B-Physics Prospects at the Tevatron Run-II

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Weak Interactions and Neutrinos
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Talk outline

- B-Physics goals
- Run II environment
  - Tevatron status
  - Detector status
- B-Physics triggers
- $\sin(2\beta)$
- $\sin(2\alpha)$
- $\sin\gamma$
- $B_s^0 - \bar{B}_s^0$ mixing
- CP violation in B_s^0
- B_c^+ physics
- Rare B decays
- Conclusion

Run II B-Physics goals

- **Precise Measurement of $|V_{td}/V_{ts}|$**
  -($\star$) B_s^0 - $\bar{B}_s^0$ flavor oscillations (also $\Delta\Gamma_s/\Gamma_s$)
  - Radiative decays:
  e.g. $B_s^0 \to K^{*0}\gamma$ vs. $B_s^0 \to \phi\gamma$ ($\star$)

- **Make competative measurements of β and α**

  { $\sin 2\beta$ **using** $B^0 \to J/\psi K_s$

  { $\sin 2\alpha$ **using** $B^0 \to \pi^+\pi^-$

- **Reconstruction of decay modes related to angle γ:**
  $B_s^0 \to D_s^{\pm}K^{\mp}$ ($\star$) **and** $B^+ \to \bar{D}^0 K^+$

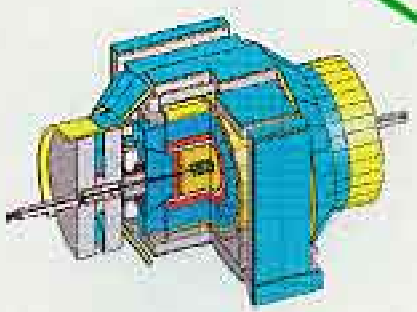
- ($\star$) **Search for CP violation in $B_s^0/\bar{B}_s^0 \to J/\psi\phi$**
  Unambiguous signal of physics beyond SM

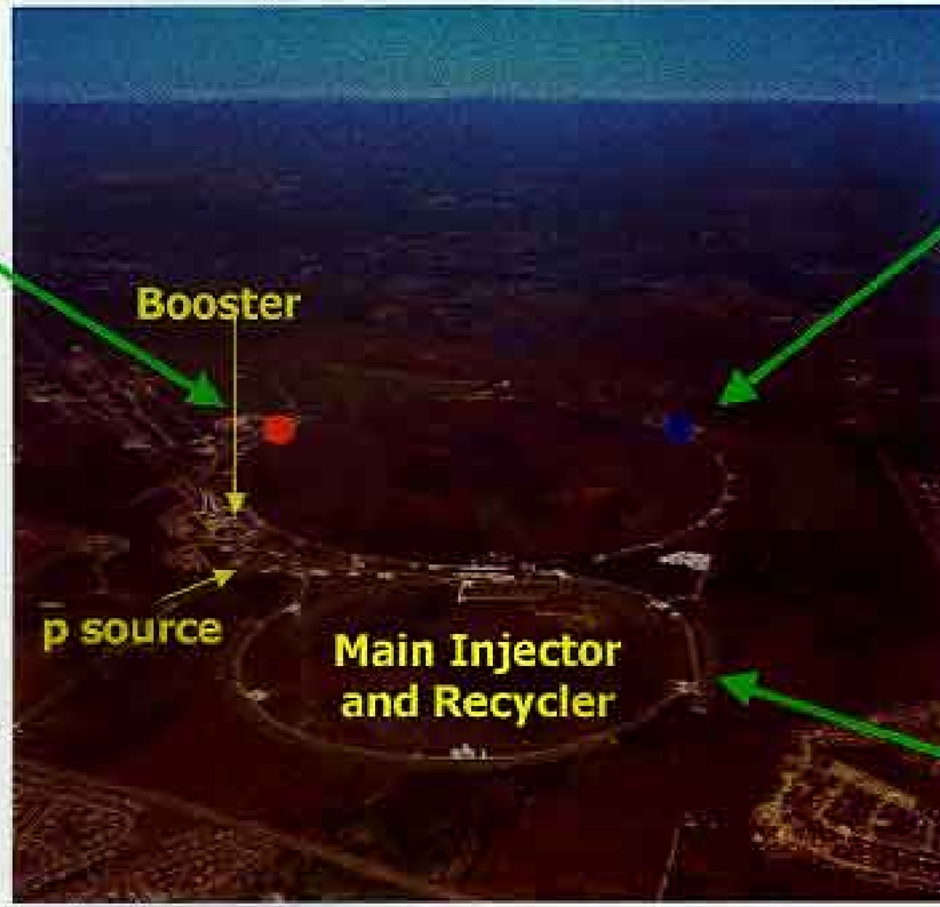
- **Observe $B^+ \to \mu^+\mu^- K^+$, $B^0 \to \mu^+\mu^- K^{*0}$,**
  $B_s^0 \to \mu^+\mu^-\phi$ ($\star$)

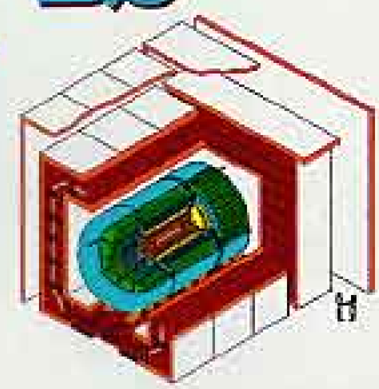
- ($\star$) **Study B_c^+ meson and b baryons**

($\star$) **Unique to Tevatron**

What's New at Fermilab?







CDF Run 2 Collaboration

North America

- 3 Natl. Labs, 25 Universities
- 2 Universities

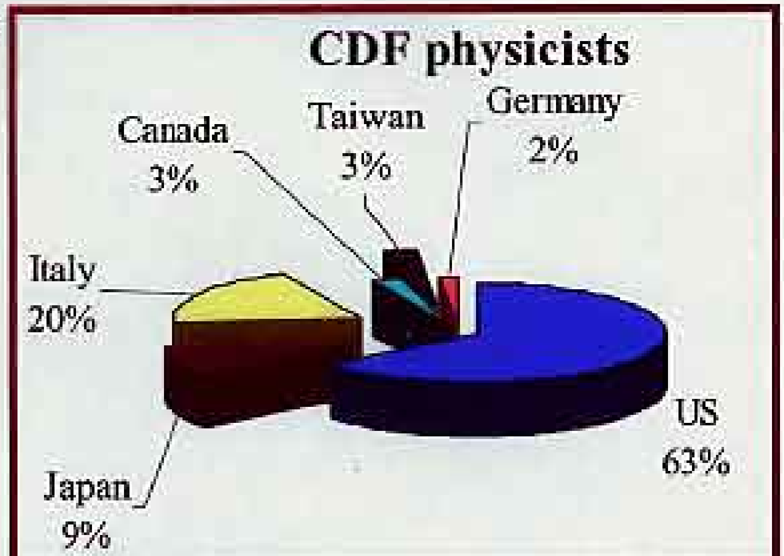
Europe

- 1 Research Lab, 6 Universities
- 1 University
- 4 Universities
- 2 Research Labs
- 1 University
- 1 University

Asia

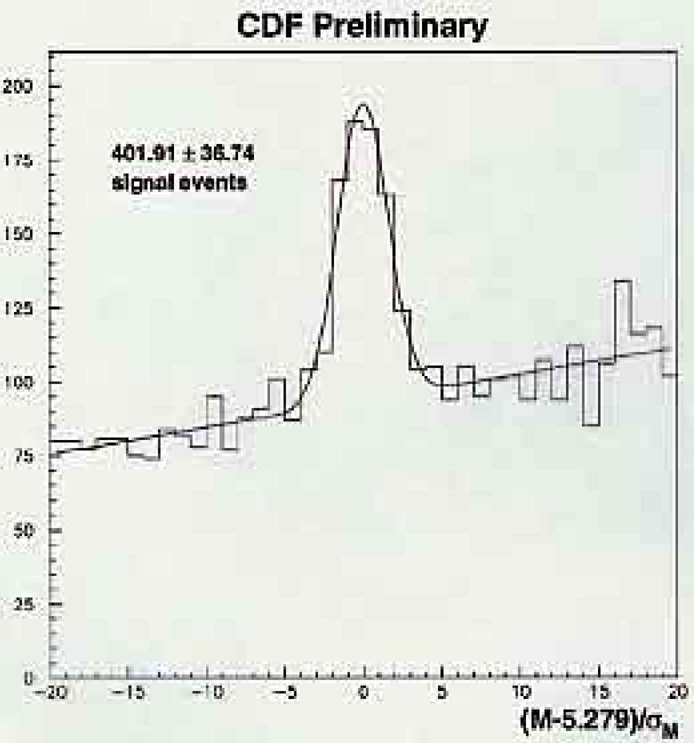
- 1 Research Lab, 4 Universities
- 1 University
- 1 University consortium

➤ **11 countries**
- 52 institutions
- 525 physicists
- 140 students:
  - More than 195 theses since 1985

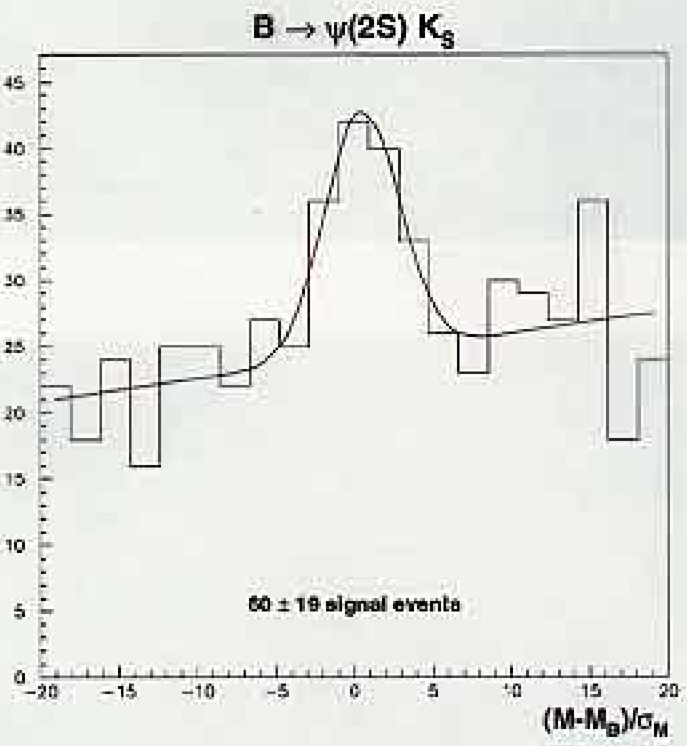


$B^0 \to J/\psi K_s^0, J/\psi \to \mu^+\mu^-, K_s^0 \to \pi^+\pi^-$

Run I, CDF



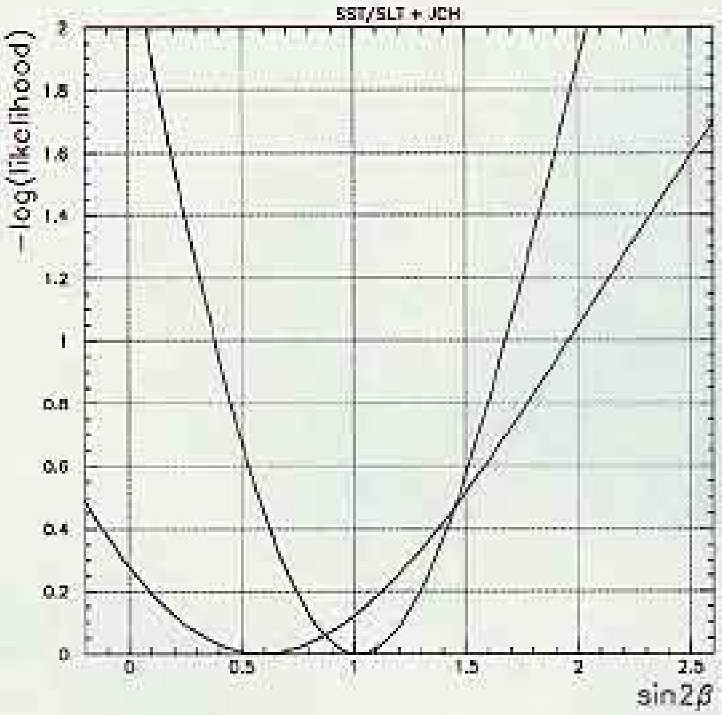
- $B^0 \to J/\psi K_s^0$
- 402±37 events

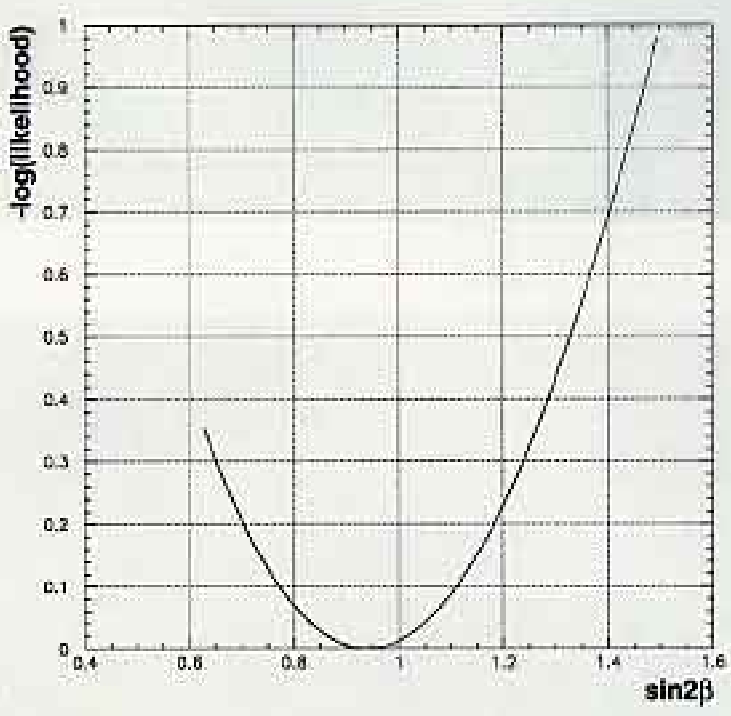


- $B^0 \to \psi(2S) K_s^0$
- 60±19 events

Log-likelihood functions

Run I, CDF

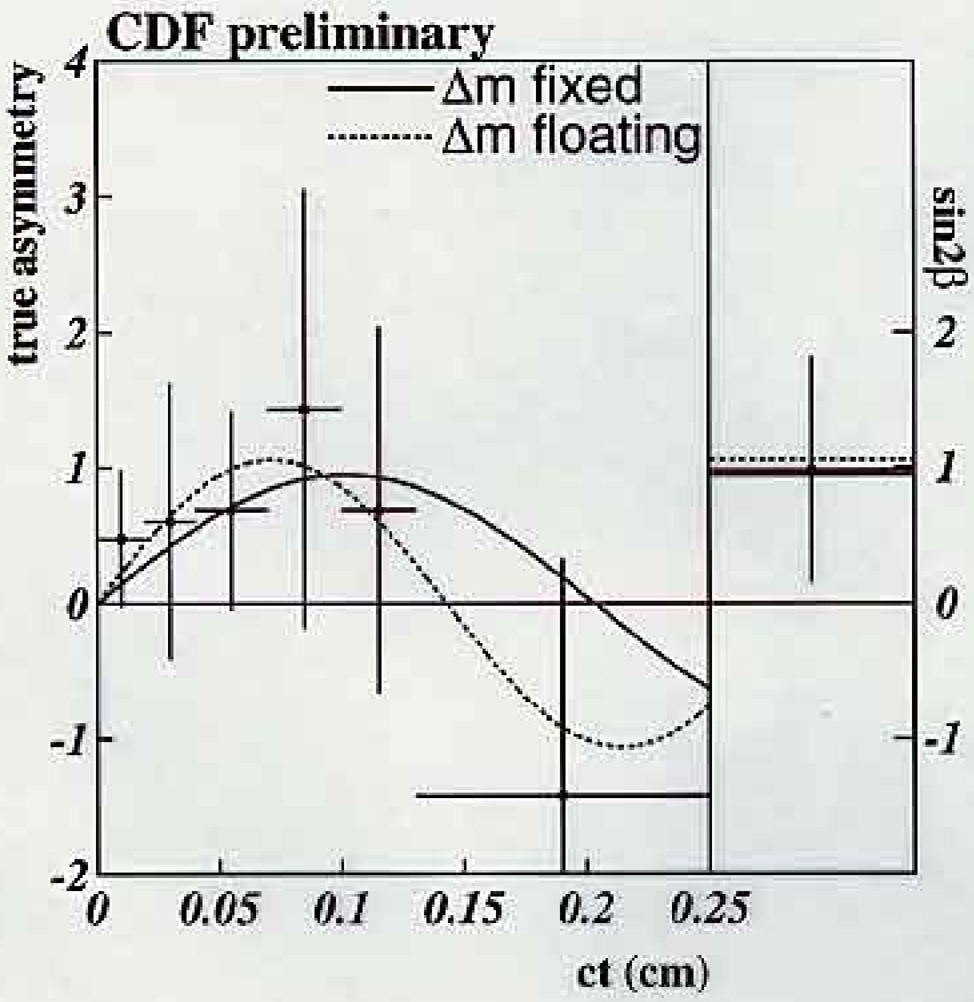




improved the opposite-side-jet tag by adding jet-kinematics tags and a kaon dE/dx tag to the jet-charge tag

sin(2β)

Run I, CDF

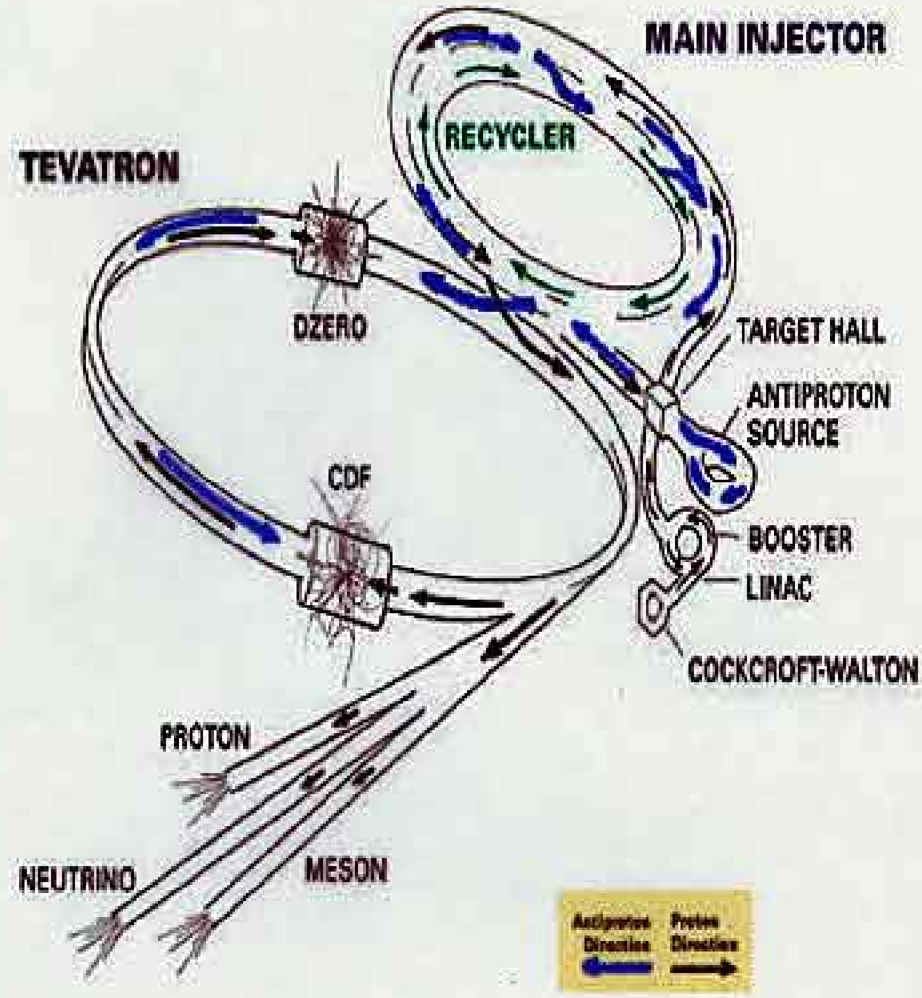


- **sin(2β)= 0.91 $\pm$ 0.32 (stat) $\pm$ 0.18 (sys)**

$$= 0.91^{+0.37}_{-0.36}$$

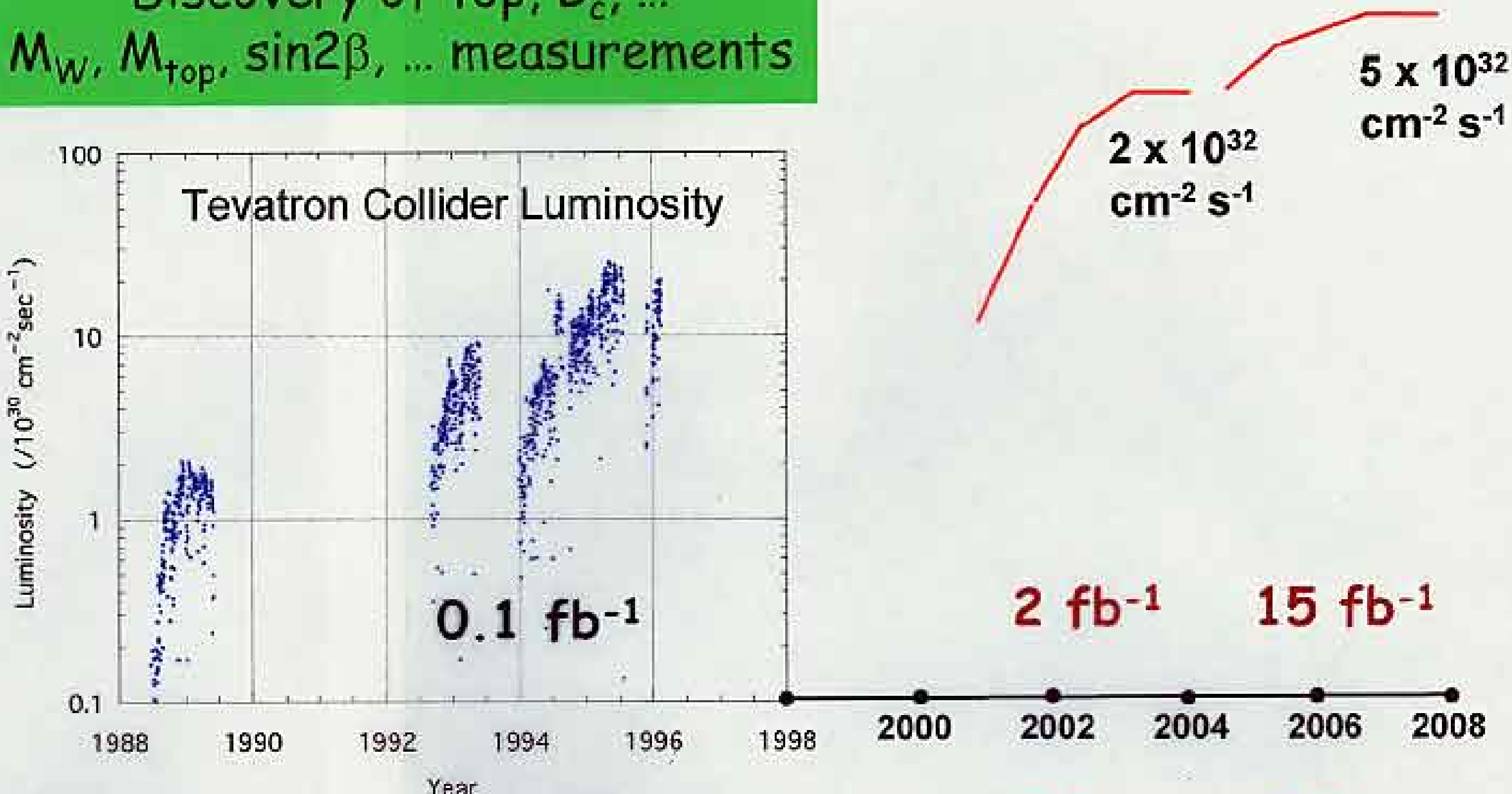
The Fermilab Accelerator Complex

- Main Injector (150 GeV proton storage ring) replaces Main Ring (the original Fermilab accelerator).
- Completely revamped stochastic cooling system for p-bars.
- A new permanent magnet Recycler storage ring for p-bars.
- Increased number of p and p-bar bunches :
  6 → 36 (396 ns) → ~100 (132 ns)
- Higher energy collisions :
  900 → 980 GeV



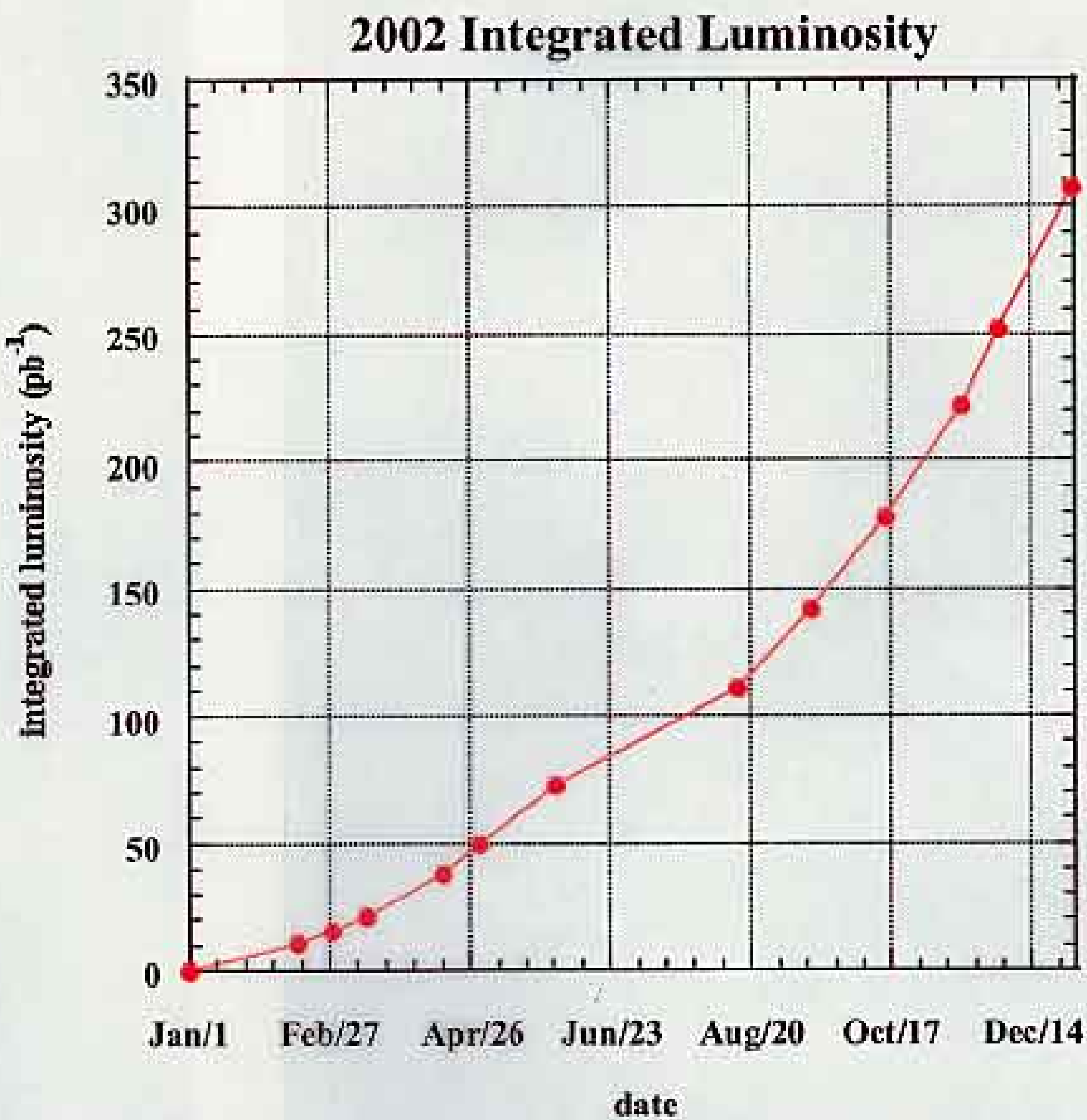
Tevatron History and Future

Discovery of top, B_c, ...
M_W, M_{top}, $\sin 2\beta$, ... measurements

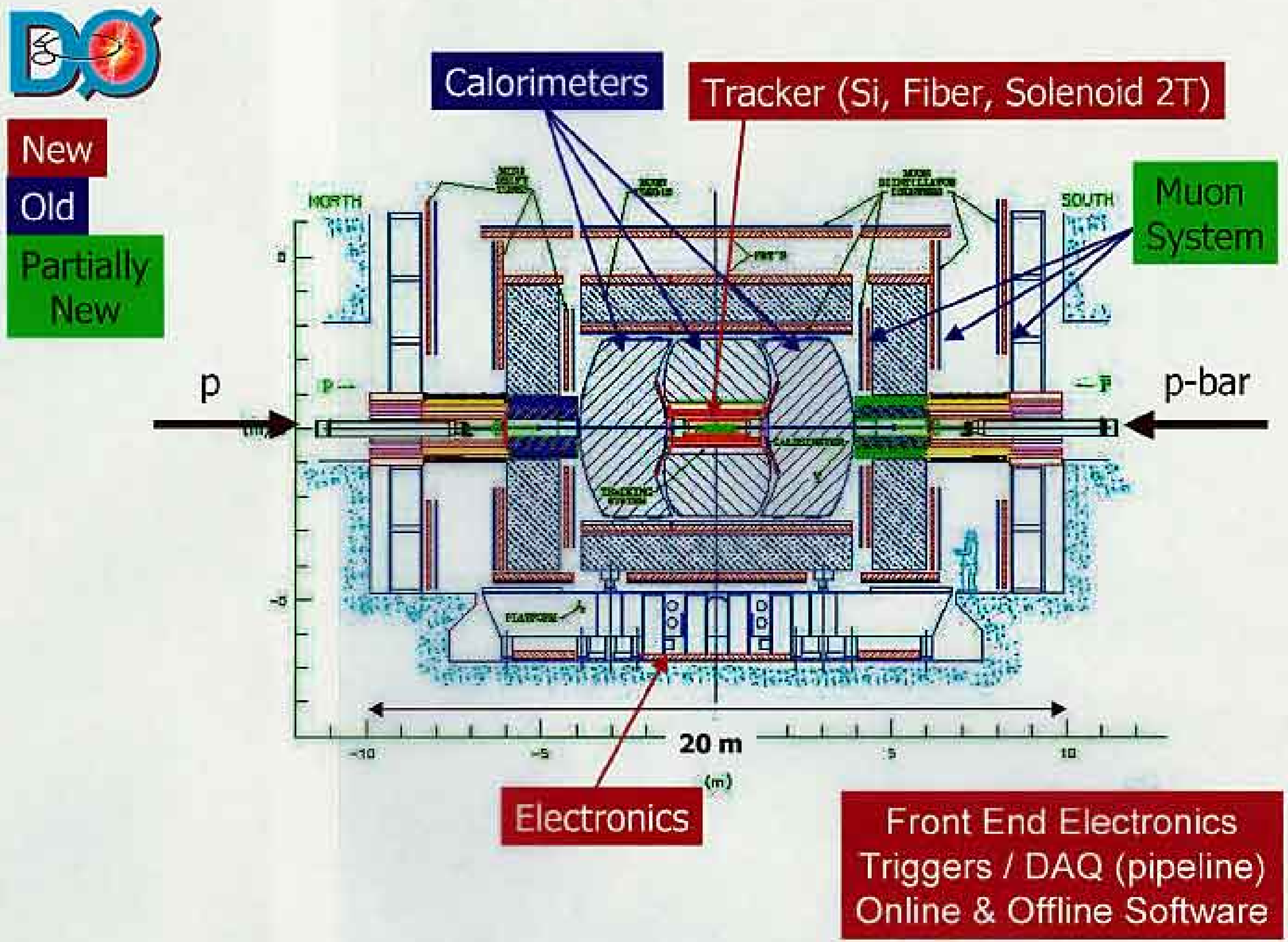


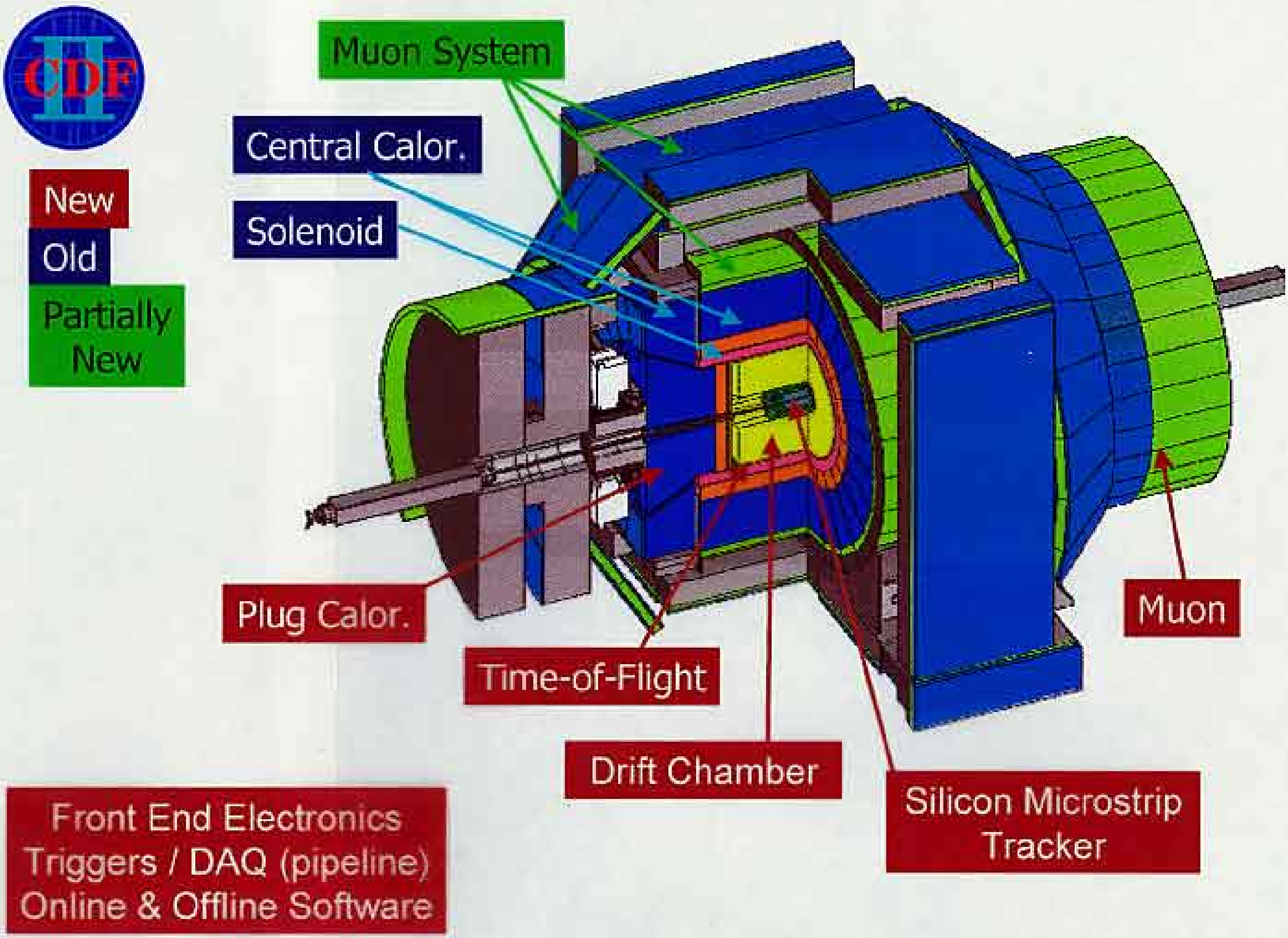
Run : 0 Ia Ib IIa IIb

$\sqrt{s}$: 1.8 TeV 1.96 TeV


2002 Integrated Luminosity
350
300
250
200
150
100
50
0
integrated luminosity (pb^{-1})
Jan/1
Feb/27
Apr/26
Jun/23
Aug/20
Oct/17
Dec/14
date

max stackrate (E10/hr)	store time (hr)	stack (E10)	pbar extraction eff.	pb/bunch (E9)	peak lum. (E31)	protons/bunch (E9)	downtime fraction	shot setup time (hrs)	studies/week (shifts)	stores/wk	pbar transfer eff.		store int. lum. (pb^{-1})	weekly int. lum. (pb^{-1})	6 month int. lum. (pb^{-1})	Note #	store hours/week	% improvement in int. lum.	calculated emittances (proton ϵ_h,ϵ_v pbar ϵ_h,ϵ_v)	Projected completion date	integrated luminosity from 1/1/02 (pb^{-1})	Performance milestone
10.0	20.0	109	0.82	7.2	0.75	128	0.30	3.0	5	3.43	0.29	pre-Fall '01 shutdown	0.38	1.37	29	1	68.6		20.5;18.4	09/24/01		
10.0	20.0	105	0.90	6.9	1.10	120	0.30	3.0	5	3.43	0.26	best initial luminosity: store 858 on 12/22/01	0.48	1.65	35	2	68.6	20	15.4;10.3	01/01/02	0.0	
10.0	20.0	120	0.90	9.0	1.77	150	0.30	3.0	5	3.43	0.30	increase proton intensity	0.73	2.53	53	3	68.6	53	15.4;10.3	02/15/02	10.6	1
10.0	20.0	120	0.90	12.0	1.97	150	0.30	3.0	5	3.43	0.40	improve MI-->Tev pbar xfer efficiency	0.86	2.96	62	4	68.6	17	15.4;15.3	03/01/02	15.7	
10.0	20.0	120	0.90	15.0	2.46	150	0.30	3.0	5	3.43	0.50	improve 8 GeV pbar transport	1.07	3.67	77	5	68.6	24	15.4;15.3	03/15/02	21.6	2
10.0	20.0	120	0.90	18.0	2.95	150	0.30	3.0	5	3.43	0.60	reduce Acc. core heating	1.27	4.38	92	6	68.6	19	15.4;15.3	04/15/02	37.9	
10.0	20.0	120	0.90	21.0	3.44	150	0.30	3.0	5	3.43	0.70	improve pbar coalescing	1.48	5.08	107	7	68.6	16	15.4;15.3	04/15/02	37.9	3
10.0	20.0	120	0.90	21.0	3.44	150	0.30	2.0	5	3.59	0.70	improve shot setup time	1.48	5.32	112	8	71.8	5	15.4;15.3	05/01/02	49.5	
10.0	20.0	120	0.90	21.0	3.93	200	0.30	2.0	5	3.59	0.70	further increase proton intensity	1.68	6.05	127	9	71.8	14	20.3;15.3	06/01/02	73.0	4
10.0	20.0	120	0.90	24.0	4.65	200	0.30	2.0	5	3.59	0.80	upgrade Acc. core cooling	1.93	6.95	146	10	71.8	15	20.3;15.3	08/15/02	111.1	5
10.0	20.0	120	0.90	24.0	4.65	200	0.20	2.0	5	4.35	0.80	reduce downtime	1.93	8.43	177	11	87.0	21	20.3;15.3	09/15/02	141.9	
10.0	20.0	120	0.90	24.0	5.82	250	0.20	2.0	5	4.35	0.80	further increase of proton intensity	2.26	9.87	207	12	87.0	17	20.3;15.3	10/15/02	178.0	6
12.0	20.0	160	0.90	32.0	7.75	250	0.20	2.0	5	4.35	0.80	improve Debuncher cooling	2.98	13.00	273	13	87.0	32	20.3;15.3	11/15/02	221.7	
16.0	20.0	160	0.90	32.0	7.75	250	0.20	2.0	5	4.35	0.80	increase pbar production repetition rate	2.98	13.00	273	14	87.0	0	20.3;15.3	12/01/02	251.4	7
18.0	14.0	165	0.90	33.0	8.64	270	0.20	1.0	5	6.38	0.80	increase AP2 aperture, reduce shot setup time, optimize store length, design proton intensity	2.61	16.75	352	15	89.3	29	20.3;15.3	12/31/02	307.2	8


New
Old
Partially New
Calorimeters
Tracker (Si, Fiber, Solenoid 2T)
Muon System
NORTH
SOUTH
p
p-bar
20 m
(m)
-10
-5
5
10
Electronics
Front End Electronics
Triggers / DAQ (pipeline)
Online & Offline Software

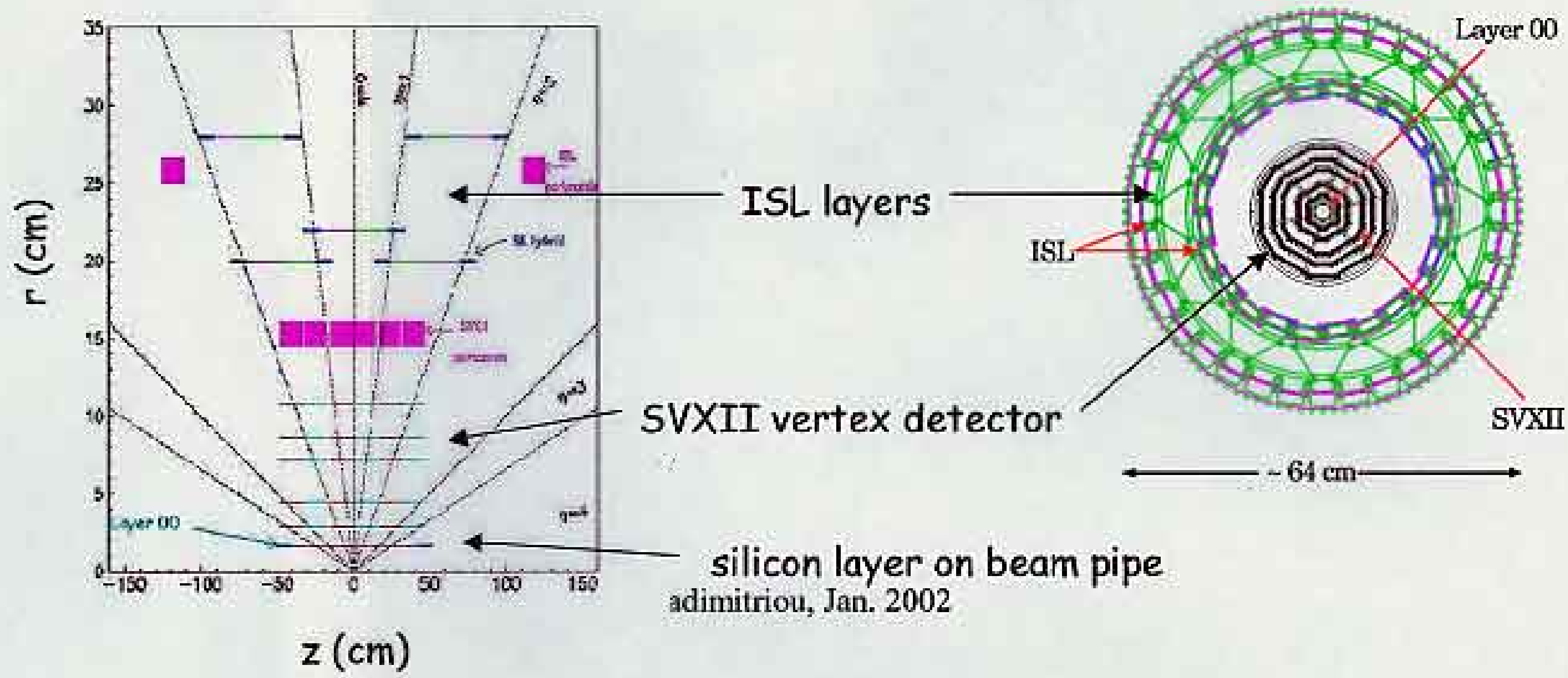


CDF II
New
Old
Partially New
Muon System
Central Calor.
Solenoid
Plug Calor.
Time-of-Flight
Drift Chamber
Silicon Microstrip Tracker
Muon
Front End Electronics
Triggers / DAQ (pipeline)
Online & Offline Software

Silicon Detector Upgrade

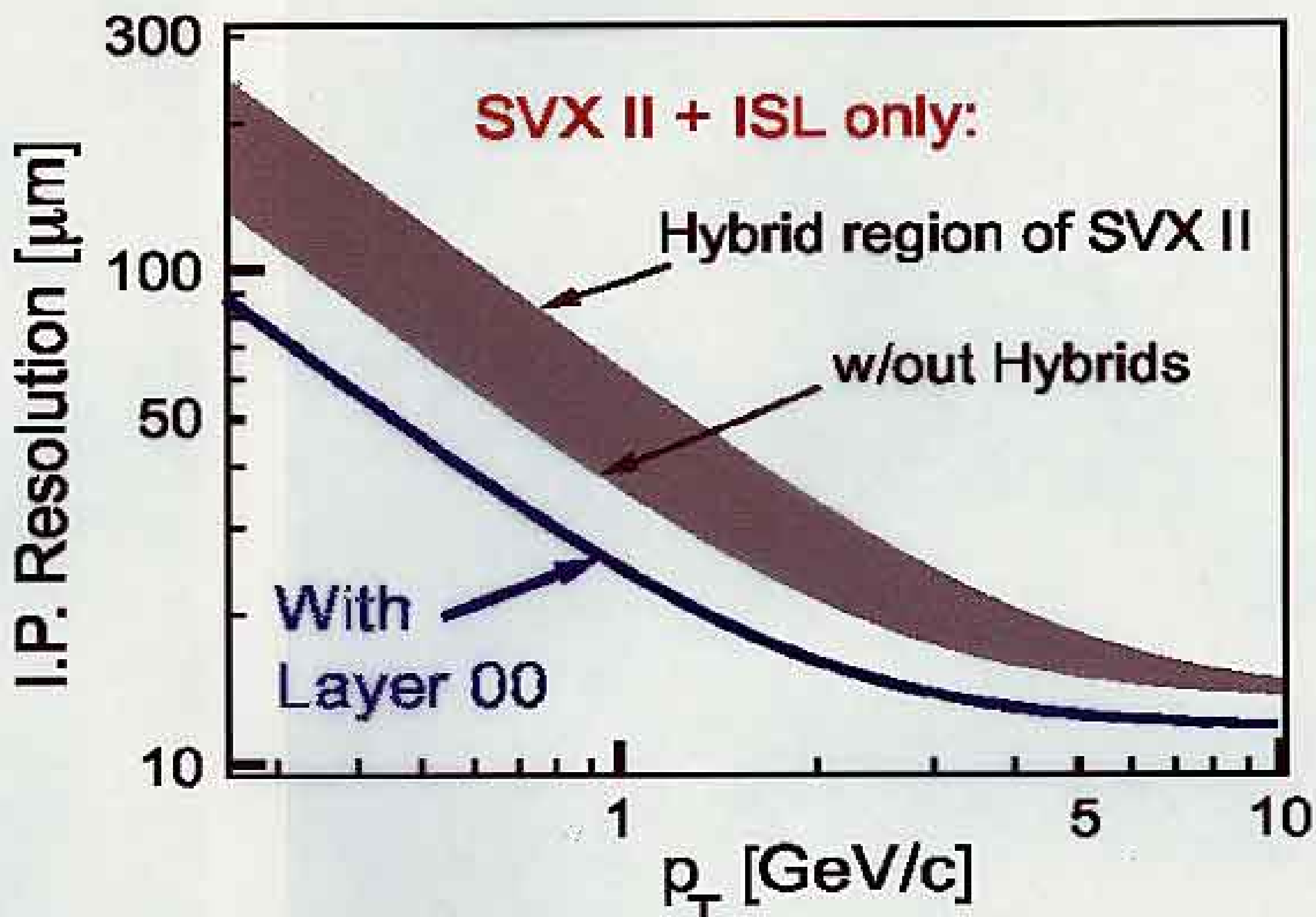
- The silicon strip detector is a stand-alone 3d tracking system
- A six layer vertex detector with impact parameter resolution

  $\sigma_d = \sqrt{a^2 + (b/P_t)^2}$ (a =7μm, b =20-30μm)
- Intermediate silicon layers for extrapolation to central outer tracker and forward tracking



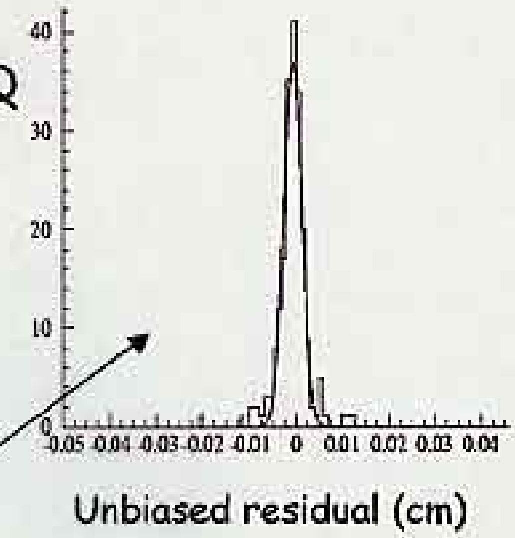
adimitriou, Jan. 2002

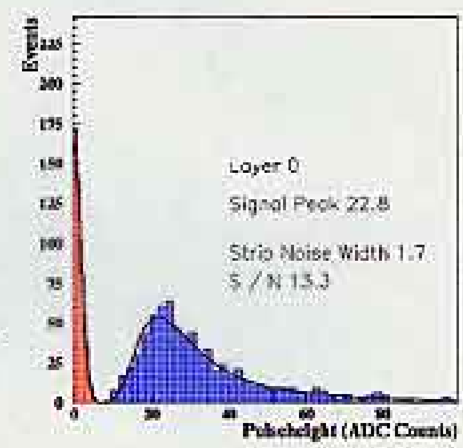
Impact Parameter Resolution



Silicon Tracking Status

- Silicon detectors are timed in and integrated with DAQ
- After October-November 2001 shutdown we have:
  - silicon layer on beam pipe being commissioned
  - > 90% of SVXII operational for tracking
  - ~ 60% of ISL ladders operational (cooling line blockages have been understood)
- Measured hit resolution $\sigma \sim 19\ \mu m$ before final alignment corrections
- Construction alignment tolerances for level 2 impact parameter trigger have been met
- Signal/noise as expected





CDF

B-Physics triggers

- **Level 1:** use lepton info + eXtremely Fast Tracker (XFT)
- **Level 2:** use Secondary Vertex Tracker (SVT) (find displaced tracks!)
- **Level 3:** develop smart algorithms to:
  - { find secondary vertex seeded by SVT track(s)
  - { (semi)exclusive B meson reconstruction

New trigger paths

- XFT, SVT, DAq: two displaced tracks (*e.g.* for $B^0 \to \pi^+\pi^-$, $B_s \to D_s\pi$)

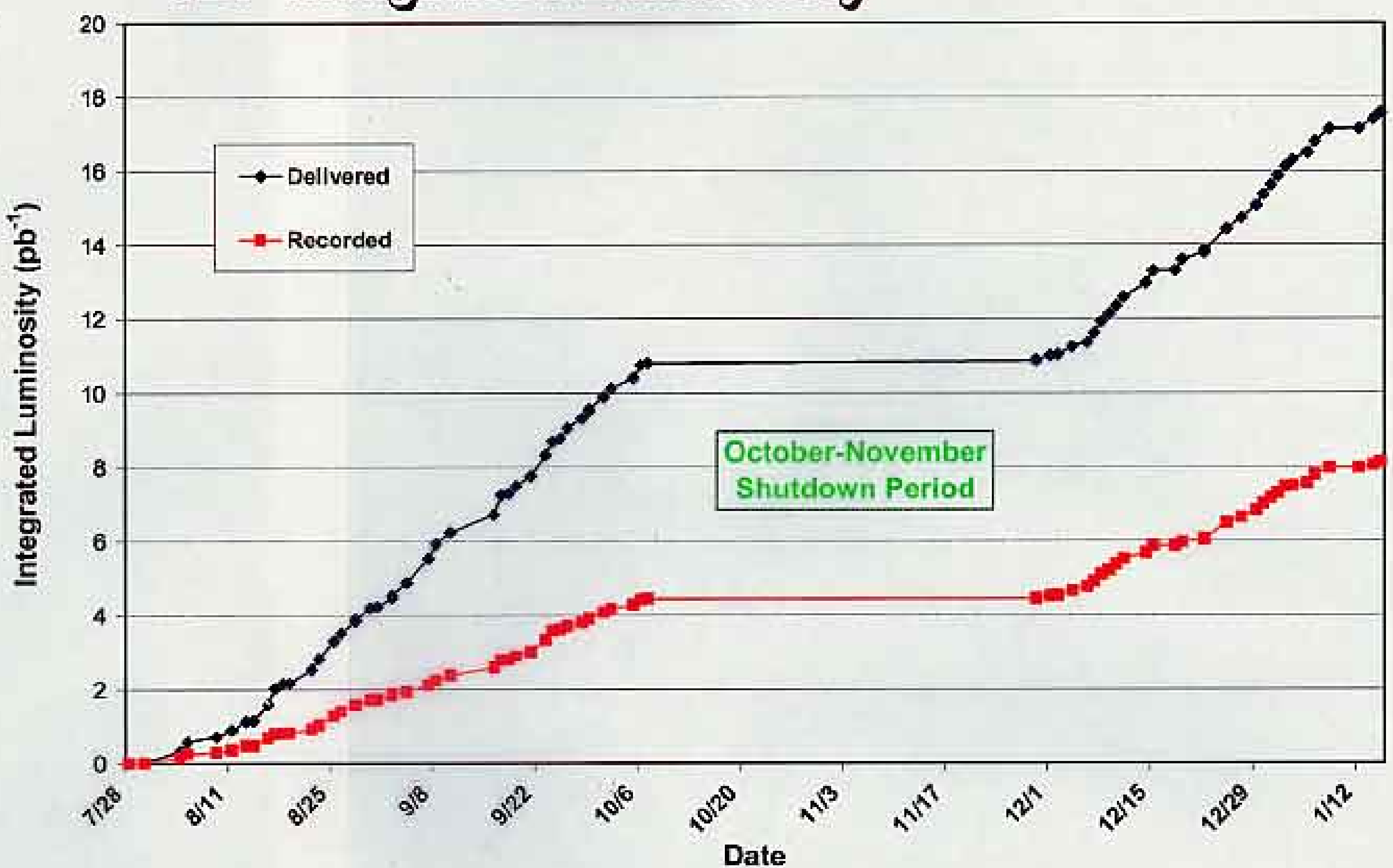
  $\Rightarrow$ [example of "offline" tagging]

- XFT, SVT: lepton $+$ displaced track(s) (*e.g.* $B_s \to D_s\pi$ with a flavor tag)

  $\Rightarrow$ [example of "tagging by the trigger"]

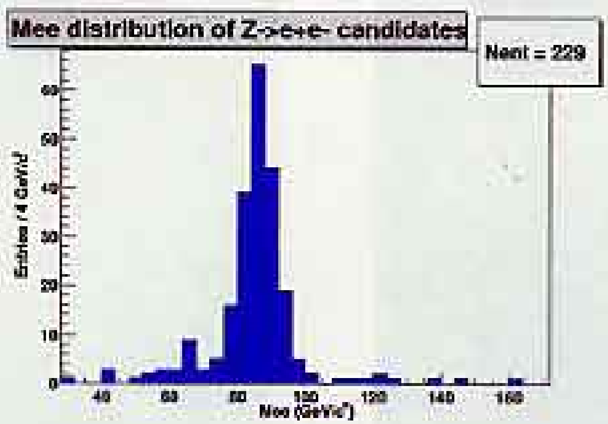
$\Rightarrow$ *Tag by the trigger wherever possible!*

CDF Integrated Luminosity (July 28, 2001 - January 15, 2002)

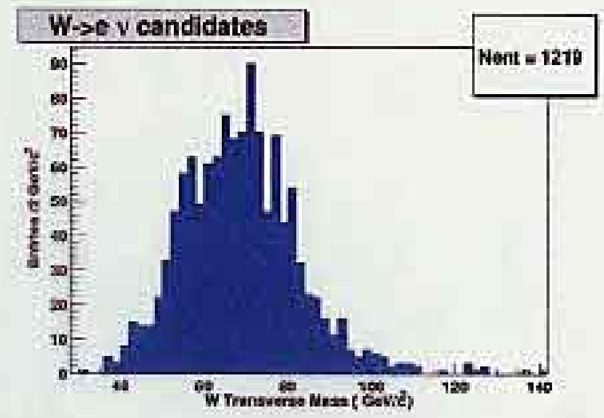


Calorimeter Data , CDF

$Z \to e^+ e^-$ invariant mass

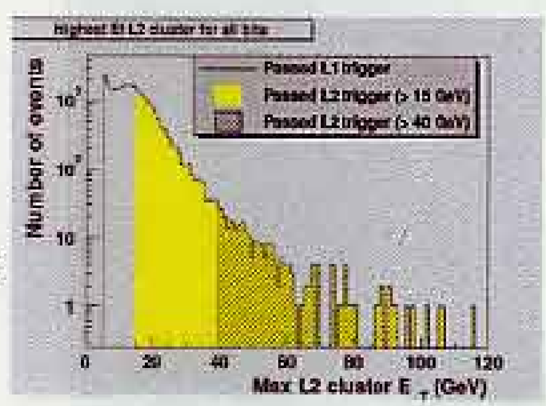


$W \to e \nu$ transverse mass

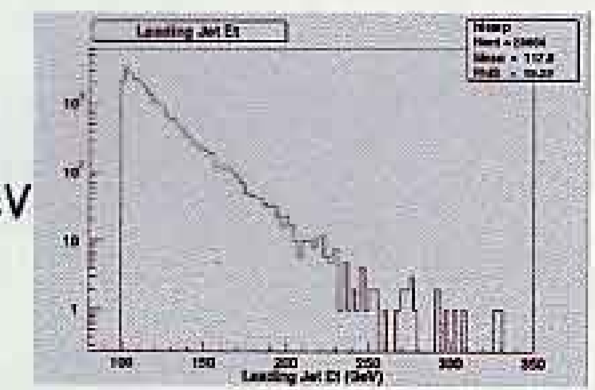


Jet selected with on-line triggers

Jets selection
with
Level 1 and 2 triggers



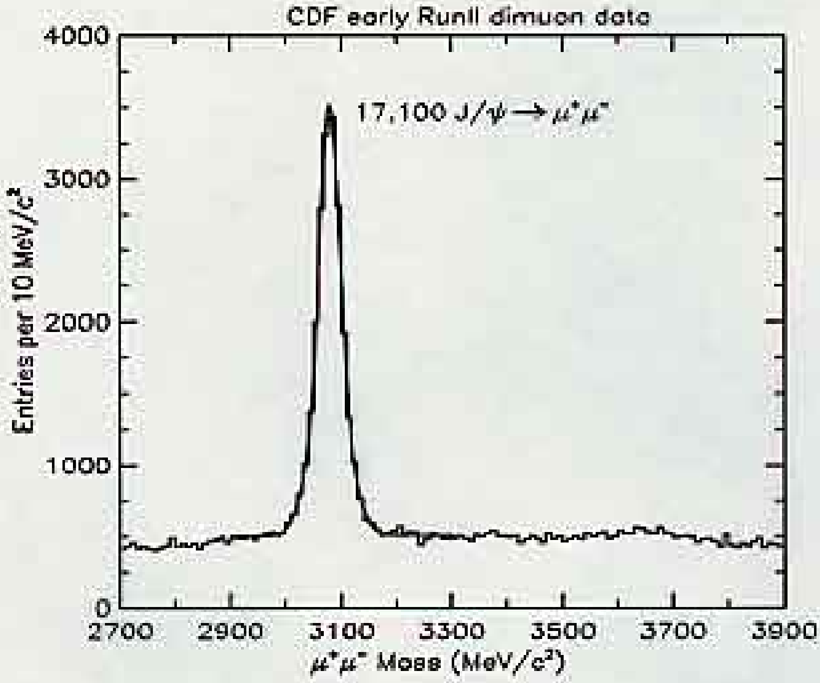
Level 3
$E_T > 100$ GeV



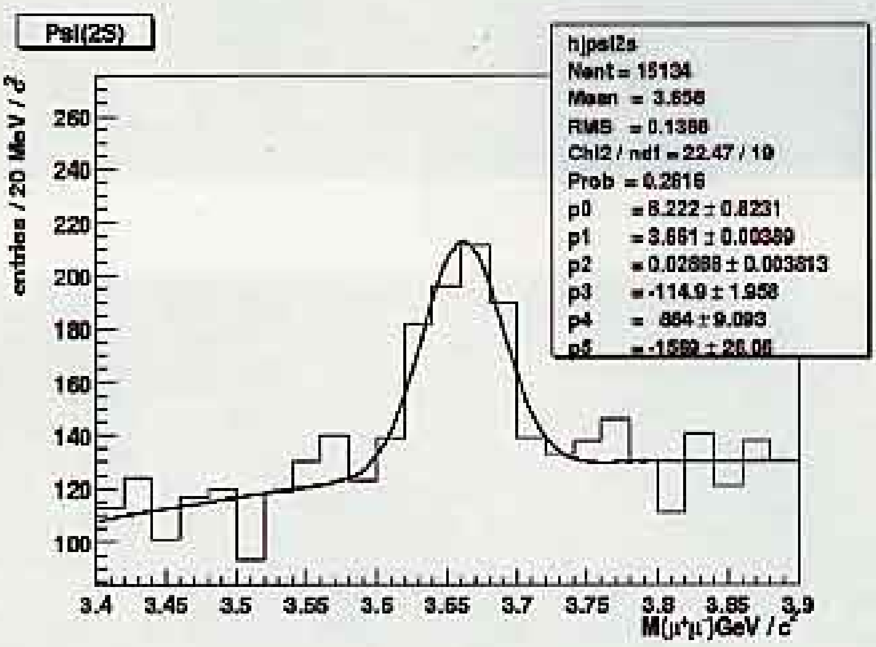
Nov. 2001

$J/\psi, \psi(2S) \to \mu^+\mu^-$

Run II, CDF



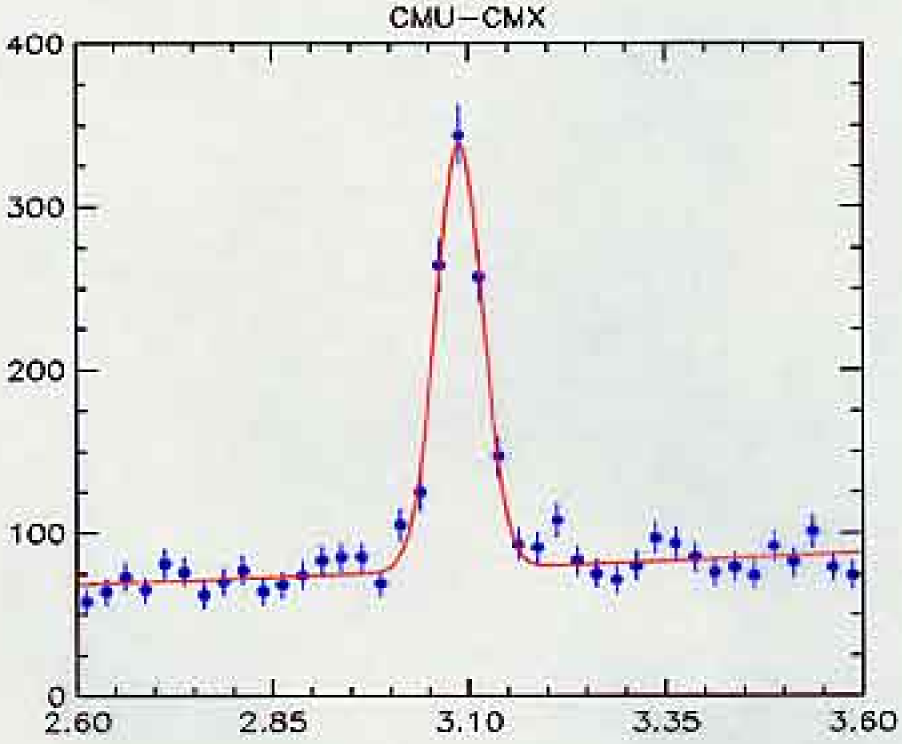
- **Two μ in CMU**
- **17100 events**



- **Two μ in CMU**

$J/\psi \to \mu^+\mu^-$

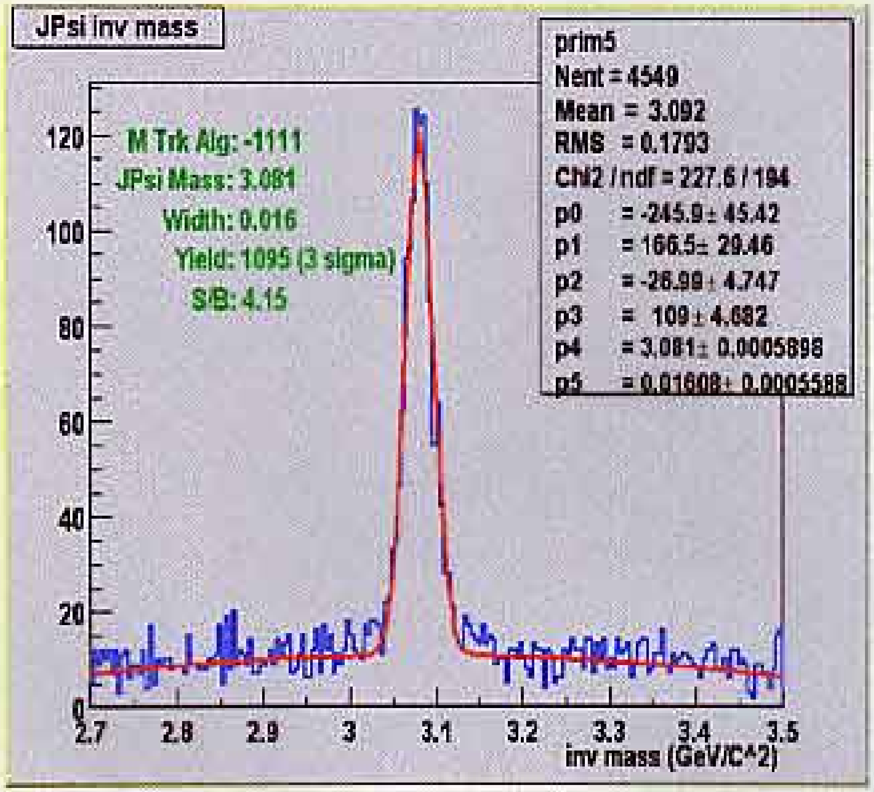
Run II, CDF



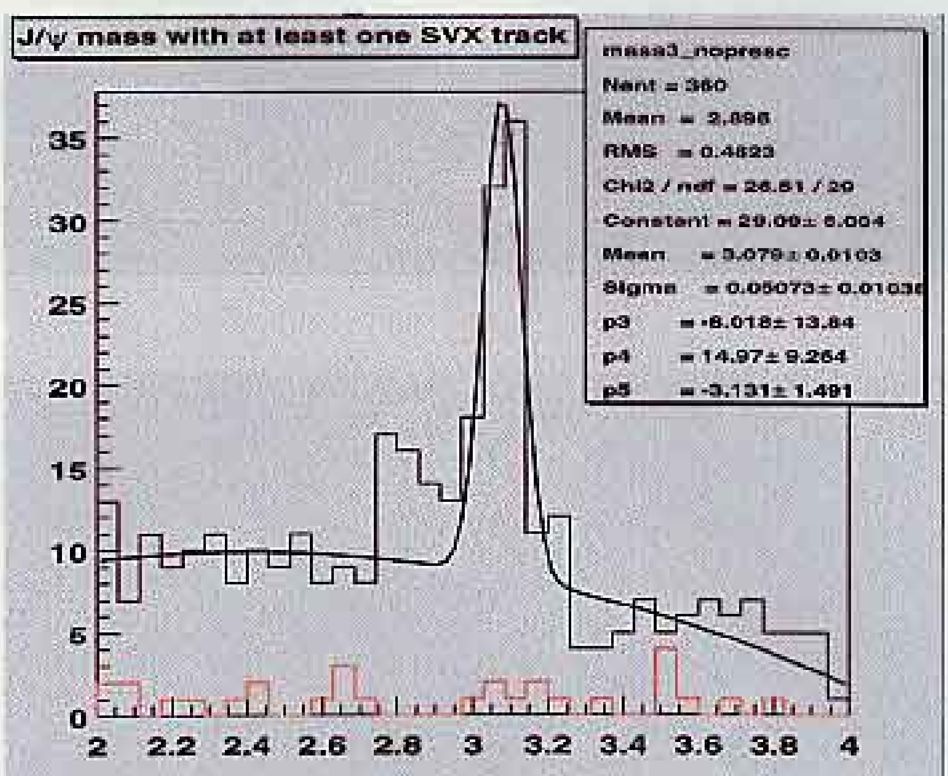
- **One μ in CMX**
- **CMX: $0.6 < |\eta| < 1.1$**

$J/\psi \to \mu^+\mu^-$, e^+e^- using SVX

Run II, CDF



- **Two μ at SVX**

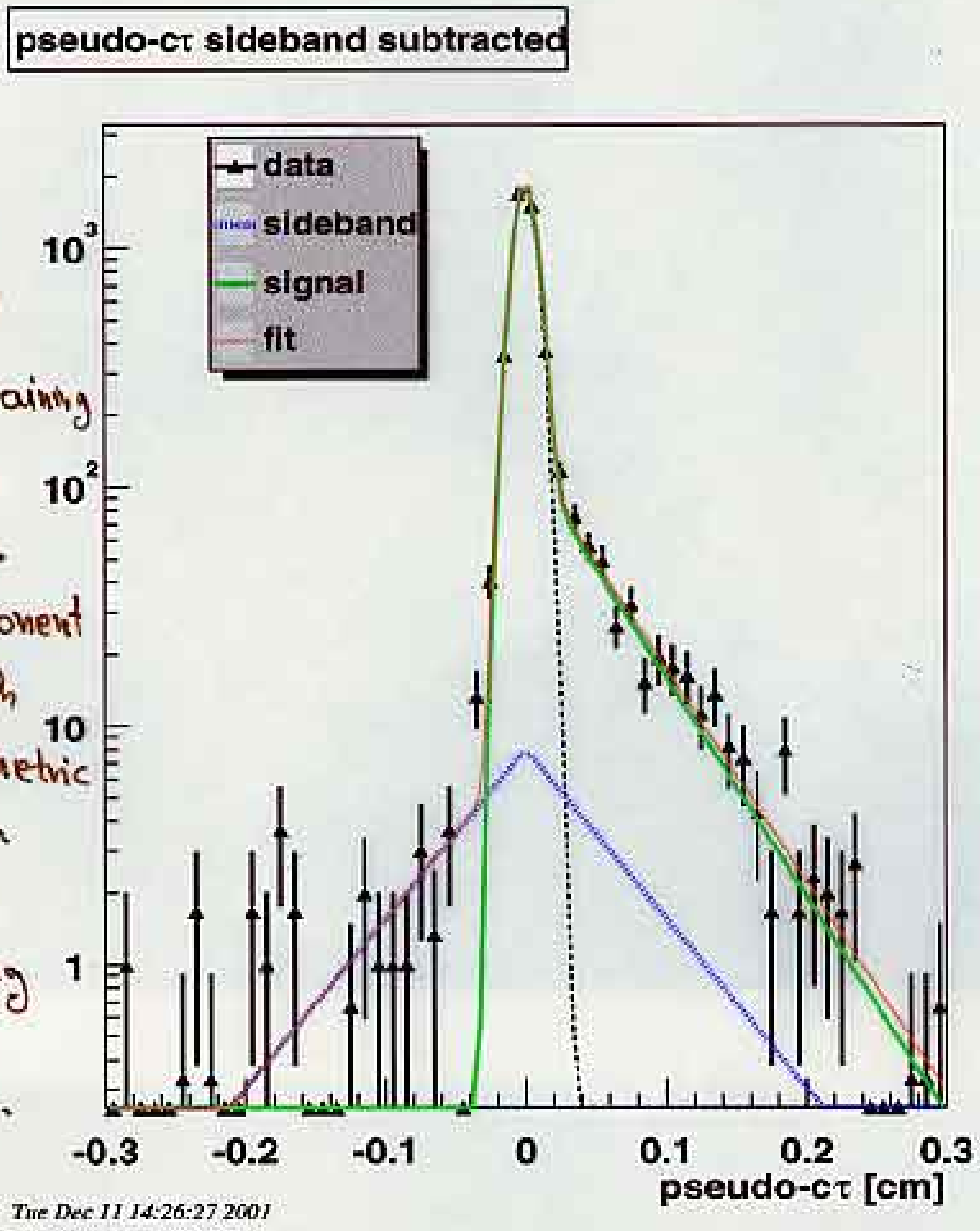


- **One e at SVX**

$J/\psi \to \mu^+\mu^-$, pseudo-cτ distribution

Run II, CDF

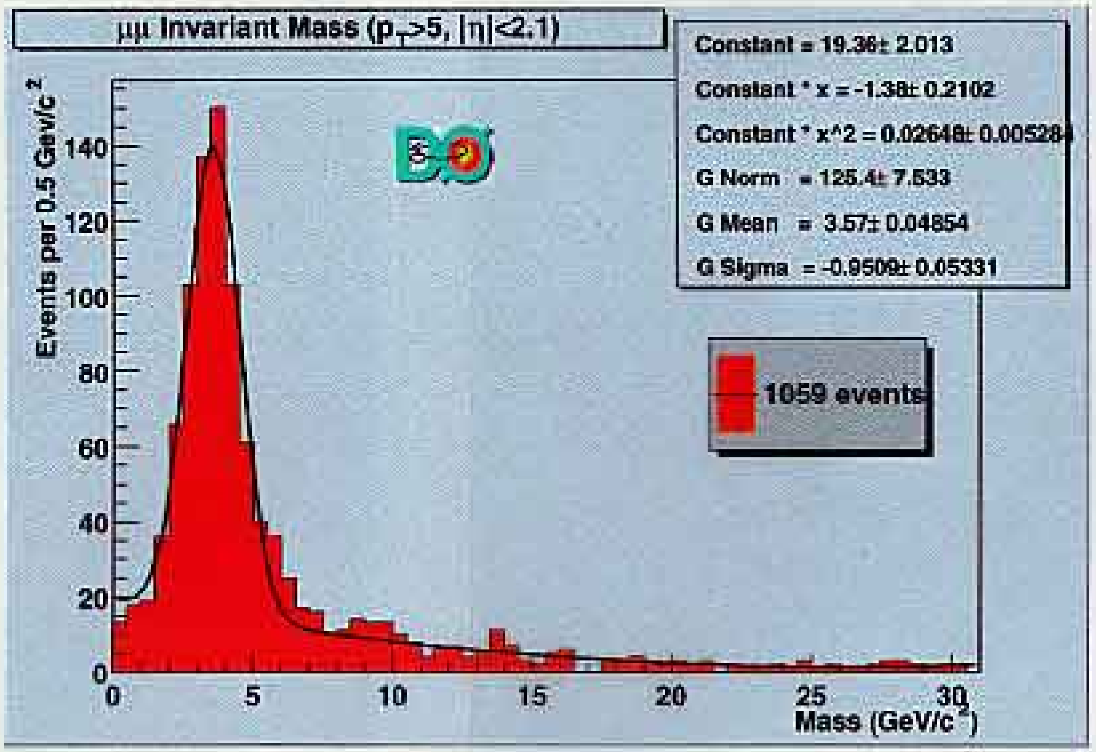
Sideband-subtracted fit in signal region. Remaining distribution modeled as prompt component smeared with Gaussian, symmetric non-Gaussian tails and a smeared long lifetime component.

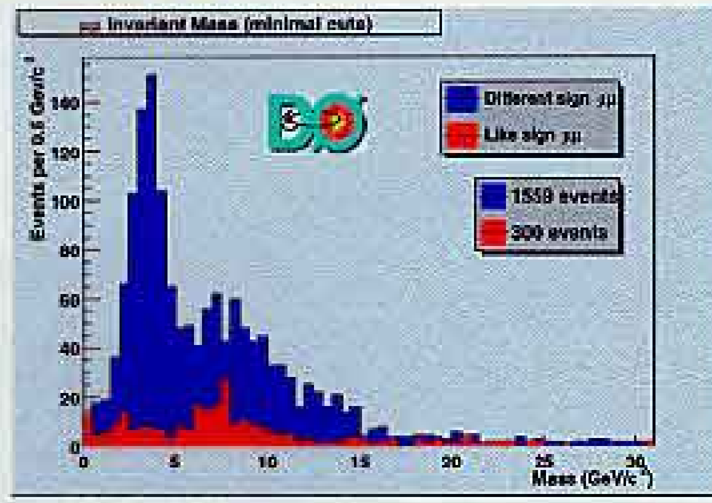


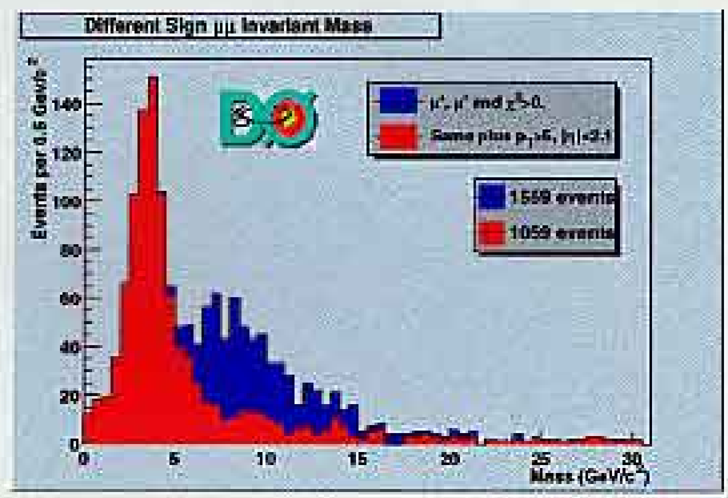
$$\lambda_c = \text{pseudo-}c\tau = L_{xy} \frac{M_{J/\psi}}{p_T^{J/\psi} F(p_T^{J/\psi})} \; ; \; F(p_T^{J/\psi}) = \frac{\lambda_B}{\lambda_{J/\psi}}$$

$J/\psi \rightarrow \mu^+\mu^-$

Di-muons reconstructed in the forward region



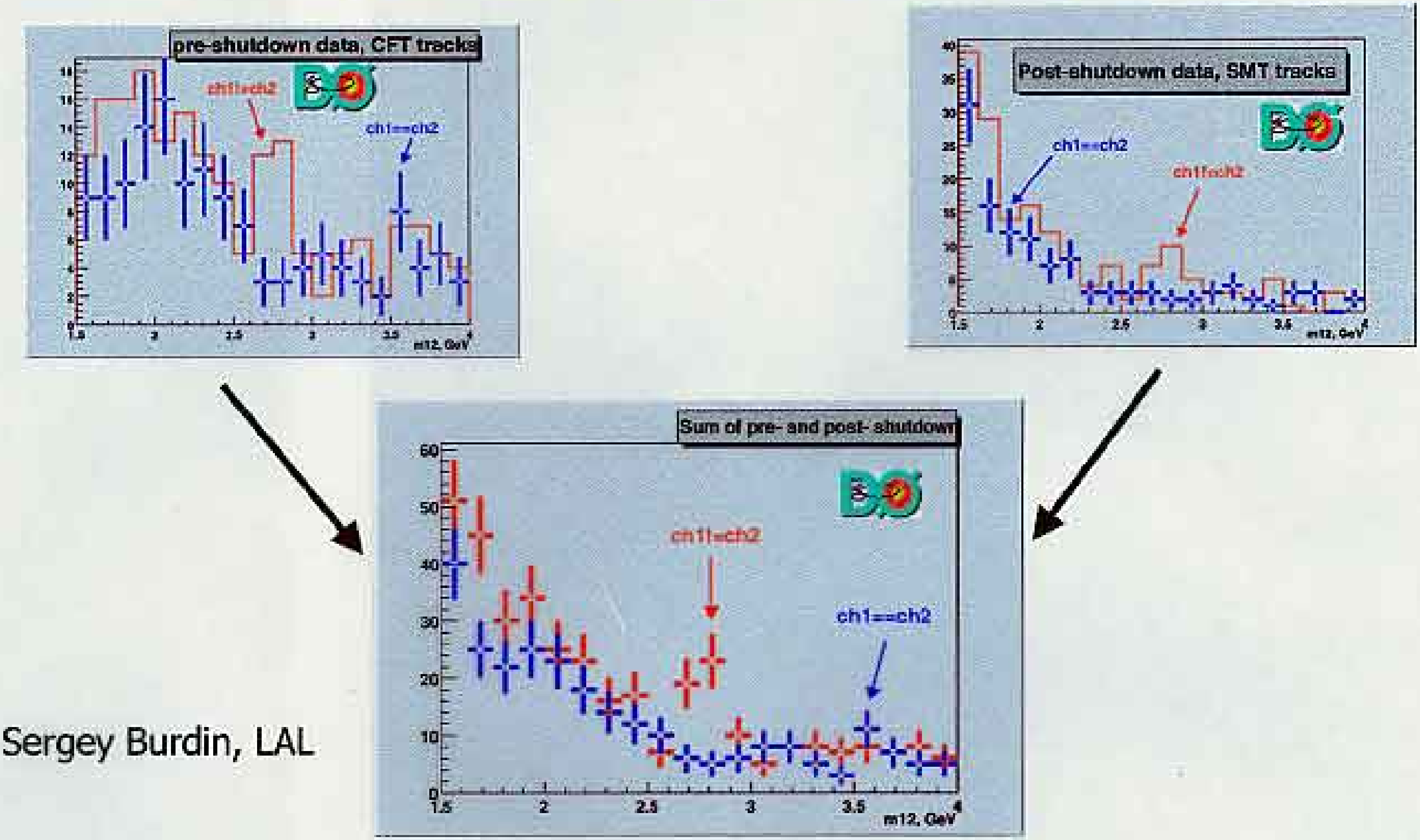




Roger Moore and
Adam Yurkewicz, MSU

$J/\psi \rightarrow e^+e^-$

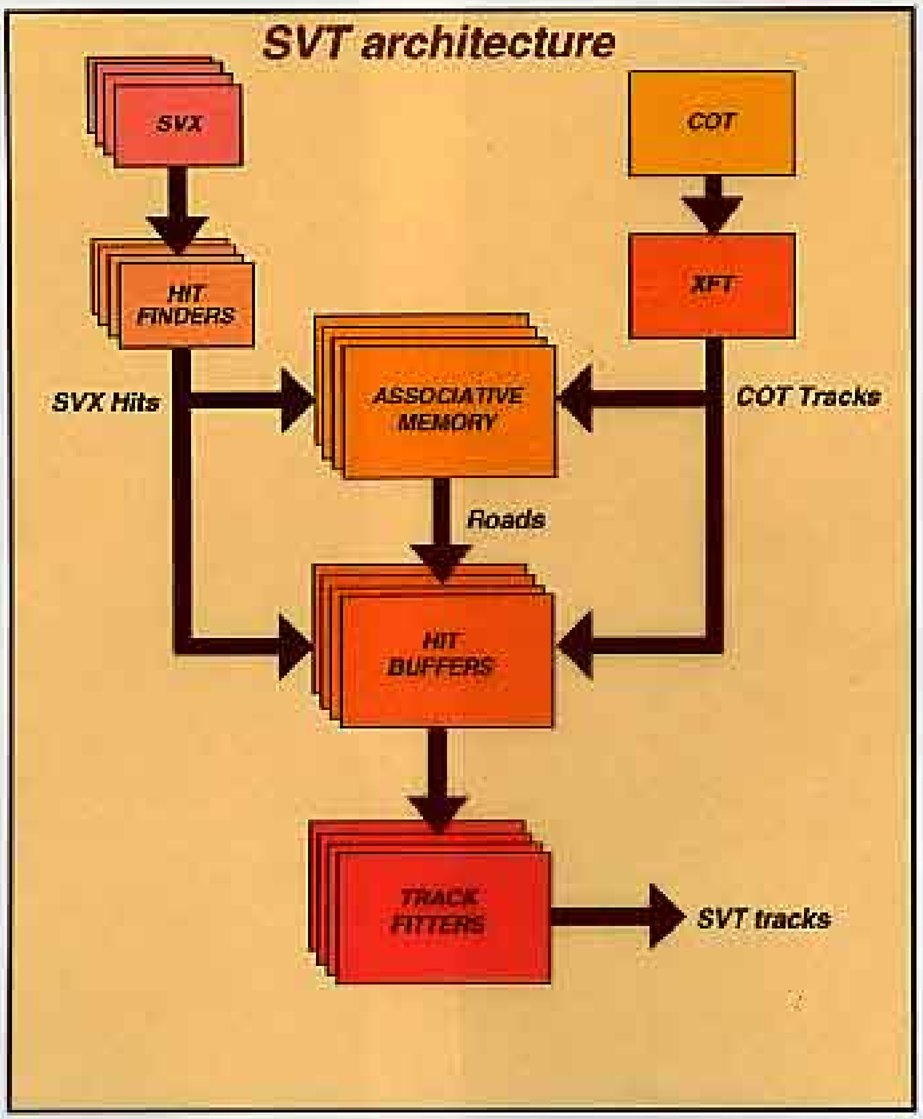
Di-electrons reconstructed in CFT and SMT



(uncalibrated EM energy scale)

Sergey Burdin, LAL

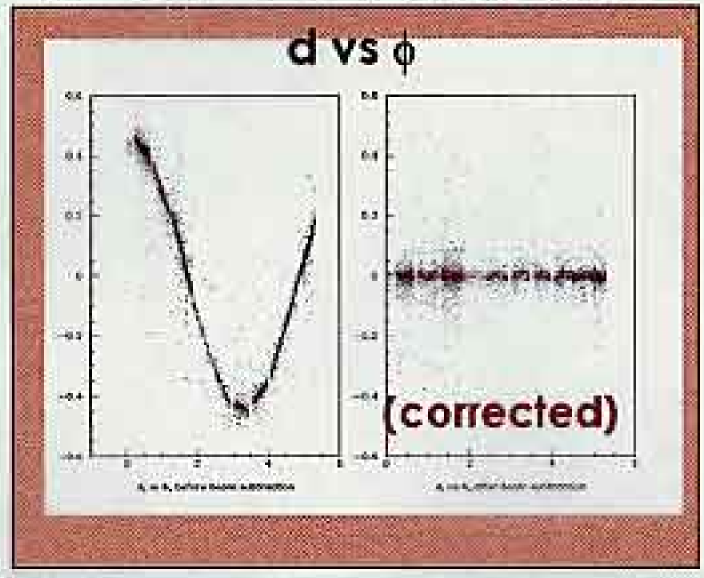
Secondary Vertex Trigger, CDF



- EXtremely Fast Tracker (XFT) finds tracks in the Drift Chamber (COT)
- Silicon Vertex Tracker (SVT) combines COT tracks with SVX hit information
  - Associative memory checks track info to see if consistent with possible preset "road" list
  - When matches are found, the data are output to track fitters
  - Final track quality is comparable to offline!
- Effectively an impact parameter trigger at L2
  - Can trigger on hadronic B decays

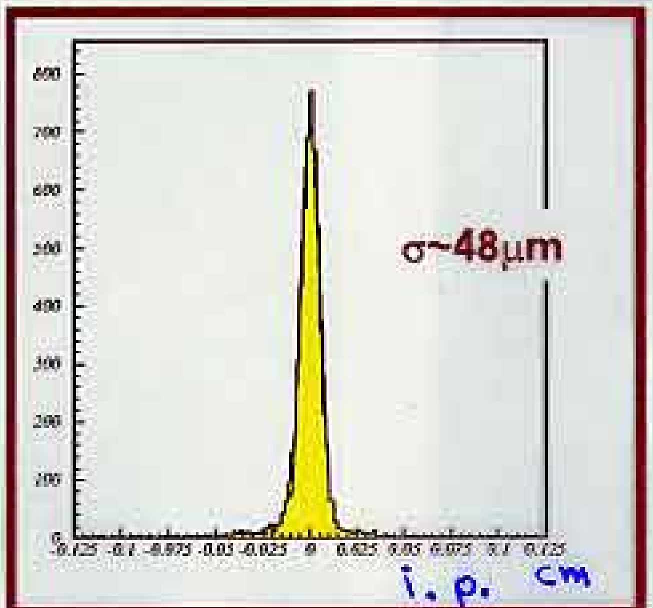
SVT Performance

Beam offset ~4mm

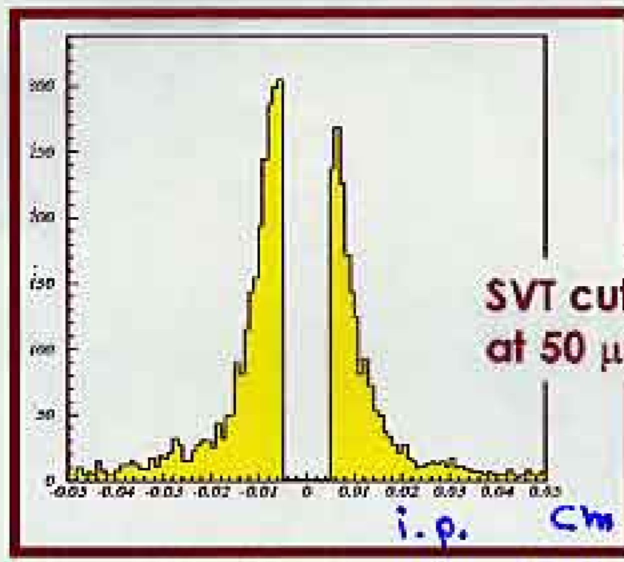


impact parameter vs φ

Beam spot + track res

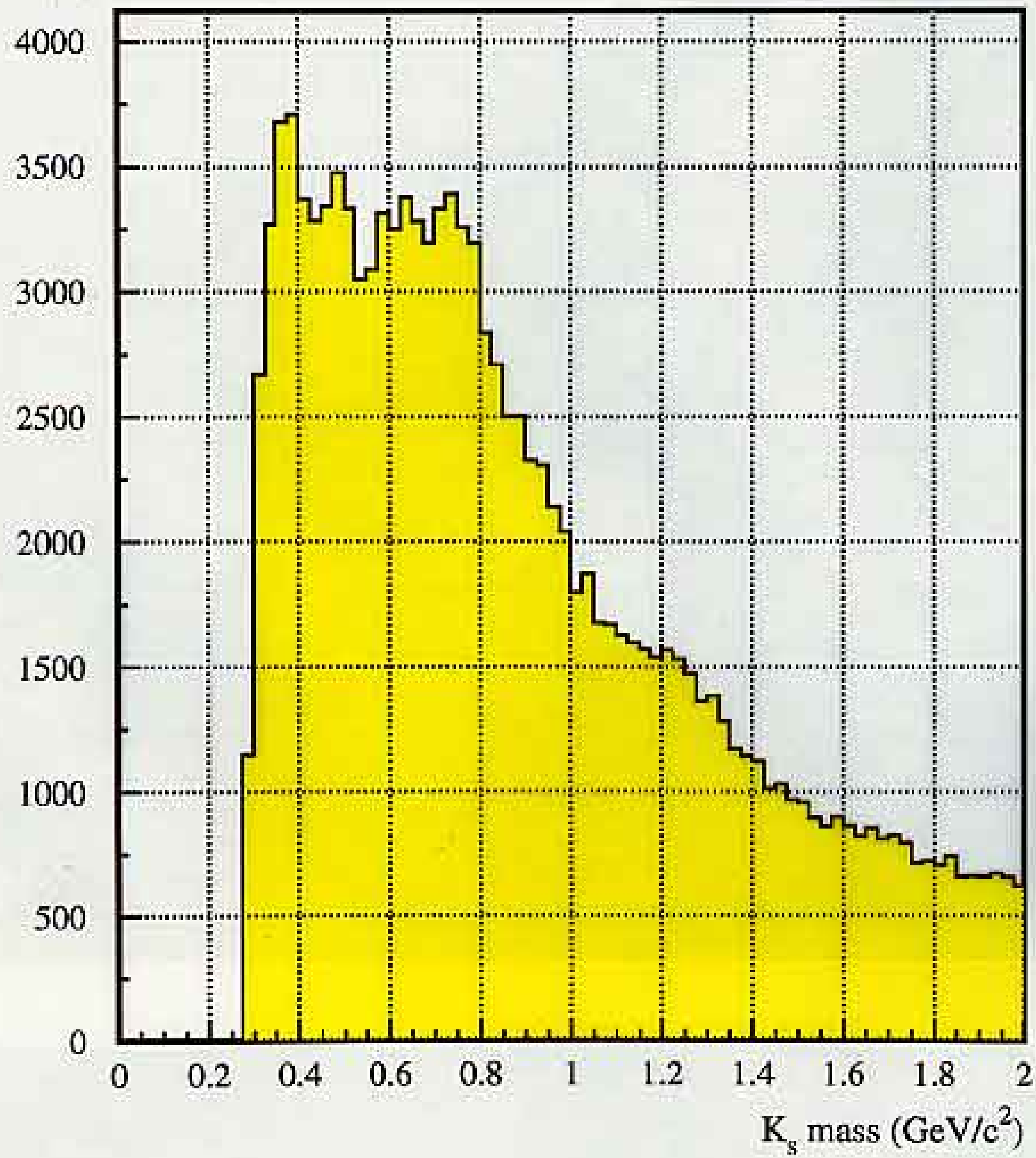


SVT 2-track trigger



CDF

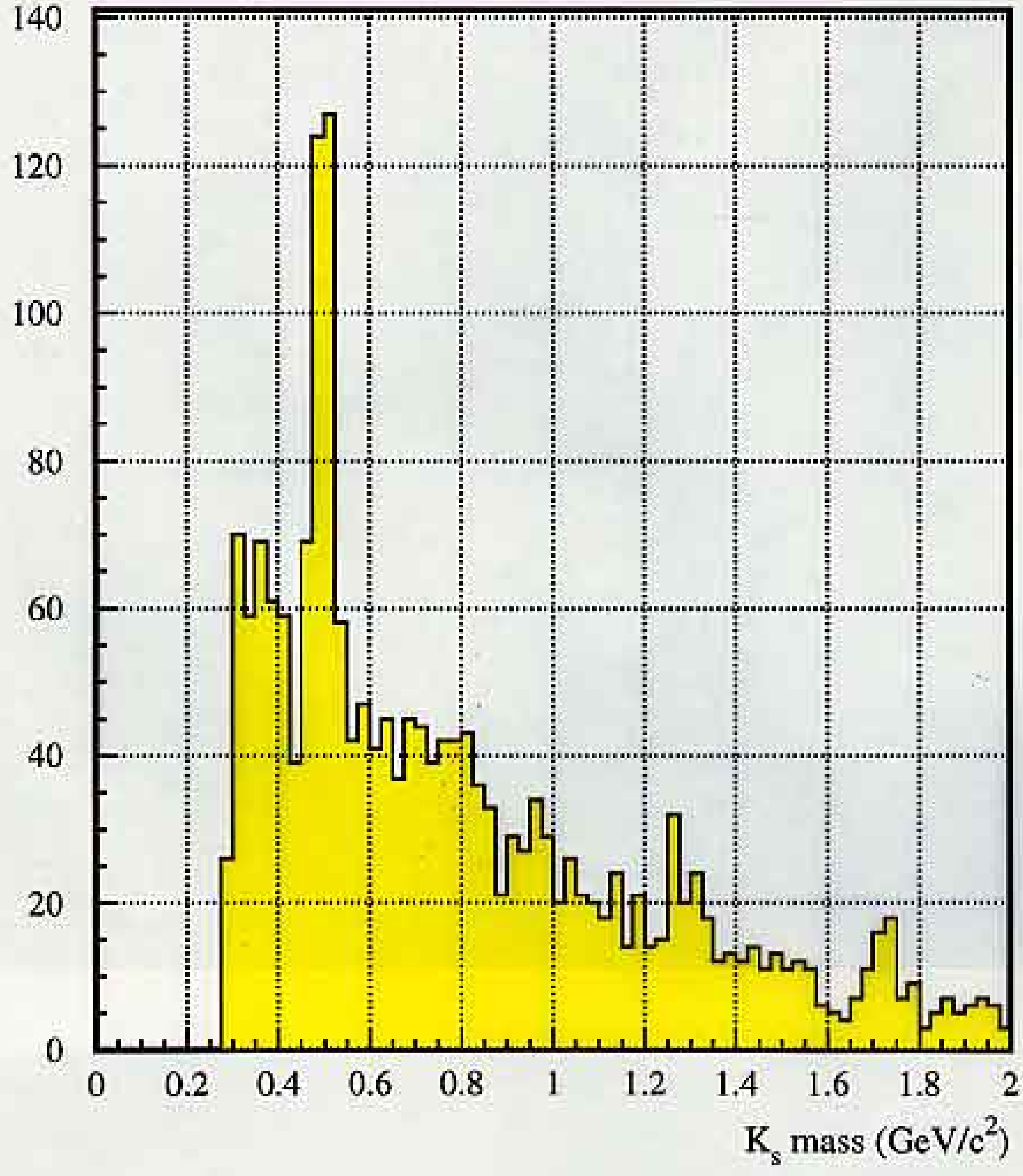
SVT tracks matched in φ with COT tracks
I.P. from SVT



all events

CDF

SVT data, $K_s \to \pi^+\pi^-$

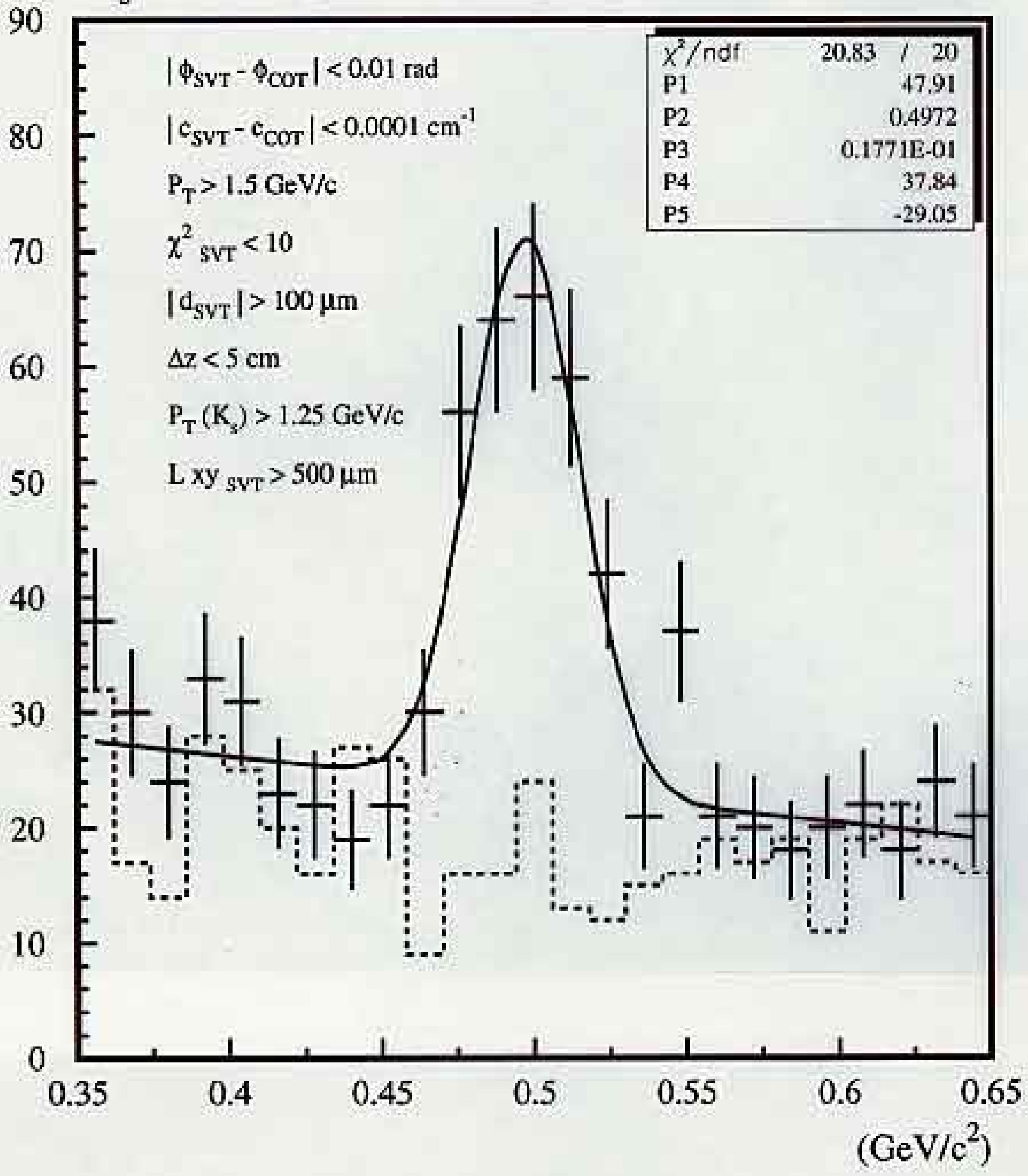


Impact parameter and Lxy cuts applied

↳ transverse decay length

CDF

$K_s \to \pi\pi$ signal from hybrid SVT-COT tracks

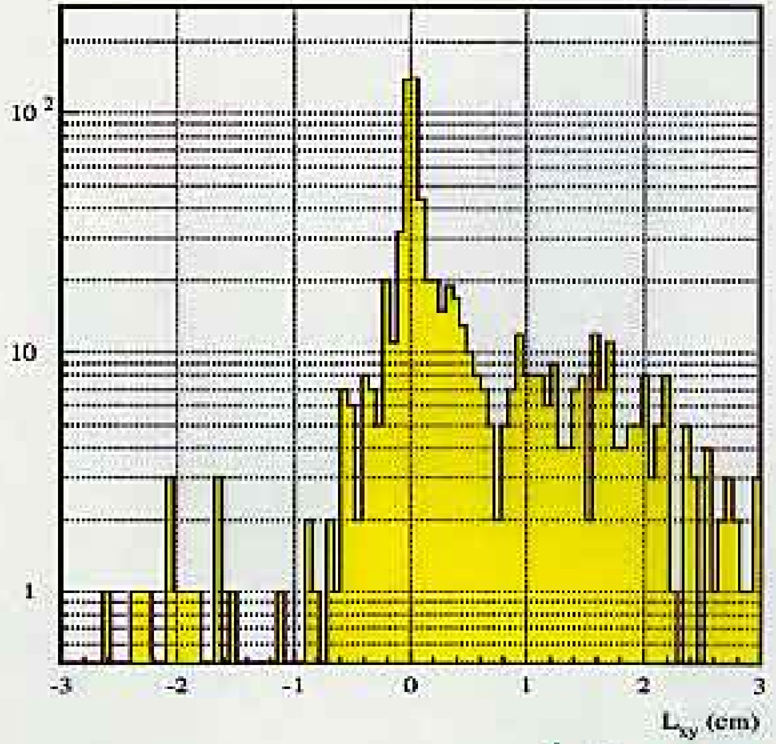


---- Lxy < −500 μm

"backward" decays

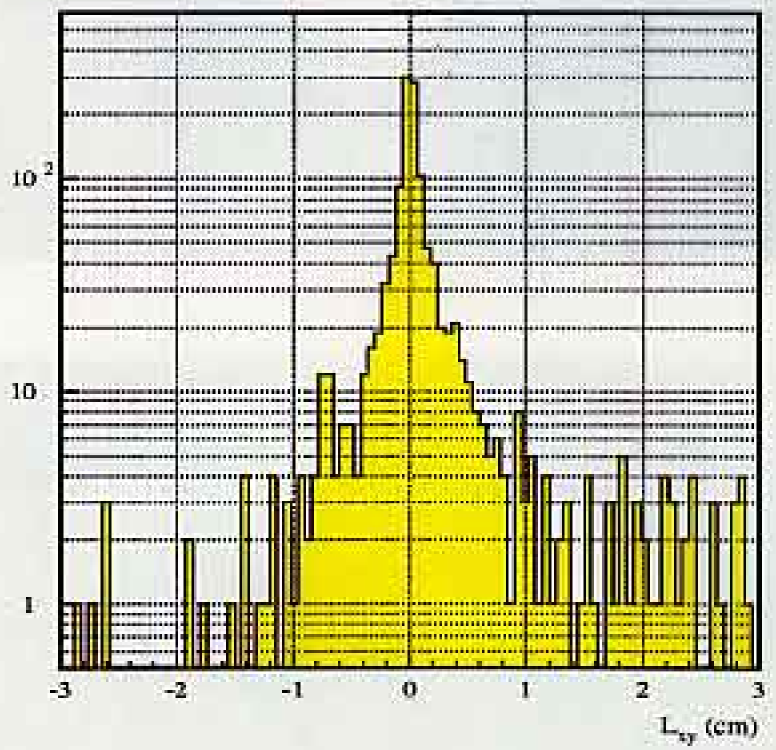
$K_s^0 \to \pi^+\pi^-$ reconstruction from SVT data

Run II, CDF



- L_{xy} from K_s^0 peak

(transverse decay length)

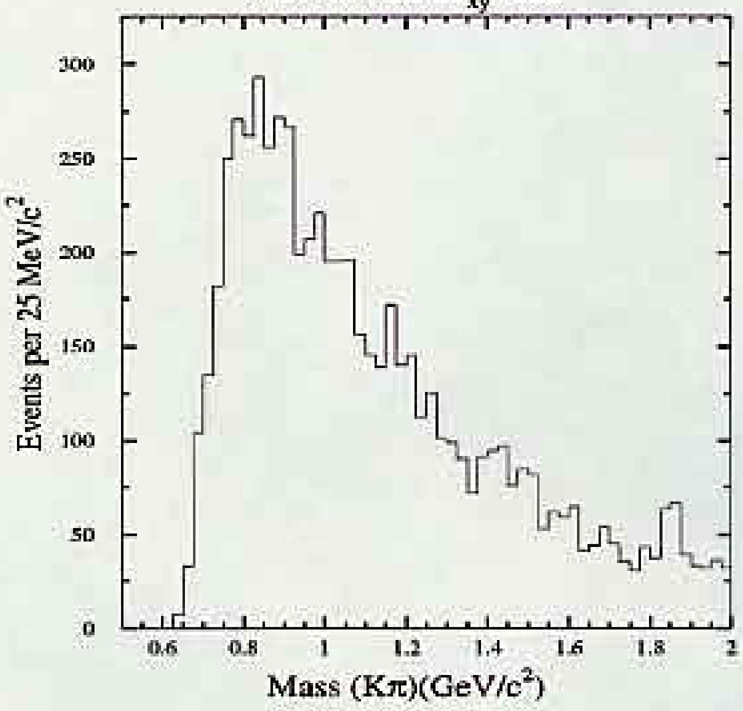


- L_{xy} from K_s^0 sidebands

$D^0 \to K^{\pm}\pi^{\mp}$ reconstruction from SVT data

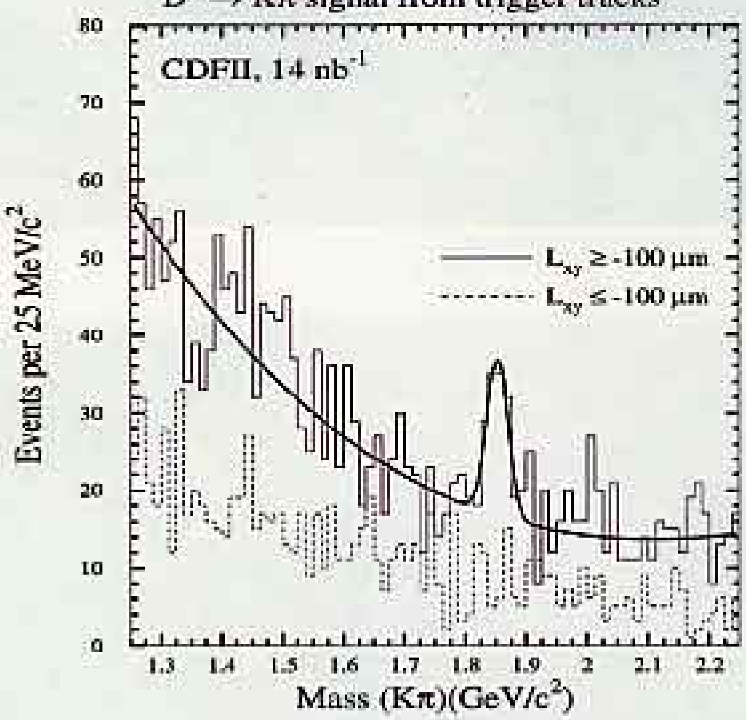
Run II, CDF

Invariant mass of trigger track pairs, after I.P. and L_{xy} cuts



- SVT tracks matched in ϕ with COT tracks. I.P from SVT.

$D^0 \to K\pi$ signal from trigger tracks



- 72 events in fitted peak
- most counted twice

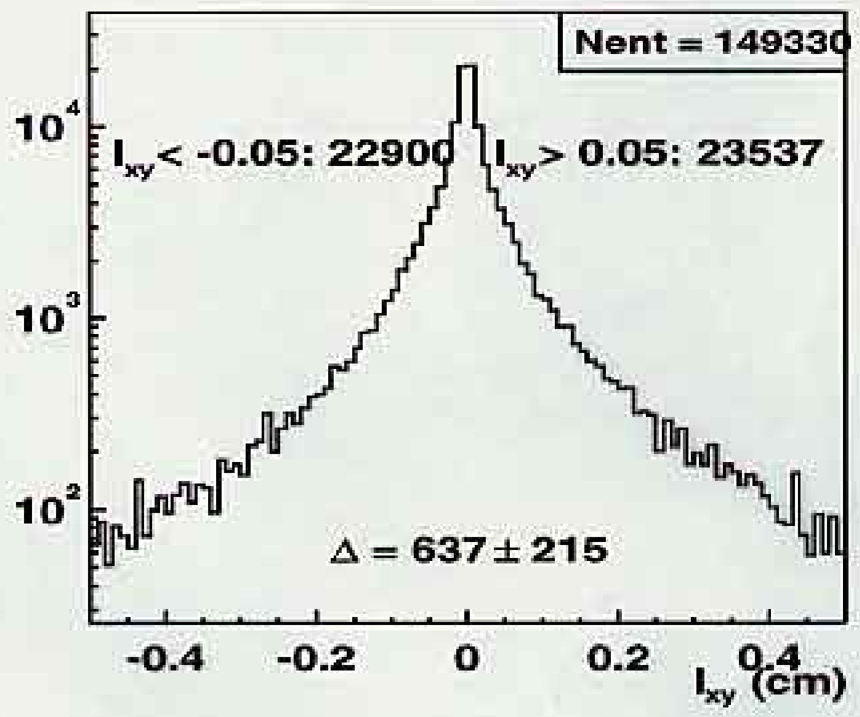
$P_T(1,2) > 1.5$ GeV/c

$100\mu m < d_{(1,2)} < 1 mm$

$D^0 \to K^{\pm}\pi^{\mp}$ reconstruction from SVT data

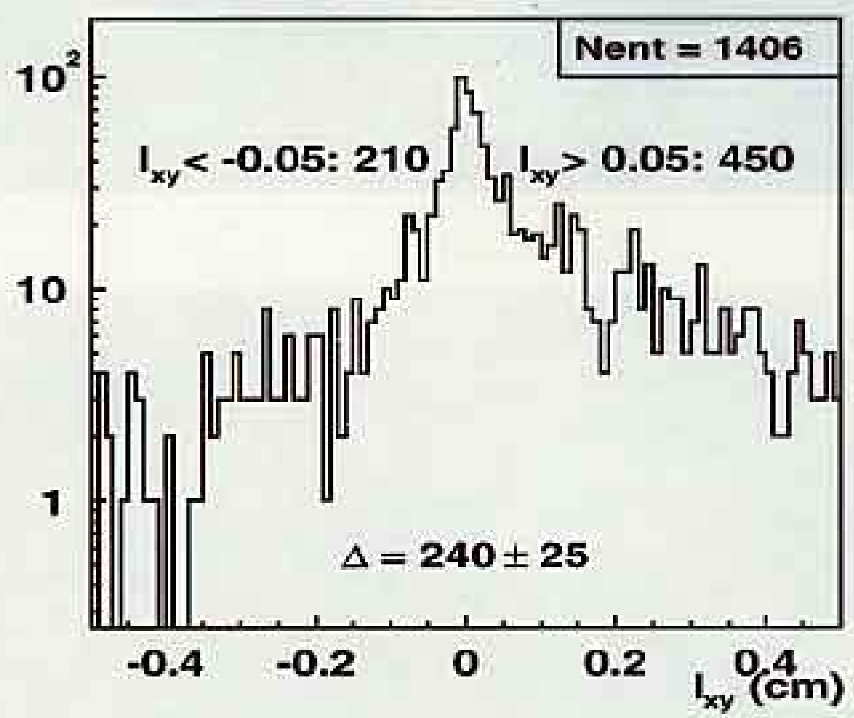
Run II, CDF

reconfirm scenario A



- Two tracks with $P_T > 2$ GeV/c using L1 trigger (XFT)

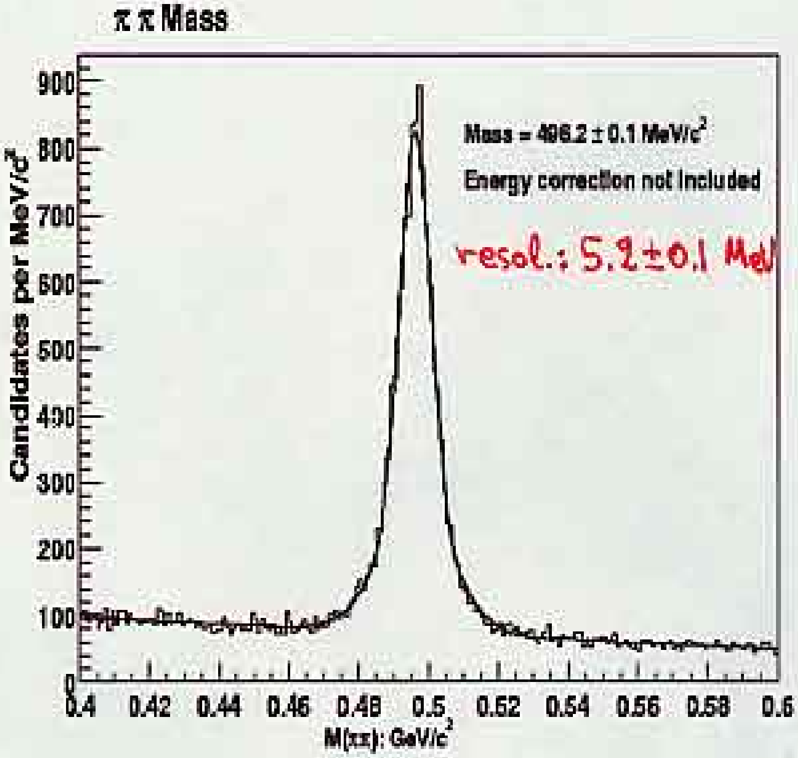
$150\mu m \leq d_0 \leq 1mm \quad 2° \leq \Delta\phi \leq 90°$



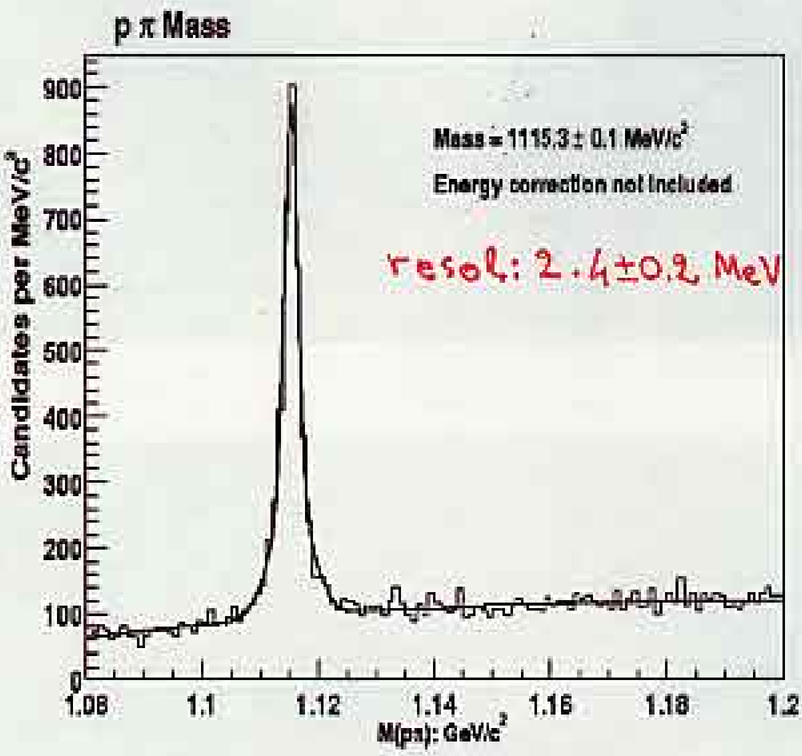
- Additional cuts using L2 SVT
- First evidence of heavy flavor selection

$K^0_s \to \pi^+\pi^-$ and $\Lambda \to p^+\pi^-$ reconstruction

Run II, CDF



- $L_{xy} > 1$cm
- $i.p./\sigma(i.p.) >$0.5

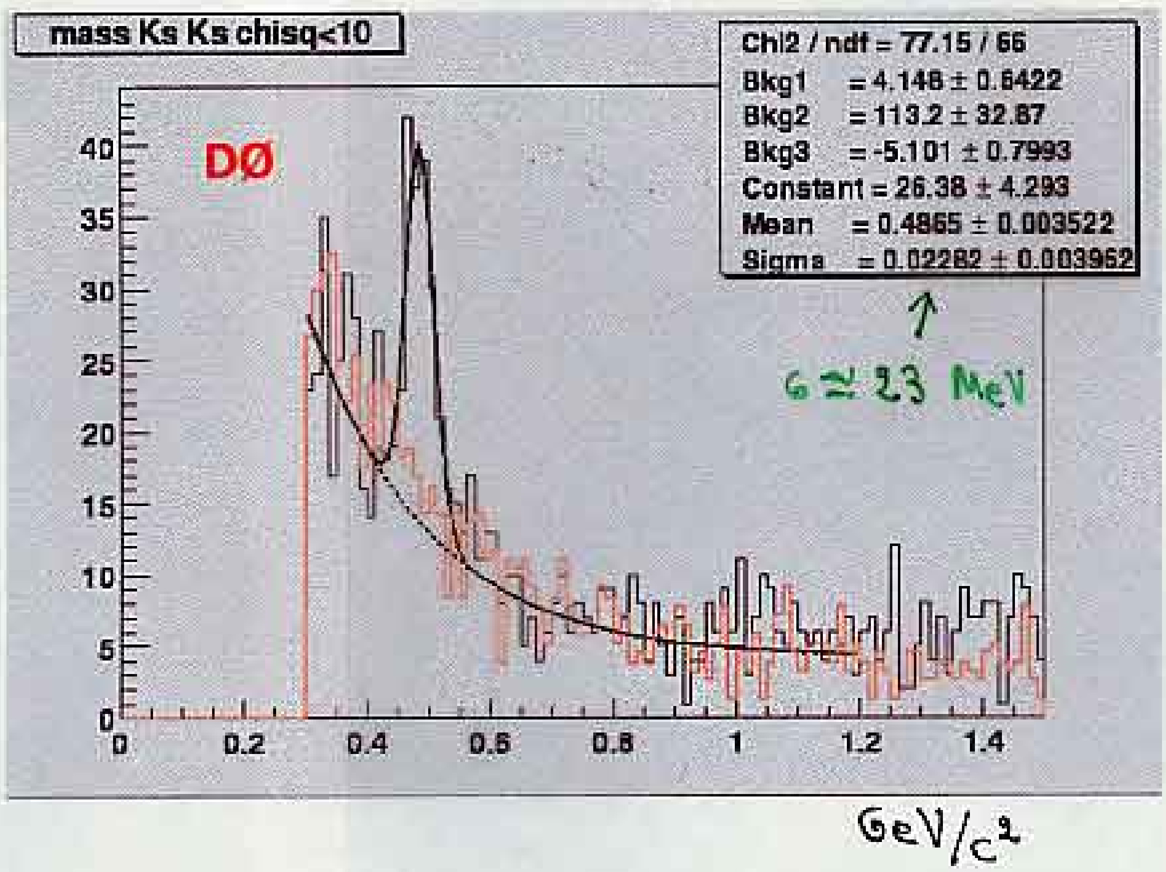


- $L_{xy} > 2.5$cm
- $i.p./\sigma(i.p.) >$0.1

$K_s \rightarrow \pi^+\pi^-$

Tracks reconstructed in the SMT detector

Brad Abbott, Oklahoma



Black histogram – opposite-sign tracks

Red histogram – same-sign tracks

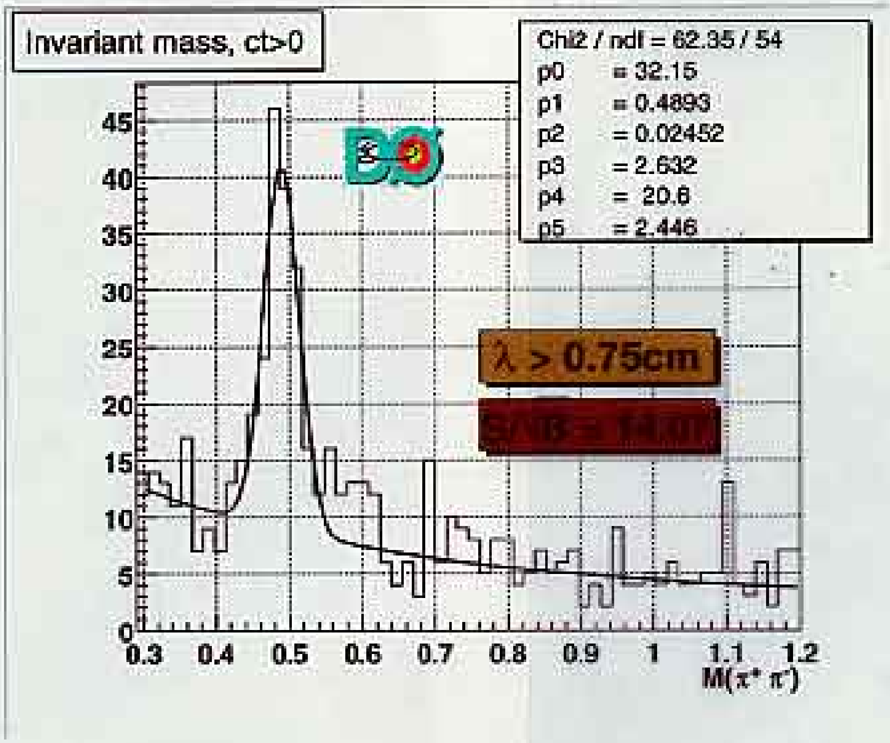
Dotted curve – fit to background

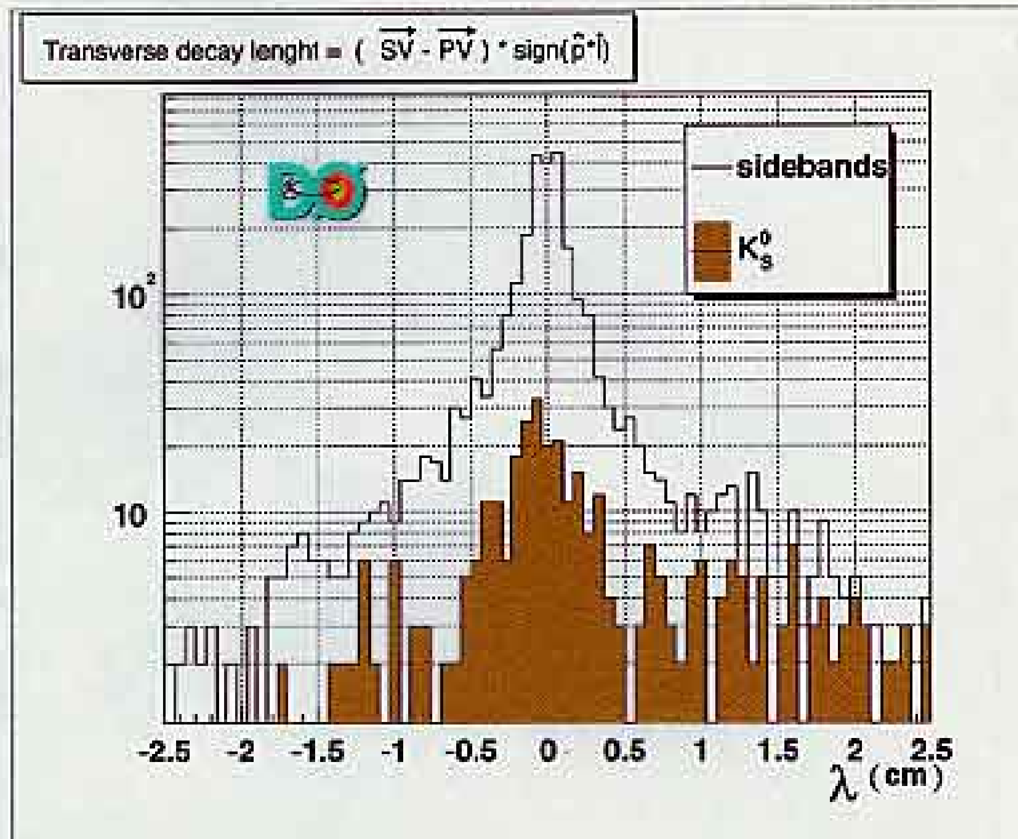
Full curve – fit to signal + background

$K_s (\rightarrow \pi^+ \pi^-)$ Lifetime

Tracks reconstructed in the SMT detector

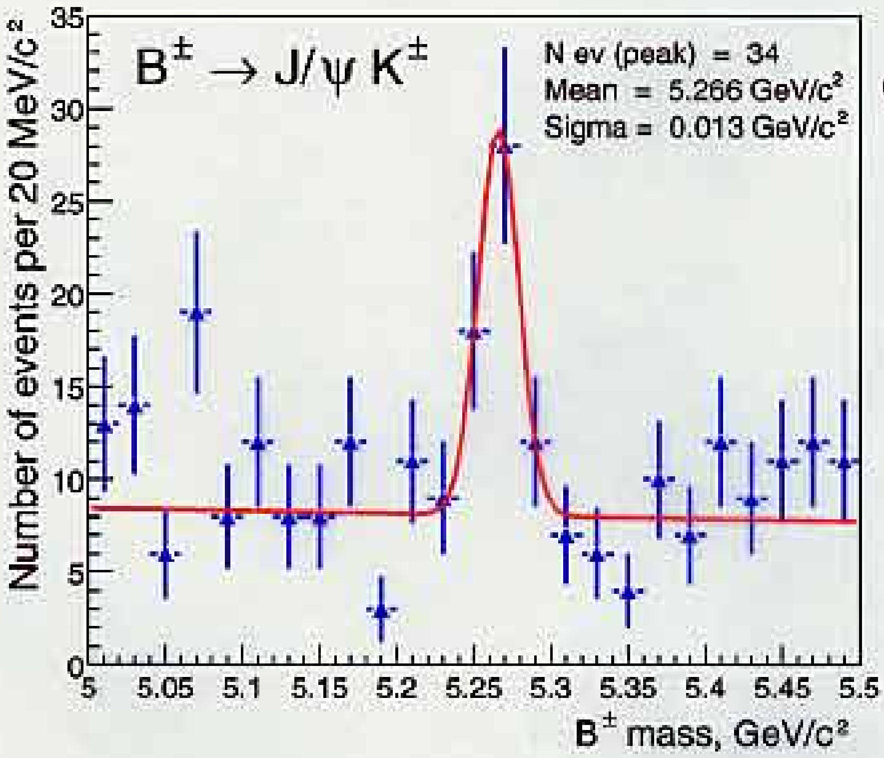
Ariel Schwartzman, Buenos Aires





$B^\pm \to J/\psi K^\pm, J/\psi \to \mu^+\mu^-$

Run II, CDF

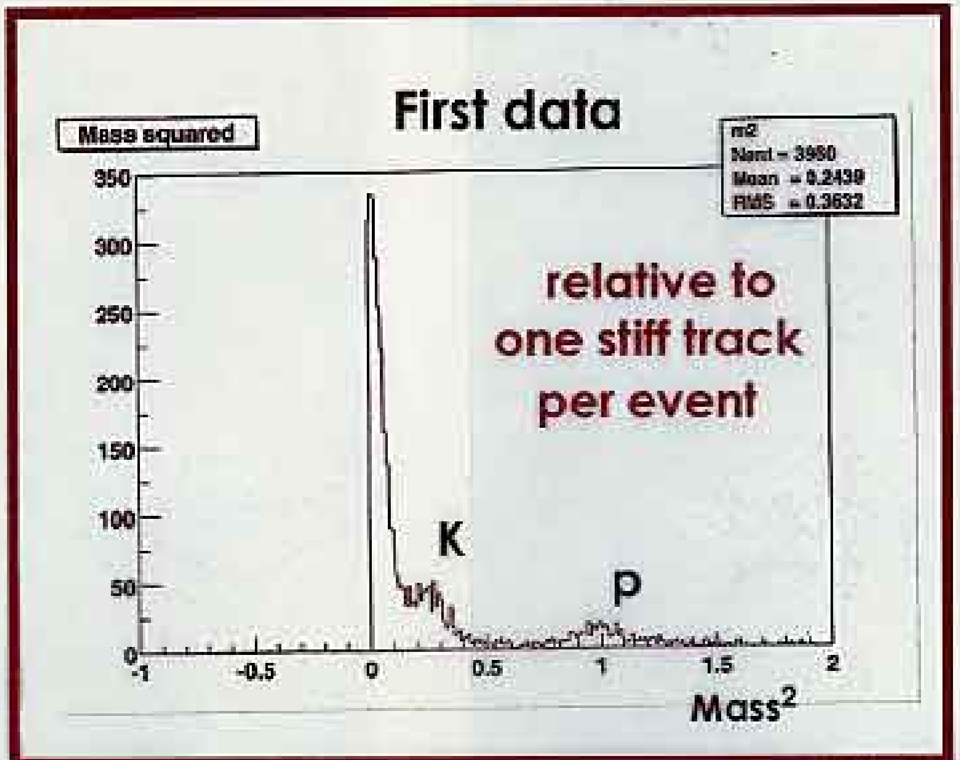


- **34 events**

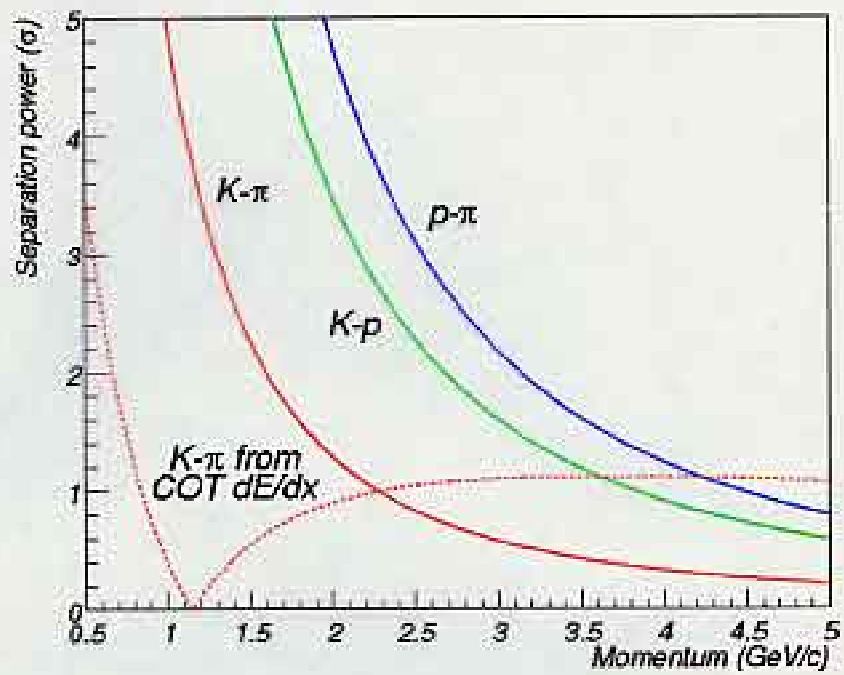
- **3.00<M(J/ψ)<3.16 GeV/c^2**
- $p_T(K) >$ **1.75 GeV/c**
- $z_0(K)$ **within 5 cm of** J/ψ **vertex**
- **Three track fit for** $B^\pm$ **meson**

Particle ID with TOF & COT, CDF

- TOF: 100 ps resolution →
  2σ separation for:
  - K/π for $p < 1.6$ GeV
  - K/p for $p < 2.7$ GeV
  - p/π for $p < 3.2$ GeV

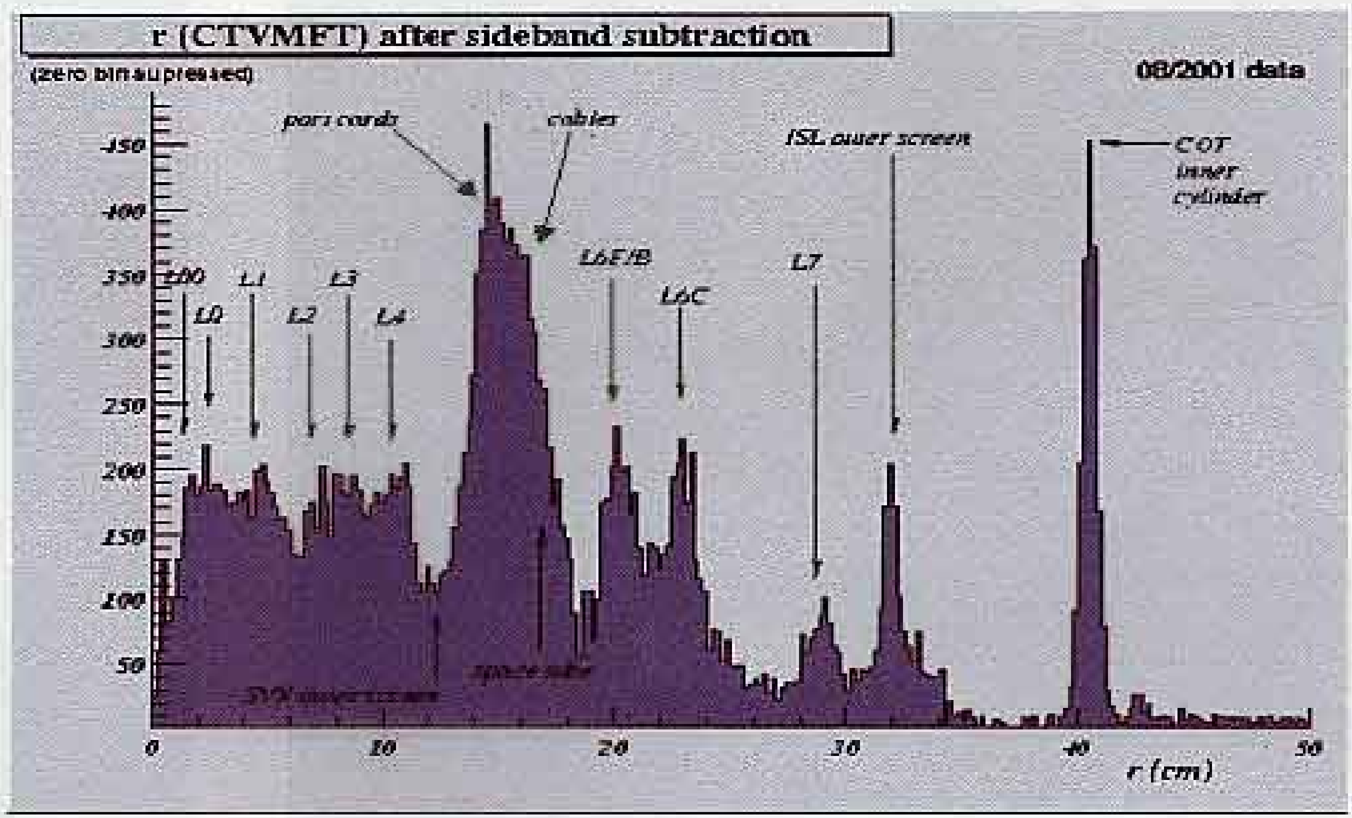


- COT dE/dx is complementary



Central outer tracker data, CDF

Photon e^+e^- pairs reconstructed with COT



Flavour tagging improvements, CDF

tagger	$\epsilon\mathcal{D}^2$ [%] measured Run I	$\epsilon\mathcal{D}^2$ [%] expected Run II	Relevant upgrade	Calib. sample
Same Side tag	$1.8 \pm 0.4 \pm 0.3$	2.0	tracking	$J/\psi K^{*0}$
Soft lepton tag	$0.91 \pm 0.10 \pm 0.11$	1.7	μ cov., trac.	$J/\psi K^+$
Jet Charge	$0.78 \pm 0.12 \pm 0.08$	3.0	tracking	$J/\psi K^+$
Opp.Side Kaon	–	2.4	ToF	$J/\psi K^+$
Combined	3.7	6.7 (9.1)		

$J/\psi K_s$ sample size

$J/\psi \to \mu^+\mu^-$:

1. Run I: 400 events
2. $\times 2000/110$ for total $\int \mathcal{L}dt$
3. extended coverage
4. better triggering
5. net increase by $\times 50$

$\Rightarrow \approx 20,000$ $J/\psi K_s$ events in Run IIa (2 fb^{-1})

$J/\psi \to e^+e^-$: harder to estimate
$\Rightarrow$ Expect up to 50% more $J/\psi K_s$ events

$\sigma(\sin 2\beta) < 0.05$ in 2 fb^{-1}
using dimuons only

CP Asymmetry in $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$

Promising method suggested by Fleischer (1999):

Measure γ by relating the CP violation observables in $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$

tree dominates   penguin dominates

Use U-spin symmetry to relate the ratio of hadronic matrix elements for penguins and trees

Use $B_s^0 \to K^+K^-$ to correct for penguin pollution in $B^0 \to \pi^+\pi^-$

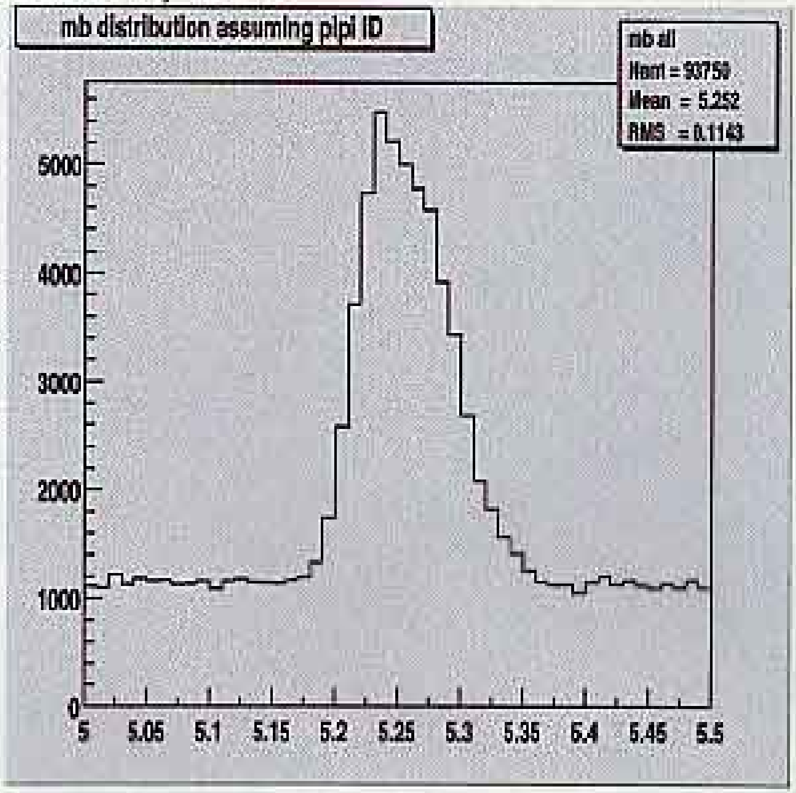
Expect following relative yields:

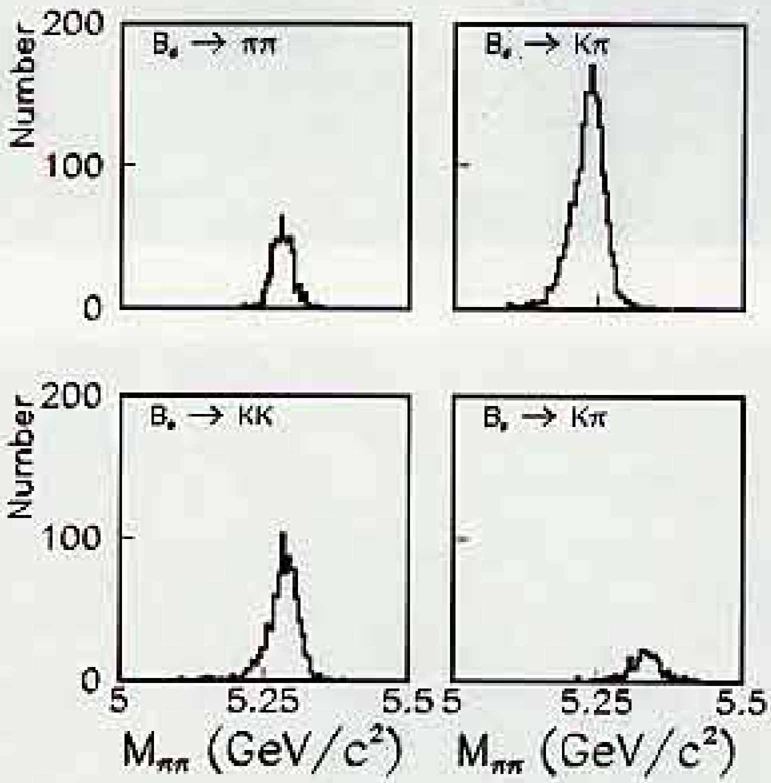
$$(B^0 \to K\pi) : (B^0 \to \pi\pi) : (B_s^0 \to KK) : (B_s^0 \to \pi K) \sim 4 : 1 : 2 : 0.5$$

With $2\,fb^{-1}$ CDF expects 5060 – 9160 fully reconstructed $B^0 \to \pi^+\pi^-$

Disentagling $\pi\pi$, Kπ, KK and πK final states

Run II, CDF





π **hypothesis**

- **20,000** $B^0 \to K^\pm \pi^\mp$
- **5,000** $B^0 \to \pi^+ \pi^-$
- **10,000** $B^0_s \to K^+ K^-$
- **2,500** $B^0_s \to K^\mp \pi^\pm$
- **on top of 56,250 events of bkg**
- **Shown separately**

Detailed studies:

$\sigma(\gamma) \sim 10^\circ$ with 4-fold ambiguity in Run IIa

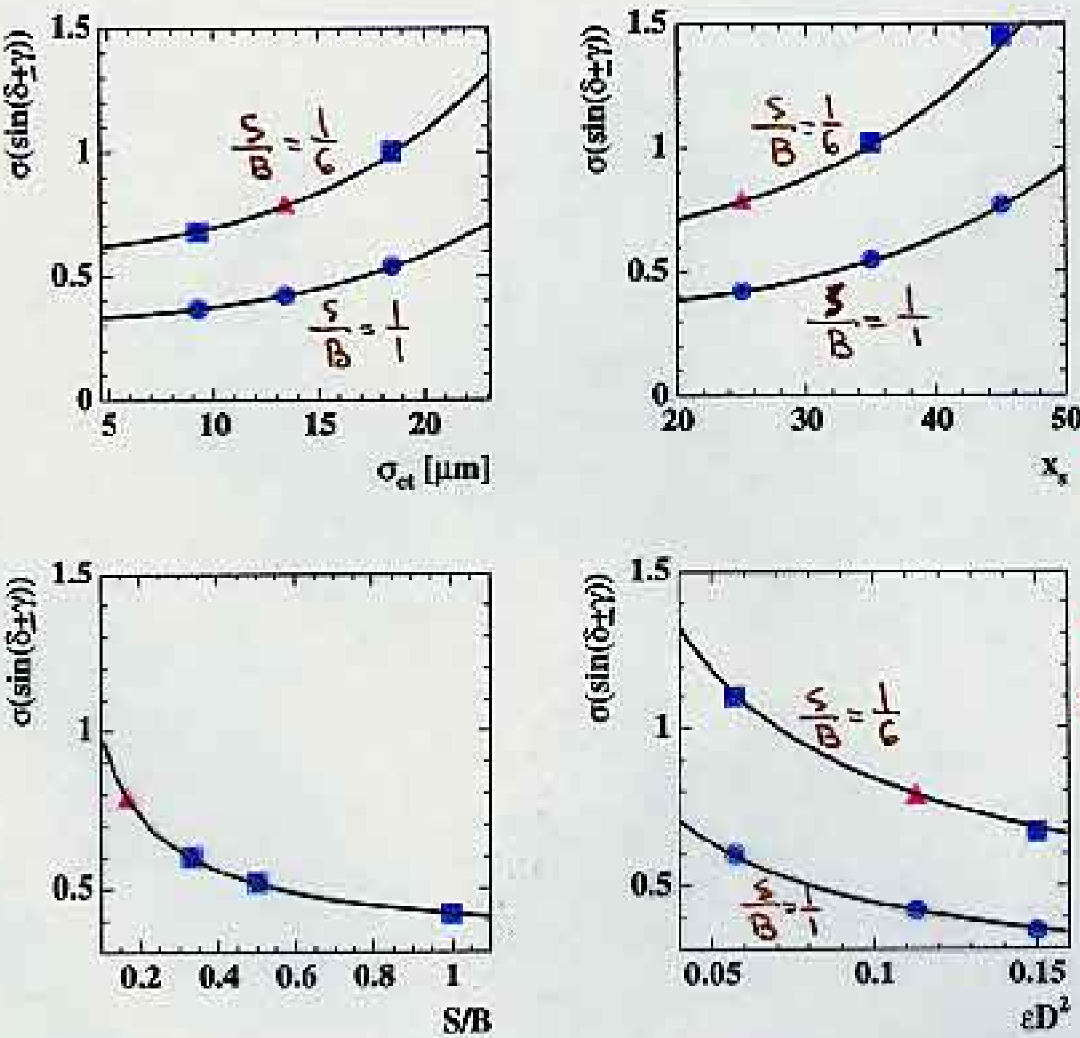
$\sigma(\gamma) \sim 3^\circ$ in Run IIb

Angle γ

points: fit results

curves: theor. expected errors

$$B_s^0 \to D_s^- K^+$$



expect ~850 events in $2 fb^{-1}$

$\frac{S}{B}$: [0.5–2]

expect $\sigma(\sin(\delta \pm \gamma))$: 0.4–0.7

Param.	Input value	Param.	CDF II Estimate
γ	$45°$	σ_t	45 fs [30 – 60 fs]
str. ph. δ	$0°$	$\varepsilon\mathcal{D}^2$	11.3% [5.7%]
x_d	0.723	N(B_s)	700
x_S	25 [20 – 50]	S/B	1:1 – 1:6

Central values of parameters used for the Toy Monte Carlo studies measuring sinγ from $B_s^0 \to D_s^- K^+$.

Review: $\sin\gamma$ from $B_S \to D_S K$

$\sin\gamma$ may be extracted from the 4 decay rates:

$$\Gamma_{B_s \to D_s^- K^+}(t) = Ae^{-t}\left[1 + R\cos(x_s t) + \sqrt{1-R^2}\sin(x_s t)\sin(\delta+\gamma)\right]$$

$$\Gamma_{B_s \to D_s^+ K^-}(t) = Ae^{-t}\left[1 - R\cos(x_s t) - \sqrt{1-R^2}\sin(x_s t)\sin(\delta-\gamma)\right]$$

$$\Gamma_{\bar{B}_s \to D_s^- K^+}(t) = Ae^{-t}\left[1 - R\cos(x_s t) - \sqrt{1-R^2}\sin(x_s t)\sin(\delta+\gamma)\right]$$

$$\Gamma_{\bar{B}_s \to D_s^+ K^-}(t) = Ae^{-t}\left[1 + R\cos(x_s t) + \sqrt{1-R^2}\sin(x_s t)\sin(\delta-\gamma)\right]$$

R is a function of the ratio of decay amplitudes;
δ is the strong phase difference

Estimate the errors using toy Monte Carlo and unbinned log likelihood fit.

Angle γ

In Run IIb, if we can maintain the trigger rates, we expect a factor of 3 improvement.

(Another option is to use trigger scenario C, but this has half the yeild for signal events.)

$B^- \to D^0 K^-$ **and** $B^- \to \bar{D}^0 K^-$**;**
$D^0, \bar{D}^0 \to K^\pm \pi^\mp$ ↓small BR

expected S/B is about 1/1

If the combinatoric backgrounds can be controlled, and the decay $B^- \to \bar{D}^0 K^-$ measured to 20%, then γ could be determined to ~15°

B_s^0 Mixing Analysis

Assumptions:

- Number of untagged decays: N $= 5,000 \rightarrow 30,000$

- $$\epsilon D^2 = \begin{cases} 5.7\% & \text{without TOF} \\ 11.3\% & \text{with TOF} \end{cases} \qquad (1)$$

- $$\sigma_{ct} = \begin{cases} 60 \text{ fs} & \text{without Layer 00} \\ 45 \text{ fs} & \text{with Layer 00} \end{cases} \qquad (2)$$

- Signal to Background ratio: S$=1/2 \rightarrow 2/1$

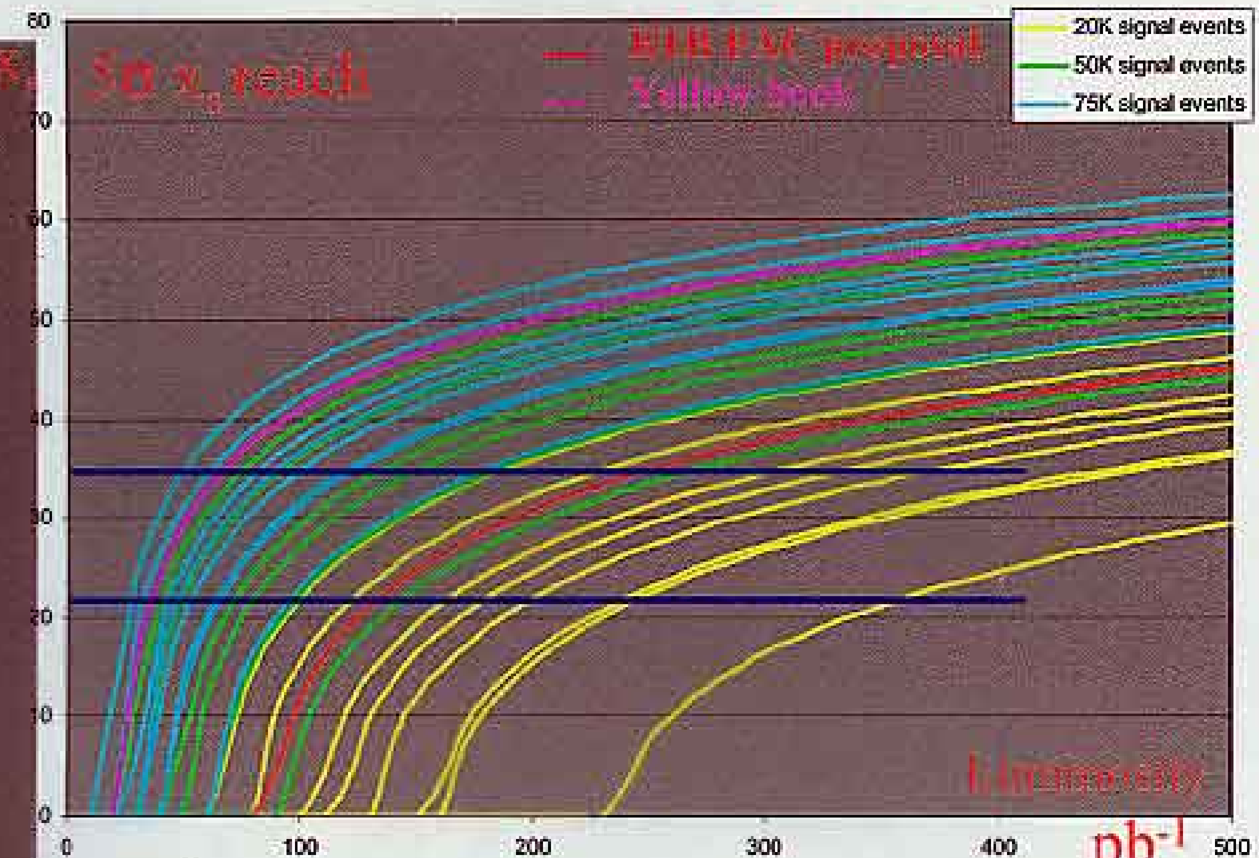
- B_s^0 lifetime, $\tau = 1.54$ ps

Projected values for $\varepsilon\mathcal{D}^2$ for Run II used in the evaluation of CDF's sensitivity to B_S^0 oscillations.

Flavour tag	$\varepsilon\mathcal{D}^2$ without ToF	$\varepsilon\mathcal{D}^2$ with ToF
SS tag (kaon)	1.0%	4.2%
Jet charge tag	3.0%	3.0%
Lepton tag	1.7%	1.7%
Kaon tag	–	2.4%
Total	5.7%	11.3%

Xs reach vs. luminosity

- **Plot all combinations**
  - $N(B_s)$ = 20, 50, 75 k in 2 fb^{-1}
  - S/N = 0.5, 1.0, 2.0
  - εD^2 = 6.3, 9.2, 11.3 %
  - $\sigma(\tau)$ = 0.045 ps
- **BTB PAC proposal:**
  - $D_s \to \phi\pi$ only
  - $N(B_s)$ = 20k, S/N = 1.0
  - εD^2 = 11.3%
  - $\sigma(\tau)$ = 0.045 ps
- **Yellow book estimate:**
  - Add $D_s \to K^{*0}K$, $K^0_S K$
  - $N(B_s)$ = 75k, S/N = 1.0
  - εD^2 = 11.3%
  - $\sigma(\tau)$ = 0.045 ps



$22.55 < x_s < 34.11$ & 95% CL
Indirect * direct limits
(hep-ph/0112133 10 Dec 2001)

Estimated x_s Reach

x_s reach for different signal yields

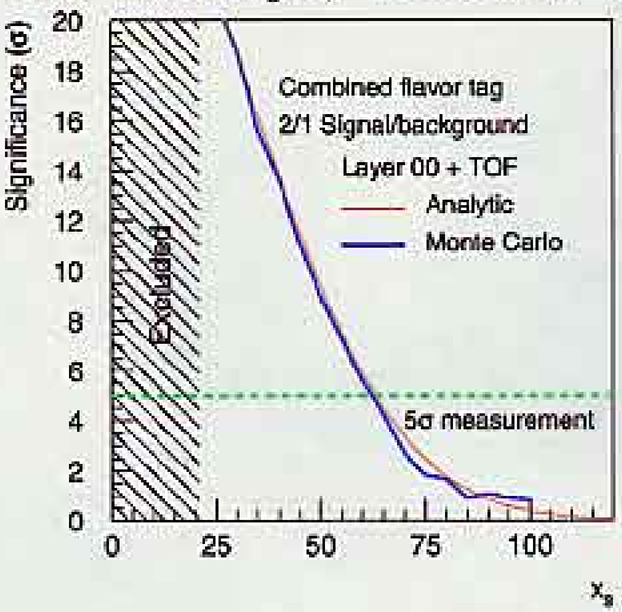
$N(B_s^0)$	S/B=2:1				S/B=1:2			
	Baseline	TOF	L00	TOF+L00	Baseline	TOF	L00	TOF+L00
5,000	30	36	40	49	21	30	27	39
10,000	37	42	49	56	30	36	40	49
20,000	42	47	56	63	37	42	49	56
30,000	45	50	61	67	40	45	53	60

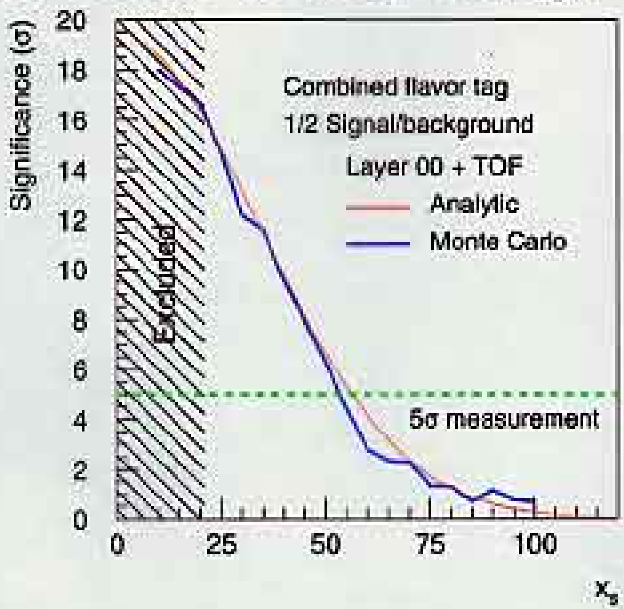
Minimum S:N required for 5σ observation

$N(B_s^0)$	$x_s = 30$				$x_s = 40$			
	Baseline	TOF	L00	TOF+L00	Baseline	TOF	L00	TOF+L00
5,000	2.20	0.53	0.61	0.24	—	—	2.20	0.53
10,000	0.52	0.21	0.23	0.11	—	1.01	0.52	0.21
20,000	0.21	0.10	0.10	0.05	0.99	0.34	0.21	0.10
30,000	0.13	0.06	0.07	0.03	0.50	0.20	0.13	0.06

B_s^0 Oscillation Sensitivity

On *average*, what is the limit of sensitivity?





$$\text{Maximum } x_s = \begin{cases} 63 & \text{for } S/B = 2:1 \\ 56 & \text{for } S/B = 1:2 \end{cases}$$

- Optimist:

  "5% of the time we could make a 5σ observation for $x_s = 73$!"

- Pessimist:

  "5% of the time we would fail to make a 5σ observation even if $x_s = 53$."

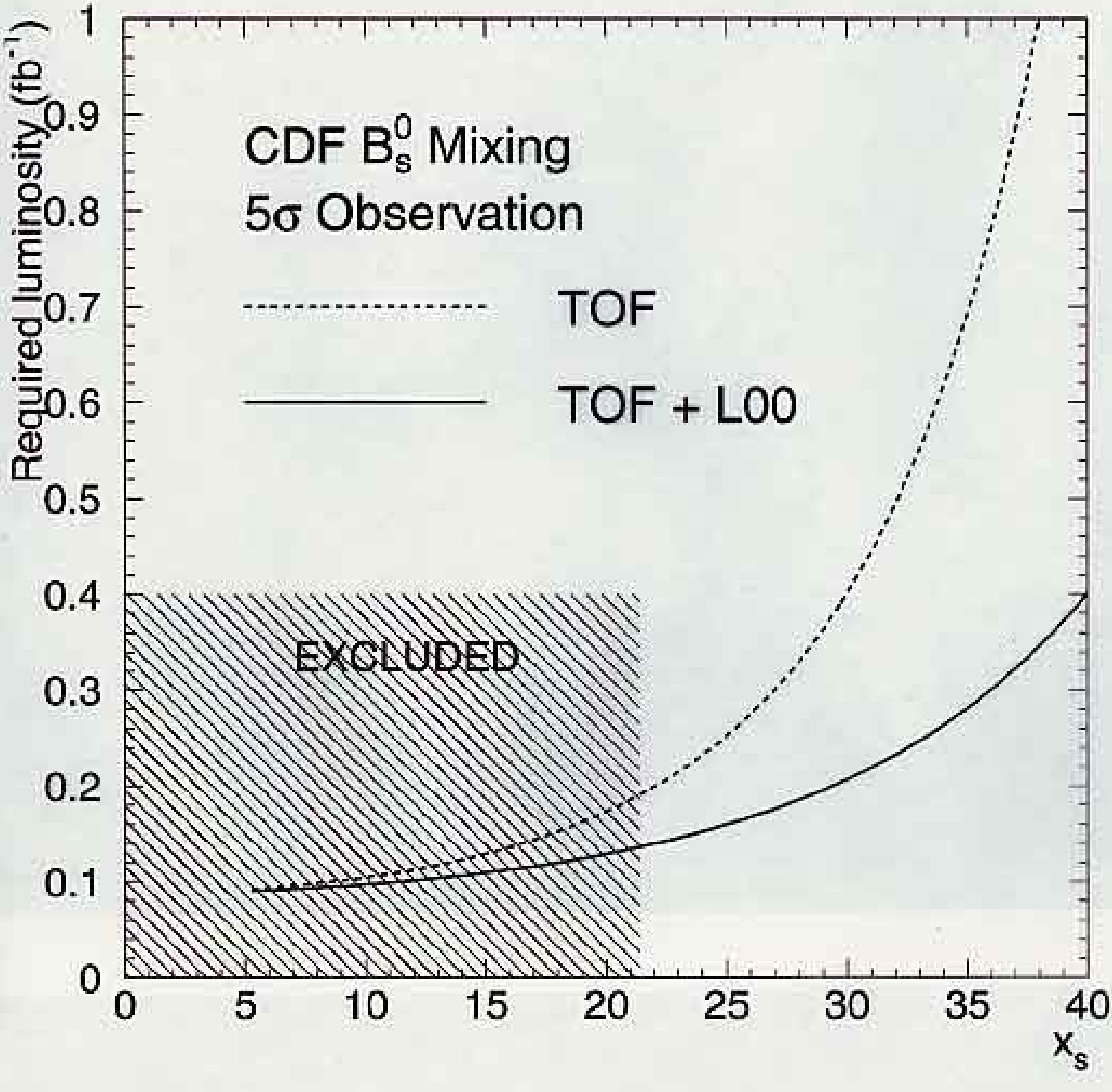
Global fits:

$$22.0 < x_s < 30.8 \text{ @ } 95\% \text{ C.L.}$$

B_s mixing

- Necessary for $|V_{ts}/V_{td}|$
- B_s flavor tagging:
  - { assume the same $\epsilon\mathcal{D}^2$ as for B^0
  - { OK for SLT, JetQ
  - { expect that Same Side Tagging tuned on Kaons will work better,
    but assume $\epsilon\mathcal{D}^2 \approx 2\%$ for now
    $\Rightarrow \epsilon\mathcal{D}^2 = 6.7\%$

- B_s data sample:
  1. use two-track trigger at Level 1 + Level 2
     ($p_T > 1.5$ GeV$/c$, $|d_0| > 150\mu$m)
  2. fully reconstruct B_s at Level 3
     Possibilities:
     - { $B_s \to D_s\pi$, $B_s \to D_s 3\pi$
     - { $B_s \to D_s^*\pi$, $B_s \to D_s^* 3\pi$
     - { Expect $\approx 24,000$ B_s candidates
  3. option: opposite side lepton
     (reduces the rate $\Rightarrow$ loosen up cuts)



Required luminosity (fb^{-1})
CDF B_s^0 Mixing
5σ Observation
TOF
TOF + L00
EXCLUDED
x_s
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40

Measuring $\Delta\Gamma_s$ in $J/\psi\phi$

- $\Delta\Gamma_s$ related to Δm_s (in S.M.!) by a scale factor independent of CKM:

$$\frac{\Delta\Gamma_s}{\Delta m_s} = -\frac{3\pi}{2}\frac{m_b^2}{m_t^2}\frac{\eta_{QCD}^{\Delta\Gamma_s}}{\eta_{QCD}^{\Delta m_s}}$$

- two-component lifetime fit in $B_s \to \nu\ell D_s$ measures $\Delta\Gamma_s$

or...

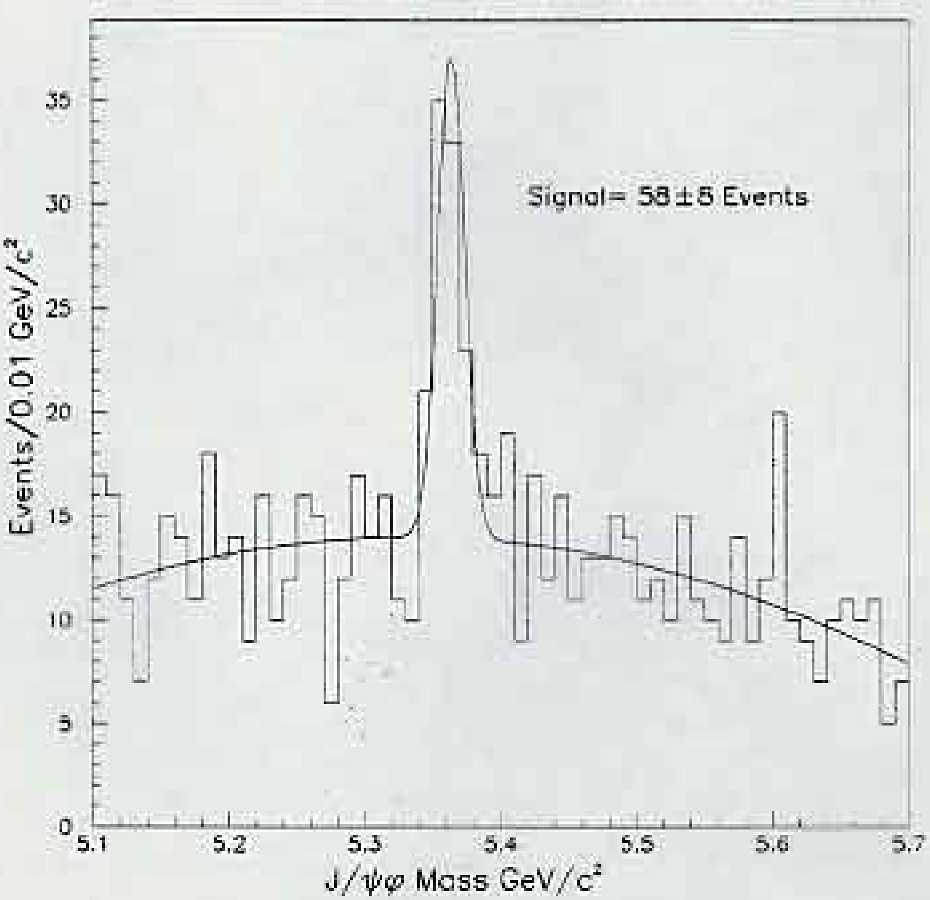
- determine CP composition of $B_s \to J/\psi\phi$ by helicity analysis, and
- measure lifetime of each CP component in $B_s \to J/\psi\phi$

Y.Grossman : *if lower limit on Δm_s and upper limit on $\Delta\Gamma_s$ miss each other $\Rightarrow$ New Physics*

$\tau(B_s^0)$ from $B_s^0 \to J/\psi\phi$

F. Abe *et al.*, Phys. Rev. Lett. **77**, 1945 (1996).

$$\tau(B_s^0) = 1.34^{+0.23}_{-0.19} \pm 0.05 \text{ ps}$$



Also:

CP-odd composition: $|A_\perp|^2 = 0.126^{+0.121}_{-0.093} \pm 0.028$

78 ± 13 events in 110 pb^{-1}, S/N = 1.6

expect ~8,000 in 2 fb^{-1}

$\mathcal{A}_{CP}(t)$ in $J/\psi\phi$

- Analogous to $B^0 \to J/\psi K_s$ (no penguins!)
- CP violation in B_s sensitive to some models beyond SM

  (B_s has no light quarks but mixes)
- CP asymmetry in $B_s \to J/\psi\phi$ proportional to η

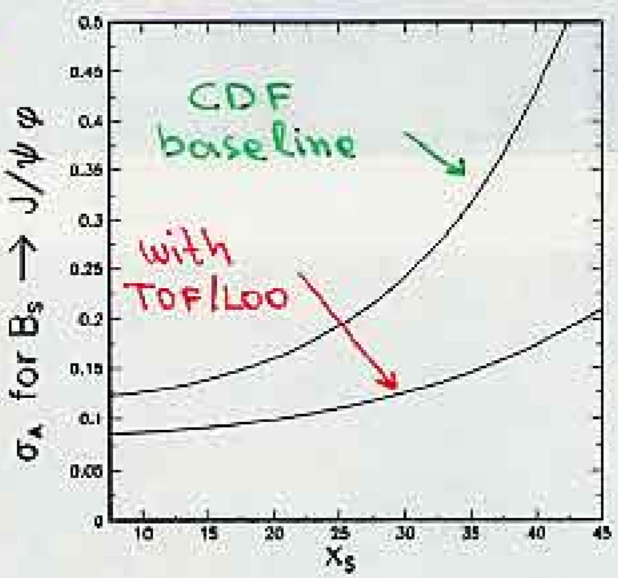
  (apex of unitarity triangle)
- SM expectations: very small

  $\Rightarrow$ *if $\mathcal{A}_{CP}$ is large, New Physics*
- needs: same as for B_s mixing:

  good tagging + good proper time resolution
- prerequisite: observation of B_s mixing

CP even fraction
0.77 ± 0.19

with 15 fb⁻¹
at $x_s = 25$
σ_A : 0.03–0.06
depending on
CP content of
final state



$\sigma_A \sim 0.1$ @ $x_s = 25$
2 fb^{-1}

B Rare Decay rates at CDF–Conservative

$$N(B_d \to K^{*0}\gamma) =$$

$$(170 \pm 50) \times \frac{\int L}{2fb^{-1}} \times \frac{Br(B_d \to K^{*0}\gamma)}{4.5 \times 10^{-5}}$$

$$N(B_s \to K^{*0}\gamma) = (12 \pm 4) \times \frac{\int L}{2fb^{-1}} \times \frac{Br(B_d \to K^{*0}\gamma)}{4.5 \times 10^{-5}}$$

$$N(\Lambda_b \to \Lambda\gamma) = (4.0 \pm 1.7) \times \frac{\int L}{2fb^{-1}} \times \frac{Br(\Lambda_b \to \Lambda\gamma)}{4.5 \times 10^{-5}}$$

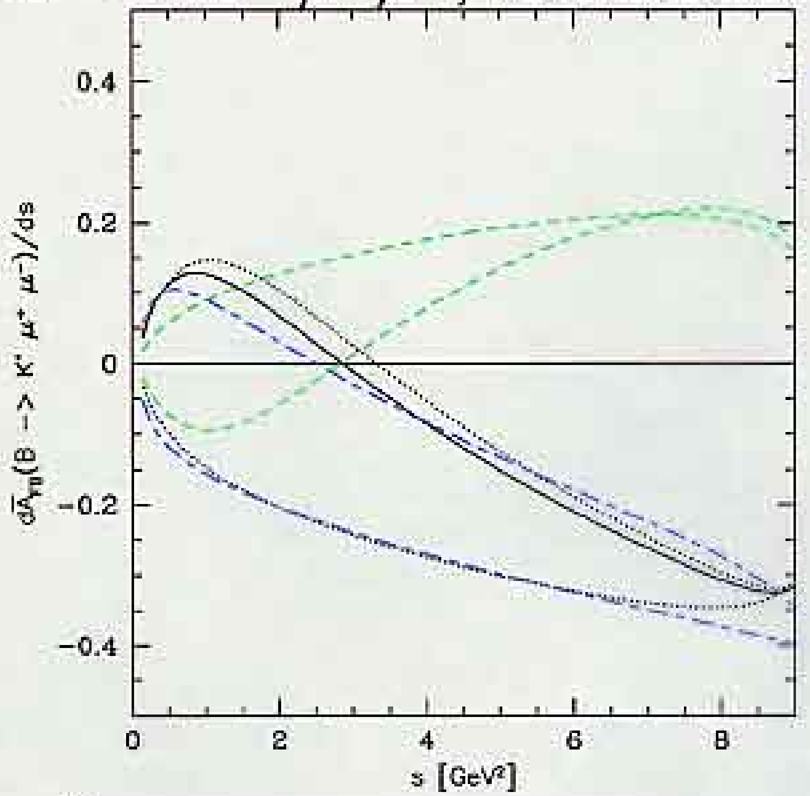
$$N(B_d \to K^{*0}\mu\mu) =$$
$$(59 \pm 12) \times \frac{\int L}{2fb^{-1}} \times \frac{Br(B_d \to K^{*0}\mu\mu)}{1.5 \times 10^{-6}}$$

$$Sensitivity(B_d \to \mu\mu) = 3.5 \times 10^{-9} \times \frac{2fb^{-1}}{\int L}$$

$$Sensitivity(B_s \to \mu\mu) = 1.0 \times 10^{-8} \times \frac{2fb^{-1}}{\int L}$$

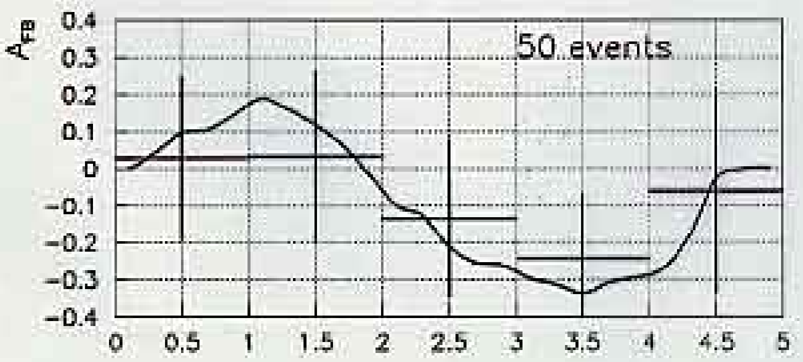
Rare B Decays

$B^0 \to K^{*0}\mu^+\mu^-$, **Forward-Backward Asymmetry**

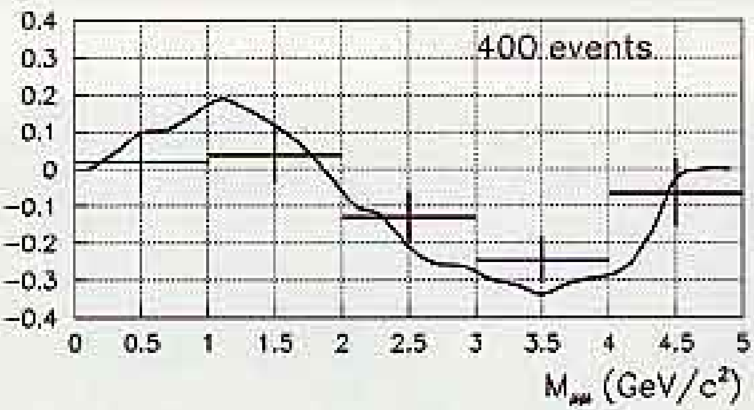


Predicted A$_{FB}$

- **SM, solid line**
- **SUGRA, dotted**
- **MIA-SUSY, dashed**



- **Expected A$_{FB}$, CDF**
- **S/B=1**

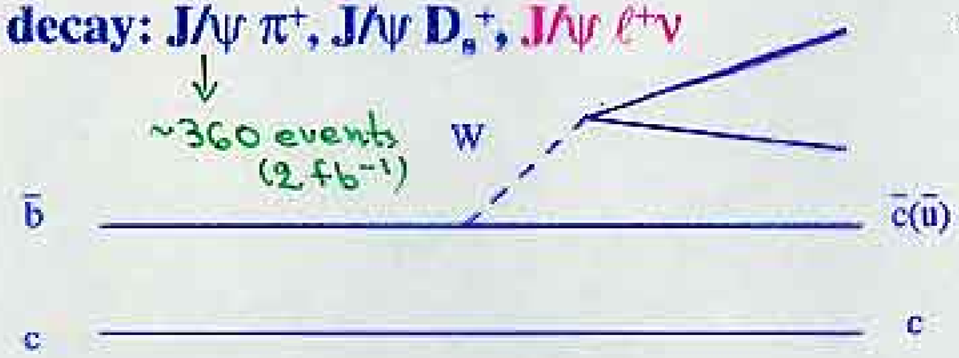


Bc+ meson

Decay Properties

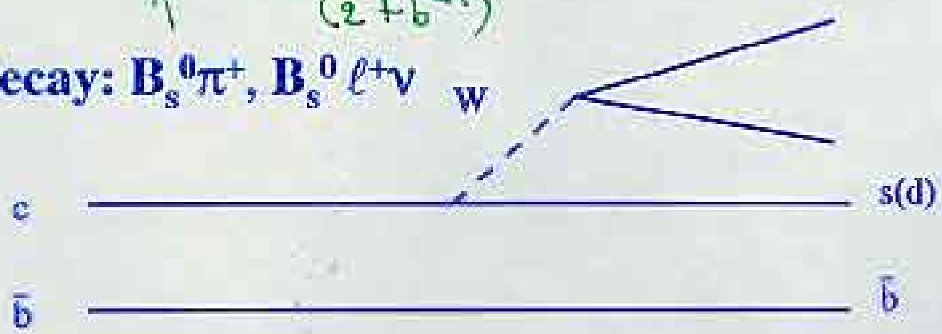
- **Three dominant processes:** ~800 events (2 fb^{-1})
  - ***b* decay: J/ψ π$^+$, J/ψ D$_s^+$, J/ψ ℓ$^+$ν**

~360 events (2 fb^{-1})

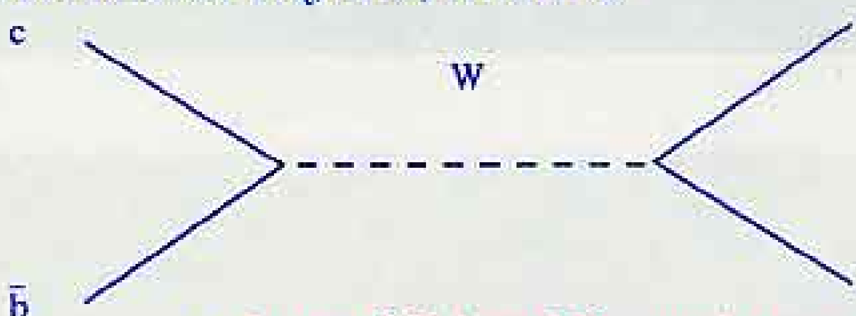


≲30 events (2 fb^{-1})

  - ***c* decay: B$_s^0$π$^+$, B$_s^0$ ℓ$^+$ν**



  - **Annihilation: τν$_τ$, DK, multi-π**



- **Large f(B$_c$) and V$_{cb}$ vertex ⇒ 400x larger annihilation width than for B$^+$**

Summary (con.)

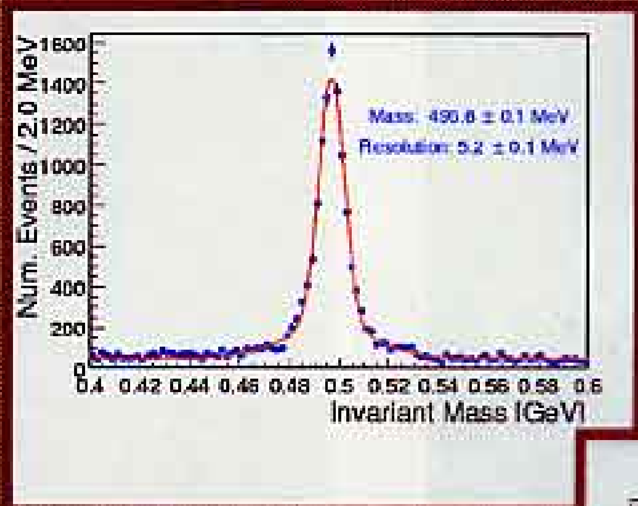
- First ~ 310 pb^{-1} by end of 2002
  - Establish basic physics program, understand detector performance
  - * B_s mixing; B *CP* violation studies; CKM matrix elements
  - First stage of new physics searches (follow up Run 1 anomalies)
- Increase integrated luminosity to > 2 fb^{-1} by 2004
  - Precision studies of top and W physics
  - Stringent tests of the SM and interesting indirect M_{Higgs} constraints
  - * Precision B physics program
  - Searches for SUSY and other new physics
- Proceed to highest attainable luminosity > 15 fb^{-1} by 2007+
  - * Push high precision B, W and top studies to the limit
  - Follow up previous discoveries or hints
  - Complete search for low mass Higgs

Conclusions-Summary

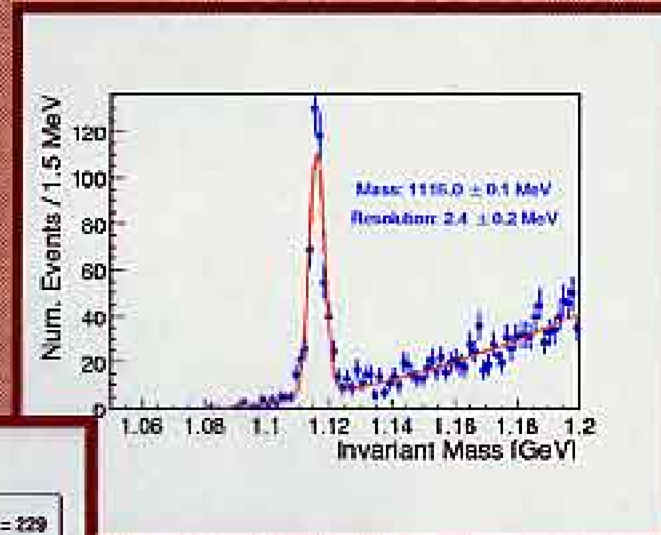
- B-Physics can be done in $p\bar{p}$ environment
- Measurement of $\sin(2\beta)$ to 0.02 (0.04)
- Observation of CP violation in $B^0 \to \pi^+\pi^-$, $B_s^0 \to K^+K^-$
- Measurement of $\sin\gamma$ to better than $\pm 3^0$ (10^0)
- Observation of B_s^0 mixing and precise determination of Δm_s
- Observation of CP asymmetry in $B_s^0 \to J/\psi\phi$, $J/\psi\eta'$
- Measurement of $\Delta\Gamma_s/\Gamma_s$ to 0.01
- Observation of exclusive B_c^+ modes
- Observation of radiative penguin decays
- Observation of rare decays $B^0 \to \mu\mu K^{*0}$ and $B^\pm \to \mu\mu K^\pm$
- Direct CP violation in $\Lambda_b \to pK, p\pi$. Expect an error on the asymmetry of about 2%

Preparing for Physics

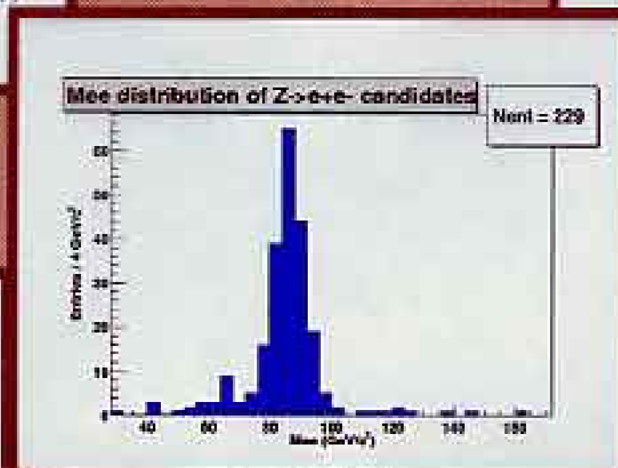
$K^0 \rightarrow \pi^+ \pi^-$



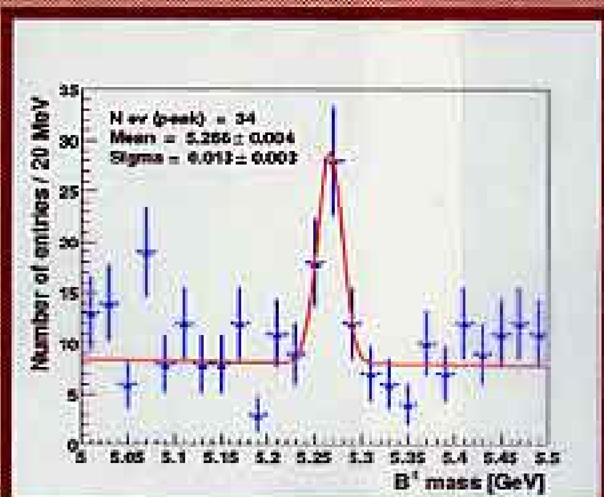
$\Lambda \rightarrow p\,\pi$



$Z \rightarrow e^+ e^-$



$B^\pm \rightarrow J/\psi\, K^\pm$



$J/\psi \rightarrow \mu^+ \mu^-$