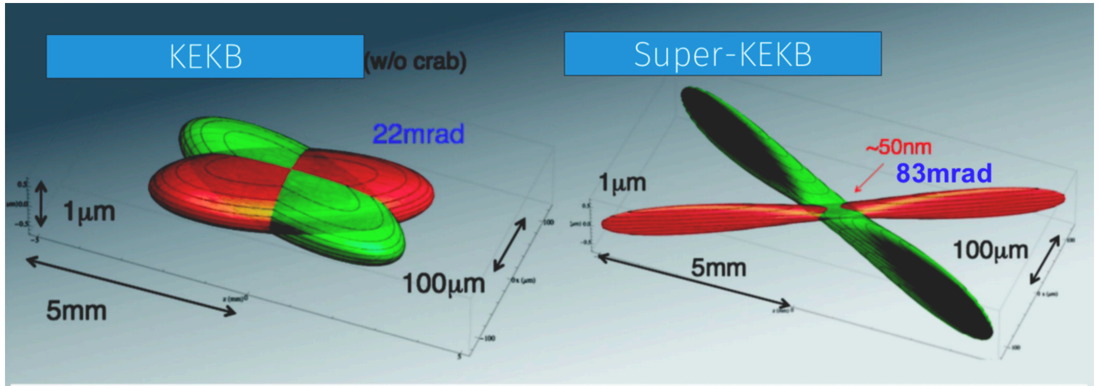
Trigger Efficiency Measurement at Belle II for ee→ττ

Petar Rados (DESY)
on behalf of the Belle II collaboration

SuperKEKB Accelerator

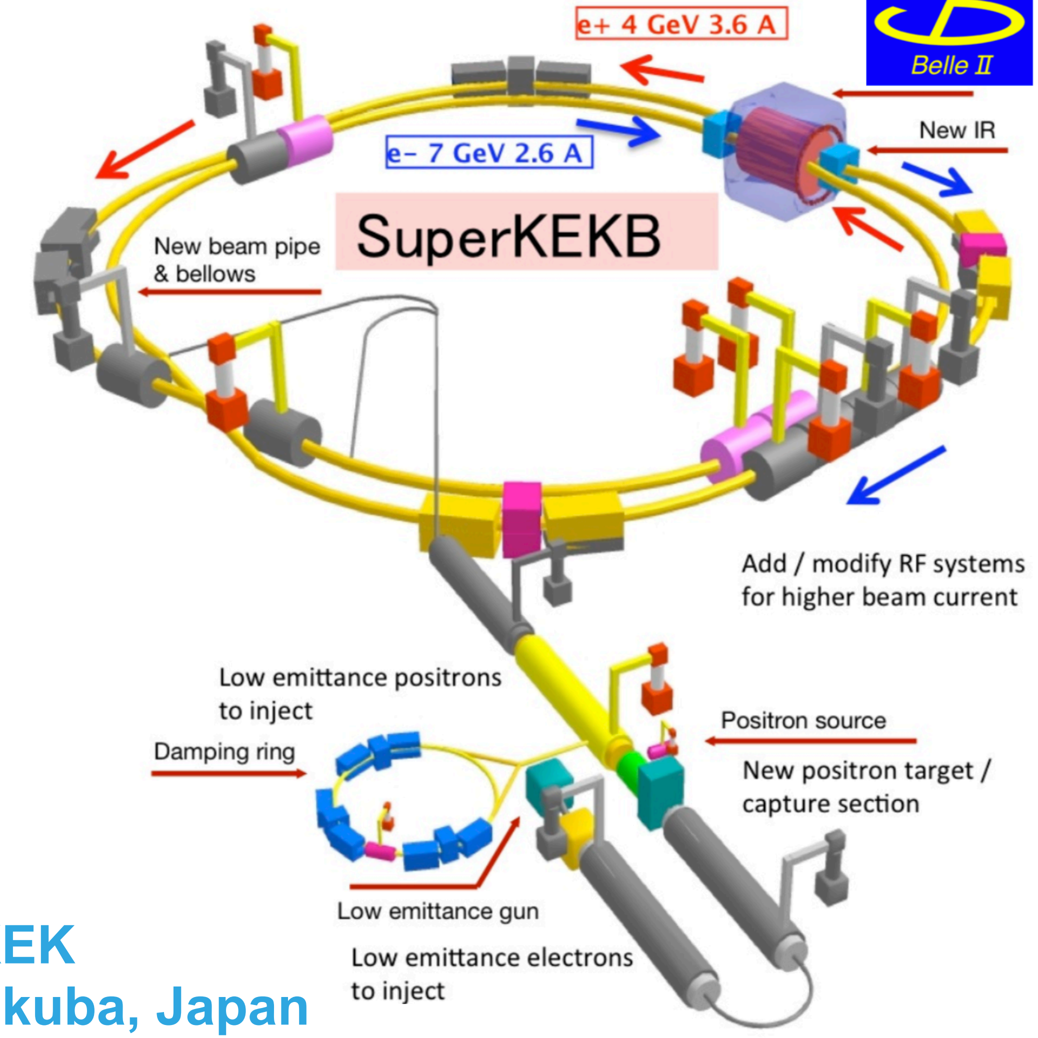
- New facility to search for new physics by studying *B*, *D* and τ decays
- Electron-positron collisions at $\sqrt{s} \approx 10.6$ GeV



	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}

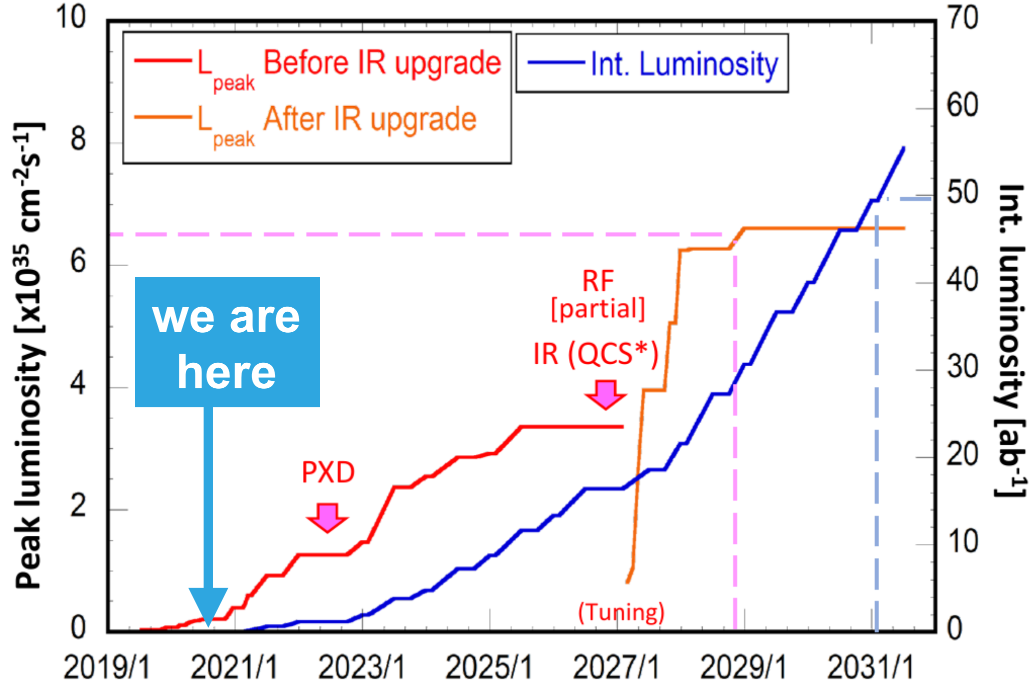
factor 20 factor 2-3

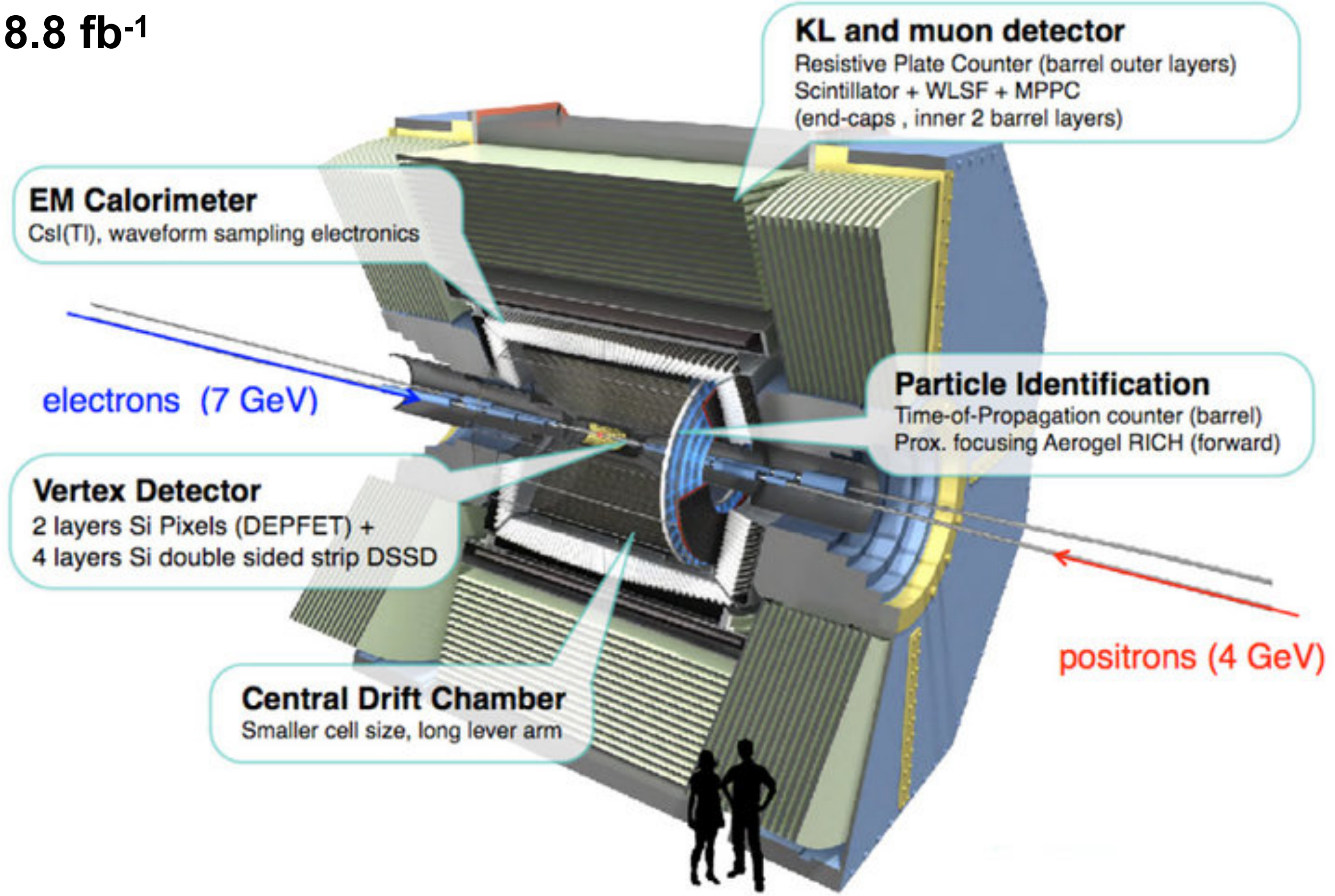
- Unprecedented design luminosity of $8{\times}10^{35}$ $cm^{-2}s^{-1}$
  Broke the world record last month!
- First beams/commissioning in 2016, Belle II rolled in 2017, first collisions in April 2018



@KEK
Tsukuba, Japan

- Phase 3 of data taking began in March 2019 ⇒ ~**74 fb^{-1}** collected so far
- Results shown today are with the 2019 dataset ⇒ **8.8 fb^{-1}**



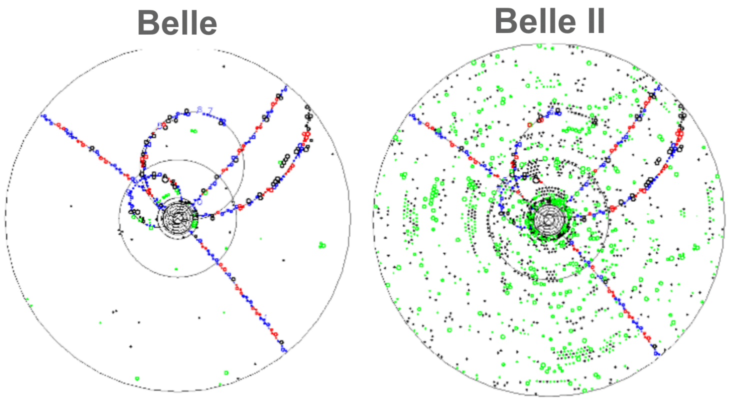


- Aiming for **50 ab^{-1}** over the next ~10 years (50 times Belle dataset)

L1 Trigger System

- Total physics event rate at SuperKEKB deign luminosity is ~20 kHz

- Sizeable machine background
  - synchotron radiation
  - Touscheck scattering
  - beam-gas
  - Bhabha scattering

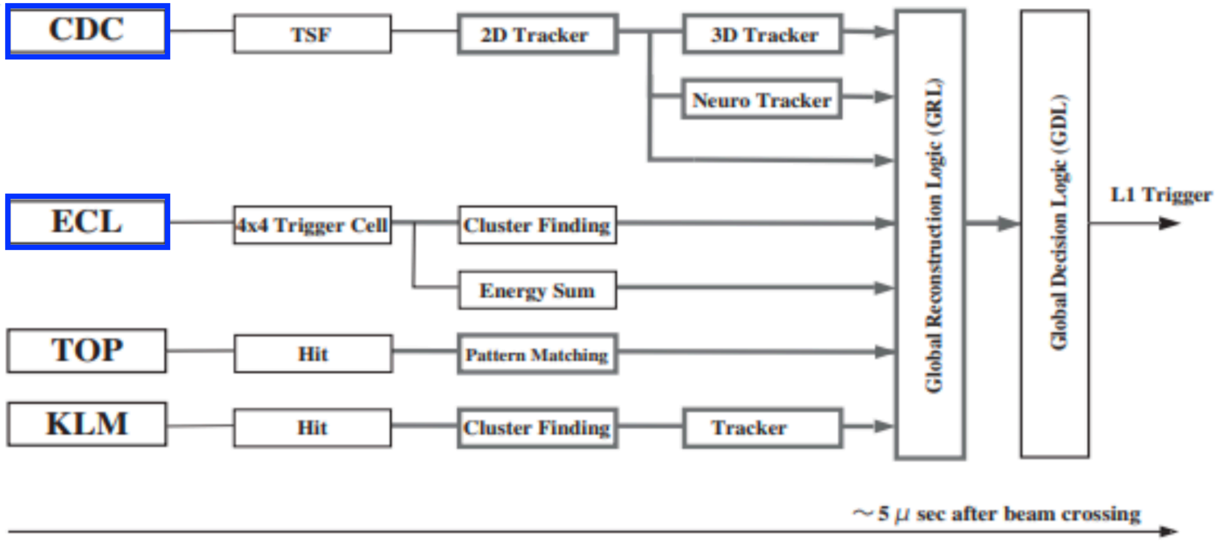


Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
$e^+e^- \to$ continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{lab} \geq 17°$)	44	350 [a]
$\gamma\gamma$ ($\theta_{lab} \geq 17°$)	2.4	19 [a]
2γ processes [b]	~ 80	~ 15000
Total	~ 130	~ 20000

- L1 trigger must reduce rate to a maximum of **30 kHz**

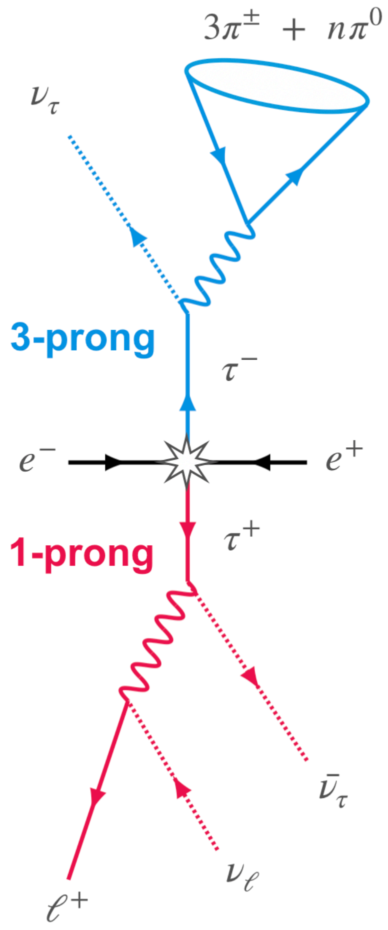
- Requirements
  - high efficiency for physics processes
  - trigger latency ~5μs, timing precision ≤ 10 ns
  - two event separation ≥ 200 ns

- Two primary components: **CDC** and **ECL** triggers
  - CDC 2D (r-ϕ space) track finding
  - ECL total energy and cluster finding, Bhabha veto



Tau reconstruction

- ee→ττ events provide an ideal testbed for the L1 trigger performance
  - large cross section: σ(ττ) ≃ σ(*BB*), at √s=$m_{\Upsilon(4s)}$
  - wide variety of signatures involving tracks (e,μ,π) and clusters (e,μ,π,π^0)



- Reconstruct 1-prong, 3-prong τ decays in 6 channels:
  - e-3π, μ-3π, π-3π, eμ, μπ, μμ

- E/p + likelihood based electron, muon and pion ID

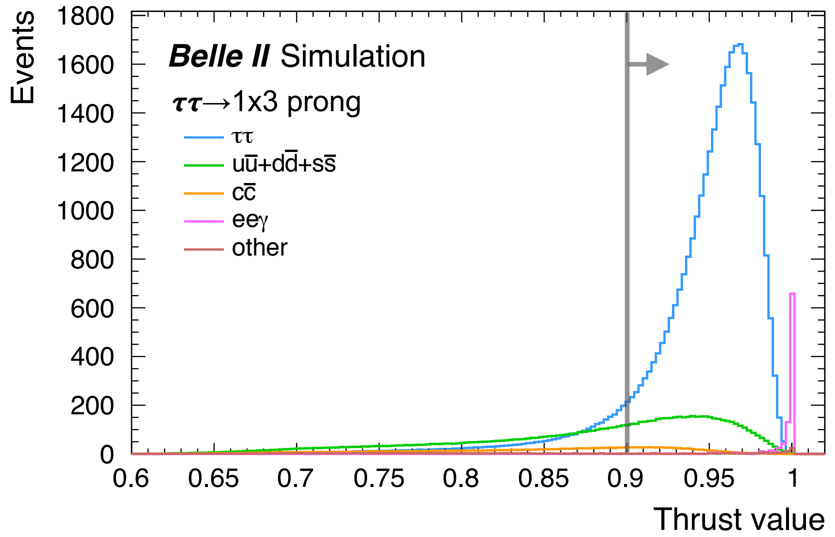
- Tracks required to be 1x3 or 1x1 wrt thrust axis

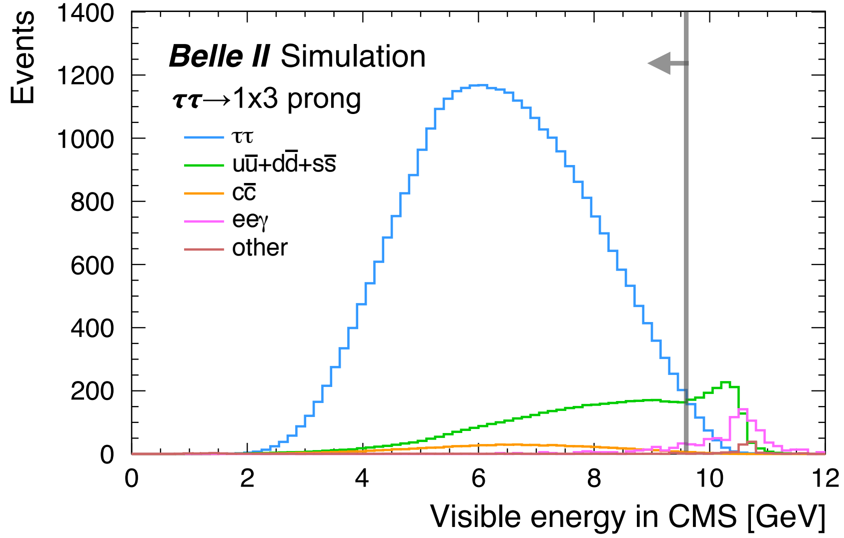
1x3 selection

- thrust value > 0.9
- E_{vis}^{cms} < 9.7 GeV
- π^0 multiplicity:
  - leptonic decay: 0
  - hadronic decay: ≤ 2
- ≤1 additional good γ in each hemisphere

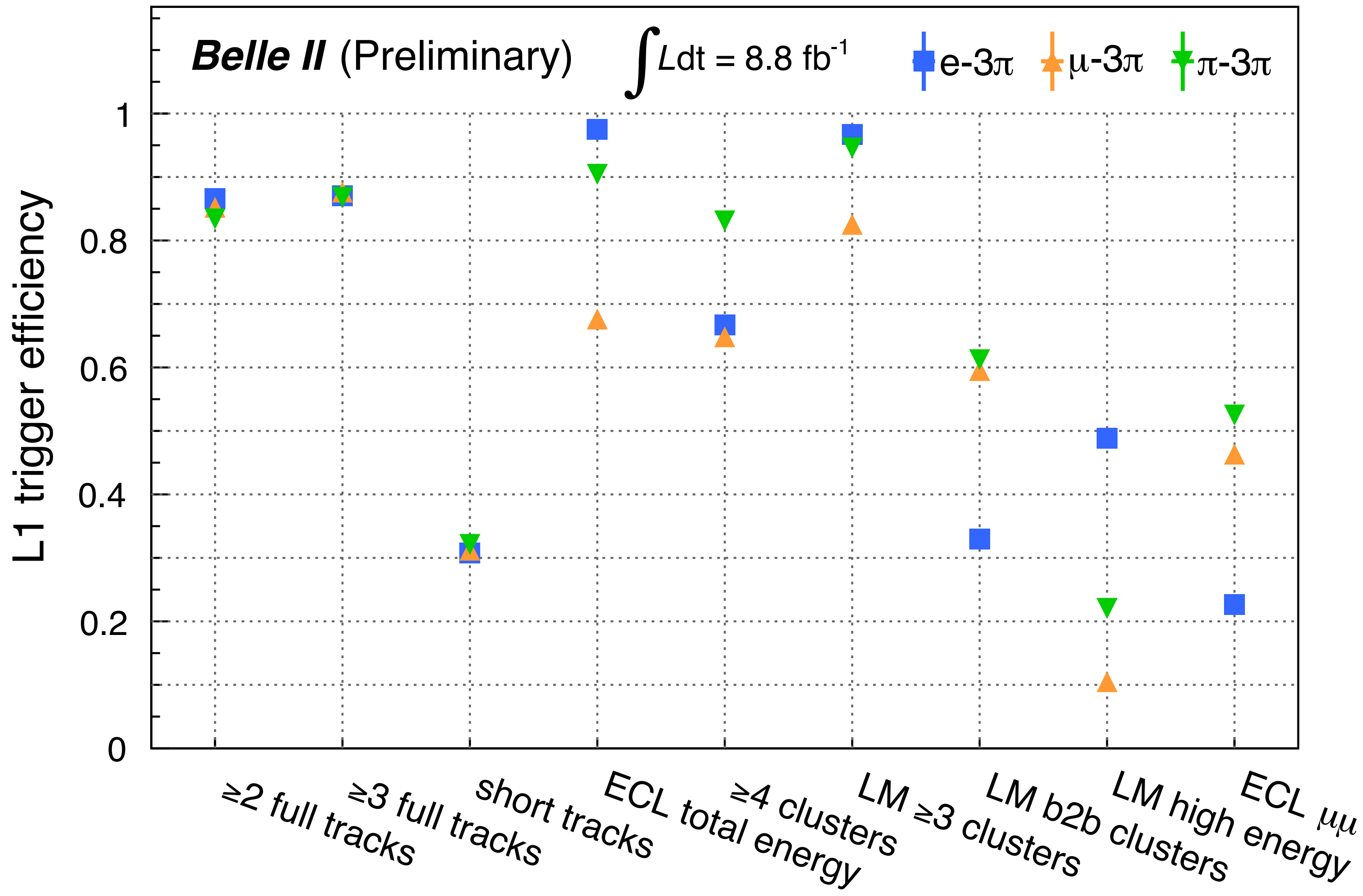
1x1 selection

- 0.89 < thrust < 0.99
- 2.35 < E_{vis}^{cms} < 9.5 GeV
- 0.59 < θ_p^{miss} < 2.8
- π^0 multiplicity:
  - leptonic decay: 0
  - hadronic decay: ≤ 2
- ≤1 additional good γ in each hemisphere





Efficiency for 1x3 prong

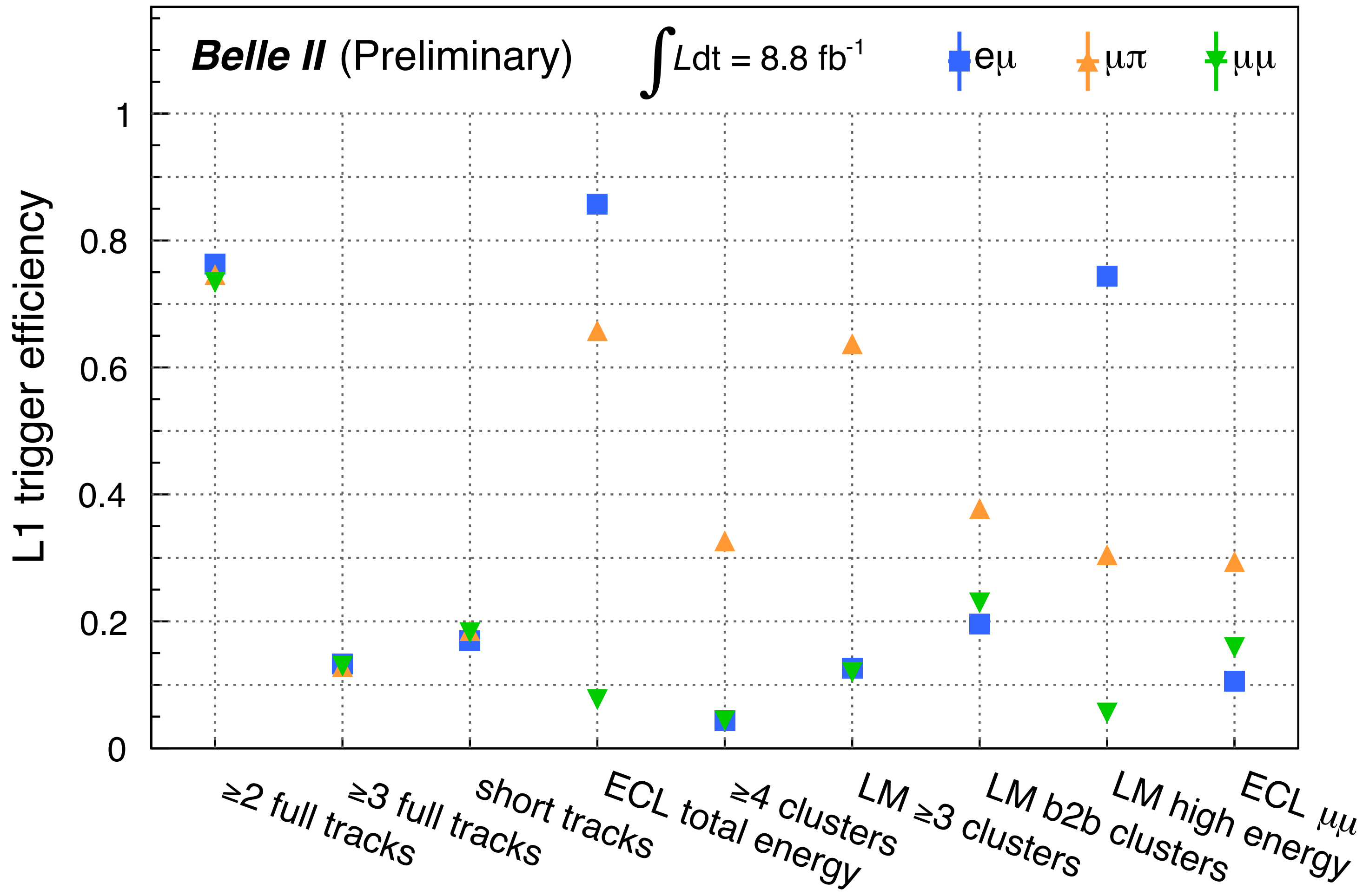


- Main trigger types for tau and other low-multiplicity physics
  (more details in coming slides)
  - CDC number of 2D full tracks
  - CDC number of 2D short tracks
  - ECL total energy threshold
  - ECL number of isolated clusters
  - ECL low multiplicity
  - ECL di-muon

- Efficiency of a CDC/ECL trigger:

$$\frac{(\text{OR of } \mathbf{ECL}/\mathbf{CDC} \text{ bits}) \text{ AND } \mathbf{CDC}/\mathbf{ECL} \text{ bit}}{(\text{OR of } \mathbf{ECL}/\mathbf{CDC} \text{ bits})}$$

Efficiency for 1x1 prong

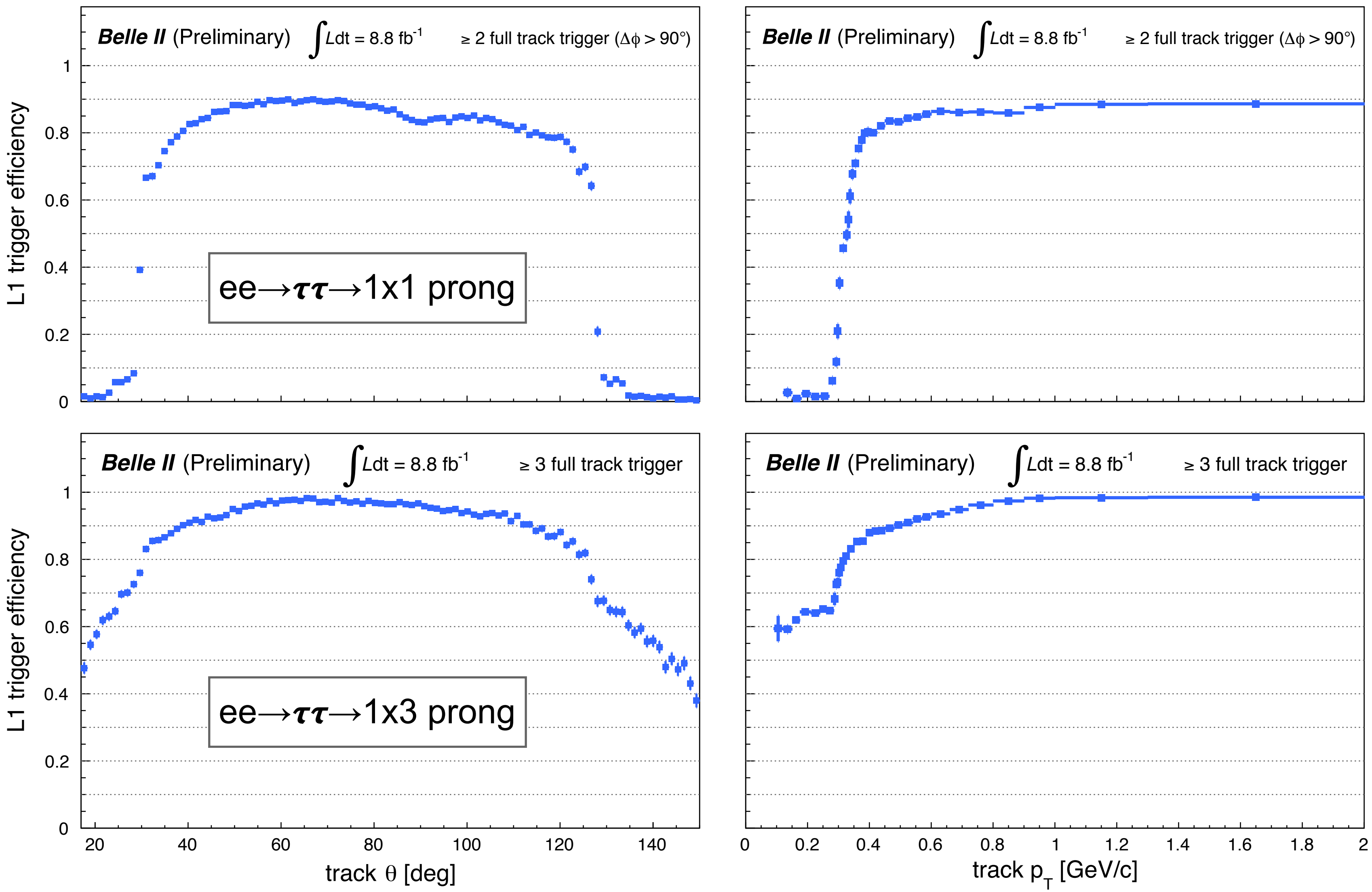


- Main trigger types for tau and other low-multiplicity physics
  (more details in coming slides)
  - CDC number of 2D full tracks
  - CDC number of 2D short tracks
  - ECL total energy threshold
  - ECL number of isolated clusters
  - ECL low multiplicity
  - ECL di-muon

- Efficiency of a CDC/ECL trigger:

$$\frac{(\text{OR of } \mathbf{ECL}/\mathbf{CDC} \text{ bits}) \text{ AND } \mathbf{CDC}/\mathbf{ECL} \text{ bit}}{(\text{OR of } \mathbf{ECL}/\mathbf{CDC} \text{ bits})}$$

Full track triggers



- L1 requirement
  - ≥2 full tracks
  - track pair with $\Delta\phi>90°$
  - ECL Bhabha veto

⇒ low efficiency in endcaps, puts limitations on tau + other low multi physics

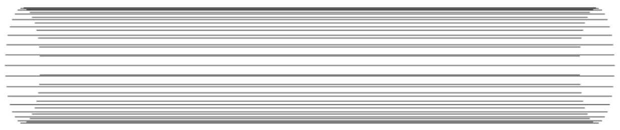
- L1 requirement
  - ≥3 full tracks

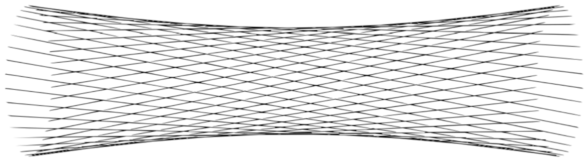
⇒ less sever drop in endcaps and at low p_T

(due to one track redundancy)

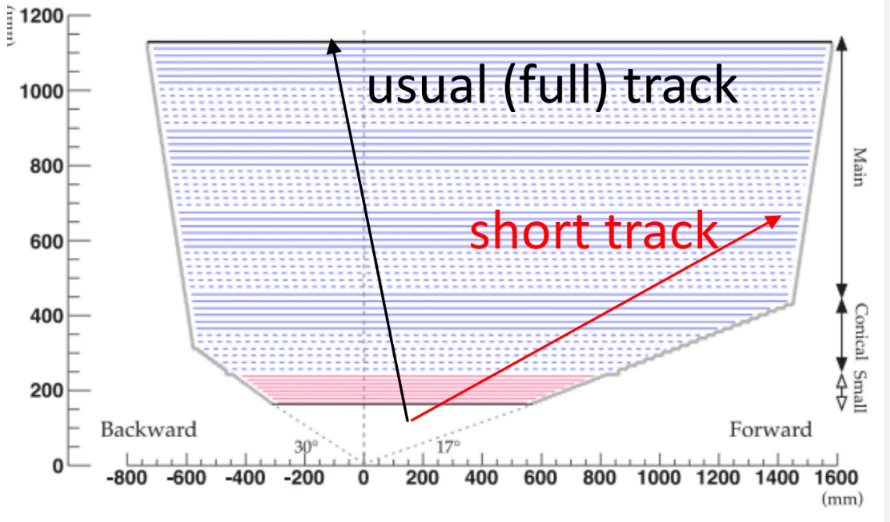
Short track triggers

- "**full tracks**" pass through all axial CDC superlayers and reach the barrel



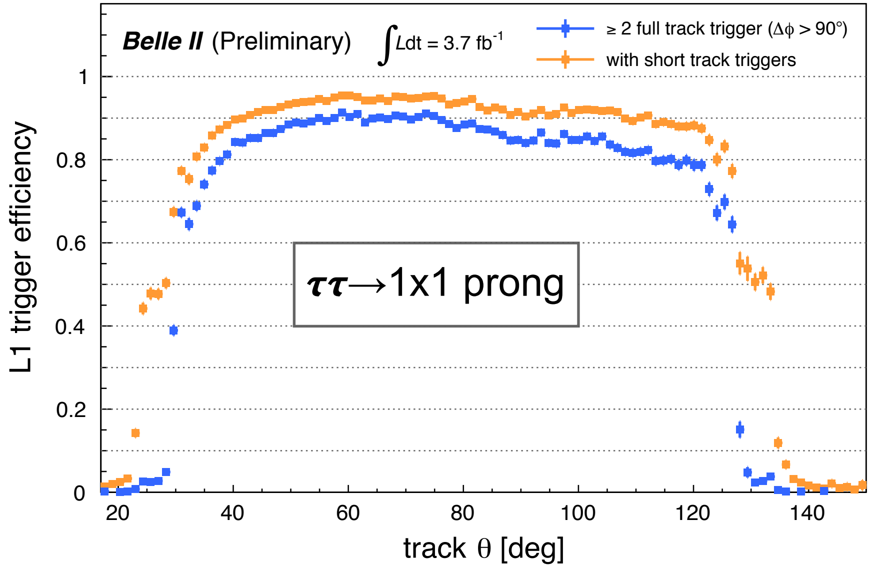


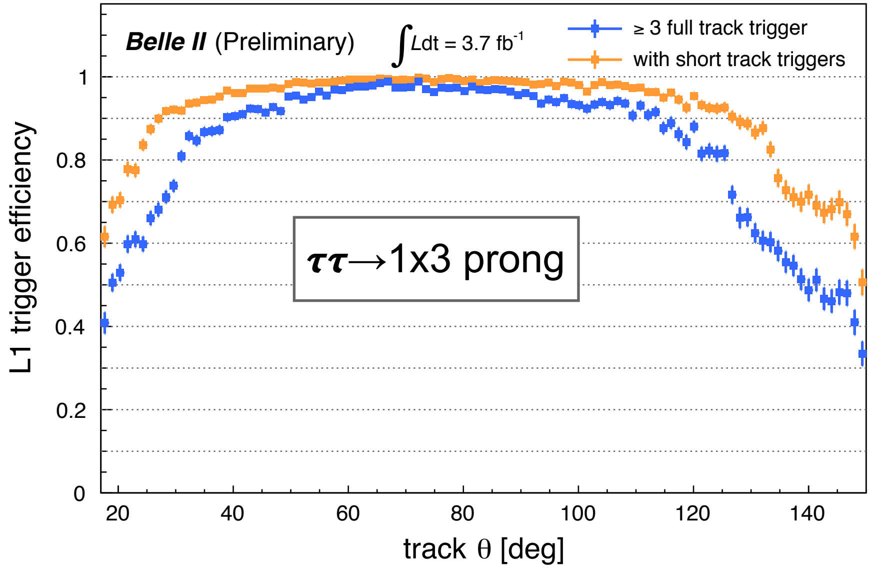
- To compensate for low efficiency in the endcaps, the CDC trigger also searches for "**short tracks**". Operational since October 2019.



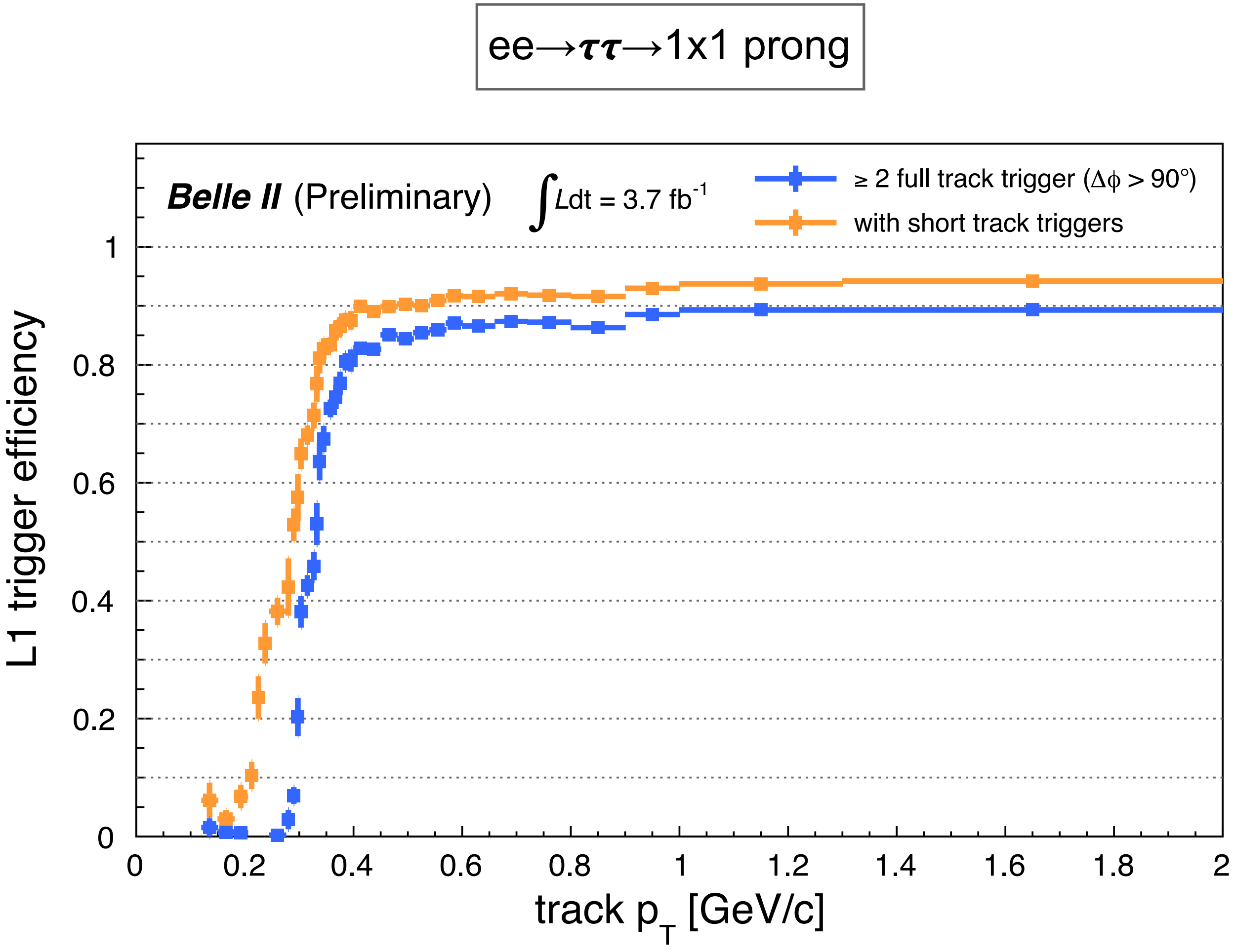
- Short tracks pass through inner most 5 axial + stereo SLs

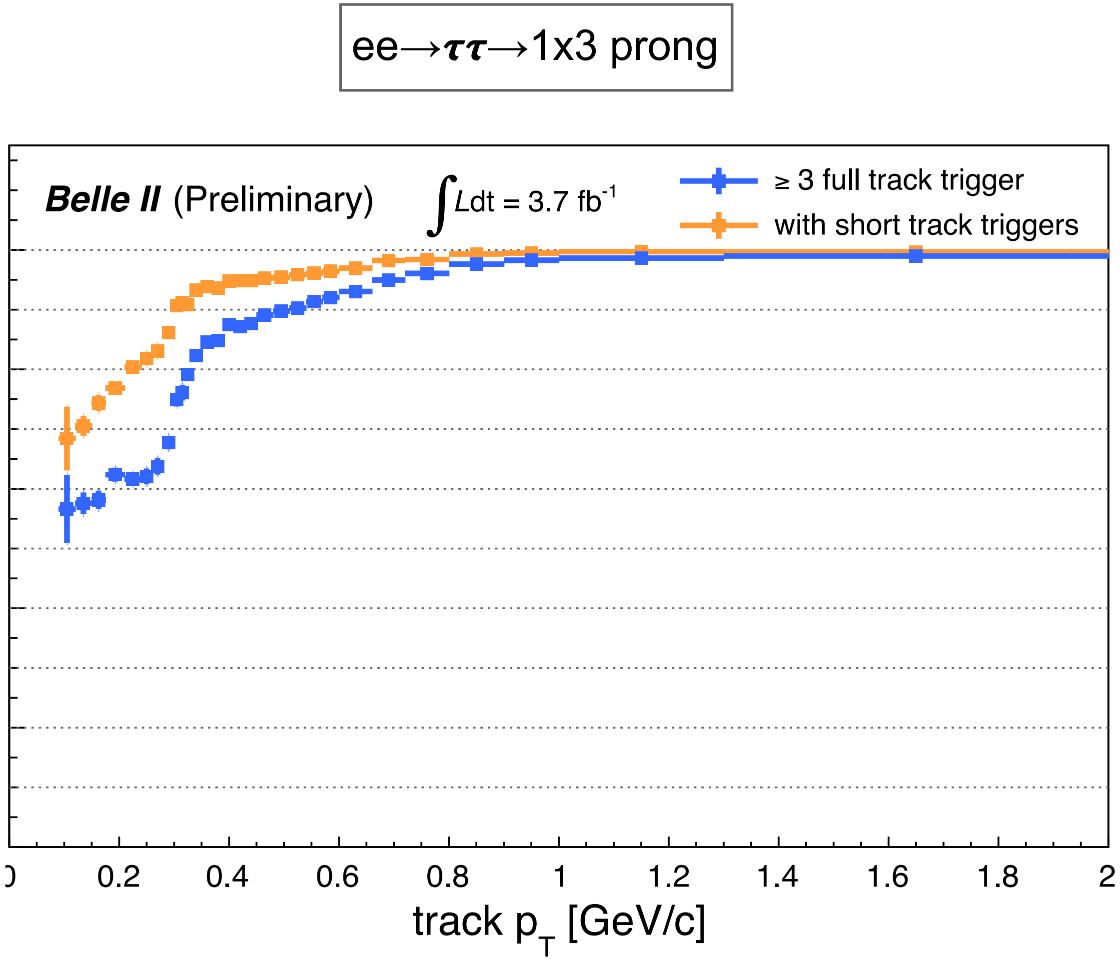
- Reaching the endcaps or curling back inside the barrel





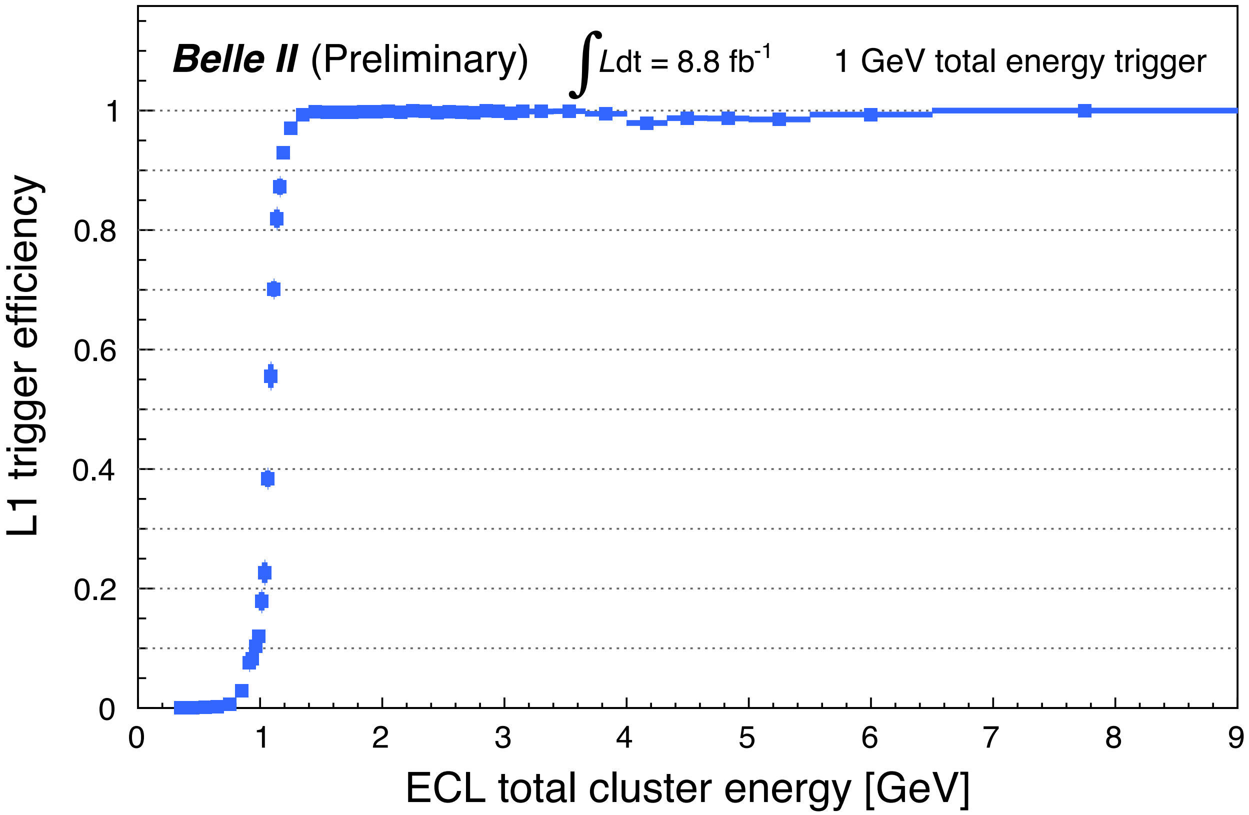
Short track triggers



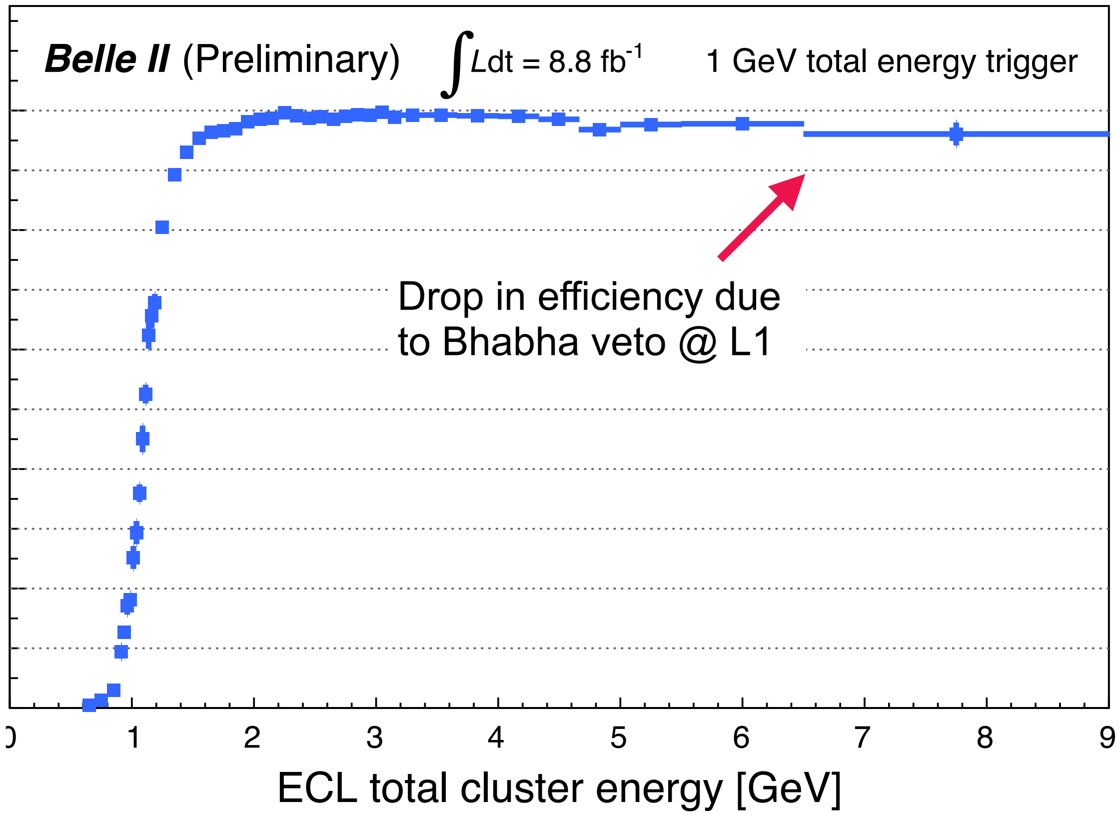


Energy threshold trigger

ee→ττ→1x1 prong



ee→ττ→1x3 prong

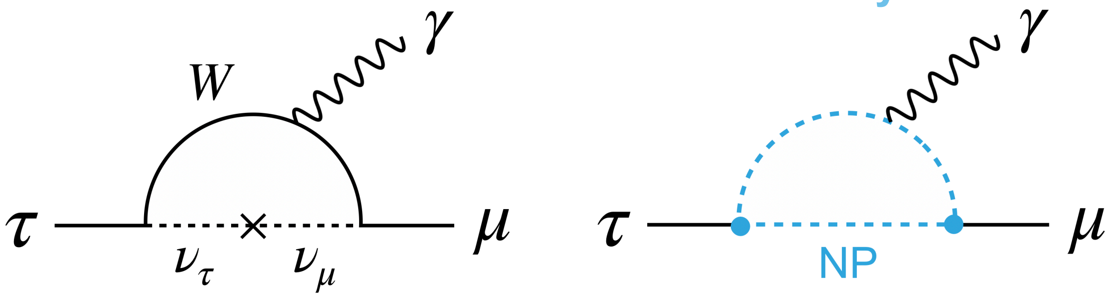


Searches for charged LFV

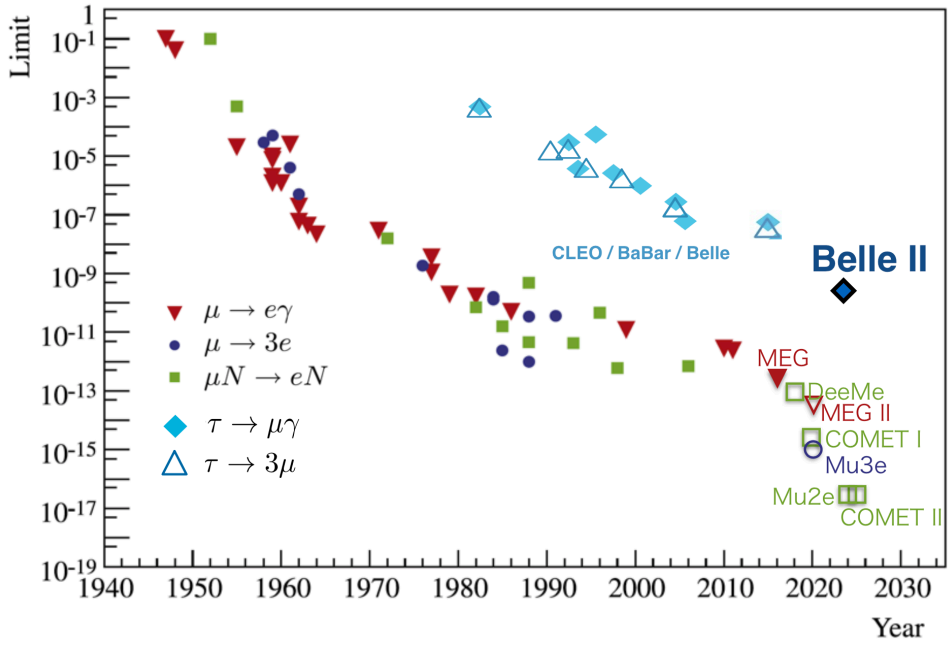
- LFV has been established for the neutrinos, but what about their charged partners (e, μ and τ)?
- In the SM, charged LFV decays via neutrino oscillation are highly suppressed and immeasurably small:

$$Br(\ell_1 \to \ell_2\gamma)_{SM} \propto \left(\frac{\delta m_\nu^2}{m_W^2}\right)^2 \sim 10^{-54}\text{-}10^{-49}$$

Standard Model **New Physics**



- **Observation of charged LFV would be a clear signature for New Physics!**
  - *Br* enhanced in many new physics models (10^{-10}-10^{-7})
  - μ→e: stringent bounds exist from MEG
  - τ→μ/e: weaker bounds (Belle, BaBar and CLEO)



- As heaviest lepton, NP can have preferential τ LFV couplings
- **Belle II will push the current τ LFV bounds forward by at least at least one order of magnitude!**

Trigger efficiency for τ LFV

- One of the golden channels for potential LFV discovery in the tau sector is **$\tau \to 3\mu$**. Most challenging τ LFV signatures to trigger on @ L1.

arXiv:1808.10567

Strategy:

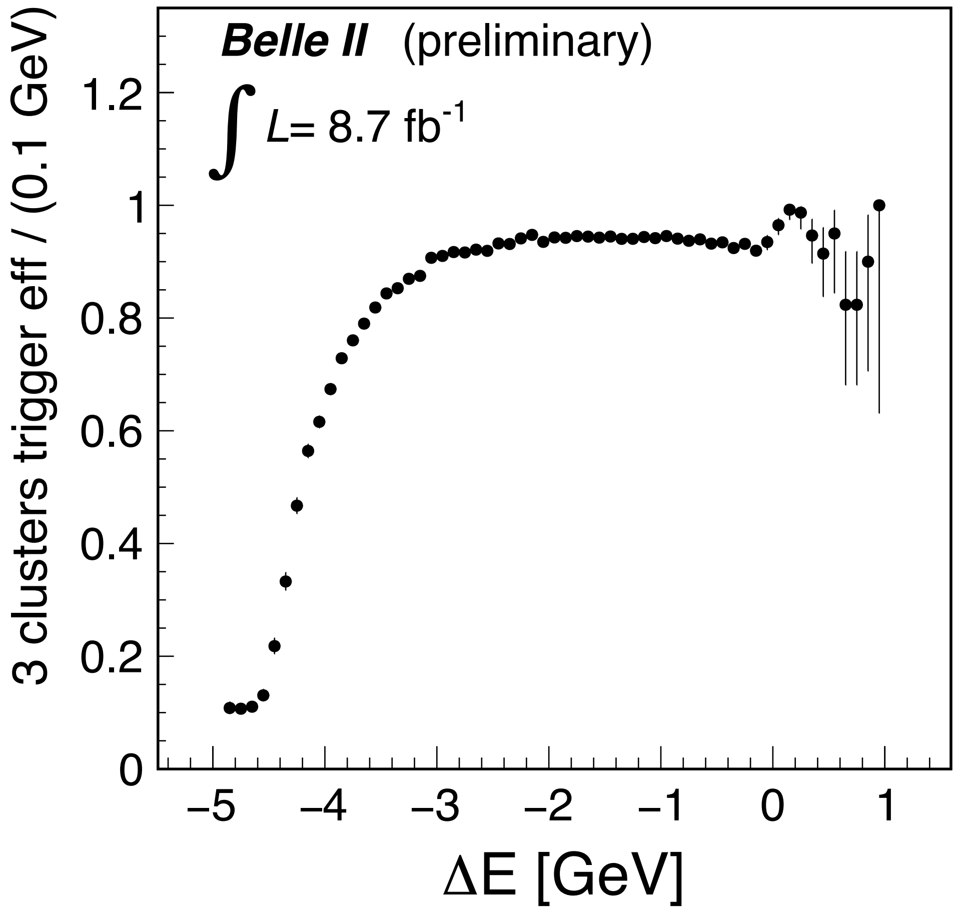
study trigger efficiency using SM τ decay mode that best mimics LFV signal

⇒ SM $\tau\tau \to$ 1x3 prong (3π instead of 3μ)

- Selections follow those of the SM decay study, but with cuts that make the SM process mimic the signal
  - p_{miss} > 0.2 GeV, thrust < 0.97
  - M_{tag} < 1.15 GeV, ΔE_{tag} < -0.7 GeV

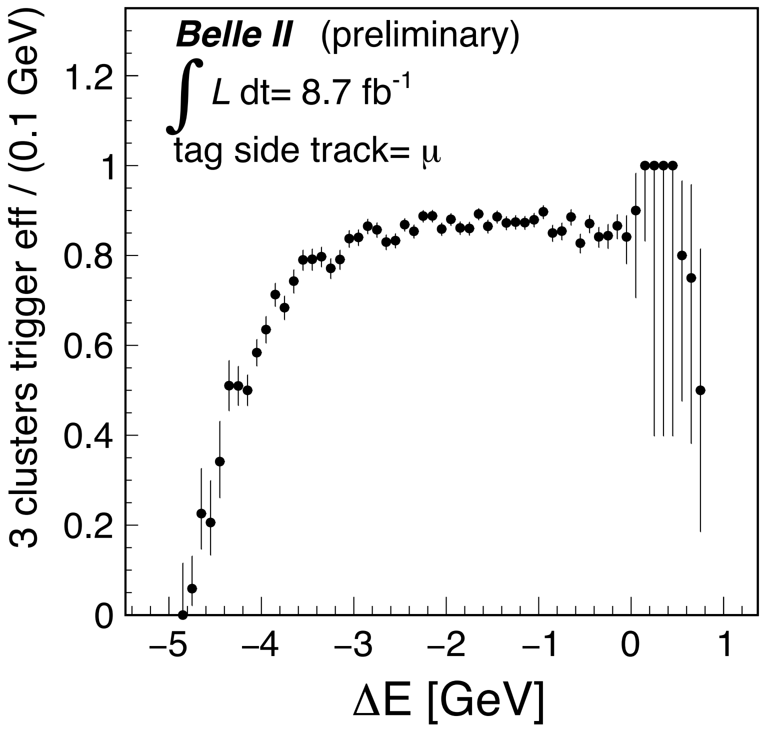
- ECL low multiplicity triggers are new at Belle II.

  Most performant for LFV-like events around $\Delta E_{signal} \sim 0$ are the ≥3 ECL cluster LM triggers

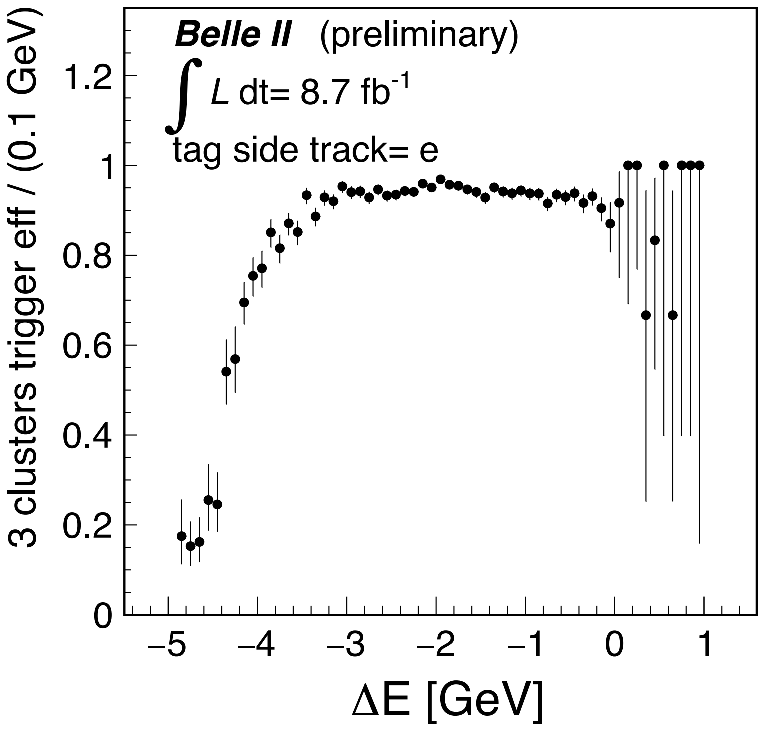


Trigger efficiency for τ LFV

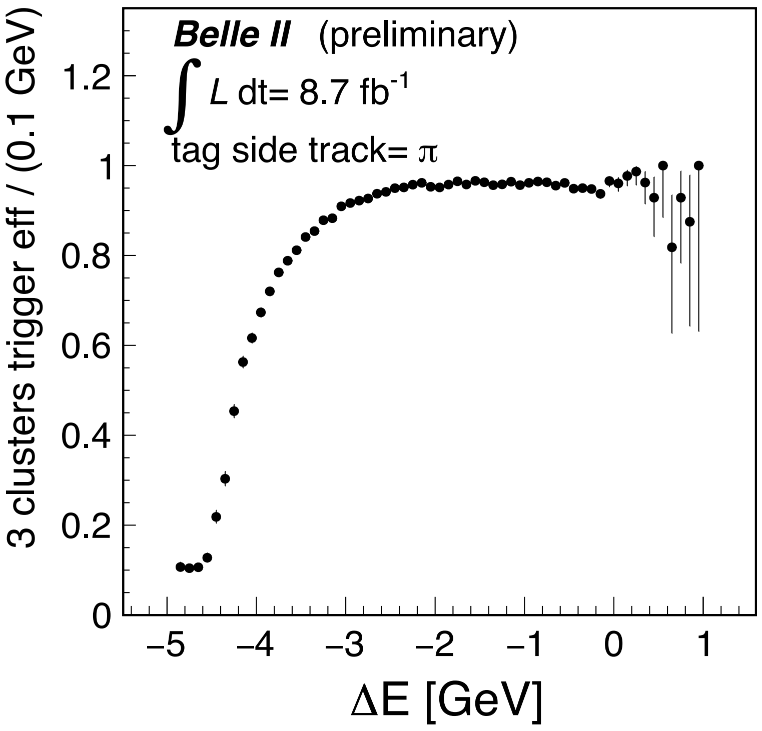
μ-3π, LFV-like event



e-3π, LFV-like event



π-3π, LFV-like event



Conclusion

- L1 trigger system plays a critical role in enabling tau and other low-multiplicity physics at Belle II

- Performance has been generally good in the early Phase 3 data

- Full track triggers have low efficiency in the endcaps, particularly for ee$\rightarrow\tau\tau\rightarrow$1x1 prong.
  New short track triggers show great promise.

- New ECL low multiplicity triggers will play an important role in future τ LFV results

- Future L1 developments:
  - neural-z triggers: compute and cut on z_0 within L1 latency, significantly reducing bkg rate
  - alternative 3D tracking techniques
  - I will ask trigger experts if there are others and add them here

BACKUP

Trigger definitions

- **ffo** : ≥ 2 full tracks, track pair with $\Delta\phi > 90°$ and not an ECL Bhabha.
- **fff** : ≥ 3 full tracks.
- **fso** : ≥ 1 full tracks, ≥ 1 short tracks, track pair with $\Delta\phi > 90°$ and not an ECL Bhabha.
- **sso** : ≥ 2 short tracks, track pair with $\Delta\phi > 90°$ and not an ECL Bhabha.
- **ffs** : ≥ 2 full tracks and ≥ 1 short tracks.
- **fss** : ≥ 1 full tracks and ≥ 2 short tracks.
- **sss** : ≥ 3 short tracks.
- **hie** : total energy above 1 GeV and not an ECL Bhabha.
- **c4** : ≥ 4 isolated clusters with energy above 100 MeV and not an ECL Bhabha.
- **eclmumu** : cluster pair each with $E^* < 2$ GeV, $165° < \sum\theta < 190°$ and $160° < \Delta\phi < 200°$.

Trigger definitions

- **lml0** : ≥ 3 clusters with at least one having $E^* > 300$ MeV, $1 < \theta_{ID} < 17$ (corresponding to $18.5° < \theta < 139.3°$, full ECL) and not an ECL Bhabha.
- **lml1** : exactly 1 cluster with $E^* > 2$ GeV and $4 < \theta_{ID} < 14$ ($32.2° < \theta < 124.6°$)
- **lml2** : ≥ 1 cluster with $E^* > 2$ GeV, $\theta_{ID} = 2, 3, 15$, or 16 ($18.5° < \theta < 32.2°$ or $124.6° < \theta < 139.3°$) and not an ECL Bhabha.
- **lml4** : ≥ 1 cluster with $E^* > 2$ GeV, $\theta_{ID} = 1$ or 17 ($\theta < 18.5°$ or $\theta > 139.3°$) and not an ECL Bhabha.
- **lml6** : exactly 1 cluster with $E^* > 1$ GeV, $4 < \theta_{ID} < 15$ ($32.2° < \theta < 128.7°$, full ECL barrel) and no other cluster with $E >$ 300 MeV anywhere.
- **lml7** : exactly 1 cluster with $E^* > 1$ GeV, $\theta_{ID} = 2, 3$ or 16 ($18.5° < \theta < 31.9°$ or $128.7° < \theta > 139.3°$) and no other cluster with $E >$ 300 MeV anywhere.
- **lml8** : cluster pair with $170° < \Delta\phi < 190°$, both clusters with $E^* > 250$ MeV and no 2 GeV cluster in the event.
- **lml9** : cluster pair with $170° < \Delta\phi < 190°$, one cluster with $E^* < 250$ MeV with the other having $E^* > 250$ MeV, and no 2 GeV cluster in the event.
- **lml10** : cluster pair with $160° < \Delta\phi < 200°$, $160° < \sum\theta < 200°$ and no 2 GeV cluster in the event.
- **lml12** : ≥ 3 clusters with at least one having $E^* > 500$ MeV, $2 < \theta_{ID} < 16$ (corresponding to $18.5° < \theta < 139.3°$, full ECL) and not an ECL Bhabha. (θ_{ID} values have to be double checked).