Prospect for β_s measurement at LHC

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Physics at LHC, 3rd october 2008

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- Analysis strategy
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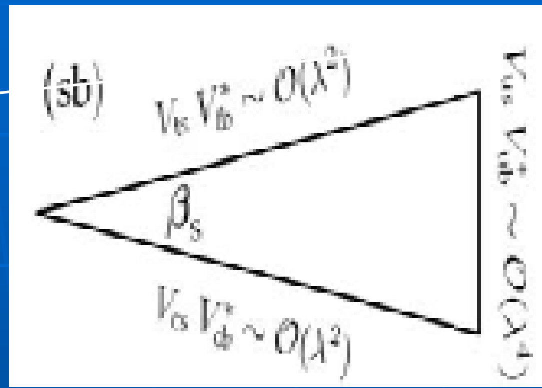
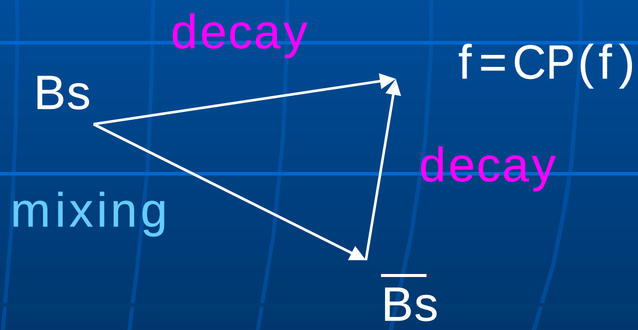
β_s angle in one slide

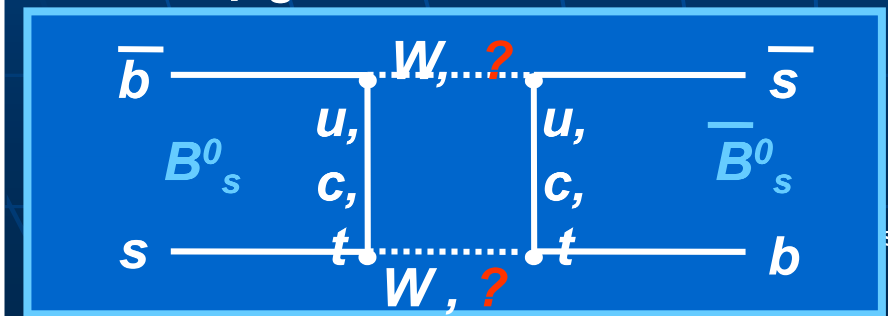
- the CKM unitarity triangle in Bs system

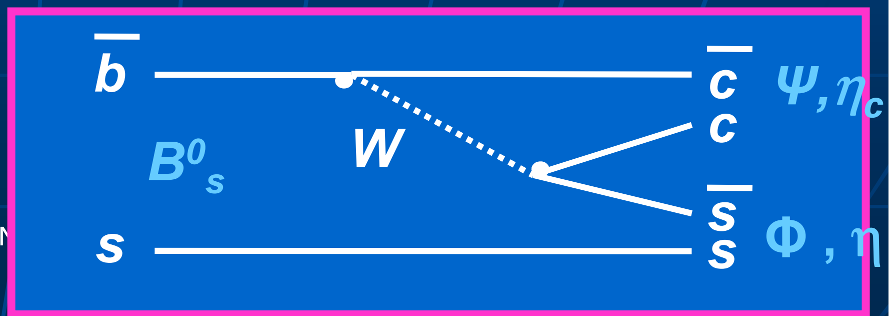


- Possible to extract $\beta_s = -\arg\left(\frac{V_{ts}V^*_{tb}}{V_{cs}V^*_{cb}}\right)$ from CPV in Bs if b→ $c\bar{c}s$ decay GOLDEN MODE $J/\psi\phi$



- SM predicts a very small value: $2\beta_s = 0.037 \pm 0.002$

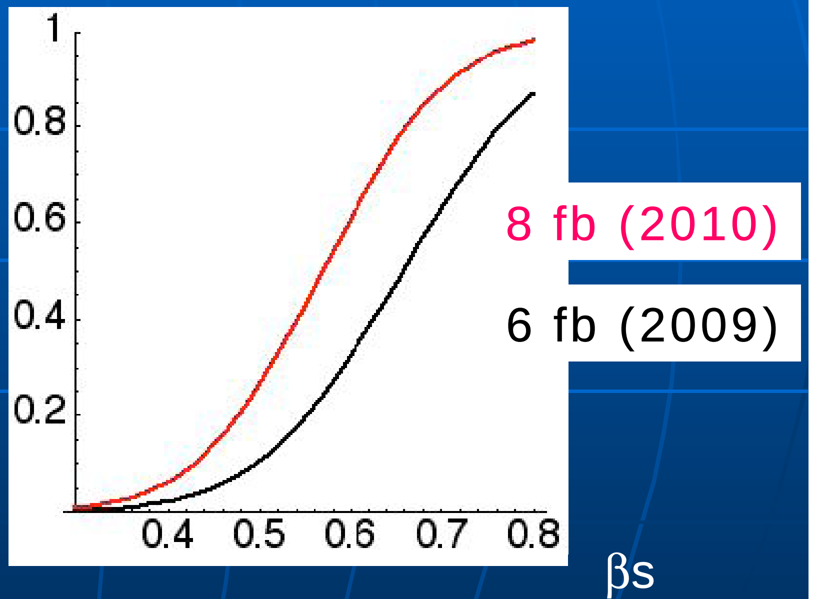




Interesting !

- Tevatron result is larger that SM prediction by 2.2 σ (arXiv:0808.1297)
- Exciting for NP searches but not easy to settle down by tevatron alone: room for LHC

CDF Probability of 5 σ observation



Formulas of decay rate

A_0, $A_\parallel$, $A_\perp$: transition amplitudes in a given polarization state

f(ρ): angular distribution for a given polarization

Untagged analysis still some sensitive to β_s

T U V :Time dependence

If P→ anti P $(U,V)^+ \rightarrow (U,V)^-$
$\eta = 1 \rightarrow -1$

Tagged analysis sensitive to cos(2β) sin(2β)

$$\frac{d^4P(t,\vec{\rho})}{dt\,d\vec{\rho}} \propto |A_0|^2\mathcal{T}_+ f_1(\vec{\rho}) + |A_\parallel|^2\mathcal{T}_+ f_2(\vec{\rho}) + |A_\perp|^2\mathcal{T}_- f_3(\vec{\rho}) + |A_\parallel||A_\perp|\mathcal{U}_+ f_4(\vec{\rho}) + |A_0||A_\parallel|\cos(\delta_\parallel)\mathcal{T}_+ f_5(\vec{\rho}) + |A_0||A_\perp|\mathcal{V}_+ f_6(\vec{\rho}),$$

$$\mathcal{T}_\pm = e^{-\Gamma t} \times [\cosh(\Delta\Gamma t/2) \mp \cos(2\beta_s)\sinh(\Delta\Gamma t/2) \mp \eta\sin(2\beta_s)\sin(\Delta m_s t)],$$

$$\mathcal{U}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp - \delta_\parallel)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp - \delta_\parallel)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)],$$

$$\mathcal{V}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp)\cos(\Delta m_s t) - \cos(\delta_\perp)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)].$$

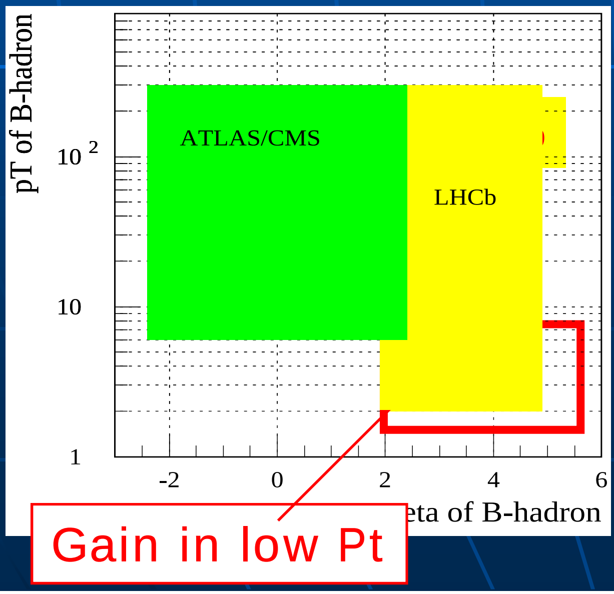
Analysis in a nutshell

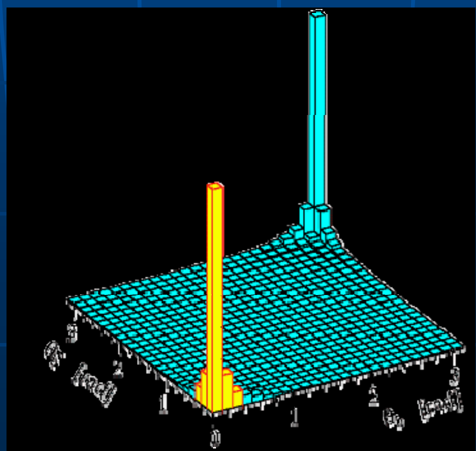
- Fit time dependent angular distribution
  - Large statistics is mandatory
    - Large σ_{bb} , good trigger
  - Good signal background separation
    - –benefit a lot for dimuon in final state
  - Good time resolution
  - Good tracking (angular resolution)
  - Good tagging (for tagged analysis)

Beauty in LHC experiment

- General purpose experiment
- $|\eta|<2.5$, $\sigma=100\mu b$
- B physics mainly first years ($L=10^{33}$)

- B dedicated experiment
- Forward spectrometer to max. bb in acceptance
- $1.9<\eta<4.5$ $\sigma=230\mu b$
- Locally reduced *L* to maximize events with one interaction





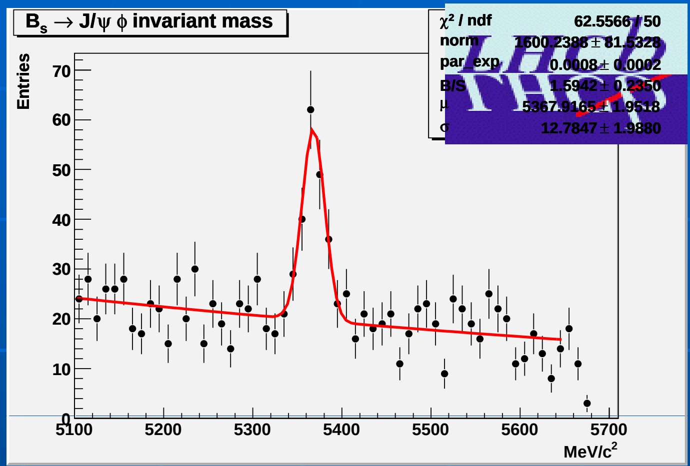
Trigger

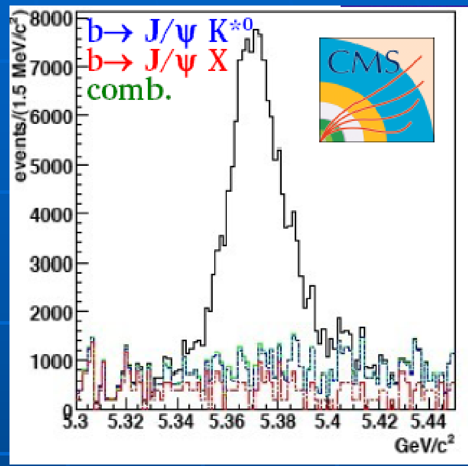
- Crucial since only 1% of σ_{tot} is b production and decay chain of interest has BR $3*10^{-5}$
- Hardware and sw levels for all experiments:
  - L0 rate 1MHz (LHCb) ~100kHz (ATLAS CMS)
  - HLT rate 2kHz (LHCb) ~100Hz (ATLAS CMS)
- ATLAS and CMS general purpose so limited bandwidth for b physics (O(10%))
- All experiments have a dimuon trigger to select signal events
  - ATLAS /CMS Pt and Mass based cut + IP, rate ~Hz
  - LHCb : 600Hz of IP unbiased dimuon trigger →signal recostruction as offline (loser cut) noIP . Very high efficiency on selected events of trigger (~ 70%)

Signal reconstruction

- Standard cuts : Pt, invariant mass, PID, vertex quality, B pointing to primary vertex, B decay length (only ATLAS & CMS)
- PID
  - Similar muon ID performance for ATLAS CMS and LHCb
  - ATLAS and CMS no Kaon pid capability, LHCb has 2 Riches that ensures good K identification $\varepsilon(K \rightarrow K) \sim 80\%$ $e(\pi \text{-} > K) \sim 3\%$

Signal and background





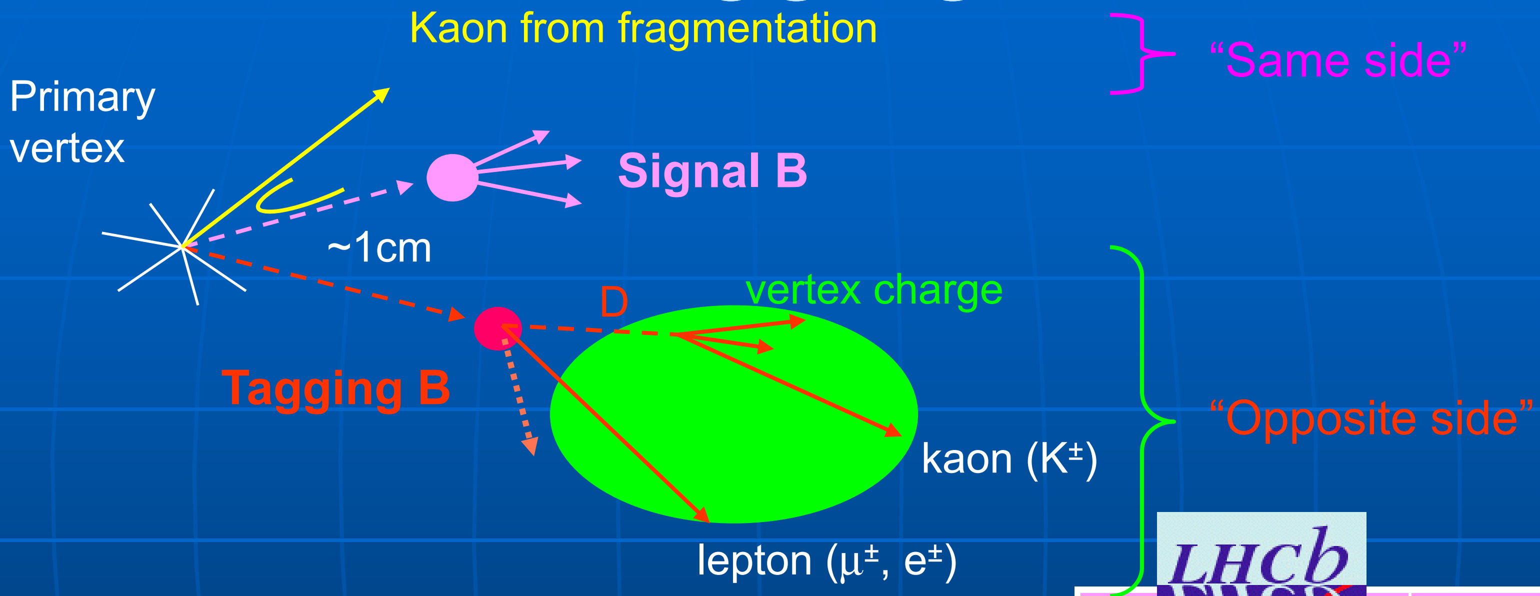
	L (fb^{-1})	ev	B/S	Background
ATLAS	10	90k	0.18	long lived B
CMS	10	109k	0.25	long lived B
LHCb	2	114k	2.0	1.8 prompt* +0.2 long lived

* Selection with no bias in IP to avoid acceptance in proper time and angle

Proper time resolution

- Need to resolve fast Bs oscillation: β_s extraction sensitivity ~ $\exp(-0.5*\sigma_t^2 \Delta m_s^2)$
- Atlas 83fs CMS 77fs LHCb 39fs
  - LHCb vertex detector close to IP (0.8cm wtr 4.4cm)
  - LHCb P resolution a factor 2 better
  - LHCb trigger collects 600Hz unbiased dimuon (also) to calibrate proper time on data

Tagging



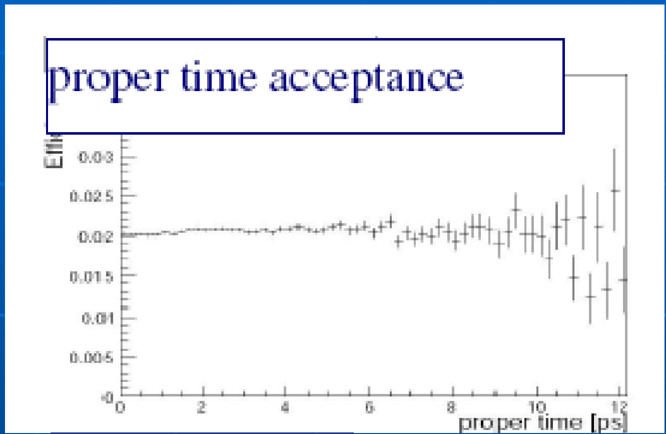
- Sensitivity goes as $\varepsilon(1-w)^2$
- ATLAS : e, μ Qjet 4.6%
- CMS : NA

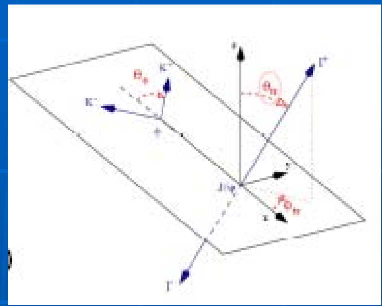
	$\varepsilon(1-2w)^2$
Muon	0.8
Electron	0.4
K (OS)	1.5
K (SS)	2.1
Q vertex	1.1
Combined	6.2

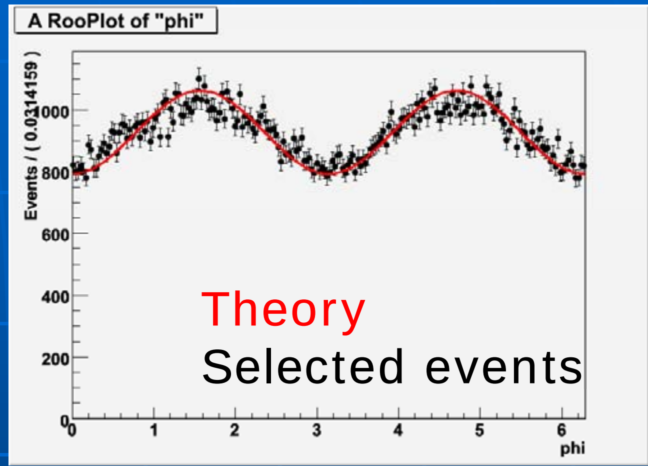
Tagging from data

- LHCb plans to extract the mistag fraction from control sample with large statistics
- Opposite Side is extracted from $B^+ \rightarrow J/\psi K^+$ or $Bd \rightarrow J/\psi K^*$
  - Common selection as much as possible with signal sample to avoid phase space bias to opposite b
  - Large statistics is expected:in 2 fb^{-1}
    - 650k $Bd \rightarrow J/\psi K^*$
    - 1 million for $B^+ \rightarrow J/\psi K^*$
- Same Side
  - From $Bs \rightarrow D_s\pi$

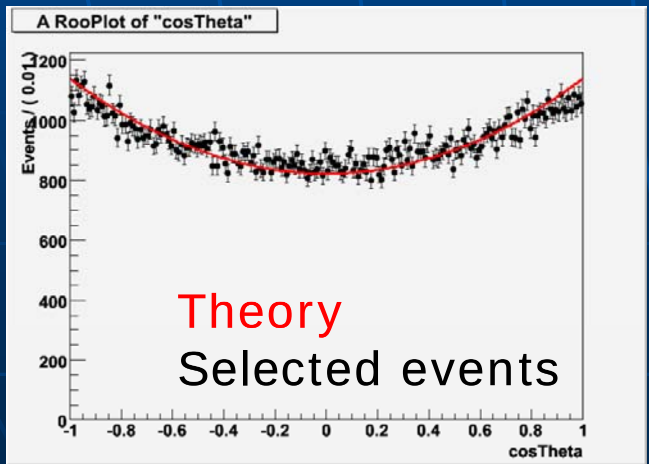
Acceptance proper time and angles



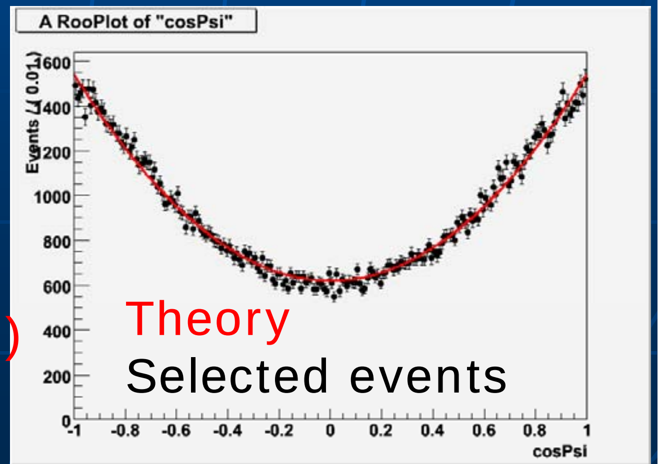




No bias from selection

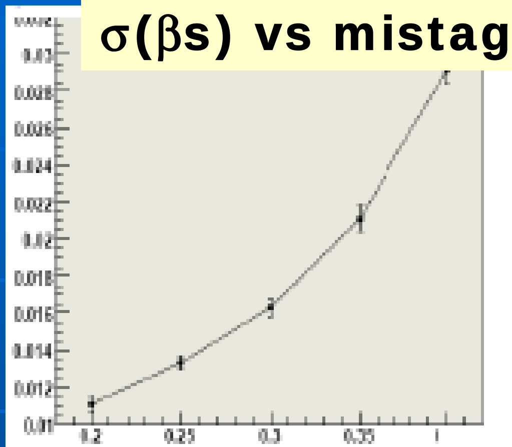


A common selection with Bd→J/Y K* allows to test the acceptance on data (650kev/2fb)

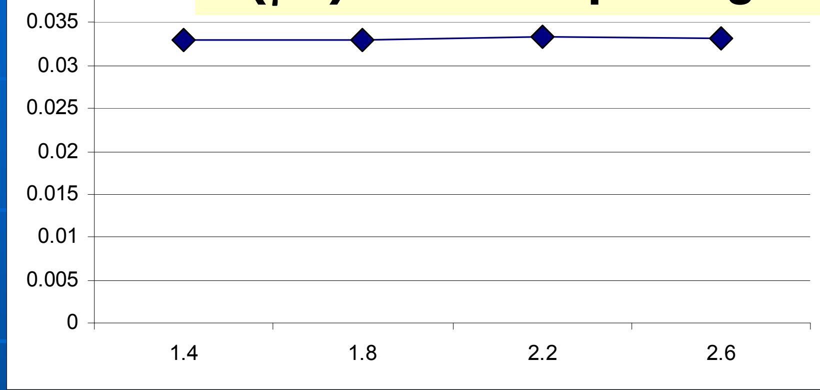


Systematic studies

σ(βs) vs mistag fraction

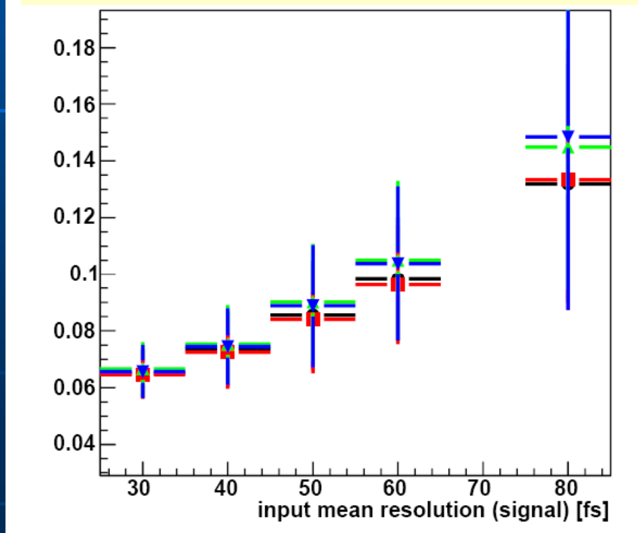


σ(βs) vs Prompt bkg fraction

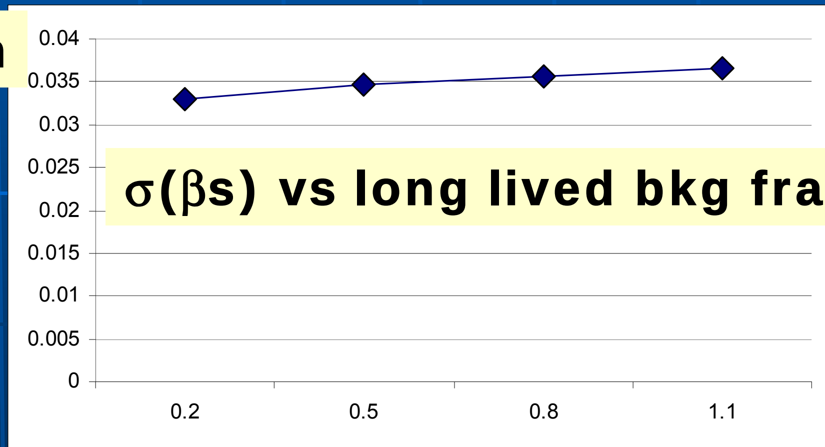


Angular resolution is very good and has negligible impact on βs error

σ(βs) vs proper time resoltuion



σ(βs) vs long lived bkg fraction



Crucial : mistag and proper time

Sensitivity

	ATLAS	CMS	LHCb
L (fb-1)	10	10	2.0
Yield (k)	90	109	114
B/S	0.18	0.25	2.0
$\sigma(M_{Bs})$ (MeV)	16.5	14	17
σ_t (fs)	83	77	39
Eff(tag) (%)	4.6	NA	6.2
$\sigma(2\beta s)$	0.08	NA	0.03

Even with fraction of one year nominal luminosity good sensitivity

More channels in LHCb

- Other $b \rightarrow c\bar{c}s$ decay can be added
  - Low yield , experimental signature more difficult, larger background , degradation of proper time resolution for Ds Ds
  - No angular analysis is required

Decay mode	Events in $2fb^{-1}$	$\sigma(2\beta s)$
$J/\Psi\eta_{\gamma\gamma}$	8.5 k	0.109
$J/\Psi\eta_{\pi\pi\pi 0}$	3 k	0.142
$J/\Psi\eta'_{\pi\pi\eta}$	2.2 k	0.154
$J/\Psi\eta'_{\rho\gamma}$	4.2 k	0.08
$\eta_c\phi$	3 k	0.108
Ds Ds	4 k	0.133
All		**0.046**

Summary

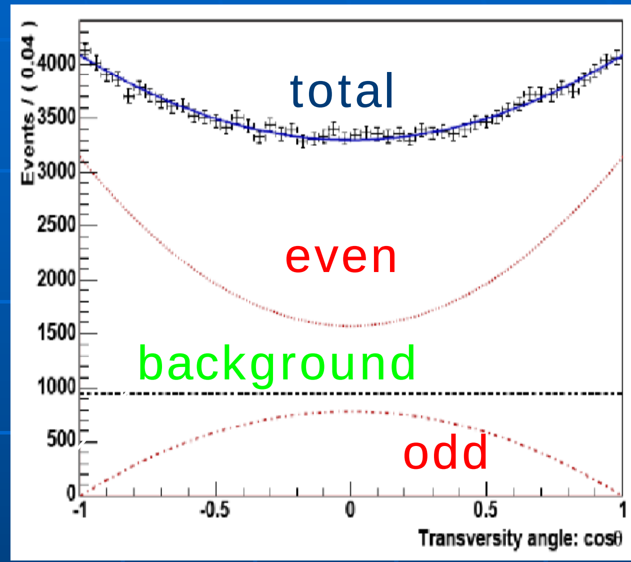
- All experiments will collect large sample of golden mode decay for βs measurement
- Great potential to improve significantly the existing measurement
  - even with fraction of nominal year

Spares

CPV in Bs → $c\bar{c}s$ (s)

- Golden mode : $J/\psi(\mu\mu)\phi(K^+K^-)$
  - Large BR
  - Clean experimental signature
  - Easy to trigger
  - Sum of even and odd CP eigenstates

  → angular analysis



- Other modes $J/\psi\eta$, $J/\psi\ \eta'$, $\eta_C\ \phi$, Ds Ds
  - Low yield , experimental signature more difficult, larger background , degradation of proper time resolution for Ds Ds
  - No angular analysis is required

Sensitivity study

Due to limited MC statistics

- we use the full Monte Carlo to estimate all the relevant quantities:
  - yield, background fraction, mass, proper time / angle distributions, resolutions and acceptances
- and plug them in hundreds of toy MC to estimate the sensitivity to 2 βs (and the others parameters), through an unbinned maximum likelihood fit:
- 6 observables:: proper time, 3 angles,, tagging answer =0,,+1,,1,mass
- 8 physical parameterrs:: 2βs,, Γs, $\Delta\Gamma$s,, R($\perp$) R(0), δ($\perp$),δ(0)
- + detector parameters (resolutions, acceptances, tagging)

CMS time and angular acceptance