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$B_s \to \phi\gamma$ prospects at LHCb

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On behalf of LHCb Collaboration

Outline

- Radiative penguins & photon polarization in $b \to s \gamma$ transitions
- Event Selection
- Probing for the photon polarization
- Summary

LHCb detector and its general capabilities are described in Patrick Koppenburg's talk

Loops and Penguins

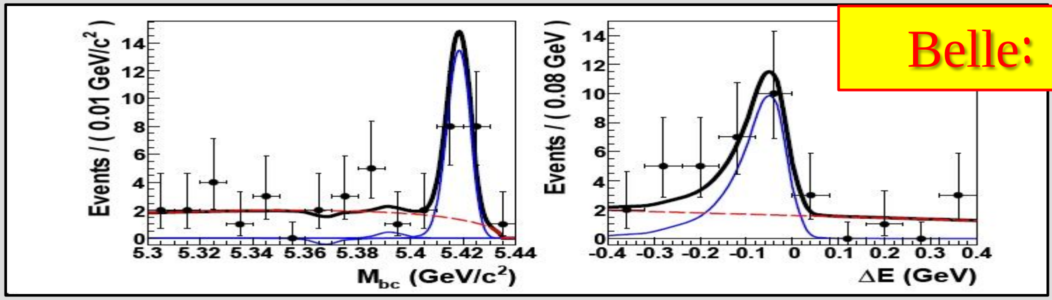
LHC(b) penguinarium

- Rare (≡ "*loop-induced*") and especially *penguin-mediated* decays are essential part of LHC(b) physics program:
  - Electroweak penguin $B^0 \to K^{*0} \mu^+\mu^-$
    - talk by *Mitesh Patel*, 12 Sep, 5pm
  - Gluonic penguin $B_s \to \phi\phi$
    - talk by *Yuehong Xie*, 10 Sep, 4pm
  - Hunting for "SUSY penguin": $B_s \to \mu^+\mu^-$
    - talk by *Sergey Sivoklokov*, 12 Sep,12:10

And the radiative penguins are here …

Radiative penguins

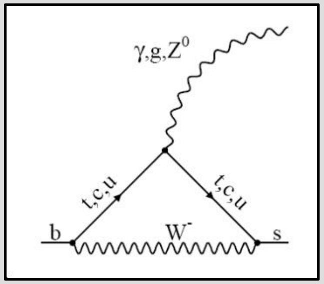
- Radiative penguin decays of B^+&B^0 mesons have been discovered by CLEO and both inclusive $b \to s\gamma$ and exclusive decays have been intensively studied by CLEO, BaBaR and Belle
  - $Br(b \to s\gamma)$ is one of the most efficient killer for New Physics Model
- Recently Belle has observed $\mathbf{B_s \to \phi\gamma}$



Belle: O(1 $B_s \to \phi\gamma$)/day at Υ(5S)

Why penguins are attractive?

- The clear picture in SM:
  - One diagram dominance
  - One Wilson coefficient $C_7^{eff}(\mu)$
  - Reliable theoretical description at (N)NLO allows the numerically precise predictions



- Loops
  - New Physics contribution can be comparable and even dominating to (small) SM amplitudes
  - NP appears not only in modifications of Br, but also in asymmetries and the angular effects
    - *"Sensitive also to spin structure of NP"*

Exclusive radiative penguins

- *Not so rare decays*

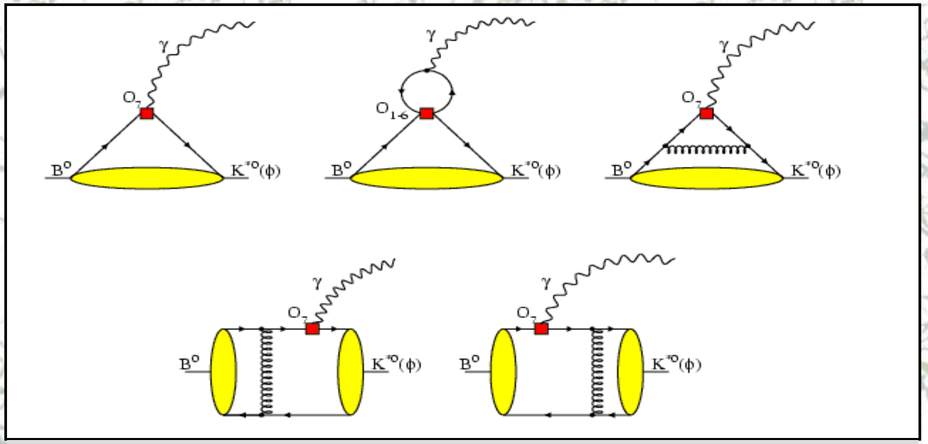
  $Br(B \to K^{*0}\gamma) = (4.3 \pm 0.4) \times 10^{-5}$

  $Br(B_s \to \phi\gamma) = (3.8 \pm 0.5) \times 10^{-5}$

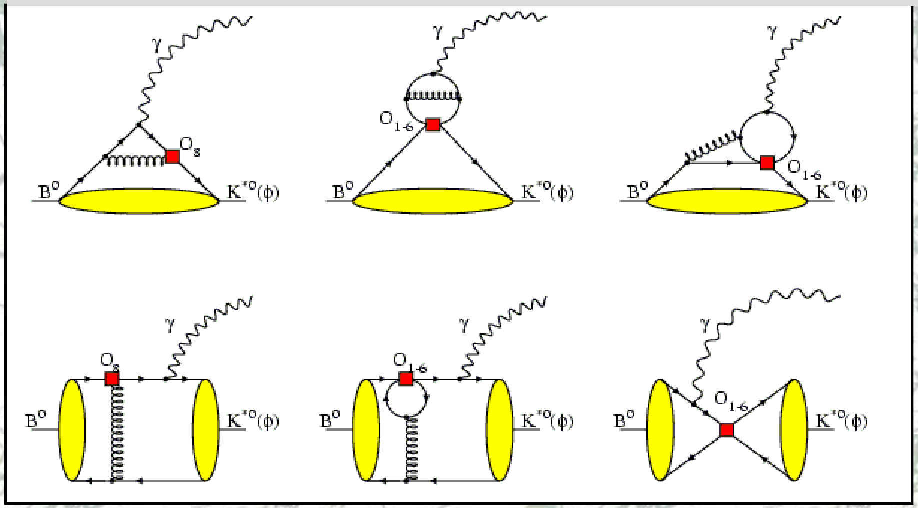
- 1-amplitude dominance
- strong phase appears at order of α_s or $1/m_b$

  $\to$"Direct" asymmetries are small (<1%) for $b \to s\gamma$ & a bit larger $\mathcal{O}(10\%)$ for $b \to d\gamma$

- Photons are polarized
  - Mixing asymmetries vanishes, *BUT*



Suppressed by : α_s , $1/m_b$ or $|V_{CKM}|$



Mixing asymmetries are vanished, but …

- $B \to f^{CP} \gamma$ is not *CP* eigenstate! $\gamma_R/\gamma_L \approx m_s/m_b$
- Take it into account:

not suppressed!

$$\Gamma(\mathrm{B}_q(\bar{\mathrm{B}}_q) \to f^{CP}\gamma) \propto e^{-\Gamma_q t}\left(\cosh\frac{\Delta\Gamma_q t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_q t}{2} \pm \right.$$
$$\left. \pm\mathcal{C}\cos\Delta m_q t \mp \mathcal{S}\sin\Delta m_q t\right)$$

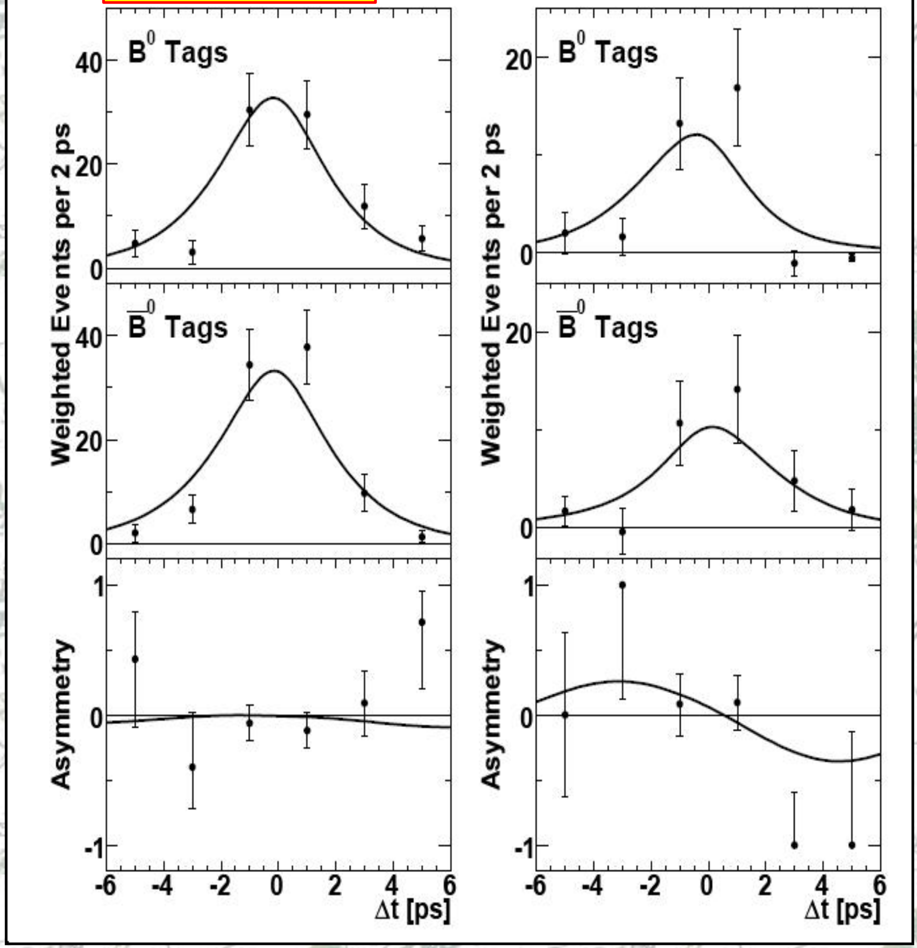
- ***SM:***
  - *C* = 0 direct CP-violation
  - S = sin2ψ sinϕ
  - A^{Δ} = sin2ψ cosϕ

$$\tan\psi \equiv \left|\frac{A(\bar{\mathrm{B}}\to f^{CP}\gamma_R)}{A(\bar{\mathrm{B}}\to f^{CP}\gamma_L)}\right|$$

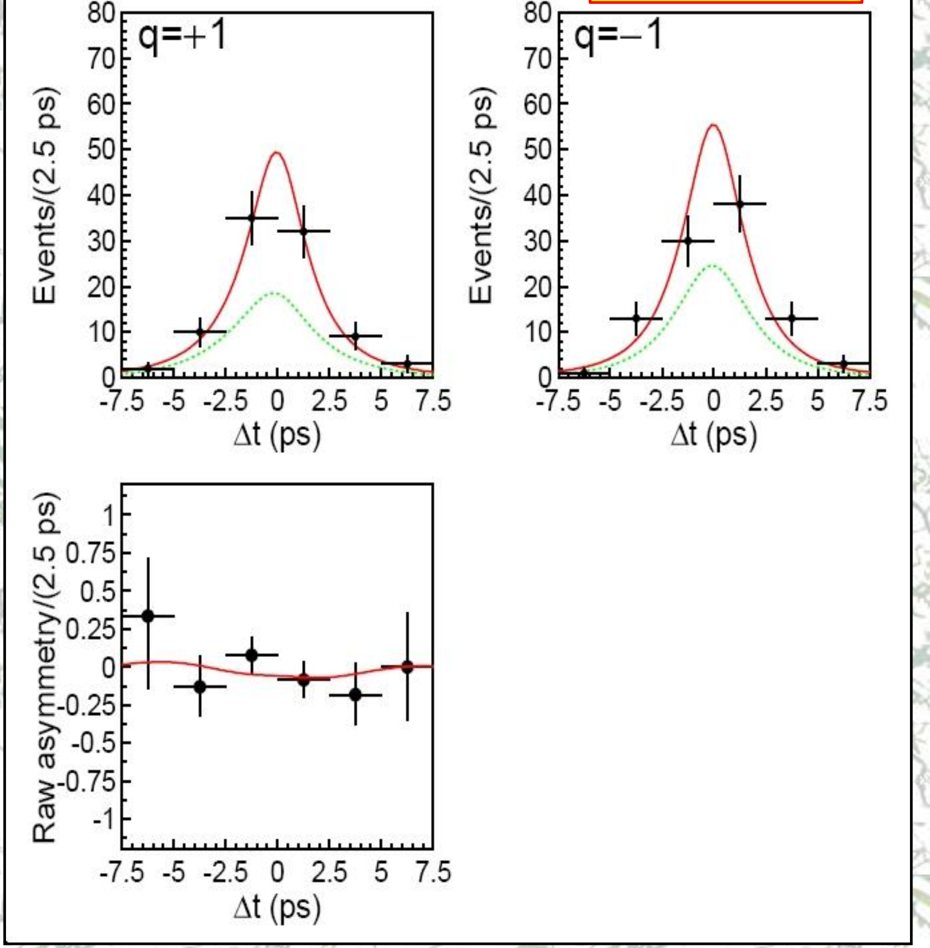
$B^0 \to K_S \pi^0 \gamma$

$\sigma(\sin 2\psi) \sim 0.4$

BaBar



Belle



$\Delta\Gamma_s/\Gamma_s \neq 0$

- *C* is practically zero
  - 1 diagram dominance
- *S* is a product of *CP*-eigenstate fraction ***and*** (small) phase of B_s oscillation and $b\to s\gamma$ penguin
  - *double smallness is SM*
- A^{Δ} is just a fraction of *CP*-eigenstate
  - $\equiv$ Fraction of wrongly polarized photons
  - *No "other" suppression factors, only* $\Delta\Gamma_s/\Gamma_s$

Essentially we study *CP*-violation in $B_s\to\phi\gamma$ as ***an instrument*** to probe Lorentz structure of $b\to s\gamma$ transitions

F.Muheim, Y.Xie & R.Zwicky, **Phys.Lett.B664:174-179,2008**

What we know about $B_s \to \phi\gamma$ at LHCb?

Full Monte Carlo simulation

- What we "**know**" now:
- The yield is 11k per 2 fb^{-1} (and 70k of $B^0 \to K^{*0}\gamma$)
- Background is
  - <6k @ 90%CL

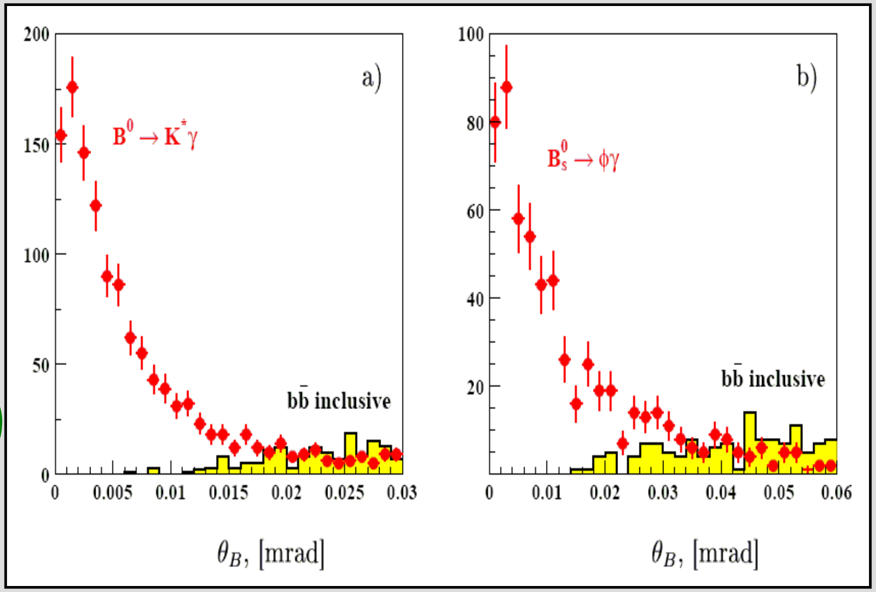
LHCb: *O*(1 $B_s \to \phi\gamma$)/hour at 2×10^{32}

- The mass resolution ~90 MeV/c^2
- The proper time resolution: $\sigma \sim 78$fs
  - 50/50 σ_1=52fs, σ_2=114fs

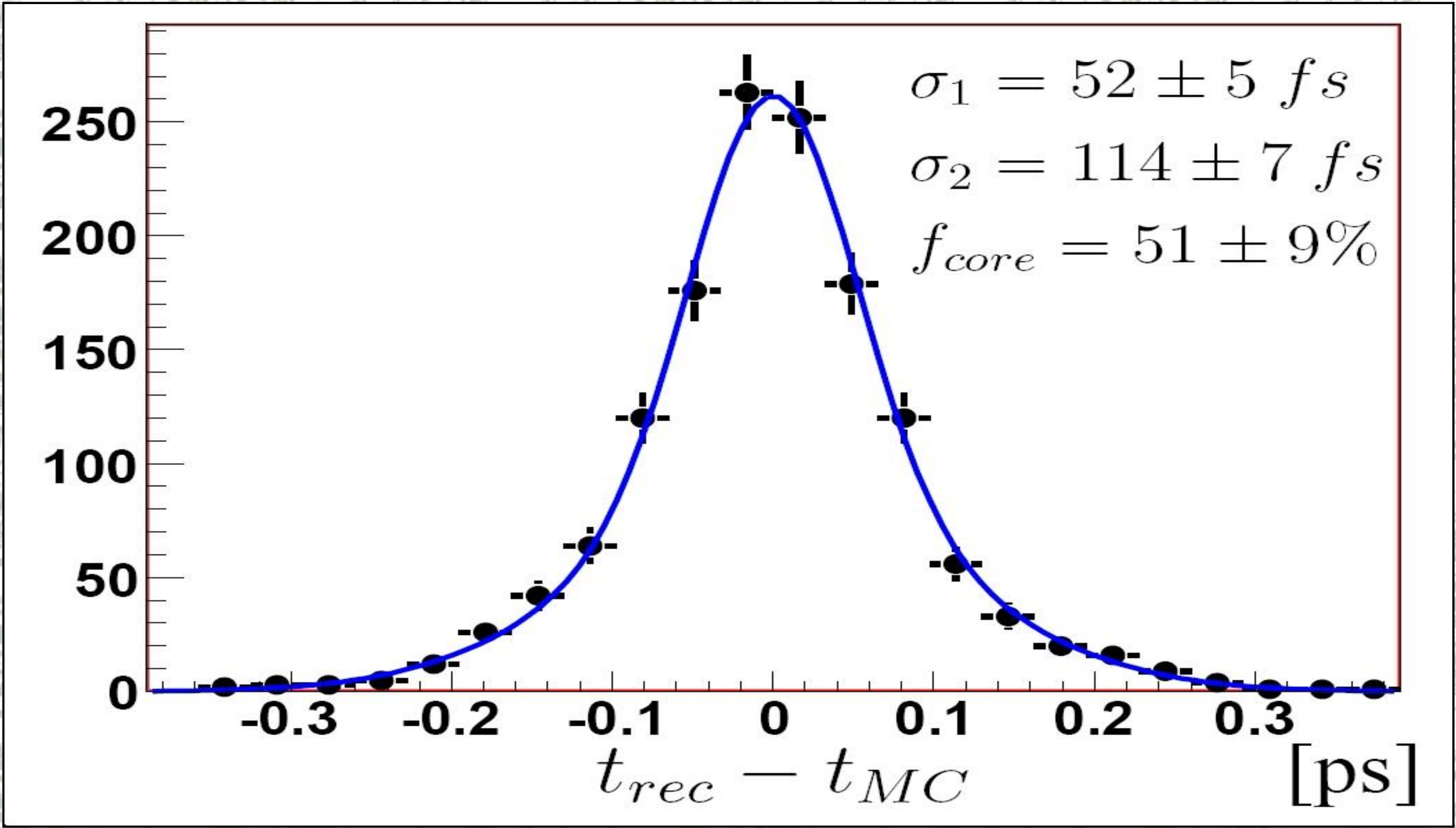
L.Shchutska *et al*, CERN-LHCb-2007-030

Event selection

- Dedicated L0 trigger for photons with high Et
- B-decay products do not point to reconstructed primary vertices
- Exclusively reconstructed B-candidate does point to primary vertex
- B-candidate is associated with the primary vertex with minimal impact parameter (significance)



Signal proper time resolution



Sensitivity to sin2ψ

- To evaluate our sensitivity to sin2ψ
  - toy Monte Carlo (10^4 experiments) using **RooFit**
- Unbinned maximum likelihood fit
  - Proper lifetime & error
  - Reconstructed mass
- Per-event proper time errors
- Resolutions & Efficiencies from full MC
- Parameterize the background from mass-sidebands
- Important ingredient – proper time acceptance function

$m(B_s) = 5.367\ \mathrm{GeV}/c^2$

$\tau(B_s) = 1.43\ \mathrm{ps}$

$\Delta\Gamma_s = 0.084\ \mathrm{ps}^{-1}$

$\Delta m_s = 17.77\ \mathrm{ps}^{-1}$

L.Shchutska *et al*, CERN-LHCb-2007-147

Likelihood

$$P_\kappa(t,m) = f_s \frac{\{e^{-\Gamma\tau}[I_+(\tau)+\kappa(1-2\omega)I_-(\tau)]\}\otimes G(t-\tau)\varepsilon(t)g_s(m)}{\int\{e^{-\Gamma\tau}[I_+(\tau)+\kappa(1-2\omega)I_-(\tau)]\}\otimes G(t'-\tau)\varepsilon(t')\mathrm{d}t'} + (1-f_s)\varepsilon_b(m,t),$$

$$\begin{aligned} I_+(\tau) &= \cosh\frac{\Delta\Gamma\tau}{2} - \mathcal{A}^\Delta \sinh\frac{\Delta\Gamma\tau}{2} \\ I_-(\tau) &= \mathcal{C}\cos\Delta m_s\tau - \mathcal{S}\sin\Delta m_s\tau \end{aligned}$$

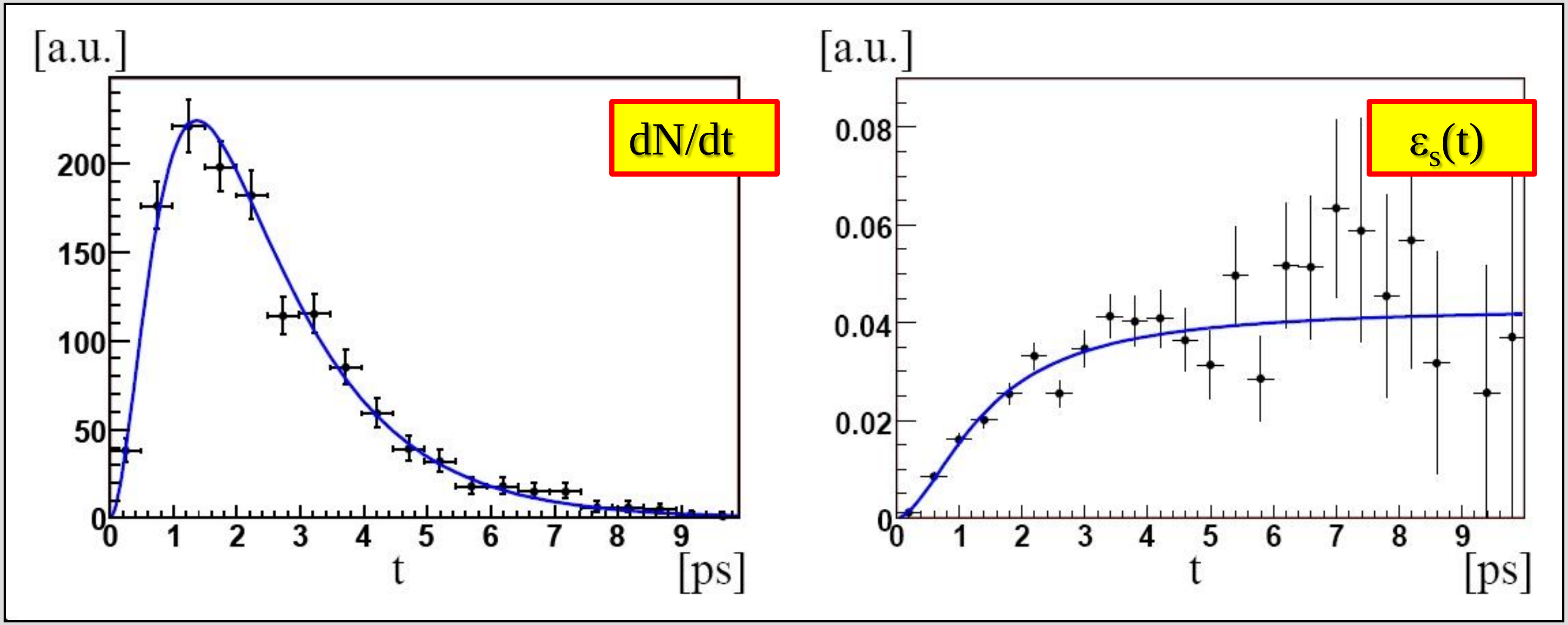
$$\mathcal{L}_0 = \prod_{i=1}^{N_{\mathrm{B_s}}} P_{-1}(m_i,t_i,\sigma_{ti}) \prod_{i=1}^{N_{\bar{\mathrm{B}}_\mathrm{s}}} P_1(m_i,t_i,\sigma_{ti}) \prod_{i=1}^{N_{untagged}} P_0(m_i,t_i,\sigma_{ti}),$$

Proper time acceptance

$a = 0.74\ \mathrm{ps}^{-1}$

$c = 1.86$

$$\varepsilon_s(t) \propto \frac{(at)^c}{1+(at)^c}$$



Proper time acceptance

- It is a vital to know it with very high precision
  - 5% bias in "a" -> bias in $\sin 2\psi \sim 0.2$

$$\varepsilon_s(t) \propto \frac{(at)^c}{1+(at)^c}$$

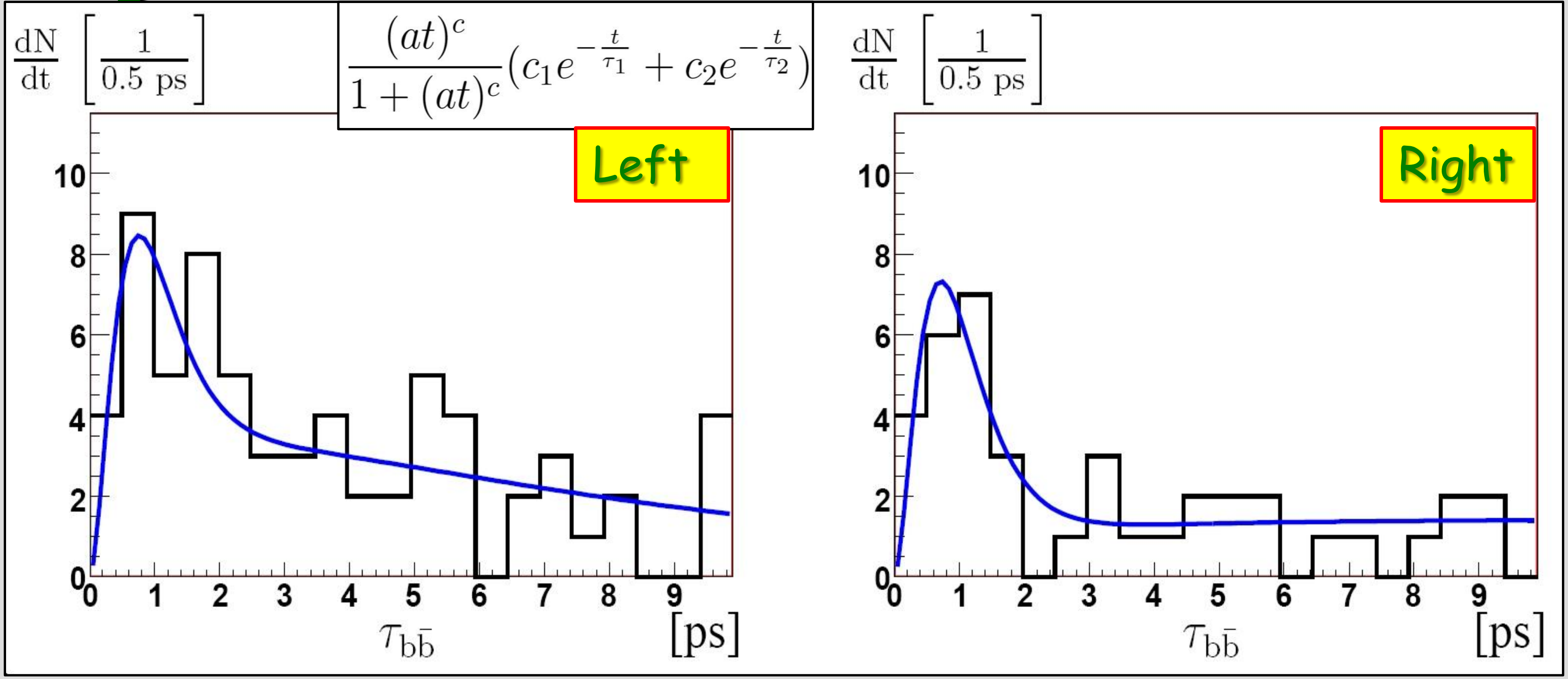
- We are planning to calibrate it using the control channels
  - $B^0 \to K^{*0}\gamma$
  - $B_s \to \phi J/\psi$
- The own acceptance could be extracted from data in both cases
  - E.g. with $\mathcal{O}(1\%)$ precision for $B^0 \to K^{*0}\gamma$
- The precision of "extrapolation" to $B_s \to \phi\gamma$ is less clear and under the intensive study now

Background parameterization

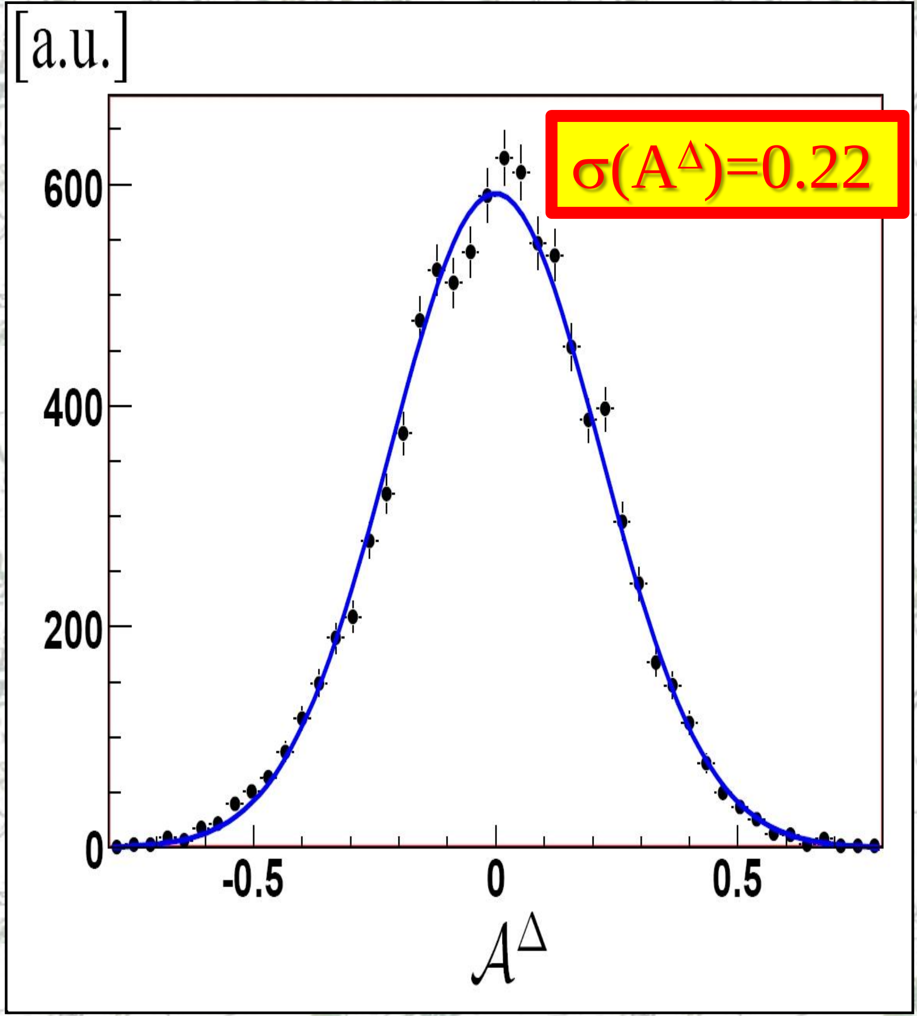
- Fit separately left and right sidebands

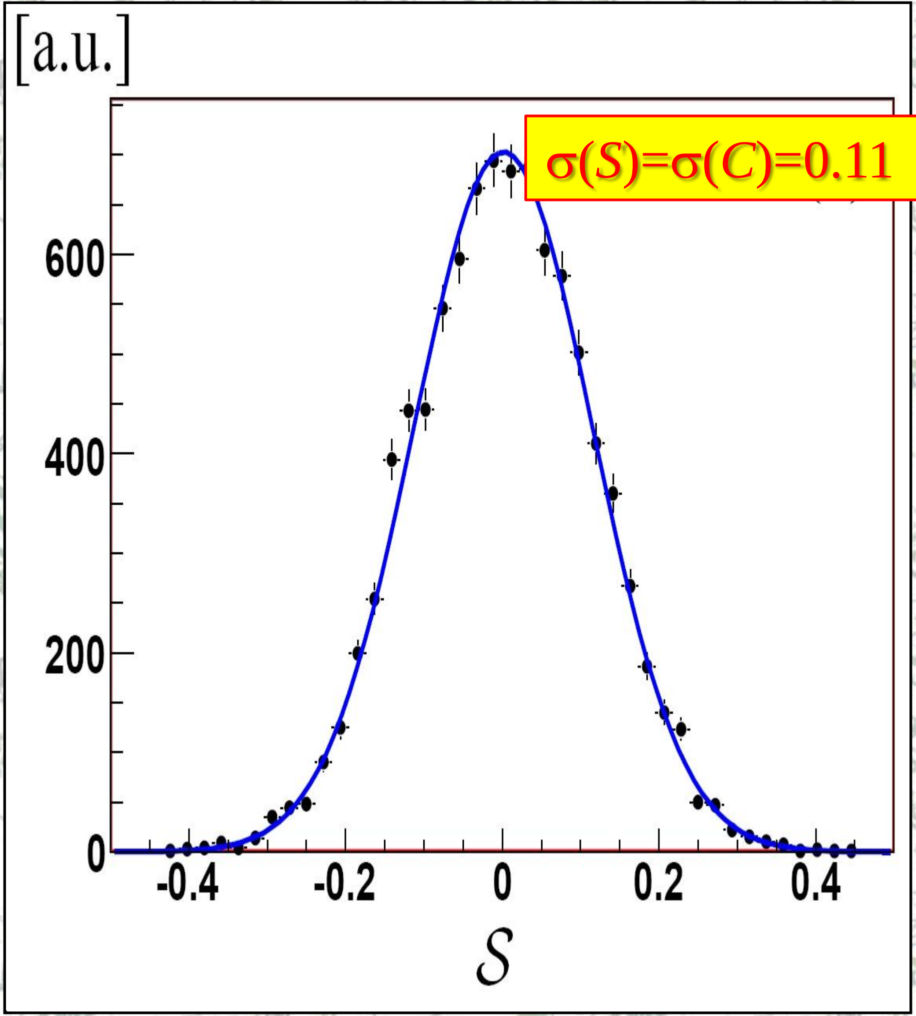
$$e^{-\mu m}\frac{(at)^c}{1+(at)^c}\left(\left(\alpha_0+\alpha_1\Delta m\right)e^{-\frac{t}{\tau_1}}+\left(\beta_0+\beta_1\Delta m\right)e^{-\frac{t}{\tau_2}}\right)$$

$$\frac{(at)^c}{1+(at)^c}\left(c_1 e^{-\frac{t}{\tau_1}}+c_2 e^{-\frac{t}{\tau_2}}\right)$$



Results: $\sigma(A^{\Delta},C,S)$





Conclusions

- LHCb has good potential for measurement of photon polarization in $B_s \to \phi\gamma$ decay
- For 2 fb^{-1}: $\sigma(A^{\Delta})=0.22$, $\sigma(S)=\sigma(C)=0.11$
  - for 500pb^{-1} ($\int Ldt$ at the end of 2k+9): $\sigma(A^{\Delta})\sim 0.4$
- The result has *moderate* dependency on *B/S*
- *The determination of proper time acceptance function from data in under the study now*

Stay tuned and wait for more news

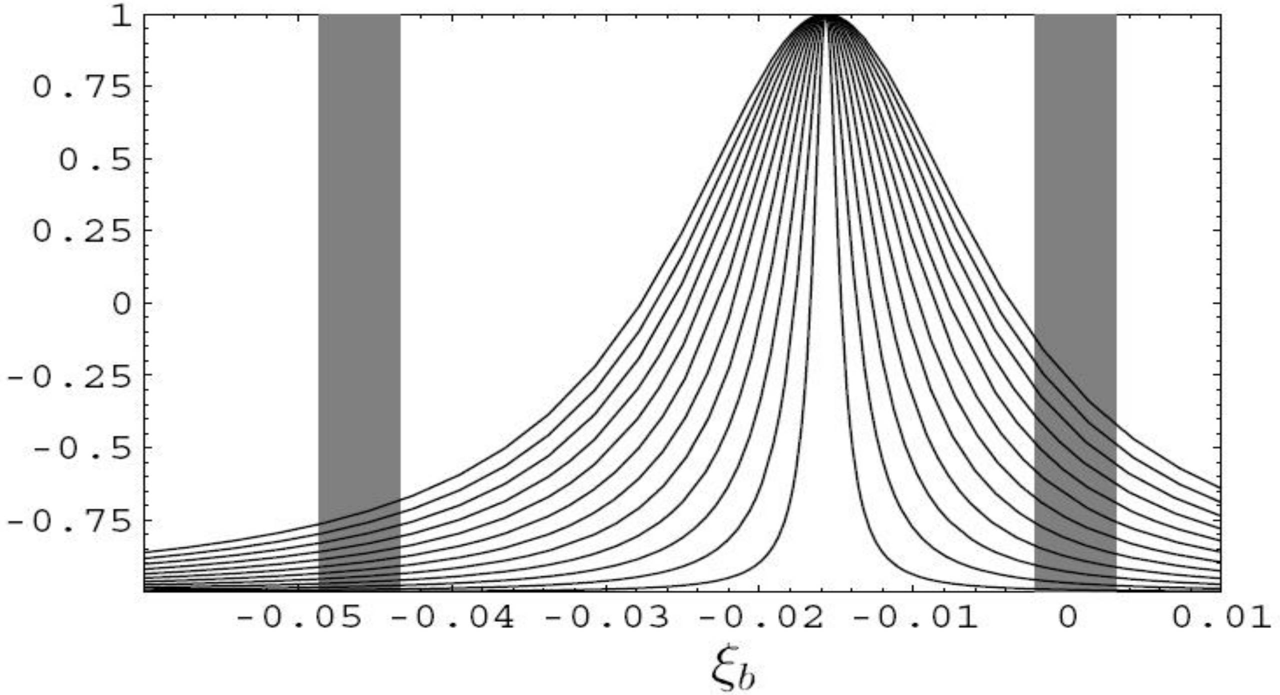
Backup slides

Example of models

- Anomalous right-handend top couplings *J.P.Lee'03*

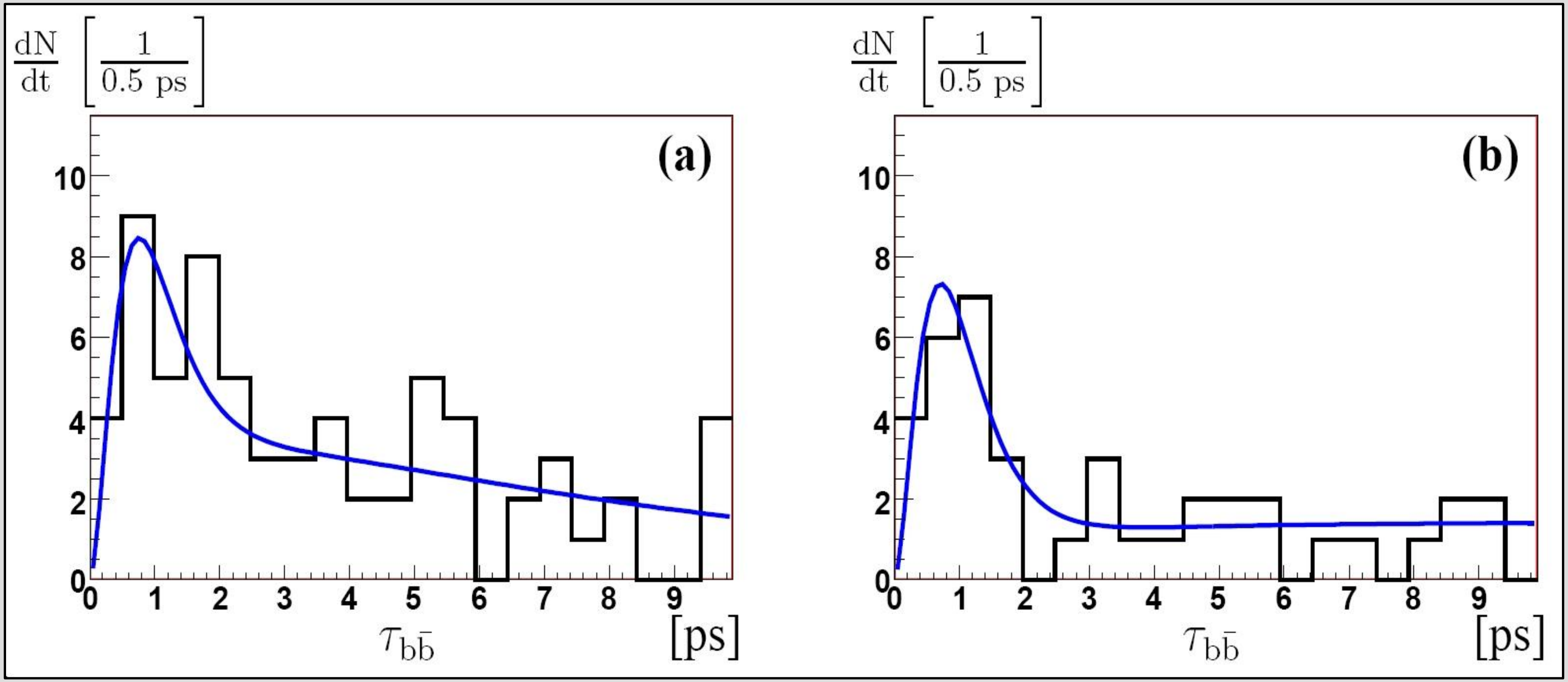
$$\mathcal{L} = -\frac{g}{\sqrt{2}} \sum_{q=s,b} V_{tq} \bar{t} \gamma^{\mu} (P_L + \xi_q P_R) q W_{\mu}^{+} + \text{h.c.} \,,$$

$\lambda_\gamma = -\cos 2\psi$



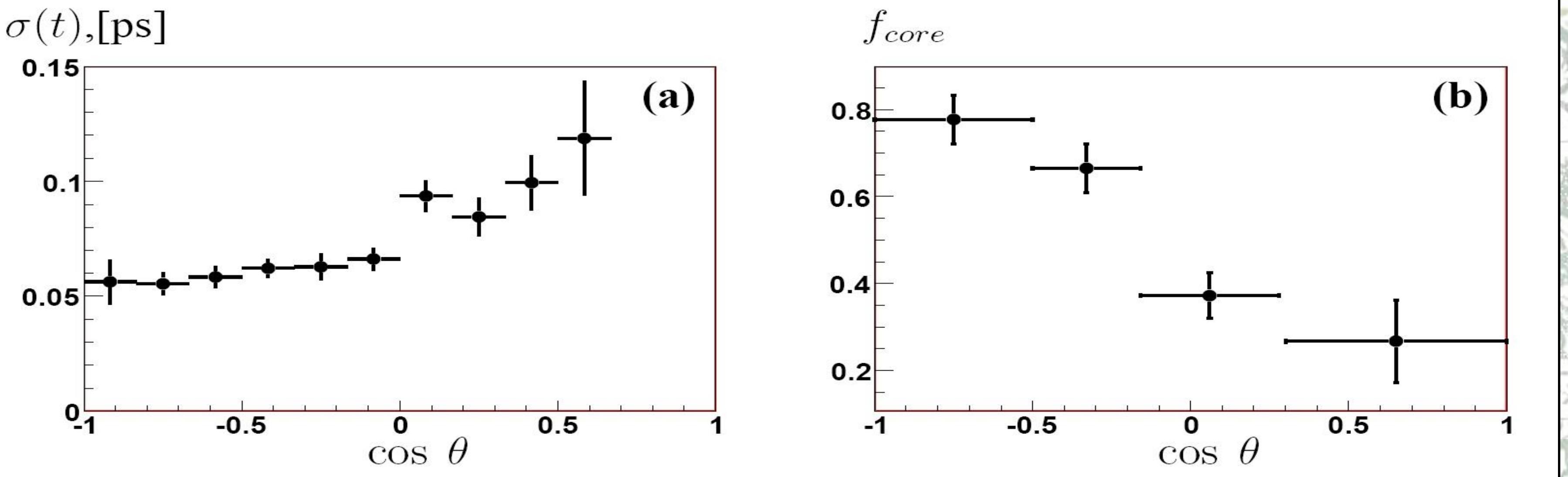
B: proper-time in sidebands

- Fit separately left and right sidebands

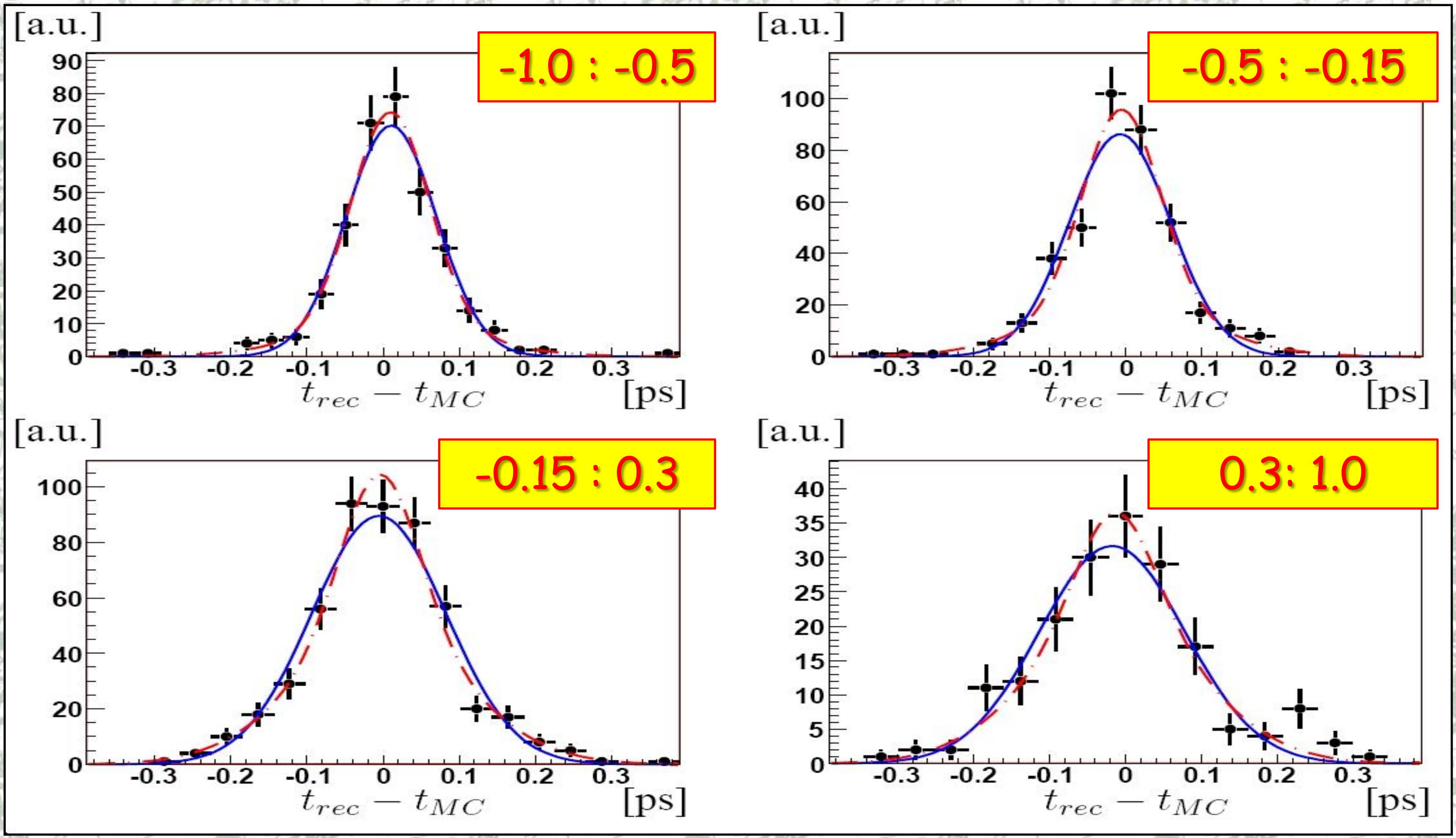


Signal proper time resolution as function of cosΘ

$\cos\theta$	mean_{1G}, fs	σ, fs	mean_{2G}, fs	f_{core}
[-1,-0.5)	10 ± 3	59 ± 3	10 ± 3	0.78 ± 0.06
[-0.5,-0.15)	-8 ± 4	66 ± 4	-6 ± 4	0.66 ± 0.06
[-0.15,0.3)	-5 ± 4	88 ± 4	-4 ± 4	0.37 ± 0.05
[0.3,1]	-18 ± 8	96 ± 7	-13 ± 8	0.27 ± 0.09

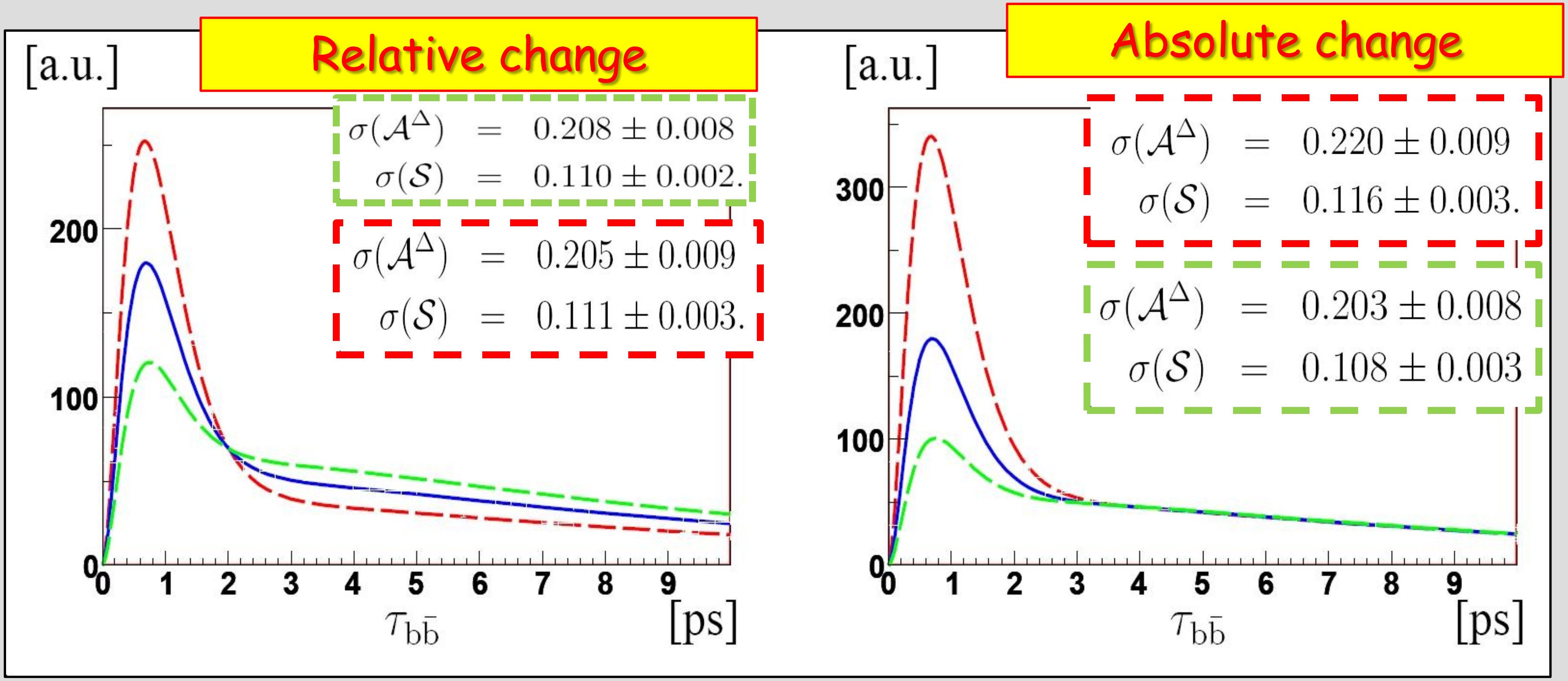


Signal proper time resolution as function of $\cos\Theta$



The shape of background

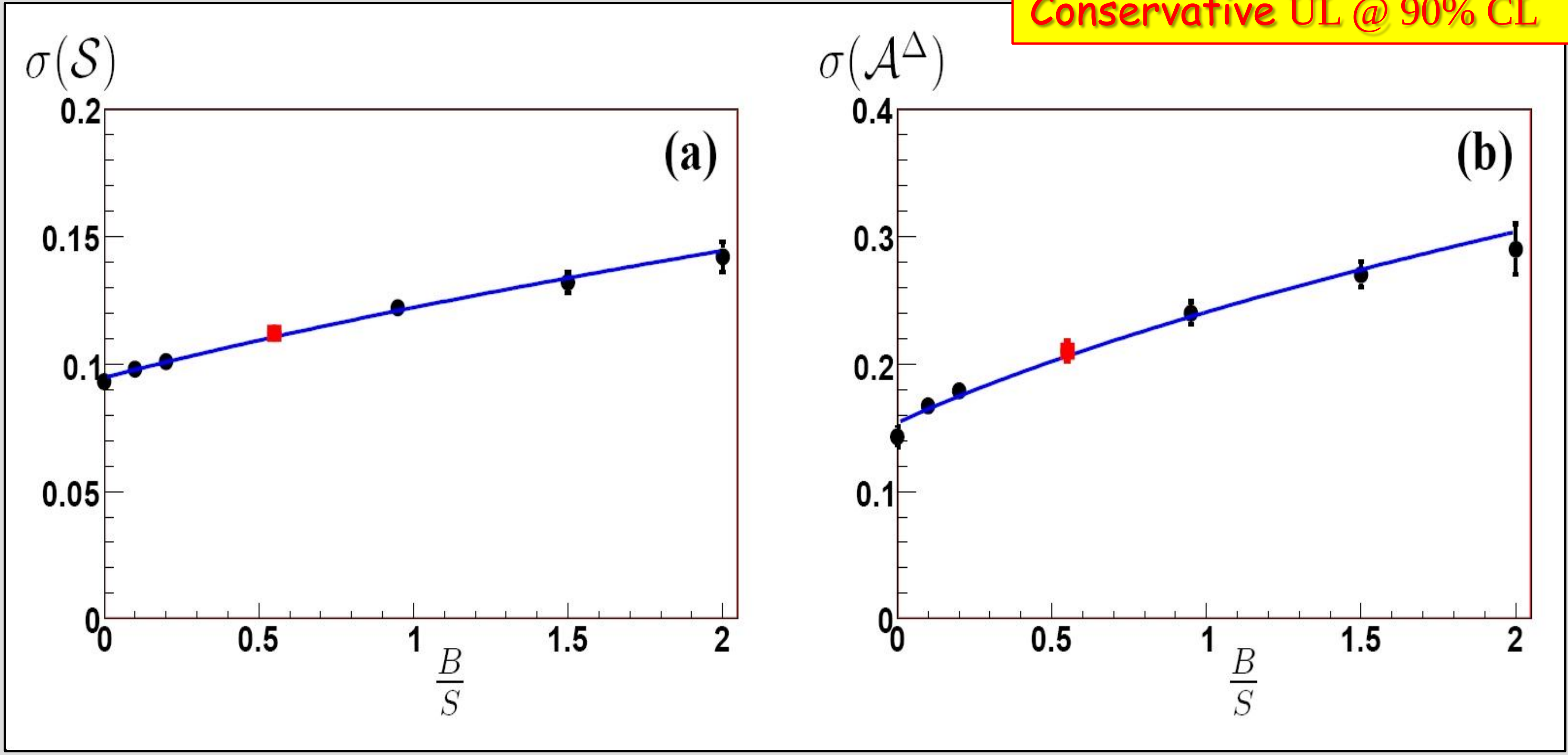
- Vary the “short/long”-lived components



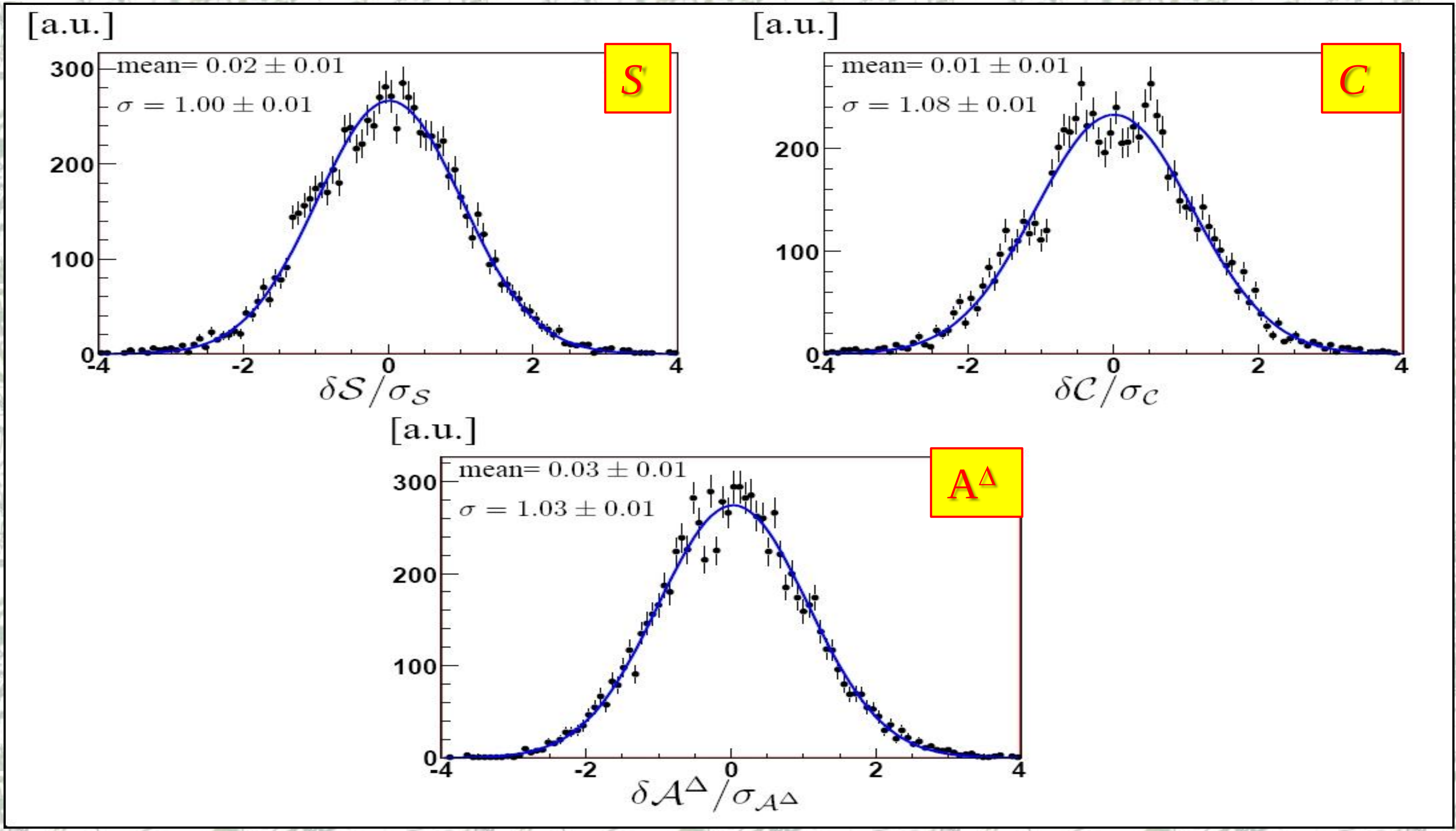
Stability tests: *B/S*

- There is some dependency on *B/S* level:

Conservative UL @ 90% CL

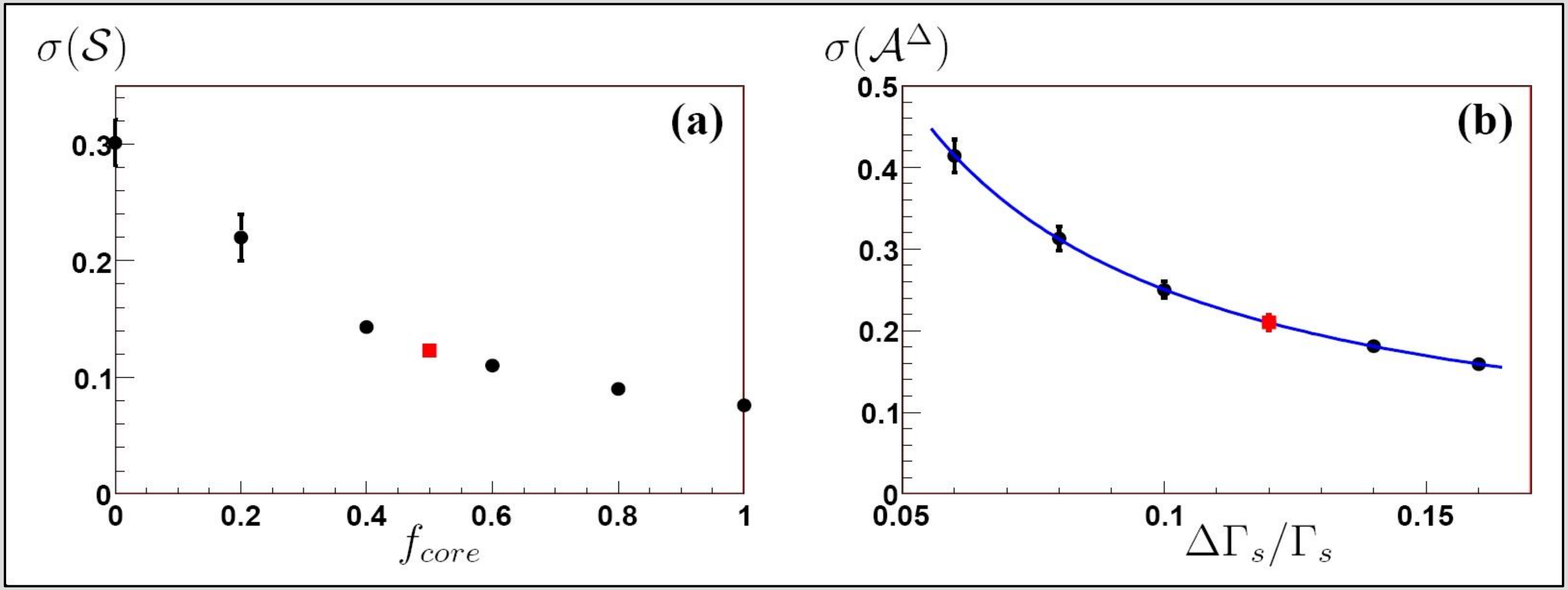


Results: pulls



Resolution and $\Delta\Gamma_s/\Gamma_s$

- Vary the proper time resolution
  - Use simple model with two Gaussians and vary the proportion



Acceptance function

Combined fit of $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$

- The acceptance function can be fully determined in $B_d \to K^*\gamma$ assuming known proper time resolution
- In this simplified test do combined fit of both channels to determine a and c in $B_d \to K^*\gamma$ and use them in $B_s \to \phi\gamma$
- Use 68 k $B_d \to K^*\gamma$ events and ignore background

$$\sigma_a = 0.01$$

$$\sigma_c = 0.02$$

$$\varepsilon(t) = \frac{(at)^c}{1+(at)^c}$$

$$a = 0.74\ \text{ps}^{-1}$$

$$c = 1.86$$

Background parameterization