Looking Deep into Hadrons in an Era of B-factories and the Large Hadron Collider

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The University of Texas at Dallas
Introduction:
from Newtonian physics to quantum mechanics
particle physics – building blocks, dynamics, hadrons
experimental apparatus – colliders and detectors

The B-factory Experiments
surprising discoveries

The Large Hadron Collider
a few highlights on the ‘high mass’ particles
observations of beauty and charm at the LHC
prospects for the near future

Conclusion and Summary
Gravity seems to apply everywhere

Gravity

\[ F_G = G \frac{Mm}{r^2} \]
Newton’s Apple and the Solar System

- Stunning success when the **gravitational force** & Newtonian physics is applied to the solar system.

- A very visible ‘**bound system**’ in which objects are confined to a finite space.

**Physics:**

- Gravitational force: $F_G = G \frac{Mm_i}{r_i^2}$

- Centripetal motion: $F_C = \frac{m_i v_i^2}{r_i}$

$$F_G = F_C; \quad r_i = G \frac{M}{v_i^2}$$

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Atoms and Molecules
Quantum Mechanics

binding of atoms: EM force

\[ -\frac{\hbar^2}{2m} \nabla^2 + V(r) \Psi(r) = E \Psi(r) \]
### Quarks, Leptons and Gauge Bosons

<table>
<thead>
<tr>
<th>generation</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>gauge bosons</th>
</tr>
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<tbody>
<tr>
<td><strong>Quarks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>u</td>
<td>c</td>
<td>t</td>
<td>gluon</td>
</tr>
<tr>
<td>(mass / strength)</td>
<td>(0.005)</td>
<td>(1.5)</td>
<td>(180)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>d</td>
<td>s</td>
<td>b</td>
<td>γ</td>
</tr>
<tr>
<td>(mass / strength)</td>
<td>(0.01)</td>
<td>(0.2)</td>
<td>(4.7)</td>
<td>1/1,000</td>
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<td><strong>Leptons</strong></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>e</td>
<td>μ</td>
<td>τ</td>
<td>Z^0</td>
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<tr>
<td>(mass / strength)</td>
<td>(.0005)</td>
<td>(0.106)</td>
<td>(1.777)</td>
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<tr>
<td></td>
<td>ν_e</td>
<td>ν_μ</td>
<td>ν_τ</td>
<td>W^±</td>
</tr>
<tr>
<td>(mass / strength)</td>
<td>&lt;7 × 10^{-9}</td>
<td>&lt;.0003</td>
<td>&lt;0.03</td>
<td></td>
</tr>
</tbody>
</table>

No Room for 4th Generation

\[ Z \rightarrow f \bar{f} \]
Radial eq. gives $E_n$.

Coulomb potential

$Y_{lm}$ same for *any* $V(r)$

Orbital Angular Momentum

\[
L^2 = \ell (\ell + 1) \hbar^2 \quad \ell = 0, 1, 2, \ldots (n - 1)
\]
\[
L_z = m \hbar \quad -\ell \leq m \leq \ell
\]

$\ell \neq 0 \Rightarrow$ magnetic dipole moment, but

$\ell \neq 0$ energies degenerate w/o spin or B field
Positronium

\[ E_n = -\frac{13.6/2}{n^2} eV = -\frac{6.8}{n^2} eV \]

\[ \vec{S} \equiv \vec{S}_{e^+}^{spin\,1/2} + \vec{S}_{e^-}^{spin\,1/2} \]

\[ |1 + 1\rangle = \uparrow\uparrow \]
\[ |1 0\rangle = \frac{1}{\sqrt{2}} (\downarrow\downarrow + \uparrow\uparrow) \]
\[ |1 - 1\rangle = \downarrow\downarrow \]
\[ |0 0\rangle = \frac{1}{\sqrt{2}} (\uparrow\downarrow - \downarrow\uparrow) \]

\[ \vec{J} \equiv \vec{L} + \vec{S} \]

\( s = 1: \ j = (\ell - 1), \ (\ell + 1) \) triplet (ortho – Ps)
\( s = 0: \ j = \ell \) singlet (para – Ps)

Positronium Fine Structure

R.A. Ferrel, Phys. Ref. 84, 858 (1951)
Mesons: most commonly produced in experiments

Q=+1, and it’s called a $\pi^+$

$M \sim 140 \text{ [MeV}/c^2]$  
Lifetime $\sim 2.6 \times 10^{-8}$ [s]

binding of mesons & baryons: strong force  
Quantum Chromodynamics (QCD)

$V_{QCD} = -\frac{4}{3} \frac{\alpha_s}{r} + kr$

gauge group SU(3)

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Baryons: most of the visible mass to us

gauge group SU(3)
overcomes electrostatic repulsion; not to cause collapse of quarks
The Mass of a Hadron

Crude mass formula

Mesons

\[ M(q\bar{q}) = m_1 + m_2 + A \frac{S_1 \cdot S_2}{m_1 m_2} \]

\[ S_1 \cdot S_2 = \hbar^2 / 4 \text{ for vector mesons; } -3\hbar^2 / 4 \text{ for pseudoscalars} \]

\[ A = 4\pi m_u / \hbar \]

<table>
<thead>
<tr>
<th>Mesons</th>
<th>Calculated (MeV)</th>
<th>Observed (MeV)</th>
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</thead>
<tbody>
<tr>
<td>(\pi)</td>
<td>139</td>
<td>138</td>
</tr>
<tr>
<td>(K)</td>
<td>487</td>
<td>496</td>
</tr>
<tr>
<td>(\eta)</td>
<td>561</td>
<td>548</td>
</tr>
<tr>
<td>(\rho)</td>
<td>775</td>
<td>776</td>
</tr>
<tr>
<td>(\omega)</td>
<td>775</td>
<td>783</td>
</tr>
<tr>
<td>(\phi)</td>
<td>1031</td>
<td>1020</td>
</tr>
</tbody>
</table>

David Griffiths

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Charmonium Family Chart

\[ V_{QCD} = -\frac{4\alpha_s}{3} \frac{1}{r} + kr \]

Each 'energy level' in the spectrum represents a physical particle.

Quark Model predicts radiative transitions.
all were well prior to 2003

FIG. 1: Predicted and observed spectrum of charmonium states (Table I). The solid lines are experiment, and the broken lines are theory (NR model left, GI right). Spin triplet levels are dashed, and spin singlets are dotted. The DD open-charm threshold at 3.73 GeV is also shown.
Where do the masses of hadrons come from?

Bound state in QCD very different from QED e.g. the binding energy of a hydrogen atom is to a good approximation the sum of its constituent masses. Similarly for nuclei the binding energy is $\mathcal{O}(\text{MeV})$. For the proton almost all the mass is attributed to the strong non-linear interactions of the gluons.

**QED**

$e^-$  

$e^+$

Hydrogen Atom

(EM force)

$M_e = 0.5$ MeV  

$M_p = 938$ MeV  

$E_{\text{binding}} = 13.6$ eV

**QCD**

$u$  

$u$  

$d$

Proton  

(Strong force)

$M_u \sim 3$ MeV  

$M_d \sim 6$ MeV  

$\delta M \approx M_p$  

$M_p = 938$ MeV
Where do the masses of hadrons come from?

**QCD – Gauge theory of the strong interaction**

- Lagrangian: formulated in terms of quarks and gluons

\[
\mathcal{L}_{\text{QCD}} = -\frac{1}{4} F^a_{\mu\nu} F^{a\mu\nu} + \sum_f \bar{\psi}_f (i\gamma^\mu D_\mu - m_f) \psi_f, \quad f = u, d, s, c, b, t
\]

\[
D_\mu = \partial_\mu - ig(\frac{1}{2}\lambda^a) A^a_\mu
\]

**Asymptotic freedom: \( g(\mu) \)**

---

Nobel Prize in Physics 2004

“...for the discovery of asymptotic freedom in the theory of the strong interaction”

David Gross  Frank Wilczek  David Politzer

[Yao et al., PDG 2006]
Where do the masses of hadrons come from?

QCD on the lattice

Where do the masses of hadrons come from?

ETM Collaboration, C. Alexandrou et al. PRD (2008)
Where do the masses of hadrons come from?

From the $q\bar{q}$ potential to the determination of nuclear forces

K. Schilling, G. Bali and C. Schlichter, 1995

A.I. Signal, F.R.P. Bissey and D. Leinweber, arXiv:0806.0644
The PEP-II $e^+e^-$ Storage Rings
Data-taking completed in 2008
470M BB events
\[ \cos \theta_c = 1/\beta n \quad (\beta = v/c > 1/n) \]

Cerenkov cone angle measures velocity

Velocity and momentum determine mass

\[ p = \frac{mv}{\sqrt{1-v^2/c^2}} \]
Discovery of the $X(3872)$

quickly confirmed by Babar, CDF, D0

$B^\pm \rightarrow K^\pm X(J/\psi \pi^+ \pi^-)$

PRL 91, 262001 (2003)
Discovery of the Y(4260) by Babar

Probe physics with Center-of-Mass energies below 10 GeV using Initial State Radiation (ISR)


Validate the technique with first BABAR data ISR $\psi(2S) \to \psi \pi^+\pi^-$


Search for new particles in $e^+e^- \to \gamma_{ISR} \psi \pi^+\pi^-$ interactions
Discovery of the Y(4260) by Babar

$Y(4260)$ Candidate

$e^+ e^- \rightarrow \gamma_{\text{ISR}} Y(4260)$

$J/\psi \pi^+ \pi^-$

$\mu^+ \mu^-$

(4260)
New X, Y, Z hadrons vs charmonium spectroscopy

B. Fulsom
August 07
What are these particles?

- X(3872)
- Z(4430)
- Z₂
- Z
- Y(4008)
- Y(4260)
- Y(4325)
- Y(4660)
- X(4630)
- X(3940)
- Z(3940)
- X(4160)
- Y(3940)
LHC by design

pp collision

7 TeV × 7 TeV

2808 bunches, $1.15 \times 10^{11}$ p/bunch

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

accelerator cooled to -271.3°C (1.9 K)
The Experiments at LHC

- **Atlas, CMS**
  General purpose detector for high $p_T$ physics

- **LHCb**
  Specialist for studying $b$ hadrons
The Large Hadron Collider
The builders of the world's biggest particle collider are being sued in federal court over fears that the experiment might create globe-gobbling black holes or never-before-seen strains of matter that would destroy the planet. (March 2008, MSNBC)

“The compression of the two atoms colliding together at nearly light speed will cause an irreversible implosion, forming a miniature version of a giant black hole. [...] Any matter coming into contact with it would fall into it and never be able to escape. Eventually, all of earth would fall into such growing micro-black-hole, converting earth into a medium-sized black hole, around which would continue to orbit the moon, satellites, the ISS, etc.” Walter F. Wagner and Luis Sancho lawsuit, filed in U.S. District Court in Honolulu.
LHC the doomsday?

- **Hum, Hawaii? Not Geneva?**  
  Reaction by a very distinguished European physicist.

- The US Large Hadron Collider lawsuit filed by Walter Wagner and Luis Sancho has **failed**. Hawaiian Federal Judge Helen Gillmor officially declared that the American judicial system has no jurisdiction over the largest experiment ever devised by mankind. (September 2008)
August 11, 2008
first proton bunch injected into the LHC
November 20, 2009
first physics at 900 GeV

End of 2009
Atlas recorded 12 µb⁻¹ at 2.36 TeV

Since March 30th 2010
LHC running at 7 TeV
~2 × 10¹¹ protons/beam
peak luminosity = 1.6×10³⁰ cm⁻²s⁻¹

Immediate goal
end of 2011 with 1fb⁻¹ of data

Lots of machine development along the way
LHC the doomsday?

We are still here and well
Introduction: Heavy Quark Production at LHC

PHYIA6.4 in $4\pi$

<table>
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<tr>
<th>$\sqrt{s}$</th>
<th>total $\sigma$</th>
<th>$\sigma(\bar{c}c)$</th>
<th>$\sigma(\bar{b}b)$</th>
</tr>
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<tbody>
<tr>
<td>7 TeV</td>
<td>91.1 mb</td>
<td>4.74 mb</td>
<td>0.46 mb</td>
</tr>
<tr>
<td>14 TeV</td>
<td>102.3 mb</td>
<td>8.31 mb</td>
<td>1.04 mb</td>
</tr>
</tbody>
</table>

LHC is a factory for B- and D-mesons:
With 1 fb$^{-1}$ for 2010/2011 run we expect
$\sim 2.5 \times 10^{11}$ B-Mesons
$\sim 4 \times 10^{12}$ D-Mesons
$\sqrt{s}=7$ TeV

LHC

for comparison –

$e^+e^-$ collider ($\Upsilon(4S)) \sim 1$ nb
Tevatron (1.96 TeV) $\sim 20$ $\mu$b ($|\eta|<1.0$)

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Introduction: Physics Expectations

- Find the Higgs(God) particle
- Dark Matter, super-symmetric particles,
- Extra dimension, surprises

Find the Higgs(God) particle
• How well does the detector work?
• How will backgrounds behave?

Answers: learn from the initial data accumulated

We are here – results based on a few pb\(^{-1}\) to full data sample

By end of 2011, many new results will be possible. Any surprises?

5 fb\(^{-1}\)
Tools vs. Objects of Study in Research

Size of particles

- Size in atoms
  - 1
  - 1/10,000
  - 1/100,000
  - 1/100,000,000

- And in meters
  - $10^{-10}$
  - $10^{-14}$
  - $10^{-15}$
  - $10^{-18}$ (at largest)

Instruments to ‘see’ objects

- How we see different-sized objects:
  - Galaxy
  - Cell
  - Atom
  - Nucleus
  - Electron microscope
  - Accelerator
  - Detector

- λ = hc/E
- $λ = (6.6 \times 10^{-34})(3 \times 10^8) / 1.6 \times 10^{-7}$
- $λ \sim 10^{-18} \text{ [m]}$
- 1 TeV
Detecting Particles at High Rate

Particle-matter interactions

- Tracking chamber
- Electromagnetic calorimeter
- Hadron calorimeter
- Muon chamber

- Photons
- $e^\pm$
- Muons
- $\pi^\pm$, p
- n

innermost Layer... → ...Outermost Layer

The Atlas detector

- Measuring charge, momentum

$P=0.3BR$

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Muon spectrometry:

Coverage out to $|\eta|<2.7$

Drift chambers & trigger chambers in an air-core toroid of 0.5 Tesla

Good standalone performance: $\sigma/p_T\sim10\%$ at 1 TeV

Inner Detector:

3 pixel layers, 4 barrel silicon strips and transition radiation tracker with 2 Tesla solenoid: total 0.5—1.5 radiation lengths

Precision track reconstruction for tracks with $|\eta|<2.5$ and $p_T>0.5$ GeV

$$\frac{\sigma_{p_T}}{p_T} \sim 0.04\% \times p_T \text{ (GeV)} + 1.5\%$$

Calorimetry:

$|\eta|<4.9$ hermetic coverage

EM calo: Liquid Argon $\sigma/E\sim11.5\%/\sqrt{E+0.5}\%$

Hadronic calo: Fe Cu-LAr $\sigma/E\sim50\%/\sqrt{E+3}\%$

The Atlas Detector
The Atlas Detector: Inner Detectors

**Atlas Tracking**

2 T B-field

**Transition Radiation Tracker**

4 mm straw tubes, |η|<2.0

0.4M channels

tracking and e PID

\( \sigma_{r\phi} \approx 130 \, \mu m \)

**Silicon Detector**

double sided Si\( \mu \) strip layers, pitch=80 \( \mu m \), 40 mrad stereo angle

6.3M channels, |η|<2.5

\( \sigma_{r\phi} \approx 17 \, \mu m, \sigma_z \approx 580 \mu m \)

**Pixel Detector**

Pixels: 50×400 \( \mu m^2 \)

80M channels, |η|<2.5

\( \sigma_{r\phi} \approx 10 \, \mu m, \sigma_z \approx 115 \, \mu m \)

Required for many B reconstructions
The Atlas Detector: The Muon Spectrometer

- Muon Spectrometer Standalone (MS) reconstruction

- MS and Inner Detector (ID) combined fit
  - Outside-in
  - Inside-out
  - Statistical combination

- Taggers
  - ID track is matched to MS segments
  - ID track is matched to a MIP in calorimeter
The Atlas Detector

Excitement in the ATLAS Detector Control Room

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The Atlas Data Sample

<table>
<thead>
<tr>
<th>Subdetector</th>
<th>Number of Channels</th>
<th>Appr. Operational Fraction</th>
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<tbody>
<tr>
<td>Pixels</td>
<td>80 M</td>
<td>97.3%</td>
</tr>
<tr>
<td>SCT Silicon Strips</td>
<td>6.3 M</td>
<td>99.2%</td>
</tr>
<tr>
<td>TRT Transition</td>
<td>350 k</td>
<td>97.1%</td>
</tr>
<tr>
<td>Radiation Tracker</td>
<td>350 k</td>
<td>97.1%</td>
</tr>
<tr>
<td>LAr EM Calorimeter</td>
<td>170 k</td>
<td>97.9%</td>
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<tr>
<td>Tile calorimeter</td>
<td>9800</td>
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<td>Hadronic endcap LAr calorimeter</td>
<td>5600</td>
<td>99.9%</td>
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<tr>
<td>Forward LAr calorimeter</td>
<td>3500</td>
<td>100%</td>
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<tr>
<td>LVL1 Calo trigger</td>
<td>7160</td>
<td>99.9%</td>
</tr>
<tr>
<td>LVL1 Muon RPC trigger</td>
<td>370 k</td>
<td>99.5%</td>
</tr>
<tr>
<td>LVL1 Muon TGC trigger</td>
<td>320 k</td>
<td>100%</td>
</tr>
<tr>
<td>MDT Muon Drift Tubes</td>
<td>350 k</td>
<td>99.5%</td>
</tr>
<tr>
<td>CSC Cathode Strip Chambers</td>
<td>31 k</td>
<td>98.5%</td>
</tr>
<tr>
<td>RPC Barrel Muon Chambers</td>
<td>370 k</td>
<td>97.0%</td>
</tr>
<tr>
<td>TGC Endcap Muon Chambers</td>
<td>320 k</td>
<td>98.4%</td>
</tr>
</tbody>
</table>

good detector efficiency
The Atlas Detector: Performance

vertex resolution \(\sim 30 \, \mu m\)

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Figure 3: The combined 95% C.L. upper limits on the signal strength modifier $\mu = \sigma/\sigma_{SM}$, obtained with the CL$_s$ method, as a function of the SM Higgs boson mass in the range 110-600 GeV/$c^2$. The observed limits are shown by solid symbols. The dashed line indicates the median expected $\mu^{0.95}$ value for the background-only hypothesis, while the green (yellow) band indicates the range expected to contain 68% (95%) of all observed limit excursions from the median.
Highlights at the Large Hadron Collider

$tt(e + \text{jets})$ candidate

Event display

$P_T^e = 79.3$ GeV
$E_T^{\text{miss}} = 43.4$ GeV
$m_T = 86.7$ GeV
4 jets (1 $b$-tag)

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Highlights at the Large Hadron Collider

top quark production rate
Highlights at the Large Hadron Collider

Heavy ion collision: lead on lead in November 2010

Jet quenching: lead-lead collisions produce jets of gluons and quarks which fly away from the collision point. The jets interact among themselves; many melt away resulting in imbalanced events of single jet topology. This JQ phenomenon has never been observed before the LHC. Seeing the JQ may shed light on the early universe when it was in the form of a quark gluon plasma — man made event closest to the Big Bang.

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Highlights at the Large Hadron Collider

- p-p collision events symmetric
- Heavy ion collision events asymmetric
- jet quenching directly observed
an Atlas asymmetric di-jet event

jet asymmetry parameter

\[ A_J = \frac{E_{T,1} - E_{T,2}}{E_{T,1} + E_{T,2}} \]
Initial Physics Results: Heavy Hadrons

- Quarkonium signals and the production cross sections
- Open charm $D^*$, $D^+$, $D_s^+$
- Exclusive B observations
Di-Lepton Invariant Mass

- Level 1 and HLT trigger capability allow to go down to rather low di-muon invariant masses at $p_T$ compatible with the instantaneous luminosity of LHC.

- Stricter triggers now in place
B Physics Results: Quarkonia

- Large samples of $J/\psi$ and $\Upsilon$ states reconstructed
- Masses are consistent with PDG values
- Resolutions match well with detector simulations

**ATLAS Preliminary**

$\sqrt{s} = 7$ TeV

$\int L \, dt = 41 \, \text{pb}^{-1}$

$N_{J/\psi} = 846000 \pm 1000$

$M_{J/\psi} = 3.095 \pm 0.003 \, \text{GeV}$

$\sigma_{J/\psi} = 65 \pm 1 \, \text{MeV}$

PDG: $M(J/\psi) = 3.09692$ GeV

**ATLAS Preliminary**

$\sqrt{s} = 7$ TeV

$\int L \, dt \sim 41.0 \, \text{pb}^{-1}$

**Barrel + Barrel**

$N(\Upsilon_{1S}) = 16300 \pm 200$ (stat.)

$N(\Upsilon_{2S}) = 4800 \pm 200$ (stat.)

$N(\Upsilon_{3S}) = 2300 \pm 100$ (stat.)
B Physics Results: Quarkonia

pseudoproper time \( \tau = \frac{L_{xy} M_{\mu\mu}}{p_T(\mu\mu)} \), \( L_{xy} \) decay length in xy-plane

\[ \ln \mathcal{L} = \sum_{i=1}^{N} \ln \mathcal{F}(\tau, \delta_\tau, m_{\mu\mu}, \delta_m) \]

LHCb

J/ψ – Prompt & Secondary

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B Physics Results: Open Charm

- Subsample (1.4 nb\(^{-1}\)) has been analyzed
- Clean D\(^{*}\pm\), D\(^\pm\) and D\(_s\)\(^\pm\) have been observed
- Masses are consistent with PDG values; mass resolutions are well matched with Monte Carlo simulations

\[ D^{*+} \rightarrow (K^- \pi^+)\pi^+ \]

\[ D^0 \rightarrow K^- \pi^+ \]

\[ D^+ \rightarrow K^- \pi^+ \pi^+ \]
B Physics Results: Open Charm

Mesons | PDG Mass (MeV/c^2) | Atlas Mass (MeV/c^2)  
--- | --- | ---  
D^{*±} - D^0 | 145.42 ± 0.01 | 145.54 ± 0.05  
D^0 | 1864.83 ± 0.14 | 1865.5 ± 1.4  
D^± | 1869.60 ± 0.16 | 1871.8 ± 1.1  
D_s^{±} | 1968.47 ± 0.33 | 1971.5 ± 4.6  

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B Physics Results: Exclusive B Decays

decay length cut $L_{xy} > 300 \, \mu m$ imposed

fit to a Gaussian signal plus a linear background

PDG: $5279.17 \pm 0.29 \, \text{MeV}$
B Physics Results: Exclusive B Decays

$B_s \rightarrow J/\psi \phi$

Fit results:

- $\mu_{\text{gauss}} = 5.3670 \pm 0.0012 \text{ GeV/c}^2$
- $\sigma_{\text{gauss}} = 16.4 \pm 1.2 \text{ MeV/c}^2$
- $N_{\text{signal}} = 377 \pm 26$
- $N_{\text{BG}} = 978 \pm 36$
- $\chi^2/\text{ndof} = 0.91$
- $S/\sqrt{(S+B)} \approx 10$
- $S/B \approx 0.4$

Trajectories before vertex fit with $p_t > 0.3 \text{ GeV/c}$ in the vicinity of the PV

$\sqrt{s} = 7 \text{ TeV}$

CMS Preliminary

$\int L dt = 39 \text{ pb}^{-1}$
X(3872) at LHC

Proof of principle

CMS Preliminary

$N_{X(3872)} = 548 \pm 104$ (stat.)

$N_{\psi(2S)} = 7346 \pm 155$ (stat.)

$\sqrt{s} = 7$ TeV

$\int L dt = 40$ pb$^{-1}$
Prospects for the Near Future: The LHC

2011 schedule

First beam: 21st February
End proton run: 10th November
A short technical stop end of 2011 resume run into 2010

<table>
<thead>
<tr>
<th></th>
<th>Days</th>
</tr>
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<tbody>
<tr>
<td>Re-commissioning</td>
<td>21</td>
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<tr>
<td>Machine development</td>
<td>22</td>
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<tr>
<td>Technical stops</td>
<td>30</td>
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<tr>
<td>(Scrubbing run)</td>
<td>(7)</td>
</tr>
<tr>
<td>Special physics runs</td>
<td>10</td>
</tr>
<tr>
<td>Ramp-up to peak luminosity</td>
<td>40</td>
</tr>
<tr>
<td>Peak luminosity</td>
<td>133</td>
</tr>
<tr>
<td>Total</td>
<td>263</td>
</tr>
</tbody>
</table>
Prospects for the Near Future: The LHC

- 3.5 or 4 TeV
- 930 bunches (75 ns)
- 3 micron emittance
- $1.2 \times 10^{11}$ protons/bunch
- $\beta^* = 2.5$ m, nominal crossing angle
- Hubner factor 0.2

<table>
<thead>
<tr>
<th>Peak luminosity</th>
<th>$\sim 6 \times 10^{32}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated per day</td>
<td>11 pb$^{-1}$</td>
</tr>
<tr>
<td>$\sim 170$ days</td>
<td>$\sim 2$ fb$^{-1}$</td>
</tr>
<tr>
<td>Stored energy</td>
<td>72 MJ</td>
</tr>
</tbody>
</table>

Lot of variations possible: 1 to 3 fb$^{-1}$ looks reasonable
$1 \times 10^{33}$ cm$^{-2}$s$^{-1}$ not out of reach – usual caveats

(20-60)$\times$
current data sample

5 fb$^{-1}$
New Results at the LHC: Some Wild Guesses

- Explore fully recently discovered states
  - confirmation or disqualification
  - understand well detectors
  - understand well at 7 TeV Standard Model physics

- Searches for new states

- The Higgs boson, super-symmetric particles and

- New Physics
The B-factories have delivered a big surprise with many new, charmonium-like states which need to be understood.

The Large Hadron Collider has provided experimentalists with initial data to understand their detectors and has given machine physicists confidence to move forward with higher luminosity and higher energy.

The detectors at the Large Hadron Collider have been fully operational.

The LHC experiments have observed quarkonia, open charm and beauty, allowing a number of initial measurements at 7 TeV.

No big surprises, yet

LHC will deliver quality data in 2011, 2012 to allow physicists to explore exciting physics: the Higgs, dark matter, super-symmetric particles, detection of new hadrons, as well as hadron spectrum and new states………

Please stay tuned