Accelerator based
High Energy Particle Physics
Particle Hunters at UTK

Stefan Spanier
Thomas Handler

P599 Seminar, Wednesday 10th October 2007
The Beginnings - Cosmic Rays

• 1785 - Coulomb notices that a charged body left in air gradually loses its charge.

• 1905 - Rutherford concludes radioactivity in the earth is responsible.

• 1912 - Victor Hess reaches 5350 m altitude in a hydrogen filled balloon and shows conclusively that the rate of discharge increases significantly with height. He concludes that there is an extraterrestrial source of radiation.

(receives Nobel prize 1936)
Early Detectors

Chamber filled with supersaturated vapor (water)

Expand and illuminate to take photograph

in magnetic field

Charged particle  Free ions  Condensation droplets
Observation of Anti-Electron
1932 C.D. Anderson (Caltech)

Fits into theory: P.A.M Dirac relativistic wave equation for electrons predicts the existence of particles with charge opposite to electrons but same mass.


- Equation is invariant under C-parity transformation (fundamental symmetry)
  \[ C \; e^- = e^+ \]

- Other important symmetry is parity P:
  \[ P \; \vec{r} = -\vec{r} \]
Accelerators

Produce particles in laboratory under well defined conditions

• Electric field switched in right moment to give particles a kick

• Charged particles on circular path in magnetic field
  Increasing radius with increasing particle momentum (kinetic energy)

Energy $E \sim 1$ Million eV hit target.

speed $\beta = p/E$

First cyclotron
1929 E. Lawrence in Berkeley
Accelerators: Resolution of smaller Dimensions

Wavelength \approx \text{dimension to be resolved}

Wavelength \propto \frac{1}{\text{Energy}}

\Rightarrow \text{The smaller dimension the higher the energy of the light (particle)}

Energy \approx 10 \text{ kilo electron Volt (eV)}

1\text{eV} = \text{kinetic energy an electron gains in a electric field of } 1\text{ Volt}

> 100 \text{ MeV}
Linear Accelerators

Electromagnetic wave is traveling, pushing particles along with it

Electromagnetic Wave as seen from above (red is +, blue -)

Moving electric wave

[Diagram of linear accelerator]

Radiation therapy

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• 2 mile long accelerator (can be seen from moon)
• Final energy of 45 GeV for electrons/positrons
• Used to fill PeP II B-factory to measure CP violation
Particle Proliferation - Particle Zoo

e.g. $e^+ - e^-$ collision at 'very high' energies

$J/\psi$ (cc)

Charm quark discovery
Particle Spectroscopy – Analogy Atomic Spectra

learn about underlying structure and forces (interaction)
e.g. hydrogen atom $\rightarrow$ electric charge of proton and electron $\rightarrow$ Coulomb force $\rightarrow$ electromagnetic interaction

Laser

Excited state

Ground state

transition with well defined quantum numbers

Lorentz shape
(Breit-Wigner resonance)

$width \sim 1/lifetime$
**Particles in the Standard Model**

**Building Blocks**

<table>
<thead>
<tr>
<th>Quarks</th>
<th>Leptons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge</td>
<td></td>
</tr>
<tr>
<td>+ 2/3</td>
<td>e^- μ^- τ^-</td>
</tr>
<tr>
<td>- 1/3</td>
<td>ν_e ν_μ ν_τ</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Anti-Particles</th>
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</thead>
<tbody>
<tr>
<td>Charge</td>
</tr>
<tr>
<td>+ 1/3</td>
</tr>
<tr>
<td>- 2/3</td>
</tr>
</tbody>
</table>

- **Particles**
- **Anti-particles**

Standard Model does not ‘predict’ any of the masses (parameters).

Forces …

Latest addition 1995
Tevatron at Fermilab
Forces in the Standard Model

4 fundamental forces

**Electric Magnetic Weak**

**Strong**

**Gravity**

**Maxwell**

**electroweak**

**Photons** $m=0$

$W^+, W^-, Z^0$ $m = 80, 90$ GeV

**Gluons** $m = 0$

**Gravitons** $?$

~ $10^{19}$ GeV

Planck energy

~ $10^{15}$ GeV $?$

GUT scale

coupling constants unify

> $100$ GeV

Standard Model

today’s accelerators just about ...

Spontaneous Symmetry Breaking during evolution of the Universe separates forces? Mechanism? Unification?

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Running Coupling Constants

<table>
<thead>
<tr>
<th>Force</th>
<th>relative coupling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong</td>
<td>$\alpha_S$ 1 $\rightarrow$ 0.12</td>
</tr>
<tr>
<td>Electromagnetic</td>
<td>$\alpha$ 1/137 $\rightarrow$ 1/128</td>
</tr>
<tr>
<td>Weak</td>
<td>$\alpha_W$ $10^{-6}$</td>
</tr>
<tr>
<td>Gravity</td>
<td>$\alpha_G$ $10^{-39}$</td>
</tr>
</tbody>
</table>

Behavior of coupling constants supports idea, but no common intersection?

- new forces
- higher symmetries e.g. Supersymmetry?
Input for Model of Evolution of the Universe?

- ~14 billion years
- 1 meV: Today (T=2.73K)
- 1 eV: Matter domination, onset of gravitational instability
- 1 MeV: Nucleosynthesis (D, He, Li)
- 1 GeV: Quark → Hadron, protons, neutrons form
- $10^3$ GeV: Electroweak Phase Transition
- Particle Desert: Supersymmetric particles?
- $10^{15}$ GeV: Grand Unification
- $10^{19}$ GeV: Planck Epoch
Energy Budget of the Universe?

- Dark Energy: ~70%
- Dark Matter: ~25%
- Antimatter: 0%

Heavy elements: 0.03%
Neutrinos: 0.3%
Stars: 0.5%
Free hydrogen and helium: 4%
Dark matter: ~25%
Dark energy: ~70%
Many Open Questions

• What, really, is mass?
• Are quarks and leptons actually fundamental?
• Are there more particles we have not seen yet?
• Why are there exactly three generations of quarks and leptons?
• Why do they have so different masses?
• Why do we observe matter and almost no anti-matter in the Universe?
• What is this "dark matter"?
  Can we find candidate particles?
• Are there extra dimensions?
• How does gravity fit into all of this?

→ Answer to any of these questions is worth a Noble Prize
Standard Model Mass Generation

and electroweak Symmetry Breaking introducing the Higgs Particle?

Particles acquire masses ...

The Higgs particle generation

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Higgs Search

Higgs Mass = 100 .. 300 GeV ?

... ongoing at Tevatron
The Large Hadron Collider (LHC) at CERN, Geneva

Starts collisions in 2008!
CERN

- Founded in 1954 (12 countries)
- Now: 20 European member states
  + United States, Russian Federation, India, Japan

Distribution of All CERN Users by Institute on 8 September 2004
CERN – Where the World Wide Web was born
• Proton-proton collider (14 TeV center-of-mass energy)
• 27 km in circumference, 50-175m deep
• between Jura mountains (France) and Lake Geneva (Switzerland)
The LHC
Simulation of a Proton-Proton Collision

Muon tracks from A Higgs particle Decay?
The Compact Muon Solenoid (CMS) Detector

CMS Detector assembled in SX5.
11 independent rings
The Compact Muon Solenoid (CMS) Detector

Solenoid Magnet Assembly

4 Tesla magnetic field

Higgs $\rightarrow$ 4 muons
The Compact Muon Solenoid (CMS) Detector
The CMS Pixel Detector

- 3-d tracking with about **66 million** channels
- Barrel layers at **radii = 4.3cm, 7.2cm and 11.0cm**
- Pixel cell size = **100 µm x 150 µm**
- ~15k front-end chips and ~**1m² of silicon**
The LHC Computing

- 1 billion proton-proton collision events per second in detector
- 100 events of interest/second recorded permanently (trigger/filter)
  ➜ 1 GByte/second
  + Raw data, processed data, simulated events
  ➜ 15 PetaBytes/year (= 15 M GBytes/year = 20 M CDs)
  ➜ computing power equivalent: ~ 100,000 standard PC processors.
  • … needs global distribution of people & resources
The LHC Global Data GRID (2007+)

CMS Experiment

Tier 0
Tier 1
Tier 2
Tier 3
Tier 4

Online System

CERN Computer Center

Korea
UK
Russia
USA

Tier 0
Tier 1
Tier 2
Tier 3
Tier 4

Physics caches

150 - 1500 MB/s
10-40 Gb/s
>10 Gb/s
2.5-10 Gb/s

Tier 4

…within the framework of the OpenScienceGrid (OSG)

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Cluster Computing at UTK

Part of the custom compute Node cluster

Assembly of Quadcore machine with 2TByte disk storage

Switch with 10GBit connection
CMS at UTK

• Many opportunities for involvement
• Main upcoming phase is commissioning and systematic studies
• Data Analysis of Standard Model Reactions
• Search for New Particles