A pure CsI Calorimeter for the BelleII experiment at SuperKEKB

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Frontier Detector for Frontier Physics
13th Pisa meeting on Advanced Detectors
BelleII at SuperKEKB

- Luminosity goal: $8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$
  - using a large crossing-angle at IP
  - squeezing the beams to nanometre-scale
- $\sim 50 \text{ ab}^{-1}$ in 10 years operation

- Redesign of all subdetectors
- Add 2 pixel layers as vertex detector
- Add Fwd PID
- Pure CsI upgrade not for day 1
• Pile up greater than 2MeV on fwd and bwd region
  o High background rate expected
  o CsI(Tl) slow crystal (500ns shaping for BelleII)
• A faster crystal would decrease pile up considerably

Last results from BelleII MC simulations

Samuel de Jong (UVic)
20th BelleII General Meeting
Pure CsI vs CsI(Tl)

• Pure CsI crystal has been proposed to replace CsI(Tl) in the forward region
• Pure CsI Pros
  o Same density (i.e. Moliére Radius, X0 ...) of CsI(Tl), no mechanical structure replacement needed
  o Fast response, ~25ns vs 1200ns of CsI(Tl)
• Pure CsI Cons
  o Low light yield, ~4% of CsI(Tl)
  o Near UV emission (315nm)
• Two type of sensors have been proposed:
  o Photopentode:
    • PMT with 5 amplification stage (G~180 in B field of ~1T)
    • big cathode surface (2inch diameter) and a good QE at 315nm (~40%) but for this option the back plane of the mechanical structure need to be replaced
  o Large Area APD:
    • 1x1 cm² with G~200
    • mechanical structure can be used as it is but reaching a good S/N is challenging
Preliminary Test on APD (I)

- Special Large Area APD from Hamamatsu
  - Standard design gain is 50, we use only selected APDs in order to work at \( G=200 \) with \( \Delta V > 20 \text{V} \)
  - Typical \( I_{\text{dark}} \approx 30 \text{nA} \)
  - Capacitance 270pF (very high!)
  - QE at 315nm \( \approx 40\% \)

- 2 APDs for each crystal with separate readout electronics
- Cosmic rays test to optimize the S/N
Preliminary Test on APD (II)

- 2 APDs for each crystal with separate readout electronics
- Cosmic rays test to optimize the S/N

Cosmic deposited energy 30MeV
Equivalent Noise Energy
  - Preamp output 1.3MeV
  - Shaper output 0.7MeV

29 May 2015 • A. Rossi - 13th Pisa Meeting on Advanced Detector
CsI(Tl) Radiation Hardness

2 Belle spare crystals has been used to test CsI(Tl) radiation hardness

- Irradiation at Calliope facility at ENEA Casaccia
  - Co60 source
- 20% Light Yield loss after 150Gy
- Saturation after 400Gy

Expected dose after 10y at BelleII

D.M. Beylin, et al.
Trapezoidal CsI(Tl) crystals

Our measurement of Crystal no.1

PiN/APD Radiation Hardness

- HAMAMATSU PIN S2744-08
  - 250Gy with gamma at ENEA Casaccia
    - x4 expected dose
  - $10^{12}$ neutrons/cm$^2$ at ENEA Frascati
    - x4 expected dose

Orders of magnitude increase after neutrons

- HAMAMATSU LAAPD S8664-1010
  - Stable QE for PIN
  - QE decrease for APDs after gamma, no further effects by neutrons
PiN Noise after Irradiation

- **After Charge Sensitive Preamplifier (CSP)**
  - ENE: NoIrr. \( \sim 630 \text{KeV} \) \( \rightarrow \) Irr. \( \sim 4.9 \text{MeV} \)

- **After Shaping (SHP)**
  - ENE: NoIrr. \( \sim 220 \text{KeV} \) \( \rightarrow \) Irr. \( \sim 1.14 \text{MeV} \)

Same studies have to be done for APDs
Matrix Prototype

- 4x4 CsI Pure crystals (all produced by Amcrys)
  - Qualification of an Italian producer (Optomaterials) is ongoing
  - First preliminary results shows a very good quality
- Each crystal equipped with 2 Hamamatsu LA-APD
- Each APD is readout with 1 Charge preamplifier
- Single channel HV regulation on frontend board
- 1 temperature sensor (Maxim 1-wire) for each channel

Charge – Preamplifier
Custom discrete amplifier at BJT transistor.
Gain = 1.4V/pC
Power dissipation = 16mW
Single power = 6V to GND
Dynamic Range 2.2V
Tau IN = 40ns
Data collected at different energies
- 100, 200, 300, 400, 450 MeV
- From MC best position is in a circle with R=1.5cm from center

Night acquisitions with cosmic trigger for calibration

Data acquired also with magnet between silicon boxes ON but not analyzed yet (not in this talk)

Beam Test Facility (BTF) @ LNF
- LINAC electron (500MeV) on tungsten target
- Energy selection of secondary electrons with 2 dipole magnets
  - From ~480MeV down to 50MeV
- Multiplicity selected with slits
  - 1-10^9 electrons/spill
Position Selection

- For each run two cuts are applied:
  - Only 1 cluster reconstructed on each plane
  - Position selection of $\frac{1}{2} \sigma$ around the mean value
    - Mean value change slightly between different run

Beam X Profile Run166 - 450MeV

- Constant: $640.2 \pm 7.1$
- Mean: $183.9 \pm 0.2$
- Sigma: $26.53 \pm 0.19$

Beam Y Profile Run166 - 450MeV

- Constant: $661.6 \pm 7.3$
- Mean: $160.7 \pm 0.2$
- Sigma: $25.97 \pm 0.19$
Beam Test results (I)

We found some distortion on energy distribution mainly at low energies

- This is due to pickup noise synchronous to BTF RF trigger
- This is evident when a comparison between pedestal with random trigger and pedestal with BTF RF trigger is performed

Calibration and temperature correction parameter extracted from cosmic data and applied event-by-event
Software Shaping

- We apply a software shaping in order to “simulate” the effect of a CR-RC\(^4\) shaping with time constant 100ns

- The CR-RC filter cut the frequency of the pickup noise (or at least the noise is attenuated)
Energy distribution fit to shaped signals

- Energy distribution with expected shape
- Better results wrt the CSP output
Beam Test results (III)

- Resolution compromised by the pickup noise
- Another effect is the beam degradation due to multiple scattering
  - Matrix – Beam pipe distance ~1.7m
  - 8 silicon layer 400 μm each
- Constant parameter c not extracted correctly
  - Probably due to the few energy points

Fit function: \( \sigma(E)/E = \frac{a}{\sqrt[4]{E}} \oplus \frac{b}{E} \oplus c \)
Conclusions

• Bellell calorimetry upgrade in the forward region is under study
• Pure CsI crystal with large area APDs has been proposed as possible upgrade
  o Fast crystal but low light yield
  o With APDs all mechanical structure don’t need to be replaced
• With APD readout reaching a good S/N is challenging
• Lab. test show the an ENE of ~0.7MeV is feasible
• CsI(Tl) gamma irradiation shows a Light loss of 20% and then saturation
• PiN/APD after irradiation shows a dark current increase of 2 order of magnitude
  o ENE of CsI(Tl)+PiN increase of a factor 6
• First beam test with 4x4 crystal matrix
  o Resolution higher than expected
  o Some problems with pickup noise
  o Beam degradation due to multiple scattering
• New beam test at Mainz at the end of July
  o Tagged photon facility
Backup
Readout sensor for Pure CsI

- The low light yield implies a “on sensor” gain factor
- Two types of sensors have been proposed:
  - Photopentode: PMT with 5 amplification stage (G~180 in B field of ~1T)
  - Large Area APD: 1x1 cm² with G~200
- Photopentode have a big cathode surface (2inch diameter) and a good QE at 315nm (~40%) but for this option the back plane of the mechanical structure need to be replaced
- With APDs the mechanical structure can be used as it is but reaching a good S/N is challenging
PiN/APD Radiation Hardness

HAMAMATSU PIN S2744-08

Orders of magnitude increase after neutrons

HAMAMATSU LAAPD S8664-1010
Optical Coupling Materials

Transmittance curves
Range: 200-800 nm

Dose rate: 5 Gy\textsubscript{air}/h
Total absorbed doses: up to 44 Gy in air, at RT

All tests performed at ENEA Casaccia
Temperature Correction

- APD gain has an high dependency with temperature
- Cosmic data used to study Gain vs T channel-by-channel dependence
- Store functions parameters for correction
- Mean $\frac{dG}{dT} -7\%/°C$
Calibration

• Selected cosmic events which pass through one matrix column
• Event-by-event dG/dT correction applied
• Fit with Landau with Gaussian convolution function and MPV extraction

• A couple of cosmic runs are not used to extract calibration constant
  o Check calibration stability and precision

Cosmic signal on single crystal

| Width     | 1.249 ± 0.072 |
| MPV       | 23.85 ± 0.14  |
| Integral  | 2615 ± 51.8   |
| Gaus Width| 3.099 ± 0.133 |

Width 0.8715 ± 0.0581
MPV 22.71 ± 0.13
Integral 2621 ± 51.3
Gaus Width 3.235 ± 0.096

ADC counts

Calib. Check

Constant 10.35 ± 2.26
Mean 0.9896 ± 0.0023
Sigma 0.01214 ± 0.00165

1.2% error on calibration