UNIVERSITY of HAWAI'I®
MĀNOA

Fast Timing Layer-based EventT0

For Belle II upgrade

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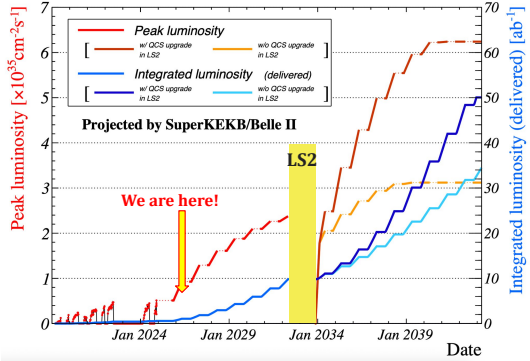
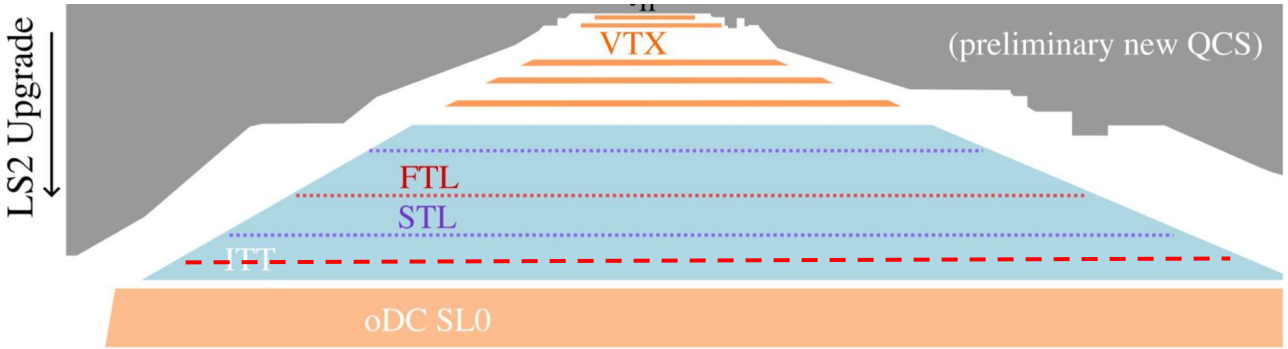
Introduction





- Fast Timing Layer (FTL) in the Belle II upgrade (~2032)
- FTL: excellent PID for low-Pt tracks
  - Further improved by looping tracks
  - Requires a good time reference for the TOF measurement
  - Assumes a close-to-perfect T0 (collision time, σ ≈ 25 ps)

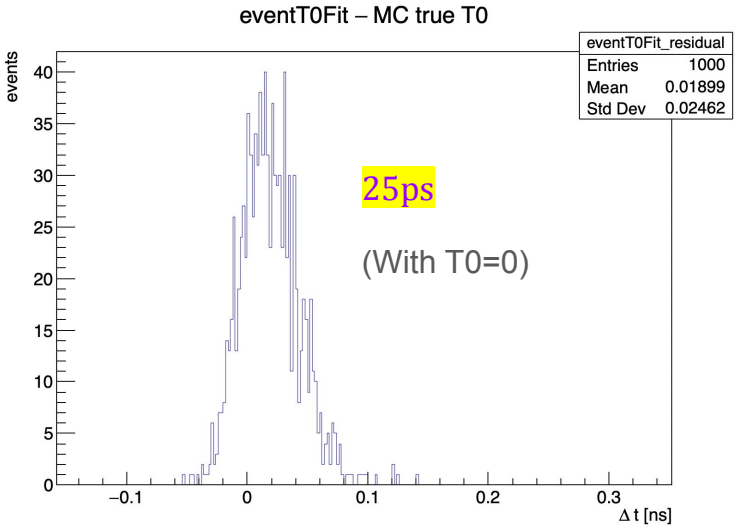
Goal: investigate the performance of FTL-based EventT0

- Current b2 EventT0 has several contributions at different stages of reconstruction
- The final value is taken with priority on the CDCchi2 extraction with σ~ 1ns

CDC_{χ^2} > SVD > $\mathrm{CDC}_{\mathrm{hit}}$

Offline EventT0

- Method to get the $T0_{event}$ giving tracking:
  - For a track with known p:
    - $T_{hit,i} = T0_{event} + T_{TOF,\ mass}$ (flight length, *mc*_mass)
    - $R_i = T_{hit,i} - T0_{event} - T_{TOF,\ mass}$
  - In each event:
    - scan of $T0_{event}$ = arg min $\sum(R^2_i/\sigma^2_i)$ (Remove outliers with pull>4ns)



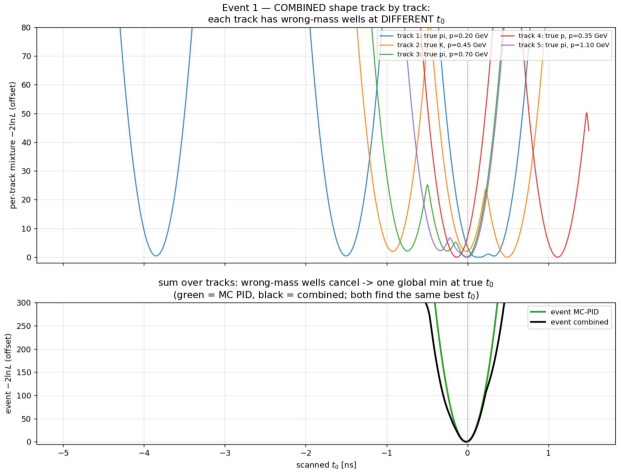
** mass from mc*

- Inputs from PID would be helpful
- EventT0 and TOF-based PID are interdependent

➔ Joint EventT0 and PID determination

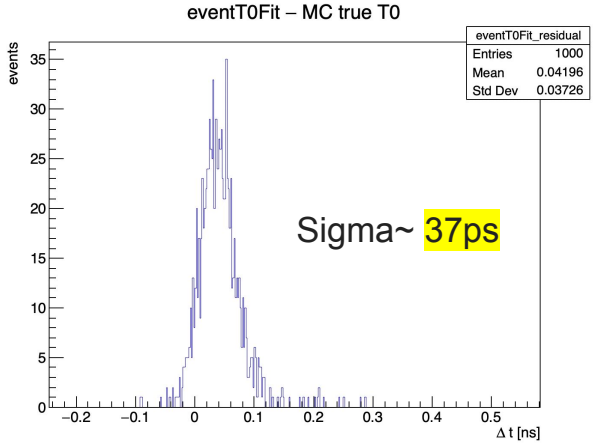
Joint EvenT0 and PID determination

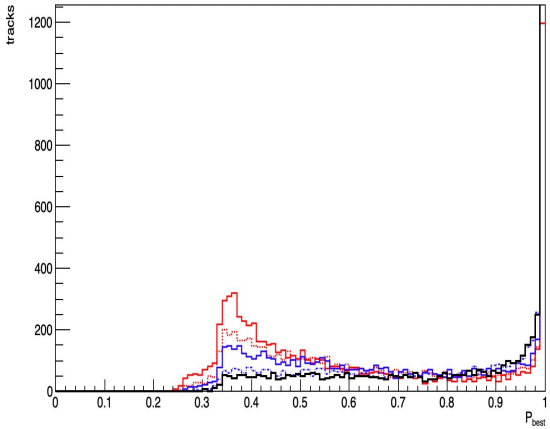
- PID Can be marginalized out:
  - Retain all particle hypotheses and estimate the T0 by maximizing the marginal likelihood over the latent PID
  - Preserve the information of the best eventT0
  - Repeat until we have stable PID (this will be improved) and T0(fit once will be fine)
- Allow determination of T0 without knowing PID (more plots in backup)
- Sigma eventT0~ 37ps



$$L_i(t_0) = \sum_{m=e,\mu,\pi,K,p} w(m)\, G\big(t_i - t_0 - \mathrm{TOF}(m)\big)$$

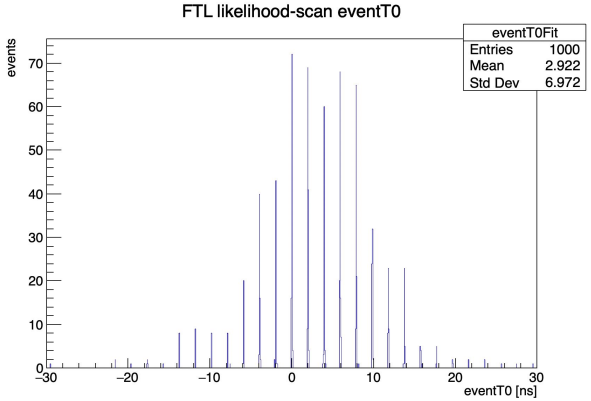
$$\prod_i L_i(t_0)$$

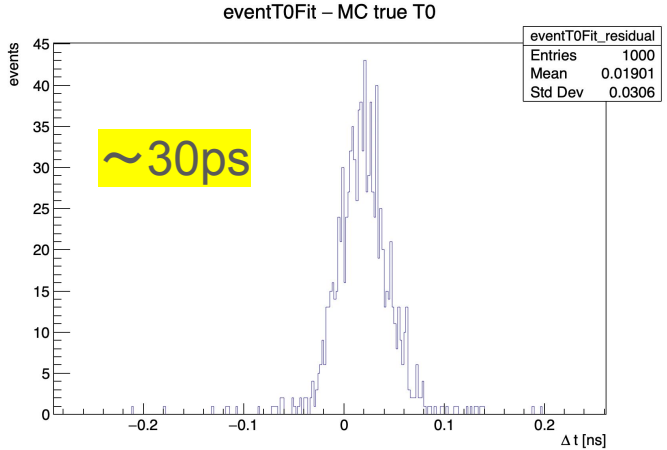


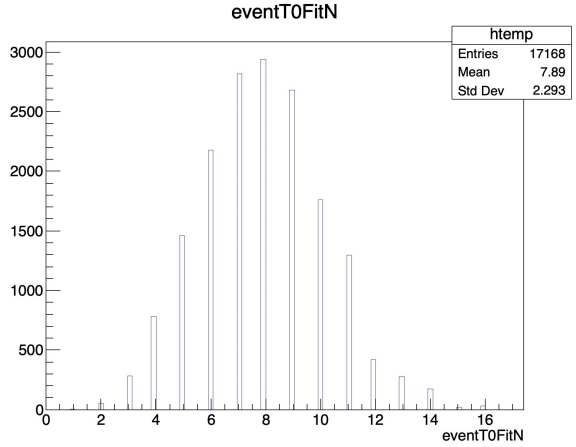


Joint EvenT0 and PID determination

- Only use higher Pt tracks (Pt >0.2 GeV/c) to determine T0, then update PID for all tracks
- (Or Tracks going through outer detectors with good PID)
- (L1 trigger activated)





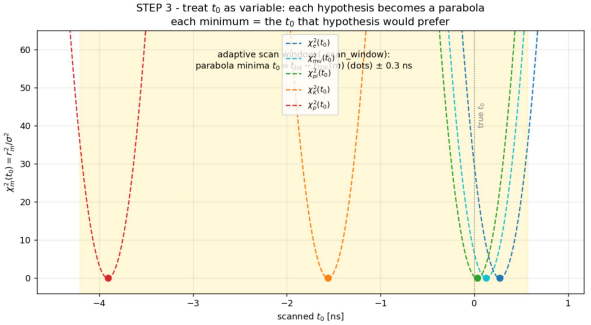


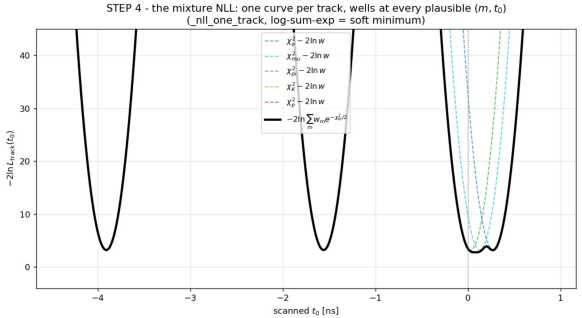
Number of tracks for fitting

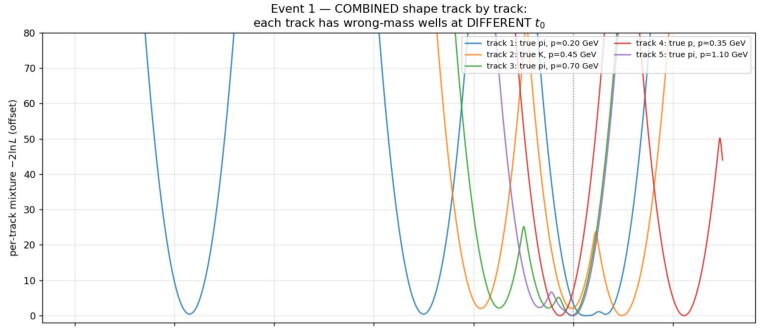
- So far answers: how well can T0 do *given* tracking?
  - ~30 ps

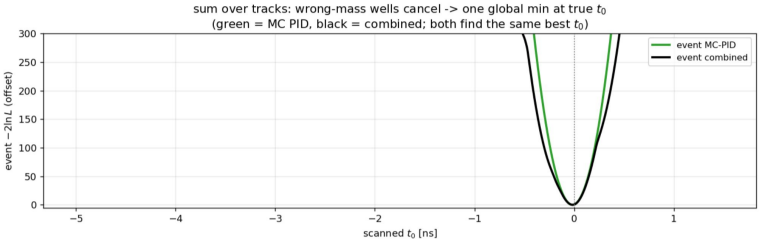
Summary

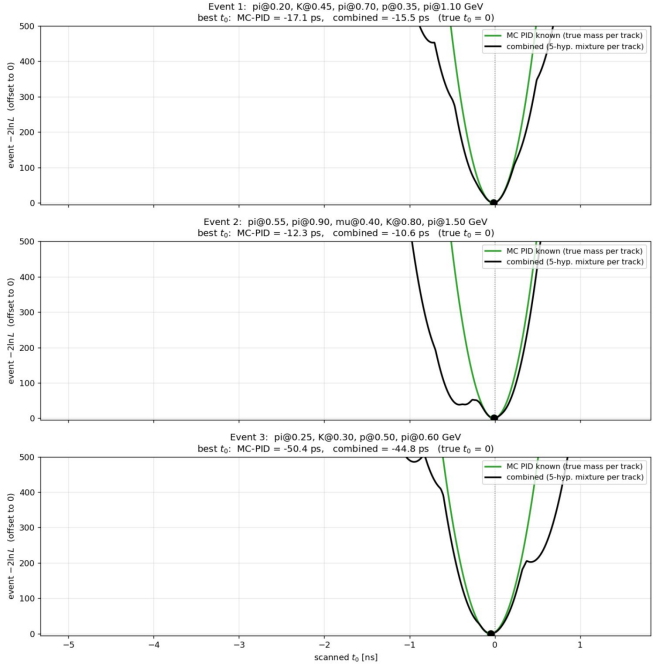
- We explored the potential improvement of EventT0 with the FTL at Belle II:
  - A joint EventT0 and PID determination could provide a EventT0 with uncertainty ~30ps
    - Significantly improved compared with current T0 uncertainty (~1ns)
  - FTL could also work with the current L1-trigger, which has a jitter ~10ns
- Implementation of FTL-based EventT0 and PID into basf2 is still on-going
- Exploration of the FTL potential for the trigger


STEP 3 - treat t_0 as variable: each hypothesis becomes a parabola
each minimum = the t_0 that hypothesis would prefer
adaptive scan
parabola minima t_0
in window):
) (dots) ± 0.3 ns
true t_0
scanned t_0 [ns]


STEP 4 - the mixture NLL: one curve per track, wells at every plausible (m, t_0)
(_nll_one_track, log-sum-exp = soft minimum)
scanned t_0 [ns]


Event 1 — COMBINED shape track by track:
each track has wrong-mass wells at DIFFERENT t_0
track 1: true pi, p=0.20 GeV
track 2: true K, p=0.45 GeV
track 3: true pi, p=0.70 GeV
track 4: true p, p=0.35 GeV
track 5: true pi, p=1.10 GeV
per-track mixture −2lnL (offset)


sum over tracks: wrong-mass wells cancel -> one global min at true t_0
(green = MC PID, black = combined; both find the same best t_0)
event MC-PID
event combined
event −2lnL (offset)
scanned t_0 [ns]


Event 1: pi@0.20, K@0.45, pi@0.70, p@0.35, pi@1.10 GeV
best t_0: MC-PID = -17.1 ps, combined = -15.5 ps (true t_0 = 0)
Event 2: pi@0.55, pi@0.90, mu@0.40, K@0.80, pi@1.50 GeV
best t_0: MC-PID = -12.3 ps, combined = -10.6 ps (true t_0 = 0)
Event 3: pi@0.25, K@0.30, p@0.50, pi@0.60 GeV
best t_0: MC-PID = -50.4 ps, combined = -44.8 ps (true t_0 = 0)
MC PID known (true mass per track)
combined (5-hyp. mixture per track)
event −2lnL (offset to 0)
scanned t_0 [ns]

Trigger slides

The Belle II TRG system

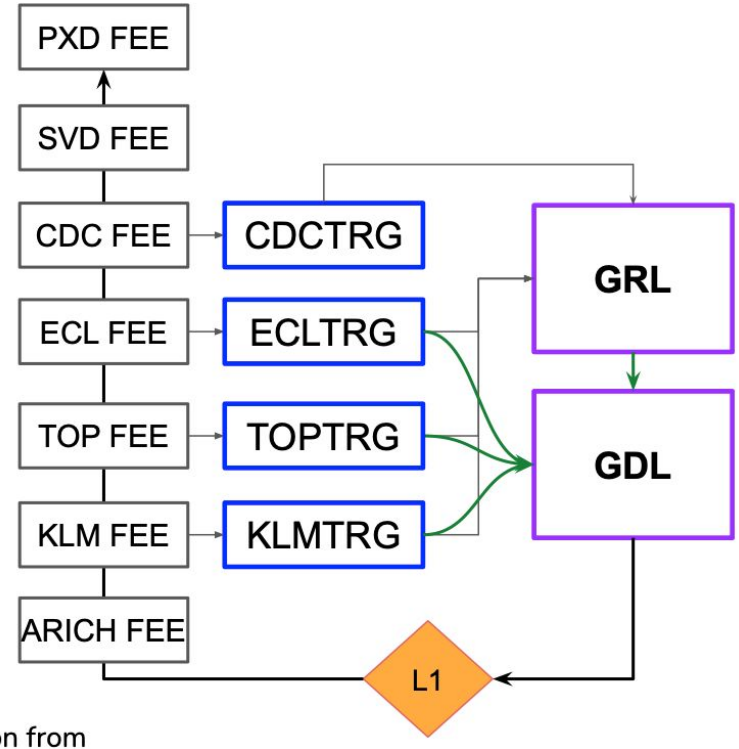
The TRG system is composed of

4 sub-trigger systems:

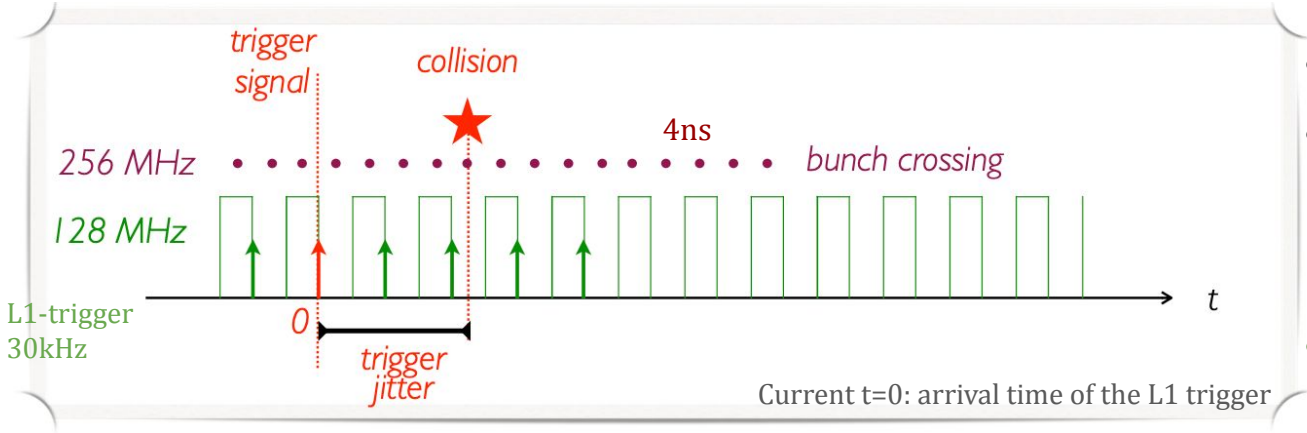
- CDCTRG
  - Charged particle tracks
- ECLTRG
  - Energy deposits and clusters
- KLMTRG
  - Muon-like activity
- TOPTRG
  - Event timing

+ 2 global trigger systems.

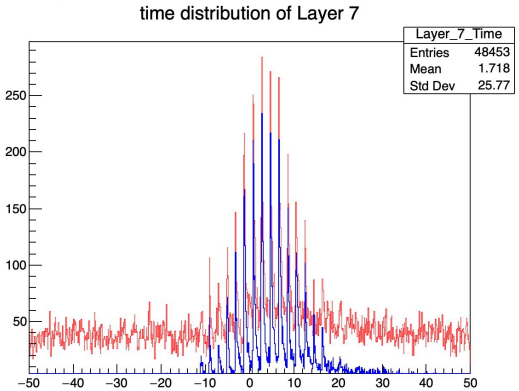
- Global Reconstruction Logic
  - Receives data from the 4 subsystems and matches hits among them
- Global Decision Logic:
  - Provides the final L1 decision with information from all subsystems + GRL

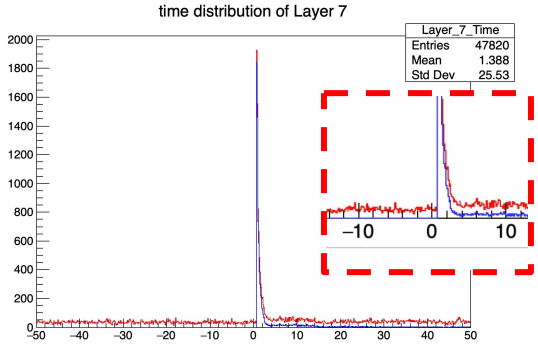


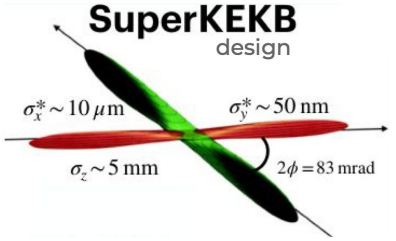
FTL for trigger

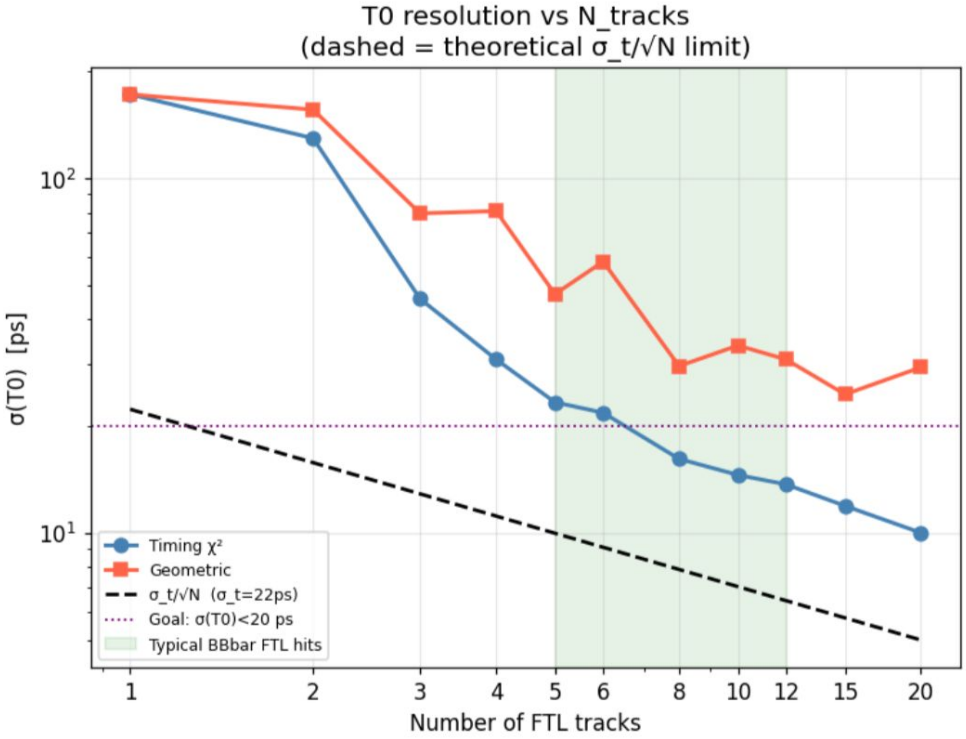


- RF: 512 MHz, every 2ns
  - σ_t~25ps
- max(Bunch crossing): 256 MHz, every 4ns,
  - $\sigma=\mathrm{sqrt}(\sigma_t^2+\sigma_B^2)$, σ_B is uncertainty of collision within bunch, depending on the beam size (σ_{B2} ~12ps)
- L1 trigger: 128 MHz
  - σ ~10ns








T0 resolution vs N_tracks
(dashed = theoretical σ_t/√N limit)
σ(T0) [ps]
10^2
10^1
Timing χ²
Geometric
σ_t/√N (σ_t=22ps)
Goal: σ(T0)<20 ps
Typical BBbar FTL hits
1
2
3
4
5
6
8
10
12
15
20
Number of FTL tracks