Studying Charm And Beauty with BTeV

Michael Ronquest

for

M.Arenton, B. Cox, S. Conetti, A. Ledovskoy, H. Powell, D. Smith, W. Stephens

and

the BTeV collaboration

What is BTeV?

BTeV is an experiment that will study the B mesons (containing beauty quarks) and D Mesons (containing charm quarks) that will stream from the proton/anti-proton collisions generated by the Tevatron Collider at Fermi National Accelerator Lab. BTeV will test Standard Model predictions of CP violation, quark mixing and rare decays, and will also be an ideal tool to use in searches for new physics beyond the Standard Model.

What Sets BTeV Apart?

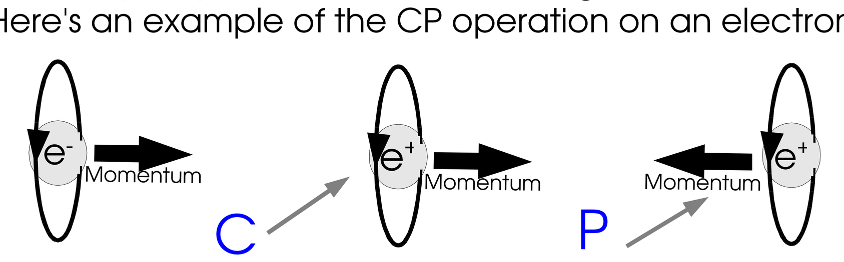
Other experiments share the prime goal of BTeV, which is to study the decays of the B_d particle. However, BTeV has more physics reach than many of these other experiments:

Both BaBar and Belle use e^- e^+ collisions, which produce cleaner events, but at much lower rates and at energies below that needed to produce the interesting B_s, B_c and Λ_b particles.

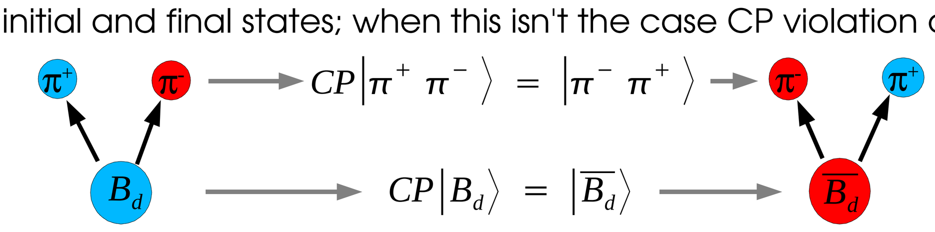
CDF and D0, the current collider experiments at Fermilab, will record all species of B mesons, but neither is designed to take advantage of the topology of b quark production at the Tevatron, which occurs most frequently at small angles to the particle beams.

What Is CP Violation?

CP is the combined transformation of charge inversion C (particle -> antiparticle) and parity reversal P (mirror image of coordinate system, x -> -x,etc.) Here's an example of the CP operation on an electron:



Most processes behave the same when the CP transformation is applied to their initial and final states; when this isn't the case CP violation occurs.



$$CP|\pi^+\pi^-\rangle = |\pi^-\pi^+\rangle$$

$$CP|B_d\rangle = |\overline{B}_d\rangle$$

CP violation is manifest when some particles behave differently than their corresponding anti- particles. An example would be a B_d decaying into a π^+ and a π^- (above left) at a different rate than its anti-particle (above right).

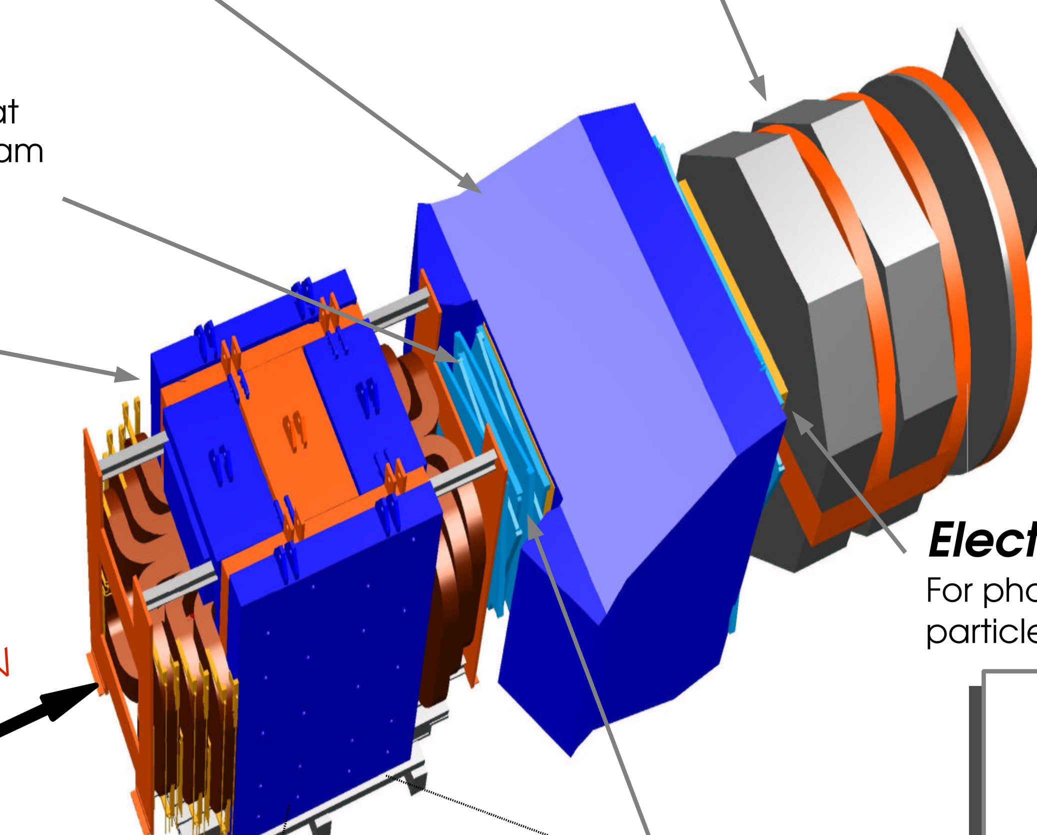
CP violation is interesting because it is the only known process in which the early universe, which was thought to have been comprised of equal amounts matter and anti-matter, could be transformed into today's matter-dominated universe. Currently, CP violation, as observed, is too small to completely account for this matter/antimatter asymmetry, but it is still a good place to search for further answers.

What Is The Origin Of CP Violation?

CP violation, as it is currently understood, occurs in the weak interaction. The CKM matrix:

$$V_{qq'} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

which describes the probability that a quark q' will change into another quark q , has some elements with imaginary parts. These elements are the origin of CP violation in the Standard Model. The CKM matrix is also unitary, and this fact allows us to construct relations between its elements. These relations can be visualized as triangles in the complex plane, with the angles being referred to as the *CP violating phases.* BTeV will make precision measurements of the CP phases α, β, γ, and χ.



Ring Imaging Cerenkov
For charged particle identification

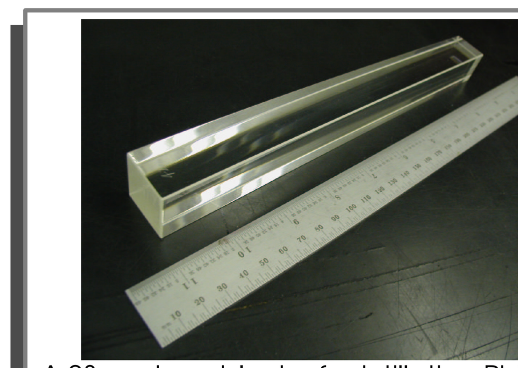
Muon Chambers and Toroids
For muon tracking and momentum measurement

Silicon Microstrips
For charged particle tracking at small angles to the particle beam

Magnet
For momentum measurement
It generates 1.6 Tesla.

Electromagnetic Calorimeter
For photon detection, π^0 reconstruction and particle identification

Pixel Detector
For track and vertex reconstruction
Each of the 3 X 10^7 pixels is 50μm X 400μm in size.

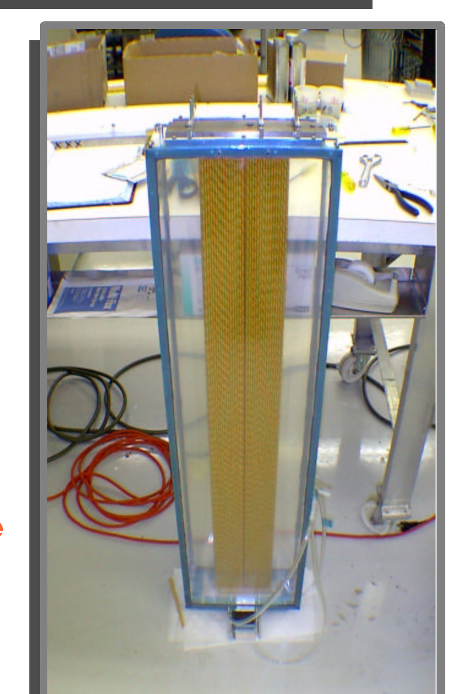


A 23 cm long block of scintillating $PbWO_4$. The calorimeter will consist of 10500 such crystals.

Straw Tube Chambers
For charged particle tracking
at large angles to the particle beam

Those of us at UVA are working on R&D and construction of the straw chambers.

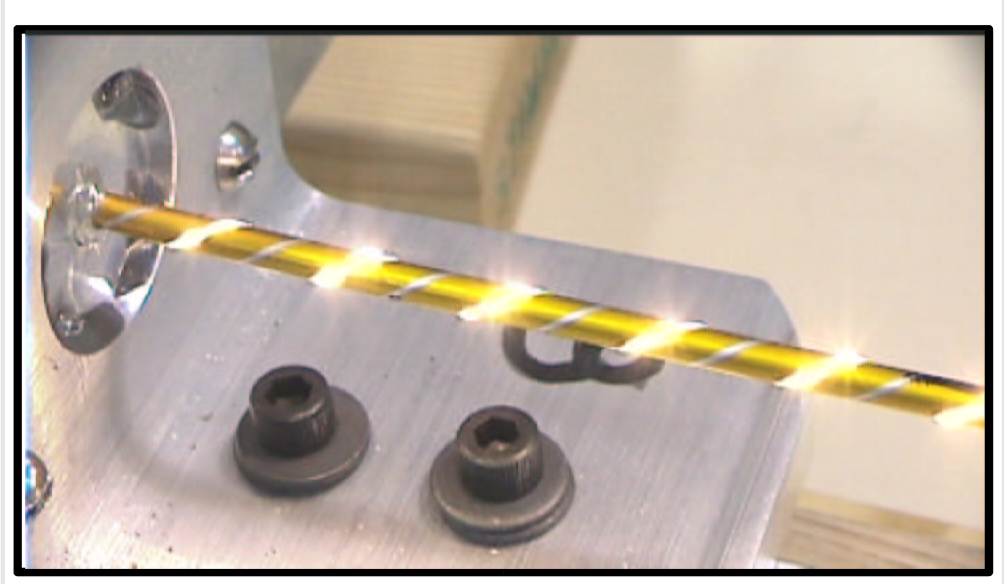
I'm currently investigating:
Magnetic field effects on chamber performance (some of the straws will be inside the magnet)
High voltage fusing ideas for the chambers. (description at left)



A 96 straw prototype. There will be ~30,000 straws in BTeV.

Straw High Voltage Fusing

Under normal operating conditions, a potential difference of 1600V is maintained between the straw and the 25μm anode wire inside. A way must be found to protect the HV power supplies in the event of a short circuit. One possibility is to use the wire as its own fusible link. This can be achieved by inserting a 1arge capacitor in parallel with the HV supply. A photo of a recent test is below. The flash is the wire vaporizing inside.

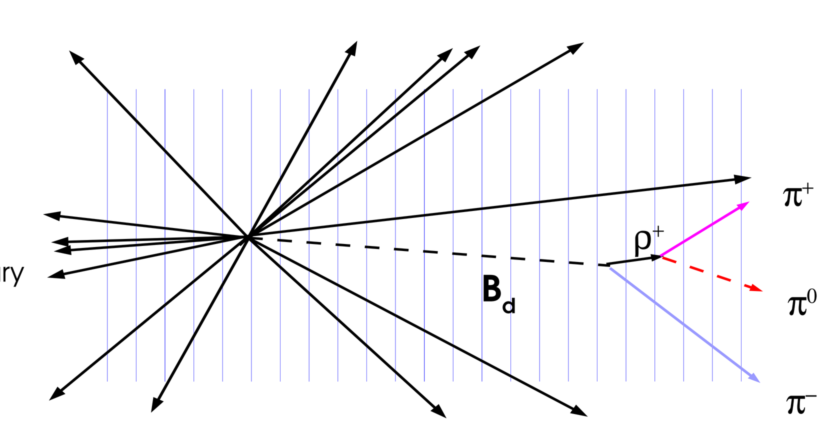


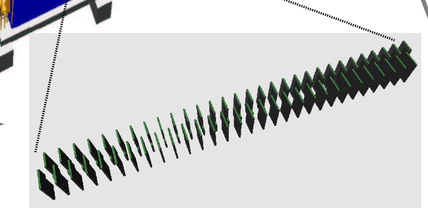
The Detached Vertex Trigger

A trigger is a tool used to pick out and record events that warrant further examination and study. BTeV's trigger is the key to the experiment; it allows a wider variety of decays to be collected than in many other experiments. Here's how it works:

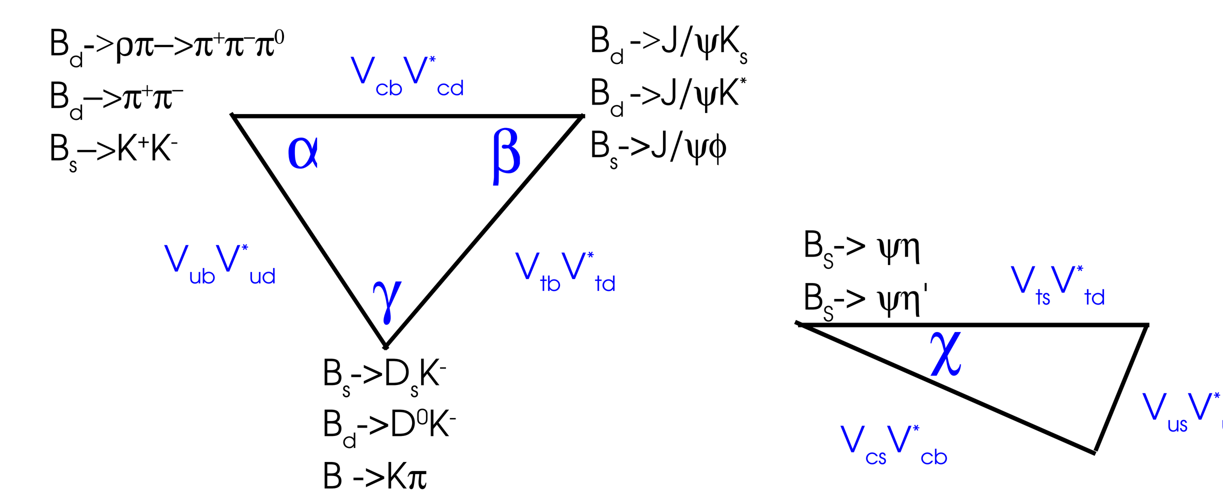
- The trigger uses charged particle tracks in the pixel detector to pinpoint the location where a proton and an anti- proton collide (primary vertex) , and the location where particles decay (secondary vertices) .
- The path between the two vertices will be that of the decaying particle.
- The momentum of the decaying particle can be found by looking at the deflection of each secondary track in the field of the central magnet.
- The proper lifetime of the particle can be found using its path length and momentum.
- The lifetime will allow for the particle's identity to be found.

At right is a cartoon of a B_d-> $\rho^+\pi^-$ decay, with the ρ^+ decaying into a π^+ and a π^0. The vertical lines represent the components of the pixel detector.





The CKM Unitarity Triangles, CP phases, And The Decays Used To Measure Them



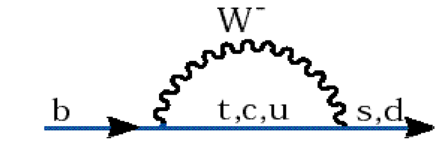
BTeV's Goals and Physics Reach

BTeV's main goal is to further constrain the elements of the CKM matrix by making precision measurements of the CP phases α, β, γ, and χ. When possible, BTeV will use multiple decays to measure each angle. If any discrepancy is found, the Standard Model is violated. Measurements of the phases also allow the unitarity triangles to be checked for closure. If they do not close, the Standard Model is violated. Another powerful test is a check of the Standard Model prediction$_{(1),(2)}$:

$$\sin(\chi) = \frac{\sin(\beta)\sin(\gamma)}{\sin(\beta+\gamma)}\sin^2(\theta_c)$$

Since the Cabbibo angle, θ_c ,is precisely known, the crucial measurement is sin(χ). BTeV will also collect enough data to confront the Standard Model prediction of CP violation in D mesons. Here, the very small SM contributions may be overshadowed by new phenomenon.

BTeV will also be able to conduct further tests of the Standard Model and search for new physics by studying rare decays of B mesons. These processes exhibit strong dependence on loop diagrams for b->s and b->d, such as :



These loops can be influenced by the existence of "new" particles, with masses up to a few TeV. In the above diagram, possible effects include replacement of the W boson with a new high mass gauge boson, or even a charged Higgs. The u,c,t quark could also be replaced by new, massive fermions. Thus, it is possible to test new theories by looking for exotic particles that may influence rare decays.

Conclusions and Outlook

BTeV will be a powerful window into the Standard Model, and beyond, by supplying precise measurements of CP violation and rare decay parameters from a variety of sources. These insights can not only help us to understand and refine the Standard Model of particle physics and its many parameters, they may also reveal violations of current theories, and provide guidance toward new ones.

References and Acknowledgments

(1) J.P Silva and L. Wolfenstein, Phys Rev. D55 5331 (1997) (hep-ph/9610208)
(2) R. Aleksanm B. Kayser and D. London, Phys. Rev. Lett. 73 18 (1994) (hep- ph/9403341)

Picture of BTeV detector courtesy of Michael Wang,John Rauch, and Alex Toukhtarov
Photo of Wilson Hall at Fermilab courtesy of the U.S. Department of Energy
Photo of BTeV straw tracker prototype courtesy of Alan Hahn
Photo of calorimeter block courtesy of the BTeV collobration
Photo of HV fusing test courtesy of Sasha Ledovskoy