$B \to X_c \ell \nu$ and $B \to X_s \gamma$ Moments from Belle

Christoph Schwanda

Institute for High Energy Physics, Austrian Academy of Sciences, Vienna, Austria

representing the Belle Collaboration

HEP2005 International Europhysics Conference on High Energy Physics

July 21^{st}-27^{th}, 2005 in Lisboa, Portugal

$|V_{cb}|$ from inclusive semileptonic decays

- master formula ($r = m_c^2/m_b^2$)

  $\Gamma(B \to X_c \ell \nu) = \frac{G_F^2 m_b^5}{192\pi^3} |V_{cb}|^2 (1 + A_{\rm ew}) A^{\rm pert}(r,\mu) A^{\rm non-pert}(r,\mu)$

- the electroweak corrections $A_{\rm ew}$ are well-known

  $1 + A_{\rm ew} \approx (1 + \frac{\alpha}{\pi} \ln \frac{M_Z}{m_b})^2 \approx 1.014$ [NPB 71, 29 (1974)]

- the perturbative corrections $A^{\rm pert}$ can be calculated to a given order in α_s

  $A^{\rm pert} \approx 0.908$ for $\sqrt{r} = 0.25$ and $\mu = 1$ GeV [NPB 665, 367 (2003)]

- the non-perturbative corrections $A^{\rm non-pert}$ arise at $\mathcal{O}(1/m_b^2)$ and can be parametrized

- moments in $B \to X_c \ell \nu$ and $B \to X_s \gamma$ decays

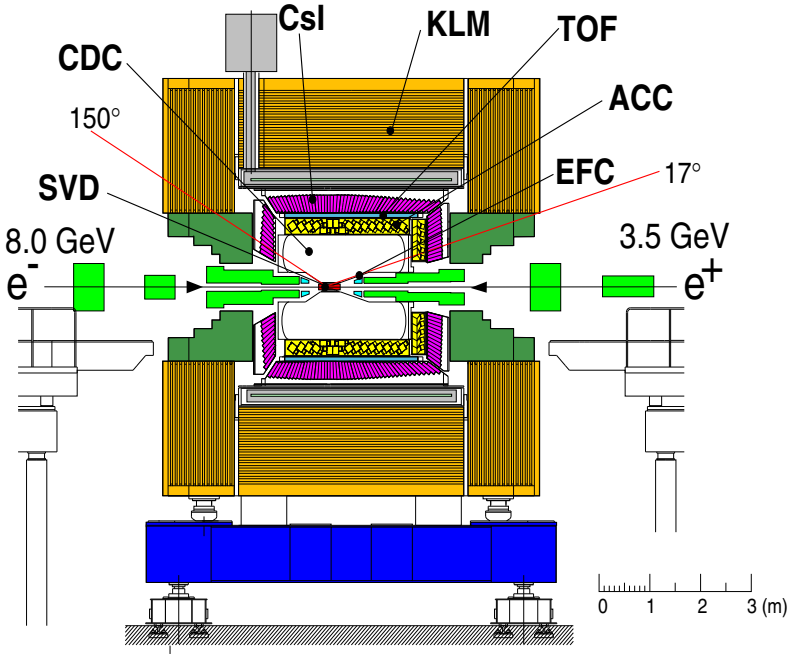
	$B \to X_c \ell \nu$		$B \to X_s \gamma$
	lepton energy	hadronic mass	photon energy
first moment	$\langle E_\ell \rangle$	$\langle M_X^2 \rangle$	$\langle E_\gamma \rangle$
second moment	$\langle (E_\ell - \langle E_\ell \rangle)^2 \rangle$	$\langle (M_X^2 - \langle M_X^2 \rangle)^2 \rangle$	$\langle (E_\gamma - \langle E_\gamma \rangle)^2 \rangle$
third moment	$\langle (E_\ell - \langle E_\ell \rangle)^3 \rangle$		

- expressions for these moments are available in terms of the *same* non-perturbative parameters as in $\Gamma(B \to X_c \ell \nu)$

- strategy: determine the non-perturbative parameters in the $\Gamma(B \to X_c \ell \nu)$ expression through measuring $B \to X_c \ell \nu$ moments

- the exact definition of these non-perturbative parameters depends on the mass scheme used: kinetic scheme [EPJ C34, 181 (2004); NPB 710, 371 (2005)], 1S scheme [PRD 67, 054012 (2003)], ...

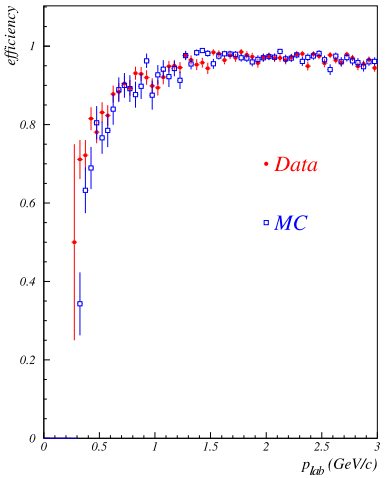
The Belle detector

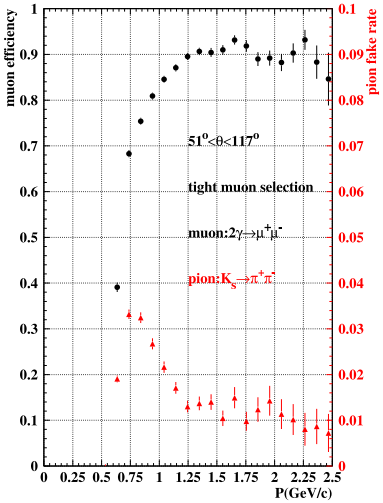


- 1.5 T superconducting solenoid
- Silicon Vertex Detector (SVD)
  3 layers of double-sided strip sensors
- Central Drift Chamber (CDC)
  50 cylindrical layers of anode wires
- Electromagn. Calorimeter (ECL)
  9736 CsI(Tl) crystals

electron id.

- track cluster matching
- E/p
- shower shape
- dE/dx in CDC
- light yield in ACC





muon id.

- range and transverse scattering in KLM

Belle electron energy moment analysis

1. Fully-reconstruct hadronic decays of the tag-side B meson in an $\Upsilon(4S)$ sample of 140 fb^{-1}

2. Identify an electron ($p > 0.4$ GeV/c) within the remaining particles in the event, to select semileptonic decays of the signal-side B
   - require correct charge correlation for B^+ tags

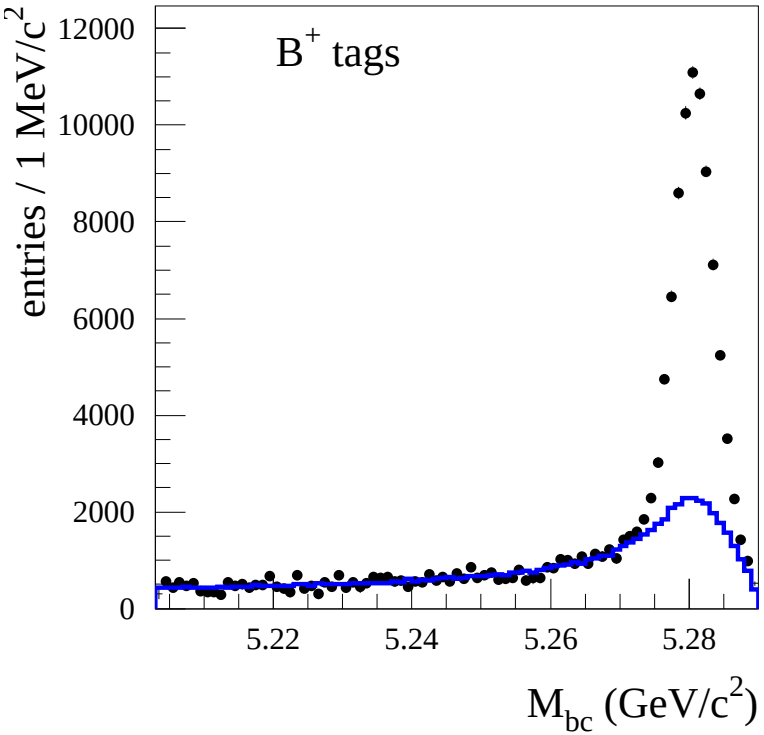
3. Estimate and subtract backgrounds in the electron energy spectrum

4. Apply corrections to the spectrum
   - add back bremsstrahlung photons ($E_\gamma < 1$ GeV) within a 50 mrad cone around the electron direction
   - correct the unfolded spectrum for $b \to u$ transitions

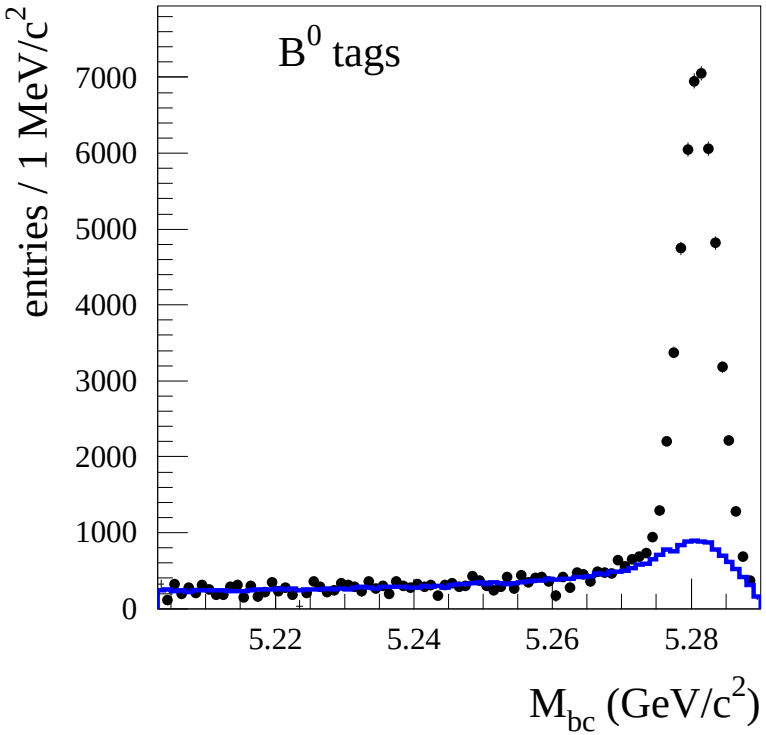
5. Unfold the electron energy spectrum

Full-reconstruction of the tag-side B

$N(B^+) = 63,155 \pm 931$



$N(B^0) = 40,032 \pm 475$

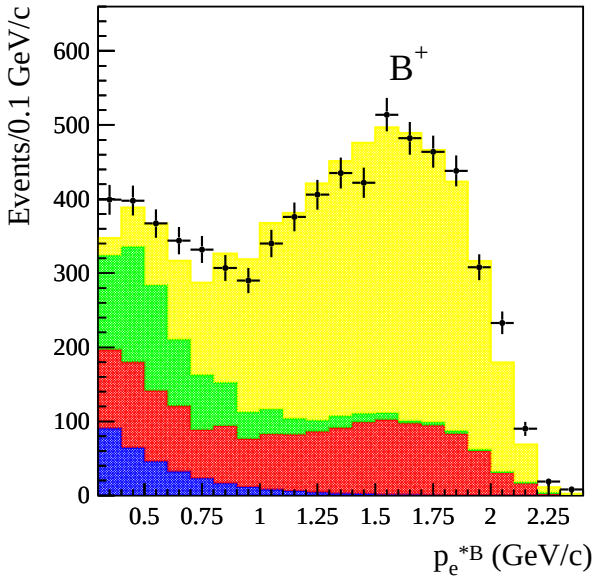


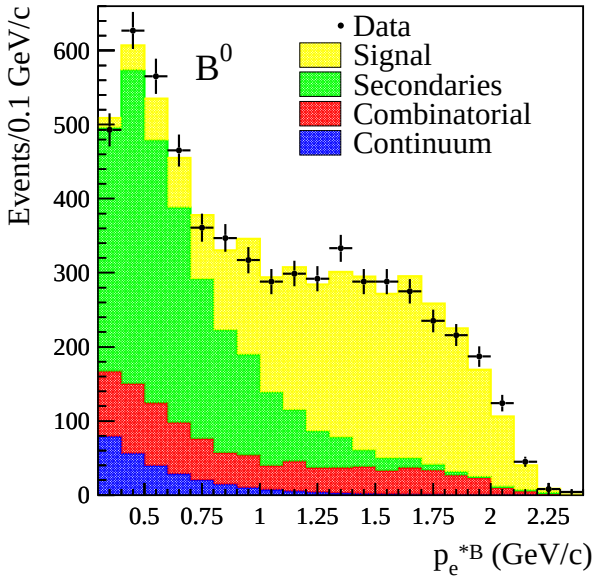
- fully reconstruct the tag-side B meson by searching the decay modes $B \to D^{(*)}\pi$, $D^{(*)}\rho$ and $D^{(*)}a_1$

Background subtraction

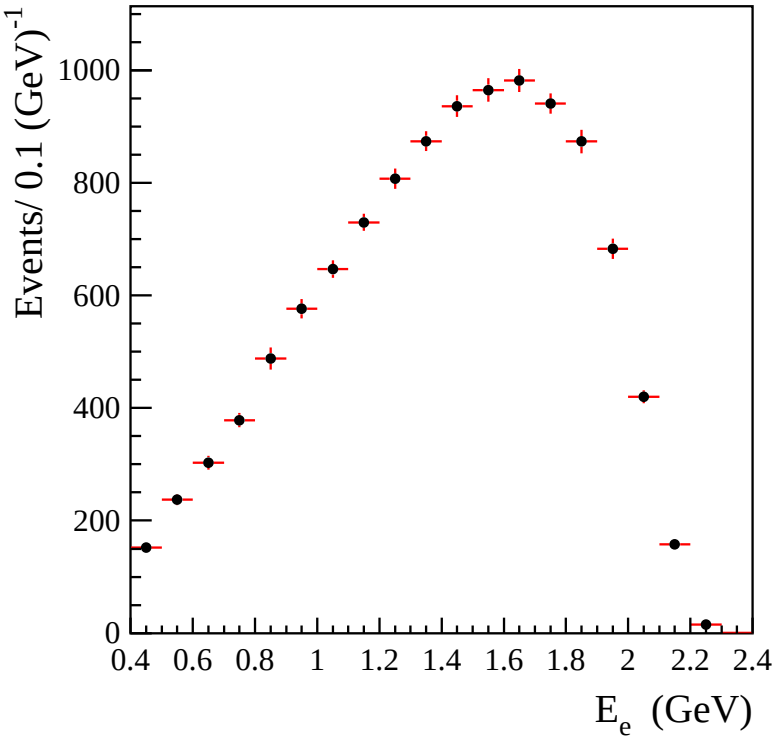
- electron yields for $p > 0.4$ GeV/c (in the B rest frame)

	B^+ tags	B^0 tags
on-resonance data	6573 ± 81	5564 ± 75
scaled off-resonance	258 ± 16	218 ± 15
misreconstructed tags	1394 ± 38	765 ± 28
secondaries	680 ± 26	1915 ± 44
hadron fakes	94 ± 10	93 ± 10
background subtracted	4240 ± 99	2665 ± 108





Unfolding



- finite detector resolution unfolded using the SVD algorithm by A.Höcker and V.Kartvelishvili [NIM A372, 469 (1996)]
- done separately for B^+ and B^0 tags
- unfolded spectrum corrected for remaining QED radiative effects using PHOTOS

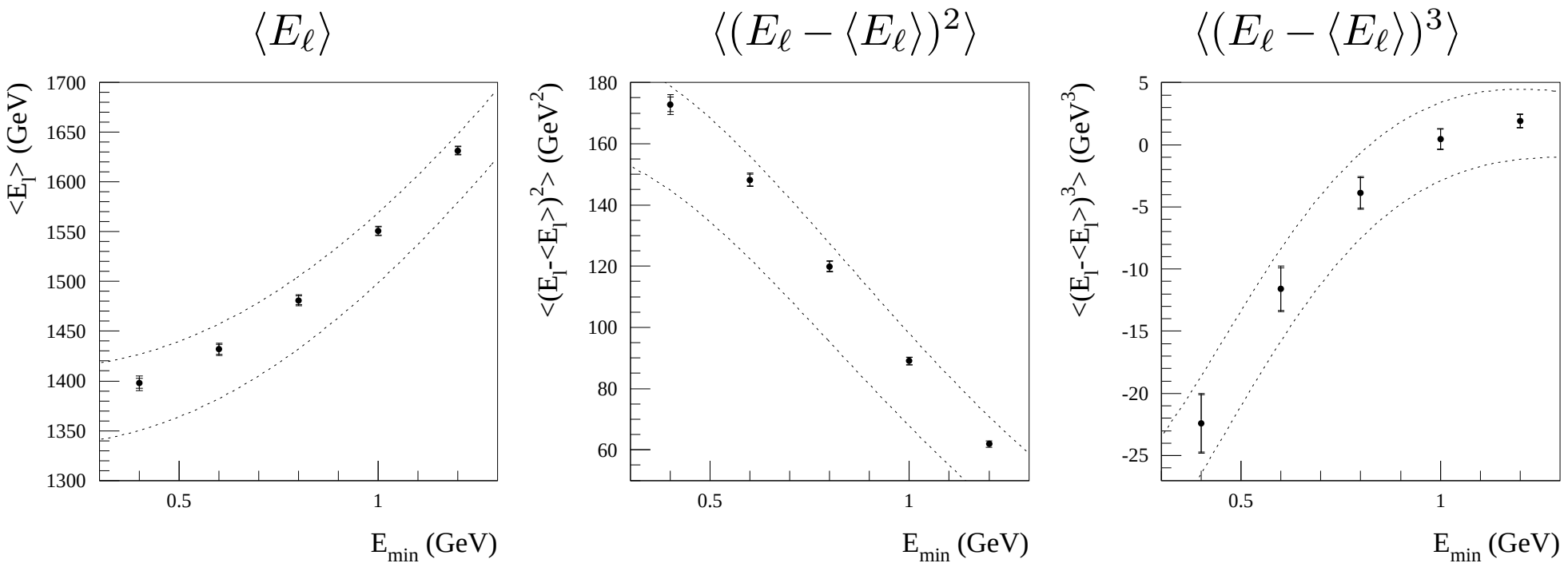
Results and systematic uncertainties

- moments calculated from unfolded spectrum for different minimum electron energies in the B rest frame

preliminary

E_{min} (GeV)	$\langle E_\ell \rangle$ (GeV)	$\langle (E_\ell - \langle E_\ell \rangle)^2 \rangle$ (GeV^2)	$\langle (E_\ell - \langle E_\ell \rangle)^3 \rangle$ (GeV^3)
0.4	$1397.7 \pm 5.1 \pm 5.4$	$172.8 \pm 2.4 \pm 2.2$	$-22.40 \pm 2.30 \pm 0.72$
0.6	$1431.8 \pm 4.8 \pm 4.3$	$148.2 \pm 1.9 \pm 1.2$	$-11.60 \pm 1.71 \pm 0.63$
0.8	$1481.0 \pm 4.4 \pm 3.4$	$119.9 \pm 1.6 \pm 0.9$	$-3.87 \pm 1.21 \pm 0.55$
1.0	$1550.8 \pm 4.0 \pm 2.9$	$89.0 \pm 1.2 \pm 0.4$	$0.45 \pm 0.80 \pm 0.31$
1.2	$1631.6 \pm 3.6 \pm 2.2$	$61.9 \pm 0.9 \pm 0.6$	$1.91 \pm 0.53 \pm 0.15$
1.5	$1775.8 \pm 3.0 \pm 2.3$	$29.4 \pm 0.6 \pm 0.3$	$1.57 \pm 0.19 \pm 0.07$

- systematics (second error) include: $b \to c$ model, background subtraction, unfolding
- the individual measurements are highly correlated due to overlapping data samples; correlations have been estimated (refer to BC-0558)



- theory curves are from P.Gambino and N.Uraltsev [EPJ C34, 181 (2004)]

Belle hadronic mass moment analysis

1. Fully-reconstruct hadronic decays of the tag-side B meson in an $\Upsilon(4S)$ sample of 140 fb^{-1}

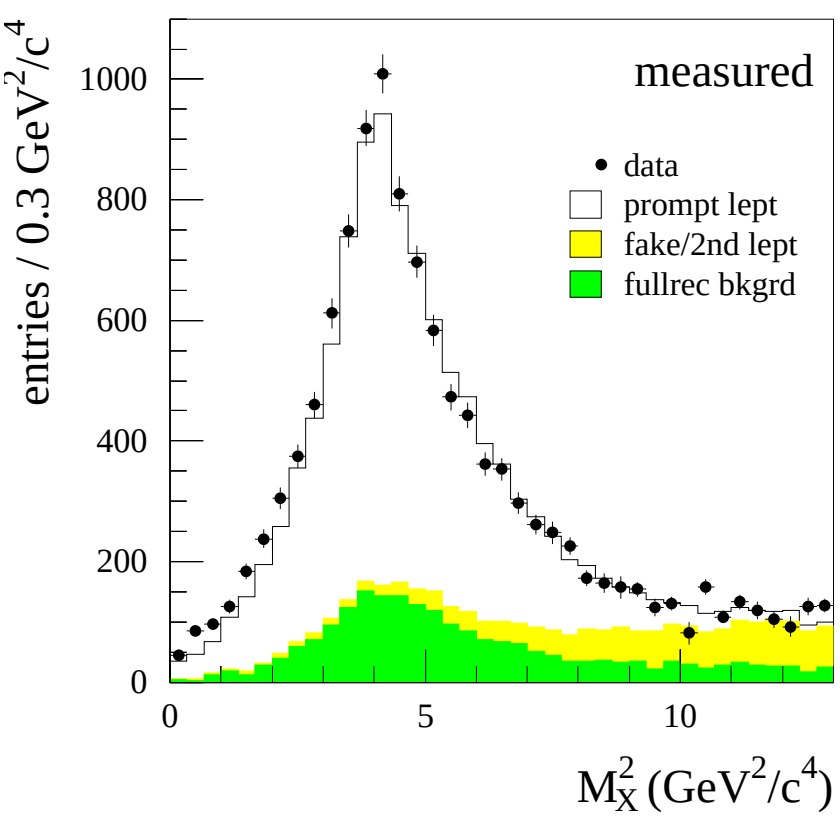
2. Select events with exactly one identified lepton (electron or muon) within the remaining particles in the event
   - require correct charge correlation for B^+ tags

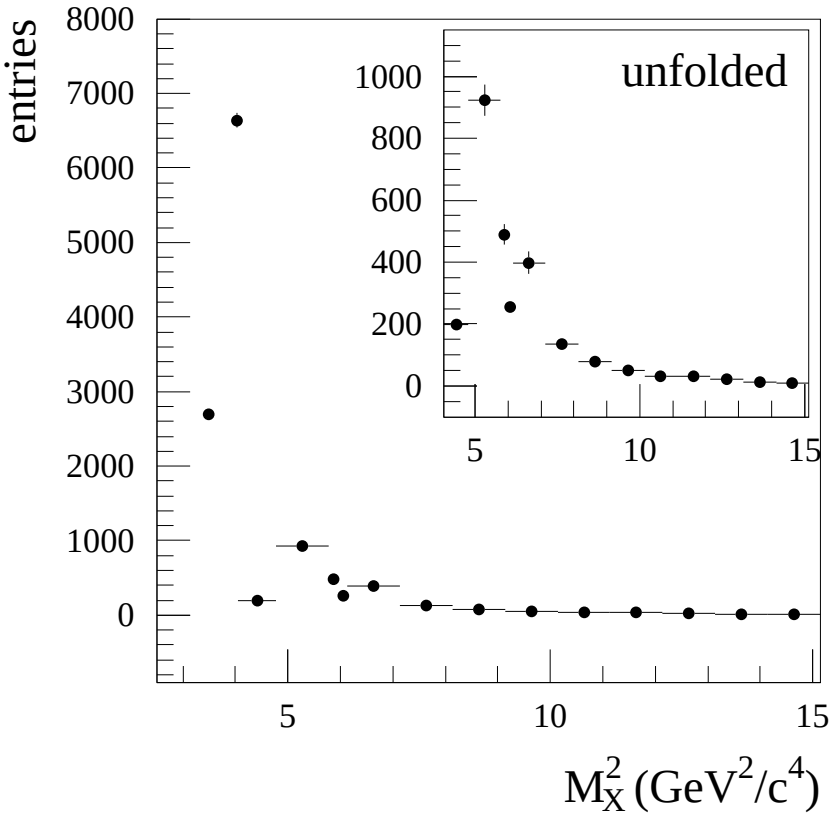
3. Reconstruct the hadronic system recoiling against $\ell\nu$
   - $M^2_{\rm miss} < 3$ GeV$^2/c^4$
   - constrain neutrino mass to zero
   - $p_X = p_{\rm beam} - p_{B_{\rm tag}} - p_\ell - p_\nu$

4. Estimate and subtract backgrounds in the M^2_X spectrum

5. Unfold the M^2_X spectrum and calculate moments

Measured and unfolded M_X^2 spectrum for $p > 0.7$ GeV/c





- M_X^2 resolution ≈ 800 MeV/c^2

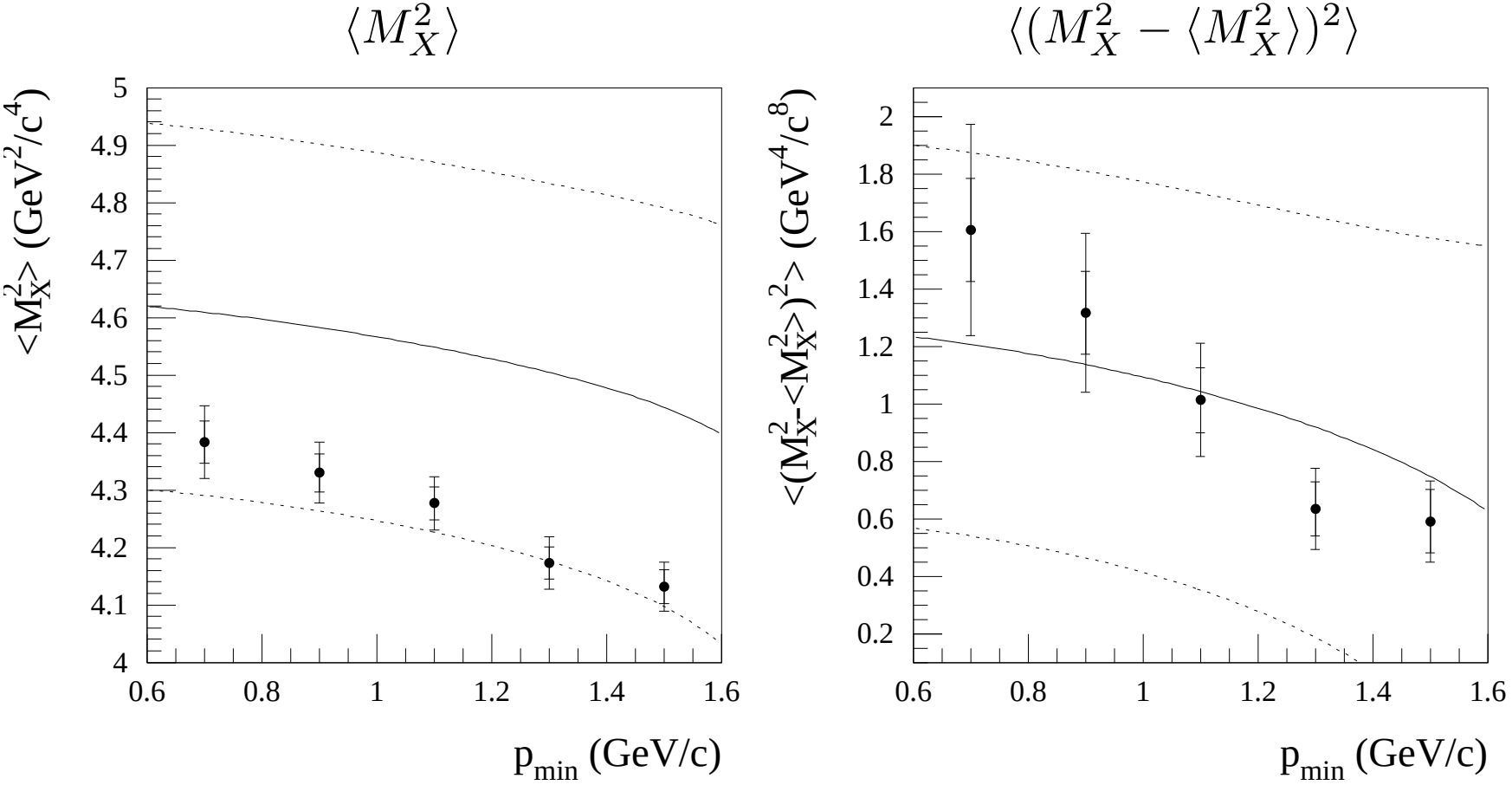
Results and systematic uncertainties

- moments calculated from unfolded spectra for different minimum lepton momenta in the B rest frame

preliminary

p_{min} (GeV/c)	$\langle M_X^2 \rangle$ (GeV/c^2)	$\langle (M_X^2 - \langle M_X^2 \rangle)^2 \rangle$ (GeV^2/c^4)
0.7	$4.383 \pm 0.037 \pm 0.051$	$1.605 \pm 0.179 \pm 0.322$
0.9	$4.330 \pm 0.033 \pm 0.041$	$1.317 \pm 0.144 \pm 0.236$
1.1	$4.277 \pm 0.029 \pm 0.035$	$1.013 \pm 0.113 \pm 0.161$
1.3	$4.173 \pm 0.028 \pm 0.037$	$0.634 \pm 0.095 \pm 0.105$
1.5	$4.132 \pm 0.030 \pm 0.031$	$0.591 \pm 0.110 \pm 0.088$

- systematics (second error) include: $b \to c$ model, background subtraction, unfolding
- the individual measurements are highly correlated due to overlapping data samples; correlations have been estimated (refer to BC-0557)



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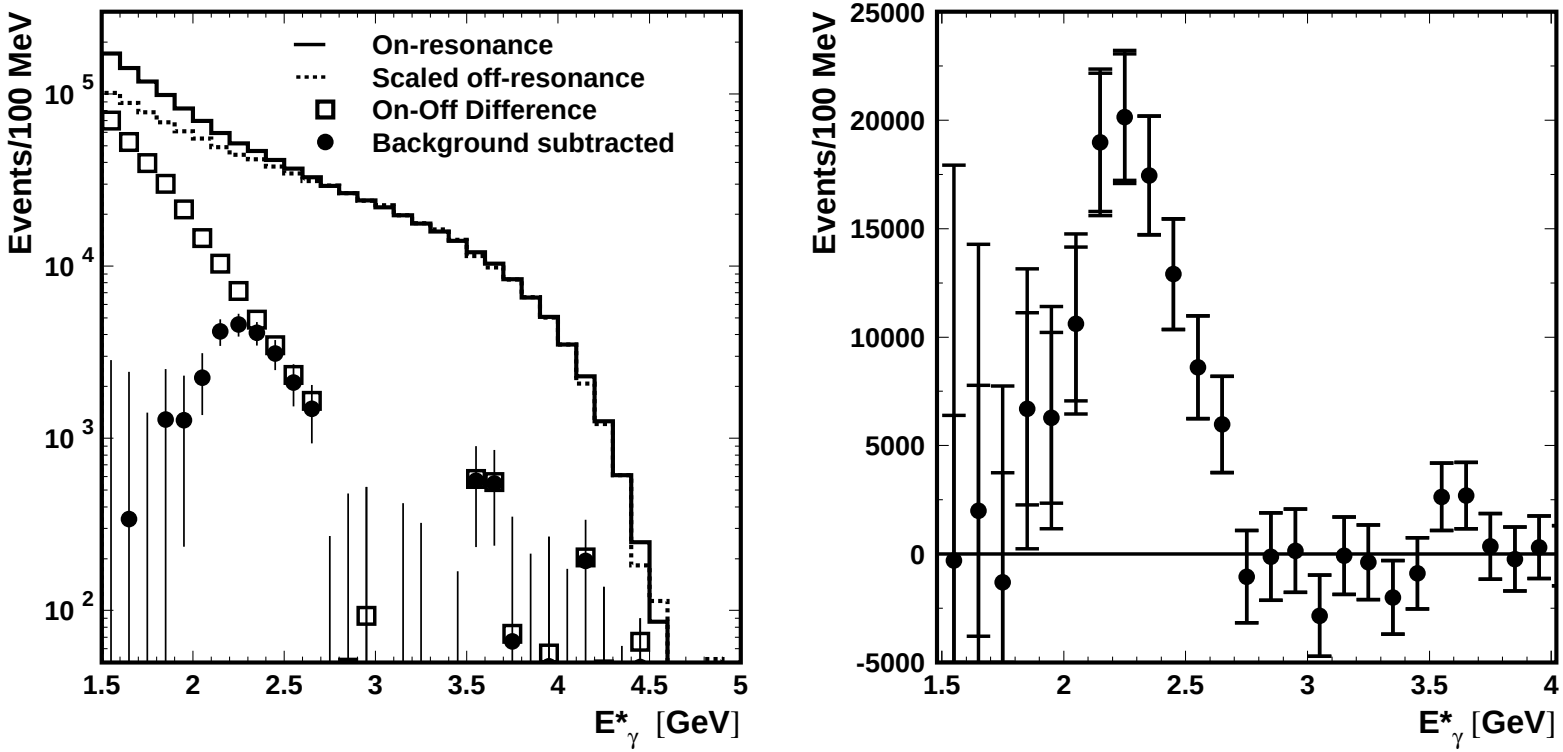
P.Koppenburg et al. (Belle Collab.)

[PRL 93, 061803 (2004)]



$B \to X_s\gamma$ moments from measured spectrum

- corrections

	$\langle E_\gamma \rangle$	$(E_\gamma - \langle E_\gamma \rangle)^2$
B meson boost	$\frac{\Delta E_{\rm boost}}{\langle E_\gamma \rangle} = 1 - \frac{m_{\Upsilon(4S)}}{2m_B} \approx 0.002$	$\left(\frac{\langle E^*_\gamma \rangle \lvert \vec{p}_B \rvert}{\sqrt{3} m_B}\right)^2 \approx 0.006$ GeV^2
binning		$\left(\frac{1}{\sqrt{12}} 0.1\text{GeV}\right)^2 \approx 0.0008$ GeV^2
energy resolution		$(\delta_{\rm ECL} \langle E^*_\gamma \rangle)^2 \approx 0.004$ GeV^2

- residual bias is estimated and corrected using signal Monte Carlo

$E_{\rm min}$ (GeV)	$\delta\langle E_\gamma \rangle$ (%)	$\delta(E_\gamma - \langle E_\gamma \rangle)^2$ (%)
1.8	+2.0	0.0
2.0	+1.2	−7.1
2.3	−0.3	−57.9

Results and systematic uncertainties

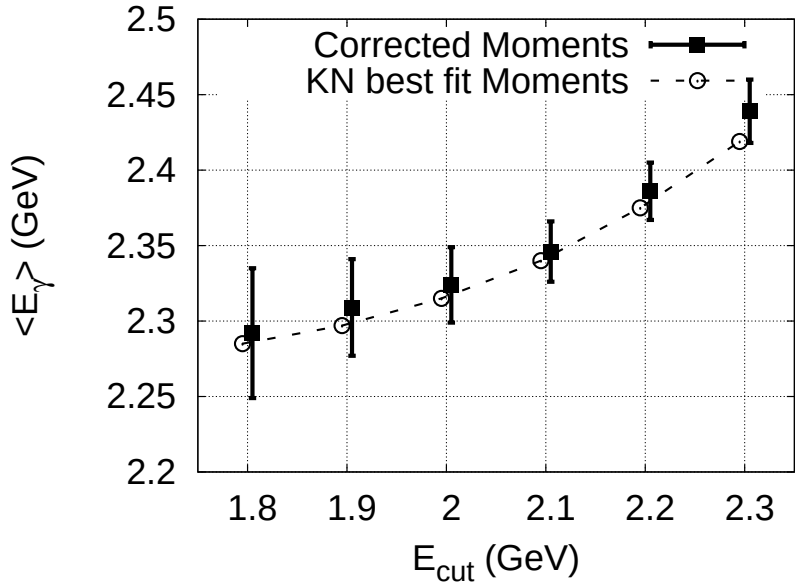
- photon energy moments for different minimum photon energies in the B rest frame

preliminary

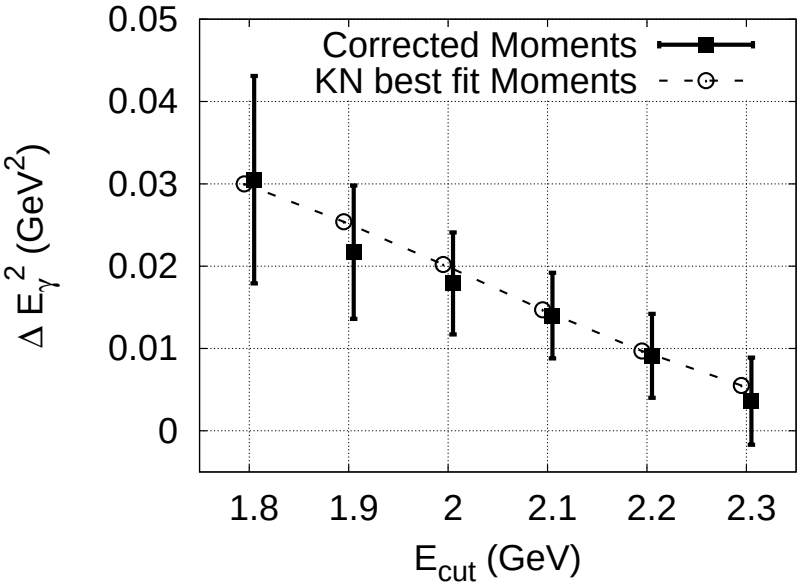
$E_{\rm min}$ (GeV)	$\langle E_\gamma \rangle$ (GeV)	$\langle (E_\gamma - \langle E_\gamma \rangle)^2 \rangle$ (GeV^2)
1.8	$2.292 \pm 0.027 \pm 0.033$	$0.0305 \pm 0.0079 \pm 0.0099$
1.9	$2.309 \pm 0.023 \pm 0.023$	$0.0217 \pm 0.0060 \pm 0.0055$
2.0	$2.324 \pm 0.019 \pm 0.016$	$0.0179 \pm 0.0050 \pm 0.0036$
2.1	$2.346 \pm 0.017 \pm 0.010$	$0.0140 \pm 0.0046 \pm 0.0024$
2.2	$2.386 \pm 0.018 \pm 0.005$	$0.0091 \pm 0.0045 \pm 0.0025$
2.3	$2.439 \pm 0.020 \pm 0.004$	$0.0036 \pm 0.0045 \pm 0.0028$

- systematics (second error) include: systematics from $B \to X_s\gamma$ spectrum, bias correction, energy resolution
- the individual measurements are highly correlated; refer to BC-0535 for the correlation coefficients

$\langle E_\gamma \rangle$



$\langle (E_\gamma - \langle E_\gamma \rangle)^2 \rangle$



- curves calculated from generated photon spectra using our best fit parameter: $m_b(\mathrm{KN}) = 4.62\ \mathrm{GeV}/c^2$ and $\mu_\pi^2(\mathrm{KN}) = 0.40\ \mathrm{GeV}^2/c^2$

Summary

- Belle has extended the $B \to X_c \ell \nu$ moment analyses, measuring now E_ℓ moments up to the third and M_X^2 moments up to the second moment
- This improves the sensitivity to the $1/m_b^3$ non-perturbative corrections
- We have also determined the first and second $B \to X_s \gamma$ moment for minimum photon energies ranging from 1.8 to 2.3 GeV
- For each analysis, the correlations between moment measurements at different thresholds have been estimated