ATLAS performance in B-physics channels sensitive to new physics

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The ATLAS B-physics programme

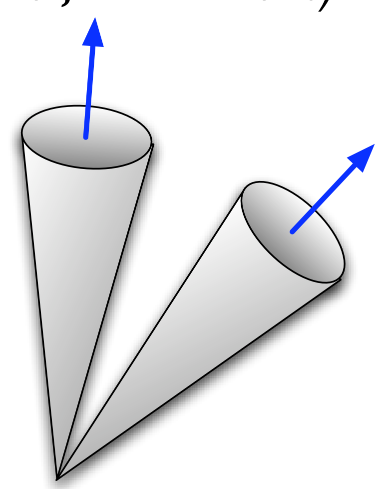
- Five main strands
  - Understanding the detector performance (alignment/tracking/trigger) using well understood B-decays
  - Measurement of production cross sections for B-hadrons and onia (J/ψ, Υ) to test QCD predictions for pp collisions at the LHC
  - Studies of the properties of the complete B-meson family (B^+, B_s, B_c, Λ_b + h.c.)
  - Precise measurements of weak B-hadron decays to search for BSM CP-violating effects
  - Searches for rare B-decays (such as $B_s \to \mu\mu$)

$\int \mathcal{L}$	Activity
<10 pb^{-1}	Validation of ID/trigger performance and alignment, data quality monitoring with J/ψ and Υ
20-200 pb^{-1}	Continuing performance studies; measurement of $bb \to J/\psi$, $pp \to J/\psi$, and $B^+ \to J/\psi K^+$ cross section ratios
200 pb^{-1} -1 fb^{-1}	Collect larger numbers of the main B-decays; start to contribute to world averages on B-hadron properties; start to set limits on rare decay branching ratios
1-30 fb^{-1}	Searches for new CP-violation in weak decays of B-mesons; rare decay searches; onia and Λ_b polarization studies;
>30 fb^{-1}	"High" LHC luminosity - main period for rare dimuon decay searches

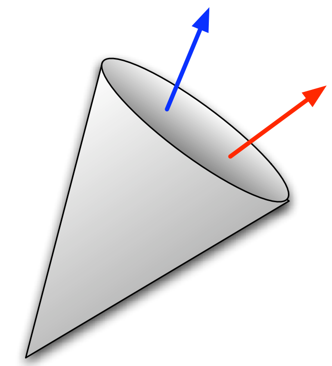
Triggers for B-physics di-muon events

- Many B-physics channels of interest involve a di-muon signature, e.g. $B \rightarrow J/\psi(\mu\mu)X$, $b \rightarrow s\mu\mu$, $B \rightarrow \mu\mu$ etc
- Muons from B-decays typically have rather low momenta (often <10 GeV)
- The most effective trigger for such events uses the di-muon signature from the lowest trigger level. This is the strategy deployed for ATLAS B-physics
  - If a single muon trigger is used we must either pre-scale or raise the threshold, to keep the rate to an acceptable level. This would have serious implications for efficiency
- Two main di-muon approaches:
  - **Topological di-muon trigger (main B-physics data taking phase)**
    - Two muons at level 1 with separate regions of interest (RoI); these muons then combined at L2 to generate an invariant mass / vertex fit which cuts are applied
  - TrigDiMuon (early data)
    - One muon at level 1, then widen RoI at L2 and search for a second muon; invariant mass cut then applied. Search for second muon candidate in the inner detector tracks and then confirm in muon detectors
- These efficient, fast and clean di-muon triggers will enable ATLAS B-physics studies to continue throughout the life of the LHC

Topological di-muon trigger (2 RoI; 2 L1 muons)

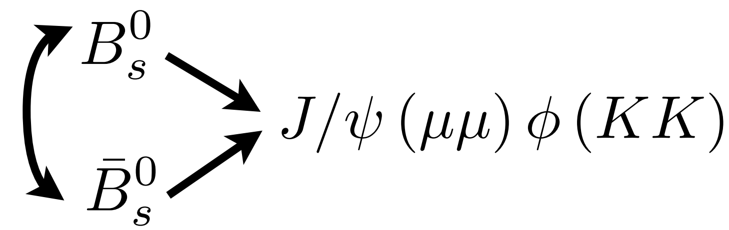


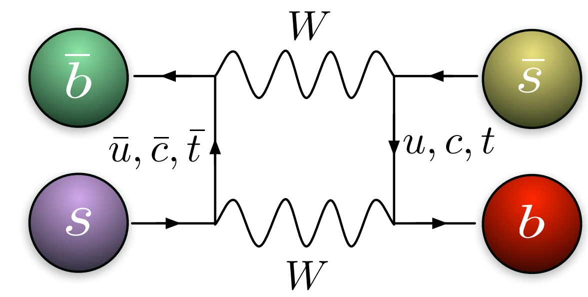
TrigDiMuon (1 RoI; 1 L1 muon)

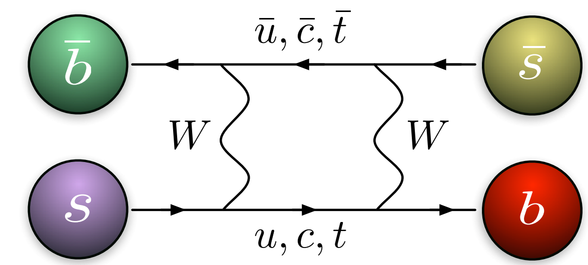


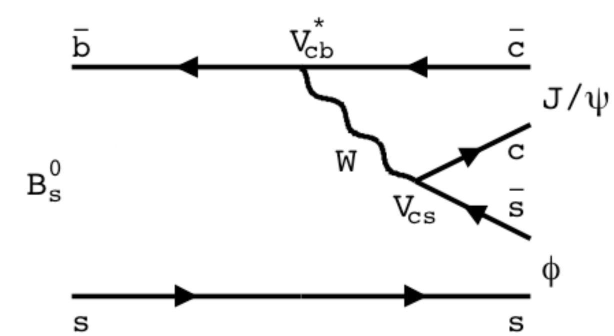
Introduction to $B_s \to J/\psi\phi$ and $B_d \to J/\psi K^{0*}$

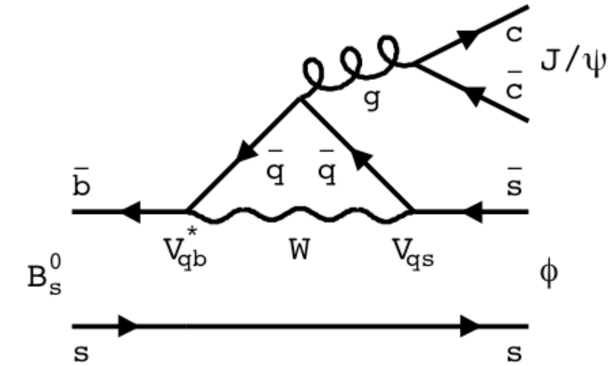
- The channel $B_s \to J/\psi\phi$ is a promising indirect route to New Physics
  - "Weak mixing phase" ϕ_s has been calculated in the SM and is very small (-0.0368±0.0018) but may be enhanced by BSM processes
- The time-dependent angular distribution of this decay depends on 7 physics parameters: 2 independent complex transversity amplitudes, mean lifetime and mass eigenstate width difference ($\Delta\Gamma$), weak mixing phase
- The analysis ultimately will involve a fit to these parameters, and is sensitive to
  - statistics, experimental resolutions of lifetime, mass and decay angles
  - flavour tagging performance, background rejection
- Early statistics do not permit the full fit - e.g. in D0/CDF a few thousand signal events allowed a 2-dimensional profile likelihood fit in the ϕ_s-$\Delta\Gamma$ plane. At the full LHC potential the simultaneous determination of all 7 parameters will be possible
- With small integrated luminosities, the ATLAS programme will begin with calibration measurements supporting this analysis
- The topologically identical $B_d \to J/\psi K^{0*}$ (15x greater statistics) is the primary background and is also essential as a control channel
  - High precision tests of lifetime measurement systematics
  - Flavour tagging calibration











$B_s \to J/\psi\phi$ and $B_d \to J/\psi K^{0*}$ with early data

- With the earliest data ATLAS will use a fit to simultaneously access the mean mass and lifetimes of the B_s and B_d mesons
- This will enable sensitive tests of our understanding of the tracking pt scale after 150 pb^{-1}, and will start to improve world precisions on these measurements after about 1 fb^{-1}
- Early on, topologically similar backgrounds will be admitted to the analysis and secondary vertex cuts will not be applied
- After 10 pb^{-1} the precision on the B_d lifetime will be 10% and similar precision for the B_s mean lifetime will be available after 150 pb^{-1}

Parameter	$B_d \to J/\psi K^{0*}$ after 10 pb^{-1}		$B_s \to J/\psi\phi$ after 150 pb^{-1}	
	Simulated value	Fit result + st error	Simulated value	Fit result + st error
Mean lifetime Γ, ps^{-1}	0.651	0.73 ± 0.07	0.683	0.743 ± 0.051
Mean mass m, GeV	5.279	5.284 ± 0.006	5.343	5.359 ± 0.006
Lifetime resolution σ, ps		0.132 ± 0.004		0.152 ± 0.001
Mass resolution σ_B, GeV		0.054 ± 0.006		0.061 ± 0.006
n_{sig}/N	0.16	0.155 ± 0.006	0.018	0.031 ± 0.005
n_{bck1}/N	0.062	0.595 ± 0.017	0.397	0.379 ± 0.006

ATLAS flavour tagging performance

- After about 1 fb^{-1} it will be possible to extract interesting parameters from the $B_s \rightarrow J/\psi\phi$ decays
  - FLAVOUR TAGGING (attempting to determine whether the decay is from a B_s or an anti-B_s) is an essential part of this decay. $B_s \rightarrow J/\psi\phi$ is not self-tagging
  - In ATLAS, the best flavour tagging performance for $B_s \rightarrow J/\psi\phi$ is obtained using the jet charge tagging algorithm, which is a "same side" tag
  - Utilize correlations between the original quark flavour and momenta, and the charge and momenta of the fragmentation products (jet charge tagging)
- Calibration of the jet-charge tag will be done with the self-tagging reference channel $B_d \rightarrow J/\psi K^{0*}$, and will validate Monte Carlo models for fragmentation
  - Validated Monte Carlo will be used to determine the tagger quality for $B_s \rightarrow J/\psi\phi$

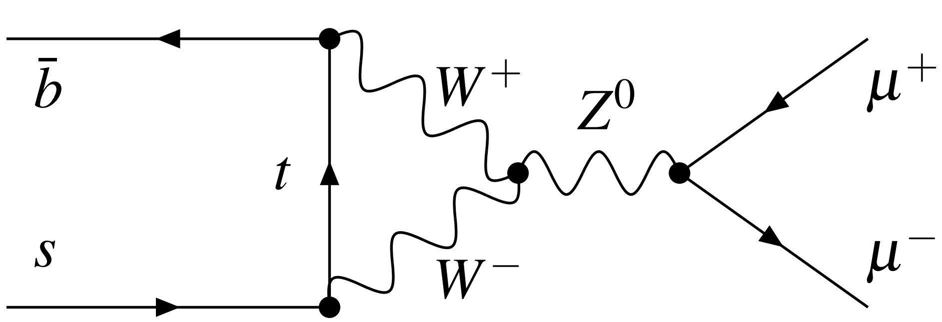
Tuned jet charge tagger performance		
Parameter	**$B_d \rightarrow J/\psi K^{0*}$**	**$B_s \rightarrow J/\psi\phi$**
Luminosity	150 pb^{-1}	1.5 fb^{-1}
Tag Efficiency	0.870 ± 0.003	0.625 ± 0.005
Wrong tag fraction	0.380 ± 0.004	0.374 ± 0.005
Dilution	0.240 ± 0.009	0.251 ± 0.010
Quality	0.050 ± 0.004	0.039 ± 0.003

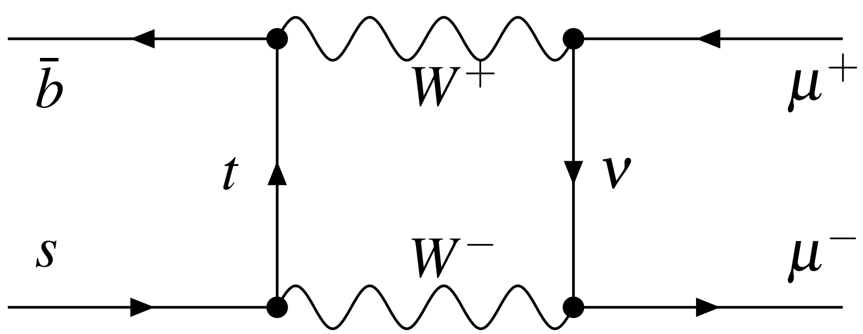
Summary of performance for $B_s \rightarrow J/\psi\phi$ with $30 fb^{-1}$

$B_s \rightarrow J/\psi\phi$			
Luminosity	30 fb-1 (≈3 years)	Signal proper time resolution	**83 fs**
Statistics	**~240 000**	J/ψ trigger efficiency wrt Monte Carlo	**72%**
Offline $J/\psi \rightarrow \mu\mu$ candidate cuts	2 oppositely charged inner detector tracks matched with muons, pt> {6,4} GeV fitting to common vertex $\chi^2<6$; $M_{\mu\mu} \in \pm 3\sigma$, σ=58 MeV	Offline $\phi \rightarrow KK$ candidate cuts	2 oppositely charged inner detector tracks not matched with muons, pt> 0.5 GeV fitting to common vertex $\chi^2<6$; $1009.2<M_{TT}<1029.6$ MeV
Offline Bs→ $J/\psi(\mu\mu)\ \phi(KK)$ candidate cuts	4 tracks from J/ψ,ϕ candidates fitting to common vertex $\chi^2<10$; resultant pt of refitted tracks > 10 GeV	Signal event selection efficiency wrt Monte Carlo	**41%** before secondary vertex cuts; **30%** after
		Background	**~30%** after secondary vertex cuts, dominated by $B_d \rightarrow J/\psi K^{0*}$ and $bb \rightarrow J/\psi X$

The rare decay $B_s \to \mu\mu$

- *Tiny* branching ratio in the Standard Model:
  - Mediated by FCNC that are forbidden at tree level (lowest-order SM-allowed diagrams below); helicity suppressed
  - $BR_{SM} = (3.42 \pm 0.52) \times 10^{-9}$
- Current experimental limits:
  - DZero ($5 fb^{-1}$): $BR_{B_s \to \mu\mu} < 4.5\ (5.3) \times 10^{-8}$ at 90% (95%) CL [D0 Note 5906-CONF 2009]
  - CDF ($2 fb^{-1}$): $BR_{B_s \to \mu\mu} < 5.8 \times 10^{-8}$ at 95% CL [Phys. Rev. Lett. 100, 101802 (2008)]
- Could use this decay to
  - Test SM to high perturbative orders
  - Look for new physics effects via a modified branching ratio

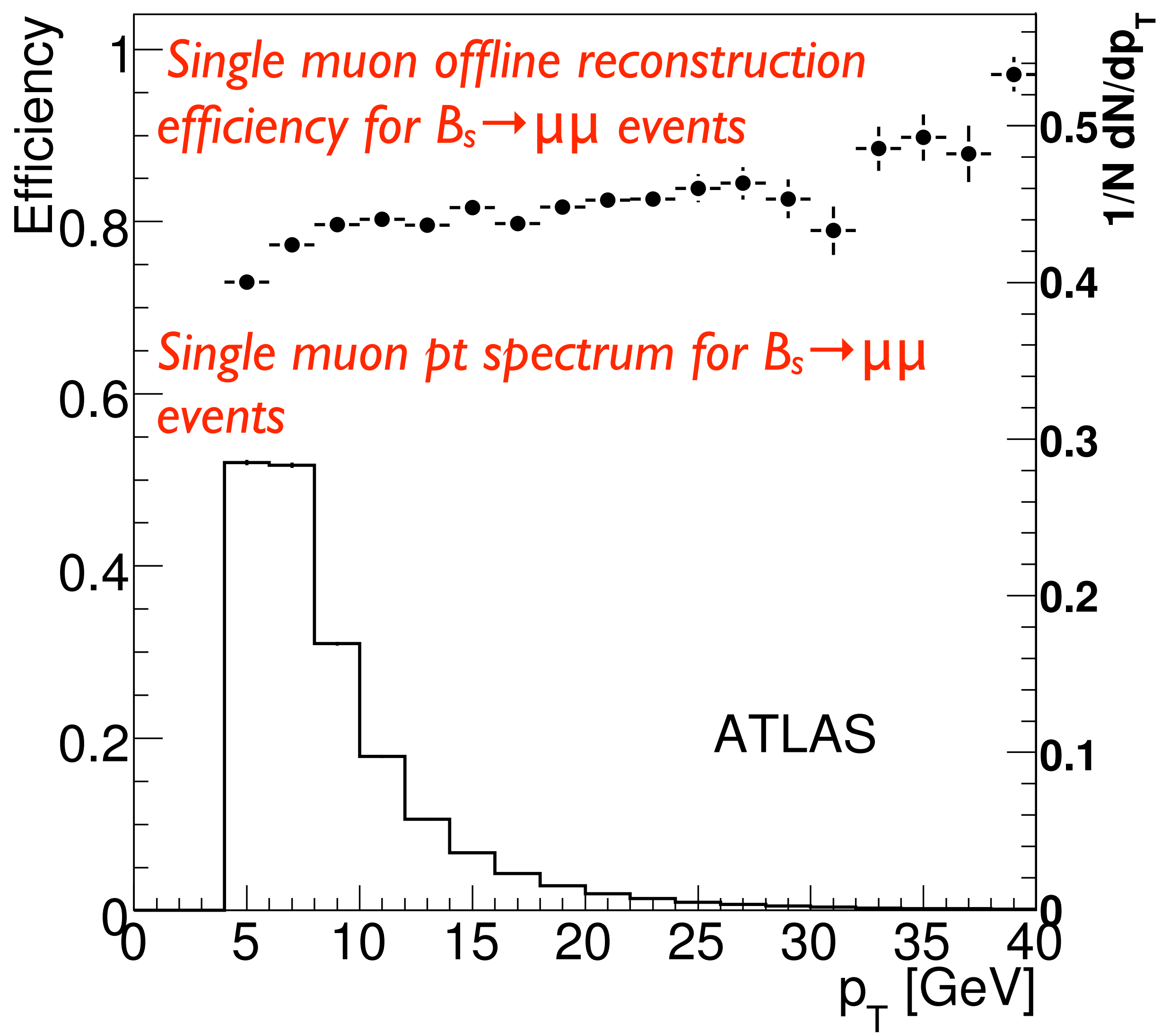




Trigger and offline muon reconstruction performance for $B_s \rightarrow \mu\mu$

- The ATLAS di-muon trigger, excellent muon identification efficiency and high beauty production cross section will give us access to this channel at $L=10^{33}$ and 10^{34} $cm^{-2}s^{-1}$
- Trigger levels 1 and 2
  - Topological di-muon trigger: pt > {6, 6} GeV; $M_{\mu\mu}$ < 7 GeV; vertex χ^2 < 10 (using L2 trigger tracking and vertexing algorithms)
- Event filter
  - As above but based on offline reconstruction algorithms and vertexing

Trigger performance for simulated $B_s \rightarrow \mu\mu$ events, $L=10^{33}$ cm^{-2} s^{-1}		
L1 x L2 efficiency	Event filter w.r.t L2	Overall
0.52	0.88	0.46



Offline analysis strategy for $B_s \rightarrow \mu\mu$

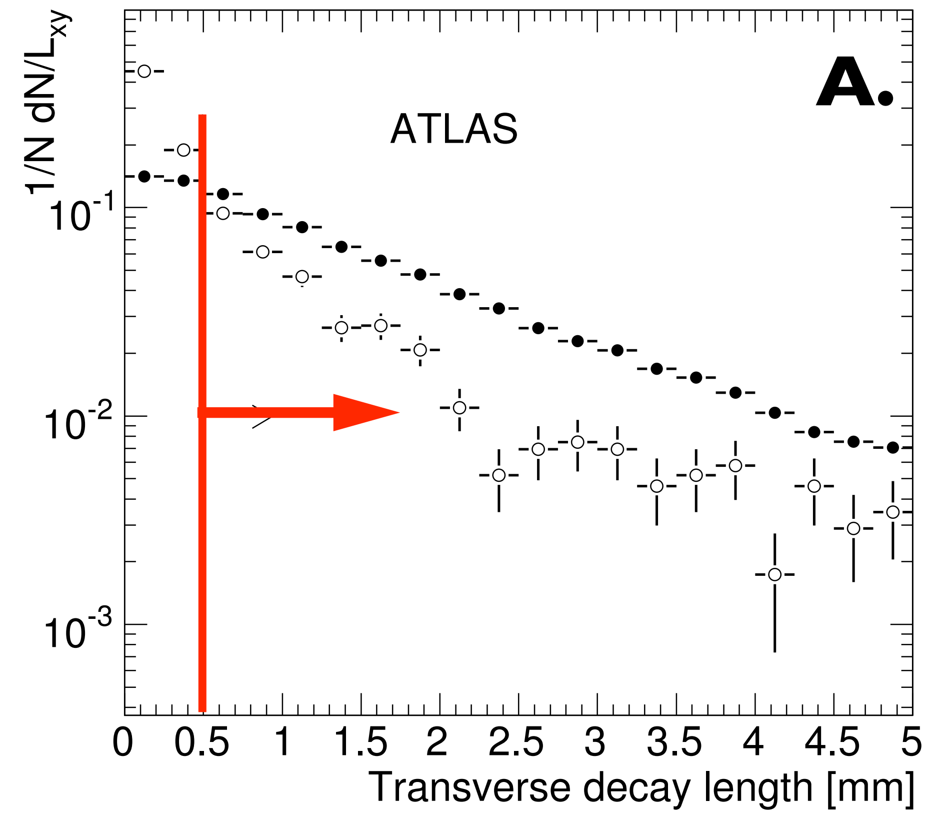
For all events passing the dimuon trigger, oppositely charged muons with pt > {6,4} GeV are fitted to a common vertex

Fit $\chi^2 < 10$

• Signal ○ Background

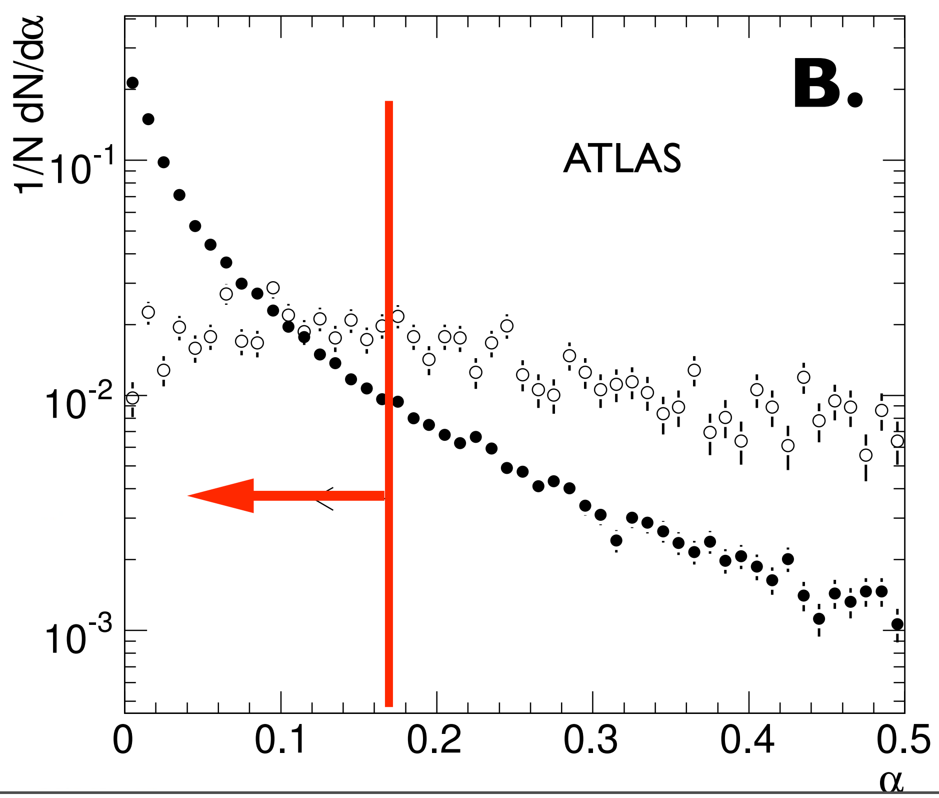
A. A cut is made on the transverse decay length L_{xy} of the B-candidate vertex

$L_{xy} > 0.5$ mm



B. Cut made on pointing angle α is between dimuon summary momenta and the direction of the reconstructed secondary vertex, in frame of primary vertex

$\alpha < 0.017$ radians



C. Cut made on

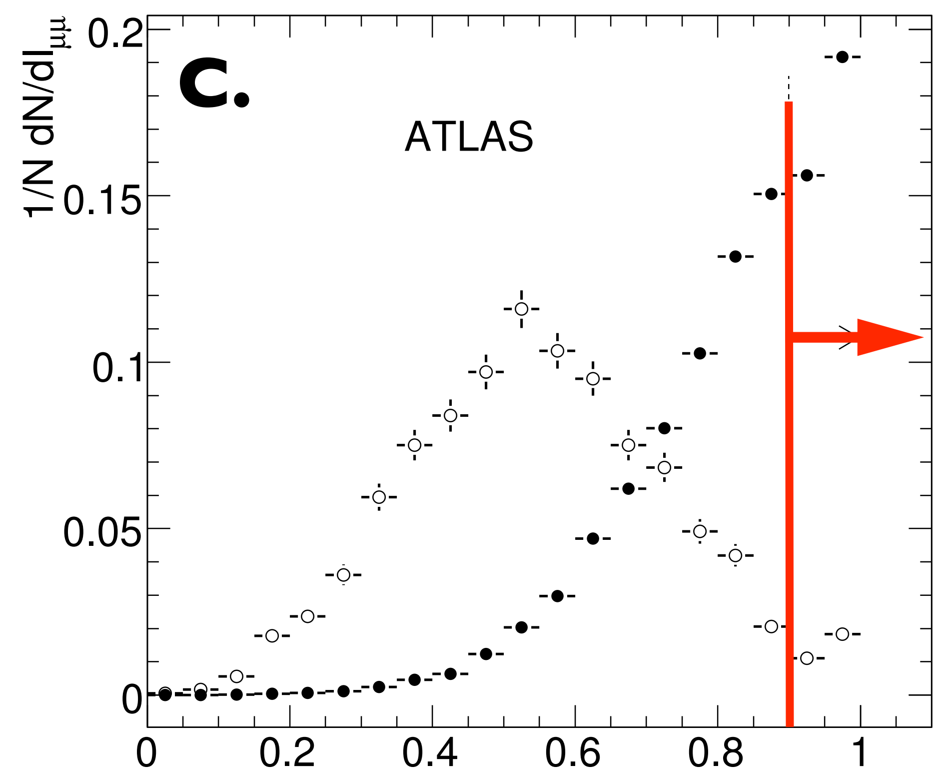
$$I_{\mu\mu} = \frac{p_T^{\mu\mu}}{\sum_i p_T^i}$$

$I_{\mu\mu} > 0.9$

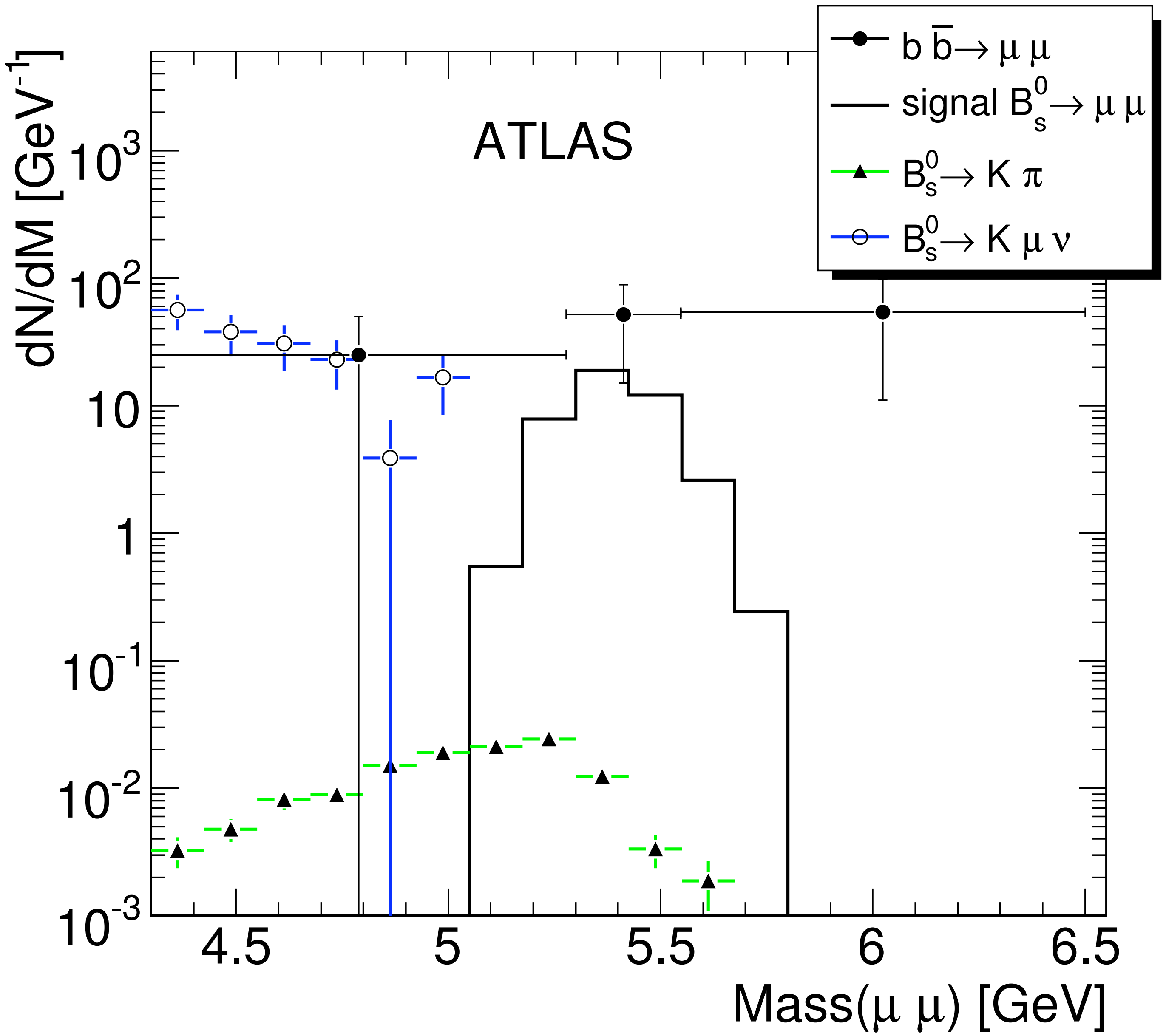
where sum is over all tracks with pt>1GeV excluding muons, within a cone of

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 1$$

defined with respect to the muon pair summary momenta



Summary of ATLAS performance for $B_s \to \mu\mu$



Effect on signal and background of all cuts, 10 fb^{-1} (assuming Standard Model)

- After 1 fb^{-1} ATLAS will have collected O(10^6) dimuons in the invariant mass range 4-7 GeV
  - This will allow tuning of cuts and potentially training of multivariate procedures
- After 10 fb^{-1} (1 year @ 10^{33}) we expect (SM):

	$B_s \to \mu\mu$	$bb \to \mu\mu X$
Efficiency	0.04	$(2.0 \pm 1.4) \times 10^{-6}$
Events yield	5.7	14^{+13}_{-10}

The ATLAS $B_s \to \mu\mu$ programme will continue throughout the lifetime of the detector

Conclusions

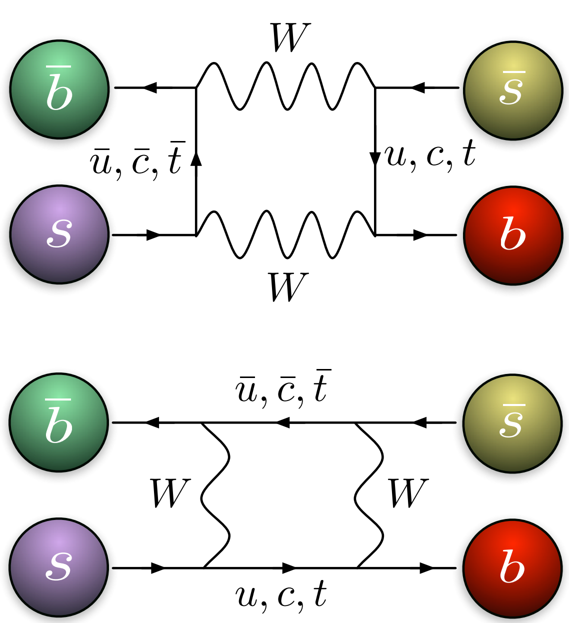
- The ATLAS B-physics programme will run from the earliest days of the experiment and will pursue indirect searches for New Physics via B-hadron decays
- An efficient, fast and clean di-muon trigger scheme will allow ATLAS to collect large numbers of B-hadron decays involving $\mu\mu$ final states, throughout the lifetime of the experiment
- After 30 fb^{-1}, ATLAS will have collected the following statistics:
  - ~270 000 $B_s \rightarrow J/\psi\phi$ events with ~30% background
  - 5.7 $B_s \rightarrow \mu\mu$ events with 14^{+13}_{-10} of the principle background assuming the Standard Model branching ratios
- Early data will provide valuable information on the detector performance, but will also allow calibration studies in support of New Physics searches.

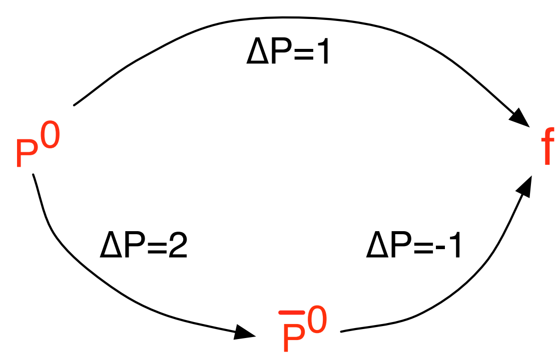
Reserve slides

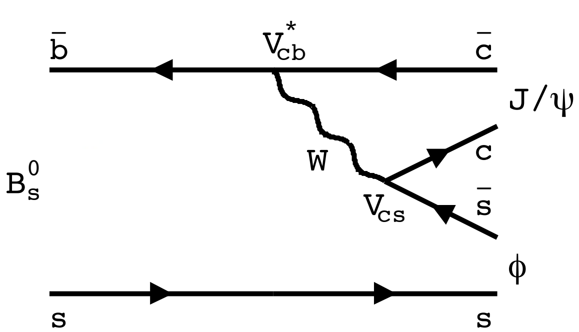
BSM physics from $B_s \to J/\psi\phi$

$$B_s^0 \rightleftarrows \bar{B}_s^0 \to J/\psi\,(\mu\mu)\,\phi\,(KK)$$

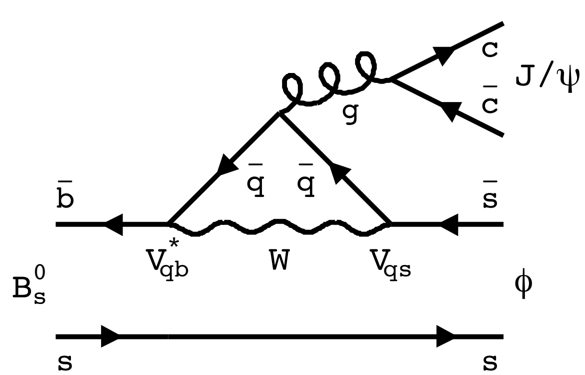
Mixing, decay and interference processes







(a)



(b)

The state and anti-state can decay to the same final state, and can also undergo mixing

New source of CP-violation may appear in the mixing, directly in the decay amplitudes, or in interference between the two processes

The main parameter of interest is the *weak mixing phase* ϕ_s

$$\phi_s \equiv 2\arg\left[V_{ts}^* V_{tb}\right] + \phi_{BSM}$$

Flavour tagging definitions

Efficiency
$$\varepsilon_{tag} = \frac{N_r + N_w}{N_t}$$

Dilution
$$D_{tag} = \frac{N_r - N_w}{N_r + N_w} = 1 - 2w_{tag}$$

Wrong-tag fraction
$$w_{tag} = \frac{N_w}{N_r + N_w}$$

Quality
$$Q_{tag} = \varepsilon D^2_{tag}$$

Extracting new physics from $B_s \to J/\psi\phi$

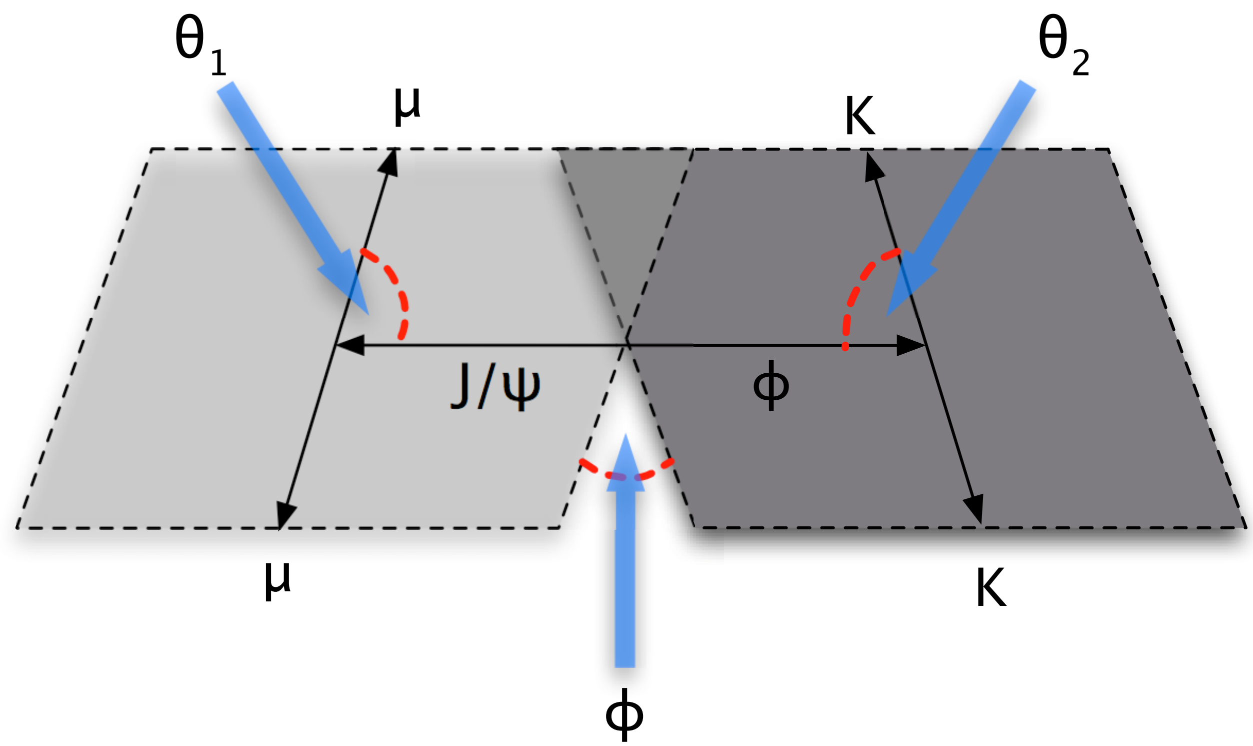
- The state and anti-state decay to the same final-state so it is necessary to separate out the CP-odd and CP-even states in order to be able to measure CP-violation

- This is done via a *transversity decomposition* where the decay amplitude is broken down into three component *transversity amplitudes* which each have a definite CP-eigenstate

- The amplitudes can only be accessed from the angles of the final decay products and the decay time of the B-meson. The angular distribution is non-trivial even in the absence of CP-violation effects since the decay is $S \to VV$

- The analysis involves identifying the decays, measuring the decay angles and decay time, and performing a maximum likelihood fit to the function which expresses the angular distribution in terms of the transversity amplitudes. The expression is model-independent.

- The weak phase can be obtained from this fit



$B(t=0) = B_s^0$

Transversity amplitudes

$$W^+(\theta_1, \theta_2, \phi, t) = \frac{d\sigma}{d\theta_1 d\theta_2 d\phi dt} = \sum_k \Omega^{(k)}(t)\, g^{(k)}(\theta_1, \theta_2, \phi)$$

$$W^-(\theta_1, \theta_2, \phi, t) = \frac{d\sigma}{d\theta_1 d\theta_2 d\phi dt} = \sum_k \bar{\Omega}^{(k)}(t)\, g^{(k)}(\theta_1, \theta_2, \phi)$$

$B(t=0) = \bar{B}_s^0$

Spin dynamics

Angular distribution and M.L. fit for $B_s \to J/\psi\phi$

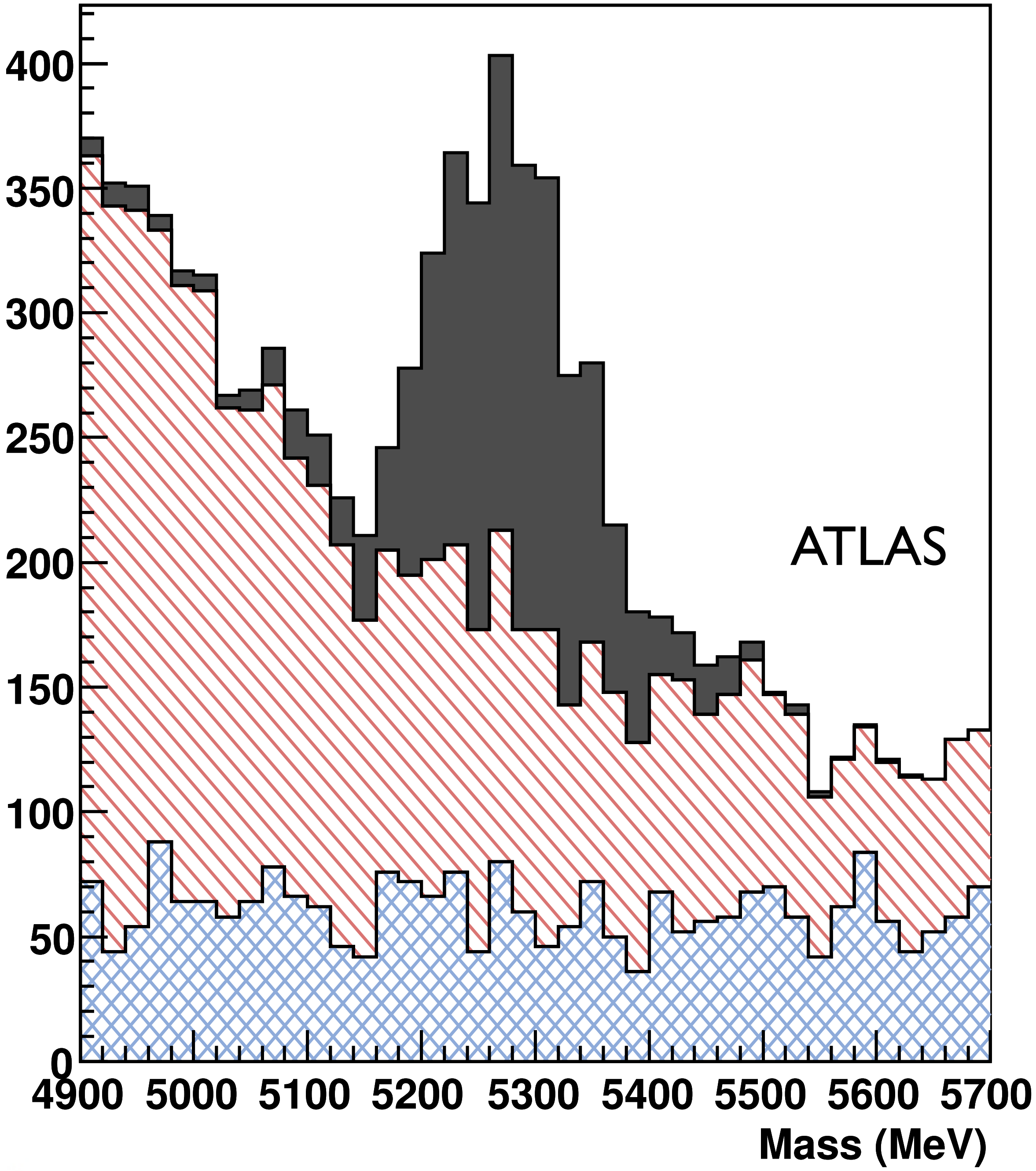
k	$\Omega^{(k)}(t)$		$g(t)$
1	$\lvert A_0(t)\rvert^2$		$4\sin^2\theta_1\cos^2\theta_2$
	$\frac{1}{2}\lvert A_0(0)\rvert^2$	$(1+\cos\phi_s)e^{-\Gamma_L^{(s)}t}+$ $(1-\cos\phi_s)e^{-\Gamma_H^{s}t}+$ $2e^{-\Gamma_s t}\sin(\Delta M_s t)\sin\phi_s$	
2	$\lvert A_\parallel(t)\rvert^2$		$(1+\cos^2\theta_1)\sin^2\theta_2-\sin^2\theta_1\sin^2\theta_2\cos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

+ h.c.

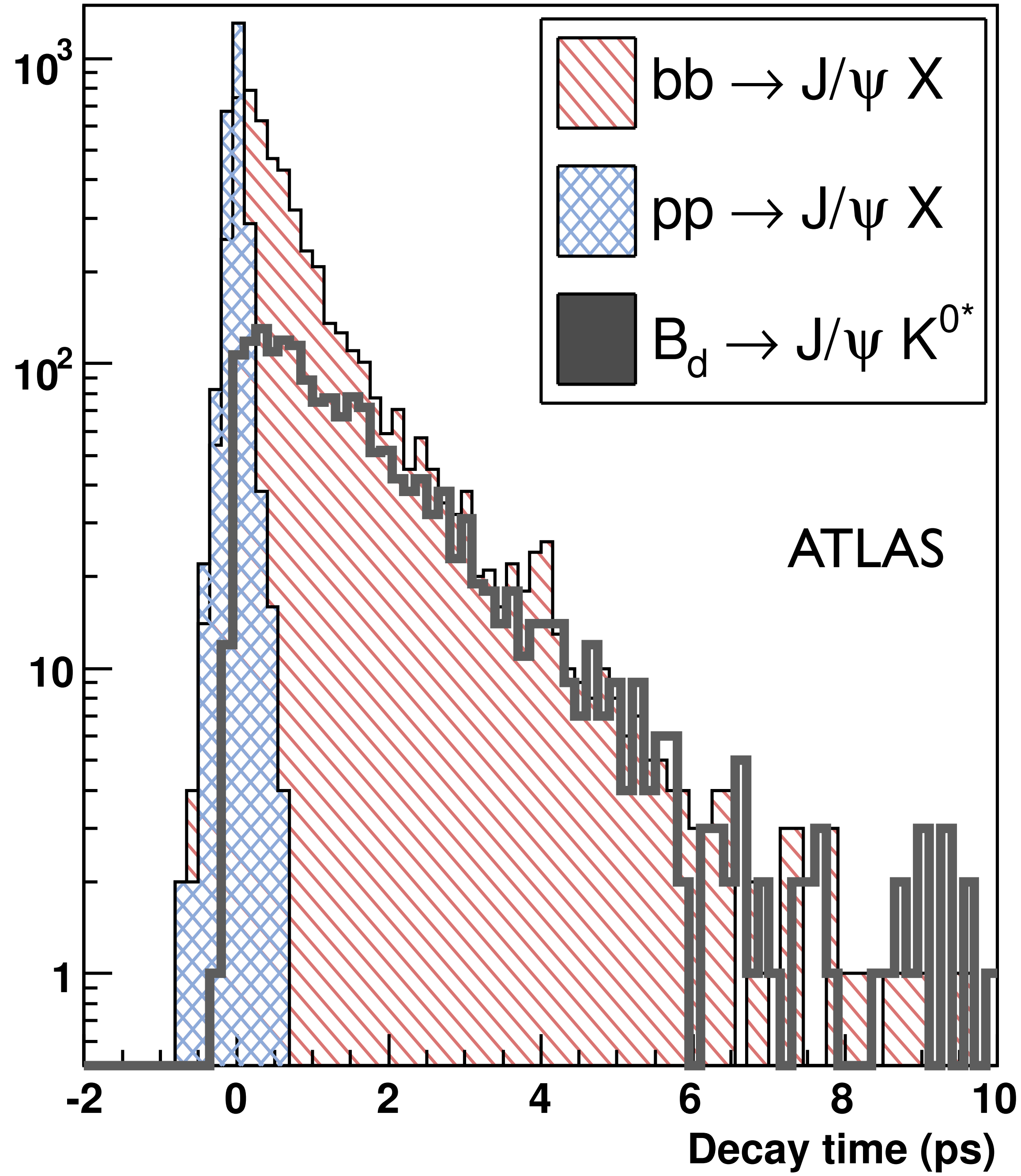
$$L=\prod_{i=1}^{N}\int_0^\infty \frac{\left(\varepsilon_{tag}^1\varepsilon_{rec}^1 W^+(t_i,\Omega)+\varepsilon_{tag}^2\varepsilon_{rec}^2 W^-(t_i,\Omega)+be^{-\Gamma_0 t_i}\right)\rho(t-t_i)dt}{\int_{t_{\min}}^{\infty}\left(\int_0^\infty\left(\varepsilon_{tag}^1\varepsilon_{rec}^1 W^+(t,\Omega)+\varepsilon_{tag}^2\varepsilon_{rec}^2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

Reconstructed $B_d \to J/\psi K^{0*}$ after $10pb^{-1}$

Invariant mass

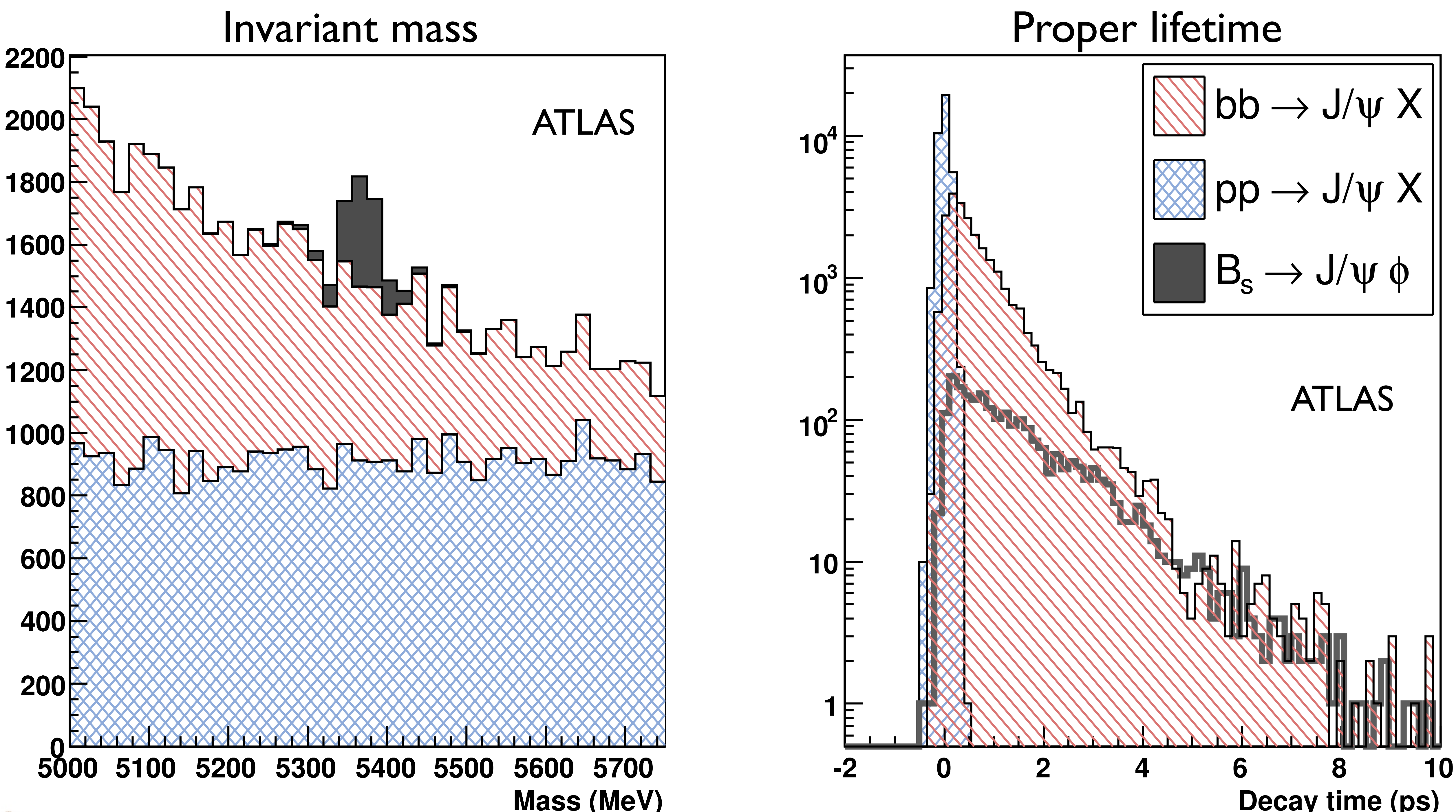


Proper lifetime



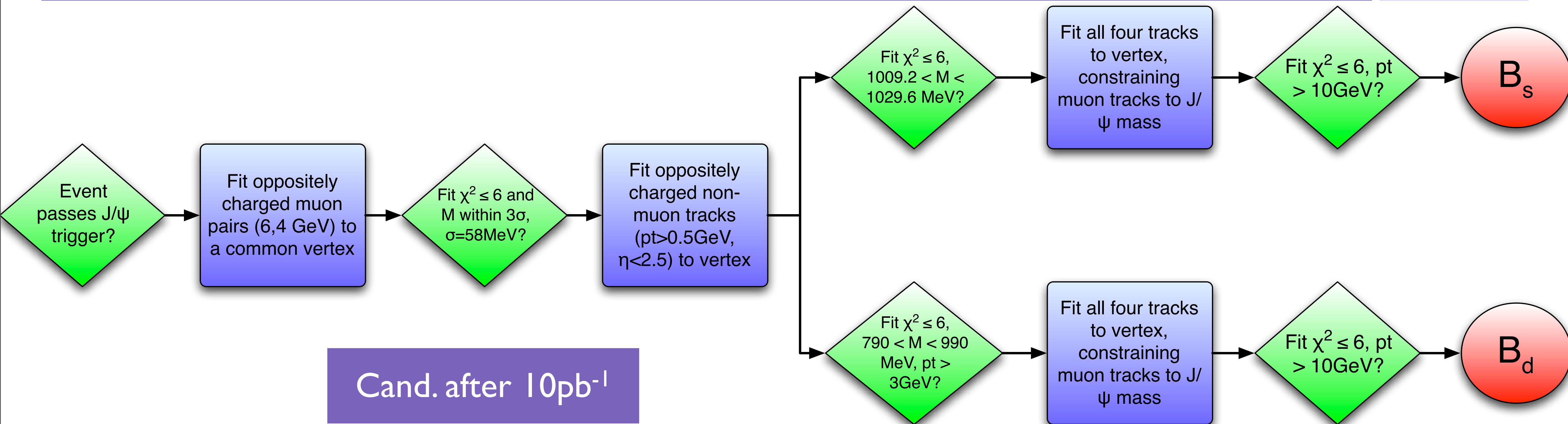
Note that the backgrounds are scaled

Reconstructed $B_s \to J/\psi\phi$ after 150pb^{-1}



Note that the backgrounds are scaled

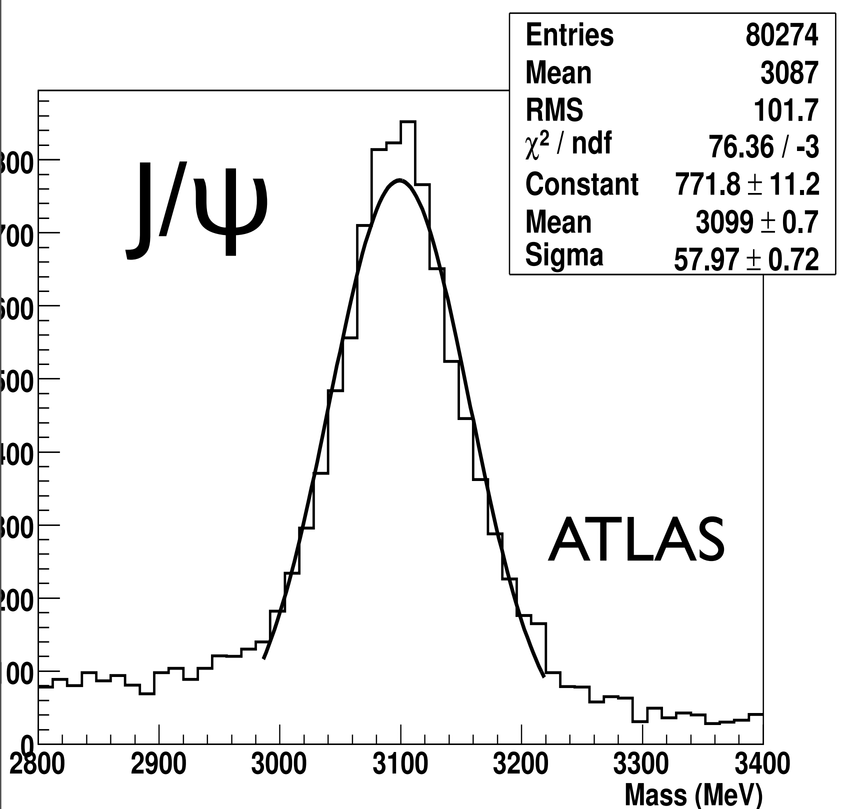
Analysis procedure for $B_s \rightarrow J/\psi\phi$ and $B_d \rightarrow J/\psi K^{0*}$

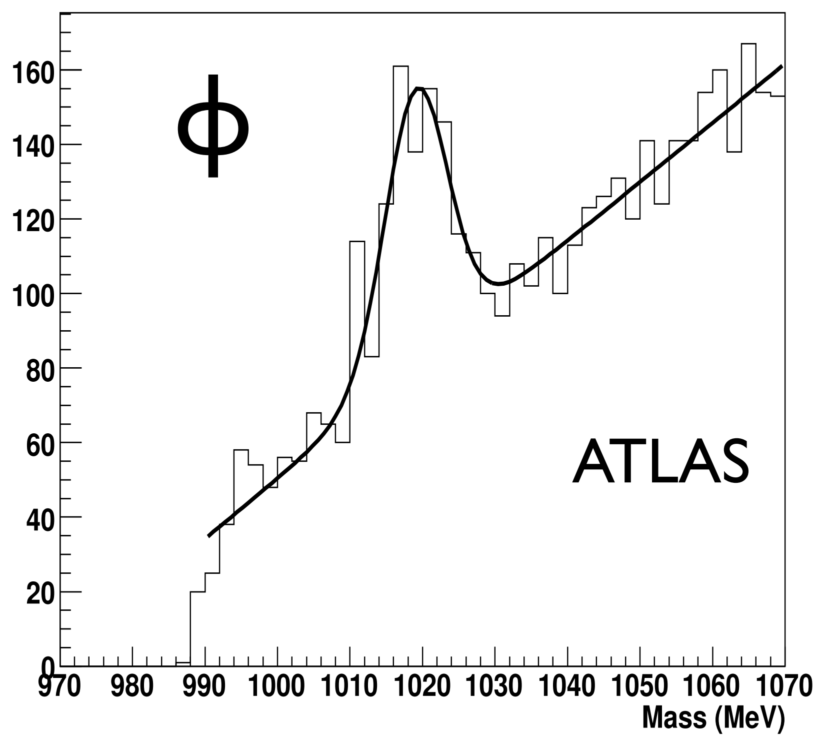


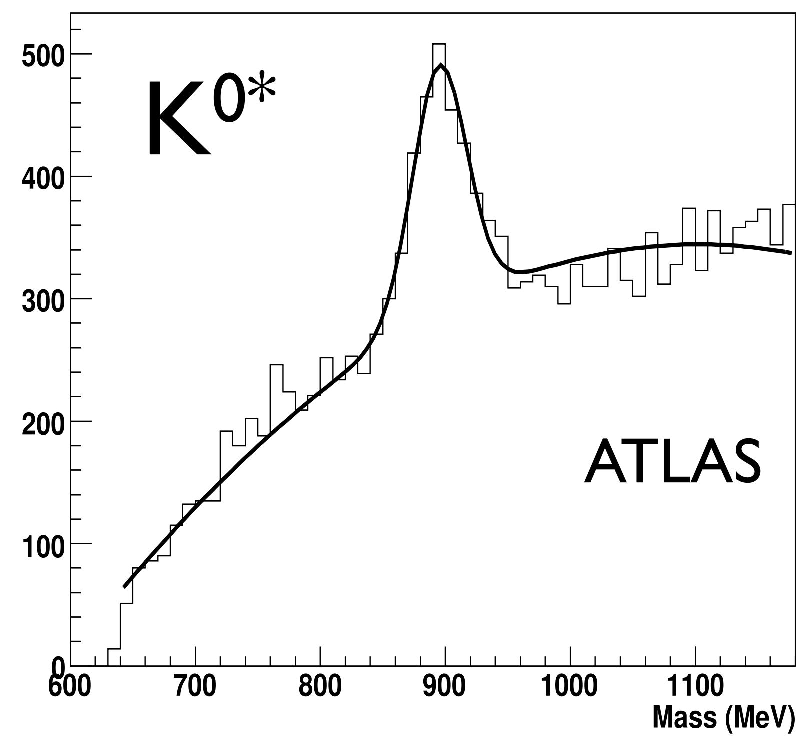
	Cand. after $10pb^{-1}$
Sig: $B_d \rightarrow J/\psi K0^*$	1024
Bck: $pp \rightarrow J/\psi X$	1419
Bck: $bb \rightarrow J/\psi X$	3970
Sig: $B_s \rightarrow J/\psi\phi$	76
Bck: $pp \rightarrow J/\psi X$	2449
Bck: $bb \rightarrow J/\psi X$	1660
All passing selections	10 323

	Reconstruction efficiency (%)	
	Before lifetime cut	After lifetime cut
Sig: $B_d \rightarrow J/\psi K0^*$	42.0	30.4
Bck: $pp \rightarrow J/\psi X$	0.67	0.0064
Bck: $bb \rightarrow J/\psi X$	3.05	1.52
Sig: $B_s \rightarrow J/\psi\phi$	40.5	30.0
Bck: $pp \rightarrow J/\psi X$	1.5	0.0058
Bck: $bb \rightarrow J/\psi X$	1.1	0.8

J/ψ, ϕ and K^{0*} invariant masses







Extracting B_s and B_d mass and lifetime from early data

With the earliest data ATLAS will use a fit to simultaneously access the mean mass and lifetimes of the B_s and B_d mesons

$$L = \prod_{i=1}^{N} \left[\frac{n_{sig}}{N} \times p_{sig}(t_i, m_i) + \frac{n_{bck1}}{N} \times p_{bkg1}(t_i, m_i) + \frac{N - n_{sig} - n_{bck1}}{N} \times p_{bkg2}(t_i, m_i) \right]$$

bkg1 = prompt background; *bkg2* = bb background

p_{sig}, p_{bkg1}, p_{bkg2} = probability density functions modelling lifetime and mass distributions for signal and backgrounds

Parameter	$B_d \to J/\psi K^{0*}$ after $10 pb^{-1}$		$B_s \to J/\psi \phi$ after $150 pb^{-1}$	
	Simulated value	Fit result + st error	Simulated value	Fit result + st error
Mean lifetime Γ, ps^{-1}	0.651	0.73 ± 0.07	0.683	0.743 ± 0.051
Mean mass m, GeV	5.279	5.284 ± 0.006	5.343	5.359 ± 0.006
Lifetime resolution σ, ps		0.132 ± 0.004		0.152 ± 0.001
Mass resolution σ_B, GeV		0.054 ± 0.006		0.061 ± 0.006
n_{sig}/N	0.16	0.155 ± 0.006	0.018	0.031 ± 0.005
n_{bck1}/N	0.062	0.595 ± 0.017	0.397	0.379 ± 0.006

Definitions of functions in Bs/Bd likelihood fit

$$L = \prod_{i=1}^{N} \left[\frac{n_{sig}}{N} \times p_{sig}(t_i, m_i) + \frac{n_{bck1}}{N} \times p_{bkg1}(t_i, m_i) + \frac{N - n_{sig} - n_{bck1}}{N} \times p_{bkg2}(t_i, m_i) \right]$$

$$p_{sig}(t_i) = \frac{\int_0^\infty \mathrm{e}^{-\Gamma t} \rho(t - t_i)\,\mathrm{d}t}{\int_{-\infty}^{\infty} \left(\int_0^\infty \mathrm{e}^{-\Gamma t} \rho(t - t')\,\mathrm{d}t \right) \mathrm{d}t'}$$

$$p_{bck2}(t_i) = \frac{\int_0^\infty \left(\Gamma_1 \mathrm{e}^{-\Gamma_1 t} + \mathrm{b}_1 \times \Gamma_2 \mathrm{e}^{-\Gamma_2 t} \right) \rho(t - t_i)\,\mathrm{d}t}{\int_{-\infty}^{\infty} \left(\int_0^\infty \left(\Gamma_1 \mathrm{e}^{-\Gamma_1 t} + \mathrm{b}_1 \times \Gamma_2 \mathrm{e}^{-\Gamma_2 t} \right) \rho(t - t')\,\mathrm{d}t \right) \mathrm{d}t'}$$

c1(c2): linear(quadratic) coefficients in non-prompt background fit

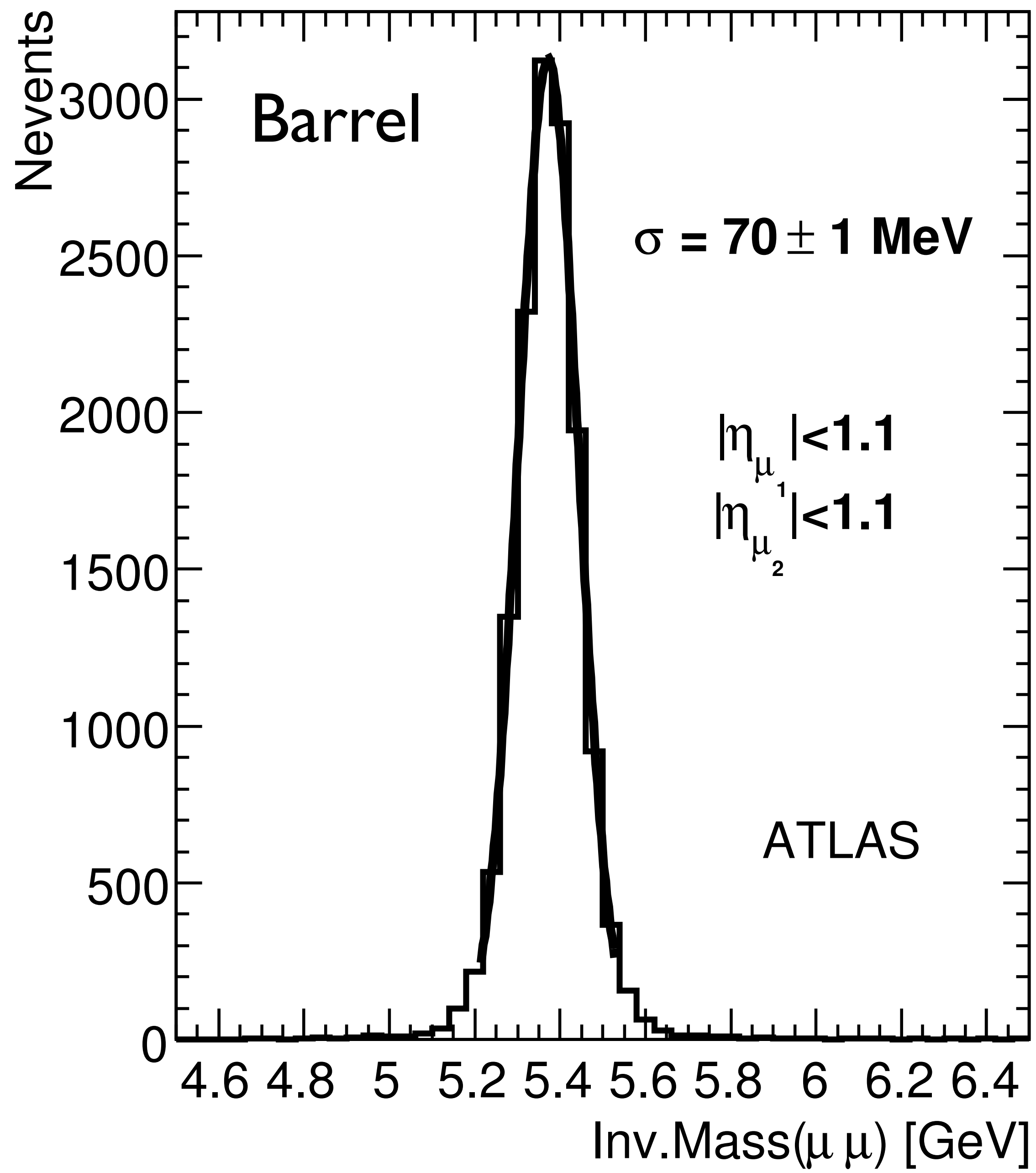
Bd

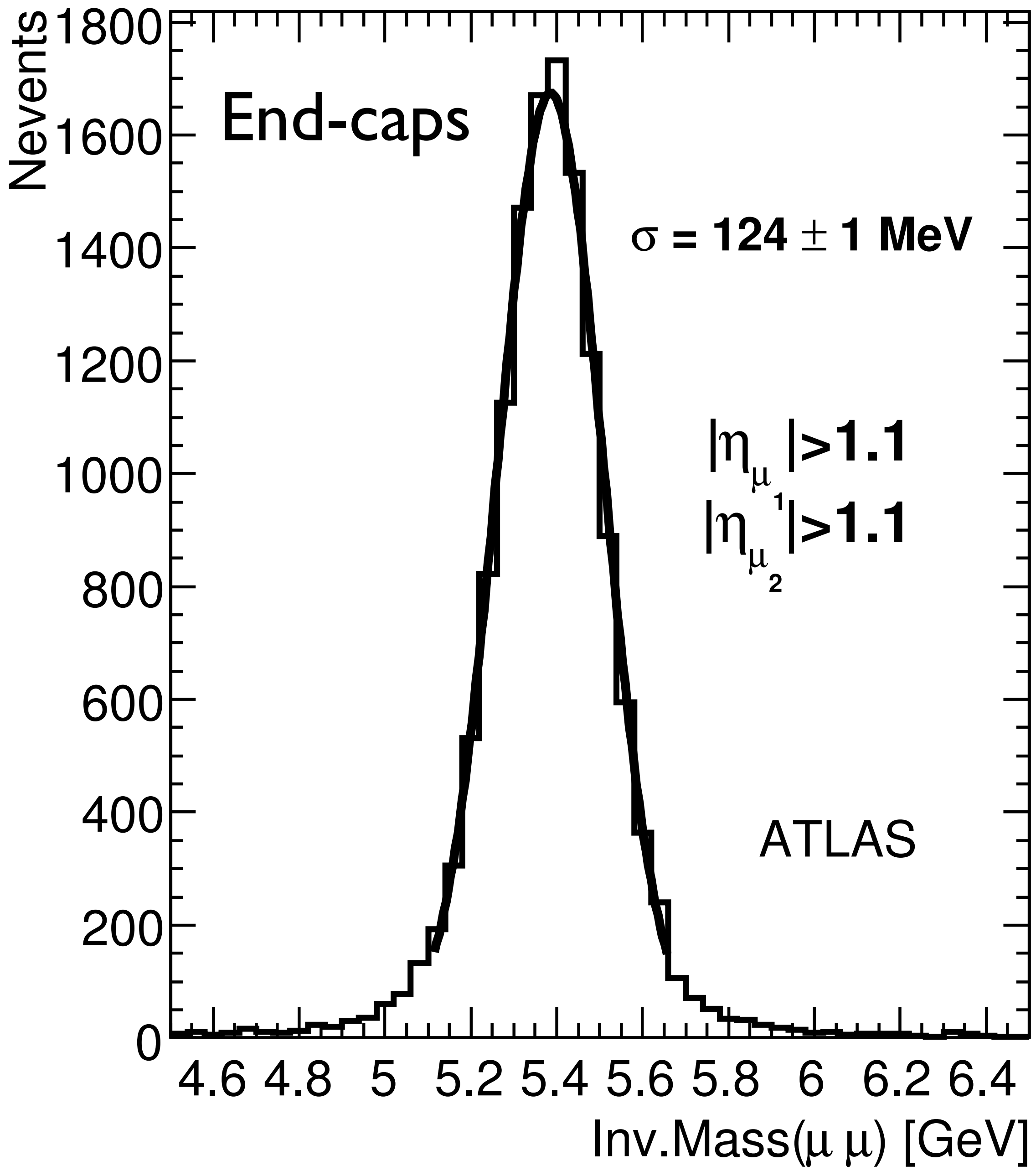
Parameter	Simulated value	Fit result with statitical error
Γ, ps^{-1}	0.651	0.73 ± 0.07
$\mathrm{m}(B)$, GeV	5.279	5.284 ± 0.006
σ, ps		0.132 ± 0.004
σ_m, GeV		0.054 ± 0.006
n_{sig}/N	0.16	0.155 ± 0.015
n_{bck1}/N	0.062	0.595 ± 0.017
b_1		1.08 ± 0.27
Γ_1, ps^{-1}		0.67 ± 0.05
Γ_2, ps^{-1}		2.4 ± 0.3
c_1		-2.75 ± 0.28
c_2		4.7 ± 1.4

Bs

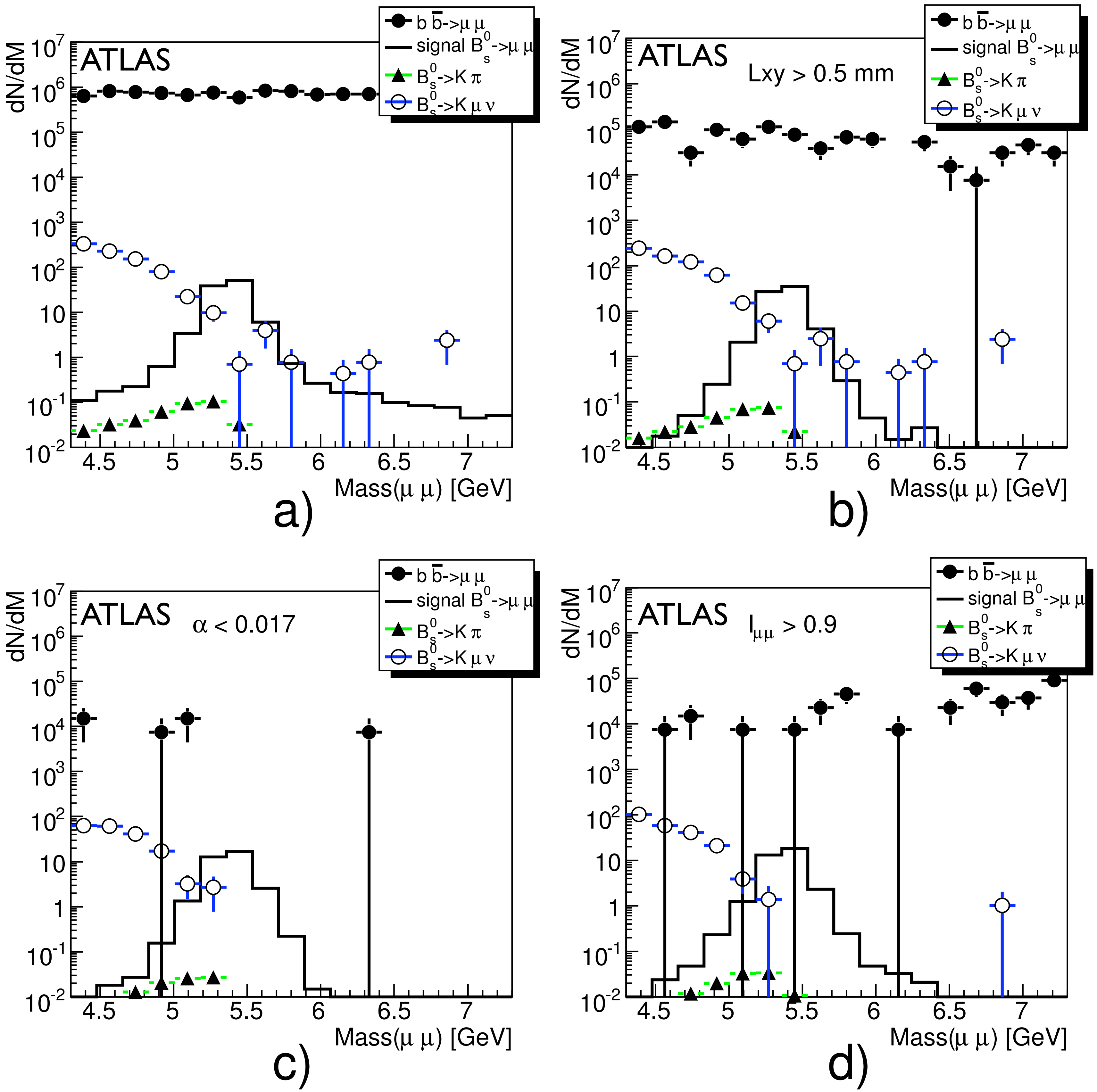
	Input	Fit result with statistical error
Γ_s, ps^{-1}	0.683	0.743 ± 0.051
$\mathrm{m}(B)$, GeV	5.343	5.359 ± 0.006
σ, ps		0.152 ± 0.001
σ_m, GeV		0.061 ± 0.006
n_{sig}/N	0.018	0.031 ± 0.005
n_{bck1}/N	0.397	0.379 ± 0.006
b_1		0.023 ± 0.01
Γ_1, ps^{-1}		1.35 ± 0.02
Γ_2, ps^{-1}		0.44 ± 0.08
c_1		-1.44 ± 0.07
c_2		2.14 ± 0.49

$B_s \to \mu\mu$ invariant mass





Effect of cuts on the signal and background



(a) preselected events
(b) after transverse decay length cuts
(c) after pointing angle cuts
(d) after isolation cuts