LHC Status and SUSY Search Preparations

Sarah Eno, U. Maryland

Thanks to the many people whose slides I stole.
Dark Matter

Strong indirect cosmological evidence for dark matter

- Can look for the ambient dark matter all around us using nuclear recoils (CDMS, liquid noble gas detectors, etc)
- Can look for evidence of dark matter through its annihilations in space producing particles that reach the earth and are detector there (GLAST, PAMELA, ATIC, INTEGRAL etc)
- We can try to directly produce the dark matter particle in accelerators.
Most dark matter searches at accelerators are framed in terms of SUSY searches. The results from most of these searches can be translated without too much difficulty to reach/limits on other models with dark matter candidates. In the rest of this talk, I'll use SUSY as the ansatz for new physics with a dark matter candidate.
Previous Accelerator-based Searches

Previous accelerator-based dark matter searches dominated by LEP and Tevatron. So far, no luck 😊 LEP, of course, has been off for years. Tevatron runs through 2010 (2011?).

FIG. 17 Region in the \((m_3, m_2)\) plane excluded by \(D\O\) (100) and by earlier experiments. The red curve corresponds to the nominal scale and PDF choices. The yellow band represents the uncertainty associated with these choices. The blue curves represent the indirect limits inferred from the LEP chargino and slepton searches.

FIG. 20 Regions in the \((m_0, m_{1/2})\) plane excluded by the \(D\O\) search for trileptons (108).
LHC Overview

- \( pp \sqrt{s} = 14 \, \text{TeV} \)  
- \( L = 10^{34} \, \text{cm}^{-2} \, \text{s}^{-1} = 10 \, \mu \text{b}^{-1} \text{MHz} \) (0.6A, 4\( \mu \)m)
- crossing rate 40 MHz (25 ns)
- circumference of 27 km (16.8 miles)
- Cost of about $3B? (depending on accounting method, conversion rate, etc)
- will start up at 10 TeV (factor 5 higher than Tevatron)
LHC Parameters

Particles used: Protons and heavy ions (Lead, full stripped 82+)
Circumference: 26,659 m.
Injector: SPS
Injected beam energy: 450 GeV (protons)
Nominal beam energy in physics: 7 TeV (protons)
Magnetic field at 7 TeV: 8.33 Tesla
Operating temperature: 1.9 K
Number of magnets: ~9300
Number of main dipoles: 1232
Number of quadruples: ~858
Number of correcting magnets: ~6208
Number of RF cavities: 8 per beam; Field strength at top energy ≈ 5.5 MV/m
RF frequency: 400.8 MHz
Revolution frequency: 11.2455 kHz.
Power consumption: ~120 MW
Gradient of the tunnel: 1.4%
Difference between highest and lowest points: 122 m.
4 Detectors

Alice

CMS

ATLAS

LHCb

2 Apr 2009

"Shedding Light on Dark Matter"
LHC History

1989: LEP comes on line (originally planned to someday run protons)

1977-1978: Physics studies show compelling case for high energy machine (the cancelled SSC)

1993: Chris Llewellyn Smith and others propose LHC, to be built in LEP Tunnel

1994: project approved by CERN council for 2002 turn-on.

2000: LEP shut down so LHC construction could start
Countdown Clock

LHC Dipole
March, 2005
LHC Progress

...27 km of dipoles...whew!
Detectors

• about $0.5B? a piece

• CMS is 14.6 m tall, ATLAS is 20 m tall.

• CMS has 2600 members, ATLAS 3600

• US is 20% of CMS, 13% of ATLAS
Slice of CMS

Key:
- Blue: Muon
- Red: Electron
- Green: Charged Hadron (e.g. Pion)
- Dashed Green: Neutral Hadron (e.g. Neutron)
- Blue Dotted: Photon

Transverse slice through CMS

Iron return yoke interspersed with Muon chambers

2 Apr 2009
"Shedding Light on Dark Matter"
They are really pretty, too
Recent events at CERN
Before Beam: cosmics

We’re not just twiddling our thumbs. We are commissioning the detector.
LHC Start-up: Sept, 2008

Lyn Evans, LHC Project Leader

MD scientists
Calling the Shots: First LHC Beam

- September 7-12 2008
  - Beam1 on collimators (upstream of CMS)
- 10 September (D-day)
  - Beam 1, then Beam 2 circulating (hundreds of turns)
- 11 September: RF capture (millions of orbits)
  - Beam halo through CMS
  - Beam-gas events
- About 40 hrs beam at or through CMS
  - All systems active except Tracker and Solenoid

- CMS Trigger and DAQ fully functional: millions of beam events recorded
CMS First Beam Measurements

BEAM SETUP: INJECTION PROBE BEAM

<table>
<thead>
<tr>
<th>TED T12 position: BEAM</th>
<th>TED T18 position: DUMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDI P2 gaps/mm</td>
<td>upstream: 20.01</td>
</tr>
<tr>
<td></td>
<td>downstream: 20.01</td>
</tr>
<tr>
<td>TDI P8 gaps/mm</td>
<td>upstream: 19.99</td>
</tr>
<tr>
<td></td>
<td>downstream: 19.98</td>
</tr>
<tr>
<td>BCT T12:</td>
<td>0.00e+00</td>
</tr>
<tr>
<td>BCT T18:</td>
<td>0.00e+00</td>
</tr>
</tbody>
</table>

Comments 07-09-2008 19:09:02:
- beam 1 in point 5
- dispersion measurement
- beam 2: finished with beam on TED in T18
- Cryo at Pt 8 - out until late Sunday...
- LHC OPERATION in CCC: 77600, 70480

LHC Operation in CCC: 77600, 70480

September 2008

"Shedding Light on Dark Matter", 18
Beam Splash Events

- Beam with $2 \times 10^9$ protons dumped onto a target (collimator) 150m upstream of CMS
  - Sept. 7,9,10,18

- Leads to a “tsunami” wave of $O(100K)$ muons coming down the tunnel!
  - A far cry from the single cosmic muon events...
CMS lights up

HCAL energy

ECAL energy

debri

DT muon chamber hits

Inner tracking systems kept OFF
ATLAS also lights up
Halo Muons (from proton beams passing through CMS)

Muons associated with beam (but outside beam pipe) arising from the decays of pions created when off-axis protons scrape collimators or other elements along beamline.

A useful tool for detector alignment and time synchronization.

Note shape of tunnel.
Black Friday(s)

- Friday night, 12-Sep.
  - 11:20pm: Lose main 30ton 12 MVA transformer at Point 8 (LHCb)
  - There are no spares, and it would take 6-9 months to procure another.
  - “Borrow” from surplus capacity at CMS
- 13-18 Sep, Hardware commissioning consolidation
  - Power, cryogenic, and vacuum problems lead to 6 days of downtime
  - Advance commissioning of magnet control system to 5 TeV beam operation for 2008 (avoid 10 day shutdown)
  - CMS investigates issues with magnet
- Thu, 18-Sep
  - Return to beam 1 operation
  - CMS takes data overnight
- Friday noon, 19-Sep
  - Massive helium loss in one arc of the tunnel (1-2 tons), cryogenics lost
  - Broke insulation vacuum in sector
Incident during powering

The magnet circuits in the seven other sectors of the LHC had been fully commissioned to their nominal currents (corresponding to beam energy of 5.5 TeV) before the first beam injection on 10 September 2008. For the main dipole circuit, this meant a powering in stages up to a current of 9.3 kA. The dipole circuit of sector 3-4, the last one to be commissioned, had only been powered to 7 kA prior to 10 September 2008. After the successful injection and circulation of the first beams at 0.45 TeV, commissioning of this sector up to the 5.5 TeV beam energy level was resumed as planned and according to established procedures.

On 19 September 2008 morning, the current was being ramped up to 9.3 kA in the main dipole circuit at the nominal rate of 10 A/s, when at a value of 8.7 kA, a resistive zone developed in the electrical bus in the region between dipole C24 and quadrupole Q24. The first evidence was the appearance of a voltage of 300 mV detected in the circuit above the noise level: the time was 11:18:36 CEST. No resistive voltage appeared on the dipoles of the circuit, individually equipped with quench detectors with a detection sensitivity of 100 mV each, so that the quench of any magnet can be excluded as initial event. After 0.39 s, the resistive voltage had grown to 1 V and the power converter, unable to maintain the current ramp, tripped off at 0.46 s (slow discharge mode). The current started to decrease in the circuit and at 0.86 s, the energy discharge switch was opened, inserting dump resistors in the circuit to produce a fast power abort. In this sequence of events, the quench detection, power converter and energy discharge systems behaved as expected.
Sequence of events and consequences

Within the first second, an electrical arc developed and punctured the helium enclosure, leading to release of helium into the insulation vacuum of the cryostat.

The spring-loaded relief discs on the vacuum enclosure opened when the pressure exceeded atmospheric, thus relieving the helium to the tunnel. They were however unable to contain the pressure rise below the nominal 0.15 MPa absolute in the vacuum enclosures of subsector 23-25, thus resulting in large pressure forces acting on the vacuum barriers separating neighboring subsectors, which most probably damaged them. These forces displaced dipoles in the subsectors affected from their cold internal supports, and knocked the Short Straight Section cryostats housing the quadrupoles and vacuum barriers from their external support jacks at positions Q23, Q27 and Q31, in some locations breaking their anchors in the concrete floor of the tunnel. The displacement of the Short Straight Section cryostats also damaged the “jumper” connections to the cryogenic distribution line, but without rupture of the transverse vacuum barriers equipping these jumper connections, so that the insulation vacuum in the cryogenic line did not degrade.
Inspection and diagnostics

The number of magnets to be repaired is at maximum of 5 quadrupoles (in Short Straight Sections) and 24 dipoles, but it is likely that more will have to be removed from the tunnel for cleaning and exchange of multilayer insulation. The exact numbers will be known once the ongoing inspections are completed (now known 39 dipoles and 14 SSS). Spare magnets and spare components appear to be available in adequate types and sufficient quantities for allowing replacement of the damaged ones during the forthcoming shutdown. The extent of contamination to the beam vacuum pipes is not yet fully mapped, but known to be limited; in situ cleaning is being considered to keep to a minimum the number of magnets to be removed. The plan for removing/reinstallation, transport and repair of magnets in sector 3-4 is being established and integrated with the maintenance and consolidation work to be performed during the winter shutdown. The corresponding manpower resources have been secured. All magnets with soot in the beam pipe will be removed. Magnets with MLI in the beam pipe will be cleaned in-situ.
19th september incident
Cryostat and cold masses longitudinal displacements

**Displacements status in sector 3-4 (From Q17R3 to Q33R3) : P3 side**

Based on measurements by TS-SU, TS-MME and AT-MCS

<table>
<thead>
<tr>
<th>Cryostat</th>
<th>Cold mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q17</td>
<td>A18</td>
</tr>
<tr>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Q21</td>
<td>A22</td>
</tr>
<tr>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Q25</td>
<td>A26</td>
</tr>
<tr>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Q29</td>
<td>A30</td>
</tr>
<tr>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
</tbody>
</table>

- **Towards P4**
- **Open interconnection**
- **Disconnected**
- **Cold mass displacement**
- **Cryostat displacement**

**Note:**

- 999 with vacuum barrier
- Values are in mm
- Not measured yet
- Dipole in short circuit
- Electrically damaged IC
- Openly damaged I.C.
Additional tests

• New diagnostics found two other less-than-optimum splices (100 and 47 nΩ)
• One other small resistance not yet diagnosed
• Nothing that should cause problems
Current goal: start taking data in fall 2009. Very short Christmas shut down, run in winter with the goal of 300 pb-1 at 10 TeV.
How would dark matter appear in our experiment? Are we ready to look when the data starts coming?
Note that the LEP (model dependent) limits are the best even though its highest center-of-mass energy (200 GeV) is less than the Tevatron (2 TeV) or even a sort of effective Tevatron parton center-of-mass (2TeV/3=700 GeV)
Proton-proton

If the particle is charged under the strong force, it's easier to make.

Large cross sections for squarks and gluinos. Cross section calculation is reliable, as it only depends on the color charge and spin of produced particle.
• neutralino usually produced at the end of a long decay chain
• neutralino does not interact in the detector -> apparent momentum imbalance in event
• lots of energy goes down beam pipe -> can not use momentum conservation in direction parallel to beam axis to infer z component of neutralino momentum
• close mass splittings lead to low energy partons. Can be too low for detector.
Because the masses and even the mass hierarchies (and the mixings for the gauginos) are unknown, the signature is not well defined:
- jets plus MET (almost certainly)
- leptons plus jets plus MET?
- dileptons plus jets plus MET?
- same sign dileptons?
- ??? Taus? b's? tops? -> jets + MET + something….

No matter what, the dark matter candidate shows up as MET, and there will be MET in every SUSY event. But, the size of the MET will in general depend on the mass splittings.
However, SUSY won’t be lonely
Yesterday’s signals are today’s backgrounds

- In jets+Met channel, backgrounds from Z->nunu + jets event, W->lnu+jets when the lepton is lost, and large and hard-to-estimate background from multijets with MET caused by instrumental effects
- in lepton+jets channels, large backgrounds from ttbar, W+jets, Z+jets
- at LHC energies especially, the QCD corrections to the cross sections and kinematics of these events can be non-negligible.
**Figure 8:** As in fig. 7, for the transverse momentum of the $t\bar{t}$ pair, without (left panel) and with (right panel) acceptance cuts.

**Figure 11:** As in fig. 10, for the transverse momentum of the $t\bar{t}$ pair, without (left panel) and with (right panel) acceptance cuts.

Herwig is parton shower
MC@NLO matches NLO and PS

Frixione, Nason, Webber, hep-ph/0305252

2 Apr 2009

"Shedding Light on Dark Matter", MD-Hopkins Mtg
Fake MET

Can be large instrumental backgrounds to MET at startup.

(personal comment: it won’t be nearly this bad for either ATLAS or CMS)
SUSY

• Show there is something beyond the backgrounds
• Measure the properties of the produced particles (including, as much as possible, the dark matter candidate)
• Show that what is produced is indeed susy
Show there is something

ATLAS 4 jets + MET

ATLAS 1 lepton + Jets +MET
SUSY @ 100 pb$^{-1}$

- Inclusive Jets*MET analysis from P-TDR

\[ M_{1/2} \text{[GeV/c}^2] \]

- Assume same acceptance - probably too optimistic

Feb 11, 2009 CMS Plenary Meeting 45

CMS AN 2009/016

too
Theorists, ATLAS and CMS have done work on deconstructing the particle spectrums (pioneering work by ATLAS)

Di-lepton edges gives mass of slepton.

Strategy is to make mass of all possible combinations of final state particles and let observed min and max values constrain intermediate masses
• but need to isolate this decay chain from particles from decay of the other squark (gluino) in the event
• and events containing this decay chain from events with other decay chains and other initial states.
SUSY combinatoric backgrounds subtracted using opposite flavor events, since chains containing a slepton will produce 2 same-flavor leptons.

End point gives mass difference between second lightest and lightest neutralino.
Similar plots from CMS
ATLAS Mass

Lepton+jets combinations

For this particular benchmark (bulk point SU3) all constraints measurable with 1 fb⁻¹!

Janus

q l⁺ l⁻ l± _l_ near _l_ far _l_ 0 _l_ 1
Mass and parameter fits

From these edges it is possible to derive the masses of particles in the decay and place limits on parameters of constrained models. Large statistical errors with 1 fb$^{-1}$. Mass differences better measured than absolute masses.

### SU3, full simulation, 1 fb$^{-1}$

<table>
<thead>
<tr>
<th>Observable</th>
<th>SU3 $m_{\text{true}}$ [GeV]</th>
<th>SU3 $m_{\text{MC}}$ [GeV]</th>
<th>SU4 $m_{\text{true}}$ [GeV]</th>
<th>SU4 $m_{\text{MC}}$ [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{\ell 1}$</td>
<td>109.6 ± 3.9 ± 0.6</td>
<td>109.7</td>
<td>102.7 ± 2.4 ± 0.0</td>
<td>102.6</td>
</tr>
<tr>
<td>$m_{\ell 1} - m_{\ell 0}$</td>
<td>526.3 ± 34.13</td>
<td>516.0</td>
<td>344 ± 53 ± 9</td>
<td>356</td>
</tr>
<tr>
<td>$m_{\ell 0}$</td>
<td>34.2 ± 3.8 ± 0.1</td>
<td>37.6</td>
<td>34.2 ± 3.8 ± 0.1</td>
<td>37.6</td>
</tr>
</tbody>
</table>

### SPS1a, fast simulation, 100 fb$^{-1}$

<table>
<thead>
<tr>
<th>Edge</th>
<th>Nominal Value</th>
<th>Fit Value</th>
<th>Syst. Error</th>
<th>Statistical Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{\ell 0}$</td>
<td>77.027</td>
<td>77.024</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>$m_{\ell 1}$</td>
<td>431.1</td>
<td>431.3</td>
<td>4.3</td>
<td>2.4</td>
</tr>
<tr>
<td>$m_{\ell 2}$</td>
<td>302.1</td>
<td>300.8</td>
<td>3.0</td>
<td>1.5</td>
</tr>
<tr>
<td>$m_{\ell 3}$</td>
<td>380.3</td>
<td>379.4</td>
<td>3.8</td>
<td>1.8</td>
</tr>
<tr>
<td>$m_{\ell 4}$</td>
<td>203.0</td>
<td>204.6</td>
<td>2.0</td>
<td>2.8</td>
</tr>
<tr>
<td>$m_{\ell 5}$</td>
<td>183.1</td>
<td>181.1</td>
<td>1.8</td>
<td>6.3</td>
</tr>
</tbody>
</table>

### Sparticle Expected precision (100 fb$^{-1}$)

<table>
<thead>
<tr>
<th>Sparticle</th>
<th>Expected precision (100 fb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ell_L$</td>
<td>$\ltimes$ 3%</td>
</tr>
<tr>
<td>$\ell_0$</td>
<td>$\ltimes$ 6%</td>
</tr>
<tr>
<td>$\ell_R$</td>
<td>$\ltimes$ 9%</td>
</tr>
<tr>
<td>$\ell_1$</td>
<td>$\ltimes$ 12%</td>
</tr>
</tbody>
</table>
Conclusions

Stay tuned for exciting discoveries in 2010!
Will the Detectors be ready?
Assembly Sequence

SURFACE: independent of underground Civil Engineering

* construct magnet barrel yoke & pre-cable
* prepare solenoid vac tanks
* construct endcap yoke & pre-cable
* assemble hadron calorimeters
* install muon chambers (barrel+endcap) in yoke
* assemble coil & insert in vac tank
* insert HCAL inside coil
* Test magnet + parts of all subsystems
* separate elements and lower sequentially

UNDERGROUND:
* re-install HCAL
* install ECAL barrel & cable central wheel
* install Tracker & cable
* install beampipe & bake-out
* install ECAL endcaps
* close & finish commissioning

2000-2007

2006-2008

15 heavy lowerings of objects of 380 tons -1920 tons
Heavy Lowering: HFs

2 Nov

9 Nov

both HF in Cavern

HF+ arriving safely in UXC
Heavy lowering: YE +3 & +2

30 Nov: YE+3 leaves garage (SX5) and 11 hours later touches down safely in cavern (UXC)
YE+1 Lowering (9 Jan)

1300 tons
YB+2 Lowering (19 Jan)
Data?
Commissioning

- Magnet Test and Cosmic Challenge (MTCC) took place in summer 2006 on the surface of the experiment location
  - Commissioning of the magnet and measuring of the field map
  - Test of a vertical slice of the detector and cosmic data taking
- Since May 2007, three- to ten-day-long exercises took place underground with the installed detector components, electronics and services
  - Increasing size and number of participants, and scope of the exercises
  - Balancing with installation schedule and detector local commissioning
Since March 2008, global runs saw an increasing focus on:
- stability of operations
- cosmic ray data taking (hence named CRUZET - Cosmic RUns at ZERo Tesla)
First Beam

- Sun and Mon, Sept. 7 and 8
  - Beam 1 (clockwise) single “shots” onto a collimator 150 meters upstream of CMS (also called “splash” events)

- Tue, Sept. 9
  - 20 additional shots as above

- Wed, Sept. 10
  - Circulating beams, beam 1 in the morning, beam 2 in the afternoon

- Thu, Sept. 11
  - RF capture of beam

- Fri, Sept. 19th
  - A faulty electrical connection between a dipole and a quadrupole failed, massive helium loss, and cryogenics and vacuum lost
  - Beam elements in the region are being extracted and replaced or repaired

During all of these activities, CMS triggered and recorded data (without CMS magnetic field and with inner tracking systems kept off).
Event Display of a Beam-on-Collimator Event

From $2 \times 10^9$ protons on a collimator 150 m upstream.
Cosmic Run At Four Tesla - CRAFT
Four weeks of continuous running
- 19 days with magnet at the operational setting of B=3.8 T
- Gained operational experience and put in evidence sources of inefficiency

Collected 370 M cosmic events, out of which 290 M with B = 3.8 T. Of those with magnetic field on:
- 87% have a muon track reconstructed in the chambers
- 3% have a muon track with strip tracker hits (~7.5 M tracks)
- \(3 \times 10^{-4}\) have a track with pixel hits (~75K tracks)

Data operation performed satisfactorily
- 600 TB of data volume transferred
- Prompt reconstruction at Tier 0 completed with a typical latency of 6h
- Tier 0 to Tier 1 at average of 240 MB/s
Tracker Performance

- On track Strip clusters S/N ratio, corrected for the track angle:
  - TOB thick sensors: S/N = 32
  - TIB/TID thin sensors: S/N = 27/25
  - TEC (mixed thickness): S/N = 30

- Track hit finding efficiency:
  - TIB and TOB layers

- Muon momentum distribution:
  - high quality tracks (8 hits, one in TIB layers 1-2, one in TOB layers 5-6)
  - Partial CRAFT statistics (expected >70k tracks at $P_T > 100$ GeV for full CRAFT)
Tracker Alignment

- Chi Square distribution
  - Using 4M tracks for alignment and 1M for validation
  - “Unaligned” is the nominal geometry
  - “CRUZET” is the geometry obtained from the B=0T runs using the Hits and Impact Point method and survey constraints
  - “CRAFTHIP” is the geometry obtained from the Hits and Impact Point algorithm applied to CRAFT data, including survey constraints
  - “CRAFTMP” is the geometry obtained from the Millepede algorithm applied to CRAFT

- Mean of residual distributions (cm)
  - Only modules with >30 hits considered
  - TIB 96%, TID 98%, TOB 98%, TEC 94%
  - HIP algorithm: TIB RMS = 26 μm, TOB RMS = 28 μm
CMS commissioning overview

<table>
<thead>
<tr>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>computing commissioning</strong></td>
<td><strong>computing commissioning</strong></td>
<td><strong>computing commissioning</strong></td>
</tr>
<tr>
<td>CSA06</td>
<td>CSA07</td>
<td>CSA08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CCRC08</td>
</tr>
<tr>
<td><strong>surface commissioning</strong></td>
<td><strong>surface commissioning</strong></td>
<td><strong>surface commissioning</strong></td>
</tr>
<tr>
<td>MTCC</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>heavy lowering</strong></td>
<td><strong>heavy lowering</strong></td>
<td><strong>heavy lowering</strong></td>
</tr>
<tr>
<td></td>
<td>Tracker installed</td>
<td>ECAL endc. installed</td>
</tr>
<tr>
<td></td>
<td>Beam pipe bake-out</td>
<td>Pixel installed</td>
</tr>
<tr>
<td></td>
<td>CMS closed</td>
<td>Magnet tests</td>
</tr>
<tr>
<td></td>
<td>1st beams</td>
<td>CRUZETs</td>
</tr>
<tr>
<td></td>
<td>Global Runs</td>
<td></td>
</tr>
</tbody>
</table>

CMS dictionary:

- **CSA** – *Computing, Software and Analysis challenge*
- **CCRC** – *Common Computing Readiness Challenges*
- **MTCC** – *Magnet Test and Cosmic Challenge*
- **CRUZET** – *Cosmic RU*n at *Zero Tesla*
Muon Cosmic with Tracker
Muon Chambers - Cosmic Ray Data

Cosmics tracks extrapolated to the surface
Can clearly see the shaft!

Probability of at least one track segment to be found at bottom if track reconstructed at top projected to the surface ⇒ shaft muons are softer

2 Apr 2009
"Shedding Light on Dark Matter", 

Muon Momentum Reconstruction in 3T

First 3T magnet test underground on Aug. 29, 2008

3.1 GeV  6.2 GeV

8.1 GeV  12.6 GeV  38.1 GeV

3T

2 Apr 2009
"Shedding Light on Dark Matter", UM D
Cosmic Muon - Spectra

- Magnet test: alignment of the muon system. Movement in 3.8 T filed tracked. Check to be “elastic”
Amassing a large cosmic dataset

Events collected by CMS in global runs during 2008

Strip tracker joins

Pixel tracker joins

DAYS after end March, 2008

Sept. 10
Thanks to James Stirling

Figure 5: Parton decomposition of the $W^+$ (solid line) and $W^-$ (dashed line) total cross sections in $pp$ and $p\bar{p}$ collisions. Individual contributions are shown as a percentage of the total cross section in each case. In $p\bar{p}$ collisions the decomposition is the same for $W^+$ and $W^-$. 

Lyn Evans
Parton luminosities at 10-14 TeV

- Thanks

![Graph showing ratios of parton luminosities at 10 TeV LHC and 14 TeV LHC](image)