Recent Results from the Tevatron

Luciano Ristori

Planck 2009
Padova - 25 Maggio 2009
CDF
♦ 15 Countries
♦ 63 Institutions
♦ 602 authors

DØ
♦ 18 Countries
♦ 90 Institutions
♦ 533 Authors
Run 2 Luminosity Progress

Record peak inst. luminosity
$3.6 \times 10^{32}$ cm$^{-2}$ s$^{-1}$

Record luminosity/week
73 pb$^{-1}$

Record luminosity/month
250 pb$^{-1}$

Total Luminosity delivered
6.5 fb$^{-1}$

100 times more data than used for Top quark discovery!

> 2 fb$^{-1}$ delivered in 2008!
Projected TeVatron Performance

Pier Oddone - March 20, 2009

Luminosity Performance and Projection

- Real data for FY02-FY08
- We are here
- ~12 fb⁻¹
- 9.3 fb⁻¹
- 7.8 fb⁻¹

Integrated luminosity (fb⁻¹)

FY04 FY05 FY06 FY07 FY08 FY09 FY10 FY11
• Tevatron performance is excellent

• Detectors are well understood

• Smooth data taking

• Smooth data processing

• Sophisticated analysis techniques
Nearly 100 journal publications last year alone
About 60 Ph.D.’s / year over the last few years
About 3500 physicists have participated on the CDF and D0 experiments
### New Results Since Summer 08

#### public web pages

- [http://www-cdf.fnal.gov/physics/W09CDFResults.html](http://www-cdf.fnal.gov/physics/W09CDFResults.html)
- [http://www-d0.fnal.gov/Run2Physics/W09D0Results.html](http://www-d0.fnal.gov/Run2Physics/W09D0Results.html)

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**Top Physics**

| Analysis | Luminosity | New Information |
|----------|------------|-----------------|
| GGF Higgs production | 2.0 fb⁻¹ | Pre-Pub |<ref>http://www-cdf.fnal.gov/physics/W09CDFResults.html</ref> |
| Drell-Yan results for heavy quark production | 0.0 fb⁻¹ | Pre-Pub |
| Measurement of B → ρπ decay rates | 0.0 fb⁻¹ | Pre-Pub |
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**CDF Results**

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**Higgs Physics**

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### c 100 new results
10 orders of magnitude
HIGGS
SM Higgs exclusion by CDF
Exclusion Decomposition

CDF Run II Preliminary, $L=2.0-3.6$ fb$^{-1}$

ZH $\rightarrow \nu\nu bb$

ZH $\rightarrow llbb$

WH $\rightarrow l\nu bb$

$H \rightarrow WW \rightarrow l\nu l\nu$
160 GeV < $M_H$ < 170 GeV is excluded at 95% CL!
SM Higgs Limit Projections

with 10/fb both experiments could reach SM cross section down to 115 GeV
$M_{\text{top}} = 173.1 \pm 0.6 \text{ (stat)} \pm 1.1 \text{ (syst)} \text{ GeV/c}^2$
$M_W = 80413 \pm 48$ MeV (CDF, 0.3 fb$^{-1}$)

$= 80401 \pm 44$ MeV (DØ, 1 fb$^{-1}$)

$\Gamma_W = 2032 \pm 73$ MeV (CDF)

world's most precise single measurements!
Precision => Higgs Constraints

Expected now with all constraints:

- $M_H = 90^{+36}_{-27}$ GeV
- $M_H < 163$ GeV @ 95% CL

With 10 fb$^{-1}$

If $dM_w=15$ MeV and $dM_{top}=1$ GeV for $M_w=80.400$

- Expect $M_H = 71^{+24}_{-19}$ GeV
- $M_H < 117$ GeV @ 95% CL
Single Top Observation
March 9, 2009

**DØ:** $\sigma_s + \sigma_t = 3.94 \pm 0.88 \text{ pb}$

**CDF:** $\sigma_s + \sigma_t = 2.3^{+0.6}_{-0.5} \text{ pb}$

- Final state is very similar to WH

**Graph:**
- High $p_T$ lepton + MET + jets
- Super Discriminant
- Events
- $>5.9 \sigma$
EXOTICS
Search for High Mass e⁺e⁻ Resonances

- CDF (DØ) exclude RS graviton with mass below 850 (900) GeV/c² for k/Mₚ=0.1
Di-muon Resonances

- Search in $1/m_{\mu\mu}$ in which detector resolution is $\sim$const:
  - For the first time beyond one TeV for SM-$Z'$!
  - 17% inverse mass resolution at 1 TeV

| $Z'$ model | $Z'$ mass limit |
|------------|-----------------|
| $Z'_{SM}$  | 1030            |
| $Z'_{I}$   | 789             |
| $Z'_{dec}$ | 821             |
| $Z'_N$     | 861             |
| $Z'_{q\bar{q}}$ | 878         |
| $Z'_X$     | 892             |
| $Z'_{\nu}$ | 982             |

CDF II preliminary \[ \int L dt = 2.3 \text{ fb}^{-1} \]
Several results show discrepancies with the SM. Are these just statistical fluctuations or hints of new physics?

2.5σ effects

Are these just statistical fluctuations or hints of new physics?
Multimuon Analyses

Motivated by three long-standing discrepancies dating back to Tevatron Run I:

1. $\sigma(pp \rightarrow b\bar{b}X)$ larger than expected from NLO QCD

2. Time-integrated mixing measured at Tevatron larger than LEP average
   
   $$\bar{\chi} = \frac{\Gamma(B^0 \rightarrow \bar{B}^0 \rightarrow l^+ X)}{\Gamma(B \rightarrow l^\pm X)} = \frac{\text{"same sign"}}{\text{"total"}}, \quad B^0 = B_d^0 \text{ or } B_s^0$$

3. low mass di-lepton spectrum inconsistent with expectations from heavy flavor.
First, re-measure $\sigma(pp\rightarrow b\bar{b}X)$

- **PRD 77, 072004 (2008)**

- **Strategy**
  - Select dimuon events enriched in $b\rightarrow\mu$, $\bar{b}\rightarrow\mu$
  - Require our highest tracking precision to separate out prompt and charm backgrounds.
  - Fit muon impact parameters to separate contributions

- **Sample**
  - Well modeled by simulation
  - High purity: ~40% $b\bar{b}$

- **Result**
  - Measurement accuracy 9%
  - Good agreement with theory
Next, investigate “other” dimuons

- observe many more events rejected by the tight selection than expected.
  - implies more background than expected.
  - Investigate this background. Much of it was not removed because it appears at large impact parameter!

- QCD sources (including heavy flavor) of dimuons have $d_0 < 0.5\text{cm}$

- “Ghost” events have much larger impact parameter!

![Graph showing Muons/0.008 cm vs. d (cm)]
Ghost sources

The rate of muons in the ghost sample is four times higher than the expectation.

Several known sources have been evaluated:
- Hadrons faking muons
- decay-in-flight of $K^\pm$, $\pi^\pm$, $K_S$, $\Lambda$, etc.
- Interactions in detector material

• At this point, these sources do not seem to explain the entire sample.
  - We are in a region of parameter space that is very challenging and largely uninvestigated.

• We have chosen to publish the current results to report what we have learned.
  - We state that we do not understand the source of these events.
  - We do not claim that the source of the events is beyond the standard model.

• Regardless of their source, this sample of events
  - has not been quantified before
  - very likely plays a role in the anomalies listed previously

• The presence of ghost events is not confirmed by D0:
  http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B57/B57.pdf
RARE DECAYS
\[ \text{B}_s \rightarrow \mu^+\mu^- \]

- Already at \(\sim 10^{10} \times \text{SM} \) with 2/fb
- Plenty of NP models already excluded

| Limit 90% (95%) \(\times 10^8\) | \(B_s^0 \rightarrow \mu\mu\) | \(B^0_d \rightarrow \mu\mu\) |
|---------------------------------|-----------------|-----------------|
| BaBar [PRD 77, 032007 (2008)] | n/a             | 5.2             |
| DØ                             | 7.5 (9.3)       | n/a             |
| CDF [PRL 100, 101802 (2008)]  | 4.7 (5.8)       | 1.5 (1.8)       |

- No improvements assumed
- \(<1 \times 10^{-8} \times (3 \times \text{SM})\) at 10/fb per experiment

[M. Carena, Moriond 2007]
\[ B_{d,s} \rightarrow e^+\mu^-, e^+e^- \]

- SM prediction very small < \(1.0 \times 10^{-15}\)
- Larger BRs in some NP models (e.g. Leptoquarks)

All measurements represent the current **world best limits!**

| Channel | CDF Run II preliminary \((2 fb^{-1})\) \((@ 90(95)\%) \text{ C.L.}\) | BaBar \((@ 90\% \text{ C.L.})\) |
|---------|-------------------------------------------------|------------------|
| \( Br(B_s^0 \rightarrow e^+\mu^-) \) | \(< 2.0(2.6) \times 10^{-7} \) | - |
| \( M_{LQ}(B_s^0) \) | \( > 47.7(44.6) \text{ TeV/c}^2 \) | - |
| \( Br(B_d^0 \rightarrow e^+\mu^-) \) | \(< 6.4(7.9) \times 10^{-8} \) | \(< 9.2 \times 10^{-8} \) |
| \( M_{LQ}(B_d^0) \) | \( > 58.6(55.7) \text{ TeV/c}^2 \) | \( > 53.1 \text{ TeV/c}^2 \) |
| \( Br(B_s^0 \rightarrow e^+e^-) \) | \(< 2.8(3.7) \times 10^{-7} \) | - |
| \( Br(B_d^0 \rightarrow e^+e^-) \) | \(< 8.3(10.6) \times 10^{-8} \) | \(< 1.13 \times 10^{-7} \) |
FLAVOR PHYSICS
\[ B^0(s) \rightarrow h^+h^- \]

CDF with its trigger on secondary vertices is a serious competitor to the B factories

- CDF has access \( B^0, B^0_s, \Lambda_b \)
- Direct \( A_{\text{CP}} B^0 \rightarrow K^+\pi^- \) was measured with precision similar to B factories
- Possible observation of direct \( A_{\text{CP}} \) in \( B^0_s \)?

about 6000 events in 1 fb\(^{-1}\)

Possible precisions with 10 fb\(^{-1}\)

\[ \begin{align*}
<1\% & \text{ on direct } A_{\text{CP}} \text{ in } B^0 \rightarrow K^+\pi^- \\
<8\% & \text{ on direct } A_{\text{CP}} \text{ in } B^0_s \rightarrow K\pi^+ \\
\text{(SM predicts large value 30-40\%)}
\end{align*} \]
B^{0}_s mixing phase: B^{0}_s \rightarrow J/\psi \phi

- B^{0}_s sector unique to Tevatron and fully unexplored
- $\Delta m_s$ excluded large NP magnitude in B^{0}_s mixing (2006)
- NP phase still unconstrained
- Probe it through time-evolution of B^{0}_s \rightarrow J/\psi \phi decays

- CDF and DØ observe a consistent fluctuation (same direction, same significance)
- Current average $\beta_s = 0.4$

NP expectations $\beta_s = 0.5 \div 0.7$

[Hou at al., Phys.Rev.D76:016004,2007]

If NP phase is large (>0.5) Tevatron will observe it

$\phi^{J/\psi \phi}_s = -2\beta^{J/\psi \phi}_s$ [rad]

$\text{Prob}(5\sigma)$

$L = 10 \text{ fb}^{-1}$

$L = 20 \text{ fb}^{-1}$ (2*CDF)
$B_s \rightarrow \phi \phi \rightarrow K^+ K^- K^+ K^-$

CDF 2009 $\sim$ 300 events

CDF 2005 - 8 events

$BR(B_s \rightarrow \phi \phi) = [1.4 \pm 0.6\text{(stat)} \pm 0.6\text{(syst)}] \cdot 10^{-5}$
$B_s \rightarrow \phi \phi \rightarrow K^+ K^- K^+ K^-$

First polarization measurement, comparing with $B_d \rightarrow \phi K^*$
NEW STATES
Mass Measurement of the X(3872) State

CDF: $m = 3871.61 \pm 0.16 \text{ (stat)} \pm 0.19 \text{ (syst) MeV/c}^2$

- This is the most precise measurement to date
- The value is below the D*D threshold, but within uncertainties. The explanation of the X(3872) as a bound D*D system is therefore still an option
Evidence for $Y(4140)$

Narrow near-threshold structure in the $J/\psi \phi$ mass spectrum in $B^+ \rightarrow J/\psi \phi K^+$

$arXiv:0903.2229$

$B^+ \rightarrow Y(4140)K^+$; $Y(4140) \rightarrow J/\psi \phi$; $J/\Psi \rightarrow \mu^+\mu^-$; $\phi \rightarrow K^+ K^-$

Production of $Y(4140)$

we measure:

- $m = 4143.0 \pm 2.9 \text{ (stat.)} \pm 1.2 \text{ (syst.) \ MeV/c^2}$
- $\Gamma = 11.7 + 8.3 - 5.0 \text{ (stat.)} \pm 3.7 \text{ (syst.) \ MeV/c^2}$

14 ± 5 events
3.8σ significance
Observation of the $\Omega_{b^-}$

Interpreted as $P(\chi^2)$ with 3 d.o.f., $= 4.0 \times 10^{-8}$, $\Rightarrow 5.5\sigma$

Fit results:
- Mass: $6055.5\pm6.6$ MeV/c$^2$
- $c\tau_0$: $338\pm100$ $\mu$m
- Yield: $18\pm5$
**Ω_b^- Mass Measurements Compared**

- **D0 finds**
  - $M(Ω_b^-) = 6165 \pm 10{\text{(stat.)}} \pm 13{\text{(syst.)}} \text{ MeV}/c^2$
  - PRL 101, 232002(2008)

- **CDF finds**
  - $M(Ω_b^-) = 6054.4 \pm 6.8{\text{(stat.)}} \pm 0.9{\text{(syst.)}} \text{ MeV}/c^2$
Final Remarks

- Scientific production of CDF and DZero is at its peak
- The Tevatron era is far from being over
- Maybe the best is yet to come