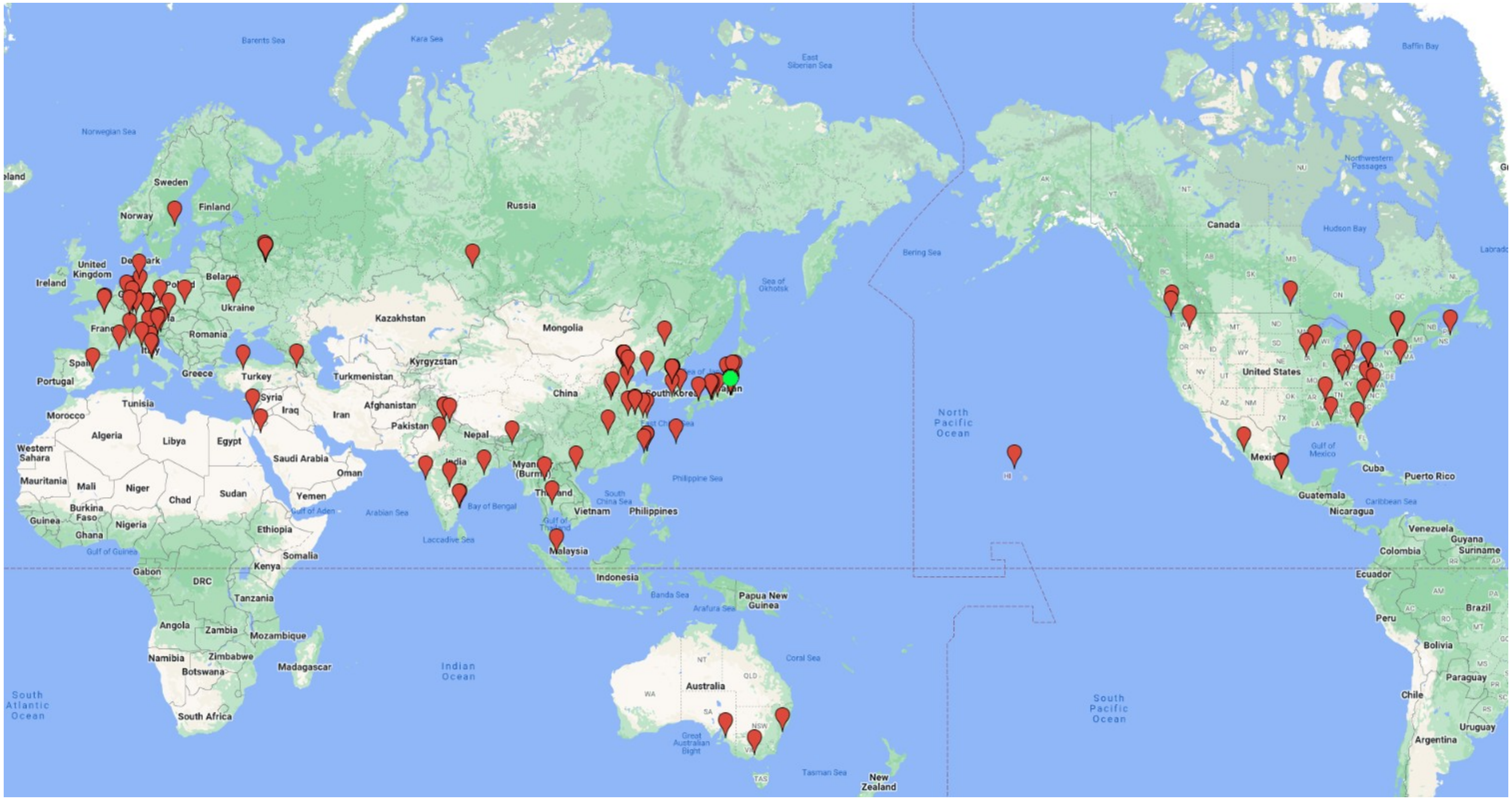
Highlights of recent Belle II results

Alessandro Gaz
University of Padova and INFN

"B1 Heavy Flavor and Dark Matter Joint Unit Symposium"

Nagoya, March 29th 2023

The Belle II Collaboration



- ➔ 27 countries/regions;
- ➔ 129 institutions;
- ➔ ~1100 active members.

Countries (institutions):

Armenia (1), Australia (3), Austria (1), Canada (6), China (15), Czechia (1), France (3), Germany (11), India (11), Israel (1), Italy (9), Japan (16), Malaysia (1), Mexico (3), Poland (1), Russia (5), Saudi Arabia (1), Slovenia (2), South Korea (10), Spain (1), Sweden (1), Taiwan (3), Thailand (2), Turkey (1), USA (18), Ukraine (1), Viet Nam (1).

The Mission

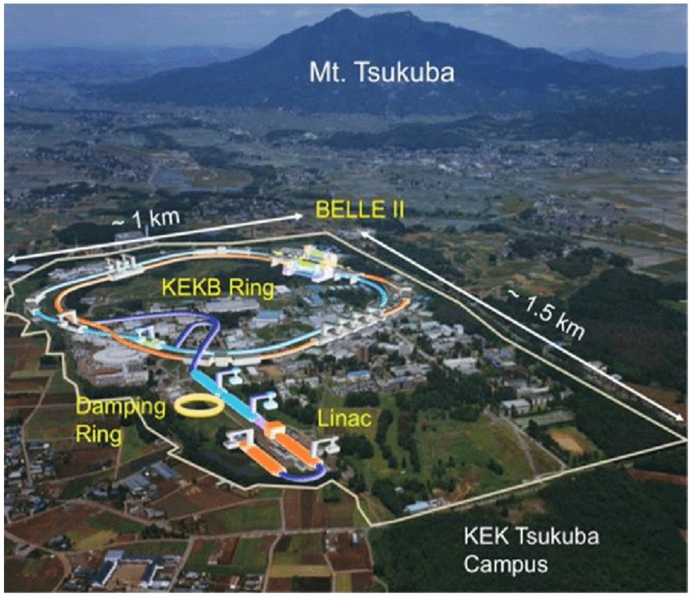
The mission of Belle II is:

- ➔ to improve the precision of the CKM parameters, and confirm the consistency of the overall picture;
- ➔ to search for new phenomena in B, charm, and τ Physics;
- ➔ to discover and study the properties of new exotic particles;
- ➔ to probe the existence of a Dark Sector;
- ➔ … ;

In general: to perform any kind of **precision measurements** that may lead to the discovery of Physics beyond the Standard Model!

Precision comes from an excellent detector and from lots of data: this is what motivates the upgrade of (KEKB, Belle) to (SuperKEKB, Belle II)

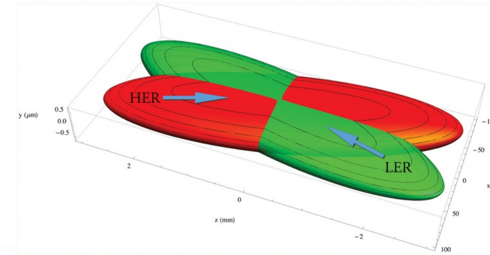
The SuperKEKB Collider

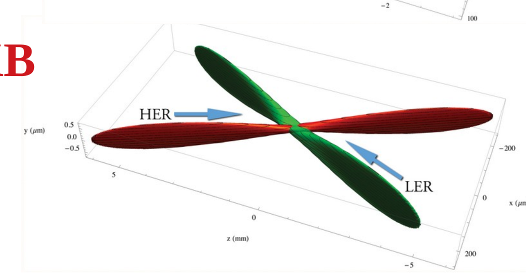


KEKB

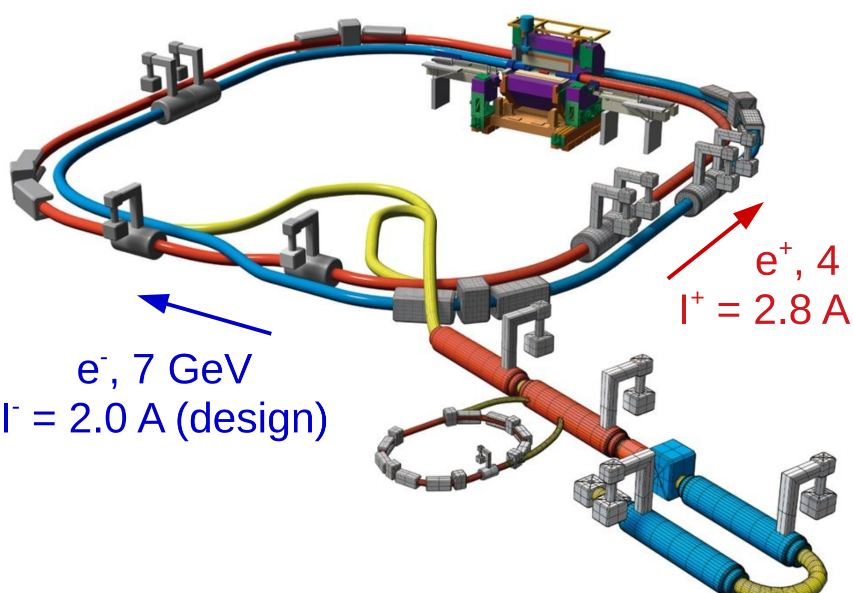
↓

SuperKEKB





$$\boxed{L = \frac{N_+ N_- n_\mathrm{b} f_0}{4\pi \sigma^*_{\mathrm{x,eff}} \sqrt{\varepsilon_\mathrm{y} \beta^*_\mathrm{y}}}}$$



e^+, 4 GeV
I^+ = 2.8 A (design)

e^-, 7 GeV
I^- = 2.0 A (design)

Improvements over KEKB:

x20 by ‘nanobeam scheme’;

x1.5 by increasing beam currents.

Goals:

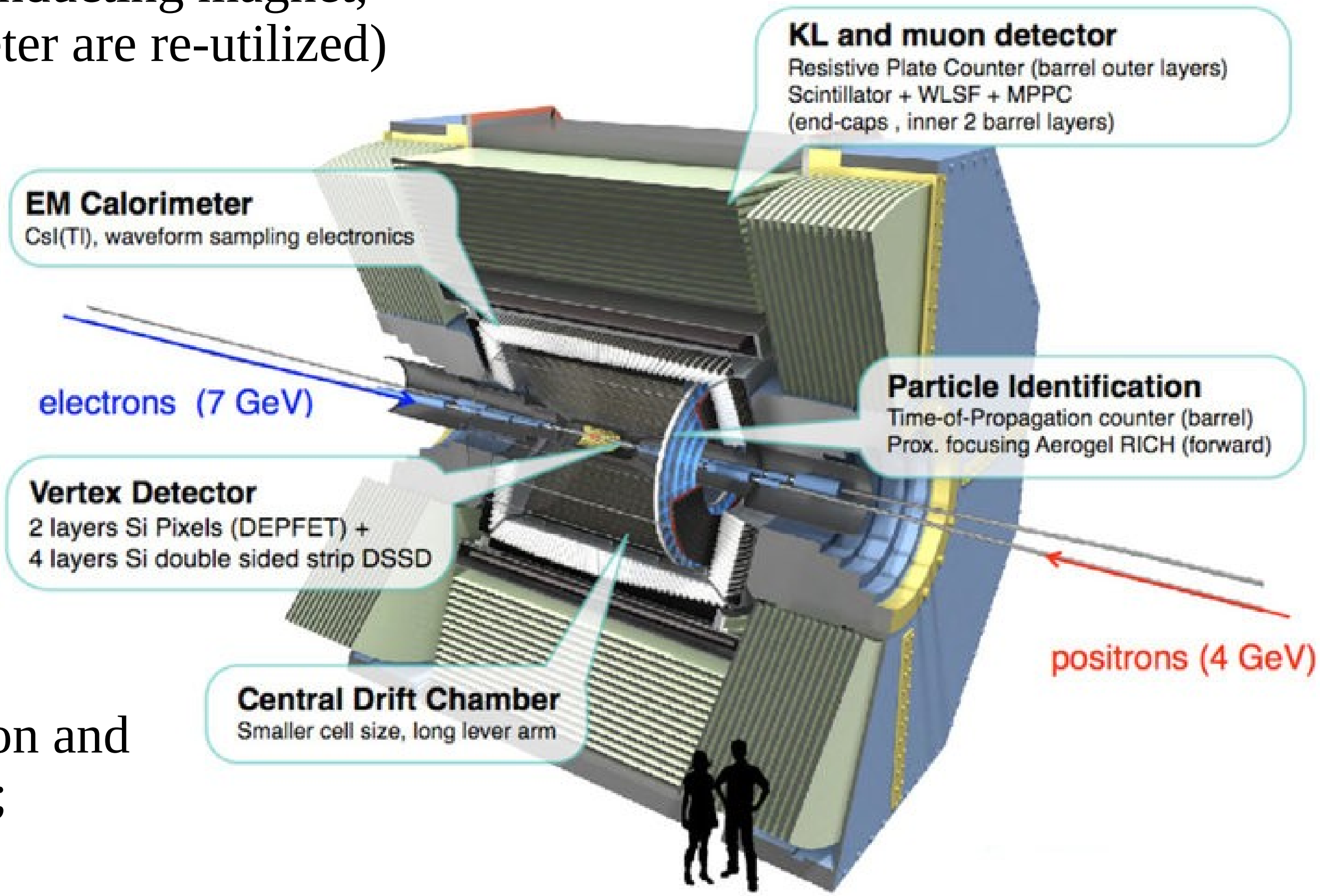
Instantaneous lumi: **6×10^{35} cm^{-2}s^{-1}**

Integrated lumi: **50 ab^{-1}**

The Belle II Detector

It looks like the old Belle, but practically it is a brand new detector!

(only the structure, the superconducting magnet, and the crystals of the calorimeter are re-utilized)



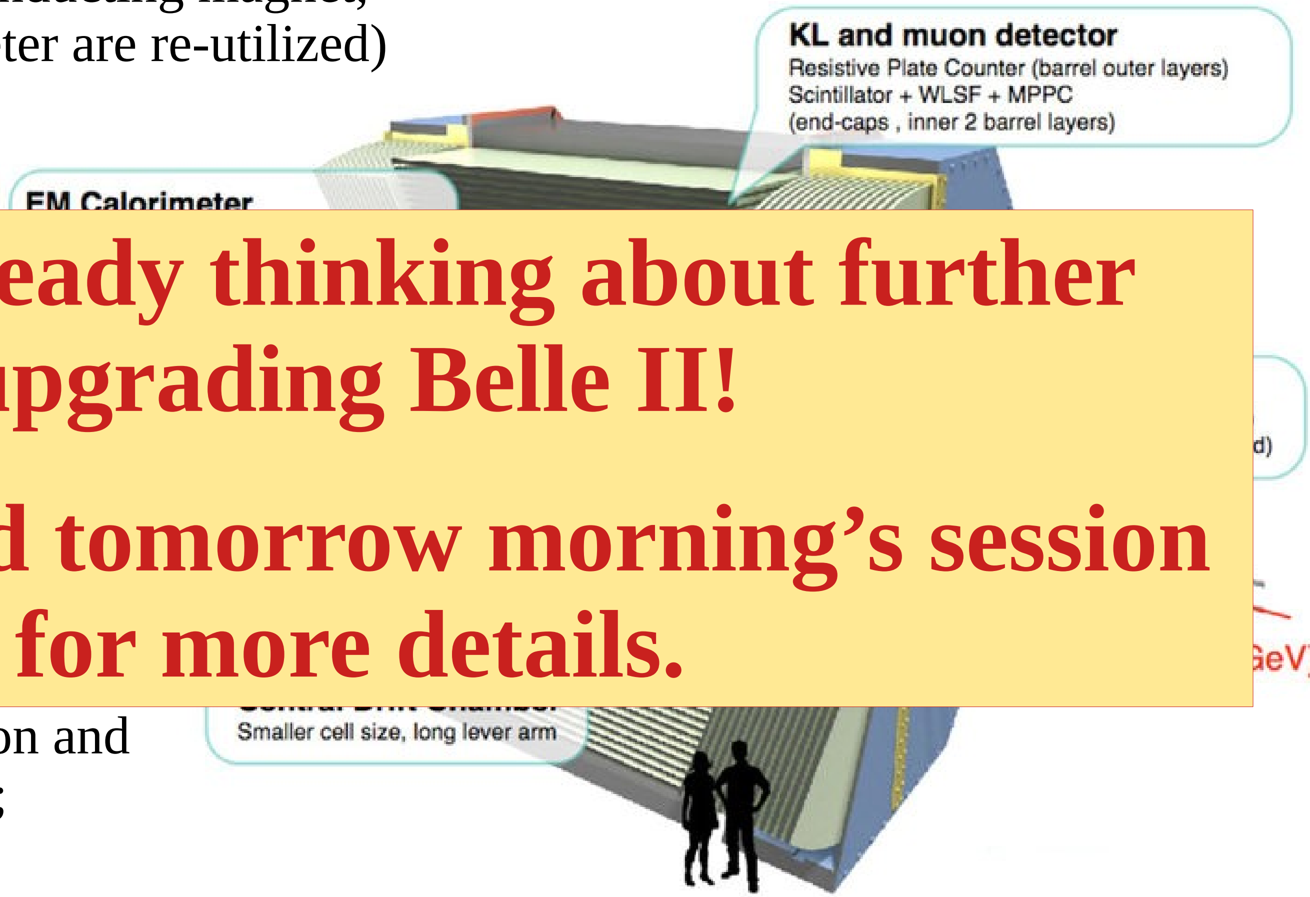
Upgrade highlights:

- improved vertexing resolution and K_S reconstruction efficiency;
- enhanced K/π separation;
- new trigger lines for Dark Sector searches, first Neural Network single track trigger;
- more efficient analysis tools, thanks to widespread use of machine learning techniques.

The Belle II Detector

It looks like the old Belle, but practically it is a brand new detector!

(only the structure, the superconducting magnet,
and the crystals of the calorimeter are re-utilized)



We are already thinking about further upgrading Belle II!

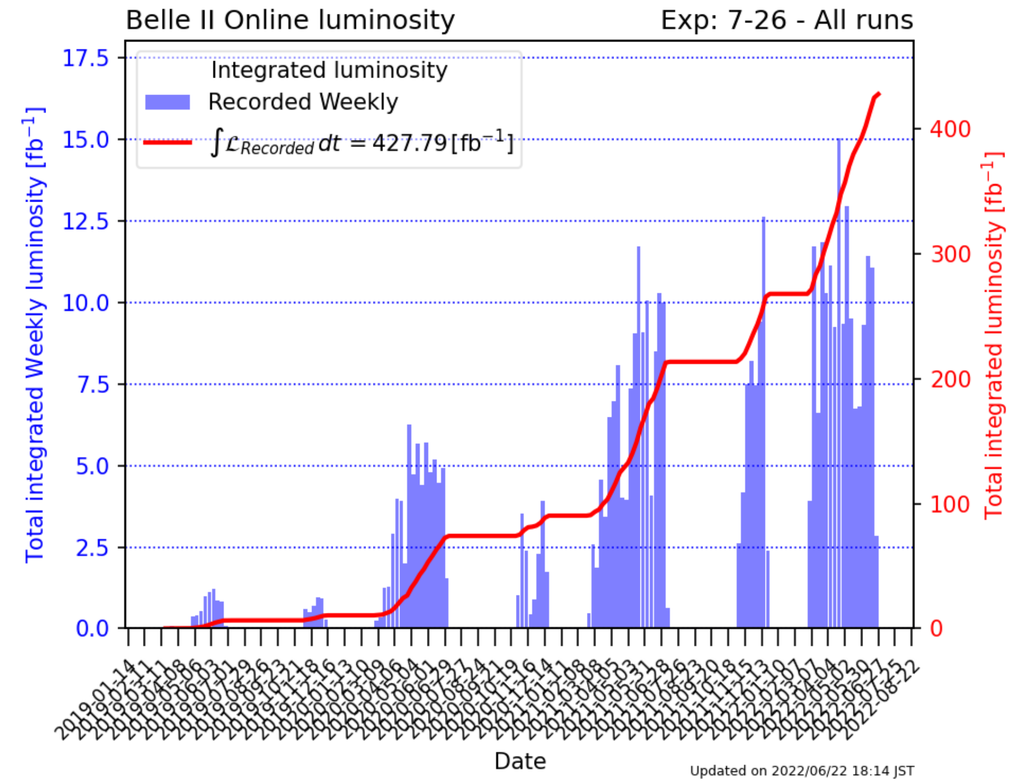
Please attend tomorrow morning's session for more details.

Upg

- improved vertexing resolution and K_S reconstruction efficiency;
- enhanced K/π separation;
- new trigger lines for Dark Sector searches, first Neural Network single track trigger;
- more efficient analysis tools, thanks to widespread use of machine learning techniques.

Data taking status

- Extraordinary effort from local people, who kept the ball rolling during COVID19 times;
- Record instantaneous luminosity (of any collider): $4.71 \times 10^{34}\ \mathrm{cm^{-2}\,s^{-1}}$;
- Recorded in total **~424 fb^{-1}**, of which:
  - **~362 fb^{-1}** taken at a CM energy of 10.58 GeV, corresponding to the mass of the $\Upsilon(4S)$, which dominantly decays to $B\bar{B}$;
  - **~42 fb^{-1}** taken 60 MeV below the $\Upsilon(4S)$ peak (for continuum background studies);
  - **~19 fb^{-1}** taken around 10.75 GeV for exotic hadron searches.



In June 2022 we started the Long Shutdown 1 period, dedicated to maintenance and upgrade work. We plan to resume operations at the end of 2023

Many of the results I will show today are based on the full statistics…

… plus in some cases we also add the Belle data!

Outline

I will try to overlap as little as possible with the talks of the afternoon session

I will present recent Belle II results on:

Improvement of resolution / analysis tools
- Charm lifetimes
- Charm flavor tagger

CKM physics
- semileptonic B decays
- ϕ_3 from $B \to DK$ decays
- time dependent CP violation in B decays

Searches for New Physics in Flavor
- $K\pi$ puzzle
- B decays from electroweak/radiative penguins
- tests of Lepton Flavor Universality

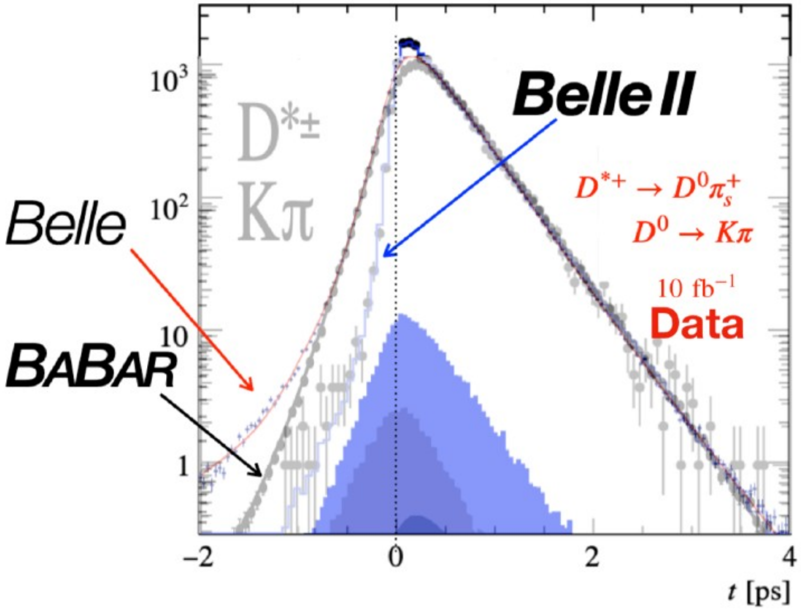
Dark sector searches
- invisibly decaying Z’
- $e^+e^- \to \mu^+\mu^-\tau^+\tau^-$
- long lived scalar in $B \to K^{(*)} S$

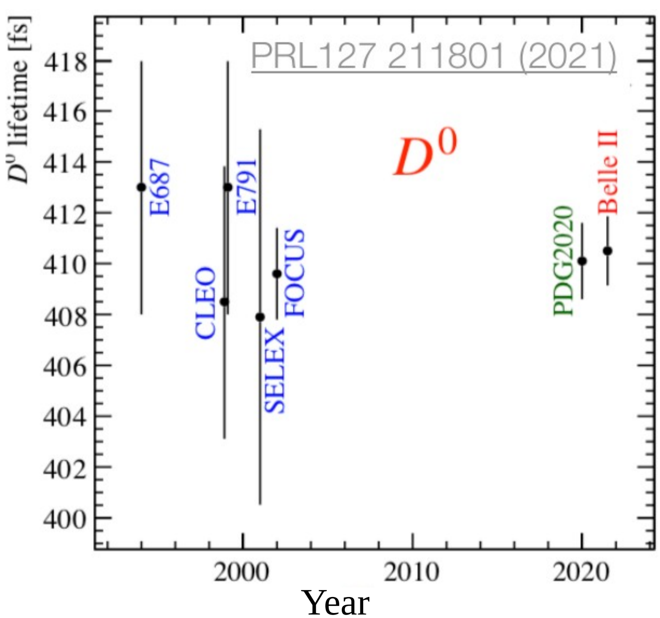
A bit of Charm Physics

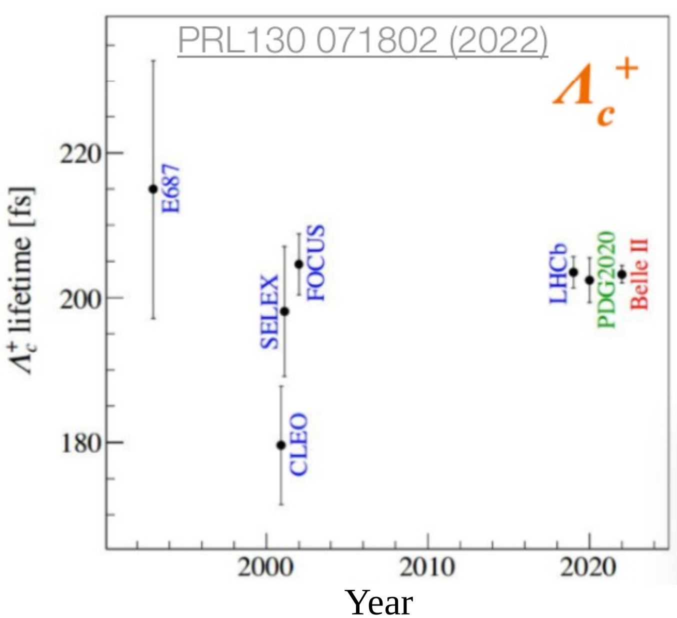
(mostly to show improvements in detector and analysis tools)

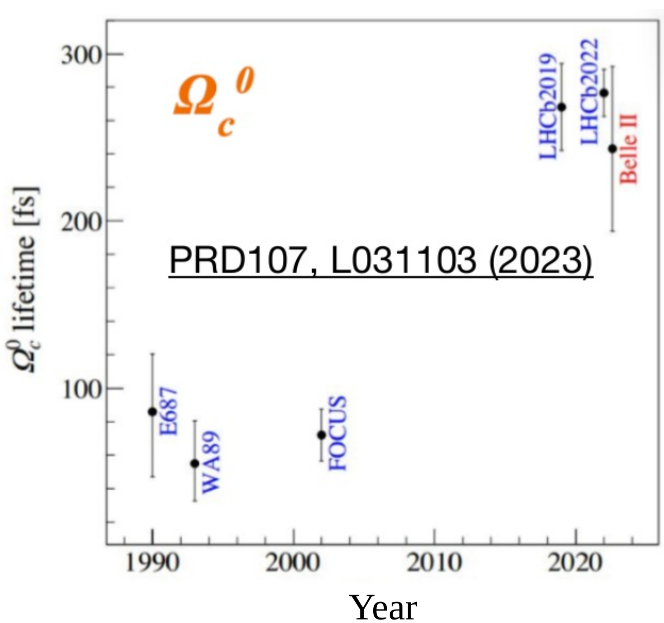
Charm lifetimes

- Dramatic step forward in terms of vertexing resolution, Belle II is a factor ~2 better over the predecessors;
- For some charmed hadrons lifetimes, Belle II leads the competition;
- For the Ω_c (still very limited by the statistics) we confirm the results of LHCb.







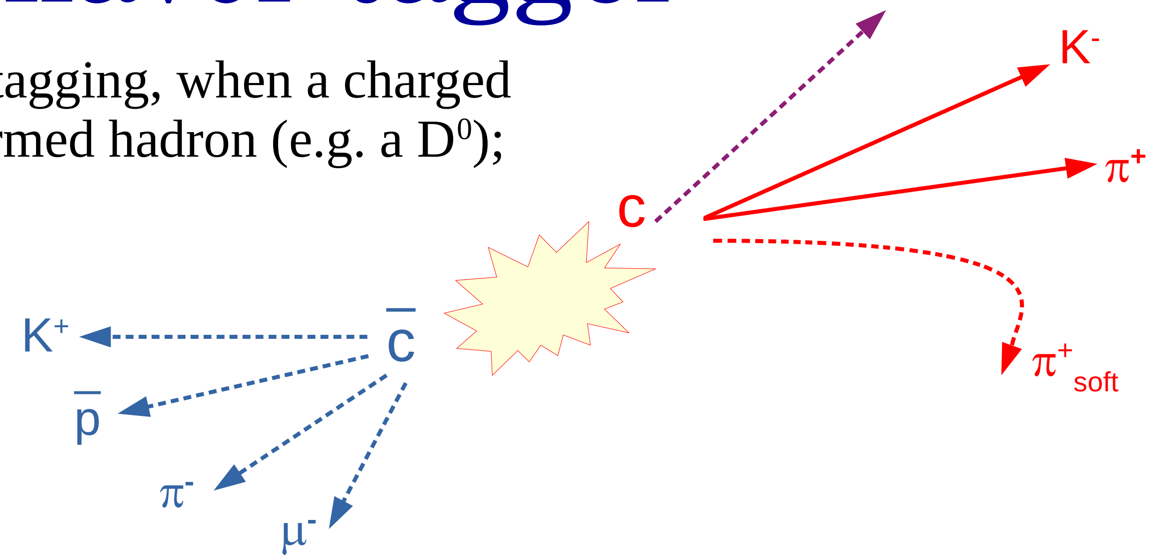


To be submitted to PRD

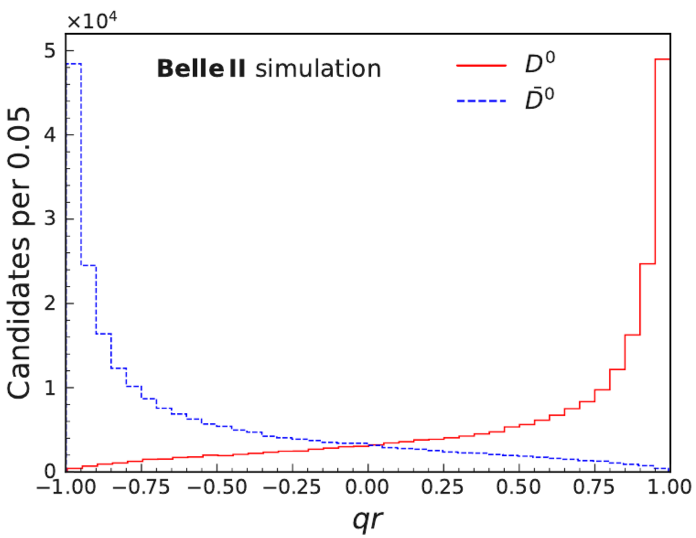
Charm flavor tagger

- Going beyond the old-fashioned D^* tagging, when a charged soft pion is not accompanying a charmed hadron (e.g. a D^0);

- We can derive information on whether the hadron originated from a c or $\bar{c}$, by looking at the angular correlations of the particles in the rest of the event;

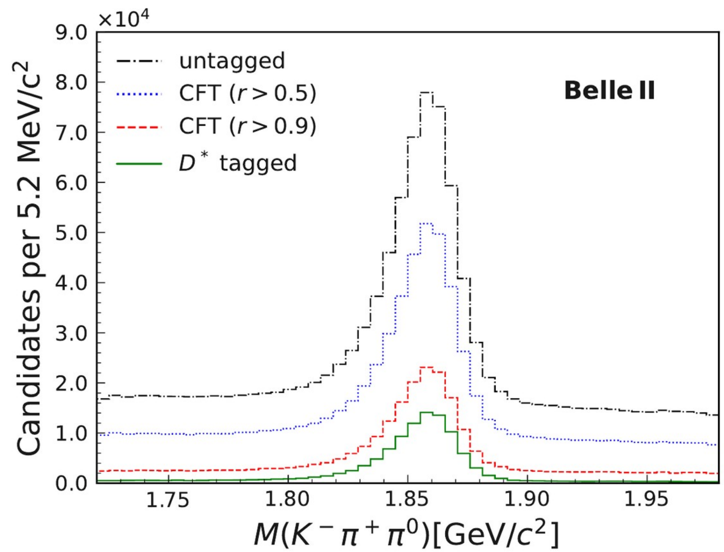


- We built a tool, based on machine learning, that gives a continuous output, similar to what is done by the B flavor tagger:



Effective flavor tagging efficiency **~48%**

Compared to the "traditional" D* tagging, we are **~doubling** the size of the charm sample for e.g. oscillation and CP violation analyses!



B Physics

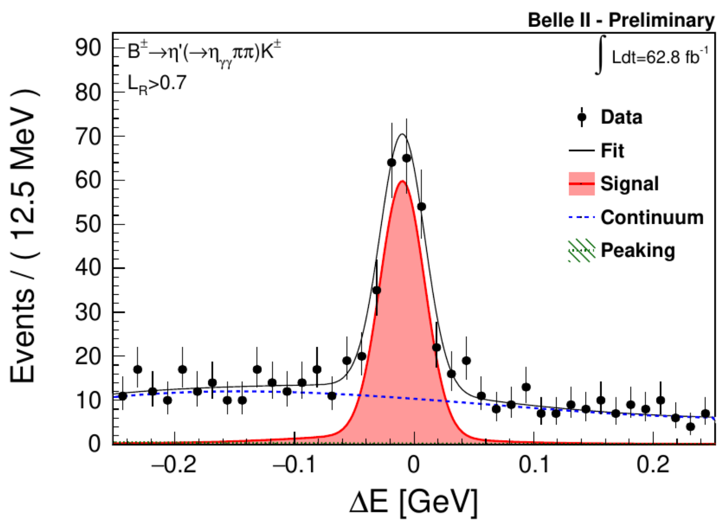
(checking the validity of SM/CKM)

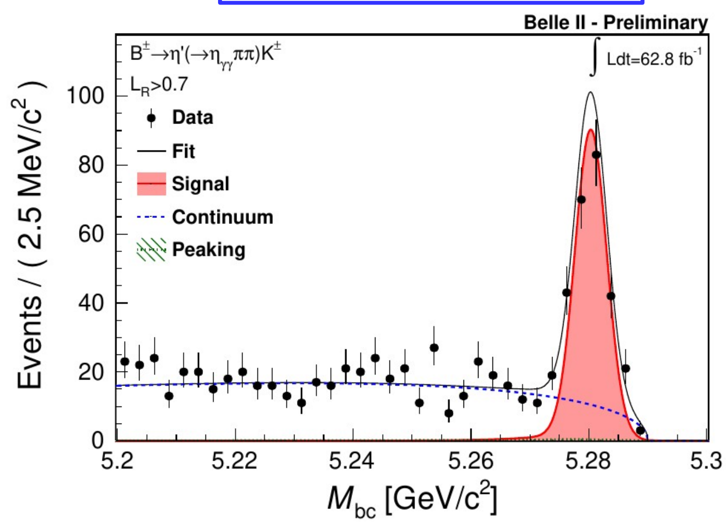
B factory variables

Two key variables discriminate against background for fully reconstructed (hadronic) final states:

$$\Delta E = E_B^* - \frac{\sqrt{s}}{2}$$

$$M_{bc} = \sqrt{\frac{s}{4} - p_B^{*2}}$$

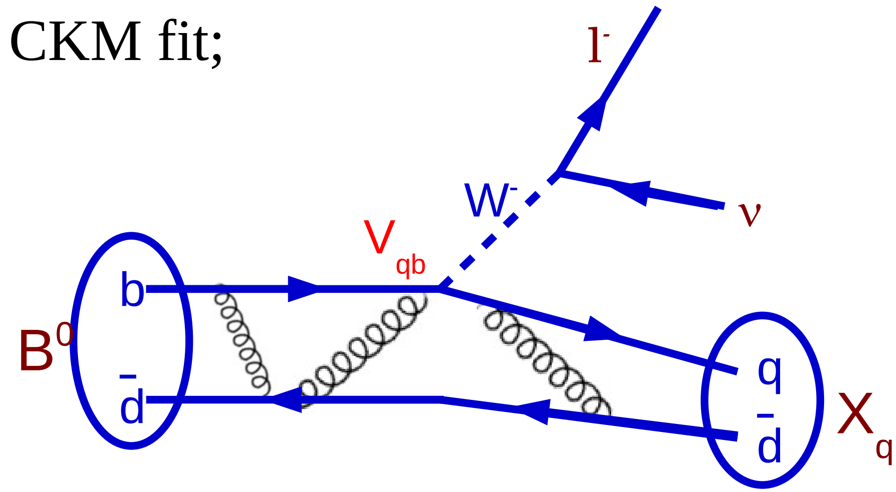


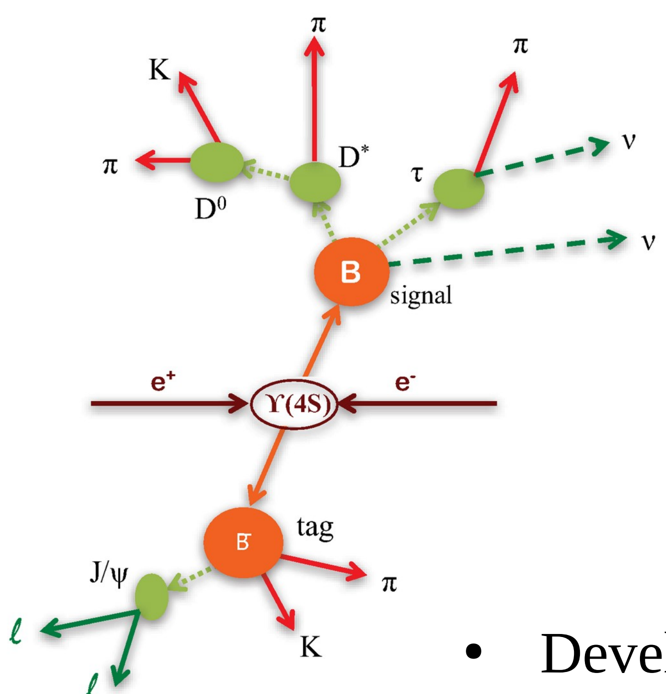


For many final states, the dominant source of background is the '$q\bar{q}$ continuum', which is suppressed based on the different topology with respect to $B\bar{B}$ events:

$|V_{ub}|$ and $|V_{cb}|$ at Belle II

- $|V_{ub}|$ and $|V_{cb}|$ are fundamental inputs for the CKM fit;
- They are measured from tree-level processes, and thus they are assumed to be unaffected by New Physics;



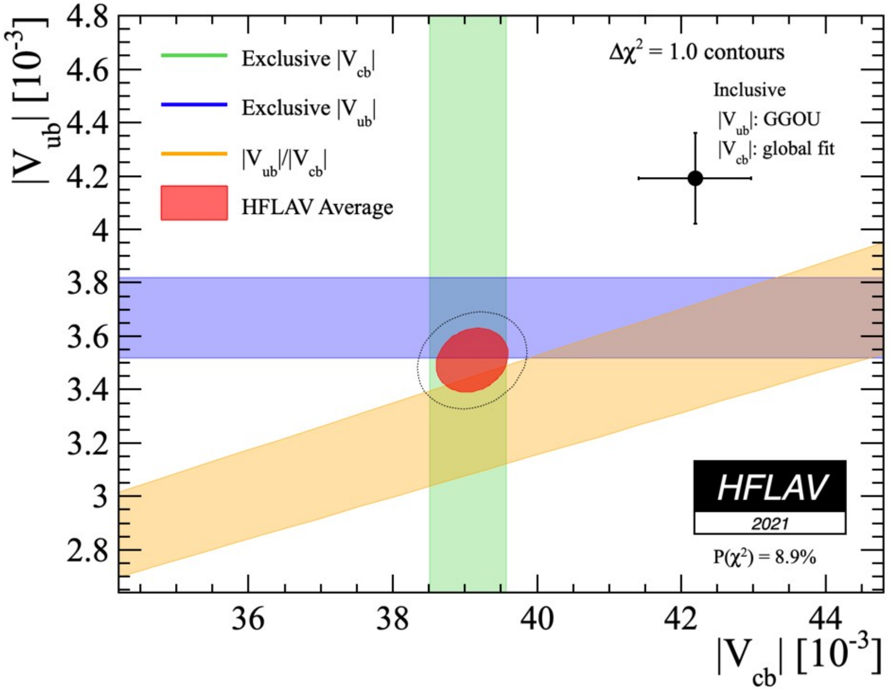


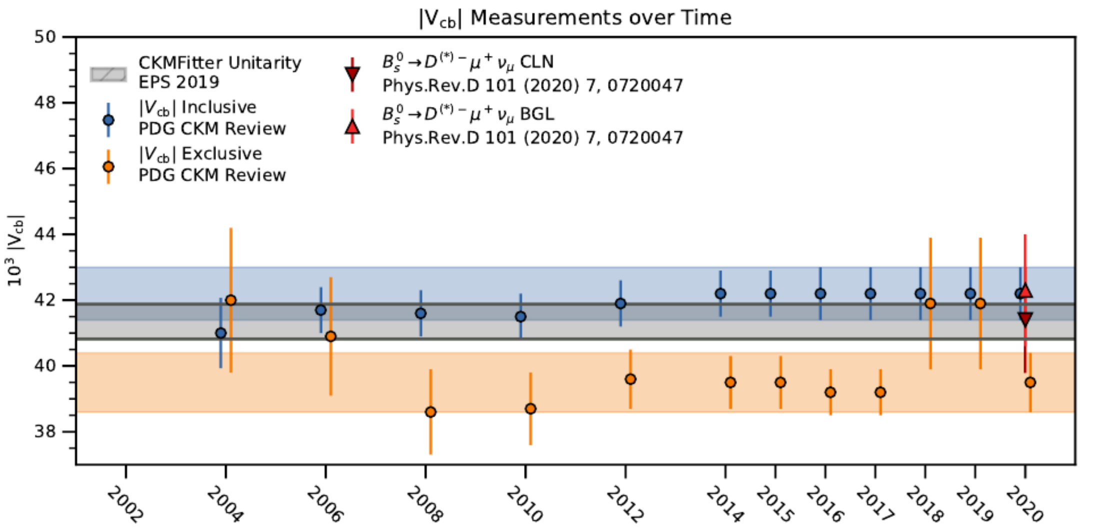
- Fundamental advantage of Belle II: we can perform a very wide spectrum of measurements:
  - inclusive vs exclusive;
  - untagged (high statistics) vs tagged (high purity);
- Developed a more powerful tool, based on machine learning, for tagged analyses: the Full Event Interpretation.

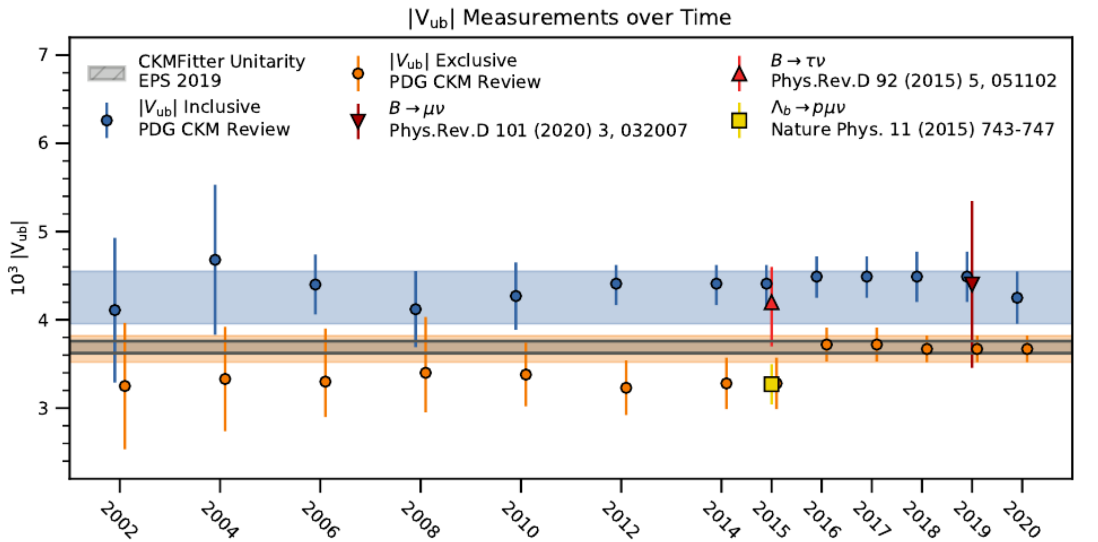
T. Keck et al., Comput. Softw. Big Sci. 3 (2019), 6

Inclusive vs exclusive V_{xb}

Long standing tension between inclusive and exclusive V_{xb} determinations:







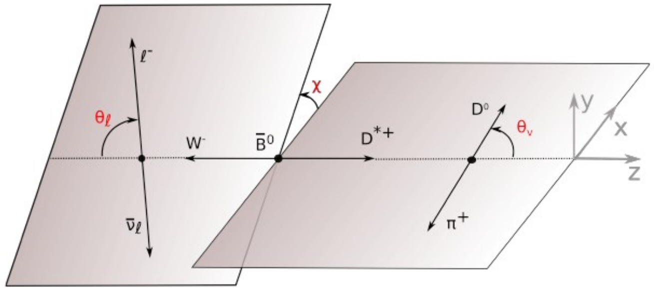
We need to attack the problem from as many sides as possible!

M. Bauer @ HQL 2021

To be submitted to PRD

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

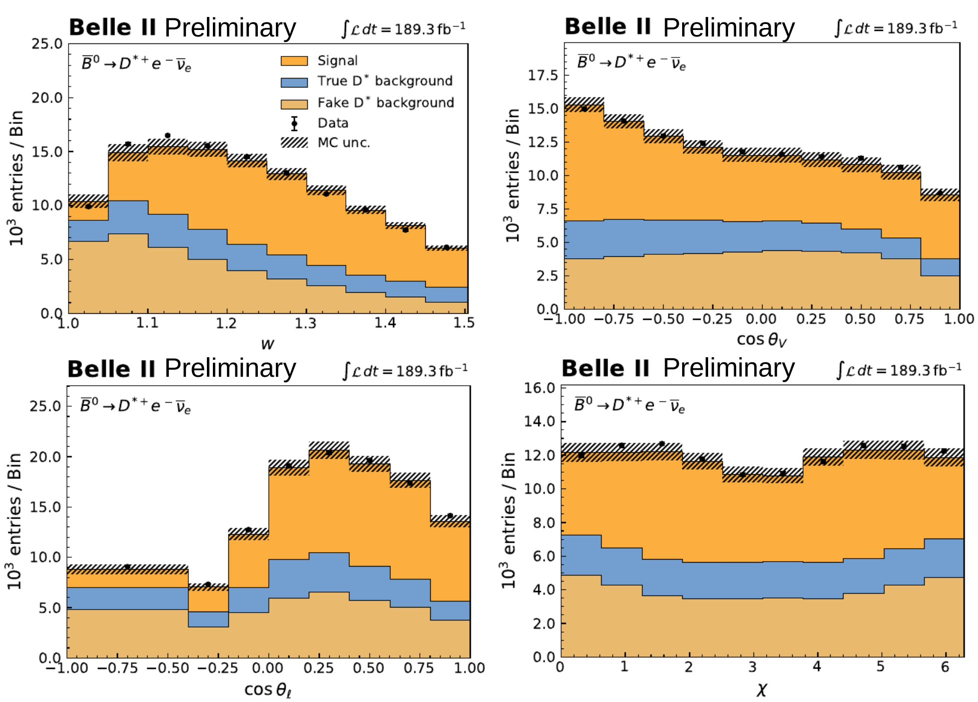
- Extraction of $|V_{cb}|$ from a fit to the distributions of the recoil parameter $w = v_B \cdot v_{D^*}$ and the decay angles θ_l, θ_V, χ:

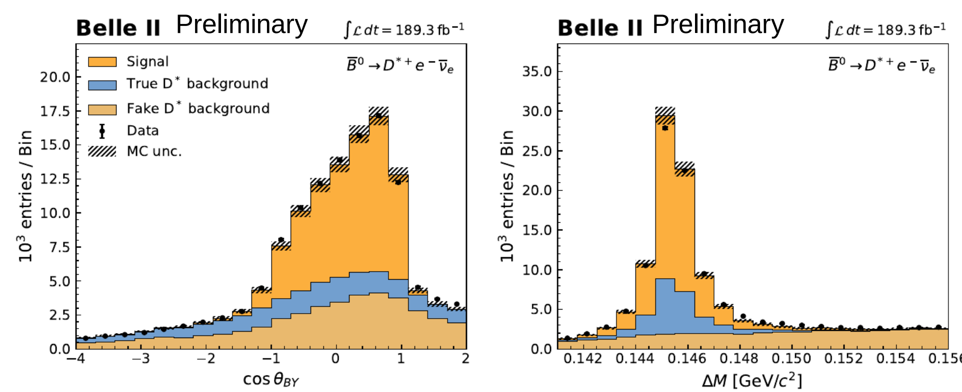


- For each bin of the above distributions, the signal yield is extracted from a fit to the $\cos\theta_{BY}$ and the $\Delta M = M(D^*) - M(D^0)$ distributions;

$Y = D^* + l$

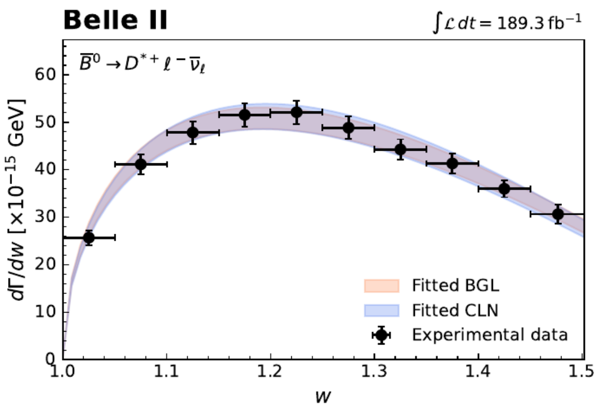
$$\cos\theta_{BY} = \frac{2E_B^{CM}E_Y^{CM} - m_B^2c^4 - m_Y^2c^4}{2|\vec{p}_B^{\,CM}||\vec{p}_Y^{\,CM}|c^2}$$

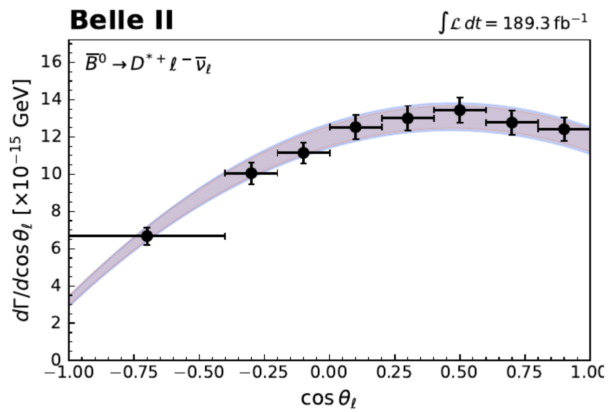


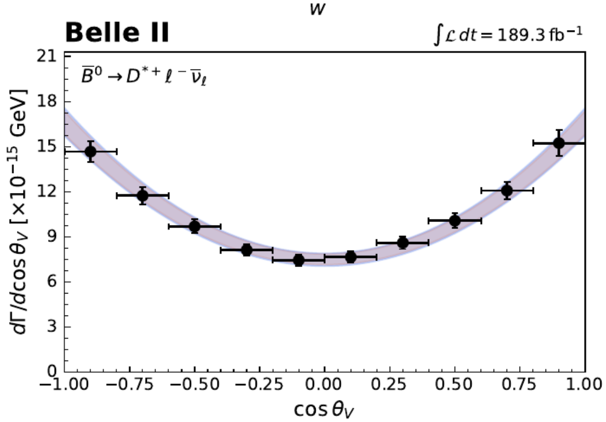


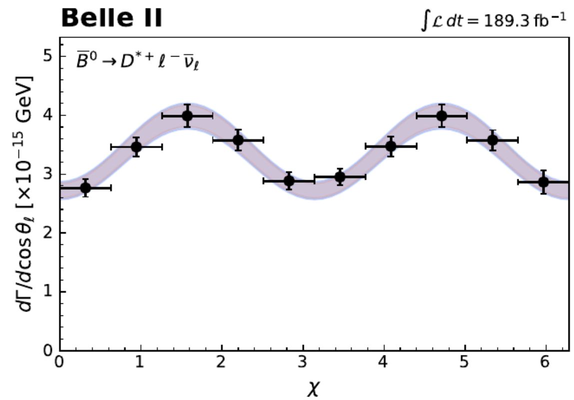
To be submitted to PRD

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









$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell) = (4.94 \pm 0.02 \pm 0.22)\%$$

$$R_{e/\mu} = 1.001 \pm 0.009 \pm 0.021$$

$$\mathcal{A}_{\mathrm{FB}} = \frac{\int_0^1 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell - \int_{-1}^0 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell}{\int_0^1 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell + \int_{-1}^0 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell}$$

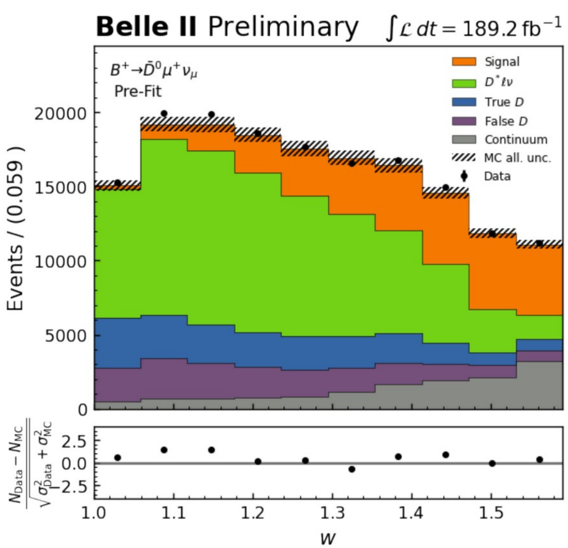
$$\mathcal{A}^e_{\mathrm{FB}} = 0.219 \pm 0.011 \pm 0.020\,,$$
$$\mathcal{A}^\mu_{\mathrm{FB}} = 0.215 \pm 0.011 \pm 0.022\,,$$
$$\Delta\mathcal{A}_{\mathrm{FB}} = (-4 \pm 16 \pm 18) \times 10^{-3}$$

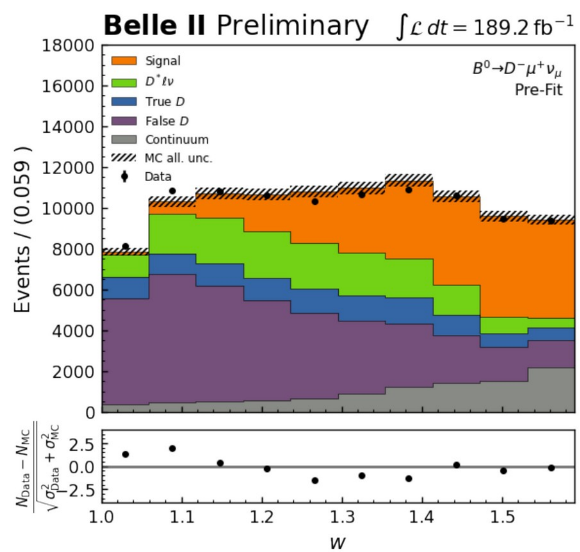
$$\boxed{|V_{cb}|_{\mathrm{BGL}} = (40.9 \pm 0.3 \pm 1.0 \pm 0.6) \times 10^{-3}}$$

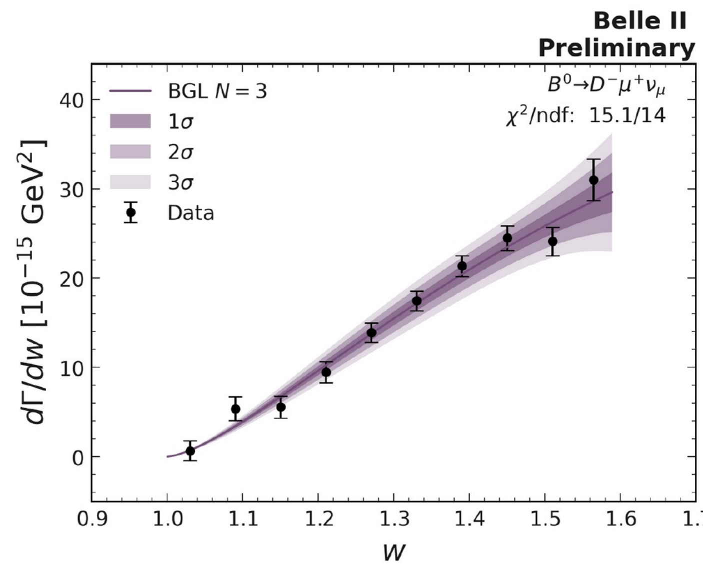
$$\boxed{|V_{cb}|_{\mathrm{CLN}} = (40.4 \pm 0.3 \pm 1.0 \pm 0.6) \times 10^{-3}}$$

Untagged B → D l ν

- We reconstruct B → D l ν decays and fit the w (recoil) distribution to extract $|V_{cb}|$;
- Using both charged and neutral B's and $D^0 \to K^- \pi^+$, $D^+ \to K^- \pi^+ \pi^+$ (and both e and μ);
- Main challenge: dealing with the very large backgrounds and feed down from the D^*;







- Using the BGL parameterization, we extract:

$$|V_{cb}|_{\mathrm{BGL}} = (38.28 \pm 1.16) \times 10^{-3}$$

arXiv:2210.13143 [hep-ex]

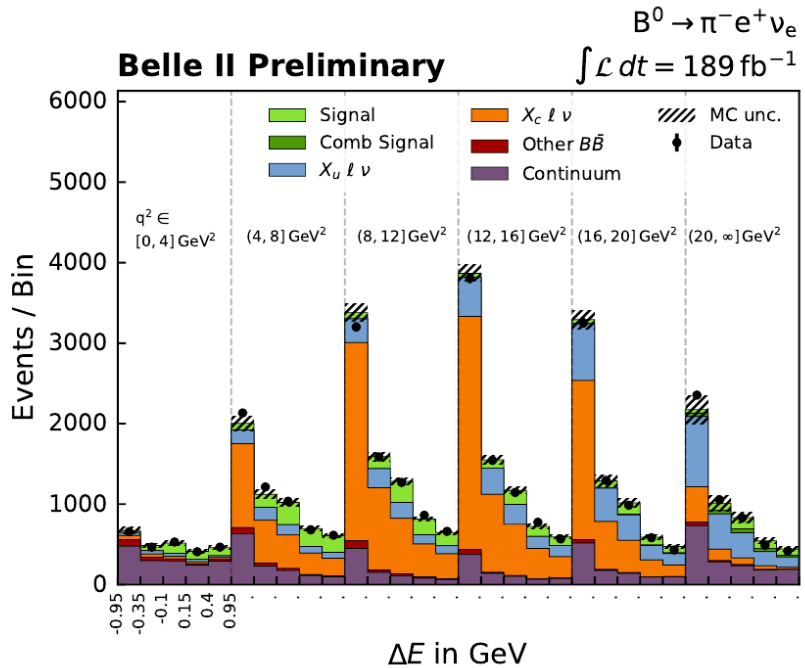
Untagged $B \to \pi l \nu$

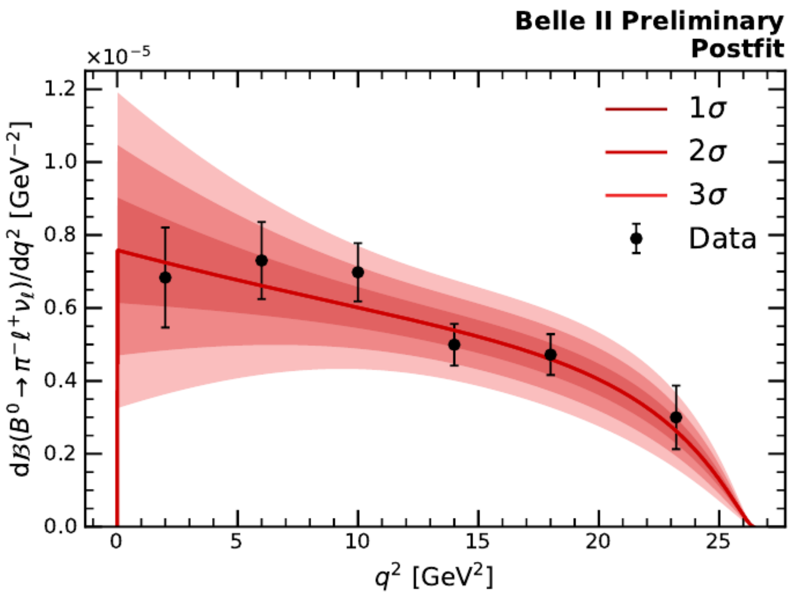
- Untagged measurement of $B^0 \to \pi^- l^+ \nu$ ($l = e, \mu$);
- The other B is not reconstructed, but the kinematics of the "rest of the event" is used to infer the ν momentum;
- The signal is extracted from a ML fit in bins of ΔE, M_{bc}, and q^2;
- Total branching ratio:

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = \\ = (1.426 \pm 0.056(\text{stat}) \pm 0.125(\text{syst})) \times 10^{-4}$$

- From the partial branching fractions (and lattice QCD inputs), we extract:

$$\boxed{|V_{ub}|_{B^0 \to \pi^- \ell^+ \nu_\ell} = \\ = (3.55 \pm 0.12(\text{stat}) \pm 0.13(\text{syst}) \pm 0.17(\text{theo})) \times 10^{-3}}$$

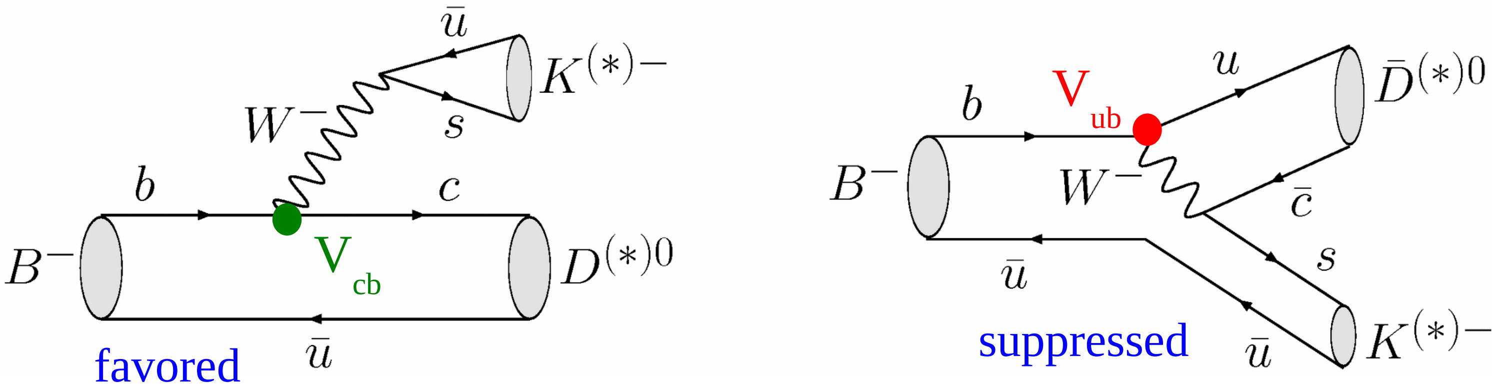




arXiv:2210.04224 [hep-ex]

ϕ_3 (γ) from GLW $B^\pm \to D_{CP} K^\pm$

- ϕ_3 (γ) is the most difficult angle at Belle II (also due to the competition from LHCb). The sensitivity comes from the interference:



- GLW method [PLB **253**, 483 (1991), PLB **265**, 172 (1991)]: consider decays of the D^0 to odd (-) and even (+) CP eigenstates and measure the observables:

$$\mathcal{A}_{CP\pm} \equiv \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) - \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)} \qquad \mathcal{R}_{CP\pm} \equiv \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D_{\mathrm{flav}}K^-) + \mathcal{B}(B^+ \to D_{\mathrm{flav}}K^+)}$$

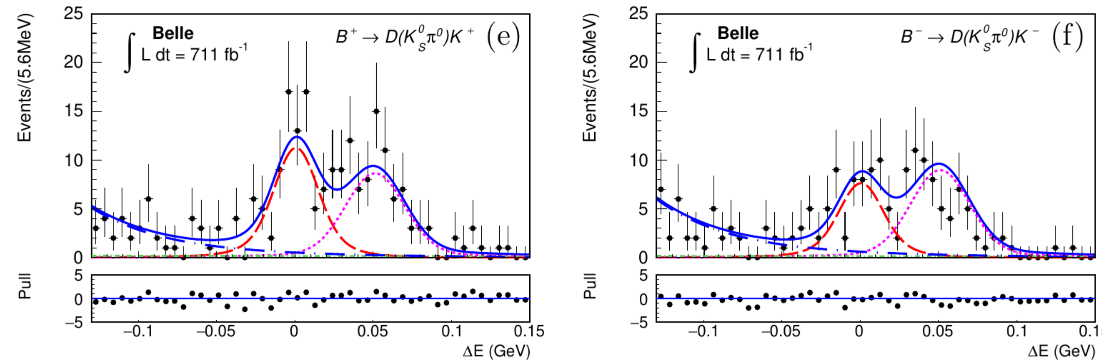
which are related to ϕ_3:

$$\boxed{\begin{aligned} \mathcal{R}_{CP\pm} &= 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\phi_3 \\ \mathcal{A}_{CP\pm} &= \pm 2r_B \sin\delta_B \sin\phi_3 \,/\, \mathcal{R}_{CP\pm} \end{aligned}}$$

ϕ_3 (γ) from GLW $B^{\pm} \to D_{CP} K^{\pm}$

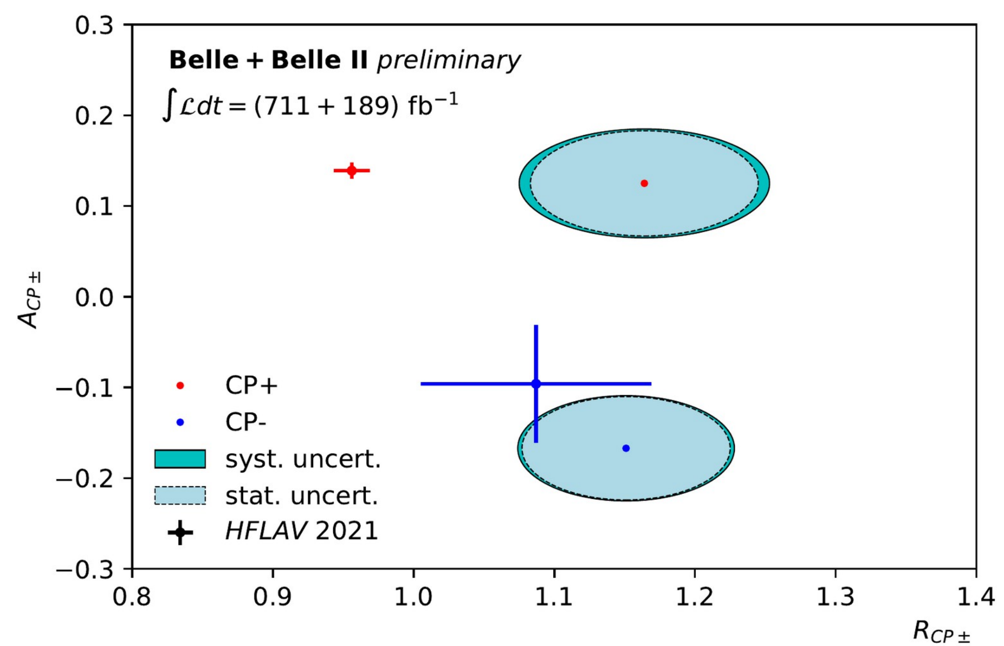
- Considering $D^0 \to K^+K^-$ as CP+, $D^0 \to K_S\pi^0$ as CP-, and $D^0 \to K^-\pi^+$ as flavor specific final state, we measure (on the Belle + Belle II data set):

$$\mathcal{R}_{CP+} = 1.164 \pm 0.081 \pm 0.036,$$
$$\mathcal{R}_{CP-} = 1.151 \pm 0.074 \pm 0.019,$$
$$\mathcal{A}_{CP+} = (+12.5 \pm 5.8 \pm 1.4)\%,$$
$$\mathcal{A}_{CP-} = (-16.7 \pm 5.7 \pm 0.6)\%.$$



- The A_{CP}'s differ from each other at ~3.5σ;
- This translates into constraints on ϕ_3:

	68.3% CL	95.4% CL
ϕ_3 (°)	[8.7, 20.5] [83.8, 96.1] [163.4, 173.1]	[4.7, 175.8]
r_B	[0.282, 0.489]	[0.069, 0.560]



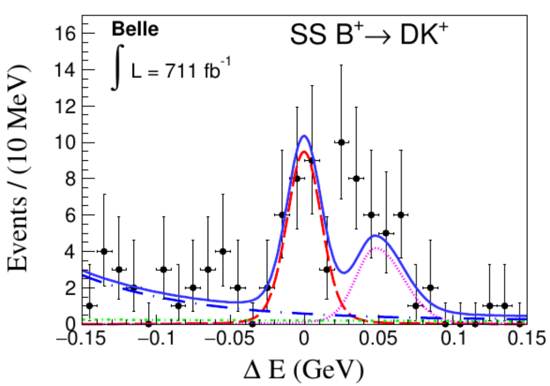
To be submitted to PRD

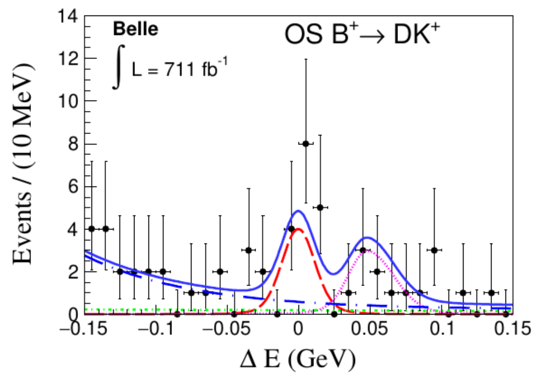
ϕ_3 (γ) from GLS $B^\pm \rightarrow D\, h^\pm$

- Other constraints on ϕ_3 can come with the GLS method [PRD **67** 071301 (2003)];
- We use the Belle + Belle II data sets to reconstruct $B^\pm \rightarrow D^0[K_S K^+ \pi^-]\, h^\pm$ events;
- Events are split into SS (K and h have same charge) and OS (K and h have opposite charge). We reconstruct the observables:

$$\mathcal{A}_m^{Dh} \equiv \frac{N_m^{Dh^-} - N_m^{Dh^+}}{N_m^{Dh^-} + N_m^{Dh^+}} \qquad \mathcal{R}_m^{DK/D\pi} \equiv \frac{N_m^{DK^-} + N_m^{DK^+}}{N_m^{D\pi^-} + N_m^{D\pi^+}} \qquad \mathcal{R}_{\mathrm{SS/OS}}^{D\pi} \equiv \frac{N_{\mathrm{SS}}^{D\pi^-} + N_{\mathrm{SS}}^{D\pi^+}}{N_{\mathrm{OS}}^{D\pi^-} + N_{\mathrm{OS}}^{D\pi^+}}$$

m = SS, OS



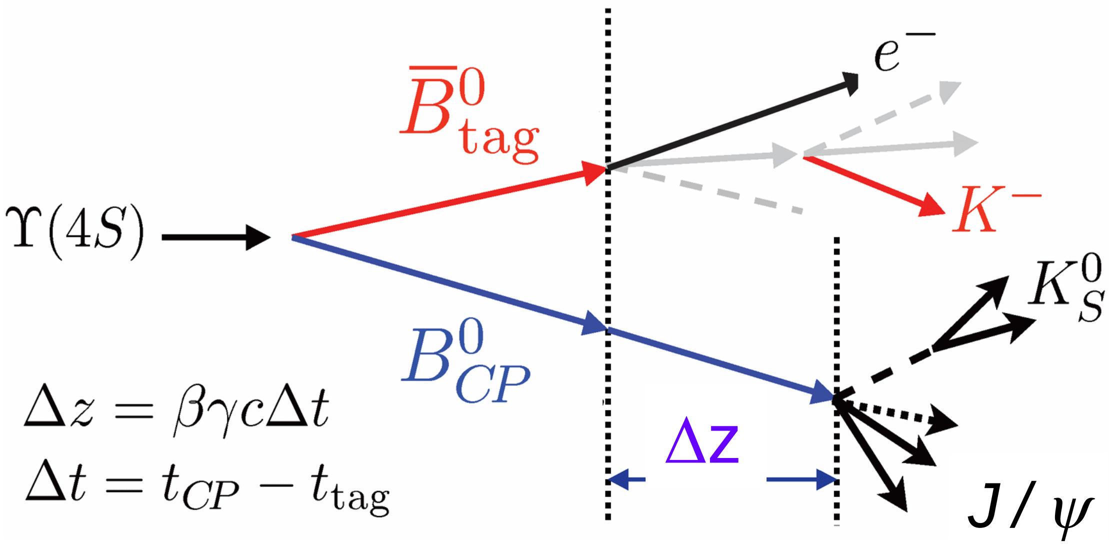


$$\begin{aligned}
A_{\mathrm{SS}}^{DK} &= -0.089 \pm 0.091 \pm 0.011,\\
A_{\mathrm{OS}}^{DK} &= 0.109 \pm 0.133 \pm 0.013,\\
A_{\mathrm{SS}}^{D\pi} &= 0.018 \pm 0.026 \pm 0.009,\\
A_{\mathrm{OS}}^{D\pi} &= -0.028 \pm 0.031 \pm 0.009,\\
R_{\mathrm{SS}}^{DK/D\pi} &= 0.122 \pm 0.012 \pm 0.004,\\
R_{\mathrm{OS}}^{DK/D\pi} &= 0.093 \pm 0.013 \pm 0.003,\\
R_{\mathrm{SS/OS}}^{D\pi} &= 1.428 \pm 0.057 \pm 0.002.
\end{aligned}$$

ϕ_3 determination requires also input from CLEO on D decay parameters (work in progress)

To be submitted to PRD

Time dependent analyses



Flagship measurement of the B Factories, still very important at Belle II;

$$\boxed{\begin{aligned} \mathcal{A}_f(\Delta t) &= \frac{\Gamma(\overline{B}^0(\Delta t) \to f) - \Gamma(B^0(\Delta t) \to f)}{\Gamma(\overline{B}^0(\Delta t) \to f) + \Gamma(B^0(\Delta t) \to f)} \\ &= S_f \sin(\Delta m_B \Delta t) + A_f \cos(\Delta m_B \Delta t) \end{aligned}}$$

<Δz> ~ 130 μm at Belle II

S_f : time dependent asymmetry

A_f : time integrated (or direct) asymmetry

Quite complicated analysis, several ingredients must be in place:

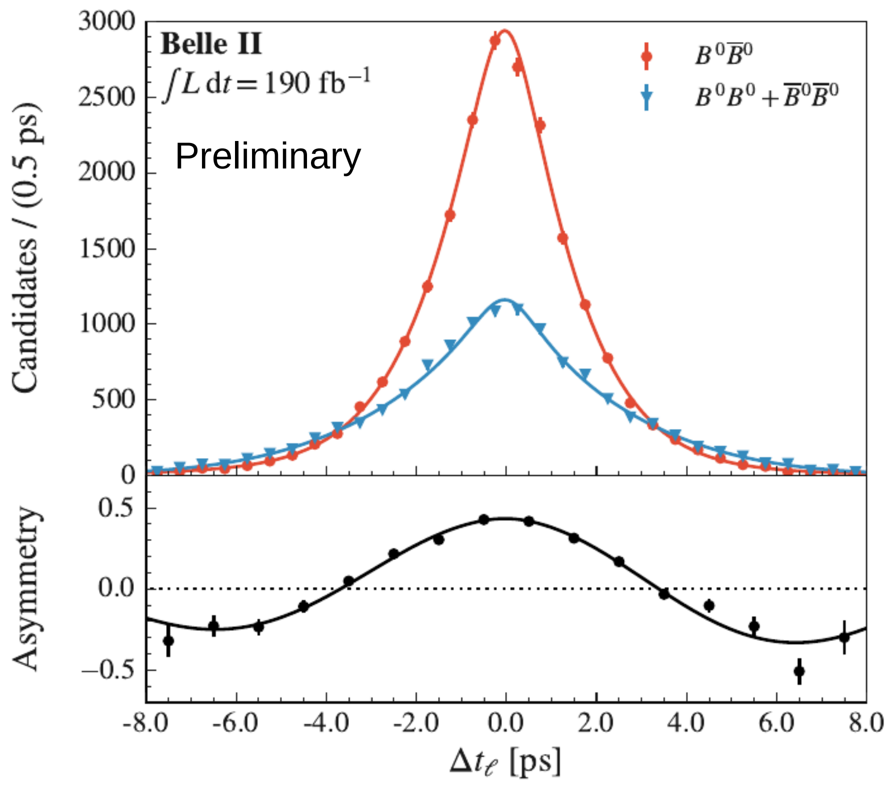
1) ability to identify the flavor (B^0 or $\overline{B}^0$) of the unreconstructed B (flavor tagging);
2) B-decay vertices resolution;
3) signal side efficiency, background modeling.

Eur. Phys. J 82, 283 (2022)

B^0 lifetime and mixing frequency

arXiv:2302.12791 [hep-ex]
submitted to PRD

- Very hard to compete with LHCb now, but fundamental step towards time dependent CP violation analyses;
- Signal side B is reconstructed in $B^0 \rightarrow D^- h^+$, $D^{*-} h^+$ ($h^+ = \pi^+, K^+$);
- Tag side vertex is determined from the remaining tracks in the event, and the flavor is assigned by the Flavor Tagger;



- The fit is performed in two steps”:

1) fit ΔE and continuum suppression BDT output, to determine ths sWeights of the signal;
2) fit τ_{B0} and Δm_d on the “background subtracted” Δt distributions:

$$\boxed{\begin{aligned}\tau_{B^0} &= 1.499 \pm 0.013\,(\mathrm{stat}) \pm 0.008\,(\mathrm{syst})\ \mathrm{ps},\\ \Delta m_d &= 0.516 \pm 0.008\,(\mathrm{stat}) \pm 0.005\,(\mathrm{syst})\ \mathrm{ps}^{-1}\end{aligned}}$$

World Averages:

$\tau_{B0} = 1.519 \pm 0.004$

$\Delta m_d = 0.5065 \pm 0.0019$

$\sin(2\phi_1)$ / $\sin(2\beta)$ from $B \to J/\psi\, K_S$

- Full time dependent analysis of the most sensitive (almost background free) of the golden channels;
- Using the same resolution function developed for the lifetime and mixing analysis, and determining common parameters from $B^0 \to D^{(*)-}h^+$ modes;
- Results:

$$S_{CP} = 0.720 \pm 0.062(\text{stat}) \pm 0.016(\text{syst})$$

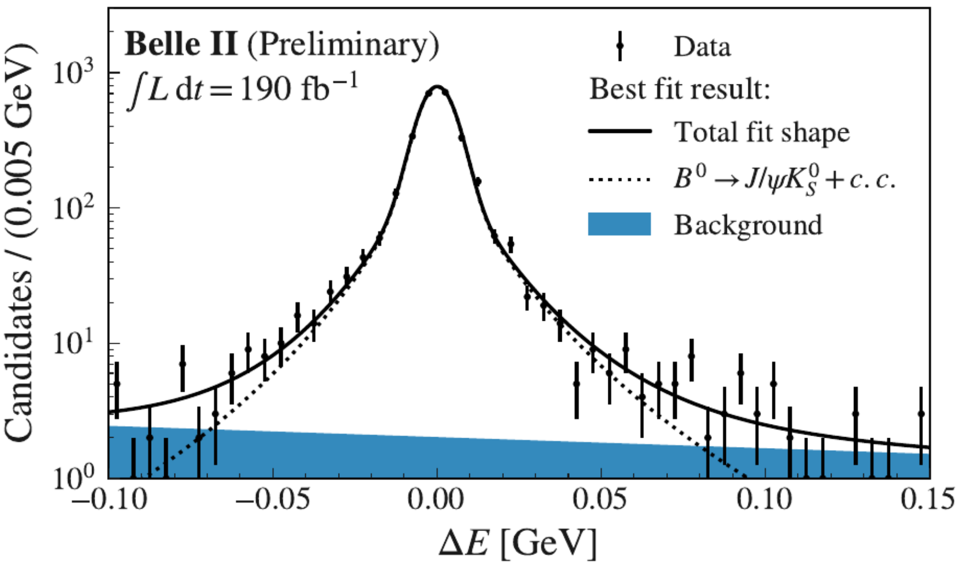
$$A_{CP} = 0.094 \pm 0.044(\text{stat})^{+0.042}_{-0.017}(\text{syst})$$

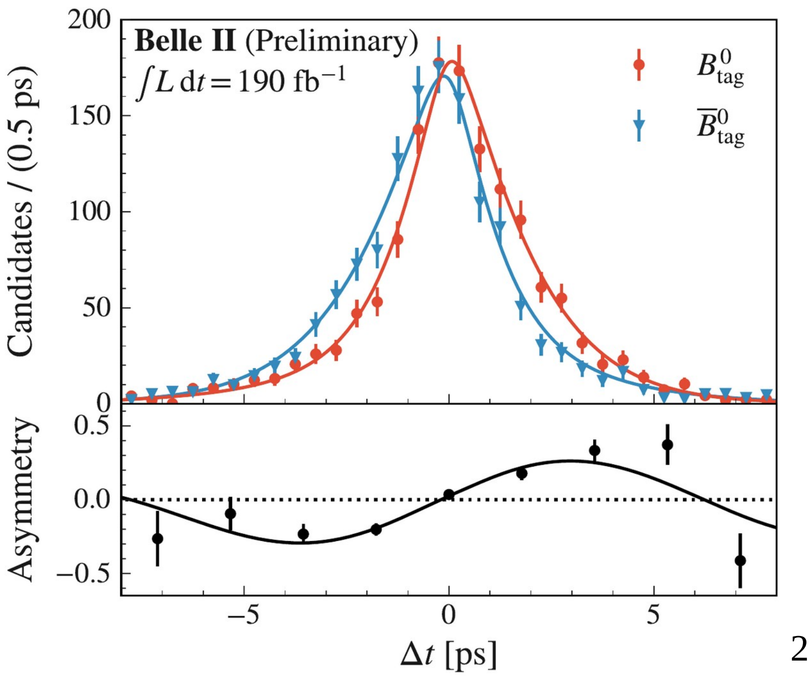
World average (K_S mode only):

$S_{CP} = 0.695 \pm 0.019$

$A_{CP} = 0.000 \pm 0.020$

- In the near future we will add the K_L and other $c\bar{c}$ resonances;
- Still very far from being limited by the systematics!





arXiv:2302.12898 [hep-ex]

$B \to \phi K_S$

To be submitted to PRD

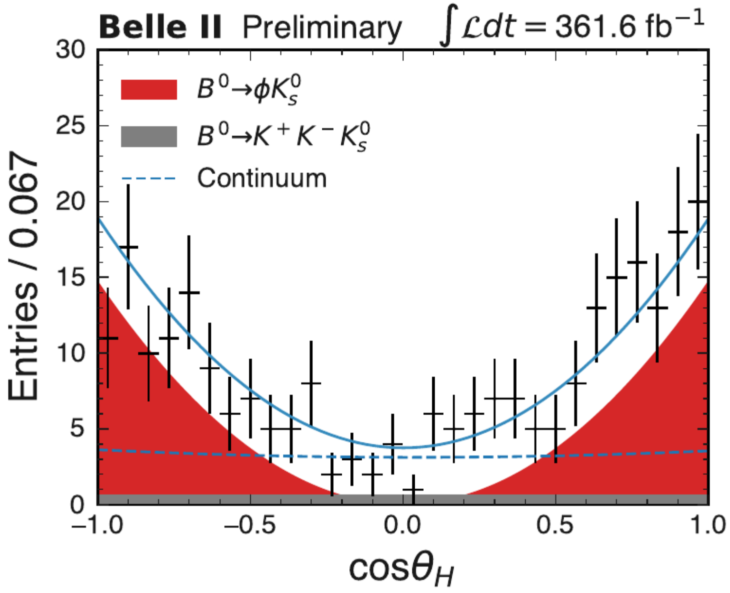
- One of the most notable examples of modes sensitive to $\sin(2\phi_1)$, but proceeding through penguin amplitudes;
- Theoretically very clean;
- We reconstruct ~160 signal events in $\phi \to K^+K^-$, $K_S \to \pi^+\pi^-$;
- Tricky part, distinguishing the nonresonant $B \to KKK$, which would dilute the CP asymmetry: we do it by employing the helicity angle of the ϕ candidate;
- Results:

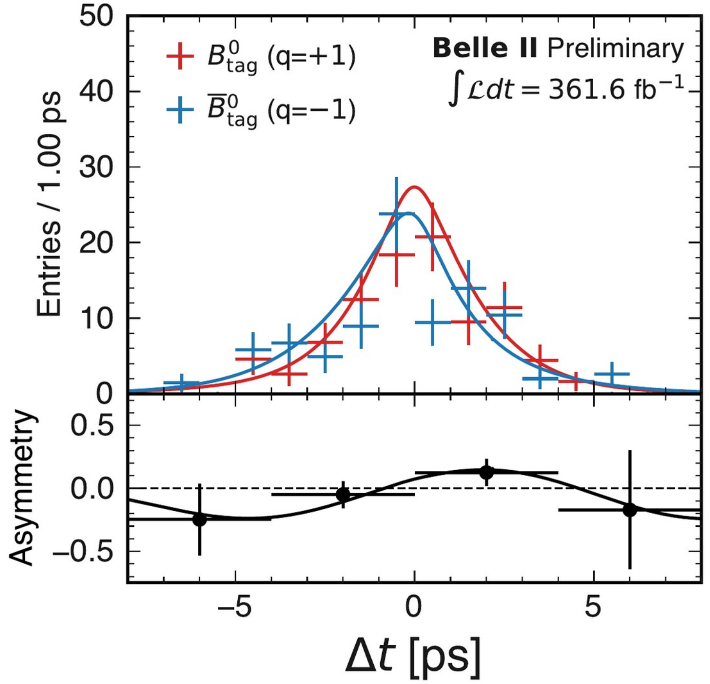
$$A_{CP} = 0.31 \pm 0.20\,^{+0.05}_{-0.06}$$
$$S_{CP} = 0.54 \pm 0.26\,^{+0.06}_{-0.08}$$

World average:

$S_{CP} = 0.74 \pm 0.12$

$A_{CP} = -0.01 \pm 0.14$

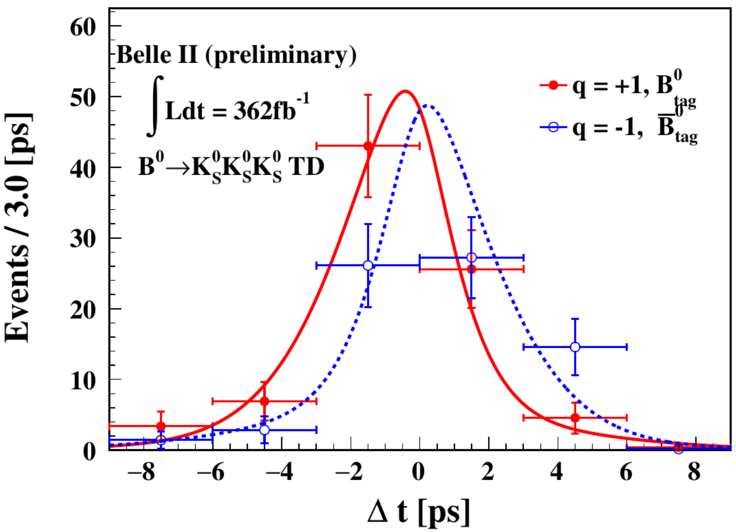




$B \to K_S K_S K_S$

To be submitted to PRD

- Decay proceeding through penguin loop diagrams, potentially sensitive to New Physics and theoretically very clean;
- No prompt tracks from signal B decay vertex, $K_S \to \pi^+\pi^-$ flight direction must be extrapolated back;
- Only candidates with sufficient hits on the silicon vertex detectors are used for the time dependent (TD) analysis, the others contribute to the time independent (TI) analysis;

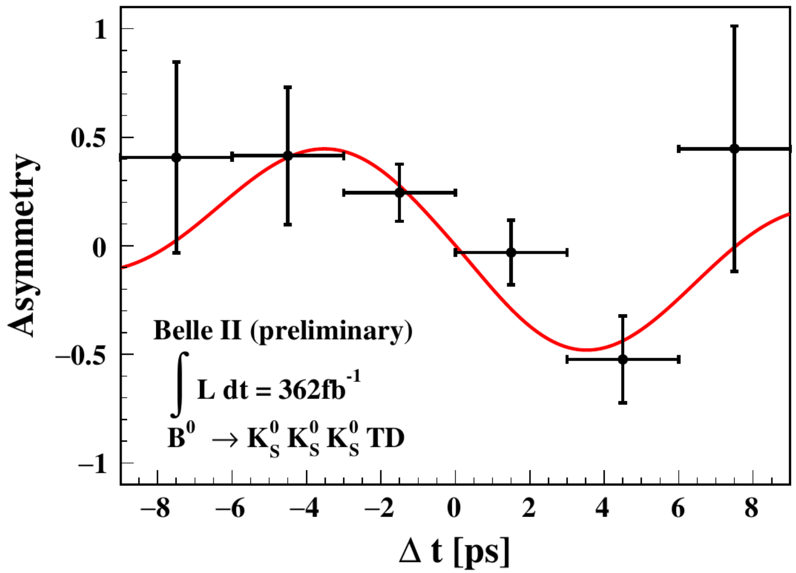


- Results:

nSig = 158 ± 14 TD events
(+62 ± 9 TI events)

$$\mathcal{S} = -1.37^{+0.38}_{-0.41}(\text{stat}) \pm 0.03(\text{syst})$$
$$\mathcal{A} = \quad 0.07^{+0.15}_{-0.20}(\text{stat}) \pm 0.02(\text{syst})$$

World average:
S_{CP} = -0.83 ± 0.17
A_{CP} = 0.15 ± 0.12



$B \to K_S \pi^0$

To be submitted to PRL

- Another tough channel, requiring backward extrapolation of the K_S flight direction;
- Also, a fundamental ingredient of the "Kπ puzzle", see next;
- A modified version of M_{bc}, that reduces the correlations with ΔE is utilized;
- Thanks to our improved π^0 reconstruction, we detect 415 ± 26 signal events;
- Results:

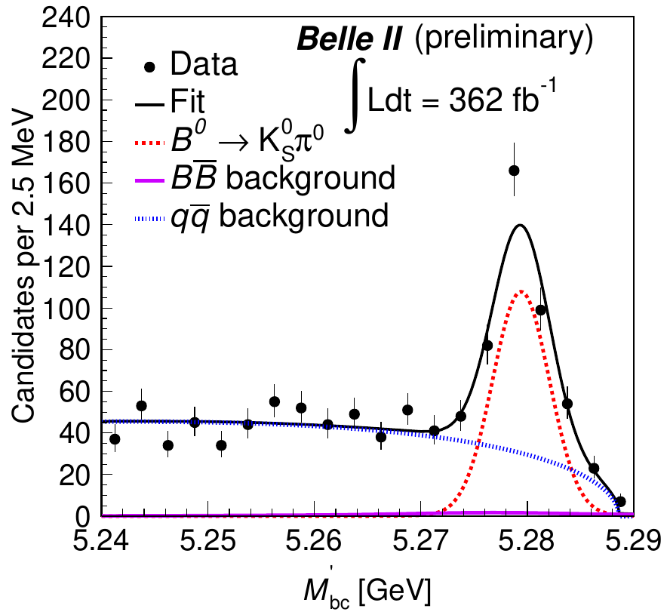
$$\mathcal{S}_{CP} = 0.75^{+0.20}_{-0.23} \pm 0.04$$

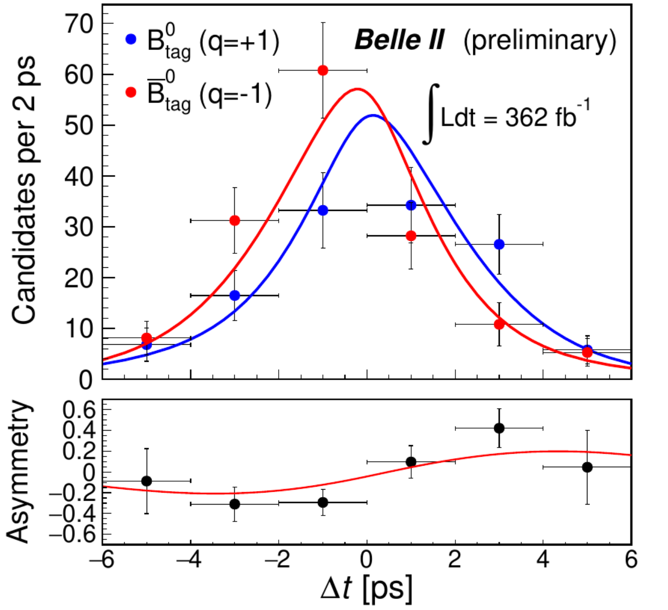
$$\mathcal{A}_{CP} = 0.04 \pm 0.15 \pm 0.05$$

World average:

$S_{CP} = 0.57 \pm 0.17$

$A_{CP} = -0.01 \pm 0.10$





$B \to K\pi / \pi\pi$ decays

- These decays are quite suppressed by CKM and/or loop diagrams;
- $B \to \pi\pi$ decays enter the determination of ϕ_2 (α), currently work in progress;
- $B \to K\pi$ decays have attracted lots of attention in the recent past, because of possible isospin breaking phenomena;
- The standard model predicts the quantity:

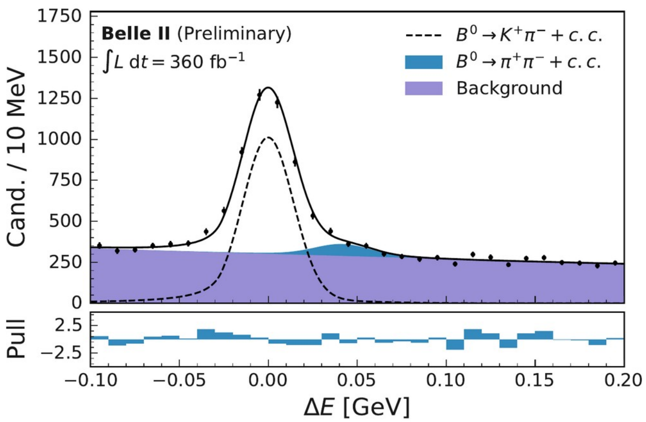
$$I_{K\pi} = \mathcal{A}_{CP}^{K^+\pi^-} + \mathcal{A}_{CP}^{K^0\pi^+} \frac{\mathcal{B}_{K^0\pi^+}}{\mathcal{B}_{K^+\pi^-}} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{CP}^{K^+\pi^0} \frac{\mathcal{B}_{K^+\pi^0}}{\mathcal{B}_{K^+\pi^-}} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{CP}^{K^0\pi^0}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

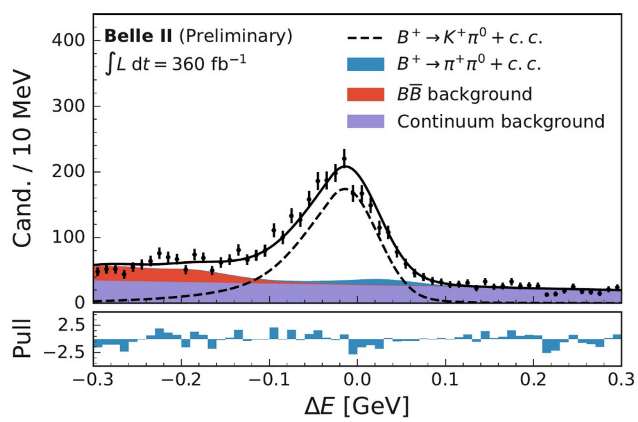
to be compatible with 0;

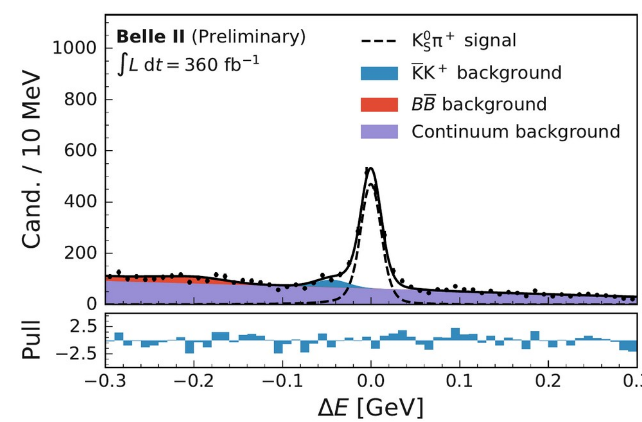
- What limits the sensitivity is the $K^0\pi^0$ channel, almost exclusive to Belle II;
- Currently the World Average gives: $I_{K\pi} = -0.13 \pm 0.11$.

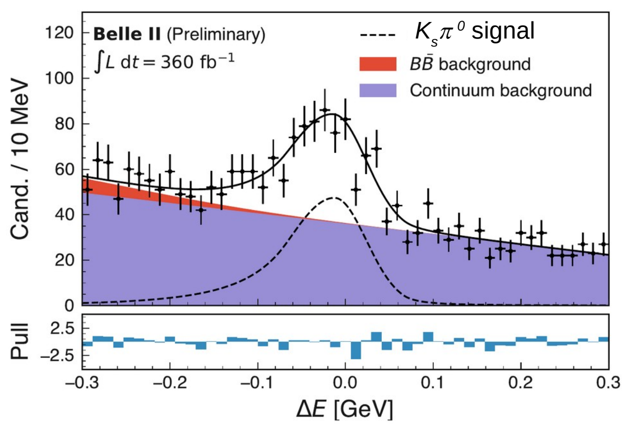
$B \to K\pi\,/\,\pi\pi$ decays

To be submitted to PRD









Channel	$\mathcal{B}[10^{-6}]$	$\mathcal{A}_{CP}$
$B^0 \to K^+\pi^-$	$20.7 \pm 0.4 \pm 0.6$	$-0.072 \pm 0.019 \pm 0.007$
$B^0 \to \pi^+\pi^-$	$5.83 \pm 0.22 \pm 0.17$	-
$B^+ \to K^+\pi^0$	$14.2 \pm 0.4 \pm 0.9$	$0.013 \pm 0.027 \pm 0.005$
$B^+ \to \pi^+\pi^0$	$5.02 \pm 0.28 \pm 0.31$	$-0.08 \pm 0.05 \pm 0.01$
$B^+ \to K^0\pi^+$	$24.4 \pm 0.7 \pm 0.9$	$0.046 \pm 0.029 \pm 0.007$
$B^0 \to K^0\pi^0$	$10.5 \pm 0.6 \pm 0.7$	$-0.01 \pm 0.12 \pm 0.05$ (*)

(*) : combined result with the time dependent analysis presented above

With our inputs we measure:

$$\boxed{I_{K\pi} = -0.03 \pm 0.13 \pm 0.05}$$

Consistent with the SM, and competitive with the World Average

Probing (some) of the anomalies

R(K) in B → J/ψ K

- Hot topic: potential LFU violation in B → $K^{(*)} l^+l^-$ decays, which proceed through loop diagrams;

arXiv:2207.11275 [hep-ex]

- Approaching step: measure R(K) in B → J/ψ K decays (tree level process, no LFU violation is expected):

$$R_K(J/\psi) = \frac{\mathcal{B}(B \to J/\psi(\mu^+\mu^-)K)}{\mathcal{B}(B \to J/\psi(e^+e^-)K)}$$

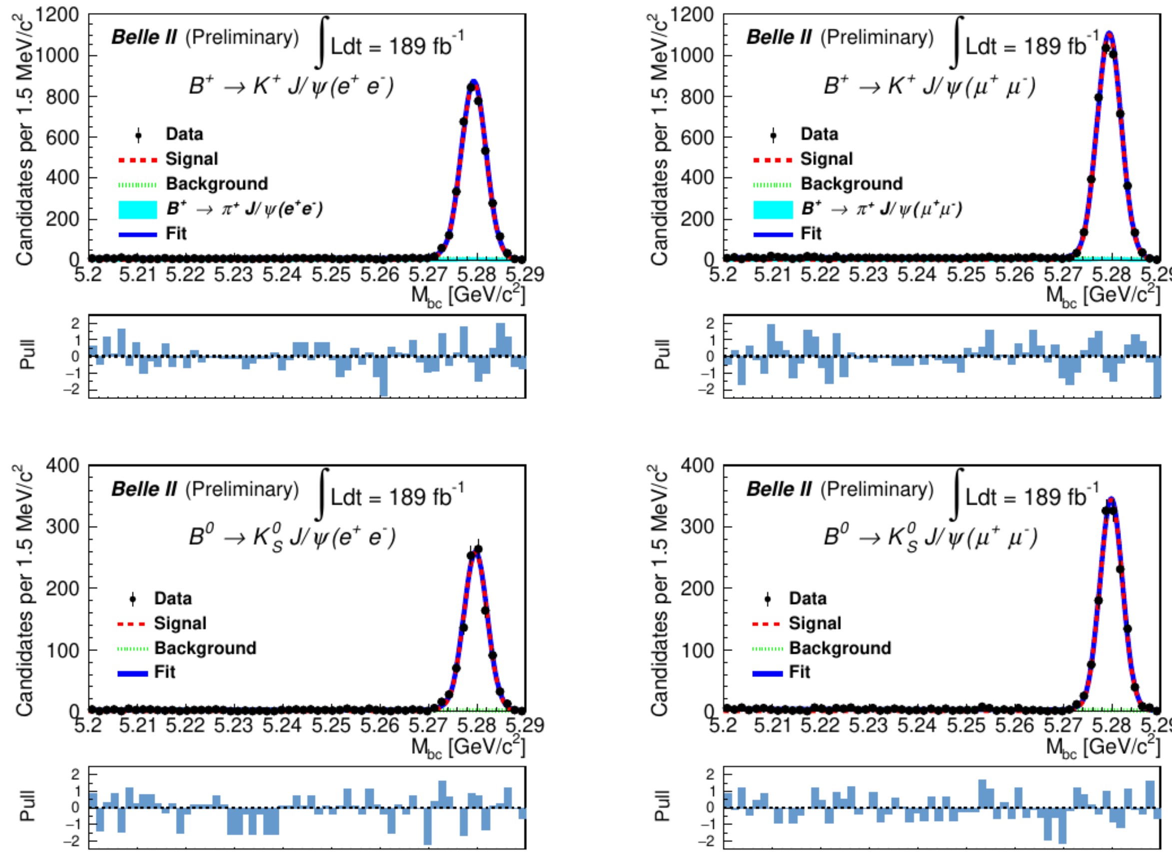
- Results:

$$R_{K^+}(J/\psi) = 1.009 \pm 0.022 \pm 0.008$$
$$R_{K^0}(J/\psi) = 1.042 \pm 0.042 \pm 0.008$$

- Also, no sign of isospin symmetry violation:

$$A_I = \frac{\Gamma[B^0 \to J/\psi K^0] - \Gamma[B^+ \to J/\psi K^+]}{\Gamma[B^0 \to J/\psi K^0] + \Gamma[B^+ \to J/\psi K^+]}$$

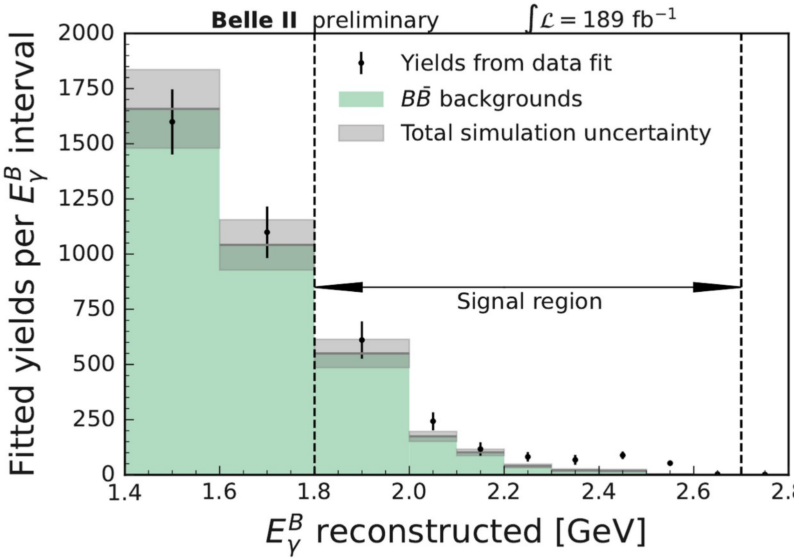
$$A_I(B \to J/\psi(e^+e^-)K) = -0.022 \pm 0.016 \pm 0.030$$
$$A_I(B \to J/\psi(\mu^+\mu^-)K) = -0.006 \pm 0.015 \pm 0.030$$



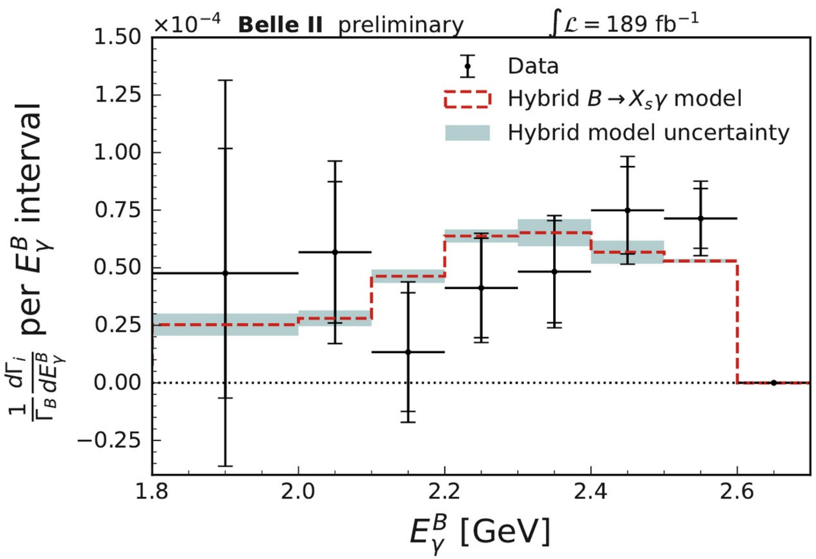
Inclusive $b \to s\gamma$

arXiv:2210.10220 [hep-ex]

- Analysis performed in the recoil of FEI reconstructed hadronic B's;
- Signal B rest frame is determined by the B_{tag} reconstruction. The signal γ is the highest energy γ in the event;
- Signal region: $1.8 < E_\gamma^B < 2.7$ GeV;
- Two-step fitting procedure:
  1) fit the tag side M_{bc} for correctly reconstructed tags;
  2) use the MC to estimate the $B\overline{B}$ background events with a good B_{tag}.



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



Already competitive with BaBar's hadronic tag measurement!

Test of Lepton Flavor Universality

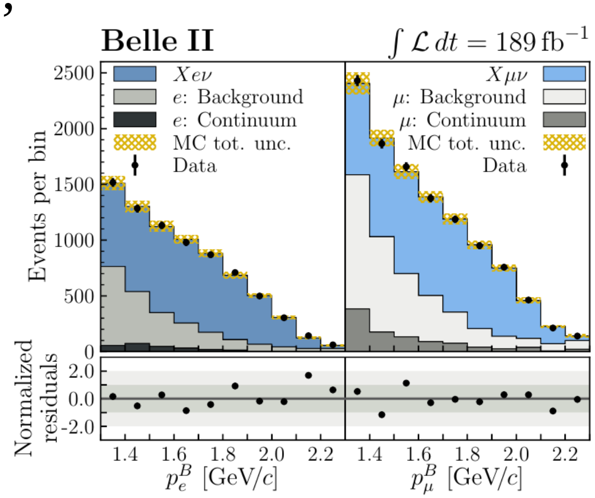
- We test the Lepton Flavor Universality in semileptonic B decays, by measuring:

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

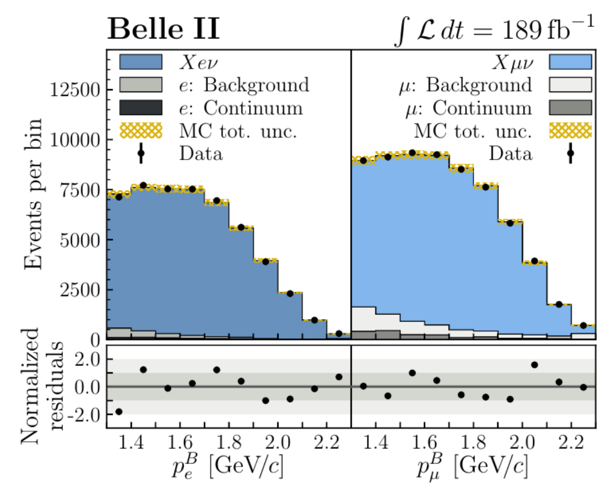
which is expected to be 1, modulo tiny correction factors;

- Analysis performed on the recoil of a hadronically reconstructed B;
- We search for a lepton among the other particles in the event, and fit its momentum spectrum;
- Backgrounds constrained from off-resonance and same-flavor control sample;
- After correcting for the different e/μ selection efficiencies, we find:

Control sample: same flavor B's



Signal region: opposite flavor B's



$$\boxed{R(X_{e/\mu}) = 1.033 \pm 0.010\ (\mathrm{stat}) \pm 0.019\ (\mathrm{syst})}$$

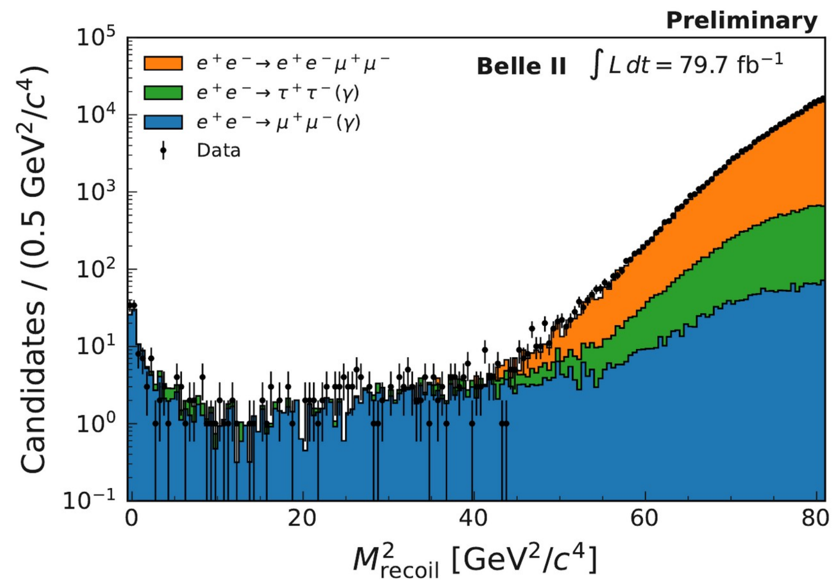
arXiv:2301.08266 [hep-ex]
submitted to PRL

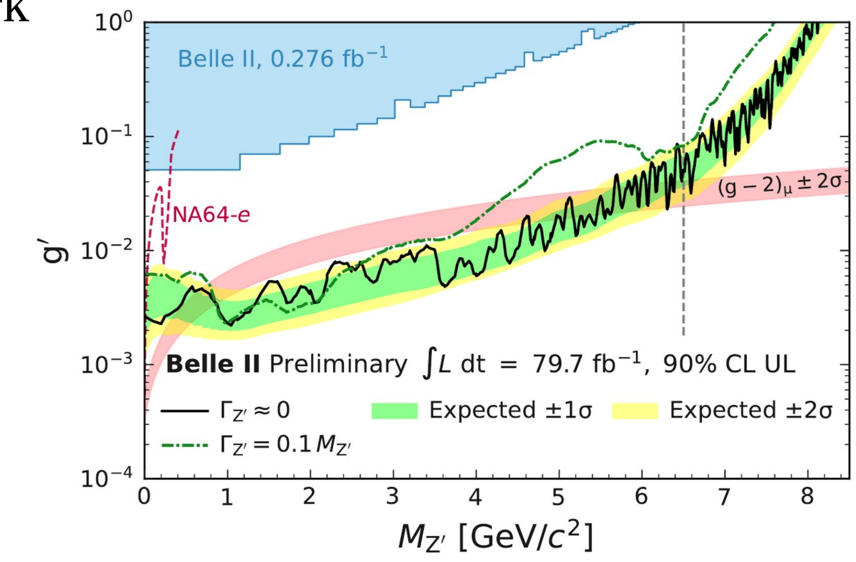
Dark Sector

Invisible Z’ in $e^+e^- \to \mu^+\mu^- Z'$

- $L_\mu - L_\tau$ model: introducing a massive Z’ boson that couples only to 2nd and 3rd generation leptons;
- Could explain the $(g\text{-}2)_\mu$ and other anomalies;
- Z’ could decay to SM particles (neutrinos) or to invisible dark particles;
- We look for a bump in the square of the mass of the system recoiling against the two muons;
- Backgrounds are suppressed using a neural network simultaneously optimized for all invariant masses;
- No significant signal is found and a large fraction of the “interesting” region for the $(g\text{-}2)_\mu$ anomaly is excluded.

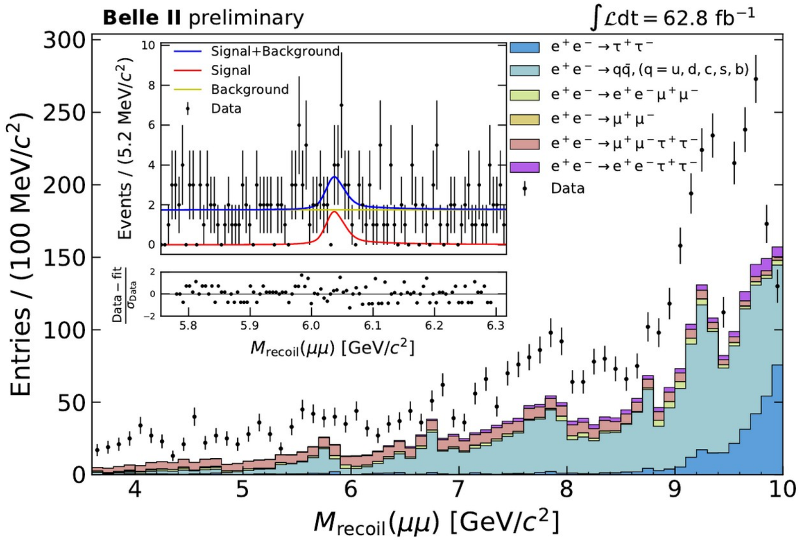
arXiv:2212.03066 [hep-ex]
submitted to PRL

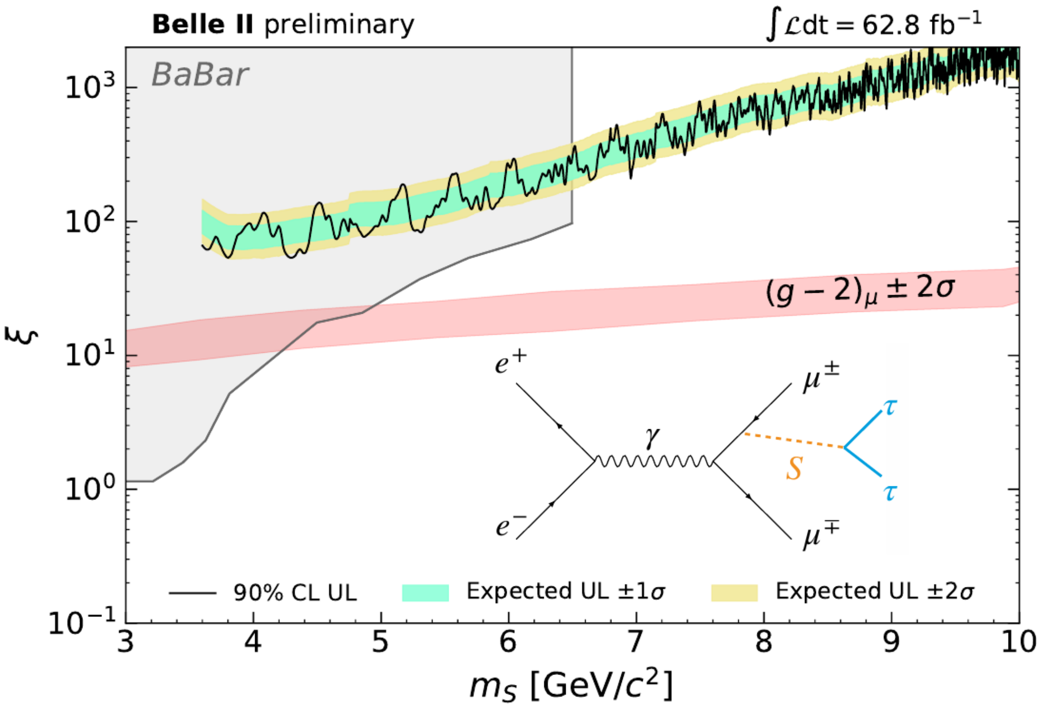




Search for a ττ resonance in ee → μμττ

- Searching for a bump in the invariant mass recoiling against the two muons;
- Using only 1-prong τ decays (the final state is 4 tracks + missing energy from the neutrinos);
- Backgrounds are suppressed using a neural network utilizing 14 input variables, related to the event kinematics;
- (non-peaking) backgrounds are estimated from the data, swapping μ's with π's;
- We can test a variety of models, including $L_\mu - L_\tau$ Z' and a leptophilic scalar S;
- We obtain the leading exclusions for S above 6.5 GeV.

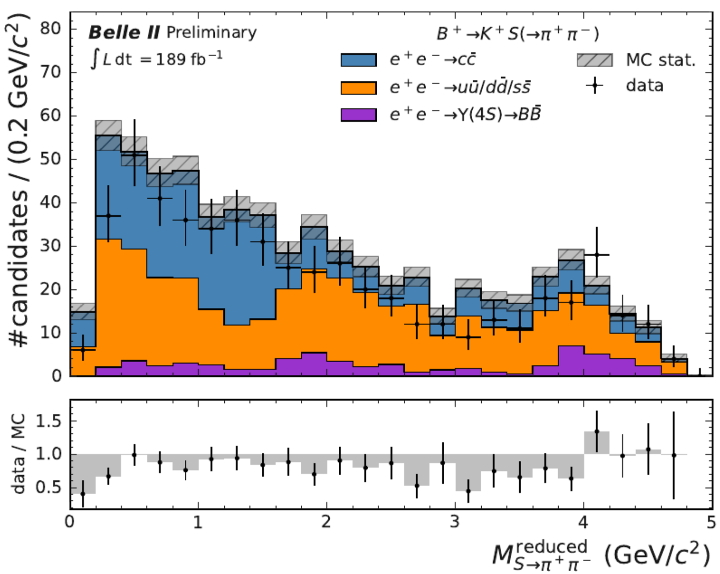


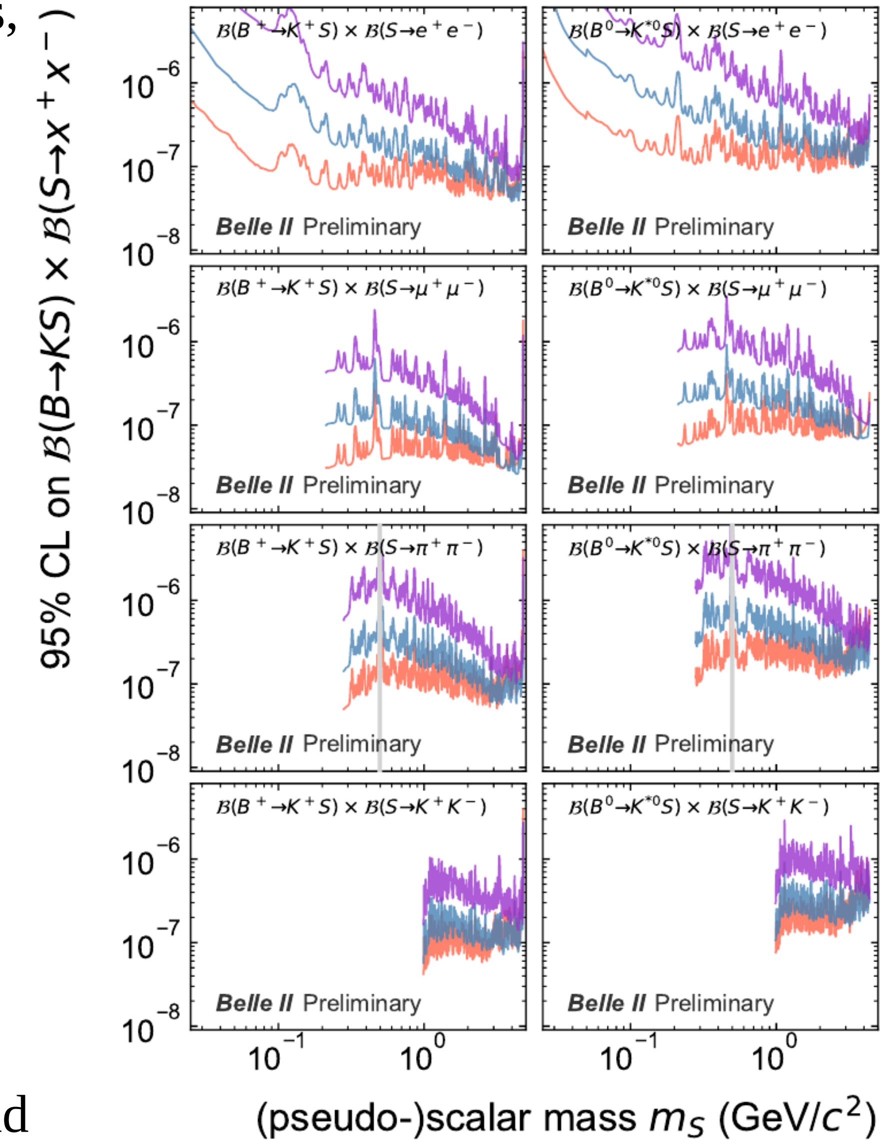


To be submitted to PRL

Long lived scalar in b → s transitions

- We search for $B^+ \to K^+S$, $B^0 \to K^{*0}[K^+\pi^-]$ S events, with $S \to ee, \mu\mu, \pi\pi, KK$;
- Veto on K_S mass window, and tight displacement requirements for known resonances;
- Efficiency corrections derived from K_S sample;
- Looking for bumps in the M_S invariant mass:





- First limits for long-lived particled decaying to had

To be submitted to PRL

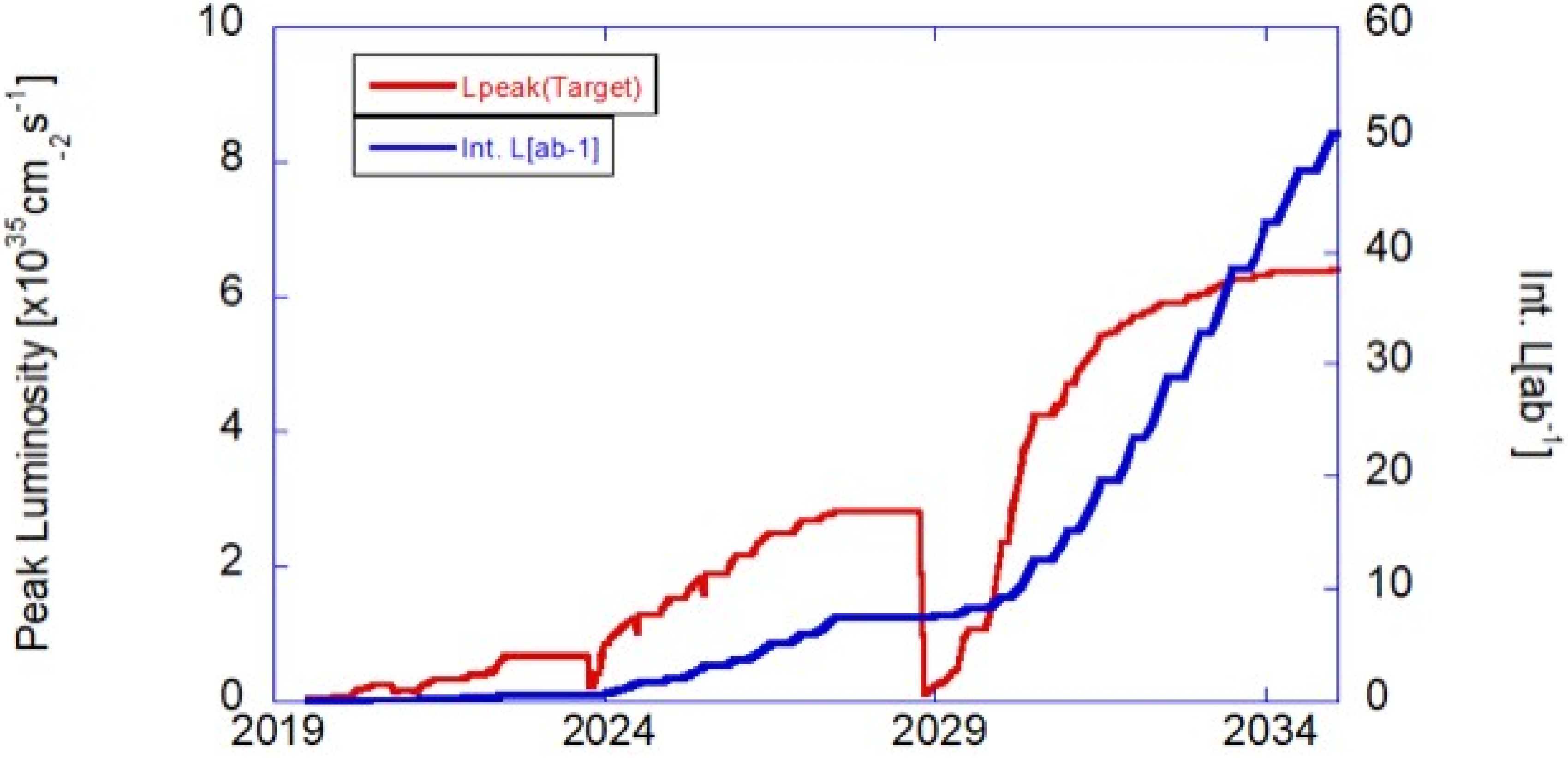
Conclusions

- Belle II has yet to surpass BaBar and Belle in terms of integrated luminosity;
- Despite this, we can already produce results that are competitive with them and the World averages;
- The detector is well understood and many analysis groups are busy analyzing the data;
- More results on this data set (and on Belle + Belle II) will come, and we expect Belle II to lead the field in many areas very soon!

- For more results and prospects, please see the talks by my colleagues this afternoon.

Backup slides

Luminosity scenario



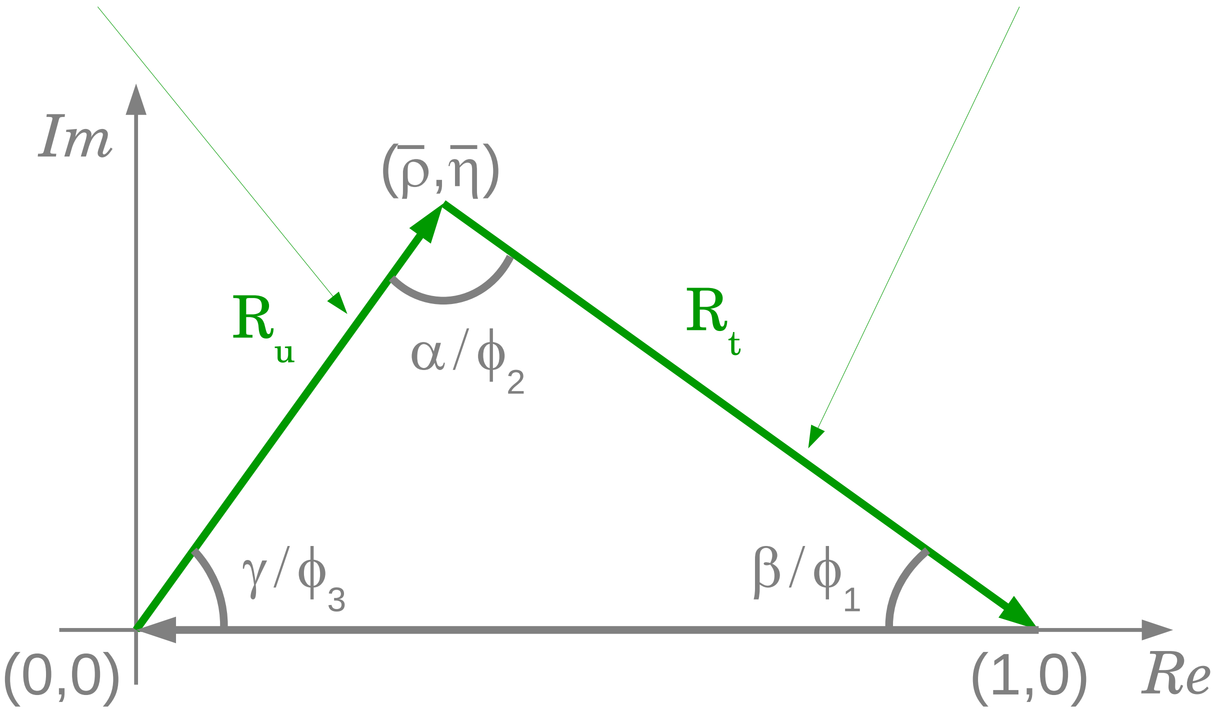
The sides of the UT

Current precision: ~5%

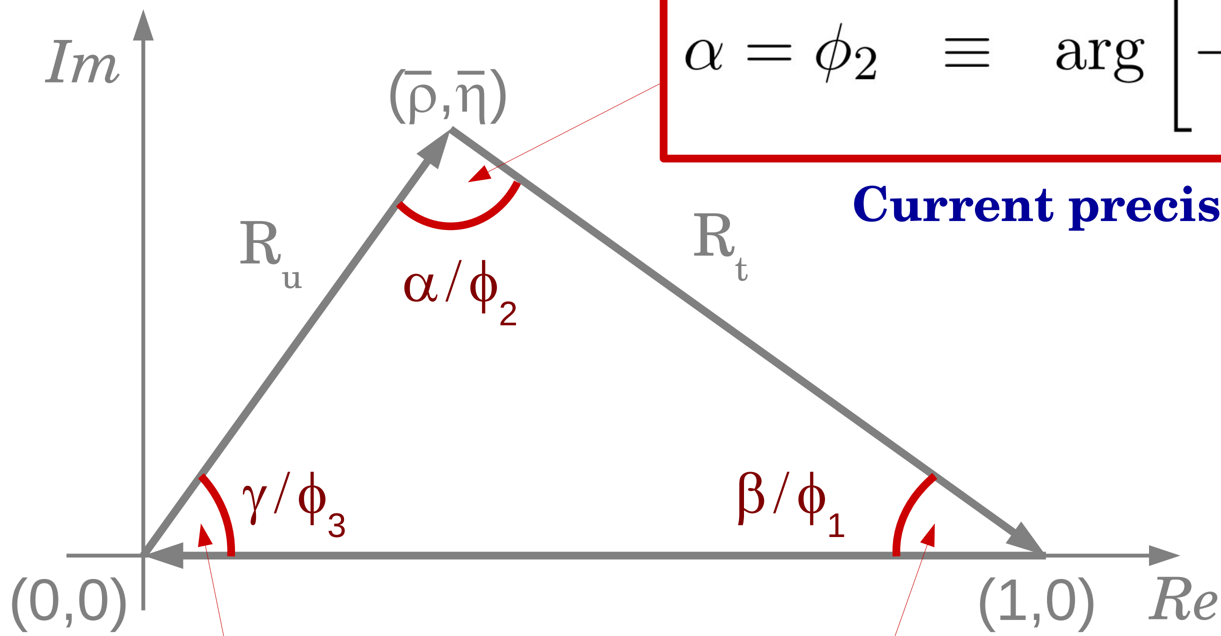
$$R_u \equiv \left| \frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right|$$

Current precision: ~1%

$$R_t \equiv \left| \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} \right|$$



The angles of the UT



$$\alpha = \phi_2 \quad \equiv \quad \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right]$$

Current precision: ~4.5º

$$\gamma = \phi_3 \quad \equiv \quad \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$

Current precision: ~3.5º

$$\beta = \phi_1 \quad \equiv \quad \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right]$$

Current precision: ~0.7º

ϕ_3 (γ) from GLS $B^\pm \to D h^\pm$

$$A_{SS}^{DK} \equiv \frac{N_{SS}^- - N_{SS}^+}{N_{SS}^- + N_{SS}^+},$$

$$A_{OS}^{DK} \equiv \frac{N_{OS}^- - N_{OS}^+}{N_{OS}^- + N_{OS}^+},$$

Physics meanings

$$A_{SS}^{DK} = \frac{2r_B r_D \kappa \sin(\delta_B - \delta_D)\sin\phi_3}{1 + r_B^2 r_D^2 + 2r_B r_D \kappa \cos(\delta_B - \delta_D)\cos\phi_3},$$

$$A_{OS}^{DK} = \frac{2r_B r_D \kappa \sin(\delta_B + \delta_D)\sin\phi_3}{r_B^2 + r_D^2 + 2r_B r_D \kappa \cos(\delta_B + \delta_D)\cos\phi_3},$$

$$R_{SS}^{DK/D\pi} \equiv \frac{N_{SS}^- + N_{SS}^+}{N_{SS}'^- + N_{SS}'^+},$$

$$R_{OS}^{DK/D\pi} \equiv \frac{N_{OS}^- + N_{OS}^+}{N_{OS}'^- + N_{OS}'^+},$$

$$R_{SS/OS}^{D\pi} \equiv \frac{N_{SS}'^- + N_{SS}'^+}{N_{OS}'^- + N_{OS}'^+},$$

Physics meanings

$$R_{SS}^{DK/D\pi} = R\frac{1 + r_B^2 r_D^2 + 2r_B r_D \kappa \cos(\delta_B - \delta_D)\cos\phi_3}{1 + r_B'^2 r_D^2 + 2r_B' r_D \kappa \cos(\delta_B' - \delta_D)\cos\phi_3},$$

$$R_{OS}^{DK/D\pi} = R\frac{r_B^2 + r_D^2 + 2r_B r_D \kappa \cos(\delta_B + \delta_D)\cos\phi_3}{r_B'^2 + r_D^2 + 2r_B' r_D \kappa \cos(\delta_B' + \delta_D)\cos\phi_3},$$

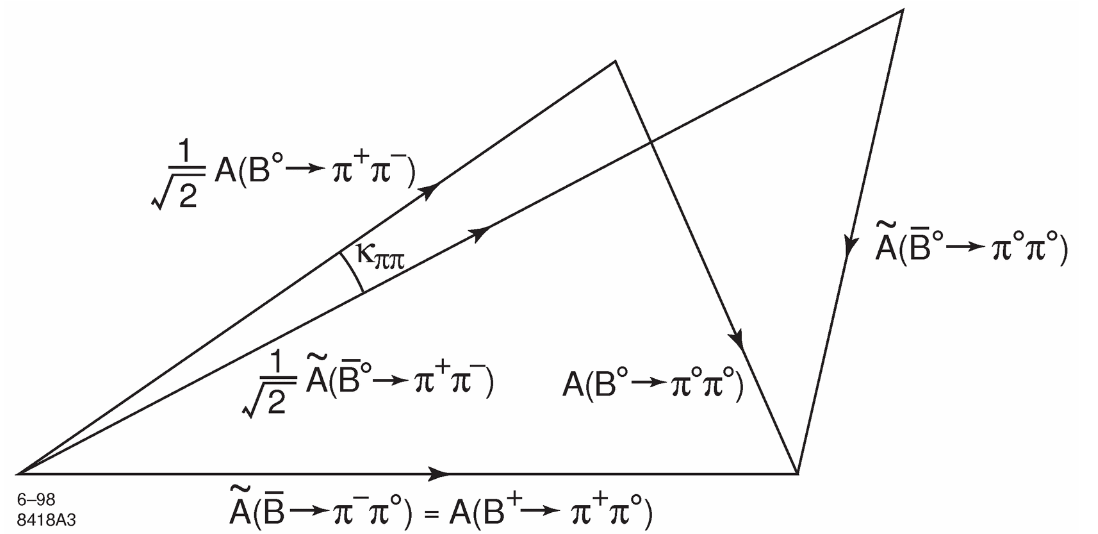
$$R_{SS/OS}^{D\pi} = \frac{1 + r_B'^2 r_D^2 + 2r_B' r_D \kappa \cos(\delta_B' - \delta_D)\cos\phi_3}{r_B'^2 + r_D^2 + 2r_B' r_D \kappa \cos(\delta_B' + \delta_D)\cos\phi_3},$$

Measurement of the ϕ_2 / α CKM angle

- The measurement of ϕ_2 from $B \to \pi\pi$ (or $B \to \rho\rho$) final states comes from an isospin analysis:

The following equalities hold:

$$\frac{1}{\sqrt{2}}A^{+-} + A^{00} = A^{+0}$$
$$\frac{1}{\sqrt{2}}\tilde{A}^{+-} + \tilde{A}^{00} = \tilde{A}^{+0}$$
$$A^{+0} = \tilde{A}^{+0}$$



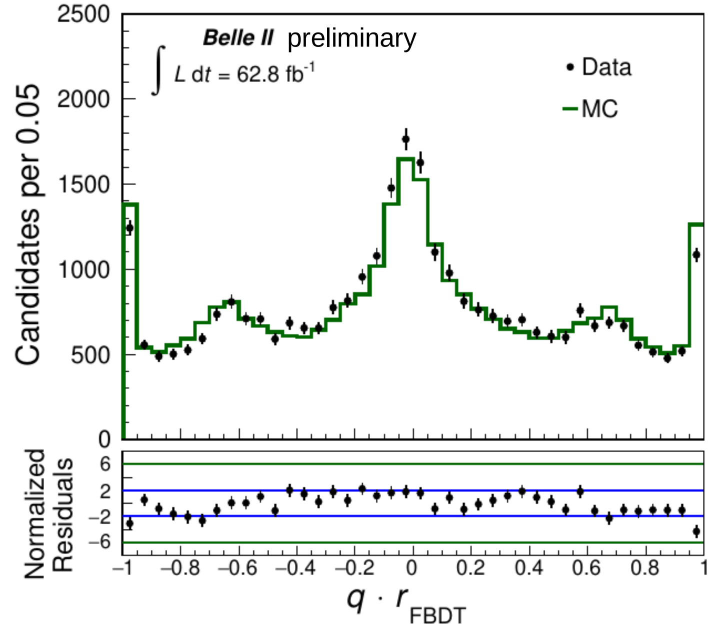
M. Gronau and D. London, PRL 65 (1990), 3381

- Observables (for e.g. $B \to \pi\pi$):
  - branching fractions of: $B^0 \to \pi^+\pi^0$, $\pi^+\pi^-$, $\pi^0\pi^0$;
  - direct (time-independent) CP asymmetries: C^{+-}, C^{00};
  - time-dependent CP asymmetries: S^{+-}, S^{00}.
- Belle II will be able to measure all these observables;
- We expect to push the sensitivity to α to ~1°.

B Flavor Tagger

- The B Flavor Tagger is a crucial tool for time-dependent CP violation analyses;
- The new Belle II Flavor Tagger makes extensive use of multivariate discriminators;
- The flavor (B or $\overline{B}$) of the unreconstructed B in the event is determined by combining information from:
  - charged leptons;
  - charged kaons and pions;
  - presence of K_S, Λ^0, … ;

Eur. Phys. J 82, 283 (2022)



Effective FT efficiency:

$$Q = \varepsilon(1-2w)^2$$

Q(Belle II) = (30.0 ± 1.2 ± 0.4)%

Q(Belle) = (30.1 ± 0.4)%

Q(Belle II MC) = ~37%