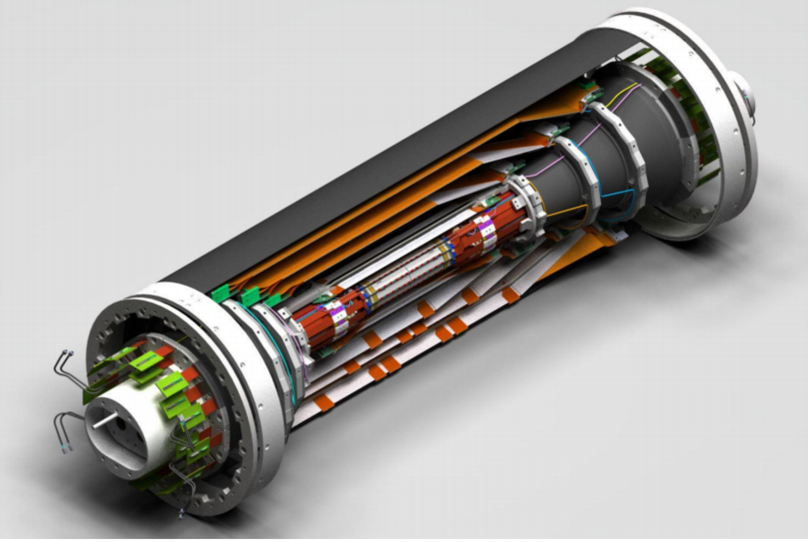
Time-dependent CP violation measurements at Belle II

Kobayashi-Maskawa Institute
for the Origin of Particles and the Universe



Alessandro Gaz

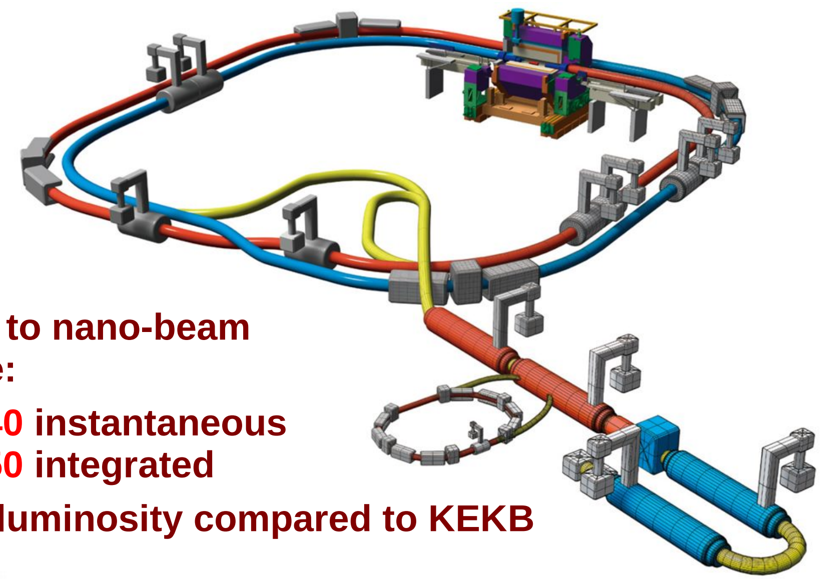
KMI, Nagoya University
on behalf of the Belle II Collaboration

ICHEP 2018

Seoul, July 6th 2018

First Collisions at SuperKEKB

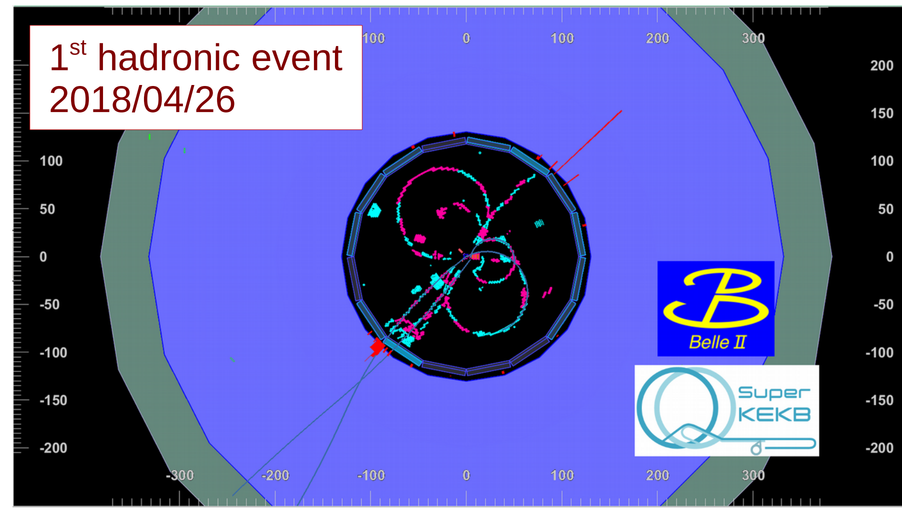
The SuperKEKB e^+e^- collider operates at a CM energy corresponding (or close to) the mass of the Y(4S) resonance:



Thanks to nano-beam scheme:

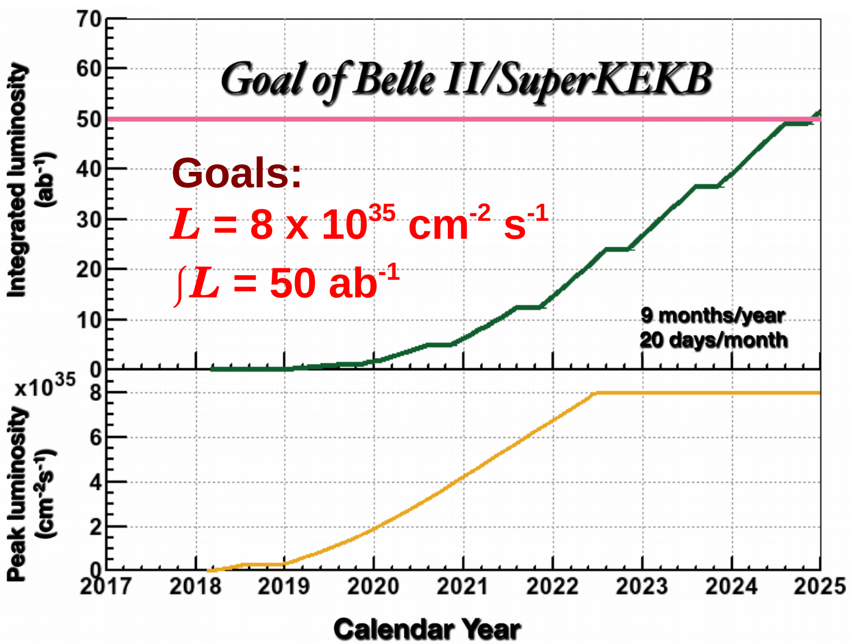
x40 instantaneous
x50 integrated

design luminosity compared to KEKB



First collisions delivered on April 26th!

Current peak lumi record ~5 x 10^{33} $cm^{-2}s^{-1}$

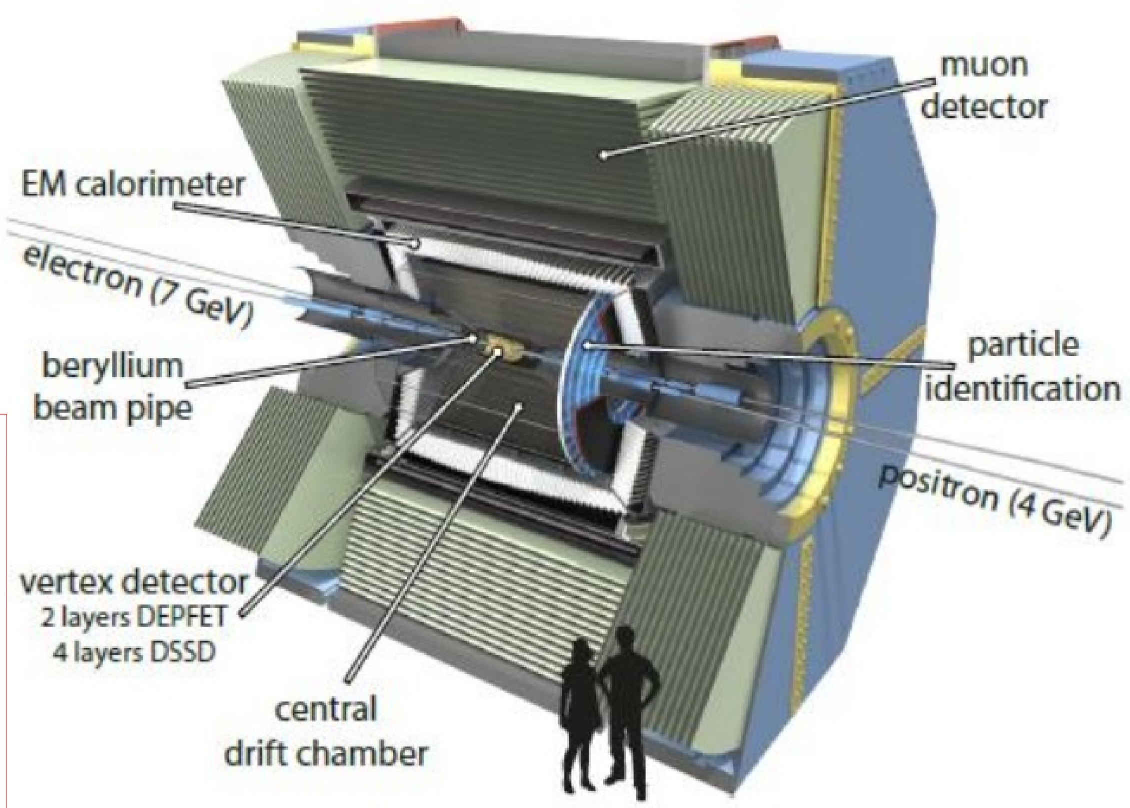


A. Gaz

The Belle II Detector

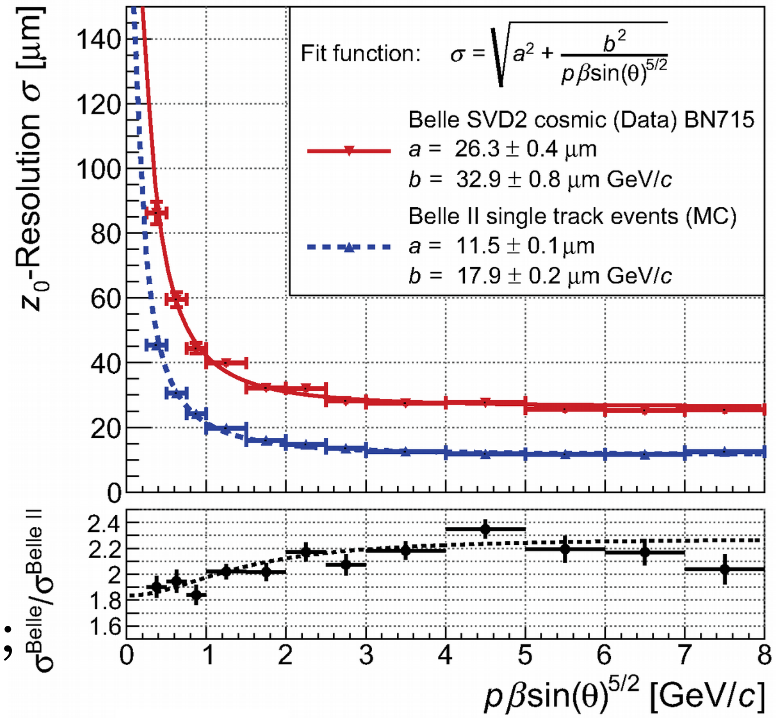
- Extensive upgrade of its predecessor (Belle) in all areas;
- Vast physics program: search for New Physics in B mesons, charm hadrons, τ decays, exotic particles, dark sector, … ;
- High luminosity does not come for free:
  - ➔ high event rate;
  - ➔ high machine backgrounds;
  - ➔ reduced energy asymmetry ($\beta\gamma$ reduced from 0.45 to 0.28).

The Vertex Detector (VXD) has not been installed yet. In its place we have a suite of detectors dedicated to background studies (the BEAST 2 detector), which include a VXD “slice” that corresponds to ~10% of the full system.



Detector highlights

Belle II simulation



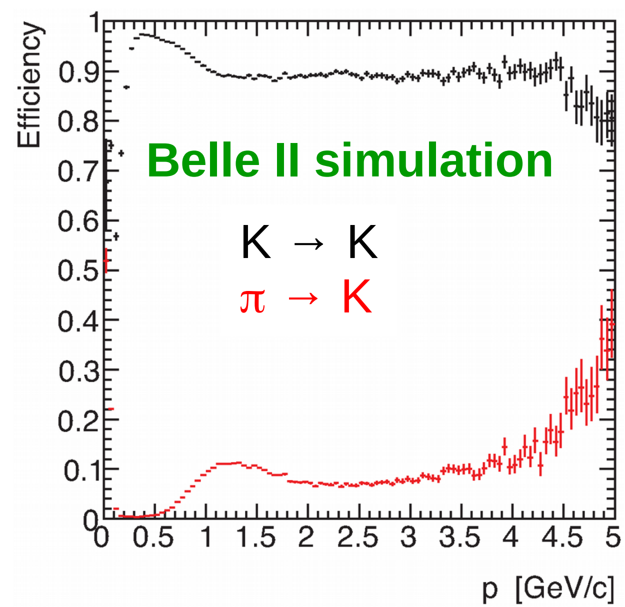
Two areas are particularly important for TD CPV measurements:

Vertex detectors:

- spatial resolution of the new vertex detector a factor ~2 better than Belle;
- despite lower Lorentz boost, we expect O(30%) improvement in the separation of the B decay vertices!
- ~30% bigger acceptance for K_S reconstruction;

Particle Identification (PID):

- K-π separation is fundamental to distinguish among important final states and backgrounds;
- crucial ingredient for B flavor tagger;
- expected performance: K (π) efficiency > 90%, with π (K) fake rate < 10% for p < 4 GeV/c.



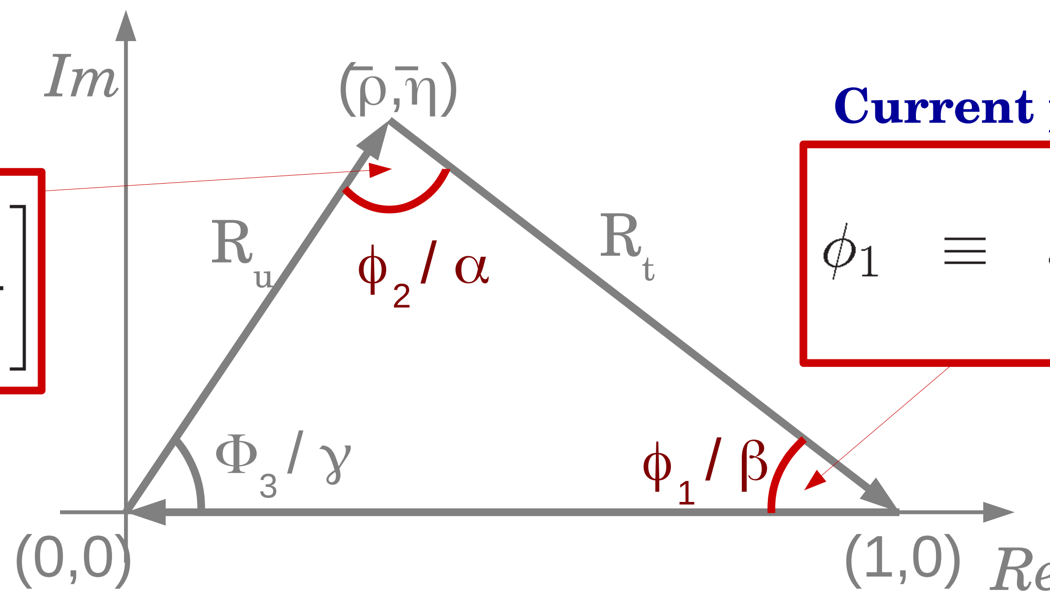
The CKM Unitarity Triangle

- The strength of the coupling of quarks via the charged weak current is described by the Cabibbo-Kobayashi-Maskawa (CKM) Matrix;
- The CKM Matrix is a 3x3 complex and unitary matrix;
- One of its unitarity conditions defines the CKM Unitarity Triangle;

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Current precision: ~5°

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



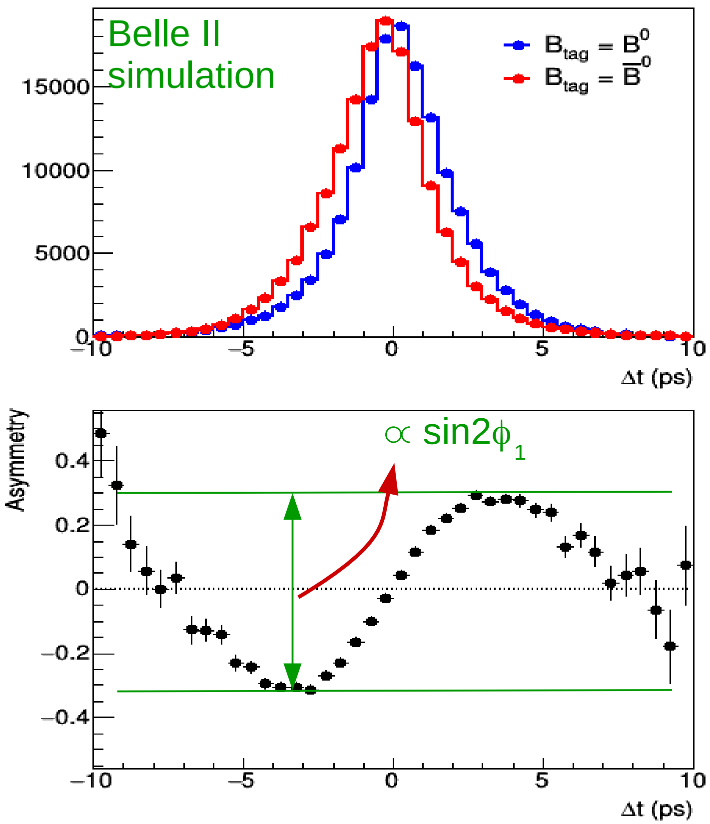
Current precision: ~0.7°

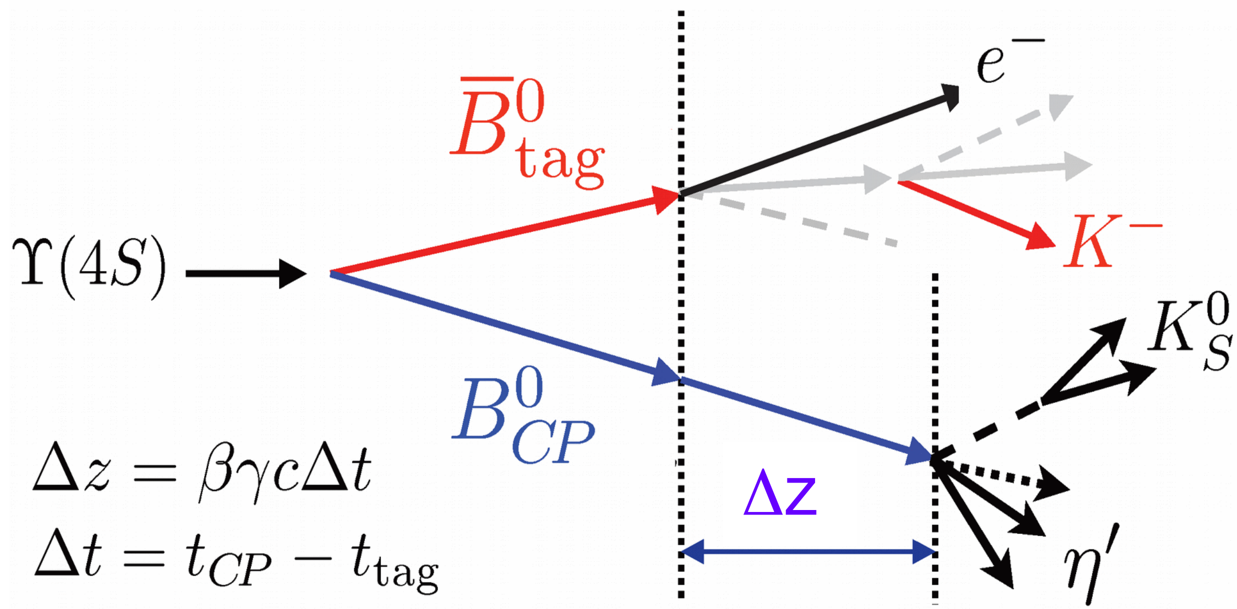
$$\phi_1 \equiv \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right]$$

- Time-dependent CP violation measurements in B_d decays allow us to measure the angles ϕ_1 and ϕ_2.

Time Dependent CPV at Belle II

- Flagship analysis technique at the B factories, exploiting the coherent state of the neutral B pairs from the Υ(4S) decay:





$$\Delta z = \beta\gamma c \Delta t$$
$$\Delta t = t_{CP} - t_{\mathrm{tag}}$$

<Δz> ~ 130 μm at Belle II

$$\mathcal{A}_f(\Delta t) = \frac{\Gamma(\overline{B}^0(\Delta t) \to \eta' K^0_S) - \Gamma(B^0(\Delta t) \to \eta' K^0_S)}{\Gamma(\overline{B}^0(\Delta t) \to \eta' K^0_S) + \Gamma(B^0(\Delta t) \to \eta' K^0_S)}$$
$$= S_f \sin(\Delta m_B \Delta t) + A_f \cos(\Delta m_B \Delta t)$$

$$S_f = -\eta_f \sin 2\phi_1$$

Flavor Tagging

- Charged leptons, kaons, pions, Λ's (and their correlations) from the unreconstructed B help determining whether it is a B^0 or a $\overline{B}^0$;
- Brand new algorithm, exploiting more variables in two layers of MVA discriminators;
- Its performance has been tested already on Belle data:

$$\overline{B}^0 \rightarrow D^{*+}\ \overline{\nu}_\ell\ \ell^-$$
$$\hookrightarrow D^0\ \pi^+$$
$$\hookrightarrow X\ K^-$$

$$\overline{B}^0 \rightarrow D^+\ \pi^-\ (K^-)$$
$$\hookrightarrow K^0\ \nu_\ell\ \ell^+$$

$$\overline{B}^0 \rightarrow \Lambda_c^+\ X^-$$
$$\hookrightarrow \Lambda\ \pi^+$$
$$\hookrightarrow p\ \pi^-$$

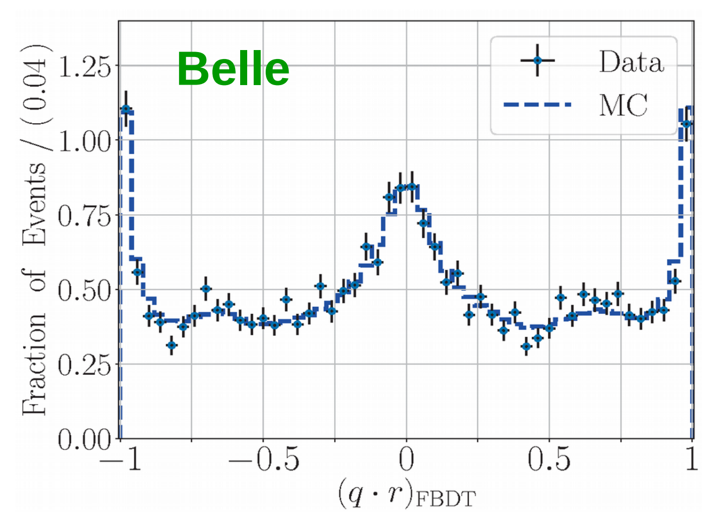
$$\varepsilon_{eff} = \sum_i \varepsilon_i (1 - 2 w_i)^2$$

ε_{eff}: effective tagging efficiency

ε_i: efficiency of category i

w_i: mis-tagging probability of category i

Old FT - Belle data:	ε_{eff} = (30.1 ± 0.4)%
New FT - Belle data:	ε_{eff} = (33.6 ± 0.5)%
New FT - Belle MC:	ε_{eff} = (34.18 ± 0.03)%
New FT - Belle II MC:	ε_{eff} = (37.16 ± 0.03)%



Improvement w.r.t. Belle largely due to better PID

$\sin 2\phi_1 (\sin 2\beta)$ – golden modes

- The best sensitivity comes from the $B^0 \to (c\bar{c})\, K^0$ modes, which have a high branching ratio and are theoretically very clean;

Int. lumi: 426 fb^{-1}	BaBar:	S = 0.687 ± 0.028 ± 0.012	PRD **79**, 072009 (2009)
Int. lumi: 711 fb^{-1}	Belle:	S = 0.667 ± 0.023 ± 0.012	PRL **108**, 171802 (2012)
Int. lumi: 3.0 fb^{-1}	LHCb:	S = 0.731 ± 0.035 ± 0.020	PRL **115**, 031601 (2015)

HFLAV Average: S = 0.691 ± 0.017

- Experimental challenge: reduce systematic uncertainties:

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

Two major sources of systematics do no scale with luminosity:

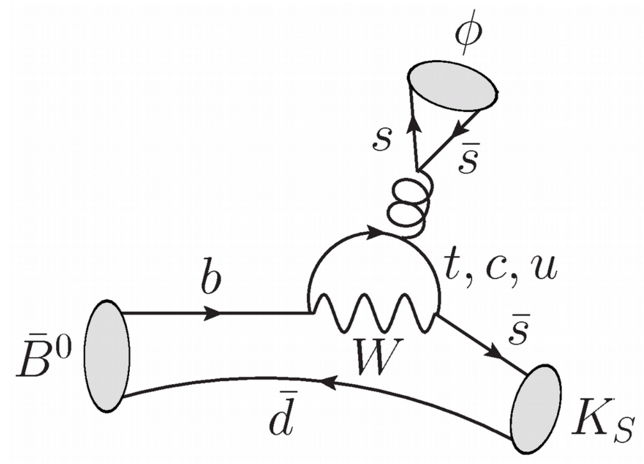
1) vertex detector alignment;

2) DCS decays on tag-side (does not affect leptonic categories)

- Measure $B^0 \to J/\psi\, \pi^0$ (+ others) to constrain penguin pollution effects.

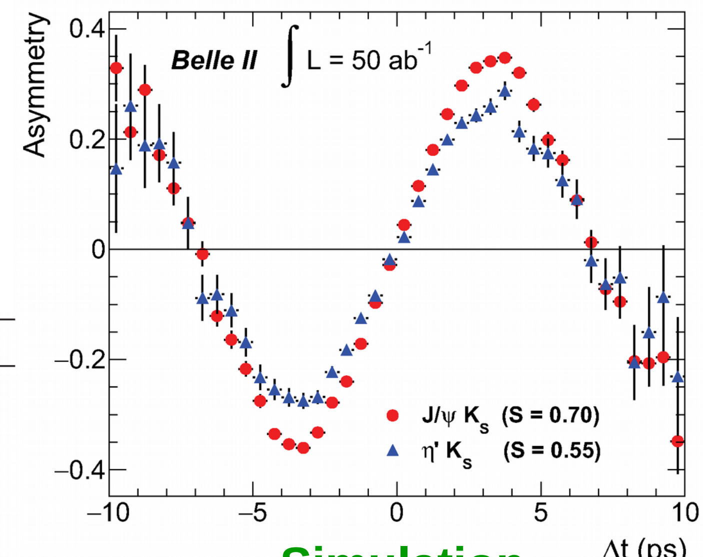
sin2ϕ$_1$(sin2β) – penguin-dominated modes

- TD CP-violation measurements of b → q$\bar{q}$s transitions (q = u, d, s) are also sensitive to sin2ϕ$_1$, but:
  - being mostly penguin-dominated, they are potentially very sensitive to competing New Physics amplitudes (and phases);
  - there are many different modes: it will be possible to disentangle long/short distance effects;



- Theory can make quite precise predictions on the difference ΔS$_f$ of the TD CPV parameter S w.r.t. the golden modes:

Mode	QCDF [32]	QCDF (scan) [32]	$SU(3)$	Data
$\pi^0 K^0_S$	$0.07^{+0.05}_{-0.04}$	$[0.02, 0.15]$	$[-0.11, 0.12]$ [36]	$-0.11^{+0.17}_{-0.17}$
$\rho^0 K^0_S$	$-0.08^{+0.08}_{-0.12}$	$[-0.29, 0.02]$		$-0.14^{+0.18}_{-0.21}$
★ $\eta' K^0_S$	$0.01^{+0.01}_{-0.01}$	$[0.00, 0.03]$	$(0 \pm 0.36) \times 2\cos(\phi_1)\sin\gamma$ [37]	-0.05 ± 0.06
ηK^0_S	$0.10^{+0.11}_{-0.07}$	$[-1.67, 0.27]$		—
★ ϕK^0_S	$0.02^{+0.01}_{-0.01}$	$[0.01, 0.05]$	$(0 \pm 0.25) \times 2\cos(\phi_1)\sin\gamma$ [37]	$0.06^{+0.11}_{-0.13}$
ωK^0_S	$0.13^{+0.08}_{-0.08}$	$[0.01, 0.21]$		$0.03^{+0.21}_{-0.21}$



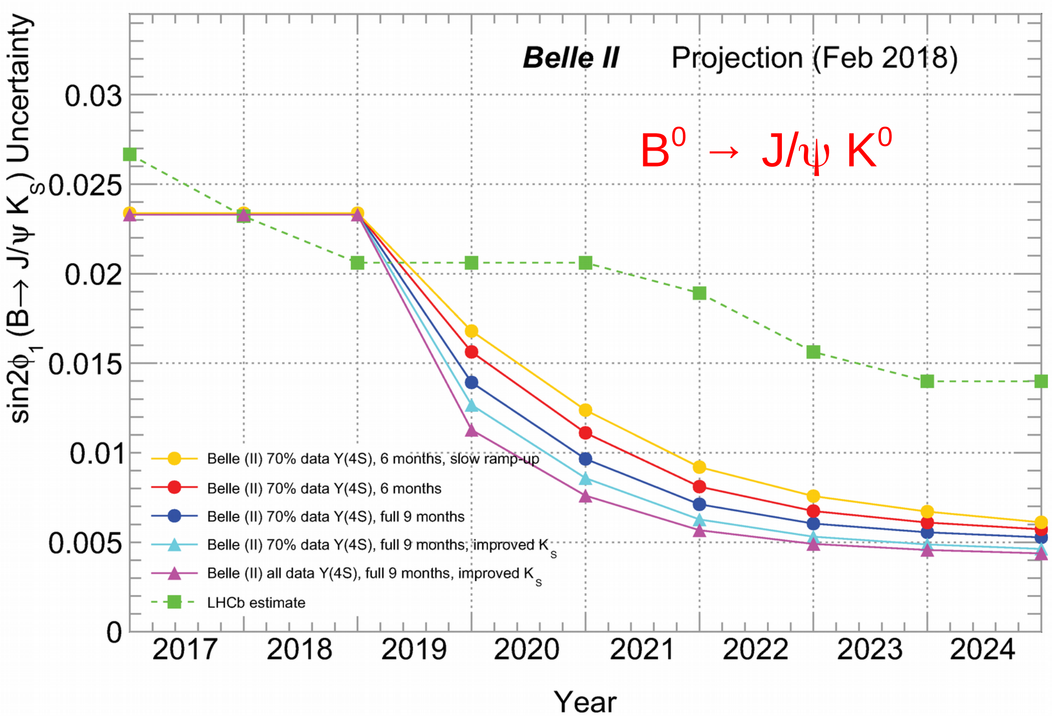
Simulation
(dream scenario)

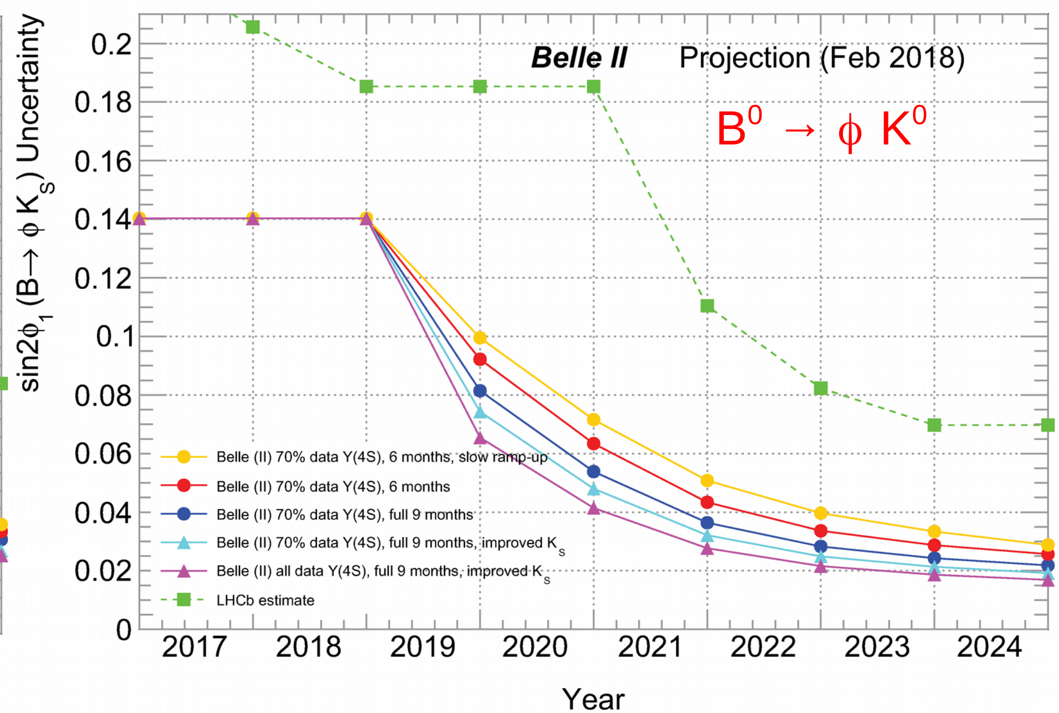
$\sin 2\phi_1 (\sin 2\beta)$ – projections

★ Full study based on Belle II simulation

♦ Extrapolation of Belle/BaBar results

	Channel	WA (2017) $\sigma(S)$	WA (2017) $\sigma(A)$	5 ab^{-1} $\sigma(S)$	5 ab^{-1} $\sigma(A)$	50 ab^{-1} $\sigma(S)$	50 ab^{-1} $\sigma(A)$
♦	$J/\psi K^0$	0.022	0.021	0.012	0.011	0.0052	0.0090
★	ϕK^0	0.12	0.14	0.048	0.035	0.020	0.011
★	$\eta' K^0$	0.06	0.04	0.032	0.020	0.015	0.008
♦	ωK_S^0	0.21	0.14	0.08	0.06	0.024	0.020
(★)	$K_S^0 \pi^0 \gamma$	0.20	0.12	0.10	0.07	0.031	0.021
♦	$K_S^0 \pi^0$	0.17	0.10	0.09	0.06	0.028	0.018





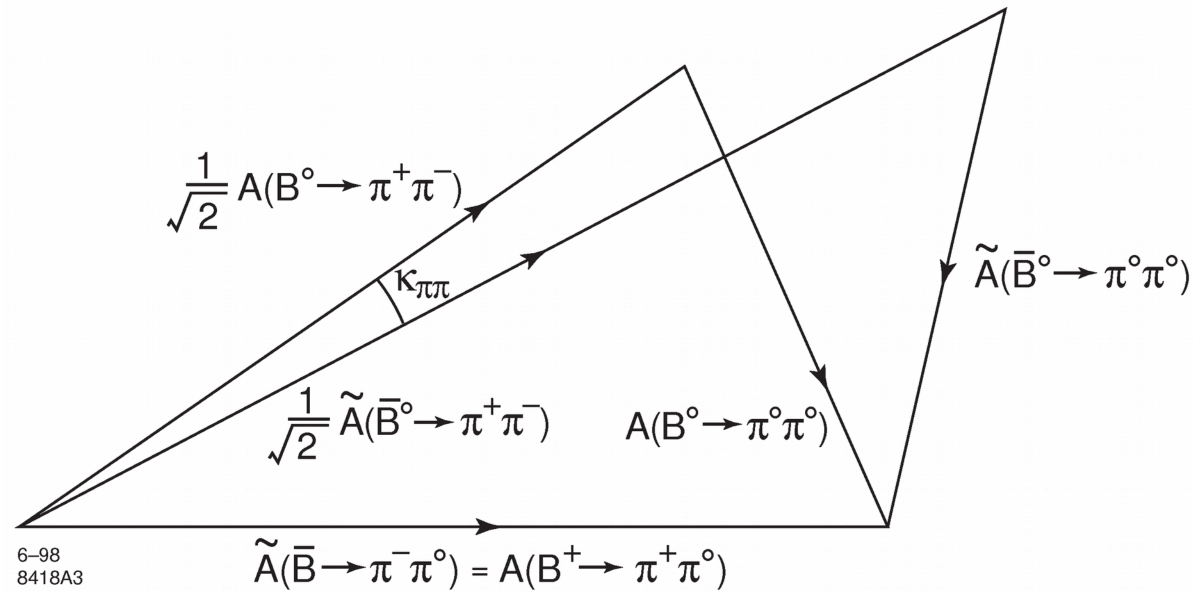
Note: extrapolations of the LHCb sensitivity are based on publicly available LHCb information

Determination of ϕ_2 (α): isospin analysis

- 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:

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



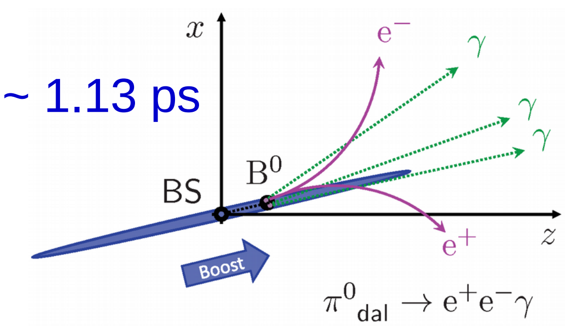
Gronau and London, PRL 65 (1990), 3381

- 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 (modes with π^0's in the final states are difficult at LHCb).

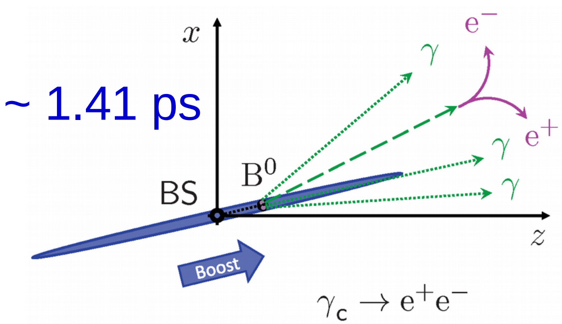
Determination of ϕ_2 (α): TD $B^0 \to \pi^0\pi^0$

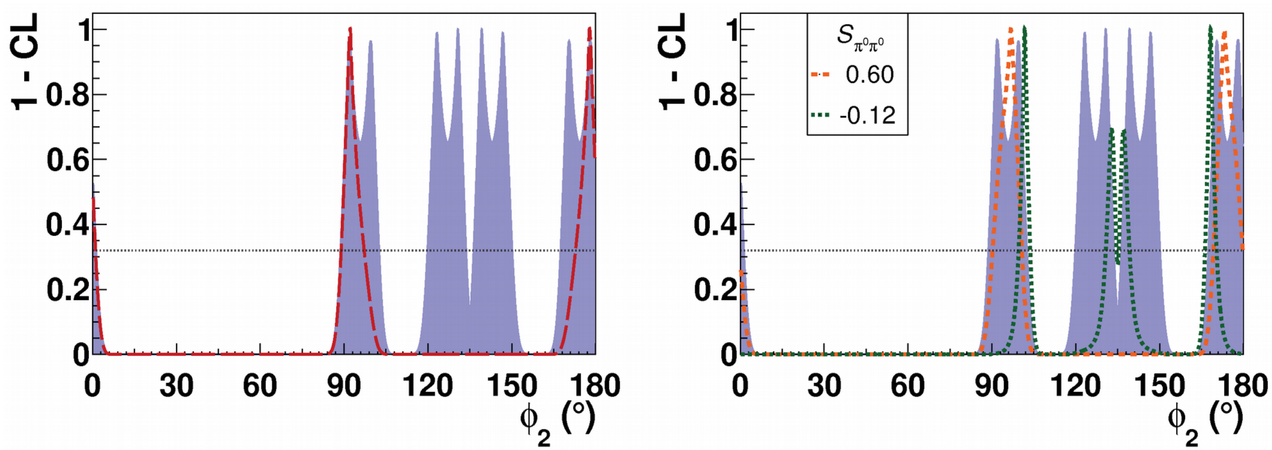
- Only at Belle II: TD CPV of $B^0 \to \pi^0\pi^0$, exploiting $\pi^0 \to \gamma e^+ e^-$ Dalitz decays and γ conversions;
- Expect ~270 signal events with full dataset;
- Predicted error on S^{00} ~ 0.28;
- This would reduce the ambiguity on ϕ_2 by a factor 2 or 4 (depending on central value).

Δt_{res} ~ 1.13 ps



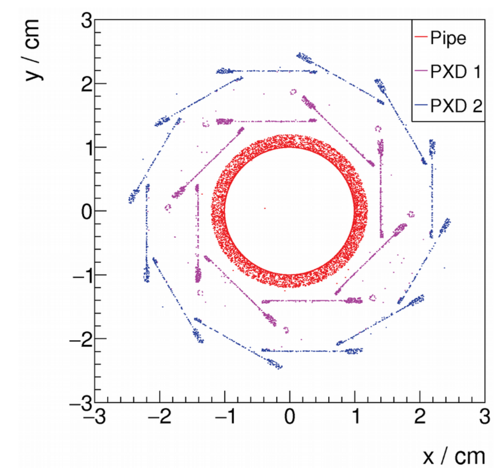
Δt_{res} ~ 1.41 ps





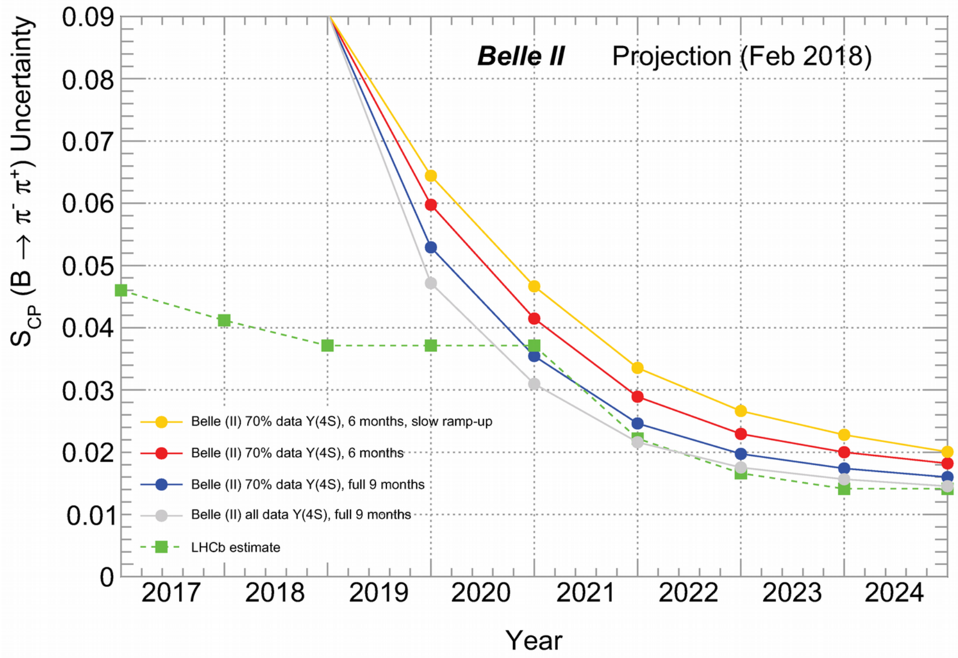
Filled area: extrapolation of Belle results to Belle II sensitivity.

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

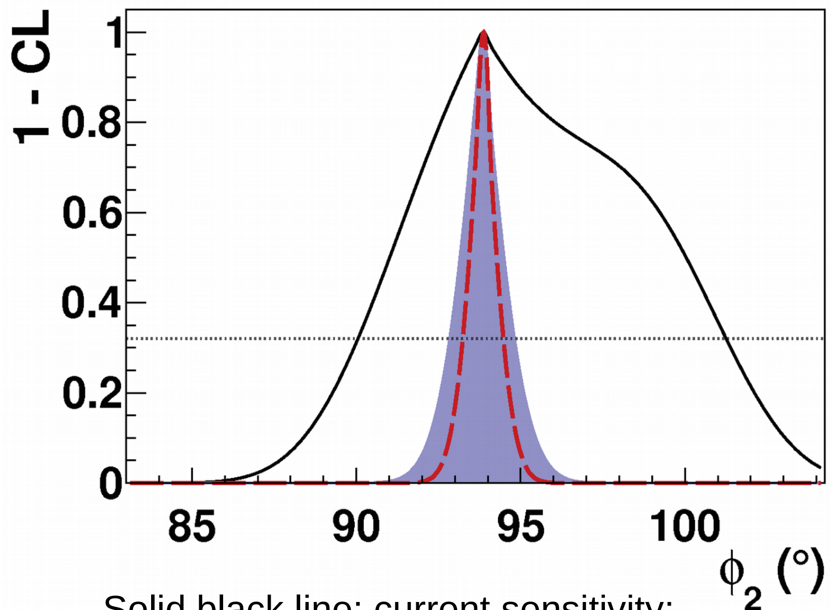


Belle II simulation
γ conversion points
(r, ϕ) view

Determination of ϕ_2 (α): projections



Channel	$\Delta\phi_2$ [°]
Current world average	$^{+4.4}_{-4.0}$
$B \to \pi\pi$	4.0
$B \to \rho\rho$	0.7
$B \to \pi\pi$ and $B \to \rho\rho$ Combined	0.6



Solid black line: current sensitivity;

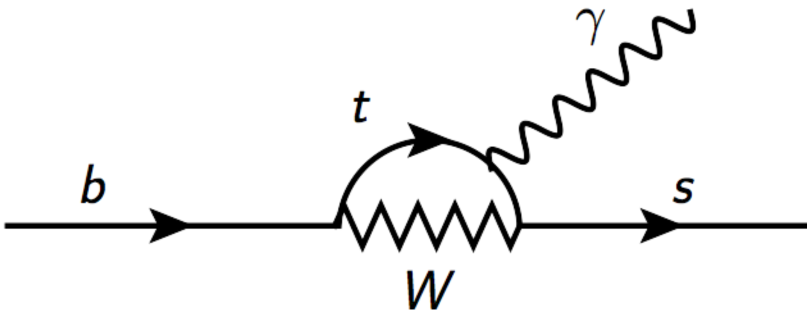
Filled area: extrapolation of Belle results to Belle II sensitivity;

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

- Also on $B^0 \to \pi^+\pi^-$ Belle II will be very competitive with LHCb;
- Unique sensitivity on $B^0 \to \rho^+\rho^-$ and $B^+ \to \rho^+\rho^0$;
- Combining all the analyses will bring the uncertainty well below 1°.

TD $b \to s\gamma$ transitions

- Even where TD CPV is not expected, we have high sensitivity to NP;
- In the SM, the photon in the $b \to s\gamma$ process is almost 100% polarized;



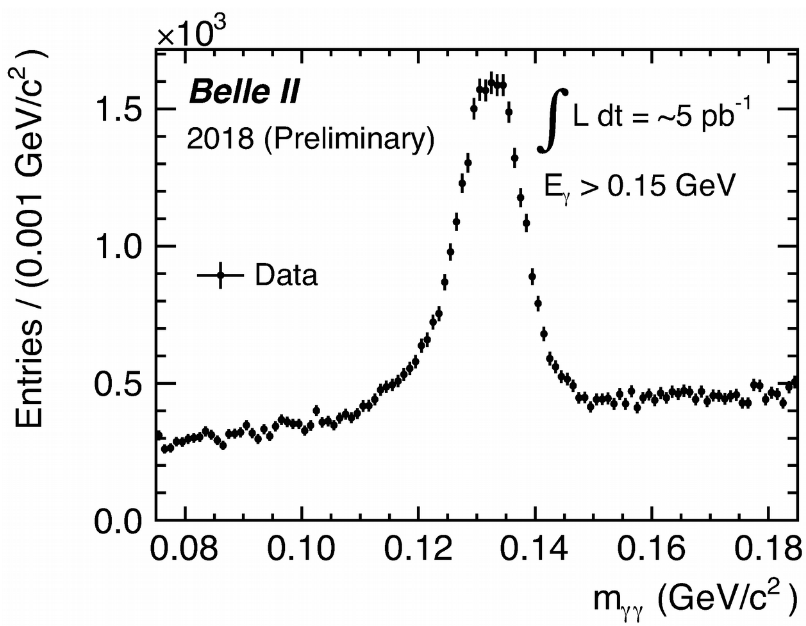
- In these kind of processes, interference between mixing and decay does not occur, so any large CP asymmetry would be an indication of New Physics (Right-handed currents, ...);
- Current WA limit on TD CPV ~0.20: plenty of space for New Physics;
- Most promising channels:
  - $B^0 \to K_S \pi^0 \gamma$; B decay vertex relies on extrapolation of K_S momentum
  - $B^0 \to K_S \pi^+ \pi^- \gamma$; Rich resonance structure, Dalitz Plot analysis

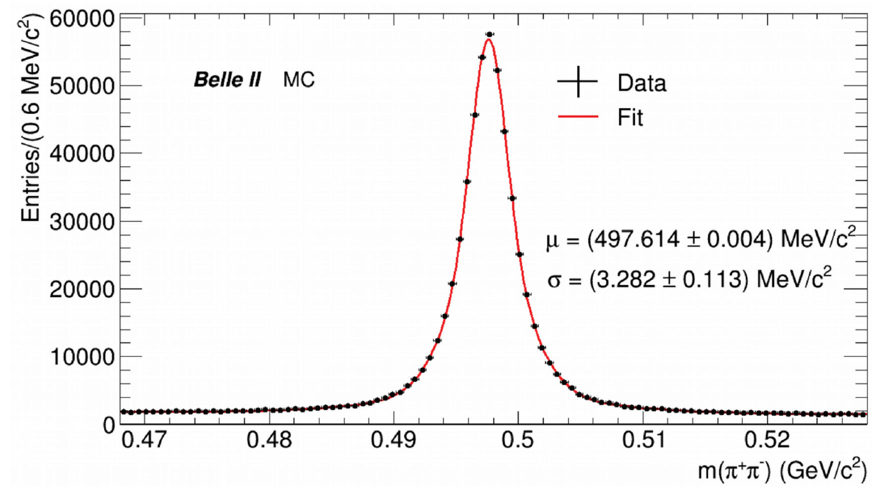
$K_S \pi^+ \pi^-$: $K_1(1270) \to K_S \rho^0 / K^{*+} \pi^-$

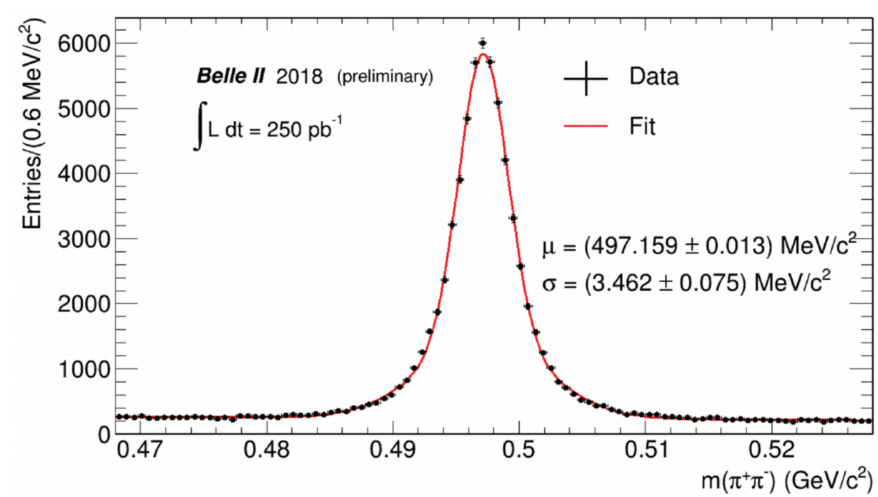
$\sigma(S)$	$5\ \mathrm{ab}^{-1}$	$50\ \mathrm{ab}^{-1}$
$K_S^0 \pi^0 \gamma$	0.10	0.031
$K_S^0 \pi^+ \pi^- \gamma$	0.12	0.037

Belle II Status

- Rediscovery of particle physics is underway!



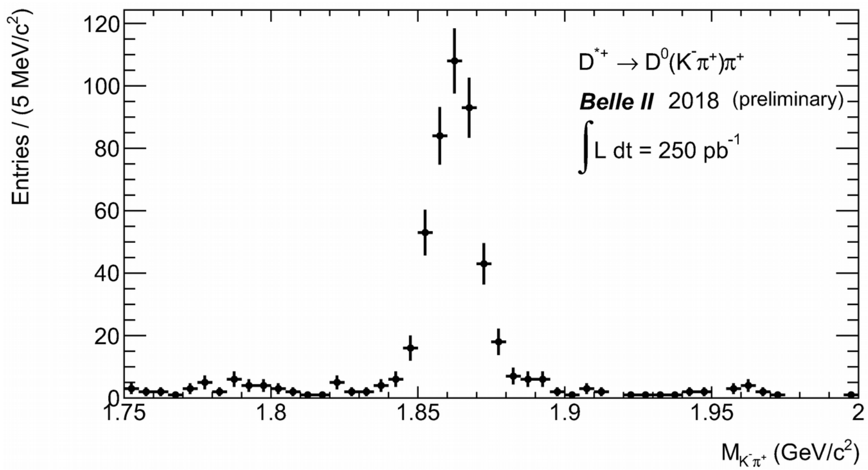


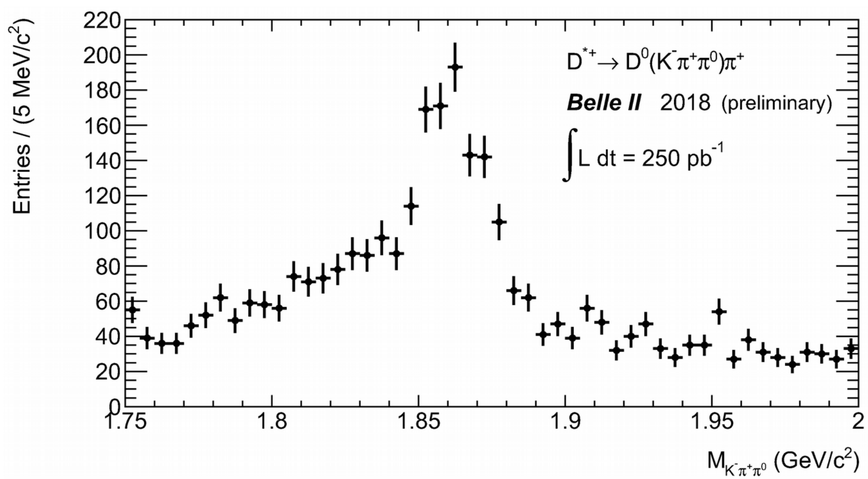


- Mass resolutions within a few % of what expected by the simulation.

Belle II Status

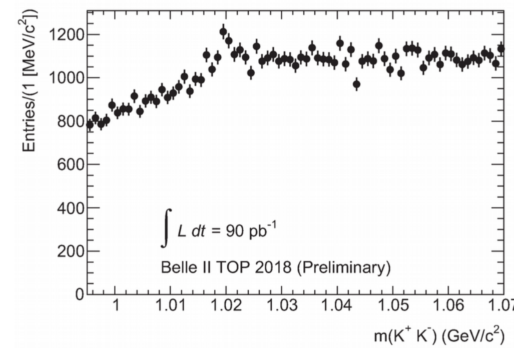
D mesons have been observed in several channels:



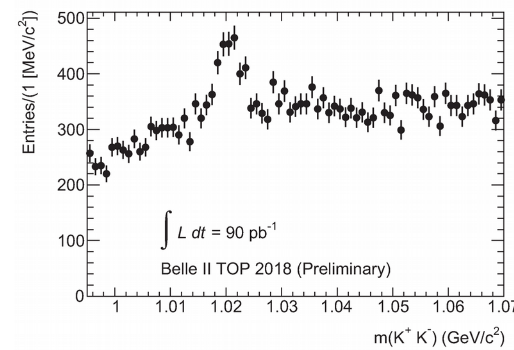


For more channels, please see
H. Atmacan's talk later this afternoon

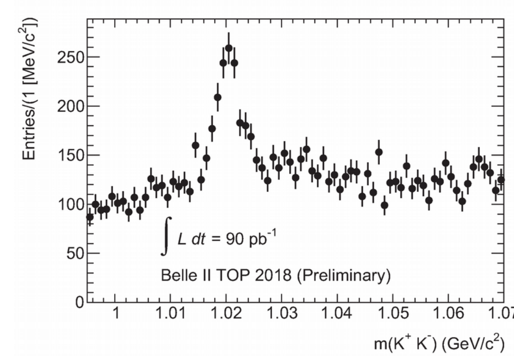
No PID selection



PID required for 1 K



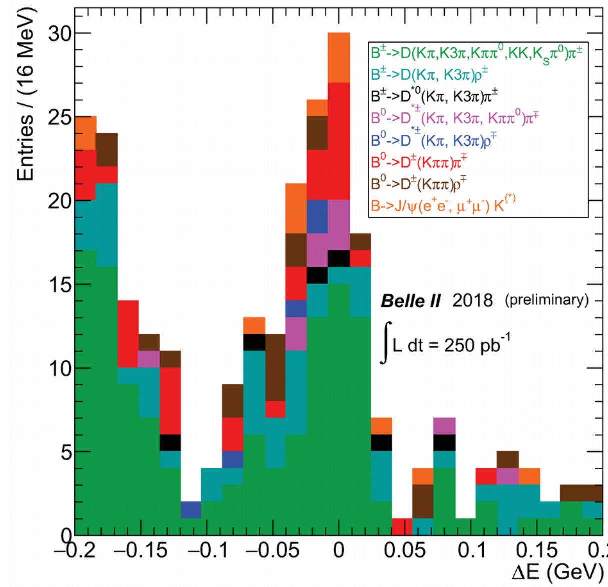
PID required for 2 K's

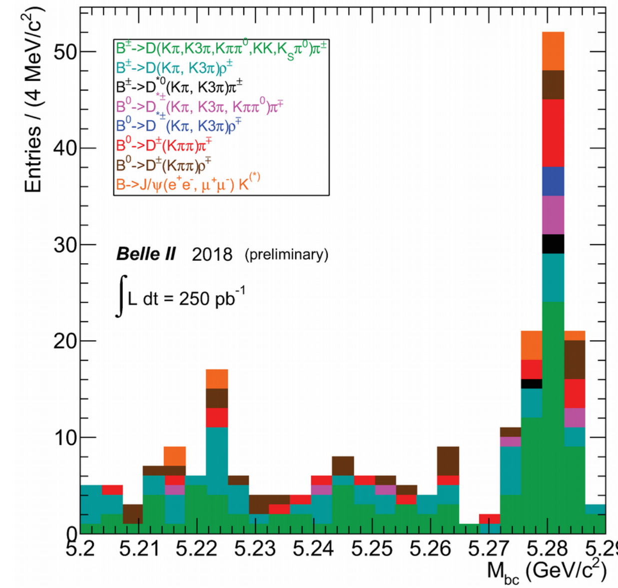


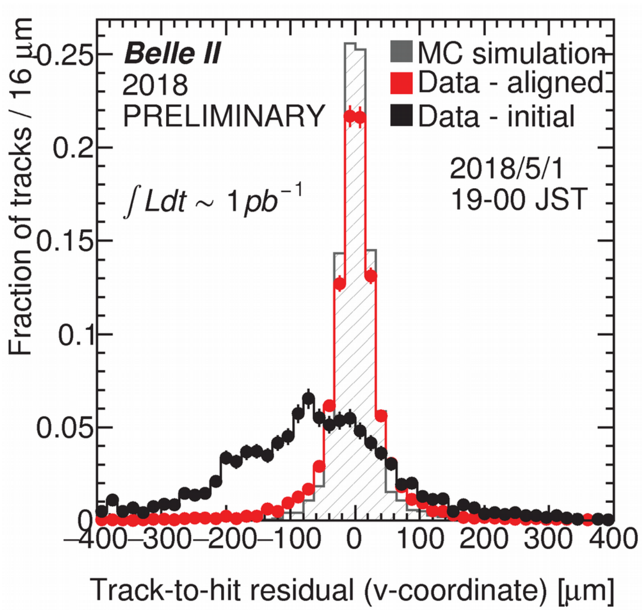
Impact of K PID on $\phi \to K^+K^-$.

Belle II Status

O(100) fully reconstructed B decays have been observed already.

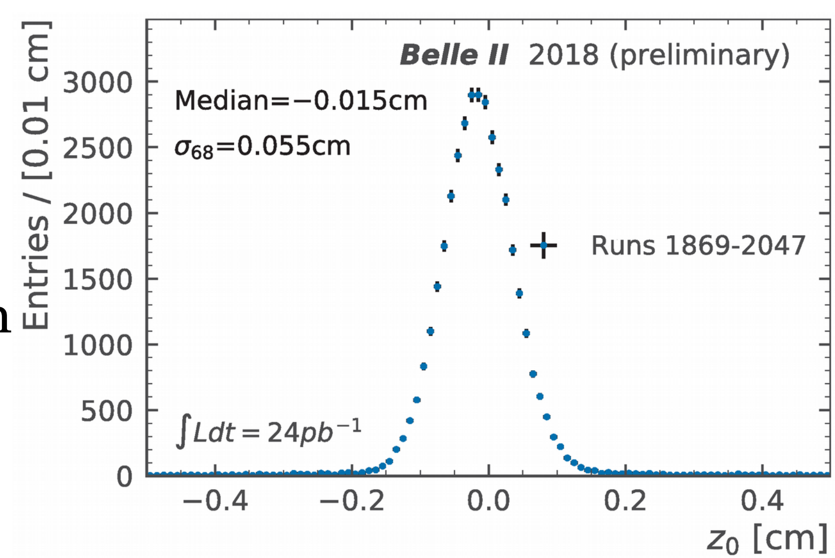




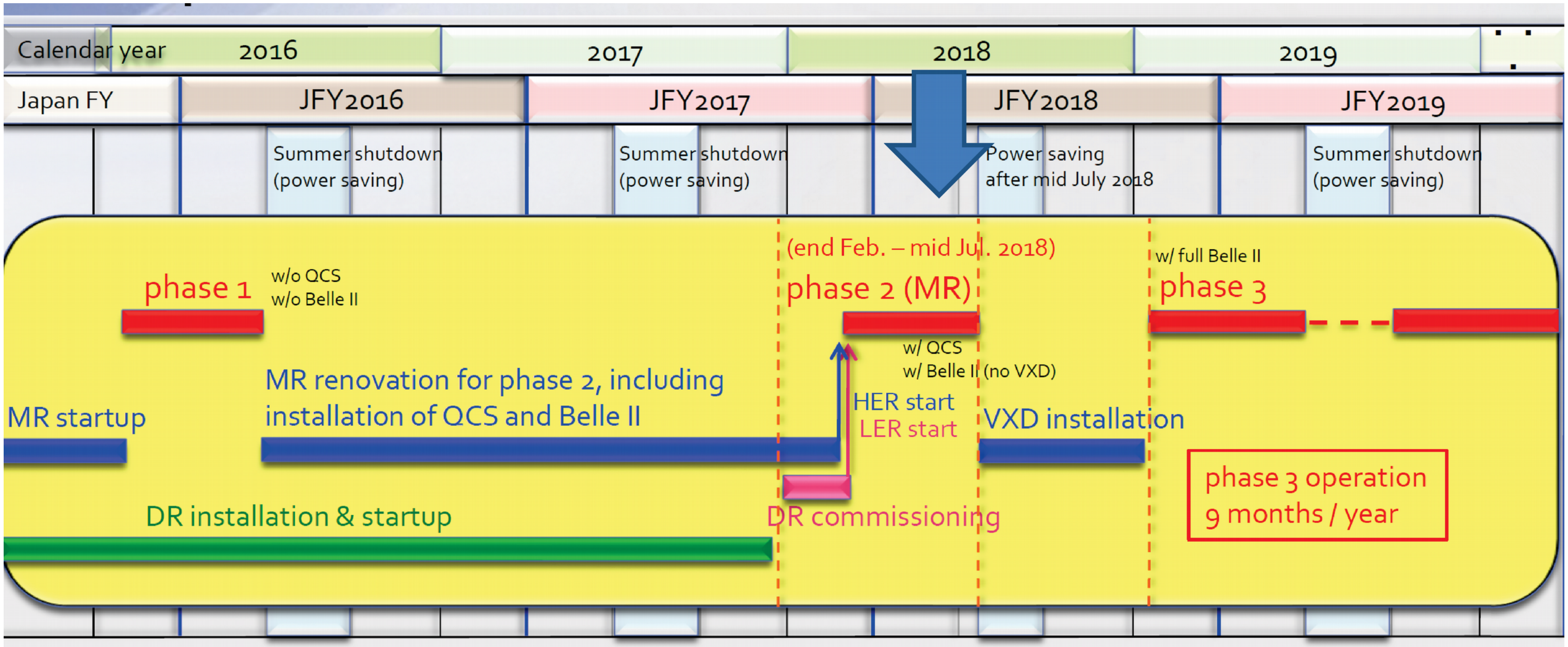


The VXD slice is already well aligned

z_0 for tracks coming from IP consistent with nano beam and 41 mrad crossing angle



Outlook



- Belle II has collected ~400 pb^{-1} (today showing results on up to ~250 pb^{-1});
- Phase 2 of commissioning ends July 17th, green light to proceed to Phase 3!
- In the Fall we will install Layer 1 (pixels) and Layers 3-6 (strips) of the vertex detector: due to technical difficulties in the construction, Layer 2 of the pixel detector will not be installed until 2020;
- Physics run with increasing luminosity will start in February 2019.

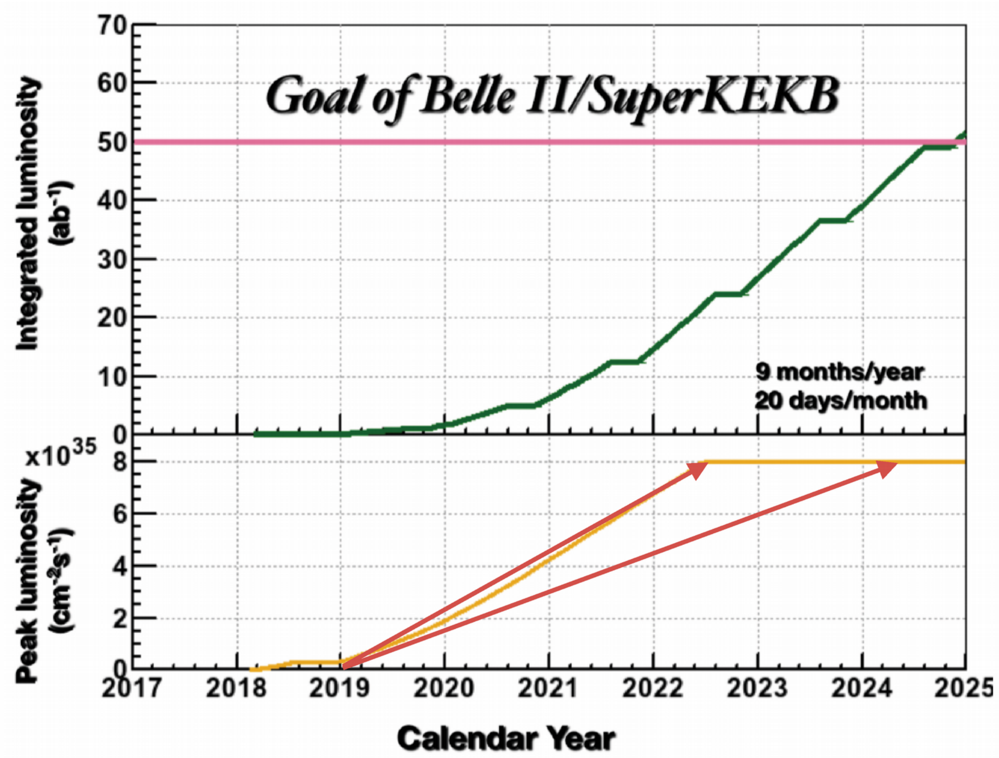
Conclusions

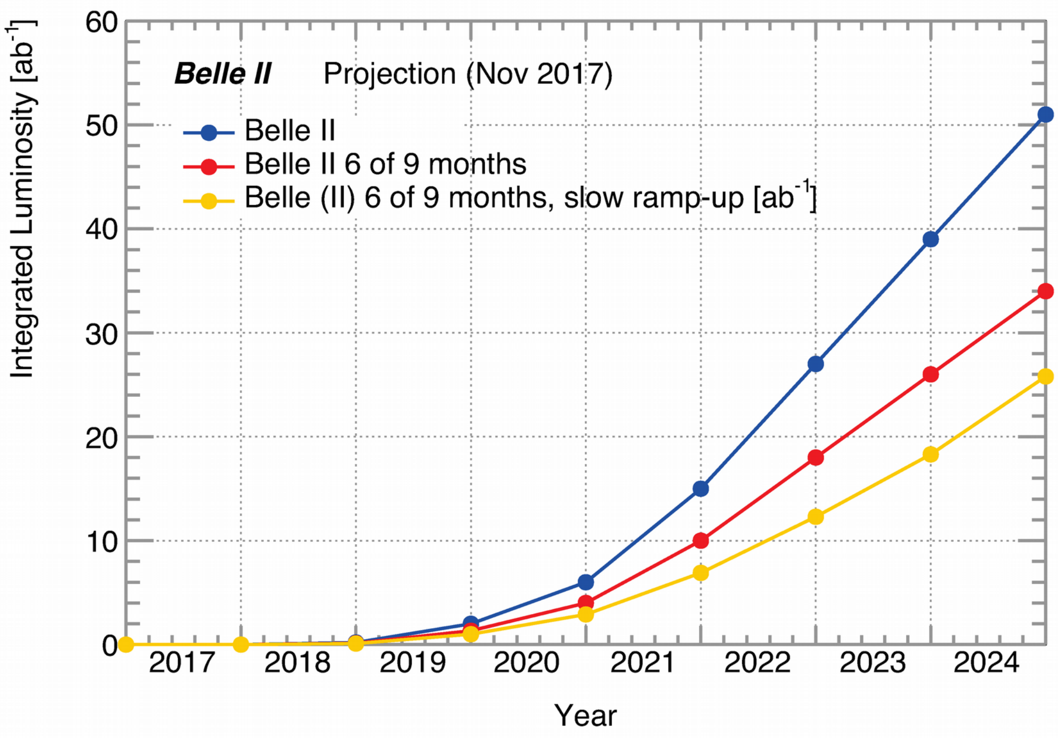
- SuperKEKB and Belle II smoothly started operations, rediscovery of B (and D, τ, …) physics is underway;
- Time-dependent CP violation is an important part of the physics program of Belle II;
- Compared to its predecessor, the Belle II Detector has enhanced vertexing, PID, and flavor tagging capabilities;
- We expect to have the best precision or be competitive with LHCb on most channels sensitive to the CKM angles ϕ_1 and ϕ_2, in particular on the penguin dominated modes;
- Channels with π^0's, $\eta^{(\prime)}$'s, K^0_L's, … in the final state will be much better determined at Belle II than LHCb;

- The physics run will start in February 2019.

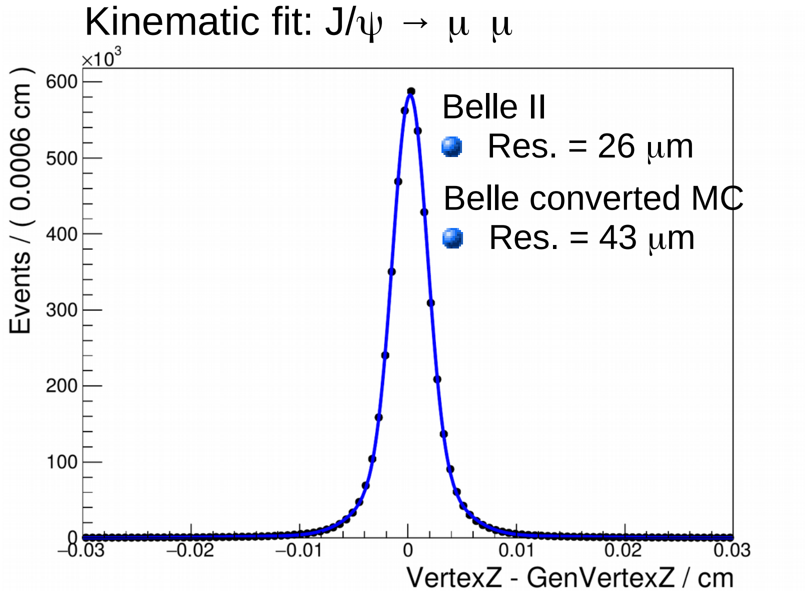
Backup slides

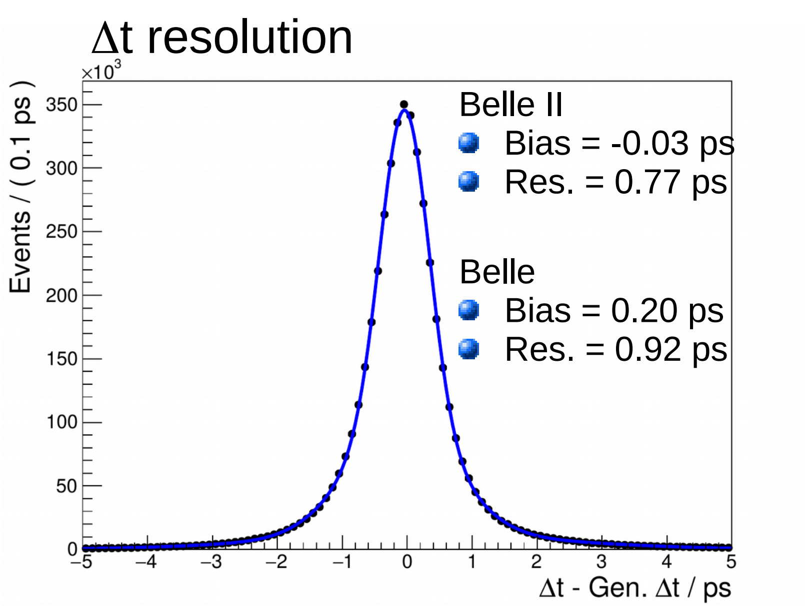
Data taking scenarios





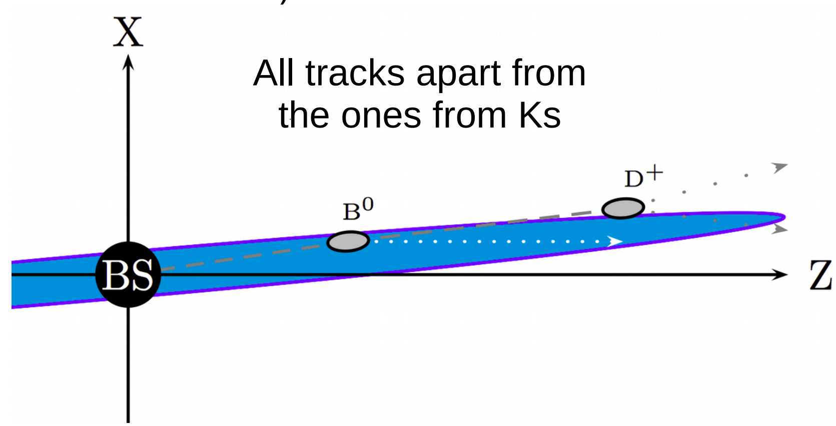
Vertexing

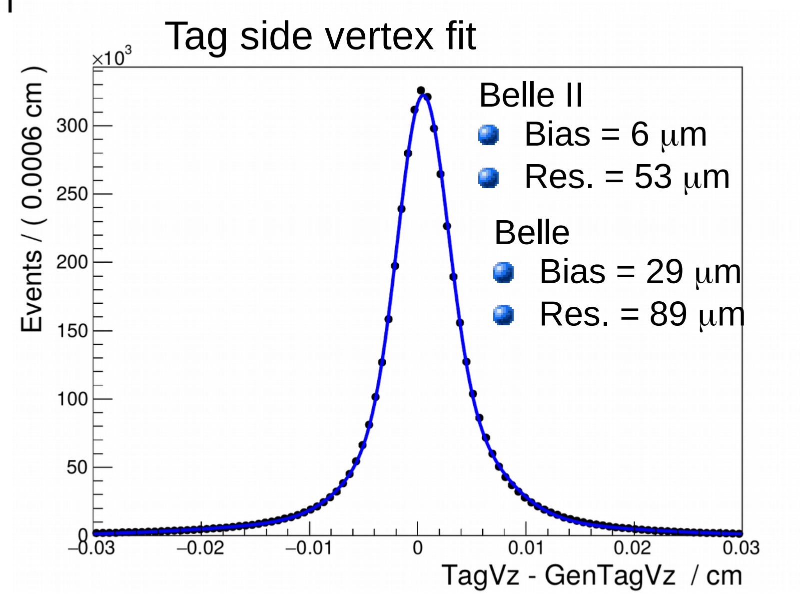




Tag side vertex fit: Using RAVE Adaptive Vertex Fit (AVF) algorithm:

Down-weights outliers dynamically, instead of using hard cutoffs (important for 3+ track vertices). CMS NOTE 2008/033.





RAVE Adaptive Vertex Fitter

Down-weights outliers dynamically, instead of using hard cutoffs (important for 3+ track vertices).

Minimization of the weighted least sum of squares

Journal of Physics G, 34:N343–N356, 2007.

$$w_i\left(\chi_i^2\right) = \frac{\exp(-\chi_i^2/2T)}{\exp(-\chi_i^2/2T) + \exp(-\sigma_{\text{cut}}^2/2T)}$$

Weight

square of the standardized residual

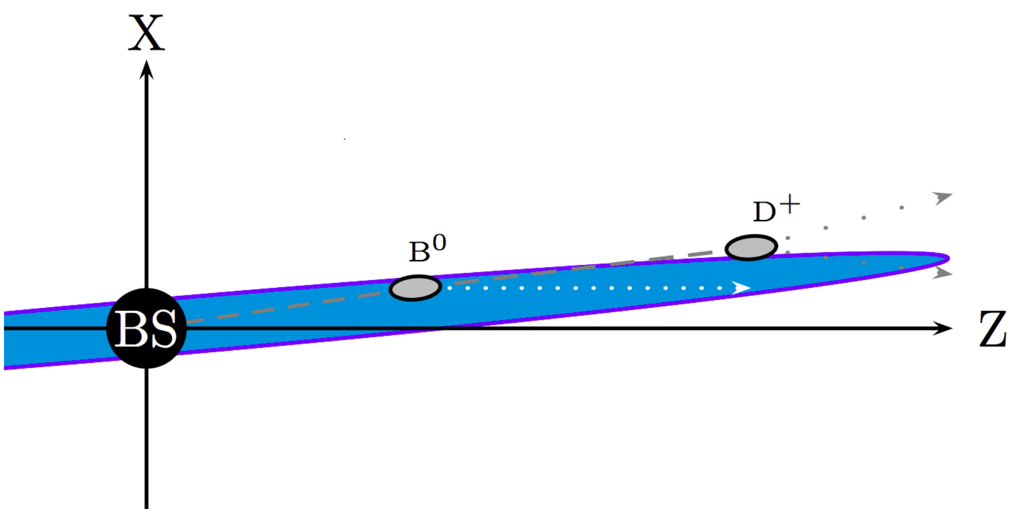
"temperature" parameter
"softness" of the weight function

cutoff parameter

in each iteration step
the temperature parameter is lowered

$$T_i = 1 + r \cdot (T_{i-1} - 1)$$

0<r<1



Flavor Tagger

Two steps process to determine the flavor of the B_{tag}:

1) Build 13 multivariate discriminators to look for the following topologies, which are (more or less) strongly correlated with the B_{tag} flavor:

Categories	Targets for $\overline{B}^0$
Electron	e^-
Intermediate Electron	e^+
Muon	μ^-
Intermediate Muon	μ^+
Kinetic Lepton	l^-
Intermediate Kinetic Lepton	l^+
Kaon	K^-
Kaon-Pion	K^-, π^+
Slow Pion	π^+
Maximum P*	l^-, π^-
Fast-Slow-Correlated (FSC)	l^-, π^+
Fast Hadron	π^-, K^-
Lambda	Λ

Underlying decay modes

$\overline{B}^0 \rightarrow D^{*+}\ \overline{\nu}_\ell\ \ell^-$

$\quad \hookrightarrow D^0\ \pi^+$

$\quad\quad \hookrightarrow X\ K^-$

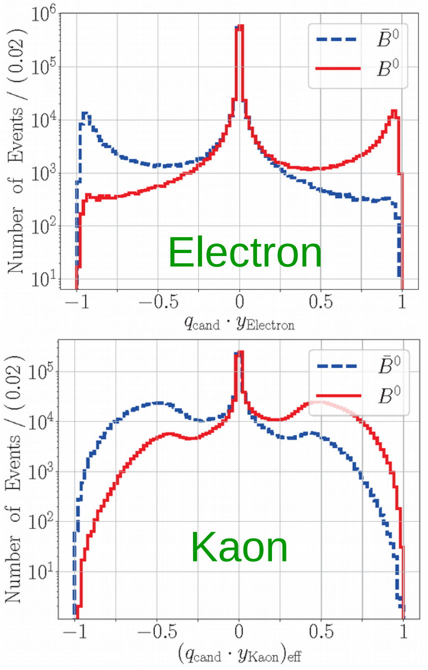
$\overline{B}^0 \rightarrow D^+\ \pi^-\ (K^-)$

$\quad \hookrightarrow K^0\ \nu_\ell\ \ell^+$

$\overline{B}^0 \rightarrow \Lambda_c^+\ X^-$

$\quad \hookrightarrow \Lambda\ \pi^+$

$\quad\quad \hookrightarrow p\ \pi^-$



2) Use the output of the 13 discriminators above as input for another multivariate algorithm, whose output $y = q \cdot r$ is used in physics analyses.

tag value (+1 or -1)

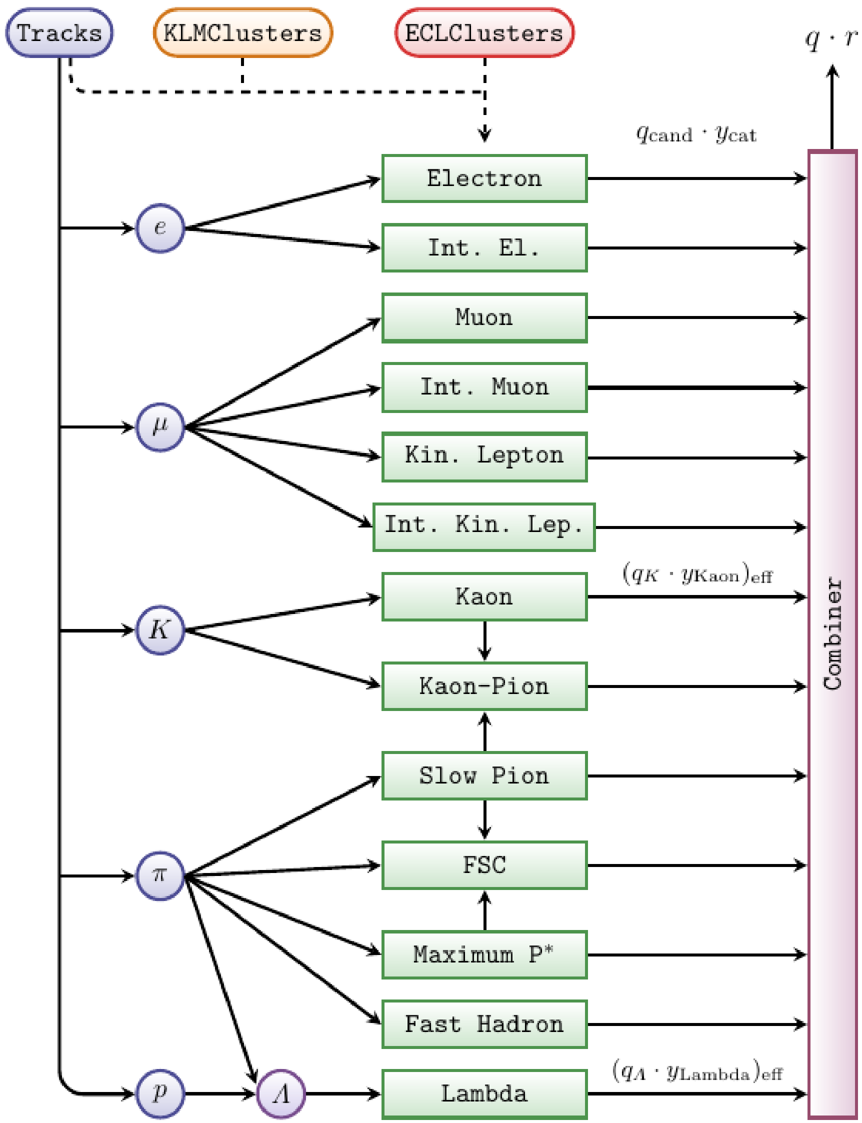
dilution factor

Flavor Tagger

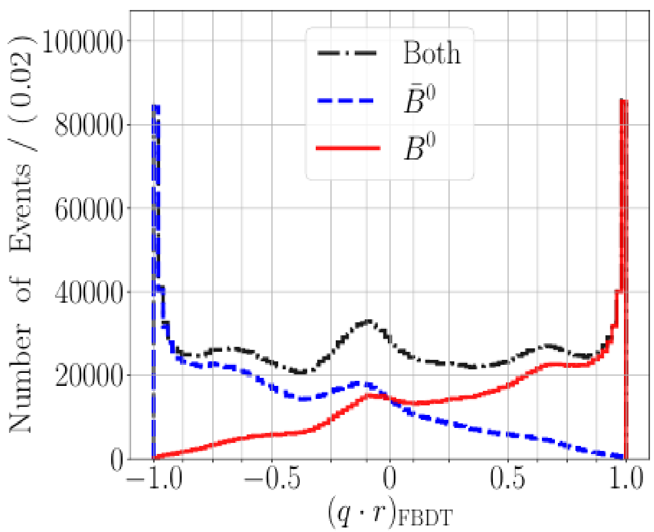
Variables entering the multivariate discriminant for each category:

Categories	Discriminating input variables
Electron Int. Electron	$\mathcal{L}_e$, p^*, $p^*_{\rm t}$, p, $p_{\rm t}$, $\cos\theta$, d_0, $\|\boldsymbol{x}\|$, $M^2_{\rm rec}$, E^W_{90}, $p^*_{\rm miss}$, $\cos\theta^*_{\rm miss}$, $\cos\theta^*_{\rm T}$, p-val.
Muon Int. Muon	$\mathcal{L}_\mu$, p^*, $p^*_{\rm t}$, p, $p_{\rm t}$, $\cos\theta$, d_0, $\|\boldsymbol{x}\|$, $M^2_{\rm rec}$, E^W_{90}, $p^*_{\rm miss}$, $\cos\theta^*_{\rm miss}$, $\cos\theta^*_{\rm T}$, p-val.
Kin. Lepton Int. Kin. Lep.	$\mathcal{L}_e$, $\mathcal{L}_\mu$, p^*, $p^*_{\rm t}$, p, $p_{\rm t}$, $\cos\theta$, d_0, $\|\boldsymbol{x}\|$, $M^2_{\rm rec}$, E^W_{90}, $p^*_{\rm miss}$, $\cos\theta^*_{\rm miss}$, $\cos\theta^*_{\rm T}$, p-val
Kaon	$\mathcal{L}_K$, p^*, $p^*_{\rm t}$, p, $p_{\rm t}$, $\cos\theta$, d_0, $\|\boldsymbol{x}\|$, $n_{K^0_S}$, $\sum p^2_{\rm t}$, $M^2_{\rm rec}$, E^W_{90}, $p^*_{\rm miss}$, $\cos\theta^*_{\rm miss}$, $\cos\theta^*_{\rm T}$, χ^2
Slow Pion Fast Hadron	$\mathcal{L}_\pi$, $\mathcal{L}_e$, $\mathcal{L}_K$, p^*, $p^*_{\rm t}$, p, $p_{\rm t}$, $\cos\theta$, d_0, $\|\boldsymbol{x}\|$, $n_{K^0_S}$, $\sum p^2_{\rm t}$, $M^2_{\rm rec}$, E^W_{90}, $p^*_{\rm miss}$, $\cos\theta^*_{\rm miss}$, $\cos\theta^*_{\rm T}$, p-val.
Kaon-Pion	$\mathcal{L}_K$, $y_{\rm Kaon}$, $y_{\rm SlowPion}$, $\cos\theta^*_{K\pi}$, $q_K \cdot q_\pi$
Maximum P*	p^*, $p^*_{\rm t}$, p, $p_{\rm t}$, d_0, $\|\boldsymbol{x}\|$, $\cos\theta^*_{\rm T}$
FSC	$\mathcal{L}_{K{\rm Slow}}$, $p^*_{\rm Slow}$, $p^*_{\rm Fast}$, $\cos\theta^*_{\rm T,\,Slow}$, $\cos\theta^*_{\rm T,\,Fast}$, $\cos\theta^*_{\rm SlowFast}$, $q_{\rm Slow}\cdot q_{\rm Fast}$
Lambda	$\mathcal{L}_p$, $\mathcal{L}_\pi$, p^*_Λ, p_Λ, p^*_p, p_p, p^*_π, p_π, q_Λ, M_Λ, $n_{K^0_S}$, $\cos\theta_{\boldsymbol{x}_\Lambda,\boldsymbol{p}_\Lambda}$, $\|\boldsymbol{x}_\Lambda\|$, σ^{zz}_Λ, p-val.

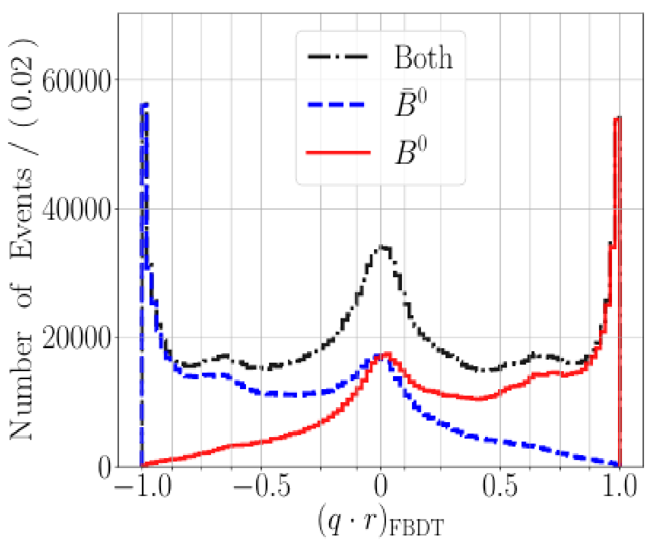
Flavor Tagger



Belle II MC: Eff = 37 %

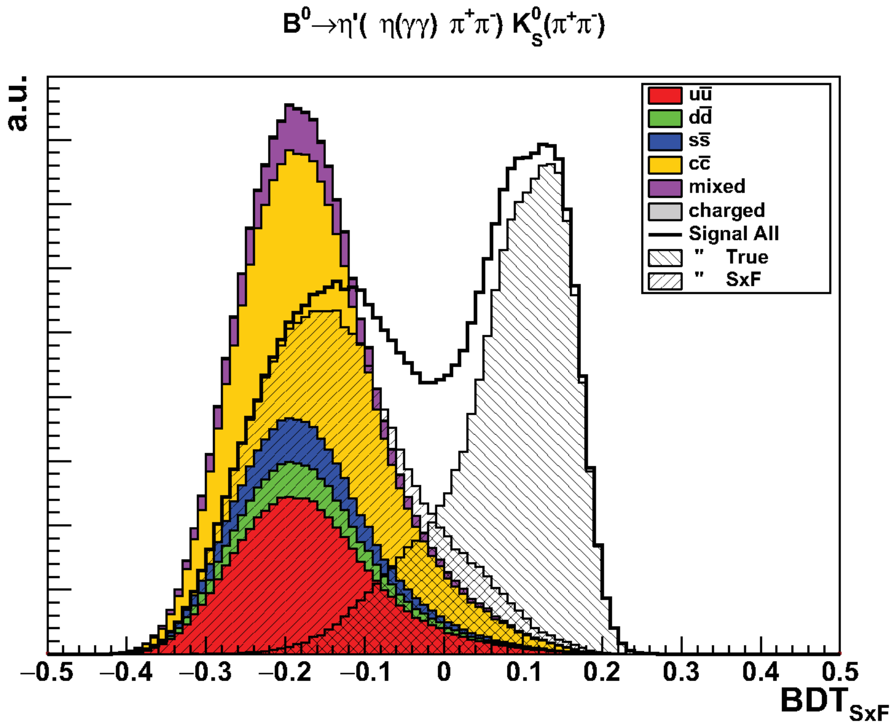


Belle MC: Eff = 34 % (Belle 30 %)



$\sin 2\phi_1$: $B^0 \rightarrow \eta' K^0$

- This is the most sensitive penguin dominated mode, one of the theoretically cleanest, and a difficult one at LHCb;
- Several different combinations of $\eta' \rightarrow \eta(\gamma\gamma)\pi^+\pi^-$, $\eta(\pi^+\pi^-\pi^0)\pi^+\pi^-$, $\rho^0\gamma$; $K_S \rightarrow \pi^+\pi^-$, $\pi^0\pi^0$; K_L;
- One of the main challenges of this analysis is the correct choice of the signal candidate (versus the Self Cross-Feed – SXF);
- Optimal choice of the signal candidate currently under discussion;



- Impact of beam background on Δt resolution is also a concern;
- This (different to most others) mode will be dominated by systematics at the end of data taking.

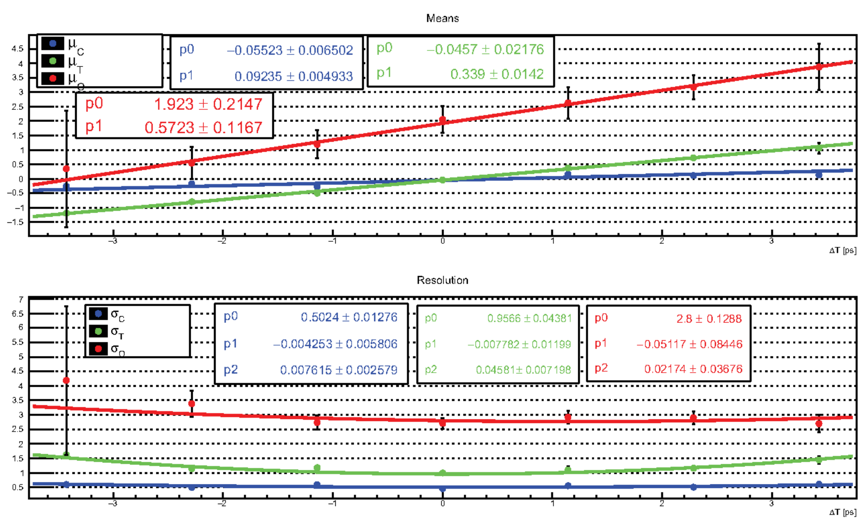
$\sin 2\phi_1$: $B^0 \to \eta' K^0$

- Crucial aspect of (every TD) analysis: Δt resolution function;
- Starting on the simulation with an approach “a la BaBar”: we fit the Δt resolution with the sum of three Gaussians;
- Fundamental to model many small effects (e.g. charm content in the ROE);
- This will be our highest priority once we get the first Phase3 data.

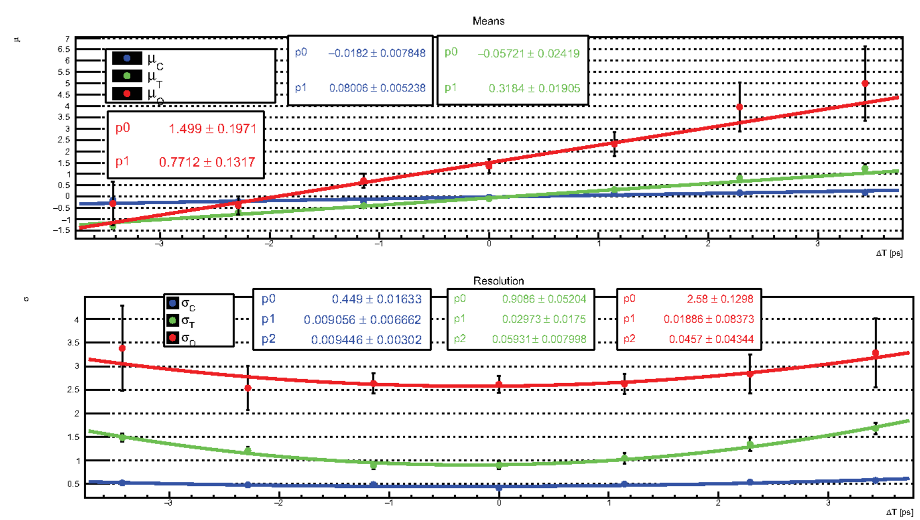
core tail outlier

$$\mathcal{R}(\delta_{\Delta T}) = \alpha \cdot \mathcal{G}(\delta_{\Delta T}, \mu_C, \sigma_C) + (1-\alpha)[\beta \cdot \mathcal{G}(\delta_{\Delta T}, \mu_T, \sigma_T) + (1-\beta) \cdot \mathcal{G}(\delta_{\Delta T}, \mu_O, \sigma_O)]$$

$\eta_{\gamma\gamma} K_S^0(\pm)$

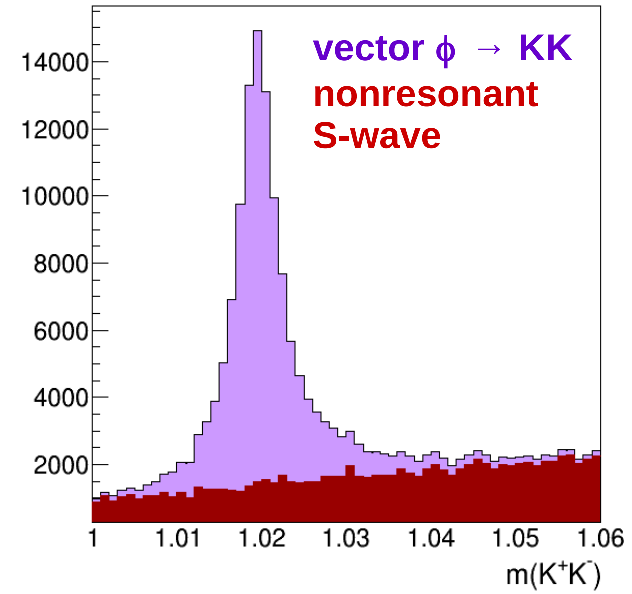


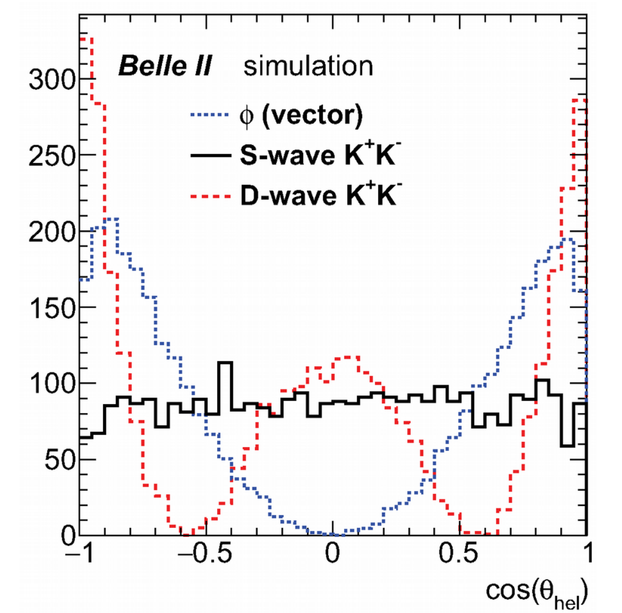
$\eta_{3\pi} K_S^0(\pm)$



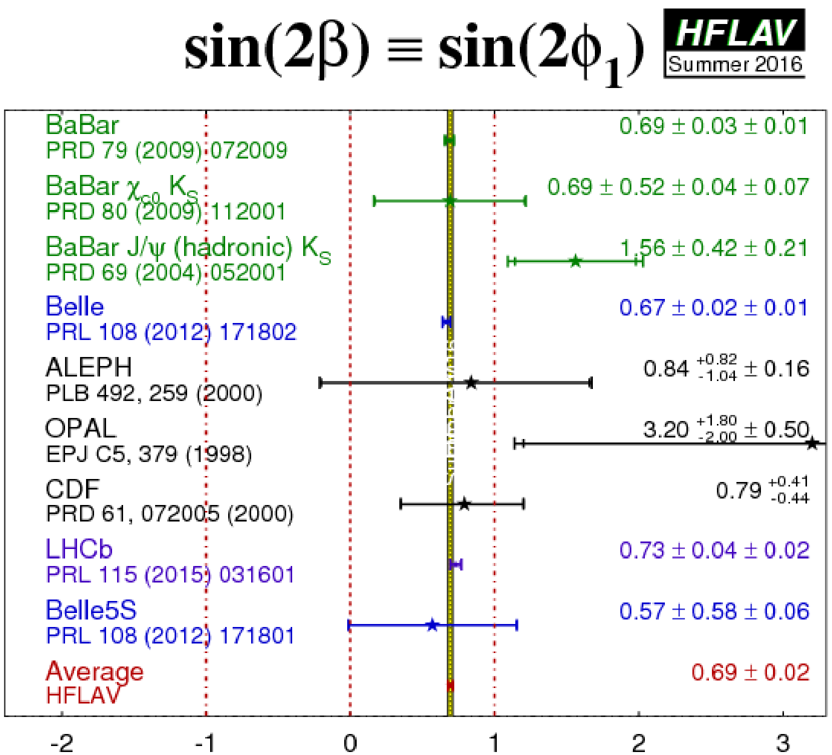
$\sin 2\phi_1$: $B^0 \to \phi K^0$

- Another theoretically clean mode, there will be competition with LHCb;
- BaBar and Belle reached the ultimate sensitivity with a Dalitz Plot analysis of $B^0 \to K^+K^-K^0$;
- In order to publish a result with the first 1-2 ab^{-1}, we propose a simpler quasi-two body approach;
- We have to separate the ϕ resonance from the non-negligible K^+K^- component, which carries a different weak phase;
- We plan to separate these two components using the pair of variables (m_{KK}, $\cos\theta_{hel}$);
- No bias seen from the simulation.

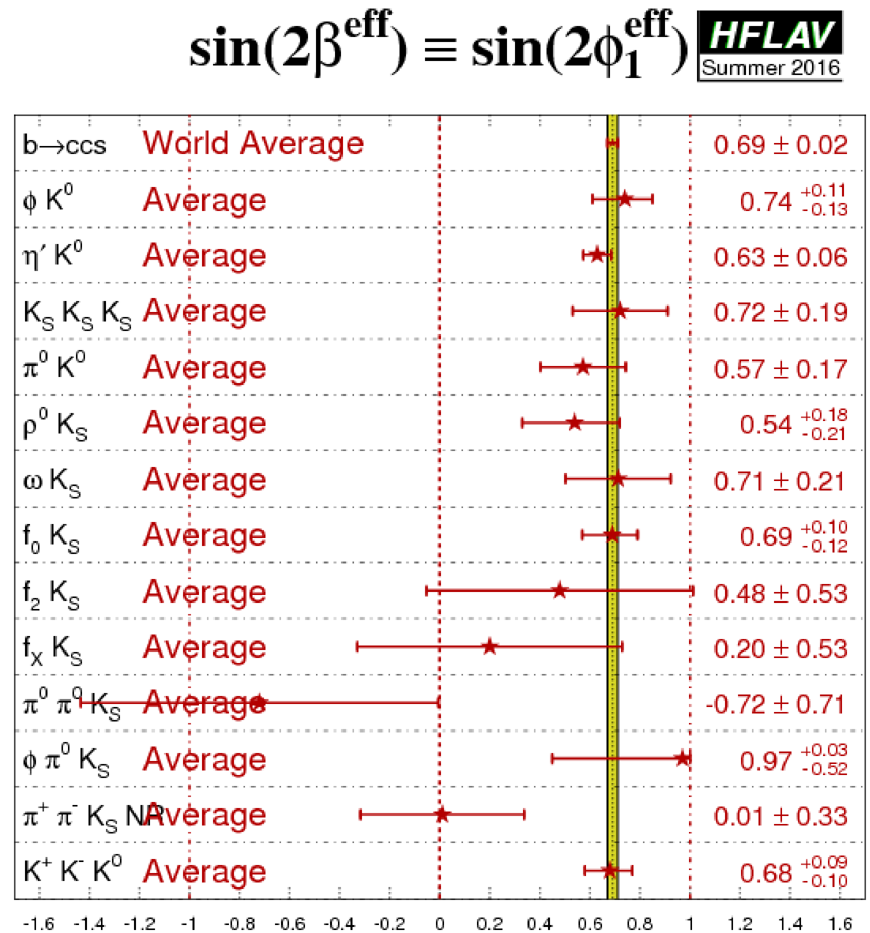




$\sin 2\phi_1$ – HFLAV WA



Golden modes



Penguin dominated modes