Institute of Astro- and Particle Physics, University of Innsbruck

CP violation measurements with the ATLAS detector

"Determination of ϕ_S and $\Delta\Gamma_S$ from the Decay $B_S \rightarrow J/\psi\ \phi$"

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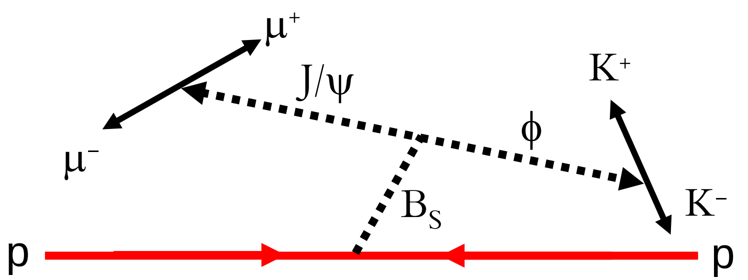
on behalf of the ATLAS collaboration
BEACH2012, Wichita, USA

Motivation

- Main physics aim of this work of doing a time dependent angular analysis of $B_S \to J/\psi\ \phi$ decays in ATLAS:



Measurement of

- CP violating weak mixing phase ϕ_S
- precise measurement of $\Delta\Gamma_S$
    - decay width difference between the mass eigenstates B_H and B_L

which could point to BSM physics.

Outline

- Introduction
  - CP violation and B_S Phenomenology
- ATLAS Detector
- The Measurement
  - Angular Correlations
  - Unbinned Maximum Likelihood Fit
- Results
  - Fit Projections
  - Systematic Uncertainties
  - Comparison with other Experiments
- Conclusions

CP violation and the CKM matrix

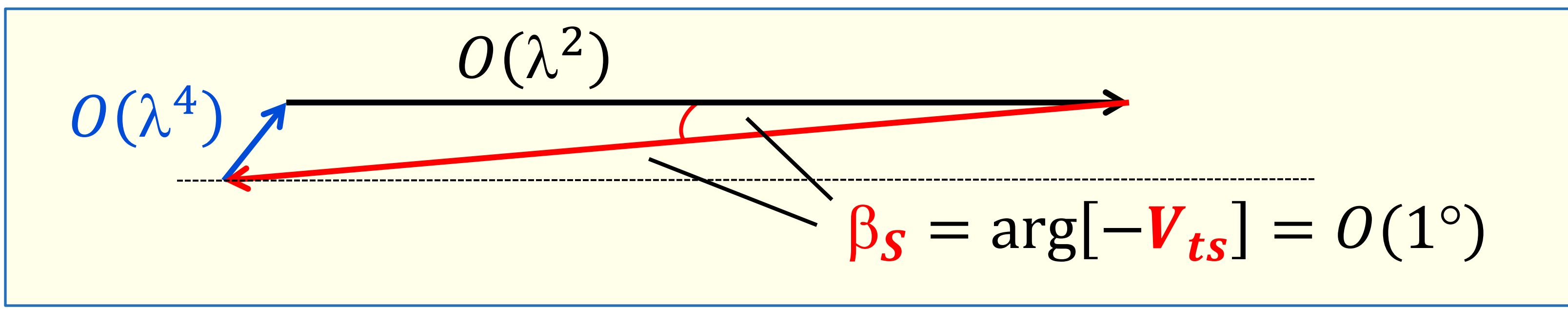
- Unitarity of CKM matrix
  - constraint from 2nd and 3rd columns:

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

$$V_{us}V_{ub}^{*} + V_{cs}V_{cb}^{*} + \boldsymbol{V_{ts}}V_{tb}^{*} = 0$$

Wolfenstein parametrization:

$$O(\lambda^4):\ \lambda \cdot A\lambda^3(\rho + i\eta)\ +\ (1 - \frac{\lambda^2}{2}) \cdot A\lambda^2\ +\ \boldsymbol{V_{ts}} \cdot 1 = 0$$



$$J = 2 \cdot \text{Area} = A\lambda^4\eta \cdot (1 - \frac{\lambda^2}{2})\, A\lambda^2 = \underline{A^2\lambda^6\eta} + A^2\frac{\lambda^8}{2}\eta + O(\lambda^{10})$$

The quantity $\sin(2\beta_S)$ can be determined from a time dependent analysis of $B_S \to J/\psi\phi$.
Experimenters prefer $\phi_S \cong -2\,\beta_S$.

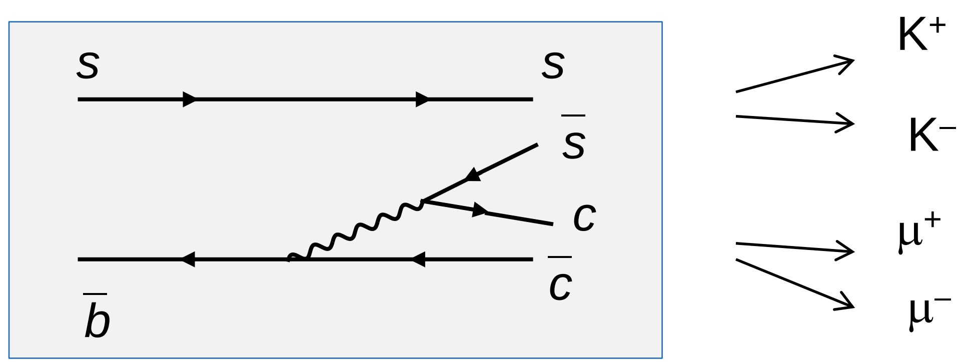
CP violation: neutral B_s system

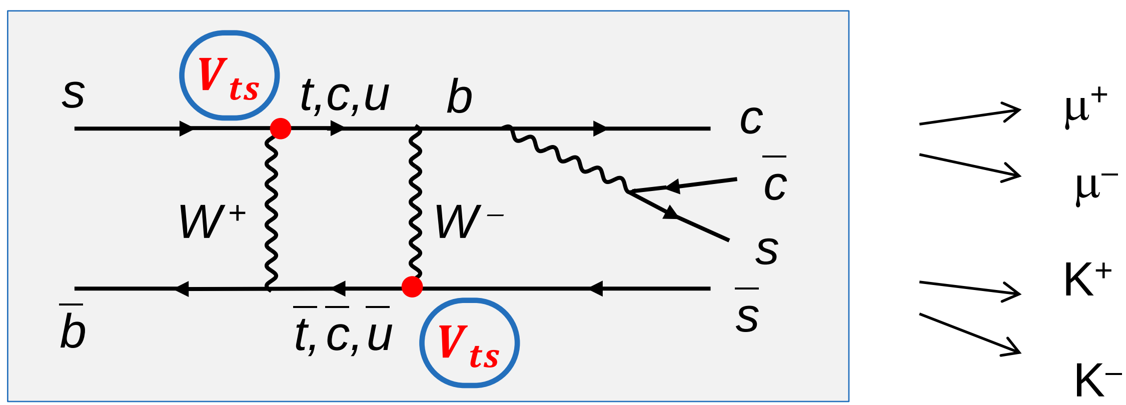
- Interference of decays with and without mixing
  - Mixing induced CP violation
    - Phase difference $\phi_s = 2 \cdot \arg[V_{ts}] = -2\beta_s$

      SM prediction: $\phi_s = -0.0368 \pm 0.0018$ rad

$$B_s \rightarrow f$$

$$B_s \rightarrow \overline{B}_s \rightarrow f$$





ϕ_s: This diagram justifies the name *weak mixing phase*.

Phenomenology of the $B_S, \overline{B}_S$ system

- Mass eigenstates B_L, B_H are linear combinations of flavor eigenstates:

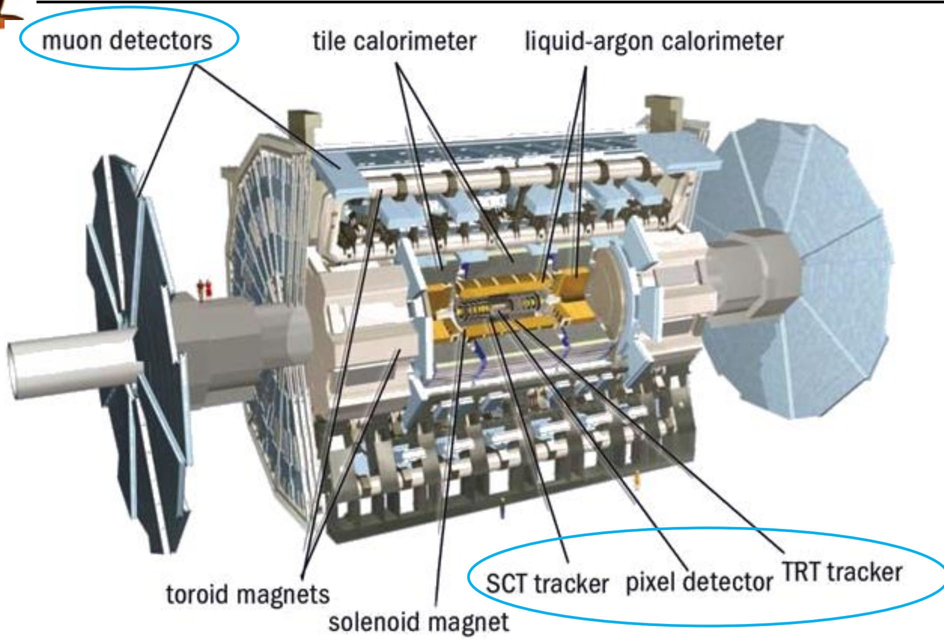
$$|B_{L,H}\rangle = p|B_S\rangle \pm q|\overline{B}_S\rangle$$

- CP violation $\rightarrow$ B_L, B_H $\neq$ CP eigenstates

- Two particle system described by 4 parameters
  - oscillation frequency Δm_S $= m_H - m_L$
  - mean width Γ_S $= (\Gamma_L + \Gamma_H)/2$
  - width difference $\Delta\Gamma_S$ $= \Gamma_L - \Gamma_H$
  - weak mixing phase ϕ_S $\neq 0$ if CP violation

(plus nonperturbative parameters)

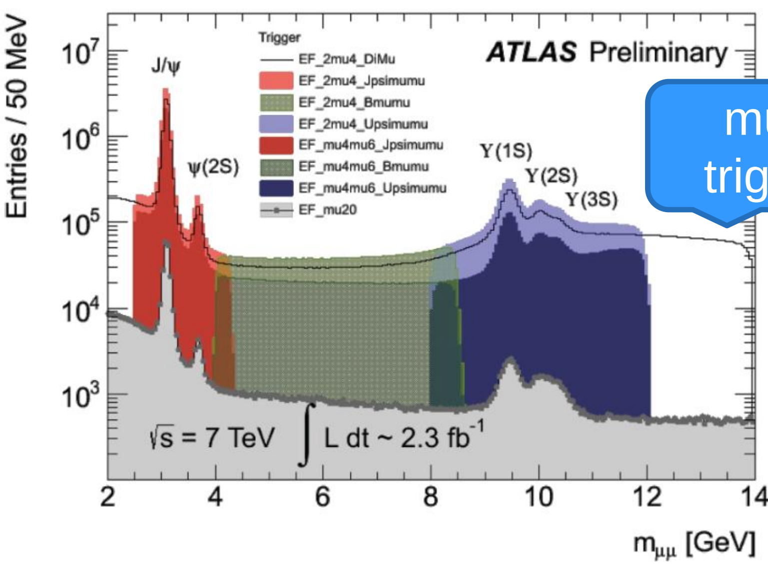
The ATLAS detector



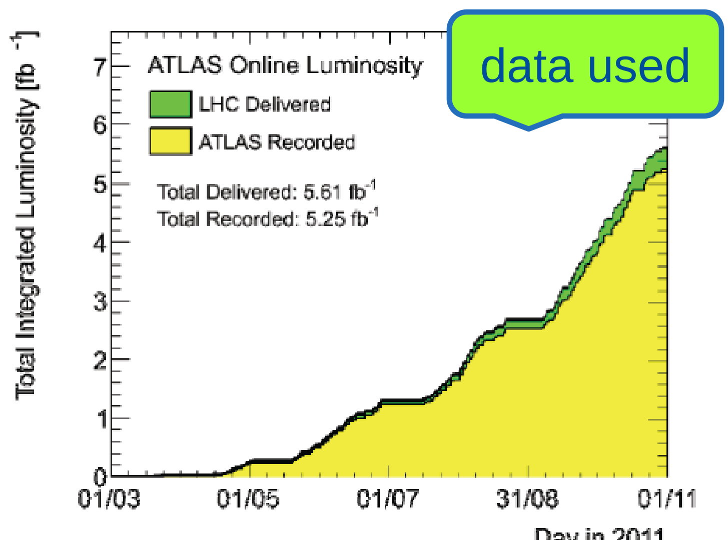
The ATLAS collaboration

38 Countries
185 Institutions
2866 Scientific Authors

every year:
several new applications and expressions of interest for membership



2011: > 5 fb^{-1} @ 7 TeV



The measurement

1. Trigger
   - using 4.9 fb^{-1} of data collected 2011
   - events selected by muon triggers (single, di-, J/ψ)
     - p_T threshold for muons: 4 – 10 GeV

2. Selection cuts
   - different $J/\psi(\mu^+\mu^-)$ **mass windows** for barrel/endcap regions
     - since mass resolution depends on $|\eta|$ of muons
   - $\phi(K^+K^-)$ invariant **mass window**: 22 MeV
     - p_T (kaons) > 1 GeV
   - B-meson **secondary decay vertex fit**: $\chi^2/\mathrm{dof} < 3$

     $\rightarrow$ mass m_i, proper decay time t_i (computed in transverse plane), decay angles

$$\underbrace{\underbrace{\mu^+ \quad \mu^-}_{J/\psi} \quad \underbrace{K^+ \quad K^-}_{\phi}}_{B_S}$$

3. Acceptance calculated on large samples of signal and background Monte Carlo events
   - e.g. $B^0 \rightarrow J/\psi\ K^{0*}$, $bb \rightarrow J/\psi\ X$, $pp \rightarrow J/\psi\ X$

$B_s(\overline{B}_s) \rightarrow J/\psi\ \phi$ and CP eigenstates

- Analysis does not distinguish the initial states, *i.e.* whether there is a B_s or a $\overline{B}_s$ at the beginning
  = "untagged analysis"
- Both initial states decay into the same final state
  - final state is a superposition of CP eigenstates
    - J/ψ, ϕ ($J^{PC} = 1^{--}, 1^{--}$) can have L = 0,1,2

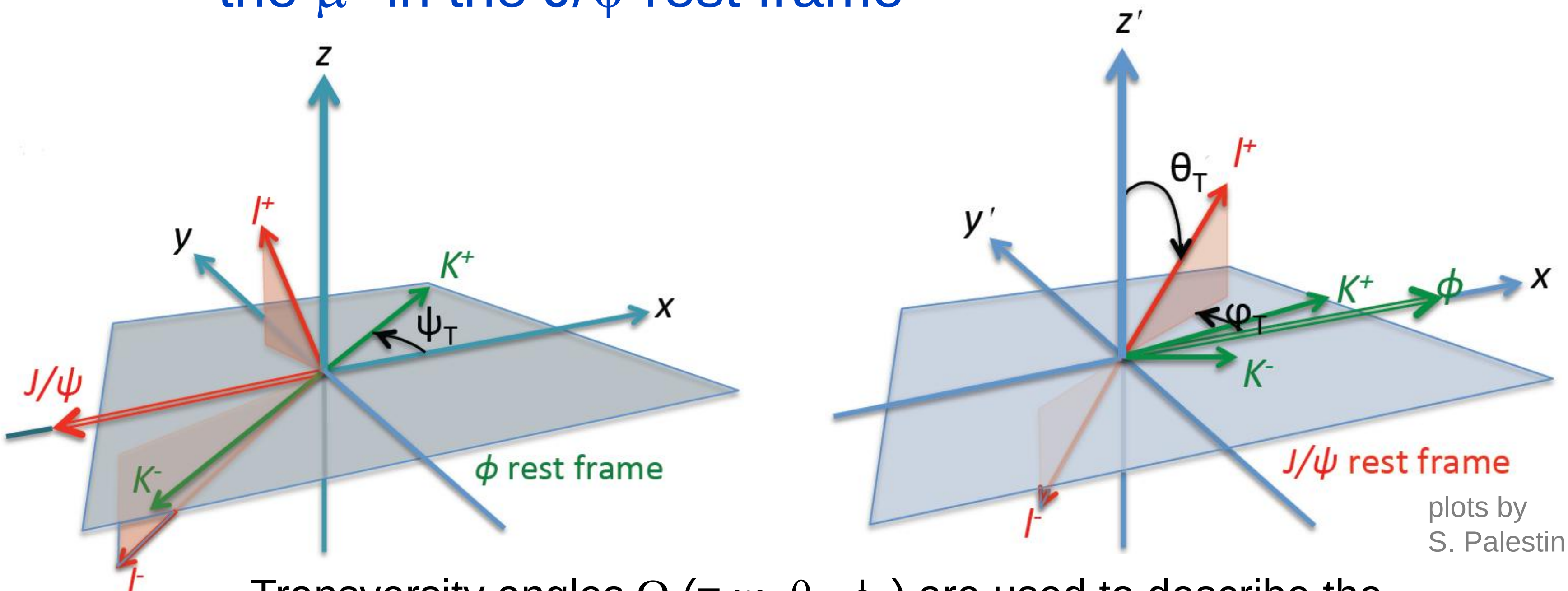
$\boxed{\text{Pseudoscalar} \rightarrow \text{Vectormeson + Vectormeson, with relative L}}$

orbital angular momentum: L = 0,2 … CP even (+1)
L = 1 … CP odd (–1)

  - CP eigenstates of final state can be distinguished (statistically) through their angular configuration
    - 4 particle final state $J/\psi\ (\rightarrow \mu^+\mu^-)\ \phi\ (\rightarrow K^+K^-)$ can be described by three angles

Kinematics of the decay

- Transversity basis
  - x-axis = direction of decay in B rest frame
  - x-y plane = decay plane of K^+K^- $(K^+ \rightarrow +y)$
  - ψ_T = angle between x-axis and K^+ direction (ϕ r.f.)
  - θ_T and ϕ_T are the polar and azimuthal angles of the μ^+ in the J/ψ rest frame



plots by S. Palestini

Transversity angles Ω (= ψ_T,θ_T, ϕ_T) are used to describe the angular distributions of the different CP (+1,-1) final states.

Angular and proper time distributions

- Differential decay rate $$\frac{d^4\Gamma}{dt\ d\Omega} = \sum_{k=1}^{10} \mathcal{O}^{(k)}(t) g^{(k)}(\theta_T, \psi_T, \varphi_T)$$

k	$\mathcal{O}^{(k)}(t)$	$g^{(k)}(\theta_T, \psi_T, \varphi_T)$	CP	polarization state
1	$\frac{1}{2}\lvert A_0(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_L^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_H^{(s)}t}\right]$	$2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\varphi_T)$	+1	long.
2	$\frac{1}{2}\lvert A_\parallel(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_L^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_H^{(s)}t}\right]$	$\sin^2\psi_T(1-\sin^2\theta_T\sin^2\varphi_T)$	+1	trans.
3	$\frac{1}{2}\lvert A_\perp(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_L^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_H^{(s)}t}\right]$	$\sin^2\psi_T\sin^2\theta_T$	–1	trans.
4	$\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\parallel(0)\rvert\cos\delta_\parallel \left[(1+\cos\phi_s)\, e^{-\Gamma_L^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_H^{(s)}t}\right]$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\varphi_T$		
5	$\frac{1}{2}\lvert A_\parallel(0)\rvert\lvert A_\perp(0)\rvert \left(e^{-\Gamma_H^{(s)}t} - e^{-\Gamma_L^{(s)}t}\right)\cos(\delta_\perp-\delta_\parallel)\sin\phi_s$	$\sin^2\psi_T\sin 2\theta_T\sin\varphi_T$		
6	$-\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\perp(0)\rvert \left(e^{-\Gamma_H^{(s)}t} - e^{-\Gamma_L^{(s)}t}\right)\cos\delta_\perp\sin\phi_s$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\cos\varphi_T$		
7	$\frac{1}{2}\lvert A_S(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_L^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_H^{(s)}t}\right]$	$\frac{2}{3}(1-\sin^2\theta_T\cos^2\varphi_T)$		
8	$-\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\parallel(0)\rvert \left(e^{-\Gamma_H^{(s)}t} - e^{-\Gamma_L^{(s)}t}\right)\sin(\delta_\parallel-\delta_S)\sin\phi_s$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\varphi_T$		
9	$\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\perp(0)\rvert \left[(1-\cos\phi_s)\, e^{-\Gamma_L^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_H^{(s)}t}\right]\sin(\delta_\perp-\delta_S)$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\varphi_T$		
10	$-\frac{1}{2}\lvert A_0(0)\rvert\lvert A_S(0)\rvert\sin(-\delta_S)\left(e^{-\Gamma_H^{(s)}t} - e^{-\Gamma_L^{(s)}t}\right)\sin\phi_s$	$\frac{4}{3}\sqrt{3}\cos\psi_T\left(1-\sin^2\theta_T\cos^2\varphi_T\right)$		

interference terms

Terms related to non-resonant and via the f_0 state K^+K^- production (S-wave) → small

Normalization: $|A_0(0)|^2 + |A_{||}(0)|^2 + |A_\perp(0)|^2 + |A_S(0)|^2 = 1$
Each amplitude A_X comes with its strong phase δ_X.
Define strong phases relative to $A_0(0)$: choose $\delta_0 = 0$
→ 3 amplitudes + 3 strong phases = 6 parameters for the fit!

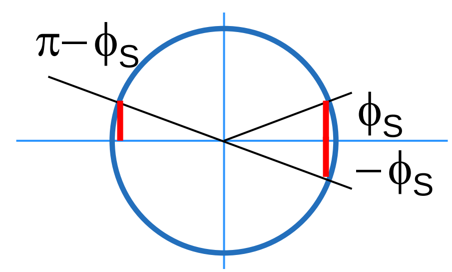
$\sin\phi_S \approx \phi_S$
$\cos\phi_S = 1 + O(\phi_S^2)$

Symmetries

- ϕ_S enters the likelihood via the 10 functions describing the proper decay time distribution, e.g. terms:

  $$f(\Delta\Gamma_S)\cos\overset{(-1)}{(\delta_\perp - \delta_{||})}\;\overset{(-1)}{\sin\phi_S}$$

  $$e^{-\Delta\Gamma_s}\cos\phi_S - e^{+\Delta\Gamma_s}\cos\phi_S$$



- Likelihood is invariant under the transformations

  $$\boxed{\{\phi_S, \delta_\perp, \delta_{||}, \delta_S, \Delta\Gamma_S\} \rightarrow \{-\phi_S, \pi-\delta_\perp, -\delta_{||}, -\delta_S, \Delta\Gamma_S\}}$$

  but also

  $$\boxed{\{\phi_S, \delta_\perp, \delta_{||}, \delta_S, \Delta\Gamma_S\} \rightarrow \{\pi-\phi_S, \pi-\delta_\perp, -\delta_{||}, -\delta_S, -\Delta\Gamma_S\}}$$

  and the combination of the two.

  - 4-fold symmetry of the fit result

- ATLAS is not yet able to resolve the ambiguities

  needs external input

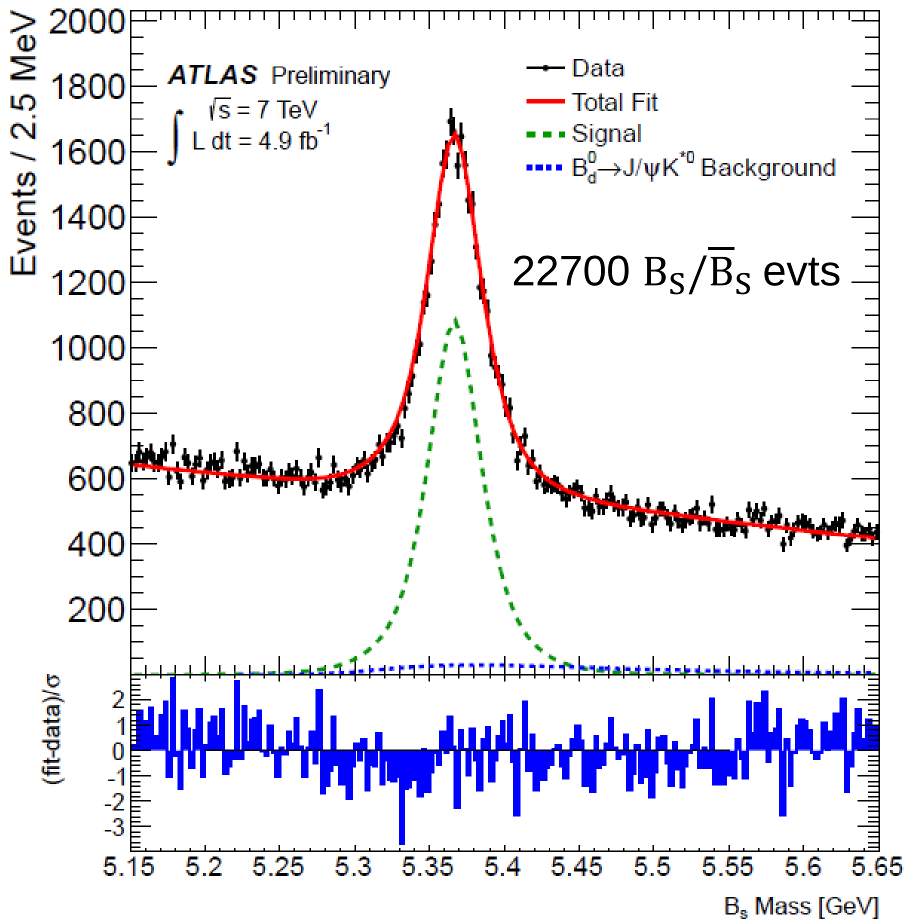
Construction of the Likelihood function $\mathcal{L}$

- Measured variables ($vars$)
  - (m_i, σ_{m_i}), (t_i, σ_{t_i}), Ω_i,
  - set of nuisance parameters to describe background
- 27 parameters in the full fit ($pars$)
  - 9 physics parameters
    - 3 parameters of the $B_S, \overline{B}_S$ system (not Δm_S)
    - 3 transversity amplitudes $|A_0|$, $|A_{||}|$, $|A_S|$
    - 3 strong phases $\delta_\perp$, $\delta_{||}$, δ_S
  - signal fraction $f_S \to$ number of signal events
  - parameters describing various distributions
    - the J/ψ signal mass distribution, angular background distributions, estimated decay time uncertainty distributions for signal and background events, scale factors

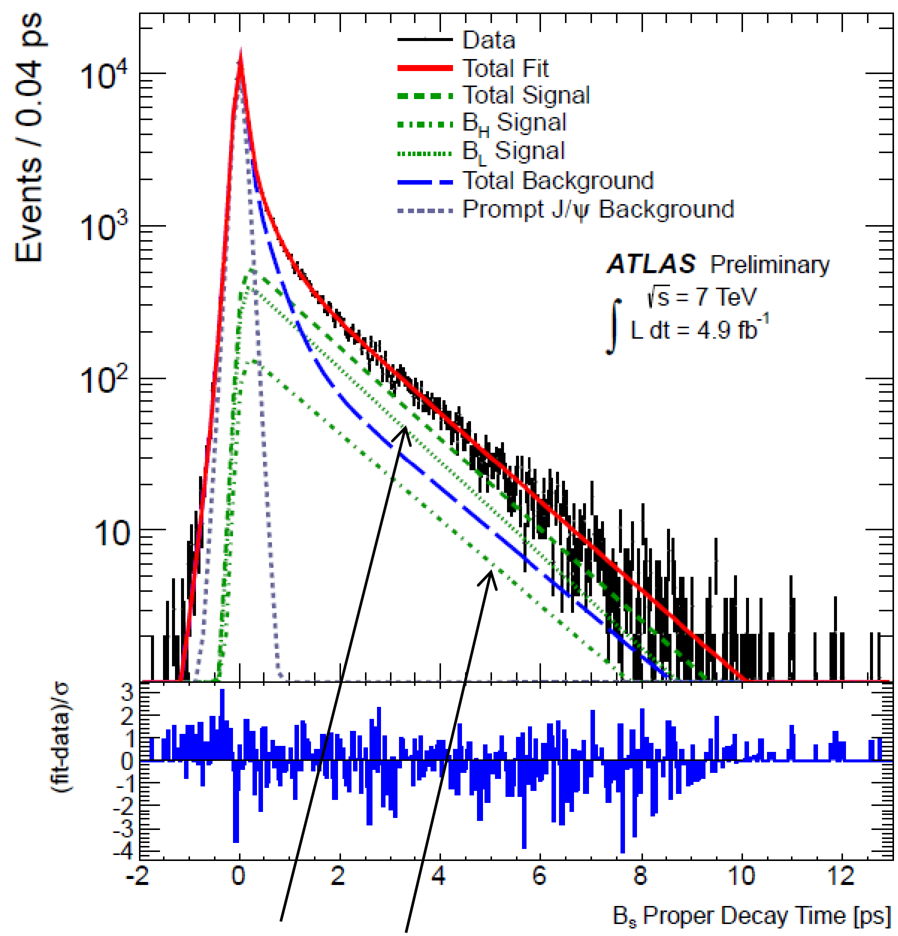
$$\max \mathcal{L}(pars; vars) \to \text{best fit}$$

Result of the fit: fit projections

B_S meson mass

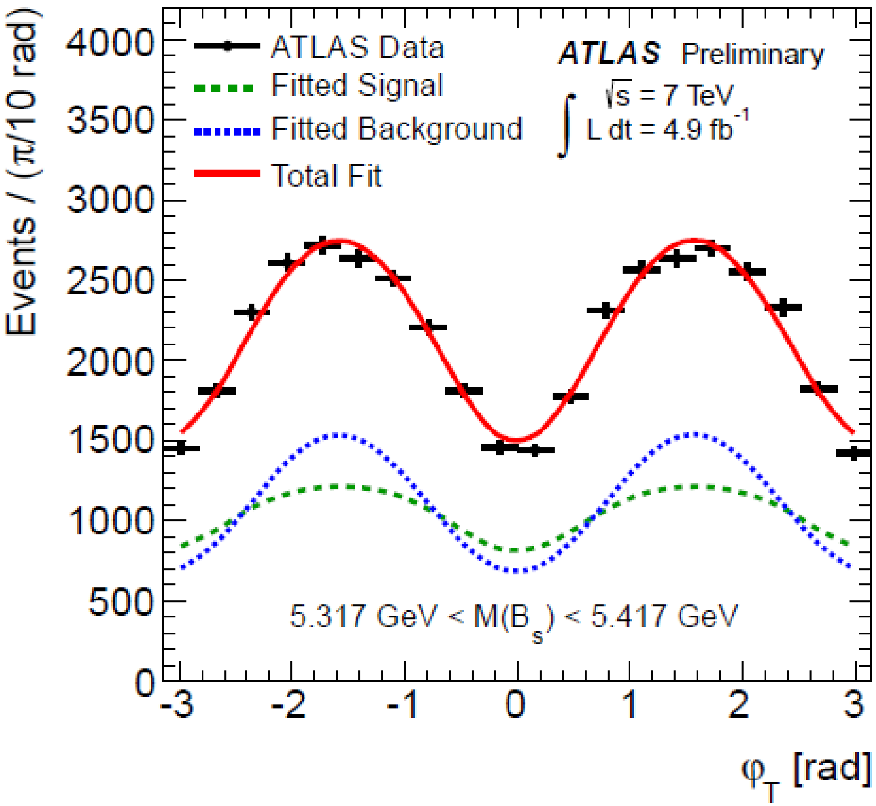


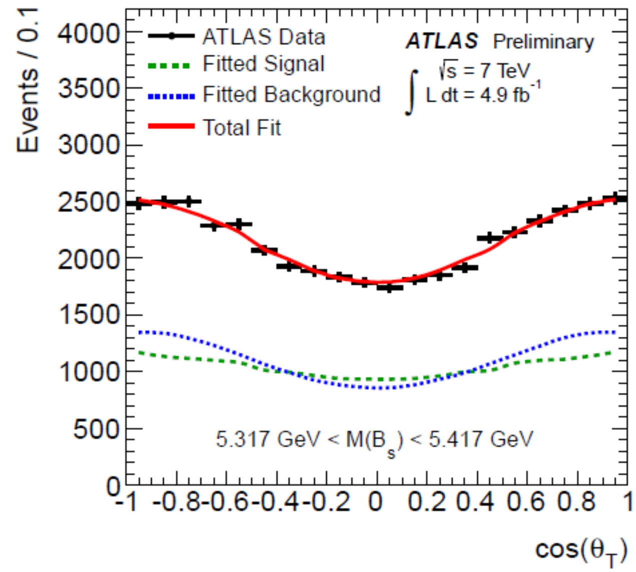
proper decay time

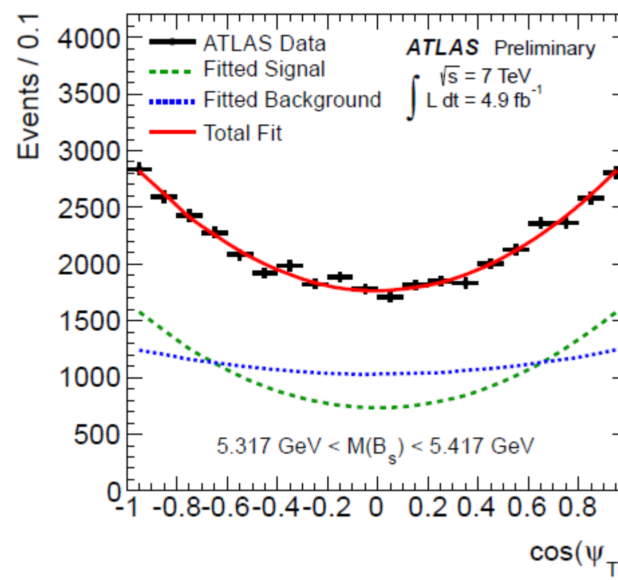


$$\Delta\Gamma_S = \Gamma_L - \Gamma_H$$

Fit projections – transversity angles







Important for measuring the absolute values of the transversity amplitudes A_0, $A_{||}$, $A_\perp$, A_S.

Systematic uncertainties

- They are calculated using **different techniques**, including changes in detector simulation (alignment), data based studies (efficiency), Monte Carlo pseudo experiments (mass models) and variations in analysis methods and assumptions.

Systematic Uncertainty	ϕ_s(rad)	$\Delta\Gamma_s$(ps^{-1})	Γ_s(ps^{-1})	$\lvert A_{\parallel}(0)\rvert^2$	$\lvert A_0(0)\rvert^2$	$\lvert A_S(0)\rvert^2$
Inner Detector alignment	0.04	< 0.001	0.001	< 0.001	< 0.001	< 0.01
Trigger efficiency	< 0.01	< 0.001	0.002	< 0.001	< 0.001	< 0.01
Signal mass model	0.02	0.002	< 0.001	< 0.001	< 0.001	< 0.01
Background mass model	0.03	0.001	< 0.001	0.001	< 0.001	< 0.01
Resolution model	0.05	< 0.001	0.001	< 0.001	< 0.001	< 0.01
Background lifetime model	0.02	0.002	< 0.001	< 0.001	< 0.001	< 0.01
Background angles model	0.05	0.007	0.003	0.007	0.008	0.02
B^0 contribution	0.05	< 0.001	< 0.001	< 0.001	0.005	< 0.01
Totals	0.10	0.008	0.004	0.007	0.009	0.02

Results of the fit in numbers

- Statistical error for ϕ_s rather large because of limited proper decay time resolution of ATLAS
  - but still competitive with Tevatron results

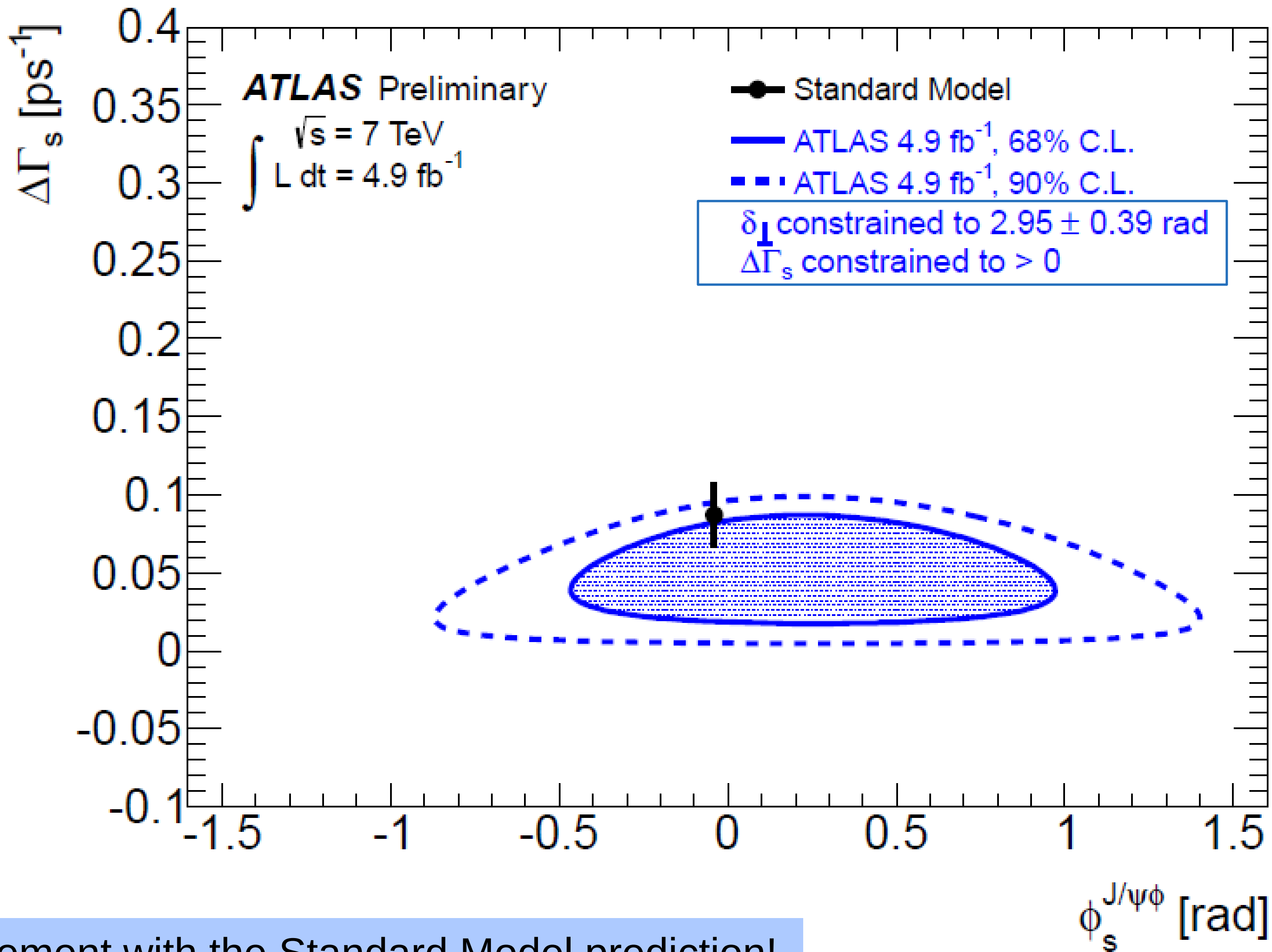
Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s(rad)	0.22	0.41	0.10
$\Delta\Gamma_s(\mathrm{ps}^{-1})$	0.053	0.021	0.008
$\Gamma_s(\mathrm{ps}^{-1})$	0.677	0.007	0.004
$\lvert A_0(0)\rvert^2$	0.528	0.006	0.009
$\lvert A_\parallel(0)\rvert^2$	0.220	0.008	0.007
$\lvert A_S(0)\rvert^2$	0.02	0.02	0.02

& correlation matrix

- Largest correlation between Γ_S and $\Delta\Gamma_S$
- B_S meson parameters are practically uncorrelated with the amplitudes.

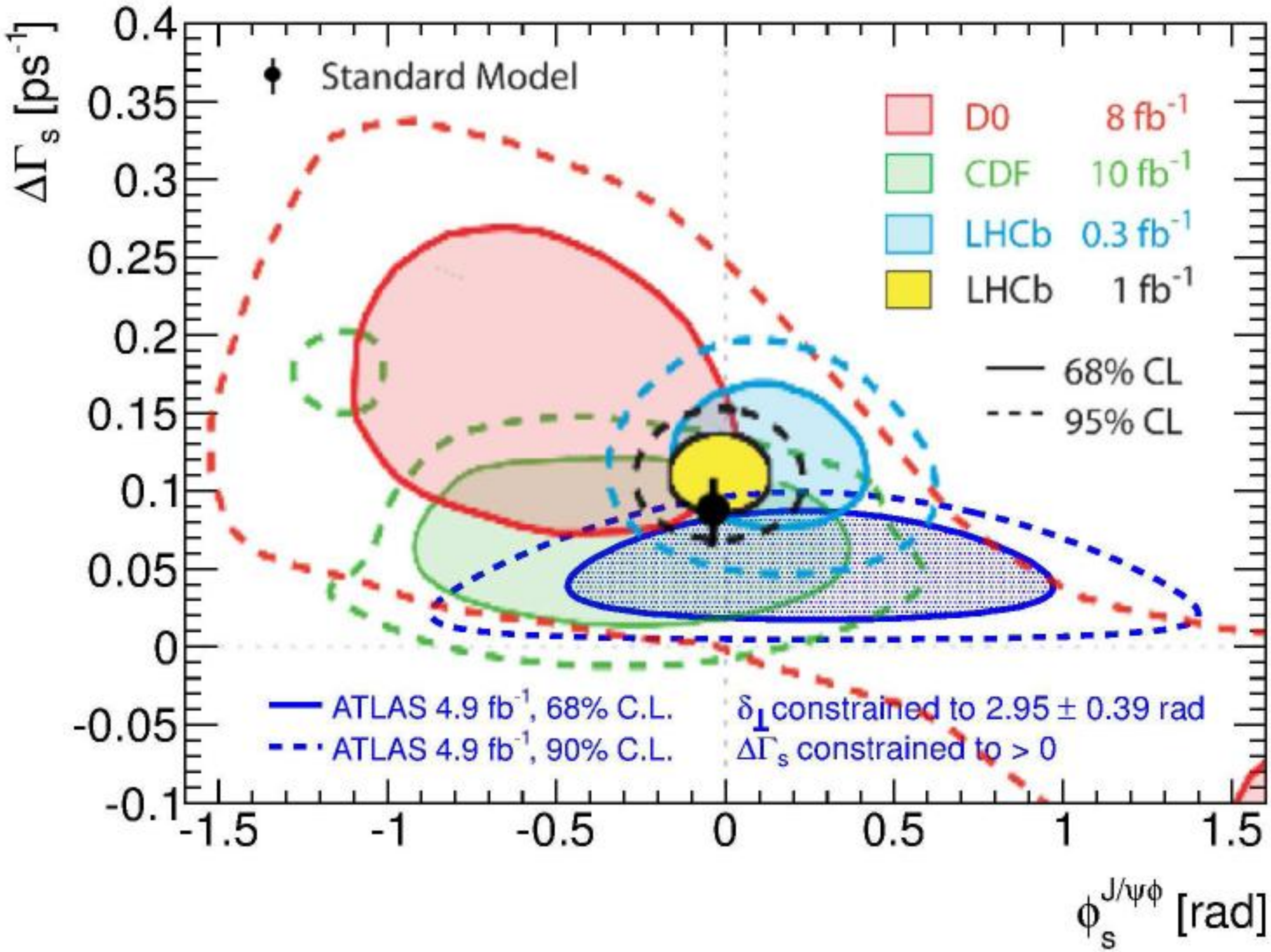
	ϕ_s	$\Delta\Gamma_s$	Γ_s	$\|A_0(0)\|^2$	$\|A_{\|\|}(0)\|^2$	$\|A_S(0)\|^2$
ϕ_s	1.00	−0.13	0.38	−0.03	−0.04	0.02
$\Delta\Gamma_s$		1.00	−0.60	0.12	0.11	0.10
Γ_s			1.00	−0.06	−0.10	0.04
$\|A_0(0)\|^2$				1.00	−0.30	0.35
$\|A_{\|\|}(0)\|^2$					1.00	0.09
$\|A_S(0)\|^2$						1.00

Likelihood contours: ϕ_s-$\Delta\Gamma_s$ plane



Agreement with the Standard Model prediction!

Comparison



Standard Model
D0 8 fb^{-1}
CDF 10 fb^{-1}
LHCb 0.3 fb^{-1}
LHCb 1 fb^{-1}
68% CL
95% CL
ATLAS 4.9 fb^{-1}, 68% C.L.
ATLAS 4.9 fb^{-1}, 90% C.L.
$\delta_\perp$ constrained to 2.95 ± 0.39 rad
$\Delta\Gamma_s$ constrained to > 0
$\Delta\Gamma_s$ [ps^{-1}]
$\phi_s^{J/\psi\phi}$ [rad]

Conclusion

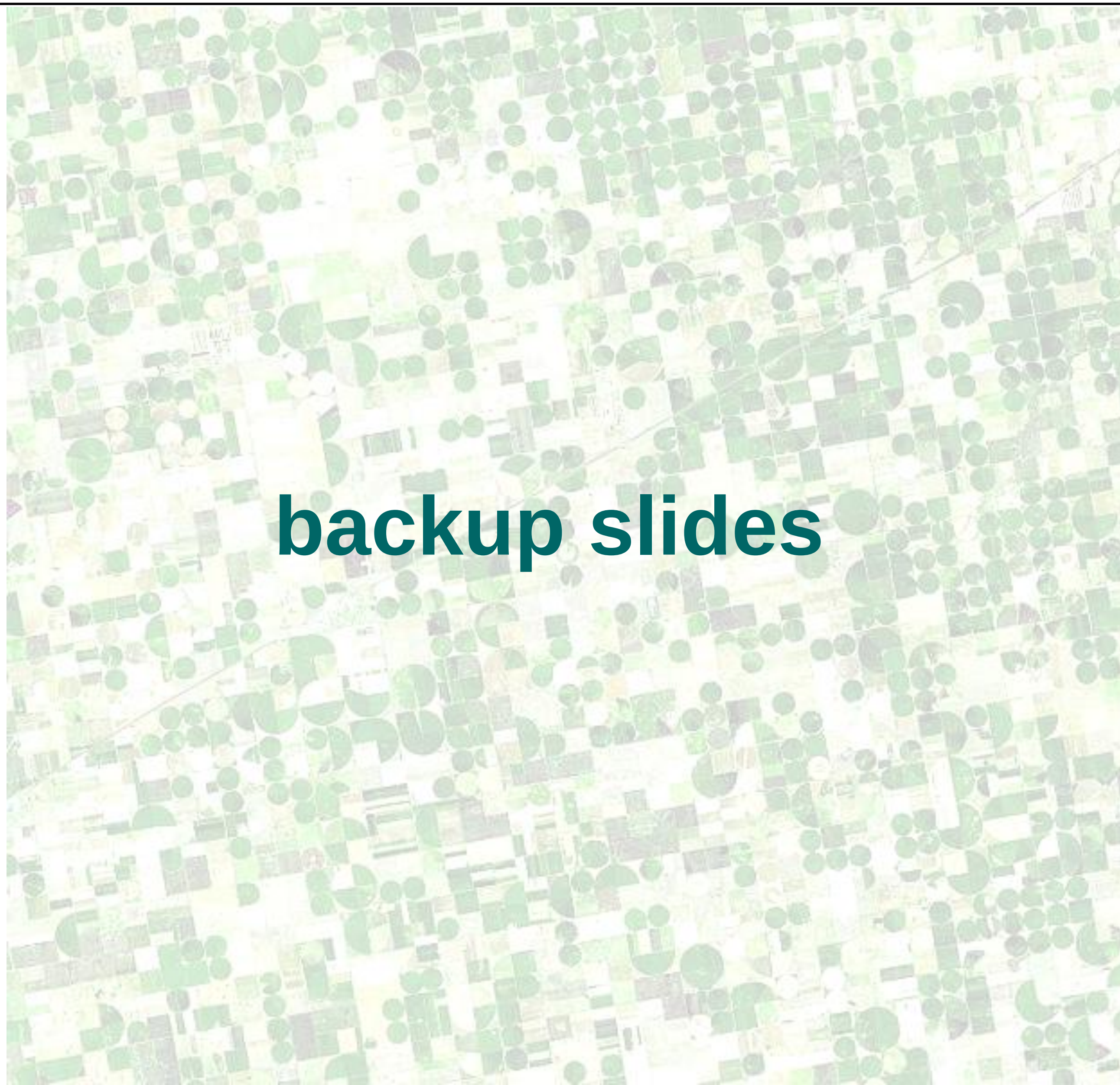
- From 4.9 fb^{-1} of data collected by ATLAS in 2011 decay time and angular distributions have been studied in a sample of 22700 $B_S/\overline{B}_S \to J/\psi\ \phi$ decays.
  Without flavor tagging, and assuming $\delta_\perp = 2.95 \pm 0.39$ rad the results of the analysis are:

$$\begin{aligned}
\phi_s &= 0.22 \pm 0.41\ (\text{stat.}) \pm 0.10\ (\text{syst.})\ \text{rad} \\
\Delta\Gamma_s &= 0.053 \pm 0.021\ (\text{stat.}) \pm 0.008\ (\text{syst.})\ \text{ps}^{-1} \\
\Gamma_s &= 0.677 \pm 0.007\ (\text{stat.}) \pm 0.004\ (\text{syst.})\ \text{ps}^{-1} \\
|A_0(0)|^2 &= 0.528 \pm 0.006\ (\text{stat.}) \pm 0.009\ (\text{syst.}) \\
|A_{||}(0)|^2 &= 0.220 \pm 0.008\ (\text{stat.}) \pm 0.007\ (\text{syst.})
\end{aligned}$$

- Future:
  - Plan to implement flavor tagging (distinguish $B_S/\overline{B}_S$)
  - Increased data sample in 2012 (~ factor 3 is realistic), but fewer events /fb^{-1} (due to increased p_T cuts); expect to half our statistical errors.

References

- SM expected values for ϕ_S, $\Delta\Gamma_S$
  - UTFit Collaboration, PRL 97, 151803 (2006)
- Decay time an angular correlation formalism
  - A. Dighe, I. Dunietz, R. Fleischer, EPJ-C 6 (1999) 647
- Results from other experiments (LHCb, CDF, D0)
  - CDF Collaboration: CDF-Public-Note-10778
  - D0 Collaboration: PRD85, 032006 (2012)
  - LHCb Collaboration: LHCb-CONF-2012-002;
    PRL 108, 101803 (2012); PRL 108, 241801 (2012)
- This ATLAS analysis
  - ATLAS Collaboration, ALTAS-CONF-2012-xxx



backup slides

ATLAS result on strong phases

Input:

δ_{perp}	Constrained to 2.95 ± 0.39 rad

Likelihood fit:

δ_{par}	Best fit: π, $1\,\sigma$ range: 3.04—3.24 rad
$\delta_{perp} - \delta_S$	0.03 ± 0.13 rad

Maximum Likelihood fit

$$\ln\ \mathcal{L} = \sum_{i=1}^{N} \{ w_i \cdot \ln(f_{\rm s} \cdot \boxed{\mathcal{F}_{\rm s}(m_i, t_i, \Omega_i)} + f_{\rm s} \cdot f_{\rm B^0} \cdot \boxed{\mathcal{F}_{\rm B^0}(m_i, t_i, \Omega_i)}$$
$$+ (1 - f_{\rm s} \cdot (1 + f_{\rm B^0})) \boxed{\mathcal{F}_{\rm bkg}(m_i, t_i, \Omega_i)}) \} + \underbrace{\ln P(\delta_\perp)}_{\text{Gaussian constraint}}$$

signal:

$$\mathcal{F}_{\rm s}(m_i, t_i, \Omega_i) = P_{\rm s}(m_i|\sigma_{m_i}) \cdot \overbrace{P_{\rm s}(\sigma_{m_i})} \cdot \underbrace{P_{\rm s}(\Omega_i, t_i|\sigma_{t_i})}_{\text{10 } O^{(k)}\text{-functions}} \cdot \overbrace{P_{\rm s}(\sigma_{t_i})} \cdot \underbrace{A(\Omega_i, p_{{\rm T}i})}_{\text{angular sculpting}} \cdot \overbrace{P_{\rm s}(p_{{\rm T}i})}$$

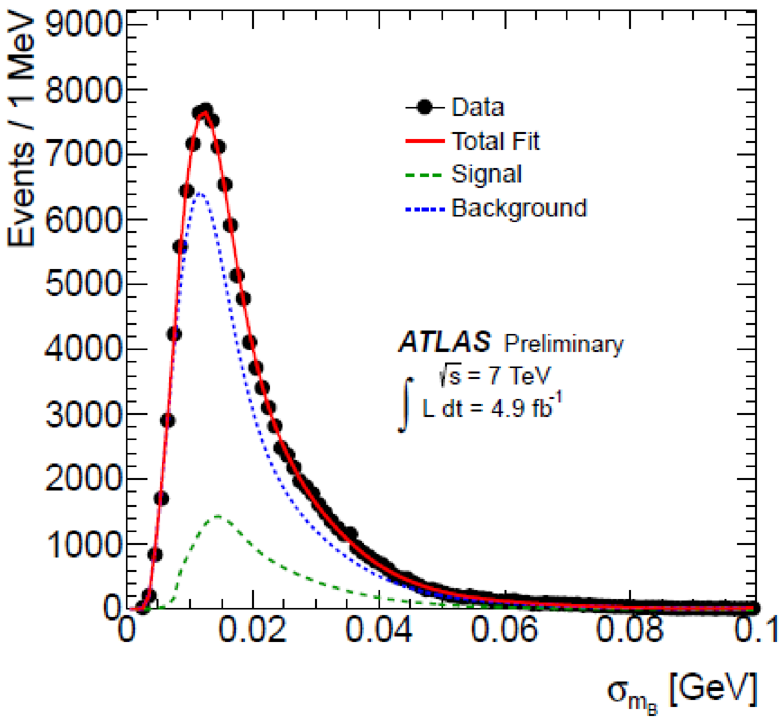
background:

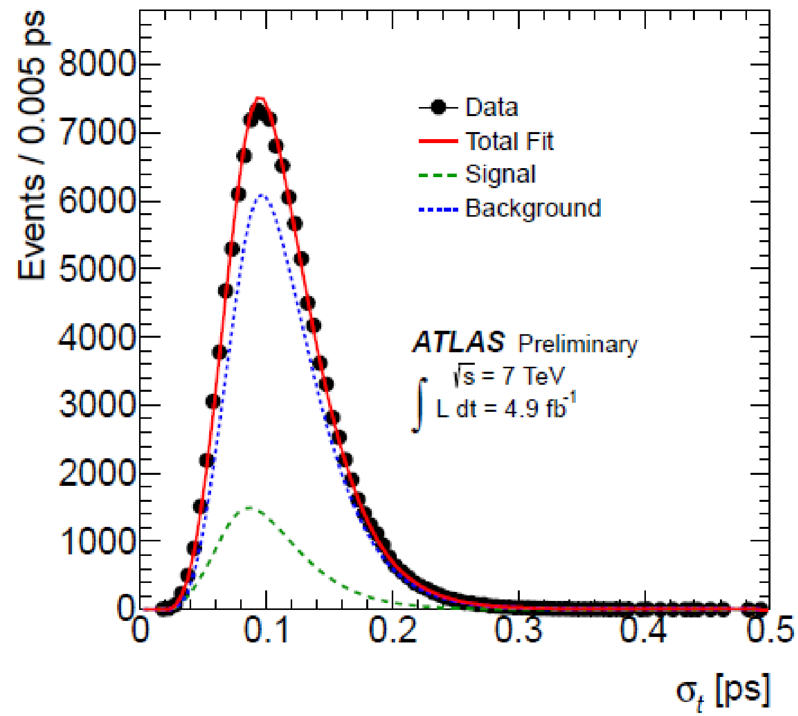
$$\mathcal{F}_{B^0}(m_i, t_i, \Omega_i) = P_{B^0}(m_i) \cdot P_{\rm s}(\sigma_{m_i}) \cdot P_{B^0}(t_i|\sigma_{t_i})$$
$$\cdot\ P_{B^0}(\theta_T) \cdot P_{B^0}(\varphi_T) \cdot P_{B^0}(\psi_T) \cdot P_{\rm s}(\sigma_{t_i}) \cdot P_{\rm s}(p_{{\rm T}i})$$

$$\mathcal{F}_{\rm bkg}(m_i, t_i, \Omega_i) = P_{\rm b}(m_i) \cdot P_{\rm b}(\sigma_{m_i}) \cdot P_{\rm b}(t_i|\sigma_{t_i})$$
$$\cdot\ P_{\rm b}(\theta_T) \cdot P_{\rm b}(\varphi_T) \cdot P_{\rm b}(\psi_T) \cdot P_{\rm b}(\sigma_{t_i}) \cdot P_{\rm b}(p_{{\rm T}i})$$

Uncertainty distributions $P_{s,b}(\sigma_{m,t})$

Mass and decay-time measurements enter the likelihood with event-by-event uncertainties. The error distributions are extracted from data. Checks done → no significant systematics.





Mass uncertainty distribution from data, the fits to the background an the signal fractions and the sum of the two fits.

Same for:
Proper decay time uncertainty distribution.

Mass distributions

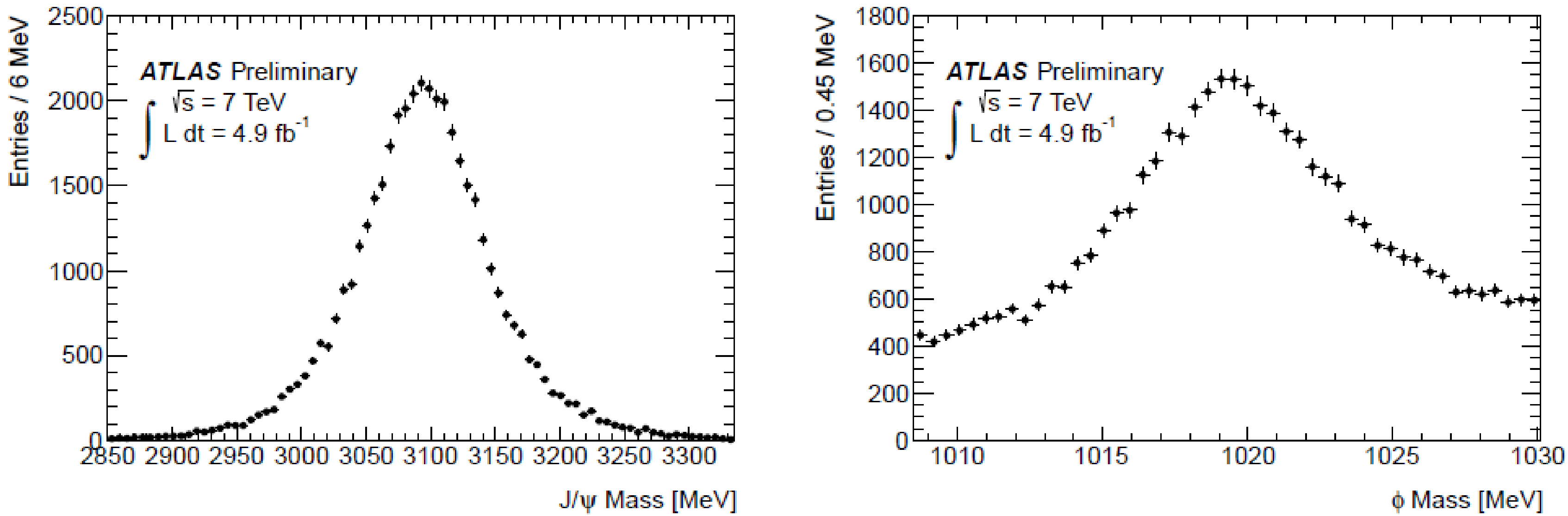
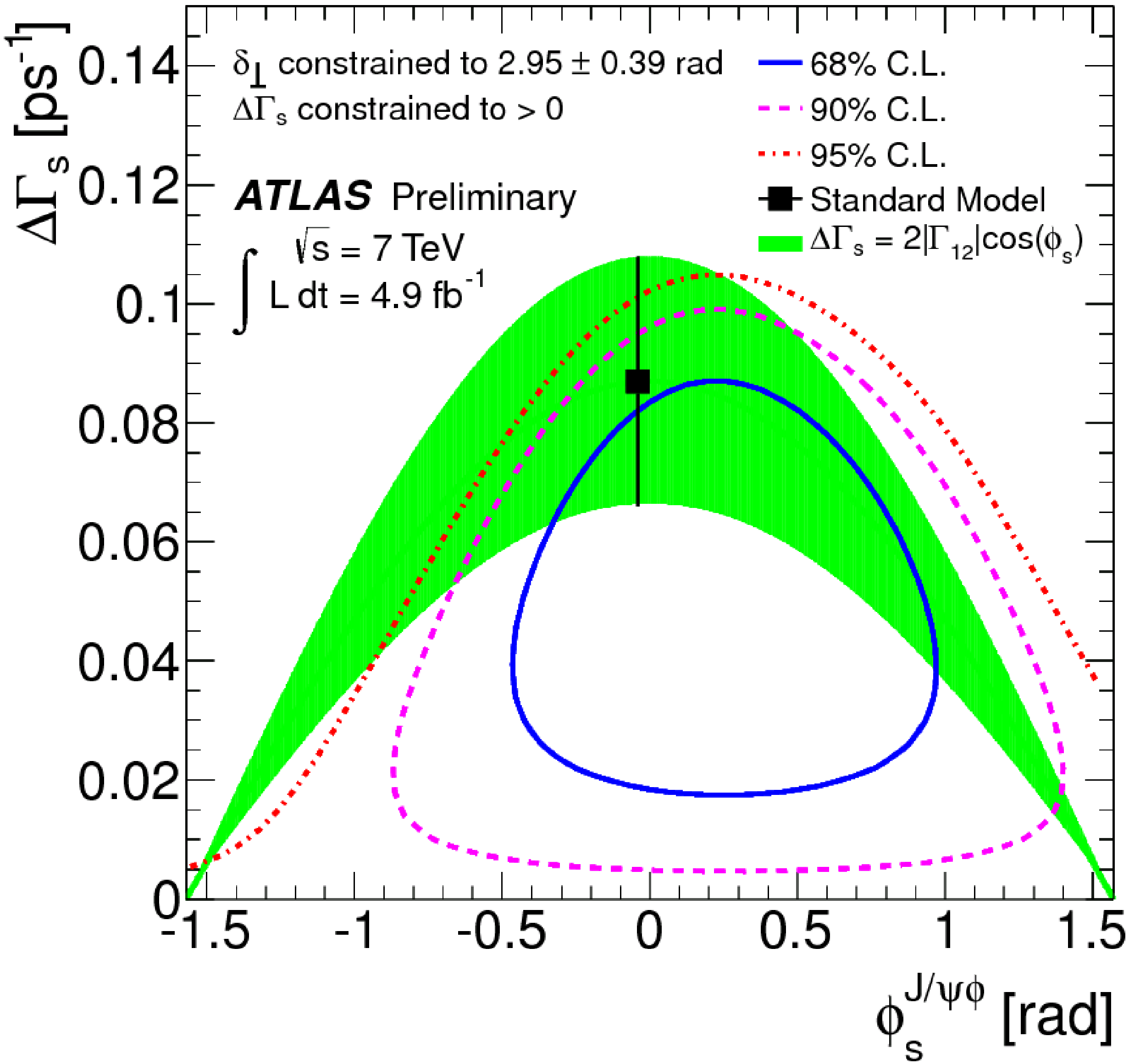
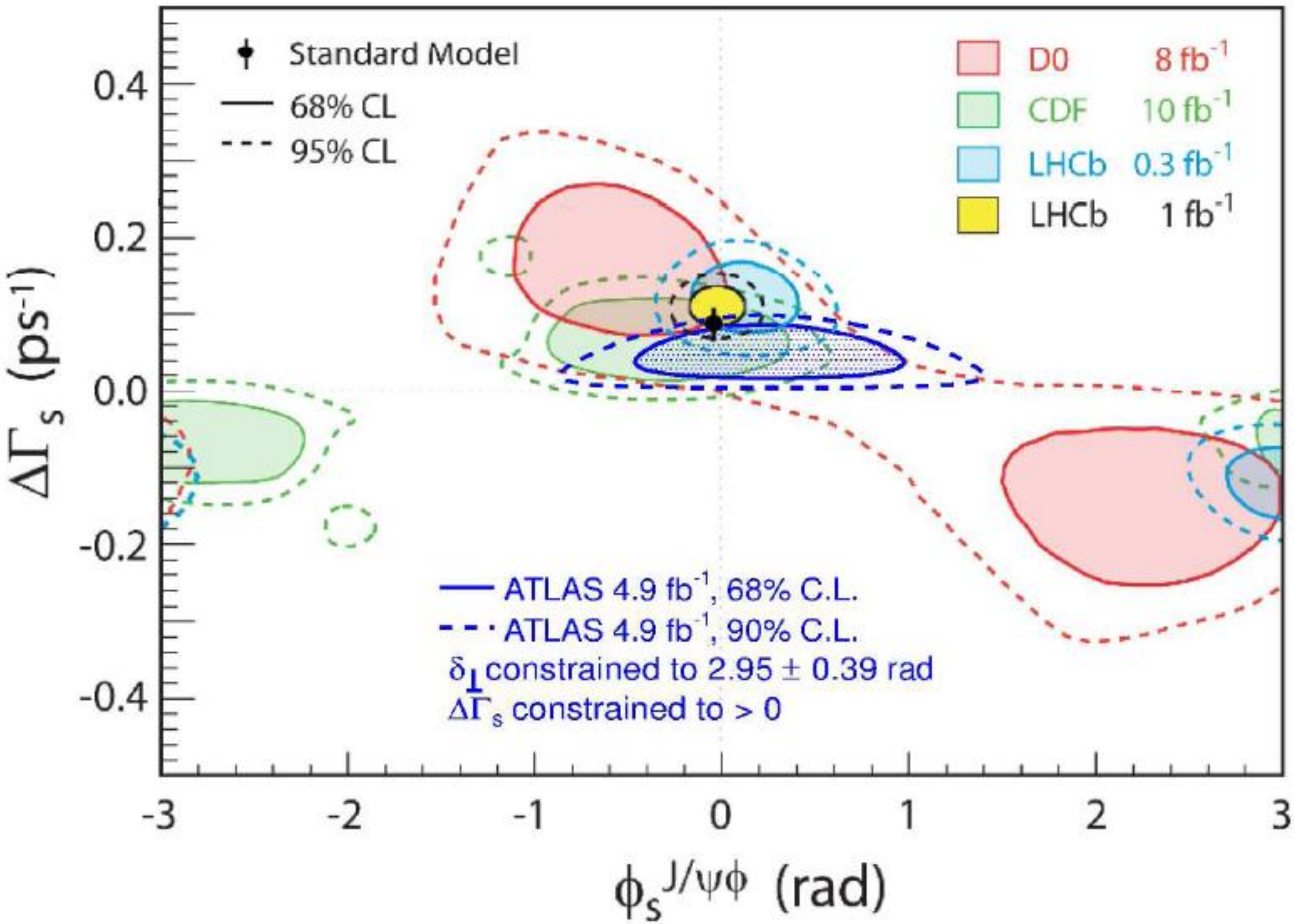


Figure 11. Mass distributions of $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$ decays for B_s^0 candidates within the signal mass range 5.317 GeV < m(B_s^0) < 5.417 GeV.

Contour plot



on a lager scale



Comparision of measurements

- compiled by S. Palestini

	Γ_s [ps-1]	$\Delta\Gamma_s$ [ps-1]	$\lvert A_0\rvert^2$	$\lvert A_{par}\rvert^2$	φ_s [rad]	$\lvert A_S\rvert^2$	δ_{perp} [rad]	δ_{par} [rad]	δ_S [rad]	Signal sample
D0 (8 fb-1, stat(+)syst $\Delta\Gamma s>0$ case)	0.693 -0.020 +0.015	0.179 -0.060 +0.059	0.565 ±0.017	0.249 -.022 +.021	-0.56 -0.32 +0.36	0.173 ±0.036 *effective*	*Near π [Assum. cos (δ_{perp}) <0]*	3.15 ±0.19	cos(δ_{perp}-δ_S) = -.20 -.27+.26	~5300
CDF (10fb^{-1}, unpublished)	0.654 ±0.008 ±0.004	0.068 ±0.026 ±0.007	0.512 ±0.012 ±0.017	0.229 ±0.010 ±0.014	=SM Fit:-0.24±0.36	*Appar. small*	2.79 ±0.53 ±0.15	*Near π*	*Small effect*	11000
LHCb (1fb^{-1}, unpublished)	0.6580 ±0.0054 ±0.0066	0.116 ±0.018 ±0.006	0.523 ±0.007 ±0.024	*0.231 ±0.021* [*]	-0.001 ±0.101 ±0.027	0.022 ±0.012 ±0.007	2.90 ±0.36 ±0.07	*Near π ±0.33 ±0.13*	2.90 ±0.36 ±0.08	21000
ATLAS (4.9fb^{-1}, preliminary)	0.677 ±0.007 ±0.004	0.053 ±0.021 ±0.008	0.528 ±0.006 ±0.009	0.220 ±0.008 ±0.007	0.22 ±0.41 ±0.10	0.02 ±0.02 ±0.02	*Assum. 2.95 ±.39*	*near π*	*Near δ_{perp}*	23000

[*] from $\lvert A_0\rvert^2$ and $\lvert A_{par}\rvert^2$, summing stat. and syst. errors in quadrature and using quoted (negative) correlation coefficient.

New Physics in $B_S - \overline{B}_S$ mixing

- Would change the off-diagonal element M_{12} of the **mass matrix** (but not significantly affect the corresponding decay matrix element Γ_{12})
  - parametrization: $M_{12}^s \equiv M_{12}^{\mathrm{SM},s} \cdot \Delta_s\,, \qquad \Delta_s \equiv |\Delta_s| e^{i\phi_s^\Delta}.$
  - correction adds linearly to the weak phase, like in $\sin\left(\phi_s^{\mathrm{SM}} + \phi_s^\Delta\right)$
  - for small ϕ_S only contributes quadratically to $\Delta\Gamma_S$: $\Delta\Gamma_s = 2|\Gamma_{12}^s| \cos\left(\phi_s^{\mathrm{SM}} + \phi_s^\Delta\right)$
  - magnitude measurable through oscillation frequency: $\Delta M_s = \Delta M_s^{\mathrm{SM}} |\Delta_s|$