LBNL CDF Program at the Tevatron

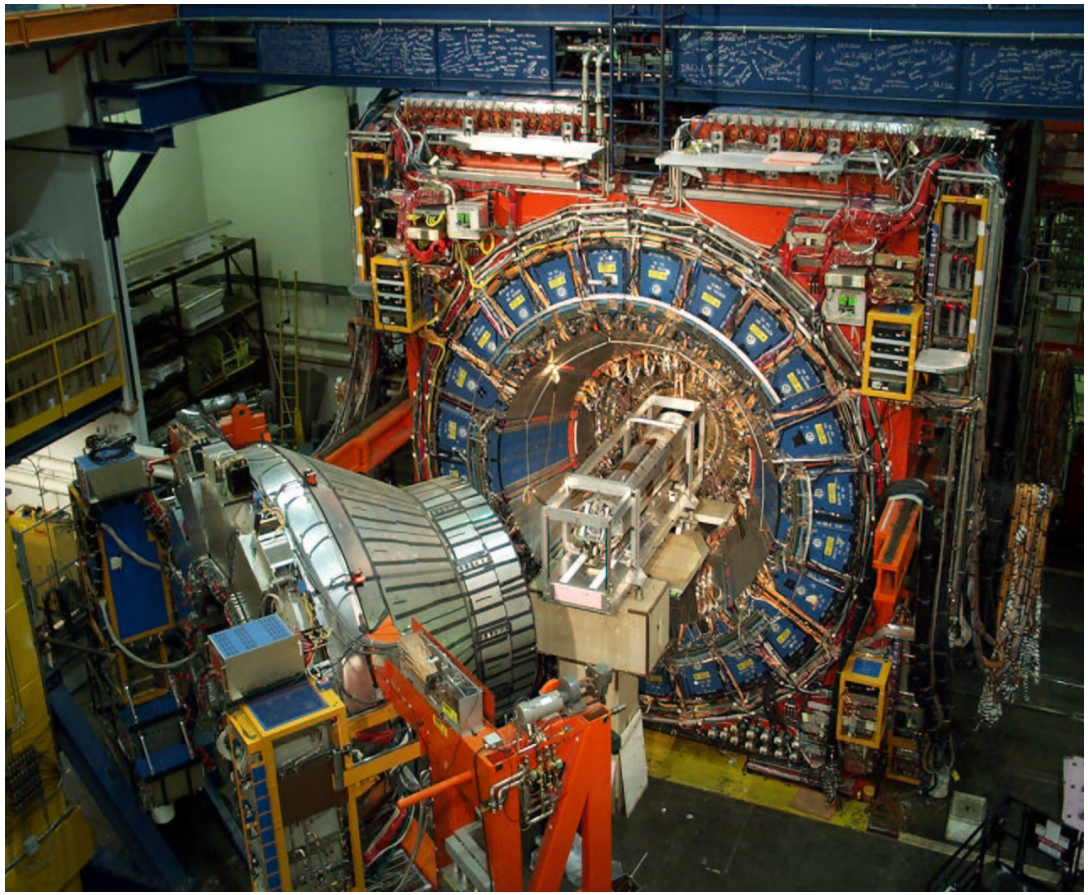
Angela Galtieri

LBNL Director Review
November 5−6, 2003

Outline

- Accelerator Status
- LBNL Group
  - Responsilities
- Silicon Detectors
  - Run IIa
  - Run IIb
- Analysis Tools
  - b−tagging
  - Jet corrections
  - Realistic Monte Carlo
- Physics Program
  - B Physics
  - EWK (W/Z/Top)
  - Higgs
  - New Physics
- Summary
- Prospects for the future

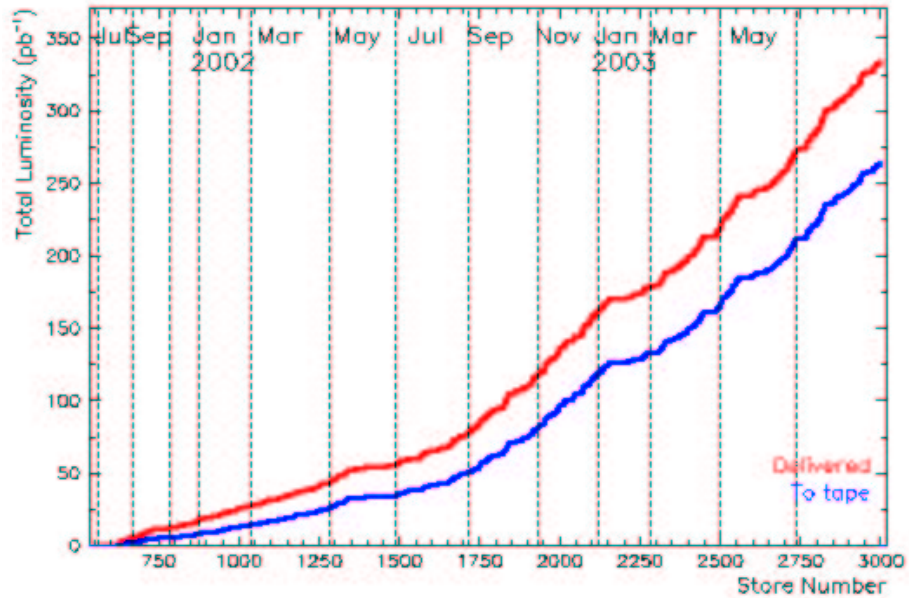
CDF Detector



Installing silicon tracker, March 2001

Run II Accelerator Status

- Run II Upgrades: $5x10^{32}$ cm^{-2} s^{-1}
- Main Injector (2001)
- Recycler (2003):
  recover antiprotons
- Bunches
  baseline 36x36 at 396 ns
- $\sqrt{s}$ = 1.96 TeV



- Current performance
  $5.2x10^{31}$ cm^{-2} s^{-1} (record)
- Integrated luminosity
  360 pb^{-1} delivered
  CDF: 260 pb^{-1} on tape
- Plan for the future

Integrated Luminosity (fb^{-1})				
	Design Projection		Base Projection	
	per year	Accumulated	per year	Accumulated
FY03	0.22	0.30	0.20	0.28
FY04	0.38	0.68	0.31	0.59
FY05	0.67	1.36	0.39	0.98
FY06	0.89	2.24	0.50	1.48
FY07	1.53	3.78	0.63	2.11
FY08	2.37	6.15	1.14	3.25
FY09	2.42	8.57	1.16	4.41

Members of the LBNL Group

Physicists−Staff (3.2 FTE)

A. Galtieri (Group leader)
M. Garcia−Sciveres*
C. Haber*
Y.K. Kim (now UC Chicago)
J. Lys *(retired)
R. Miquel**
M. Shapiro* (UC Berkeley)
J. Siegrist* (UC Berkeley)
W. Yao**

Physicists−Term (6.0 FTE)

A. Cerri
A. Dominguez
J. Nielsen
B. Orejudos
L. Vacavant
I. Volobouev***

Fellows (2 FTE)

C. Currat (now gone)
M. Weber
P. M. Fernandez (July ’03)

Grad. Students(8.5 FTE)

T. Affolder++ (’96 Run II/I)
A. Connolly++ (’96 Run II/I)
G. Veramendi++ (’98)
H.C. Fang (’98)
E. Brubaker (’99)
H. Bachacou (’99)
A. Gibson (’00)
J. Freeman (’00)*
J. Muelmenstaedt (’02)+
A. Deisher (’02)+
P. Lujan (’03)

Undergrad. Students

L. Tompkins
E. Feng

Visitors

F. Zetti (Pisa)
M. Tavi (Finland)

Engineers, Designers

B. Krieger
H. von−der−Lippe
J.P. Walder
E. Mandelli
B. Holmes

*ATLAS, ** PDG
*** Supported by UC Chicago in FY04

+ Start on CDF on ’04
++ Thesis completetd

Leadership roles at CDF (last 3 years)

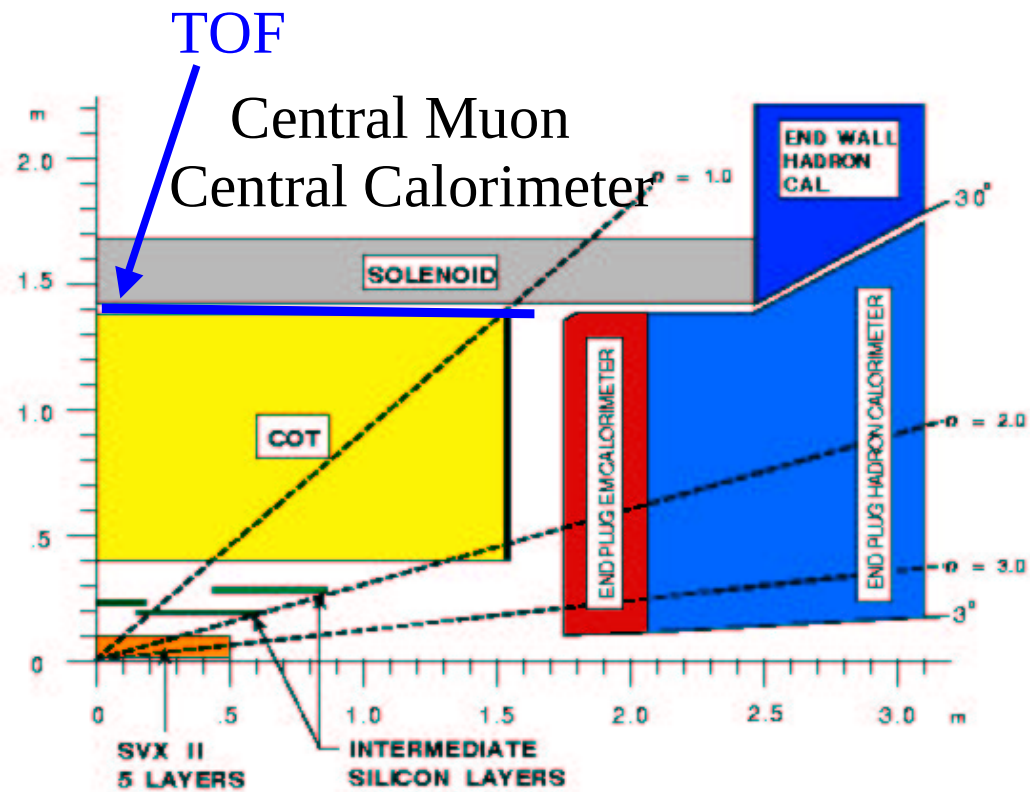
- Marjorie Shapiro
  - **Offline Project Manager (March 98−October 2001)**
  - **Co−coordinator: CDF simulation group (October 2001−October 2003)**
  - **Co−coordinator: B physics group (since January 2002)**
- Young−Kee Kim (left Jan. ’03)
  - **Associate Head of CDF Operations Department (to Dec. 2001)**
    - **in charge of commissioning**
    - **setting milestones, schedule and priorities**
  - **L3 group co−leader (end ’02)**
- Bill Orejudos
  - **Co−coordinator of the COT group**
  - **CDFII Operation Manager (to June 02)**
- Alex Cerri
  - **Co−convener of the Semileptonic B Physics group**
- Weiming Yao
  - **Co−convener : Higgs group (to 9/2003)**
- Aaron Dominguez
  - **Co−convener : b−tagging (to 9/03)**
  - **Co−convener: silicon studies (to 5/03)**
  - **Co−convener: Higgs Physics group**
- Lina Galtieri
  - **Co−convener: Jet corrections (to 5/03)**
- Greg Veramendi
  - **Co−convener: High Pt Electrons (to 2/03)**

LBNL Contributions to CDF II

I. Construction

- Silicon detectors
  - SVX3 chip (co−design with FNAL), test, probe
  - hybrids for L00, SVXII, ISL
  - associated electronics
- COT
  - inner cylinder, field sheets
  - Conceptual design of alignment
  - Time calibration system
- TOF
  - Study laser calibration system
  - Install fibers, online monitoring

Schematics of CDFII Detector



II. Commissioning

- Associated Project Manager (YK Kim)
- COT Commissioning (Orejudos)
- Silicon commissioning (Affolder, Dominguez, Nielsen)

III. Operation

- CDF II Operation Manager (Orejudos)
- SVT operation (Cerri, pager, ongoing)

LBNL Contributions to CDFII

IV. Computing and software

- Project manager (M. Shapiro)
- Codgen for relational data bases
- Data handling software for early tests
- Silicon Code librarian (A.Dominguez)

V. Detector Operation (MOU)

- Online silicon monitoring (H. Bachacou)
- Offline Silicon calibration (Nielsen,pager)
- Online data monitoring (YMON) (Gibson)
- COT calibration (Orejudos, pager)

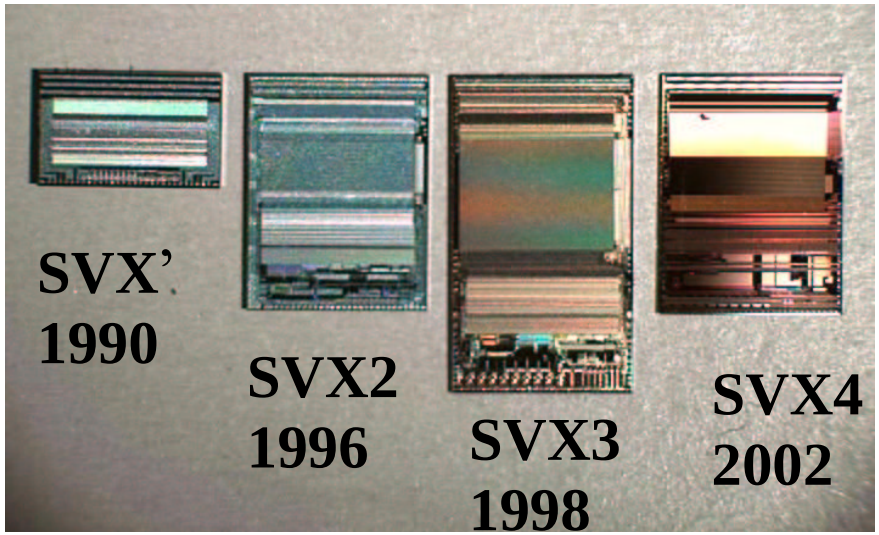
•Ongoing responsibilities

- MC generators : ISAJET (L. Galtieri), HERWIG, Wbbgen (J. Lys) **MOU**
- Silicon Tracking (W. Yao)
- Secondary vertices code (W. Yao, A. Dominguez)
- Passive material (L. Vacavant)

In FY04 we have to hand out most of our responsibilities (MOU and others) to other groups because of lack of manpower in FY05 in the LBNL group

Silicon Detectors: LBNL contributions

Rad hard chips for Silicon Detectors



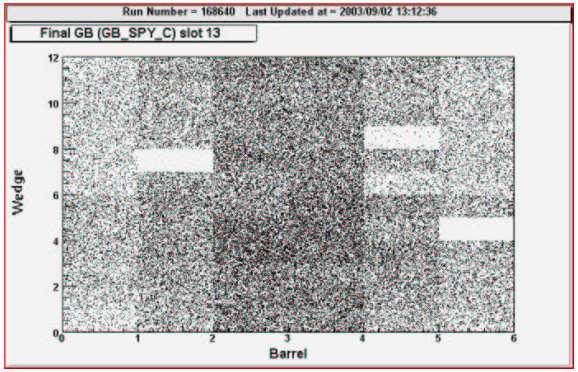
- LBNL designed SVX, SVX'.
- Joint designs with FNAL since.
- SVX4: technology transfer of SVX3 plus enhancements
- Conversion to quarter micron CMOS technology proposed by LBNL
- LBNL/FNAL/Padova design
  LBNL: integration and simulation

Run IIa Silicon detector Status

- 4% dead strips
- 5% have readout problems
- 92% of ladders integrated
- Tracking efficiency 90%
- Expected lifetime: 4−6 fb^{-1}

SVT, displaced vertex trigger

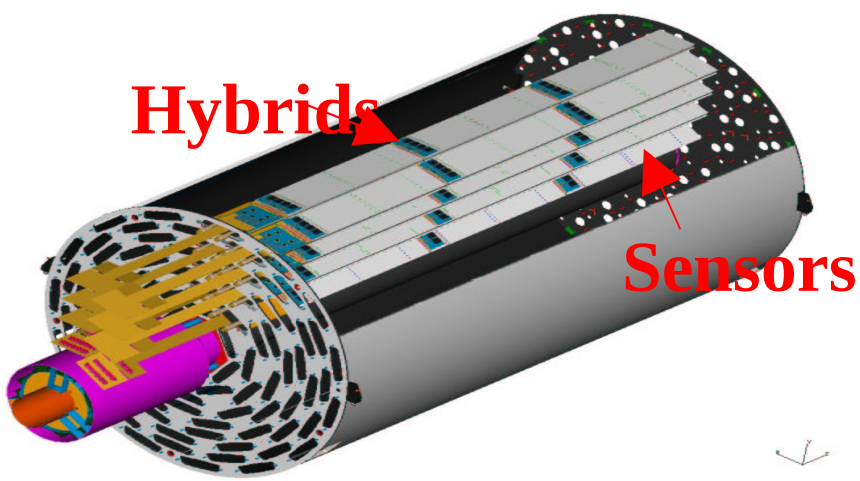
Tracks reconstrucetd 4/5 layers
TT trigger efficiency ~78%



Run II b Silicon Tracker Upgrade

M. Garcia−Sciveres, C. Haber, M. Weber, W. Yao, L. Galtieri (physicists), A. Gibson, J. Freeman, P. Lujan, E. Feng (students)

- For high luminosity run much of silicon tracking will not survive.
- CDF had plans replace L00 and the 5 layers SVXII detector in 2006.
- Plans now canceled due to low Lum.
- Simplified construction and assembly. Single sided detectors.



- A new chip (SVX4) and a new concept "the stave" have been developed. They work
- We reached pre−production stage. The project continues to 3/ 2004

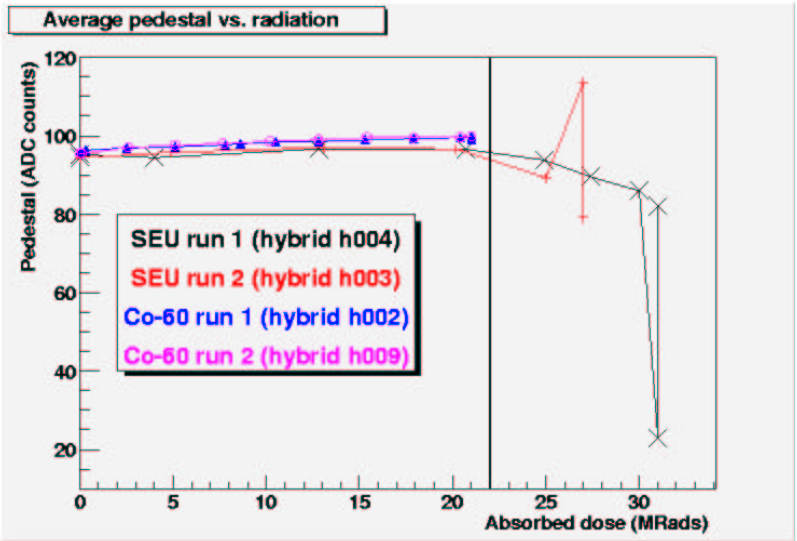
- LBNL group participation:
  - **LBNL−IC group lead SVX4 chip design (with FNAL and Padova).** Chip to be used by both CDF and D0. Testing and irradiation.
  - Design and pre−prod. of hybrids
  - **Proposed ' stave 'concept: bus cable: design, prototype and testing**
  - Systematic studies of electrical performance of "stave" concept.

SVX4 and Hybrid Work at LBNL

SVX4 chip

- 7000 pre−production chips in hand
- No changes needed for production
- D0 physicist participated at LBNL
- Extensive radiation studies done

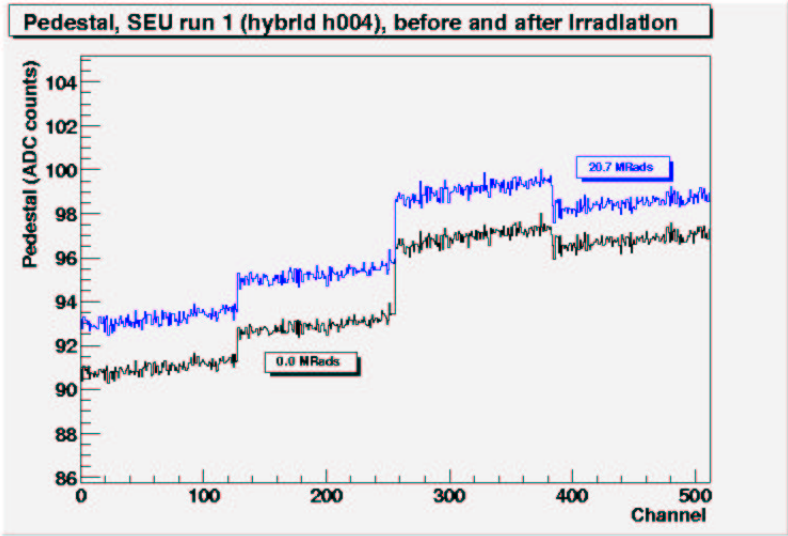
Radiation tests of chips done with CO source and Davis cyclotron (SEU). Breakdown at 25 Mrad



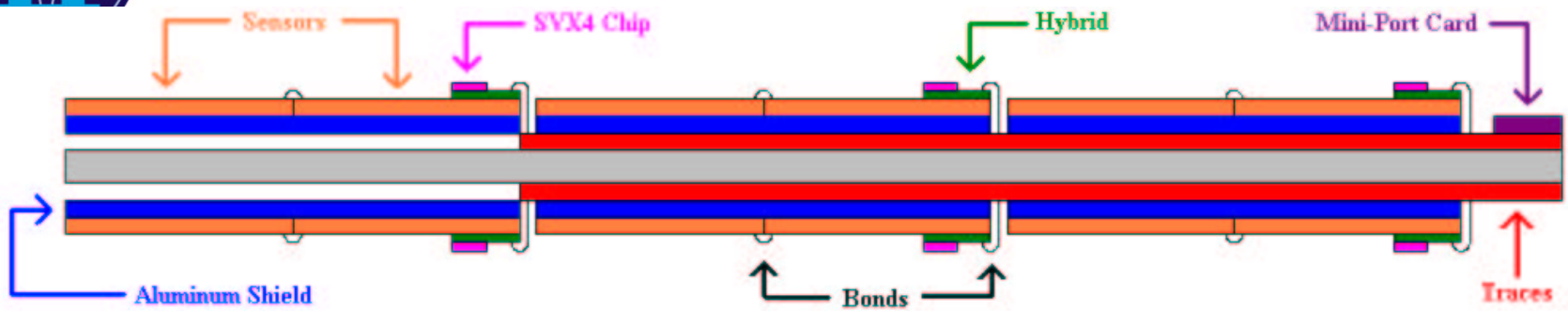
Hybrids Pre−production

- Only two types of Hybrids (13 types in Run IIa)
- LBL responsibility, augmented by visitors from Italy and Finland
- 90 hybrids produced: 90% perfect, others can be fixed

Radiation test on the 4 chips:
OK up to 20.6 Mrad

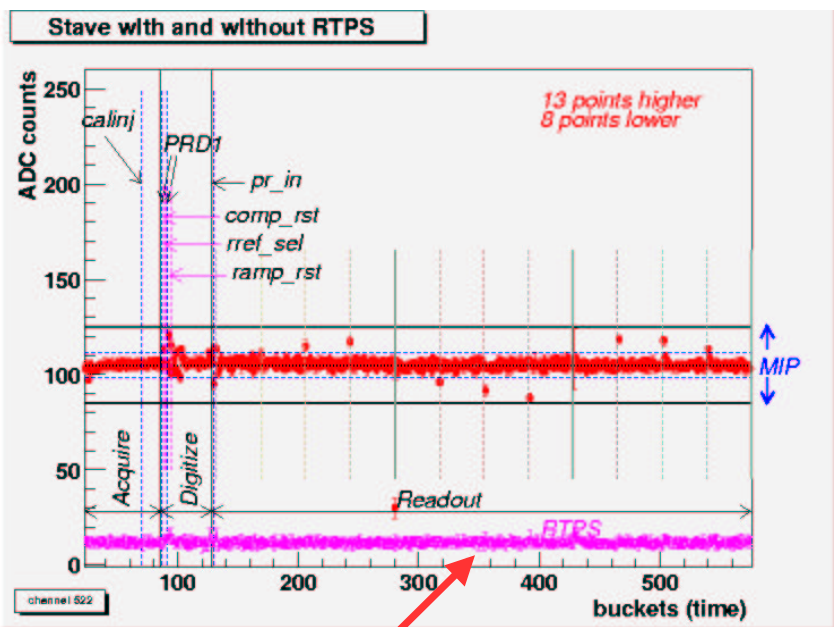


The 'Stave'



Highly integrated electrical, mechanical & cooling unit (66 cm long).

Current Stave Performance



Real Time Pedestal Subtraction

Stave Bus

Stave contains integrated data/power bus, serving all hybrids/sides.

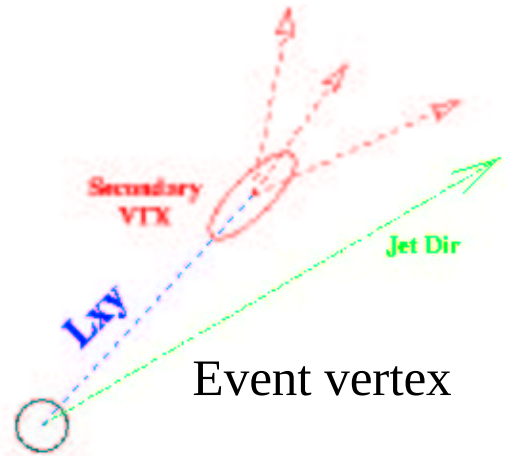
57 cables fabricated and tested at LBL. Delivered to FNAL

- **Status and plans:**
  - FNAL to build ~12 staves
  - Study of stave performance is continuing at LBNL (through March 2003).
  - NIM papers being written

B tagging using displaced vertices

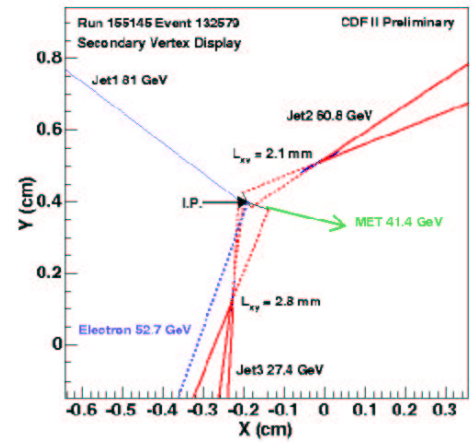
A. Dominguez (co−coordinator), W−M Yao, H. Bachacou

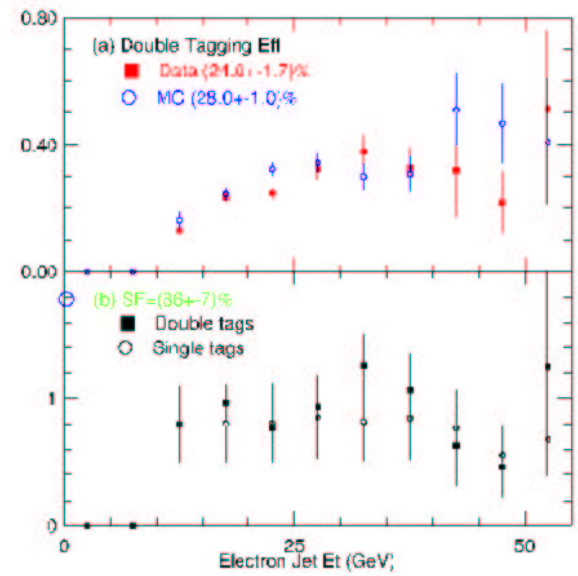
Displaced vertex algorithm allows detection of b quarks, important for B physics, top, and Higgs



- Reconstruct secondary vertex with ≥ 2 tracks
- Require $L_{xy}/\sigma_{xy} > 3$
  $\sigma_{xy} \sim 150\ \mu$
- Performance, alignment of Si detector crucial

Double tagged top event





- Efficiency for two tags in top event
  (24.0±1.7)%
- Efficiency to tag a ttbar event =(55±1±5)%
- Relative difference between data and MC =
  (86 ± 7)%

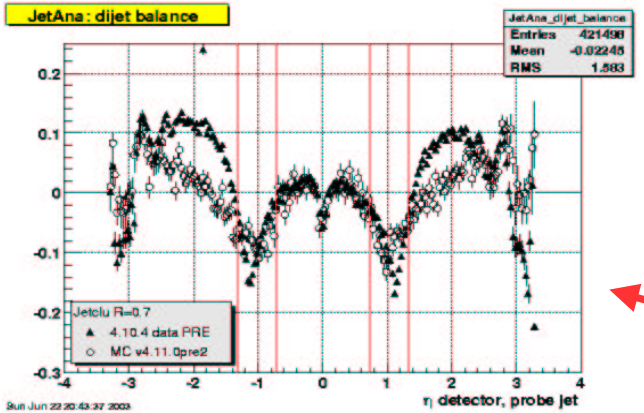
Jet Energy corrections and systematics

Galtieri (Co−convener jet correction group), Currat, Lys

Many studies done since 2001 to provide jet corrections to CDF

LBNL contributions: Plug calorimeters studies, simulation tuning

Preliminary result: absolute energy scale known within 3% in Central

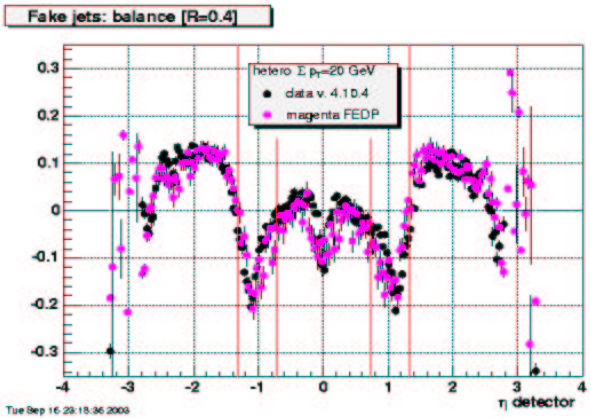


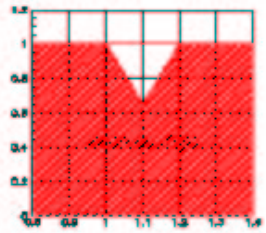
- Plug E−scale determined from jet−jet balance
- Scale checked in Central Calorimeter using γ−jet balance .

6/03 Bad agreement above η=1.

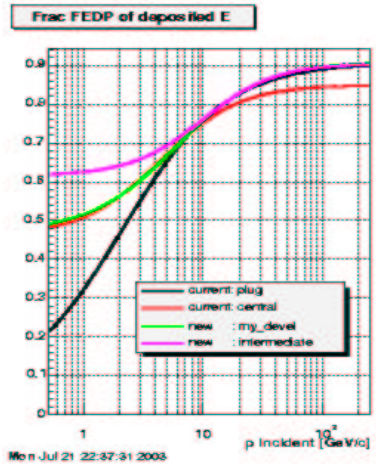
9/03: much better

New extrapolation at the low particle P_T (magenta curve)





Notch in crack region



Due to lack of funds, we could not retain C. Currat. Project ended here.

Realistic Monte Carlo

A. Dominguez, A. Cerri, H−C Fang, M. Shapiro

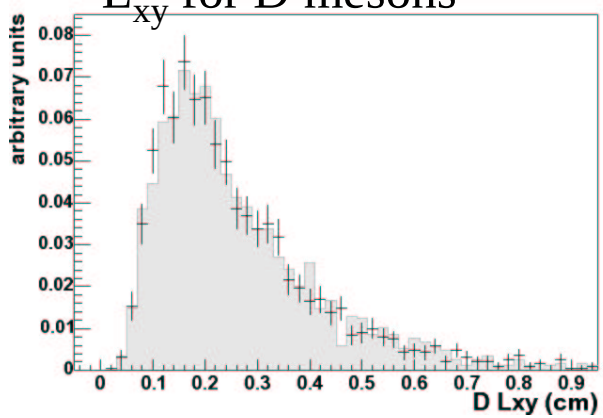
Detailed simulations of detector performance are needed to evaluate efficiencies and acceptance for most physics processes.

Detector conditions vary during a long data taking period. Need to evaluate average conditions during the data interval used. Include:

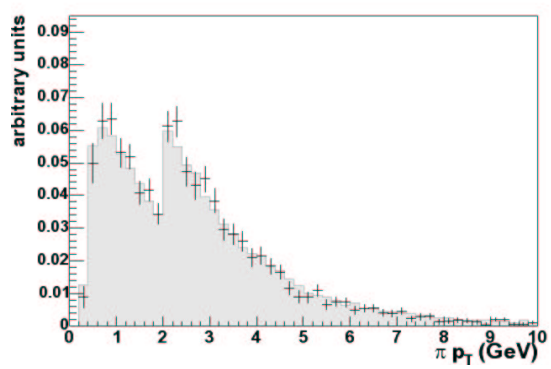
- Silicon dead channels, misalignment
- Trigger L1 and L2 emulations
- SVT trigger turn on and efficiency

Some examples from the lepton+SVT trigger data used by the B group

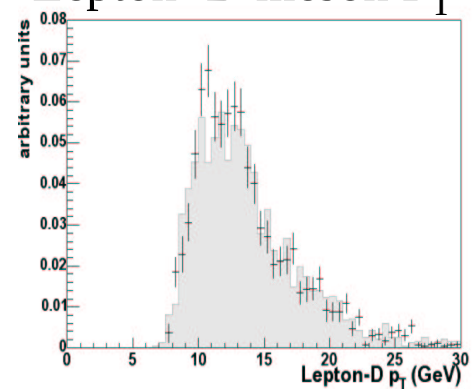
L_{xy} for D mesons



Pion P_T



Lepton+D meson P_T



LBNL Group Physics Program

EWK/Top/Higgs Physics

- People : Bachacou, Brubaker, Currat, Dominguez, Fernandez, Freeman, Garcia−Sciveres, Galtieri, Gibson, Lys, Nielsen, Orejudos, Siegrist, Veramendi, Volobouev, Yao
- Physics Interest :
  - M_{top}
    - The flagship analysis, to be done by the whole Top group.
  - Top : σ, ratio of σ's, spin correlation, and W couplings
  - $\sigma(W)$,Z : A_{FB} at $s > M_Z^2$
  - Higgs Searches: SM and SUSY
  - New particle Searches

B Physics

- People : Cerri, Deisher,Fang, Miquel, Muelmenstaedt, Shapiro, Vacavant
- Physics Interest :
- V_{cb} and Semileptonic decays
  - Major LBL goal for Fall 2003 Addresses timely CKM matrix issues.
- B_s mixing
  - Requires much larger samples
  - Validate technique with B_d mixing
  - Optimization of taggers using semileptonic samples
  - Optimize B_s reconsruction and measure B_s branching ratio.

B Physics

Alessandro Cerri,

First observation of $B_s \to D_s \pi$

Silicon Vertex Trigger (SVT) revolutionizes B Physics at CDF

Essential for planned program including CP violation and B_s mixing

- SVT allows study of the hadronic decays

  $B \to hh$ and $B_s \to D_s \pi$

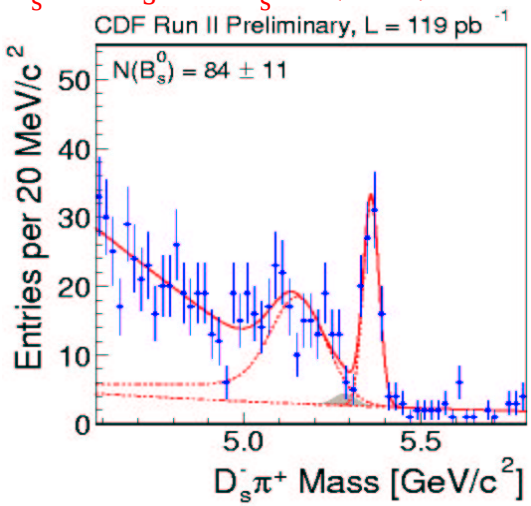
B_s mixing requires fully reconstructed decays to reach high values of x_s

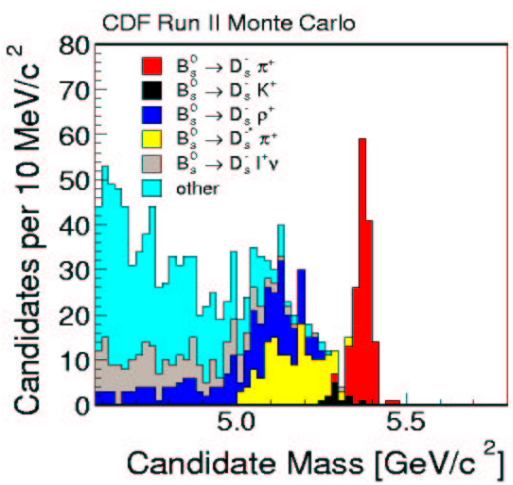
- CDF has reconstructed $B_s \to D_s \pi$ decays obtained with the SVT two tracks trigger.
- Measured its branching ratio with respect to $B_d^0 \to D^+ \pi$.
- Used Monte Carlo to model shape of physics background (B reflections).
- Likelihood fit to signal (gaussian), combinatoric background (exponential) and B reflections (templates).

B_s Reconstructed events

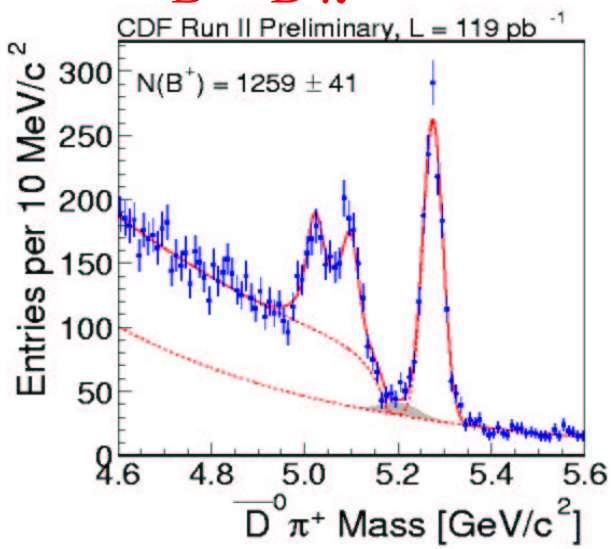
$f_s.BR(B_s \to D_s \pi^+) / f_d.BR(B^0 \to D \pi^+) = 0.35 \pm 0.05(stat) \pm 0.04(sys) \pm 0.09(BR)$

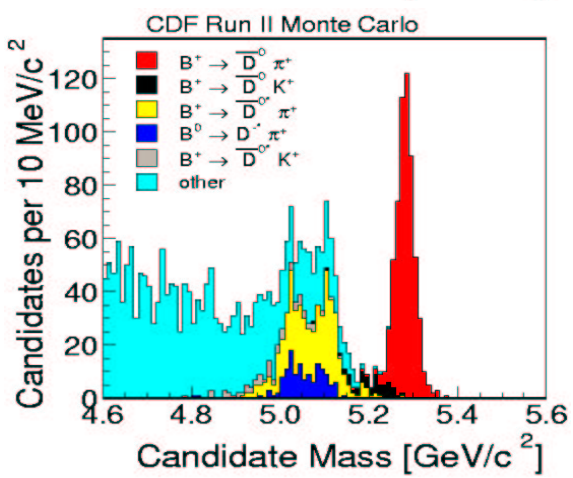
$B_s \to D_s \pi$, $D_s \to \phi\pi$, $\phi \to KK$





$B^0 \to D \pi$





Use f_s/f_d from PDG

Future plans for LBNL group:

- Other D_s decay modes
- More statistics
- B tagger optimization
- PHD thesis (H−C Fang) on Cabibbo suppressed mode $B^+ \to D K^+$ provides information for the measurement of the angle γ

B Physics: Moment Analysis

M. Shapiro, A. Cerri, H−C Fang, R. Miquel, L. Vacavant

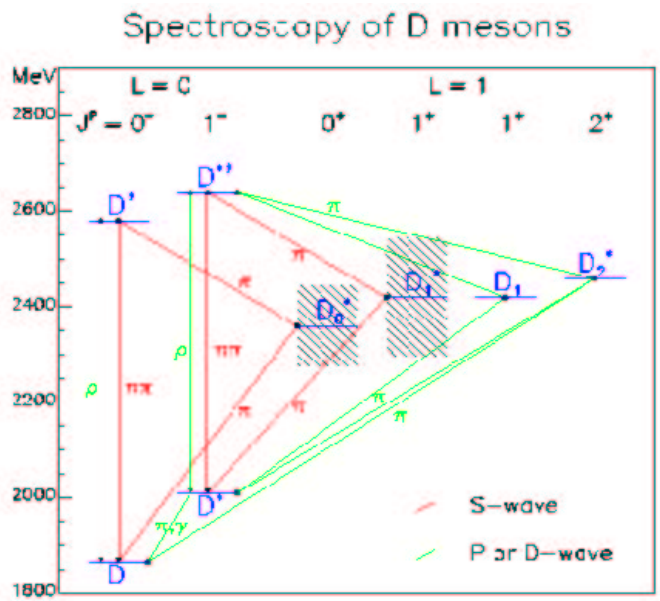
- Measurement of V_{cb} from inclusive semileptonic rate:

  OPE provides expansion in terms of α_s, Λ_{QCD}/m_b , ...
- Need comparison of theory and experiments for many quantities: build confidence in predictions by testing them
- Theory does not provide detailed knowledge of hadronic states, but makes prediction for inclusive quantities, e.g.

  $\langle M_{hadronic} \rangle$, $\langle M^2_{hadronic} \rangle$,.....

  these are the "hadronic mass" moments

  $B \rightarrow X_c \, l \, \nu_l$



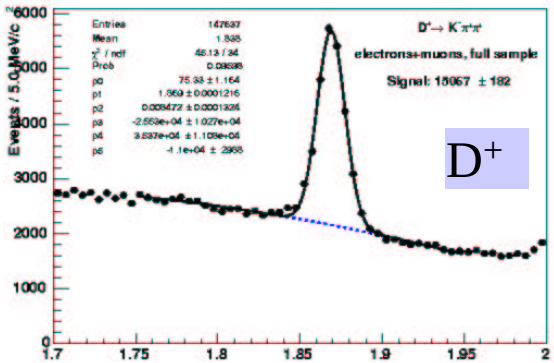
- X_c is D, D*, D** , where D** is any charm state, resonant or not with $M_{D^{**}} > M_{D^*}$
- BR($B \rightarrow l\nu D,D^*$) and M for D and D* known .
- **Goal: first CDF measurements by end 2003**

Moments Analysis: D and D* states

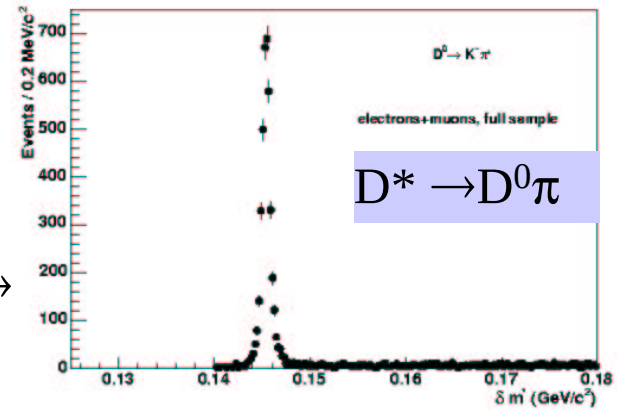
Sample mass plots for the lower states. (CDF Preliminary)

120 pb^{-1} Lepton (μ or e) + SVT trigger

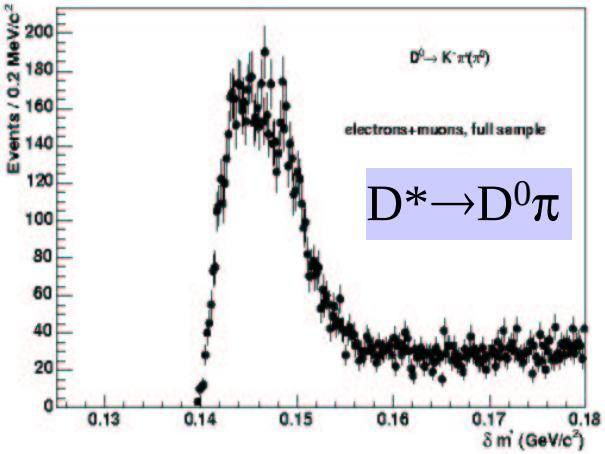
$D^+ \rightarrow K\pi\pi^+$ (15067 $\pm$182 ev)



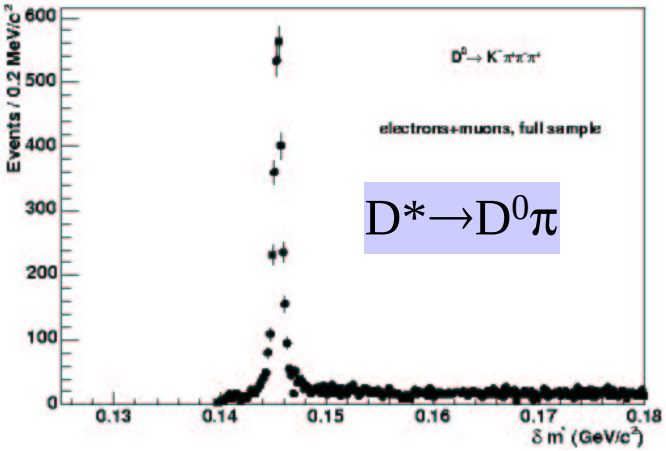
$D^0 \rightarrow K\pi$ 3890$\pm$63 events



$D^0 \rightarrow K\pi\pi^0$ (6638$\pm$98 ev)

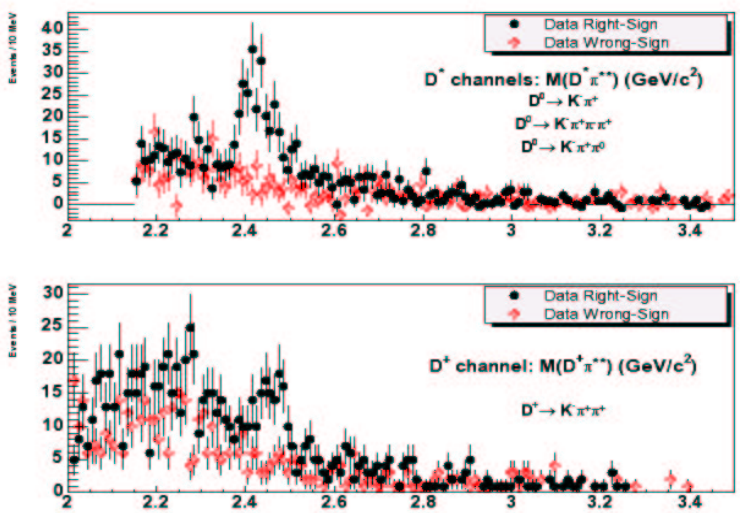


$D^0 \rightarrow K\pi\pi\pi$ (2994$\pm$57)

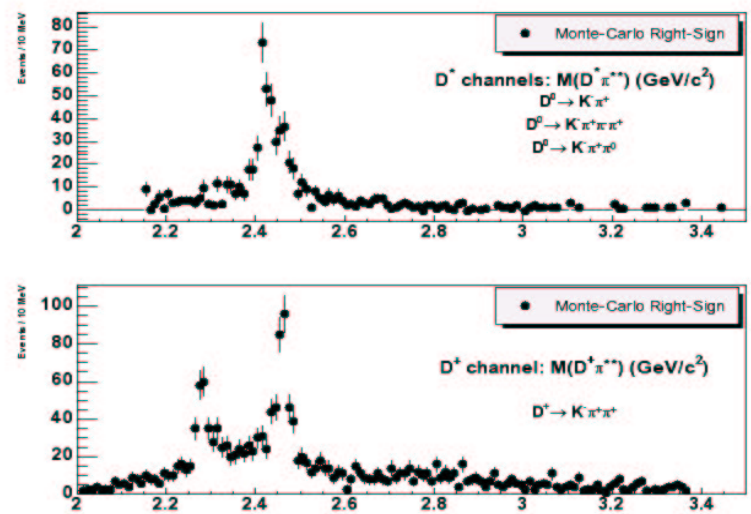


Moments analysis

Lepton+D**$^{+}\pi$ and lepton+D$^{+}\pi$ data

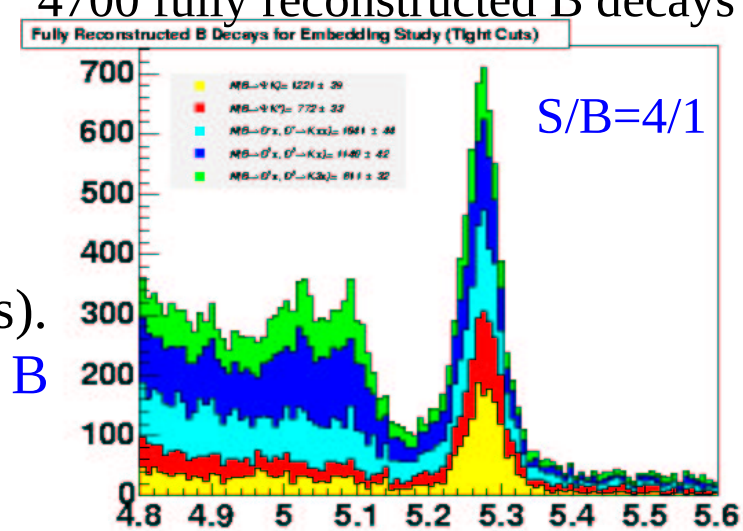


Evtgen+Sim prediction for lepton+ D**



- Raw M** distribution shows resonant D**.
- To extract correct M** distribution, must model background shape.
- Wrong Sign combinations cannot be used (possible contributions from radial excitations).
- Use Fully reconstructed B decays and replace B with MC semileptonic events to determine : fragmentation, underlying event backgrounds

4700 fully reconstructed B decays



High P_T Physics Activities

Bachacou, Brubaker, Currat, Dominguez, Fernandez, Freeman, Garcia−Sciveres, Galtieri, Gibson, Lys, Nielsen, Orejudos, Siegrist, Veramendi, Volobouev, Yao

Group Activities:

- Z asymmetry
- Top cross section
- Several top mass analyses
- SM Higgs sensitivity Studies
- MSSM Higgs search
- Heavy long lived particles (CHAMP) search

Results presented at Conferences:

- **Z asymmetry** (Veramendi's PHD thesis)
  ready for publication, first draft to Collaboration soon
- **Top cross section** using b−tagged events (Bachacou's PHD thesis)
- Conventional **top mass** measurement (Brubaker's PHD thesis)
- **CHAMP search**

$Z \rightarrow e^+ e^-$ Asymmetry

Y. K. Kim, Veramendi, Brubaker, Gibson, Tompkins

Asymmetry of $Z \rightarrow e^+ e^-$ at the Tevatron is expected to agree with LEP measurement. The Standard Model predicts A_{FB} at all M(e+e−) .

High mass reach unique to the Tevatron

Probe Z−γ interference

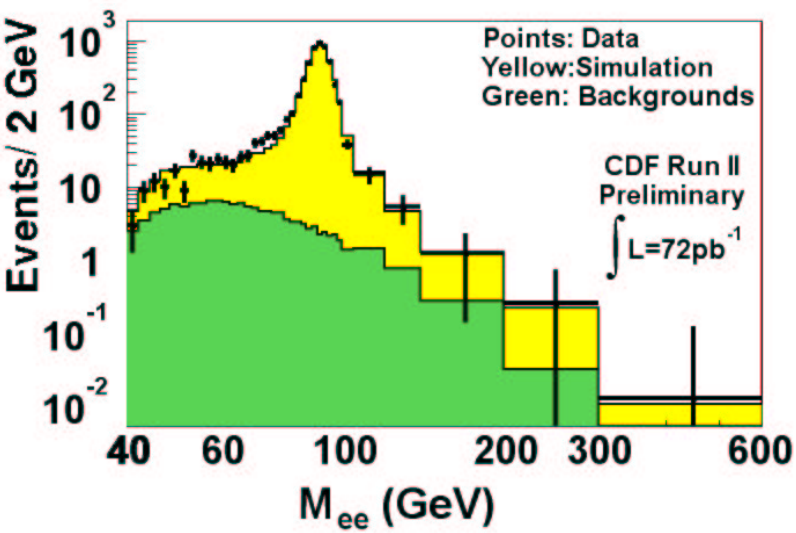
Complements direct Z' search

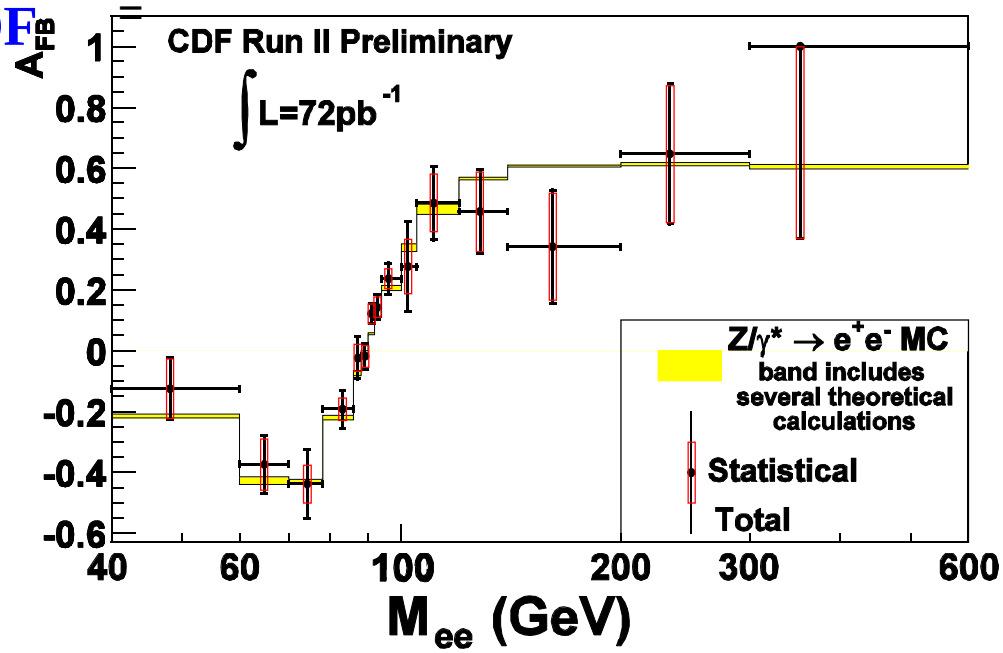
Results agree with the SM

Publication ready for review by CDF

Electrons up to η=3 used

$$A_{FB} = \frac{d\sigma(\cos\theta>0) - d\sigma(\cos\theta<0)}{d\sigma(\cos\theta>0) + d\sigma(\cos\theta<0)}$$





Top Quark property Measurements

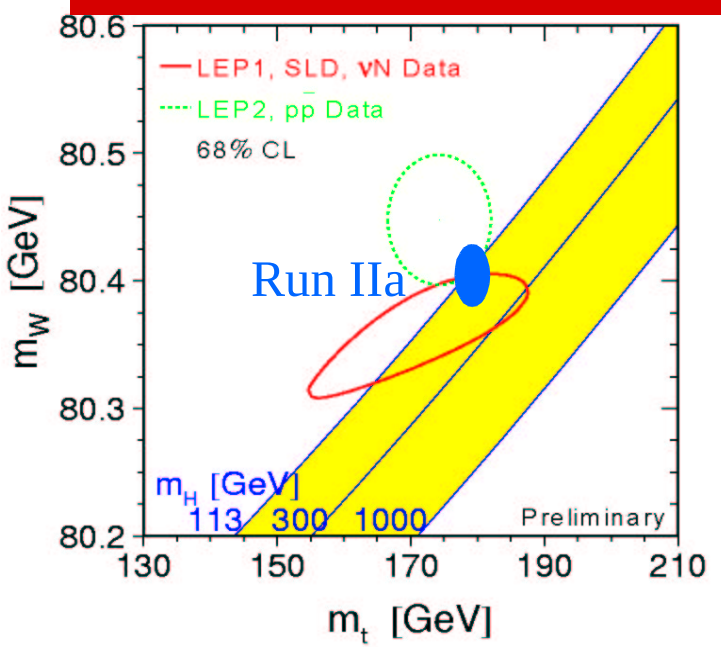
Bachacou, Brubaker, Fernandez, Freeman, Galtieri, Gibson, Lys, Volobouev, Yao

Short term goal:

- Top cross section and mass measurement.
- The Standard Model predicts the Higgs mass once the W and Top mass are measured with high precision.
- In Run II we need to improve on the systematic on the mass, work on this aggressively pursued (jets, methodology, etc.

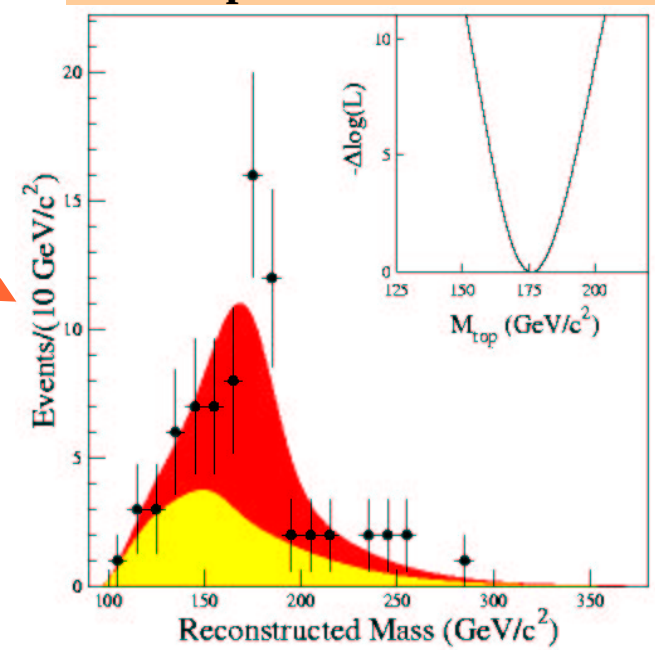
M(top) = 174.3± 5.1 GeV CDF+D0 comb.

Electroweak Precision Measurements



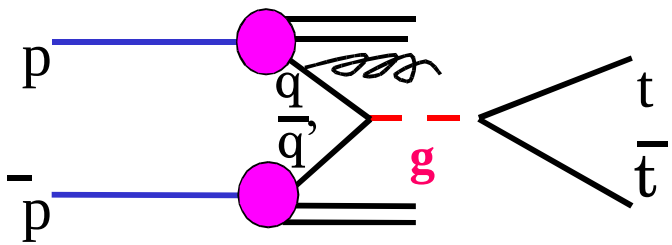
Run I

CDF Top mass measurement



Top Physics Studies

$t\bar{t}$ Production at the TeV:



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

Final states (2 b−jets + 2 W):

- dilepton (2 W→$l\nu$)
- lepton+jets (W→$l\nu$,W→qq)
- all hadronic (2 W→4q)

Lepton + jets channel preferred:

statistics advantage over the dilepton, less backgr. then the all hadronic

2/3 signatures: lepton and ½ b jets

Top quark is heavy: decays very fast!

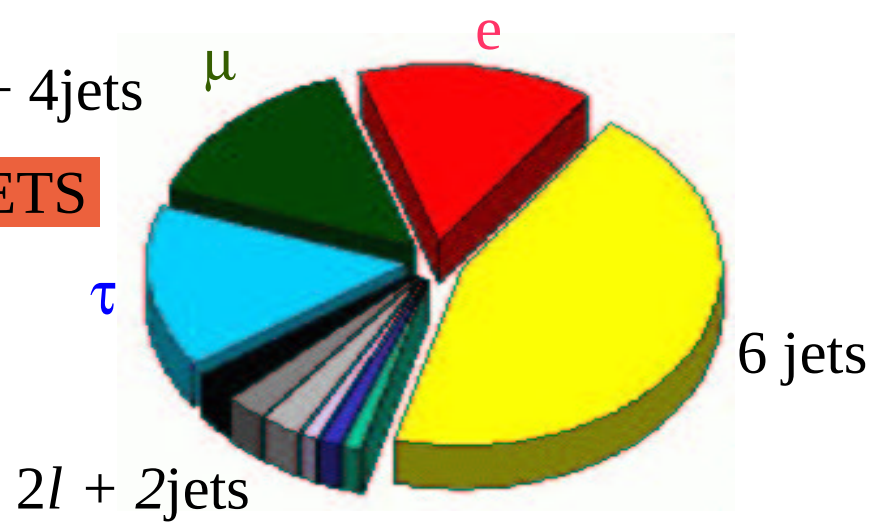
$\Gamma(t \rightarrow Wb) \sim 1.5$ GeV, $t=4\times10^{-25}$sec

$\Lambda_{QCD} = 100$ Mev, $\Lambda^{-1} = 10^{-23}$ sec

No hadronization:

No top mesons or baryons

W + JETS



Sample is the same as W sample.

Top events are preferentially in W+≥ 3 jets

Top Cross section

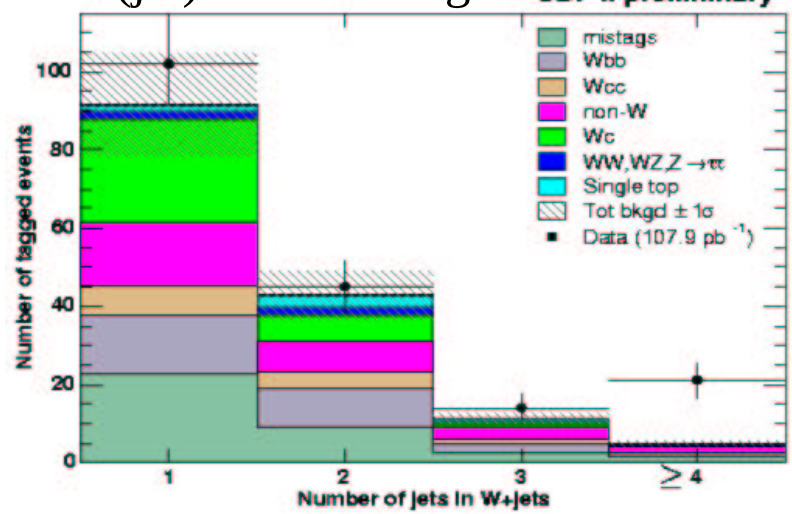
W−M Yao, H. Bachacou, J. Nielsen

- **High P_T lepton, high MET, ≥3 jets**
- **1 b−tag by the SVX algorithm**

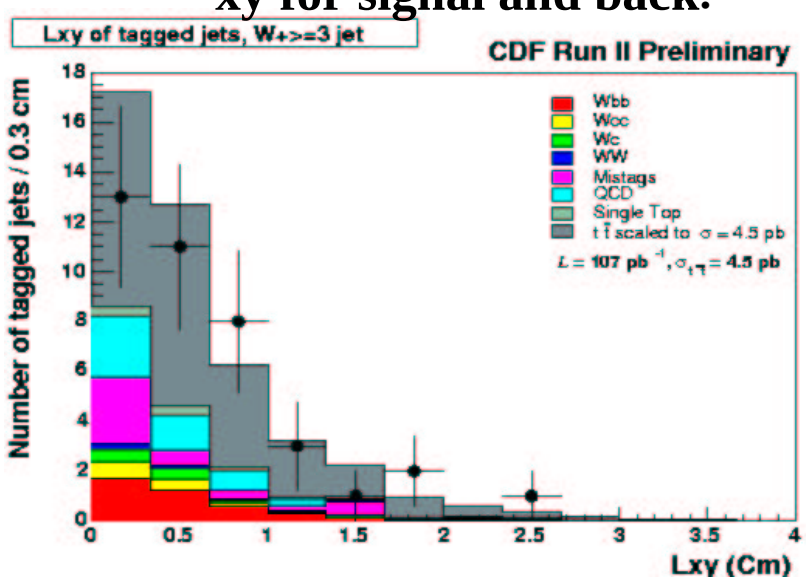
  $L_{xy} > 3\,\sigma_{Lxy}$
- **Nev (≥3 jets) = 35 events (108pb^{-1})**
- **Expect (back.) = 15.1 ± 2.0 events**

$\sigma(tt) = (4.5 \pm 1.4 \pm 0.8)$ pb

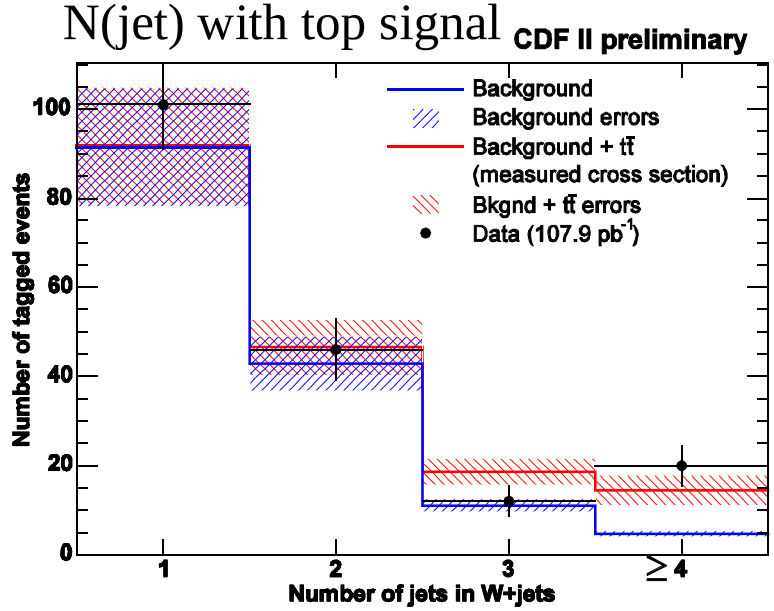
N(jet) with 1 b−tag



L_{xy} for signal and back.



N(jet) with top signal



Run II Top mass measurement: lepton+jets

E. Brubaker, A. Gibson, Y.K.Kim

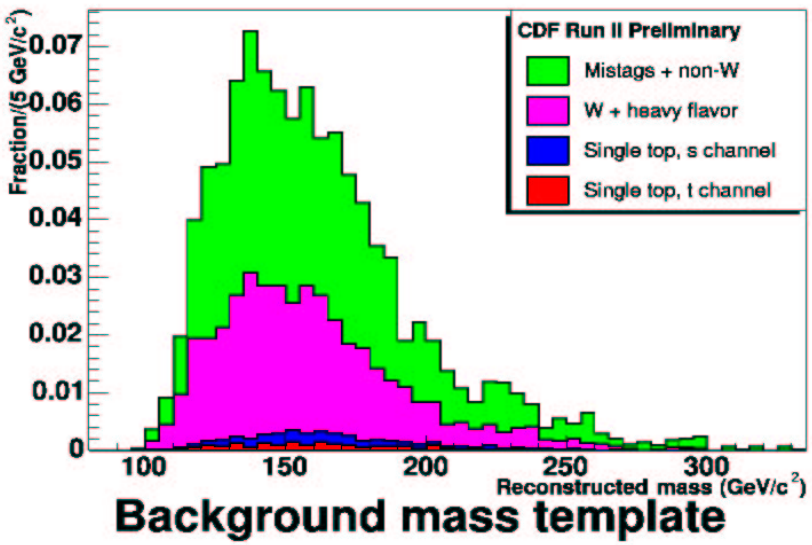
1 high PT lepton, high MET, 1 b−tag

Jets (1−3) E_T>15 GeV, Jet (4) E_T>8 GeV,

Find 22 candidate events
Expect 5.9±2.1 background

Find:

$M = 177.5 \pm^{12.7}_{9.4}(stat) \pm 7.1(syst)$ GeV

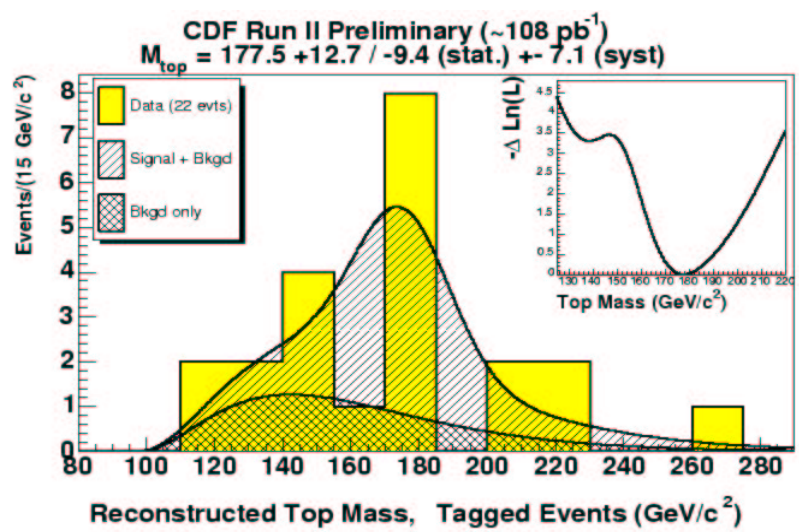


Analysis follows run I methodology

- Kinematic fitting of event to $t\bar{t} \rightarrow W^+bW^-\bar{b}$ (12 combinations)
- Likelihood comparison of fit events with templates from MC

All events use the same templates

CDF Run II preliminary 108 pb^{-1}



Top mass: improved methods

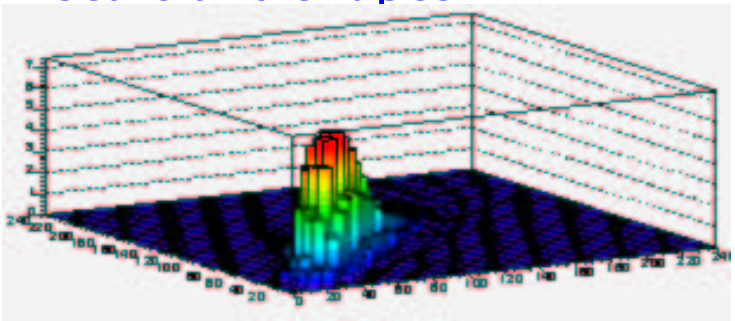
I. Volobouev, J. Freeman, P. Fernandez, L. Galtieri, J. Lys, A. Gibson

Major source of systematic errors are from jets P_T, combinatorics.

Need methods to improve dependence upon jet E−scale and shapes

First approach (as D0): A. Gibson and others

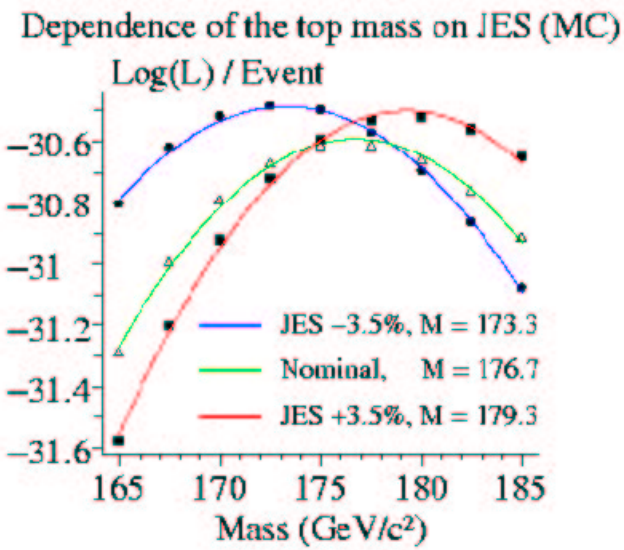
- Use directly the expected jet energy shapes (transfer functions)
- Use matrix elements for top production in the likelihood



Partons−vs−jets energies

Second approach (LBNL new method) :

- Jet E−scale allowed to vary within a gaussian shape in W mass fit
- W Breit−Wigner is integrated correctly
- Multivariate templates for mass fitting (fast method developed)
- Fits include events with/without b−tags

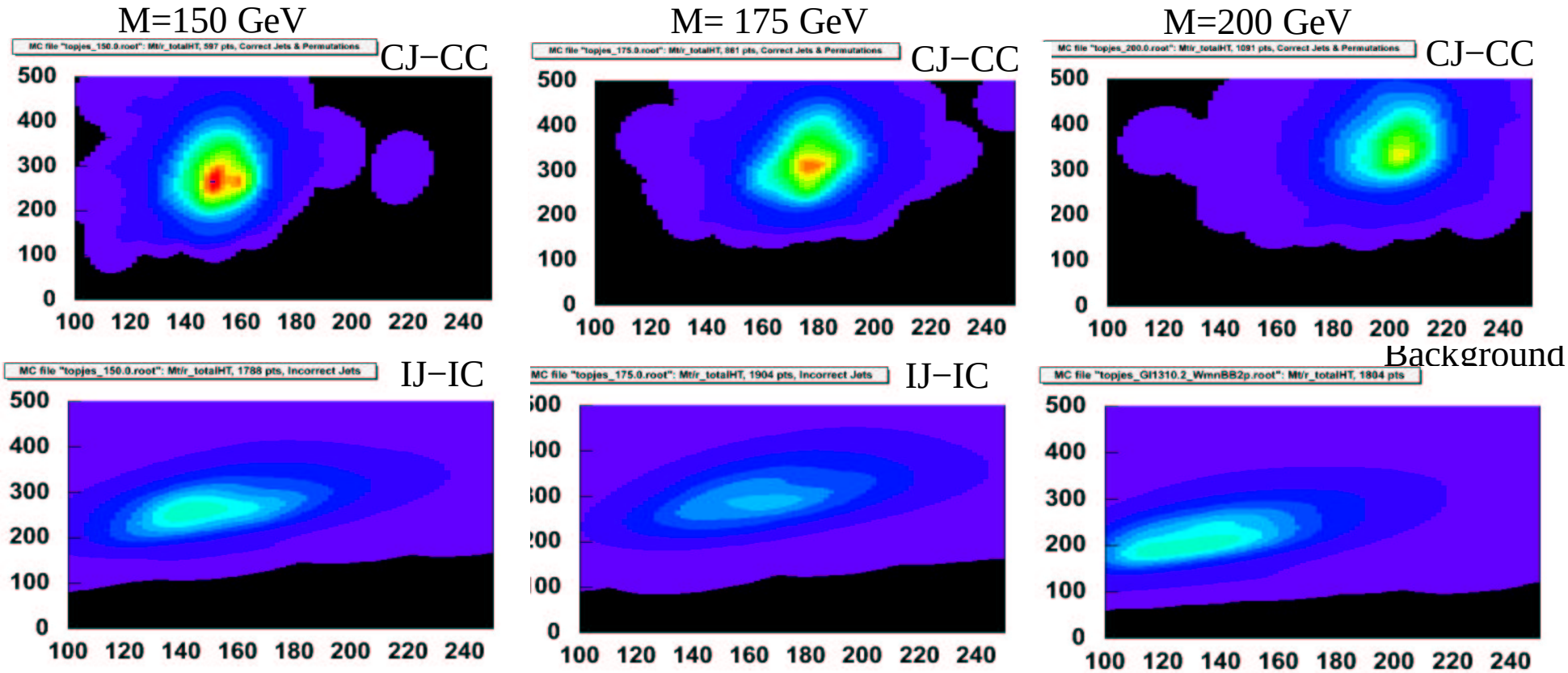


Top mass: improved methods

- Separate templates for incorrect permutations. Probability of correct choice determined from χ^2 of permutation.
- Templates change with mass resolution on event by event basis

Two dimensional templates: mass and H_T (total event E_T)

Increase discrimination between top and background, as well as top masses

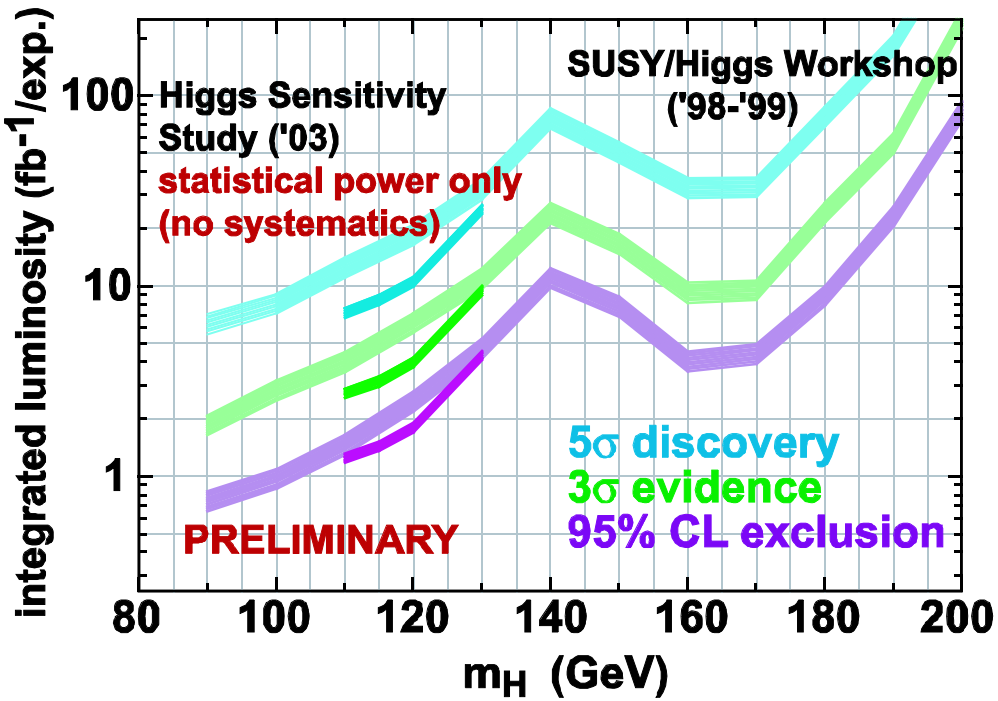


Higgs search

Yao (co−convener Higgs group), Dominguez (new conv.), Tompkins

Standard Model Higgs needs large integrated luminosity

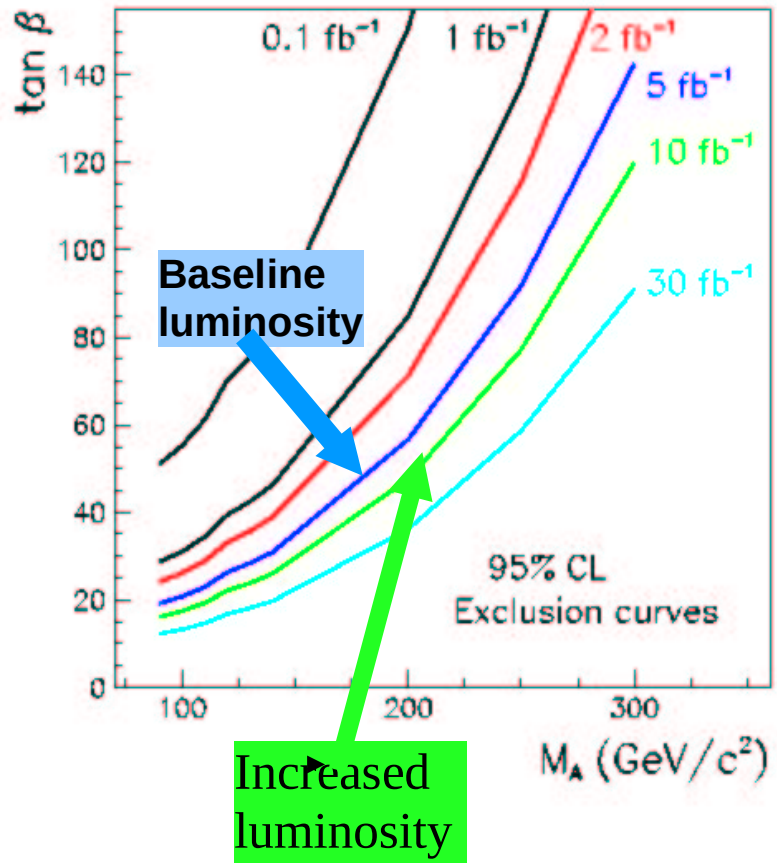
2003 sensitivity estimates are lower need better understanding of background



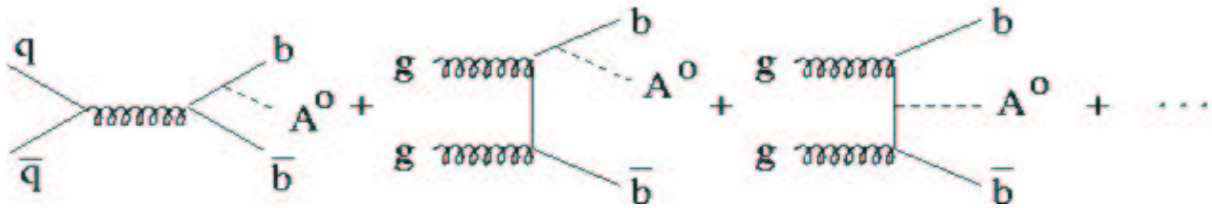
LEP m_H>114.4 GeV @95% CL

SUSY Higgs can have a large cross section for large values of tanβ.

Study the A/H → ττ, bb channels

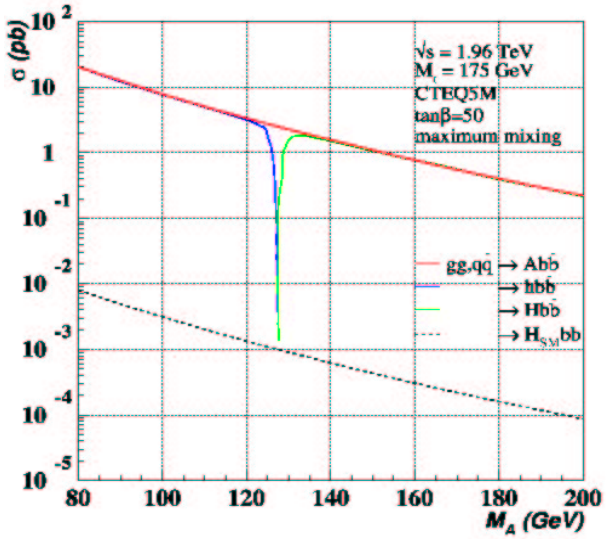


SUSY Higgs A/H in ττ, bb



bb(h/H/A) enhanced at large tan β

A → $\bar{b}$b, so 4 b's in final state



Work in progress:

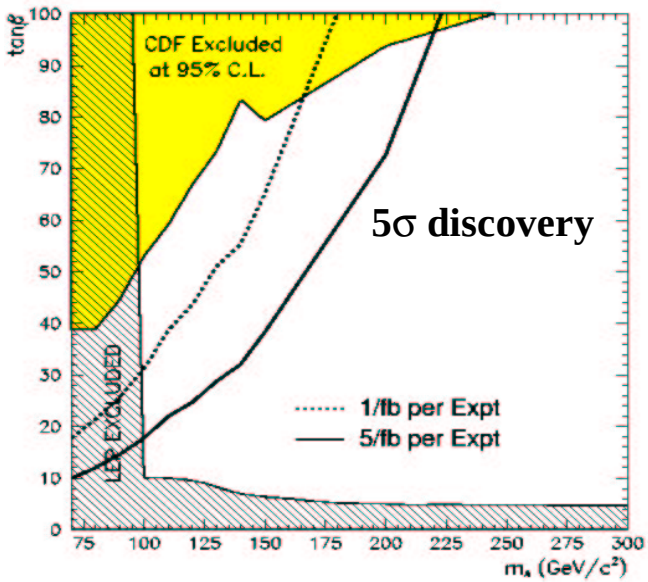
- Higgs multijet trigger studies
- 4 jets QCD background
- b−mistag studies for background

Run Ib Amy Connollys PhD Thesis

A → ττ,

Run I analysis: 4 jets, 3 b tags

Run II 5σ discovery: M=175 for tanβ=50 with 5 fb^{-1}



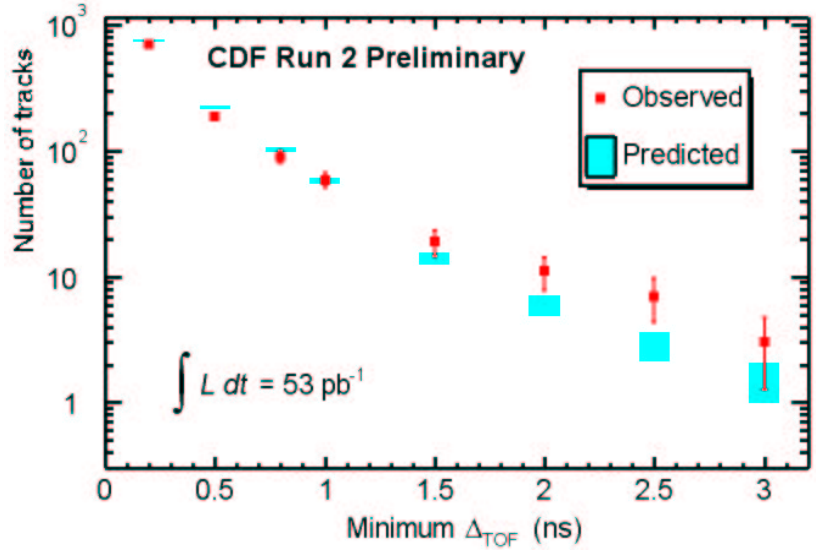
Search for Long Lived Heavy Particles

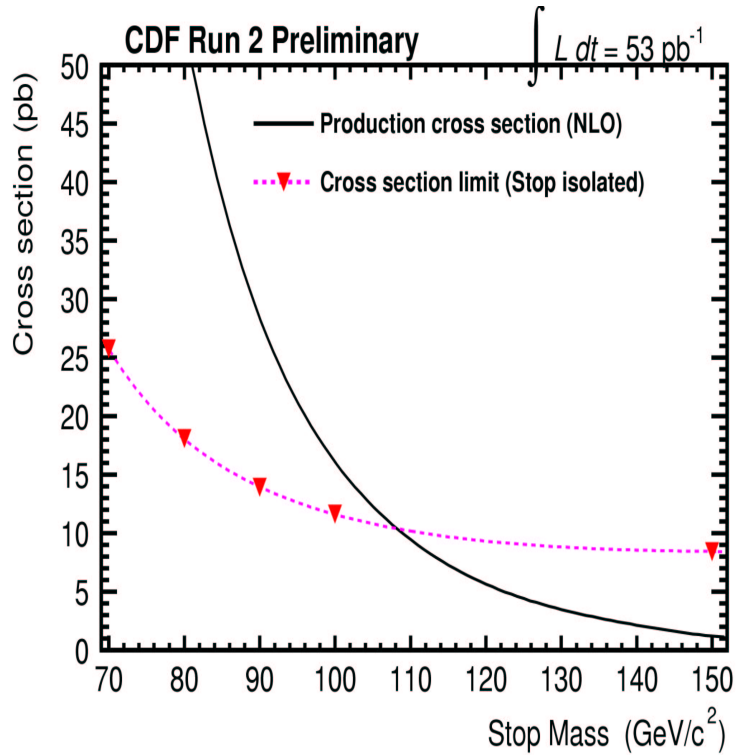
Bill Orejudos

what can such particles be?
SUSY: stable stau, stop

Long−lived massive charged particles?

- **Move slowly Measure time−of−flight!**
- **ΔTOF=TOF candidate – TOF expect.**
- **Events from μ trigger used here**





Selection

Tracks with P_T>40 GeV

ΔTOF>2.5 ns

Observe 7 events in 53pb^{-1}

Expect 2.9 ± 0.7(stat) ± 3.1(syst)

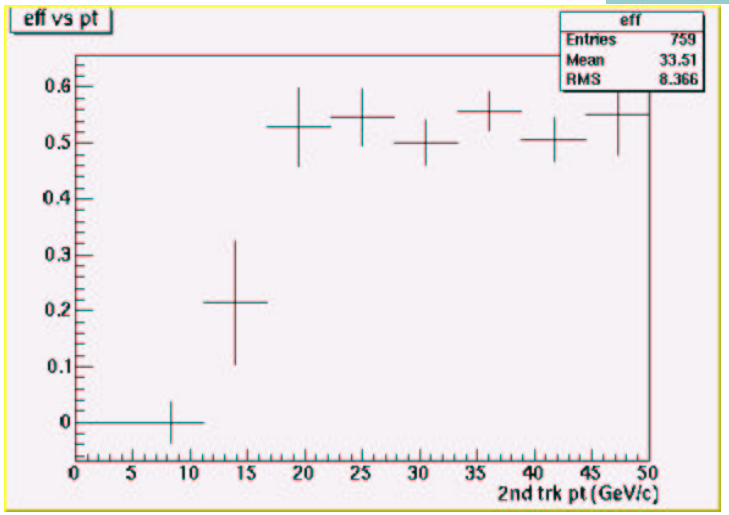
Consistent with no signal
m(stop)> 107 GeV @95% C.L.
LEP limit is 95 GeV

Long Lived Heavy Particles

New trigger: 2 high p_T tracks

Efficiency measured with Z−data:
54.5% ± 1.8%

Trigger fully efficient when both tracks > 20 GeV/c



Trigger efficiency−vs−P_T

Total (trigger+analysis efficiency):

	Winter 03	Current
100 GeV stable stop	1.71% +/− 0.42%	2.54% +/− 0.63%
150 GeV stable stop	2.18% +/− 0.53%	3.19% +/− 0.78%

Expected Limit using all data currently on tape: ~140 GeV/c²
(current limit :107 GeV/c²)

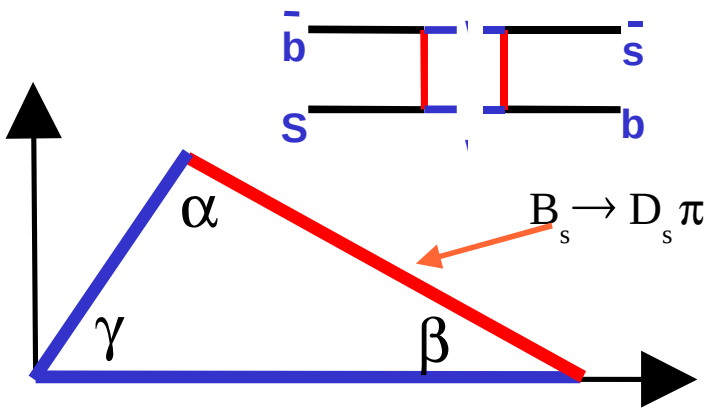
Summary

- Tools for physics analysis have been available for a while.
  As always, improvements are being made constantly.

- **LBNL group presented many results at Conferences**
  Two papers in preparation for publication
  First observation of reconstructed $B_s \rightarrow D_s \pi$
  Z asymmetry (ready for publication)
  Long lived particle search
  Top cross sections
  Top mass measurement

- **Run IIb silicon detector work coming to an end**
  Project very successful and ahead of schedule
  Project canceled by FNAL, due to low luminosity expectation at the Tevatron
  SVX4 chip design lead by LBNL, very successful
  Hybrids preproduction complete
  'Stave'concept, proposed by LBNL, has been successful as well

Prospects for B_s Physics at CDF



CKM matrix triangle

- **B_s mixing World Average @95% C.L.**

  $\Delta m_s \geqslant 14.4\ ps^{-1}$

- Will need good proper time resolution, 50fs
  Minimize error on P_T with fully reconstructed $B_s \to D_s \pi$

- Needs improved flavor tagging: **εD^2**

B_S meson properties:

- **Mass**
- **Lifetime**
- **Δm_S frequency**
- **$\Delta\Gamma_S$**
- **CP violation**
- **CKM angle γ**

- Present performance: **εD^2~4%, σ_t=67fs**

5σ sensitivity for Δm_S=15ps^{-1} with 0.5fb^{-1} data

- Modest improvements: **εD^2~5%, σ_t=50fs**

5σ sensitivity for Δm_S=18ps^{-1} with 1.7fb^{-1} data

5σ sensitivity for Δm_S=24ps^{-1} with 3.2fb^{-1} data

Prospects for High PT physics

Measure top quark properties

Mass to 3 GeV, Top cross section to 10%

Verify SM decay properties

Any non SM processes hide in top events?

Higgs production

SM Higgs: it is a big challenge, but try

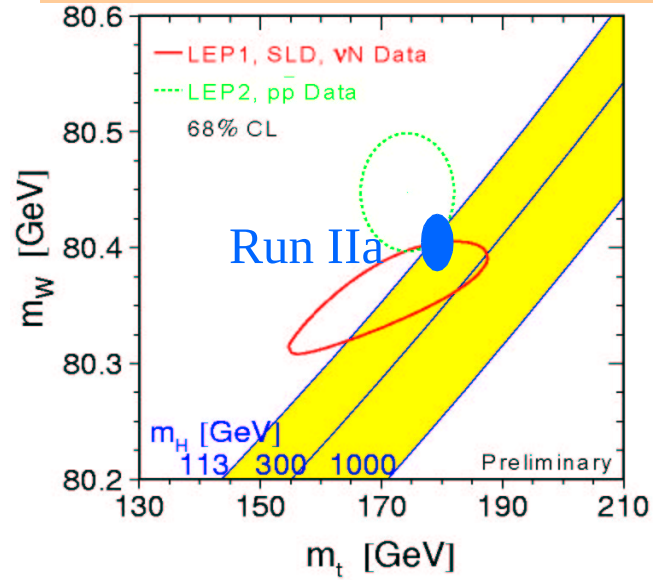
SUSY: $\tan\beta=50$ 5σ discovery possible of H/A with M=175 GeV (5 fb^{-1})

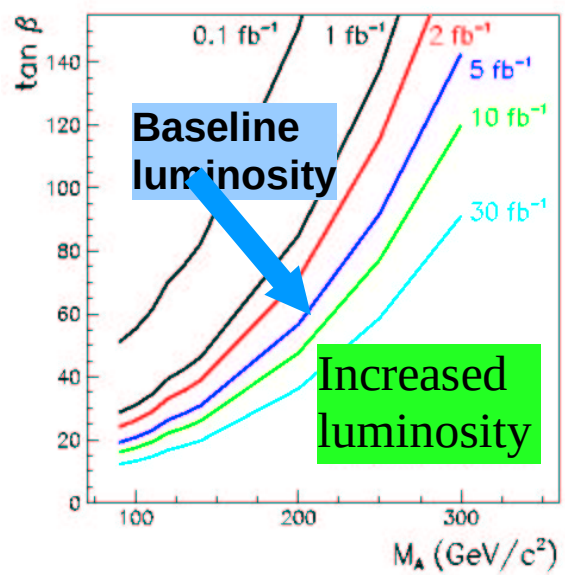
SUSY:

Some of the parameter space for squarks and gluinos can be explored long lived stable particles , trileptons, etc. offer many ways to search

Many other searches: W'. Z', leptoquarks , extra dimensions etc.

Electroweak Precision Measurements





Conclusions

Large contributions to CDF over the last 22 years
Contributed 10 PHD thesis, 12 postdocs.
14 of these have faculty or lab staff positions.

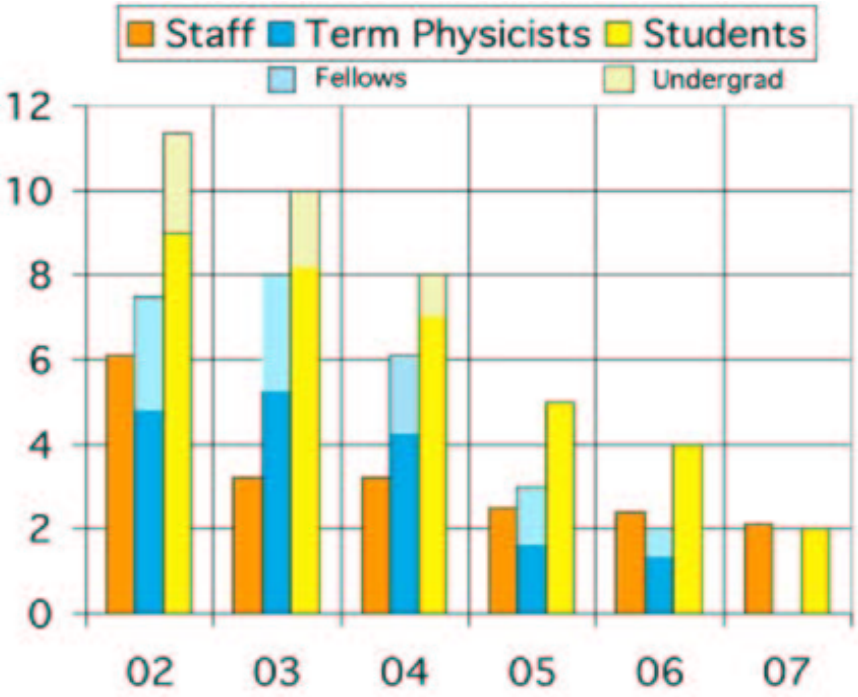
Contributed to top discovery, precision top and W mass measurements, properties of B mesons, Higgs studies etc.

We will soon have a lot of data (40 times what we had in Run I).
We can finally understand details of phenomena we have barely observed.
We are now on the verge of measuring Bs mixing.
Great high P_T physics potential before the LHC!!
Great opportunity to prepare for the challenges of LHC physics.

However, funding is not adequate.

If there is no course change, the CDF group may have no postdocs left by FY06 (well ahead of LHC data).

CDF Group members



Assumes no new students will join CDF

CDF−LBL postdocs and students now with permanent positions:

- M. Franklin (Harvard)
- R. Harris (FNAL)
- C. Haber (LBL)
- W. Wester (FNAL)
- P. Tipton (Rochester)
- M. Gold (New Mexico)
- O. Schneider (Lausanne)
- W−M Yao (LBL)
- M. Lancaster (U. College, London)
- M. Paulini (Carnegie Mellon)
- M. Garcia−Sciverez (LBL)
- H. Wenzel (FNAL)
- Y.K. Kim (Chicago)
- B. Ashmanskas (Ass. Prof. Cornell)