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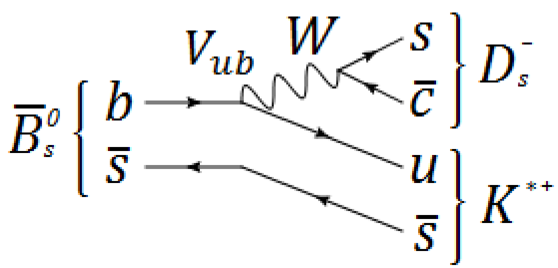
The CKM parameters sensitivity studies using the time dependent analysis for $B^0 \to DK$ decay channels

Piotr Bednarski, Agnieszka Obłąkowska-Mucha

The CKM Matrix

- **The CKM Matrix describes weak interactions using 4 parameters.**
- **The least known parameter is γ angle**

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



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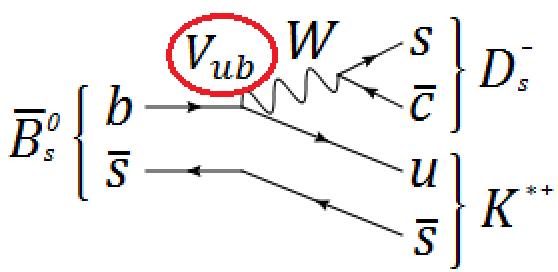
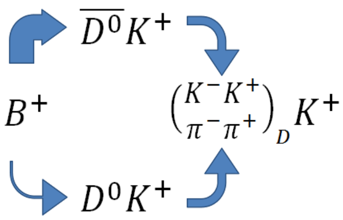
$weak\ eigenstates$

$mass\ eigenstates$

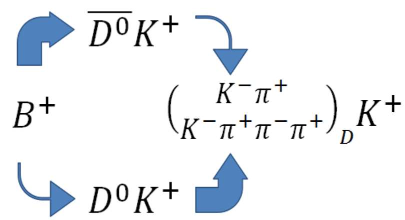


Methods for the CKM γ Angle Extraction

GLW



ADS

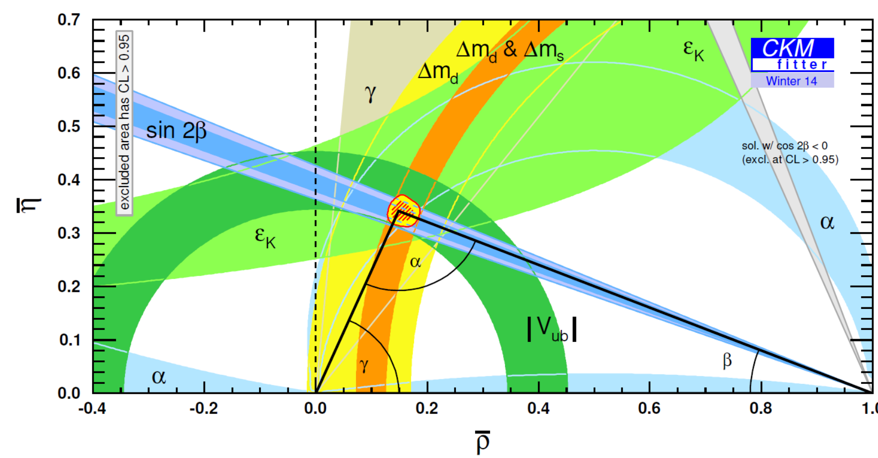


a) $B^+ \to DK^+$

- Theoretically clean
- GLW and ADS methods

b) $B^0 \to hh$

- Rather big loop diagram contribution
- Knowledge of hadronic factors is necessary



c) Time dependent methods

- Measurement of $B^0 - \overline{B}^0$ oscillations,
- Experimentally difficult,
- No penguin pollution,
- High sensitivity for γ angle,
- Can be used as a reference point for New Physics studies.

B Meson Decay Rates Equations

$$\Gamma_{B_s^0\to f}(t) = |A_f|^2\left(1+|\lambda_f|^2\right)\frac{e^{-\Gamma_s t}}{2}\cdot\left(\cosh\frac{\Delta\Gamma_s t}{2} + D_f \sinh\frac{\Delta\Gamma_s t}{2} + C_f\cos\Delta m_s t - S_f \sin\Delta m_s t\right)$$

$$|B_{H,L}\rangle = p|B_s^0\rangle \mp q|\bar{B}_s^0\rangle$$

$$D_f = \frac{2Re\lambda_f}{1+|\lambda_f|^2}\ ,\qquad D_{\bar f} = \frac{2Re\bar\lambda_{\bar f}}{1+|\bar\lambda_{\bar f}|^2}\ ,$$

$$C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\ ,\qquad C_{\bar f} = \frac{1-|\bar\lambda_{\bar f}|^2}{1+|\bar\lambda_{\bar f}|^2}\ ,$$

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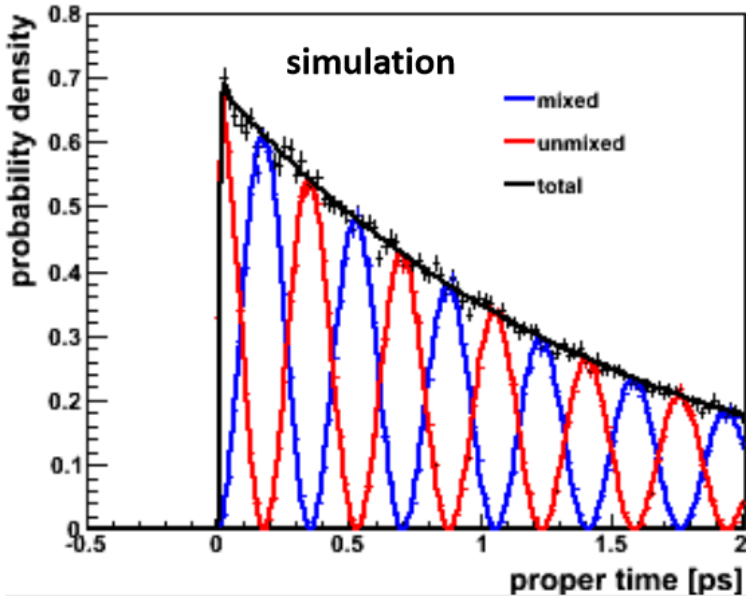

where:

$$A_f = \langle f|T|B_s^0\rangle\ ,\qquad \bar A_{\bar f} = \langle \bar f|T|\bar B_s^0\rangle,$$

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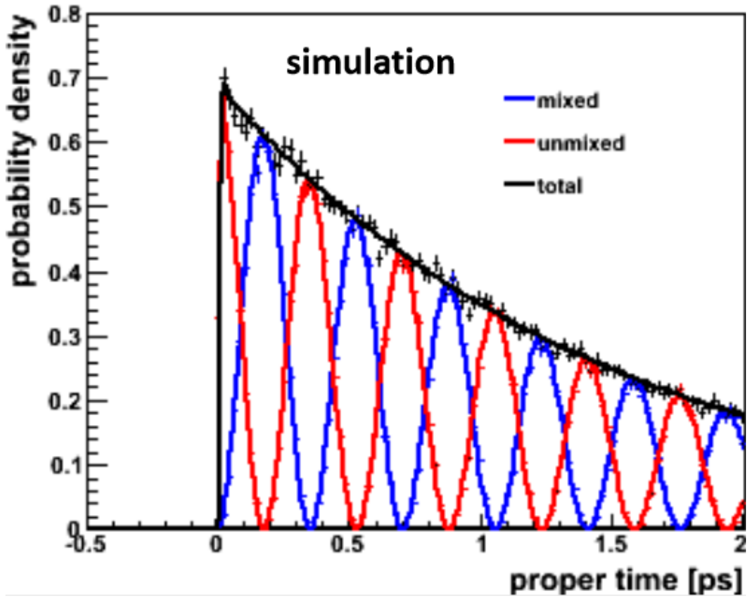

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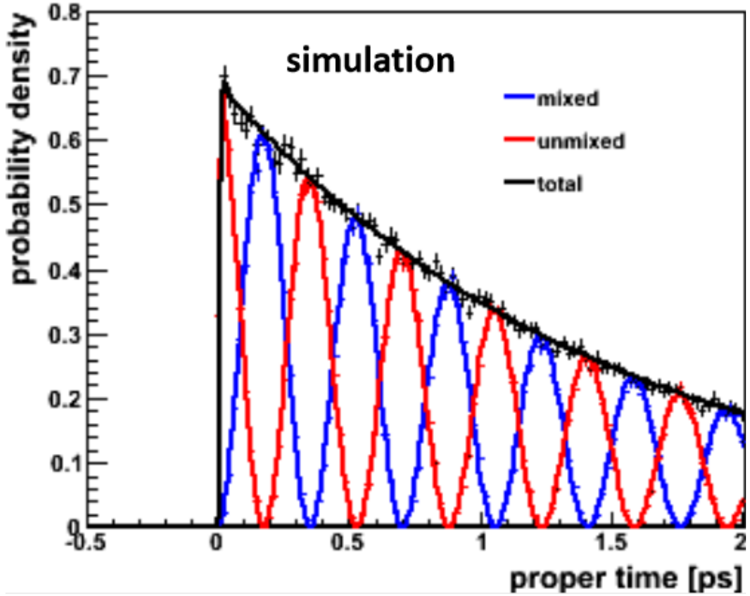

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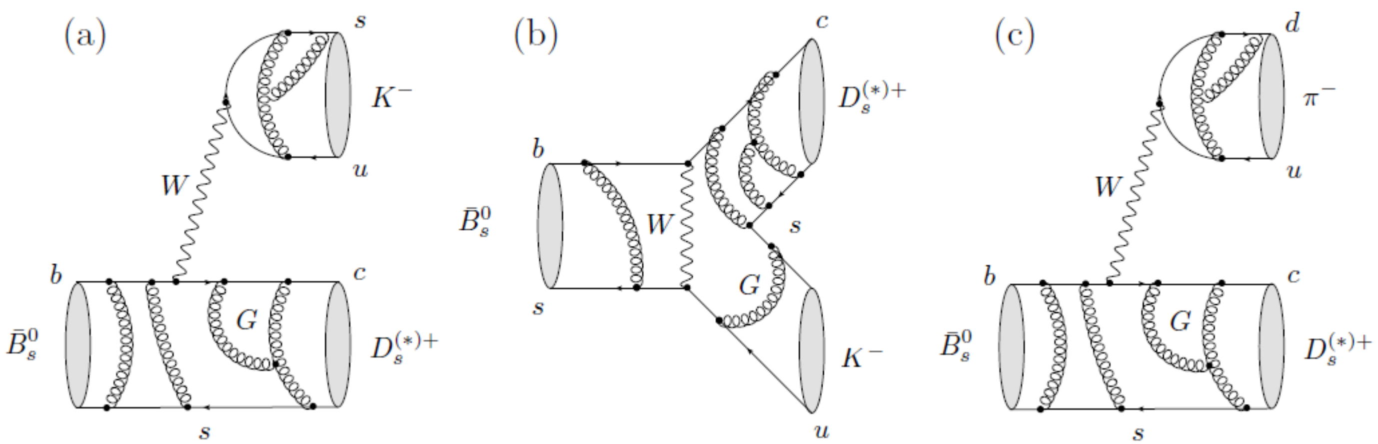
$B^0 \rightarrow Dh$ time dependent study

1. **First succesful time dependent analysis were performed in B-factories**
   - **The measurements were done using $B^0 \rightarrow J/\Psi K_s^0$ (measurement of β angle)**
   - **Thanks to large statistics in LHCb $B_s^0 \rightarrow J/\Psi\Phi$ channel can also be used (for measurement of weak phase Φ_s)**
2. **Nowadays different $B^0 \rightarrow Dh$ decays are used:**



$B^0 \rightarrow Dh$ time dependent study

a) $B_d^0 \rightarrow D^{\pm}\pi^{\mp}, D^{*\pm}\pi^{\mp}$

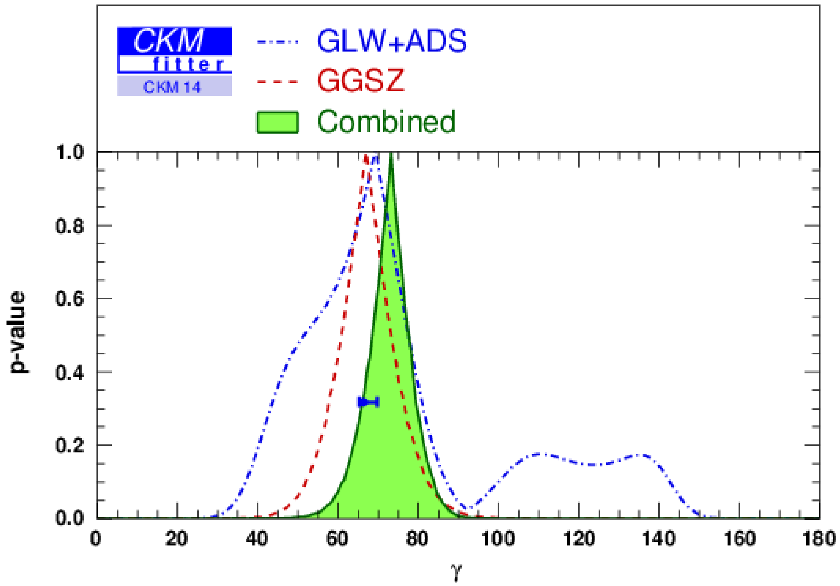
- Sensitive to γ
- Large BR

b) $B_s^0 \rightarrow D_s^+\pi^-$

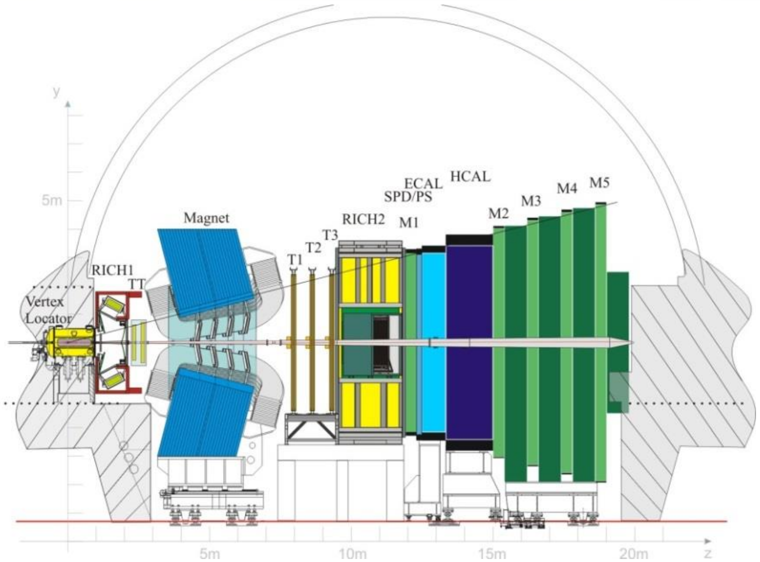
- Large BR
- Clear reconstruction
- Flavour specific (no tagging required)
- Information on $\Delta\Gamma_s$ and $\left|\frac{q}{p}\right|$

c) $B_s^0 \rightarrow D_s^- K^+, D_s^{(*)-}K^{(*)+}$

- Sensitive to $(\gamma + \Phi_s)$
- Tree dominated – precise calculations
- Small BR
- Tagging and good PID required
- Angular analysis for vector mesons
- Due to my interest in this particular decay most of the examples will be based on it



The Experiment - LHCb

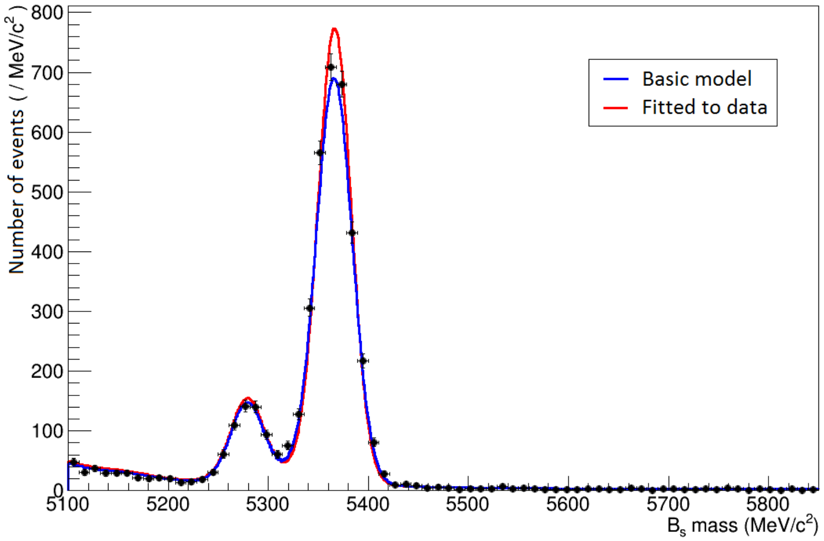


LHCb – modern B-factory:

- **10-300 mrad of space acceptance**
- **VELO (VErtex LOcator) – precise vertices location**
- **Calorimeters**
- **RICH – Cherenkov Radiation Detectors**
- **Track detectors**
- **Mion detectors**
- **$10fb^{-1}$ of data in Run 2!**

Toy Monte Carlo study

35 000	signal events $B_s \to D_s K^*$
3 400	$B_d \to D_s^* K^*$ physical background events
3 500	$B_d \to D_s K^*$ physical background events
3 000	$B_d \to D K^*$ physical background events
500	$B_s \to D_s X$ physical background events
10 000	combinatorial background events



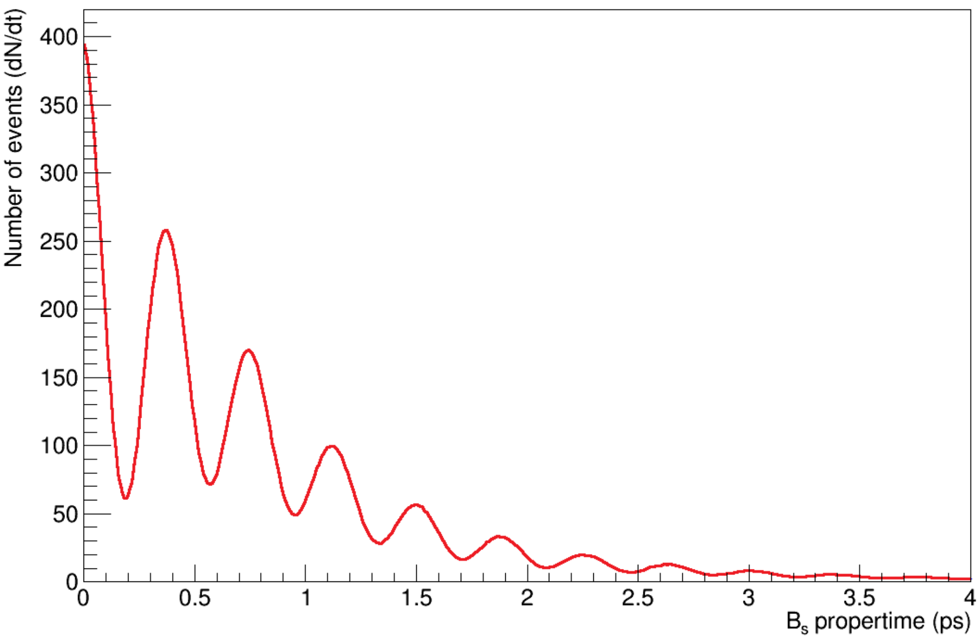
- **Much faster than full simulation**
- **Almost as accurate if used properly - remember about the background and detector effects!**
- **The $B_s \to D_s K^*$ decay simulation number of events (per 10 fb^{-1}) are shown in the table above**

Detector Effects

Detector effects have huge impact on the shape of the lifetime curve (mass curve stays almost intact).

Three main effects are:

- **time resolution**
- **time acceptance,**
- **mistagging.**

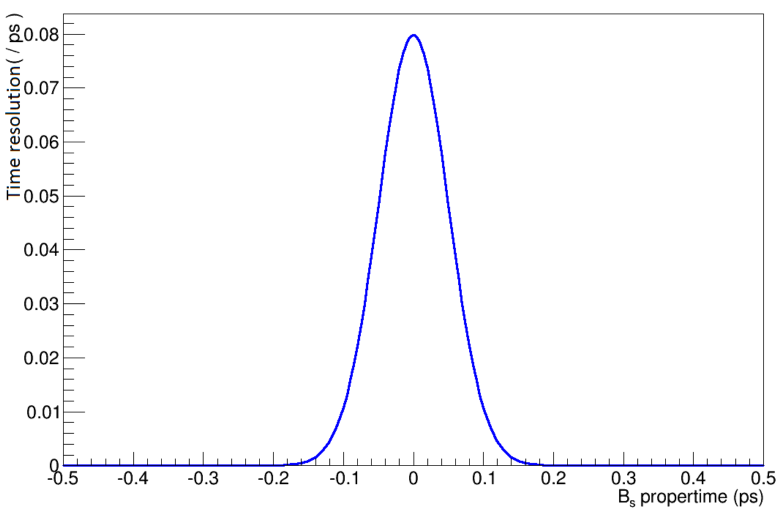


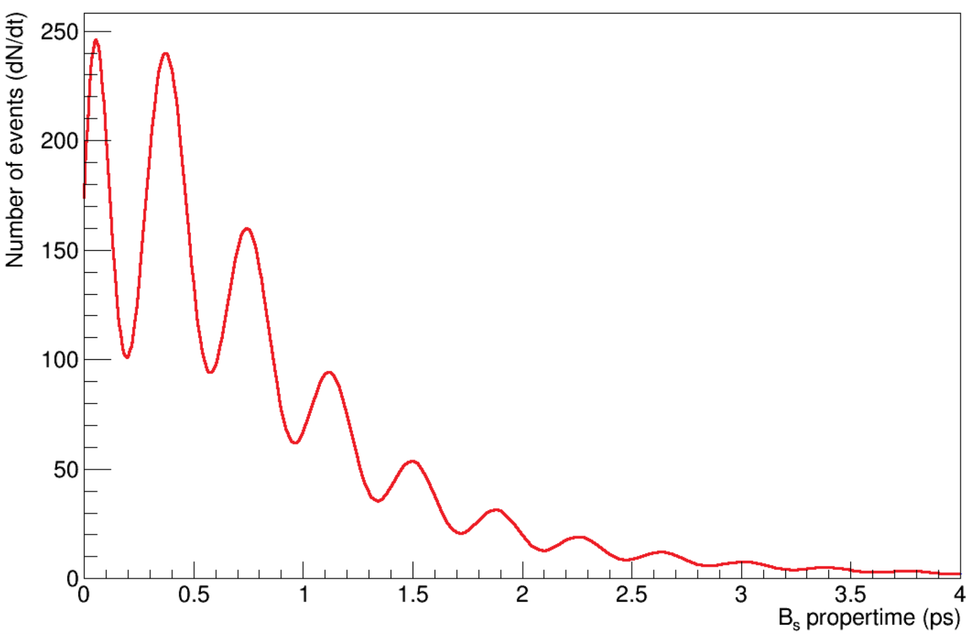
Detector Effects – Time Resolution

- **Time Resolution has a finite value**
- **The effect can be estimated as a sum of 3 gaussians:**

$$R(t) = f_1 G(t;\ \mu, \sigma_1) + f_2 G(t;\ \mu, \sigma_2) + (1 - f_1 - f_2) G(t;\ \mu, \sigma_3)$$

- **Observed PDF is theoretical PDF convoluted with** $R(t)$



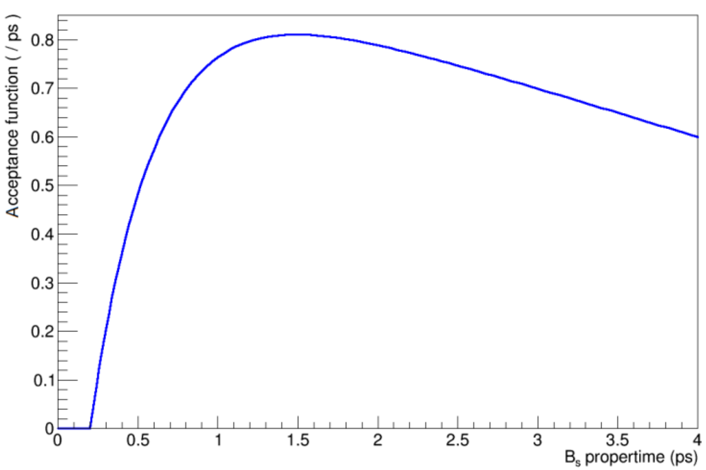


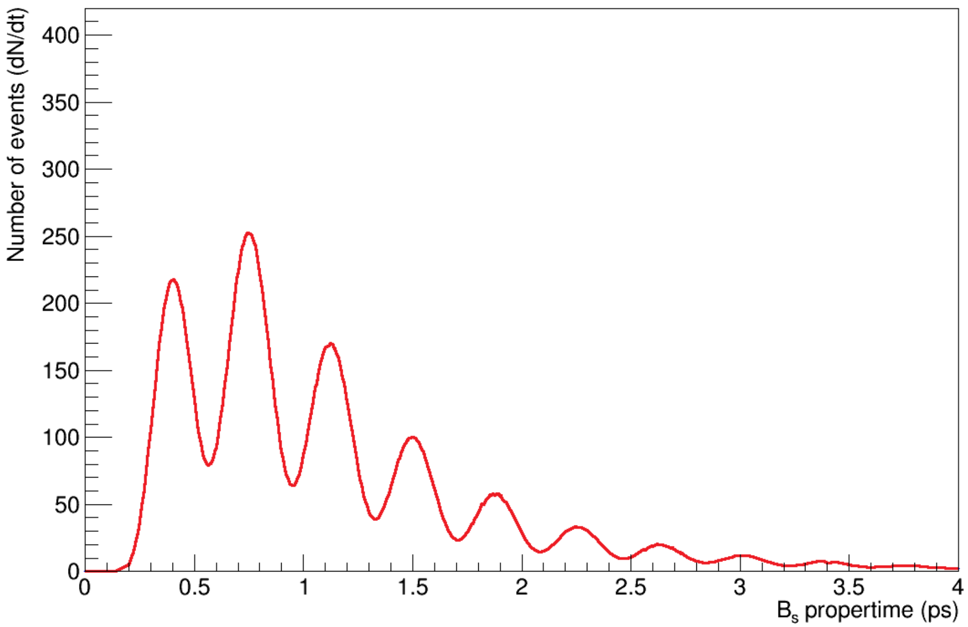
Detector Effects – Time Acceptance

- **Short living particles are harder to observe**
- **Many different empirical models**

$$acc(t) = \begin{cases} 0, & t - b < 0 \\ (1 - exp[-a(t-b)])(1 - \beta t), & a(t-b) < 0 \\ 1 - \beta t, & otherwise \end{cases}$$

with $a = 2.36,\ b = 0.2ps,\ \beta = 0.1ps^{-1}$

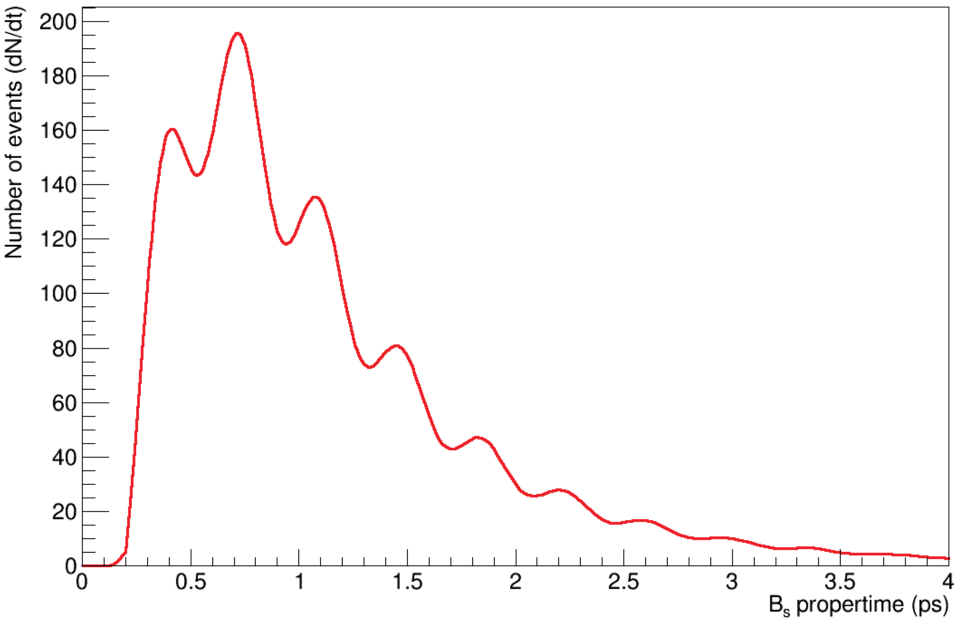




Detector Effects – Mistagging

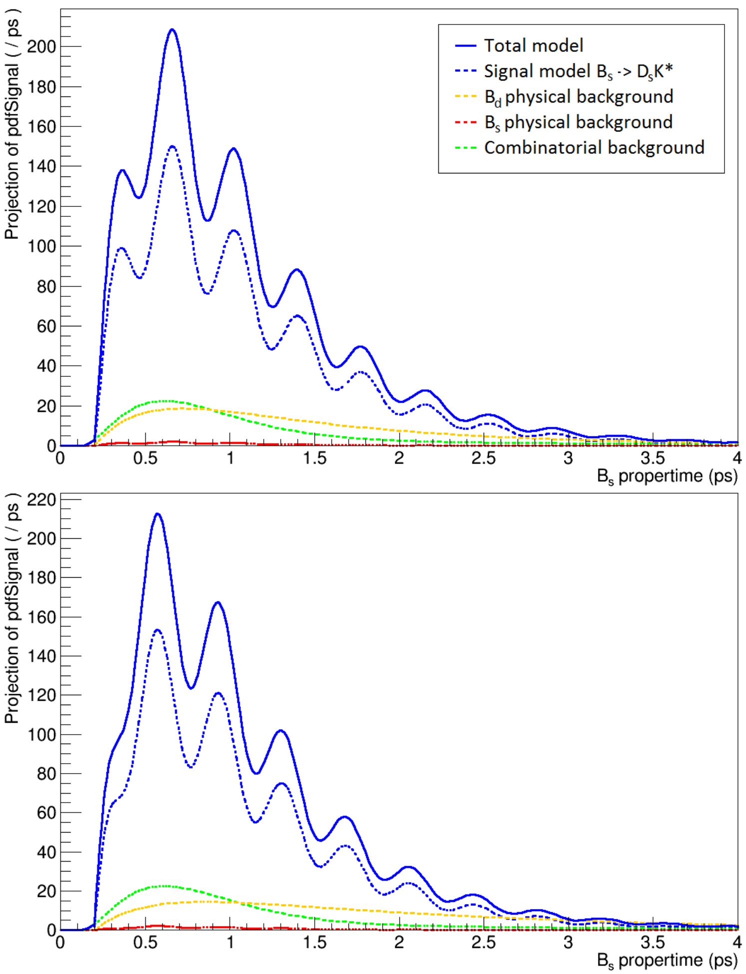
- **Mistagging – decrese of amplitude by a factor of $(1-2\omega)$**
  - **A couple of different tagging methods – OS tagger, SSK tagger**
  - **Both initial and final states need to be tagged**
  - **Tagging can be expressed as follows:**

$$\Gamma_{obs}(tagged\ B(\tau)\rightarrow f)=\epsilon(\tau)\epsilon_{tag}[(1-\omega_{tag})\Gamma'_{\mathrm{obs}}(B(\tau)\rightarrow f)+\omega_{tag}\Gamma'_{\mathrm{obs}}(\bar{B}(\tau)\rightarrow f)]$$

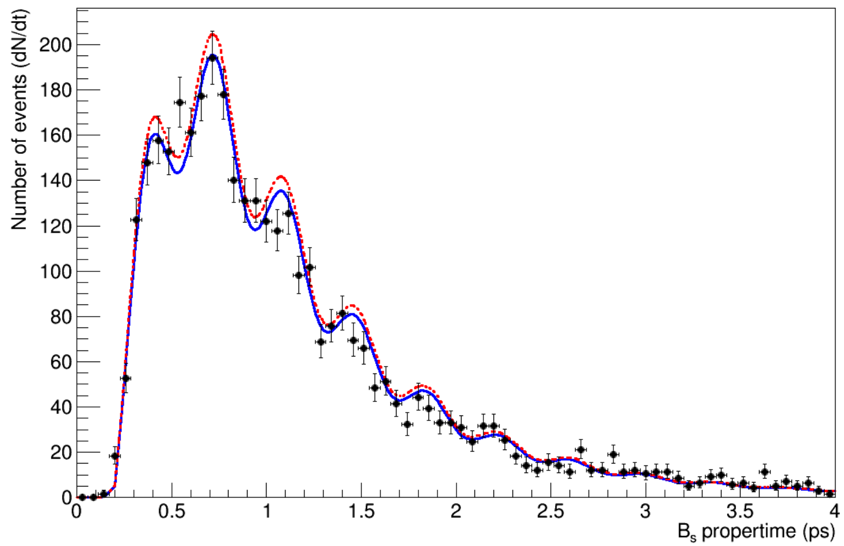


$B_s^0 \to D_s K^*$ Decay Model and sensitivity

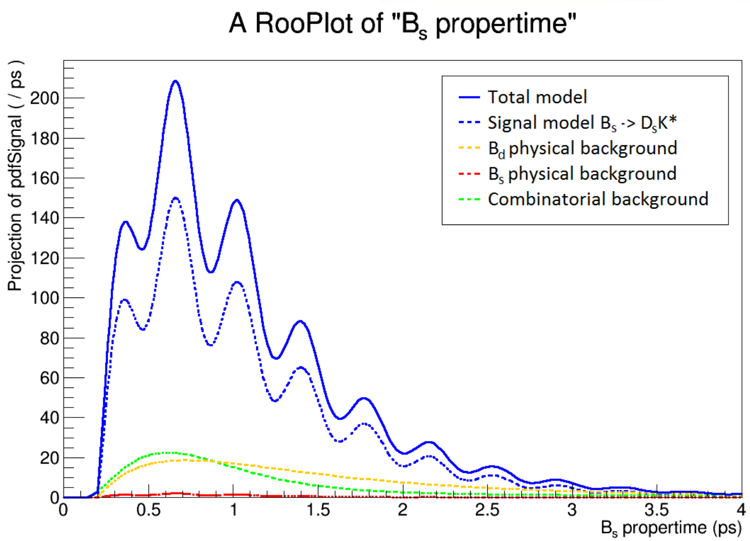
Different final states:

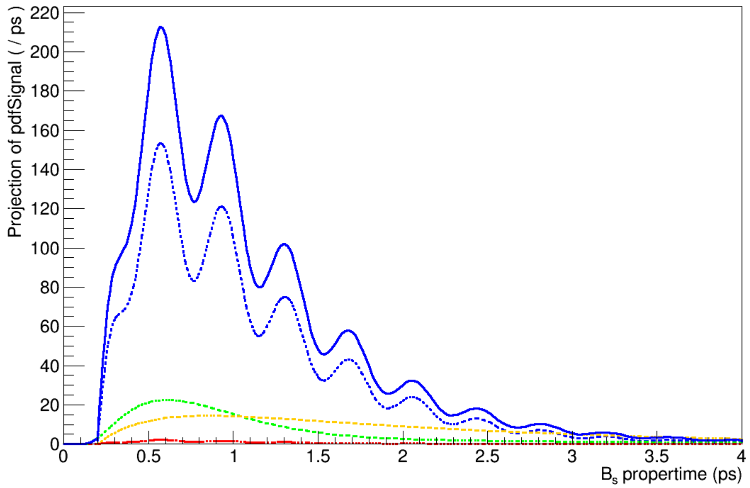


- **Data points are generated according to created model**
- **Performing a fit to the generated data is an ‚experiment'**
- **One can obtain fitted parameters and calculate γ**
- Having done multiple such experiments one can create a pull distribution
- The pull distribution translates to sensitivity to γ



$B_s^0 \to D_s K^*$ Decay Model and sensitivity





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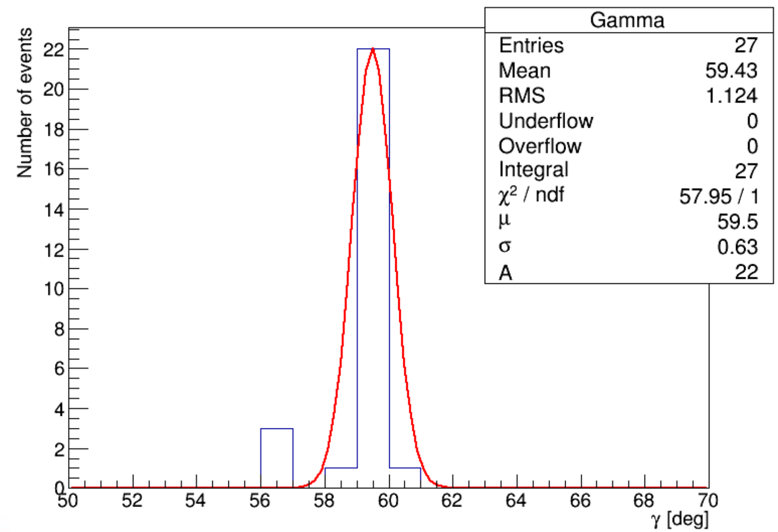

Conclusions

- The γ angle in the CKM Matrix is least known parameter,
- Knowing its value with more precission will allow to investigate the New Physics,
- Many different methods of γ extraction were proposed – each of them with pros and cons,
- Method presented here has big advantage of no penguin pollution and high sensitivity,
- Fitter can be used when the data is collected in Run 2,
- γ angle value obtained with this method might be used as a starting point to study the Physics Behind the Standard Model.

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Thank you!

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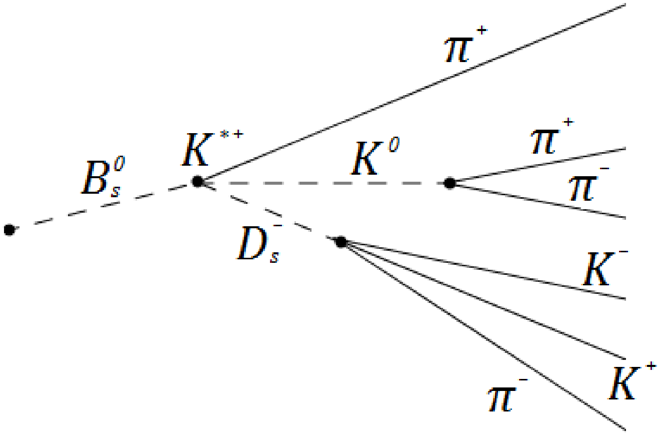
Backup slides

The kinematics of $B_s \to D_s K^*$ decay



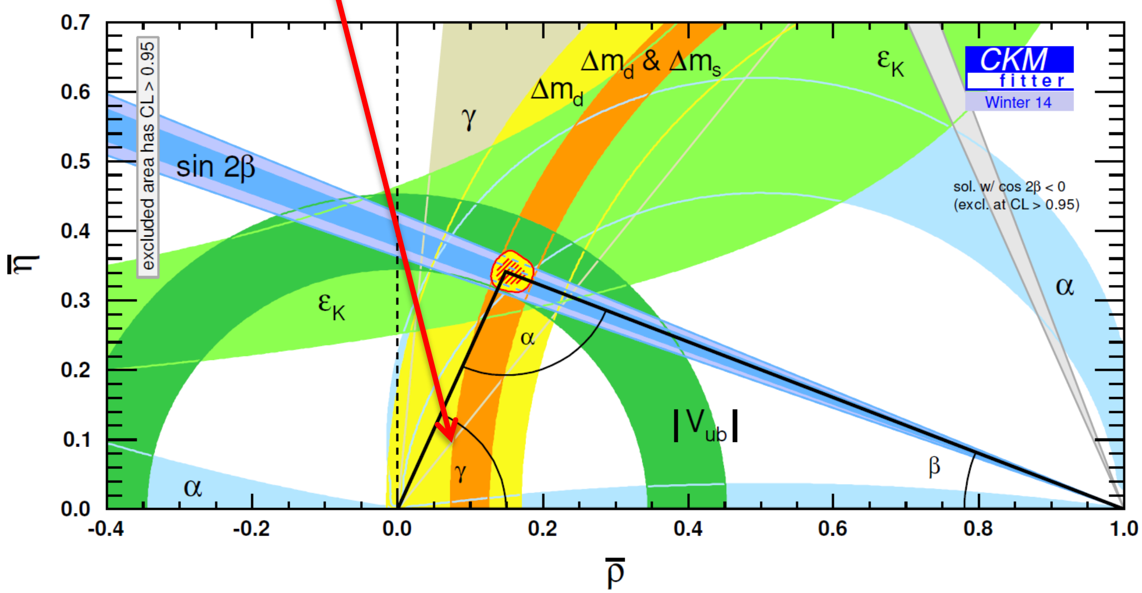
Decay	Branching Ratio
$B_s^0 \to D_s^- K^{*+}$	$4{,}7 \cdot 10^{-5}$
$K^{*+} \to \bar{K}^0 \pi^+$	65%
$\bar{K}^0 \to \pi^+ \pi^-$	66%
$D_s^- \to K^+ K^- \pi^-$	11,6% (including resonance states)
Total	**$2{,}33 \cdot 10^{-6}$**

- **Six particles in final state**
- **Rarely measured**
- **$B_s - \overline{B_s}$ mixing can provide information about New Physics**
- **Good tagging is required**

Unitarity Triangles

$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix}$$

γ – least known CKM parameter



B2DXFitters – technical details

- **Big part of my work is based on B2DXFitters package.**
- **Thanks to Eduardo Rodriguez I managed to understand basics of the implementation.**
- **B2DXFitters is a part of Urania (v2r4 in my case).**
- **The study is being developed basing on two scripts:**
  - ***runBdMassFitterToyMC***
  - ***runBdDeltaMFitterToyMC***
- **My main part of analysis is 2-dimensional fit – simultaneous in mass and time.**