K*ll : electrons vs muons ?

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LHCb collaboration

- Focusing on the low q^2 region
- K*ee and K*mumu decays
- Experimental challenges with electrons

Slides prepared for discussion

Work done with T. Blake, J. Lefrancois, M. Nicol, F. Polci, J. Serrano and N. Serra

Very strong link with what was presented on Monday by Tom Blake

Focusing on the low q^2 region

Differential partial rate :

$$\frac{d\Gamma}{d\cos\Theta_K d\cos\Theta_\ell d\phi} = \frac{9}{32\pi}[I_1^s \cdot (1-\cos^2\Theta_K) + I_1^c \cdot \cos^2\Theta_K + (I_2^s \cdot (1-\cos^2\Theta_K) + I_2^c \cdot \cos^2\Theta_K)\cdot(2\cos^2\Theta_\ell - 1) +$$

$$I_3^s \cdot (1-\cos^2\Theta_K)\cdot(1-\cos^2\Theta_\ell)\cos 2\phi + I_6^s \cdot (1-\cos^2\Theta_K)\cdot\cos\Theta_\ell + I_9^s \cdot (1-\cos^2\Theta_K)\cdot(1-\cos^2\Theta_\ell)\sin 2\phi]$$

$$I_1^s = \frac{3}{4}\left(|A_\perp|^2 + |A_\parallel|^2\right)\left(1-\frac{x}{3}\right) + \frac{x}{2}\left(|A_\perp|^2 + |A_\parallel|^2\right) = \frac{1}{4}\left(|A_\perp|^2 + |A_\parallel|^2\right)(3+x)$$

$$I_1^c = |A_0|^2 \cdot (1+x)$$

$$I_2^s = \frac{1}{4}\left(|A_\perp|^2 + |A_\parallel|^2\right)(1-x)$$

$$I_2^c = -|A_0|^2 \cdot (1-x)$$

$$I_3^s = \frac{1}{2}\cdot(1-x)\cdot\left(|A_\perp|^2 - |A_\parallel|^2\right)$$

Sensitive to C$_7$'

$$I_6^s = 2\sqrt{1-x}\cdot \mathrm{Re}\left(A_{\parallel L}A_{\perp L}^* - A_{\parallel R}A_{\perp R}^*\right)$$

$$I_9^s = (1-x)\cdot \mathrm{Im}\left(A_{\parallel L}A_{\perp L}^* + A_{\parallel R}A_{\perp R}^*\right)$$

Sensitive to C$_7$'

$$x = \frac{4m_\ell^2}{q^2}$$

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\Theta_K d\cos\Theta_\ell d\phi dq^2} = \frac{9}{16\pi}[F_L\cos^2\Theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\Theta_K)+$$

$$\frac{1}{4}(1-F_L)(1-\cos^2\Theta_K)\cos 2\Theta_\ell - F_L\cos^2\Theta_K\cos 2\Theta_\ell +$$

$$\frac{1}{2}(1-F_L)A_T^{(2)}(1-\cos^2\Theta_K)(1-\cos^2\Theta_\ell)\cos 2\phi + \frac{4}{3}A_{FB}(1-\cos^2\Theta_K)\cos 2\Theta_\ell$$

$$+\frac{1}{2}(1-F_L)A_T^{(\mathrm{Im})}(1-\cos^2\Theta_K)(1-\cos^2\Theta_\ell)\sin 2\phi]$$

with : $$\Gamma = \int\frac{d\Gamma}{d\cos\Theta_K d\cos\Theta_\ell d\phi dq^2}d\cos\Theta_K d\cos\Theta_\ell d\phi =$$

$$|A_{0L}|^2 + |A_{0R}|^2 + |A_{\parallel L}|^2 + |A_{\parallel R}|^2 + |A_{\perp L}|^2 + |A_{\perp R}|^2$$

4 parameters :

$$F_L = \frac{|A_{0L}|^2 + |A_{0R}|^2}{|A_{0L}|^2 + |A_{\parallel L}|^2 + |A_{\perp L}|^2 + |A_{0R}|^2 + |A_{\parallel R}|^2 + |A_{\perp R}|^2}$$

$$A_{FB} = \frac{3}{2}\frac{Re(A_{\parallel L}A^*_{\perp L}) - Re(A_{\parallel R}A^*_{\perp R})}{|A_{0L}|^2 + |A_{\parallel L}|^2 + |A_{\perp L}|^2 + |A_{0R}|^2 + |A_{\parallel R}|^2 + |A_{\perp R}|^2}$$

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

$$A_T^{(2)}(0) = \frac{2\,\mathrm{Re}\left[C_7^{\mathrm{eff}}C_7'^{\mathrm{eff}*}\right]}{|C_7^{\mathrm{eff}}|^2 + |C_7'^{\mathrm{eff}}|^2}.$$

$$A_T^{(\mathrm{im})}(q^2) = -\frac{2\,\mathrm{Im}\left[A_\parallel^L(q^2)A_\perp^{L*}(q^2) + A_\parallel^R(q^2)A_\perp^{R*}(q^2)\right]}{|A_\perp(q^2)|^2 + |A_\parallel(q^2)|^2},$$

$$A_T^{(\mathrm{im})}(0) = \frac{2\,\mathrm{Im}\left[C_7^{\mathrm{eff}}C_7'^{\mathrm{eff}*}\right]}{|C_7^{\mathrm{eff}}|^2 + |C_7'^{\mathrm{eff}}|^2}$$

At low q^2, $A_T^{(2)}$ and $A_T^{(Im)}$ are sensitive to C'_7 (linear dependence)
At low q^2, the diagrams with photon dominate

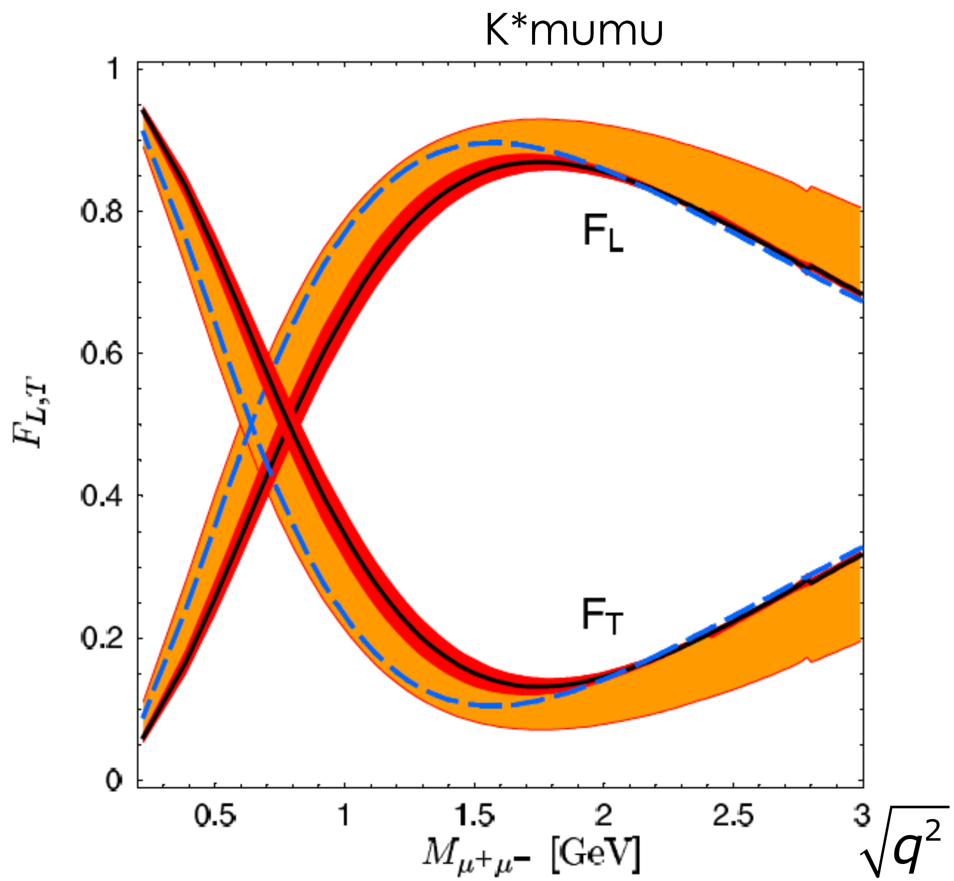
$$\frac{1}{2}(1 - F_L) \times A_T^{(2)} \left(1 - \cos^2 \Theta_K\right)\left(1 - \cos^2 \Theta_\ell\right)\cos 2\phi$$

$$\frac{1}{2}(1 - F_L) \times A_T^{(\mathrm{Im})} \left(1 - \cos^2 \Theta_K\right)\left(1 - \cos^2 \Theta_\ell\right)\sin 2\phi$$

The sensitivity to C'_7 varies with q^2

One needs to measure $A_T^{(2)}$ $A_T^{(Im)}$ AND F_L
Possible through a full angular fit

At M(mumu)=2 : very low sensitivity to C'_7 because F_L=1

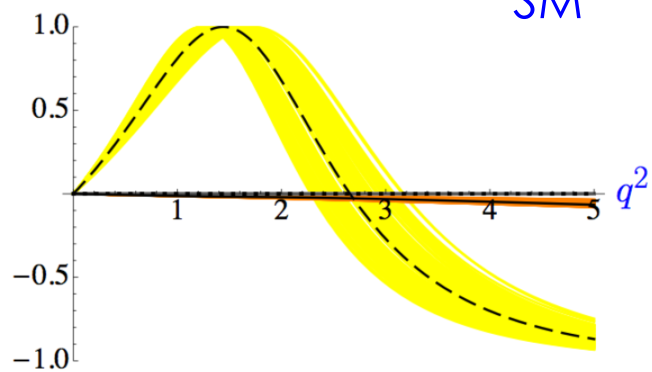


http://arxiv.org/abs/hep-ph/0502060v2
Frank Krüger, Joaquim Matias

$A_T^{(2)}$ $A_T^{(Im)}$ $(4/3)*A_{FB}/(1-F_L)$

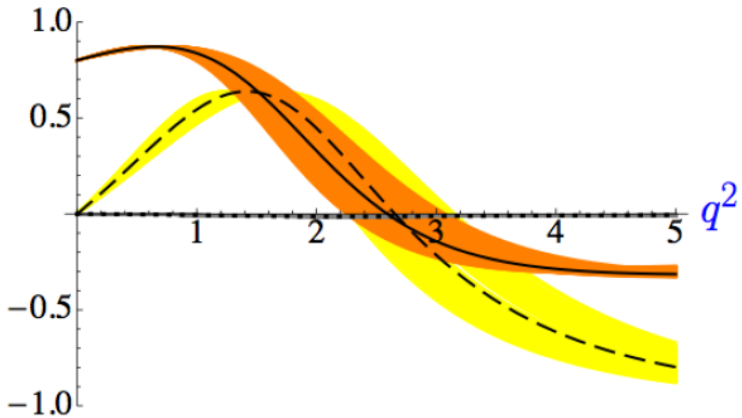
(C_9, C'_9) and (C_{10}, C'_{10}) : SM

SM



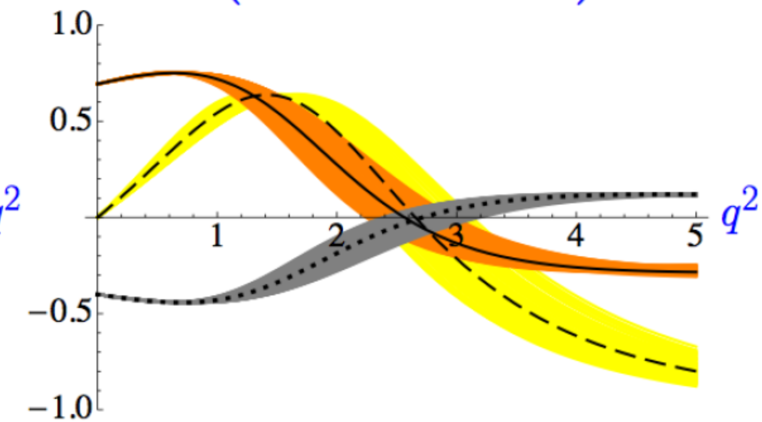
(C_7, C'_7)

$\left(C_7^{SM}, C_7^{SM}/2\right)$



(C_7, C'_7)

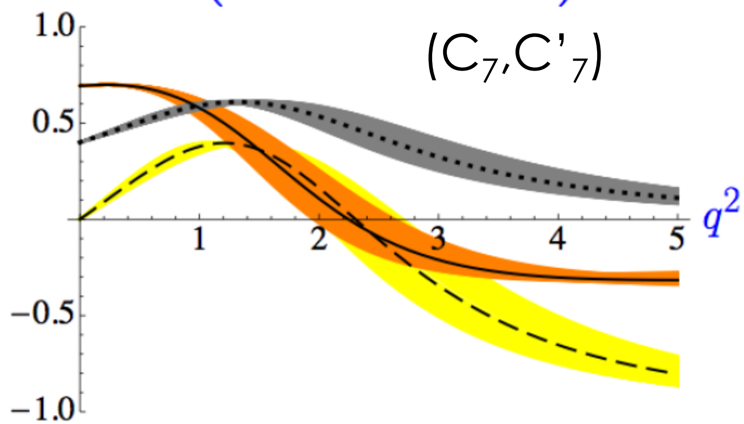
$\left(C_7^{SM}, -|C_7^{SM}/2|e^{i\pi/6}\right)$



Becirevic, Schneider
arXiv:1106.3283v4

$\left(-|C_7^{SM}|e^{i\pi/6}, C_7^{SM}/2\right)$

(C_7, C'_7)



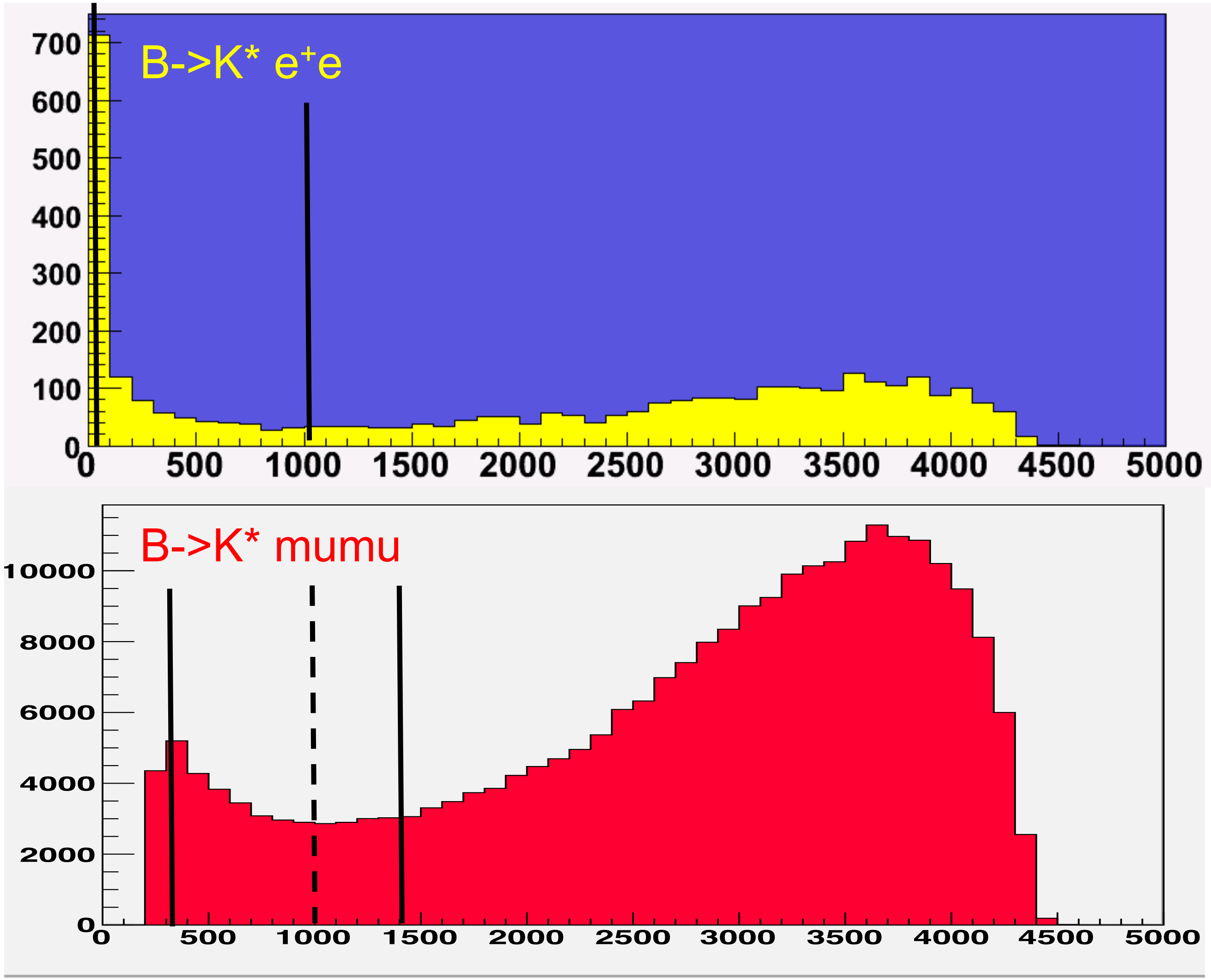
The low q^2 region is very important

K*ee and K*mumu decays

To explore the very low q^2 region use electrons !

events (SM):

arbitrary normalization between electrons and muons



$M(\ell^+\ell^-)$ (MeV/c^2)

Not that easy (see later)

$$\frac{1}{\Gamma}I_1^S = \left(\frac{3}{4}(1-F_\mathrm{L}) \times (1-\frac{4m_\mu^2}{3q^2}) + \frac{1}{\Gamma}\frac{4m_\mu^2}{q^2}\Re\left(A_{\perp\ L}A^*_{\perp\ R} + A_{\parallel\ L}A^*_{\parallel\ R}\right)\right)\sin^2\theta_K$$

$$\frac{1}{\Gamma}I_1^C = \left(F_\mathrm{L} + \frac{1}{\Gamma}\frac{4m_\mu^2}{q^2} \times \left(|A_t|^2 + 2\Re(A_{0\ L}A^*_{0\ R})\right)\right)\cos^2\theta_K$$

$$\frac{1}{\Gamma}I_2^S = \frac{1}{4}(1-F_\mathrm{L})(1-\frac{4m_\mu^2}{q^2})\sin^2\theta_K$$

$$\frac{1}{\Gamma}I_2^C = -F_\mathrm{L}(1-\frac{4m_\mu^2}{q^2})\cos^2\theta_K$$

$$\frac{1}{\Gamma}I_3 = \frac{1}{2}(1-F_\mathrm{L})A_\mathrm{T}^2\left(1-\frac{4m_\mu^2}{q^2}\right) \times \sin^2\theta_K$$

$$\frac{1}{\Gamma}I_6 = 2A_T^{Re}(1-F_\mathrm{L})\sqrt{(1-\frac{4m_\mu^2}{q^2})} \times \sin^2\theta_K$$

$$\frac{1}{\Gamma}I_9 = \frac{1}{2}(1-F_\mathrm{L})A_T^{Im}\left(1-\frac{4m_\mu^2}{q^2}\right) \times \sin^2\theta_K$$

New amplitude terms

New kinematical terms

http://arxiv.org/abs/hep-ph/0502060v2
Frank Krüger, Joaquim Matias

$$\frac{1}{\Gamma}I_1^C = \left(F_{\rm L} + \frac{1}{\Gamma}\frac{4m_\mu^2}{q^2}\times\left(|A_t|^2 + 2\Re(A_{0\ L}A_{0\ R}^*)\right)\right)\cos^2\theta_K$$

Using :

All C_i^{eff} can be complex

$$A_{\perp L,R} = \sqrt{2}Nm_B(1-\hat{s})\left[(C_9^{\rm eff} \mp C_{10}) + \frac{2\hat{m}_b}{\hat{s}}(C_7^{\rm eff} + C_7^{\rm eff\prime})\right]\xi_\perp(E_{K^*}),$$

$$A_{\parallel L,R} = -\sqrt{2}Nm_B(1-\hat{s})\left[(C_9^{\rm eff} \mp C_{10}) + \frac{2\hat{m}_b}{\hat{s}}(C_7^{\rm eff} - C_7^{\rm eff\prime})\right]\xi_\perp(E_{K^*}),$$

$$A_{0L,R} = -\frac{Nm_B}{2\hat{m}_{K^*}\sqrt{\hat{s}}}(1-\hat{s})^2\left[(C_9^{\rm eff} \mp C_{10}) + 2\hat{m}_b(C_7^{\rm eff} - C_7^{\rm eff\prime})\right]\xi_\parallel(E_{K^*}),$$

$$A_t = \frac{Nm_B}{\hat{m}_{K^*}\sqrt{\hat{s}}}(1-\hat{s})^2 C_{10}\xi_\parallel(E_{K^*}),$$

$$\frac{|A_t|^2 + 2\Re(A_{0\ L}A_{0\ R}^*)}{|A_0|^2} = 1$$

$$\Rightarrow \frac{1}{\Gamma}I_1^C = (1+x)\times\left(|A_{0L}|^2 + |A_{0R}|^2\right)$$

No additional parameter

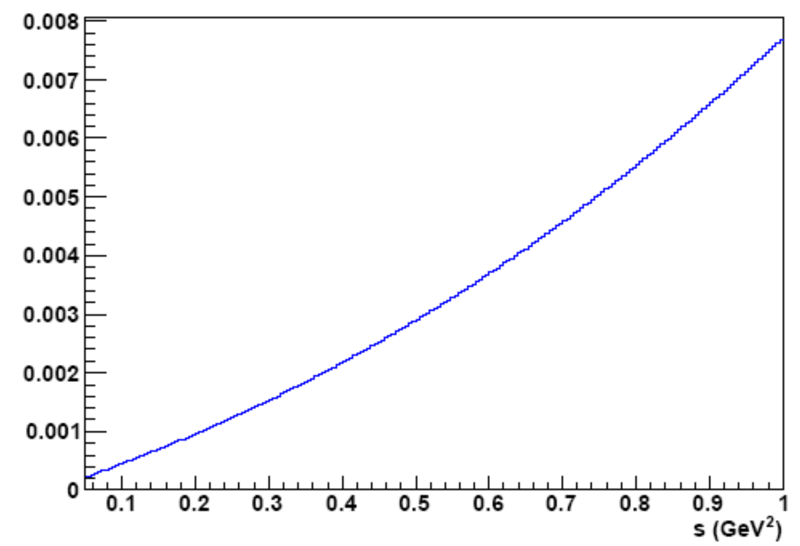
$$\frac{1}{\Gamma}I_1^S = \left(\frac{3}{4}(1-F_L)\times(1-\frac{4m_\mu^2}{3q^2}) + \frac{1}{\Gamma}\frac{4m_\mu^2}{q^2}\Re\left(A_{\perp\ L}A^*_{\perp\ R} + A_{\parallel\ L}A^*_{\parallel\ R}\right)\right)\sin^2\theta_K$$

$$\begin{aligned}\delta_a &= \frac{\Re(A_{\perp\ L}A^*_{\perp\ R}+A_{\parallel\ L}A^*_{\parallel\ R})}{\Gamma}\\ &= (1-F_L)\times\frac{\Re(A_{\perp\ L}A^*_{\perp\ R}+A_{\parallel\ L}A^*_{\parallel\ R})}{|A_T|^2+|A_\perp|^2}\\ &= \frac{1}{2}\times(1-F_L)\times\left[1-\frac{2|C_{10}|^2}{|C_9^{\rm eff}|^2+|C_{10}|^2+4\frac{m_b m_B}{s}\Re(C_9^{\rm eff}C_7^{\rm eff*})+4\frac{m_b^2 m_B^2}{s^2}(|C_7^{\rm eff}|^2+|C_7^{\rm eff\prime}|^2)}\right]\end{aligned}$$

$$\Rightarrow \frac{1}{\Gamma}I_1^S = \frac{3}{4}(1-F_L)\left[1+\frac{x}{3}-\frac{2x}{3}K\right]$$

K

same conclusion for a wide range of C_i coeff



$$C_7^{\rm eff} = -0.304,\ C_9^{\rm eff} = 4.73,\ C_{10} = -4.103$$

$$\Rightarrow \frac{1}{\Gamma}I_1^S \approx \frac{3}{4}(1-F_L)\left[1+\frac{x}{3}\right]$$

No additional parameter

The I formulae are modified but no additional parameters are needed

$$I_1^c = \left(|A_{0L}|^2 + |A_{0R}|^2\right)$$
$$I_1^s = \frac{3}{4}\left(|A_{\parallel L}|^2 + |A_{\parallel R}|^2 + |A_{\perp L}|^2 + |A_{\perp R}|^2\right)$$
$$I_2^c = -\left(|A_{0L}|^2 + |A_{0R}|^2\right)$$
$$I_2^s = \frac{1}{4}\left(|A_{\parallel L}|^2 + |A_{\parallel R}|^2 + |A_{\perp L}|^2 + |A_{\perp R}|^2\right)$$
$$I_3 = \frac{1}{2}\left(|A_{\perp L}|^2 - |A_{\parallel L}|^2 + |A_{\perp R}|^2 - |A_{\parallel R}|^2\right)$$
$$I_6 = 2\left(Re(A_{\parallel L}A_{\perp L}^*) - Re(A_{\parallel R}A_{\perp R}^*)\right)$$
$$I_9 = \left(Im(A_{\parallel L}A_{\perp L}^*) + Im(A_{\parallel R}A_{\perp R}^*)\right)$$

$$I_1^s = \frac{3}{4}\left[1 - \frac{x}{3}\right](|A_\parallel|^2 + |A_\perp|^2) + \frac{x}{2}(|A_\parallel|^2 + |A_\perp|^2)$$
$$I_1^c = [1 + x]\,|A_0|^2$$
$$I_2^s = \frac{1}{4}[1 - x]\,(|A_\parallel|^2 + |A_\perp|^2)$$
$$I_2^c = -[1 - x]\,|A_0|^2$$
$$I_3 = \frac{1}{2}[1 - x]\,(|A_\perp|^2 - |A_\parallel|^2)$$
$$I_6 = 2\left[\sqrt{1 - x}\right] Re(A_{\parallel L}A_{\perp L}^* - A_{\parallel R}A_{\perp R}^*)$$
$$I_9 = [1 - x]\,Im(A_{\parallel L}A_{\perp L}^* + A_{\parallel R}A_{\perp R}^*)$$

$$x = \frac{4m_\ell^2}{q^2}$$

Which modifies the whole distribution and the extraction of the parameters

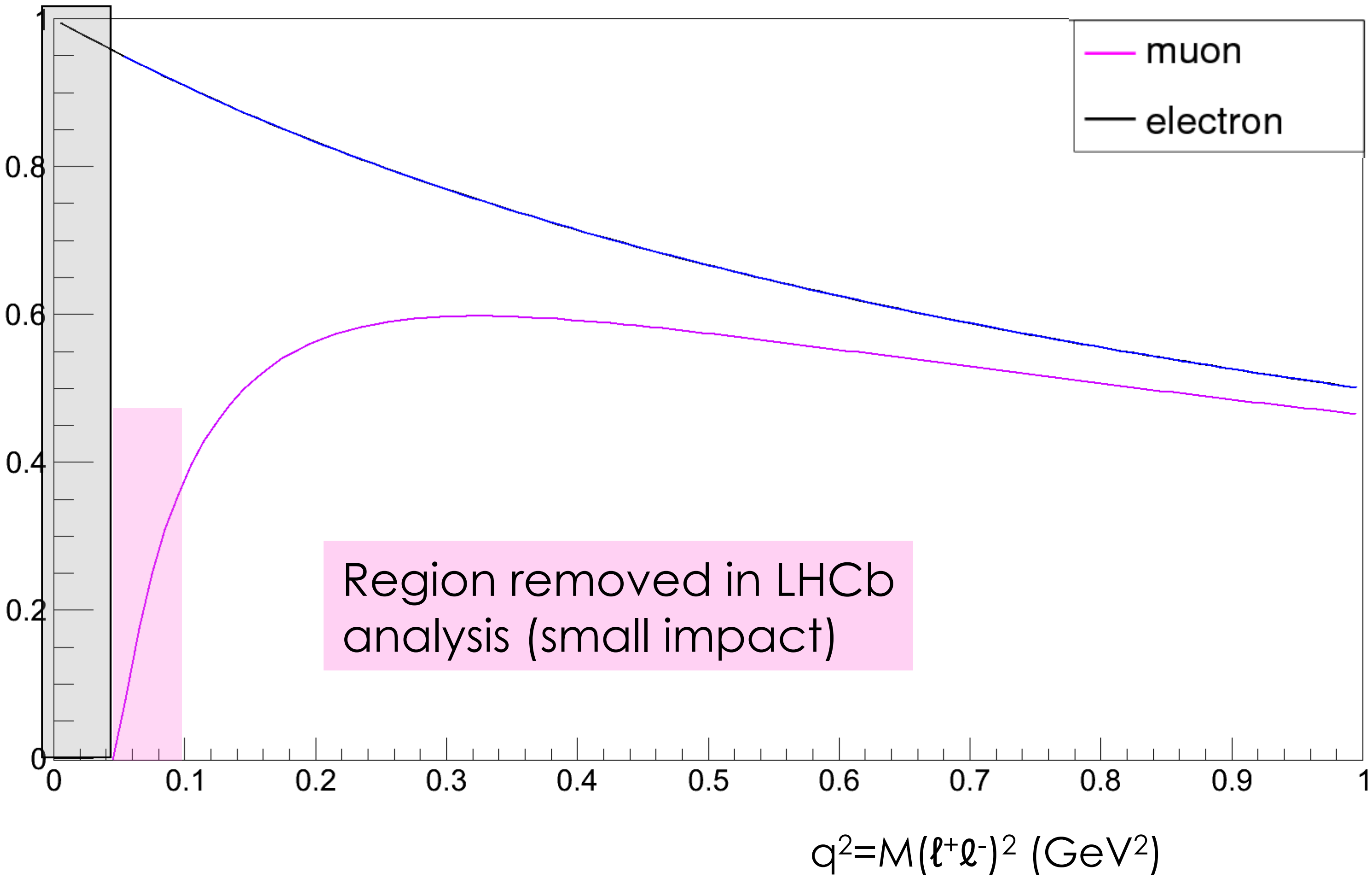
$$\Gamma = \left(|A_{0L}|^2 + |A_{0R}|^2 + |A_{\parallel L}|^2 + |A_{\parallel R}|^2 + |A_{\perp L}|^2 + |A_{\perp R}|^2\right) \times \left(1 + \frac{x}{2}\right)$$

$$\frac{1}{2}(1-F_L)A_T^{(2)}\left(1-\cos^2\Theta_K\right)\left(1-\cos^2\Theta_\ell\right)\cos 2\phi$$

$$\rightarrow \frac{1}{2}(1-F_L)\frac{1-x}{1+\frac{x}{2}}A_T^{(2)}\left(1-\cos^2\Theta_K\right)\left(1-\cos^2\Theta_\ell\right)\cos 2\phi$$

$$(1-F_L)\frac{1-x}{1+\frac{x}{2}}$$

$$(1-F_L)$$

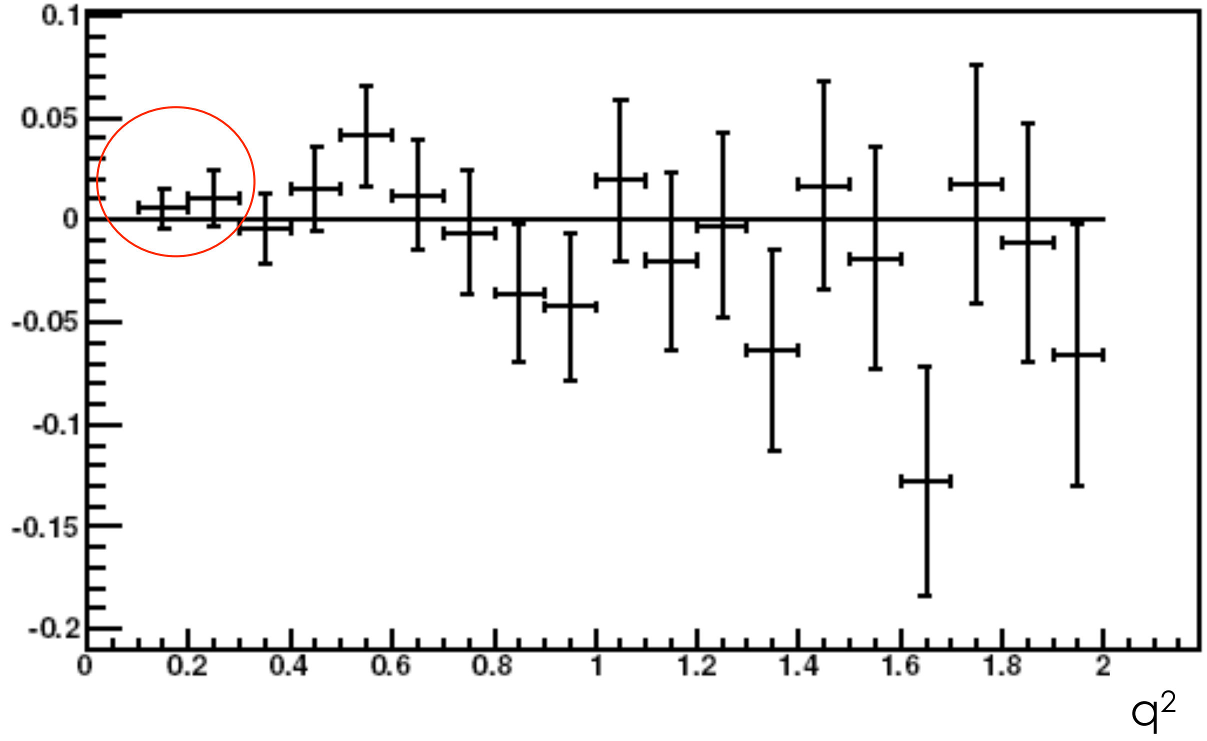


$$1-F_L=\frac{1}{1+q^2}$$

The sensitivity to $A_T^{(2)}$ is reduced

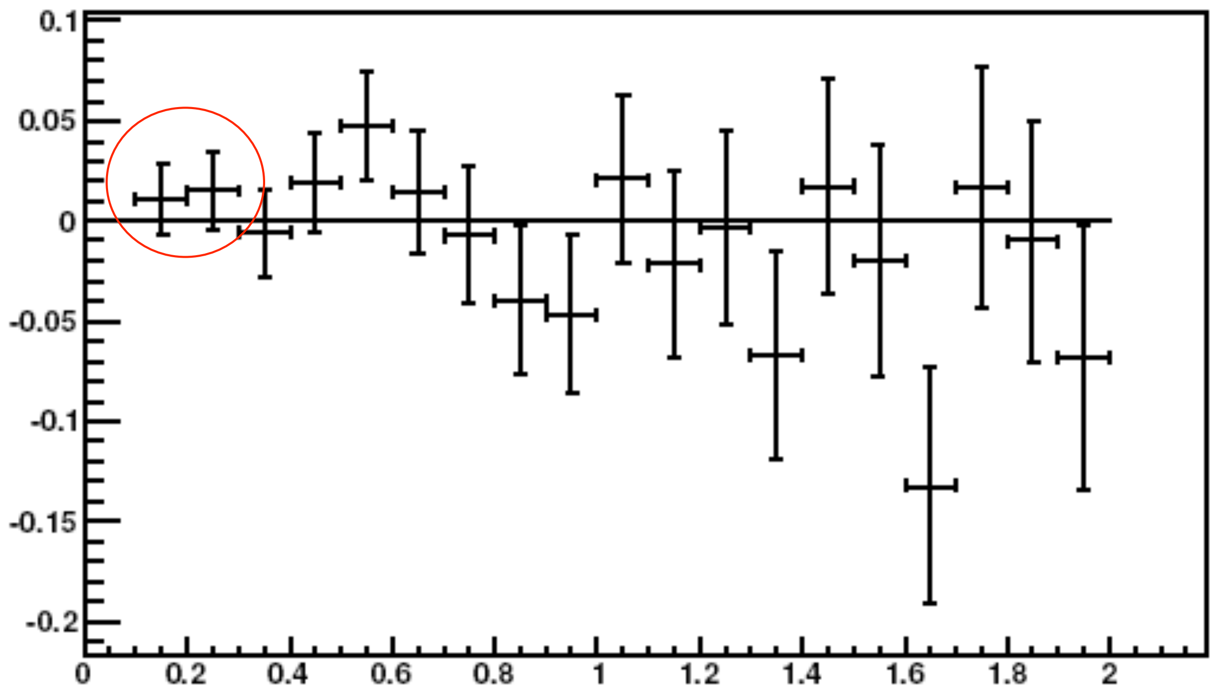
$A_T^{(2)}$

Ignoring the threshold terms



The uncertainty is underestimated !

With the threshold terms :



The analysis is fitting in a (large) q^2 bin (0.1 to 2 GeV^2 in LHCb case) :

=> One needs to correct

-for the q^2 variation of the parameters in the bin

-for the threshold terms which were not taken into account

Hypotheses (SM):

$$F_L\left(q^2\right)=\frac{a\times q^2}{1+a\times q^2}$$

$$A_T^{(\mathrm{Re})}=b\times q^2$$

$$A_T^{(2)} \text{ and } A_T^{(\mathrm{Im})}=C$$

$$Corr(A_T^2) = Corr(A_T^{Im}) = \frac{\sum_{i=1}^{N}(\frac{1-x_i}{1+\frac{x_i}{2}})(1-F_L(q_i^2))}{\sum_{i=1}^{N}(1-F_L(q_i^2))}$$

$$Corr(A_T^{Re}) = \frac{\sum_{i=1}^{N}(\frac{\sqrt{1-x_i}}{1+\frac{x_i}{2}})(1-F_L(q_i^2))}{\sum_{i=1}^{N}(1-F_L(q_i^2))}$$

$$A_T^{(2)} = A_T^{(2)}\left[\mathrm{fit}\right]\times 1.3$$

$$\sigma\left(A_T^{(2)}\right)= \sigma\left(A_T^{(2)}\right)\left[\mathrm{fit}\right]\times 1.25$$

A non-negligible effect

Experimental challenges with electrons

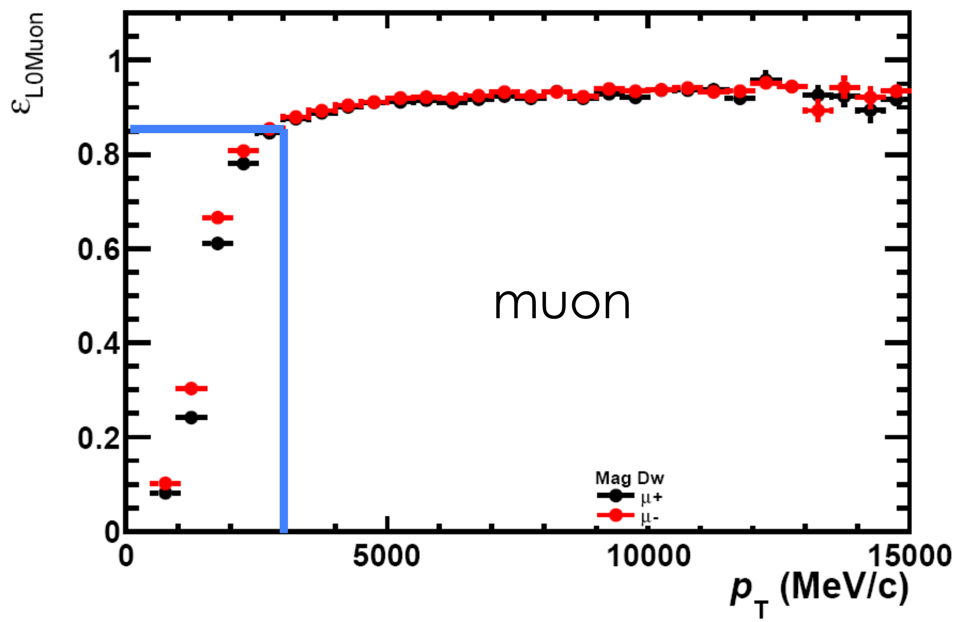
At B-factories : electrons are not more complicated than muons : same efficiency (see for example BaBar arXiv:1204.3933v2)

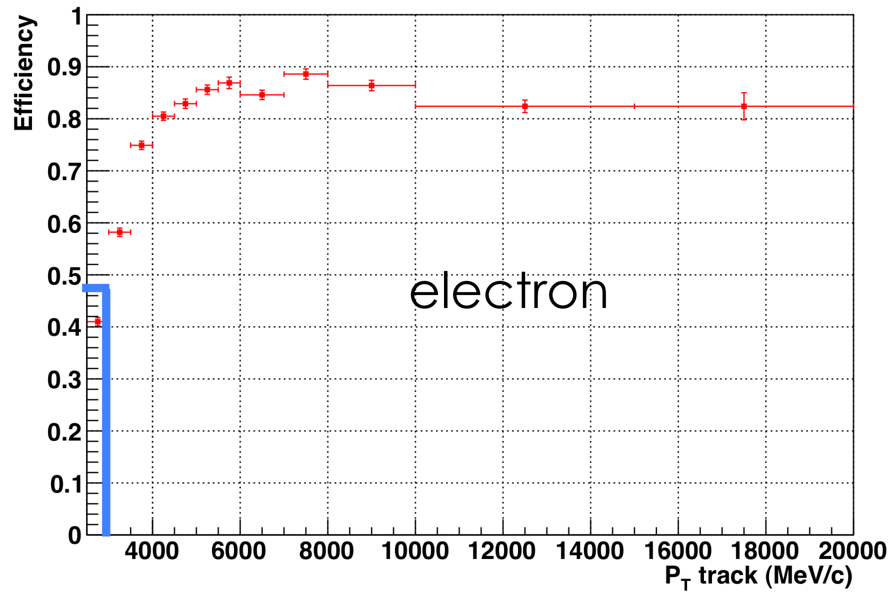
In hadronic environment things are more complicated :

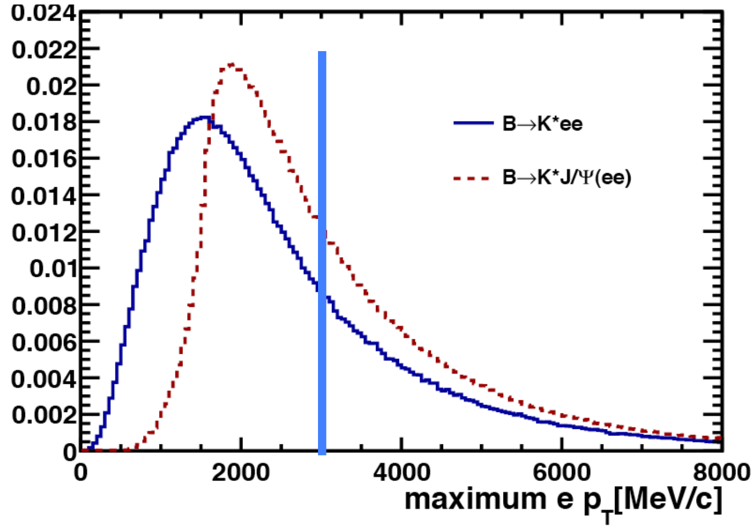
- CDF has only published K*mumu results

- LHCb :
  - trigger efficiency comparison for electrons and muons
  - particle ID efficiency is not *very* different
  - Bremsstrahlung effect for K*ee : higher background level

Example of trigger efficiencies at LHCb :





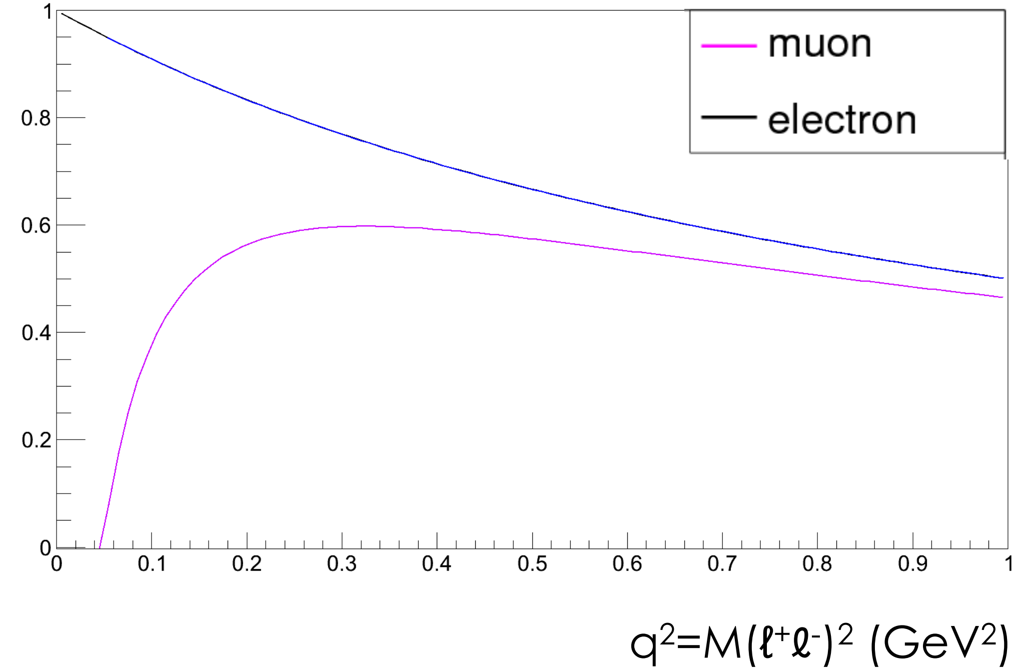


Bremstrahlung experimental consequences justify to stay within $q^2 < 1$:

BR(B->Jpsi(->ee)K*) = (300-350) BR(B->eeK*)

$$(1 - F_L)$$

$$(1 - F_L)\frac{1 - x}{1 + \frac{x}{2}}$$

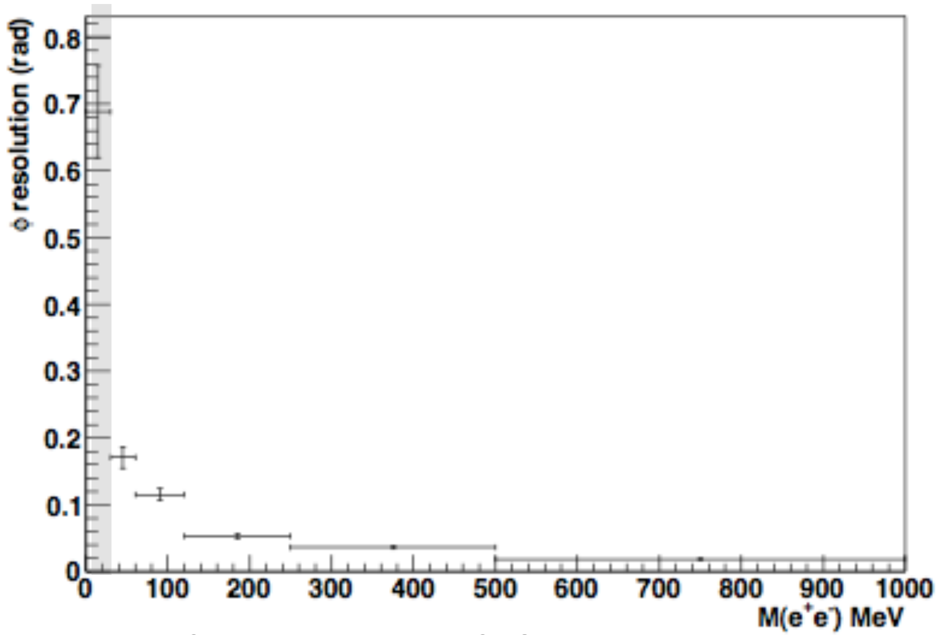


At 1 GeV^2 : electrons are not better than muons … not useful for LHCb !

$$BR\left(B \to K^{*} ee\right)^{M_{Min}-M_{Max}} = BR\left(B \to K^{*}\gamma\right) \times \frac{\alpha}{3\pi} \times \ln\left(\frac{M_{Max}}{M_{Min}}\right)^{2}$$

BR : $B_d \rightarrow K^*(K\pi)ee$ with M(ee) (30MeV-1000 MeV) = 1.5×10^{-7}

M(ee) < 30 MeV : the (ee) opening angle is very small + multiple scattering => bad Φ measurement



.01 0.25 1 q^2 (GeV^2)

What can LHCb expect to see ?

Taking into account the LHCb acceptance and assuming S/B=1

With 200 signal events :

$$\sigma\left(A_T^{(2)}\right) \sim 0.2$$

Expected signal yield for 3 fb^{-1} (2011-2012 data) at 7- 8TeV : about 150 events with S/B > 1 in the bin .0009 – 1 GeV^2

$$\sigma\left(A_T^{(2)}\right) \sim 0.20 \text{ to } 0.25$$

Similar to K*mumu performances (with 1 fb^{-1} : 0.38 for the 0.1 – 2 GeV^2 bin with 140 events)

Higher sensitivity to C'_7 (closer to $q^2 = 0$), how to quantify it ? Extraction of the Wilson coefficients ?

What about Super-B factories ?

BaBar paper ArXiv 1204.3933 claims an efficiency of 17% for the bin between 0.1 to 2 GeV^2

With 75 ab^{-1} in the bin .0009 to 1 GeV^2 they will have about 2000 reconstructed events ….

$$\sigma\left(A_T^{(2)}\right) \sim 0.06$$

Conclusion

In the low q^2 region :
• experimentalists' life is not that easy …

- efficiency drops at small q2
- triggering is more difficult
- low p_T electron reconstruction is not trivial in hadronic environment

• for electrons channel life will be easier at Super-B factories

• LHCb will probably revisit the first bin for the K*mumu analysis : .1 to 1 GeV^2 and 1-2 GeV^2 ?

• With 3 fb^{-1} LHCb (data from 2011-2012) should be able to measure $A_T^{(2)}$ with a precision of the order of 0.15 … but it will take some time to reach that precision.

Backup slides