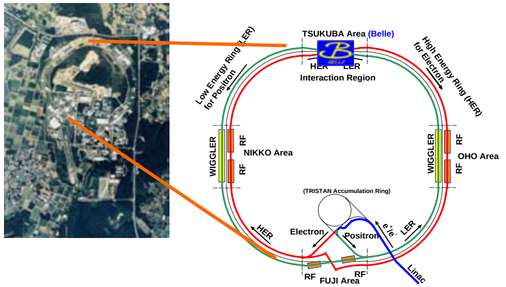
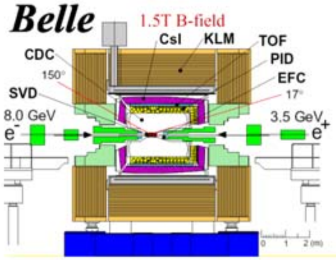
Status of V_{ub} from Belle



Youngjoon Kwon
Yonsei University
for the Belle collaboration



Course

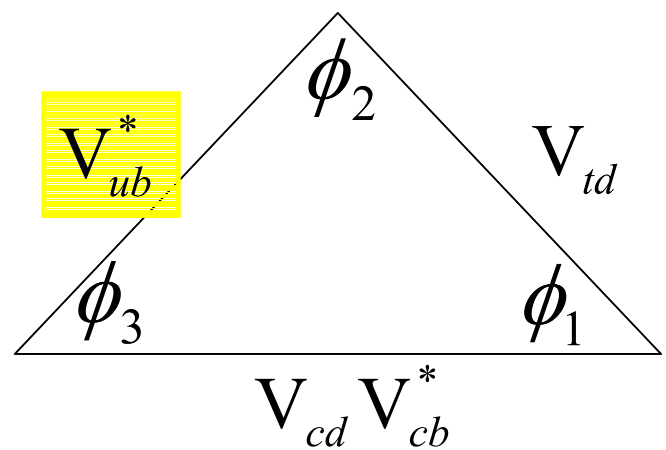
- Appetizer: *W*-annihilation modes with V_{ub} vertex
- Entree: decay modes that we (can) use to measure V_{ub}
- Dessert: to finish with something sweet

The Unitarity Trianlge

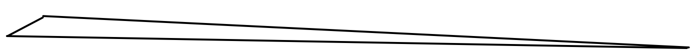
$$\mathbf{V}_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$V_{ud} V_{ub}^{*} + V_{cd} V_{cb}^{*} + V_{td} V_{tb}^{*} = 0$$

$$V_{ud} \cong V_{tb} \cong 1$$



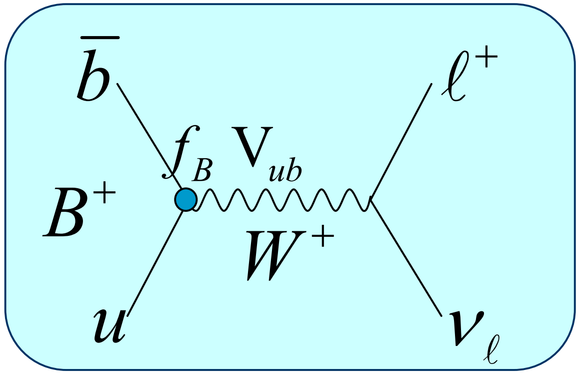
* *other triangles are difficult to measure*



W-annihilation decays with V_{ub} vertex

- The cleanest mode with V_{ub} vertex is fully leptonic *B* decays

$$B^+ \to \ell^+ \nu_\ell$$

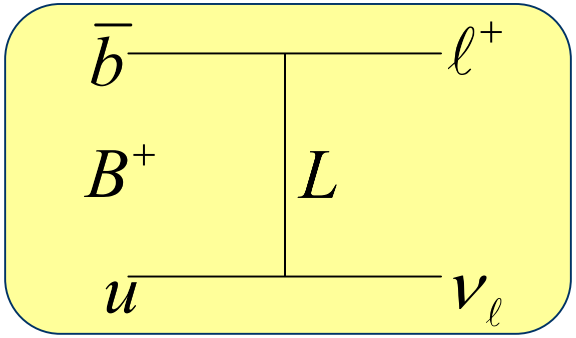


– uncertainty in f_B

– BF is very small for $\ell = e,\ \mu$
(helicity suppression)

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

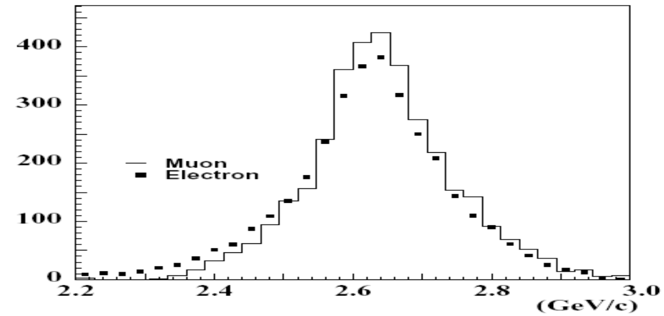
– or experimentally very messy due to multiple neutrinos for $B \to \tau\nu$



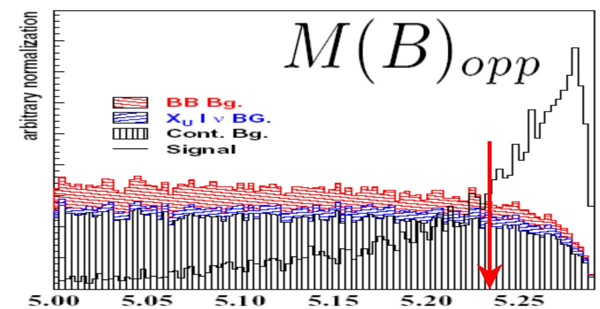
– a good place to search for new physics

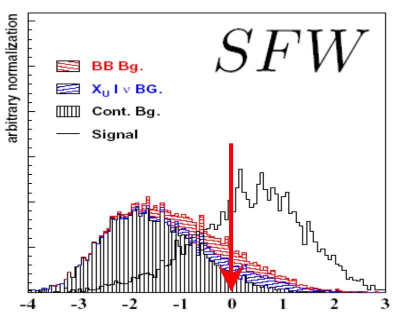
$B^+ \to \ell^+ \nu_\ell$ Event Selection

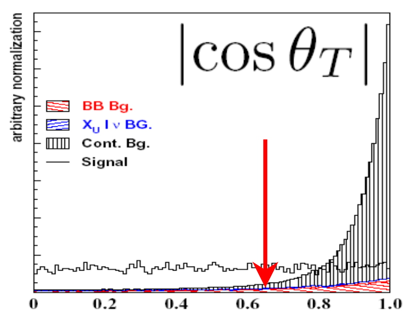
- Main feature
  - a monochromatic lepton in B rest frame
  - $2.2 < p_\ell^* < 2.9$ (GeV/c)

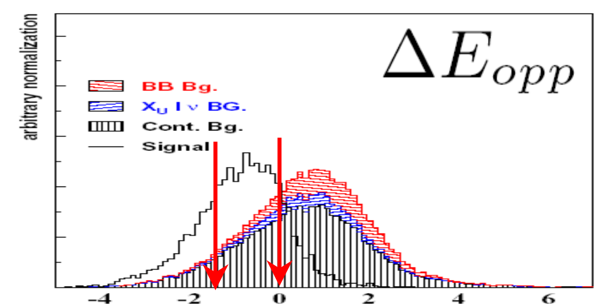


- Background suppression
  - $M(B)_{opp} > 5.23$ GeV/c^2
  - $-1.5 < \Delta E_{opp} < 0.0$ GeV
  - $SFW > 0$ and $|\cos\theta_T| < 0.65$ for continuum suppression









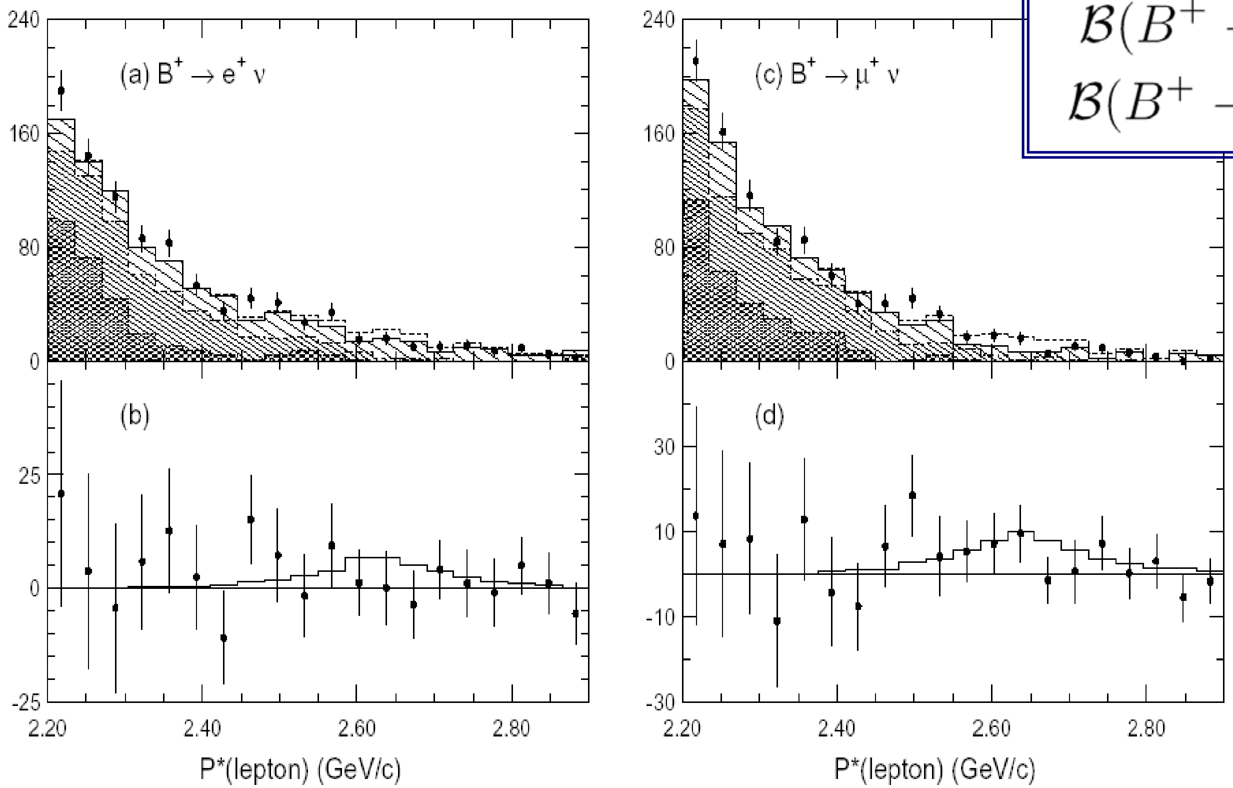
$B^+ \to \ell^+ \nu_\ell$ Results

Preliminary

- Fitting p_l distribution
  - no evidence of signals => 90% CL upper limits

$$\mathcal{B}(B^+ \to e^+\nu_e) < 5.4 \times 10^{-6}$$
$$\mathcal{B}(B^+ \to \mu^+\nu_\mu) < 6.8 \times 10^{-6}$$

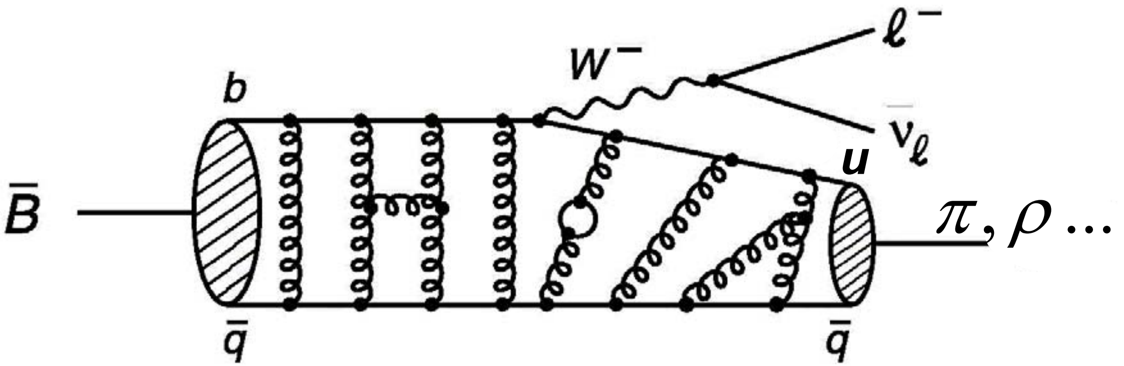
$$\int L_{ON} dt = 60\, fb^{-1}$$



Semileptonic *B* decays for V_{ub}

- Semileptonic *B* decays provide the best opportunity for measuring $|V_{ub}|$

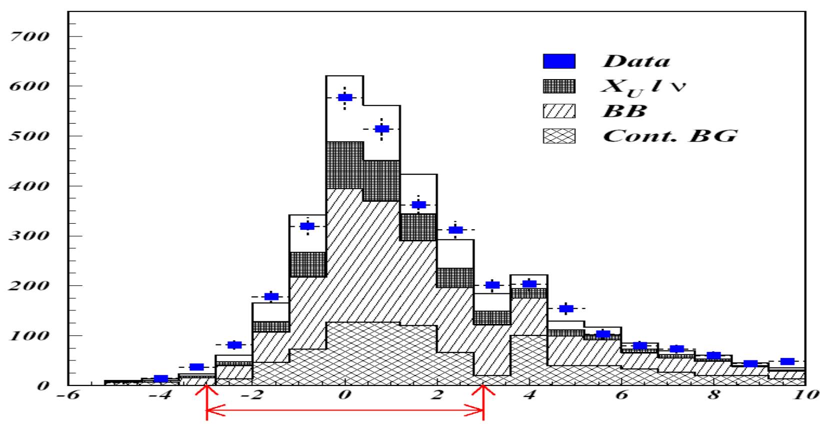
  - *strong interaction effects are much simplified due to the two leptons in the final state*



V_{ub} from $B^0 \to \pi^- l^+ \nu$

- use detector hermeticity to "measure" undetected neutrino
- the events should be consistent with
  - **hermeticity** assumption

    $|Q_{total}| < 2$; only one ID'ed lepton ; $17^o < \theta_{miss} < 150^o$
  - only one missing neutral particle = ***neutrino***

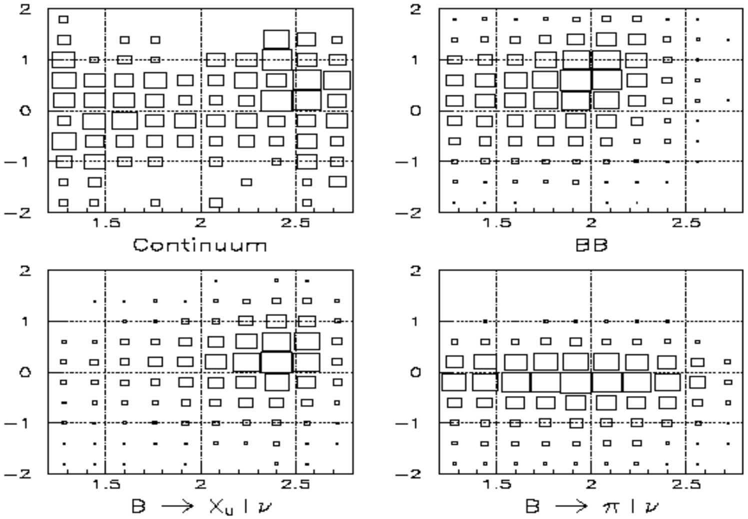


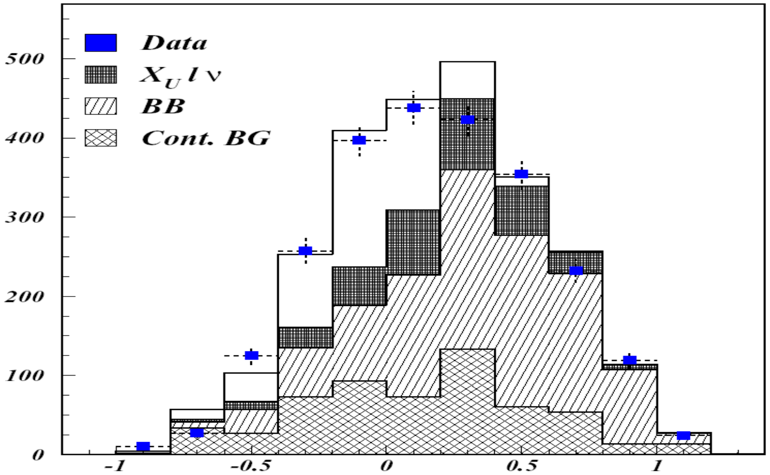
- attribute missing (E,p) to the neutrino

$B^0 \to \pi^- l^+ \nu$

$$\int L_{ON} dt = 60\, fb^{-1}$$
$$\int L_{OFF} dt = 9\, fb^{-1}$$

- Other requirements
  - $1.2 < p_\ell < 2.8$ GeV/c
  - $|p_\ell| + |p_\pi| > 3.3$ GeV/c
  - $q^2_{\rm obs} > 1.5$ GeV^2
  - $R2 < 0.35$, $|\cos\theta_T| < 0.8$
  - $|\cos\theta_{B-\pi\ell}| < 1$
  - best candidate based on M_{bc}
  - then, $M_{bc} > 5.25$ GeV/c^2
- Signal yield is extracted by binned max. likelihood fit to ΔE and p_ℓ





Preliminary

BF($B^0 \to \pi^- l^+ \nu$) & V_{ub}

- Need models
  - to obtain efficiency, hence $\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell)$
  - to calculate $|V_{ub}|$

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = \tau_{B^0} \Gamma(B^0 \to \pi^- \ell^+ \nu_\ell) = \tau_{B^0} \gamma_\pi |V_{ub}|^2$$

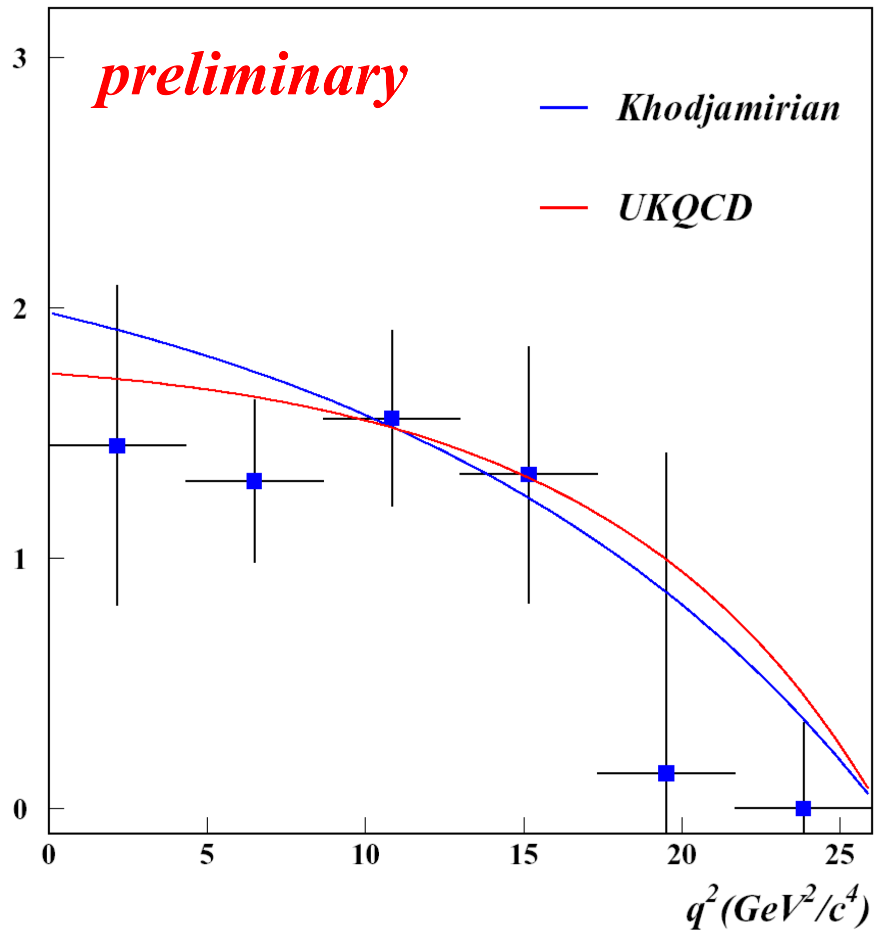
$$\tau_{B^0} = 1.554 \pm 0.036 \text{ps (Belle 2002)}$$

(Khodjamirian *et al.*)

model	UKQCD	LCSR
Reference	PLB 486, 111 (2000)	PRD 62, 114002 (2000)
good for	large q^2	small q^2
γ_π	9^{+3+2}_{-2-2}	7.3 ± 2.5
effi. (%)	2.9	3.1
$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell)$	$(1.35 \pm 0.11 \pm 0.21) \times 10^{-4}$	$(1.31 \pm 0.11 \pm 0.20) \times 10^{-4}$
$\lvert V_{ub}\rvert$	$(3.11 \pm 0.13 \pm 0.24 \pm 0.56) \times 10^{-3}$	$(3.58 \pm 0.15 \pm 0.28 \pm 0.63) \times 10^{-3}$

q^2 distribution of $B \to \pi\, l\, \nu$

$d\Gamma / dq^2 (/10^2 \mathrm{ns}^{-1} / 4.3\mathrm{GeV}^2 / c^4)$



Unfolding of true q^2 distribution from observed distribution, by considering **efficiency**/**smearing**

Belle-CONF-0242

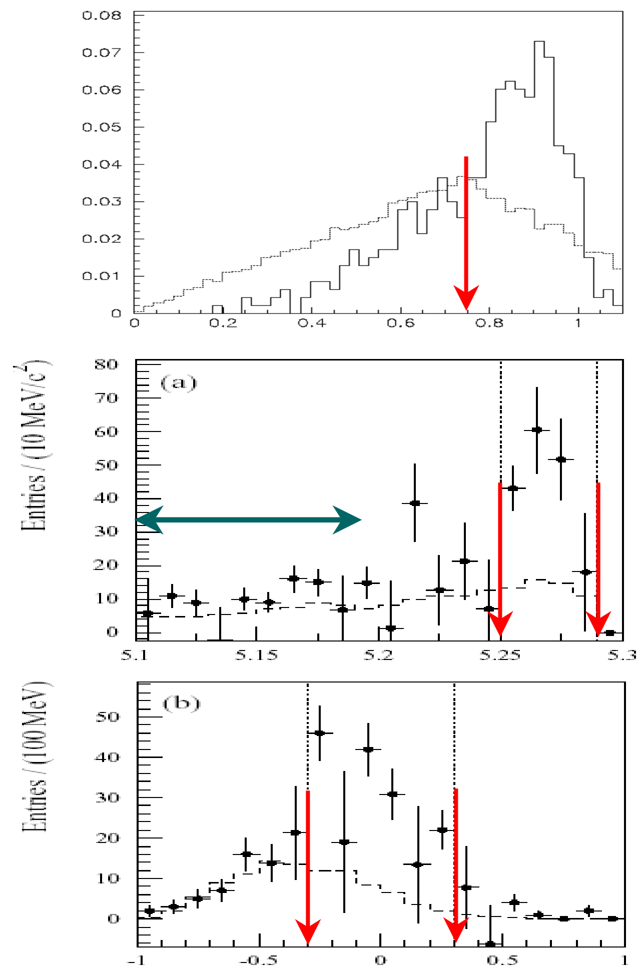
$B^+ \to \omega e^+ \nu$

$\int L_{ON} dt = 60\, fb^{-1}$

$\int L_{OFF} dt = 6\, fb^{-1}$

E2

- Hermeticity requirement
  - ⋆ $|Q_{\rm total}| \leq 2$
  - ⋆ single lepton with $p_\ell > 2.2$ GeV/c
  - ⋆ $|M^2_{\rm miss}| < 3.0$ (GeV/c^2)
- Continuum suppression
  - ⋆ $R2 < 0.4$
  - ⋆ energy flow distribution around lepton
- ω selection
  - ⋆ $E_\gamma > 0.03$ GeV ; $0.12 < M(\gamma\gamma) < 0.15$ GeV/c^2
  - ⋆ $p_{3\pi} > 0.3$ GeV/c $\quad p_{\pi^0} > 0.2$ GeV/c
  - ⋆ Dalitz amplitude $|\vec{p}_{\pi^+} \times \vec{p}_{\pi^-}| > 0.75 \times (max)$
- Signal region
  - ⋆ $|\cos\theta_{B-e\omega}| < 1.0$
  - ⋆ $5.25 < M_{bc} < 5.29$ GeV/c^2, $|\Delta E| < 0.3$ GeV
  - ⋆ $5.10 < M_{bc} < 5.19$ GeV/c^2, as a side-band



$B^+ \to \omega e^+ \nu$

- N(events) in the signal region

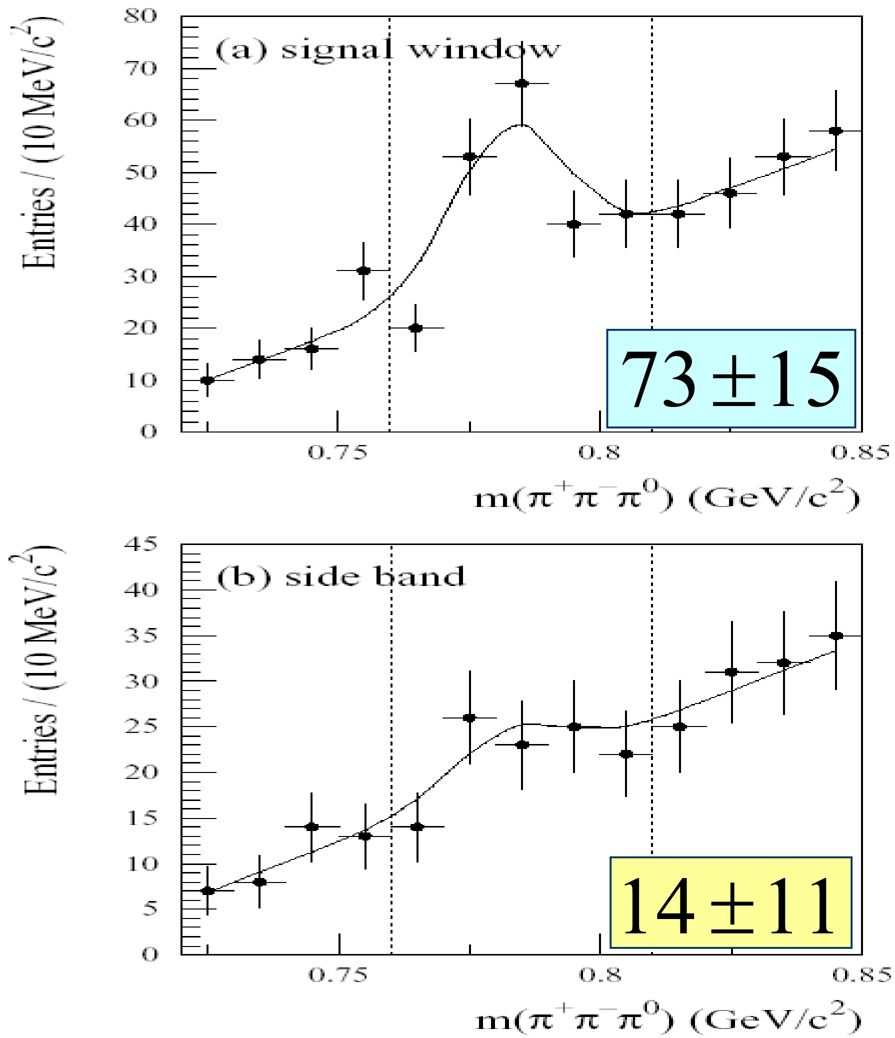
  with $0.76 < m(3\pi) < 0.81$

222 ± 15 (total)	
48 ± 10 $(b \to c)$	MC est.
2 ± 2 (fake)	MC est.
47 ± 21 (cont.)	MC est.

- Excess in $m(3\pi)$

  after side-band subtraction

  $= 59 \pm 15$ events



$B^+ \to \omega e^+ \nu$

- Systematic uncertainties

– background est.	18.0%
– signal fitting	9.2%
– MC statistics	5.1%
– tracking	6.0%
– photon-finding	4.0%
– electron ID	3.0%

– Total: 22.3%

preliminary

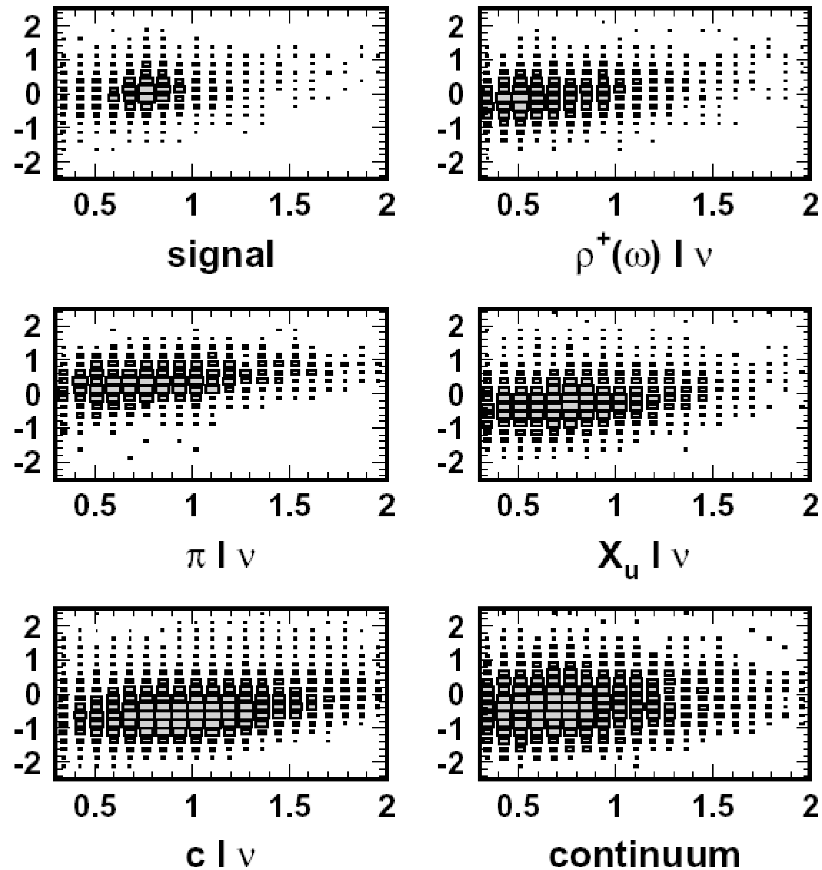
$$\mathcal{B}(B^+ \to \omega e^+ \nu) = (1.4 \pm 0.4 \pm 0.3) \times 10^{-4}$$

$B^+ \to \rho^0 \ell^+ \nu$

- Similar "*neutrino reconstruction*" using hermeticity

$$\begin{aligned} &2.0 < p_\ell < 2.8 \ \text{GeV/c} \\ &|Q_{\text{total}}| \le 2 \\ &-2 < M^2_{\text{miss}} < 4 \quad (\text{GeV}/c^2)^2 \\ &|\cos\theta_{\text{miss}}| < 0.9 \end{aligned}$$

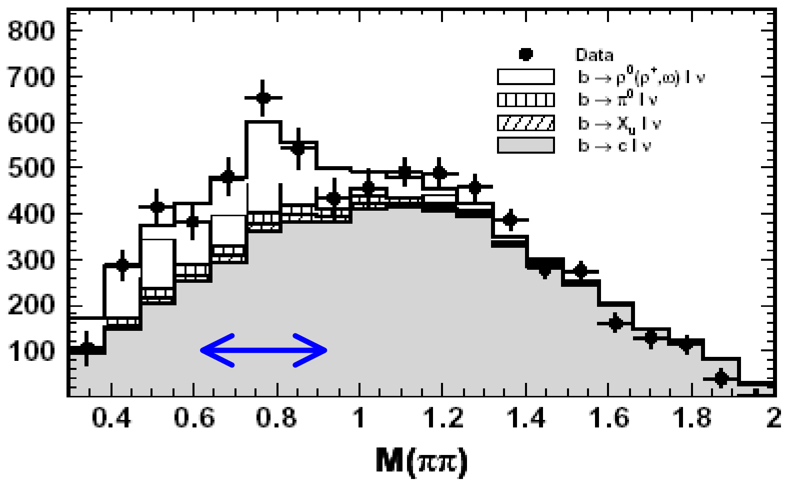
- 2-dim. fit to ΔE vs. M(ππ)

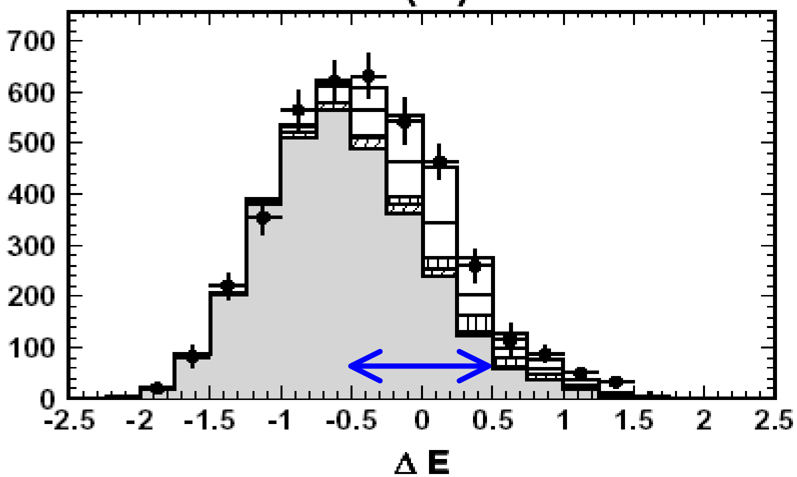


$B^+ \to \rho^0 \ell^+ \nu$

$\int L_{ON} dt = 29\, fb^{-1}$
$\int L_{OFF} dt = 3\, fb^{-1}$

- Projections onto ΔE and M(ππ)





- Tentatively, **using ISGW2** for
  - efficiency, hence BF; and
  - V_{ub}

preliminary

$$\mathcal{B}(B^+ \to \rho^0 \ell^+ \nu) = (1.44 \pm 0.18 \pm 0.23) \times 10^{-4}$$

$$|V_{ub}| = (3.50 \pm 0.20 \pm 0.28) \times 10^{-3}$$

V_{ub} from $B \to D_s^{(*)} X_u$ decays

- Instead of $\ell\bar{\nu}$, we can use $D_s^{(*)}$
- signal B is fully reconstructed $\to$ no need to worry about missing neutrino
- Currently, the largest uncertainty is in the $D_s^+ \to \phi\pi^+$ branching fractions: $\delta\mathcal{B}/\mathcal{B} \approx 25\%$
- Such uncertainties can be removed by taking the ratios, *e.g.*
  (Kim, Kwon, Lee & Namgung, PRD 63, 094506 (2001))

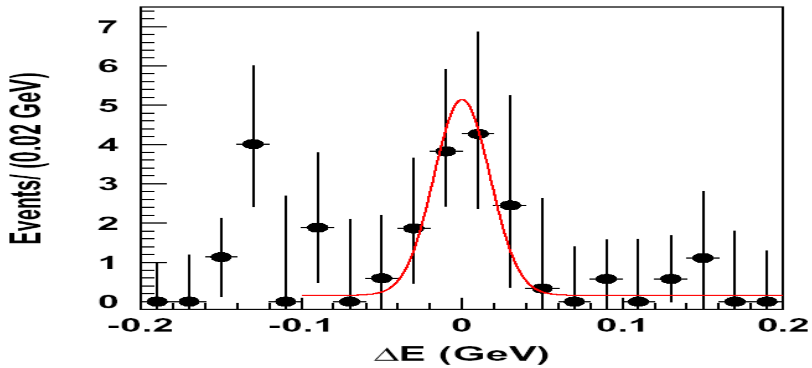
$$\frac{\Gamma(B \to D_s^{(*)}\pi)}{\Gamma(B \to D_s^{(*)}D)}$$

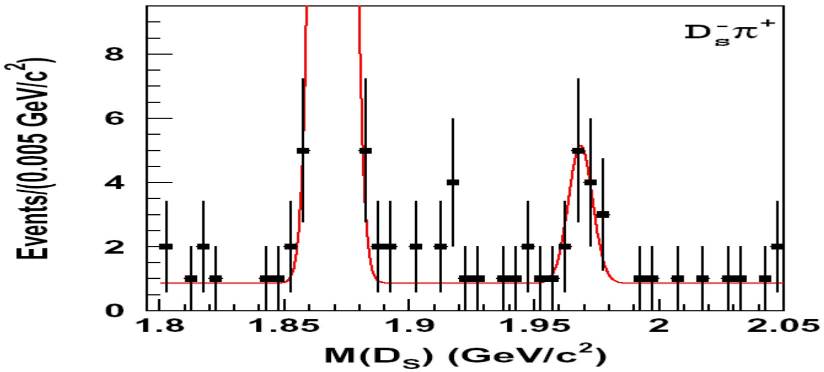
  – Theory error from form factor uncertainty is $O(10\%)$:
    within the generalized factorization scheme; penguin effects are considered

D1

$B^0 \to D_s^+ \pi^-$

$\int L_{ON} dt = 79\, fb^{-1}$
$\int L_{OFF} dt = 8\, fb^{-1}$





- For more details
  $\Rightarrow$ hear P. Krokovny (HQ3)
- D_s^+ decay modes used
  $D_s^+ \to \phi\pi^+,\ K_S^0 K^+,\ \bar{K}^{*0} K^+$
- 2-dim. fit to $\Delta E - M(D_s)$
- consistency check
  $\mathcal{B}(\bar{B}^0 \to D^+\pi^-) = (2.8 \pm 0.2) \times 10^{-3}$

a 3.6 σ significance

preliminary

$$\mathcal{B}(B^0 \to D_s^+ \pi^-) = (2.4^{+1.0}_{-0.8} \pm 0.7) \times 10^{-5}$$

We also have $\mathrm{B}(B^+ \to D_s^{*+}\pi^0) < 1.4 \times 10^{-4}$

preliminary

D1

$|V_{ub}/V_{cb}|$ from $B^0 \to D_s^+\pi^-$

- Using Kim *et al.* (PRD (2001)), with the PDG value of $\mathcal{B}(B^0 \to D_s^+ D^-)$, we calculate the ratio

$$R \equiv \frac{\Gamma(B^0 \to D_s^+\pi^-)}{\Gamma(B^0 \to D_s^+ D^-)} = (0.424 \pm 0.041) \times \left|\frac{V_{ub}}{V_{cb}}\right|^2$$
$$= (3.0^{+1.8}_{-1.6}) \times 10^{-3}$$

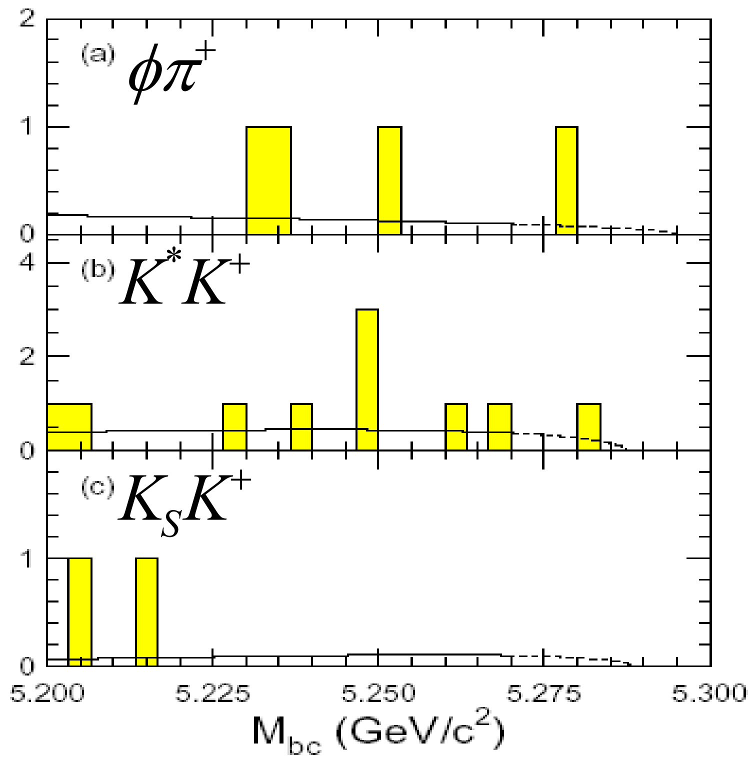
$$\Longrightarrow \boxed{\left|\frac{V_{ub}}{V_{cb}}\right| = 0.084^{+0.025}_{-0.023}}$$

- Using PDG2002 for V_{cb}, $|V_{cb}| = (41.2 \pm 2.0) \times 10^{-3}$

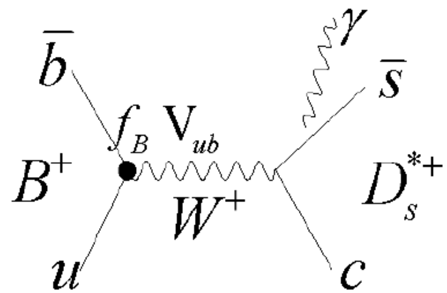
$$\Longrightarrow \boxed{|V_{ub}| = (3.5^{+1.0}_{-0.9}) \times 10^{-3}}$$

$B^+ \to D_s^* \gamma$

$\int L_{ON} dt = 60\, fb^{-1}$



- back to W-annihilation decay with V_{ub} vertex
- $D_s^* \to D_s \gamma$
- same 3 D_s decay modes



Mode	Signal Efficiency(%)	Expected background	Events in signal region	Branching fraction upper limit (90% CL)
$\phi\pi^+$	8.5	0.4 ± 0.3	1	6.1×10^{-5}
$\bar{K}^{*0}K^+$	4.9	1.4 ± 0.5	1	7.3×10^{-5}
$K_S^0 K^+$	4.3	0.4 ± 0.3	0	5.2×10^{-5}
all combined			***preliminary***	2.6×10^{-5}

preliminary

Conclusion (1)

- Belle's new measurements of exclusive $B \to X_u \ell\nu$ semileptonic decays with $\int L dt = 60 \mathrm{fb}^{-1}$
  - $\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.33 \pm 0.11 \pm 0.21) \times 10^{-4}$ (*updated!*)
  - $\mathcal{B}(B^+ \to \omega e^+ \nu) = (1.4 \pm 0.4 \pm 0.3) \times 10^{-4}$ (*new!*)
  - $\mathcal{B}(B^+ \to \rho^0 \ell^+ \nu) = (1.44 \pm 0.18 \pm 0.23) \times 10^{-4}$ ($\int L dt = 29 \mathrm{fb}^{-1}$)
- Evidence of $B^0 \to D_s^+ \pi^-$

$$\mathcal{B}(B^0 \to D_s^+ \pi^-) = (2.4^{+1.0}_{-0.8} \pm 0.7) \times 10^{-5}$$

- upper limits on W-annihilation decay modes
  - $\mathcal{B}(B^+ \to e^+ \nu_e) < 5.4 \times 10^{-6}$
  - $\mathcal{B}(B^+ \to \mu^+ \nu_\mu) < 6.8 \times 10^{-6}$
  - $\mathcal{B}(B^+ \to D_s^{*+} \gamma) < 2.6 \times 10^{-5}$

preliminary

Conclusion (2)

- Calculation of $|V_{ub}|$ from $B^0 \to \pi^- \ell^+ \nu_\ell$ using LCSR and L-QCD models

$$|V_{ub}| = \begin{cases} (3.11 \pm 0.13 \pm 0.24 \pm 0.56) \times 10^{-3} \\ (3.58 \pm 0.15 \pm 0.28 \pm 0.63) \times 10^{-3} \end{cases}$$

UKQCD

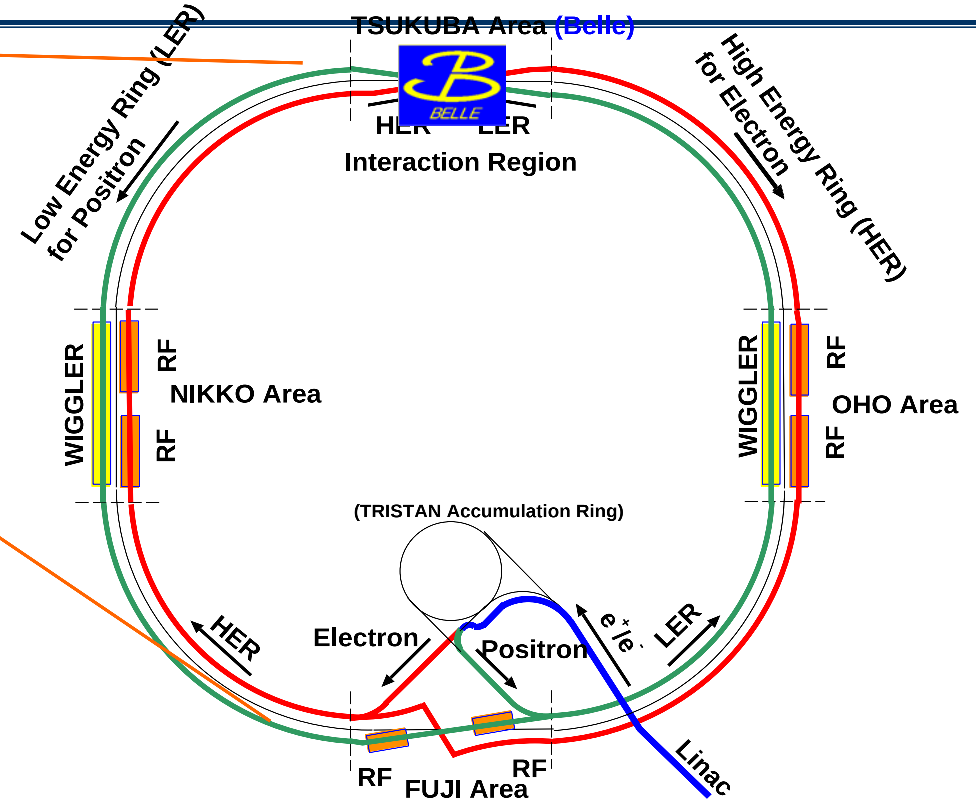
Khodjamirian, et al. **(LCSR)**

- From new measurement of $B^0 \to D_s^+ \pi^-$ and using factorization-based calculation

$$|V_{ub}| = (3.5^{+1.0}_{-0.9}) \times 10^{-3}$$

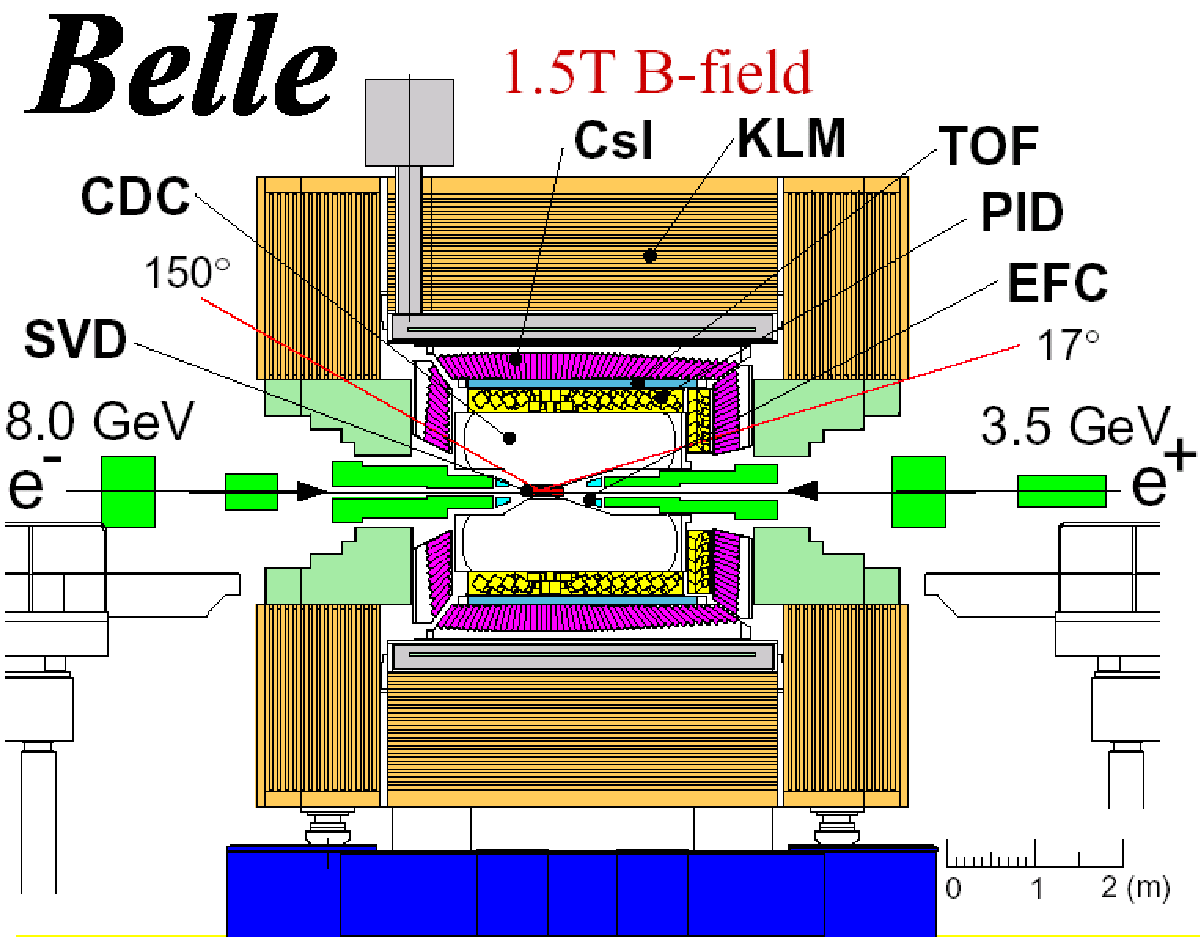
Backup slides

The KEKB Collider



- asymmetric energy
  e^+ (3.5 GeV) e^- (8 GeV)
- design Luminosity = 10^{34} /cm^2/s
- E(cm) = 10.58 GeV on resonance of Υ(4S) production

The Belle detector



SVD: 3 DSSD lyr
$\sigma \sim 55\mu m$

CDC: 50 layers
$\sigma_p/p \sim 0.35\%$
$\sigma_\pi (dE/dx) \sim 7\%$

TOF: $\sigma \sim 95ps$

Aerogel
(n = 1.01 ~ 1.03)
K/π ~3.5 Gev/c

CsI :
$\sigma_E/E_\gamma \sim 1.8\%$

KLM: RPC 14 ly

(@1GeV)