ACHIEVEMENTS OF THE TEVATRON FIXED-TARGET PROGRAM

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Tevatron II (1983-2000)

- 43 experiments in many different beamlines
- > 400 doctorates from >100 Universities in 18 countries
- More than 300 publications

http://conferences.fnal.gov/tevft/ has it all
 Achievements

- Charm Physics and new technologies
- CP violation and rare kaon decays
- Nucleon spin and structure — anti-quarks and gluons
- QCD tests at many scales
- Hyperons galore
- Precision measurements of standard model parameters ($V_{us}$, $V_{dc}$, $\alpha_S$, $\theta_W$ ...)
- Creation and detection of $\nu_\tau$
Every minute ramp from 0-800 GeV

Deliver up to $3 \times 10^{13}$ protons/cycle

> 10 dipoles gave their lives for TeV II
Why fixed target?

Collider
Tevatron I

\[ E_{CM} \approx 2E_{beam} \]
\[ \sim 1960 \text{ GeV} \]

Fixed Target
Tevatron II

\[ E_{CM} \approx \sqrt{2ME_{beam}} \]
\[ \sim 40 \text{ GeV} \]
Advantages

- Higher Luminosity
  - $10^{13} \text{ p/min}$ instead of $10^{13} \text{ p/day}$
  - $10^{36} / \text{cm}^2 / \text{sec}$ vs $10^{32} / \text{cm}^2 / \text{sec}$

- Longer, more flexible detector designs

- Hot and cold running exotic particle beams

- Smaller groups
Generic detector (E687)

Target
- Silicon microstrips
- Scint. Counters
- Tracking chambers
- Particle ID
- EM calorimeter
- Hadron calorimeter
- Muon detector
 Photon

High statistics Charm physics
Use silicon strip detectors to identify charm in humungous background

E687 – photon beam
Charm rates at E791

- Pion beam at 2 MHz
- The target consisted of 5 foils:
  - A 0.5 mm Pt target and
  - Four 1.6 mm C (diamond) targets
- Interaction rate of 40 kHz – 10 kHz written to tape
- Only 1/1000 of the events were charm
- A total of $2 \times 10^{10}$ events were recorded.

![Graph showing D^+ and D_s peaks with M(K^- K^+ pi^+) and M(K^+ K^- pi^-) distributions in GeV.](slides_from_mpurohit)
E791 charm

Before

VME crate

To four additional VME crates

RS485 Data Paths

Exabyte Drives

VME crate

FIFO Buffers

Data from Digitizing Electronics

VAX 11/780

12345678

Exabyte Drives

Branch Bus

12345678

12345678
Data Volume per experiment (in Gbyte)
KTeV: high intensity kaon beams
KTeV Pure CsI Calorimeter

- 3100 crystals, 1.9mx1.9m
- 27 $X_0$ deep (50cm)
- 0.6% energy resolution

$K_L \rightarrow \pi^+ \pi^- e^+ e^-$
Example of Intensity

Discovery of $K_L \rightarrow \pi^+ \pi^- e^+ e^-$

Branching fraction of $4 \times 10^{-7}$

- 5000 events observed, sensitivity $< 10^{-10}$.
- Large T-odd, CP asymmetry observed.


$\sin \phi \cos \phi < 0$; Clear: $\sin \phi \cos \phi > 0$
Proton Structure

Naïve expectation
anti-\(u\) = anti-\(d\) = anti-\(s\)

NUSEA – proton on protons

Collide protons on protons
Annihilate quarks and anti-quarks
Momentum fractions

- If you can pick out a type of quark, you can measure its momentum fraction.
- Vital input to almost all collider physics.
Hydrogen and deuterium targets

- 50% u
- 50% d

- 67% u
- 33% d
Drell-Yan Cross Section Ratio and $d_{bar}/u_{bar}$

\[
\frac{\sigma^{pd}}{2\sigma^{pp}} \bigg|_{x_b \gg x_t} \approx \frac{1}{2} \left[ 1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)} \right]
\]
Use neutrinos to see strange quarks

< 0.1% anti-ν in ν
< 0.3% ν in anti-ν

Tevatron 800 GeV
Main Ring 150 GeV

NuTeV Sign Selected beam

Booster 8 GeV p
Linac 200 MeV H
Cockcroft-Walton 750 KeV H
Switchyard

BeO Target
Quad Magnets
Decay Pipe
Beam Dump

Muon Shield (Berm)
Lab E NuTeV Detector
Mike Shaevitz on top of the 690 Ton target
NUTeV luminosity was $\sim 3000 \text{ fb}^{-1}$
Strangeness

Neutrinos scattering can pick out strange quarks through the process

\[ \nu + s \rightarrow \mu^- + c \]

\(c\) decays to \(\mu^+\)

Dimuons at NuTeV measure

- Strange content \(s(x)\)
- \(s/\text{anti-}s\) difference
- \(V_{sc}/V_{dc}\)
\[ \sin^2 \theta_W = \frac{1}{2} - \frac{\sigma(\nu_\mu N \rightarrow \nu_\mu X) - \sigma(\bar{\nu}_\mu N \rightarrow \bar{\nu}_\mu X)}{\sigma(\nu_\mu N \rightarrow \mu^- X) - \sigma(\bar{\nu}_\mu N \rightarrow \mu^+ X)} \]

Ratio of neutral to charged current interactions

Need the sign selected beam
Discovery of the tau neutrino (DONUT)

Make a $\nu_\tau$ beam

Detect a $\tau$ decay
Emulsion modules and drift chambers

Emulsion plates interleaved with 1mm steel plates: total target mass 260 kg (not kt !)

Recycled drift chamber electronics
Saw 9 candidates $7.52 \nu \rightarrow \tau + 1.48$ background

\[ \sim 80 \text{ GeV} \] $\tau$: $\tau$ probability $0.99+$

\[ \sim 9 \text{mm} \text{ decay length} \]

digitized emulsion information shown
Conclusions

- Tevatron II legacy
  - Led to Detectors and computing used in all modern experiments
  - High intensity and highest energy ever in fixed target
    - Charm physics
    - Kaon physics to $10^{-10}$
    - Proton Structure
    - Precision Standard Model Parameters
    - Discovery of $V_\tau$
Not over yet

- Fermilab fixed target lives at 8 and 120 GeV
- Neutrino physics at 8 and 120 GeV
  - Cross sections (MINERvA)
  - Oscillations (MINOS, NOvA, MiniBooNE, MicroBooNE, LBNE ....)
  - ???
- Kaon Physics with ORKA
- Proton Physics
  - SEAQUEST – son of NUSEA
- Your idea here
The beginning

October 1

1983

Start of the Tevatron fixed-target program at 400 GeV with five fixed-target experiments.

Learn more