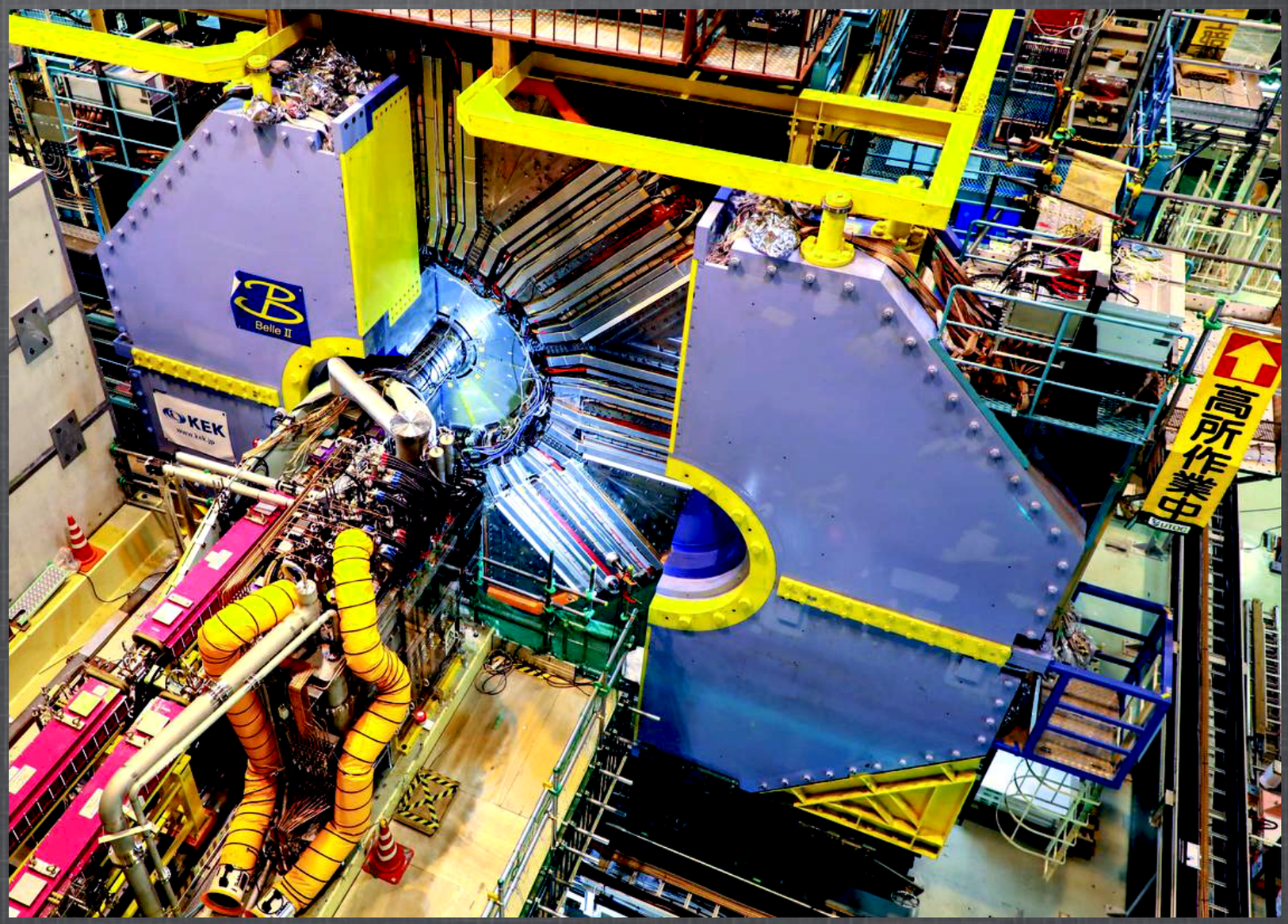
Recent Results From the Belle II Experiment

Eugenio Paoloni INFN & Università di Pisa
on behalf of the Belle *II collaboration*

Summary

- The SuperKEKB collider.
- The Belle II detector.
- Search for:
  - Z' in invisible,
  - $\tau^+\tau^-$ resonances,
  - long lived particles in $b \to s$ transitions.
- Conclusions



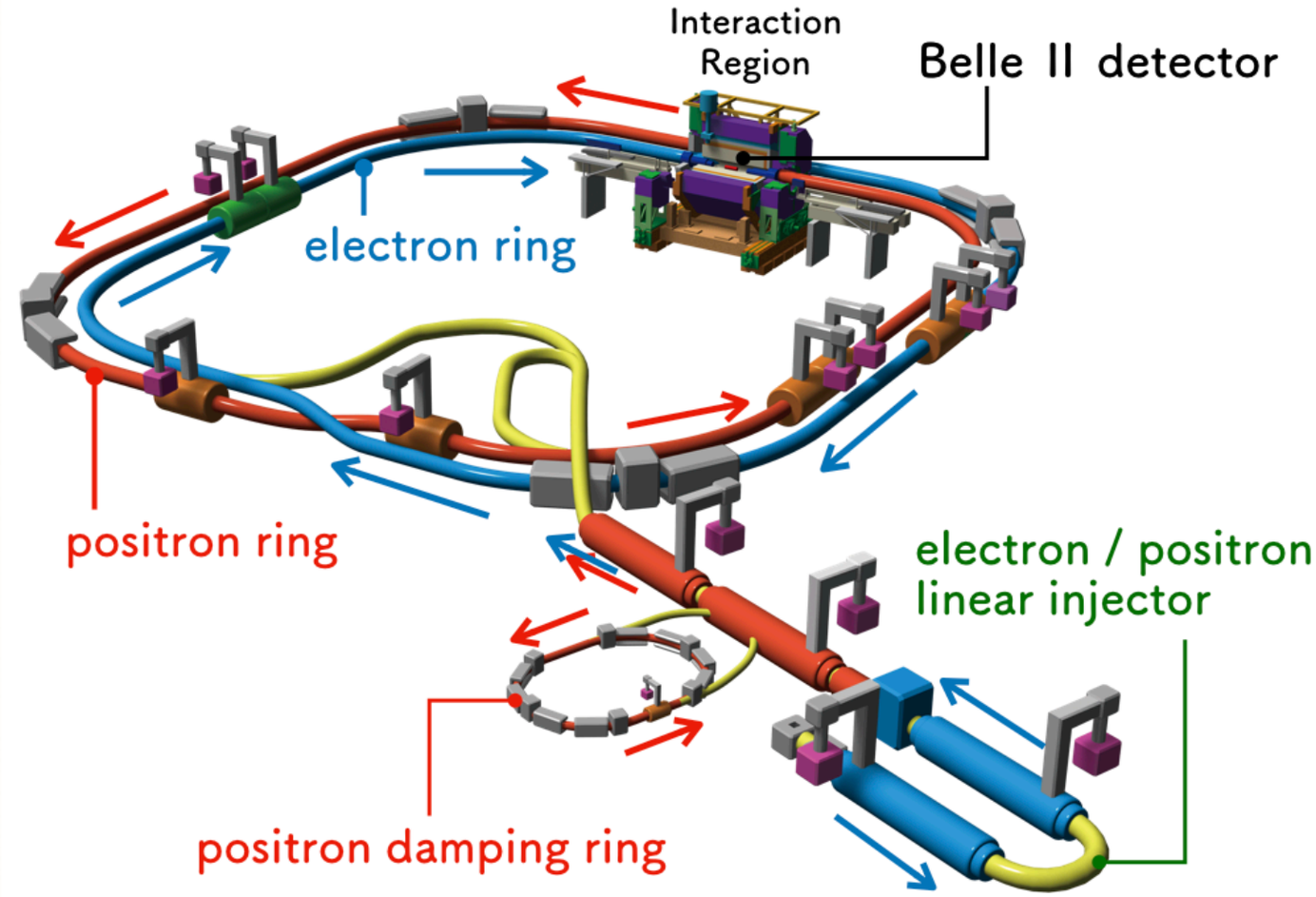
TAUP 2023
Vienna, August the 29th 2023

The SuperKEKB collider

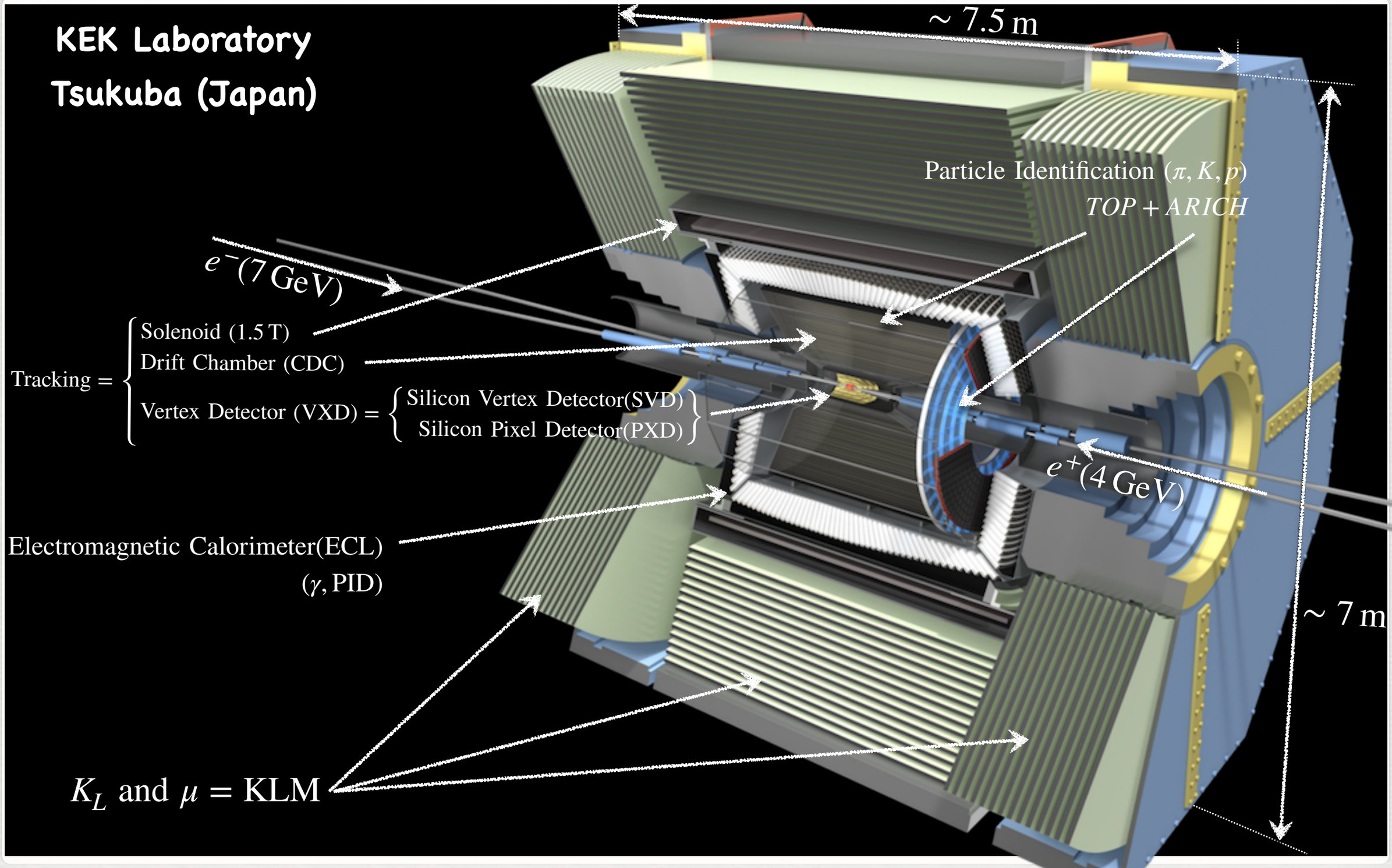
- Asymmetric $e^+(4\,GeV)e^-(7\,GeV)$ collider operating close to the $\Upsilon(4S)$ peak (10.58 GeV)
- Center of mass frame boost $\beta\gamma = 0.28$
- World record luminosity: $4.65 \times 10^{34}\,\mathrm{cm^{-2}s^{-1}}$ ($4.71 \times 10^{34}\,\mathrm{cm^{-2}s^{-1}}$ w/o Belle II data taking)
- Luminous region size:
  $250\mathrm{nm} \times 25\mu\mathrm{m} \times 250\mu\mathrm{m}$
- Integrated luminosity: $427\,\mathrm{fb}^{-1}$
- In long shut-down till fall 2023
  - Installation of the full PXD
  - Machine improvements to reduce the machine bkg. and improve luminosity.
- Aiming for:

  $\mathscr{L} > 6 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}} = 600\,\mathrm{nb^{-1}/s}$

  $\int \mathscr{L} dt > 50\,\mathrm{ab}^{-1}$



The Belle II Detector



Belle II & SuperKEKB Key Points

- Initial state kinematic extremely well defined:
  - initial energy and momentum, interaction point (IP)
- Small cross sections for the main Physics searches $\mathcal{O}$(1nb)
  - very mild requirements on the L1 trigger event selection, e.g.:
    - single muon trigger using KLM
    - single photon trigger
  - negligible pile-up.
    - Bunch crossing ~ 250 MHz, L1 trigger rate ~ 10^4 cps.

Search for Z' in Invisible

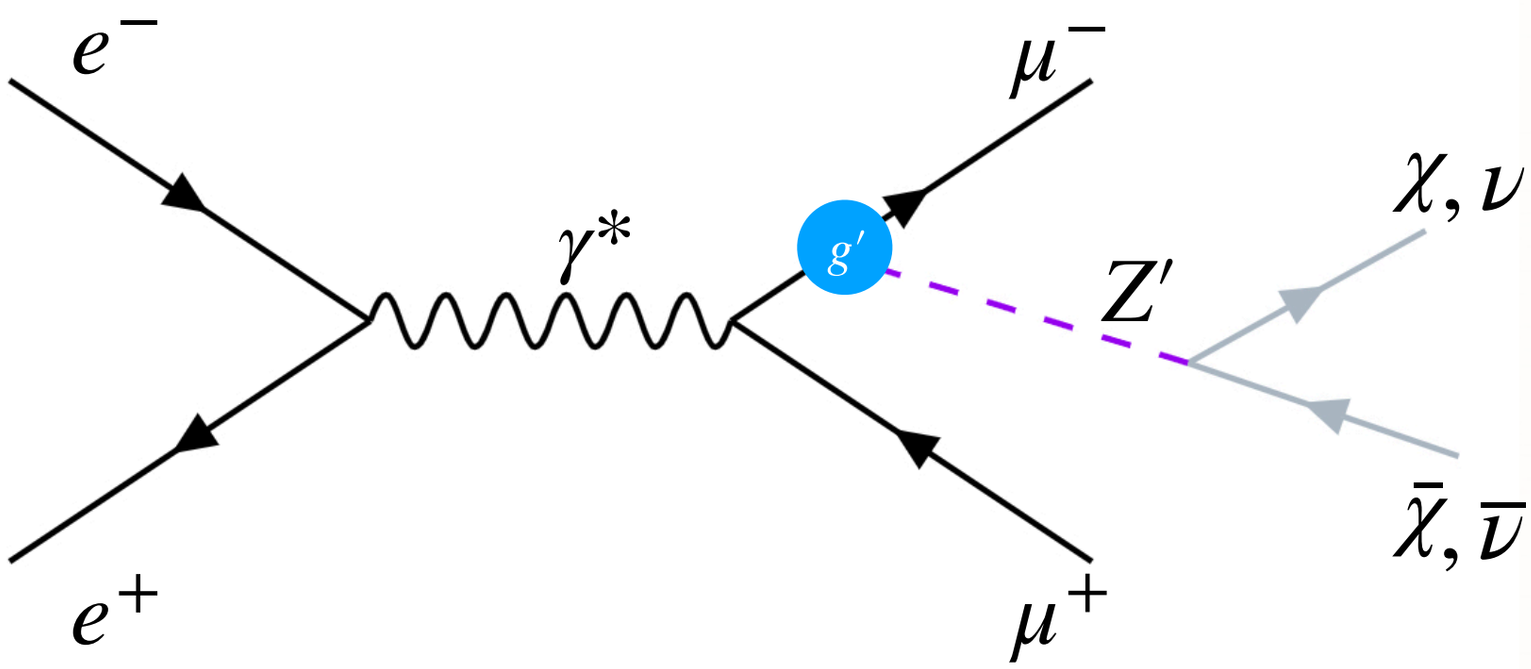
Phys. Rev. Lett. 130, 231801 (2023)

- Our Z' candidate is a massive neutral vector boson mediating a new force associated to $L_\mu - L_\tau$
- The interaction is described by the interaction lagrangian density [1]:

$$\mathscr{L}_I = -\frac{1}{4}\left(\partial_\mu Z'_\nu - \partial_\nu Z'_\mu\right)\left(\partial^\mu Z'^\nu - \partial^\nu Z'^\mu\right) + \frac{1}{2}m^2_{Z'}Z'_\mu Z'^\mu +$$

$$+ g' Z'^\mu \left(\overline{\mu_R}\gamma_\mu \mu_r - \overline{\tau_R}\gamma_\mu \tau_r + \dots\right) + g'_D\left(\text{Dark Sector Particles}\right)$$

1. cfr: Phys. Rev. D 89, 113004 (2014),Phys. Rev. Lett. 113, 091801 (2014), J. High Energy Phys. 12 (2016) 106.



- $\text{BF}(Z' \to \nu\bar{\nu}) \sim 33 - 100\,\%$ (Vanilla model)
- $\text{BF}(Z' \to \chi\bar{\chi}) \sim 100\,\%$ if kinematically allowed

Event Signature And Main Backgrounds

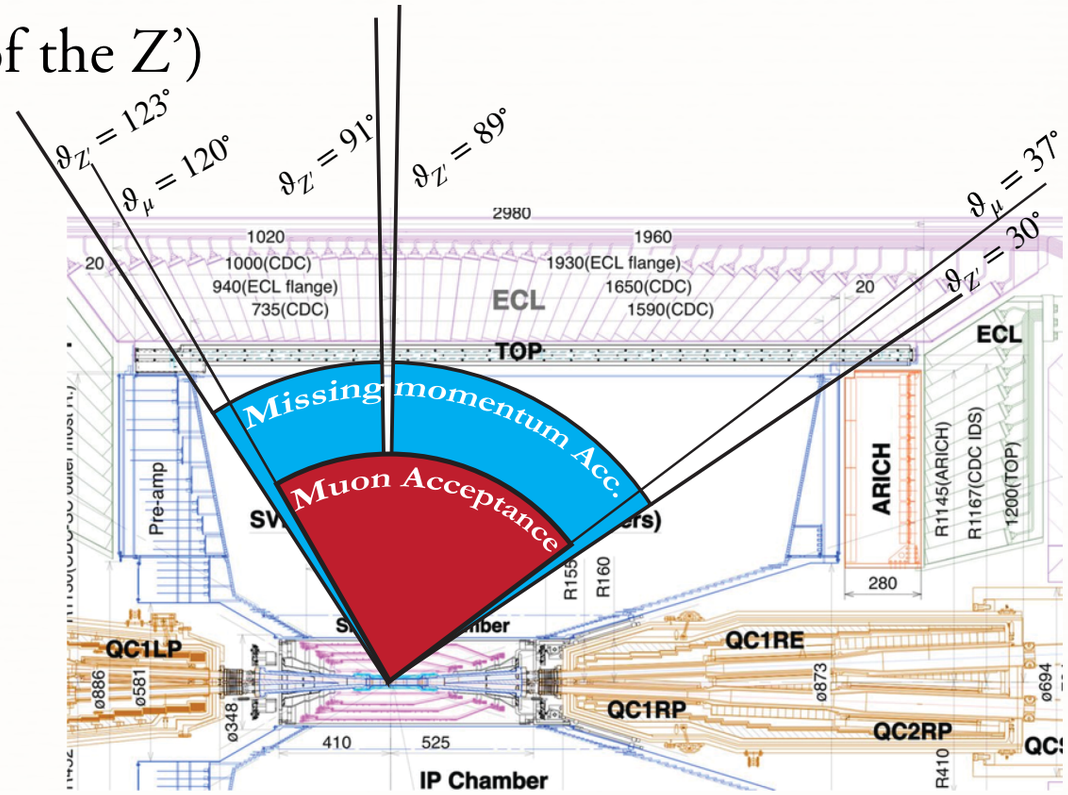
Phys. Rev. Lett. 130, 231801 (2023)

- Event signature: two oppositely charged muons.
  - Negligible activity in the calorimeter
  - Missing momentum squared = $M^2_{Z'}$ (unknown)
- Dominant background sources:
  - $e^+e^- \to e^+e^-\mu^+\mu^-$ with the final e^+e^- pair undetected
  - $e^+e^- \to \tau^+\tau^-(\gamma)$ with leptonic τ decays and missing neutrinos
  - $e^+e^- \to \mu^+\mu^- n(\gamma)$ with undetected gammas
  - Key quantity: missing four momentum

Analysis Strategy

Phys. Rev. Lett. 130, 231801 (2023)

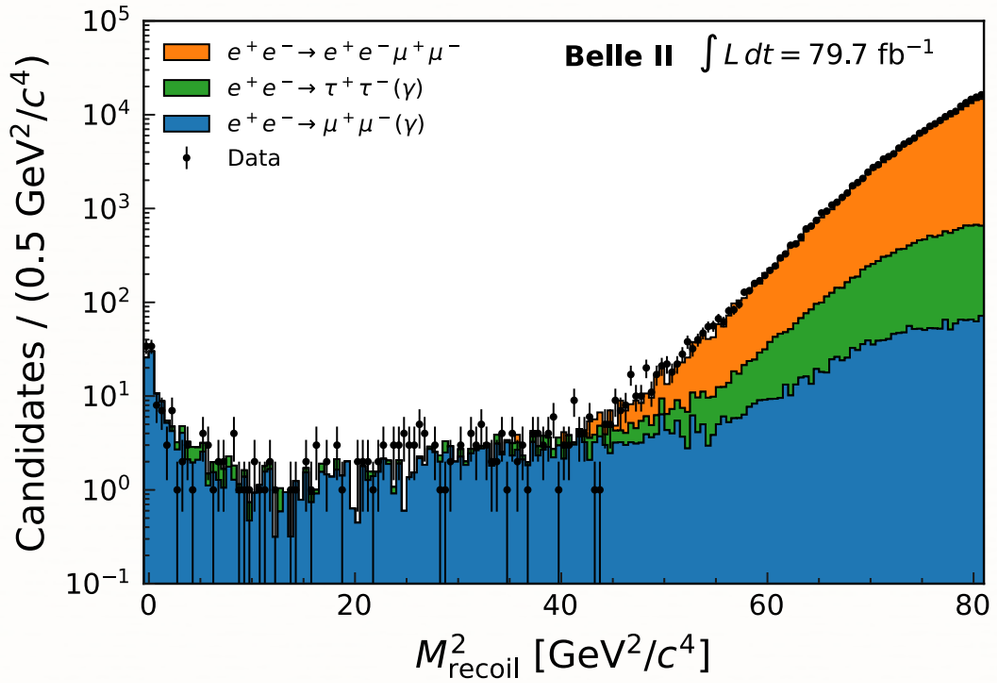
- Online trigger:
  - at least two charged tracks in the region $120^\circ > \vartheta > 37^\circ$
  - transverse opening angle of the two muon candidates > 90° ,2019 (30° ,2020)
- Offline event selection:
  - exactly two oppositely charged tracks identified as muons
  - photon veto: ECL energy of neutral particles < 500 MeV
  - missing momentum $\vec{p}_{\text{miss.}}$ (i.e. momentum of the Z') well within the barrel ECL acceptance:
  - $|\vec{p}^{\,t}_{\text{miss.}}| > 500$ MeV/c
  - no ECL detected photons within 15° from the missing momentum

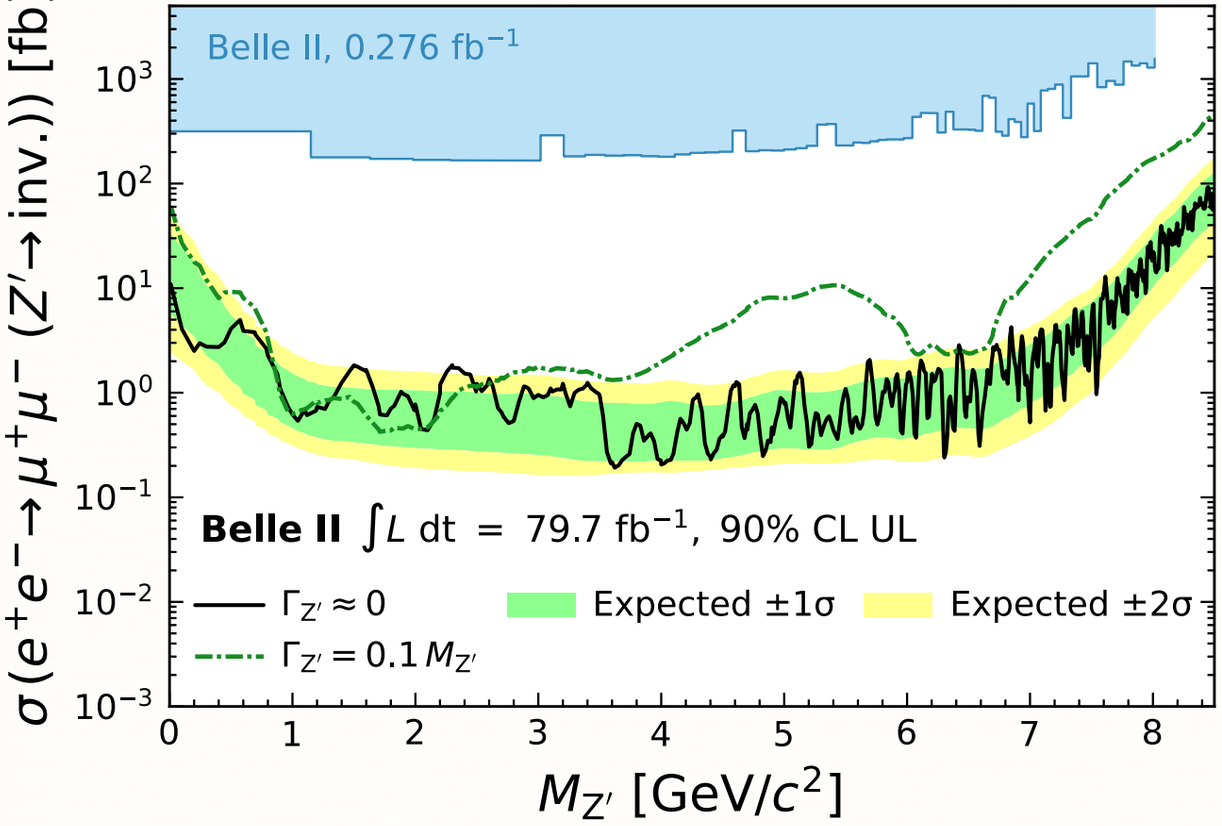


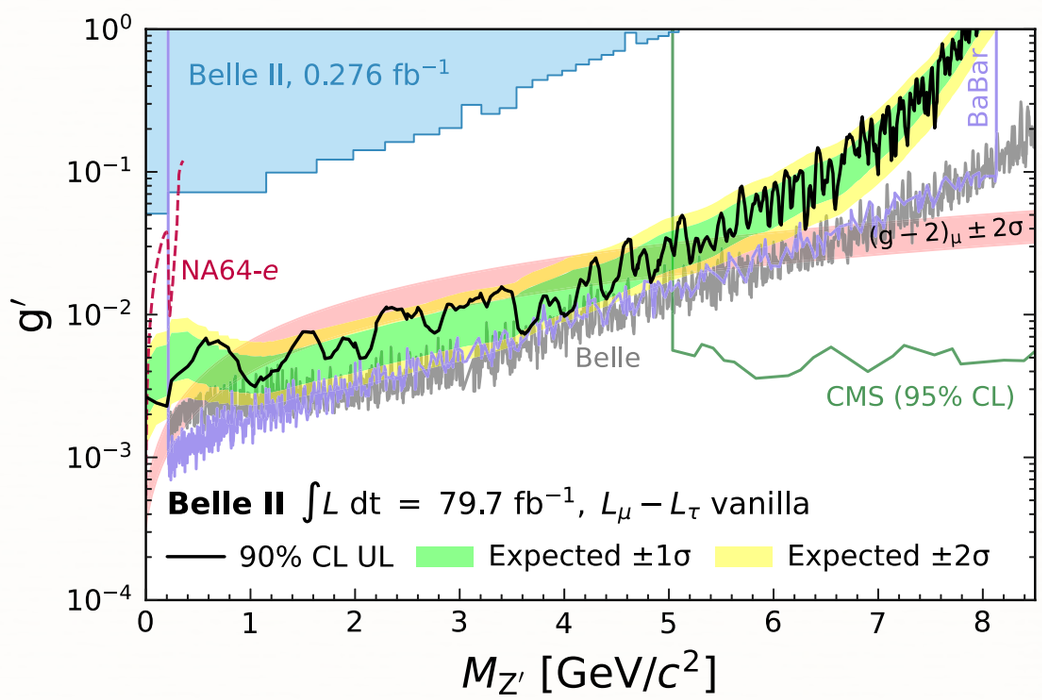
Analysis Results

Phys. Rev. Lett. 130, 231801 (2023)

- Data-set 2019-2020: $\int \mathscr{L} dt = 79.7$ fb^{-1}
- Neural network to further suppress tau bkg.
- Overall efficiency ~ 5%
- No excess observed for $M^2_{\text{recoil}} < 80\,\text{GeV}^2/c^4$

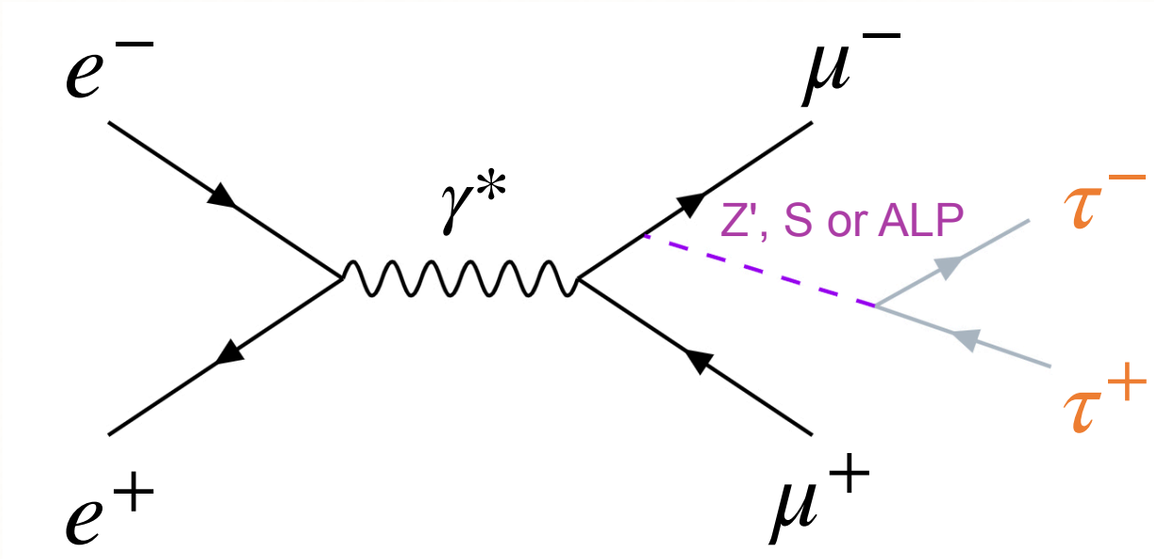




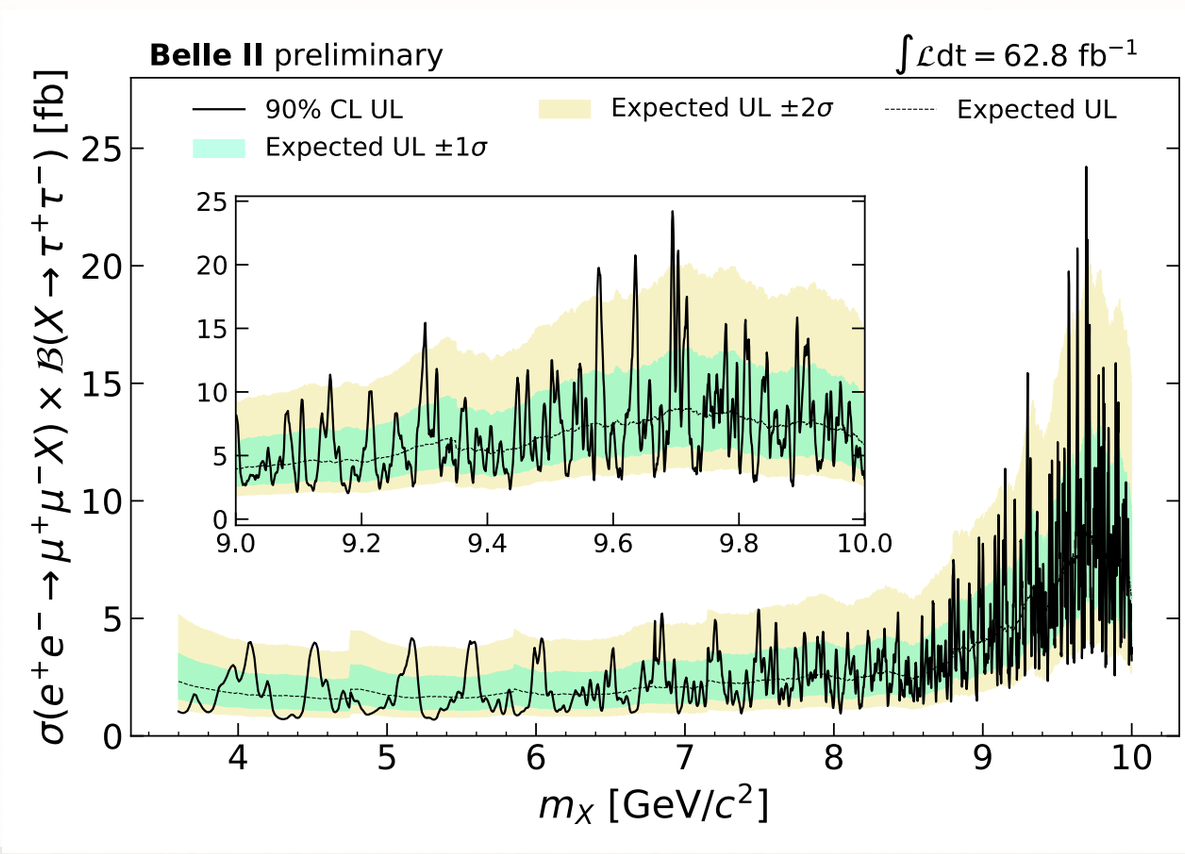


Search For $\tau^+\tau^-$ Resonance In $e^+e^- \to \mu^+\mu^-\tau^+\tau^-$

Accepted for publication by PRL, arXiv:2306.12294



- A pair of oppositely charged muons
- A pair of oppositely charged tau → 1 prong
- Missing energy and missing momentum from the neutrinos

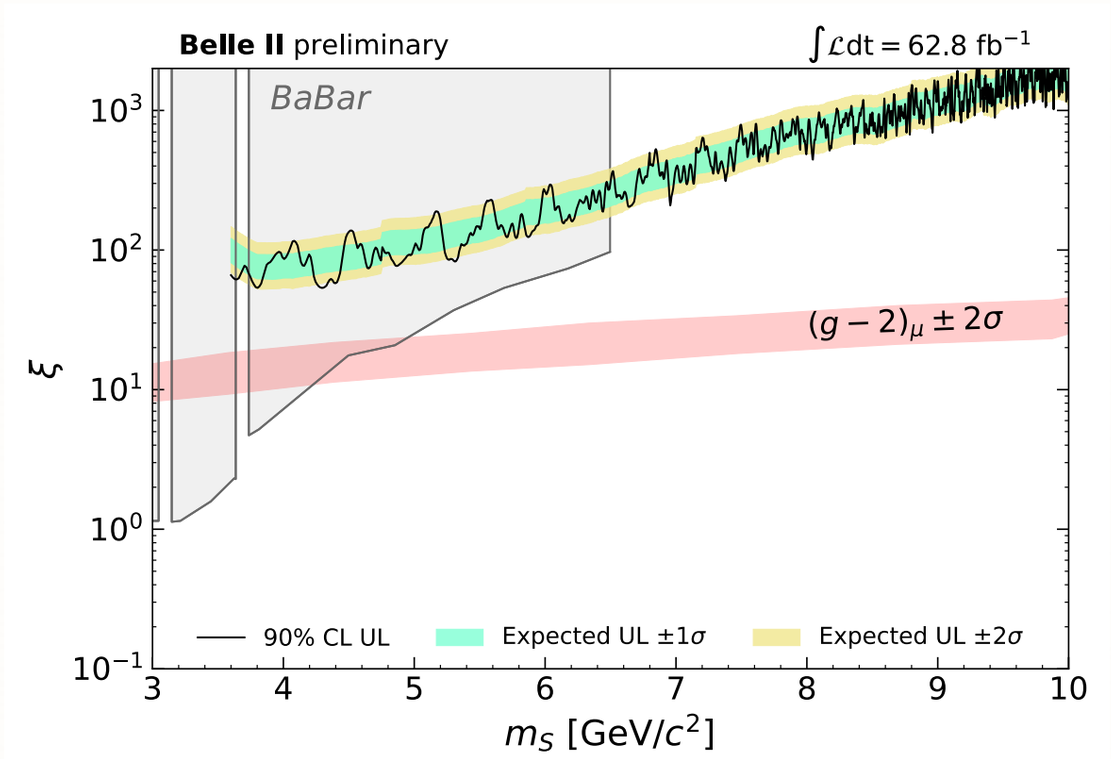


- The four momentum of the X (Z',S or ALP) is:
  $p_X = p_{e^+} + p_{e^-} - p_{\mu^+} - p_{\mu^-}$
- No peaking structure observed on the p_X^2 spectrum

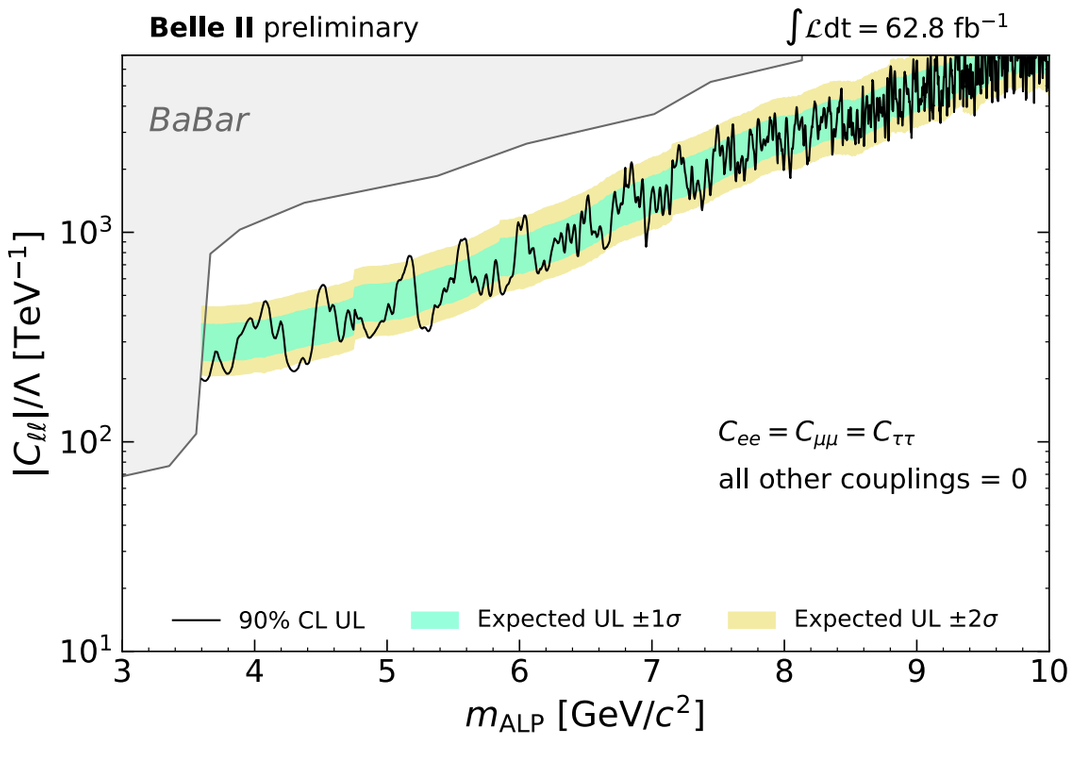
Limits on Model Parameters

Accepted for publication by PRL, arXiv:2306.12294

- Limits on the cross section translated to limits on Model Parameters



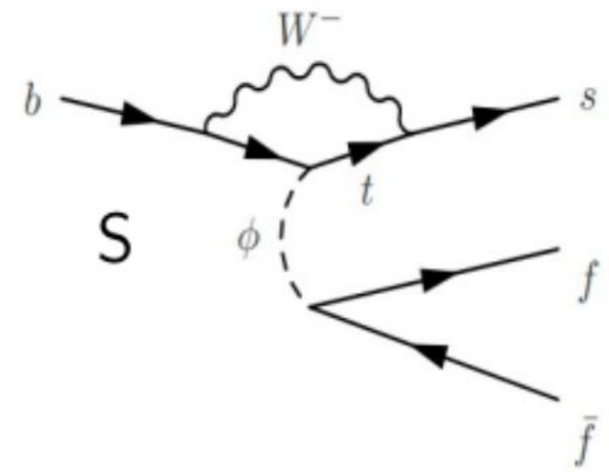
Leptophilic Scalar, S



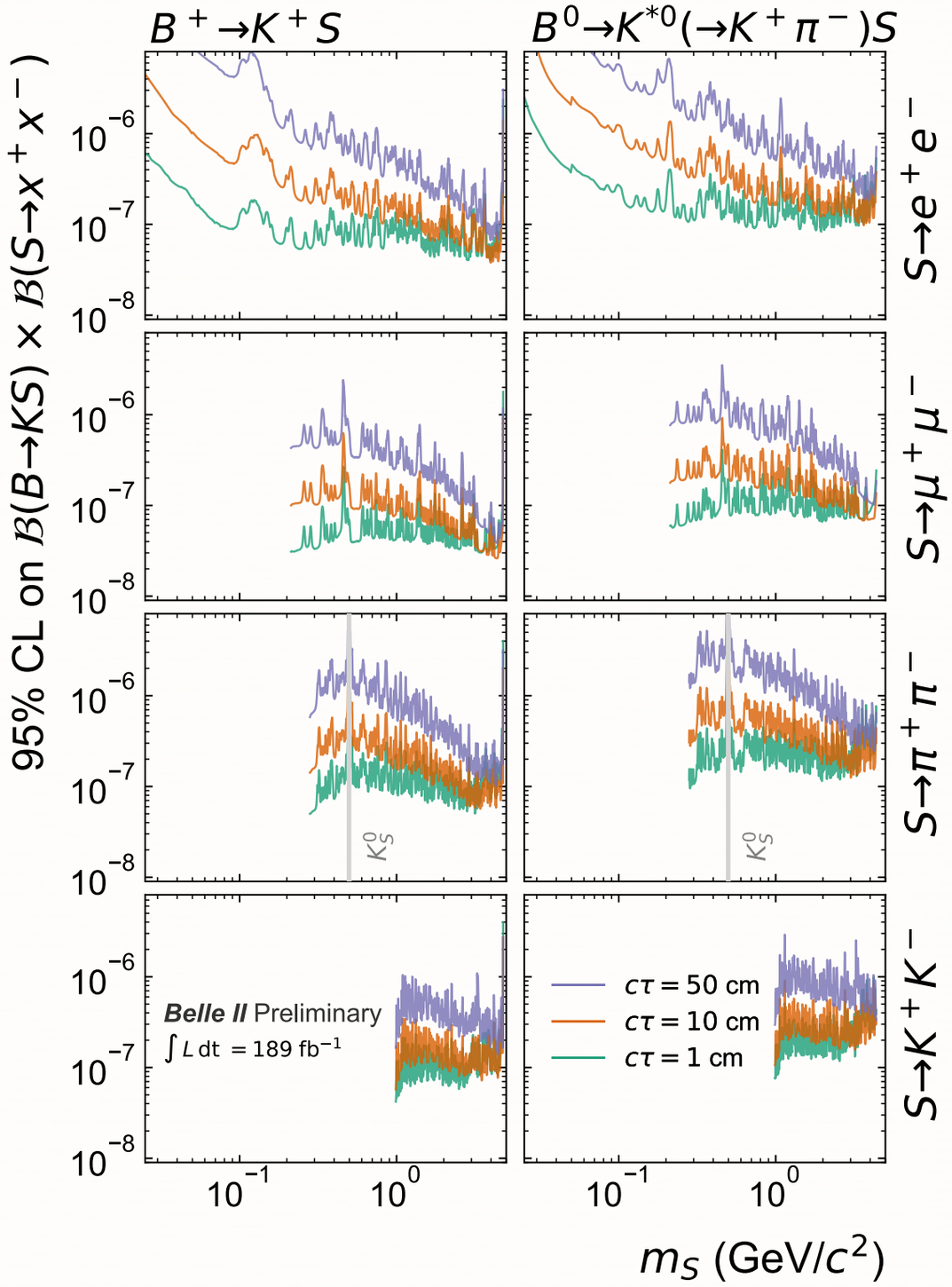
Axion Like Particle

Search For Long Lived Particles In $b \to s$ Transitions

arXiv:2306.02830



- Search for a long lived (Pseudo) Scalar particle S ($100\,\text{cm} > c\tau > 10\,\mu\text{m}$) decaying inside the tracking volume in
  - $e^+e^-, \mu^+\mu^-, \pi^+\pi^-, K^+K^-$
- S is produced by the decay $B^+ \to K^+S$ or $B^0 \to K^{*0}S$
- No excess found in 189 fb^{-1} , limits are set



Conclusions

- The clean environment of Belle II together with a large amount of data, good detector performance, dedicated and talented people make the Belle II experiment an ideal place for the study of the Dark Sector.

- No excess still observed, new competitive limits are set

- The long shut down is ending and a larger data set together with an improved detector is on the way.

- Stay tuned for more to come.

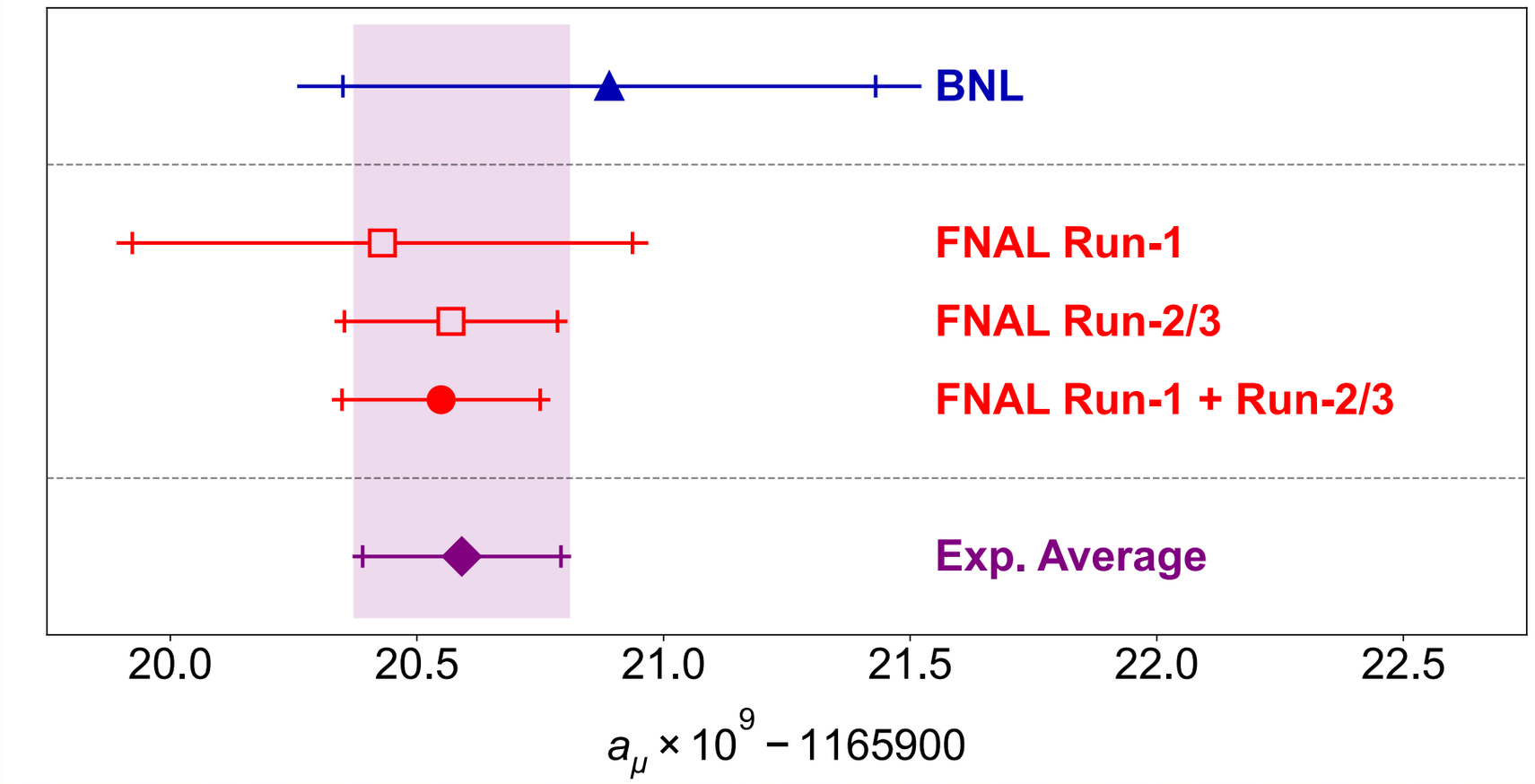
Backup material

Caveat Emptor (Hot From the Press)

Measurement of the Positive Muon Anomalous Magnetic Moment to 0.20 ppm

(The Muon $g-2$ Collaboration)

(Dated: 10th August, 2023)



In the following it is still assumed a $_\mu$ = 116 592 061 (41) x 10^{-11} instead of the last world average a $_\mu$ = 116 592 059 (22) x 10^{-11}