CDF Physics Results and Detector Status

Luciano Ristori (Pisa INFN)
and
Nigel Lockyer (University of Pennsylvania)

URA Visiting Committee
March 12th, 2004

Entry to Physics at CDF
http://www-cdf.fnal.gov/CDForg/Physics_Groups_1.html
# The CDF Collaboration

<table>
<thead>
<tr>
<th>North America</th>
<th>Europe</th>
<th>Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Natl. Labs</td>
<td>1 Research Lab</td>
<td>4 Universities</td>
</tr>
<tr>
<td>28 Universities</td>
<td>6 Universities</td>
<td>1 Research Lab</td>
</tr>
<tr>
<td>2 Universities</td>
<td>1 University</td>
<td>1 University</td>
</tr>
<tr>
<td>12 countries</td>
<td>4 Universities</td>
<td>3 Universities</td>
</tr>
<tr>
<td>62 institutions</td>
<td>2 Research Labs</td>
<td></td>
</tr>
<tr>
<td>800 physicists</td>
<td>1 University</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 University</td>
<td></td>
</tr>
</tbody>
</table>
Luminosity and Efficiency

• Efficiency to tape reached \(<85>\%\)
• Lower recently due to COT 80%
• Increasing again

• Instantaneous initial luminosity as measured by CDF

• Best is 7.2E31
Luminosity Delivered and To Tape

- Total data recorded for physics is about 300 pb-1
- Run 1 X 3
- Expect Run1 X 4 by end of summer
Outline of Presentation

• Detector Performance
  – COT aging status
  – Tracking performance
  – Offline performance

• Status of analyses and publication plan
  – Heavy Flavors
  – Exotics
  – Electroweak
  – QCD
  – Top

• Conclude
Detector
CDF status

- CDF detector working well, but...
- COT is having “early” aging problems
- Focused effort to understand and fix the problem
- We are always concerned about silicon safety - beam incidents highlight concerns
- Beam position centered by Accelerator Division
  - This was an essential move for us because of trigger efficiency
  - CDF appreciates the large effort by Accelerator Division
- Offline production proceeding well
  - ~8 million events/day
- Central Analysis Facility (CAF) big success
Offline Operations-the numbers

- 595M unique events have been processed
- 747 TB on tape, 48 TB/day moved
- We have deployed 1382 cpus and 318 TB of disk in production and analysis farms
- Still not enough => 25% more offsite computing at 6 sights in time for Jun04
Reconstruction improvements

• Big improvements to robustness and speed of code. In the latest release:
  – 0.5 to 3.7cpu-sec/event
  – 1 crash every 2Mevents, hardware errors

• Concentrate on new run 2 detectors
  – L00, BMU

• Improvements in calibrations including beamline determination => data that comes out of production is more useful
COT (Central Outer Tracker)

- 8 Superlayers:
  - 4 Axial, 4 Stereo (+/- 2°)
- Spans 40 < R < 138 cm
  - SL1 – 47 cm, SL8 – 129 cm
- 168(SL1) – 480(SL8) cells/SL
- Each cell has 29 wires
  - 12 sense, 13(+4) potential
- Au/Mylar planes between cells
What does “COT Aging” mean?

• Drift chamber aging
  – Decline in operating performance with time
  – More specifically, loss of gain under irradiation
  – Usually caused by deposits on wire surfaces

• How do we detect aging
  – Loss of gain means less charge – shorter pulse widths
  – Decrease of COT hit widths, COT/XFT efficiency
  – Small chambers directly monitor gas going to chamber

• Details:
Time Dependence for Regions of SL2

- 6 Regions: 3 in $\phi \times 2(z<0, z>0)$
- Divisions in $\phi$ for SL2
  1. Cells 176-191, 0-47
  2. Cells 48-111 (All Good for $z<0$)
  3. Cells 112-175 (All Bad for $z>0$)
SL2 versus Run Number Widths
COT Relative Widths SL2/SL8

SL2 Width Relative to Good Region vs Run

- Z>0 Cells 176-48
- Z>0 Cells 48-112
- Z>0 Cells 112-176
- Z<0 Cells 176-48
- Z<0 Cells 48-112
- Z<0 Cells 112-176
- MeanSL2/MeanSL8
Silicon Tracking Performance
and b-jet tagging
(continuing to improve on ongoing work)
Silicon Tracking Efficiency

- Sample of muons from J/psi’s
- Track is in fiducial volume
  - 3 SVXII layers needed
- Top two curves are axial and stereo acceptance (ladders alive)
- Bottom two curves are efficiency
- 3-hits define a track (5 layers total)
- 3-D uses available stereo(2) & Z(3) strips
- Ratios provide rating for pattern recognition
Rate of Mis-measured Tracks

- Negative impact parameters define possibly mis-measured tracks
- Fakes beyond 3 sigma plotted
- Triangles have stereo information
- Much better than Run 1
Forward Tracking Efficiency

- $Z \rightarrow ee$ central+plug
- plug energy is denominator
- ISL+SVXII only
- Two 3-D hits & vertex seed silicon track (SISA)
- OI seeded by COT hits
- IO attaches COT hits to SISA
b-jet tagging Efficiency

- 8 GeV electrons
- Vertex algorithm
- Fiducial jets 15 GeV
- No requirement on tracks or hits
- Tag away jet and measure efficiency on the electron jet
- 2-D SVXII
- Heavy flavor content is needed
- Gives scale factor

![Double Tag Method B-Tagging Efficiency](image)
b-jet tagging Efficiency

- 8 GeV electron sample
- Jetprob algorithm
- Uses impact parameter
- Data is black, MC is red
- Top plot is 1% cut less fakes
- Bottom plot 5% cut more fakes
- Bottom plot higher eff than secvtx
- More charm with jetprb
b-jet tagging in top events

- Work in progress, not yet final
- Efficiency to tag at least one b-jet in a top event is 52.3 +/- 0.3 +/- 7.0%
- TDR 65%
- Will look into getting forward going jets with silicon stand alone tracking and IE tracking +3-D tagging may help
- Layer00 will be included (two double bulkheads for three barrels of silicon)
- Recent improvements in tracking not yet included
Physics Opportunities Run2

• Explore the high energy frontier
• Experiments will guide theory
• Probe high statistics top
• No clear paradigm for new physics
• SUSY, extra dimensions, leptoquarks
Publication plans

• We have recorded about 220 pb\(^{-1}\) of physics quality data up to the end of August 2003
• We consider this a complete dataset - twice Run1
• All physics groups are planning to publish analyses on this dataset
• The time scales for publication vary from short term (next week) to the end of the year
• This is due to different degrees of sophistication required by each particular analysis
• We expect to publish 20-40 papers on this dataset
Heavy Flavors
Heavy Flavors

• 4 papers submitted or published
  – Observation of X(3872) - used 220pb⁻¹ (PRL comments--sent back)

• 6 papers in godparent publication review
  – D* relative BR and CP asymmetry
  – Pentaquark search
  – Inclusive J/Psi cross section
  – B hadron masses (including Bs and Λb)
    – BR of Λb → Λc π
    – BR of Bs → Ds π

• 3 analyses blessed – godparents soon
• 10 more papers moving towards blessing and pub
**BR(B_s \rightarrow \mu \mu):** Why is this interesting?

- **BR(B_s \rightarrow \mu \mu) in the SM is few 10E-9**
- **Unique to Tevatron so complements b-factory work**

- **Can be enhanced by 10-1000 in SUSY**
  - Consistent with $\Delta a_\mu$, and $\Omega_{cdm}$
  - Observable with ~2 fb-1
  - Would imply light Higgs $M_h \sim 120$ GeV
How do we discriminate signal from bckg?

Discriminating Variables
- Invariant mass
- $\lambda : c \, L_{xy} \cdot M / P_{T_B}$
- $\Delta \Phi : \phi(B) - \phi(\text{vtx})$
- Isol: $P_{t_B} / (\Sigma_{\text{trk}} + P_{t_B})$

Choose optimal selection criteria a priori ("blind")
Results

BR($B_s \rightarrow \mu \mu$) < 5.8 E-7
BR($B_d \rightarrow \mu \mu$) < 1.5 E-7
(at 90% CL)

- $B_s \rightarrow \mu \mu$ limit x3 improvement relative to previous limit
- $B_d \rightarrow \mu \mu$ limit better than Belle’s recent publication
- Expect to increase acceptance (CMX), reduce background and collect more data
Results: Exclusions

- SO$_{10}$ space excluded by this result
  - Hep-ph/0304101

- also excludes large parts of R-parity violating models

- smaller exclusion in standard mSugra MSSM
$B\rightarrow h^+h^-$ Decays

- $B_d\rightarrow\pi\pi$ and $B_s\rightarrow KK$ modes are sensitive to CP angle $\gamma$. (Fleischer)
- $B_{(d,s)}\rightarrow K\pi$ and above modes are separated statistically by kinematics and particle ID.
- $B(B_d\rightarrow\pi\pi)/B(B_d\rightarrow K\pi) = 0.26\pm0.11\pm0.055$.
- First observation of $B_s\rightarrow K^+K^-$. 
- New results soon—much improved dE/dx

CDF Run 2 Preliminary

- $B_s\rightarrow KK$
- $B_d\rightarrow \pi\pi$
- $B_s\rightarrow K\pi$
- $B_d\rightarrow K\pi$

180 pb$^{-1}$

891 ± 47 signal events
Mean 5.240 ± 0.002 GeV/c$^2$
Width 0.036 ± 0.002 GeV/c$^2$
**BR(B_s \to K^+K^-)**

**Fitted contributions:**

<table>
<thead>
<tr>
<th>mode</th>
<th>Yield (65 pb^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>B^0 \to K\pi</td>
<td>148\pm17(stat.)\pm17(syst)</td>
</tr>
<tr>
<td>B^0 \to \pi\pi</td>
<td>39\pm14(stat.)\pm17(syst)</td>
</tr>
<tr>
<td>B_s \to KK</td>
<td>90\pm17(stat.) \pm17(syst)</td>
</tr>
<tr>
<td>B_s \to K\pi</td>
<td>3\pm11(stat.) \pm17(syst)</td>
</tr>
</tbody>
</table>

**First observation of B_s \to K^+K^- !!**

Result:

\[
\frac{f_s \cdot \text{BR}(B_s \to KK)}{f_d \cdot \text{BR}(B^0 \to K\pi)} = 0.74 \pm 0.20 \pm 0.22
\]

Measure A_{CP}

\[
\frac{N(\bar{B} \to K^- \pi^+) - N(B \to K^+ \pi^-)}{N(\bar{B} \to K^- \pi^+) + N(B \to K^+ \pi^-)} = 0.02 \pm 0.15 \pm 0.02
\]
**B_s hadronic yields (B_s mixing)**

CDF Run II Preliminary, \( L = 119 \) pb\(^{-1}\)

**Candiates per 10 MeV/c\(^2\)**

**Candidate Mass [GeV/c\(^2\)]**

- \( B^0_s \to D^-_s \pi^+ \)
- \( D^-_s \to \phi \pi^- \) and \( \phi \to K^- K^+ \)

\[
\frac{f_s \, BR (B^0_s \to D^-_s \pi^+)}{f_d \, BR (B^0 \to D^- \pi^+) } = 0.35 \pm 0.05 \text{ (stat)} \pm 0.03 \text{ (syst)} \pm 0.09 \text{ (BR)}
\]

\[
\frac{BR (B^0_s \to D^-_s \pi^+)}{BR (B^0 \to D^- \pi^+) } = 1.4 \pm 0.2 \text{ (stat)} \pm 0.1 \text{ (syst)} \pm 0.4 \text{ (BR)} \pm 0.2 \text{ (PR)}
\]
World’s best mass measurements for $B_s$ and $\Lambda_B$:

$M(B_s) = 5365.50 \pm 1.29 \pm 0.94$ MeV and $M(\Lambda_B) = 5620.4 \pm 1.6 \pm 1.2$ MeV

Lifetime measurements for $B_s$ and $\Lambda_B$:

$B_s$ lifetime $1.33 \pm 0.14_{(\text{stat})} \pm 0.02_{(\text{sys})}$ ps (PDG $1.461 \pm 0.057$ ps)

$\Lambda_B$ lifetime $1.25 \pm 0.26_{(\text{stat})} \pm 0.10_{(\text{sys})}$ ps (PDG $1.229 \pm 0.08$ ps)

First lifetime from fully reconstructed $\Lambda_b$ decay!
Exotic Spectroscopy

- Recall CDF $X(3872)$ confirmed Belle discovery
  - $> 10 \sigma$ result
- Pursing production mechanisms
- Search for exotic $S=-2$ Baryons (pentaquark)
- NA49 claim of $\theta^+$ & cascade $\pi$
- CDF uses standalone silicon tracking for long lived cascade hyperons (jet $20+SVT$ trigger sample)
Exotic Spectroscopy

- NA49 has about 2000 cascades
- CDF has 36,000 cascades
- See big cascade (1530) signal
- Search for cascade’(1860)
- 95% CL UL 0.04 double charged
- 95% CL UL 0.07 neutral
Exotics
Exotics

• 2 papers in godparent publication review
  – $\text{B}^d, \text{B}_s \rightarrow \mu\mu$ (complete and PRL should be sent out March 18th)
  – $W/Z + \text{gamma}$

• Formed godparent committees for 5 analyses
  – Search for $Z' \rightarrow ee, \mu\mu$
  – Search for 1st and 2nd generation leptoquarks
  – Search for leptoquarks in missing ET
  – $e^* \rightarrow e \text{ gamma}$
  – $H^{++} \rightarrow ee, \mu\mu, e\mu$

• 12 analyses moving towards final blessing
• ~ 20 additional analyses under way
Search for the $Z'$

- Search for high mass opposite sign dilepton pairs
- Assume narrow resonance

CDF Run II Preliminary (200 pb$^{-1}$)

CDF RUN II Preliminary

$\int L dt = 126$ pb$^{-1}$
Z' and RS Graviton Mass Limits

e^+e^- and \( \mu^+\mu^- \) combined

CDF Run II Preliminary (200 pb\(^{-1}\))

- \( \sigma \cdot Br(Z'\rightarrow ll) \) limit (95% C.L.)
- \( \sigma \cdot Br(Z'\rightarrow ll) \) LO\(\times1.3\)

- 570 GeV (Z_1)
- 610 GeV (Z_\chi)
- 625 GeV (Z_\psi)
- 650 GeV (Z_\eta)
- 750 GeV (Z' SM coupling)

Graviton mass (GeV/c\(^2\))

CDF Run II Preliminary (200 pb\(^{-1}\))

- \( \sigma \cdot Br(G\rightarrow ee) \) limit(95% C.L.)
- \( \sigma \cdot Br(G\rightarrow ee) \) PYTHIA\(\times1.3\)

- Randall-Sundrum Model

Graviton mass (GeV/c\(^2\))

March 12, 2004
Search for the $H^{++}$ in same sign dileptons

- Doubly-charged Higgs particles predicted by LR symmetric models,
- SUSY LR models predict low-mass $H^{++}$ (~100 GeV to 1 TeV)
Search for 1st & 2nd Generation LeptoQuarks

- Some models beyond SM have an extra symmetry between quarks and leptons
- Leptoquarks transition between leptons and quarks
- Have lepton and baryon numbers with unknown couplings
- Search for two muons and two jets $M(LQ) > 240 \text{ GeV/c}^2$
- Two electrons and two jets reported $M(LQ) > 230 \text{ GeV/c}^2$
- 1 electron + 2 jets + missing $E_T$ $M(LQ) > 166 \text{ GeV/c}^2$
Search for Any Generation LQs

- Signal is missing $E_T$ plus two jets

CDF Run II Preliminary

$\int L \, dt = 191 \, \text{pb}^{-1}$

- Data
- QCD prediction
- + SM EWK / $t\bar{t}$ prediction
- LQ ($m = 125 \, \text{GeV} / c^2$)

CDF Run II Preliminary (191 pb$^{-1}$)

- CDF Upper Limit, 95% CL
- Theoretical cross section (PRL 79, 1997)
  - CTEQ5M, $Q=m(LQ)$
  - CTEQ5M, $Q=0.5m(LQ), 2m(LQ)$

Exclude 78 - 117 GeV/c$^2$
Electro-Weak
Electro-Weak

- 2 papers in godparent publication review
  - Forward-backward asymmetry in $Z \rightarrow e^+e^-$
    - Second draft ready for Collaboration in ~2 weeks
  - $W/Z$ cross section $e, \mu$
    - First draft ready
- Formed godparent committee
  - $WW$ cross section in dilepton channel
- Forming godparent committee for
  - $W/Z$ cross section in tau channel
- Moving towards final blessing
  - $W$ mass
W&Z Cross Section and W width

\[ \sigma \times \text{Br}(W \rightarrow h\nu) \]

\[ \sigma \times \text{Br}(Z \rightarrow \gamma\gamma) \]

- Standard Model
- World Average (RPP 2002) (includes Run I results)
- CDF II combined
- CDF II(\(e\)) preliminary
- CDF III(\(\mu\))
- D0 \(Ia+b(\(e\))
- CDF \(Ia(\(e\))
- UA2(\(e\))
- UA1(\(e+\mu\))

\[ E_{\text{cm}} \text{ (TeV)} \]

\[ \Gamma(W) \]

March 12, 2004

CDF Physics Results and Detector Status - Luciano Ristori & Nigel Lockyer - URA Visit
W/Z production: understanding the systematic effects

\[ \sigma(pp \to W \to l\nu) = 2777 \pm 10_{\text{stat}} \pm 52_{\text{syst}} \pm 167_{\text{lum}} \text{ pb} \]

\[ \sigma(pp \to Z/\gamma^* \to ll) = 254 \pm 3.3_{\text{stat}} \pm 4.3_{\text{syst}} \pm 15.2_{\text{lum}} \text{ pb} \]

\[ R = 10.34 \pm 0.15_{\text{stat}} \pm 0.13_{\text{syst}} \]
Wy production: agreement with SM
Zγ with 200 pb\(^{-1}\): indications of a new physics?

\[ pp \rightarrow Z\gamma \rightarrow \ell^+\ell^-\gamma \]

2 leptons with \( E_T > 25 \) GeV
1 photon with \( E_T > 7 \) GeV,
\( \Delta R(\ell,\gamma) > 0.7 \)

CDF Run 2 Preliminary 202(pb)

\[ M_{\text{inv}}(\ell,\gamma) \text{ (GeV/c}^2\text{)} \]

\[ M_{\text{inv}}(\ell,\ell) \text{ (GeV/c}^2\text{)} \]

- 35 \( Z\gamma \rightarrow \mu^+\mu^-\gamma \) events
- 34 \( Z\gamma \rightarrow e^+e^-\gamma \) events
- \( Z\gamma \rightarrow \ell^+\ell^-\gamma \) MC

March 12, 2004
CDF Physics Results and Detector Status - Luciano Ristori & Nigel Lockyer- URA Visit
W mass measurement: finalizing the results

CDFII Preliminary
200 pb⁻¹
QCD

• Form godparents early soon
  – Underlying event studies
  – Jet shapes/energy flow

• Form godparents by summer
  – Inclusive jet cross-section
  – Dijet mass
  – Heavy Flavor + gamma

• Form godparents by fall
  – Diffractive exclusive $\chi_c$ production…
  – $W+$jets cross section
  – $B$ jet cross section
  – Dijet angular distributions
Inclusive Jet cross section

CDF Run II Preliminary
Integrated L = 177 pb^{-1}
JetClu Cone R = 0.7

Uncorrected

CDF Run II Preliminary
Integrated L = 177 pb^{-1}
0.1 < |\eta| < 0.7
JetClu Cone R = 0.7

Uncorrected
• Theoretical error dominated by PDF’s
• Data currently agrees with NLO prediction within estimated errors
Top
Top

• First Paper draft for top dilepton to collaboration
  – Comments back and positive
  – Final draft in preparation
  – hopefully send to PRL by end of month

• Formed godparent committees for Top cross-sections
  – Kinematic cross section (Ht)
  – Kinematic cross section (ET+b-tag)
  – W+jets – vertex tag of b-jet
  – W+jets – soft lepton tag

• Formed godparent committee for Top mass
  – Expect to publish by end of year (several new methods)
  – Bless new result hopefully for Moriond

• Forming godparent committee for single top

• Moving towards final blessing
  – W helicity
  – Single top with neural net
Run 1 Dilepton kinematics

- Events at large missing ET
- Study run2 sample
Top Dilepton Cross Section

Tight $e/\mu$ selection complemented by $e/\mu$ + tracks selection

Lepton + track sample has looser ID requirements for second lepton

Sensitive also to $\tau$ lepton final states

2 lepton + 2 jets sample is small but very clean for top signal
Cross Section Results using Tagging

Counting experiments with vertex tag and soft muon tag in 3,4-jet bins

Estimate backgrounds in the lepton + jets sample from first principles:
- Using data as much as possible (non-W QCD, fake tags)
- Some MC calculations for diboson and W + heavy flavor backgrounds
Kinematic Fits to Lepton + Jets Sample

Provides another way of estimating the background contribution

Sample before tagging

CDF Preliminary (195 pb⁻¹)

Vertex-tagged sample

CDF Run II preliminary (~108 pb⁻¹)

W+3 or more jets

<table>
<thead>
<tr>
<th>Type</th>
<th>Plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>t\bar{t} + BKG</td>
<td><img src="chart1.png" alt="Graph" /></td>
</tr>
<tr>
<td>t\bar{t} (Herwig)</td>
<td><img src="chart2.png" alt="Graph" /></td>
</tr>
<tr>
<td>BKG (from data)</td>
<td><img src="chart3.png" alt="Graph" /></td>
</tr>
</tbody>
</table>
CDF Top Cross Section Summary

**Top Production Cross Sections**

CDF Run 2 Preliminary

- **L + Jets: Vertex Tag + Kinematic**
- **L + Jets: Lepton Tag**
- **L + Jets: Vertex Tag**
- **L + Jets: Kinematic**
- **Lepton + Track**
- **Dilepton**

**Cross Sections**

- **108 pb⁻¹**: 6.9^{+1.6/-1.8}_{stat.} ± 0.9 (syst.)
- **126 pb⁻¹**: 4.1^{+4.0/-2.8}_{stat.} ± 2.2 (syst.)
- **108 pb⁻¹**: 4.5^{+1.4/-1.3}_{stat.} ± 0.8 (syst.)
- **195 pb⁻¹**: 4.7 ± 1.6(stat.) ± 1.8 (syst.)
- **202 pb⁻¹**: 6.9^{+2.7/-2.4}_{stat.} ± 1.3 (syst.)
- **193 pb⁻¹**: 8.7^{+3.9/-2.6}_{stat.} ± 1.5 (syst.)
Conclusion

- The CDF detector overall is working very well (silicon stable)
- Complex 3-level trigger in good shape
- COT aging needs to be understood and fixed (short and long term issue)
- Physics publications from all groups this year—very busy good progress
- Top cross section publication this month to PRL (first hipt pub)
- Top mass > 1 method for APS
- Bottom group very busy with many topics
  - Bs mixing —will be hard—
- Taus: good signal-to-noise longer term potential for discovery encouraging
- W’s and Z’s to leptons look good—W mass coming along
- Searches far exceed RunI level
- Double the data again by summer hopefully (4X Run 1)
- Opportunity for discovery good with new confidence in luminosity