CDF Recent Results:
B Physics, Top Properties, Higgs search

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Reunión Anual DPyC SMF 2007

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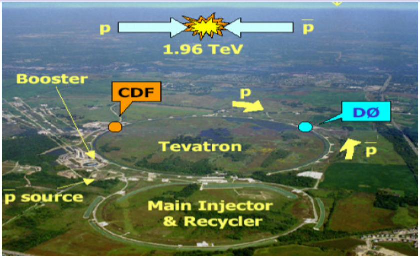
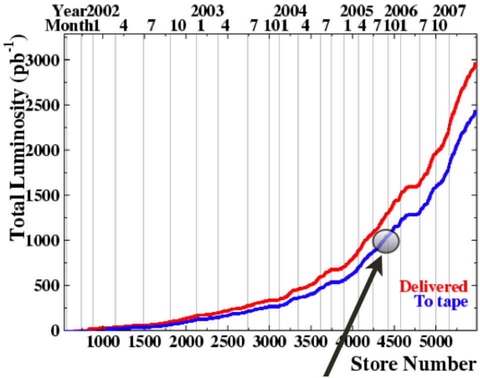
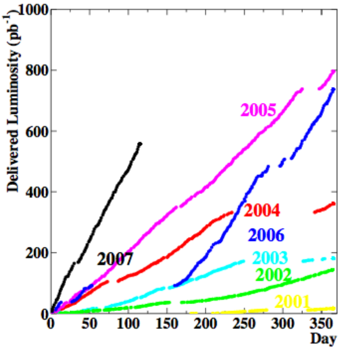
Tevatron Description

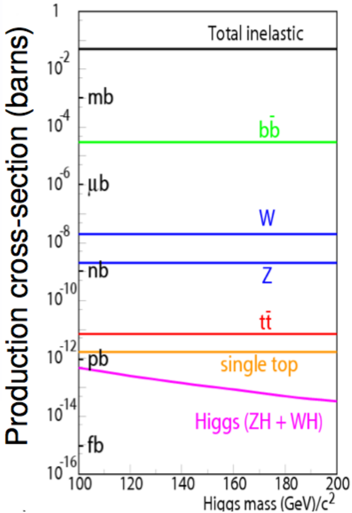
- $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV
- Peak luminosity $\sim 3 \times 10^{32}$ cm^{-2}s^{-1}
- CDF II collected > 2 fb^{-1}
  - Analyses today use $\sim$ 1 fb^{-1}
  - $\sim$ 2 fb^{-1} analized for the summer







Tevatron Collisions I



In 1 fb^{-1}

- $b\bar{b}$: 1 x 10^{11}
- W: 6 x 10^6
- Z: 6 x 10^5
- $t\bar{t}$: 14,000
- single top: 5,000
- Higgs: 100 ~ 10

Two main areas

- B Physics
- "High" Pt Physics
  - ⇨ SM (QCD)
  - ⇨ SM(EWK)
  - ⇨ SM(Top)
  - ⇨ Higgs, BSM

- Trigger and analyses being retuned to match the challenge
- As luminosity increases experiments are forced to deal with new challenges

At stake the capability to go down the ladder and explore the fb region

CDF & D0 RUN II

CDF underwent serious upgrades:

- New tracking system
  - ⇨ COT, new silicon tracker (6-7 layers DS+1 SS)
- New forward calorimetry
- Tracking at trigger level
  - ⇨ Tracks at L1
  - ⇨ Displaced from PV@L2

D0: change of philosophy

- New tracking system
  - ⇨ Based on a 2T solenoid
  - ⇨ New 8 layers fiber tracker
  - ⇨ Secondary vertices capability (SVX)
  - ⇨ Recently added (IIb) an extra layer of silicon sensors
- Improved muon coverage
- Upgraded trigger (IIa, IIb)

Some D0 Results

After ICHEP

- B physics:
  - LB lifetime in 1.3 fb^{-1}
  - Search for Bs oscillations in 1.2 fb^{-1}
- QCD
- EWK
  - Wg in 900 pb^{-1}
- Top
  - σ(ttbar)
- Searches
  - GMSB SUSY
  - Fermiophobic Higgs
  - ZH

Winter 07

- B Physics
  - $B_s \to \mu\mu$ 2 fb^{-1}
- QCD
  - Triple jet differential cross section 1.1 fb^{-1}
- EWK
  - $Z\gamma^* \to 4l$ 1 fb^{-1}
- Top
  - σ(ttbar)
    - → Dilepton
    - → L+jets
  - Top mass
  - Single top
- Searches
  - 2nd generation LQ
  - WH (many channels)
  - Updated SM Higgs limit
  - $H \to \tau\tau$

Some CDF Results

QCD
- b-bbar dijet production cross section (260 pb^{-1})
- Z+jets cross section measurement (1.1 fb^{-1})
- Z→ b-bbar
- Dijet production cross section measurement (1.13 fb^{-1})

B Physics
- Lifetime measurements:
  - B+, B0, Bs and Λ_B (1fb^{-1})
- Rare decay searches:
  - $B^+ \to \mu^+\mu^- K+$, $B^0 \to \mu^+\mu^- K^*$, $B_s \to \mu^+\mu^- \phi$ (1fb^{-1})
  - B→hh

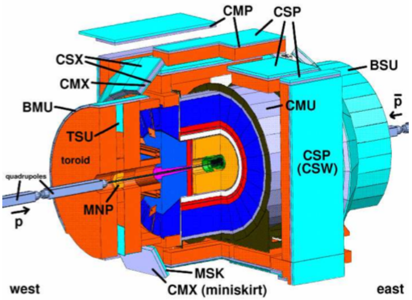
EWK
- Observation of WZ production
- Evidence for ZZ production
- W mass, width

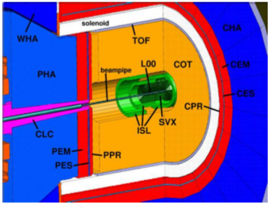
Top
- Top mass in all-jets channel
- Production cross section (lepton+isolated track)
- Search for W' using the single top sample
- Top Production Mechanism (gg vs qq)
- Top Charge

New Phenomena
- Search for New Particles Coupling to Z+jets (b'->Z+b) in 1.1 fb^{-1}
- SUSY trilepton combined limit - 0.7 to 1 fb^{-1}
- High-mass dielectron (Z' search) - 1.3 fb^{-1}

Higgs (fb^{-1})
- $H \to \tau\tau$ SUSY Higgs
- H→WW ME-based analysis
- ZH→llbb 2D-NN and MET fitter analysis

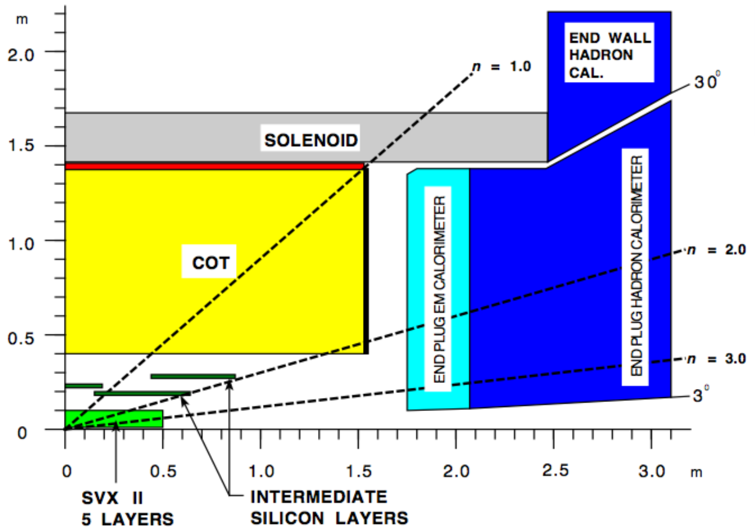
CDF Detector Overview





- Good tracking resolution, $\sigma(p_T)/p_T^2 \sim 0.1\%\ \mathrm{GeV}^{-1}$
  - Precise mass resolution
- Silicon Vertex Detector
  - Excellent vertex resolution
  - Crucial for triggering
- Large acceptance and good ID for leptons
- Kaon/pion separation
  - dE/dX in the COT
  - Time of Flight

CDF Tracking System



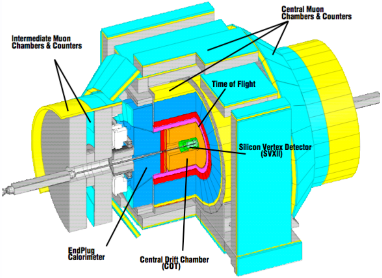
Universidad Iberoamericana Participation at CDF

Aug 2005

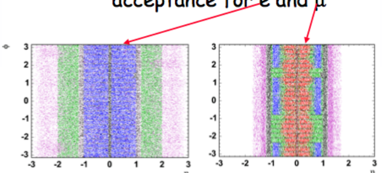
- Fabiola Vázquez
- Salvador Carrillo
  One year at Fermilab:
  Togheter with Univ. Wisconsin we set ready the most forward CDF muon detector (Rec.& ID Eff).

Jan 2007

- Miguel Mondragón
  Postdoc for 2 years at CDF:
  Started working on Silicon Detector.
  Now also starting in IMU & trilepton SUSY analysis



Winter 07: CDF improved its analysis by extending acceptance for e and μ



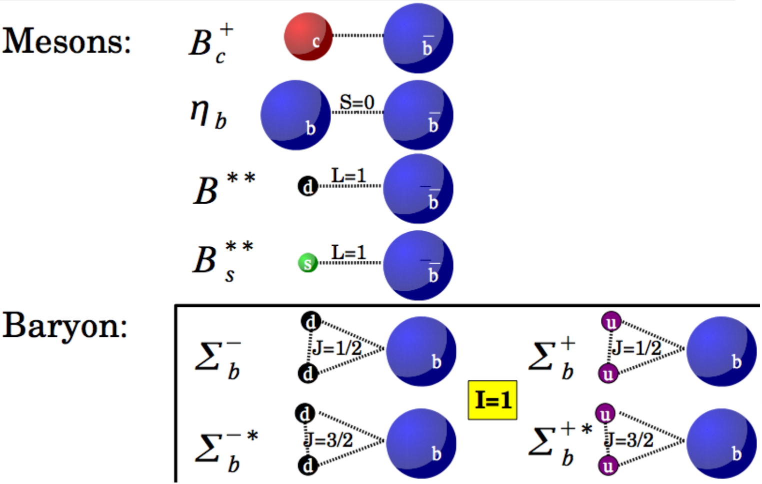
B Physics at an Hadron Collider

Thought to be almost impossible

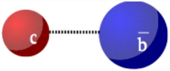
- Exploits large cross section
  - Need tight selection at trigger level
  - Tracking capability at L1 and displaced track trigger at L2 at CDF

  Challenge at high luminosity
- Some very recent results:
  - Bs oscillations [Observed by CDF with 1fb^{-1}]
  - $B \to hh$ [1fb^{-1}]
    - $\to A_{CP}$ in $B^0 \to K\pi$, $B^0_s \to K\pi$
    - $\to$ BF: $B \to KK$, $B \to \pi K$, $B \to \Lambda p$
  - Search for rare B decays [D0 with 2 fb^{-1}]
    - $\to Bs \to \mu\mu$, $B_d \to \mu\mu$
  - Measurement of B_c mass, new B Baryons states, excited states

B states covered in this talk

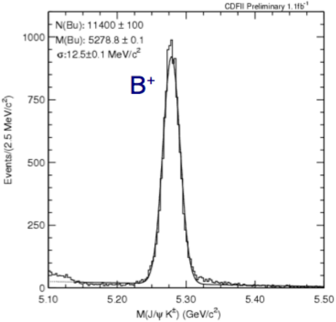


B_c^+ First direct Observation

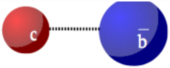


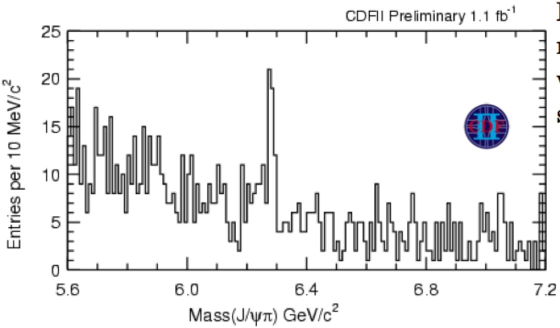
- Low production rate: $f(b \to B_c) \sim 0.05\ \%$
- Weak interaction decay, e.g.
  - $J/\psi\ \mu/e\ X$
    - observation + lifetime, lepton easy to find, but ν missing => unprecise mass measurement
  - $J/\psi\ \pi^+$ (exclusive!)

✗ Optimize selection cuts on $B^+ \to J/\psi\ K^+$



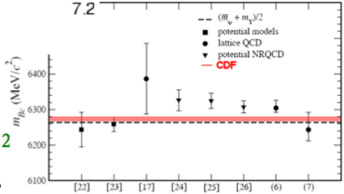
B_c^+ Observation (cont.)





Peak in $J/\psi\ \pi$ mass spectrum with **> 6σ** significance

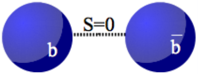
Experiment better than theory



$m(B_c) = 6400 \pm 400 MeV/c^2$
(old world average)

$m(B_c) = 6276.5 \pm 4.0 \pm 2.7 MeV/c^2$

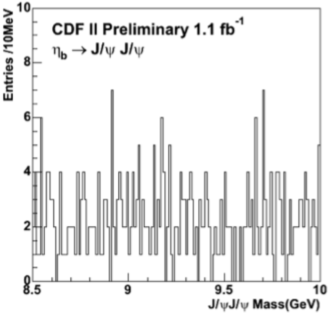
η_b Search



- pseudo-scalar $b\bar{b}$ state η_b not observed yet, LAST undiscovered ground state meson
- Predictions:
  - $BR(\eta_b \to J/\psi\ J/\psi) = 7 \times 10^{-4\pm1}$ $\Rightarrow$ 0.2 – 20 visible events per fb^{-1}
  - $m(\Upsilon(1S)) - m(\eta_b) = 30 - 160\ MeV/c^2$
  - $\Gamma(\eta_b) < \Gamma(\eta_c) = 25.5 \pm 3.4\ MeV$

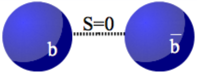
→ Search for $\eta_b \to J/\psi\ J/\psi$

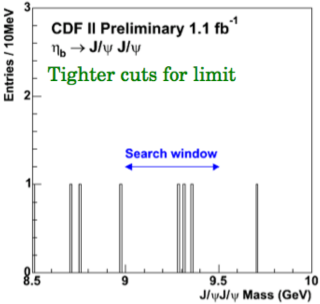
Optimized cuts for search

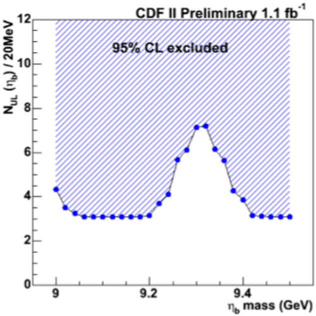


No evident resonance ==> make a limit

η_b Search (cont.)







$$\frac{\sigma(p\bar{p}\to\eta_b X;\ |\eta(\eta_b)|<0.6,\ P_T(\eta_b)>3.0GeV)\times Br(\eta_b\to J/\psi J/\psi)}{\sigma(p\bar{p}\to H_b\to J/\psi X;\ |\eta(J/\psi)|<0.6,\ P_T(J/\psi)>3.0GeV)} < 5.0\times10^{-3}\ (95\%)$$

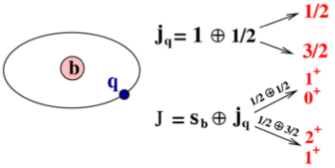
combined with other results

$$\sigma(p\bar{p}\to\eta_b X;\eta,p_t\ cuts)\times Br(\eta_b\to J/\psi\, J/\psi)\times[Br(J/\psi\to\mu\mu)]^2 < 2.6pb\ (95\%)$$

Orbitally excited (L=1) $B_{(s)}$ Mesons ($B_{(s)}^{**}$)

HQET ($m_b \to \infty$):

spins of quarks decouple



- j_q =1/2 states are broad

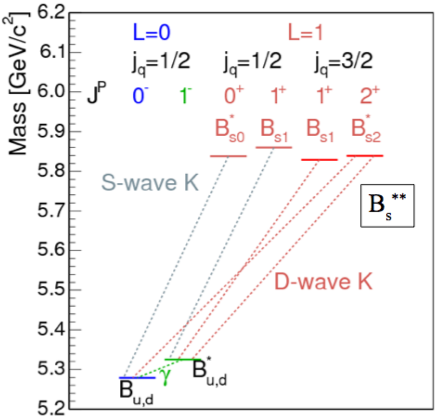
➔ don't expect to observe them

- According to HQET spin of b-quark is decoupled

=> D-wave needed for Spin-Parity conservation ($B_{(s)1}(3/2)$)

➔ j_q = 3/2 states are narrow

Orbitally excited (L=1) B Mesons (B^{**}, B_J)



Pions instead of Kaons in case of B_d^{**}

- B_d^{**} decays to $B^{(*)}\pi$
- B_s^{**} decays to $B^{(*)}K$,

$B_s^{(*)}\pi$ forbidden by isospin

→ expect 3 peaks

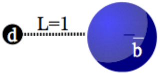
$B_{(s)1} \rightarrow B^*_{u,d} \quad \pi^{(-)}(K^{(-)})$

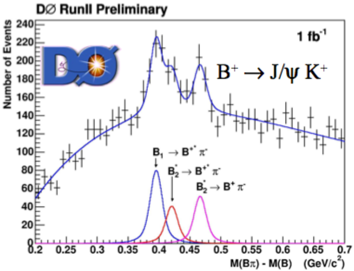
$B^*_{(s)2} \rightarrow B^*_{u,d} \quad \pi^{(-)}(K^{(-)})$

$B^*_{(s)2} \rightarrow B_{u,d} \quad \pi^{(-)}(K^{(-)})$

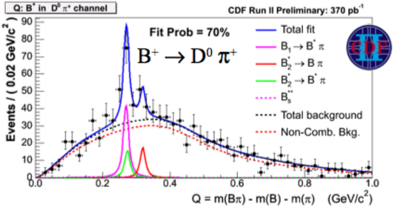
B Physics

B^{**} First direct Observation





$B^{**} \to B^{(*)+} \pi^-$, $B^{*+} \to B^+ \gamma$ (γ undetected)



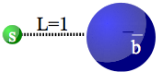
use of Likelihood ratios

($B^+ \to J/\psi K^+$ not shown)

	D0 (1 fb^{-1})	CDF (370 pb^{-1})
$m(B_1)$ [MeV/c^2]	5720.8 ± 2.5 ± 1.1	5734 ± 3 ± 2
$m(B_2^*)-m(B_1)$ [MeV/c^2]	25.2 ± 3.0 ± 1.1	4 ± 6 ± 2

Update to 1 fb^{-1} in progress

B_s^{**} Observation

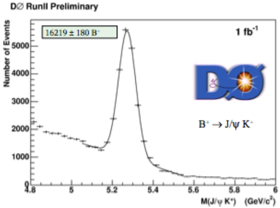


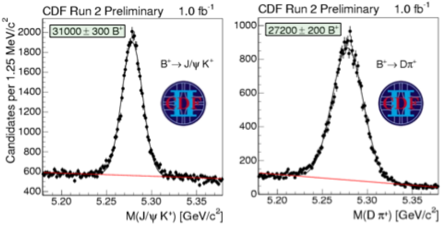
- Reconstruct $B_s^{**} \to B^{(*)+} K^-$

  $B^{*+} \to B^+ \gamma$ (γ undetected)

  $B^+ \to J/\psi\, K^+$ (D0, CDF)

  $B^+ \to D^0 \pi^+$ (CDF)





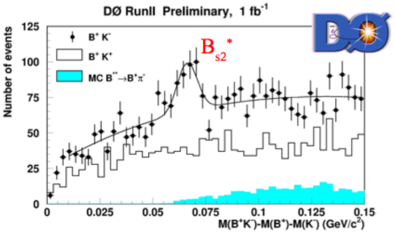
Use of multivariate analysis methods

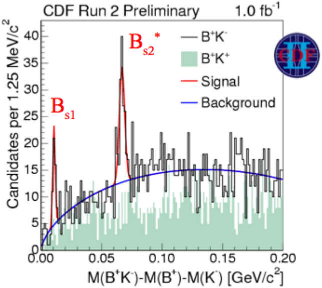
Neural Network (CDF)

Likelihood Ratio (D0)

B_s^{**} *Observation* (cont.)

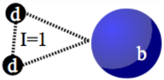
First observation of B_{s2}^* and B_{s1}



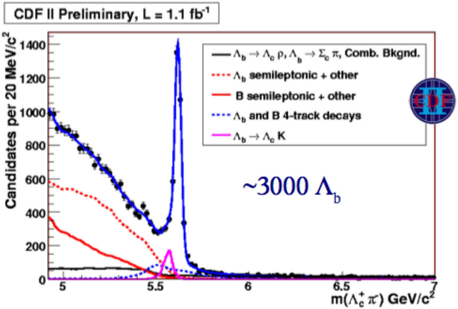


$m(B_{s2}^*)$ [MeV/c^2]	$5839.1 \pm 1.4 \pm 1.5$	D0
	$5839.64 \pm 0.30 \pm 0.14 \pm 0.5$ (PDG)	CDF
$m(B_{s1})$ [MeV/c^2]	$5829.41 \pm 0.21 \pm 0.14 \pm 0.6$ (PDG)	CDF

Σ_b Observation



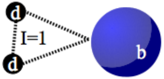
- Λ_b only established b baryon
- $\Sigma_b^{(*)\pm} \to \Lambda_b^0 \pi^\pm$ with $\Lambda_b^0 \to \Lambda_c^+ \pi^-$, $\Lambda_c^+ \to p K^- \pi^+$ in a blind analysis



		J= 1/2	J= 3/2
I_3 = -1	bdd	Σ_b^-	Σ_b^{*-}
I_3 = 0	bdu	Σ_b^0	Σ_b^{*0}
I_3 = + 1	buu	Σ_b^+	Σ_b^{*+}

Σ_b property	Expected values (MeV/c^2)
m(Σ_b) - m(Λ_b^0)	180 – 210
m(Σ_b^*) - m(Σ_b)	10 – 40
m(Σ_b^-) - m(Σ_b^+)	5 – 7
$\Gamma(\Sigma_b), \Gamma(\Sigma_b^*)$	~8, ~15

Σ_b Observation



- Four peaks in unblinded signal region
- Significance > 5σ

➔ First observation of charged $\Sigma_b^{(*)}$ baryons

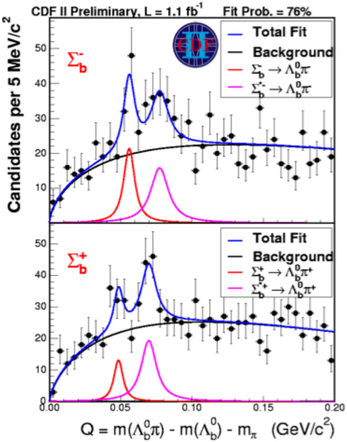
- Unbinned fit:

$m(\Sigma_b^-) = 5816\ ^{+1.0}_{-1.0} \pm 1.7\ \text{MeV/c}^2$

$m(\Sigma_b^+) = 5808\ ^{+2.0}_{-2.3} \pm 1.7\ \text{MeV/c}^2$

$m(\Sigma_b^{*-}) = 5837\ ^{+2.1}_{-1.9} \pm 1.7\ \text{MeV/c}^2$

$m(\Sigma_b^{*+}) = 5829\ ^{+1.6}_{-1.8} \pm 1.7\ \text{MeV/c}^2$



B Physics

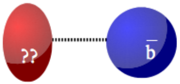
Broad spectrum of very competitive or even unique B state studies at the Tevatron:

- First direct observation of B_c
- Most stringent limit on η_b production
- Most precise mass measurement of both B^{**} states
- First observation of B_{s2}^* and B_{s1}
- First observation of Σ_b^+, Σ_b^{+*}, Σ_b^-, Σ_b^{-*}

For more information see
www-cdf.fnal.gov/physics/new/bottom/bottom.html
www-d0.fnal.gov/Run2Physics/WWW/results/b.htm

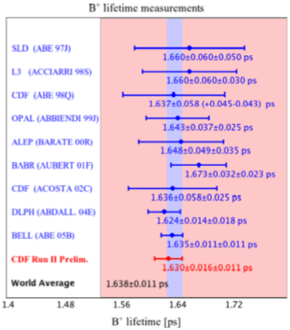
Much more data expected to come

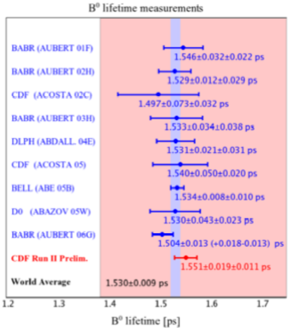
→ Improved precision, new discoveries?

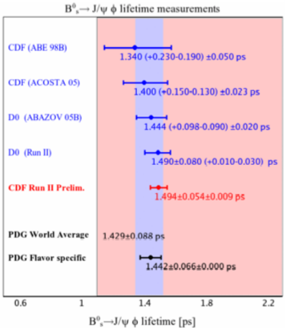


Life Times

- Update on B^+, B^0, B_s and Λ_b lifetimes using exclusive decays containing a J/Ψ







➥ Measurement for B_s more precise than PDG value

Bs oscillations

D0 has a limit (900 pb^{-1})

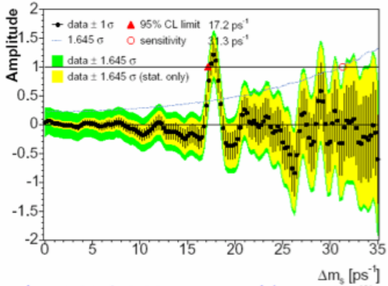
- $14.9 < \Delta m_s < 21\ ps^{-1}$ (90% CL)

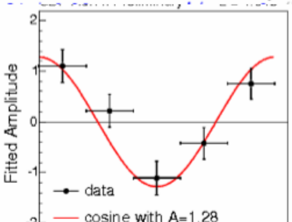
CDF, with 1fb^{-1} presents

- Observation of B_s Oscillations

PRL 97, 242003 2006

- $\Delta m_s = 17.77 \pm 0.10(stat) \pm 0.07 (syst)\ ps^{-1}$: > 5σ observation
- Same data set used for previous (spring 06) limit
  - Improved selection
  - Improved analysis technique
  - A lot of efforts





Di-muon

$J/\Psi \rightarrow \mu\mu$, $B \rightarrow \mu\mu$

- $p_T(\mu) > 1.5$ GeV

One displaced track + lepton

$B \rightarrow \ell\nu X$

- $p_T(\ell) > 4.0$ GeV
- $p_T(track) > 2.0$ GeV
- $120 < d_0 < 1000\,\mu m$

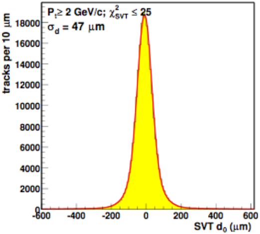
Two displaced tracks

$B \rightarrow hh$, Σ_b, B_s mixing

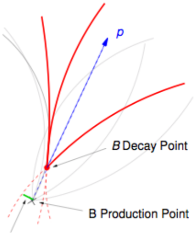
- $p_T > 2.0$ GeV
- $\sum p_T > 5.5$ GeV
- $120 < d_0 < 1000\,\mu m$

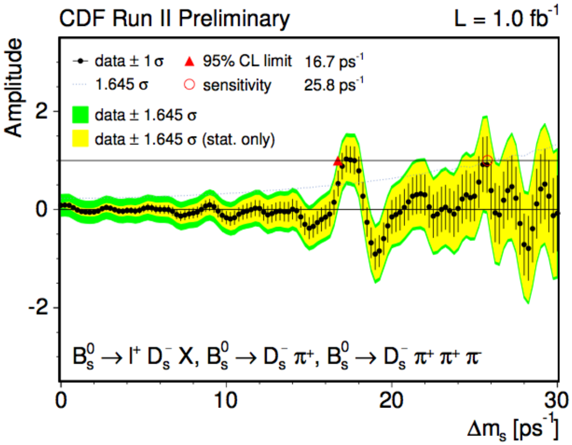
Silicon Vertex Trigger (SVT)

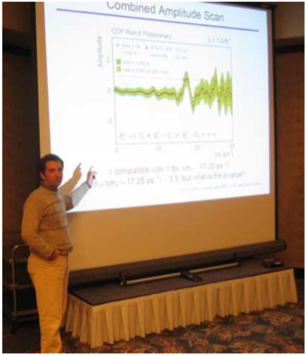
- Exploits long B lifetimes
- d_0 resolution $\sim 50\,\mu m$ (includes beam width)
- Very fast response at L2



Sketch of a B Decay



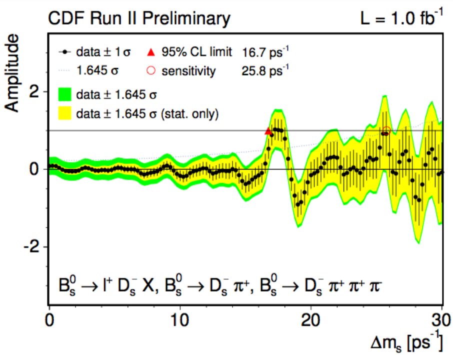




Evidence of B_s oscillations at 3σ significance shown

$$\Delta m_s = 17.31^{+0.33}_{-0.18}(\text{stat.}) \pm 0.07(\text{syst.})\ \text{ps}^{-1}$$

Bs Oscillations



Neutral B mesons ($b\bar{q}$, with $q = d, s$ for $\overline{B}_d^0$, $\overline{B}_s^0$) oscillate from particle to antiparticle due to flavor-changing weak interactions. The probability density P_+ (P_-) for a $\overline{B}_q^0$ meson produced at proper time $t = 0$ to decay as a $\overline{B}_q^0$ (B_q^0) at time t is given by

$$P_\pm(t) = \frac{\Gamma_q}{2} e^{-\Gamma_q t} \left[1 \pm \cos(\Delta m_q t)\right] ,$$

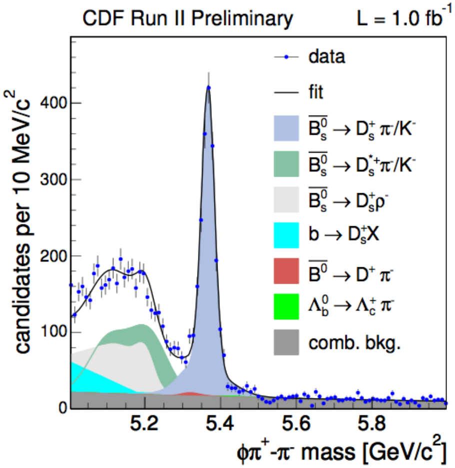
where Δm_q is the mass difference between the two mass eigenstates $B_{q,H}^0$ and $B_{q,L}^0$ [1], and Γ_q is the decay width, which is assumed to be equal for the two mass eigenstates. The mass differences Δm_d and Δm_s can be used to determine the fundamental parameters $|V_{td}|$ and $|V_{ts}|$, respectively, of the Cabibbo-Kobayashi-Maskawa

Evidence of B_s oscillations at 3σ significance shown

$$\Delta m_s = 17.31^{+0.33}_{-0.18}(\text{stat.}) \pm 0.07(\text{syst.})\ \text{ps}^{-1}$$

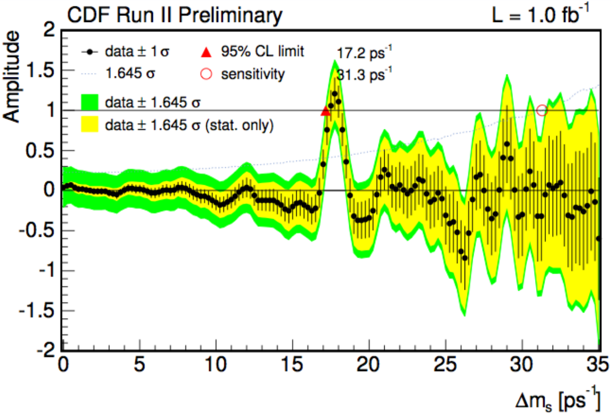
Bs Oscillations

Are we able to reach a 5σ observation with the same data sample of $1\,\text{fb}^{-1}$ but improved tecniques?



- PID information to reject background from D^- mass missassignments
- New trigger paths for semileptonic analysis: 37,000 $\rightarrow$ 61,500
- Neural Network selection for hadronic modes: 3,600 $\rightarrow$ 5,600
- Inclusion of partially reconstructed hadronic modes: 3,100
- Neural Network to combine OS taggers: 15 % improvement in ϵD^2
- Neural Network SSK tagger: 8 % improvement in ϵD^2

Bs Oscillations



Observed signal consistent with B_s oscillations at significance $> 5\sigma$

$$\Delta m_s = 17.77 \pm 0.10(\text{stat.}) \pm 0.07(\text{syst.})\ \text{ps}^{-1}$$

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.2060 \pm 0.0007(\text{exp.})^{+0.0080}_{-0.0060}(\text{theor.})$$

Observation of Ξ_b

Ξ_b

observation at CDF

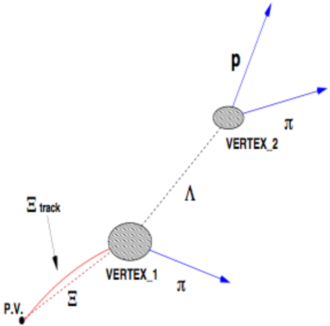
Dmitry Litvintsev (Fermilab CD)

for CDF

June 15, 2007

Cascades at CDF

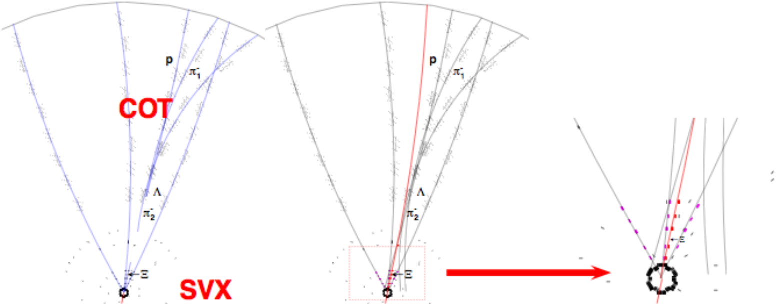
- Ξ^- long lived & charged
- Can be tracked in the SVX (technique previously used at LEP)
- CDF developed tracking of Ξ. 1st in hadron collider experiment.
  - Form of a Ξ candidate using standard decay chain $\Xi \to \Lambda\pi$, $\Lambda \to p\pi^-$
  - Convert Ξ momentum and vertex position into helix in CDF track parameter $(cu, \phi_0, d_0, \lambda, z_0)$ basis and convert elements of Vertex fit error matrix into track 5×5 error matrix
  - Use this track to seed Outside In (OI)Z tracking
  - Attach silicon hits starting from vertex point and going to PV
  - Store SVX Ξ tracks in the event record on the file for subsequent analysis.
- Φ pentaquarks search was based on this technique (Phys.Rev.D75:032003,2007)



Ξ_b Observation

Cascade Tracked!

Event Display of generated Hyperons Tracked in Silicon

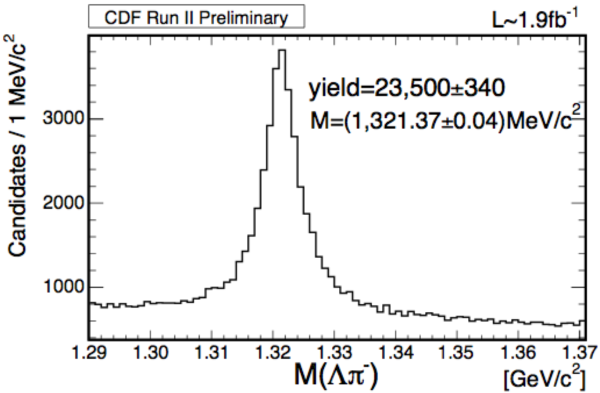


$$\Xi_b \to \Xi_c^+ \pi^- \quad \Xi_c^+ \to \Xi^- \pi^+ \pi^+ \quad \Xi^- \to \Lambda \pi_2^- \quad \Lambda \to p \pi_1^-$$

- Reduce random background - clean Ξ samples
- Improvement in Ξ impact parameter resolution

Ξ_b Observation

Cascade Yield in J/ψ trigger

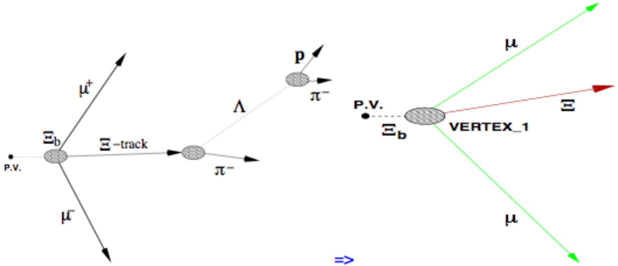


- 23.5K events
- Mass is consistent with PDG
- Almost no cuts, just minimum of 2 $r-\phi$ SVX hits

Ξ_b Observation

Analysis Strategy

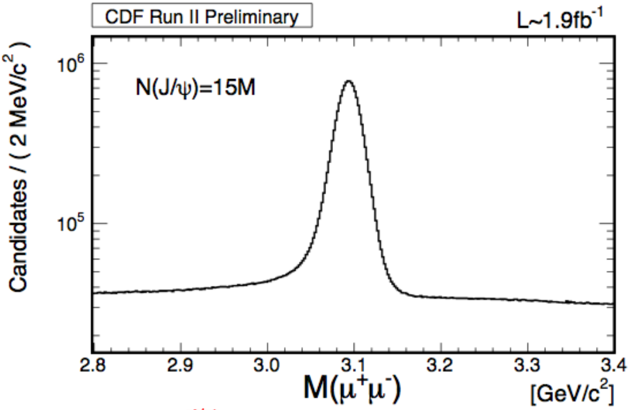
- Use silicon Ξ tracks to look for $\Xi_b \to J/\psi \Xi$



- Collapse 3-track Ξ candidate to 1-track.
- Ξ_b becomes like $B^+ \to J/\psi K^+$. Use $B^+ \to J/\psi K^+$ as control sample.
- Selection is data driven & independent of signal under study.
- Optimized cuts for best $B^+ \to J/\psi K^+$ signal. Applied same cuts to $\Xi_b \to J/\psi \Xi$ candidates.
- Approach is based on assumption "$B^+ \to J/\psi K^+$ look similar to $\Xi_b \to J/\psi \Xi$". Validated assumption with Simulation.
- Same approach used to discover $B_c \to J/\psi \pi$. Should work even better for $\Xi_b \to J/\psi \Xi$.

Ξ_b Observation

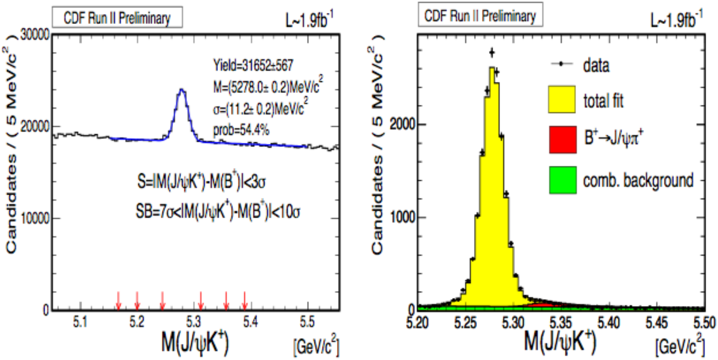
$J/\psi \to \mu\mu$



15M J/ψs using sideband subtraction counting

Ξ_b Observation

$B^+ \to J/\psi K^+$

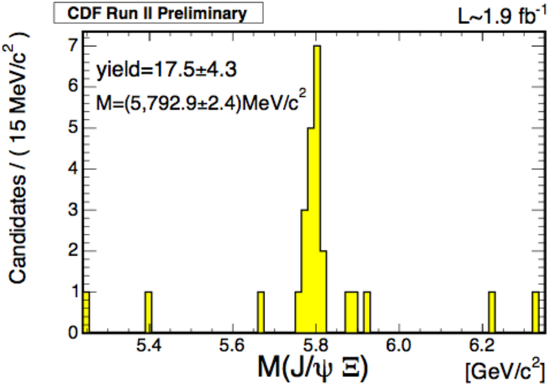


- Loose cuts – 31K B^+
- Optimized cuts 16K B^+.
- Signal effi ciency 52%, background reduced by factor of 500

Ξ_b Observation

The Ξ_b

Unbinned fit uses estimate of mass uncertainty of each candidate to improve mass resolution. Linear background



Yield	Mass
17.5 ± 4.3	$(5,792.9 \pm 2.4)\ \mathrm{MeV}/c^2$

Ξ_b^- Significance

- Assume flat distribution of events in the mass region $[5.7-6.5]$ GeV$/c^2$
- The p-value is defined as probability to toss $N_{total} = 23$ events contained in this interval, so that there are $N_{signal} = 17$ observed events in 60 MeV$/c^2$ signal range ($\pm 2\sigma$).

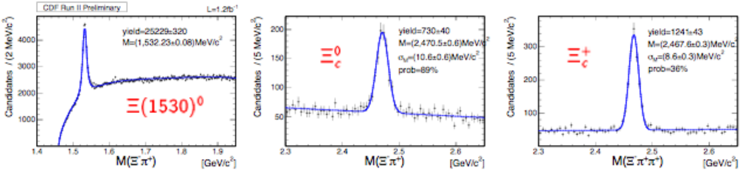
$$p = 1 - \sum_{i=0}^{N_{signal}-1} \mathcal{B}(i, N_{total}, \frac{60}{800})$$

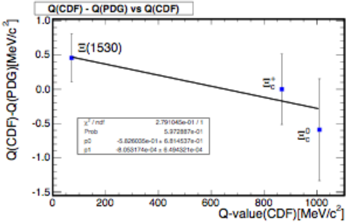
- putting in the numbers we get $4.1 \cdot 10^{-15}$ which corresponds to 7.8σ Gaussian significance.

Ξ_b Observation

Mass Systematics

- check on large samples in TTT that Ξ tracking does not introduce any additional tracking systematics

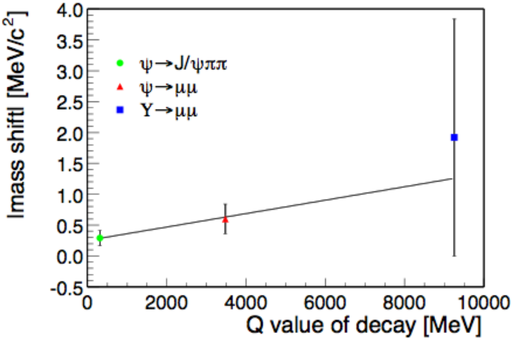




- projected shift at Ξ_b mass is $\delta m = (-1.69 \pm 1.54)$ MeV/c^2. Not significant.

Ξ_b Observation

Tracking Momentum Scale



$$\delta m = 1.09 \cdot 10^{-4} \cdot Q + 0.25[MeV]$$

Phys.Rev.Lett.96:202001,2006.

Fit model variation

Fit	yield	mass
base	17.5	$(5,792.9)\ \mathrm{MeV}/c^2$
free sigma	17.4	$(5,791.8)\ \mathrm{MeV}/c^2$
double Gaussian	18.1	$(5,794.4)\ \mathrm{MeV}/c^2$

- Reasonable variation of background function and fi t range does not change parameters of the peak appreciably
- Take maximum deviation as $\pm 1.5\ \mathrm{MeV}/c^2$

Ξ_b Observation

Summary Systematics

Error source	value
Tracking Momentum scale	$\delta m = \pm 0.4$ MeV/c^2
PDG Masses(J/ψ, Ξ, Λ)	$\delta m = \pm 0.14$ MeV/c^2
Mass scale calibration	$\delta m = \pm 0.6$ MeV/c^2
Fit model/resolution	$\delta m = \pm 1.5$ MeV/c^2
Total	$\delta m = \pm 1.7$ MeV/c^2

$$M(\Xi_b^-) = (5,792.9 \pm 2.4(stat.) \pm 1.7(syst.))\ \text{MeV}/c^2$$

Accessible channels at CDF

- J/ψ trigger:

$$\Xi_b \to \boxed{J/\psi}\ \Xi^- + n\pi \quad (\hookrightarrow \Lambda\pi^-), \quad \Omega_b \to \boxed{J/\psi}\ \Omega^- + n\pi \quad (\hookrightarrow \Lambda K^-)$$

- TTT trigger:

$$\Xi_b \to \Xi_c + n\boxed{\pi} \quad (\hookrightarrow \Xi^- + n\boxed{\pi},\ \hookrightarrow \Lambda\pi^-), \quad \Omega_b \to \Omega_c + n\boxed{\pi} \quad (\hookrightarrow \Omega^- + n\boxed{\pi},\ \hookrightarrow \Lambda K^-)$$

$$\Xi_b \to D^0\Lambda,\ \Omega_b \to D^0\Xi^-$$

$$\Xi_b \to \Lambda_c K + n\pi,\ \Omega_b \to \Xi_c K + n\pi$$

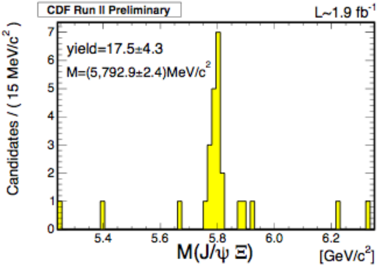
- SVT+lepton trigger:

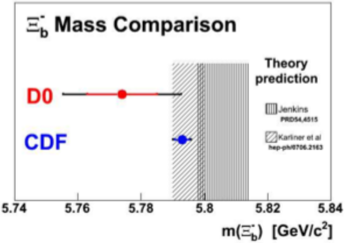
$$\Xi_b \to \Xi_c + \boxed{\ell^-}X \quad (\hookrightarrow \Xi^- + n\boxed{\pi},\ \hookrightarrow \Lambda\pi^-), \quad \Omega_b \to \Omega_c + \boxed{\ell^-}X \quad (\hookrightarrow \Omega^- + n\boxed{\pi},\ \hookrightarrow \Lambda K^-)$$

Conclusion

- CDF observes Ξ_b. Significance is 7.8σ
- The Ξ_b mass is measured to be

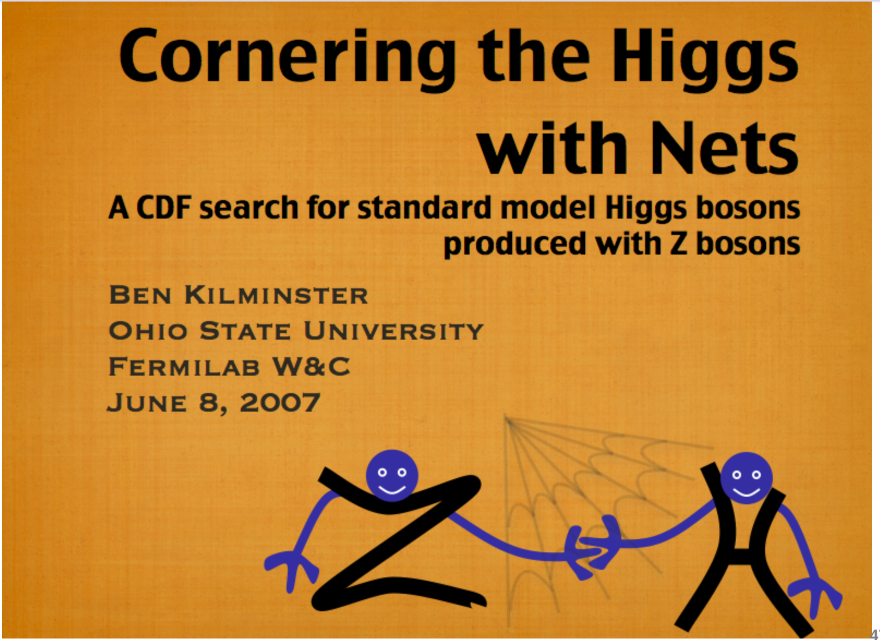
$$M(\Xi_b^-) = (5,792.9 \pm 2.4(stat.) \pm 1.7(syst.))\ \mathrm{MeV}/c^2$$



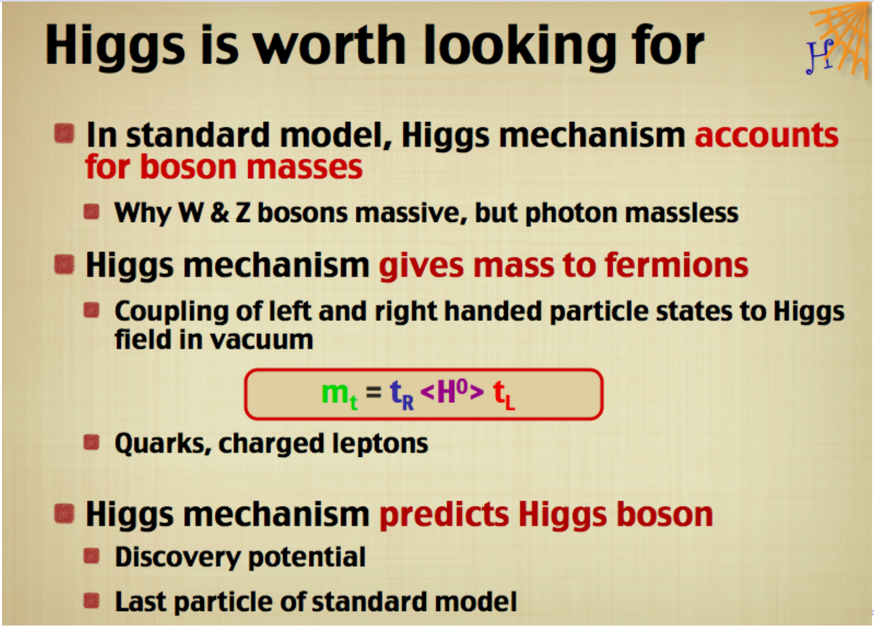


- PRL in preparation. There is much more to come from us.

Higgs Search



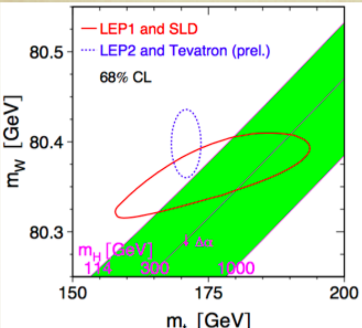
Higgs Search

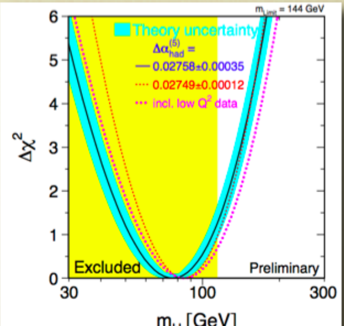


Experimental Constraints on Higgs

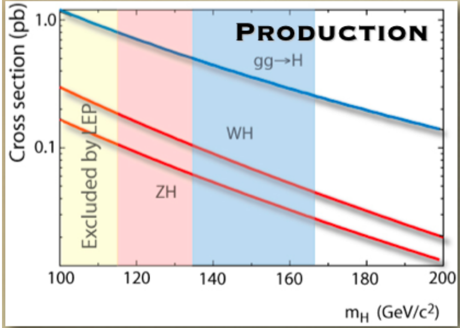
- Higgs searches ongoing for 30 years
  - Direct searches at LEP: $m_H > 114$ GeV @ 95% CL
  - Indirect searches :
    - Driven by new CDF/D0 $m_t = 170.9 \pm 1.8$ GeV and $m_W = 80.398 \pm 0.025$ GeV

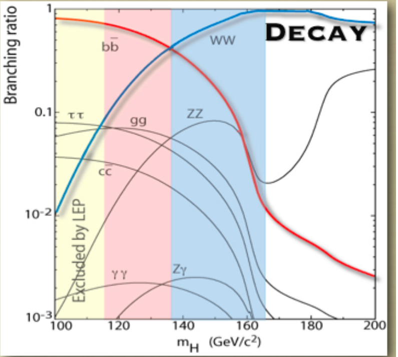
$m_H = 76^{+33}_{-24}$ GeV, $m_H < 144$ GeV @ 95 % CL





Higgs at the Tevatron





Higgs Production

- **< 1 pb**

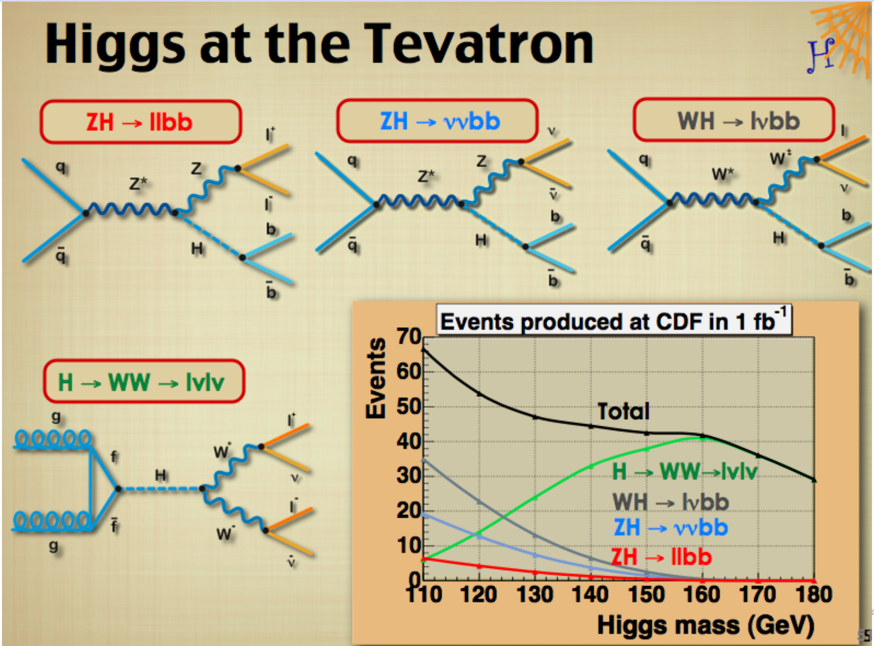
Compare to

- 12 pb WW
- 7 pb top pair
- 3 pb top single
- 2 pb ZZ

Most sensitive Tevatron searches

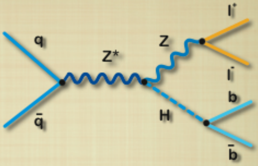
- **If low mass (m_H<135 GeV):**
  - Production with W or Z
  - Decay to a b-quark pair
- **If high mass (m_H>135 GeV):**
  - Direct production
  - Decay to a W-boson pair

Higgs Search



Then why search for ZH → llbb ?

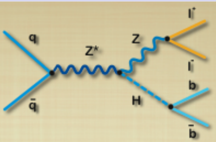
- May have smallest signal yield



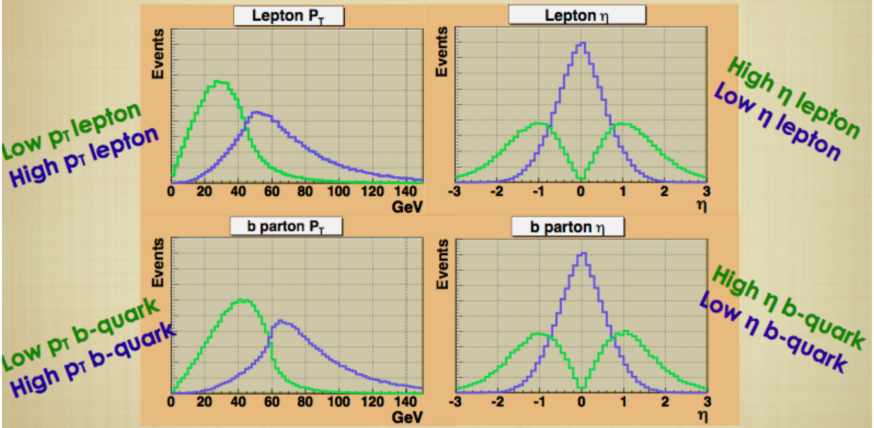
- Some benefits
  - Only fully constrained channel
    - No neutrinos
  - Both Z and H resonances
    - Powerful for separating Higgs from backgrounds
  - Fake lepton backgrounds small
    - Hard to fake two leptons with Z mass

- Can we make this channel competitive ?

What to expect ?



- Ask Pythia what ZH looks like



Use these distributions as a guide to determine selection

Higgs Search

BEFORE ANY EVENT SELECTION

Higgs events : Everything else

5 : 100,000,000,000,000

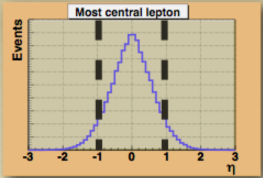
in 1 fb^{-1} data

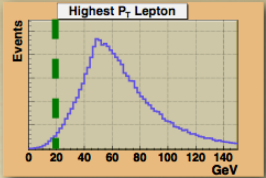
Higgs Search

Maximizing ZH Acceptance

Higgs Search

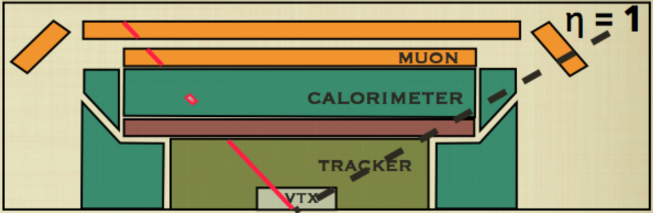
Online selection first lepton





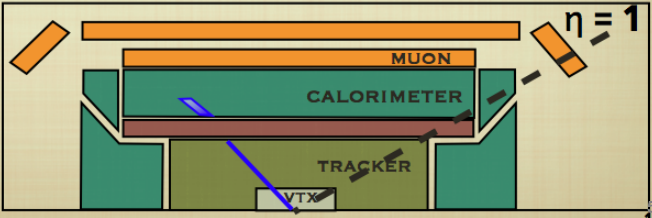
MUONS

- Track p_T > 18 GeV
- |η| < 1
- Muon segment
- Isolated
- Quality cuts



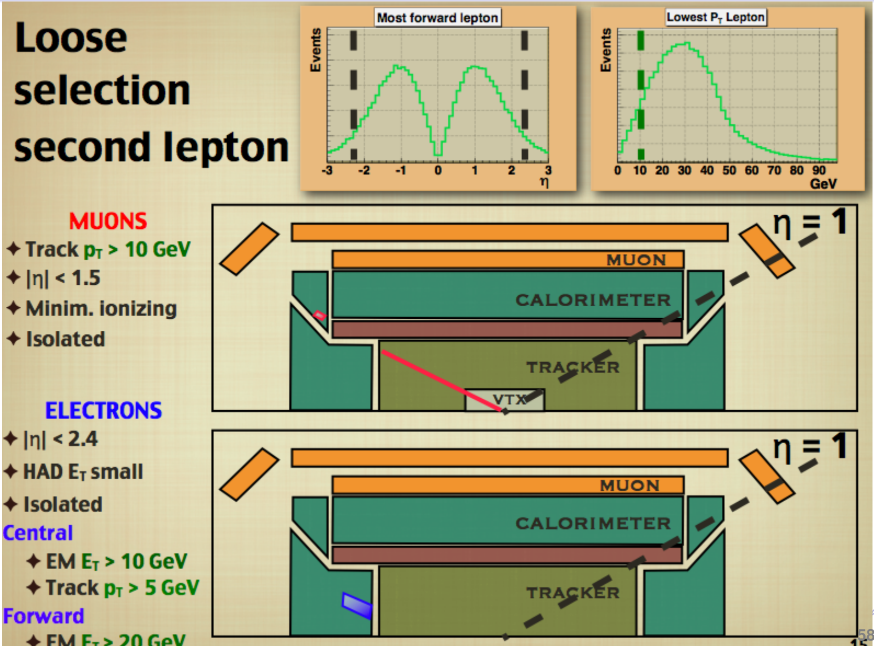
ELECTRONS

- EM E_T > 18 GeV
- |η| < 1
- Track p_T > 8
- HAD E_T small
- Isolated
- Quality cuts



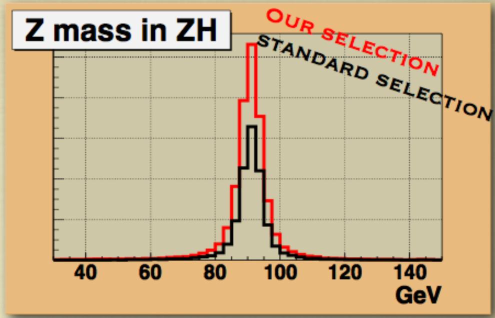
Higgs Search

Higgs Search



Improved Higgs acceptance

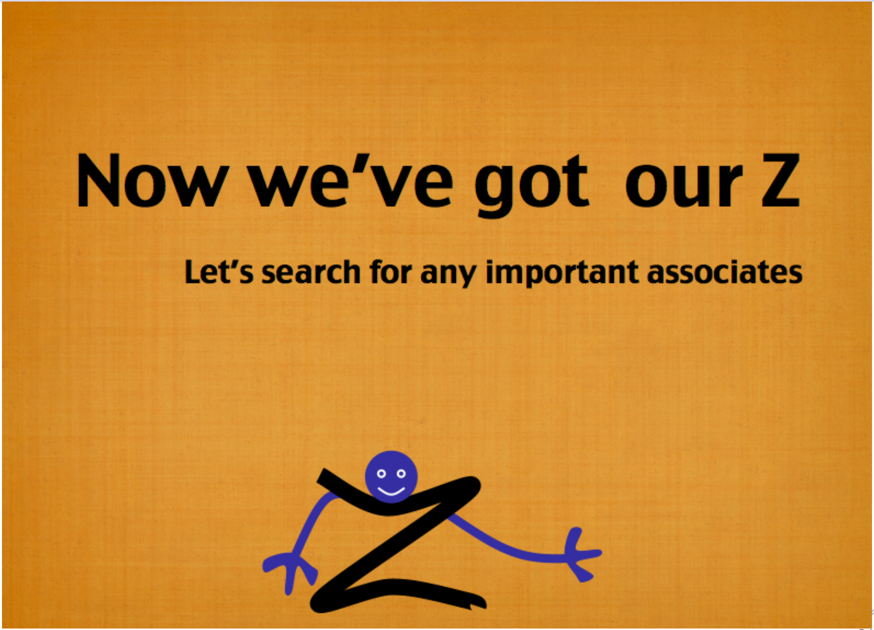
- Efforts pay off
- 70% more signal acceptance than cuts used in top dilepton group
- 0.9 → 1.5 ZH events after Z selection



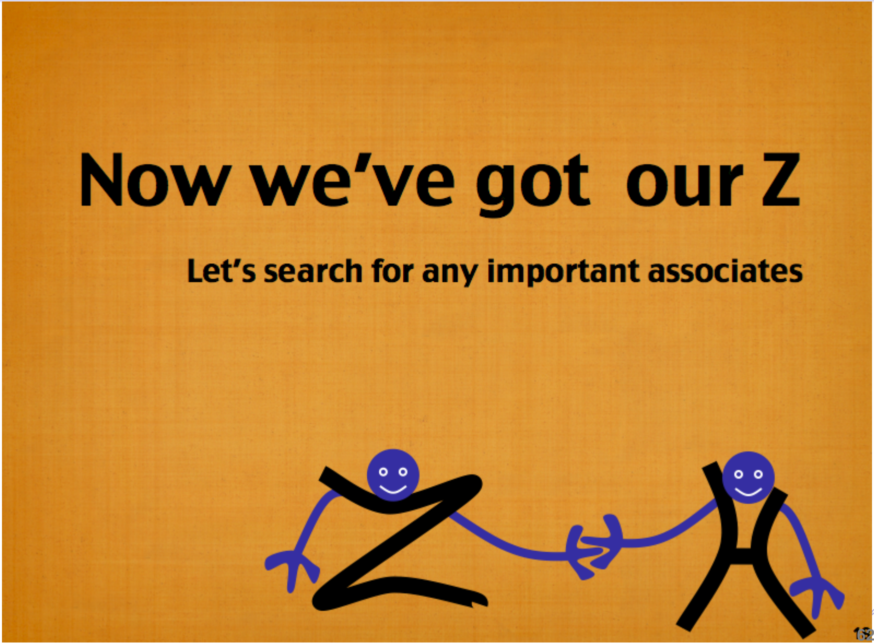
- **What about background from "fake" leptons ?**
  - Rate to for leptons to be mis-reconstructed evaluated in jet-enhanced data & same-charge dilepton events
  - "Fake Z bosons" < 2% of Z boson candidate sample !

Higgs Search

Higgs Search

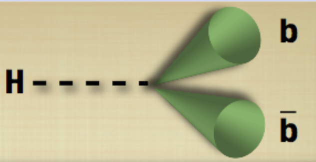


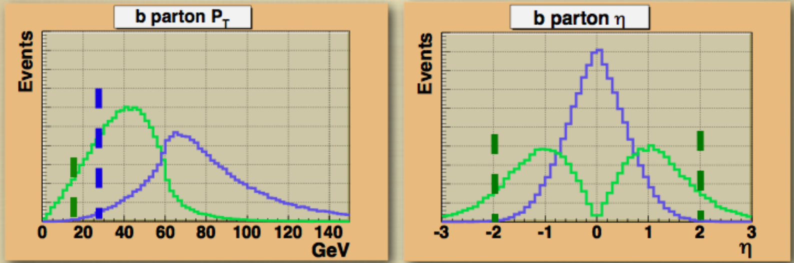
Higgs Search

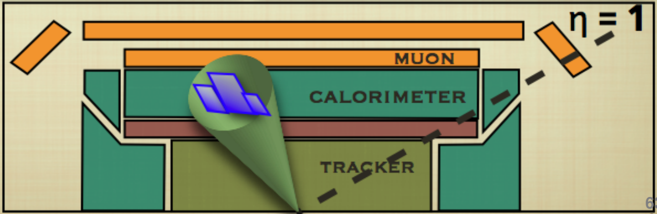


Higgs Search

Selection of Jets







1st jet

- $E_T > 25$ GeV
- $|\eta| < 2.0$

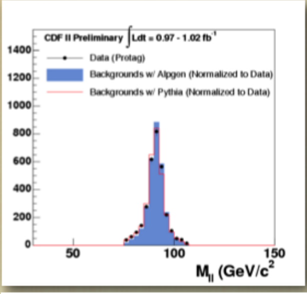
≥2nd jet

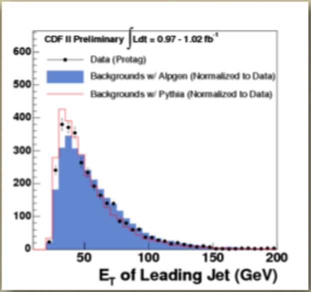
- $E_T > 15$ GeV
- $|\eta| < 2.0$

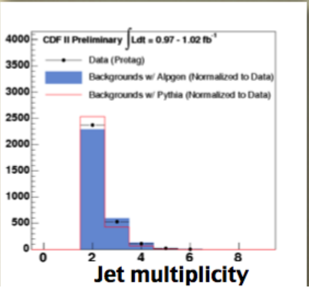
Modeling of Z + ≥ 2 jets

- Compare data to background model
  - 95% Z+jets
    - Model with Alpgen + Herwig
      - Better at modeling harder extra jet activity
    - Compare to Pythia
      - Well-tuned to our data : "Tune A", "Z p_T tune"
  - 4% comes from
    - Fakes (for instance, W+jets with a jet misidentified as a lepton)
      - Model from data
    - ZW, ZZ, tt
      - Model from Pythia

Data / Model Comparisons for Z + ≥2 jets



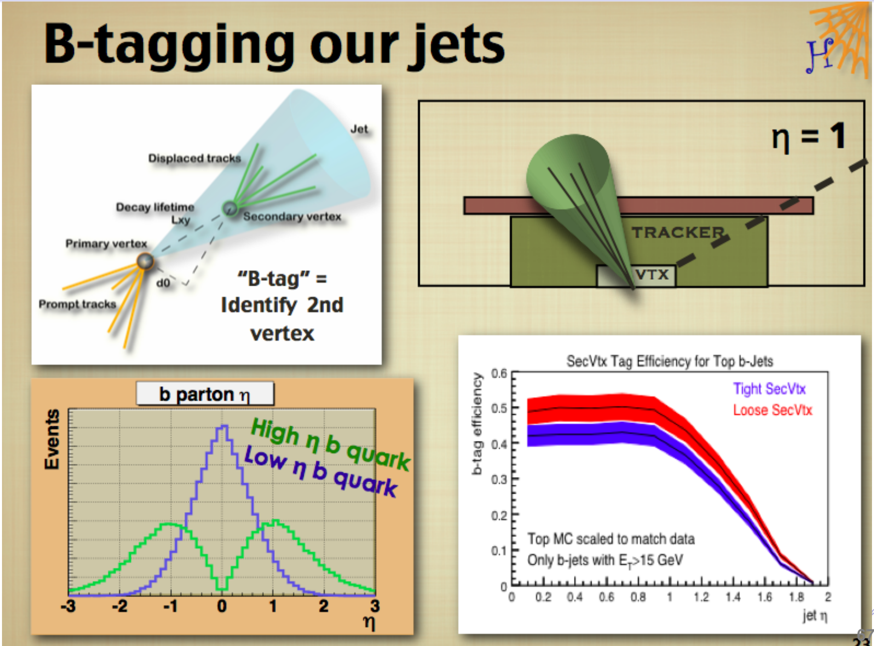




Two models span data well

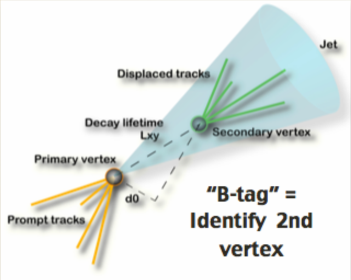
Higgs Search

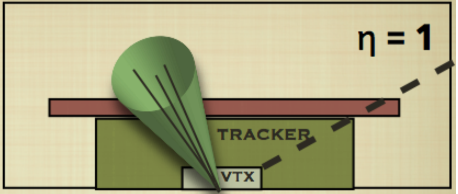
Higgs Search

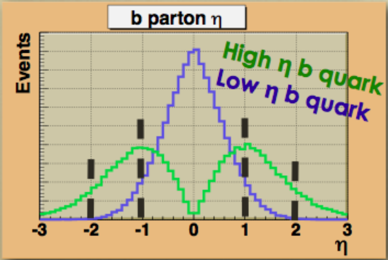


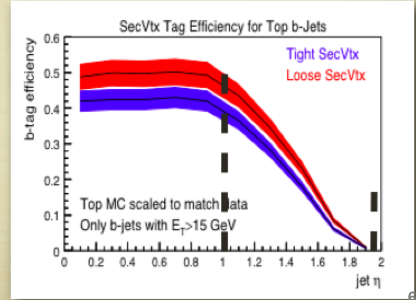
Higgs Search

B-tagging our jets









Higgs Search

Smarter b-tagging

- **Split events** into exclusive categories
  - Two loose b-tags
    - Each 50% efficient, 1.5% fake rate
    - Subsample with better signal to background
  - One tight b-tag
    - 40% efficient, 0.5% fake rate
  - Separating **improves sensitivity** to ZH signal

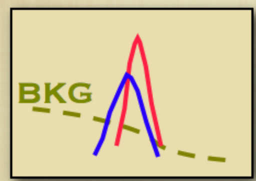
Events w/one tag 1 fb^{-1}		
Signal	0.44	1/200
Z+bb	35	
Z+fake B	32	1/3
Total background	102	
Data	100	

Events w/two tags 1 fb^{-1}		
Signal	0.23	1/50
Z+bb	6.3	
Z+fake B	1.0	1/12
Total background	12.4	
Data	11	

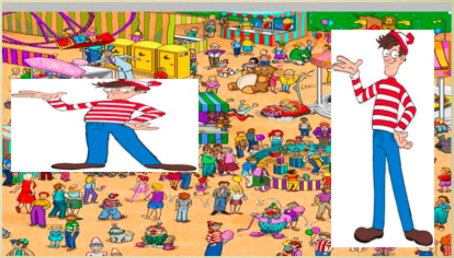
Higgs Search

Distinguishing Z+jets from ZH

- Best sensitivity to H→bb should be with M_{bb}
  - Easier to find Higgs if dijet mass resolution is narrower



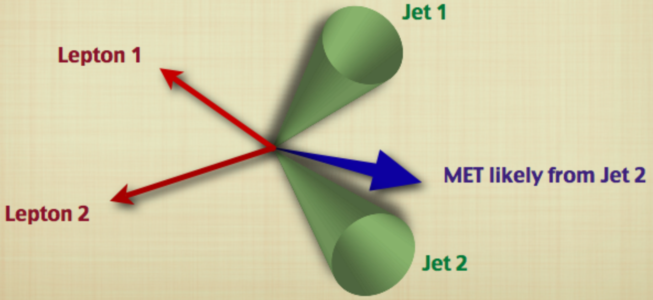
Less background under narrower signal



Where's Higgs ?

Using MET to improve M_{jj}

- In ZH → llbb, there should be no missing transverse energy
  - Leptons measured well
  - MET results from mismeasured jets



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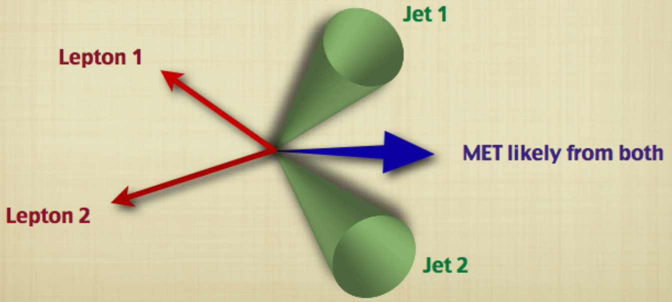


Dijet energy fitting function

- Goal is to correct jet energies to parton level
  - Improve dijet mass resolution
- (Jet 1 E_T, Jet 2 E_T) = function (Jet variables, MET variables)
  - Jet variables : E_T, η, ϕ, jet projection onto MET direction
  - MET variables : magnitude and ϕ
- How to determine above variable correlations ?
  - We use an Artificial Neural Network
    - Will refer to as "NN"
  - Training NN
    - Inputs: Jet and MET variables + parton energies
    - Samples: ZH Monte Carlo for $60 < m_H < 180$ GeV
    - Outputs: corrected Jet 1 and Jet 2 energies

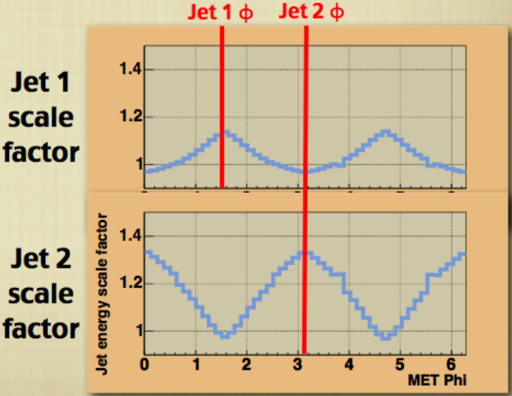
NN for jet energy corrections

- Example: Determine jet scale factors as function of MET ϕ (everything else fixed)

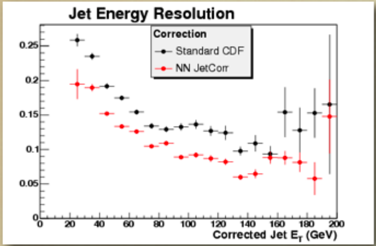
MET : 20 GeV

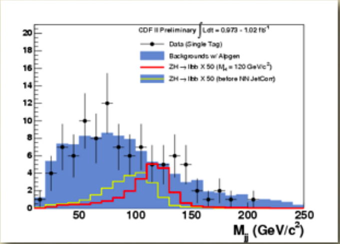
Jet 1 :
- $\phi = \pi/2$
- E_T = 85 GeV
- η = 1.0

Jet 2 :
- $\phi = \pi$
- E_T = 45 GeV
- η = 1.0



Resulting M_{jj} improvement





M_{JJ} one b-tag data

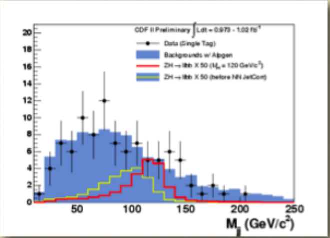
- **Validation using Z+jets data before b-tag**
  - **Compare jet energies, dijet mass, MET distribution**
  - **Energy resolution verified by balancing dijet recoil against Z boson**

- **For events w/ two b-tags, dijet mass resolution improves from 18% to 11%**

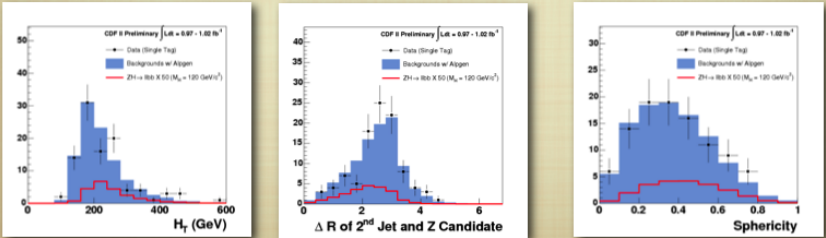
Separating Higgs from background

Multivariate Higgs identification

- Dijet mass is good discriminant but not best

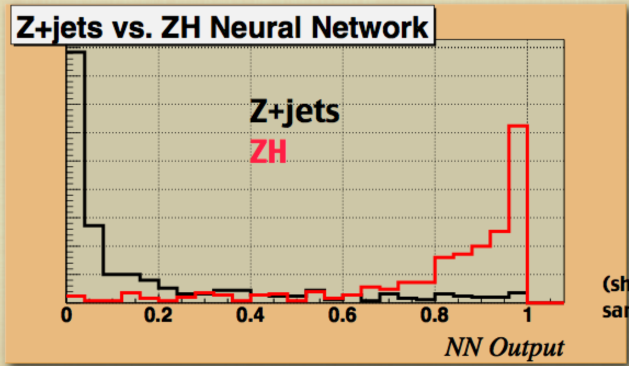


- Better to use **multiple distributions** which all separate signal from background



Separate ZH from Z+jets

- NN Network trained to distinguish Z+jets and ZH

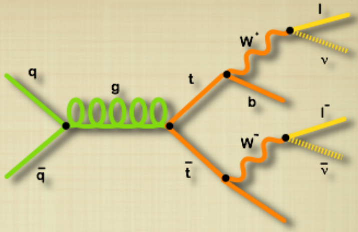


(shown with same area)

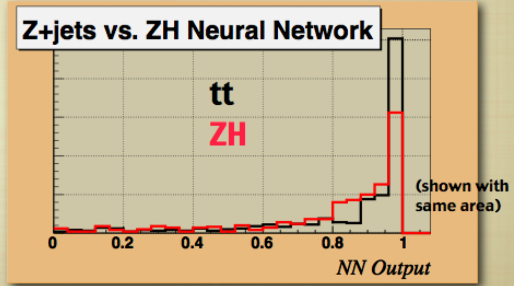
Separation much better than dijet mass alone

The top problem

- Two leptons, two b quarks, two neutrinos
  - Neutrinos may decay back to back
  - High sum E_T events

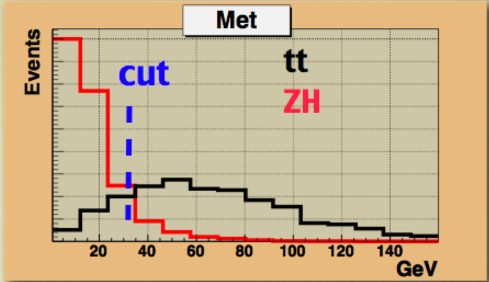


- tt looks more like ZH than ZH does !
- tt is 20% of background in 2-tag data
- 10 times the size of ZH

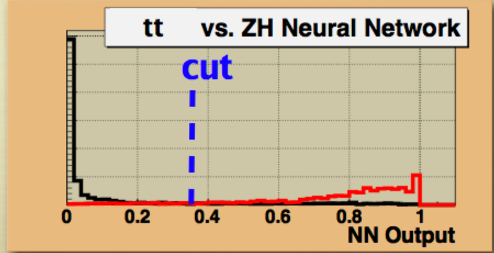


How to reject top

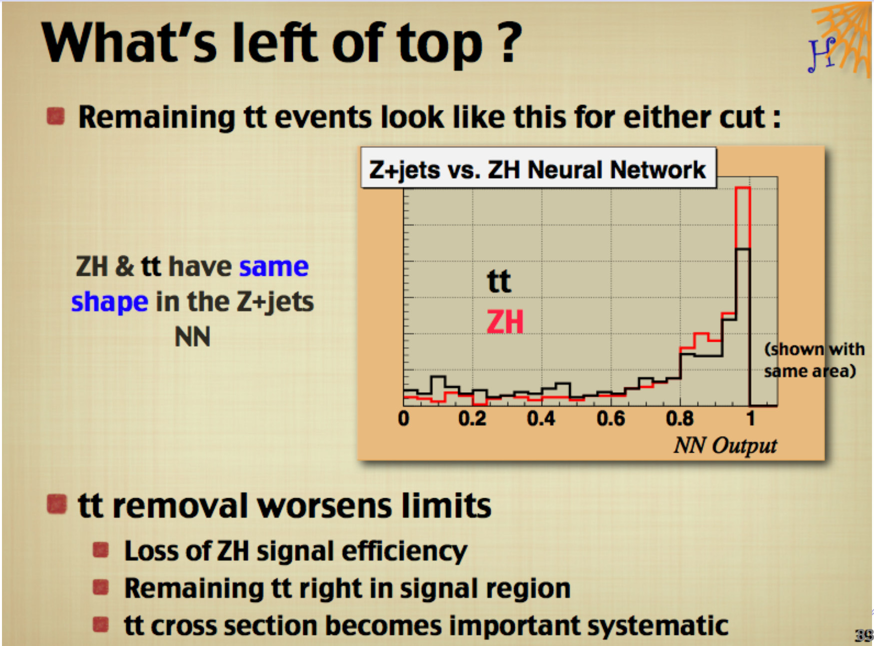
- Remove events with MET > 33 GeV
  - Rejects 80% tt
  - Rejects only 10% ZH



- Train NN to separate ZH vs tt
  - Rejects 80% tt
  - Rejects only 5 % ZH



Higgs Search

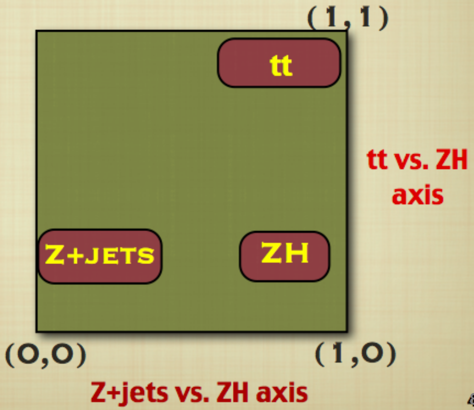


Can Z+jets and tt be separated simultaneously ?

- Signal / Background discriminant with Two outputs

2D NN

✦ Training: Z+bb, tt, ZH



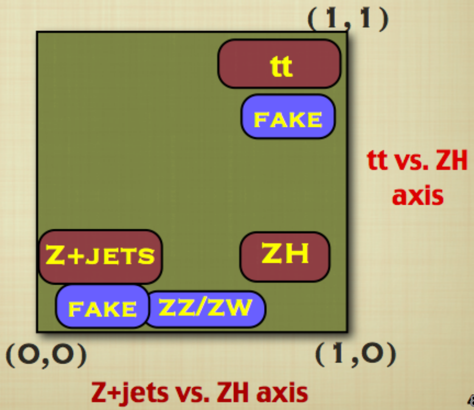
Can Z+jets and tt be separated simultaneously ?

- Signal / Background discriminant with Two outputs

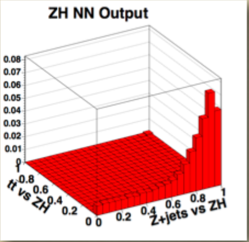
2D NN

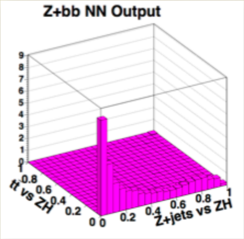
✦ Training: Z+bb, tt, ZH

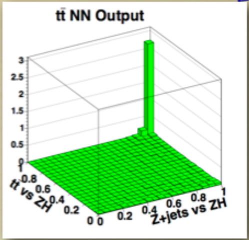
✦ Shapes generated in 2D plane also for fakes, Z +mistag, Z+cc, ZZ, ZW



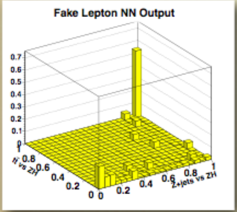
NN output for ZH well separated from Z+bb and tt

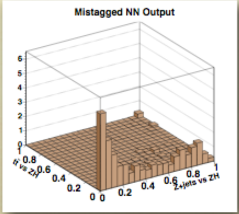


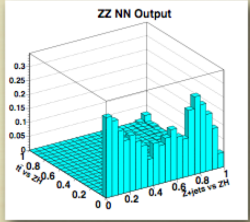




NN outputs determined from data





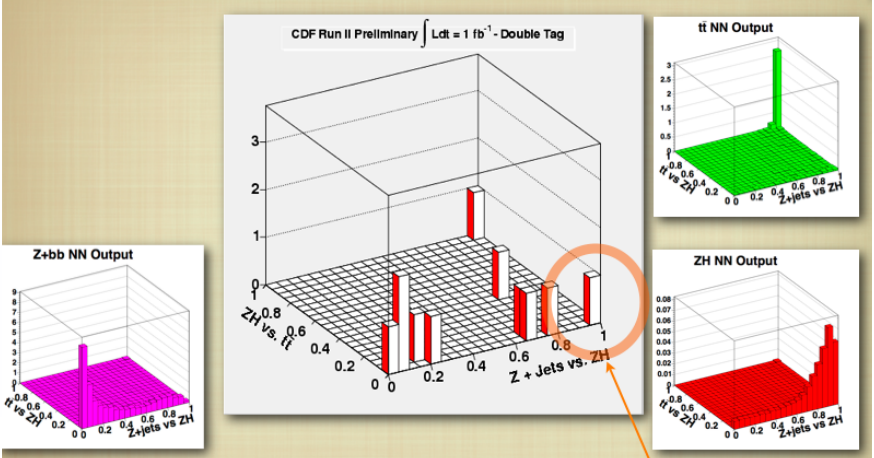


Fake Z's well separated

ZZ →llbb has shape most similar to ZH

Higgs Search

Signal region : events with two b-tags



Expected : 12.8 ± 3.5
Data : 11 events

Higgs Search

Remember, we started with 5: 100,000,000,000,000

IN BEST NN BIN WITH TWO TAGS

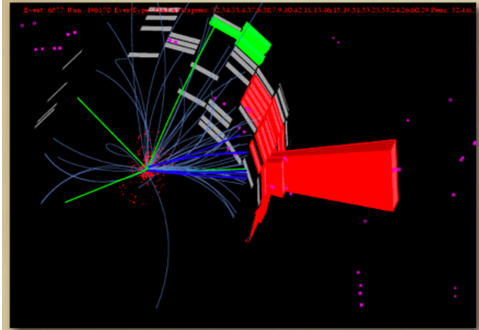
Higgs events : Everything else

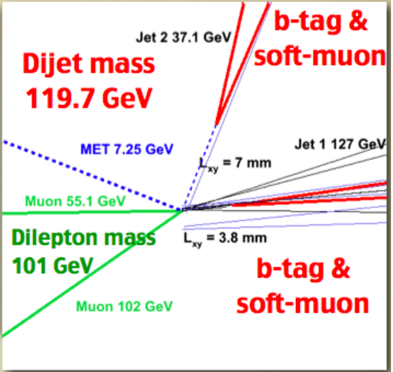
in most signal-like bin 0.042 : 0.18

Higgs Search

Higgs candidate S:B = 1:4

RUN 196170 EVENT 6577





Background in this bin

60% Z+bb
11% tt
9% Z+cc
9% ZZ
5% Z+qq (light)

Higgs ~ 2 times tt

Putting it all together

- We search for ZH contribution in all bins of 2D NN output in 1 b-tag and 2 b-tag data

CDF II Preliminary, 1fb^{-1}

1 fb^{-1} dataset	Events with 1-tag	Events with 2-tags
Expected (w/ no SM Higgs)	101.6 ±17.8	12.8 ± 3.5
Data	100	11
SM Higgs Signal	0.5	0.2

Putting it all together

- **We search for ZH contribution in all bins of 2D NN output in 1 b-tag and 2 b-tag data**

CDF II Preliminary, 1fb^{-1}

1 fb^{-1} dataset	Events with 1-tag	Events with 2-tags
Expected (w/ no SM Higgs)	101.6 ±17.8	12.8 ± 3.5
Data	100	11
SM Higgs Signal	0.5	0.2

We currently observe no significant excess

Putting it all together

- No significant excess with 1 fb^{-1}
- We proceed to fit all bins of 2D NN data output for the maximum ZH cross-section contribution
  - So-called "upper limit"
  - One-tag and two-tag samples fit independently
  - Use Monte Carlo shapes for ZH, tt, Z+bb, Z+cc, ZZ, ZW
  - Use Data shapes for Fake Z, Z+fake b-jets
- Fit code called "mclimit" (from Tom Junk)
  - Produces upper limit of σ_{ZH} in data
  - Produces expected limits by fitting pseudo-data from background-only model
  - Fit code handles both correlated and uncorrelated systematics

Systematic uncertainties

Results in 14% increase in expected limit

- Largest systematic uncertainties are those which affect signal acceptance
  - 12% from b-tag efficiency uncertainty (from difference between Monte Carlo and data)
    - Uncertainty per jet: hurts two-tag sample more
  - 7% from luminosity uncertainty
- Next largest systematic
  - 6% due to 40% uncertainty on Z+bb and Z+cc
- Other systematic uncertainties considered – small
  - Jet energy scale (acceptance & shape change)
  - Fake b-tag rate
  - ZZ, ZW, tt cross-section
  - Z+jets MC generator (shape change)
  - Parton distribution functions & initial/final state radiation (acceptance & shape change)
  - Lepton ID
  - Charm tagging efficiency

Results

- 95% CL upper limits on $\sigma_{ZH} \bullet BR(H \to bb)$ for m_H = 115 GeV

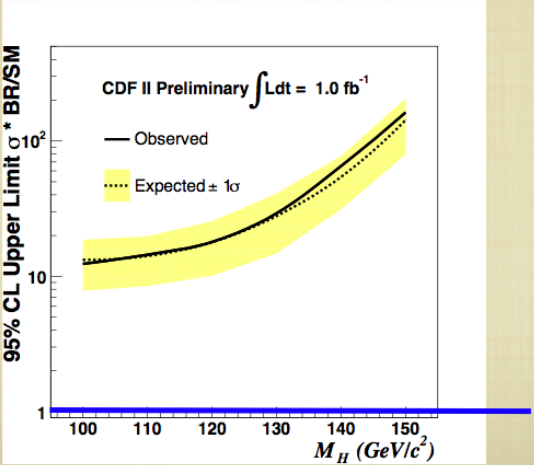
Limits CDF II Preliminary, 1fb^{-1}

1 fb^{-1} dataset	1-tag	2-tags	Combined
Observed (expected)	2.3 pb (2.2 pb)	1.9 pb (1.8 pb)	1.3 pb (1.3 pb)
As ratio of upper limit / SM expected cross-section	28 (27)	23 (22)	16 (16)

Higgs Search

Limit as a function of mass

- 95% CL upper limits on Higgs cross-section



σ/SM = 1

means 95% exclusion or ~2 σ evidence

In perspective

- **Compare 95% CL upper limit to other CDF channels**

Limits CDF II Preliminary, 1fb^{-1}

m_H = 115 GeV	ZH → llbb	ZH → vvbb	WH → lvbb	H → WW
$\sigma_{U.L.}$ @ 95% CL observed (expected)	16 * SM (16)	22 * SM (14)	26 * SM (17)	>50 * SM (>50)°

°For m_H = 160 GeV, H → WW is 3.4*SM (4.8)

ZH → llbb is most sensitive CDF channel at m_H = 115 GeV

- **Combined 1 fb^{-1} CDF expected limit is ~9*SM**
  - **Ideas used in this channel will also improve other channels**
  - **All analyses will update with improvements and more data**

Future for ZH → llbb

- More data
  - Statistical scaling alone :

    Limit would be 5 times SM with 8 fb^{-1}
- However, CDF has many other improvements in progress
  - These can also be applied to other Higgs channels
    1. Increased b-tagging
    2. New lepton categories
    3. Looser lepton categories
    4. Tau lepton channels
    5. Specialized & secondary triggers
    6. Further jet energy resolution improvements
    7. Matrix element discriminants incorporated
    8. Reduction of systematic uncertainties
- Each factor is incremental, but :
  - for instance, $1.25^8 = 6$, taking CDF ZH → llbb to 2 times SM

Conclusions

- **Retained as much signal as possible**
  - **Looser lepton selection gave us 1.7 times data equivalent**
  - **Splitting 1-tag and 2-tag data gave us 1.5 * X**
- **Narrowed Higgs resonance compared to backgrounds**
  - **Improving M_{jj} resolution gave us 1.3 * X**
- **Used multivariate approach to get best signal separation from background**
  - **Using 2-D Neural Network gave us 2 * X**
- **All together, gained a factor 7 times more data**

Many other improvements and more data coming later this year

Combined with similar improvements to other channels (work ongoing), we're going to be close to finding the Higgs at the Tevatron !

Anouncements

Backup

BACKUP

BMU Reconstruction Efficiencies for bhmu0i

bhmu0i period 9

- Run range 222529 - 228596
- Integrated Luminosity
  $L_{int}{}^{CMUP,BMU} = 164\ pb^{-1}$
  $L_{int}{}^{CMX,BMU} = 159\ pb^{-1}$
- MC Phytia zewkcm (6.1.4)

bhmu0i period 10

- Run range 228664 - 233111
- Integrated Luminosity
  $L_{int}{}^{CMUP,BMU} = 262\ pb^{-1}$
  $L_{int}{}^{CMX,BMU} = 268\ pb^{-1}$
- MC Phytia zewkdm (6.1.4)