Recent highlights from Belle II

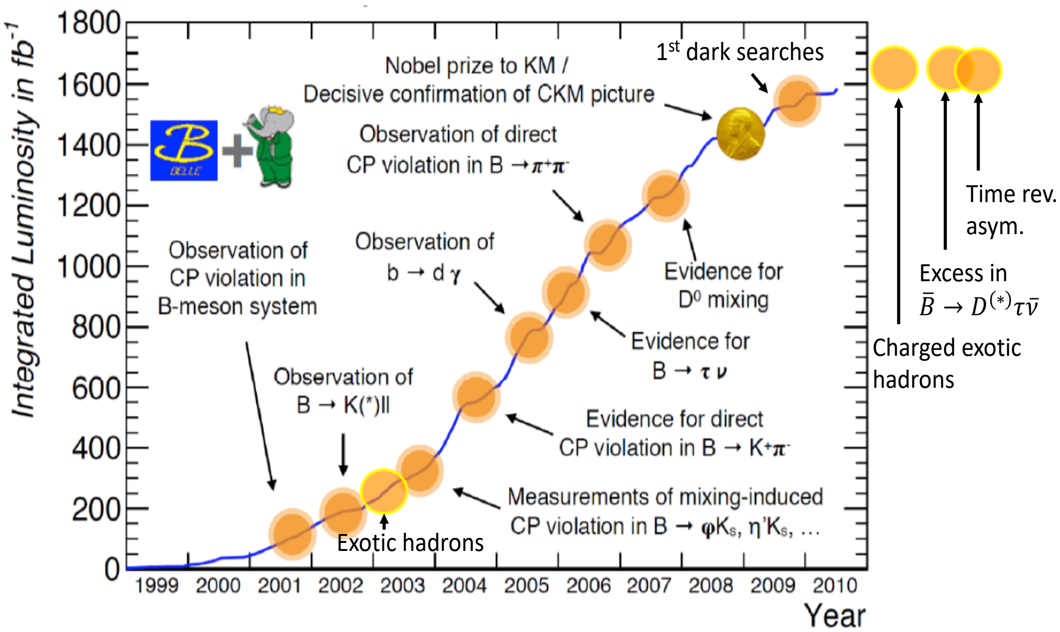
*Mario Merola**

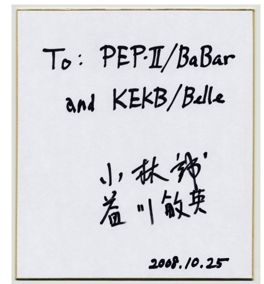
on behalf of the Belle II Collaboration

*University of Naples Federico II

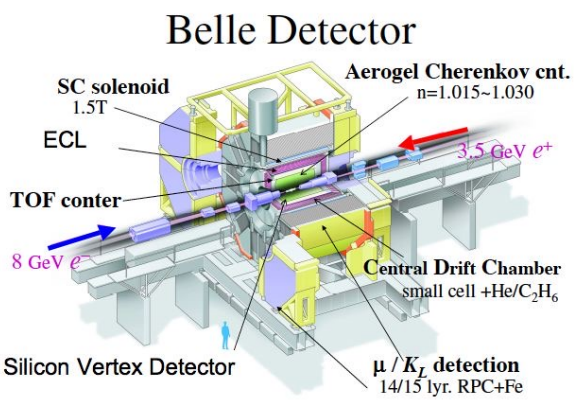
HADRON 2023

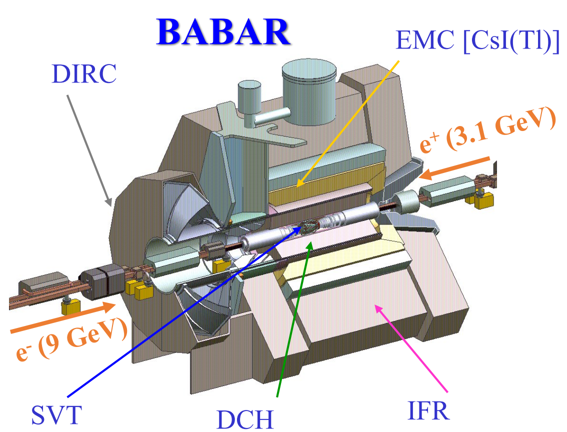
Babar and Belle achievements





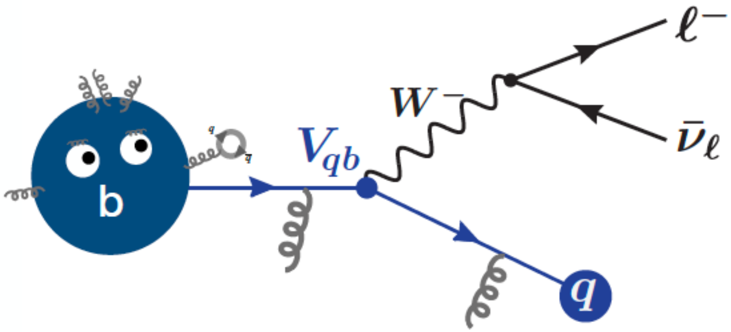
Kobayashi, Maskawa nobel prize in 2008





Successful experimental program
Established CP violation in B system and remarkable consistency of the CKM mechanism of the SM

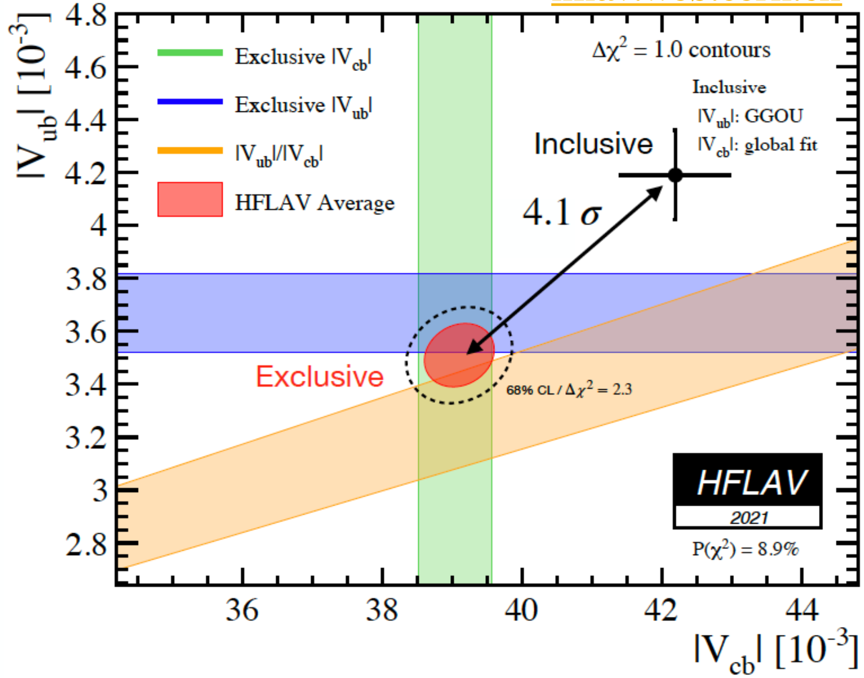
Hot topics (1): Inclusive and exclusive V_{xb} determinations



- **Tension** between inclusive and exclusive determinations via semileptonic B decays: ~3σ for both $|V_{cb}|$ and $|V_{ub}|$

- $X_c l\nu$ decays are a clear test of the SM LFU: **NP** (charged Higgs in 2HDM models or Leptoquarks) **can affect the BR and $|V_{cb}|$**

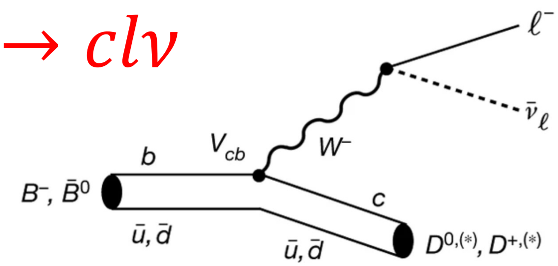
hflav.web.cern.ch



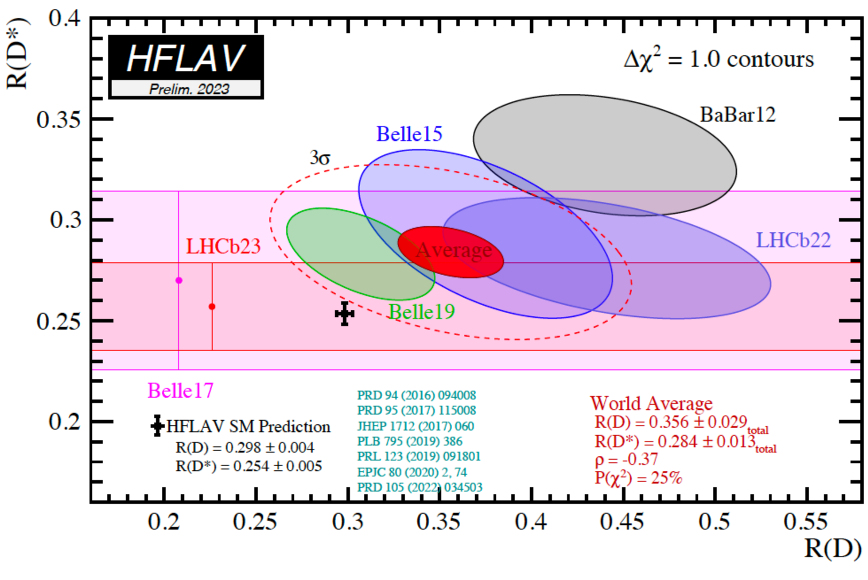
New physics or theoretical issue ?

Hot topics (2): LFV in B decays

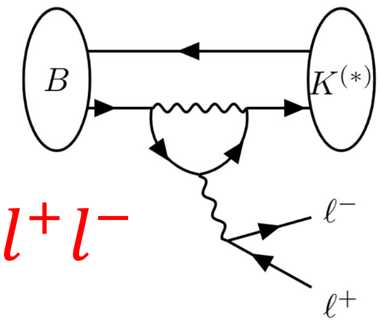
$b \to c l \nu$



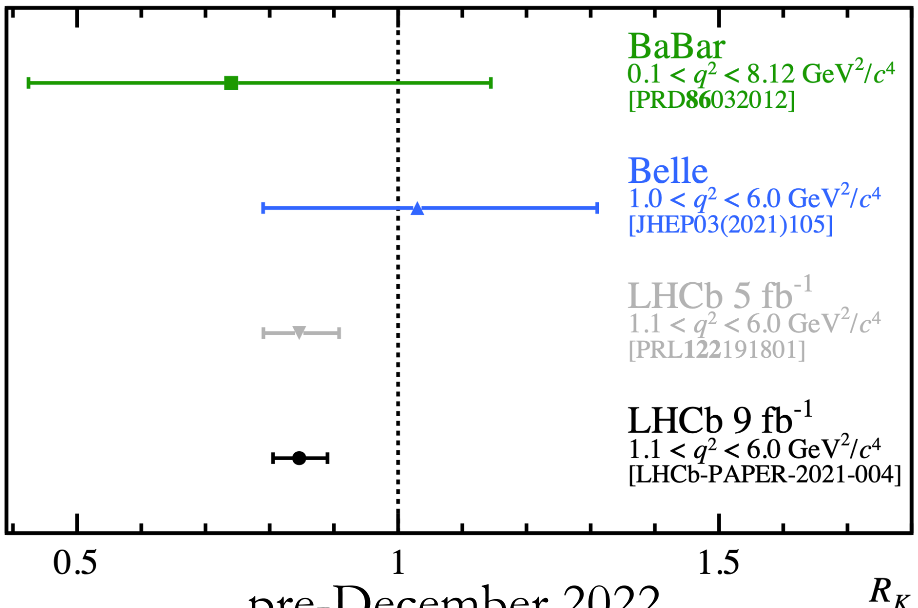
$$R(D^{(*)}) = \frac{\mathscr{B}(B \to D^{(*)}\tau\nu)}{\mathscr{B}(B \to D^{(*)}\ell\nu)}$$



$b \to s l^+ l^-$



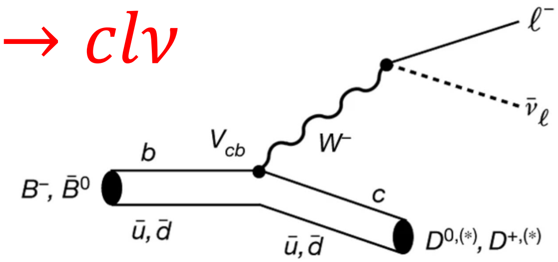
$$R(K) = \frac{\mathscr{B}(B^+ \to K^+\mu\mu)}{\mathscr{B}(B^+ \to K^+ee)}$$



pre-December 2022

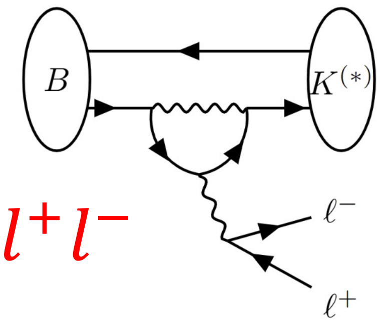
Hot topics (2): LFV in B decays

$b \to cl\nu$

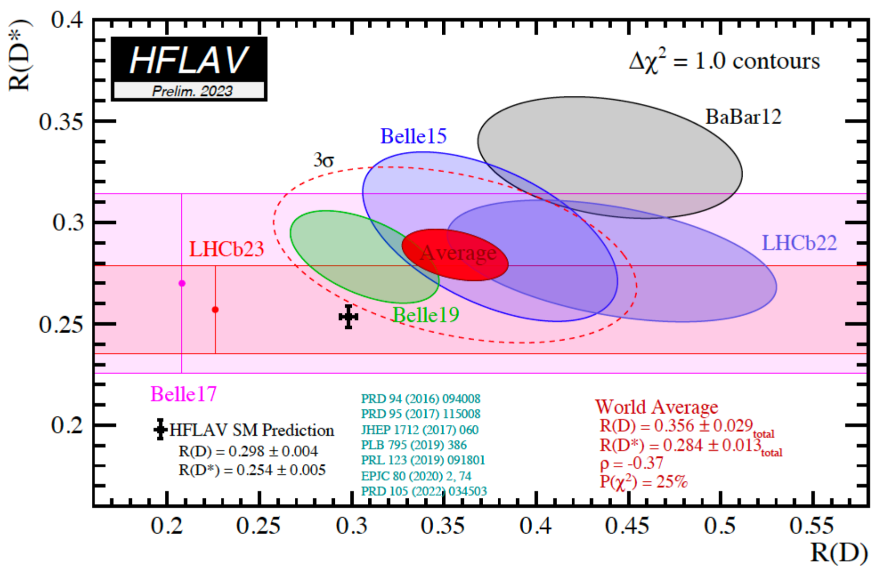


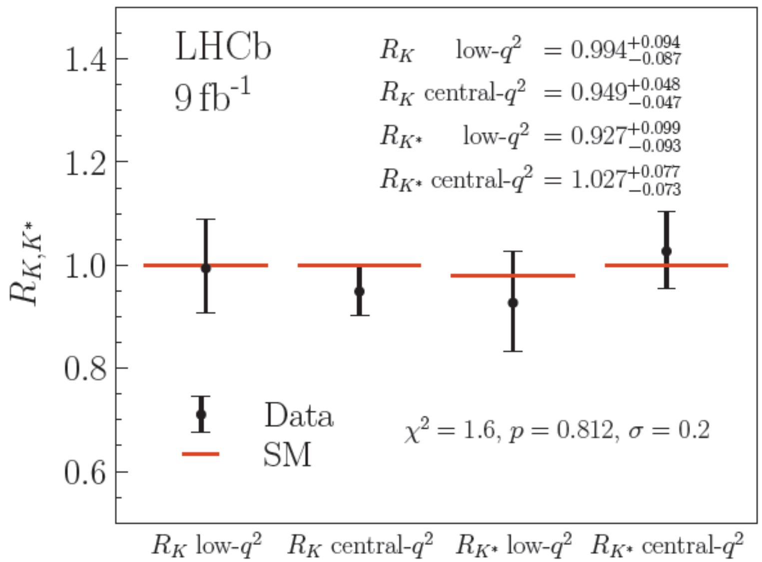
$$R(D^{(*)}) = \frac{\mathscr{B}(B \to D^{(*)}\tau\nu)}{\mathscr{B}(B \to D^{(*)}\ell\nu)}$$

$b \to sl^+l^-$



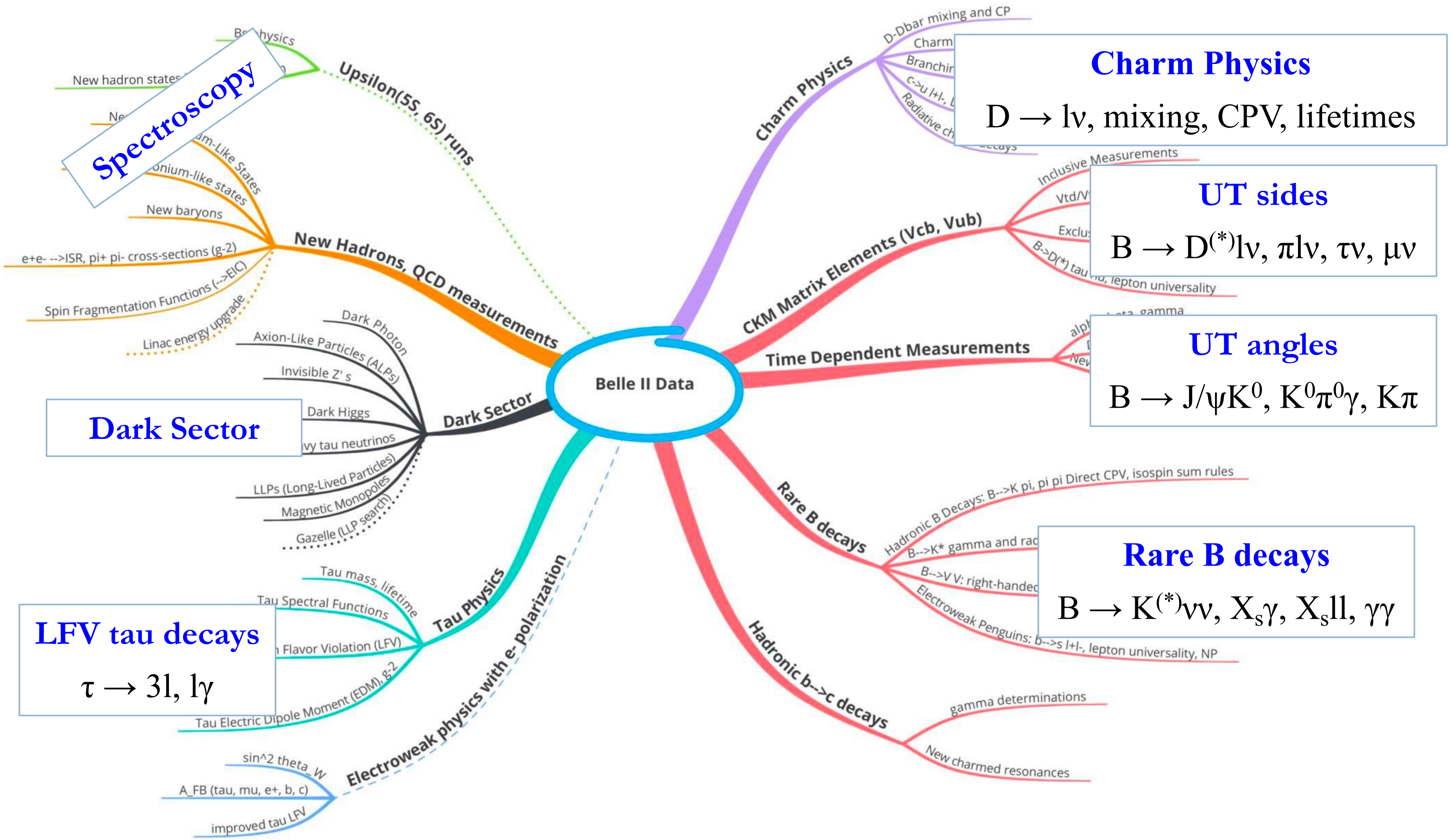
$$R(K) = \frac{\mathscr{B}(B^+ \to K^+\mu\mu)}{\mathscr{B}(B^+ \to K^+ee)}$$





arXiv:2212.09153v1

Belle II physics program



Spectroscopy

Charm Physics

$D \to l\nu$, mixing, CPV, lifetimes

UT sides

$B \to D^{(*)}l\nu, \pi l\nu, \tau\nu, \mu\nu$

UT angles

$B \to J/\psi K^0, K^0\pi^0\gamma, K\pi$

Dark Sector

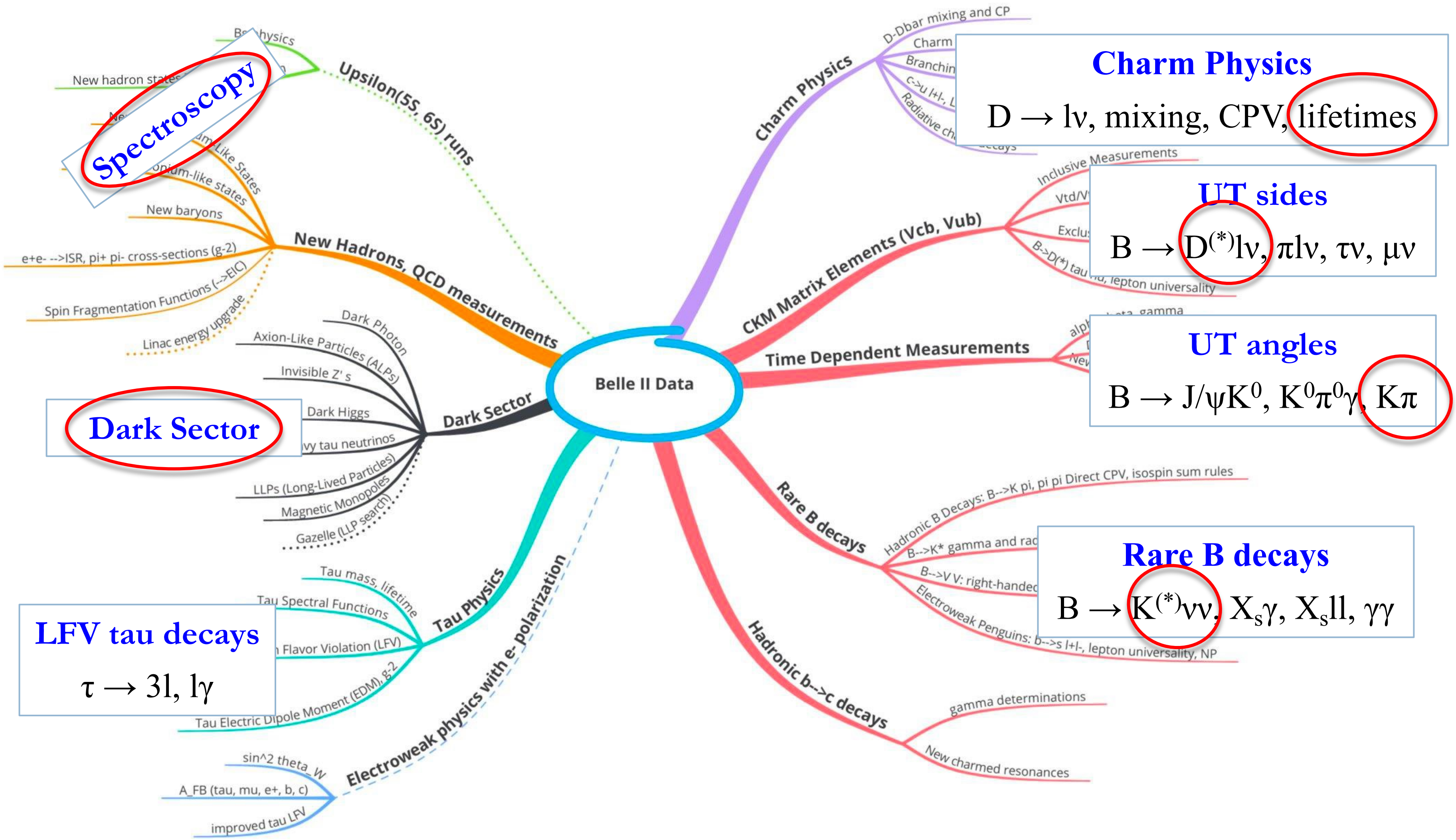
Rare B decays

$B \to K^{(*)}\nu\nu, X_s\gamma, X_s ll, \gamma\gamma$

LFV tau decays

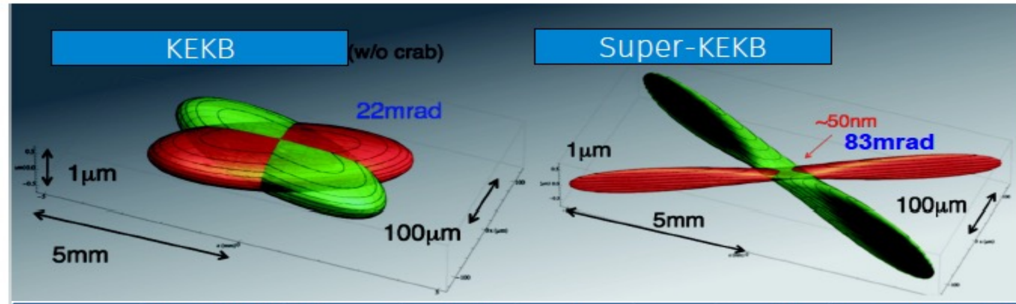
$\tau \to 3l, l\gamma$

Belle II physics program



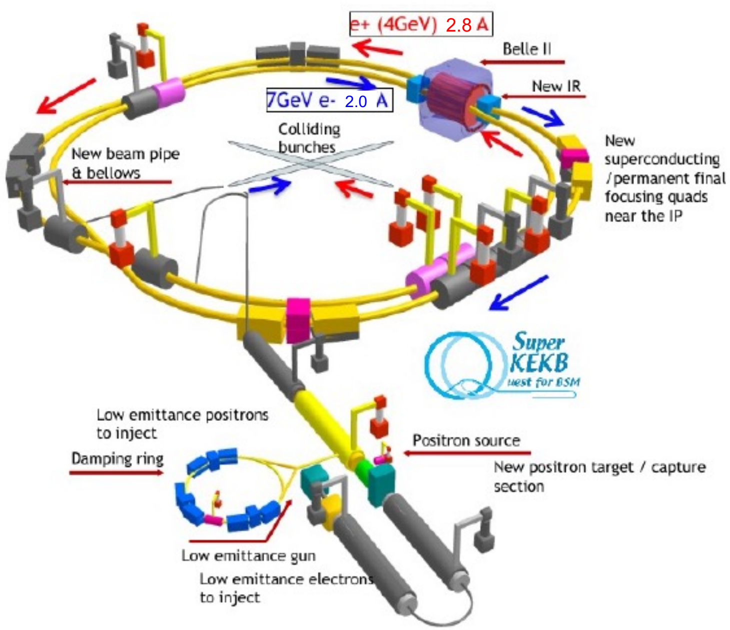
SuperKEKB

- Asymmetric energy $e^+(4\ GeV)\ e^-(7\ GeV)$ collider, at Υ(4S) mass
- Situated at KEK (Tsukuba, Japan), upgrade of KEKB

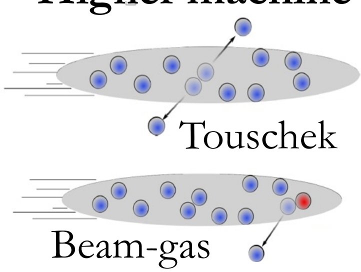


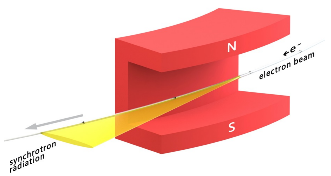
	Energy (GeV) LER/HER	β_y^* (mm) LER/HER	ε_x (nm) LER/HER	ξ_y LER/HER	φ (mrad)	I_{beam} (A) LER/HER	Luminosity ($cm^{-2}s^{-1}$) x 10^{34}
KEKB Achieved	3.5/8.0	5.9/5.9	18/24	0.13/0.09	11	1.6/1.2	2.11
SuperKEKB	4.0/7.0	0.27/0.3	3.2/2.4	0.09/0.09	41.5	2.8/2.0	65

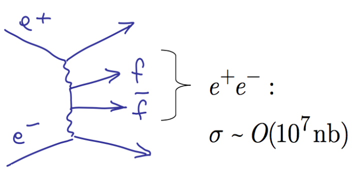
factor 20 factor 1.5



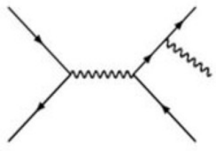
Higher machine induced and luminosity backgrounds



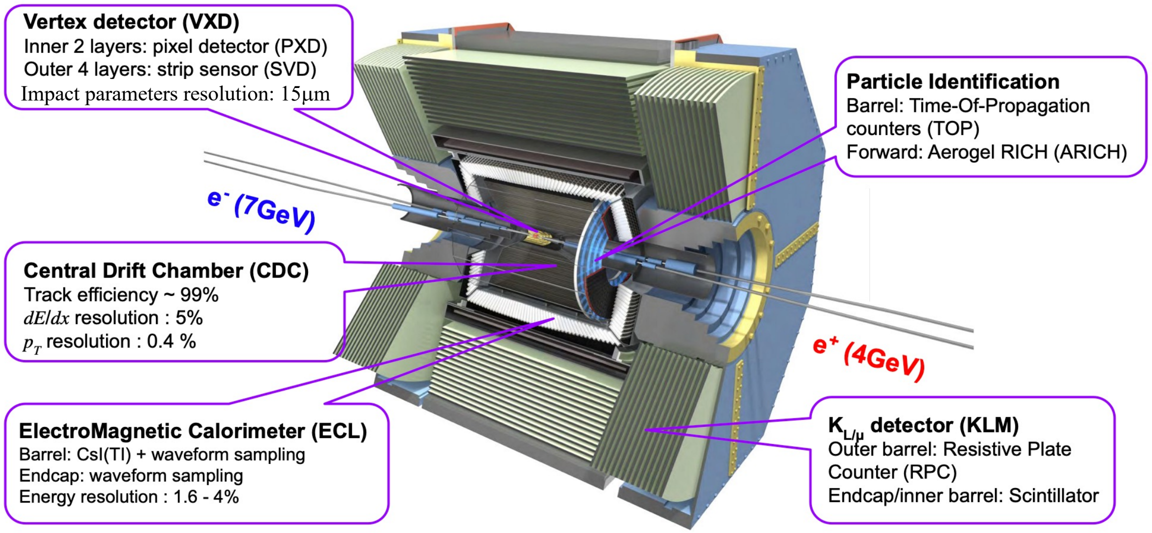


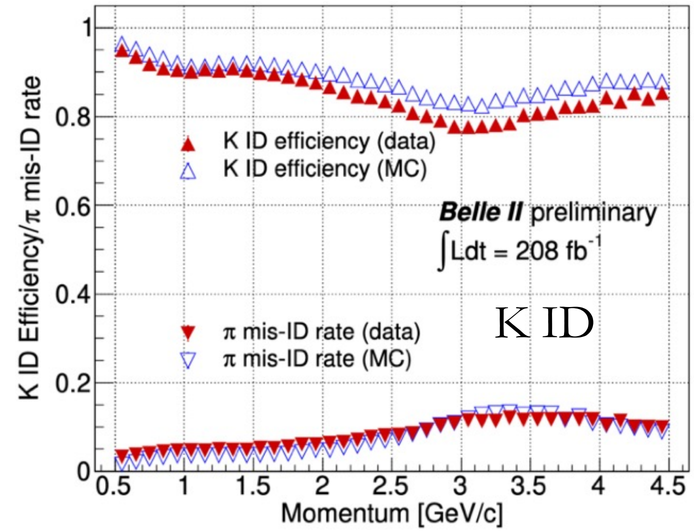


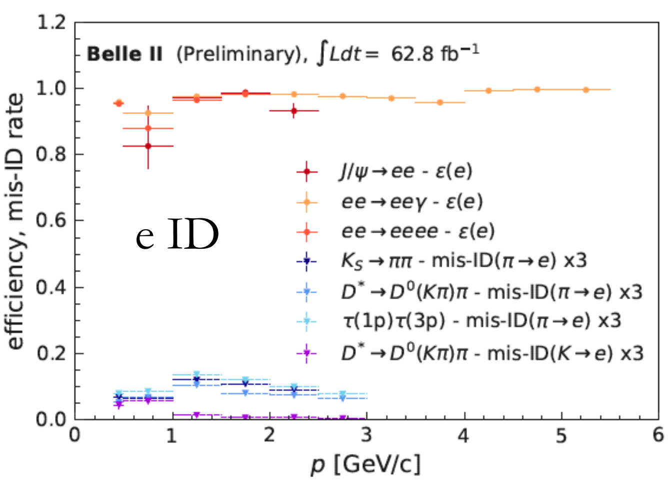
- Radiation damage
- Occupancy in inner detectors
- Fake tracks

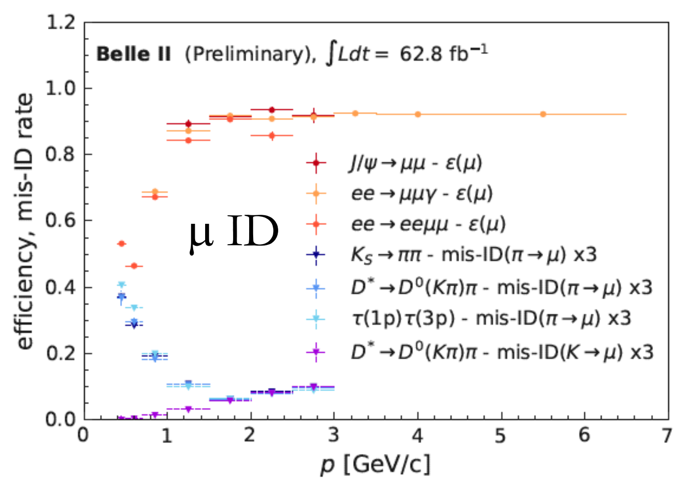

Radiative Bhabha

The Belle II Detector





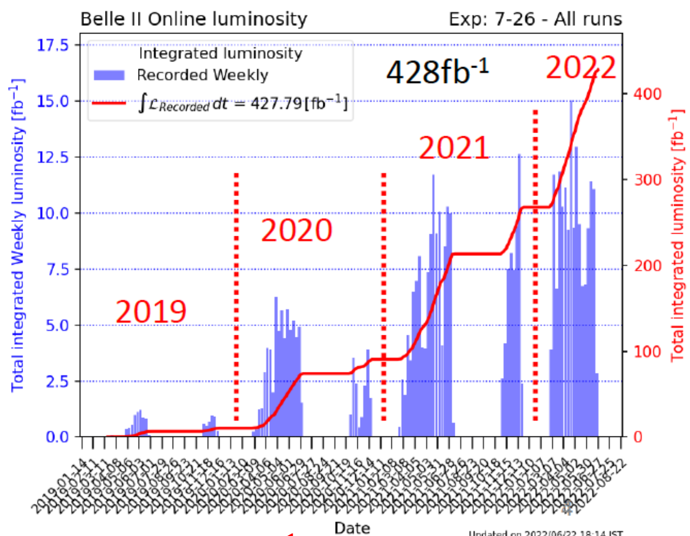




Particle ID and separation

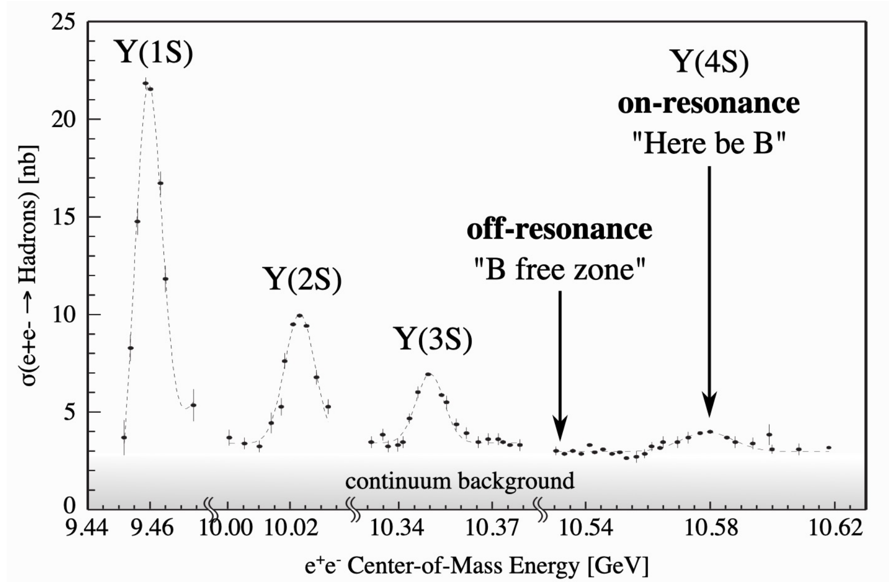
- K/π: ε ~90% @ 5–10% fake
- μ/π: ε~90% @ 7% fake
- e/π: ε ~86% @ <1% fake

Luminosity and projections



$L_{int} = 428\ fb^{-1}$ ~ Babar dataset

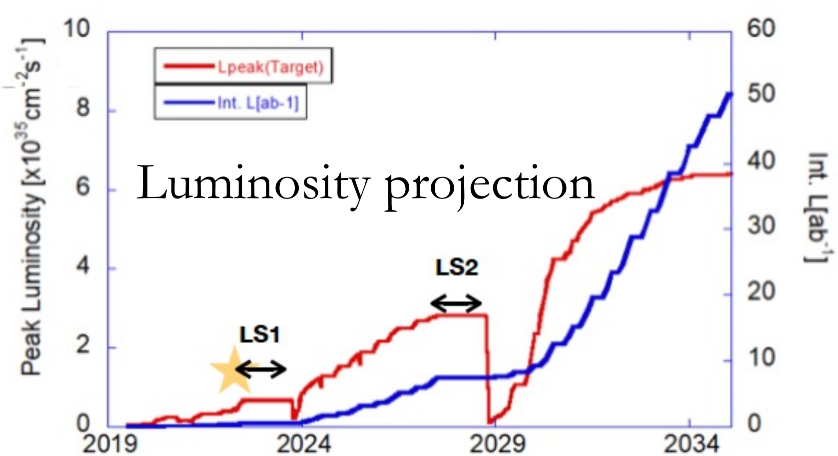
$L = 4.7\times10^{34}\ cm^{-2}\ Hz$ record



85% taken at Υ(4S) peak – **BB pairs**

10% taken 60 MeV below Υ(4S) – **continuum (qq, ll, 2γ)**

5% taken around 10.75 GeV - **spectroscopy**

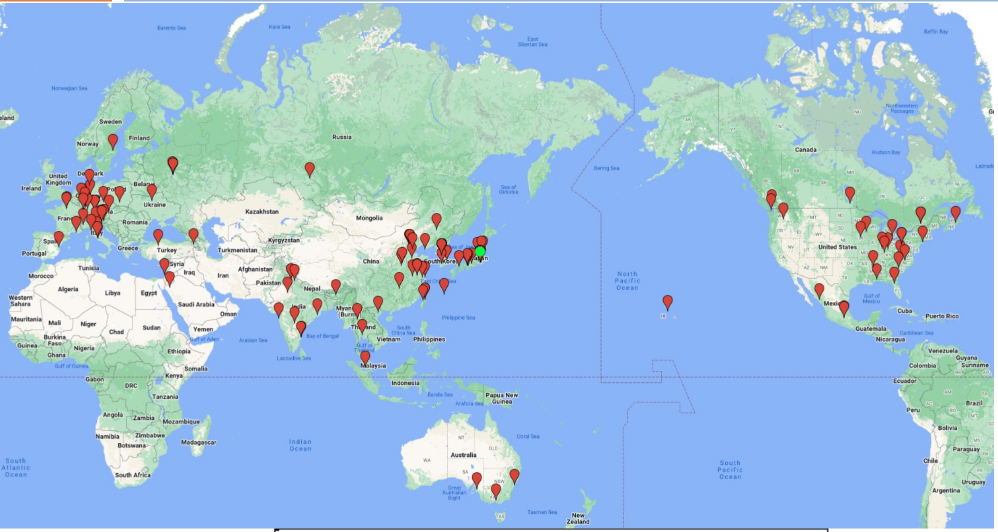


A long journey ...

- 1st Long shutdown (LS1) in 2022-2023 (PXD, beam pipe, TOP)
- 2nd Long shutdown (LS2) in ~2028 (QCS, RF)

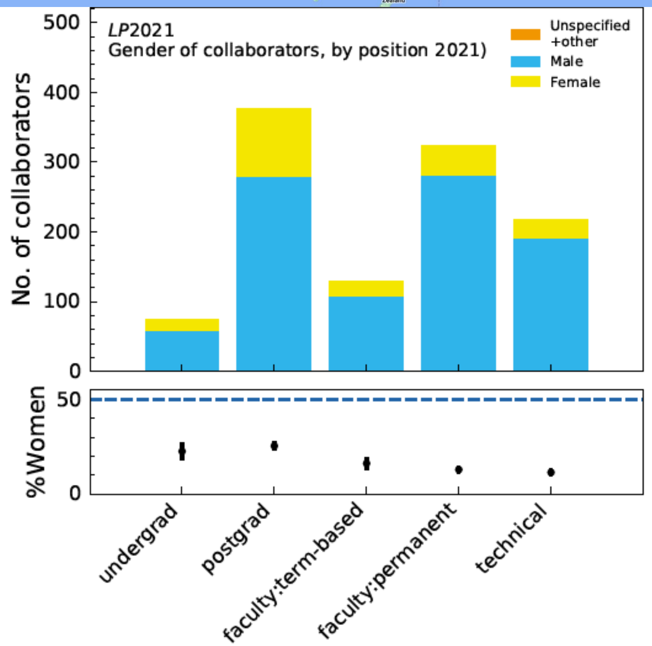
Goal is to accumulate 50 ab^{-1}

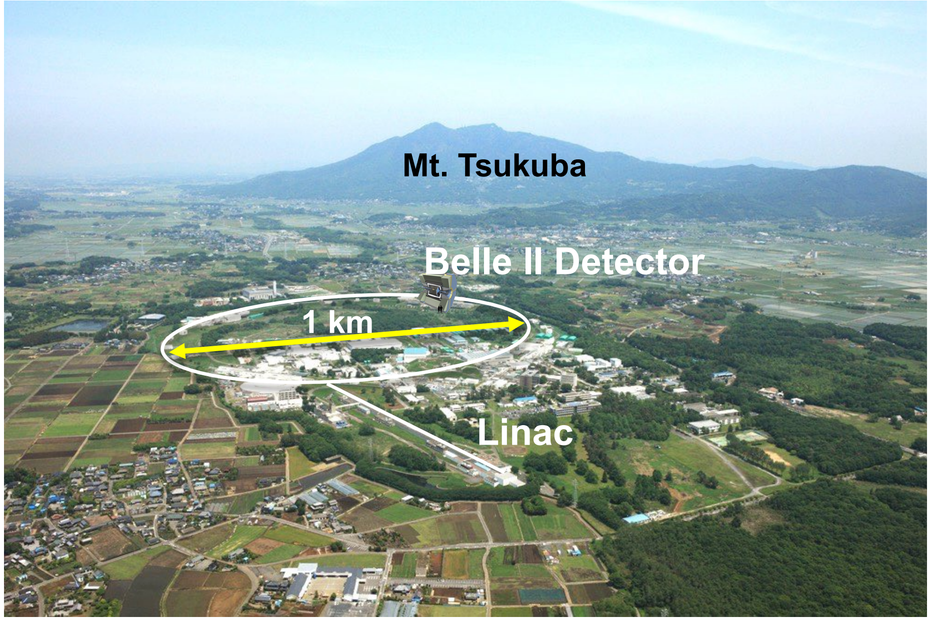
Belle II collaboration



Belle II: ~1160 collaborators
124 institutions
27 regions/countries

250 PhD students
150 postdocs

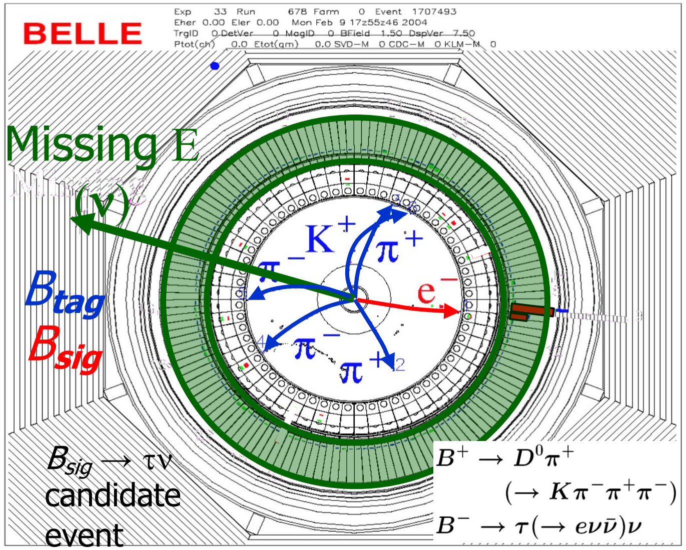


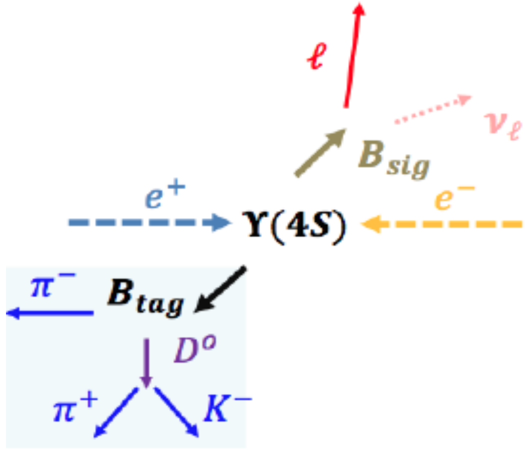


Unique capabilities of e^+e^- B factories

- **Beam energy constraint**
- **Clean experimental environment:** high B, D, K, τ lepton reconstruction efficiency
- Long lived particles (e.g. **K_S**), **π^0s** and **photons** well reconstructed
- Capability of **inclusive measurements**
- **BB produced in quantum correlated state:** high flavour tagging effective efficiency (30% vs 5%@LHCb)
- The **full reconstruction of one B (B_{tag})** constraints the 4-momentum of the other B (B_{sig})
- Reconstruction of **channels with missing energy**

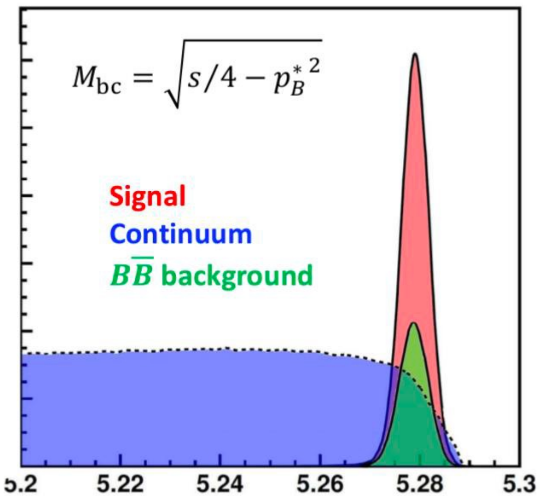
$$p_\nu = p_{e^+e^-} - p_{B_{tag}} - p_{B_{sig}}$$



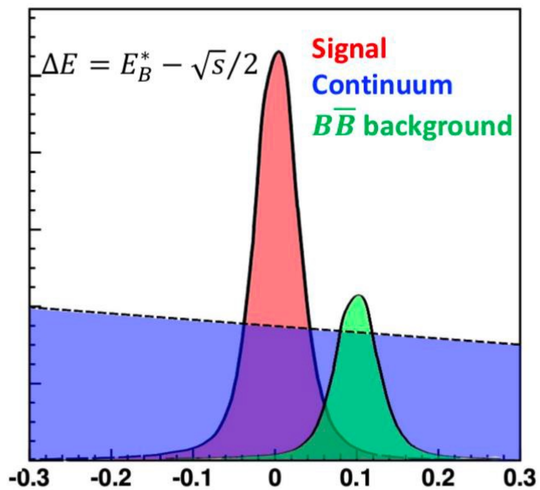


Unique capabilities of e^+e^- B factories

Stringent kinematic constraints

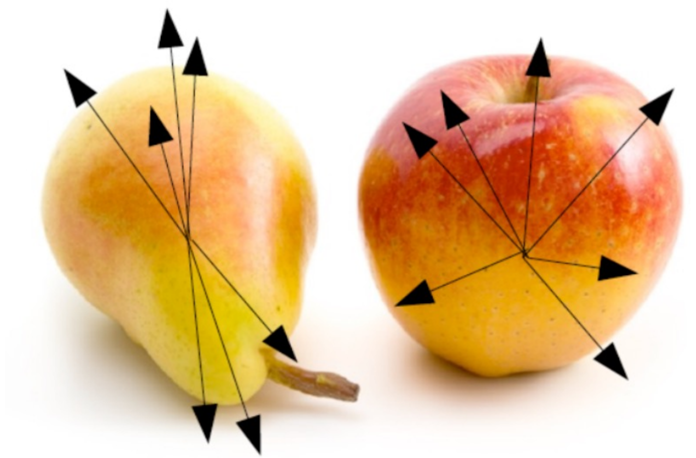


Invariant B mass with B energy replaced by half of the collision energy



Difference between expected and observed B energy

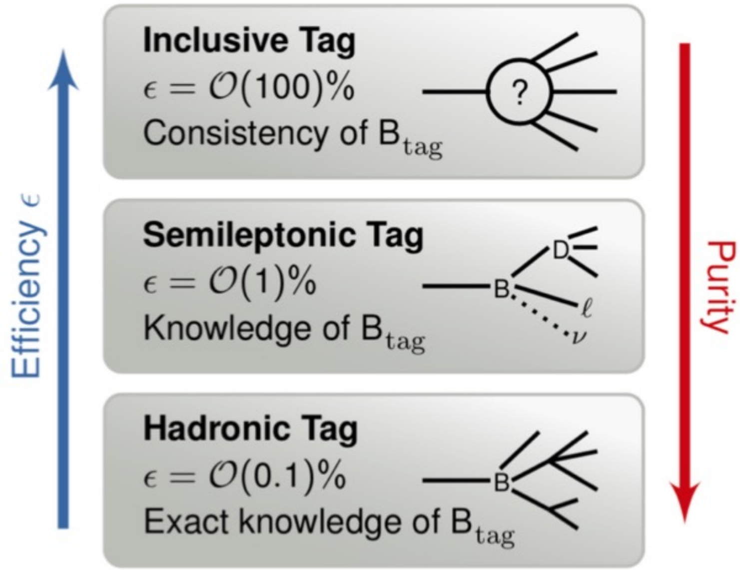
Use of event shape variables

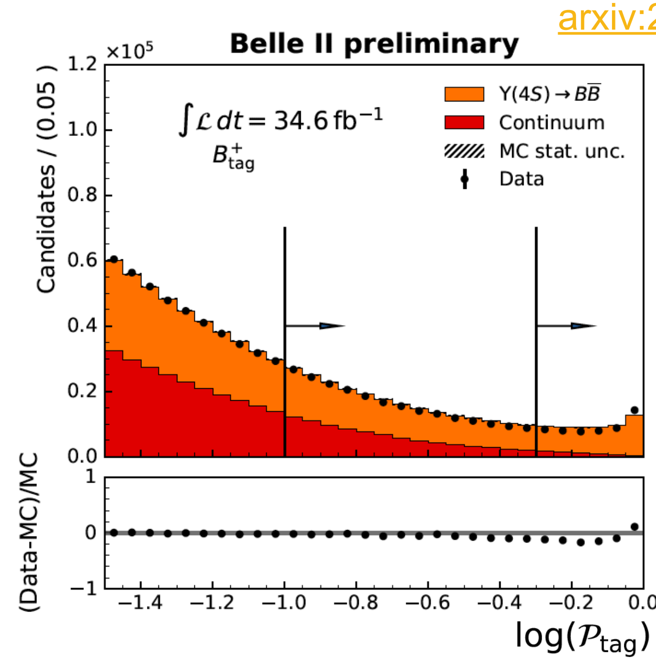


Continuum **BB**

Reconstruction of events with missing energy: Full Event Interpretation (FEI)

arxiv:2008.06096





The FEI uses a multivariate technique to reconstruct the B-tag side (semileptonic or hadronic) through $O(10^3)$ decay modes in a Υ(4S) decay.

Tagging efficiency (evaluated on Belle MC) @10% purity

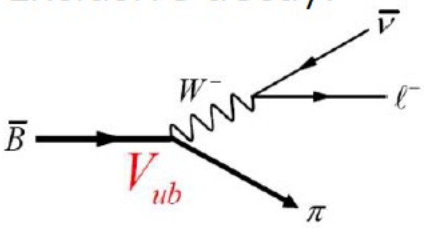
Tagging Algorithm	Had B^+/B^0 (%)	SL B^+/B^0 (%)
Full Reconstruction Belle	0.28/0.18	0.67/0.63
FEI Belle	0.78/0.46	1.80/2.04

Belle algorithm: NIM A 654, 432-440 (2011)
Belle II FEI: Keck, T., Abudinén, F., z, F.U. et al. Comput Softw Big Sci (2019) 3: 6. https://doi.org/10.1007/s41781-019-0021-8

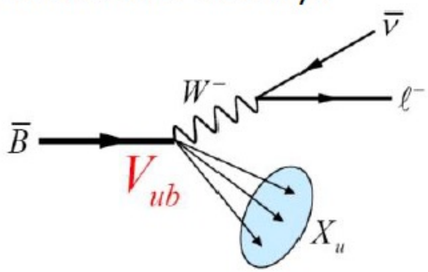
Semileptonic B decays

	Experiment	Theory
Exclusive	1. Lower signal efficiency 2. Lower background	Lattice QCD
Inclusive	1. Higher signal efficiency 2. Higher background	Heavy Quark Effective Theory (HQET)

Exclusive decay:



Inclusive decay:



I will focus on:

- Inclusive $B \to X_{c,u}\ell\nu$
- Exclusive $B \to D^*\ell\nu$

$|V_{cb}|$ measurement and test of LFUV

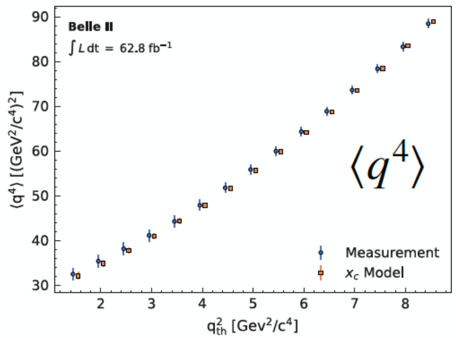
$|V_{cb}|$ determination: mass squared moments in $B \to X_c \ell \nu$

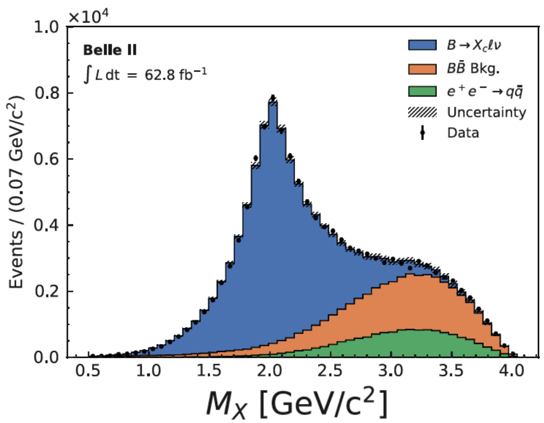
Total decay rate expressed as expansion of non-perturbative matrix elements (heavy quark expansion, HQE)

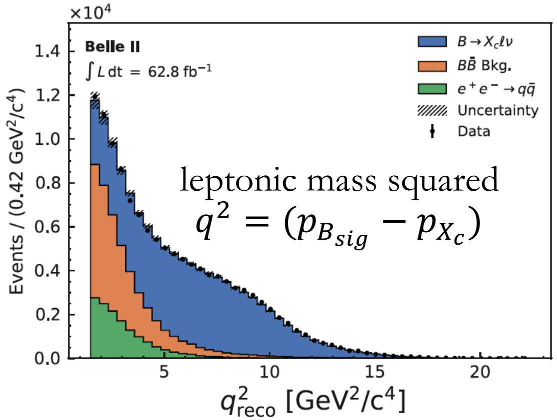
Hadronic tagged analysis

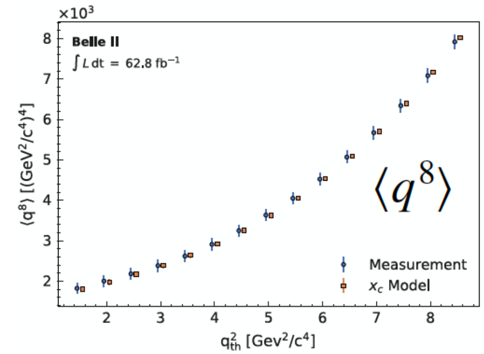
$$\Gamma = \frac{G_F^2 m_b^5}{192\pi^2}|V_{cb}|^2\left(1 + \frac{c_5(\mu)\langle O_5\rangle(\mu)}{m_b^2} + \frac{c_6(\mu)\langle O_6\rangle(\mu)}{m_b^3} + \mathcal{O}\left(\frac{1}{m_b^4}\right)\right)$$

Measure the **spectral moments** (moments of lepton energy or hadronic mass) in order to simultaneously determine the non perturbative elements and $|V_{cb}|$









Novel approach to determine $V_{cb} \to |V_{cb}| = (41.69 \pm 0.63) \cdot 10^{-3}$

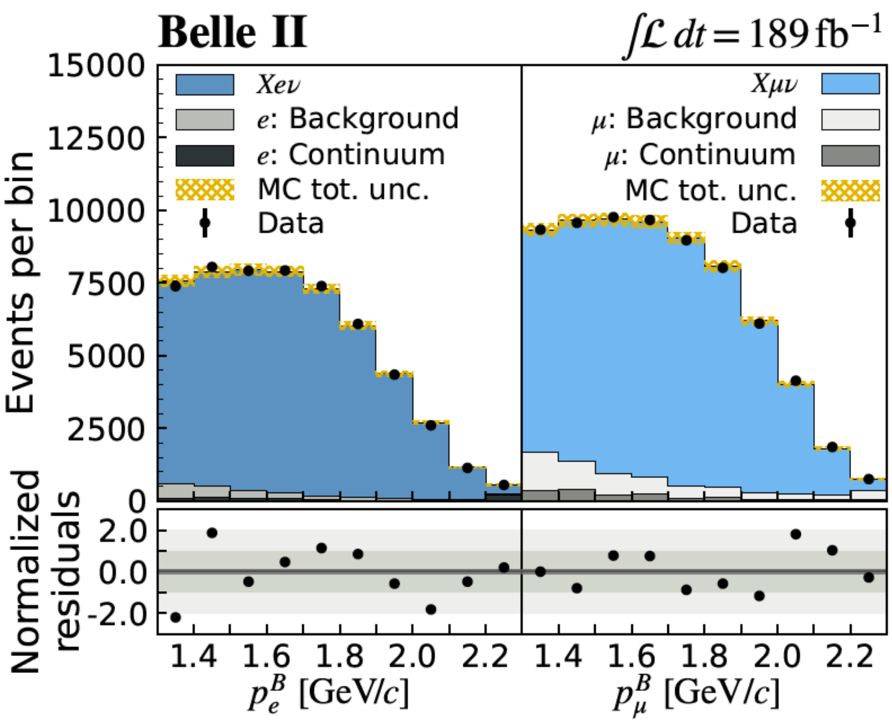
Competitive with world average $|V_{cb}^{incl}| = (42.19 \pm 0.78) \cdot 10^{-3}$

JHEP02(2019)177
PhysRevD.107.072002
JHEP10(2022)068

Test of lepton flavour universality: inclusive $B \to X\ell\nu$

$$R(X_{e/\mu}) = \mathcal{B}(B \to Xe\nu)/\,\mathcal{B}(B \to X\mu\nu)$$

Hadronic tagged analysis



Signal extraction from a binned log-likelihood fit in p_l^B with backgrounds constrained in the incorrect charge sideband

$$R(X_{e/\mu}) = 1.007 \pm 0.009 \text{ (stat)} \pm 0.019 \text{ (syst)}$$

Source	Uncertainty [%]
Sample size	0.9
Lepton identification	1.9
$X\,\ell\,\nu$ branching fractions	0.2
$X_c\,\ell\,\nu$ form factors	0.1
Total	2.1

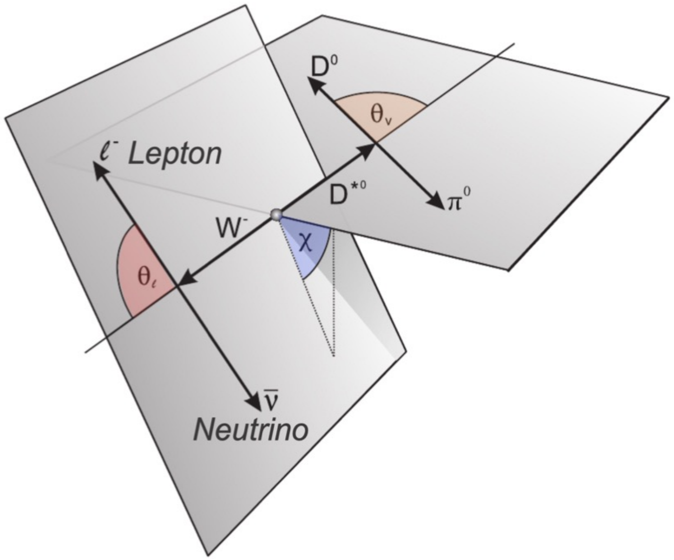
SM: $R(X_{e/\mu}) = 1.006 \pm 0.001$

arxiv:2301.08266, accepted by PRL

Test of lepton flavour universality: angular asymmetries in $B \to D^{*}\ell\nu$

We tested lepton universality by comparing five angular asymmetries of e and μ

$$\Delta\mathcal{A}_x(w) = \mathcal{A}_x^{\mu}(w) - \mathcal{A}_x^{e}(w)$$



Recoil parameter $w = \dfrac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$

A_{FB} : $dx = d(\cos\theta_\ell)$

S_3 : $dx = d(\cos 2\chi)$

S_5 : $dx = d(\cos\chi \cos\theta_V)$

S_7 : $dx = d(\sin\chi \cos\theta_V)$

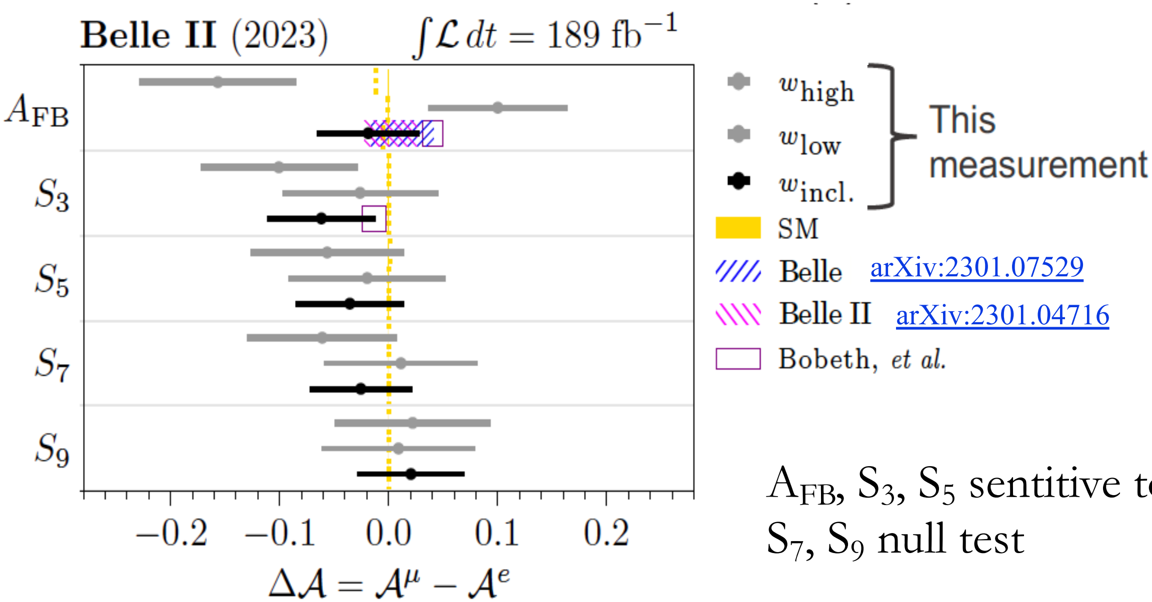
S_9 : $dx = d(\sin 2\chi)$

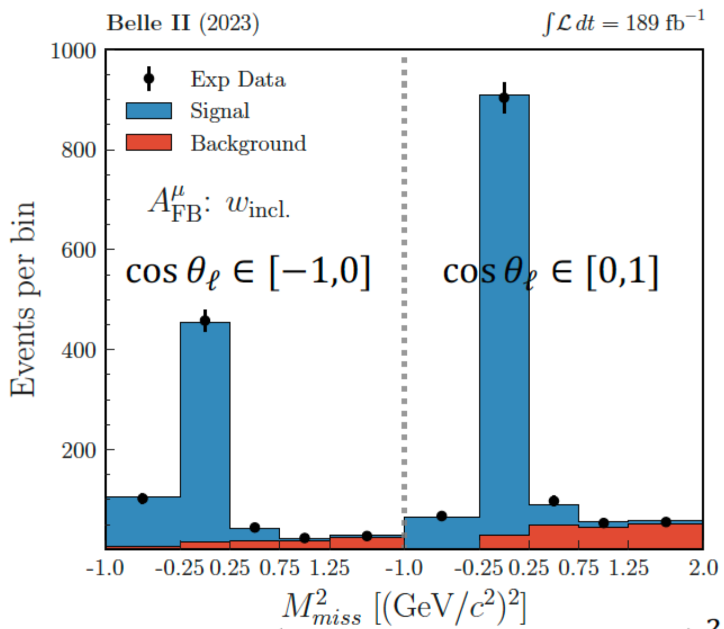
$$\mathcal{A}_x(w) = \frac{N^+ - N^-}{N^+ + N^-}$$ forward backward asymmetry

Test of lepton flavour universality: angular asymmetries in $B \to D^*\ell\nu$

Hadronic tagged analysis

Signal events determined with fits of the missing mass distribution - peaks at zero (neutrino mass) for signal





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

A_{FB}, S_3, S_5 sentitive to LFUV

S_7, S_9 null test

Consistent with SM within 5-10%

Semileptonic B decays: projections

Snowmass white paper
[arXiv:2207.06307](https://arxiv.org/abs/2207.06307)

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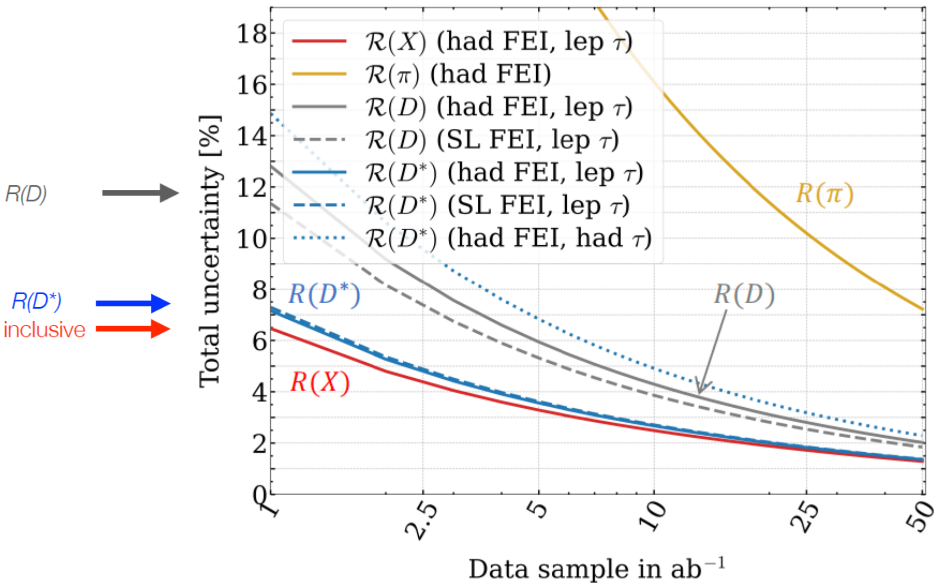
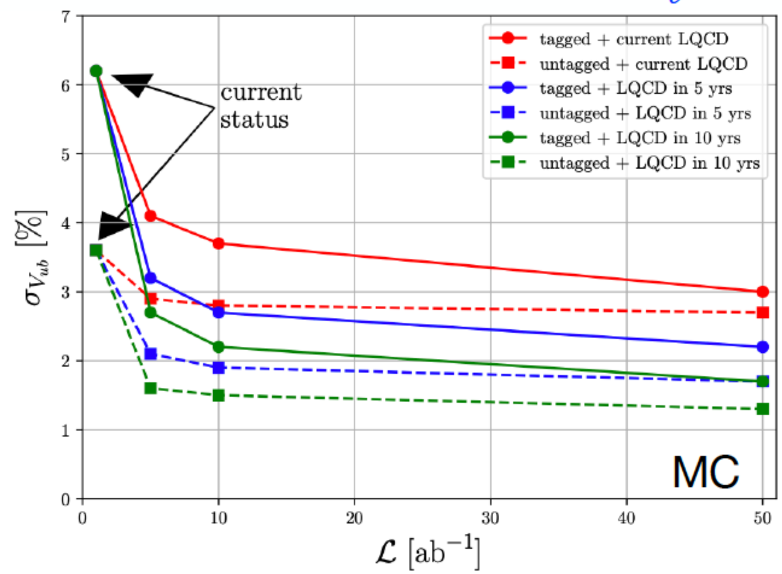


V_{ub} with $\bar{B}^0 \to \pi^+ \ell^- \bar{\nu}_\ell$

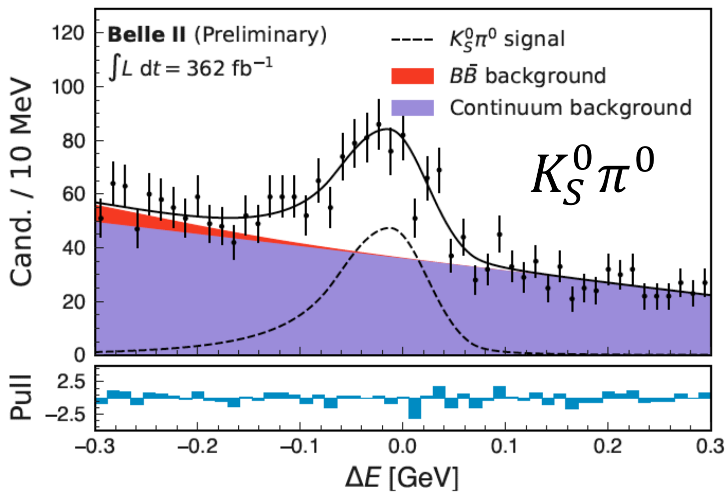


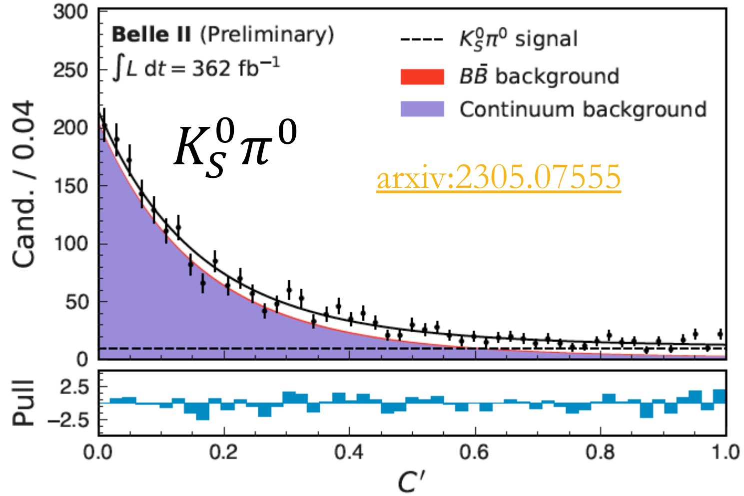
Testing the SM in hadronic B decays: Isospin sum rule

CP asymmetries in B → Kπ decays. Dynamical symmetries (isospin, heavy-quark, and SU(3) flavor) relate CP asymmetries and BF into a reliable and precise SM null test

$$I_{K\pi} = \mathcal{A}_{K^+\pi^-} + \mathcal{A}_{K^0\pi^+}\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^+\pi^0}\frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^0\pi^0}\frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)} = 0$$

Phys. Lett B627 (2005) 82-8





Fit to decision-tree combination of discriminating variables separates bkg

Belle II measures all final states, with unique access to $B \to K^0\pi^0$

$$\mathcal{A}_{K^0\pi^0} = -0.01 \pm 0.12(stat) \pm 0.05(syst)$$

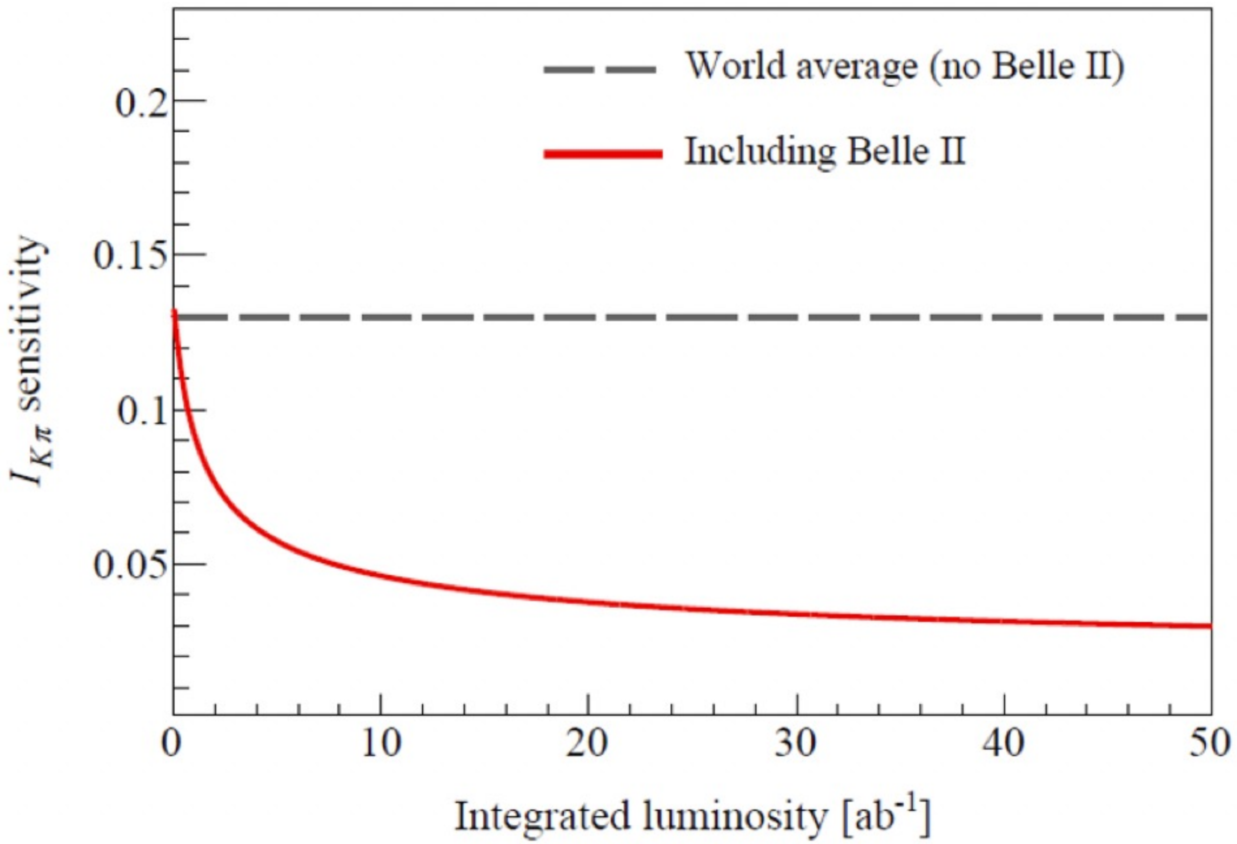
$$\mathcal{B}(B^0 \to K^0\pi^0) = [10.5 \pm 0.6(stat) \pm 0.7(syst)] \times 10^{-6}$$

$$I_{K\pi} = -0.03 \pm 0.13(stat) \pm 0.05(syst)$$

Competitive with world-average -0.13 ± 0.11

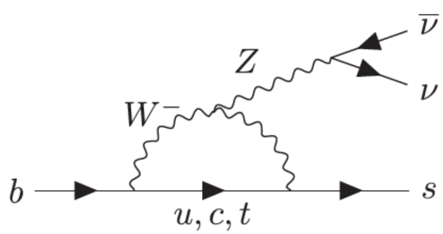
Testing the SM in hadronic B decays: Isospin sum rule

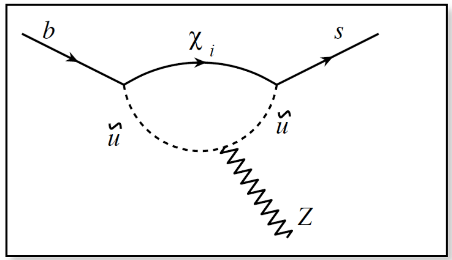
arxiv:2207.06307

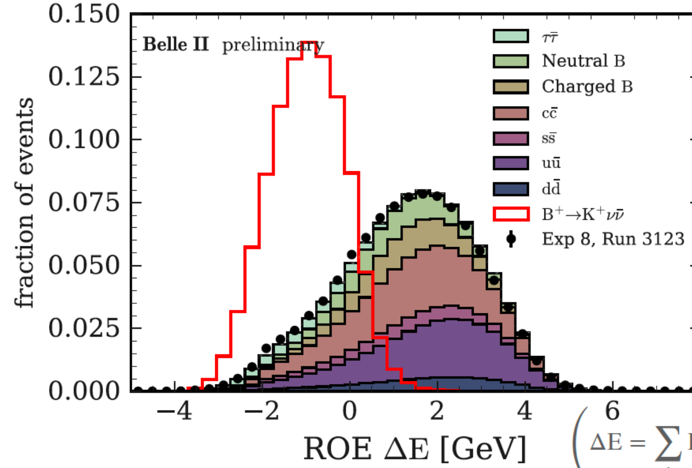


Belle II world-leading in most final states with π^0 and/or K^0 now and for the foreseeable future

Rare decays: $B^+ \to K^+ \nu\nu$

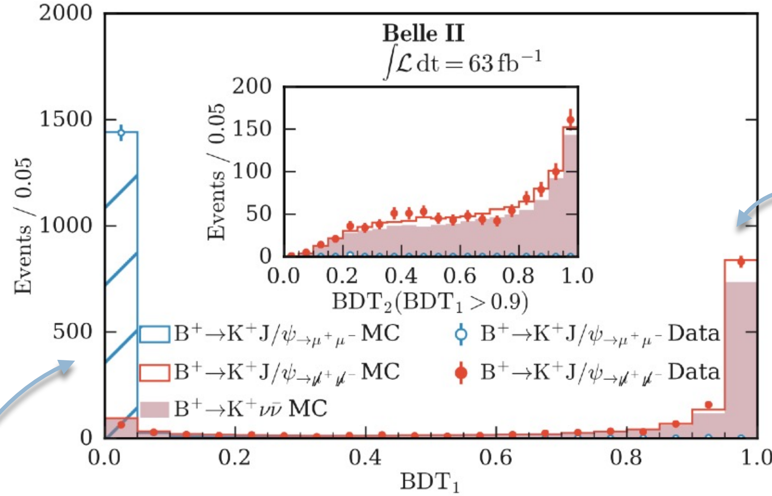






$\left(\Delta E = \sum_i E_i^{CMS} - E_{beam} \right)$

- Novel approach at Belle II: inclusive tagging
- Higher backgrounds suppressed with two BDTs expoliting event shape and kinematics



$B^+ \to K^+ J/\psi(\to \mu^+\mu^-)$ events where $\mu\mu$ are ignored and K^+ kinematics updated.

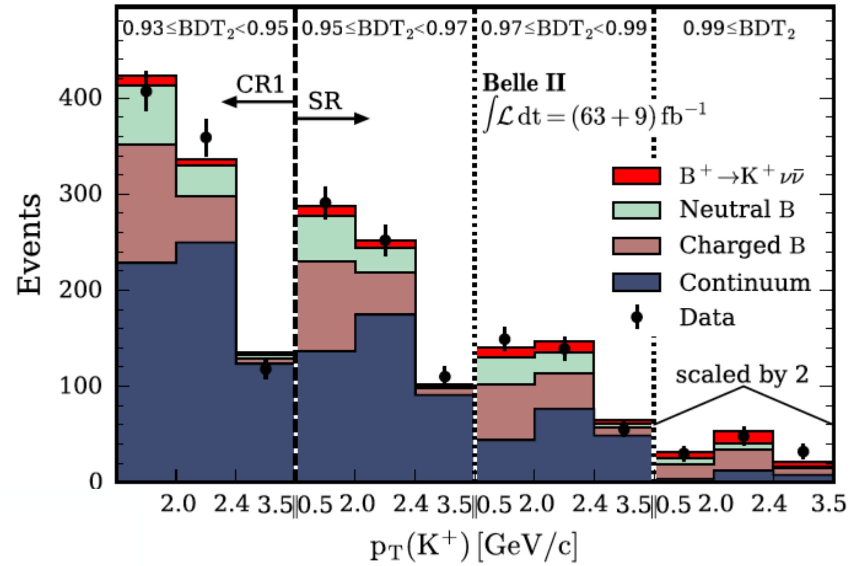
$B^+ \to K^+ J/\psi(\to \mu^+\mu^-)$ events

- Validation using $B^+ \to K^+ J/\psi(\to \mu^+\mu^-) \to$ data/MC agreement for both BDTs

Rare decays: $B^+ \to K^+\nu\nu$

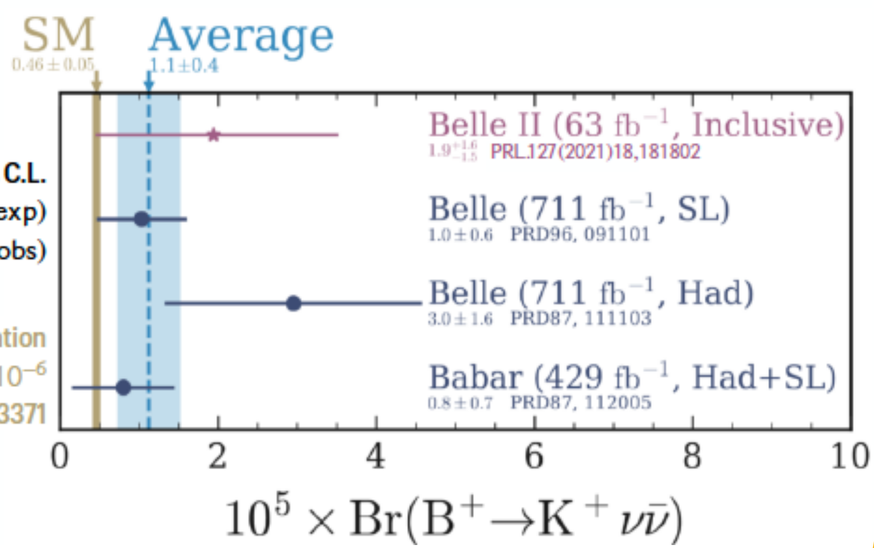
Fitted signal strength (in SM $\mu = 1$)

$$\mu = 4.2^{+2.9}_{-2.8}(\text{stat})^{+1.8}_{-1.6}(\text{syst})$$



90% C.L.
2.3×10^{-5} (exp)
4.1×10^{-5} (obs)

New estimation
$(5.67 \pm 0.38) \times 10^{-6}$
2207.13371



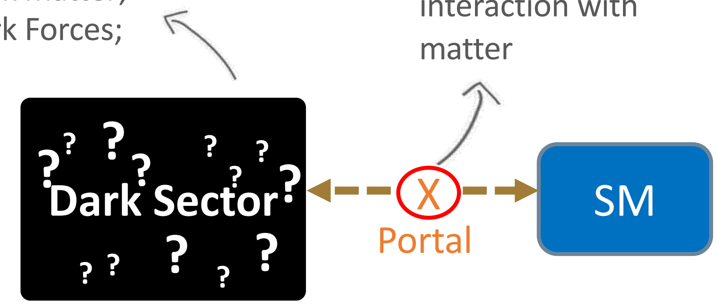
Competitive with previous measurement despite the much smaller dataset (63/fb vs 429/fb @BaBar and 711/fb @Belle)

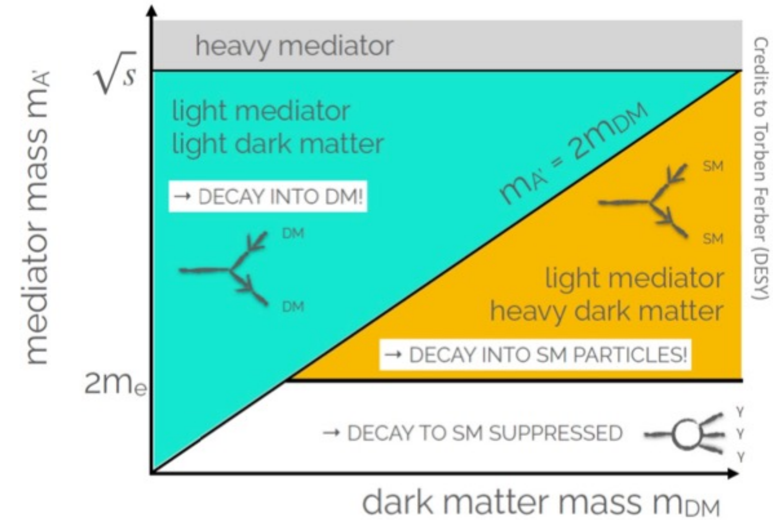
Phys.Rev.Lett. 127 (2021) 18, 181802

Dark sector searches

- Dark matter;
- Dark Forces;
- ……

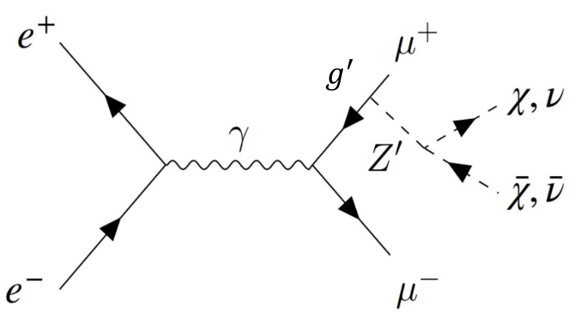
Non-gravitational interaction with matter





Special triggers for low-multiplicity events: single track, muon, photon

Search for a Z' invisible decay

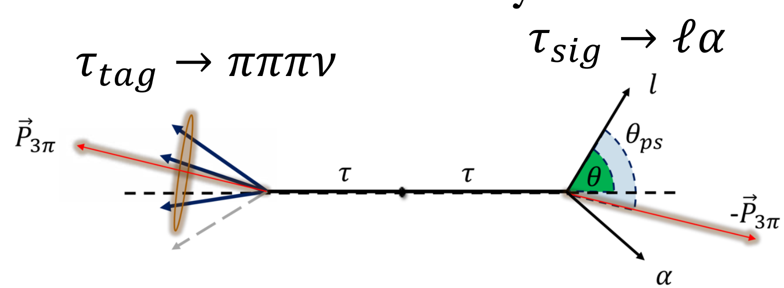


Massive gauge boson **Z'** coupling only to the 2nd and 3rd generation of leptons

Z' recoiling against μμ pairs

Search for axion-like particles in tau decay

$\tau_{tag} \to \pi\pi\pi\nu$ $\quad$ $\tau_{sig} \to \ell\alpha$

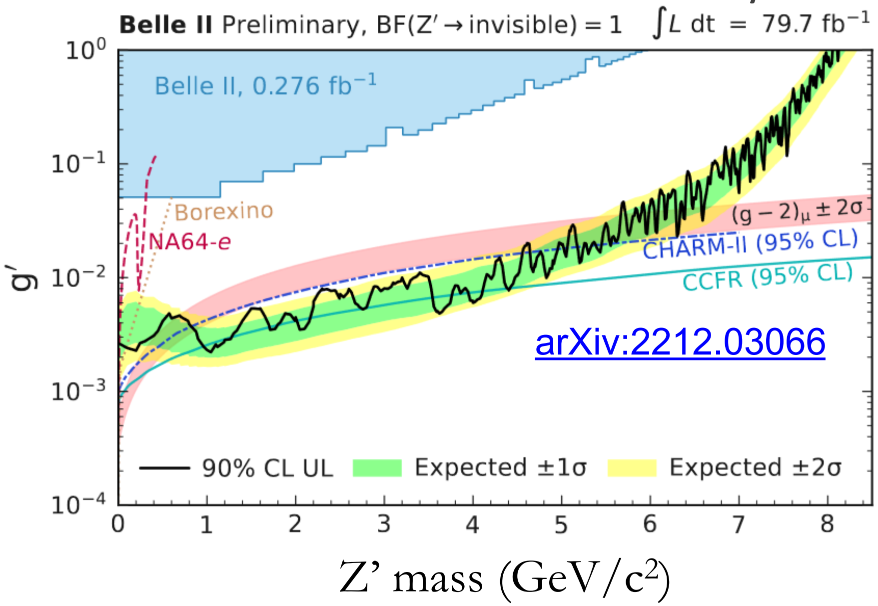


ALP seen as a bump in lepton energy

Phys. Rev. D **89** (2014)
JHEP **106** (2016)
Phys. Rev. Lett. 124, 211803 (2020)

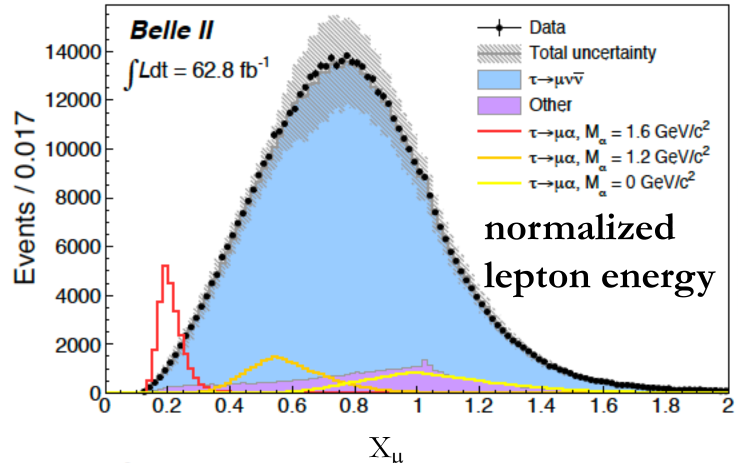
Dark sector searches

Search for a Z' invisible decay



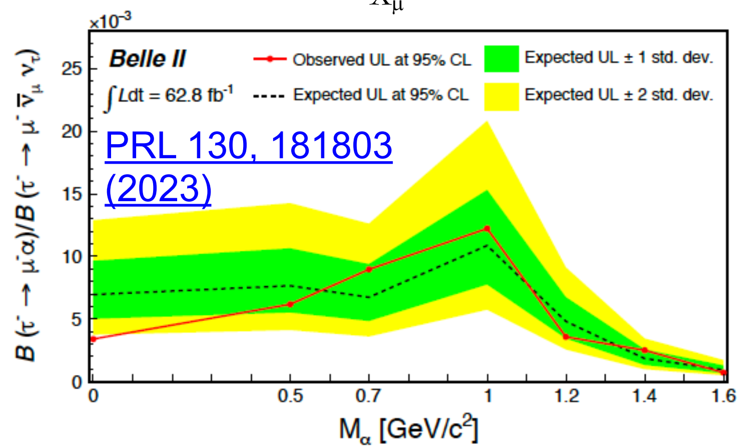
- Search for $e^+e^- \rightarrow \mu^+\mu^-$ + missing energy
- Excluding a fully invisible Z' boson as an explanation of the $(g-2)_\mu$ anomaly for $0.8 < M_{Z'} < 5$ GeV/c^2

Search for ALPs in tau decay



normalized lepton energy

$$X_\ell = \frac{2E_\ell^*}{m_\tau c^2}$$



These 95% CL limits are 2.2 to 14 times more stringent than best previous limits set by ARGUS

Tau-lepton mass measurement

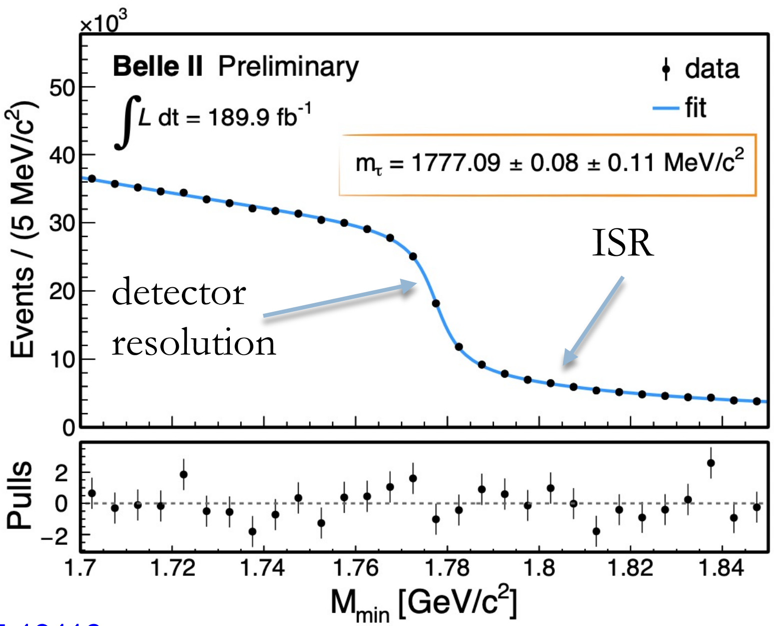
Belle II is also a tau-lepton factory !

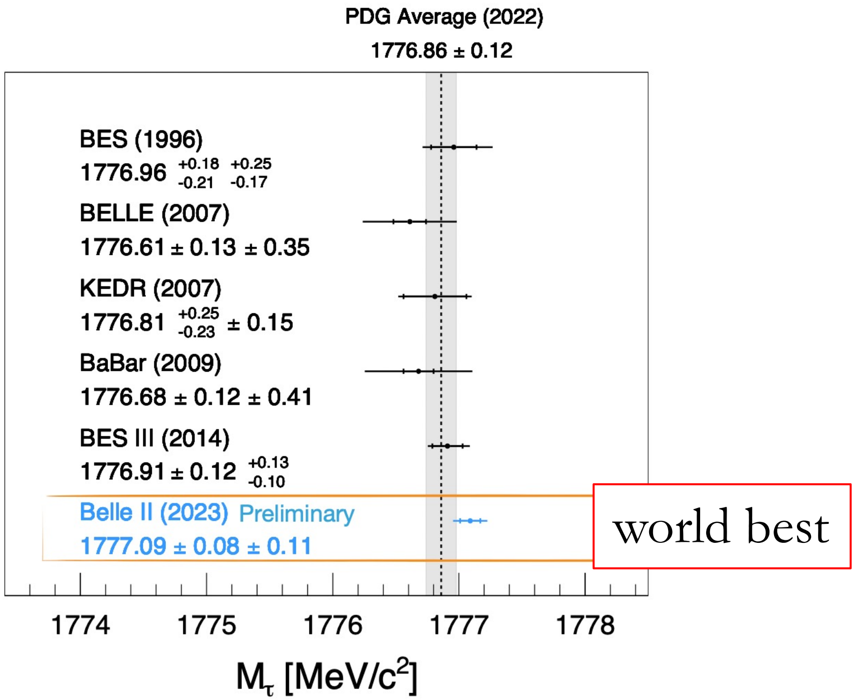
330M ττ pairs in Belle II dataset

Using 1-prong and 3-prong events for tag side

Crucial knowledge of beam energy and its resolution (ARGUS method)

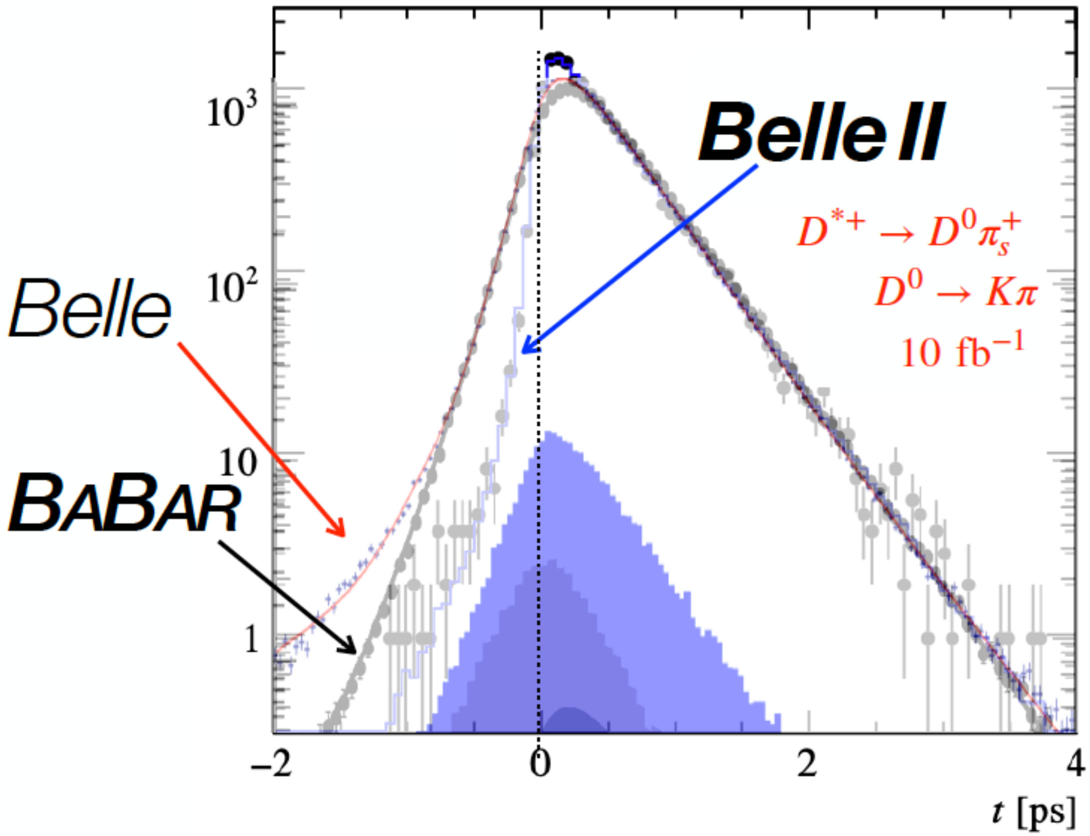
$$M_{\min} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)} \leq M_\tau .$$





arXiv:2305.19116

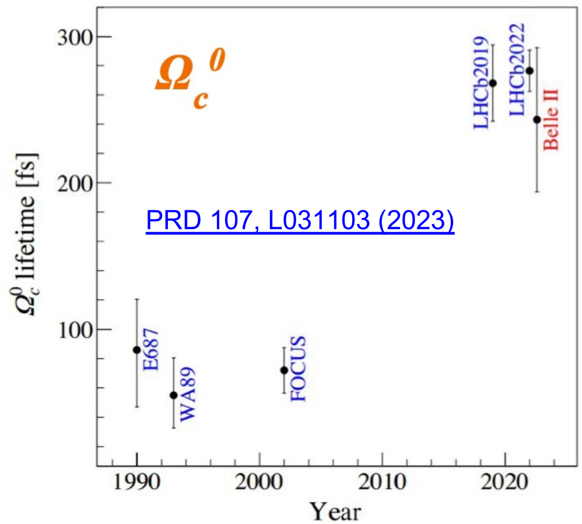
Charm lifetimes

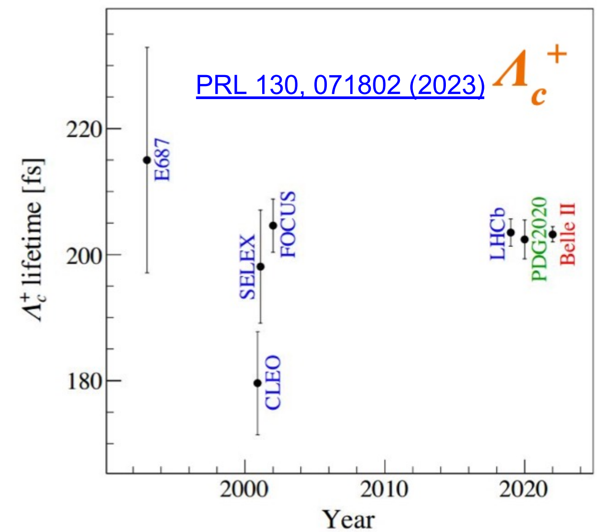


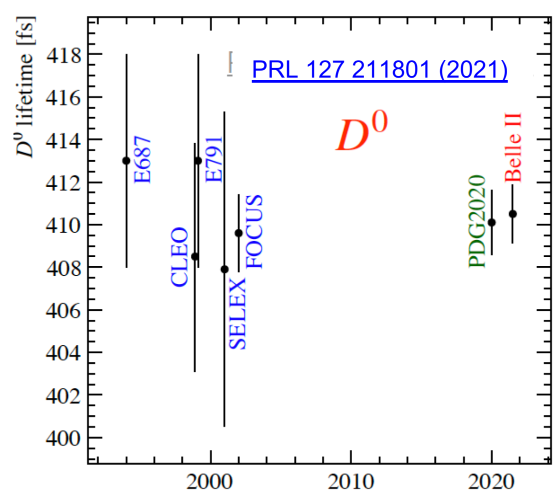
Improved proper time resolution:
2x better decay time resolution than Belle

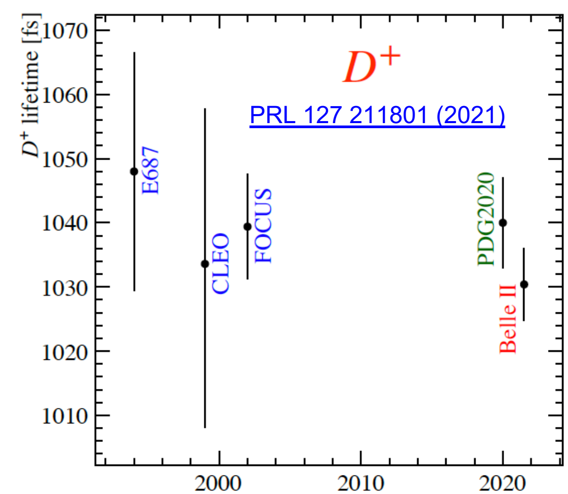
Charm lifetimes

- HQE predicted hierarchy of hadron lifetimes, disproved by LHCb Ω_c lifetime measurement*
- Belle II confirms the new picture !
- World's most precise measurements of the Λ_c (~200/fb), D^0 and D^+ lifetimes (72/fb)
- Few per-mill accuracy establishes the excellent performance of our detector!





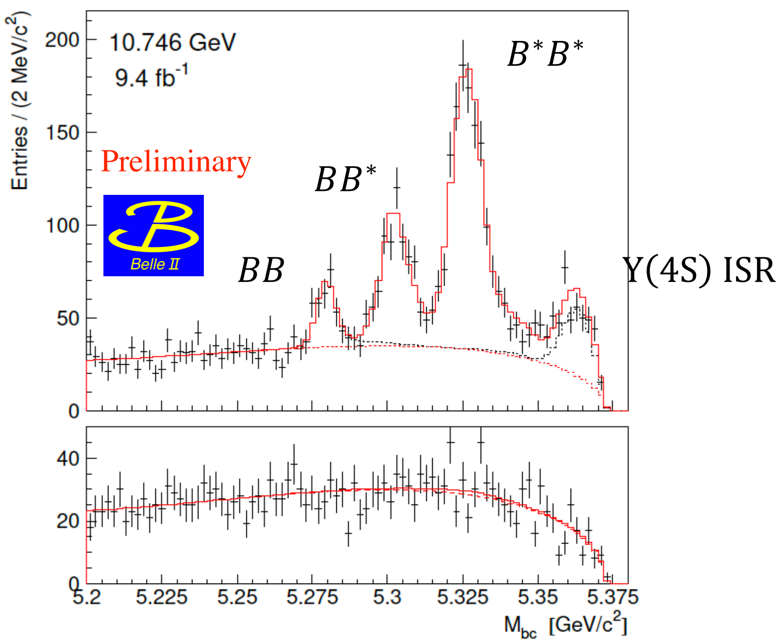




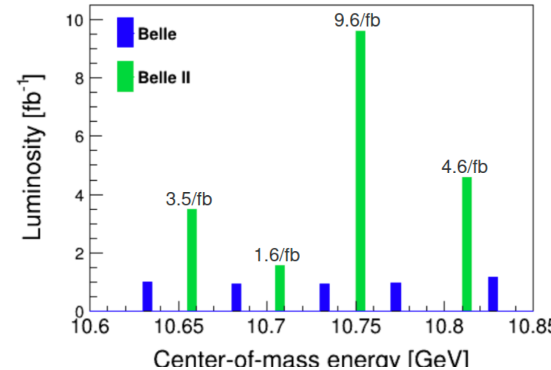
*PRL, 121, 092003 (2018)

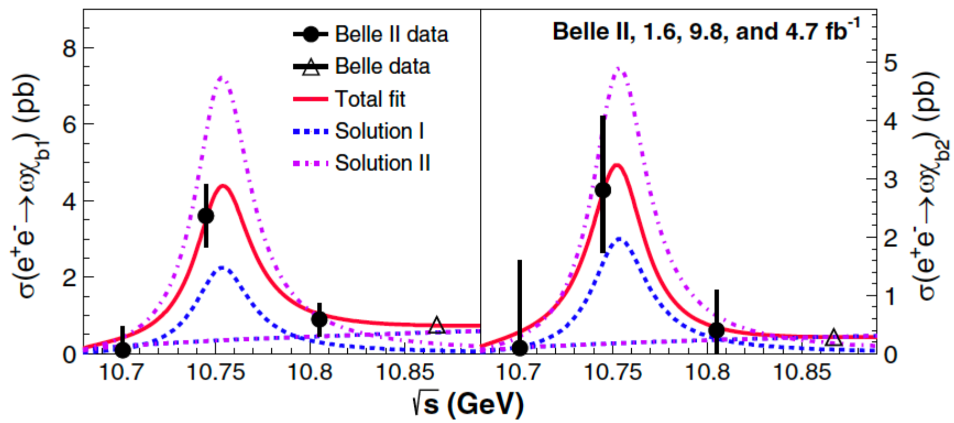
Quarkonium

In 2021 SuperKEKB ran above Υ(4S) resonance



Measurement of the energy dependence of the $ee \rightarrow BB, BB^*, B^*B^*$ cross sections





- Measurement of cross-section peak, consistent with Υ(10753) state
- First observation of $\omega\chi_{bJ}(1P)$ signal at 10.745 GeV

See talk Friday morning by Valentina Zhukova
"Recent quarkonium results from Belle and Belle II"

[PRL 130, 091902 (2023)]

Conclusions

Belle II experiment has collected a sample that matches the size of BaBar's and is half the size of Belle's.

Belle II is not only a high luminosity Belle Experiment. With the use of novel analyses techniques we have already achieved results that compete with previous measurements and some results that are exclusive to us.

We plan to resume collisions next winter and in few years Belle II will get the sensitivity to shed light on the anomalies in the Standard Model

Outlook

Luminosity matters

Observable	Past 2022 Belle(II), BaBar	Soon Belle-II 5 ab^{-1}	Target Belle-II 50 ab^{-1}	Dream Belle-II 250 ab^{-1}
$\sin 2\beta/\phi_1$	0.03	0.012	0.005	0.002
γ/ϕ_3 (Belle+BelleII)	11°	4.7°	1.5°	0.8°
α/ϕ_2 (WA)	4°	2°	0.6°	0.3°
$\lvert V_{ub}\rvert$ (Exclusive)	4.5%	2%	1%	$<1\%$
$S_{CP}(B \to \eta' K^0_S)$	0.08	0.03	0.015	0.007
$A_{CP}(B \to \pi^0 K^0_S)$	0.15	0.07	0.025	0.018
$S_{CP}(B \to K^{*0}\gamma)$	0.32	0.11	0.035	0.015
$R(B \to K^* \ell^+ \ell^-)^\dagger$	0.26	0.09	0.03	0.01
$R(B \to D^* \tau \nu)$	0.018	0.009	0.0045	<0.003
$R(B \to D \tau \nu)$	0.034	0.016	0.008	<0.003
$\mathcal{B}(B \to \tau \nu)$	24%	9%	4%	2%
$B(B \to K^* \nu \bar{\nu})$	–	25%	9%	4%
$\mathcal{B}(\tau \to \mu \gamma)$ UL	42×10^{-9}	22×10^{-9}	6.9×10^{-9}	3.1×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$ UL	21×10^{-9}	3.6×10^{-9}	0.36×10^{-9}	0.073×10^{-9}

Table 2: Projected precision (total uncertainties, or 90% CL upper limits) of selected flavour physics measurements at Belle II.(The † symbol denotes the measurement in the momentum transfer squared bin $1 < q^2 < 6$ GeV$/c^2$.)

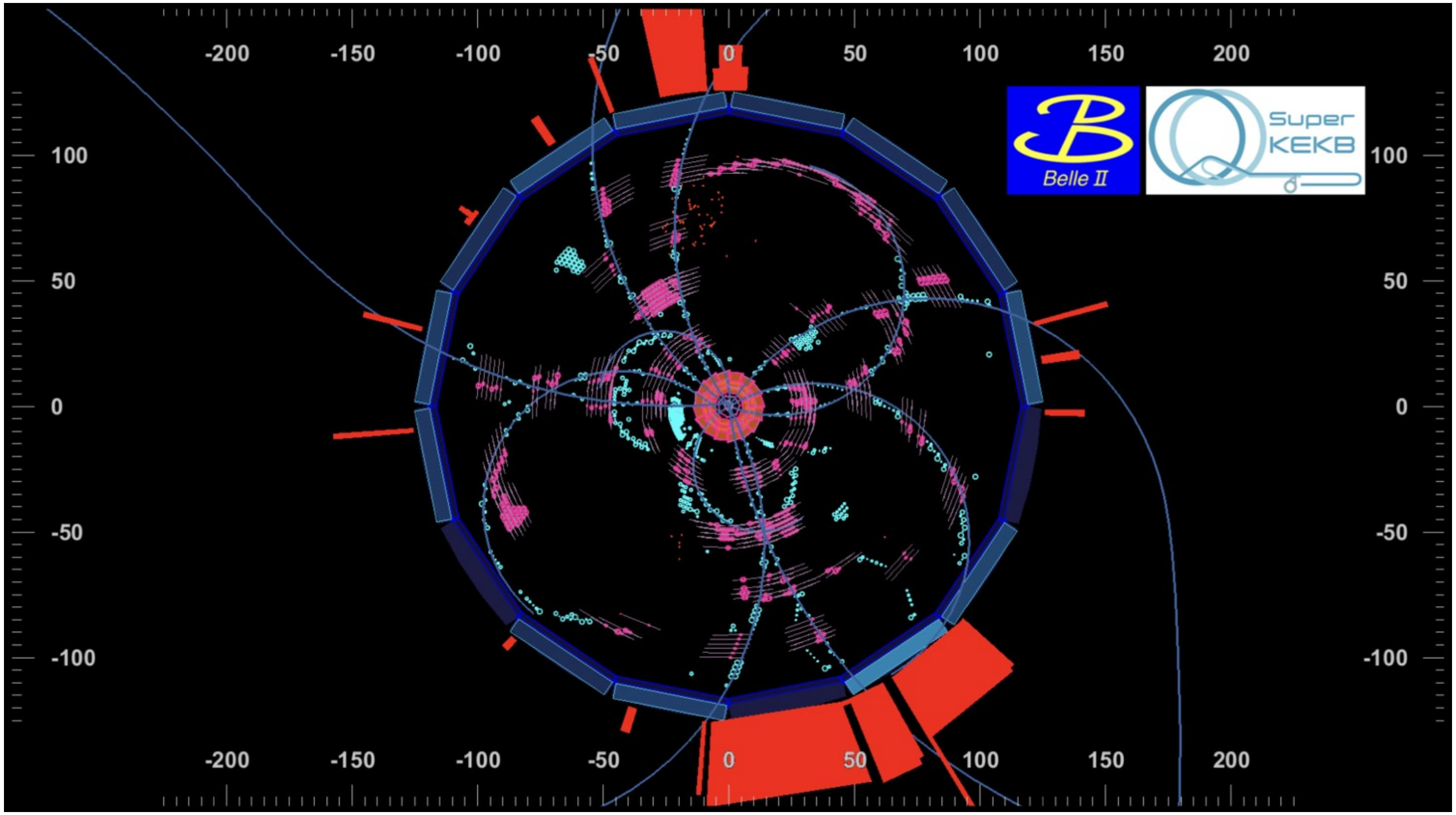
Snowmass White Paper:
Belle II physics reach and plans for the next decade and beyond

https://arxiv.org/abs/2207.06307

Snowmass Whitepaper:
The Belle II Detector Upgrade Program

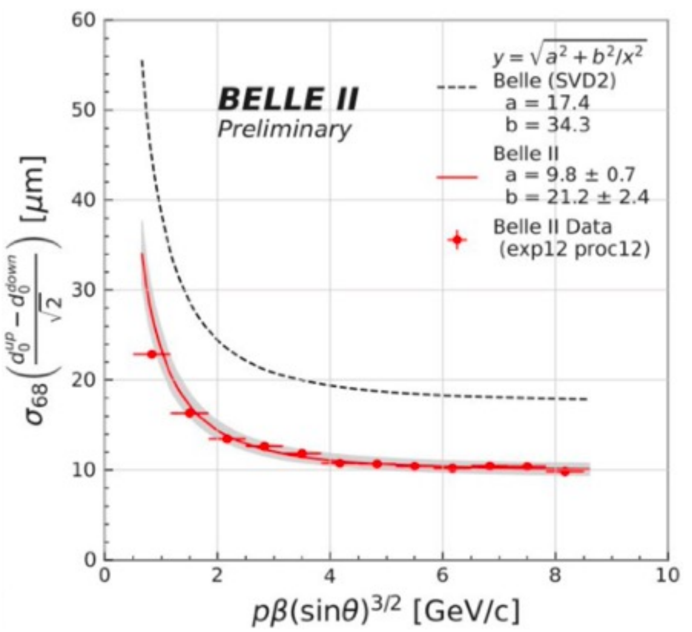
https://arxiv.org/abs/2203.11349

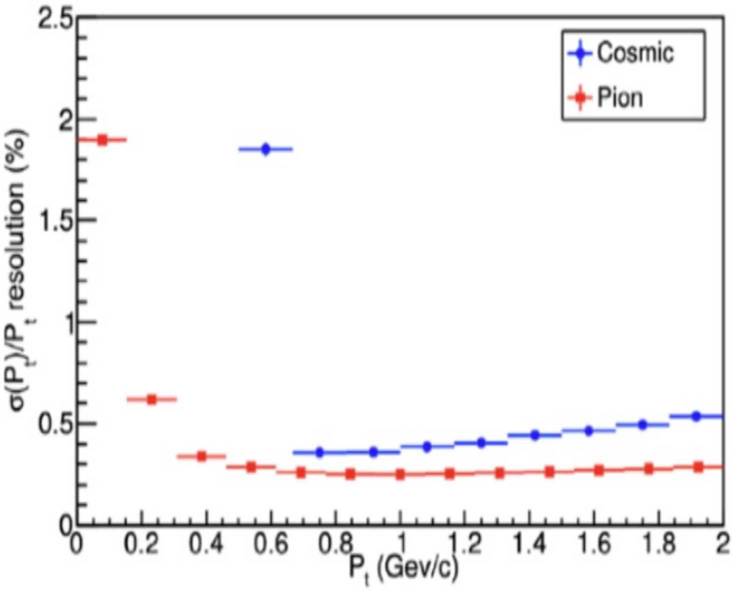
Thanks !


-200
-150
-100
-50
0
50
100
150
200
100
50
0
-50
-100
Belle II
Super
KEKB

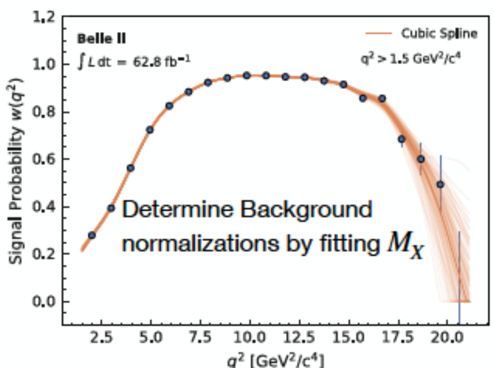
Backup

Detector performance

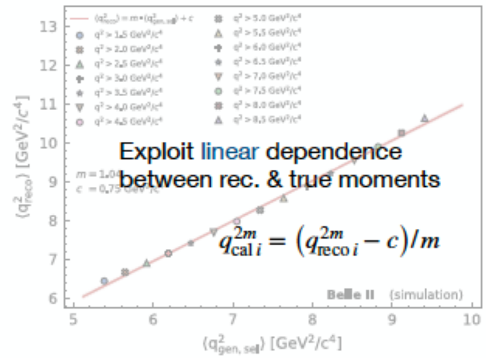




$|V_{cb}|$ from q^2 spectral moments



Step #1: Subtract Background

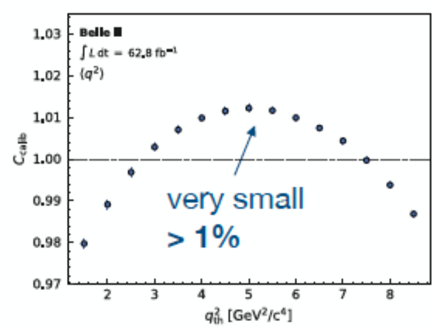


Step #2: Calibrate moment

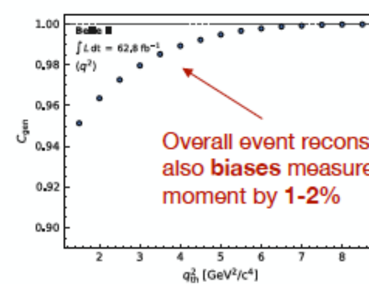
Event-wise **Master-formula**

$$\langle q^{2n} \rangle = \frac{\sum_i^{N_{\mathrm{data}}} w(q_i^2) \times q^{2n}_{\mathrm{calib},i}}{\sum_j^{N_{\mathrm{data}}} w(q_j^2)} \times \mathcal{C}_{\mathrm{calib}} \times \mathcal{C}_{\mathrm{gen}}$$

Step #3: If you fail, try again



Step #4: Correct for selection effects

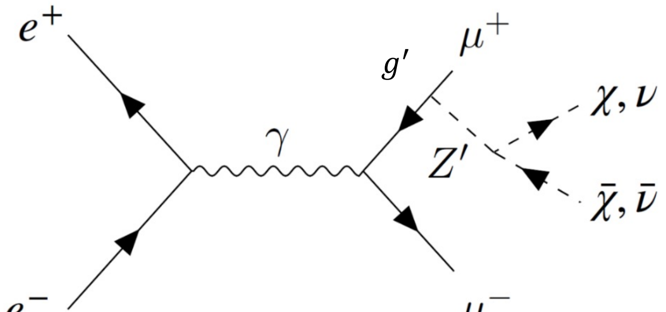


Search for a Z’ invisible decay

Introduction

[1] Shuve et al., *Phys. Rev. D* **89** (2014)
[2] Altmannshofer et al., *JHEP* **106** (2016)

Hypothetical massive gauge boson **Z’** coupling only to the 2nd and 3rd generation of leptons in the framework of $\boldsymbol{L_\mu - L_\tau}$ model [1,2].



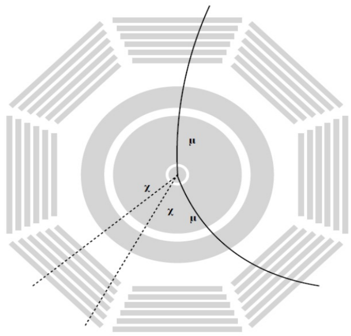
$e^+e^- \rightarrow \mu^+\mu^- Z'$
↳ invisible

Seek to explain:

- $(g\text{-}2)_\mu$ anomaly;
- anomalies in B decays to leptons;
- the Dark Matter puzzle;

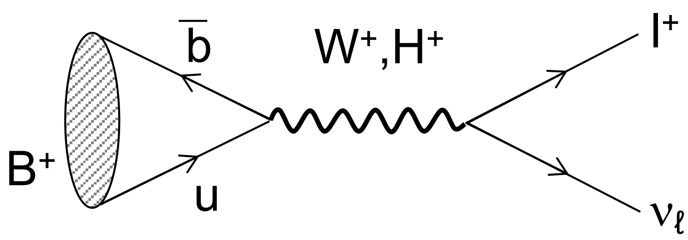
State of the art:

- Existing limits from BaBar, CMS and Belle for a Z’ visible decay into a couple of muons and from NA64-e for a Z’ invisibly decaying;
- **Brand new searches Belle II for a Z’ invisible decay;**



Experimental signature:
Two opposite sign muons + missing energy
a peak in the recoil mass distribution against two muons

Leptonic decays

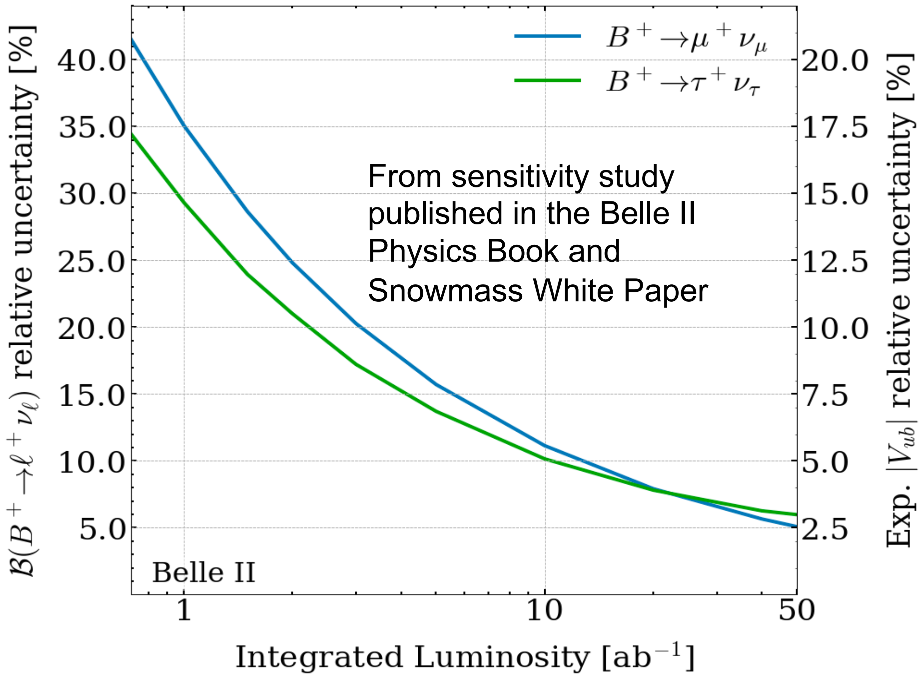


$$\mathcal{B}(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$\mathcal{B}(B \to l\nu) = \mathcal{B}(B \to l\nu)_{SM} \times r_H$$

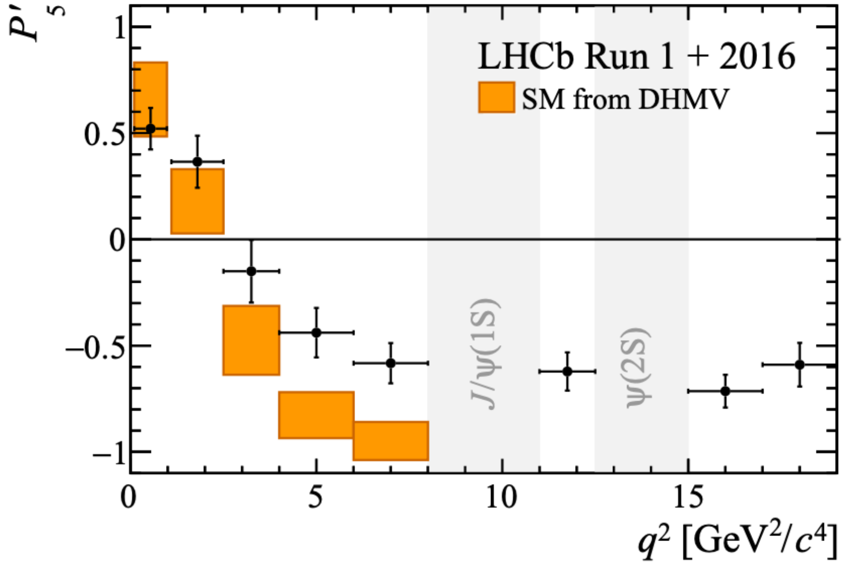
$$r_H = \left(1 - \tan^2\beta \, \frac{m_B^2}{m_H^2}\right)^2$$

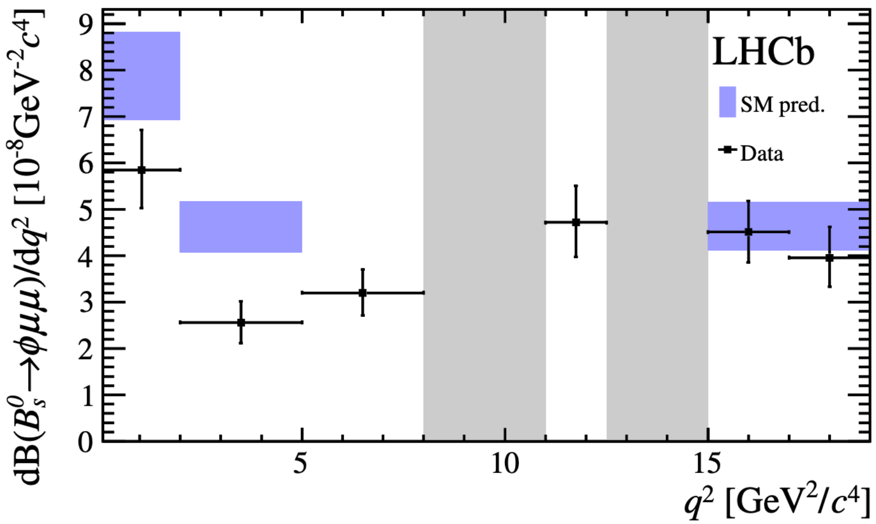
in 2HDM type II



- Very clean theoretically, hard experimentally
- SM is helicity suppressed
- Sensitive to NP contribution (for ex: Charged Higgs)

b -> s $\mu^+\mu^-$





$B \rightarrow K^*\mu^+\mu^-$

[LHCb, 2003.04831]

$B_s \rightarrow \phi\mu^+\mu^-$

[LHCb, 1506.08777]

$B \to X_s\gamma$

2210.10220

Unfolded result

- Consistent with theoretical expectations
- Uncertainty is comparable with other had-tagged measurement

[BaBar 210 fb^{-1} (E_0=1.9 GeV), PRD.77.051103]

E_γ^B threshold [GeV]	$\mathcal{B}(B \to X_s\gamma)$ $[10^{-4}]$
1.8	3.54 ± 0.78 (stat.) $\pm$ 0.83 (syst.)
2.0	3.06 ± 0.56 (stat.) $\pm$ 0.47 (syst.)
2.1	2.49 ± 0.46 (stat.) $\pm$ 0.35 (syst.)

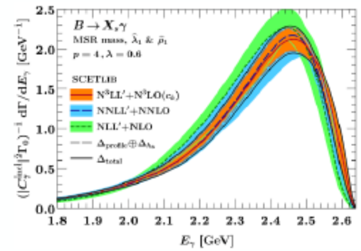
Reminder (For $E_\gamma > 1.6$ GeV)

$$\mathcal{B}_{TH}(b \to s\gamma) = (3.40 \pm 0.17) \times 10^{-4}$$ JHEP06(2020)175

$$\mathcal{B}_{EX}(b \to s\gamma) = (3.49 \pm 0.19) \times 10^{-4}$$ HFLAV-10/2022

All tagging approaches

Updated γ spectrum prediction, 2211.07663



Improved scenario relies on ongoing studies of $\pi^0/\eta \to \gamma\gamma$ veto modelling

Prospects 2207.06307

Lower E_γ^B threshold	Statistical uncertainty 1 ab^{-1}	5 ab^{-1}	10 ab^{-1}	50 ab^{-1}	Baseline (improved) syst. uncertainty
1.4 GeV	10.7%	6.4%	4.7%	2.2%	10.3% (5.2%)
1.6 GeV	9.9%	6.1%	4.5%	2.1%	8.5% (4.2%)
1.8 GeV	9.3%	5.7%	4.2%	2.0%	6.5% (3.2%)
2.0 GeV	8.3%	5.1%	3.8%	1.7%	3.7% (1.8%)

Background

Theory unc.

Lower E_γ^B thresholds ⇔ more challenging analysis due to larger $B\bar{B}$ backgrounds

LS1 on-going work: SuperKEKB

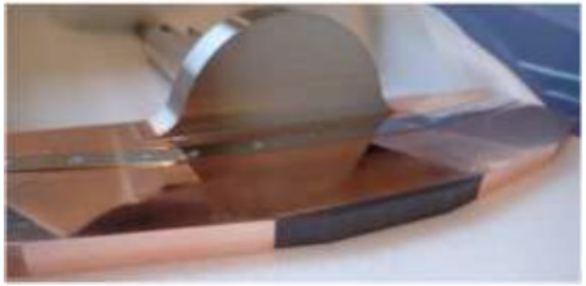
- Countermeasures against sudden beam loss
  - Additional real-time monitoring
  - Faster abort system
- Additional shielding
  - Against neutrons
    - around final focusing magnets (QCS)
    - Around end-caps
- Collimators
  - Non-linear types ⟶ background mitigation
  - Harder head material ⟶ better resilience
- Injection
  - New beam-pipe + faster kicker magnets + new quadrupole magnet

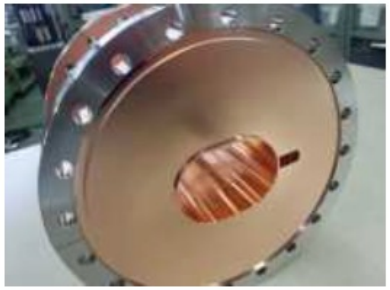
  ⟶ Higher efficiency & mitigated background
- RF cavity replacement

  ⟶ More stable operation and larger beam currents

Shielding on QCS bellow

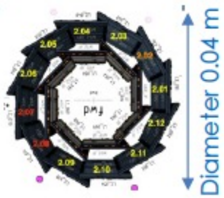
Carbon collimator head

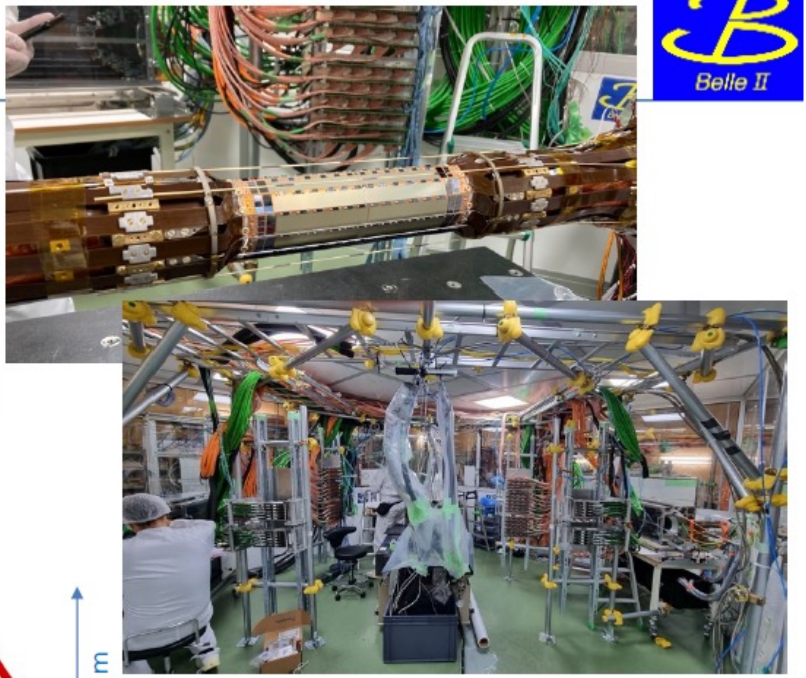



Larger pipe injection

LS1 work: Belle II

- **Completion of pixel layers**
  - Entirely new 2 complete layers of DEPFET sensors
    - Previously 2nd layer was 17% complete





- **Time of Propagation robustness**
  - Replacement to Atomic Layer Deposited (ALD) Micro-Channel Plate PMT

  ⟶ Increased lifespan & hit rate limit (3⟶5 MHz/cm^2)

- **DAQ**
  - New PCIe40 boards used by all subsystems
    - But PXD (specific data path)

- **CDC**
  - Improved gas distribution & monitoring syste
    - Better gain stability