Angular analysis of $B_d \to K^*ee$ at the LHCb experiment

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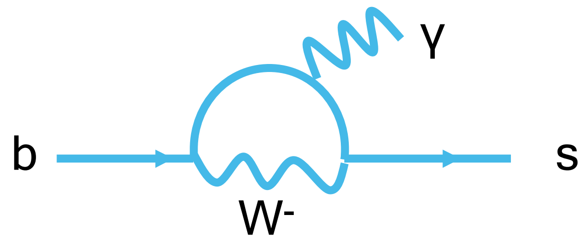
Motivation

b →s γ proceeds through FCNC loops,
thus is sensitive to new physics



In SM, the photon from $\overline{B}^0$ is predominantly
left handed with small corrections due to s mass (A_R/A_L~0.04)

Measure γ polarization and:

Signal of right handed component = indication of new physics

(eg. Increased A_R in eg. Left-Right symmetric models and some SUSY models)

Various methods to measure the γ helicity. For sensitivity, require method which determines interference between A_R and A_L

Currently in PDG from study of interference effects between B and $\overline{B}$ decays: σ(A_R/A_L~0.16) [1]

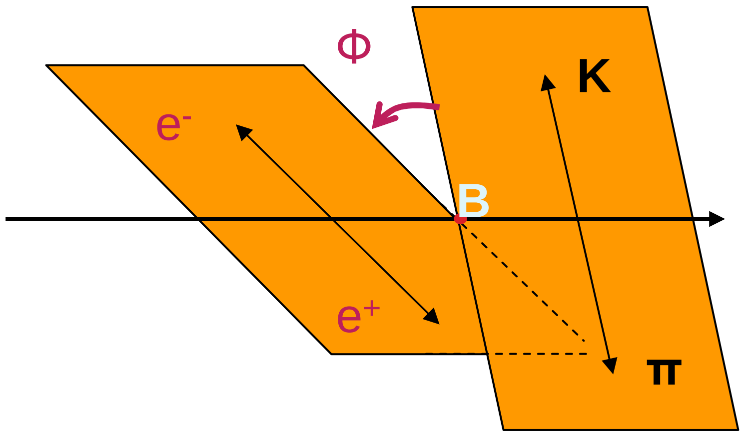
Plans

Two studies carried out at LHCb:

- Time dependant rates of $Bs \rightarrow \varphi\gamma$

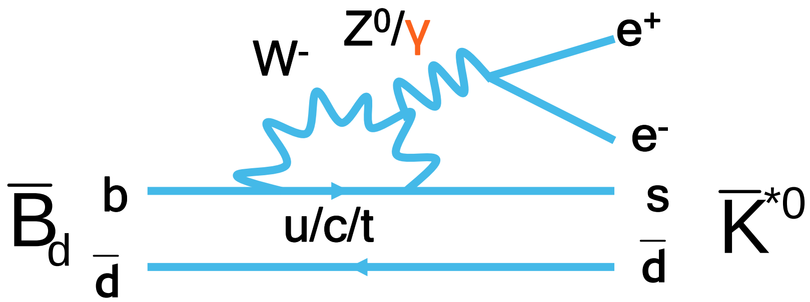
  (σ_{A_R/A_L}~0.1 in one nominal year: $2fb^{-1}$) [2]
- **Study of photon polarization in $B \rightarrow K^*e^+e^-$ [3]**

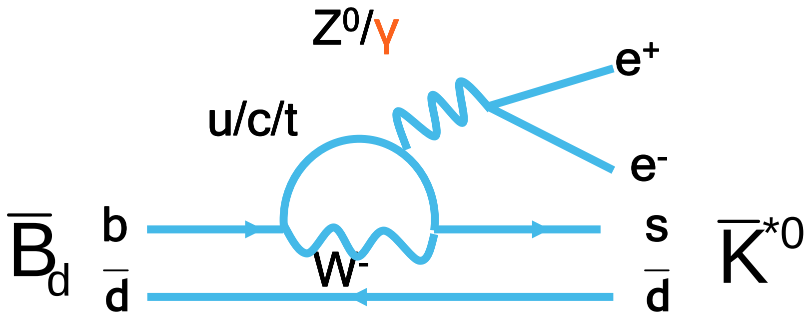
As shown in [4] measurement of φ allows access to the photon polarisation.

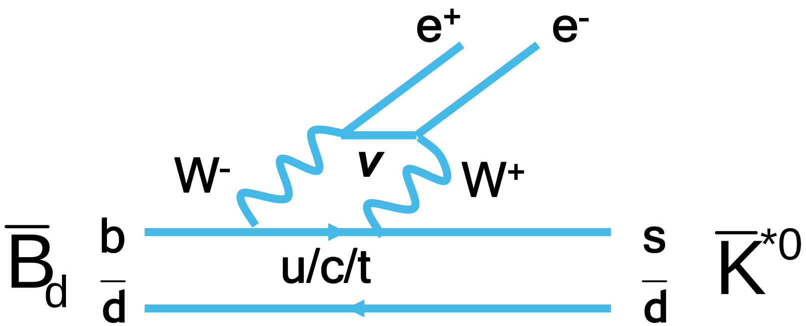


But the electron pair must come from a photon…

Theoretical Introduction







Contributions vary with q^2

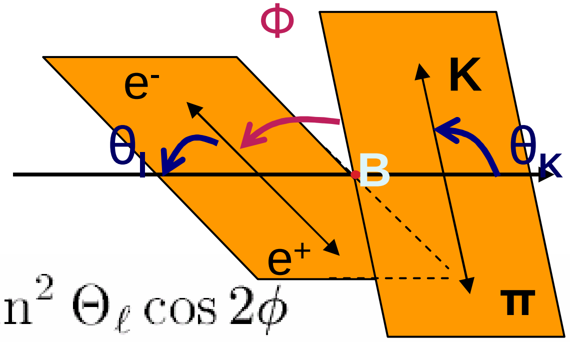
At 1Gev, longitudinal term ~ transverse term

→ less sensitive to photon polarization measurement

Restrict analysis to 30Mev<M(ee)<1000MeV

However, due to other contributions, one requires full formalism…

Formalism



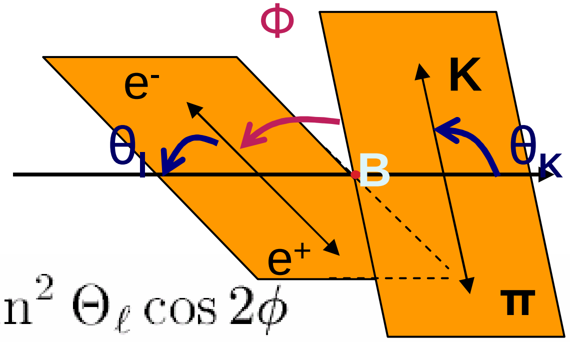
[5] $$\frac{d\Gamma}{dq^2\, d\cos\Theta_\ell\, d\cos\Theta_K\, d\phi} =$$

$$\frac{9}{32\pi}\,[\,I_1(\cos\Theta_K) + I_2(\cos\Theta_K)\cos 2\Theta_\ell + I_3(\cos\Theta_K)\sin^2\Theta_\ell\cos 2\phi$$
$$+ I_4(\cos\Theta_K)\sin 2\Theta_\ell\cos\phi + I_5(\cos\Theta_K)\sin\Theta_\ell\cos\phi + I_6\cos\Theta_\ell$$
$$+ I_7(\cos\Theta_K)\sin\Theta_\ell\sin\phi + I_8(\cos\Theta_K)\sin 2\Theta_\ell\sin\phi + I_9(\cos\Theta_K)\sin^2\Theta_\ell\sin 2\phi]$$
$$\times\varepsilon(\cos\Theta_\ell, \cos\Theta_K, \phi, q^2)$$

Where $\varepsilon(\cos\theta_l, \cos\theta_K, \varphi, q^2)$ is the angular acceptance.

Assuming ε is factorizable and even, can fold φ over (-π,0) to (0,π) Thus cosφ and sinφ terms disappear without harming sensitivity to cos2φ and sin2φ. Can do similar folding for θ_l from (0,+π/2) to (+π/2,+π).

Formalism



[5] $$\frac{d\Gamma}{dq^2\, d\cos\Theta_\ell\, d\cos\Theta_K\, d\phi} =$$

$$\frac{9}{32\pi}\left[\, I_1(\cos\Theta_K) + I_2(\cos\Theta_K)\cos 2\Theta_\ell + I_3(\cos\Theta_K)\sin^2\Theta_\ell\cos 2\phi \right.$$
$$+ I_4(\cos\Theta_K)\sin 2\Theta_\ell\cos\phi + I_5(\cos\Theta_K)\sin\Theta_\ell\cos\phi + I_6\cos\Theta_\ell$$
$$\left. + I_7(\cos\Theta_K)\sin\Theta_\ell\sin\phi + I_8(\cos\Theta_K)\sin 2\Theta_\ell\sin\phi + I_9(\cos\Theta_K)\sin^2\Theta_\ell\sin 2\phi\right]$$
$$\times\varepsilon(\cos\Theta_\ell, \cos\Theta_K, \phi, q^2)$$

Where $\varepsilon(\cos\theta_l, \cos\theta_K, \varphi, q^2)$ is the angular acceptance.

Assuming ε is factorizable and even, can fold φ over (-π,0) to (0,π) Thus cosφ and sinφ terms disappear without harming sensitivity to cos2φ and sin2φ. Can do similar folding for θ_l from (0,+π/2) to (+π/2,+π).

Relevant terms are now I_1 I_2 I_3 I_9

Formalism

$$I_1(\cos\theta_K) = \frac{3}{4}(1-F_L)\times(1-\cos^2\theta_K) + F_L\times\cos^2\theta_K$$

$$I_2(\cos\theta_K) = \frac{1}{4}(1-F_L)\times(1-\cos^2\theta_K) - F_L\times\cos^2\theta_K$$

$$I_3(\cos\theta_K) = \frac{1}{2}(1-F_L)\times A_T^{(2)}\times(1-\cos^2\theta_K)$$

$$I_9(\cos\theta_K) = A_{Im}\times(1-\cos^2\theta_K)$$

3 parameters to fit, depending on (transversity) amplitudes as

$$F_L = \frac{|A_0|^2}{|A_0|^2 + |A_\perp|^2 + |A_{||}|^2}$$

Roughly varies as q^2.

~12% for 30MeV<M(ee)<1000MeV from MC

$$A_T^{(2)} = \frac{|A_\perp|^2 - |A_{||}|^2}{|A_\perp|^2 + |A_{||}|^2}$$

In helicity amplitudes, $A_T \sim -2A_R/A_L$

$$A_{Im} = \frac{\Im\left(A^*_{||L}A_{\perp L}\right) - \Im\left(A^*_{||R}A_{\perp R}\right)}{|A_0|^2 + |A_\perp|^2 + |A_{||}|^2}$$

A^2_T and A_{im} are very small in SM. Aim of analysis is to measure or set upper limits

Expectations for LHCb

Expected yields from MC studies

$$\text{Signal} = \int L\,dt \cdot \sigma_{bb} \cdot BR_{Vis}\left(B \to K^{*} e^{+} e^{-}\right)^{30-1000\,MeV} \cdot BR(\bar{K}^{*} \to K^{+}\pi^{-}) \cdot 2 \cdot f_{d} \cdot \eta_{\theta}^{sig} \cdot \varepsilon_{sel}$$

With $\int \mathcal{L}\,dt$ = 1fb^{-1}

σ_{bb} = 280 μb

$BR_{Vis}\left(B \to K^{*} e^{+} e^{-}\right)^{30-1000\,MeV}$ = 2.2x10^{-7}

$BR\left(K^{*} \to K^{+}\pi^{-}\right)$ = 2/3

f_d= 0.4

η_θ= 0.18

ε_{sel} = 0.026

150 signal with 1fb^{-1} before trigger
(550 signal in nominal year with 2 fb^{-1} and σ_{bb}=500 μb)

Background studies show S/B~1 is achievable (see backups for details)

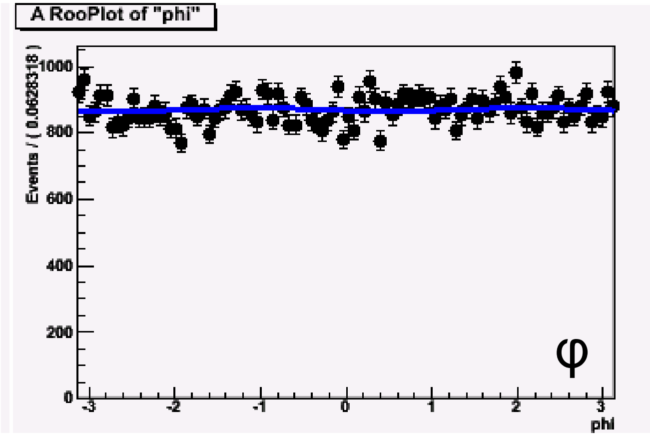
Fitting procedure

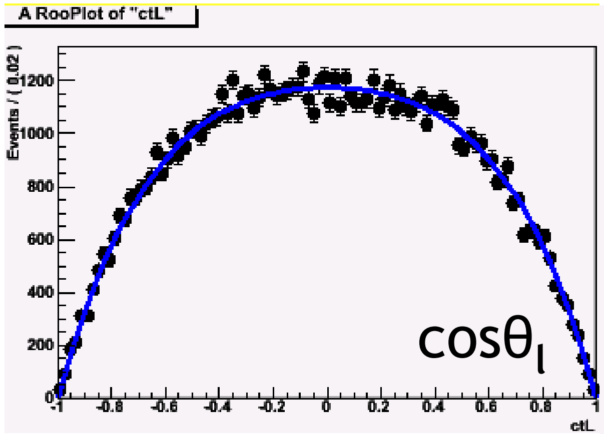
3D fits with LHCb angular acceptance

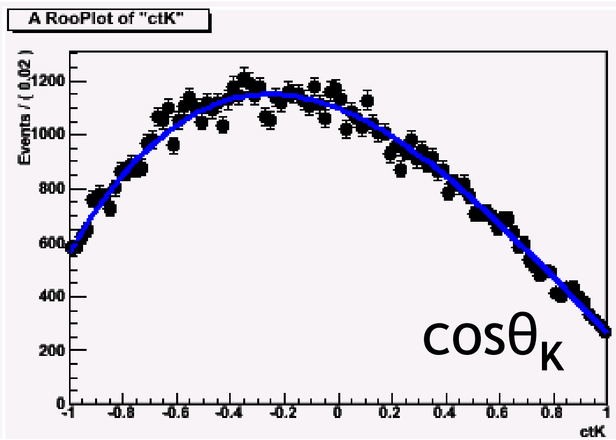
Limited LHCb MC signal available, so generate 190k EvtGen events

Use the $\cos\theta_l$ and $\cos\theta_K$ acceptance functions obtained from LHCb MC (φ acceptance found to be constant)

Can perform 3D fit (now ~87k events available)







Results for three fitted parameters:

$$F_L = 0.12387 \pm 0.00172$$

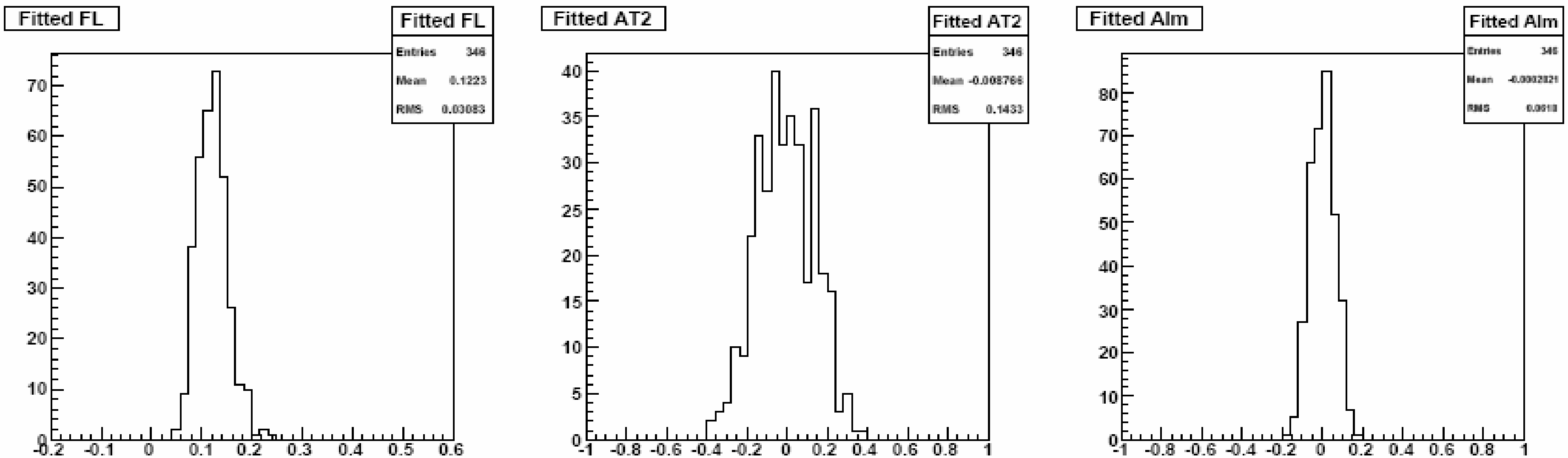
$$A_T^{(2)} = -0.00499 \pm 0.00774$$

$$A_{Im} = -0.00369 \pm 0.00340$$

} Compatible with 0 as expected from generator

Expected precision in LHCb nominal year

Split the EvtGen events into files of 250 events (estimate of signal yield in nominal year after trigger) and fit.



$\sigma(F_L) \sim 0.03$ $\sigma(A_T^{(2)}) \sim 0.14$ $\sigma(A_{Im}) \sim 0.06$

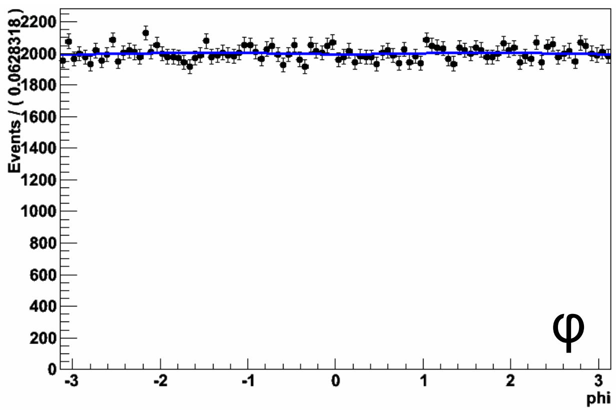
(Assuming S/B~1) $\sigma(A_T^{(2)}) \sim 0.14 \times \sqrt{2} = 0.2$

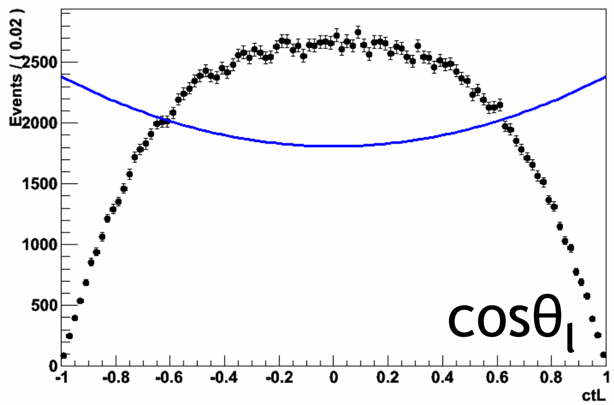
→ $\sigma(A_R/A_L) \sim 0.1$

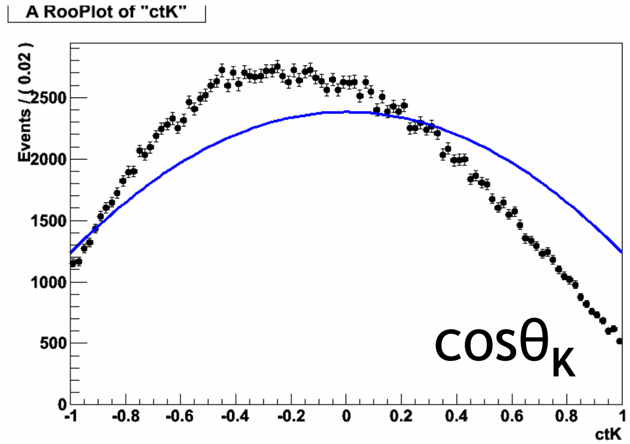
At present running conditions with $1 fb^{-1}$, $\sigma_{b\bar{b}} = 280\ \mu b$, $\varepsilon_{trigger} \sim 35\%$ expected $\sigma(A_R/A_L) \sim 0.2$

Sensitivity to angular acceptance description

Test influence of knowledge of angular acceptance by generating toy MC events distributed according to the LHCb acceptance, and fitting with a flat acceptance (generated $A_T^{(2)}=0$ $A_{Im}=0$ $F_L=0.1$)







Parameter	3D fit
F_L	$.20558 \pm .00151$
$A_T^{(2)}$	$-.00619 \pm .00540$
A_{Im}	$-.00066 \pm .00214$

Incorrect description of $\cos\theta_l$ and $\cos\theta_k$ doesn't introduce φ modulation

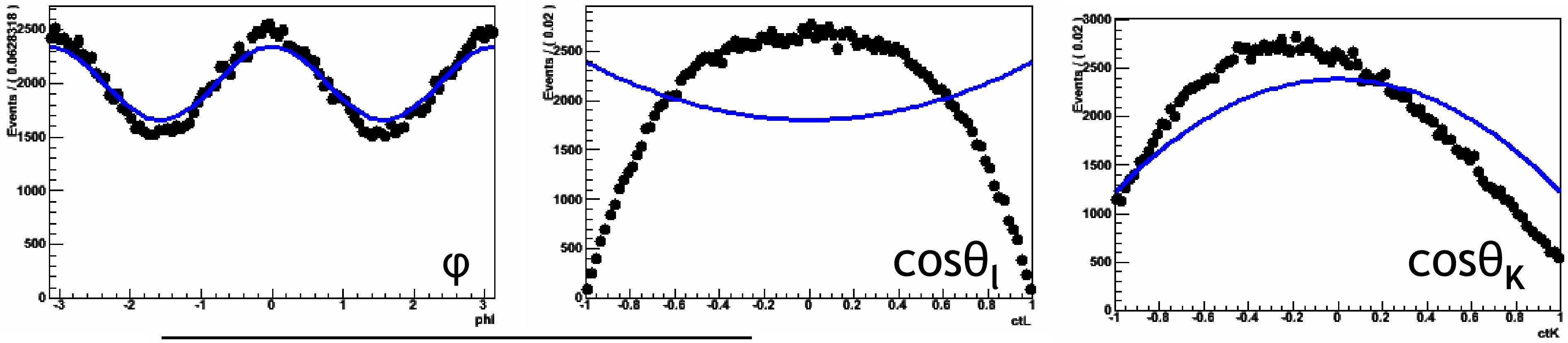
→ doesn't bias $A_T^{(2)}$ or A_{Im}

(Not the case for F_L)

In case of new physics…?

Test the case with non SM values (generated $A_T^{(2)}$=0.4 A_{Im}=0 F_L=0.1)

To check AT and Aim are not sensitive to angular acceptance description in the case where they are different to 0, test with a flat angular acceptance.



Parameter	3D fit
F_L	$.20355 \pm .00150$
$A_T^{(2)}$	$.43077 \pm .00516$
A_{Im}	$-.00130 \pm .00211$

F_L is biased but only small bias on $A_T^{(2)}$

(3D fit is necessary so as to not bias any possible new physics effects)

Conclusions

- Presented analysis to measure the photon polarization in $b \rightarrow s\gamma$ by performing an angular analysis of $B \rightarrow K^{*}e^{+}e^{-}$ at the low invariant mass region

- Shown that in a nominal LHCb year, with 250 events after trigger and S/B~1, can achieve $\sigma(A_R/A_L)$~0.1 (similar precision expected to that of LHCb $B \rightarrow \varphi\gamma$ analysis

- With the current σ_{bb}=280μb and $\int L = 1 fb^{-1}$, can expect ~50-60 events after trigger and $\sigma(A_R/A_L)$~0.2

- Even in the case of the presence of a new physics signal, the analysis is not very sensitive to the angular acceptance description, and therefore the systematic uncertainty should be small

- Next step is to acquire more data for further background studies

Backups

References

[1] K.Nakamura et al.(Particle Data Group), J. Phys. G **37** (2010) 075021

[2] L. Shchutska et al. LHCb-2007-147

[3] J. LeFrançois, M.H. Schune, LHCb-2009-008

[4] Y. Grossman and D. Pirjol, J. High Energy Phys. 06 (2000) 029

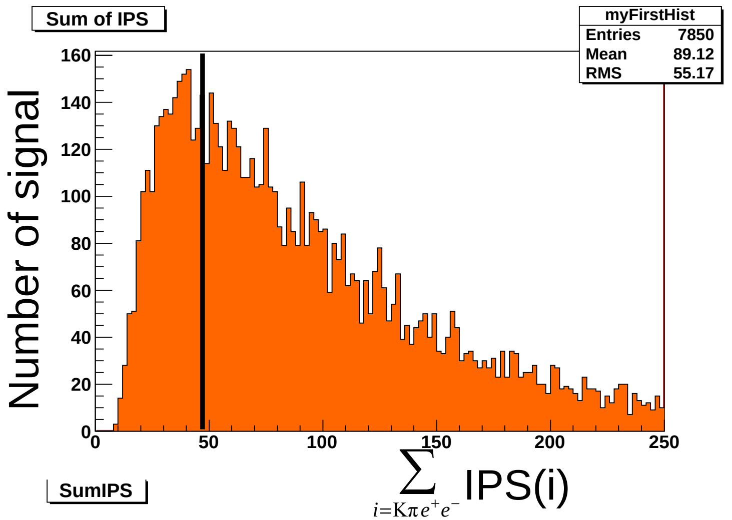
[5] F. Kruger and J. Matias, Phys. Rev. D**71** (2005) 094009

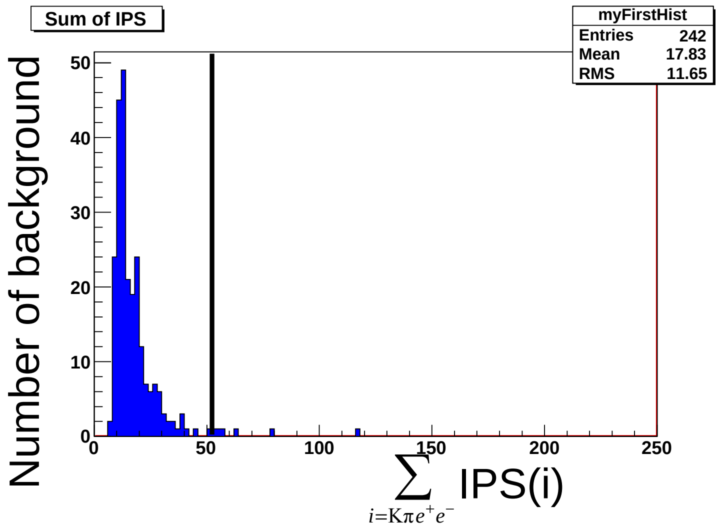
A word on the background

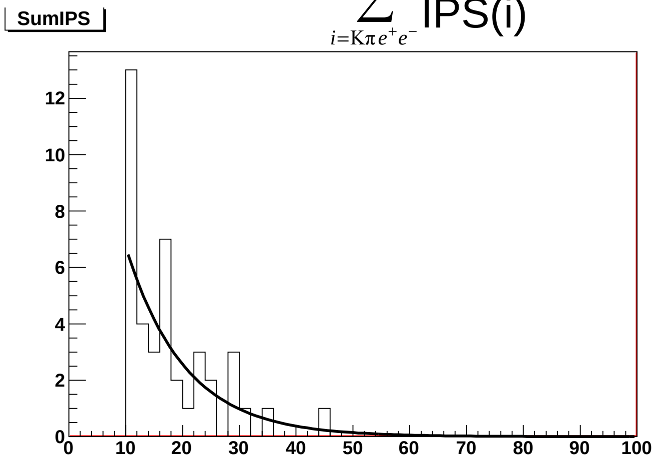
Not enough MC $b\bar{b}$ events to perform full study on background…

Selecting 0 events over all statistics ⟹ B/S<11 at 90% C.L.

Use Sum of IPS of K,π,e+,e- to extrapolate background



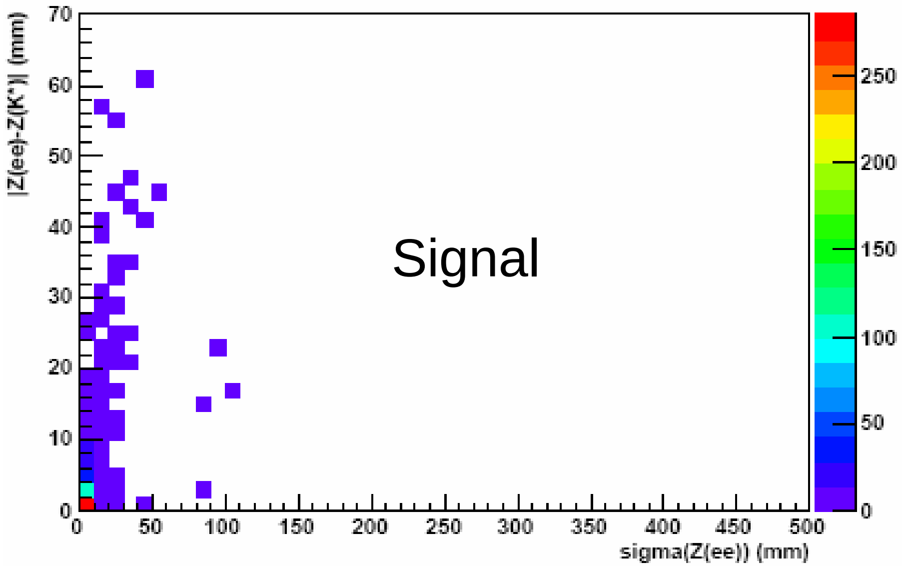


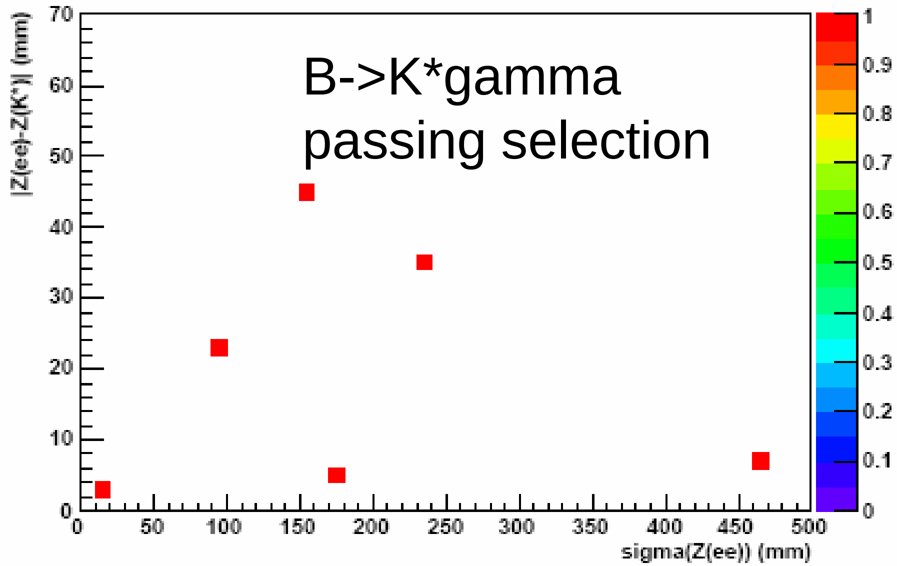


Extrapolate 0.14 background with SumIPS > 50
Upper limit on background selected < 0.04
Number of background in 2 fb^{-1} = 330
B/S~1

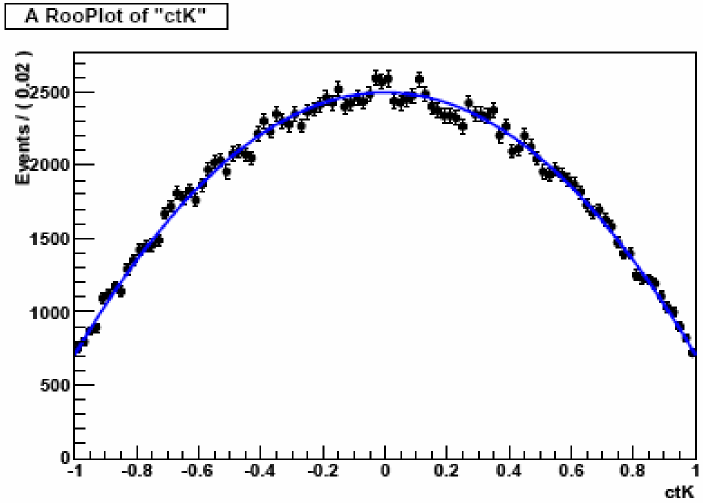
Specific background

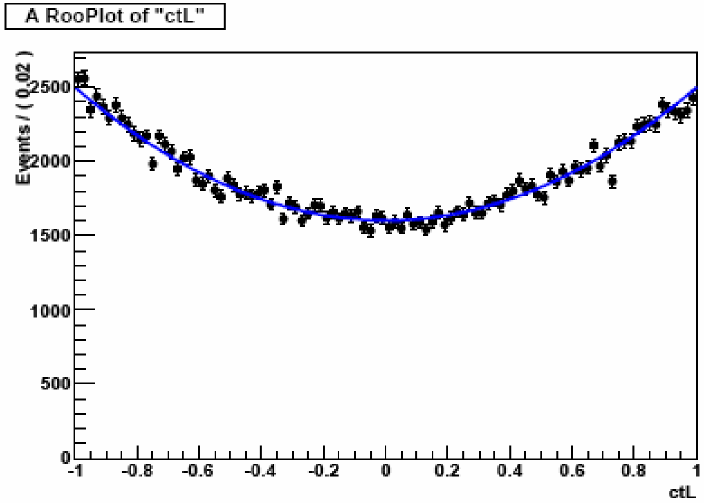
B->K*gamma is specific background. No reason in theis case for z coordinate of ee pair to coincide with z coordinate of K* vertex. Cut on vertex errors keep this under control.

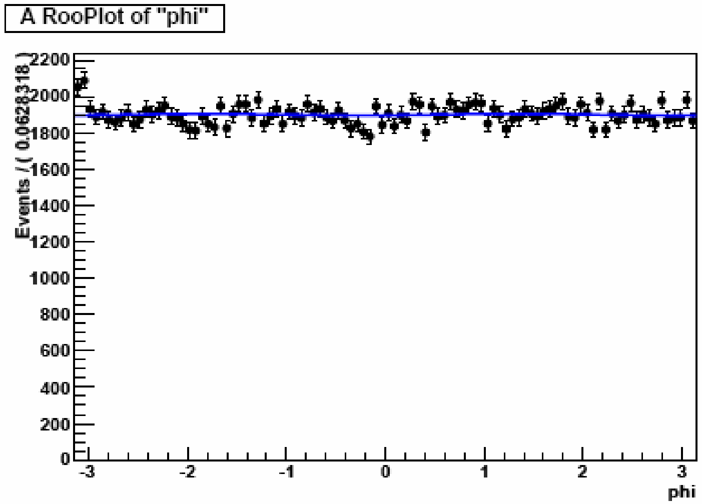




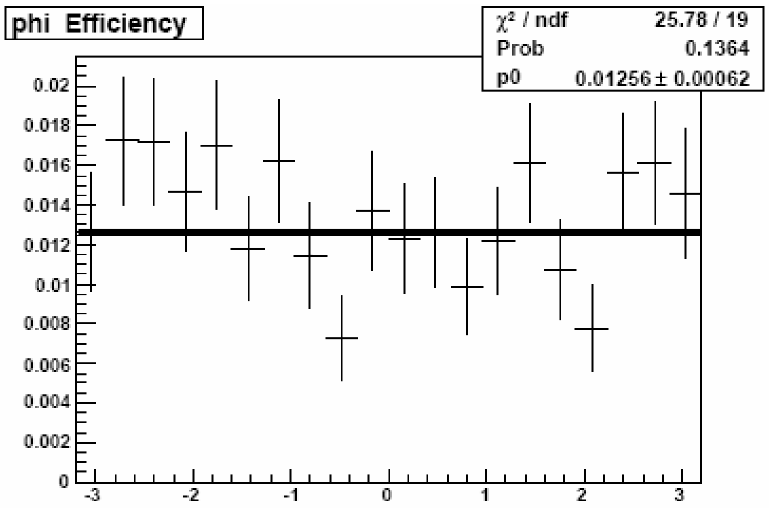
Generator acceptance level

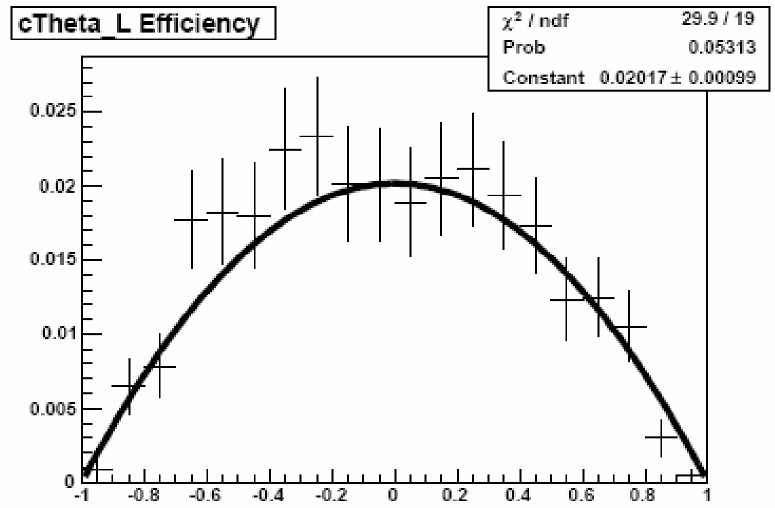


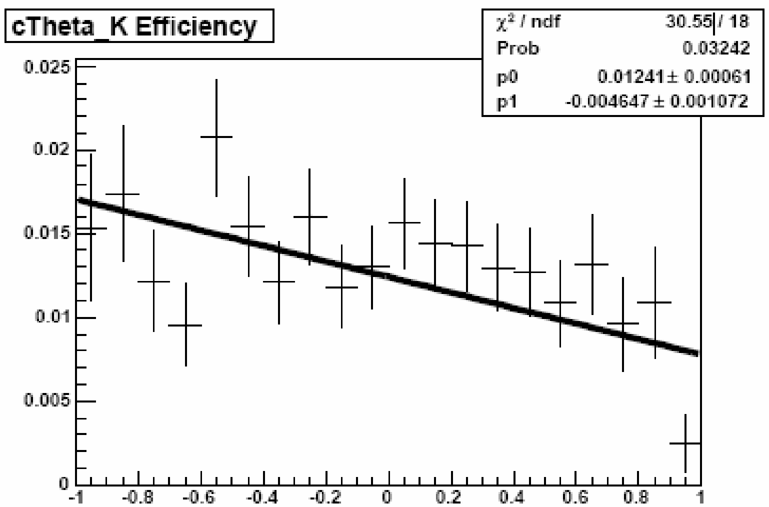


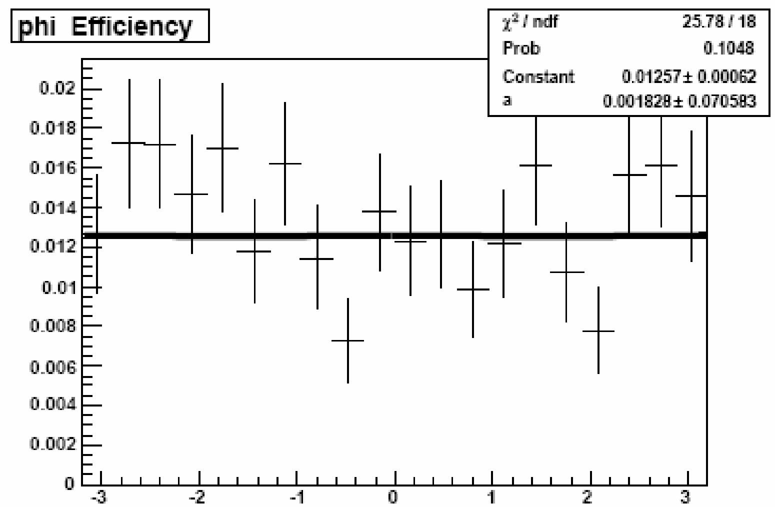


MC acceptance



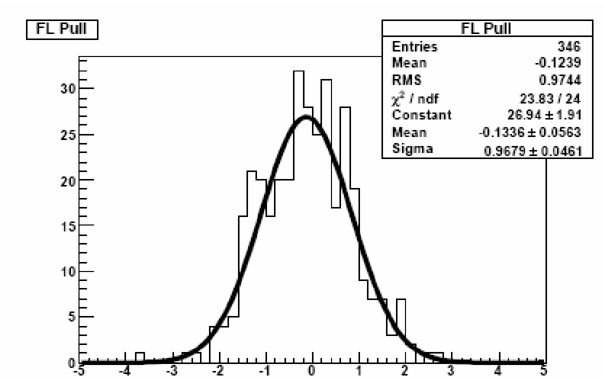


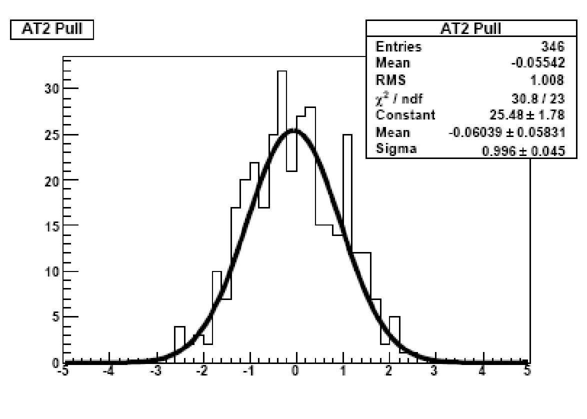


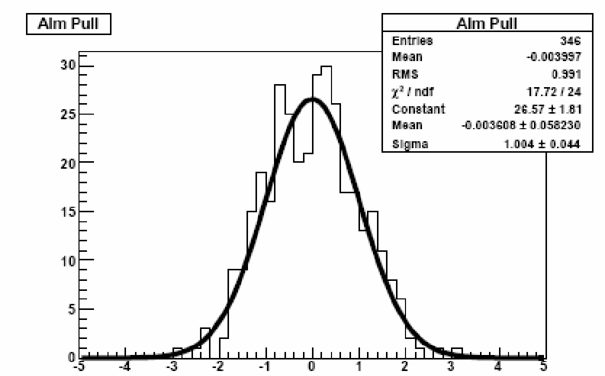


Toy MC pull plots

Split the EvtGen events into files of 250 events and plot the pull distribution for each fit parameter







From distribution of measured parameters:

$\sigma(F_L) \sim 0.03$ $\sigma(A_T^{(2)}) \sim 0.14$ $\sigma(A_{Im}) \sim 0.06$

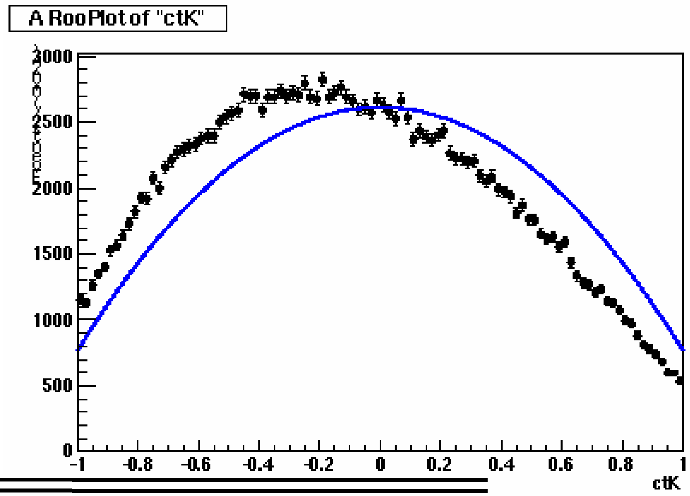
Assuming S/B~1, $\sigma A_T \sim 0.14 \times \sqrt{2} = 0.2$

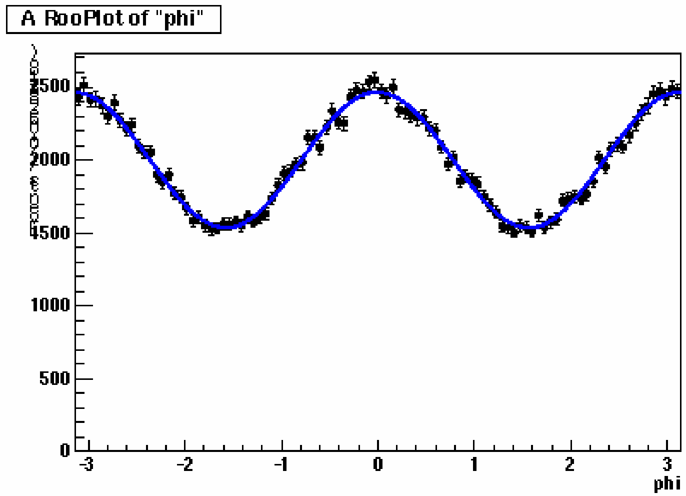
→ AR/AL~0.1

In case of new physics...?

Test the case with non SM values (generated AT=0.4 AIm=0 FL=0.1)

To check AT and Aim are not sensitive to angular acceptance description in the case where they are different to 0, test with a flat angular acceptance. First look at 2D case





Parameter	2D fit
F_L	$.12807 \pm .00136$
$A_T^{(2)}$	$.53361 \pm .00694$
A_{Im}	$-.00314 \pm .00307$

The fit looks better: close to data points. Without the cosθl information, fits φ correctly, but relative weights are incorrect and gives wrong AT2 value.