Particle Physics in the LHC Era
Organizers: Cao Zexian and Sabine Lammers

CHAIR:
Reinhard Schwienhorst, Michigan State University

SPEAKERS:
Particle Physics beyond Standard Model
Wang Qing, Tsinghua University, Beijing

The Status, Challenge and Promise of the Big Bang Machine and Its Experiments
Junjie Zhu, University of Michigan
Particle Physics in the LHC Era

Introduction

Reinhard Schwienhorst
Michigan State University

Chinese-American
Kavli Frontiers of Science
2011
The LHC question
The LHC question

- What happened in the very first moments after the big bang?
The LHC questions

Dark Matter?

and Dark Energy?
The LHC questions

Dark Matter?

and Dark Energy?

Matter-Antimatter asymmetry?
The LHC questions

- Dark Matter?
- Origin of particle mass?
- and Dark Energy?
- Matter-Antimatter asymmetry?
The LHC questions

Dark Matter?

Origin of particle mass?

Matter-Antimatter asymmetry?

Why is the sun not exploding?
What makes the LHC era special

• We are now in a position to answer several of these questions

• Particle masses:
  – We will find the Higgs boson or we will find that there is no SM Higgs

• Matter-antimatter asymmetry:
  – We hope to find symmetry-breaking mechanisms

• Dark matter:
  – We expect to find the particle responsible for dark matter and measure its properties
Large Hadron Collider
Proton accelerator, quark/gluon collider

incoming proton 1

LHC

ew particle

decay products

decay products

incoming proton 2

space

time

detector

Saturday, November 5, 2011
LHC experiments
LHC experiments

CMS

ATLAS
LHC experiments

CMS

LHCb

ATLAS
Expected LHC measurements

• Everyone dreams!
• Find new particles
  – Find Higgs particle
  – Find dark matter particle
• Find answers to our puzzles
  – Higgs, dark matter, matter vs antimatter
• Find something unexpected
  – Find many other new particles
  – Find new puzzles
LHC measurements have started

• Lots of measurements already made
  – With first year dataset

• Sensitivity for many measurements now best of the world

• No new particles discovered yet

• No new mechanisms discovered yet

• Uncharted territory
  – Precision measurements are important
  – Double beam energy in 2014
  – Run for the next 20 years
Reinhard Schwienhorst

Three neutrinos and oscillations

- LHC will (likely) not be able to probe neutrino mass origins
- Several experiments ongoing to understand neutrino masses better
- See poster by Chris Walter
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Backup slides
Global physics experiments

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GERMANY  1221
GREECE  109
HUNGARY  55
ITALY  1428
NETHERLANDS  171
NORWAY  82
POLAND  193
PORTUGAL  134
SLOVAKIA  61
SPAIN  329
SWEDEN  72
SWITZERLAND  351
UNITED KINGDOM  701

6361

OBSERVER STATES
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ISRAEL  60
JAPAN  204
RUSSIA  829
TURKEY  67
USA  1664

2935

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ALBANIA  2
ARGENTINA  11
ARMENIA  12
AUSTRALIA  19
AZERBAIJAN  1
BELARUS  20
BRAZIL  79
CANADA  150
CHILE  3
CHINA  84
CHINA (TAIPEI)  50
COLOMBIA  9
CROATIA  16
CUBA  4
CYPRUS  8
EGYPT  5
ESTONIA  11
ESTONIA  11
ESTONIA  11
EGYPT  5

LITHUANIA  12
MALTA  1
MEXICO  32
MONTENEGRO  1
MOROCCO  5
NEW ZEALAND  8
PAKISTAN  16
PERU  2
QATAR  1
ROMANIA  62
SAUDI ARABIA  2
SLOVENIA  29
SOUTH AFRICA  11
THAILAND  1
TUNISIA  1
UKRAINE  18
UZBEKISTAN  1

828
LHC Physics Program

![Graph showing the cross-sections for various processes as a function of center-of-mass energy (E_{CM})](image)

- \(\sigma_{\text{TOT}}\) (black line)
- \(\sigma_{b}\) (gray line)
- \(\sigma_{W}\) (blue line)
- \(\sigma_{Z}\) (light blue line)
- \(\sigma_{\text{Jet} (E_T>100\text{GeV})}\) (red line)
- \(\sigma_{\text{Top}}\) (green line)
- \(\sigma_{\text{Higgs} (m_H=150\text{GeV})}\) (red line, labeled with 7 TeV)

Events/sec for L = \(10^{33}\) cm\(^{-2}\)s\(^{-1}\)
Particle production at the LHC

Production cross-section (femtobarns)

- $10^{14}$ particles
- $10^{12}$ particles
- $10^{10}$ particles
- $10^{8}$ particles
- $10^{6}$ particles
- $10^{4}$ particles
- $10^{2}$ particles

LHC

Quark-antiquark production

- Bottom quark pairs
- W bosons
- Z bosons
- Top quarks

Origin of dark matter & particle masses

Something unexpected?
ATLAS and the LHC - reaching beyond
ATLAS and the LHC - reaching beyond
10^{-6} \text{ seconds after the big bang}

lead-lead

10^{-12} \text{ seconds after the big bang}

incoming proton 1 \rightarrow \text{new particle} \rightarrow \text{decay particles}

incoming proton 2 \rightarrow \text{new particle} \rightarrow \text{decay particles}
The Questions have been clear for a while

• Origin of electroweak symmetry breaking
  – Why does the sun shine and not explode?
• Origin of particle masses
  – Why isn’t everything moving at the speed of light?
• Matter-antimatter asymmetry
  – Why haven’t I annihilated with my antimatter self?
• Dark matter
  – 80% of the matter in the universe is invisible
• Dark energy
  – 95% of the energy in the universe is in an unknown form
Particle Physics in the LHC era session

• Junjie Zhu, University of Michigan Experimental overview

• Wang Qing, Tsinghua University, Beijing Theoretical challenges

• Discussion