particles
quarks
leptons
force particles
Higgs field...

cosmology
extra dimensions
dark matter
dark energy
black holes

http://www.rockefeller.edu/events/string_fever/transcript.php
### The laboratory

#### STUDENTS
http://physics.rockefeller.edu/dino/myhtml/students.html

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>HEP lab established on campus, R. Cool HOL</td>
<td>KG Associate Professor</td>
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<tr>
<td>1971</td>
<td>CERN: co-establish existence of quarks</td>
<td>KG Associate Professor</td>
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<tr>
<td>1970s</td>
<td>Fermilab: confirm rising total cross sections</td>
<td>KG Associate Professor</td>
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<tr>
<td>1980s</td>
<td>Brookhaven: νp scattering $\rightarrow$ evidence for $Z$</td>
<td>KG Associate Professor</td>
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<td>1981</td>
<td>Fermilab: top-quark discovery</td>
<td>KG Associate Professor</td>
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<tr>
<td>1995</td>
<td>Fermilab: top-quark discovery</td>
<td>KG Associate Professor</td>
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<tr>
<td>1996</td>
<td>Fermilab: quark sub-structure search</td>
<td>KG Associate Professor</td>
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<tr>
<td>2000</td>
<td>Fermilab: running of strong coupling</td>
<td>KG Associate Professor</td>
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<tr>
<td>2009</td>
<td>HERA @DESY lepto-quark search</td>
<td>KG Associate Professor</td>
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<tr>
<td>2009</td>
<td>Fermilab: top-quark mass</td>
<td>KG Associate Professor</td>
</tr>
<tr>
<td>2010</td>
<td>Fermilab: W-mass</td>
<td>KG Associate Professor</td>
</tr>
</tbody>
</table>

**1971 - Diffraction** - npQCD (KG+lab) $\rightarrow$ dark energy?

- Visiting fellow: Renata Rodrigues
- Adjunct faculty: Sebastian White, Michele Gallinaro, Valery Khoze
- Instrument shop: Vadim Sherman (supervisor), Josip Golia
- Admin. secretary: Janet Kallo

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RU@LHC 24 May 2010

Experimental HEP at RU

K. Goulianos
1970s @ CERN: evidence for quarks

NY times, April 20, 1988

Dr. Cool, a professor of high-energy physics at Rockefeller University, also conducted research at the European Center for Nuclear Research in Geneva. It was there in the 1970's that he and colleagues performed experiments that, together with data from other investigators, showed the quark to be a building block of neutrons and protons. Previously, the neutron, proton and electron had been regarded as the fundamental particles in nature.
RU and the SM

Glashow, Salam, and Weinberg - 1979 Nobel prize
predict C in 1979 - Glashaw, Iliopoulos (RU), Miani

CERN 1970s
My PhD thesis@ CU 1962 (thesis ’63)

evidence for q’s

Quarks

up
charm
top

down
strange
bottom

Leptons

electron
muon
tau

νₑ
ν₅μ
ν₅τ
W
Z

ν₅μp → ν₅μp

BNL 1981

Fermilab 1995

Evidence for Z

Z discovered directly in 1983 at CERN

Mγ, g = 0
M_W, Z ~ 100 M_p
M_top ~ M_gold

Higgs field generates mass
The big bang
Blow-hole at Grand Cayman
black hole eats star!

In this illustration, an arrow points to the doomed star. Part of its mass, shown by the white stream, was swallowed by the black hole.

Star No Match for Black Hole
Elementary Particles

Aristotle 450 BC

demokritos 1869

Mendeleyev 1897

Thomson 1910

Rutherford 1962

Gell-Mann

earth
water
air
fire
atom
periodic table
electron
nucleus
quarks

Rutherford Experiment

Source → α-particles

Large angle scattering → atoms have nuclei
Searching for quark substructure at Fermilab

No substructure found down to ~ $10^{-17}$ cm

CDF Run II Preliminary

- NLO pQCD EKS CTEQ 6.1M, $(\mu = m_T^{1/2})$
- Midpoint $R_{\text{core}} = 0.7$, $f_{\text{nwq}} = 0.75$, $R_{\text{sep}} = 1.3$
- $0.1 < |y| < 0.7$
- $L = 385$ pb$^{-1}$

10 orders of magnitude!
SYMMETRY

Strangeness: $S$

- $u$: $I_3 = 1/2$, $S = 0$, $Q = 2/3$
- $d$: $I_3 = -1/2$, $S = 0$, $Q = -1/3$
- $s$: $I_3 = 0$, $S = -1$, $Q = -1/3$

Isotopic spin: $I_3 = Q - (B + S)/2$
String Theory

Particles correspond to the vibration modes of a string in 10 dimensions

Gravity is included!

Pythagoras applied it to music in 400 BC:

\[ 1 + 2 + 3 + 4 = 10 \]

http://www.aboutscotland.com/harmony/prop.html
The MiniPlugs @ CDF – made @RU
About 1500 wavelength shifting fibers of 1 mm dia. are 'strung' through holes drilled in 36 lead plates sandwiched between reflective Al sheets and guided into bunches to be viewed individually by multi-channel photomultipliers.
QCD - Quantum Chromo-Dynamics
The Theory of Strong Interactions

COLOR FORCE

proton (colorless)

αs

asymptotic freedom - 1973

0 1
Distance 1 fermi

Strong coupling

αs