B-meson rare decays and CKM matrix elements from Belle

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Selected topics from many (>60) results:

Rare and radiative decays:

Mode	Relevant for:	$\int$ Ldt	Status
$\pi\pi$, $K\pi$, KK	φ_3 (φ_2), DCPV	29.1 fb^{-1}	Preliminary
$D_{CP}K^-$	φ_3	29.1 fb^{-1}	Preliminary
$\phi K^{(*)}$	φ_1, DCPV	21.6 fb^{-1}	Preliminary
$\eta' K^{(*)}$	φ_1, DCPV	10.4 fb^{-1}	Published
$\eta K^{(*)}$	φ_1, DCPV	21.3 fb^{-1}	Preliminary
$K\pi\gamma$, $K\pi\pi\gamma$, $\rho\gamma$	V_{td}/V_{ts}, DCPV	29.1 fb^{-1}	Preliminary
$K^{(*)}l^+l^-$, $X_s l^+l^-$	V_{td}/V_{ts}, DCPV	29.1 fb^{-1}	Published

Semileptonic (& exclusive) decays:

Mode	Relevant for:	$\int$ Ldt	Status
$D^{-}l^{+}\nu$, $D^{*-}l^{+}\nu$	V_{cb}	10.2 fb^{-1}	Published
$Xe^{+}\nu$	V_{cb}	5.1 fb^{-1}	Preliminary
$\pi^{-}l^{+}\nu$	V_{ub}	29.1 fb^{-1}	Preliminary
$D_s^{+}\pi^{-}$	V_{ub}	21.3 fb^{-1}	Preliminary

B-decay dynamics:

$D^{(*)0}h^0$ (π^0,η,ω)	Colour supp.	21.3 fb^{-1}	Published
$KK\pi$, $K\pi\pi$, KKK	Factor., φ_3/φ_1	29.1 fb^{-1}	Submitted
$\chi_{c0}K^{+}$	Factorization	29.1 fb^{-1}	Published
$p\bar{p}K^{+}$	Dynam., DCPV	29.4 fb^{-1}	Submitted
$p\bar{p}$, $\bar{\Lambda}p$, $\bar{\Lambda}\bar{\Lambda}$	Dynam.	29.4 fb^{-1}	Submitted

Rare decays: Technique

Background suppression

Continuum $e^+e^- \rightarrow qq$ (2jets) background dominant in most of rare decays :

$\sigma_{B\bar{B}} \cdot BF/\sigma_{qq} \sim O(10^{-5} - 10^{-6})$

- Various event shape variables : Fox-Wolfram moments, thrust... ($B\bar{B}$: spherical, continuum: jetty)
- Angle between B thrust axis and thrust of the remaining tracks (continuum: aligned)
- B angular distribution: $\sin^2\theta$ (continuum: $1+\alpha\cos^2\theta$)
- Fisher discriminat to maximize signal/background separation

Identification of B

(momenta and energies in the $\Upsilon(4S)$ rest frame)

$E_B = 5.28$ GeV and $|\vec{p}_B| \approx 0.350$ GeV are known $\Rightarrow$ use energy-momentum conservation:

- $\Delta E = \sum E_i - E_{beam}$ (energy difference)
- $M_{bc} = \sqrt{E_{beam}^2 - \left(\sum \vec{p}_i\right)^2}$ (beam energy constrained mass)

K/π separation

likelihood ratio $L_{K(\pi)}$ formed from the PID system info (dE/dx, aerogel Cherenkov, TOF)

$L_K/(L_\pi + L_K) \sim 1 \Rightarrow$ kaon, $\sim 0 \Rightarrow$ pion

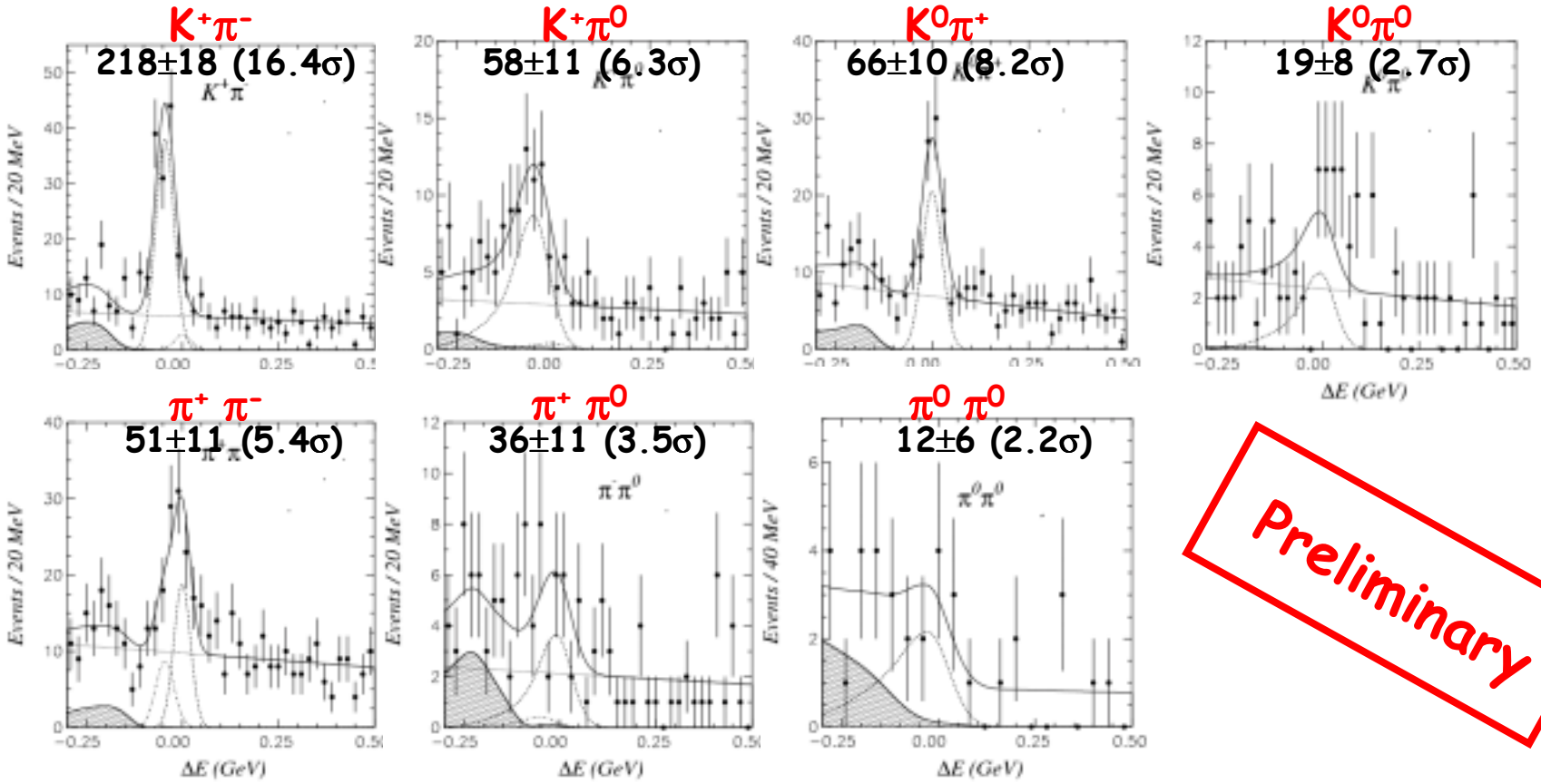
(some K/π separation also in ΔE)

$B \to \pi\pi/K\pi/KK$ (1)

Updated results (31.7M BB):

- Signal/background separation optimized for each decay mode
- Feed-across charmless decays background studied carefully
  $\Rightarrow$ well controlled fit systematics

ΔE calculated with $\pi^{\pm}$ mass



Preliminary

$B \to \pi\pi/K\pi/KK$ (2)

DCPV via T- P interference

- measure BF's and their ratios $\to \varphi_3$ (theoreticaly challenging)

Observations:

- Hierarchy: $K^+K^- < \pi^+\pi^- < K^+\pi^-$
  $\to$ $K^+\pi^-$ mostly penguin?
- Isospin invariance (penguin dominance sum rule):
  $BF(K^+\pi^-) + \tau_0/\tau_+ \bullet BF(K^0\pi^+) - 2[\, BF(K^0\pi^0) + \tau_0/\tau_+ \bullet BF(K^+\pi^0)\,] = (0.08 \pm 0.9)\times 10^{-5}$
  $(\tau_0/\tau_+ = 1.09 \pm 0.04$ Belle)
  $\to$ penguin dominance?
- $\pi^0\pi^0$ not observed yet

BF $[10^{-5}]$(UL@90% CL)

$K^+\pi^-$	$2.18 \pm 0.18 \pm 0.15$
$K^+\pi^0$	$1.25 \pm 0.24 \pm 0.12$
$K^0\pi^+$	$1.88 \pm 0.30 \pm 0.15$
$K^0\pi^0$	$0.77 \pm 0.32 \pm 0.16$
$\pi^+\pi^-$	$0.51 \pm 0.11 \pm 0.04$
$\pi^+\pi^0$	$0.70 \pm 0.22 \pm 0.08$
$\pi^0\pi^0$	< 0.56
K^+K^-	< 0.05
K^0K^+	< 0.38
K^0K^0	< 1.3

Preliminary

$B \to \pi\pi/K\pi/KK$ (3)

Branching fractions ratios:

$2BF(K^+\pi^0)/BF(K^0\pi^+) = 1.33\pm0.33\pm0.14$ (A)

$BF(K^+\pi^-)/2BF(K^0\pi^0) = 1.43\pm0.60\pm0.28$ (B)

$\tau_+/\tau_0 BF(K^+\pi^-)/2BF(K^0\pi^+)$ (C)
$= 1.27\pm0.23\pm0.09\pm0.04$

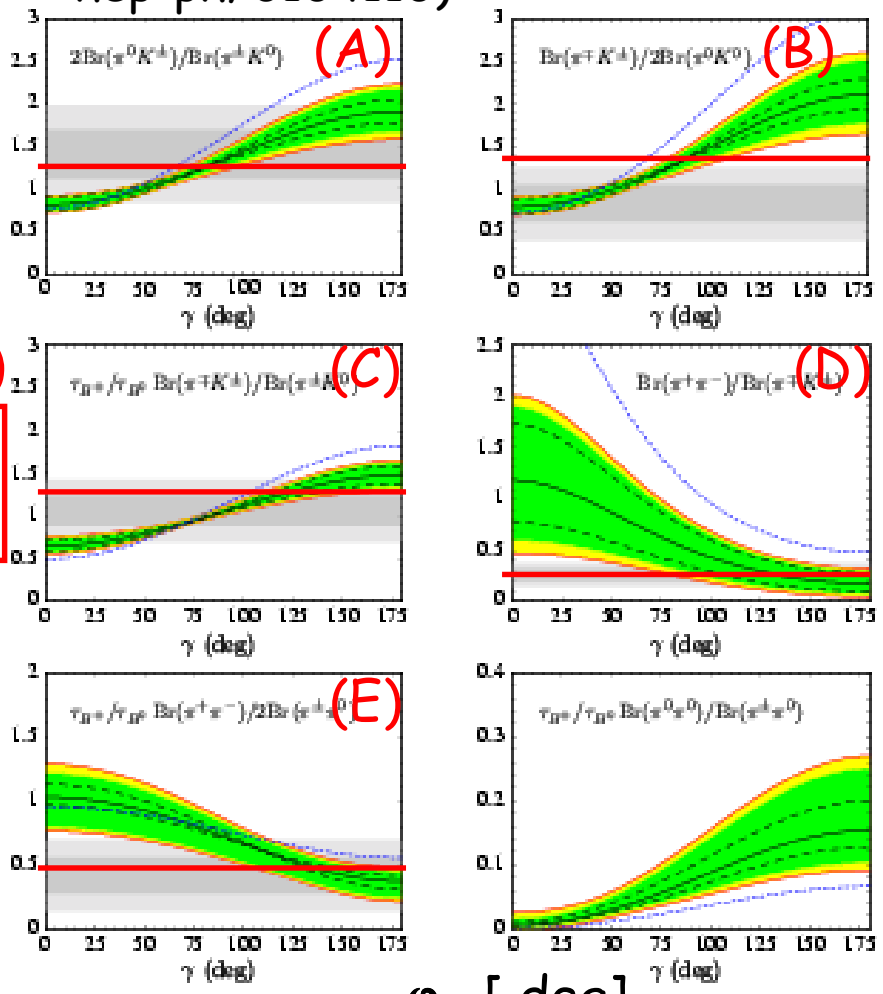
$BF(\pi^+\pi^-)/BF(K^+\pi^-) = 0.24\pm0.06\pm0.02$ (D)

$\tau_+/\tau_0 BF(\pi^+\pi^-)/2BF(\pi^+\pi^0)$ (E)
$= 0.40\pm0.15\pm0.05\pm0.01$
$\neq 1$ ($\approx 4\sigma$ effect)

$\Rightarrow$ clear evidence for large interf. in $\pi\pi$ system ($\Delta\varphi$ and/or $\Delta\delta$?)

All pointing to large φ_3, but still consistent with indirect determinations

BF ratios vs φ_3 (QCD factorization)
(Beneke,Buchalla,Neubert,Sachrajda hep-ph/0104110)



φ_3 [deg]

$B^- \to D^0 K^-$ (1)

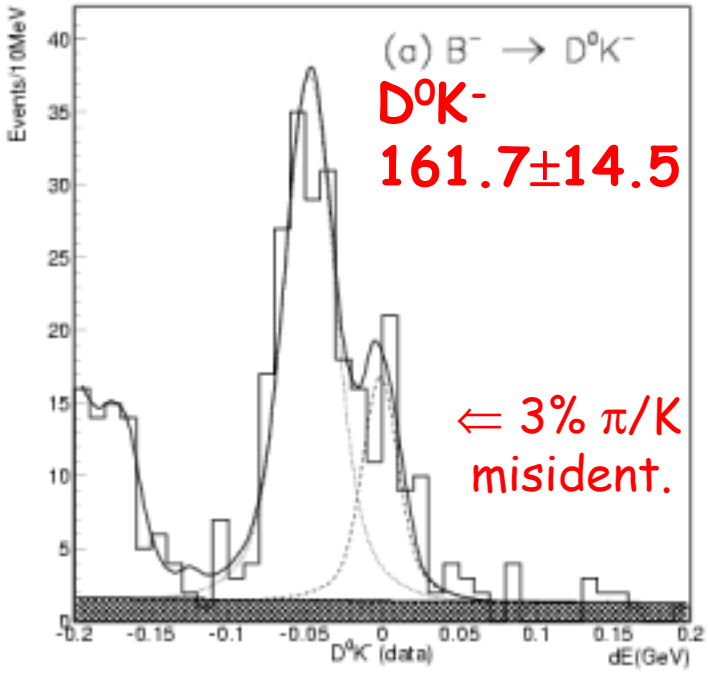
- interference of tree processes $b\to c$ / $b\to u$ in $B^- \to D^0 K^-$ / $\overline{D}^0 K^-$
  $\Rightarrow \varphi_3$ measurement
  several methods : Gronau,Wyler(91) ... Atwood,Dunietz,Soni(97)

e.g. charge asymmetries in $B^\pm \to D_{1(2)} K^\pm$
$CP(D_1) = +$, $CP(D_2) = -$

However:

1. good PID needed to suppress $D^0\pi^\pm$
   $BF(D^0K^\pm)/BF(D^0\pi^\pm) \approx 0.07$ (Belle) $\Rightarrow$
2. Small ratio:
   $r = A(B^- \to \overline{D}^0 K^-)/ A(B^- \to D^0 K^-)$
   $\approx |V^*_{ub} * V_{cs}| / |V^*_{ub} * V_{cs}| *$ [col.sup.]
   $\approx 0.4 * 0.25 \approx 0.1$
   $\to$ asymmetries 'not large'
3. $BF(D^0 \to X_{CP}) \approx 1\%$

ΔE calculated with $\pi^\pm$ mass



(Preliminary)

$B^- \to D^0 K^-$ (2)

- Results for 31.1 M BB:
  D_1 : K^+K^- , $\pi^+\pi^-$
  D_2 : $K_S^0\pi^0$, $K_S^0\omega$, $K_S^0\phi$, $K_S^0\eta(\gamma\gamma)$, $K_S^0\eta'(\eta\pi^+\pi^-)$

- Cabibbo suppression:
  $BF(D^0K^-)/BF(D^0\pi^-)=0.094\pm0.009\pm0.007$
  $BF(D_1K^-)/BF(D_1\pi^-)=0.125\pm0.036\pm0.010$
  $BF(D_2K^-)/BF(D_2\pi^-)=0.119\pm0.028\pm0.006$

- Charge asymmetries:

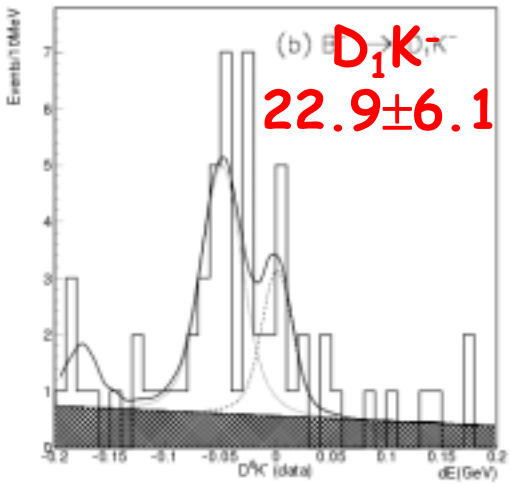
$A_{CP}(D_1K^-) = +0.29^{+0.29}_{-0.24} \pm 0.05$
$A_{CP}(D_2K^-) = -0.22^{+0.26}_{-0.21} \pm 0.04$

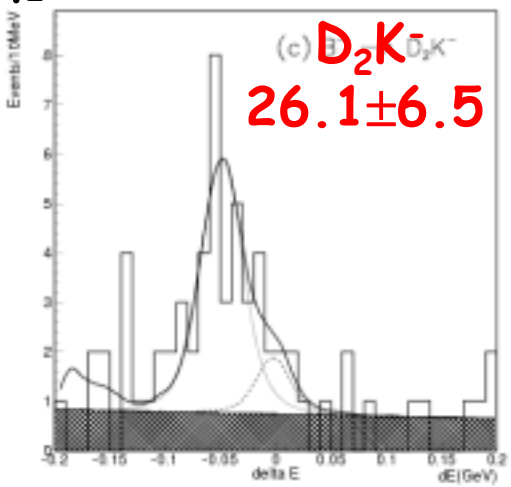
($\delta A_{1(2)}, \delta R_{1(2)} \approx 0.1$ @ 300 fb^{-1})

$$A_{CP} = \frac{2r*\sin\delta*\sin\varphi_3}{1+r^2+2r*\cos\delta*\cos\varphi_3}$$

$$\left(R_{1(2)} = \frac{BF(D_{1(2)}K)/BF(D_{1(2)}\pi)}{BF(D^0K)/BF(D^0\pi)}\right)$$

$$(\delta \to \delta + \pi \quad \text{for } D_2)$$

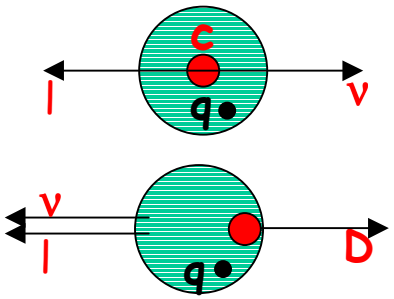




(Preliminary)

$B \to D^{(*)+} l^- \nu$

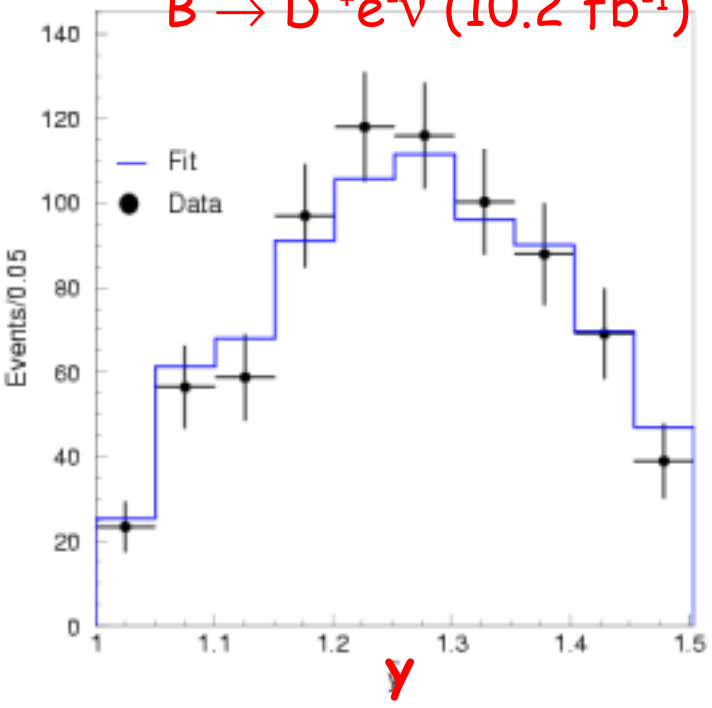
- **Technique:** 'ν **reconstruction**' (good hermecity and calorimetry needed)
- $B \to X l \nu$: $\vec{p}_\nu = -\sum \vec{p}_i$, $P_\nu = (|\vec{p}_\nu|, \vec{p}_\nu)$
  (just another 4-momentum for ΔE , M_{bc})
- Cuts to improve resolutions: no other leptons in the event, $|Q_{tot}| \leq 1$
- Consistency cuts:
  $|M^2_{miss}| = |E^2_{miss} - p_\nu^2| < 2GeV^2$
  $(E_{miss} = 2E_{beam} - \Sigma E_i)$
  $|\cos\theta_{B,-Xl}| \leq 1$
  $(\cos\theta_{B,-Xl} = (2E_B E_{Xl} - M_B^2 - M_{Xl}^2)/2p_B p_{Xl})$
- $B \to D^{(*)+} l^- \nu$
  $|V_{cb}|$ from dN/dy ; $y = v_B v_{D^*}$
  ($\gamma(D^{(*)})$ in B rest frame)



$y = 1$

$y > 1$

$B \to D^{*+} e^- \nu$ (10.2 fb^{-1})



$B \to D^{(*)+} l^- \nu$

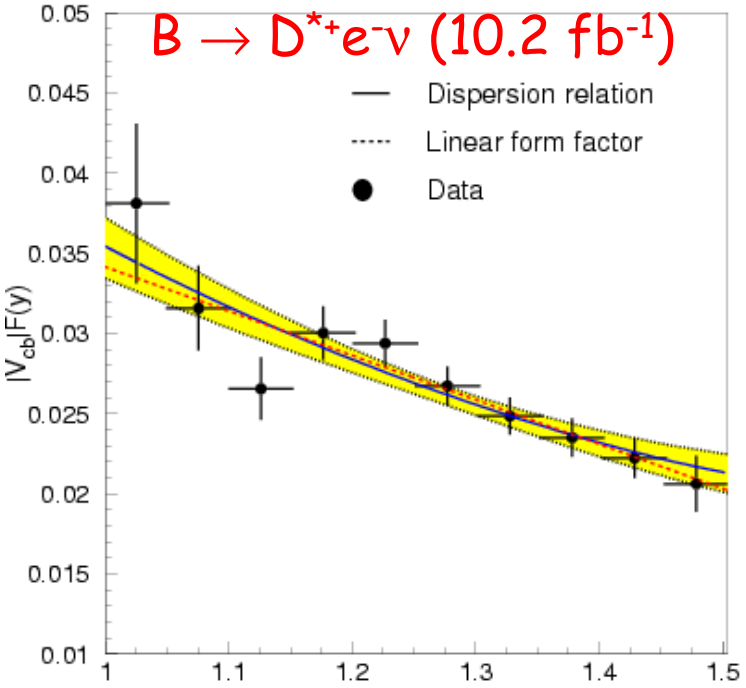
The decay rate:

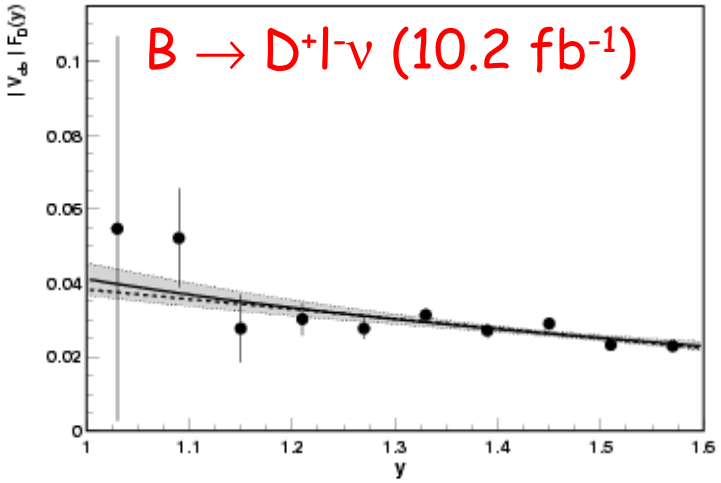
$$\frac{d\Gamma}{dy} = \frac{G_F^2}{48\pi^3} |V_{cb}|^2 |F_D(y)|^2 K_D(y)$$

- $K_D(y)$ - known kinematic factors
  $K_D \propto (y^2-1)^{3/2}$, $K_{D^*} \propto (y^2-1)^{1/2}$
  $\to$ at y=1: V-A kinematics favours $D^* l\nu$

- $F_D(y)$ – $B \to D^{(*)}$ form factor
  HQET relations simplify the F_D
  HQS : $M_Q \to \infty$, $F(1) \to 1$
  (+ HQS-breaking corr.)
  QCD dispersion relations constrain
  the shape: $F_D = F(1)(1-\rho^2(y-1)+\ldots)$

Extrapolate to y=1 to extract $F(1)|V_{cb}|$
$\to F(1)|V_{cb}|$, ρ^2 correlated





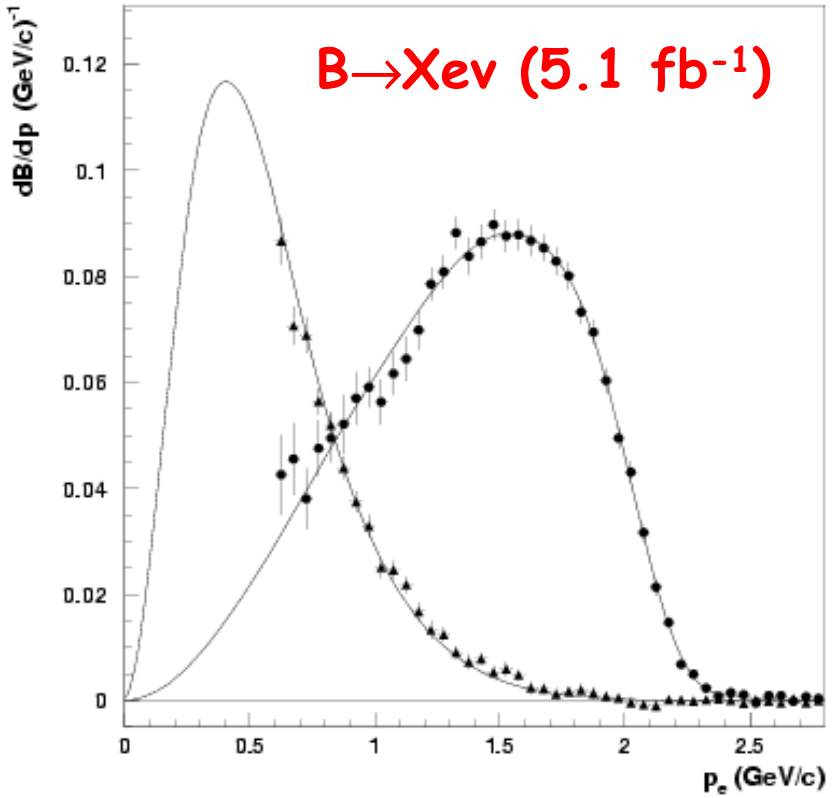
$B \to D^{(*)+} l^- \nu$

	$D^+ l^- \nu$	$D^{*+} e^- \nu$
$\|V_{cb}\| F_D(1) (\times 10^{-2})$	$4.11 \pm 0.44 \pm 0.52$	$3.54 \pm 0.19 \pm 0.18$
ρ^2	1.12 ± 0.22	$1.35 \pm 0.17 \pm 0.19$
$F_D(1)$ used	0.98 ± 0.07	0.913 ± 0.042
$\|V_{cb}\| (\times 10^{-2})$	$4.19 \pm 0.45 \pm 0.53 \pm 0.30$	$3.88 \pm 0.21 \pm 0.20 \pm 0.19$
BF (%)	$2.13 \pm 0.12 \pm 0.39$	$4.77 \pm 0.38 \pm 0.48$

- Dominant systematics: ν reconstruction modeling, tracking efficiency, π_{slow} reconstruction
- $D^+ l^- \nu$ less precise but valuable for F_D studies

$B \to X e^+ \nu$

- $B\bar{B}$ tagged with a lepton (e,μ)
  $p^* > 1.4$ GeV
- $B \to X e^+ \nu$ tagged with $e^\pm$ on the 'other side'
- Lepton charge correlation to separate $b \to l^-$ and $b \to c \to l^+$
- B^0-$\bar{B}^0$ mixing unfolded
- BF($B \to X e \nu$) = 10.86 ± 0.14 ± 0.47 %
  $|V_{cb}|$ = (4.0 ± 0.1 ± 0.4)* 10^{-2}
  (ISGW model)



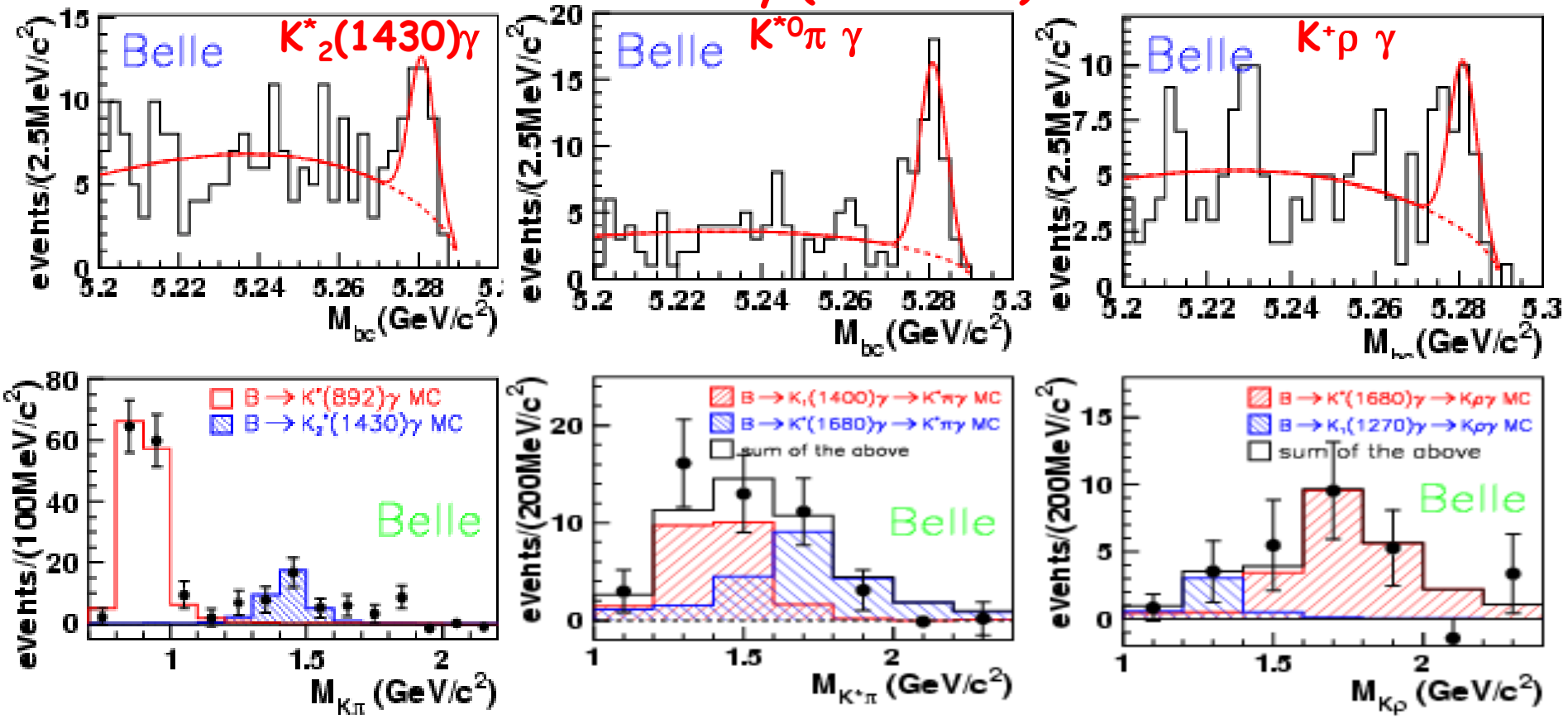
Preliminary

Exclusive $B \to X_s\gamma$

- Semi-inclusive $X_s\gamma$ (X_s=K + 1-4 π's) difficult experimentally, neverthless a big success of theory:
  Belle (5.8 fb^{-1}) : BF($B \to X_s\gamma$) = $(3.36 \pm 0.53 \pm 0.42 \pm 0.52) * 10^{-4}$
  Theory (NLO) : $(3.57 \pm 0.30) * 10^{-4}$ (M. Misiak 2002)

- Try to decompose X_s into exclusive 'kaonic' final states

Preliminary (21.3 fb^{-1})



Exclusive $B \to X_s\gamma$

	BF [10^{-5}]
$K^{*0}\gamma$	$4.96 \pm 0.67 \pm 0.45$
$K^{*+}\gamma$	$3.89 \pm 0.93 \pm 0.41$
$K_2^{*0}(1430)\gamma$	$1.26 \pm 0.66 \pm 0.10$
$K^{*0}\pi^+\gamma$	$5.6 \pm 1.1 \pm 0.9$
$K^+\rho^0\gamma$	$6.5 \pm 1.7 \pm 1.1$

Preliminary (21.3 fb^{-1})

- A large fraction (> 60%) of BF($X_s\,\gamma$) accounted for
- Interesting angular analyses possible in future (photon helicity measurement)
- $B \to \rho\gamma$ not seen yet : BF($\rho\gamma$)/BF($K^*\gamma$) < 0.19 (90% C.L.) (preliminary, 10.4 fb^{-1})

Summary

- Many new decay modes have been observed in the $\leq$ 30 fb^{-1} data sample
- Some of them start to be interesting for φ_3 , φ_1 measurements
- Measurements of $|V_{cb}|$, $|V_{ub}|$ are steadily improving
- Many new analyses are becoming possible with the large data sample