ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

BSM at Belle: $B \to K^* \ell^+ \ell^-$ and search for leptonic B decays

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Les Rencontres de Physique de la Vallée d'Aoste,
La Thuile, Italy, March 10, 2006

Summary

- *B* physics at Belle
- The $B \to K^* \ell^+ \ell^-$ channel
  - ➔ forward-backward asymmetry
  - ➔ measurement of Wilson coefficients
- $B \to \ell \nu_\ell$ searches
- $B \to \ell^+ \ell^-$ searches
- Future prospects
- Conclusions

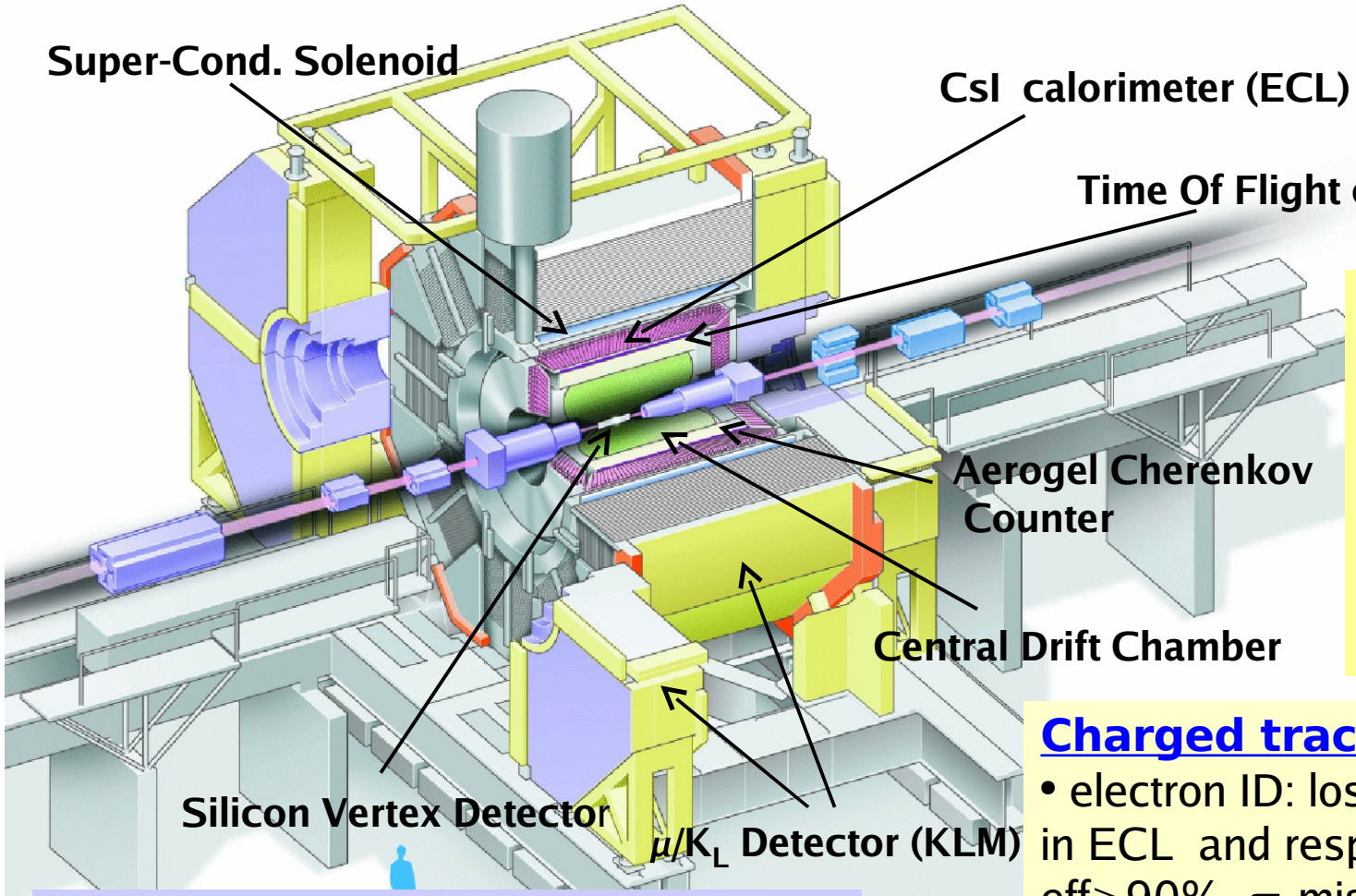
Notation:

- $B^0 \equiv B^0_d$
- Charge-conjugate modes always included

SM: Standard Model

BSM: Beyond the Standard Model

B physics at Belle



***B* production**

BB pairs produced at KEKB in e^+e^- (3.5 GeV on 8 GeV) collisions at the $\Upsilon(4S)$ resonance. Collected so far more than 500 fb^{-1}

***B* signal selection:**

typically based on event shape variables with signal window defined using

$$M_{bc} = \sqrt{E_{beam}^2 - p_B^2} \quad (\approx m_B)$$

and $\Delta E = E_B - E_{beam} \quad (\approx 0)$

Charged tracks reconstruction/ID:

- electron ID: loss in CDC, shower shape in ECL and response of ACC; eff≥90%, π-misID rate ≈ 0.1%
- muon ID: based on ECL and KLM; eff≥90%, π-misID rate ≈ 1%
- $K^{\pm}$ selected using ACC, TOF and CDC; eff ≥90% and π-misID rate ≈6%.
- Other charged tracks identified as $\pi^{\pm}$

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

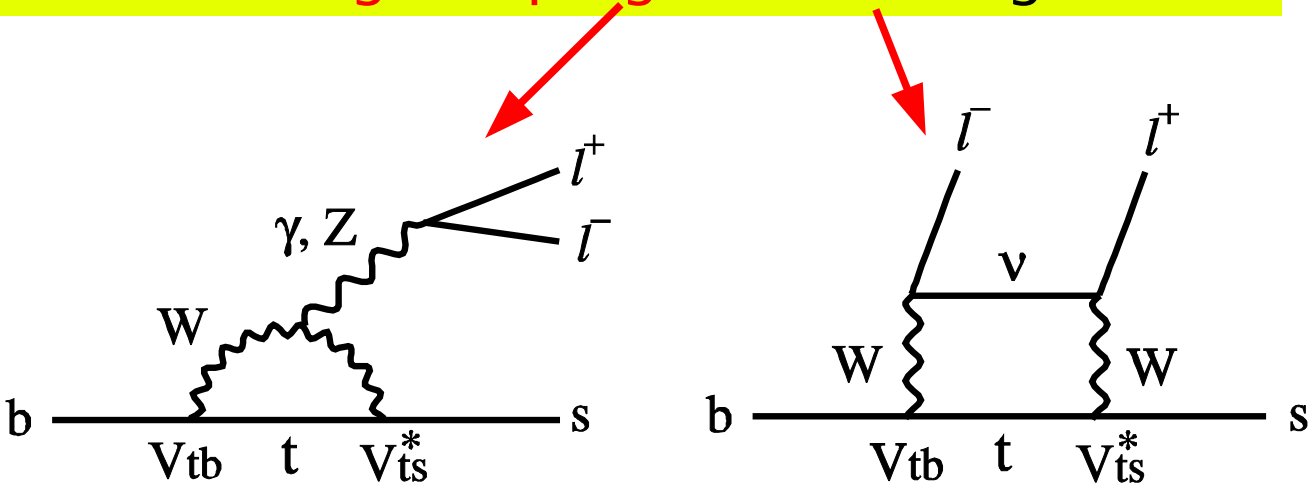
$B \to K^* \ell^+ \ell^-$: a window on BSM physics

SM:

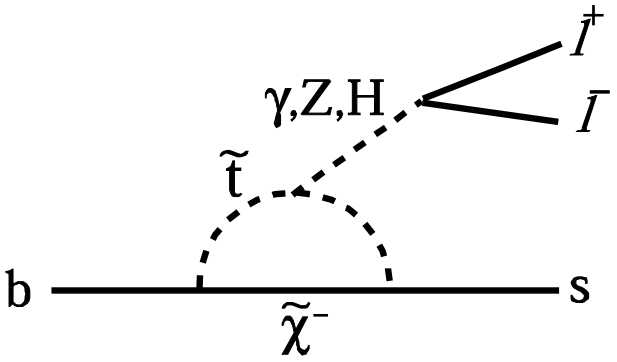
- $b \to s \ell \ell$: FCNC process, forbidden at tree level
- at lowest order via electromagnetic penguin or box diagrams

Lepton pair yields useful observables for testing the theory:

- forward-backward asymmetry (A_{FB})
- invariant mass (q^2)



BSM:



Sensitive to new physics via insertion of heavy particles in the internal lines.

$B \to K^* \ell^+ \ell^-$: Wilson coefficients

New Physics at the one loop level can be described in terms of an effective Hamiltonian:

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

Local operators

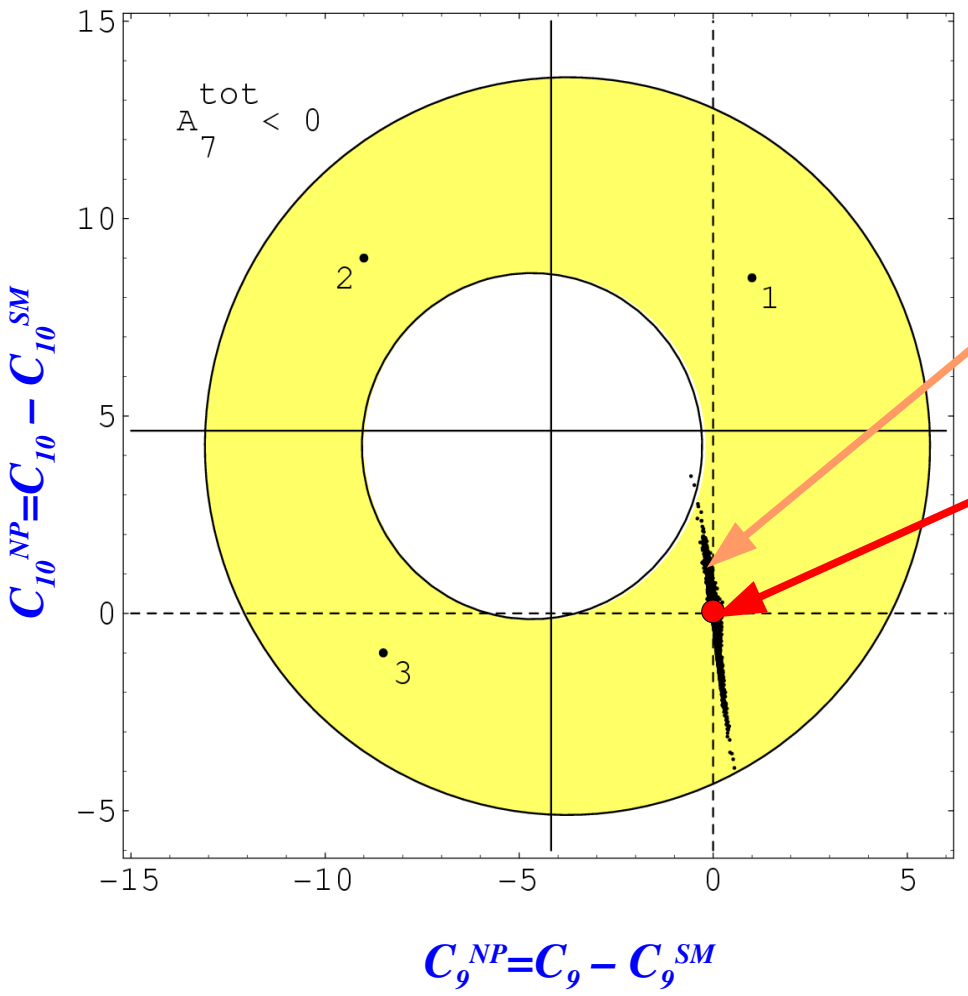
- $C_i(\mu)$ Wilson coefficients: effective strength of short distance interactions
- To leading order, only O_7, O_9 and O_{10} contribute to $b \to s\ell\ell$
- C_i computed perturbatively up to NNLO: $C_i = A_i$ + *higher order terms*
- The $B \to K^* \ell^+ \ell^-$ amplitude depends on A_7, A_9 and A_{10} under the assumption that higher order terms behave like in the SM.

SM VALUES: $A_7 = -0.330$, $A_9 = 4.069$, $A_{10} = -4.213$

H.H. Asatryan *et al.* Phys. Lett. B 507, 162 (2001); A. Ali *et al.* Phys. Rev. D 66, 034002 (2002)

Constraints on Wilson coefficients

The absolute value of C_7 is constrained by $B \to X_s \gamma$; constraints on C_9 and C_{10} (donut-shape) are derived from the $B \to X_s \ell^+ \ell^-$ branching fractions.



Allowed region at 90% CL, based on NNLO and experimental bounds on $B \to X_s \gamma$ and $B \to X_s \ell^+ \ell^-$ Br's; $A_7 < 0$

A. Ali *et al.* Phys.Rev. D 66, 034002 (2002)

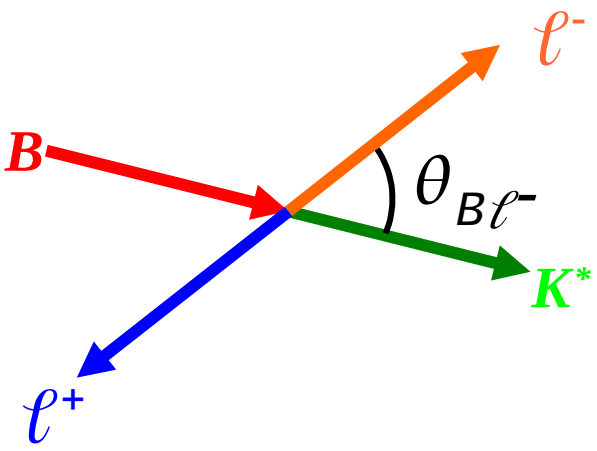
SUSY Extended-MFV

SM:

To determine sign of C_7 and to measure C_9 and C_{10} need to look at the differential distributions in $B \to K^* \ell^+ \ell^-$

Forward-backward asymmetry in $K^*\ell^+\ell^-$

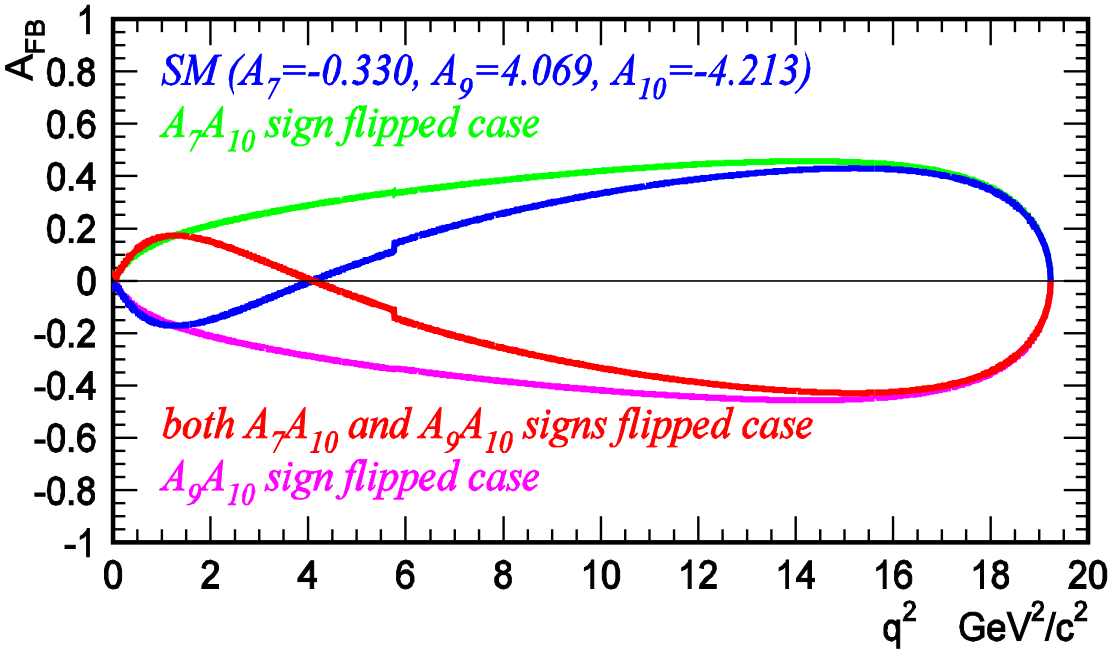
$$A_{\rm FB}(q^2) = \frac{\Gamma(q^2, \cos\theta_{B\ell^-} > 0) - \Gamma(q^2, \cos\theta_{B\ell^-} < 0)}{\Gamma(q^2, \cos\theta_{B\ell^-} > 0) + \Gamma(q^2, \cos\theta_{B\ell^-} < 0)}$$



- $\theta_{B\ell^-}$ ($\equiv\theta$): angle between B and ℓ^- in the dilepton rest frame
- $A_{\rm FB}$ is a function of q^2 of the dilepton system
- $A_{\rm FB}$ non-zero due to interference of vector (C_7, C_9) and axial vector (C_{10}) couplings

More generally, one can extract the coefficients by fitting the double-differential decay width:

$d^2\Gamma / dq^2\, d\cos\theta$



$B \to K^* \ell^+ \ell^-$ selection

- Dataset: 357 fb^{-1} = 386M BB pairs
- Modes: $K^{*+} \to K^+ \pi^0$, $K_S \pi^+$; $K^{*0} \to K^+ \pi^-$
- lepton = e, μ
- Charmonium (J/ψ, $\psi(2S)$) veto
- Dominant background: BB with both B's decaying semileptonically: suppressed using E_{miss} and $\cos\theta_B^*$
- $B \to K \ell^+ \ell^-$ used as "null test": $A_{FB} \approx 0$ in SM, small BSM

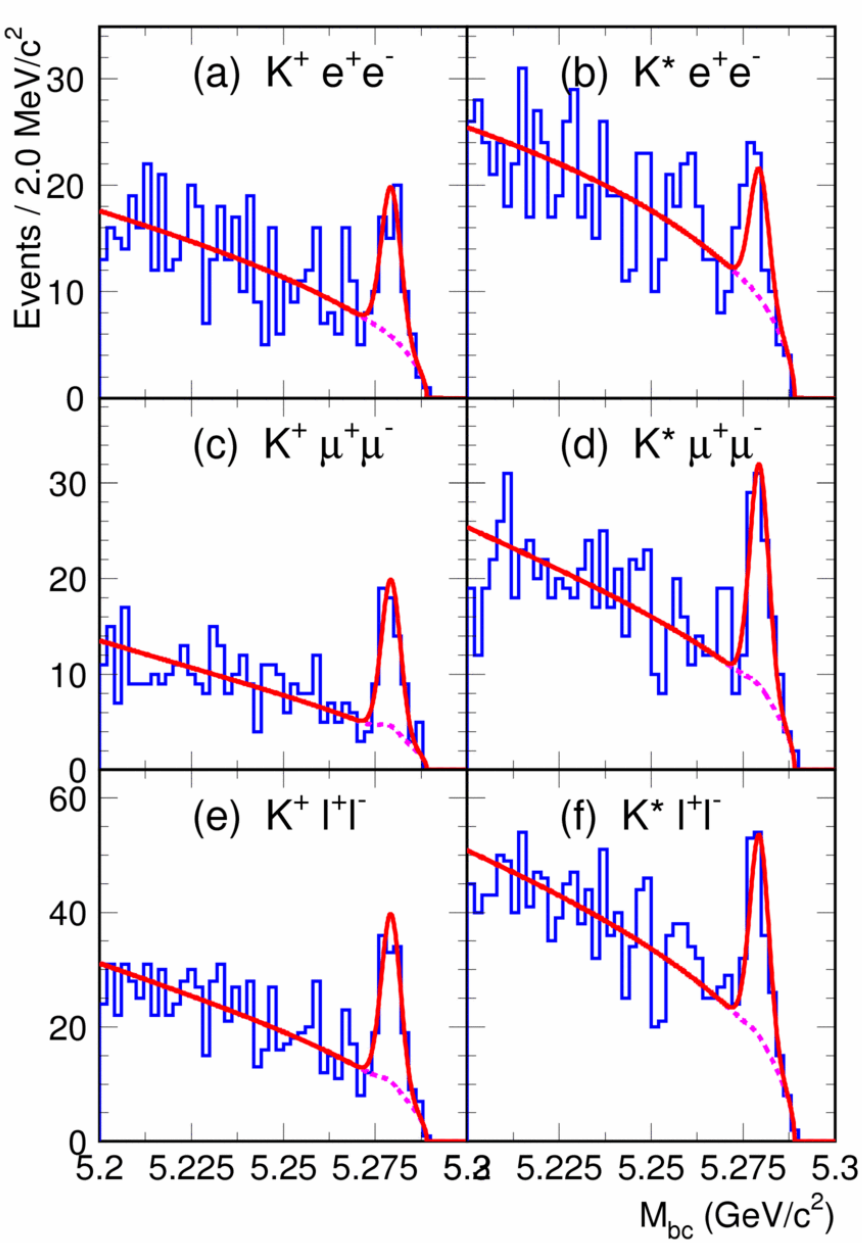
D.A. Demir *et al.* Phys.Rev. D66 (2002) 034015

Signal yield: $N_{sig} = 114 \pm 13$

Consistent with Belle measurement (140fb^{-1}):

$Br(B \to K^* \ell^+ \ell^-) = (11.5^{+2.6}_{-2.4} \pm 0.8 \pm 0.2) \times 10^{-7}$

A. Ishikawa *et al.* Phys.Rev. Lett. 91, 261601 (2003)



Extraction of A_{FB} and Wilson coeffs.

- Extract the ratio of Wilson coefficients A_9/A_7, A_{10}/A_7 ($A_7 = A_7^{SM} = -0.330$) from an unbinned maximum likelihood fit on events in the signal window with a pdf including $g(q^2,\theta) = d^2\Gamma/dq^2\, d\cos\theta$.
- Several event categories:
  - signal + "cross feeds" from misreconstructed $B\to K^{(*)}\ell^+\ell^-$ or other $b\to s\ell\ell$
  - 4 background sources – dominated by dilepton (80%)

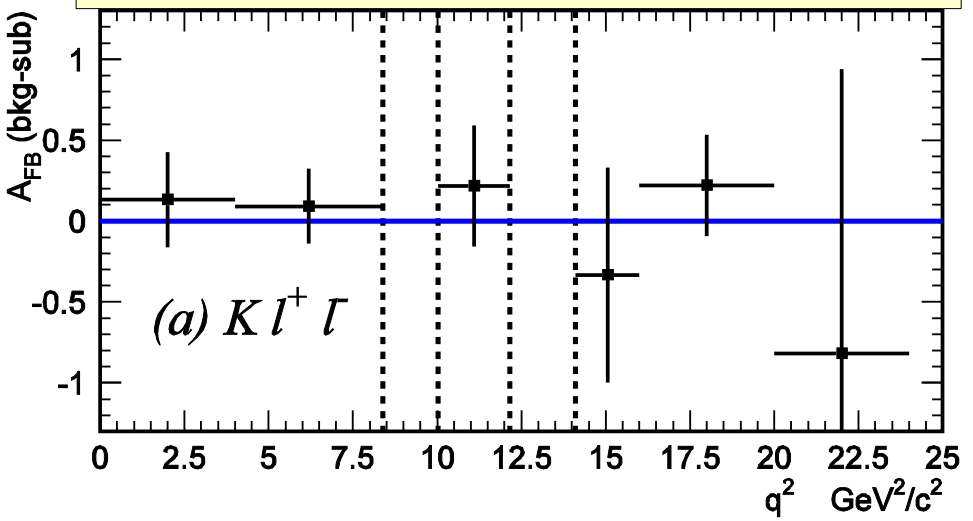
A_{FB} simply obtained by integration: $$\mathcal{A}_{\rm FB}(q^2) = \frac{\int_{-1}^{1} \mathrm{sgn}(\cos\theta) g(q^2,\theta)\, d\cos\theta}{\int_{-1}^{1} g(q^2,\theta)\, d\cos\theta}$$

Null test: extract A_{FB} for $B\to K\ell^+\ell^-$

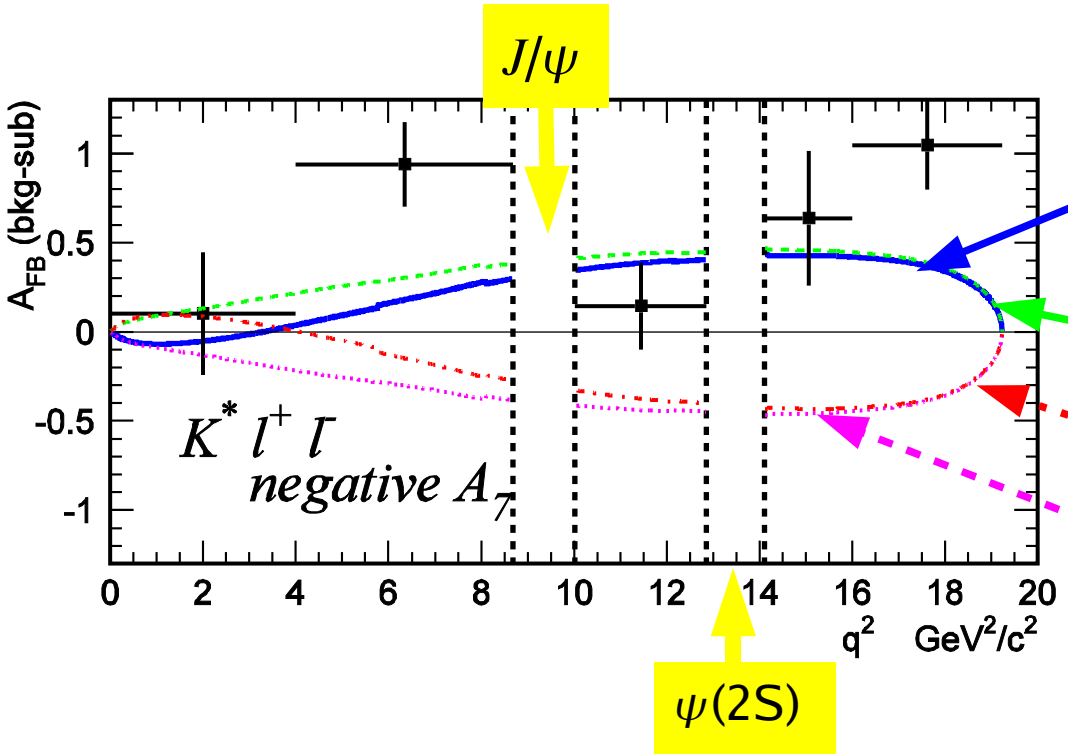
$$A_{FB}^{\rm bkg-sub}(B\to K^+\ell\ell) = 0.09 \pm 0.14(\text{stat.})$$

consistent with 0!

background subtracted A_{FB} in bins of q^2



Fit results hep-ex/0603018 submitted to PRL



fix $A_7 = -0.330$; $A_{FB} > 0$ at 3.4σ

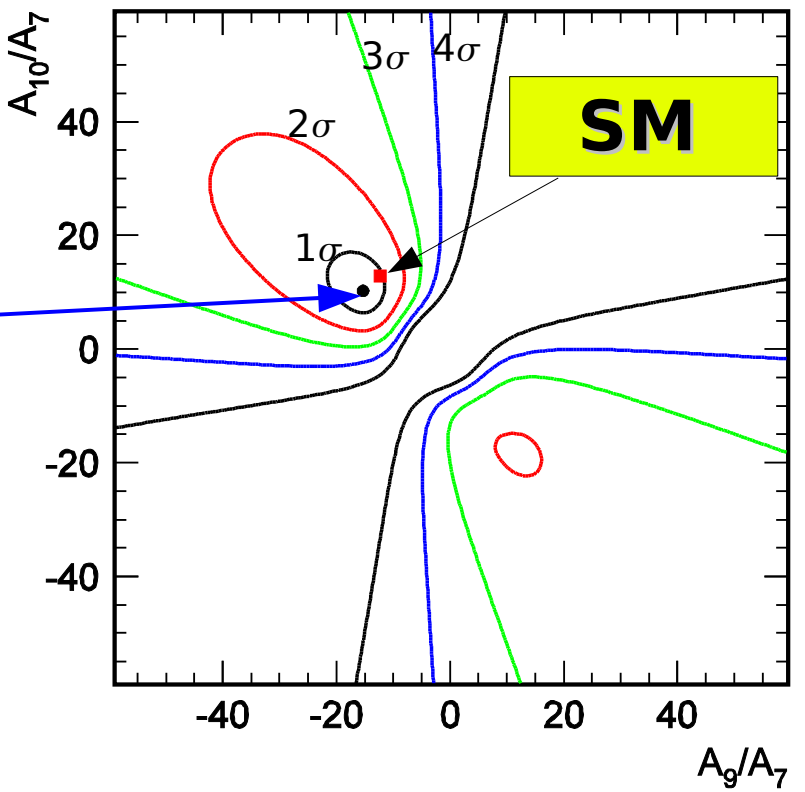
$A_{FB}^{\text{bkg-sub}}(B \to K^* \ell\ell) = 0.56 \pm 0.13$ (stat.)

A_7A_{10} sign flipped — slightly worse fit, but OK

Both A_7A_{10} and A_9A_{10} signs flipped

A_9A_{10} sign flipped

} excluded!



Wilson coefficients:

$A_9/A_7 = -15.3^{+3.4}_{-4.8} \pm 1.1$

$A_{10}/A_7 = 10.3^{+5.2}_{-3.5} \pm 1.8$ (A_7^{SM})

$-1401 < A_9 A_{10} / A_7^2 < -26.4$ (any A_7)

SM: $A_9/A_7 = -12.3$, $A_{10}/A_7 = 12.8$.

LEPTONIC B DECAYS

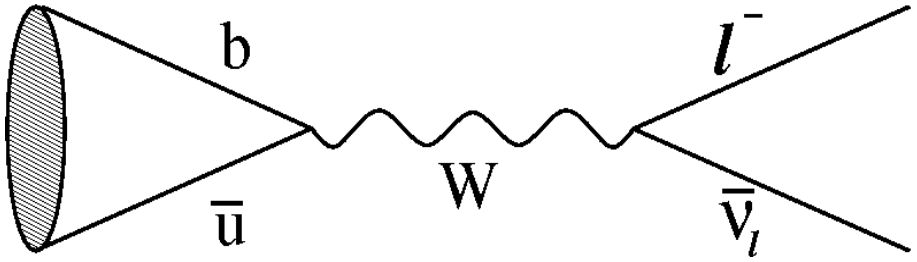
$B^- \to \ell^- \bar{\nu}_\ell$

SM:

B lifetime

$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

Direct Measurement of decay constant f_B!



- Br($B \to \tau \nu_\tau$) $\simeq$ 1 x 10^{-4}
- Other leptons suppressed $\sim(m_\ell)^2$: by 1/225 for $B \to \mu \nu_\mu$, 10^{-7} for $B \to e \nu_e$

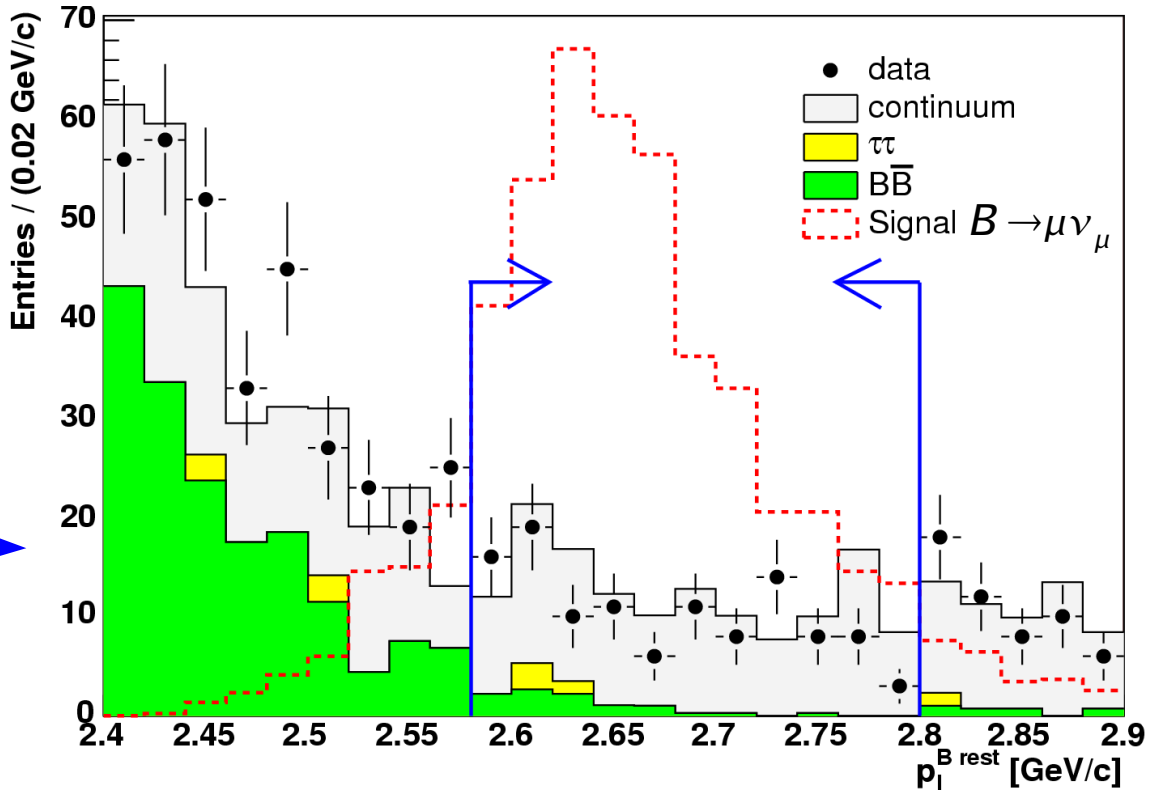
BSM:

Possible enhancements of BF in

- MSSM (charged Higgs): can explore the (M_H, tanβ) plane.
- Pati-Salam models: can set limit on the mass of LQ

$B^- \to e^- \bar{\nu}_e$ and $B^- \to \mu^- \bar{\nu}_\mu$

- One highly energetic lepton
- Charmonium veto
- Large missing E and p
- Signal window defined on ΔE and M_{bc} of the companion B
- Cut on lepton momentum in B rest frame



BELLE results at 90% CL

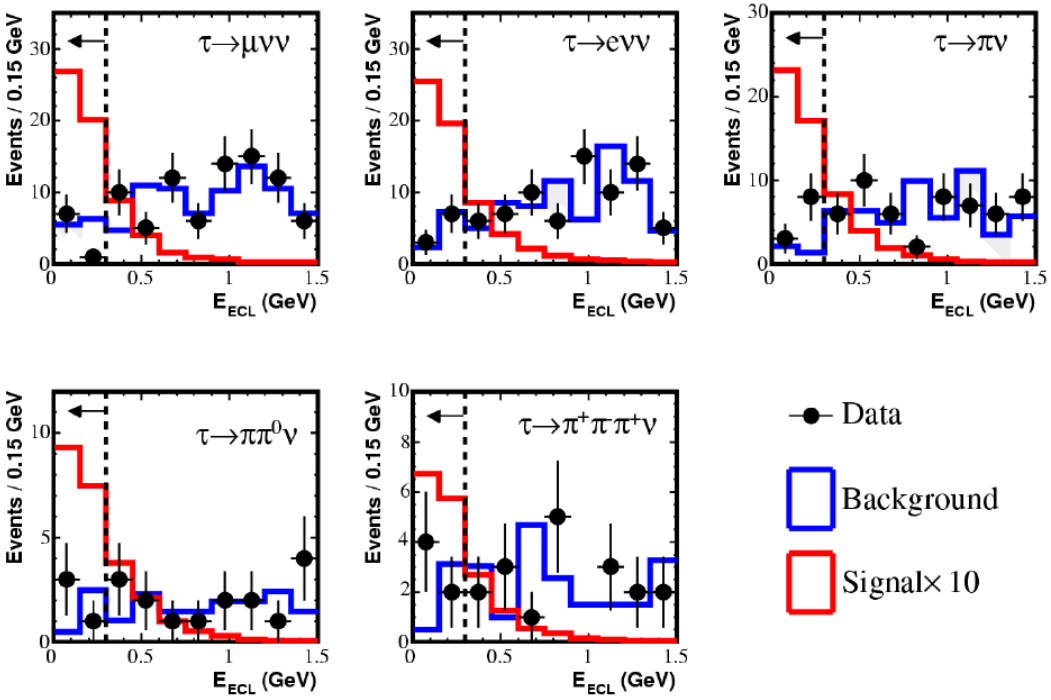
$\mathrm{Br}(B \to \mu\nu_\mu) < 2.0 \times 10^{-6}$ hep-ex/0408132, 140 fb^{-1}

$\mathrm{Br}(B \to e\nu_e) < 5.4 \times 10^{-6}$ Belle-conf-0247, 60 fb^{-1}

update coming soon!

$B^- \to \tau^- \bar{\nu}_\tau$

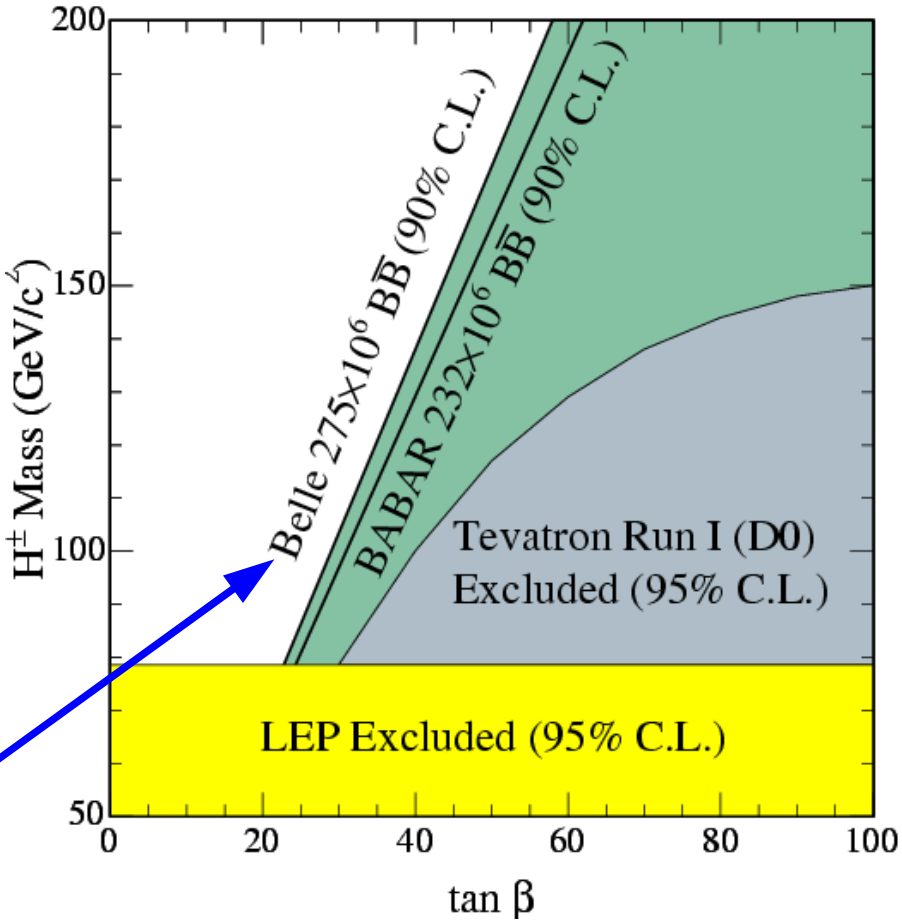
- Reconstruct the companion B in exclusive $D^{(*)0}h^+$ and $D^{(*)0}D^{(*)+}_s$ channels to get a pure (55%) B^+B^- sample (4×10^5 evts)
- Reconstruct signal from remaining particles in the event
- Final selection based on remaining energy in ECL: $E_{ECL} \cong 0$ for signal



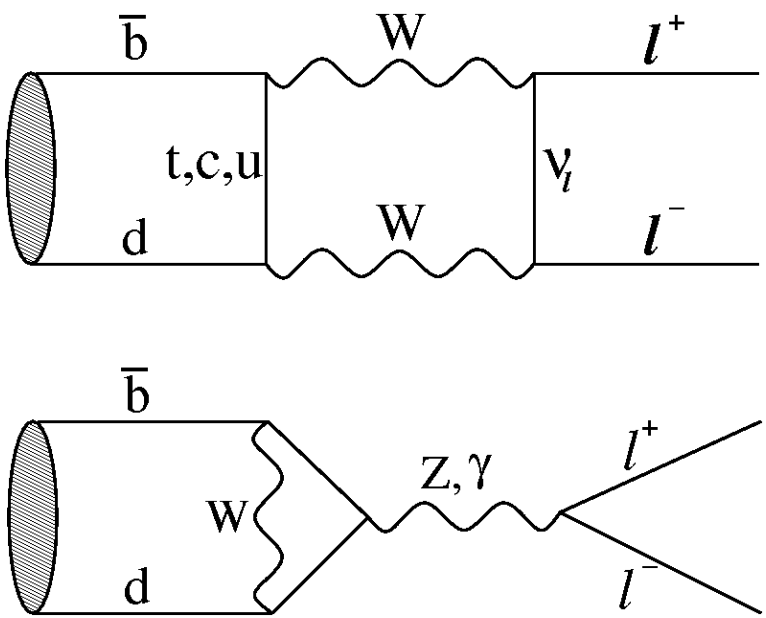
BELLE result

update coming soon!

$\mathrm{Br}(B \to \tau \nu_\tau) < 1.8\times10^{-4}$ hep-ex/0507034, 253 fb^{-1}



$B^0 \to \ell^+\ell^-$



SM:

- Box or annihilation diagram
- Br($B^0 \to \mu^+\mu^-$) = (1.0±0.1) x 10^{-10}
- Br($B^0 \to e^+e^-$) = (2.3±0.3) x 10^{-15}
- Br($B^0 \to \mu^\pm e^\mp$) ≈ 0 (neutrino osc.)
- Helicity suppressed ~$(m_\ell)^2$

BELLE results

90% CL limits based on 78 fb^{-1}

Phys. Rev D 68, 111101(R) (2003)

Br($B \to \mu^+\mu^-$) < 1.6x10^{-7}

Br($B \to e^+e^-$) < 1.9x10^{-7}

Br($B \to \mu^\pm e^\mp$) < 1.7x10^{-7}

limit on the Pati-Salam LQ mass:

M_{LQ} > 46 TeV/c^2 at 90% CL

BSM:

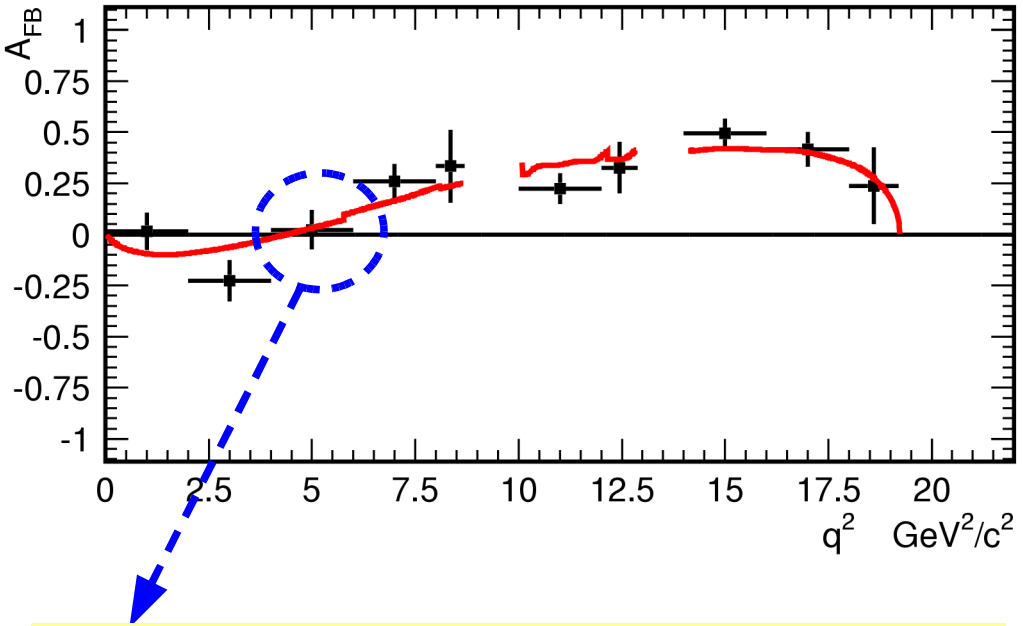
- Enhancement of BF($B^0 \to \mu^+\mu^-$, e^+e^-) in high tanβ MSSM (2 orders of magnitude) and SUSY
- $B^0 \to \mu^\pm e^\mp$ allowed in Pati-Salam (leptoquark) and SUSY models

Super Belle: expected performance

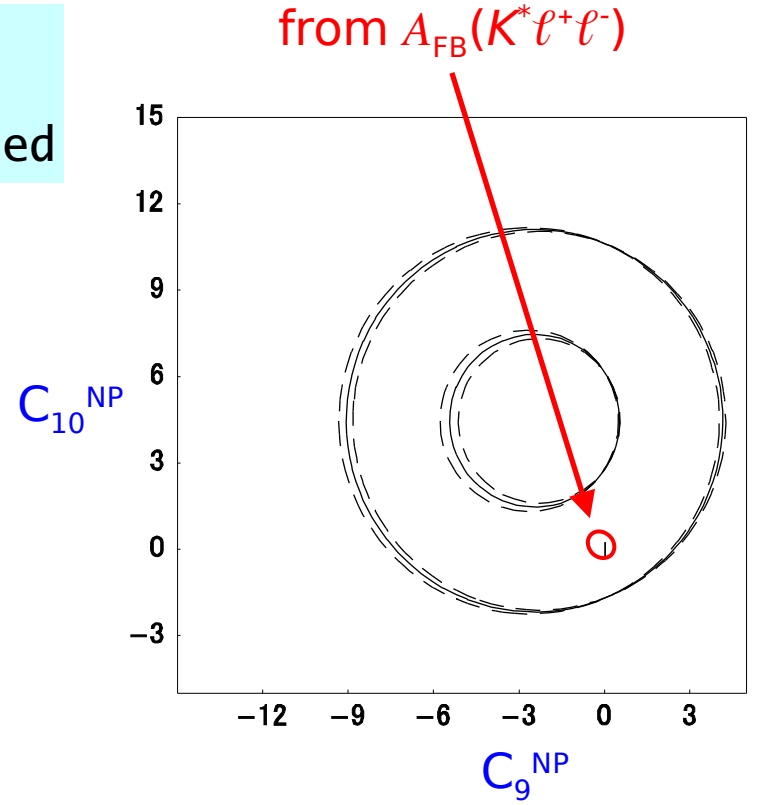
Goal: $\mathcal{L}$=5x10^{35}cm^{-2} s^{-1}; in 1 year $\int\mathcal{L}$=5 ab^{-1}

expected performance on $B\to K^*\ell^+\ell^-$

with 1 year of data taking no syst. errors included



zero of $A_{FB}(q^2)$ is very sensitive to BSM effects. Will be able to measure it.



$\Delta A_9/A_9$~11%

$\Delta A_{10}/A_{10}$~13%

A. Ishikawa at Lake Louise 2006

Conclusions

- Belle performed the first measurement of Wilson Coefficients in $B \to K^* \ell^+ \ell^-$:
  - Integrated forward-backward asymmetry significantly >0
  - First determination of sign of $A_9 A_{10}$
  - Results compatible with SM prediction and ruling out many BSM scenarios
- *B* leptonic decays set constraints on BSM parameter space
  - M_H–tanβ in MSSM
  - M_{LQ} in Pati-Salam models
  - Limits on $B \to \tau \nu_\tau$ and $B \to \mu \nu_\mu$ close to SM prediction!
- Still a lot to come from Belle and hopefully Super Belle!

BACKUP SLIDES

Operators in $\mathcal{H}_{\text{eff}}$

$$
\begin{aligned}
\mathcal{O}_1 &= (\overline{s}_\alpha \gamma_\mu L c_\beta)(\overline{c}_\beta \gamma^\mu L b_\alpha), \\
\mathcal{O}_2 &= (\overline{s}_\alpha \gamma_\mu L c_\alpha)(\overline{c}_\beta \gamma^\mu L b_\beta), \\
\mathcal{O}_3 &= (\overline{s}_\alpha \gamma_\mu L b_\alpha) \sum_{q=u,d,s,c,b} (\overline{q}_\beta \gamma^\mu L q_\beta), \\
\mathcal{O}_4 &= (\overline{s}_\alpha \gamma_\mu L c_\beta) \sum_{q=u,d,s,c,b} (\overline{q}_\beta \gamma^\mu L q_\alpha), \\
\mathcal{O}_5 &= (\overline{s}_\alpha \gamma_\mu L b_\alpha) \sum_{q=u,d,s,c,b} (\overline{q}_\beta \gamma^\mu R q_\beta), \\
\mathcal{O}_6 &= (\overline{s}_\alpha \gamma_\mu L c_\beta) \sum_{q=u,d,s,c,b} (\overline{q}_\beta \gamma^\mu R q_\alpha), \\
\mathcal{O}_7 &= \frac{e}{16\pi^2} \overline{s}_\alpha \sigma_{\mu\nu} (m_s L + m_b R) b_\alpha F^{\mu\nu}, \\
\mathcal{O}_8 &= \frac{g}{16\pi^2} \overline{s}_\alpha \sigma_{\mu\nu} (m_s L + m_b R) T^a_{\alpha\beta} b_\beta G^{a\mu\nu}, \\
\mathcal{O}_9 &= \frac{e^2}{16\pi} \overline{s}_\alpha \gamma^\mu L b_\alpha \overline{\ell} \gamma_\mu \ell, \\
\mathcal{O}_{10} &= \frac{e^2}{16\pi} \overline{s}_\alpha \gamma^\mu L b_\alpha \overline{\ell} \gamma_\mu \gamma_5 \ell,
\end{aligned}
$$

Details of the fit

The Probability Density Function:

$$
\begin{aligned}
& P(M_{\rm bc}, q^2, \cos\theta; A_9/A_7, A_{10}/A_7) \\
= \; & \frac{1}{N_{\rm sig}} f_{\rm sig} \epsilon_{\rm sig}(q^2, \cos\theta) g(q^2, \cos\theta) \\
+ \; & \frac{1}{N_{\rm CF}} f_{\rm CF} \epsilon_{\rm CF}(q^2, \cos\theta) g(q^2, \cos\theta) \\
+ \; & \frac{1}{N_{\rm IF}} f_{\rm IF} \epsilon_{\rm IF}(q^2, \cos\theta) g(q^2, -\cos\theta) \\
+ \; & (1 - f_{\rm sig} - f_{\rm CF} - f_{\rm IF} - f_{K^*hh} - f_{\psi X_s}) \times \\
& \left\{ (f_{K^*\ell h} \mathcal{P}_{K^*\ell h}(q^2, \cos\theta) + (1 - f_{K^*\ell h}) \mathcal{P}_{\rm dl}(q^2, \cos\theta) \right\} \\
+ \; & f_{K^*hh} \mathcal{P}_{K^*hh}(q^2, \cos\theta) + f_{\psi X_s} \mathcal{P}_{\psi X_s}(q^2, \cos\theta).
\end{aligned}
$$

ϵ : efficiency functions, estimated from data and MC

f : event by event signal and background probability, from M_{bc} fit

Systematic uncertainties

source	negative A_7 solution		positive A_7 solution	
	A_9/A_7	A_{10}/A_7	A_9/A_7	A_{10}/A_7
A_7	+0.29 -0.03	+0.01 -0.03	+0.13 -0.27	+0.36-0.15
m_b	+0.69 -0.68	+0.45 -0.46	± 0.63	± 0.42
Form factor model	± 0.66	± 1.72	± 1.04	+2.23
q^2 resolution	± 0.28	± 0.39	± 0.28	± 0.39
efficiency	± 0.08	± 0.03	± 0.10	± 0.06
signal fraction	+0.43 -0.47	+0.22 -0.33	+0.43 -0.46	+0.37 -0.40
total	**+1.12-1.10**	**+1.83-1.84**	**+1.33-1.36**	**+2.36 -2.34**

Positive A_7 solution

Best fit for positive A_7 (non-SM like):

$$A_9/A_7 = -16.3\,^{+3.7}_{-5.7} \pm 1.4,$$
$$A_{10}/A_7 = 11.1\,^{+6.0}_{-3.9} \pm 2.4,$$

SM $A_9/A_7 = -12.3,$ $A_{10}/A_7 = 12.8.$