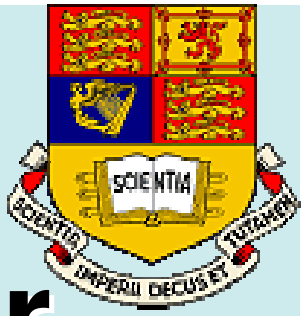

LHCb performance for $B_s \rightarrow D_s \pi$ (B_s mixing) and $B_s \rightarrow D_s K$ decays (γ)

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Outline

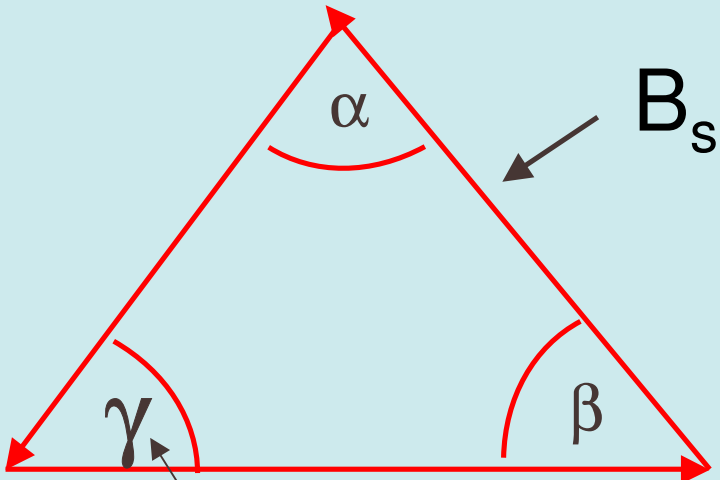
- The Physics
  - CKM matrix and Unitarity Triangles
  - Mixing in B_s^0 system
- Event selection at LHCb
- Annual event yields and backgrounds
- Sensitivity to Δm_s and γ
  - Extraction method
  - Results
- Current B-physics experiments can't explore the B_s sector
  - Need LHCb for this

Unitarity Triangles

By exploiting the Unitarity of the CKM matrix, one can form triangles in the complex plane. For the B-system:

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

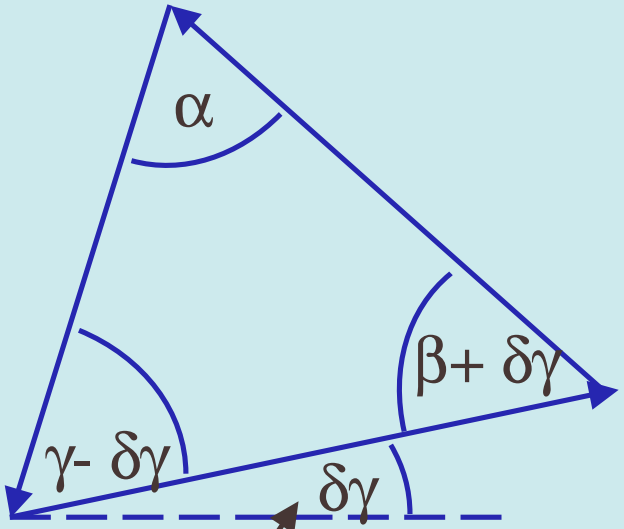
$$V_{cd}V^*_{cb} + V_{td}V^*_{tb} + V_{ud}V^*_{ub} = 0$$



$B_s \rightarrow D_s \pi$

$B_s \rightarrow D_s K\ (\gamma - 2\delta\gamma)$

$$V_{ts}V^*_{us} + V_{td}V^*_{ud} + V_{tb}V^*_{ub} = 0$$



$B_s \rightarrow J/\Psi\phi$

Formalism

The two mass eigenstates $|B_l\rangle$ and $|B_h\rangle$ are given by:

$$\left|B_{l(h)}\right\rangle = \frac{1}{\sqrt{p^2+q^2}}\left[\,p\left|B_s\right\rangle \pm q\left|\overline{B}_s\right\rangle\right]$$

Time-dependent rates for initial flavour eigenstates B_s and $\overline{B}_s$ decaying into final states f or $\overline{f}$ are:

$$R_f(t) \propto \frac{\left|A_f\right|^2}{2} e^{-\Gamma t}\left[I_+(t)+I_-(t)\right] \qquad \overline{R}_f(t) \propto \frac{\left|A_f\right|^2}{2}\left|\frac{p}{q}\right|^2 e^{-\Gamma t}\left[I_+(t)-I_-(t)\right]$$

$$\overline{R}_{\overline{f}}(t) \propto \frac{\left|\overline{A}_{\overline{f}}\right|^2}{2} e^{-\Gamma t}\left[\overline{I}_+(t)+\overline{I}_-(t)\right] \qquad R_{\overline{f}}(t) \propto \frac{\left|\overline{A}_{\overline{f}}\right|^2}{2}\left|\frac{q}{p}\right|^2 e^{-\Gamma t}\left[\overline{I}_+(t)-\overline{I}_-(t)\right]$$

Where A_f is the instantaneous decay amplitude for $B_s \to f$

$$I_+(t) = (1+|\eta|^2)\cosh\tfrac{\Delta\Gamma}{2}t - 2\Re(\eta)\sinh\tfrac{\Delta\Gamma}{2}t$$

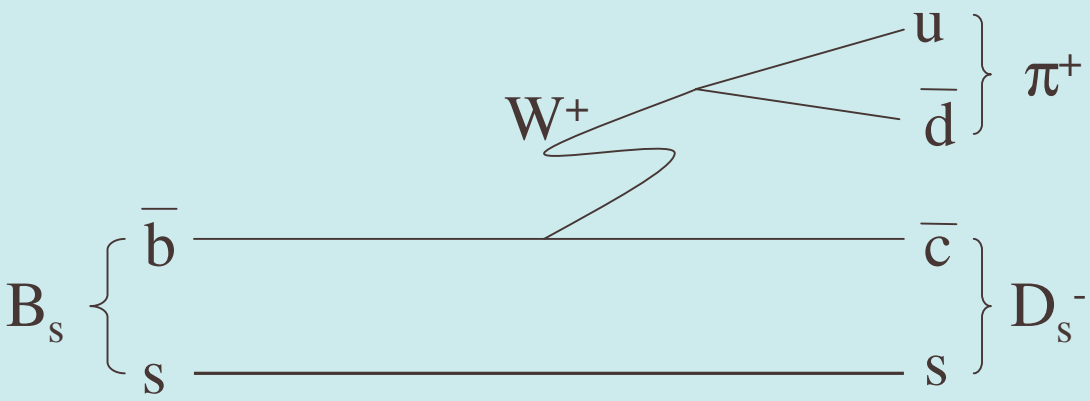
$$I_-(t) = (1-|\eta|^2)\cos\Delta m t - 2\Im(\eta)\sin\Delta m t$$

$$\eta = \frac{q}{p}\frac{\overline{A}_f}{A_f} \text{ and } \overline{\eta} = \frac{p}{q}\frac{A_{\overline{f}}}{\overline{A}_{\overline{f}}}$$

In the Standard Model: $q/p = e^{2i\delta\gamma}$

$B_s \rightarrow D_s \pi$

This channel has a flavour specific final state hence:



$$A_{\bar{f}} = \bar{A}_f = 0$$

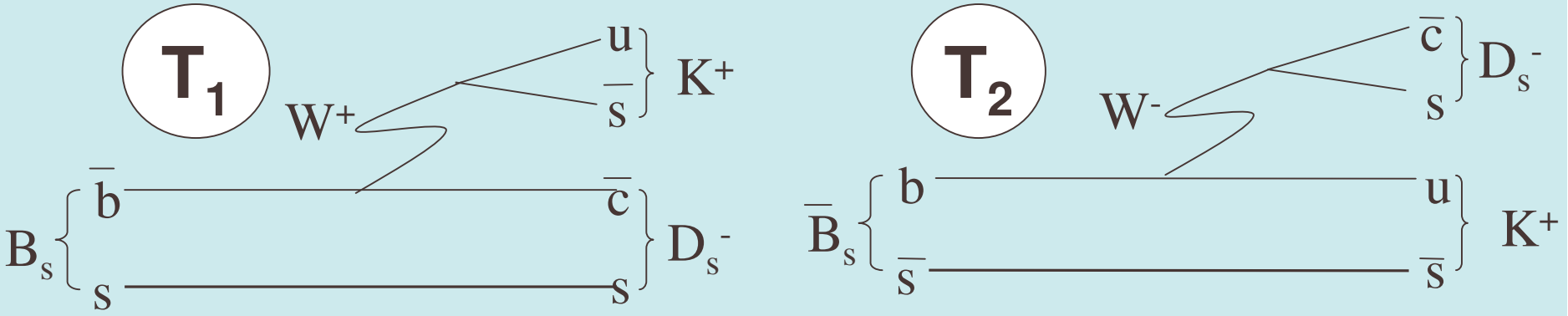
$$\eta = \bar{\eta} = 0$$

$$R_{D_s^-\pi^+}(t) \propto \frac{\left|A_{D_s^-\pi^+}\right|^2}{2} e^{-\Gamma t}\left[\cosh\frac{\Delta\Gamma t}{2} + \cos(\Delta m t)\right]$$

Can be used to measure Γ_s, $\Delta\Gamma_s$ and Δm_s

Branching ratio assumed same as $B_d \rightarrow D^- \pi^+$: 3×10^{-3}

$B_s \rightarrow D_s K$



B_s and $\bar{B}_s$ can go to same final state.

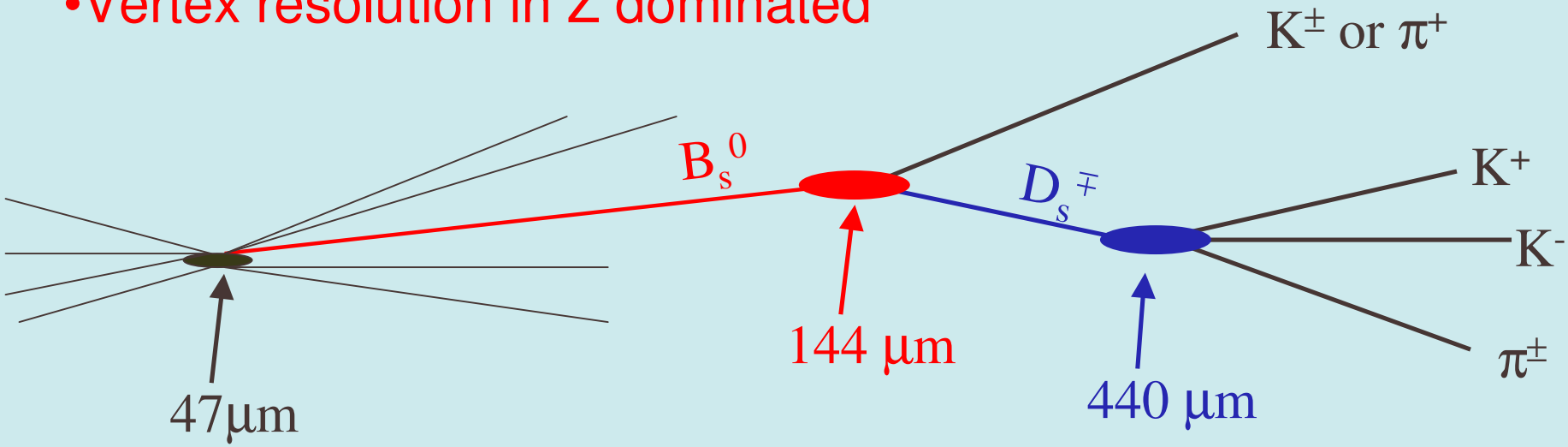
$$\arg \eta = -\gamma + 2\delta\gamma + \Delta_{T_1/T_2}$$

$$\arg \bar{\eta} = \gamma - 2\delta\gamma + \Delta_{T_1/T_2}$$

- From the two time-dependent Rates $R_{D_s^- K^+}$ and $R_{D_s^+ K^-}$ measure $\gamma - 2\delta\gamma$ and strong-phase difference Δ_{T_1/T_2}
- Branching ratio assumed same as $B_d \rightarrow D^- K^+$ and $B_d \rightarrow D_s^+ \pi^-$: 2×10^{-4} and 4.8×10^{-5}.
- Rapid oscillations make time-dependent analysis essential

$B_s \rightarrow D_s h$ Kinematics at LHCb

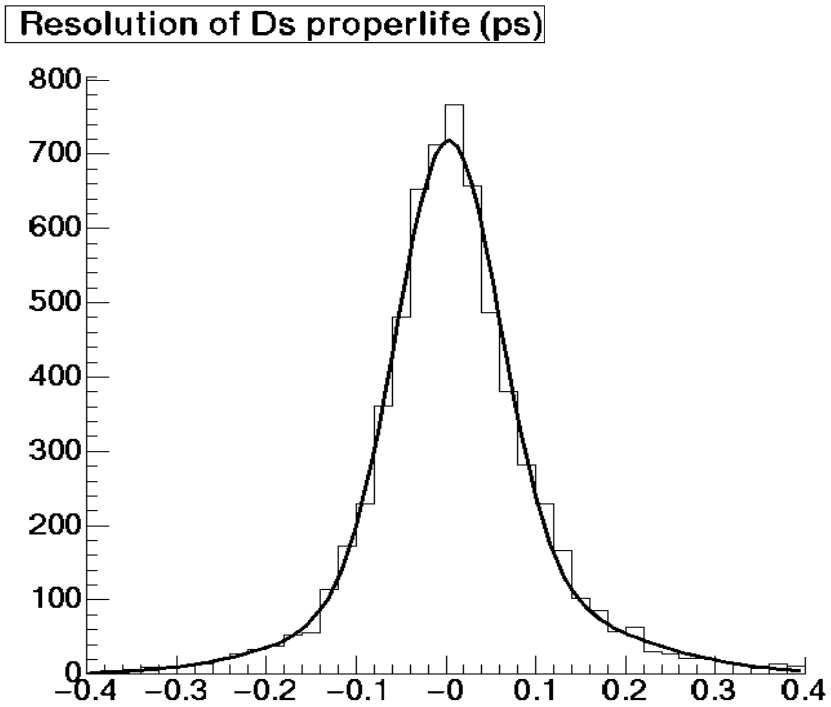
- The B_s is heavily boosted in the beam direction (Z)
- Vertex resolution in Z dominated

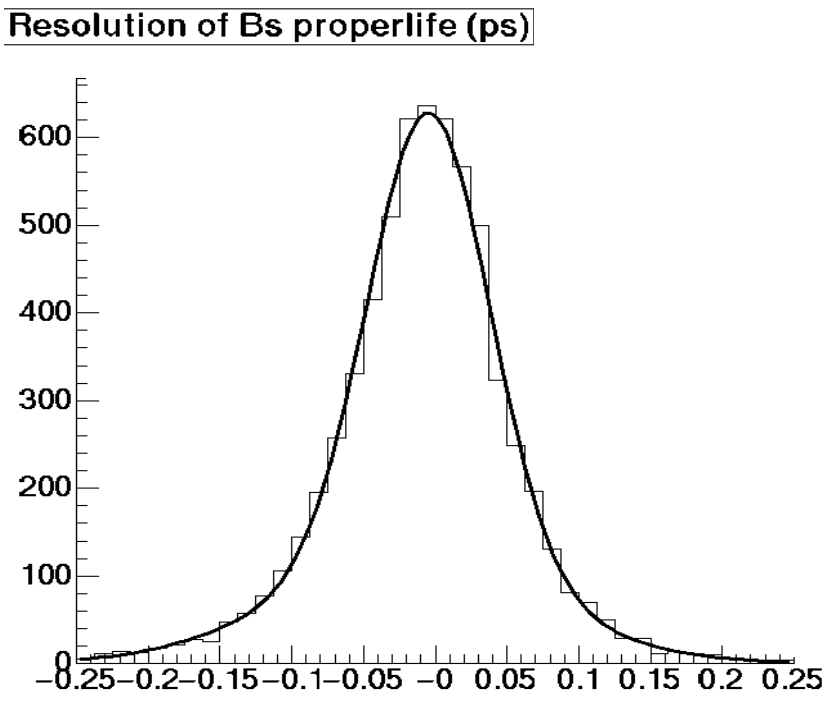


- Choose $D_s \rightarrow KK\pi$ since fully reconstructible and high branching ratio
- $D_s \pi$ acts as a background to $D_s K$ (12 – 15 times x-section)
- Very small kinematic difference between $D_s \pi$ and $D_s K$ – the K/π separation provided by the two RICH systems is critical.

Proper Time Resolution

Define proper time as: $\tau = \frac{m\mathbf{x}\cdot\mathbf{p}}{cp^2}$





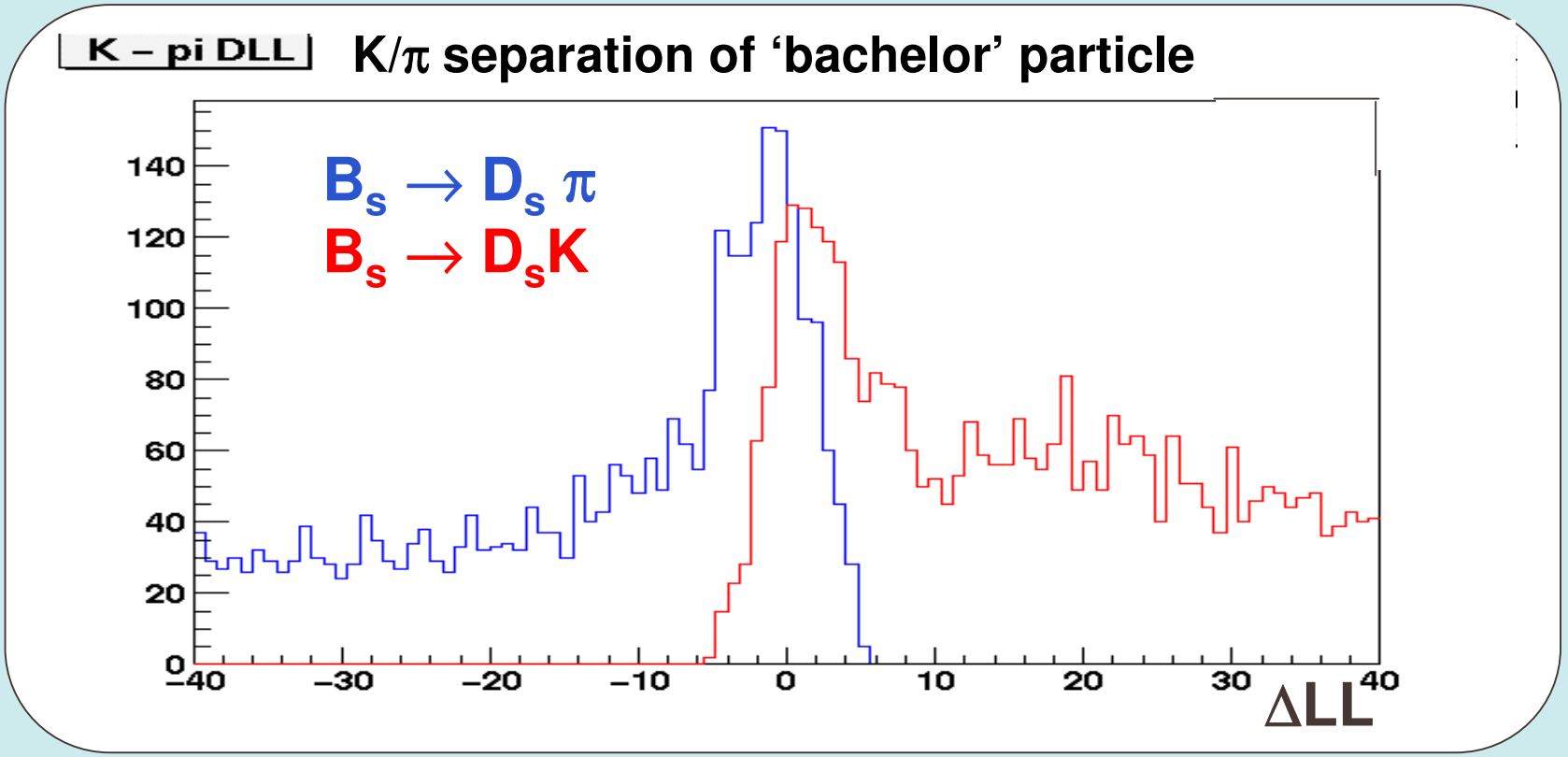
- Double Gaussian fits to reconstructed – MC truth values
- D_s core resolution of 57 fs with 78% in core
- B_s core resolution of 42 fs with 77% in core ➡ $\Delta m_s = 30\ ps^{-1}$ gives period of 209 fs – sufficient resolution

Event selection

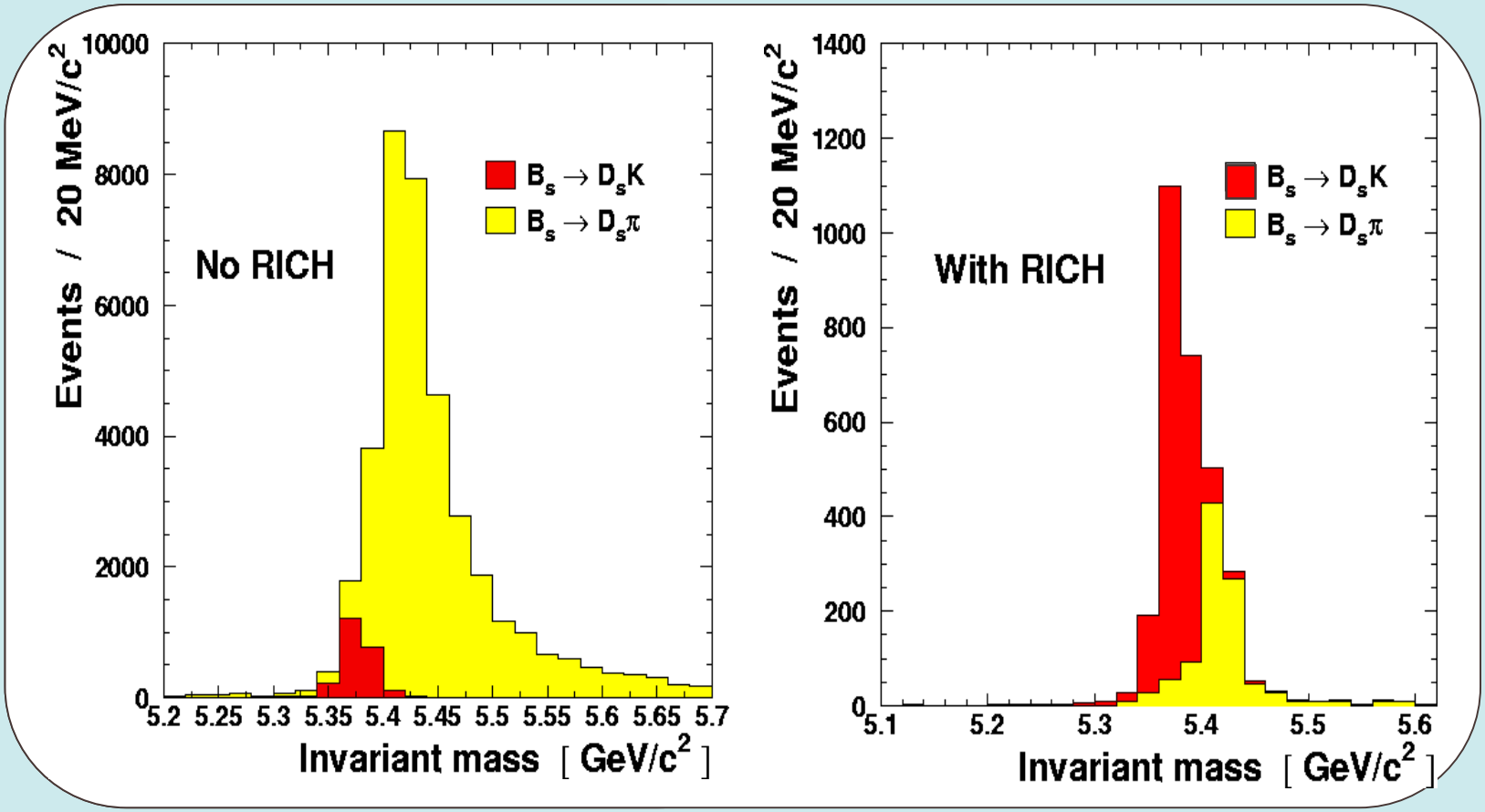
Common selection for $B_s \rightarrow D_s \pi$ and $B_s \rightarrow D_s K$

- Track impact parameter, quality and momentum
- Vertex fits
- Mass windows
- Lifetimes
- Exploit D_s resonance decays
  - Mass and angular cuts

RICH PID critical for separating the two channels



Separation of $B_s \to D_s K$ from $B_s \to D_s \pi$



Without RICH you are dead in the water

With it, can handle main background

Yields and Backgrounds

Annual number for untagged events

Signals

current selections yield:

87K $B_s \to D_s\pi$ 6.1K $B_s \to D_sK$

Specific backgrounds

D_sK pollution of $D_s\,\pi$ signal negligible

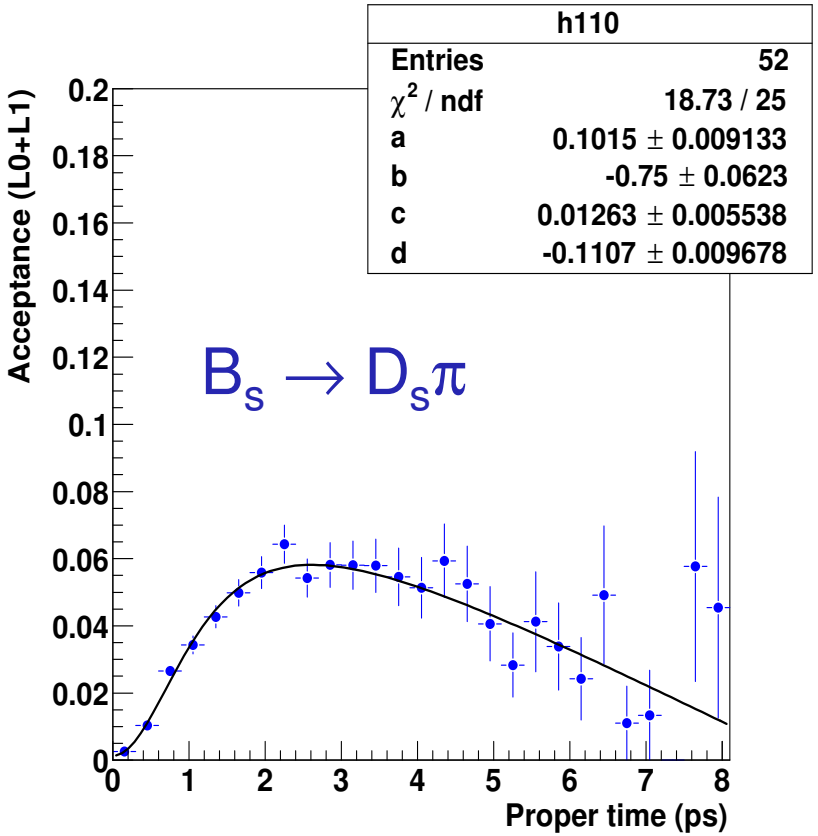
$D_s\pi$ pollution of D_sK signal B/S = [0.06,0.21] 90% CL

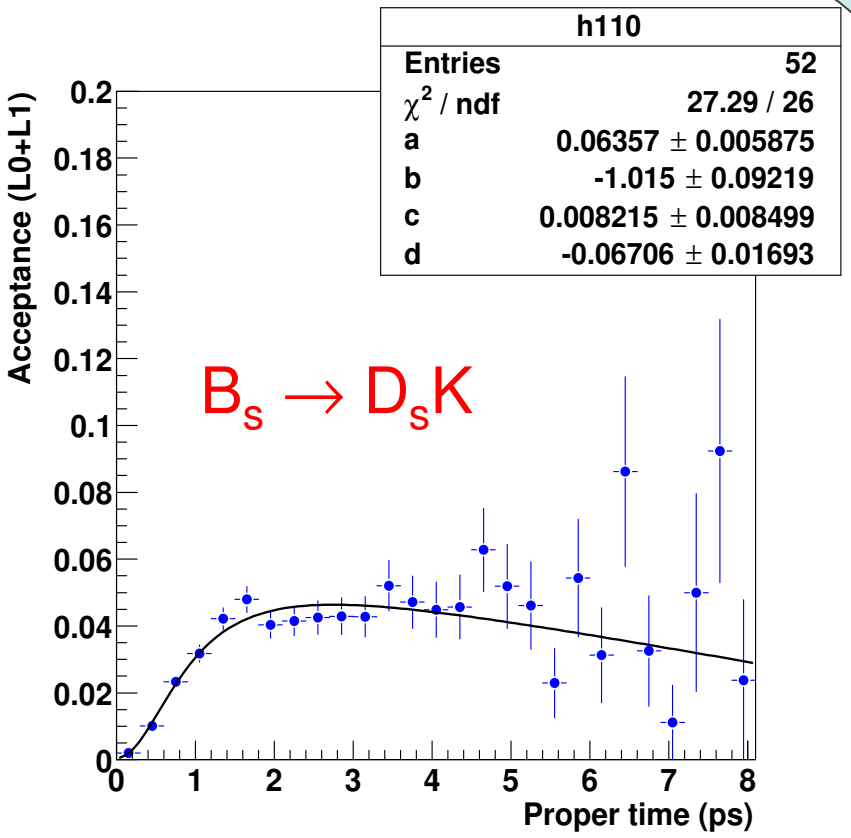
bb background

D_sK B/S = [0.0,4.2] 90% CL ⟹ zero selected in 10.2M sample

$D_s\pi$ B/S = [0.01,0.53] 90% CL

Acceptance Functions





- Short lifetimes suppressed because visible secondary vertex needed
- Large lifetimes can give large B_s impact parameter

Evaluation of Sensitivities

- Decay at some proper time t reconstructed at time t_{rec}
- Error in proper time, Δt_{rec}, from momentum and vertex resolution, determined event by event

- $R_+(t)$ is rate for specific initial state to required final state e.g. $B_s \rightarrow D_s^- \pi^+$
- $R_-(t)$ is rate for CC of specific initial state to required final state e.g. $\bar{B}_s \rightarrow D_s^- \pi^+$
- So: $R_{sig}(t) = (1-\omega_{tag})\, R_+(t) + \omega_{tag}\, R_-(t)$
- Background rate $R_{bkg}(t) = \Gamma e^{-\Gamma t}$

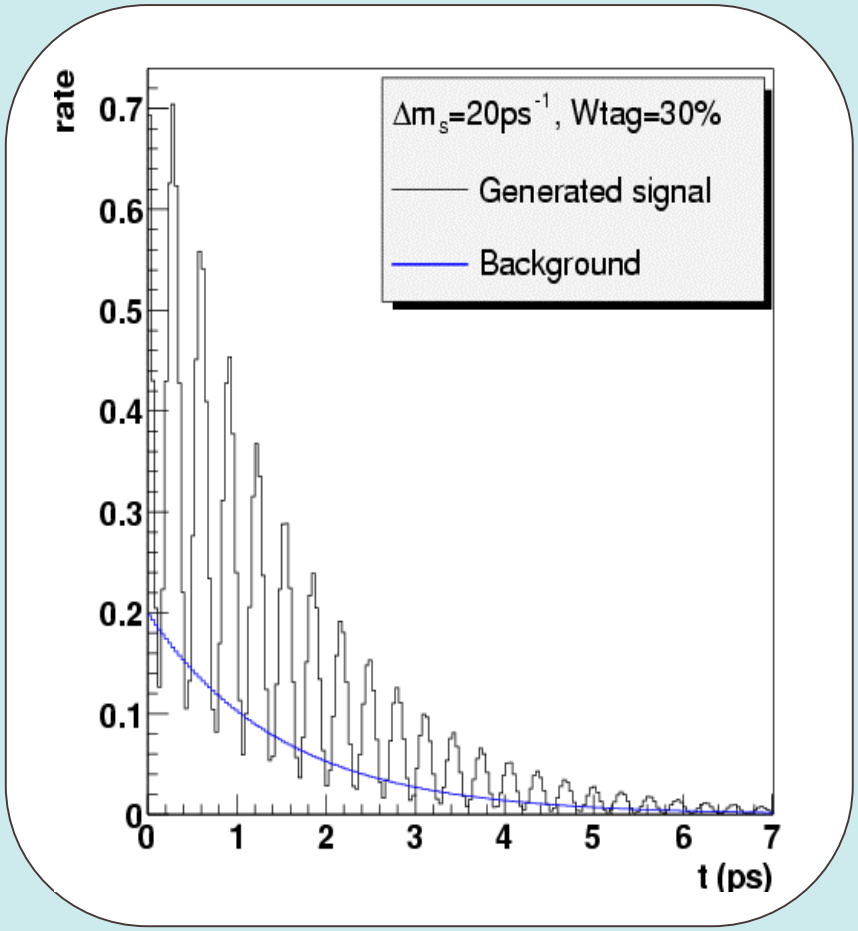
Then $$P_i(t_{rec}) = \int_0^\infty [(1-f)R_{sig}(t) + fR_{bkg}(t)]a(t)s(t_{rec}-t)dt$$

Where $$s(t_{rec}-t) = \frac{1}{\sqrt{2\pi}\Delta t_{rec}} e^{-(t_{rec}-t)^2/2(\Delta t_{rec})^2}$$

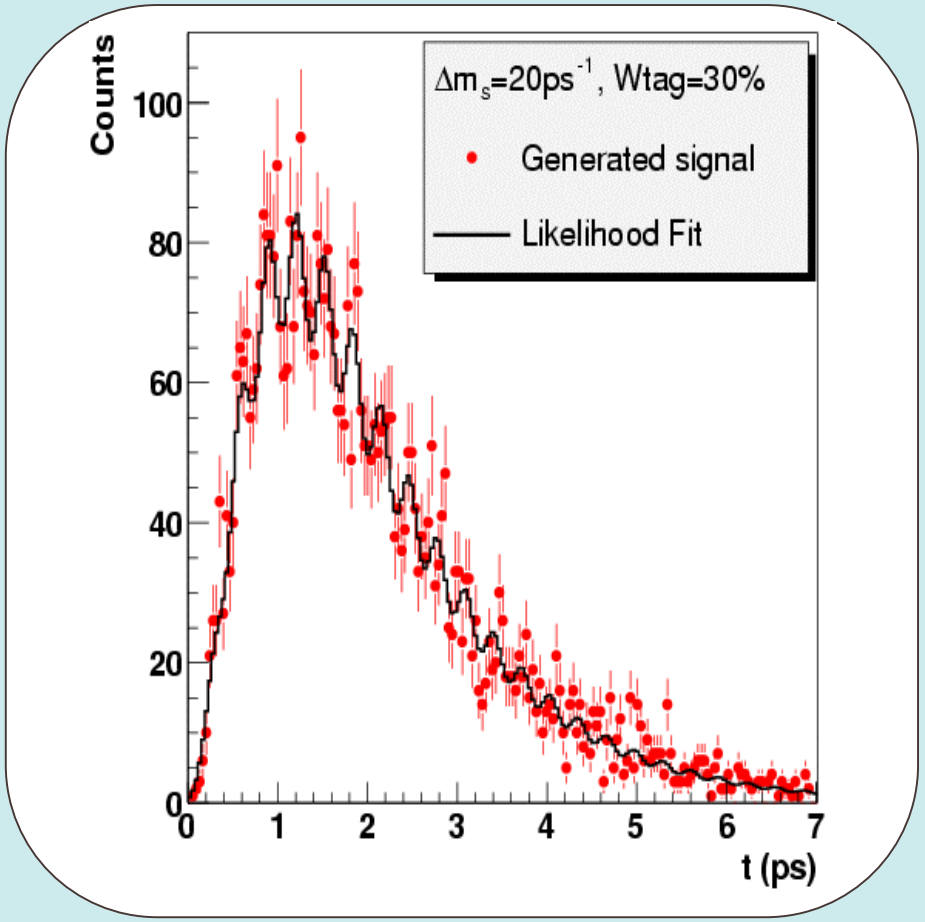
Likelihood $$L = \prod_i^{N_{evt}} P_i$$ ⇒ **Can extract Γ_s, $\Delta\Gamma_s$, Δm_s, η, $\bar{\eta}$, arg(η) and arg($\bar{\eta}$)**

Examples

Initial pure B_s decaying to $D_s^- K^+$ at time t.



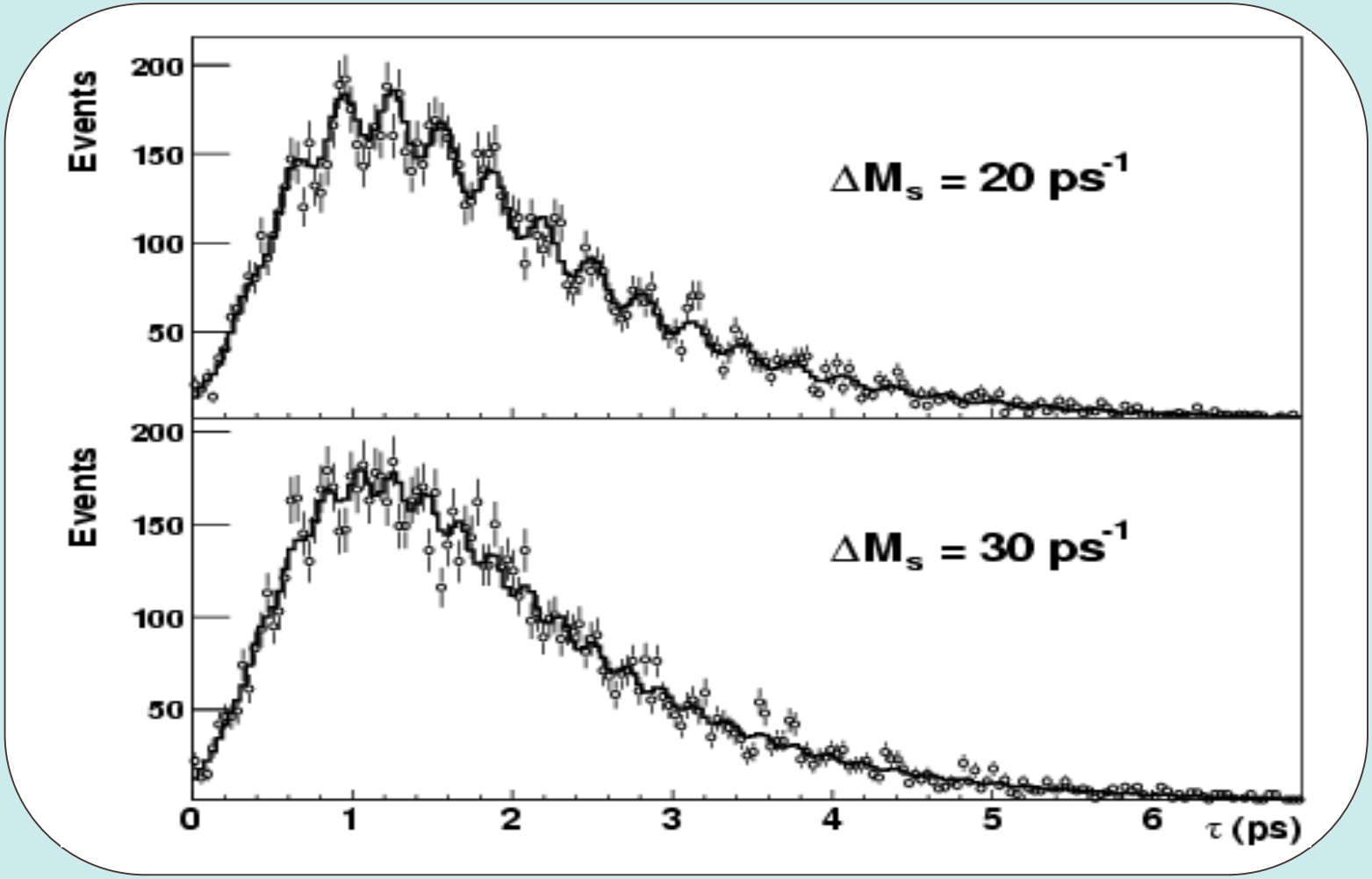
No smear and perfect acceptance



Realistic picture with ω_{tag} = 0.3

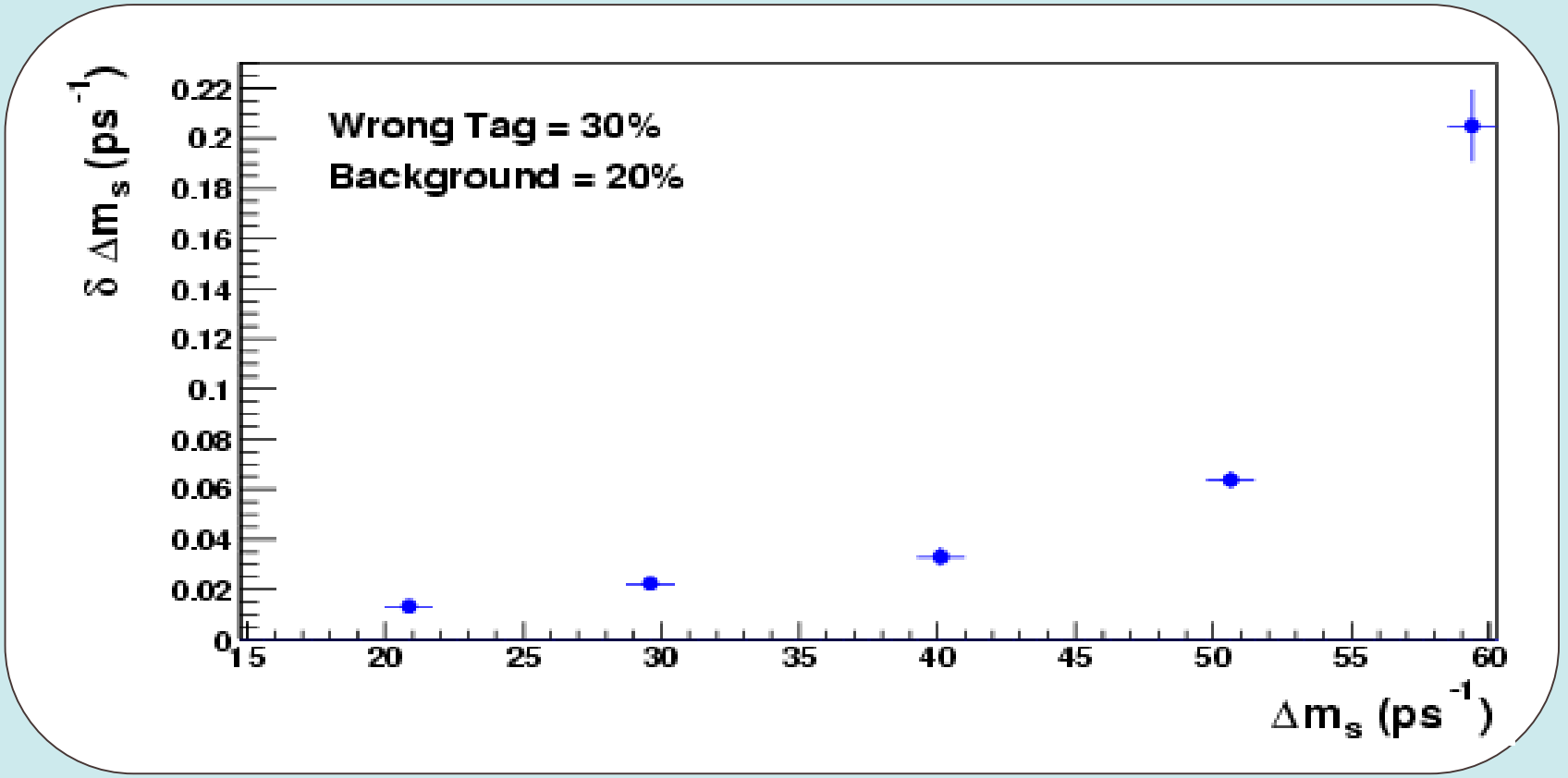
Examples

$B_s \rightarrow D_s \pi$ with two different Δm_s

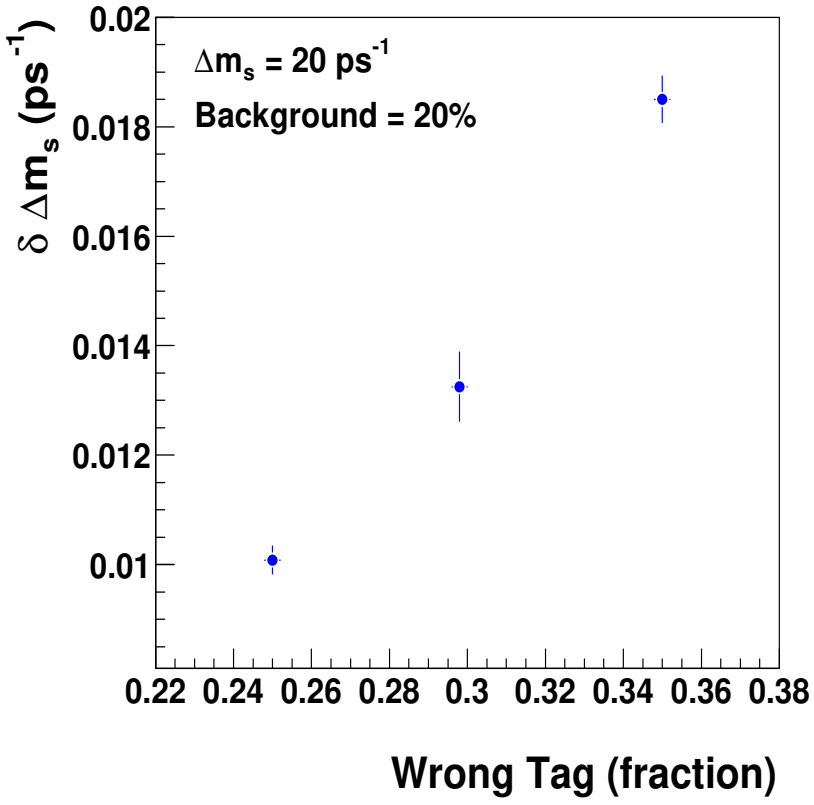


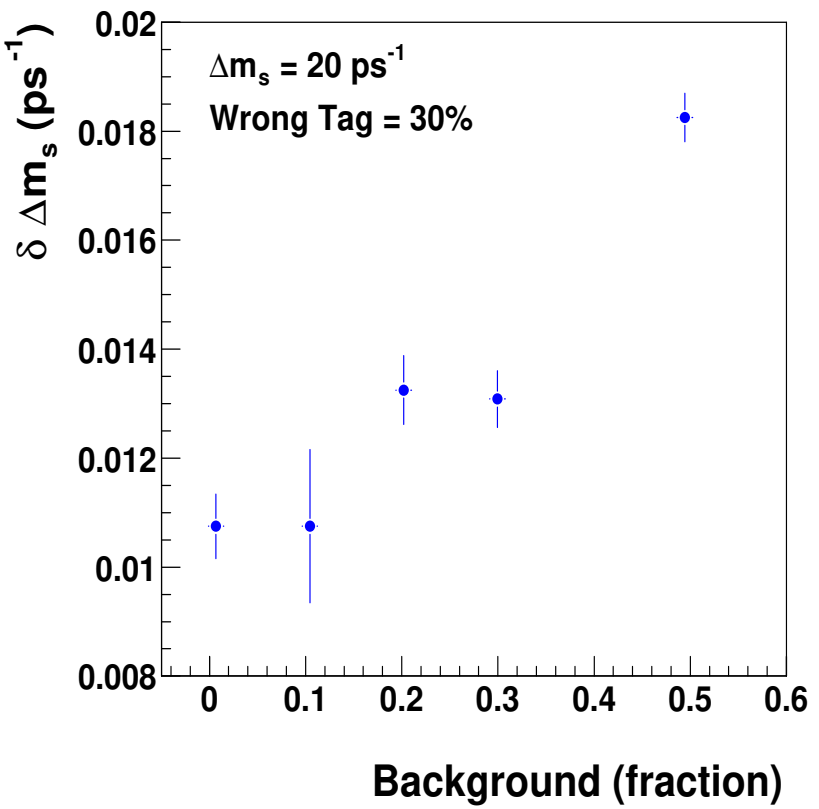
Sensitivity to Δm_s
From $B_s \rightarrow D_s\pi$

- Standard Model predicts : $\Delta m_s = 14.3 - 26\ ps^{-1}$ and $\Delta\Gamma_s / \Delta m_s = (4 \pm 2)\times 10^{-3}$
- Error on Δm_s irrelevant: Sensitive up to $\Delta m_s = 60\ ps^{-1}$



Sensitivity to tagging and Background Level



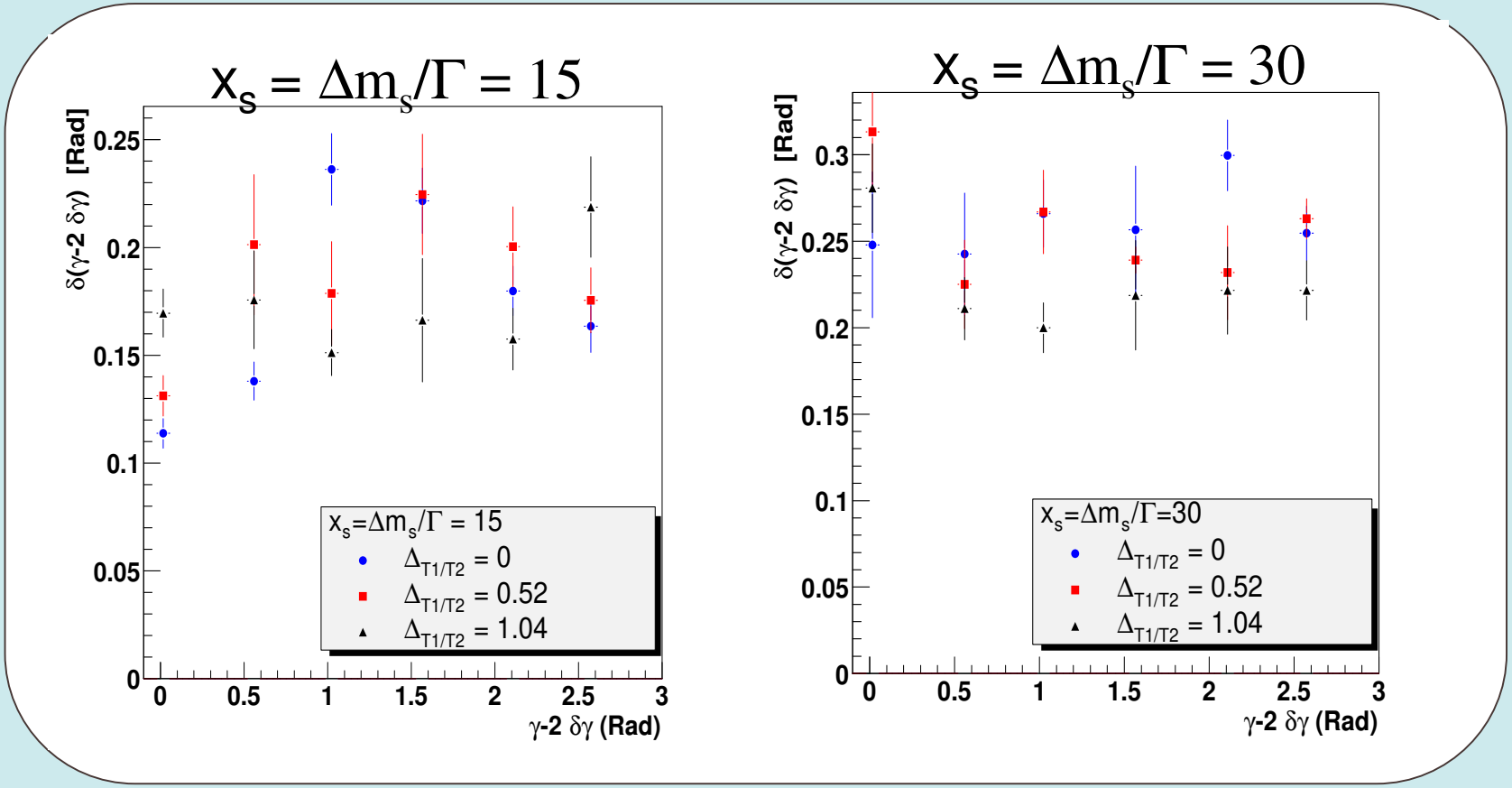


- Nominal ω = 30% and f = 20%
- Linear dependence, but $\sigma(\Delta m_s)$ largely irrelevant anyway

Sensitivity to $\gamma - 2\delta\gamma$
From $B_s \rightarrow D_s K$

Different values of strong phase difference:

$\Delta_{T_1/T_2} = 0$ $\Delta_{T_1/T_2} = 0.5$ $\Delta_{T_1/T_2} = 1.0$



Sensitivity only weakly dependent on Δ_{T_1/T_2}

Summary

- $\delta(\Delta m_s)/\Delta m_s < 1\%$ for $\Delta m_s < 60\ ps^{-1}$: Good sensitivity up to this point
- $\gamma - 2\delta\gamma$ only weakly dependent on strong phase difference

$\Delta_{T_1/T_2} = 0.6$		
$\gamma - 2\delta\gamma$ (rad)	$\Delta m_s = 20$	$\Delta m_s = 30$
0	0.26	0.36
0.6	0.23	0.48
1.2	0.31	0.26

- **LHCb capable of measuring B_s mixing and γ to high precision**
- $B_s \rightarrow D_s K$ gives very clean extraction of γ