Bs mixing at LHCb

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- Introduction
- Features of the analysis
- First results & expectations

Neutral B Meson Mixing

Two-state mixing system:

- "heavy" and "light" mass eigenstates
- $B\ (\bar{b}s)$ and $\overline{B}\ (b\bar{s})$ weak eigenstates:

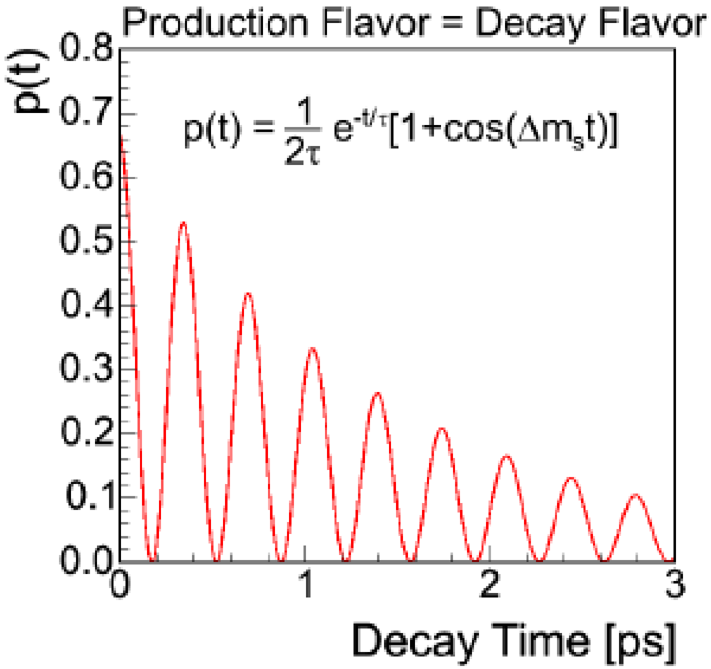
  $$|B_s\rangle = \frac{1}{\sqrt{2}}(|B_{s,H}\rangle + |B_{s,L}\rangle)$$

  $$|\overline{B}_s\rangle = \frac{1}{\sqrt{2}}(|B_{s,H}\rangle - |B_{s,L}\rangle)$$

- B_H and B_L may have different mass and decay width
  - $\Delta m = M_H - M_L$
  - $\Delta\Gamma = \Gamma_H - \Gamma_L$
- Solution in proper time ($\Delta\Gamma = 0$)

  $$P(t)_{B_s \to B_s} = \frac{1}{2\tau} e^{-t/\tau}(1 + \cos \Delta m_s t)$$

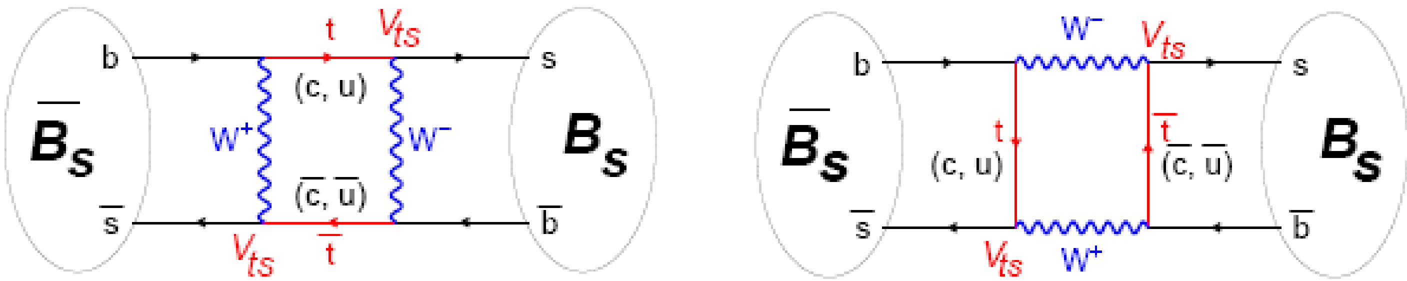
  $$P(t)_{B_s \to \overline{B}_s} = \frac{1}{2\tau} e^{-t/\tau}(1 - \cos \Delta m_s t)$$



Standard Model Prediction

CKM Matrix: transformation from mass to weak quark eigenstates

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



- Access to fundamental SM Parameters:

$$\Delta m_s = \frac{G_F^2 M_W^2 \eta S(m_t^2/m_W^2)}{6\pi^2} m_{B_s} f_{B_{B_s}}^2 |V_{ts}^* V_{tb}|^2$$

- Hadronic uncertainties cancel in ratio: $\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}$

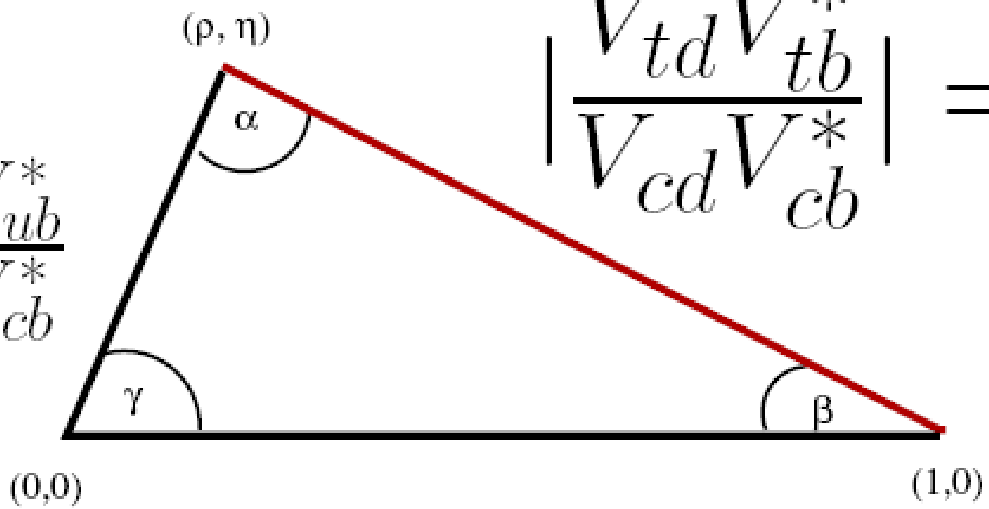
improved lattice QCD: ξ = 1.210 $^{+0.047}_{-0.035}$ (hep/lat-0510113)

Unitarity Triangle

CKM Matrix Unitarity Relation

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

$$\frac{V_{ud}V_{ub}^{*}}{V_{cd}V_{cb}^{*}}$$

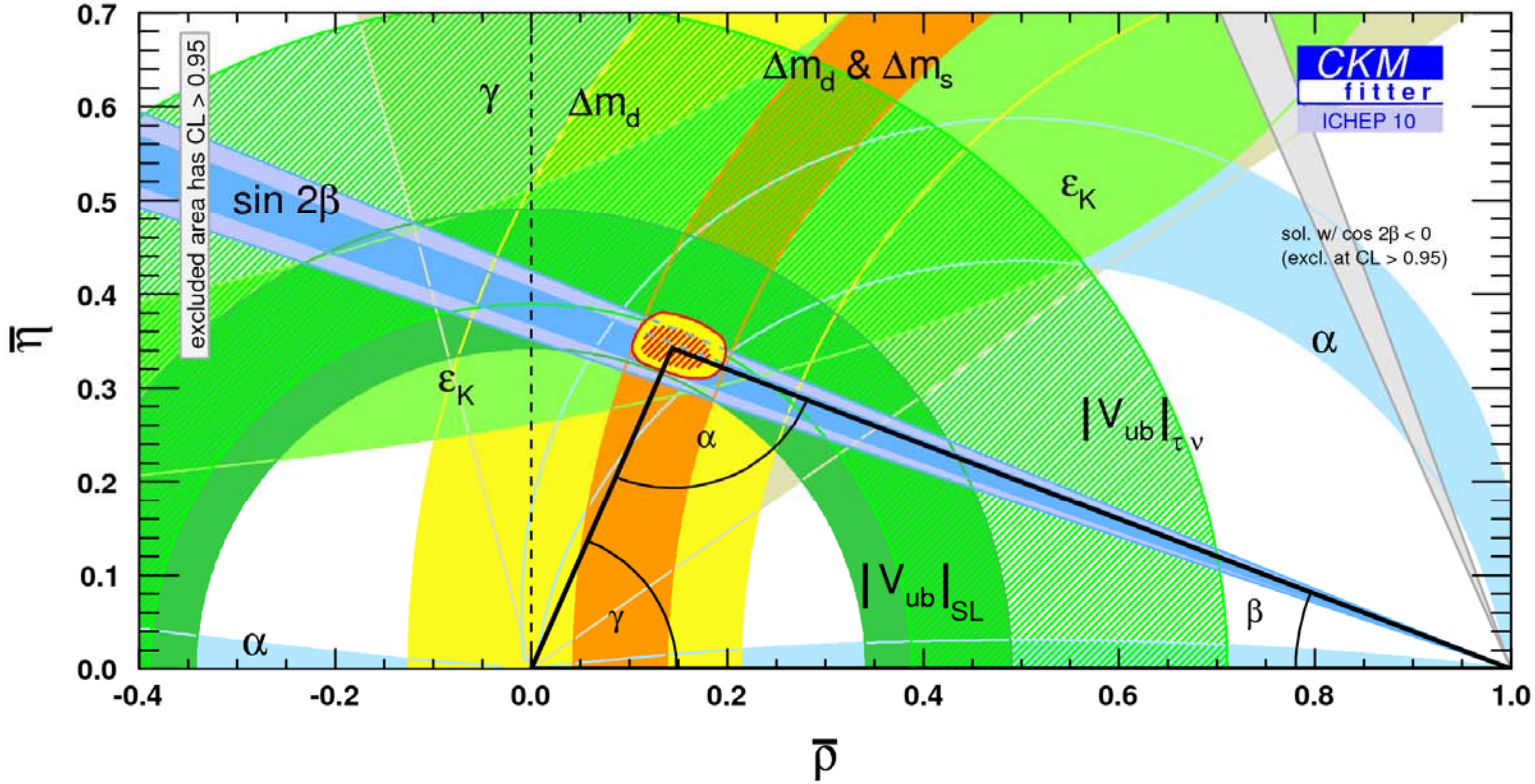


$$\left|\frac{V_{td}V_{tb}^{*}}{V_{cd}V_{cb}^{*}}\right| = \frac{|V_{td}|}{|V_{ts}|} \times \frac{1}{|V_{cd}|}$$

$$\frac{\Delta m_d}{\Delta m_s}$$

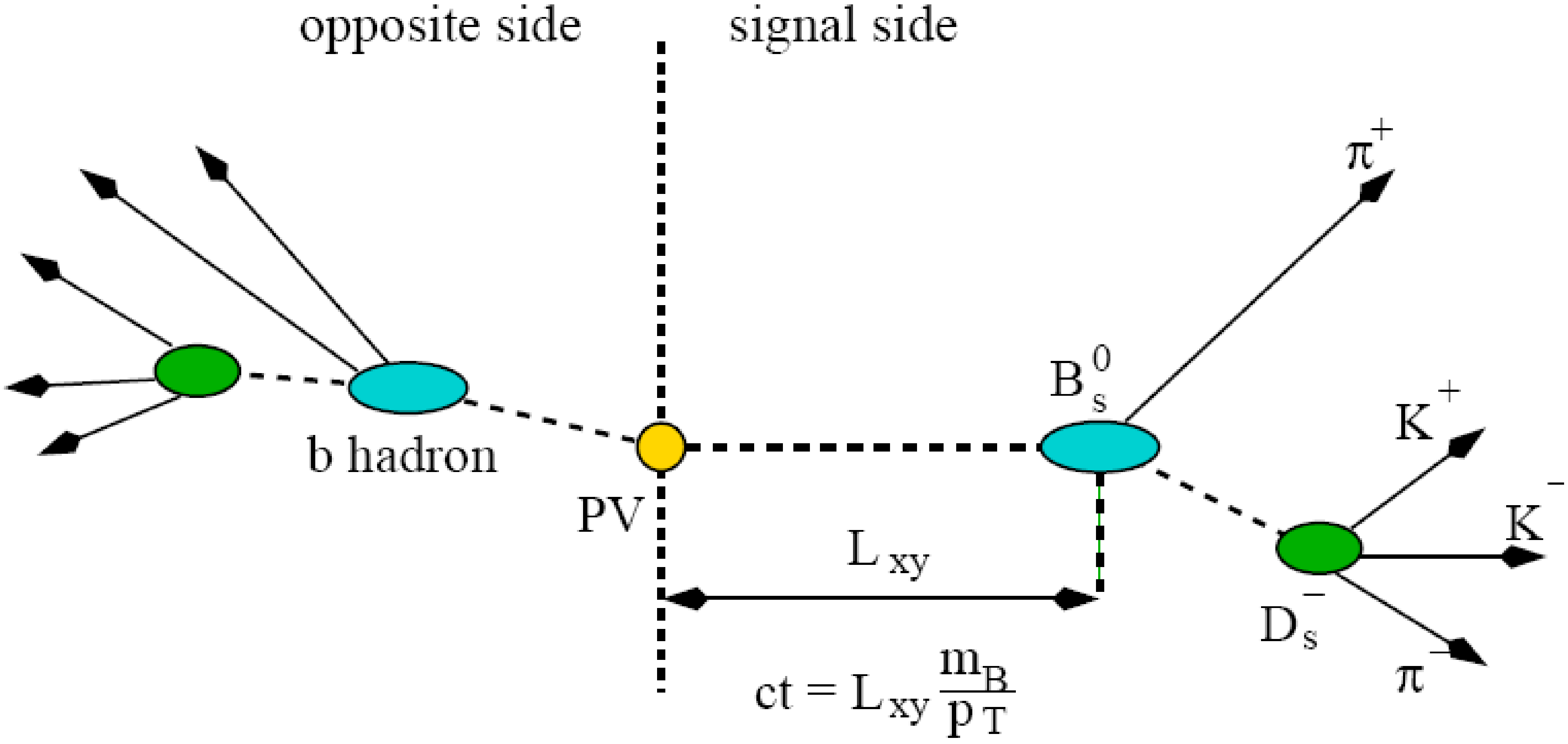
Unitarity Triangle Fit

- Many measurements from kaon and bottom physics constraint the triangle $\longrightarrow$ indirect measurements of Δm_s



Δm_s = 17.77 ± 0.10 (stat) ± 0.07 (syst) ps^{-1} CDF (Run II)

$B_s - \bar{B}_s$ Mixing Analysis



1) B_s selection & reconstruction
2) Measurement of proper decay time ct & ct resolution
3) Flavor tagging (main challenge at hadron colliders)

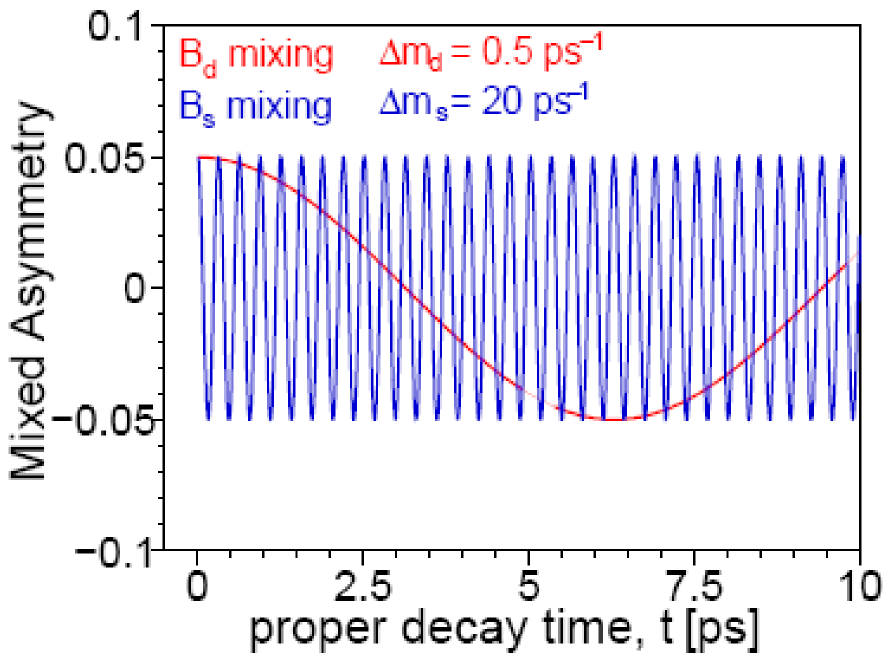
Why is it so difficult?

B_s Mixing is very very fast!

Challenges:

- High vertex resolution
- High momentum resolution
- Large statistics
- Good tagging

Very complex analysis!



$$\text{significance} = \sqrt{\frac{S\epsilon D^2}{2}}\frac{S}{S+B}e^{-\frac{(\Delta m_s \sigma_{ct})^2}{2}}$$

ϵD^2: tagging performance (efficiency ϵ and dilution D = 1-2*P_{mistag}),

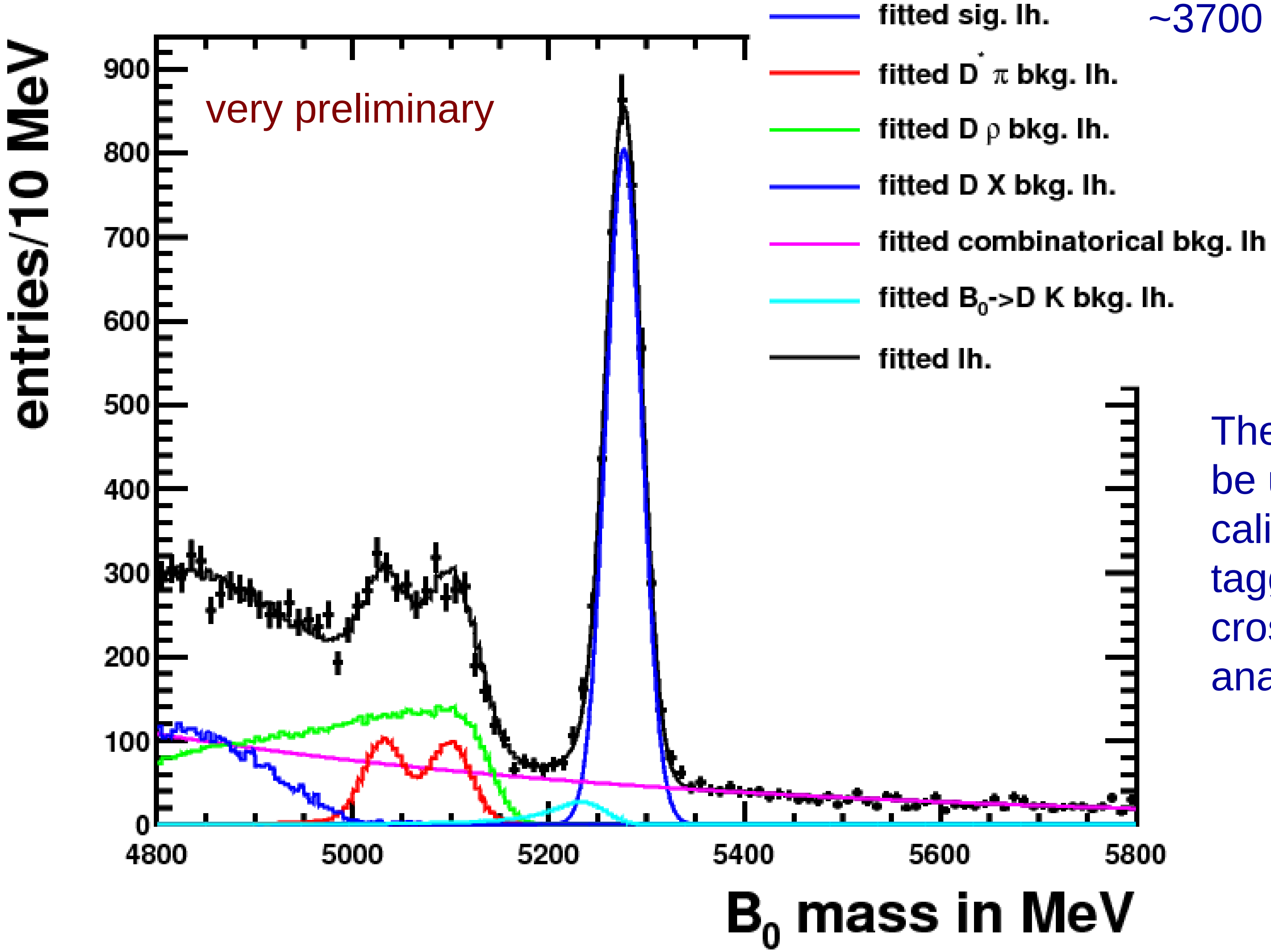
$\sigma(ct)$: proper time resolution, for high Δm_s, $\sigma(ct)$ is crucial!

S,B: signal and background yields

Signal Reconstruction

$$\sqrt{\frac{S\epsilon D^2}{2}\frac{S}{S+B}e^{-\frac{(\Delta m_s \sigma_{ct})^2}{2}}}$$

Selection & reconstruction: B_d -> D π

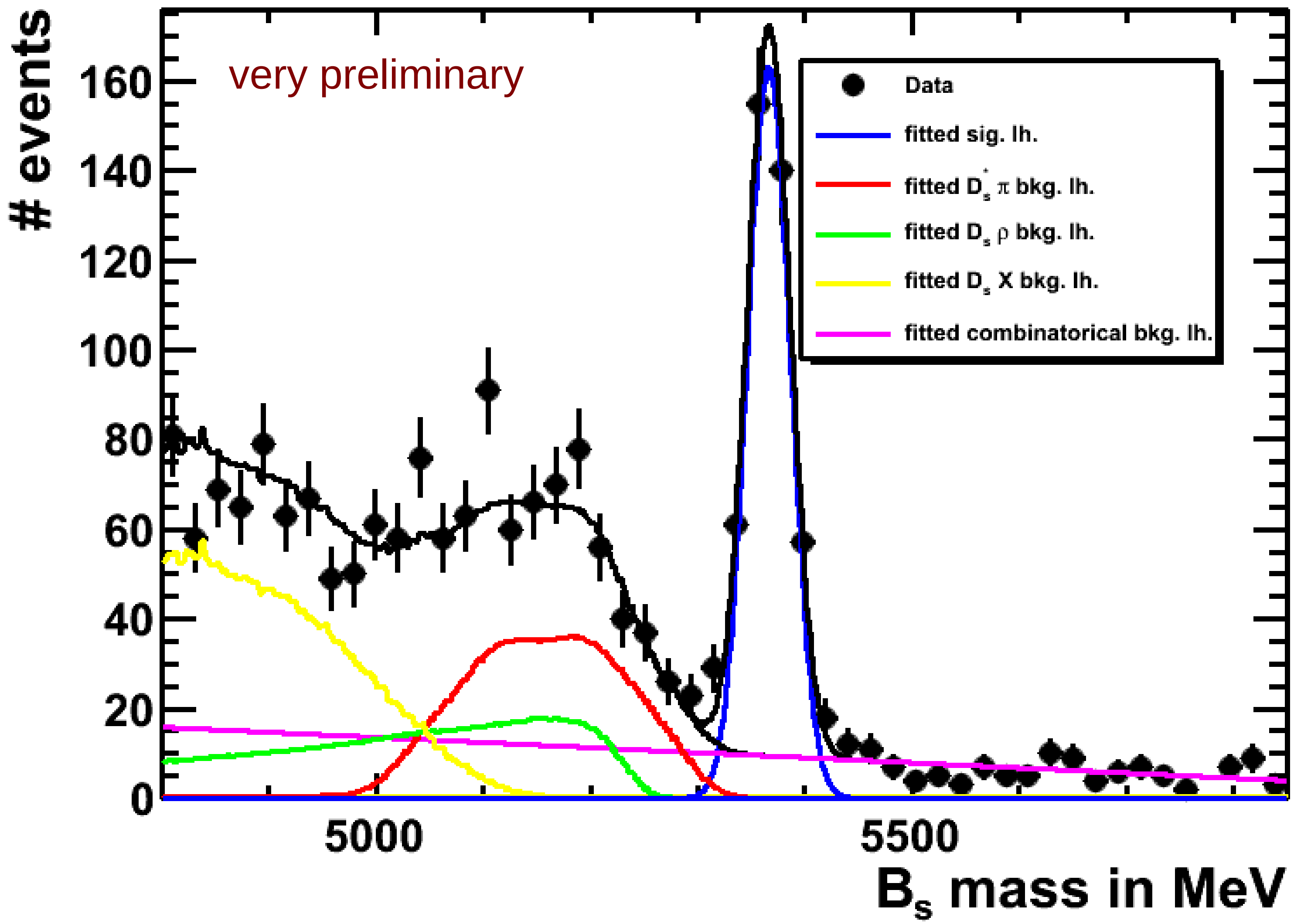


~3700 signal events

These events can be used to calibrate the flavor tagger, and to cross-check the analysis procedure

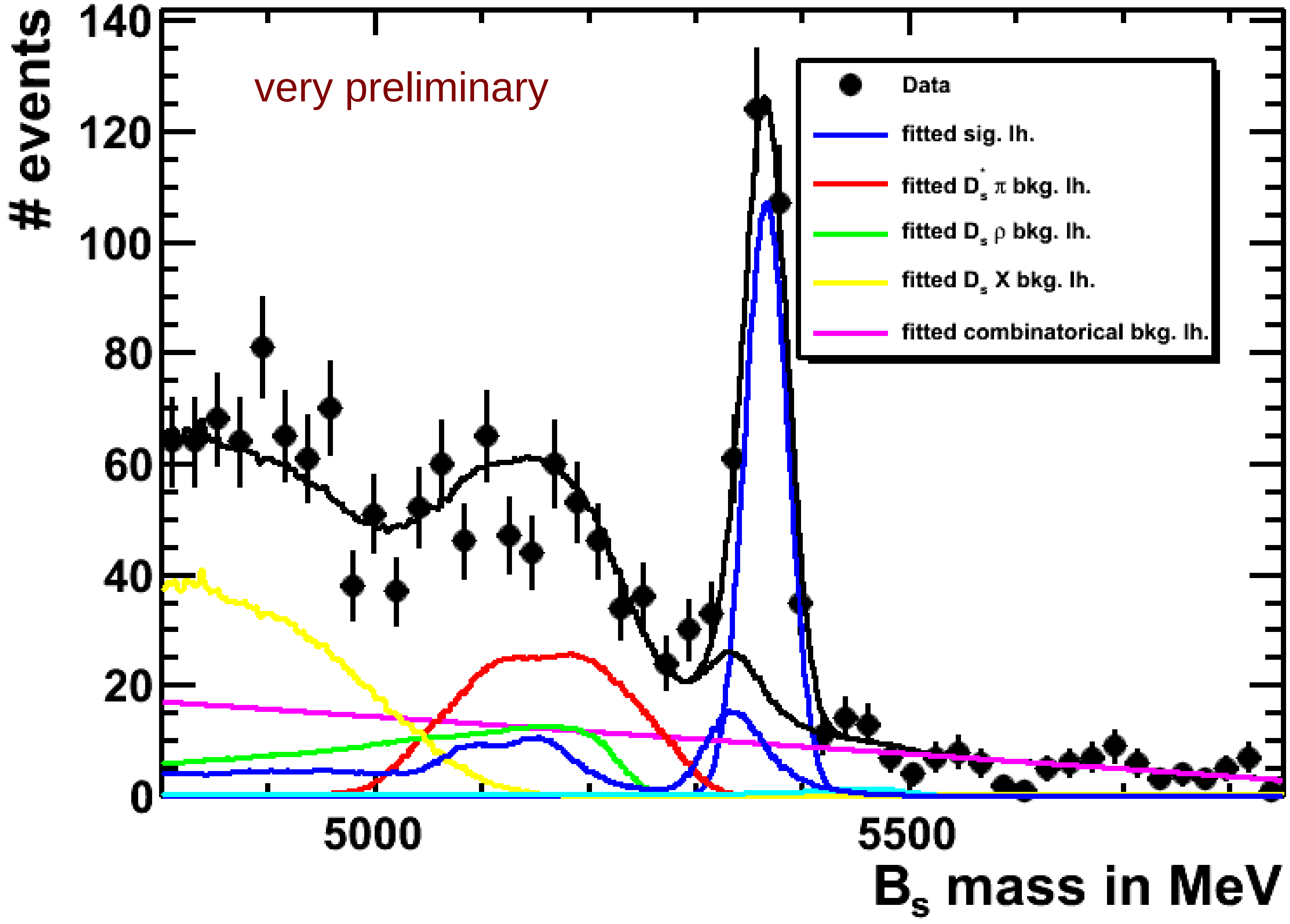
$B_s \to D_s \pi$, $D_s \to \phi\pi$

~400 signal events



B_s -> D_s π , D_s -> K^*K

~300 signal events



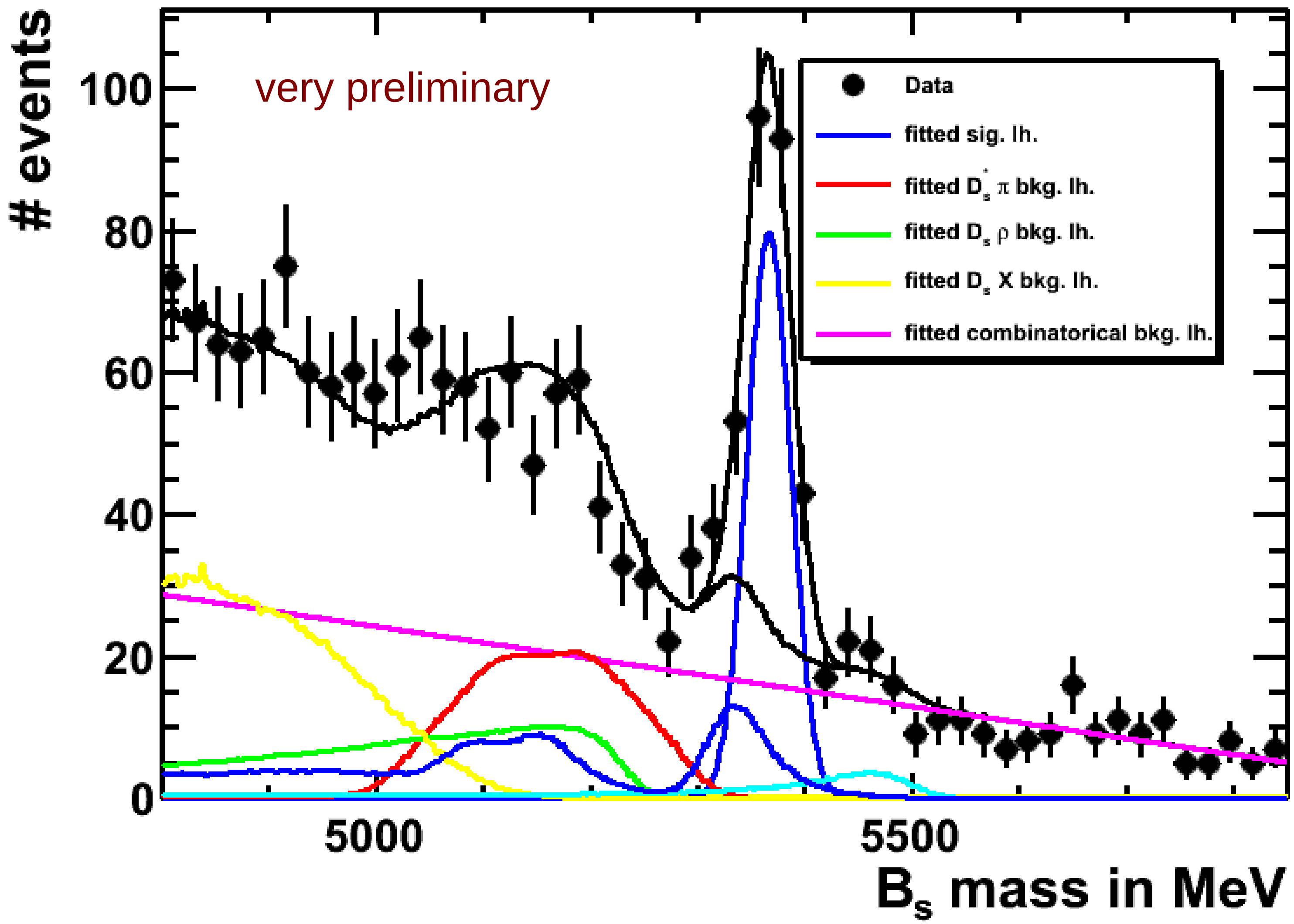
misID background:

B_d->Dπ,

D->K$\pi\pi$

B_s -> D_s π , D_s -> KKπ (rest)

~200 signal events



misID background:

Λ_b->$\Lambda_c\pi$,

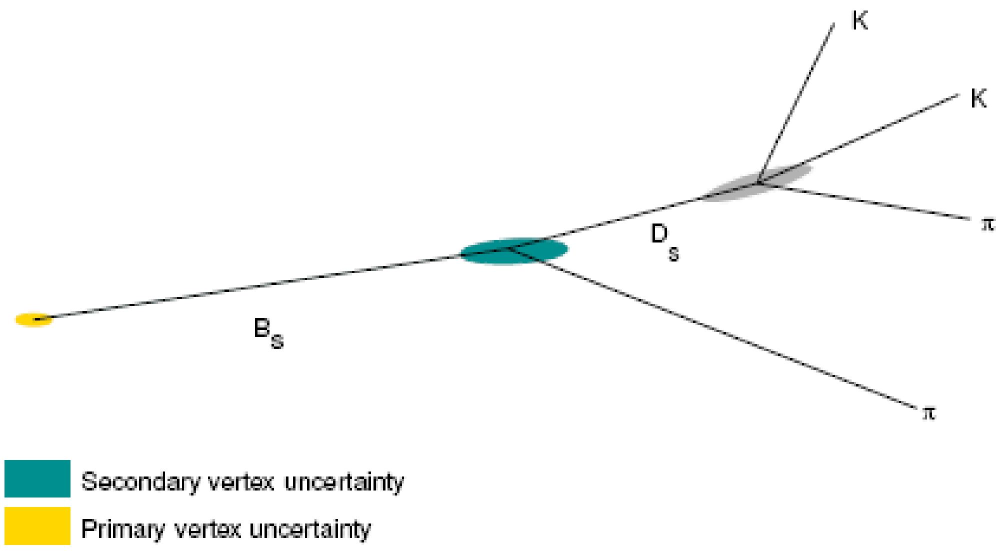
Λ_c->pKπ

Proper Decay Time Resolution

$$\sqrt{\frac{S\epsilon D^2}{2}\frac{S}{S+B}e^{-\frac{(\Delta m_s\sigma_{ct})^2}{2}}}$$

Proper time resolution

- consider decay $B_s \longrightarrow D_s(KK\pi)\pi$

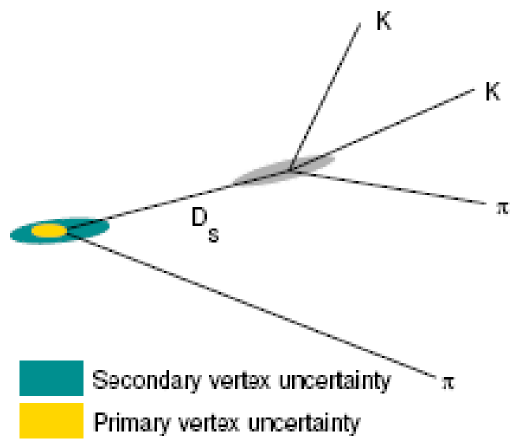


- proper time: $ct = \vec{d} \cdot \frac{\vec{p}}{|\vec{p}|} \frac{m}{|\vec{p}|}$
  - $\vec{d}$ is distance from PV to SV, $\vec{p}$ is B_s momentum
- σ_{ct} has contributions from:
  - SV position uncertainty (usually biggest contribution)
  - momentum resolution
  - PV position uncertainty

Proper time resolution

Need to mimic B_s decay signature such that we know ct_{true} without MC. . .

- to measure σ_{ct}, use a prompt D_s plus a π from the PV
  - form a pseudo-B_s, know $ct_{true} = 0$

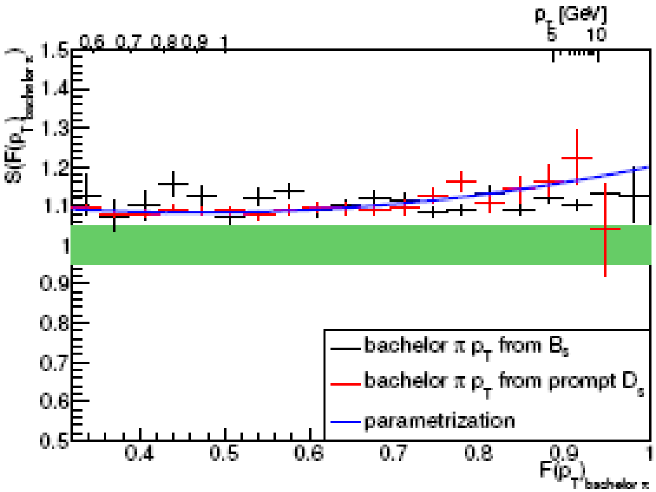


- proper time resolution scaling factors can be measured in data with ±5% accuracy
  - correct for p and p_T of bachelor π and B_s and D_s vertex probabilities
  - after correction, scaling factors flat in all variables (at the given level of accuracy)

Proper time resolution

- most influential variables seem to be:
  - bachelor π p and p_T
  - B_s and D_s vertex probabilities
- 5 parametrisation steps

- scale factors are determined from prompt D_s sample
  - parametrisation for next step is shown in blue
- for control reasons, proper time pull for true B_s is shown as well (black)
- ±5% band is shown in green

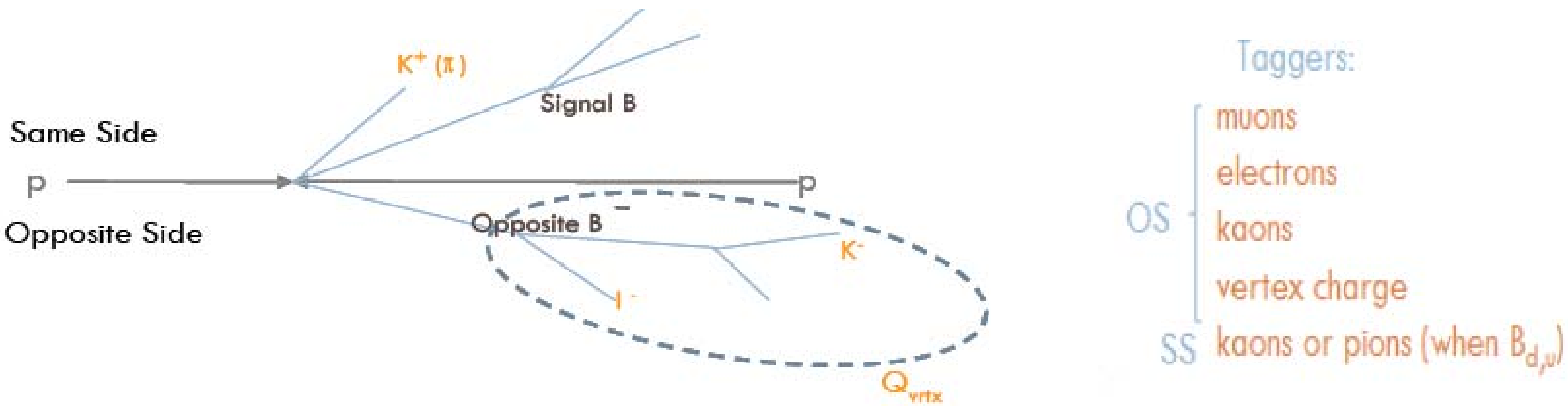


Flavor Tagging

$$\sqrt{\frac{S\epsilon D^2}{2}\frac{S}{S+B}}e^{-\frac{(\Delta m_s \sigma_{ct})^2}{2}}$$

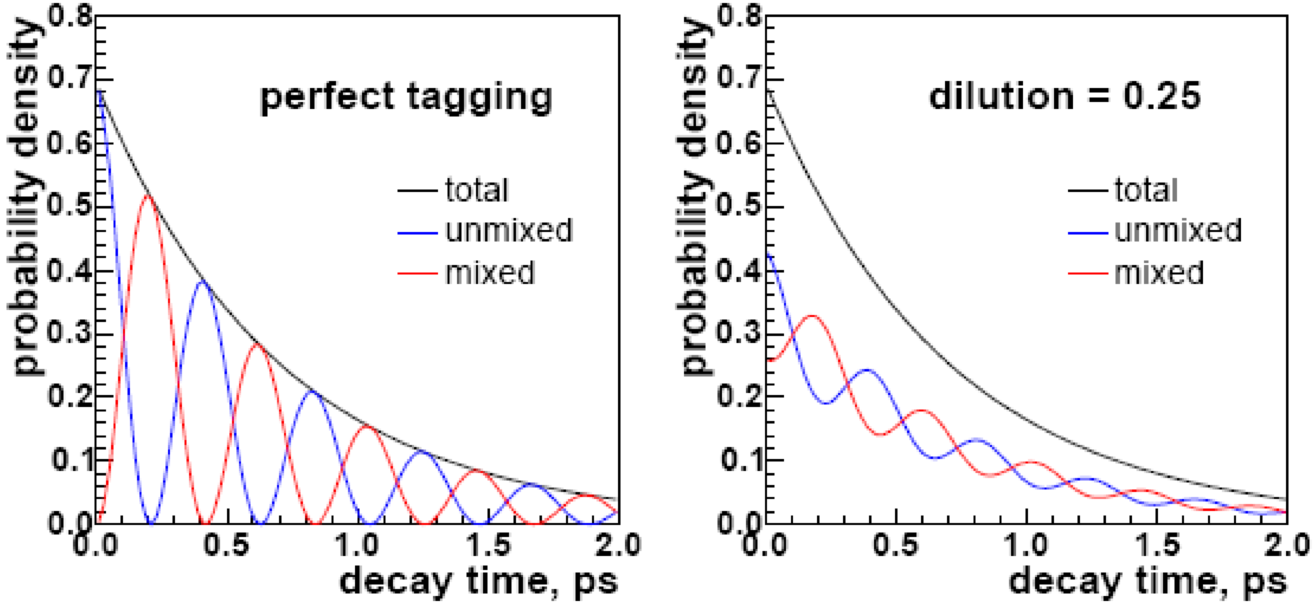
Flavor tagging

- Need to determine Bs flavor at production time.
- Two methods: Same Side (Kaon flavor) and Opposite Side (other B flavor)
- Two key parameters: efficiency (ε) and dilution factor ($D=1-2\omega$)
- Effective tagging power proportional to εD^2
- OST is calibrated on data using self-tagged B decays: $B^{\pm}>D^{*+}\mu\nu$, $J/\Psi K^{+}$
- SST calibration: using double tag method



Effect of Imperfect Tagging

Dilution dampens the observed oscillation!



$\mathcal{D}$ = 25% $\longrightarrow$ 62.5% of the events are correctly tagged.

$$\mathcal{A}(t) \equiv \frac{N(t)_{mixed} - N(t)_{unmixed}}{N(t)_{mixed} + N(t)_{unmixed}} = \mathcal{D}\cos(\Delta m_s t)$$

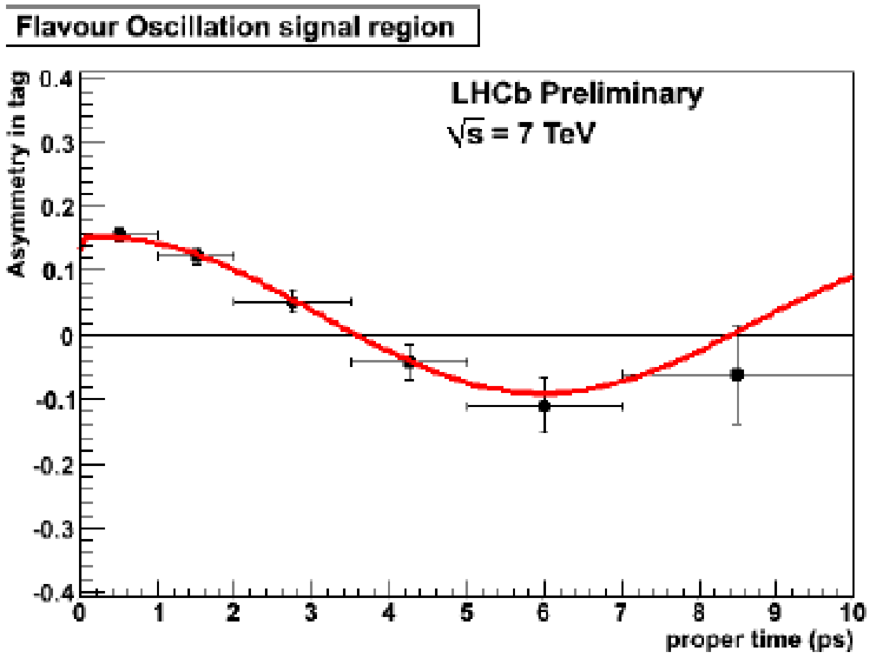
(in this example: Δm_s = 2.5 ps $^{-1}$)

Flavor Tagging

Expected Tagging performance:
(MC simulation)

algorithm	ϵD^2 [%]
OS kaon	1.25 ± 0.07
OS muon	0.76 ± 0.05
OS electron	0.38 ± 0.04
OS vtx charge	1.09 ± 0.07
all OS*	3.32 ± 0.15

Uncalibrated tagging algorithms applied to $B^0 \rightarrow D^{*-}(D^0\pi^-)\mu^+\nu$ evts :



Observed amplitude proportional to dilution

$\varepsilon D^2 = 1.73 \pm 0.20\%$

~50% of expected performance.
Calibration & tuning ongoing.

Sensitivity estimation

Toy MC:

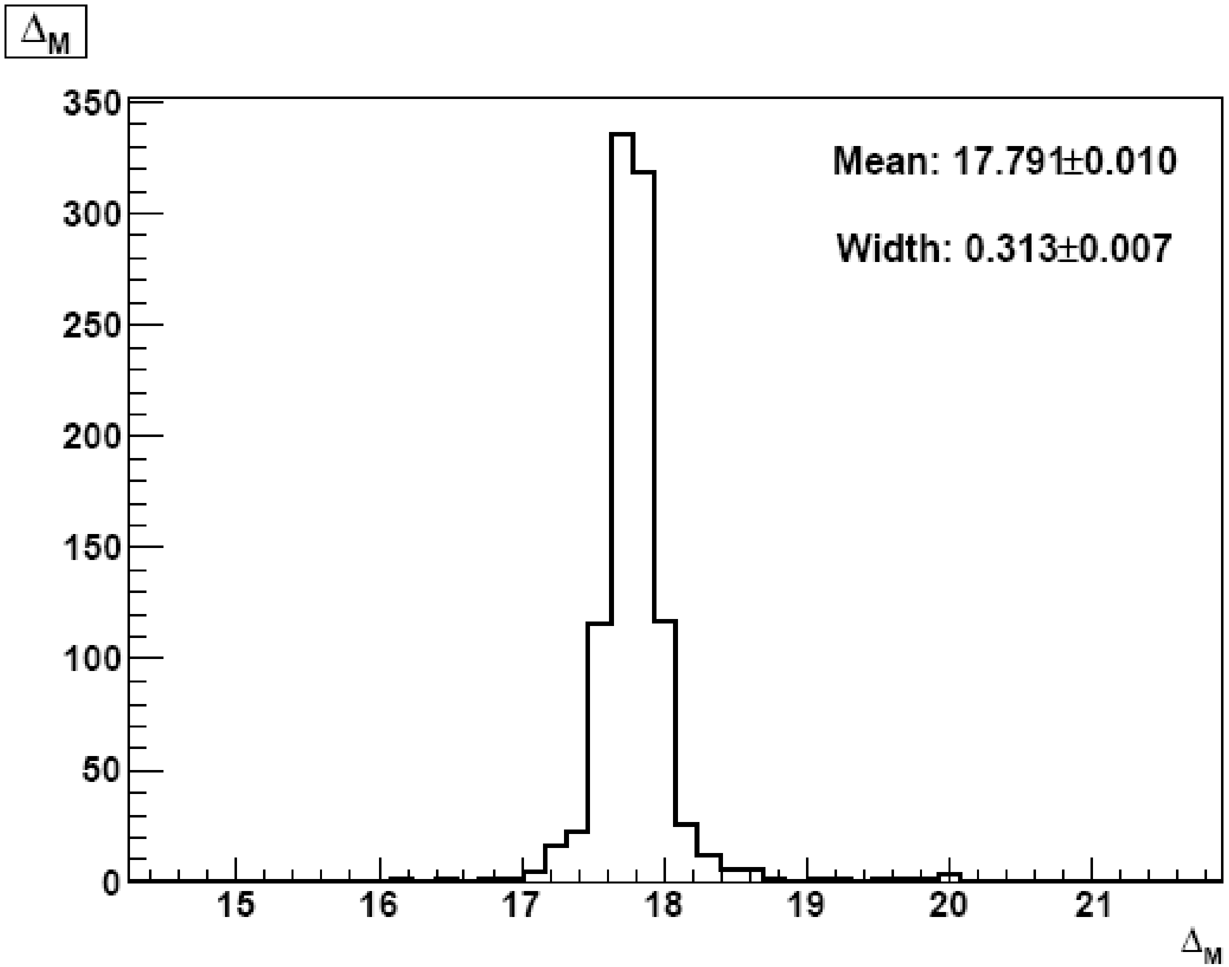
1000 events,

εD^2 = 3.5%,

σ_t = 52 fs

Result:

$\sigma(\Delta m_s)$ = 0.3 ps^{-1}

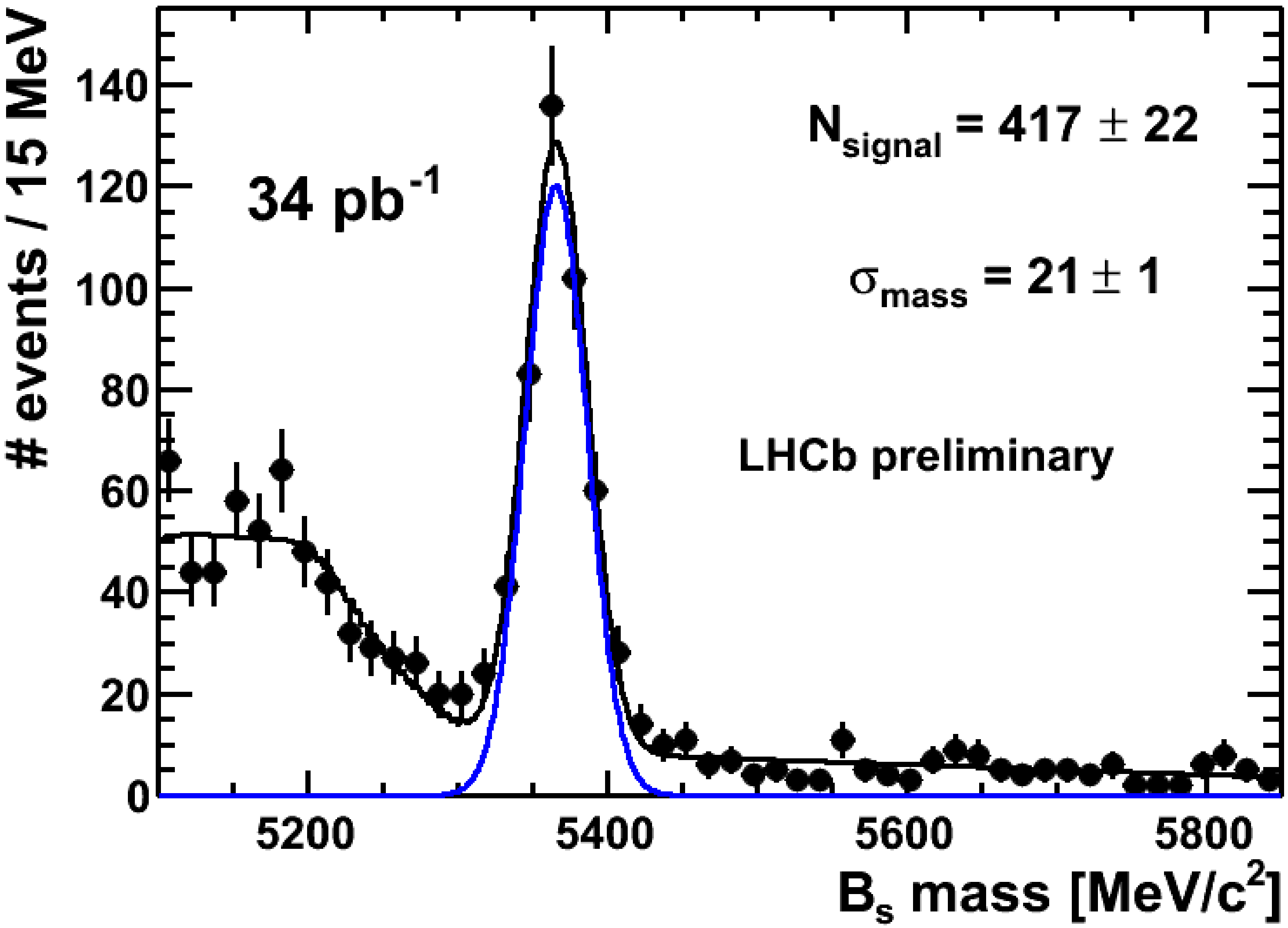


Conclusion

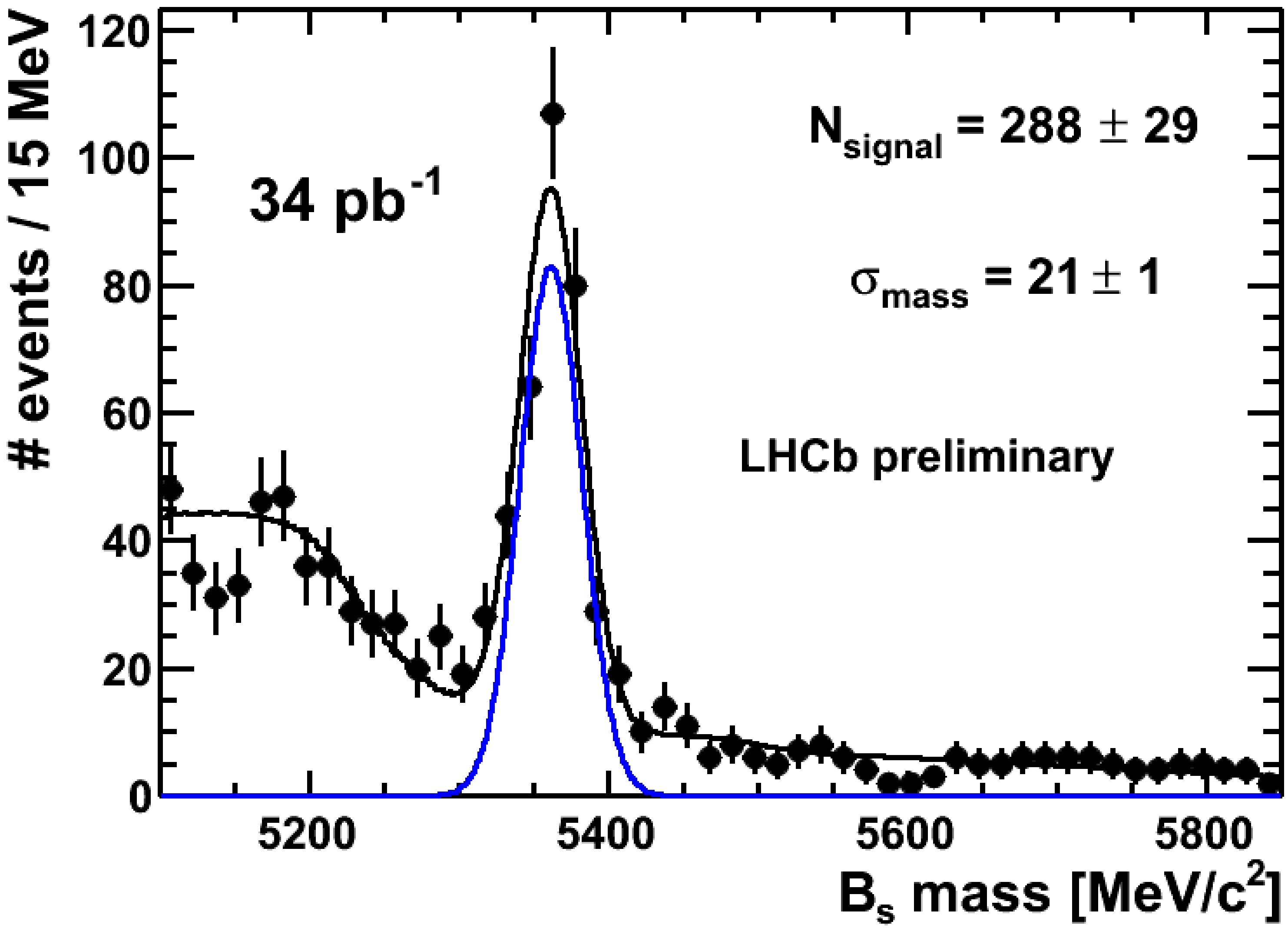
- LHC and the LHCb experiment perform well.
- LHCb has recorded 37 pb^{-1} of high-quality data in 2010.
- ~4000 $B_d \to D\pi$ and ~1000 $B_s \to D_s\pi$ events have been observed.
- This data should allow a measurement of the Bs mixing.

Backup

B_s -> $D_s\ \pi$, D_s -> $\phi\pi$



$B_s \to D_s\pi$, $D_s \to K^*K$



$B_s \to D_s\,\pi$, $D_s \to KK\pi$ (rest)