First Look at CKM Parameters from Early Belle II Data

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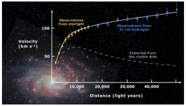
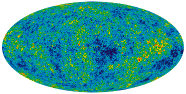
Belle II

The Need for Belle II

Strong evidence that physics beyond the SM exists:

- Temperature fluctuations of cosmic background radiation and rotation curves from spiral galaxies indicate existence of Dark Matter.

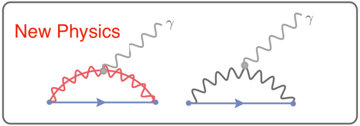




- CP violation predicted by the CKM matrix is several orders of magnitudes too small to account for the observed matter anti-matter asymmetry in the universe.

Intensity Frontier Experiments:

Indirect search of New Physics through quantum effects.

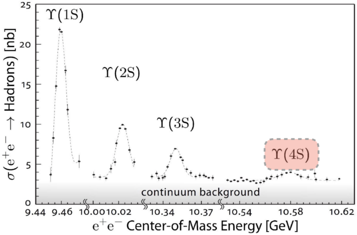


Belle II produces large quantities of b quarks for such searches.

For $e^+e^- \to \tau^+\tau^-$, e.g., F. Tenchini @Flavor2019

Physics of an e^+e^- B Factory

- Collide e^+ and e^- at $\sqrt{s} = 10.58$ GeV to create $\Upsilon(4S)$ resonance.



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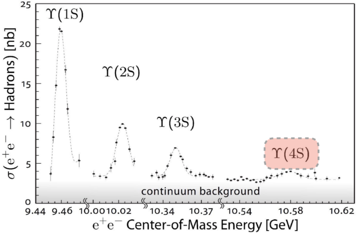

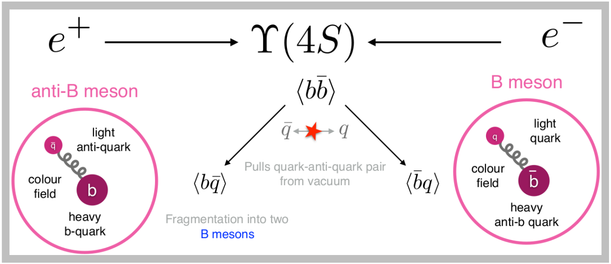

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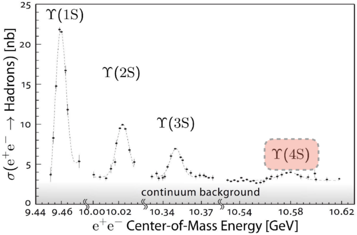
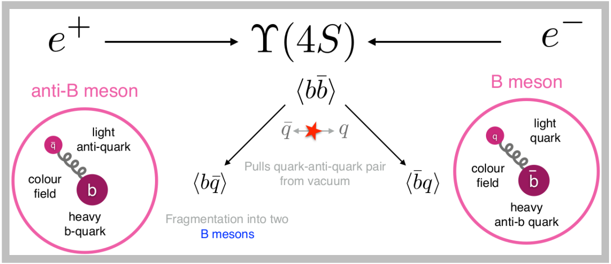
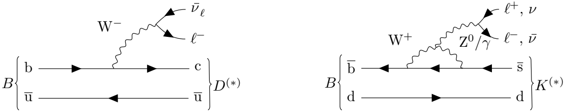
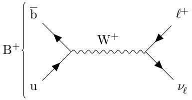
- $\Upsilon(4S)$ decays to B^+B^- and $B^0\bar{B}^0$ 96% of the time.
- Reconstruct B mesons from final state particles in detector.









Broad program to search for New Physics in B, D and τ decays

- **New CP violating phases?**
  - $\Rightarrow$ *CPV in B and D decays.*
- **Signatures of charged Higgs bosons or leptoquarks?**
  - $\Rightarrow$ $B^+ \to \ell^+ \nu$ *and* $D^{(*)}\tau\nu$ *decays.*
- **Right-handed currents from new physics?**
  - $\Rightarrow$ *Photon polarization in radiative decays.*
- **New physics in flavor changing neutral current transitions?**
  - $\Rightarrow$ *Electroweak penguin decays* $b \to s\ell^+\ell^-, s\nu\bar{\nu}$.
- **Exotic tetraquark, pentaquark and hybrid QCD states?**
- **Hidden dark sector accessible from B decays?**

The Belle II Physics Book (1808.10567)
[All MC plots/projections shown today]

Observables	Expected the. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	1.0	Belle II
ϕ_3 [°]	***	1.0	LHCb/Belle II
$\lvert V_{cb}\rvert$ incl.	***	1%	Belle II
$\lvert V_{cb}\rvert$ excl.	***	1.5%	Belle II
$\lvert V_{ub}\rvert$ incl.	**	3%	Belle II
$\lvert V_{ub}\rvert$ excl.	**	2%	Belle II/LHCb
CP Violation			
$S(B \to \phi K^0)$	***	0.02	Belle II
$S(B \to \eta' K^0)$	***	0.01	Belle II
$\mathcal{A}(B \to K^0\pi^0)[10^{-2}]$	***	4	Belle II
$\mathcal{A}(B \to K^+\pi^-)$ $[10^{-2}]$	***	0.20	LHCb/Belle II
(Semi-)leptonic			
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**	3%	Belle II
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	7%	Belle II
$R(B \to D\tau\nu)$	***	3%	Belle II
$R(B \to D^*\tau\nu)$	***	2%	Belle II/LHCb
Radiative & EW Penguins			
$\mathcal{B}(B \to X_s\gamma)$	**	4%	Belle II
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***	0.005	Belle II
$S(B \to K_S^0\pi^0\gamma)$	***	0.03	Belle II
$S(B \to \rho\gamma)$	**	0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\bar{\nu})$ $[10^{-6}]$	***	15%	Belle II
$\mathcal{B}(B \to K\nu\bar{\nu})$ $[10^{-6}]$	***	20%	Belle II
$R(B \to K^*\ell\ell)$	***	0.03	Belle II/LHCb
Charm			
$\mathcal{B}(D_s \to \mu\nu)$	***	0.9%	Belle II
$\mathcal{B}(D_s \to \tau\nu)$	***	2%	Belle II
$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	**	0.03	Belle II
$\lvert q/p\rvert(D^0 \to K_S^0\pi^+\pi^-)$	***	0.03	Belle II
$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	***	4	Belle II
Tau			
$\tau \to \mu\gamma$ $[10^{-10}]$	***	< 50	Belle II
$\tau \to e\gamma$ $[10^{-10}]$	***	< 100	Belle II
$\tau \to \mu\mu\mu$ $[10^{-10}]$	***	< 3	Belle II/LHCb

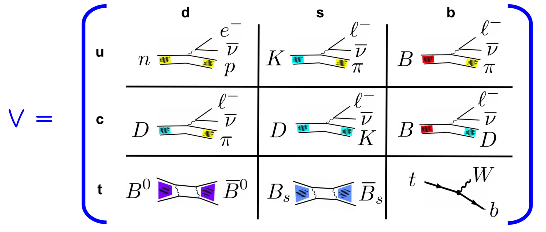
& Quarkonium... Dark Sector...

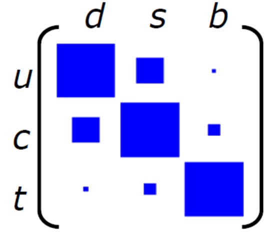
CKM Matrix & Unitarity Triangle

The weak interaction couples different generations of quarks

$$\underbrace{\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}}_{\text{Weak Eigenstates}} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{\text{CKM Matrix}} \underbrace{\begin{pmatrix} d \\ s \\ b \end{pmatrix}}_{\text{Mass Eigenstates}}$$

The value of the CKM matrix elements are not predicted by the SM and must be determined by experiment.





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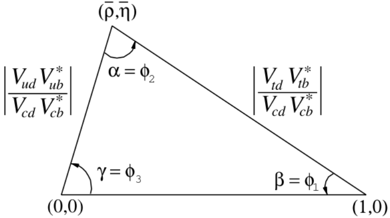
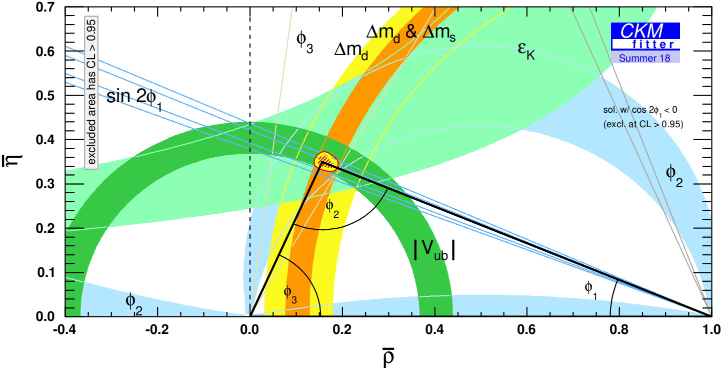
Unitarity implies: $V_{CKM} V_{CKM}^{\dagger} = I$

$V_{id} V_{ib}^{*} = 0$ represents the orthogonality condition between the first and third column of V_{CKM}.
All lengths involve b decays.



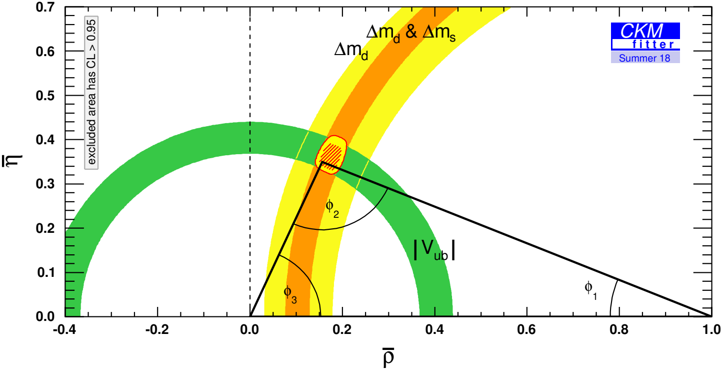
The angles can be written in terms of CKM matrix elements as:

$$\phi_1 = \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right], \quad \phi_2 = \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right], \quad \phi_3 = \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$



- Global CKM fit: 68% CL.
- CP conserving: $|V_{ub}|/|V_{cb}|$, Δm_d, Δm_s, $B^+ \to \tau^+\nu_\tau$.
- CP violating: $\sin 2\phi_1$, ϕ_2, ϕ_3, ϵ_k.
- Tree: $\phi_3(DK)$, ϕ_2 from Isospin analysis.
- Loop.

CKM Fits



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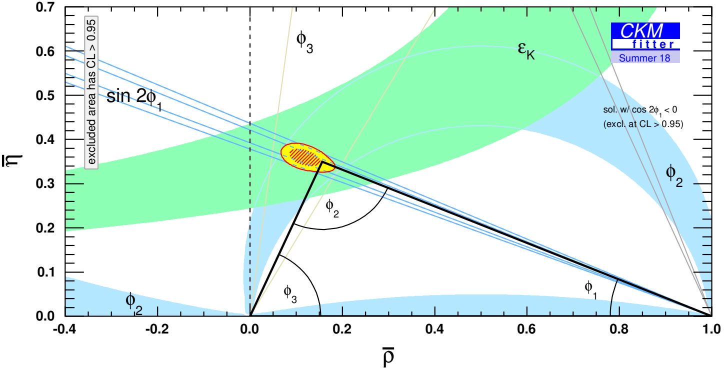

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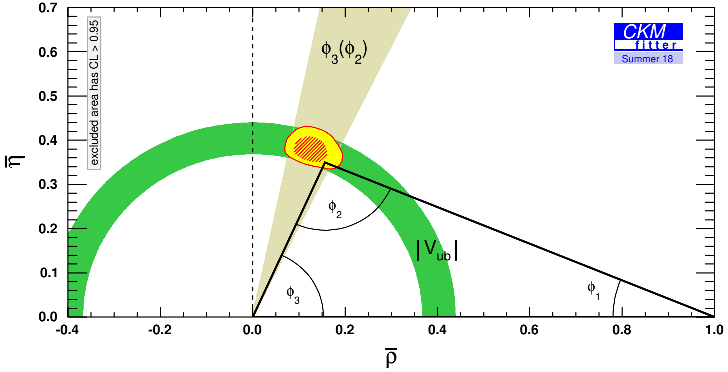

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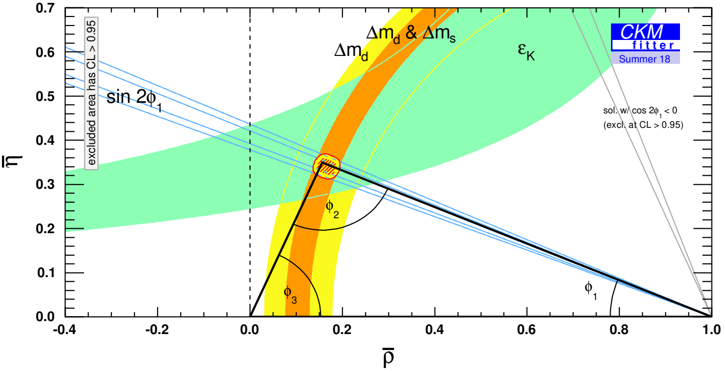

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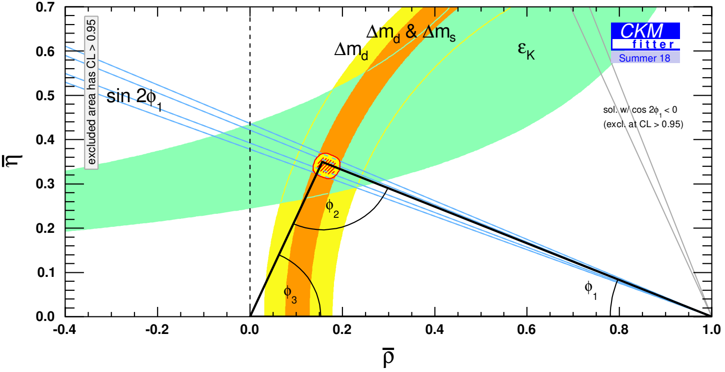

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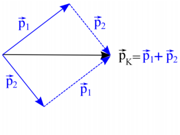
- Loop. $\Rightarrow$ *Still room for corrections from NP at $\mathcal{O}(0.1)$.*

Lesson from Flavor

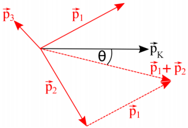
Unwise to assume 0.1% is "good enough" in flavor.

1962: "A special search at Dubna was carried out by E. Okonov and his group. They have not found a single $K_L \to \pi^+\pi^-$ event among 600 decays into charged particles (Anikira et al, JETP 1962). At that stage the search was terminated by administration of the Lab. The group was unlucky." L.B. Okun, "Spacetime and vacuum as seen from Moscow" (2002)

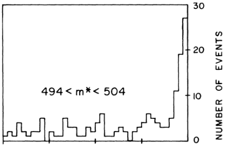
1964: Cronin & Fitch observed 45 $K_L \to 2\pi$ decays (out of 22,700 Kaon decays) a long distance from the production point: $\mathcal{B}(K_L \to 2\pi) = 2 \times 10^{-3}$. PRL **13** 138 (1964)



2π decay



3π decay

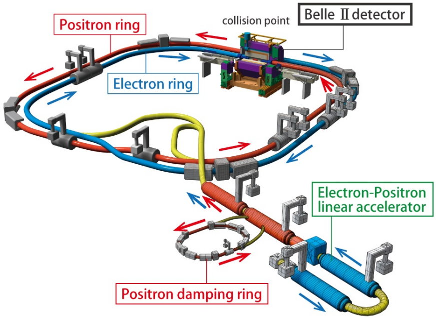


cos θ

Intensity Frontier: *SuperKEKB Accelerator*

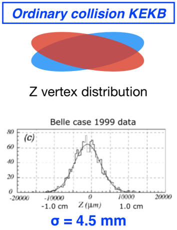
Upgrade to achieve 40x peak $\mathcal{L}$ under 20x bkgd

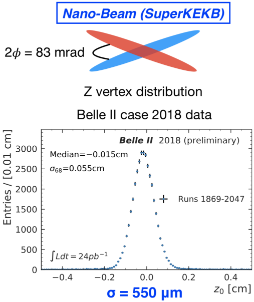
$$\mathcal{L} = \frac{\gamma_{e\pm}}{2 e r_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_{\mathcal{L}}}{R_{\xi_y}}\right)$$



Doubling the beam currents.

Reduction in the beam size by 1/20 at the IP.





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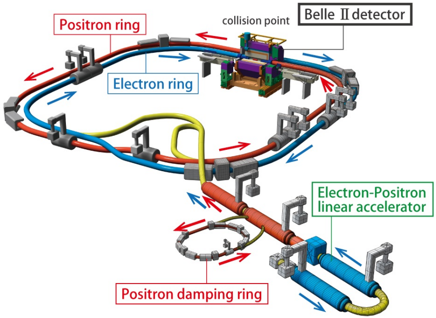

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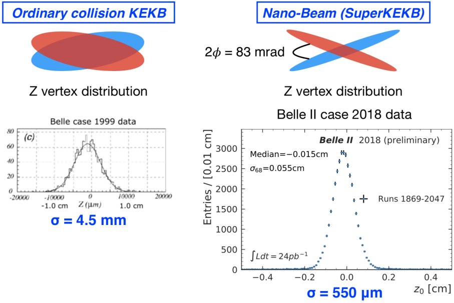

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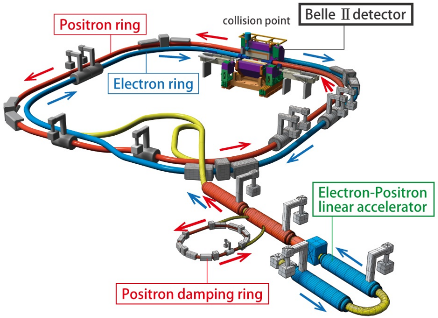

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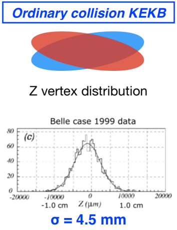
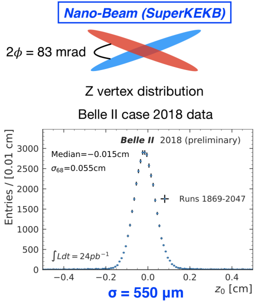
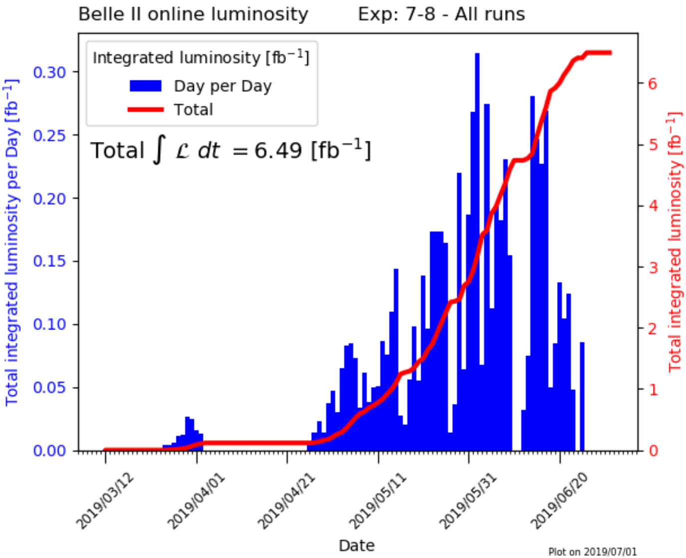




2019 Spring Physics Run



$\mathcal{L}_{\mathbf{Inst.}} = \mathbf{1.2 \times 10^{34}}$ (peak)

Results shown today are from a sub-set of this data

The Belle II Detector

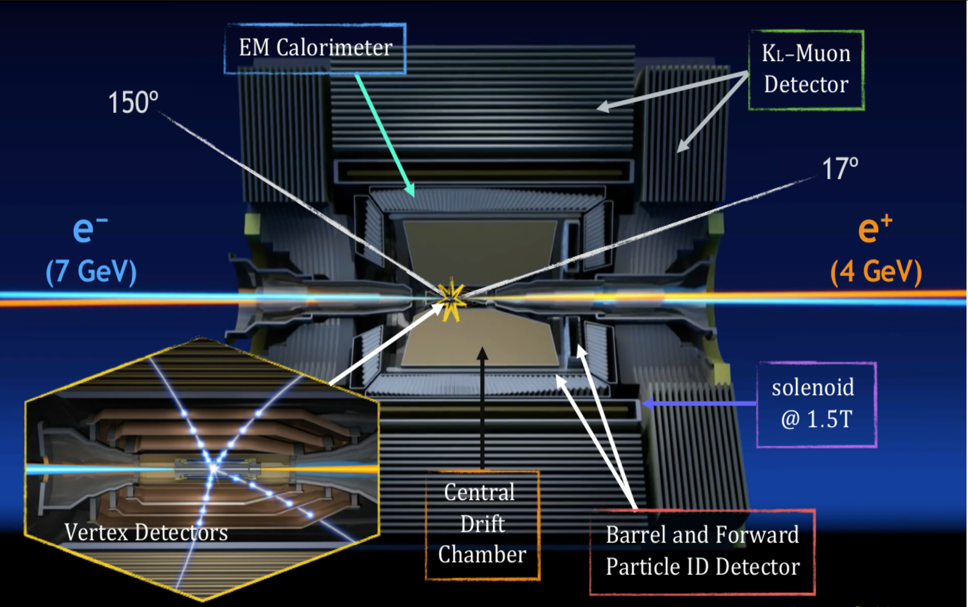
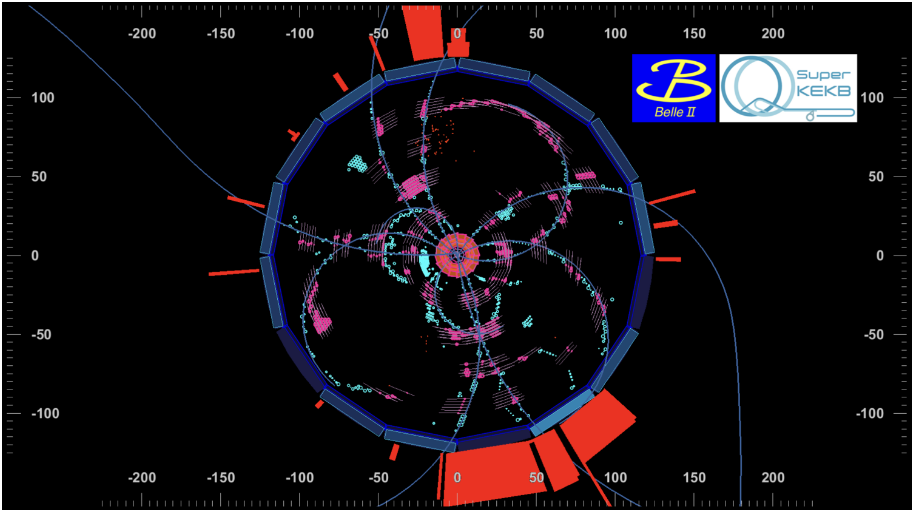
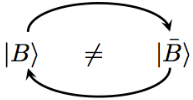


Image: C. Marinas

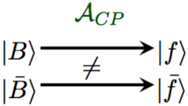
First $B\overline{B}$ Event in Phase 3



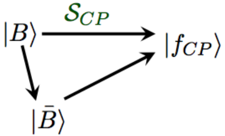
CPV in mixing



Direct CPV in Decay



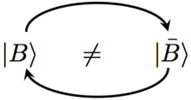
CPV in the interference between mixing and decay



$$\boldsymbol{\mathcal{P}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left[1 + q\left(\mathcal{A}_{CP} \cos \Delta m_d \Delta t + \mathcal{S}_{CP} \sin \Delta m_d \Delta t\right)\right]}$$

CP Violation Measurements

CPV in mixing



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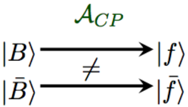
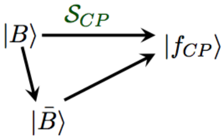


CPV in the interference between mixing and decay



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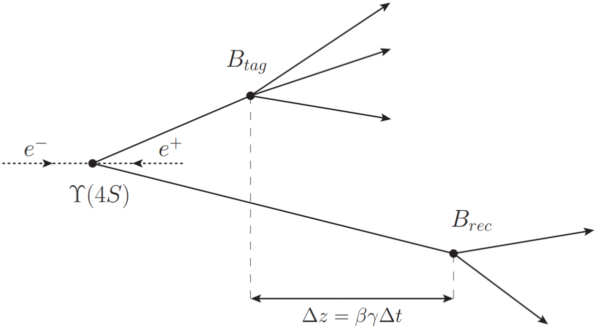
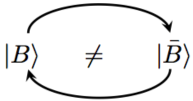
Key ingredients:

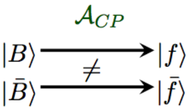
- Vertex position measurement.
- B meson flavor tagging.



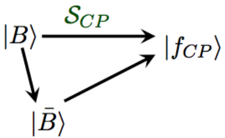
CPV in mixing



Direct CPV in Decay



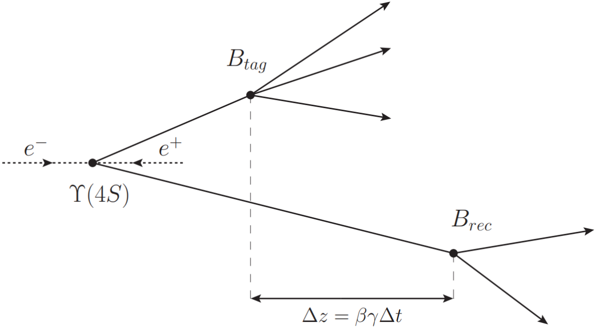
CPV in the interference between mixing and decay



$$\mathcal{P}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[1 + q\left(\mathcal{A}_{CP}\cos\Delta m_d \Delta t + \mathcal{S}_{CP}\sin\Delta m_d \Delta t\right)\right]$$

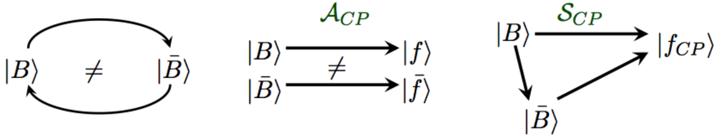
Key ingredients:

- Vertex position measurement.
- B meson flavor tagging.



CP Violation Measurements

CPV in mixing — Direct CPV in Decay — CPV in the interference between mixing and decay



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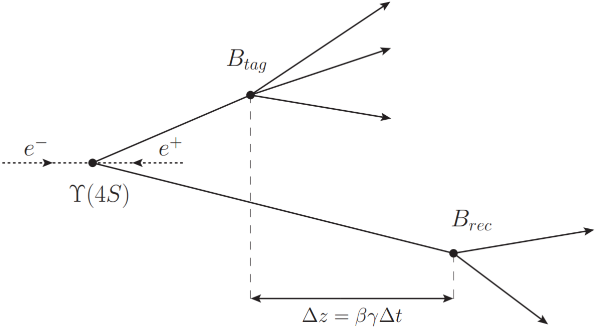
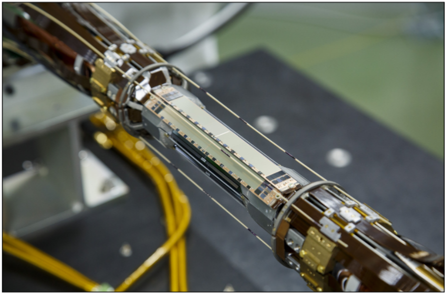
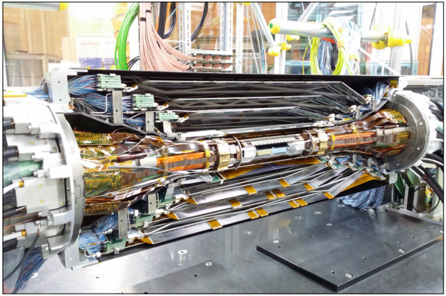


Vertex Detectors



PXD mounted on beam pipe



PXD combined with one half of SVD

- 1^{st} pixel layer at $r = 14mm$ to IP.

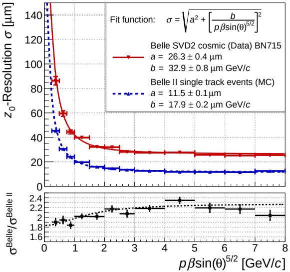
  [Belle at $r = 20mm$]

  Improves vertex resolution along z-axis.

- Larger SVD w/outer layer at $r = 135mm$.

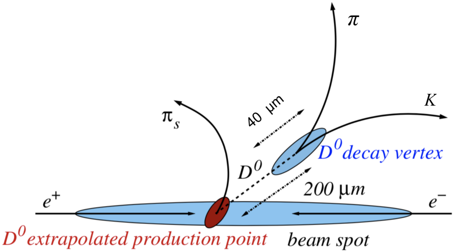
  [Belle at $r = 88mm$]

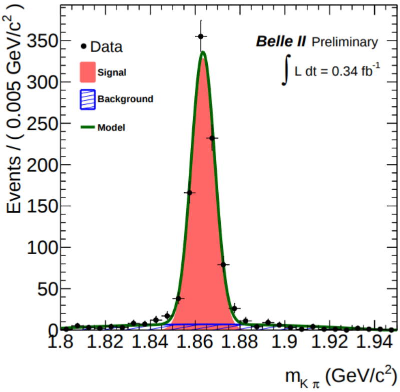
  Higher fraction of K_S' with vertex hits improves vertex resolution.



D^0 Lifetime Measurement: $D^{*+} \to \left[D^0 \to K^-\pi^+\right]\pi^+$

Requires the reconstruction of 2 vertices:





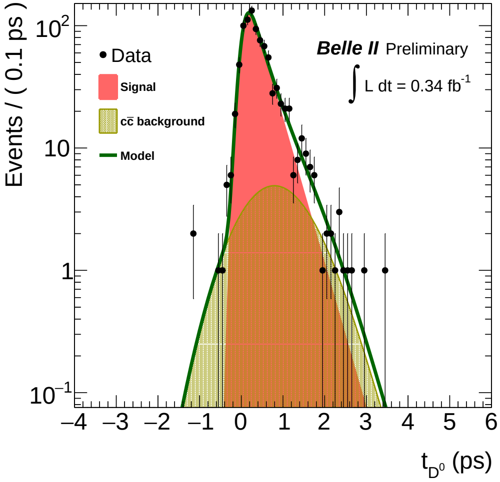
1) D^0 decay vertex from K and π daughters.
2) D^0 production point from the reconstructed D^0 momentum and crossing of π_s.

$\Rightarrow$ Calculate D^0 decay length: $L_{\text{dec}} = \left(\mathbf{r}_{\text{decay}} - \mathbf{r}_{\text{production}}\right) \cdot \hat{\mathbf{p}}_D$.

$\Rightarrow$ $t_{\text{flight}} = \frac{m_D L_{\text{dec}}}{c p_D}$.

D^0 Lifetime Measurement: $D^{*+} \to \left[D^0 \to K^-\pi^+\right]\pi^+$

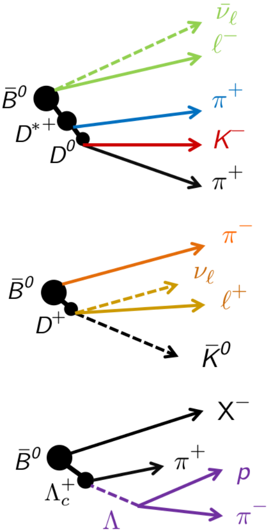
$$\boldsymbol{\tau_{D^0} = (380 \pm 40)\ \mathrm{fs}}$$

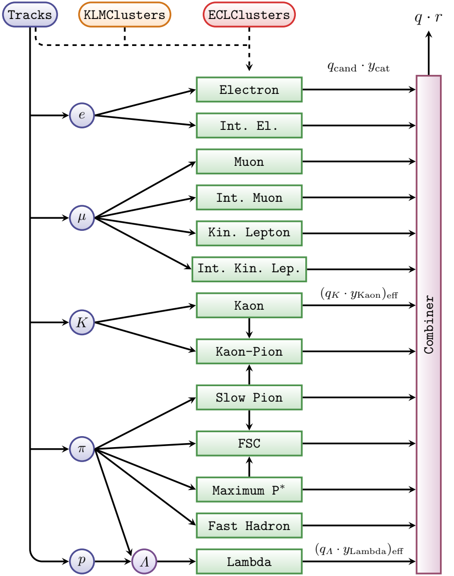


Clear demonstration of the combined performance of the PXD and SVD

$$\tau_{D^0}^{\mathrm{PDG}} = (410.1 \pm 1.5)\ \mathrm{fs}$$

Flavor Tagging





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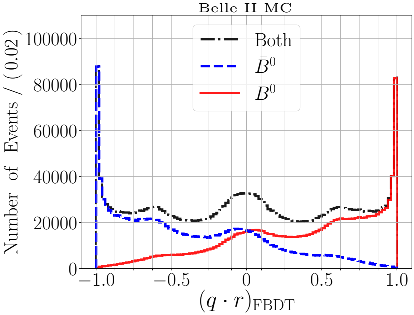
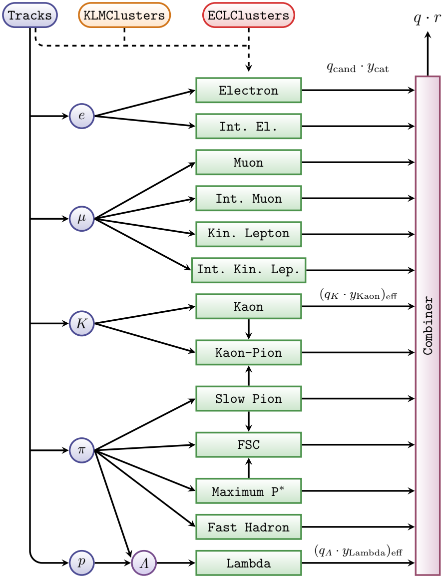


- Total expected tagging efficiency: $\Sigma\epsilon_i \times (1 - 2\omega_i)^2 = (37.16 \pm 0.03)\,\%$.
  [30 − 33% @ Belle, *BABAR*]

- Dilution factor r due to mistag ω:
  $r = 1 - 2\omega \Rightarrow$
  $$\mathcal{A}_{CP}^{\mathrm{obs}} = (1 - 2\omega) \cdot \mathcal{A}_{CP}$$

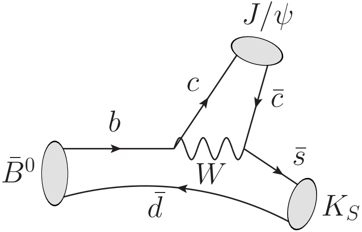


Belle II Prospects for ϕ_1

Most precisely measured UT parameter: $\phi_1^{\text{CKM Fitter}} = \left(22.51^{+0.55}_{-0.40}\right)^\circ$.

Tree-dominated $b \to c\bar{c}s$ *golden* mode
$\boldsymbol{B^0 \to J/\psi K_S^0}$ $\boldsymbol{\mathcal{A}_{CP} = 0,\ S_{CP} = \sin(2\phi_1)}$:

- Theoretically and exp. precise.
- Expected total uncertainty $\delta\phi_1 \lesssim 0.1^\circ$ w/50ab^{-1}.



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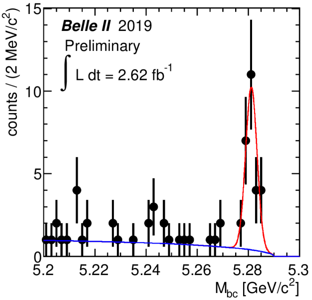

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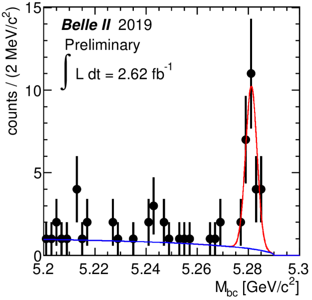
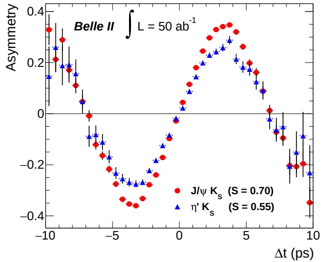


- *CP* asymmetry projection @50ab^{-1}.



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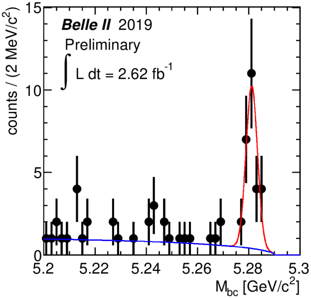

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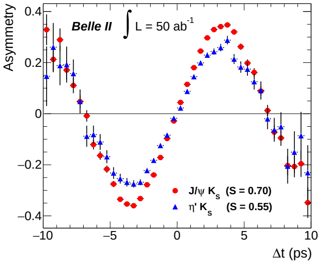
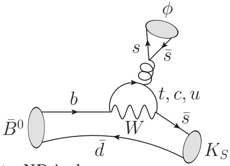


Gluonic-penguin-dominated $b \to q\bar{q}s$



Sensitive to NP in loop

← ▲ NP would be discovered

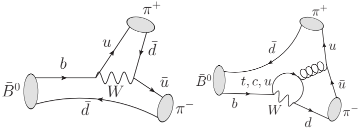
(e.g. $\eta' K_S^0$ w/o competition from LHCb)

Belle II Prospects for ϕ_2

Current precision: $\phi_2^{\text{CKM Fitter}} = \left(91.6^{+1.7}_{-1.1}\right)^\circ$.

- Sizeable penguin contribution:

  $\mathcal{A}_{CP} \neq 0,\ S_{CP} = \sqrt{1 - \mathcal{A}_{CP}^2}\sin(2(\phi_2 + \Delta\phi_2))$



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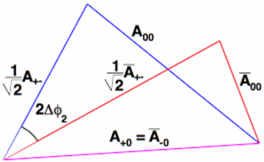
  PRL **65, 3381 (1990)**



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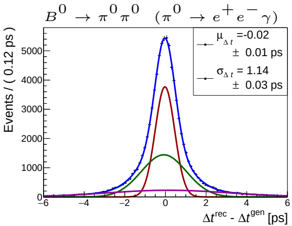

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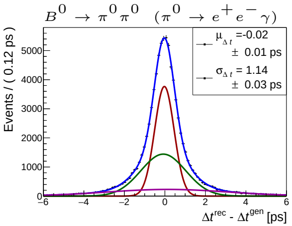
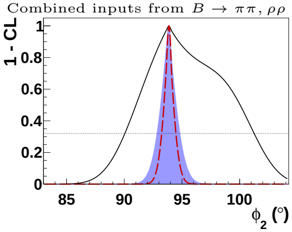
- Expected total uncertainty on ϕ_2 with the combined inputs from $B \to \pi\pi, \rho\rho$ is 0.6°





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- The standard candle, along with $|V_{ub}|/|V_{cb}|$: $\phi_3 \approxeq \arg|V_{ub}^*|$.
- Very precise theoretical prediction of $\delta\phi_3/\phi_3 \sim 10^{-7}$. JHEP 1401 (2014)
- Limited by the small $\mathcal{B}$ of the processes used in its measurement. *Large experimental gain can be made with Belle II.*
- $b \to c\bar{u}s$ and $b \to u\bar{c}s$ tree amplitudes in $B^\pm$ meson decays to open-charm final states.

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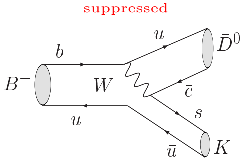

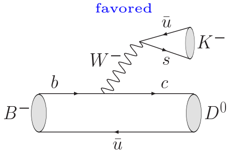

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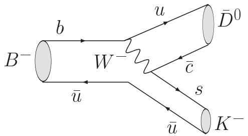
$\Delta E \equiv E_B - E_{\text{Beam}}$

suppressed



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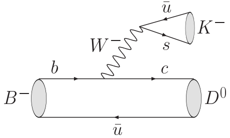

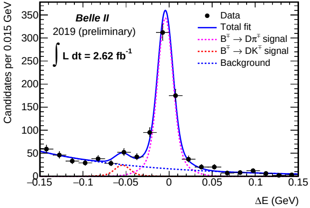

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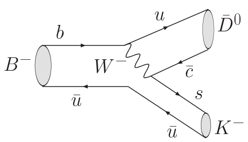

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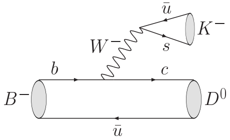
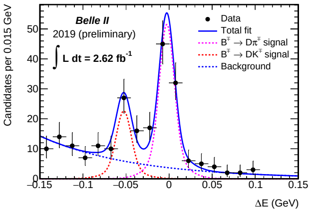
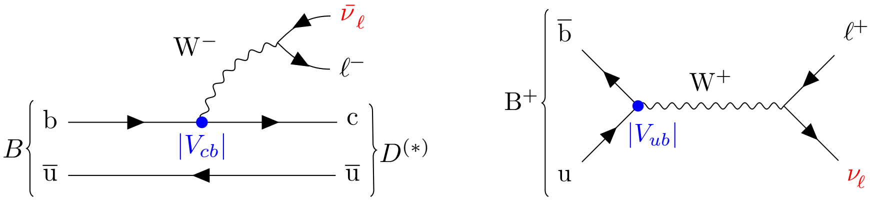


High-momentum PID



$|V_{ub}|$ and $|V_{cb}|$ via Missing Energy Decays

Several key B decay channels for measuring CKM elements contain neutrinos in the final state: $\bar{B} \to D^{(*)}\ell\bar{\nu}_\ell$, $B^+ \to \ell^+\nu_\ell$



Cannot be directly reconstructed

$|V_{ub}|$ and $|V_{cb}|$ via Missing Energy Decays

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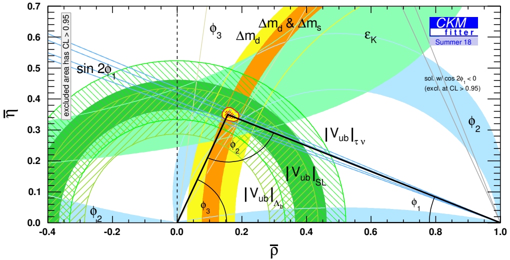

- ← $|V_{ub}|$ from inclusive and exclusive semileptonic B decays.
- ← $|V_{ub}|$ from $B^+ \to \tau^+\nu_\tau$.
- ← $|V_{ub}|/|V_{cb}|$ from Λ_b decays.

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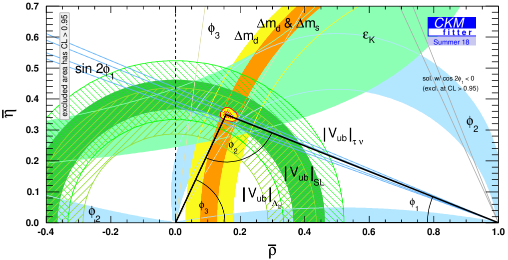

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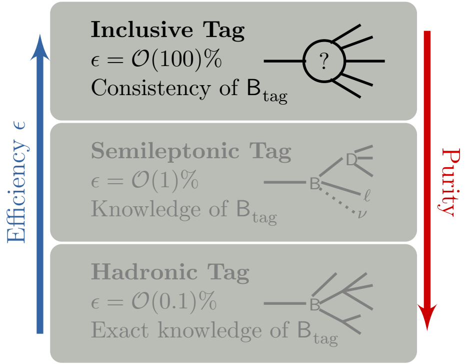
← $|V_{ub}|/|V_{cb}|$ from Λ_b decays.

Take advantage of experimental setup of B-factories:

- **$B\bar{B}$ pairs are produced without any additional particles;**
- **Detectors enclose the interaction region almost hermetically;**
- **Collision energy (initial state) is precisely known:**

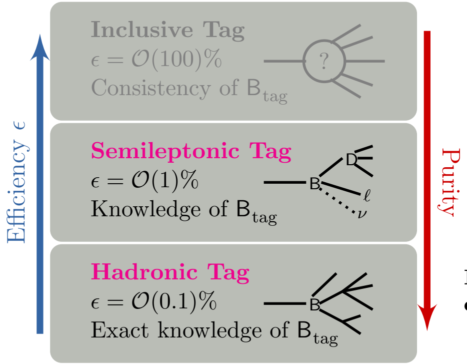
$$p_{e^+} + p_{e^-} = p_B + p_{\bar{B}}.$$

B Tagging



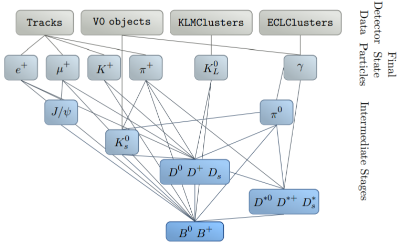
Efficiency ϵ
Inclusive Tag
$\epsilon = \mathcal{O}(100)\%$
Consistency of B_{tag}
?
Semileptonic Tag
$\epsilon = \mathcal{O}(1)\%$
Knowledge of B_{tag}
B
D
ℓ
ν
Hadronic Tag
$\epsilon = \mathcal{O}(0.1)\%$
Exact knowledge of B_{tag}
B
Purity

B Tagging



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

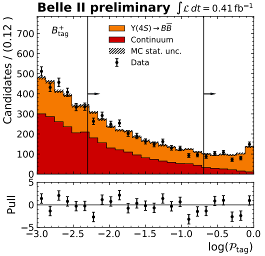
Exclusive Tagging:
The Full Event Interpretation (FEI)



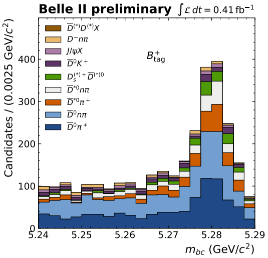
Hierarchical tag-side B-meson recombination algorithm for Belle II.

- Utilizes $\mathcal{O}(200)$ decay channels with BDTs trained for each decay.
- Reconstructs $\mathcal{O}(10k)$ unique decay chains in 6 stages.
- 3x higher MC reconstruction efficiencey than predecessor algorithm.

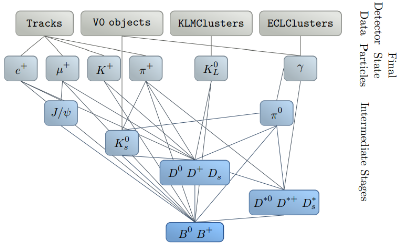
Tag-side B^+ meson classifier output.



Tag-side B^+ meson categories.



Exclusive Tagging: The Full Event Interpretation (FEI)

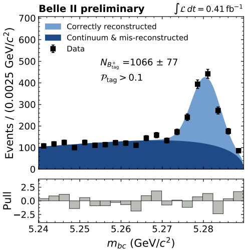


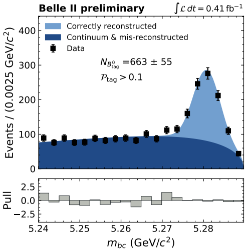
Hierarchical tag-side B-meson recombination algorithm for Belle II.

- Utilizes $\mathcal{O}(200)$ decay channels with BDTs trained for each decay.
- Reconstructs $\mathcal{O}(10\text{k})$ unique decay chains in 6 stages.
- 3x higher MC reconstruction efficiencey than predecessor algorithm.

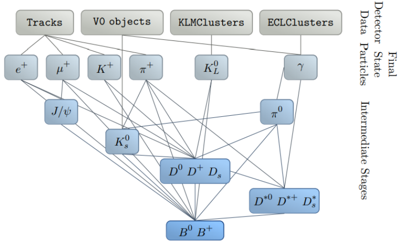
2019 Belle II Data $\mathcal{L} = 0.41\ \text{fb}^{-1}$

Observe ∼ 1729 fully reconstructed B mesons.





Exclusive Tagging: The Full Event Interpretation (FEI)



Hierarchical tag-side B-meson recombination algorithm for Belle II.

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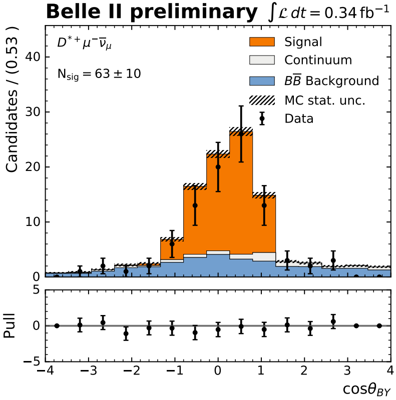
First look at $\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_\ell$ decays $(\ell = e, \mu)$

Observed 146 events in untagged sample:

- $N_{\mathrm{sig}} = 63 \pm 10$ events for $\ell = \mu$.

$\ell = \mu$



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

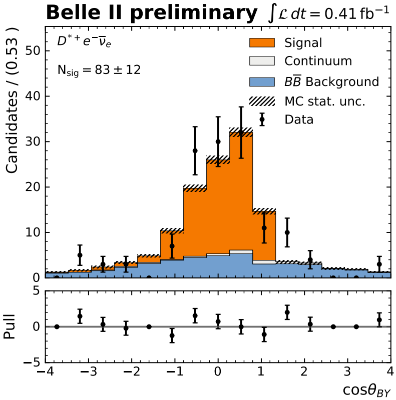
Y = visible final state system $(D^* e)$

First look at $\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_\ell$ decays $(\ell = e, \mu)$

Observed 146 events in untagged sample:

- $N_{\mathrm{sig}} = 63 \pm 10$ events for $\ell = \mu$.
- $N_{\mathrm{sig}} = 83 \pm 10$ events for $\ell = e$.

$\ell = e$



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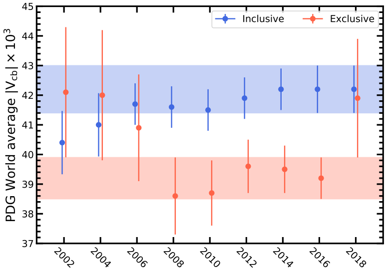
Observed 146 events in untagged sample:

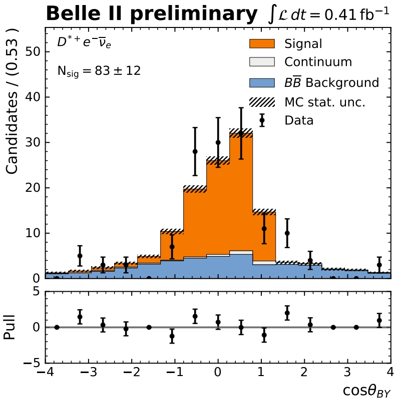
- $N_{\text{sig}} = 63 \pm 10$ events for $\ell = \mu$.
- $N_{\text{sig}} = 83 \pm 10$ events for $\ell = e$.

Branching fraction of $\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_\ell$ decays is a key ingredient in resolving the 3.5σ tension in exclusive vs. inclusive measurements of $|V_{cb}|$.



2018 exclusive avg. includes unpublished Belle 1702.01521

$\ell = e$



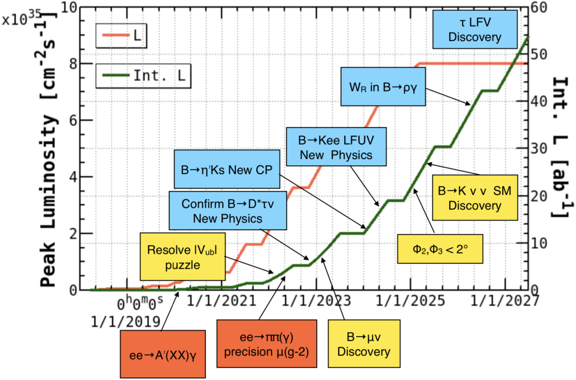
$$\cos\theta_{BY} = \frac{2E_B^* E_Y^* - M_B^2 - m_Y^2}{2p_B^* p_Y^*}$$

Y = visible final state system (D^*e)

Summary

Belle II poised to usher in a new era of precision flavor physics with 50 ab^{-1} of data collected at the SuperKEKB accelerator.

- Measurements of CKM parameters will improve very quickly with initial 5-10 ab^{-1}.
- Potential for many more exciting results.



Thank you!

Extra material

Expected errors at Belle II

Expected errors on $|V_{ub}|$ and $|V_{cb}|$.

Observables	Belle	Belle II	
	(2017)	5 ab^{-1}	50 ab^{-1}
$\lvert V_{cb}\rvert$ incl.	$42.2 \cdot 10^{-3} \cdot (1 \pm 1.8\%)$	1.2%	–
$\lvert V_{cb}\rvert$ excl.	$39.0 \cdot 10^{-3} \cdot (1 \pm 3.0\%_{\text{ex.}} \pm 1.4\%_{\text{th.}})$	1.8%	1.4%
$\lvert V_{ub}\rvert$ incl.	$4.47 \cdot 10^{-3} \cdot (1 \pm 6.0\%_{\text{ex.}} \pm 2.5\%_{\text{th.}})$	3.4%	3.0%
$\lvert V_{ub}\rvert$ excl. (WA)	$3.65 \cdot 10^{-3} \cdot (1 \pm 2.5\%_{\text{ex.}} \pm 3.0\%_{\text{th.}})$	2.4%	1.2%

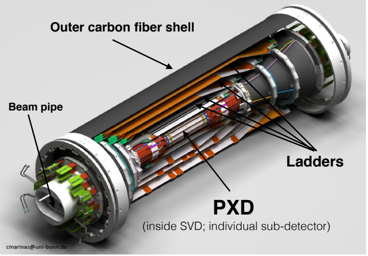
Expected errors on several selected observables related to the measurement of time dependent CP violation in B decays and the measurement of the UT angles ϕ_1 and ϕ_2.

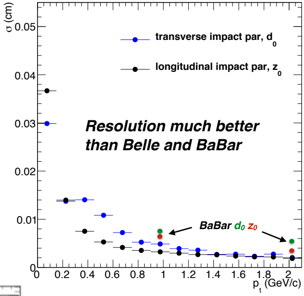
Observables	Belle	Belle II	
	(2017)	5 ab^{-1}	50 ab^{-1}
$\sin 2\phi_1 (B \to J/\psi K^0)$	$0.667 \pm 0.023 \pm 0.012$	0.012	0.005
$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	0.048	0.020
$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.032	0.015
$S(B \to J/\psi \pi^0)$	$-0.65 \pm 0.21 \pm 0.05$	0.079	0.025
ϕ_2 [°]	85 ± 4 (Belle+BaBar)	2	0.6
$S(B \to \pi^+\pi^-)$	$-0.64 \pm 0.08 \pm 0.03$	0.04	0.01
$Br.(B \to \pi^0\pi^0)$	$(5.04 \pm 0.21 \pm 0.18) \times 10^{-6}$	0.13	0.04
$S(B \to K^0\pi^0)$	-0.11 ± 0.17	0.09	0.03

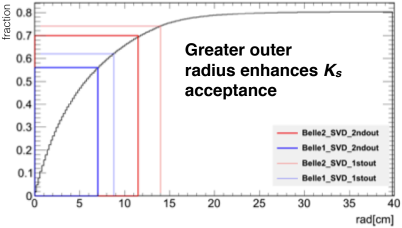
Si pixel (2 layers) and strip (4 layers):

- 1st pixel layer at $r = 14mm$ to IP
  [Belle at $r = 20mm$]
  Improves vertex resolution along z-axis

- Larger SVD w/outer layer at $r = 135mm$.
  [Belle at $r = 88mm$]
  Higher fraction of K_S' with vertex hits improves vertex resolution



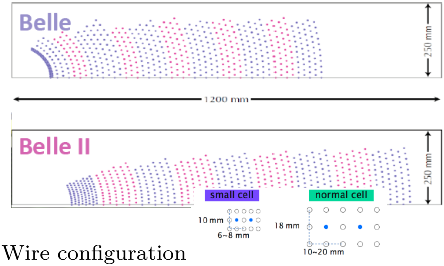




Tracking Detector

Central Drift Chamber:

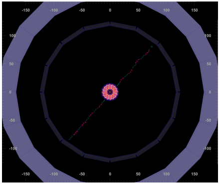
- $He(50\%)\ C_2H_6(50\%)$.
- Larger outer radius of 1111mm (Belle 863mm) allows for improved p resolution.
- Smaller cells with lower occupancy and capacity for higher hit rate.



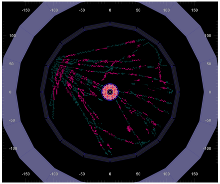
Wire configuration

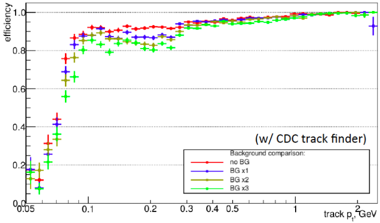
Full readout of the CDC

Single track



Showering event



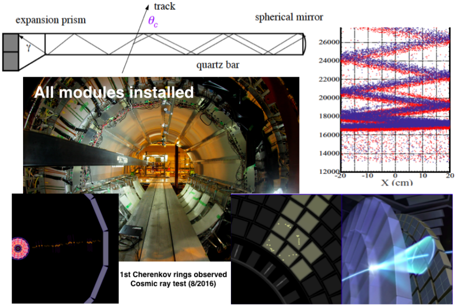


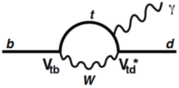
Simulated track reconstruction efficiency

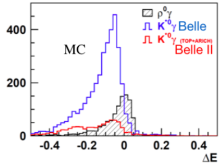
Stable performance for up to 3x predicted beam BG

Two RICH systems covering full momentum range

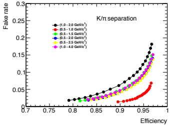
- Barrel: Time of Propagation (TOP) counter (16 modules).
  ⇒ *Measure x-y position of Cherenkov γ's and their arrival time.*
- Forward Endcap: Aerogel Ring Imaging Cherenkov detector (ARICH)
  ⇒ *Proximity focusing with silica aerogel (4σ separation at* $1 - 3.5$ GeV/*c)*

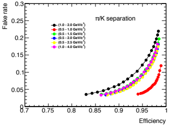






Average ϵ_K *vs.* π *fake rate improved: Fake rate decreases by* ≈ 3 *for the same* ε *w.r.t. Belle*



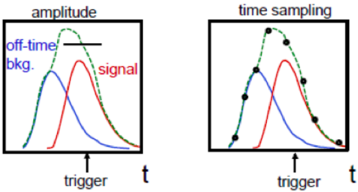


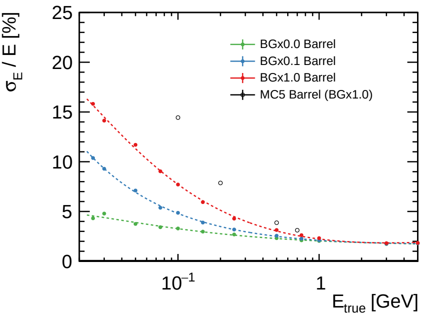
The background $B \to K^*\gamma$ (Belle/Belle II) $\approx 30x$ more abundant than $B \to \rho\gamma$.

Electromagnetic Calorimeter

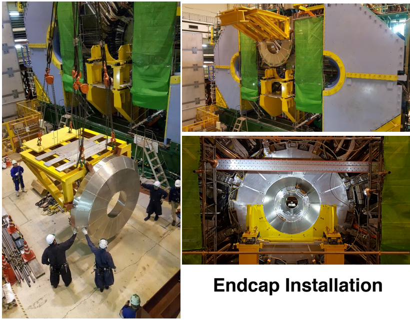
Re-usage of Belle's CsI(TI) crystal calorimeter, but with new electronics with 2MHz wave form sampling to compensate for the larger beam-related backgrounds and the long decay time of CsI(TI) signals.

⇒ *Resolution much better at Belle II*





Peak energy resolution in the ECL barrel as a function of true photon energy

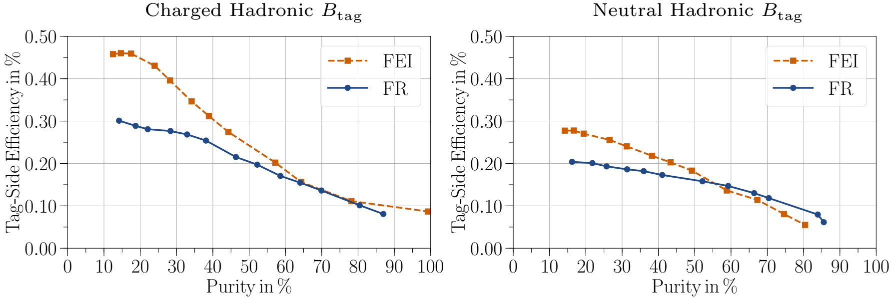


Endcap Installation

Performance on Belle Data

Applicable in Belle *and* Belle II analyses within the Belle II analysis software framework:

Allows one to make a benchmark comparison of the tag-side efficiency with the predecessor Belle Full Reconstruction (FR) algorithm.

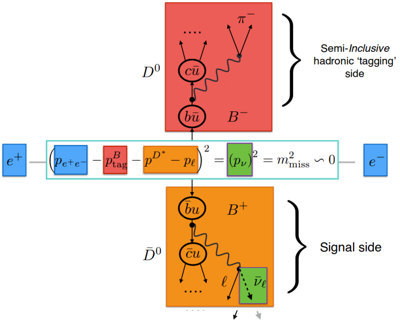


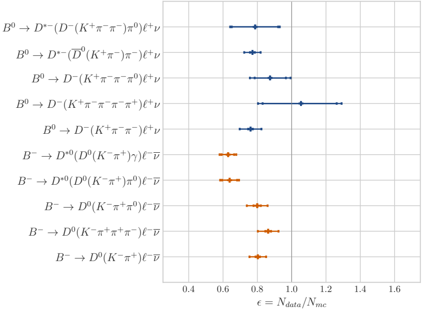
∗ Perform physics analysis on Belle data with increased statistics (from the same 711 fb^{-1}), *while we await a large Belle II dataset*.

Calibration of FEI

Use the FEI on Belle data to reconstruct several well known semileptonic decays.

$\epsilon = N_{DATA}/N_{MC}$

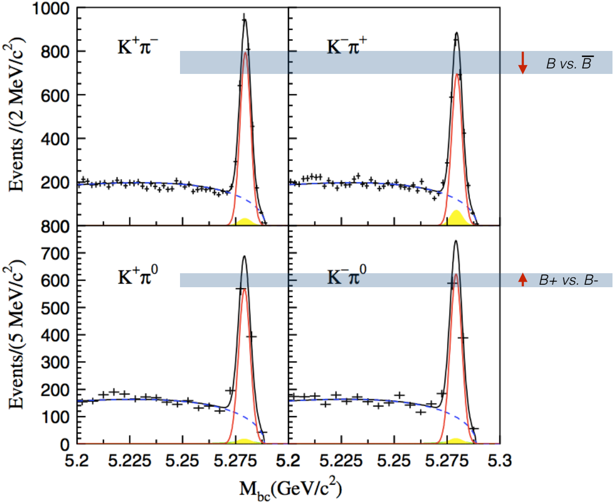




$\epsilon_{\text{charged}} = 0.74 \pm 0.05$ $\quad\quad$ $\epsilon_{\text{neutral}} = 0.86 \pm 0.07$

$K^+\pi^-$ vs. $K^+\pi^0$ Belle, PRD 87, 031103(R) (2013)

Measurements of $DCPV$ in $B^+ \to K^+\pi^0$ found to be different than $B^0 \to K^+\pi^-$

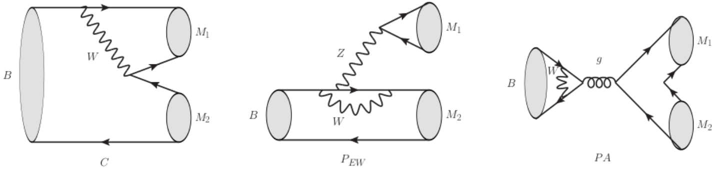


$$\mathcal{A}_{K^+\pi^0} - \mathcal{A}_{K^+\pi^-} = 0.112 \pm 0.027 \pm 0.007 \quad (4\sigma)$$

Additional SM Diagrams or New Physics?

The difference could be due to:

- Neglected diagrams contributing to B decays (theoretical uncertainty is still large).
  $K^+\pi^-: T + P + P^C_{EW}$
  $K^+\pi^0: T + P + C + P_{EW} + P^C_{EW} + PA$



- Some unknown NP effect that violates Isospin.

⇒ **In combination with other $K\pi$ measurements** *and with the larger Belle II dataset, strong interaction effects can be controlled and the validitiy of the SM can be tested in a model-independent way.*

$B \to K\pi$: Test-of-sum Rule

Asymmetry (test-of-sum) rule for NP nearly free of theoretical uncertainties, where the SM can be tested by measuring all observables: [PLB 627, 82(2005), PRD 58, 036005(1998)]

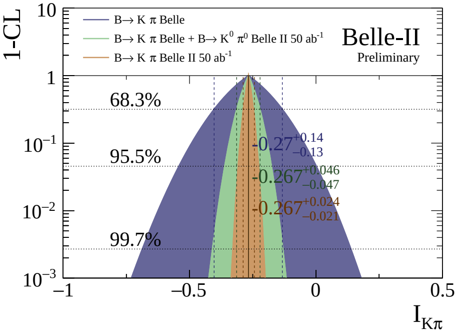
$$I_{K\pi} = \mathcal{A}_{K^+\pi^-} + \mathcal{A}_{K^0\pi^+}\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^+\pi^0}\frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^0\pi^0}\frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

$\left(I_{K\pi} = -0.0088^{+0.0016+0.0131}_{-0.0017-0.0091}\right)$ [@NNLO] PLB 750(2015)348-355

$$\boldsymbol{I_{K\pi} = -0.270 \pm 0.132 \pm 0.060}\ \textbf{[Belle]}$$

- Most demanding measurement is $K^0\pi^0$ final state: $\mathcal{A}_{K^0\pi^0} = 0.14 \pm 0.13 \pm 0.06$.
  Belle, PRD 81, 011101(R) (2010)
- With Belle II, the uncertainty on $\mathcal{A}_{K^0\pi^0}$ from time-dep. analysis is expected to reach $\sim 4\%$.

  $\Rightarrow$ *Sufficient for NP studies*



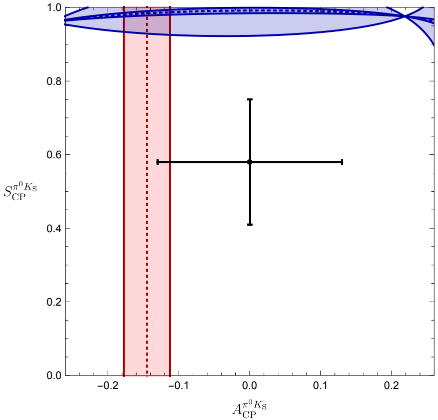
Modified P_{EW} Sector

R. Fleischer *et al.*, arXiv:1712.02323, Moriond QCD

- Data point is the WA for $\mathcal{A}_{K^0\pi^0}$ and $\mathcal{S}_{K^0\pi^0}$.
- The $\mathcal{A}_{K^0\pi^0}$ value obtained from the sum rule with WA inputs for all other $\mathcal{A}_{K\pi}$ and $\mathcal{B}(K\pi)$ values.
- Isospin relation involving tighter constraints from CKM angle γ:

$$\sqrt{2}\mathcal{A}_{K^0\pi^0} + \mathcal{A}_{K^+\pi^0} = -\left(\hat{T} + \hat{C}\right)\left(e^{i\gamma} - qe^{i\phi}e^{i\omega}\right).$$

EW penguin effects described by $qe^{i\phi}e^{i\omega} \equiv -\left(\hat{P}_{EW} + \hat{P}^{C}_{EW}\right) / \left(\hat{T} + \hat{C}\right)$.



- Discrepancy can be resolved if: CP asymmetries move by $\approx 1\sigma$; $\mathcal{B}(K^0\pi^0)$ moves by $\approx 2.5\sigma$.
- **Or NP from EW Z penguins that couple to quarks:** ***Includes models with extra Z' bosons, which can be used to resolve anomalies in $B \to K^{(*)}\ell\ell$ measurements.***

Reducible vs. Irreducible Errors

Reducible

- The systematic uncertainties of the PDF parameters.
- Particle identification requirements.
- The possible CP violation effect in the accompanying B meson decays.
- Vertex resolution.
- Δt resolution function parametrization.
- Tag-side interference.

Irreducible

- Uncertainties in the interaction-point profile.
- Dependence on the vertex selection-criteria.
- The effect of detector misalignment.
- Possible bias in the ΔZ determination.
- $K^{\pm}$ $\pi^{\pm}$, π^{0} detection efficiency.
- Uncertainty in branching fraction measurements.
- Asymmetry of charged particle detection efficiency (in A measurements).
- Vertex reconstruction uncertainty originating from the SVD mis-alignment (in S measurements)