Studies on B hadron production, spectroscopy and decays at CMS

Kruger 2012

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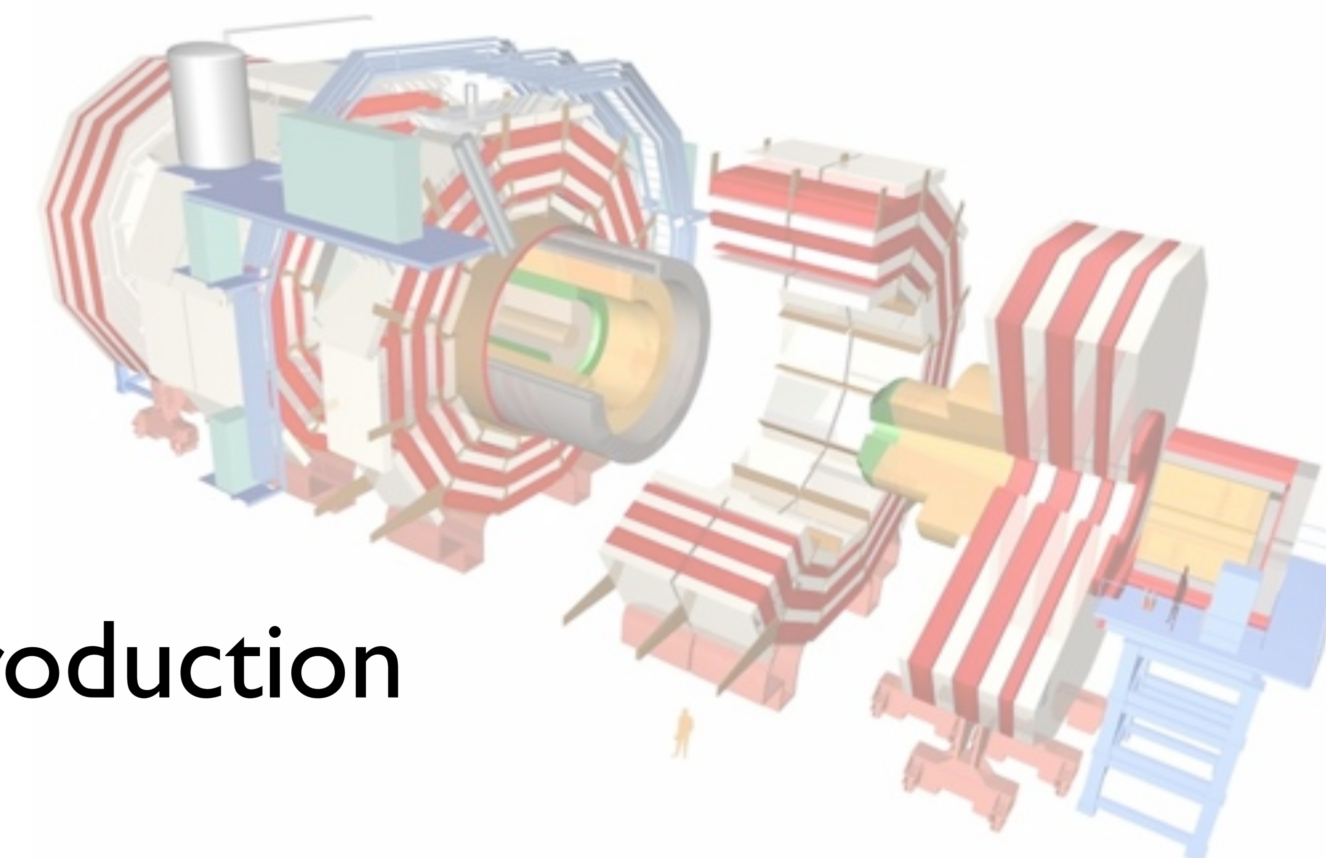
On behalf of CMS collaboration

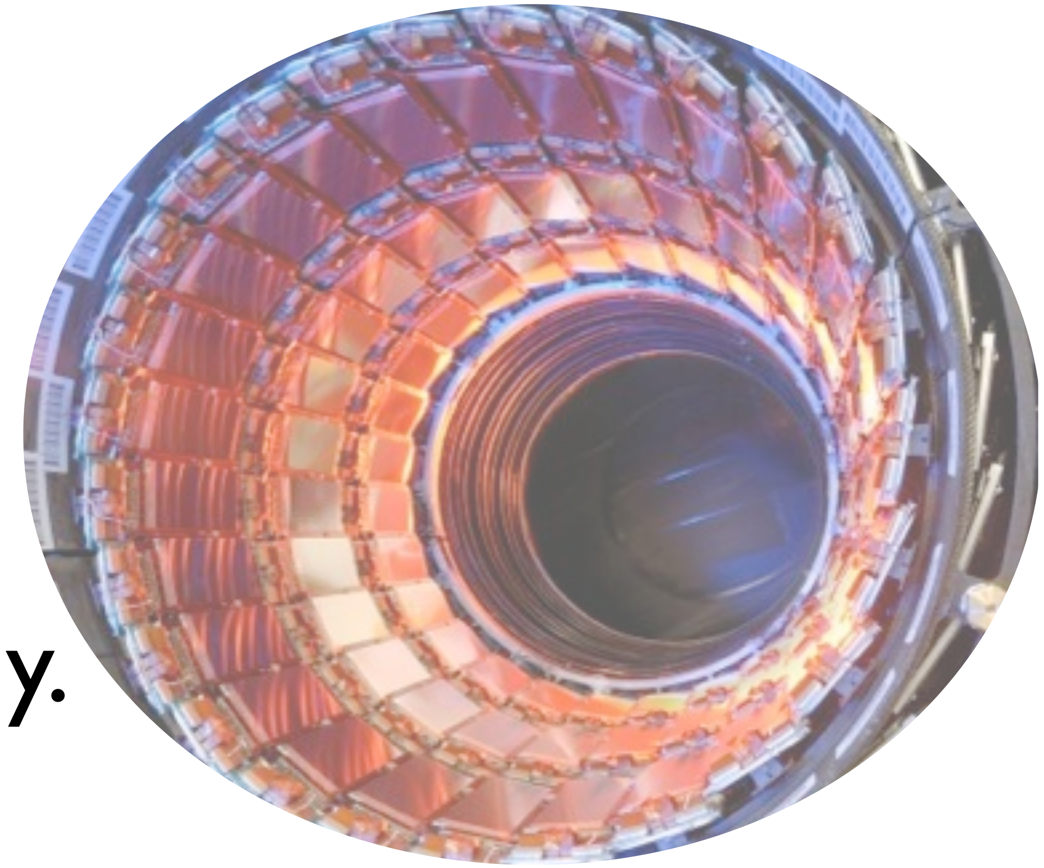
Outline



- Introduction
- B-Hadron Production
- Λ_b lifetime
- B_s lifetime difference ($\Delta\Gamma_s$)
- Summary

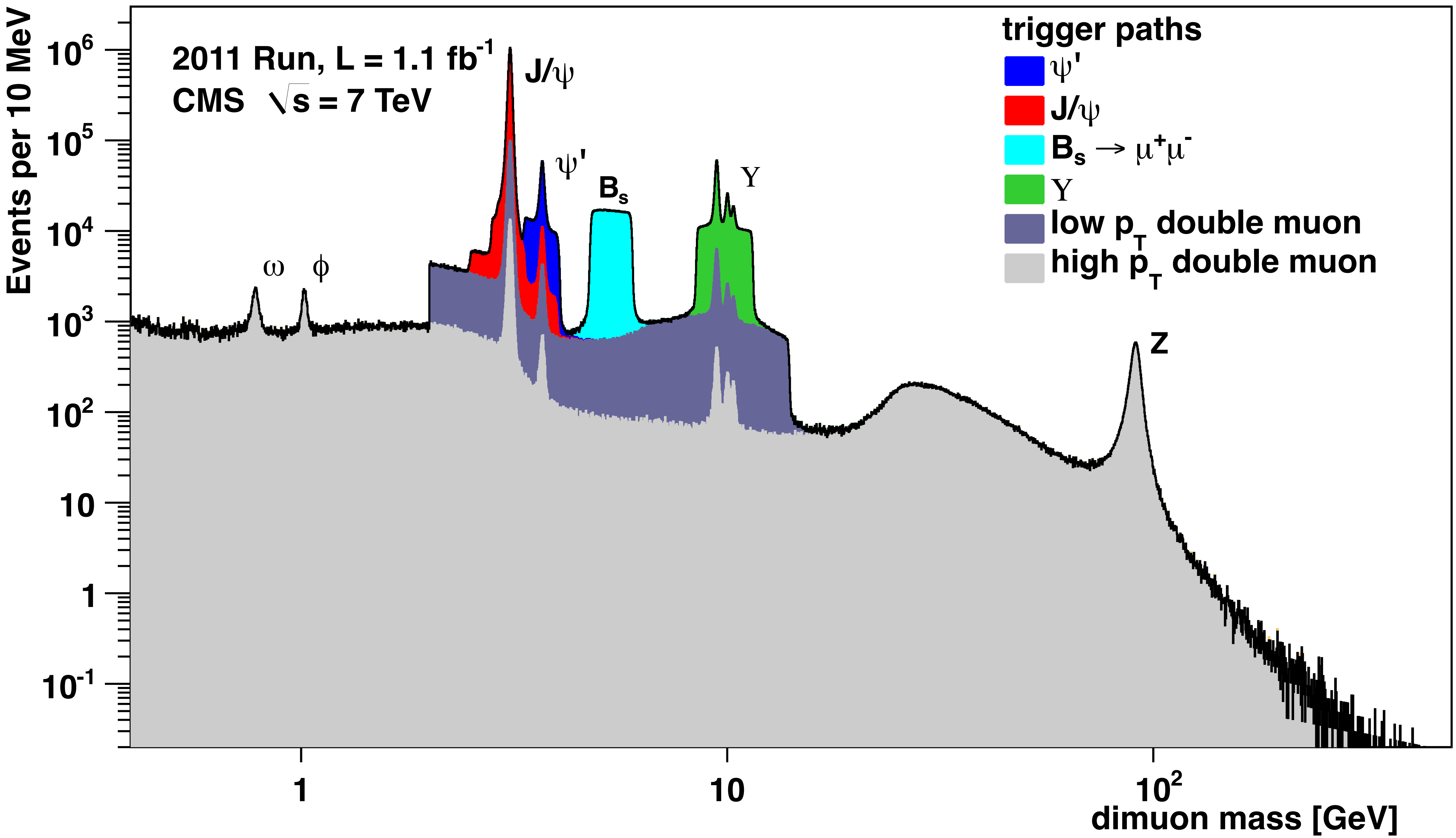
Introduction

- CMS is a general purpose detector at the LHC.
- Inner tracker consists of silicon pixel and silicon strip layers.
- Muons are measured by drift tubes (DT), cathode strip chambers (CSC) and resistive plate chambers (RPC).



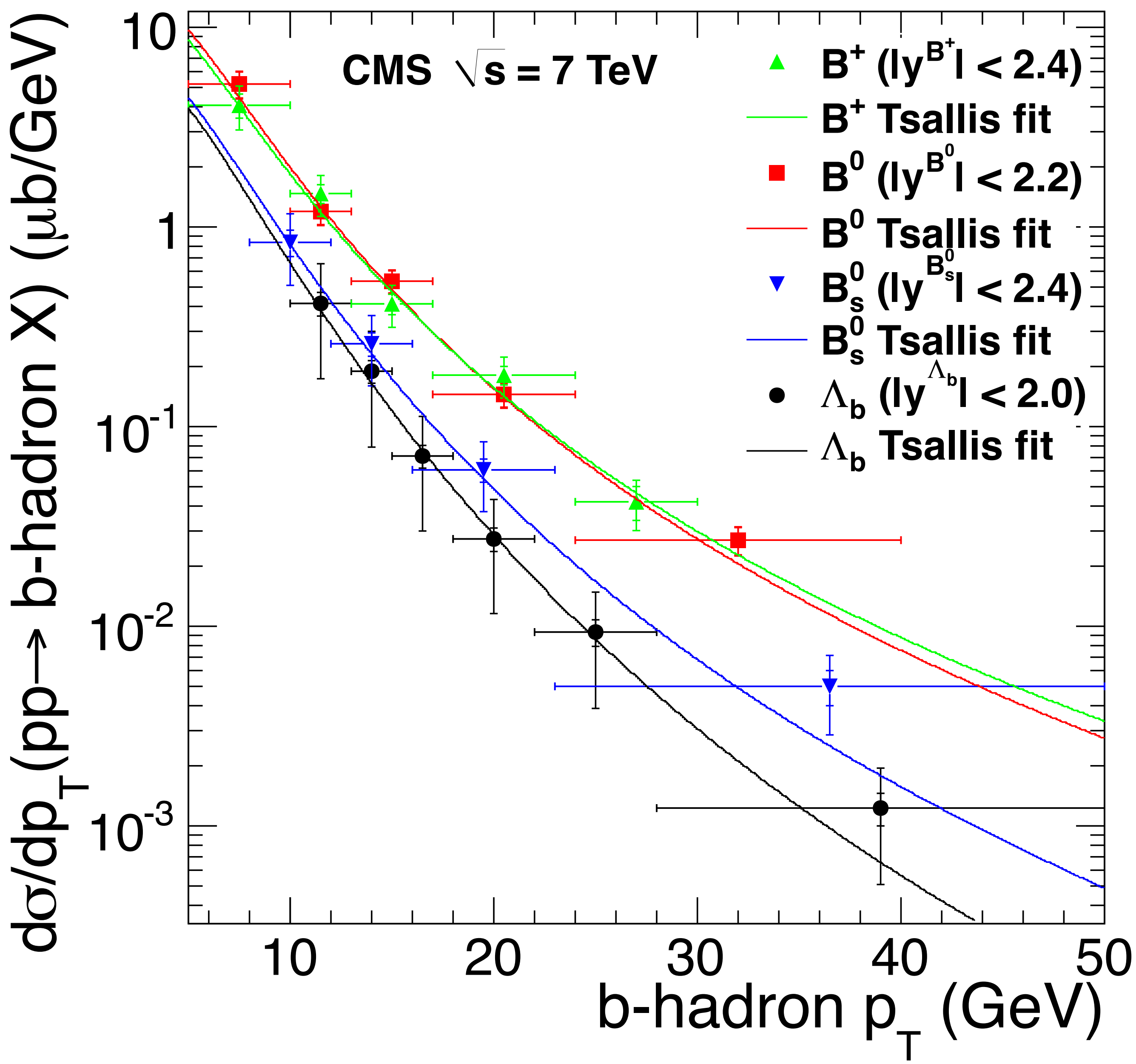
- The dimuon mass resolution is less than 1%.
- Powerful tool for B-physics study.

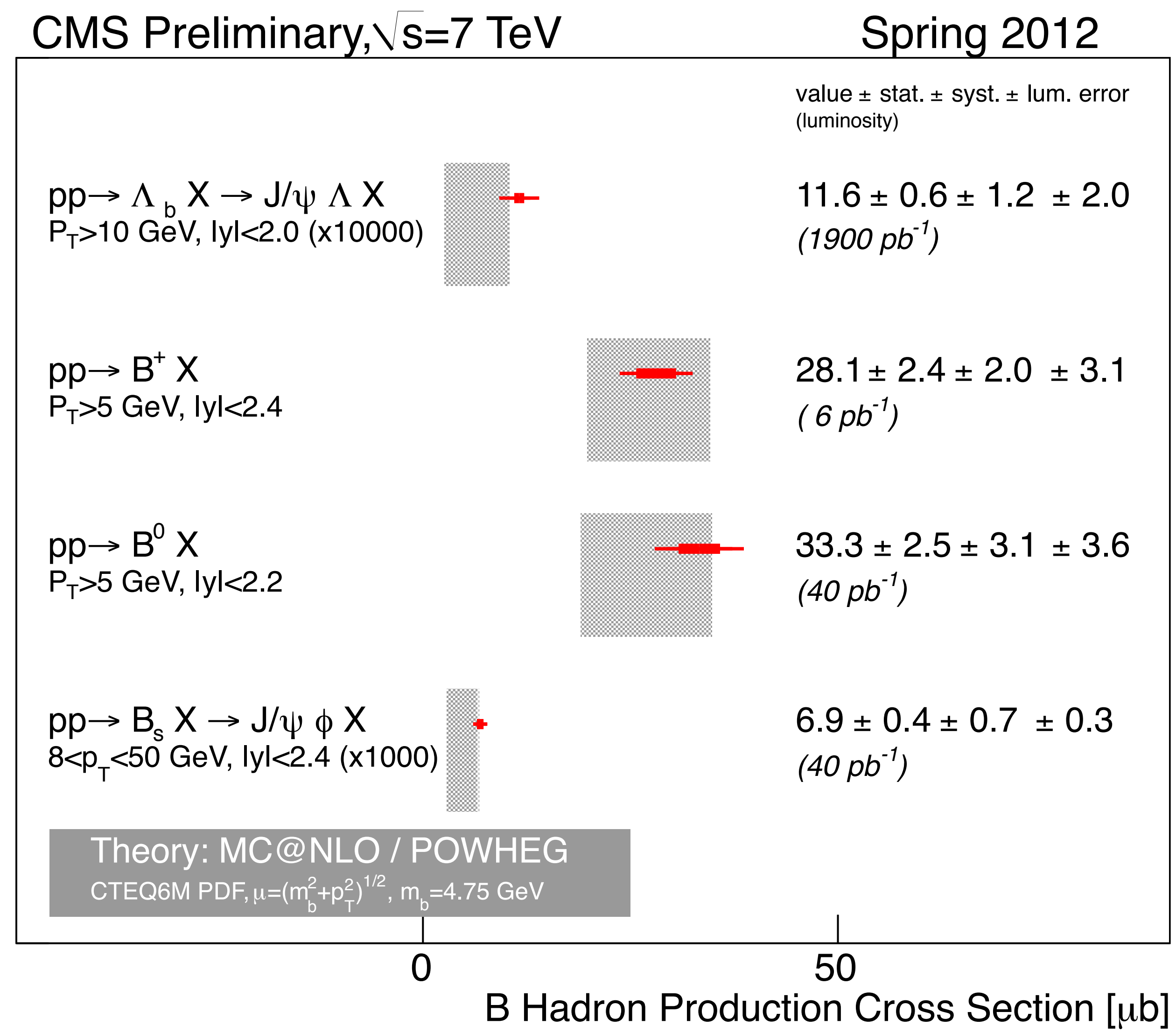
Dimuon mass distribution



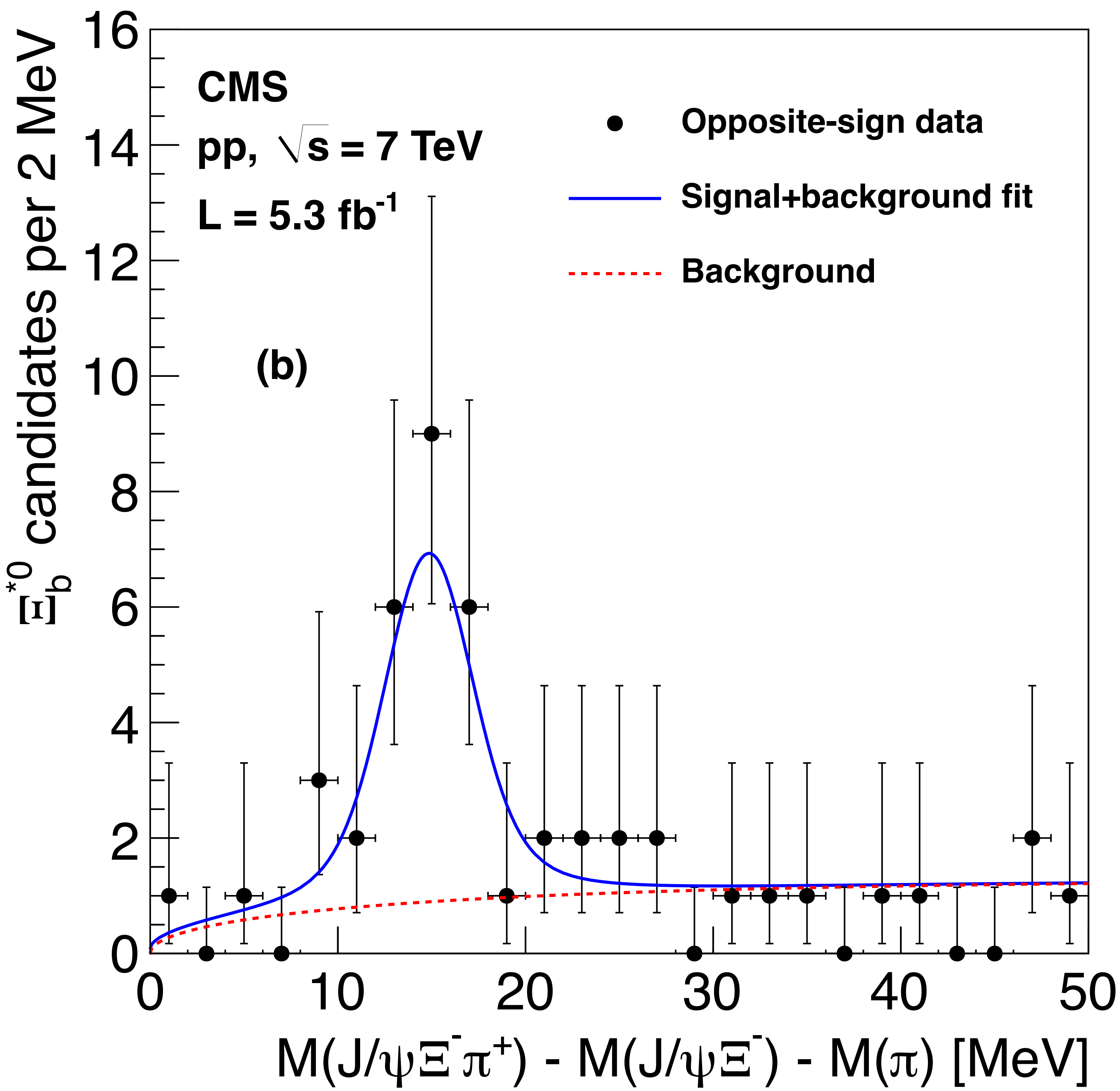
- Dimuon mass distribution collected with various dimuon triggers.

B-Hadron Production

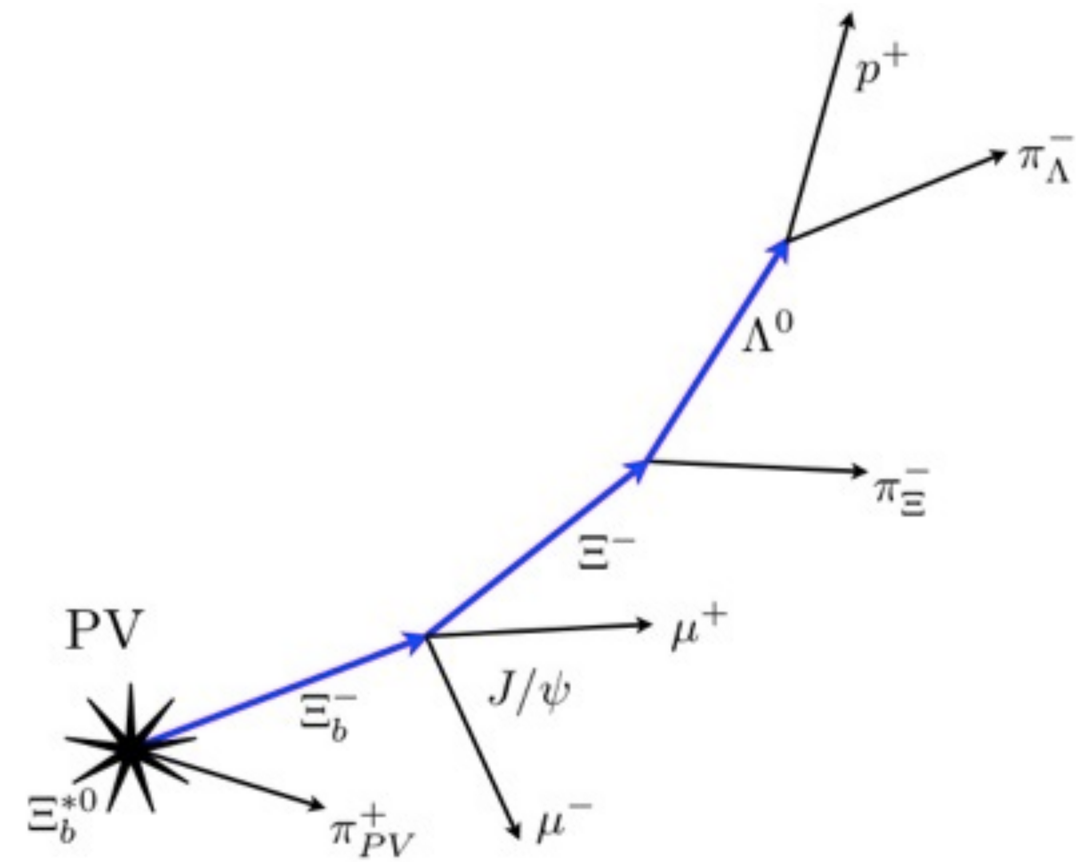




Observation of Ξ_b^{*0}



14.84 ± 0.74 (stat.) ± 0.28 (syst.) MeV
Γ = 2.1 ± 1.7 (stat.) MeV



- M (Ξ_b^{*0}) = 5945.0 ± 0.7 (stat.) ± 0.3 (syst.) ± 2.7 (PDG) MeV
- Measured mass and width are compatible with theoretical expectations for the $J^P = 3/2^+$ baryon*

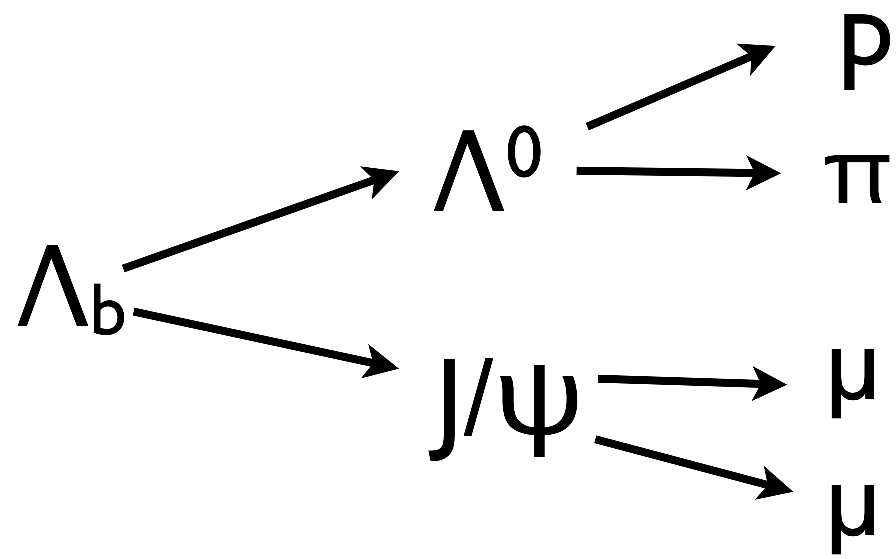
* arXiv:1203.3378.

Measurement of the Λ_b lifetime

Λ_b Lifetime Measurement

- Study of b-baryons is an important ingredient in understanding b-hadron production.
- The non-perturbative QCD model of Heavy Quark Theory provides predictions.
- Recent measurements include those from CDF, D0 and ATLAS.
- Use $\Lambda_b \rightarrow J/\psi\Lambda^0$, $J/\psi \rightarrow \mu\mu$, $\Lambda^0 \rightarrow p\pi$.

Event Selection



- Two oppositely charged muons.
- Constrain the dimuon invariant mass to the known J/ψ mass.
- Select two other oppositely charged tracks as the proton and pion with the p_T(proton) > p_T(pion).
- Constrain the proton-pion invariant mass to the Λ^0 mass,
  - reject events with m(pπ) close to K_s mass.

Likelihood Fit and Efficiency

- 2-D unbinned maximum likelihood fit:

Signal: Double Gaussian in m, decay in t ← proper time

$$M_{\text{sig}}(m) \cdot M_{\text{sig}}(t) = G_{\text{sig}}(m; \mu_m, \sigma_1, \sigma_2, f) \cdot D_{\text{sig}}(t; \tau, \sigma_1, \sigma_2, f)$$

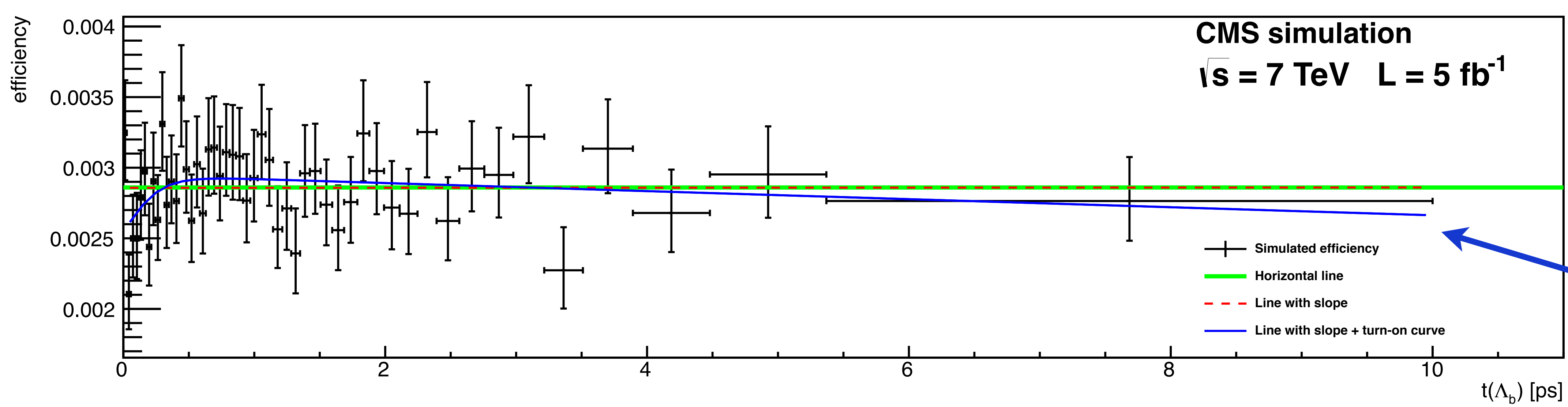
Prompt background: Linear in m, Double Gaussian in t

$$M_{\text{prompt}}(m) \cdot M_{\text{prompt}} = (a_0 + a_1 m) \cdot G_{\text{prompt}}(t; \mu_t, \sigma_1, \sigma_2, f)$$

Non-prompt background: Linear in m, decay in t ← different b-hadrons with wrong assumptions in the mass or incompletely reconstructed events

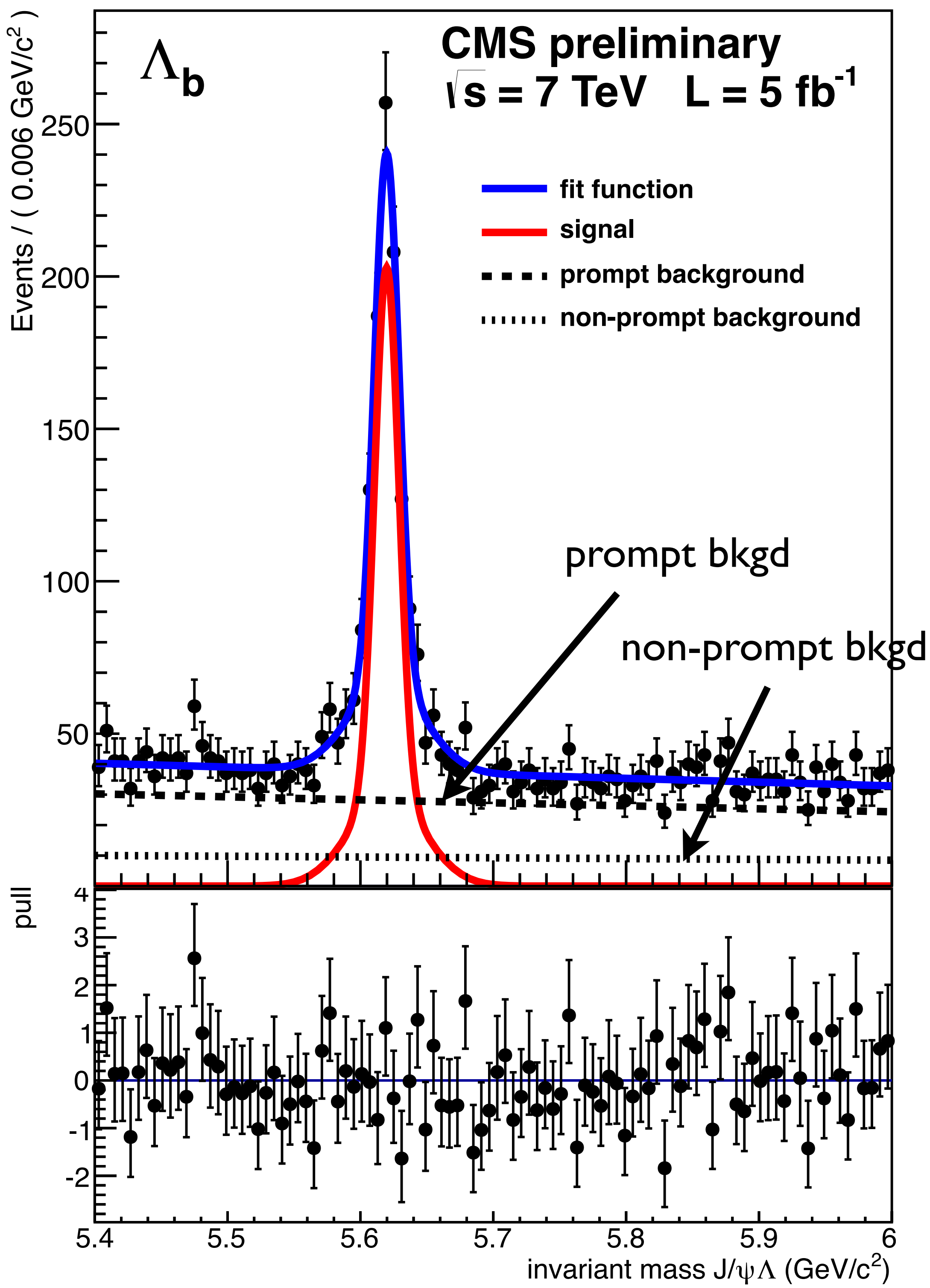
$$M_{\text{non-prompt}}(m) \cdot M_{\text{non-prompt}} = (a_0 + a_1 m) \cdot D_{\text{non-prompt}}(t; \tau, \sigma_1, \sigma_2, f)$$

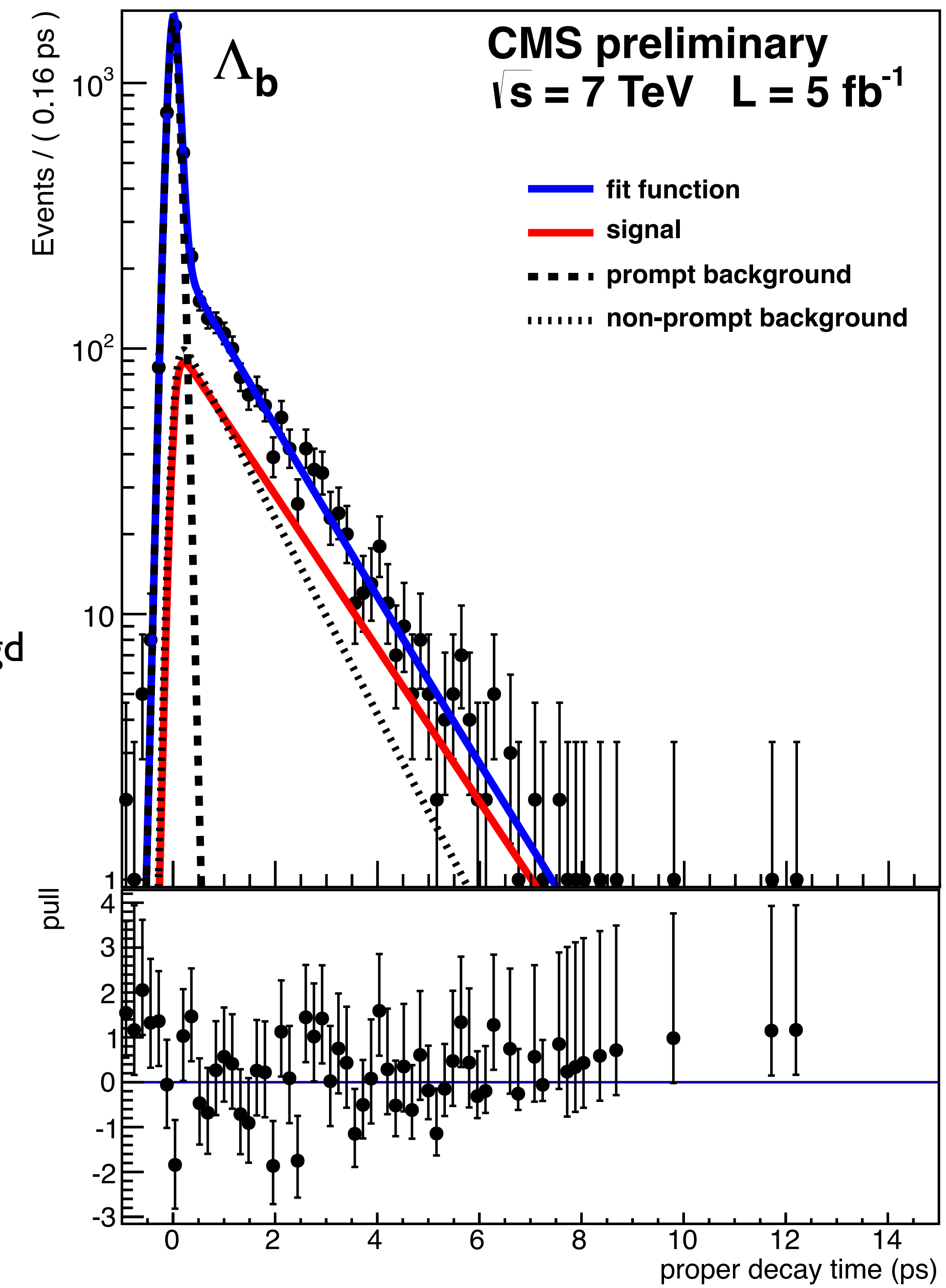
- Constant efficiency



fit with turn-on curve for systematic study.

Fit Projection Λ_b





See backup for B^0 fits.

Systematic and Results

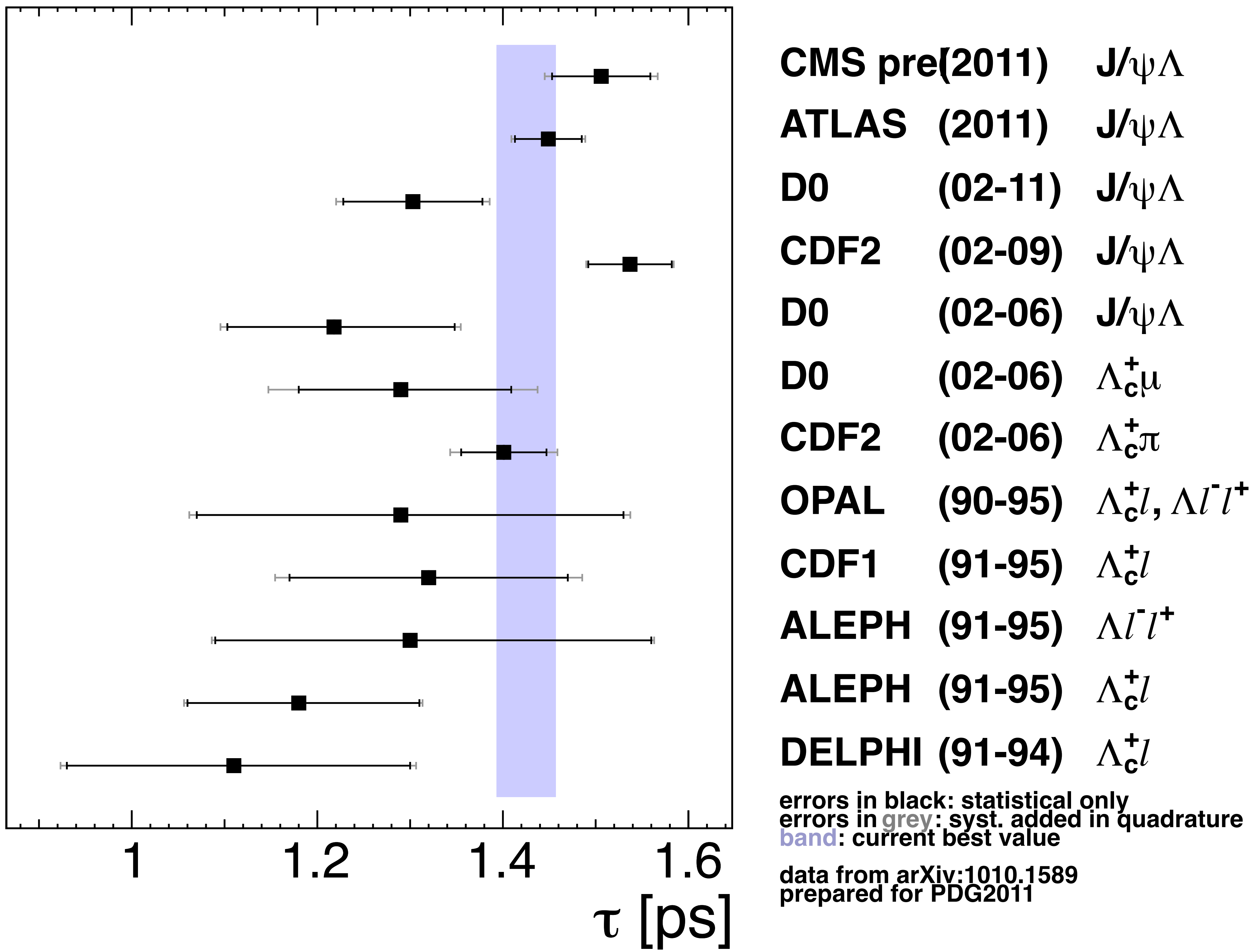
- Systematic uncertainty sources:
  - Efficiency (main source)
  - Alignment
  - Event selection
  - Fit model

- Final results Λ_b lifetime:

$$1.503 \pm 0.052\ (\text{stat.}) \pm 0.031\ (\text{syst.})\ \text{ps}$$

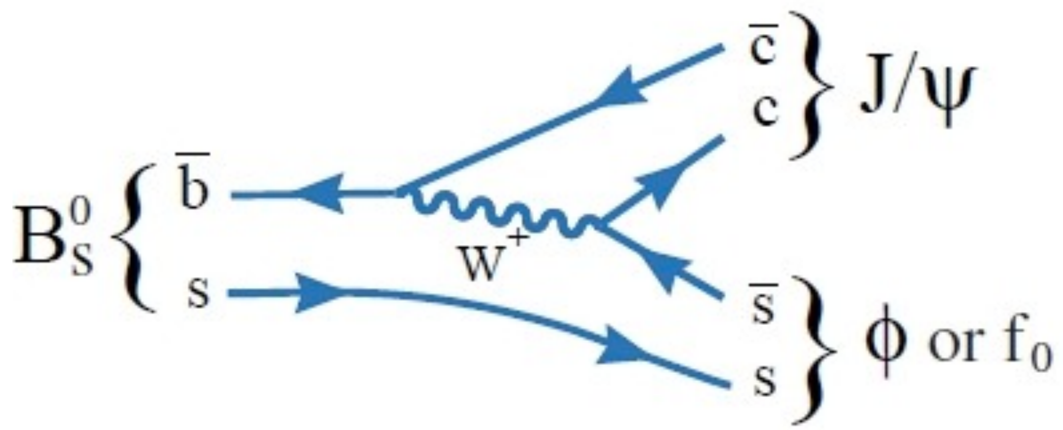
Comparison with Previous Results

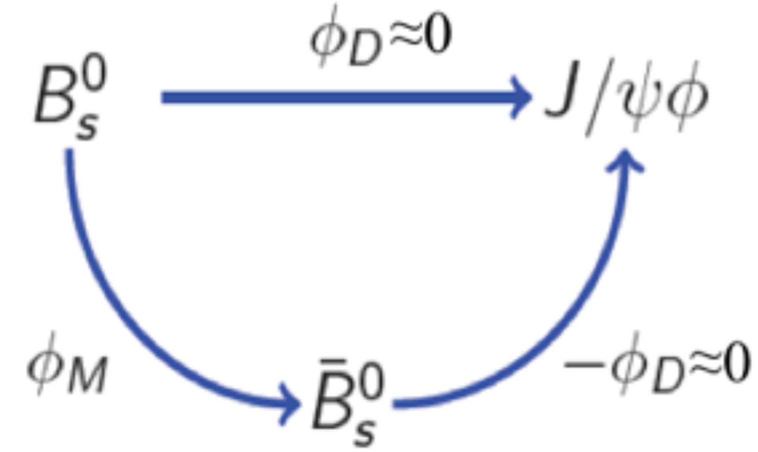
Λ_b lifetime



Measurement of the B_s lifetime difference

$$B_s \to J/\psi\phi \text{ with } J/\psi \to \mu^+\mu^- \text{ and } \phi \to K^+K^-$$



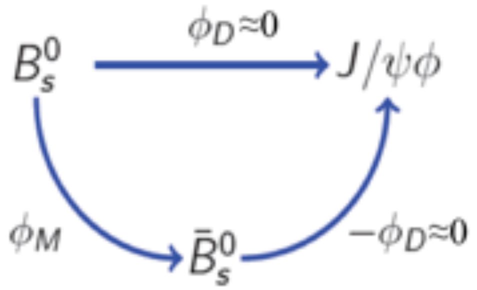


- Two flavour eigenstate of B_s oscillate.
- B_s -$\overline{B}_s$ mixing gives rise to a CP violation phase:

$$\Phi_s = \Phi_M - 2\Phi_D$$

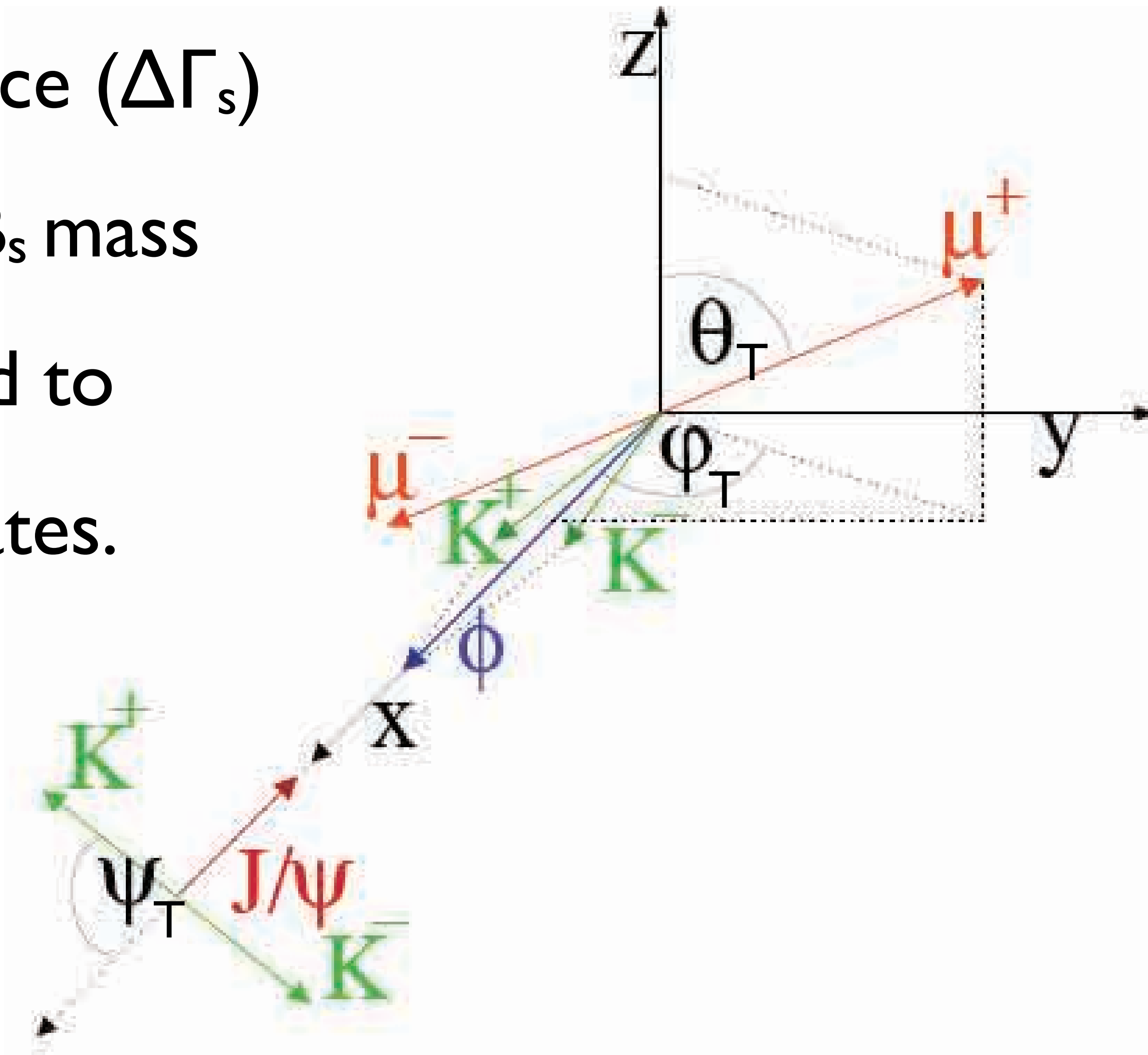
- The final state is an admixture of the CP-even and CP-odd eigenstates.

B_s lifetime difference



- Since B_s is a pseudo-scalar meson, while J/ψ and Φ are vector mesons, the orbital angular momentum can have the values L = 0, 1, 2.
- To measure the lifetime difference ($\Delta\Gamma_s$) for the decay rates of the two B_s mass eigenstates, an analysis is needed to disentangle the two CP eigenstates.
- Decay topology is described by:

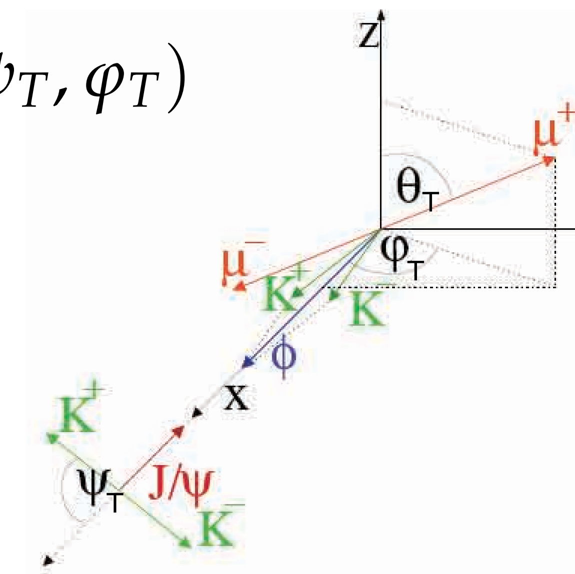
$$\Theta = (\theta_T, \psi_T, \varphi_T)$$



B_s Decay Formula

- The differential decay rate:

$$\Theta = (\theta_T, \psi_T, \varphi_T)$$



$$\frac{d^4\Gamma(B_s(t))}{d\Theta\, dt} = f(\Theta, t; \alpha) = \sum_{i=1}^{6} O_i(\alpha, t).g_i(\Theta)$$

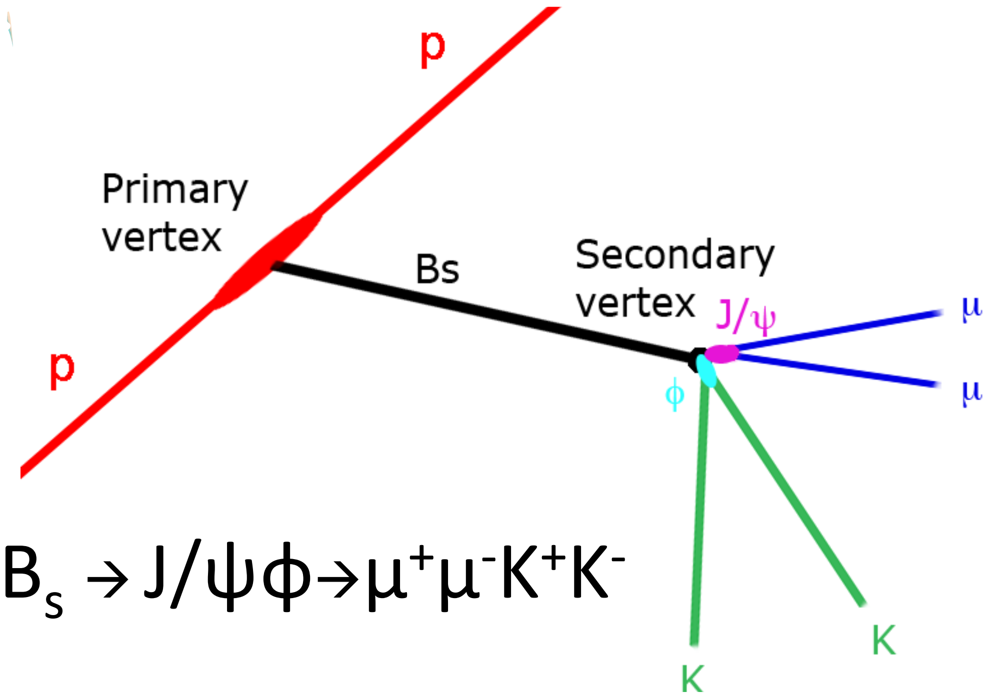
- t: proper decay time
- α: physics parameters of interest
- $O_i(\alpha, t)$: kinematics-independent observables
- $g_i(\Theta)$: angular distributions

Physics parameters of interest:

$$(\Gamma_s,\ \Delta\Gamma_s,\ |A_0|^2,\ |A_\perp|^2,\ \delta_{||})$$

- $|A_0|^2$: longitudinal amplitudes
- $|A_\perp|^2$: transverse amplitudes
- $\delta_{||}$: strong phase

Event Selection



$B_s \rightarrow J/\psi\phi \rightarrow \mu^+\mu^- K^+K^-$

- Two oppositely charged muons.
- Two oppositely charged tracks.

- Build B_s from 4-track vertex fit:
  - Constrain the dimuon invariant mass to the known J/ψ mass.
  - Constrain the K^+K^- to the φ mass.

Efficiency Study

- The overall efficiency includes: detector acceptance, the trigger conditions, and the selection cuts.
- No sizable correlation between the proper time and the angular variables is found.
- The correlation amongst the angular observables is also negligible.
- The proper decay length efficiency is almost flat in the range [0.02-0.3]cm.

Maximum likelihood fit

- Event likelihood function:

$$\mathcal{L} = L_{\text{signal}} + L_{\text{background}} ,$$
$$L_{\text{signal}} = (f(\Theta, t; \alpha) \otimes G(t, \kappa, \sigma(t))]) \cdot M(m) \cdot \epsilon(t)\epsilon(\Theta) ,$$
$$L_{\text{background}} = b(\Theta, t, m) ,$$

signal mass PDF (sum of two Gaussian) → $M(m)$

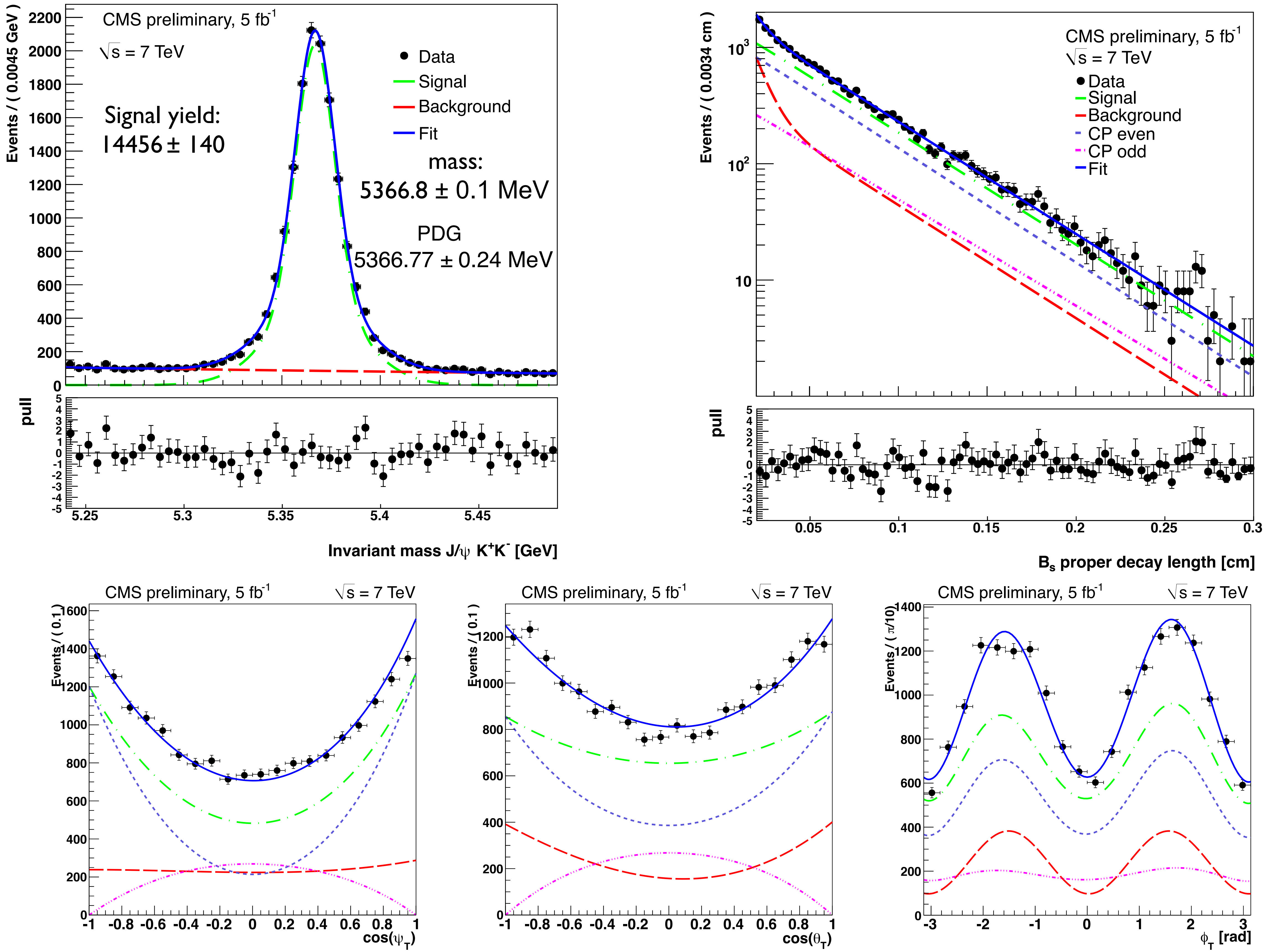
proper decay time uncertainty → $\sigma(t)$

Gaussian resolution function → G

Legendre polynomials and sinusoidal function → $b(\Theta, t, m)$

- 5-D fit procedure
  - 1-D fit of Bs mass to get the mean and the smaller of the two Gaussian function widths.
  - Fit sideband region for the angular background shapes.
  - Fit the full mass range.

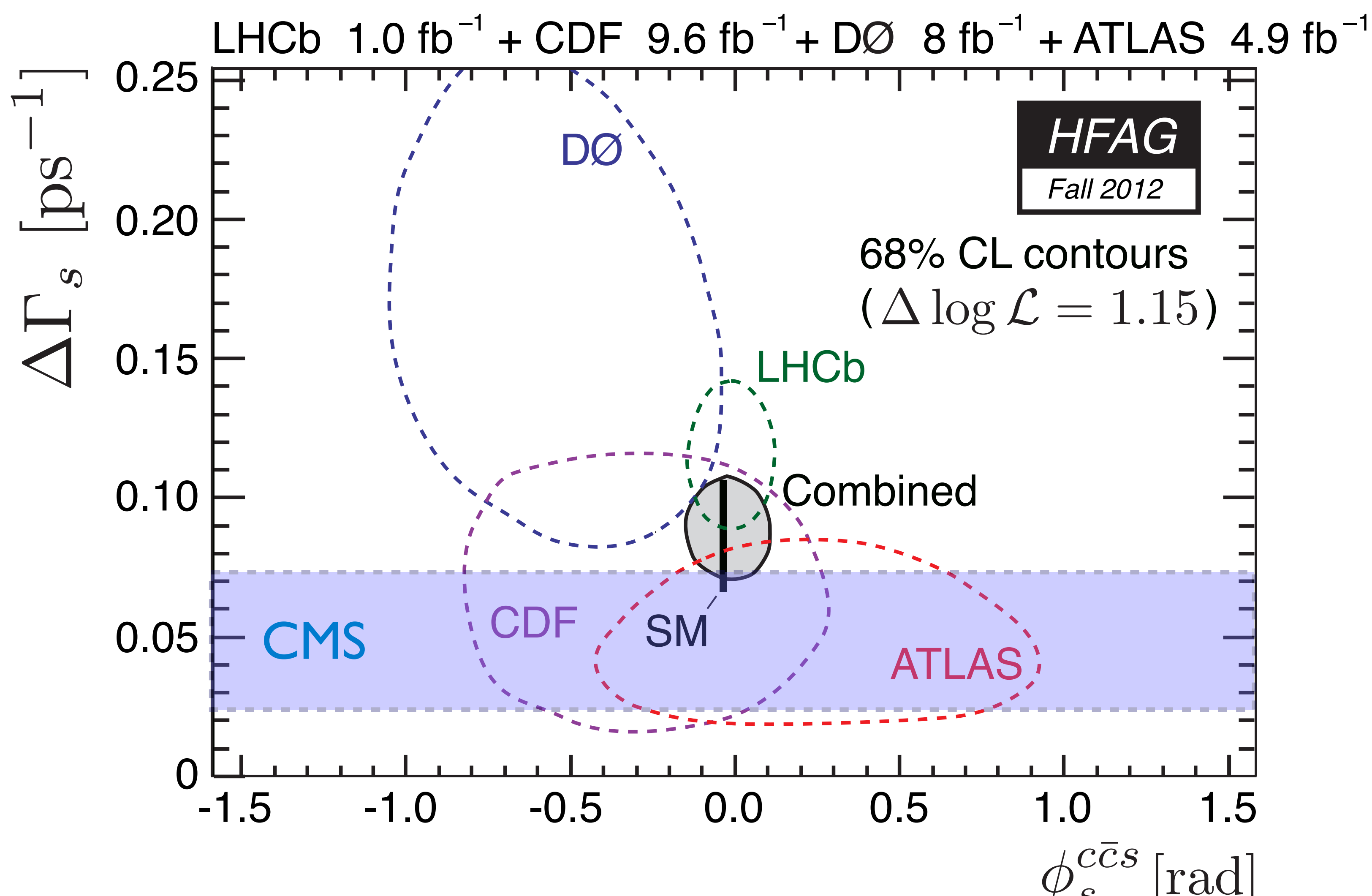
Fit to the Data



Systematics

Uncertainty source	$\Delta\Gamma_s$ [ps^{-1}]	$c\tau$ [cm]	$\lvert A_0 \rvert^2$	$\lvert A_\perp \rvert^2$	$\delta_{\lvert\lvert}$ [rad]
Signal PDF modeling					
Signal mass model	0.00072	0.00012	0.0022	0.0006	0.039
Proper time resolution	0.00170	0.00006	0.0007	0.0000	0.007
ϕ_s approximation	0.00000	0.00001	0.0000	0.0000	0.002
S-wave assumption	0.00109	0.00001	0.0130	0.0066	0.056
Background PDF modeling					
Background mass model	0.00019	0.00000	0.0000	0.0001	0.003
Background lifetime model	0.00040	0.00000	0.0001	0.0002	0.003
Peaking B^0 background	0.00025	0.00006	0.0002	0.0022	0.050
Background angular model	0.00175	0.00003	0.0001	0.0064	0.161
Limited simulation statistics					
Angular efficiency parameters	0.00019	0.00002	0.0057	0.0055	0.037
Temporal efficiency parameters	0.00000	0.00005	0.0000	0.0000	0.000
Temporal efficiency parametrization	0.00181	0.00014	0.0005	0.0007	0.001
Angular efficiency parametrization	0.00063	0.00003	0.0021	0.0086	0.007
Likelihood function bias	0.00000	0.00004	0.0004	0.0000	0.014
Total uncertainty	0.00341	0.00022	0.0146	0.0140	0.187

$$
\begin{aligned}
\Delta\Gamma_s &= 0.048 \pm 0.024\,(\text{stat.}) \pm 0.003\,(\text{syst.})\,\text{ps}^{-1}\,,\\
c\tau_{B_s} &= 0.04580 \pm 0.00059\,(\text{stat.}) \pm 0.00022\,(\text{syst.})\,\text{cm}\,,\\
|A_0|^2 &= 0.528 \pm 0.010\,(\text{stat.}) \pm 0.015\,(\text{syst.})\,,\\
|A_\perp|^2 &= 0.251 \pm 0.013\,(\text{stat.}) \pm 0.014\,(\text{syst.})\,,\\
\delta_{||} &= 2.79 \pm 0.14\,(\text{stat.}) \pm 0.19\,(\text{syst.})\,\text{rad}\,.
\end{aligned}
$$



Summary

- CMS is a powerful detector for studying B physics because of its excellent tracking and lepton identification.
- New measurement of the Λ_b lifetime:

$$1.503 \pm 0.052\ (\text{stat.}) \pm 0.031\ (\text{syst.})\ \text{ps}$$

- New measurement of the B_s lifetime difference:

$$\Delta\Gamma_s = 0.048 \pm 0.024\ (\text{stat.}) \pm 0.003\ (\text{syst.})\ \text{ps}^{-1}$$

- Stay tuned for more exciting B physics results!

All public results can be found at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH

Backup

Kinematic observables

$$\frac{d^4\Gamma(B_s(t))}{d\Theta\, dt} = f(\Theta, t; \alpha) = \sum_{i=1}^{6} O_i(\alpha, t).g_i(\Theta)$$

$$\begin{aligned}
O_1 &= |A_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma_s t}[\cosh(\Delta\Gamma_s t/2) - \cos\phi_s \sinh(\Delta\Gamma_s t/2)] \\
O_2 &= |A_{||}(t)|^2 = |A_{||}(0)|^2 e^{-\Gamma_s t}[\cosh(\Delta\Gamma_s t/2) - \cos\phi_s \sinh(\Delta\Gamma_s t/2)] \\
O_3 &= |A_\perp(t)|^2 = |A_\perp(0)|^2 e^{-\Gamma_s t}[\cosh(\Delta\Gamma_s t/2) + \cos\phi_s \sinh(\Delta\Gamma_s t/2)] \\
O_4 &= Im(A_{||}^*(t) A_\perp(t)) = |A_{||}(0)||A_\perp(0)| e^{-\Gamma_s t}[-\cos(\delta_\perp - \delta_{||}) \sin\phi_s \sinh(\Delta\Gamma_s t/2)] \\
O_5 &= Re(A_0^*(t) A_{||}(t)) = |A_0(0)||A_{||}(0)| \cos\delta_{||} e^{-\Gamma_s t}[\cosh(\Delta\Gamma_s t/2) - \cos\phi_s \sinh(\Delta\Gamma_s t/2)] \\
O_6 &= Im(A_0^*(t) A_\perp(t)) = |A_0(0)||A_\perp(0)| e^{-\Gamma_s t}[-\cos\delta_\perp \sin\phi_s \sinh(\Delta\Gamma_s t/2)] \,,
\end{aligned}$$

$$\begin{aligned}
g_1 &= 2\cos^2(\psi_T)(1 - \sin^2(\theta_T)\cos^2(\varphi_T)), \\
g_2 &= \sin^2(\psi_T)(1 - \sin^2(\theta_T)\sin^2(\varphi_T)), \\
g_3 &= \sin^2(\psi_T)\sin^2(\theta_T), \\
g_4 &= -\sin^2(\psi_T)\sin^2(2\theta_T)\sin(\varphi_T), \\
g_5 &= \frac{1}{\sqrt{2}}\sin(2\psi_T)\sin^2(\theta_T)\sin(2\varphi_T), \\
g_6 &= \frac{1}{\sqrt{2}}\sin(2\psi_T)\sin(2\theta_T)\sin(\varphi_T)\,.
\end{aligned}$$

Fit Projection B^0