First Results and Prospects for the LFV decay $\tau \to \ell\alpha$(invisible) at Belle II

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on behalf of the Belle II Collaboration

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Introduction

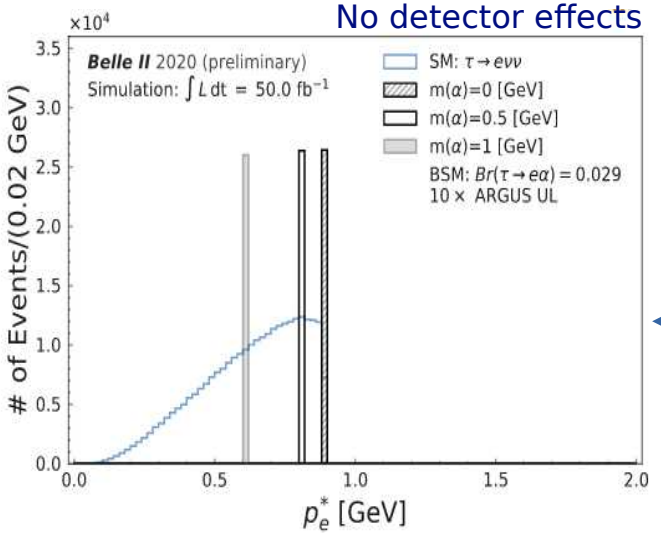
- Search for the LFV decay channels:
  τ→eα and τ→μα
  being α a BSM invisible particle.

- This decay appears in several NP models: Axion-like particles, Z' gauge boson, etc.

- **Idea**: Search for a two body decay.

  The momentum spectrum of the signal lepton will manifest as a peak in the τ rest frame with a position depending on the α mass.

No detector effects

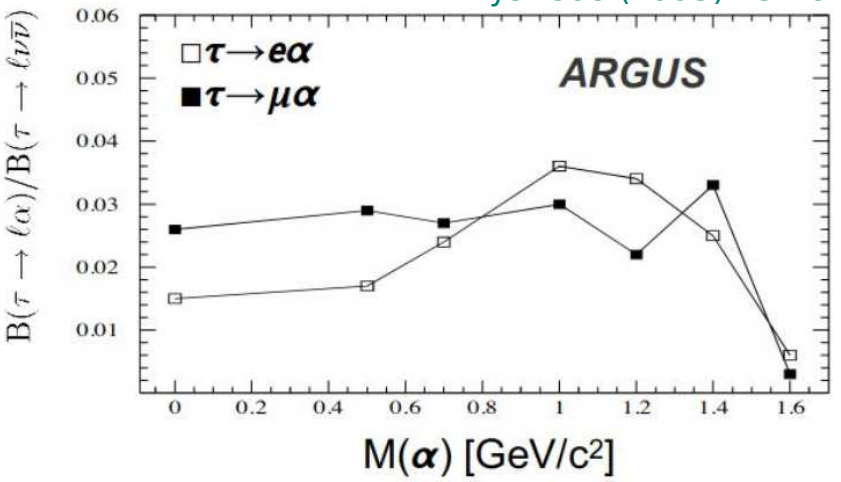


Signal vs Bkg
- Same final state
- Different kinematics

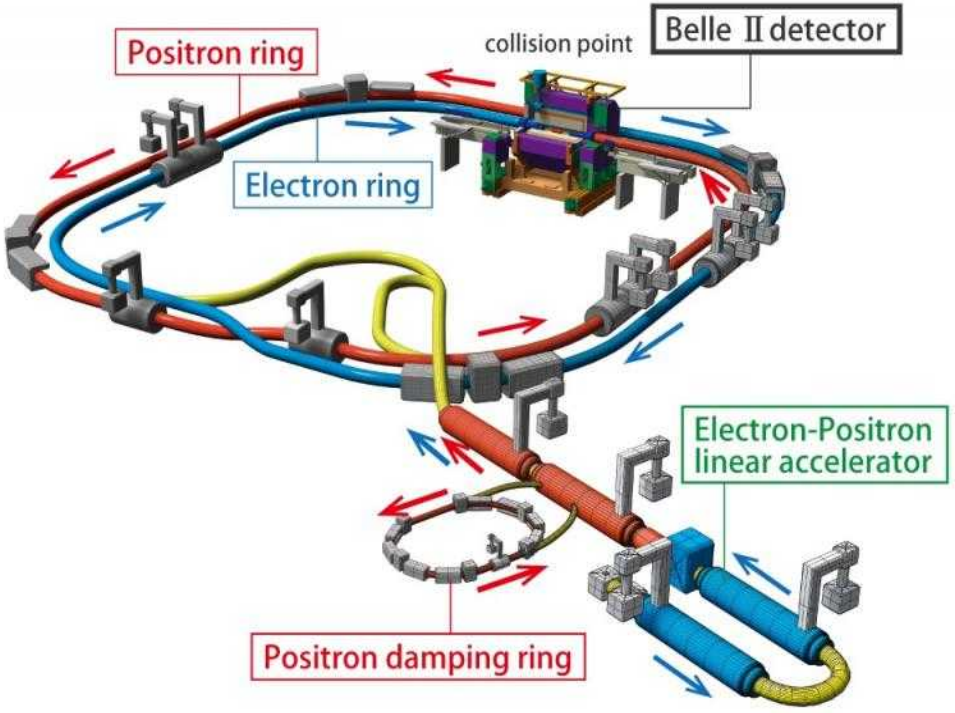
Previous searches

- Mark III (1985, 9.4 pb^{-1})
- ARGUS (1995, 472 pb^{-1})

Z.Phys. C68 (1995) 25-28

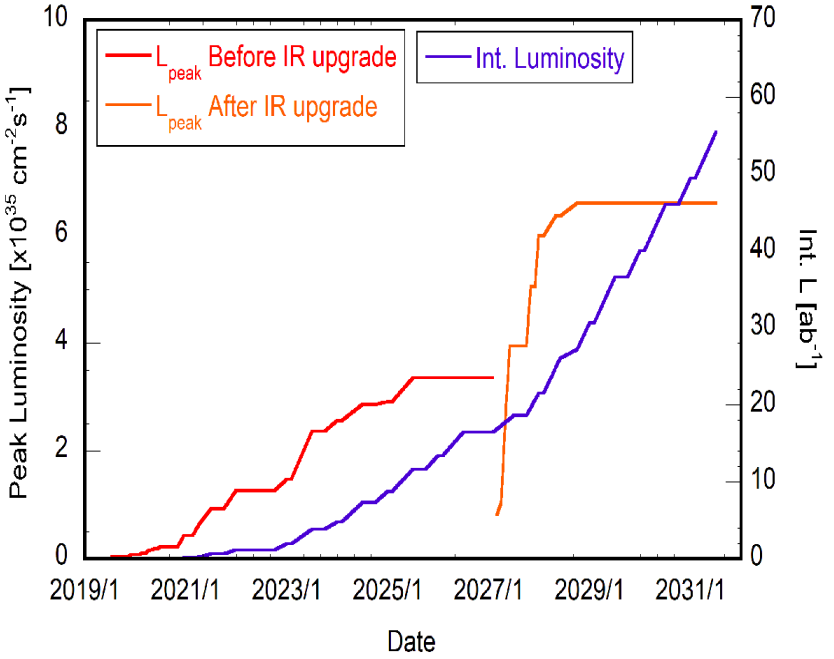


SuperKEKB Collider



@Tsukuba, Japan

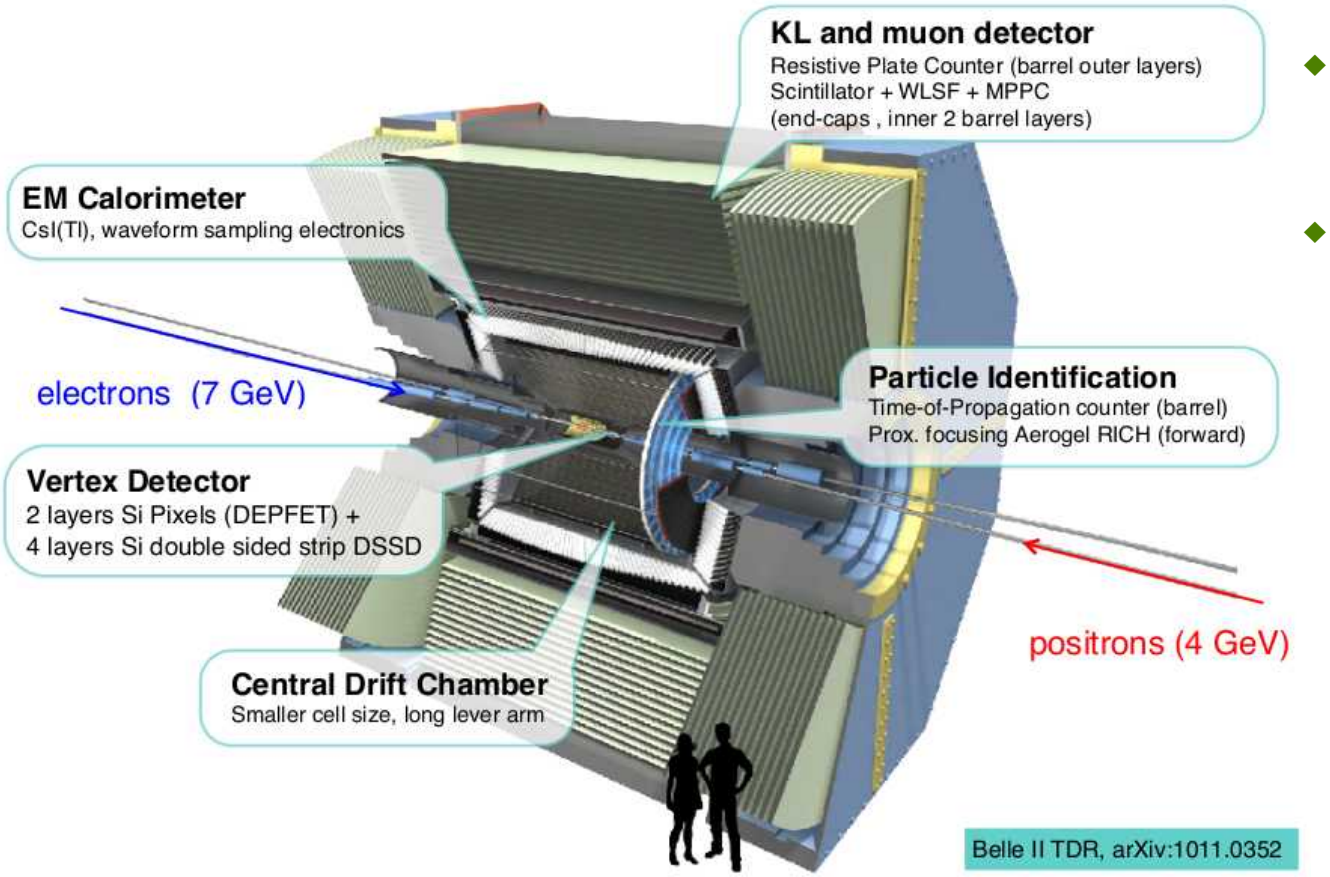
- Asymmetric collision of e^+e^-:
  - Electron (7 GeV) – Positron (4 GeV)
  - CM energy at $\Upsilon(4S)$ resonance [10.58 GeV]
  - At this energy:
    - $\sigma(e^+e^- \to \Upsilon(4S)) = 1.1$ nb (B-factory)
    - $\sigma(e^+e^- \to \tau^+\tau^-) = 0.9$ nb (**τ-factory**)
- Target:
  - $\mathcal{L} = 6.5 \times 10^{35} cm^{-2}s^{-1}$ (30 x KEKB)
  - Integrated L = 50 ab^{-1} (50 x KEKB)



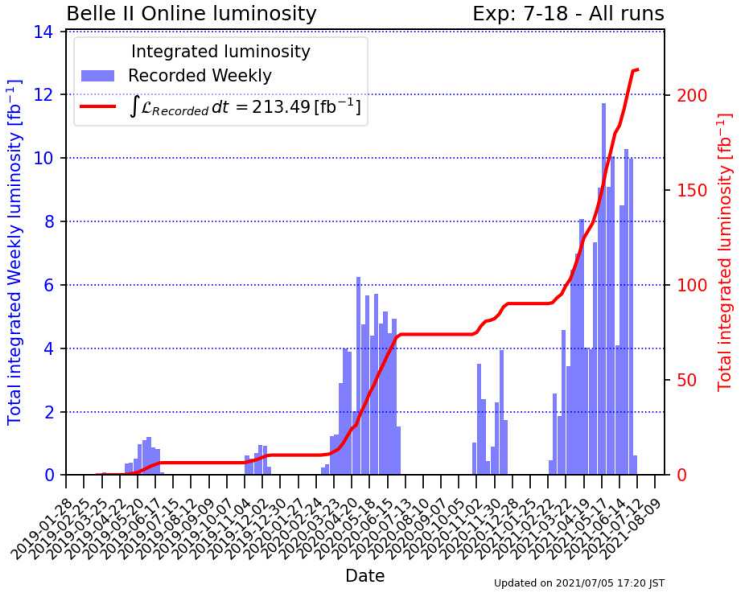
- Luminosity projection for the coming years

See: Luminosity projection

Belle II at SuperKEKB



- General purpose detector
- Solid angle coverage > 90%
  - High hermiticity
- So far: Integrated L ~ 200 fb^{-1}



See: Luminosity projection

- Regular data-taking despite Covid-19 pandemics

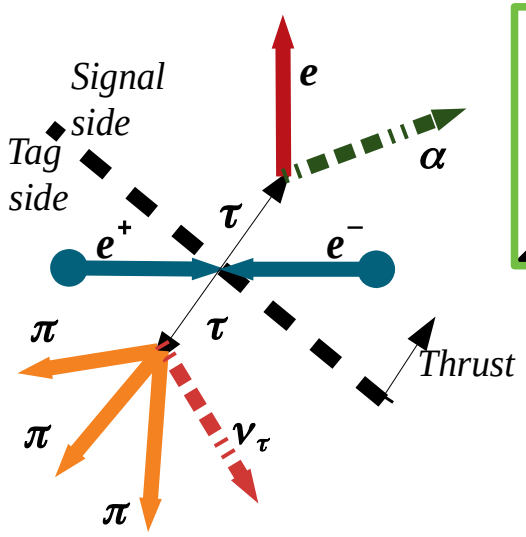
Event selection

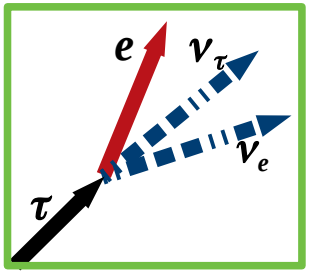
- 3x1 prong $\tau^+\tau^-$ events:
  - $\tau \to l\alpha$ & $\tau \to 3\pi\nu$
  - Exactly 4 tracks per event
  - Hemisphere separation using thrust vector
    - 1 track in the signal side
    - 3 tracks in the tag side

- Dominant bkg: **$\tau \to l\nu\nu$**
  - We can not suppress it
  - We optimize for
    $e^+e^- \to \tau(3\pi\nu)\tau(l\nu\bar{\nu})$

- Other bkgs:
  - $\tau\tau$ (no 3x1)
  - $B\bar{B}$, $q\bar{q}$, ee(γ), μμ(γ)

- Preselection cuts:





$$V_{thrust} = \frac{\sum_i |\vec{p}_i{}^{cm} \cdot \hat{n}_{thrust}|}{\sum_i |\vec{p}_i{}^{cm}|}$$

Tracks	Photons	π^0	Particle ID
|dz| < 3.0 cm dr < 1.0 cm	Within the acceptance E(γ) > 200 MeV	Same as photons but E(γ) > 100 MeV 115 < M(γγ) < 152 MeV/c^2	Lepton ID Pion ID

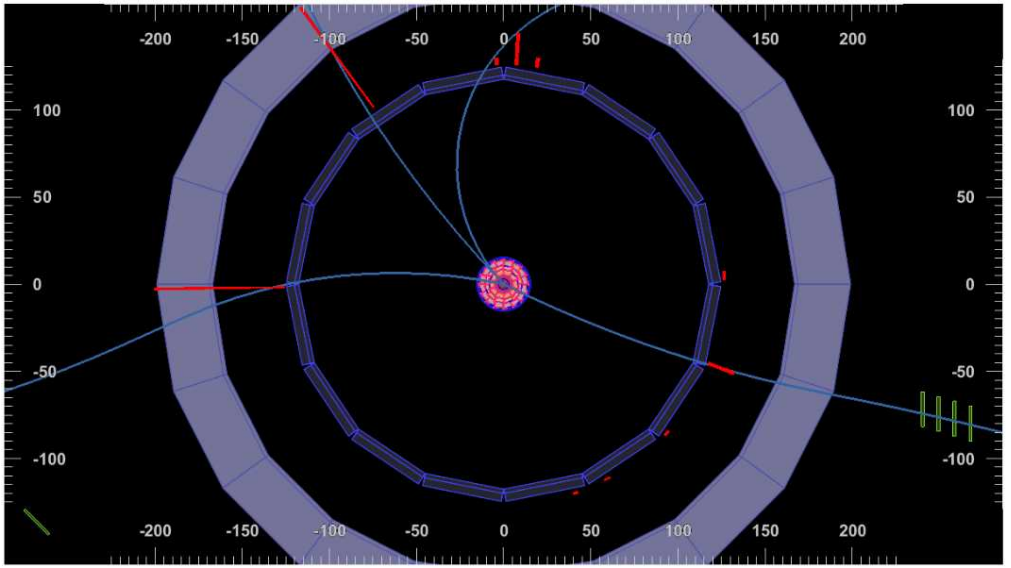
Background suppression I

- Vertex fit
  - 3-prong side (reject failed fits)

- Neutrals
  - $\#\gamma_{1prong} = \#\gamma_{3prong} = 0$
  - $\#\pi^0_{1prong} = \#\pi^0_{3prong} = 0$

- 3-prong tracks with asymmetric p_t cuts
  - Ranking the p_t (leading, sub-leading, third)
  - Optimal cuts based on the figure of merit

$$FOM = \frac{S}{\sqrt{S+B}}$$



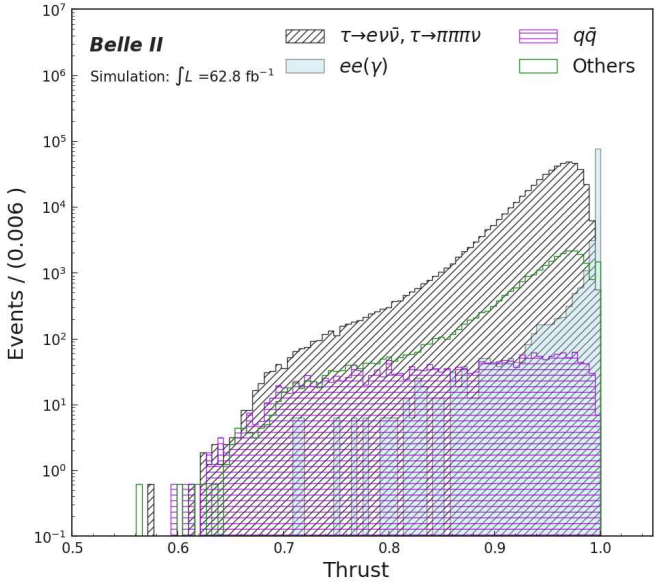
- Electron channel
  - Leading $p_t > 0.69$ GeV/c
  - Sub-leading $p_t > 0.29$ GeV/c
  - Third $p_t > 0.08$ GeV/c

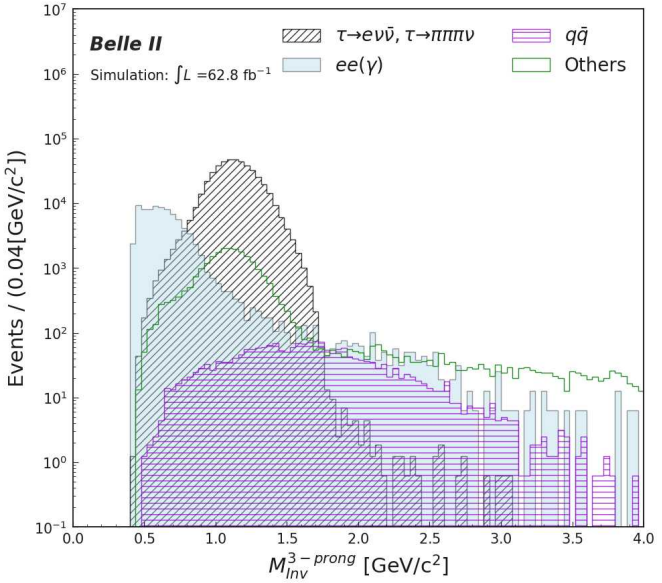
- Muon channel
  - Leading $p_t > 0.47$ GeV/c
  - Sub-leading $p_t > 0.17$ GeV/c
  - Third $p_t > 0.04$ GeV/c

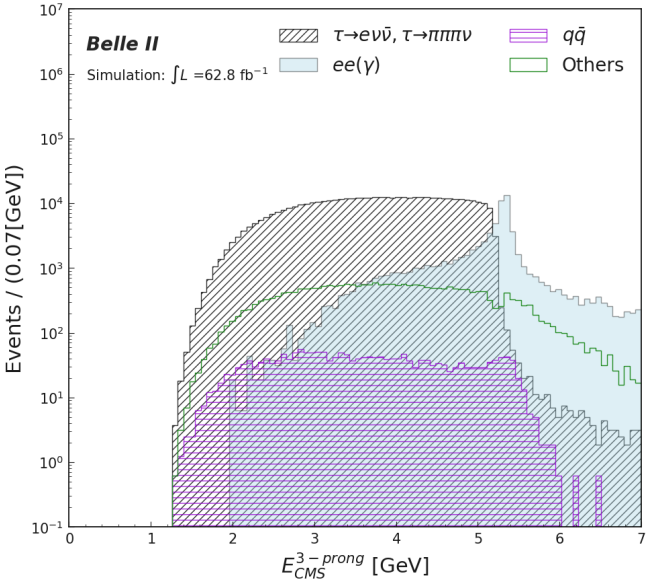
Background suppression II

- Variables:
  - Thrust of the event
  - Invariant mass of the 3-prong system
  - Energy of the 3-prong system

- Cuts optimized by the figure of merit: $FOM = \frac{S}{\sqrt{S+B}}$







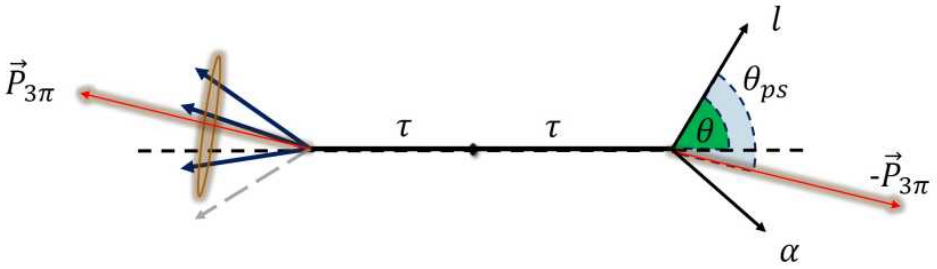
- Electron channel
  - 0.9 < thrust < 0.99
  - 0.5 < Inv M(3-prong) < 1.7 GeV/c²
  - 1.2 < E_{CMS}(3-prong) < 5.3 GeV

- Muon channel
  - 0.9 < thrust < 1.0
  - 0.4 < Inv M(3-prong) < 1.7 GeV/c²
  - 1.1 < E_{CMS}(3-prong) < 5.3 GeV

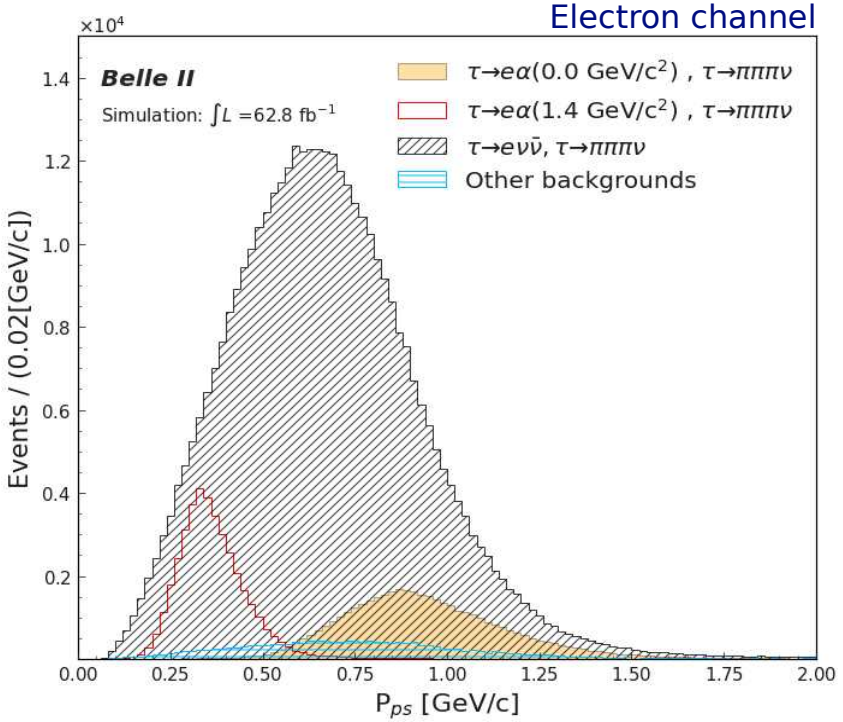
τ Pseudo-rest Frame

- In the signal τ rest frame, the momentum of the lepton will be a monoenergetic peak with position depending on the α mass.

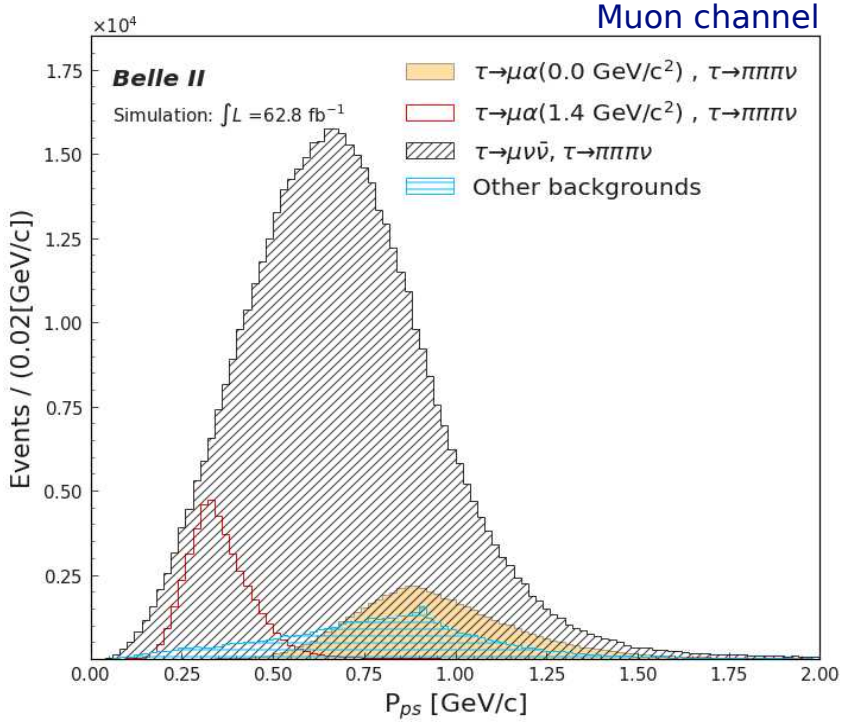
- We cannot access the τ rest frame directly due to missing particles
  - Use ARGUS method
    - $E_\tau = \sqrt{s}/2$
    - Approximation:
      τ flight direction given by the momentum of the 3-prong system



Electron channel



Muon channel



Statistical treatment

- Template based analysis
  - Fit the lepton momentum spectrum
  - Hypothesis test

- The data can be modeled as

$$F(x) = N_{e\alpha}\, f_{e\alpha}(x) + N_{e\nu\nu} f_{e\nu\nu}(x) + N_{bkg} f_{bkg}(x)$$

$$= \frac{\varepsilon^{e\alpha}}{\varepsilon^{e\nu\nu}} N_{e\nu\nu}\; poi\; f_{e\alpha}(x) + N_{e\nu\nu} f_{e\nu\nu}(x) + N_{bkg} f_{bkg}(x)$$

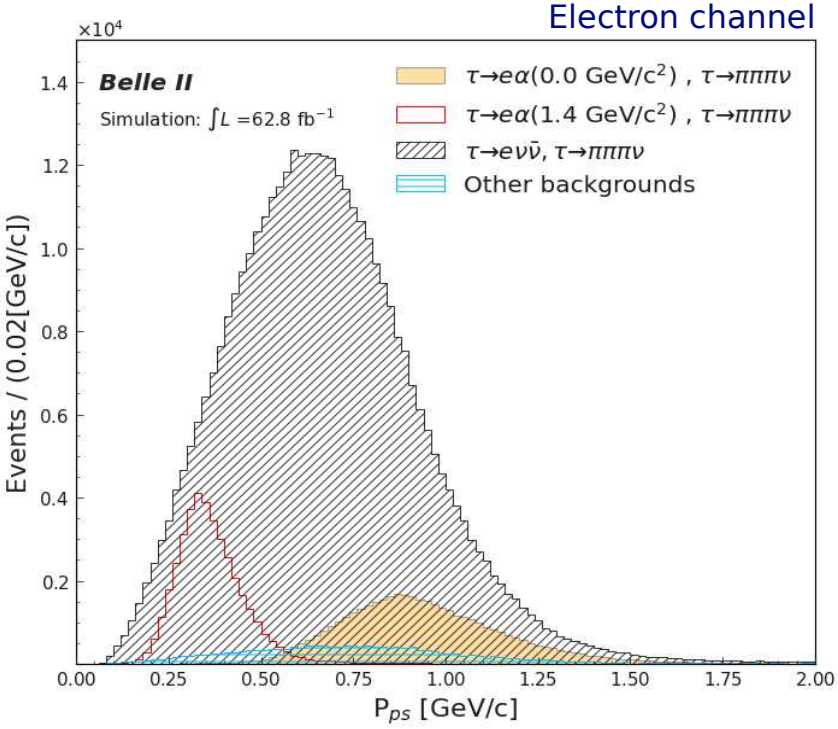
where f is pdf for each contribution and

$$poi \overset{\text{def}}{=} \frac{N_{e\alpha}}{N_{e\nu\nu}} \frac{\varepsilon^{e\nu\nu}}{\varepsilon^{e\alpha}} = \frac{Br(\tau \to e\,\alpha)}{Br(\tau \to e\,\nu\,\nu)}$$

- Upper limit estimation (MC-based) for poi:
  - Modified frequentist approach: CL_s
  - UL at 95% CL

- Bayesian approach (work in progress)

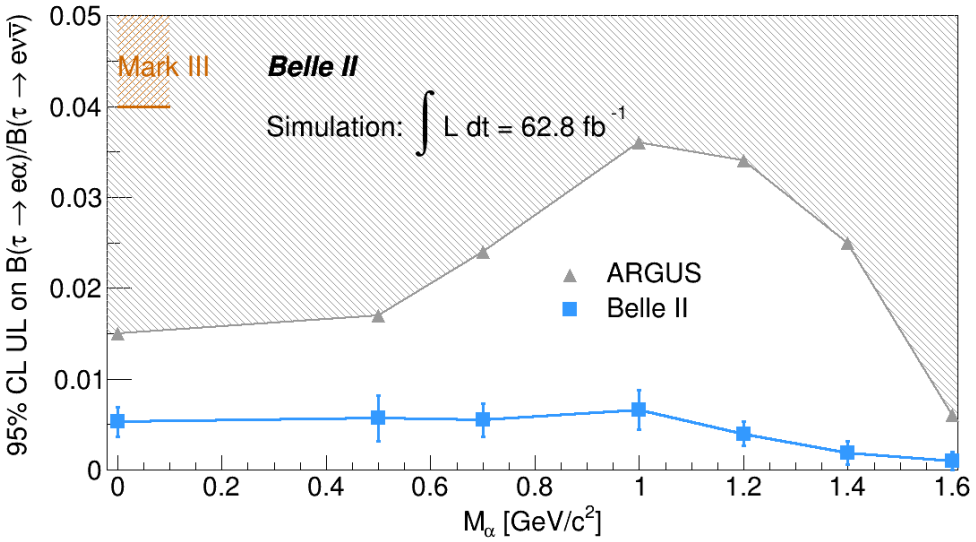
Electron channel



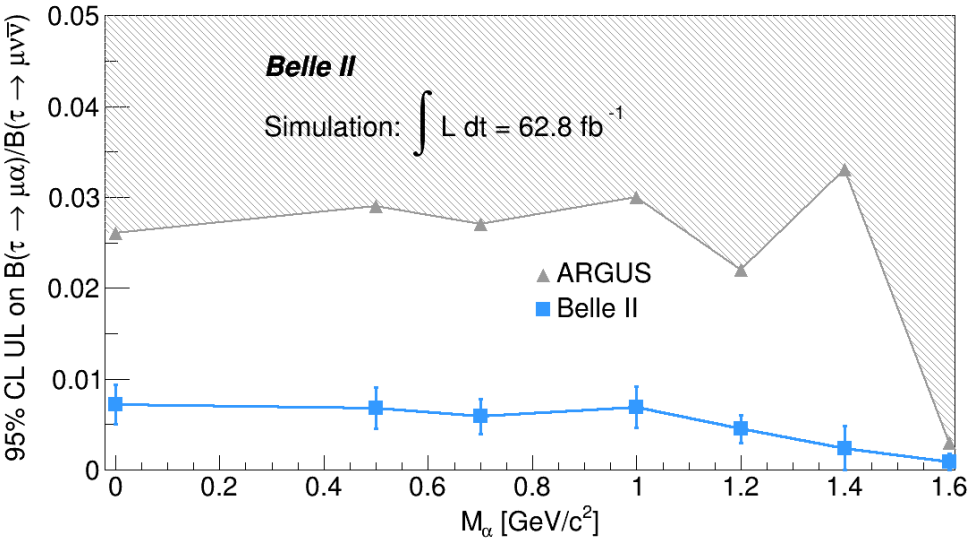
Upper limit sensitivity

- We provide the UL sensitivity for Br(τ→lα)/Br(τ→lνν) at 95% CL for L_{int} = 62.8 fb^{-1}
- No systematic uncertainties are included

Electron channel



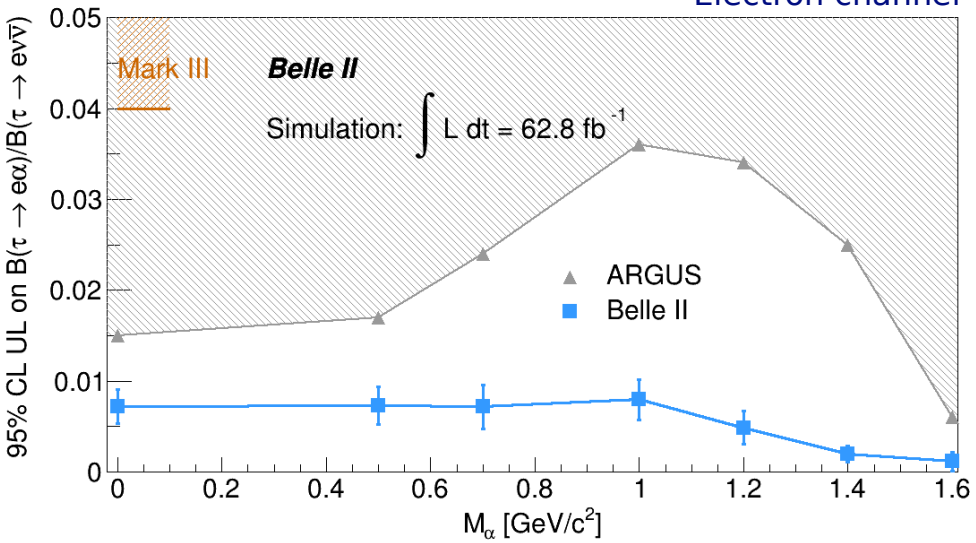
Muon channel



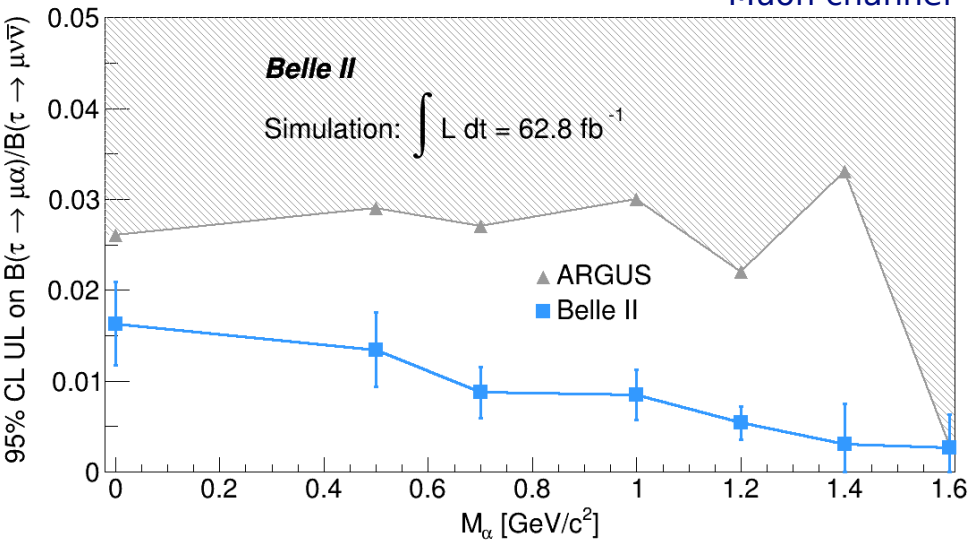
UL: systematic uncertainties

- We provide the UL sensitivity for Br(τ→lα)/Br(τ→lνν) at 95% CL for L_{int} = 62.8 fb^{-1}
- We have identified the sources of dominant systematic uncertainties
  - LID
  - Trigger

Electron channel



Muon channel



- A scenario with reduced systematic effects is expected.

Conclusions & perspectives

- We estimate the UL sensitivity for Br(τ→lα)/Br(τ→lνν) at 95% CL for L_{int} = 62.8 fb^{-1}

- We identify possible sources of systematic effects:
  - Some of them seem to be negligible
  - For the non-negligible sources, we included their effects in the upper limit estimation

- This is a closed box analysis
  - Data-MC validation procedure is ongoing
  - We aim to open the box in the near future

  Stay tuned!

Thank you for your attention!

Backup