Early Physics Searches with CMS:

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Special thanks to P. Jenni, H. Frisch, Ian Low, P. de Jong, J. Alcaraz, P. Sphicas, C. Campagnari and many others.
Early Discoveries

• Several categories come to mind
  – Self-Calibrating
    • mass peaks, peculiar groupings of events in an otherwise empty portion of phase space
  – Overwhelming
    • Event count >> than the SM prediction
  – Shapely
    • Distribution of kinematical quantity overtly inconsistent with the SM

• Not necessarily strict boundaries
  • In the absence of such characteristics, the job is difficult and could be slow
The Importance of Being (Ready) Early

“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° < θ < 135°) 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.

Hadron Colliders History: SpPbS

- First Physics Run 1982 ~20 nb⁻¹
  - Actually Very First: 1981 ~1 nb⁻¹
- 2 of the first few UA2 publications:
    - 1st dijets at a hadron collider
    - Co-discovery of the W
- 1983 ~ 130 nb⁻¹
  - Evidence for Z₀ ---> e+e-
    - Co-discovery of the Z

<table>
<thead>
<tr>
<th>Operational features</th>
<th>1982</th>
<th>1983</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy (GeV)</td>
<td>273</td>
<td>273</td>
</tr>
<tr>
<td>β_H (m)</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>β_T (m)</td>
<td>0.75</td>
<td>0.65</td>
</tr>
<tr>
<td>Integrated luminosity [nb⁻¹]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>average per store</td>
<td>0.5</td>
<td>2.1</td>
</tr>
<tr>
<td>average per day</td>
<td>0.4</td>
<td>1.8</td>
</tr>
<tr>
<td>per year</td>
<td>2.8</td>
<td>153</td>
</tr>
<tr>
<td>Luminosity [10^{29} cm⁻² s⁻¹]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>peak</td>
<td>0.5</td>
<td>1.1</td>
</tr>
<tr>
<td>average per store</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Hours scheduled</td>
<td>1750</td>
<td>2064</td>
</tr>
<tr>
<td>Hours realised</td>
<td>748</td>
<td>888</td>
</tr>
<tr>
<td>Number of stores</td>
<td>56</td>
<td>72</td>
</tr>
<tr>
<td>Average store duration (h)</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>% stores terminated by faults</td>
<td>41</td>
<td>40</td>
</tr>
</tbody>
</table>
First dijets at a hadron machine Publication came out of the 1981 run!

6 events and the W was discovered!

UA2 saw 4 W events. Coincidentally, they obtained a central value of 80 GeV for $M_W$.
The importance of being prepared

Good stuff comes early...and late.
Overall (CMS) plan

• Global priorities:
  1. Detector completion and commissioning
  2. Detector Performance
  3. Physics Objects
  4. Physics Analysis

• Physics-wise: focus on discovery
  – Standard Model studies: a necessary step
    • Obviously, lots of good physics
    • But priority is the new physics that the LHC is conceived for

• And, of course, to do physics, we also need to:
  – Complete and commission trigger
  – Complete software
  – Deploy computing model – and use it effectively
CMS
Late Feb.
Late April.
EB installation
Tracker is now complete
Critical Path

- **Schedule**
  - Services
    - Cooling, power, cabling…
    - Power supplies
  - Pixels
    - Aiming for installation in November
  - Tracker installation
    - Late August (more likely September)

- **General readiness issues**
  - Commissioning $\sim 10^8$ channels!

- **Alignment and Calibration**
  - Calibration of the calorimeters + muons ($t_0$) etc.
  - Alignment of the pixels + tracker + muons that will determine our real ability to do physics

- The work is daunting… but at the moment, there are no showstoppers
Alignment Considerations

- Tracker (~99.9% operational channels)
  - Construction alignments
    - Sensors in ~10k modules internally aligned to ~5 \( \mu \text{m} \)
    - Construction alignment (Outer Barrel)
      » 5208 Modules in 688 rods aligned to 10-30 \( \mu \text{m} \)
      » Rods in 6 layers aligned to ~150-200 \( \mu \text{m} \) which is comparable to strip pitch
    - End caps and inner barrel more difficult: 2-3 times
  - Now taking cosmics ~12% of tracker
    - Can reach 150 \( \mu \text{m} \) everywhere
  - Will align relatively quickly with tracks from pp collisions.
Construction alignment check

- **Cosmics in the TOB:**
  - Take a layer out of the track fit and interpolate to that layer to measure (unbiased) residual (distance to hit).
  - No alignment corrections applied whatsoever

~200 μm “out of the box”

- **We’ll take cosmics for several months**
  - Reasonable alignment
    ~100 μm ($r\phi$) of central tracker could be possible before collisions
Laser Alignment System

Track-based alignment: 9 (20) μm inner (outer) barrel, 20 μm forward with 0.5 fb⁻¹
Alignment Scenarios

6.6. Alignment


Table 6.17: Expected RMS values for $\Delta x$, $\Delta y$, $\Delta z$ and $R_z$ for layers and disks (after laser alignment). These values are used for the “First Data Taking” scenario.

<table>
<thead>
<tr>
<th></th>
<th>$\Delta x$ ($\mu$m)</th>
<th>$\Delta y$ ($\mu$m)</th>
<th>$\Delta z$ ($\mu$m)</th>
<th>$R_z$ ($\mu$rad)</th>
<th>LAS available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel Barrel</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>no</td>
</tr>
<tr>
<td>Pixel Endcap</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>no</td>
</tr>
<tr>
<td>Strip Inner Barrel</td>
<td>100</td>
<td>100</td>
<td>500</td>
<td>90</td>
<td>yes</td>
</tr>
<tr>
<td>Strip Outer Barrel</td>
<td>70</td>
<td>70</td>
<td>500</td>
<td>60</td>
<td>yes</td>
</tr>
<tr>
<td>Strip Inner Disk</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>100</td>
<td>no</td>
</tr>
<tr>
<td>Strip Endcap</td>
<td>60</td>
<td>60</td>
<td>500</td>
<td>45</td>
<td>yes</td>
</tr>
</tbody>
</table>

- Two alignment scenarios considered in studies
  - “First Data” (~0.1 fb$^{-1}$): no track-based alignment of strip tracker due to limited statistics for high momentum tracks.
  - “Long-term” (~1.0 fb$^{-1}$): Assumes full track-based alignment everywhere. Strips improve by order of magnitude
- Pixels aligned with tracks in both cases to ~ 20 $\mu$m
ECAL Calibration with Cosmics

Cosmic calibration resolution vs $\eta$. 

![Graph showing cosmic calibration resolution vs $\eta$.]
Trigger, DAQ, Online, Offline

• **L1 Trigger and High Level Trigger**
  - Much is done and there’s work in progress
    • L1 Hardware now in and being operated at Pt 5
      - L1 emulator well developed and tested
    • HLT processors now being installed
      - Lot of work speeding up algorithms

• **DAQ and Online**
  - Commissioning underway already for many major systems
    • Tracker operating millions of channels
    • Portions of all systems have been run in Magnet test and cosmic challenge etc.

• **Offline**
  - New framework CMSSW has been validated to a large degree.
    • ~All analyses now use CMSSW
    • Almost all tools have been ported
  - Series of releases now in progress
    • Huge and exhausting effort underway with the goal of stable offline sometime ahead of first data in 2008
New Physics Searches with CMS

• **Source:** Physics Technical Design Report Vol. II
    • A huge amount of good work
    • General Focus: low luminosity ($2 \times 10^{33}$) operation and integrated luminosities up to 30-60 fb$^{-1}$
    • Many studies also considered very early data
      – From a few pb$^{-1}$ to a few fb$^{-1}$

• **Will draw on this work for this talk**
  • Cannot cover everything (fortunately for you)
  • Not an expert on these analyses (except $t \bar{t}H$, $H \rightarrow b \bar{b}$ which we seem to have killed…)
    – A few of the areas where it appeared that new physics could reveal itself in $< 1$ fb$^{-1}$

• **NB:** We are now in the process of doing a dedicated exercise: 10 pb$^{-1}$, 100 pb$^{-1}$, 1 fb$^{-1}$
Next six months

• Approach “1fb^{-1}” by successive approximations.
  – 10pb^{-1} and 100 pb^{-1} stages as well.
  – What will we get done with these amounts of data?

• By June: a preliminary look at the 100pb^{-1} studies.

• October: Results for 10, 100 pb^{-1} and 1fb^{-1}
  – Brief note (30 pages) on the “CMS plan for X pb^{-1}” summarizing each of these stages (10, 100, 1000 pb^{-1}) across all groups

• NB: Detector Groups are to provide new guidance on expectations and requirements for these startup datasets
Rules of Thumb

- At 1 TeV
  - $gg$: 1 fb$^{-1}$ at FNAL is like 1 nb$^{-1}$ at LHC
  - $qq$: 1 fb$^{-1}$ at FNAL is like 1 pb$^{-1}$ at LHC
**Early and Late**

- **Parton Luminosity falls steeply**
  - In multi-TeV region, ~ by factor 10 every 600 GeV
  - New states produced near threshold
  - Suppose you have a limit on some pair-produced object, M > 1 TeV
  - Question: In searching for new pair-produced particles how does your sensitivity improve with more data?
    - Answer: by ~ (600/2)=300 GeV = 30% for 10 times more integrated luminosity

Improving sensitivity is tough....but you can turn evidence into an observation
Mainly jets!
~ 10 $\mu$b/GeV @ 100 GeV
~ 0.1 pb/GeV @ 1 TeV

But also: $b\bar{b}$, $W$, $Z$, $t\bar{t}$
- $\sigma(b\bar{b}$, high $P_T$) ~ 1 $\mu$b
- $\sigma(W \to l\nu)$ ~ 60 nb
- $\sigma(WW)$ ~ 200 pb
- $\sigma(t\bar{t})$ ~ 1 nb
Events per experiment*

\[ l = e \text{ or } \mu \]

- Number of events after all cuts vs. \( \int L dt \) (pb\(^{-1}\))

- Days at \( 10^{32} \)
- Months at \( 10^{32} \)

- Selection efficiencies assumed:
  - \( W \rightarrow l\nu \): 20%
  - \( Z \rightarrow ll \): 20%
  - \( t\bar{t} \rightarrow l\nu + X \): 1.5% (no b-tag)

Similar statistics to CDF, D0 today
Higgs

Close, maybe even a cigar,

If ATLAS helps…
Photons: $H \rightarrow \gamma \gamma$

**Generation:** PYTHIA + k-factors

**Full simulation**

**Resolution:** 0.3% (EB) to 1% (EE)

**Isolation**
Tracks: none with $p_t > 1.5$ in $\Delta R < 0.3$
Calo: Barrel (Endcap) < 6(3) GeV in $0.06 < \Delta R < 0.35$

- 1 fb$^{-1}$
  - Above: Signal x 10 and backgrounds
  - Signal efficiency is of order 20-30%
- Need ~ 10 fb$^{-1}$
  - At right: 120 GeV Higgs in 7.7 fb$^{-1}$
Electrons: $H \rightarrow ZZ^{(*)} \rightarrow eeee$

- $30 \text{ fb}^{-1}$ shown: 1 fb$^{-1}$ signal is too small
  - $\sigma \cdot B \sim 1 - 4 \text{ fb (NLO)}$
- Backgrounds (Direct $ZZ^{(*)}$, $Zb\bar{b}$, $t\bar{t}$) $\sim 20,120,200 \text{ fb}$
Mystery of dark matter in the universe solved: it’s in front of CMS/ATLAS ECAL...

Affects electrons and photons: energy loss, conversions

From P. De Jong - Moriond 2007
Electrons (below 50 GeV)

- substantial bremsstrahlung at low energies
  - Use an energy loss model in tracking to take Brem into account. Momentum at innermost layer $p_{\text{in}} > p_{\text{out}}$ outermost layer and difference is correlated with Radiated energy
  - ECAL superclusters incorporate radiated energy
$f_{brem}$ used to estimate material budget
Classifying Low E Electrons

- Four Classes
  - Different corrections
- $E_{sc}/P_{in} > 0.9$
  - Golden
    - $F_{brem} < 0.2$
    - $\Delta \phi < 0.15$
  - Big Brem
    - $F_{brem} > 0.5$
    - $\Delta \phi < 0.15$
  - Narrow
    - Complement of the other two
- All the rest
  - Showering

<table>
<thead>
<tr>
<th>Class</th>
<th>ECAL barrel</th>
<th></th>
<th>ECAL endcaps</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>fraction (%)</td>
<td>jets (%)</td>
<td>fraction (%)</td>
<td>jets (%)</td>
</tr>
<tr>
<td>Golden</td>
<td>24</td>
<td>4</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Narrow</td>
<td>9</td>
<td>1</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>Big Brem</td>
<td>4</td>
<td>0.5</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td>Showering</td>
<td>53</td>
<td>85</td>
<td>69</td>
<td>96</td>
</tr>
<tr>
<td>Boundary</td>
<td>10</td>
<td>9.5</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

Electrons
5-50 GeV
Jets
25-50 GeV
ECAL versus Tracker: Electron Resolution

\[ \sigma_{\text{eff}} / E \]

- ECAL
- Tracker
- Combined

\[ E^e (\text{GeV}) \]
Results for $H \rightarrow ZZ^*$

- $4 \mu$ channel has some potential for 95% CL exclusion at a few fb$^{-1}$
- 10’s of fb$^{-1}$ for 5 $\sigma$ discovery
muons

Muon in Silicon Tracker

Hits and Track Segments

Key:
- Blue: Muon
- Red: Electron
- Green: Charged Hadron (e.g., Pion)
- Gray dashed: Neutral Hadron (e.g., Neutron)
- Gray dotted: Photon

Global Muon Track

Standalone Muon Track
H → WW(*)

• H → WW → ℓν ℓν
  
  gg→H, q̅q → V V q’̅q’→Hq’̅q’

• counting experiment
  – Must understand backgrounds by direct measurement of SM and fakes.

• Backgrounds:
  
  qq→WW, gg→WW, tt→WWbb, 
  tWb→WWb(b), ZW→llνν, ZZ→llνν etc.
Cross sections: $H \rightarrow WW(*)$

- **All processes LO**
  - Signal and W-pair
  - background phase-space dependent
  - NLO k-factor reweightings

- Match PYTHIA $p_T$ distributions of the H and WW systems respectively to those predicted by MC@NLO

---

### Table 3.1. The cross section at the next-to-leading order for Higgs production through gluon fusion and vector boson fusion (VFB) processes and the number of generated events are reported.

<table>
<thead>
<tr>
<th>Higgs mass (GeV/c²)</th>
<th>$o^{NLO} \times BR(2l)$ Gluon Fusion (pb)</th>
<th>$o^{NLO} \times BR(2l)$ VBF (pb)</th>
<th>num. of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>0.94</td>
<td>0.12</td>
<td>20000</td>
</tr>
<tr>
<td>140</td>
<td>1.39</td>
<td>0.19</td>
<td>20000</td>
</tr>
<tr>
<td>150</td>
<td>1.73</td>
<td>0.25</td>
<td>17000</td>
</tr>
<tr>
<td>160</td>
<td>2.03</td>
<td>0.31</td>
<td>44000</td>
</tr>
<tr>
<td>165</td>
<td>2.04</td>
<td>0.32</td>
<td>49000</td>
</tr>
<tr>
<td>170</td>
<td>1.95</td>
<td>0.31</td>
<td>40000</td>
</tr>
<tr>
<td>180</td>
<td>1.71</td>
<td>0.28</td>
<td>20000</td>
</tr>
</tbody>
</table>

### Table 3.2. The cross section at the next-to-leading order for the background processes. The $gg \rightarrow WW$ process is generated using a matrix element program linked to PYTHIA for the showering [70]. This process is only known at LO. (*) For $bb \rightarrow 2\mu$ the pre-selection $p_T > 20, 10$ GeV/c was applied.

<table>
<thead>
<tr>
<th>Channel</th>
<th>$o^{NLO} \times BR(p\bar{b})$</th>
<th>num. of ev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$qq \rightarrow WW \rightarrow 2l$</td>
<td>11.7</td>
<td>164000</td>
</tr>
<tr>
<td>$tt$</td>
<td>840</td>
<td>548000</td>
</tr>
<tr>
<td>$gg \rightarrow WW \rightarrow 2l$</td>
<td>0.54 (LO)</td>
<td>50000</td>
</tr>
<tr>
<td>$\gamma^*, Z$</td>
<td>145000</td>
<td>2700000</td>
</tr>
<tr>
<td>$bb \rightarrow 2\mu$</td>
<td>710 (LO)(*)</td>
<td>640000</td>
</tr>
<tr>
<td>$ZW \rightarrow 3l$</td>
<td>1.63</td>
<td>72000</td>
</tr>
<tr>
<td>$tW b \rightarrow 2l$ (TevReX)</td>
<td>3.4</td>
<td>191000</td>
</tr>
<tr>
<td>$ZZ \rightarrow 2l$</td>
<td>1.52</td>
<td>99000</td>
</tr>
</tbody>
</table>
**Selection**

- **Trigger**
  - Single $\mu$ 97% eff.
- **Optimize separately**
  - Isolation variables
    - To kill $b\bar{b}$
  - Jet and MET thresholds
    - Central jet veto kills $t\bar{t}$
      - $E_T > 15$
    - MET Kills DY
      - Net efficiency a few per 10 million!
### Table 3.3. The list of cuts applied to the signal and background samples.

<table>
<thead>
<tr>
<th>Cut Description</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1+HLT dimuon</td>
<td>6</td>
</tr>
<tr>
<td>MET &gt; 50 GeV</td>
<td></td>
</tr>
<tr>
<td>2 $\mu$ opposite charge</td>
<td>7</td>
</tr>
<tr>
<td>$35 \text{ GeV/c} &lt; P_T(\mu_{\text{max}}) &lt; 55 \text{ GeV/c}$</td>
<td></td>
</tr>
<tr>
<td>Isolation</td>
<td>8</td>
</tr>
<tr>
<td>$25 \text{ GeV/c} &lt; P_T(\mu_{\text{min}})$</td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>\eta</td>
</tr>
<tr>
<td>$m_{\mu_1\mu_2} &lt; 50 \text{ GeV/c}^2$</td>
<td></td>
</tr>
<tr>
<td>Jet Veto</td>
<td>10</td>
</tr>
<tr>
<td>$\Delta \phi_{\mu_1\mu_2} &lt; 0.8$</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3.4. The expected number of events for a luminosity of 1fb$^{-1}$ for the signal with Higgs masses between 130 and 180 GeV/c$^2$ and for the backgrounds.

<table>
<thead>
<tr>
<th>Process</th>
<th>Events</th>
<th>$\epsilon_{\text{tot}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_H = 130 \text{ GeV/c}^2$</td>
<td>112</td>
<td>$0.68 \pm 0.19$ (0.07 ± 0.02)%</td>
</tr>
<tr>
<td>$m_H = 140 \text{ GeV/c}^2$</td>
<td>162</td>
<td>$1.7 \pm 0.4$ (0.12 ± 0.03)%</td>
</tr>
<tr>
<td>$m_H = 150 \text{ GeV/c}^2$</td>
<td>228</td>
<td>$5.3 \pm 0.8$ (0.26 ± 0.04)%</td>
</tr>
<tr>
<td>$m_H = 160 \text{ GeV/c}^2$</td>
<td>256</td>
<td>$12.6 \pm 0.7$ (0.58 ± 0.04)%</td>
</tr>
<tr>
<td>$m_H = 165 \text{ GeV/c}^2$</td>
<td>264</td>
<td>$14.3 \pm 0.8$ (0.64 ± 0.04)%</td>
</tr>
<tr>
<td>$m_H = 170 \text{ GeV/c}^2$</td>
<td>259</td>
<td>$11.0 \pm 0.7$ (0.53 ± 0.03)%</td>
</tr>
<tr>
<td>$m_H = 180 \text{ GeV/c}^2$</td>
<td>233</td>
<td>$5.9 \pm 0.8$ (0.30 ± 0.04)%</td>
</tr>
<tr>
<td>$qq \rightarrow WW$</td>
<td>1040</td>
<td>$4.1 \pm 0.5$ (0.036 ± 0.005)%</td>
</tr>
<tr>
<td>$t\bar{t} \rightarrow 2\mu2\nu$</td>
<td>17007</td>
<td>$2.6 \pm 0.3$ (0.012 ± 0.001)%</td>
</tr>
<tr>
<td>$gg \rightarrow WW$</td>
<td>58</td>
<td>$1.0 \pm 0.1$ (0.18 ± 0.02)%</td>
</tr>
<tr>
<td>$\gamma^*, Z \rightarrow 2\mu$</td>
<td>720653</td>
<td>$0.3 \pm 0.3$ (4 ± 4) $10^{-5}$%</td>
</tr>
<tr>
<td>$b\bar{b} \rightarrow 2\mu2\nu$</td>
<td>69374</td>
<td>0 0%</td>
</tr>
<tr>
<td>$Wt$</td>
<td>615</td>
<td>$0.57 \pm 0.10$ (0.017 ± 0.003)%</td>
</tr>
<tr>
<td>$ZZ$</td>
<td>218</td>
<td>$0.18 \pm 0.05$ (0.012 ± 0.003)%</td>
</tr>
<tr>
<td>$ZW$</td>
<td>384</td>
<td>$0.13 \pm 0.05$ (0.008 ± 0.003)%</td>
</tr>
</tbody>
</table>
Background Estimates

- **Use Data control Samples**
  - E.g. back off central jet veto and add b tagging to get a tt enriched sample
    \[ S = \frac{N^{MC}(s\_region)}{N^{MC}(cntrl\_region)} \times N^{Data}(cntrl\_region) \]
  - WW region harder to isolate – have to estimate and subtract other processes
    - E.G. normalize DY by selecting in Z peak
    - Normalize tt by requiring two b tags etc…
Results

$H \rightarrow WW \rightarrow 2\mu 2\nu$
Higgs @ 1fb$^{-1}$

![Graph showing the luminosity for 5σ discovery vs. $M_{H,\text{GeV/c}^2}$ for different decay modes of the Higgs boson. The graph includes the CMS collaboration's result for $H\rightarrow\gamma\gamma$ cuts, $H\rightarrow\gamma\gamma$ opt, $H\rightarrow ZZ\rightarrow 4l$, and $H\rightarrow WW\rightarrow 2l2\nu$.](image-url)
High mass dimuons:

Z’, graviton resonances, large extra dimensions...

Tracking: alignment and propagation muons ↔ tracker important
As noted yesterday: Mass resolution (and so discovery potential) not too strongly affected by tracker alignment scenario.

Efficiencies from data
Massive Z’s

• Generate
  – Pythia with 3-way interference terms
    • $K_{QCD}^{\text{NNLO}}=1.35$ applied
    • CTEQ6L – LHAPDF set
  – Background Pythia with $K=1.35$ also
    • DY mainly
    • $V V$, $tt$ at percent of DY
    • Dijets, cosmics, $W+j$, $bb$, punch-through not studied yet

– Reconstruction
  • Includes search & recovery for photons in $\Delta R<0.1$
• 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 point then extended to the $m_{1/2}-m_0$ plane using FAMOS
  – 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 : $\tilde{\chi}^0_2$ 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 ≥3 jets

• Cleanup
  – Instrumental bkds, halo, cosmics, etc.
  – Require a primary vertex
  – And total EM fraction $F_{em} > 0.175$
    • $F_{em} = E_T$ weighted EM fraction in $|\eta|<3$
  – and 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’ and near DAQ TDR point 4.
* $m(\bar{g}) \geq m(\bar{q})$, hence $\bar{g} \rightarrow \bar{q}q$ is dominant.
* $B(\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_R \ell) = 11.2\%$, $B(\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1 \tau) = 46\%$, $B(\tilde{\chi}_1^\pm \rightarrow \tilde{\nu}_L \ell) = 36\%$.

Specifically the gluino and squark decays proceed as follows:

\[
\begin{align*}
\bar{g} & \rightarrow q \bar{q}_{L,R}, \quad \text{or} \quad \bar{g} \rightarrow \bar{q}q_{L,R} \\
\bar{q}_R & \rightarrow q \tilde{\chi}_1^0, \quad (100\%) \\
\bar{q}_L & \rightarrow q + \tilde{\chi}_2^0, \quad (30\%) \\
\bar{q}_L & \rightarrow q + \tilde{\chi}_1^+, \quad (70\%)
\end{align*}
\]

while the charginos and neutralinos decay as follows:

\[
\begin{align*}
\tilde{\chi}_2^0 & \rightarrow \tilde{\ell}_R \ell, \quad (11.2\%) \\
\tilde{\chi}_2^0 & \rightarrow \tilde{\tau}_1 \tau, \quad (46\%) \\
\tilde{\chi}_1^+ & \rightarrow \tilde{\nu}_L \ell, \quad (36\%).
\end{align*}
\]
MET in QCD events

- MET in QCD (left)
  - QCD MET tends to be along leading or 2nd leading jet directions
  - SUSY populates a distinct region
Veto Electrons (Indirectly)

- To eliminate W, Z +jets, tt etc.
  - Require the two leading jets to be non-EM
    - $\text{EM}/(\text{Had}+\text{EM}) < 0.9$
Calibrate $Z \rightarrow \nu \nu + \text{jets}$ with $Z \rightarrow \mu \mu + \text{jets}$

- **MET+ $\geq$3 jets**
  - Expected from
    - $Z \rightarrow \nu \nu + \geq 3\text{jets}$
    - $W \rightarrow \tau \nu + \geq 2\text{jets}$, 3rd jet the $\tau$ hadronic decay
    - Possible residual contrib. from $W \rightarrow e\nu, \mu\nu + \geq 3\text{jets}$
  - MC prediction for
    - $Z \rightarrow \mu \mu + \geq 3\text{jets}$ with $P_T^Z > 200$
    - Ditto for $W$ decays
  - Normalized to data (for higher stats)
    - $Z \rightarrow \mu \mu + \geq 2\text{jets}$ with $P_T^Z > 200$
  - Assume these ratios are correctly calculated in MC e.g. Alpgen
Concern:

Modeling the tails of the MET distribution.

A somewhat ad-hoc enhancement was done (up-weighting events for which the jets are poorly reconstructed as determined by comparison of reconstructed ET with initial parton ET).

Even very substantial tail enhancement does not qualitatively alter the result.
Jets + Missing $E_T$

Low mass SUSY

Normalizing $Z \rightarrow \nu\nu$ $E_T^{\text{miss}}$ to $Z \rightarrow \mu\mu$ using data
Final event counts

Table 4.3. Selected SUSY and Standard Model background events for 1 fb⁻¹.

<table>
<thead>
<tr>
<th>Signal</th>
<th>$t\bar{t}$</th>
<th>single $t$</th>
<th>$Z(\rightarrow \nu\bar{\nu}) + \text{jets}$</th>
<th>$(W/Z, WW/ZZ/ZZ) + \text{jets}$</th>
<th>QCD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6319</td>
<td>53.9</td>
<td>2.6</td>
<td>48</td>
<td>33</td>
</tr>
</tbody>
</table>

- Final Cuts on $E_T$ of $j_1,j_2,H_T > 180,110,500$ GeV
- Global signal efficiency 13%, S/B~26
Inclusive SUSY searches

- Low-mass SUSY ($M_{sp} \sim 500\,\text{GeV}$) accessible with $O(10^{-1})\,\text{fb}^{-1}$. $\Delta t$ to discovery determined by:
  - Time to understand detector performance: $E_{T}^{\text{miss}}$ tails, jet performance and energy scale, lepton id
  - Time to collect control samples -- e.g. $W+$jets, $Z+$jets, WW, top..
Prior to data, backgrounds are an open issue…. And are more of a relevant issue for High Mass (HM) points
SUSY signals (cascades)

Can be discovery channel for the Higgs

CMS

$\chi_1 \Rightarrow E_T^{\text{miss}}$

$\chi_0 \Rightarrow E_T^{\text{miss}}$

$1 \text{ fb}^{-1}$
But we will probably see something that is not so easy to interpret
Summary

- Many studies documented in PTDR
- Much achieved, but much more to learn
  - Focus on the 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
Additional Information
1 fb^{-1} is well into new territory.
Jets up to ~3-3.5 TeV
Di-jet masses up to ~5-6 TeV

Challenges:
- Jet energy scale
- Parton density functions (PDF)
- Underlying event
- Trigger
- Jet definition

CDF Run II Preliminary

Deviation from SM

CDF

\( N_{\text{Comp.}} - N_{\text{SM}} \) / \( N_{\text{SM}} \)

\( E_T \) (GeV)

\( \Lambda_{\text{QCD}} = 20000 \) GeV
\( \Lambda_{\text{QCD}} = 30000 \) GeV
\( \Lambda_{\text{QCD}} = 40000 \) GeV

Deviation from SM
QCD: jet production

- **Dominant part of the cross section**
  - With 100 pb\(^{-1}\): reach \(\sim 2\) TeV (\(E_T\))
  - With 1 fb\(^{-1}\): \(\sim 10^4\) events with \(E_T > 1\) TeV

- **Systematic uncertainties:**
  - detector: jet energy scale
  - theory: PDFs

![Graph showing jet production cross section](image)

\[
\frac{d\sigma}{dp_T} = \int L = 0.1\text{ fb}^{-1} \leq 0.1\text{ events GeV}^{-1}\text{GeV}
\]

![Graph showing PDF uncertainty](image)
b-tag

• Combined secondary-vertex b-tagger
  – Still early days (but promising)
Particle flow & tau-ID

- **Available today:**
  - List of Identified Particles (without double counting energy)
    - Photons, charged Hadrons, neutral hadrons
  - Can form taus, jets (...even MET!) using standard JetMET algos
  - People actively looking at, playing with, and providing feedback
  - P-flow not optimised yet (obviously).

- **Working on:**
  - Particles not yet included in Particle Flow list
    - Electrons, muons
  - Particle Flow Algorithm not yet ready in End-caps!
  - $V^0$’s, Pile-up tracks, nuclear interactions, ...
  - Calorimeter cluster calibrations
  - Clustering in PS, HF, and ECAL/HCAL overlap/transition regions
  - Satisfactory Linking Algorithm
  - Energy/momentum determination using full detector
P-flow & tau-ID

- First application: tau-ID
  - Very significant improvement

- Then, to jets. Adding tracks:
  - Still early stages…

- Very, very promising…

![Graph showing significant improvement in track quality cuts before and after adding jets.](image)
Higgs physics

- **2007 analyses:**
  - SM inclusive:
    - $ZZ^* \rightarrow 4 \ell$
    - $WW^* \rightarrow 2 \ell 2\nu$
    - $\gamma \gamma$
  - SM VBF $(qqH)\tau \tau$
  - SUSY, $gg \rightarrow (bb)\phi \mu \mu$
  - SUSY, $t \rightarrow bH^\pm$, $gb \rightarrow tH^\pm\tau\nu$

Efficiency of finding an e above $P_T^e$ in a jet with $p_{T\text{hat}} > 25$ GeV/c
SUSY-BSM physics

- **2007 analyses:**
  - SUSY leptonic (# leptons: 1-2-3) searches
  - SUSY hadronic searches (classical jet+MET; add b tag)
  - Heavy Stable particle (+GMSB)
  - High-Energy pairs (ee, μμ, γγ, jet-jet)
Maybe nature has some REAL SURPRISES in store…

Large extra dimensions, Planck scale $\sim$ EW scale

Possible micro black hole production; decay via Hawking radiation into photons, leptons, jets...

CMS and ATLAS might see this with $1$-$100$ pb$^{-1}$!

From P. DeJong
Moriond 2007