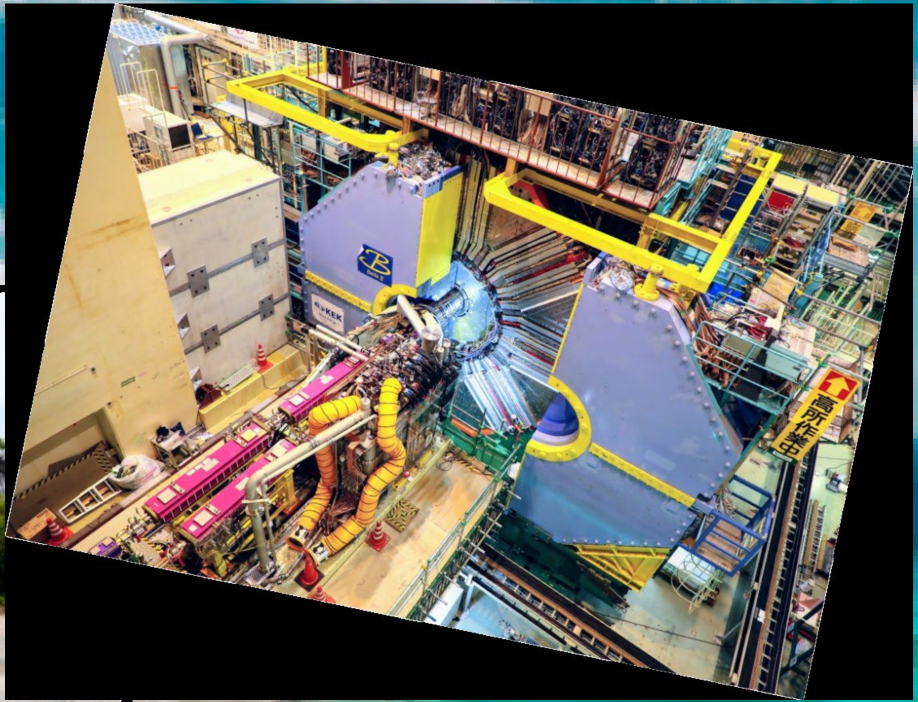
Belle II status and prospects



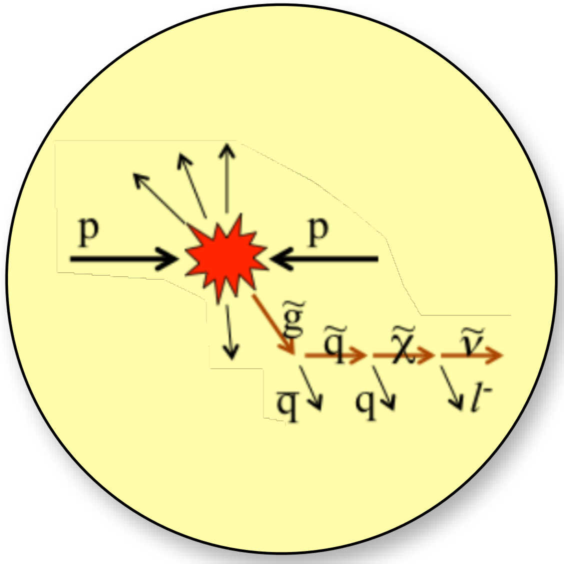
Paolo Branchini
INFN Roma Tre
ICNFP 2021

Outline

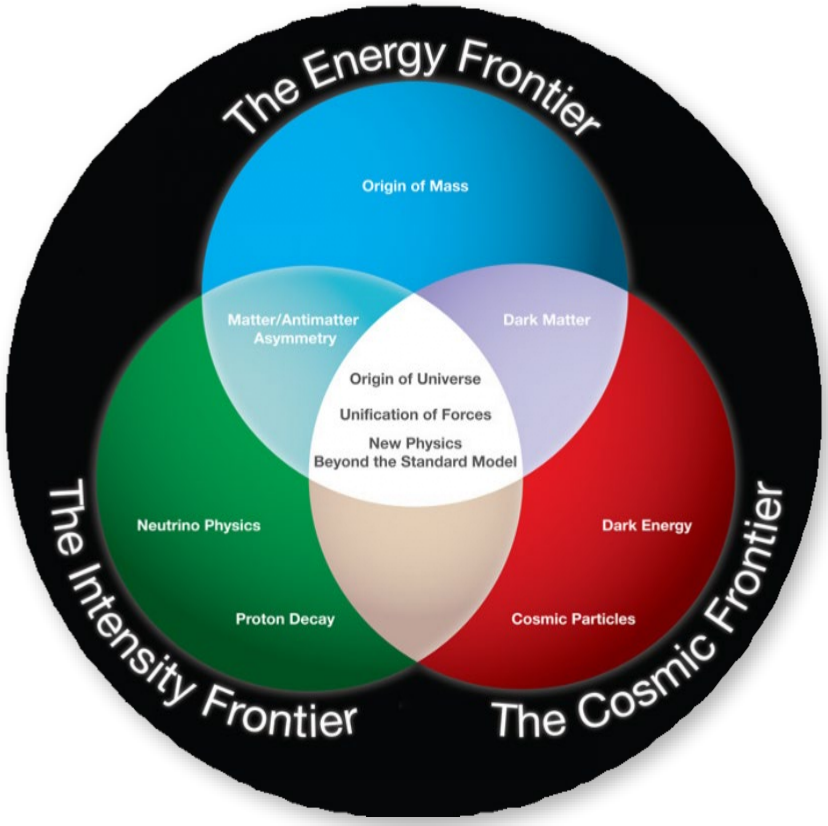
- Experimental conditions
- Recent results
  - Towards Measurements of $|V_{ub}|$ and $|V_{cb}|$
  - $b \to sll$ transitions
  - Dark matter searches
  - τ physics and prospects
  - Matter antimatter asymmetries
- Outlook and conclusions

Complementary Pathways to New Physics

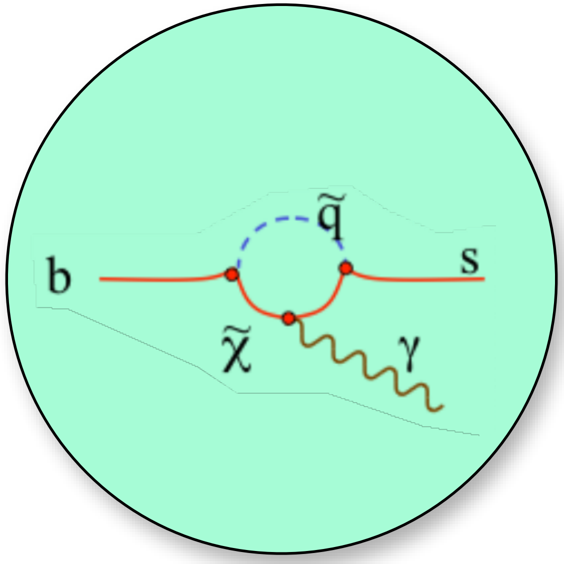
Energy frontier



Direct production of new particles



Intensity frontier

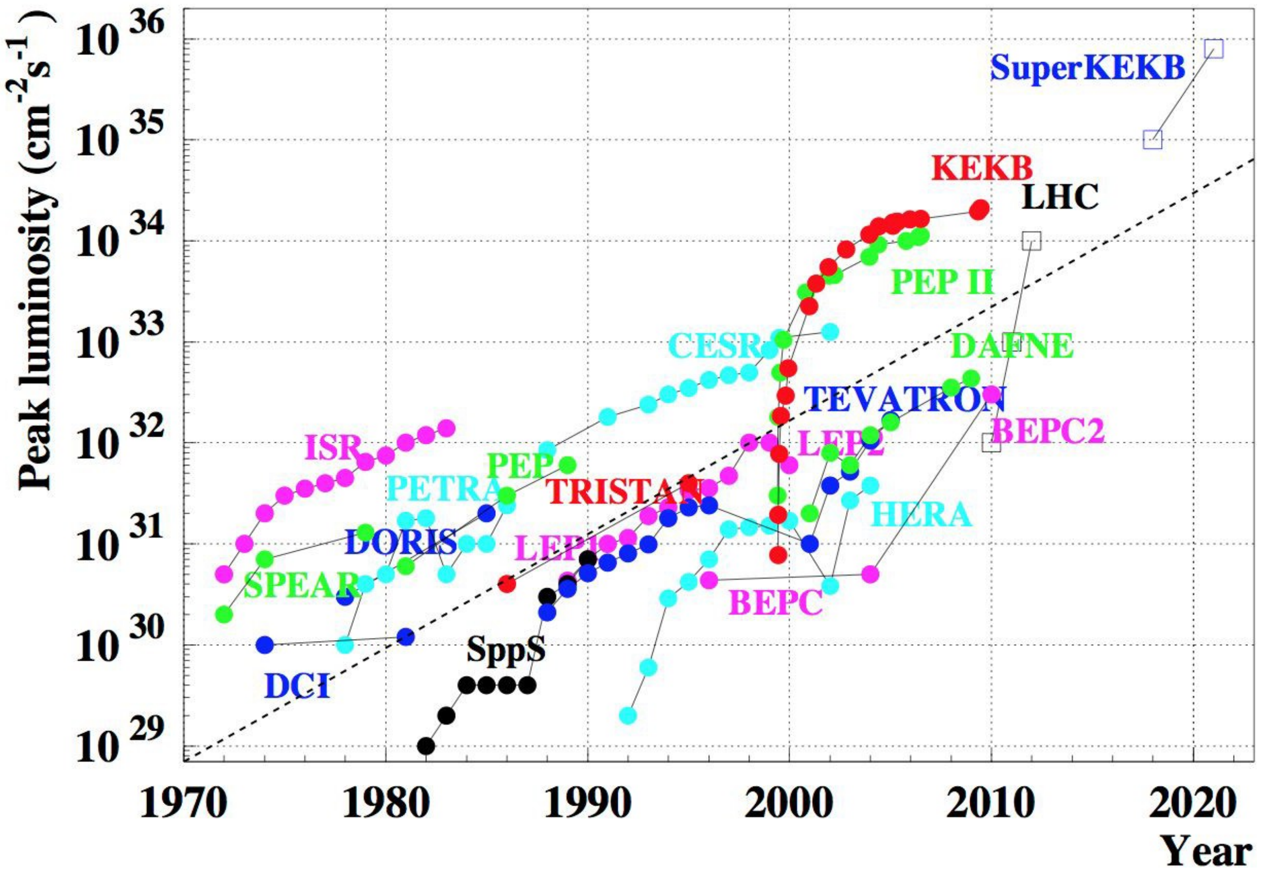


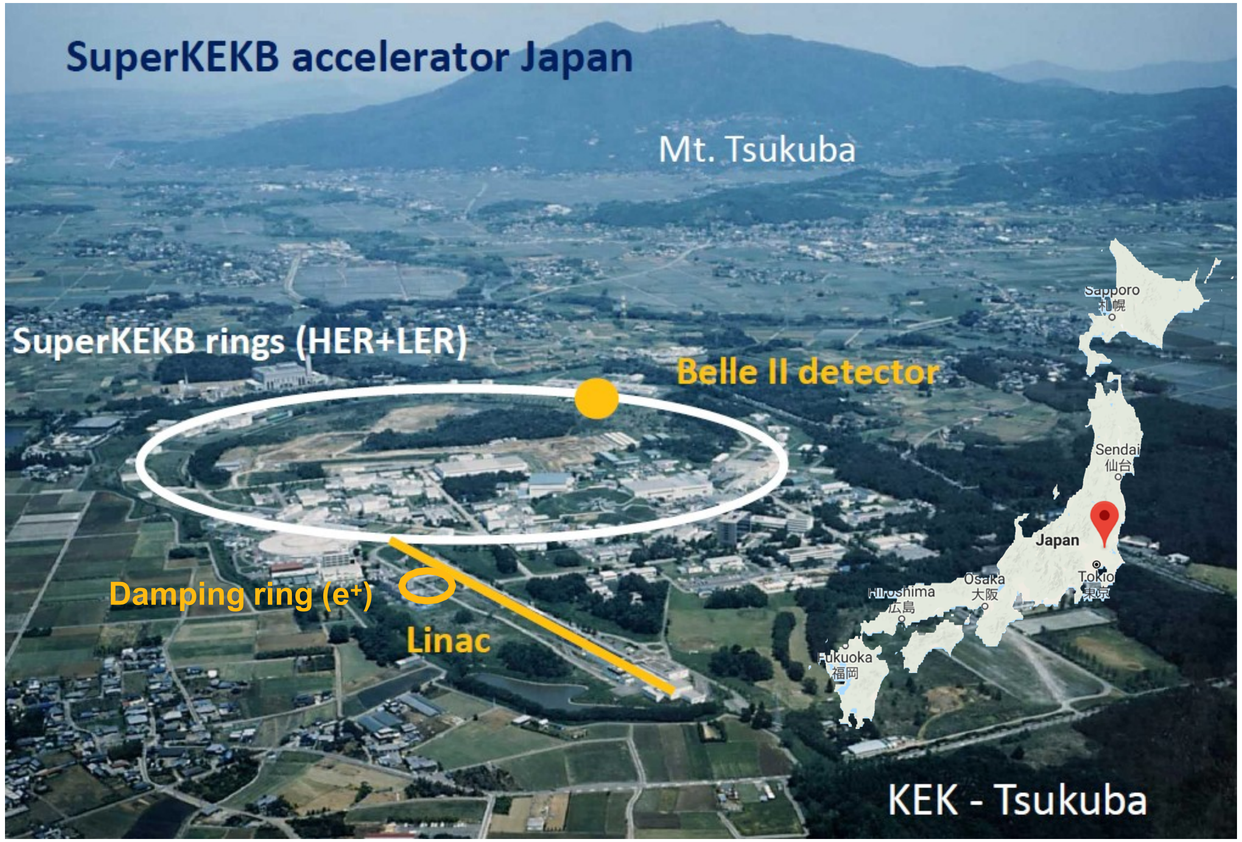
Indirect sensitivity through loops

- Presently no unambiguous evidence for Beyond Standard Model (BSM) physics at the high energy frontier
- Intensity frontier offers indirect sensitivity to very high scales: recent observation of **"Flavour Anomalies"**

Belle II

Ambitious Next Step at Luminosity Frontier: SuperKEKB



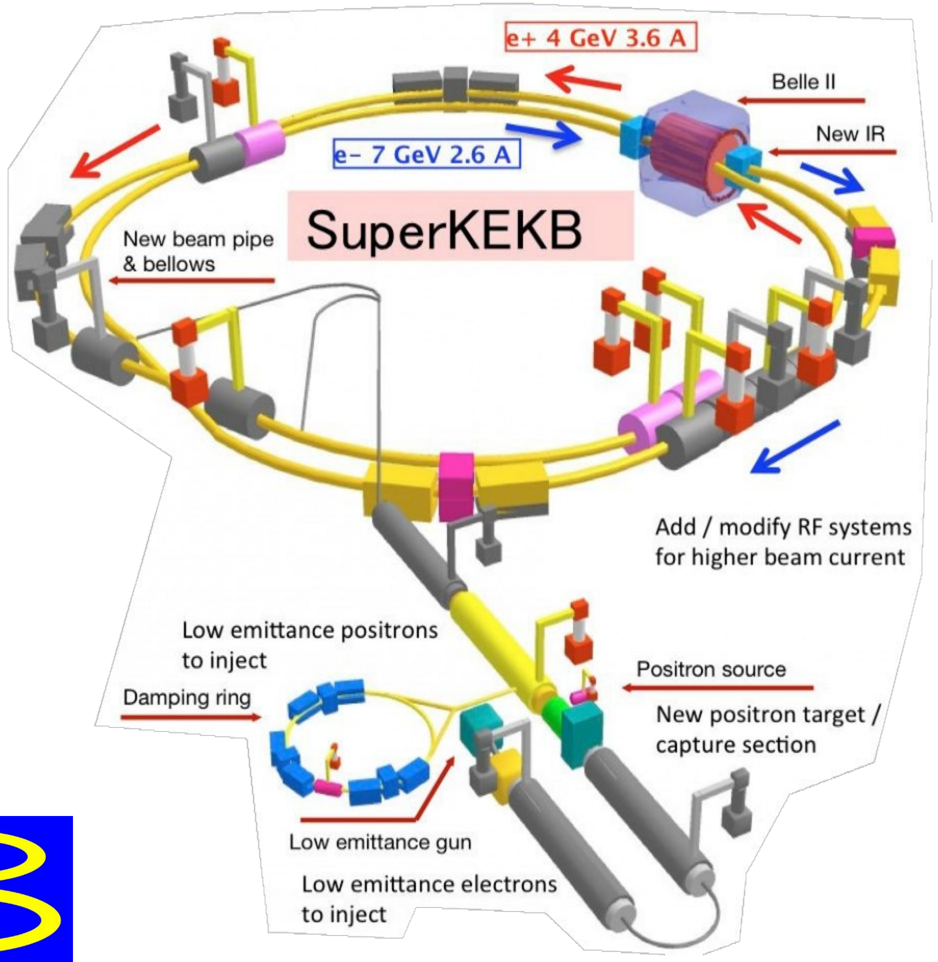


Belle II

SuperKEKB and Nano-Beam Scheme

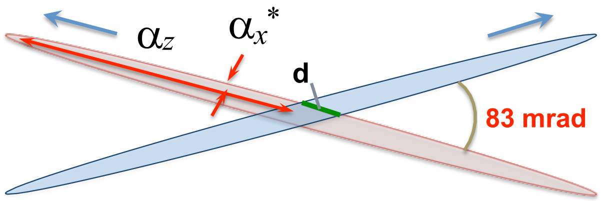
beam current **x1.5**, beam-beam param. **x1**, vertical beta function **x 1/20**

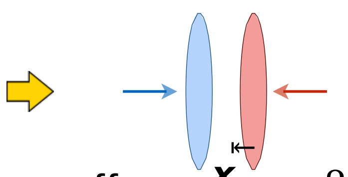
$$L = \frac{\gamma_{\pm}}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{\pm}\,\xi_{y\pm}}{\beta_{y\pm}^*}\right)\left(\frac{R_L}{R_{\xi}}\right)$$



LER / HER	KEKB	SuperKEKB	Effect
Energy [GeV]	3.5 / 8	4.0 / 7.0	boost x 2/3
Crossing angle $2f_x$ [mrad]	22	**83**	
β_y^* [mm]	5.9 / 5.9	**0.27 / 0.30**	**L x 20**
$I_{\pm}$ [A]	1.64 / 1.19	**2.8 / 2.0**	**L x ~1.5**
$\varepsilon_y = \sigma_y \times \sigma_{y'}$ [pm]	140 / 140	**13 / 16**	
$\xi_y \sim (\beta_y^*/\varepsilon_y)^{1/2} / \sigma_x^*$	0.129 / 0.09	**0.09 / 0.09**	**L x 1**
Luminosity [10^{34} cm^{-2} s^{-1}]	2.1	**60**	**L x 30**

Nano-Beam scheme (P. Raimondi):
Squeeze beta function at the IP (β_x^*,β_y^*) and minimize longitudinal size of overlap region to avoid hourglass effect

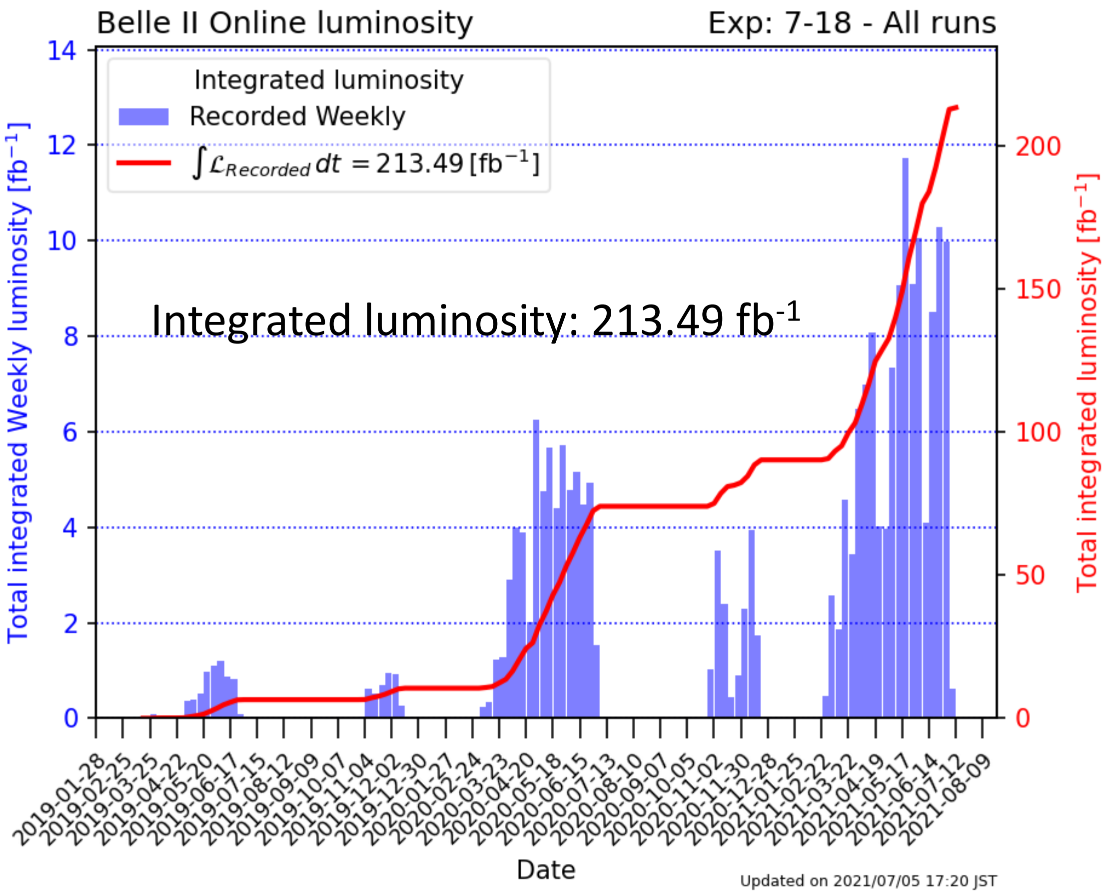


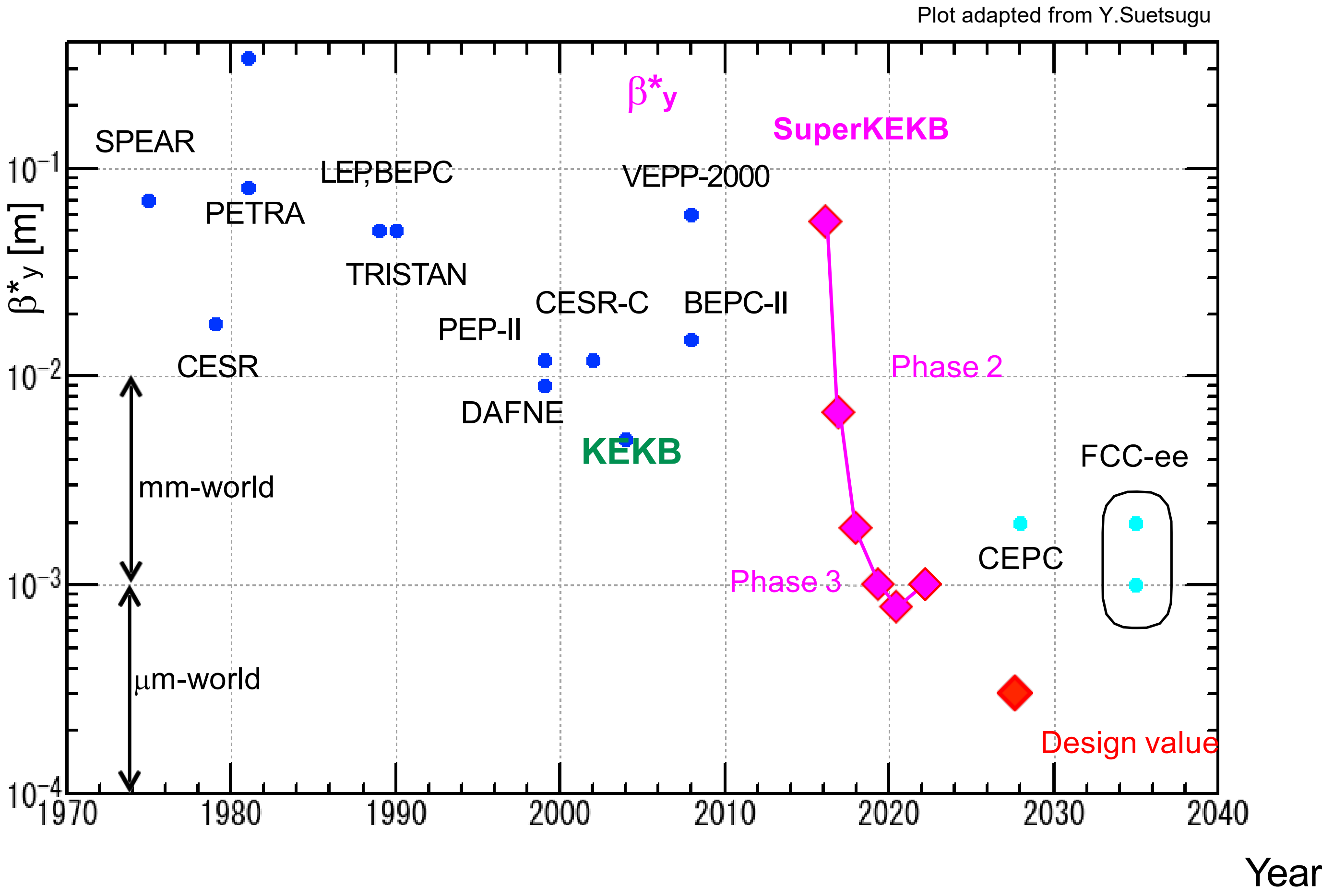


$$\sigma_z^{eff} = \frac{\sigma_x^*}{\phi_x} < \beta_y^*$$

Strong focusing of beams down to vertical size of ~ 50 nm requires **very low emittance beams** and **large crossing angle (83 mrad)**
we Need **powerful** and **sophisticated final focus** system (QCS)

SuperKEKB Achievements





Ramping up machine performance proves more challenging than initially hoped for

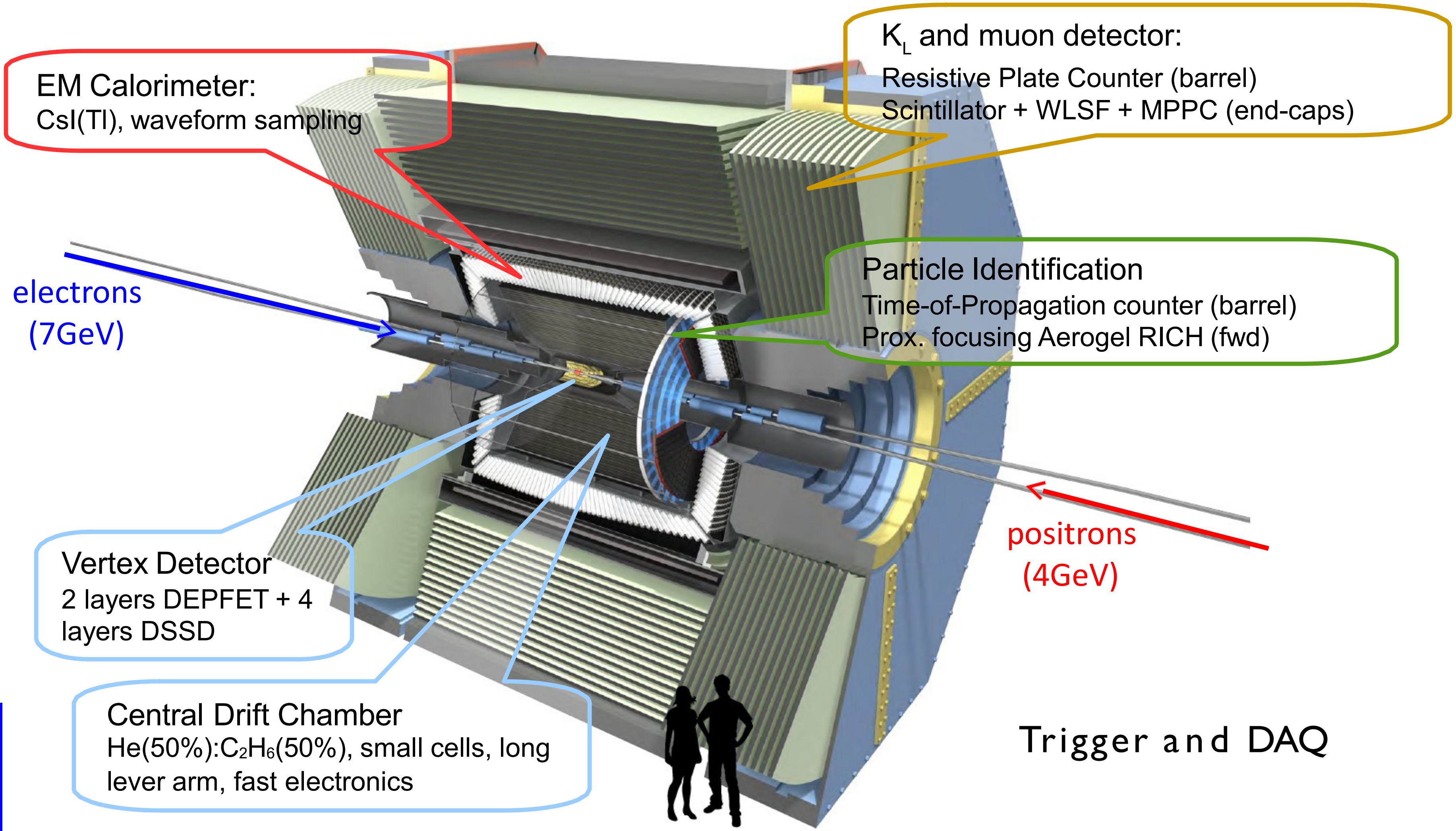
-short beam lifetime, injector power limit, low bunch-current limit, vertical beam size blow-up (crab-waist scheme)

Despite these difficulties: world record reached in instantaneous luminosity of $3.12 \times 10^{34} cm^{-2}s^{-1}$ on June 22nd

Belle II

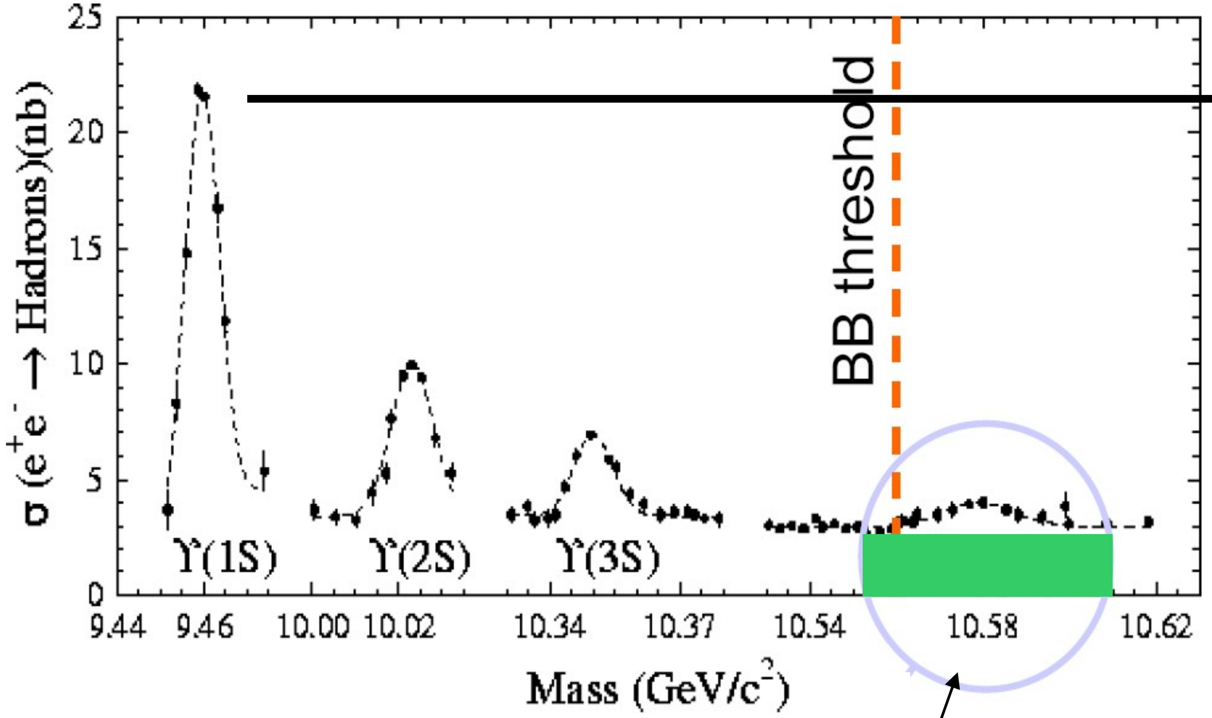
Belle II Detector

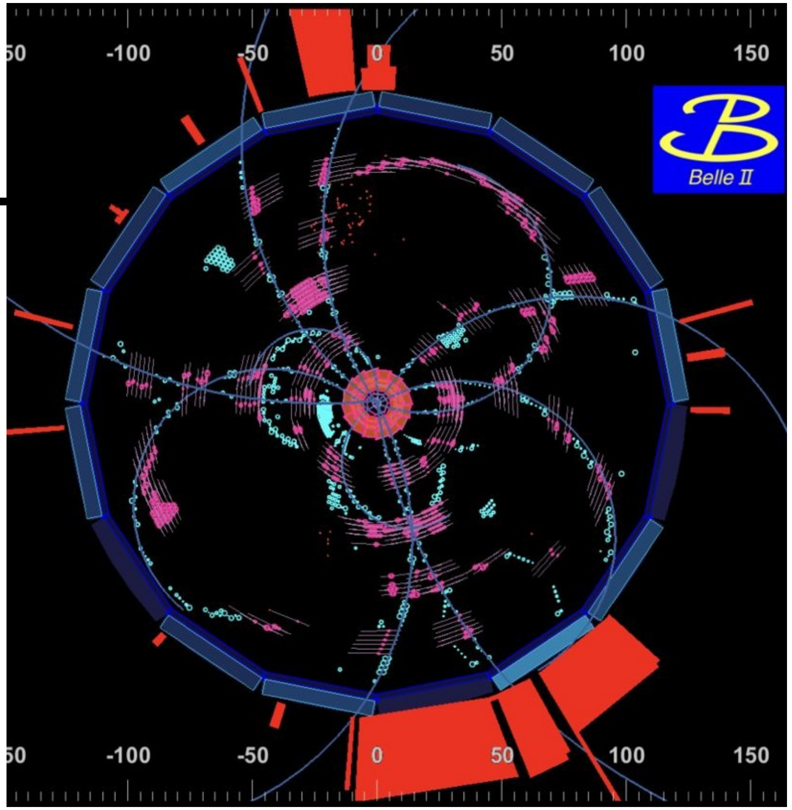
TDR: arXiv:1011.0352



Trigger and DAQ

Event types





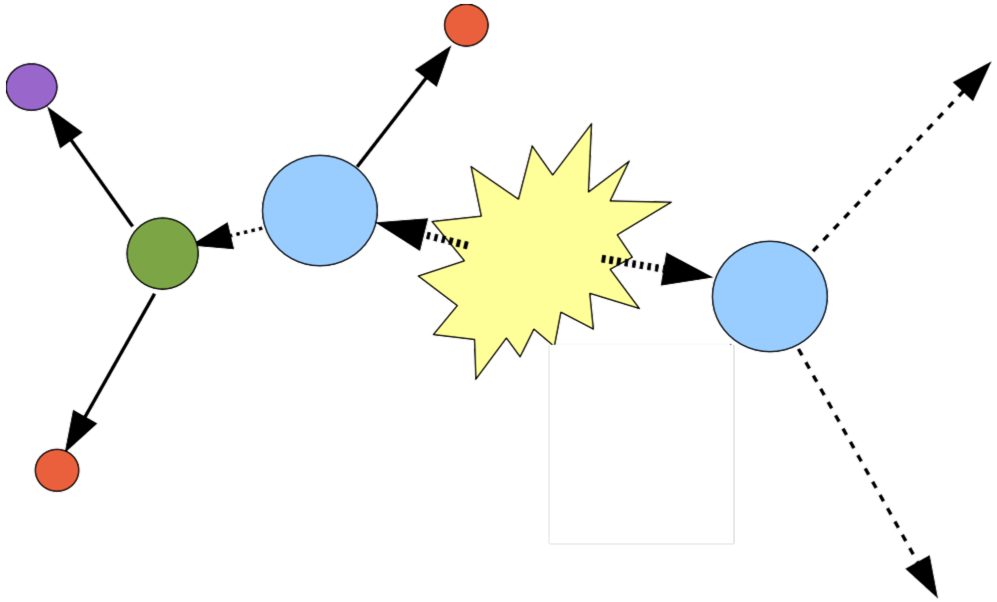
$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$

$\rightarrow q\overline{q}$ (continuum bkg.)

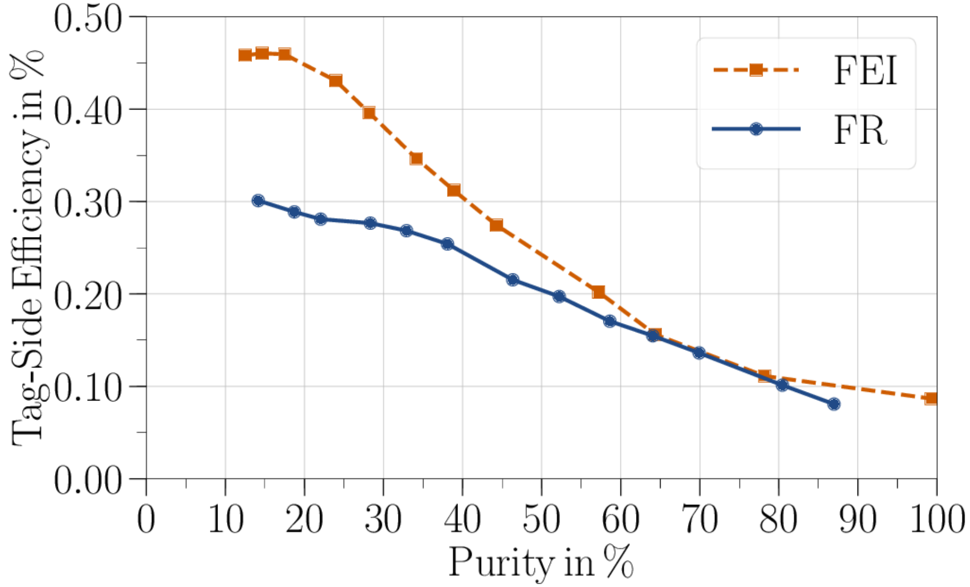
$\rightarrow \tau^+\tau^-$

$\rightarrow \mu^+\mu^-(\gamma)$, $e^+e^-(\gamma)$, …

Reconstruction of Undetected Particles



Comput. Softw. Big Sci. 3 (2019) 1, 6



Full reconstruction of B_{tag} decay in O(10.000) different decay chains with a sequence of BDTs → Full Event Interpretation (FEI)

✓ All remaining particles in the event belong to B_{sig} (→ hermeticity)

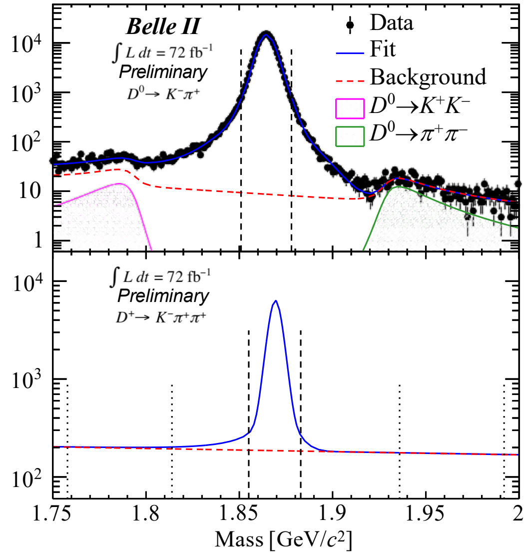
✓ 4-momentum of B_{sig} → 4-momentum of undetected particles

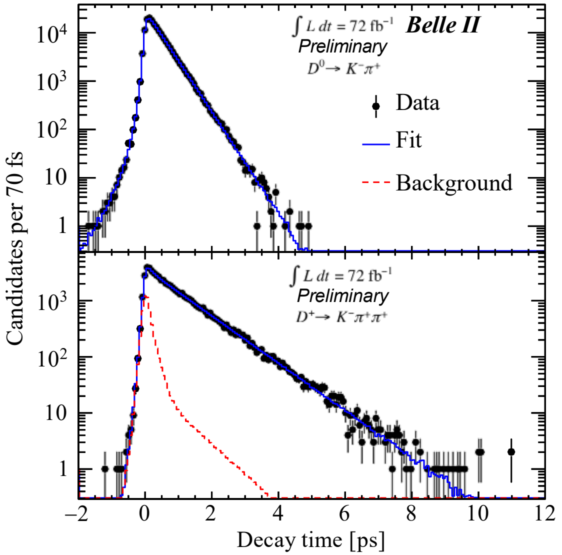
Belle II

D^0, D^+ lifetime

D^0 and D^+ Lifetime Measurement

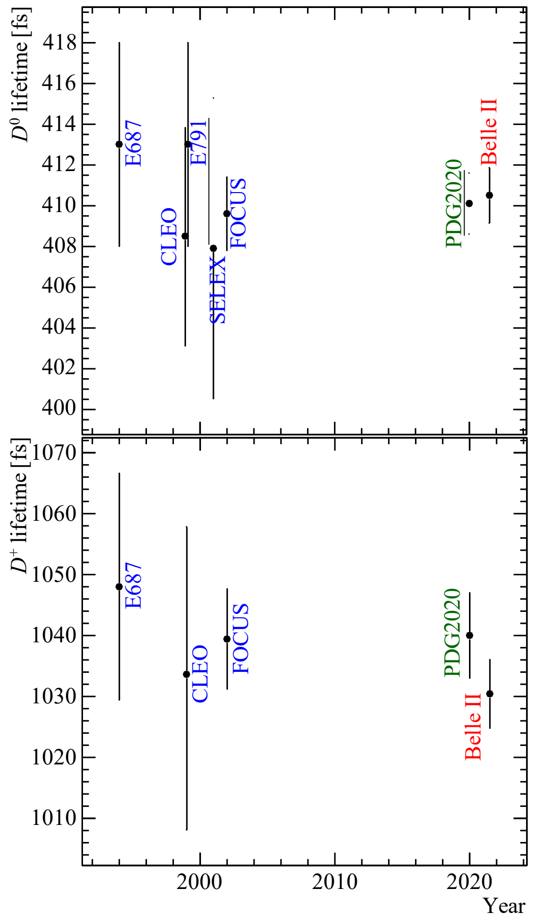
https://arxiv.org/abs/2108.03216





Source	Uncertainty (fs)	
	$D^0 \to K^-\pi^+$	$D^+ \to K^-\pi^+\pi^+$
Statistical	1.1	4.7
Resolution model	0.16	0.39
Backgrounds	0.24	2.52
Detector alignment	0.72	1.70
Momentum scale	0.19	0.48
Total systematic	0.8	3.1

	Belle II	World average
	$\tau(D^0) = (410.5 \pm 1.1 \pm 0.8)$ fs	(410.1 ± 1.5) fs
	$\tau(D^+) = (1030.4 \pm 4.7 \pm 3.1)$ fs	(1040 ± 7) fs



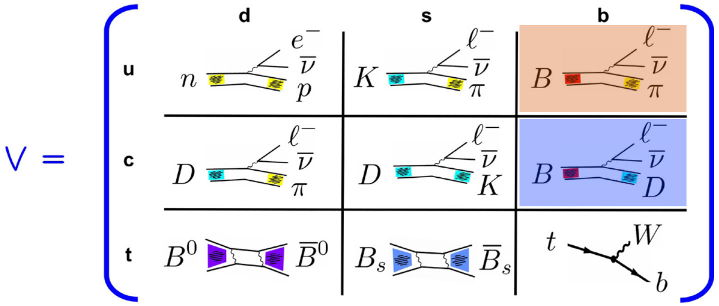
- Select high-purity samples of D-tagged $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ decays
- Fit the distribution of the decay time with accurate modelling of the resolution
  - dominant systematic uncertainties come from residual mis-alignment (D^0) and from background modelling (D^+)
  - results not yet limited by systematics
- Preliminary results consistent with, and more precise than, respective world averages
- Demonstration of excellent vertexing capabilities of Belle II

Belle II

$|V_{ub}|$, $|V_{cb}|$ and R(D) prospects

Belle II

Towards Measurements of CKM Matrix Elements $|V_{ub}|$ and $|V_{cb}|$

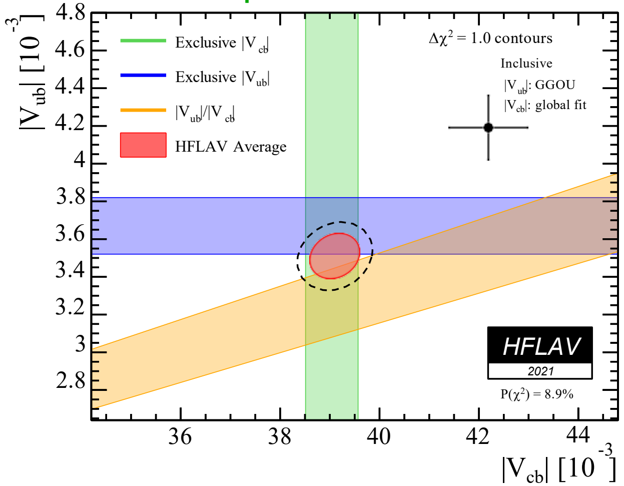


Long-standing discrepancy between inclusive and exclusive determinations of CKM matrix elements $|V_{ub}|$ and $|V_{cb}|$

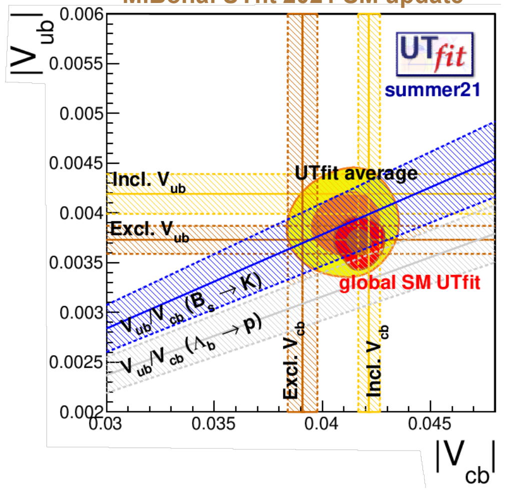
Analysis of inclusive and exclusive semi-leptonic B decays using both tagged and untagged approach

- $|V_{ub}|$: $B \to X_u l \nu$, $B \to \pi(\rho,\eta) l \nu$ $(l = e, \mu)$
- $|V_{cb}|$: $B \to X_c l \nu$, $B \to D^{(*)} l \nu$ $(l = e, \mu)$

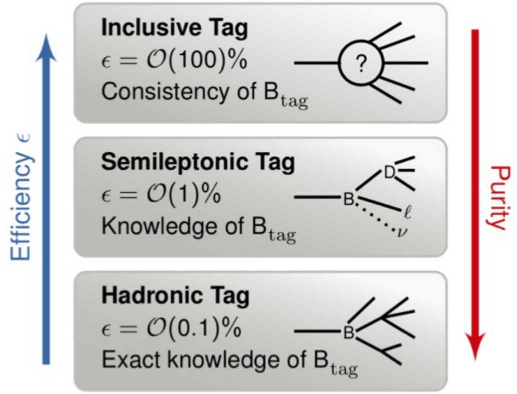
https://hflav.web.cern.ch

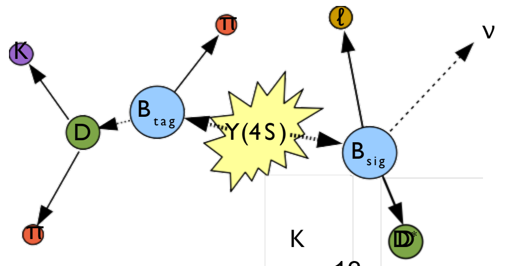


M.Bona: UTfit 2021 SM update



- Tagged approach exploits Belle II **F**ull **E**vent **I**nterpretation (FEI) algorithm Comput Softw Big Sci 3, 6 (2019)
  - hierarchical multivariate technique (>200 BDTs) to reconstruct the B-tag side (semi-leptonic or hadronic) through $O(10^4)$ different decay modes
  - results in significantly increased tagging efficiency compared to Belle

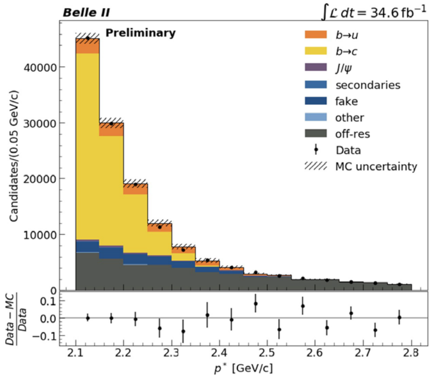




Inclusive and Exclusive $b \to (c,u) l \nu$ Branching Fractions

- A large variety of different analysis strategies will help to resolve the remaining discrepancies
- Alternative approaches, such as the recently proposed use of q^2-moments, are expected to further enhance sensitivity to V_{cb}

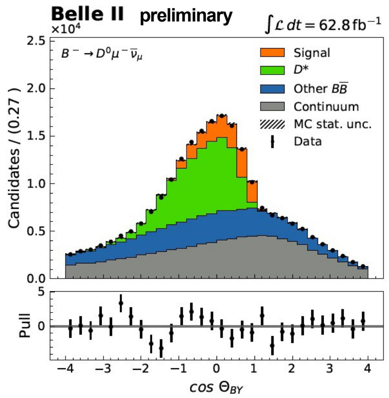
Untagged inclusive $X_u l \nu$



arXiv:2103.02629

3σ significance for b-u

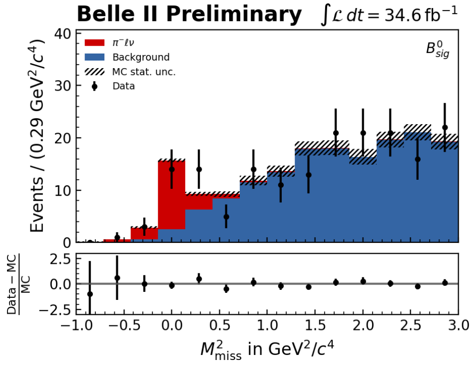
Untagged exclusive $B \to D^0 l \nu$



new for this conference, to be submitted

$\mathcal{B}(B^- \to D^0 \ell^- \overline{\nu}_l) = (2.293 \pm 0.053_{\text{stat}} \pm 0.084_{\text{syst}})\%$

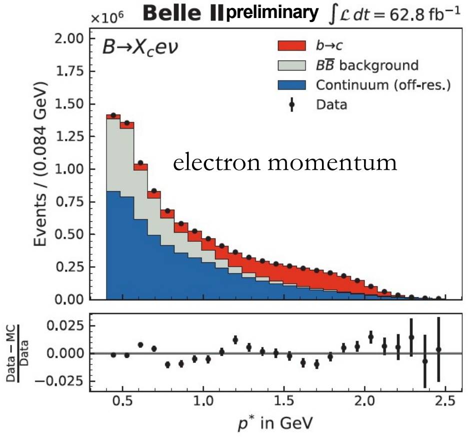
FEI hadronic tag excl. $B^0 \to \pi^- l \nu$



arXiv:2008.08819

$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell)$ $(1.58 \pm 0.43_{\text{stat}} \pm 0.07_{\text{sys}}) \times 10^{-4}$

Untagged inclusive $X_c l \nu$

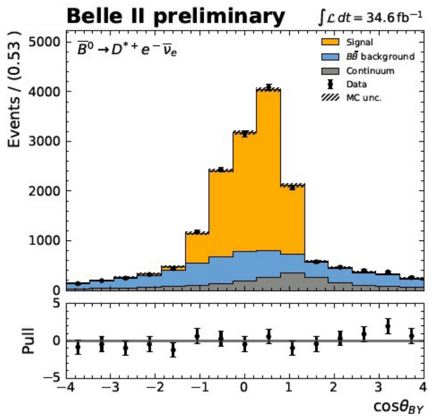


new for this conference, to be submited

$\mathcal{B}(B \to X_c \ell \nu) = (9.75 \pm 0.03(stat) \pm 0.47(syst))\%$

CMS electron momentum p*

Untagged exclusive $B^0 \to D^* l \nu$

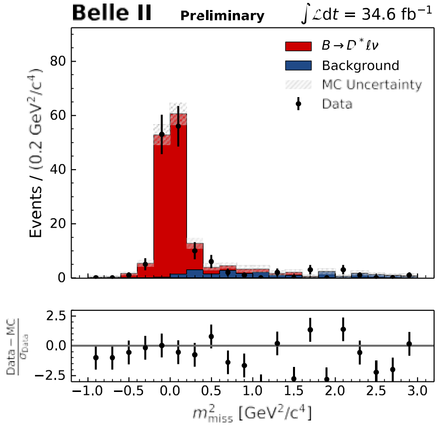


arXiv:2008.07198

$\mathcal{B}(\overline{B}^0 \to D^{*+} \ell^- \overline{\nu}_l) = (4.60 \pm 0.05_{\text{stat}} \pm 0.17_{\text{syst}} \pm 0.45_{\pi_s})\%$

θ_{BY} angle between B and Dl

FEI hadronic tag excl. $B^0 \to D^* l \nu$



arXiv:2008.10299

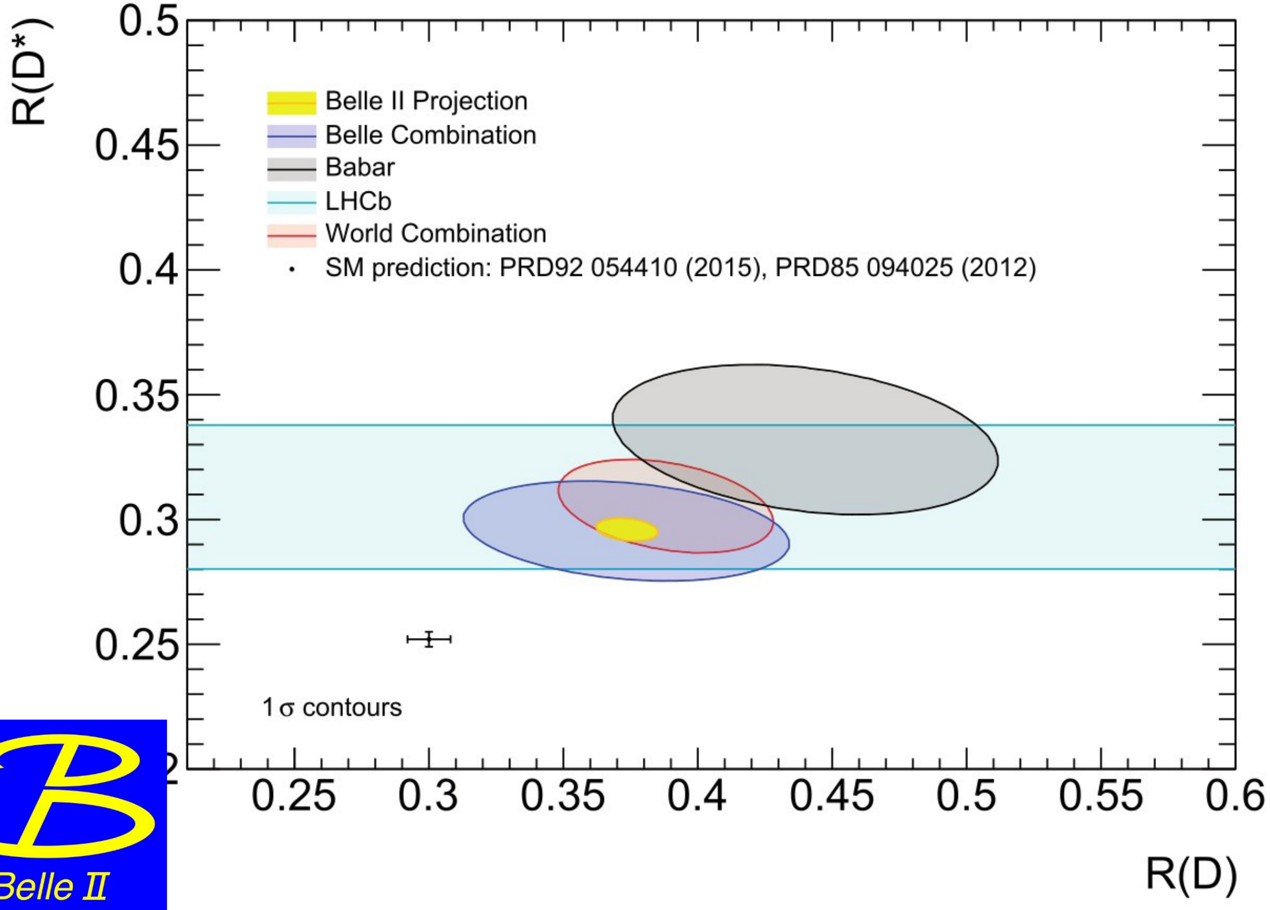
$\mathcal{B}(\overline{B}^0 \to D^{*+} \ell^- \overline{\nu}_l) = (4.51 \pm 0.41_{\text{stat}} \pm 0.27_{\text{syst}} \pm 0.45_{\pi_s})\%$

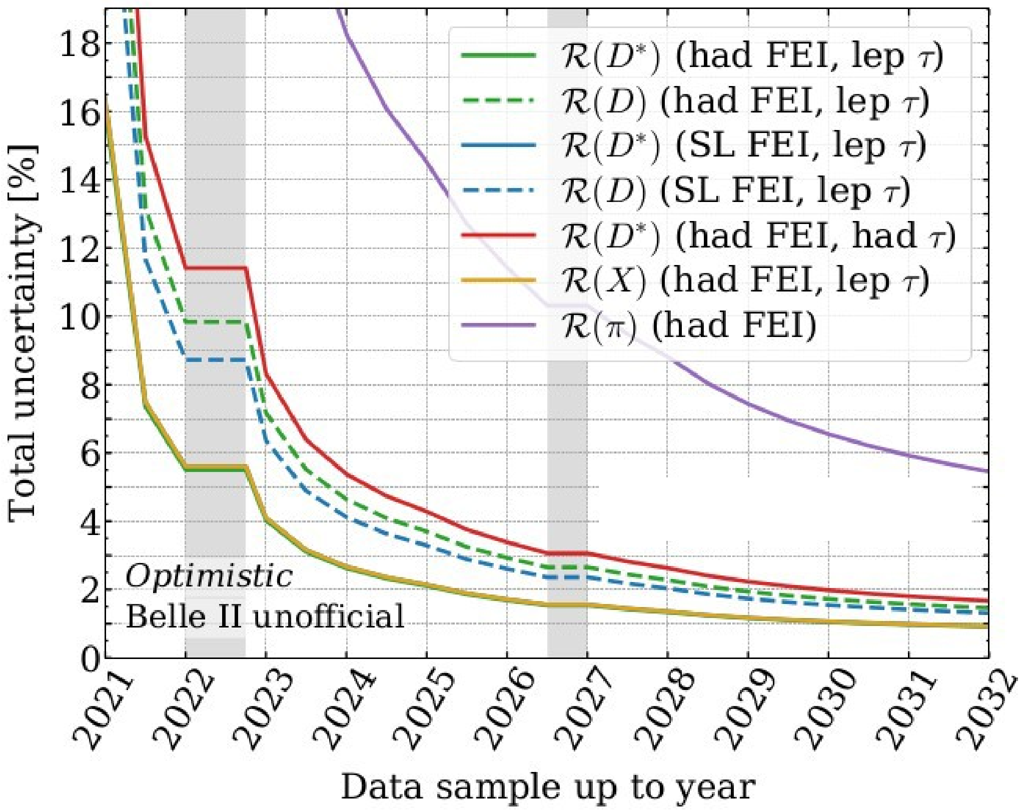
$m^2_{miss} = \left(p_{e^+e^-} - p_{B_{tag}} - p_{D^*} - p_\ell\right)^2$

Belle II

Prospects for R(D$^{(*)}$)

$$R_{D^{(*)}} = \frac{\mathrm{Br}(B \to D^{(*)}\tau\nu_\tau)}{\mathrm{Br}(B \to D^{(*)}\ell\nu_\ell)}$$





Belle II

First paper on B physics: $B^+ \to K^+ \nu\nu$

First paper on B physics!

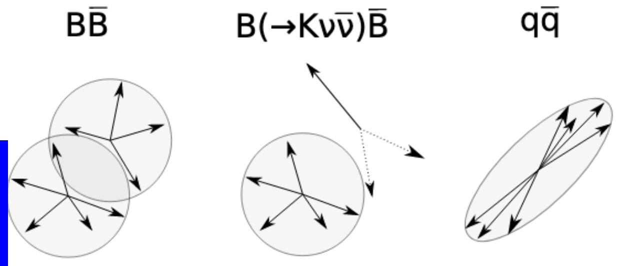
https://arxiv.org/abs/2105.05754

- "Search for $B^+ \to K^+ \nu\nu$ decays using an inclusive tagging method at Belle II"

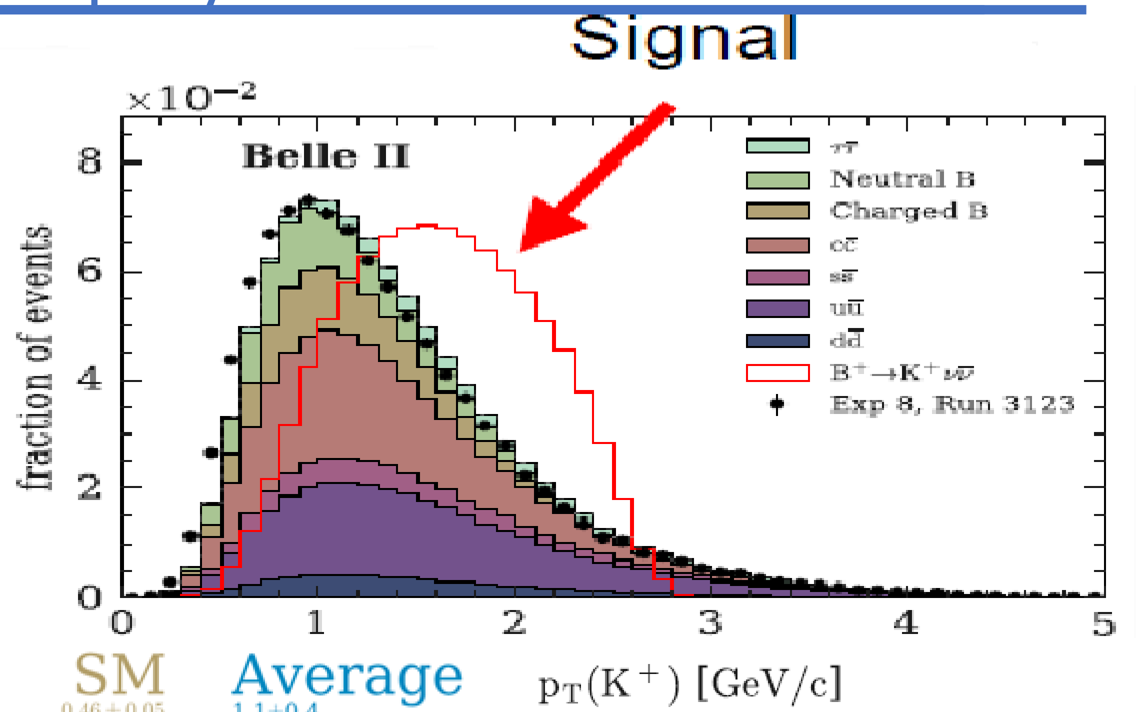
b⟶sνν searches, unique to BelleII

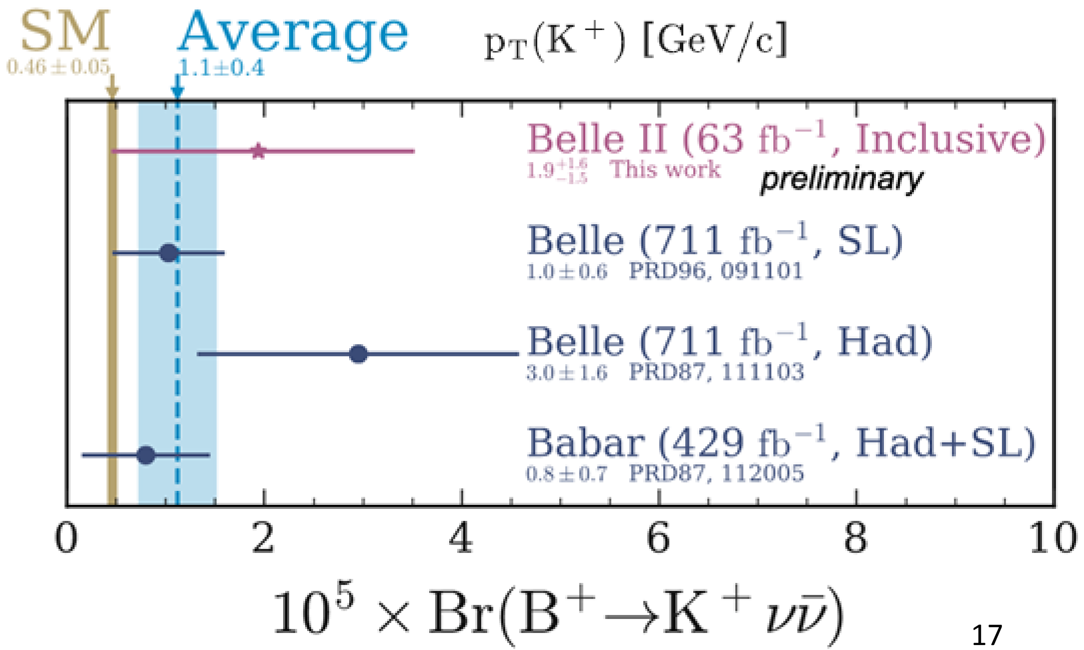
- FCNC with missing energy in the final state, searched for at BaBar and Belle using hadronic and semileptonic tagging methods

- New method used with early BelleII data: inclusive tagging method exploiting kinematic, event shape and vertexing variables



Same level precision with 10 times less statistics





Belle II

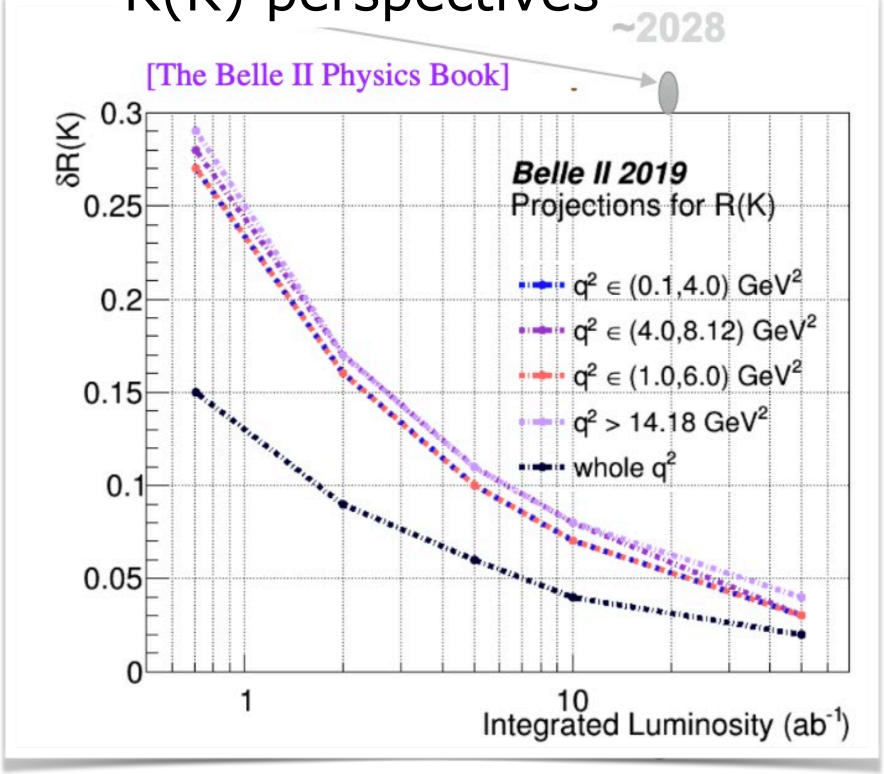
Belle II and flavour anomalies : $R(K^{(*)})$

- B factories measurements + LHCb latest results points to tensions with SM predictions on lepton flavour universality in b→sll and b→clυ
- What can Belle II say on those modes: $R(K^{(*)})$

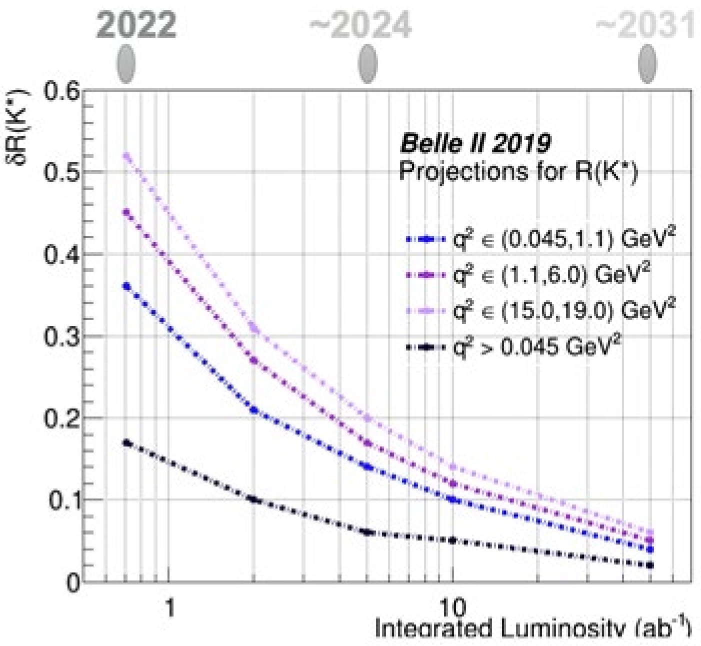
$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)}$$

- R(K) measurement statistically limited in the short term,
- main syst from leptonID data-MC corrections
- ~ 20 ab^{-1} needed to reach 5σ level

R(K) perspectives



R(K*) perspectives



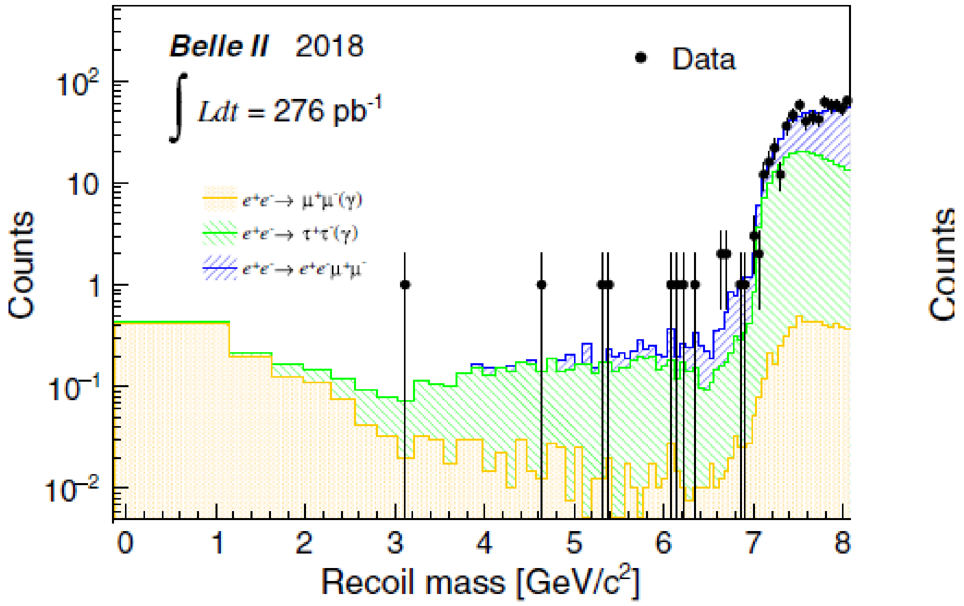
Dark sector studies

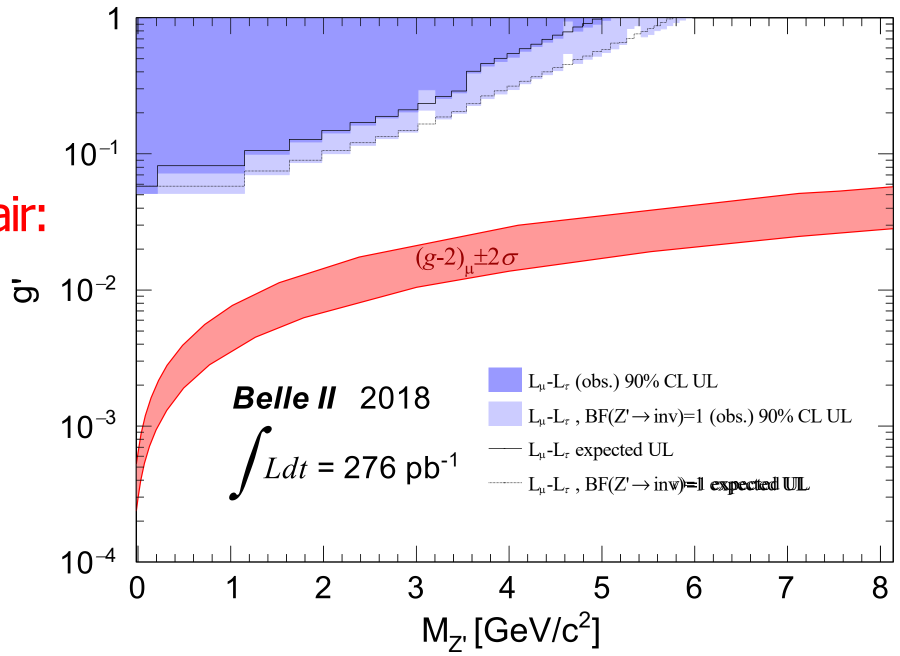
$L_\mu - L_\tau$ model: Z' to invisible

$L_\mu - L_\tau$ model: Phys. Rev. D, 89, 113004. June 2014

- Z' does not interact with 1st generation leptons
- includes dark matter candidate
- potentially addresses $(g-2)_\mu$ anomaly

Search for resonance in mass of system recoiling against muon pair:





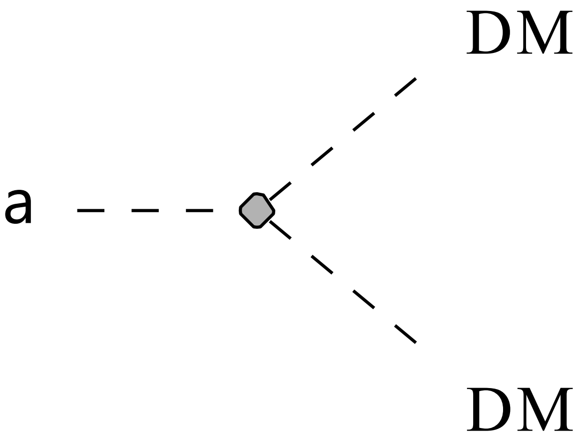
- Simulations: can probe $(g-2)_\mu$ band with ~ 50 fb^{-1}

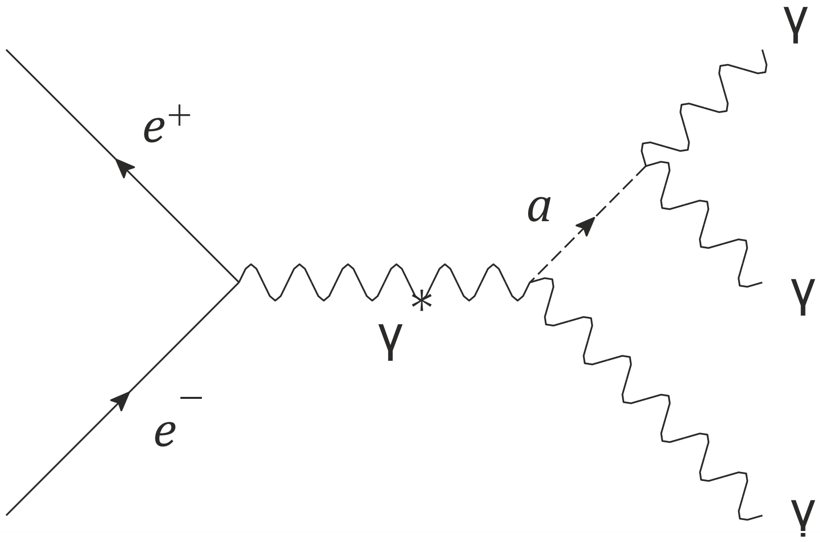
Belle II, Phys. Rev. Lett. 124, 141801. April 2020, BELLE2-NOTE-PL-2020-012

Axion-Like Particles: a → $\gamma\gamma$

An Axion-like particle, a

- couples to bosons. Here focus on a → $\gamma\gamma$
- could be a "portal" or "mediator" to connect SM to Dark Matter candidates if $m_a \sim O(1\ \mathrm{GeV}/c^2)$



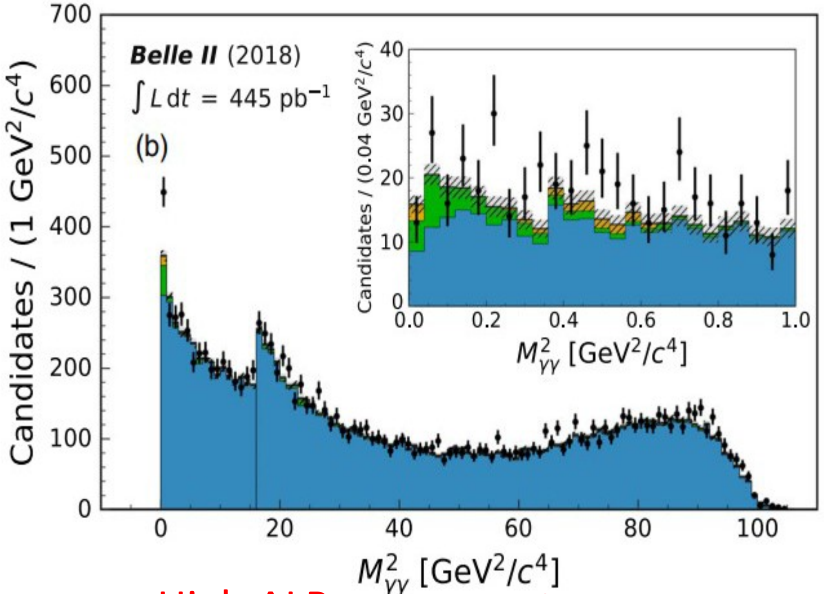


Belle II

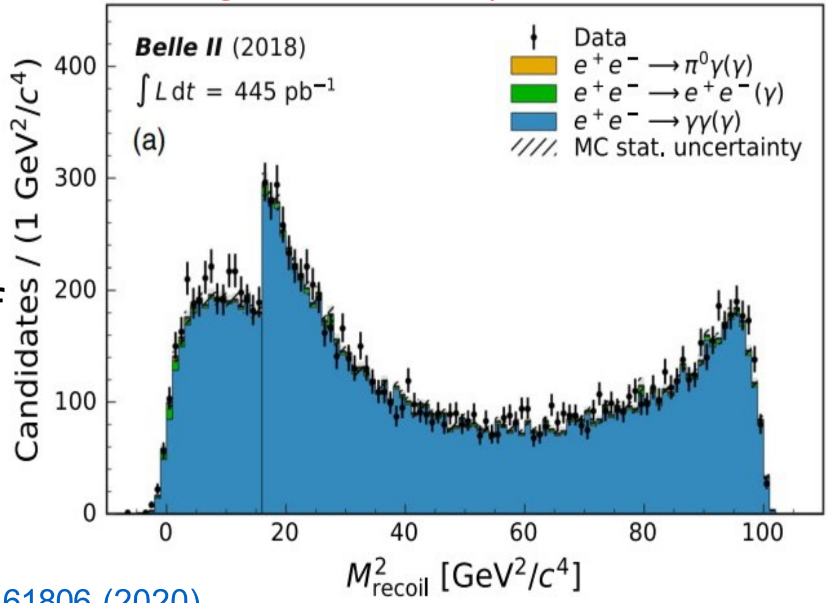
Axion-Like Particles: $a \to \gamma\gamma$

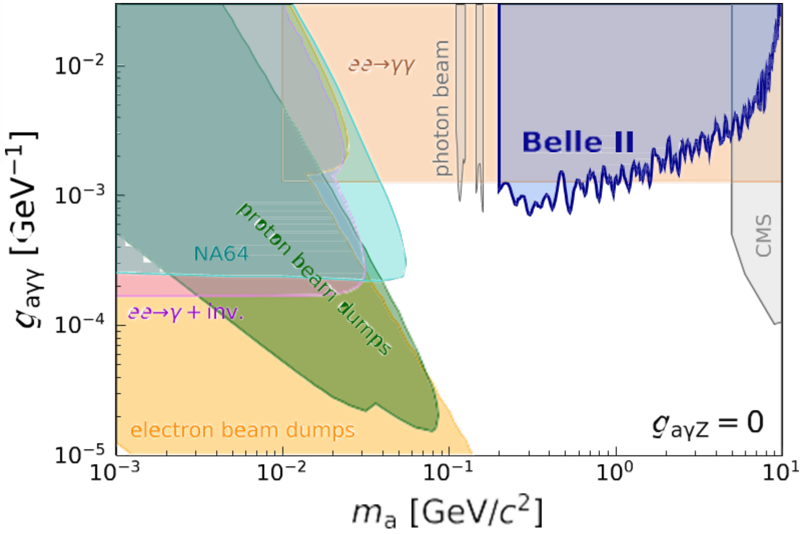
- $445 \pm 3\text{pb}^{-1}$ of data taken in 2018
- Search for bump on large $ee \to \gamma\gamma\gamma$ background
- Require that the photon $t/\Delta t$ are all consistent with each other
- No tracks from the interaction point
- $0.88\sqrt{s} \le m_{\gamma\gamma\gamma} \le 1.03\sqrt{s}$
- No significant excesses observed
- Even with a small data set, results exclude previously unexplored parts of phase space.

Low ALP mass spectrum



High ALP mass spectrum



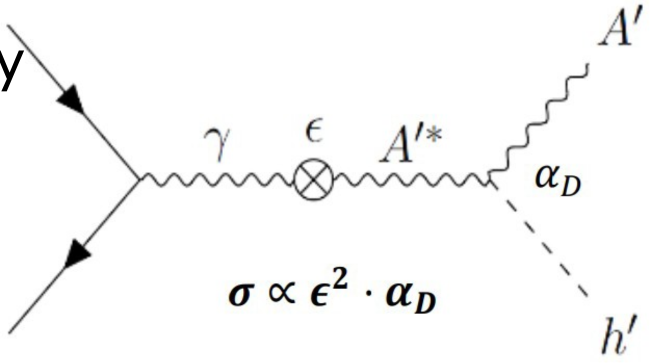


Belle II, Physics Review Letters 125, 161806 (2020)

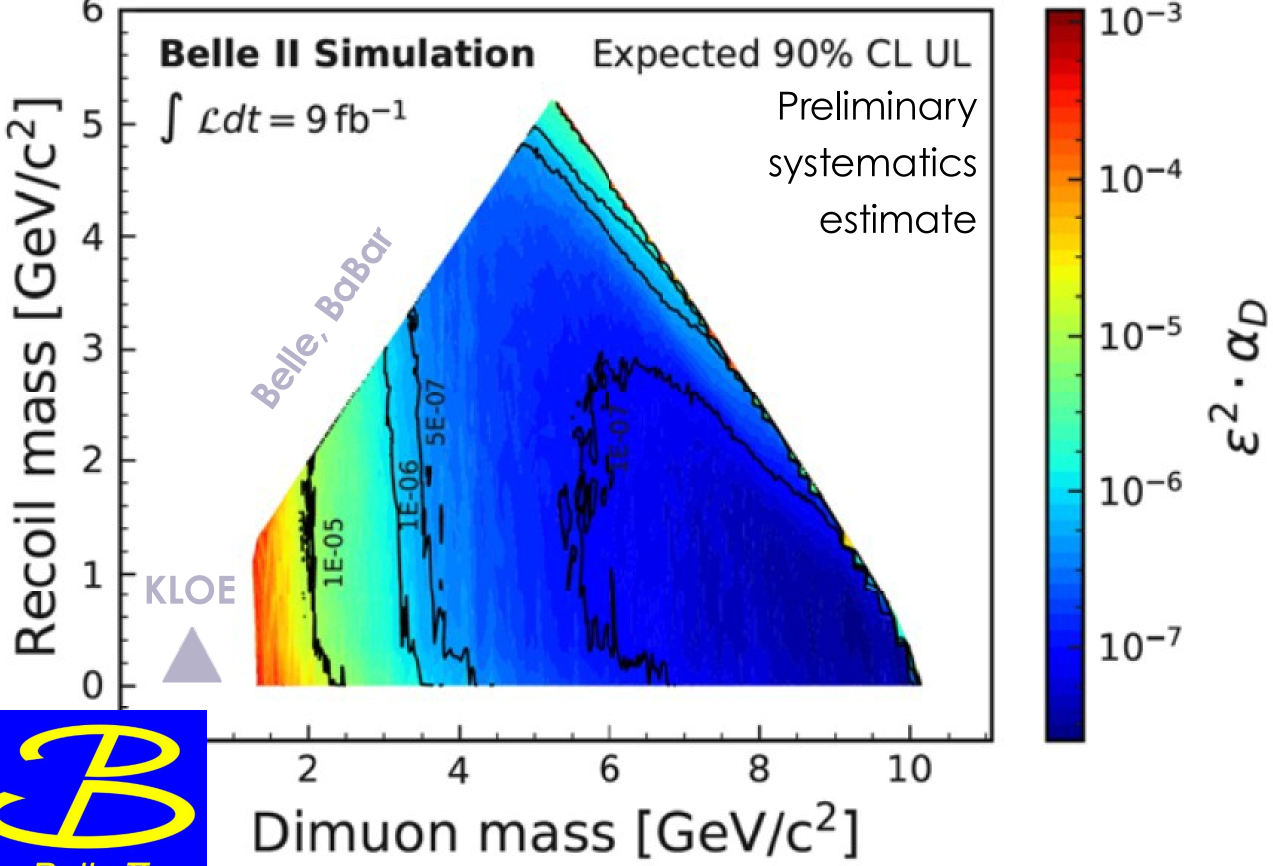
Dark Higgsstrahlung

Dark Photon (A’) mass could be generated via a spontaneous symmetry breaking mechanism, adding a Dark Higgs boson (h’) to the model:

- Dark Higgsstrahlung process: $e^+ e^- \rightarrow A'^* \rightarrow A' h'$



Belle II expected sensitivity on $\varepsilon^2\alpha_D$



At Belle II we are exploring the invisible h’ decay ($m_{h'} < m_{A'}$), constrained only by **KLOE**:

Babusci et al. (2015), arXiv:1501.06795

$$e^+ e^- \rightarrow A'^* \rightarrow A'(\rightarrow \mu^+ \mu^-)\ h'(\rightarrow \text{inv.})$$

Very promising results even considering only the 2019 data set (9 fb^{-1}):

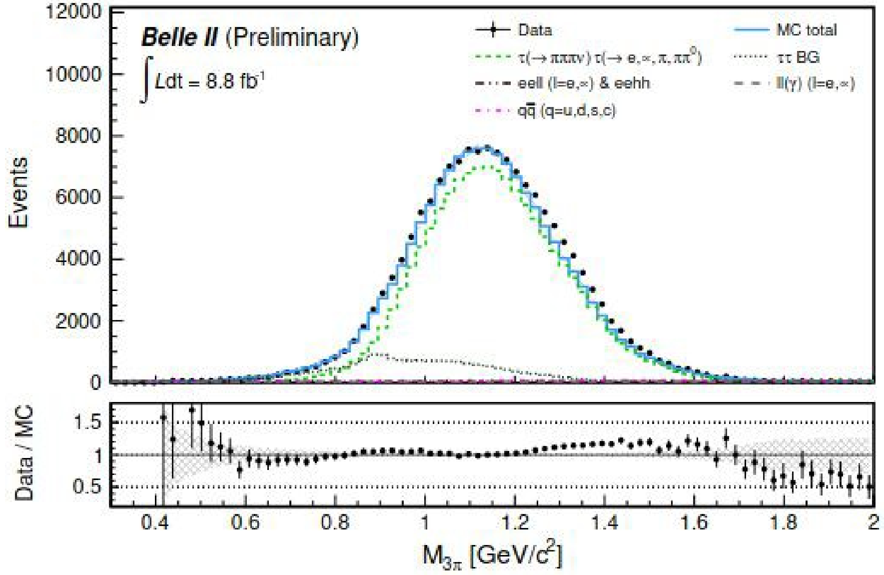
- accessing an unconstrained region beyond the KLOE coverage;
- probing non-trivial $\varepsilon^2\alpha_D$ couplings.

τ physics and prospects

τ mass measurement

$$\frac{\Gamma(\mu \to e\nu\bar{\nu})}{\Gamma(\tau \to e\nu\bar{\nu})} \sim \left(\frac{g_\mu}{g_\tau}\right)^2 \frac{m_\mu^5}{m_\tau^5}$$

Accuracy of lepton universality measurements.

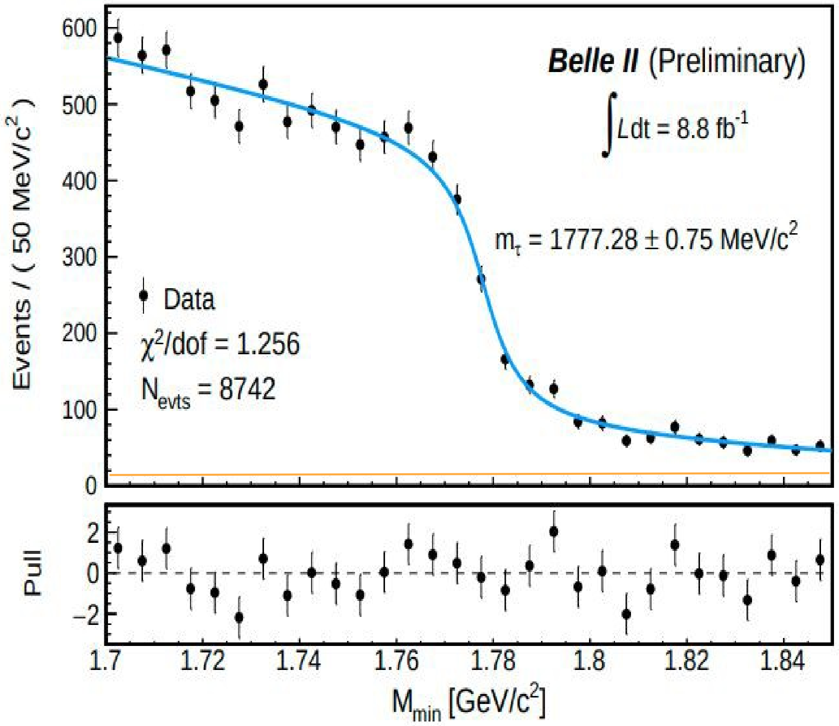


The measurement is performed in the decay mode $\tau \to 3\pi\nu$ (3x1 prong topology), using a pseudomass technique developed by the ARGUS collaboration:

$$M_{min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})}$$

* The distribution of the pseudomass is fitted to a empirical edge function to estimate τ lepton mass.

$$F(M_{min}, \vec{P}) = (P_3 + P_4 \cdot M_{min}) \cdot tan^{-1}[(M_{min} - \mathbf{P_1})/P_2] + P_5 \cdot M_{min} + 1$$



m_τ=1777.28 ± 0.75 (stat) ± 0.33 (syst) MeV/c²

Systematic uncertainty	MeV/c^2
Momentum shift due to the B-field map	0.29
Estimator bias	0.12
Choice of p.d.f.	0.08
Fit window	0.04
Beam energy shifts	0.03
Mass dependence of bias	0.02
Trigger efficiency	≤ 0.01
Initial parameters	≤ 0.01
Background processes	≤ 0.01
Tracking efficiency	≤ 0.01

to be reduced

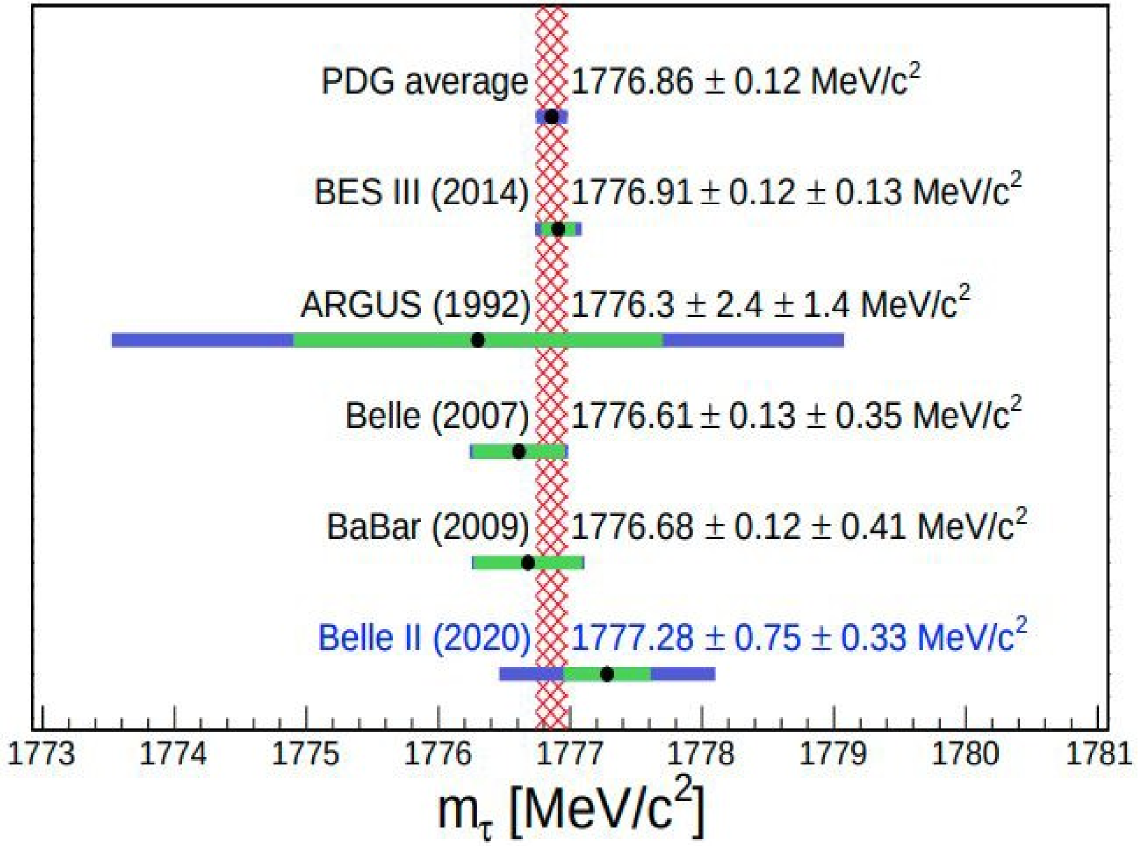
Public Belle II note

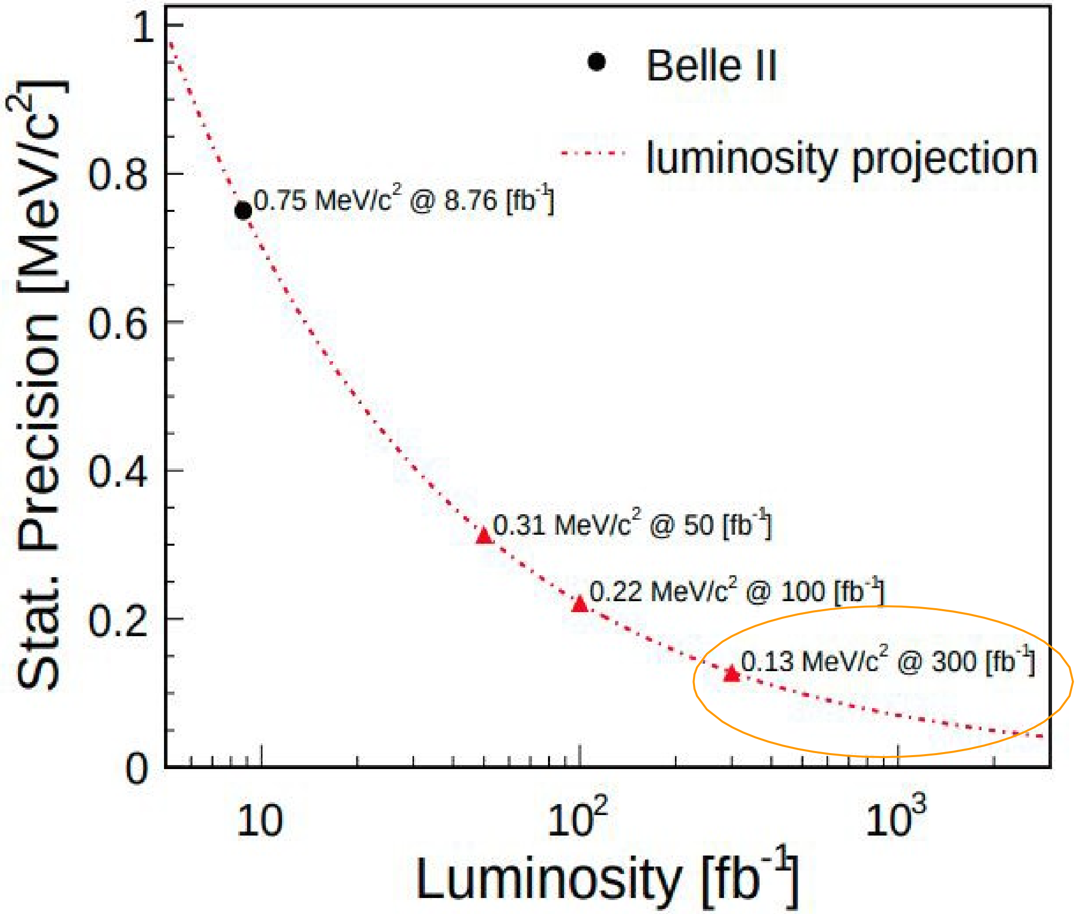
→arxiv.2008.04665

τ mass measurement

The goal is to the best m_τ precision among pseudomass measurements.

arxiv.2008.04665





Belle II have compatible results with previous experiments and comparable sys. errors with previous B factories BaBar and Belle.

~300 fb^{-1} statistical precision as Belle/BaBar.

τ lifetime

- Important parameter in the SM.
- Test of the lepton flavor universality (LFU).
- World best measurement by Belle (711 fb^{-1}):

τ_τ = (290.17 ± 0.53(stat)±0.33(sys)) fs

Measurement strategy:

❖ **Proper decay time** distribution.

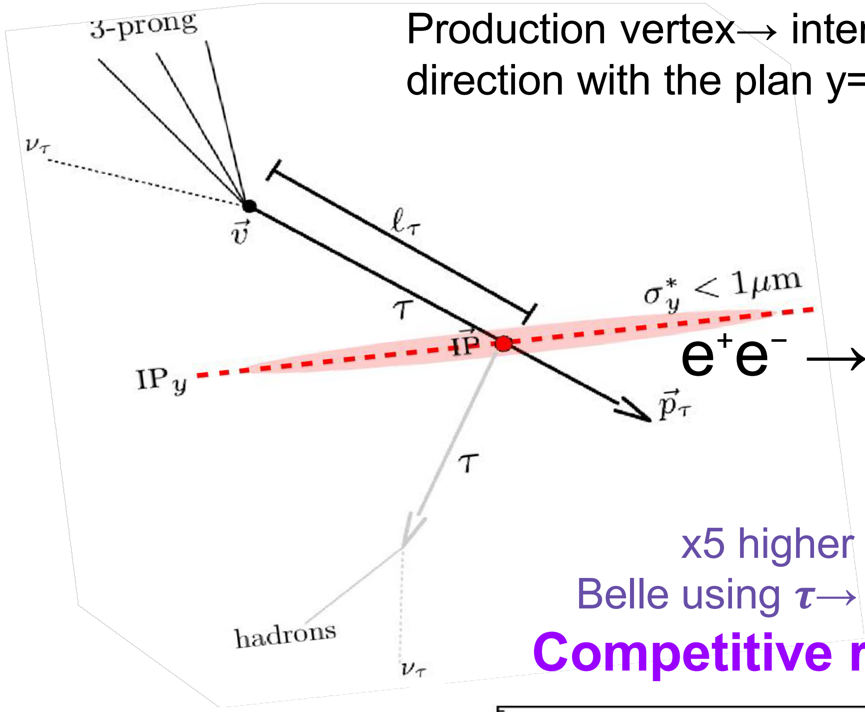
$$p(t,\tau_\tau) = \frac{1}{\tau_\tau} e^{-\frac{t}{\tau_\tau}} \cdot R(t)$$

Proper time resolution

❖ Proper time related to the decay length and the momentum.

$$t = \frac{l_\tau}{\beta\gamma c} = l_\tau \frac{m_\tau}{p_\tau c}$$

l_τ and p_τ to be reconstructed from measurements.



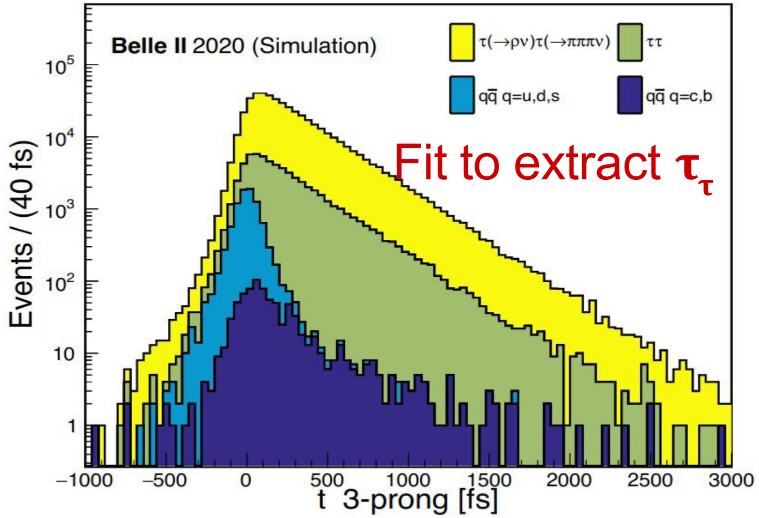
Production vertex→ intersection of the $\vec{p}_t$ direction with the plan y=**IP**y.

3x1 topology

$e^+e^- \to \tau^-\tau^+$ → $\rho\nu$ ($\rho \to \pi\pi^0$), $\pi\pi\pi\nu$

x5 higher efficiency than Belle using $\tau \to 3\pi\nu$ x $\tau \to 3\pi\nu$ topology.

Competitive results at 150 fb^{-1}!

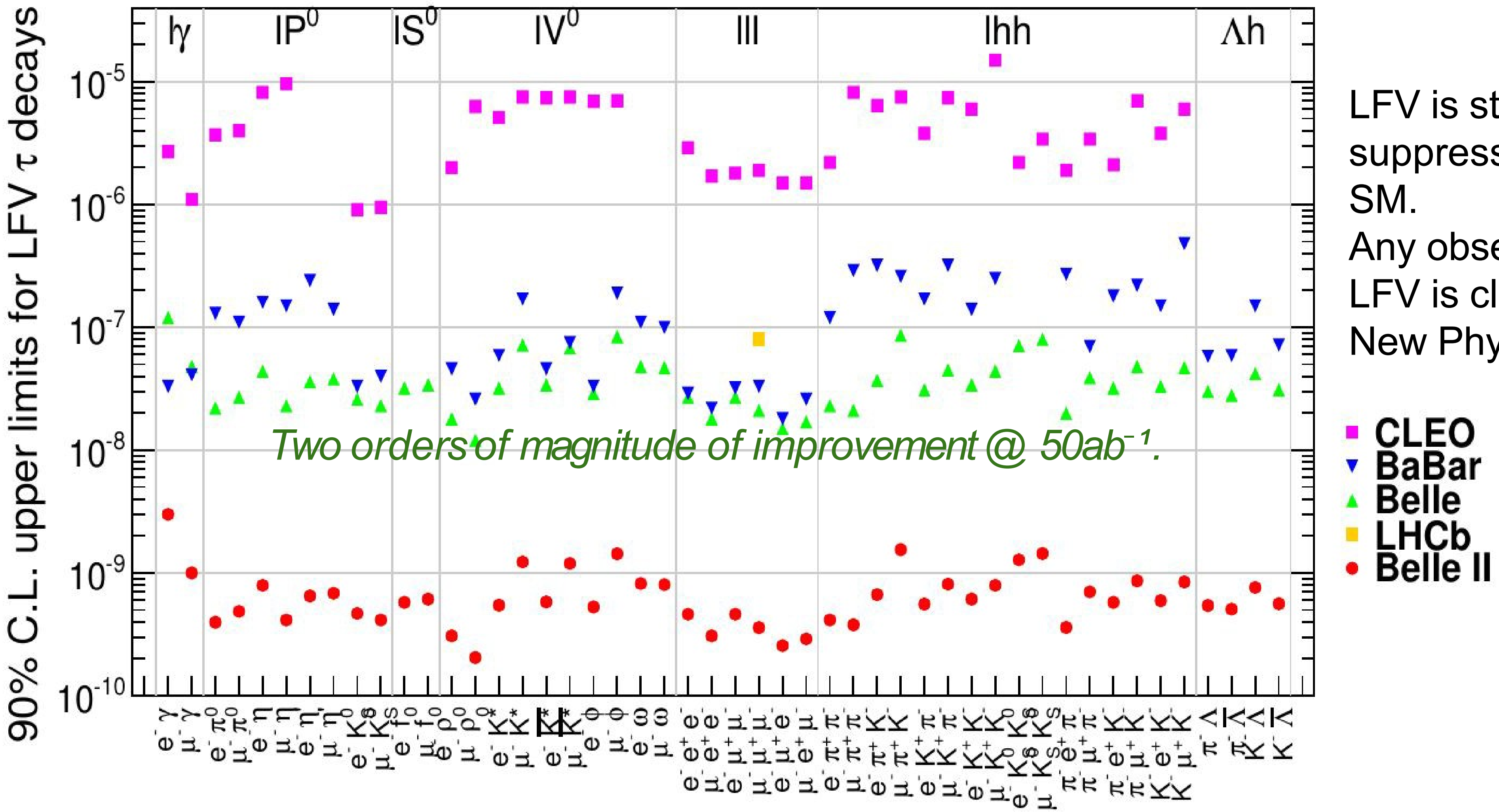


Epiphany conference talk

τ LFV decays

Belle II Physics Book

NP models



LFV is strongly suppressed within the SM.
Any observation of LFV is clear signal for New Physics!

τ is the heaviest charged lepton ⇨ Large variety of leptonic and semi-leptonic decays to search for LFV(LNV).

Matter anti-matter Asymmetries

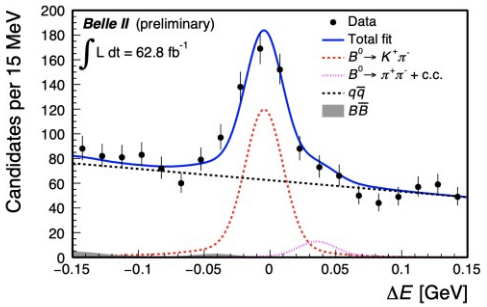
Isospin sum rule : $B \to K^+\pi^-, K^+\pi^0, K^0\pi^+$

Sensitive test for non-SM physics

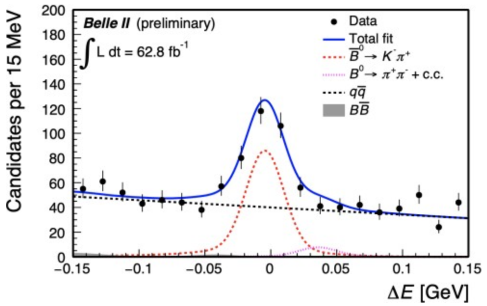
$$I_{K\pi} = A_{CP}^{K^+\pi^-} + A_{CP}^{K^0\pi^+}\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^+\pi^0}\frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^0\pi^0}\frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)} \approx 0$$

M. Gronau (Phys. Lett. B **627** (2005) no.1, 82-88)

$B^0 \to K^+\pi^-$

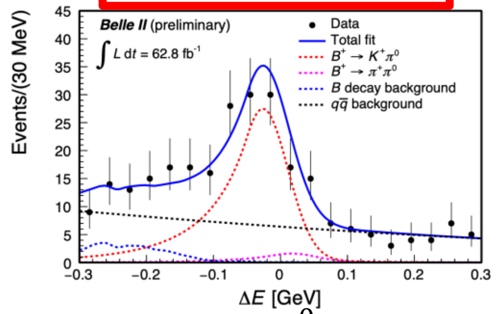


$\bar{B}^0 \to K^-\pi^+$

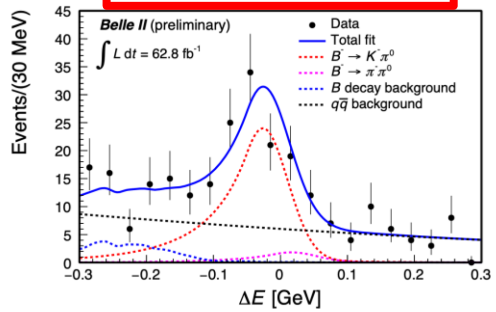


Probes tracking & PID separation

$B^+ \to K^+\pi^0$

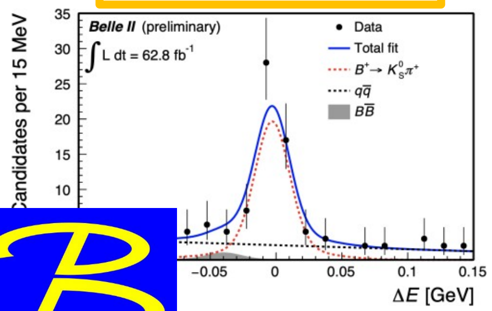


$B^- \to K^-\pi^0$

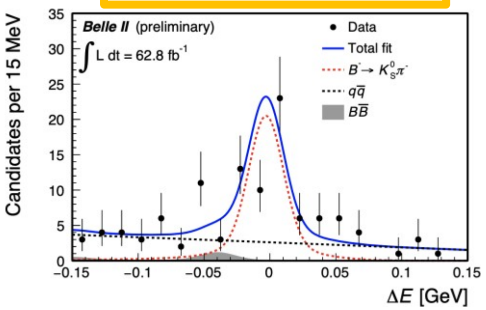


Probes π^0 reconstruction & PID separation

$B^+ \to K^0\pi^+$



$B^- \to K^0\pi^-$



K_S^0 reconstruction

$\mathcal{B}(B^0 \to K^+\pi^-) = [18.0 \pm 0.9(stat) \pm 0.9(syst)] \times 10^{-6}$

$A_{CP}(B^0 \to K^+\pi^-) = -0.16 \pm 0.05(stat) \pm 0.01(syst)$

arXiv:2106.03766

$\mathcal{B}(B^+ \to K^+\pi^0) = [11.9^{+1.1}_{-1.0}(stat) \pm 1.6(syst)] \times 10^{-6}$

$A_{CP}(B^+ \to K^+\pi^0) = -0.09 \pm 0.09(stat) \pm 0.03(syst)$

arXiv:2105.04111

$\mathcal{B}(B^+ \to K^0\pi^+) = [21.4^{+2.3}_{-2.2}(stat) \pm 1.6(syst)] \times 10^{-6}$

$A_{CP}(B^+ \to K^0\pi^+) = -0.01 \pm 0.08(stat) \pm 0.05(syst)$

Belle II

Isospin sum rule : $B \to K^0\pi^0$

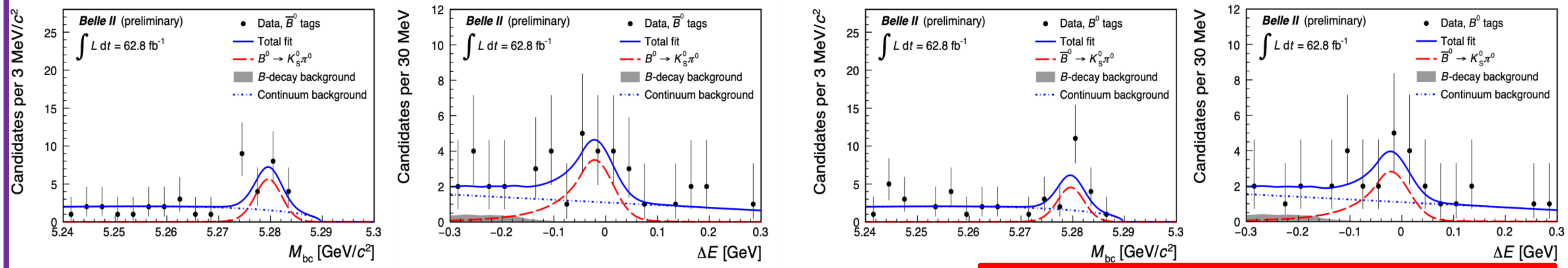
Belle II: unique access to this channel !

$I_{K\pi}$ precision is dominated by this channel

$$I_{K\pi} = A_{CP}^{K^+\pi^-} + A_{CP}^{K^0\pi^+}\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^+\pi^0}\frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^0\pi^0}\frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)} \approx 0$$

Flavor-tagging technique in Belle II arXiv:2008.02707

$\overline{B^0}$ *tags* $\qquad$ B^0 *tags*



$N(B^0 \to K^0\pi^0) = 45^{+9}_{-8}$ $\qquad$ $\mathcal{B}(B^0 \to K^0\pi^0) = [8.5^{+1.7}_{-1.6}(stat) \pm 1.2(syst)] \times 10^{-6}$

$A_{CP}(B^0 \to K^0\pi^0) = -0.40^{+0.46}_{-0.44}(stat) \pm 0.04(syst)$

arXiv:2104.14871

First measurement in Belle II data!

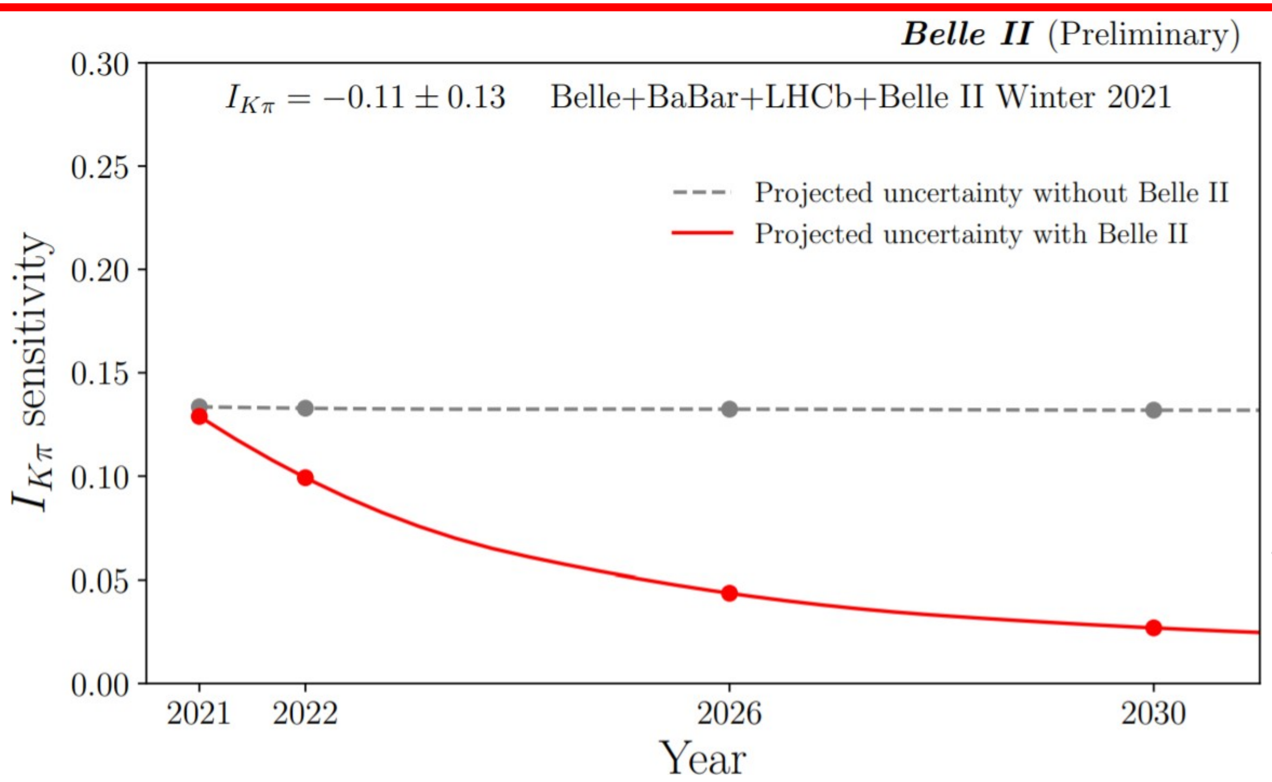
Belle II

Isospin sum rule – projected uncertainty

Procedure

- $K^0\pi^0$: Dominant uncertainty from $A_{CP}(K^0\pi^0)$. Calculate $\sigma_{I_{K\pi}}$ with Belle II results
- $K^+\pi^-$,$K^+\pi^0$, and $K^0\pi^+$: Take world best measurements, and investigate

future projections with Belle II and LHCb expected luminosities.



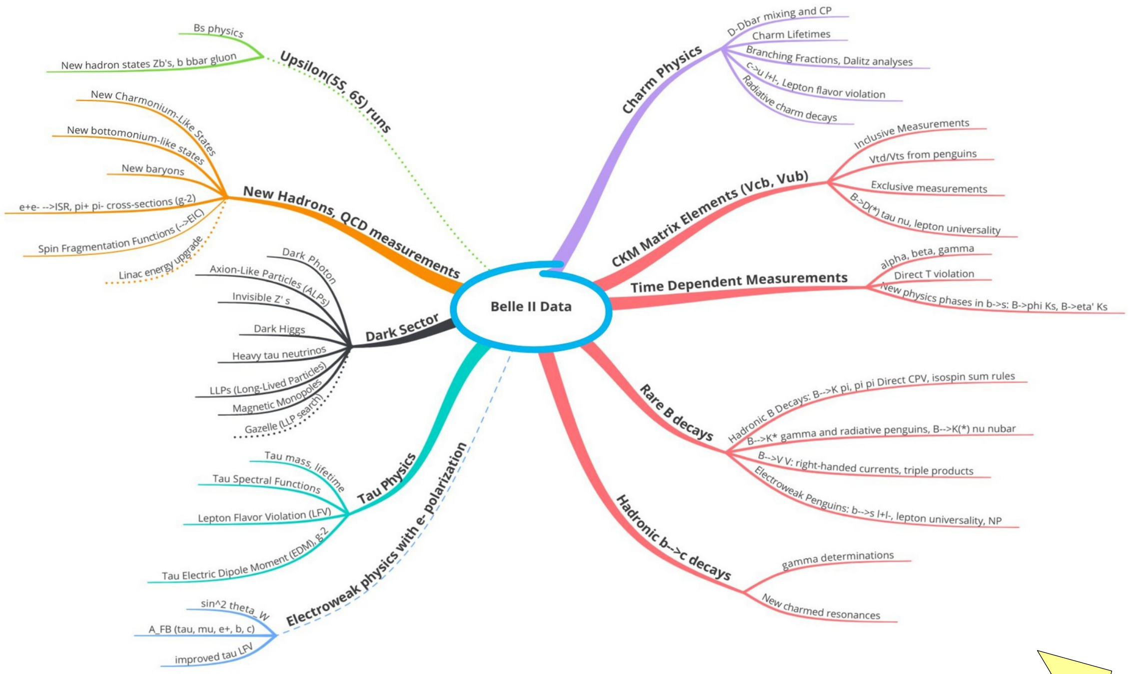
arXiv:2104.14871

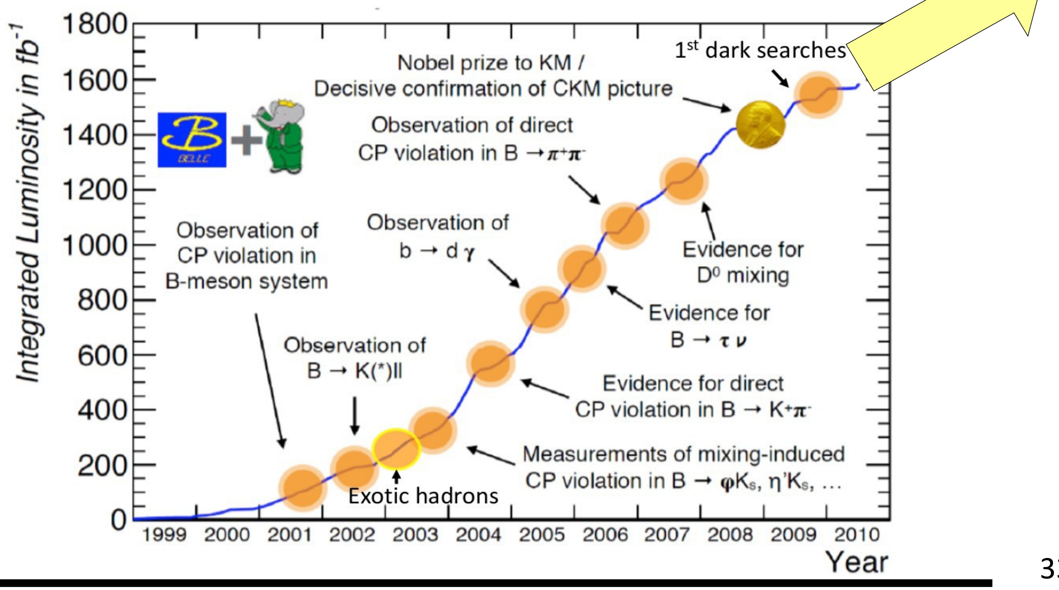
The projected uncertainty on $I_{K\pi}$

Fundamental role of Belle II in improvement of precision !

Conclusions

- Belle II produced interesting and competitive results with little data already
- The Belle II physics program is very broad
- New ideas are extending the physics reach
- Searching for new physics phenomena. Stay tuned.





Back up slides

A comparison with LHCb

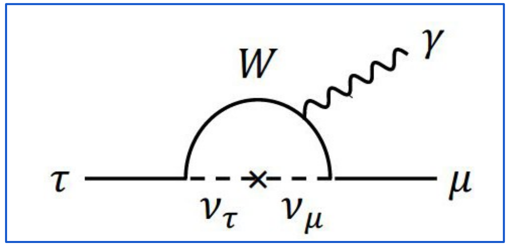
Property	LHCb	Belle II
$\sigma_{b\bar{b}}$ (nb)	~150,000	~1
$\int L\, dt$ (fb^{-1})	~25	~50,000
Background level	High	Low
Typical efficiency	Low	High
π^0, K_S efficiency	Low	High
Initial state	Not well known	Well known
Decay-time resolution	Excellent	Good
Collision spot size	Large	Tiny
Heavy bottom hadrons	B_s, B_c, b-baryons	Partly B_s
τ physics capability	Limited	Excellent
B-flavor tagging efficiency	3.5 - 6%	36%

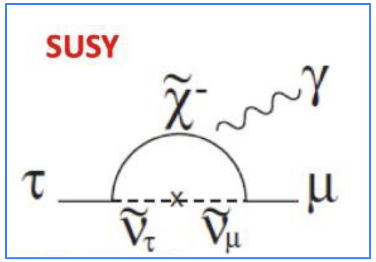
Belle II

$\tau \rightarrow l + \gamma$, $\tau \rightarrow 3\,l$

In SM LFV is highly suppressed Br ~ O(10^{-54})

$$\mathcal{B}(\tau \to \mu\gamma) = \frac{3\alpha}{32\pi} \left| \Sigma U^*_{\tau i} U_{\mu i} \frac{\Delta m^2_{3i}}{m^2_W} \right|^2$$





Full reconstructed

$e^+e^- \rightarrow \tau^-\tau^+$

→ 1 prong + missing(ν,γ)

→ $\mu\gamma$, $\mu\mu\mu$ (LFV mode)

Golden channels

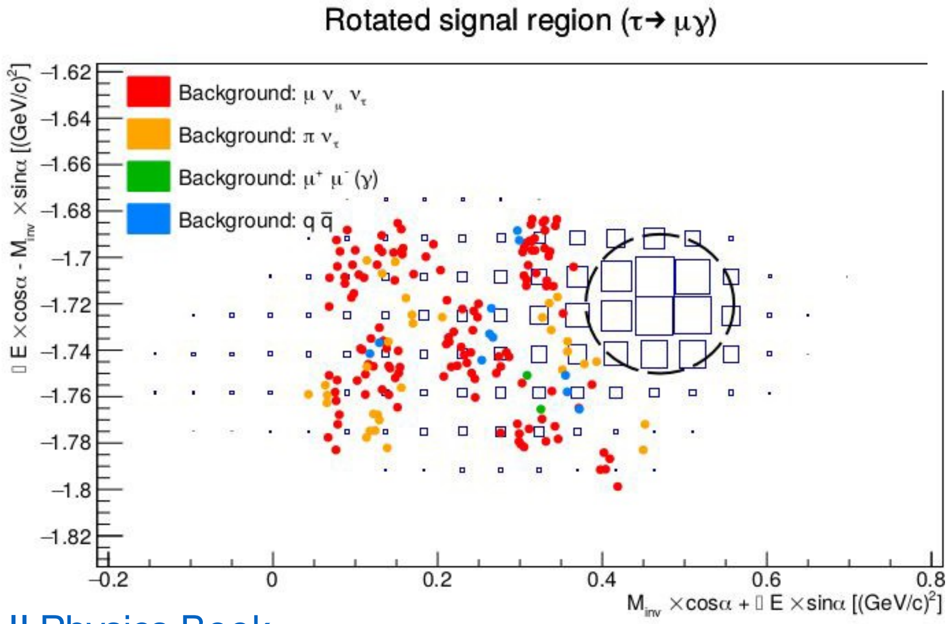
NP model predictions: O(10^{-10}-10^{-8}).

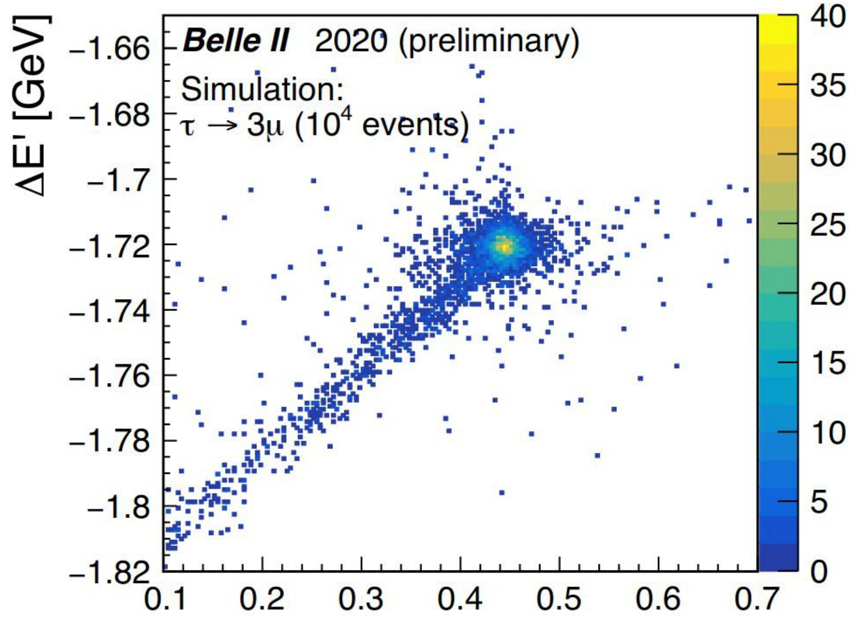
Signal determination as $\tau \rightarrow \mu\gamma$.

$$M^{\mu\gamma}_{inv} = \sqrt{E^2_{\mu\gamma} - P^2_{\mu\gamma}}$$

$$\Delta E = E^{CM}_{\mu\gamma} - E^{CM}_{beam}$$

$$\begin{pmatrix} M'_\tau \\ \Delta E' \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} M_\tau \\ \Delta E \end{pmatrix}$$





Belle II Physics Book.

BKG free selection w/ 1 ab^{-1}.

BR($\tau \rightarrow \mu + \gamma$) < 2.72 x 10^{-8}

Improvement ~Belle limit/2.

(no sys. unc. included)

Belle: 2.1 x 10^{-8} (782fb^{-1}).

Belle II: ~10^{-10}.

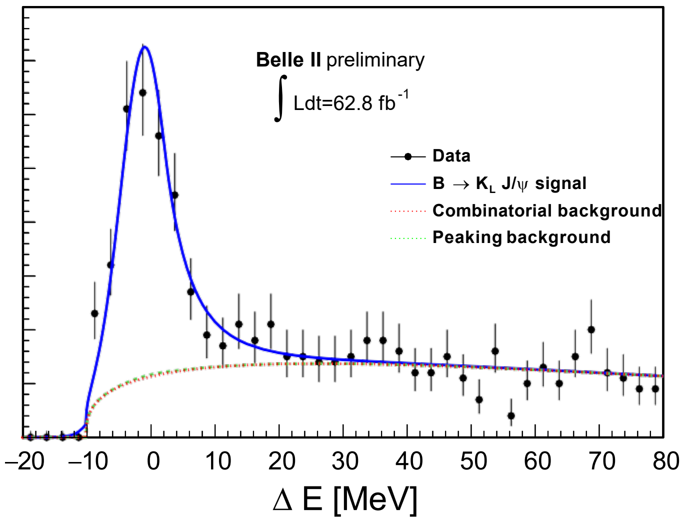
Belle II Physics Book

Rediscoveries of $B \to J/\psi K^0_L$ and $B \to \eta' K$

- The measurement of $\sin(2\varphi_1/\beta)$ using $B^0 \to J/\psi K^0_L$ complements the one from $B^0 \to J/\psi K^0_S$
  - signal yield compatible with Belle result (no sys. error yet)
  - next to come: precise measurement of B^0 lifetime and mixing frequency
- Rediscovery of rare hadronic penguin diagram mediated decay $B \to \eta' K$
  - particularly sensitive to new physics in the hadronic loop
  - measured branching ratio in agreement with world average

arXiv:2104.06224

Rediscovery of $B \to J/\psi K^0_L$



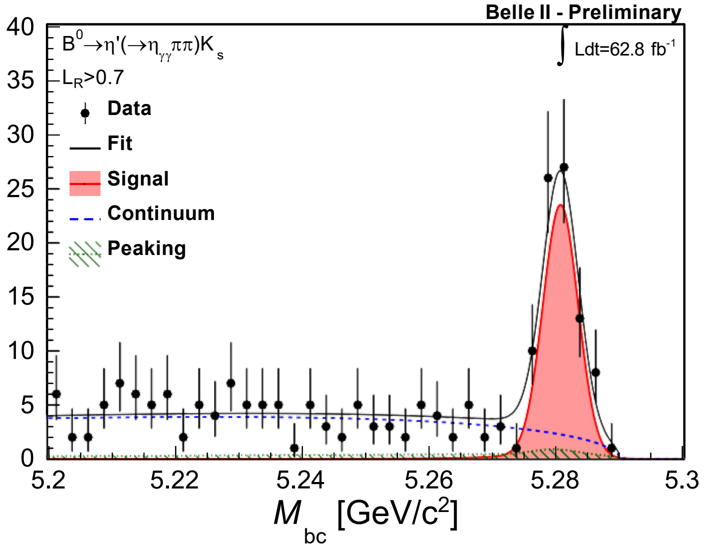
$$\Delta E = E^*_B - E_{beam}$$

$$N_{sig}(\mu^+\mu^-) = 267 \pm 21(stat) \pm 28(peaking)$$

$$N_{sig}(e^+e^-) = 226 \pm 20(stat) \pm 31(peaking)$$

arXiv:2106.13547

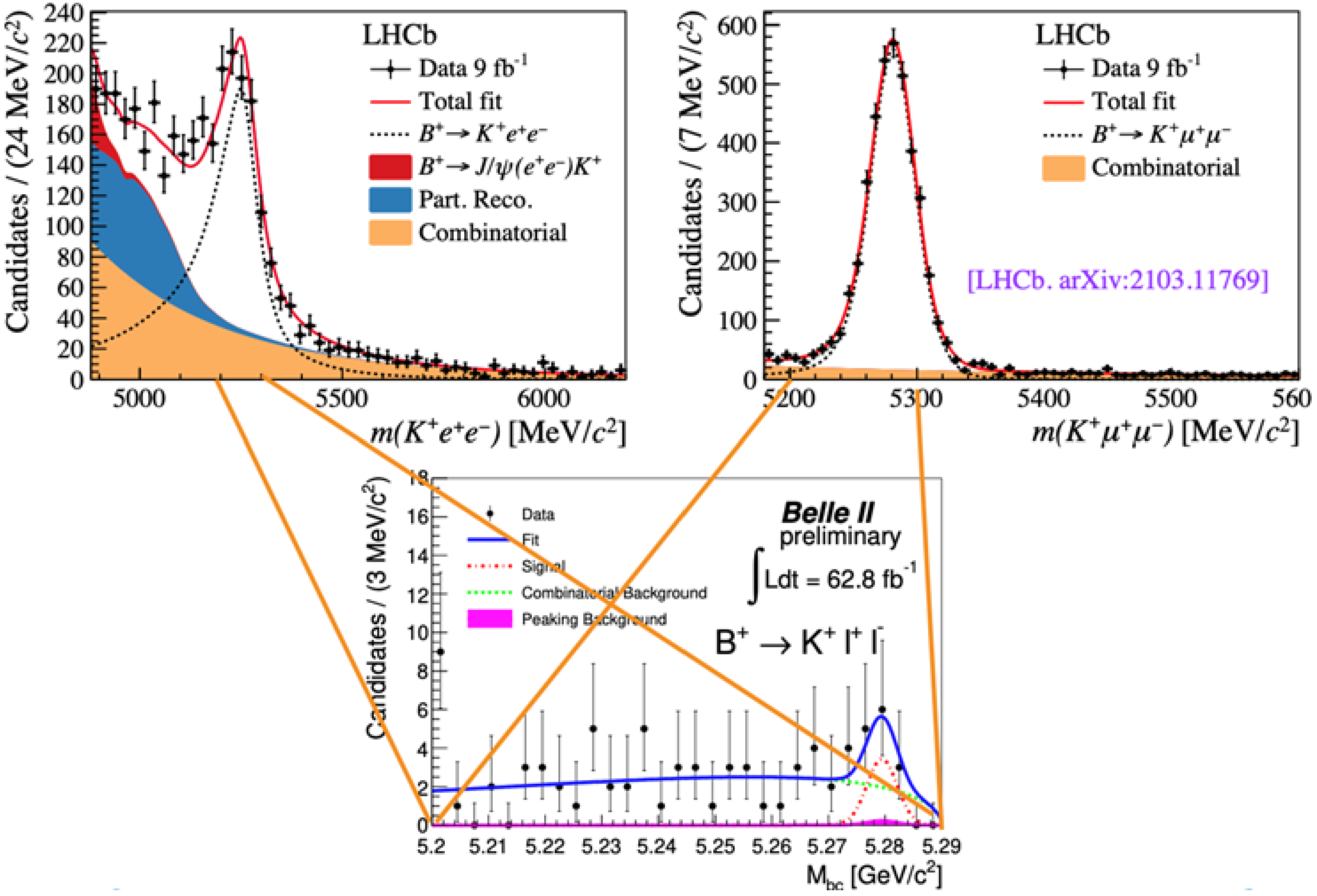
Rediscovery of $B \to \eta' K$



$$M_{bc} = (E^{*2} c^4 - p^{*2} c^2)^{0.5}$$

Channel	This analisis $\mathcal{B}$ $(\times 10^6)$	World average [?]
$B^\pm \to \eta' K$	$63.4\,^{+3.4}_{-3.3}(\text{stat}) \pm 3.2(\text{syst})$	70.6 ± 2.5
$B^0 \to \eta' K^0$	$60.4\,^{+3.3}_{-3.4}(\text{stat}) \pm 2.9(\text{syst})$	66 ± 4

R(K) Belle2 vs LHCb



	Belle II	LHCb
Signal	K^+, K_s	K^+
Same K e e Statistics	1 ab^{-1}	1 fb^{-1}
B->K mu mu Efficiency	30 %	~5 %
B->K e e Efficiency	30 %	<5% Lower due to tracking and trigger
B->K e e Resolution	Better thanks to M_{bc}	Worse because of Brems
High q^2 bin	Accessible	Hard

Probing τ-μ Universality and LFV in ϒ(3S) Decays

Phys. Rev. Lett. 125.241801

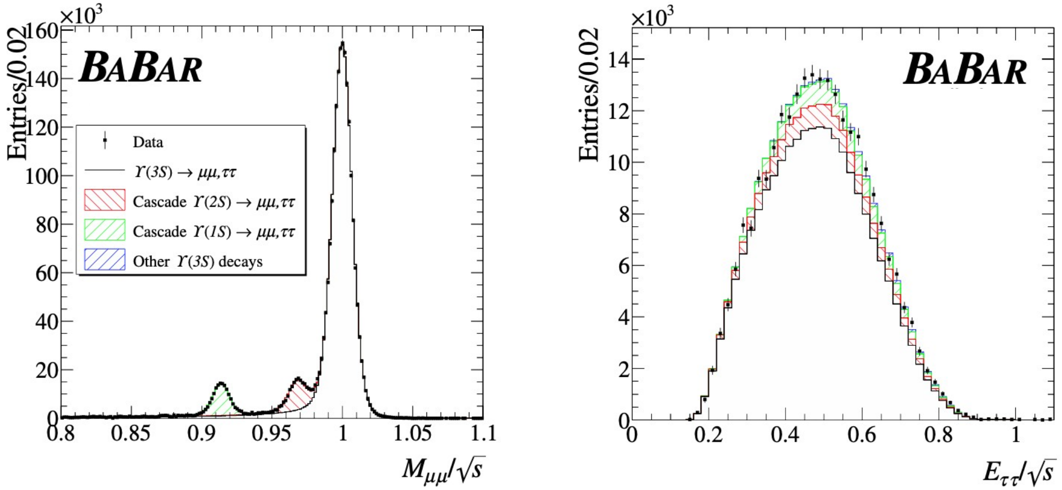
- The decay widths of a $q\bar{q}$ bound state into a pairs of leptons can be precisely calculated
- The ratio of decay widths in τ pairs and μ pairs $R_{\tau\mu}$ is therefore a sensitive probe for New Physics such as
  - light CP-odd Higgs in 2HDM (Type-II) models with large tanβ
  - New Physics contributions that might resolve tensions in R(D*) measurements
- Based on ϒ(3S), ϒ(4S) and off-resonance data the Babar measurement exploits differences between resonant and off-resonant di-muon processes to improve the precision
- The result is six times more precise than previous measurement and agrees with the SM prediction of 0.9948 within ± 2σ

$$\Gamma_{\Upsilon\to\ell\ell} = 4\alpha^2 e_q^2 \frac{|\Psi(0)|^2}{M^2}(1+2m_\ell^2/M^2)\sqrt{1-4m_\ell^2/M^2}$$

$$R_{\tau\mu} = \frac{\Gamma_{\Upsilon\to\tau\tau}}{\Gamma_{\Upsilon\to\mu\mu}} = \frac{(1+2m_\tau^2/M^2)\sqrt{1-4m_\tau^2/M^2}}{(1+2m_\mu^2/M^2)\sqrt{1-4m_\mu^2/M^2}}$$

$V(nS)$	SM prediction
$\Upsilon(1S)$	$0.9924 \pm \mathcal{O}(10^{-5})$
$\Upsilon(2S)$	$0.9940 \pm \mathcal{O}(10^{-5})$
$\Upsilon(3S)$	$0.9948 \pm \mathcal{O}(10^{-5})$

Result of template fit after continuum background subtraction



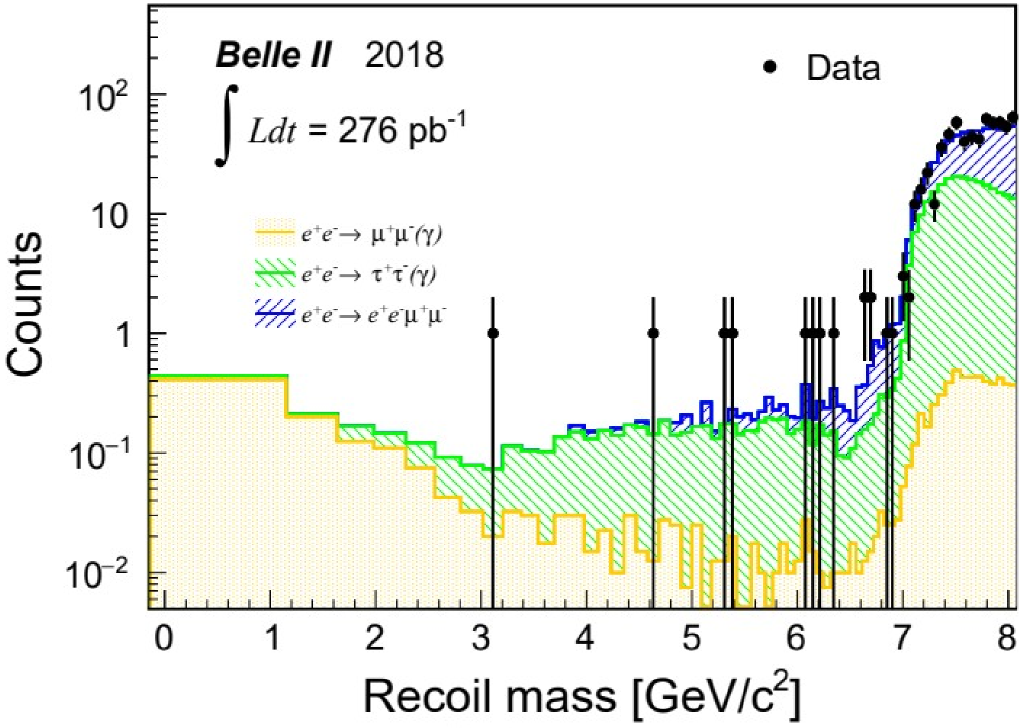
$$R_{\tau\mu}^{\Upsilon(3S)} = \frac{\Gamma_{\Upsilon\to\tau^+\tau^-}}{\Gamma_{\Upsilon\to\mu^+\mu^-}} = 0.966 \pm 0.008_{stat} \pm 0.014_{syst}$$

- The data are also used to derive an upper limit on electron-muon flavor violation in ϒ(3S) decays: $\mathcal{B}(\Upsilon(3S) \to e^{\pm}\mu^{\mp}) < 3.6 \times 10^{-7}$ at 90% CL

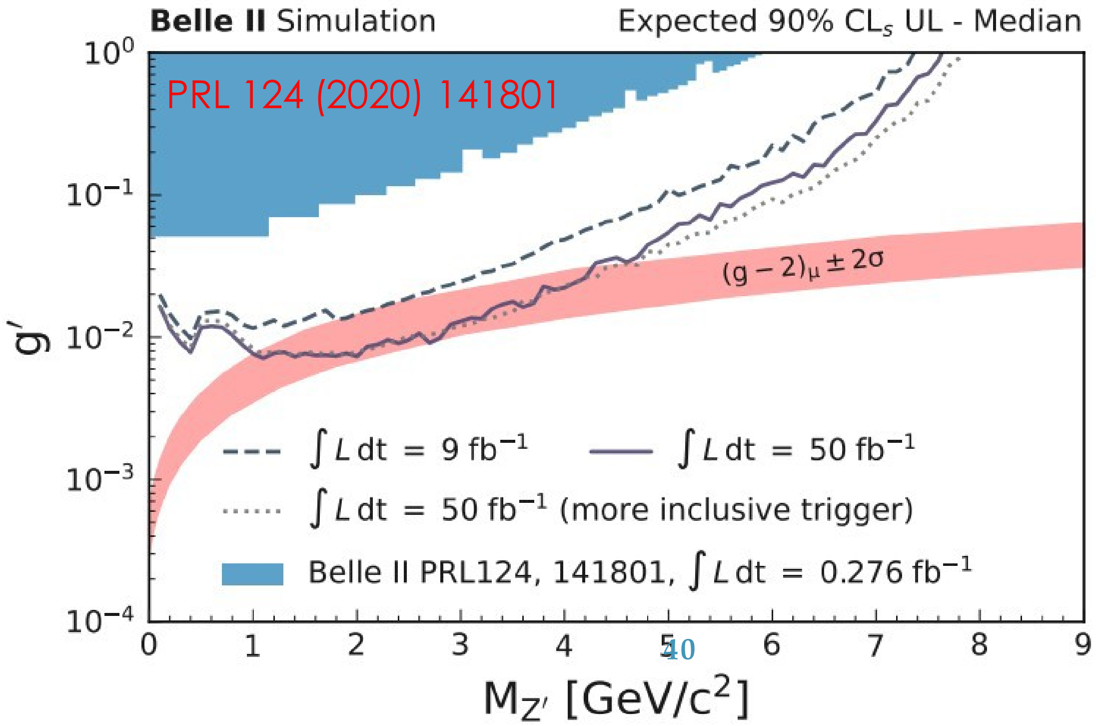
$L_\mu - L_\tau$ model: Z' to invisible

Measurement done using **2018 pilot run data**: only 276 pb^{-1} usable due to trigger conditions.
Looking for:

- a peak in the mass distribution of the system recoiling against the dimuon pair;
- nothing else in the rest of the event.

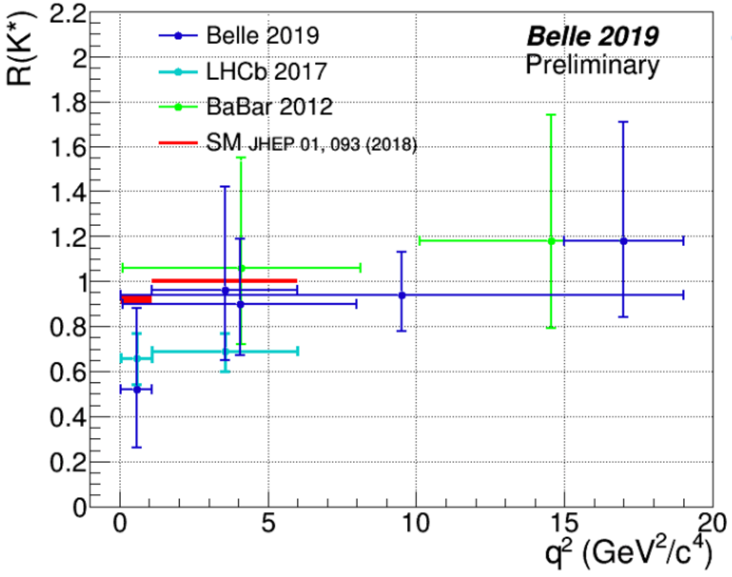


90% CL upper limit on the g′ coupling constant



Starting to probe the $(g-2)_\mu$ band already with 50 fb^{-1}

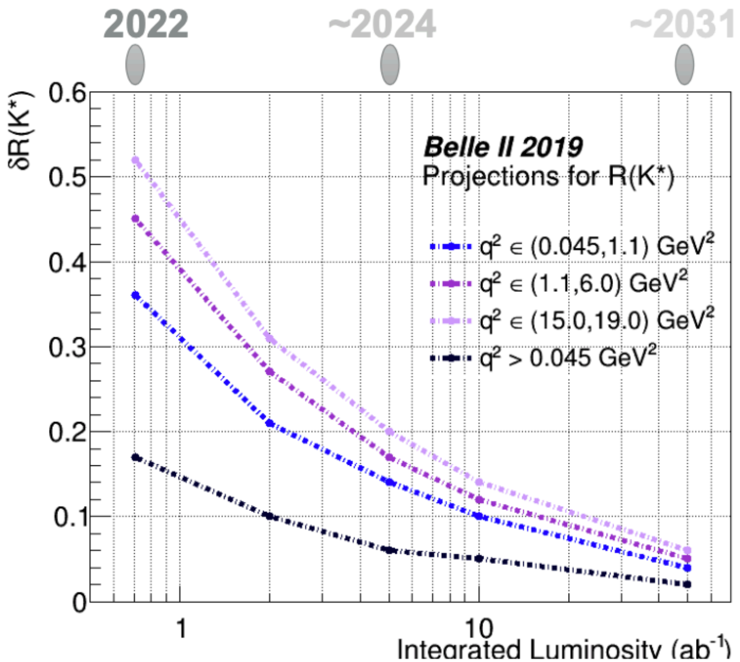
Belle II Prospects (R(K*), angular)

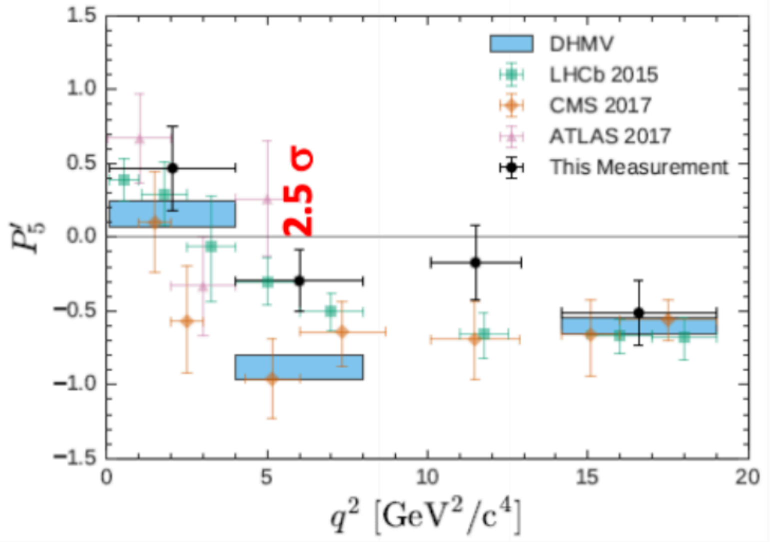


[Belle arXiv: 1904.02440]

Belle (R(K*))

- Largest deviation in the low q^2 bin

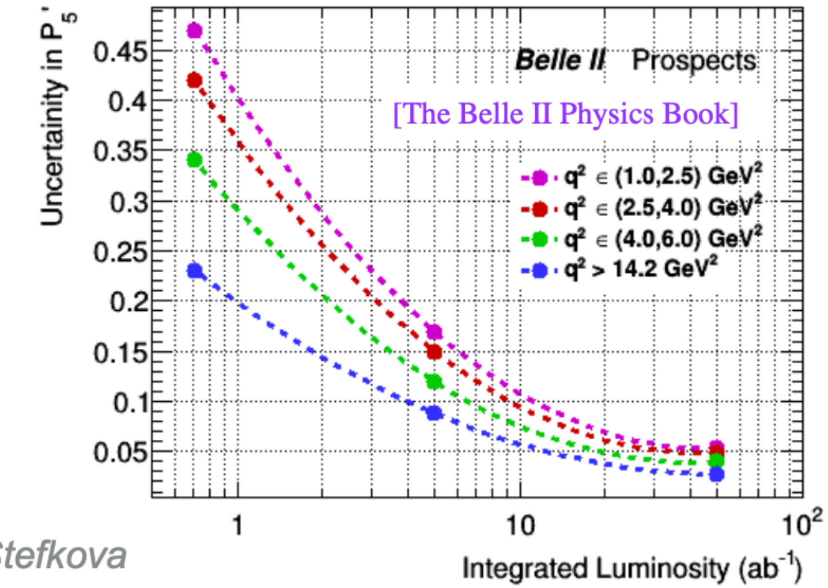




[Belle Phys. Rev. Lett. 118, 111801]

Belle P'_5

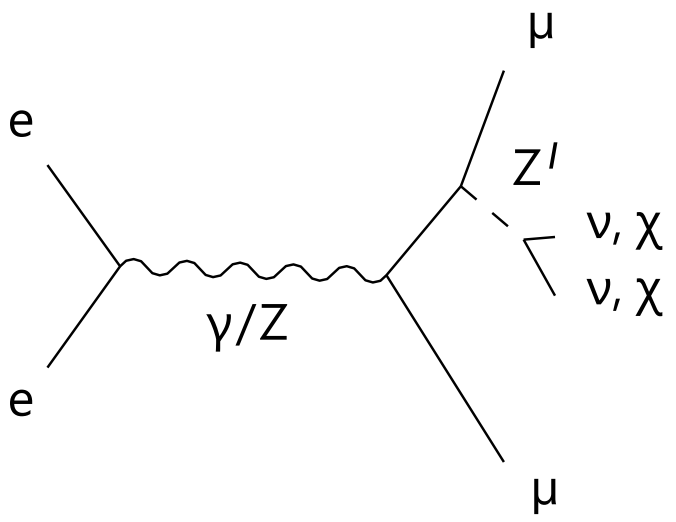
- The largest deviation with 2.6 sigma observed in muon channel
- Electron channel is deviating with 1.1 sigma
- With 2.8 ab^{-1} the uncertainty on P'_5 (both e & mu) will be comparable to LHCb 3 fb^{-1} (mu only)



L – L model: Z' to invisible

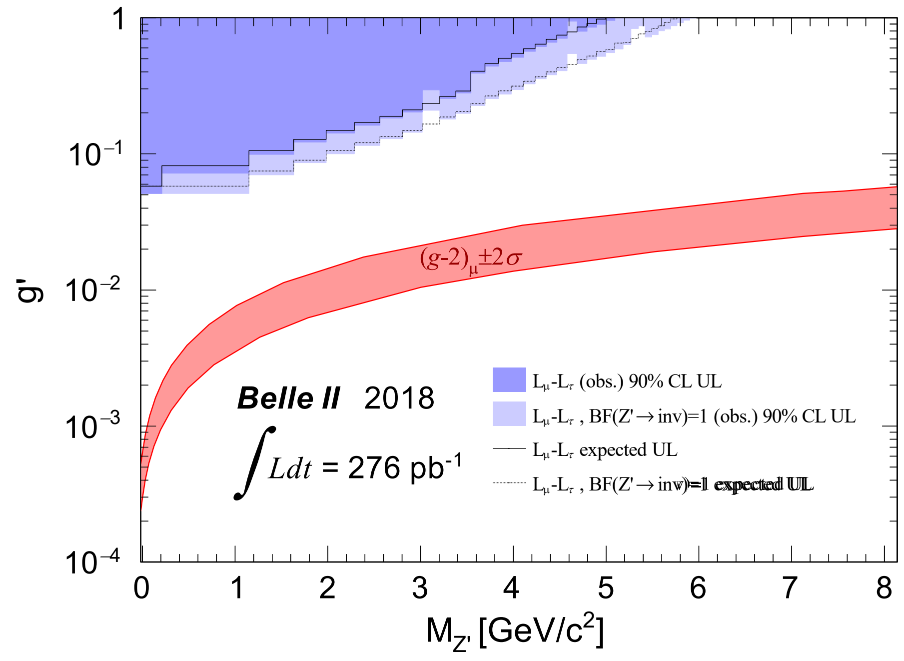
$L_\mu - L_\tau$ model:

- Z` does not interact with 1st generation leptons
- includes dark matter candidate
- potentially addresses $(g-2)_\mu$ anomaly



Phys. Rev. D, 89, 113004. June 2014

Search for resonance in mass of system recoiling against muon pair:



- Simulations: can probe $(g-2)_\mu$ band with $\sim 50\ \text{fb}^{-1}$

Belle II, Phys. Rev. Lett. 124, 141801. April 2020, BELLE2-NOTE-PL-2020-012

Axion-Like Particles: $a \to \gamma\gamma$

- $445 \pm 3 \mathrm{pb}^{-1}$ of data taken in 2018
- Search for bump on large $ee \to \gamma\gamma\gamma$ background
- Require that the photon $t/\Delta t$ are all consistent with each other
- No tracks from the interaction point
- $0.88\sqrt{s} \le m_{\gamma\gamma\gamma} \le 1.03\sqrt{s}$
- No significant excesses observed
- Even with a small data set, results exclude previously unexplored parts of phase space.

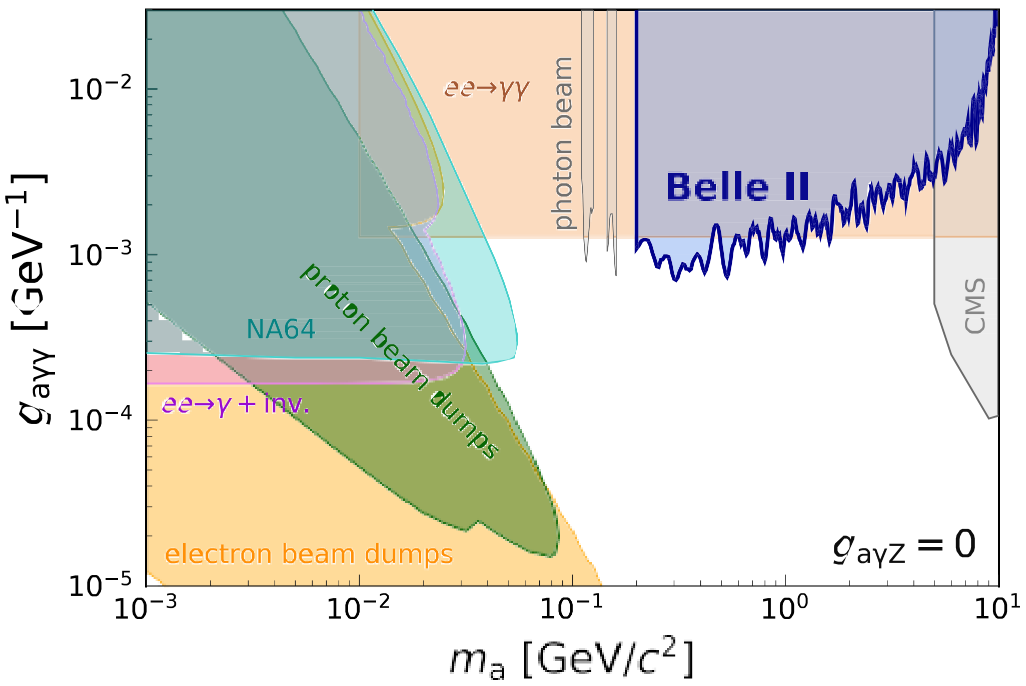


FIG. 5. Upper limit (95% C.L.) on the ALP-photon coupling from this analysis and previous constraints from electron beam-dump experiments and $e^+e^- \to \gamma +$ invisible [6,9], proton beam-dump experiments [8], $e^+e^- \to \gamma\gamma$ [11], a photon-beam experiment [12], and heavy-ion collisions [13].

Belle II, Physics Review Letters 125, 161806 (2020)