I.1 Outline of ATLAS & CMS Lectures

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<td>Part II: Experimental Environment, pp Collisions, Kinematics, ATLAS &amp; CMS</td>
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I.2 List of References / Suggested Reading

**General/Overview:**

**ATLAS & CMS:**

**Proton-Proton Collisions:**
I.2 List of References / Suggested Reading

Higgs:


Supersymmetry:


Exotic New Physics:


Chapter I:
Introduction, the Standard Model and its Problems
I.3 The LHC Ring, ATLAS & CMS
Across the street from the CERN main gate
I.5 Underground Cavern at Pit-1: ATLAS

Length = 45 m
Width = 32 m
Height = 35 m
I.6 Grand Unification & Running Couplings

• **GUTs = Grand Unified Theories**

• Best explanation for quark charges, generations of quarks and leptons

• Predictions:
  - Unified interactions at large energies $\rightarrow$ same couplings
  - Couplings at other energies depend on quantum corrections
    $\rightarrow$ Renormalization Group Equations (RGE) for masses and couplings

\[ \text{QED} \quad \text{QCD: Gluon self-interaction} \]
I.7 Measurements of Running Couplings

Electromagnetic interaction

Strong interaction

\[ e^+e^- \rightarrow e^+e^- \]

LEP

\[ 1.81 \text{GeV}^2 < -Q^2 < 6.07 \text{GeV}^2 \]
\[ 12.25 \text{GeV}^2 < -Q^2 < 3434 \text{GeV}^2 \]
\[ 1800 \text{GeV}^2 < -Q^2 < 21600 \text{GeV}^2 \]

\[ \alpha_s(Q) \]

\[ \alpha = \text{constant} = 1/137.04 \]

\[ \alpha_s(M_Z) = 0.1189 \pm 0.0010 \]
I.8 Extrapolation of Couplings in the SM

Rotation: \( \alpha_1 \), \( \alpha_2 \), \( \alpha_3 \)

\[ \alpha_s(M_Z) = 0.117 \pm 0.005 \]
\[ \sin^2 \theta_{\text{MS}} = 0.2317 \pm 0.0004 \]

\[ \rightarrow \text{Grand Unification not possible} \]
I.9 Dark Matter in our Universe

Evidence from:

- Rotational curves of galaxies: $\Omega_{DM}$
- Gravitational lensing: $\Omega_{DM}$
- Cosmic microwave background (CMB): $\Omega_\Lambda \Omega_{DM}$
- Expansion of the universe (supernovae): $\Omega_\Lambda \Omega_M$
- Big Bang Nucleosynthesis: $\Omega_B$

$\Omega$: energy density
$M$ = Matter
$DM$ = Dark Matter
$\Lambda$ = cosm. constant
$B$ = Baryons
I.10 Dark Matter in Galaxies

- Gravitation $\sim 1/r^2 \rightarrow$ Rotation curves à la Kepller

$\Rightarrow$ Halo of invisible matter
I.11 Gravitational Lensing

Contribution from dark matter?!
I.12 Dark Matter & Colliding Galaxies

Here is the Hubble Space Telescope Image:

analysis of Bradac, Clowe, Gonzalez, Marshall, Forman, Jones, Markevitch, Randall, and Schrabback

From talk by M. Peskin (SLAC)
I.12 Dark Matter & Colliding Galaxies

Here is the mass distribution reconstructed from gravitational lensing

From talk by M. Peskin (SLAC)
I.12 Dark Matter & Colliding Galaxies

The atomic matter is mainly in hot gas, emitting X-rays. The Chandra satellite measures this component (red). The gravitating mass is elsewhere (blue)!

From talk by M. Peskin (SLAC)
I.13 Dark Matter

Dark-Matter properties:

- Gravitationally interacting
- Not short-lived
- Not hot
- Not baryonic

→ Unambiguous evidence for new physics!