First Direct Two-Sided Bound on the Bs Oscillation Frequency

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On behalf of the DØ Collaboration

Joint Experimental Theoretical Seminar

"Wine & Cheese"

3/24/06

FNAL

Outline

- Motivation
- Detector
- Analysis Outline
- Analysis Details
- Results
- Conclusion

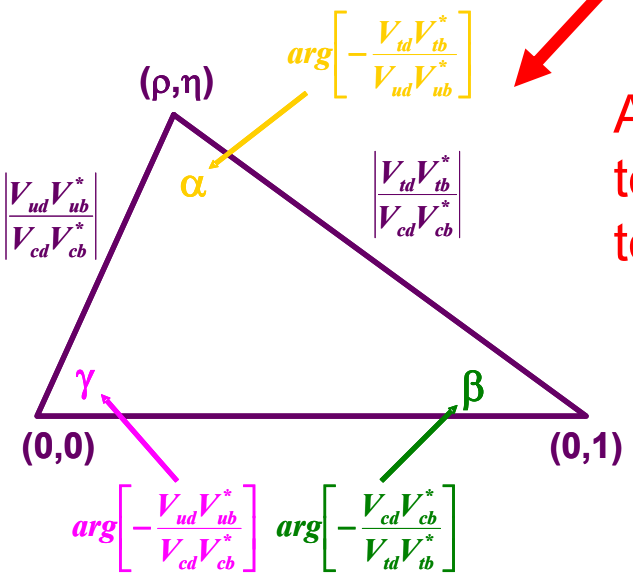
Motivation

- **Standard Model Lagrangian**

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

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

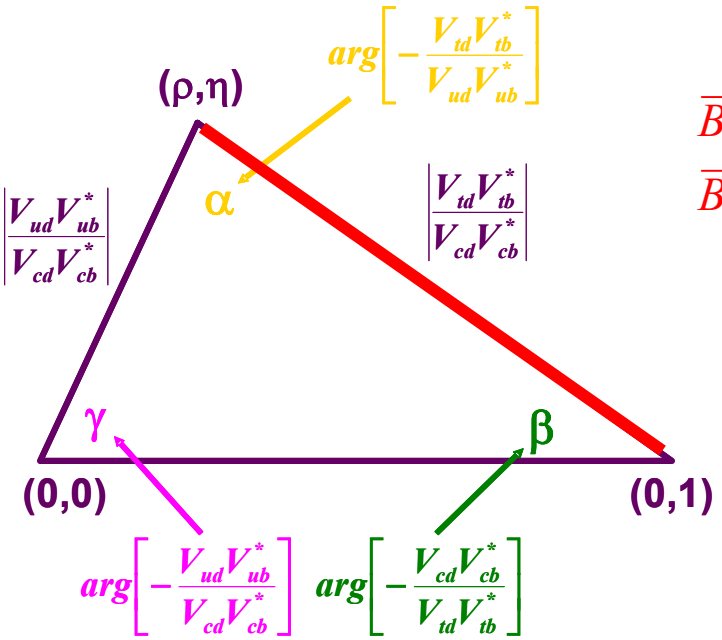
Unitarity

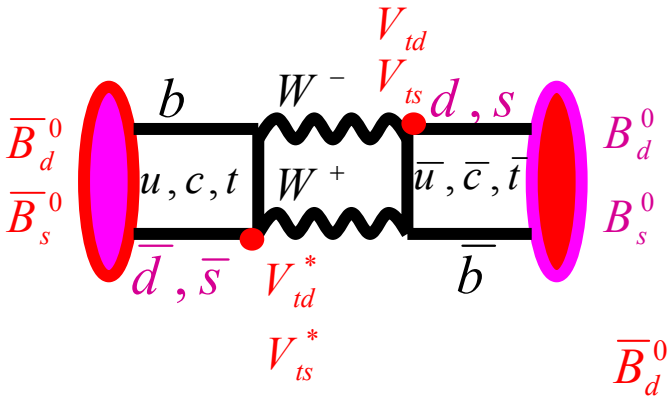


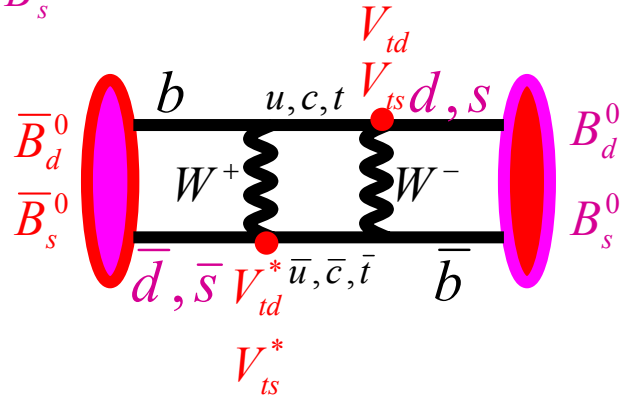
Area of the Unitarity Triangle is proportional to the CP violation in the Standard Model due to CKM Matrix

Sides and angles of the Triangle could be determined using many physics processes → Consistency check

Triangle Side From B Mixing







B_d oscillation frequency $\Delta m_d = \left|V_{tb}^* V_{td}\right|^2 \cdot (QCD\,parameters)$

Cancellation of many QCD parameters in ratio $\frac{\Delta m_s}{\Delta m_d} \propto \left|\frac{V_{ts}}{V_{td}}\right|^2$

→ **Determination of V_{td} with much better precision**

$B - \bar{B}$ Mixing and Oscillations

$$|B_1\rangle = \frac{1}{\sqrt{2}}\left(|B^0\rangle + |\bar{B}^0\rangle\right) = |B_H\rangle$$

$$|B_2\rangle = \frac{1}{\sqrt{2}}\left(|B^0\rangle - |\bar{B}^0\rangle\right) = |B_L\rangle$$

Mass Eigenstates (and CP eigenstates if ignore CP violation)

Weak Eigenstates

$$\hat{H}\begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2} \end{pmatrix}\begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix}$$

- Then B_1 and B_2 are eigenstates with

masses: $m_{1,2} = M \pm \frac{\Delta m}{2}$ and lifetimes: $\Gamma_{1,2} = \Gamma \pm \frac{\Delta\Gamma}{2}$

$B - \bar{B}$ Mixing and Oscillations

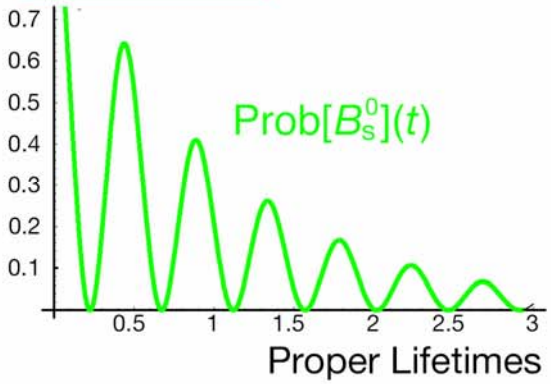
Extract frequency

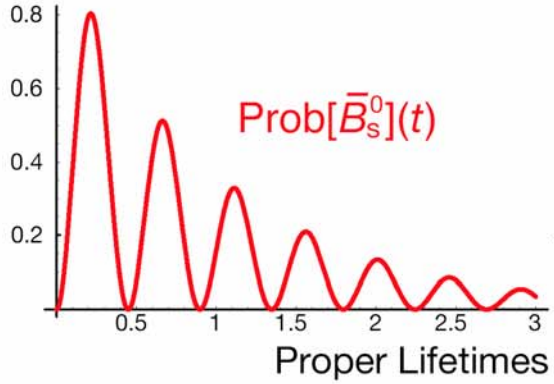
- If initially start with a B_s^0

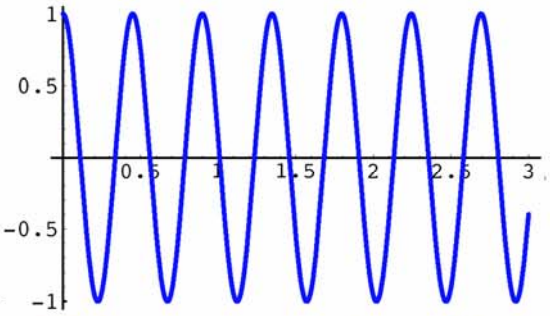
$$\text{Prob}[B_s^0](t) = \frac{1}{4}\left[\exp(-\Gamma_1 t) + \exp(-\Gamma_2 t) + 2\exp(-\Gamma t)\cos(\Delta m_s t)\right]$$

$$\text{Prob}[\bar{B}_s^0](t) = \frac{1}{4}\left[\exp(-\Gamma_1 t) + \exp(-\Gamma_2 t) - 2\exp(-\Gamma t)\cos(\Delta m_s t)\right]$$

- For B_s^0







Take asymmetry of two:

$$A = \frac{N[B^0](t) - N[\bar{B}^0](t)}{N[B^0](t) + N[\bar{B}^0](t)}$$

$$A \propto \cos(\Delta m_s t)$$

- What we get from it: $\Delta m_s \propto |V_{tb}^* V_{ts}|^2$

- $\Delta m_d \propto |V_{tb}^* V_{td}|^2$ (~ 1, tiny)
- $\Delta m_s \propto |V_{tb}^* V_{ts}|^2$ (~ 1, still small, but larger than V_{td})

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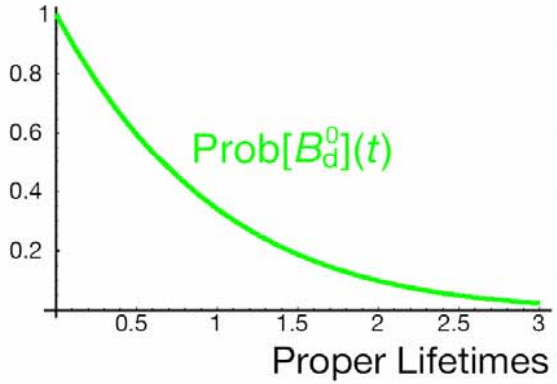

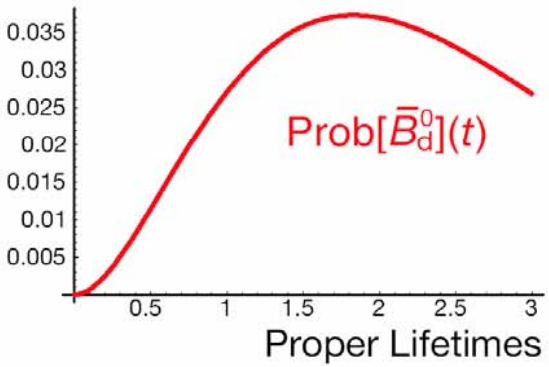

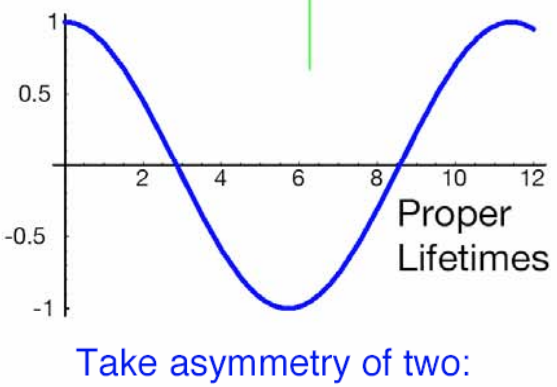

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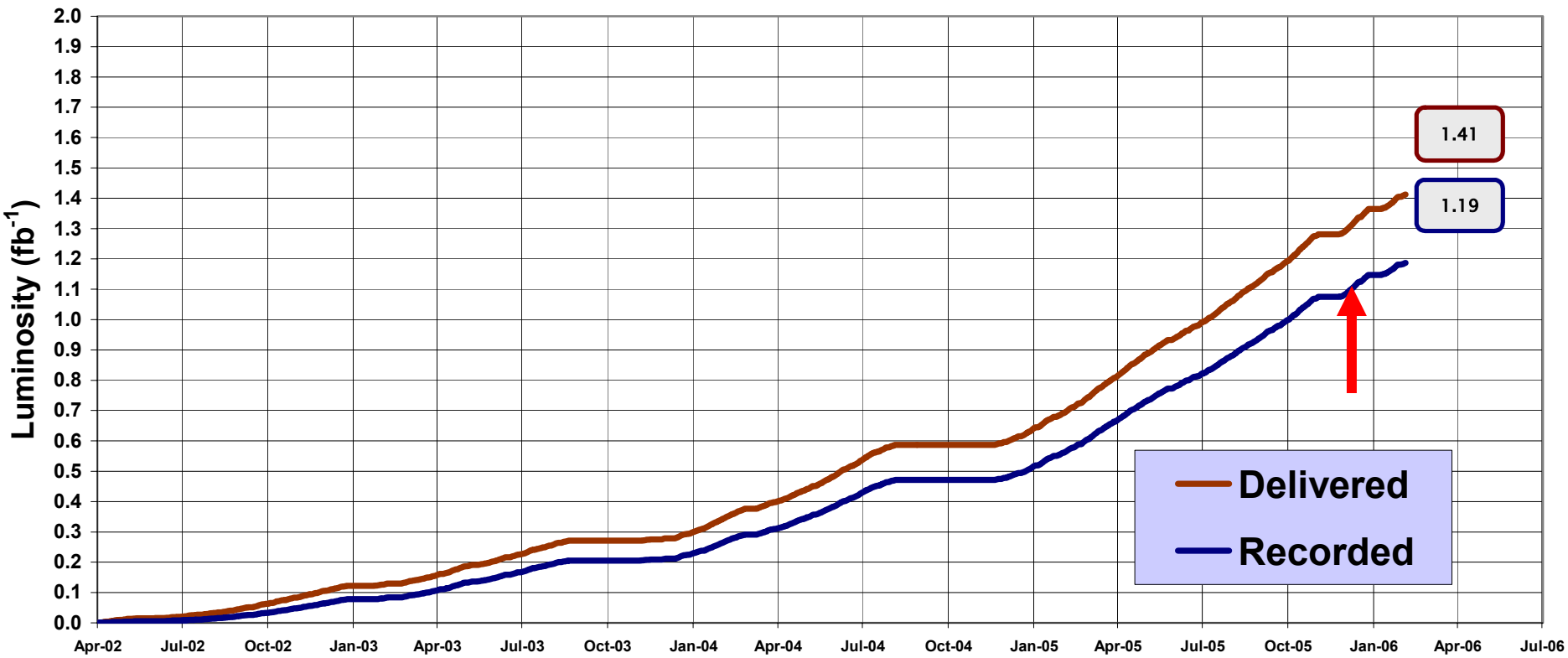
DØ Bs Mixing: from Simple to Complex

- **2003**
  - *Reconstruction of semileptonic B decays: μD^0, $\mu D^{*\pm}$, $\mu D^{\pm}$, μD_s*
  - *Understanding of sample composition, resolution, K-factor (momentum of non-reconstructed particles)*
- **2004**
  - *Measurements of Bd oscillations*
    - ✓ Opposite-side muon tagging for Moriond 2004
    - ✓ Same-side tagging and combined tagging for ICHEP 2004
- **2005**
  - *First Bs mixing results*
    - ✓ For Moriond 2005
    - ✓ Update in Summer 2005
- **2006**
  - *Increased statistics*
  - *Improved initial state flavor tagging*
    - ✓ Added opposite-side electron tagging
  - *Improved analysis technique*
  - *First indication of the Bs oscillations signal presented at Moriond 2006*

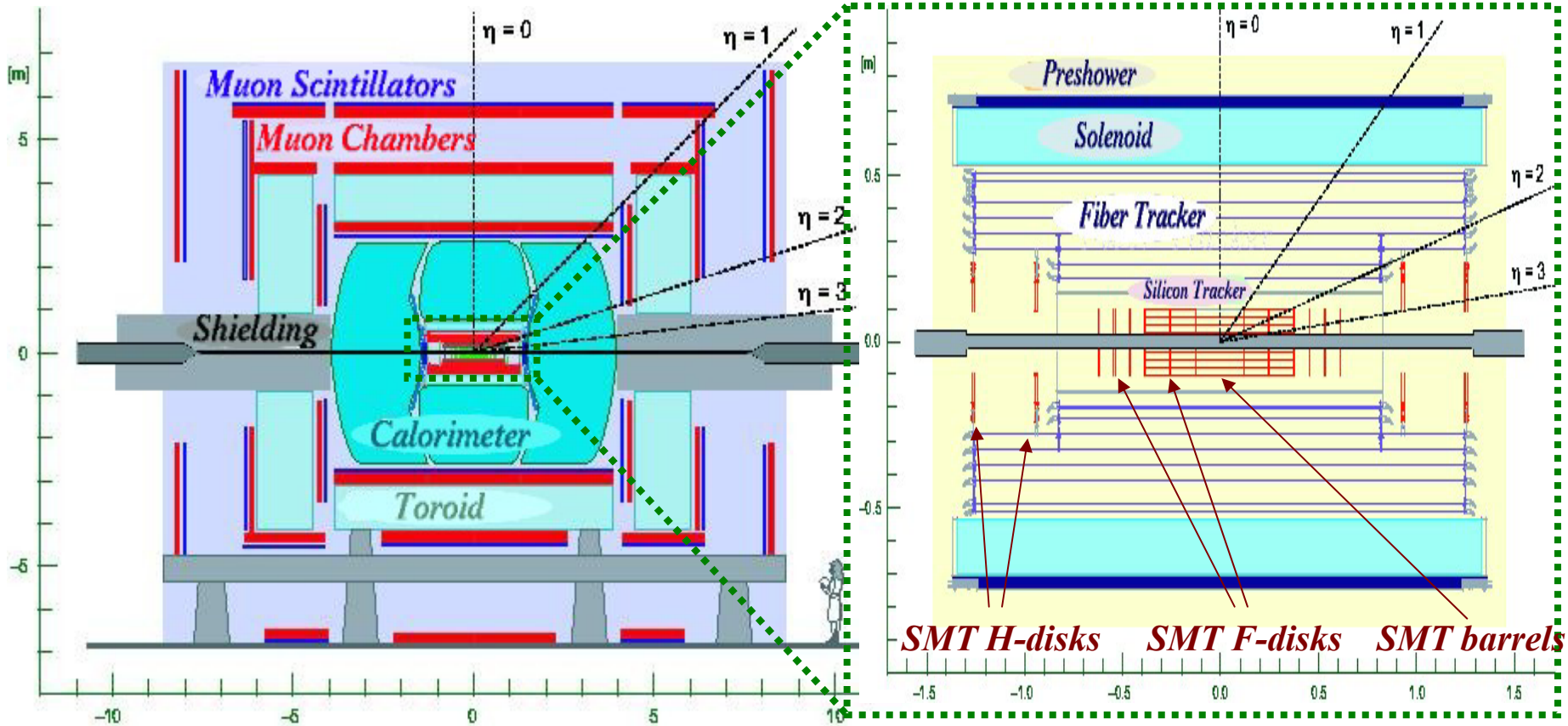
Excellent Tevatron Performance



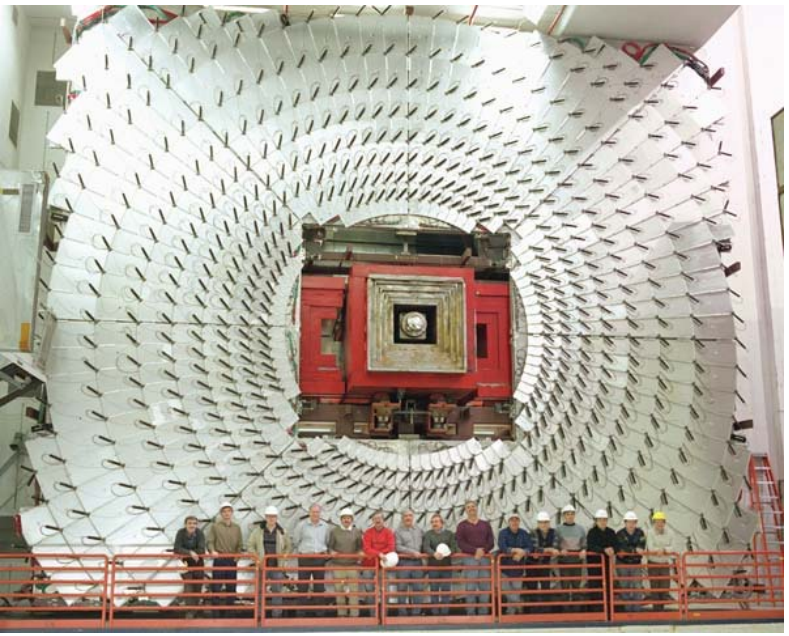
- Data sample corresponding to over 1 fb^{-1} of the integrated luminosity used for the Bs mixing analysis
- Full dataset is ready

DZero Detector

- Spectrometer : Fiber and Silicon Trackers in 2 T Solenoid
- Energy Flow : Fine segmentation liquid Ar Calorimeter and Preshower
- Muons : 3 layer system & absorber in Toroidal field
- Hermetic : Excellent coverage of Tracking, Calorimeter and Muon Systems

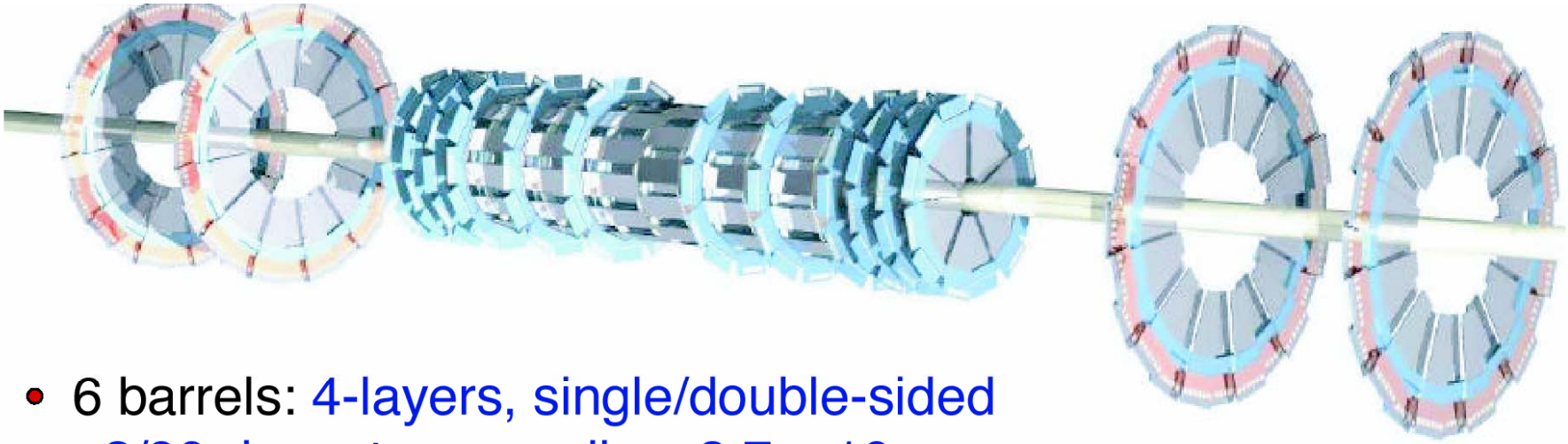


Muon Triggers



- **Single inclusive muons**
  - *$|\eta|<2.0$, $p_T > 3,4,5$ GeV*
  - *Muon + track match at Level 1*
  - *No direct lifetime bias*
    - ✓ Still could give a bias to measured lifetime if cuts on decay length are imposed in offline
  - *Prescaled or turned off depending on inst. lumi.*
  - *B physics triggers at all lumi's*
    - ✓ Extra tracks at medium lumi's
    - ✓ Impact parameter requirements
    - ✓ Associated invariant mass
    - ✓ Track selections at Level 3
- **Dimuons: other muon for flavor tagging**
- **e.g. at $50 \cdot 10^{-30}$ cm^{-2}s^{-1}**
  - *20 Hz of unbiased single μ*
  - *1.5 Hz of IP+μ*
  - *2 Hz of di-μ*
- **No rate problem at L1/L2**

Silicon Microvertex Tracker (SMT)

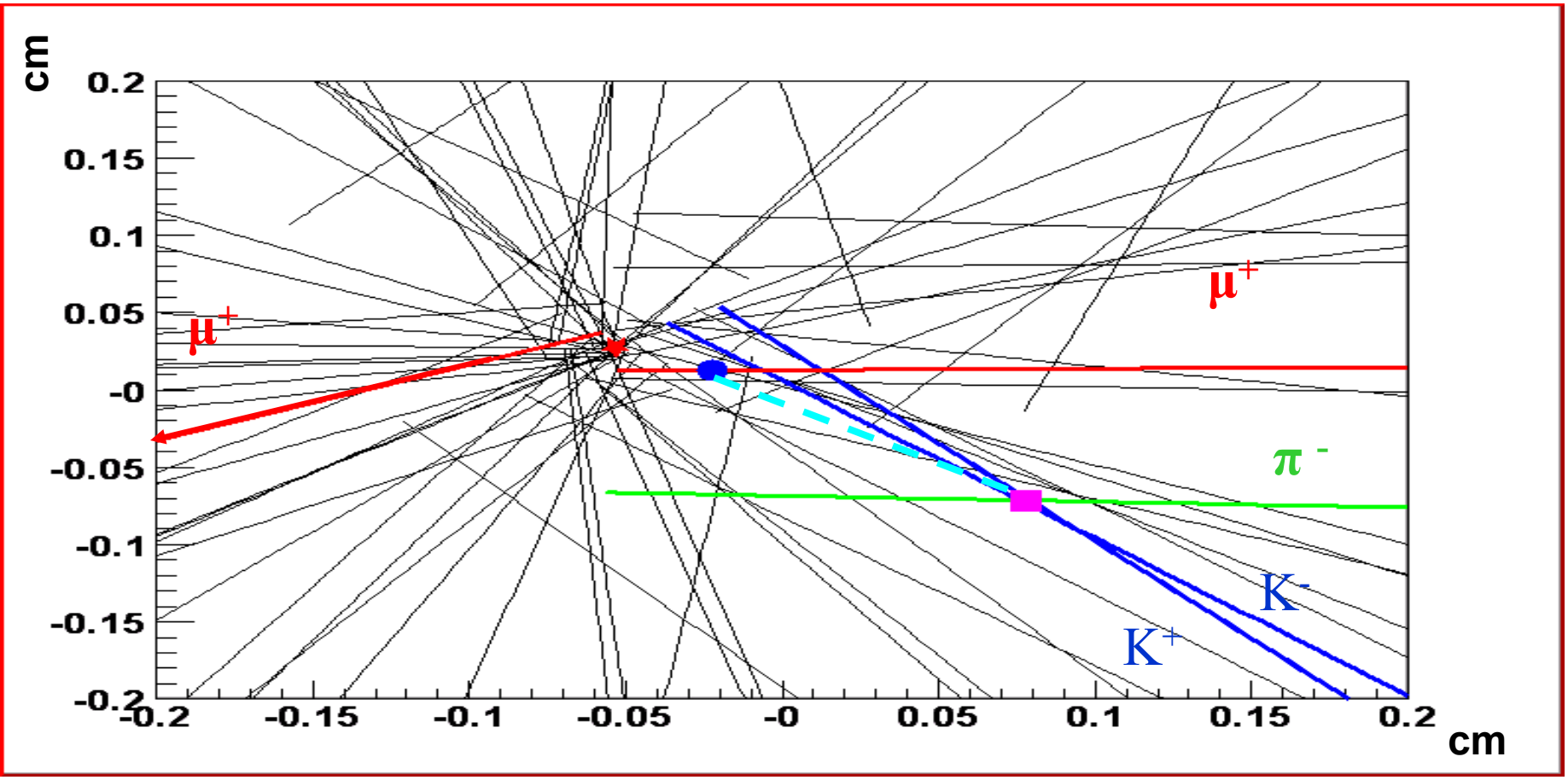


- 6 barrels: 4-layers, single/double-sided
  2/90 deg. stereo, radius: 2.7 – 10 cm
- 12 central F disks: double-sided, ± 15 deg. stereo
- 4 forward H disks: single-sided, ±7.5 deg. stereo,
  |z| = 1.2 m, radius: 9.5 – 20 cm

- **Asymptotic (high momentum) resolution of 15μm**
  - ***Will be improved with Layer 0***

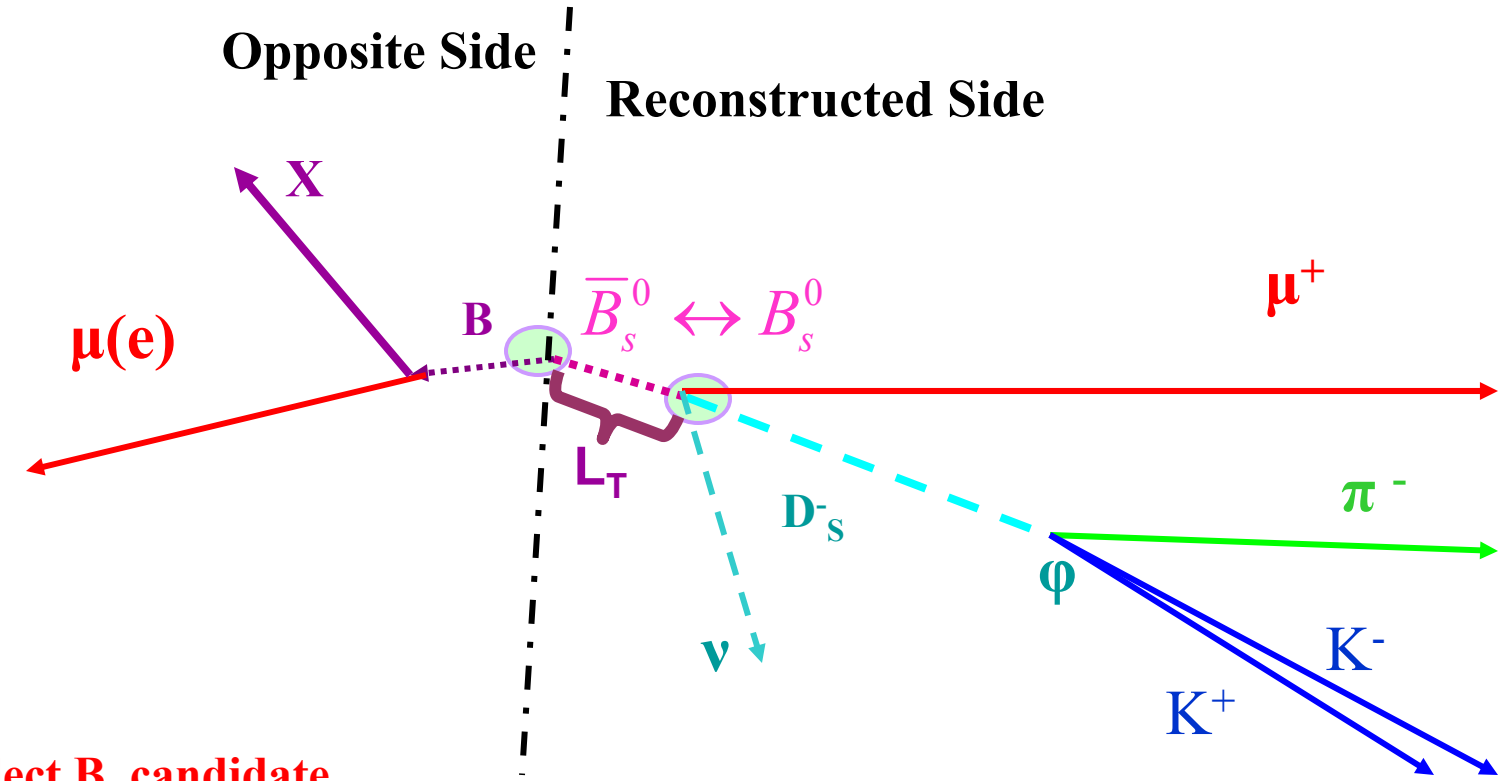
Layer 0 is being inserted!

Challenge: High Track Multiplicity



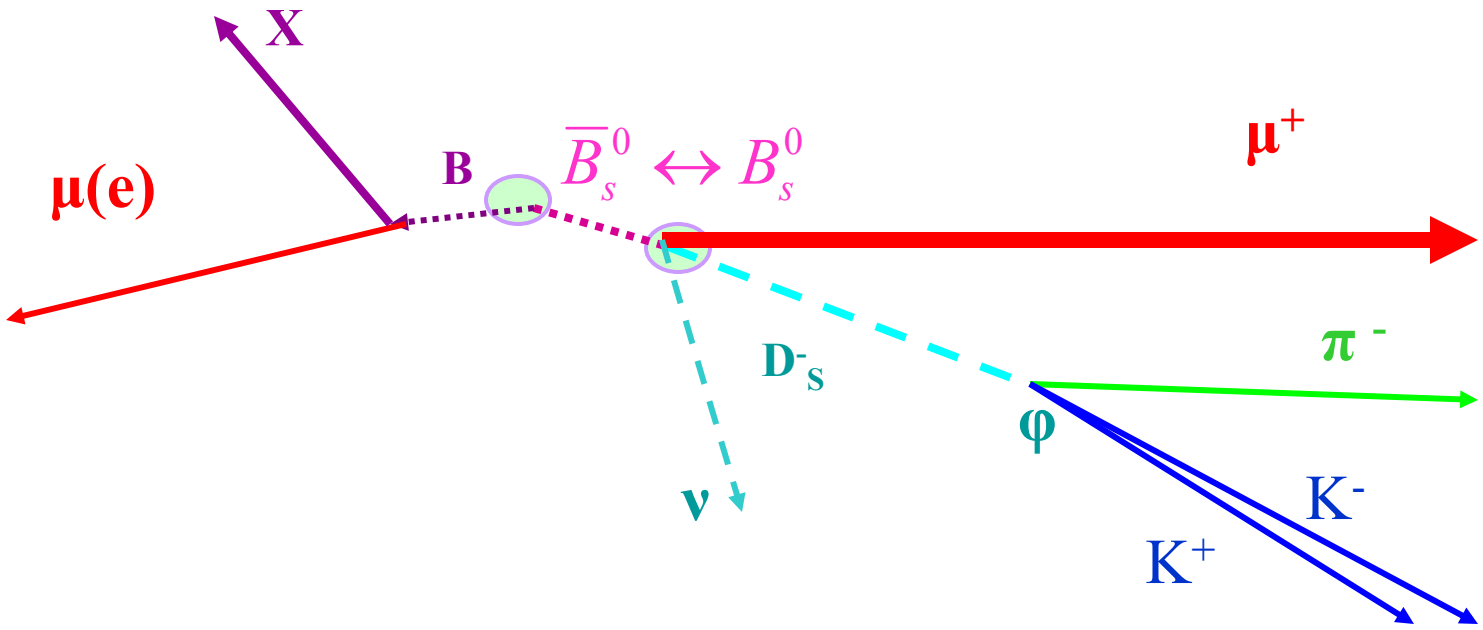
$$\overline{B}_s^0 \to B_s^0 \to \nu\mu^+ \overbrace{\pi^- \underbrace{K^+ K^-}_{\phi}}^{D_s^-}$$

Analysis Outline



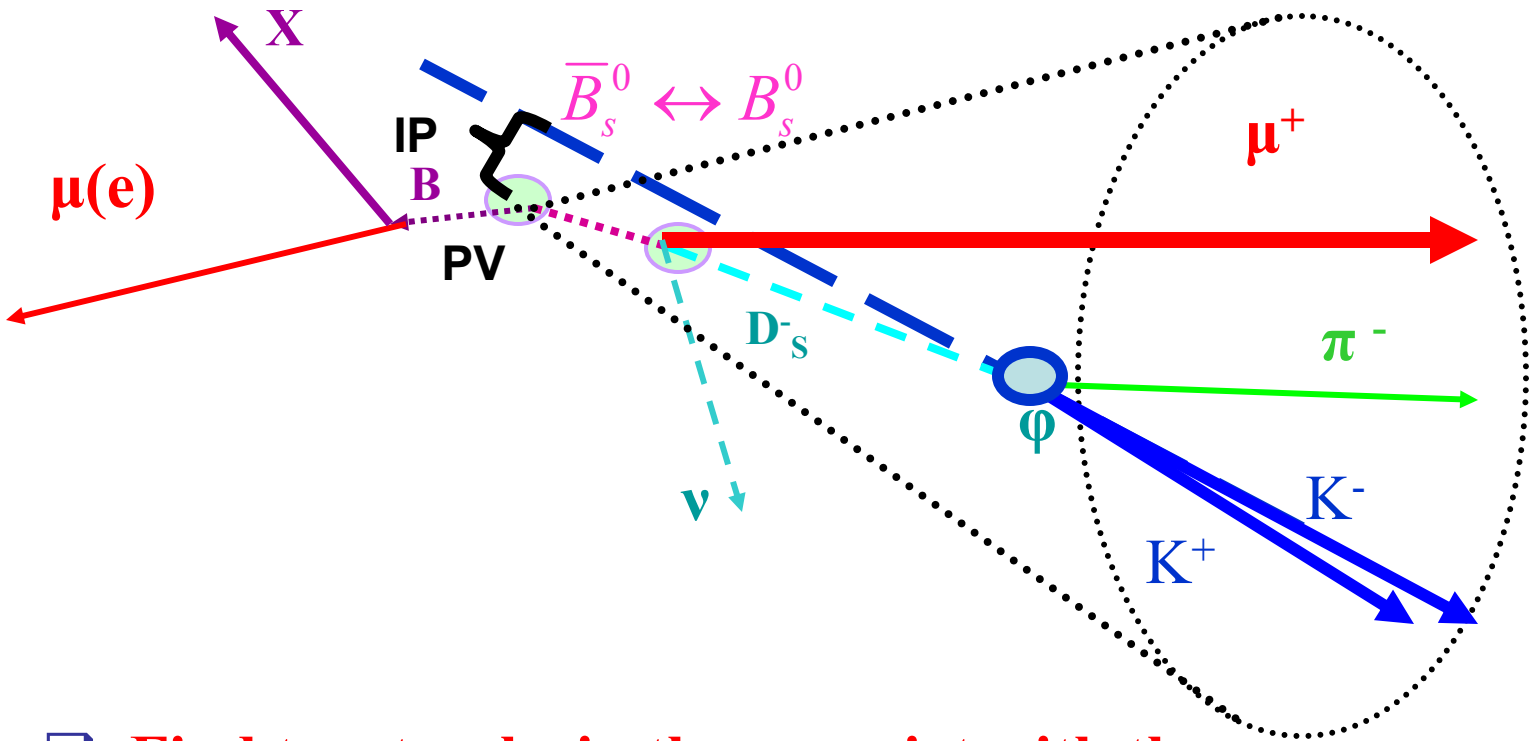
- **Select B_s candidate**
  - *Concentrate on the most clean decay mode $B_s \rightarrow \nu\mu D_s(\rightarrow\varphi\pi)$*
- **For each B_s candidate**
  - *B_S flavor at decay time from muon sign at the reconstructed side*
  - *Transverse length L_T and its error*
  - *Transverse momentum $P_T(B_s)$ (use $P_T(D_s\mu)$)*
  - *B-hadron flavor at the opposite side (indicates B_S flavor at production time)*

Signal Selection



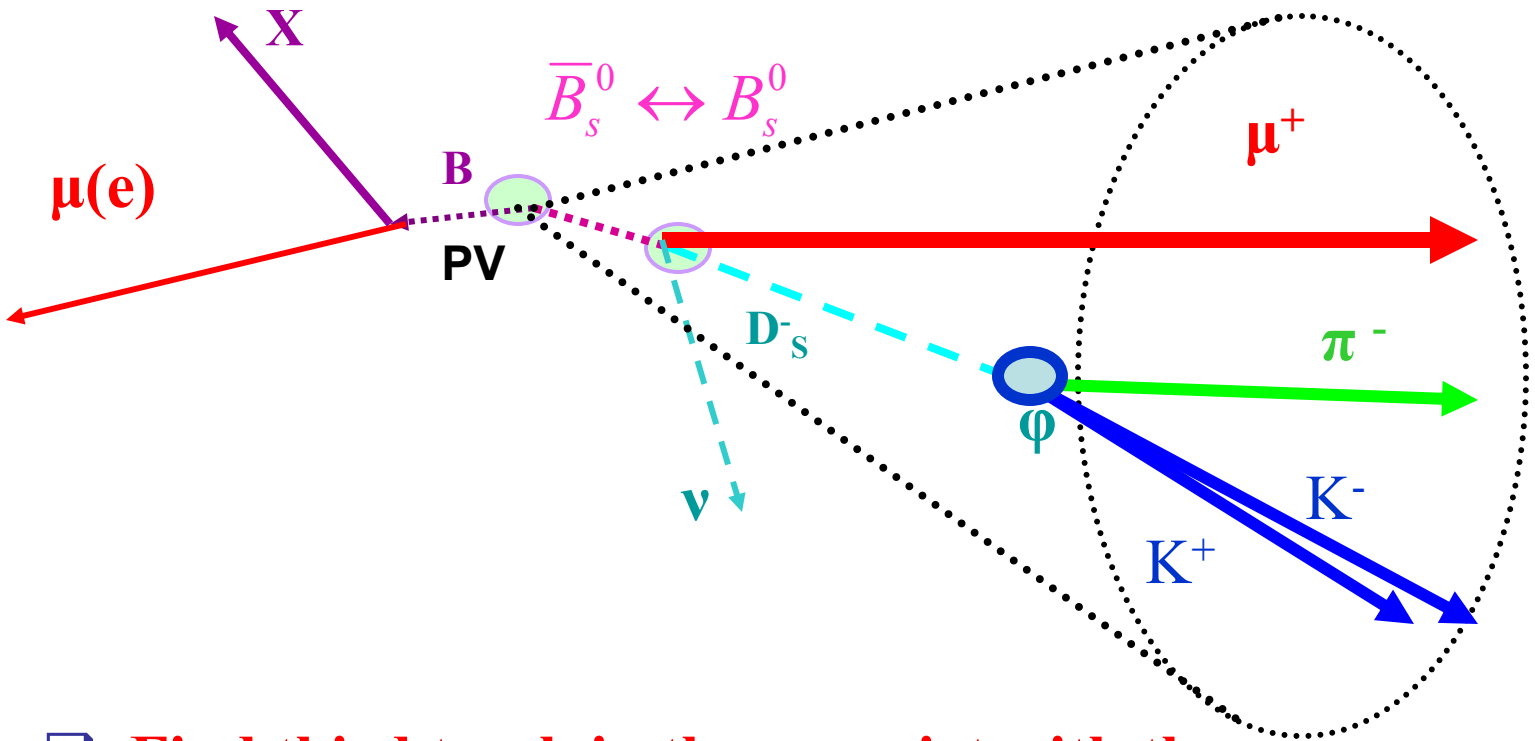
- Select events with a muon

Signal Selection



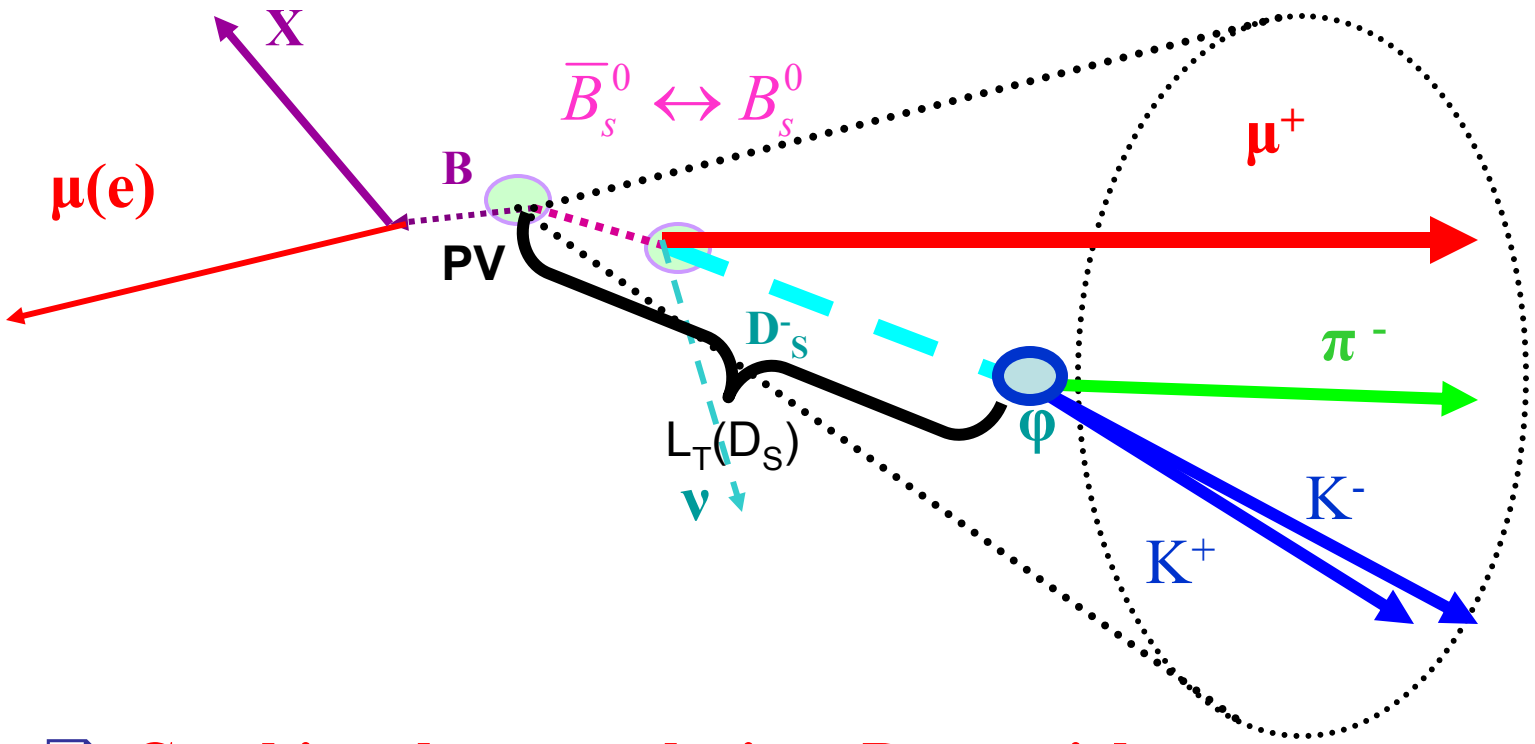
- **Find two tracks in the same jet with the muon**
  - *different signs*
  - *Impact Parameter significances with respect to the Primary Vertex*
  - *common vertex*
  - *φ mass*

Signal Selection



- **Find third track in the same jet with the muon**
  - *sign opposite to the muon*
  - *Impact Parameter significance with respect to the Primary Vertex*
  - *common vertex with kaons*
  - *D_S mass*

Signal Selection



- **Combine three tracks into Ds particle**
  - *Decay Length significance with respect to the Primary Vertex*
  - *common vertex with the muon*
  - *some constraints on the μD_S invariant mass*

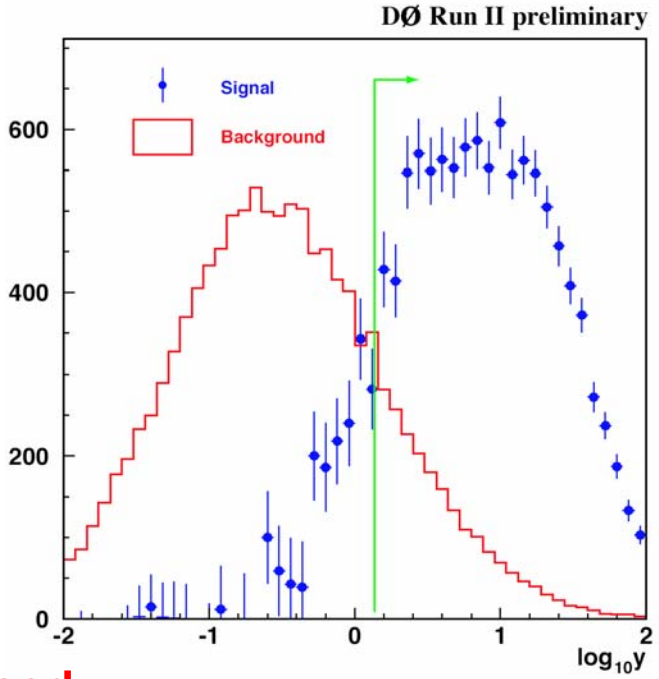
Signal Selection Function

Further improvement in S/B following initial vertex, lifetime & mass window cuts:

- Set of discriminating variables x_i constructed for each event
- Cut on combined variable, product of likelihood ratios

(PDFs for background and signal from data):

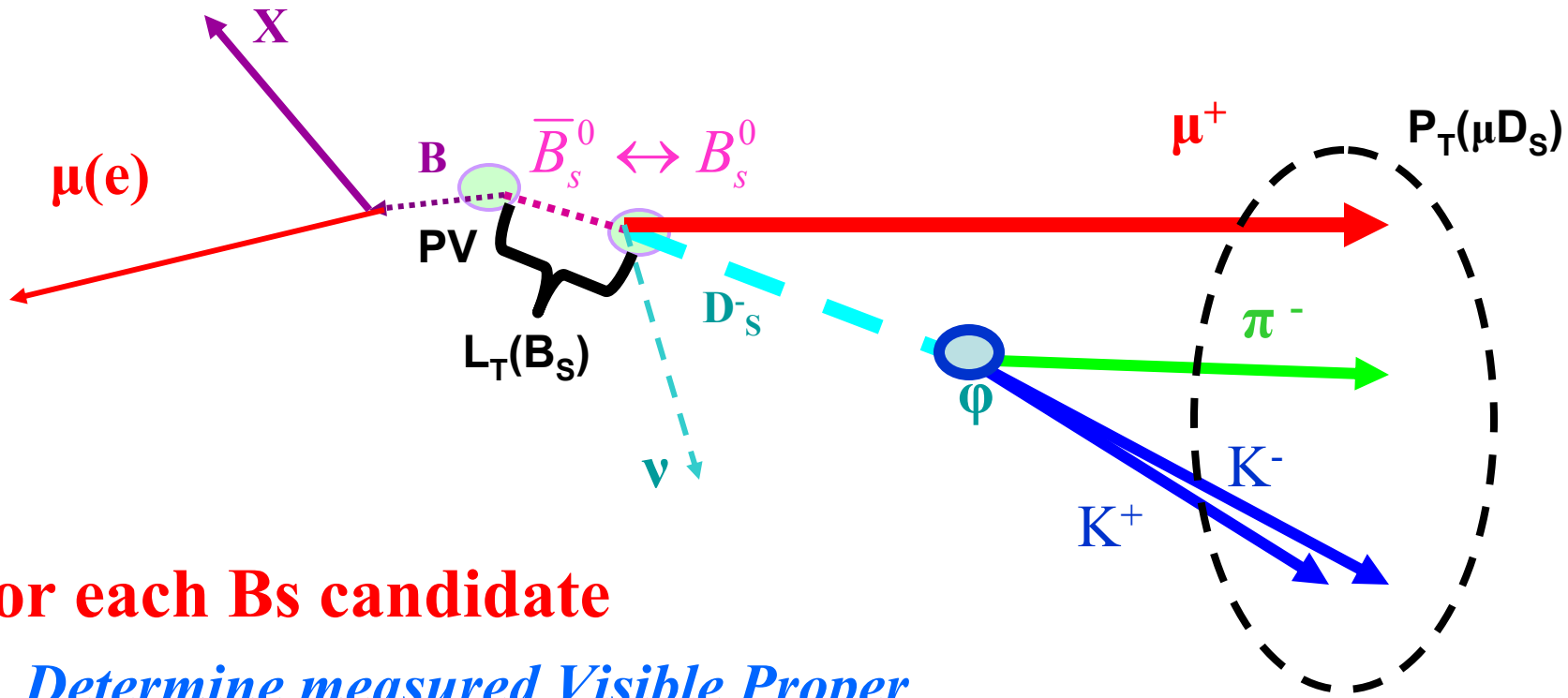
$$y = \prod_i^n y_i \; ; \quad y_i = \frac{PDF_i^s(x_i)}{PDF_i^b(x_i)}$$



The following discriminating variables were used:

- Helicity angle, defined as the angle between the D_s and K_1 momenta in the (K_1, K_2) center of mass system;
- Isolation, computed as $Iso = p^{tot}(\mu D_s)/(p^{tot}(\mu D_s) + \sum p_i^{tot})$. The sum $\sum p_i^{tot}$ was taken over all charged particles in the cone $\sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.5$, where $\Delta\eta$ and $\Delta\phi$ are the pseudorapidity and the azimuthal angle with respect to the (μD_s) direction. The μ, K_1, K_2 and π were not included in the sum;
- $p_T(K_1K_2)$;
- Invariant mass, $M(\mu D_s)$;
- χ^2 of the D_s vertex fit;
- $M(K_1K_2)$.

Signal Selection



- **For each Bs candidate**
  - ***Determine measured Visible Proper Decay Length***

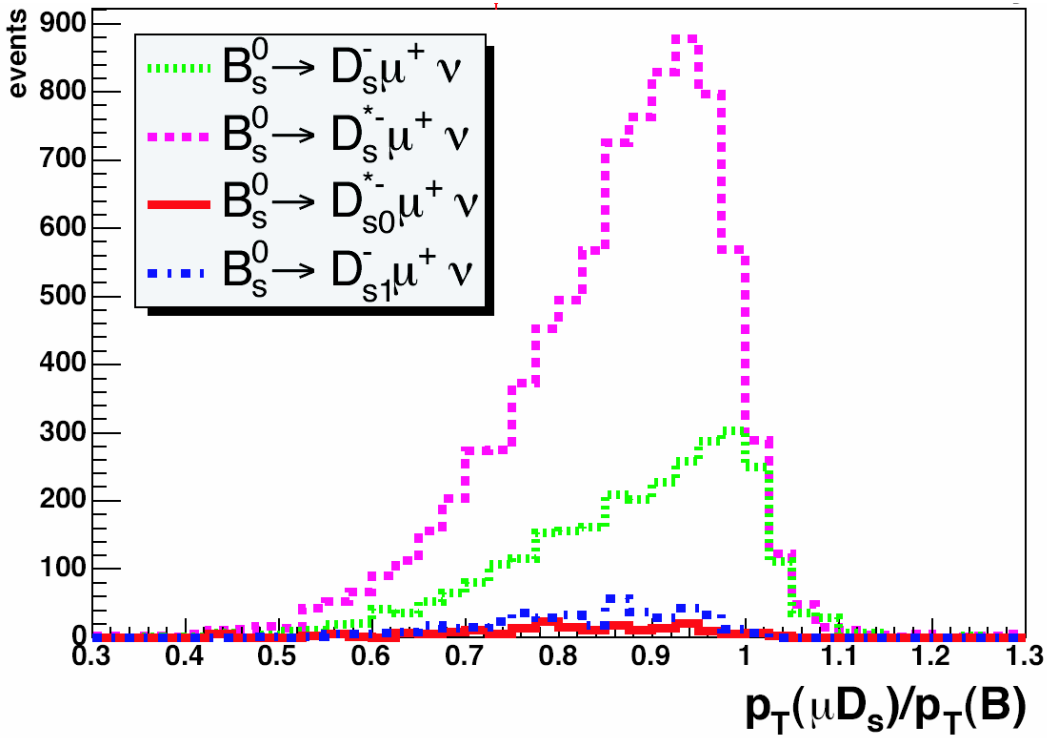
$$x^M = m_{B_s} \cdot \left(\vec{L}_T \cdot \vec{p}_T^{\,D_s\mu}\right) \Big/ \left(p_T^{D_s\mu}\right)^2$$

Proper Decay Length

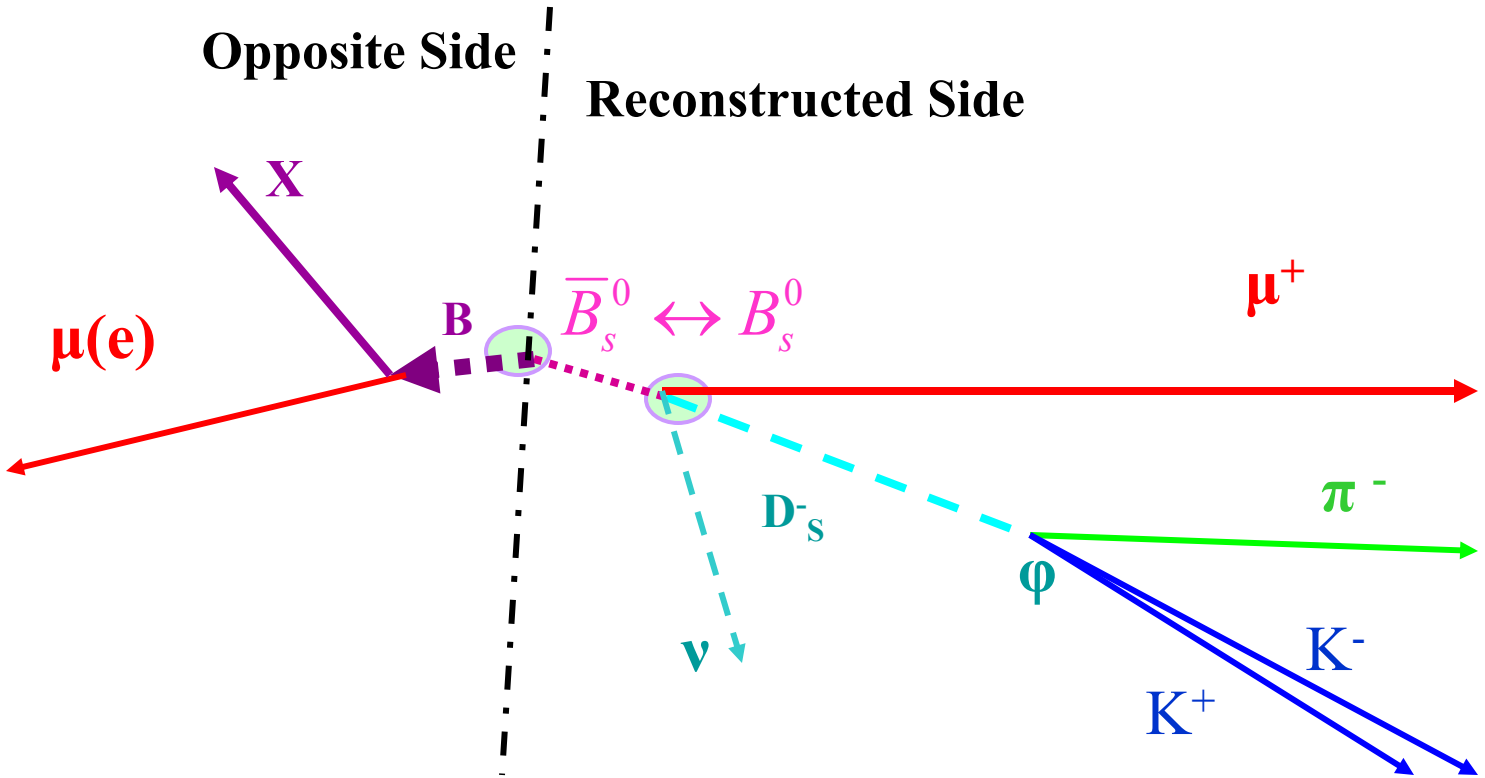
- Proper Decay Length is determined from the Visible Proper Decay Length
- K Factor takes into account the escaping neutrino and other missing particles
  - $B_s^0 \rightarrow D_s^{*-} \mu^+ \nu$, $D_s^{*-} \rightarrow D_s^- \gamma$
- From MC, each decay mode

$$ct_{B_s} = x^M K$$

$$K = p_T^{D_s \mu} / p_T^{B_s}$$

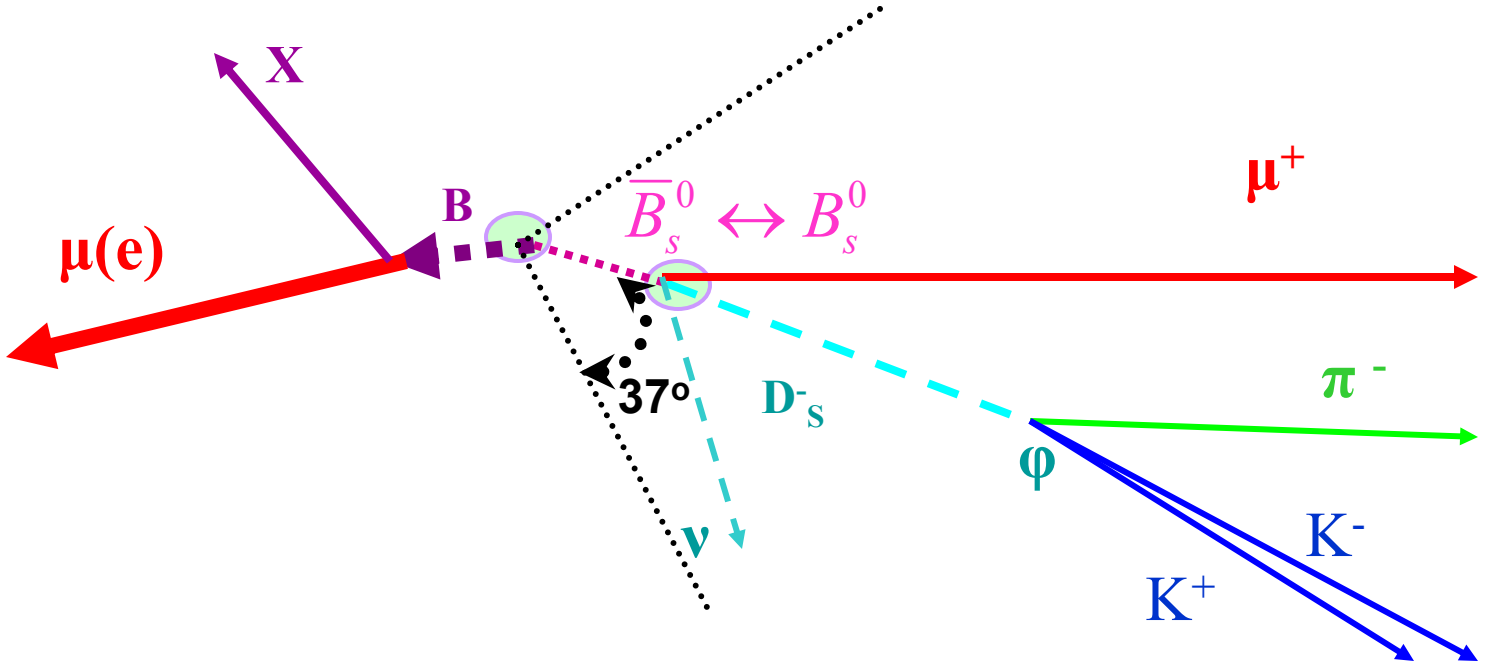


Initial State Tagging



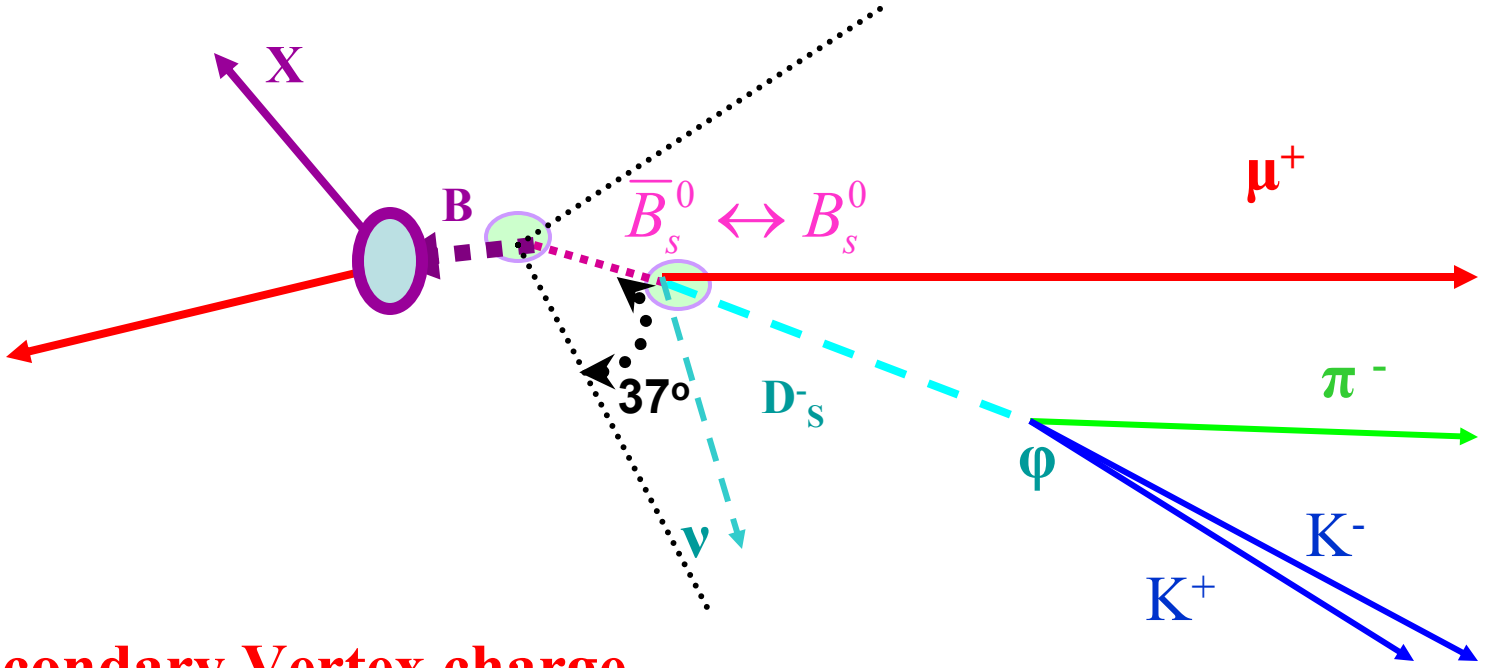
- **Use Opposite Side B-hadron**
  - ***$b\bar{b}$ pairs are produced***

Initial State Tagging



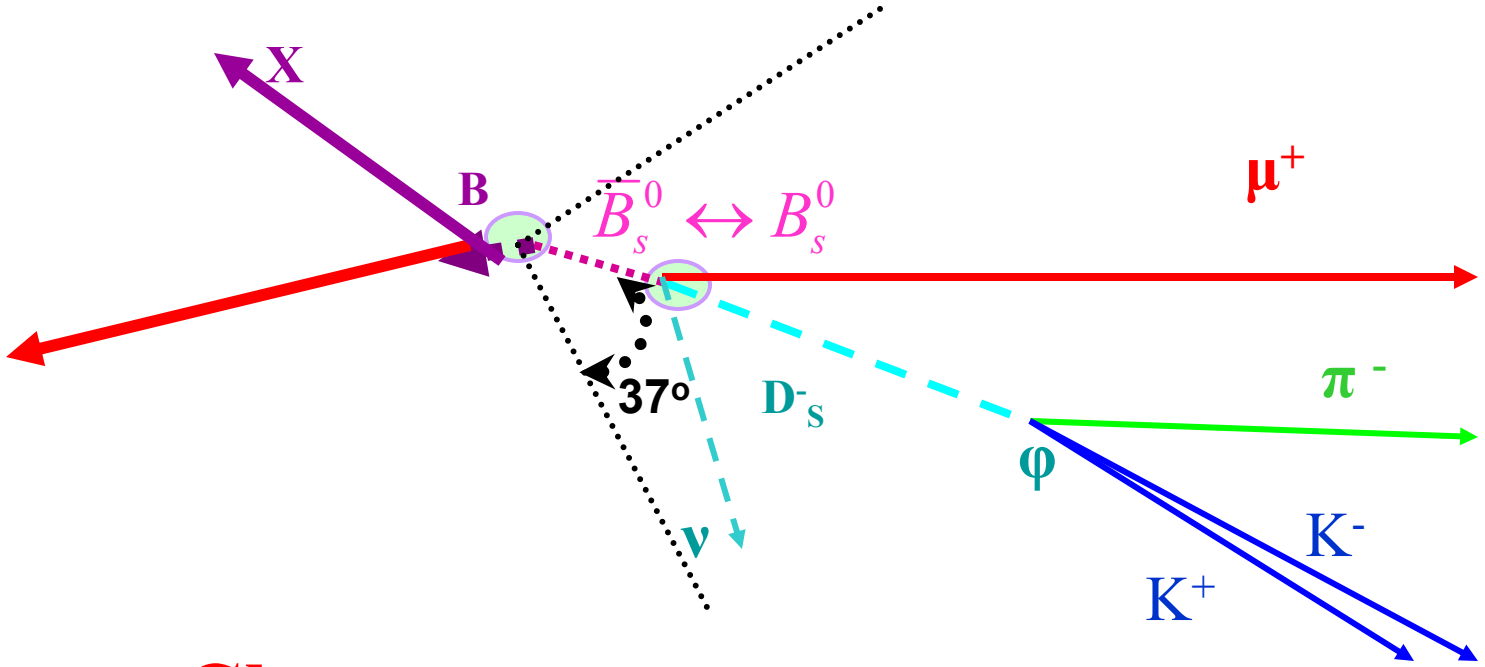
- **If muon or electron at opposite side is found then use the muon (electron) jet charge**
  - *assume B semileptonic decays*
  - *clean from background (cascade decays) using weighting technique*

Initial State Tagging



- **Secondary Vertex charge**
- **Find Secondary Vertex at opposite side**
  - *formed by tracks with Impact Parameter significances with respect to the Primary Vertex*
  - *has decay length significance with respect to the Primary Vertex*
- **Sum weighted charges of tracks in this vertex**

Initial State Tagging



Event Charge

- *Sum weighted charges of tracks with $p_T > 0.5$GeV*
  - ✓

$$Q_{EV} = \frac{\sum p_T q}{\sum p_T}$$

Combination of Initial Flavor Tagging Variables

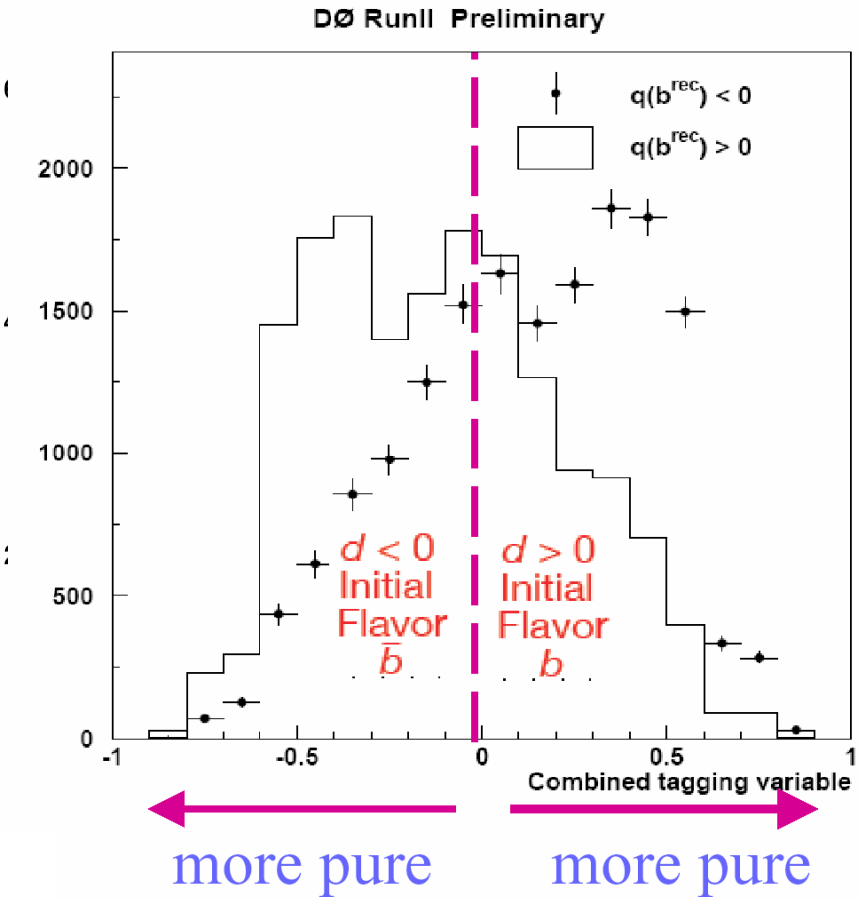
- Each flavor discriminating variable x_i as used described previously, likelihood ratio:

$$y = \prod_i^n y_i \; ; \quad y_i = \frac{PDF_i^{\bar{b}}(x_i)}{PDF_i^{b}(x_i)}$$

From *data*, $B_d^0 \to D^{*-}\,\mu^+\nu$ wrong-sign subtracted, at short lifetimes *(non-oscillated)*

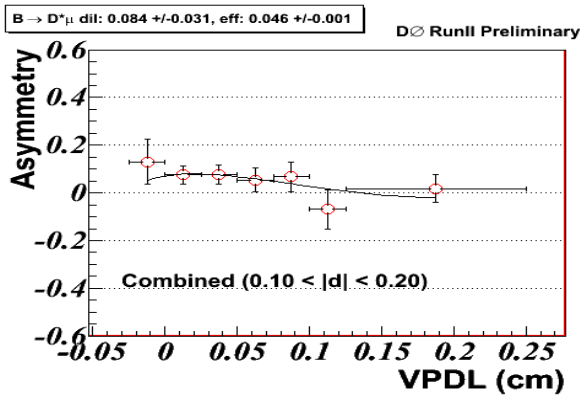
- Form single flavor-tag variable

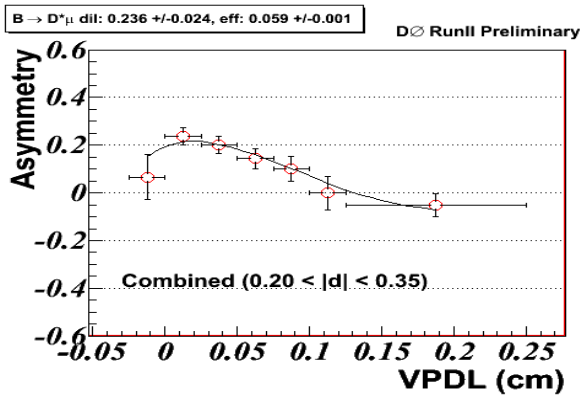
$$d = \frac{1-y}{1+y}$$

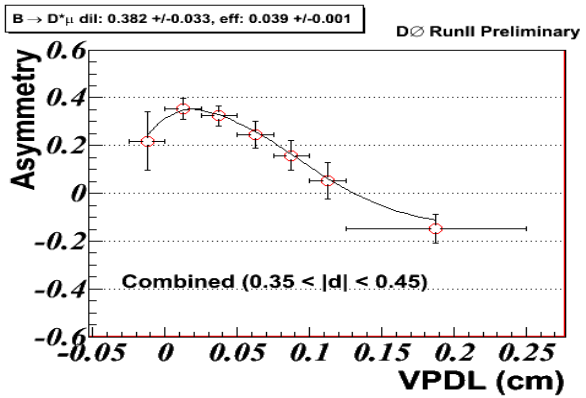


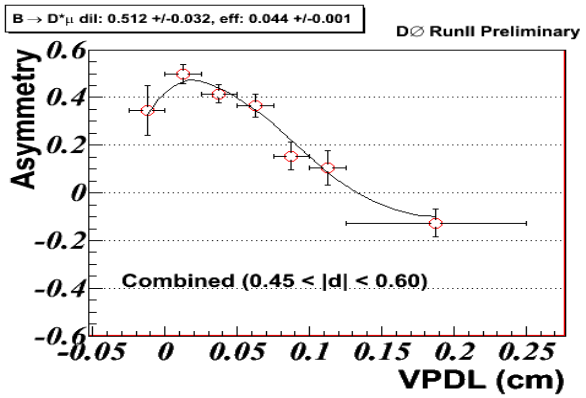
Calibration of Dilution Using $B_d \rightarrow D^{*\pm}\mu\nu X$

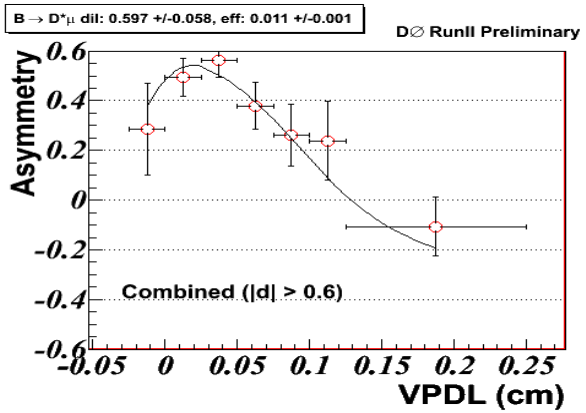
Increasing dilution











Increasing dilution

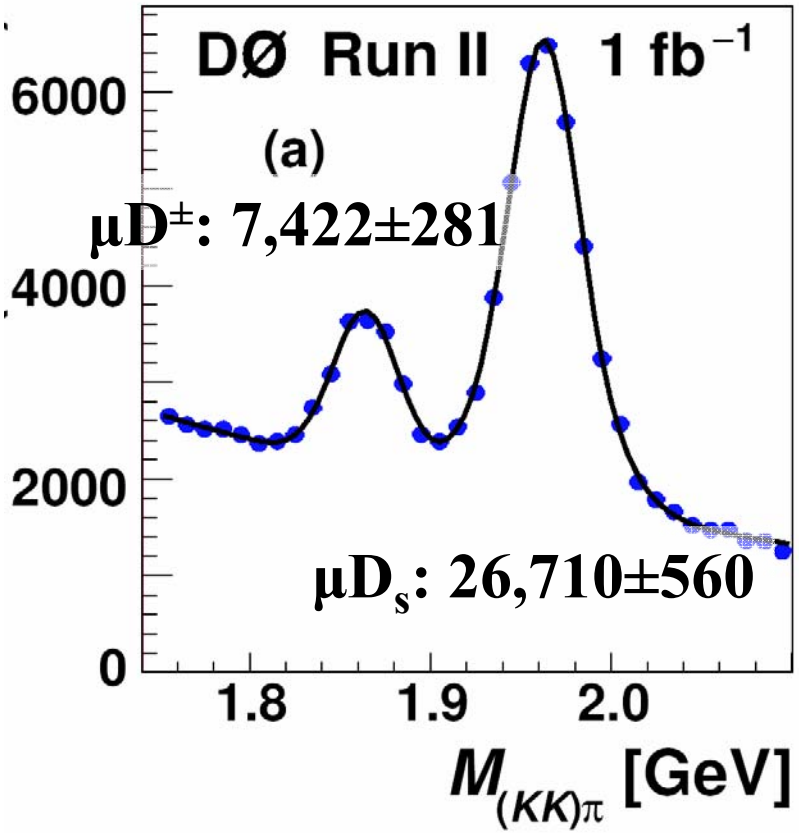
$\Delta m = 0.506 \pm 0.020$ (stat.) ps^{-1}

$\varepsilon D^2 = (2.48 \pm 0.21)$ (%) (stat.)

$\varepsilon = (19.9 \pm 0.2)$ (%) (stat.)

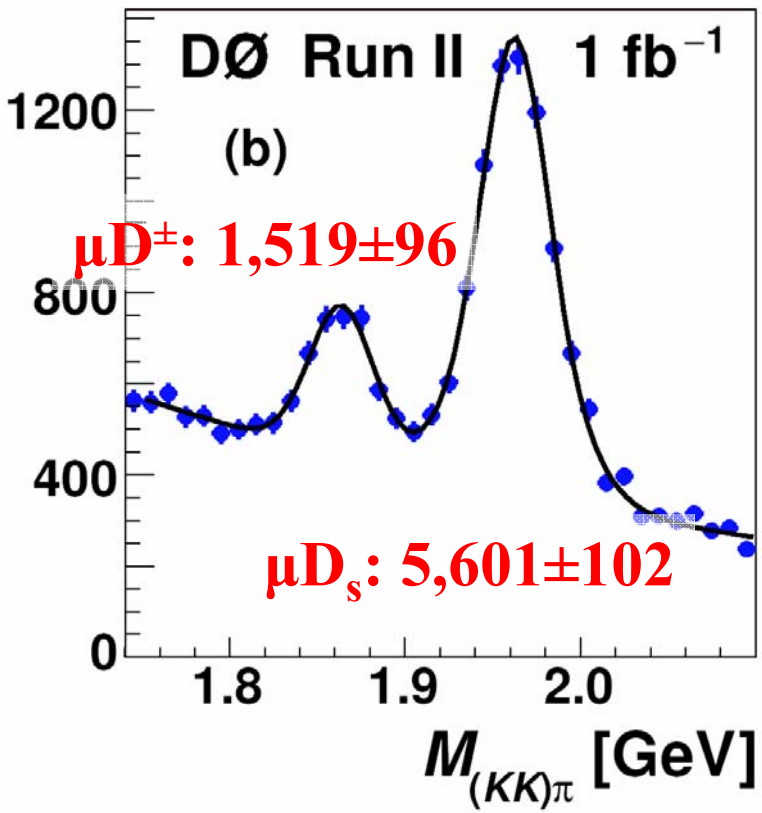
$\Delta m_{HFAG} = 0.507 \pm 0.004\ ps^{-1}$

$\mu\phi\pi$ sample @ D0 (~1 fb^{-1})



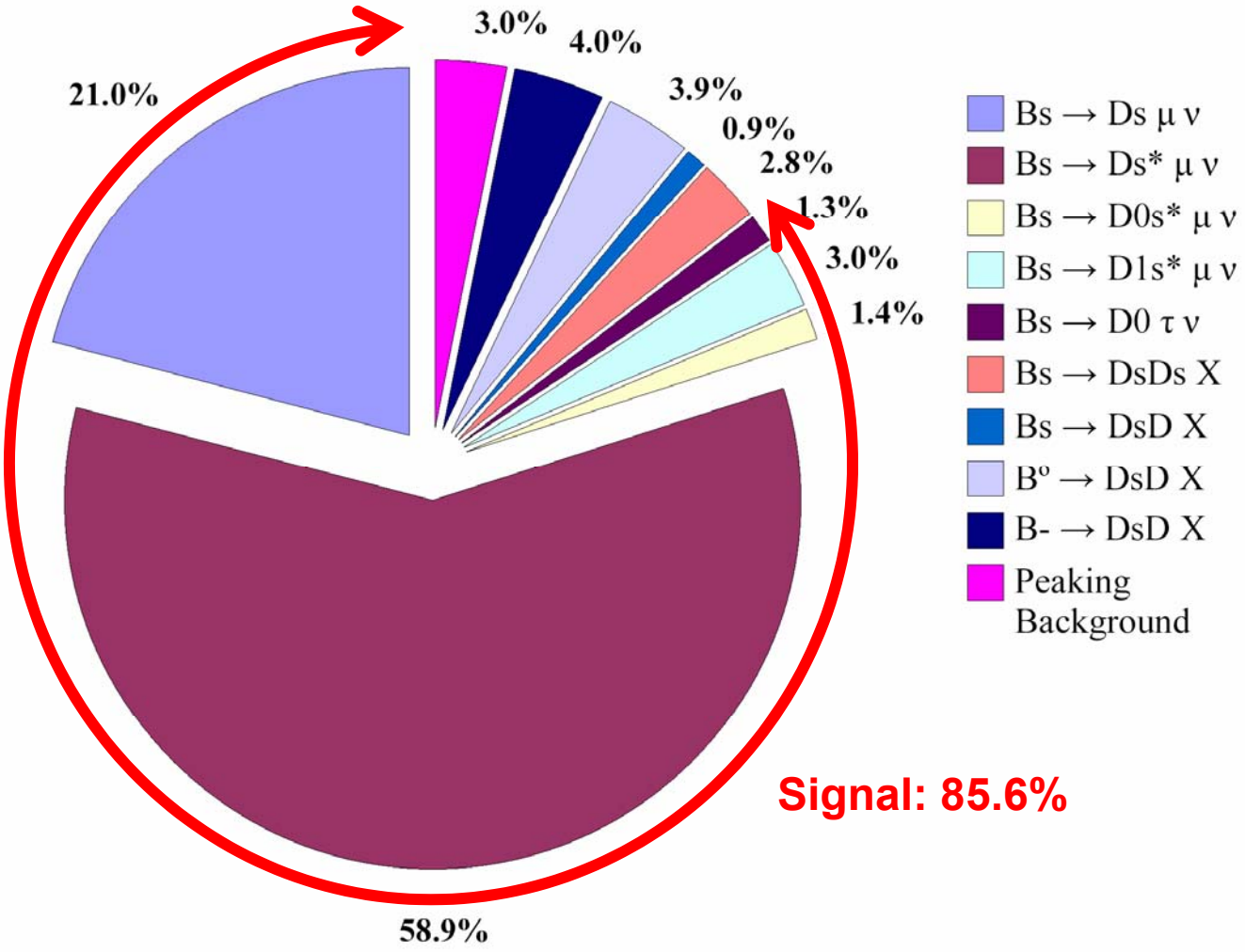
Tagging efficiency ~20%

Opposite-side flavor tagging



Sample Composition

- **The signal peak (μ+Ds)**
  - Estimate using MC simulation, PDG Br's, Evtgen exclusive Br's



Expected Asymmetry

$$p_s^{nos/osc} = \frac{K}{c\tau_{B_s}} e^{-\frac{Kx}{c\tau_{B_s}}} \cdot 0.5 \cdot \left(1 \pm \mathcal{D} \cos\left(\Delta m_s \cdot Kx / c\right)\right)$$

Efficiency

$$\varepsilon = \frac{N_{\text{total flav. tagged events}}}{N_{\text{total events}}}$$

Purity

$$\eta = \frac{N_{\text{correct flav. tagged events}}}{N_{\text{total flav. tagged events}}}$$

Dilution

$$\mathcal{D} = 2\eta - 1$$

(less than 1, ~ multiplier of "ideal" ±1 amplitude of asymmetry)

$$\mathcal{D} = \mathcal{D}(d)$$

Effective flavor tagging power

Proper time resolution

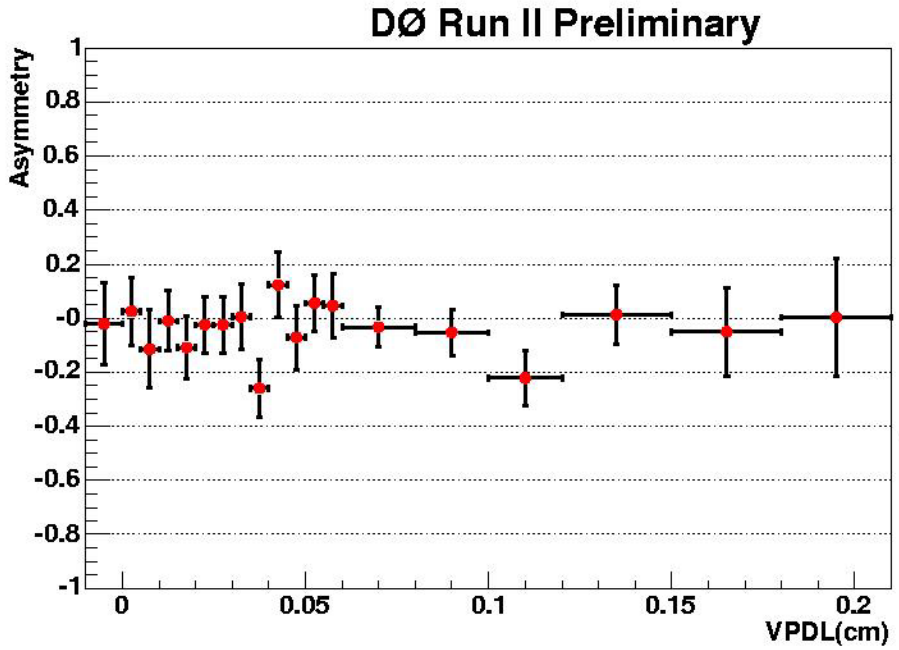
$$Signif = \sqrt{\frac{S\varepsilon\mathcal{D}^2}{2}} e^{-\frac{(\Delta m_s \sigma_\tau)^2}{2}} \sqrt{\frac{S}{S+B}}$$

Amplitude Method

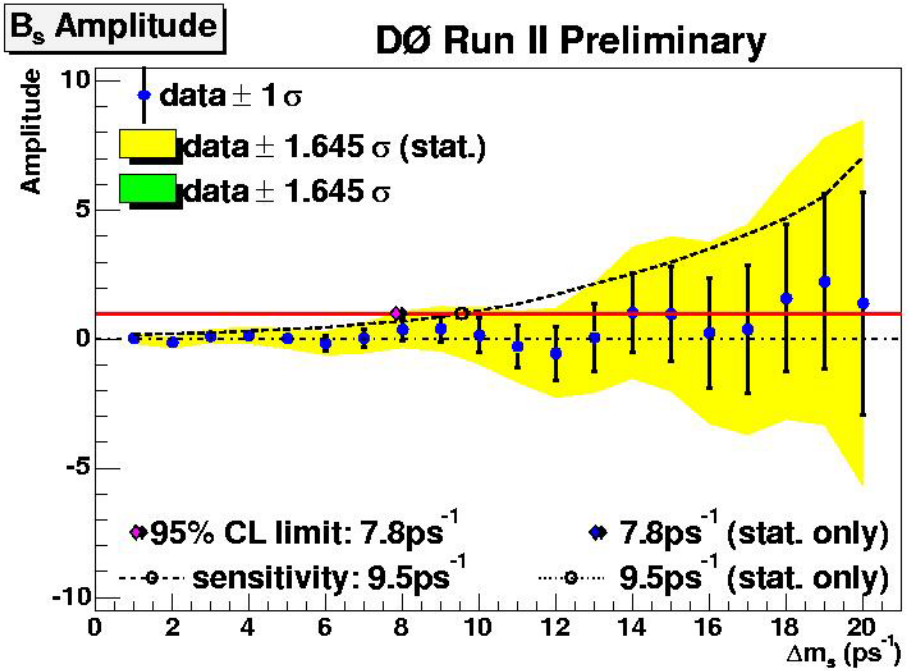
$$p_s^{nos/osc} = \frac{K}{c\tau_{B_s}} e^{-\frac{Kx}{c\tau_{B_s}}} \cdot 0.5 \cdot \left(1 \pm \mathcal{D} \cos\left(\Delta m_s \cdot Kx/c\right) \cdot \mathcal{A}\right)$$

- **If mixing signal with Δm_s, amplitude $\mathcal{A} = 1$ otherwise $\mathcal{A} = 0$**
- **Scan Δm_s, for each value find $\mathcal{A} \pm \Delta\mathcal{A}$ from the fit to the VPDL distributions**
  - ***fit to asymmetry vs. VPDL represents a simplified case***

Binned Asymmetry Fit (Old technique)



Summer 2005 Result (610 pb^{-1}):
95% CL limit: 7.0 ps^{-1}
Expected limit: 8.1 ps^{-1}



Current data set:
95% CL limit: 7.8 ps^{-1}
Expected limit: 9.5 ps^{-1}
Improved Flavor Tagging and increased statistics

Upgrade to Event-by-Event Fit

Minimize $-2\ln f$

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

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

- **Probability Density Functions (PDF) for each source**
  - **Proper Decay Length**
  - **Dilution**
  - **Proper Decay Length Error**
  - **Mass**
  - **Signal Selection Variable**

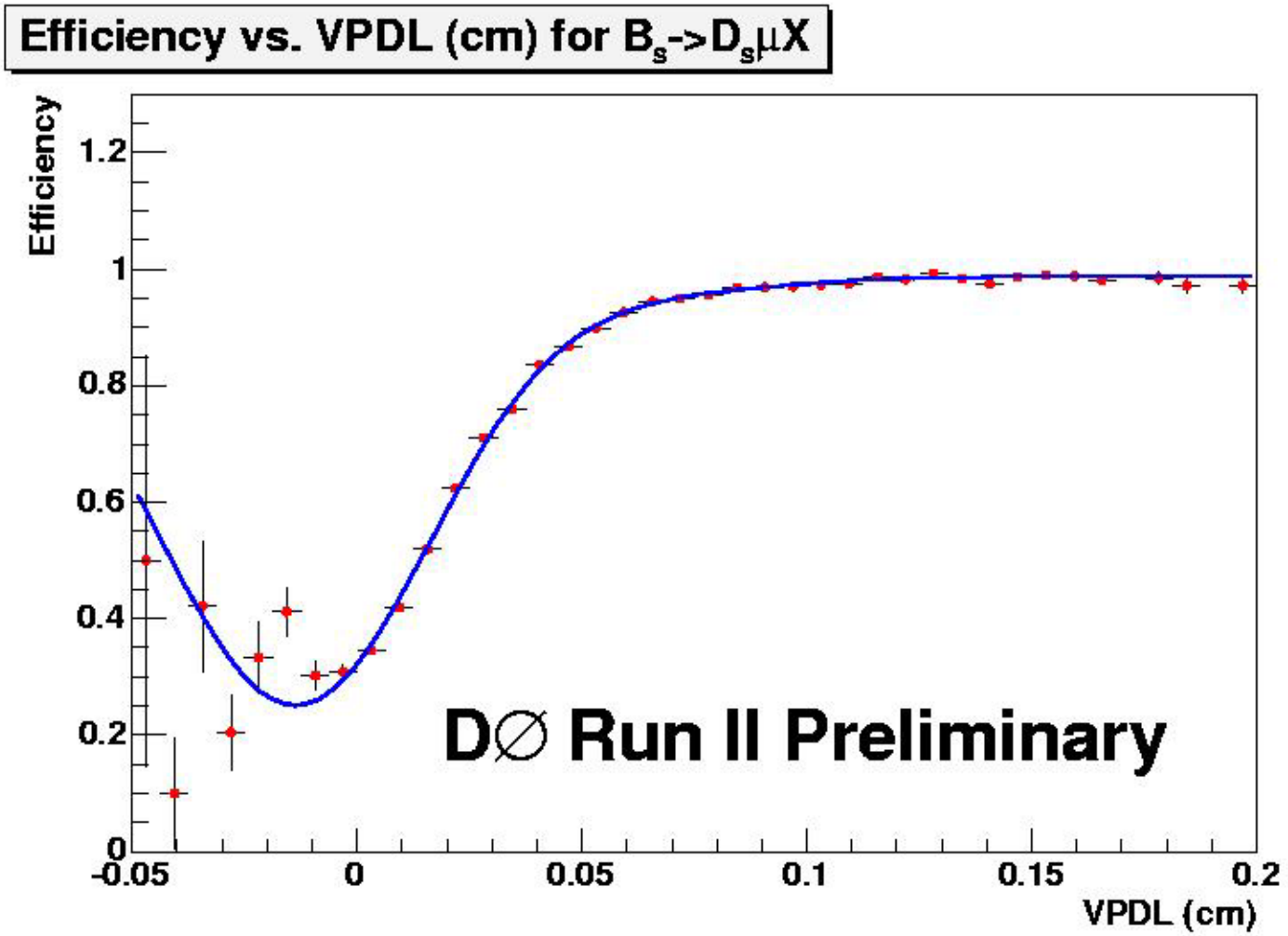
Proper Decay Length

- **Signal**

$$P_{sig}^{x^M} = \int_{K_{\min}}^{K_{\max}} D(K)dK\left(\frac{1}{N}\right)Eff\left(x^M\right)\int_0^{\infty} dx \cdot G\left(x - x^M, s\sigma_{x^M}\right)p^{nos/osc}$$

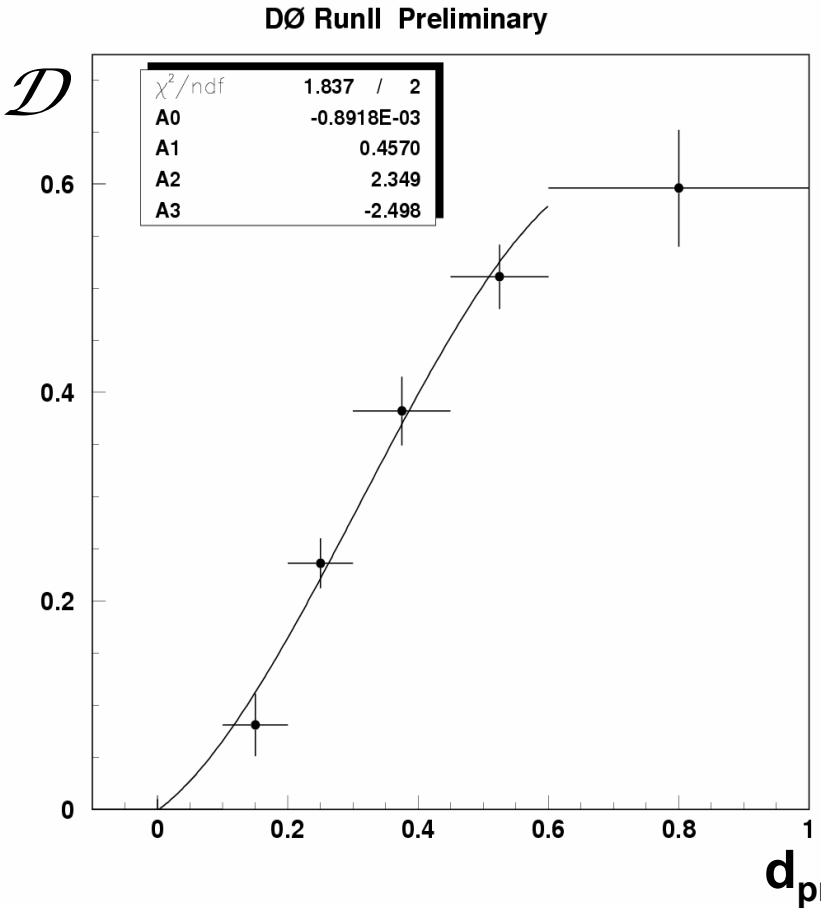
- **Combinatorial background**
  - **Long-lived background**
    - ✓ Non-sensitive to the tagging
    - ✓ Sensitive to the tagging
      - ✓ Non-oscillating
      - ✓ Oscillating with Δm_d frequency
  - **Prompt background**
    - ✓ Width depends on resolution
    - ✓ Constant width

Efficiency Dependence on VPDL

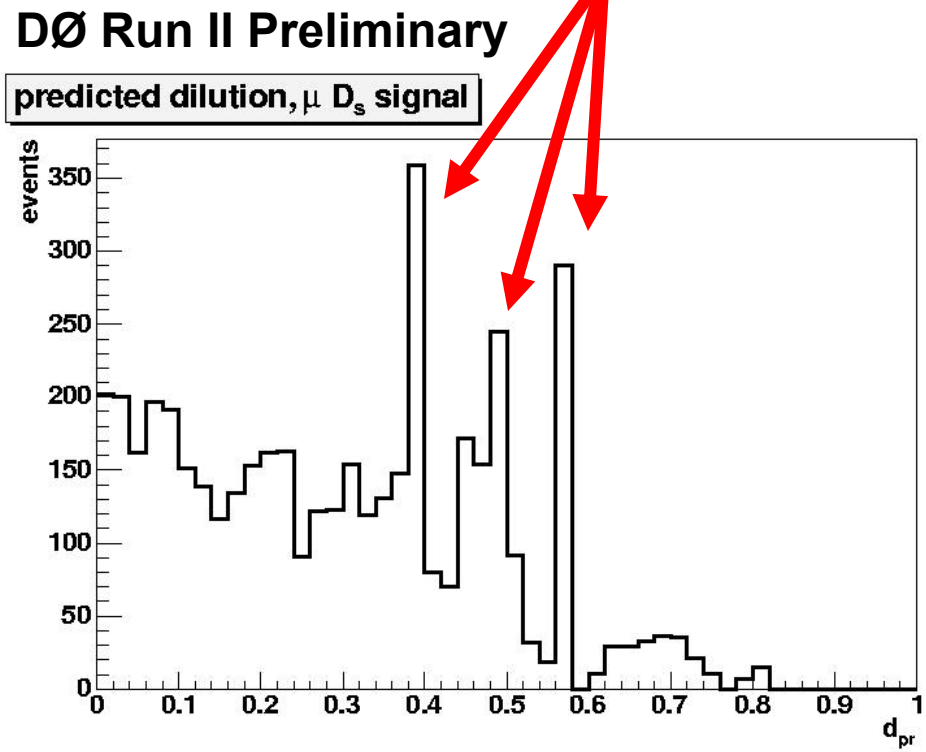


- From MC
  - Cross-checked and tuned using data
- Note that efficiency at VPDL=0 is not 0

Dilution

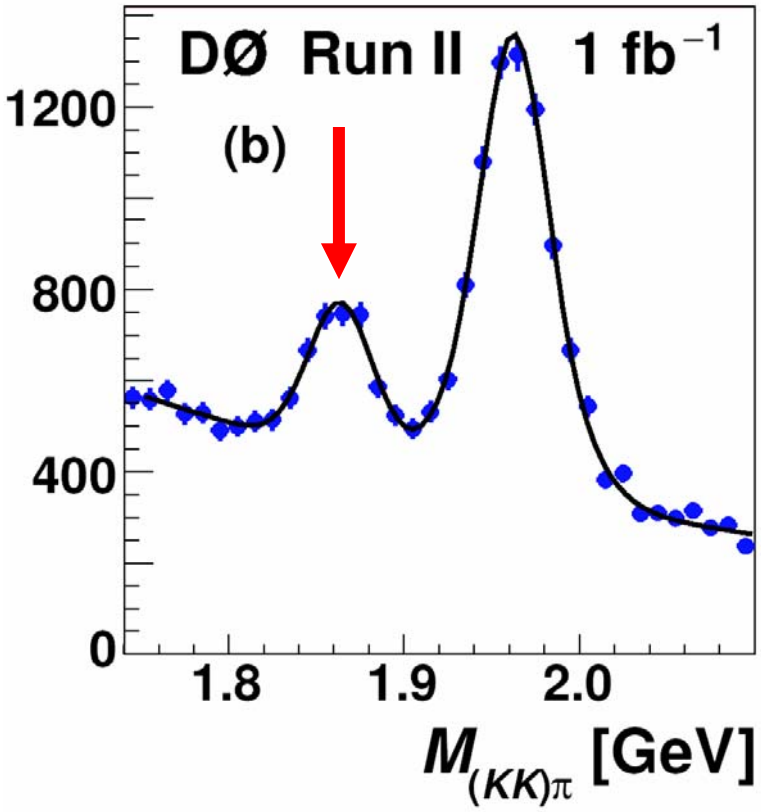


Isolated tagging muons (electrons)

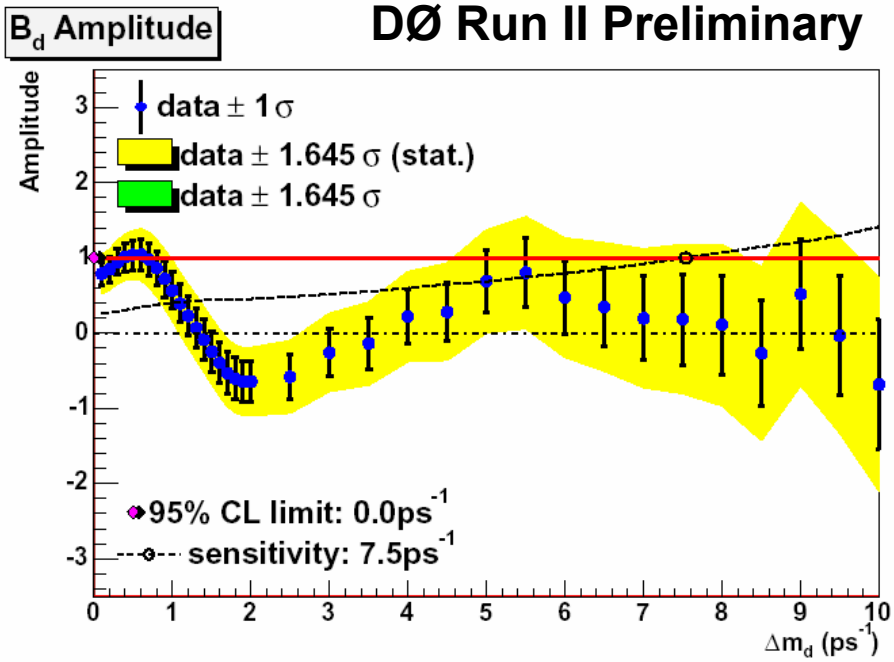


- Determine dilution on event-by-event basis

Cross-check Using $B_d \rightarrow X\mu D^{\pm}(\rightarrow \phi\pi)$

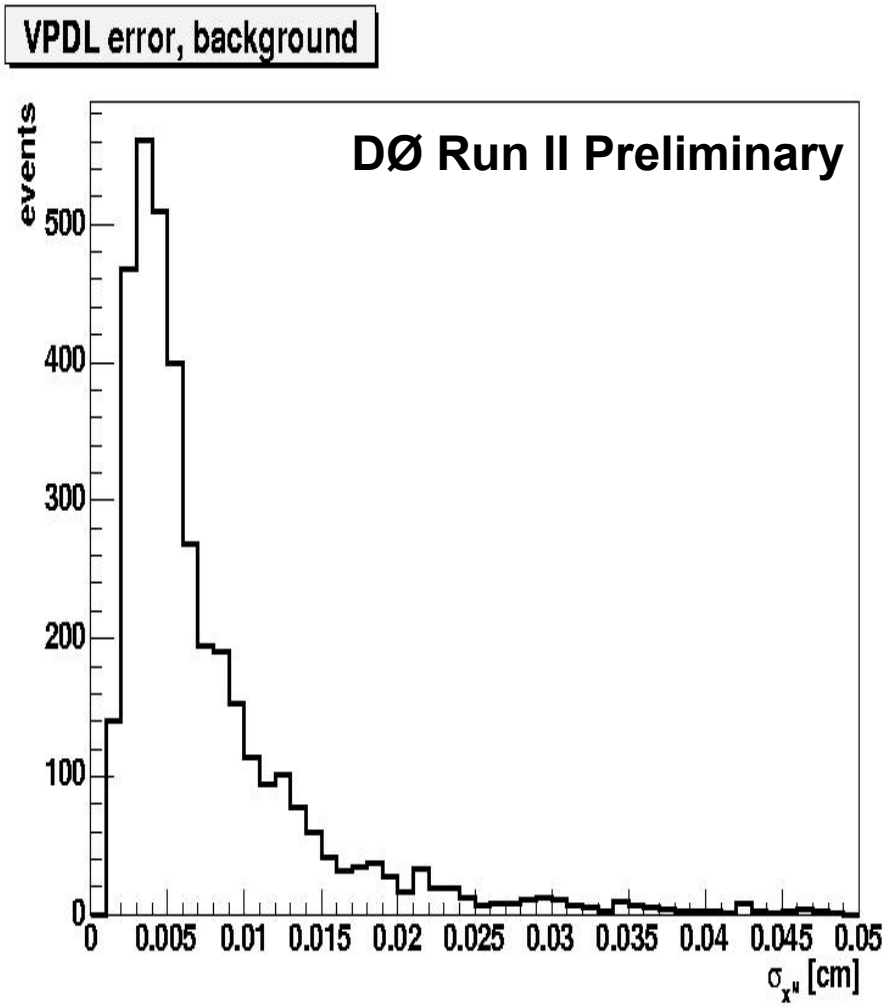


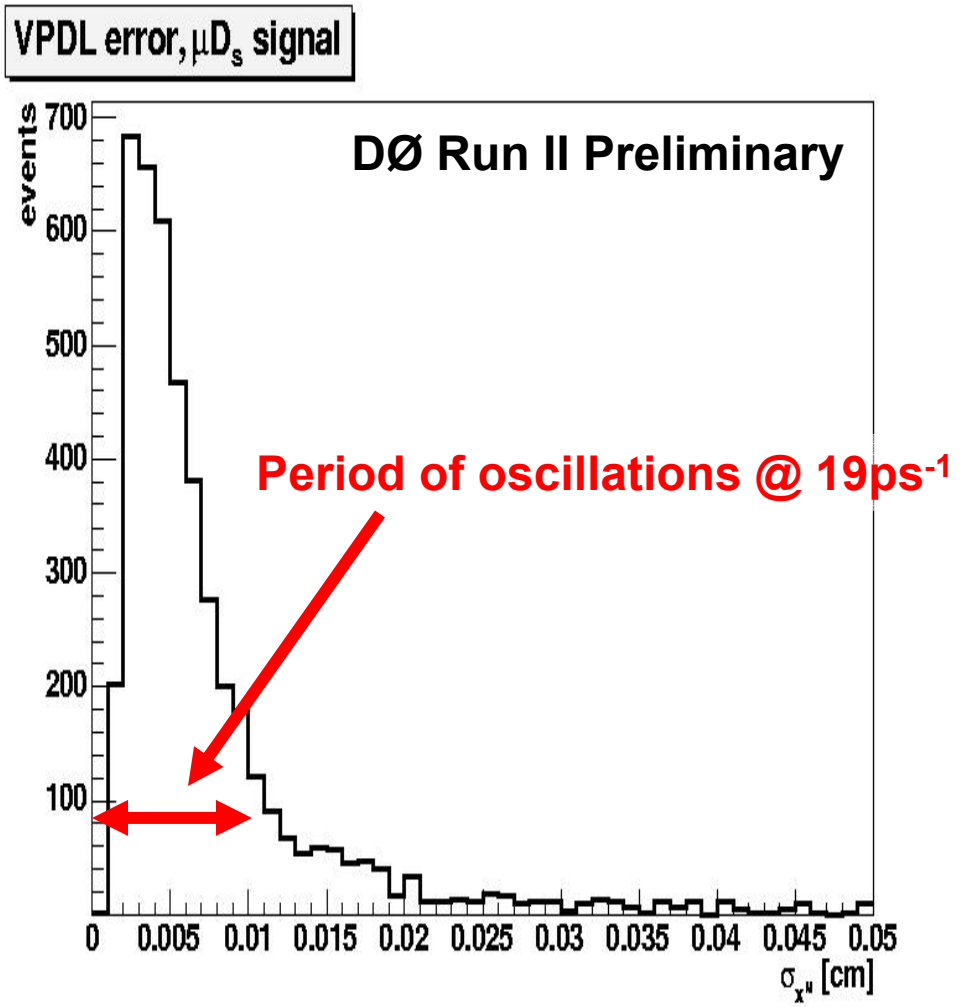
Amplitude Scan



- The Amplitude Scan reveals the Bd oscillations
  - at correct place → no lifetime bias
  - with correct amplitude → correct dilution calibration

Vertex Resolution

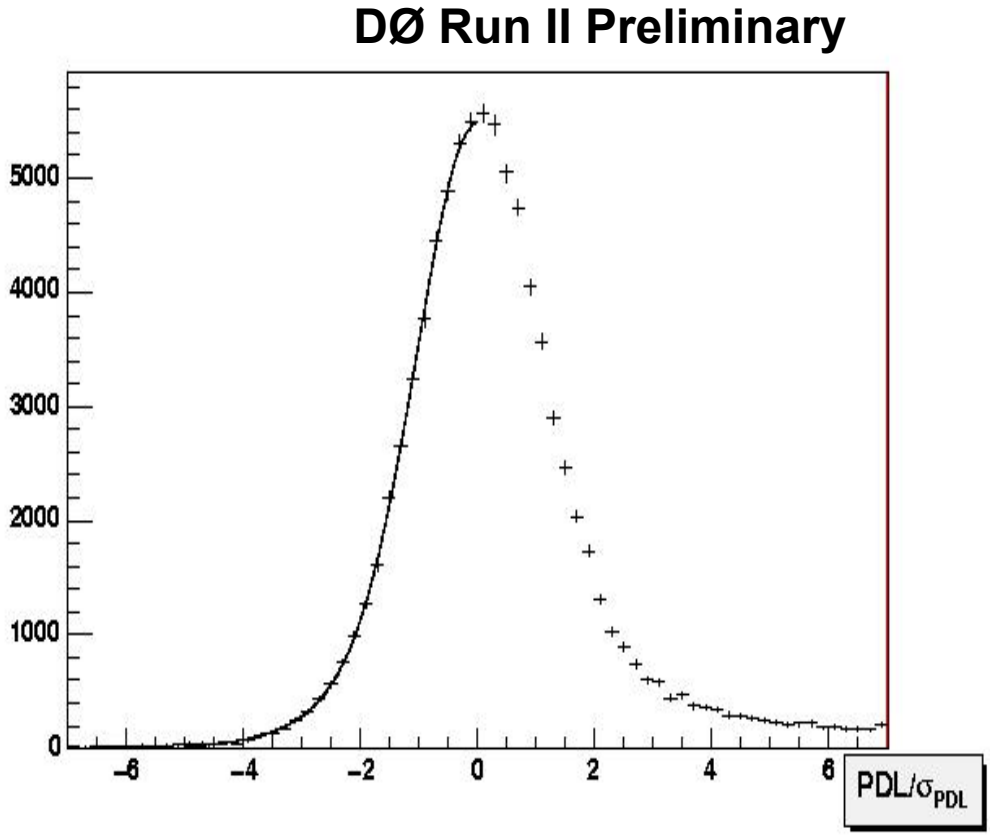


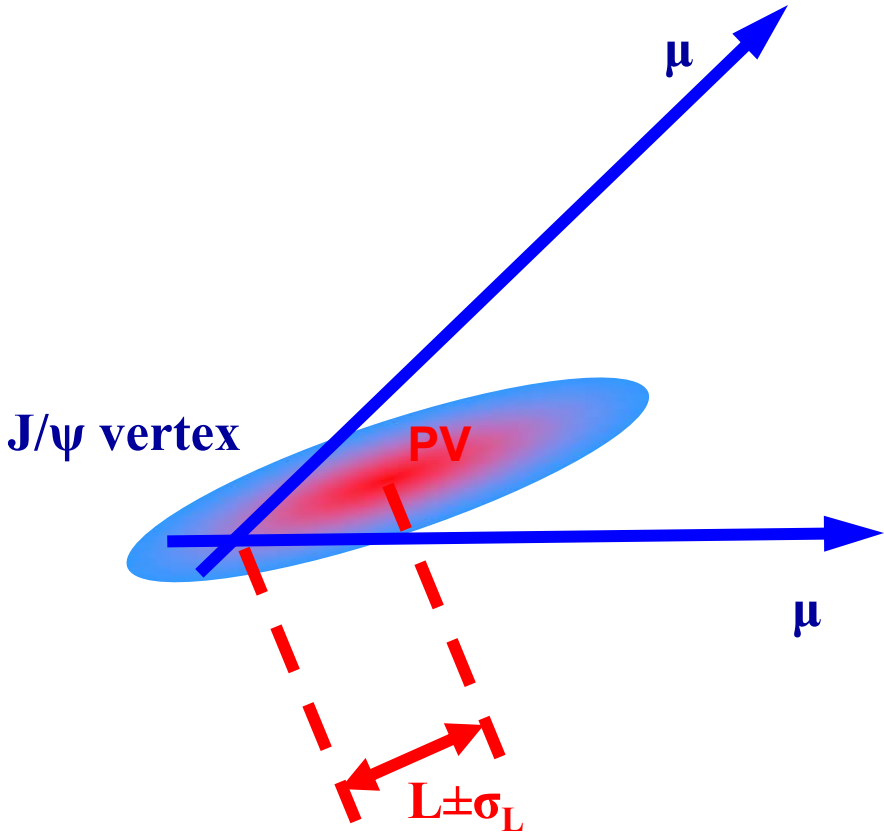


- Determined by vertex fitting procedure

Tuning Resolution Using Data

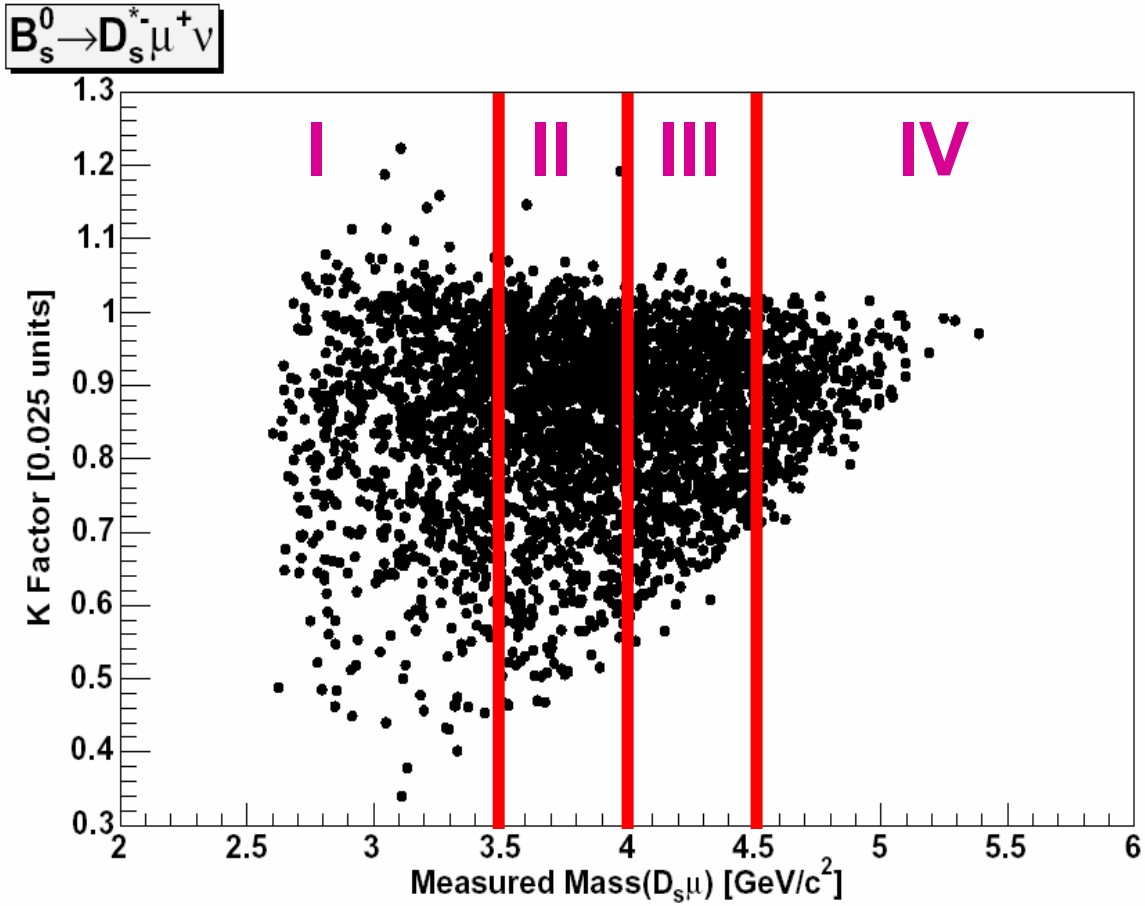
- **Use J/ψ→μμ sample**
  - Fit pull distribution for J/ψ Proper Decay Length with 2 Gaussians
  - Resolution Scale Factor is 1.0 for 72% of the events and 1.8 for the rest
  - Confirmed by Impact Parameter tuning procedure in MC





K-factors

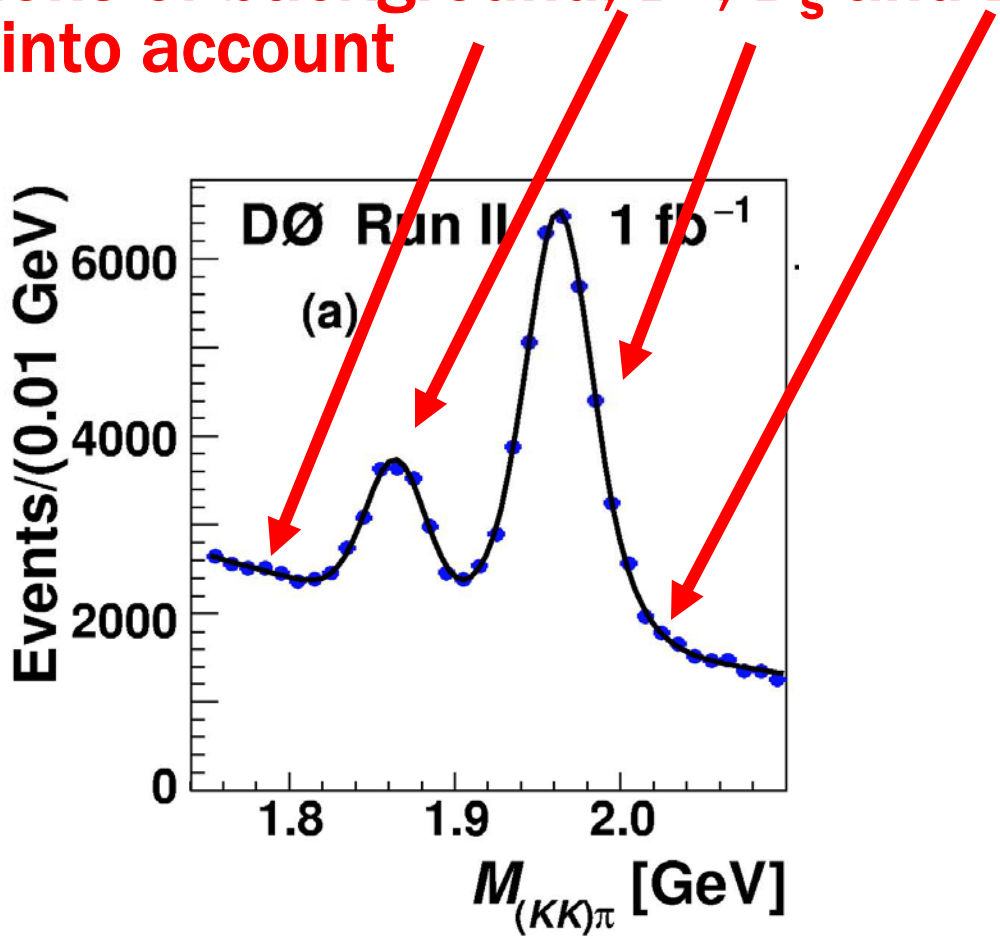
- Use different K-factor distributions depending on the mass of μD_s system for D_s and D_s^* samples



$$K = p_T(\mu D_s^-)/p_T(B)$$

$(KK)\pi$ Mass

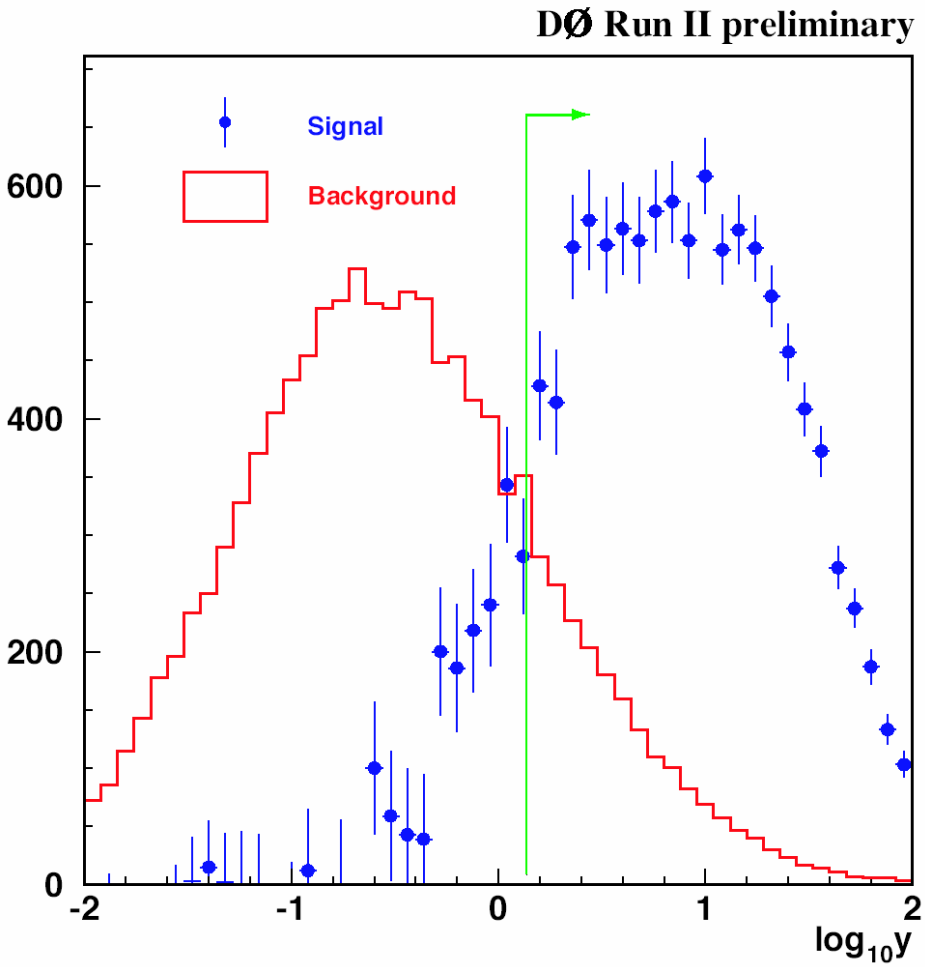
- Contributions of background, D^+, D_s and D^+ reflections are taken into account



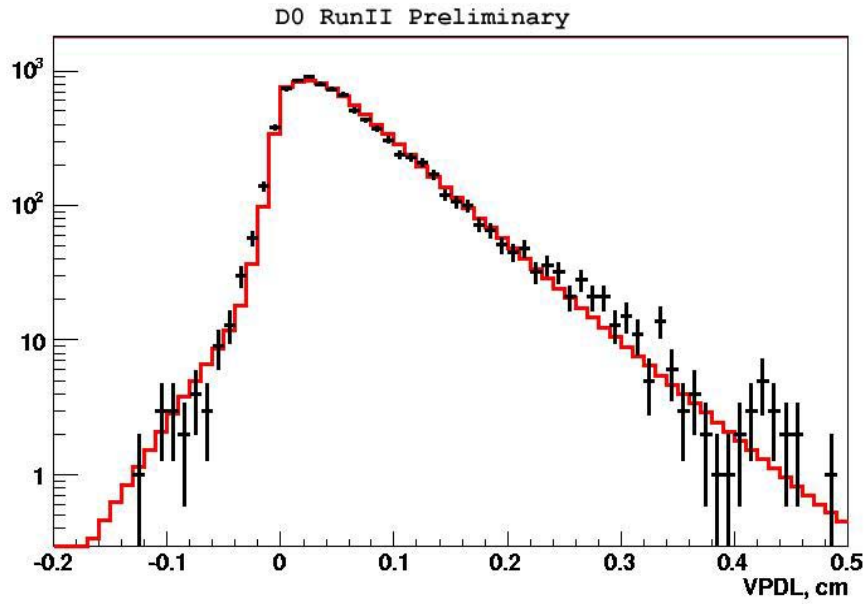
- Fit in the entire mass region from 1.72 to 2.22 GeV

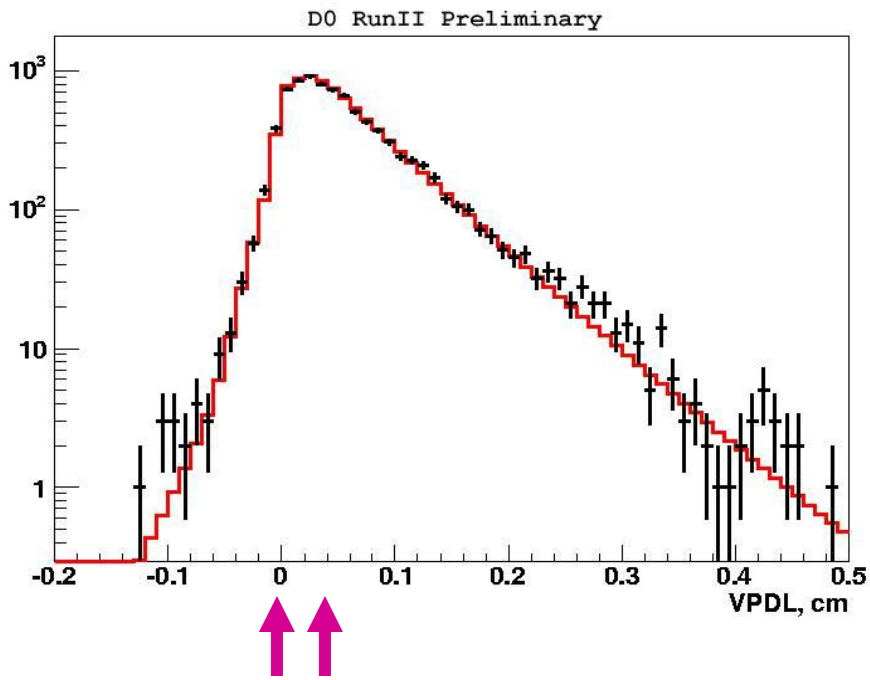
Signal Selection Function

- **Use the signal selection function in the likelihood**
  - Use the full information to weight the events



Results of the Lifetime Fit



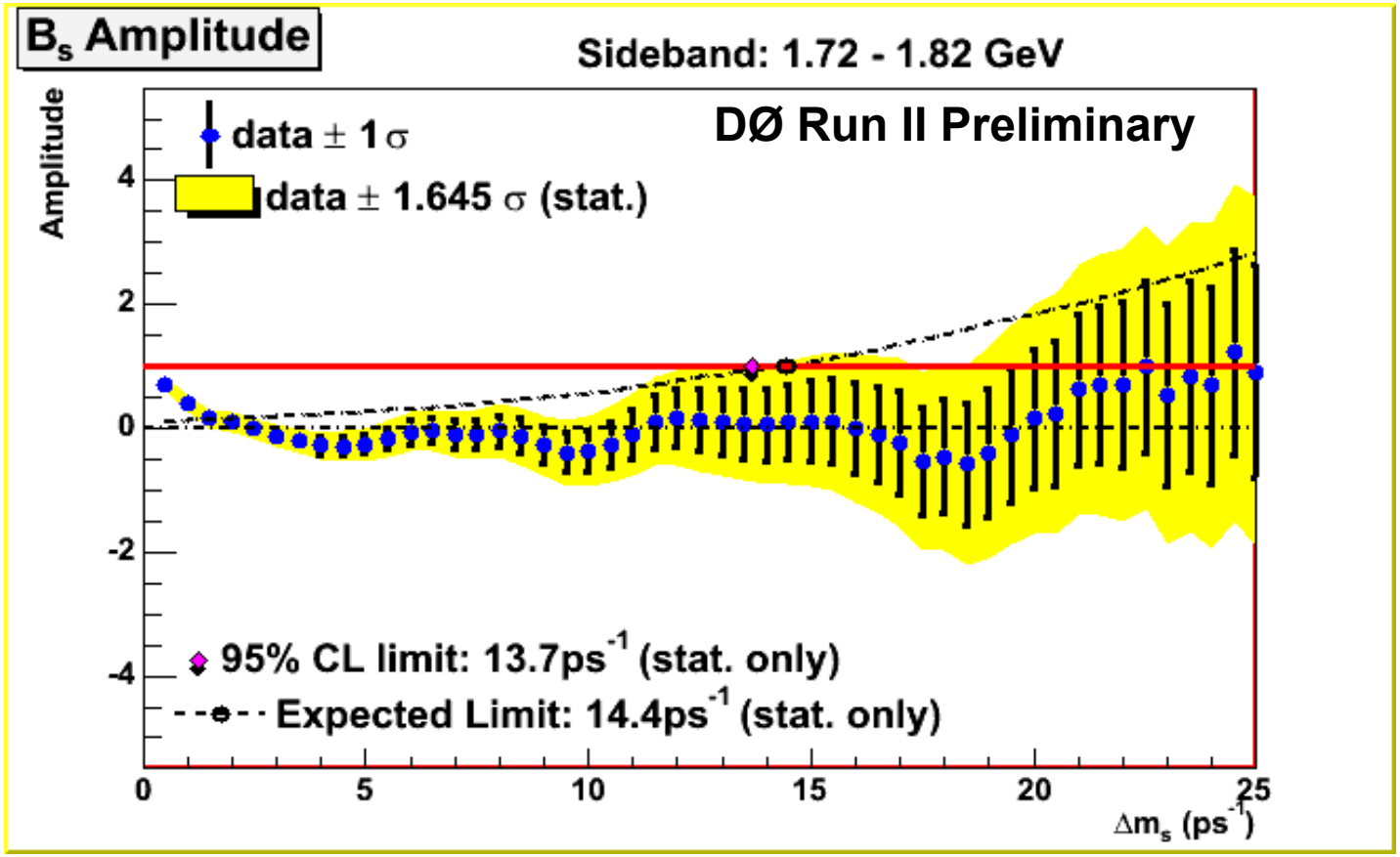


Most important region

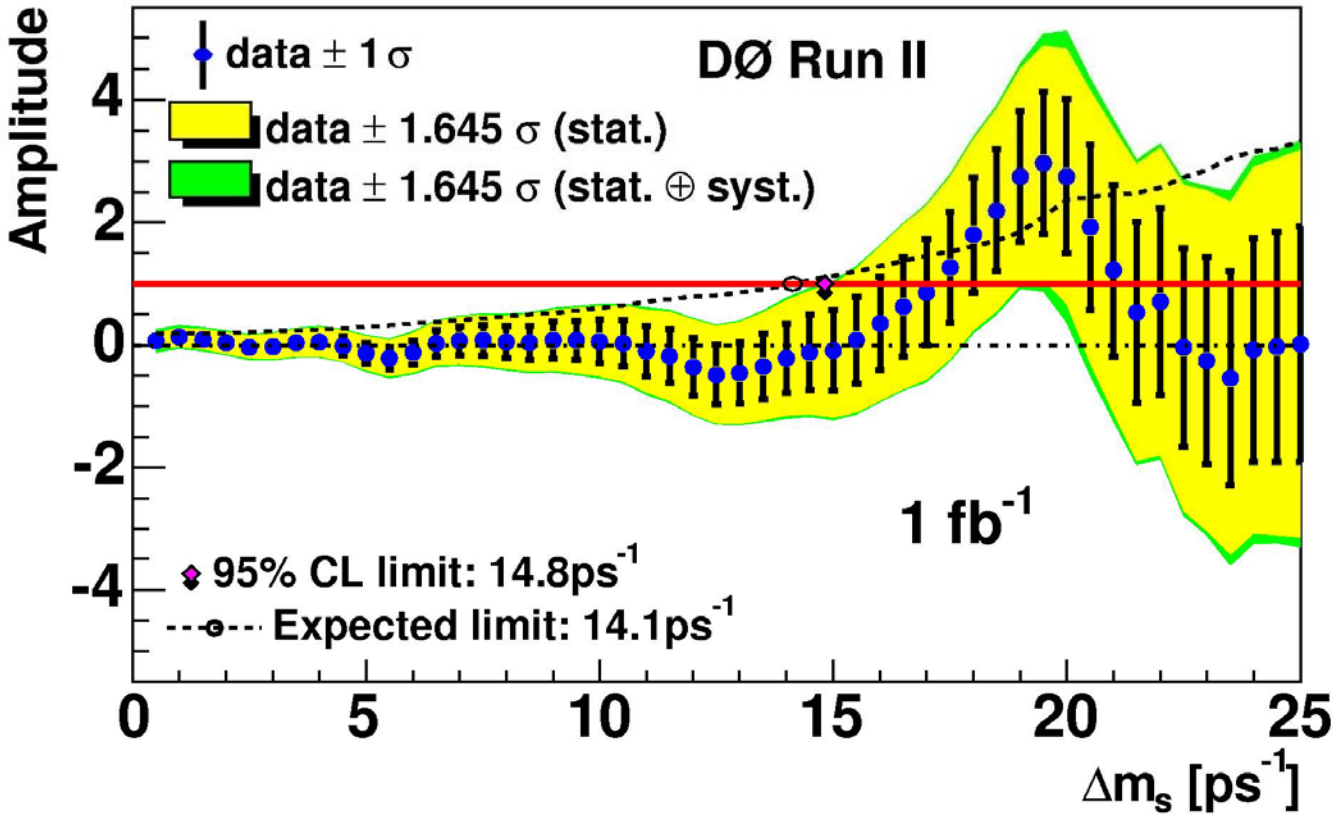
- **Different background models are used for cross-check and systematic errors**
- **Trigger biases have been studied**
  - **Different efficiency models**
- **Central values for $c\tau_{Bs}$ = 404 − 416 μm**
  - **Statistical error ~10 μm**
  - **HFAG value $c\tau_{Bs}$ = 438 ± 12 μm**

Results for Bs Mixing

Amplitude Scan for Sideband



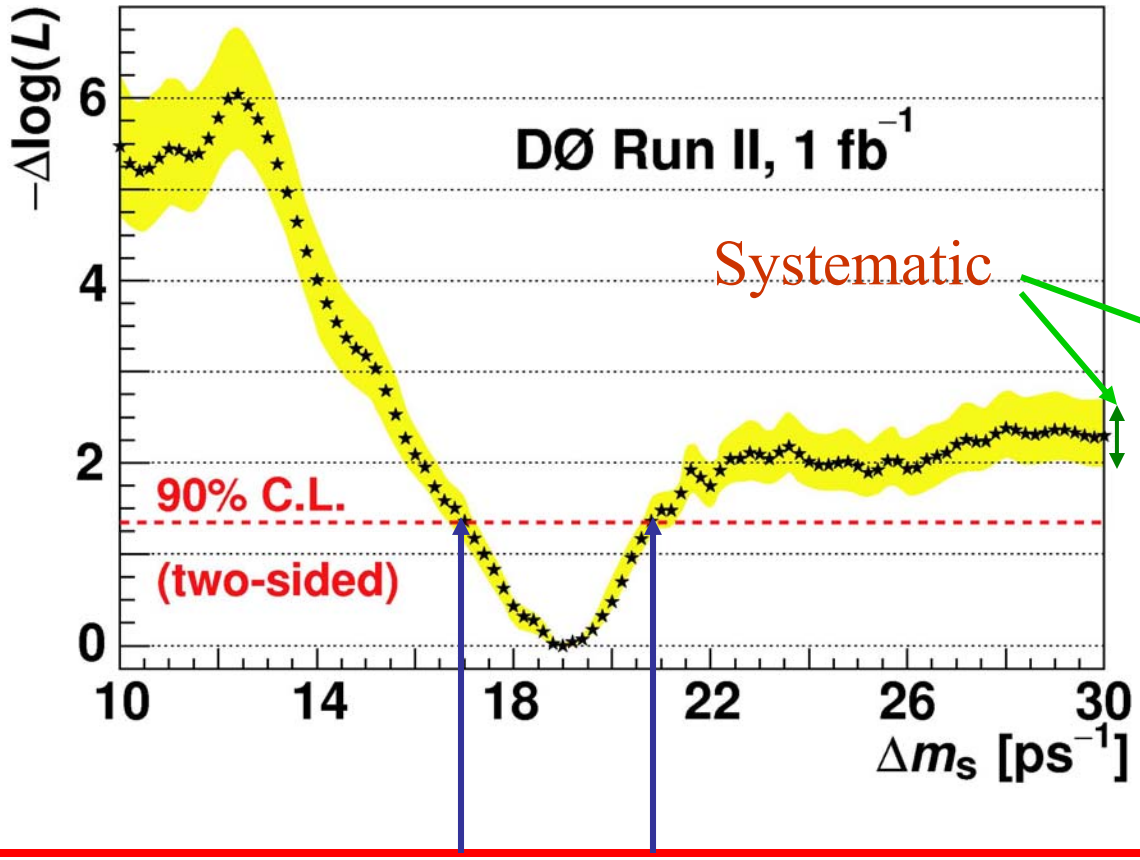
Amplitude Scan



- Deviation of the amplitude at 19 ps-1
  - 2.5σ from 0
  - 1.6σ from 1

Log Likelihood Scan

In agreement with the amplitude scan



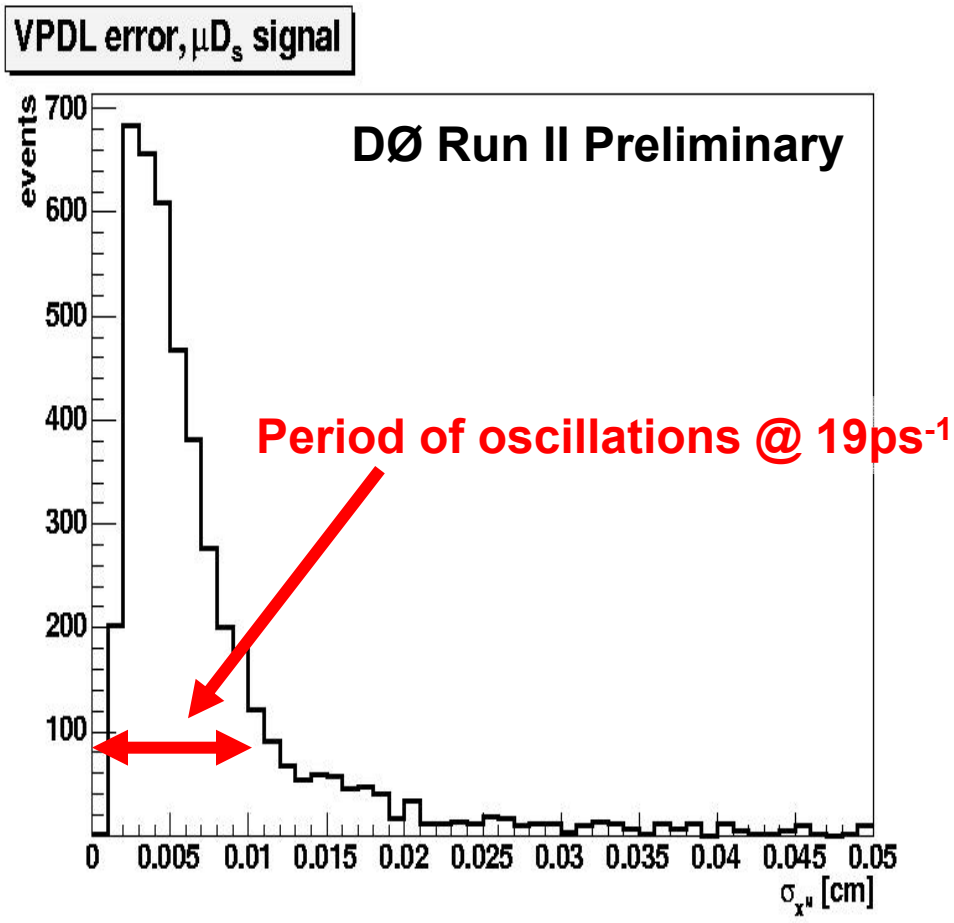
- Resolution
- K-factor variation
- BR ($B_s \to \mu D_s X$)
- VPDL model
- BR ($B_s \to D_s D_s$)

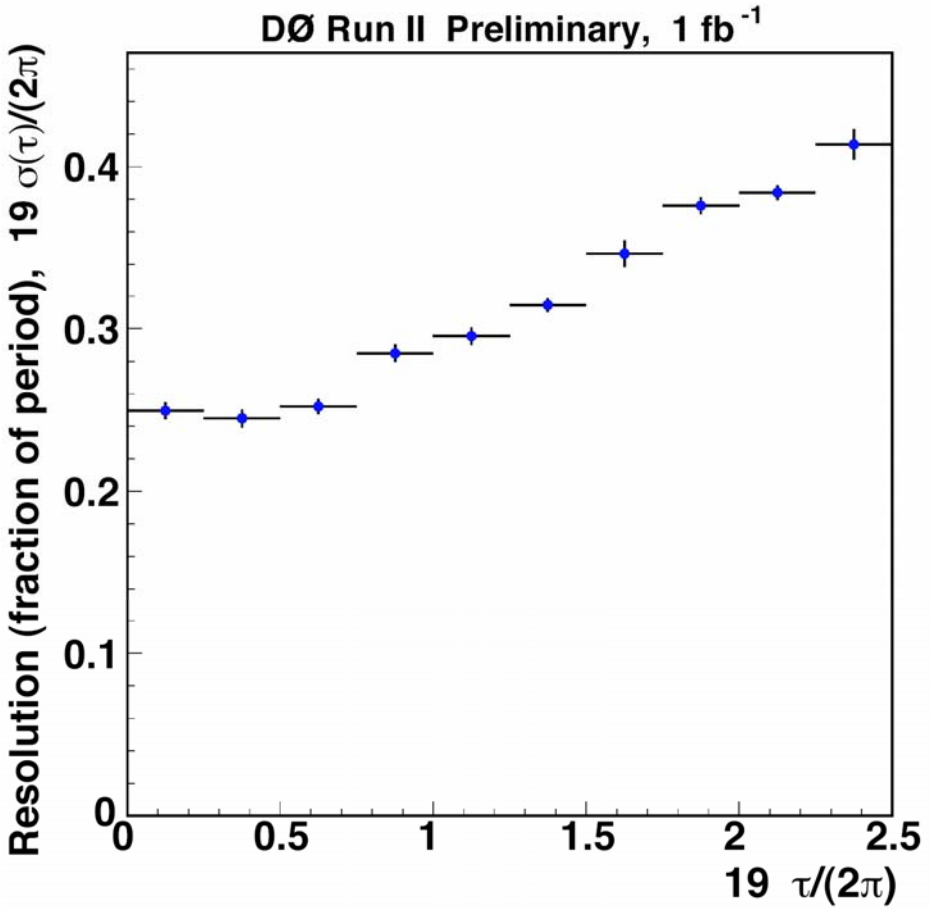
Have no sensitivity above 22 ps^{-1}

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

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

"Golden" Events for Visualization



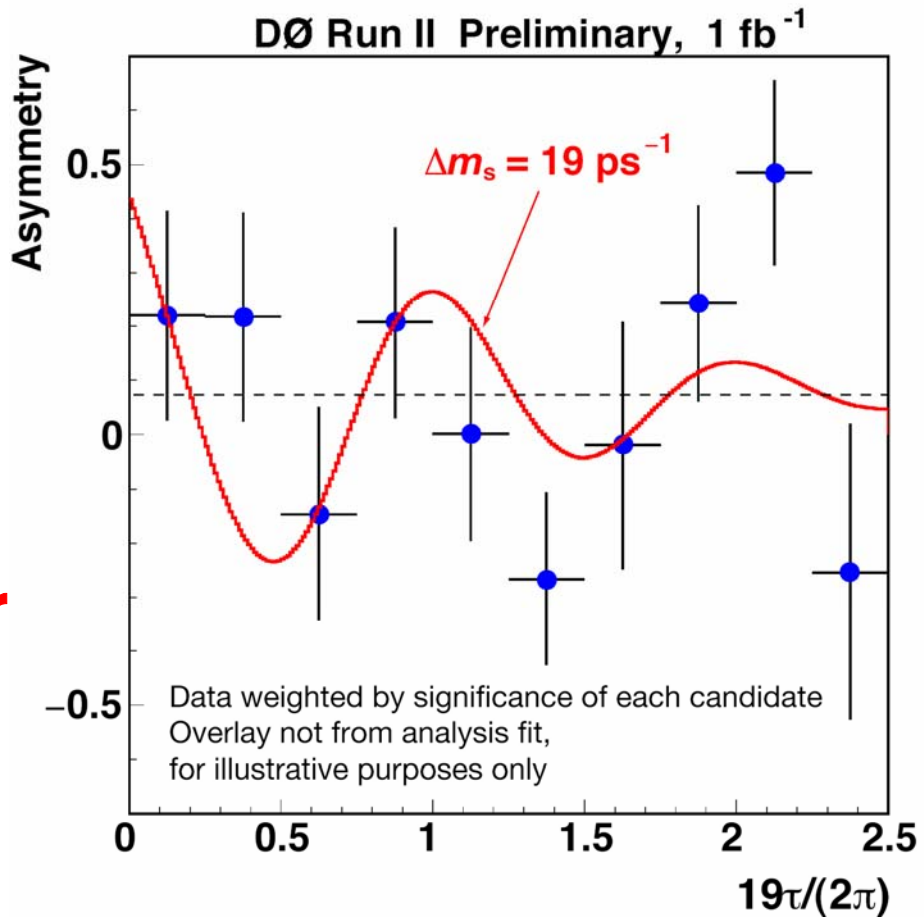


- **Weight events using**

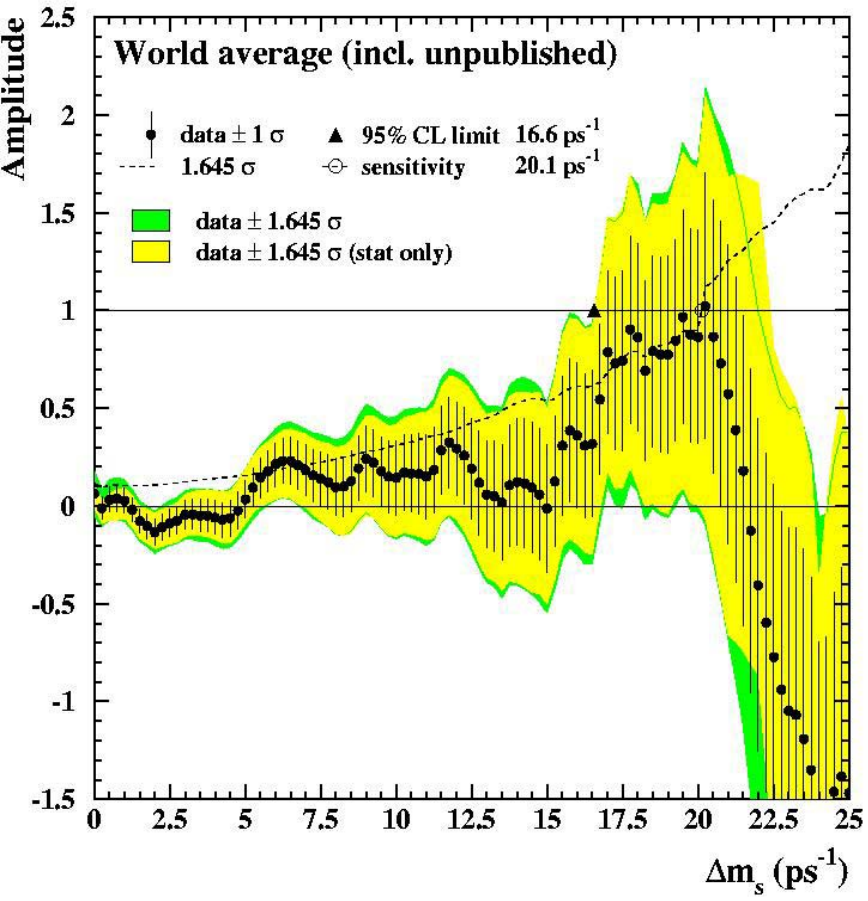
$$Signif = \mathcal{F}_{sig}\left(M_{\phi\pi}, \log_{10} y\right) \cdot \left|\mathcal{D}\right| \cdot e^{-\frac{\left(\Delta m_s \sigma_\tau\right)^2}{2}}$$

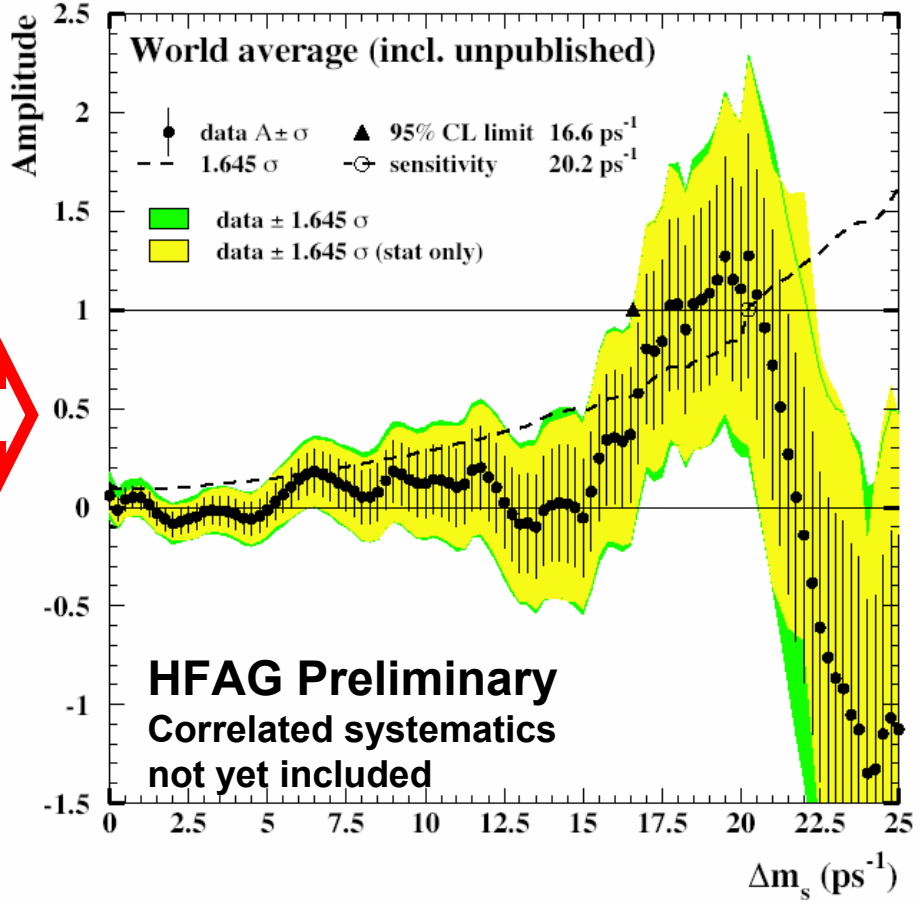
See Bs Oscillations By Eye!

- Weighted asymmetry
- This plot does not represent the full statistical power of our data



World Average



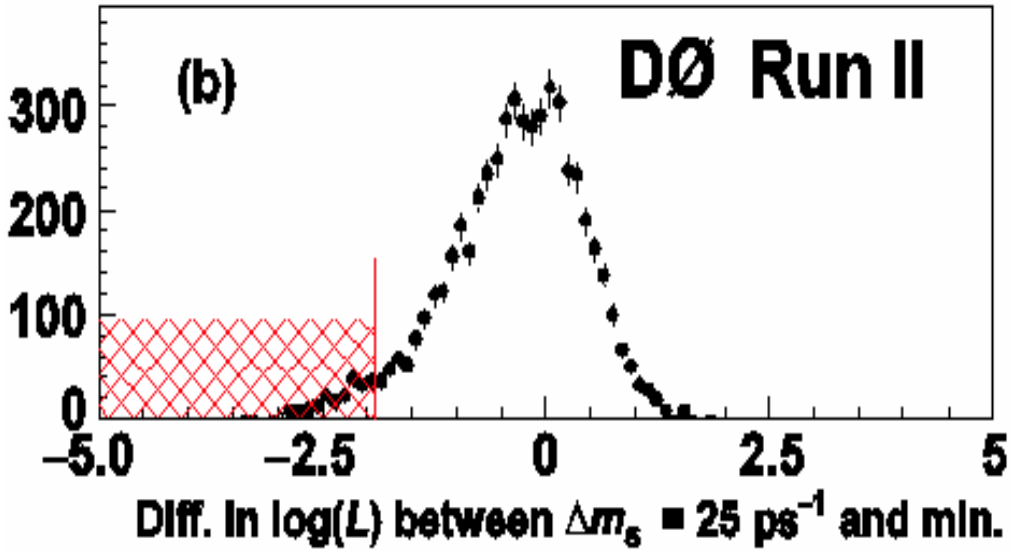


@19ps^{-1}: 1.5σ → 2.3σ

Ensemble Tests

Using data

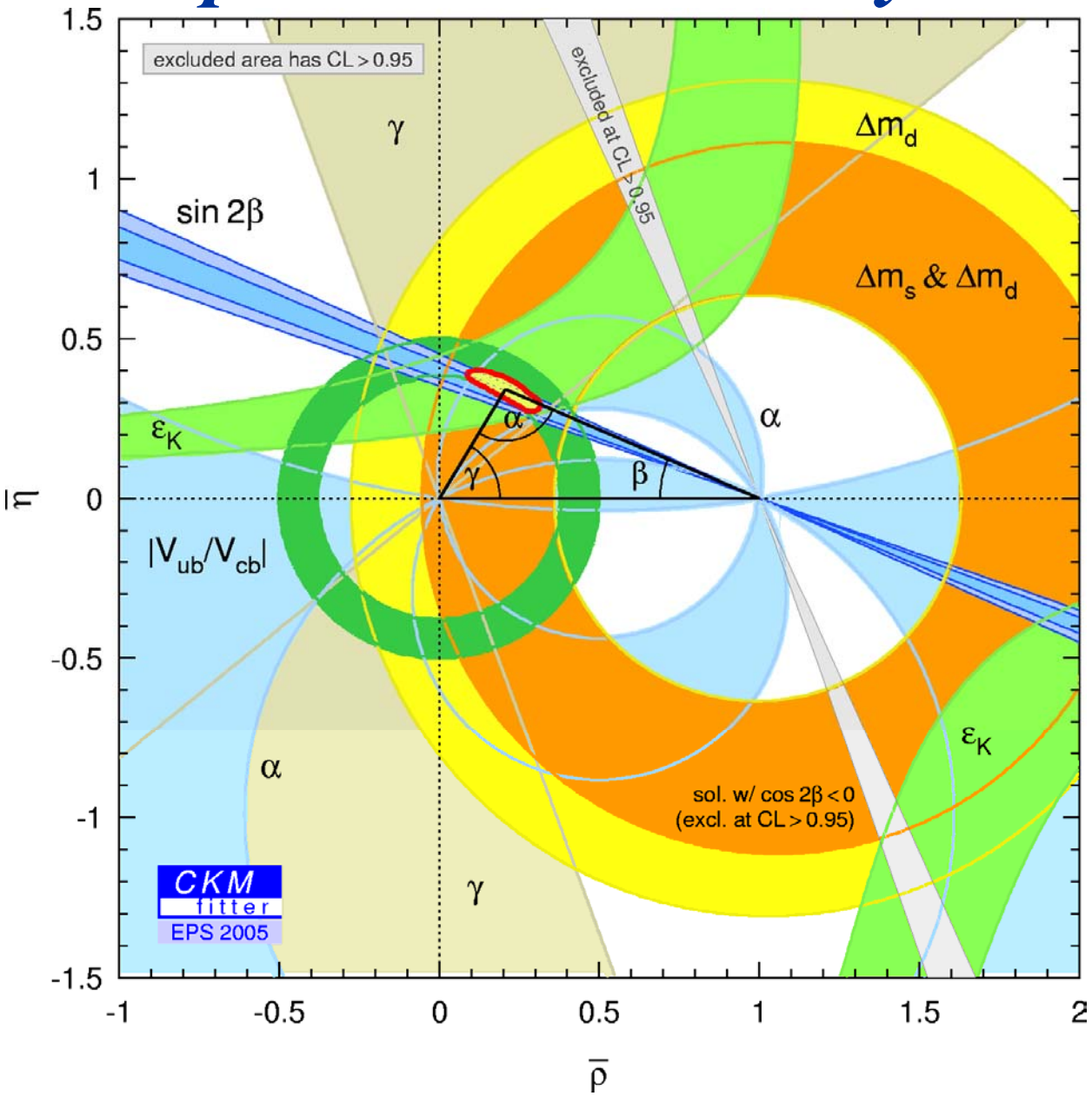
- Simulate $\Delta m_s = \infty$ by randomizing the sign of flavor tagging
- Probability to observe $\Delta\log(L) > 1.9$ (as deep as ours) in the range $16 < \Delta m_s < 22$ ps^{-1} is 3.8%
  - ✓ 5% using lower edge of syst. uncertainties band
  - ✓ Region below 16 ps^{-1} is experimentally excluded
  - ✓ No sensitivity above 22 ps^{-1}



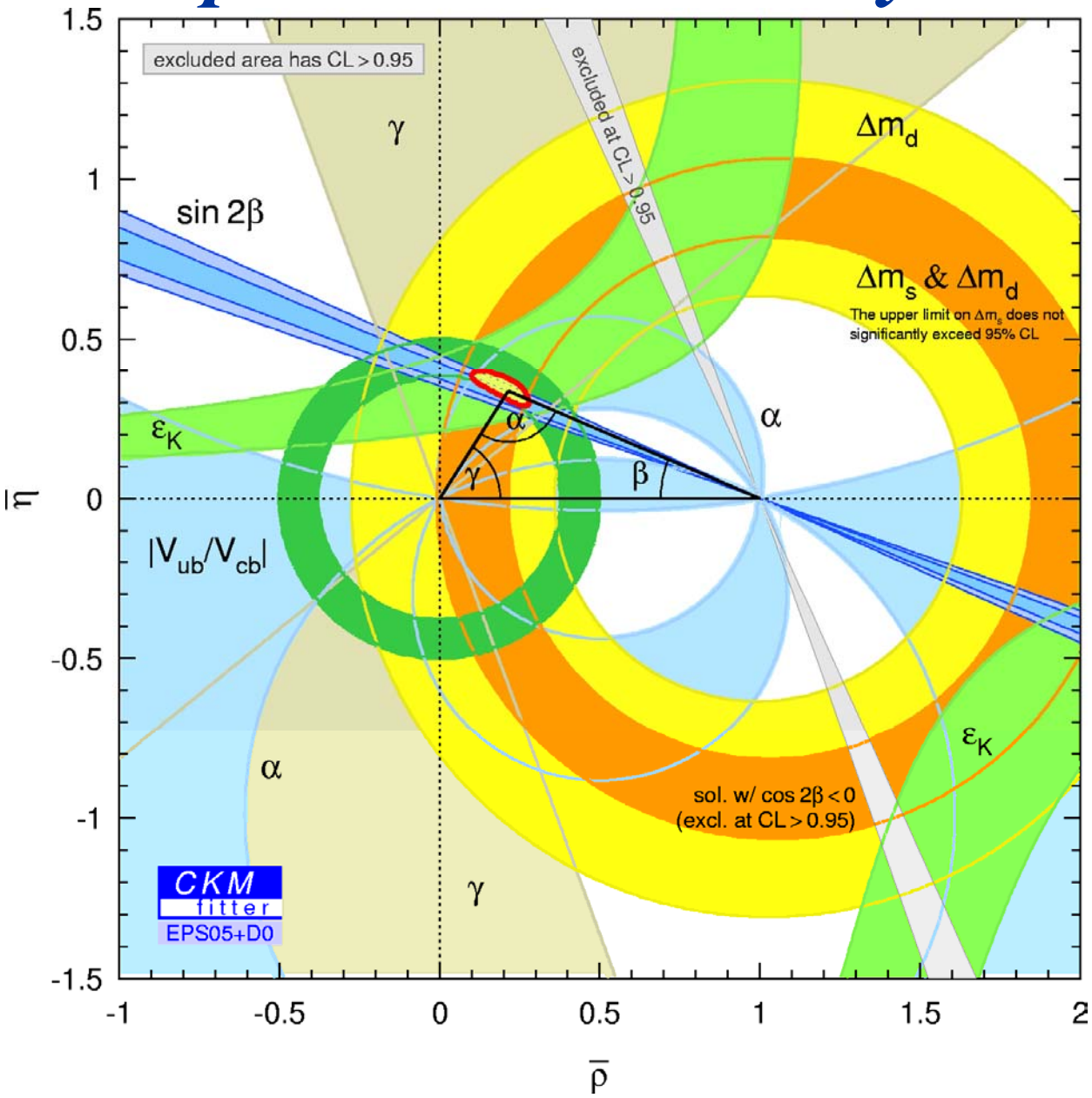
Using MC

- Probability to observe $\Delta\log(L) > 1.9$ for the true $\Delta m_s = 19$ ps^{-1} in the range $17 < \Delta m_s < 21$ ps^{-1} is 15%

Impact on the Unitarity Triangle



Impact on the Unitarity Triangle



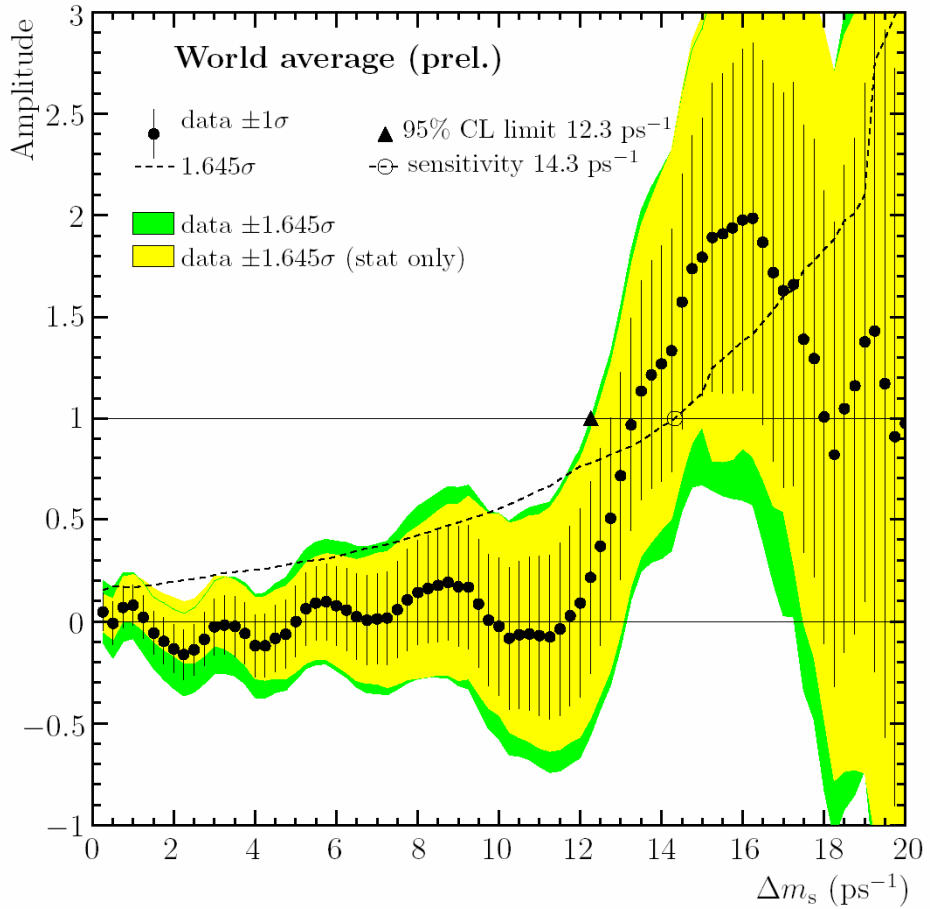
Conclusion

- 1 fb^{-1} Data sample was used for the Bs oscillation measurement
- 2.5σ deviation from 0 is observed in the amplitude scan at 19 ps^{-1}
  - in agreement with the loglikelihood scan
  - 90% C.L. interval for Δm_s: 17 – 21 ps^{-1} assuming Gaussian errors
- Improvements for the summer
  - New decay modes in the semileptonic analyses
    - ✓ $D_s \rightarrow K^*K$, K_SK, 3π
    - ✓ $e+D_s$
  - Hadronic Modes
  - Same-Side Tagging
- Layer 0 is being installed
- Stay Tuned

Backup Slides

Analysis of the Combination of Experimental Results by Abbaneo & Boix (1999)

JHEP08 (1999) 004



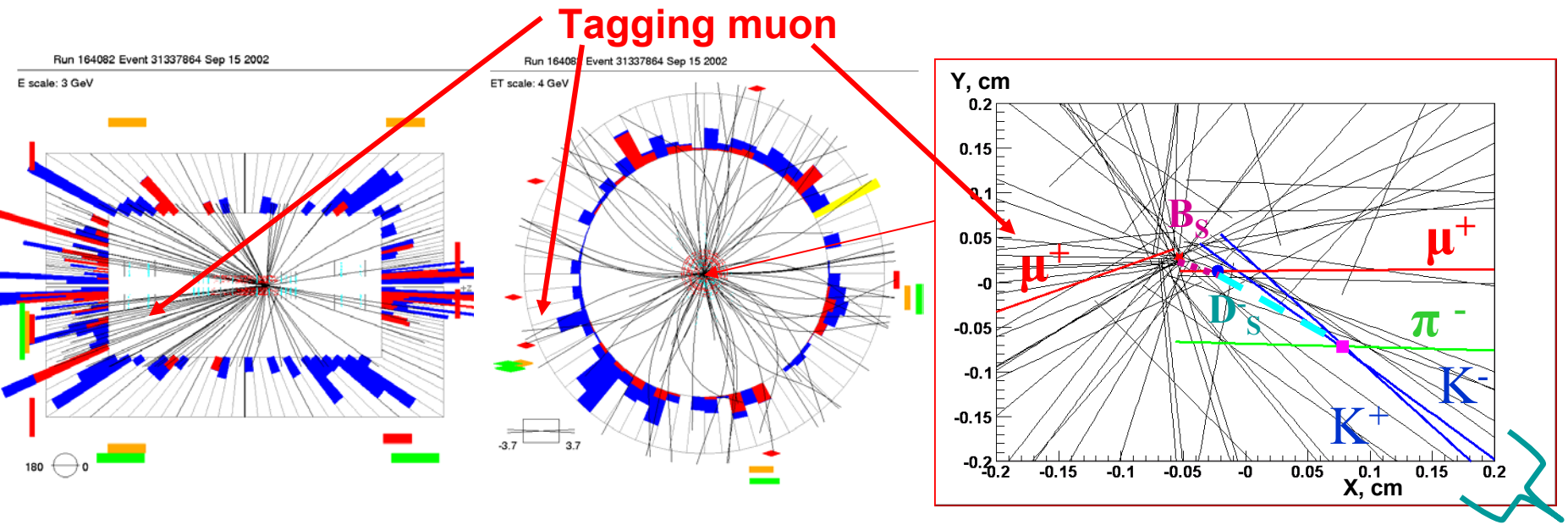
- **Probability of statistical fluctuation: 1 - C.L.≈3%**
- $\Delta m_s = 14.8^{+2.7}_{-1.8}\ ps^{-1}$ → **interval 13.0 — 17.5 ps^{-1}**

Systematic Uncertainties

Osc. frequency		1 ps^{-1}	3 ps^{-1}	5 ps^{-1}	7 ps^{-1}	9 ps^{-1}	11 ps^{-1}	13 ps^{-1}	15 ps^{-1}	17 ps^{-1}	19 ps^{-1}	21 ps^{-1}	23 ps^{-1}	25 ps^{-1}
$\mathcal{A}$		0.128	−0.025	−0.134	0.073	0.079	−0.100	−0.459	−0.093	0.858	2.749	1.218	−0.253	0.018
Stat. uncertainty		0.090	0.124	0.167	0.231	0.299	0.410	0.504	0.659	0.864	1.068	1.413	1.690	1.920
Br($D_s D_s$) = 4.7%	$\Delta\mathcal{A}$	−0.003	+0.000	+0.003	−0.002	−0.002	+0.003	+0.010	+0.001	−0.022	−0.059	−0.021	+0.012	+0.009
	$\Delta\sigma$	−0.002	−0.003	−0.004	−0.005	−0.006	−0.009	−0.010	−0.014	−0.018	−0.023	−0.029	−0.035	−0.040
Br($D_s\mu X$) = 6.7%	$\Delta\mathcal{A}$	+0.006	−0.003	−0.005	−0.004	−0.001	−0.003	−0.011	−0.004	+0.012	+0.046	+0.023	−0.001	+0.011
	$\Delta\sigma$	+0.002	+0.002	+0.003	+0.004	+0.005	+0.007	+0.009	+0.011	+0.015	+0.019	+0.024	+0.030	+0.035
$p_{T_\mu} > 6$ GeV/c	$\Delta\mathcal{A}$	−0.015	+0.009	+0.013	+0.010	−0.001	+0.010	+0.029	+0.013	−0.045	−0.124	−0.044	−0.023	−0.019
	$\Delta\sigma$	−0.004	−0.006	−0.008	−0.011	−0.014	−0.019	−0.024	−0.031	−0.042	−0.054	−0.066	−0.081	−0.093
K-factor variation	$\Delta\mathcal{A}$	−0.000	+0.006	−0.024	+0.001	+0.010	−0.041	+0.045	+0.104	+0.231	+0.207	−0.380	+0.006	−0.001
2%	$\Delta\sigma$	+0.000	+0.001	+0.002	+0.004	+0.007	+0.012	+0.011	+0.027	+0.025	+0.059	+0.040	+0.049	+0.050
K-factor distribution	$\Delta\mathcal{A}$	+0.000	−0.000	−0.001	+0.001	−0.002	+0.013	+0.006	+0.036	+0.028	−0.003	+0.171	+0.033	+0.032
smoothed	$\Delta\sigma$	+0.000	+0.000	+0.000	+0.000	+0.001	+0.001	+0.002	+0.003	+0.003	+0.005	+0.004	+0.008	+0.009
K-factor from	$\Delta\mathcal{A}$	−0.000	−0.001	+0.003	+0.001	−0.009	+0.026	+0.003	+0.055	+0.048	−0.021	+0.248	+0.003	−0.050
measured momenta	$\Delta\sigma$	+0.000	+0.000	+0.000	+0.001	+0.001	+0.002	+0.003	+0.005	+0.004	+0.006	+0.006	+0.005	+0.011
Fraction of peaking bkg.	$\Delta\mathcal{A}$	+0.002	+0.001	−0.000	−0.001	−0.000	+0.000	−0.000	+0.001	+0.004	+0.012	+0.007	+0.002	+0.008
(combinatorial bkg.)	$\Delta\sigma$	+0.000	−0.000	−0.000	+0.000	+0.000	+0.000	+0.001	+0.001	+0.001	+0.001	+0.003	+0.004	+0.004
Fraction of peaking bkg.	$\Delta\mathcal{A}$	+0.001	−0.000	−0.002	−0.000	−0.002	−0.007	−0.016	−0.013	+0.004	+0.055	+0.014	−0.035	−0.021
(signal)	$\Delta\sigma$	+0.001	+0.001	+0.001	+0.002	+0.002	+0.004	+0.005	+0.007	+0.012	+0.014	+0.026	+0.034	+0.039
$c\tau_B_s$	$\Delta\mathcal{A}$	+0.001	+0.001	+0.002	−0.000	−0.001	+0.003	+0.003	−0.001	−0.010	−0.029	+0.003	+0.013	+0.000
	$\Delta\sigma$	−0.000	−0.000	−0.001	−0.001	−0.002	−0.002	−0.003	−0.004	−0.006	−0.007	−0.011	−0.014	−0.015
uncertainty in	$\Delta\mathcal{A}$	−0.002	+0.001	−0.001	+0.001	+0.002	+0.002	−0.001	−0.003	+0.000	+0.008	+0.008	+0.002	−0.001
reflection	$\Delta\sigma$	+0.000	+0.000	+0.000	+0.001	+0.001	+0.001	+0.001	+0.001	+0.002	+0.002	+0.003	+0.004	+0.004
Stat. fluctuation of	$\Delta\mathcal{A}$	−0.001	+0.000	+0.000	+0.001	−0.000	−0.001	−0.000	+0.003	+0.008	+0.016	+0.011	+0.004	+0.009
N_D_s	$\Delta\sigma$	+0.000	+0.001	+0.001	+0.001	+0.001	+0.002	+0.002	+0.003	+0.004	+0.004	+0.008	+0.009	+0.009
resolution	$\Delta\mathcal{A}$	+0.001	+0.002	+0.004	+0.010	+0.007	−0.000	−0.019	−0.012	+0.019	+0.075	+0.040	+0.025	+0.076
(signal)	$\Delta\sigma$	+0.000	+0.001	+0.002	+0.004	+0.007	+0.012	+0.016	+0.023	+0.035	+0.046	+0.068	+0.087	+0.102
resolution	$\Delta\mathcal{A}$	+0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.002	−0.003	−0.006	−0.009	−0.009	−0.011
(bkg.)	$\Delta\sigma$	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.001	−0.001
dilution	$\Delta\mathcal{A}$	−0.005	−0.002	+0.008	+0.021	−0.010	−0.006	+0.001	+0.002	−0.015	−0.042	+0.037	+0.112	+0.129
	$\Delta\sigma$	−0.001	−0.001	−0.001	−0.002	−0.003	−0.005	−0.004	−0.005	−0.004	−0.002	−0.017	−0.018	−0.018
Fr_tsens	$\Delta\mathcal{A}$	−0.010	+0.006	+0.003	+0.003	+0.003	+0.000	−0.002	−0.004	−0.005	−0.004	−0.000	+0.001	−0.005
	$\Delta\sigma$	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	+0.000	+0.000	−0.000
Fr_osc	$\Delta\mathcal{A}$	−0.005	−0.000	+0.000	−0.001	−0.001	−0.001	−0.001	−0.002	−0.002	−0.003	−0.004	−0.006	−0.006
	$\Delta\sigma$	+0.000	+0.000	+0.000	+0.000	0.000	+0.000	−0.000	−0.000	+0.000	+0.000	0.000	−0.000	0.000
Fit to	$\Delta\mathcal{A}$	+0.008	+0.010	+0.014	+0.030	+0.041	+0.044	+0.004	+0.026	+0.129	+0.379	+0.291	+0.149	+0.363
VPDL distribution	$\Delta\sigma$	+0.002	+0.001	+0.001	+0.003	+0.006	+0.013	+0.021	+0.034	+0.045	+0.043	+0.100	+0.147	+0.179
Non-zero $\Delta\Gamma$	$\Delta\mathcal{A}$	+0.000	+0.000	+0.001	+0.000	+0.000	+0.001	+0.001	+0.000	−0.001	−0.005	−0.003	+0.001	−0.001
	$\Delta\sigma$	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.001	−0.001	−0.001	−0.002	−0.002	−0.002
Total syst.	σ_{tot}^{sys}	0.071	0.057	0.056	0.068	0.090	0.106	0.117	0.194	0.286	0.337	0.565	0.309	0.497
Total	σ_{tot}	0.115	0.137	0.176	0.241	0.313	0.423	0.517	0.687	0.910	1.119	1.522	1.718	1.983

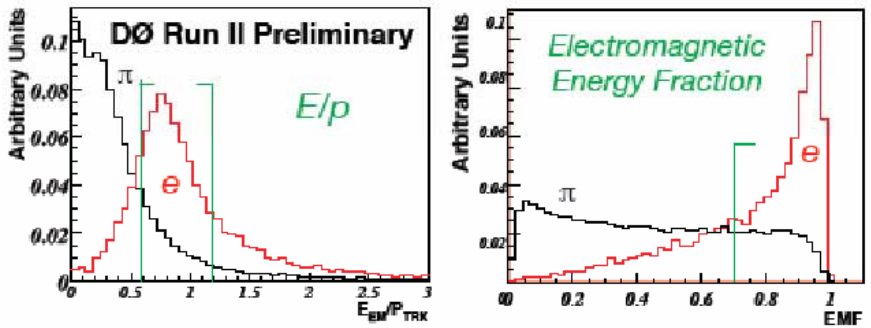
Oscillated B_S candidate in Run 164082 Event 31337864

- **Two same sign muons are detected**
  - *Tagging muon has η=1.4*
  - *See advantage of muon system with large coverage*
- **M_{KK}=1.019 GeV, $M_{KK\pi}$=1.94 GeV**
- **$P_T(\mu_{Bs})$=3.4 GeV; $P_T(\mu_{tag})$=3.5 GeV**



Flavor Tagging

- Semleptonic b decay - Lepton tag (Muon and Electron). Charge of the lepton tags the flavor of b.
  - First use of low pt electrons in a heavy-flavor analysis. ($P_T > 2$ GeV , $|\eta| < 1.1$)



- Secondary Vertex Charge $Q_{SV} = \frac{\sum_i (q^i p_L^i)^k}{\sum_i (p_L^i)^k}$

  $\cos\phi(p_{SV}, p_B) < 0.8$

  Sum over tracks assoc. to secondary vertex.

- Event charge

  $\cos\phi(p, p_B) < 0.8$ $\quad Q_{EV} = \frac{\sum_i q^i p_T^i}{\sum_i p_T^i}$

Combine variables into a single tagging variable

Flavor tagging (Combined tag algorithm)

- Get tag on opposite side and construct PDF's for variables discriminating b (μ^-) and $\bar{b}$ (μ^+) (Use B+ → D0 (X) decays in data)

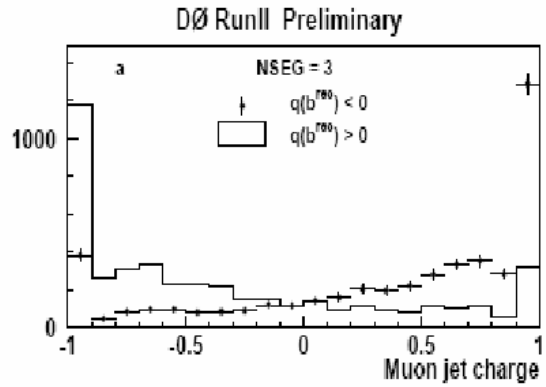
$$y = \prod_{i=1}^{n} y_i; \quad y_i = \frac{f_i^{\bar{b}}(x_i)}{f_i^{b}(x_i)}$$

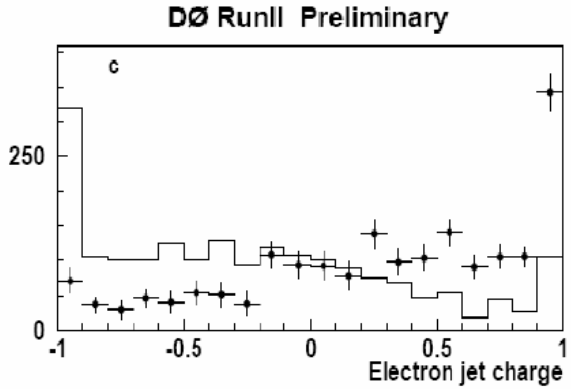
$$d = \frac{1-y}{1+y}$$

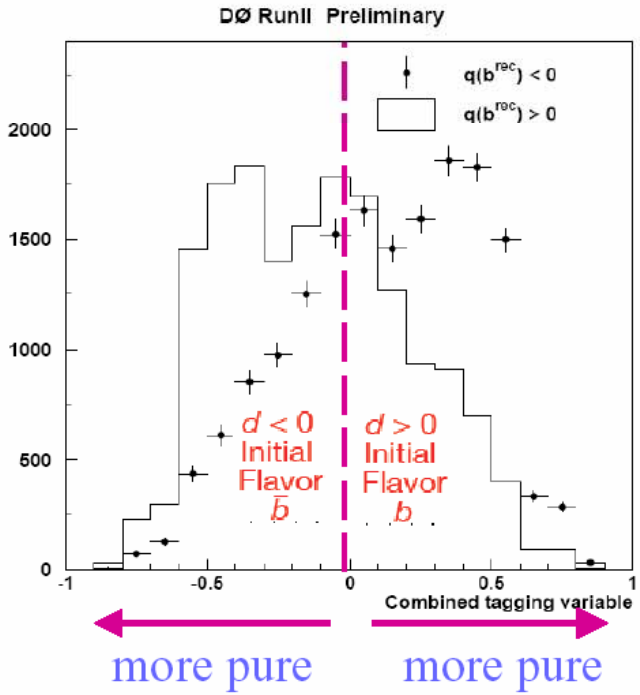
- Discriminating variables (x^i):

$$Q_J^{\mu} = \frac{\sum_i q^i p_T^i}{\sum_i p_T^i} \qquad Q_{SV} = \frac{\sum_i (q^i p_L^i)^k}{\sum_i (p_L^i)^k} \qquad Q_{EV} = \frac{\sum_i q^i p_T^i}{\sum_i p_T^i}$$

Electron/Muon *SV Tagger*

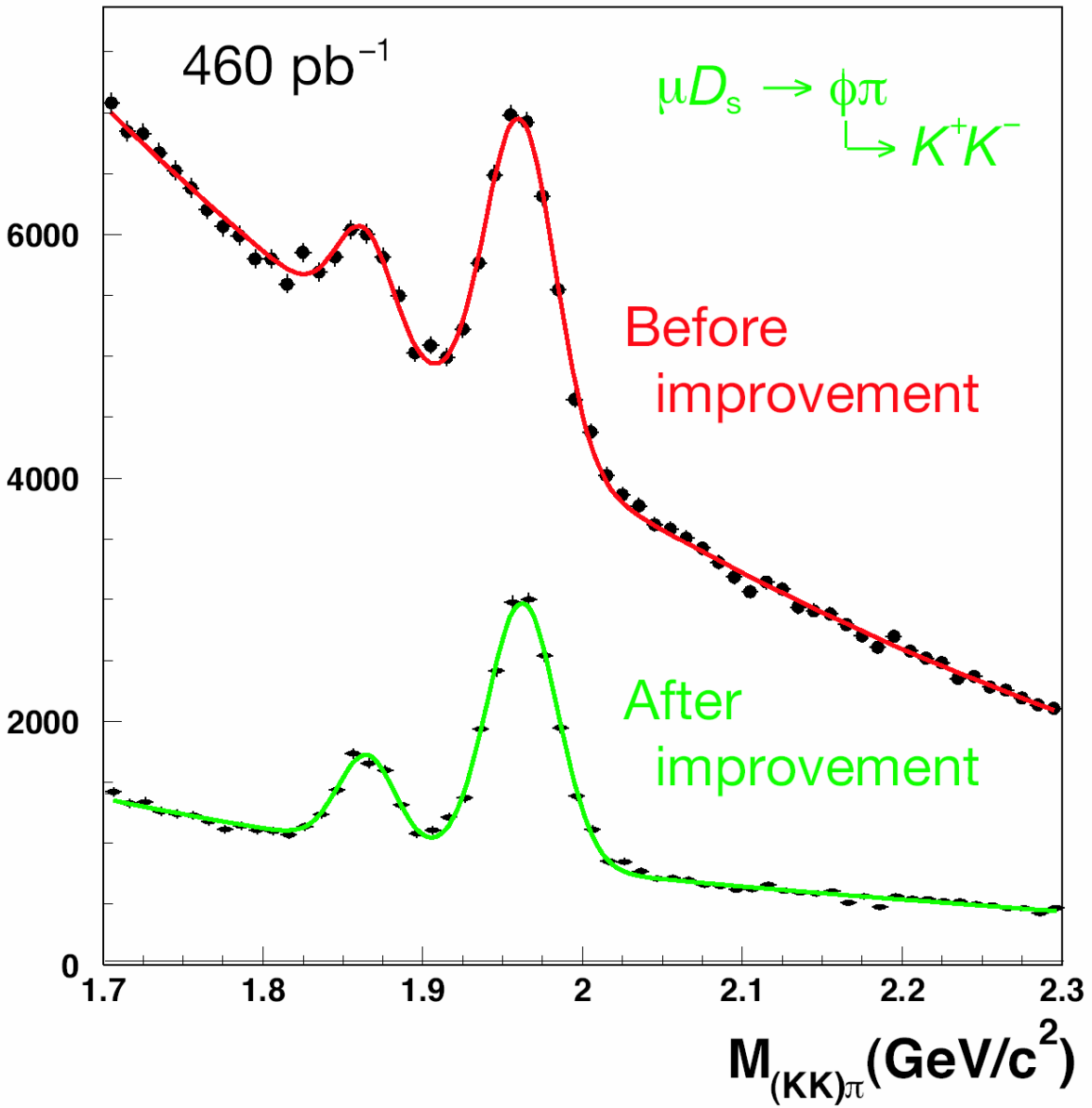






Performance of Different Taggers

Tagger	$\varepsilon(\%)$	$\mathcal{D}_d$	$\varepsilon\mathcal{D}_d^2(\%)$
Muon ($\|d\| > 0.3$)	6.61 ± 0.12	0.473 ± 0.027	1.48 ± 0.17
Electron ($\|d\| > 0.3$)	1.83 ± 0.07	0.341 ± 0.058	0.21 ± 0.07
SVCharge ($\|d\| > 0.3$)	2.77 ± 0.08	0.424 ± 0.048	0.50 ± 0.11
Combined ($\|d\| > 0.3$)	11.14 ± 0.15	0.443 ± 0.022	2.19 ± 0.22
Multidim ($\|d\| > 0.37$)	10.98 ± 0.15	0.395 ± 0.022	1.71 ± 0.19


460 pb^{-1}
$\mu D_s \rightarrow \phi\pi$
$\hookrightarrow K^+K^-$
Before improvement
After improvement
6000
4000
2000
0
1.7
1.8
1.9
2
2.1
2.2
2.3
$M_{(KK)\pi}$(GeV/c^2)