Tevatron Physics for Run III

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Proposal

• Run the Tevatron for a 3-year period after 2011
• Purpose: further doubling of data to attain the ultimate goals of the Tevatron program.
• Presentations:
  – Physics program I: Overview/CPV at Tevatron
    • Giovanni Punzi
  – Physics program II: EWSB at Tevatron
    • Stefan Soldner
  – CDF detector and collaboration outlook
    • Robert Roser
  – D0 detector and collaboration outlook
    • Dmitri Denisov
Luminosity and Efficiency

CDF shown, D0 similar
Reminder: a program at its peak

- About 60 Ph.D.’s / year over the last few years
- Scores of results Summer’09 => Winter’10 => Summ’10

The program is not winding down, and a replacement is not yet here.

But what should we expect next?
On the Brink Of Discovery

• The Tevatron is not the energy frontier anymore. However, it is on the brink of discovery on two central HEP questions:
  – The mechanism of EWSB
  – The search for anomalous CP violation
• They require INTENSITY more than ENERGY, unlike other searches for BSM physics (SUSY,…)
• We are just now crossing the threshold of the place where the answers of those questions lie: this is where the real game begins.
• The program is a SURE THING: a short-range extrapolation from current results.
• Many Tevatron results will stay as a legacy as they are complementary to other facilities
On crossing thresholds

MILESTONE Higgs paper from CDF+D0 (>1000 authors!)

It took us 25 year of hard work, lowering the curve, with no result on the Higgs.

Finally we touchdown, giving the start to the Higgs program:

\[ M_H \] excluded 162-166 GeV

From now on, progress will be fast. Discussion in next talk

Should we stop running now?
On crossing thresholds, #2

- $A_{sl}$ is 3.2 $\sigma$ from SM
- Long-awaited first evidence for BSM CPV
- If real, we should see the effect in other measurements as well

Should we stop running now?
Continuously pushing boundaries

- Steady flow of quality physics results - As data increases, not just increase in statistics, but wider range of opportunities: new measurements and new channels. Continuously pushing boundaries. Little to do with Sqrt(L) law.
- On top of ~200 Higgs/year: More B’s than B-factories, more D’s than charm-factories.
- The overall impact on science of the myriad of results is difficult to describe in a talk but is indeed very relevant.
- Tevatron an unmatched training ground for new and old physicists
Remarks on Run 3

- In addition to doubling the data, a 3-year period allows reloading a new generation of students.
- Keeps a whole community engaged, allowing for multiple interests within the collaboration while pursuing the most fundamental questions.
- A great opportunity to keep up a rich and healthy scientific production while other programs are starting. Also considering the LHC shutdown at the end of 2011.
- Even LHC people come to the Tevatron as a source of crucial comparison data and knowledge.
CPV
CP violation: why it is important

[A. Masiero, FNAL Users’ meeting 2008]

A FUTURE FOR FLAVOR PHYSICS IN OUR SEARCH BEYOND THE SM?

- The traditional competition between direct and indirect (FCNC, CPV) searches to establish who is going to see the new physics first is no longer the priority, rather

- COMPLEMENTARITY between direct and indirect searches for New Physics is the key-word

- Twofold meaning of such complementarity:
  1) synergy in “reconstructing” the “fundamental theory” staying behind the signatures of NP,
  2) coverage of complementary areas of the NP parameter space (ex.: multi-TeV SUSY physics)

Add to it the unsolved question of Baryon Asymmetry
Tantalizing Hints

• The D0 results on lepton asymmetries is only the last of a series of hints:
  – The 5-$\sigma$ difference in Direct CPV in $B^0 \rightarrow K^+\pi^- \ B^+ \rightarrow K^+\pi^0$ from $\Upsilon(4S)$ experiments.
  – Slight excesses in $B^0 \rightarrow K^*\ell\ell$ FB asymmetry
  – Difference in $\sin(2\beta)$ between ccbar/penguin
  – Hints of nonzero mixing phase in the Bs

• All point to an anomalous source of CPV around the corner, and provide a strong motivation to investigate further.
Summary & Conclusions (I)

- While for now no compelling evidence against CKM-picture, several fairly sizeable effects (~2 - ~3.5 $\sigma$) in B, Bs CP asymmetries are difficult to understand in SM3.

- Being careful, "conservative" & cautious in such instances means hunting down seriously the underlying cause. ... Effects may well have been misinterpreted (downplayed) rather widely in the US with detrimental implications.

- CDF/D0 finding of Bs->psi phi "anomaly" is especially interesting since, 1) it follows from others, 2) unlike the other effects, this is theoretically very clean. Consequently, it is extremely important that FERMILAB follows it up & clarifies it with a very high priority.
The strengths of the Tevatron

• Strengths:
  – Large hadronic production: more fully reconstructed B hadrons than at Y(4s)
  – p-pbar symmetric initial state: low asymmetry systematics, needed for sub-% resolution
  – Hi-resolution central detectors
  – A refined trigger, with hardware online vertexing
  – The weight of accumulated experience

• Some parts of the program are unique.
  – Even those that are not, are important enough to justify the need for more than a single experiment
  – Their deliverance at the Tevatron is virtually certain
  – They come at no cost as part of the package
**CPV in Bs mixing status**

- The parameters of the Bs mixing are good probes into BSM
- $\Delta m_s$ - precisely known, agrees with SM within theory uncertainty
  \[ \Delta m_s = 17.77 \pm 0.10 \pm 0.07 \text{~ps}^{-1} \]
- The phase $\phi_s^{J/\psi \phi} = -2 \beta_s^{J/\psi \phi}$ is the most interesting item.
  Small in SM, can receive large BSM contributions.
  PREDICTED to be large in some models
- Hints of deviations have raised strong excitement
- Must be large to produce large $A_{SL}$: 
  \[ A_{SL} = \left( \frac{\Gamma_{12}}{\Delta m_s} \right) \cdot \sin(2\beta_s) \]

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**Diagram:**

- **CDF Run II Preliminary + DØ 2.8 fb$^{-1}$**
  - 68% CL
  - 95% CL
  - 99% CL
  - SM

- **CDF-D0 combination Summer 09**
  - $\sim 2.1\sigma$ from SM

- **Latest CDF update**
  - $\sim 0.8\sigma$ from SM
  - (combination not yet available)
**\( \beta_s \) Outlook for run III**

- **Significant increase in discovery probability**
  - \( \Rightarrow \) Enough data for a *yes/no* result (discovery or exclusion) over most of the interesting range.
  - Assumes constant data taking efficiency and no analysis improvements
  - No external constraint or additional information (e.g. ASL)

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CDF Simulated Data, Assume \( \beta_s = 0.4 \)

\[
\begin{array}{c}
\beta_s = 0.4 \\
-3 \sigma \\
4 \sigma \\
5 \sigma \\
\end{array}
\]

Integrated Luminosity (fb\(^{-1}\))

- Previous
- Latest
- Next

Prob(5\(\sigma\))

Discover-or-Exclude Threshold

[arXiv:physics/0308063v2]
**ΔΓ_s outlook**

- **Width difference ΔΓ_s is related to phase:**
  \[ ΔΓ_s = Γ_L - Γ_H ≈ 2|Γ_12| \cos(φ_s) \]
- **If large phase, must be decreased from its SM value:**
  \[ ΔΓ_s = 0.088 ± 0.017 \text{ ps}^{-1} \]  
  [JHEP0706:072,2007]
- **It can reveal new physics on its own.**

**Latest Measurements:**

- **D0 (2.8fb-1)**  \( ΔΓ_s = 0.14 ± 0.07 \text{ ps}^{-1} \)
- **CDF(5.2fb-1)**  \( ΔΓ_s = 0.075 ± 0.035 \text{ ps}^{-1} \)

**Run 3 statistics:**  \( σ(ΔΓ_s) = 0.016 \text{ ps}^{-1} \)

5-σ between SM and zero.
\[ \Delta \Gamma_s \text{ outlook} \]

- **Width difference** \( \Delta \Gamma_s \) **is related to phase:**
  \[ \Delta \Gamma_s = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}| \cos(\phi_s) \]

- **If large phase, must be decreased from its SM value:**
  \[ \Delta \Gamma_s = 0.088 \pm 0.017 \text{ ps}^{-1} \]
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**Latest Measurements:**
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With run3 the hadronic BsKK channel become important independent contribution (unique to CDF):
\[ \sigma(\Delta \Gamma_s / \Gamma_s) = 0.035 \quad (4\sigma \text{ level}) \]
2nd part of comments from Soni

Summary & Conclusions (II)

- If the effects stand further scrutiny, SM4 with mt’, mb’ (400-600 GeV) provides a very simple explanation of the anomalies.
- SM4 opens up important new avenues for baryogenesis, DMC, unification, and most likely also crucial for EWSB...thereby it may well lead to a possible resolution to the hierarchy problem.
- Underlying nature of the “4th gen.” has to be significantly different.

On more general grounds BCP-anomalies means relative low scale for NEW PHYSICS with lots of accessible manifestations at LHC but also, for sure, means that SBF & (S)LHCb will have a very important role to play.
World’s best DCPV measurements

A whole array of DCPV measurements are the best existing. Improving them will cover new and promising territory from multiple directions.

- $A_{CP}(J/\psi K^+)$
  4th generation predict $O(1\%)$ [PRL 95 (2005) 141601]
  Best B-factory result: Babar $\sigma = 1.4\%$
  D0 published 0.6% statistical
  CDF expect 0.4% statistical in 5fb$^{-1}$
  Run 3 statistics allows observation at 5 sigma

- $A_{CP}(B_s \rightarrow K\pi)$
  A crucial test of the SM nature of CPV in $B^0$ and $B^+$
  Unique to CDF. Will measure with $\sigma = 0.05$

- $A_{CP}(K\pi)$
  CDF has World’s largest sample (3k/fb$^{-1}$)
  will measure $A_{CP}(K^+\pi^-)$ to < 1%
  World’s best resolution on the first anomaly.
Further CPV: angle $\gamma$

- A further way to test consistency of CKM scheme
- Measurements in hadronic channels hard to do without an hardware vertex trigger

Current CDF published results from 1fb$^{-1}$ only

1fb$^{-1}$ CDF $\equiv$ $\sim$350fb$^{-1}$ @B-factory
10fb$^{-1}$ CDF $\equiv$ $\sim$3.5ab$^{-1}$ @B-factory

RUN 3 adds a good chunk of data
The cleanest, highest-intensity charm factory on earth

- CDF accumulates at rate 10xBelle (at peak) using a vertex trigger. Enough motivation for a dedicated experiment.
- Recently added dedicated trigger selection.
- CPV in CS modes of D⁰ unambiguos sign of NP (expect O(1%)). [Phys.Rev.D75:036008,2007]
  In particular from 4th-gen [hep-ph/0611154]
- Current PDG (Babar+Belle+CDF)
  \[ \sigma (A_{\text{CP}}(D^0 \rightarrow \pi\pi)) = 4.0 \times 10^{-3} \]
- Tevatron run III hits the needed 1.0 \times 10^{-3}
- Very likely the ONLY chance to observe CPV in the charm sector.
- NO OTHER EXPERIMENT CAN ACHIEVE THIS SENSITIVITY (possibly superB?)
- Bonus: high-precision determination of D⁰ mixing parameters.
Direct test for the existence of a 4th sequential generation of quarks

- A very good explanation for the pattern of hints emerging is the presence of a sequential 4th generation of quarks of 300-500GeV.
- This would provide a solid explanation for the BAU, and EWSB.
- It can easily make the the Higgs boson invisible or push it to high masses (>300GeV), so very important to test if it is there.
- Past CDF measurements show hints at 2.5 sigma level.

\[
M_{t'} > 335 \text{ GeV} \quad @ \quad 95\%\text{CL}
\]
Direct test for the existence of a 4th sequential generation of quarks

- We don’t need to speculate on the existence of a 4th generation.
- If it exists, it cannot be far from our current limits, and we will find out.
- The current slight excess would turn into solid observation.
- If we don’t find it, we will exclude an important candidate explanation.

CDF-only projections, expect similar from D0
Expect joint sensitivity beyond 450GeV

**4th gen top-like quark**

**Current Limits:**

\[ M_{t'} > 335 \text{ GeV} \text{ @ 95\%CL} \]

**4th gen bottom-like quark**

**Current Limits:**

\[ M_{b'} > 338 \text{ GeV} \text{ @ 95\%CL} \]
Other anomalies may surprise us: e.g. Top Properties

- NLO QCD predicts non-zero forward-backward asymmetry in top production $\sim 5\%$
- Measurement of $A_{fb}$ can only be done in p-pbar
- Currently see an excess - Several new physics models predict large $A_{fb}$ (Axigluons)

$A_{fb} = 19 \pm 7\%$

$A_{fb} = 12 \pm 8\%$
SOME IMPORTANT QUESTIONS WE CAN ANSWER WITH RUN 3

– ARE THE ANOMALOUS CPV HINTS REAL?
– IS THERE CPV IN THE CHARM SECTOR?
– IS THIS DUE TO A 4TH GENERATION OR SOME OTHER BSM SOURCE OF CPV?

The next talk will discuss THE UNIQUE CONTRIBUTION OF THE TEVATRON TO THE UNDERSTANDING OF EWSB.