Belle II calorimetry and analysis R&D

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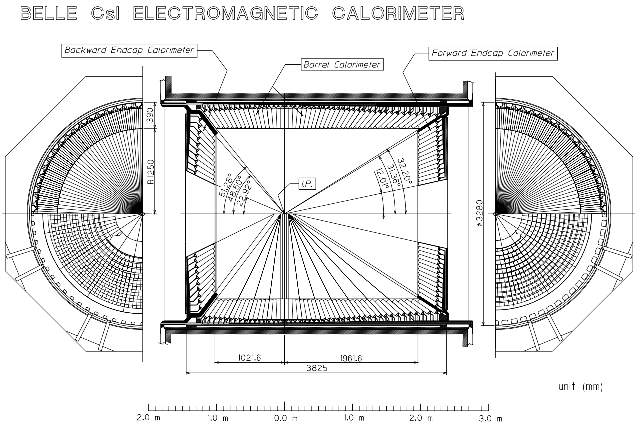
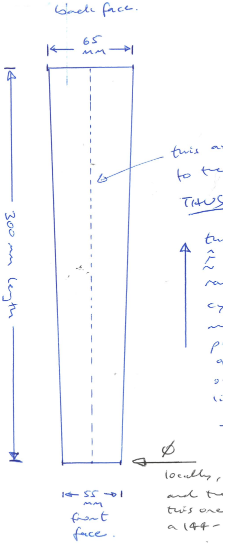
- I have been on Belle for 20 years, with a wide range of physics analysis interests, including charm, CPV (ϕ_3/γ), and spectroscopy
- most recently I was general editor for *The Physics of the B Factories*
- the area with maximum (interest $\times$ potential / work-already-done) on Belle II is IMO **calorimetry development & treatment of neutrals**
- working on this for a few years with Frank Meier (postdoc on DP17) and some students, currently Priyanka Cheema (honours 2019)

ECL: Belle / Belle II's electromagnetic calorimeter





- between inner detector (Si vertexing, drift chamber, PID) & magnet (solenoid, flux return instrumented w scints, RPCs)
- 8736 CsI(Tl) crystals, $16.2\,X_0$, $(91-3)\% \times 4\pi$, $\sigma_E/E \sim 2.5\%$
- 43-ton structure in v.gd condition after Belle, and so re-used for Belle II
- readout completely replaced by waveform-sampling electronics

Improving calorimetry (1): clustering and matching

The improved electronics are needed to offset Belle II's more demanding running conditions: higher backgrounds; overlays within the (long) CsI(Tl) response time.

- Some colleagues are working on ways of further exploiting the electronics.
- Another possibility: reshuffle recon and analysis in Belle's basic approach —

$\rightarrow$ standalone clustering

$\rightarrow$ basic object: 5×5 grid

$\rightarrow$ is it matched to an extrapolated track?

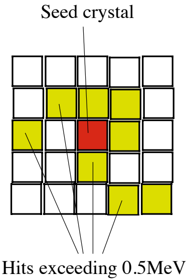
☑ due to the track; discriminate e / non-e

☒ treated as neutral; discriminate γ / other

Shower recon. is done by;

- Crystal hits < 0.5MeV are sparsified by TDC readout.
- Seed crystal: local max. >10MeV.
- Recorded hits inside the 5×5 matrix surrounding the seed crystal are clustered.

- Energy: summing up each hits.
- Position: energy-weighted center of gravity.



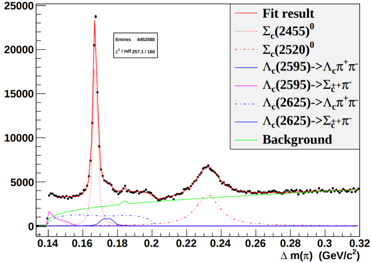
Exploring with students: *begin with the tracks* and cluster in a way specific to each PID hypothesis; leads to multiple but more sensitive event reconstructions

Improving calorimetry (2): calibration for neutrals

- the ECL response was studied in a test-beam campaign 20 years ago
- $\pi^{\pm}$, $e^{\pm}$, γ
- there's also continuous calibration using
  - built-in {light,charge} calibration sources on each crystal
  - high rate, low multiplicity physics events,
    e.g. radiative Bhabha $e^+e^- \to e^+e^-\gamma$
- n, $\overline{n}$, and K_L^0 response is $\sim$ unmeasured for these detectors at these energies, *and* known to be imperfectly simulated
- no realistic test beam is available
- idea: a ***virtual test beam*** can be skimmed from $1\,\mathrm{ab}^{-1}$ of Belle data
  - this *sort* of approach is used in analysis,
    but has not (to my knowledge) been used for quite this task
  - use charmed baryon decay chains: many constraints available
  - aim: tag relatively pure samples of n, $\overline{n}$ and provide $\vec{p}(n)$ case-by-case
- ultimate goal is to truly distinguish tracks, had-interaction splitoffs,
  beam backgrounds, and neutrals

Analysis of $\Sigma_c \to \Lambda_c^+ \pi$

- baryonic decay chain with protons or neutrons in the final state



- two decay channels (+ cc):
  $\Sigma_c^{++} \to \Lambda_c^+ \pi^+$ and $\Sigma_c^0 \to \Lambda_c^+ \pi^-$
- slow pion features peak in Δm
- 1 ab^{-1} of Belle data $\Rightarrow \sim 75\,000\ \Lambda_c^+$

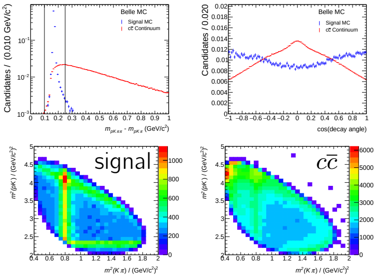
- exploit mass and pointing constraints $\Rightarrow$ over-constrained system
- ultimate goal: analysis of $\Lambda_c^+ \to n \overline{K}^0 \pi^+$ and $\overline{\Lambda}_c^- \to \overline{n} K^0 \pi^-$
- first step: reconstruction using $\Lambda_c^+ \to p K^- \pi^+$
- second step: omit proton information in reconstruction

Selection of $\Sigma_c \to \Lambda_c^+ \pi$ with $\Lambda_c^+ \to pK^-\pi^+$

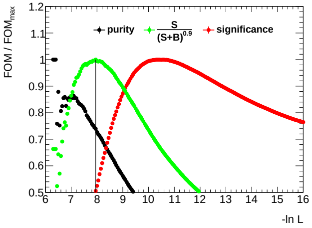
- particle identification requirements on all tracks

- restricted mass window for Δm
- mass constraint on Λ_c^+
- decay and azimuthal angles

- Dalitz plot of m_{pK} vs $m_{K\pi}$
- resonant structure for intermediate states $\overline{K}^{*0}$, $\Delta(1232)^{++}$, $\Lambda\,(1520)$

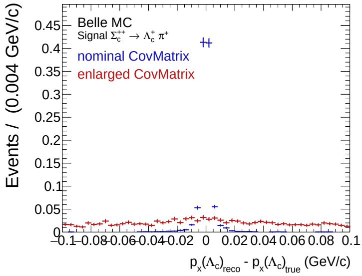


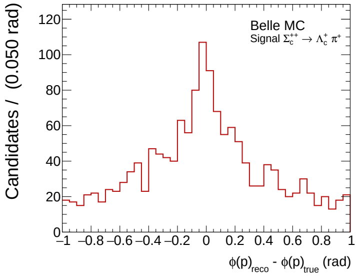
- construct total likelihood function from angles, Dalitz plot, vertex fit quality, and Σ_c momentum
- find optimal cut point
- achieve signal-to-background ratios of 23 and 35 for Λ_c^+ from Σ_c^{++} and Σ_c^0



Reconstruction ignoring detector measurements of proton quantities

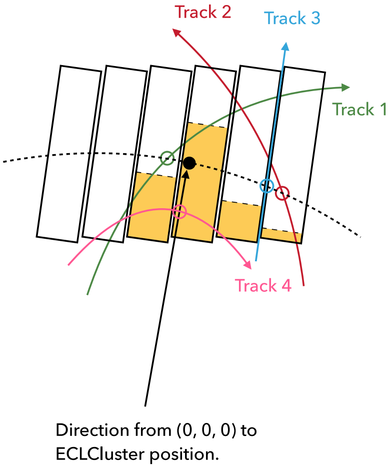
- simulation of neutron case by reconstructing $\Lambda_c^+ \to pK^-\pi^+$ without proton
- possible thanks to over-constrained system:
  - kaon and pion define Λ_c^+ decay vertex
  - bachelor pion + other prompt tracks define primary vertex
  - direction of Λ_c^+ constrained by pointing between the two vertices
  - $p(\Lambda_c^+)$ constrained by Σ_c mass and flight direction of bachelor pion
- angular resolution for protons in normal reconstruction $\sim 0.8\,$mrad
- without proton 70 - 90 $\times$worse but probably good enough

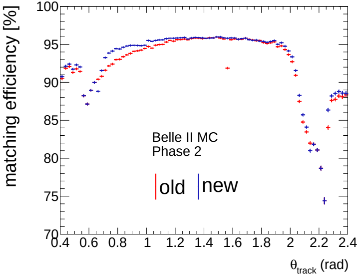




Track-cluster matching

- neutral and charged particles create clusters in the ECL
- clusters matched by tracks considered charged, all the others neutral
- new matching principle based on angular distance





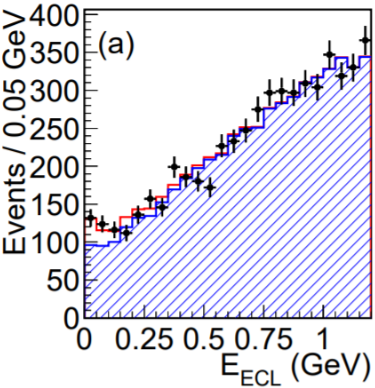
- improved matching efficiency
- confirmed on real data
- mis-match rate kept below 2 %

$B^- \to \tau^- \overline{\nu}_\tau$ analysis

› Semileptonic tagging

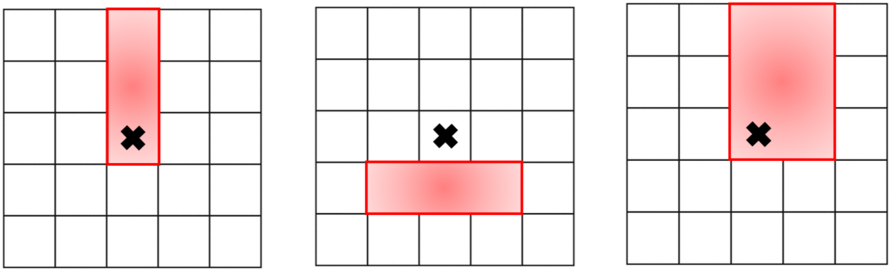
- Signal: $B^- \to \tau^- \overline{\nu}_\tau$
- Example tagging mode: $B^+ \to \overline{D}^0 l^+ \nu_l$ with $\overline{\mathrm{D}}^0 \to K^+\pi^-, \mathrm{K}^+\pi^-\pi^0$
- Background events come from $q\overline{q}$ continuum and $\mathrm{B}\overline{B}$ events

› Fit to E_{ECL} to obtain signal yields



Decay Mode	*Signal Yield*	ϵ, 10^{-4}	$\mathcal{B}$, 10^{-4}
Combined	143^{+36}_{-35}	14.13×10^{-4}	$1.54^{+0.38+0.29}_{-0.37-0.31}$

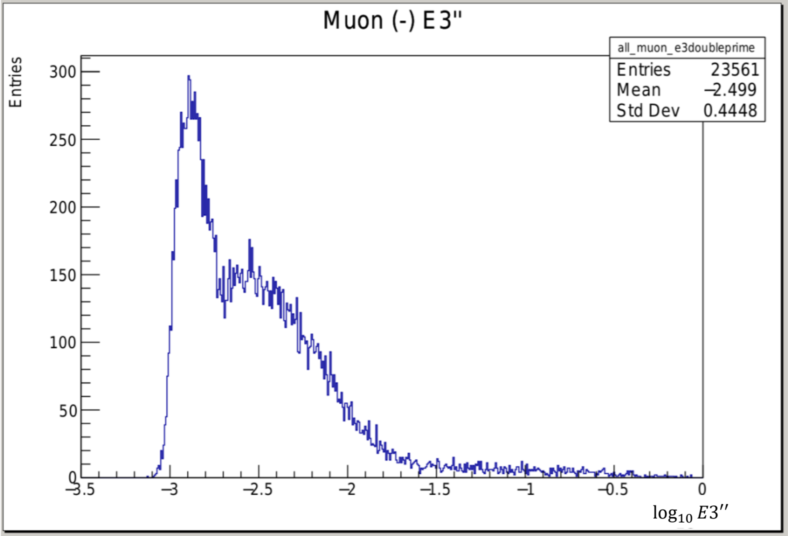
Crystal Grid Division



E3 E3'' E6

- Denote E3'' to be energy deposited in this shaded region
- Expect to be higher for hadrons

Our Algorithm - Muons



Our Algorithm - Hadrons