Belle-II calorimeter endcap upgrade

CAP Conress / Congrès de l'ACP
Sudbury, June 17th 2014

Alexandre Beaulieu[1] for the Canadian Belle-II group

[1]University of Victoria, Canada

The Belle-II experiment

An overview

- Next-gen. asymmetric e^+e^- collider:
  - *B* Factory: nominally operating at 10.58 GeV, just above $B\bar{B}$ threshold
  - Instantaneous luminosity: $8 \times 10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ (40× Belle $\mathcal{L}$)
  - Target integrated luminosity: $50\,\mathrm{ab}^{-1}$
  - Scheduled first physics run: Q4 2016
- Scientific program:
  - Probe new physics (NP) at the luminosity frontier
  - Study of rare and search for forbidden decays: testable NP contributions
    - *e.g.* $B \to \tau\nu$, $B \to K\pi$, $\tau \to \mu\gamma$
  - Precision measurement of SM parameters, CKM matrix, CP violation
- See Dr. Hearty's talk in M2-9 session

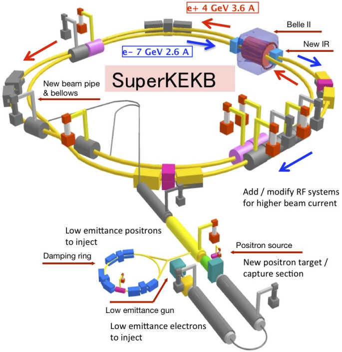


Image credits: KEK

The Belle-II experiment

The detector

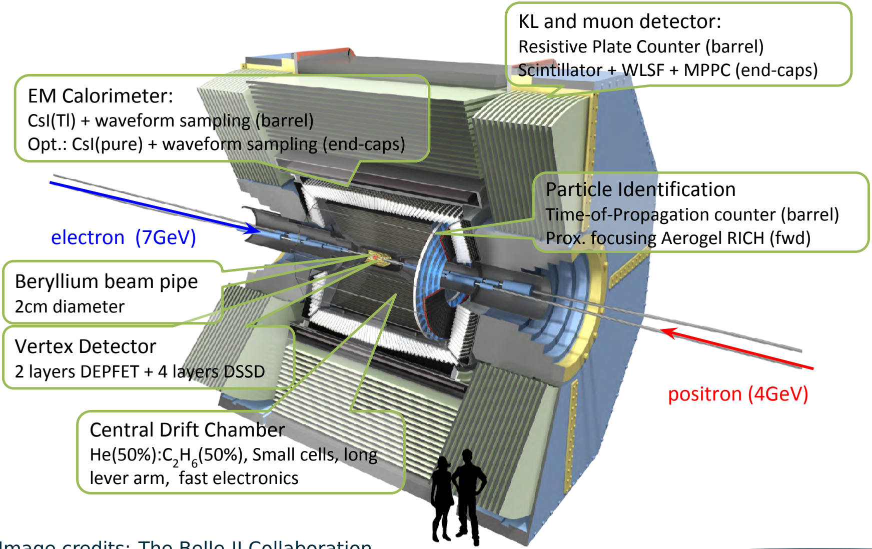
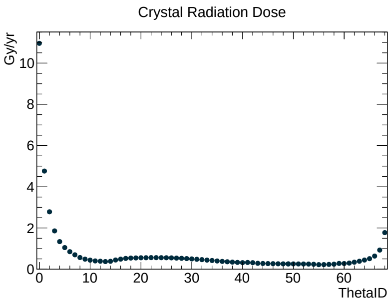


Image credits: The Belle-II Collaboration

The planned ECL end-cap upgrade

- Aging Belle CsI(Tl) crystals and sensors due to radiation damage
- Belle-II: 40× higher $\mathcal{L}_{\text{int}}$ than Belle
- Pile-up noise in the forward end-cap might become an issue

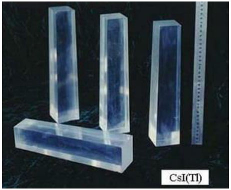


Sam de Jong

The goal

Upgrade the end-cap by changing the crystals to CsI(pure), update the photo-detectors and electronics for the rows 1–8

The planned ECL end-cap upgrade



Crystals[1]

Before: CsI(Tl)

- Light yield: 54 $\gamma/\,\mathrm{keV}_\gamma$
- Decay time: 1000 ns
- λ_{max}: 550 nm

After: CsI(pure)

- Light yield: 2.2 $\gamma/\,\mathrm{keV}_\gamma$
- Decay time: 16 ns
- λ_{max}: 315 nm

- Shorter decay time:
  - Better immunity to pile-up noise
  - Needs faster electronics (shaping time, feature extraction DSP)
- Different emission profile $\longrightarrow$ upgrade photo-detectora
  - Lower light yield: need more sensitivity
  - Shorter emission wavelength

[1] Data for St-Gobain crystals

The planned ECL end-cap upgrade

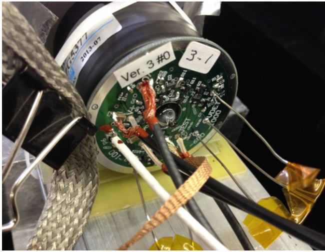
Photo-sensors, pre-amp and enclosure

Fine-mesh PMTs

- Operates under *B*-Field
- Spectral response range: 185 – 650 nm
- Anode dark current: 10 nA
- Anode sensitivity: 7.2 A/W

Pre-amp and enclosure from UdeM

- Charge-accumulating circuit
- Sensitivity = 0.5 V/pC
- $\approx$3 mV for 0.66 MeV photon
- Enclosure:
  - Acts as a Faraday cage,
  - holds PMT in contact with crystal
- R&D work shows good progress



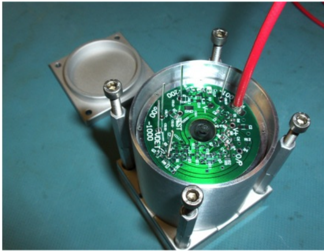


Image credits: Nikolai Starinski

In the meantime

Modification of existing pre-amps

For Belle-II commissioning:

- Use Belle crystals, PIN diodes and pre-amplifiers
- Radiation damage → higher diode dark current
- Must change resistor values to keep bias ~ 50 V
- 1152 channels in the forward end-cap

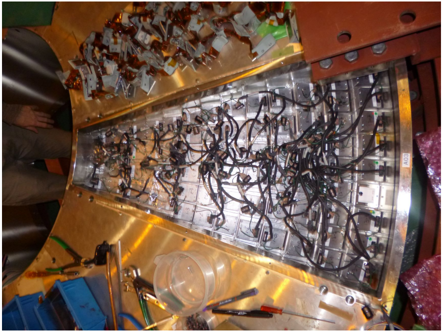
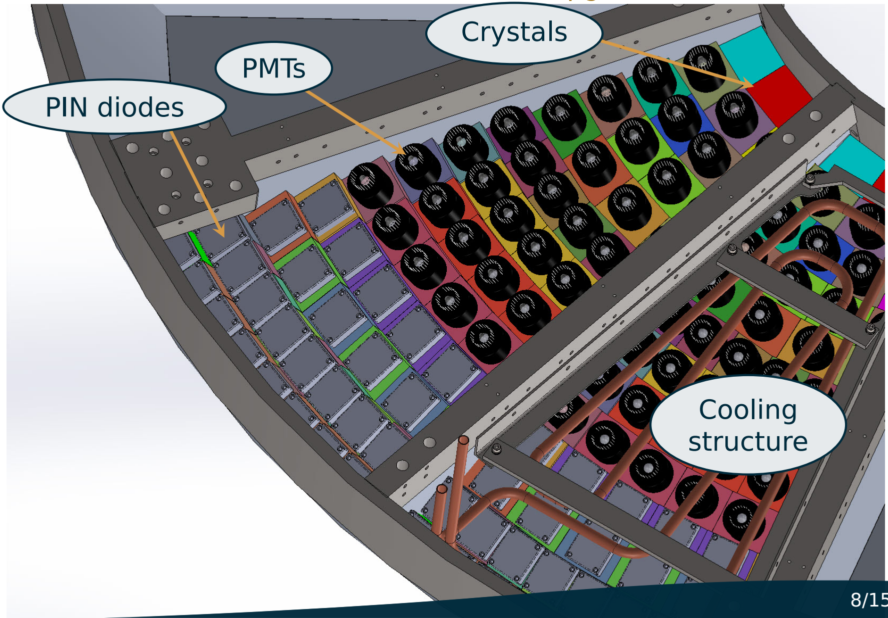


Image credits: Dr. Chris Hearty

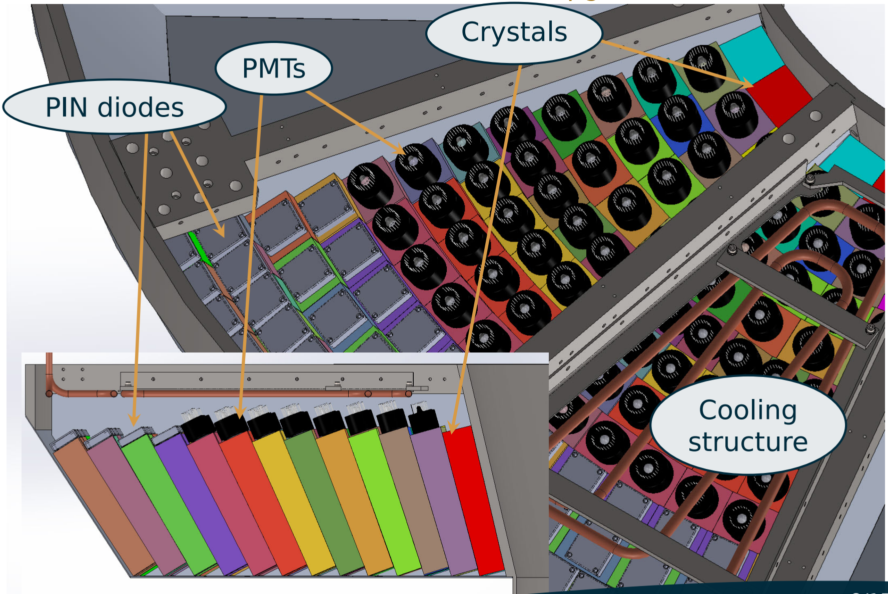
Supporting structure and integration

Need to upgrade inner structure:



Supporting structure and integration

Need to upgrade inner structure:



Supporting structure and integration

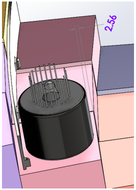
Specifications and constraints

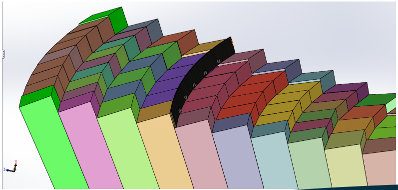
Main functions

- Support crystals
  - Adapt to different height (±10 mm);
  - Provide required normal force (51 N/crystal);
  - Transmit loads to outer structure (with *S.F.* > 4)
- Evacuate heat
  - Provide thermal link to cooling pipes (370 mW/ch. $T_{max} < 25\,°C$);
  - Electrically insulate structure and PMT enclosure ($10^9\,\Omega$)

Constraints

- Allow removal of PMT while supporting crystals
- Leave room for cable bundles, optical fibers, connectors





Supporting structure and integration

Concept selection and validation

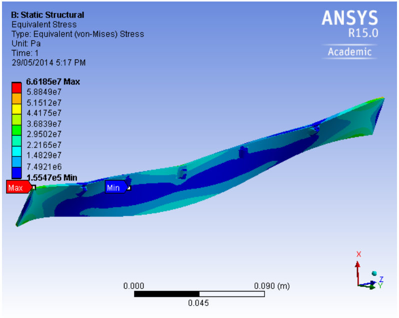
- Translate functions into concepts
  - Group and individual idea generation session
  - Systematic evaluation of each concept

Supporting structure and integration

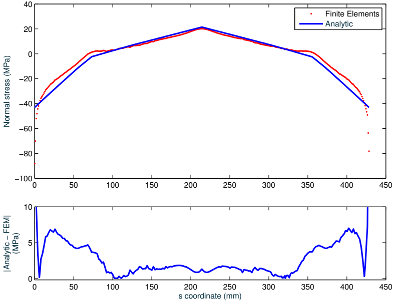
Concept selection and validation

- Translate functions into concepts
  - Group and individual idea generation session
  - Systematic evaluation of each concept
- Example: validation of the support strength

Finite-elements study



Validation with analytical model



Measuring the neutron flux

PhD work of Samuel de Jong (U.Victoria)

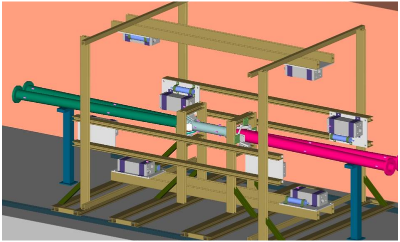


Image credits:
M. Rosen (top); S.R. de Jong (bottom)

- Need to validate background and radiation simulations
- Thermal neutron detectors:

$$^{3}\mathrm{He} + {}^{1}n_{\mathrm{th.}} \rightarrow {}^{3}\mathrm{T} + {}^{1}\mathrm{H} + 764\,\mathrm{keV}$$

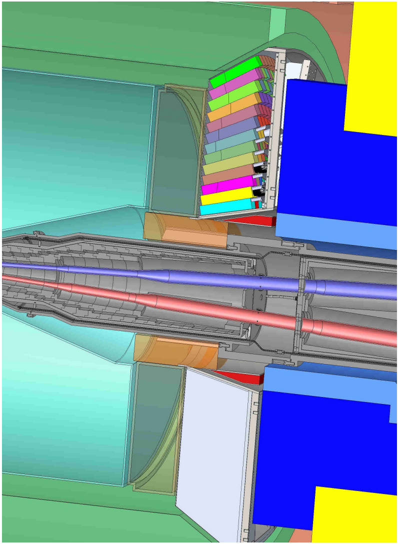
- $\sigma_{\mathrm{capture}} = 5330\,\mathrm{b}$ for $n_{\mathrm{th.}}$
- $\sigma_{\mathrm{capture}} \propto \mathrm{velocity}^{-1}$ up to $T \sim 0.5\,\mathrm{MeV}$
- Commissioning phase-I (2 detectors):

Q4 2014

Shielding the ECL end-cap

Overview of the situation

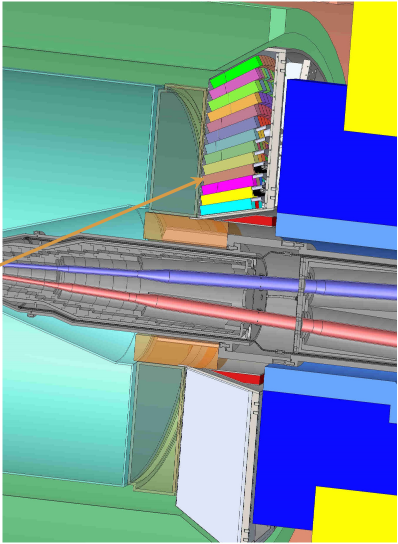
- Forward end-cap: high radiation environment
- Affects longevity of crystals near beam axis (start of fiducial volume)
- Doses from beam background radiation (no end-cap shield):
  - Crystal radiation dose
    ~ 200 rad/10^7s
  - Photo-sensor radiation dose
    ~ 850 rad/10^7s
- Estimated pile-up noise level
  ~ 2 MeV for third row
- Need shield: reduce background & protect crystals, sensors



Shielding the ECL end-cap

Overview of the situation

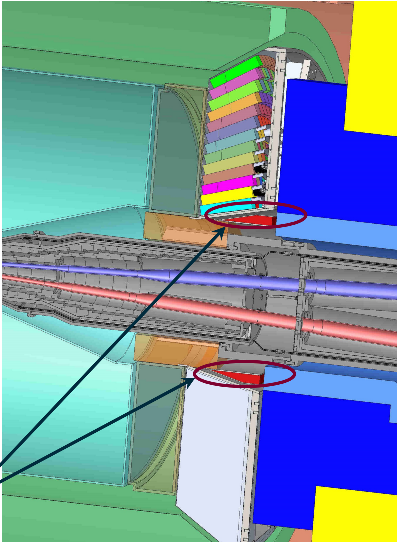
- Forward end-cap: high radiation environment
- Affects longevity of crystals near beam axis (start of fiducial volume)
- Doses from beam background radiation (no end-cap shield):
  - Crystal radiation dose
    $\sim 200\ \text{rad}/10^7\text{s}$
  - Photo-sensor radiation dose
    $\sim 850\ \text{rad}/10^7\text{s}$
- Estimated pile-up noise level
  ~ 2 MeV for third row
- Need shield: reduce background & protect crystals, sensors



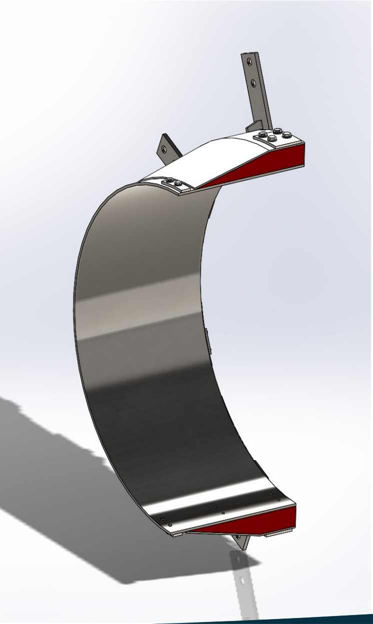
Shielding the ECL end-cap

Overview of the situation

- Forward end-cap: high radiation environment
- Affects longevity of crystals near beam axis (start of fiducial volume)
- Doses from beam background radiation (no end-cap shield):
  - Crystal radiation dose
    ~ 200 rad/10^7s
  - Photo-sensor radiation dose
    ~ 850 rad/10^7s
- Estimated pile-up noise level
  ~ 2 MeV for third row
- Need shield: reduce background & protect crystals, sensors



Belle shield and performance



- Lead cast into stainless steel shell
- According to GEANT4 simulation[a], this reduces:
  - Crystal dose by a factor of 3.3;
  - Diode dose by a factor of 11;
  - Neutron flux by a factor of 3.4.
- No element provides specific neutron radiation mitigation

Studies addressing neutron shielding just started

[a]Thanks to Samuel de Jong, U.Victoria

Can this be improved?

Use of different materials

- Neutron moderator: Polyethylene (PE)
  - H atoms slow n down by multiple scattering
  - Need 11.6 cm to thermalize 1.5 MeV neutron
  - Reaction $^{1}\mathrm{H}\,(n,\gamma)\,\mathrm{D}$: 2.22 MeV photon emitted
- Neutron absorber: Boron
  - Thermal neutron absorption $\sigma = 770$ b (2300 that of PE)
  - Reaction $^{10}\mathrm{B}\,(n,\alpha)\,^{7}\mathrm{Li}$: 0.49 MeV photon emitted
- Radiation absorber: stainless steel and lead

Photon energy (MeV)	Attenuation length (cm) PE	304SS	Pb
0.5	10.8	1.49	0.55
2.22	22.2	3.03	1.95

- Need careful design; more isn't necessarily better!

Summary

- Planned Canadian contribution to Belle-II experiment: upgrade ECL end-cap to enhance resolution
- Preliminary studies have been conducted:
  - electronics and signal processing;
  - mechanical integration;
  - radiation level simulations;
  - shielding
- Performance studies by Dr. Hearty (UBC):
  - Upgrade would enhance energy resolution in the region

  but
  - Gains in terms of accessible Physics are not evident under current understanding of machine background if current design includes appropriate shielding

Questions / Comments?

Many thanks to:

- my supervisor Dr. Roney,
- Dr. Chris Hearty at UBC, Sam de Jong at UVictoria and the Canadian Belle-II group,
- Dr. A. Kuzmin at BINP (Russia),
- Dr. Nakayama-san at KEK (Japan)

My work is funded by:

NSERC CRSNG

University of Victoria