery of this effect has made possible the construction of high-field solenoid magnets!

The Nobel Prize in Physics 2003

"for pioneering contributions to the theory of superconductors and superfluids"



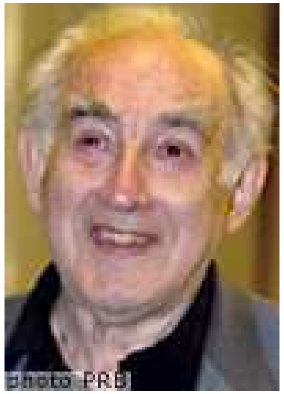
Alexei A. Abrikosov

1/3 of the prize

USA and Russia

Argonne National Laboratory
Argonne, IL, USA

b. 1928



Vitaly L. Ginzburg

1/3 of the prize

Russia

P.N. Lebedev Physical Institute
Moscow, Russia

b. 1916

Anthony J. Leggett

1/3 of the prize

United Kingdom and USA

University of Illinois
Urbana, IL, USA

b. 1938

The Nobel Prize in Physics 2003
Prize Announcement
Press Release
Advanced Information
Information for the Public

Alexei A. Abrikosov
Nobel Lecture
Other Resources

Vitaly L. Ginzburg
Nobel Lecture
Other Resources

Anthony J. Leggett
Nobel Lecture
Other Resources

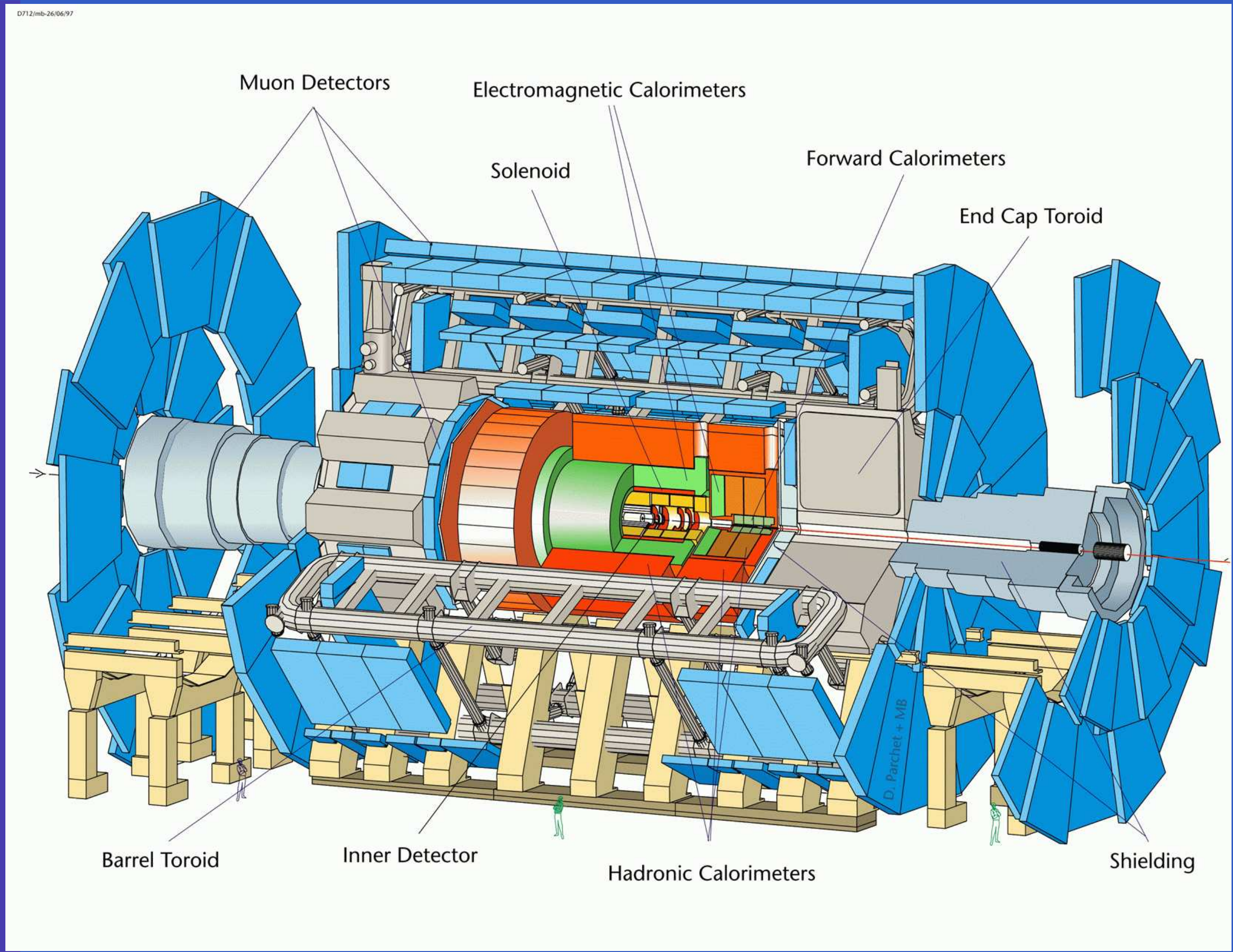
2002

The 2003 Prize in:
Physics
Chemistry
Physiology or Medicine
Literature
Peace
Economic Sciences

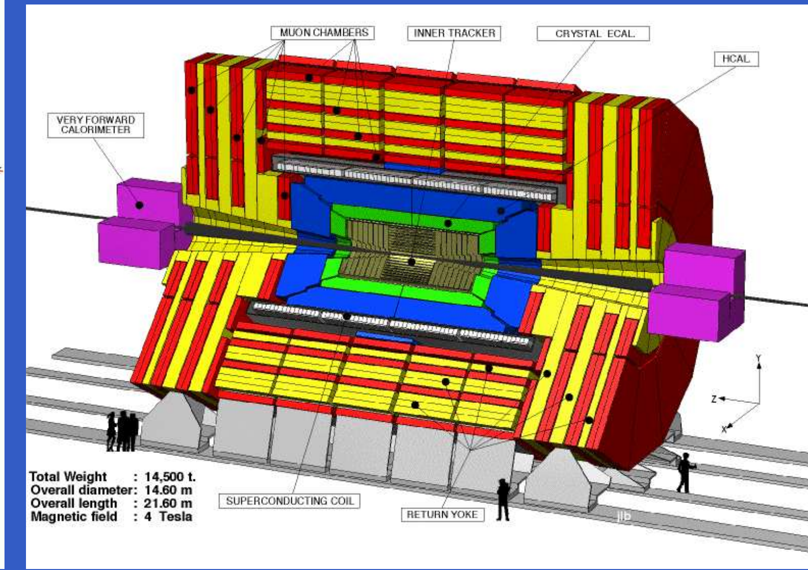
Find a Laureate:
Name GO

ITEP LHC 26 km of superconducting magnets

SLHC Detectors overview



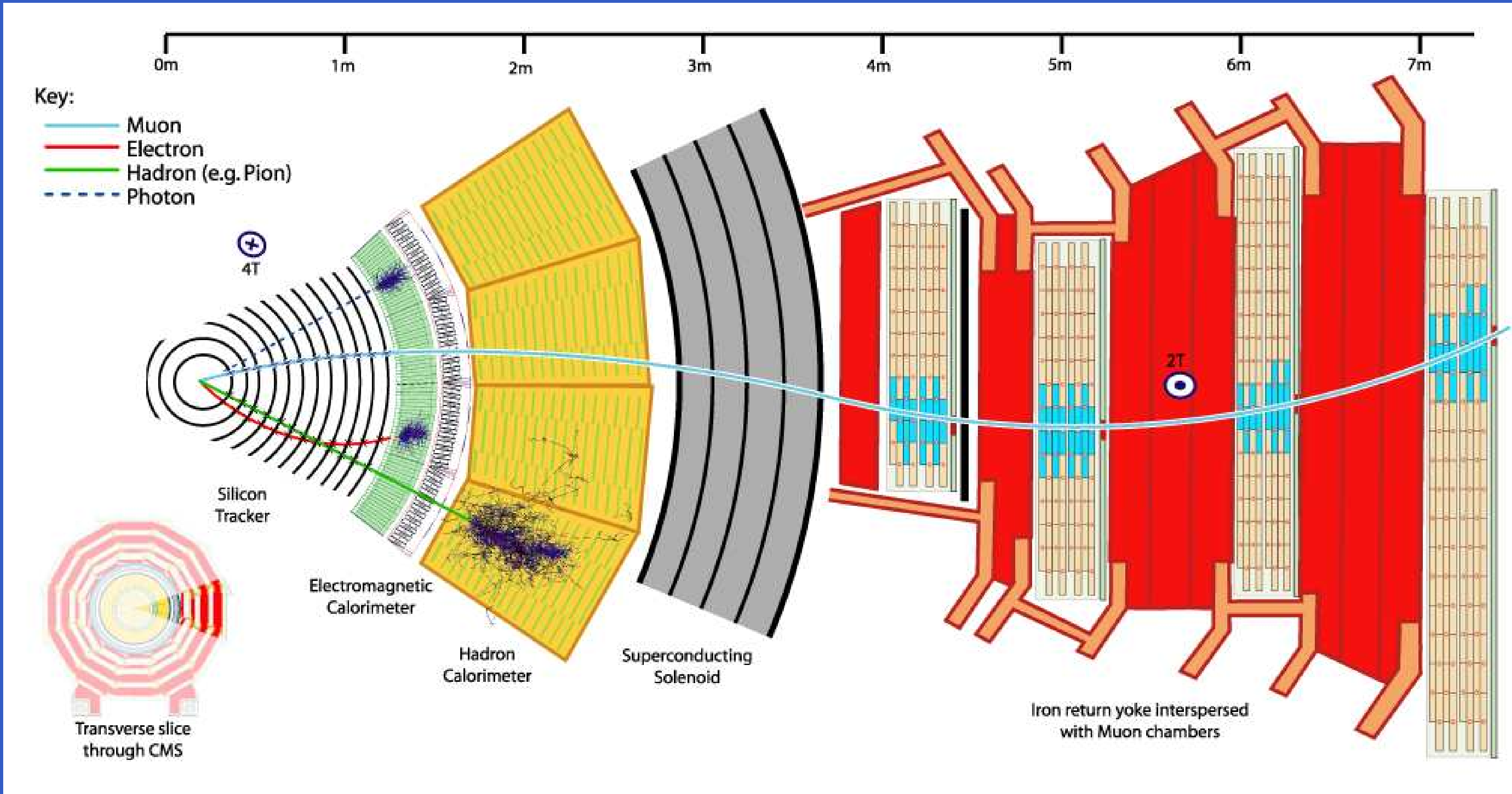
- tracking in B field
- EM calorimetery
- had. calorimetry
- muon detectors



A Toroidal Large hadron collider ApparatuS (ATLAS) 7 kTons
0.5 T toroid, 2 T solenoid
25 m $\times$ 46 m

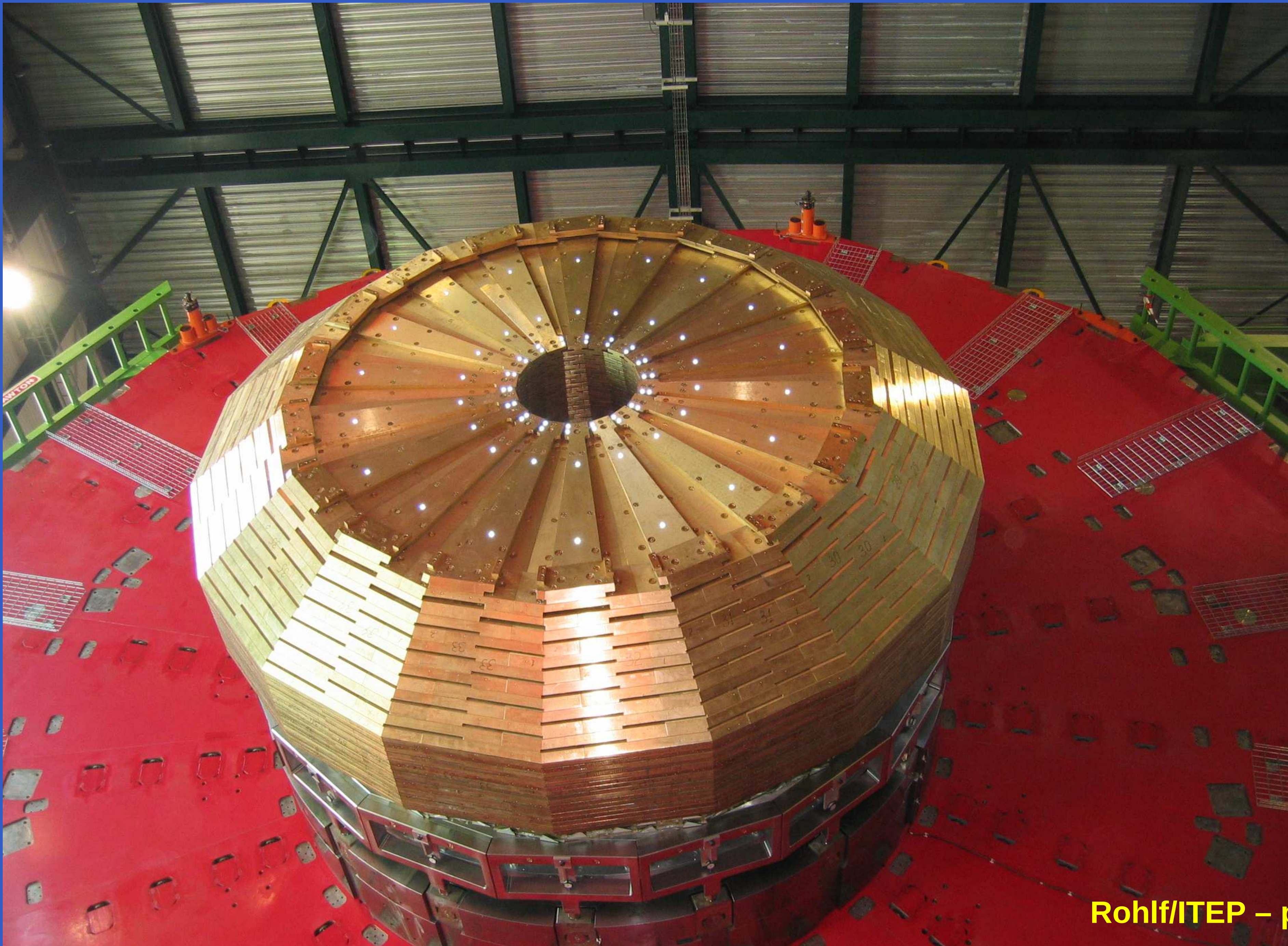
Compact Muon Solenoid (CMS) 14 kTons
4 T solenoid
15 m $\times$ 22 m

ITEP CMS slice

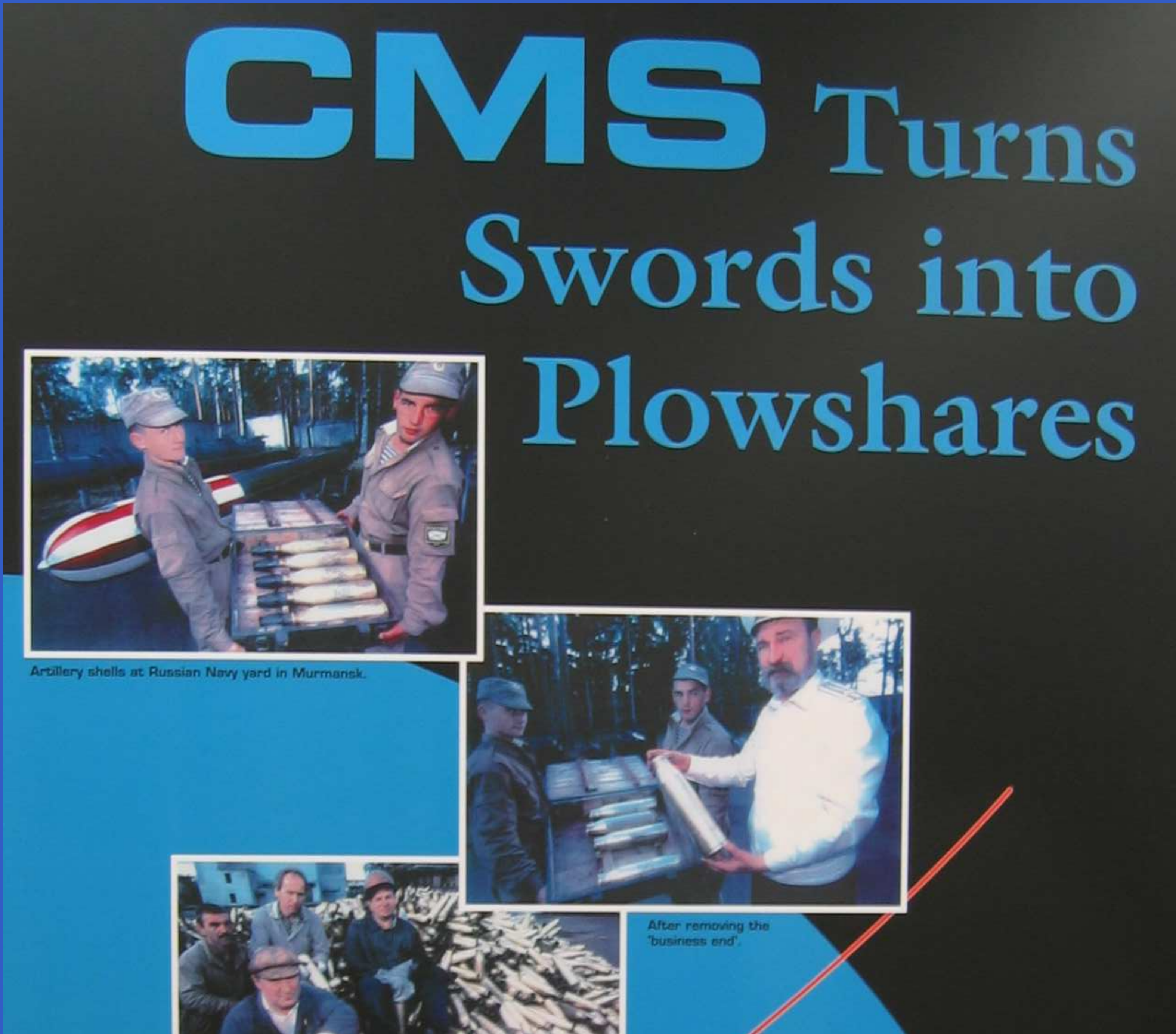


ITEP CMS 4T magnet

ITEP CMS end cap Russian brass



ITEP CMS endcap contribution of Russian Navy

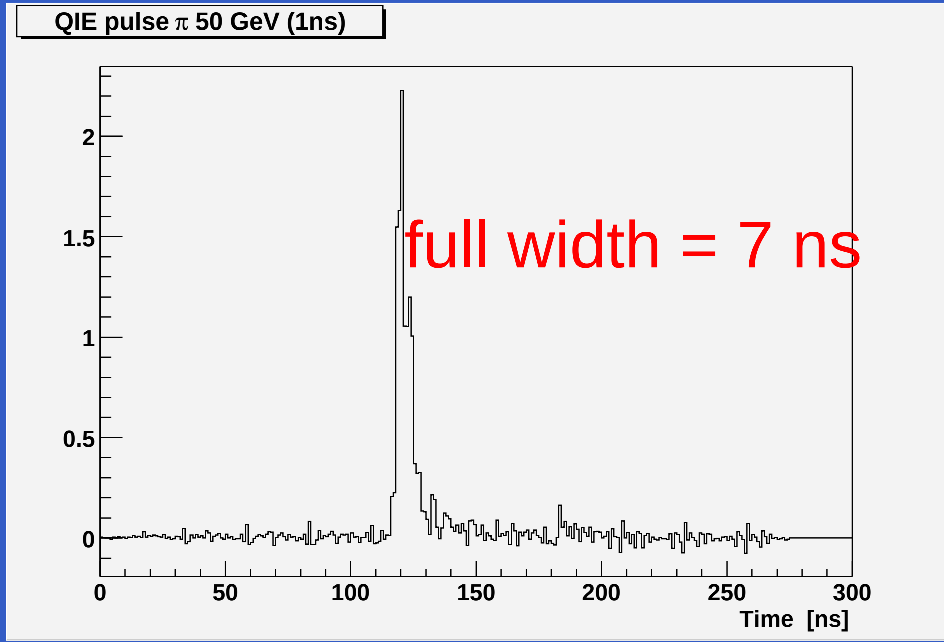


Quartz-fiber Čerenkov calorimeter

First device of its kind.

200k quartz fibers.

Test beam results Aug. 2003

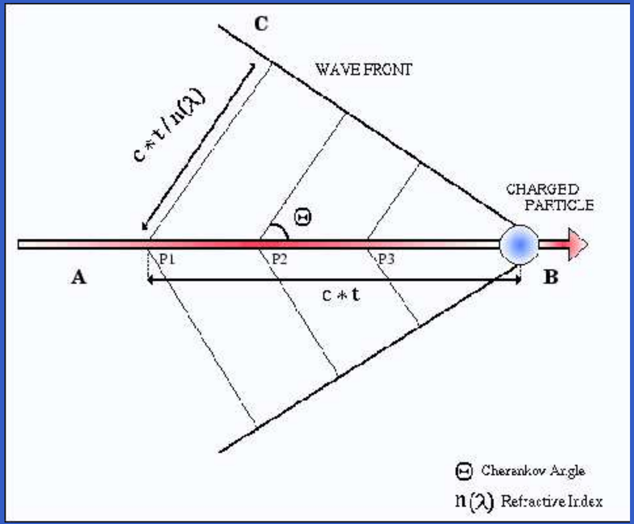


Read out with 2000 phototubes (about as many as used by UA1 to discover the W and Z!)

ITEP Vavilov-Čerenkov radiation

Sergei I. Vavilov and Pavel A. Čerenkov (1934)

Moving faster than light

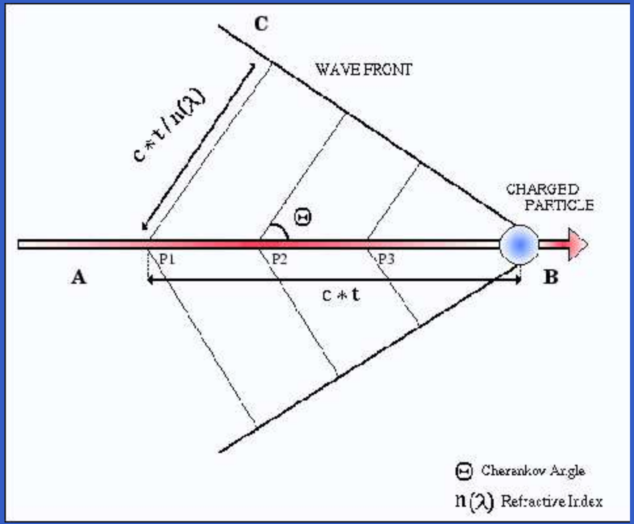


Theoretical explanation (prediction):
Il'ya Frank and Igor Tamm

ITEP Vavilov-Čerenkov radiation

Sergei I. Vavilov and Pavel A. Čerenkov (1934)

Moving faster than light



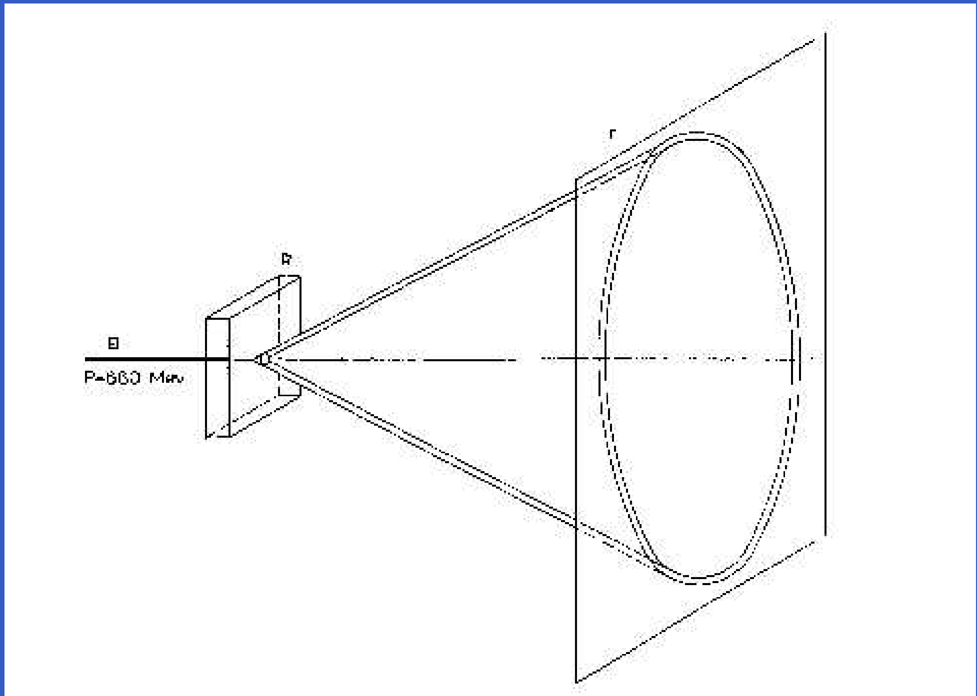
Theoretical explanation (prediction):

Il'ya Frank and Igor Tamm

"All science is either physics or stamp collecting."

Ernest Rutherford

ITEP Čerenkov ring



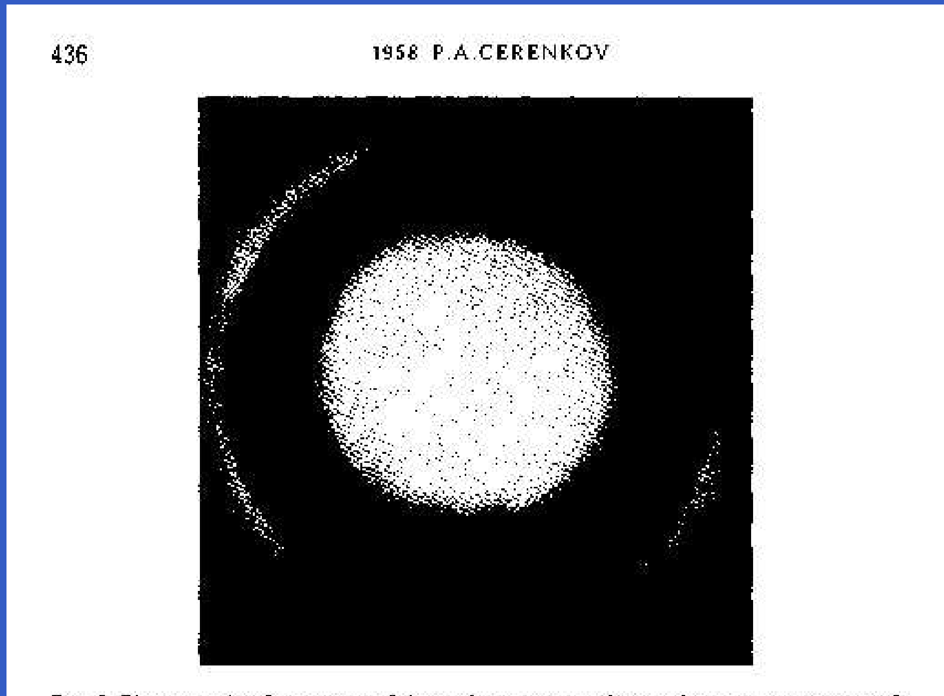
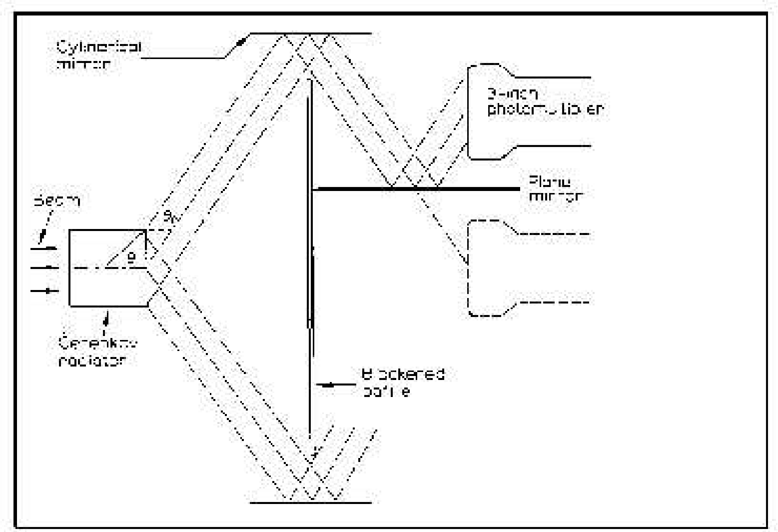


Fig. 6. Photograph of a section of the radiation cone obtained in an experiment of which Fig. 5 is a diagram. The central patch is the track of the proton ray.

Pavel A. Čerenkov, "Radiation of particles moving at a velocity exceeding that of light, and some of the possibilities for their use in experimental physics," *Nobel Lecture, Dec. 11, 1958*

ITEP Čerenkov counters famous discoveries

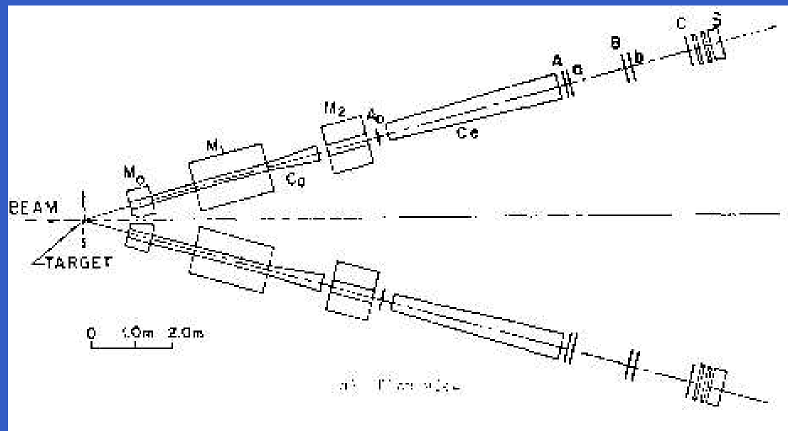
Antiproton (1955)



“Our own work was built directly on the previous accomplishments of many eminent scientists, including especially... P. A. Čerenkov.”
Owen Chamberlain, Nobel Lecture (1959).

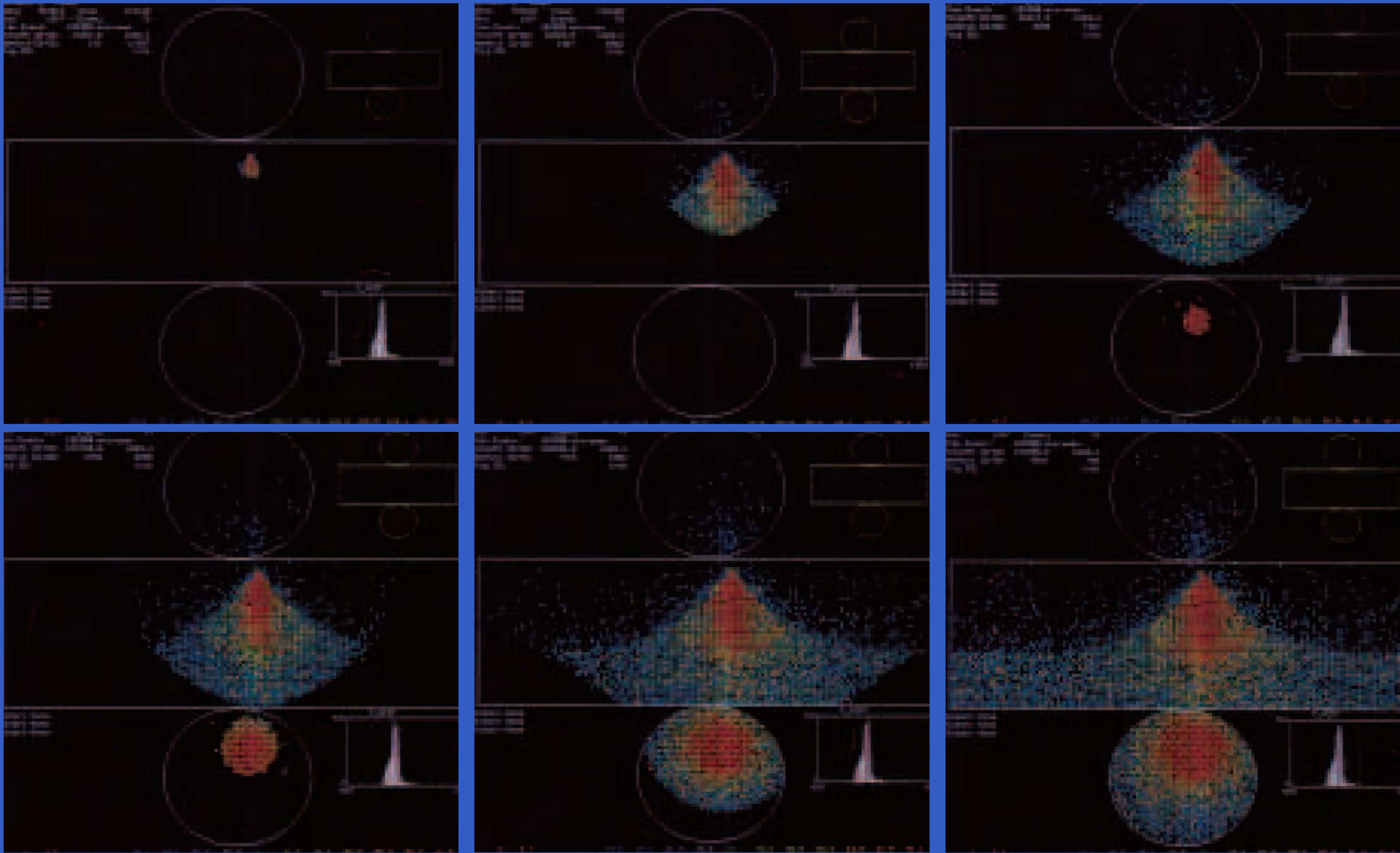
“The Čerenkov counters marked $\check{C}_0$ and $\check{C}_e$ together with the lead-glass and shower counters marked S enable one to have a rejection against hadron pairs by a factor of $>> 10^8$.”
Sam Ting, Nobel Lecture (1976).

J particle (1974)



ITEP Super-Kamiokande water Čerenkov

11,000 giant phototubes: muon at 50μs intervals



Masatoshi Koshiba, Nobel Lecture (2002).

ITEP Transition radiation

Explained (predicted) by Frank and Ginzburg (1946).

Atlas:
Transition radiation tracker

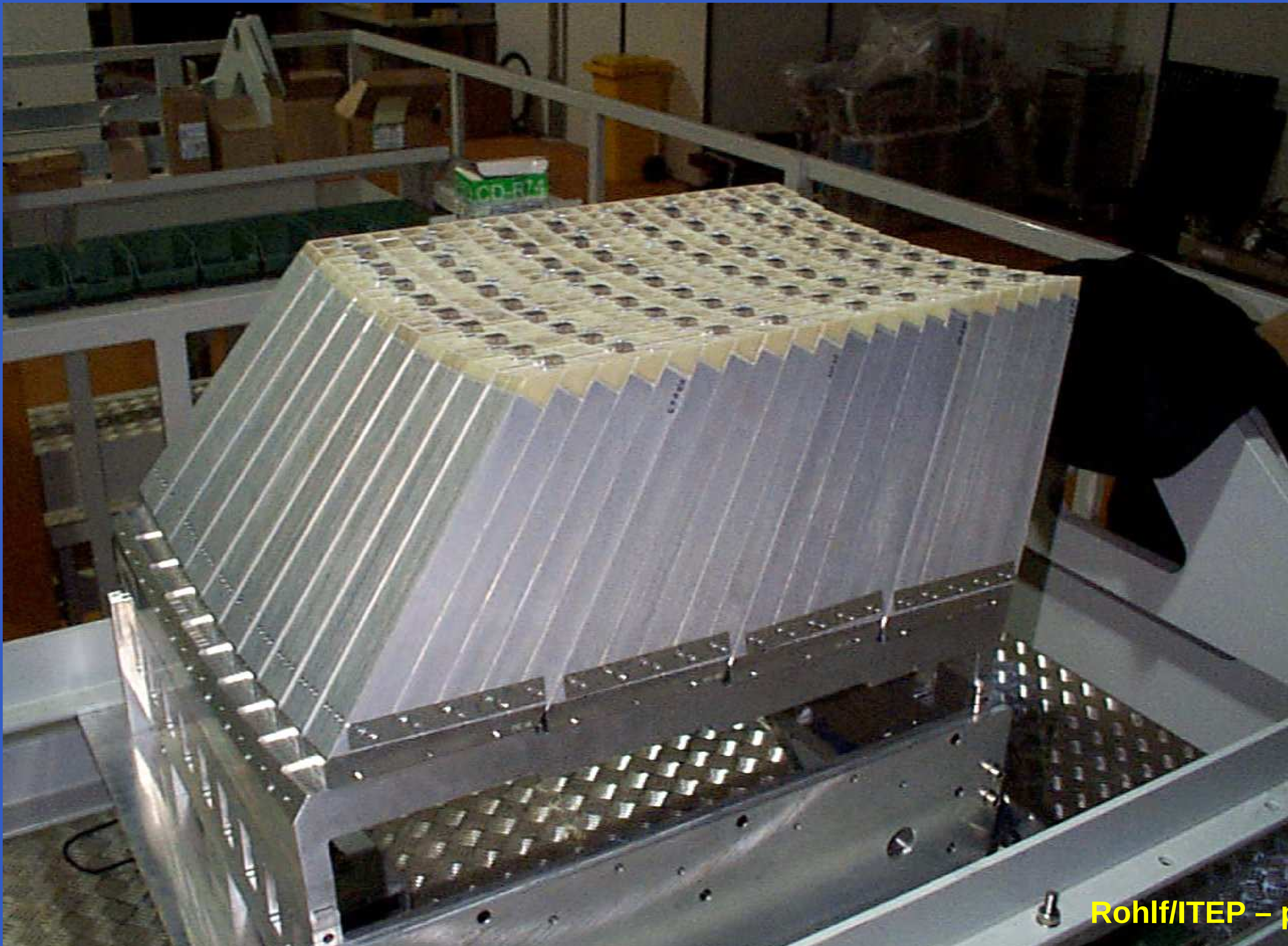
$$I \sim \alpha\gamma$$

"This is important because it is very difficult to use for this purpose the Vavilov-Čerenkov effect for ultra-relativistic particle. As is well known, the angle at which the Vavilov-Čerenkov radiation is directed, and its intensity, attain in this case a practically constant value. The use of transition radiation is, however, impeded by the fact that its intensity is very low..."

Il'ya M. Frank, Nobel lecture (1958).

ITEP **CMS endcap** muon chambers

ITEP Crystal calorimeter



ITEP CMS Si tracker

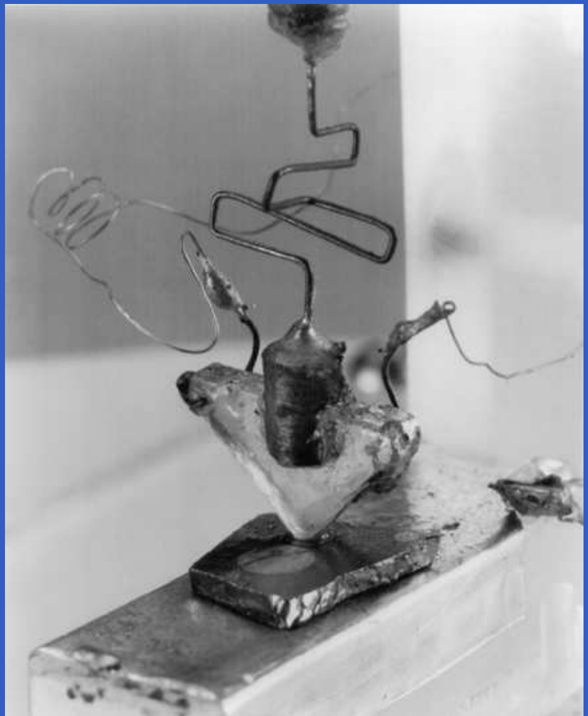
Readout 10-100 million channels

The readout is made possible by two important developments in the last 5-10 years:

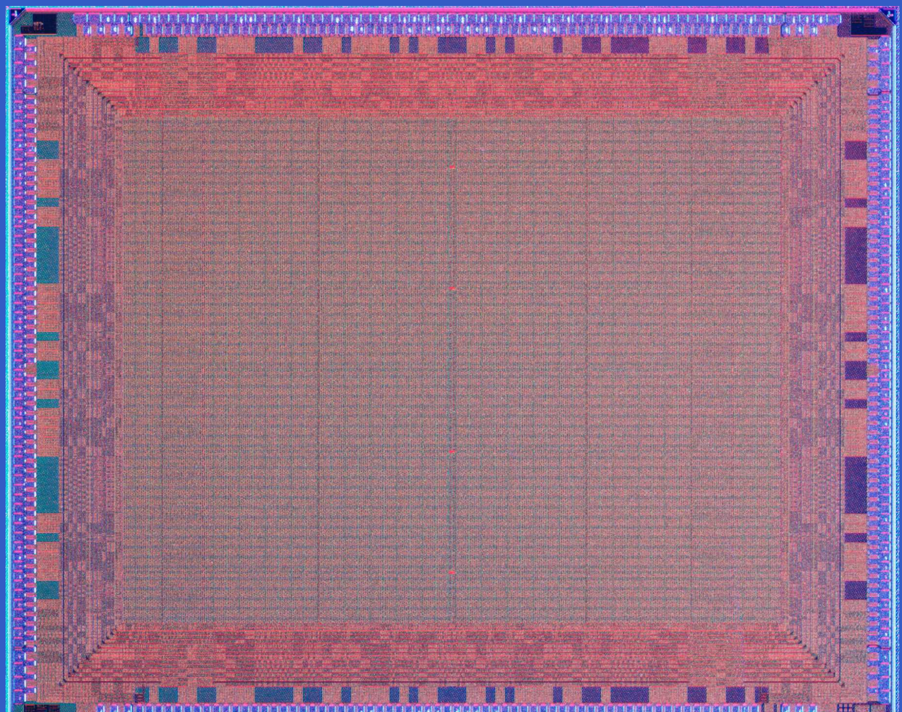
- availability of millions of logic gates in a single package at low cost (< $\$10^{-4}$ per "transistor")
- availability of radiation hard electronics

  cold war dividend

First transistor 1947



Modern FPGA 2003



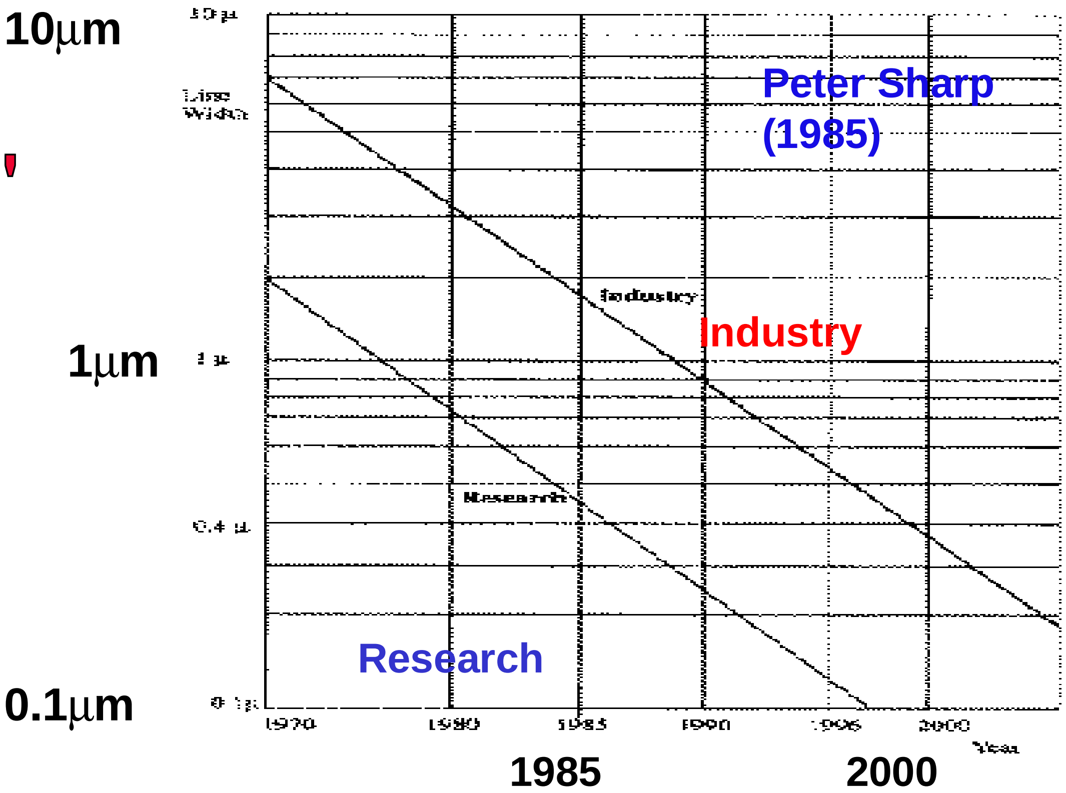
Moore's Law prediciting the trend

What has been Learnt from the last 15 Years ?

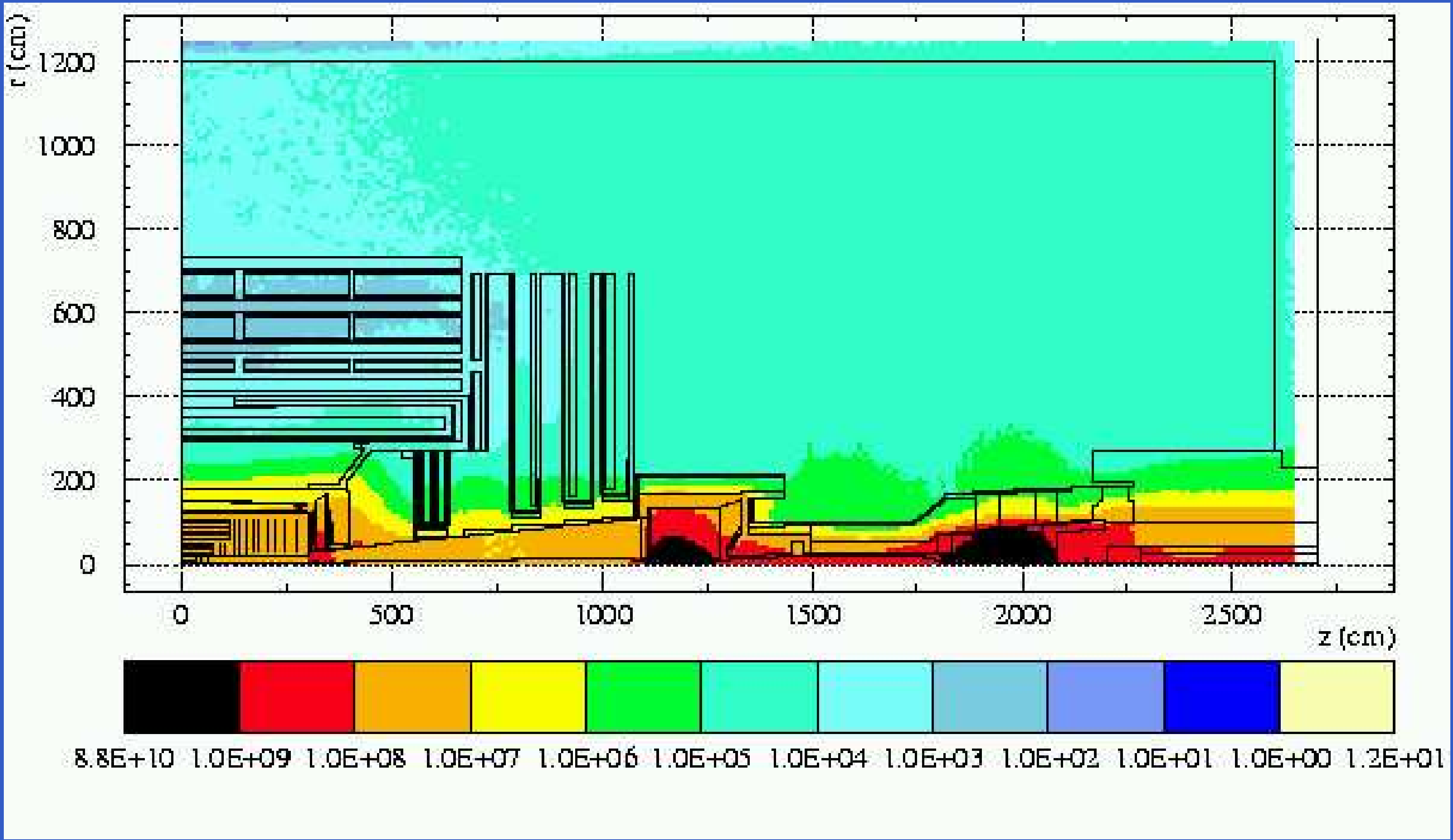
' Moores Law '

A plot made in 1985

Evolution of Line Width



ITEP Radiation levels neutron flux



ITEP Super LHC reaching for $10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ and beyond

How do we get there?

N_b = protons per bunch

f = collision frequency

σ^* = transverse beam size at IP

σ_z = bunch length

circular beams crossing at angle θ_c

$$L = \frac{N_\mathrm{b}^2 f}{4\pi\sigma^{*2}} \frac{1}{\sqrt{1+\frac{\theta_\mathrm{c}^2\sigma_z^2}{4\sigma^{*2}}}}$$

Phase 0:	*no hardware upgrades* ATLAS and CMS only, 9 T in dipoles	$\rightarrow 2.3 \times 10^{34}\ \mathrm{cm}$ $\sqrt{s} = 15\ \mathrm{TeV}$
Phase 1: **SLHC**	*no changes to LHC arcs* lower beta, increase N_b, 12.5 ns	$\rightarrow 9.2 \times 10^{34}\ \mathrm{cm}$ $\sqrt{s} = 15\ \mathrm{TeV}$
Phase 2: **EDLHC**	*major hardware upgrades* new magnets and injector	$\rightarrow 2 \times 10^{35}\ \mathrm{cm}$ $\sqrt{s} = 25\ \mathrm{TeV}$

O. Brüning *et al.*, LHC Luminosity and Energy Upgrade: A Feasibility Study

ITEP LHC/SLHC comparison

	LHC	*SLHC*
pp c.m. energy	14 TeV	15 TeV
luminosity	$10^{34}\ \mathrm{cm^{-2}s^{-1}}$	$10^{35}\ \mathrm{cm^{-2}s^{-1}}$
collision rate	1 GHz	10 GHz
W/Z^0 *rate*	1 kHz	10 kHz
bunch spacing	25 ns	12.5 ns
interactions per crossing	20	100
$\frac{dN_{\mathrm{ch}}}{d\eta}$ *per crossing*	150	750
track flux @ 1 m	$10^{5}\ \mathrm{cm^{-2}s^{-1}}$	$10^{6}\ \mathrm{cm^{-2}s^{-1}}$
calorimeter pileup noise	nominal	$\times$2-3
rad. dose @ 1 m *for* $2500\ \mathrm{fb}^{-1}$	1 kGy	10 kGy

ITEP **Stored energy** unprecedented

$$E = 2E_{\mathrm{p}}N_{\mathrm{b}}N_{\mathrm{p}}$$

$$E = (2)(1.5\times10^{13}\ \mathrm{eV})(1.6\times10^{-19}\ \mathrm{J/eV})(2808)(1.1\times10^{11}) \simeq 1.5\ \mathrm{GJ}$$

The problem becomes even more severe for the next proton machine!

ITEP Stored energy unprecedented

$$E = 2E_{\rm p}N_{\rm b}N_{\rm p}$$

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Kuznetsov

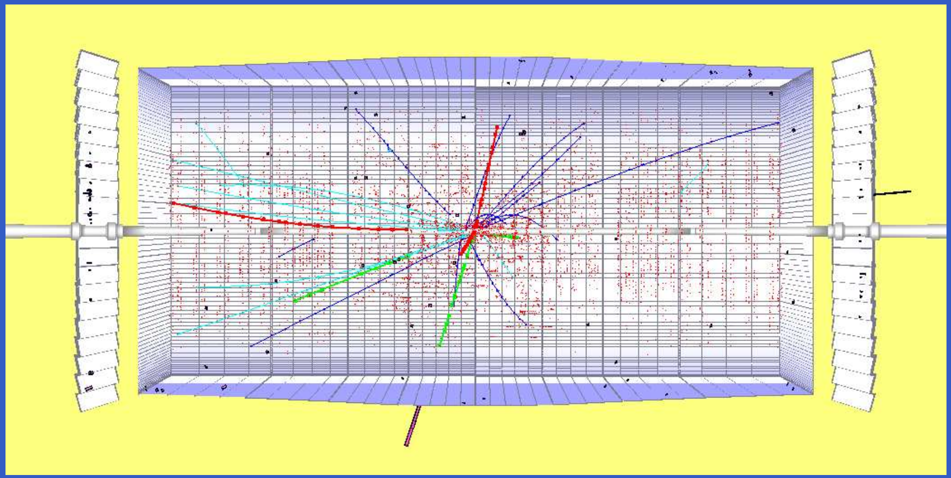
$$m = 55,000\ {\rm tons}$$

same kinetic energy at 15 knots as the LHC beams!

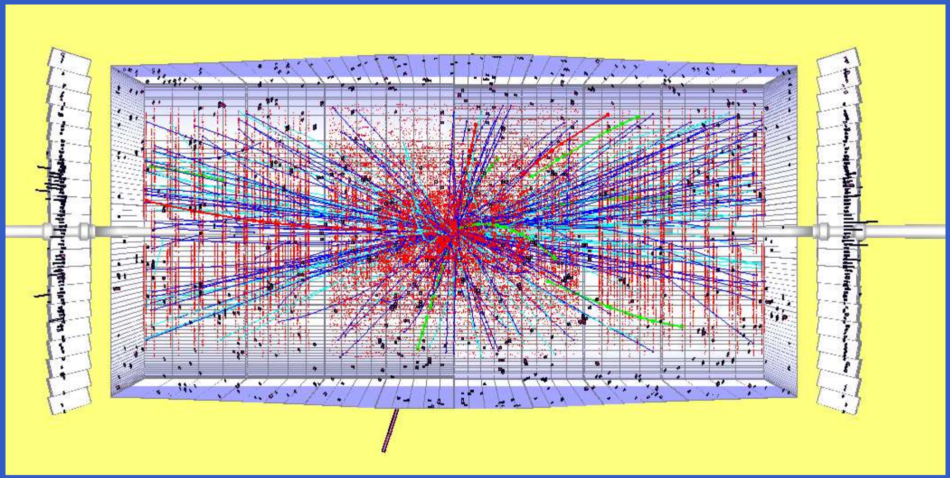
The problem becomes even more severe for the next proton machine!

ITEP ZZ $\longrightarrow$ 4 lepton event

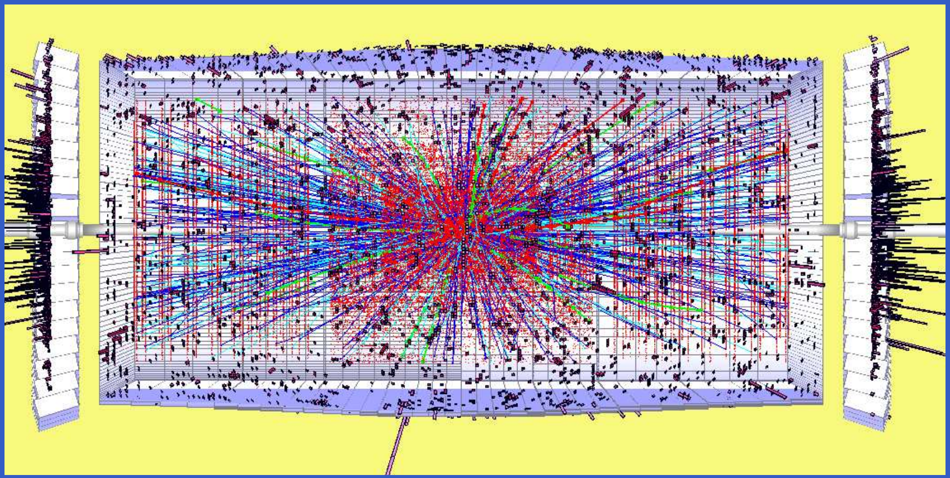
$10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$



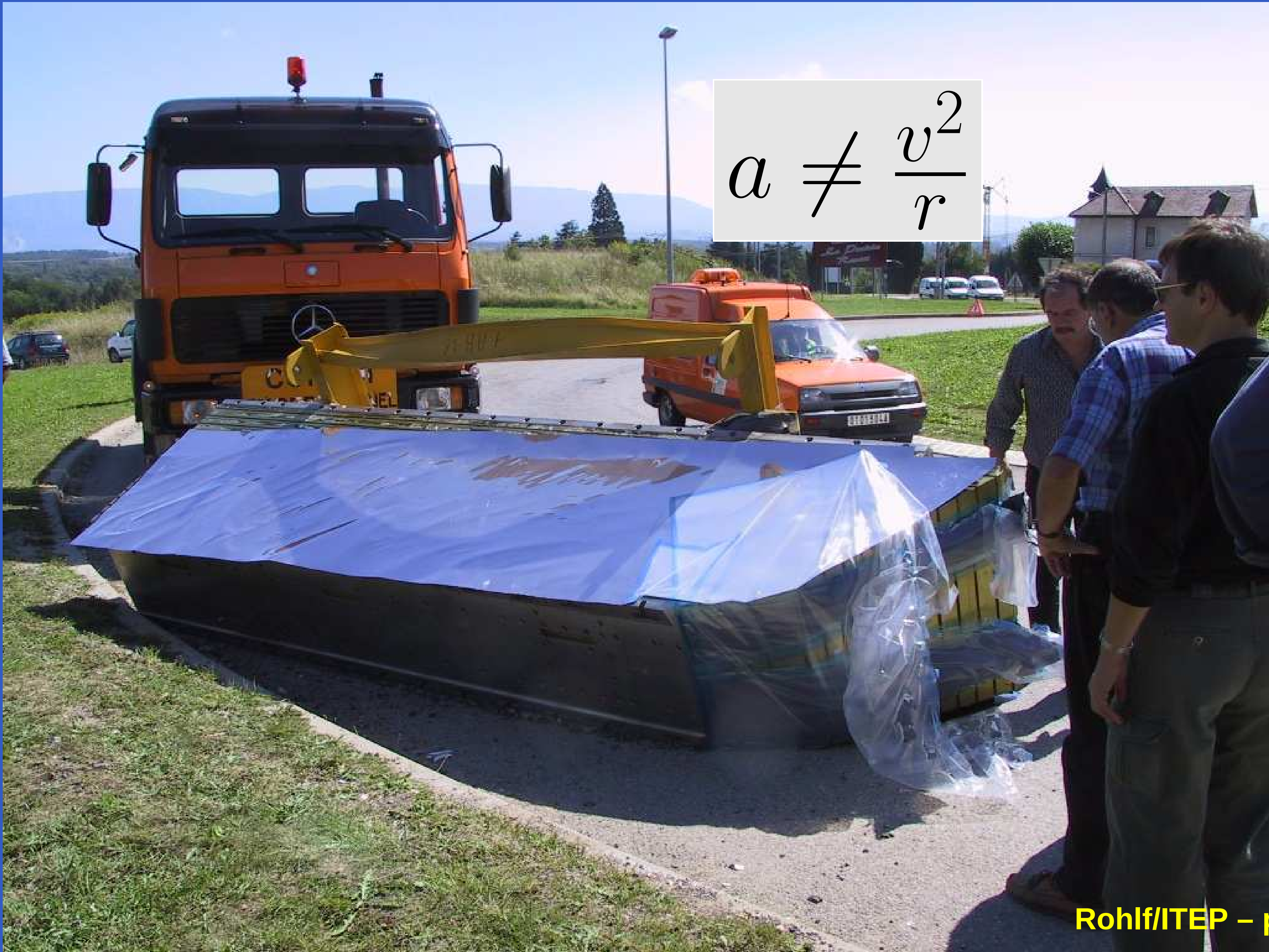
$10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$



$10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$



ITEP Physics will not go as planned...



$$a \neq \frac{v^2}{r}$$

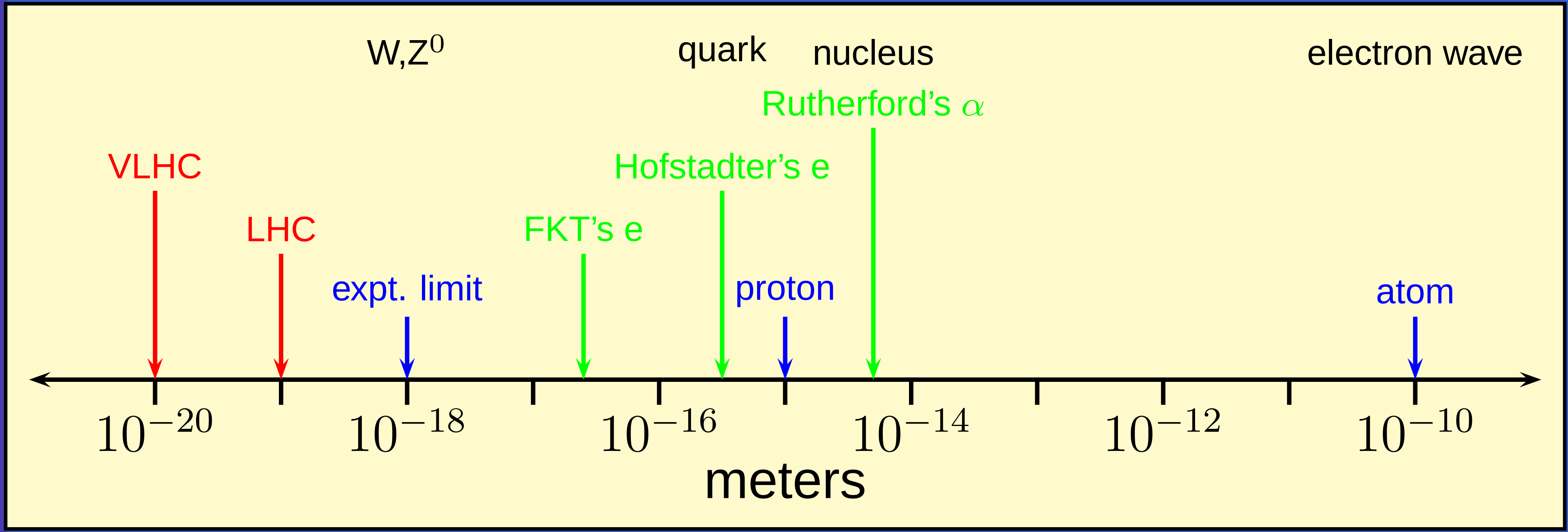
ITEP Beyond the SLHC

The LHC+SLHC physics program will bring our fundamental understanding of matter down to a distance scale of

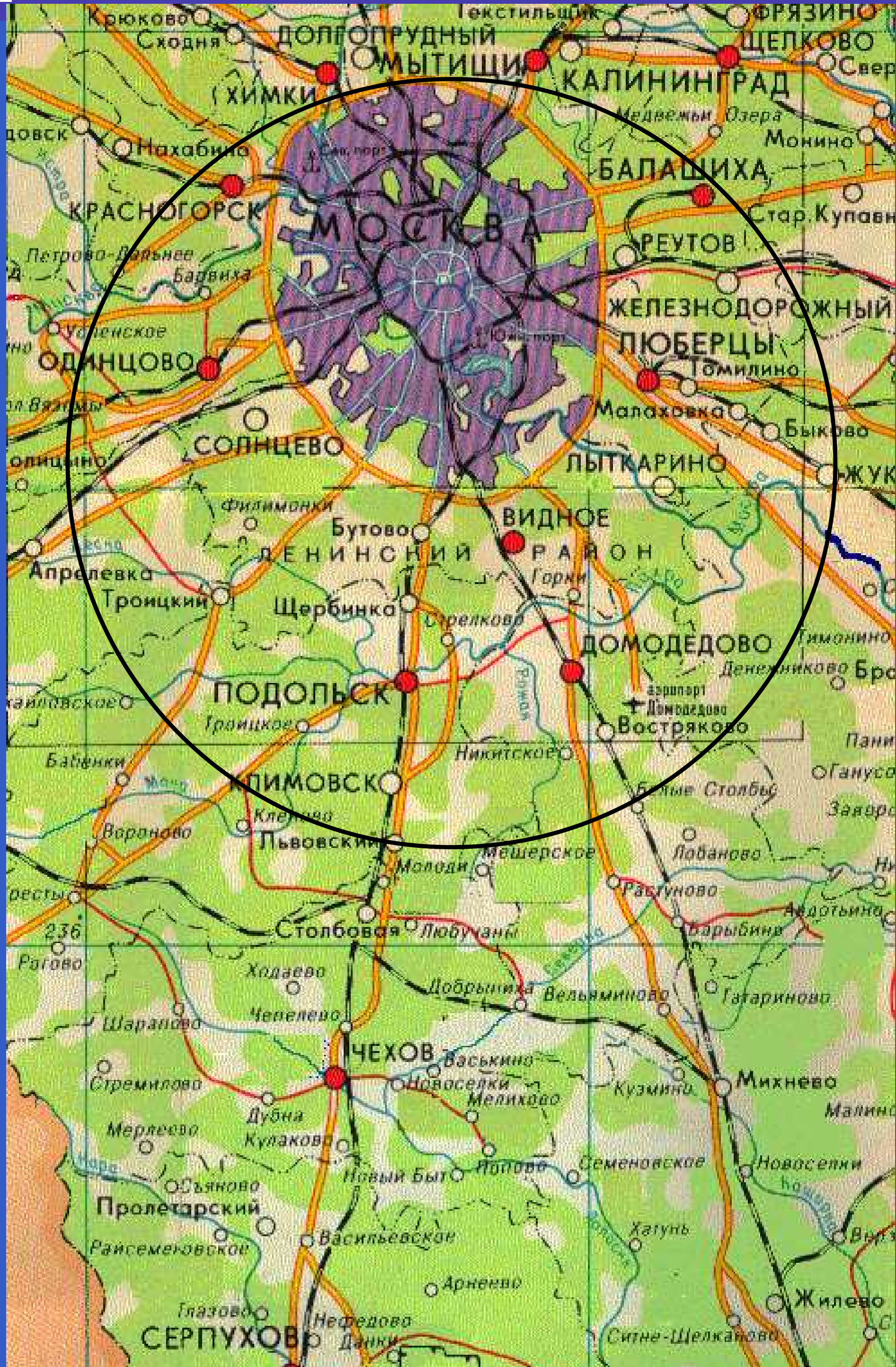
$$d \sim \frac{\hbar}{p} \simeq \frac{0.2\ \text{GeV}\cdot\text{fm}}{2\ \text{TeV}} = 10^{-19}\ \text{m}$$

To make the next step we need a BIG hadron collider. This hypothetical machine is referred to generically as the Very Large hadron Collider (VLHC).

ITEP Distance Scale summary

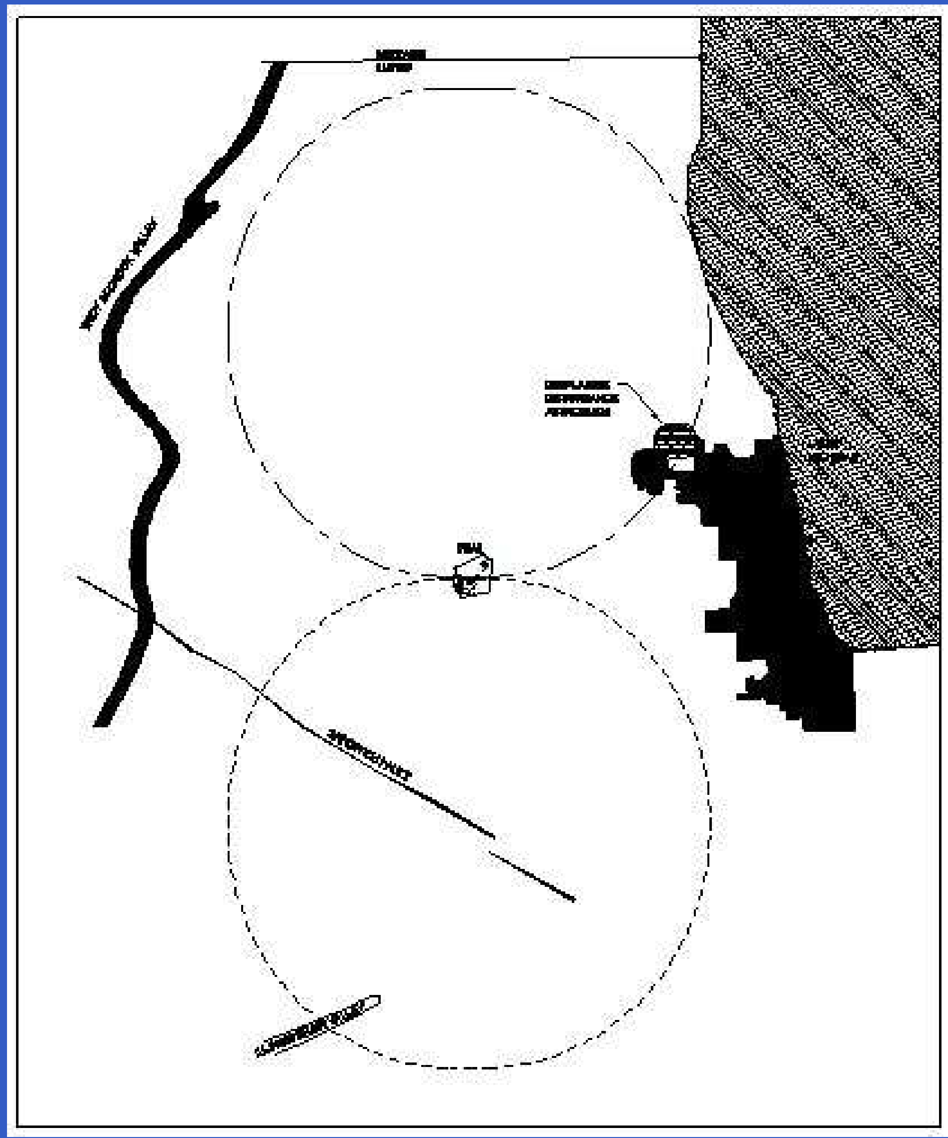


ITEP VLHC here

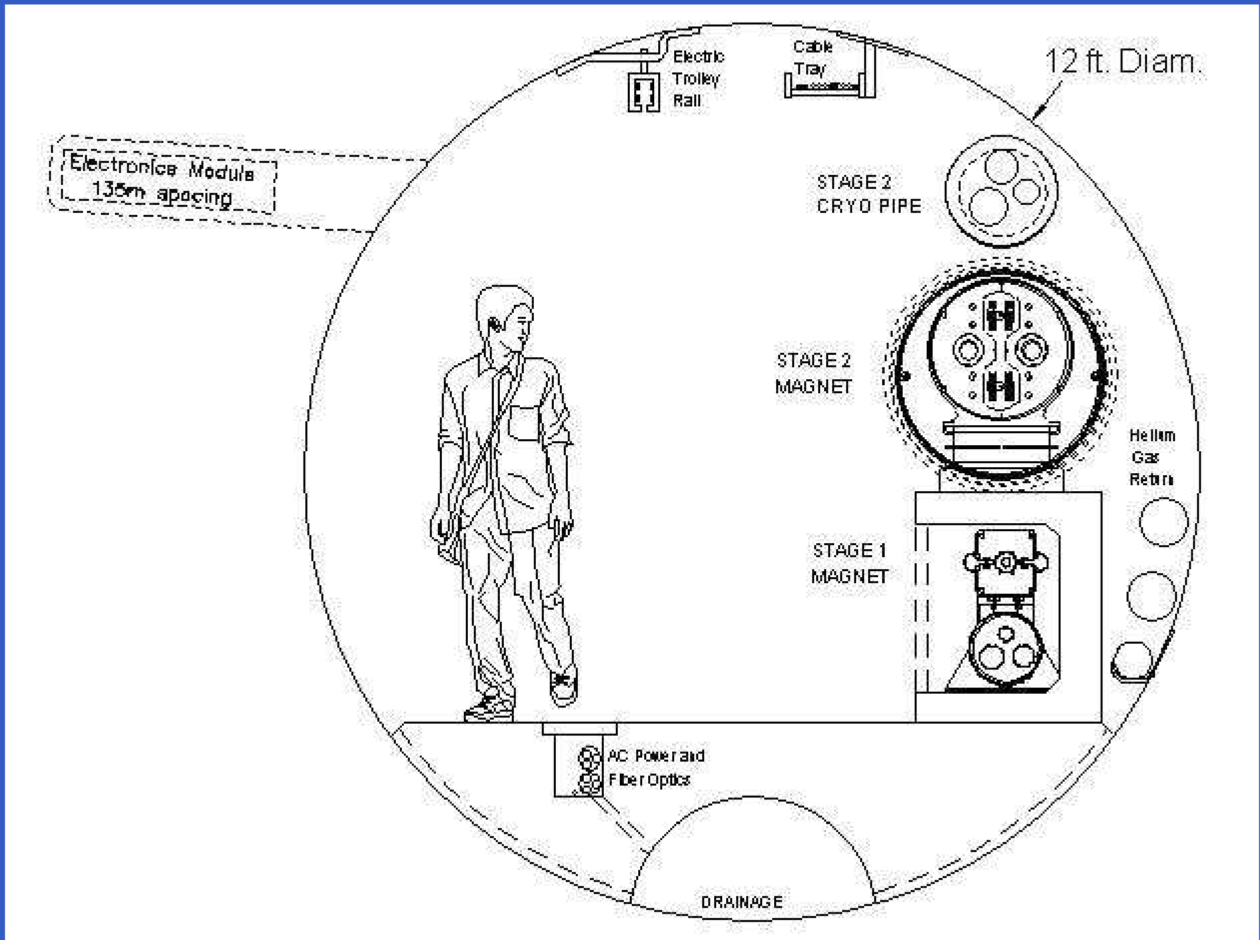


ITEP VLHC at CERN

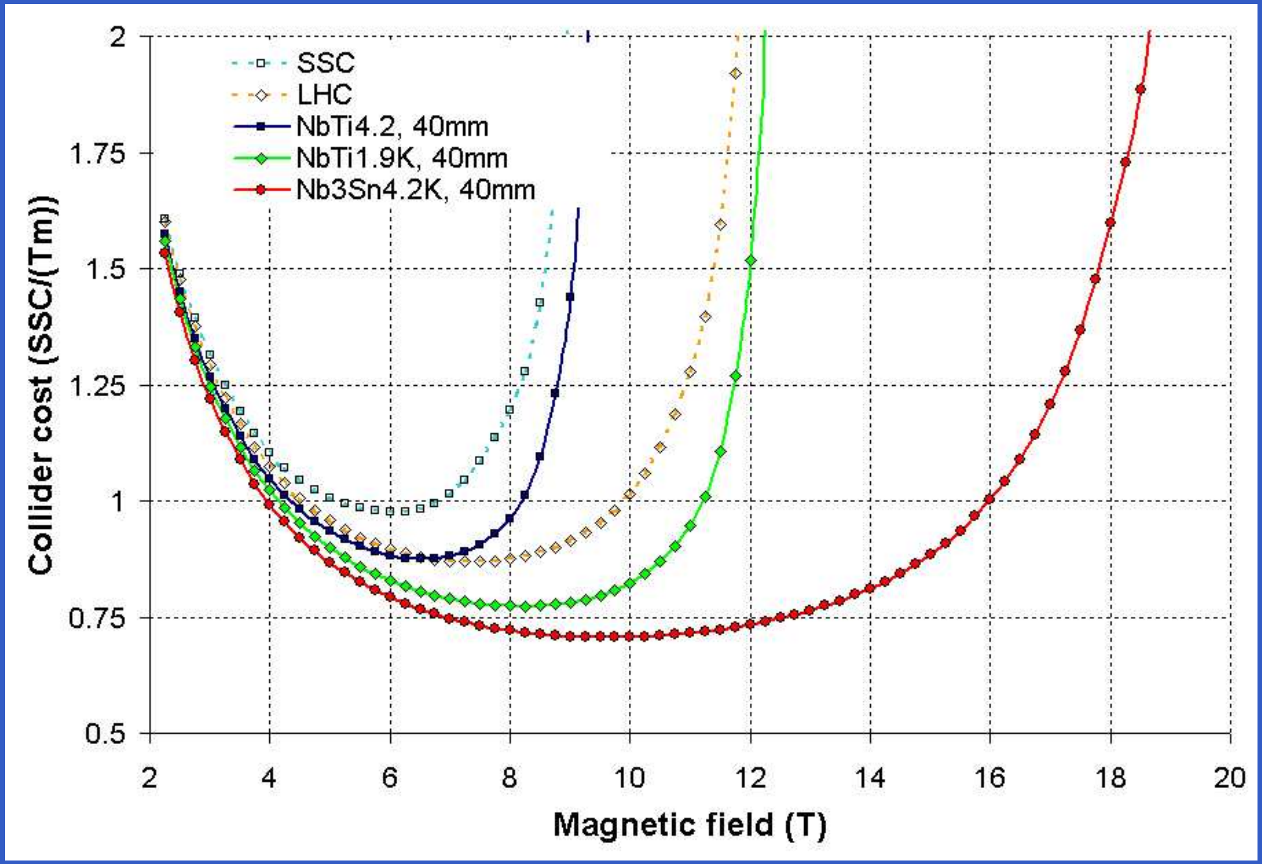
ITEP VLHC at Fermilab



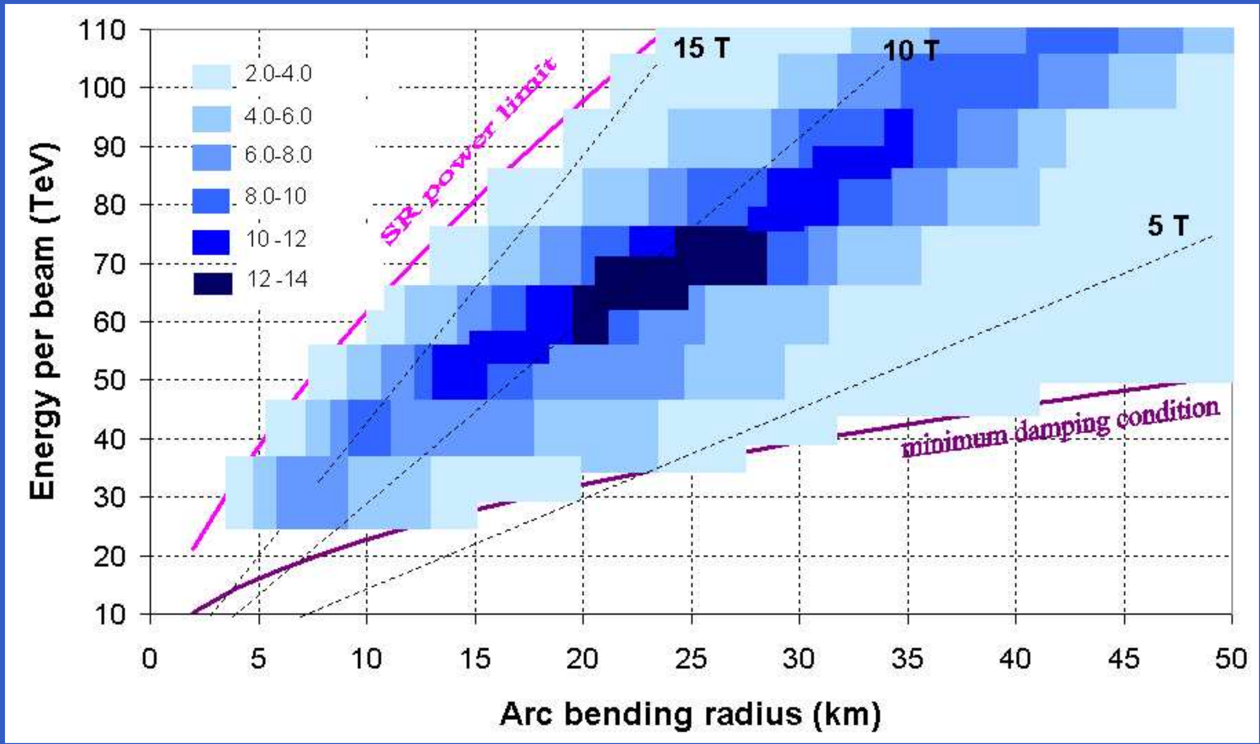
tunnel


Electric Trolley Rail
Cable Tray
12 ft. Diam.
Electronics Module 135m spacing
STAGE 2 CRYO PIPE
STAGE 2 MAGNET
Helium Gas Return
STAGE 1 MAGNET
AC Power and Fiber Optics
DRAINAGE

ITEP VLHC cost



ITEP **VLHC** size



Very Large Hadron Collider

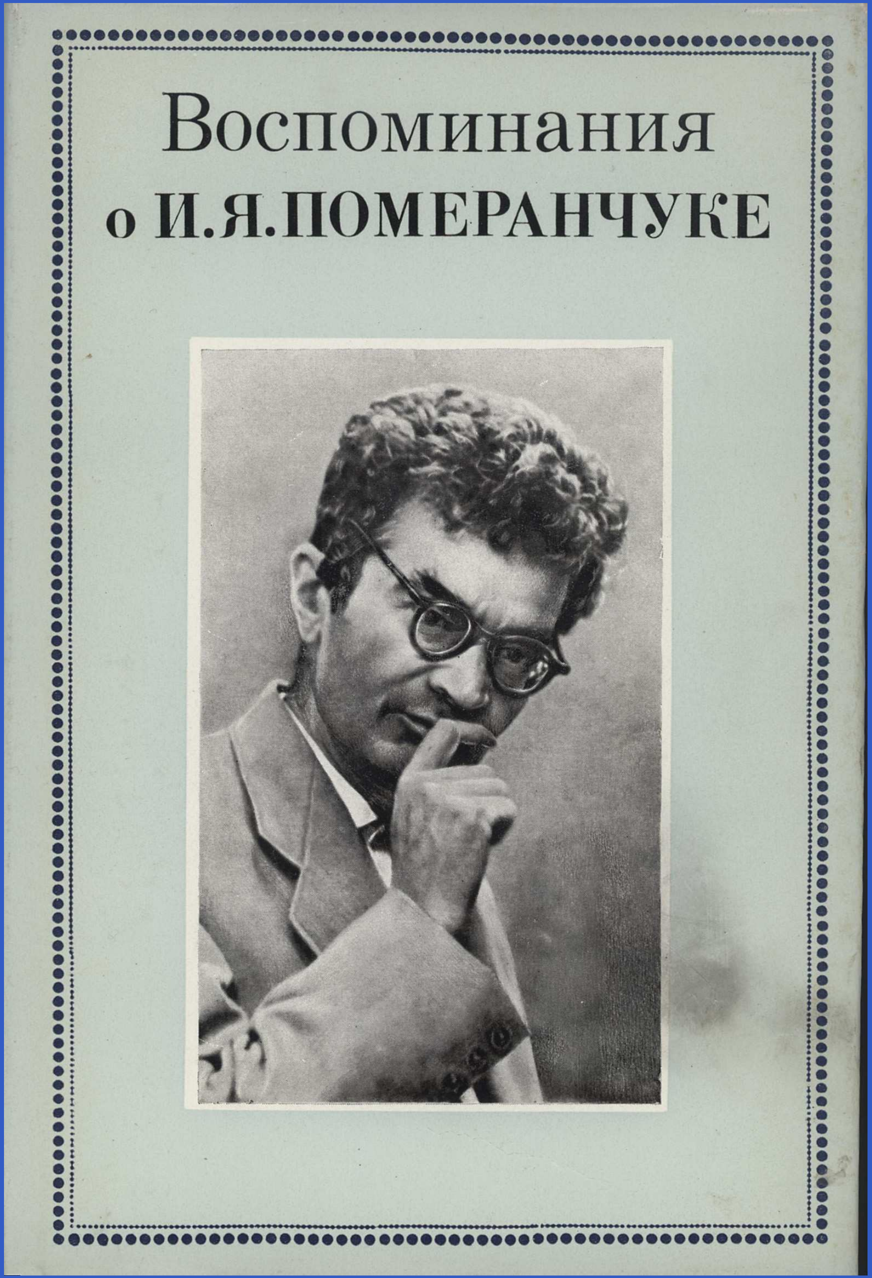
Stage-2 VLHC Conclusions

- The Stage 2 VLHC can reach 200 TeV in the 233 km tunnel.
- A large-circumference ring is a great advantage for the high-energy Stage-2 collider. A small-circumference high-energy VLHC may not be realistic.
  - The optimum magnetic field for a 100-200 TeV collider is less than the highest field strength attainable because of synchrotron radiation, total collider cost and technical risk.
- The minimum aperture of the magnet is determined by beam stability and synchrotron radiation, not by field quality.
- There is the need for magnet and vacuum R&D to demonstrate feasibility and to reduce cost.
  - This R&D will not be easy, will not be quick, and will not be cheap.

P. Limon

Two books

On a previous visit to ITEP, I received as a present two books:



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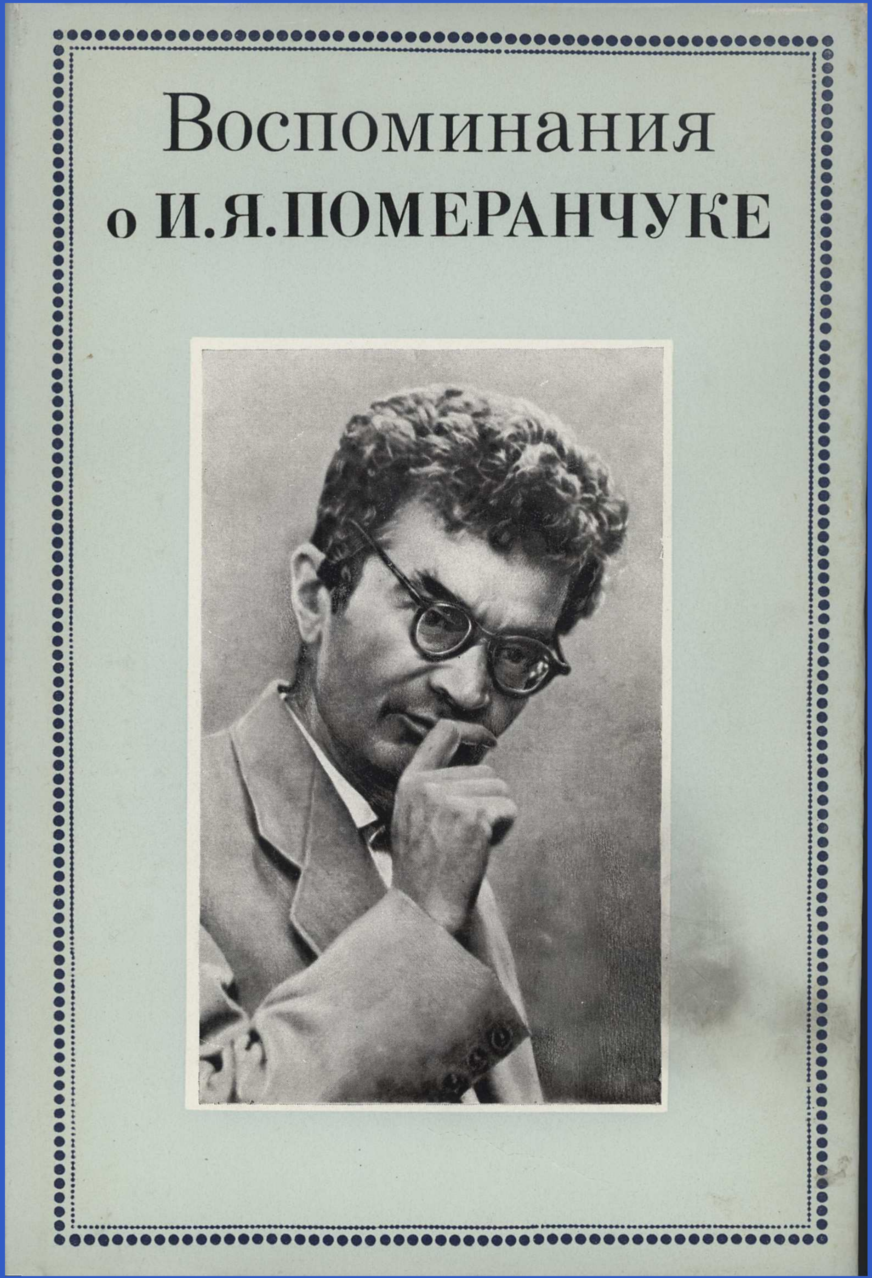
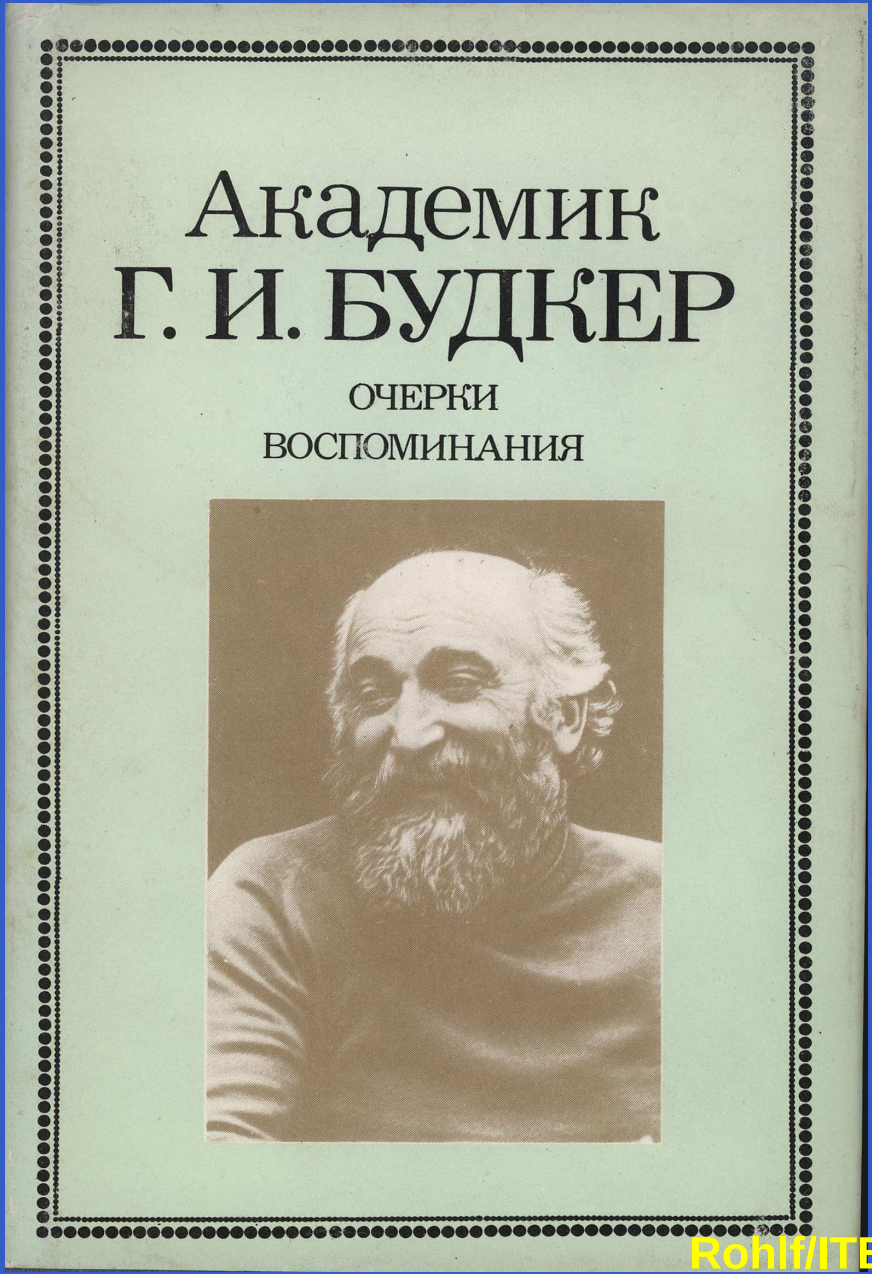
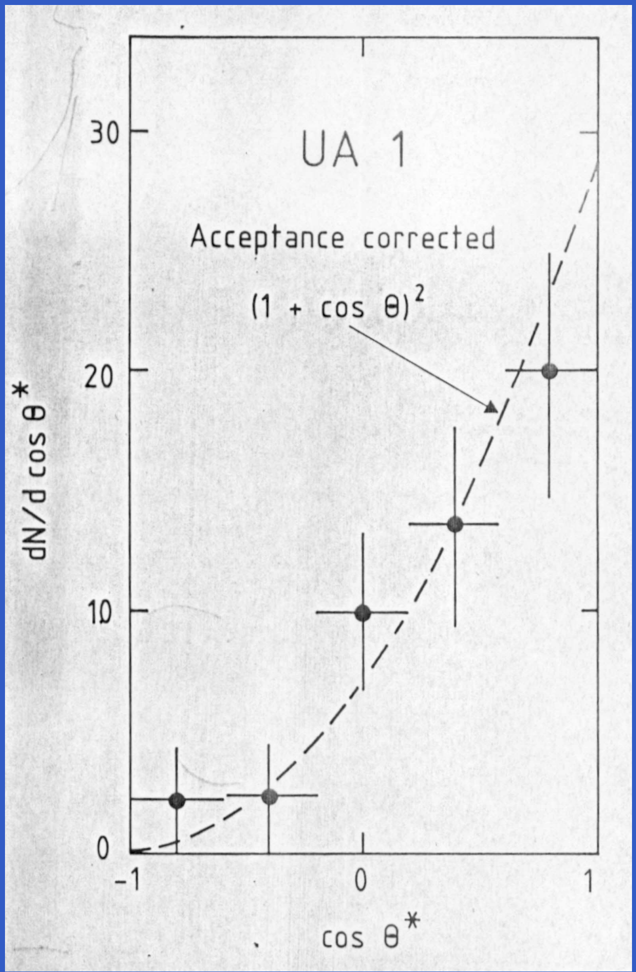




ITEP Personal note One letter

Shortly, after the publication of the W discovery in 1983, I received a letter from Lev Okun. In this letter he pointed out that the electron from Event C was traveling in the wrong direction...



J. Rohlf, Proceedings of the 12th International Conference on High Energy Accelerators, Fermilab August 11, 1983.

Supercollider physics explained in 5 slides...

L. Okun

FOREWORD: AN ENVELOPE

1. Transparencies
   swiss-watch-like LEP
   congratulations to L3
2. Program (Agenda)
   tight
3. Invitation
   a few words of encouragement
   Pomeranchuk.

To Prof. S. Ting:
Thank you for encouraging this talk.
L. Okun
ITEP Moscow
09.10.89

---

(1)

PHYSICS AT SSC

I SSC IS A FEW TeV MACHINE
1. SCALARLAND
2. SUPERWORLD
3. COMPOSITNESS

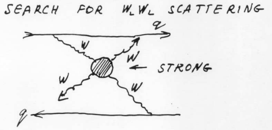
II SCALARLAND
1 ONE HIGGS
2. MANY HIGGSES
3 MASSES, MIXING ANGLES, CP-VIOLAT.
4. SELFCONSISTENCY

III LONGITUDINAL WIONS
1. WION ≡ WEAK INTERMEDIATE BOSON
   GENERIC W (W^+, W^-, Z^0)
2. LONGITUDINAL WIONS ⇒ LIONS
   MNEMONIC: W_L
3. HIGGSES TAME LIONS

---

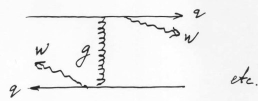
(2)

4. WILD LIONS VIOLATE UNITARITY
5. UNITARITY LIMIT : $\sqrt{s} = 1{,}7$ TeV
   $G_F s = 8\sqrt{2}\pi$, NOT $G_F s = 1$.
6. SEARCH FOR $W_L W_L$ SCATTERING



$Z_L Z_L$, W^+W^+, W^-W^-

7. BACKGROUND PROCESSES



8. TeV-hadrons ≡ Tadrons
   LIGHTEST OF THEM TeV-"pions"
   MAY BE MUCH LIGHTER THAN 1 TeV,
   LOOK LIKE HIGGSES.

---

(3)

IV HIGGS MASS
1. LOWER LIMIT ~ 10 GeV
2. UPPER LIMIT ~ 700 GeV
3 $m_H = 2\lambda\eta$, WHERE
   $V(\varphi) = \lambda^2(|\varphi|^2 - \eta^2)$, $\eta = 2^{-3/4} G_F^{-1/2} = 174$ GeV
4. LANDAU - POMERANCHUK GHOST
   λ IS LOGARITHMICALLY RUNNING
   $\lambda \sim 1/\ln(\Lambda/Q)$
5. QUADRATIC DIVERGENCIES
   WHY $\eta \ll m_{Pl}$?

V TWO POSSIBLE ANSWERS
1. SUPERSYMMETRY
2. CompositNESS

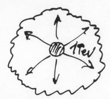
VI SUPERWORLD OF SPARTICLES
1. LIGHTEST OF "INOS" HAVE $M \lesssim 1$ TeV
2. SPARTICLES AND SUPERUNIFICATION

---

(4)

VII COMPOSITNESS
1. A LOT OF TADRONS
2. AN EXAMPLE: TECHNICOLOR

VIII A PARADOX
1. THEORISTS' HEADAKES ⇒
   EXPERIMENTALISTS' PROSPECTS
2. IS IT NOT DANGEROUS ?
3. UTOPIA IS DANGEROUS ...
4. THIS IS NOT A DOGMATIC UTOPIA
5. PLURALISTIC AND PRAGMATIC APPROACH



6. WHATEVER DIRECTION WE CHOOSE...

IX HISTORIC ANALOGY
1. CLASSICAL RADIUS OF ELECTRON
   $r_0 = e^2/mc^2 \simeq 10^{-13}$ cm
   AT $r < r_0$ CED FAILED.

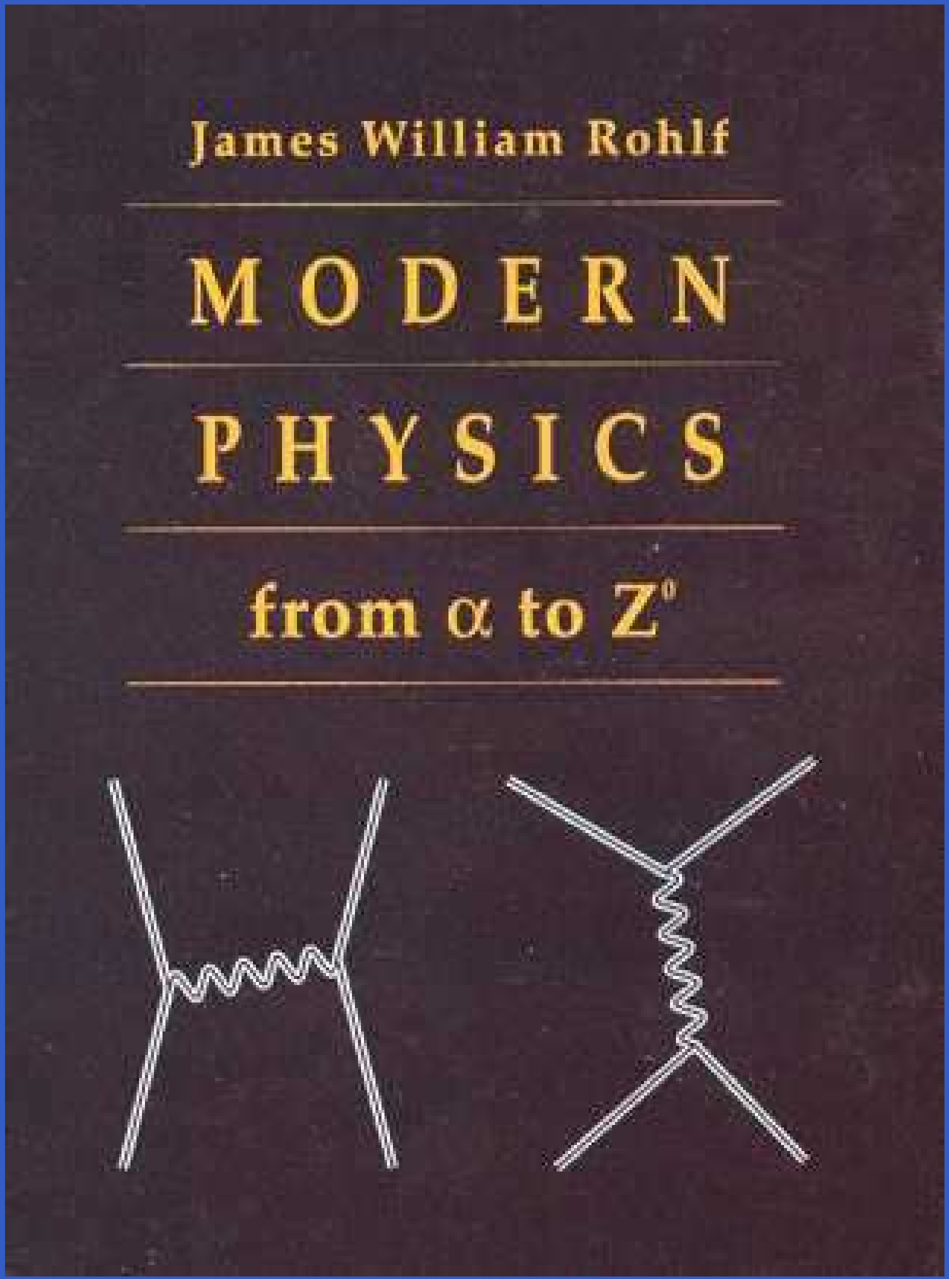
---

(5)

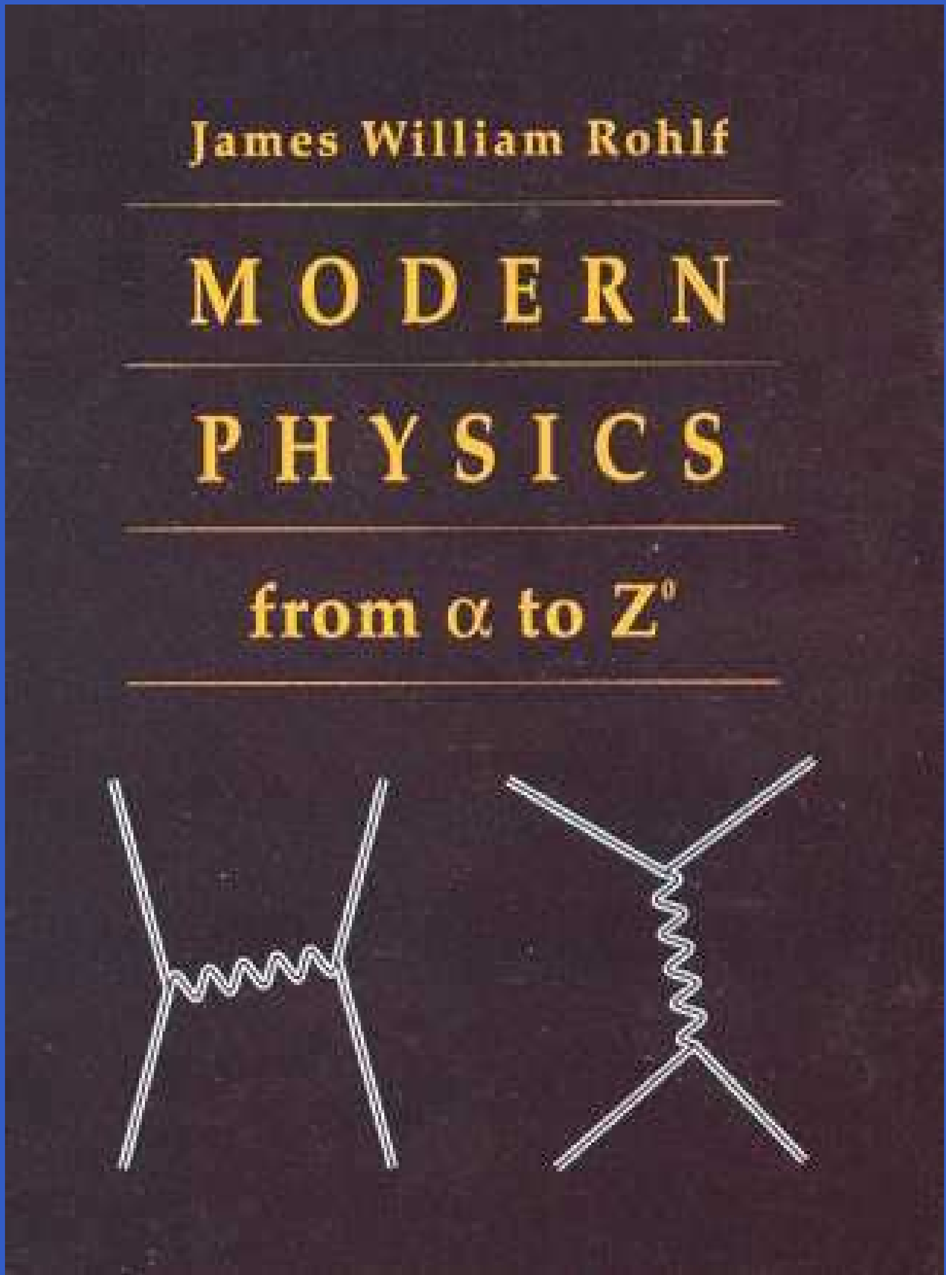
BUT THERE IS NOTHING SPECIAL
at $r \sim 10^{-13}$ cm OR $p \sim 400$ MeV/c
r_0 – "A PAPER TIGER".
2. HOWEVER AT $r_B = r_0/\alpha^2 = \hbar^2/me^2$
   NEW FUNDAMENTAL PRINCIPLE
   QUANTUM MECHANICS
3. AND AT $\lambda_C = r_0/\alpha = \hbar/mc$
   RELATIVISTIC QUANTUM FIELD
   THEORY
   r_B and λ_C WERE REAL "TIGERS"

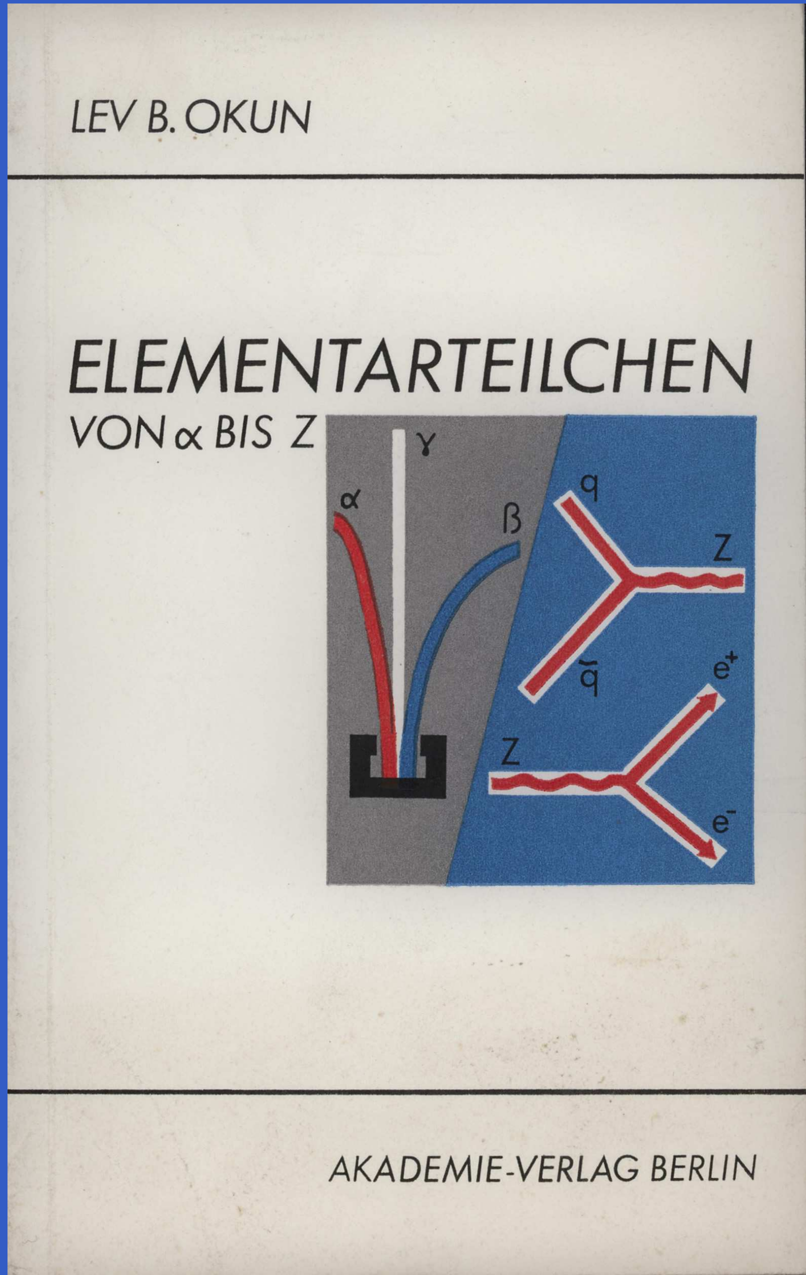
X CONCLUSIONS
1. EXTRAPOLATION FROM 0.1 TeV to 1 TeV
2. NEW FUNDAMENTAL PRINCIPLE?
3. NEW FUNDAMETAL PARTICLES!
4. NEW UNDERSTANDING
   NEW CONNECTIONS
   NEW VISTAS!

ITEP **Personal note** Two more books...



ITEP **Personal note** Two more books...





ITEP Personal note

Thanks to Lev Okun and Michael Danilov
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