Belle II Status and First Results

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On behalf of the Belle II Collaboration

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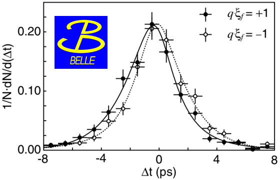
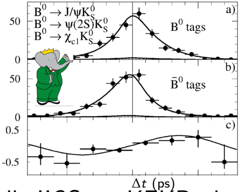
Outline

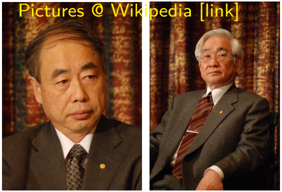
Outline

Introduction to B-factory in e^+e^- collider

- B-factory produces abundant B meson pairs in a clean environment.
- First generation B-factories: Belle@KEKB, BaBar@PEPII. Observe the first signals for CP violation in the B meson sector[a][b] $\Rightarrow$ leads to Nobel Prize for Kobayashi-san and Maskawa-san due to explanation of the origin of CP violation.





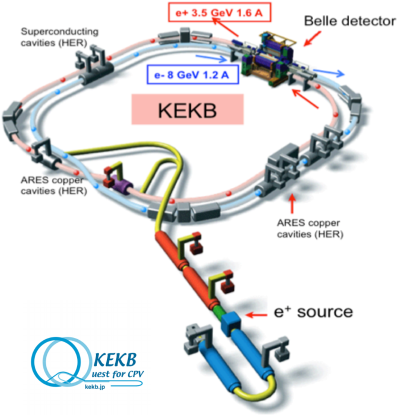


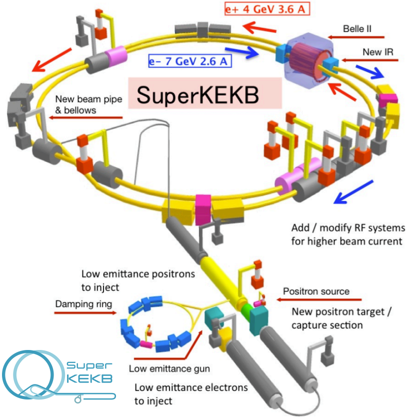
- Next generation B-factory: Belle II@SuperKEKB, designed to find New Physics, operates at asymmetric energy e^+e^- collider
  - Meson pairs boosted; clean background; individual quantum-correlated $B\bar{B}$ pairs; ...
- Complementary to LHCb experiment (pp collider, B produced with large monentum)

[a] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. Lett. **83**, 091801 (2001)
[b] K.Abe *et al.* (Belle Collaboration), Phys. Rev. Lett. **87**, 091802 (2001)

Accelerator: KEKB Vs. SuperKEKB

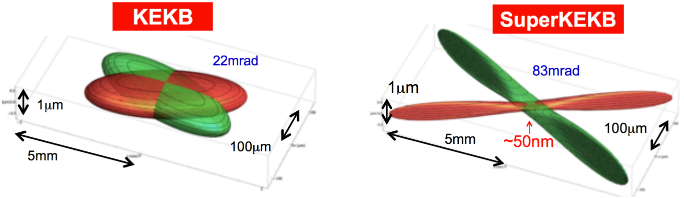
- KEKB and SuperKEKB have similarities along with more differences
  - damping ring: for a high-intensity e^+ beam.
  - beam energy: admit a lower asymmetry to mitigate Touschek effects.
  - beam current: about twice increased to contribute to higher luminosity.





Nano-Beam Scheme

- SuperKEKB upgrade uses so-called 'Nano-beam' scheme to achieve higher lumin.
- Basic idea is to squeeze the vertical beta function β_y^* at the IP by minimizing the longitudinal size of the overlap region of the two beams at the IP.



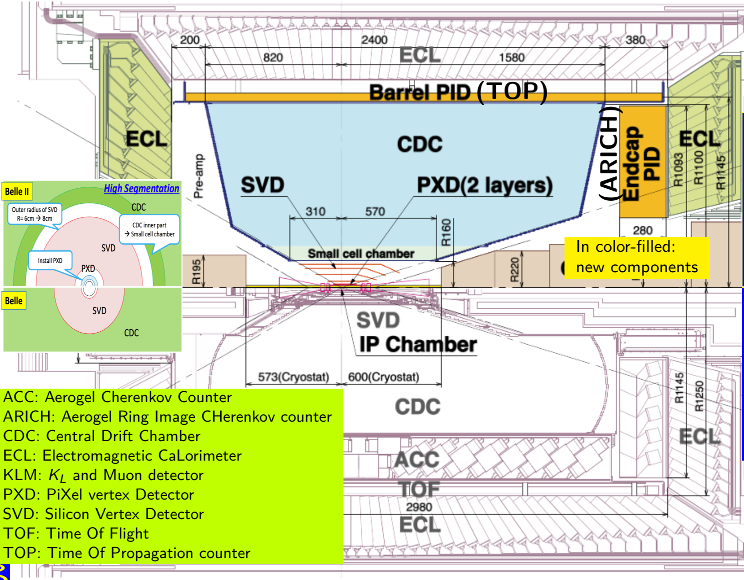
luminosity

$$\mathcal{L} = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_L}{R_{\xi_y}}\right)$$

beam size: σ^*, beam-beam par.: $\xi_\pm$,
beam current: $I_\pm$, beta function: β^*

	$E_\pm$ (GeV) LER/HER	Cross Angle (mrad)	$I_\pm$ (A) LER/HER	β_y^* (mm) LER/HER	$\mathcal{L}$ $(cm^{-2}s^{-1})$
KEKB	3.5/8.0	22	1.64/1.19	5.9/5.9	2.1×10^{34}
SuperKEKB	4.0/7.0	83	3.60/2.60	0.27/0.31	80×10^{34}
	$\beta\gamma \sim 2/3$		$\times 2$	$\times 20$	$\times 40$

Detector: Belle Vs. Belle II



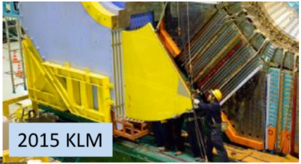
ACC: Aerogel Cherenkov Counter
ARICH: Aerogel Ring Image CHerenkov counter
CDC: Central Drift Chamber
ECL: Electromagnetic CaLorimeter
KLM: K_L and Muon detector
PXD: PiXel vertex Detector
SVD: Silicon Vertex Detector
TOF: Time Of Flight
TOP: Time Of Propagation counter

Detector Installation

[This slide is referred to the talk of Prof. Kwon at IMFP29]

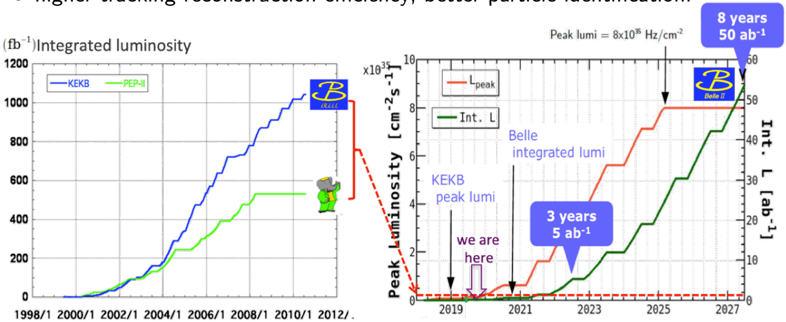
- 2010, Belle and KEKB operation completed
  - Started upgrade to Belle II and SuperKEKB

Sub-detector installation



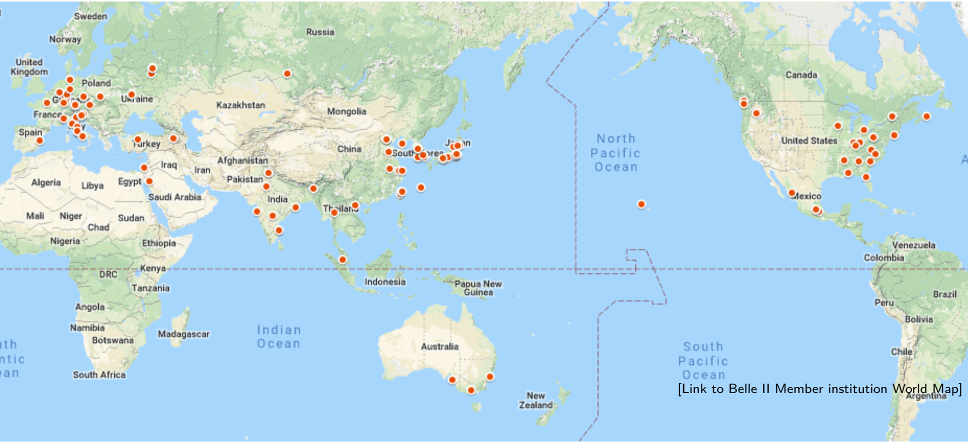
Highlights and Data Set

- Higher luminosity brings 20 times machine backgrounds; and 10 times event rate. To fight with these difficulties, Belle II has lots of improved performances, i.e.
  - improved L1 trigger: 30 kHz (only 500 Hz for Belle).
  - vertex detector (VXD): brings a better spatial resolution than Belle.
  - VXD brings $\sim 30\%$ a larger acceptance for K^0_S reconstruction
  - higher tracking reconstruction efficiency; better particle identification.



- Belle II, with 50 ab^{-1}, gives us large different datasets:
  - $\sim 5.5 \times 10^{10}$ $B\bar{B}$; $\sim 6.5 \times 10^{10}$ $c\bar{c}$; $\sim 4.5 \times 10^{10}$ $\tau^+\tau^-$ $\Rightarrow$ super B-τ-c factory
  - wide effective $E_{c.m}$=[0.5-10] GeV via ISR process.

A big family in Belle II Collaboration



[Link to Belle II Member institution World Map]

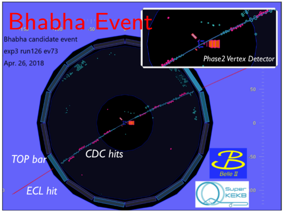
- Belle Collaboration : 536 colleagues, 91 institutions, 20 countries/regions
- Belle II Collaboration: 952 colleagues, 116 institutions, 26 countries/regions
- including 8 institutions from China mainland: IHEP, USTC, PKU, Beihang, Fudan, LNNU, Soochow, SDU.

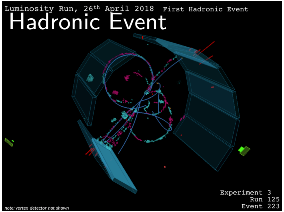
Outline

Phase II: some 'first' events and particle re-discoveries

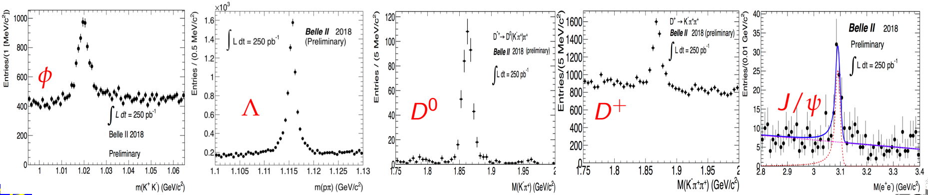
- On Apr 26 last year, we welcome the first collision, and see some 'First' events

Cheer up for First collision





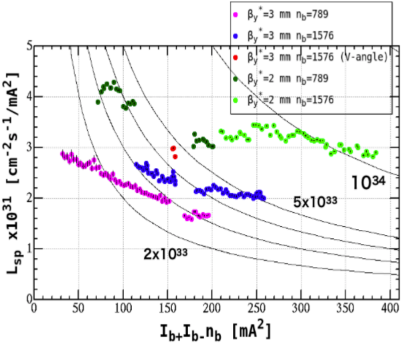
- lots of particles are re-discovered, based on Phase II dataset.
- Belle II first paper: measurement of lumin. of Phase II, to be submitted to CPC.

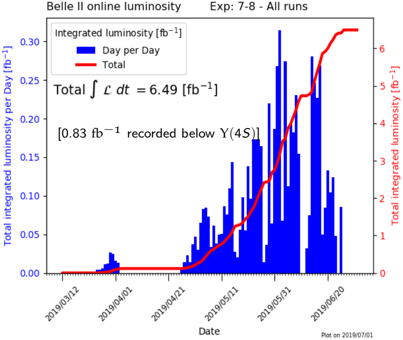


Outline

Phase III for physical run with full detector

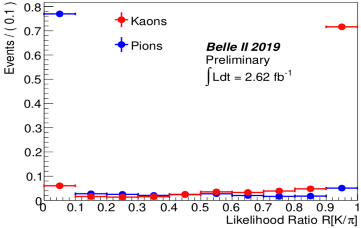
- Phase III: with full detector after the VXD installation. first physics run [March 26-July 1, 2019]
- reach peaking lumin.: $\mathcal{O}(10^{34})$ cm^{-2}s^{-1}
- achieve dataset with integrated lumin.: 6.49 fb^{-1}

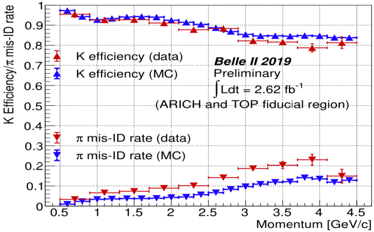




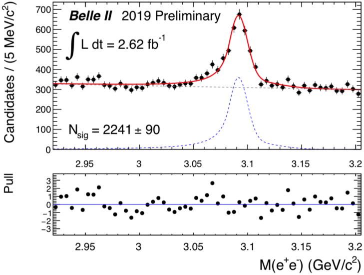
Particle Identification Performances: global hadron and lepton ID

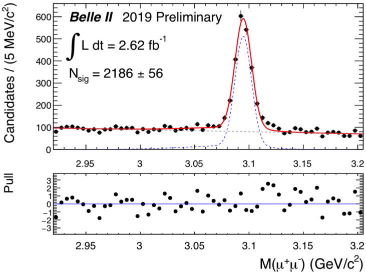
- hadron ID: Kaon and pion identification using $D^{*+} \to D^0[\to K^-\pi^+]\pi^+$





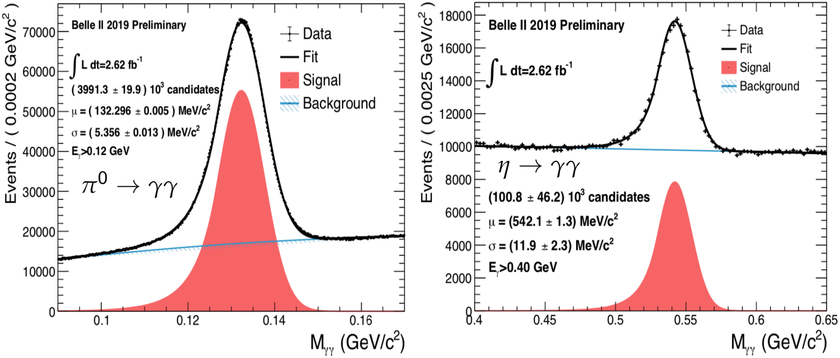
- lepton ID: using $J/\psi \to \ell^+\ell^-$ ($\ell = e,\ \mu$) with electron or muon ID (>0.95).





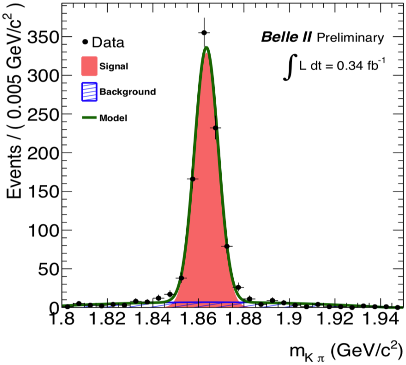
Neutral particle reconstruction: $\pi^0/\eta \to \gamma\gamma$

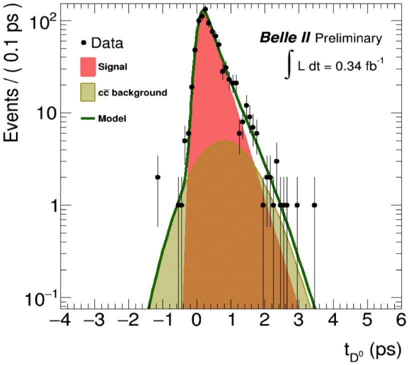
- E_γ >120 (400) MeV; with good energy deposit in ECL crystals: $E_9/E_{25} > 0.9$, $N_{hits} > 1.5$ for π^0 (η) channel.
- The mass resolution is comparable with Belle as expected.



Study of D^0 lifetime

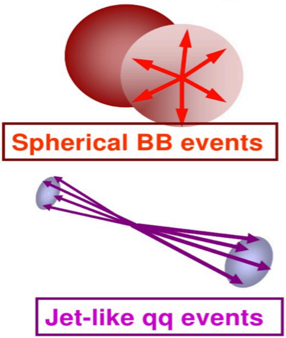
- Reconstruct $D^{*+} \to D^0[\to K^-\pi^+]\pi_s^+$ to obtain a clear D^0 sample using 0.34 fb^{-1}.
- D^0 lifetime, $\tau = 370 \pm 40$ fs is consistent with PDG value.
- Compared with Belle, D^0 lifetime resolution is much improved as expected due to a better detector performance, i.e. PXD, CDC with smaller cell, etc.
- Good to charm analyses at Belle II, i.e. time-depended measurements of D^0-$\bar{D}^0$ mixing and CP violation.

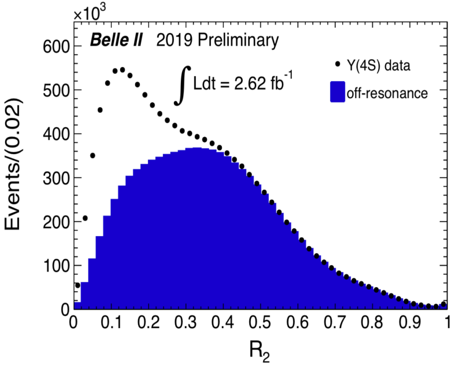




Study of event shape variable R_2

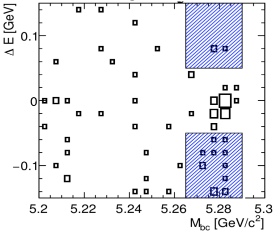
- Event shape $R_2 = H_2/H_0$ with Fox-Wolfram moments $H_l = \sum_{i,j} \frac{|P_i||P_j|}{E_j^{vis}} P_l(\cos\theta_{ij})$ where θ_{ij} is the opening angle between charged tracks or photons i and j.
- $B\bar{B}$ (continuum) event is spherical (jet-like) shape, $\Rightarrow R_2 \rightarrow 0$ (1).
- The overall selection efficiency on the $B\bar{B}$ sample is 98.8%.
- The off-res. contribution is normalized to the luminosity of the on-res. data.

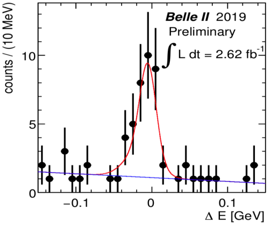


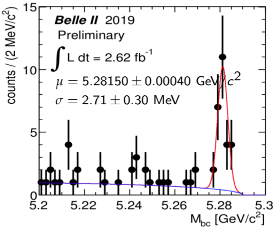


Study of B hadronic decays including J/ψ

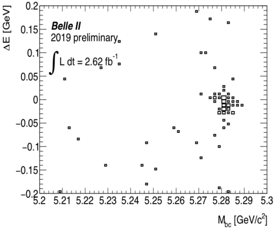
- $B^0 \to J/\psi K^0_S$ (CP eigenstate) with $J/\psi \to \ell^+\ell^-$ (ℓ=e, μ)

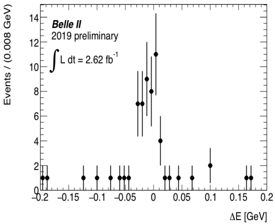


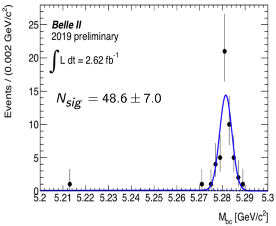




- $B^0 \to J/\psi K^{*0}$ with $K^{*0} \to K^+\pi^-$ (also study B decay vertex resolution)

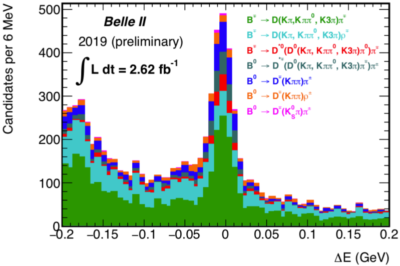


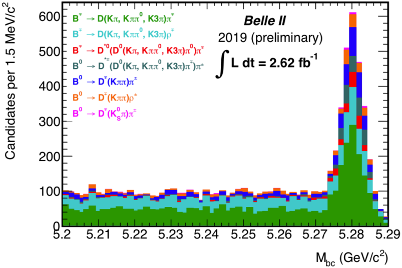




B charmed hadronic decays: $B^{+,0} \to D^{(*)} h^+$

- rediscovery of $B^{+,0} \to D^{(*)}\pi^+$, reconstructed in 2.62 fb^{-1}





- Yields for each channel:

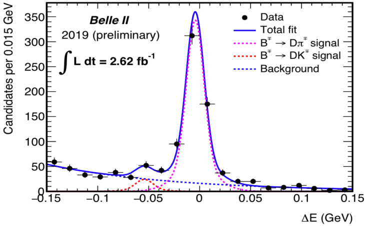
Decay	Yield
$B^- \to D^0(\to K\pi, K\pi\pi^0, K\pi\pi\pi)\pi^-$	944 ± 35
$B^- \to D^0(\to K\pi, K\pi\pi^0, K\pi\pi\pi)\rho^-$	369 ± 28
$B^- \to D^{*0}(\to D^0(\to K\pi, K\pi\pi^0, K\pi\pi\pi)\pi^0)\pi^-$	140 ± 13
$B^0 \to D^{*-}(\to D^0(\to K\pi, K\pi\pi^0, K\pi\pi\pi)\pi^-)\pi^+$	236 ± 16
$B^0 \to D^-(\to K\pi\pi)\pi^+$	351 ± 21
$B^0 \to D^-(\to K\pi\pi)\rho^+$	156 ± 17
$B^0 \to D^-(\to K^0_S\pi)\pi^+$	21 ± 5

- Modes with neutrals mesons are efficiently reconstructed along with all-charged final states containing kaons and pions.

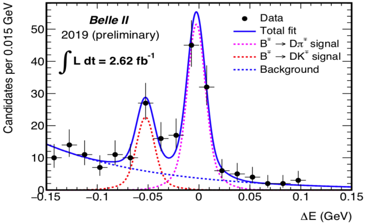
B charmed hadronic decays: $B^{+,0} \to D^{(*)} h^+$

- Observation of $B^- \to D^0 K^-$ with $D^0 \to K\pi / K\pi\pi^0 / K3\pi$: $N = 38 \pm 8$ (6σ)

No PID requirement

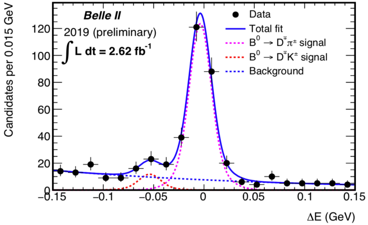


With high momentum PID

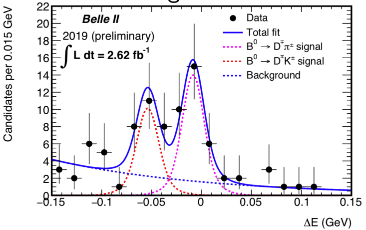


- Evidence of $B^0 \to D^- K^+$ with $D^- \to K\pi\pi / K_S^0\pi$: $N = 20 \pm 6$ (3.3σ)

No PID requirement

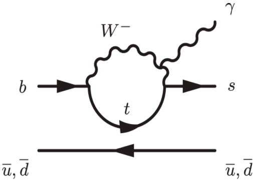


With high momentum PID

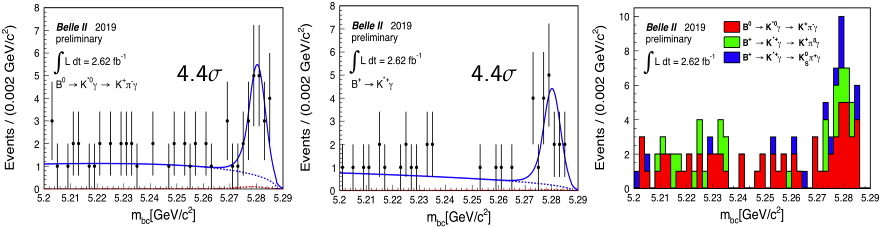


Study of B radiative decay: $B^0 \to K^{*0}\gamma$

- $b \to s\gamma$ process is a sensitive probe for New Physics.
- $B \to K^*\gamma$: the cleanest exclusive decay among $B \to X_s\gamma$.

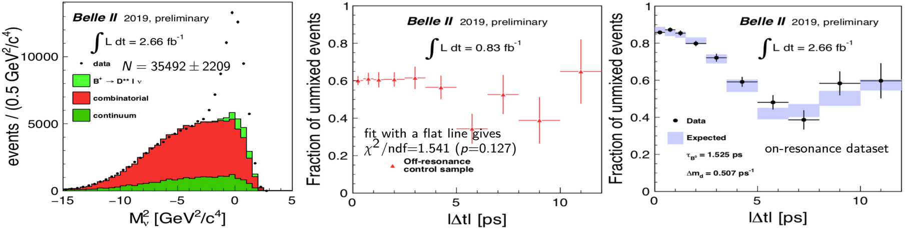


- re-discovery of $K^{*0}\gamma$ and $K^{*+}\gamma$ channels with 2.62 fb^{-1} (1/2 of the initial Phase III dataset). Yields $N_{sig} = 35.5 \pm 6.9$, consistent with W.A. branching fraction.



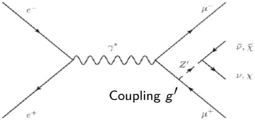
Study of B lifetime and mixing

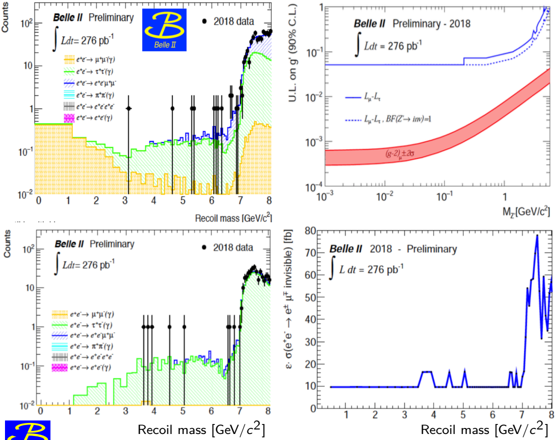
- using partially reconstructed $B^0 \to D^{*-}\ell^+\nu$ (ℓ=e, μ) decays: obtained yields 18514 ± 1128 for e channel and 16625 ± 1111 for μ channel.
- Meaurement of the mixed-unmixed yield asymmetry a function of $|\Delta t|$. (Total $N_U = 1642 \pm 133$, $N_M = 253 \pm 45$ with correction factor $\epsilon_U/\epsilon_M = 1.35 \pm 0.10$)
- $|\Delta t|$ dependent fraction of unmixed event for on-resonance data.
- Good agreement is seen between the data and the expectations, proving that the physics capabilities of Belle II detector are sufficient to observe the expected pattern of B^0-$\bar{B}^0$ oscillations.



Search for dark Z' →nothing

- A novel result on the dark sector (Z' →nothing) recoiling against $\mu\mu$ or $e\mu$ pair. Both possibilities are poorly constrained at low Z' mass and in the first case, may explain the muon g-2 anomaly.





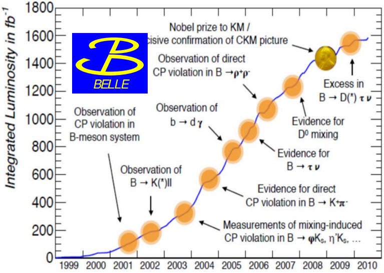
- $e^+e^- \to \mu^+\mu^- Z'$: No excess above 3σ.
- $e^+e^- \to \mu^\pm e^\mp Z'_{LFV}$: No significant excess.
- More studies, like $\Upsilon(nS)$ and $\psi(nS)$, and prospects, see other Belle II talks.
  - *Aug 21, Sen Jia, Exotic and Conventional Quarkonium Physics Prospects at Belle II*
  - *Aug 17, Hikari Hirata, Sensitivity to X(3872) total width at the Belle II experiment*

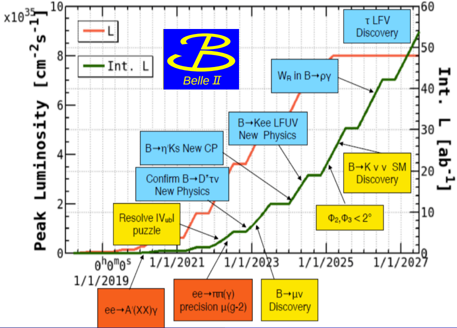
Outline

1. Belle to Belle II experiment
   - Accelerator and Nano-beam
   - Detector and Installation
   - Highlights and Data Set
2. Phase II Results
3. Phase III Results
   - Particle Identification performances
   - Study of D^0 lifetime
   - Study of B hadronic decays
   - Study of B radiative decay
   - Study of B lifetime and mixing
   - Search for dark Z' $\rightarrow$nothing
4. Summary and Prospects

Summary and Prospects

- Belle II has been back to the game: on her long but exciting way to reach 50 ab^{-1} collected by Belle II detector at SuperKEKB (with world's highest lumin.), aiming at reveal of new physics and precise measurement of heavy flavor decays, etc.
- Phase II has finished: calibration, particle rediscovery, FEI, first paper soon.
- Phase III, physical run with full detector, started in March 2019. collect 6.49 fb^{-1}; approval plots with 2.62 fb^{-1}, first physics result (dark sector).
- Belle brings us fruitful achievements. Let's look forward to more exciting news from our Belle II. Why not? She is really second belle and charming.





Back up

Thank you for your attention.

谢谢！

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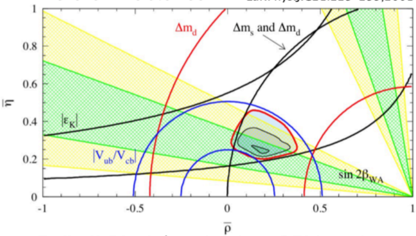
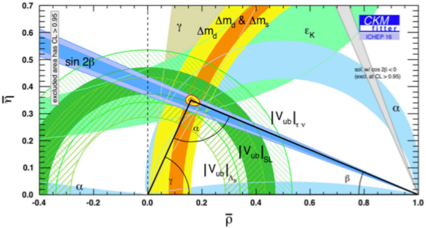
Before B-factories

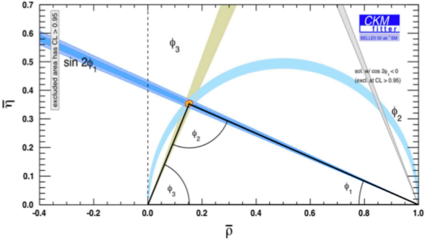
Eur.Phys.J.C21:225-259,2001



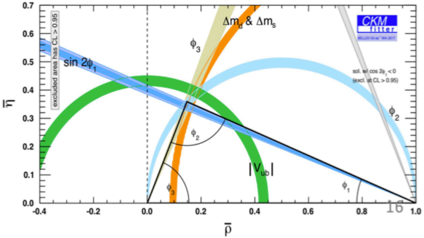
After B-factories



Belle II 50 ab^{-1} projection, CPV modes only



Belle II 50 ab^{-1} projection, all constraints



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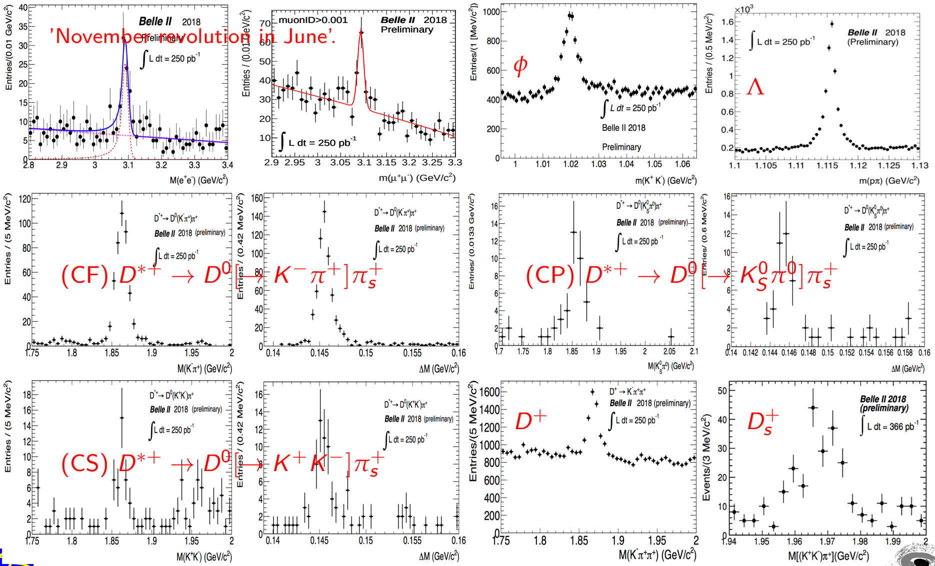
Some of Particle Re-discoveries based on Phase II dataset



Full Event Interpretation (FEI)

T. Keck *et al.*, Comput. Softw. Big Sci (2019)3:6, arXiv:1807.08680

- FEI: Fast BDT-based algorithm fully reconstructs B decays with more than thousands B decay modes
- useful for channels with weak signature, e.g., missing momentum (vs in final state)
- performance on early data shows improvement compared to predecessor algorithm.