Super KEKB and Belle II
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(on behalf of the Belle II collaboration)

Outline of the talk:

- Physics Motivation
- Accelerator Upgrade: SuperKEKB
- Detector Upgrade: Belle II
- Conclusions
**B- Factories (KEKB&PEP-II): A Success Story**

Discovery of CP violation in the B system

- $B^0 \rightarrow J/\psi K^0$
- $\bar{B}^0 \rightarrow J/\psi K^0$

Asymmetry $= (\bar{N}-N) / (\bar{N}+N)$

Measurements of the CKM matrix elements

PDG 2008
“... As late as 2001, the two particle detectors BaBar at Stanford, USA and Belle at Tsukuba, Japan, both detected broken symmetries independently of each other. The results were exactly as Kobayashi and Maskawa had predicted almost three decades earlier.”
Already a Year earlier

The High Energy and Particle Physics Prize

2007
Makoto Kobayashi, Toshihide Maskawa

For the proposal of a successful mechanism for CP violation in the Standard Model, predicting the existence of a third family of quarks.
Further Continuation of Flavour Physics possible at a Super B Factory

- What is the next experimental step? Precision measurements
  - Much larger sample needed for this purpose \(\rightarrow\) Super B factory

- Hopefully new phenomena might be seen:
  - CPV in $B$ decays from the physics outside the KM scheme.
  - Lepton flavor violations in $\tau$ decays.

- Physics models can be identified (if new effects are observed) or new ones can be constrained (if nothing is seen).

- Even in the worst case scenario (e.g. for MFV), $B \rightarrow \tau\nu$, $D\tau\nu$ can probe the charged Higgs in the large $\tan\beta$ region.

- Physics motivation is independent of LHC.
  - If LHC finds NP, precision flavour physics is compulsory.
  - If LHC finds no NP, high statistics $B/\tau$ decays would be a unique way to search for the TeV scale physics.
How to do it? Upgrade KEKB & Belle
The KEKB Collider & Belle Detector

- $e^-$ (8 GeV) on $e^+$ (3.5 GeV)
  - $\sqrt{s} \approx m_{\Upsilon(4S)}$
  - Lorentz boost: $\beta\gamma = 0.425$
- 22 mrad crossing angle
- Operating since 1999

Peak luminosity (WR!): $2.1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
The KEKB Performance

Luminosity Records:

- Peak $L = 2.1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ (2x the design value)
- Daily $\int L dt = 1.5 \text{ fb}^{-1}$ (2.5 x the design value)
- Total $\int L dt \sim 950 \text{ fb}^{-1}$ (as of July 2009)
Crab Cavities

RF deflector (crab cavity)

Kick

electrons

positrons

crossing angle

head-on collision

Crab crossing

Installed in KEKB (Feb. 2007)
Luminosity Prospects

Results from Belle II @
~10ab⁻¹
LHC(b)
Prospects of ILC...

3-year shutdown
for upgrade

10ab⁻¹ (initial target) ~ 2016

50ab⁻¹ by ~2020

L~2x10^{35} cm^{-2}s^{-1}

L~8x10^{35} cm^{-2}s^{-1}
Strategies for Increasing Luminosity

L = \frac{\gamma_{e^\pm}}{2er_e} \left( 1 + \frac{\sigma^*_y}{\sigma^*_x} \left( \frac{I_{e^\pm\xi_y}}{\beta^*_y} \right) \right) \left( \frac{R_L}{R_{\xi_y}} \right)

(1) Smaller $\beta^*_y$
(2) Increase beam currents
(3) Increase $\xi_y$

High-Current Option

Nano-Beam Option

Lumi. reduction factor (crossing angle) &
Tune shift reduction factor (hour glass effect) 0.8 ~ 1 (short bunch)

Vertical beta function@IP

Beam size ratio@IP 1 ~ 2 % (flat beam)

Classical electron radius

Beam current

Beam-beam parameter

Lorentz factor
## Luminosity: Two Options

<table>
<thead>
<tr>
<th><strong>High Current</strong></th>
<th><strong>Nano-Beam</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Slightly smaller $\beta_y^*$</td>
<td>Smaller $\beta_y^*$</td>
</tr>
<tr>
<td>$6.5$ (LER)/$5.9$ (HER) $\rightarrow$ $3.0/6.0$</td>
<td>$6.5$ (LER)/$5.9$ (HER) $\rightarrow$ $0.21/0.37$</td>
</tr>
<tr>
<td>Increase beam currents</td>
<td>Slightly increase beam currents</td>
</tr>
<tr>
<td>$1.8$ A (LER)/$1.45$ A (HER) $\rightarrow$ $9.4$ A/$4.1$ A</td>
<td>$1.8$ A (LER)/$1.45$ A (HER) $\rightarrow$ $3.6$ A/$2.1$ A</td>
</tr>
<tr>
<td>Increase $\xi_y$</td>
<td>Close to original KEK design</td>
</tr>
<tr>
<td>$0.1$ (LER)/$0.06$ (HER) $\rightarrow$ $0.3$ or more</td>
<td>Keep $\xi_y$</td>
</tr>
<tr>
<td></td>
<td>$0.1$ (LER)/$0.06$ (HER) $\rightarrow$ $0.09/0.09$</td>
</tr>
</tbody>
</table>

Evolution of design in original Letter of Intent (LoI) for SuperKEKB (2004)

Proposed by P. Raimondi et al., along with Crab Waist, for use at Italian Super B Factory

Decision expected 2009
### Comparison of Parameters

<table>
<thead>
<tr>
<th></th>
<th>KEKB Design</th>
<th>KEKB Achieved (): with crab</th>
<th>SuperKEKB High-Current Option</th>
<th>SuperKEKB Nano-Beam Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_y^*$ (mm)(LER/HER)</td>
<td>10/10</td>
<td>6.5/5.9 (5.9/5.9)</td>
<td>3/6</td>
<td>0.24/0.37</td>
</tr>
<tr>
<td>$\varepsilon_x$ (nm)</td>
<td>18/18</td>
<td>18(15)/24</td>
<td>24/18</td>
<td>2.8/2.0</td>
</tr>
<tr>
<td>$\kappa$ (%)</td>
<td>1</td>
<td>0.8-1</td>
<td>1/0.5</td>
<td>1.0/0.7</td>
</tr>
<tr>
<td>$\sigma_y$ (μm)</td>
<td>1.9</td>
<td>1.1</td>
<td>0.85/0.73</td>
<td>0.084/0.072</td>
</tr>
<tr>
<td>$\xi_y$</td>
<td>0.052</td>
<td>0.108/0.056 (0.101/0.096)</td>
<td>0.3/0.51</td>
<td>0.09/0.09</td>
</tr>
<tr>
<td>$\sigma_z$ (mm)</td>
<td>4</td>
<td>~ 7</td>
<td>5(LER)/3(HER)</td>
<td>5</td>
</tr>
<tr>
<td>$I_{\text{beam}}$ (A)</td>
<td>2.6/1.1</td>
<td>1.8/1.45 (1.62/1.15)</td>
<td>9.4/4.1</td>
<td>3.6/2.1</td>
</tr>
<tr>
<td>$N_{\text{bunches}}$</td>
<td>5000</td>
<td>~ 1500</td>
<td>5000</td>
<td>2119</td>
</tr>
<tr>
<td>Luminosity (10^{34} cm^{-2} s^{-1})</td>
<td>1</td>
<td>1.76 (2.08)</td>
<td>53</td>
<td>80</td>
</tr>
</tbody>
</table>

High Current Option includes crab crossing and travelling focus.
Low emittance positrons to inject

Redesign the HER arcs to squeeze the emittance.

Replace long TRISTAN dipoles with shorter ones (HER).

TiN coated beam pipe with antechambers.

Low emittance electrons to inject

Low emittance gun

Add / modify rf systems.

New Superconducting / permanent final focusing quads near the IP.

Damping ring

Colliding bunches

New positron target / capture section

New beam pipe & bellows

Nano-Beam SuperKEKB

Belle II

Low emittance positrons to inject

New IR

Neglect

$e^+ 3.7 \text{ A}$

$e^- 2.1 \text{ A}$

$\gamma = \frac{1}{1 - \frac{\beta_y^*}{\gamma}}$

$L = \frac{\gamma}{2e\gamma} \left( 1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \left( \frac{R_L}{R_y} \right)$
Critical issues at $L = 8 \times 10^{35}/\text{cm}^2/\text{sec}$

- **Higher background**
  - radiation damage and occupancy
  - fake hits and pile-up noise in the EM

- **Higher event rate**
  - higher rate trigger, DAQ and computing

- **Require special features**
  - low $p\mu$ identification $\rightarrow s_{\mu\mu}$ recon. eff.
  - hermeticity $\rightarrow \nu$ “reconstruction”
Belle Upgrade for the Super B Factory

SC solenoid 1.5T

CsI(Tl) $16X_0$ → pure CsI (endcap)

$\mu / K_L$ detection 14/15 lyr. RPC+Fe → tile scintillator

New readout and computing systems

CDC: Tracking + $dE/dx$ small cell + He/C$_2$H$_6$ remove inner lyr.

Si vtx. det. 4 lyr. DSSD → 2 DEPFET pixel lyr. + 4 lyr. DSSD

Aerogel Cherenkov counter + TOF counter → "TOP" + Aerogel RICH

“sBelle Detector Study Report” posted as arXiv: 0810.4084
• Sensors of the innermost layer:
  Normal double sided Si detector (DSSD) → DEPFET Pixel sensors

• Configuration: 4 layers → 6 layers
  (outer radius: 8cm → 14cm)
  - More robust tracking
  - Higher Ks vertex reconstruction efficiency

• Inner radius: 1.5cm → 1.3cm
  - Better vertex resolution

• Strip Readout chip: VA1TA → APV25
  - Reduction of occupancy coming from beam background.
  - Pipeline readout to reduce dead time

Slant layer to keep the acceptance

2 pixel layers
p-channel FET on a completely depleted bulk

A deep n-implant creates a potential minimum for electrons under the gate ("internal gate")

Signal electrons accumulate in the internal gate and modulate the transistor current ($g_q \sim 400 \text{ pA/e}^-$)

Accumulated charge can be removed by a clear contact ("reset")

Invented in MPI Munich

**Fully depleted:**
- large signal, fast signal collection
- Low capacitance, internal amplification → low noise

**Depleted p-channel FET**
- Transistor on only during readout: low power
- Complete clear → no reset noise
DEPFET Performance

Very preliminary
(single tracks, no background)

Parameters included (might differ for finally used)

**DEPFET:**
- L1 1.3 cm (32µm x 50µm)
- L2 1.6 cm (32µm x 50µm)
- thickness: 50µm, noise 100e

**DSSD** L3/L4/L5/L6:
- 4.5/7.0/10/13.8cm (50µm x 75µm)
- thickness 300µm,
- noise 1600e
- beam pipe radius: 1cm (Be with 10µm Au layer)

Substantial improvement compared to Belle SVD2

PXD will be delivered by European groups
SuperKEKB is a lab priority, apart of the KEK Roadmap.

The Japanese government has allocated 32 oku-yen ($32 M, €23 M) for upgrade R&D in FY 2009, as a part of its economic stimulus package.

KEK has submitted a budget request for FY 2010 and beyond of $350 M for construction.

Funding in other countries on the way (D,SLO)

We are proceeding with R&D while awaiting approval of the construction budget request.
New Collaboration (Belle II)

Belle II is a new international collaboration
- Regular collaboration meetings (next 18-19 Nov 2009)
- Significant European participation (A, CH, CZ, D, PL, RUS, SLO)
- Spokesperson P. Križan, Ljubljana
Belle II is a new international collaboration.
- Significant European participation (A, CH, CZ, D, PL, RUS, SLO)
- Regular collaboration meetings (next 18-19 Nov 2009)

Near-term plan
- Detector study report has been completed.
- Detector proposals (by Dec. 2009).
- TDR by March 2010
Summary

- B factories have proven to be an excellent tool for flavour physics.
- Major upgrade of KEKB and Belle planned for 2009-2012
  -> **Super B factory**; Luminosity: x10 -> x40
  ... expect a new, exciting era of discoveries,
  complementary to LHC...
  ... You could be a part of it, since:

  **New groups and individuals are highly welcome.**
Backup
### Physics reach at a Super KEKB/Belle

<table>
<thead>
<tr>
<th></th>
<th>Belle'06 (~0.5ab⁻¹)</th>
<th>5ab⁻¹</th>
<th>50ab⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔS(ϕK⁰)</td>
<td>0.22</td>
<td>0.073</td>
<td>0.029</td>
</tr>
<tr>
<td>ΔS(η′K⁰)</td>
<td>0.11</td>
<td>0.038</td>
<td>0.020</td>
</tr>
<tr>
<td>ΔS(K_sK_sK_s)</td>
<td>0.33</td>
<td>0.105</td>
<td>0.037</td>
</tr>
<tr>
<td>ΔS(K_sπ⁰γ)</td>
<td>0.32</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>Br(X_sϕ)</td>
<td>13%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A_CP(X_sϕ)</td>
<td>0.058</td>
<td>0.01</td>
<td>0.005</td>
</tr>
<tr>
<td>C_9 [A_FB(K*II)]</td>
<td>---</td>
<td>11%</td>
<td>4%</td>
</tr>
<tr>
<td>C_10 [A_FB(K*II)]</td>
<td>---</td>
<td>13%</td>
<td>4%</td>
</tr>
<tr>
<td>Br(B⁺ → K⁺γγ)</td>
<td>&lt;9Br(SM)</td>
<td>33ab⁻¹ for 5σ discovery</td>
<td></td>
</tr>
<tr>
<td>Br(B⁺ → τντ)</td>
<td>3.5σ</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>Br(B⁺ → µνµ)</td>
<td>&lt;2.4Br(SM)</td>
<td>4.3ab⁻¹ for 5σ discovery</td>
<td></td>
</tr>
<tr>
<td>Br(B⁺ → Dτν)</td>
<td>---</td>
<td>7.9%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Br(τ → µγ)</td>
<td>&lt;45</td>
<td>&lt;30</td>
<td>&lt;8</td>
</tr>
<tr>
<td>Br(τ → µηµ)</td>
<td>&lt;65</td>
<td>&lt;20</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Br(τ → 3µ)</td>
<td>&lt;209</td>
<td>&lt;10</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Δsin2θ₁</td>
<td>0.026</td>
<td>0.016</td>
<td>0.012</td>
</tr>
<tr>
<td>ΔΦ₂ (ρπ)</td>
<td>68° −95°</td>
<td>3°</td>
<td>1°</td>
</tr>
<tr>
<td>ΔΦ₃ (Dalitz)</td>
<td>20°</td>
<td>7°</td>
<td>2.5°</td>
</tr>
<tr>
<td>ΔV_{ub} (incl.)</td>
<td>7.3%</td>
<td>6.6%</td>
<td>6.1%</td>
</tr>
</tbody>
</table>

---

Search for $H^\pm$ in $B\rightarrow\tau\nu\nu$

50ab⁻¹ assume 5σ discovery

Upper limits

CKM at 50ab⁻¹

---

Physics at Super B Factory [hep-ex/0406071]  Currently being updated.
### Comparison with the LHCb

<table>
<thead>
<tr>
<th>$e^+e^-$ has advantages in...</th>
<th>LHCb has advantages in...</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPV in $B \to \phi K_S$, $\eta' K_S$,...</td>
<td>CPV in $B \to J/\psi K_S$</td>
</tr>
<tr>
<td>CPV in $B \to K_S \pi^0\gamma$</td>
<td>Most of $B$ decays not including $\nu$ or $\gamma$</td>
</tr>
<tr>
<td>$B \to K \nu \nu$, $\tau \nu$, $D(*)\tau \nu$</td>
<td>Time dependent measurements of $B_S$</td>
</tr>
<tr>
<td>Inclusive $b \to s \mu \mu$, see $\tau \to \mu \gamma$ and other LFV</td>
<td>$B_{(s,d)} \to \mu \mu$</td>
</tr>
<tr>
<td>$D^0 D^0$ mixing</td>
<td>$B_c$ and bottomed baryons</td>
</tr>
</tbody>
</table>

**Complementary!!**
## Luminosity gain and upgrade items (preliminary)

<table>
<thead>
<tr>
<th>Item</th>
<th>Gain</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam pipe</td>
<td>x 1.5</td>
<td>high current, short bunch, electron cloud</td>
</tr>
<tr>
<td>$IR(\beta^*_x/y=20\text{cm}/3\text{ mm})$</td>
<td>x 1.5</td>
<td>small beam size at IP</td>
</tr>
<tr>
<td>low emittance (12 nm) $v_x \rightarrow 0.5$</td>
<td>x 1.3</td>
<td>mitigate nonlinear effects with beam-beam</td>
</tr>
<tr>
<td>crab crossing</td>
<td>x 2</td>
<td>mitigate nonlinear effects with beam-beam</td>
</tr>
<tr>
<td>RF/infrastructure</td>
<td>x 3</td>
<td>high current</td>
</tr>
<tr>
<td>DR/e$^+$ source</td>
<td>x 1.5</td>
<td>low $\beta^*$ injection, improve e$^+$ injection</td>
</tr>
<tr>
<td>charge switch</td>
<td>x ？</td>
<td>electron cloud, lower e$^+$ current</td>
</tr>
</tbody>
</table>

3 years shutdown
KEKB track record

Integrated Luminosity (log)

~ 1.5 Billion $B\bar{B}$ pairs
~ 1.4 ab$^{-1}$

$L_{\text{peak}}$ (KEKB) = $2.1 \times 10^{34}$/cm$^2$/sec (design 1.0)
Crab cavity commissioning

![Graph showing crab cavity commissioning](image)

- Crab Crossing
- \( \beta x^* = 80, 84 \text{ cm} \)
- \( \beta x^* = 80 \text{ cm} \)
- \( \beta x^* = 68 \text{ cm} \)
- \( \beta x^* = 100 \text{ cm} \)
- 3.06 bucket spacing
- 22 mrad crossing
- Simulation
  - Head-on
  - 22 mrad

Specific Luminosity/bunch

\[ \left( \frac{10^{30} \text{ cm}^{-2} \text{s}^{-1}}{\text{mA}^2} \right) \]

\[ I_{\text{bunch HER}} \times I_{\text{bunch LER}} \text{ [mA}^2\text{]} \]
Specific Luminosity with & without crab crossing
(Data + K. Ohmi Simulations)

$\xi_y (\text{HER}) = 0.09$

Sim.
With Crab

Sim.
W/out Crab
# Major KEKB components: Cost & effects

<table>
<thead>
<tr>
<th>Item</th>
<th>Object</th>
<th>Oku-yen ~1.0 M$</th>
<th>Luminosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>New beam pipes</td>
<td>Enable high current</td>
<td>178</td>
<td>x 1.5</td>
</tr>
<tr>
<td></td>
<td>Reduce e-cloud</td>
<td>(incl. BPM, magnets, etc.)</td>
<td></td>
</tr>
<tr>
<td>New IR</td>
<td>Small β*</td>
<td>31</td>
<td>x 2</td>
</tr>
<tr>
<td>e+ Damping Ring</td>
<td>Allow injection with small increase e+ capture</td>
<td>40 incl. linac upgrade</td>
<td>if not, x 0.75</td>
</tr>
<tr>
<td>More RF and cooling systems</td>
<td>High current</td>
<td>179</td>
<td>x 3</td>
</tr>
<tr>
<td></td>
<td>(incl. facilities)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crab Cavities</td>
<td>Higher beam-beam param.</td>
<td>15</td>
<td>x (2 – 4)</td>
</tr>
</tbody>
</table>

Items are interrelated.

- Tunnel already exists.
- Most of the components (magnets, klystrons, etc.) will be re-used.
Beam Background (after 1\textsuperscript{st} optimization)

Conservative, robust detector should handle \~20x more background.
**Effective background with new hardwares**

<table>
<thead>
<tr>
<th></th>
<th>How</th>
<th>Reduction factor</th>
<th>Effective bkg</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVD</td>
<td>Shorter $t_p$</td>
<td>$50/800=1/16\approx1/12.5$</td>
<td>0 ~ 1</td>
</tr>
<tr>
<td>CDC</td>
<td>Smaller cell</td>
<td>&lt;2/3</td>
<td>4 ~ 13 (*)</td>
</tr>
<tr>
<td>PID</td>
<td>Brand new device</td>
<td>Good enough</td>
<td>0 ~ 1</td>
</tr>
<tr>
<td>B-ECL</td>
<td>Waveform fitting</td>
<td>1/7</td>
<td>1 ~ 2</td>
</tr>
<tr>
<td>E-ECL</td>
<td>Pure CsI (shorter t)</td>
<td>1/200</td>
<td>0 ~ 1</td>
</tr>
<tr>
<td>KLM</td>
<td>Faster detector, finer segment</td>
<td>Under control</td>
<td>0 ~ 1</td>
</tr>
</tbody>
</table>

(*) Software efforts needed for CDC

**Background effects on tracking**

Gain in reconstruction efficiency of $B\rightarrow D^*D^*(D^*\rightarrow D\pi_s, D\rightarrow K3\pi)$

<table>
<thead>
<tr>
<th></th>
<th>Present Belle</th>
<th>Software update</th>
<th>+SVD tracker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>$\varepsilon=4.3%$</td>
<td>$\varepsilon=7.1%$ (+65%)</td>
<td>$\varepsilon=11.9%$ (+177%)</td>
</tr>
<tr>
<td>$\times5$ BG</td>
<td>$\varepsilon=6.3%$ (+47%)</td>
<td>$\varepsilon=11.2%$ (+160%)</td>
<td></td>
</tr>
<tr>
<td>$\times20$ BG</td>
<td>$\varepsilon=3.8%$ (−12%)</td>
<td>$\varepsilon=8.8%$ (+105%)</td>
<td></td>
</tr>
</tbody>
</table>
Thinning Technology

- Sensor wafer bonded on “handle” wafer.
- Rigid frame for handling and mechanical stiffness
- 50 μm thickness produced
- Samples of 10x1.3 cm² & frame of 1 & 3 mm width
- Electrical properties ok (diodes)
Main challenge: R+D of a photon detector for operation in high magnetic fields (1.5T)

Candidates:
• MCP PMT: excellent timing, could be also used as a TOF counter
• HAPD: proximity focusing mode, problems with the stability
• SiPMs: easy to handle, but never before used for single photon detection (high dark count rate with single photon pulse height) → use a narrow time window and light concentrators

First Cherenkov photons observed with SiPMs!
• Larger outer radius: 752mm → 978mm
  - Longer lever arm → better $P_t$ reso.
  - More samplings → better dE/dx reso.
• Smaller cell size: 12mm, 64cells → 8mm, 160cells
  - Improved background tolerance
• New ASD with fast shaping
Barrel PID: Time of propagation (TOP) counter

- Cherenkov ring imaging with precise time measurement.
- Reconstruct angle from one coordinate and the time of propagation of the photon
  - Quartz radiator (2cm)
  - Photon detector (MCP-PMT)
    - Good time resolution < ~ 40 ps
    - Single photon sensitive under 1.5 T
End-cap PID: Aerogel RICH

- Proximity focusing RICH with aerogel radiator

Highly transparent aerogel: $\Delta t > 40\text{mm}$ (\(\lambda = 400\text{nm}\))

Multi-pixel photodetector to measure single photon positions in B=1.5T
→ Hybrid Avalanche PhotoDiode
→ Micro Channel Plate - PMT
→ Geiger mode Avalanche PhotoDiode
ECL upgrade

- Increase of dark currents due to neutron flux
- Fake clusters & pile-up noise

- Barrel:
  0.5\(\mu\)s shaping + 2MHz w.f. sampling.

- Endcap:
  pure CsI + photopentods
  30ns shaping + 43MHz w.f. sampling

Barrel

x1/1.5

Pure CsI & photopentods

BW endcap

x1/5
Scintillator-based KLM (endcap)

- Two independent (x and y) layers in one superlayer made of orthogonal strips with WLS read out
- Photo-detector = avalanche photodiode in Geiger mode (SiPM)
- ~120 strips in one 90º sector
  (max L=280cm, w=25mm)
- ~30000 read out channels
- Geometrical acceptance > 99%

Mirror 3M (above groove & at fiber end)

Optical glue increase the light yield ~ 1.2-1.4

WLS: Kurarai Y11 Ø1.2 mm

Diffusion reflector \((\text{TiO}_2)\)

Strips: polystyrene with 1.5% PTP & 0.01% POPOP