Present and future CKM studies from B physics at e^+e^- colliders

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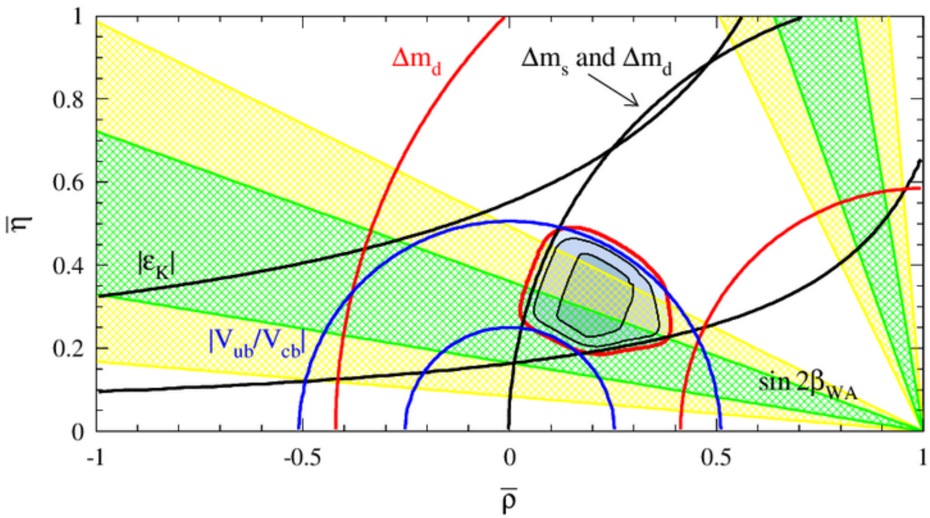
on behalf of the Belle II Collaboration

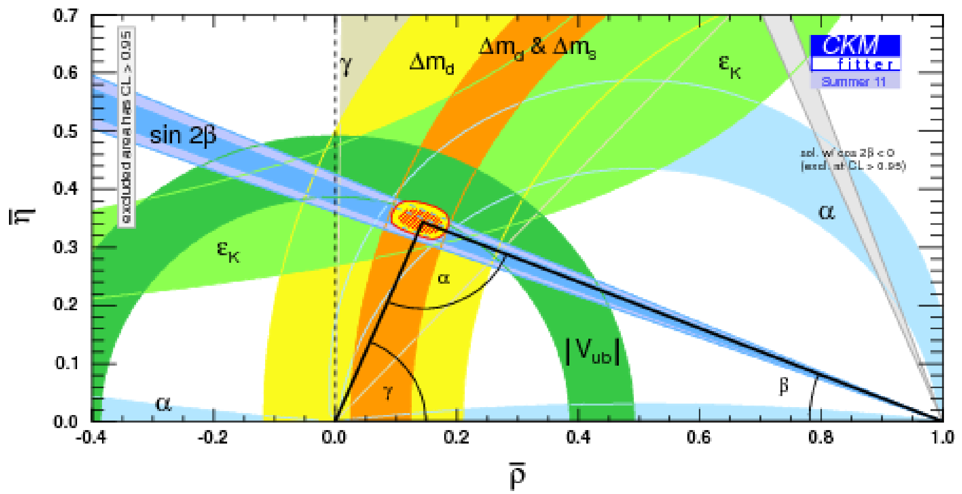
"11th International Workshop on the CKM Unitarity Triangle"
Melbourne (+ virtual), November 22nd 2021

The legacy from the B Factories

State of the art of the CKM UT fit (contributions from LEP, Tevatron, K experiments, …):



Spring 2001 (pre sin2β from B Factories)

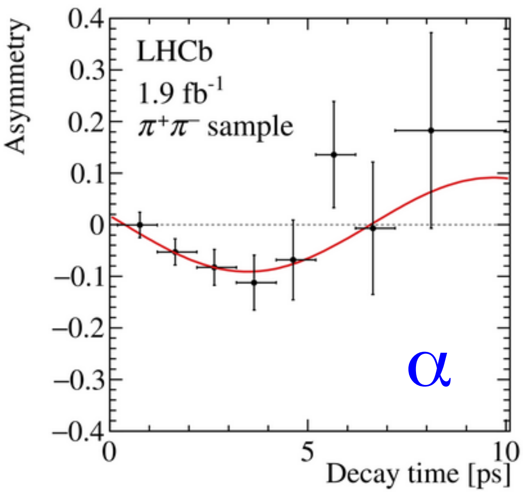


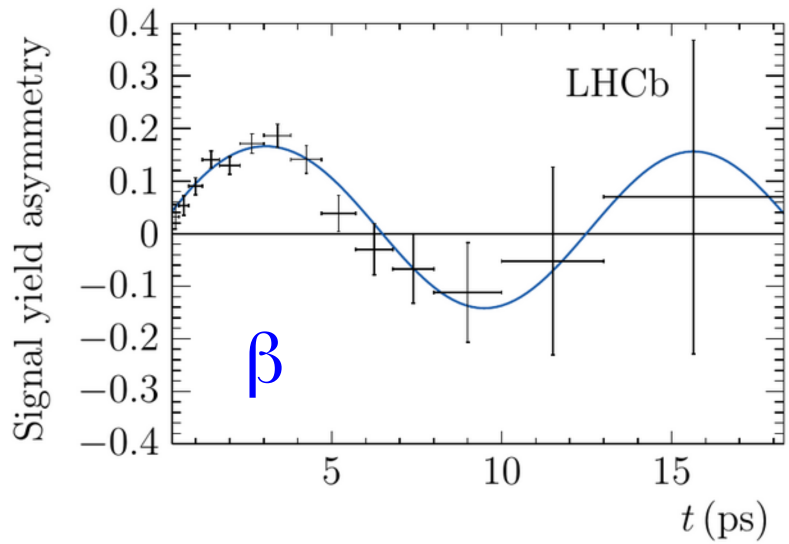
Summer 2011 (pre LHCb)

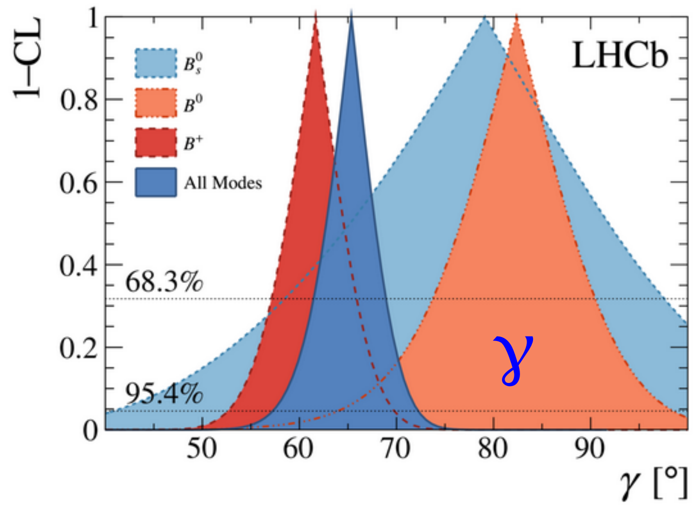
Tremendous progress from the B-Factory experiments (BaBar and Belle) in one decade of Flavor Physics:

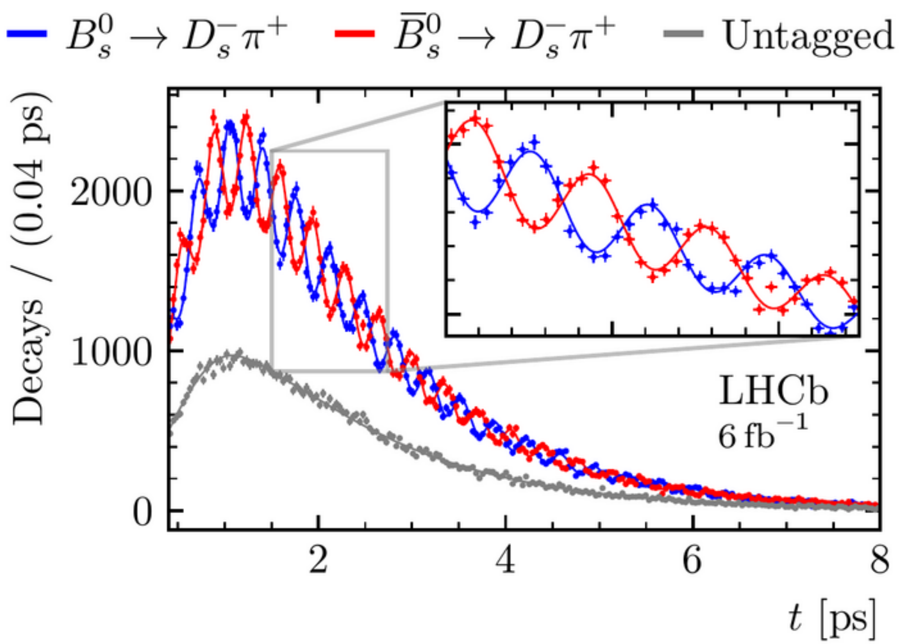
- discovery of CP violation in B mesons;
- measurements of all UT angles, improvement on the knowledge of its sides;
- spectacular confirmation of the CKM paradigm.

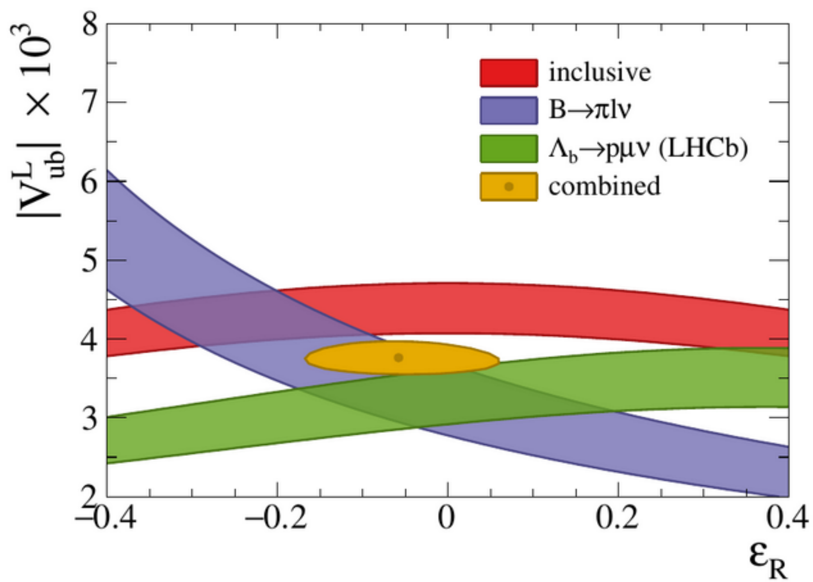
Strong competition from LHCb











Why pursuing the e^+e^- approach

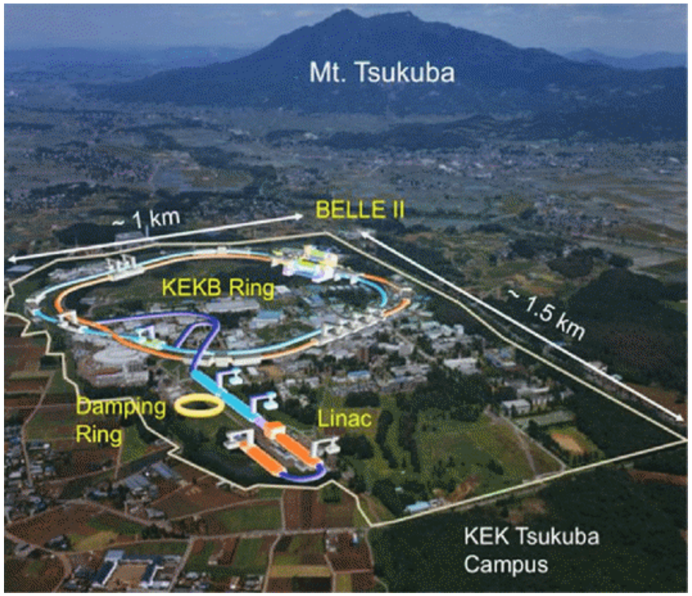
- Is it worth continuing on the e^+e^- path?

- Competition on final states containing only charged particles and/or where vertexing can be exploited to suppress backgrounds is hopeless;
- Still, many of the interesting modes are unique to B Factories:
  - ➔ channels with π^0, K_L, $\eta^{(\prime)}$, … ;
  - ➔ final states with one or more ν's;
  - ➔ modes affected by "difficult" backgrounds, where the full knowledge of the kinematics in the event is the only way to control them;

- In general: a wider spectrum of measurements allows for a better understanding (or highlights our lack of…);

- And of course, there is not only CKM Physics!

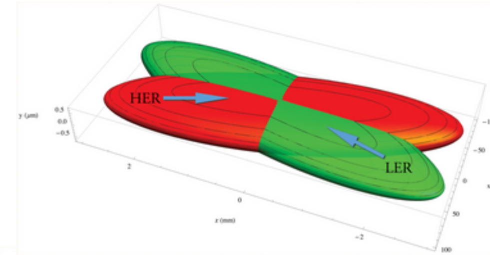
The SuperKEKB Collider

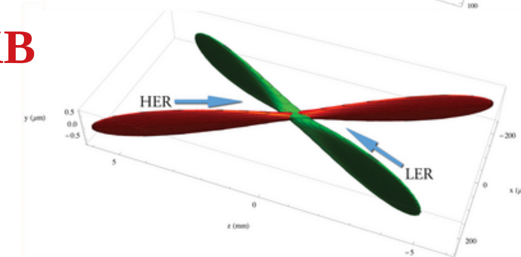


KEKB

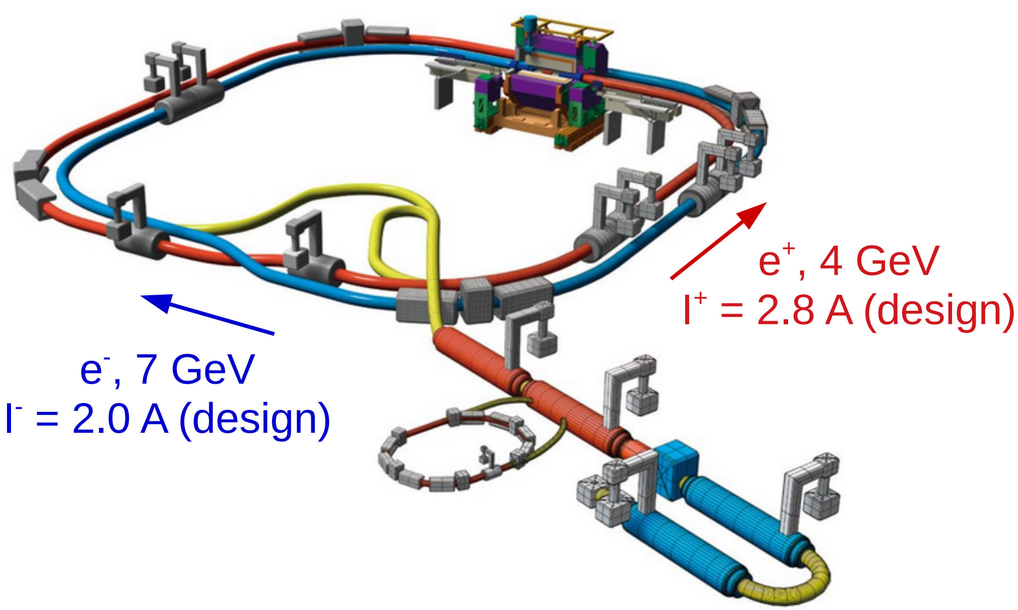
↓

SuperKEKB





$$\boxed{L = \frac{N_+ N_- n_b f_0}{4\pi \sigma^*_{x,\mathrm{eff}} \sqrt{\varepsilon_y \beta^*_y}}}$$



Improvements over KEKB:

x20 by ‘nanobeam scheme’;

x1.5 by increasing beam currents.

Goals:

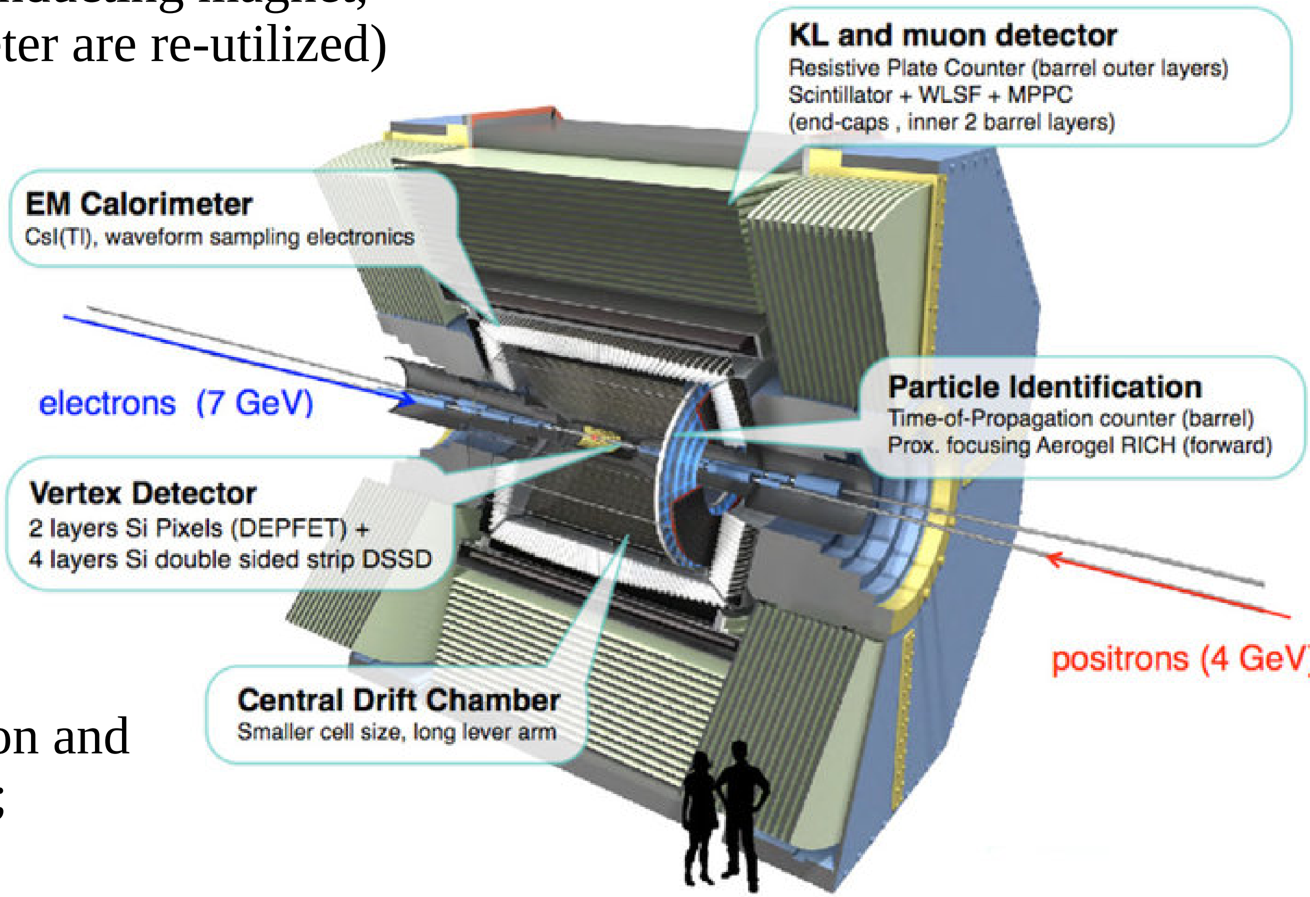
Instantaneous lumi: ~6 x 10^{35} cm^{-2}s^{-1}

Integrated lumi: 50 ab^{-1}

The Belle II Detector

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

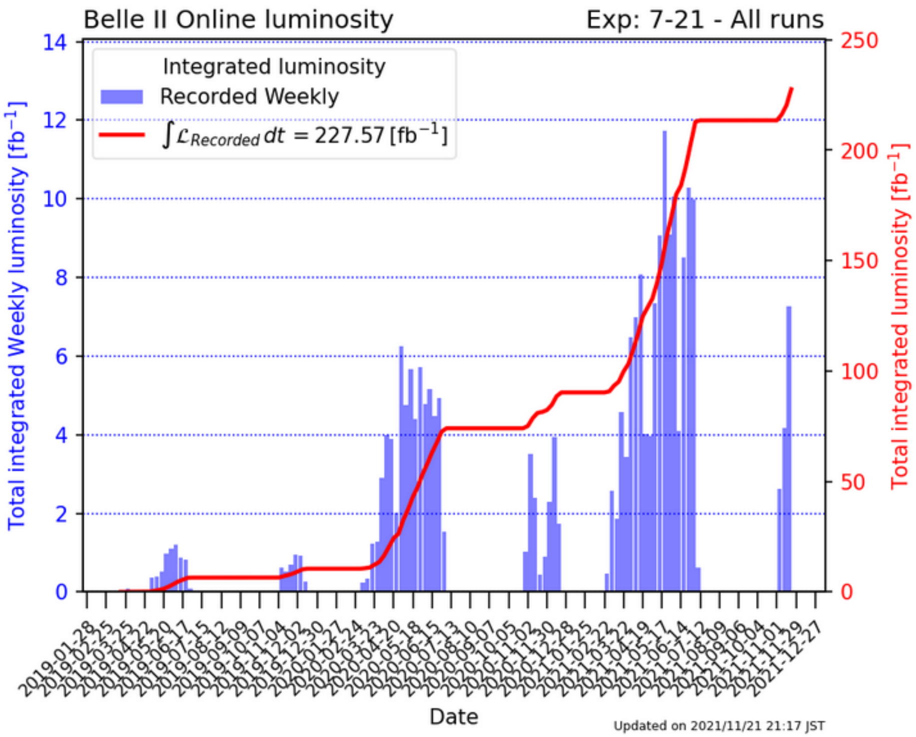
(only the structure, the superconducting magnet, and the crystals of the calorimeter are re-utilized)

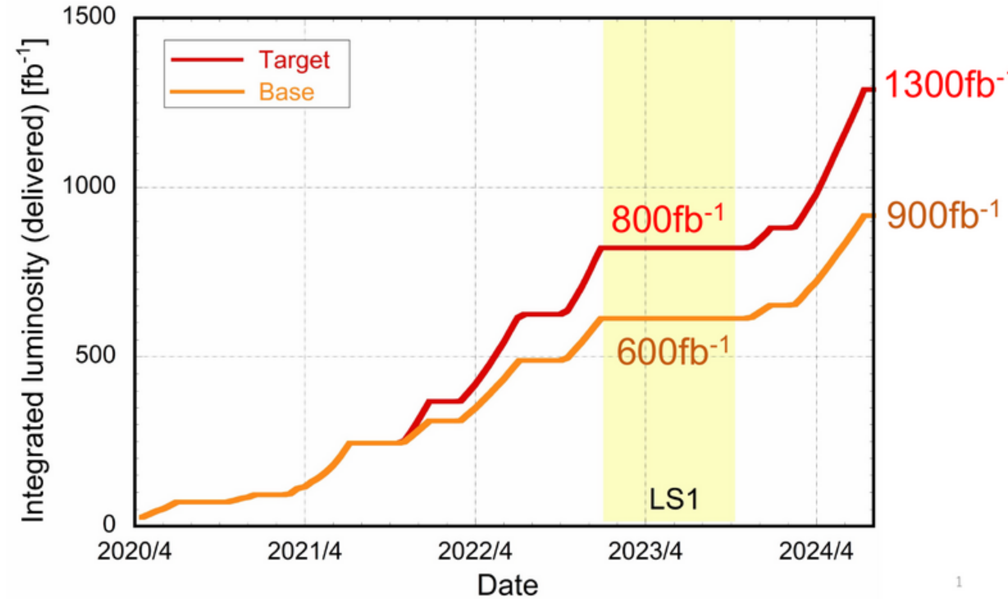


Upgrade highlights:

- 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.

Data taking, status and plans





- Extraordinary effort from local people, who kept the ball rolling during COVID19 times;
- Record instantaneous luminosity: 3.12×10^{34} cm^{-2} s^{-1};
- Now running for the first time above the Y(4S), at ~10.75 GeV.

- Still a long way to go, before reaching 50 ab^{-1}!
- In 2023 we will have a ~9 months long shutdown to replace the (incomplete) pixel vertex detector;
- A second shutdown will probably take place after 2026.

So far, we produced physics results using up to ~128 fb^{-1}

Outline

- In the following, I will cover results (actual or expected) relevant to the:
  - CKM UT sides;
  - CKM UT angles;

- Particular emphasis will be put on those measurements in which Belle (II) has unique sensitivity;

- Only a cursory overview will be given: for more details and discussion, please attend also:
  - N. Rout, “First results of $B \rightarrow DK$ at Belle II” (Monday, WG5)
  - T. Humair, “Mixing and mixing related CPV in B system” (Tuesday, WG4)
  - S. Hazra, “Charmless B decay measurements at Belle II” (Wednesday, WG5)
  - N. Toutounji, “Belle II new results on B semileptonic decays (Thursday, WG2)

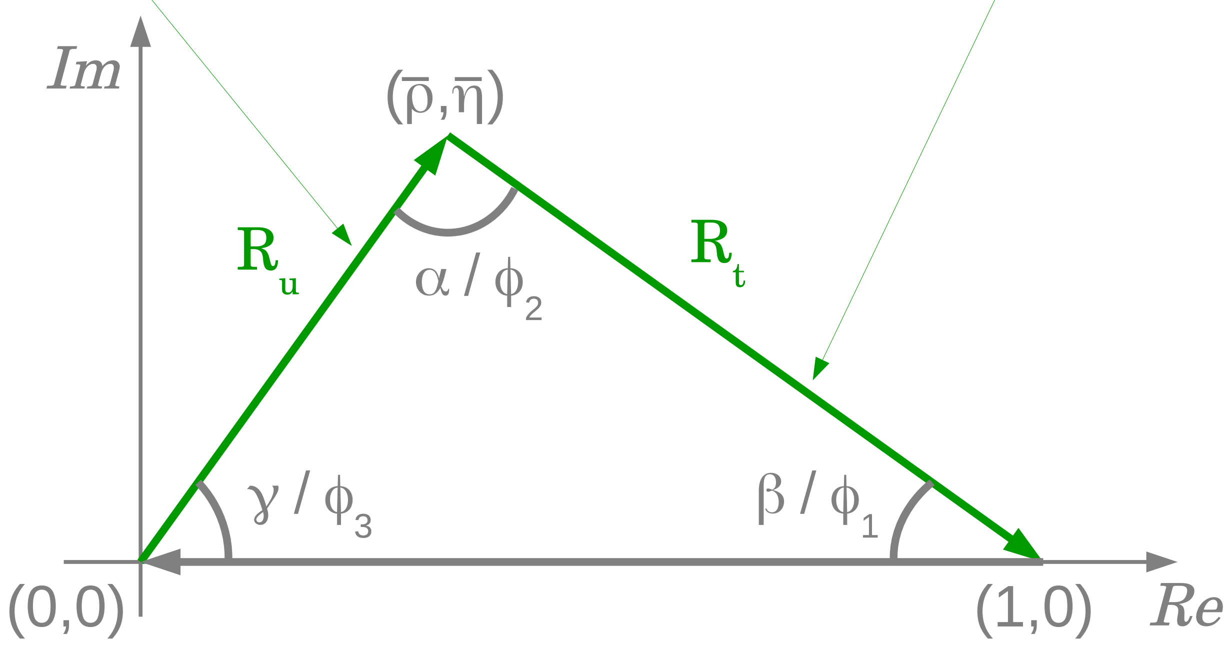
The sides of the UT

Current precision: ~5%

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

Current precision: ~1%

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



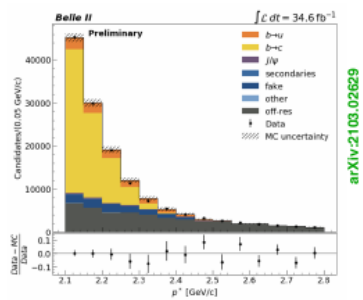
$|V_{ub}|$ and $|V_{cb}|$ at Belle (II)

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

M.Merola: Towards first Vub and Vcb measurements at the Belle II experiment

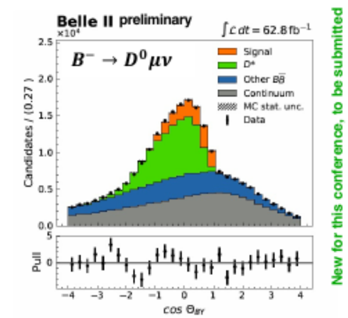
- A large variety of different analysis strategies will help to resolve the remaining discrepancies
- Alternative approaches, such as the recently proposed use of inclusive q^2-moments, are expected to further enhance sensitivity to V_{cb}

Untagged inclusive $X_u \ell \nu$



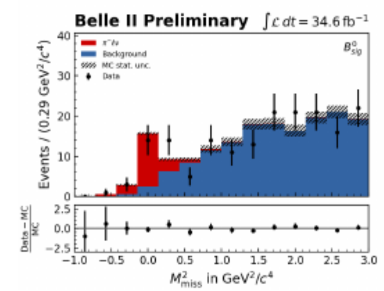
3σ significance for b-u

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



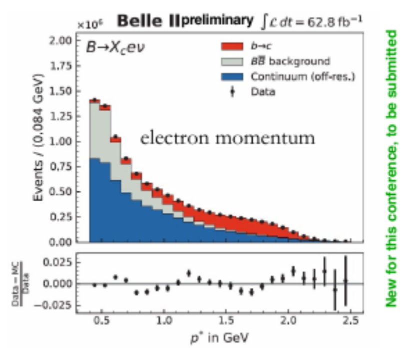
$\mathcal{B}(B^- \to D^0 \ell^- \bar{\nu}_l) = (2.293 \pm 0.053_{\text{stat}} \pm 0.084_{\text{syst}})\%$

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



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

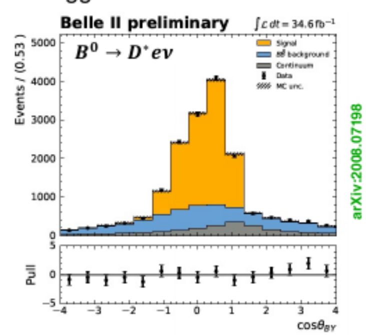
Untagged inclusive $X_c \ell \nu$



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

Lepton momentum p* in the CMS

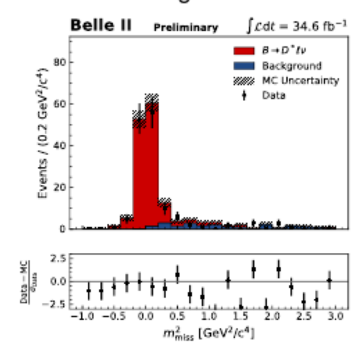
Untagged exclusive $B^0 \to D^* \ell \nu$



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

θ_{BY} angle between B and $D\ell$ system

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



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

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

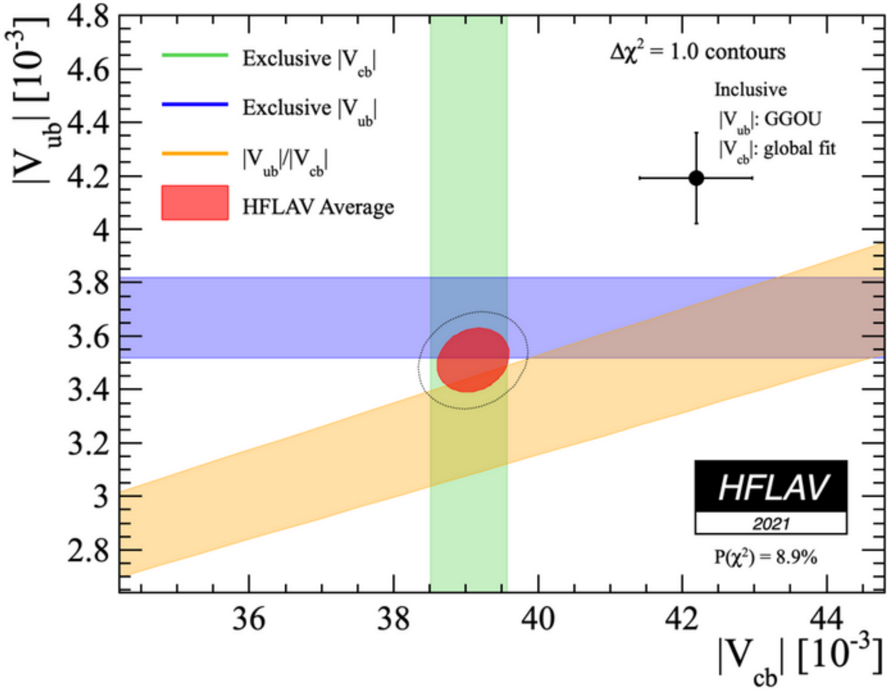
EPS-HEP 2021: Belle II Highlights and Flavour Physics in e+e- 13

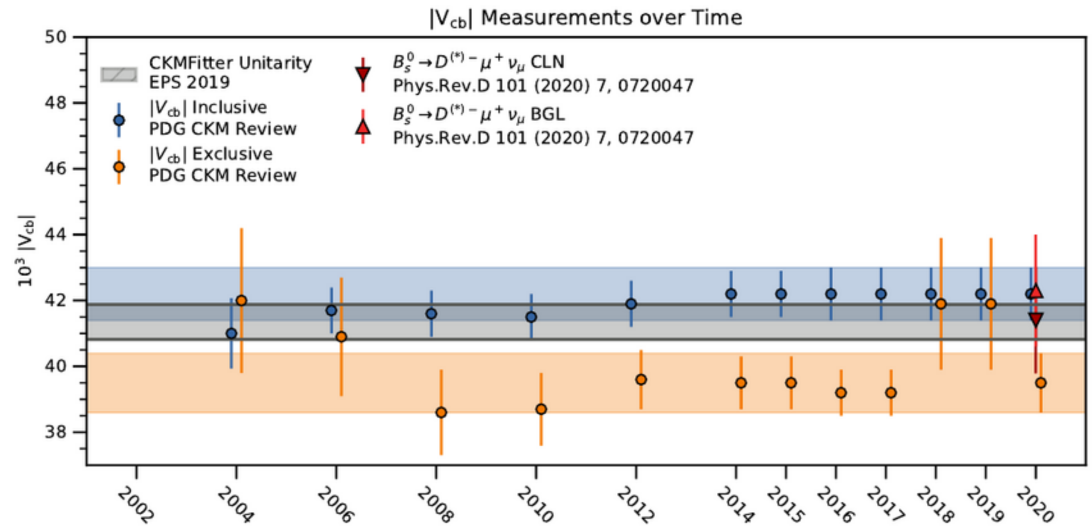
carsten.niebuhr@desy.de

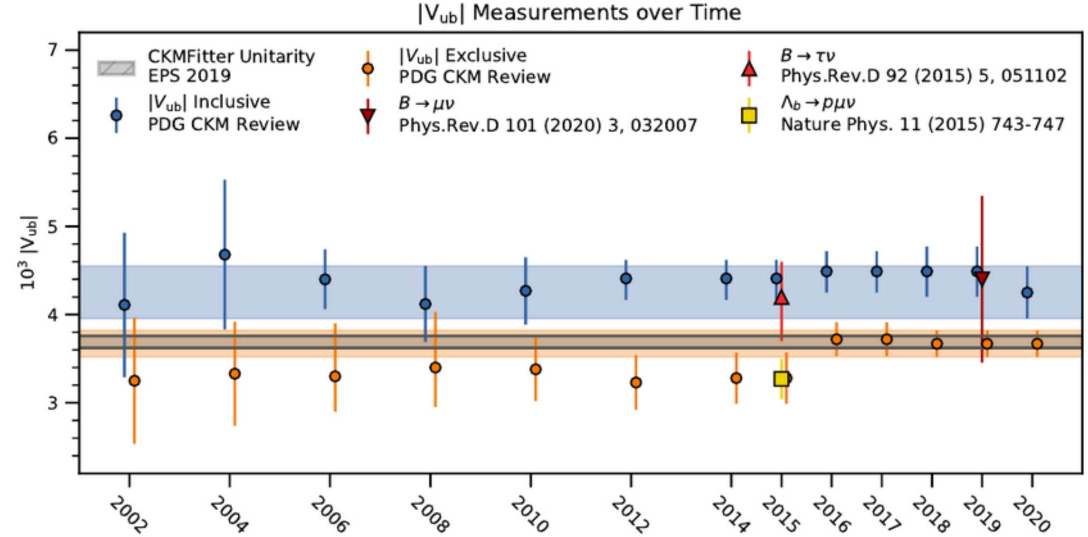
M. Merola / C. Niebuhr, EPS 2021

Inclusive vs exclusive V_{xb}

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







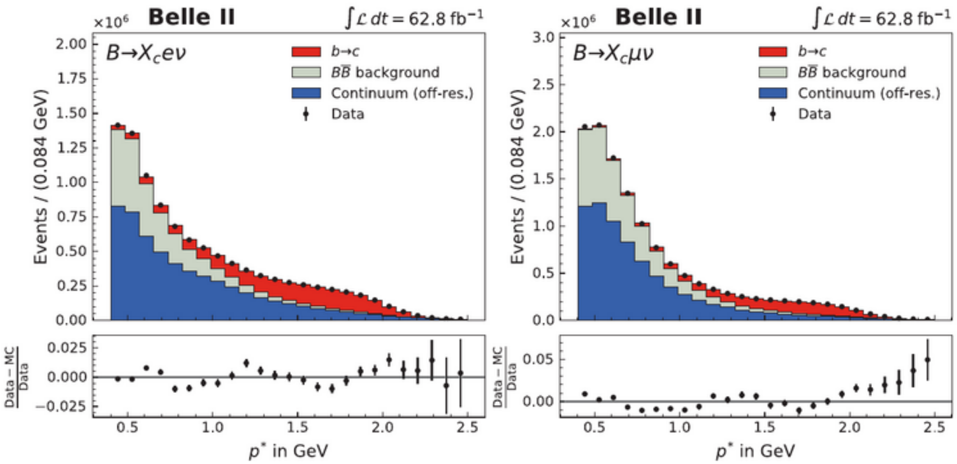
We need to attack the problem from as many sides as possible!

M. Bauer, HQL 2021

Inclusive and exclusive $B \to X_c \, l \, \nu$

arXiv: 2111.09405 [hep-ex]

Inclusive $B \to X_c \, l \, \nu$:



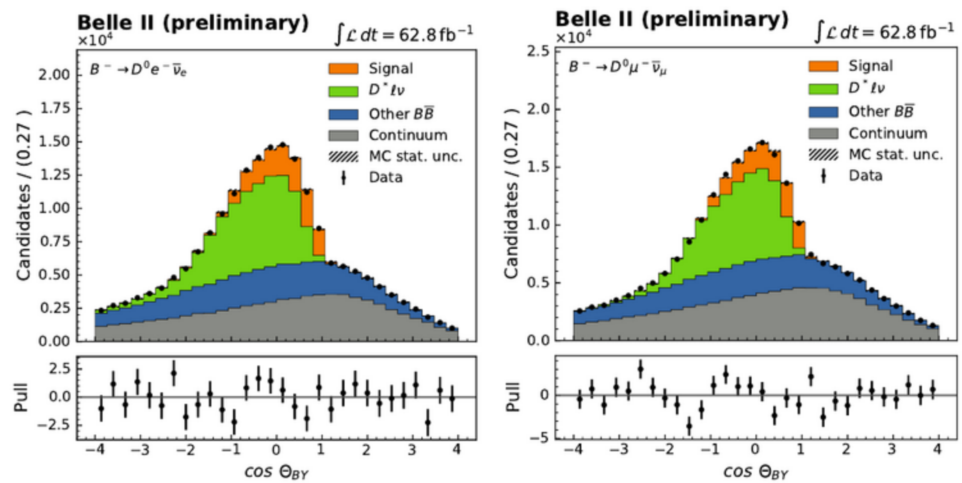
$$\mathcal{B}(B \to X_c e \nu_e) = (9.97 \pm 0.03(\text{stat}) \pm 0.38(\text{sys}))\%$$
$$\mathcal{B}(B \to X_c \mu \nu_\mu) = (9.47 \pm 0.05(\text{stat}) \pm 0.45(\text{sys}))\%$$

Good description of our data.
Dominant systematics from continuum modeling, lepton ID, and signal shape.

arXiv: 2110.02648 [hep-ex]

Branching ratio of $B^- \to D^0 l^- \nu$:

$$\cos\theta_{BY} = \frac{2\,E_B^* E_Y^* - m_B^2 - m_Y^2}{2|p_B^*||p_Y^*|}$$



$$\mathcal{B}(B^- \to D^0 e^- \bar{\nu}_e) = (2.34 \pm 0.08_{\text{stat}} \pm 0.07_{\text{syst}})\%$$
$$\mathcal{B}(B^- \to D^0 \mu^- \bar{\nu}_\mu) = (2.24 \pm 0.08_{\text{stat}} \pm 0.08_{\text{syst}})\%$$

No evidence of Lepton Flavor Universality violation here, but we will want to push on the precision of this test, with more data and a better understood detector!

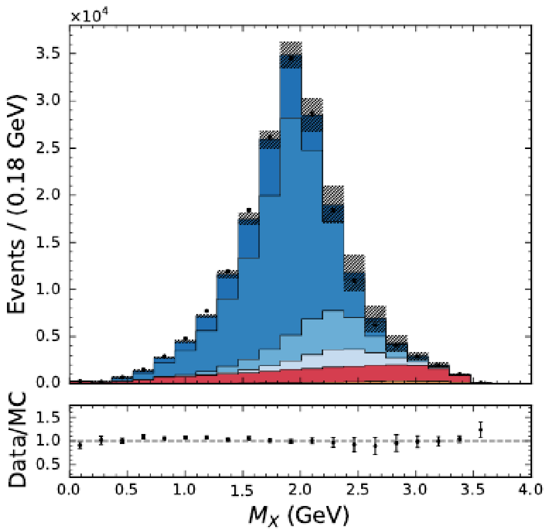
$|V_{cb}|$ from q^2 moments

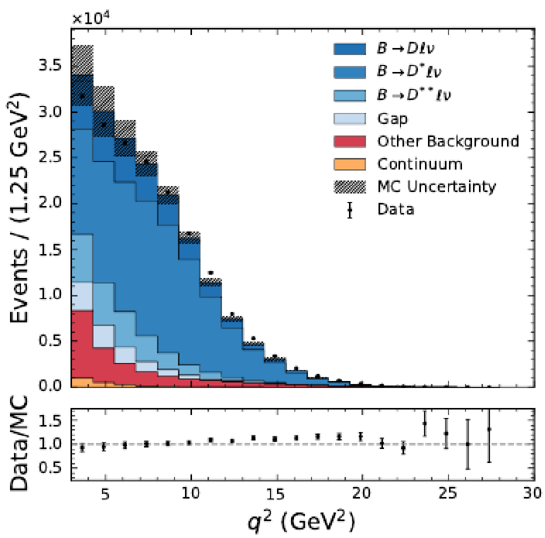
Measurement of the q^2 moments, that allows the extraction of $|V_{cb}|$, utilizing the method proposed in JHEP 02 (2019) 177:

Belle, full data set (711 fb^{-1}):
arXiv: 2109.01685 [hep-ex]
submitted to Phys. Rev. D

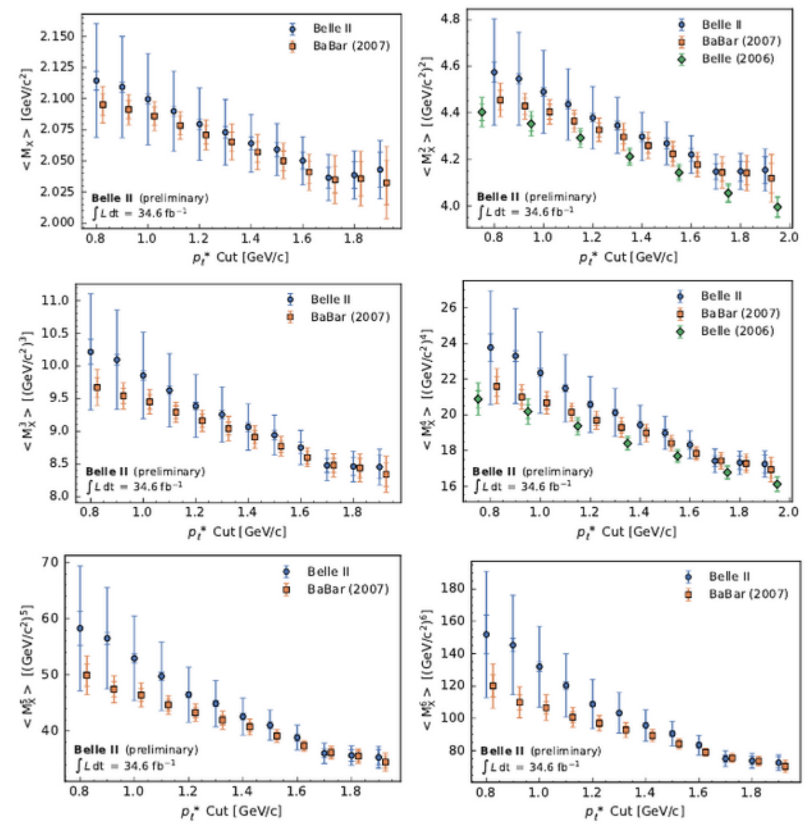
Analysis performed on the recoil of a fully reconstructed B meson: exploiting the clean environment of the e^+e^- collider!

The measured moments will serve as input for a new $|V_{cb}|$ determination.





Belle II: arXiv: 2009.04493 [hep-ex]



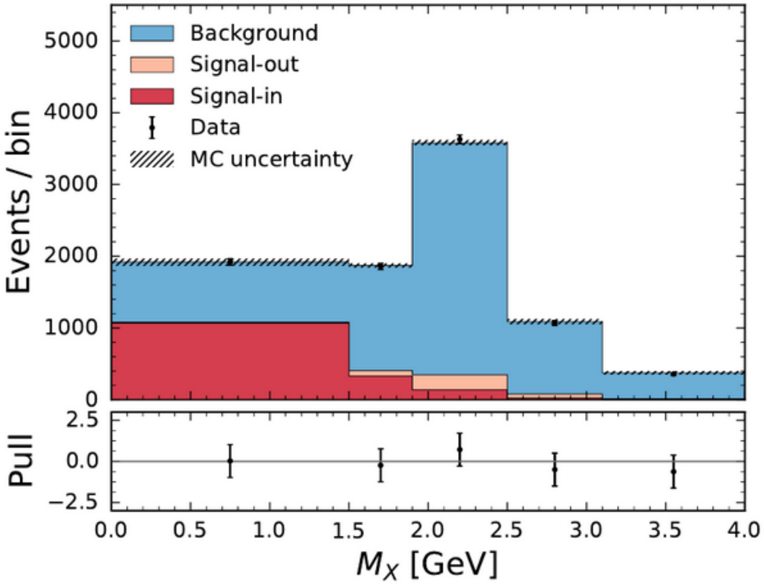
Soon Belle II will submit for publication results based on ~63 fb^{-1}

Exclusive $|V_{ub}|$ @ Belle

Phys. Rev. D104, 012008 (2021)

Inclusive $B \to X_u l \nu$:

The $B \to X_c l \nu$ background is strongly suppressed with the use of a BDT



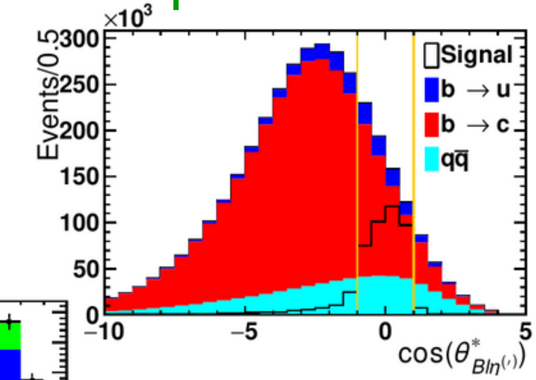
$$\Delta\mathcal{B}(B \to X_u \ell^+ \nu_\ell) = (1.09 \pm 0.05 \pm 0.08) \times 10^{-3}$$

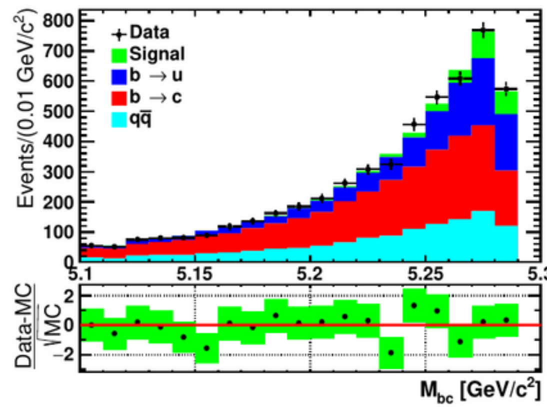
$$|V_{ub}| = (4.10 \pm 0.09 \pm 0.22 \pm 0.15) \times 10^{-3}$$

arXiv: 2104.13354 [hep-ex], submitted to Phys. Rev. D

Branching ratios of $B^- \to \eta^{(\prime)} l^- \nu$:

No reconstruction of the tag side B, to keep signal efficiency high





(a) $M_{\rm bc}(\eta \to \gamma\gamma)$

No restriction on the q^2 range, to reduce model uncertainty

$$\mathcal{B}(B^+ \to \eta \ell^+ \nu_\ell) = (2.83 \pm 0.55_{\rm (stat.)} \pm 0.34_{\rm (syst.)}) \times 10^{-5}$$

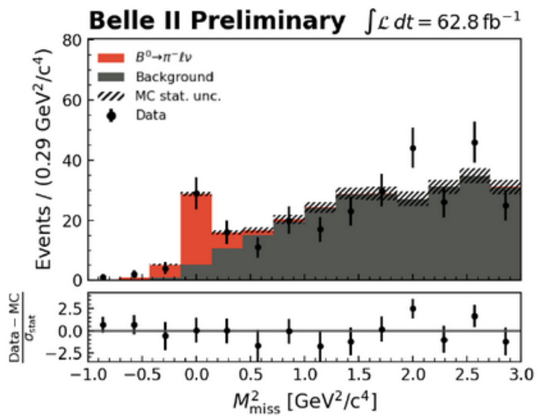
$$\mathcal{B}(B^+ \to \eta' \ell^+ \nu_\ell) = (2.79 \pm 1.29_{\rm (stat.)} \pm 0.30_{\rm (syst.)}) \times 10^{-5}$$

Exclusive $|V_{ub}|$ @ Belle II

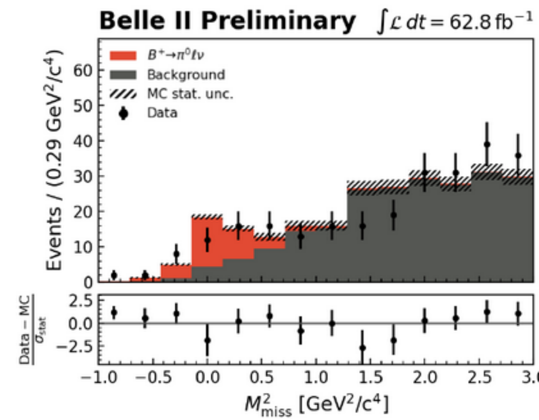
"Golden modes" for $|V_{ub}|$, measured on the recoil of fully reconstructed B mesons:

arXiv: 2111.00710 [hep-ex]

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.47 \pm 0.29(\text{stat}) \pm 0.05(\text{syst})) \times 10^{-4}$$

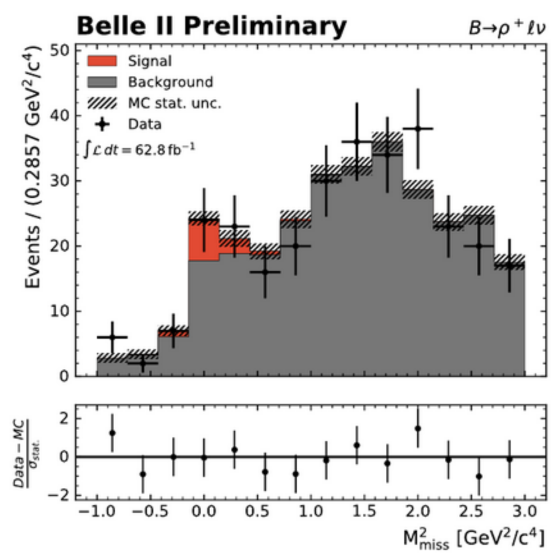


$$\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu_\ell) = (8.29 \pm 1.99(\text{stat}) \pm 0.46(\text{syst})) \times 10^{-5}$$



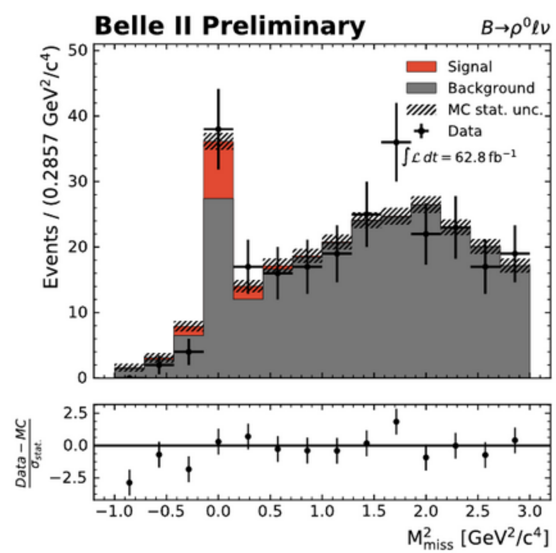
$$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu_\ell) < 3.37 \times 10^{-4}$$

(signal significance 1.4σ)



$$\mathcal{B}(B^+ \to \rho^0 \ell^+ \nu_\ell) < 19.7 \times 10^{-5}$$

(signal significance 1.5σ)



R_u outlook

- Thanks to the progress of Lattice QCD, we can aim at < 2% uncertainty on $|V_{ub}|$:

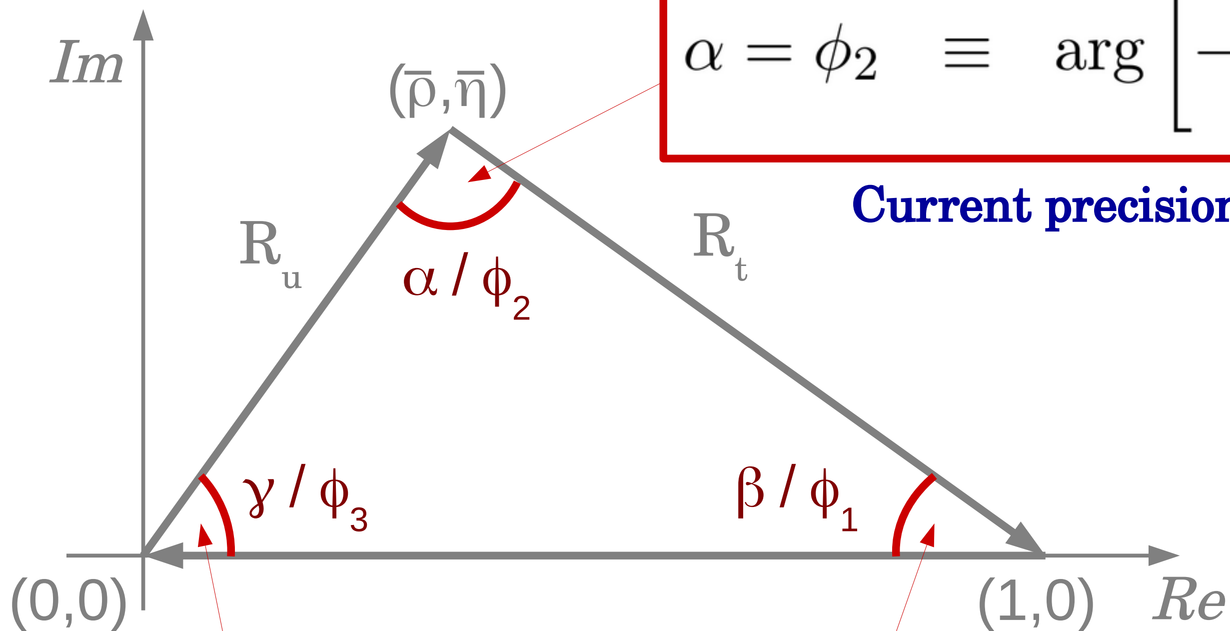
	Belle	**Belle II 5 ab^{-1}**	**Belle II 50 ab^{-1}**
$\lvert V_{ub}\rvert$ exclusive (tagged)	$(3.8 \oplus 7.0)\%$	$(1.8 \oplus 1.7)\%$	$(1.2 \oplus 0.9)\%$
$\lvert V_{ub}\rvert$ exclusive (untagged)	$(2.7 \oplus 7.0)\%$	$(1.2 \oplus 1.7)\%$	$(0.9 \oplus 0.9)\%$
$\lvert V_{ub}\rvert$ inclusive	$(6.0 \oplus 2.5\text{-}4.5)\%$	$(2.3 \oplus 2.5\text{-}4.5)\%$	$(1.7 \oplus 2.5\text{-}4.5)\%$

Belle II Physics Book, E. Kou et al., PTEP (2019)

- Key factors:
  - keep backgrounds under control;
  - perform measurements on the widest possible regions of the phase space, to minimize theory error;
  - measure many channels, with different techniques, check for patterns;
  - try new ideas...

- Collaboration with theorists will be crucial!

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: ~4.5°

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

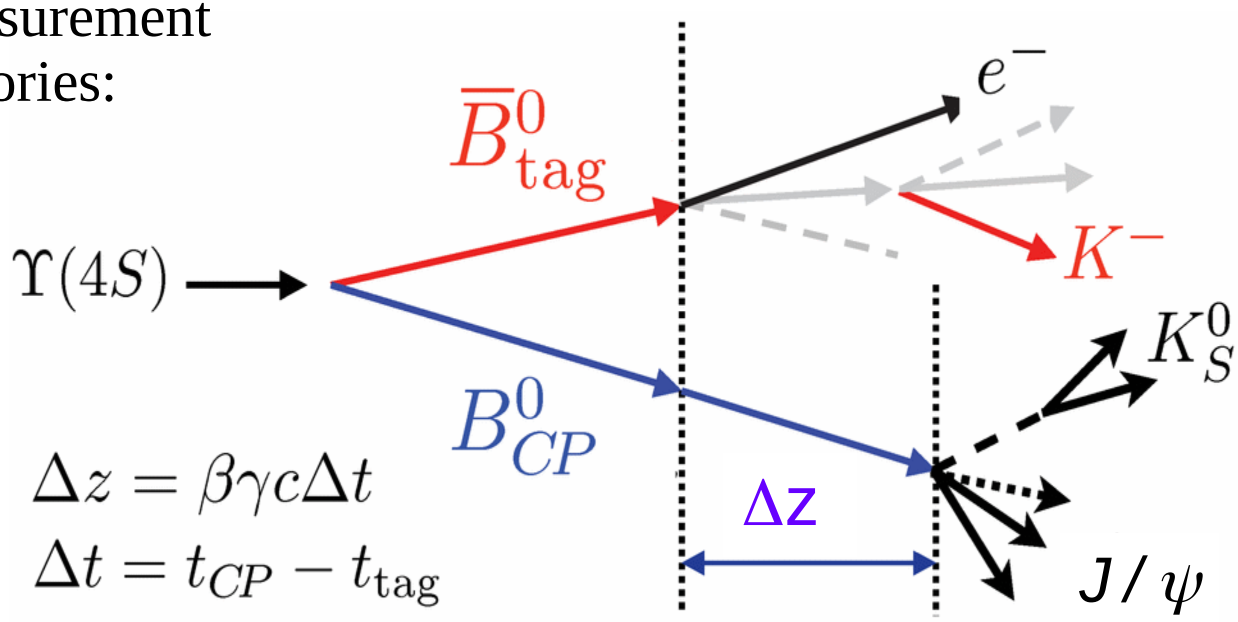
Current precision: ~3.5°

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

Current precision: ~0.7°

Time dependent CPV in B decays

- Flagship measurement of the B Factories:



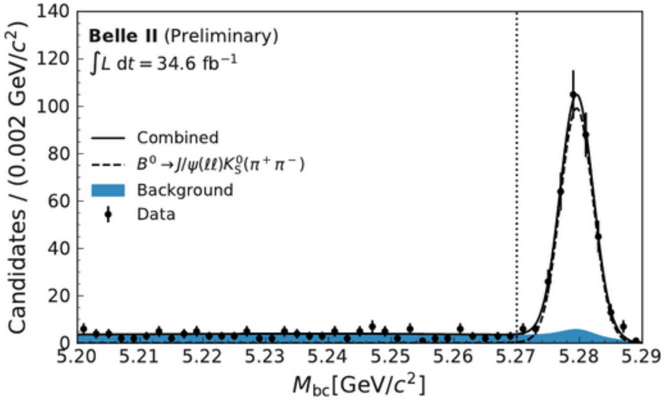
<Δz> ~ 130 μm at Belle II

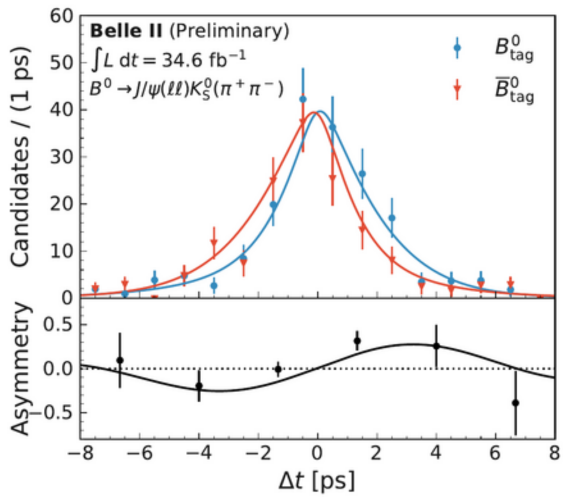
$$\boxed{\begin{aligned} \mathcal{A}_f(\Delta t) &= \frac{\Gamma(\overline{B}^0(\Delta t) \to f) - \Gamma(B^0(\Delta t) \to f)}{\Gamma(\overline{B}^0(\Delta t) \to f) + \Gamma(B^0(\Delta t) \to f)} \\ &= S_f \sin(\Delta m_B \Delta t) + A_f \cos(\Delta m_B \Delta t) \end{aligned}}$$

- sin(2β) is still a fundamental input for the CKM UT fit, it will be a golden channel at Belle II until the end of data taking.

$\sin(2\beta / \phi_1)$ from $B \rightarrow J/\psi\, K^0$

First crack at time dependent CP violation at Belle II:





$S = 0.55 \pm 0.21 \pm 0.04$

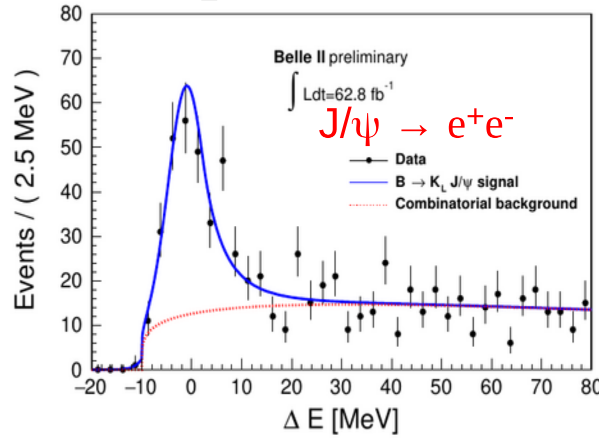
(significance ~2.7σ)

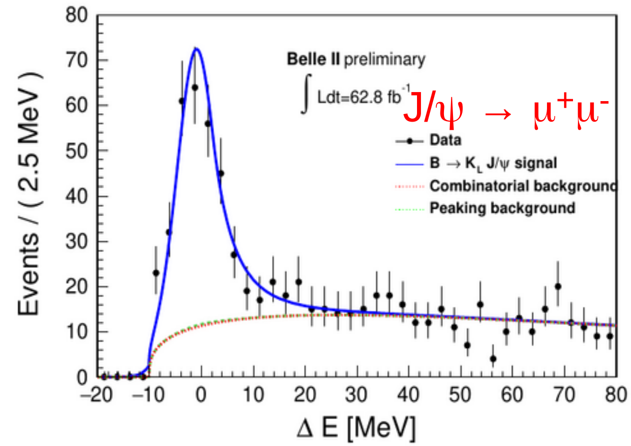
WA: $\sin(2\beta/\phi_1) = 0.699 \pm 0.017$

BELLE2-NOTE-PL-2020-011

K^0_L reconstruction:

arXiv: 2106.13547 [hep-ex]





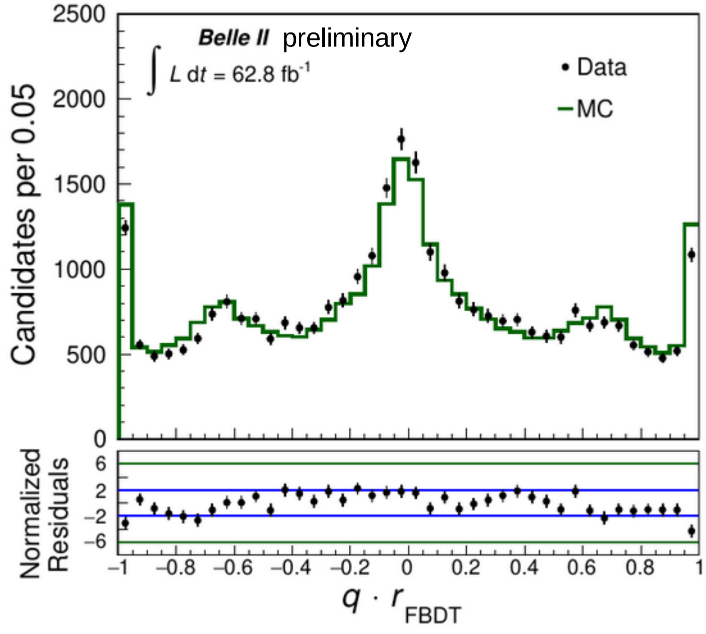
Next steps:

- Moriond 2022: measurement of $\tau(B^0)$ and Δm_d with both hadronic and semileptonic decays;
- Summer 2022: first competitive measurement of $\sin(2\beta)$.

B Flavor Tagger

arXiv: 2110.00790 [hep-ex], submitted to EPJC

- 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 $\overline{\text{B}}$) 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, … ;



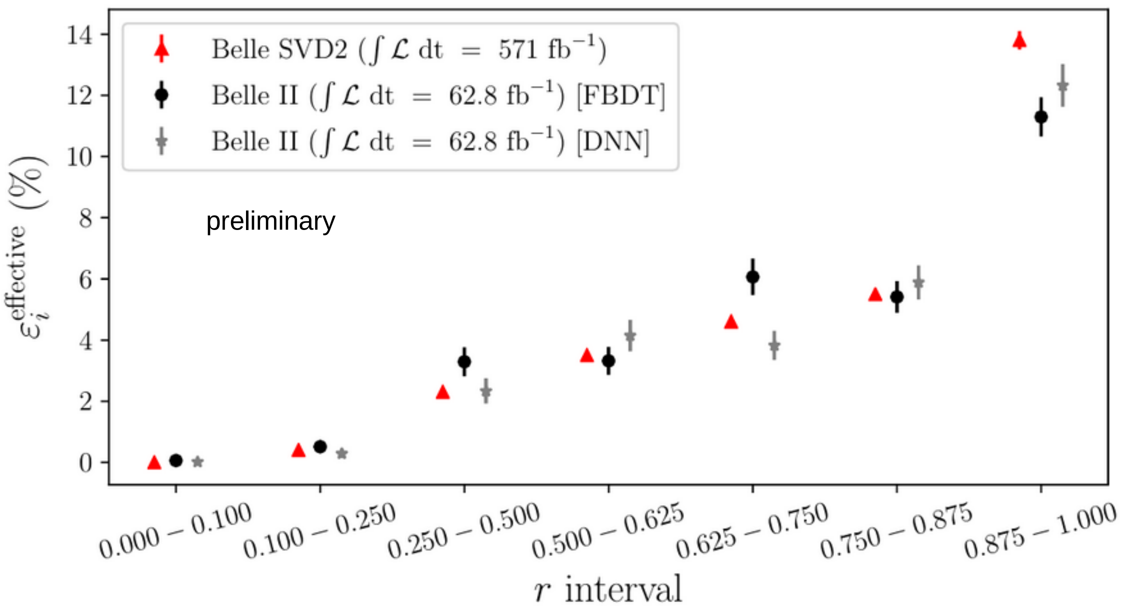
Effective FT efficiency:

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

Q(Belle II) = (30.0 ± 1.2 ± 0.4)%

Q(Belle) = (30.1 ± 0.4)%

Q(Belle II MC) = ~37%



$\sin(2\beta/\phi_1)$ outlook

- $\sin(2\beta)$ from $J/\psi\, K^0$ will be systematics dominated @50 ab^{-1};
- Irreducible systematic uncertainties from alignment of the vertex detector and Doubly Cabibbo Suppressed Decays on the tag side;

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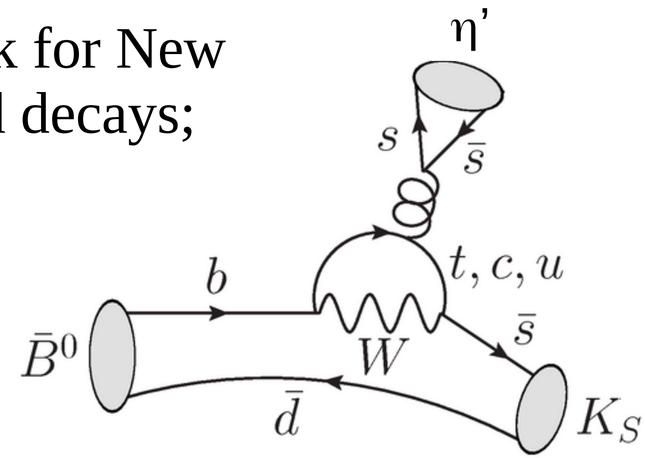
	No improvement	Vertex improvement	Leptonic categories
$S_{c\bar{c}s}$ (50 ab^{-1}) time dependent CP parameter			
stat.	0.0027	0.0027	0.0048
syst. reducible	0.0026	0.0026	0.0026
syst. irreducible	0.0070	0.0036	0.0035
$A_{c\bar{c}s}$ (50 ab^{-1}) direct CP asymmetry			
stat.	0.0019	0.0019	0.0033
syst. reducible	0.0014	0.0014	0.0014
syst. irreducible	0.0106	0.0087	0.0035

- *Penguin pollution* can no longer be ignored and must be constrained from $B \rightarrow J/\psi\, \pi^0$ and other SU(3) related channels.

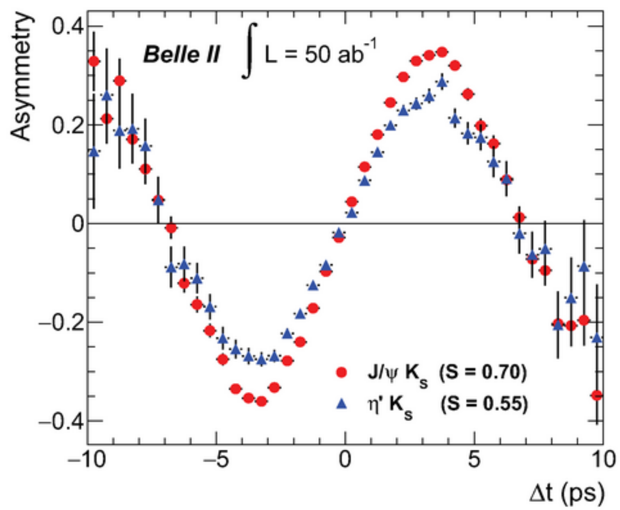
sin(2β/ϕ_1) from 'penguins'

- Not strictly relevant for precision, but important to look for New Physics: measuring sin(2β/ϕ_1) from penguin dominated decays;

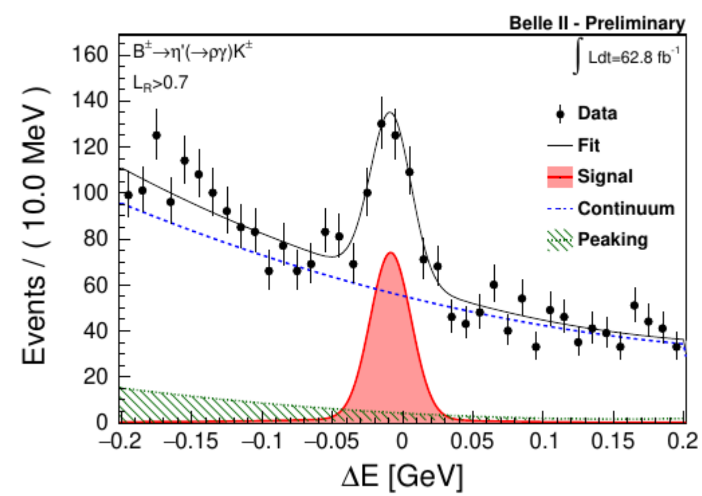


- Any significant deviation of the measured TD CP violation parameter from what is measured in J/ψ K^0, would be a smoking gun for New Physics;

arXiv: 2104.06224 [hep-ex]



Simulation (dream scenario)



- Golden channels: $B^0 \to \eta' K^0$, ϕ (K^+K^-) K^0, $K_SK_SK_S$;
- In most of these modes, we expect Belle II to have best sensitivity.

$$\mathcal{B}\left(B^{\pm}\to\eta' K^{\pm}\right) = \left(63.4\,^{+3.4}_{-3.3}\,(\mathrm{stat}) \pm 3.2\,(\mathrm{syst})\right)\times 10^{-6}$$

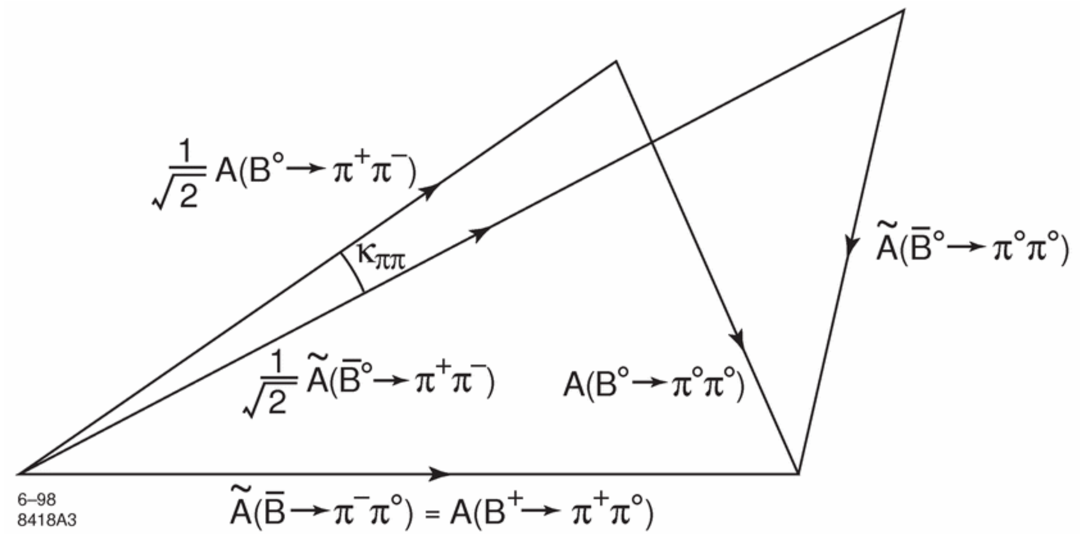
$$\mathcal{B}\left(B^{0}\to\eta' K^{0}\right) = \left(59.9\,^{+5.8}_{-5.5}\,(\mathrm{stat}) \pm 2.9\,(\mathrm{syst})\right)\times 10^{-6}$$

α / ϕ_2 at Belle (II)

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

The following equalities hold:

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



- Observables (for e.g. B $\rightarrow \pi\pi$):
  - branching fractions of: $B^0 \rightarrow \pi^+\pi^0$, $\pi^+\pi^-$, $\pi^0\pi^0$;
  - direct (time-independent) CP asymmetries: C^{+-}, C^{00};
  - time-dependent CP asymmetries: S^{+-}, S^{00}.

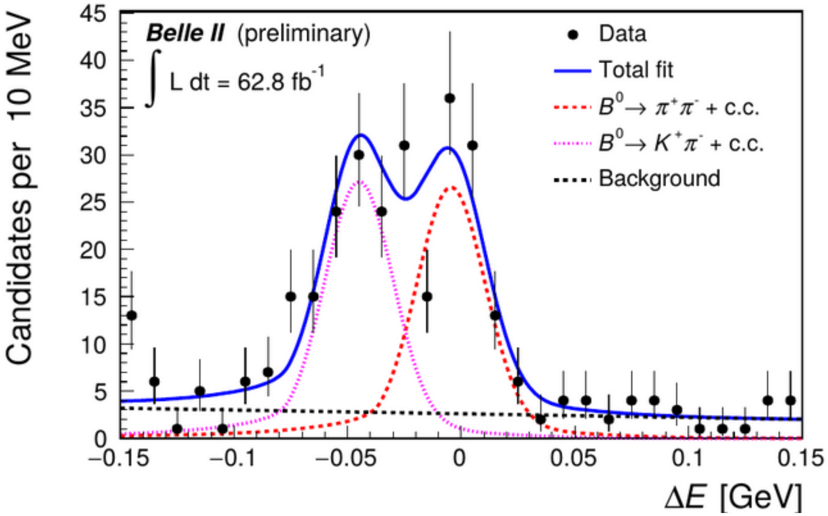
Gronau and London, PRL 65 (1990), 3381

- Belle II will be able to measure all these observables;
- We expect to push the sensitivity to α to ~1°.

α related measurements at Belle II

arXiv:2106.03766 [hep-ex]

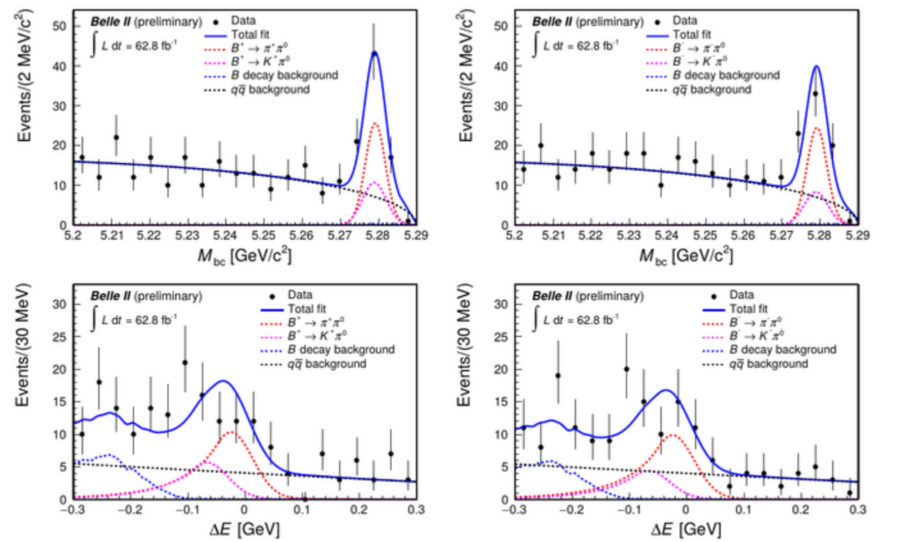
Measurement of $B^0 \to h^\pm h^\mp$



$$\mathcal{B}(B^0 \to \pi^+\pi^-) = [5.8 \pm 0.7(\text{stat}) \pm 0.3(\text{syst})] \times 10^{-6}$$

arXiv:2105.04111 [hep-ex]

Measurement of $B^\pm \to h^\pm \pi^0$



$$\mathcal{B}(B^+ \to \pi^+\pi^0) = [5.5^{+1.0}_{-0.9}(\text{stat}) \pm 0.7(\text{syst})] \times 10^{-6}$$

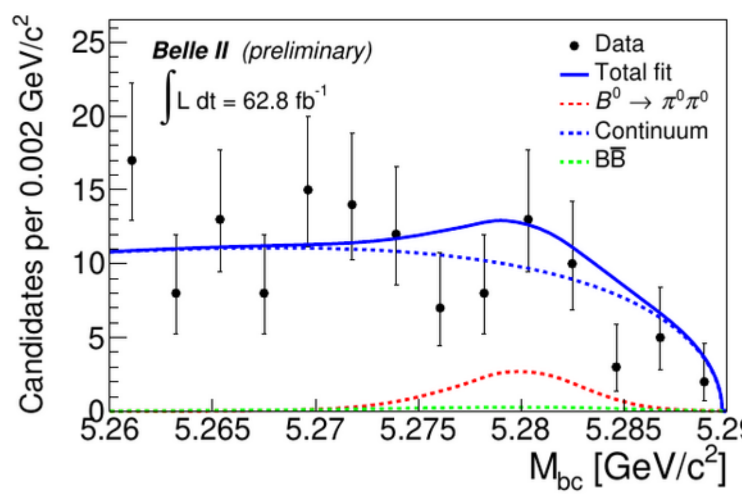
$$\mathcal{A}_{CP}(B^+ \to \pi^+\pi^0) = -0.04 \pm 0.17(\text{stat}) \pm 0.06(\text{syst})$$

arXiv:2107.02373 [hep-ex]

First evidence of $B^0 \to \pi^0\pi^0$

$$\mathcal{B}(B^0 \to \pi^0\pi^0) = (0.98^{+0.48}_{-0.39} \pm 0.27) \times 10^{-6}$$

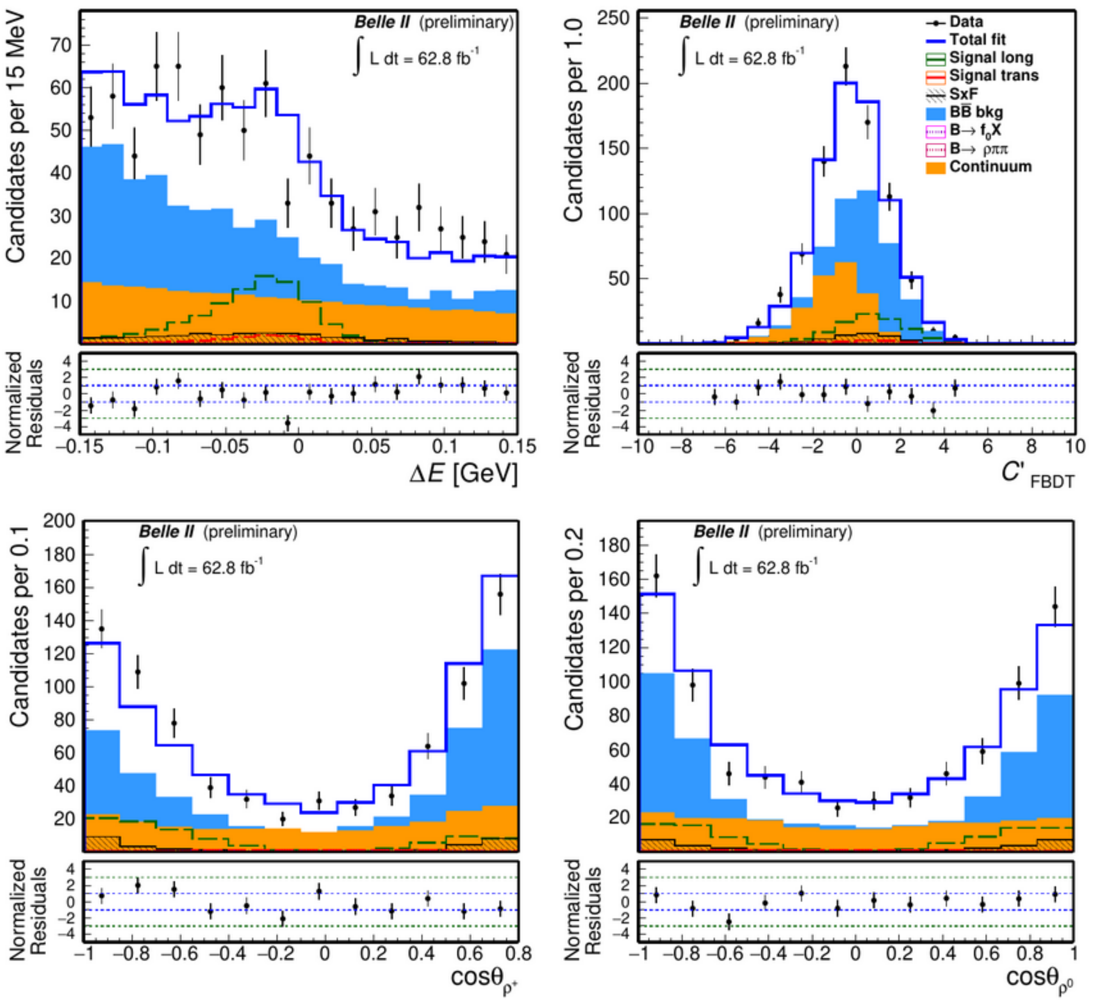
(signal significance 3.4σ)



$B \to \rho^+\rho^0$

arXiv:2109.11456 [hep-ex]

- $B \to \rho\rho$ isospin analysis comes with the additional complication that it needs the longitudinal polarization fraction f_L of the decay (as the CP eigenvalues depend on the helicity state);
- A complex, multi-dimensional analysis is mandatory for this kind of final states;
- The branching ratio and f_L are compatible with the WA;
- Also on this case we see better performance compared to Belle.

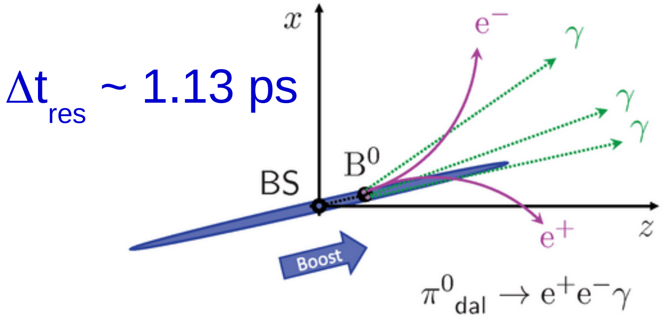


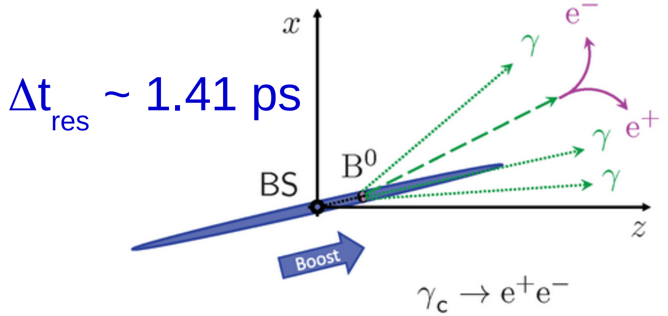
$$\mathcal{B}(B^+ \to \rho^+\rho^0) = [20.6 \pm 3.2(\text{stat}) \pm 3.1(\text{syst})] \times 10^{-6}$$

$$f_L(B^+ \to \rho^+\rho^0) = 0.936^{+0.049}_{-0.041}(\text{stat}) \pm 0.021(\text{syst})$$

TD CPV analysis of $B^0 \to \pi^0 \pi^0$

- Only at Belle II: TD CPV of $B^0 \to \pi^0\pi^0$, exploiting π^0 Dalitz decays and γ conversions;
- Expect ~270 signal events with full dataset;
- Predicted error on S^{00} ~ 0.28;
- We will do it not only because it is cool: this would reduce the ambiguity on α/ϕ_2 by a factor 2 or 4 (depending on central value).





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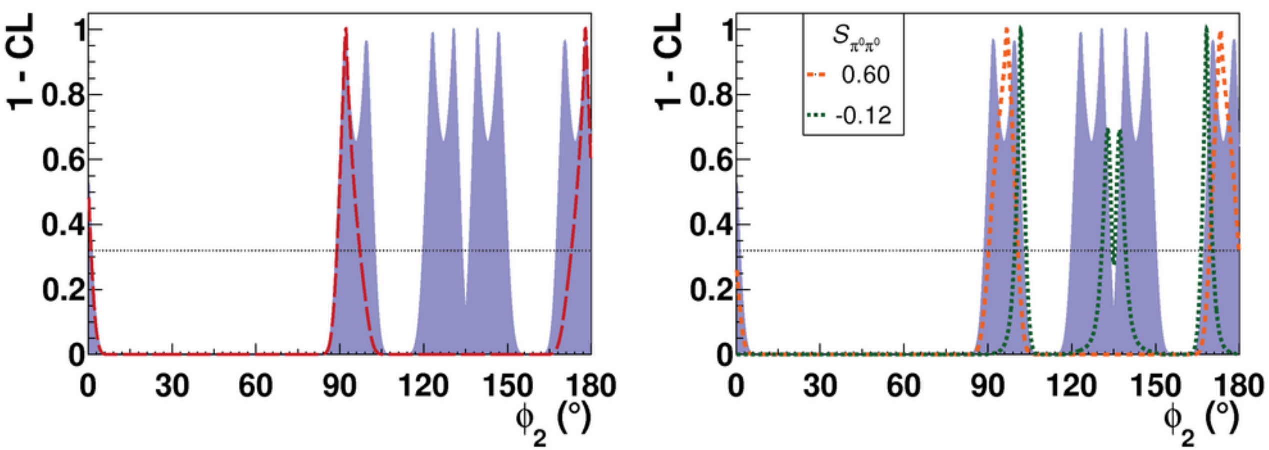
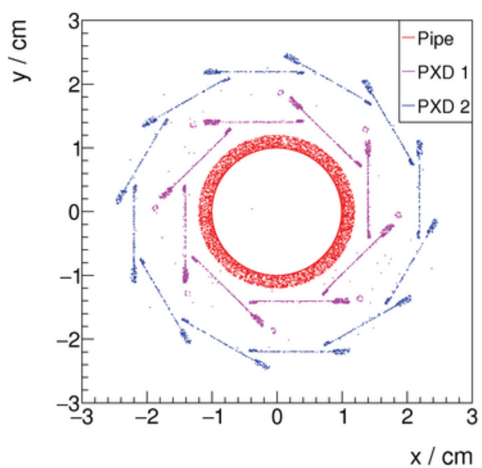


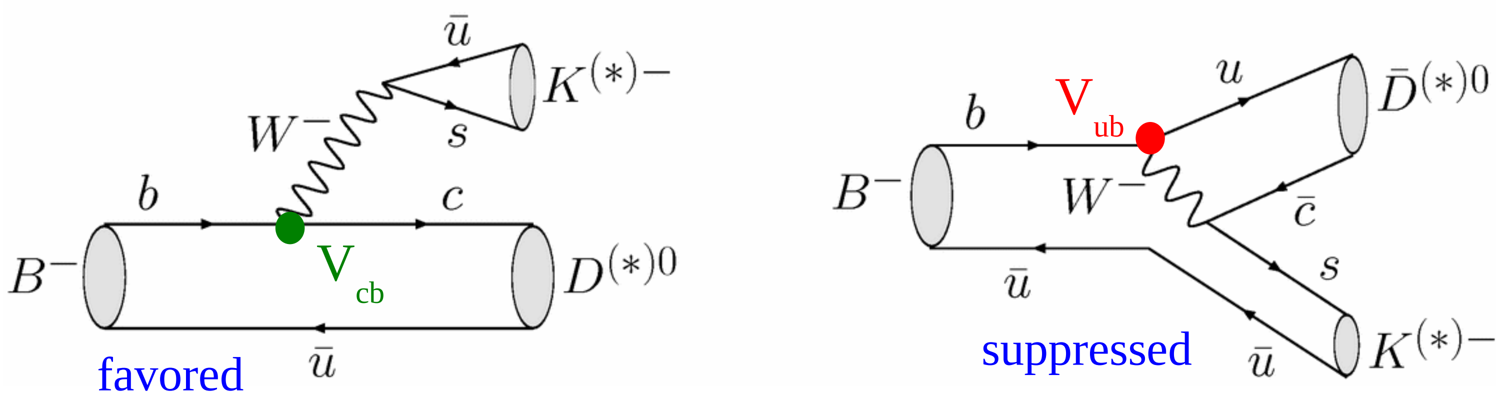


Filled area: extrapolation of Belle results to Belle II sensitivity

Dashed line: same as above, but adding S^{00}

γ / ϕ_3 at Belle II

- Most difficult angle to compete with LHCb, but the importance of this input for the CKM fit fully justifies the effort;
- Sensitivity comes mostly from time integrated measurements of $B^+ \to \overset{(-)}{D}{}^0 K^+$:



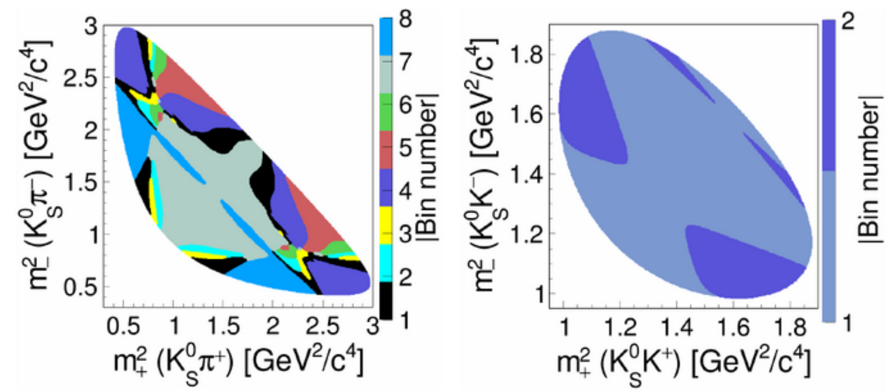
- Several methods exist to extract the weak phase: GLW (D^0 decaying to CP eigenstates), ADS (interference between CF and DCS decays), BPGGSZ (exploiting the Dalitz Plot interference);
- Belle II will have unique sensitivity to modes with neutrals in the final state:
  - GLW: $K_S\pi^0$, $K_S\,\eta$;
  - ADS using $D^{*0} \to D^0\gamma$, $D^0\pi^0$;
  - BPGGSZ of $\pi^+\pi^-\pi^0$, $K^+K^-\pi^0$, …;

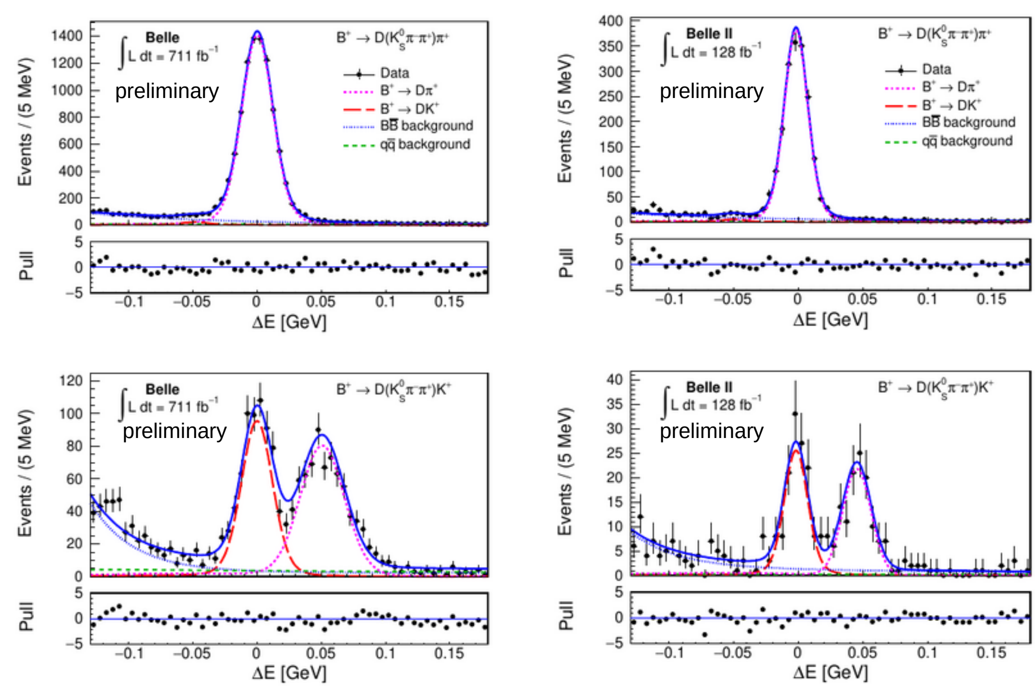
BPGGSZ @ Belle + Belle II

arXiv: 2110.12125 [hep-ex], submitted to JHEP

- First analysis on the combined Belle (711 fb^{-1}) + Belle II (128 fb^{-1}) data set;
- Final states: $B^+ \to D^0 (K_S h^+ h^-) h^+$, $h = \pi, K$;
- The Belle data have been converted to the same format of Belle II, so that the latest and greatest tools can be used;
- Full re-optimization of selection and continuum suppression;
- Better sensitivity compared to previous Belle analysis on the same data set.

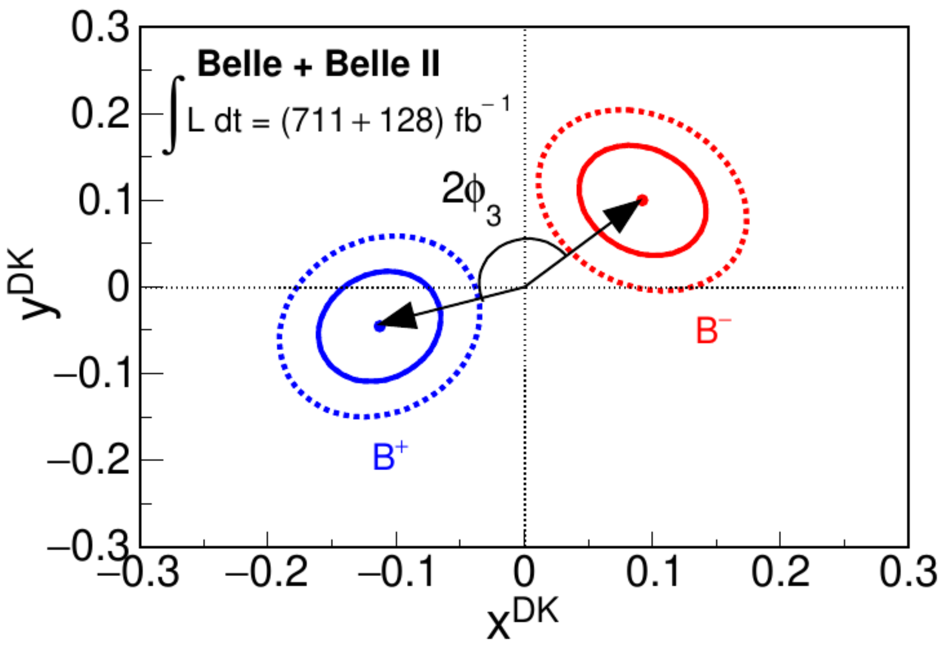
(model independent) binned DP's





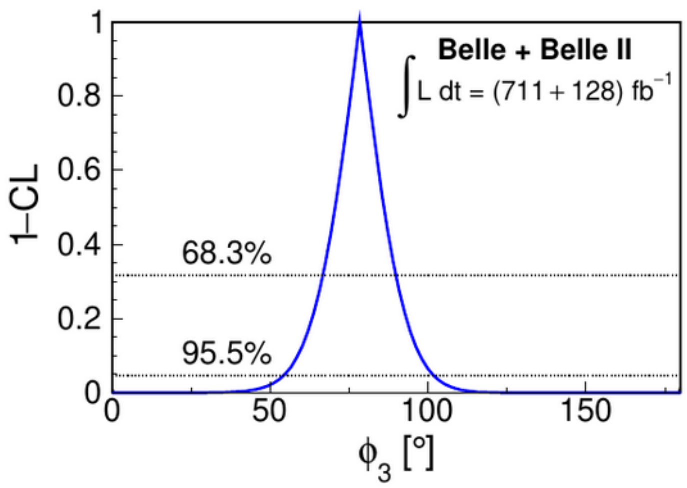
BPGGSZ @ Belle + Belle II

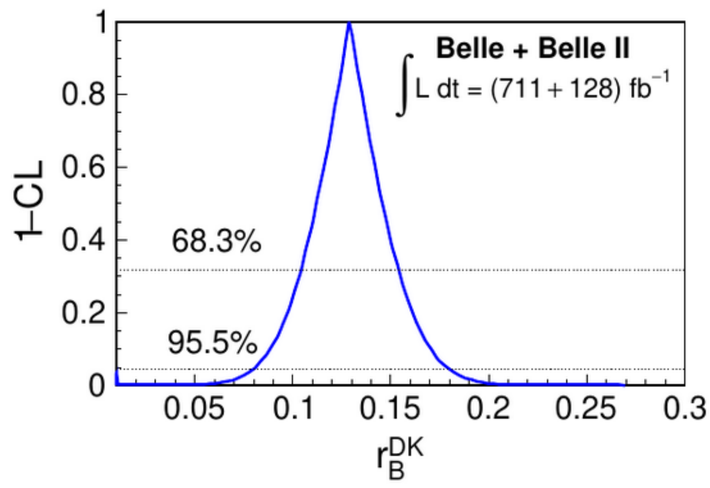
arXiv: 2110.12125 [hep-ex], submitted to JHEP



$$\phi_3 = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)^\circ\,,$$
$$r_B^{DK} = 0.129 \pm 0.024 \pm 0.001 \pm 0.002,$$
$$\delta_B^{DK} = (124.8 \pm 12.9 \pm 0.5 \pm 1.7)^\circ\,.$$

(third error comes from external measurements on the D strong phase)





Conclusions

- The start of the Belle II Experiment was slower than expected, but we are now in a position to have competitive measurements (especially if we combine with Belle);

- Complex and ambitious analyses have been shown already, more will come in the near future;

- Our Physics Program will cover most of the inputs relevant for the CKM UT analysis:
  - ➔ clear advantage of LHCb on some inputs, on others Belle II will have unique sensitivity;
  - ➔ complementarity will be the name of the game!

- Strategy: do not leave any stones unturned, precision measurements on known processes may lead the way to New Physics.

Backup Slides

The Belle II Collaboration

- ➔ 26 countries;
- ➔ 123 institutions;
- ➔ ~1100 active members.

Countries (institutions):

Armenia (1), Australia (3), Austria (1), Canada (5), China (12), Czechia (1), France (3), Germany (12), India (9), Israel (1), Italy (9), Japan (16), Malaysia (1), Mexico (3), Poland (1), Russia (6), Saudi Arabia (1), Slovenia (2), South Korea (9), Spain (1), Taiwan (3), Thailand (2), Turkey (1), USA (18), Ukraine (1), Viet Nam (1).

The Belle II Physics Book

- The "Belle II Physics Book" has been published by PTEP;
- This is the results of several years of collaboration between Belle II and the Theory Community;
- Sensititivity estimates on the golden (and silver) channels are given.

arXiv: 1808.10567
DOI: 10.1093/ptep/ptz106

750+ citations

KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047
UWThPh 2018-26

The Belle II Physics Book

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Process	Observable	Theory	Sys. dom. (Discovery) [ab^{-1}]	vs LHCb	vs Belle	Anomaly	NP
$B \to \pi \ell \nu_\ell$	$\lvert V_{ub}\rvert$	★★★	10-20	★★★	★★★	★★	★
$B \to X_u \ell \nu_\ell$	$\lvert V_{ub}\rvert$	★★	2-10	★★★	★★	★★★	★
$B \to \tau \nu$	$Br.$	★★★	>50 (2)	★★★	★★★	★	★★★
$B \to \mu \nu$	$Br.$	★★★	>50 (5)	★★★	★★★	★	★★★
$B \to D^{(*)} \ell \nu_\ell$	$\lvert V_{cb}\rvert$	★★★	1-10	★★★	★★	★★	★
$B \to X_c \ell \nu_\ell$	$\lvert V_{cb}\rvert$	★★★	1-5	★★★	★★	★★	★★
$B \to D^{(*)} \tau \nu_\tau$	$R(D^{(*)})$	★★★	5-10	★★	★★★	★★★	★★★
$B \to D^{(*)} \tau \nu_\tau$	P_τ	★★★	15-20	★★★	★★★	★★	★★★
$B \to D^{**} \ell \nu_\ell$	$Br.$	★	-	★★	★★★	★★	-

Process	Observable	Theory	Sys. dom. (Discovery) [ab^{-1}]	vs LHCb	vs Belle	Anomaly	NP
$B \to J/\psi K_S^0$	ϕ_1	★★★	5-10	★★	★★	★	★
$B \to \phi K_S^0$	ϕ_1	★★	>50	★★	★★★	★	★★★
$B \to \eta' K_S^0$	ϕ_1	★★	>50	★★	★★★	★	★★★
$B \to \rho^\pm \rho^0$	ϕ_2	★★★	>50	★	★★★	★	★
$B \to J/\psi \pi^0$	ϕ_1	★★★	>50	★	★★★	-	-
$B \to \pi^0 \pi^0$	ϕ_2	★★	>50	★★★	★★★	★★	★★
$B \to \pi^0 K_S^0$	S_{CP}	★★	>50	★★★	★★★	★★	★★

Pro’s and Con’s of Belle II

☺

- The kinematics of the collision is known precisely;
- In $\Upsilon(4S) \rightarrow B\bar{B}$ events, no additional particles are produced (we can use B-tagging);
- $B\bar{B}$ pairs are produced in a quantum entangled state;
- Low-multiplicity and τ pair processes are easily accessible (we can trigger on final states with a single visible particle);
- High efficiency and purity of neutrals (π^0, $\eta^{(\prime)}$, K^0_L, …);

😐

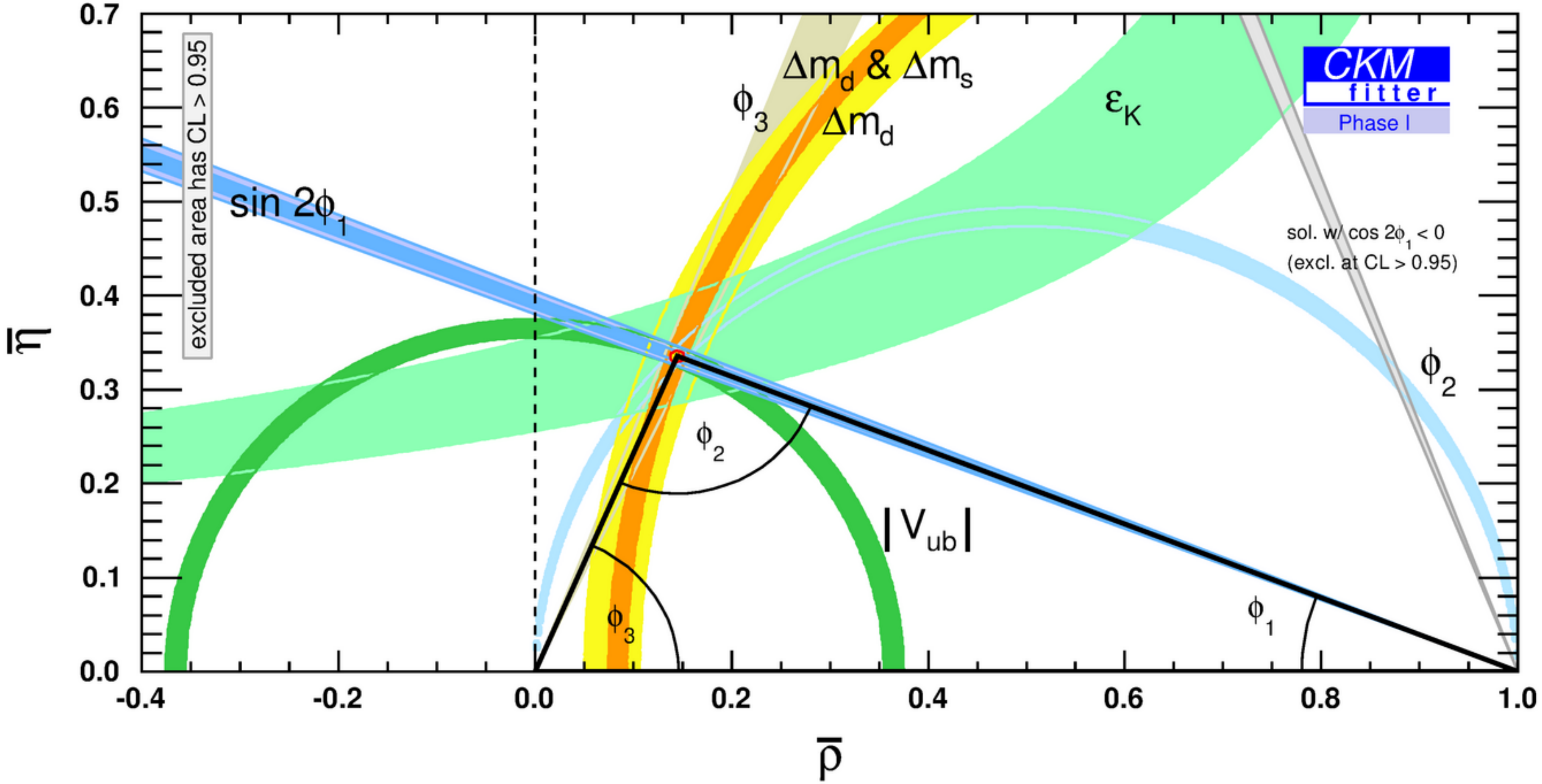
- “Manageable” backgrounds (but machine backgrounds will be a challenge for both detector, trigger, and analysis at high-lumi conditions);

☹

- Low cross-section (compared to hadron machines);
- Relatively low boost of B and D mesons (time-dependent analyses of B_s’s is out of question)
- Cannot go much higher in energy than the mass of the $\Upsilon(4S)$.

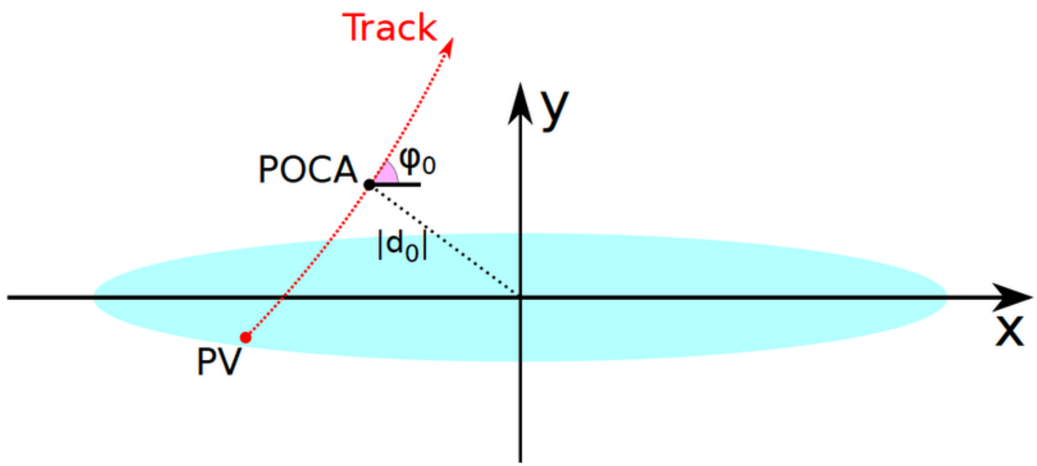
CKM UT: outlook

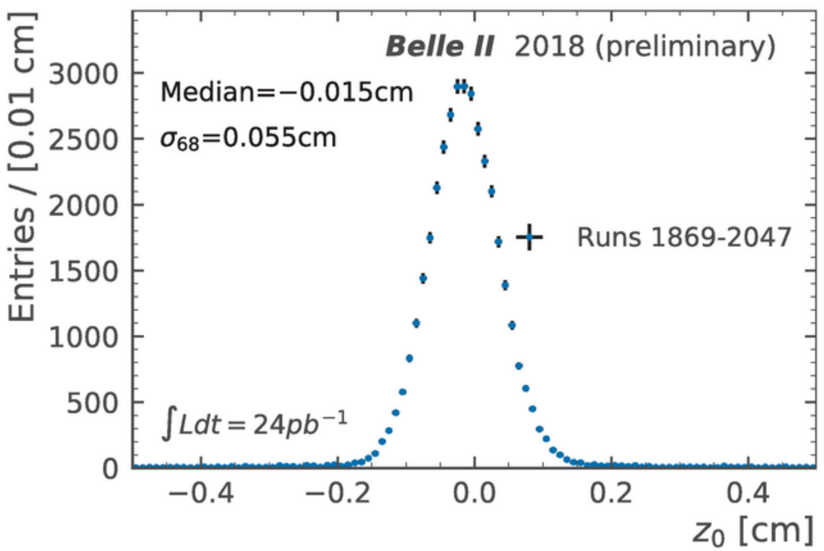
CKM Unitarity Triangle ~10 years from now:

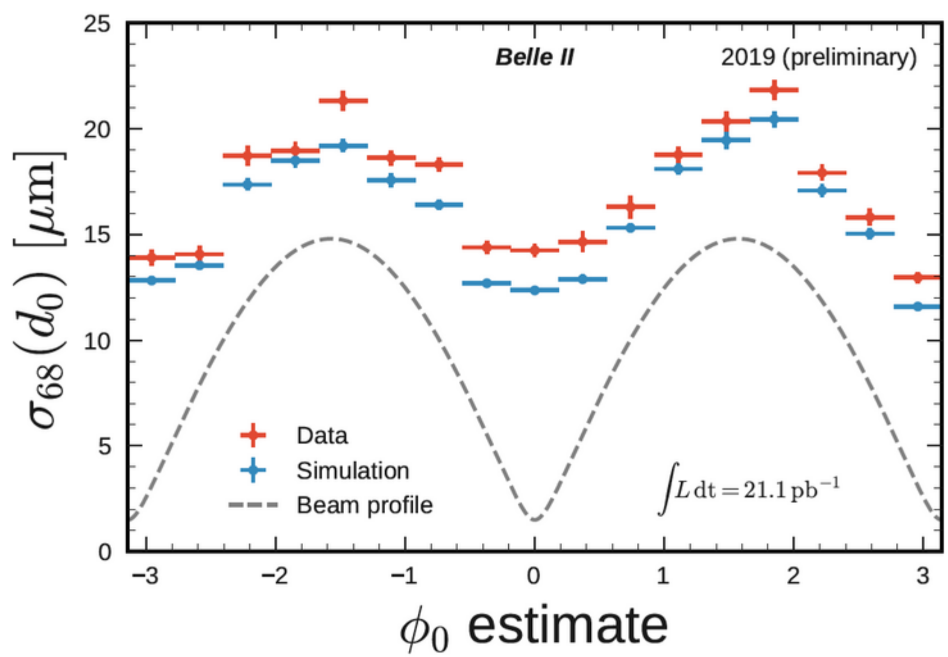


Assumptions: Belle II 50 ab^{-1}, LHCb 23 fb^{-1}

Beamspot and Vertexing







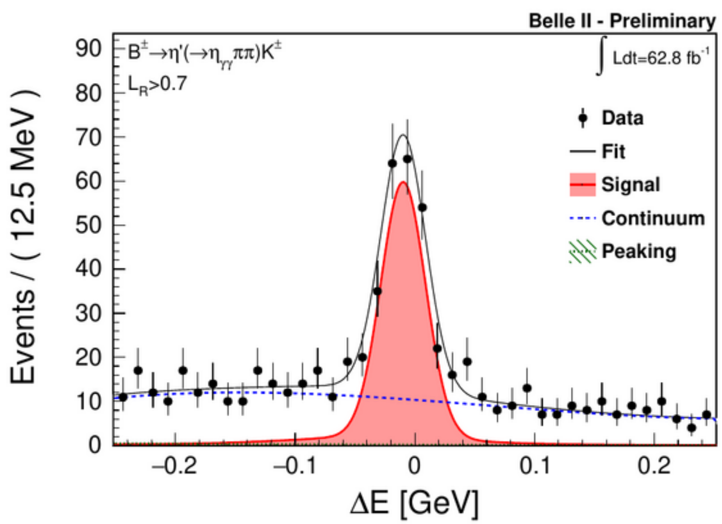
The position of the Point Of Closest Approach is consistent with the expectations based on the current beam sizes and the 41 mrad crossing angle

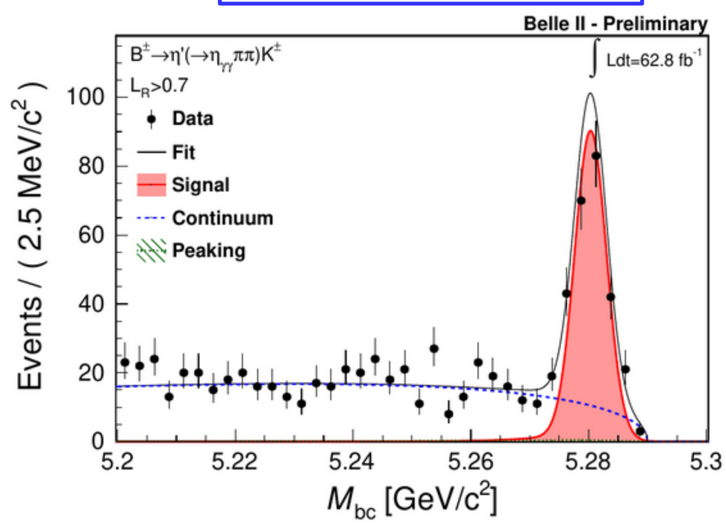
B-factory variables

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

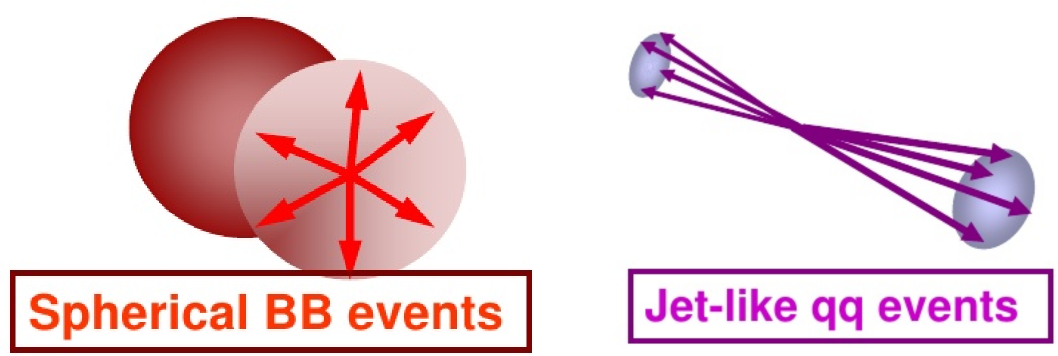
$$\Delta E = E_B^* - \frac{\sqrt{s}}{2}$$

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





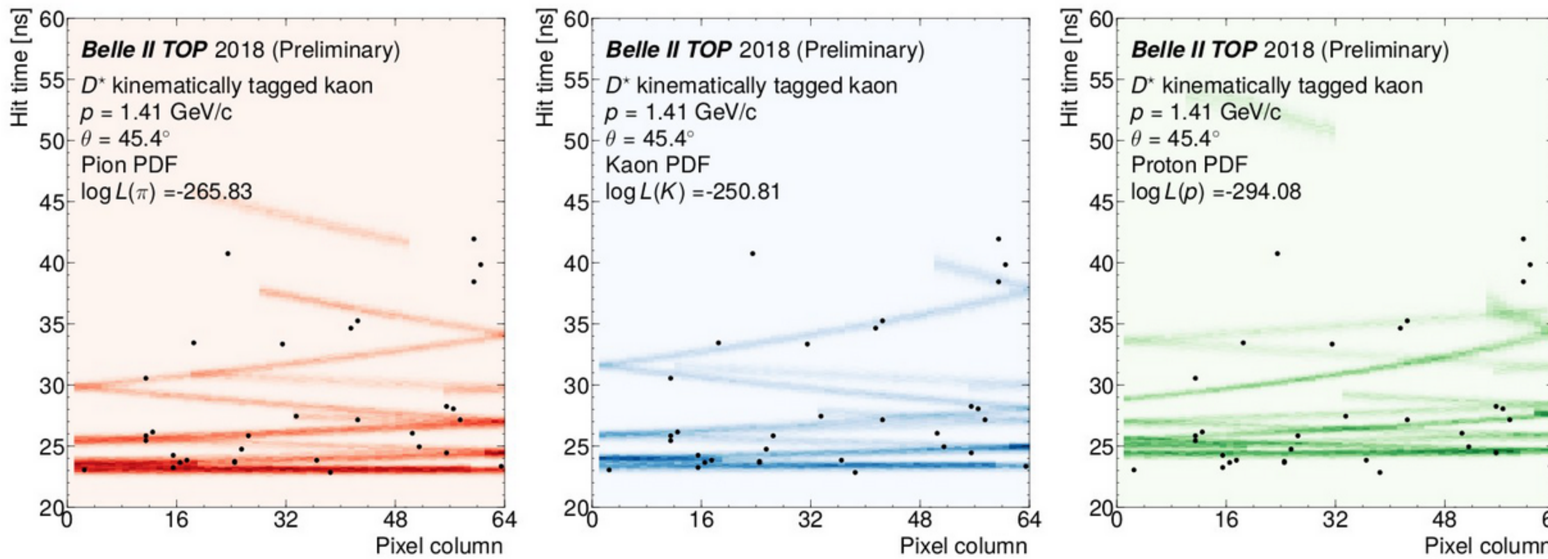
For many final states, the dominant source of background is the ‘$q\bar{q}$ continuum’, which is suppressed based on the different topology with respect to $B\bar{B}$ events:



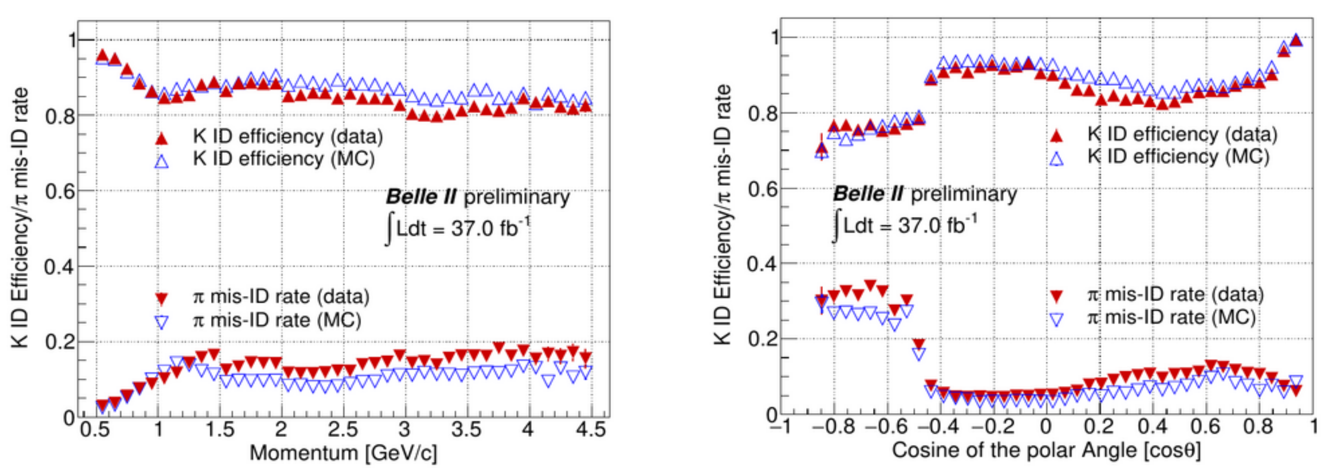
Particle identification (K/π separation)

Main control sample: $D^{*+} \rightarrow D^0 \pi^+_s$, $D^0 \rightarrow K^- \pi^+$

Example:
a K candidate
traversing a
TOP module

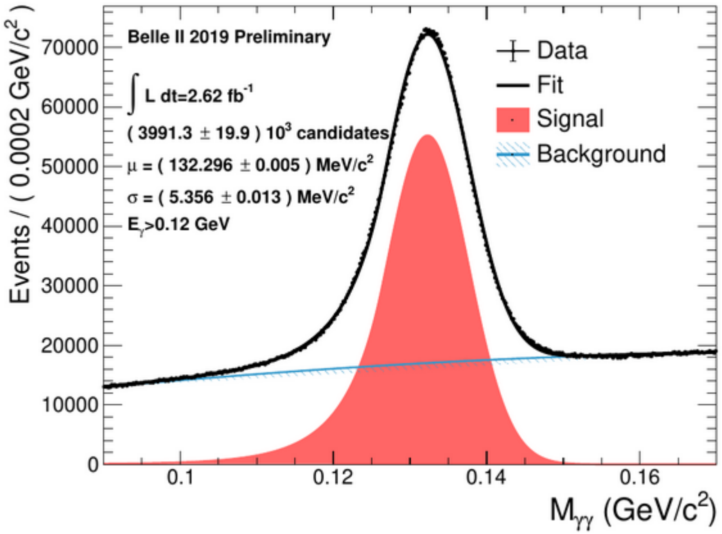


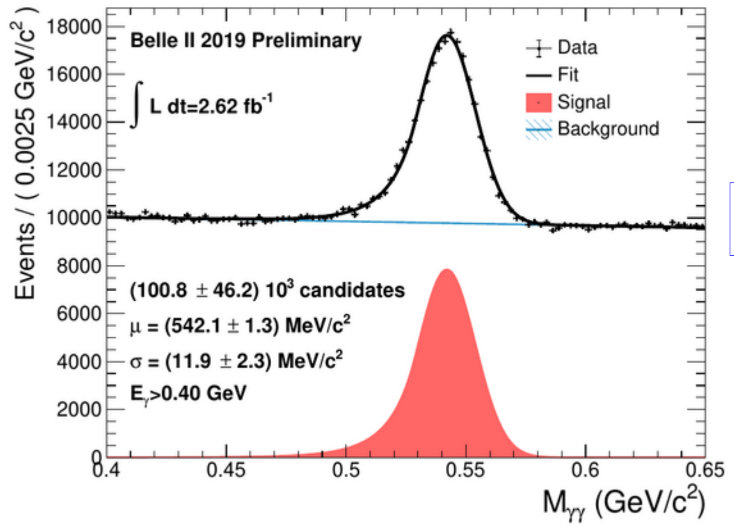
Still some work to do in order to push down the π misID probability...



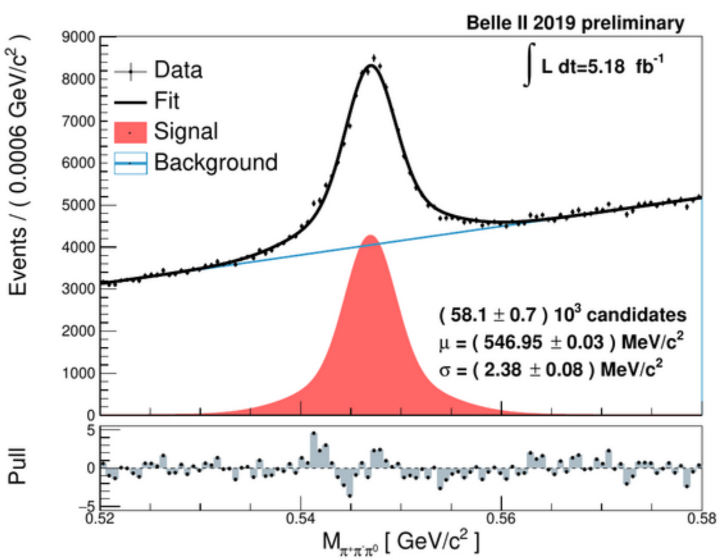
K/π separation at low momentum heavily relies on dE/dx from vertex detector, see talk by Abdul Basith at the Detectors parallel session

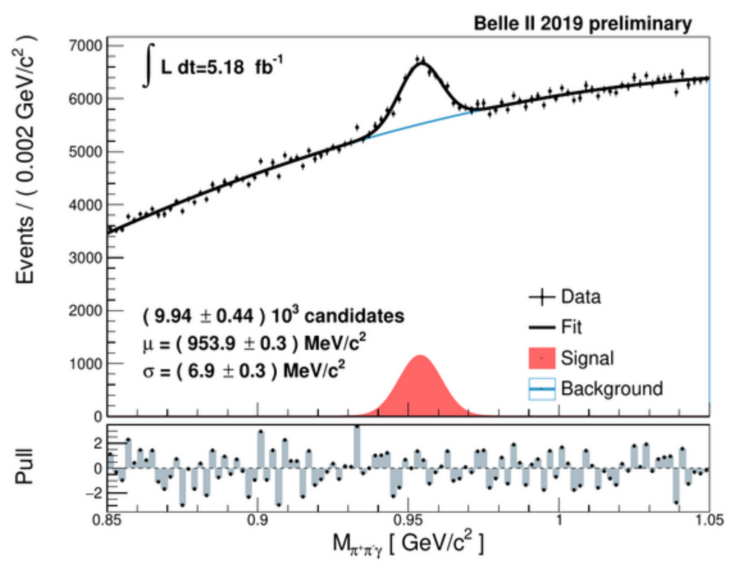
Neutrals reconstruction





BELLE2-NOTE-PL-2019-019





BELLE2-NOTE-PL-2020-003

Full Event Interpretation

- Advanced tool to analyze final states with difficult backgrounds;
- One of the two B mesons in the event is reconstructed into a hadronic or semileptonic final state: O(1000) decay chains are considered;
- Significant impact on the overall efficiency, but dramatic increase in background control, especially in modes with ν's in the final state;

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