Reaching the Top

Pekka K. Sinervo
University of Toronto

1. What is Our World Made Of?
2. How Do We Find These Building Blocks?
3. The Search for Top
4. What's Next?

Brandon University Alumni
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Where We Stand....

Always been fascination with what makes up our world

- Greeks proposed four constituents
  - earth, water, fire and air

When I was an Ontario high school student....

- taught that atoms existed
  - consisted of a nucleus (protons & neutrons)
  - cloud of electrons

- atoms were put together to form molecules
  - VESPR theory
  - gave you all the chemistry you wanted

But Scientific American told me much more...

How It All Worked (circa 1980)

The Standard Model of Elementary Particle Physics

- Three "generations" of quarks and leptons

$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$$

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix} \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}$$

Come in "pairs" because of the way forces acted on them

- Forces carried by bosons

Electromagnetic force	γ
Weak force	$W^{\pm}, Z^{\circ}$ bosons
Strong force	eight gluons
Gravity	gravitons

$\boxed{\text{What's Missing}}$

But not all the pieces of this puzzle are there

1. "Unification" of forces hasn't panned out
   - don't have a clue as to how to understand gravity
   - only have hints that forces are unified
2. Don't understand mass at all
   - Enter the "Higgs" boson.....
3. Missing the last quark

But the rest of it works extremely well!

- Many tests have been made over last 20 years

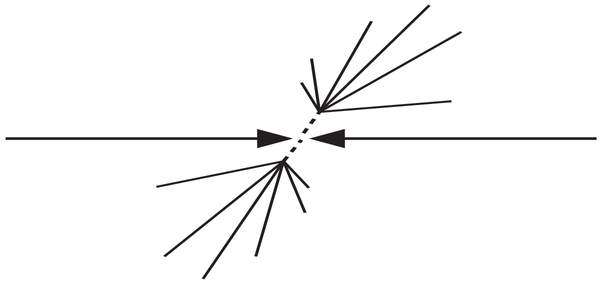
To learn more, have to "test" the theory

- $\Rightarrow$ search for the missing pieces

$\boxed{\textbf{Searching for Top}}$

A heavy quark can be pair-produced in collisions

- Require high energy matter-antimatter collisions
- Need tons of data (they are rare events)



$p\bar{p}$ Collider at Fermilab is the "only" choice

- High luminosities ($\mathcal{L} \sim 25 \times 10^{30}$ cm^{-2}s^{-1})
  - compare to radiation through this room $\mathcal{L} \sim 2\times10^{-2}$ cm^{-2}s^{-1})
- Highest energies ($\sqrt{s} = 1800$ GeV)
  - Enough energy to form fairly complex molecule

Why are Heavy Quarks Hard to Find

Hard to produce

- Must sift through lots of matter-antimatter collisions
- Happens about 1 in every billion collisions?

They Decay!

- A top quark decays via the weak force into a bottom quark
- The bottom quark then decays into lighter quarks

Ya can't see free quarks

- Quarks are "not allowed" to appear unescorted in public
- Have to "dress" themselves up around other quarks
- Result in "jets" of particles

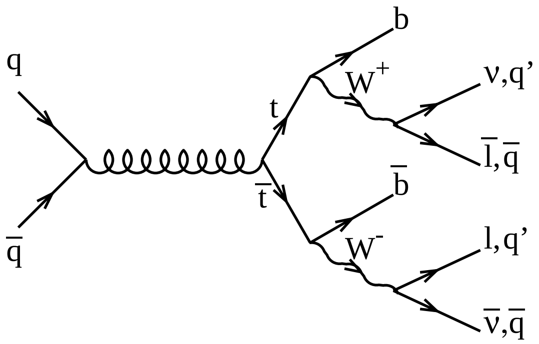
Top Quark Signatures

Top quarks only decay via the weak force

$$t \rightarrow W^{+} b$$

$\quad\quad\longrightarrow u\bar{d}$ or $c\bar{s}$

$\quad\quad\longrightarrow e^{+}\nu_e$ or $\mu^{+}\nu_\mu$ or $\tau^{+}\nu_\tau$



This results in two, potential signatures

- Dilepton events with two, energetic $e^{\pm}$ and $\mu^{\mp}$
- Lepton + Jet events with at least one b quark

The CDF Experiment

CDF is detector designed to study $\overline{p}p$ interactions

- Collisions with $\sqrt{s} = 1.8$ TeV created by Tevatron Collider
- Large 5000 ton detector

Collaboration consists of

- 35 institutions from US, Japan, Italy, Canada and Taiwan
- 440 physicists

The Canadian group consists of

	McGill University	**University of Toronto**
Faculty	Ken Ragan	Pekka Sinervo
RA	Kurt Biery Klaus Strahl	
Grad Students	Yunling Ye Kostas Kordas	George Sganos Andreas Warburton Hyunsoo Kim Wendy Taylor Rob Spekkens

$\boxed{\textbf{1992-94 Collider Run}}$

Took data at the Tevatron Collider starting in 1992

- scanned $\sim 5 \times 10^{12}$ collisions
- Collected 50×10^{6} events on tape

Most sensitive dataset acquired to date

- If top exists with a mass of 160 GeV/c^2
  - Expect 5000 produced $t\bar{t}$ events
  - Should observe 5 dilepton events
  - Should observe 10 lepton + jet events

Dilepton Top Quark Search

$t\bar{t}$ decaying into 2 leptons create unique signature

- Two charged leptons from $W^{\pm}$ decay
- Imbalance in total energy due to undetected neutrinos
- Two jets from bottom quarks

Observe a total of 6 candidate events

- Observe 1 $\mu^{+}\mu^{-}$ event and 5 $e\mu$ events
- Expect 1.3 ± 0.3 events from background

Probability of background fluctuation is 3.3×10^{-3}

Lepton + Jets Search Philosophy

Decay mode with the greatest sensitivity is "lepton+jets"

- About 30% of $t\bar{t}$ events decay this way
- Look for $W \to l\nu_l$ decay
- Require two jets from $W \to q\bar{q}$ decay
- Require at least one more jet from b quarks
  - must "tag" at least one b quark jet

Searched for these types of $W+\geq 3$ jet events

- Have 203 events before b tagging
- Expect ~ 30 to come from $t\bar{t}$ production

B Tagging Techniques

Use two properties of b quarks to identify them

1. About 20% of b's decay via

$$b \to e^- \nu_e X \quad \text{and} \quad b \to \mu^- \nu_\mu X$$

   - Look for jets with "soft" leptons in them
   - Call these soft-lepton tags (SLT's)
   - Expect 15% of $t\bar{t}$ events to have at least one SLT tag

2. "Long" b lifetime – $c\tau \sim 450$ microns

   - CDF uses Silicon Vertex Detector to identify jets with a secondary vertex
   - We call these "SVX" tags
   - Expect 42% of $t\bar{t}$ events to have at least one SVX tag

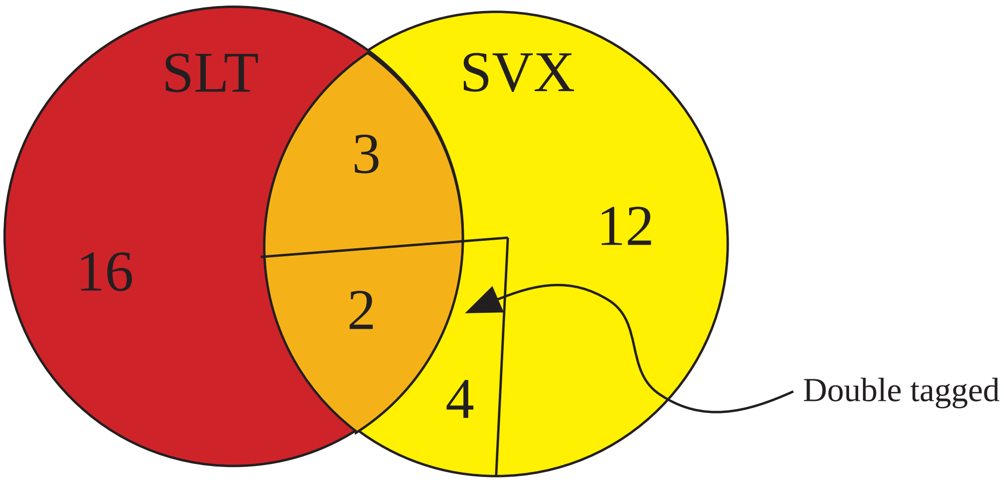
Idea is to just "count" number of tagged events

b Quark Tagging in W+Jet Events

Applied these tagging techniques to W+jet events

Sample	SVX bkg	SVX tags	SLT bkg	SLT tags
W+$\geq$ 3 jet	6.7 ± 2.1	27	15.4 ± 2.3	23

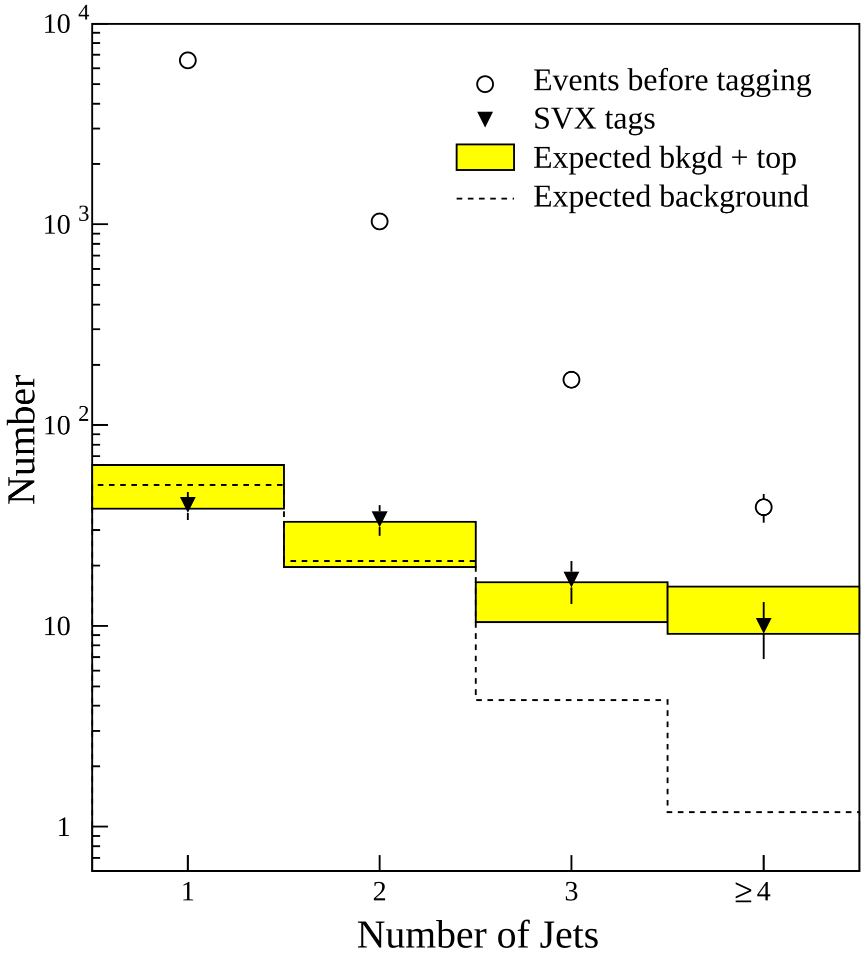
- Probability of background fluctuation is 1×10^{-6}
  - Combining SVX, SLT and DIL channels
- Agrees well with expected rate from $t\bar{t}$ production



SVX Tagging Results

The SVX tagged sample is single most significant observation

- Observe 27 tags when we expect 6.7 ± 2.1 background
- Probability of background fluctuation 2×10^{-5}



So Is This a Top Discovery?

Tough question to answer

- Sure don't want to be wrong
- On the other hand, don't want to avoid the facts

In February, agreed that we were observing something new

- probability of "being wrong" extremely low
- exactly what we expected to find

Checked the data in lots of ways

- Everything points to the same conclusion
- Another experiment has also looked and agree with us

What Next?

Continuing to take data and get more top quarks events

- measure its properties
  - mass
  - how it decays
  - how it gets produced
- All provide additional tests of the theory

So now there is only one missing piece – Higgs Boson

- Quest for that is now beginning
- Building a new proton-proton collider in Geneva
  - Large Hadron Collider
  - 7 times more energetic than Fermilab Tevatron
  - 100 times higher collision rate
  - experimental teams have over 1000 scientists
- But don't hold your breath
  - Turn-on scheduled for 2003!

So Why is This Important

It won't lead to a "better mousetrap?"

No, but that's not what we're all about

- Important to understand how our world works

But for those who don't like this answer....

- the following resulted from "basic research"
  1. nuclear medicine (and warfare...sigh)
  2. the transistor
  3. gene research
  4. antibiotic drugs

Continually challenging ourselves to learn is part of being human

- Universities provide that setting
- An environment where learning is the most important goal

And It's Not Just About Research

"Research" is not the only source of new ideas

- Teaching and learning is in itself a challenge
- There is no "ivory tower" that researchers live in

Teaching for me is a fundamentally important activity, eg.

- organise the Ontario Physics Olympiad
  - Year-long programme involving high-school students
- I mentor one or two high school students every year
- teach 40-50 undergraduates every year
- have 5 graduate students who work closely with me
- I speak to groups and schools about physics