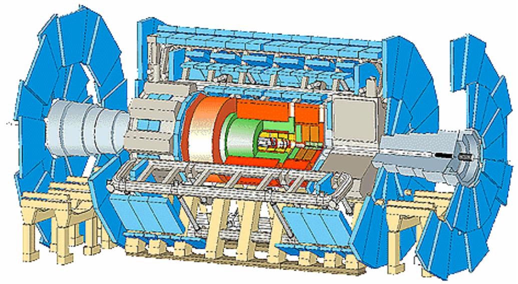

High Precision Measurements of B_s Parameters in $B_s \rightarrow J/\psi\phi$

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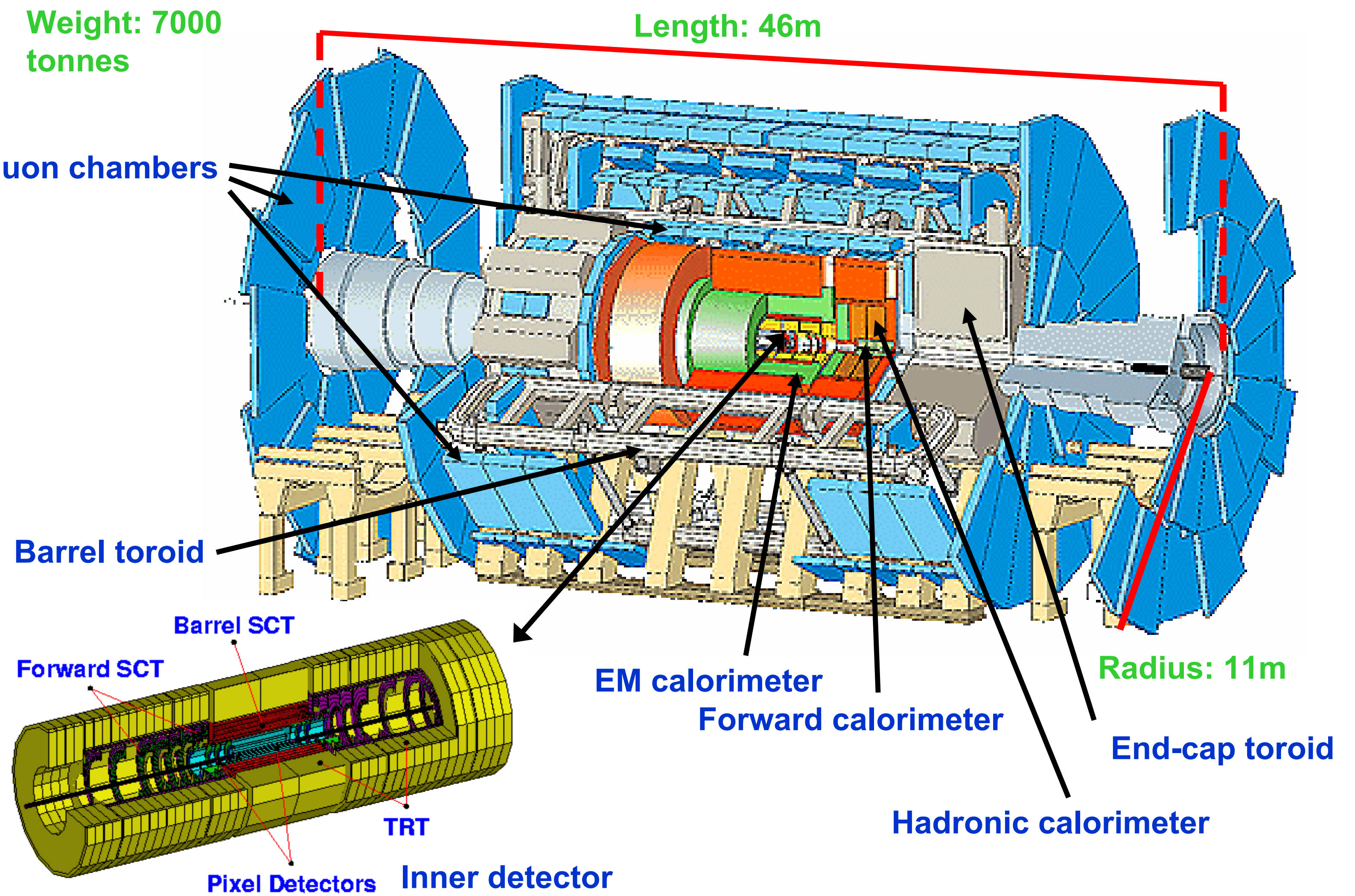
Beauty 2005, Assisi, Italy

Overview of ATLAS



The LHC Environment

- pp collisions: 14 TeV centre of mass energy
- Luminosity:
  - 2007: 50 days @ 0.5 x 10^{33} $cm^{-2}s^{-1}$ — Tuning
  - 2008-2009: 200 days @ 2 x 10^{33} $cm^{-2}s^{-1}$ — "Low"
  - 2010+: 10^{34} $cm^{-2}s^{-1}$ — "High"
  - Drops by factor ~2 during 10 hour run
- 1 proton bunch crossing every 25ns
  - 4.6/23 pp collisions/crossing @ low/high luminosity
  - ~1% of pp collisions produce a bb pair
- At luminosity 2 x 10^{33} $cm^{-2}s^{-1}$
  - bb events produced with rate of 10^6 Hz
  - 10Hz output to permanent storage for B-physics

→ so highly selective and adaptable B-physics trigger required

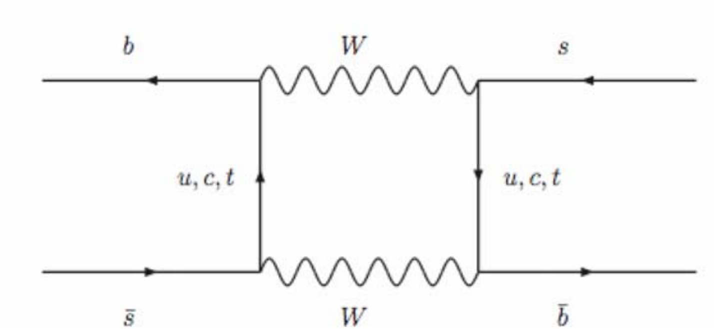
B-physics trigger strategies (see Natalia Panikashvili)

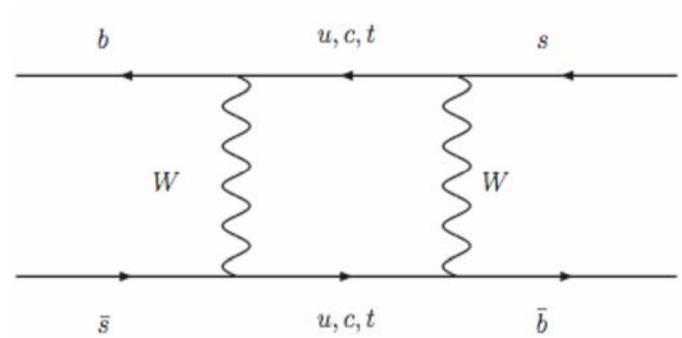
Trigger	LVL1	LVL2 & event filter	Example channels
Di-muon L @ 2.10^{33} ($L \approx 10^{34}$)	**2 muons** $p_T > 6$ GeV (barrel) 3 GeV (end-caps)	Confirm muons Refit tracks in ID Decay vertex reconstr. Select decays using mass/decay length cuts	$B_d \rightarrow J/\psi(\mu\mu)K^0_S$ $B_s \rightarrow J/\psi(\mu\mu)\varphi$ $B \rightarrow \mu\mu$ $B \rightarrow K^{0*}\mu\mu$ $B \rightarrow \phi\mu\mu$ $\Lambda_b \rightarrow \Lambda^0 J/\psi(\mu\mu)$ $\Lambda_b \rightarrow \Lambda^0 \mu\mu$
EM+μ $L < 2.10^{33}$	**1 muon** $p_T > 6$ GeV **1 EM cluster** $E_T > 2$GeV	Confirm muons & EMC Decay vertex reconstr. Refit tracks Selections	$B_d \rightarrow J/\psi(\mu\mu)K^0_S + b \rightarrow eX$ $B_d \rightarrow J/\psi(ee)K^0_S + b \rightarrow \mu X$ $B_d \rightarrow K^{0*}\gamma$ $B_s \rightarrow \phi\gamma + b \rightarrow \mu X$
Hadronic $L < 2.10^{33}$	**1 muon** $p_T > 6$ GeV **1 jet cluster** $E_T > 5$GeV	Confirm muons & j.c. Decay vertex reconstr. Refit tracks Selections	$B_s \rightarrow D_s(\varphi(KK))\pi$ $B_s \rightarrow D_s (\varphi(KK))\, a_1(\rho^0\pi^+)$ $B^+ \rightarrow K^+K^+\pi^-$ $B_d \rightarrow \pi^+\pi^-$ $(+ b \rightarrow \mu X)$

As luminosity drops during the fill, more triggers are turned on

B_s-$\bar{B}_s$ mixing

- General box diagrams for B_s-$\bar{B}_s$ mixing:



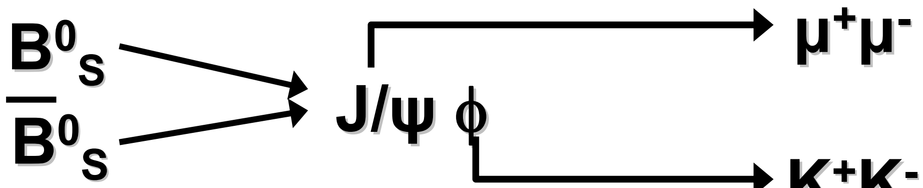


- $\Gamma_s = ½ (\Gamma_H + \Gamma_L)$
- $\Delta\Gamma_s = \Gamma_L - \Gamma_H$
- $\Delta M_s = M_H - M_L$
- $X_s = \Delta M_s / \Gamma_s$

- ϕ_s : mixing phase $= 2 \sin \theta_c \sin \gamma |V_{ub}| / |V_{cb}|$
  - Arises through the interference of mixing and decay
  - Highly sensitive to SUSY contributions
  - Parameter is small in the Standard Model (~0.02) so challenging measurement

$B_s \rightarrow J/\psi\phi$

1



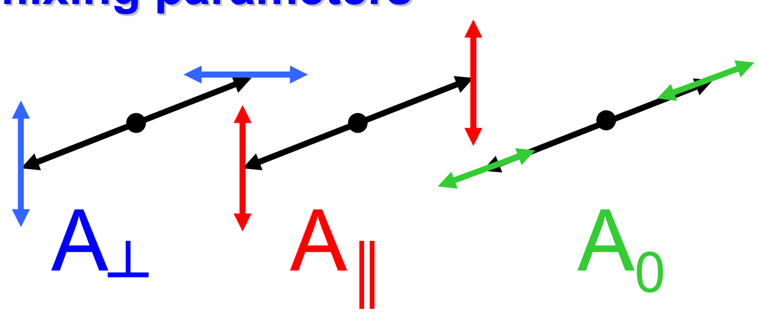
Extracting mixing parameters requires separation of CP eigenstate amplitudes

2

Scalar → Vector + Vector decay: final state described by three helicity amplitudes

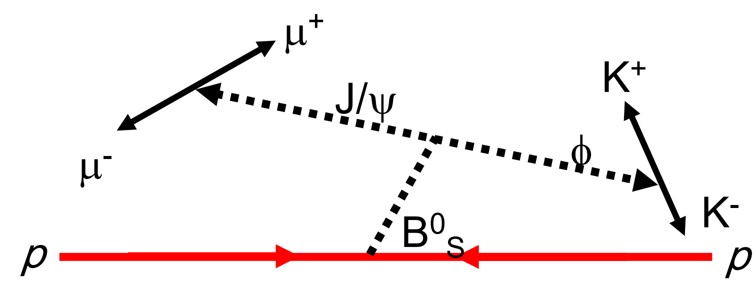
3

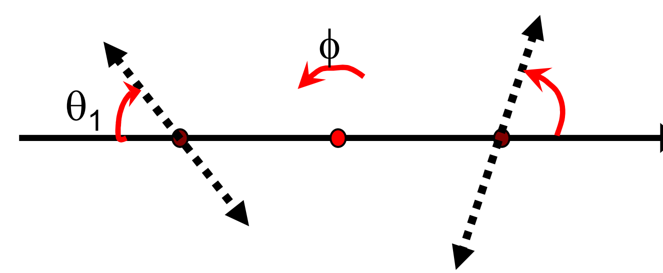
Transversity basis: linear combinations of helicity amplitudes which are CP-eigenstates. Complete determination yields mixing parameters



4

Determined by the angular distribution of the decay, and also proper times and tag





Decay parameterization

- **3 transversity amplitudes**
  - **2 independent magnitudes and 2 independent phases:**

    $|A_{\parallel}|$ $|A_{\perp}|$ δ_1 δ_2

- **3 mixing parameters, 1 weak phase**

  Γ_s $\Delta\Gamma_s$ ΔM_s ϕ_s

⇒ 8 parameters to be extracted from the data

Theoretical distribution

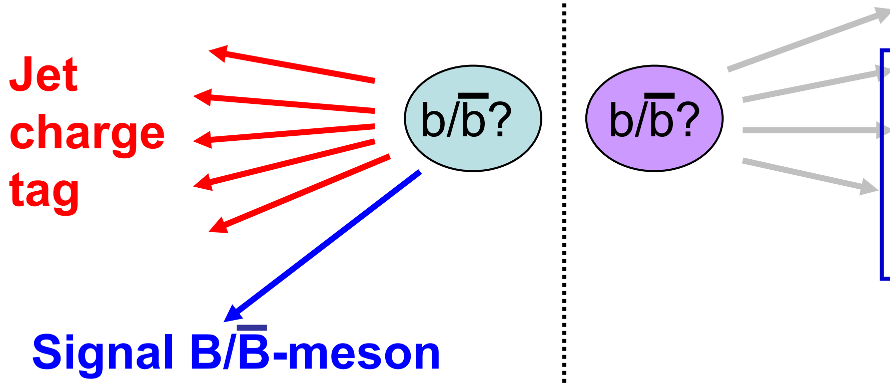
k	$\Omega^{(k)}(t)$		$g(t)$
1	$\lvert A_0(t)\rvert^2$		$4\sin^2\theta_1\cos^2\theta_2$
	$\frac{1}{2}\lvert A_0(0)\rvert^2$	$(1+\cos\phi_s)e^{-\Gamma_L^{(s)}t}+$ $(1-\cos\phi_s)e^{-\Gamma_H^{s}t}+$ $2e^{-\Gamma_s t}\sin(\Delta M_s t)\sin\phi_s$	
2	$\lvert A_\parallel(t)\rvert^2$		$(1+\cos^2\theta_1)\sin^2\theta_2-\sin^2\theta_1\sin^2\theta_2\cos 2\chi$
	$\frac{1}{2}\lvert A_\parallel(0)\rvert^2$	$(1+\cos\phi_s)e^{-\Gamma_L^{(s)}t}+$ $(1-\cos\phi_s)e^{-\Gamma_H^{s}t}+$ $2e^{-\Gamma_s t}\sin(\Delta M_s t)\sin\phi_s$	
3	$\lvert A_\perp(t)\rvert^2$		$(1+\cos^2\theta_1)\sin^2\theta_2+\sin^2\theta_1\sin^2\theta_2\cos 2\chi$
	$\frac{1}{2}\lvert A_\perp(0)\rvert^2$	$(1-\cos\phi_s)e^{-\Gamma_L^{(s)}t}+$ $(1+\cos\phi_s)e^{-\Gamma_H^{s}t}-$ $2e^{-\Gamma_s t}\sin(\Delta M_s t)\sin\phi_s$	
4	$\mathcal{R}\{A_0^*(t)A_\parallel(t)\}$		$2\sin^2\theta_1\sin^2\theta_2\sin 2\chi$
	$\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\parallel(0)\rvert\cos(\delta_2-\delta 1)$	$(1+\cos\phi_s)e^{-\Gamma_L(t)}+$ $(1-\cos\phi_s)e^{-\Gamma_H^{(s)}t}+$ $2e^{-\Gamma_s t}\sin(\Delta M_s t)\cos\phi_s$	
5	$\mathcal{I}\{A_\parallel^*(t)A_\perp(t)\}$		$-\sqrt{2}\sin 2\theta_1\sin 2\theta_2\cos\chi$
	$\lvert A_\parallel(0)\rvert\lvert A_\perp(0)\rvert$	$e^{-\Gamma_s t}\{\sin\delta_1\cos(\Delta M_s t)-$ $\cos\delta_1\sin(\Delta M_s t)\cos\phi_s\}-$ $\frac{1}{2}\left(e^{-\Gamma_H^{(s)}t}-e^{-\Gamma_L^{(s)}t}\right)\cos\delta_1\sin\phi_s$	
6	$\mathcal{I}\{A_0^*(t)A_\perp(t)\}$		$\sqrt{2}\sin 2\theta_1\sin 2\theta_2\cos\chi$
	$\lvert A_0(0)\rvert\lvert A_\perp(0)\rvert$	$e^{-\Gamma_s t}\{\sin\delta_2\cos(\Delta M_s t)-$ $\cos\delta_2\sin(\Delta M_s t)\cos\phi_s\}-$ $\frac{1}{2}\left(e^{-\Gamma_H^{(s)}t}-e^{-\Gamma_L^{(s)}t}\right)\cos\delta_2\sin\phi_s$	

+ h.c.

Accurately modelled by EvtGen

Distribution is model-independent – new physics enters through the modification of existing values

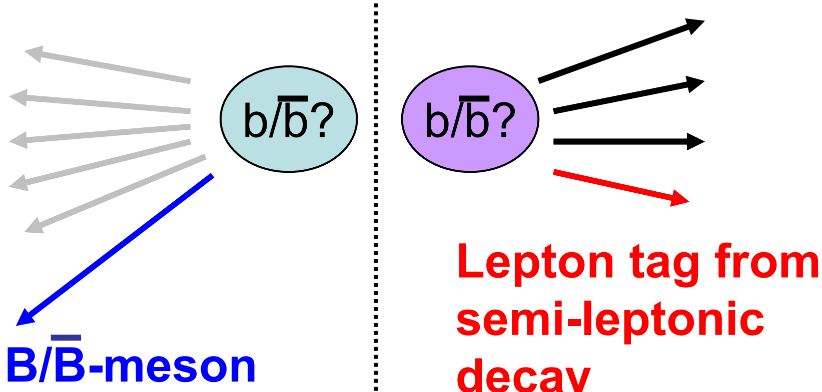
Is it a B or a $\bar{B}$? (Tagging)



For $B_{d(s)} \to J/\psi(\mu 6 \mu 3) K^0_S$

Tagging efficiency ε_{tag} = 0.64 (0.62)

Wrong-tag fraction W_{tag} = 0.42 (0.39)



$\varepsilon_{tag(electron)}$ = 0.012

$\varepsilon_{tag(muon)}$ = 0.025

$W_{tag(electron)}$ = 0.27

$W_{tag(muon)}$ = 0.24

The workflow

1	**EVENT GENERATION**: PythiaB, EvtGen
2	**SIMULATION/DIGITIZATION/RECONSTRUCTION**
3	**‘AS REAL’ ANALYSIS**
4	**PARAMETER EXTRACTION**: maximum likelihood using detector performance parameters derived from full simulation.

Details of Analysis

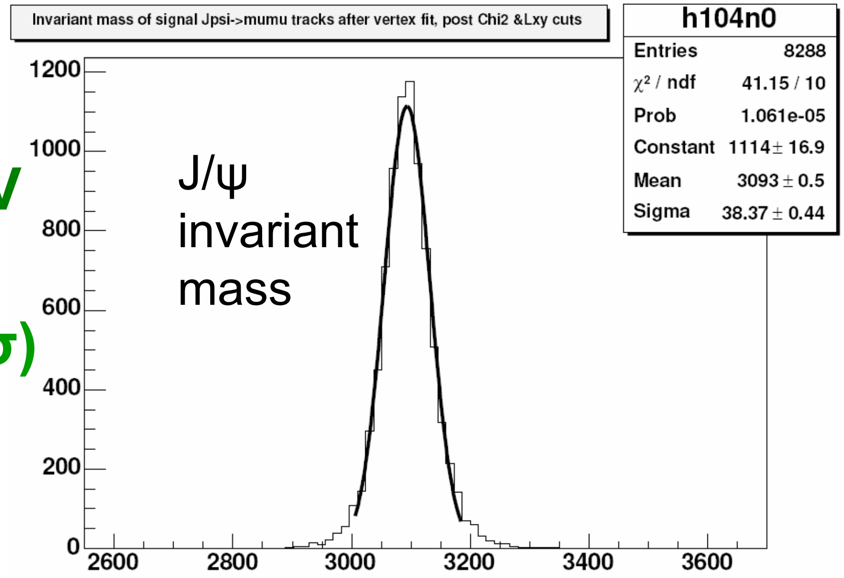
$B_S \rightarrow J/\psi(\mu\mu)\phi(KK)$

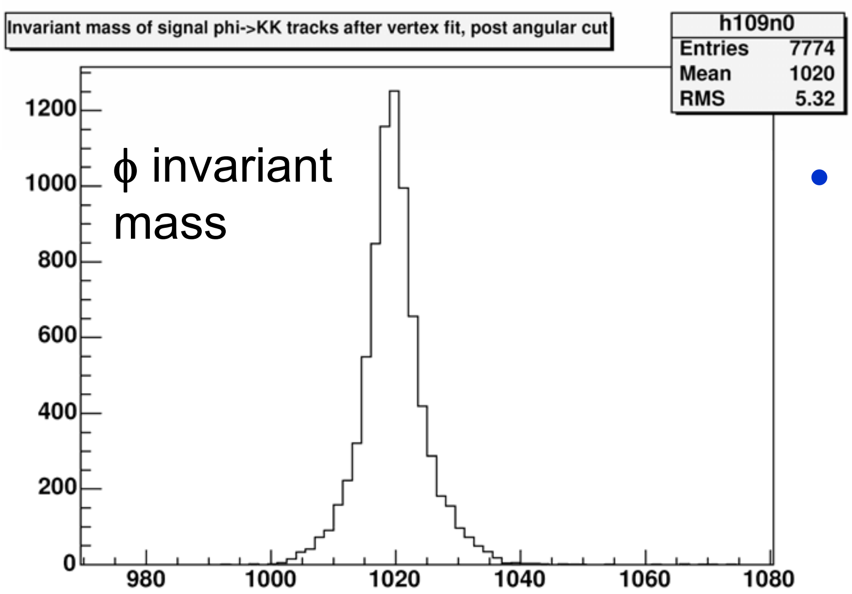
- **All studies based on fully simulated ATLAS events and using the current reconstruction software**
  - **1 000 000 B_s decays produced with PythiaB and EvtGen to generate the correct angular distribution and mixing**
    - **(model input: $A_\perp, A_\parallel, \delta_1, \delta_2, \Gamma_s, \Delta\Gamma_s, \phi_s, \Delta M_s$)**
  - **Cuts: 1 muon > 6 GeV; 1 muon > 3 GeV; kaons > 0.5 GeV**

All computations performed and all results stored on the Grid (LCG)

'As real' Analysis

- Fit track pairs to J/ψ hypothesis:
  - $p_T(\mu_1) > 3GeV$ && $p_T(\mu_2) > 3GeV$
  - $|\eta(\mu)| < 2.4$
  - $\chi^2/DoF < 6$ && $m(J/\psi) \in (-3\sigma, 3\sigma)$
  - $\sigma = 38MeV$

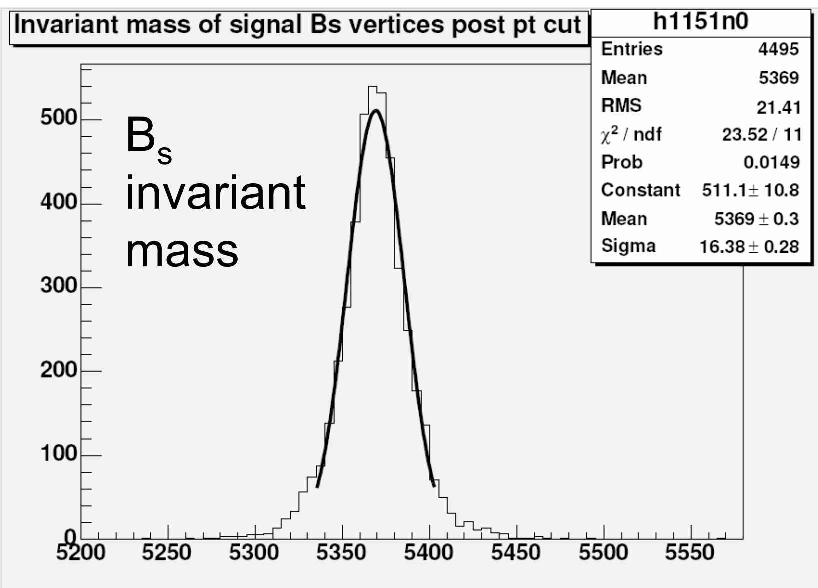


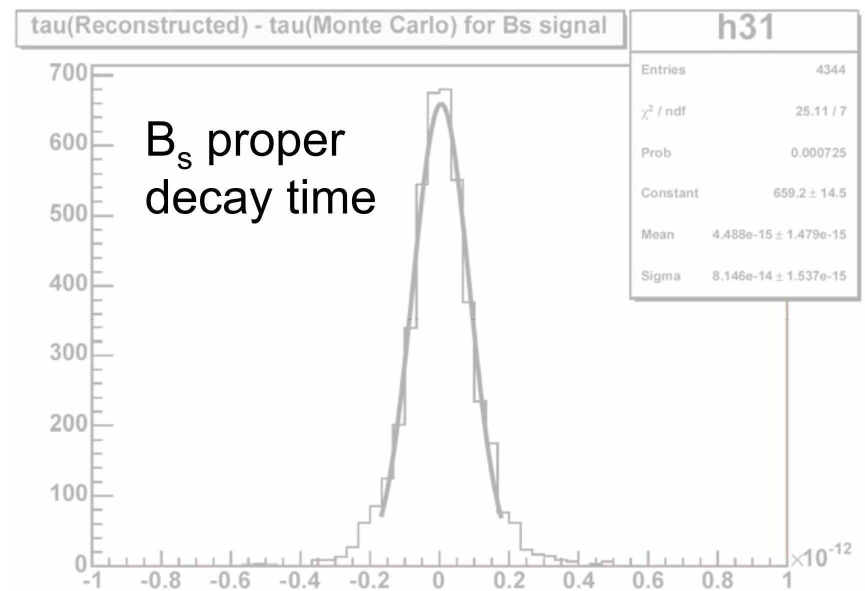


- Fit track pairs to ϕ hypothesis
  - $p_T(K) > 0.5GeV$
  - $|\eta(K)| < 2.4$
  - $\chi^2/DoF < 6$ && $m(\phi) \in (1009.2, 1029.6)$ GeV

‘As real’ Analysis

- B_s fit
  - Four-track fit to single vertex; χ^2/DoF < 10
  - must point at primary vertex
  - B_s proper decay time > 0.5ps
  - $p_T(B_s)$ > 10 GeV
  - $m(B_s) \in (-3\sigma, 3\sigma)$; σ = 17MeV





Analysis Results and projections

Total number of signal events within kinematic cuts after 30 fb^{-1}: 810 000

LVL1/LVL2 trigger di-muon efficiency: 77%

Number of signal events after trigger: 623 700

	Reconstruction Efficiency	Number of events after 30 fb^{-1}
Signal events with 4 reconstructed tracks	86.9%	542 000
Signal J/ψ reconstructed	80.6%	502 700
Signal ϕ reconstructed	72.6%	452 800
Successful Bs fits	53.4%	333 000
After cuts	43.4%	270 700

Background analysis

$B_d \rightarrow J/\psi(\mu\mu)K^{0*}(K^+\pi^-)$ (background 1)

$bb \rightarrow J/\psi(\mu\mu)X$ (background 2)

Background 1:

- Identical spin structure and topology to signal
  - S/B ~ 15.1

Background 2:

- Angular structure assumed to be isotropic
  - S/B ~ 6.8

- Simulation/digitization/reconstruction:
  - Identical to signal
- Analysis
  - Same analysis code run over background to calculate acceptance

Normalised Maximum Likelihood Estimator

Tagging efficiency.
B-tag: $\varepsilon_{tag1} = 1 - w$; $\varepsilon_{tag2} = w$
(Anti B)-tag: $\varepsilon_{tag1} = w$; $\varepsilon_{tag2} = 1 - w$
No tag: $\varepsilon_{tag1} = \varepsilon_{tag2} = 0.5$

Convolution with Gaussian to account for proper decay time resolution

$$L = \prod_{i=1}^{N} \int_0^{\infty} \frac{\left(\varepsilon_{tag}^1 \varepsilon_{rec}^1 W^+(t_i,\Omega) + \varepsilon_{tag}^2 \varepsilon_{rec}^2 W^-(t_i,\Omega) + b e^{-\Gamma_0 t_i}\right)\rho(t-t_i)dt}{\int_{t_{\min}}^{\infty}\left(\int_0^{\infty}\left(\varepsilon_{tag}^1 \varepsilon_{rec}^1 W^+(t,\Omega) + \varepsilon_{tag}^2 \varepsilon_{rec}^2 W^-(t,\Omega) + b e^{-\Gamma_0 t_i}\right)\rho(t'-t)dt'\right)dt}$$

Reconstruction efficiency and acceptance corrections: determined from simulation

Theoretical PDF:
W^+ for B^0 at production
W^- for anti-B^0 at production

Background (level determined from simulation)

Maximum Likelihood test results

- X_S fixed: can be determined with $B_s \rightarrow D_s \pi$
- Uncertainties on ϕ_s are a function of X_s

Uncertainties:

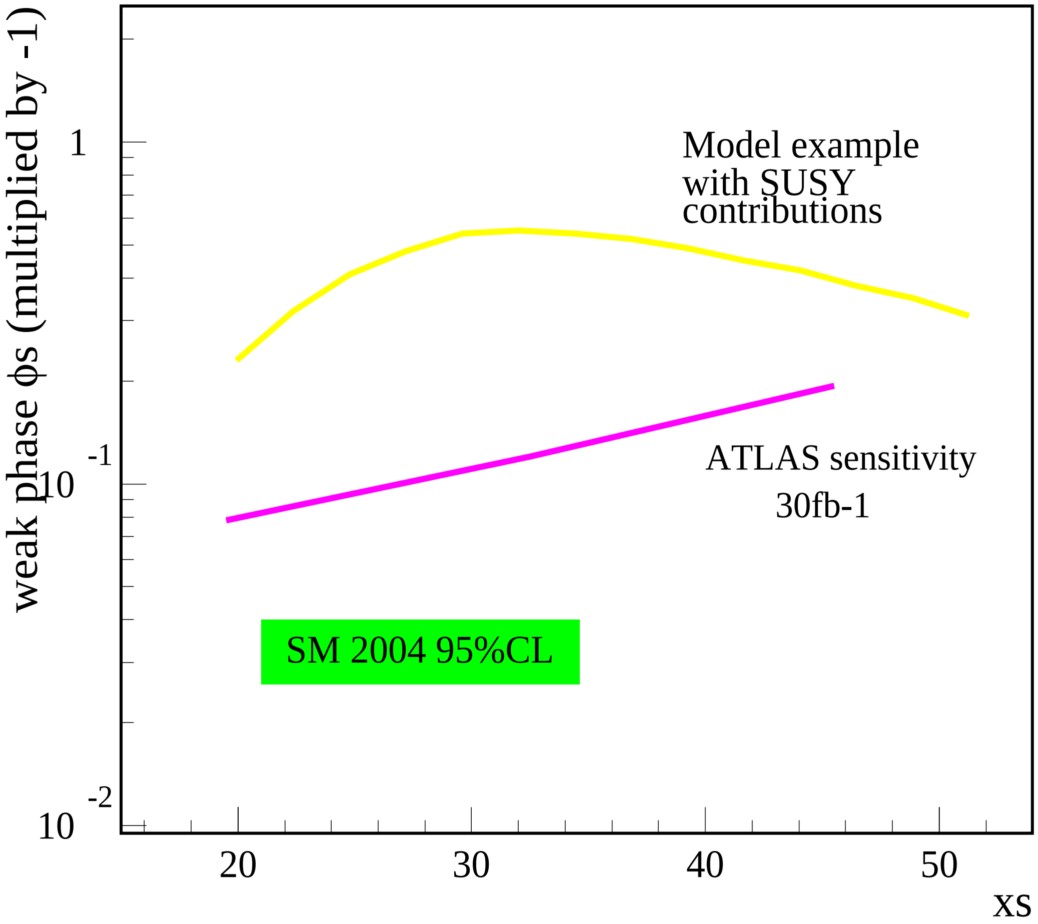
$\Delta\Gamma s$	12%
Γs	0.7%
$A_{\parallel}$	0.8%
$A_{\perp}$	3%
ϕ_s (X_s = 20)	0.03
ϕ_s (X_s = 40)	0.05

Correlations:

	Γ_s	$\Delta\Gamma_s$	δ_1	δ_2
Γ_s		70%		
$\Delta\Gamma_s$				
δ_1				98%
δ_2				

$\sigma(\tau_{Bs})$=85fs
$\Delta\Gamma_s/\Gamma$=0.1

Conclusion: Estimated reach of ATLAS



- No sensitivity to Standard Model values
  - (nor have LHCb or CMS)
- CDF recently made a unexpectedly large measurement of $\Delta\Gamma_s/\Gamma_s$
- Study of this "Golden Channel" in ATLAS should provide a rich yield of interesting data