Bs Mixing at DØ

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On behalf of :
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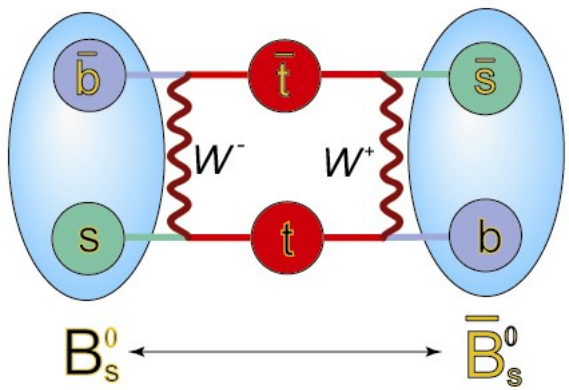
Bs mixing phenomenology

- Mixing or oscillation : Particle – anti-particle transitions via second-order weak interaction.
- Mass eigenstates a mixture of flavor eigenstates.



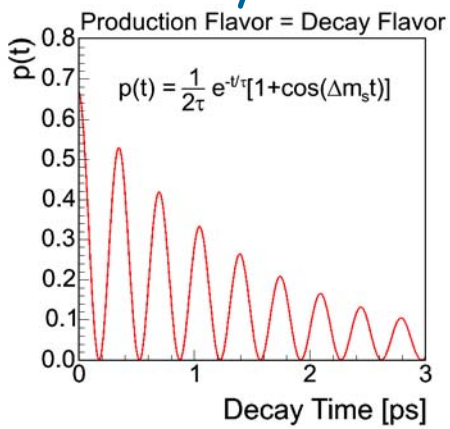
$$|B_H\rangle = \left(q|B\rangle + p|\bar{B}\rangle\right)$$

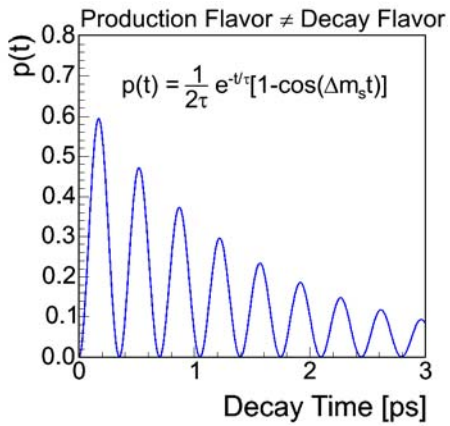
$$|B_L\rangle = \left(q|B\rangle - p|\bar{B}\rangle\right)$$

- Probability of mixed and unmixed decays:

$$p(B \to B) = \frac{e^{-t/\tau}}{2\tau}(1+\cos\Delta mt)$$

$$p(B \to \bar{B}) = \frac{e^{-t/\tau}}{2\tau}(1-\cos\Delta mt)$$





Want to measure

Bs mixing Current Status

- CDF Measurement (Published) = $17.7 \pm 0.1 \pm 0.07$ ps^{-1}
- D0 Limits (Published) = $17 < \Delta m_s < 21$ ps^{-1}
- From Global fit to experimental inputs (CKM Fitter) –
  - $\Delta m_s = 17.7^{+6.4}_{-2.1}$
  - $\Delta m_d = 0.63^{+0.06}_{-0.12}$ (Experimental : 0.507 ± 0.005)
- From Theoretical calculation within SM framework :
  - Δm_s(SM) = 19.30 +- 6.68 ps-1

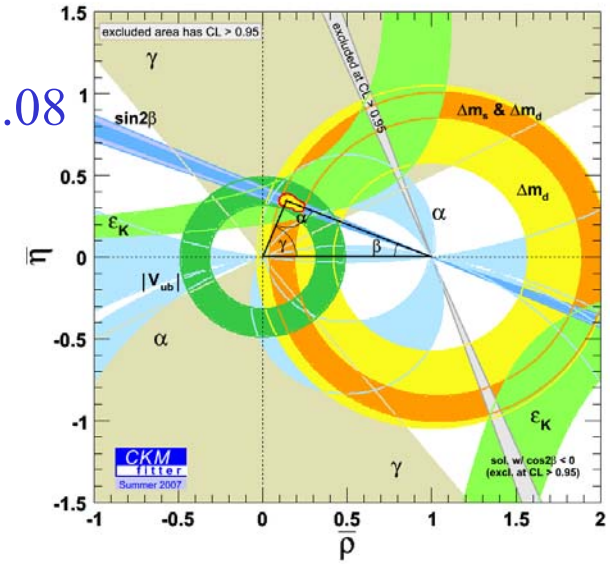
(hep-ph/0612157 Lenz, Nierste)

Values are consistent among each other and experimental results confirm validity of Standard model so far.

B_s mixing physics reach

$$\frac{\Delta m_s}{\Delta m_d} = \frac{M_{Bs}}{M_{Bd}} \frac{f_{Bs}^2}{f_{Bd}^2} \frac{B_{Bs}}{B_{Bd}} \left| \frac{V_{ts}}{V_{td}} \right|^2$$

$f_{Bs}/f_{Bd} = 1.20 \pm 0.05 \pm 0.08$
$B_s/B_d = 1.00 \pm 0.02$

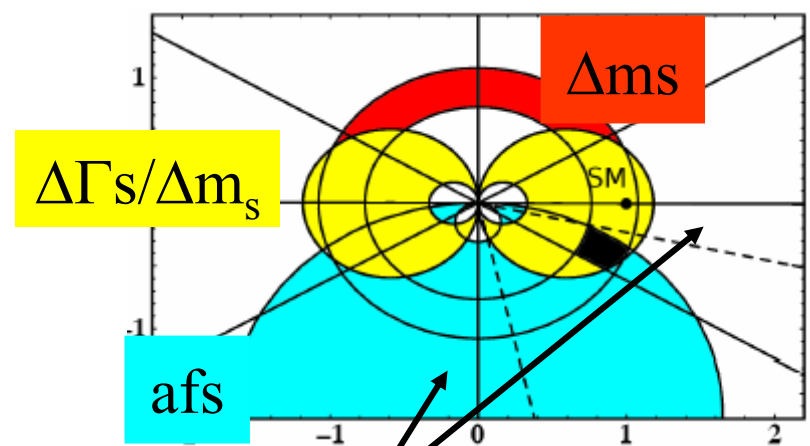


Extraction of CKM Matrix Element V_{td} within SM framwork

Many New Physics effects also cancel in the ratio

$$\Delta m_s = \Delta m_s^{SM} \left| \Delta_s \right|$$

Test of New Physics : Limited by precision of Lattice computation. Need to add experimental information from ϕs, $\Delta\Gamma$ and a_{fs} (flavor specific asymmetry)



Angular analysis
Bs → J/Ψ ϕs

(hep-ph/0612157 Lenz, Nierste)

Analysis Overview

Reconstruct Bs decays - Strive for high statistics (S) and low background (B/S low)

$e.g. \quad B_s \rightarrow D_s \mu \nu X,\ D_s \rightarrow \phi\pi, \phi \rightarrow K^+K^-$

$$\frac{1}{\sigma} = \sqrt{\frac{S\varepsilon\mathcal{D}^2}{2}} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$

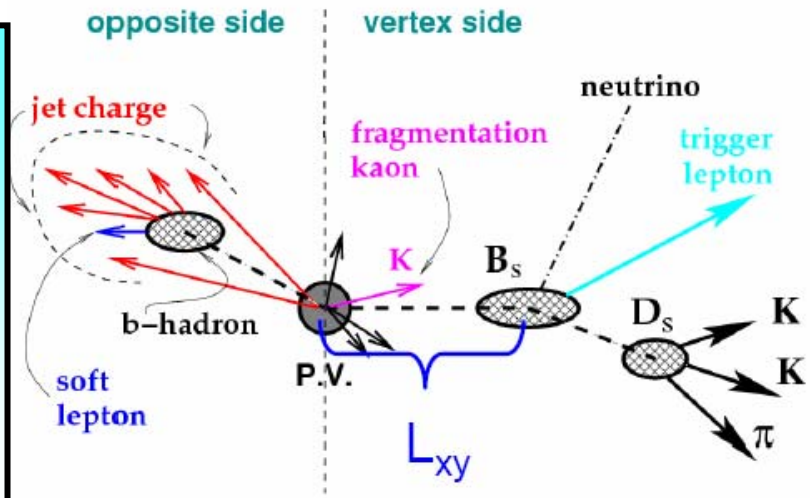
Accurate determination of flavor with good efficiency (Flavor Tagging) --- Strive for high $\varepsilon\mathcal{D}^2$

Reconstruct decay Length → strive for small resolution (σ_t)

Flavor Tagging Method (OST and SSKT)

OST : Use B decays opposite to reconstructed Bs - Use Charge correlation between B and :

- Lepton from B decay
- pT weighted sum of tracks associated to a found secondary vertex
- pT weighted sum of all tracks in absence of secondary vertex

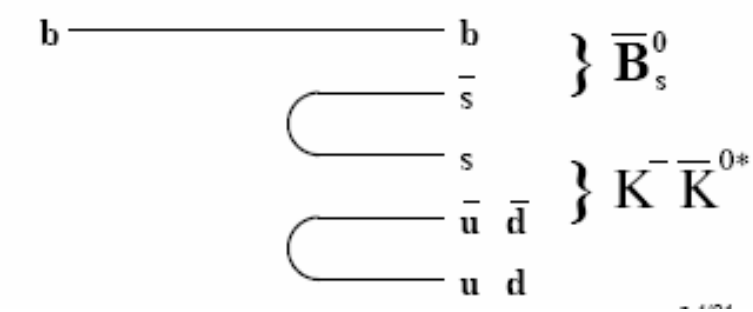


SSKT: Use Charge correlation between reconstructed Bs and fragmentation kaon

Construct PDF's using data (OST) and MC (event-by-event dilution)

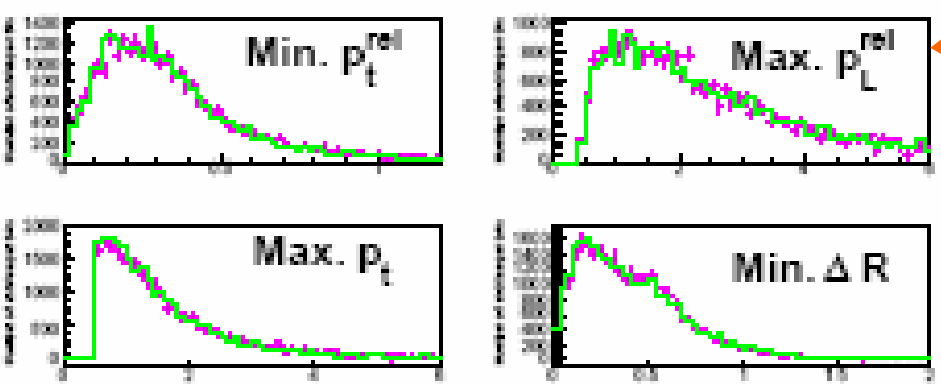
$$r_i = \frac{f_i^{\bar{b}}(x_i)}{f_i^{b}(x_i)} \qquad r = \prod_{i=1}^{n} r_i, n \equiv Tag\ Methods$$

$$d = \frac{1-r}{1+r} \left| \begin{array}{l} d > 0\,(b) \\ d < 0\,(\bar{b}) \end{array} \right.$$



Combined Flavor Tagging

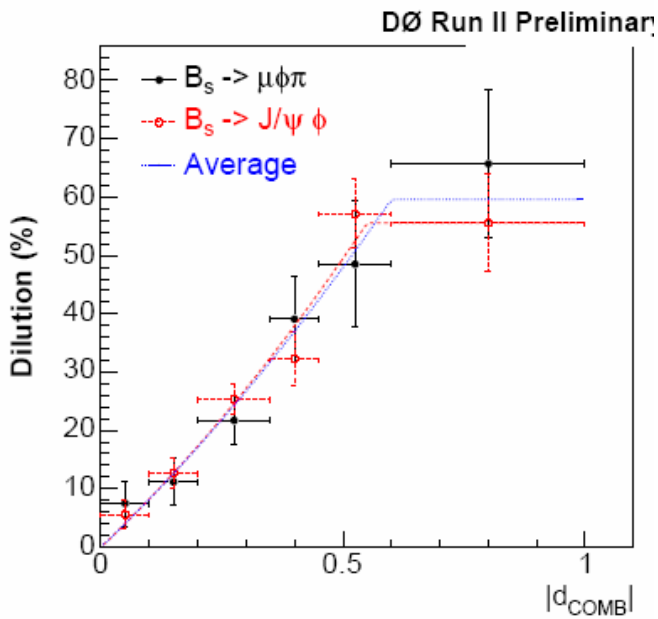
- SSKT and "Event charge" are new additions to flavor tagger. Tagger calibrated using data (OST) and MC(SSKT)
- Use information from all events for tagging – Efficiency = 100%



DATA-MC Match – Kaon track for SSKT

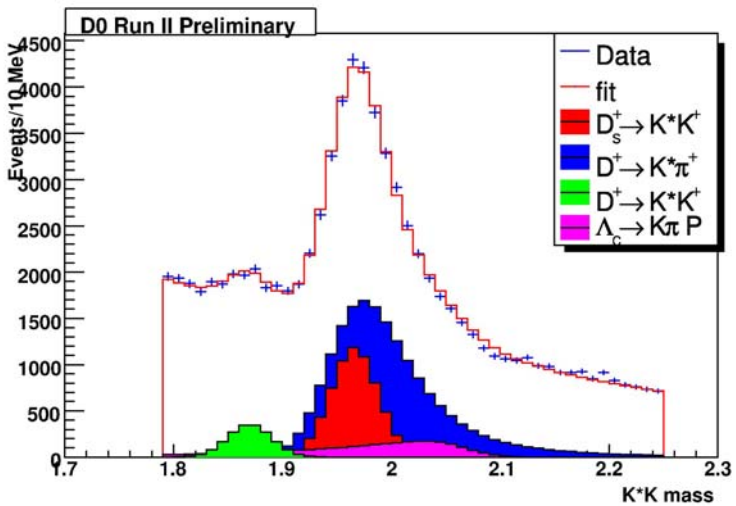
Tagger	ϵD^2
Comb. SST	$1.7 \pm 0.6\%$
Comb. OST without Evt. Charge	$2.5 \pm 0.2\%$
Evt. Charge	$1.5 \pm 0.5\%$
All	$4.5 \pm 0.9\%$

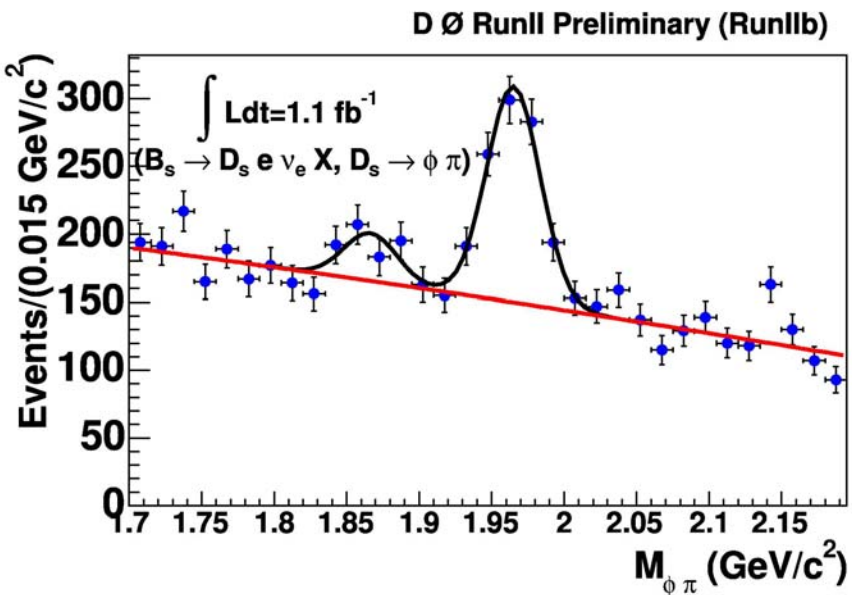
Combined OST+SST

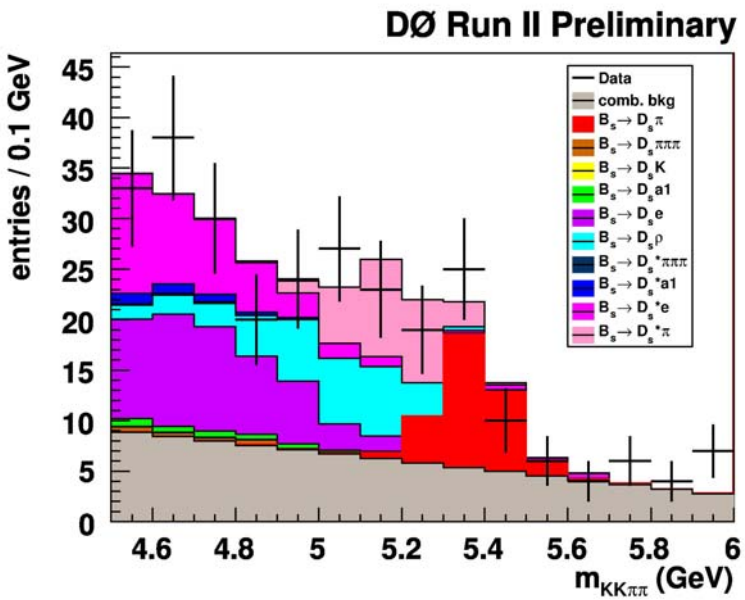


Data Sample

Decay Modes	Ns
$B_s \to D_s \mu \nu X,\ D_s \to \phi\pi$	44000
$B_s \to D_s \mu \nu X,\ D_s \to K^{*0} K$	18000
$B_s \to D_s \mu \nu X,\ D_s \to K_s K$	600
$B_s \to D_s e \nu X,\ D_s \to \phi\pi$	1600
$B_s \to D_s^{(*)} \pi,\ D_s \to \phi\pi$	200
TOTAL	64400







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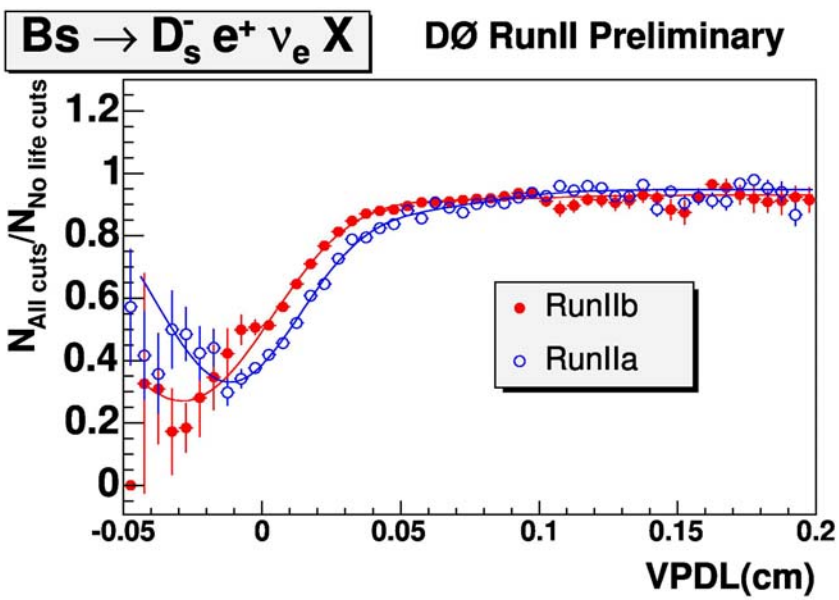
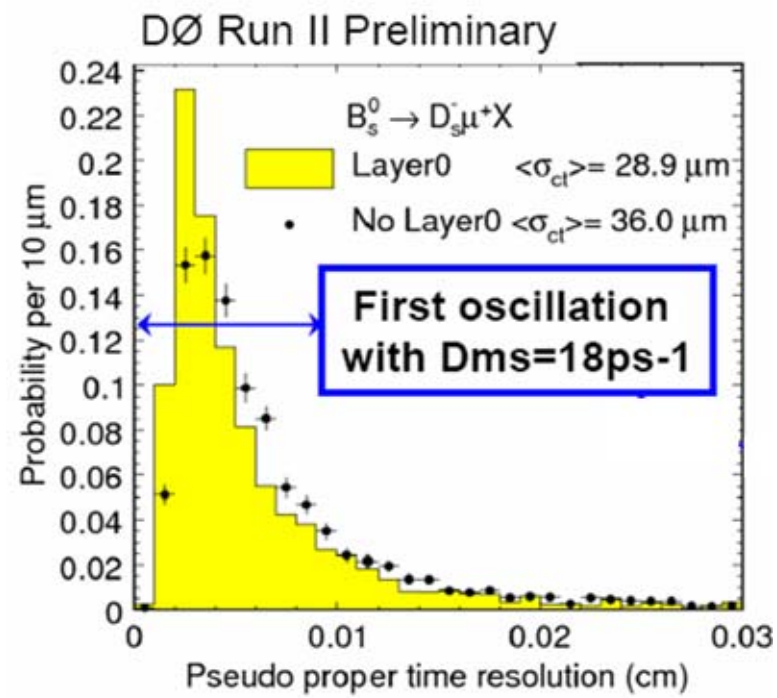
Proper Time Resolution

Layer 0 installed in Silicon detector.
Event-by-Event Scale factor to correct impact parameter resolution





Better Lifetime cuts efficieny

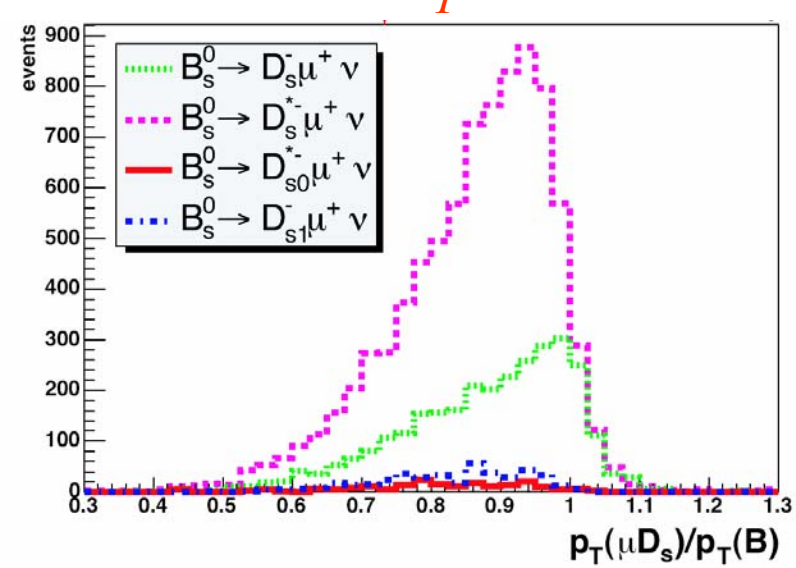
Proper time and unreconstructed particles

$$e.g.\ B_s^0 \to D_s^{*-}\mu^+\nu_\mu \ \ (D_s^{*-} \to D_s^-\gamma)$$

- Cannot determine P_T^B. Determine correction factor (K-factor) from simulated events.

$$c\tau_B = \frac{L_{XY}^B}{(\beta\gamma)_T^B} = L_{XY}^B \cdot \frac{M_B}{P_T^B} = L_{XY}^B \cdot \frac{M_B}{P_T^{\mu/eD_s}} \cdot K$$

$$K = \frac{P_T^{Ds\mu/e}}{P_T^{B_s}}$$



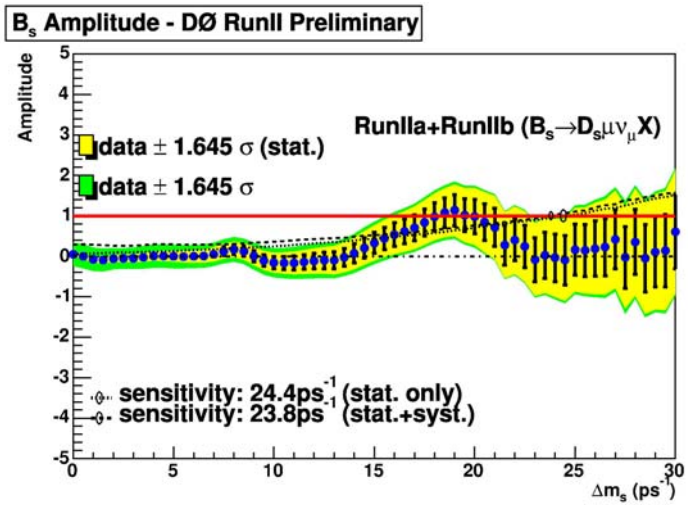
Worsened resolution

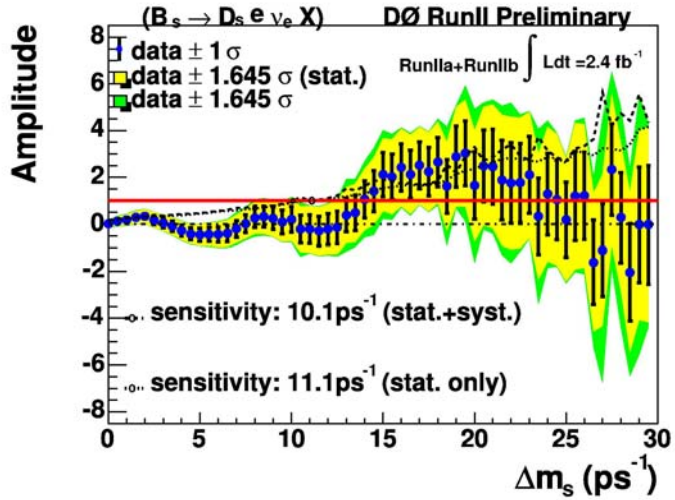
$$\sigma_t = t\sqrt{\frac{\sigma_L^2}{L^2} + \frac{\sigma_K^2}{K^2}}$$

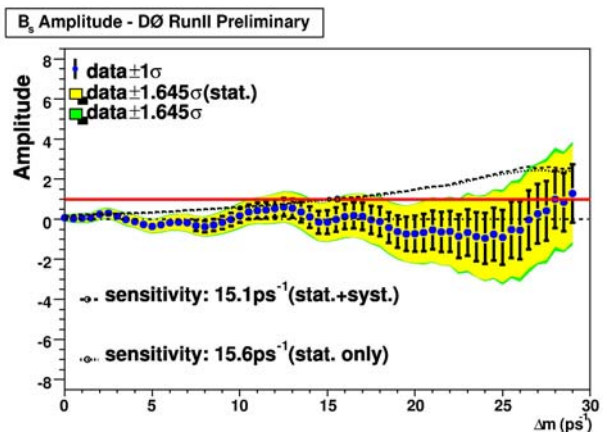
Amplitude Scans

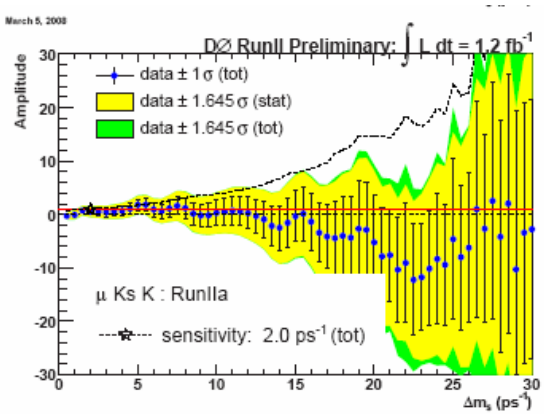
$$p_s^{nos/osc}(x) \propto \left(1 \pm \mathcal{D}\,\boxed{\mathcal{A}}\cos\left(\Delta m_s \cdot Kx/c\right)\right)$$

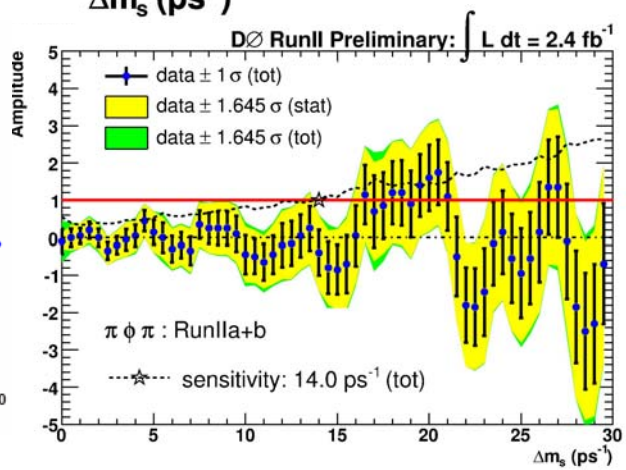
Sensitivity :
$1.645\ \sigma_A = 1$



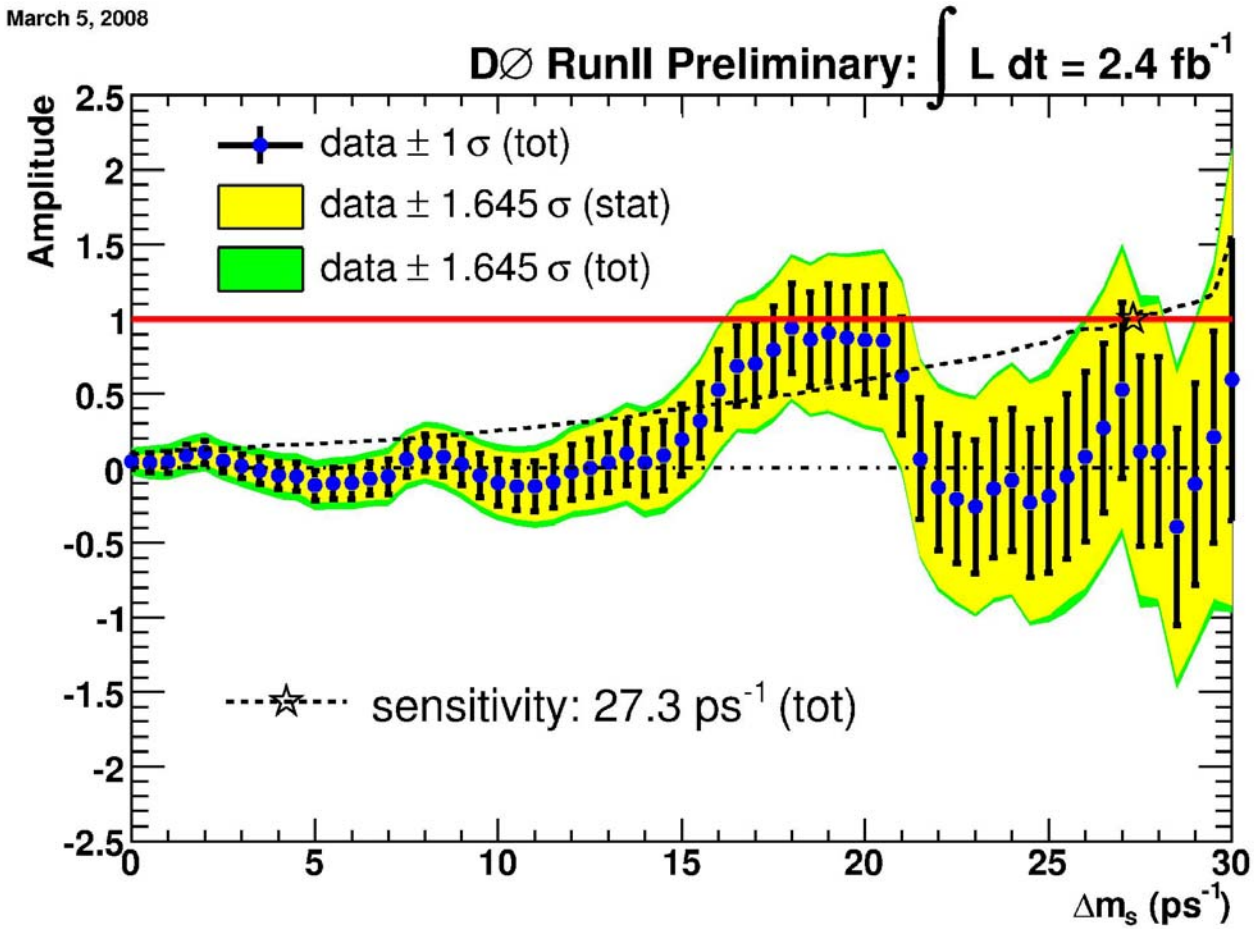






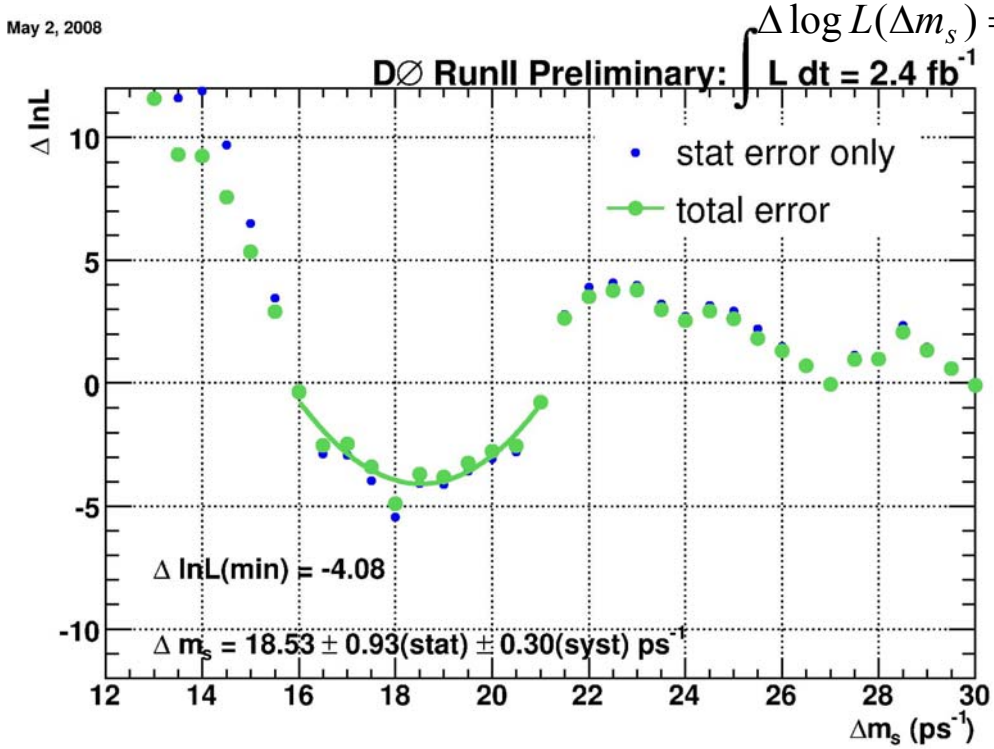


Combined Semileptonic and Hadronic



Δm_s from Likelihood Scan

$$\Delta \log L(\Delta m_s) = \log L_{\Delta m_s}(A=1) - \log L\infty = 0.5 \times \left(\left(\frac{1-\bar{A}}{\sigma_A} \right)^2 - \left(\frac{\bar{A}}{\sigma_A} \right)^2 \right)$$



ΔlogL translated from amplitude scan :

Minimum at value of Δm_s = 18.53 ps^{-1} with 3.0 σ (stat. only) and 2.9 σ (syst. Included)

Systematic errors –
Fit errors on background fractions estimated from lifetime fit.
Fit errors on Bs lifetime extracted from lifetime fit.
Statisitical errors in BF's used in sample composition,
Lifetime cuts efficiency uncertainty,
K-factor mean and resolution.

Summary

- Δm_s and $|V_{td}/V_{ts}|$ measured to be :

$$\Delta m_s = 18.53 \pm 0.93(stat.) \pm 0.30(syst.)\ ps^{-1}(2.9\sigma)$$

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.2018 \pm 0.005(\exp)^{+0.0081}_{-0.0060}(theor.)$$

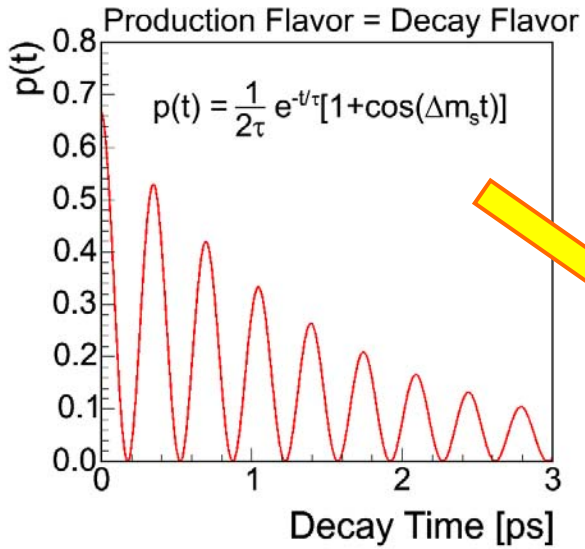
$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.2059 \pm 0.0007(\exp)^{+0.0081}_{-0.0060}(theor.)$$ HFAG

- Both CDF and D0 have measured Δms. With improvements in theoretical calculations, and other inputs, a precision measurement of Δms may be worth pursuing at LHC as a testing ground for new physics.

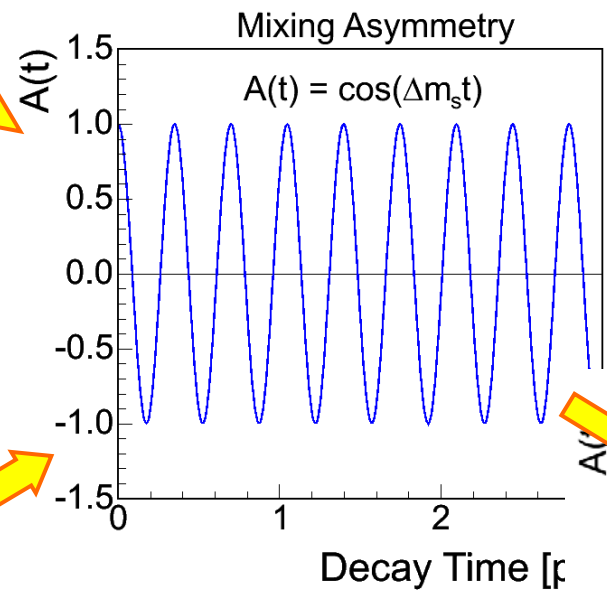
BACKUP SLIDES

Bs Oscillations in ideal and real world

"Opposite sign"

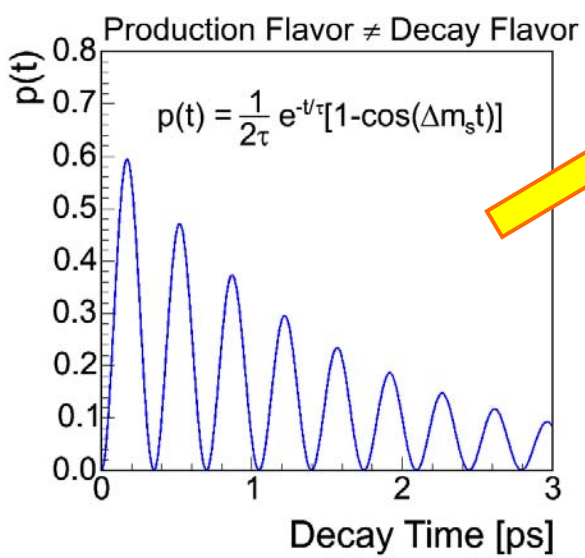


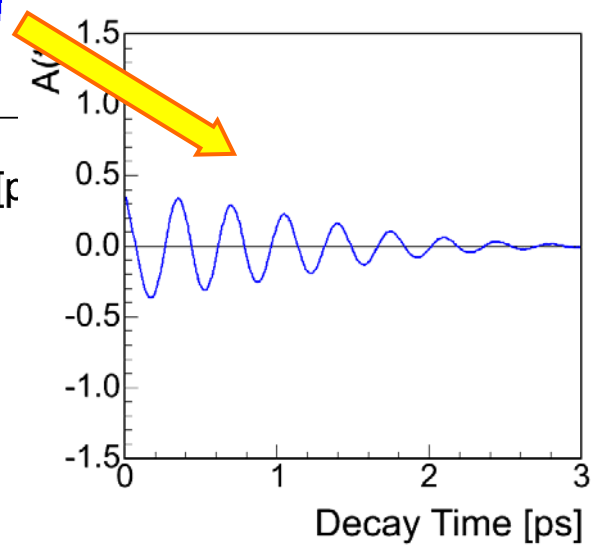
Oscillations with amplitude = 1.0 and Frequency = Δms.



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

"Same sign"





"Inaccurate flavor tag"

finite precision in determination of momentum and decay length

CKM matrix and B mixing

Why are we interested to study B meson oscillations

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Wolfenstein parametrisation - expansion in λ.

$$\begin{pmatrix} 1-\lambda^2 & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\lambda^2 & A\lambda^2 \\ A\lambda^3(\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

$$\lambda = \sin\theta_c = 0.2265 \pm 0.002$$

$$A = 0.801^{+0.029}_{-0.018}$$

$$\bar{\rho} = (1-\lambda^2/2)\rho$$

$$\bar{\eta} = (1-\lambda^2/2)\eta$$

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

complex

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

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

B Mixing

$$|B_q^0(t)\rangle = g_+(t)\,|B_q^0\rangle + \frac{q}{p}\,g_-(t)\,|\overline{B}_q^0\rangle$$

$$|\overline{B}_q^0(t)\rangle = g_+(t)\,|\overline{B}_q^0\rangle + \frac{p}{q}\,g_-(t)\,|B_q^0\rangle$$

$$|g_\pm(t)|^2 = \frac{e^{-\Gamma_q t}}{2}\left[\cosh\left(\frac{\Delta\Gamma_q}{2}t\right) \pm \cos(\Delta m_q t)\right]$$

In general, probability for unmixed and mixed decays Pu,m(B) $\neq$ Pu,m($\overline{B}$). In limit, $\Gamma_{12} << M_{12}$ ($\Delta\Gamma << \Delta M$) (Standard model estimate and confirmed by data), the two are equal.

$$p(B \to B) = \frac{e^{-t/\tau}}{2\tau}(1+\cos\Delta m t)$$

$$p(B \to \overline{B}) = \frac{e^{-t/\tau}}{2\tau}(1-\cos\Delta m t)$$

$$\left|\frac{\Gamma_{12}}{M_{12}}\right| \simeq \frac{3\pi}{2}\frac{m_b^2}{m_W^2}\frac{1}{S_0(m_t^2/m_W^2)} \sim \mathcal{O}\left(\frac{m_b^2}{m_t^2}\right) \sim 10^{-3}$$

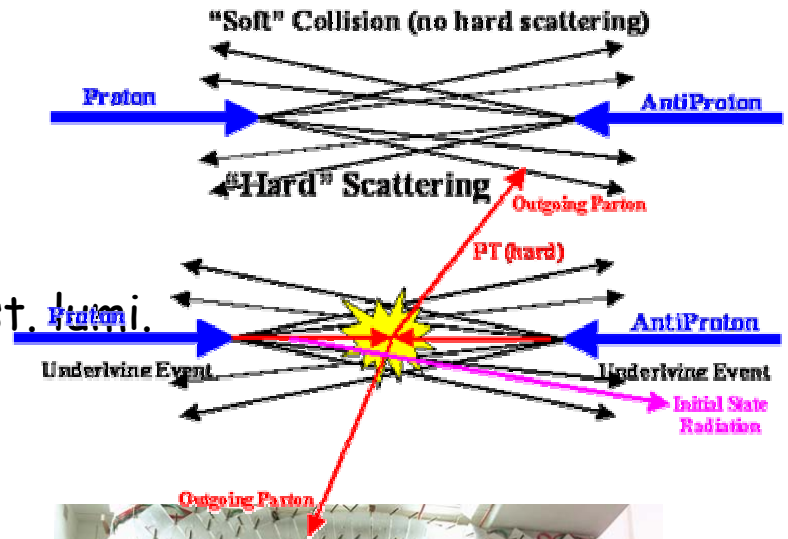
$$1 - \left|\frac{q}{p}\right|^2 \simeq \mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)$$

~ 10^{-4} for Bs system

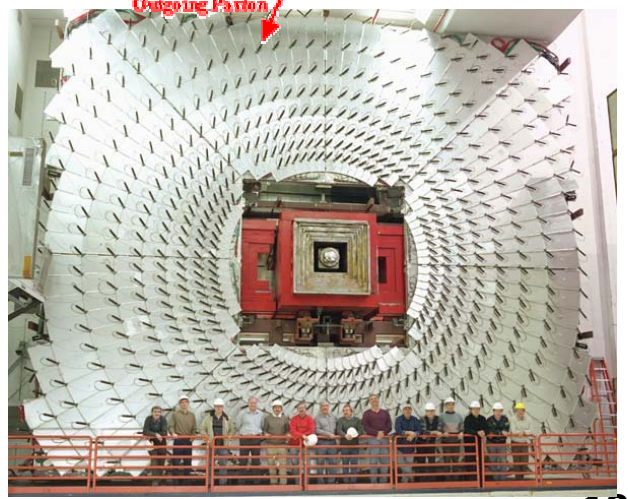
~ 10^{-3} for Bd system

Muon Triggers

- Limitation of data recording. Triggers are needed to select useful physics decay modes. 396 ns bunch crossing rate ~ 2.5 MHz → ~50 Hz for data to be recorded.



- Single inclusive muon Trigger:
  - $|\eta|<2.0$, $p_T > 3,4,5$ GeV
  - Muon + track match at Level 1
  - Prescaled or turned off depending on inst. lumi.
  - We have B physics triggers at all lumi's
    - ***Extra tracks at medium lumi's***
    - ***Impact parameter requirements***
    - ***Associated invariant mass***
    - ***Track selections at Level 3***
- Dimuon Trigger : other muon for flavor tagging
- e.g. at $50 \cdot 10^{-30}$ $cm^{-2}s^{-1}$, L3 trigger rate :
  - 20 Hz of unbiased single μ
  - 1.5 Hz of IP+μ
  - 2 Hz of di-μ
  - No rate problem at L1/L2



Details of likelihood fit

- probability as function of *true* visible proper decay length, *x*

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

- Prob. Function as a function of measured visible decay length, x^M

$$p_j^{nos/osc}(x^M) = \int dx\, \underbrace{g(x - x^M, x)}_{\text{VPDL Resolution}} \int \underbrace{dK\ f_j(K)}_{\text{K-Distribution}}\ \underbrace{\varepsilon_j(x^M)}_{\text{Efficiency due to lifetime cuts}}\ p_s^{nos/osc}(x, K)$$

j'th decay mode

- Integrate over VPDL bins, sum over decay modes (Fractions from MC) . Form likelihood. Minimize -2 lnL.

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