Reconstruction of a missing particle with vertex information

Andrey Starodumov

IPP, ETH Zurich

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Introduction

Decays with a missing particle

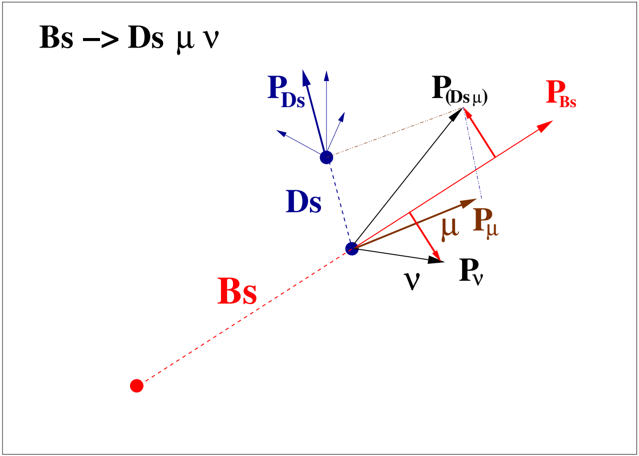
- Generally considered as not fully reconstructible
- Few well known exceptions:
  - momentum of the decaying particle and all but one of the decay products are known
  - detector hermeticity: missing energy measured precisely
  - collinear approximation ($H^0 \to \tau^+\tau^-$)
  - k-factor in semileptonic B decays
- But: 4-momentum of missing particle can be reconstructed with additional topological information

Decay channel example

- Example decay: $B_s^0 \to D_s^- \ell^+ \nu$
- Six unknown variables: P_B^i, P_ν^i, $i = x, y$ and z
- Four equations

$$\begin{aligned} \sqrt{m_B^2 + \vec{P}_B^2} &= \sqrt{m_{(D_s\ell)}^2 + \vec{P}_{(D_s\ell)}^2} + |\vec{P}_\nu| \\ \vec{P}_B &= \vec{P}_{(D_s\ell)} + \vec{P}_\nu \end{aligned}$$

Event topology



New system of equations

$$\sqrt{m_B^2 + \vec{P_B}^2} = \sqrt{m_{(D_s\ell)}^2 + \vec{P}_{(D_s\ell)}^2} + |\vec{P_\nu}|$$

$$|\vec{P_B}| = P_{(D_s\ell)}^{\parallel} + P_\nu^{\parallel}$$

$$P_\nu^{\perp} = -P_{(D_s\ell)}^{\perp}$$

Solution

$$P_\nu^{\parallel} = -a \pm \sqrt{r}$$

where

$$a = \frac{(m_B^2 - m^2 - 2 \cdot P_\perp^2) \cdot P_\parallel}{2 \cdot (P_\parallel^2 - E^2)}$$

$$r = \frac{(m_B^2 - m^2 - 2 \cdot P_\perp^2)^2 \cdot E^2}{4 \cdot (P_\parallel^2 - E^2)^2} + \frac{E^2 \cdot P_\perp^2}{P_\parallel^2 - E^2}$$

Here we use the following notations: $P_\perp = P^\perp_{(D_s\ell)}$, $P_\parallel = P^\parallel_{(D_s\ell)}$, $E = E_{(D_s\ell)}$, $m = m_{(D_s\ell)}$

Event generation

Decay channel : $B_s^0 \rightarrow D_s^- \mu^+ \nu_\mu$, $D_s^- \rightarrow \phi\pi^-$, $\phi \rightarrow K^+K^-$
MC generator: PYTHIA V6.227, E_{CM}=14 TeV.

Kinematics and resolutions

- Hadrons: $p_T \geq 1\,\mathrm{GeV}/c$, muon: $p_T \geq 3\,\mathrm{GeV}/c$.
- momentum uncertainty:
  - pseudorapidity: $\sigma_\eta = 5.8 \times 10^{-4}$,
  - ϕ: $\sigma_\phi = 0.58\,\mathrm{mrad}$,
  - transverse momentum: $\sigma_{(1/p_T)} = 0.013(\,\mathrm{GeV}/c)^{-1}$.
- The primary vertex: $\sigma_{x,y} = 20\,\mu\mathrm{m}$, the secondary vertex: $\sigma_{||} = 70\,\mu\mathrm{m}$ in flight direction of the B_s^0 and $\sigma_\perp = 10\,\mu\mathrm{m}$ in the perpendicular direction.

Proper time

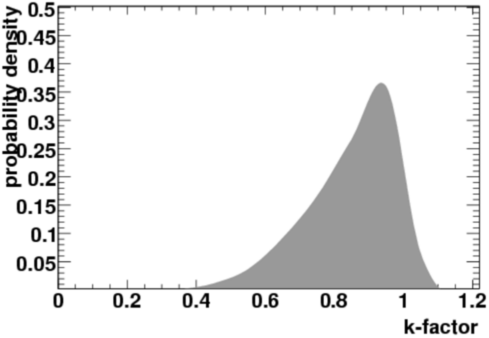
The most important ingredient in the measurement of the B_s^0 oscillation frequency is the proper time

$$c\tau = \frac{L_{xy}\, m(B_s^0)}{p_T(B_s^0)}$$

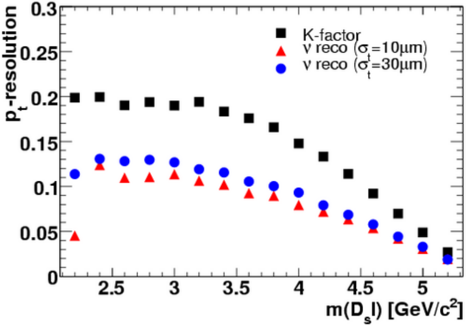
$$c\tau = \frac{L_{xy}\, m(B_s^0)}{p_T(D_s\ell)} \times k$$

$$k = \frac{p_T(D_s\ell)}{p_T(B_s^0)}$$

k-factor distribution

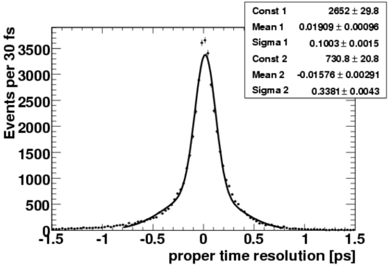


Momentum resolution

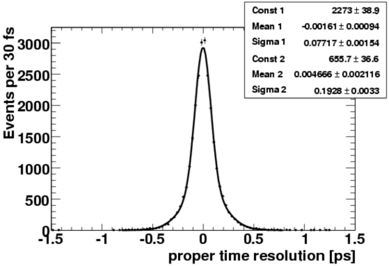


Proper time resolution I

k-factor method



neutrino reconstruction method



Proper time resolution II

The distributions are fitted with two Gaussian, the average width σ:

$$\sigma^2 = \frac{N_n^2\sigma_n^2 + N_w^2\sigma_w^2}{N_n^2 + N_w^2},$$

here σ_n (σ_w) and N_n (N_w) are the width and normalization of the narrow (wide) Gaussian.

	σ_n	σ_w	σ	N_n	N_w
k-factor	100 fs	338 fs	132 fs	2700	730
ν-reco	77 fs	193 fs	91 fs	2300	660

Amplitude method

- Candidates split into two samples:
  - the same flavor (**P_{unmix}**) and
  - the opposite flavor (**P_{mix}**) at production and decay.
- Proper decay time of the B_s^0 mesons is reconstructed.
- Two samples are used to define the time-dependent asymmetry:

$$a(t) = \frac{P_{unmix} - P_{mix}}{P_{unmix} + P_{mix}} \propto A \times D \times \cos(\Delta m_s t)$$

where D is a global dilution factor accounting for background, miss-tagging and proper-time resolution and A is the amplitude.

Amplitude fit

- In the fit the oscillation frequency Δm_s is fixed, leaving the amplitude A as a free parameter.
- A scan over Δm_s is performed starting from zero.
- If Δm_s is consistent with the true one, the $A \simeq 1$, else $A \simeq 0$.
- The error on the A is calculated according to

$$\sigma_A = \frac{1}{1-2W} \times \sqrt{\frac{2}{S+B}} \times \frac{S+B}{S} \times e^{\frac{\Delta m_s^2 \sigma_t^2}{2}}$$

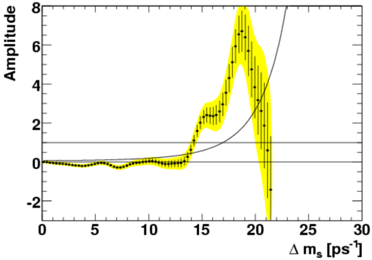
where W is the mistagging probability, S the number of signal, B the number of background events, and σ_t the proper time resolution.

Assumptions

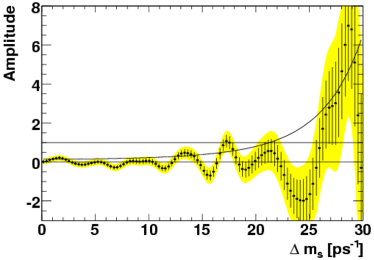
- Number of signal events: 45000
- Signal to Background ratio: 1:1
- Mistagging probability: 40%
- Simulated oscillation frequency: $\Delta m_s = 17.25\ \mathrm{ps}^{-1}$

Results

k-factor method



neutrino reconstruction method



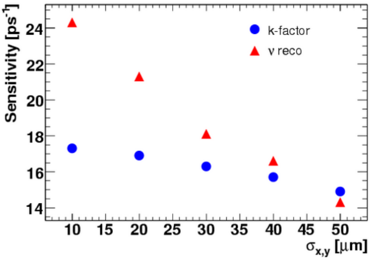
S/B for the 2 methods

- Smaller number of signal and background events due to negative radicand r (factor 2)
- More background events: second (wrong) solution of quadratic equation for signal and background (factor 3)

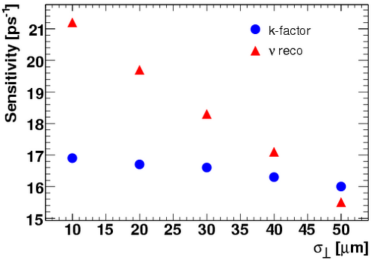
- k-factor method: 1:1
- neutrino reconstruction method: 1:3.
- But the sensitivity of ν-reconstruction method is at higher values of Δm_s due to better proper time resolution!

Sensitivity of the method

sensitivity vs σ_{xy}



sensitivity vs $\sigma_{\perp}$



Conclusion

- Missing particles can be reconstructed using vertex information
- Example: $B_s^0\bar{B}_s^0$ oscillations with semileptonic B_s^0 decays
- The sensitivity of proposed method is higher than of conventional k-factor method except if the vertex resolution is too bad
- Proposed method can be used in some other cases where the known topology of a decay compensate for the incompleteness of kinematical information

Other examples

- Life time measurements in the semileptonic B decays
- τ reconstruction in $\tau \to 3h^{\pm} + \nu_{\tau}$ decays
  - $H^0 \to \tau^+\mu^-$ (?)
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  - $B_s^0 \to \tau^+\tau^-$ (???)
- $B_s^0 \to \mu^+\mu^- + \gamma$ (?)
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