Status of CMS and preparations for early physics

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in random order

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The LHC physics potential is well known
  - Main goals: New Physics at the TeV scale, the Higgs
  - One or the other appears to be a necessity
  - Finding neither would also have major implications

The LHC is a hadron collider
  - Ideal for searches that are not well-specified
    - Broad band production
    - High rates
  - Less ideal for precision measurements
    - Broad band production means you can have backgrounds from energy scales far different than your signal
    - No beam energy constraint means that one relies on cast reserves of information from previous experiments such as parton distribution functions from DIS studies at HERA
    - Multiple interactions in each bunch crossing
Hadron colliders

A brief history
Hadron Collider History: ISR

“The ISR missed the J/ψ and later missed the Υ “*

…it took a long time to overcome two major difficulties of collider physics. The first… the relatively low luminosity… The second… the very wide angle spread over which particularly interesting events, such as lepton pair events, may occur…

The answer is, of course, sophisticated detectors covering at least the whole central region ($45^\circ < \theta < 135^\circ$) and full azimuth.”

“…they stumbled on an unexpectedly strong hadron yield; large-$p_T$ production had been discovered, a witness, as we now know, to the pointlike structure within hadrons.

• Early ISR experiments were not prepared for the J/ψ and later ones were too late for the Υ. They nevertheless learned a lot and paved the way for UA1 and UA2 which were well-prepared and on-time.

September 1981:
first (small) run
for UA2

First observation of
jets in hadronic
collisions
Hadron Colliders History: SppS

- Engineering run 1981 ~1 nb⁻¹
  - 1st dijets at a hadron collider!


- Physics run 1982 ~20 nb⁻¹
  - Co-discovery of the W

Observation of Single Isolated Electrons of High Transverse Momentum...

- Inclusive Charged Particle Production...

- 1983 ~ 130 nb⁻¹
  - Co-discovery of the Z

Evidence for $Z^0 \rightarrow e^+e^-$
First dijets at a hadron machine
Publication came out of the 1981 run!

6 events in UA1 and the W was discovered!

UA2 saw 4 W events: they obtained a central value of 80 GeV for $M_W$
Displaced Vertex b tagging helped discover the Top in CDF

- CDF and DØ successfully found the top quark even though $\sigma_{t\bar{t}} \sim 10^{-10} \sigma_{\text{tot}}$

- CDF: $168.3 \pm 12.5 \text{ GeV/c}^2$ Dilepton
- DØ: $173.3 \pm 7.8 \text{ GeV/c}^2$ Lepton+jets
- Combined: $172.1 \pm 7.1 \text{ GeV/c}^2$

- CDF: $167.4 \pm 11.4 \text{ GeV/c}^2$ Dilepton
- DØ: $175.9 \pm 7.2 \text{ GeV/c}^2$ Lepton+jets
- Combined: $176.0 \pm 8.5 \text{ GeV/c}^2$

- Tevatron combined: $174.3 \pm 5.1 \text{ GeV/c}^2$
Great things comes early...and late.

- SPS
  - 683 GeV com and ~100 GeV mean com partons

- Tevatron I
  - 1800 GeV com and ~270 GeV mean com partons

- SPS & Tevatron Discoveries
  - SPS turn-on led to quick major discoveries
  - Not true at the Tevatron

- SPS had a lot of data
  - Already probed quite a bit higher than the mean constituent com energy (~100 GeV)
  - Tevatron needed to ~match SPS integrated luminosity to in order to probe a “new” energy domain
    - And then discovered top!

- Early discoveries have been followed by other important results at hadron colliders – but these have generally come late
LHC will startup in new territory

• At 1 TeV constituent com energy
  - \( gg \): 1 fb\(^{-1} \) at Tevatron is like 1 nb\(^{-1} \) at LHC
  - \( qq \): 1 fb\(^{-1} \) at Tevatron is like 1 pb\(^{-1} \) at LHC
Hadron Colliders in Summary

- Higher Energy
- Broadband production

⇒ Discovery machines
- Large physics cross-section
- What is interesting is rare
- The ability to find rare events when they appear is the consequence of evolved detector design and technological innovations

- Multi-level trigger systems and high speed, pipe-lined electronics
- Precision, high rate, calorimetry
- High rate wire tracking detectors
- Radiation-tolerant Silicon microstrip and Pixel detectors
LHC Experimental Challenge

- LHC requires a new generation of detectors
  - $10^9$ pp interactions/sec
    - Can record few $10^2$ out of every $4 \times 10^7$ crossings
  - Level-1 trigger decision takes $\sim 2-3 \mu s$
    - $\Rightarrow$ store data locally (pipelining)
  - Large Particle Multiplicity
    - $\Rightarrow$ Need granularity, time resolution for low occupancy
      - $\Rightarrow$ Large number of channels ($\sim 100 \text{ M}$)
  - Must handle high radiation levels
    - $\Rightarrow$ radiation hard (tolerant) detectors and electronics
Design Criteria (CMS)

- Very good muon identification and momentum measurement
  - Trigger efficiently with good resolution at high $p_T$: $\Delta p_T/p_T \sim 10\%$ @ 1 TeV
- High energy resolution electromagnetic calorimetry
  - $\sim 0.5\% @ E_T \sim 50$ GeV
- Powerful inner tracking systems
- Hermetic calorimetry
  - Good missing $E_T$ (MET) resolution
- (Affordable detector)

SM Higgs provides a good benchmark for performance of a detector
MUON BARREL CALORIMETERS

ECAL
76k scintillating PbWO4 crystals

HCAL
Scintillator/brass sandwich

4T Solenoid

IRON YOKE

MUON ENDCAPS
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)

TRACKER
Pixels
Silicon Microstrips
210 m² of silicon sensors
9.6M channels

MUON BARREL
Drift Tube Chambers (DT)
Resistive Plate Chambers (RPC)

Total weight 12500 t
Overall diameter 15 m
Overall length 21.6 m
7 meter lever arm for tracking muons
CMS evolution in pictures
CMS SOLENOID - sets the scale
CMS Surface Hall in Feb 2006
Experiment Cavern

2003

2004
Lowering of Heavy Elements

YE+1 (Jan’07)
Lowering of Heavy Elements

Y80 landing in the CMS experiment hall
Insertion of HCAL Barrel

April 07

J. Incandela (UCSB), RAL, April 23, 2008
HCAL Endcaps
Insertion of Barrel ECAL

J. Incandela (UCSB), RAL, April 23, 2008
Lowering of YE-1

22 Jan 08
Services and Thermal Screens (+side)
Tracking environment and granularity

Fluence over 10 years of LHC Operation

>1000 particles every bunch crossing (25ns)

\begin{align*}
\text{Ch. Hadrons (cm}^{-2} \text{)} & \\
7 \text{ cm} & \leq 4 \times 10^7 \text{ h}^\pm/\text{cm}^2/\text{s} \\
21 \text{ cm} & \leq 4 \times 10^6 \text{ h}^\pm/\text{cm}^2/\text{s} \\
49 \text{ cm} & \leq 4 \times 10^5 \text{ h}^\pm/\text{cm}^2/\text{s} \\
75 \text{ cm} & \\
111 \text{ cm} & \\
\end{align*}
Si pixels surrounded by silicon strip detectors

Pixels: \( \sim 1.1 \, \text{m}^2 \) of silicon sensors, 66. M pixels, 100x150 \( \mu\text{m}^2 \), \( r = 4, 7, 10 \) cm

Strips: \( \sim 207 \, \text{m}^2 \) of silicon sensors, 9.6 M strips, 10 layers, \( r \sim 20 - 110 \) cm

Automated strip-module assembly & micro-bonding (17k modules)
Number of Points*

<table>
<thead>
<tr>
<th>Sub-Detector</th>
<th>Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixels</td>
<td>$66 \times 10^6$</td>
</tr>
<tr>
<td>Silicon microstrips</td>
<td>$9.6 \times 10^6$</td>
</tr>
<tr>
<td>ECAL crystals</td>
<td>$0.076 \times 10^6$</td>
</tr>
<tr>
<td>Preshower strips</td>
<td>$0.137 \times 10^6$</td>
</tr>
<tr>
<td>HCAL</td>
<td>$0.01 \times 10^6$</td>
</tr>
<tr>
<td>Muon chambers</td>
<td>$0.576 \times 10^6$</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$76.5 \times 10^6$</td>
</tr>
</tbody>
</table>

*Does not include 3 pixel points. Black=total, green double-sided.

Tracking layers vs. pseudorapidity:
Total, double(axial+stereo), double inner, double outer.
3 barrel Layers

R = 4.4, 7.3, 10.2 cm

18M forward and 48M barrel pixels

2 disks per end

z = ±35.5, ±46.5 cm
Operation

40 MHz clock.
Buffer 3.2μs for L1 accept

Tracking

• 3 space points to $|\eta|=2.5$
• Seeds most tracking > 95% efficiency
• Vertexing
• Standalone in High Level Trigger (HLT)

10 (20) μm resolution in r-φ
(r-z) measured in Test Beam
Barrel Pixels Module mounting complete

All modules thermally cycled and recalibrated
Status of the FPIX Detector

- 4 half-cylinders with 2 half-disks each
- All delivered to CERN: April-Dec ‘07

Construction of the FPIX detector is now complete!
Pixel Status (April 08)

- FPIX ready for installation
- First half Barrel Pixels being tested at PSI.

“There is time to ensure that everything is prepared for the very Efficient Installation, Checkout and Commissioning of the Pixel Systems into CMS”

– Peter Sharp

- Planned Trial Installation within next week or two
Si Modules and Electronics Chain

J. Incandela (UCSB), RAL, April 23, 2008

Ride on technology wave

75k chips using 0.25\(\mu\)m technology

50 ns CR-RC shaper

\(\Rightarrow\) Total charge on strip in a single 25 ns bunch crossing obtained by de-convolution of signals in 3 successive samplings (25ns apart)

\(\Rightarrow\) Low noise and power
Si Tracker Assembly
Si Tracker: Inner Barrel & End Cap
Cosmics in the Tracker

Quality

- Dead or Noisy Strips < 3/1000
- Signal: Noise > 25:1
Initial layer efficiencies in cosmics

J. Incandela (UCSB), RAL, April 23, 2008
Low and lower noise

“Wing” noise during assembly:
Sensitivity to ground line noise

Noise inside of CMS (point 5):
Patch Panel 1 design a success!
Status of Tracker

- A Delay in the Operation of the Tracker Cooling Plants has caused a delay of a couple of weeks in commissioning plans.
  - Will start large-scale operation on 5 May for ~ 1 Week.
  - Commission the Complete Tracker throughout May

- A 2\textsuperscript{nd} Global Run at the Beginning of June.
  - Will involve the complete strip tracker
  - Hope to collect ~ 20 million Triggers at 0T to thoroughly understand the noise performance & test alignment procedure
Assembly of ECAL

Submodule: 2x5 crystals

Module: 400 crystals

Supermodule: 1700 crystals

Total 36 Supermodules
All ECAL supermodules recorded cosmics for 1 week
⇒ crystal inter-calibration of ~ 1.5%.
ECAL: Assembly and Performance

- ECAL: All 36 supermodules commissioned in CMS.

- Last Endcap
  - Crystals all delivered.
  - Most have been mounted.

Response to high energy electrons
A 1\textsuperscript{st} measurement

Cosmic muons momentum distribution

Cosmic muons charge ratio ($\mu^+ / \mu^-$)

(Awaiting definitive alignment constants)

Prior to lowering the detector

M. Aldaya, P. Garcia, et al

J. Incandela (UCSB), RAL, April 23, 2008
Global Commissioning Progression

Subsystem - detector and trigger separately - are added as they came in: size of the box represents which fraction was included (0, 25%, 50%, 75%, 100%).

- First cosmic muon triggers
- Upgrade to final DAQ software architecture
- First coincidence of 2 subsystems
- Reached scale of MTCC’06
- Final DAQ hw
- Final services

Global runs
Preparing to search for new physics at the LHC

What we will confront (i.e. Standard Model) and what we hope to see early (i.e. Beyond the Standard Model)
Past versus future discoveries

- **W & Z**
  - Masses and production rates were predicted
  - Signals stood out “like being hit on the head with a hammer”
  - Interpretation was unambiguous

- **Top**
  - Signal was a bit harder to dig out (initially a counting experiment) and less straightforward to interpret but…
  - We knew it had to be “somewhere”
  - Production and decay properties were predicted

- **Higgs**
  - Like top – for a given mass, we know its production and decay properties in the SM and alternative BSMs. For some masses, counting experiments may be the first sign.
  - Or maybe like W & Z – the signal could appear as a striking mass peak

- **New Physics (NP)**
  - Don’t know what to expect. Theory provides examples, some are compelling, none are guaranteed ...
BSM Physics at the LHC: pp @ 14 TeV

New Gauge Bosons?

$Z_\psi \rightarrow \mu^+ \mu^-$

$\sigma L = 0.1 \text{ fb}^{-1}$

Hidden Valleys?

ZZ/WW resonances?

Technicolor?

Extra Dimensions?

Black Holes???

Little Higgs?

Split Susy?

Starts to look like we have more models than theorists..

*We do not know what is out there for us...*
### BSM Signatures

- **A few thoughts...**
  - Models of new physics provide ideas for unexpected signatures
    - Uncertain which if any will be seen, but there are benefits to models:
      - We prepare more broadly
      - We are motivated to look at generic things from a different perspective
        - e.g. very boosted top quarks, very high Eₜ leptons, triggering on jets when there’s no beam!
    - The number and variety of theories are indicative of something else...
  - This is an experimentalist’s era:
    - What is needed is data!

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### New Physics Signatures

Many channels in New Physics: Typical signals
- Di-leptons (like sign/same sign)
- Leptons + MET
- Photons + MET
- Multi-jets (2 → ~10)
- Multi-jets + MET (few 10 → few 100 GeV)
- Multi jets + leptons + MET...
- B/τ final states...

**Also: new unusual signatures**
- Large displaced vertices
- Heavy ionizing particles (heavy stable charged particles)
- Non-pointing photons
- Special showers in the calorimeters
- Unexpected jet structures
- Very short tracks (stubs)...
Our job description

- Efficiently acquire all interesting data and understand it in detail, as it unfolds with increasing luminosity
- Understand the SM to the extent our data and existing MC allow (with likely development and tuning of the latter due to the former)
- And then to see what is there that we cannot explain
- Not to be biased by any particular models
- To be like Faraday: Focus on the data, and improving our measurements.

“If we see something odd in a given final state, it is not by appealing to, or freshly concocting, a new physics model that gives rise to precisely this anomaly that makes the signal more likely or more credible. The process of discovery … should be based solely on the careful examination of whether indeed this signal violates the SM expectation.” M.L. Mangano

“Understanding the Standard Model, as a bridge to the discovery of new phenomena at the LHC”
http://arxiv.org/abs/0802.0026v2
Good things come early

So far, hadron colliders have an unbroken streak of discovery opportunities:

Low mass SUSY or some other source of Dark Matter could appear early at the LHC.
“SUSY-Proper” Analysis

- Focus on generic “model independent” signatures (RP-conserving)
  - missing energy, multi-jets, leptons...
  - need to confirm discovery through multiple signatures

**Missing Energy:**
- from LSP

**Multi-Jet:**
- from cascade decay (gaugino)

**Multi-Leptons:**
- from decay of charginos/neutralinos

Need to have control of detector and **SM background** for the generic signature of **Jets+E_{T}^{miss}+0,1,2,3 leptons**
SUSY Signatures

- Different topologies for new physics will overlap different SM processes. Examples
  - Jets + MET (but no leptons)
    - Backgrounds: QCD, (t\bar{t}, Z+Jets, tW)
  - Jets + MET+2 OS leptons
    - Background: mainly t\bar{t}
    - SS leptons not a given

- Different classes of observations require different levels of scrutiny
  - A mass peak or edge is self-calibrating and unambiguous but
    - “… almost certainly pass through a period where the signal is marginal.”
  - Anomalous kinematics are more tricky but can be a smoking gun
  - A counting experiment requires the most effort to be fully convincing
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A new window

- We ‘ll see portions of the SM that have never been seen.
- It will look somewhat familiar but it will be ornamented with jets to a degree that we have not previously encountered.
SM at 10-14 TeV

- **Low initial luminosity**
  - Study Min Bias
    - Narrow down the extrapolations of PDFs, $dN^{\pm}/d\eta$ etc.
  - Study Jets
    - Initial optimization of jet algorithms on real data for resolution, scale, lepton and $\gamma$ fakes, etc.
  - Then more complex final states
- **Also calibrate with known objects**
  - Study “candles” for leptons and photons
    - $\pi^0, \psi, \gamma$ initially to understand detector, tracking, leptons & other objects
    - Extend to $W$ or $Z \rightarrow$ lepton(s)
  - Compare to MC V+Jets
  - Extend into $t\bar{t}$ core region and then
  - Deal with tails…
"The LHC is a very Jetty place"*

**Jets at the LHC**

<table>
<thead>
<tr>
<th>$p_T^{min}$ (TeV/c)</th>
<th>$\sigma$ (nb)</th>
<th>Events/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>100</td>
<td>$\approx 10^6$</td>
</tr>
<tr>
<td>1.0</td>
<td>0.1</td>
<td>$\approx 10^3$</td>
</tr>
<tr>
<td>2.0</td>
<td>$1.0 \times 10^{-4}$</td>
<td>$\approx 1$</td>
</tr>
<tr>
<td>3.0</td>
<td>$1.3 \times 10^{-6}$</td>
<td>$\approx 0.01$</td>
</tr>
</tbody>
</table>

Year → 2008: 10 pb$^{-1}$

LHC ≠ Tevatron
Small typical momentum fractions $x$ in many key searches:
- dominance of gluon and sea quark scattering
- large phase space for gluon emission and thus for production of extra jets

LHC will be a very jetty environment!!

NLO inclusive jet cross sections (EKS)
Life at low x in a pp collider

- LHC ≠ Tevatron
  - Small momentum fractions x in many key searches:
    - Large phase space for gluon emission
  - Consider tt:
    - For a jet threshold of ~15 GeV, essentially all tt events will have 1 or more additional jets
  - Consider V+jets
    - Ratio of LHC to Tevatron production cross sections for W/Z + n jets becomes huge as n increases

![Graph showing the dependence of the LO tt+jet cross section on the jet-defining parameter pT, min, together with the top pair production cross sections at LO and NLO.](image)

**Figure 95.** The dependence of the LO tt+jet cross section on the jet-defining parameter pT, min, together with the top pair production cross sections at LO and NLO.
V+jets a bridge between data and theory

- Theory has (generally) kept pace
  - W+jets a key background for top discovery. Estimated with data+MC
- Recent CDF results versus theory:
  - Top Left: $p_{T,jet}$ for $Z+ \geq 1j, Z+ \geq 2j$
  - Bottom: $W+n$ jets
    - Very good agreement at NLO
    - ME+PS matching routines – also agree up to a constant k factor
**W+Jets: Jet $E_T$ spectra at LHC**

http://arxiv.org/abs/0802.0026v2

Projected $E_T$ spectra of nth jet ($n=1,2,3,4$) in $W+n$ jet events at the LHC using various ME+PS MC and compared to Alpgen

With one exception all are within $\pm50\%$

- **Studies in data are greatly facilitated by ratios**
  - $[Z+(n+1)\text{jets}] / [Z+n \text{ jets}]$
  - $[W+n \text{ jets}] / [Z+ n \text{ jets}]$
- Many systematics cancel at least partially
Next we have to deal with $t\bar{t}$

- The additional jets complicate reconstruction/isolation of top.
  - Top is not like W or Z
  - “Top is not a candle, it’s more like a candelabra”
    - Ken Bloom (U. Nebraska)

- Once we understand the control regions - W/Z + n jets for low n, and QCD fakes - we can begin to tackle the core regions of $t\bar{t}$.

- Then, have to understand the tails
  - If there is a substantial BSM signal overlapping any region of top, this will be a difficult job and we will likely have to rely even more on MC than we did for V+jets
New physics involving high mass processes with sequential decays will have to face the challenge of understanding the tails of $t\bar{t}$+jets production.

- We’ll need to develop/tune MC, and work quite hard…
SM processes we can’t initially isolate: single top

- Accounted as backgrounds even before we can show they are there
- They are thus not critical to very early searches but will become very useful as data accumulates.

**Single top**

- Window to new physics:
  - $t'$, $W'$, FCNC, SUSY
- Access to top properties

**Also Dibosons**

- $t$ channel 9.9% @10fb-1
- W-associated ~20% @ 10 fb-1
- S-channel 36% @10fb-1
CMS SUSY Benchmark Points (PTDR)

- Selection of 13 Points
  - Low mass
    LM1 → LM9
  - High mass
    HM1 → HM4

- Important: different topologies/decay modes, i.e. on different signatures
  - LM1,2,6,9 are also close to WMAP benchmarks
Signature based analyses

- A Variety of inclusive analyses @ a specific benchmark points then extended to the $m_{1/2}$-$m_{\chi_0}$ plane using FAMOS (CMS fast detector simulation)
  - MET + jets @ LM1: MET > 200
  - Muons + MET + jets @ LM1: MET > 130
  - Same sign di-muons @ LM1: MET > 200
  - Opposite sign dileptons @ LM1: MET > 200
  - Di-taus @ LM2: $\tilde{\chi}_2^0$ decays 95% to $\tau\tau$: MET > 150
  - Inclusive analysis with Higgs @LM5: MET > 200
  - Inclusive $Z^0$ @LM4: MET > 230
  - Inclusive top @ LM1: Top plus leptons: MET > 150
LM1: MET and $\geq 3$ jets

- Cleanup instrumental bkds, halo, cosmics, etc.
- E.g. require
  - primary vertex
  - Total EM fraction $F_{em} > 0.175$
    - $F_{em} = E_T$ weighted EM fraction in $|\eta|<3$
  - Event charged fraction $F_{ch} > 0.1$
    - $F_{ch} = P_T$ of charged tracks associated to jets over calorimeter jet $E_T$ in $|\eta|<1.7$

Point LM1:
- Same as post-WMAP benchmark point B'
- $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}\tilde{q}$ is dominant.
- $B(\tilde{\chi}^0_2 \to \tilde{l}_R l) = 11.2\%$, $B(\tilde{\chi}^0_2 \to \tilde{\tau}_1 \tau) = 46\%$, $B(\tilde{\chi}^+_1 \to \tilde{\nu}_1 l) = 36\%$.

Specifically the gluino and squark decays proceed as follows:

- $\tilde{g} \to q\tilde{q}_{L,R}$, $\tilde{g} \to \tilde{q}\tilde{q}_{L,R}$
- $\tilde{q}_R \to q\tilde{\chi}^0_1$, (100%)
- $\tilde{q}_L \to q + \tilde{\chi}^0_2$, (30%)
- $\tilde{q}_L \to q + \tilde{\chi}^+_1$, (70%)

while the charginos and neutralinos decay as follows:

- $\tilde{\chi}^0_2 \to \tilde{\ell}_R \ell$, (11.2%)
- $\tilde{\chi}^0_2 \to \tilde{\tau}_1 \tau$, (46%)
- $\tilde{\chi}^+_1 \to \tilde{\nu}_L \ell$, (36%).
MET in QCD events

- MET in QCD multijet events tends to be along leading or 2\textsuperscript{nd} leading jet directions

- Not so for signal
  - But QCD jets could still be a nuisance
QCD MET from data
Calibrate $Z \rightarrow \nu \bar{\nu} +$ jets with $Z \rightarrow \mu \mu +$ jets

Z-candle normalization, $E^\text{miss}_T > 200$ GeV

Selected $Z \rightarrow \nu \bar{\nu} + \geq 2\text{jets}$

Selected $Z \rightarrow \mu \mu + \geq 2\text{jets}$
with $PT(Z) > 200$
Muons excluded

Concern:
Model the $Z \rightarrow \nu \bar{\nu}$ background using $Z \rightarrow \mu \mu$ is great but takes a lot of data to get enough dimuon events.
Couple alternatives recently considered
Using $W+jets$

The simplest example: $Z \rightarrow \nu\nu+jets$
[irreducible backg. Jets+$E_{T}^{mis}$ search]

ATLAS

$Z(\nu\nu)+n$jets
Estimated [$W(\mu\nu)$]

Events/50GeV/1fb$^{-1}$

$E_{T}^{miss}$ [GeV]

signal region

ATLAS preliminary
Using $\gamma + \text{jets}$!

$Z$ just a massive $\gamma$

But you don’t pay the branching ratio penalty

$\text{BR}(Z \rightarrow \mu \mu) \sim 3\%$
Jets + Missing $E_T$

Low mass SUSY

CMS $E_T^{\text{miss}}$ + multijets, 1 fb$^{-1}$

- mSUGRA LM1
- Zinv+tt
- Zinv+tt+EWK
- +QCD

MET
LM1
Final Cuts on $E_T$ of $j_1, j_2, H_T > 180,110,500$ GeV

Global signal efficiency 13%, $S/B \sim 26$

But we won’t know QCD and instrumental backgrounds well until we see the whites of their eyes…
Prior to data, backgrounds are not really known…
- More of a relevant issue for High Mass (HM) points

Figure 4.20. HM1 signal and Standard Model background distributions (1 fb$^{-1}$) for $E_T^{\text{miss}}$ (left) and $H_T$ (right).
### Early LHC Discovery Potential

<table>
<thead>
<tr>
<th>Model</th>
<th>Mass reach</th>
<th>Luminosity (fb⁻¹)</th>
<th>Early Systematic Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact Interaction</td>
<td>( \Lambda &lt; 2.8 ) TeV</td>
<td>0.01</td>
<td>Jet Eff., Energy Scale</td>
</tr>
<tr>
<td>( Z' )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALRM</td>
<td>( M \sim 1 ) TeV</td>
<td>0.01</td>
<td>Alignment</td>
</tr>
<tr>
<td>SSM</td>
<td>( M \sim 1 ) TeV</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>LRM</td>
<td>( M \sim 1 ) TeV</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>E6, SO(10)</td>
<td>( M \sim 1 ) TeV</td>
<td>0.03 – 0.1</td>
<td></td>
</tr>
<tr>
<td>Excited Quark</td>
<td>( M \sim 0.7 – 3.6 ) TeV</td>
<td>0.1</td>
<td>Jet Energy Scale</td>
</tr>
<tr>
<td>Axigluon or Colouron</td>
<td>( M \sim 0.7 – 3.5 ) TeV</td>
<td>0.1</td>
<td>Jet Energy Scale</td>
</tr>
<tr>
<td>E6 diquarks</td>
<td>( M \sim 0.7 – 4.0 ) TeV</td>
<td>0.1</td>
<td>Jet Energy Scale</td>
</tr>
<tr>
<td>Technirho</td>
<td>( M \sim 0.7 – 2.4 ) TeV</td>
<td>0.1</td>
<td>Jet Energy Scale</td>
</tr>
<tr>
<td>ADD Virtual ( G_{KK} )</td>
<td>( M_D \sim 4.3 – 3 ) TeV, ( n = 3-6 )</td>
<td>0.1</td>
<td>Alignment</td>
</tr>
<tr>
<td></td>
<td>( M_D \sim 5 - 4 ) TeV, ( n = 3-6 )</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ADD Direct ( G_{KK} )</td>
<td>( M_D \sim 1.5-1.0 ) TeV, ( n = 3-6 )</td>
<td>0.1</td>
<td>MET, Jet/photon Scale</td>
</tr>
<tr>
<td>SUSY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet+MET+0 lepton</td>
<td>( M \sim 1.5 – 1.8 ) TeV</td>
<td>1</td>
<td>MET, Jet Energy Scale, Multi-Jet backgrounds, Standard Model backgrounds</td>
</tr>
<tr>
<td>Jet+MET+1 lepton</td>
<td>( M \sim 0.5 ) TeV</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Jet+MET+2 leptons</td>
<td>( M \sim 0.5 ) TeV</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>mUED</td>
<td>( M \sim 0.3 ) TeV</td>
<td>0.01</td>
<td>ibid</td>
</tr>
<tr>
<td>( \text{TeV}^{-1} (Z_{KK}^{(1)}) )</td>
<td>( M_{Z1} &lt; 5 ) TeV</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>RS1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>di-jets</td>
<td>( M_G \sim 0.8-2.3 ) TeV, ( c=0.01-0.1 )</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Early LHC Runs:** 0.1 to 1 fb⁻¹

*If we can handle the SM (and the detector...)*
Conclusions

- There are good reasons to believe that there is something new at the energy scales accessible to the LHC that could appear early.
- Indications are that ATLAS and CMS will be ready to exploit this opportunity.
- Documented studies abound
- Much achieved, but much more to learn
  - Focus on first data (0.01 to 1.0 fb⁻¹) from now until first collisions
  - Many improvements in tools and our understanding of our capabilities are expected
- Initial detector performance and speed of optimization will be crucial
- Understanding SM will be critical, and could prove very challenging.
New Physics Searches with CMS

- **Sources:** Physics Technical Design Report Vol. II
  - General Focus: low luminosity ($2 \times 10^{33}$) operation and integrated luminosities up to 30-60 fb$^{-1}$
  - Also considered very early data from a few pb$^{-1}$ to a few fb$^{-1}$

- CMS now preparing for really early data: 10 pb$^{-1}$ -100 pb$^{-1}$
  - Studies are underway and some completed. See 2008 results:

- 1000’s of pages of documented studies