B→K*ll (and related physics) at SuperB

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SEZIONE DI PISA

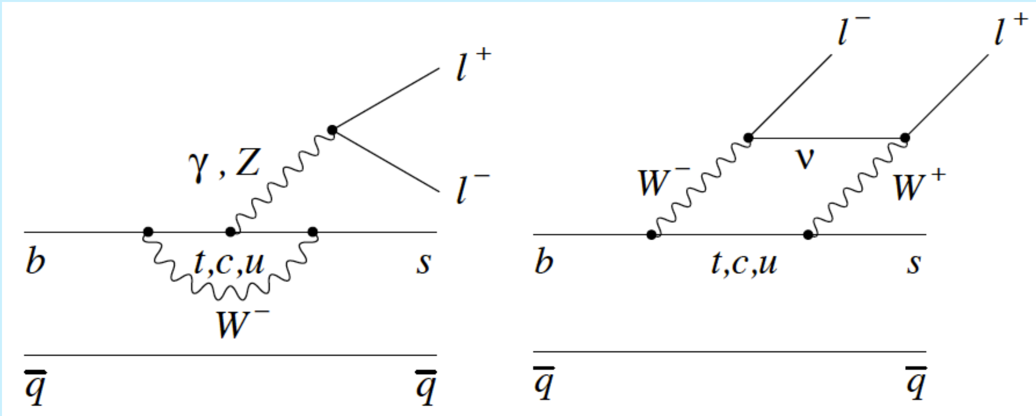
Outline

- Introduction/Motivations
- Phenomenology: notation
- $B \to X_s l^+ l^-$
  - general characteristics
  - observables
  - current results
- Expectations for SuperB
  - inclusive $B \to X_s l^+ l^-$
  - expected sensitivities
- Conclusions

Note on notation: SuperB will study many modes in the K(*)ll family, including the inclusive process $B \to X_s l^+ l^-$. I will often use **$B \to K(*)ll$** or **$B \to X_s l^+ l^-$** to indicate this whole family of channels.

Introduction/Motivations

- Flavour-changing neutral current process: prohibited at tree level in the Standard Model → New Physics contributions enter at same order as SM physics



- In many NP models, the SM particles in the loops are replaced by new heavy particles, new masses, new couplings → modify quantities that we can measure
  - Branching Fractions, CP and Isospin asymmetries, observables from angular distributions ⇒ more on observables in a bit

Introducing Wilson coefficients...

- Effective Hamiltonian:

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} [C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu)],$$

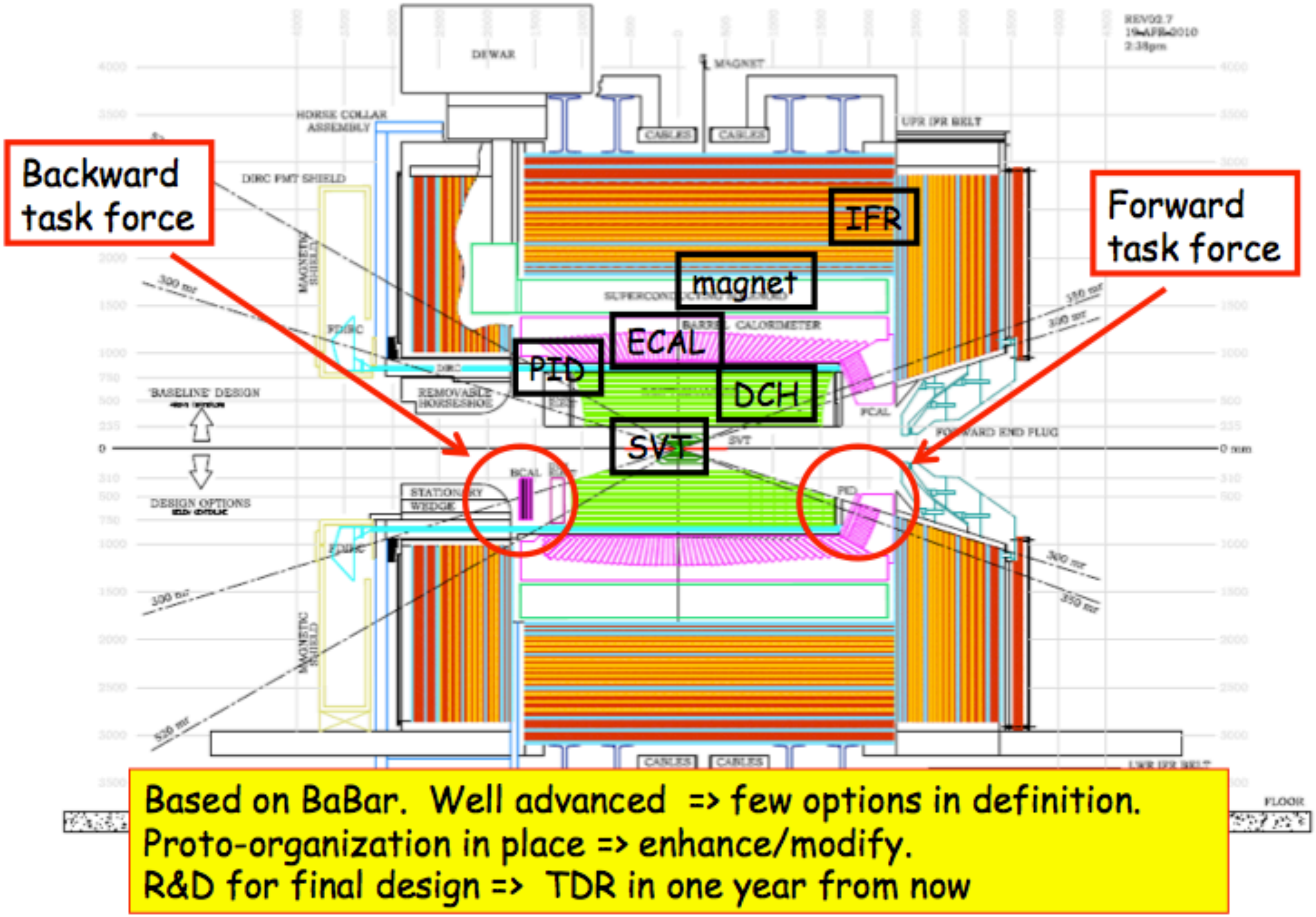
- Relevant operators for this physics:

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b (\bar{s}\sigma_{\mu\nu} P_R b) F^{\mu\nu}, \quad \mathcal{O}_9 = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu l), \quad \mathcal{O}_{10} = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu \gamma_5 l),$$

- The C_i are the Wilson coefficients, which are calculable perturbatively in SM and NP models
- C_7: coefficient of dipole operator. $|C_7|$ determined by $B(B \to X_s \gamma)$
- C_7, C_9, C_{10} all affected by $B \to X_s l^+ l^-$

SuperB Detector

- Expect similar performance to BaBar detector
- Reduced boost ($\beta\gamma$=0.23, was 0.56 in BaBar)
- Same decay time resolution (layer 0 of SVT)
- Somewhat increased efficiencies for B reco



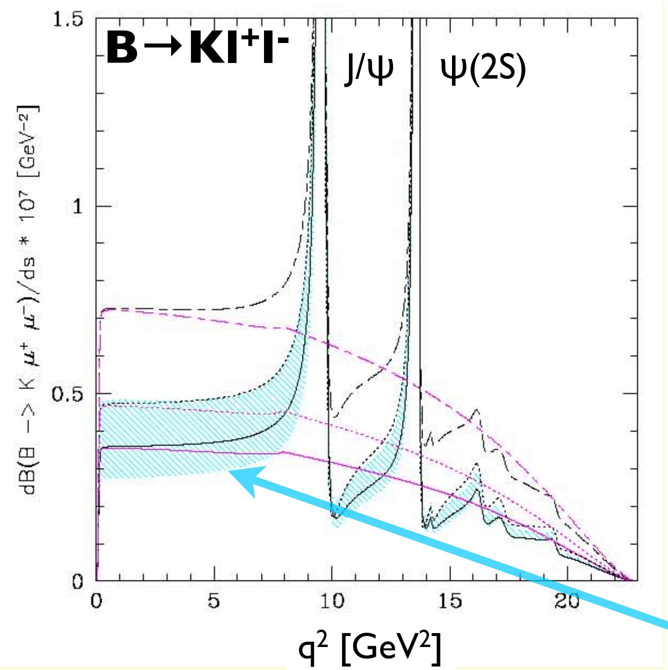
$B \to X_s l^+ l^-$: General characteristics

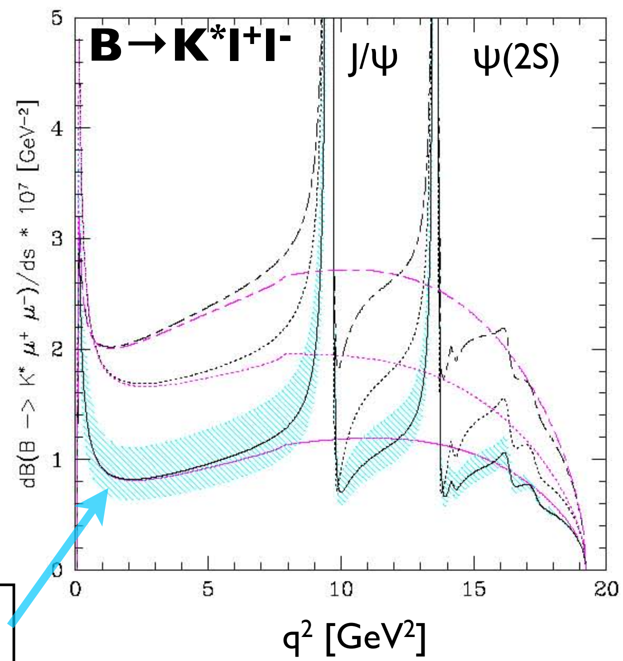
- Lepton pair in final state offers many more observables than $B \to X_s \gamma$
- Theory predicts observables as function of $q^2 \equiv m_{\ell\ell}^2$, so experiment aims to measure as function of q^2 → strong tool for revealing NP
- Very small BF: ~ 1.5 x 10^{-6} →
  - current experimental results are limited to small statistics
  - most exp. focus has been on exclusive states: **$B \to K^{(*)} l^+ l^-$**
- For the exclusive modes, $B \to J/\psi(\to l^+ l^-)K(*)$ is both a background, which is explicitly vetoed and a very valuable control sample which reduces the use of MC.

Characteristics of $B \to X_s l^+ l^-$ Decays

$$q^2 = m^2_{\ell^+\ell^-} \equiv s$$

- The overall shape of the $B \to K^{(*)} l^+ l^-$ spectra is determined by the q^2-dependence of $C^9_{eff}(q^2)$
- At $q^2=0$, $B \to K^* l^+ l^-$ has a singularity (due to $B \to K^* \gamma$), while $B \to K l^+ l^-$ is finite at $q^2=0$.
- Resonances from $B \to J/\psi K^{(*)}$ and $B \to \psi(2S) K^{(*)}$ decays are explicitly removed -- they form a very important large statistics control sample





SM

Analysis techniques at e^+e^- machines

- Fully reconstruct 10 $B \rightarrow K^{(*)} l^+ l^-$ final states
  - K^+, K^0_s, $K^+\pi^-$, $K^+\pi^0$ and $K^0_s\pi^+$ paired with e^+e^- or $\mu^+\mu^-$
- Identify leptons and require $p_e > 0.3$ GeV and $p_\mu > 0.7$ GeV
- Require good charged particle ID for K, π
- Select $K^0_s \rightarrow \pi^+\pi^-$ and $\pi^0 \rightarrow \gamma\gamma$

- Main background: leptons from semileptonic decays of both B's or a B and D meson in the same event
  - suppress with multivariate techniques: neural nets, boosted decision trees, etc.
  - event shape variables, vertexing and missing energy
  - optimize for each mode and for each bin of q^2

Discriminating variables:

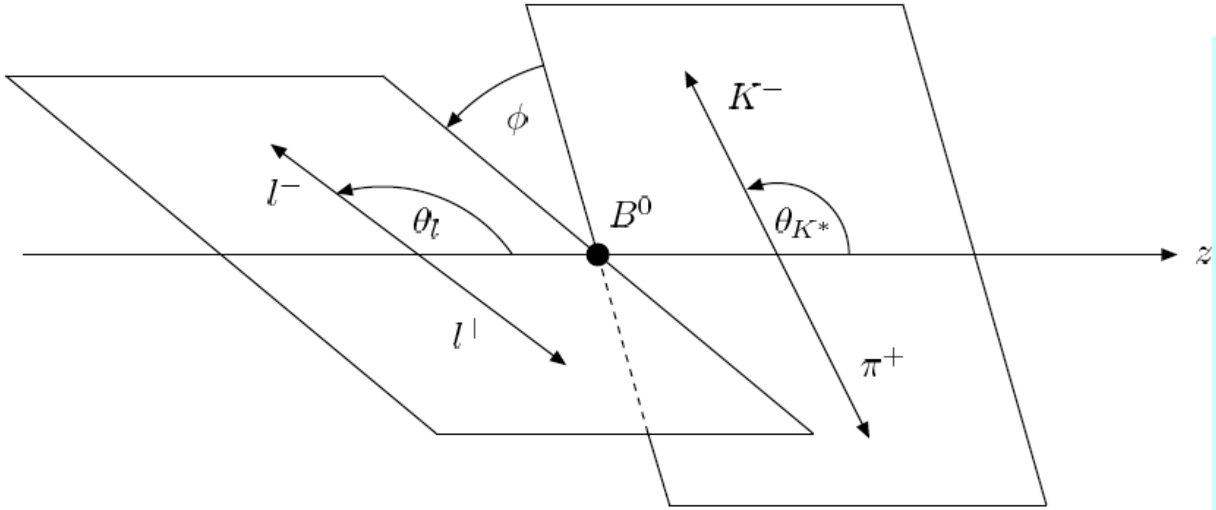
$$m_{ES} = \sqrt{E^{*2}_{\mathrm{beam}} - p^{*2}_B}$$

$$\Delta E = E^*_B - E^*_{\mathrm{beam}}$$

$B \to X_s l^+ l^-$: Observables

- The rich final state leads to several observables:
  - **A_{FB}**, the forward-backward lepton asymmetry
  - **s_0**, the A_{FB} zero crossing: this observable has particularly low theoretical uncertainties, thanks to cancellations
  - **F_L**, the K* longitudinal polarization fraction in $B \to K^* ll$
  - **$R_{K(*)}$**, the ratio of $B \to K(*)\mu\mu / B \to K(*)ee$
  - **A_{CP}** - the direct CP asymmetry
  - **A_I** - the isospin asymmetry
  - **BF**, measured in bins of q^2 – most relevant for inclusive measurement
  - Additional "new" angular variables, **$A_T^{(2)}$**, etc.

Lepton forward-backward asymmetry: A_{FB}

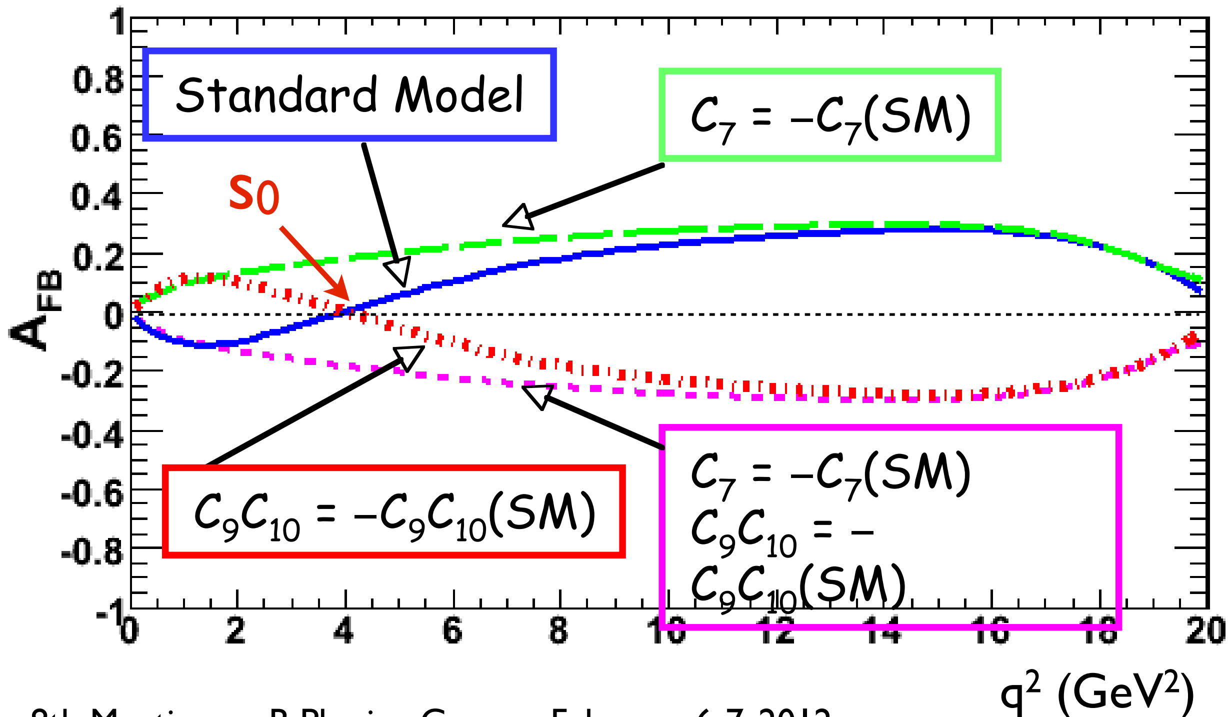


- Angular variables have good sensitivity to NP
- **K* longitudinal polarization F_L** → θ_K angle between K and B in K* rest frame

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

- **Lepton forward/backward asymmetry** A_{FB} → θ_l angle between l^+ (l^-) and B ($\underline{B}$) in l^+l^- rest frame

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$



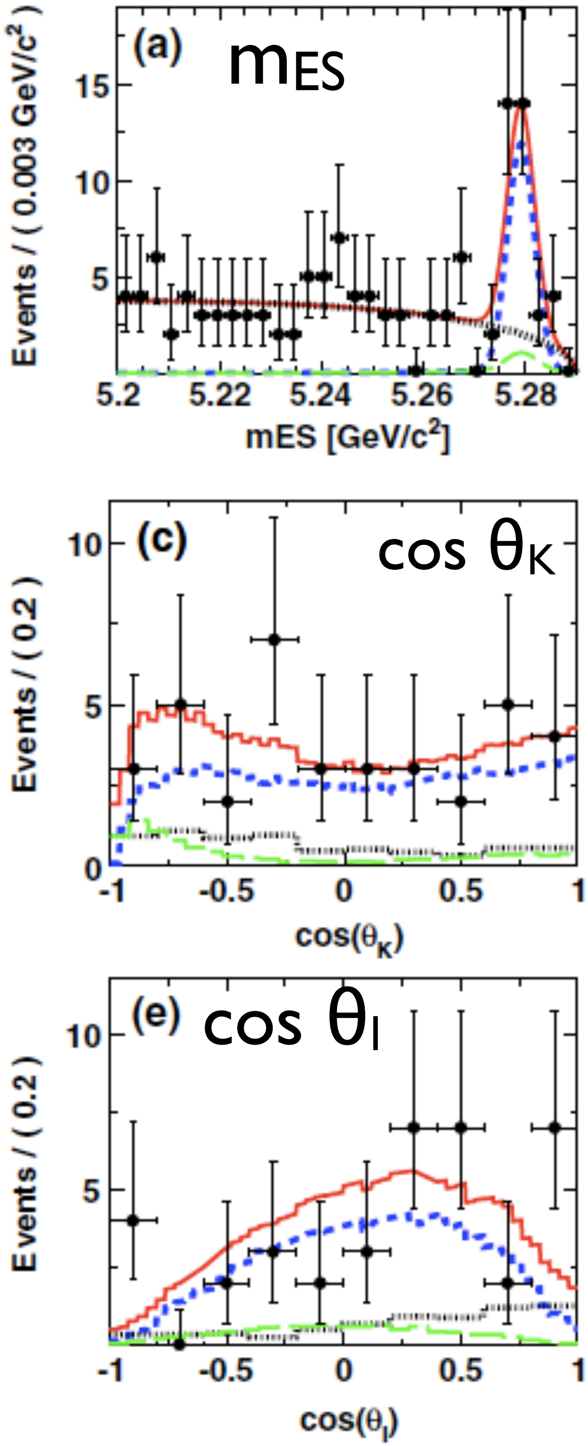
A_{FB} zero crossing: SM

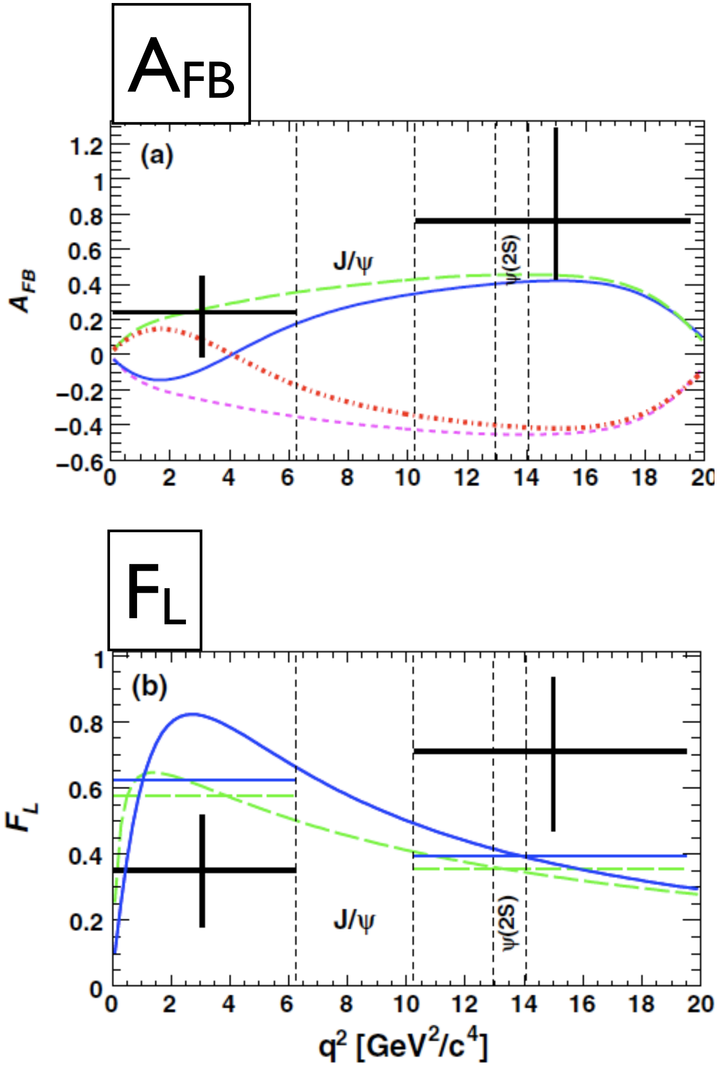
$$s_0 = (4.2 \pm 0.6)\ \text{GeV}^2$$

$B \to K^{(*)}ll$: angular observables

$q^2 < 6.25\ \mathrm{GeV}^2$

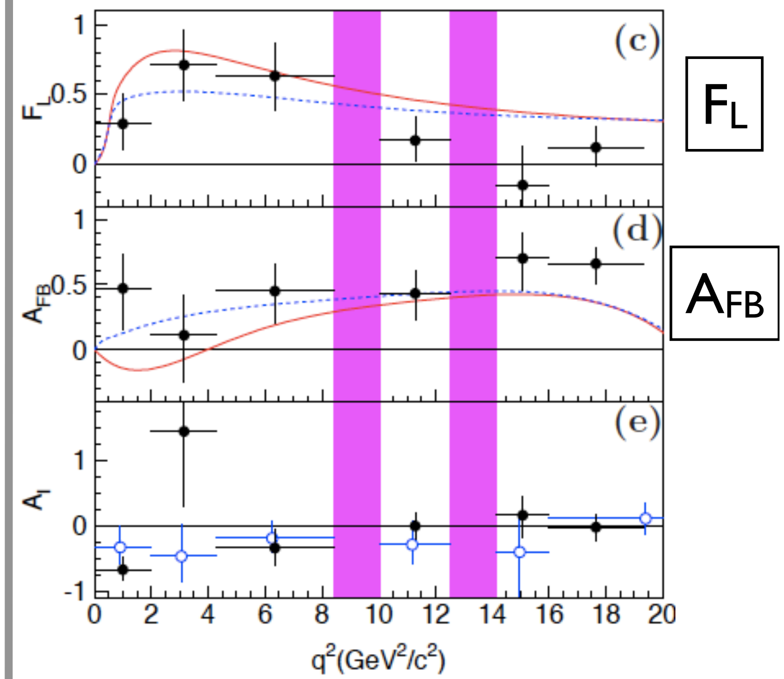
BaBar





[PRD 79 031102(R) (2009)]

Belle

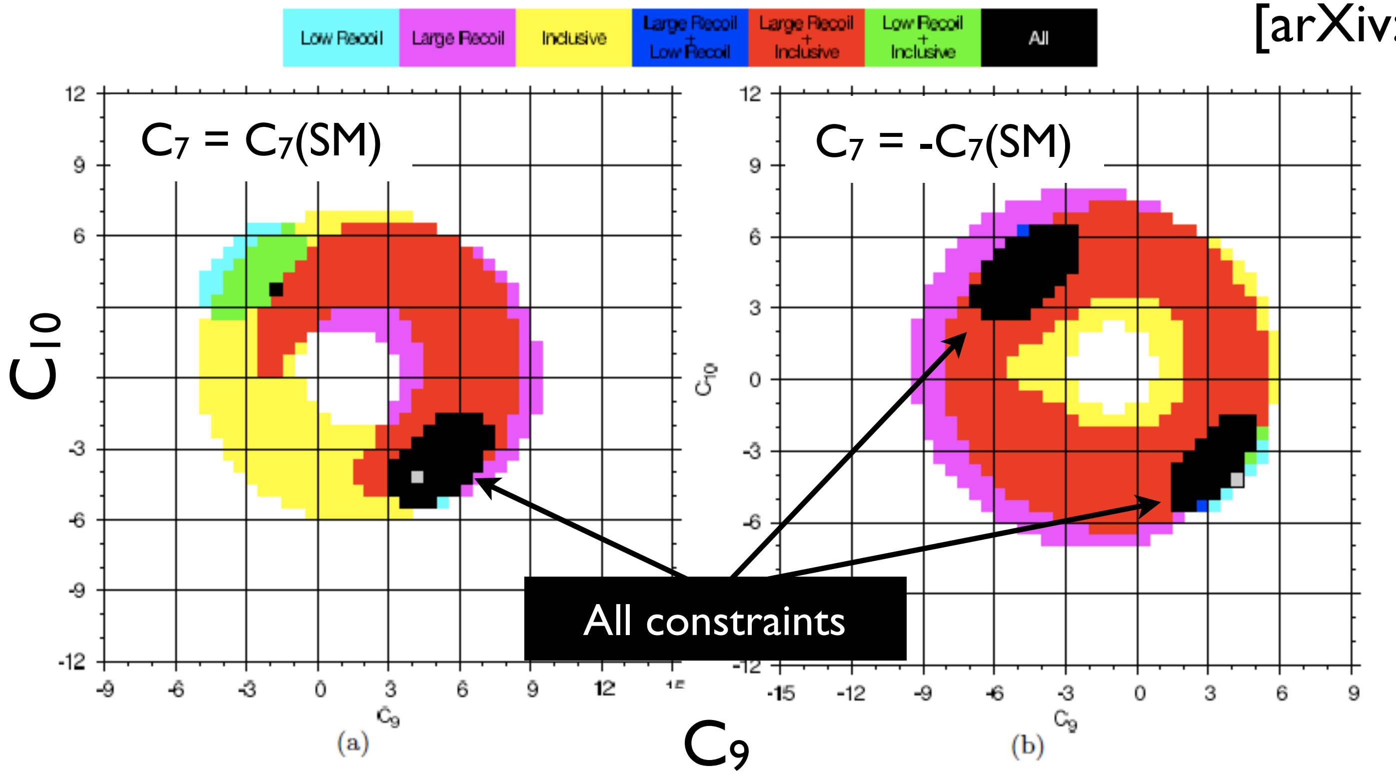


[arXiv:0904.0770]

Constraining Wilson coefficients with $B \to X_s l^+ l^-$

- C_{10} vs. C_9 plane
- Use exclusive and inclusive $B \to X_s l^+ l^-$ data
- Two cases: $C_7 = C_7(SM)$ and $C_7 = -C_7(SM)$

[arXiv:1006.5013]



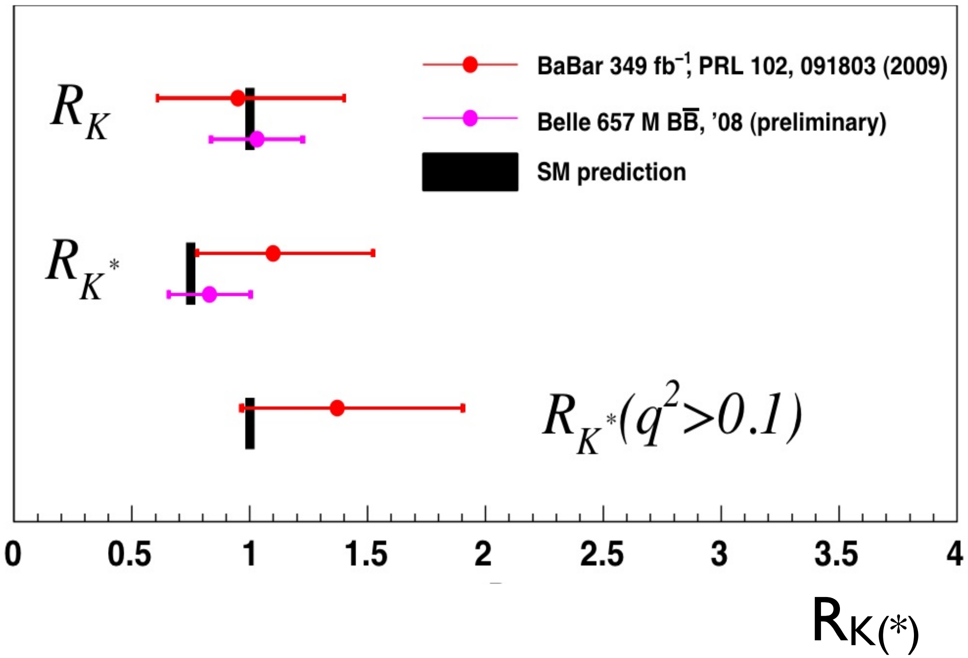
pre-LHCb

Lepton flavour ratios

- With both lepton flavours measured, we can determine the lepton flavor ratios:

$$R_K \equiv \frac{B(B \to K\mu^+\mu^-)}{B(B \to Ke^+e^-)} \qquad R_K^* \equiv \frac{B(B \to K^*\mu^+\mu^-)}{B(B \to K^*e^+e^-)}$$

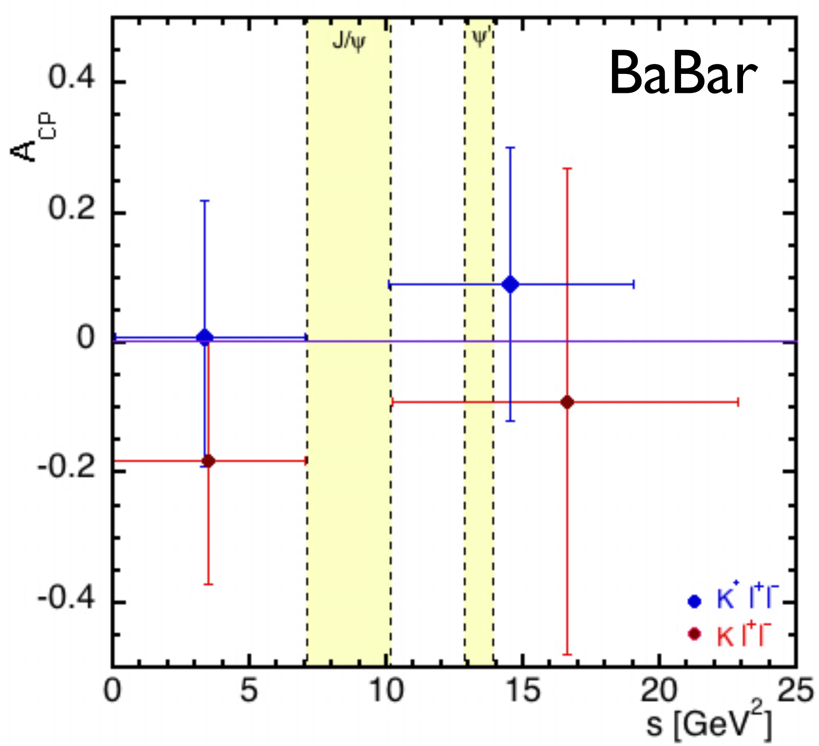
- In the SM, R_K=1 and R_{K^*}=0.75 (if pole region is excluded, R_{K^*}=1), but these can be substantially altered in NP models (2HDM, presence of neutral Higgs boson)
- To date, Babar and Belle measure RK(*) values that are consistent with the SM



CP Asymmetry

- Define: $A_{CP} = \dfrac{B(\bar{B} \to \bar{X}_s \ell^+ \ell^-) - B(B \to X_s \ell^+ \ell^-)}{B(\bar{B} \to \bar{X}_s \ell^+ \ell^-) + B(B \to X_s \ell^+ \ell^-)}$

- In SM, A_{CP} < 1% level, can be significantly enhanced with NP
- Charged modes and $B \to K^+ \pi^- l^+ l^-$ are self-tagging, no need for additional tags
- Current measurements from Babar and Belle consistent with A_{CP}=0 with rather larger errors.



Isospin Asymmetry

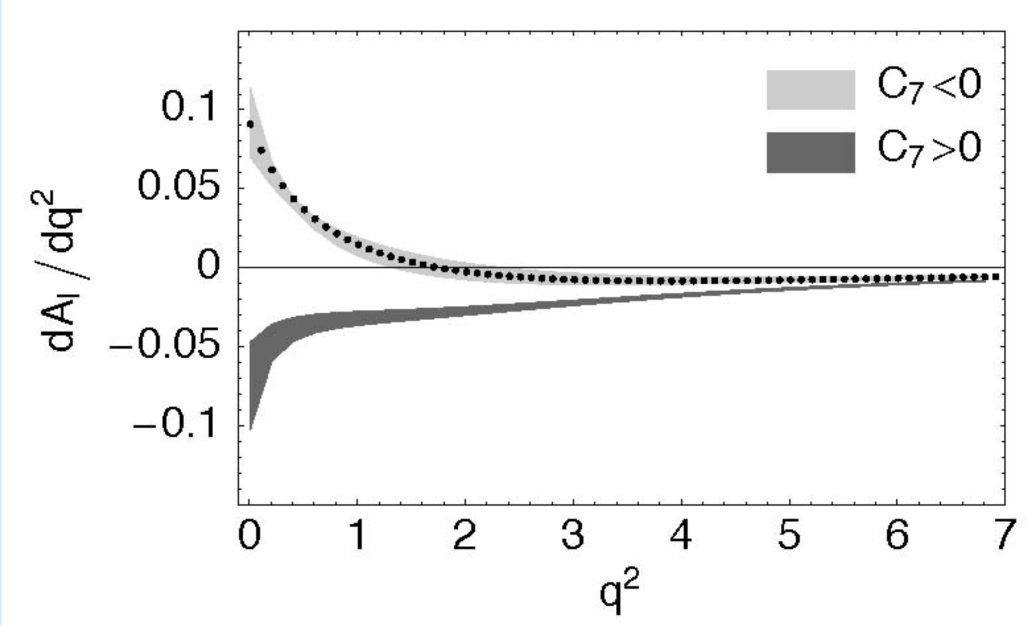
- Measure isospin asymmetry in bins of q2:

$$A_I^i = \frac{B_i(B^0 \to K^{(*)0}\ell^+\ell^-) - rB_i(B^+ \to K^{(*)+}\ell^+\ell^-)}{B_i(B^0 \to K^{(*)0}\ell^+\ell^-) + rB_i(B^+ \to K^{(*)+}\ell^+\ell^-)}$$

  - where the index i refers to q^2 bin and $r = \tau_0/\tau_+ = 1.071 \pm 0.009$

- In SM, **A_I** expected small (<15%), but with q^2 dependence at low q^2
  - sensitivity to sign of C_7

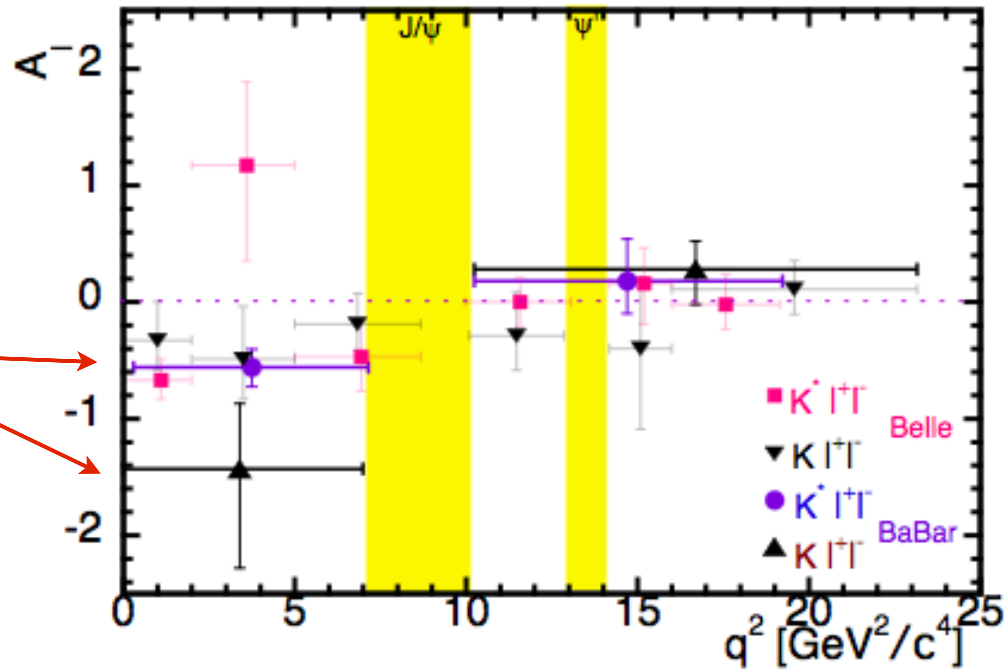
Feldmann & Matias, JHEP 0301, 074 (2003)



Isospin asymmetry results

- Babar (2009) measured a large value of A_I in the low-q^2 region:

large negative A_I



- Taking K*ll and Kll together, this is a 3.9σ effect.
- Belle's results are consistent with SM (and also with BaBar results)
- Need more data to sort this out (updated Babar measurement coming within weeks)

@SuperB: $B^0 \to K^{*0}\mu^+\mu^-$ and more

- Goal: Explore fully the full landscape of $b \to s\ell^+\ell^-$ decays
  - Both lepton flavors: $B \to K^*\mu^+\mu^-$

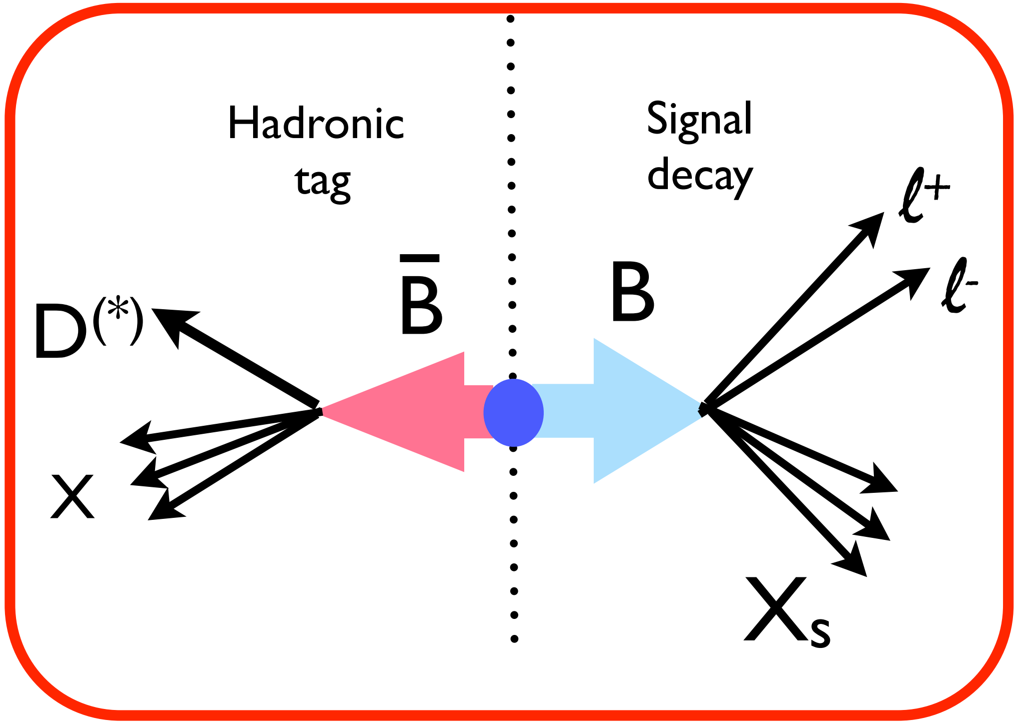
    $B \to K^*e^+e^-$ (suited to e+e- machines)
  - Both B^0 and B^+ decays: $B^0 \to K^{*0}\ell^+\ell^-$ (including: $K^{*0} \to K^0_S\pi^0$

    $B^+ \to K^{*+}\ell^+\ell^-$ $K^{*+} \to K^+\pi^0, K^0_S\pi^+$
  - Inclusive channel: $B \to X_S\ell^+\ell^-$
    - can separate e, μ channels and B^0/B^+ decays

- The ability to explore all these channels gives access to a number of interesting observables that are sensitive to New Physics
  - several of which are not measurable at hadronic machines

Inclusive $B \to X_s l^+ l^-$

- Measurement of inclusive $B \to X_s l^+ l^-$ observables has long been a goal of B-factories, but current results severely limited by statistics and are not really inclusive
- Large statistics @ SuperB will make inclusive $B \to X_s l^+ l^-$ a possibility by tagging with fully reconstructed hadronic (and semileptonic decays)
- Tag B gives much information on signal B: 4-momentum, charge, B or Bbar, etc.
- Can also do (quasi) fully reconstructed semileptonic tags



$$B \to D^{(*)} X$$

$$\begin{array}{lcl} D^0 & \to & K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^-\pi^+, \\ & & K^0_s\pi^0, K^0_s\pi^+\pi^-, K^0_s\pi^+\pi^-\pi^0 \\ & & K^+K^-, \pi^+\pi^- \\ D^{*0} & \to & D^0\pi^0, D^0\gamma \end{array}$$

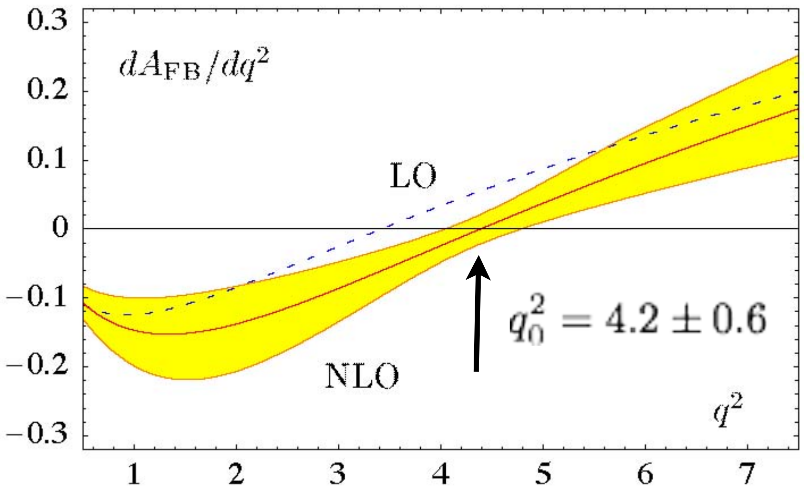
$$X = n\pi^\pm + mK + p\pi^0 + qK^0$$

$$n + m \leq 5, \quad m, p, q \leq 2$$

Precision SM predictions for inclusive $B \to X_s l^+ l^-$

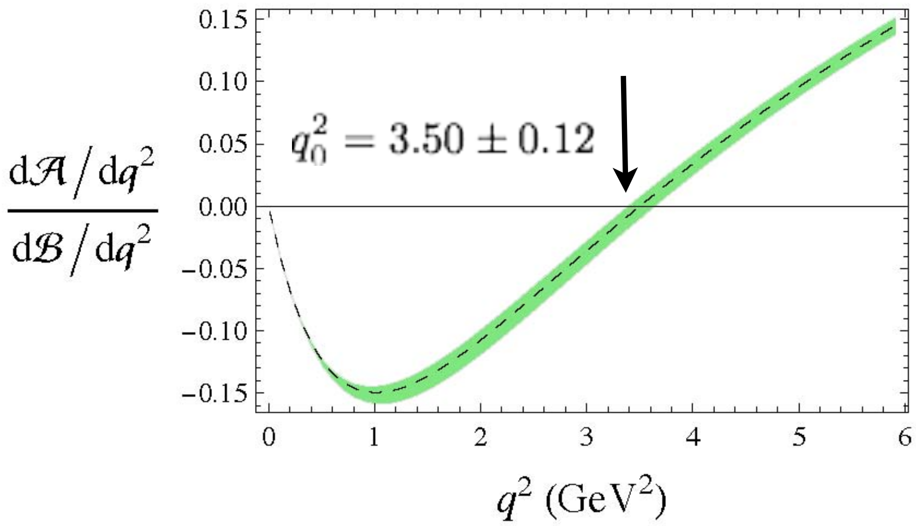
- SM BFs for **exclusive modes** suffer from **~30% uncertainties** due to form factor uncertainties
- For inclusive decay:
  - low q^2: $B_{\mu\mu}^{low} = (1.59 \times 10^{-6})(1 \pm 0.07)$
  - high q^2: $R_{\mu\mu}^{high} \equiv \frac{B(B \to X_s \ell\ell)}{B(B \to X_u \ell\nu)} = (2.29 \times 10^{-3})(1 \pm 0.13)$
- Furthermore, essentially all observables discussed can be measured in inclusive channel

$B \to K^* l^+ l^-$



Feldmann, Matias JHEP 0301, 074(2003)

$B \to X_s \mu^+ \mu^-$ NNLO + QED



Huber, Hurth, Lunghi hep-ph/0712.3009

SuperB: expected sensitivities

- With 75 ab^{-1} we expect to accumulate quite large samples in all the relevant channels
- These statistics will permit very good measurements of the interesting observables

Channel	No. events (1000s)
$B \to K^* \mu\mu$	10-15
$B \to K^* ee$	10-15
$B \to K \mu\mu$	8-12
$B \to Kee$	8-12
$B \to X_s ll$	6-9

More details: arXiv:1008:1541, arXiv:1109.5028

	Observable	Uncertainty	Theo. uncertainty
Exclusive	$A_{FB}(K^*ll)$	0.04	0.02
	$A_I(K^*ll)$	0.02	~0.01
	$A_{CP}(Kll)$	0.02	~0.01
	R_K	0.04	<0.01
	R_{K^*}	0.05	<0.01
Inclusive	$BF(X_s ll)$	0.05	0.07
	R_{X_s}	0.06	<0.01
	$A_{CP}(X_s ll)$	0.02	~0.01
	$A_I(X_s ll)$	0.05	?
	$A_{FB}(X_s ll)$	0.04	?

Based on extrapolation of B-factory results. More refined studies using SuperB fast simulation are underway.

Conclusions

- The $b \to s l^+ l^-$ transition provides an excellent "laboratory" to search for the effects of New Physics
- The B-factories (BaBar and Belle) have made a good start in exploring the physics of $b \to s l^+ l^-$, but the uncertainties remain large
- SuperB, with its very high statistics dataset, will measure a large set of observables that are sensitive to NP
  - many exclusive channels, with both lepton species
  - first measurements of the fully inclusive mode $B \to X_s l^+ l^-$
- SuperB capabilities are largely complementary to those of LHCb (and its upgrade), which will focus primarily on $B^0 \to K^{*0} \mu^+ \mu^-$, with even higher statistics
- Together with Belle 2 these experiments will fully explore the rich sector of $b \to s l^+ l^-$ physics