# $B_s$ Mixing Studies at D0

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29th August, 2006

# OUTLINE

- Introduction
- Why study Bs mixing
- D0 Detector
- Trigger upgrade and Monitoring
- Analysis strategy
- Mass fitting procedure
- Electron tagging
- Bs Mixing in K*K channel
- Combined Bs mixing
- Conclusions

# The "Beauty"

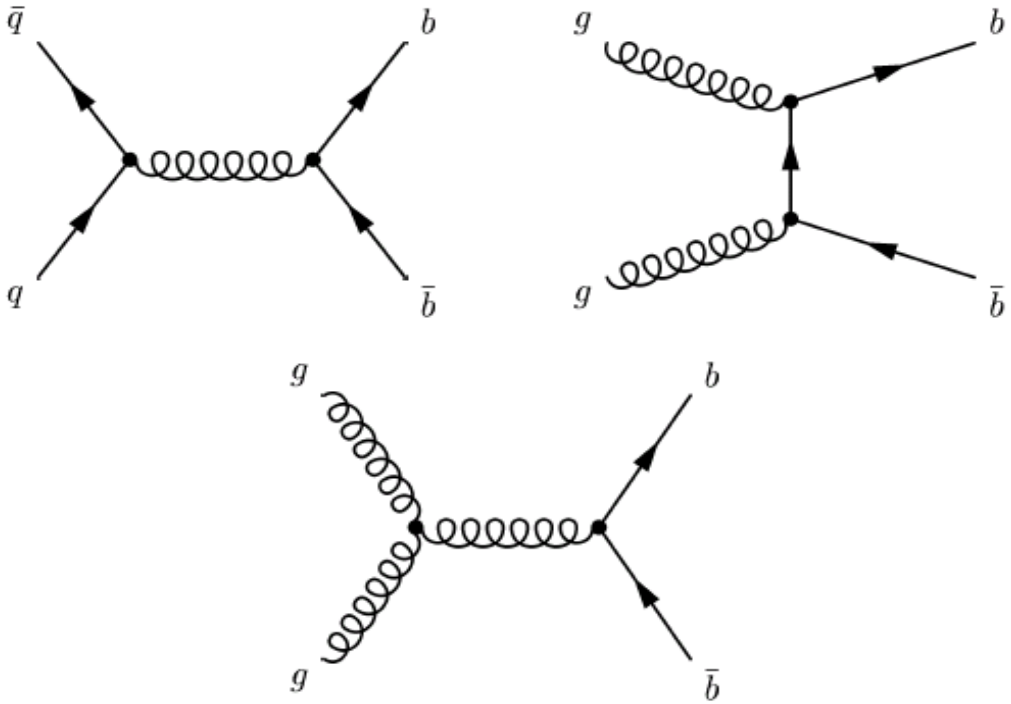
The "bottom" or the "b" quark

- Second Heaviest quark amongst the quark family
- Discovered at Fermilab in 1977, in a fixed target experiment.
- Produced at the Tevatron in abudance via three main processes:

✓ Direct production

✓ Gluon fragmentation

✓ Flavor excitation



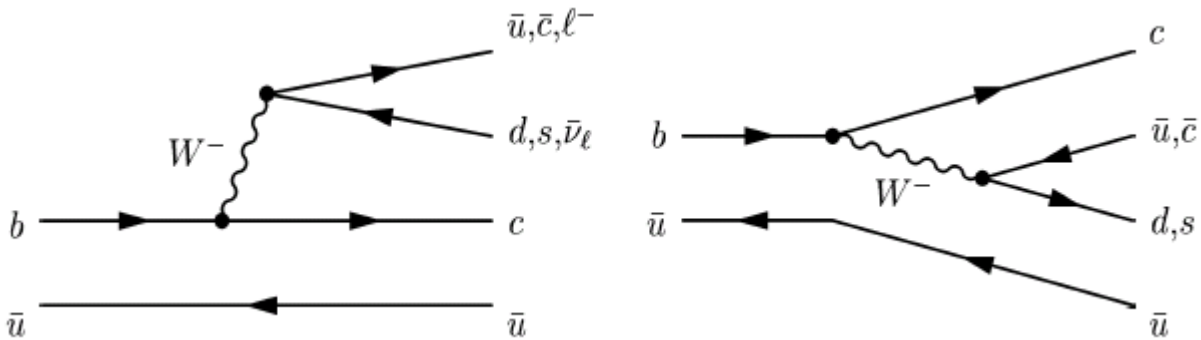
# B Hadron

B hadrons – Produced as a result of hadronization of b quark

| B meson | Composition | %age production | Lifetime (ps) |
|---|---|---|---|
| $B^+$ | $\bar{b}\,u$ | 38 | 1.671+-0.018 |
| $B^0$ | $\bar{b}\,d$ | 38 | 1.536+-0.014 |
| $B_s$ | $\bar{b}\,s$ | 10 | 1.461+-0.057 |
| $B_c$ | $\bar{b}\,c$ | 0.001 | 0.46+-0.16 |

Rest $\Lambda_b$ baryons

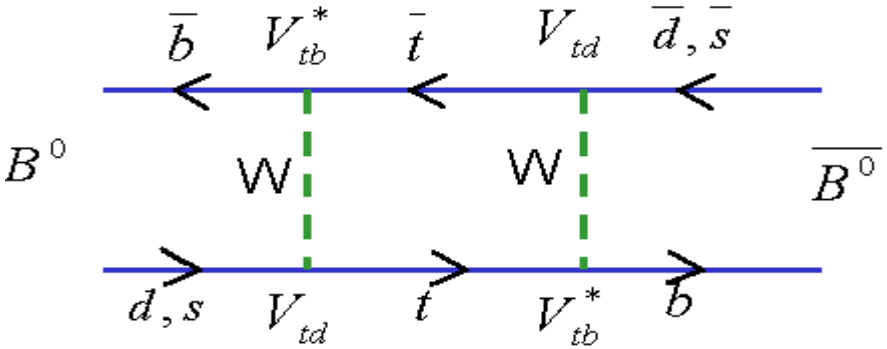
B hadrons decay via weak interaction – simplest description by spectator model



# Mixing

Mixing: The transition of neutral particle into it's anti-particle, and vice-versa

- First observed in the K meson system.
- In the B meson system, first observed in an admixture of $B^0$ and $B_s^0$ by UA1 and then in $B^0$ mesons by ARGUS in 1987.




These oscillations are possible because of the flavor-changing term of the Standard Model Lagrangian,

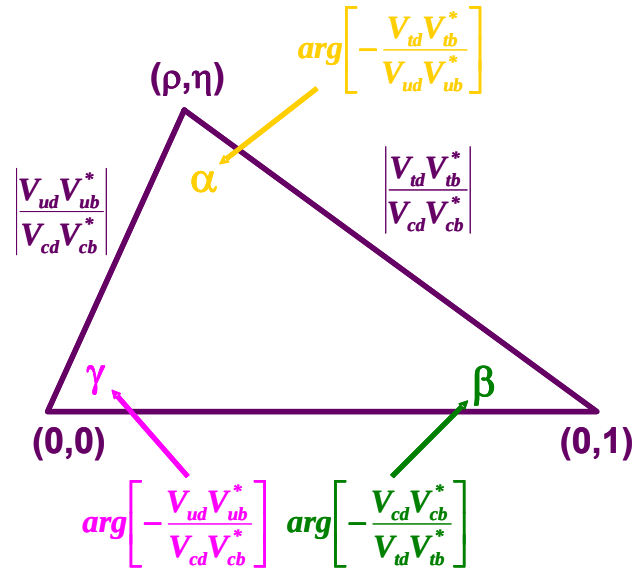
$$L = \frac{g}{\sqrt{2}} \left(\overline{u}, \overline{c}, \overline{t}\right)_L V_{CKM} \gamma_\mu \begin{pmatrix} d \\ s \\ b \end{pmatrix}_L W^\mu + h.c.$$

# CKM Formalism

Where $V_{CKM}$ is the CKM matrix;

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda(1+iA^2\lambda^4\eta) & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Wolfenstein parametrisation- expansion in $\lambda \sim 0.22$




CP violation in the Standard Model originates due to a complex phase in the CKM matrix (quark mixing).

$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$$

$$V_{ub} = |V_{ub}|\, e^{-i\beta}$$

$$V_{td} = |V_{td}|\, e^{-i\gamma}$$

$$-\frac{V_{ud}V^*_{ub}}{V_{cd}V^*_{cb}} - \frac{V_{td}V^*_{tb}}{V_{cd}V^*_{cb}} = 1$$

# Mixing in B mesons

Time evolution follows from a simple perturbative solution to the schrondinger's equation

$$i\frac{d}{dt}\begin{pmatrix}|B(t)>\\ |\bar{B}(t)>\end{pmatrix}=\begin{pmatrix}M_{11}-i\Gamma_{11} & M_{12}-i\Gamma_{12}\\ M_{21}-i\Gamma_{21} & M_{22}-i\Gamma_{22}\end{pmatrix}\begin{pmatrix}|B(t)>\\ |\bar{B}(t)>\end{pmatrix}$$

Light and Heavy B mesons mass eigenstates differ from flavor eigenstates:

$$|B_L>=p|B>+q|\bar{B}>$$

$$|B_H>=p|B>-q|\bar{B}>$$

$$\sqrt{p^2+q^2}=1$$

Eigenvalues are,

$$\lambda_{H,L}=m_{H,L}-\frac{i}{2}\Gamma_{H,L}$$

$$\Delta m=M_H-M_L \qquad \Delta\Gamma=\Gamma_L-\Gamma_H$$

# Mixing in B mesons

Time evolution of $B^0$ and $\overline{B^0}$ states

$$P(B \to B) = \frac{e^{-\Gamma t}}{2}\left(\cosh\frac{\Delta\Gamma t}{2} + \cos\Delta m t\right)$$

$$P(B \to \overline{B}) = \frac{e^{-\Gamma t}}{2}\left(\cosh\frac{\Delta\Gamma t}{2} - \cos\Delta m t\right)$$

In case $\Delta\Gamma \to 0$,

$$P_{u,m}(t) = \frac{1}{2}\Gamma e^{-\Gamma t}(1 \pm \cos\Delta m t)$$

$$\Delta m_d = \frac{G_F^2 m_t^2 \eta F(m_t^2/m_W^2)}{6\pi^2} m_{B_d} f_{B_d}^2 B_{B_d} |V_{td}^* V_{tb}|^2$$

Similar equation for $\Delta m_s$

$|V_{td}|$ from $\Delta m_d$ limited by ~15%

$f^2_{Bd}B_{Bd}$ = (228±30±10 MeV)$^2$

$\therefore$ consider ratio

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \frac{f_{B_s}^2 B_{B_s}}{f_{B_d}^2 B_{B_d}} \frac{|V_{ts}|^2}{|V_{td}|^2} = \frac{m_{B_s}}{m_{B_d}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}$$

$$\xi^2 = 1.21 \pm 0.02^{+0.035}_{-0.014}$$

2

# Why $B_s$ mixing is important

standard model Expectation:

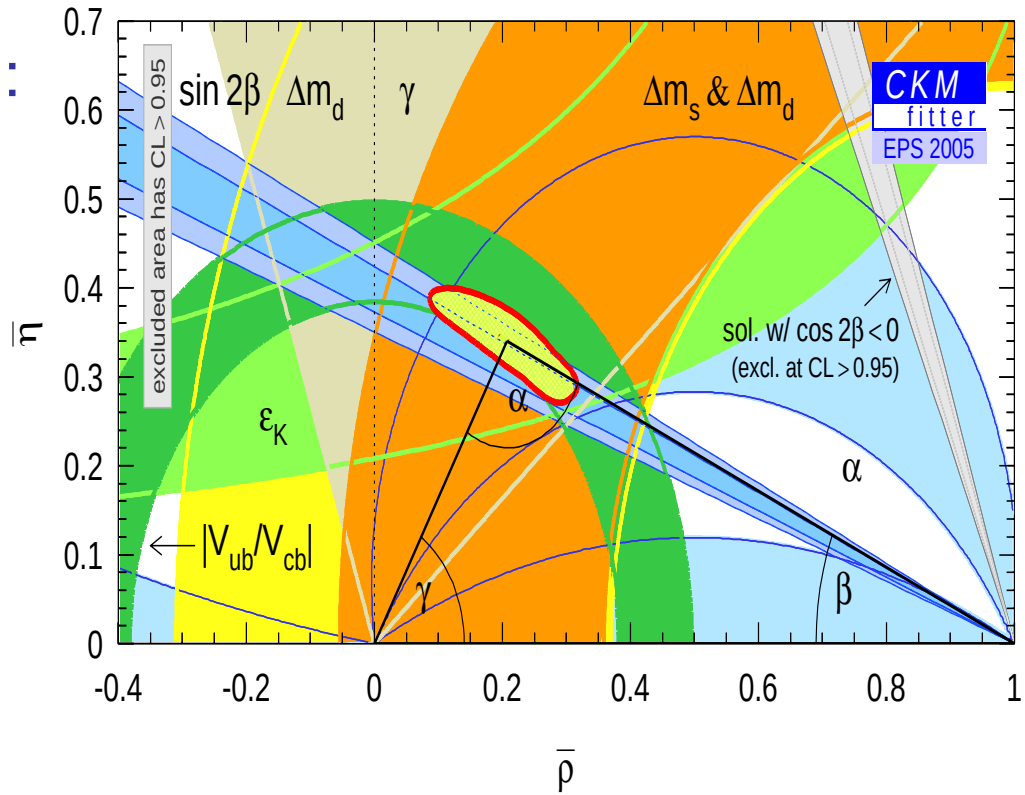
$\Delta m_s = 14 - 28 ps^{-1}$

$\Delta m_d = 0.5 ps^{-1}$

measurement of $\Delta m_s / \Delta m_d$

$\rightarrow V_{ts}/V_{td}$

constrain unitary triangle




Determine $|V_{ts}|/|V_{td}|$ ~ 5% precision

K mixing $\Rightarrow$ direct & indirect CPV

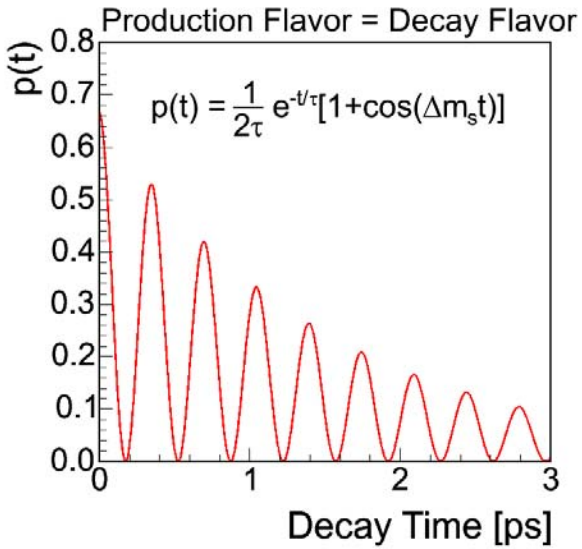
$B_d$ mixing $\Rightarrow$ heavy top mass

$\nu$ mixing $\Rightarrow$ neutrino mass $\neq 0$

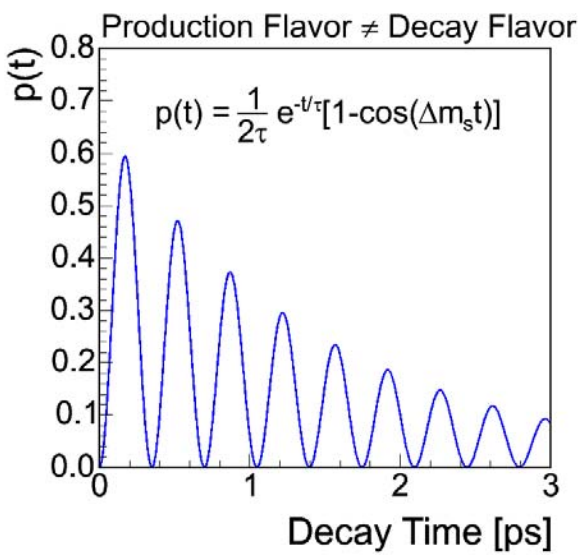
**$B_s$ mixing $\Rightarrow$ ????**

# In an Ideal Scenario..

"Opposite sign"

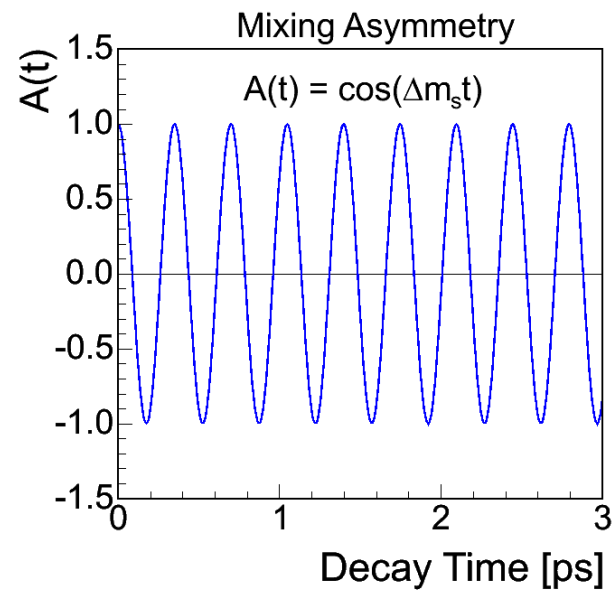



"Same sign"




Oscillations with amplitude = 1.0 and Frequency = Δms.

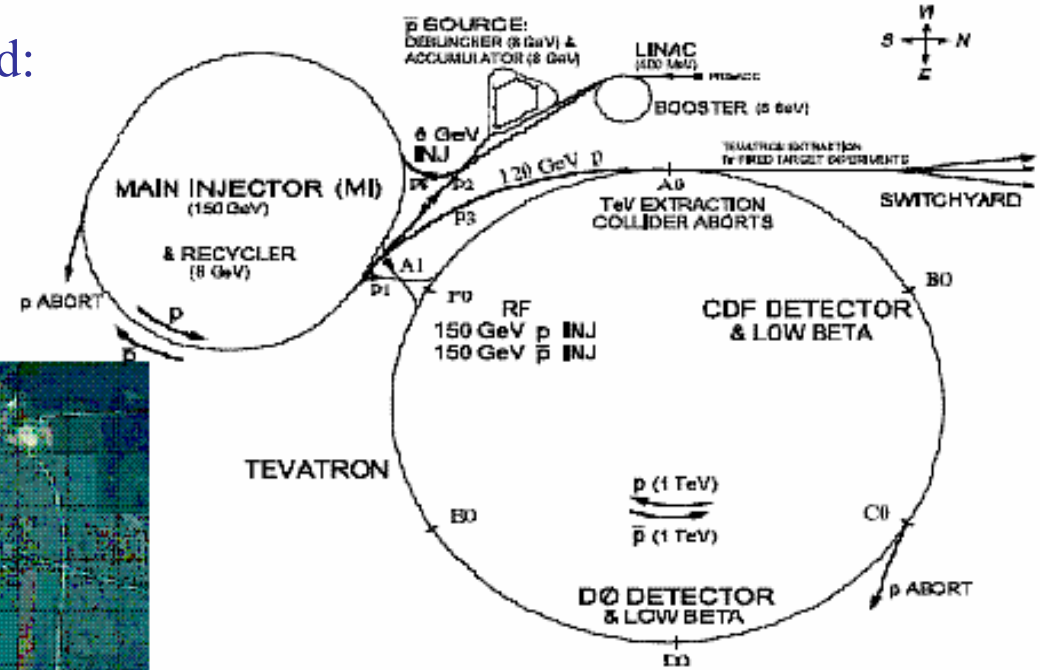
$$A_i(t) = \frac{N_{OS} - N_{SS}}{N_{OS} + N_{SS}}$$

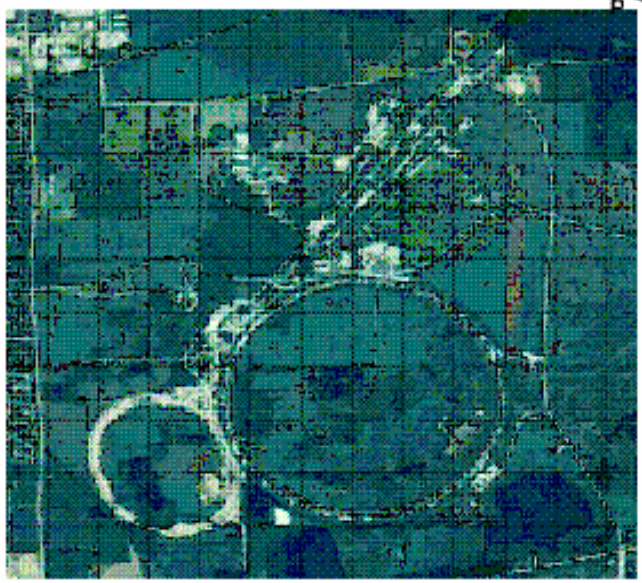


# Fermilab Tevatron

Highest Luminosity achieved:

$1.9 \times 10^{32}$ cm$^{-2}$/s



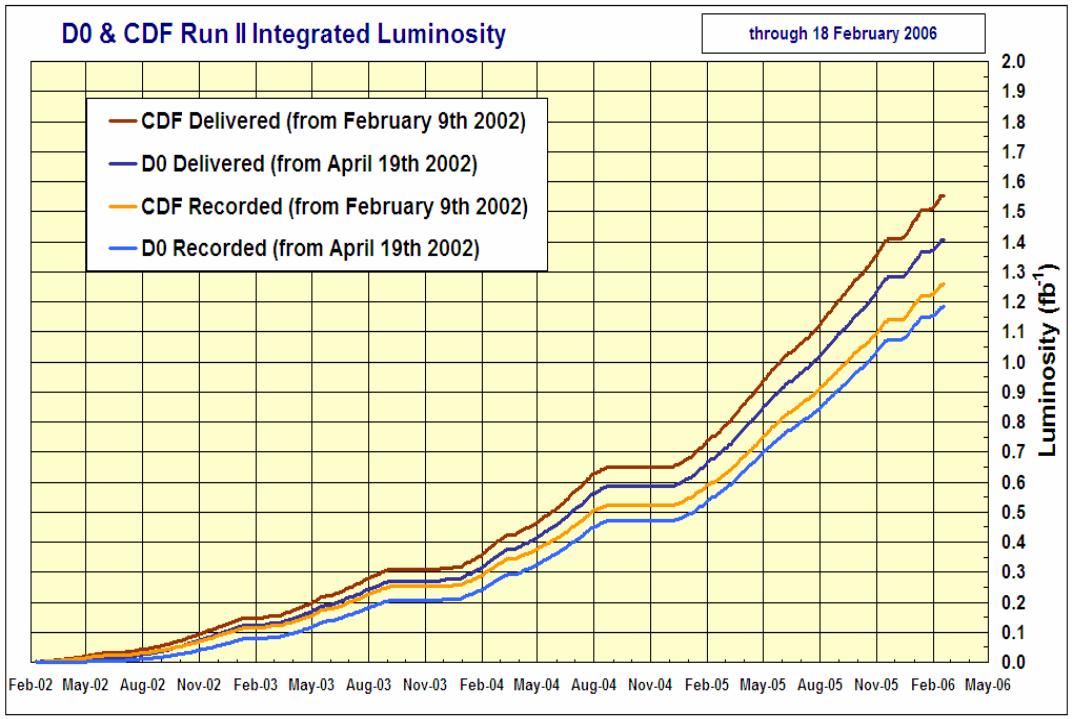
Expected: 2 – 3 x $10^{32}$ cm$^{-2}$/s

$\Rightarrow$ 4-8 fb$^{-1}$ before LHC

All B species produced including Bs mesons

# Data Taking

Excellent performance by the Tevatron and we are doubling our data set every year.




$Pb^{-1}$

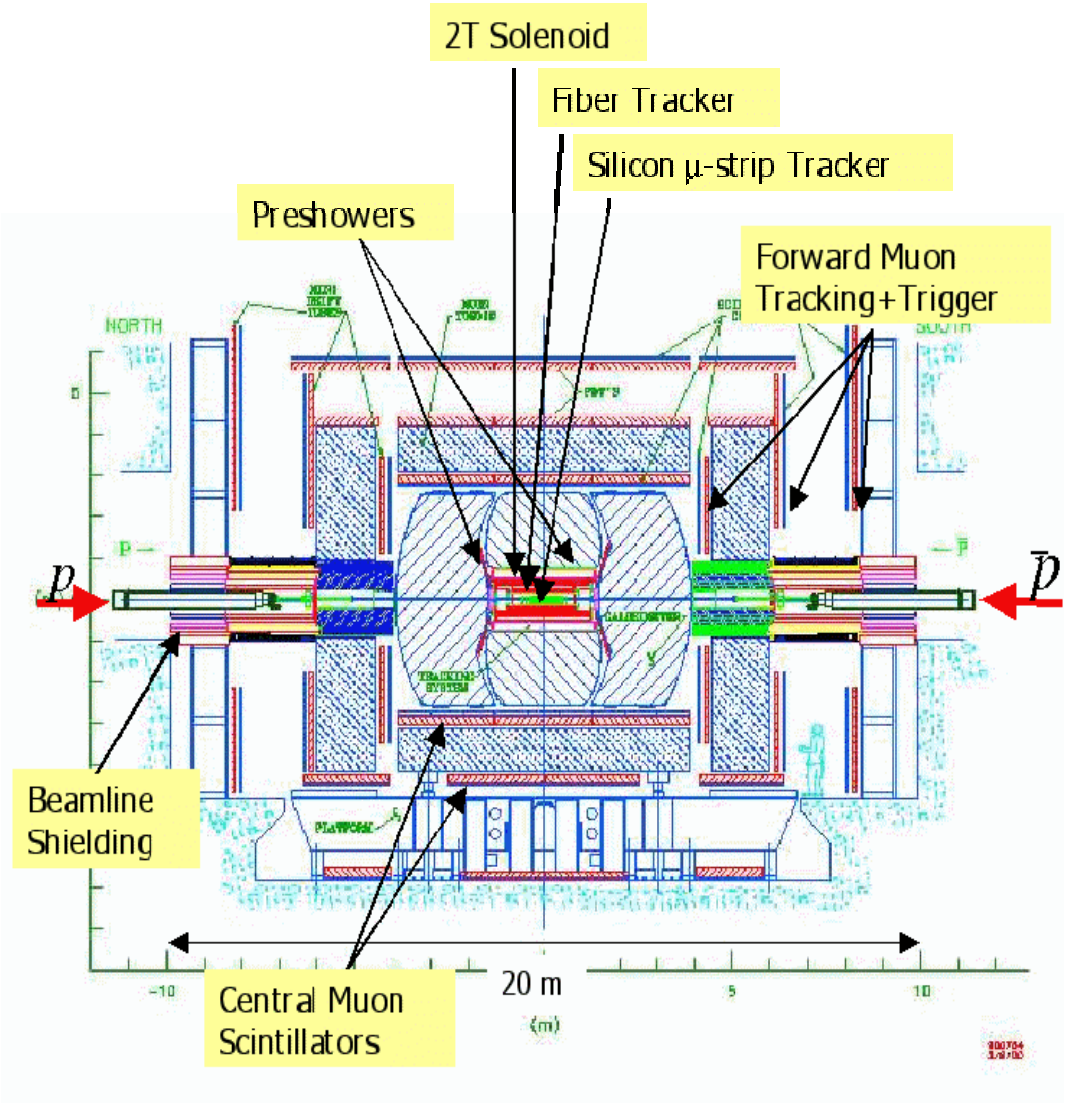
Data taking efficiency is ~ 85%.

We already have collected about 10 times of run 1 data.

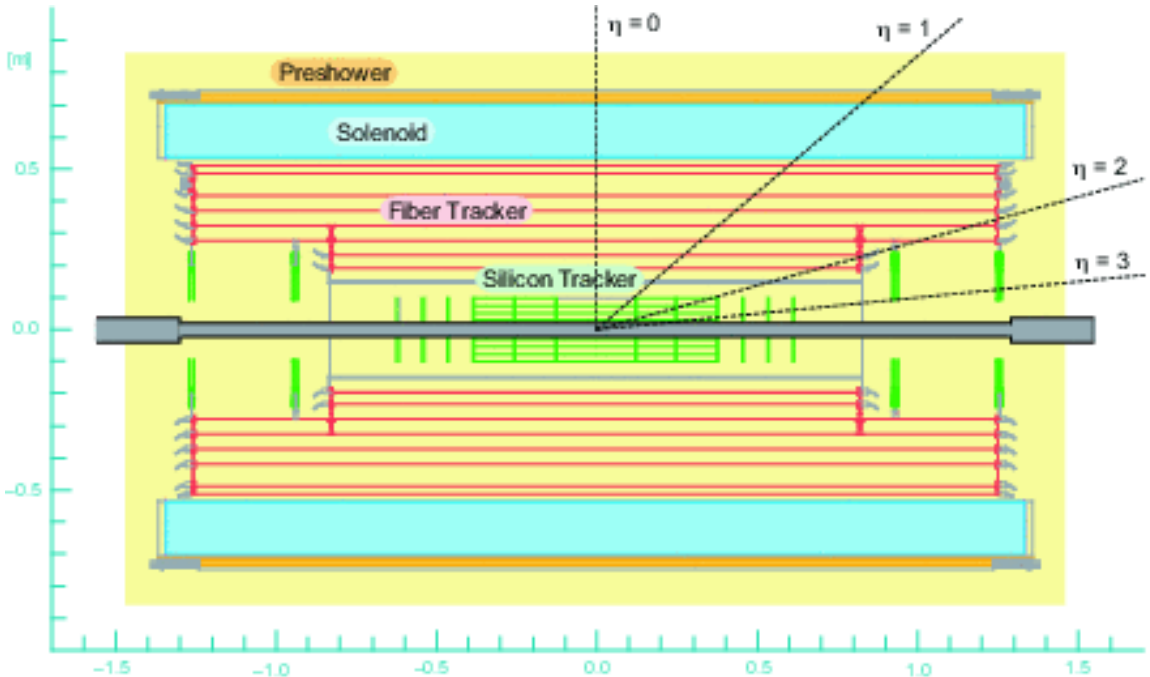
# D0 Detector

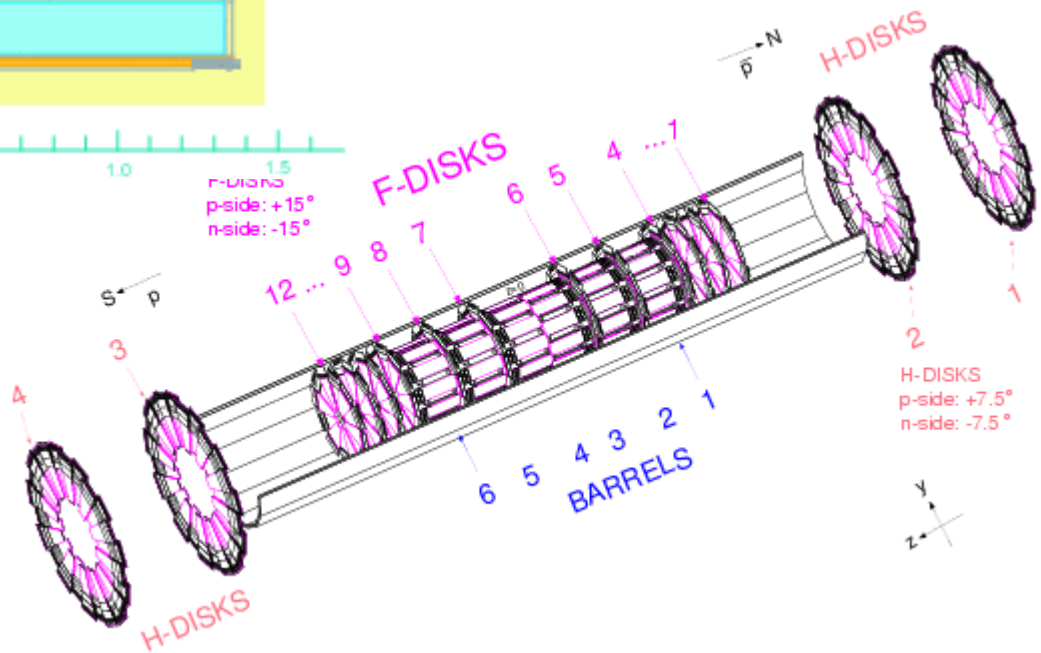
- 2T solenoid
- Fiber Tracker
  - 8 double layers
- Silicon Detector
  - up to $|\eta|\sim3$
- forward Muon + Central Muon detectors
  - excellent coverage $|\eta|<2$

EM and Hadronic Calorimeter



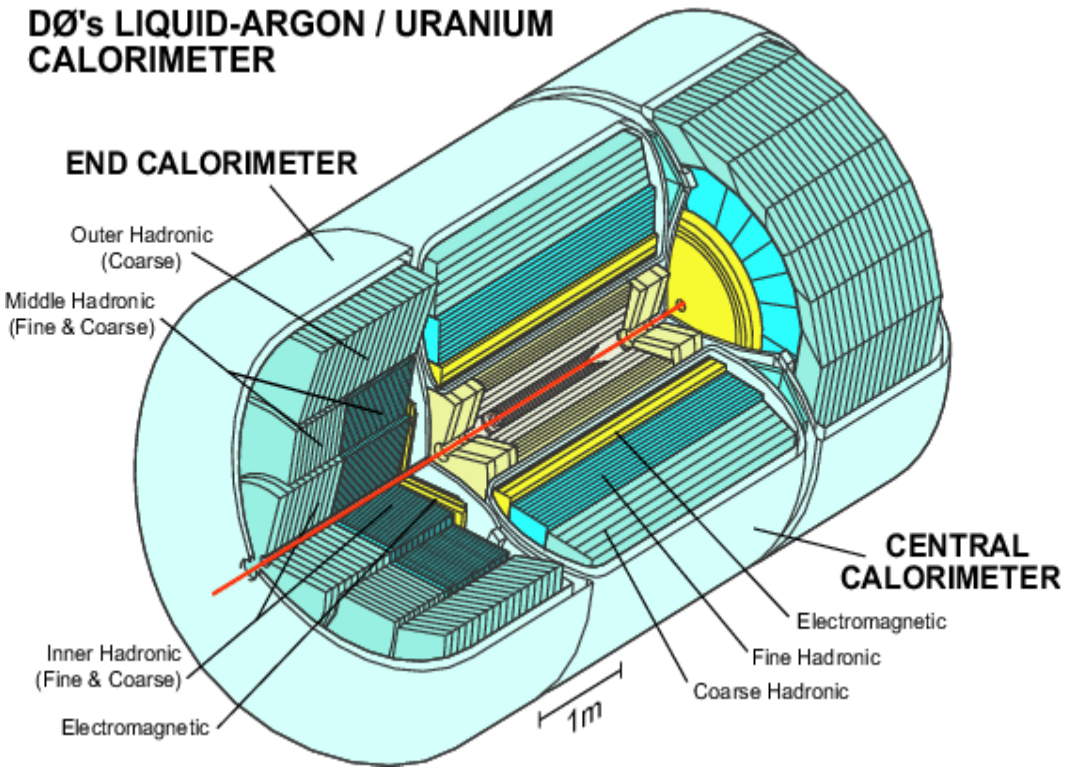
# D0 Tracking System

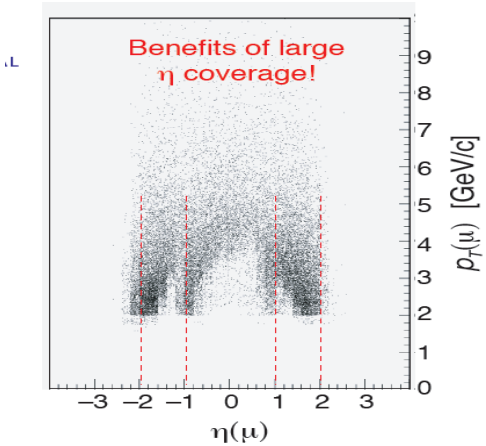


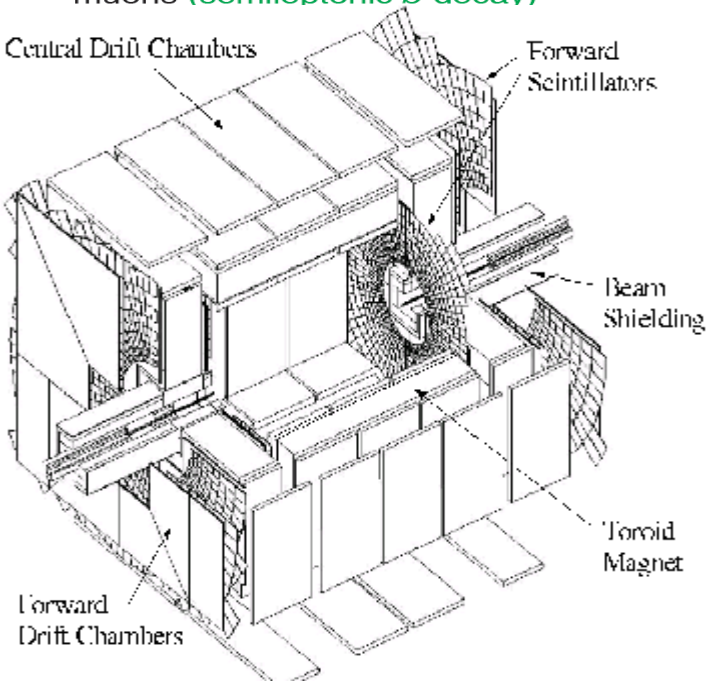

- 6 barrels: 4 layers, single/double sided
- Single hit resolution of 10 μm, S/N > 10
- Tracking out to $|\eta| \sim 3$ ($\theta \sim 6^0$)
- Layer "0" installed at r ~ 1.7 cm

# Calorimeter and Muon System




Triggered *and* reconstructed muons (semileptonic *b* decay)




Single inclusive muon triggers $|\eta|<2.0$, $P_T>3,4,5$ GeV

Muon + track match at Level1 and muon at L2.

Dimuon trigger: Other muon for flavor tagging

At low luminosity 15 -20 X $10^{30}$ $cm^{-2}/s$: 25 Hz out of 50 Hz at L3

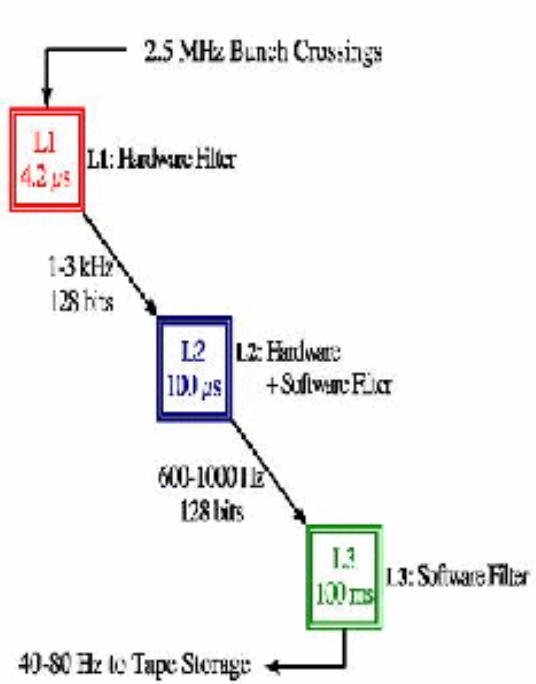
# D0 Trigger System

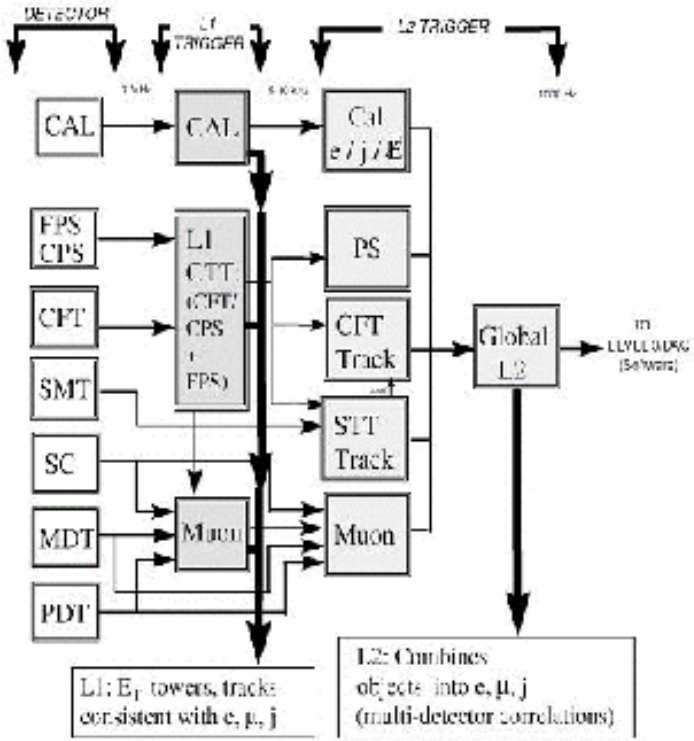
1.7 M Collisions/Second – Not all interesting

Three Level of Trigger system – To select events of interest

Muon Triggers:

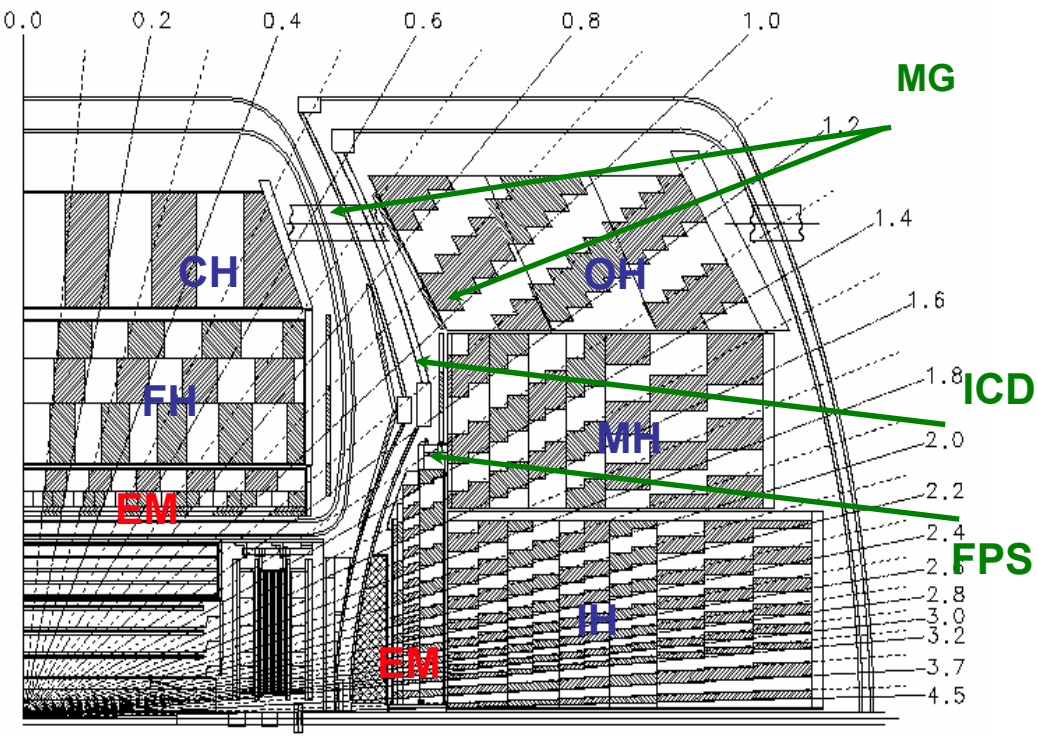
Single and double muon triggers are un-prescaled at low luminosities and prescaled or turned off at medium and higher luminosities.




Level 1 Calorimeter trigger upgraded completely this summer

# CALORIMETER CUT VIEW




- Transverse segmentation
  $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
- At shower max. (EM3)
  $\Delta\eta \times \Delta\phi = 0.05 \times 0.05$

| Layer | CC |
|---|---|
| EM1,2,3,4 | $X_O$ : 2,2,7,10<br>3mm Ur |
| FH1,2,3 | $\lambda_O$ : 1.3,1.0,0.9<br>6mm Ur |
| CH1 | $\lambda_O$ : 3.0<br>46.5mm Cu |

Make Optimal use of fine granulairty of the D0 calorimeter

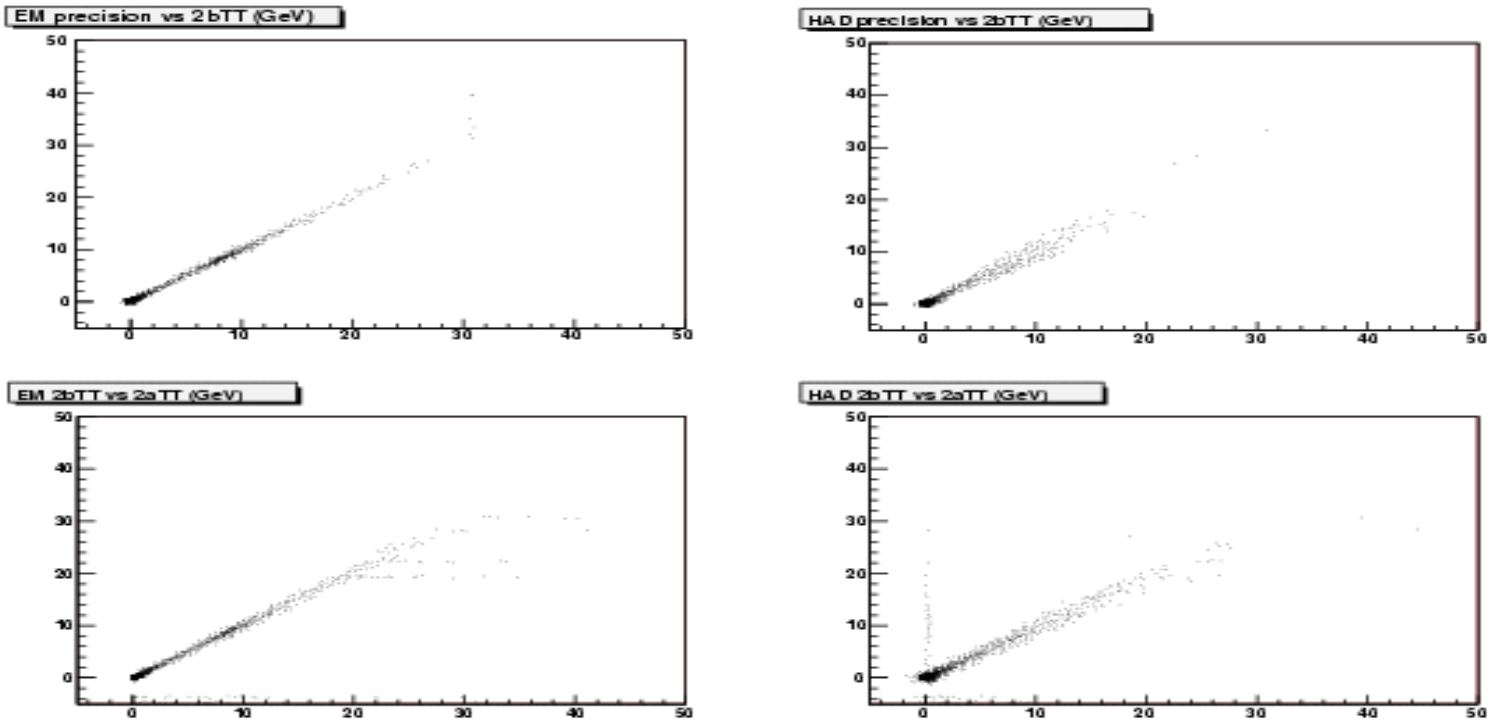
# Level -1 Cal Trigger

Four Adjacent calorimeter towers ⟶ Trigger Tower

Total of 1280 EM and 1280 Hadronic TTs.

Upgraded in order to:

- Cope with the high luminosity in RunIIb
- Correctly assign the bunch crossing number, Sharper turn on curve, etc.



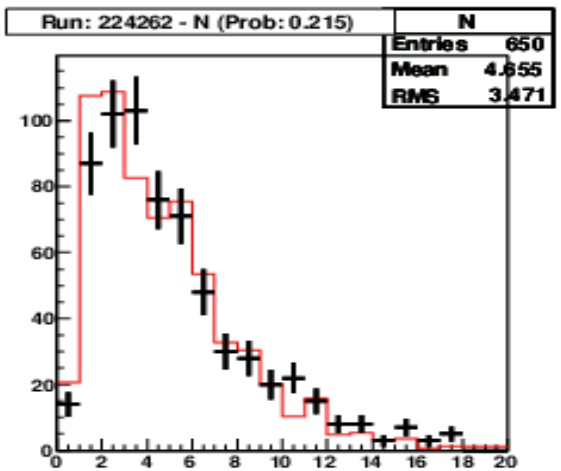
# Online Monitoring

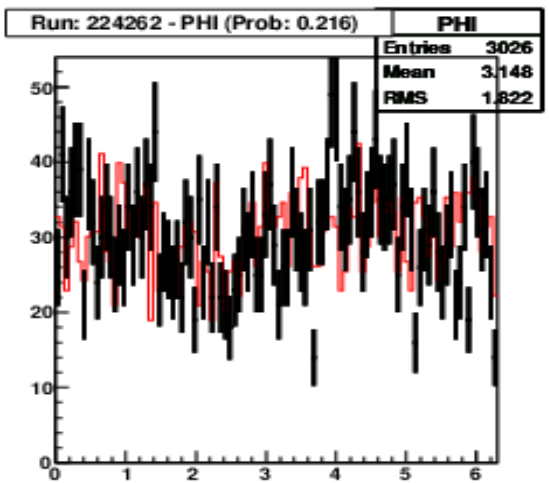
Once we have our detector and trigger running, we reconstruct the data online in real time and display the distribution of high level physics objects using a suite of software called “Global Monitoring”.

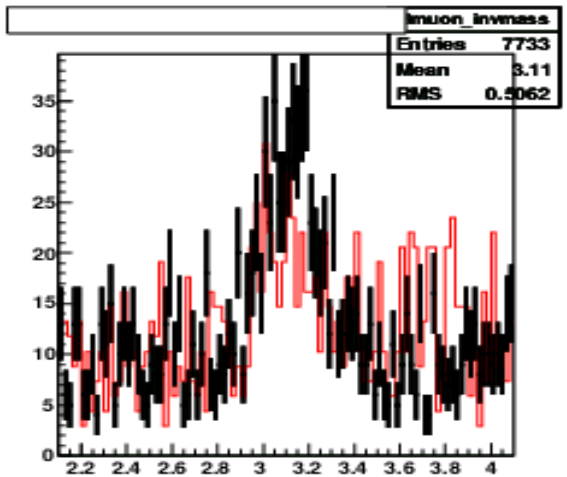
Two examines runnig 24X7 and the plots monitored by the shifter.

Trigger examine: monitor the triggers by reconstructing the triggered objects.

Physics Examine: Monitor the physics part by reconstructing the physics objects like electrons, muons, etc.



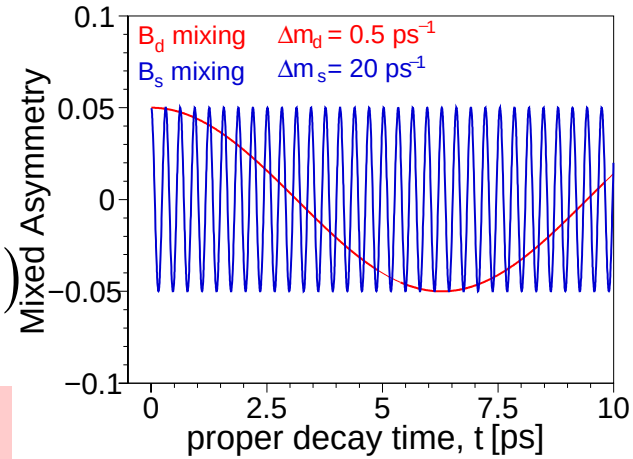



# Analysis strategy

❖Measuring $B_s$ oscillations is much more difficult than $B_d$ oscillations because of the fast mixing frequency.

In order to measure,

$$A_{mix}(t) = \frac{N_{unmix}(t) - N_{mix}(t)}{N_{unmix}(t) + N_{mix}(t)} = D * \cos(\Delta m_s t)$$




$$sensitivity \propto \sqrt{\frac{S}{S+B}} \sqrt{\frac{N\varepsilon D^2}{2}} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}}$$

We need to:

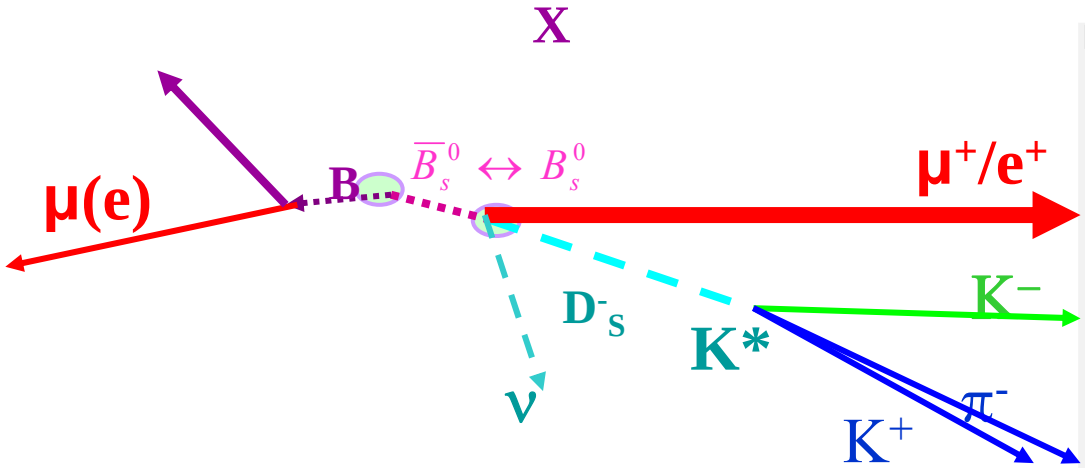
**Reconst-ruction** → Reconstruct the $B_s$ signal.

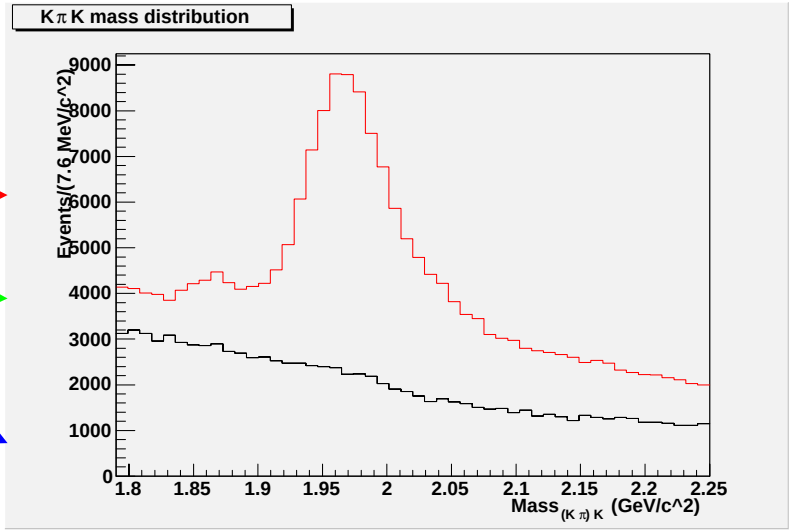
**Flavor tagging** → Know the flavor of the meson at it's production time (Flavor tagging) and get $\varepsilon D^2$

$$\varepsilon = \frac{N_R + N_W}{N} \qquad D = \frac{N_R - N_W}{N}$$

**Proper time** → Proper decay length resolution

$$sensitivity \propto \sqrt{\frac{S}{S+B}}\sqrt{\frac{N\varepsilon D^2}{2}}e^{-\frac{(\Delta m_s \sigma_t)^2}{2}}$$




# Signal Selection

Look for tracks displaced from primary vertex in same jet as μ/electron

- ❖ Two tracks should form a vertex and be consistent K* mass (K*K → KKπ)
- ❖ KKπ invariant mass should be consistent with Ds mass

# Mass Fitting

Large reflection due to mis-identification of kaon and pion.

Event by event fit based on the dependence of mass shift which depends on kinemetic properties of the event.

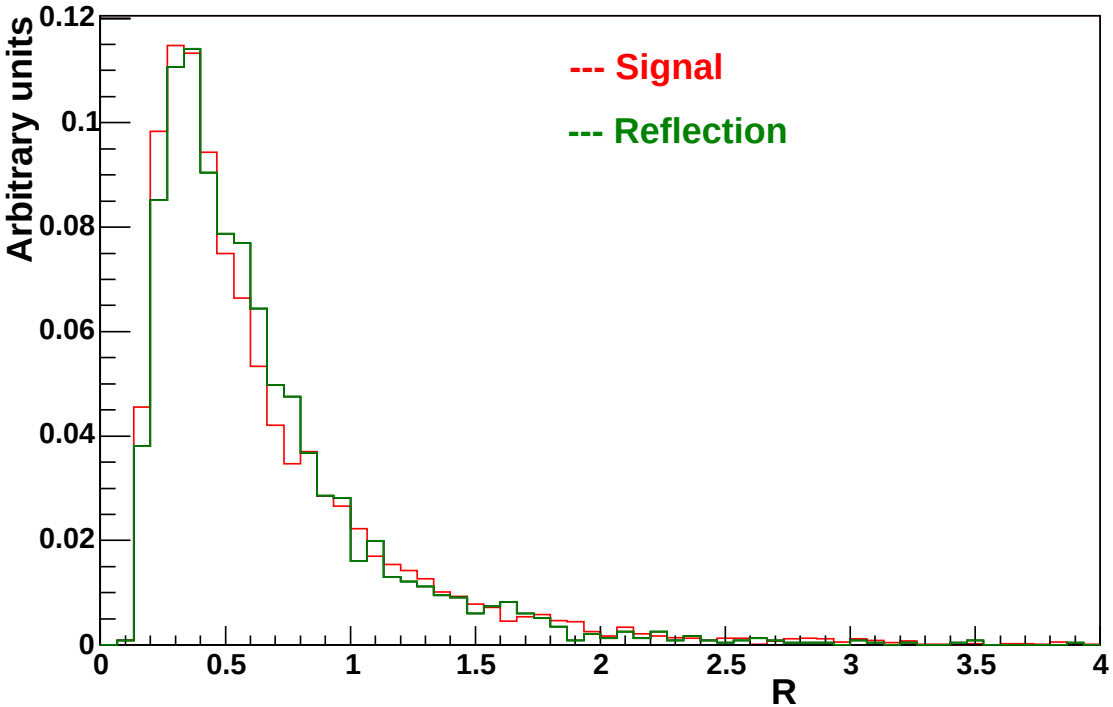
The Reflection variable R is given as

$$R = E_{k\pi}(E_k - E_\pi) / (M_k^2 - M_\pi^2)$$

For a given $E_{k\pi}$ and $p_{tr}$ (= $p_k$ or $p_\pi$), R is constant

For a given $E_{k\pi}$ and $P_{tr}$, the mass distribution of reflection is determined only by the detector resolution so can be approximated by a simple Gaussian.

# Reflection Variable R

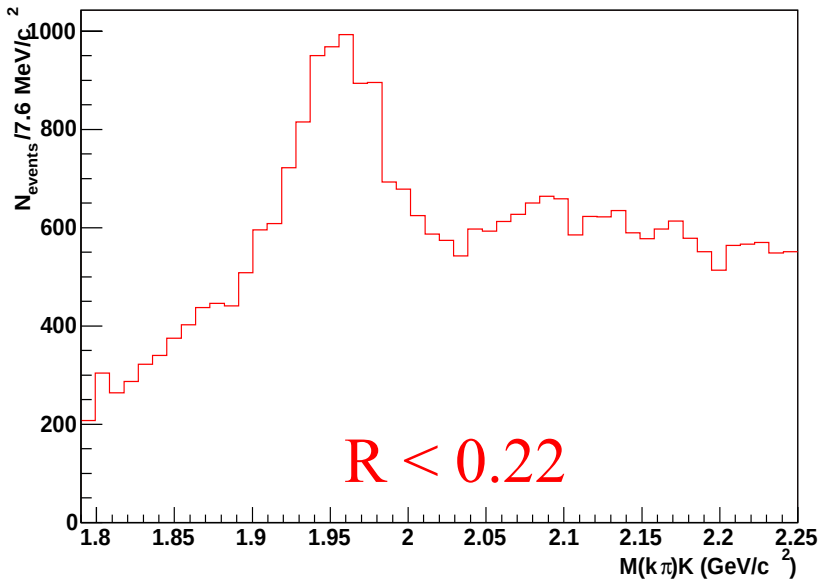


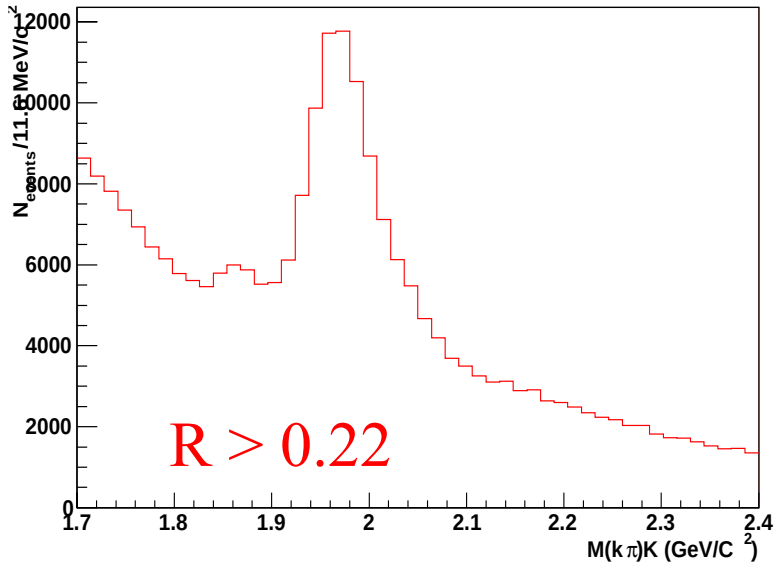

Distribution of R for signal and reflection MC

Both signal and $D^{+} \rightarrow k^{+}\pi^{-}\pi^{+}$ has similar distribution for R

# Background function

Background is highly dependent on the variable R and can not be fit with a simple function.



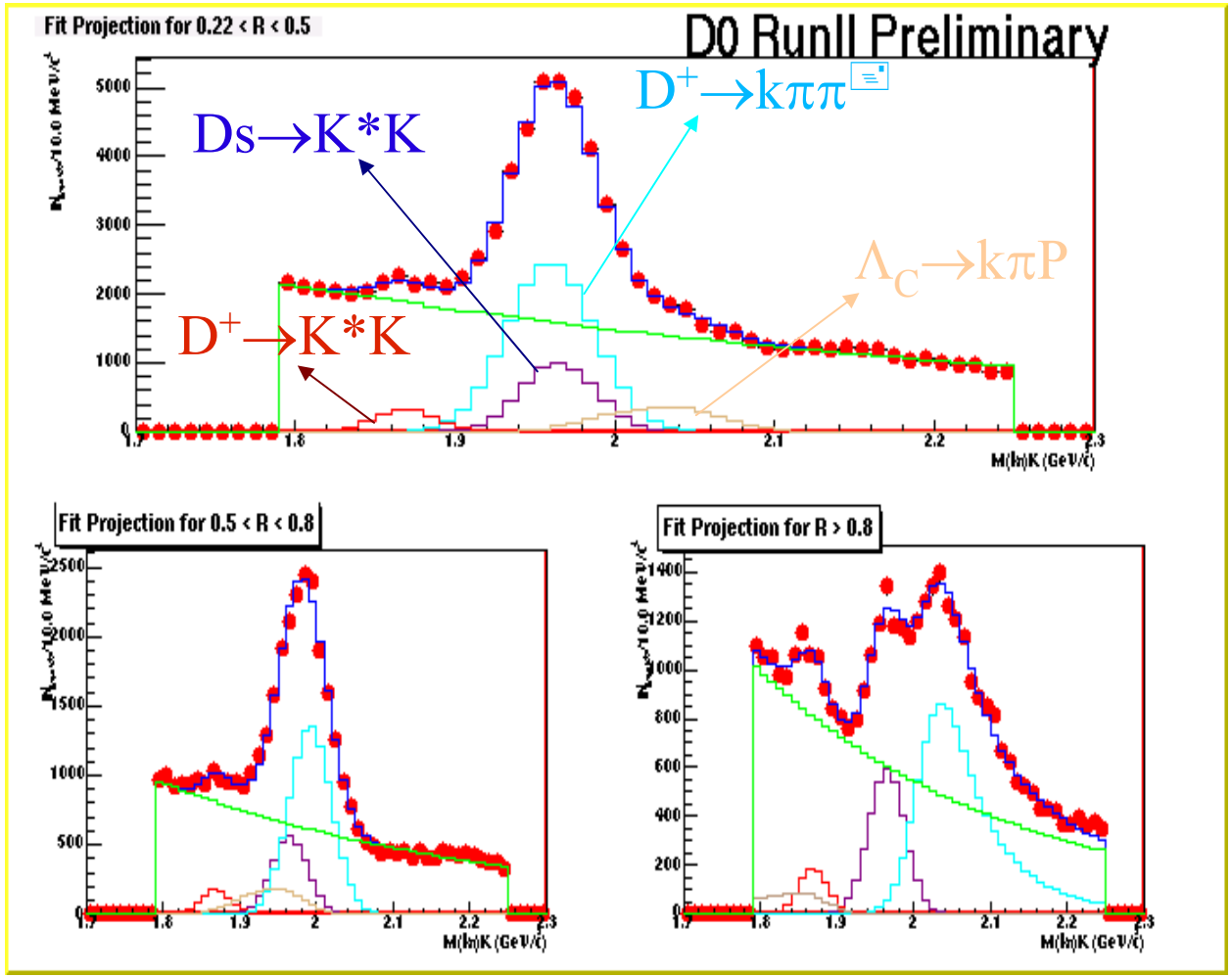




For R > 0.22, background is approximated with an exponential and parametrized as

exp (-M/M0);

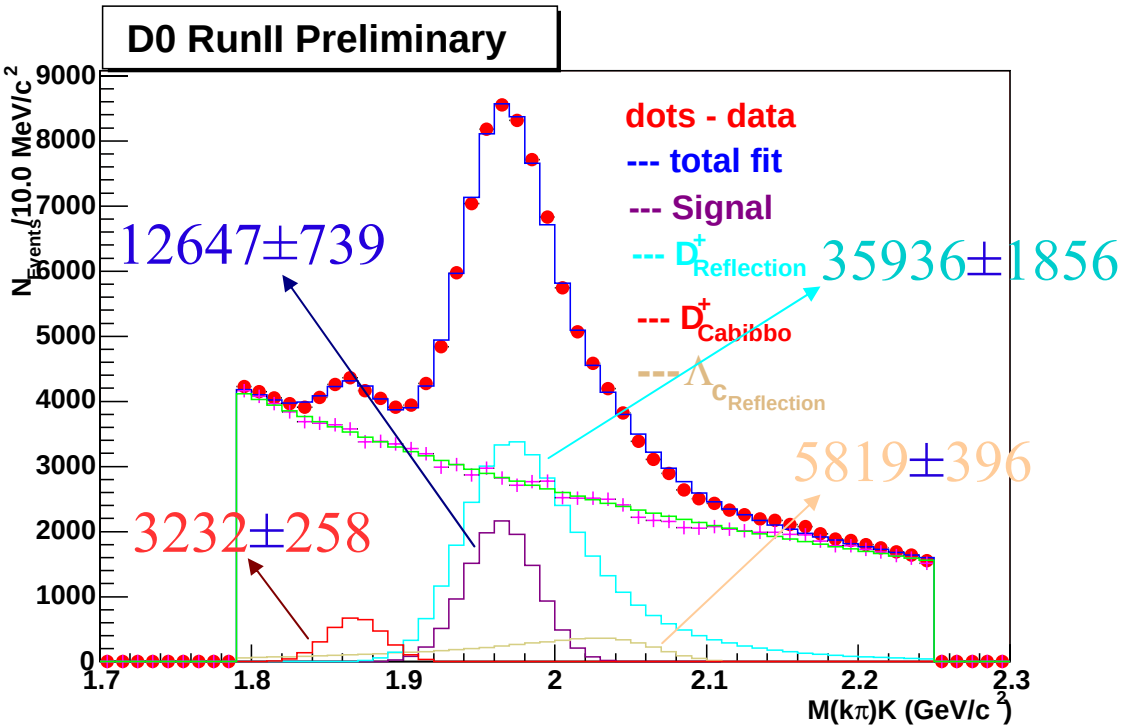
M0 = A0+A1*R+A2*R*R+A3*R*R*R+A4*R*R*R*R

# Fit projections for untagged in R bins




Fraction of background changes as a function of R

# Total Untagged




$Ds \rightarrow K^*K$

1.9647±0.0006307

0.02576±0.000058

$D^+ \rightarrow k\pi\pi$

1.86034±0.00025

0.023347±0.00062

$D^+ \rightarrow K^*K$

1.86881±0.00138

0.01877±0.00115

$\Lambda_C \rightarrow k\pi P$

2.2779±0.000911

0.02281±0.00092

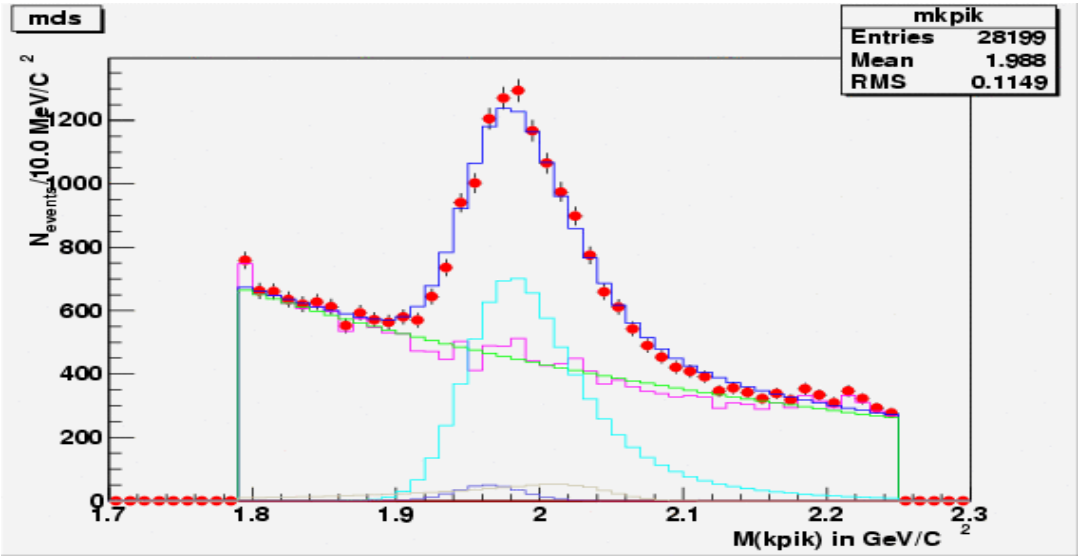
All Run IIA data ~ 1.2 fb$^{-1}$

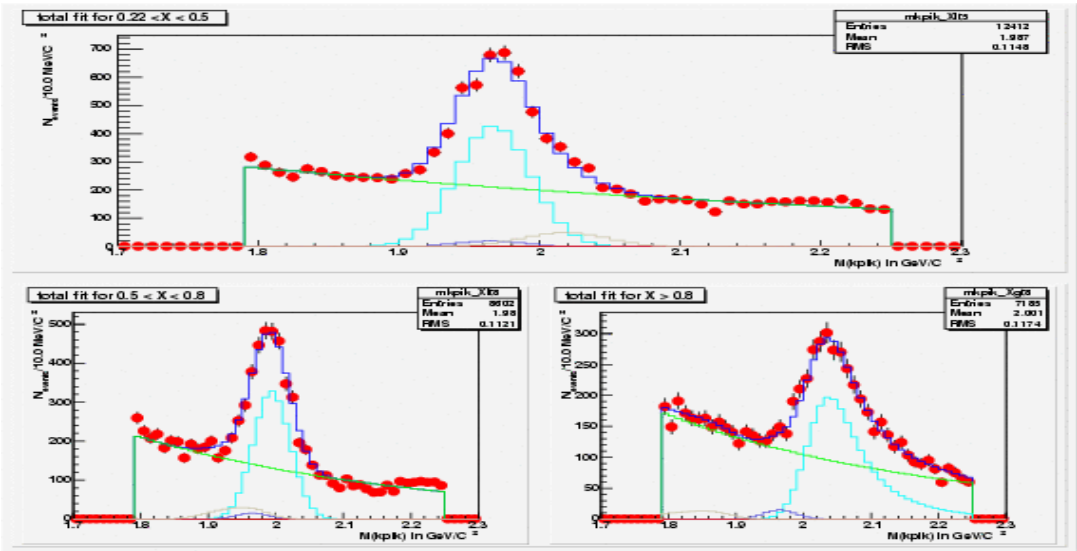
Fit only for R > 0.22

# Total untag for M(kπ) > 1.0 GeV

For M(Kπ) > 1.0 GeV, all the signal events are supposed to be rejected.

If the fitting technique is correct then this should reveal in the fit for the M(kπ) > 1 .0 GeV sample.



$$sensitivity \propto \sqrt{\frac{S}{S+B}} \boxed{\sqrt{\frac{N\varepsilon D^2}{2}}} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}}$$

Reconst-ruction

Flavor tagging

Proper time

**Soft Lepton Tagging (μ or e):**

- Charge of the leptons provides the flavor of b.

**Jet Charge Tagging:**

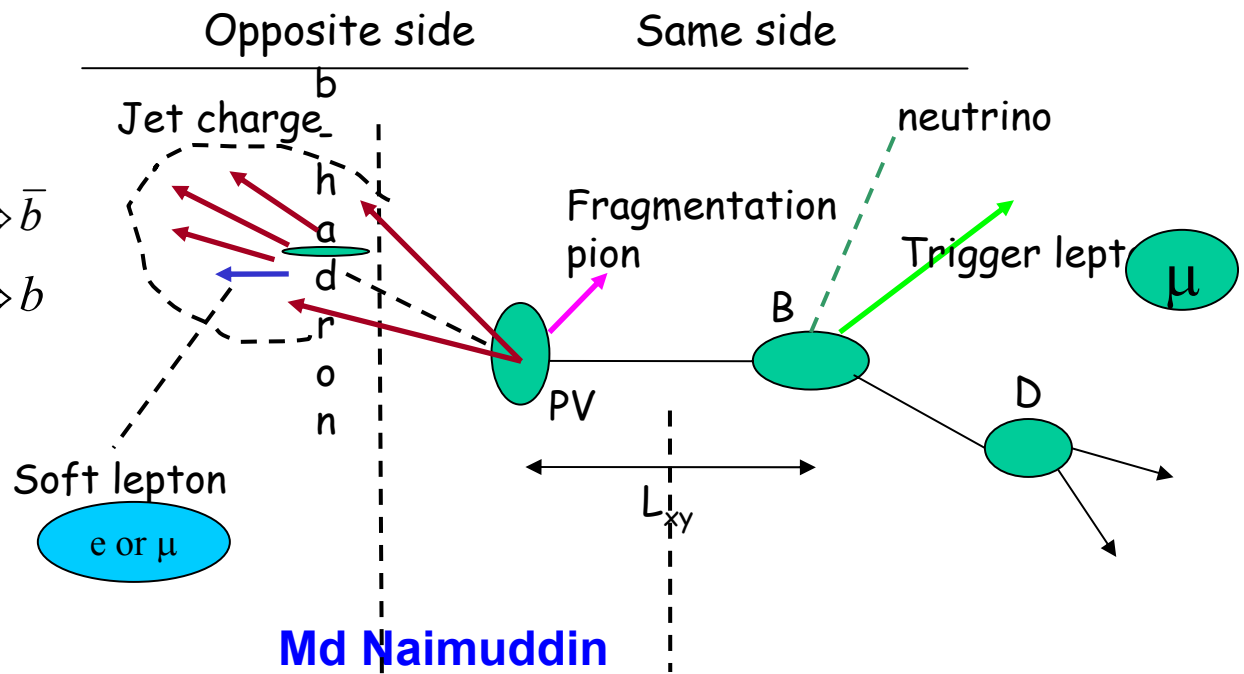
- Sign of the weighted average charge of opposite B jet provides the flavor of b.

**Same Side(Kaon) Tagging**

- B meson is likely to be accompanied by a close K/π
- particle Id helps

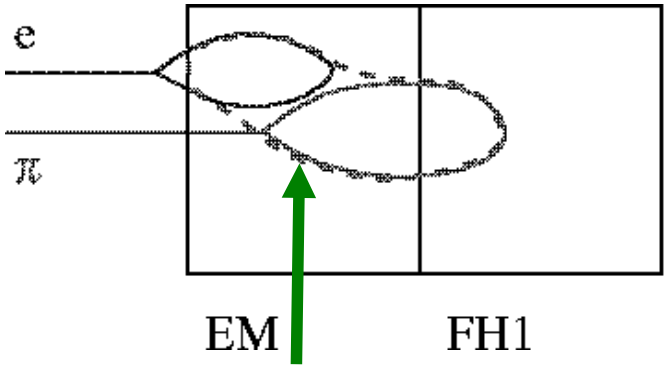
$$jetQ < 0 \Rightarrow \bar{b}$$

$$jetQ > 0 \Rightarrow b$$



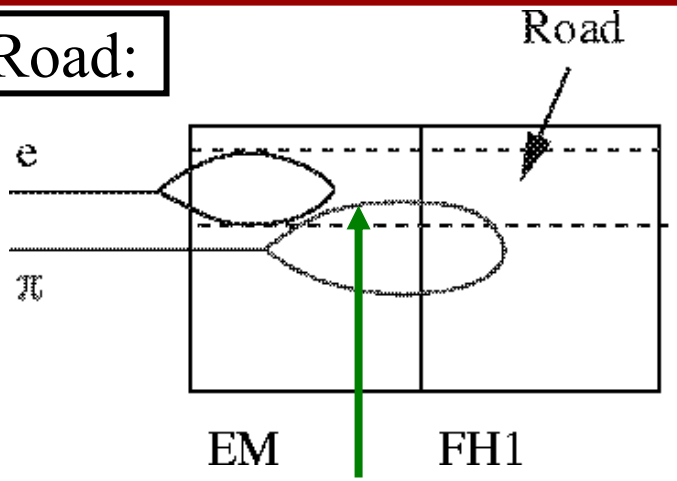
# ROAD METHOD

Clusters:




**One cluster, not purely EM**

Road:

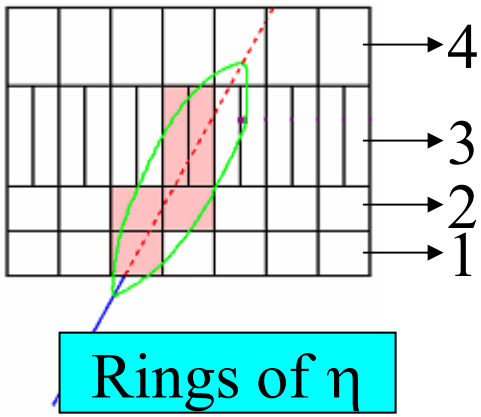



**Isolate EM cluster & reduce hadronic contribution.**

→ Try to keep as much energy information as possible. The width of the Road is adjusted to signal strength.

→ Road based on the extrapolation of the track through the calorimeter.

Road takes into account the transverse extension of the shower



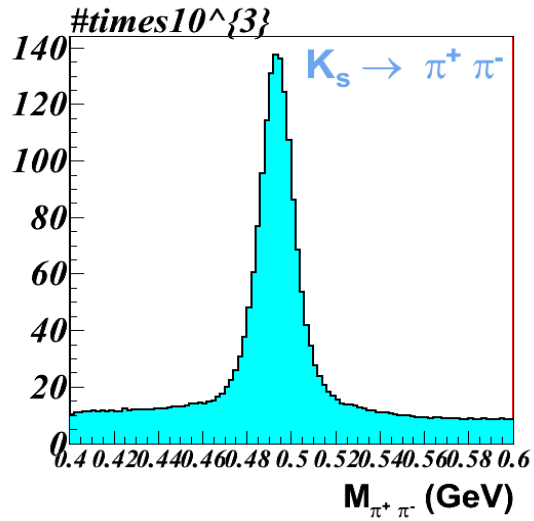
# EM ID AND e-π SEPARATION

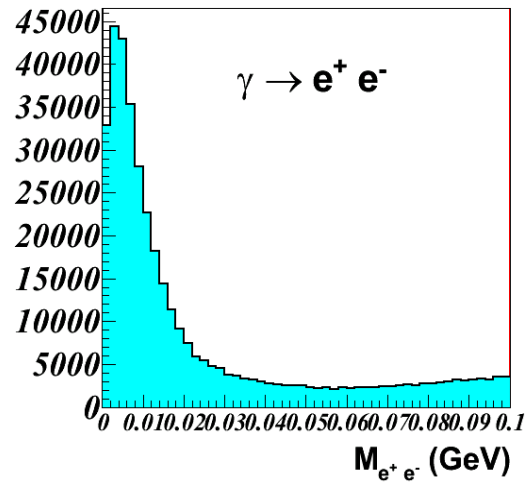
$\int Ldt = 460\ pb^{-1}$

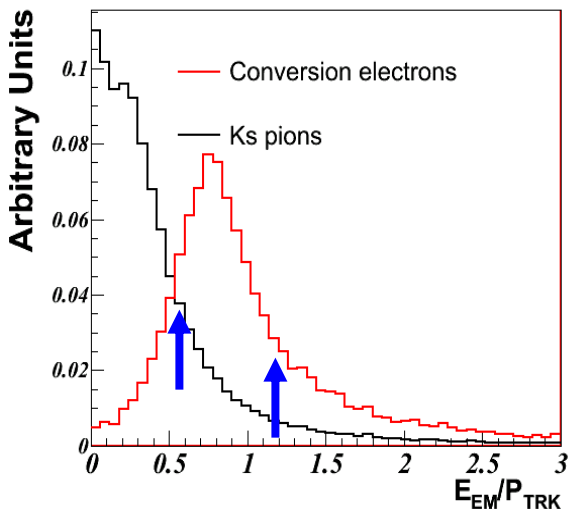
Distinguished electrons and pions using conversions ($\gamma \rightarrow e^+e^-$) and $K_s \rightarrow \pi^+\pi^-$ decays in data

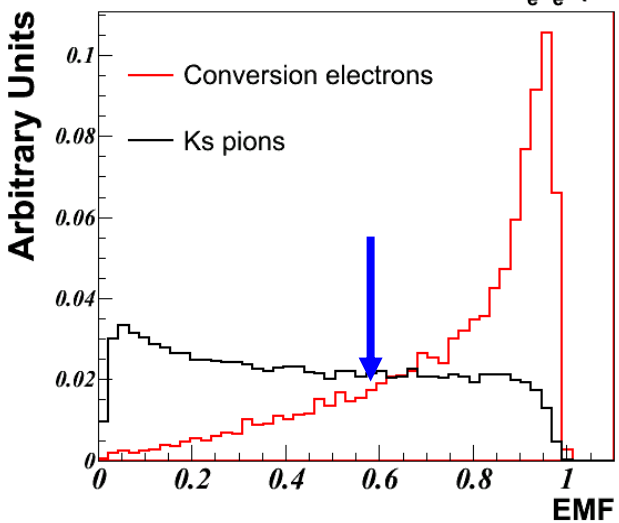
$$EMF = \frac{E_{EM}}{E_{TOT}}$$

$$\frac{E}{P} = \frac{E_T}{P_T\ (track)}$$



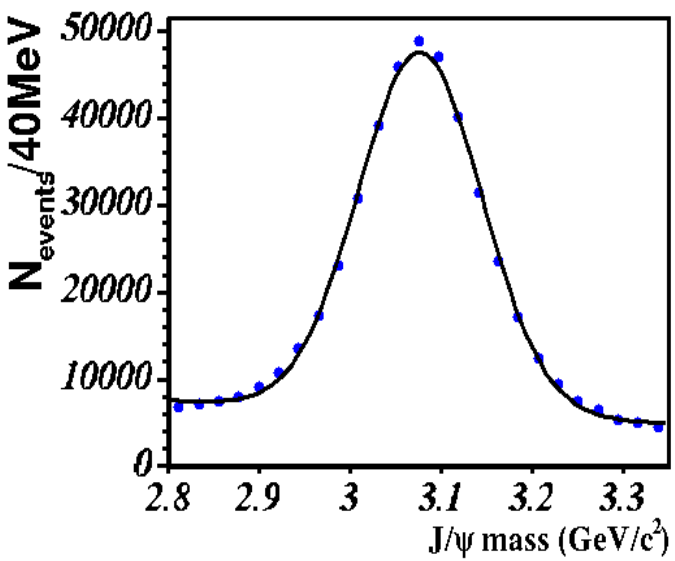



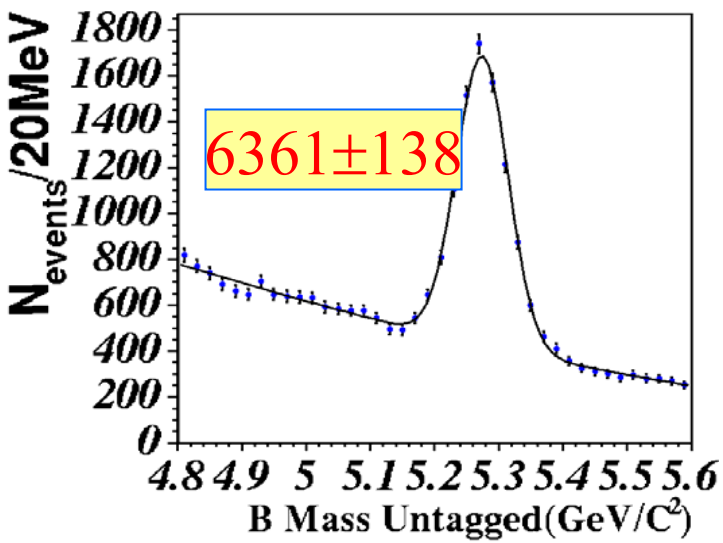



# Feasibility test in J/ψK sample

- Reconstructed $B^{\pm}$ from J/ψ & Kaon.
- J/ψ is reconstructed from two muons of $P_T$>1.5 and of opposite charge.
- Kaon $P_T$>0.5 and decay length significance of the B candidate is >4.5.
- The decay length significance of the B candidate is required to be > 5.5, if $P_T$(Kaon)<1.0GeV.




❖ **Since $B^{\pm}$ don't mix so one can measure the dilution directly in J/ψK sample.**

# TAGGING IN J/ψK SAMPLE

## *Electron Tagging:*

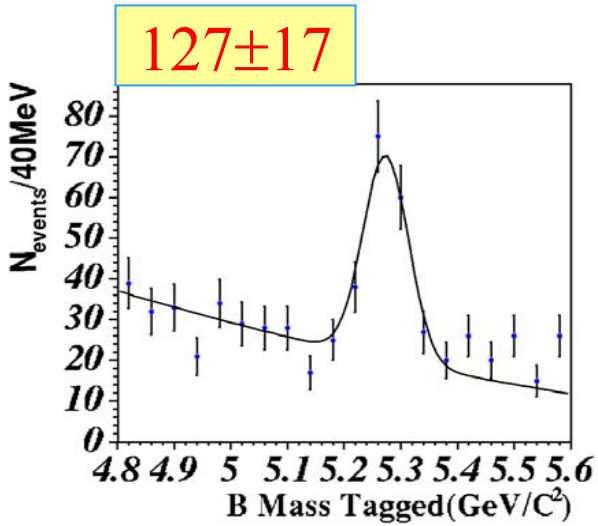
- Look for an electron with $p_T$>2.0 GeV
- EMF>0.7 , 0.6<E/P<1.1 and |η|<1.1.
- Angle between the electron direction and B direction i.e. Δϕ should be greater than 2.5 rad.

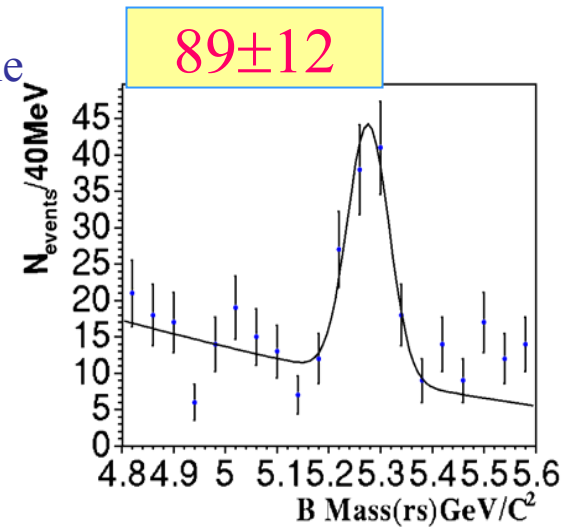
❖**Right Sign (R):** Kaon charge opposite to the electron charge.

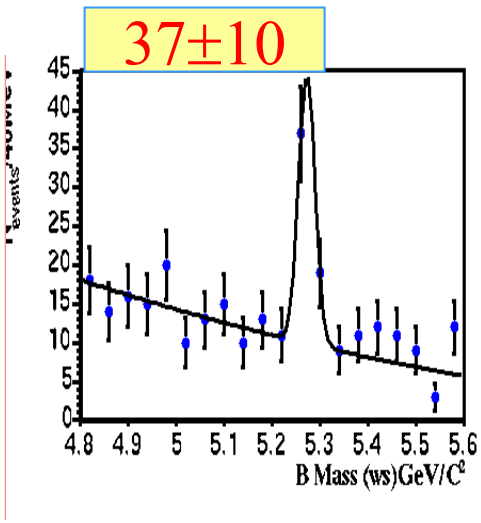
❖**Wrong Sign (W):** Kaon charge same as electron charge.

## *Fit:*

- Fit with a Gaussian and a second degree polynomial.
- Tagged, RS and WS is fitted with background fixed from the total untagged fit.



# RESULTS FOR J/ΨK

How often the tagging algorithm 'fires'

$$Efficiency \quad (\varepsilon) = \frac{R+W}{N}$$

**ε=(2.0 ±0.2)%**

Estimate of how often the tagging algorithm gives the correct answer

$$Dilution \quad (D) = \frac{R-W}{R+W}$$

**D=(41.2 ±12.0)%**

**Goal is to maximize $\varepsilon D^2$**

$$Tagging\ Power = \varepsilon . D^2$$

**$\varepsilon D^2$=(0.34±0.19)%**

## For muon tagger:

Tagging Power, $\varepsilon D^2$ ~1%

# RECONSTRUCTION IN SEMILEPTONIC SAMPLE

$B_d^0 \rightarrow D^{*+}\mu^- X$

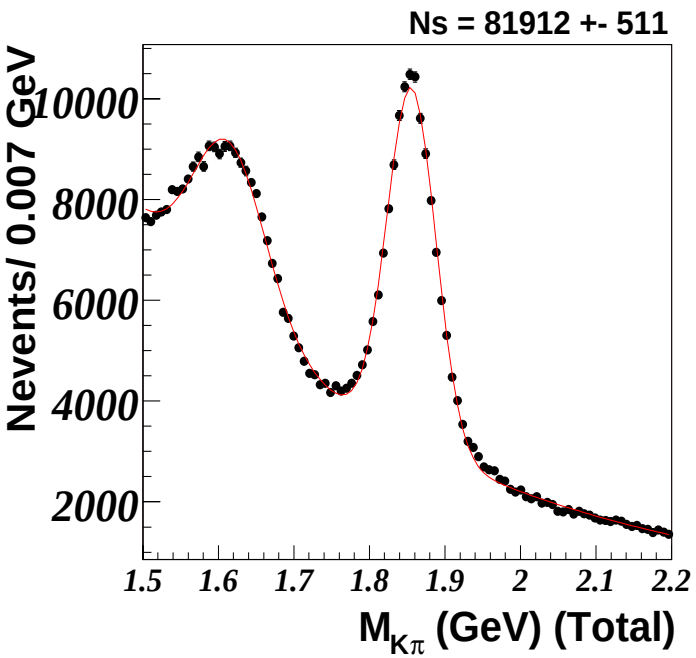
$\hookrightarrow D^0\pi$

$\hookrightarrow K\pi$

$B^+ \rightarrow D^0\mu^+ X$

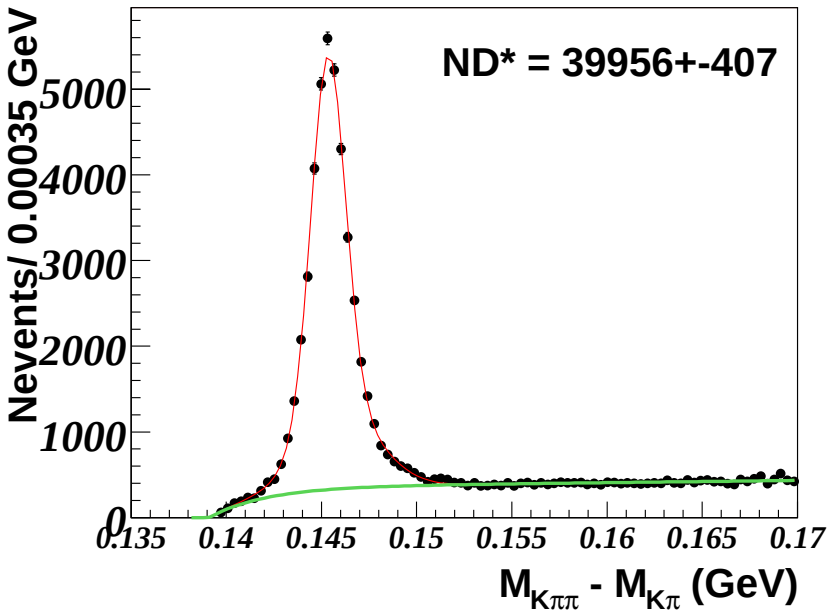
$\hookrightarrow K\pi$

- We reconstruct $D^0$ using two tracks of opposite charge.
- Add another track of pion to $D^0$ track to get $D^*$ mass and adding a muons track gives $B_d$.
- Since we can't reconstruct $B_d$ mass accurately due to missing neutrino so we find the total number of $D^*$-$D^0$ candidates which will give us the total number of $B_d$ candidates.



# FITTING PROCEDURE

- We fit the D* sample by a double gaussian describing the signal region and a third degree polynomial for shaping the background.
- To fit the $D^0$ sample we use double gaussian and a second degree polynomial.
- For Tagged sample in different VPDL bins, rms and ratio of the fraction of events in mixed and unmixed are fixed from untagged sample in that VPDL bin.
- The background is fixed from a fit to the total wrong sign untagged events.



# TAGGING IN SEMILEPTONIC SAMPLE

- Opposite side electrons with $P_T$>2.0 GeV and $|\eta|$<1.1.
- Angle between B direction and electron direction >$60^0$.
- Should not come from a conversion or a Ks decay.
- Using $P_T$ dependent cuts for other electron variables

| Variable | $P_T^e$ < 3.5 GeV | $P_T^e$ > 3.5 GeV |
|---|---|---|
| E/P | >0.55 | >0.50 |
| E/P | <1.0 | <1.1 |
| EMF | >0.8 | >0.7 |
| Min CPS $SCL_E$ | >4.0 | >2.0 |

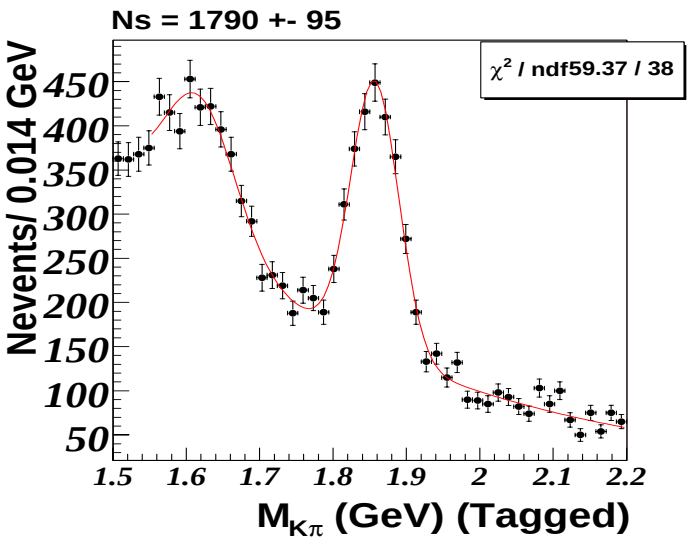
➢ After tagging we divide the tagged sample into seven different bins of Visible Proper Decay Length (VPDL).

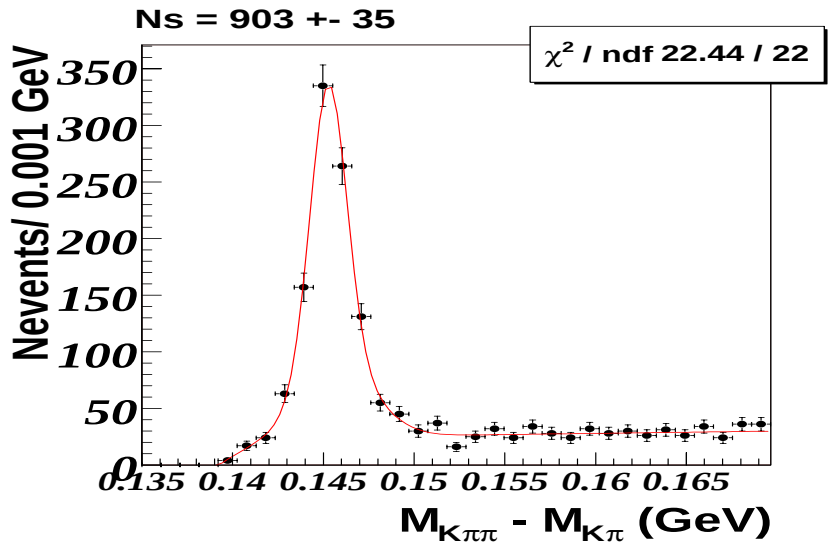
$$VPDL = \frac{L_{xy}.M_B.C}{P_T^{\mu D^0}}$$

$L_{xy}$: Distance between primary vertex and $\mu D^0$ vertex

➢ We get the number of signal candidates by fitting the mass peak plot.

# TAGGING …




- For each VPDL bins we calculate 'Asymmetry' as follows:

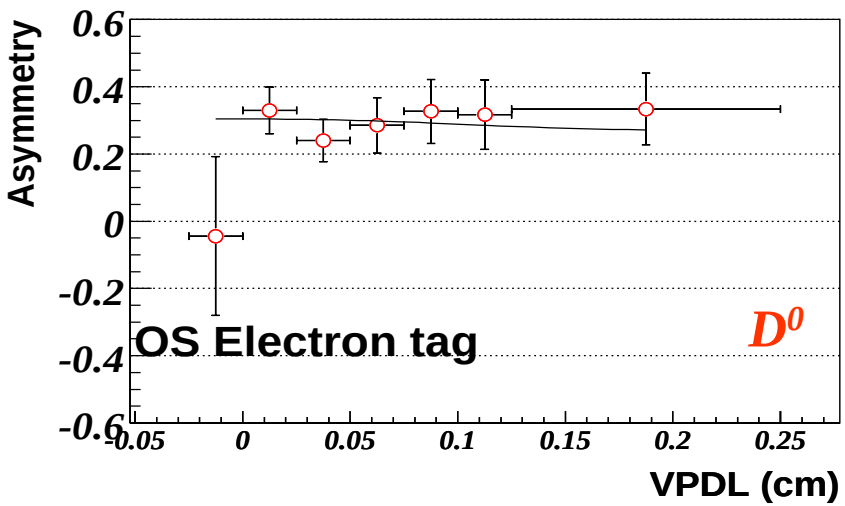
$$A_i = \frac{N_i^{non-osc} - N_i^{osc}}{N_i^{non-osc} + N_i^{osc}}$$

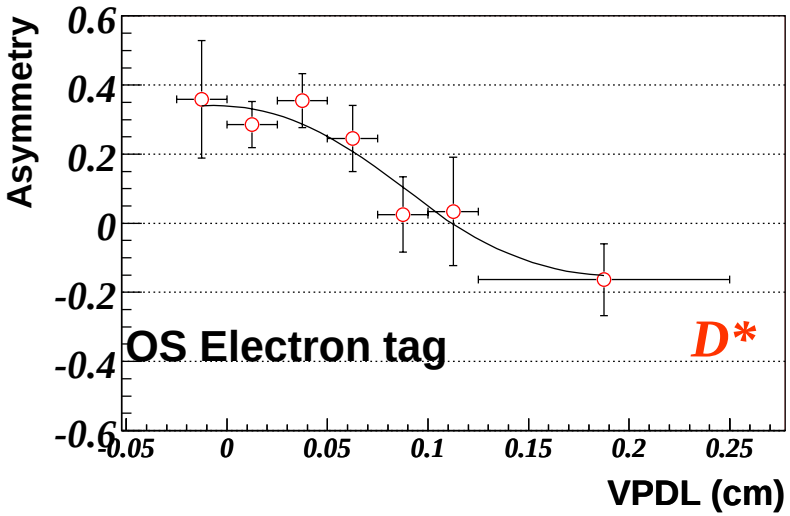
$N_i^{non\text{-}osc}$: When charge of electron and muon are opposite.

$N_i^{osc}$: When charge on electron and muon are same.

# RESULTS

Asymmetry (oscillation) for entire VPDL bin:



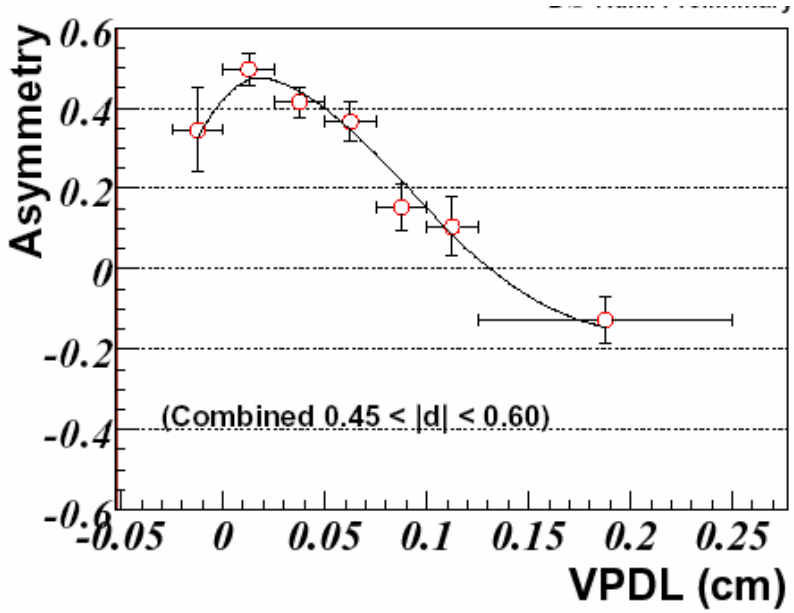



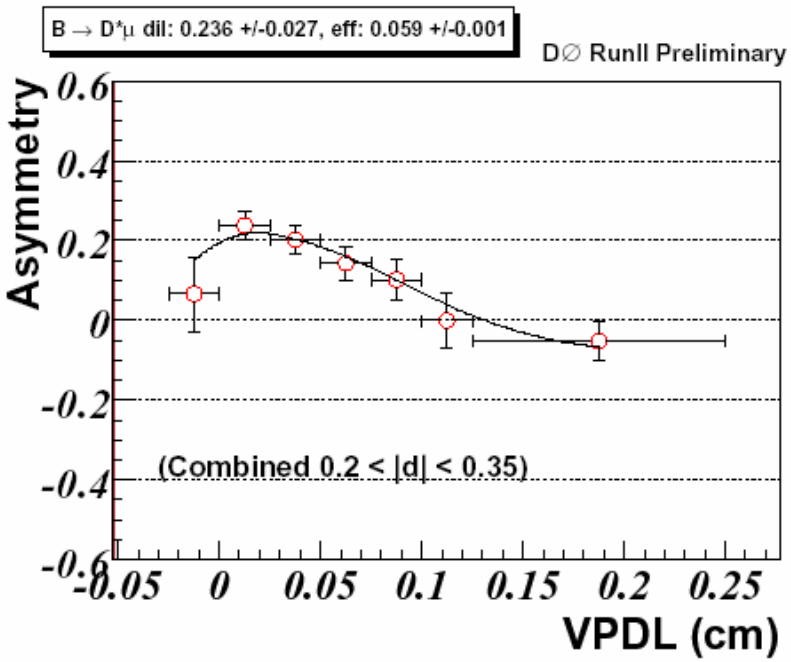

Efficiency=(2.18±0.09)% Dilution=(34.0±4.0)%

Mixing Parameter $\Delta m_d = 0.560 \pm 0.087(\text{stat.})\text{ps}^{-1}$

# Combined Tagging

- Using only Opposite side e, μ, secondary vertex or jet charge for tagging



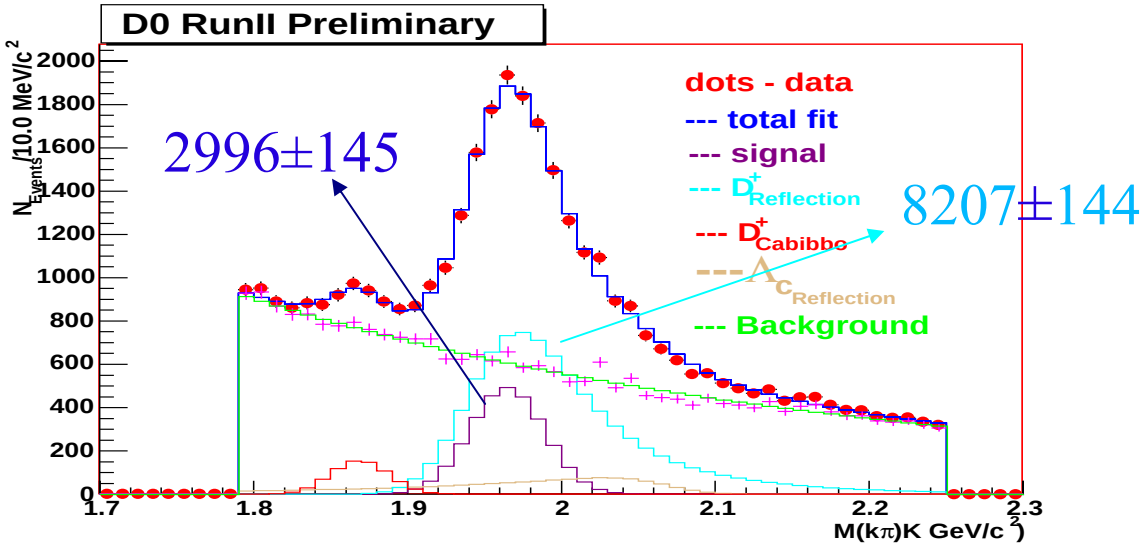

$$\varepsilon D^2 = (2.48 \pm 0.21^{+0.08}_{-0.06})\%$$

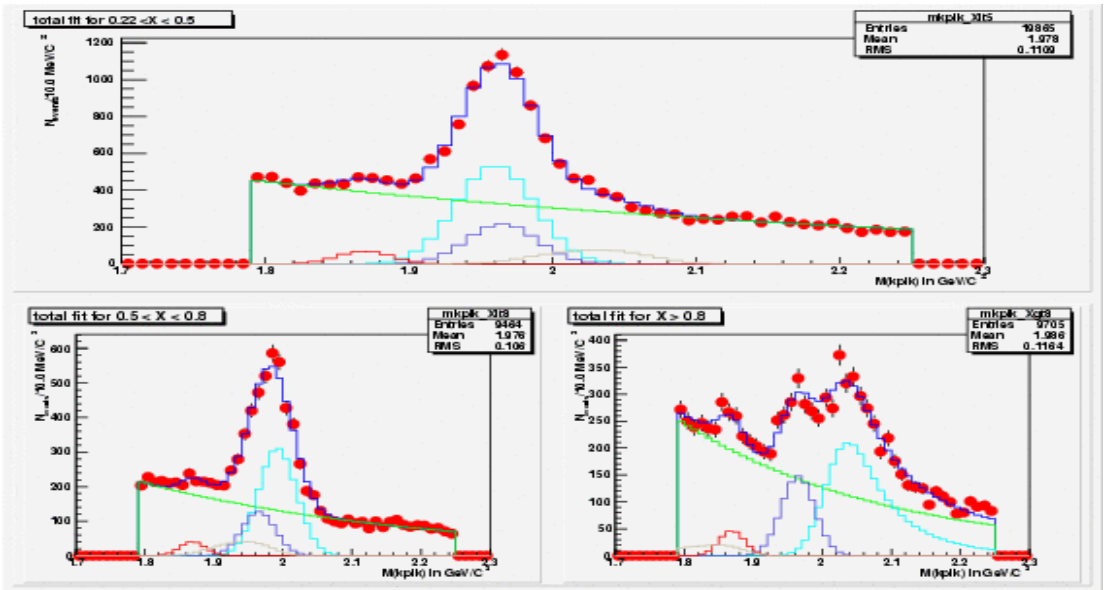
Tagger tuned using $B_d$ mixing measurement

$$\Delta m_d = 0.506 \pm 0.020 \pm 0.014\ ps^{-1}$$

# Total Tagged (K*K)

All the parameters except the fraction of the events and background slope was fixed to fit the total tagged sample.



$$sensitivity \propto \sqrt{\frac{S}{S+B}}\sqrt{\frac{N\varepsilon D^2}{2}}e^{-\frac{(\Delta m_s \sigma_t)^2}{2}}$$

**Reconst-ruction**

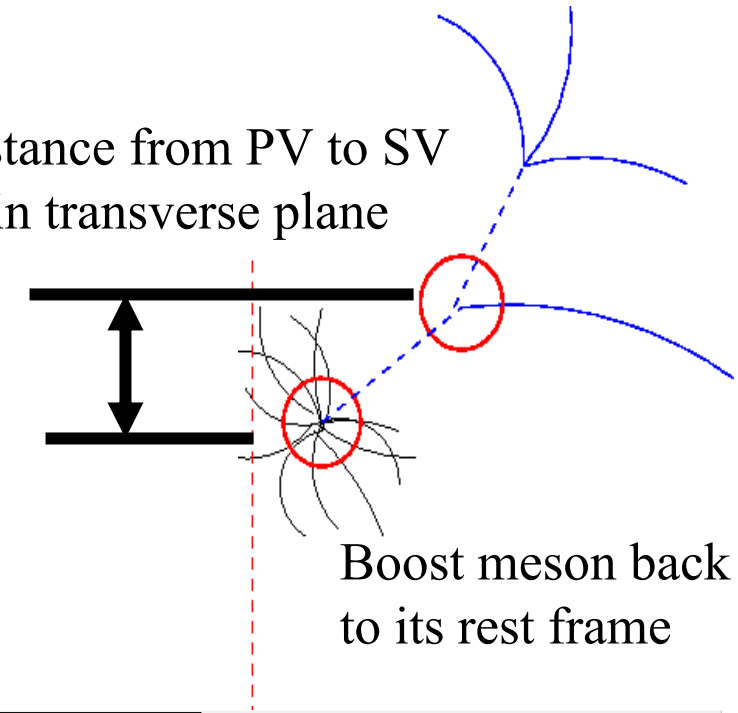
**Flavor tagging**

**Proper time**

## Easier to calculate for Hadronic decays

Proper decay time given as :

$$ct = L_{xy}\frac{m_B}{P^T}$$




## Due to missing neutrino, it becomes little tricky in semileptonic sample

Missing momentum ⇒ increased ct error ( $\sigma_{ct}$)

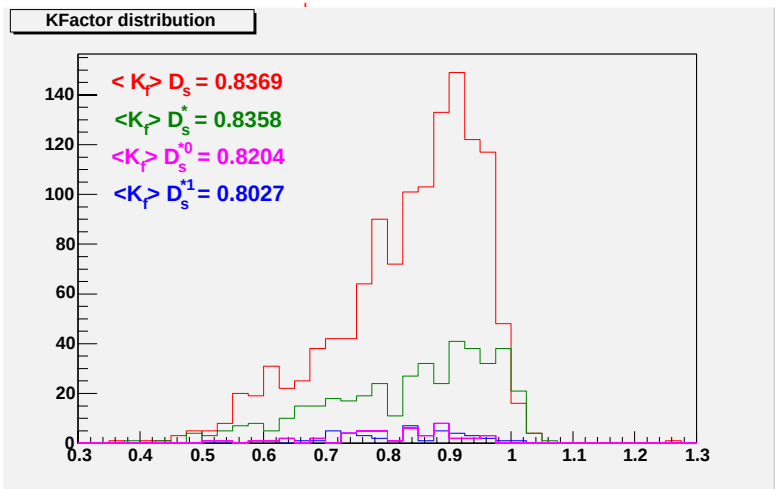
Proper decay time given as:

$$ct = L_{xy}\frac{m_B}{P^T} * K$$

where

$$K = \frac{P^T_{lD_s}}{P^T_B}$$

← from MC

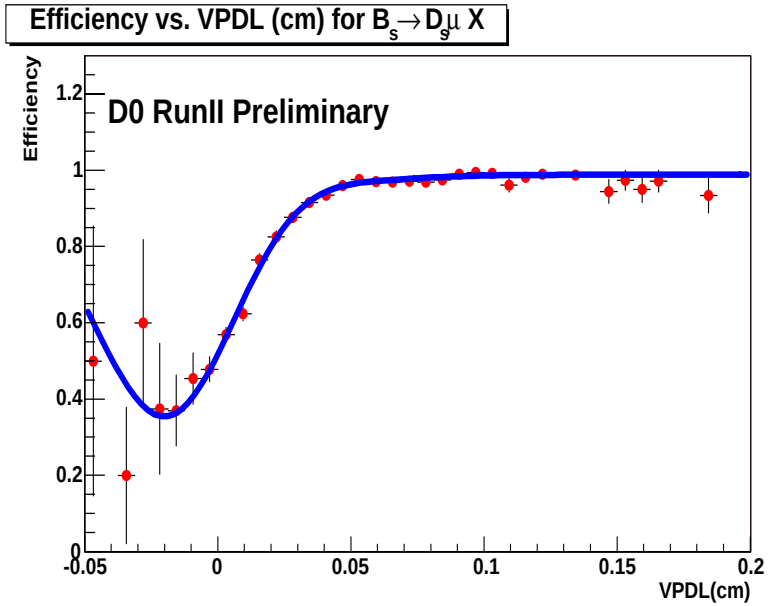


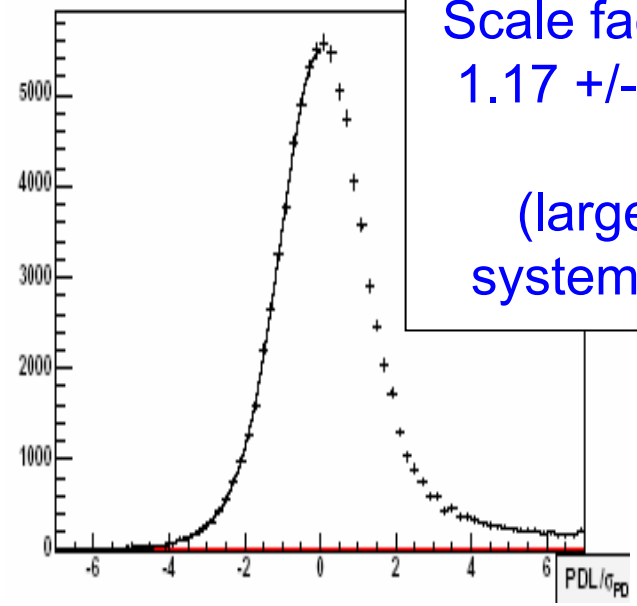
$$sensitivity \propto \sqrt{\frac{S}{S+B}}\sqrt{\frac{N\varepsilon D^2}{2}}e^{-\frac{(\Delta m_s \sigma_t)^2}{2}}$$

Reconst-ruction

Flavor tagging

Proper time




Scale factor = 1.17 +/- 0.02

(largest systematic)

Best estimate of errors used in track fitting, any additional scaling determined from data

Pull of $J/\psi$ vertex from the primary vertex for prompt $J/\psi$ s

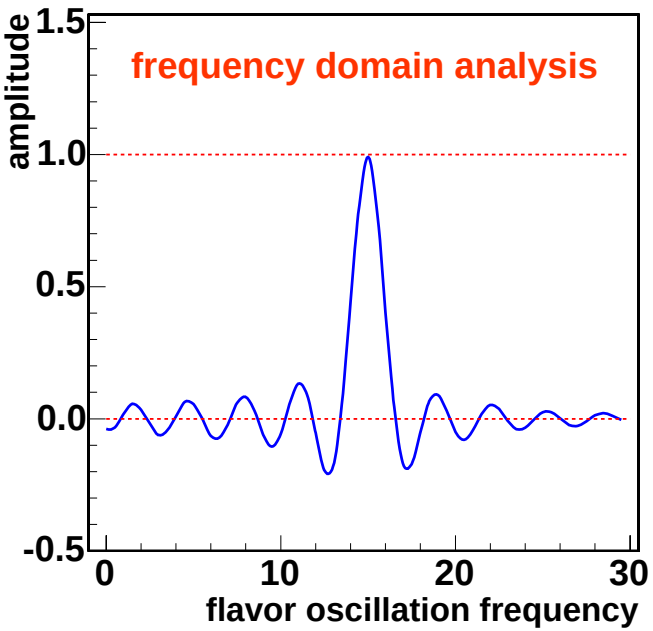
# Fitting Procedure

## Amplitude Fitting approach:

- Introduce amplitude

$$P(t) \sim \left(1 \pm AD \cos \Delta m_s t\right)$$

- Fit for A at different $\Delta m_s$
- Traditionally used for $B_s$ mixing search
- Easy to combine experiments




## Likelihood approach:

- Search for $\nu_{min}$, which minimizes the $-\ln(L)$,

$$\Delta L^{\min}(\nu) = -\ln[L(\nu)] + \ln[L(\nu_{\min})]$$

where $\nu_{min}$ is the estimator of the true frequency.

- Difficult to combine the results from different experiments.

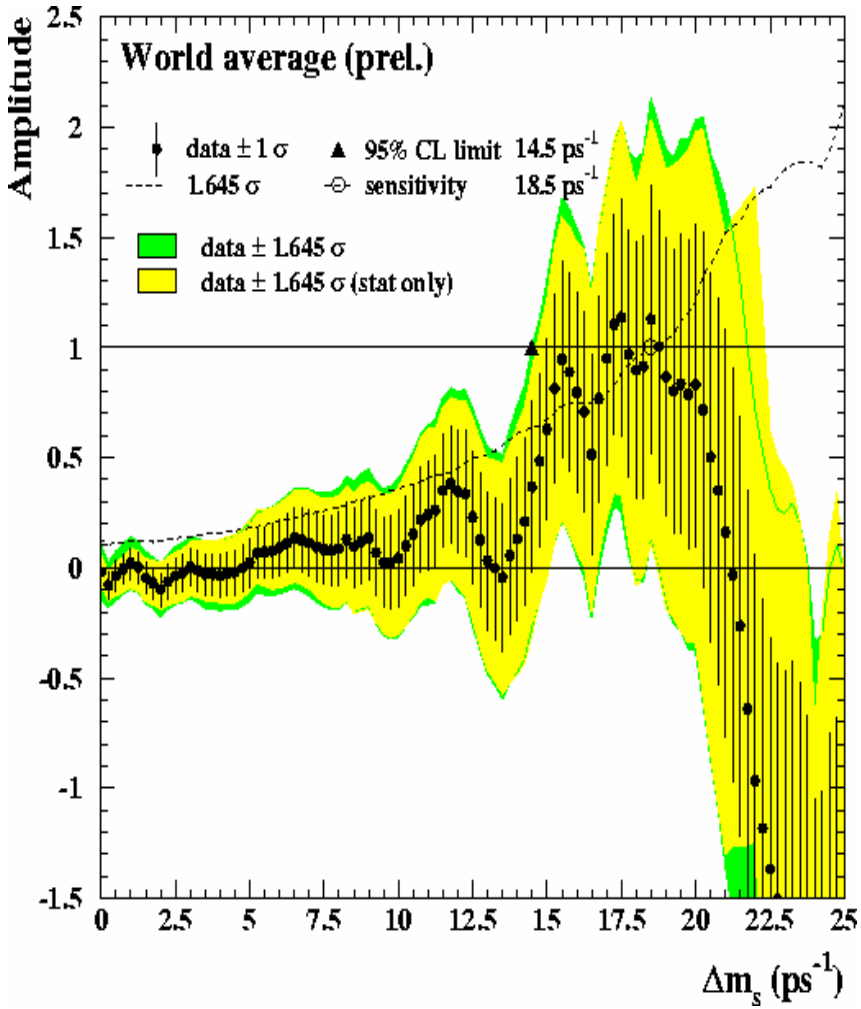
# Amplitude Fit Method

- Fit to data - $A$ free parameter

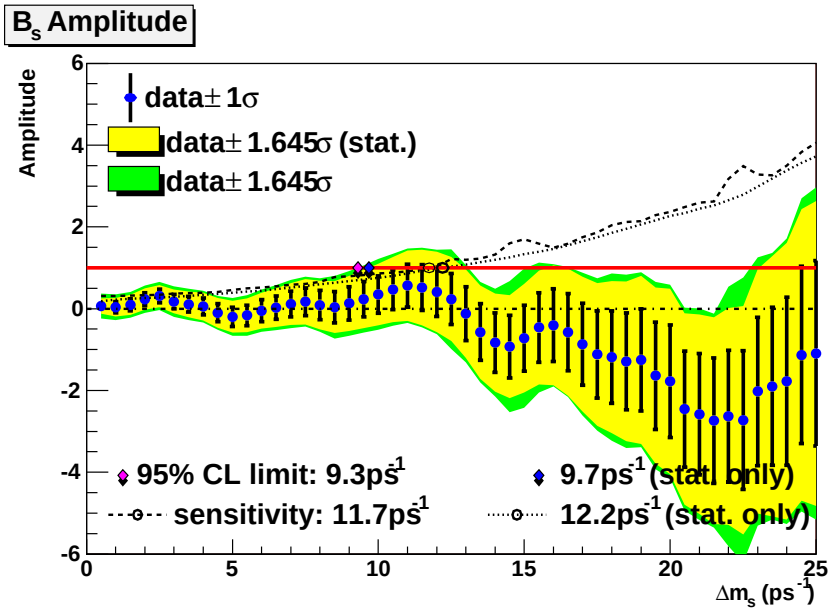
$$p = \frac{1}{2}\Gamma e^{-\Gamma t}[1 \pm A\cos(\Delta m_s t)]$$

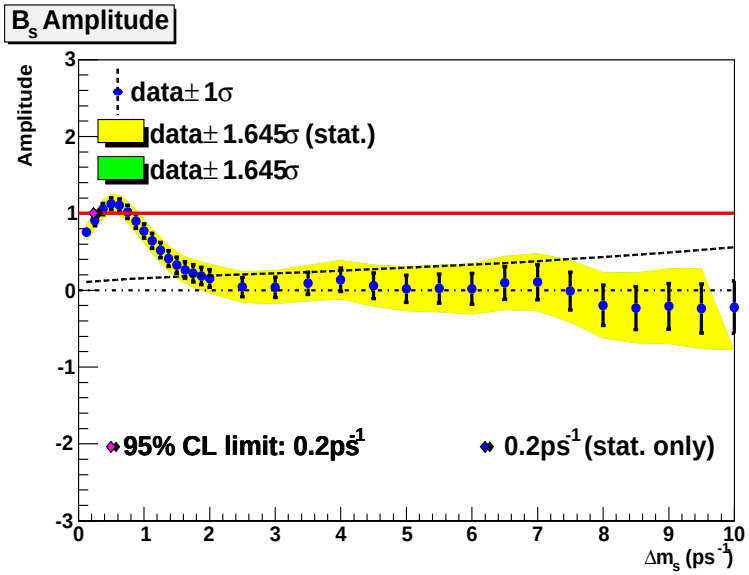
- Obtain $A$ as a function of $\Delta m_s$
- Measurement of $\Delta m_s$ gives $A = 1$ and $A = 0$ otherwise
- At 95% CL
- sensitivity $1.645\,\sigma_A = 1$
- excluded $A + 1.645\sigma_A < 1$
- Systematics is given by

$$\sigma_A^{sys} = \Delta A + (1 - A)\frac{\Delta\sigma_A}{\sigma_A}$$



# Bs mixing limit (K*K)




**Dominant sources of systematic uncertainty:**
Scale factor, K factors, Sample composition and mass fitting procedure.

**Limit: $\Delta m_s$ > 9.3 ps$^{-1}$ @ 95% confidence**

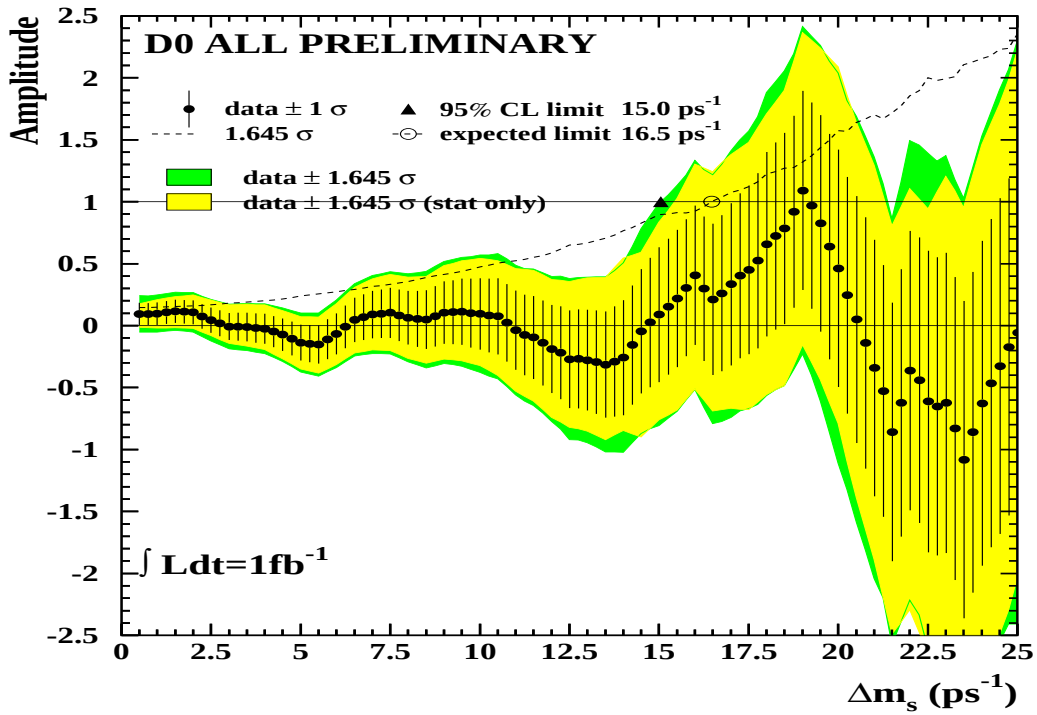
**Expected Limit: 11.7 ps$^{-1}$ @ 95% confidence**

# Bs mixing limit (Combined)

$Ds \rightarrow \phi\pi$

**Limit: $\Delta m_s > 14.8\ ps^{-1}$ @ 95% confidence**

**Expected Limit: $14.1\ ps^{-1}$ @ 95% confidence**

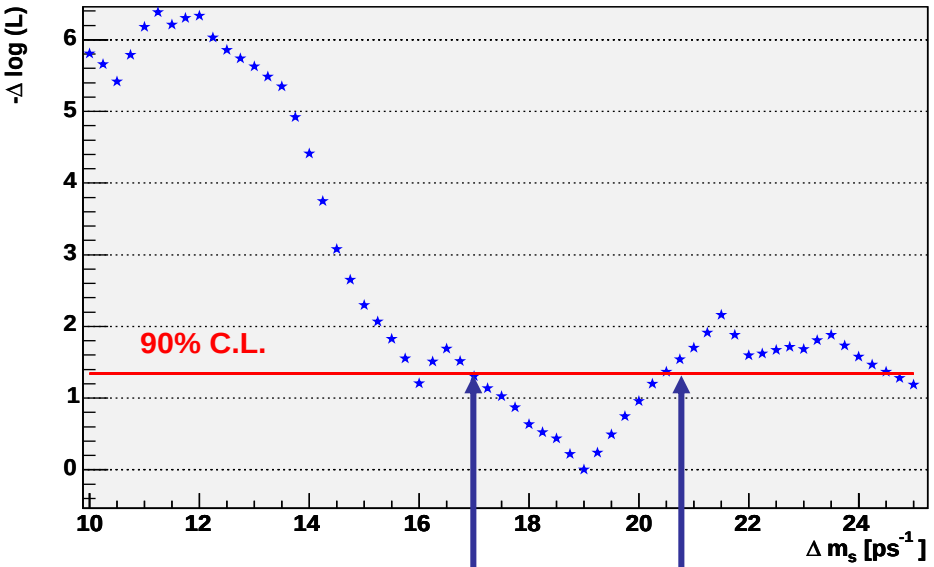



$eDs(\rightarrow \phi\pi)$

**Limit: $\Delta m_s > 7.8\ ps^{-1}$ @ 95% confidence**

**Expected Limit: $8.2\ ps^{-1}$ @ 95% confidence**

# Likelihood scan

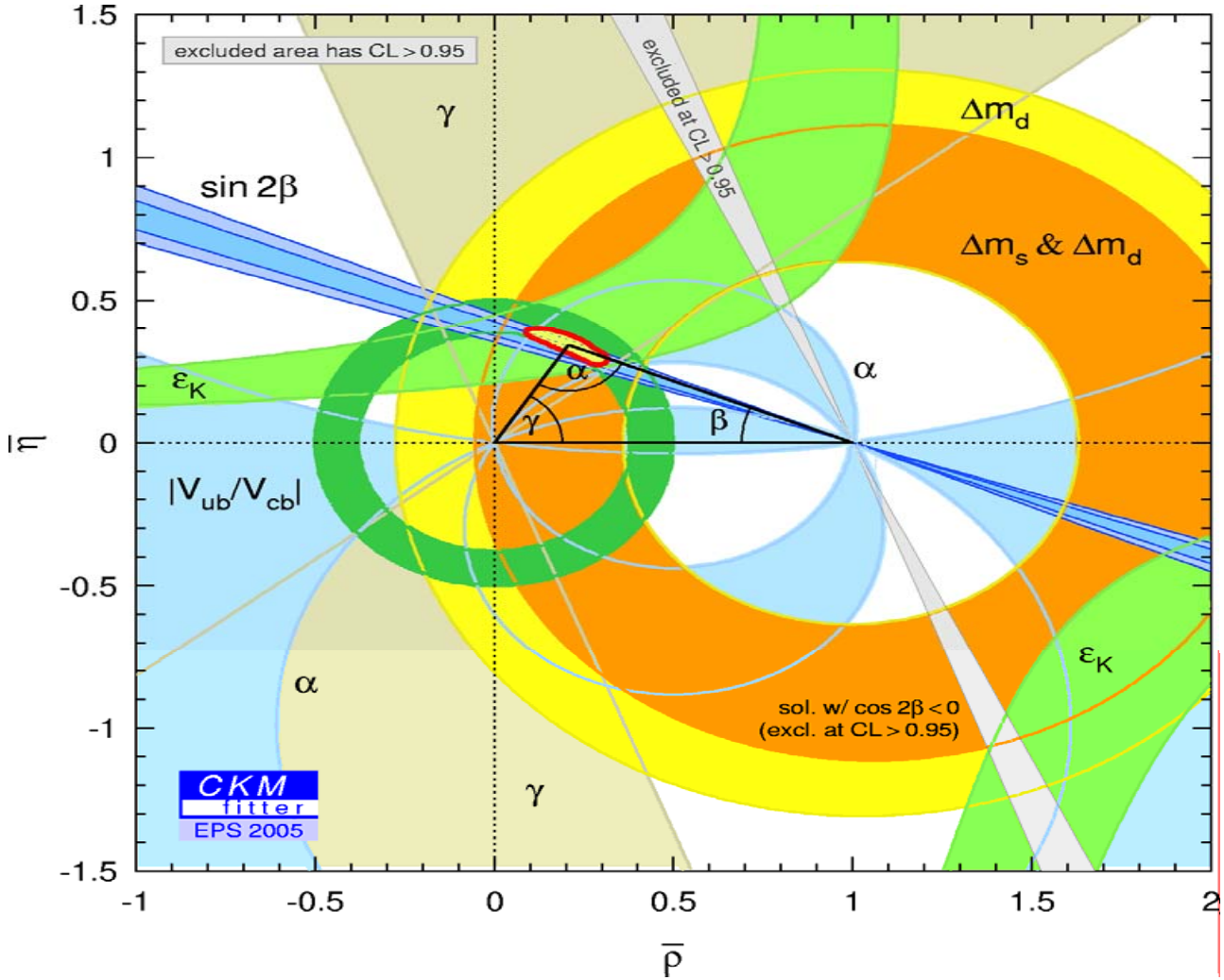



Probability for this measurement to lie in the range
16 < Δms < 22 ps-1
Given a true value of
Δms > 22 $ps^{-1}$: 8.0%

***17 < Δ$m_s$ < 21 $ps^{-1}$ @ 90% CL***

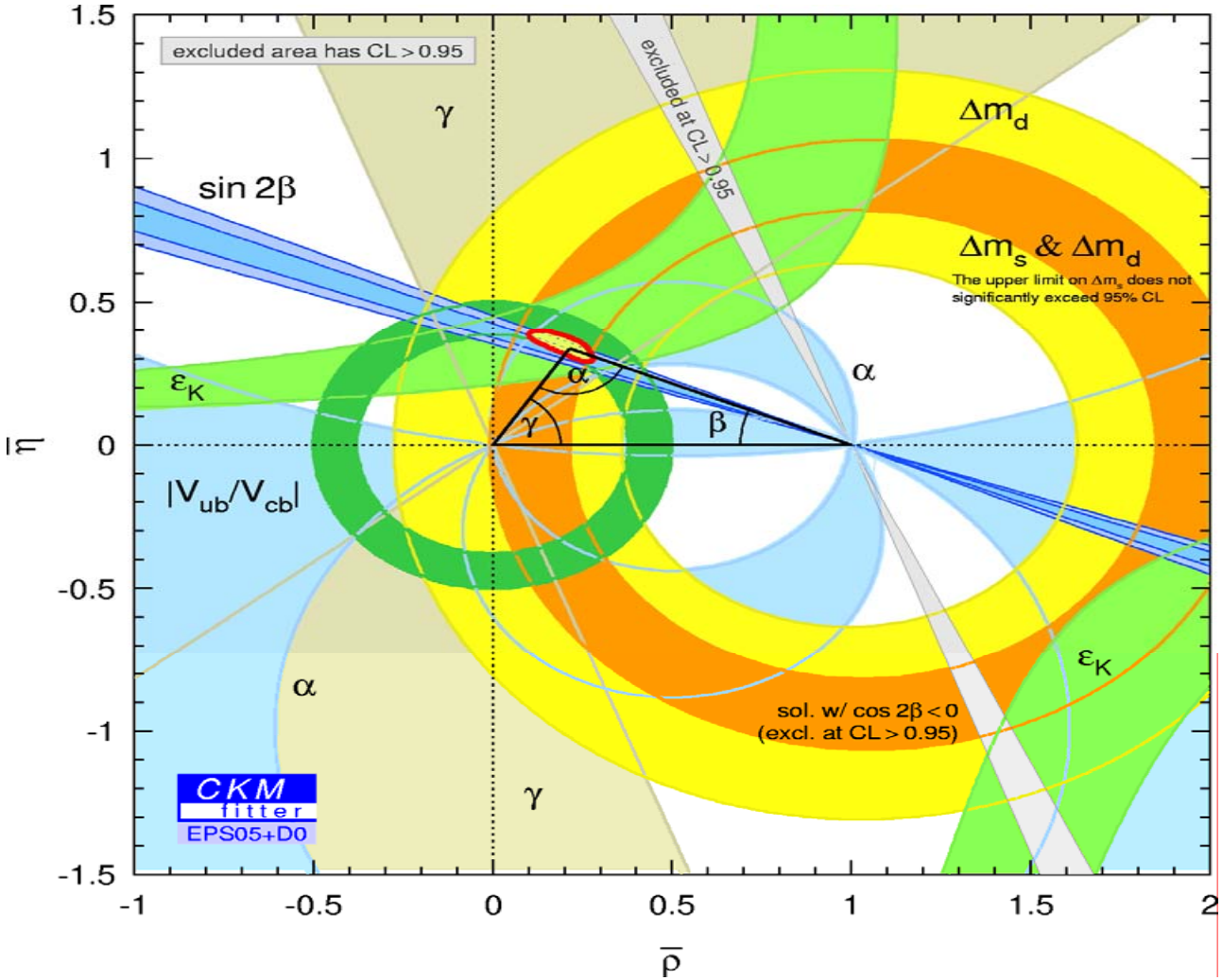
**Most probable value of *Δ$m_s$* = 19 $ps^{-1}$**

# CKM fit without new D0 result



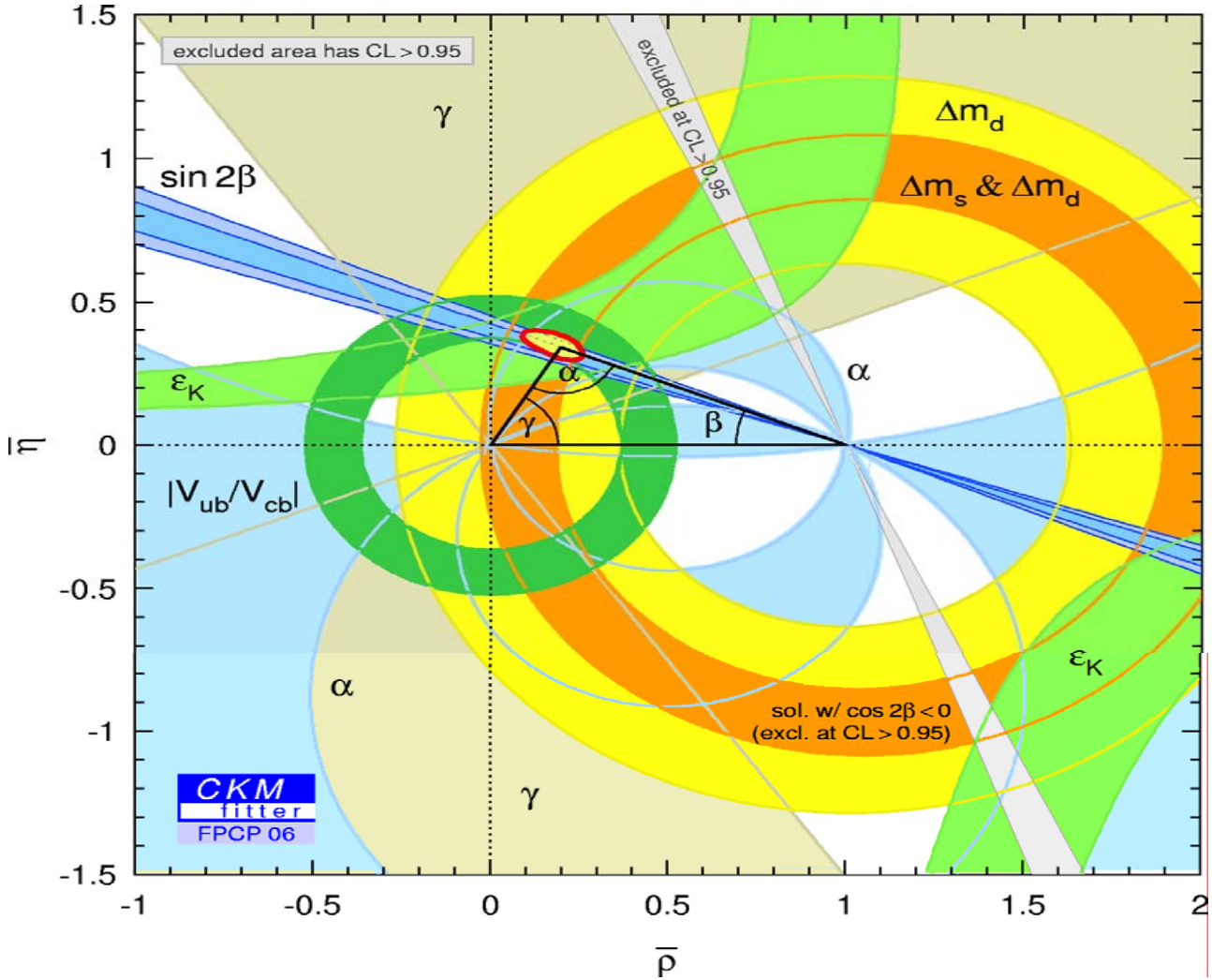

Does not include new CDF result either

# CKM fit with D0 result




Does not include new CDF result yet

# CKM fit with D0 and CDF results




CDF Measurement

$$\Delta m_s = 17.31^{+0.33}_{-0.18} \pm 0.07$$

# CONCLUSIONS

Amplitude Scan

| Decay Channel | $\Delta m_s$($ps^{-1}$) Limit@95% C.L | Sensitivity($ps^{-1}$) @ 95% C.L |
|---|---|---|
| $D_s \rightarrow \phi\pi$ | 14.8 | 14.1 |
| $D_s \rightarrow K^*K$ | 9.3 | 11.7 |
| $eD_s \rightarrow \phi\pi$ | 7.8 | 8.2 |
| Combined | 15.0 | 16.5 |

Likelihood scan combined

$17 < \Delta m_s < 21\ ps^{-1}$ @ 90% CL

**Most probable value of $\Delta m_s = 19\ ps^{-1}$**

✓We are on the edge of $B_s$ mixing discovery and entering into the precision era.

# FUTURE IMPROVEMENTS

**Several major improvements are expected in the future:**

More decay modes ($D_s \rightarrow 3\pi$, $K_s\pi$)

- ✓ Use of same side tagging.
- ✓ Use of hadronic modes.
- ✓ Additional Layer of silicon.
- ✓ Proposal to increase the bandwidth.

More data: On track for 4-8 $fb^{-1}$ of data by 2009.

- Back-up slides

# Mixing in B mesons

In case $\Delta\Gamma \rightarrow 0$,

$$|B_L\rangle = \frac{p+q}{2}\left[\left(|B\rangle + |\bar{B}\rangle\right) + \frac{1-q/p}{1+q/p}\left(|B\rangle - |\bar{B}\rangle\right)\right]$$

$$\boxed{\frac{1-q/p}{1+q/p} \equiv \varepsilon_B}$$

Measure of the amount by which $|B_L\rangle$ and $|B_H\rangle$ differ from CP eigenstates

$$\boxed{m = \frac{M_H + M_L}{2}} \qquad \boxed{\Gamma = \frac{\Gamma_H + \Gamma_L}{2}}$$

# B mixing and new physics

In the limit of no CP violation in mixing (q/p =1), unmixed and mixed decay probabilities become

$$P_{u,m}(t) = \frac{1}{2}\Gamma e^{-\Gamma t}(1 \pm \cos \Delta m t)$$

These oscillations can be used to measure the fundamental parameters of the standard Model and have other far reaching effects such as breaking the matter anti-matter symmetry of the Universe.

Constraining the CKM matrix redundantly using different measurements of the angles/sides is a sensitive probe of New Physics

# PDF's

$$f_i = P_i^{x^M}(x^M, \sigma_{x^M}, d_{pr}) P_i^{\sigma_{x^M}} P_i^m P_i^{d_{pr}} P_i^y .$$

The following sources were considered for the entire mass region:

- $\mu D_s(\rightarrow K * K)$ signal with fraction $Fr_{\mu D_s}$.
- $\mu D^{\pm}(\rightarrow K * K)$ signal with fraction $Fr_{\mu D^{\pm}}$.
- $\mu D^{\pm}(\rightarrow K\pi\pi)$ reflection with fraction $Fr_{\mu D^{\pm}_{refl}}$.
- $\mu \Lambda^{\pm}(\rightarrow K\pi P)$ reflection with fraction $Fr_{\mu \Lambda^{\pm}_{refl}}$.
- Combinatorial background with fraction $(1 - Fr_{\mu D_s} - Fr_{\mu D^{\pm}} - Fr_{\mu D^{\pm}_{refl}} - Fr_{\mu \Lambda^{\pm}_{refl}})$.

$$F_n = Fr_{\mu D_s} f_{\mu D_s} + Fr_{\mu D^{\pm}} f_{\mu D^{\pm}} + Fr_{\mu D^{\pm}_{refl}} f_{\mu D^{\pm}_{refl}} + Fr_{\mu \Lambda^{\pm}_{refl}} f_{\mu \Lambda^{\pm}_{refl}} + \left(1 - Fr_{\mu D_s} - Fr_{\mu D^{\pm}} - Fr_{\mu D^{\pm}_{refl}} - Fr_{\mu \Lambda^{\pm}_{refl}}\right) f_{bkg}$$

$$\mathcal{L} = -2 \sum_n \ln F_n$$

# PDF's (cont'd..)

$$p_s^{nos}(x, K, d_{pr}) = \frac{K}{c\tau_{B_s}} \exp(-\frac{Kx}{c\tau_{B_s}}) \cdot 0.5 \cdot (1 + \mathcal{D}(d_{pr}) \cos(\Delta m_s \cdot Kx/c))$$

$$p_s^{osc}(x, K, d_{pr}) = \frac{K}{c\tau_{B_s}} \exp(-\frac{Kx}{c\tau_{B_s}}) \cdot 0.5 \cdot (1 - \mathcal{D}(d_{pr}) \cos(\Delta m_s \cdot Kx/c))$$

$$p_{DsDs}^{osc}(x, K) = \frac{K}{c\tau_{B_s^0}} \exp(-\frac{Kx}{c\tau_{B_s^0}}) \cdot 0.5$$

$$p_{DsDs}^{nos}(x, K) = \frac{K}{c\tau_{B_s^0}} \exp(-\frac{Kx}{c\tau_{B_s^0}}) \cdot 0.5$$

$$p_u^{nos}(x, K, d_{pr}) = \frac{K}{c\tau_{B^+}} \exp(-\frac{Kx}{c\tau_{B^+}}) \cdot 0.5 \cdot (1 - \mathcal{D}(d_{pr}))$$

$$p_u^{osc}(x, K, d_{pr}) = \frac{K}{c\tau_{B^+}} \exp(-\frac{Kx}{c\tau_{B^+}}) \cdot 0.5 \cdot (1 + \mathcal{D}(d_{pr}))$$

# Likelihood

$$p_d^{nos}(x, K, d_{pr}) = \frac{K}{c\tau_{B_d^0}} \exp(-\frac{Kx}{c\tau_{B_d^0}}) \cdot 0.5 \cdot (1 - \mathcal{D}(d_{pr}) \cos(\Delta m_d \cdot Kx/c))$$

$$p_d^{osc}(x, K, d_{pr}) = \frac{K}{c\tau_{B_d^0}} \exp(-\frac{Kx}{c\tau_{B_d^0}}) \cdot 0.5 \cdot (1 + \mathcal{D}(d_{pr}) \cos(\Delta m_d \cdot Kx/c)).$$

$$p_\Lambda^{nos}(x, K, d_{pr}) = \frac{K}{c\tau_\Lambda} \exp(-\frac{Kx}{c\tau_\Lambda}) \cdot 0.5 \cdot (1 - \mathcal{D}(d_{pr}))$$

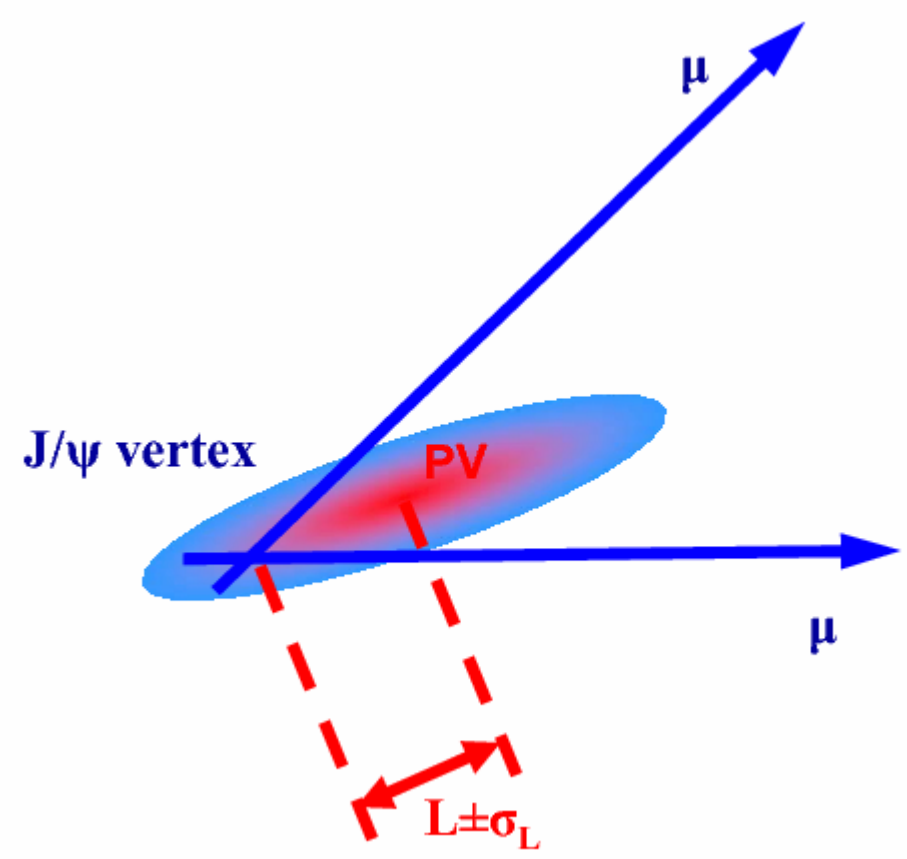
$$p_\Lambda^{osc}(x, K, d_{pr}) = \frac{K}{c\tau_\Lambda} \exp(-\frac{Kx}{c\tau_\Lambda}) \cdot 0.5 \cdot (1 + \mathcal{D}(d_{pr}))$$

**Minimize** $\mathcal{L} = -2 \ln f$

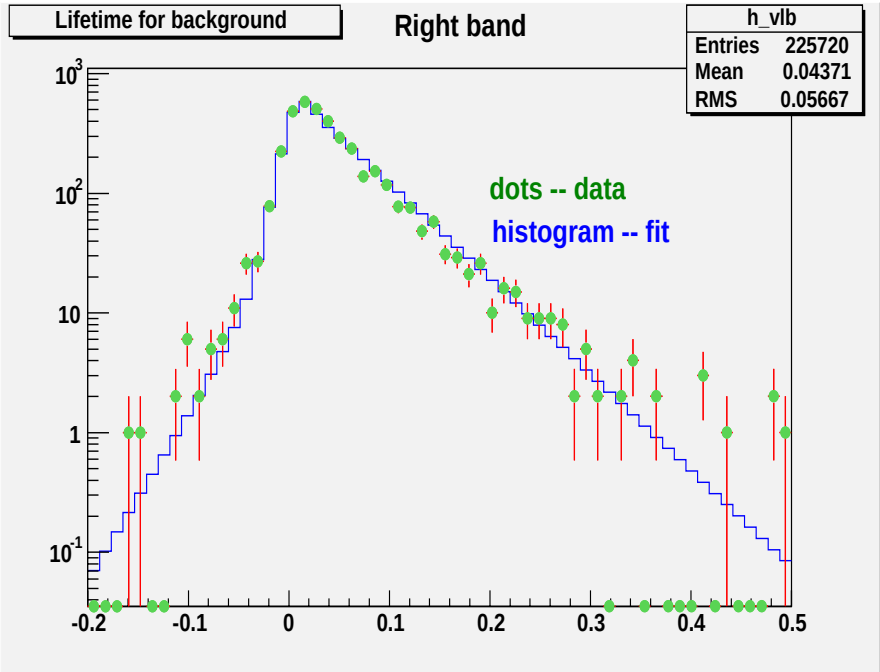
$$f = \prod_{candidates} \left( (1 - \mathcal{F}_{sig}) f_{i,bg} + \mathcal{F}_{sig} f_{i,sig} \right)$$

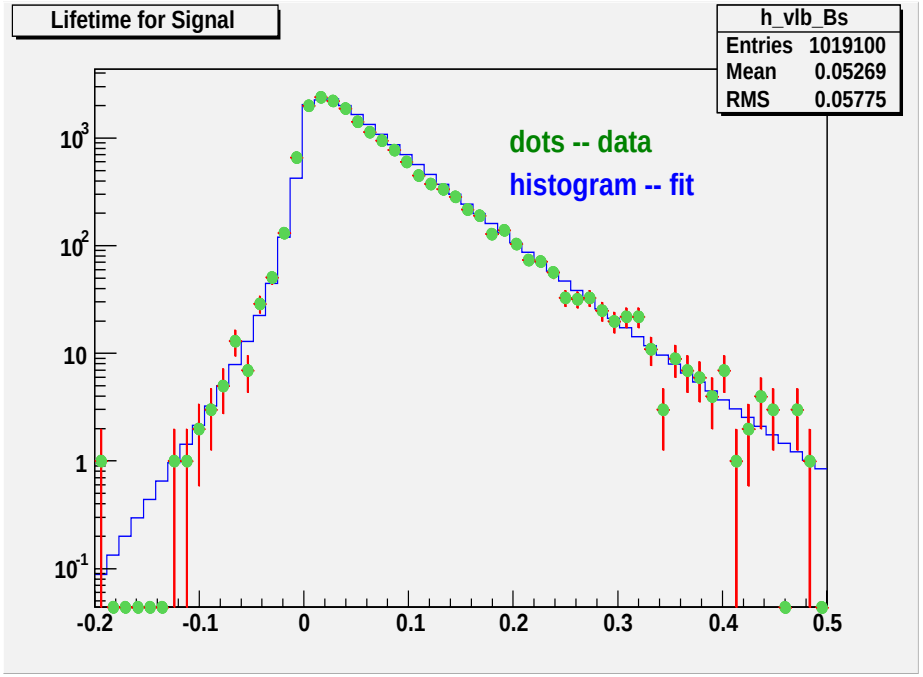
$$f_i = P^{VPDL}(VPDL, \sigma_{VPDL}, d_{pr}) P^{\sigma_{VPDL}} P^{d_{pr}} P^{M_{\phi\pi}} P^{-\log_{10} y}$$

# Scale Factor



# Lifetime Fit




Fit described by three components:

Prompt background, peaking background, long lived background and a negative and positive exponential for the outliers

Lifetime ($c\tau_{Bs}$) : $407 \pm 22$ μm