ANTI-NEUTRON MEASUREMENT WITH THE TOP SUBDETECTOR AT BELLE II

NOVEMBER UPDATE: TOP FEATURE SELECTION AND DATA/MC AGREEMENT

- MANTRA Meeting

Monday 3rd November
9:00 CET

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1. MOTIVATE THAT EVENTS WITH $\bar{n}$-ANNIHILATIONS AROUND TOP ***THAT ALSO LEAVE SIGNAL*** ARE NOT AN UNCOMMON OCCURRENCE

We saw that 31.34% of $\bar{n}$ from Particle Gun that annihilate around the TOP also leave a signal

2. SHOW THAT 'BACKGROUND' TOP TIMING DISTRIBUTIONS, LIKE $\bar{n}$-ANNIHILATIONS, HAVE STRUCTURE AND ARE NON-NEGLIGIBLE (I.E. NOT FLAT)

We have shown in Particle Gun that neutral particles *can* induce signal in TOP through their annihilations

3. DEMONSTRATE THAT THERE IS CORRELATION IN MEASURED TOP TIMING AGAINST THE SIMULATED PENETRATION DEPTH OF $\bar{n}$

We saw that the hit time extracted from TOP signal pertaining to the $\bar{n}$ was measured to be later when $\bar{n}$ annihilated deeper into the detector

previous GOALS (presented at RICH2025)

New GOALS

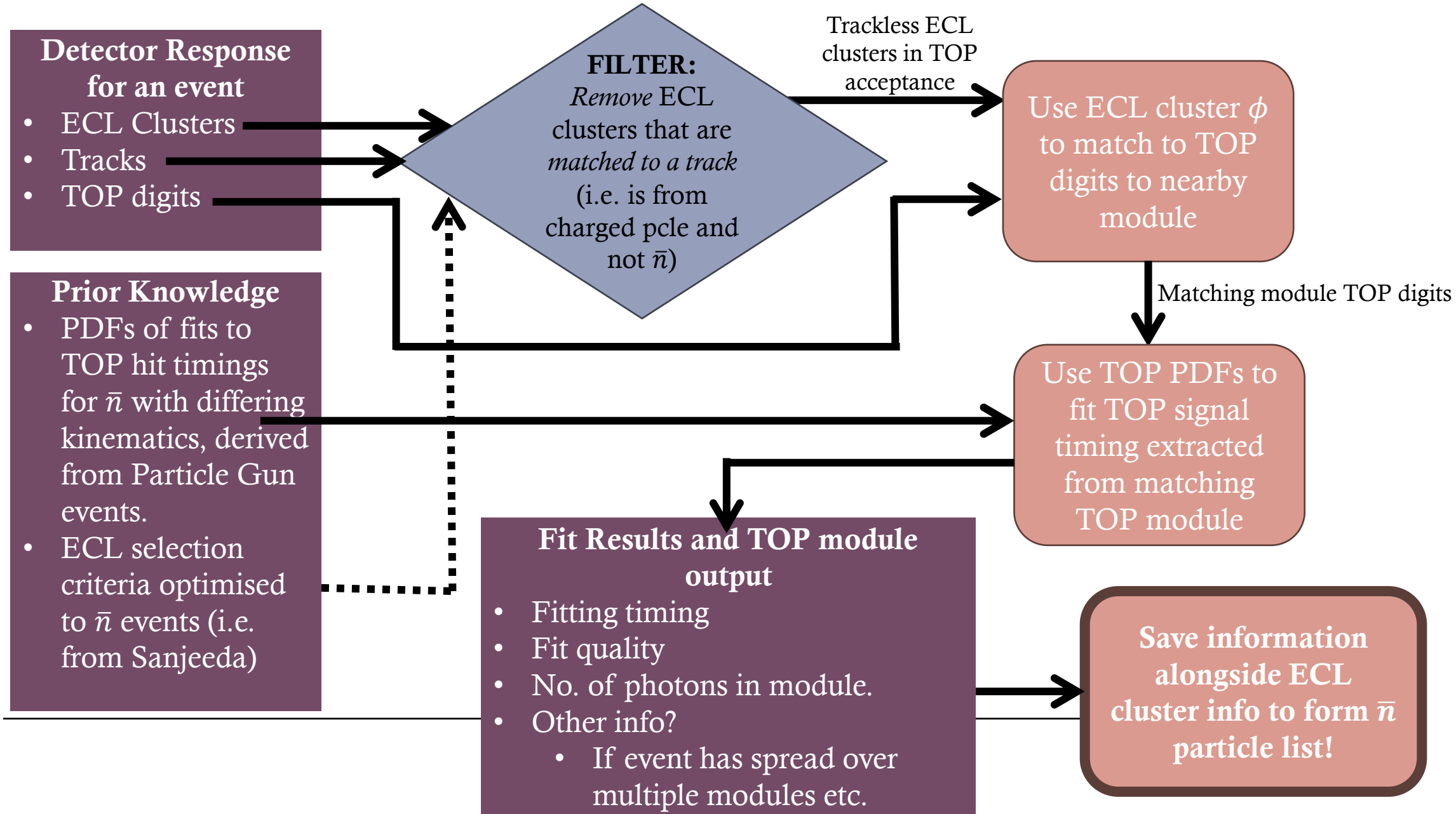
1. DEMONSTRATE GOOD DATA/MC AGREEMENT OF TOP SIGNAL FROM $\bar{n}$ EVENTS.

2. DESIGN A *BASF2* SOFTWARE MODULE TO PERFORM "$\bar{n}$ FEATURE EXTRACTION" IN TOP I.E. TO PRODUCE VARIABLES FROM TOP INFORMATION THAT CAN BE USED TO IMPROVE $\bar{n}$ PARTICLE SELECTION.

1. DATA/MC ANALYSIS OF $\bar{n}$ SIGNAL

- Use a channel that can be used to reliable isolate $\bar{n}$ signal in both data and MC
  - **i.e.** $e^+e^- \to p\bar{n}\pi^-\pi^+\pi^-(\pi^-\pi^+)(\pi^-\pi^+)(K^-K^+)$, identify $\bar{n}$ through recoil & neutral ECL clusters
- Reconstruct channel in signal MC, as well as generic MC (i.e. $B\bar{B}$ and continuum events)
  - Need ***cdst*** to create ntuples with TOP signal saved.
  - ***cdst*** are much larger files than what is usually used (mdst), have had to request data production assist in their generation!
- Reconstructing in data: Currently focusing on "chunk 1" of Belle II dataset measured at $\Upsilon(4S)$ energy due to size of *cdst* files. Equivalent to 54.573/fb.
- **Goal:** Look at hist2d of extracted timing and ECL cluster energy in data and MC.
- **Blocker:** Waiting on DP to process generic MC request.

2. DESIGNING A *BASF2* MODULE



2. DESIGNING A *BASF2* MODULE

Detector Response for an event
- ECL Clusters
- Tracks
- TOP digits

FILTER: *Remove* ECL clusters that are *matched to a track* (i.e. is from charged pcle and not $\bar{n}$)

Trackless ECL clusters in TOP acceptance

ECL cluster ϕ to match to TOP digits to nearby module

Matching module TOP digits

Prior Knowledge
- PDFs of fits to TOP hit timings for $\bar{n}$ with differing kinematics, derived from Particle Gun events.
- ECL selection criteria optimised to $\bar{n}$ events (i.e. from Saajeeda)

Use TOP PDFs to fit TOP signal timing extracted from matching TOP module

Fit Results and TOP module output
- Fitting timing
- Fit quality
- No. of photons in module.
- Other info?
  - If event has spread over multiple modules etc.

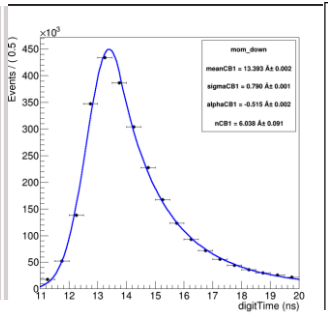
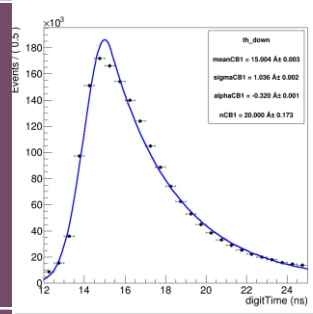
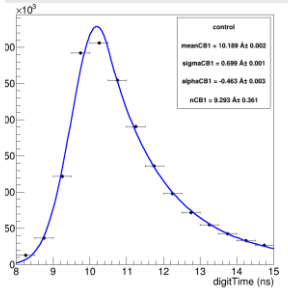
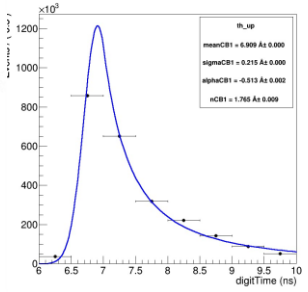
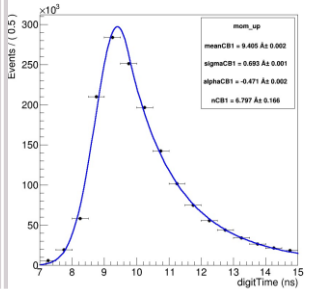
Save information alongside ECL cluster info to form $\bar{n}$ particle list!

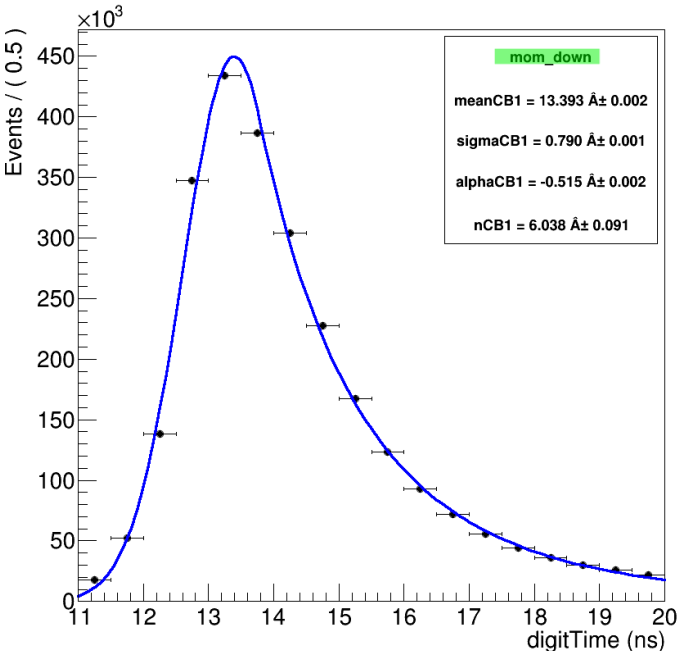
Module deadline: April 2026, to be available in basf2 release 11

What I'm currently working on

OBTAINING TOP PDFS FOR VARYING $\bar{n}$ KINEMATICS

200k Particle Gun events with varying $\bar{n}$ momentum/angles, fit to initial peak in *digitTime* **for all events** with module that matches $\bar{n}$ azimuthal angle and that is in TOP angular acceptance. Fit using RooCrystalBall. Also will extend fit to second peak as well!

p/θ	62°	92°	122°
0.5 GeV/c	TO DO!	 mom_down meanCB1 = 13.393 ± 0.002 sigmaCB1 = 0.790 ± 0.001 alphaCB1 = -0.515 ± 0.002 nCB1 = 6.038 ± 0.091	TO DO!
1 GeV/c	 th_down meanCB1 = 15.004 ± 0.003 sigmaCB1 = 1.036 ± 0.002 alphaCB1 = -0.320 ± 0.001 nCB1 = 20.000 ± 0.173	 control meanCB1 = 10.189 ± 0.002 sigmaCB1 = 0.699 ± 0.001 alphaCB1 = -0.463 ± 0.003 nCB1 = 9.293 ± 0.361	 th_up meanCB1 = 6.909 ± 0.000 sigmaCB1 = 0.215 ± 0.000 alphaCB1 = -0.513 ± 0.002 nCB1 = 1.765 ± 0.009
1.5 GeV/c	TO DO!	 mom_up meanCB1 = 9.405 ± 0.002 sigmaCB1 = 0.693 ± 0.001 alphaCB1 = -0.471 ± 0.002 nCB1 = 6.797 ± 0.166	TO DO!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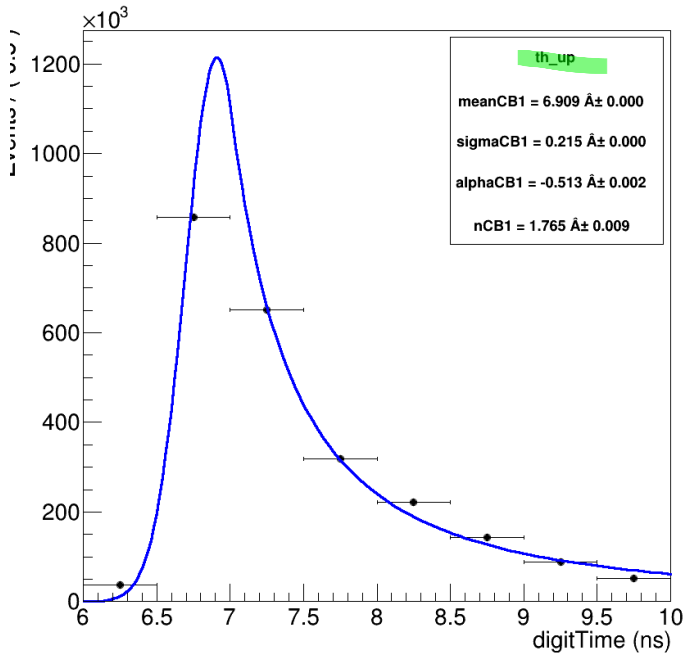
Events / (0.5)
digitTime (ns)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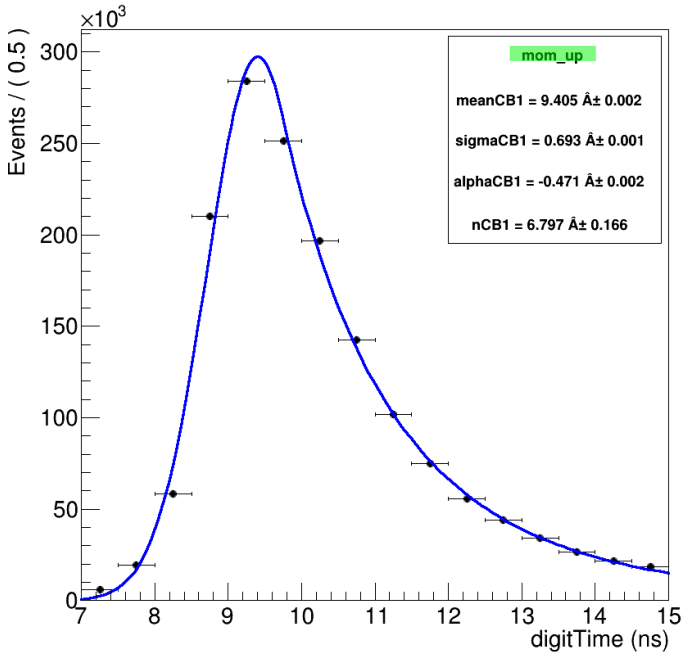
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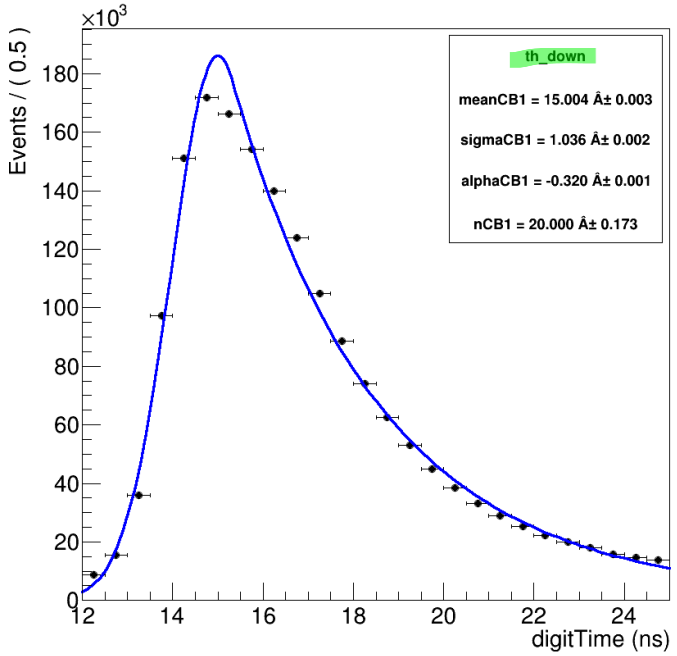
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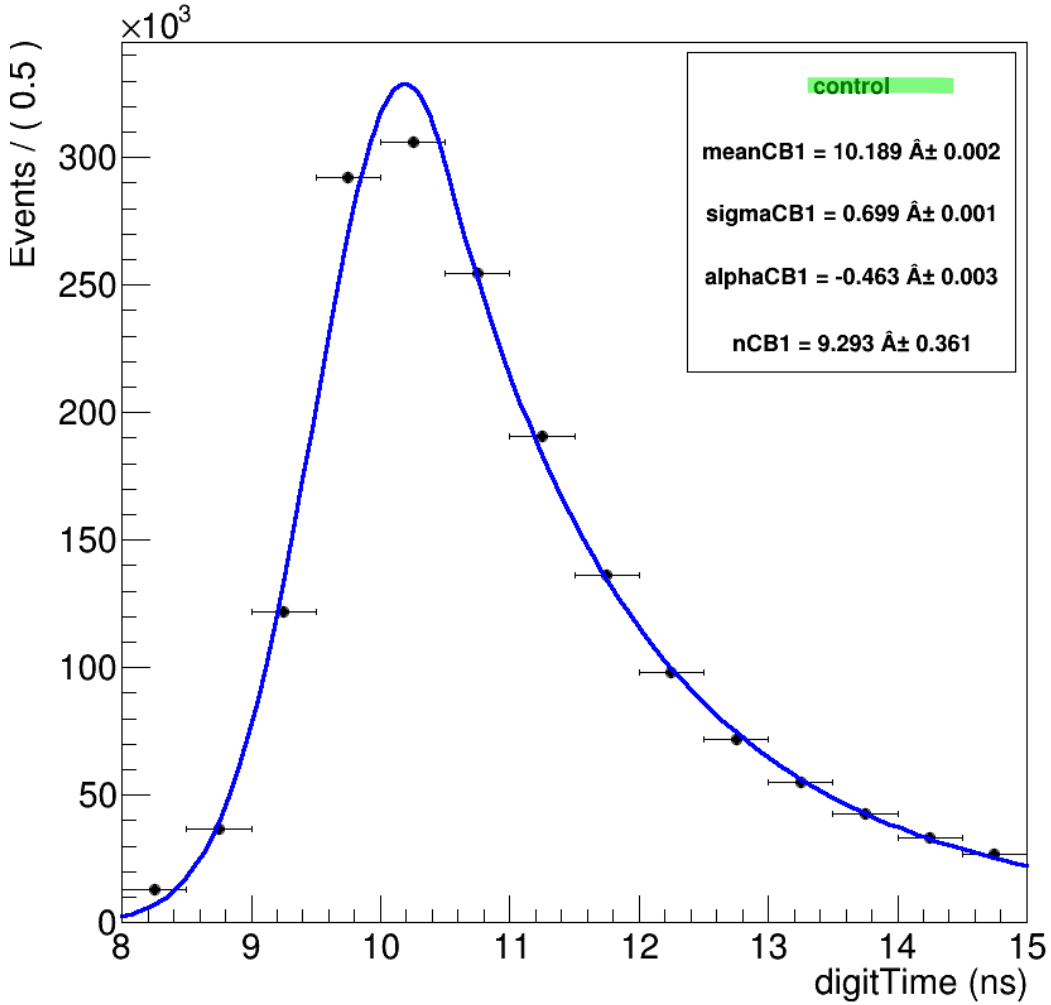
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"Japanese flowering cherry"
Collegno (Torino),
April 2025

TO DO

- *Data/MC agreement*
  - Look into reconstructing $e^+e^- \to p\bar{n}X_{had}$ modes in data and MC and make comparison, when available
- *Designing an $\bar{n}$ basf2 module*
  - Improve fit model for TOP *digitTime,* including looking at pull plots.
  - Incorporate more angular/momentum combinations.
  - Look at fits to modules *adjacent* to $\bar{n}$ slot, for cases were TOP signal spills between modules
  - Begin looking into how to format a *basf2* software module.

Cheers!
Ciao!

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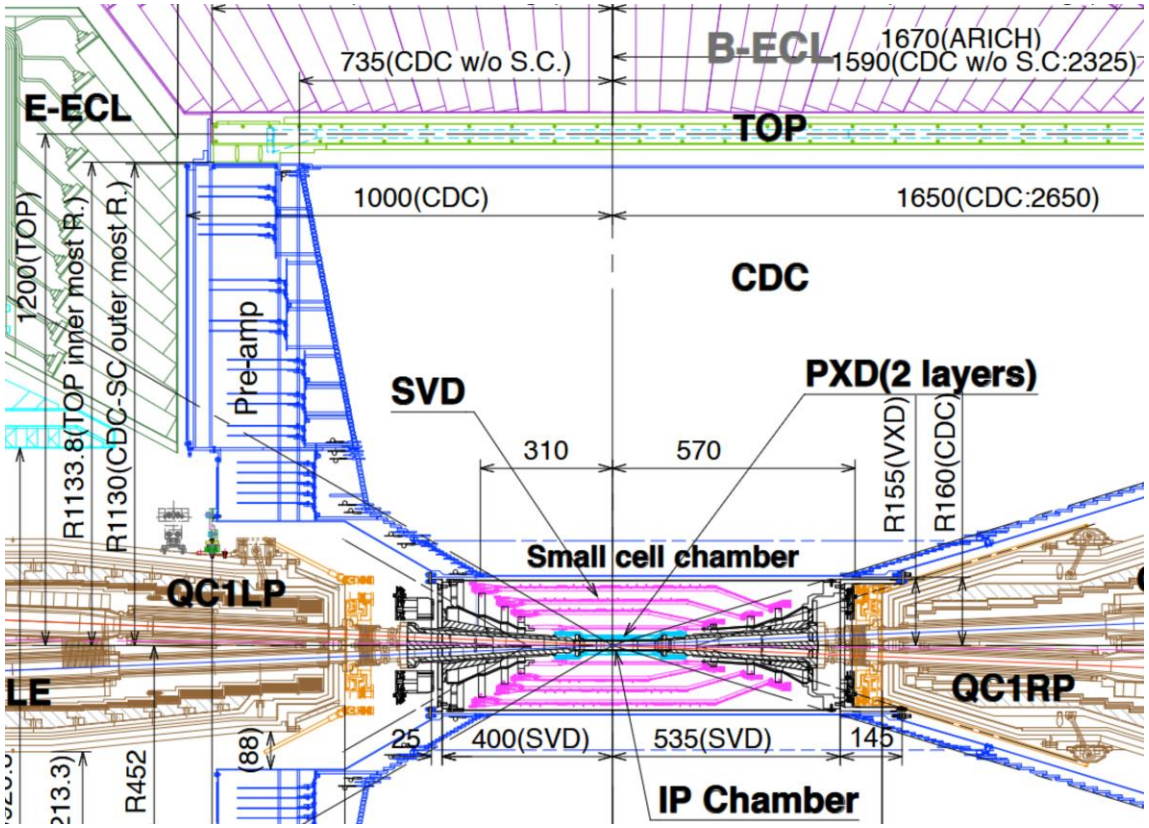
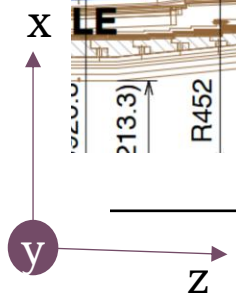
(Back-up slides following)

OUR GOAL:

Determine a method of measuring the properties of anti-neutrons ($\bar{n}^0$ or "n-bar"), via the timing signatures of their annihilation in detector volumes.





- Our case-study: the **TOP sub-detector** of the Belle II experiment.
- Anti-neutron identification differs from standard neutrons, in that they can be **identified via annihilation** events within detector volumes.
- **IF** anti-neutron annihilation induces an **electromagnetic shower in the ECL**, the full $\bar{n}^0$ energy can be measured.
- **IF** anti-neutron annihilation instead induces a **hadronic shower where charged products escape the ECL**, measurements can be incomplete.
- Can improve $\bar{n}^0$ measurement by studying **cases where annihilation products back-scatter** into the Time-of-Propagation (TOP) subdetector, a timing-based Cherenkov radiation detector.
- Additionally, can look at cases where anti-neutron annihilation **occurs slightly before or within the TOP**, where products can be detected before **further measurement when entering the ECL.**

HOW CAN THE TOP COUNTER BE USED TO COMPLEMENT MEASUREMENTS OF ANTI-NEUTRON SHOWERING IN THE ECL?

- Measurement of the anti-neutron annihilation within ECL depend heavily shower containment:
  - **If** annihilation particles produces an **electromagnetic shower**, the full $\bar{n}^0$ energy can be measured.
  - **Else if** the annihilation particles produces a **hadronic shower where charged products escape the ECL**, energy measurements is incomplete.
- TOP measurements can complement ECL information in situations where charged products transverse the TOP and scatter in ECL, such as when $\bar{n}^0$ annihilates…
  - … in material slightly ***before TOP*** (110 cm – 118 cm away from IP), and charged products transverse the TOP **before** entering ECL.
  - … ***within TOP*** active volume or shielding (118 cm – 125cm), and charged products transverse the TOP before entering ECL.
  - …in ***ECL*** (125 cm – 162 cm), where the charged products back-scatter through the ECL and then transverse the TOP.