Study of the decay $B_s^\circ \rightarrow J/\psi\phi \rightarrow \mu^+\mu^- K^+ K^-$ at CMS and ATLAS

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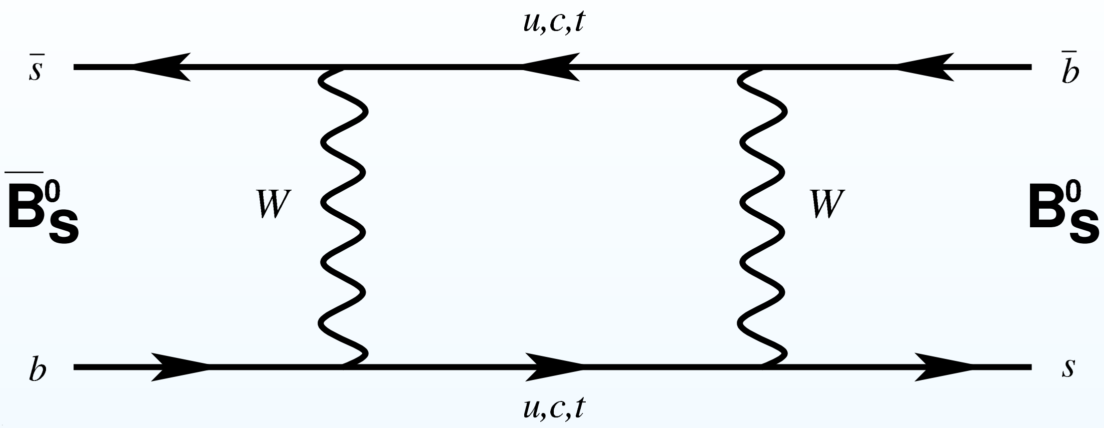
for the ATLAS and CMS collaborations

Outline

- the $B_s^\circ \to J/\psi\,\phi$ decay
- rates & backgrounds
- selection
- angular analysis
- expected sensitivity

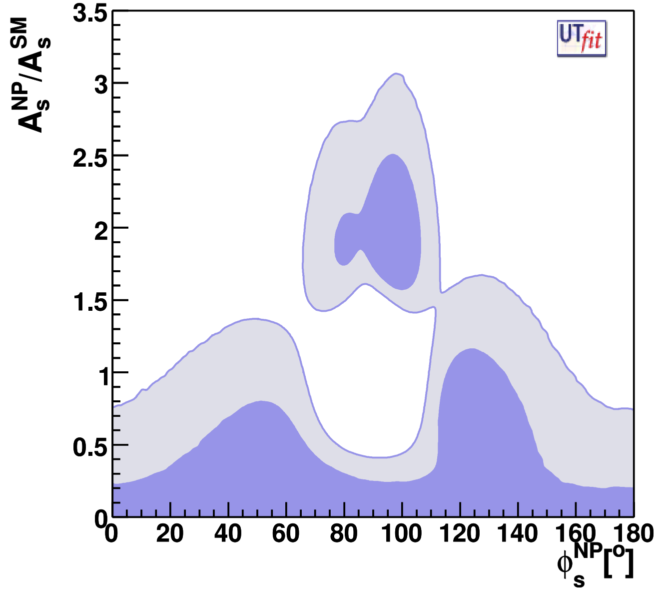
BB Mixing

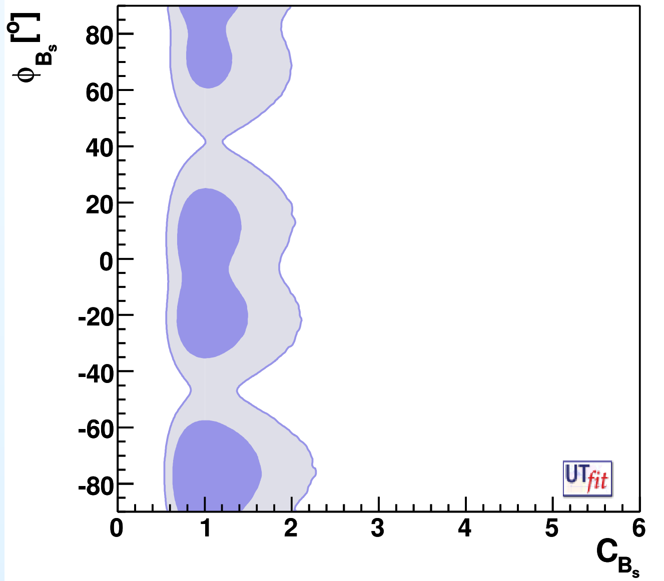


two CP eigenstates B_s^H and B_s^L observed, different masses & decay rates :

- mass difference $\Delta m_s = m_H - m_L$
- width difference $\Delta\Gamma_s = \Gamma_H - \Gamma_L$
- weak phase ϕ_s

ϕ_s sensitive to new physics contribution





$B_s^0 \to J/\psi\phi$

- $J/\psi\phi$:
  mixture of CP odd & even states, described by 3 helicity amplitudes:

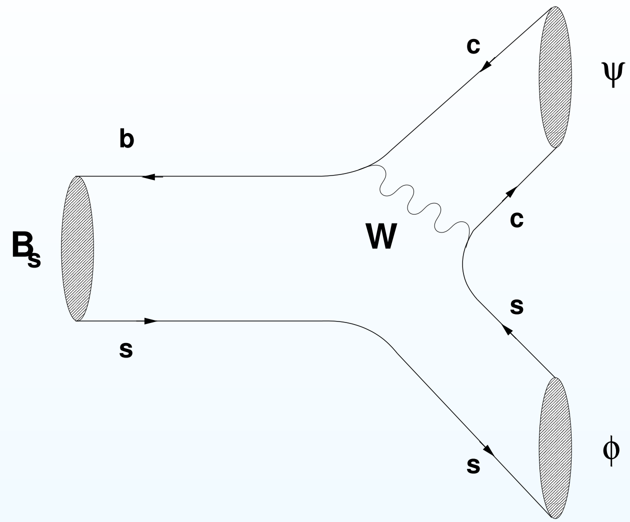
  $A_\perp, A_\parallel, A_0$

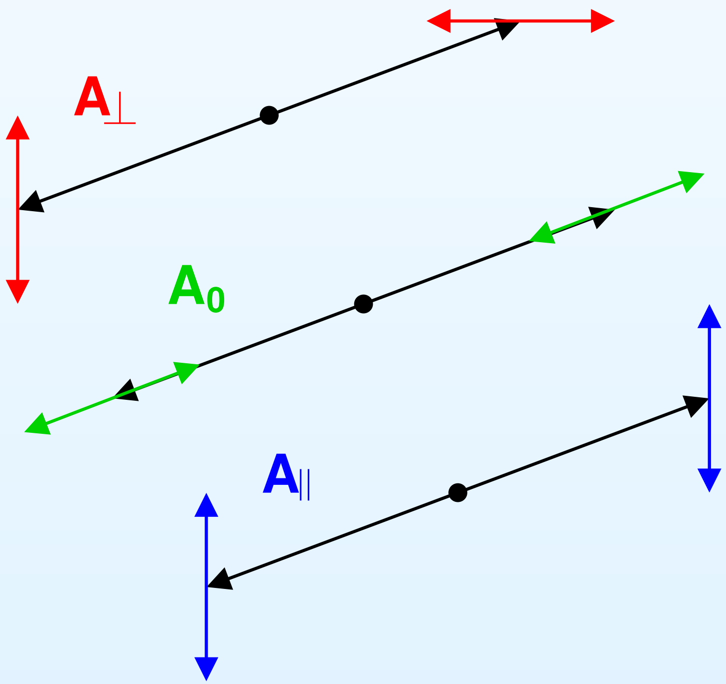
- angular analysis extracts:

  $\Delta\Gamma_s$, ϕ_s & Δm_s

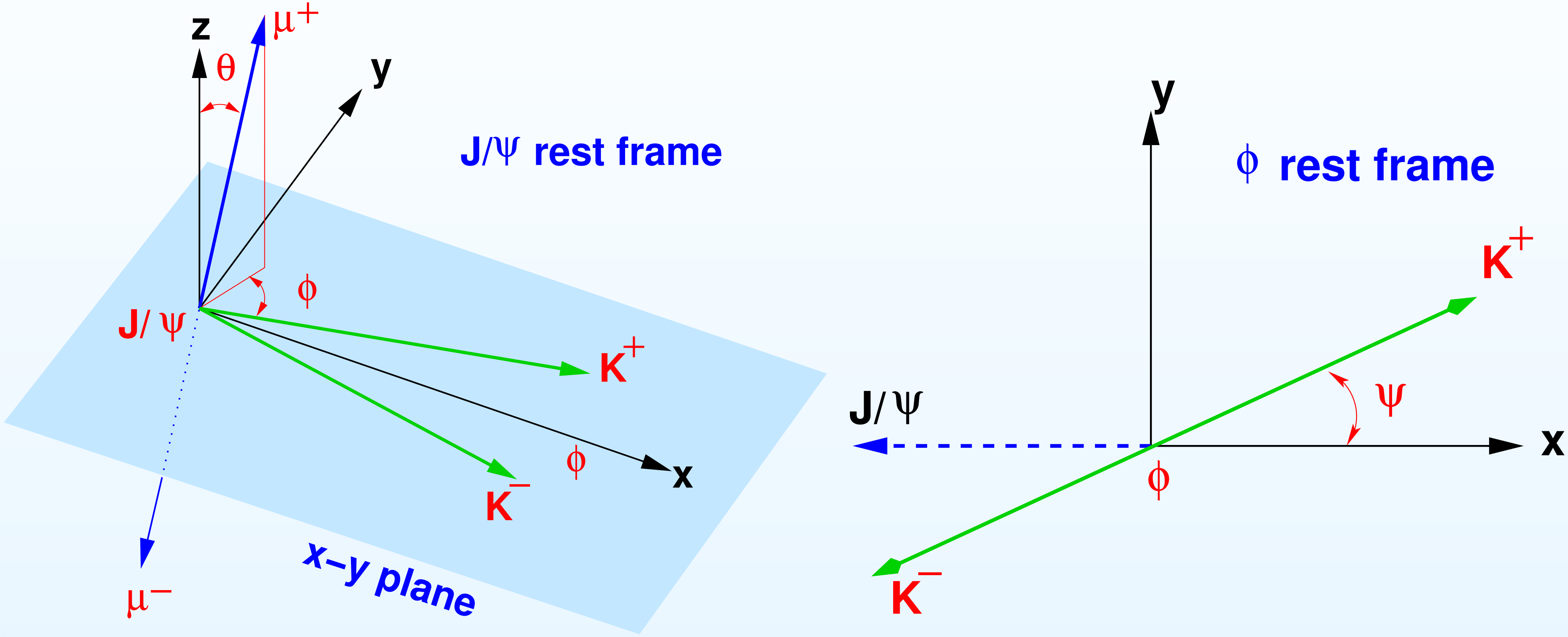
$$\frac{d^4\Gamma(B_s(t))}{d\Theta dt} = f(\Theta,\alpha,t) = \sum_{i=1}^{6} O_i(\alpha,t)\cdot g_i(\Theta)$$

- $O_i(\alpha,t)$:
  kinematic independent observables
- $g_i(\Theta)$:
  angular distributions





Coordinate Frame



transverse basis:

- use three angles Θ, ϕ, ψ

polar coordinates defined in rest frames of J/ψ and ϕ

Measured Quantities

- untagged analysis:
  - CP decay amplitudes $A_{\|}(0)$ and $A_{\perp}(0)$
  - strong phases δ_1 and δ_2
  - average decay width $\Gamma_s = \frac{\Gamma_H + \Gamma_L}{2}$
  - width difference of partial width $\Delta\Gamma_s = \Gamma_H - \Gamma_L$
  - (weak phase ϕ_s)
- tagged analysis:
  - all above
  - mass difference of two eigenstates$\Delta m_s = m_H - m_L$
  - better sensitivity on ϕ_s

Existing Measurements

quantity	measured	sm prediction
Δm_s[ps^{-1}]	$17\,ps^{-1} < \Delta m_s < 21$ (D0) D0 Note 5207 $17.77 \pm 0.1 \pm 0.07$ (CDF) hep-ex/0606027	$23.4^{+4.1}_{-4.9}$ CKM fitter 2007
$\Delta\Gamma_s/\bar{\Gamma}_s$[%]	(25^{+14}_{-15}) (D0) D0 Conference Note 5144 $(65^{+25}_{-33} \pm 1)$ (CDF) Phys.Rev.Lett. 94(2005)101803	12 ± 6 Phys.Rev.D63 114015(2001)
ϕ_s	$-0.79 \pm 0.56 \pm 0.001$ (D0) D0 Conference Note 5144	O(0.03)

measurements mainly limited by statistics...

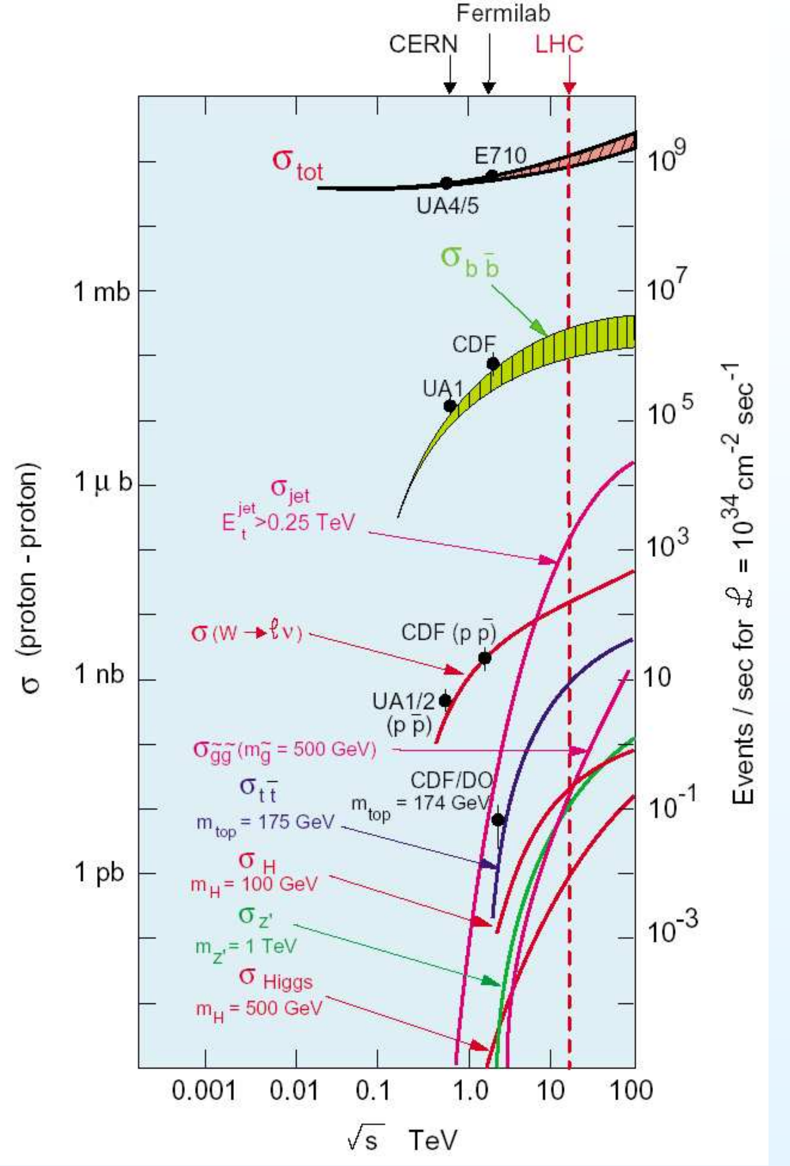
Cross Sections

σ@ LHC energies $\sqrt{s} = 14$ TeV:

- $\sigma_{b\bar{b}} = 0.5$ mb
- $\sigma_{B_s^0 \to J/\psi\phi \to \mu^+\mu^- K^+K^-} = 3$ nb

backgrounds:

- exclusive:
  $\sigma_{B^0 \to J/\psi K^{\star 0} \to \mu^+\mu^- K^+\pi^-} = 20$ nb
- inclusive:
  $\sigma_{b \to J/\psi X \to \mu^+\mu^- X} = 0.7\ \mu$b
  $\sigma_{pp \to J/\psi X \to \mu^+\mu^- X} = 8\ \mu$b



LHC startup luminosity $\mathcal{L} = 2x10^{33}$ cm^{-2}s^{-1}

Backgrounds

main background processes:

1. prompt $pp \to J/\psi X$
   - ϕ from fragmentation or fake reconstruction
   - from primary vertex
   - isotropic angular distribution
2. $b \to J/\psi X$
   - ϕ from fragmentation or fake reconstruction
   - isotropic angular distribution
3. $B^{\circ} \to J/\psi K^{\star 0} \to \mu^{+}\mu^{-}K^{+}\pi^{-}$
   - misidentified Kaon
   - angular distribution has same functional description as signal - with other parameters

Analysis

$\mu^{\pm}$: tracks from μ-chambers & tracker

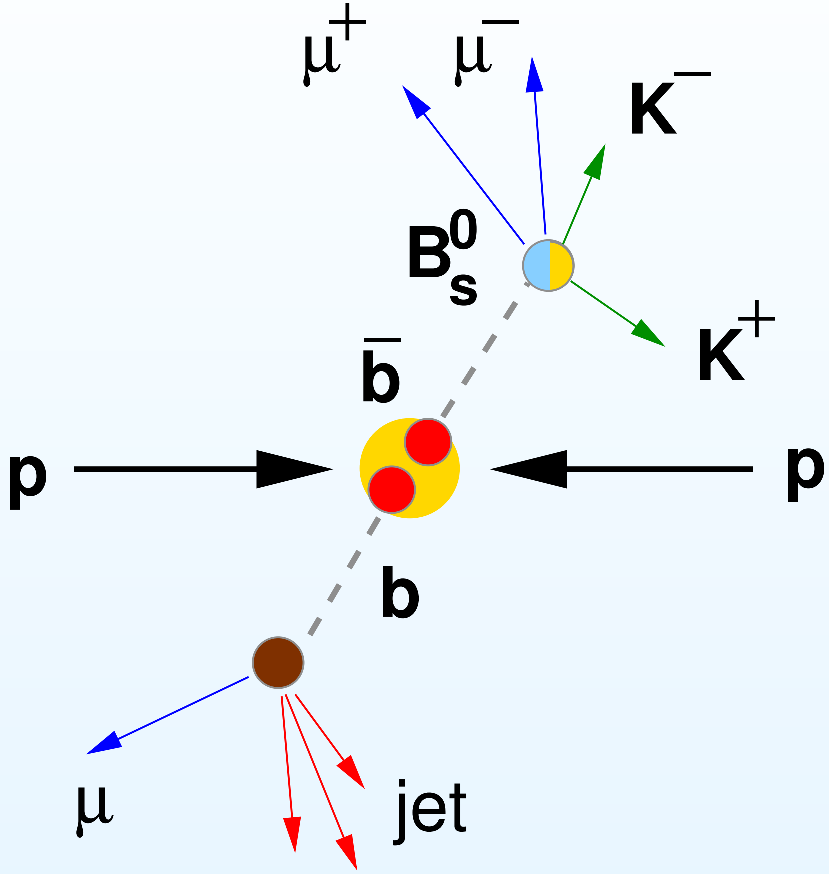
- $\mu - ID$: μ-chambers
  - reconstr. J/ψ from opposite charged $\mu-$tracks
  - mass & P_T-cut

$K^{\pm}$: tracks from tracker

- reconstr. ϕ from opposite charged K-tracks
- mass & P_T-cut

B_s^0: kinematic fit on $\mu^{\pm}-$& $K^{\pm}-$tracks

- constraints on mass, P_T
- flavour tagging (ATLAS)



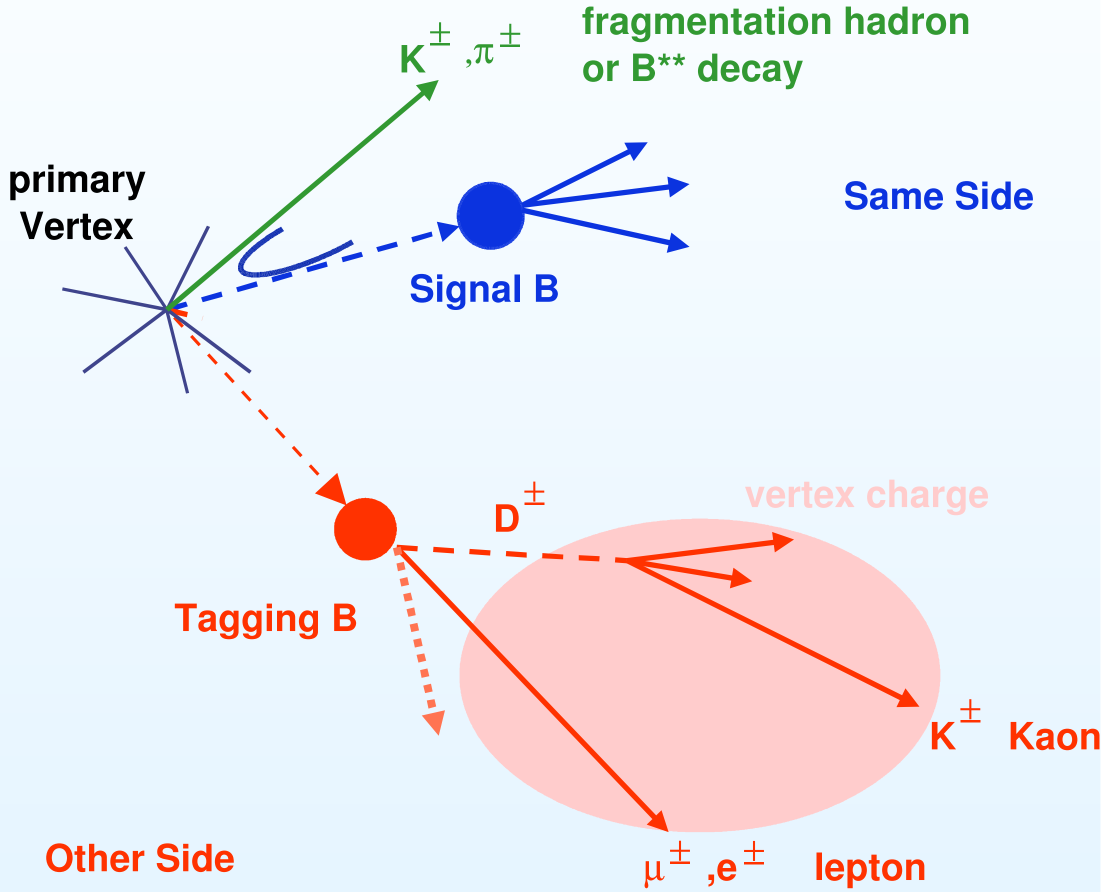
Flavour Tagging in ATLAS

same side tag:

- jet charge or soft π, K
- tag efficiency:
  $\varepsilon_{tag} = 0.62$
- wrong tag:
  $W_{tag} = 0.39$

other side tag:

- lepton tag
- $\varepsilon_{tag}(e/\mu) = 0.012/0.025$
- $W_{tag}(e/\mu) = 0.27/0.24$



Offline Analysis

$\mu^{\pm}$:

- $P_T > 3$ GeV
- $|\eta| < 2.4$
- $\chi 2/DoF < 6$

J/ψ :

- $\left|\Delta m_{J/\psi}\right| < 3\sigma, \sigma = 38$ MeV
- $P_T > 4$ GeV

$K^{\pm}$:

- $P_T >$0.5 GeV / 0.7 GeV (CMS)
- $|\eta| < 2.4$
- $\chi 2/DoF < 6$

ϕ :

- $\left|\Delta m_{\phi}\right| <$10 MeV / 8 MeV (CMS)
- $P_T > 1$ GeV

B_s^0:

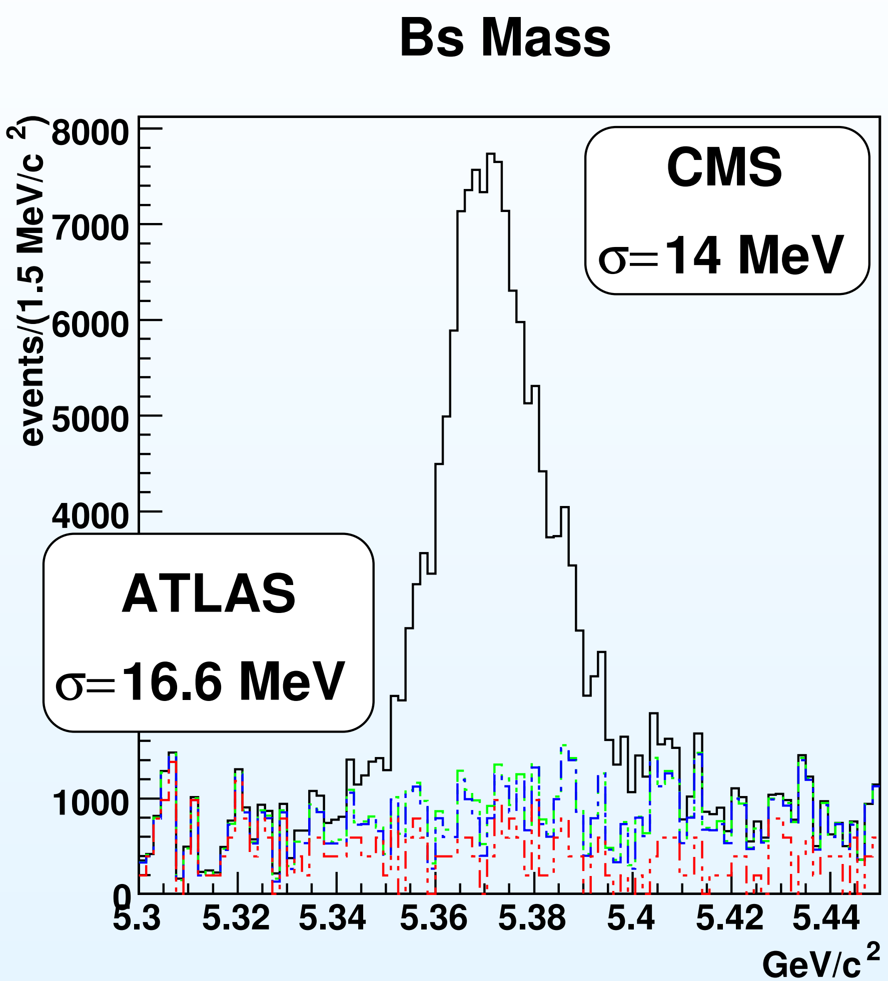
- $P_T > 10$ GeV / pointing angle $(\vec{P}_T, sec.\vec{V}ertex) < 12°$(CMS)
- proper time delay > 0.5 ps / significance >3 (CMS)
- $\chi 2/DoF < 10$
- $\left|\Delta m_{B_s^0}\right| < 3\sigma, \sigma = 17$ MeV / no cut (CMS)

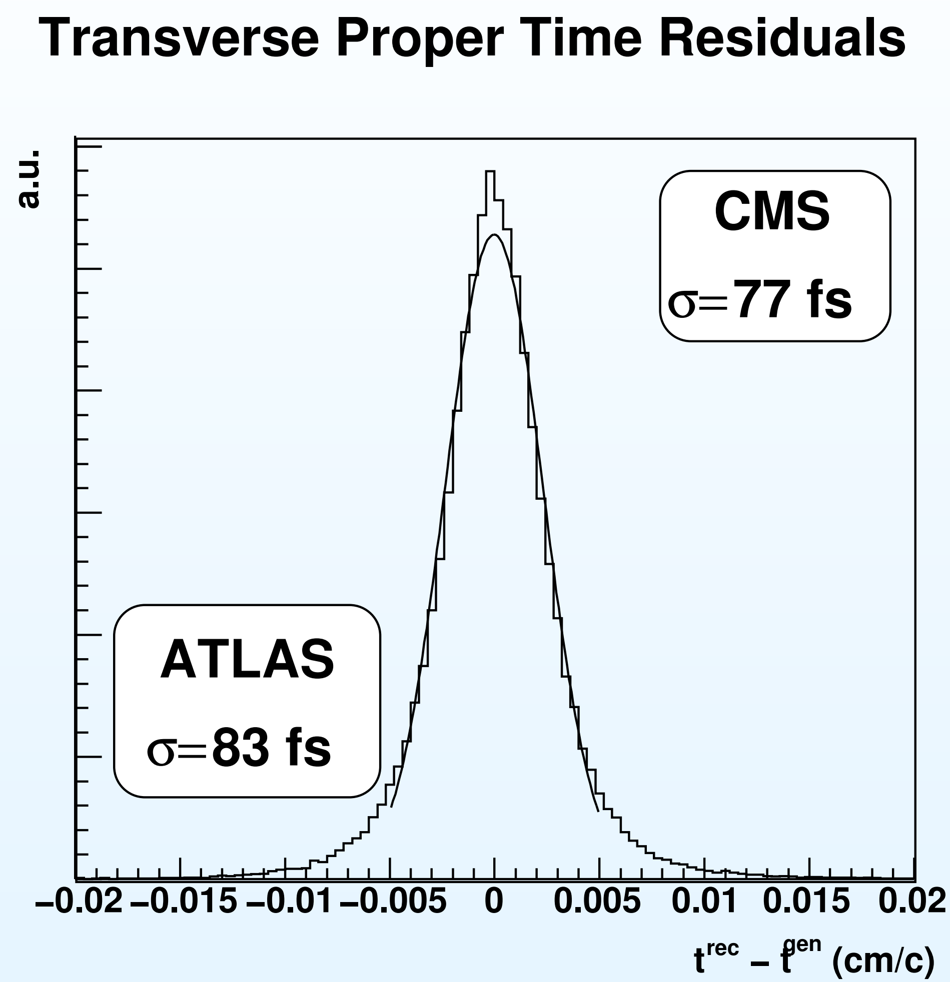
Event Samples

event type	ATLAS (30 fb^{-1})	CMS (6.8 fb^{-1})
signal w. cinematic cuts	810000	508000
signal after trigger cuts	623700	105000
signal after offline cuts	270700	75000
background fraction	15 %	*20 %

*no cut on B_s^0-mass

Residuals





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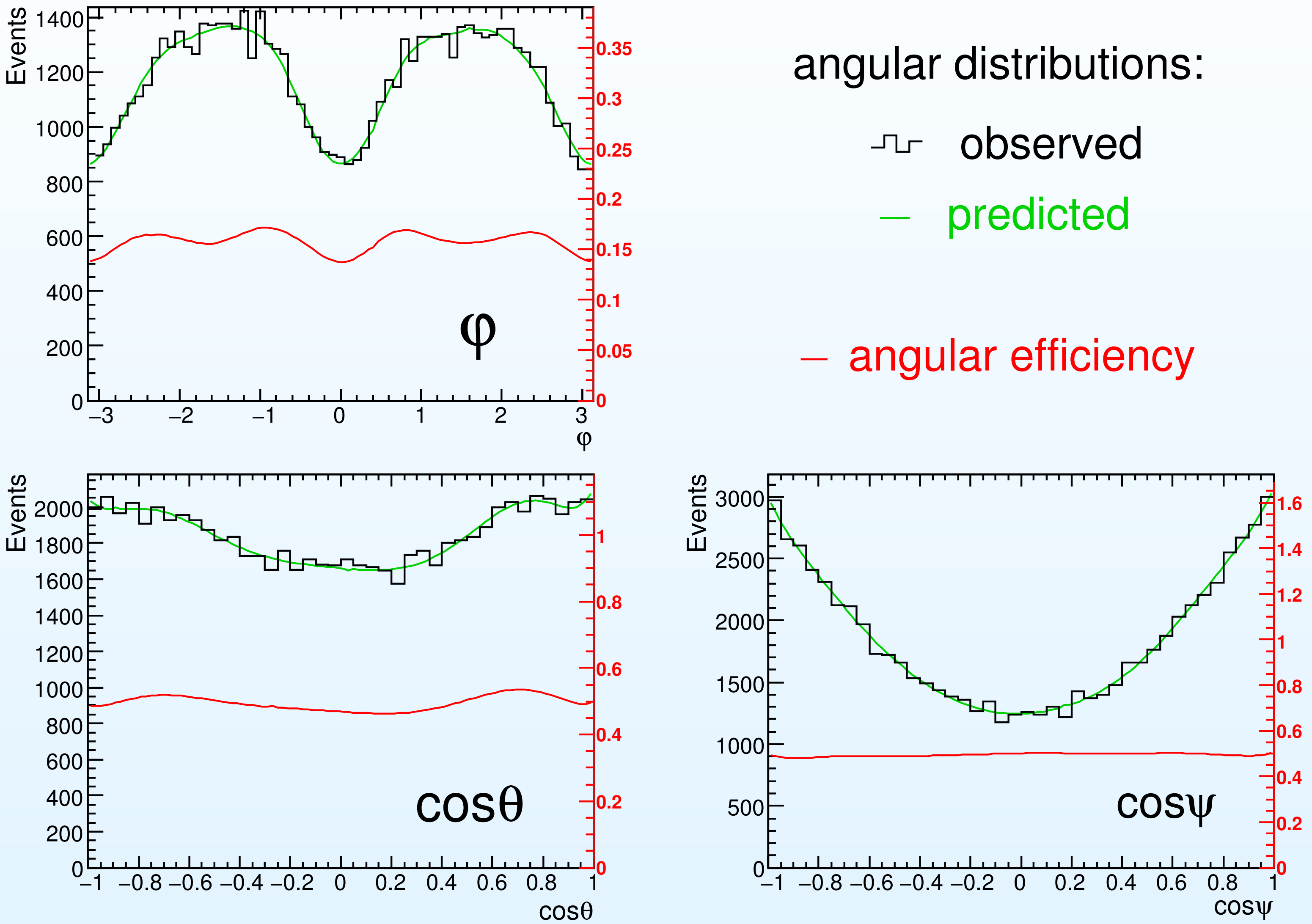
Angular Analysis (untagged)

maximum likelihood fit:

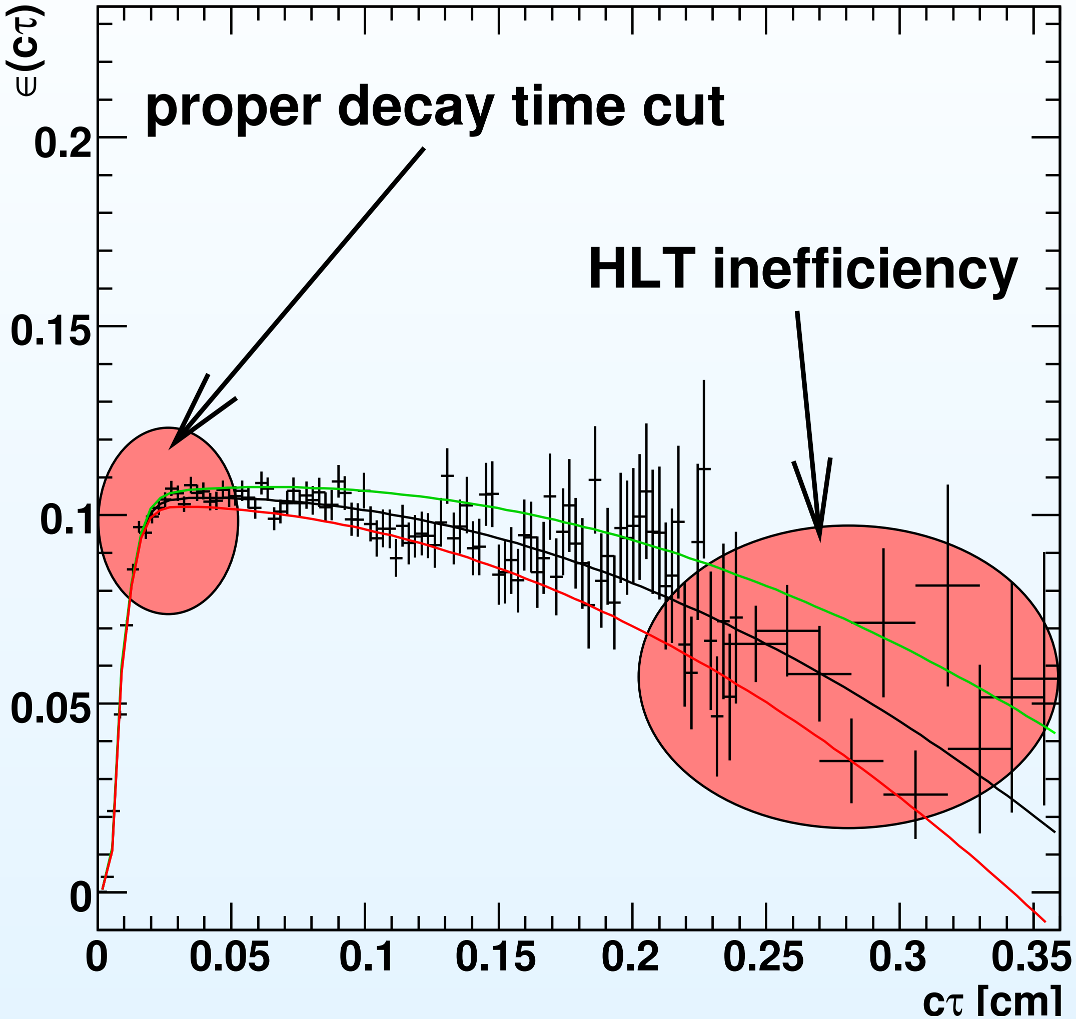
$$
\begin{aligned}
P.D.F. \quad &= (1-b_d-b_c)\cdot\varepsilon(t,\Theta)\cdot f(\Theta,\alpha,t)\cdot G_s(m;m_s,\sigma_s) && \textit{Signal}\\
&+b_d\cdot f_d(\Theta)\cdot\varepsilon(t)\cdot\frac{1}{\tau_d}e^{-t/\tau_d}\cdot G_d(m;m_d,\sigma_d) && B^\circ\to J/\psi K^{\star 0}\\
&+b_c\cdot\varepsilon(t)\cdot(\frac{1}{\tau_{cs}}e^{-t/\tau_{cs}}+\frac{1}{\tau_{cl}}e^{-t/\tau_{cl}})\cdot L(m) && \textit{combinatorical BG}
\end{aligned}
$$

- $\varepsilon(t,\Theta)$ selection efficiency
- $G_{s/d}(m;m_{s/d},\sigma_{s/d})$ gaussian mass distribution of B_s or B^0
- L(m) flat mass distribution of combinatorical BG
- b_d, b_c rate of misidentified B^0 or combinatorical BG events

Angular Selection Efficiency



Time Dependent Selection Efficiency



implicit cut in HLT degrades $\varepsilon(t)$

$\Rightarrow$ correct with $B^{\circ} \to J/\psi K^{\star 0}$ data

total selection efficiency: $\varepsilon = 14\ \%$

Expected Sensitivity ATLAS - tagged Analysis

tagged analysis based on 30 fb^{-1}:

assumptions:

- $\Delta m_s = 20$ ps^{-1}
- $\Delta\Gamma_s/\Gamma_s = 0.1$

$\sigma(\phi_s)$	0.046
$\sigma(\Delta\Gamma_s)/\Delta\Gamma_s$	13 %
$\sigma(\Gamma_s)/\Gamma_s$	1 %
$\sigma(A_\parallel)/A_\parallel$	0.9 %
$\sigma(A_\perp)/A_\perp$	3 %

δ_1, δ_2 highly corelated

$\Longrightarrow$ no results given

Expected Sensitivity CMS - Untagged Analysis

$\Delta m_s = 17.8$ ps^{-1}	sys. error	stat. error (30 fb^{-1} extrap.)		
int. Lumin.	1.3 fb^{-1}	1.3 fb^{-1}	6.8 fb^{-1}	30 fb^{-1}
$\sigma(\lvert A_0(0)\rvert^2)$	2.6 %	1.1 %	0.4 %	0.23 %
$\sigma(\lvert A_\parallel(0)\rvert^2)$	2.9 %	3.6 %	2.1 %	1.1 %
$\sigma(\lvert A_\perp(0)\rvert^2)$	4.6 %	3.2 %	1.9 %	0.9 %
$\sigma(\bar{\Gamma}_s)$	3.2 %	1.1 %	0.5 %	0.24 %
$\sigma(\Delta\Gamma_s)$	-	17.7 %	8 %	3.5 %
$\sigma(\Delta\Gamma_s/\Gamma_s), \Delta\Gamma_s/\Gamma_s = 0.2$	8.5 %	18.4 %	8.4 %	**4 %**
$\sigma(\delta_1), \delta_1 = \pi$	-	-	0.63	0.3
$\sigma(\delta_2), \delta_2 = 0$	-	-	0.64	0.31
$\sigma(\phi_s), \phi_s = 0.04$	-	-	0.076	**0.036**

systematic errors gouverned by uncertainty of $\varepsilon(t,\Theta)$
calibration via $B^\circ \to J/\psi K^{0\star}$ possible.

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Conclusion

$B_s^\circ \to J/\psi\phi \to \mu^+\mu^- K^+ K^-$ studies @ ATLAS & CMS:

- both use maximum likelihood analysis:
  - ATLAS tagged / CMS untagged
- expected sensitivity (30 fb^{-1}):
  - ATLAS:
    - $\sigma(\Delta\Gamma_s)/\Gamma_s = 0.13$ for $\Delta\Gamma_s/\Gamma_s = 0.1$
    - $\sigma(\phi_s) = 0.046$ for $\Delta m_s = 20\, ps^{-1}$
  - CMS:
    - $\sigma(\Delta\Gamma_s)/\Gamma_s = 0.04$ for $\Delta\Gamma_s/\Gamma_s = 0.2$
    - $\sigma(\phi_s) = 0.036$ for $\Delta m_s = 17.8\, ps^{-1}$
- any big effects of new physics on ϕ_s visible with 30 fb^{-1}