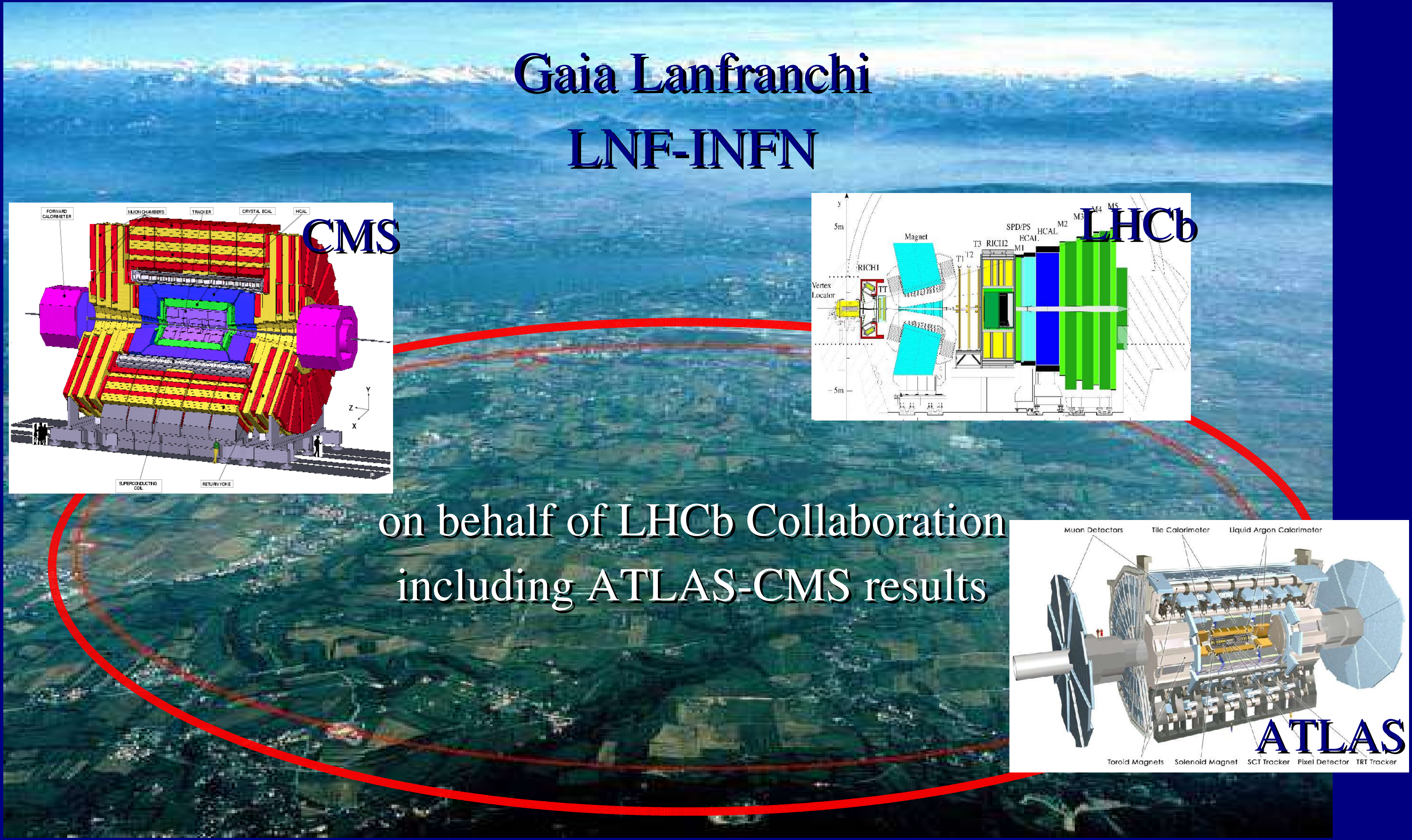
Search for New Physics in $B_s \to J/\psi\ \phi$ decay @ LHC



Gaia Lanfranchi

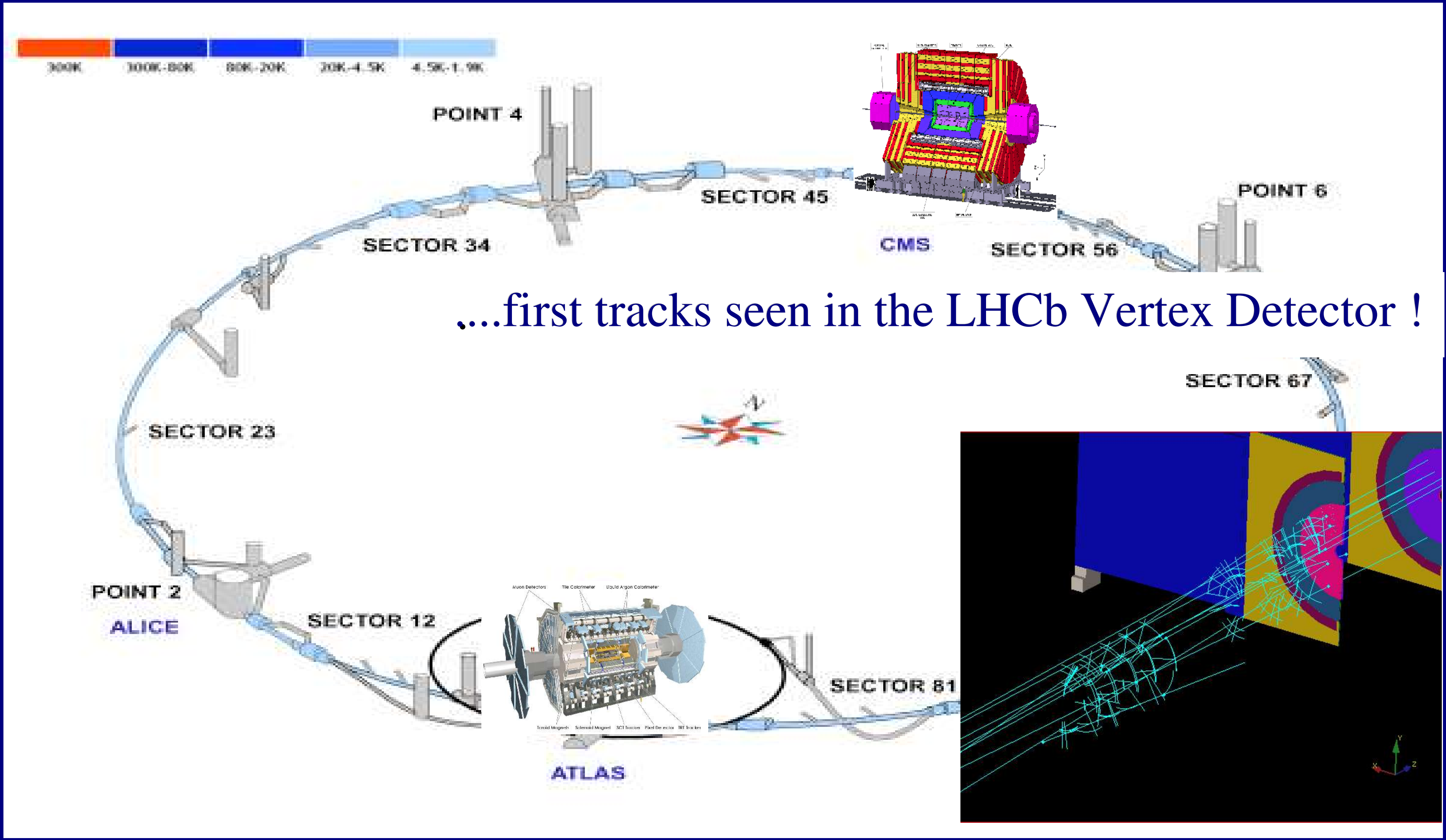
LNF-INFN

on behalf of LHCb Collaboration
including ATLAS-CMS results

CKM Workshop, Rome, September 9th-12th, 2008

Hunt for New Physics @ LHC is started......

August 22-24th: first injection test.....

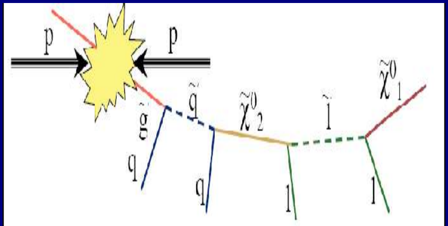


....first tracks seen in the LHCb Vertex Detector !

.....Yesterday first circulating beams...

.......and we have two complementary ways to catch it:

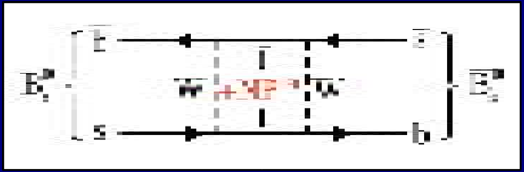
Direct searches:



we can go directly there

Viking landing on Mars

Indirect Searches:



we can look through a telescope..

Mars from Hubble Space Telescope

...If we follow the second way we need to know where to look and a powerful telescope to look into....

B_s mixing phase in $B_s \rightarrow J/\psi\, \phi$ decay:

- Introduction, phenomenology
- Key ingredients for sensitivity:
  - luminosity, cross section, triggers
  - offline selections
  - proper time resolution
  - tagging
- Sensitivity studies at LHCb,ATLAS,CMS
- Conclusions and prospects

Introduction (I)

- The phase Φ arising from interference between B decay with and without mixing is a sensitive probe of New Physics:

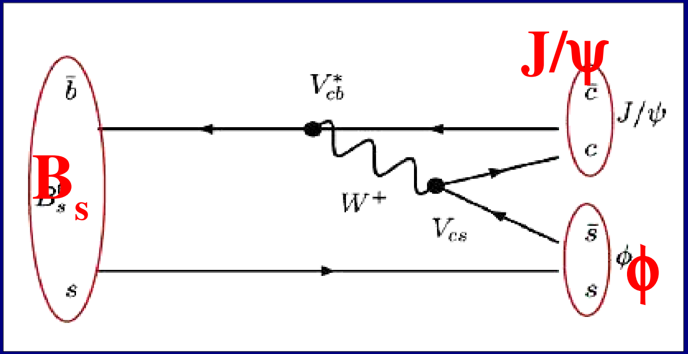
$$\Phi = -\arg(\lambda_f)$$

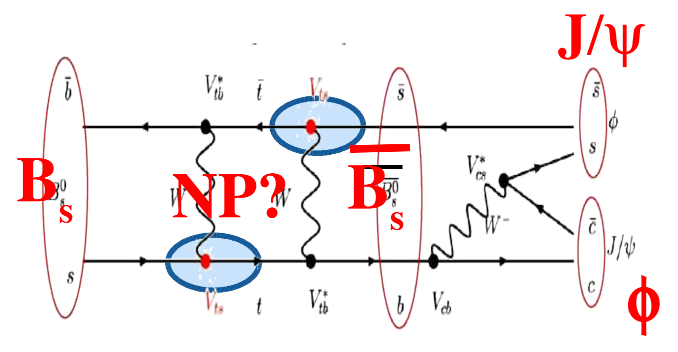
$$\lambda_f = q/p\ \bar{A}_f/A_f = \eta_f\ e-^{i(\Phi M-2\Phi D)}$$

$$\begin{tikzcd}
B \arrow[rr, "-\Phi_D"] \arrow[dr, "\Phi_M"'] & & f \\
& \bar{B} \arrow[ur, "\Phi_D"'] &
\end{tikzcd}$$

- Bs → J/ψ ϕ is dominated by a tree:

  → NP may enter in the box





Introduction (II)

- The observable weak phase is: $\Phi = \Phi^{SM} + \Phi^{NP}$

- In the Standard Model is small.....

$$\Phi^{SM}(B_s \to J/\psi\,\phi) = 2\arg(V_{ts}^{*}\,V_{tb}) - 2\arg(V_{cs}^{*}\,V_{cb}) = -2\beta_s \cong o(\lambda^2)$$

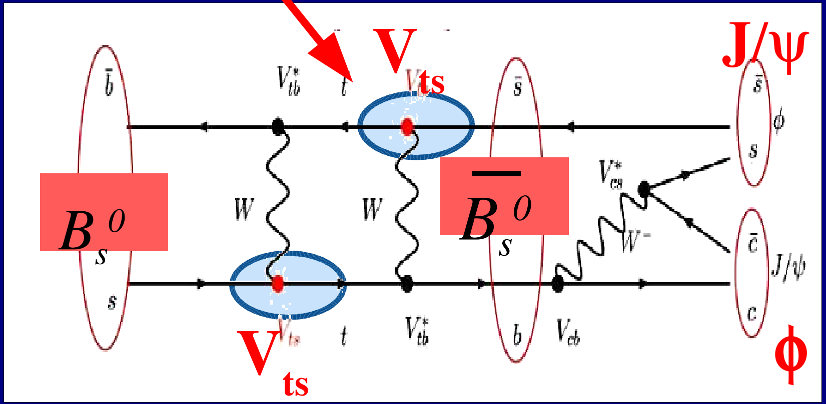
$$V_{\rm CKM} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda+\frac{1}{2}A^2\lambda^5[1-2(\rho+i\eta)] & 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4(1+4A^2) & A\lambda^2 \\ A\lambda^3[1-(1-\frac{1}{2}\lambda^2)(\rho+i\eta)] & \boxed{-A\lambda^2+\frac{1}{2}A\lambda^4[1-2(\rho+i\eta)]} & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix}$$

.... and well known:

$$\Phi^{SM}(B_s \to J/\psi\,\phi) = -2\beta_s = -0.0368 \pm 0.0017 \text{ (CKMFitter, summer07)}$$

- In presence of New Physics:

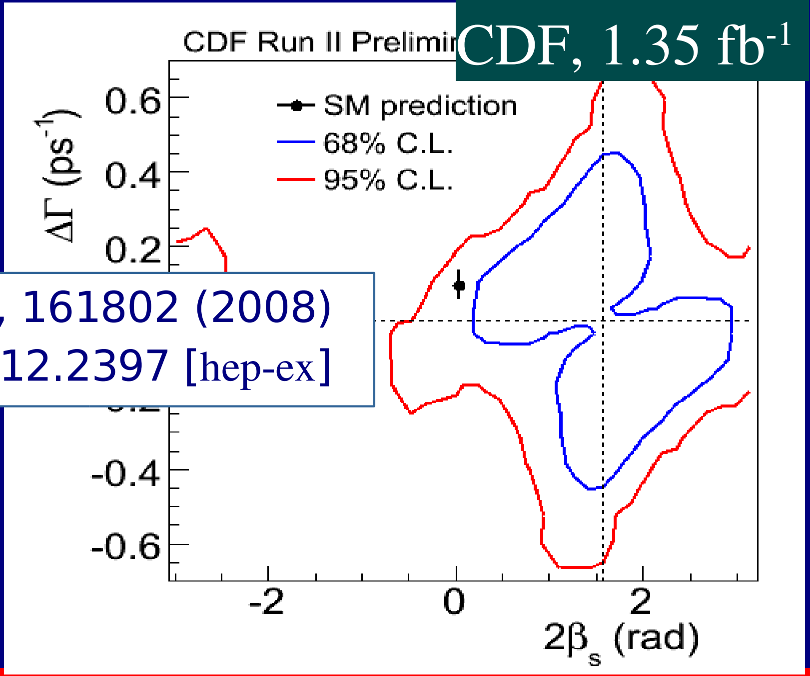
$$\Phi(B_s \to J/\psi\,\phi) = -2\beta_s + \Phi^{NP}_{M}$$



New Physics in Bs mixing?

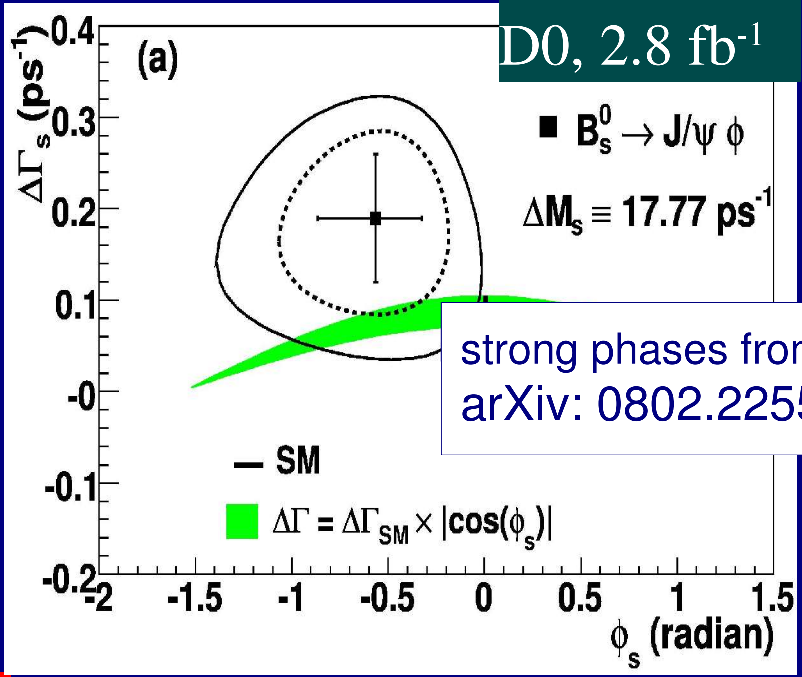
- Results from Tevatron (tagged analysis): a brief history....

~6 months ago



CDF, 1.35 fb^{-1}

PRL 100, 161802 (2008)
arXiv:0712.2397 [hep-ex]



D0, 2.8 fb^{-1}

strong phases from Bd→J/ψ K*
arXiv: 0802.2255 [hep-ex]

Feldman-Cousin approach:
$2\beta_s = [0.32, 2.82]$ @ 68% CL
1.5σ consistency with SM (p=15%)

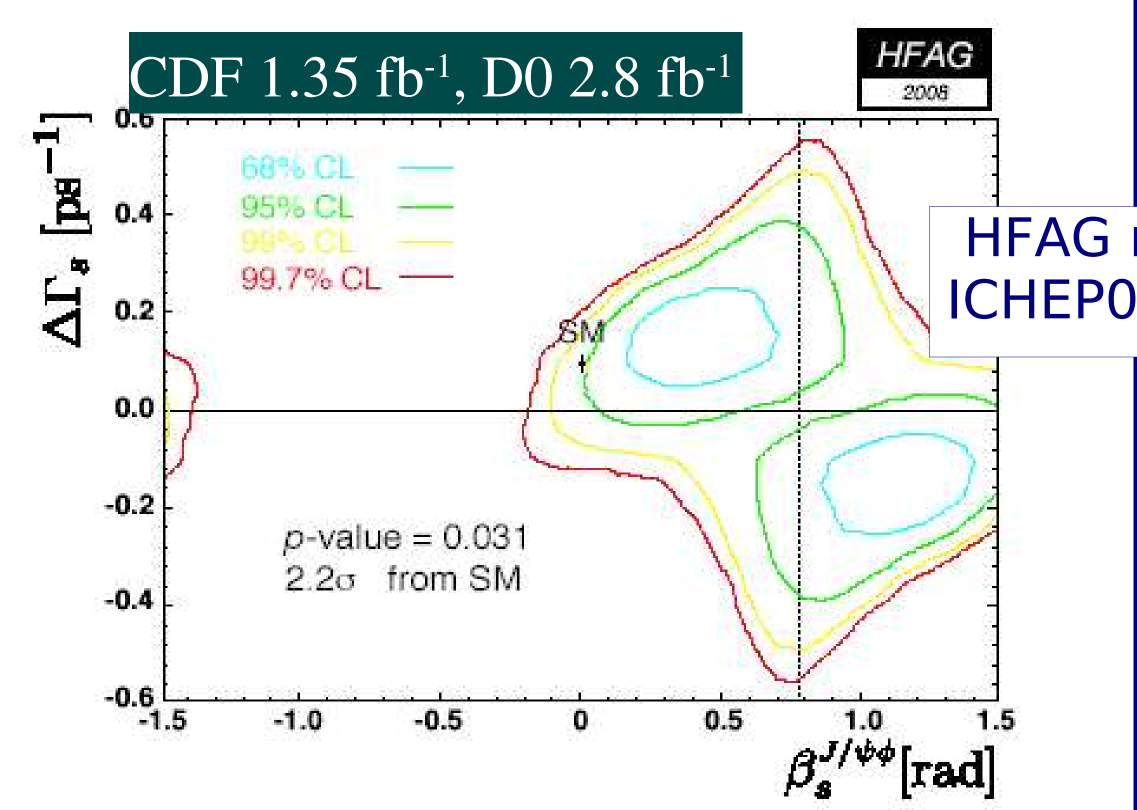
$\phi_s = -2\beta_s = -0.57^{+0.24}_{-0.30}\,(stat)^{+0.07}_{-0.02}\,(syst)$
1.8σ consistency with SM (p=6.6%)

UTFit coll: 3.7σ evidence for new physics (arXiv:0803.0659)

New Physics in Bs mixing?

- New combined CDF and D0 iso-CL regions, after removal of strong phases constraint:

~2 months ago



CDF 1.35 fb^{-1}, D0 2.8 fb^{-1}

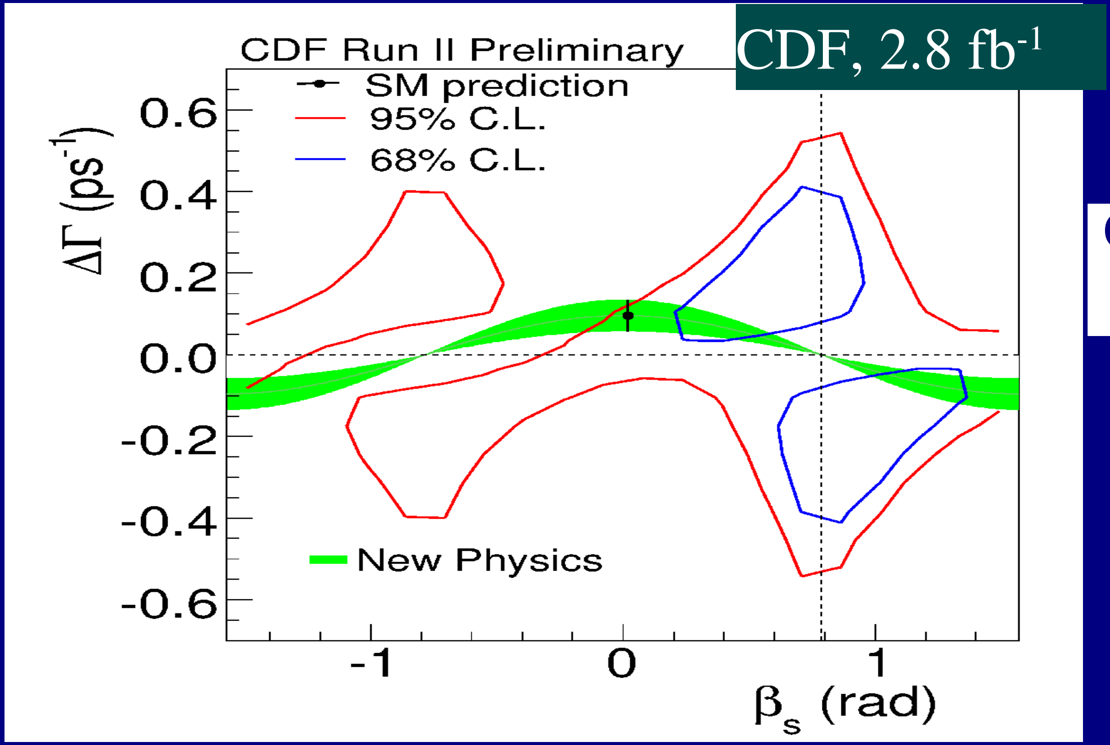
HFAG result, ICHEP08 (august 2008)

2.2 σ consistency with SM

New Physics in Bs mixing?

- CDF increases the analyzed data sample (1.3 $\mathrm{fb}^{-1} \rightarrow$ 2.8 fb^{-1})....

~1 months ago



CDF, 2.8 fb^{-1}

CDF Public Note 9458
(August 2008)

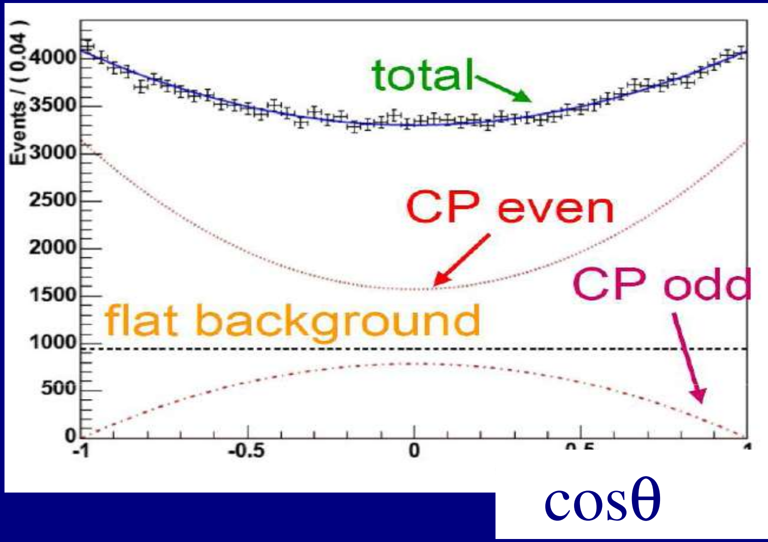
.......and consistency to SM decreases from 15% → 7%

⇒ situation is getting more and more interesting.......

CP violation in $B_s \to J/\psi\ \phi$ decay

Bs→ J/ψ(μμ) φ(KK) is a “golden” channel:

→ **high yield (BR~3×10^{-5}), clean signature**



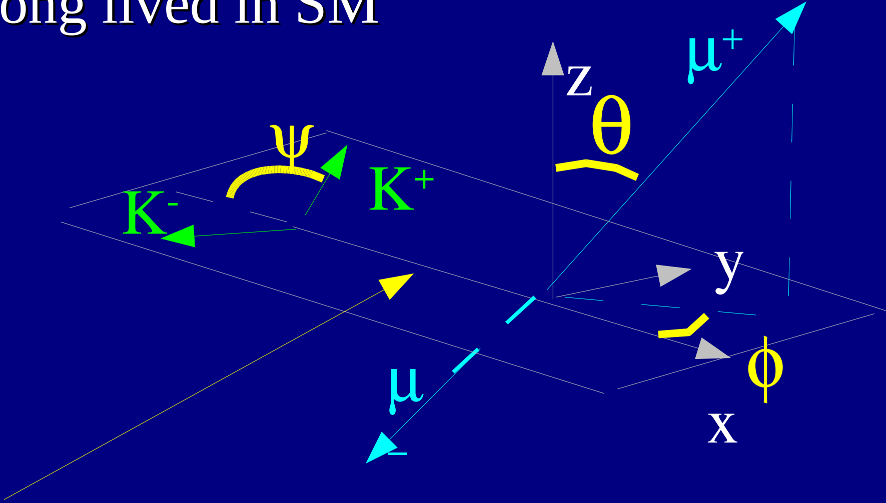
but it is a “complex” channel:

→ **two particles decaying in three final states!**

Two particles:

$| B^0_{S,L}\rangle = p\,|B^0_S\rangle + q\,|\bar{B}^0_S\rangle$ Light, CP-even, short lived in SM

$| B^0_{S,H}\rangle = p\,|B^0_S\rangle - q\,|\bar{B}^0_S\rangle$ Heavy, CP-odd, long lived in SM



Three final states:

J/ψ φ in S-wave - CP-even, A_0

J/ψ φ in D-wave – CP-even, $A_{\parallel}$

J/ψ φ in P -wave – CP-odd, $A_{\perp}$

The three final states need to be statistically separated through an angular analysis

CP violation in $B_s \rightarrow J/\psi\ \phi$ decay (II)

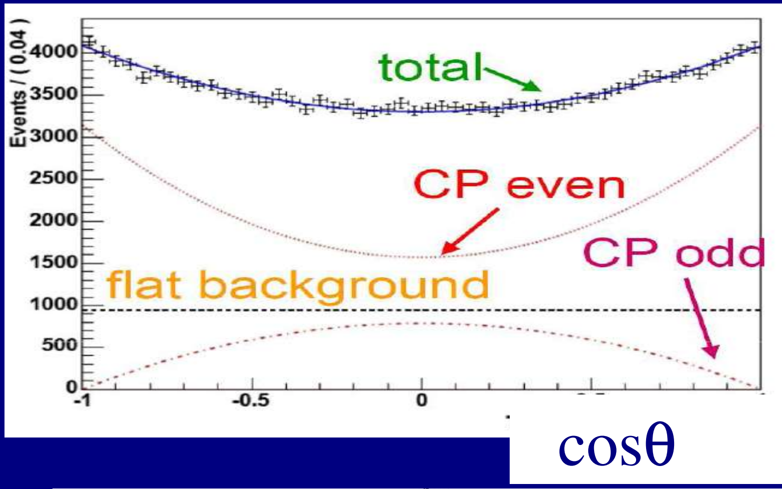
♦ Decay rate is 3 independent decay amplitudes: A_0, $A_{\parallel}$ = CP-even, $A_{\perp}$ = CP-odd which evolve in time with a frequency Δms:

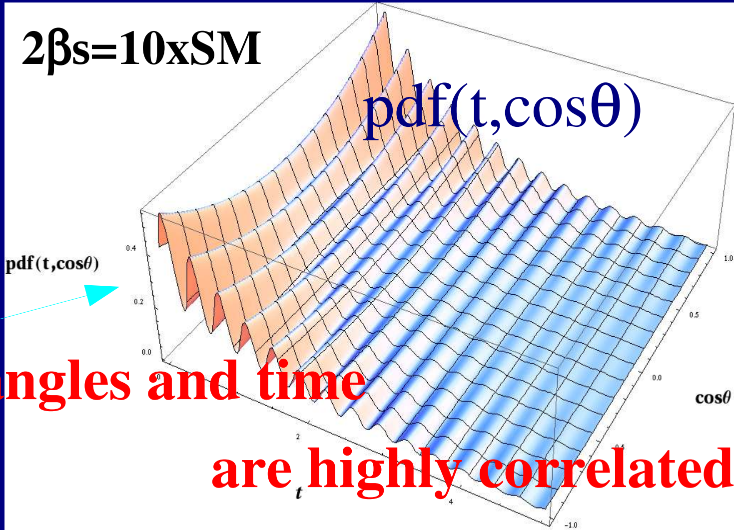
→ these amplitudes are a function of time, decay angles w = (θ,ϕ,ψ), and parameters ΔΓs, 2βs, Δms, Γs, $\delta_{\parallel}=\arg[A_{\parallel}]$, $\delta_{\perp}=\arg[A_{\perp}]$, R_0, $R_{\perp}$

$$
\begin{aligned}
d^4\Gamma(t,\mathbf{w})/dt\,d\mathbf{w} \propto\ & |A_0|^2\, T_+ f_1(\mathbf{w}) + |A_{\parallel}|^2\, T_+ f_2(\mathbf{w}) + \\
& + |A_{\perp}|^2\, T_- f_3(\mathbf{w}) + |A_{\parallel}|\,|A_{\perp}|\, U_+ f_4(\mathbf{w}) \\
& + |A_0|\,|A_{\parallel}| \cos\delta_{\parallel}\, T_+ f_5(\mathbf{w}) \\
& + |A_0|\,|A_{\perp}|\, V_+ f_6(\mathbf{w})
\end{aligned}
$$

fi(1,..6) encodes the different angular distributions

T+,T-,U+,V+ encode the time dependence




2βs=10xSM

pdf(t,cosθ)

angles and time are highly correlated

♦ The measurement is an analysis of time-dependent angular distributions:

⇒ The amplitude of the oscillation is the phase 2βs we are looking for....

CP violation in Bs→J/ψ φ decay (III)

$$
\begin{aligned}
d^4P(t,\mathbf{w})/dt\,d\mathbf{w} \propto\ & |A_0|^2\, T_+\, f_1(\mathbf{w}) + |A_\parallel|^2\, T_+\, f_2(\mathbf{w}) + \\
& + |A_\perp|^2\, T_-\, f_3(\mathbf{w}) + |A_\parallel|\,|A_\perp|\, U_+\, f_4(\mathbf{w}) \\
& + |A_0|\,|A_\parallel| \cos\delta_\parallel\, T_+\, f_5(\mathbf{w}) \\
& + |A_0|\,|A_\perp|\, V_+\, f_6(\mathbf{w})
\end{aligned}
$$

$P \rightarrow VV$

$(U^+,V^+ \rightarrow U^-,V^-$ for $P \rightarrow \overline{P}$)

$$
\begin{aligned}
T_\pm = e^{-\Gamma t}\ & [\cosh(\Delta\Gamma\, t/2) \mp \cos(2\beta s)\sinh(\Delta\Gamma\, t/2)] \\
& \mp\ \eta\ \sin(2\beta s)\sin(\Delta Ms\, t) \qquad \eta = +1\ (-1) \text{ for } P\ (\overline{P})
\end{aligned}
$$

$$
\begin{aligned}
U_\pm = \pm\ e^{-\Gamma t}[\ & \sin(\delta_\perp - \delta_\parallel)\cos(\Delta Ms\, t) \\
& - \cos(\delta_\perp - \delta_\parallel)\cos(2\beta s)\sin(\Delta Ms\, t) \\
& \pm \cos(\delta_\perp - \delta_\parallel)\sin(2\beta s)\sinh(\Delta\Gamma\, t/2)]
\end{aligned}
$$

$$
\begin{aligned}
V_\pm = \pm\ e^{-\Gamma t}[\ & \sin(\delta_\perp)\cos(\Delta Ms\, t) \\
& - \cos(\delta_\perp)\cos(2\beta s)\sin(\Delta Ms\, t) \\
& \pm \cos(\delta_\perp)\sin(2\beta s)\sinh(\Delta\Gamma\, t/2)]
\end{aligned}
$$

terms with Δms dependence
flip sign with initial Bs flavor
→ disappear summing $Bs+\overline{B}s$
(untagged strategy)
→Still some sensitivity
to $|\sin(2\beta s)|$ and $|\cos(2\beta s)|$
(4 fold ambiguity)

ATLAS/LHCb: tagged analysis

CMS: untagged analysis ⇒ no sensitivity on 2βs presented today

CP violation in Bs→J/ψ ϕ decay (IV)

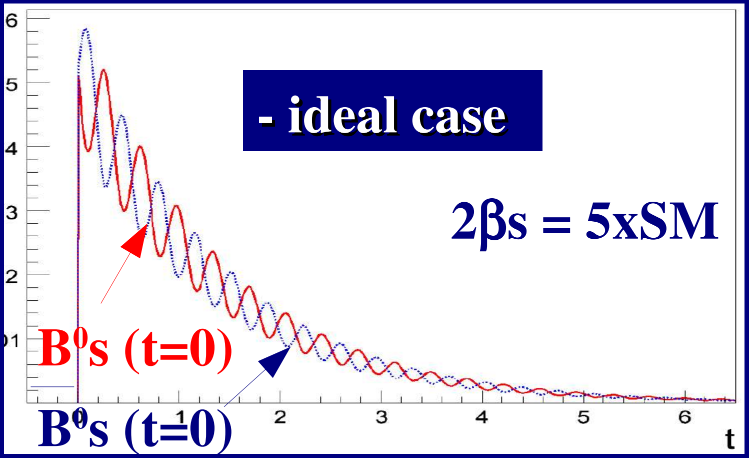
Experimental factors that can affect the amplitude of the oscillations:

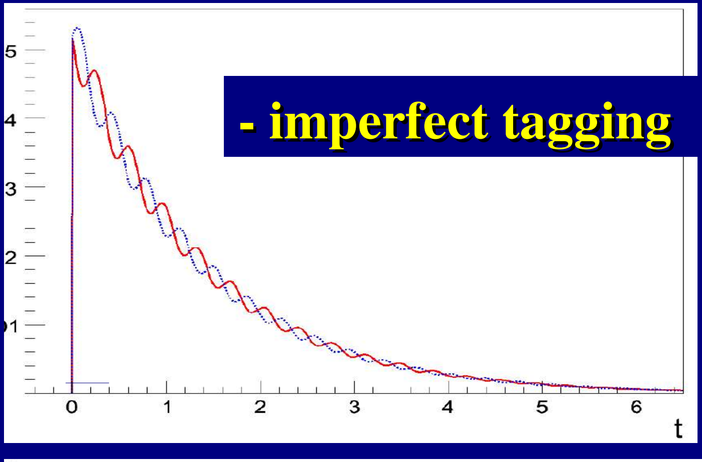
→ imperfect tagging: $D^2=(1-2\omega)^2$

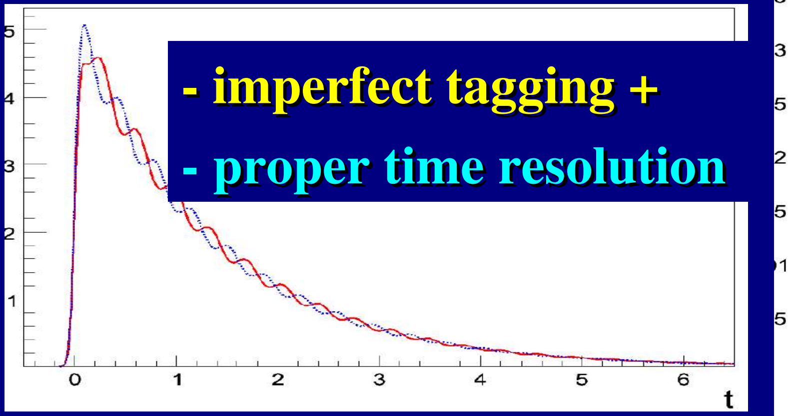
→ proper time resolution: $\exp(-0.5*\sigma_t^{\,2}\Delta ms^2)$

→ poor knowledge of the angular and proper time acceptances

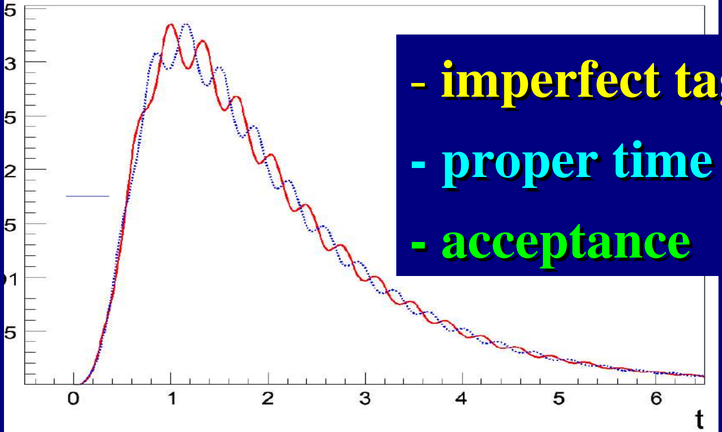
→ background contamination


- ideal case


- imperfect tagging


- imperfect tagging +

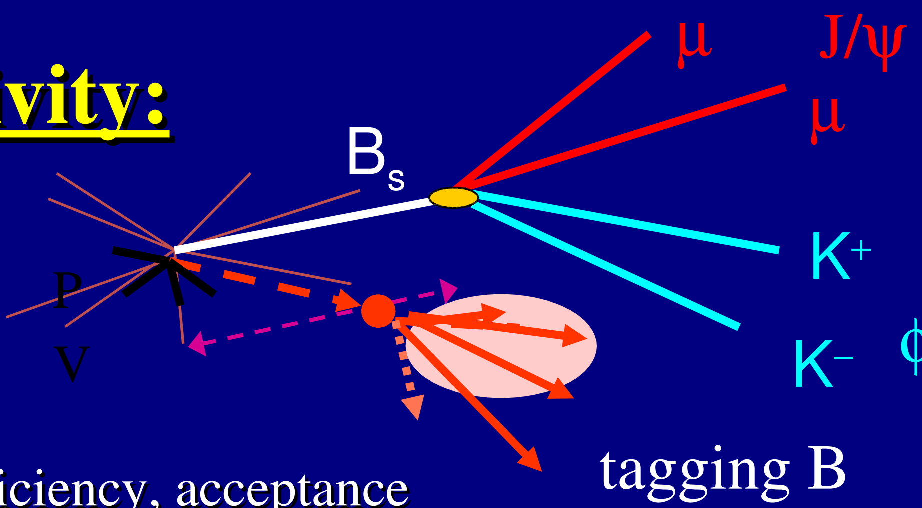
- proper time resolution


- imperfect tagging

- proper time resolution

- acceptance

Key ingredients for sensitivity:



1. Large signal yield;

→ L, production cross section, trigger efficiency, acceptance

2. Good momentum resolution:

→ B_s mass window defines the amount of background contamination

3. Good PID capability

→ to control background and for tagging

4. Excellent Proper Time resolution

→ to follow the B_s fast oscillations

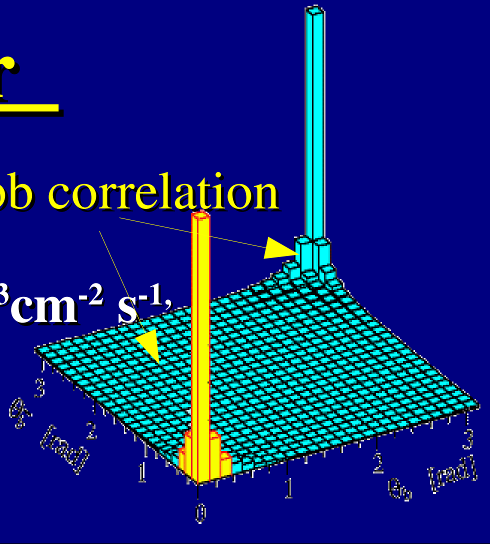
5. High tagging performance

→ high tagging efficiency, low and well known mistag

6. Good control of proper time and angular acceptances

→ to avoid heavy systematic biases.

Luminosity, Cross section, Trigger



bb correlation

1) Luminosity:

LHCb ~ 2 x 10^{32} cm^{-2} s^{-1}, ATLAS/CMS (in low L regime) ~ $10^{33}$$cm^{-2}$ s^{-1},

2) bb production cross section at 14 TeV:

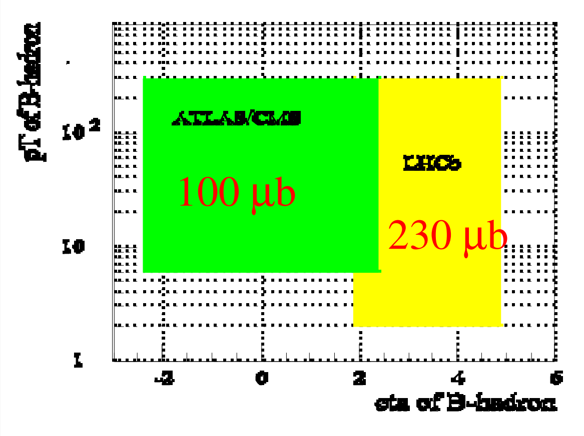
σ_{bb}~ 500 μb (X5 Tevatron value)

ATLAS/CMS: |η|<2.4 → σ_{bb}~ 100 μb

LHCb: 1.9<η<5.9 → σ_{bb}~230 μb

pt of b-hadron

Pythia production cross section



η of b-hadron

Large gain from lower p_T

3) Trigger: di-muon line

	L0(1) pt cut [GeV/c]	**HLT pt-cut [GeV/c]**	**HLT-μ rate [Hz]**
ATLAS (2 μ)	**pt(μ1)> 6**	**pt(μ1) (μ2)>6 (4)**	**~few Hz**
CMS (2μ)	**pt(μ)> 3**	**pt(μ)> 4**	**~few Hz**
LHCb (2μ)	**Σpt(μμ)> 1.3 GeV/c**	**no IP cut, no pt cut**	**~ 600 Hz**

ATLAS/CMS run at higher L but with higher pt thresholds (lower ε on signal)

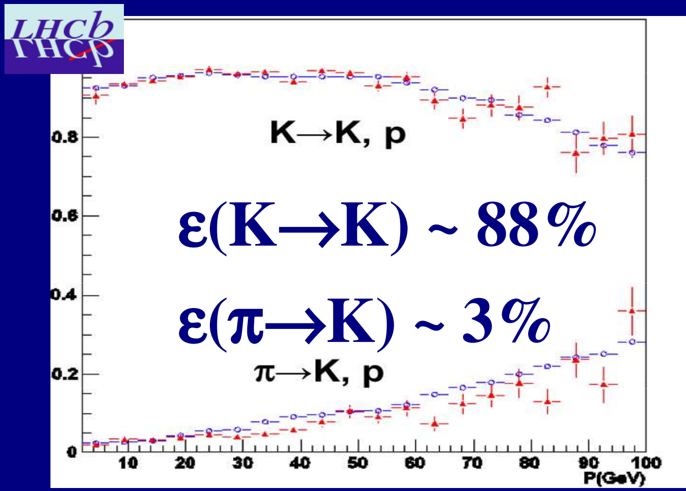
Offline Selection

Cut based selection for the three experiments:

→ PID, pT of decay products, vertex χ^2, pointing, b-vtx displacement (ATLAS/CMS)

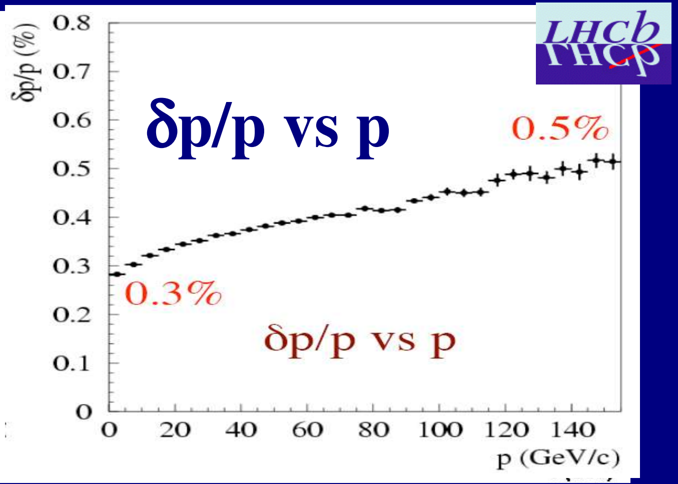
Main experimental features:

- → MuonID capability is similar for the three experiments:
  - → ε(μ→μ) = 90% for ε(hadron →μ) ~ 1% (CMS: ε(μ→μ) depends on η,pT)
- → LHCb has a higher hadron PID capability (thanks to RICHs!)
  - → ε(K→K)~ 88% for ε(π →K)~3%
- → LHCb has better momentum resolution:
  - → δ(p)/p ~ 0.3-0.5% (ATLAS/CMS: 1-2%)



ε(K→K) ~ 88%

ε(π→K) ~ 3%



δp/p vs p

But ATLAS/CMS work with higher pt threshold:

⇒ less combinatorial background.....

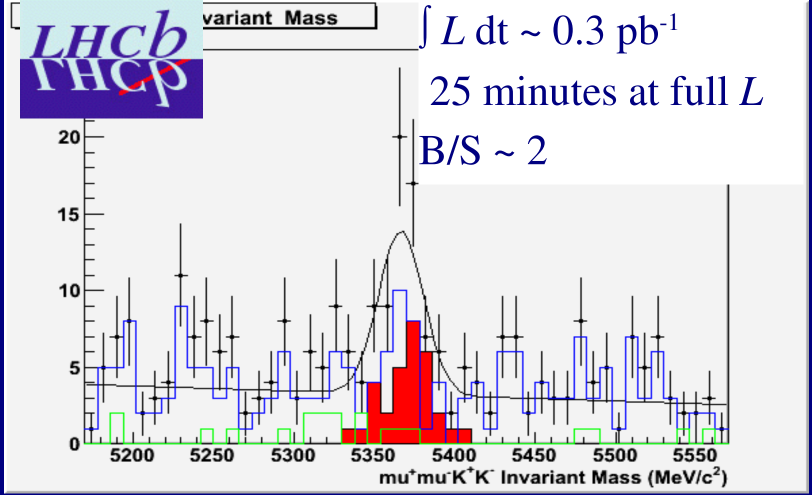
Signal Yield and Background rate

ATLAS/CMS use B_s lifetime related cuts:

→ main background is long-lived, mainly b→J/ψX (with some B→J/ψ K*)

LHCb does not use B_s lifetime related cuts:

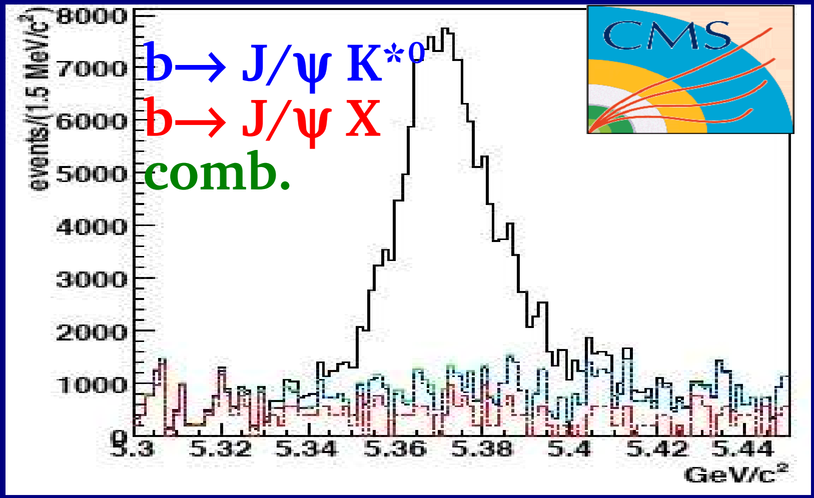
→ main background is prompt (mainly J/ψ prompt + combinatorics)



$\int L\,dt \sim 0.3$ pb^{-1}

25 minutes at full L

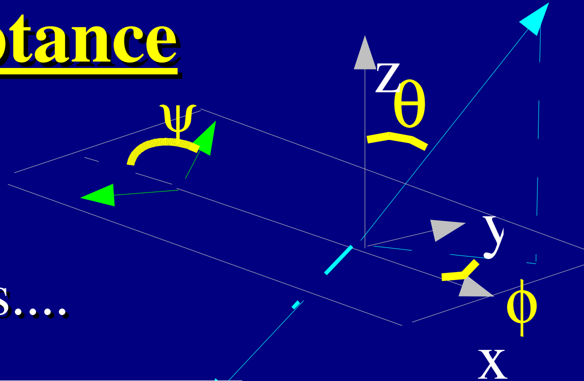
B/S ~ 2



	ATLAS	**CMS**	**LHCb**
L_{int} [1 nominal year]	**10 fb^{-1}**	**10 fb^{-1}**	**2 fb^{-1}**
Yield [untagged, L0-HLT included]	**~90k**	**~110k**	**~115k**
σ_m [MeV/c^2]	**16.5*)**	**14*)**	**17**
B/S	**0.18**	**0.25**	**2**
	[long-lived]	[long-lived]	[~90% prompt, 10% long-lived]

*) with J/ψ mass constraint

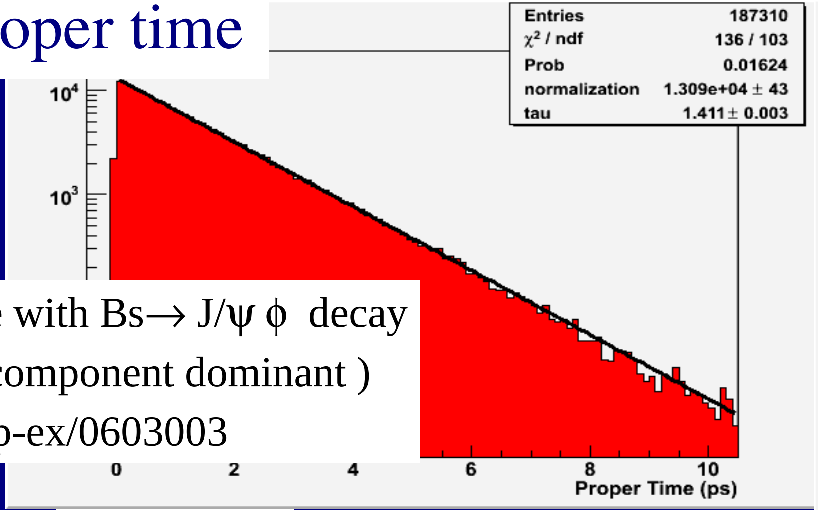
LHCb: Proper Time and Angular Acceptance



LHCb strategy:

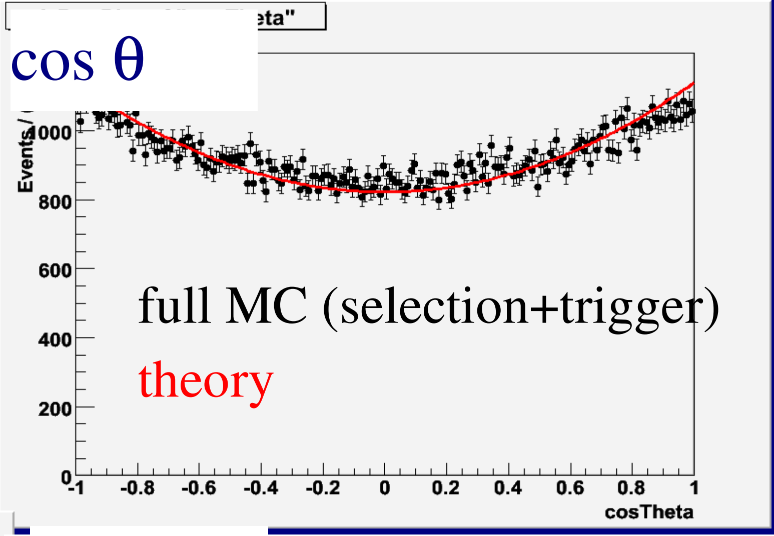
Trigger and select events without biasing -
as much as possible - proper time and angular distributions....

proper time

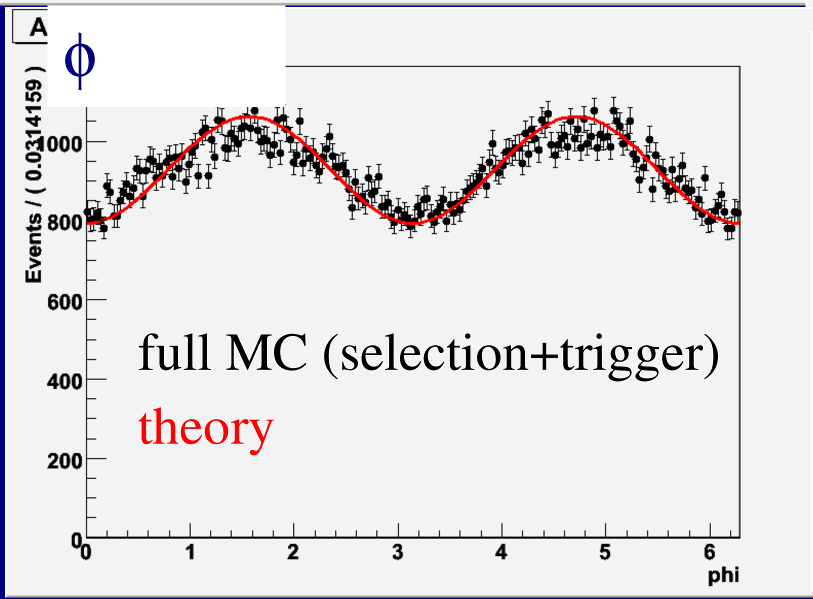


compatible with Bs→ J/ψ φ decay
(CP-even component dominant)
HFAG hep-ex/0603003

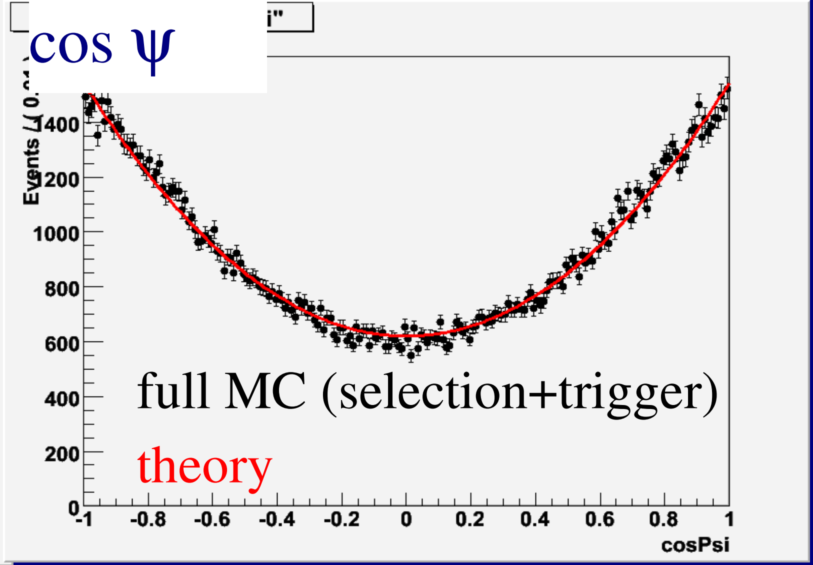
cos θ



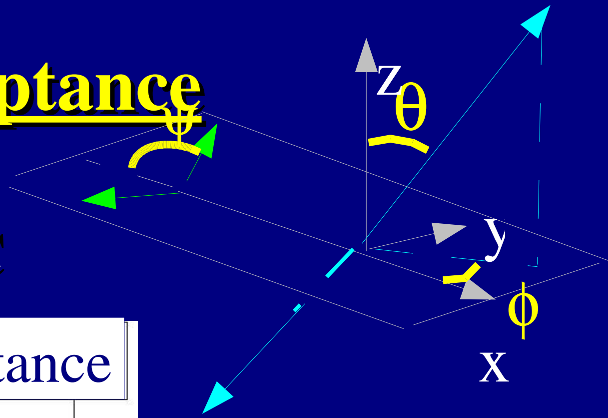
φ



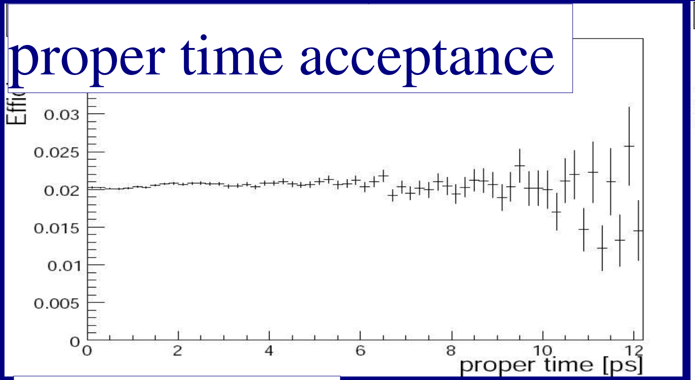
cos ψ

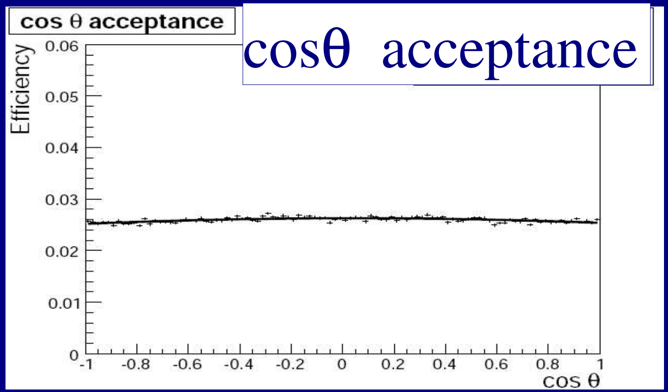


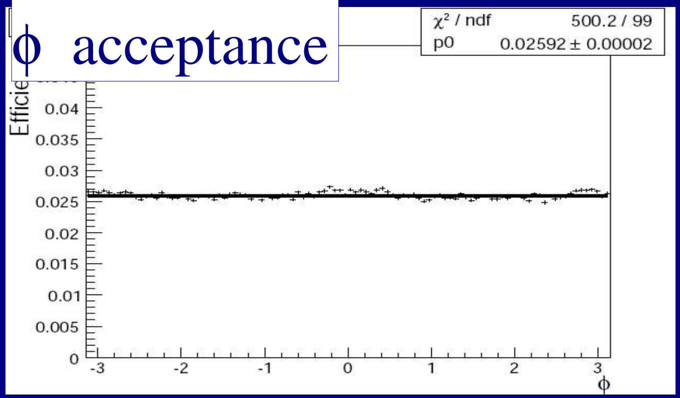
LHCb: Proper Time and Angular Acceptance

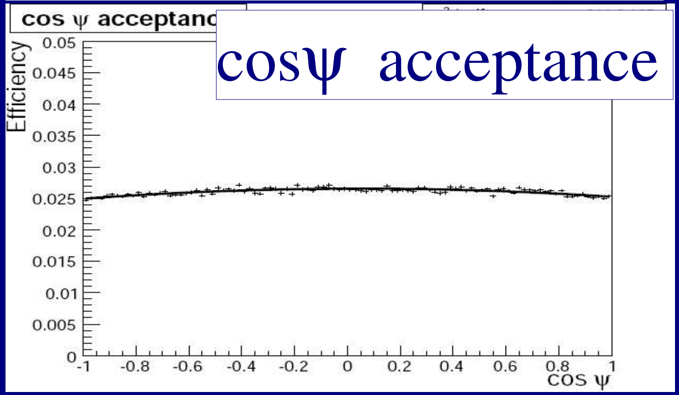


Proper time and Angular acceptances are ~flat in MC


proper time acceptance


cosθ acceptance


φ acceptance

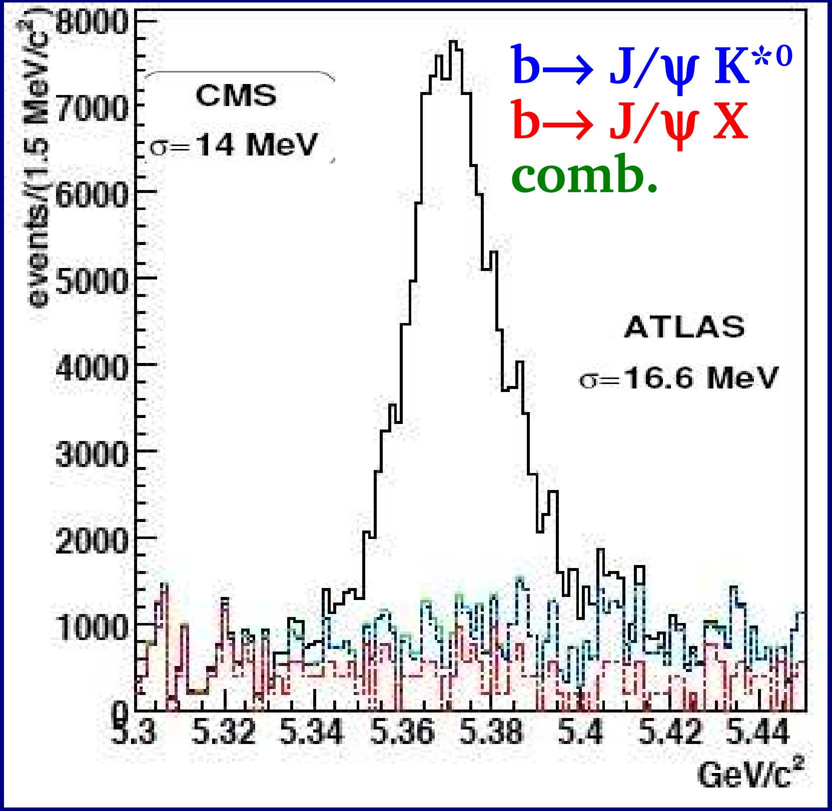

cosψ acceptance

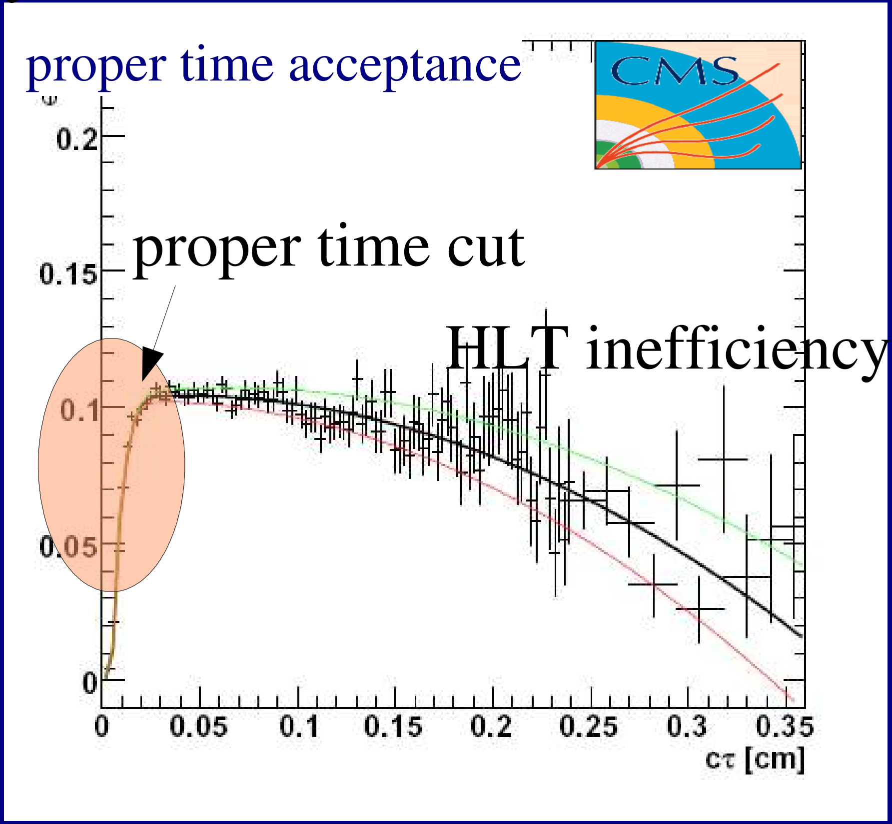
⇒ MC acceptance in data can be checked by using the high statistics $B_d \rightarrow J/\psi K^*$ sample (~650 kEvents/year)

⇒ same P→VV transition and parameters well known from Babar [Phys.Rev.D 76, 031102, 2007]

ATLAS/CMS: Proper Time and Angular Acceptances

Lifetime biased selection (already at HLT level)



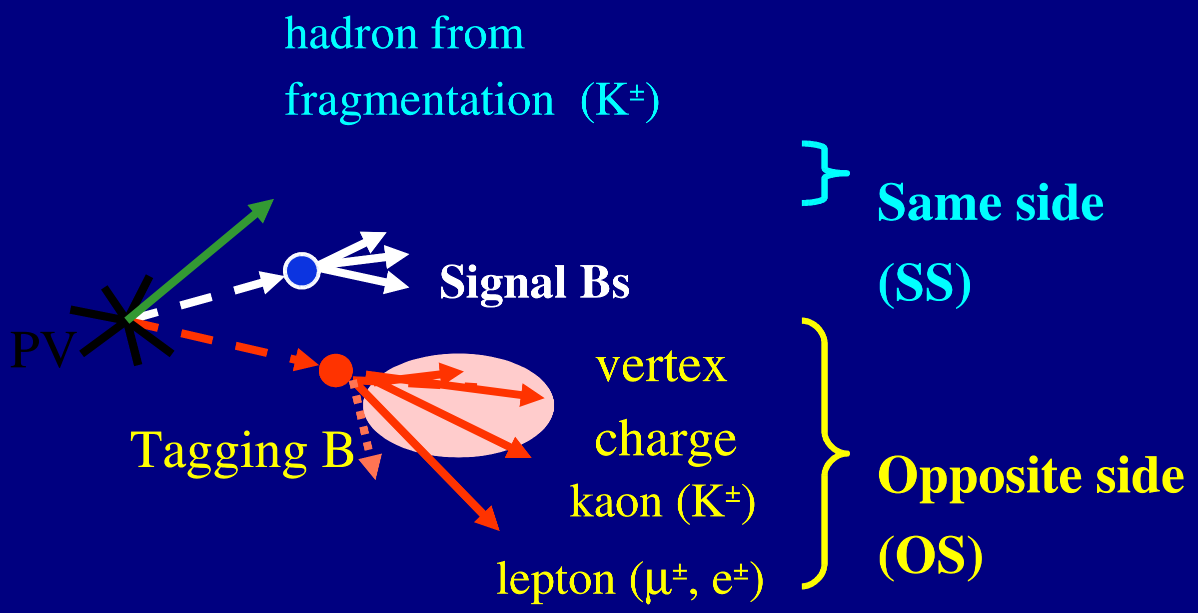


less background (dominated by long lived b→ J/ψ X) .....

.... But non negligible proper time/angular acceptance

⇒ dominant systematics (for the time being)

Tagging



hadron from fragmentation (K±)

Same side (SS)

Signal Bs

PV

vertex charge

Tagging B

kaon (K±)

lepton (μ±, e±)

Opposite side (OS)

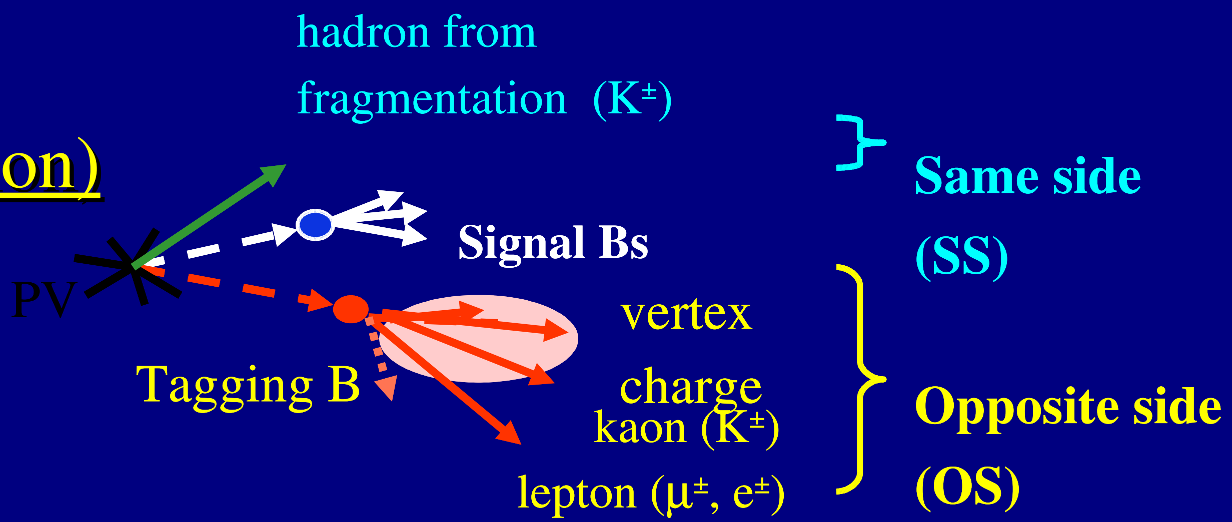
ATLAS: e, μ, Qjet (OS). $\varepsilon D^2 = 4.6\%$

CMS: ongoing

LHCb: e, μ, K, vertex charge (OS) + kaon (B_s) (SS). $\varepsilon D^2 = 6.2\ \%$

	$\varepsilon_{eff} = \varepsilon_{tag}\ (1-2\omega)^2$ [%]	ε_{tag} [%]	ω [%]
Muon	0.75 ± 0.05	6.2	32.6
Electron	0.45 ± 0.04	2.8	29.9
Kaon opp. side	1.49 ± 0.07	15.3	34.4
Kaon same side	2.13 ± 0.09	25.5	35.6
Q vertex	1.14 ± 0.07	43.3	41.9
Combined	6.18 ± 0.14	56.6	33.3

Tagging (calibration)



hadron from fragmentation (K±)

Same side (SS)

PV

Signal Bs

Tagging B

vertex charge

kaon (K±)

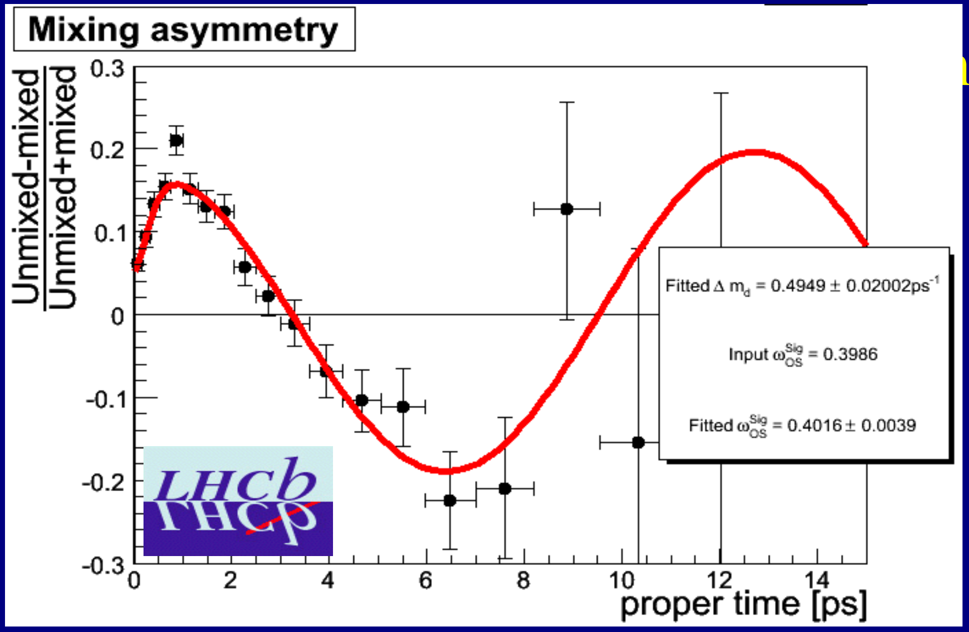
lepton (μ±, e±)

Opposite side (OS)

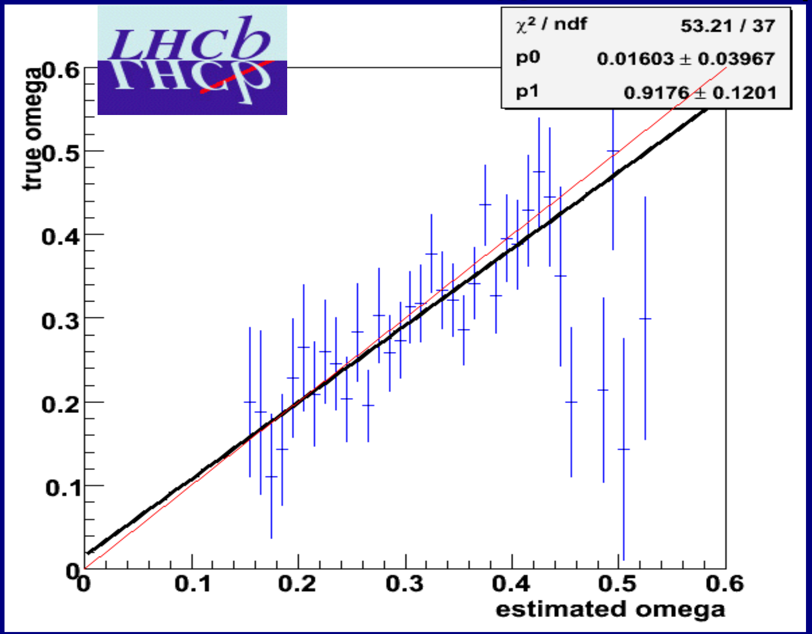
LHCb: mistag evaluation directly on data using high statistics flavor specific control channels:

- ⇒ **OS: $B_d \to J/\psi K^*$ (650 kEvents/2fb^{-1}), $B^\pm \to J/\psi K^\pm$ (1 Mevents /2 fb^{-1})**
- ⇒ **SS : $Bs \to Ds\ \pi$**

OS mistag extraction from Bd →J/ψ K* asymmetry

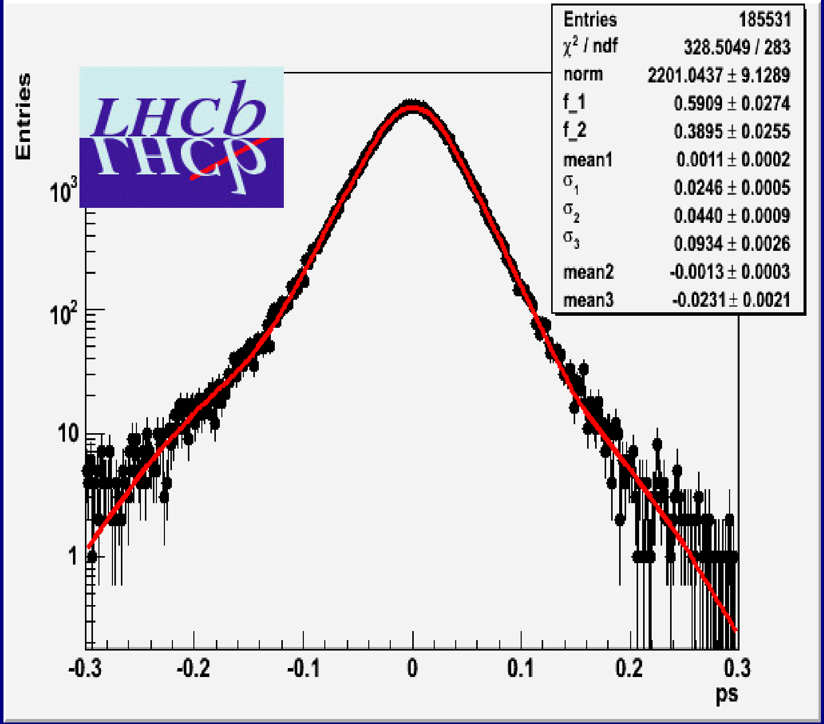


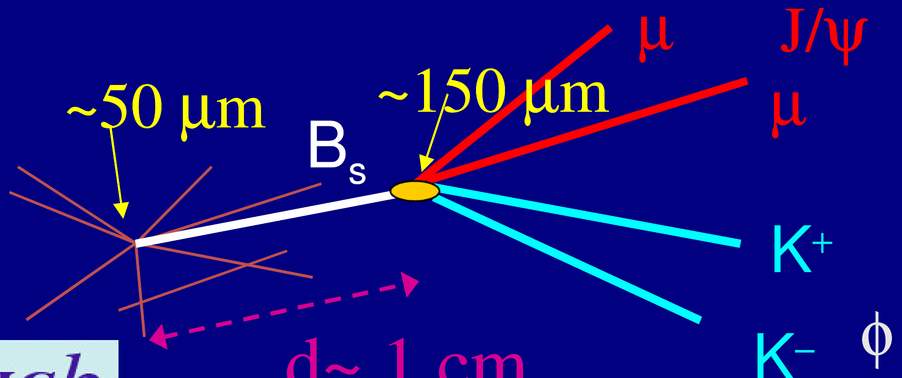
OS mistag for muon tagger in $B^\pm \to J/\psi K^\pm$

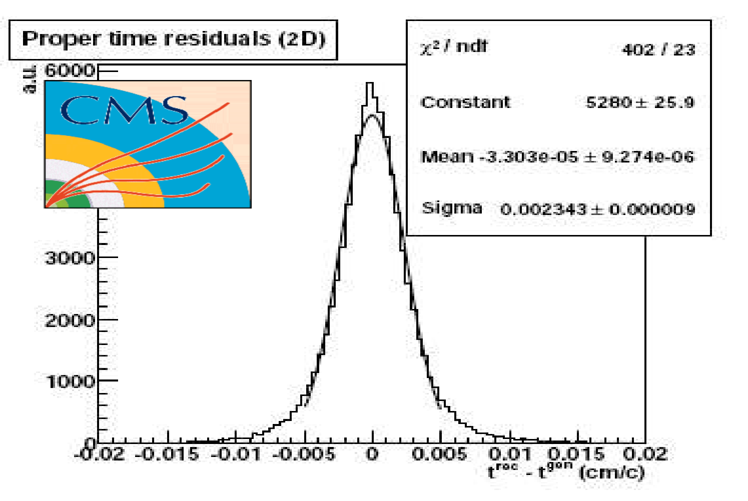


Proper Time resolution:

	ATLAS [pixel]	CMS	LHCb [VELO]
Surface	65 m²	210 m²	0.23 m²
N.channels	6M	66 M	170 k
Pixel size [μm]	50(rϕ)x400(z)	100(rϕ)x150(z)	40[strip]
Distance to beam	4.4 cm	4.4 cm	0.8 cm
σ_τ [fs]	**~83**	**~77**	**~40**

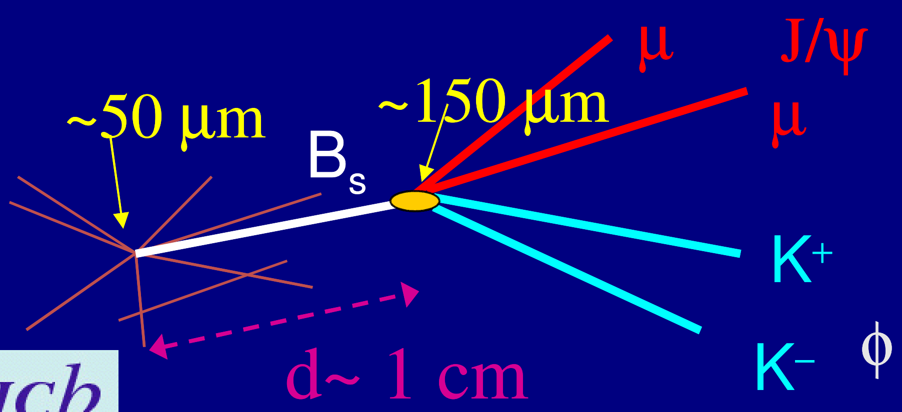


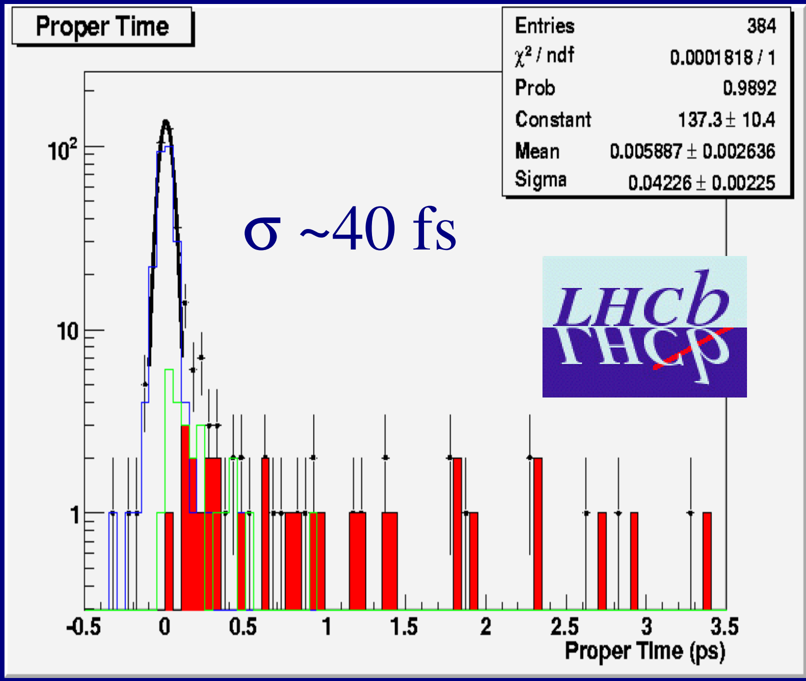


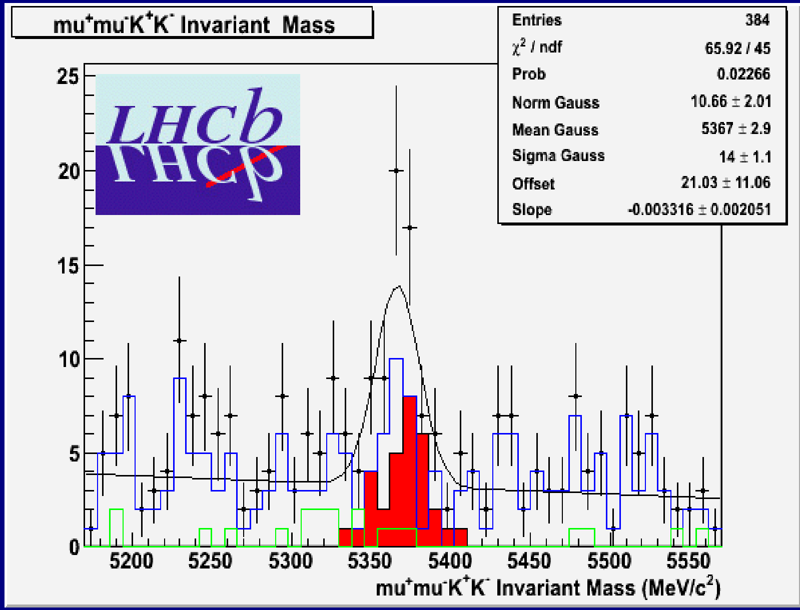


Proper Time resolution (calibration):

	ATLAS [pixel]	**CMS**	**LHCb** [VELO]
Surface	65 m²	210 m²	0.23 m²
N.channels	6M	66 M	170 k
Pixel size [μm]	50(rφ)x400(z)	100(rφ)x150(z)	40[strip]
Distance to beam	4.4 cm	4.4 cm	0.8 cm
σ_τ [fs]	**~83**	**~77**	**~40**







Sensitivity Studies

Due to limited MC statistics

- **7 pb^{-1} of inclusive $J/\psi(\mu\mu)$ for LHCb, 20 pb^{-1}/50pb^{-1} of $b \to J/\psi(\mu\mu)X$ for ATLAS/CMS**

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 parameters: 2βs, ΔΓs, Γs, , $R_\perp$, R_0, $\delta_\perp$, δ_0**
- **+ detector parameters (resolutions, acceptances, tagging)**

Parameters	**Input**	**sensitivity**
$\Delta\Gamma_s$	**0.084 [ps^{-1}]**	**0.008**
Γ_s	**0.696 [ps^{-1}]**	**0.003**
R_0	**0.56**	**0.004**
$R_\perp$	**0.233**	**0.005**
$2\beta_s$	**0.0368**	**0.030**
$\delta_{\|\|}$	-2.93 [rad]	0.07
$\delta_\perp$	2.91 [rad]	0.10

LHCb

Results of 200 Toys,

event yield for 1 nominal year

(L~2 fb^{-1}) tagged and untagged events

fitted simultaneously

Sensitivity Prospects with 2009 data:

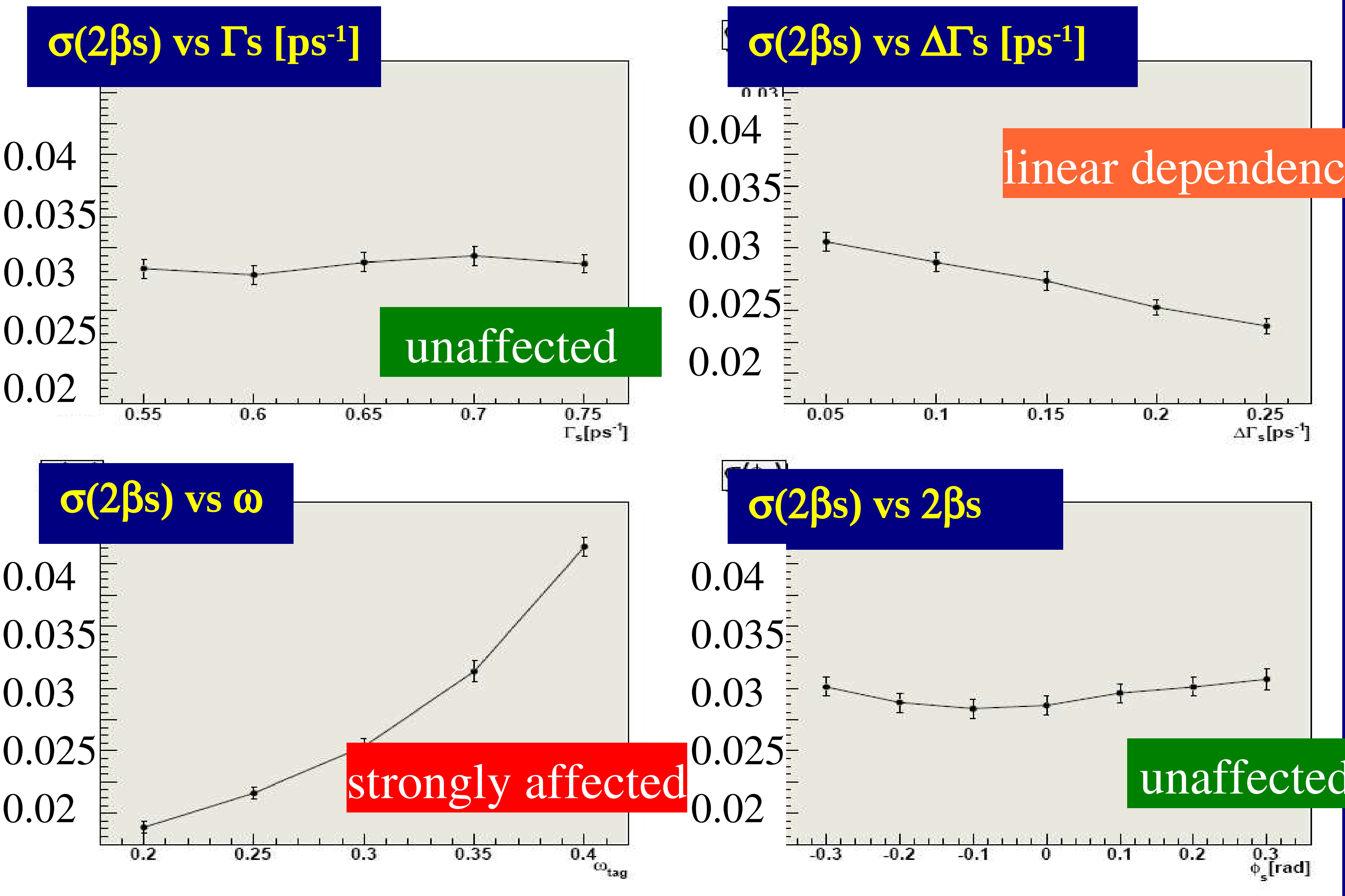
Assume that in 2009 run LHCb collects 0.5 fb^{-1}, ATLAS/CMS: 2.5 fb^{-1}:

	ATLAS	CMS	LHCb
L[fb^{-1}] ¼ of nominal year	2.5	2.5	0.5
Yield[untagged]	23k	27k	28.5k
B/S	0.18 dominated by b→J/ψ X	0.25 dominated by b→J/ψ X	2 dominated by prompt background
Flavor Tagging (εD^2)	4.6%	N/A	6.2%
σ(τ) [fs]	83	77	40
$\sigma(2\beta_s)$ (*)	0.16	N/A	0.06
$\sigma(\Delta\Gamma_s/\Gamma_s)/(\Delta\Gamma_s/\Gamma_s)$(*)	0.45	0.28	0.17

(*)we assume $\Delta\Gamma_s/\Gamma_s \sim 0.1$, $-2\beta_s \sim 0.04$

BSM effects down to the level of SM can be seen already with 2009 data

Systematic Studies: LHCb (I)



σ(2βs) vs Γs [ps^{-1}]

unaffected

σ(2βs) vs ΔΓs [ps^{-1}]

linear dependence

σ(2βs) vs ω

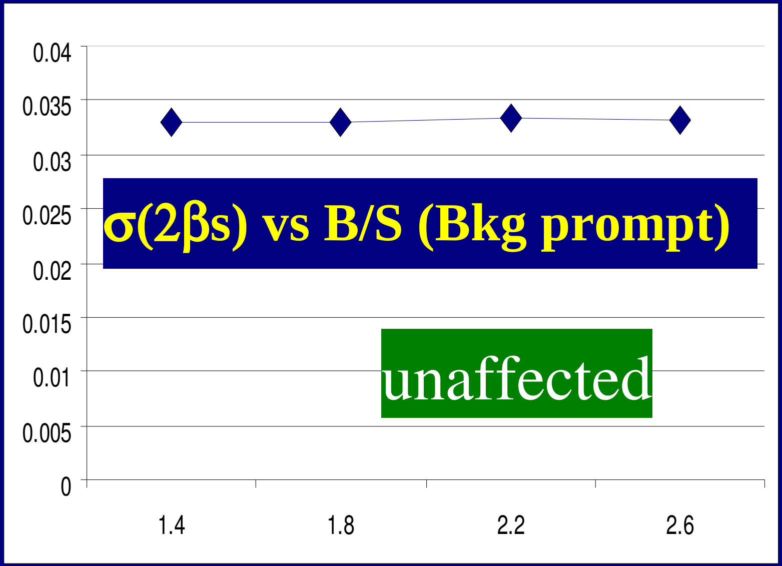
strongly affected

σ(2βs) vs 2βs

unaffected

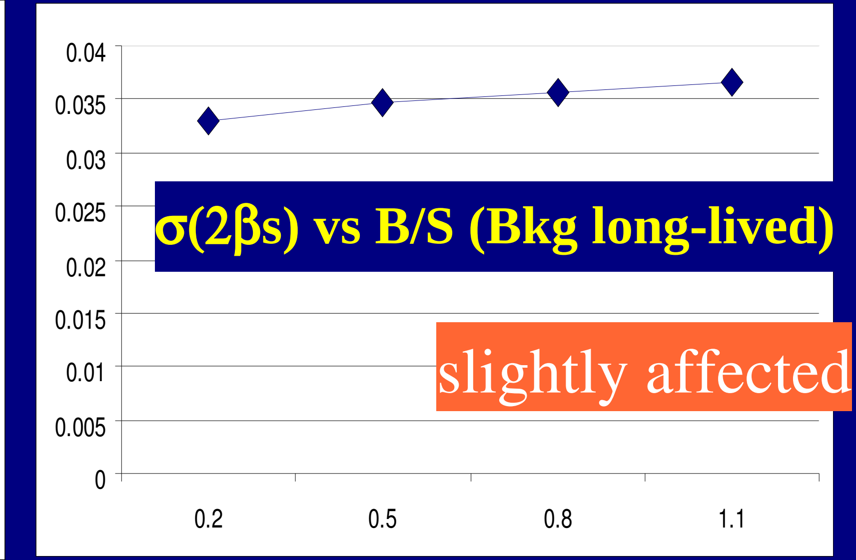
⇒ sensitivity on 2βs strongly depends on mistag as ~ $(1-2\omega)^2$

Systematic Studies: LHCb (II)



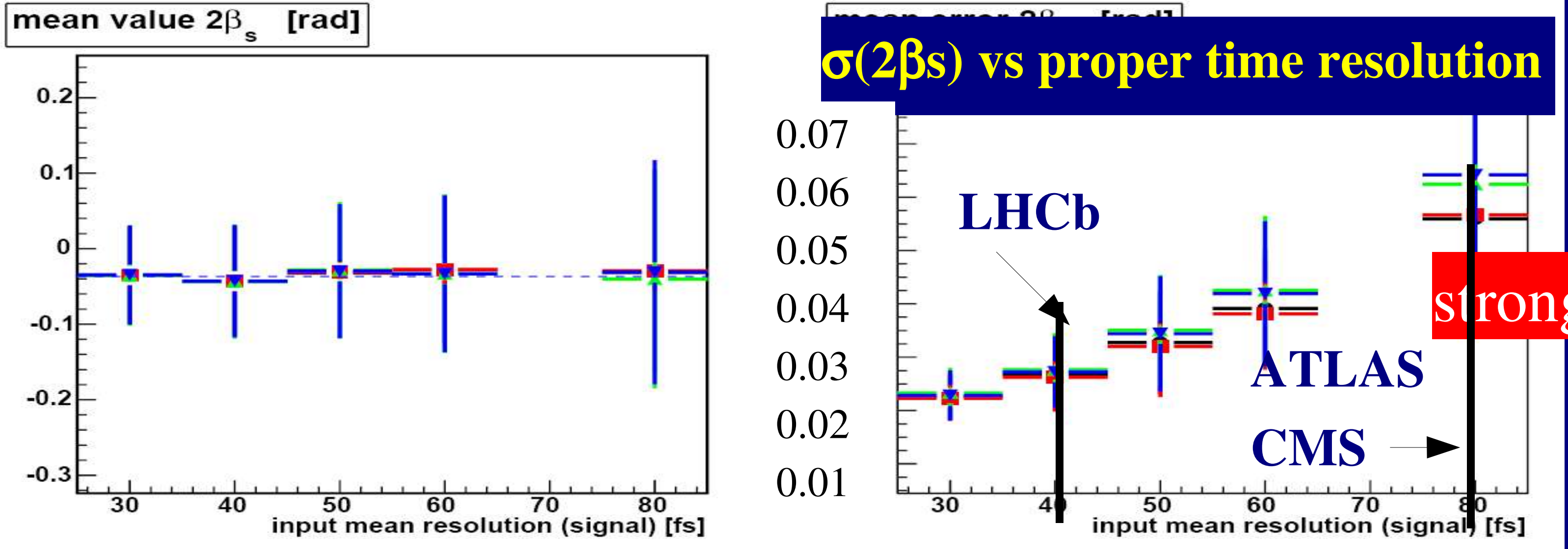
$\sigma(2\beta s)$ vs B/S (Bkg prompt)

unaffected



$\sigma(2\beta s)$ vs B/S (Bkg long-lived)

slightly affected



$\sigma(2\beta s)$ vs proper time resolution

LHCb

ATLAS

CMS

strongly affected

Most critical parameters are mistag and proper time resolution

⇒ sensitivity on $2\beta s$ goes as ~ $(1-2\omega)^2 \exp(-\Delta m_s^2 \sigma^2(\tau)/2)$

Systematic Studies: CMS

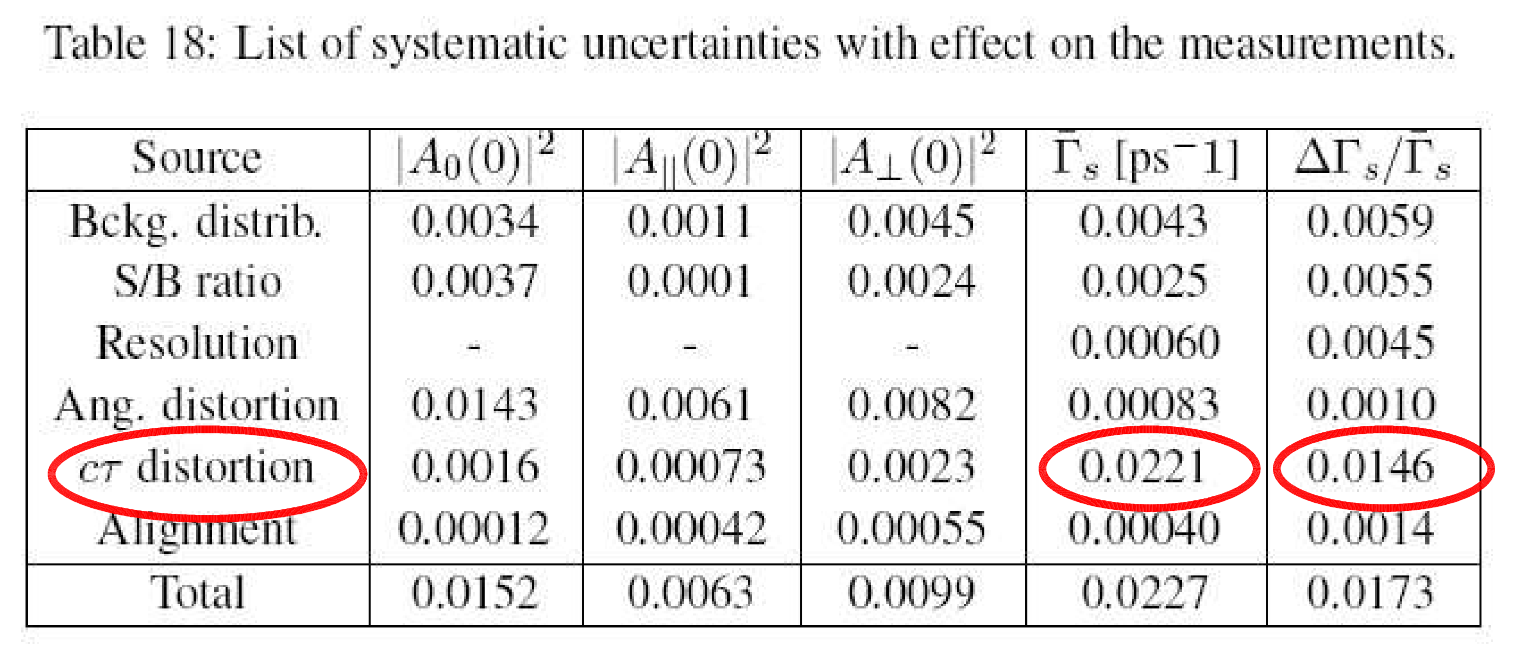


Table 18: List of systematic uncertainties with effect on the measurements.

Source	$\|A_0(0)\|^2$	$\|A_\|(0)\|^2$	$\|A_\perp(0)\|^2$	$\bar{\Gamma}_s$ [ps^{-}1]	$\Delta\Gamma_s/\bar{\Gamma}_s$
Bckg. distrib.	0.0034	0.0011	0.0045	0.0043	0.0059
S/B ratio	0.0037	0.0001	0.0024	0.0025	0.0055
Resolution	-	-	-	0.00060	0.0045
Ang. distortion	0.0143	0.0061	0.0082	0.00083	0.0010
$c\tau$ distortion	0.0016	0.00073	0.0023	0.0221	0.0146
Alignment	0.00012	0.00042	0.00055	0.00040	0.0014
Total	0.0152	0.0063	0.0099	0.0227	0.0173

Main systematics on Γs,ΔΓs at CMS comes from evaluation of proper time acceptance

Conclusions and Prospects

Simulations show that LHC has a big potential to improve 2βs sensitivity already with 2009 data sample.....

	ATLAS	**CMS**	**LHCb**	**CDF *)**	**D0*)**
L[fb^{-1}]	**2.5**	**2.5**	**0.5**	**1.3**	**2.8**
Yield [untagged]	**~23k**	**~27k**	**~33k**	**~ 2k**	**~2k**
2βs sensitivity	**0.16+)**	**not yet done**	**0.06+)**	**[0.32,2.82]@68%CL**	**$0.57^{+0.24}_{-0.30}$**
σ(ΔΓs/Γs)/(ΔΓs/Γs)	**0.45**	**0.28**	**0.17**	**0.75**	**0.50**
[for ΔΓs/Γs~0.1]				*) published results	*) published results

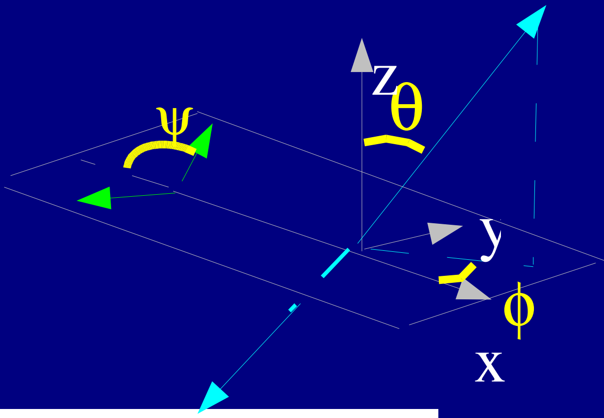
+) assuming SM value

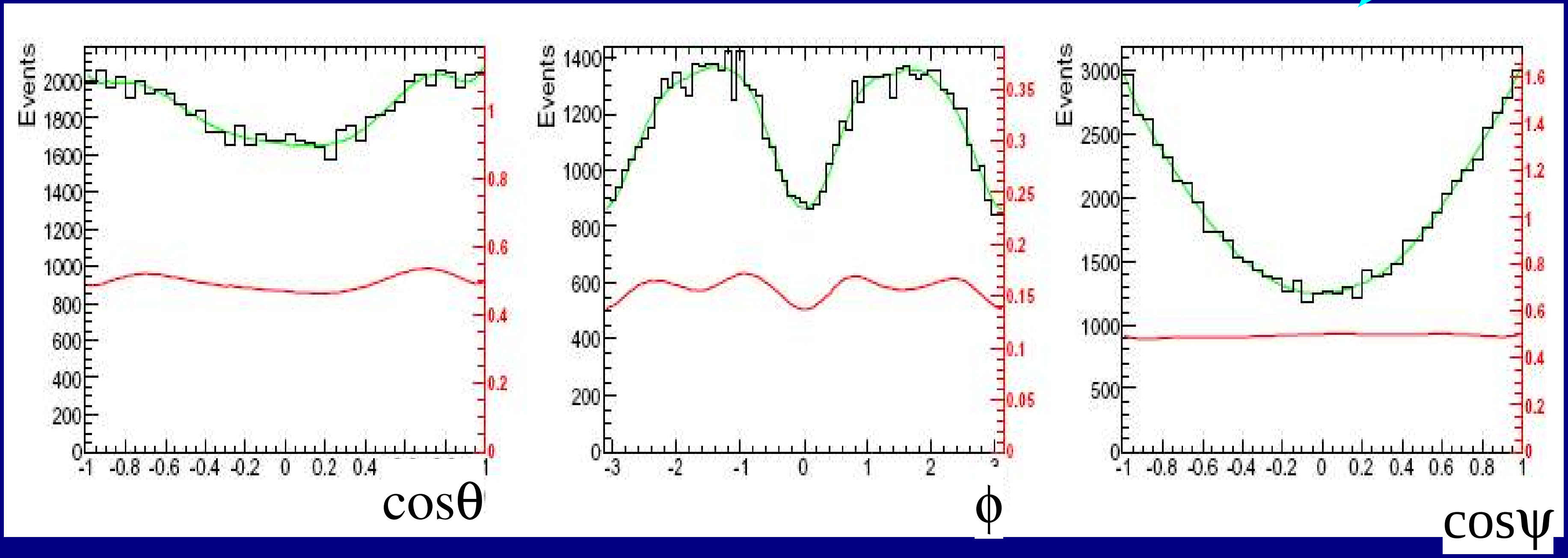
...potential to be realized in real life:

working hard at present to develop methods to extract quantities (resolutions, mistag, acceptances,etc.) from data using control samples

SPARES

CMS: angular acceptances

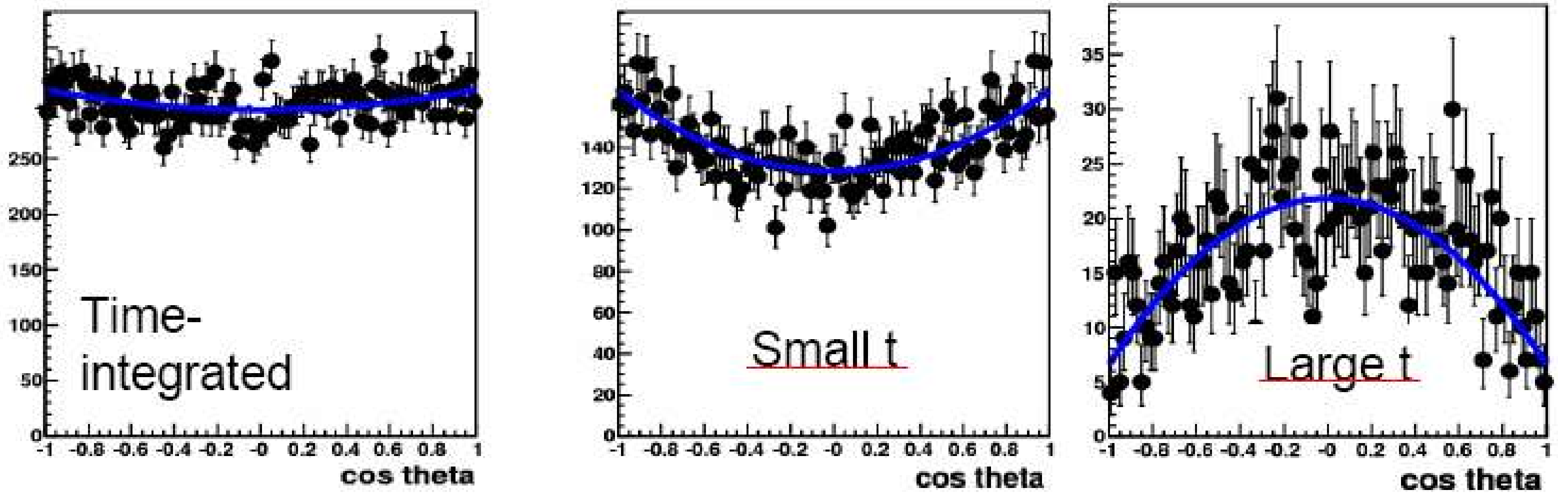




- full MC
- theory corrected for acceptance
- acceptance

For larger time the *CP*-odd behaviour becomes dominant, especially for large $\Delta\Gamma$

$$\boxed{\text{CP-even: } e^{-\Gamma_L t}\cos^2\theta,\ \text{CP-odd: } e^{-\Gamma_H t}\sin^2\theta}$$



Since $\tau_H > \tau_L$ we see more CP-odd as time increases

Present Sensitivity (a brief history)

6 months ago:

CDF : tagged analysis with 1.35 fb^{-1}

Feldmann-Cousin approach: $2\beta s = [0.32, 2.82]$ @ 68% CL

⇒ 1.5 σ consistency with SM (p=15%) [PRL 100, 161802 (2008)]

D0: tagged analysis, 2.8 fb^{-1}, strong phases from $Bd \rightarrow J/\psi\ K^*$

$$2\beta s = 0.57^{+0.24}_{-0.30}\,(\text{stat})\,{}^{+0.07}_{-0.02}\,(\text{syst})$$

⇒ 1.8 σ consistency with SM (p=6.6%) [arXiv:0802.2255 (hep-ex)]

UTFit Coll. : **⇒ 3.7 σ evidence for new physics** [arXiv:0803.0659]

1 month ago:

ICHEP08: CDF/D0 combination presented after the removal of strong phases constraint

⇒ 2.2 σ consistency with SM

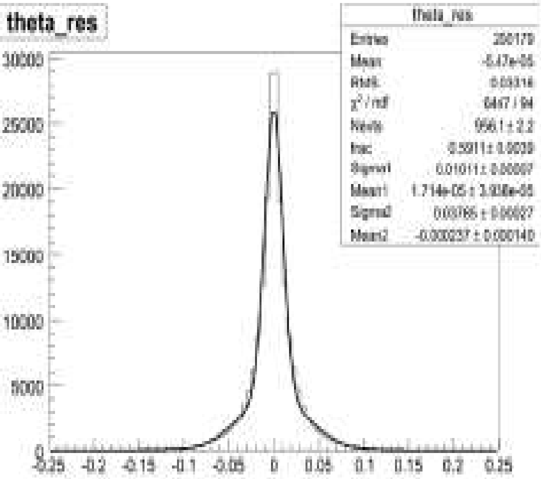
1 month ago:

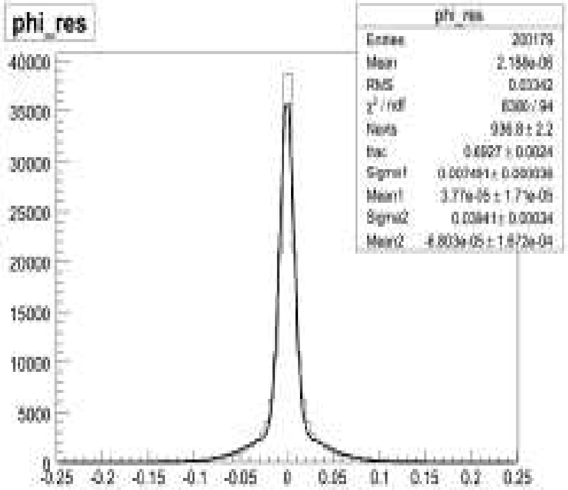
CDF: updated result with 2.8 fb^{-1} (without SS tagging)

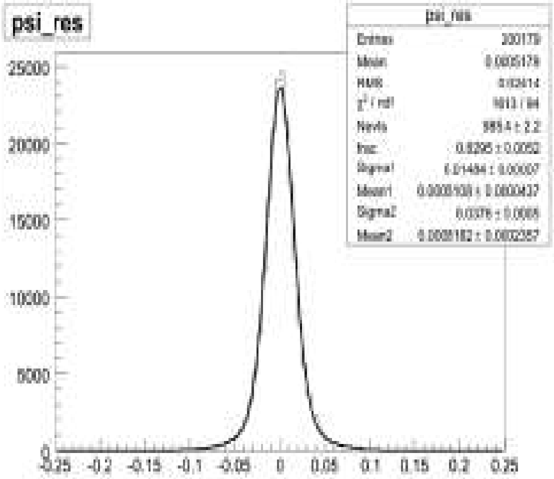
⇒ consistency with SM degrades 1.5 σ → 1.8 σ (CDF alone, Public Note 9758)

Angular resolutions

- angular resolution of $B_s \to J/\psi(\mu\mu)\phi$ unified selection = (reconstructed angle - true angle)







	Theta	Phi	Psi
DC04	0.019	0.019	0.015
DC06	0.033	0.033	0.024

- Does not affect β_s sensitivity
  - Even if 2 times worse in real data

LHCb Performance with Lifetime Biased Selection, Monte Carlo production of 2004:

$BR^{vis}[B_s \rightarrow J/\psi(\mu\mu)\phi(K^+K^-)] = (30.9 \pm 11.0) \times 10^{-6}$

"Easy" trigger on muon

- Trigger efficiencies w.r.t. offline selected events
  - L0: 93.5%
  - High Level Trigger: 84.9%
  - Total: 79.4 %

Reconstruct $J/\psi \rightarrow \mu\mu$; $\phi \rightarrow K^+K^-$; standard PID/kinematical cuts

B_s mass resolution ~14MeV

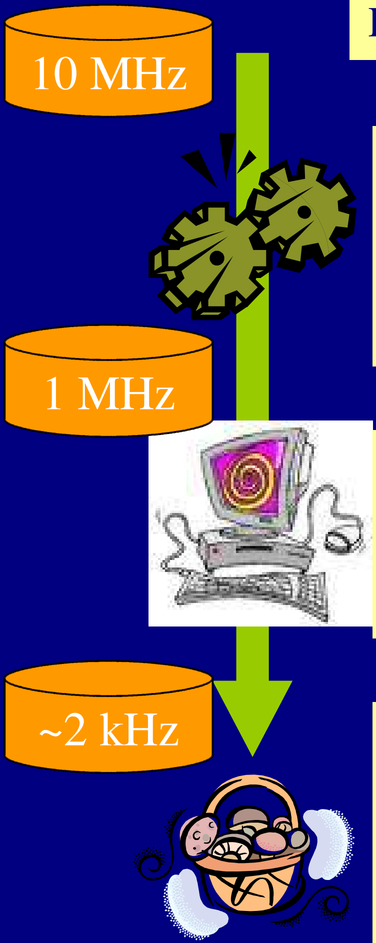
Untagged yield ~130k / $2fb^{-1}$

B_{bb}/S ~0.12, long-lived

tagging power: $\varepsilon D^2 = 6.6\%$ ($\varepsilon \sim 57\%$, $\omega \sim 33\%$)

LHCb Trigger

Nominal conditions:



Visible collisions

$L = 2\ 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

L0: [hardware]

high Pt particles

calorimeter + muons

4 µs latency

HLT [software]

1 MHz readout

~1800 nodes farm

On tape: 2 kHz

Exclusive selections

Inclusive streams

HLT rate	Event type	Physics
200 Hz	Exclusive B candidates	B (core program)
600 Hz	High mass di-muons	J/ψ, $b \to J/\psi X$ (unbiased)
300 Hz	D* candidates	Charm (mixing & CPV)
900 Hz	Inclusive b (e.g. $b \to \mu$)	B (data mining)

Fit distributions for δ_1

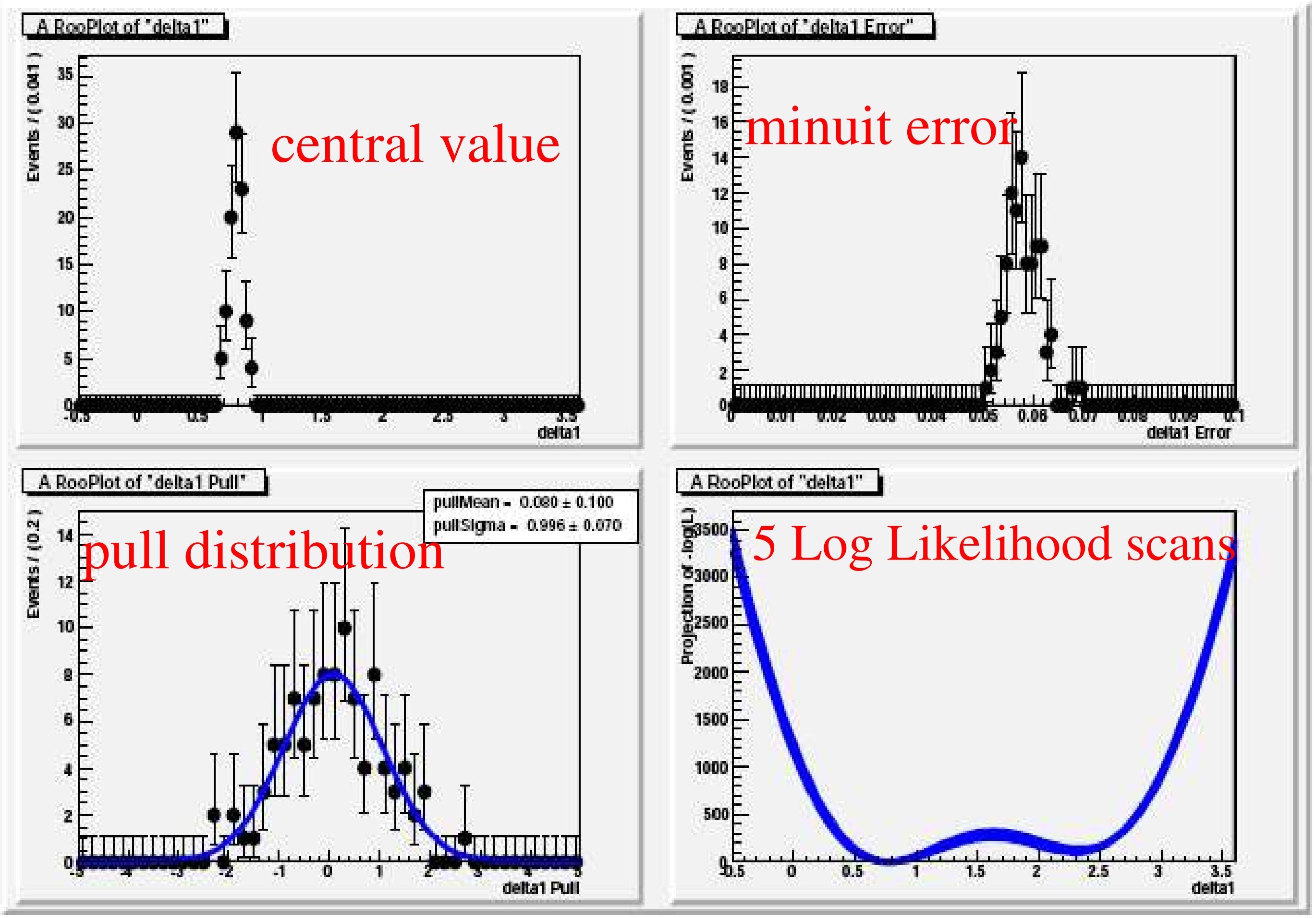


Figure 12 Fit distributions for δ_1. In this case $\delta_1 = \pi/4$ and $\delta_2 = 3\pi/2$.Shown are (i) central value (ii) Minuit error (iii) pull distribution (iv) 5 different LL scans.