



e^+e^- *B* factory highlights

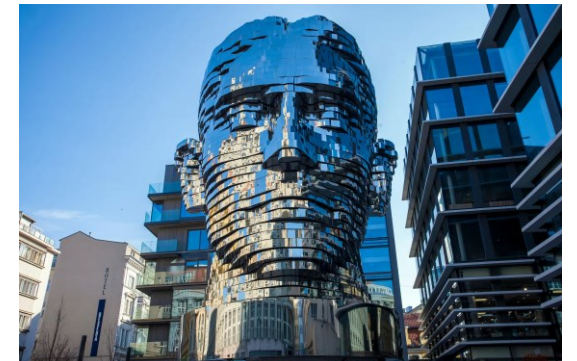
Jim Libby - Indian Institute of Technology Madras



22/7/2024



B factory highlights - Jim Libby



Keywords

(Partial) definition: an e^+e^- B factory operates at the **intensity frontier** to collect samples of B mesons for **precision measurements** and searches for **rare/forbidden decays**, i.e., **indirect searches** for beyond-the-standard-model (BSM) physics with **high luminosity**

Keywords

(Partial) definition: an e^+e^- B factory operates at the **intensity frontier** to collect samples of B mesons for **precision measurements** and searches for **rare/forbidden decays**, i.e., **indirect searches** for beyond-the-standard-model (BSM) physics with **high luminosity**

An important note: programme is mostly **complementary** to that of LHCb and other hadron experiments

Outline

1. The Castle

- Why e^+e^- at $Y(4S)$?
- Cabibbo-Kobayashi-Maskawa matrix measurements

2. The Trial

- Results related to B anomalies

3. The Metamorphosis

- Beyond B physics
- Belle II status and plans

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Franz Kafka: 1883-1924

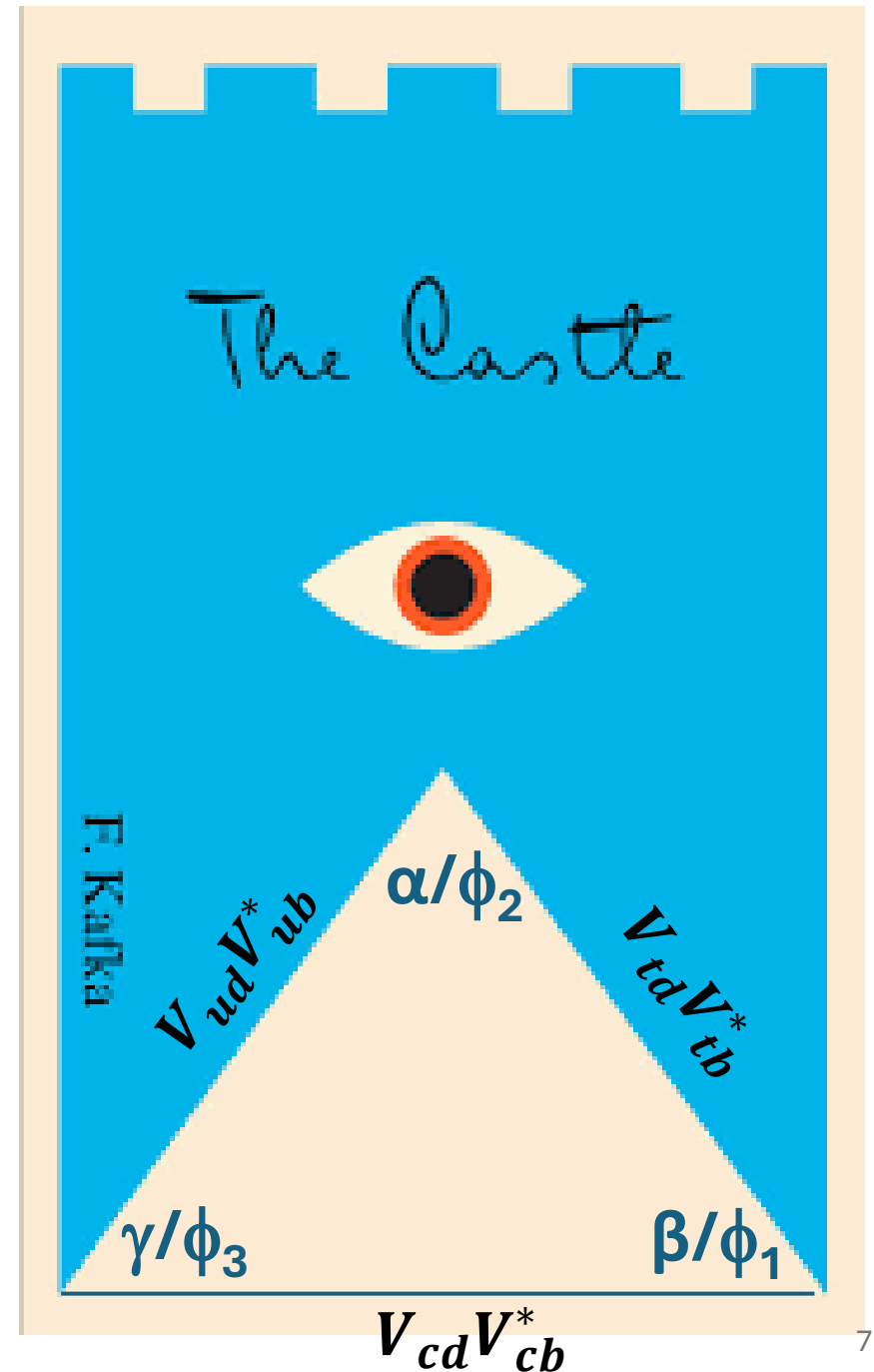
The Castle

Tale of K.'s relentless, unavailing struggle with an inscrutable authority in order to gain access to the Castle.

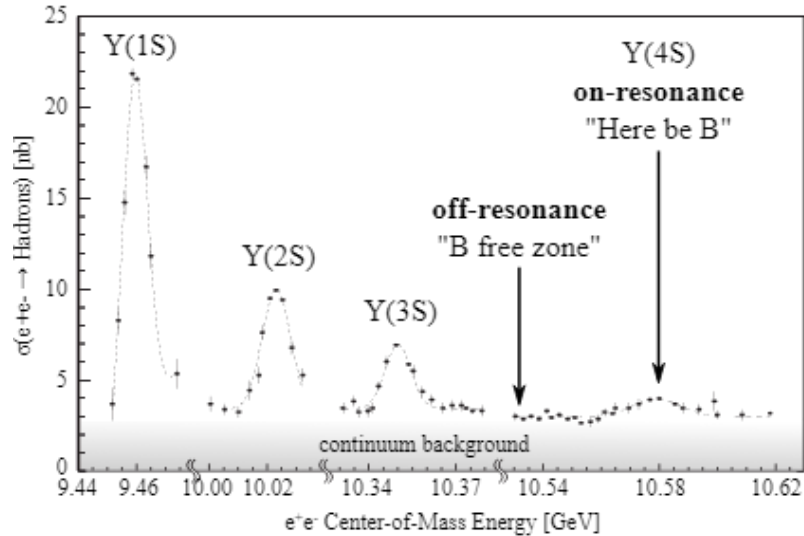


The Castle

Tale of **our** relentless, unavailing struggle with an inscrutable **standard model** in order to gain access to **BSM**.

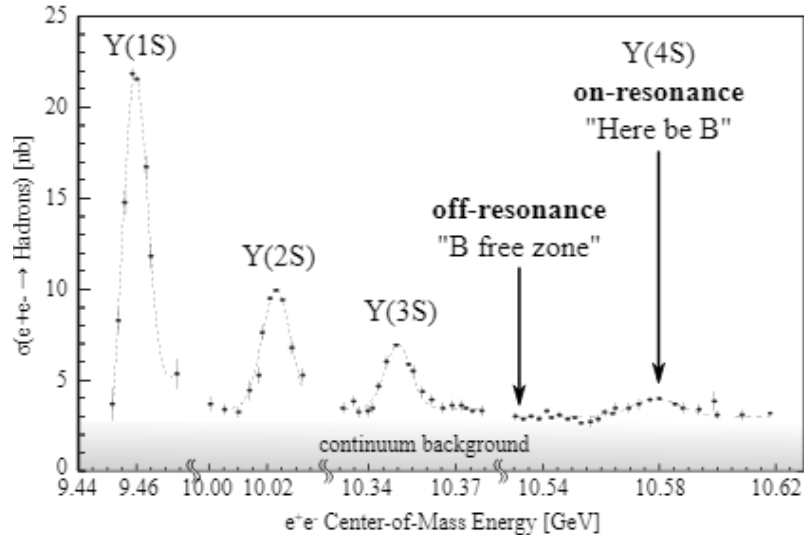


Why asymmetric e^+e^- at $Y(4S)$?



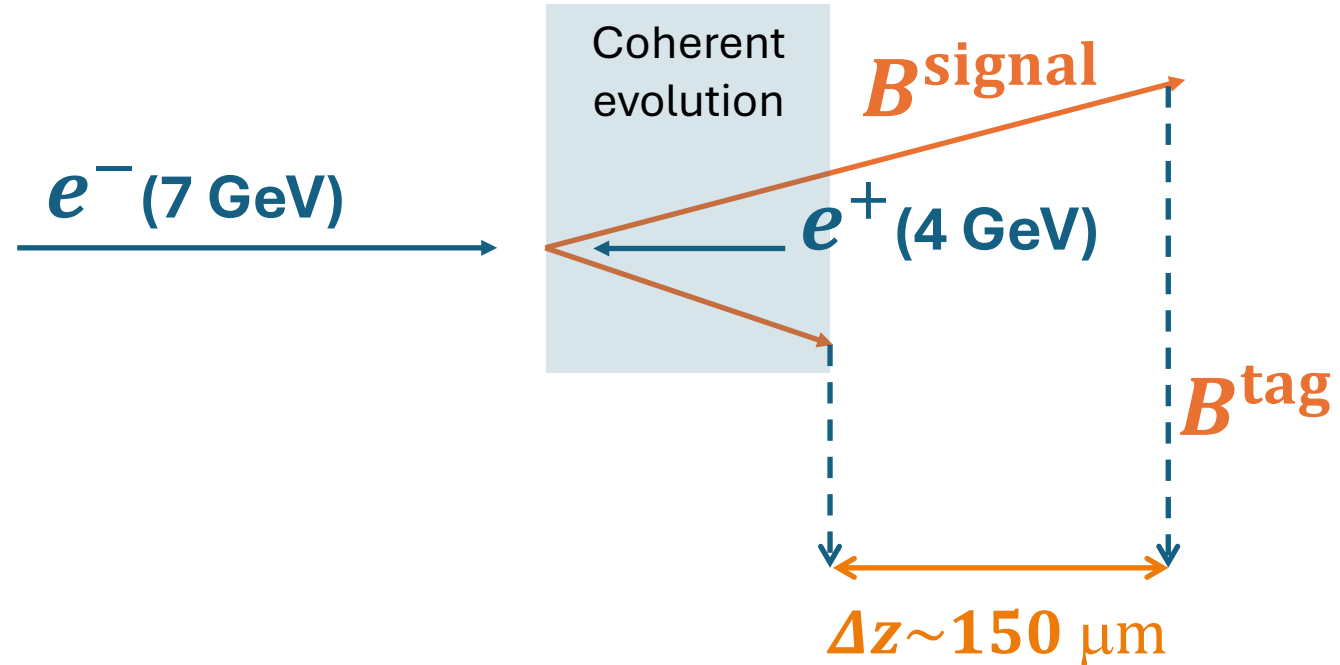
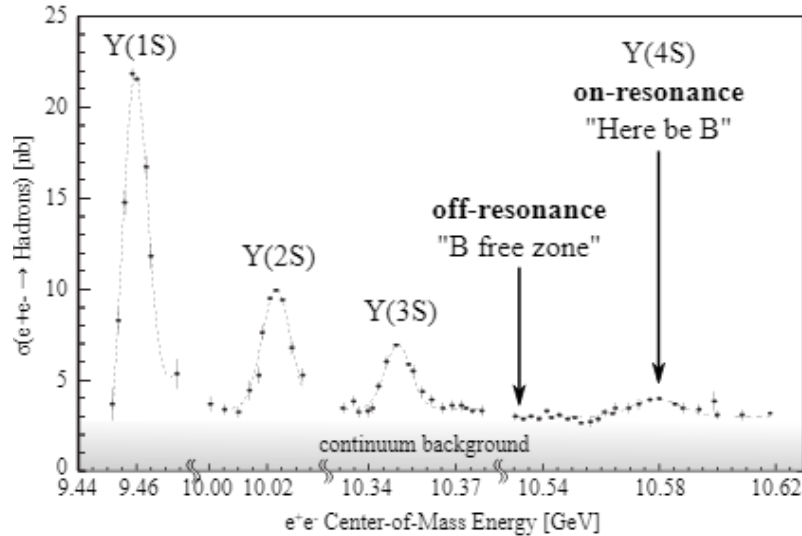
- **$Y(4S)$** – cross section of $B\bar{B}$ **one quarter** of continuum: $e^+e^- \rightarrow q\bar{q}$, $q = u, d, s, c$

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- **e^+e^-** - constrained kinematics and **no other particles** at threshold
 - Excellent neutral and missing four-momentum reconstruction
 - Full event reconstruction – **hadronic B tagging**

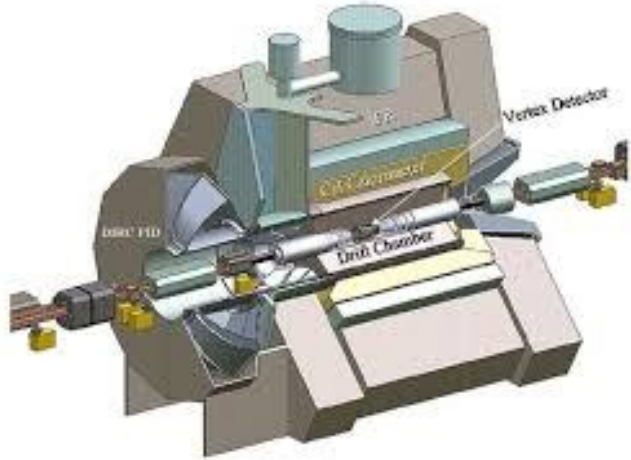
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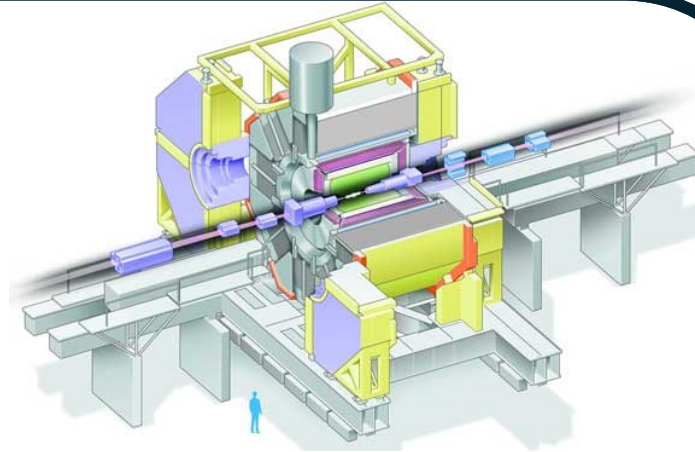
- **Asymmetric** – boosted B s to allow measurements of time-dependent CP violation
 - Tagging power increased by quantum **coherent production** from $Y(4S)$

The protagonists



SLAC - PEP II collider

462 fb⁻¹ at Y(4S) [1999-2008]

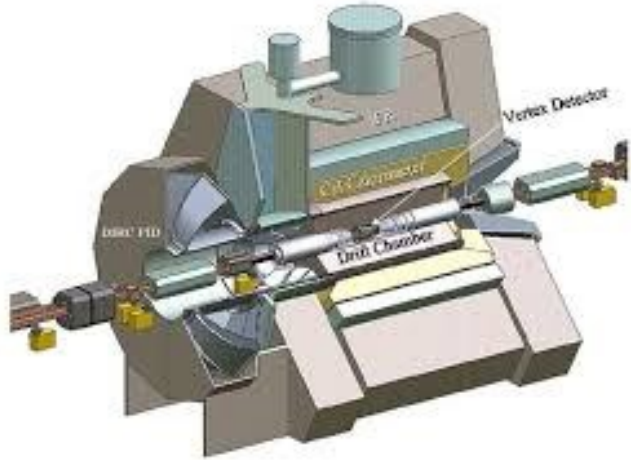


KEK – KEKB collider

711 fb⁻¹ at Y(4S) [1999-2010]

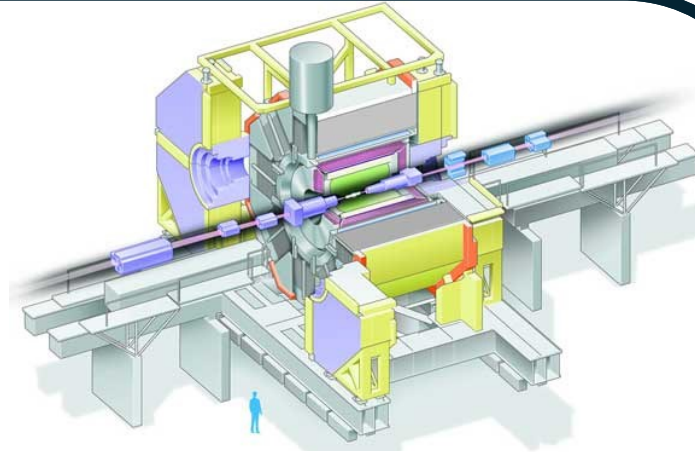
1st generation *B* factory

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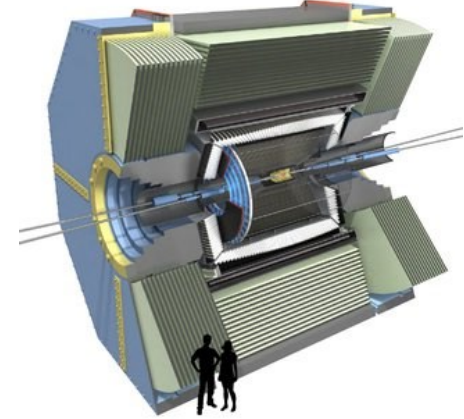
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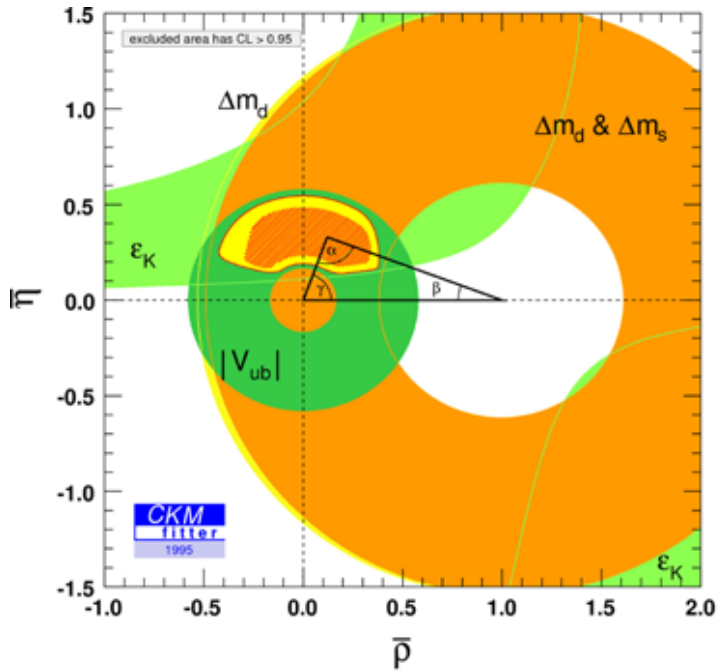
KEK – Super KEKB collider

450 fb⁻¹ at Y(4S) [2019-2024+]

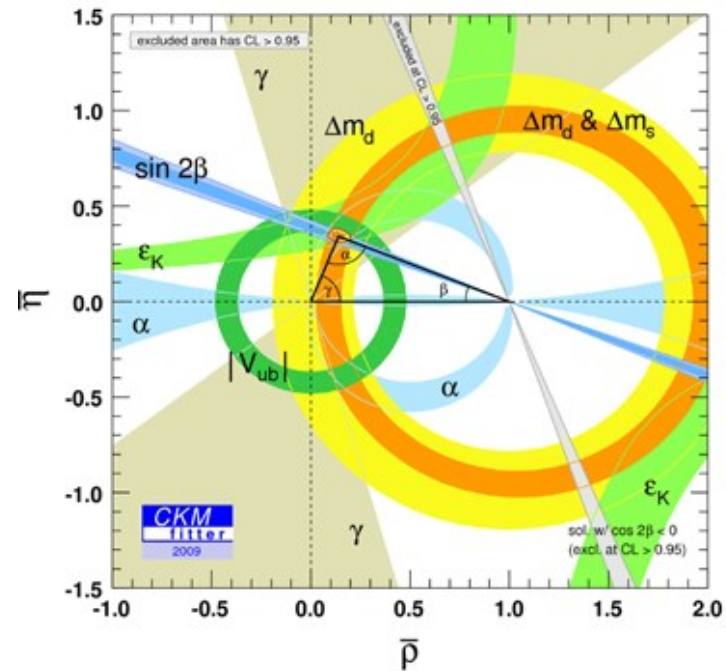
364 fb⁻¹ or less used for results presented here

1st generation *B* factory

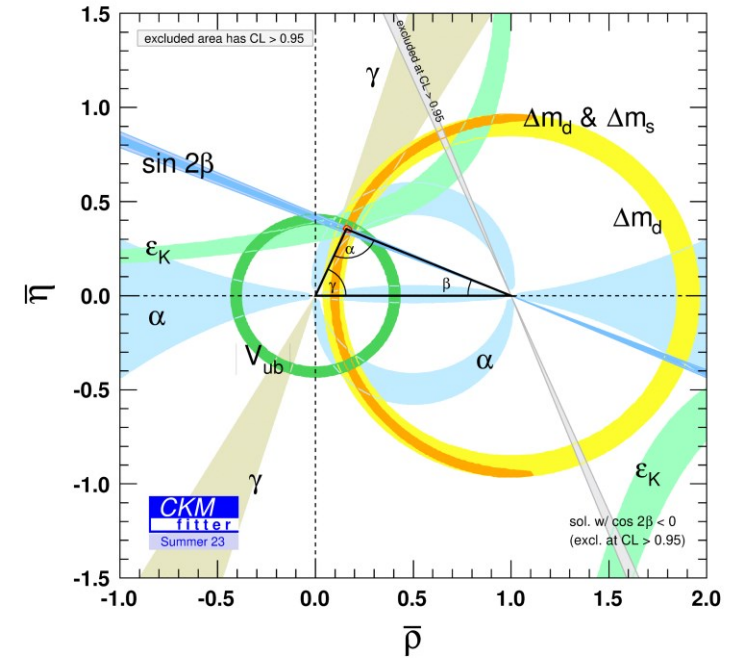
CKM/Unitarity triangle measurements



Pre 1st generation *B* factories

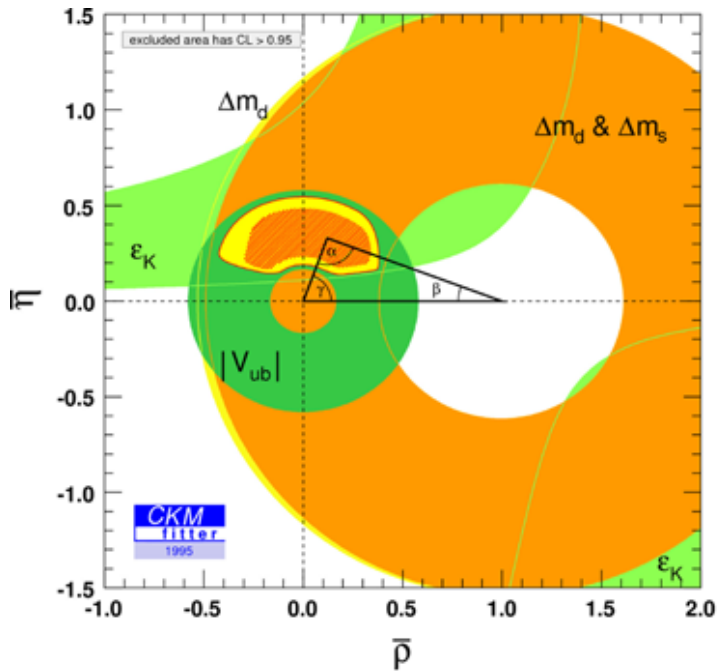


Post 1st generation *B* factories
+ CDF B_s mixing

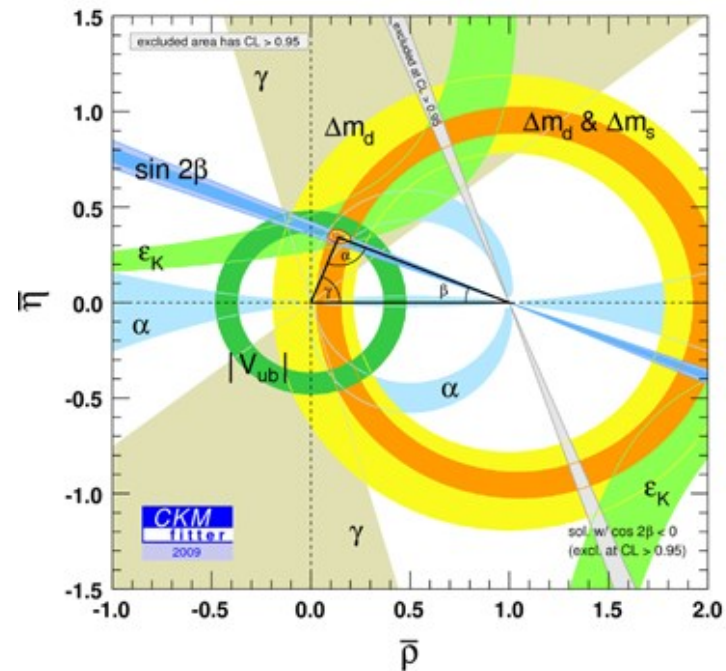


Today
+ LHCb and improved theory

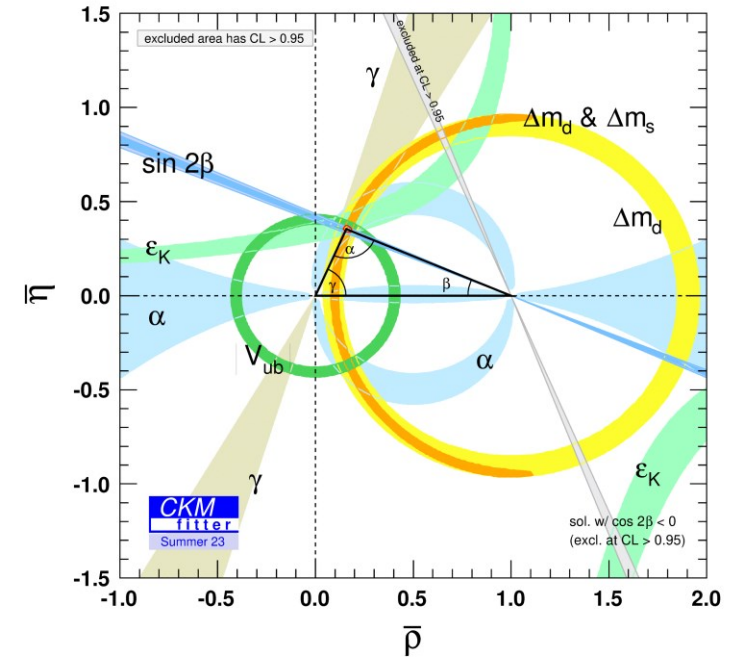
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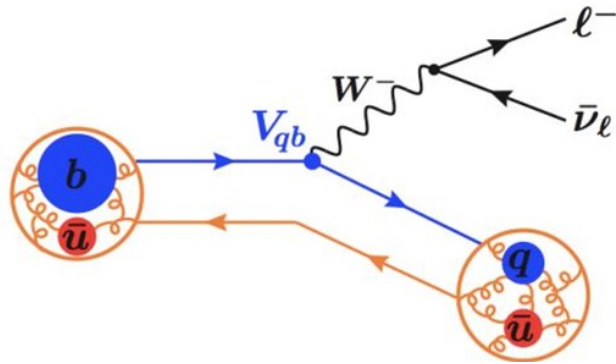
Q: Is this still interesting?

A: Yes, two SM parameters, yet many measurements, including with loops, so discrepancies can be BSM

Semileptonic B decay: V_{cb}

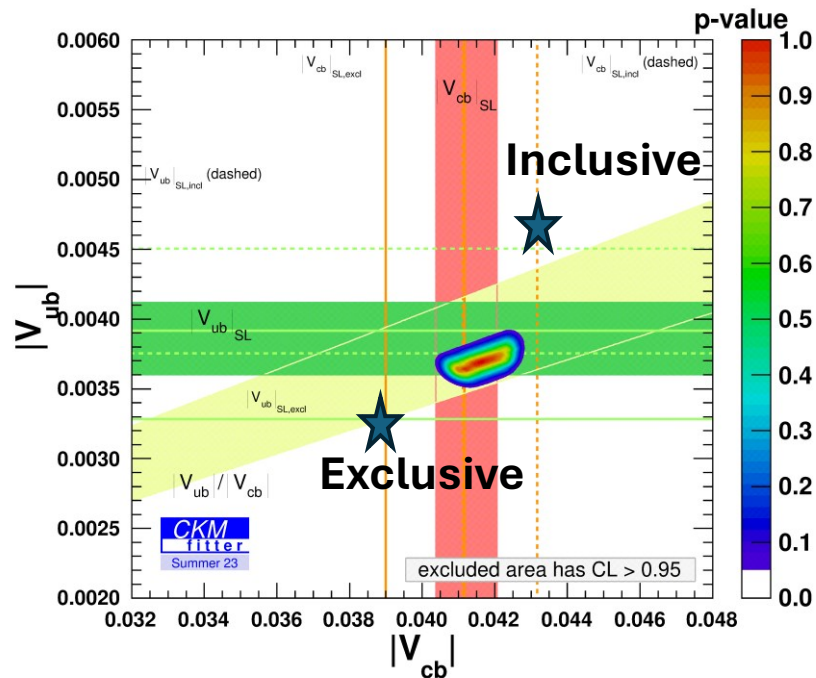


Talk by [G. Eigen](#) Talk by [M. Aversano](#)



- Longstanding tension between **inclusive** (anything in the hadronic final state) or **exclusive** (D, D^*, \dots)

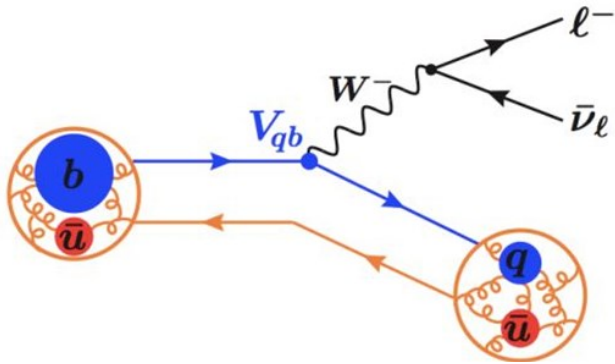
- Approximately **3 standard deviations**
- Theory inputs key, e.g., form factors



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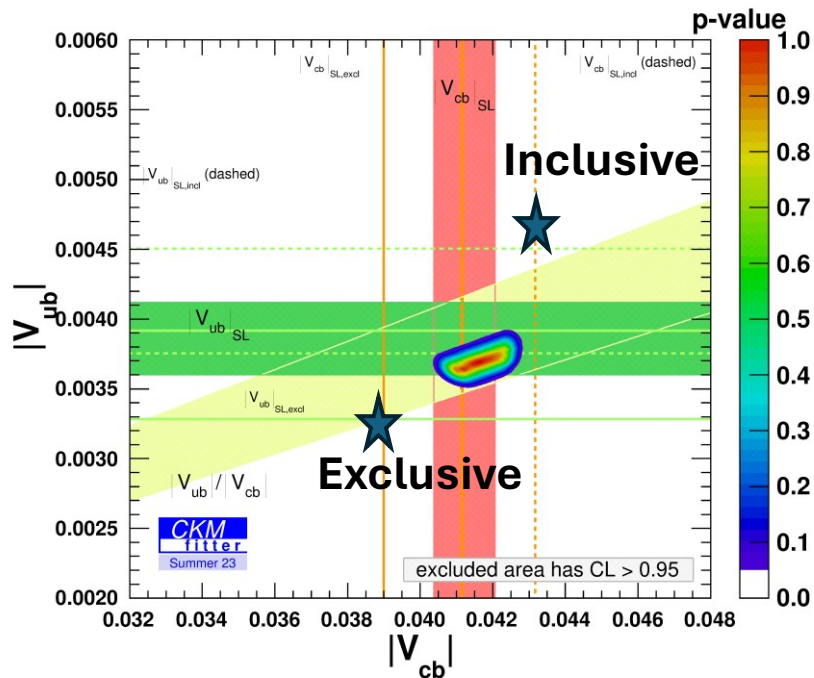
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 - Approximately **3 standard deviations**
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- New exclusive measurements from Babar with $B \rightarrow D/\nu$ and Belle with $B \rightarrow D^*/\nu$ using **full differential information** for the first time
 - $|V_{cb}| = (41.1 \pm 1.2) \times 10^{-3}$
 - Babar [arXiv:2311.15071 \[hep-ex\]](#), to appear in PRD
 - $|V_{cb}| = (41.0 \pm 0.7) \times 10^{-3}$
 - Belle [arXiv:2310.20286 \[hep-ex\]](#), to appear in PRL

- Compatible with inclusive – **perhaps we are on the right path to resolve these tensions?**

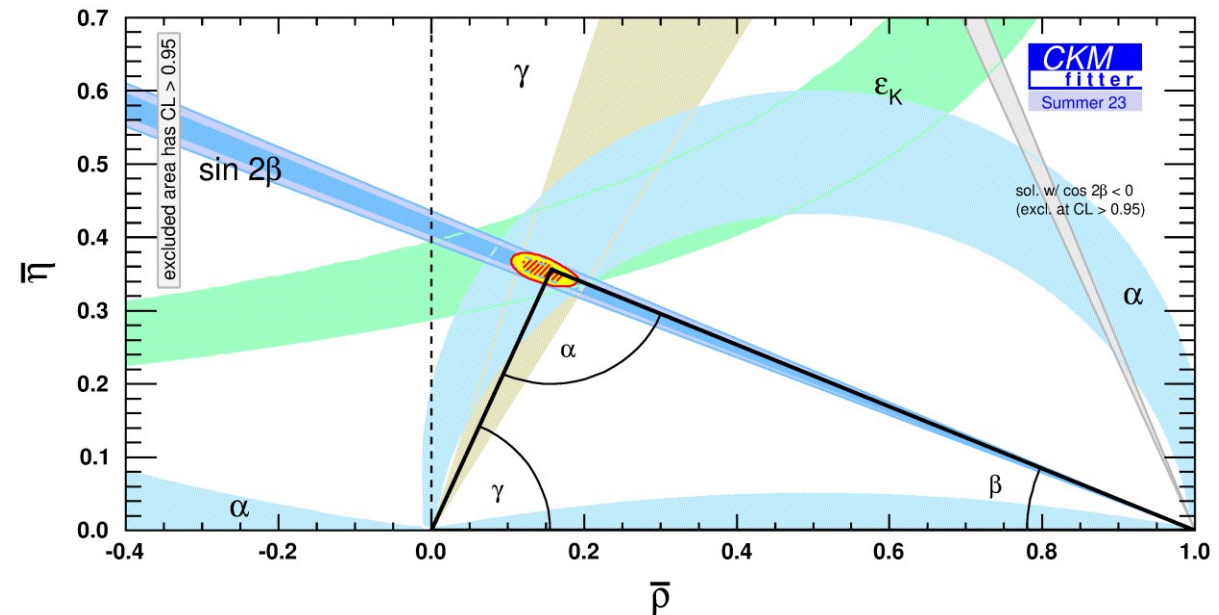


$\alpha/\phi_2: B^0 \rightarrow \pi^0 \pi^0$



Talk by [Y. Nakazawa](#)
Paper in preparation

- α/ϕ_2 now the least precise angle of the unitarity triangle
- Isospin relations among all $B \rightarrow \pi\pi$ branching fractions and CP asymmetries provide constraints
 - [Gronau and London PRL 65 3381 \(1990\)](#)
- Weakest link: $B^0 \rightarrow \pi^0 \pi^0$

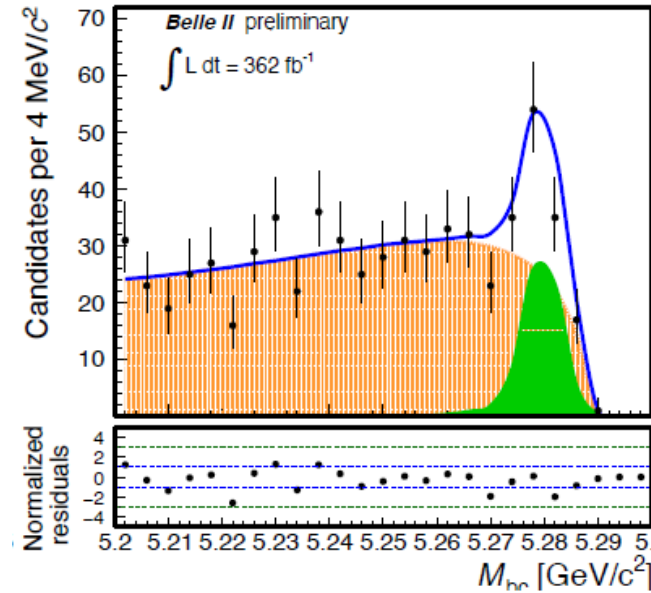


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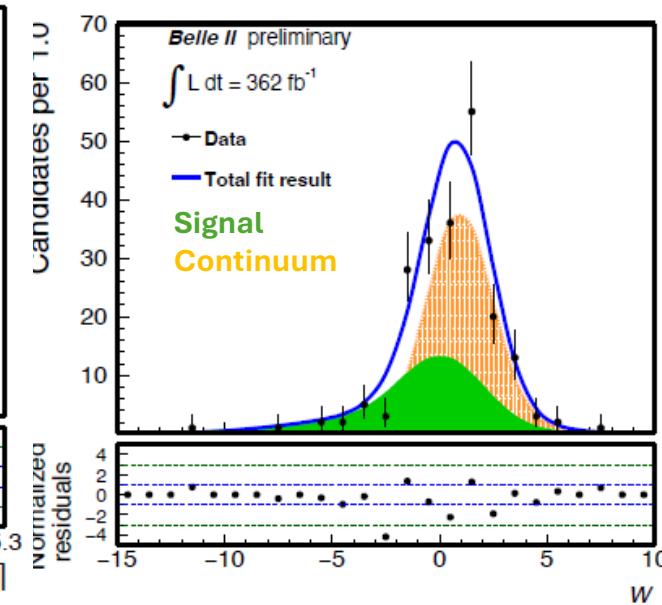


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- Weakest link: $B^0 \rightarrow \pi^0 \pi^0$
- New result from Belle II
 - 4-D fit including tagging probability
 - Graph-neural-network based tagger
 - 18% more powerful than before
 - [arXiv:2402.17260 \[hep-ex\] \(acc. PRD\)](#)



Beam-energy constrained
 $\pi^0\pi^0$ invariant mass

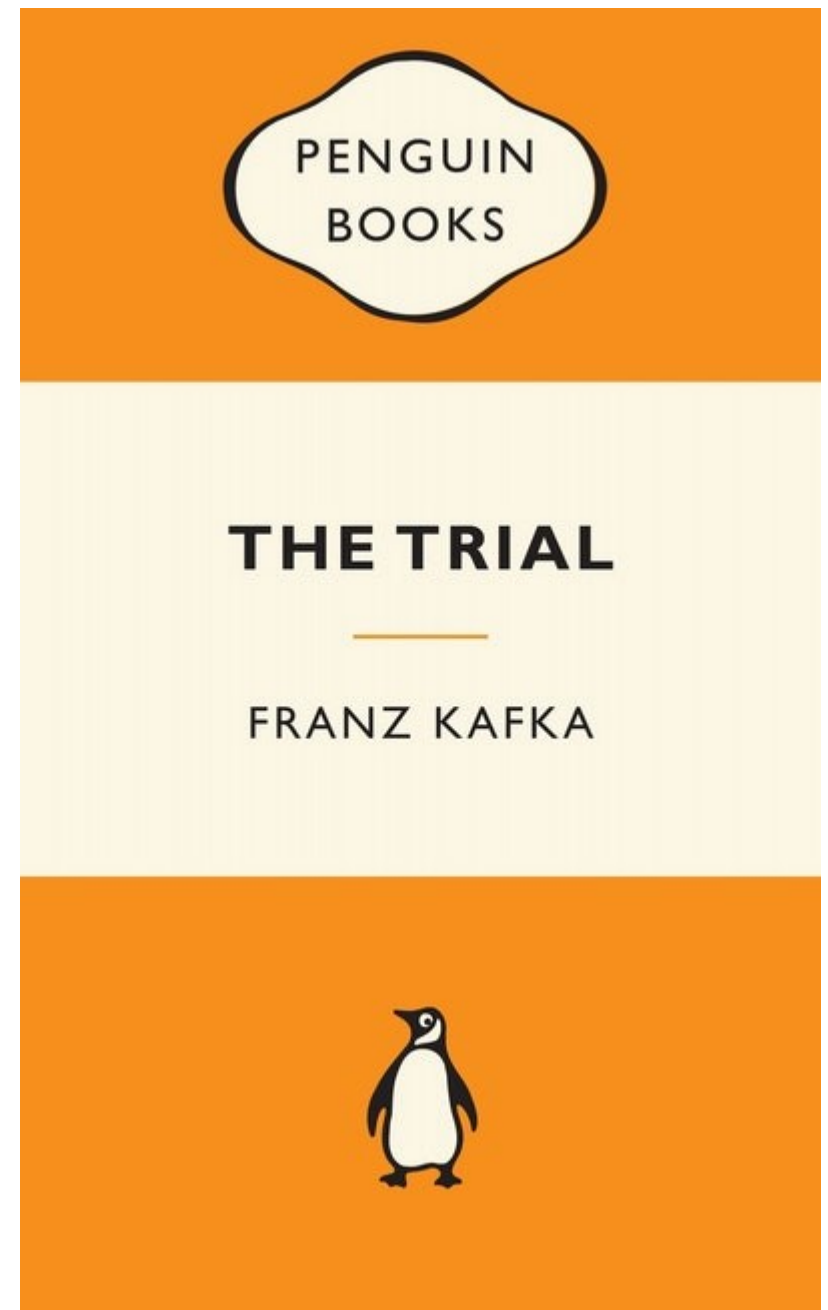


Transformed wrong-
flavour-tag probability

$$\mathcal{B} = (1.26_{-0.19}^{+0.20} \pm 0.11) \times 10^{-6}$$
$$A_{CP} = 0.06 \pm 0.30 \pm 0.06$$

The Trial

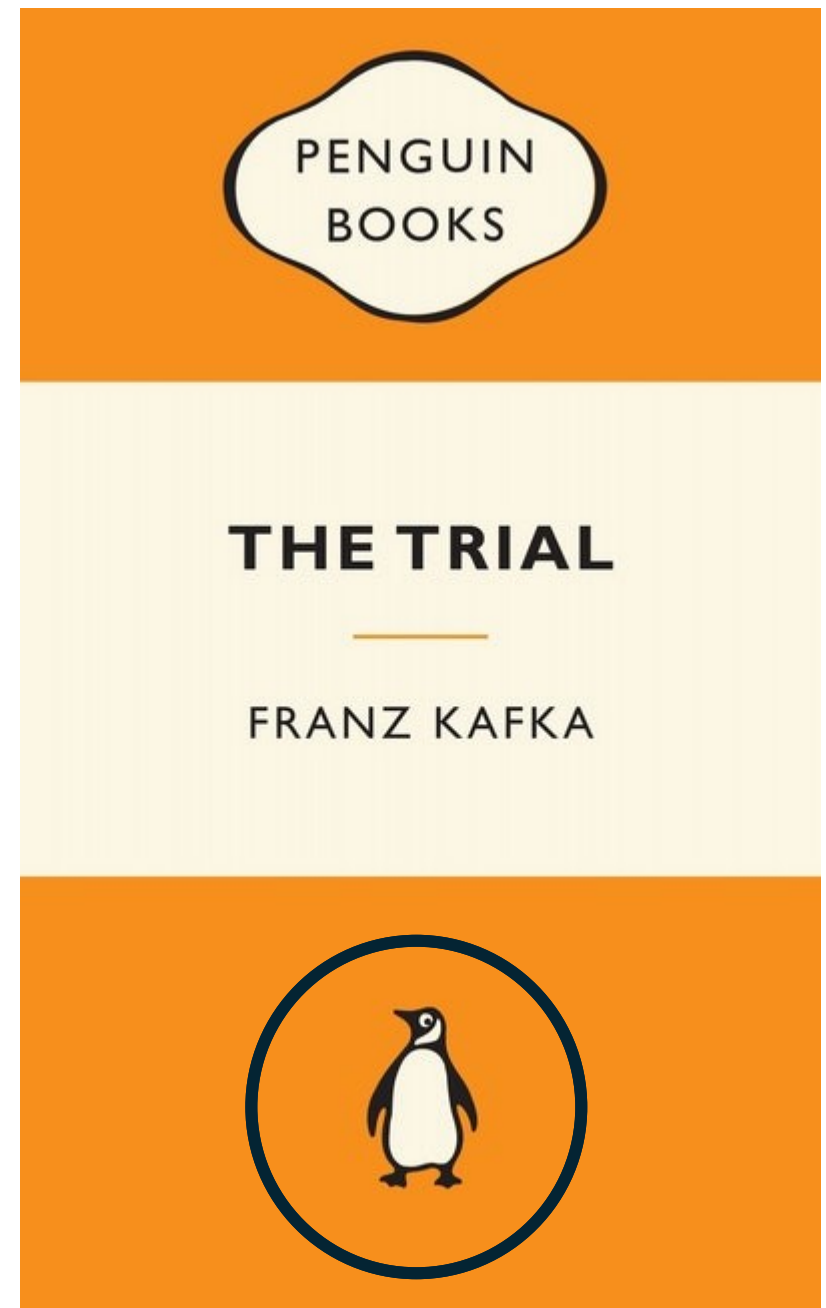
The story of Josef K., a man arrested and prosecuted by a remote, inaccessible authority, with the nature of his crime revealed neither to him nor to the reader.



The Trial

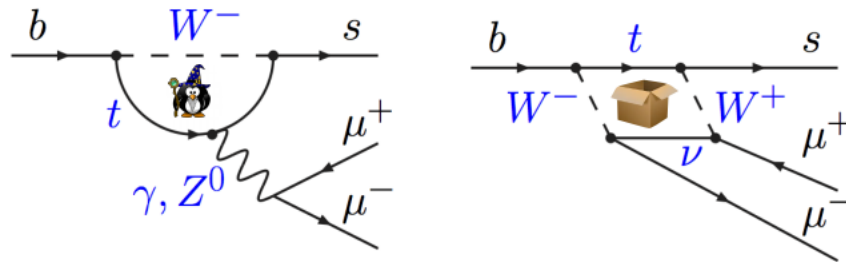
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An allegory of 'B anomalies' in the past decade?



B anomalies – two varieties

- $b \rightarrow sll$ – flavour-changing neutral current – **loop only in SM**

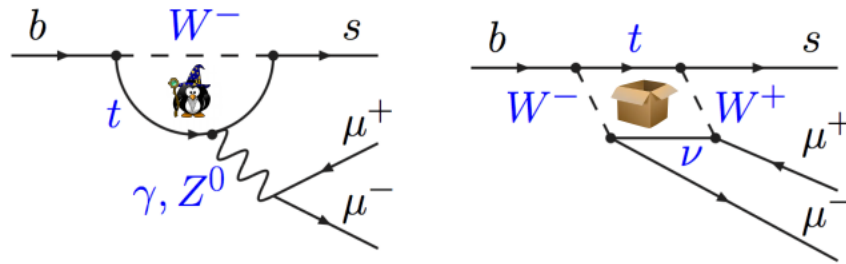


- 2-3 standard deviation tensions in angular distributions and absolute branching fractions
 - but long-distance contributions must be considered, which weaken these tensions
 - LHCb [arXiv:2405.17347](https://arxiv.org/abs/2405.17347)
- Lepton-universality violation in ratios cancelled Christmas 2022
 - LHCb [PRD 108, 032002](https://arxiv.org/abs/1808.07502)

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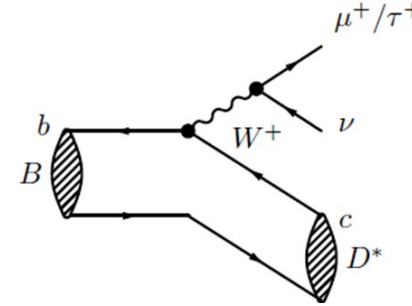
For related results on radiative decays see talk by [M. Angelsmark](#)

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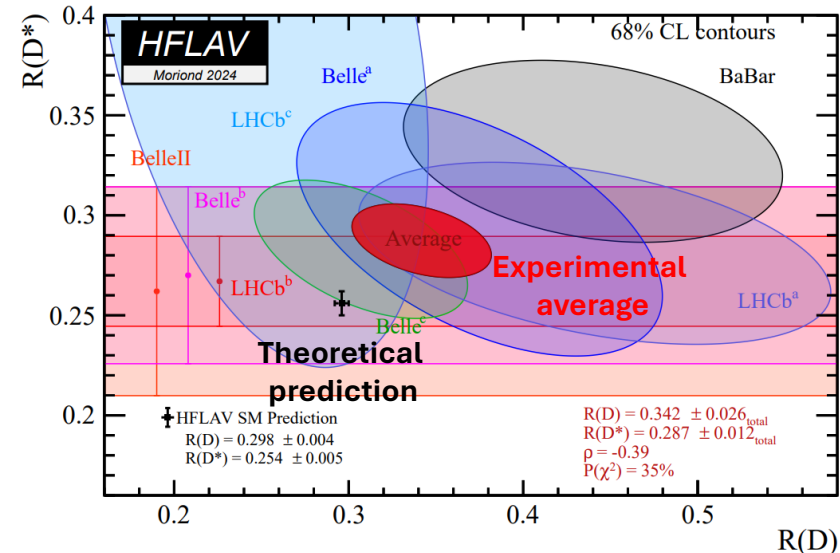


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- $b \rightarrow c\tau\nu$ - measured relative to light lepton decay in exclusive decays



**Longstanding
~3 standard
deviation tension**



$B^+ \rightarrow K^+ \nu \bar{\nu}$: a new one

[PRD 109, 112006 \(2024\)](#)



Talk
by [M. Liu](#)

- Theoretically clean and third generation sensitive $b \rightarrow sll$ transition

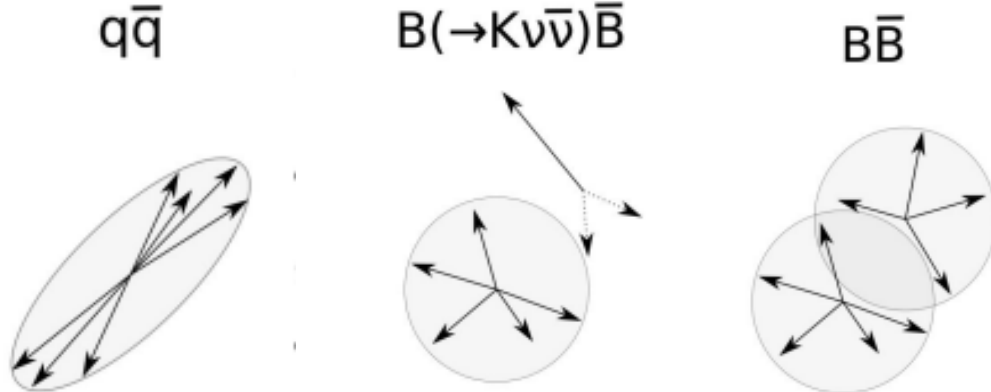
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PRD 109, 112006 (2024)



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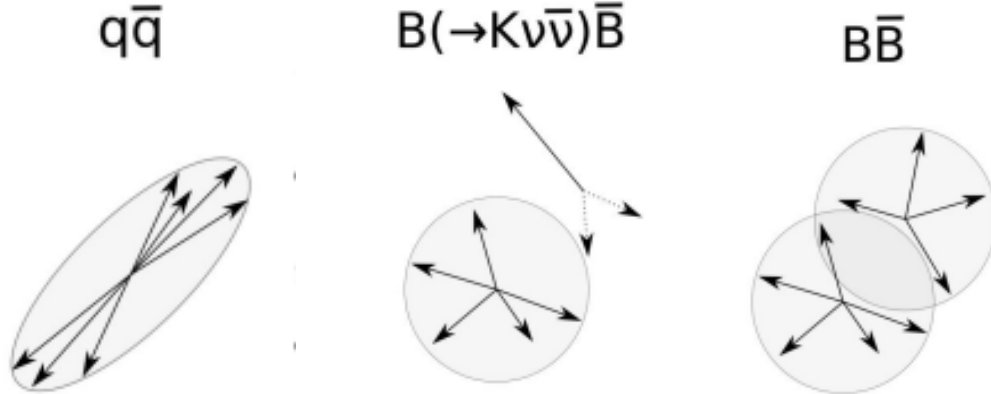
- Theoretically clean and third generation sensitive $b \rightarrow sll$ transition
- Inclusive tag developed that exploits topology
 - 8% efficiency



- Fit to invariant mass of neutrinos (q^2) and classifier
 - Checked and combined with lower efficiency hadronic B tag

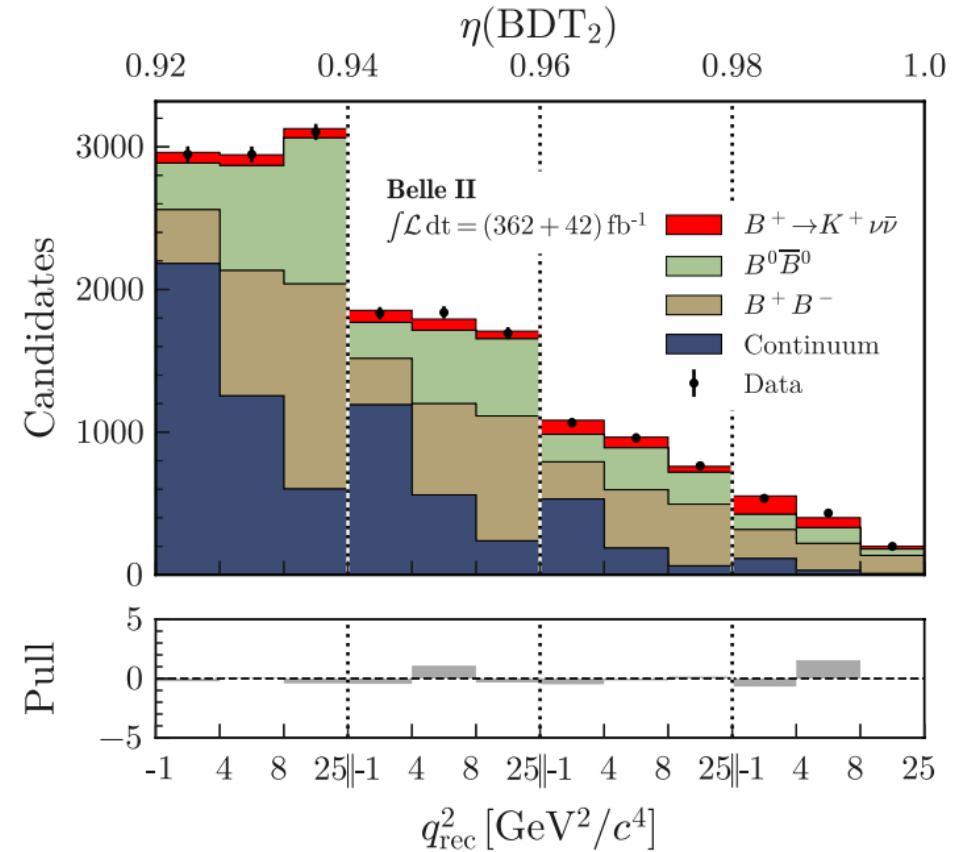
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$$\mathcal{B}(B^+ \rightarrow K^+ \nu \bar{\nu}) = (2.3 \pm 0.5(\text{stat})_{-0.4}^{+0.5}(\text{syst})) \times 10^{-5}$$

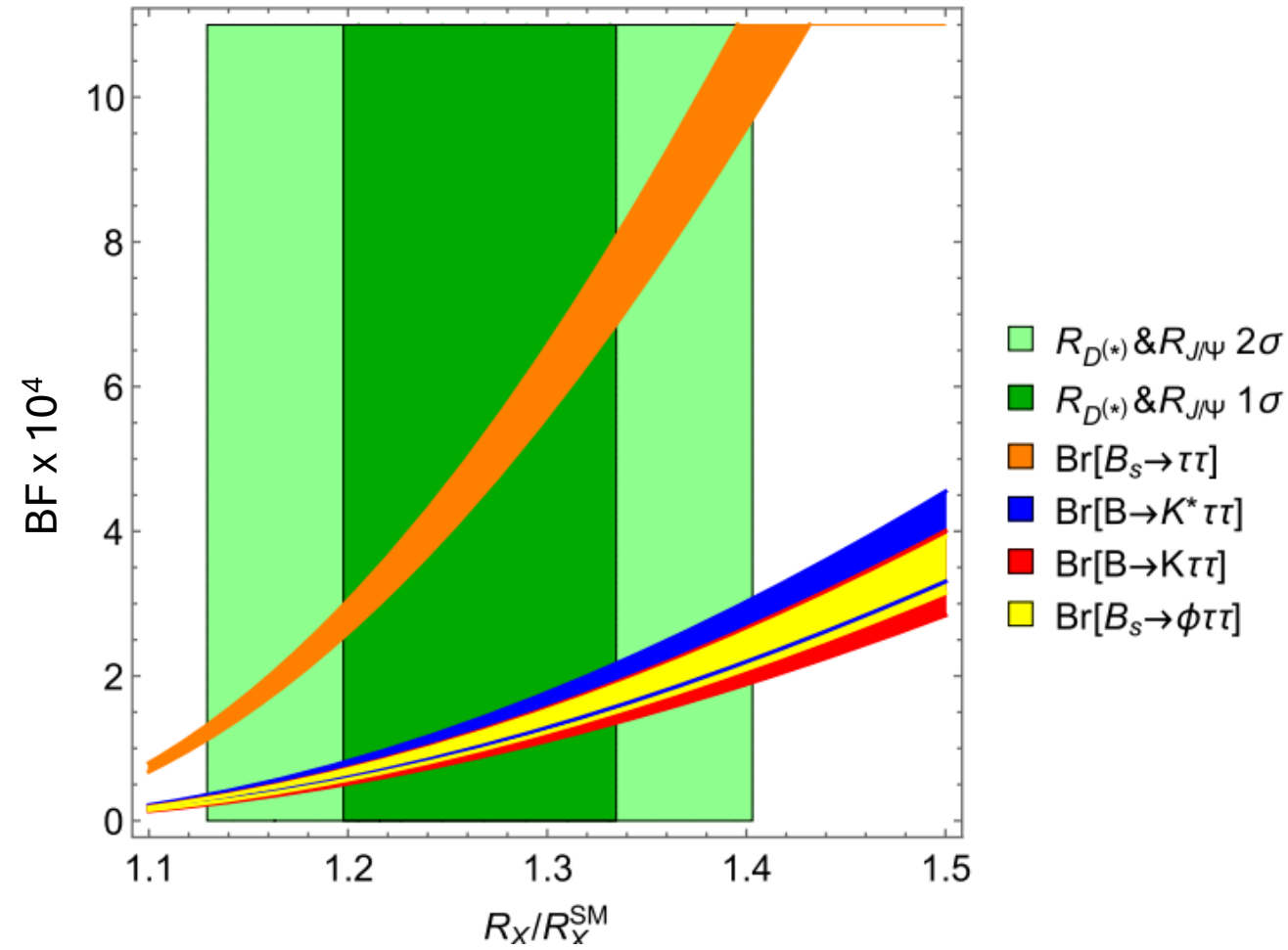


Evidence @ 3.5 σ
Tension with SM prediction of 0.6×10^{-5} @ 2.7 σ

$$B^0 \rightarrow K^{*0} \tau^+ \tau^-$$

- Very sensitive to explanations of the other anomalies
 - SM branching fraction prediction 10^{-7}

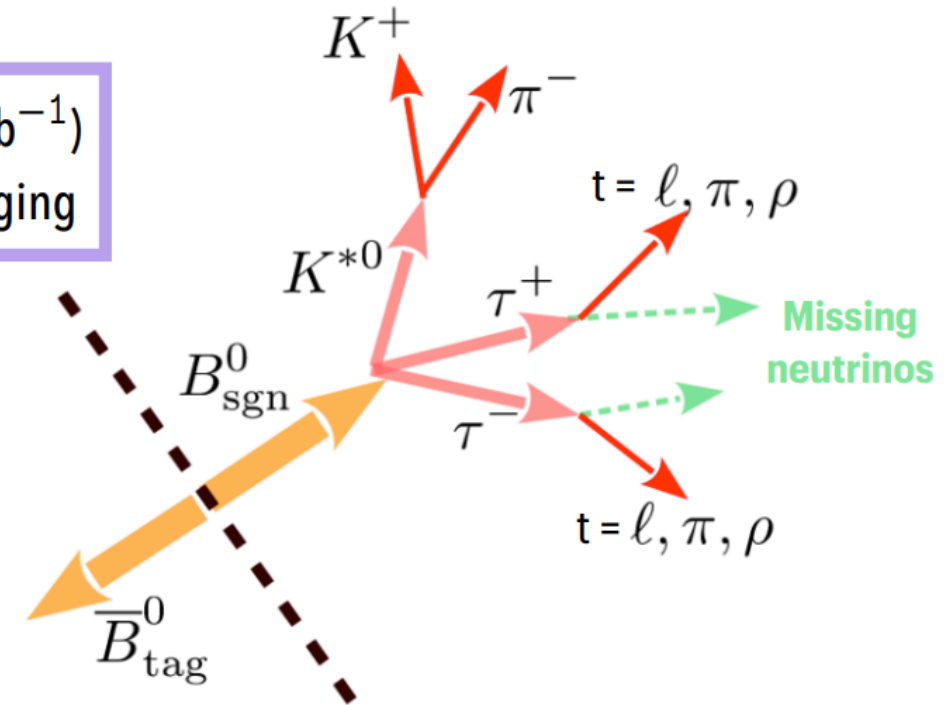
PRL 120, 181802 (2018)



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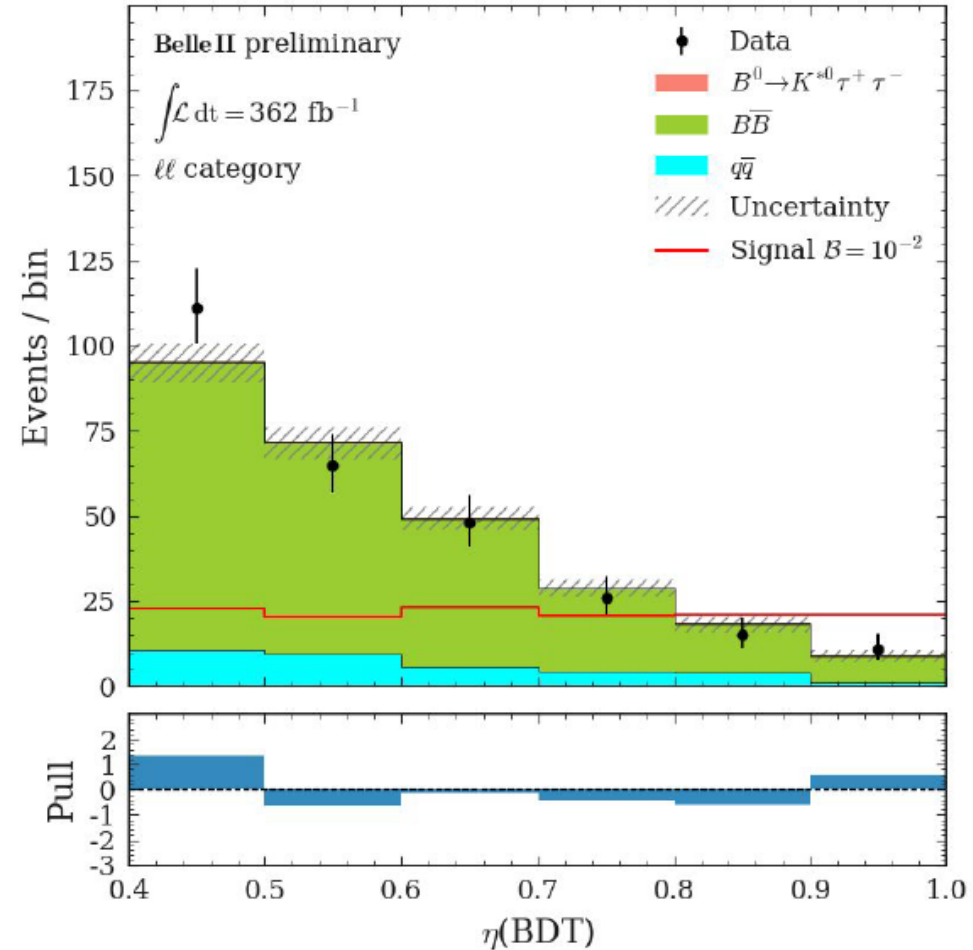
- Very sensitive to explanations of the other anomalies
 - SM branching fraction prediction 10^{-7}
- Hadronic B tagging
 - Fully reconstruct $B \rightarrow D^{(*)} n \pi$ final states
 - Must model these decays well
 - Talk by V. Vismaya
- Different of classes of tau decay
 - Missing energy, no additional energy in calorimeter,... into a **classifier that is fit to extract yield**

Belle II (362 fb^{-1})
hadronic B-tagging



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- **Limit twice improved over Belle**
 - **Improved tagging and signal efficiency**

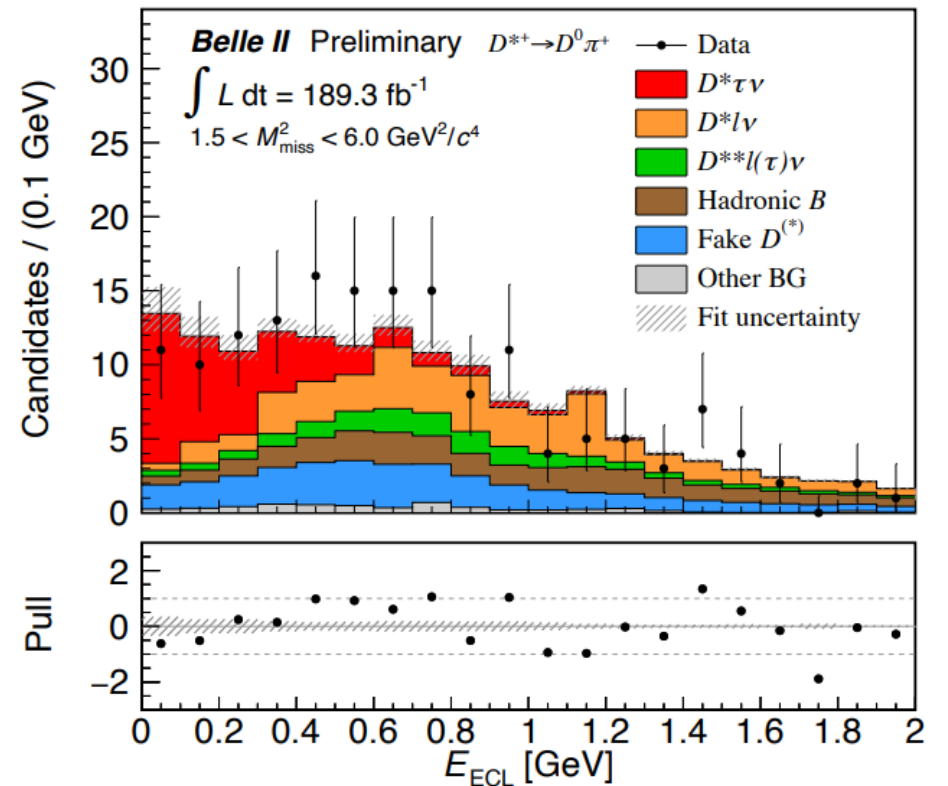


$$BF(B^0 \rightarrow K^{*0} \tau^+ \tau^-) < 1.8 \times 10^{-3} \text{ at 90\% CL}$$

First Belle II $R(D^*)$ measurement

- Hadronic tag then search for $B \rightarrow D^* \tau \nu$ in the remaining tracks and clusters
 - leptonic tau decay
 - charged and neutral B
- Additional energy in calorimeter and missing mass used as signal extraction variables

$$R(D^*) = \frac{BF(B \rightarrow D^* \tau \nu)}{BF(B \rightarrow D^* l \nu)}$$



Additional energy in calorimeter (GeV)



Talk by
M. Prim

First Belle II R(D*) measurement

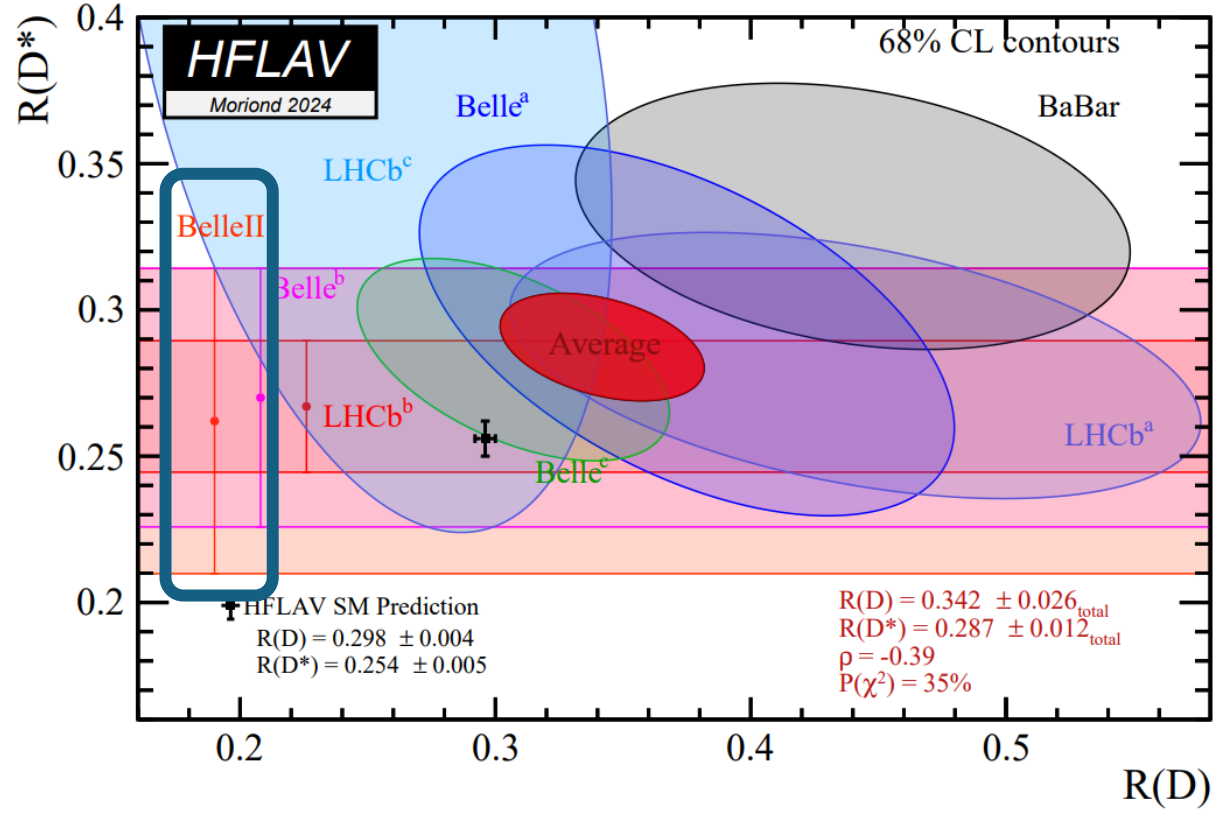
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- Additional energy in calorimeter and missing mass used as signal extraction variables

$$R(D^*) = 0.26 \pm 0.04^{+0.04}_{-0.03}$$

- Systematic uncertainty related mainly to size of control samples
- Comparable precision to equivalent Belle result with 1/4 the sample



The Metamorphosis

“As Gregor Samsa awoke one morning from uneasy dreams he found himself transformed in his bed into a gigantic insect...”

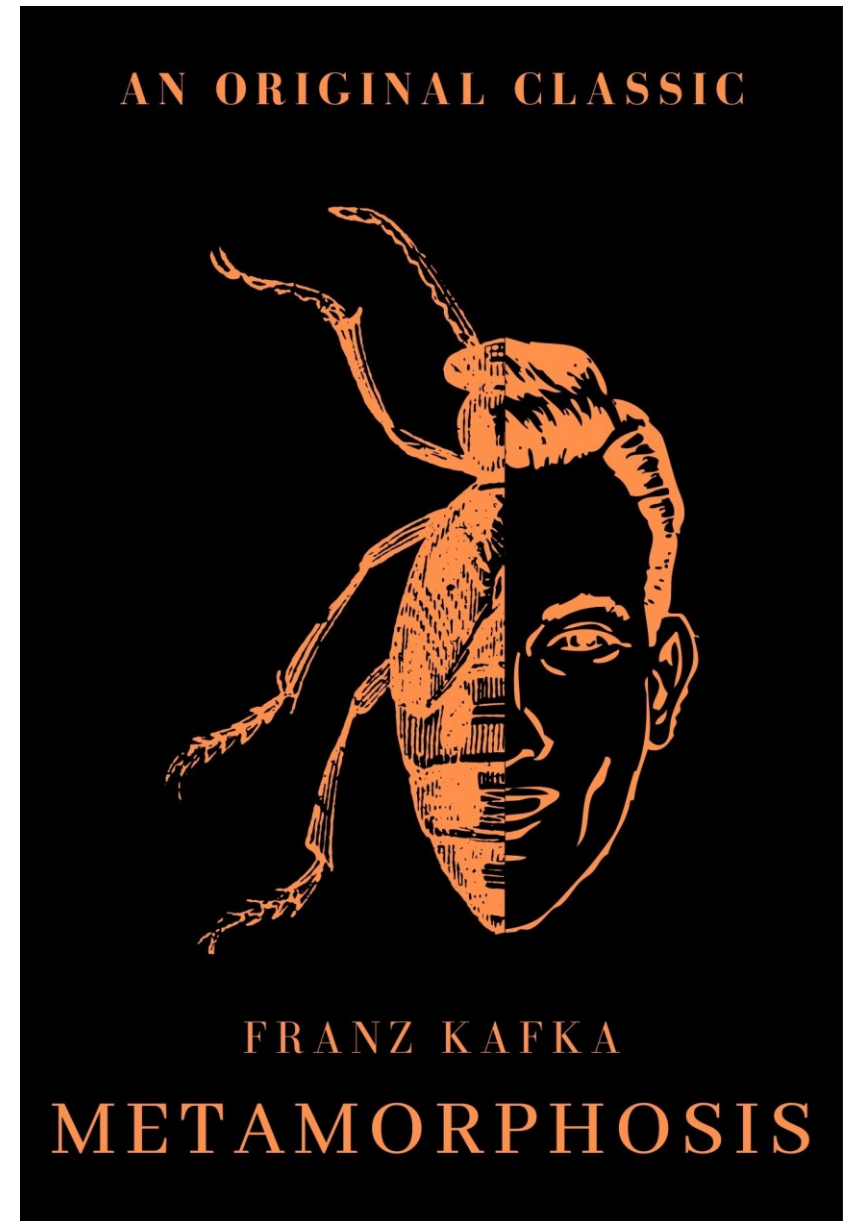


The Metamorphosis

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Double meaning

1. $B \rightarrow c$, hadron, τ and possibly dark factory
2. Belle II transition from 1st to 2nd generation

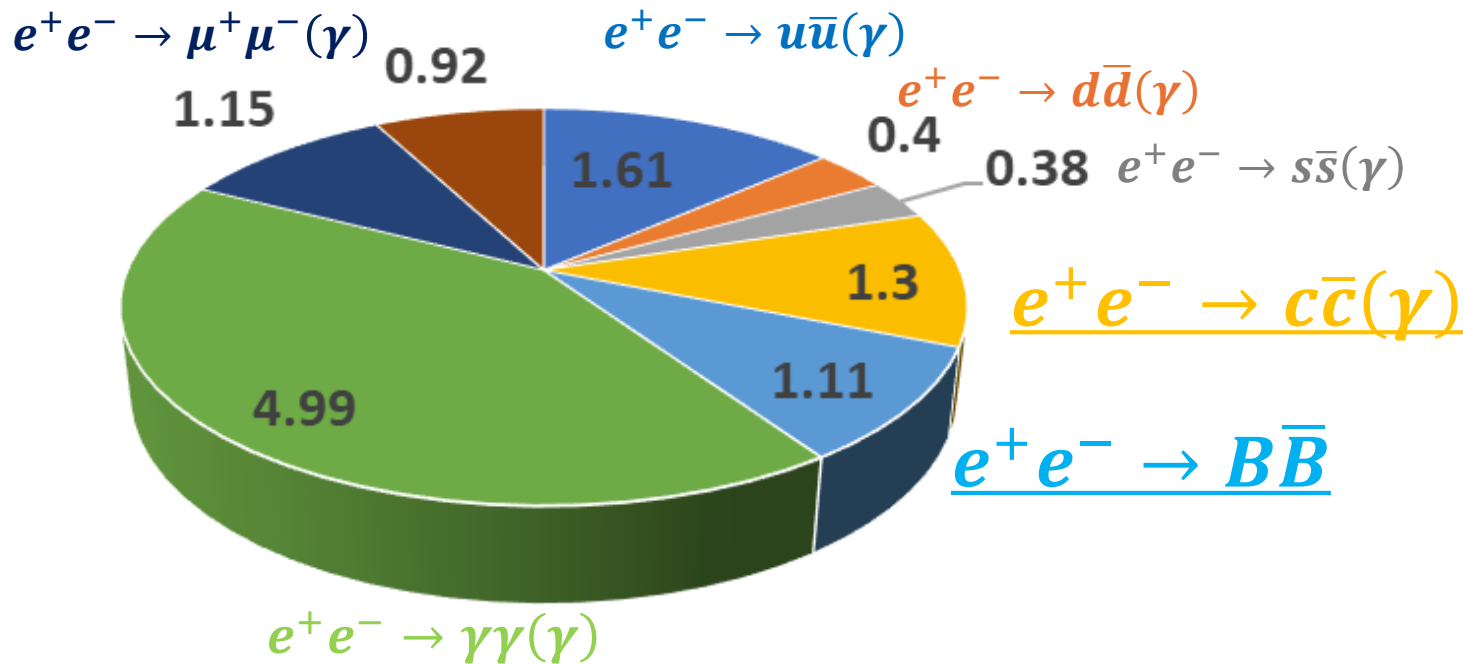


Much more than a B factory

Cross section in nb at 10.58 GeV

(not shown: $e^+e^- \rightarrow e^+e^-(\gamma)$ and four-fermion)

$$\underline{e^+e^- \rightarrow \tau^+\tau^-(\gamma)}$$



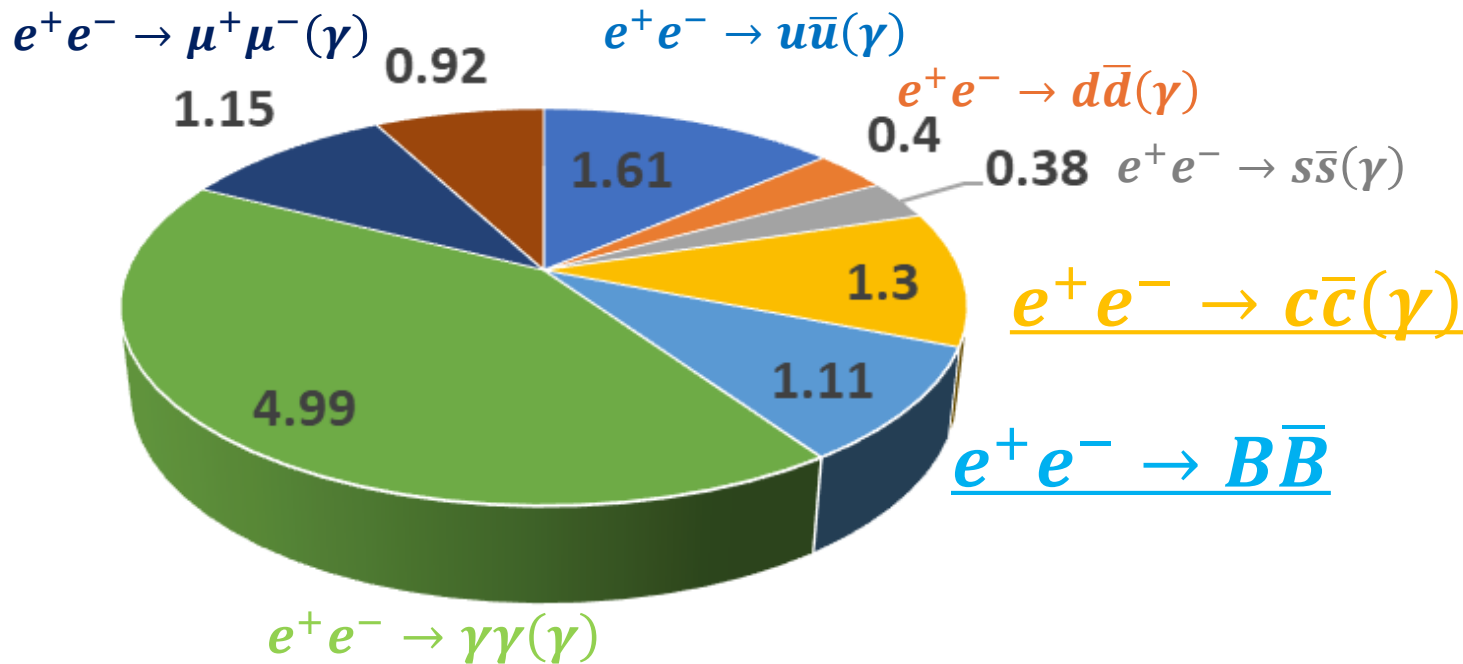
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 - Advantages of neutral reconstruction and missing momentum work here too
 - Charm talks by [M. Bertemes](#) & [Y.-J. Kim](#)

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 - Charm talks by [M. Bertemes](#) & [Y.-J. Kim](#)
- Samples away from $Y(4S)$ for spectroscopy and B_s physics
 - Belle samples: $Y(1S)$, $Y(2S)$, $Y(5S)$,...
 - Babar: $Y(3S)$
 - Talk by [N. Tasneem](#)
 - These are used for tau and charm physics too

Observation of $P_{cs}(4459)$

- OZI suppressed decays of $Y(1S)$ and $Y(2S)$ rich in gluons
 - enhanced baryon production
 - **pentaquark production?**

Paper in preparation
NEW FOR ICHEP



Talk
by [R. Mizuk](#)

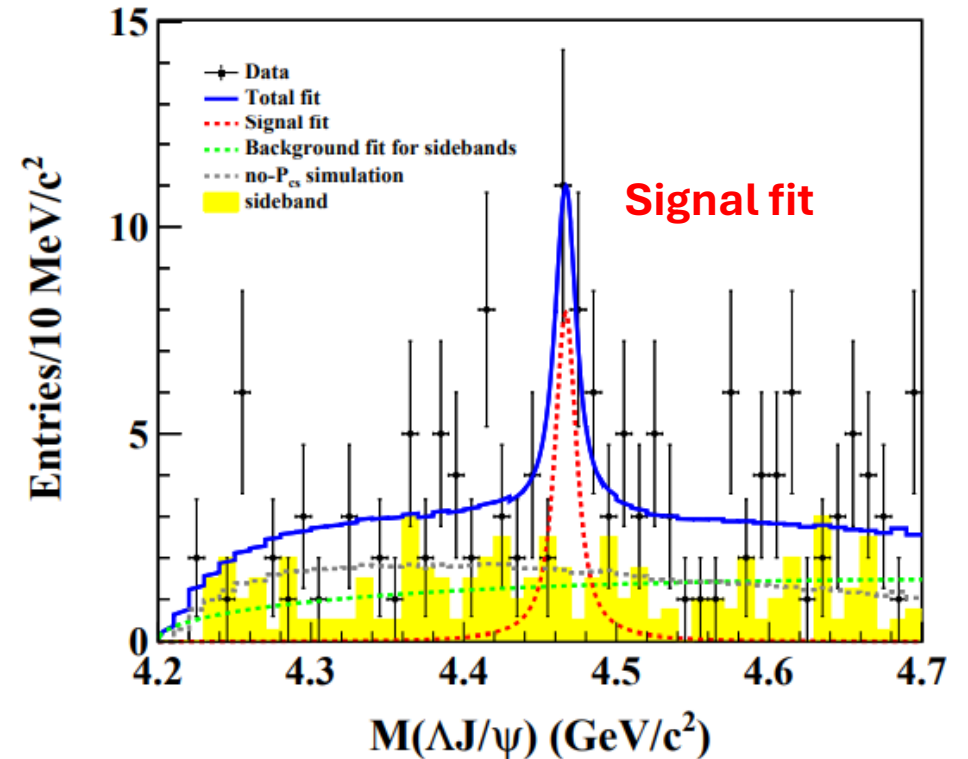
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- Measure inclusive $Y(1S,2S) \rightarrow J/\psi \Lambda + X$ decays
- Search $m(J/\psi \Lambda)$ for pentaquark signal
 - **background from sideband and off resonance**

Paper in preparation
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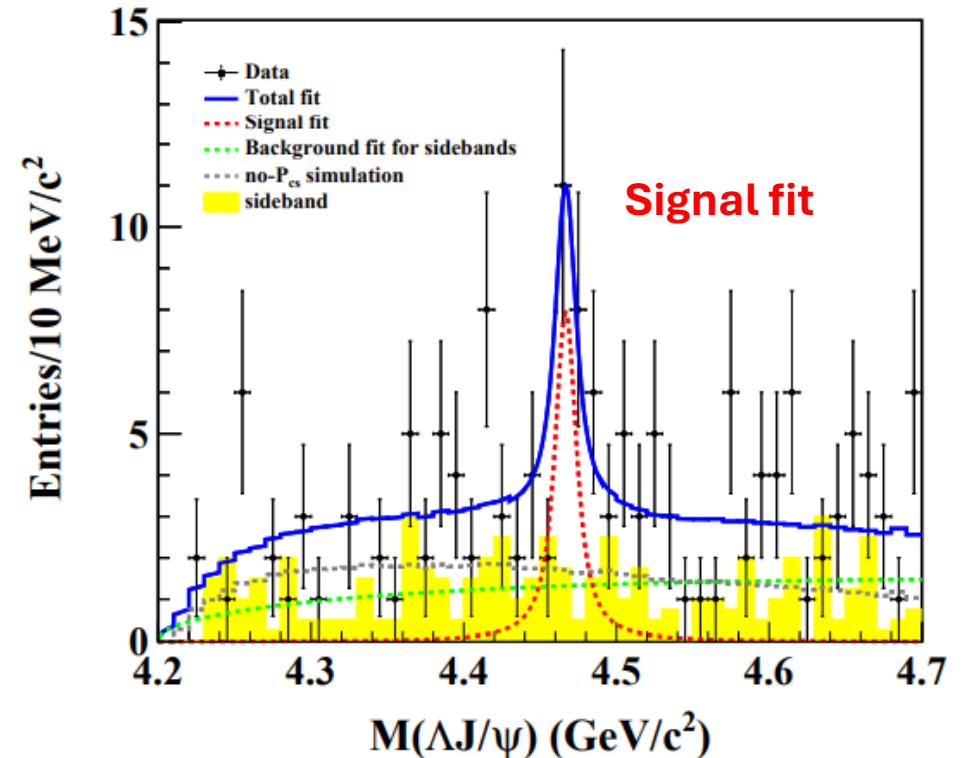
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 - **background from sideband and off resonance**
- Use LHCb mass and width for their observation in Ξ_b decay - [Sci. Bulletin 66, 1278 \(2021\)](#)
 - **3.3 standard deviation significance observation**
 - free mass and width 4 standard deviation local significance

Paper in preparation
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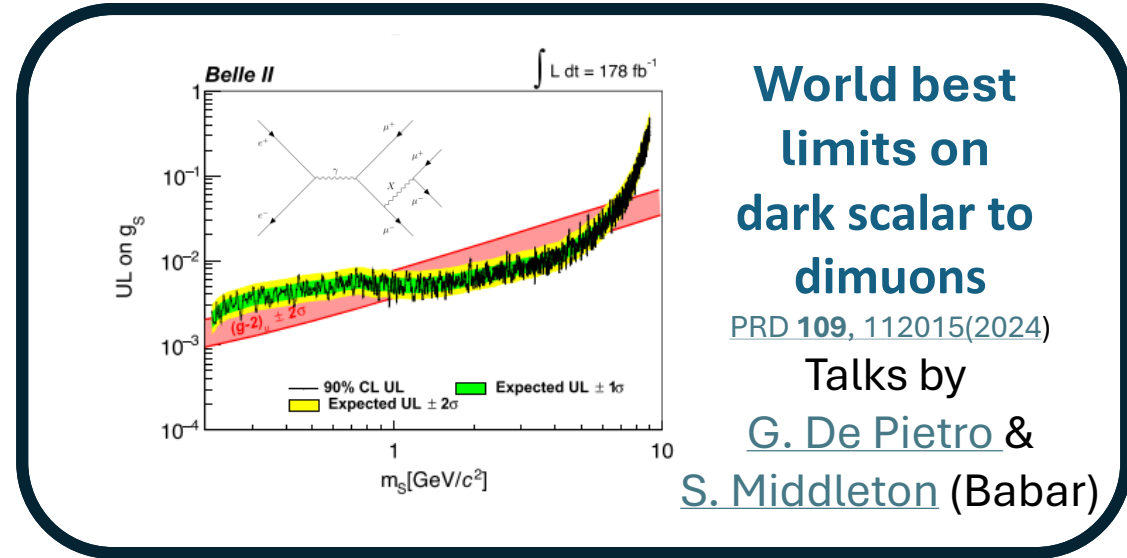
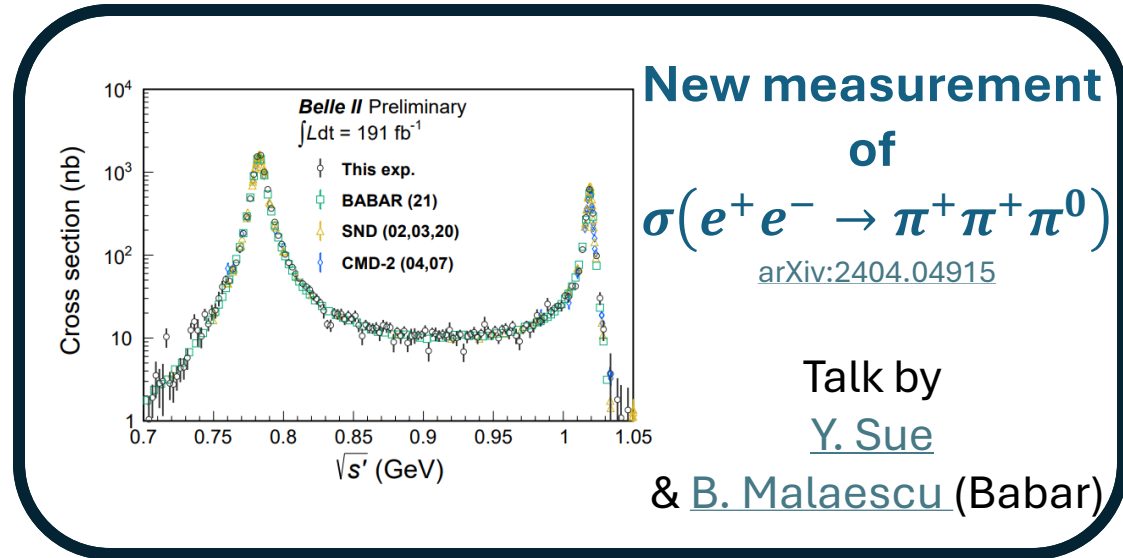
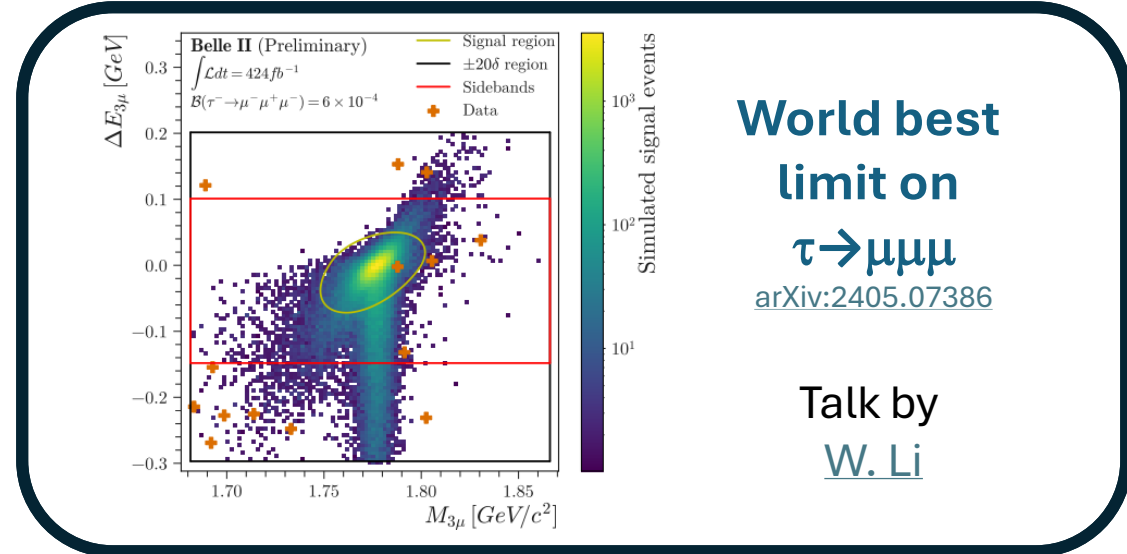
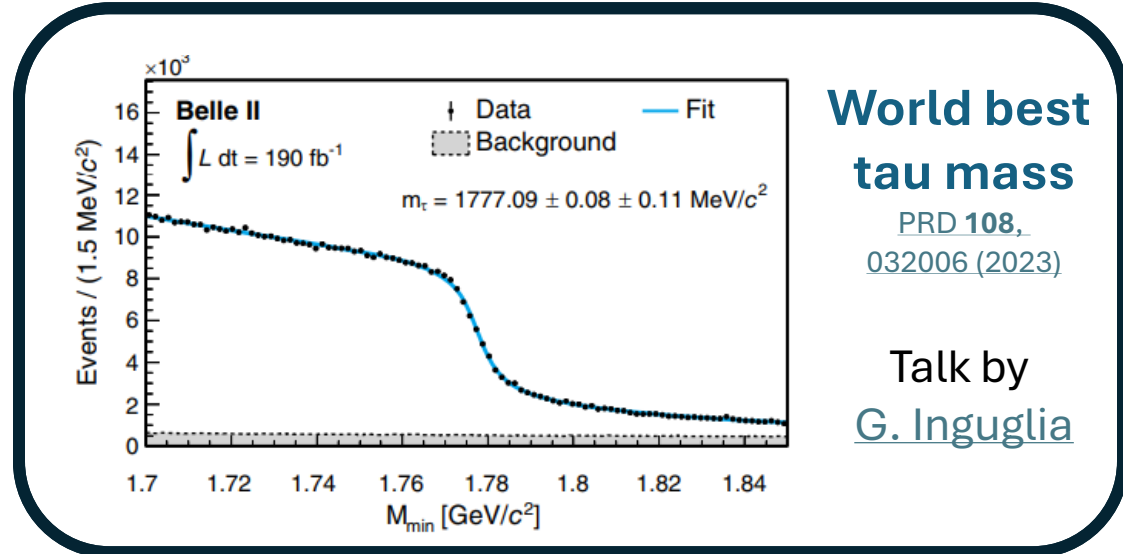
Talk
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Tau and low multiplicity physics



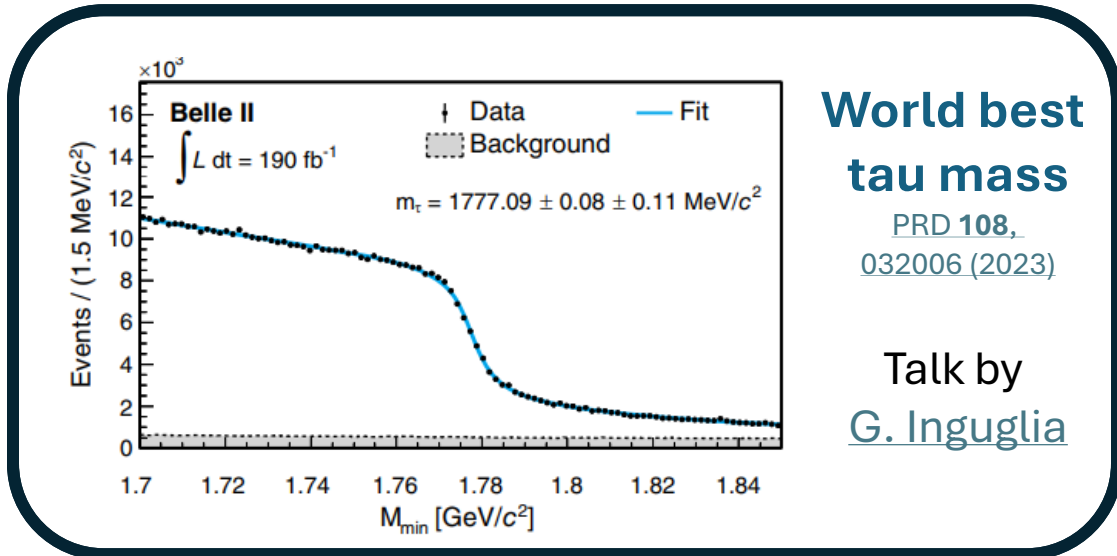
BABAR



Tau and low multiplicity physics



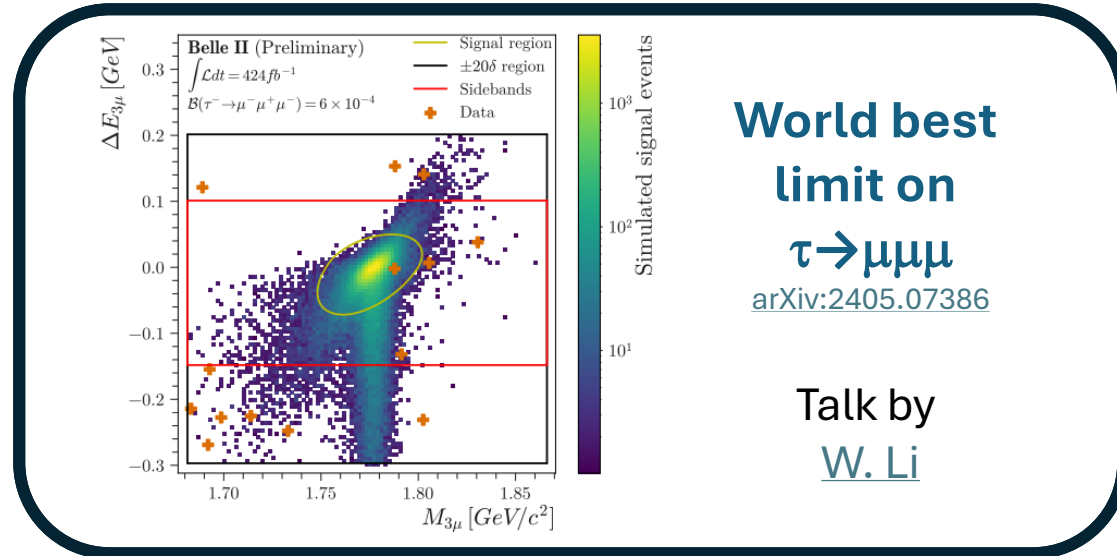
BABAR



World best tau mass

PRD 108,
032006 (2023)

Talk by
G. Inguglia

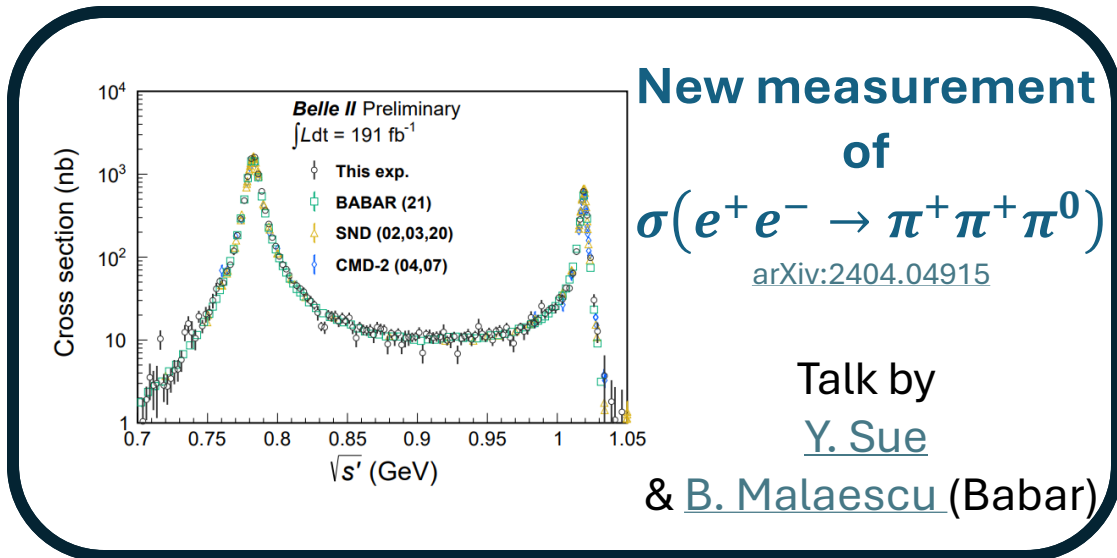


World best limit on

$\tau \rightarrow \mu \mu \mu$

arXiv:2405.07386

Talk by
W. Li



New measurement of

$\sigma(e^+e^- \rightarrow \pi^+\pi^+\pi^0)$

arXiv:2404.04915

Talk by
Y. Sue

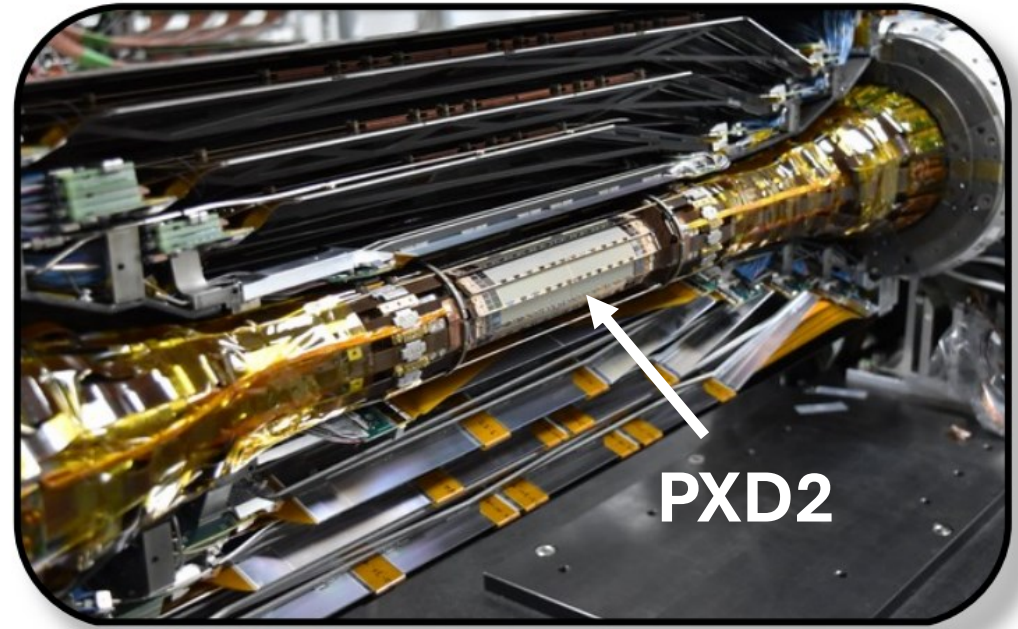
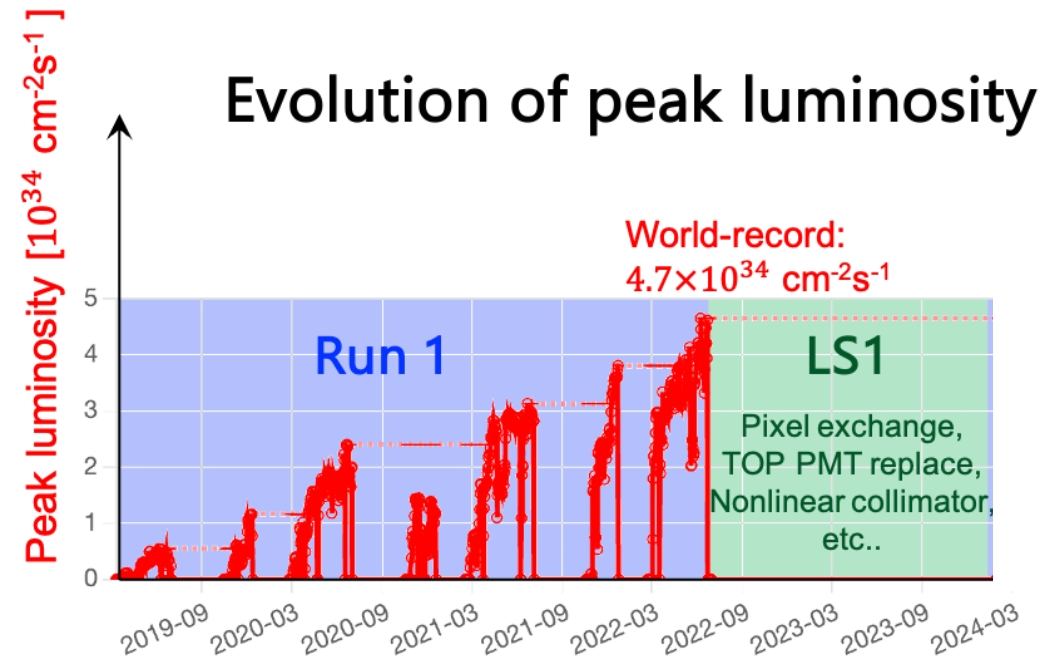
& B. Malaescu (Babar)

**Lepton Flavour Physics
and EDMs**

Toru Iijima

Plenary Wed 11:35 CEST

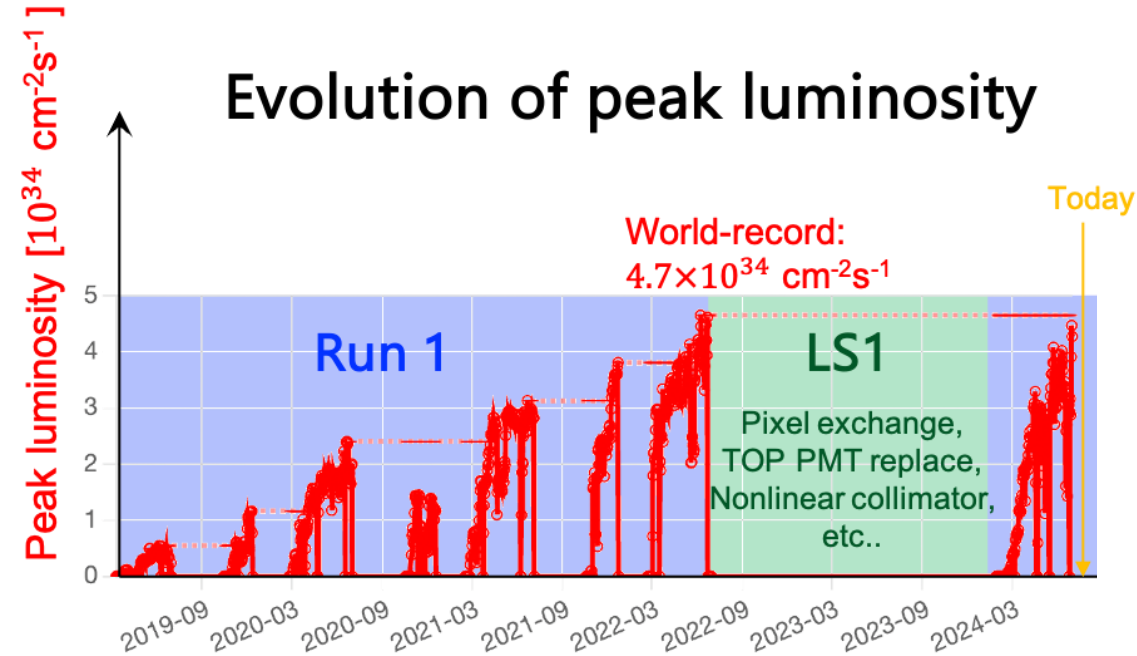
SuperKEKB/Belle II status and plans



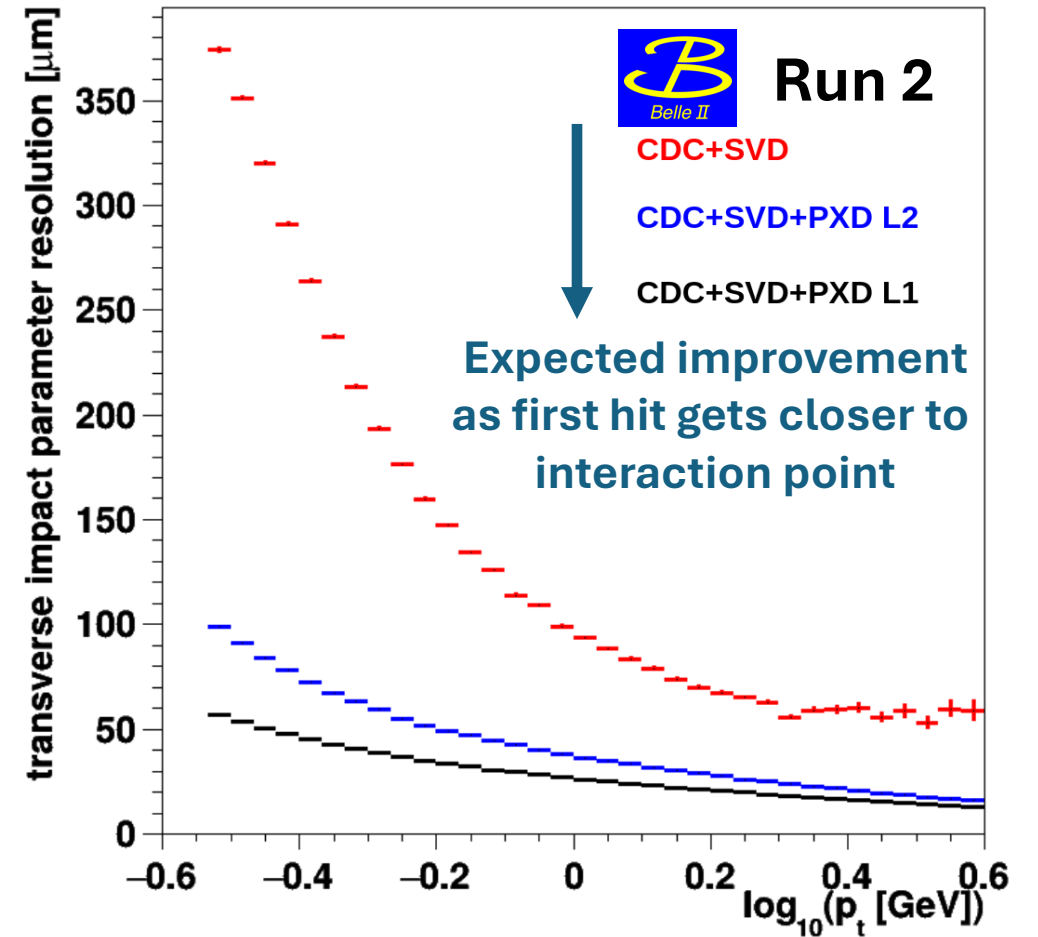
- Run 1 (2019-2022) – **similar data set to 1st generation B factory**
- Long shutdown 1 – LS1 (2022-2024)
 - detector improvements – mainly installation of full **two-layer pixel detector (PXD2)**
 - accelerator improvements, e.g., non-linear collimators to combat beam background

SuperKEKB/Belle II status and plans

Evolution of peak luminosity



- Run 2 (2024 –)
 - back to operation at $4 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
 - detector performance as before or better
 -but the goal in this run is luminosity of $\sim 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$

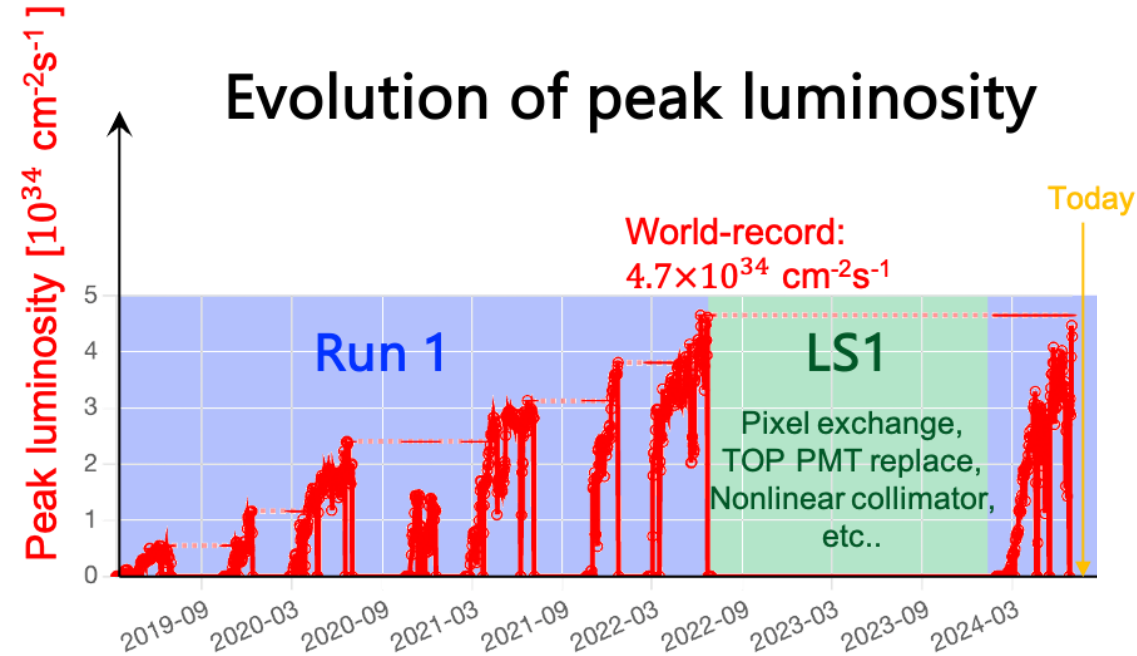


SuperKEKB/Belle II status and plans



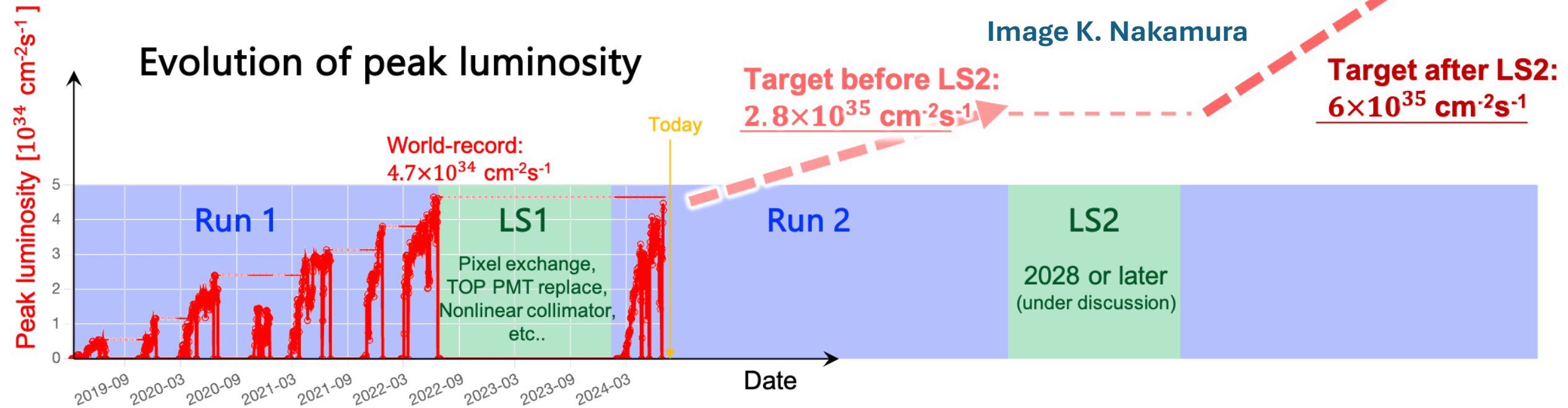
Talk
by [K. Shibata](#)

Evolution of peak luminosity



- Run 2 (2024 –)
 - Sudden beam loss has happened frequently that can lead to v. large dose in the detector
 - Hampering increasing luminosity
 - Two such losses led to damage of 2% of PXD2 gates
 - **turned off PXD2 as a precautionary measure until beam losses mitigated**
 - So far Run 2 has been largely dedicated to machine studies
 - only $\sim 100 \text{ fb}^{-1}$ collected
 - **Some understanding of how the losses start**
 - remediation begun in summer shutdown

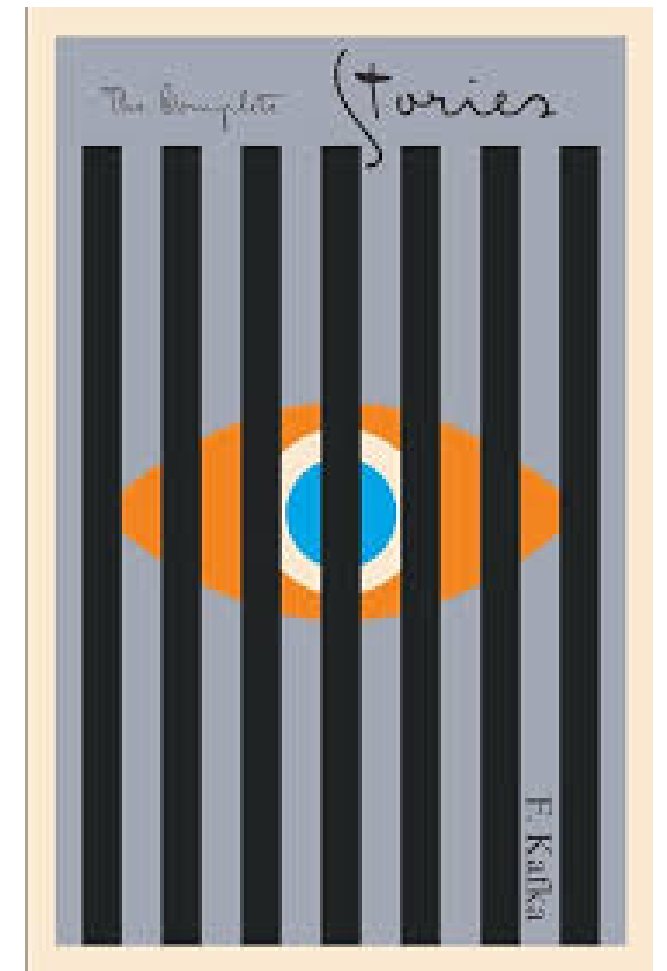
SuperKEKB/Belle II status and plans



- Run 2 is long – end 2028 or later
 - Steady accumulation at $\sim 2 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ for several ab^{-1} – 2nd generation
 - After Run 2 – upgrade proposal for reach design luminosity and tens of ab^{-1}
 - Talks by [K. Nakamura](#) and [M. Roney](#) (polarized beams) – Framework CDR [arXiv:2406.19421](#)

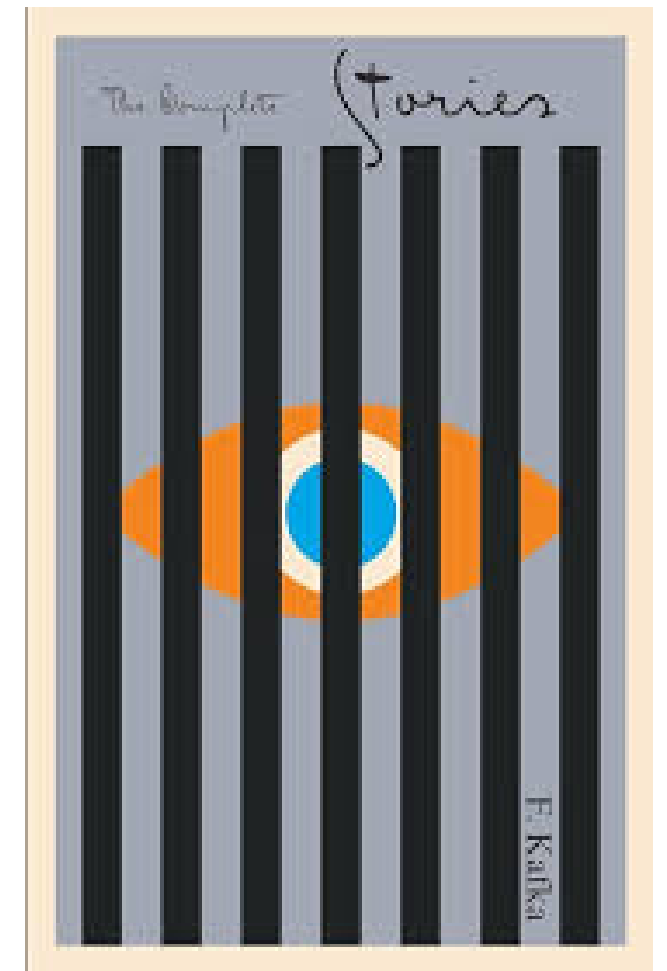
Conclusions

- Rich physics programme with e^+e^- at $Y(4S)$
 - Historically Belle and Babar...
- ...now Belle II
 - 51 papers on arXiv and 12 preliminary results
 - On CKM physics, rare decays and non-B physics
 - Belle II results with smaller current data set, comparable or better than first generation
- The future
 - **It is challenging operating at the intensity frontier**
 - However, early days and we have a roadmap to collect multi- ab^{-1} data sets in the next decade



Conclusions

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"Youth is happy because it has the capacity to see **beauty**. Anyone who keeps the ability to see **beauty** never grows old.", The Hungry Artist

Extra

$D^+ \rightarrow K_S^0 K^- \pi^+ \pi^+$ - CP violation

Talks by M. Bertemes & Y.-J. Kim

- CP violation in charm observed at $O(10^{-4})$ in singly Cabibbo suppressed decays $D^0 \rightarrow \pi^+ \pi^-$ and $D^0 \rightarrow K^+ K^-$
 - LHCb
 - Other measurements essential to test if SM or not
- New measurement uses combined **Belle and Belle II** data set of 1.4 ab^{-1}
 - T-odd observables such as $p_{K_S^0} \cdot (p_{K^+} \times p_{\pi^+})$ can be used to construct asymmetries between D^+ and D^-
 - Belle II additional weight due to improved efficiency and background rejection
 - **Null results at the $O(10^{-3})$**

