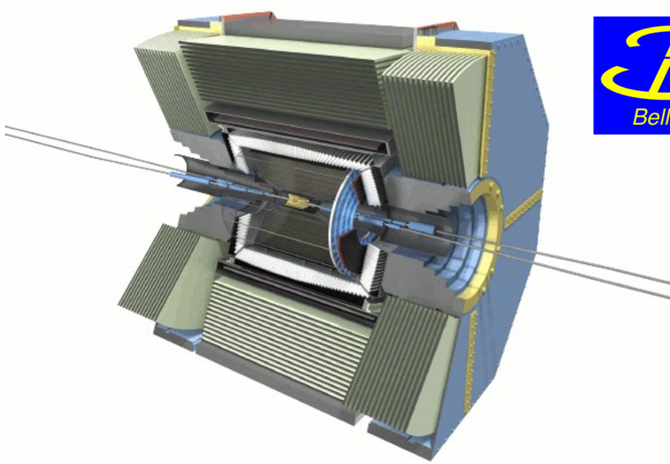
Highlights from Belle II and Belle



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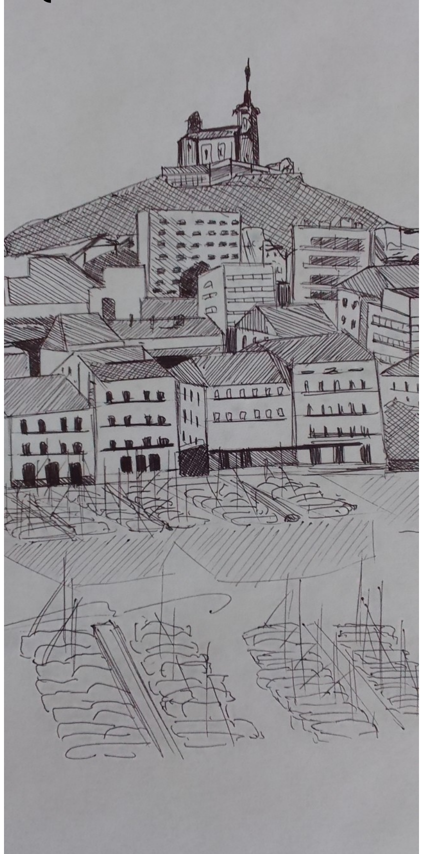
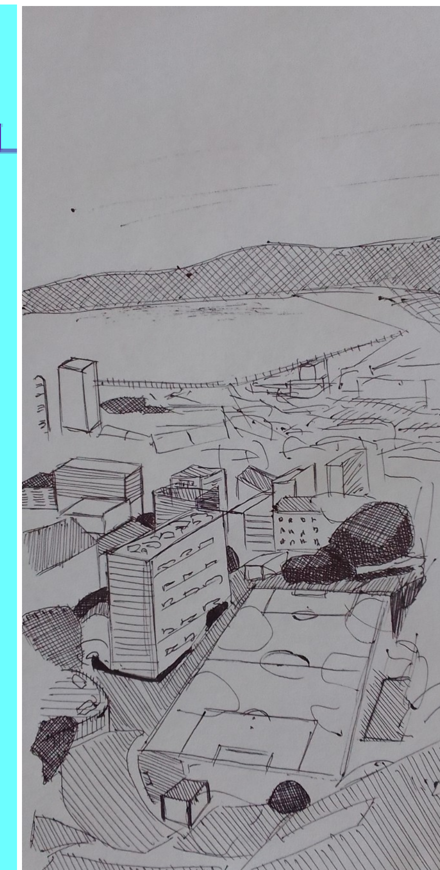
Quand tu allais...





(credits: Issa)

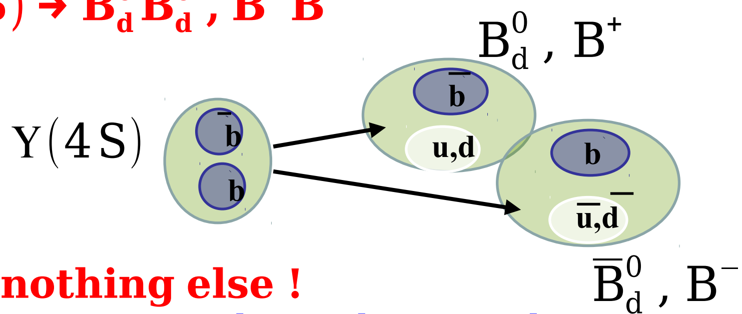
SuperKEKB/Belle II, a flavour-factory, a rich physics program...

- We collect e^+e^- collisions at (or close to) the $\Upsilon(4S)$ resonance, so it is:

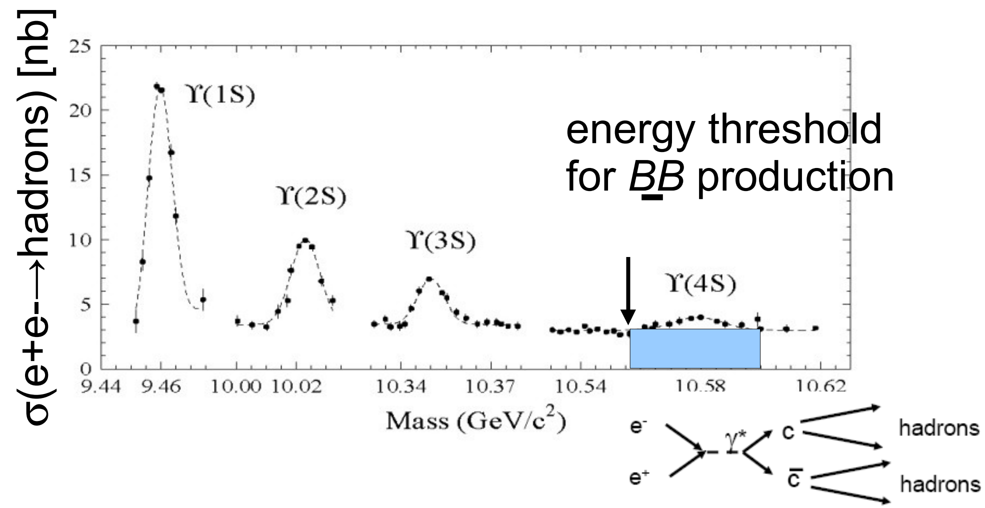
– a (Super) B-factory ($\sim 1.1 \times 10^9$ $B\bar{B}$ pairs per ab^{-1})

''on resonance'' production

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B_d^0 \bar{B}_d^0$, B^+B^-



- **2 B's and nothing else !**
- 2 B mesons are created simultaneously in a L=1 coherent state



– a (Super) charm factory ($\sim 1.3 \times 10^9$ $c\bar{c}$ pairs per ab^{-1})

(but also charmonium, X, Y, Z, pentaquarks, tetraquarks, bottomonium...)

– a (Super) τ factory ($\sim 0.9 \times 10^9$ $\tau^+\tau^-$ pairs per ab^{-1})

– exploit the clean e^+e^- environment to probe the existence of exotic hadrons, dark photons/Higgs, light Dark Matter particles, ALPs, LLPs ...

⇒ to ultimately reach $6 \times 10^{35}\,cm^{-2}s^{-1}$

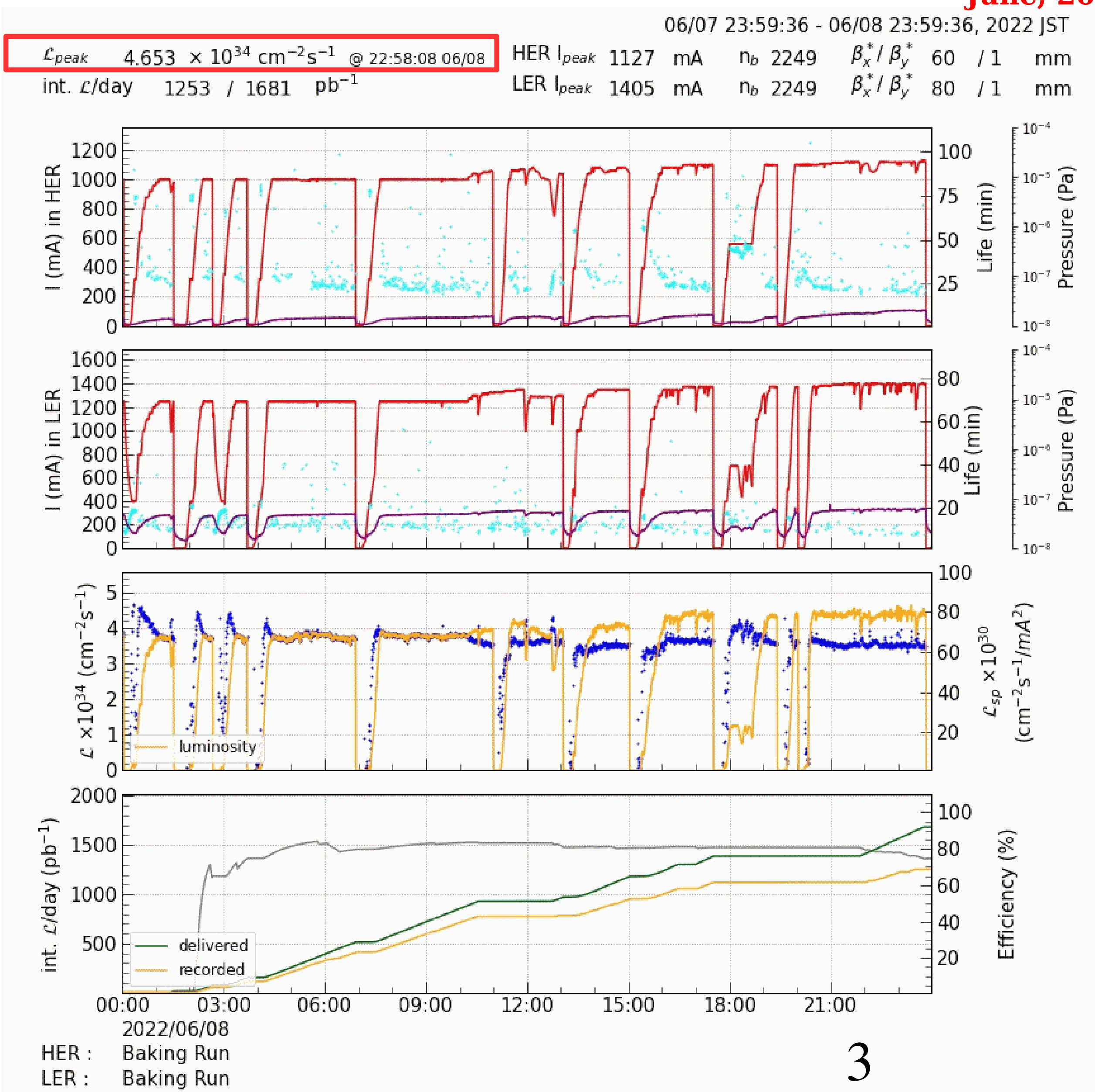
Belle II run 1 (2019 - 2022)

data taking from March 2019 to June 2022

→ despite difficult conditions since March 2020 (Covid, war in Ukraine, energy cost...)

luminosity: $4.7\times10^{34}/cm^2/s$! > 2 fb^{-1} per day !

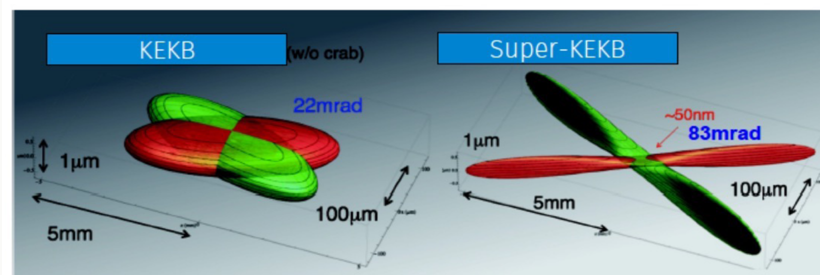
June, 2022



→ β^*_y = 1 mm, $I_{LER/HER}$ = 1.4/1.2 A

record of KEKB/Belle
$2\times10^{34}/cm^2/s$ currents > 1 A

record of PEPII/BaBar
$1\times10^{34}/cm^2/s$ currents > 2 A

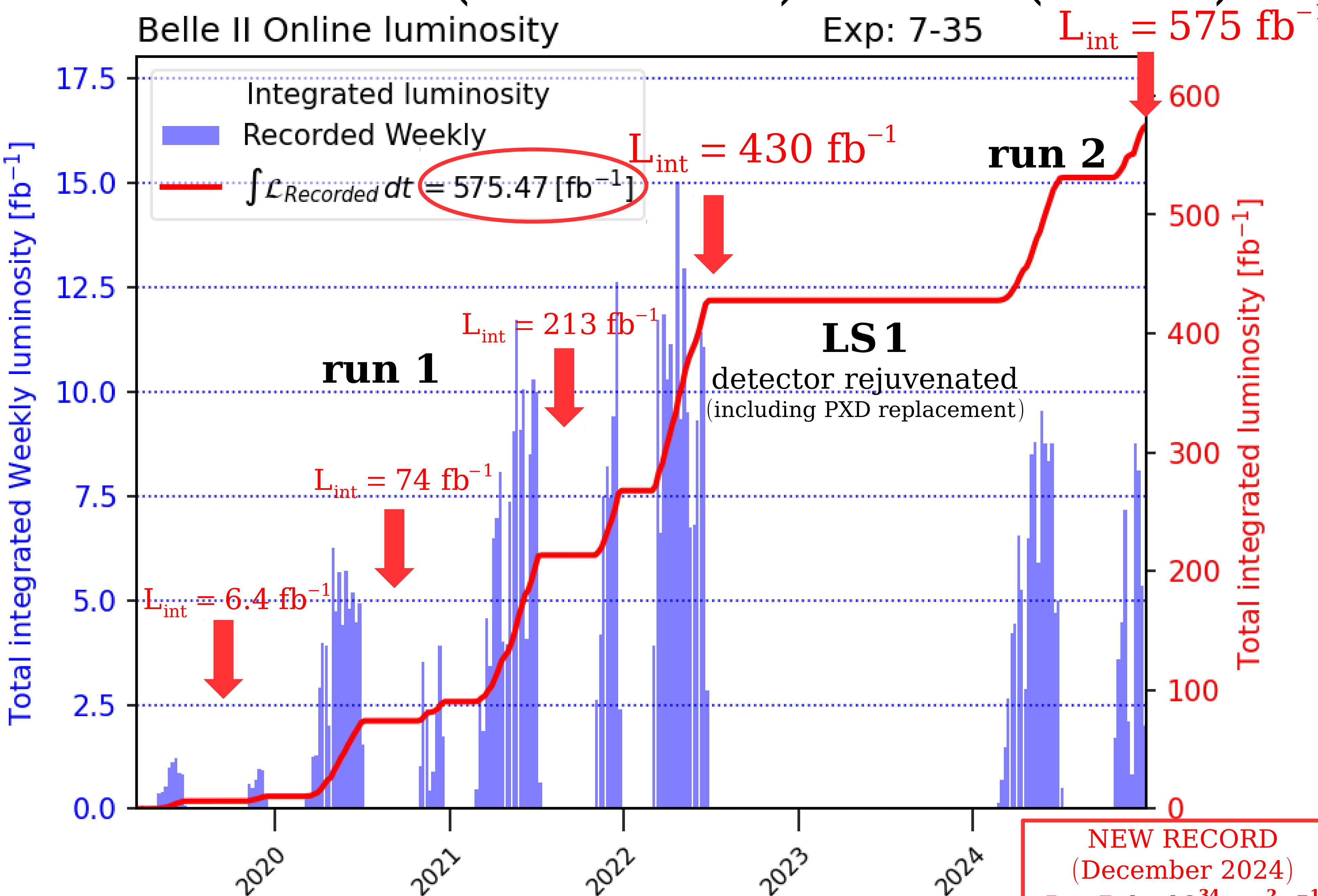


	E (GeV) LER/HER	β*y (mm) LER/HER	β*x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L (cm⁻²s⁻¹)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10³⁴
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10³⁴

factor 20 factor 2-3

doubling (or more) the currents
⇒ L > $10^{35}/cm^2/s$ after LS1
then squeeze further the beams

Belle II run 1 (2019 - 2022), run 2 (2024 -)



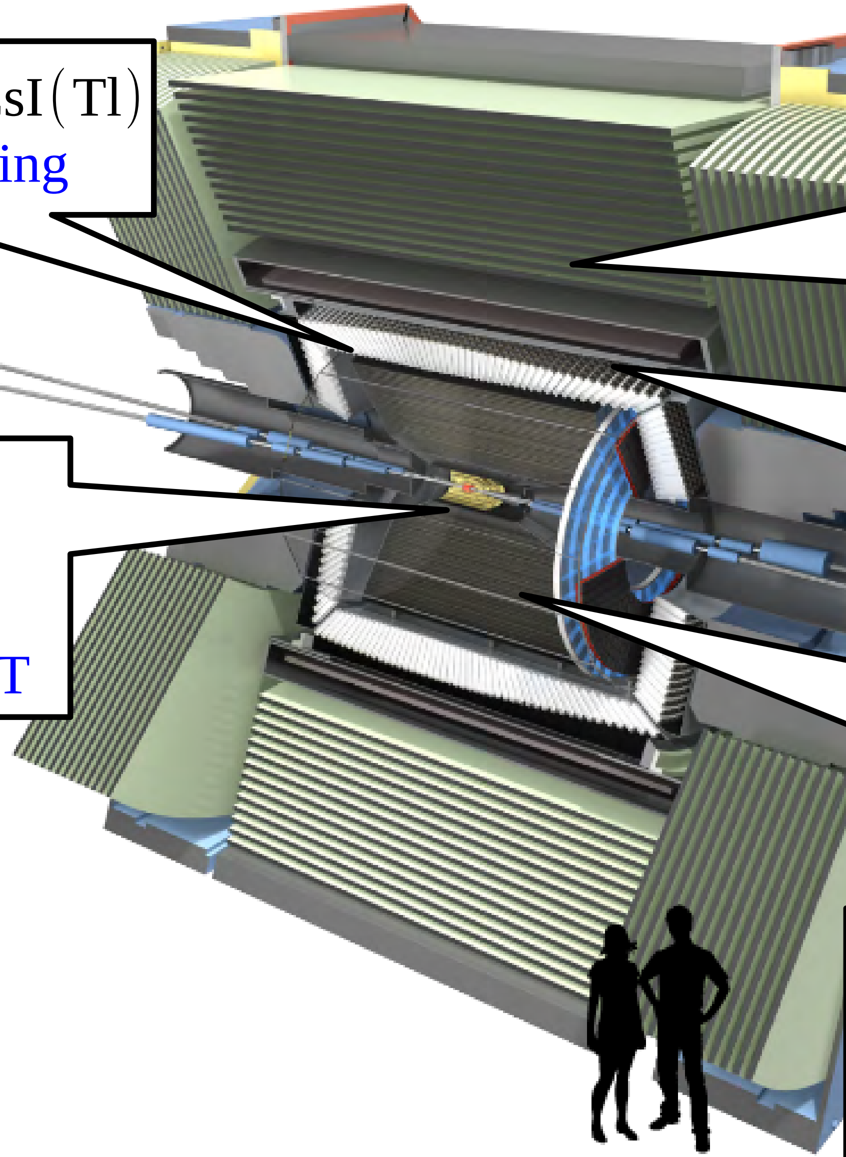
NEW RECORD
(December 2024)
$L = 5.1 \times 10^{34}\ cm^{2}\ s^{-1}$

run 1: data sample used for all results presented here
and when possible/relevant add the Belle data sample (+ 1ab^{-1})

Belle II detector

EM Calorimeter: CsI(Tl)
waveform sampling

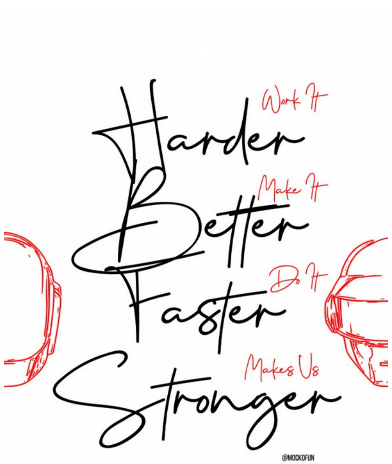
K_L and muon detector
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC
(endcaps)



Particle Identification
Time-Of-Propagation
counter (barrel)
Prox. focusing Aerogel RICH

Vertex Detector
4 layers DSSD
+
1/2 layers DEPFET

Central Drift Chamber
He(50%):C_2H_6 (50%)
small cells, long level arm,
fast electronics



DAQ upgrade
PCIe40 board, capable of reading via high speed optical links and to write to computer at rate of 100 Gb/s: limited number of boards (20) enough to read entire Belle II detector

Main challenge: Preserve detector performance while luminosity (so beam background) increases

Belle(II), LHCb side by side

Belle (II)

$e^+e^- \to \Upsilon(4S) \to b\bar{b}$

- **2 B's and nothing else !**
  2 B mesons are created simultaneously in a L=1 coherent state
- **clean events**

- high eff: γ, π^0, K^0_S
- B-tagging (missing energy), τ-tagging
- initial conditions are precisely known

$\sigma_{b\bar{b}} \sim 1\,\text{nb} \Rightarrow 1\ \text{fb}^{-1}$ produces $10^6\ B\bar{B}$

$\sigma_{b\bar{b}}/\sigma_{total} \sim 1/4$

LHCb

$pp \to b\bar{b}X$

production of B^+, B^0, B_s, B_c, Λ_b...
but also a lot of other particles in the event

$\Rightarrow$ lower reconstruction efficiencies

$\sigma_{b\bar{b}}$ much higher than at the $\Upsilon(4S)$

	$\sqrt{s}$ [GeV]	$\sigma_{b\bar{b}}$ [nb]	$\sigma_{b\bar{b}}/\sigma_{tot}$
HERA pA	42 GeV	~30	~10^{-6}
Tevatron	2 TeV	5000	~10^{-3}
LHC	8 TeV	~3×10^5	~ 5×10^{-3}
	14 TeV	~6×10^5	~10^{-2}

$b\bar{b}$ production cross-section at LHCb ~ 500,000 × BaBar/Belle !!

higher luminosity

$\sigma_{b\bar{b}}/\sigma_{total}$ much lower than at the $\Upsilon(4S)$
$\Rightarrow$ lower trigger efficiencies

B mesons live relatively long

mean decay length $\beta\gamma c\tau \sim 200\ \mu m$

mean decay length $\beta\gamma c\tau \sim 7$ mm
(displaced vertices)

data taking period(s)

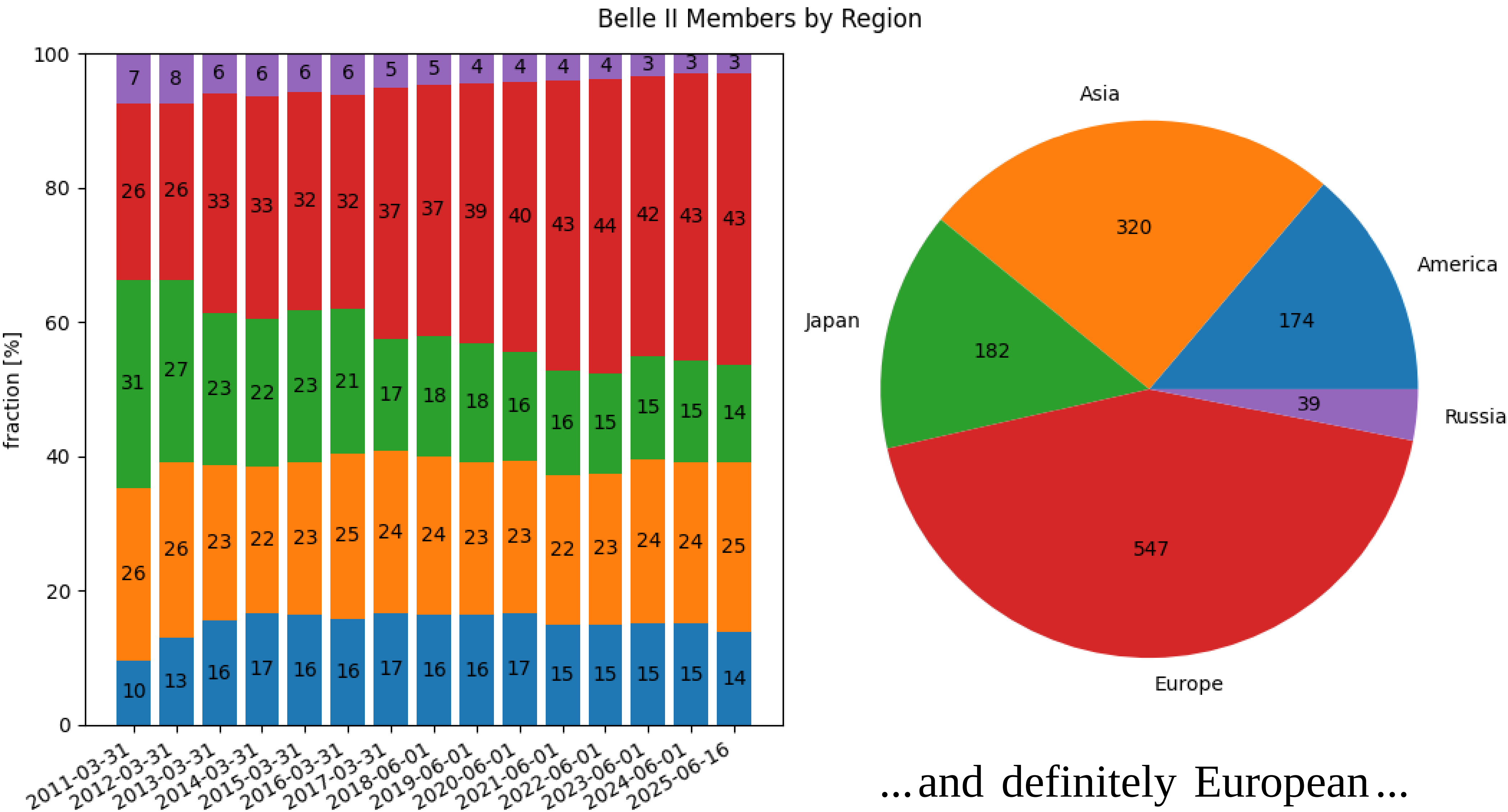
[1999-2010] = 1 ab^{-1}
[run I: 2019-2022] = 0.4 ab^{-1}
[run II: 2024-...]

[run I: 2010-2012] = 3 fb^{-1}
[run II: 2015-2018] = 6 fb^{-1}
[run III: 2022-...]

Belle II collaboration – breakdown by region

125 institutes - 28 countries/regions

Belle II is an international collaboration...

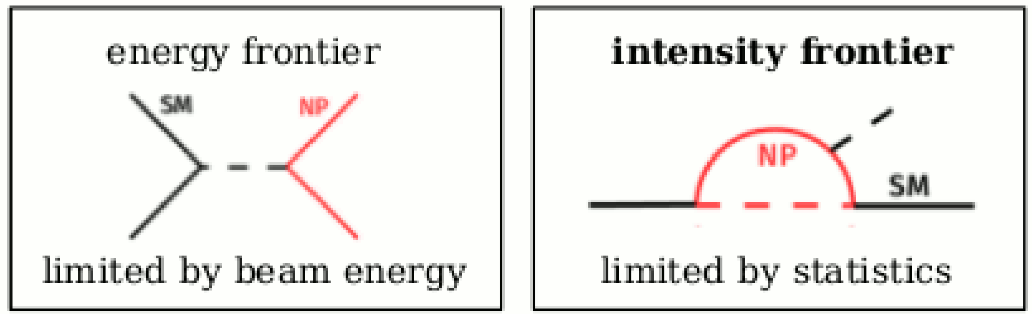


...and definitely European...

How do you we search for new physics ?

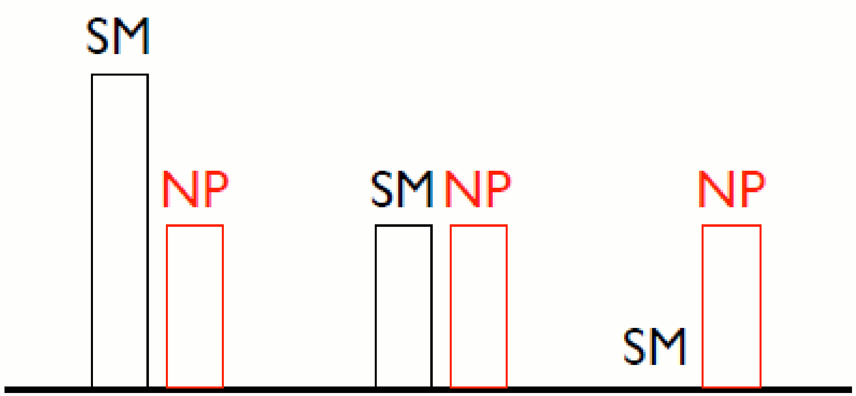
Direct vs Indirect Searches

Why flavor physics ?



Three classes of SM processes

$$\mathcal{O}_{\text{obs}} = \mathcal{O}_{\text{SM}} + \mathcal{O}_{\text{NP}}$$



SM tree	loop	forbidden
extremely precise ($|V_{cb}|$, $|V_{ub}|$...)	precision (**rare B...**)	good but... (**LFV τ...**)

Missing energy modes and B-tagging

Many interesting B-physics studies involve missing energy:

$D^{(*)} l \nu$, $D^{(*)} \tau \nu$, $K^{(*)} \tau l$, $K^{(*)} \tau \tau$, $\pi l \nu$, $\tau \nu$, $\mu \nu$...

which require B-tagging:

hadronic tag

$B \to D^{(*)} \pi$, $D^{(*)} \rho$...

$\epsilon < 1\%$

semileptonic tag

$B \to D^{(*)} l \nu X$

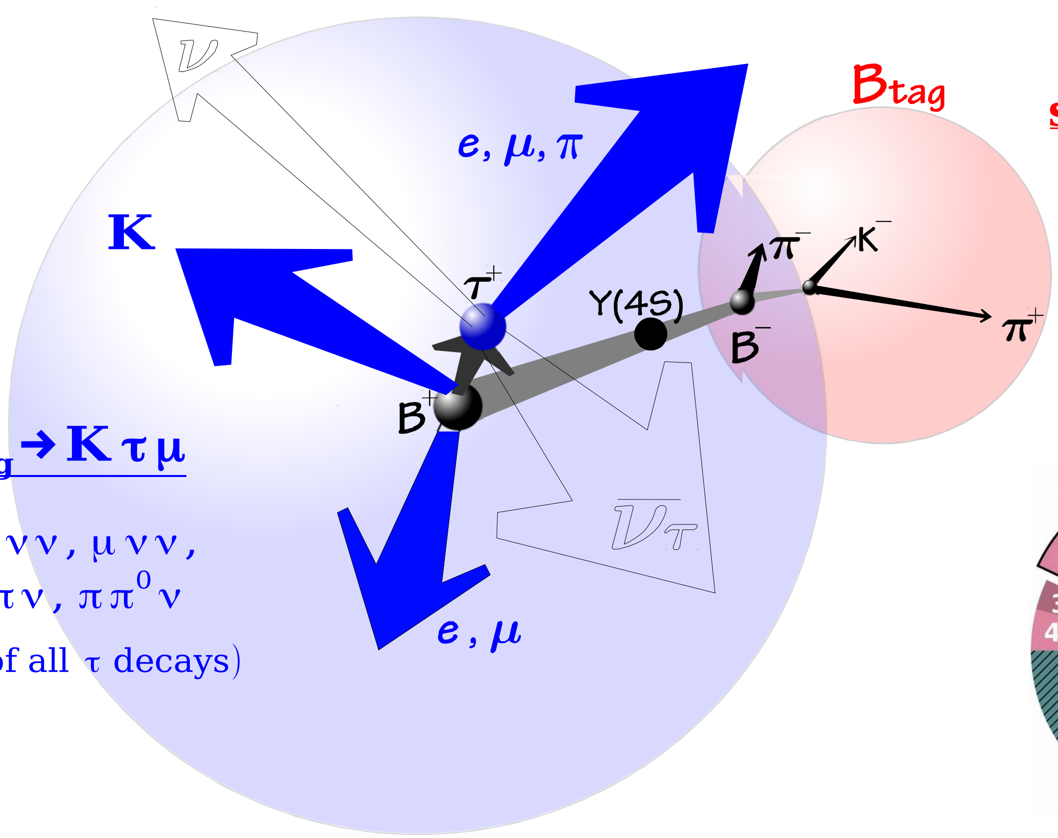
$\epsilon \sim 2\%$

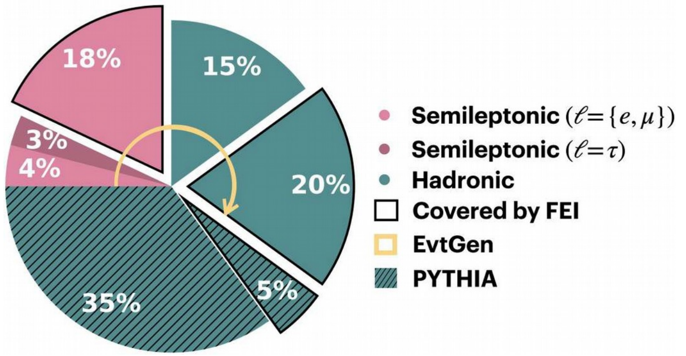
$B_{sig} \to K \tau \mu$

$\tau \to e \nu \nu$, $\mu \nu \nu$,

$\tau \to \pi \nu$, $\pi \pi^0 \nu$

(70 % of all τ decays)





B-tagging is a key tool for missing energy analyses

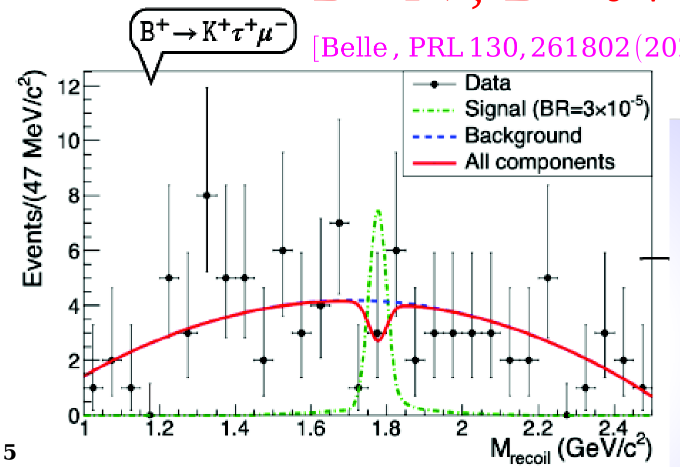
- low efficiency (efficiency for hadronic B-tagging < 1%)

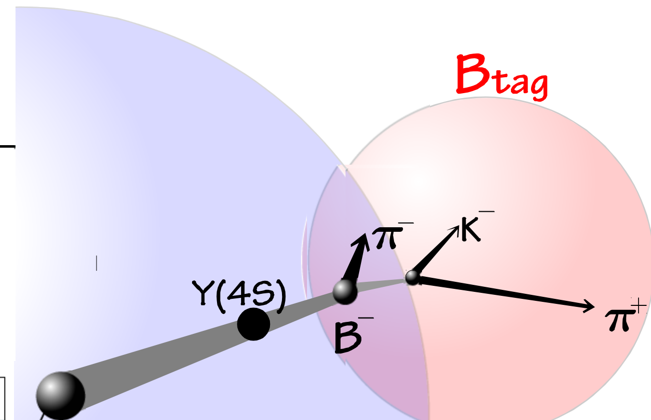
Missing energy modes and B-tagging

Many interesting B-physics studies involve missing energy:

$D^{(*)} l \nu$, $\mathbf{D^{(*)} \tau \nu}$, $\mathbf{K^{(*)} \tau l}$, $\mathbf{K^{(*)} \tau \tau}$, $\pi l \nu$, $\boldsymbol{\tau \nu}$, $\mu \nu$...

[Belle, PRL 130, 261802 (2023)]





hadronic tag

$B \to D^{(*)}\pi$, $D^{(*)}\rho$...

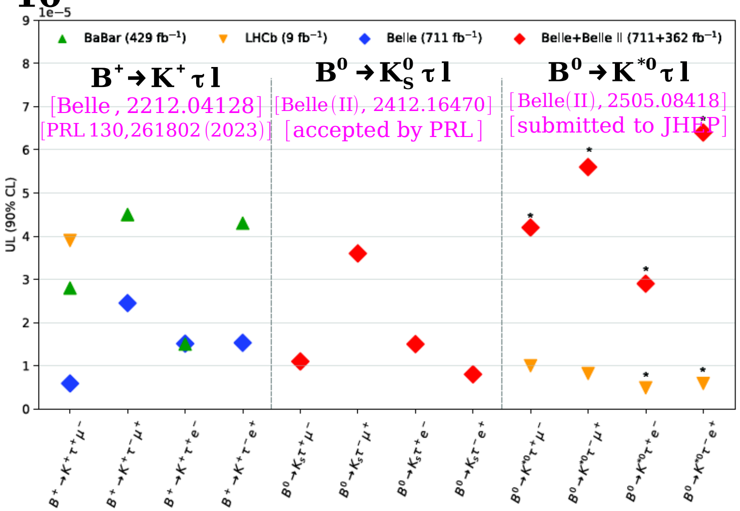
$\epsilon < 1\%$

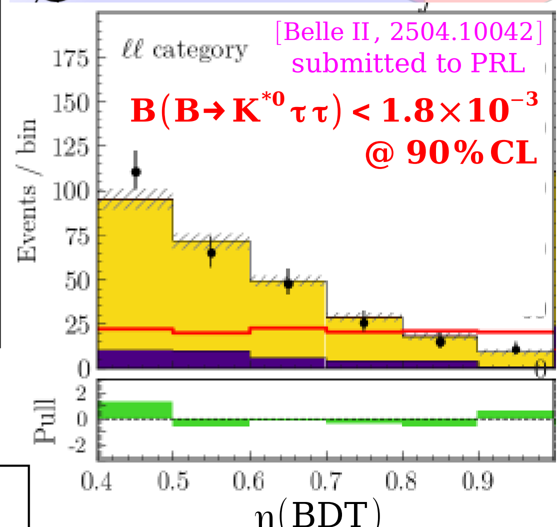
semileptonic tag

$B \to D^{(*)} l \nu X$

$\epsilon \sim 2\%$

10^{-5}

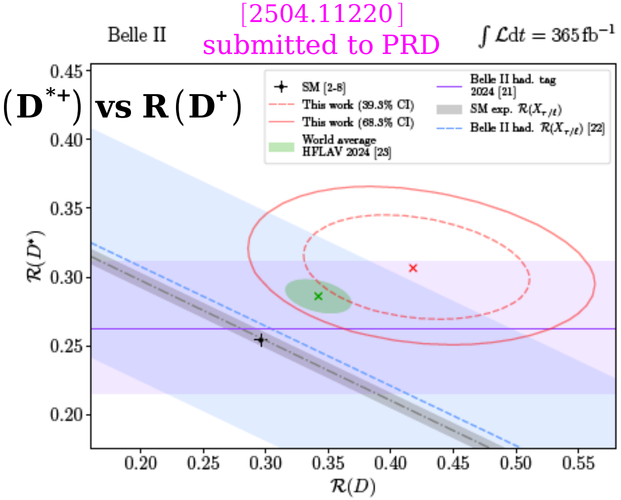


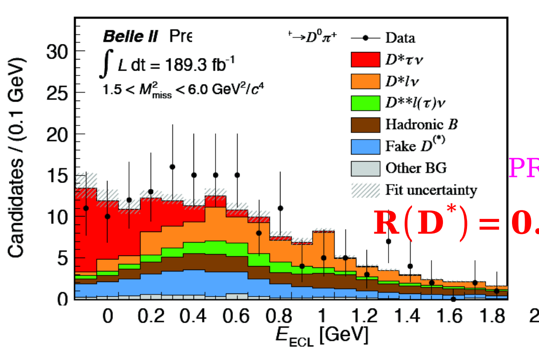


$\mathbf{B(B \to K^{*0} \tau\tau) < 1.8 \times 10^{-3}}$ **@ 90% CL**

[2504.11220]
submitted to PRD

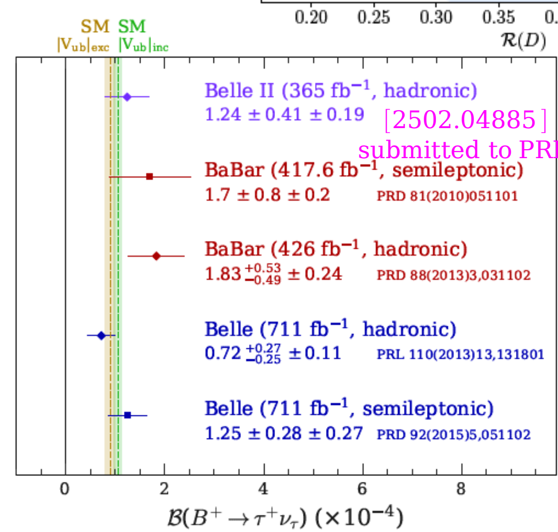
$R(D^{*+})$ vs $R(D^+)$





[Belle II, 2401.02840]
PRD 110, 072020 (2024)

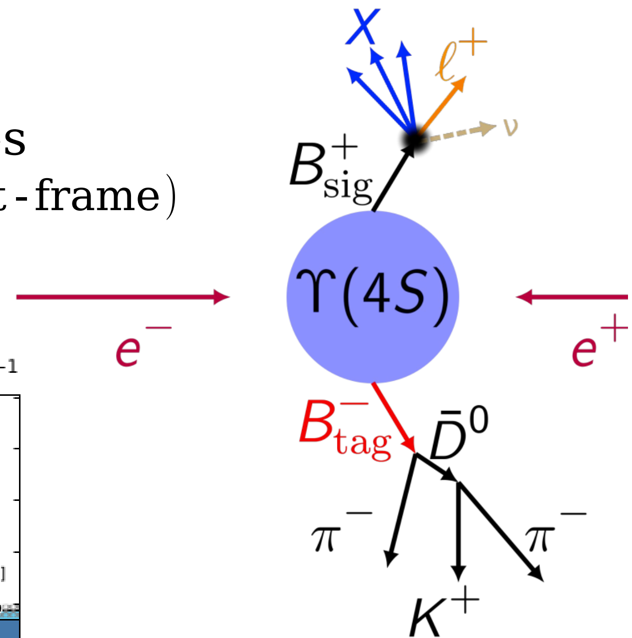
$$\mathbf{R(D^*) = 0.262^{+0.041}_{-0.039}(stat)^{+0.035}_{-0.032}(syst)}$$

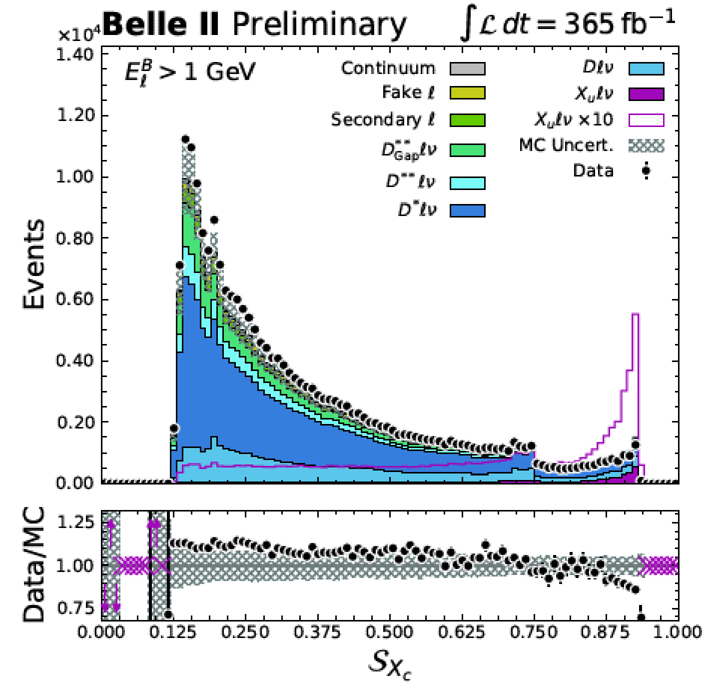


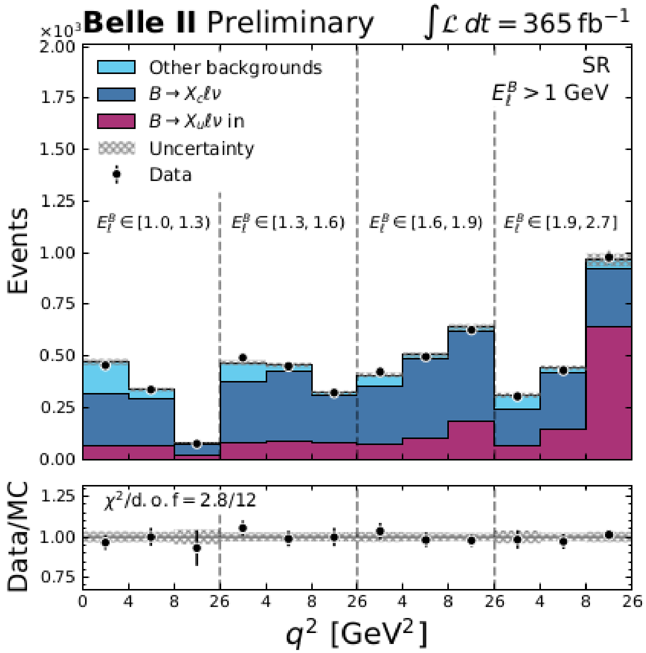
$|V_{ub}|$ from inclusive $B \to X_u l \nu$ decays (had tag)

[PRELIMINARY]

- First Belle II measurement
- Hadronic B-tagging
- 3 main kinematical variables
  - $E_l^{(B)}$: lepton energy (in B_{sig} rest-frame)
  - M_X: mass of hadronic system
  - q^2: momentum transfer

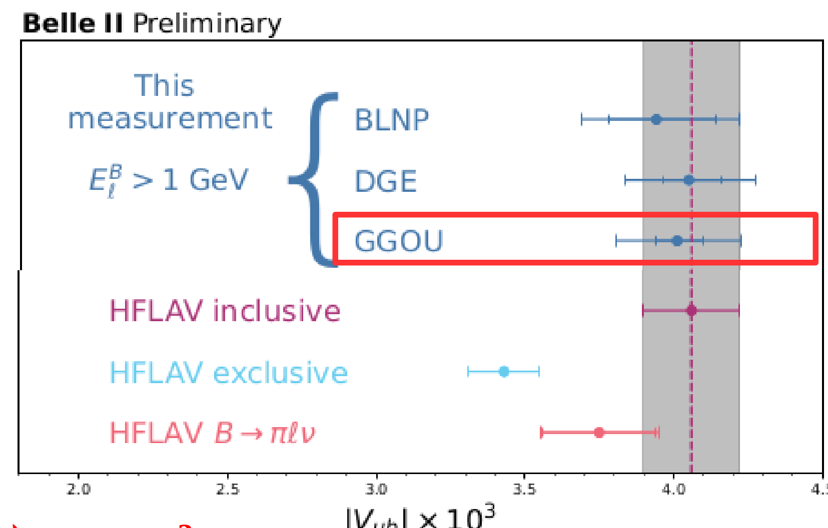






Extract $|V_{ub}|$ from partial BR using the predicted partial decay rate over a given phase-space region

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u \ell \nu)}{\tau_B \Delta\Gamma(B \to X_u \ell \nu)}}$$



$$|V_{ub}|_{GGOU} = (4.01 \pm 0.11(\text{stat}) \pm 0.16(\text{syst})\ ^{+0.09}_{-0.07}(\text{theo})) \times 10^{-3}$$

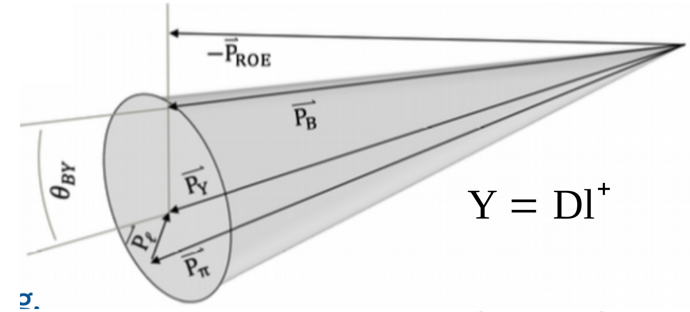
$$|V_{ub}|^{HFLAV}_{incl} = (4.06 \pm 0.16) \times 10^{-3}$$

"Measurements of semileptonic and leptonic B decay at Belle and Belle II" (G.Gaudino)

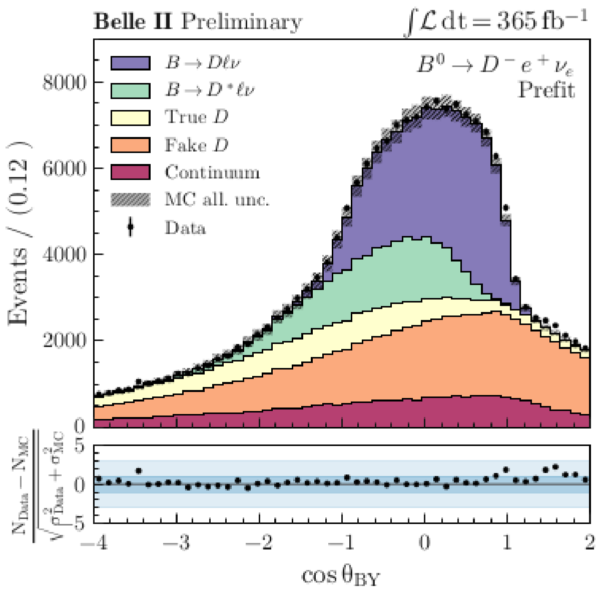
$|V_{cb}|$ from $B \to D l \nu$

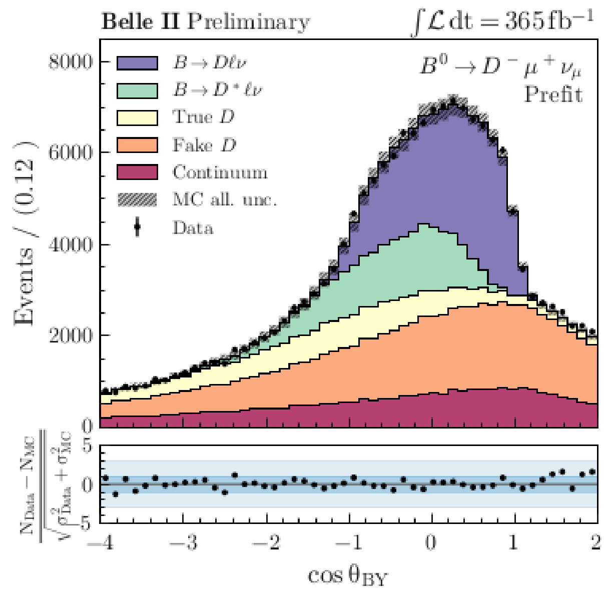
[arXiv:2506.15256]

- $B^0 \to D^- l^+ \nu$ and $B^+ \to \overline{D}^0 l^+ \nu$, with l (e, μ) and $D \to K\pi(\pi)$
- smaller BF than $D^* l \nu$, significant background
- described by single form factor $f_+(q^2)$, no soft pion rec.
- inclusive tag side



$$\cos\theta_{BY} = \frac{2E_{\text{Beam}}E_Y - m_B^2 - m_Y^2}{2|\vec{p}_B||\vec{p}_Y|}$$



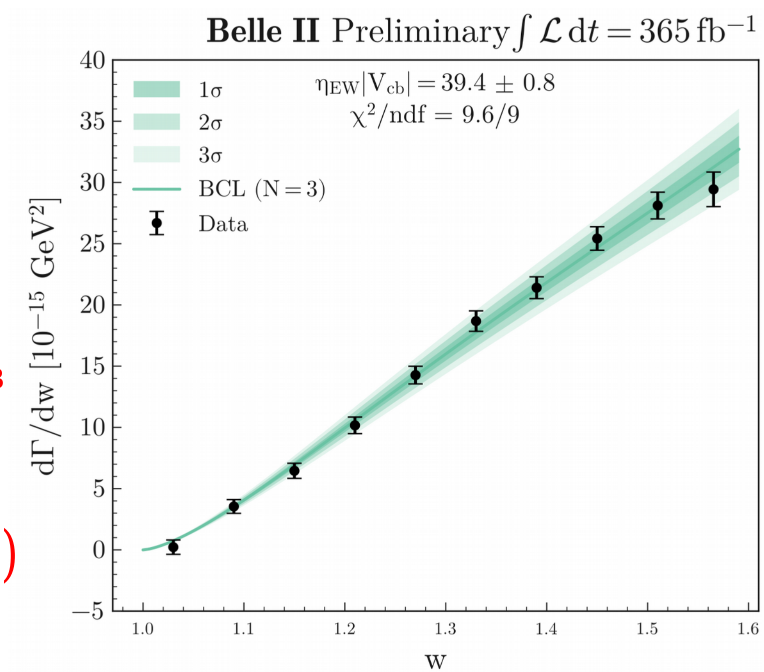


Simultaneous maximum likelihood fit to 10 bins (w) of $\cos\theta_{BY}$

$$w = \frac{m_B^2 + m_D^2 - q^2}{2m_B m_D}$$

$|V_{cb}|$ extraction:

Fit differential decay rates using Bourrely-Caprini-Lellouch (BCL) parameterization of form factor

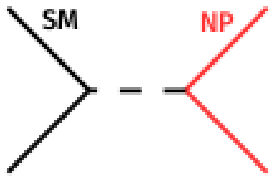


$$|V_{cb}|_{BCL} = (39.2 \pm 0.4(\text{stat}) \pm 0.6(\text{syst}) \pm 0.5(\text{theo})) \times 10^{-3}$$

Most precise measurement to date using $B \to Dl\nu$ decays
(2.3 % precision, even more precise than our $|V_{cb}|$ with $D^* l \nu$)

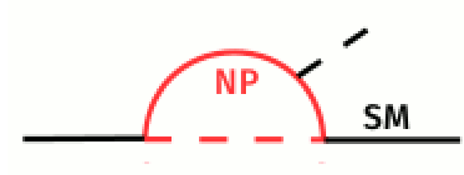
Rare/Forbidden B decays

energy frontier



limited by beam energy

intensity frontier

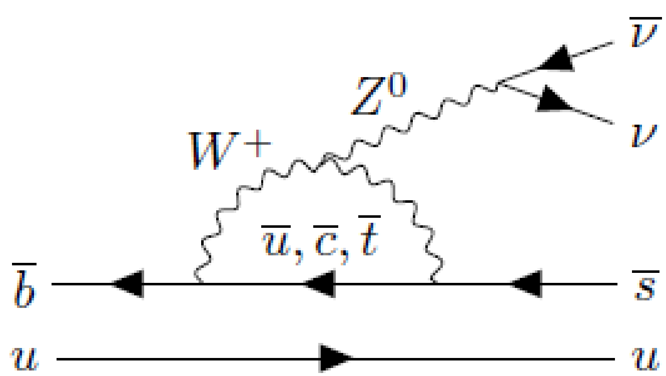


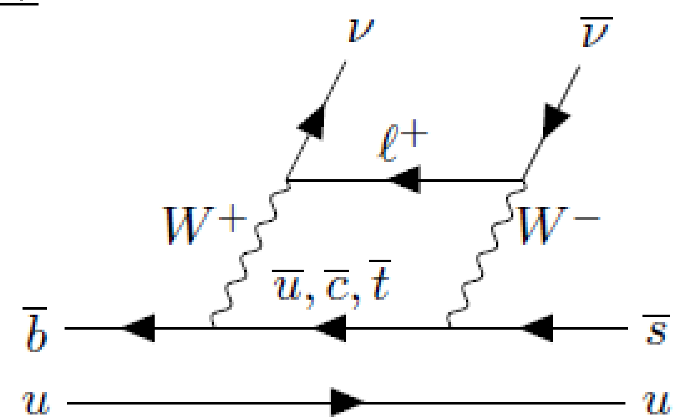
limited by statistics

→ NP beyond the direct reach of the LHC

New particles can for example contribute to loop or tree level diagrams
by enhancing/suppressing decay rates, introducing new sources of CP violation or modifying the angular distribution of the final-state particles

$B \to K \nu \bar{\nu}$



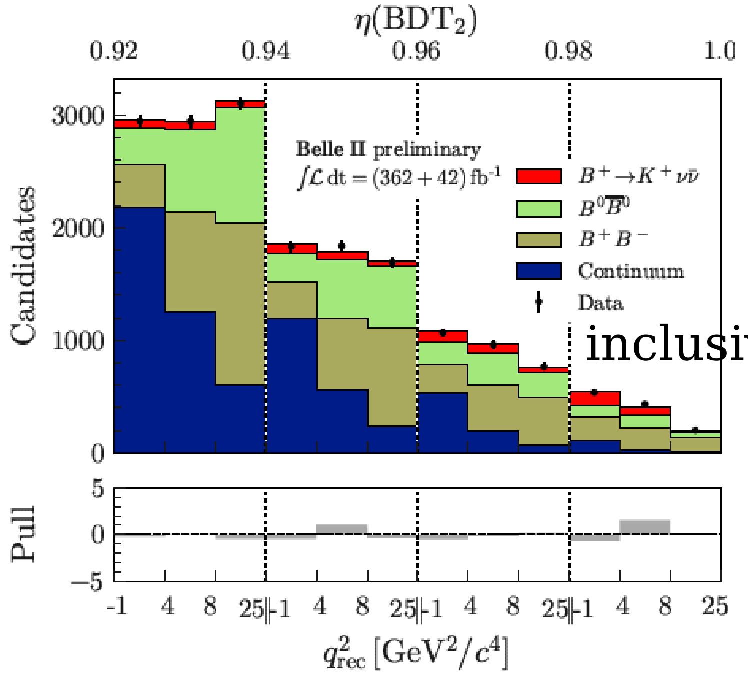


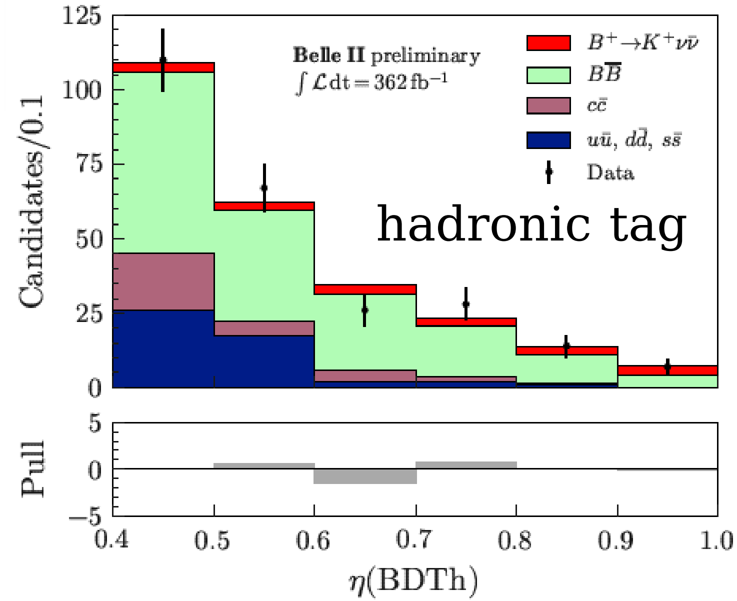
- $B \to K \nu \nu$ is known with high accuracy
  $B(B \to K \nu \nu) = (5.6 \pm 0.4) \times 10^{-6}$ [arXiv:2207.13371]
- Extensions beyond SM may lead to significant rate increase
- Very challenging experimentally, not yet observed
  - Low branching fraction, high background contributions
  - 3-body kinematics ⇒ no peaking variables to isolate signal
- Unique for Belle II

Evidence of $B \to K \nu \bar{\nu}$

[arXiv:2311.14647]
PRD109, 112006 (2024)

- Two analyses: more sensitive **inclusive** (eff = 8%), conventional **hadronic** tagging (eff = 0.4%)
- Use event properties to suppress background with multiple variables combined
- Use classifier output as (one of) the fit variables, use simulation for signal and background templates
- Use multiple control channels to validate simulation with data





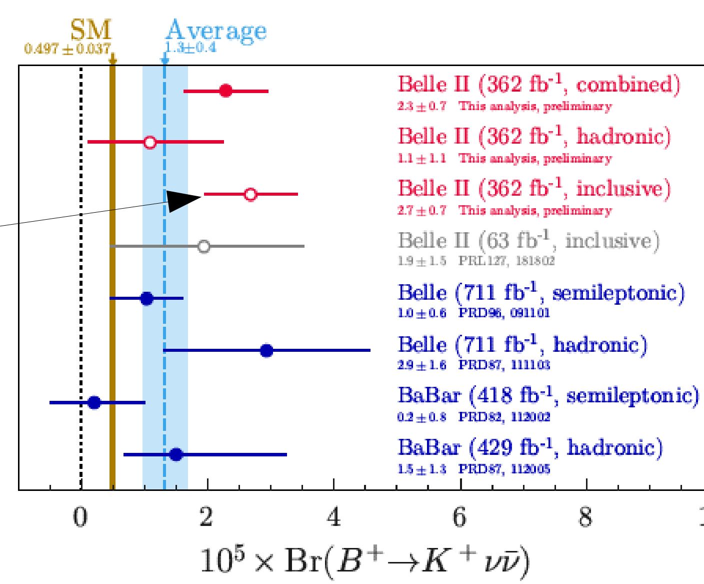
- Max. likelihood fit to data using signal and bckg templates

  $\mathbf{B_{incl} = (2.7 \pm 0.5\,(stat) \pm 0.5\,(syst)) \times 10^{-5}}$

  $\mathbf{B_{had} = (1.1\,^{+0.9}_{-0.8}\,(stat)\,^{+0.8}_{-0.5}\,(syst)) \times 10^{-5}}$

- For inclusive analysis, evidence for $B \to K \nu \bar{\nu}$ at 3.5σ branching fraction within **3σ** of SM
- For hadronic tag, the result is consistent with null hypothesis and SM at 1.1σ and 0.6σ

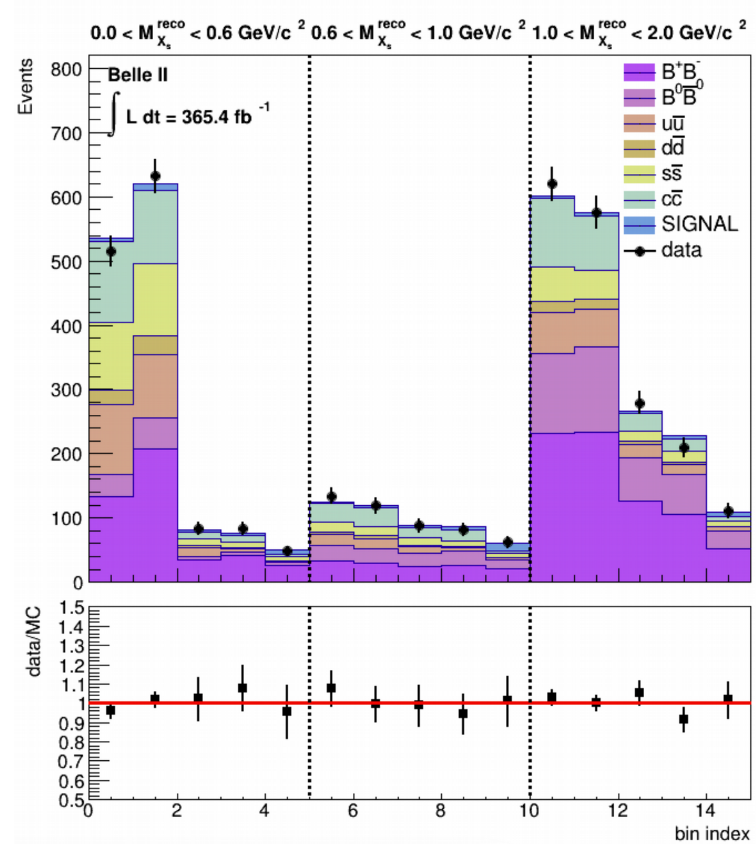
⇒ Combination of two analyses provides first evidence of the decay at 2.7σ from SM



Search for $B \to X_s \nu \bar{\nu}$ decays [PRELIMINARY]

- $\mathcal{B}_{SM} = (2.9 \pm 0.3) \times 10^{-5}$ [JHEP 02 (2015) 184]
- $\mathcal{B} < 6.4 \times 10^{-4}$ at 90% C.L. [ALEPH, EPJC 19 (2001) 213]
- using Belle II sample of 362 fb^{-1}
- Hadronic B-tagging
- Sum-of-exclusive from 30 decay modes (~90% of inclusive)

	$B^0\bar{B}^0$			$B^\pm$		
K	K_S^0			$K^\pm$		
$K\pi$	$K^\pm\pi^\mp$	$K_S^0\pi^0$		$K^\pm\pi^0$	$K_S^0\pi^\pm$	
$K2\pi$	$K^\pm\pi^\mp\pi^0$	$K_S^0\pi^\pm\pi^\mp$	$K_S^0\pi^0\pi^0$	$K^\pm\pi^\mp\pi^\pm$	$K_S^0\pi^\pm\pi^0$	$K^\pm\pi^0\pi^0$
$K3\pi$	$K^\pm\pi^\mp\pi^\pm\pi^\mp$	$K_S^0\pi^\pm\pi^\mp\pi^0$	$K^\pm\pi^\mp\pi^0\pi^0$	$K^\pm\pi^\mp\pi^\pm\pi^0$	$K_S^0\pi^\pm\pi^\mp\pi^\pm$	$K_S^0\pi^\pm\pi^0\pi^0$
$K4\pi$	$K^\pm\pi^\mp\pi^\pm\pi^\mp\pi^0$	$K_S^0\pi^\pm\pi^\mp\pi^\pm\pi^\mp$	$K_S^0\pi^\pm\pi^\mp\pi^0\pi^0$	$K^\pm\pi^\mp\pi^\pm\pi^\mp\pi^\pm$	$K_S^0\pi^\pm\pi^\mp\pi^\pm\pi^0$	$K^\pm\pi^\mp\pi^\pm\pi^0\pi^0$
$3K$	$K^\pm K^\mp K_S^0$			$K^\pm K^\mp K^\pm$		
$3K\pi$	$K^\pm K^\mp K^\pm\pi^\mp$	$K^\pm K^\mp K_S^0\pi^0$		$K^\pm K^\mp K^\pm\pi^0$	$K_S^0K^\pm K^\mp\pi^\pm$	



- For background suppression, use BDT
  (include sum of remaining energy in ECL)
- signal extraction in (BDT output) $\times M_{X_s}$ plane

$$\mathcal{B}(B \to X_s \nu \bar{\nu}) < \begin{cases} 2.5 \times 10^{-5} & (0.0 < M_{X_s} < 0.6 \text{ GeV}/c^2) \\ 1.0 \times 10^{-4} & (0.6 < M_{X_s} < 1.0 \text{ GeV}/c^2) \\ 3.5 \times 10^{-4} & (1.0 < M_{X_s}) \end{cases}$$

"Measurements of electroweak penguin and LFV B decays with missing energy at Belle and Belle II" (V. Bertacchi)

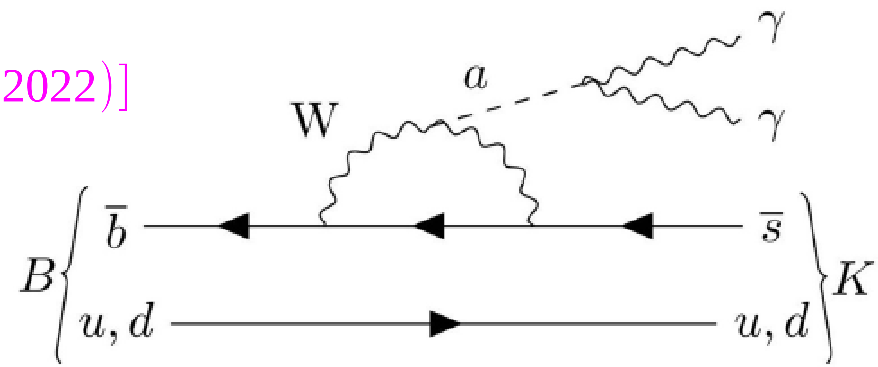
$\mathcal{B}(B \to X_s \nu \bar{\nu}) < 3.6 \times 10^{-4}$ at 90% C.L.

$\Rightarrow$ The most stringent upper limit on $B \to X_s \nu \bar{\nu}$ decay

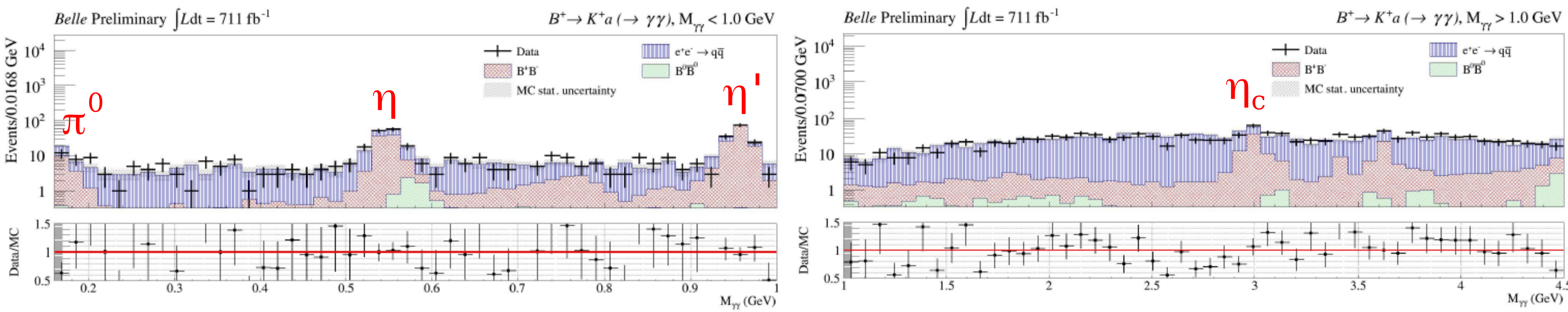
Search for $B \to K^{(*)} a(\to \gamma\gamma)$

[arXiv:2507.01249] submitted to JHEP

- Search for an ALP in the MeV-GeV scale
- Previous result on $B^+ \to K^+ a$ [BaBar, PRL 128, 131802 (2022)]



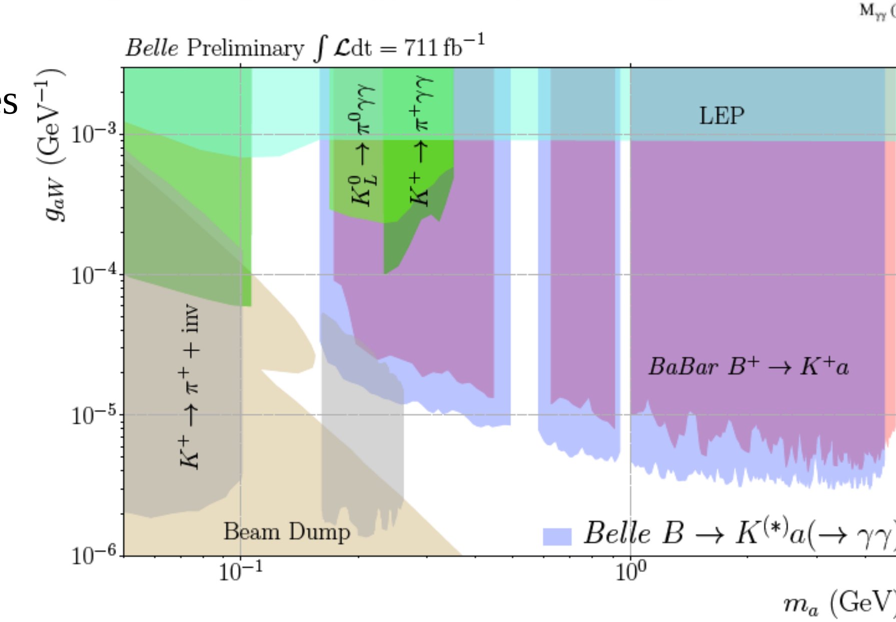
- using Belle sample ($711\ fb^{-1}$)
- four kaon modes included: K_S^0, K^+, K^{*+}, K^{*0}
- $B(a \to \gamma\gamma) \sim 100\%$ when $m_a \ll m_{W^+}$
- m_a investigated from 160 MeV/c^2 to the kinematic end-point



- Main background is continuum ($e^+e^- \to q\bar{q}$) rejected with BDTs based on kinematics and topology variables
- fit di-photon invariant mass to extract signal yield
- Peaking background regions vetoes (π^0, η, η')
- $B \to K\eta, K\eta'$ as validation modes

For each ALP mass hypothesis, simultaneous fit performed on four kaon modes to obtain the coupling constant g_{aW}

⇒ improved at least by factor 2 from BaBar



"Searches for dark sector particles at Belle II" (L.Salutari)

CPV in isospin-related $D^{0,+} \to \pi^{0,+} \pi^{0}$ modes

Sum-rule for CPV in $D \to \pi\pi$, to determine the source of CPV:

$$R = \frac{A_{CP}^{\rm dir}(D^0 \to \pi^+\pi^-)}{1 + \frac{\tau_{D^0}}{\mathcal{B}_{+-}}\left(\frac{\mathcal{B}_{00}}{\tau_{D^0}} - \frac{2}{3}\frac{\mathcal{B}_{+0}}{\tau_{D^+}}\right)} + \frac{A_{CP}^{\rm dir}(D^0 \to \pi^0\pi^0)}{1 + \frac{\tau_{D^0}}{\mathcal{B}_{00}}\left(\frac{\mathcal{B}_{+-}}{\tau_{D^0}} - \frac{2}{3}\frac{\mathcal{B}_{+0}}{\tau_{D^+}}\right)} + \frac{A_{CP}^{\rm dir}(D^+ \to \pi^+\pi^0)}{1 - \frac{3}{2}\frac{\tau_{D^+}}{\mathcal{B}_{+0}}\left(\frac{\mathcal{B}_{00}}{\tau_{D^0}} + \frac{\mathcal{B}_{+-}}{\tau_{D^0}}\right)}$$

if $R \neq 0$, CPV from $\Delta I = 1/2$ amplitude; if $R = 0$ and at least one $A_{CP}^{\rm dir} \neq 0$, CPV from beyond SM $\Delta I = 3/2$ amplitude

Raw asymmetry of $D^0 \to \pi^0\pi^0$ using tagged events (D^{*+}) [arXiv:2505.02912]

$$A^{\pi^0\pi^0} = A_{CP}(D^0 \to \pi^0\pi^0) + A_{\rm P}^{D^{*+}} + A_{\epsilon}^{\pi_s}$$

$A_{\rm P}^{D^{*+}}$: forward-backward asymmetric production of D^{*+} in $e^+e^- \to c\bar{c}$ events

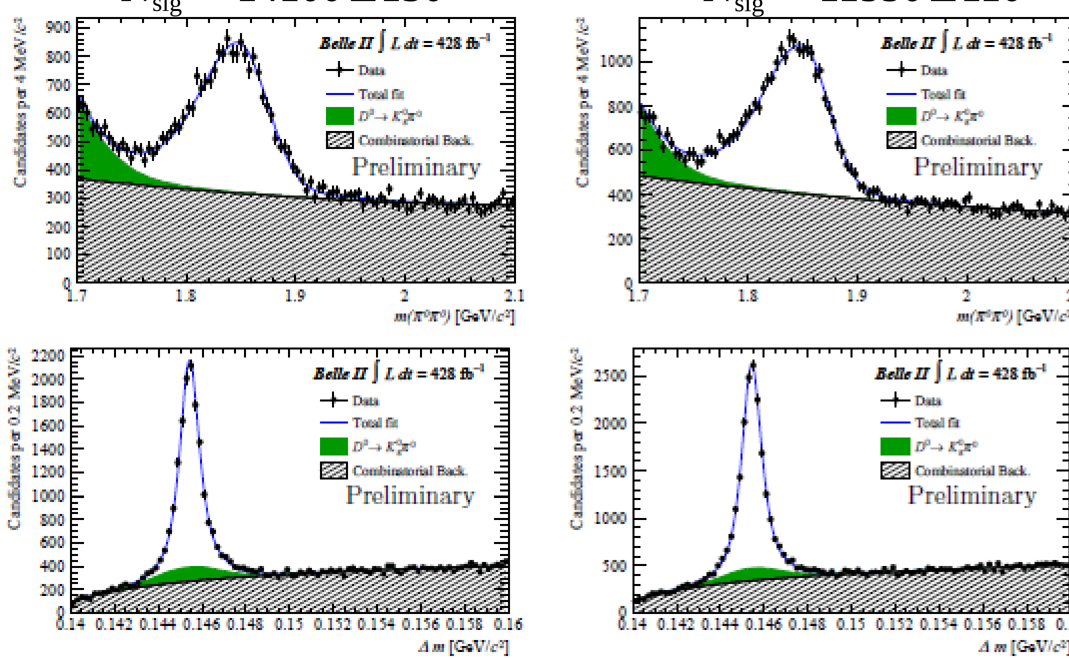
$A_{\epsilon}^{\pi_s}$: charge asymmetry in detection efficiency

$$A_{CP}(D^0 \to \pi^0\pi^0) = A_{\rm avg}^{\pi^0\pi^0} - A_{\rm avg}^{K\pi} + A_{\rm avg}^{K\pi,\,{\rm untag}}$$

$$A_{\rm avg}^{f} = (A^{f}(\cos\theta^* < 0) + A^{f}(\cos\theta^* > 0))/2$$

$\cos\theta^*(D^{*+}) > 0$ — $N_{\rm sig} = 14100 \pm 130$

$\cos\theta^*(D^{*+}) < 0$ — $N_{\rm sig} = 11550 \pm 110$



Belle II with 428 $\rm fb^{-1}$:

$A_{CP}(D \to \pi^0\pi^0) = (+0.30 \pm 0.72 \pm 0.20)\%$

(Belle with 980 $\rm fb^{-1}$: $(-0.03 \pm 0.64 \pm 0.10)\%$)
[PRL 112 (2014) 211601]

$\Rightarrow$ $R = (1.5 \pm 2.5) \times 10^{-3}$

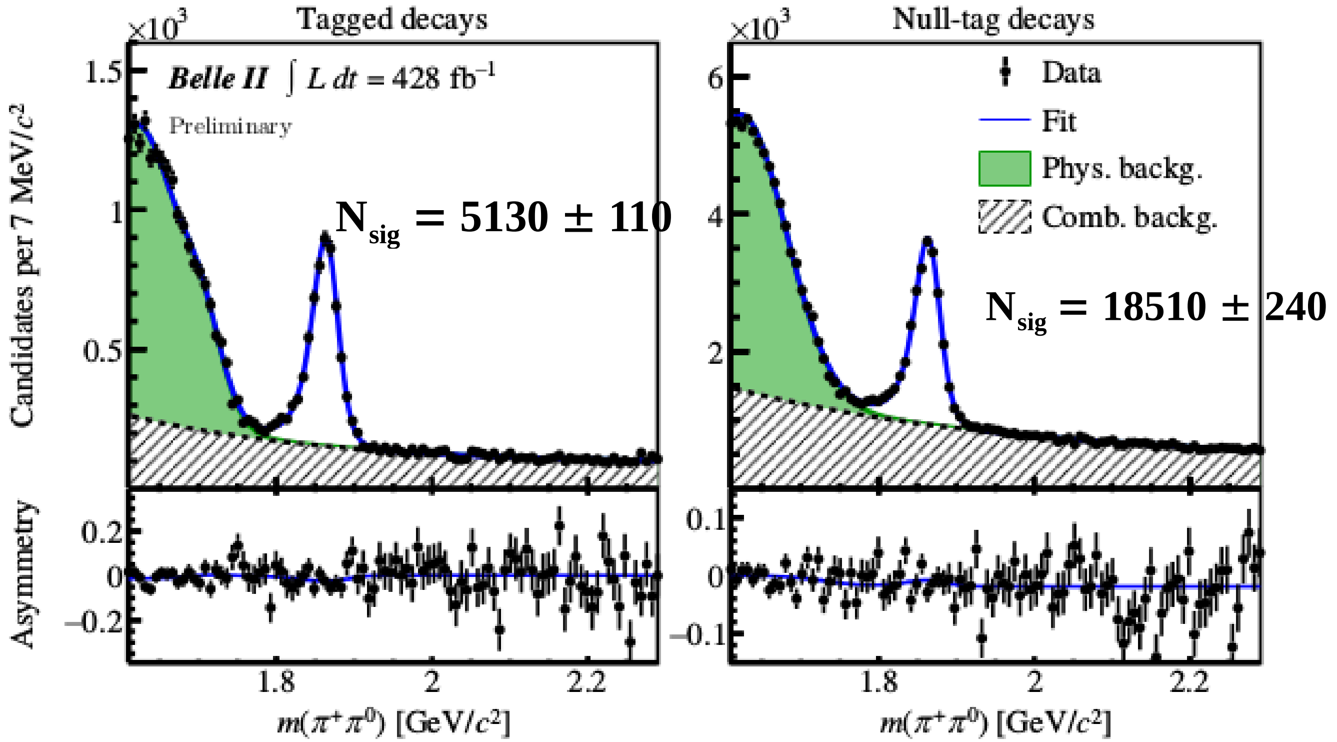
improve by ~20% w.r.t current HFLAV result

$A_{CP}(D^+ \to \pi^+ \pi^0)$ at Belle and Belle II [arXiv:2506.07879]

Split sample as tagged (from $D^{*+} \to D^+ \pi^0$) and not

Using $D^+ \to K_S^0 \pi^+$ to eliminate common asymmetry sources: A_{prod}^{D} and $A_{\epsilon}^{\pi^+}$

$$A_{CP}^{\pi^+\pi^0} = A_{raw}^{\pi^+\pi^0} - A_{raw}^{K_S^0\pi^+} + A^{\overline{K}^0}$$



$A_{CP}^{tag} = (-3.9 \pm 1.8 \pm 0.2)\%$ $A_{CP}^{null} = (-1.1 \pm 1.0 \pm 0.1)\%$

Belle II combining A_{CP}^{tag} and A_{CP}^{null} with 428 fb^{-1}:

$$\mathbf{A_{CP}(D \to \pi^+ \pi^0) = (-1.8 \pm 0.9 \pm 0.1)\%}$$

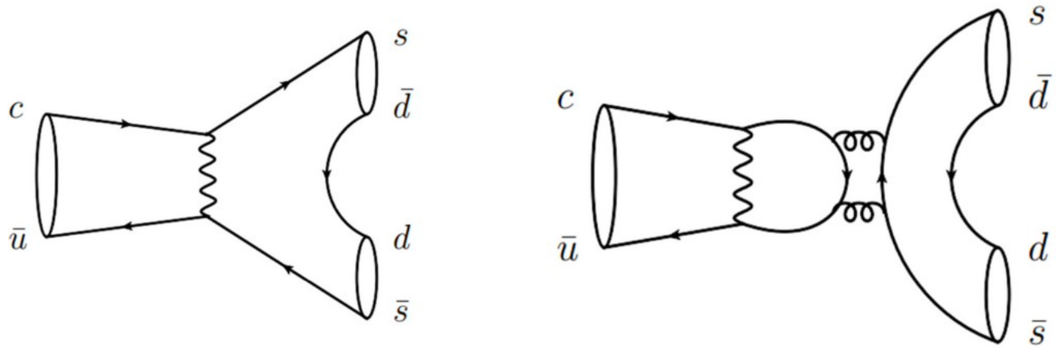
(Belle with 980 fb^{-1}: $(+2.31 \pm 1.24 \pm 0.23)\%$) [PRD 97 (2018) 011101]

improved by ~30%, better purity achieved through an improved event selection thanks to Belle II's superior performance in reconstruction of neutral pions and displaced charged particles

$A_{CP}(D^0 \to K^0_S K^0_S)$ measurement using D^{*+}-tagged sample

[arXiv:2411.00306 - PRD 111 (2025) 012015]

CPV in $D \to K^0_S K^0_S$ enhanced to an observable level due to interference btw $c \to u s \bar{s}$ and $c \to u d \bar{d}$



$$A_{CP}(D^0 \to K^0_S K^0_S) = \frac{\Gamma(D^0 \to K^0_S K^0_S) - \Gamma(\bar{D}^0 \to K^0_S K^0_S)}{\Gamma(D^0 \to K^0_S K^0_S) + \Gamma(\bar{D}^0 \to K^0_S K^0_S)}.$$

Belle (921 fb^{-1}): $(0.0 \pm 1.5 \pm 0.2)\%$
[PRL 119, 171801 (2017)]

LHCb (6 fb^{-1}): $(-3.1 \pm 1.2 \pm 0.4 \pm 0.2)\%$
[PRD 104, L031102 (2021)]

Unbinned fit to $(m(D^0 \pi_s), S_{min})$ of D^0 and $\bar{D}^0$ candidates for $D^0 \to K^0_S K^0_S$

flight significance variable $S_{min} = \log(\min(L_i/\sigma_i))$: separate peaking background $D^0 \to K^0_S \pi^+ \pi^-$

$$A_{CP}^{K^0_S K^0_S} = (A_{raw}^{K^0_S K^0_S} - A_{raw}^{K^+K^-}) + A_{CP}^{K^+K^-}$$

$$A_{raw}^{K\bar{K}} = \frac{N(D^0) - N(\bar{D}^0)}{N(D^0) + N(\bar{D}^0)} = A_{FB}^{D^{*+}} + A_{CP}^{K\bar{K}} + A_{\varepsilon}^{\pi_s}$$

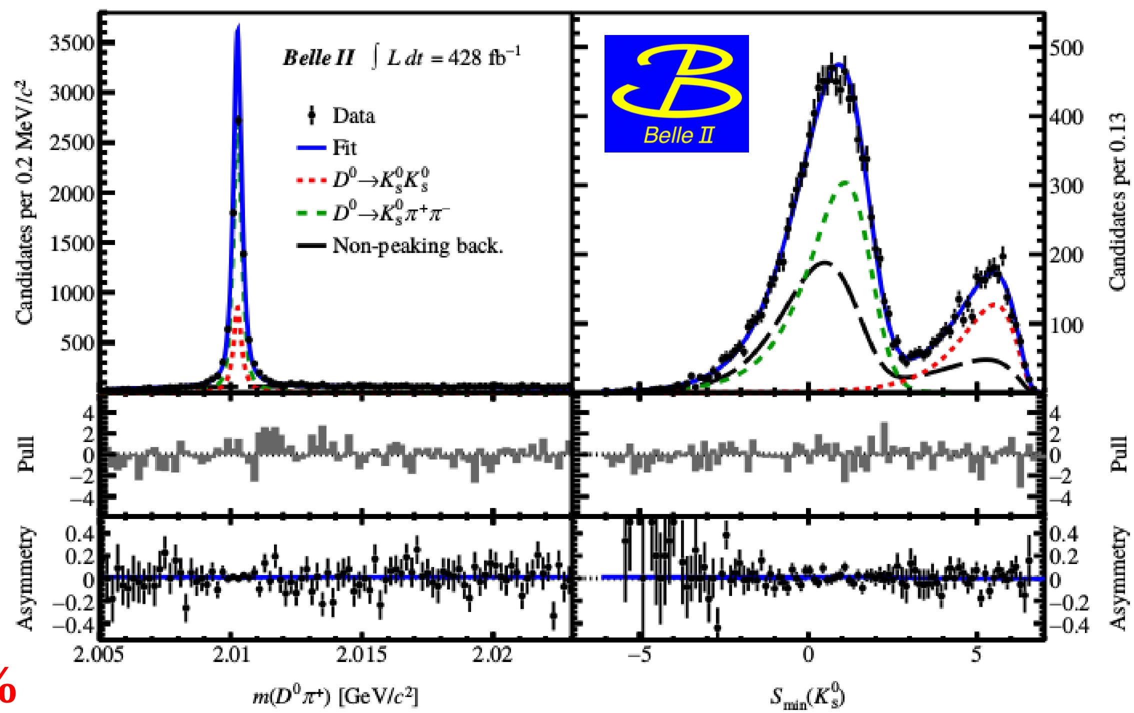
Control mode $D^0 \to K^+ K^-$:

$$A_{CP}^{K^+K^-} = A_{CP}^{dir} + \Delta Y = (6.7 \pm 5.4) \times 10^{-4}$$

Belle (980 fb^{-1}): $(-1.1 \pm 1.6 \pm 0.1)\%$

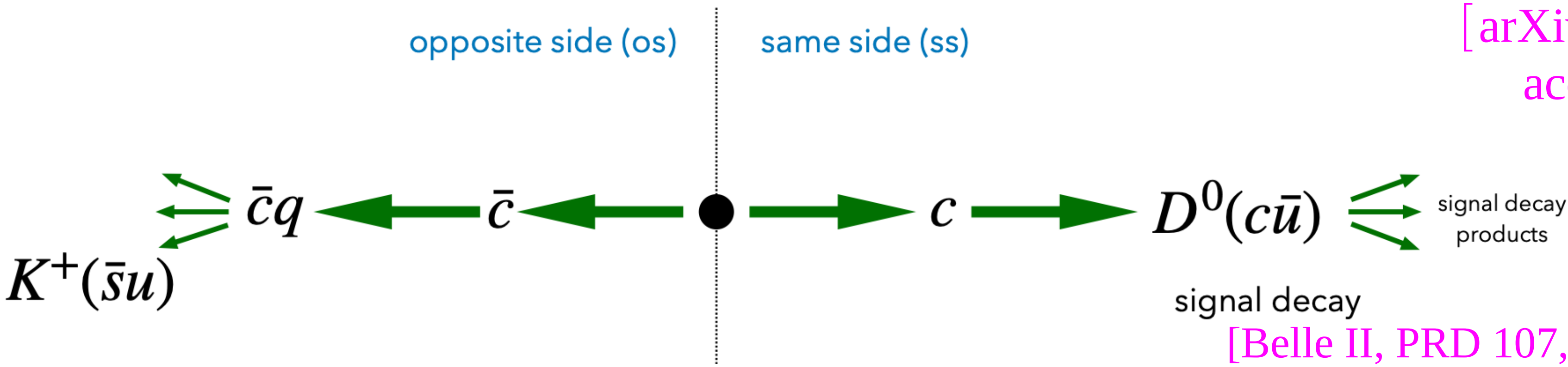
Belle II (428 fb^{-1}): $(-2.2 \pm 2.3 \pm 0.1)\%$

$$A_{CP}(D^0 \to K^0_S K^0_S) = (-1.4 \pm 1.3 \pm 0.1)\%$$



$A_{CP}(D^0 \rightarrow K^0_S K^0_S)$ measurement using opposite-side flavor tagging

[arXiv:2504.15881]
accepted PRD

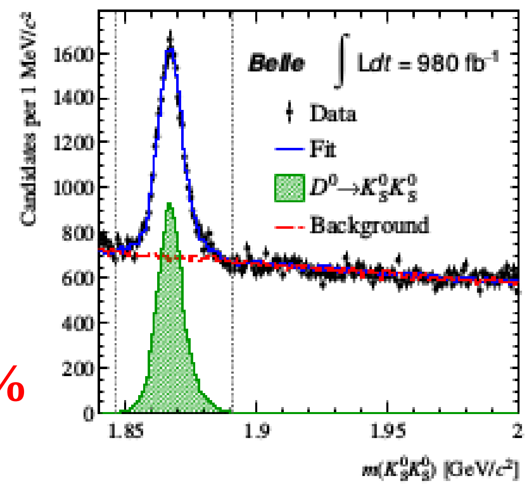


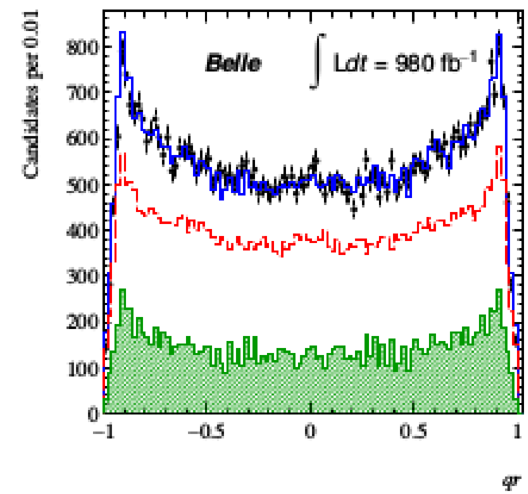
[Belle II, PRD 107, 112010 (2023)]

Candidates reconstructed in D^{*+}- tagged analysis are removed:

Belle $(980\ \text{fb}^{-1})$: $(+2.5 \pm 2.7 \pm 0.4)\%$
Belle II $(428\ \text{fb}^{-1})$: $(-0.1 \pm 3.0 \pm 0.3)\%$

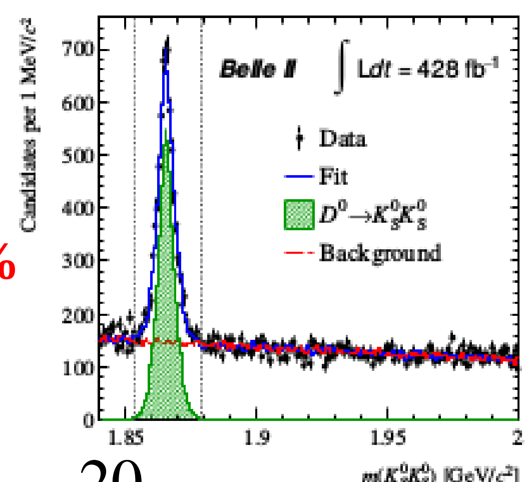
$A_{CP}(D^0 \rightarrow K^0_S K^0_S) = (+1.3 \pm 2.0 \pm 0.2)\%$

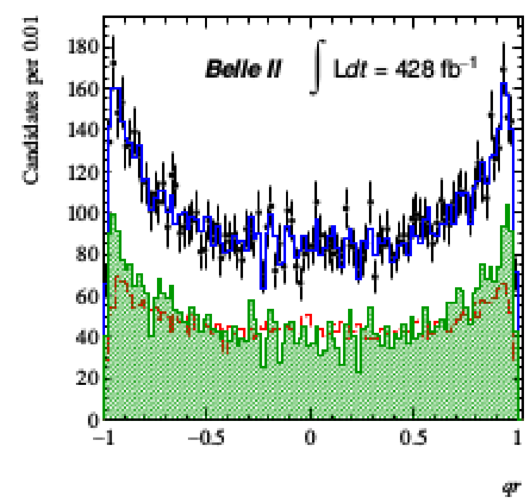




Final result (Belle + Belle II: 1.4 ab^{-1}) with two flavor tagging methods:

$A_{CP}(D^0 \rightarrow K^0_S K^0_S) = (-0.6 \pm 1.1 \pm 0.1)\%$

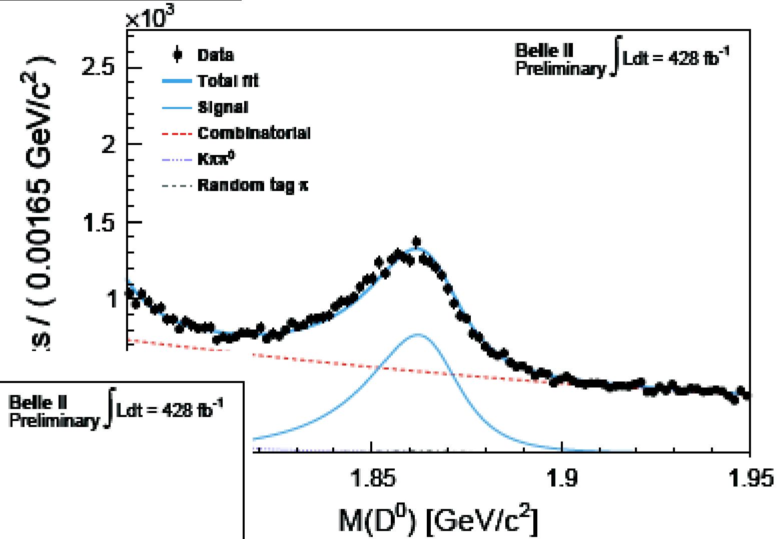


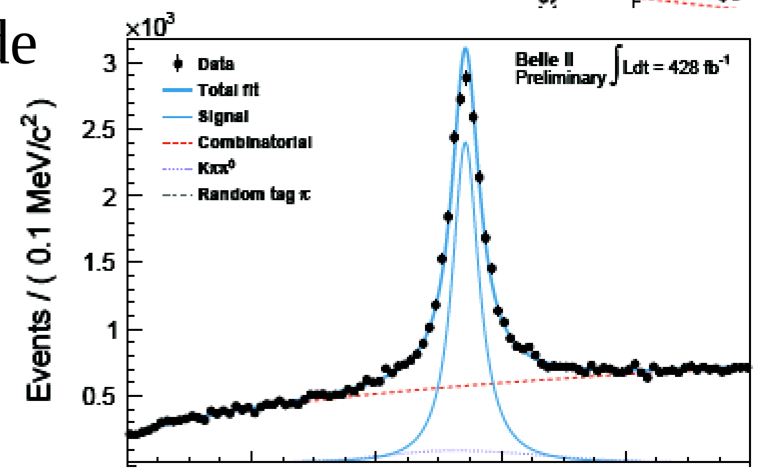


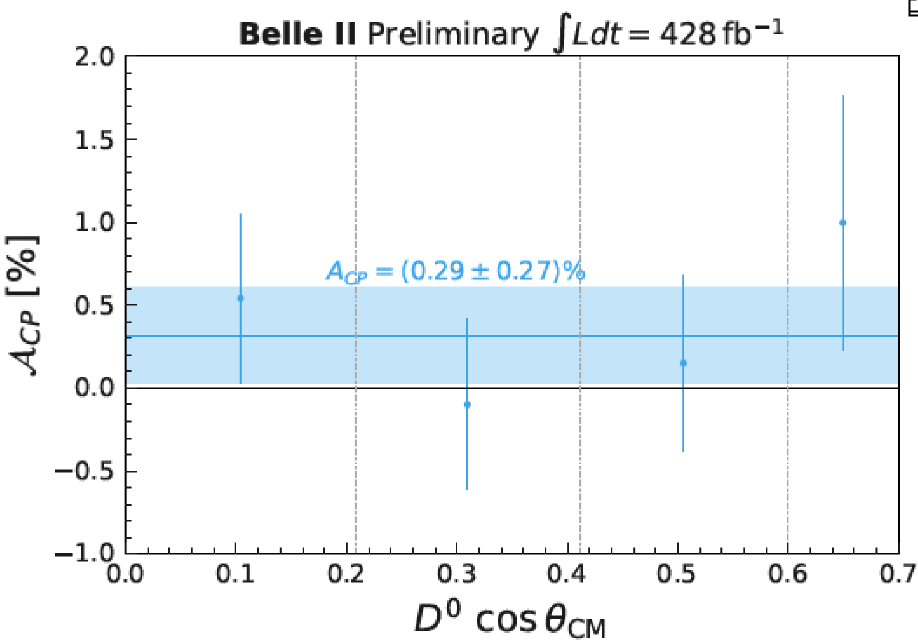
"Mixing and CPV measurements with D mesons at Belle and Belle II" (L. Massaccesi)

A_{CP} in $D \to \pi^+ \pi^- \pi^0$ with Belle II [PRELIMINARY]

- D^0 flavor tagged through $D^{*+} \to D^0 \pi^+$
- signl extraction with 2D fit in M_D and ΔM
- Split in 8 symmetric bins of $\cos\theta_{CM}$ to correct production asymmetry
- $D^0 \to K^- \pi^+$ as reference mode







$$A_{CP} = (0.29 \pm 0.27 \pm 0.13)\,\%$$

- No asymmetry
- Compatible with previous measurements [Belle, BaBar]
- 34% improvement (stat) w.r.t world's best (BaBar)

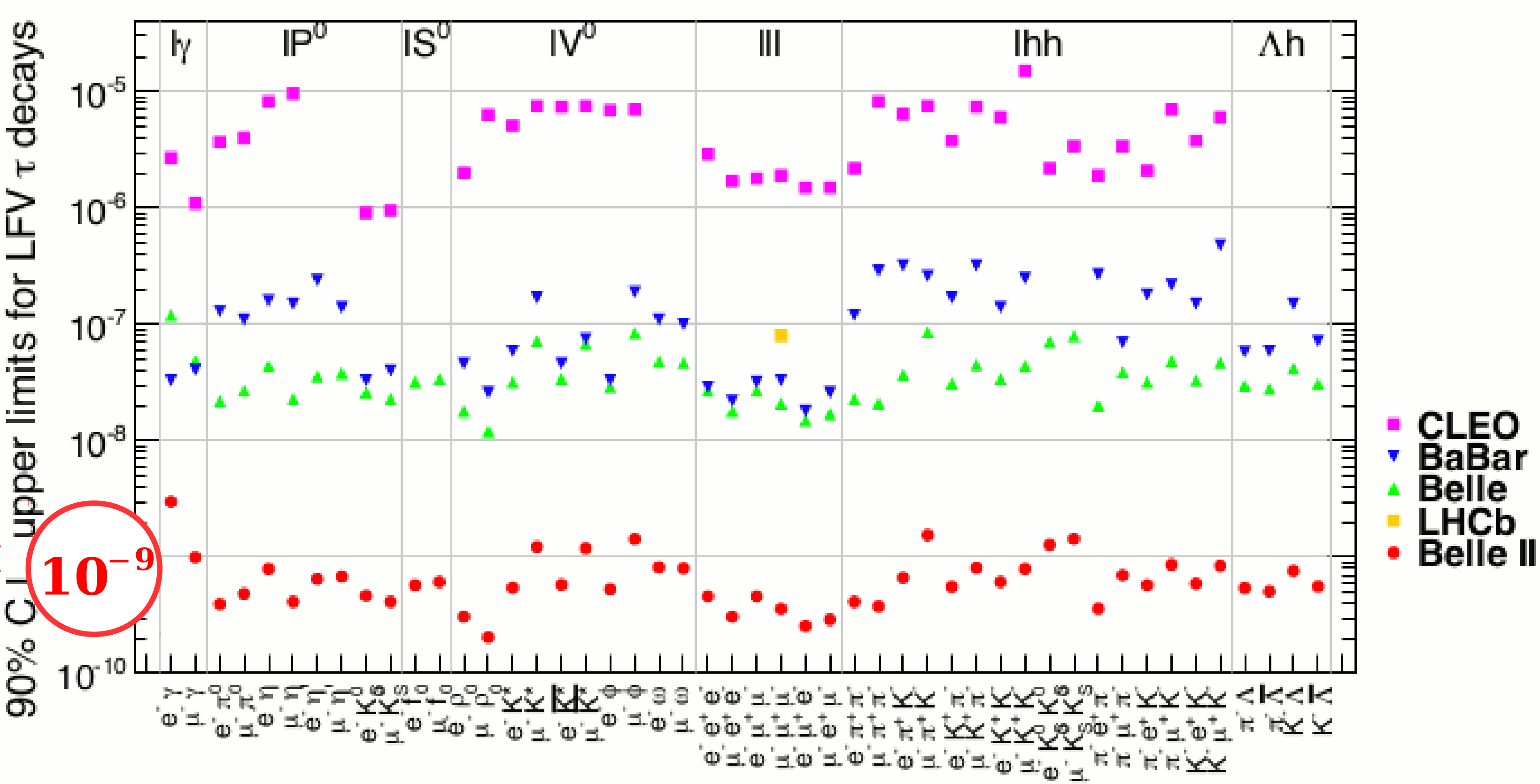
''τ center''

- **Belle II is also a τ-factory!**
- **lepton flavour violating decays of the τ as NP probe**

⇒ Lepton flavor conservation accidental symmetry of SM, many NP models can naturally break this symmetry

Model	Reference	$\tau\to\mu\gamma$	$\tau\to\mu\mu\mu$
SM+ ν oscillations	EPJ C8 (1999) 513	10^{-40}	10^{-55}
SM+ heavy Maj ν_R	PRD 66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66 (2002) 115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566 (2003) 217	10^{-10}	10^{-7}

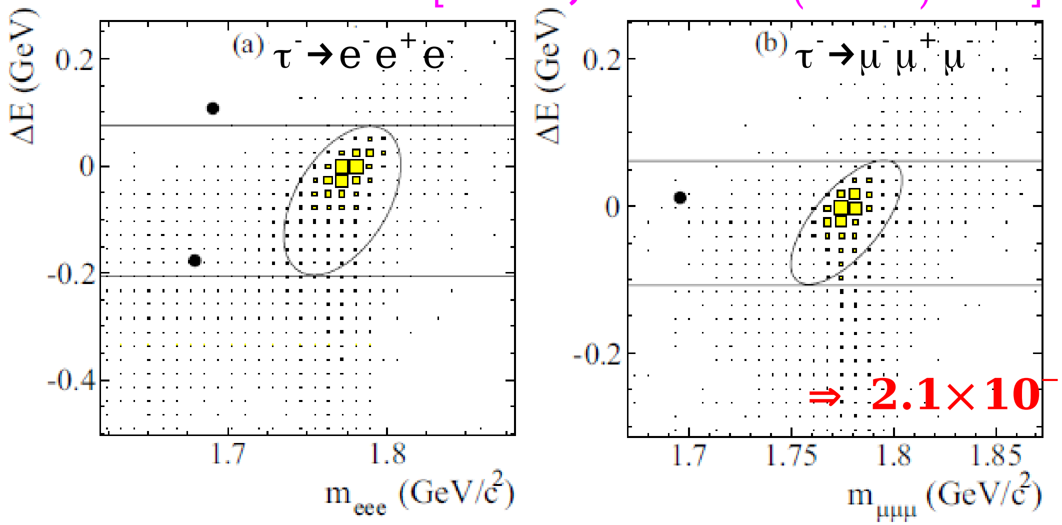
expected Belle II sensitivity



cLFV : beyond the Standard Model

τ LFV searches at Belle II are extremely clean with very little background (if any), thanks to pair production and double-tag analysis technique.

[Belle, PLB 687 (2010) 139]



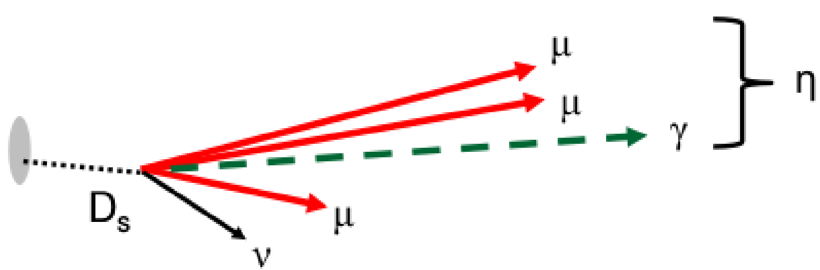
⇒ 2.1×10^{-8} at 90% CL

how to improve further ?

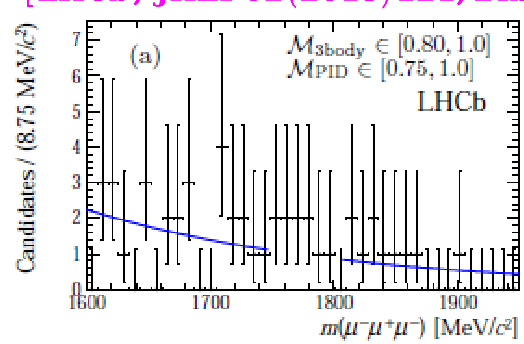
…considering $\tau \to \mu/e\, h^+ h^-$ in function of one prong tag categories

…for $\tau \to 3$ muons, improve μ-ID at low mom (ECL info)

In contrast, hadron collider experiments must contend with larger combinatorial and specific backgrounds



[LHCb, JHEP02(2015)121, 2 fb^{-1}]



⇒ 4.6×10^{-8} at 90% CL

Background modes normalised to $D_s \to \eta(\mu\mu\gamma)\mu\nu$ (BR ~ 10^{-5})

Decay channel	Relative abundance
$D_s \to \eta(\mu\mu\gamma)\mu\nu$	1
$D_s \to \varphi(\mu\mu)\mu\nu$	0.87
$D_s \to \eta'(\mu\mu\gamma)\mu\nu$	0.13
$D \to \eta(\mu\mu\gamma)\mu\nu$	0.13
$D \to \omega(\mu\mu)\mu\nu$	0.06
$D \to \rho(\mu\mu)\mu\nu$	0.05

CMS, full Run 2 dataset: 2.9×10^{-8} at 90% CL [2312.02371]

Most improvement in coming decade is expected from Belle II, which can reach 1×10^{-9} [arXiv:1011.0352] and will do even better if can achieve ~ zero bckgd

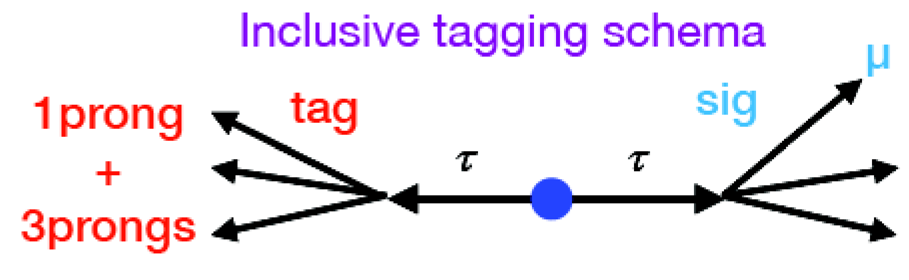
$\tau \to 3\mu$ at Belle II

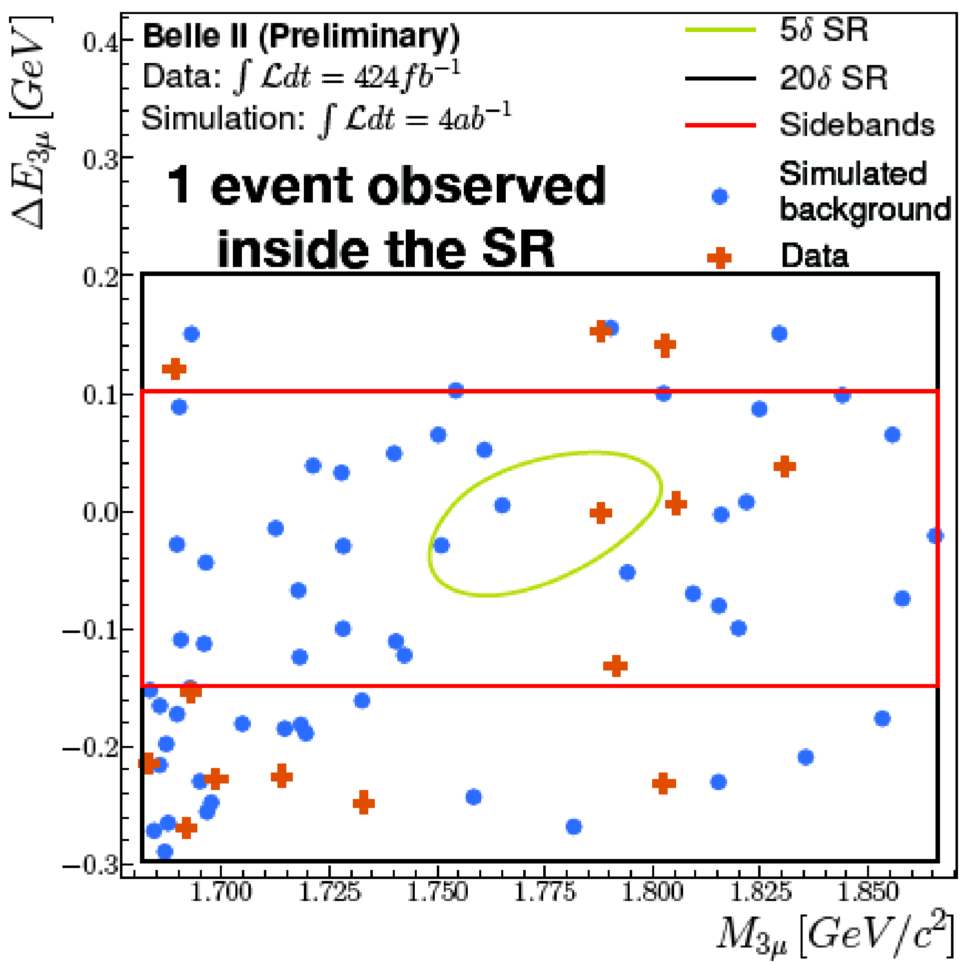
Analysis selection and results: inclusive approach

BDT trained on 32 variables:
inputs from signal τ^-, event tag side, event shape and kinematics

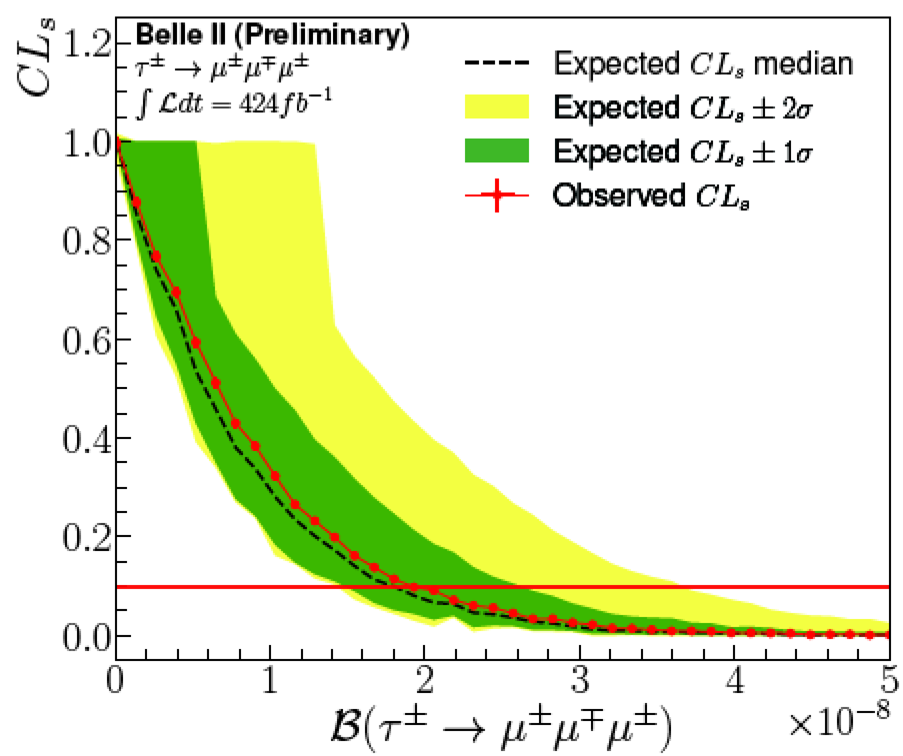
$\epsilon_{sig} = (20.42 \pm 0.06)\%$ ($3 \times$ larger than Belle)

Expected BKG: $0.5^{+1.4}_{-0.5}$ evts





No significant excess in 424 fb^{-1} of data



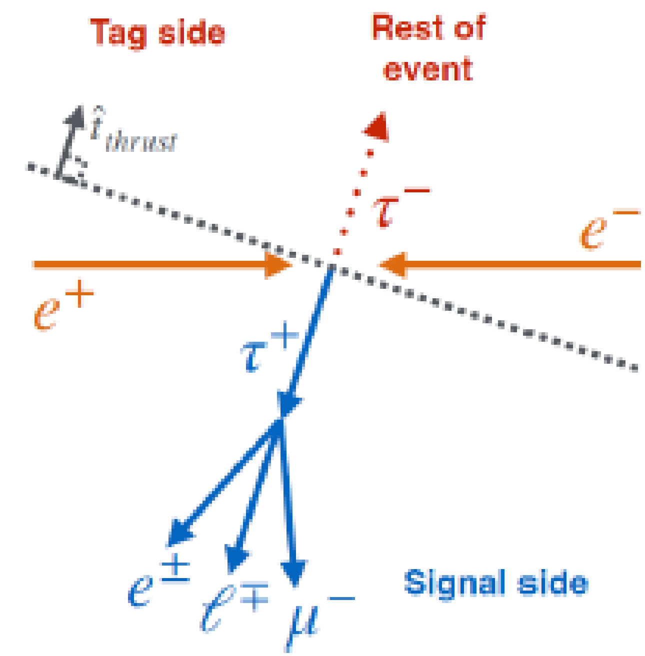
Obtained most stringent limit
1.9×10^{-8}

[2405.07386, JHEP 2024 (2024) 62]

Search for $\tau^- \to e^\pm l^\mp l^-$ at Belle II

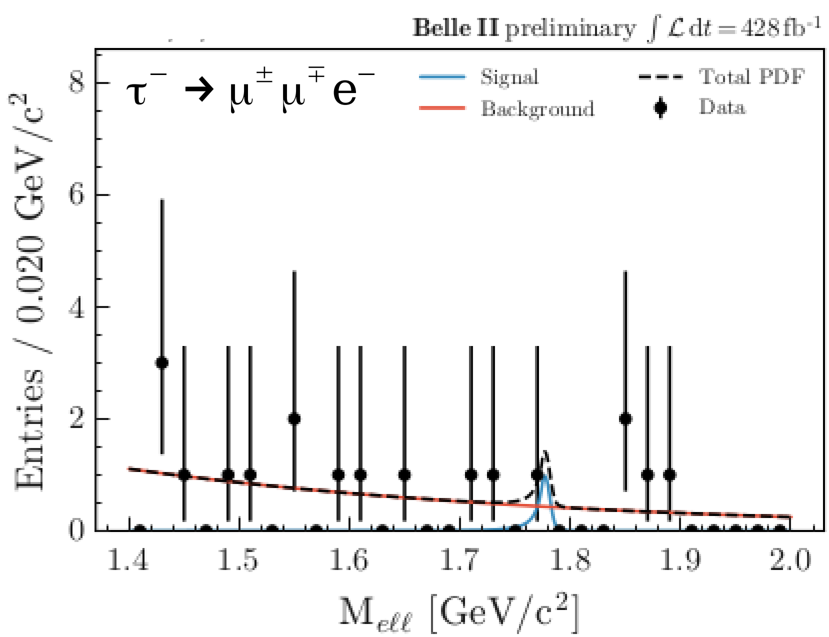
[PRELIMINARY]

Extend previous study to 5 more modes
with at least one electron in the final state:
$\tau \to e^- e^+ e^-$, $e^- e^+ \mu^-$, $e^- \mu^+ e^-$, $\mu^- \mu^+ e^-$, $\mu^- e^+ \mu^-$



- inclusive-tagging reconstruction
- BDT to suppress background
  - rely on rest of event and kinematic variables
  - trained on sideband in data
  - reject the main four leptons backgrounds
- signal extracted by fitting M_{ell}

No significant excess was observed in 428 fb^{-1}



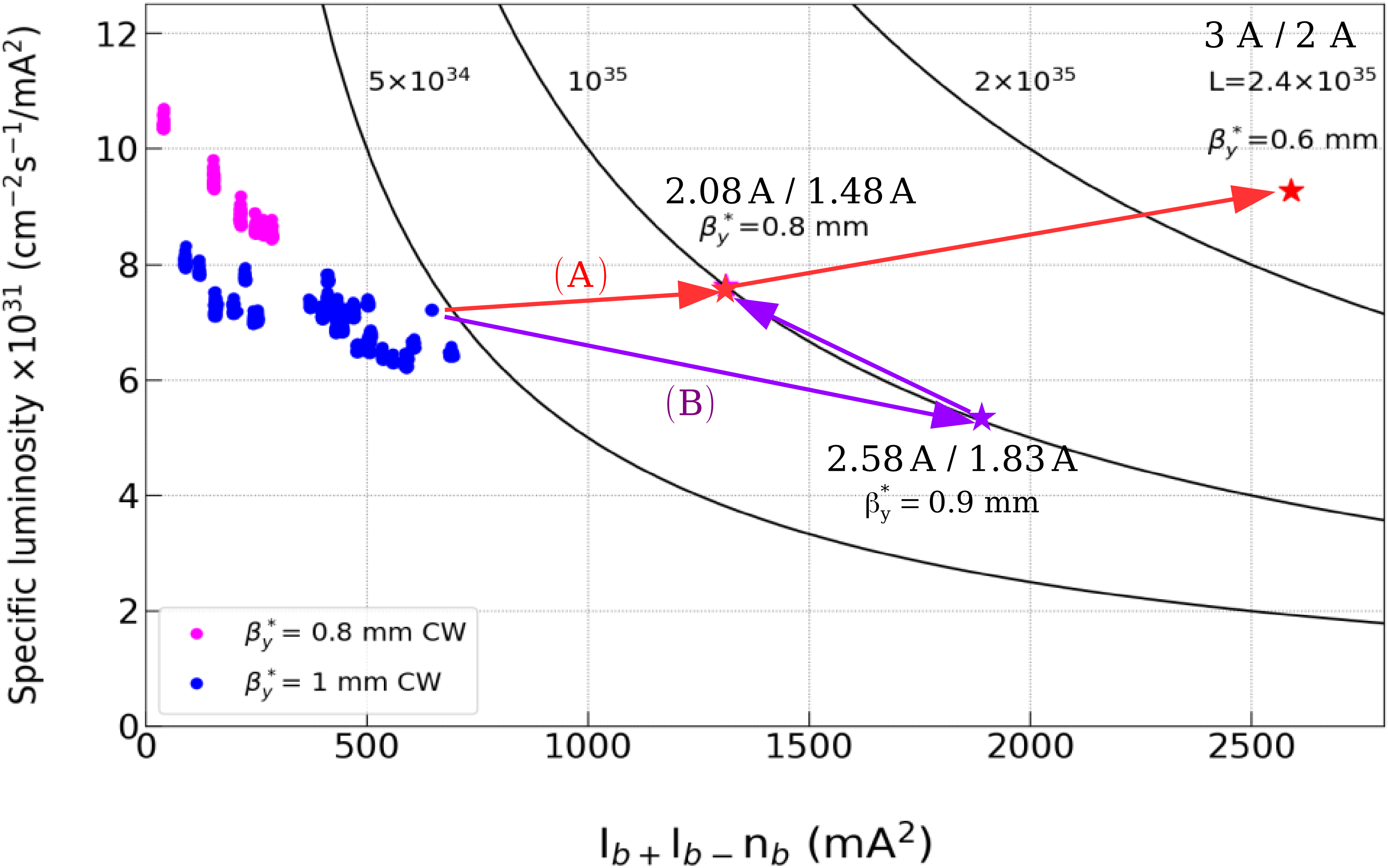
	N_{exp}	$\mathcal{B}^{UL}_{exp} \times 10^{-8}$	$\mathcal{B}^{UL}_{obs} \times 10^{-8}$
$e^-e^+e^-$	$6.1^{+4.3}_{-2.9}$	2.7	2.5
$e^-e^+\mu^-$	$12.1^{+5.7}_{-4.3}$	2.1	1.6
$e^-\mu^+e^-$	$10.5^{+5.3}_{-4.3}$	1.7	1.6
$\mu^-\mu^+e^-$	$20.7^{+6.6}_{-5.5}$	1.6	2.4
$\mu^-e^+\mu^-$	$7.5^{+4.5}_{-3.2}$	1.4	1.3

⇒ **Most stringent upper limit on all modes**
(even compared to Belle with 782 fb^{-1})

''Searches for lepton-flavour violation in tau decays at Belle and Belle II'' (L.Zani)

Strategy toward > 10^{35} $cm^{-2}s^{-1}$ (*)

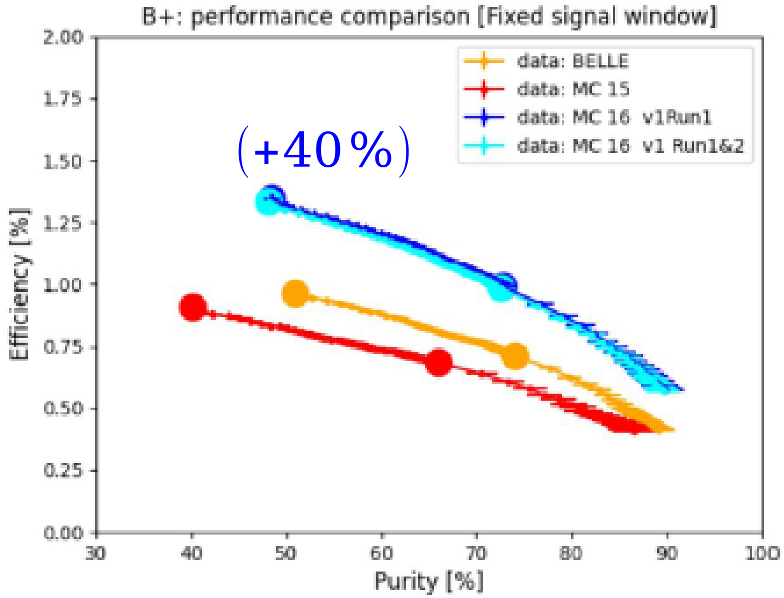
⇒ Resume data taking in November 2025 for a long run of 7 months



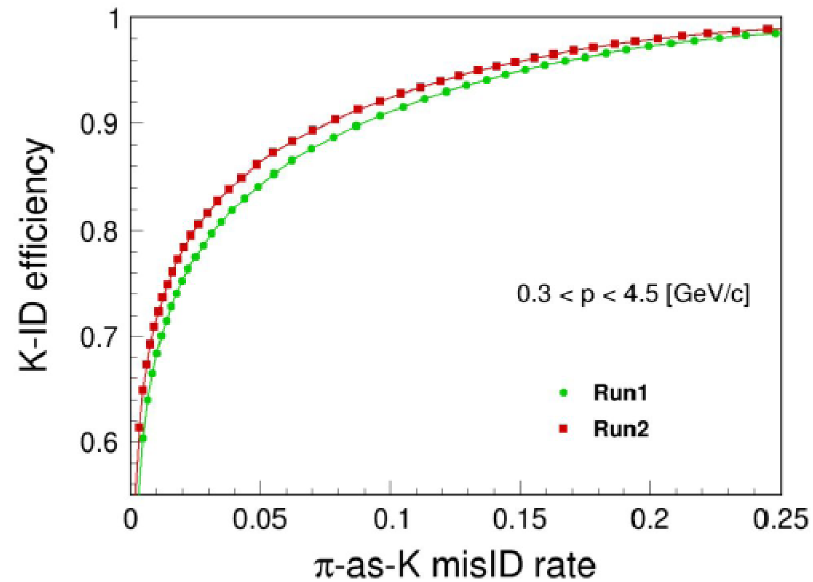
(*) $10^{35} cm^{-2} s^{-1}$ corresponds to $\sim 1\, ab^{-1}$/year (for 8 months data taking period)

Further improvements...

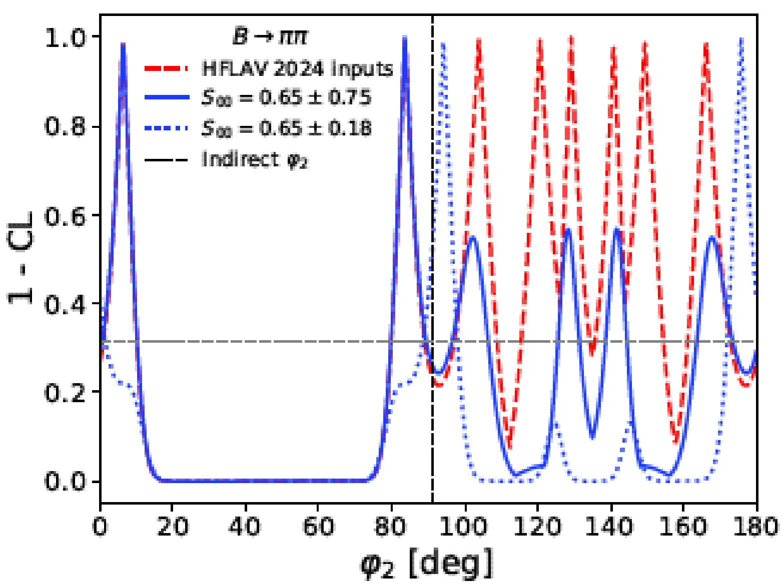
significantly improved B-tagging
for coming run 1+2 analyses



data quality in run 2
similar to run 1



Time-dependent CP violation without signal vertex



arXiv:2506.11196,
M.Dorigo, S.Raiz, D.Tonelli, R.Zlebcik
also hep-ph/9907277, A.D.Foland

— — — with run 1 data sample
...... with 5 ab^{-1}

Summary

- Belle (II) is a unique environment to study modes with missing energy
  $\mathbf{B \rightarrow K^{(*)}\nu\bar{\nu}, K^{(*)}\tau\tau, K^{(*)}\tau l}, \tau\tau, \tau l, \mathbf{D^{(*)}\tau\nu, \tau\nu}, \mu\nu$...
- but also perform precise measurements of CKM UT (CPV or not), τ sector, low mutiplicity, dark sector... and many other opportunities

- Belle II with $\sim 400\ \mathrm{fb}^{-1}$ (run 1) has a sensitivity similar (often better) than Belle ($\sim 1\ \mathrm{ab}^{-1}$)

SuperKEKB is making a tremendous effort to enter in $10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ world (with precious help from CERN (FCCee team), IHEP, DESY...)

Goal of Run 2: by LS2 (2032), accumulate > $5\ \mathrm{ab}^{-1}$
⇒ many unique results from Belle II

''Measurements of time-dependent CP violation in B decay at Belle and Belle II''
(Oskar Tittel)

''Measurements of electroweak penguin and LFV B decays with missing energy at Belle and Belle II'' (Valerio Bertacchi)

''Searches for lepton-flavour violation in tau decays at Belle and Belle II''
(Laura Zani)

''Mixing and CP-violation measurements with D mesons at Belle and Belle II''
(Ludovico Massaccesi)

''Measurements of hadronic B decay rates at Belle and Belle II''
(Xiaodong Shi)

''Rare and baryonic decays of charmed hadrons at Belle and Belle II''
(Marko Staric)

''Measurements of lepton-flavour universality in semileptonic B decay at Belle II''
(Michele Mantovano)

''Measurements of semileptonic and leptonic B decays at Belle and Belle II''
(Giovanni Gaudino)

''Searches for dark sector particles at Belle II''
(Laura Salutari)

''Belle II measurements from a centre of mass energy scan near the $\Upsilon(4S)$''
(Alexander E.Bondar)

''Hadron spectroscopy at Belle and Belle II''
(Stefan Wallner)

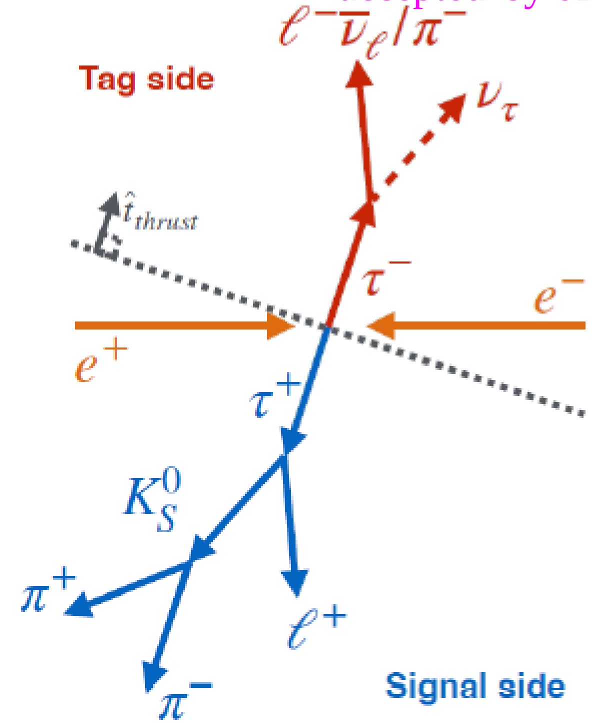
''The Belle II upgrade programme''
(Ezio Torassa)

Search for $\tau \to l K_S^0$ at Belle II (+ Belle)

[arXiv:2506.15745]
accepted by JHEP

Belle + Belle II ($980\ \mathrm{fb}^{-1}$ + $428\ \mathrm{fb}^{-1}$)

Reconstruct 4 charged particles (0 net charge) in 1x3 topology
K_S^0 reconstruct from $\pi^+\pi^-$



Preselection rectangular cuts and BDT classifier

- Use track kinematics, event shape and neutral variables
- Resulting efficiency 10%

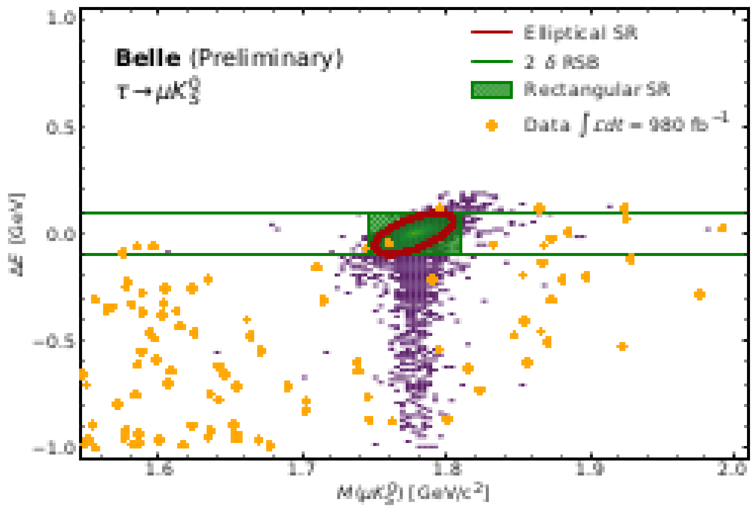
Extract signal yield from 2D plane (M_τ, $\Delta E = E_\tau - E_{beam}$)

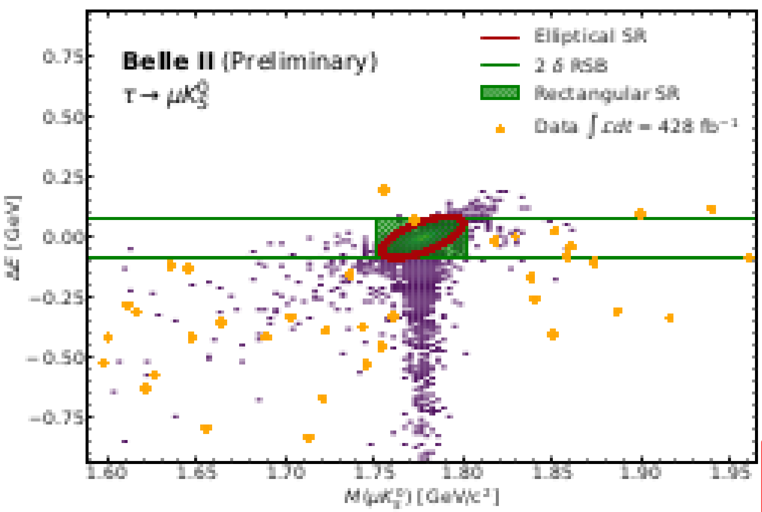
no significant signal observed in $1.4\ \mathrm{ab}^{-1}$

$\mathcal{B}(\tau \to e K_S^0) < 0.8 \times 10^{-8}$ at 90% C.L.

$\mathcal{B}(\tau \to \mu K_S^0) < 1.2 \times 10^{-8}$ at 90% C.L.

World most stringent upper limit on all modes (improved by factor 2)





more results on τ soon
(coming tau 2025 conference)

SuperKEKB, the first new collider in particle physics since the LHC in 2008 (electron-positron $(e^+ e^-)$ rather than proton-proton (p-p))

Phase 1

Background , Optics commissioning
Feb - June **2016**
Brand new 3 km positron ring

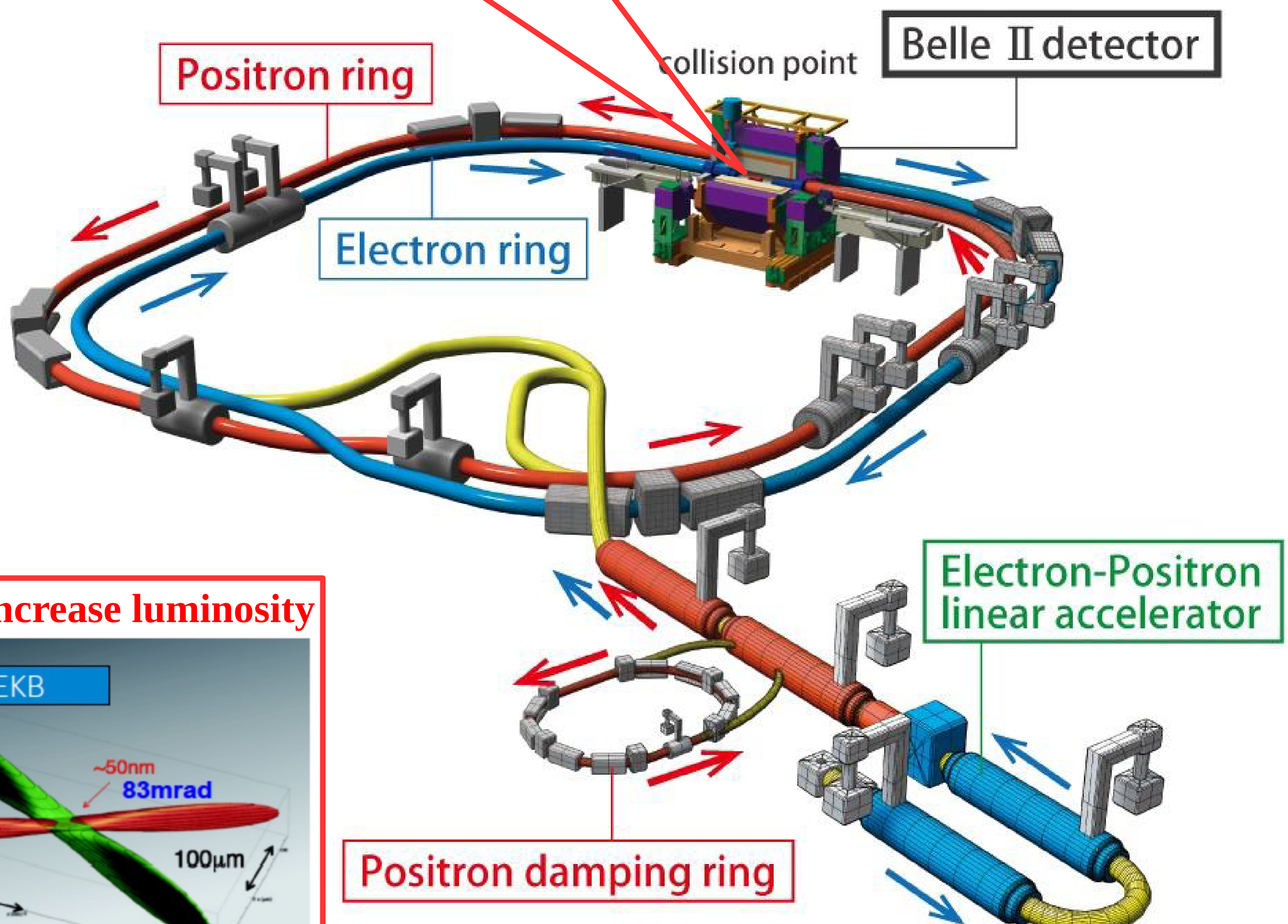
Phase 2: Pilot run

Superconducting Final Focus
add positron damping ring
First Collisions $(0.5\ \mathrm{fb}^{-1})$
April 27 - July 17, **2018**

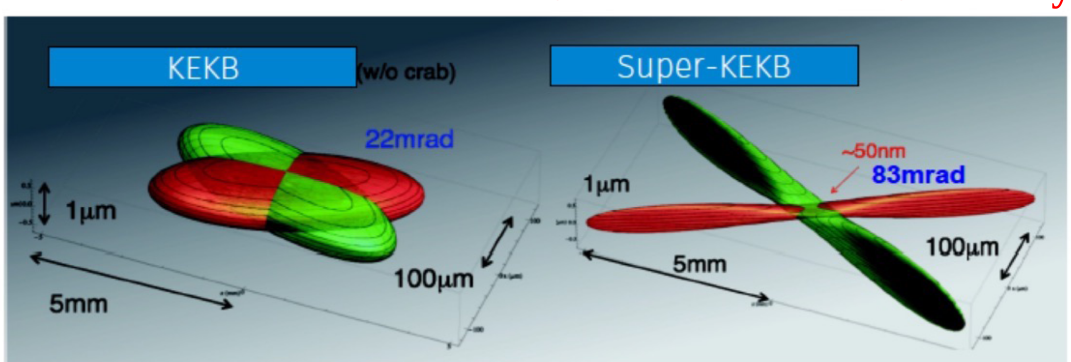
Phase 3: Physics run

Since April , **2019**

Squeeze strongly at IP



Nano-beams and more beam current to increase luminosity



	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}
		factor 20			factor 2-3	

⇒ **to reach $\sim 6 \times 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$**

⇒ **cumulate 50 ab^{-1} by ~2040**

SuperKEKB

Major works during shutdown

1. Beam pipe cleaning (vacuum sealant (VACSEAL) removal)
   - Countermeasure against SBL
   - @IR (HER/LER), LER wiggler sections (D04, D10, D11)

   ⇨ Improvement of accelerator stability
2. Collimator works
   - Relocation (LER, D06V2 -> D03V4)
   - Damaged jaw replacement (LER D02V1, D05V1)
   - New water-cooled collimator (HER D09V3)

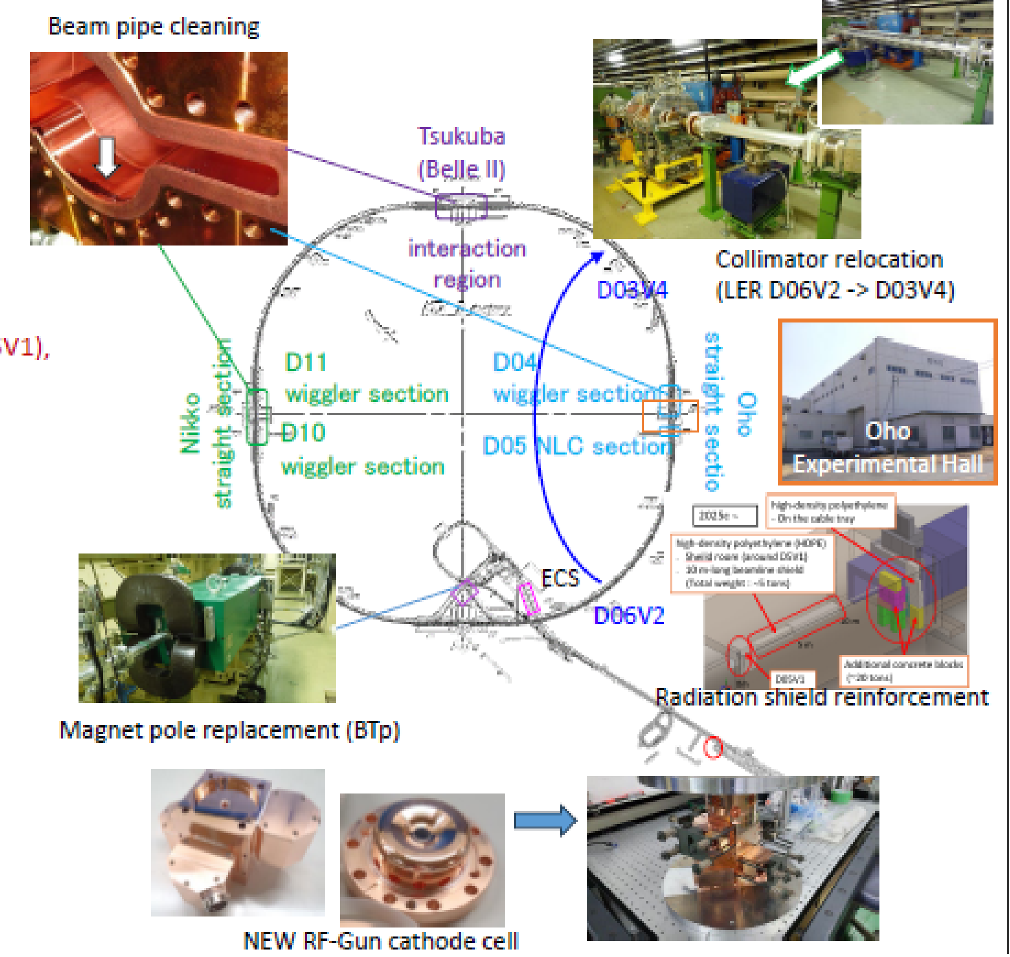
   ⇨ Protection of Belle II from SBL (D03V3), Beam impedance reduction (D02V1, D05V1), Suppression of abnormal pressure rise (D09V3)
3. Radiation shield reinforcement for full-scale use of NLC
   - Shielding radiation generated by NLC
   - Expansion of radiation control area around Oho experimental Hall

   ⇨ Background reduction, Beam impedance reduction
4. Electron RF gun replacement
   - New RF-Gun less prone to discharge

   ⇨ Stable two-bunch injection
5. Installation of ECS into electron BT line
   - Reduction of energy spread of high charged bunch

   ⇨ Improvement of injected beam quality and injection efficiency
6. Magnet pole replacement of positron BT line
   - Emittance growth mitigation by improving the magnetic field.

   ⇨ Improvement of injected beam quality and injection efficiency

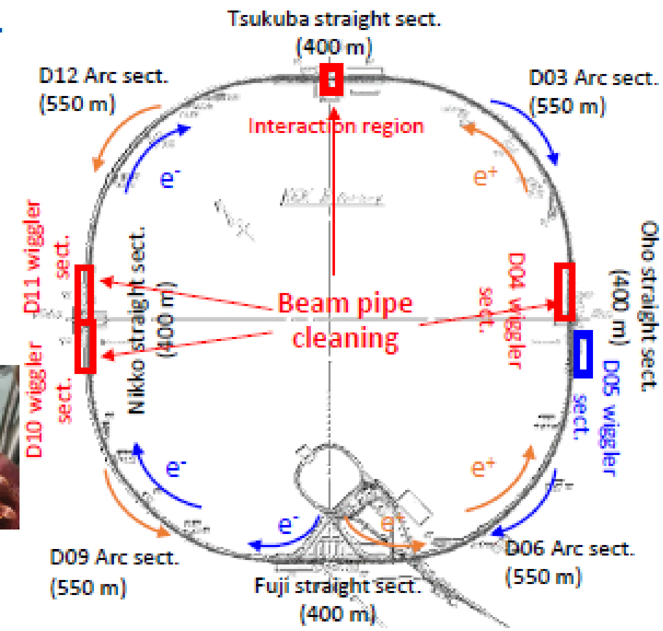


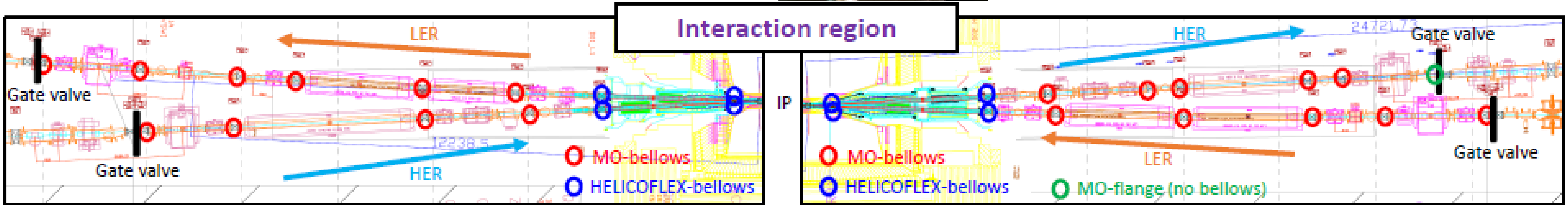
Beam pipe cleaning 2

- Black stains are thought to be consist of liquid-type vacuum sealant (VACSEAL).
  - VACSEAL can enter the beam pipe via the MO-flange.
    - Strong SR irradiation turned VACSEAL into black stains?
  - Some black stains are flaky and easily turn to dusts.
- Black stain removal are being conducted.
  - At MO-flange connections most-likely with VACSEAL.
    - It is impossible to identify all MO-flanges with VACSEAL due to lack of records.
  - In sections where many pressure burst was observed with SBLs.

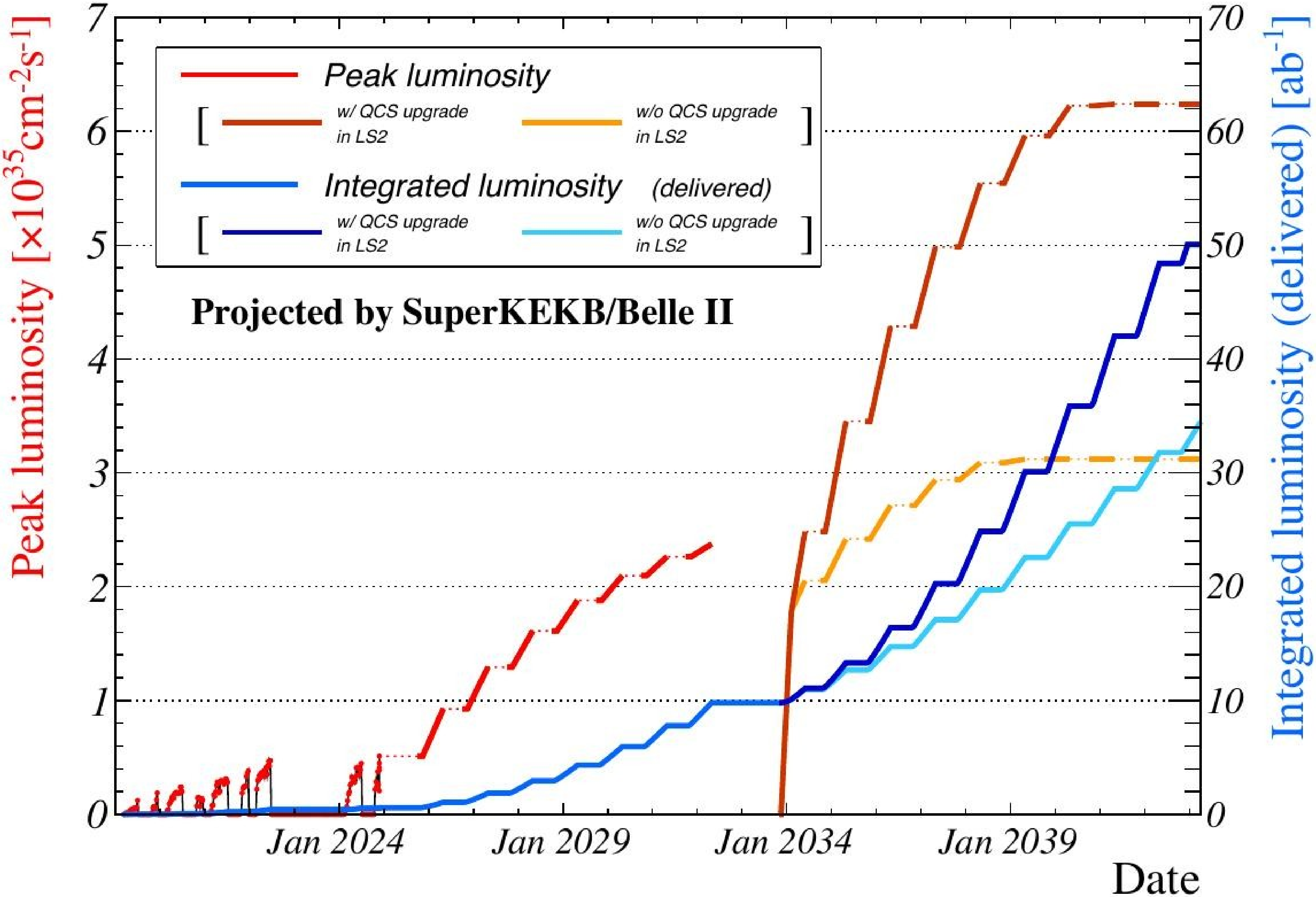
⇨ At interaction region (IR), LER wiggler sections (D04, D10, D11)
Not at HELICOFLEX-flange (No black stains have been found so far.)

- IR : All MO-flange connections were cleaned.
  - 41 MO-flange connections were opened.
  - Black stains were found in many MO-flanges and removed.
  - 16 HELICOFLEX flange connections left uncleaned.

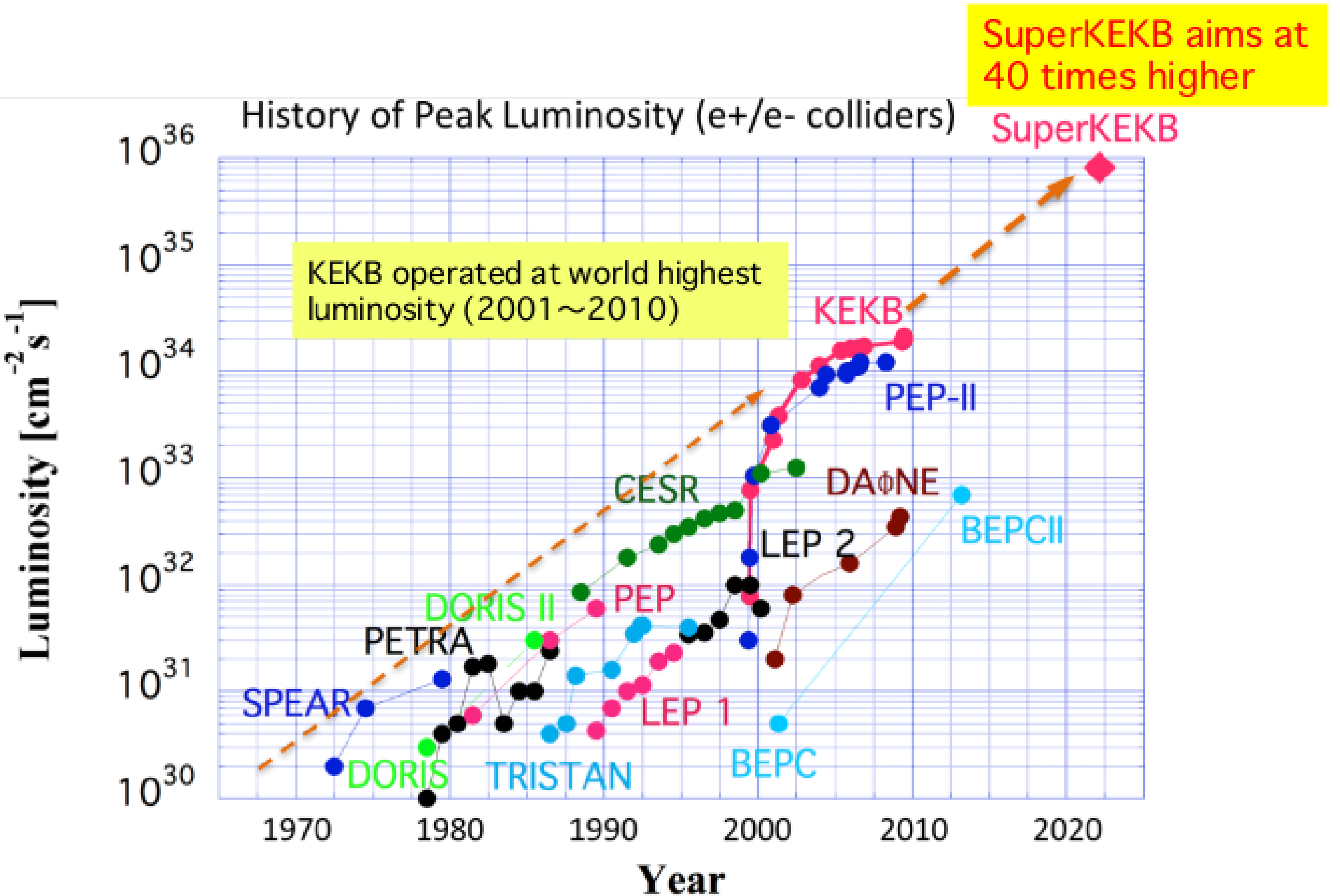




Luminosity projection plot
(plan for the coming years)



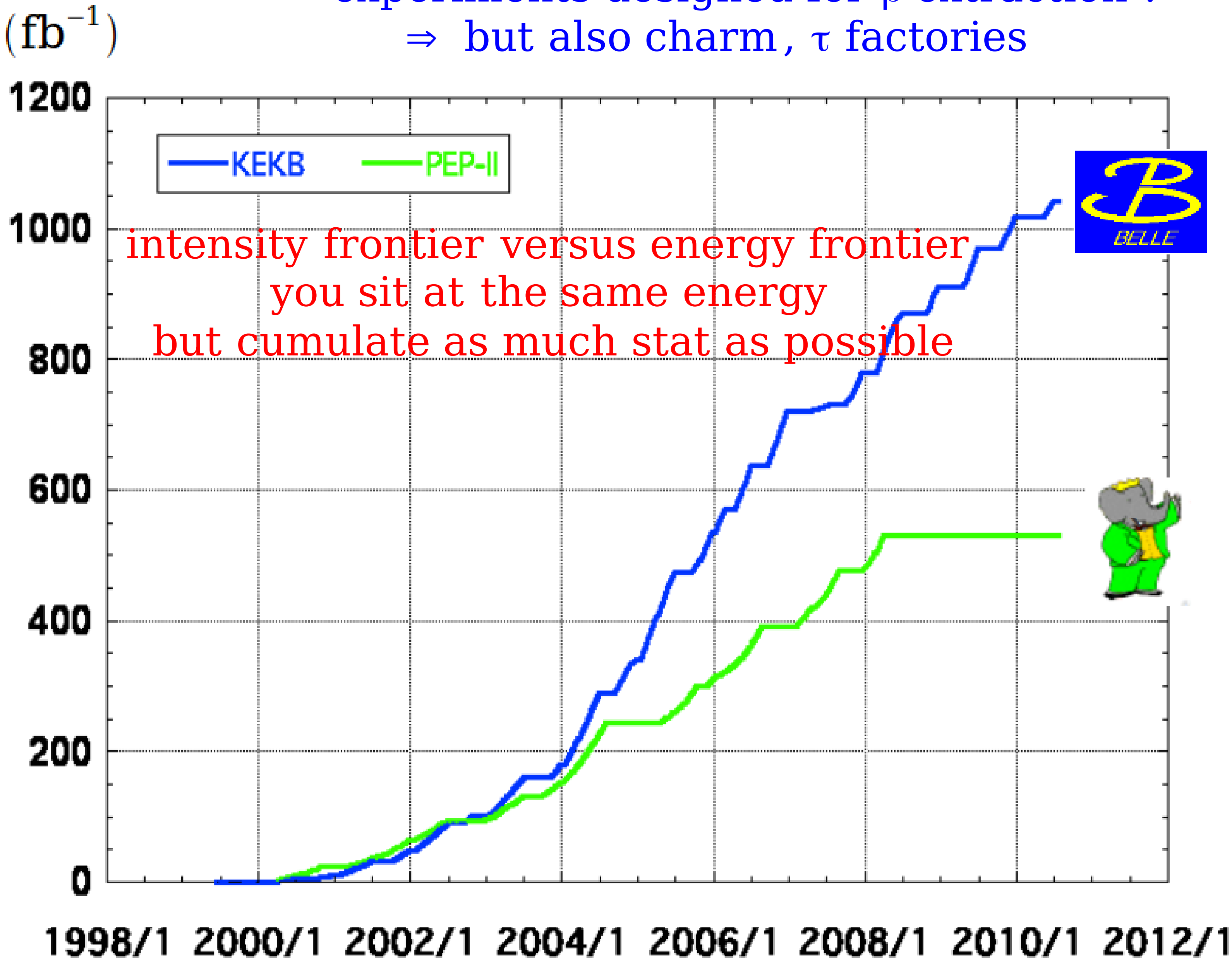
Luminosity frontier of e^+e^- colliders



B factories: BaBar$^{(PEP-II)}$ and Belle$^{(KEKB)}$ (old slide…)

⇒ experiments designed for β extraction !

⇒ but also charm, τ factories



intensity frontier versus energy frontier
you sit at the same energy
but cumulate as much stat as possible

> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

$\sim$ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

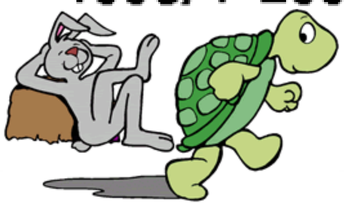
$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

$\sim$ 54 fb^{-1}



final samples $\begin{cases} \textbf{BaBar: } 467 \times 10^6 B\bar{B} \textbf{ pairs} \\ \textbf{Belle: } 772 \times 10^6 B\bar{B} \textbf{ pairs} \end{cases}$