The Belle II experiment Status and Prospects

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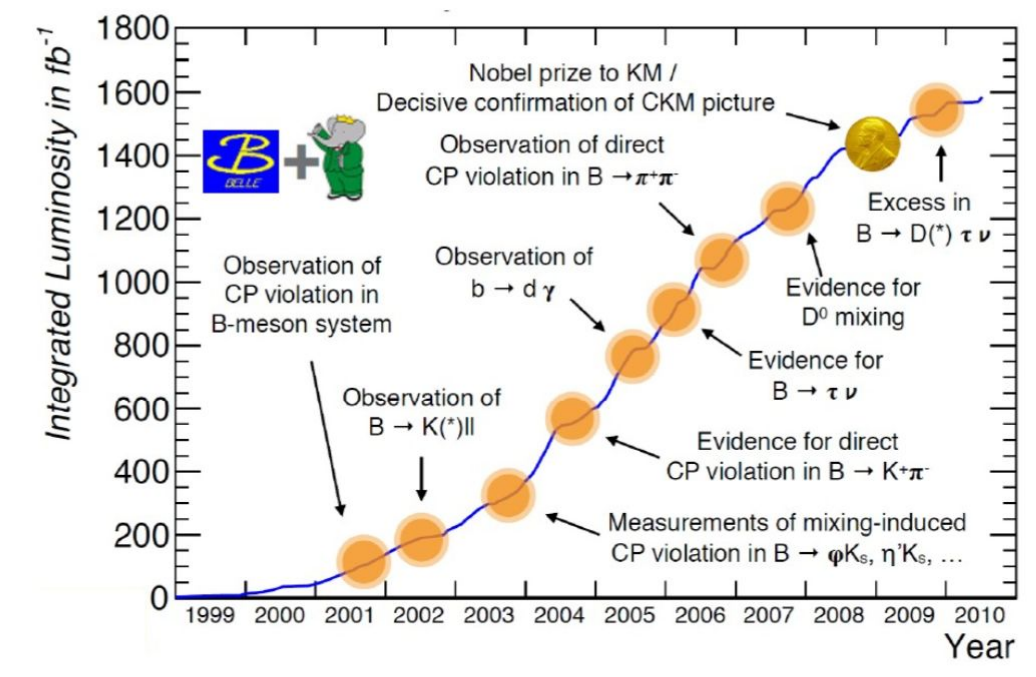
Outline

- SuperKEKB accelerator and Belle II detector
  - Road to high Luminosity
    - Operation of Phase 3
  - Performance of Phase 2 and phase 3
- Physics Prospects
- Particle re-discovered @ Belle II
- Decay mode re-discovered @ Belle II

B factory experiment milestones

- Belle and Babar experiments operated until ~2010 used e^-e^+ accelerator with asymmetry energies to produce mass of B mesons. 1.5 ab^{-1} data are recorded.
- Target of luminosity of SuperKEKB/Belle II is 50 ab^{-1} .
- High luminosity, boosted B meson.
  - CKM matrix unitary angles
  - CP violation
  - Rare B/D meson decays
- LFV/LNV in tau decays
- Search for tetraquark & pentaquark



KEKB to SuperKEKB

Lorentz factor

Beam current

Beam-beam factor

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

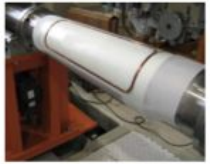
Beam aspect ratio (flat beam ~ 1-2%)

Vertical beta function at IP

Geometrical corrections (Hourglass effect...)

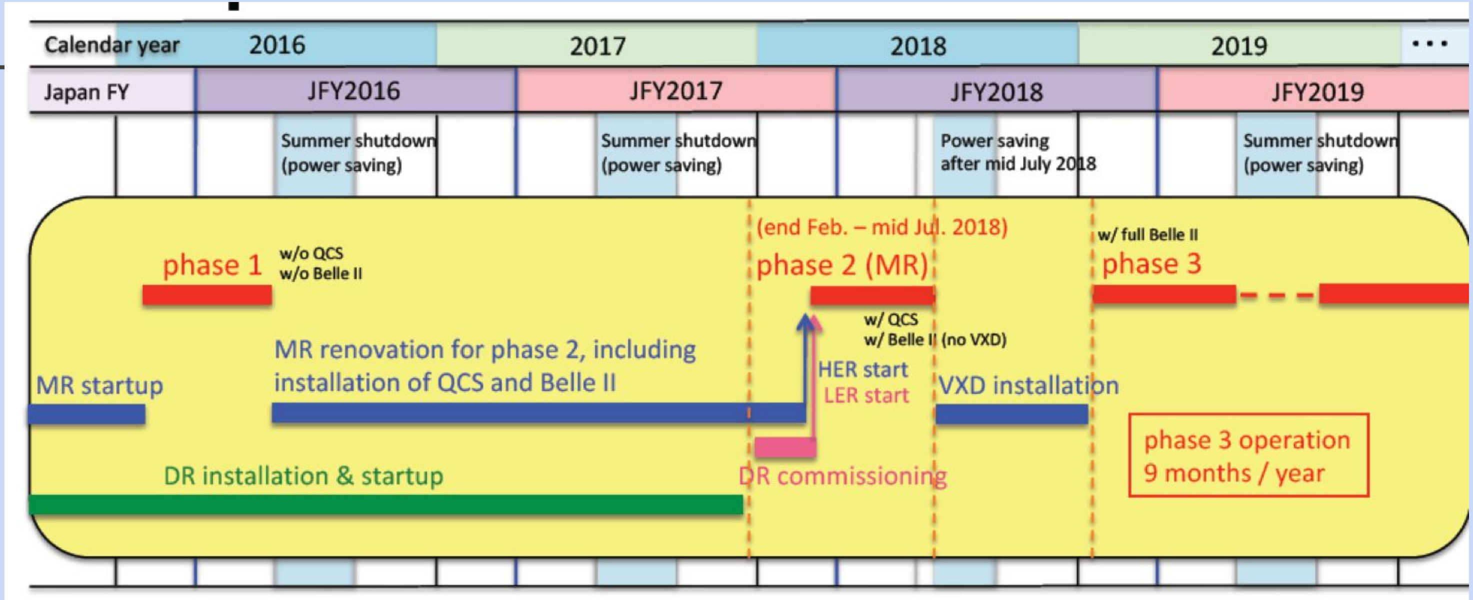
Colliding bunches

New superconducting /permanent final focusing quads near the IP



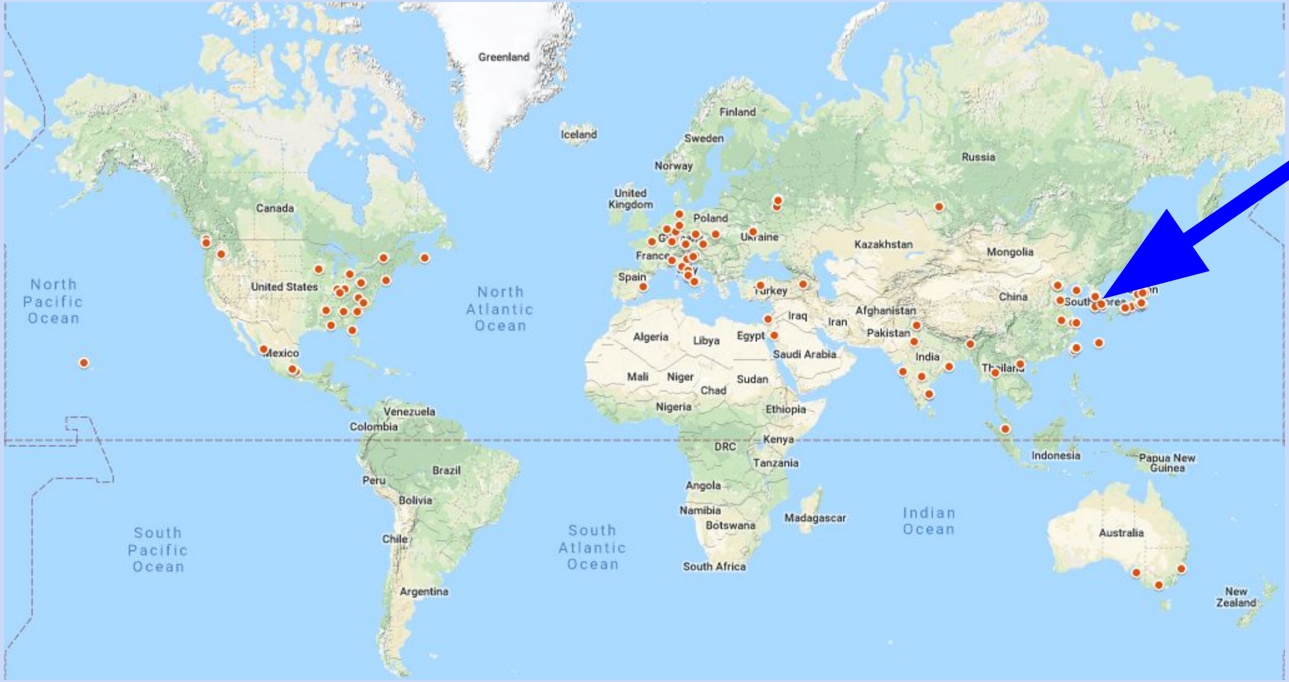
		KEKB		SuperKEKB		units	
		LER	HER	LER	HER		
Beam energy	E_b	3.5	8	4	7.007	GeV	
Beam crossing angle	ϕ	22		83		mrad	
β function @ IP	β_x^*/β_y	1200/5.9		32/0.27	25/0.30	mm	X 1/20
Beam current	I_b	1.64	1.19	3.6	2.6	A	X ~2
Peak Luminosity	L	2.1×10^{34}		80×10^{34}		$cm^{-2}s^{-1}$	X ~40

SuperKEKB & Belle II schedule



- Phase 1: Background, Optics Commissioning, Feb-June 2016. No Collision.No Belle Detector.
- Belle II Detector rolled-in to the beamline, Apr., 2017
- Phase 2: Pilot run, Superconducting Final Focus, add positron damping ring, First Collisions (0.5 fb^{-1}). No VXD detector. April 27-July 17, 2018
- Phase 3: Physics run started in 27 March 2019. Will continue with 7 months/year. Full Belle detector.

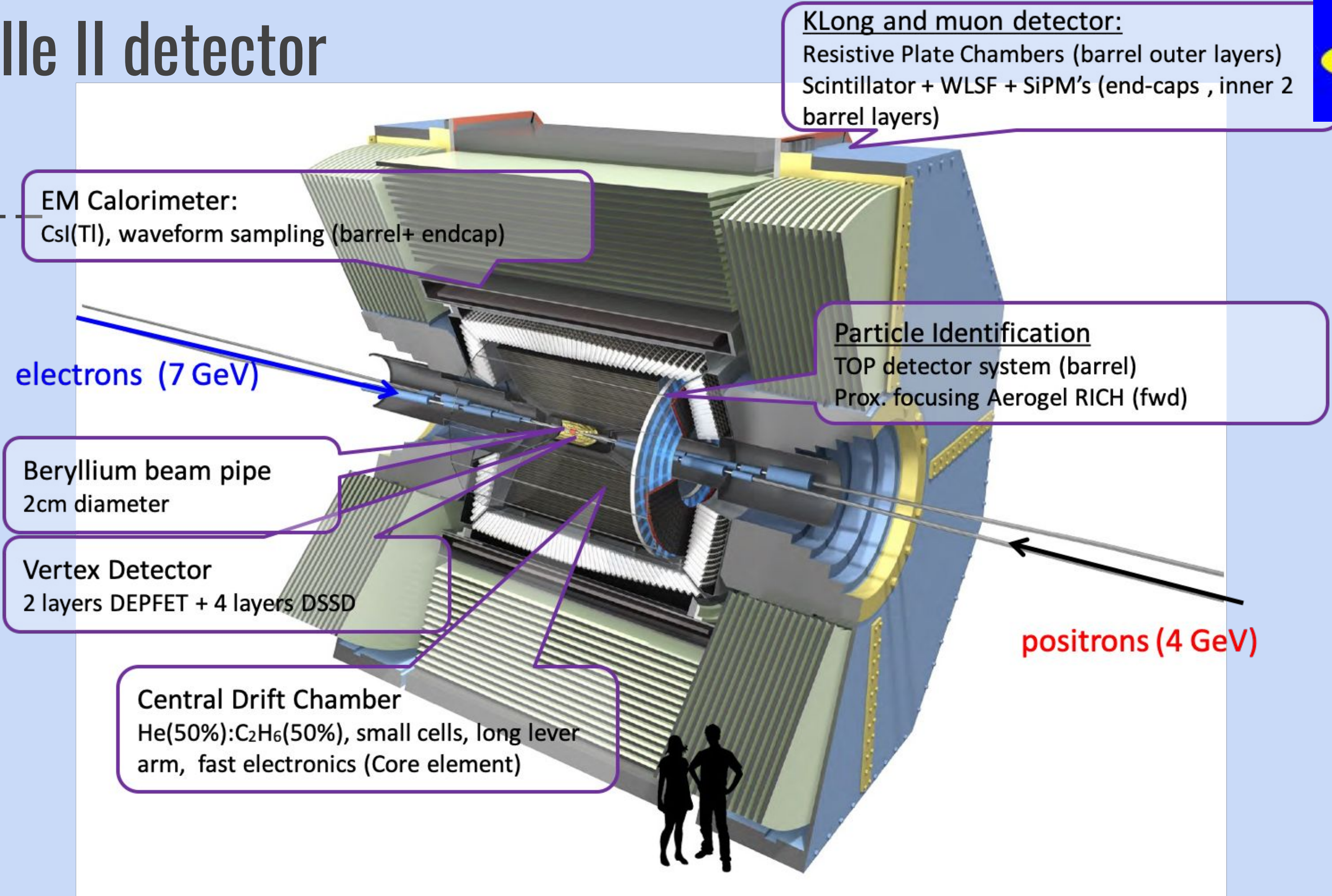
Belle II collaboration



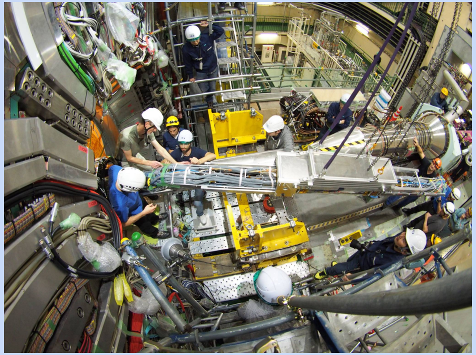
<u>Korea institutes:</u>
Chonnam, Gyeongsang, Hanyang, KISTI, Korea, Kyungpook, Seoul, Soongsil, Yonsei

- **Belle II now has grown to ~948 researchers from 26 countries.**
- **Youth and potential: There are 330 graduate students in the collaboration.**

Belle II detector



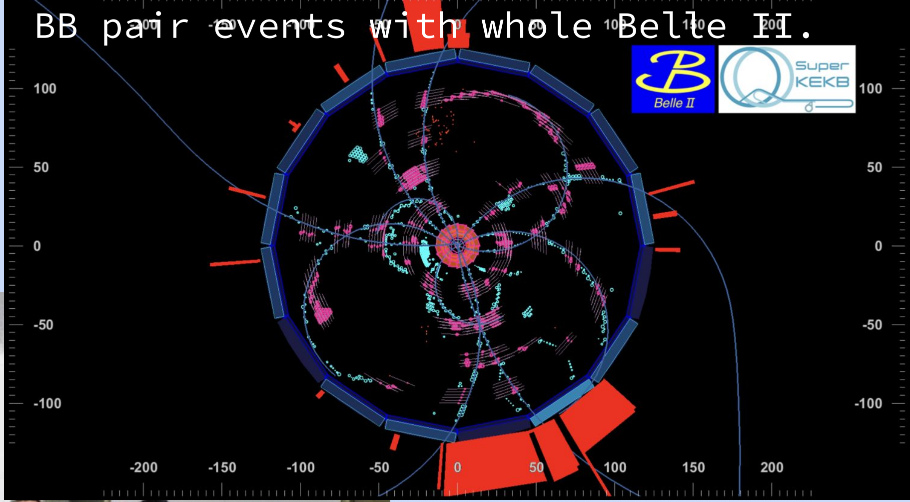
VXD (PXD+SVD) detector installed in Phase 3



Installation work finished Nov. 2018.

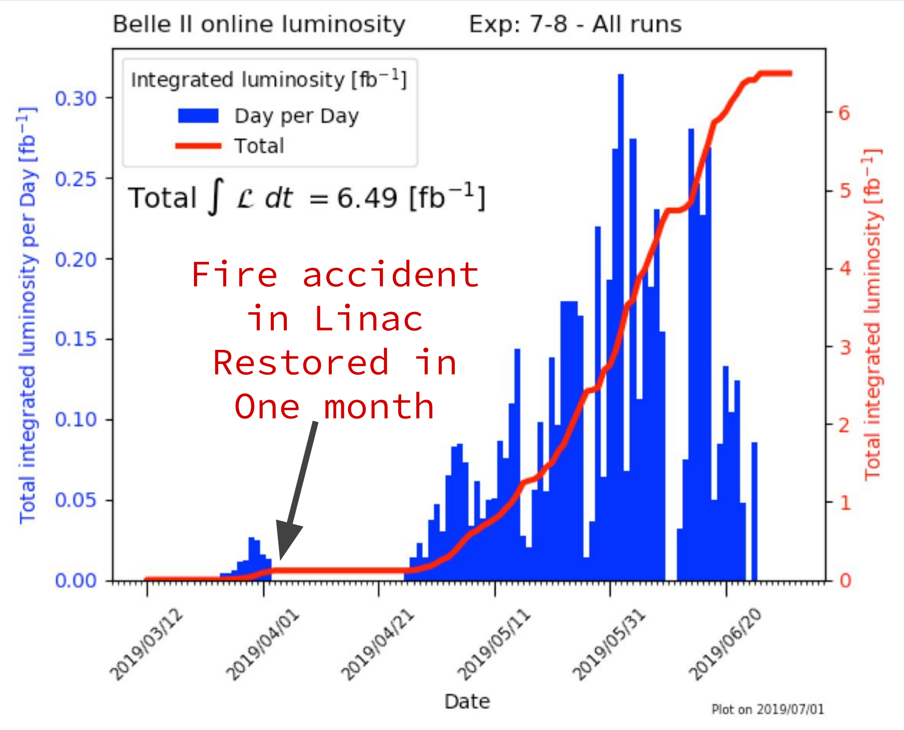
- PXD: Two layers of DEPFET pixel sensors r=14mm, r=22mm.
    - Only inner layer and small part of outer layer installed, replacement with full system in 2021
- SVD: Four layers of double sided strip detectors r=39mm to r=140mm

First Collisions in Phase 3

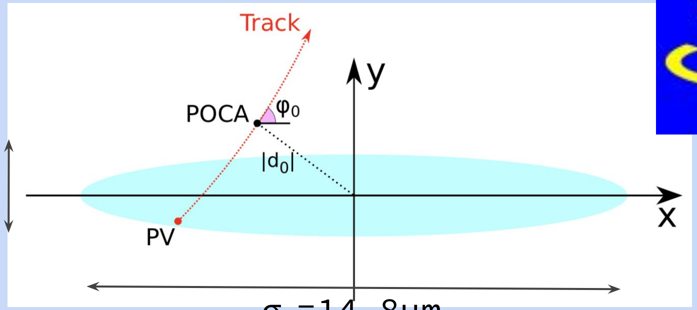


Luminosity of SuperKEKB/Belle II phase 3

Parameter	Achieved In phase 3	Target
I_{LER}(A)	0.880	2.6
I_{HER} (A)	0.940	3.6
β_y(mm)	2	0.3
# of bunches	1576	2364
L_{peak} ($cm^{-2}s^{-1}$)	Det on 6.1×10^{33}	8×10^{35}
	Det off 12×10^{33}	

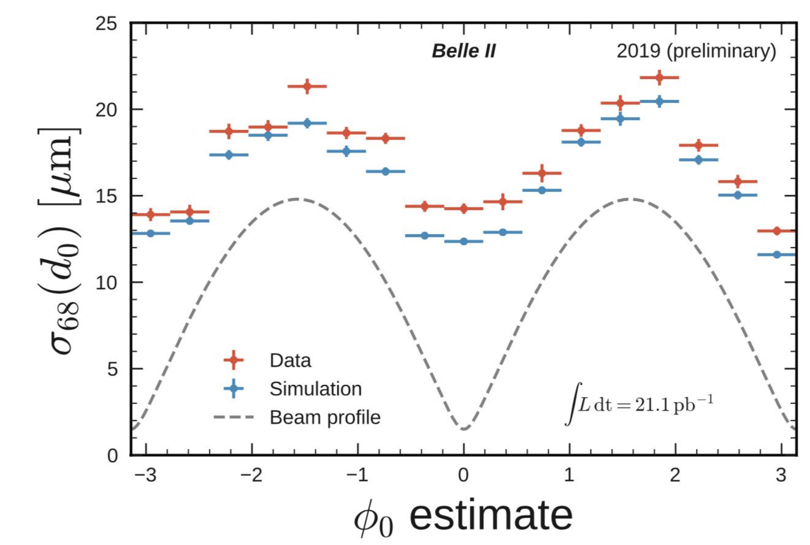


Impact parameter resolution

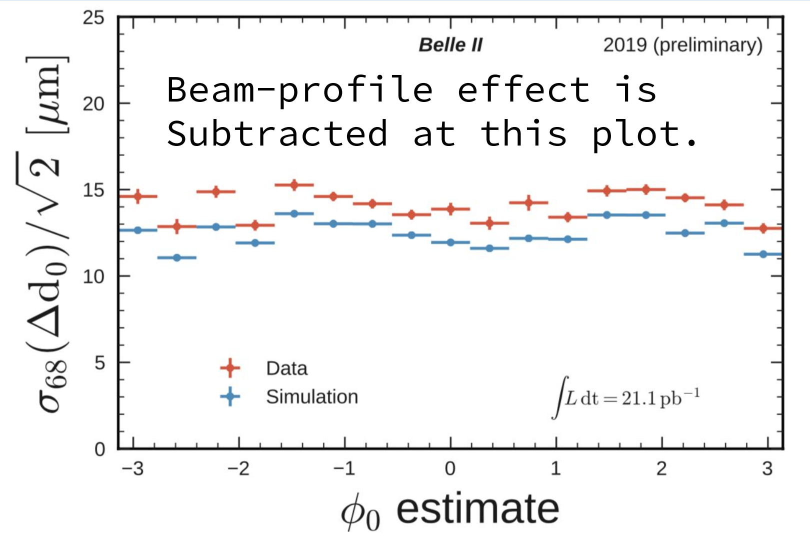


σ_y~1.5μm

σ_x=14.8μm

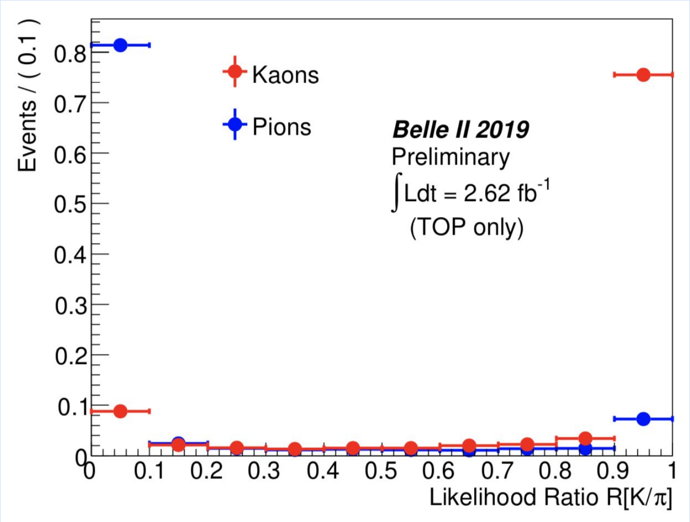


VXD resolution in impact parameter ~14 μm

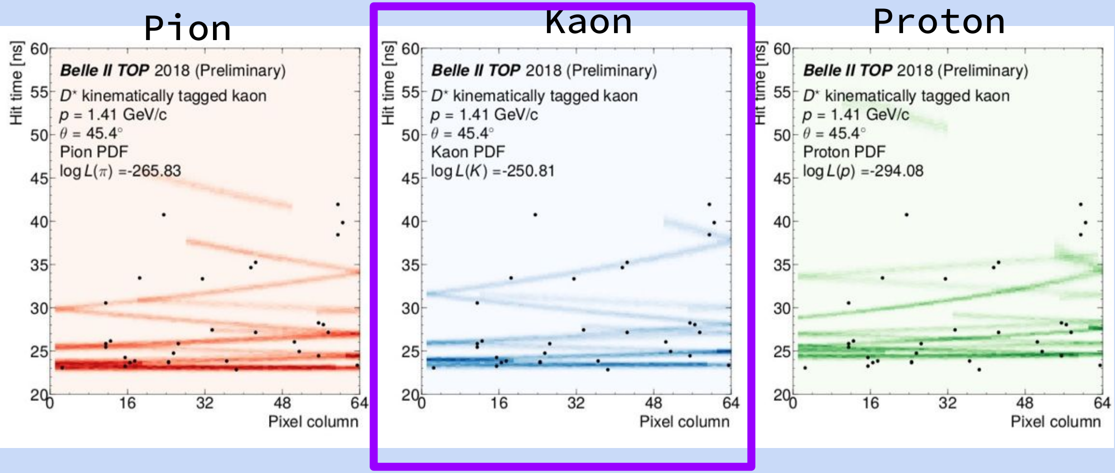


Impact parameter distributions in two-track events. Alignment and calibration are working well.

K/π identification by TOP detector



K and π tracks are tagged from the charge of the slow π (daughter of D*+) in the decay of $D^{*+} \rightarrow D^0[K^-\pi^+]\pi^+$.



A kaon track consist with the kaon-hypothesis PDF.

Physic Prospect

Rich Physics in Belle II

The Belle II Physics Book
arXiv:1808.10567
accepted by PTEP

Integrated Luminosity target: 50 ab^{-1}

● Golden mode

● Silver mode

Leptonic/Semi-leptonic

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

Radiative/EWP

Process	Observable	Theory	Sys. limit	vs LHCb	vs Belle	Anomaly	NP
$B \to K^{(*)} \nu \nu$	$Br.$, F_L	★★★	>50	★★★	★★★	★	★★
$B \to X_{s+d} \gamma$	A_{CP}	★★★	>50	★★★	★★★	★	★★
$B \to X_d \gamma$	A_{CP}	★★	>50	★★★	★★★	-	★★
$B \to K_S^0 \pi^0 \gamma$	$S_{K_S^0 \pi^0 \gamma}$	★★	>50	★★	★★★	★	★★★
$B \to \rho \gamma$	$S_{\rho\gamma}$	★★	>50	★★★	★★★	-	★★★
$B \to X_s l^+ l^-$	$Br.$	★★★	>50	★★★	★★	★★	★★★
$B \to X_s l^+ l^-$	R_{X_s}	★★★	>50	★★★	★★★	★★	★★★
$B \to K^{(*)} e^+ e^-$	$R(K^{(*)})$	★★★	>50	★★	★★★	★★★	★★★
$B \to X_s \gamma$	$Br.$	★★	1-5	★★★	★	★	★★
$B_{d,(s)} \to \gamma\gamma$	$Br.$, A_{CP}	★★	> 50(5)	★★	★★	-	★★
$B \to K^* e^+ e^-$	P_5'	★★	>50	★★★	★★	★★★	★★★
$B \to K \tau l$	$Br.$	★★★	>50	★★	★★★	★★	★★★

CPV

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

Φ_3

GGSZ	ϕ_3	★★★	>50	★★	★★★	★	★★
GLW	ϕ_3	★★★	>50	★★	★★★	★	★★
ADS	ϕ_3	★★	>50	★★	★★★	★	★★★
Time-dependent	$\phi_3 - \phi_2$	★★	-	★★	★★	★	★

Hadronic

$B \to \pi^0 K^0$	A_{CP}, $I_{K\pi}$	[illegible]	[illegible]	★★★	★★★	★★★	★★
$B \to \rho K$	A_{CP}, $I_{K\rho}$	★	-	★★	★★★	-	★★
$B \to \ell \nu \gamma$	λ_B	★★	-	★★★	★★★	★	★★
$B \to \rho K^*$	γ polari.	★★	-	★★	★★	-	★★★
$B \to K^+ K^- / \pi^+ \pi^-$	$Br.$, A_{CP}	★★	-	★	★★★	★★	★★
$B \to K\pi\pi, KKK$	A_{CP}	★★	-	★	★	★★★	★
$B_s \to K^0 \overline{K}^0$	lifetime	★	-	★★	★★★	-	★★

Charm

$D^0 \to K_S^0 K_S^0$	A_{CP}	★★★	[illegible]	[illegible]	★★	★	★
$D^+ \to \pi^+ \pi^0$	A_{CP}	★★★	-	★★★	★★	★	★★
$D_s \to \ell^+ \nu$	f_{D_s}	★★★	-	★★★	★	-	★★
$D^0 \to V\gamma$	A_{CP}	★	-	★★	★★	★★	★★
$D^0 \to \gamma\gamma$	$Br.$	★	-	★★	★★	★★	★★
$D^0 \to \nu\bar{\nu}$	$Br.$	★★★	-	★★★	★★	★★★	★★★
$D \to \ell^+ \nu$	f_D	★★★	-	★	★	-	★★

Tau

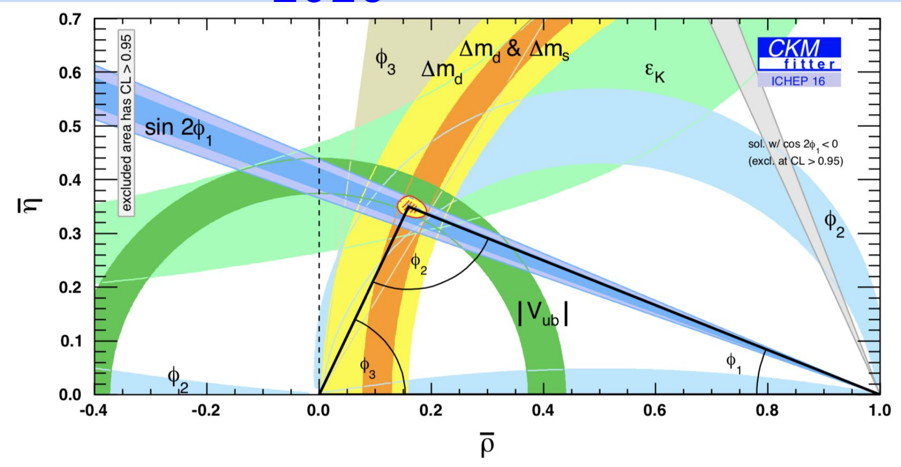
$\tau \to \mu\gamma$	$Br.$	[illegible]	>50	★★★	★★★	★	★★★
$\tau \to lll$	$Br.$	★★★	>50	★★★	★★★	★	★★★
$\tau \to K\pi\nu$	A_{CP}	★★★	-	★★★	★★★	★★	★★
$e^+e^- \to \gamma A'(\to \text{invisible})$	σ	★★★	-	★★★	★★★	★	★★★
$e^+e^- \to \gamma A'(\to \ell^+\ell^-)$	σ	★★★	-	★★★	★★★	★	★★★
π form factor	$g-2$	★★	-	★★★	★★	★★	★★★
ISR $e^+e^- \to \pi\pi$ g-2	$g-2$	★★	-	★★★	★★★	★★	★★★

Belle II also has **Quarkonium** and **Dark** sectors.

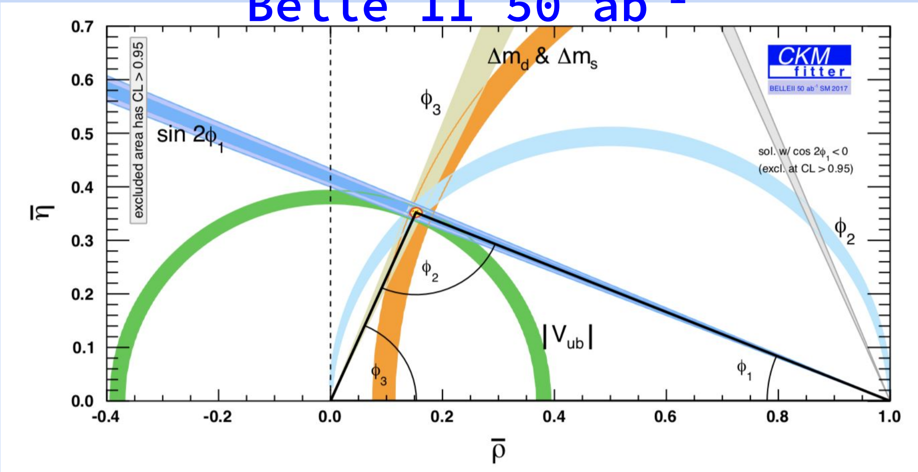
Few selected topics are mentioned later.
"The Belle II Physics Book" has more exciting topics.

CKM unitarity triangle global fit

2016



CKM global fit with Belle II 50 ab^{-1}



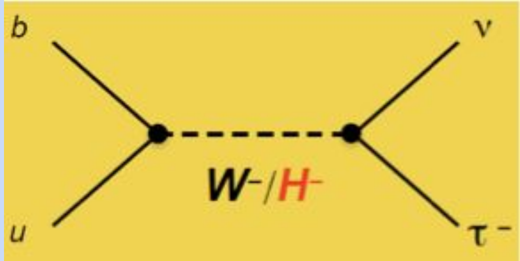
Error depress much

PRL 121, 031801

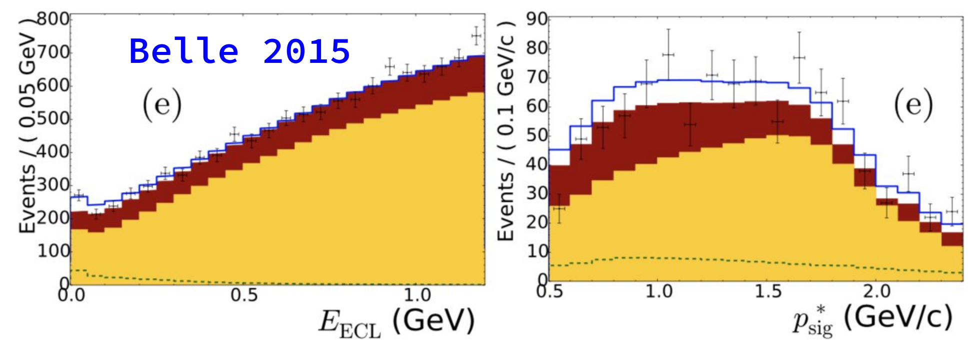
Lepton	B_{SM}
e	$(8.89\pm0.73)\times10^{-12}$
μ	$(3.80\pm0.31)\times10^{-7}$
τ	$(8.45\pm0.70)\times10^{-5}$

Leptonic Decays of $B^+\to\mu^+\nu$ & $B^+\to\tau^+\nu$

- Leptonic decay: Tree process. Branching fractions of $B^+\to\ell^+\nu$ in SM is proportional to m_ℓ^2 as below function.
- $$\mathbf{B}(B^+\to l^+\nu)_{SM} = \frac{G_F^2 M_B M_l^2}{8\pi}\left(1-\frac{M_l^2}{M_B^2}\right) f_B^2 |V_{ub}|^2 \tau_B$$
- Clean processes with accurate theoretical BF.
- Small theoretic uncertainties in SM
  - Good probe for new physics in tree process.
- The effect of two Higgs doublet models (2HDM II) to branching ratio of $\mu^+\nu$ is as below:
- $$\mathbf{B}_{2HDM\,II} = r_H \mathbf{B}_{SM},\ r_H \sim \left(1 - t_\beta^2 \frac{m_B^2}{m_H^2}\right)^2$$ arXiv:1903.0301
- If NP affects only on $\tau^+\nu$ mode, to eliminate uncertainties of f_B and $|V_{ub}|$. The below ratios are used to prove NP.



$$R_{pl} = \frac{\tau_{B^0}}{\tau_{B^+}} \frac{\mathbf{B}(B^+\to\tau^+\nu_\tau)}{\mathbf{B}(B^0\to\pi^- l^+\nu_l)} \qquad R_{pl} = \frac{\mathbf{B}(B^+\to\tau^+\nu_\tau)}{\mathbf{B}(B^+\to\mu^+\nu_\mu)}$$



$B^+ \to \tau^+ \nu$

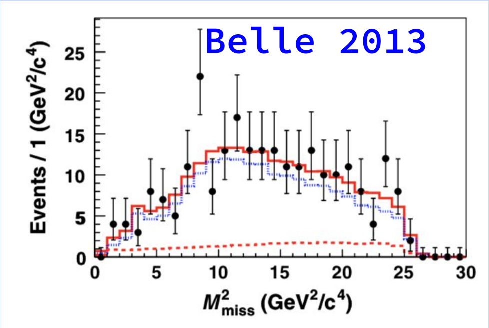
Belle result:

Semileptonic tag (PRD 92(5),051102,2015)

$BF=[1.25\pm0.28(stat.)\pm0.27(syst.)]\times10^{-4}$.

Hadronic tag (PRL 110,131801,2013)

$BF=[0.72+0.27-0.25(stat.)\pm0.11(syst.)]\times10^{-4}$



- $|V_{ub}|$ measurement
- Exploit new method of Full Event Interpretation (**FEI**) to select correct reconstruction of B_{sig} & B_{tag}.
  - B_{tag} can be hadronic tag or semileptonic
  - Efficiency (total few 10^{-3}) is higher than the method used in Belle.
- Feature: 2 or 3 neutrinos in final state. M_{miss}^2 :large in τ leptonic, small in τ hadronic
- Due high rate of beam background, cluster timing, crystal energy E_9/E_{25} → select π^0.

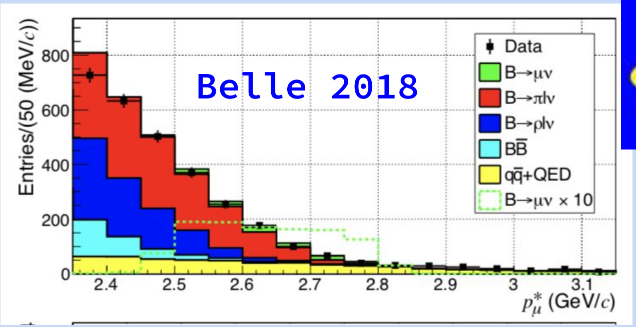
E_{ECL}		< 1 GeV	< 0.25 Ge
Belle II	Background yield [events]	7420	1348
	Signal yield [events]	188	136
	Signal efficiency (‰)	2.2	1.6
Belle	Background yield [events]	2160	365
	Signal yield [events]	97	60
	Signal efficiency (‰)	1.2	0.7

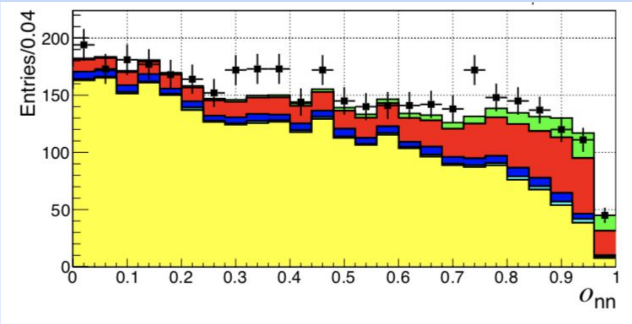
$B^+ \to \mu^+ \nu$

Belle result: (PRL 121,031801,2018)

BF=[6.46±2.22(stat.)±1.60(syst.)]×10^{-7}.@ 2.4σ

- As the tag efficiency is low, better not to use tag method.
- Background: continuum, πℓv, ρℓv, and BB generic.
- Neural Network/GBDT is used to suppress background.
  - 14 input parameters that is uncorrected with $|P_\mu|$. Output:O_{nn}
- P_μ^* in CM frame
- Feature: $P_\mu^B \sim M_B/2$ in B rest frame.
  - Convert P_μ^* to P_μ^B
- Likely to claim observation at 5 ab^{-1}.





ℓ	$\mathcal{B}_{SM}$	711 fb^{-1}	5 ab^{-1}	50 ab^{-1}
τ	$(7.71 \pm 0.62) \times 10^{-5}$	61200 ± 5000	430000 ± 35000	4300000 ± 350000
μ	$(3.46 \pm 0.28) \times 10^{-7}$	275 ± 23	1930 ± 160	19300 ± 1600
e	$(0.811 \pm 0.065) \times 10^{-11}$	0.0064 ± 0.0005	0.0453 ± 0.0037	0.453 ± 0.037

Luminosity	R_{ps}	R_{pl}
5 ab^{-1}	$[-0.22, 0.20]$	$[-0.42, 0.29]$
50 ab^{-1}	$[-0.11, 0.12]$	$[-0.12, 0.11]$

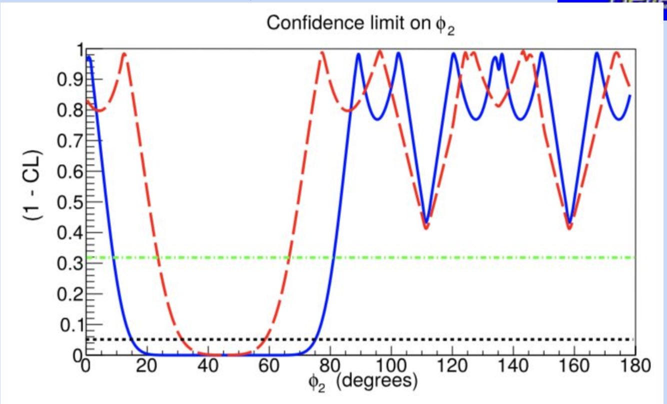
$B^0 \to \pi^0 \pi^0$ decay

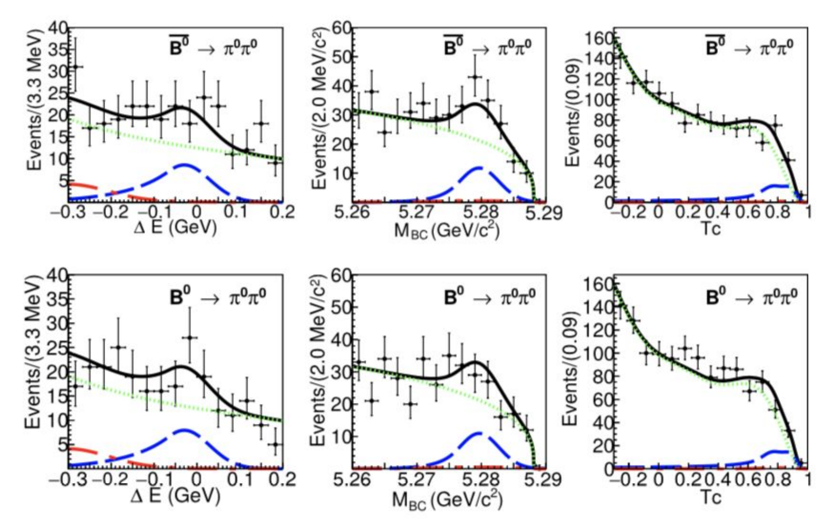
$$\Delta E = E(B\text{ cand.}) - E_{beam}$$

$$M_{bc} = \sqrt{E_{beam}^2 - P(B\text{ cand.})^2}$$

Belle
PRD **96**, 032007(2017)

- Color suppressed tree process. Experimental result is BF=[1.31±0.19(stat.)±0.18 (syst.)]×10^{-6} Belle 2017
  - Theory paper for this enhancement:PRD 73,114014 (2006), PRD 83,034023 (2011)
  - More data and lower sys error are needed.
- Φ_2 angle measurement by direct CP violation. $A_{CP} = 0.14 \pm 0.36 \pm 0.10$
- Due to high rate of beam background, timing and E_9/E_{25} selection of γ are important.
- Flavor tag of B_{tag}
- Spreaded signal shape in ΔE





$B^0 \to \pi^0\pi^0$ decay

$$\Delta E = E(B\ \text{cand.}) - E_{beam}$$

$$M_{bc} = \sqrt{E_{beam}^2 - P(B\ \text{cand.})^2}$$

- Color suppressed tree process. Experimental result is BF=[1.31±0.19(stat.)±0.18 (syst.)]×10^{-6} Belle 2017
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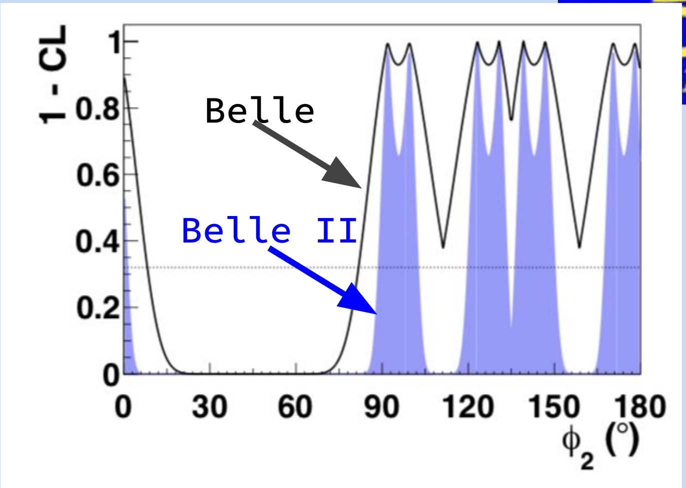
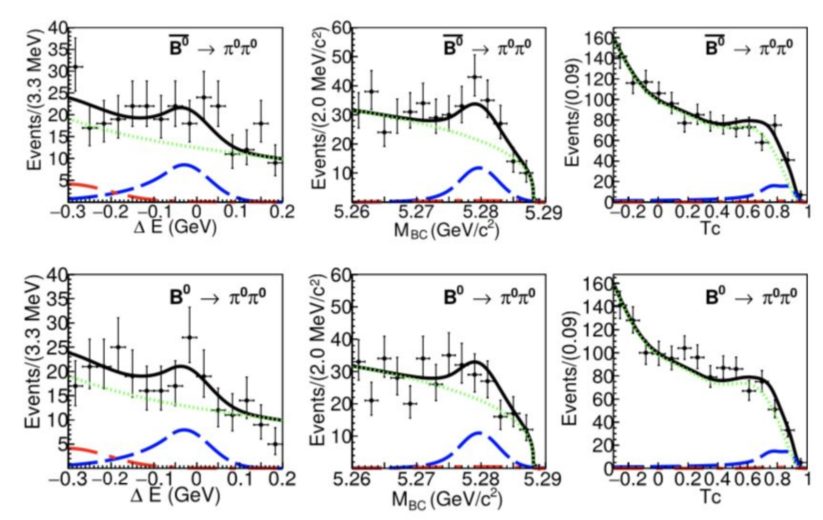
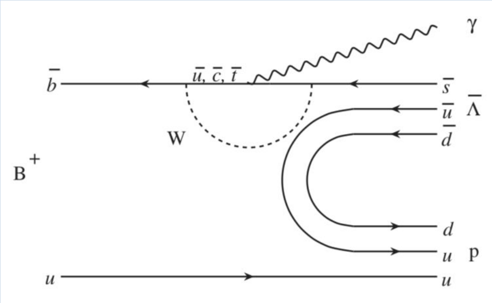




Charmless Baryonic B decays

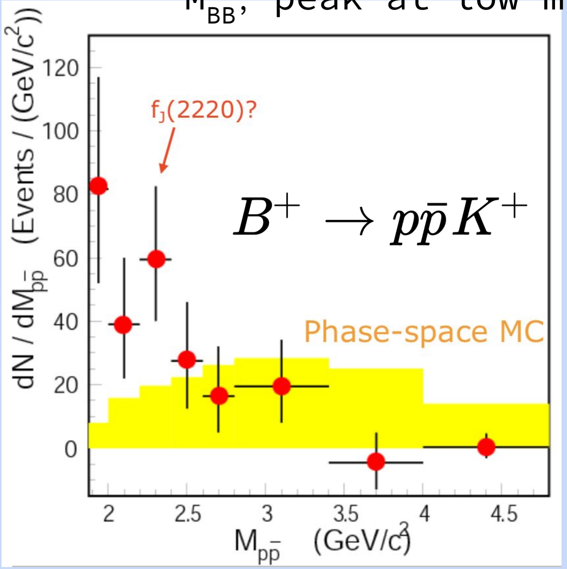
Baryonic B decay is B meson decay to two baryons+etc.

$$B \to \mathbf{B}\bar{\mathbf{B}}'m$$

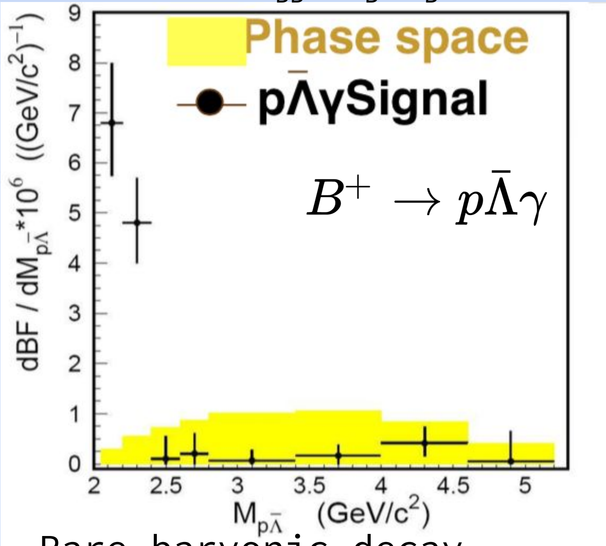


Threshold enhancement:

$M_{BB'}$ peak at low mass region: $M_{BB'} \sim m_B + m_{B'}$



First found rare baryonic decay in Belle, 2002

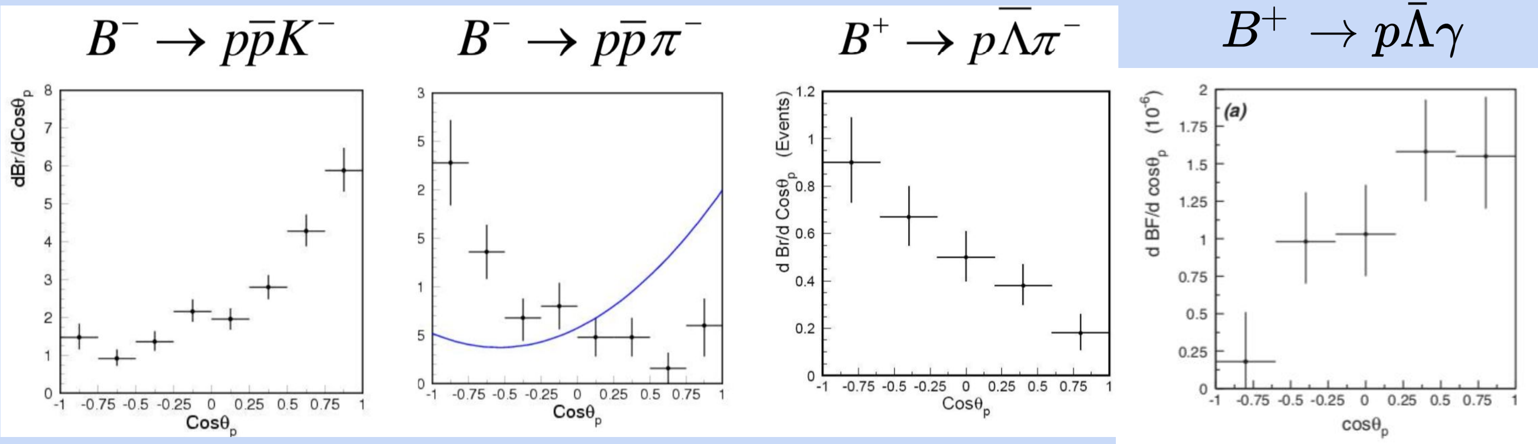


Rare baryonic decay Through b->sγ process, Belle 2005

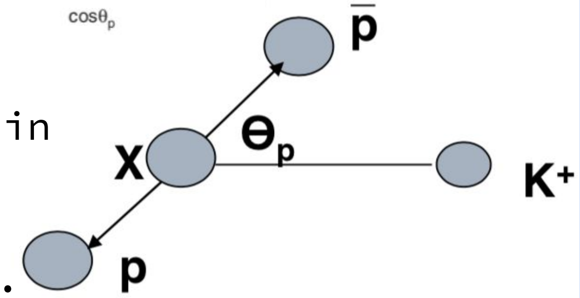
- Threshold enhancement is an universal feature in baryonic B decay.
- Possible Theory
  - Baryon form factor
    - Cheng & Yang PRD 66 014020 ('02)
    - Chua, Hou, Tsai PRD 66 054004 ('02)
  - Quasi 2-body decay
    - Chua, Hou, Tsai PLB 544 139 ('02)
- Direct CP violation is also shown in $B^+ \to p\bar{p}K^+$ at $M_{pp} < 2.85$ GeV by LHCb

Angular asymmetries of Baryonic B decays

θ_p:angle between p direction and the meson/photon direction in BB-bar rest frame.



- Angle asymmetries are large and unexpected.
- LHCb found that angle asymmetries is function of M_{pp} in $B^+\to p\bar{p}K^+$ and $B^+\to p\bar{p}\pi^+$ (PRL 113, 141801 (2014))
- This issue is still a puzzle.
  - Need more data for search asym. in more modes.



Possible topics

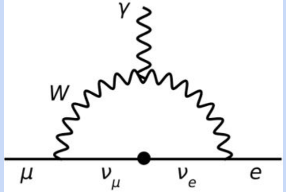
- $B^+ \to p\bar{p}\rho^+$
- $B^0 \to p\bar{\Sigma}^0\pi^-$
- $B^0 \to p\bar{p}\pi^0$
- $B^- \to p\bar{p}\ell\nu$
- $B^- \to p\bar{n}K^-$
- $\bar{B}^0 \to \bar{n}\Lambda^0\gamma$
- etc.

Lepton Flavor Violation τ Decays at Belle II

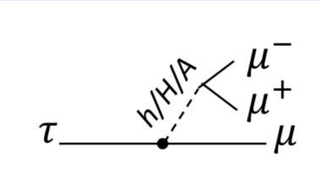
- **Super B-Factory, and τ factory too!**
  σ(e+e- –> Υ(4s)) = 1.05 nb
  σ(e+e- –> $\tau\tau$) = 0.92 nb

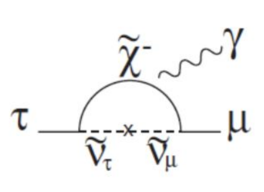
- Charged LPV process occur oscillations in loops. In SM, small rate is immeasurable (10^{-49}~10^{-54}) for all LFV decays.

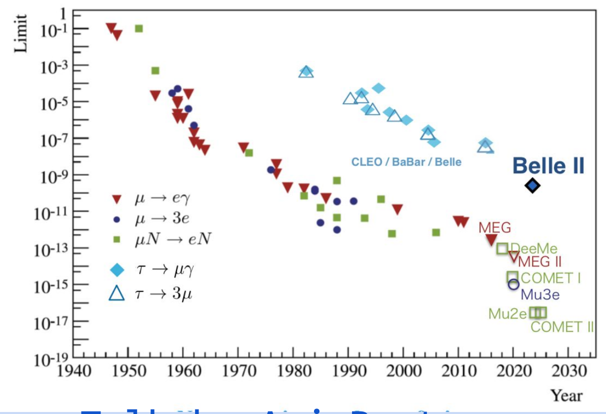
$$B(l_1 \to l_2\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{l_1,i}U_{l_2,i}\frac{\Delta m^2_{i1}}{M_W^2}\right|^2$$



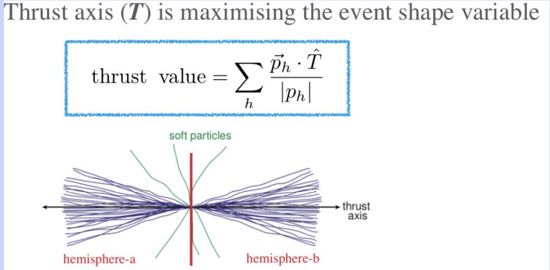
- Charged LFV enhanced in many NP models (10^{-7}~10^{-10})





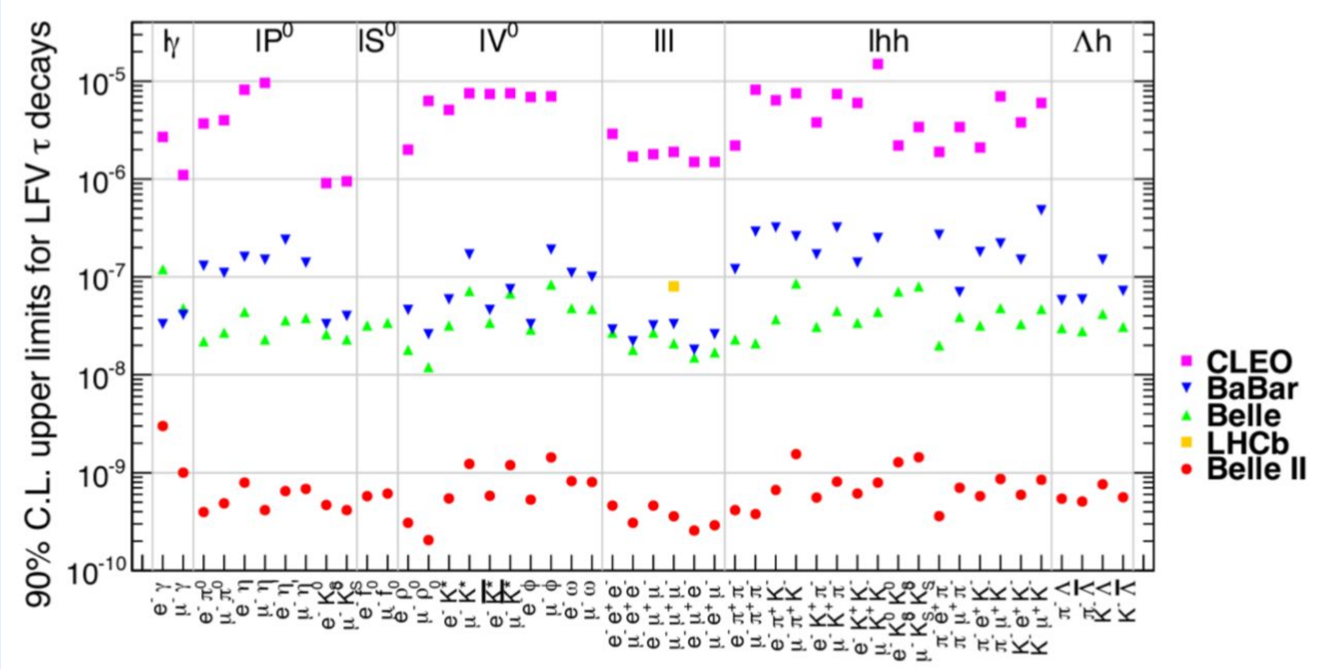


Talk by Ami Rostomyan at TAU 2018



Thrust and visible energy are useful variables in analysis.

LFV τ Decays at Belle II



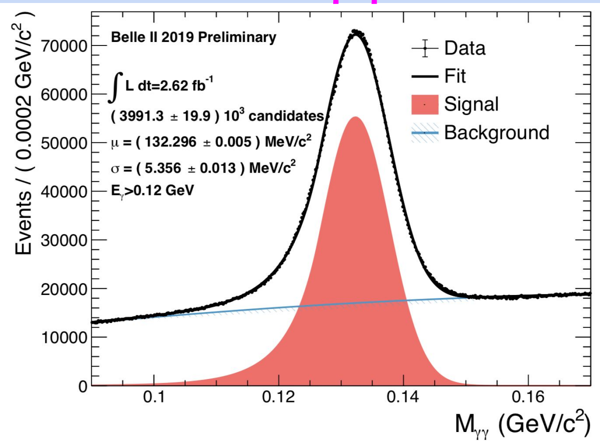
- Observation of LFV is a clear signature of New Physics.
- Lower the upper limit by two order of magnitude.

Particle re-discover

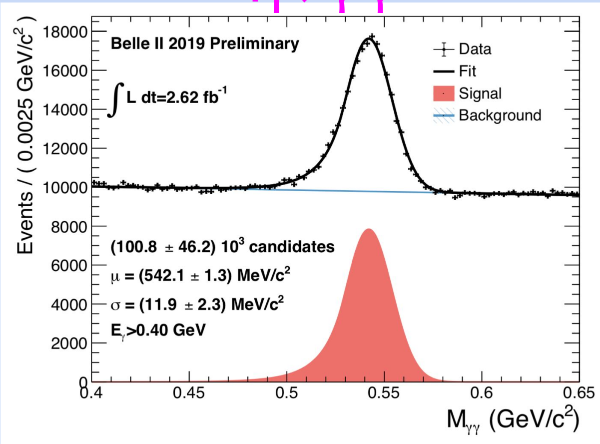
Mass peaks

E_9/E_{21} selection

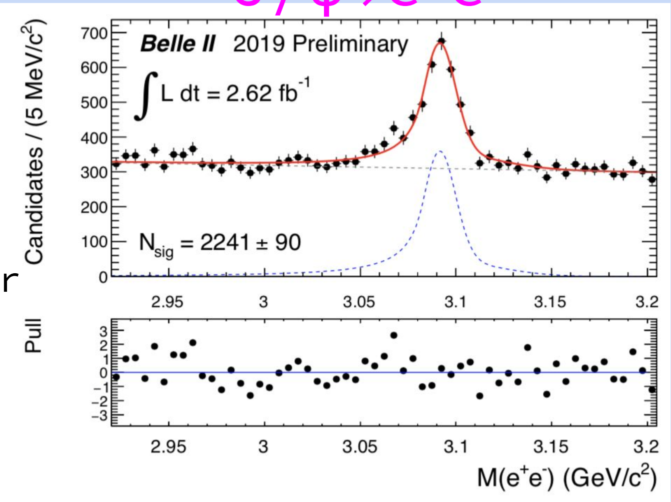
$\pi^0 \to \gamma\gamma$



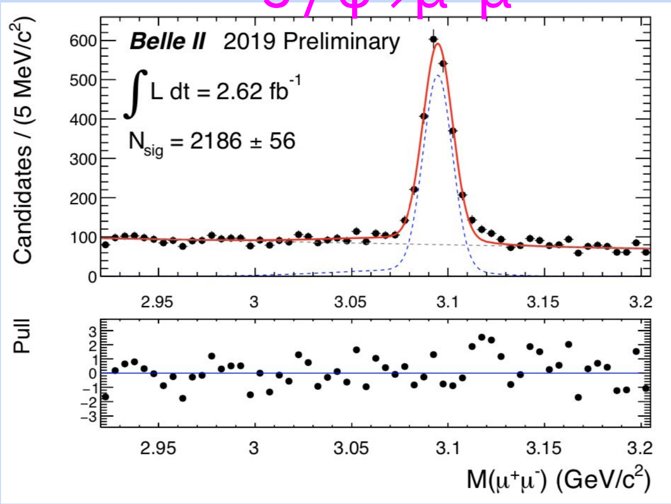
$\eta \to \gamma\gamma$



$J/\psi \to e^+e^-$



$J/\psi \to \mu^+\mu^-$



Impact parameter
Vertex fitting

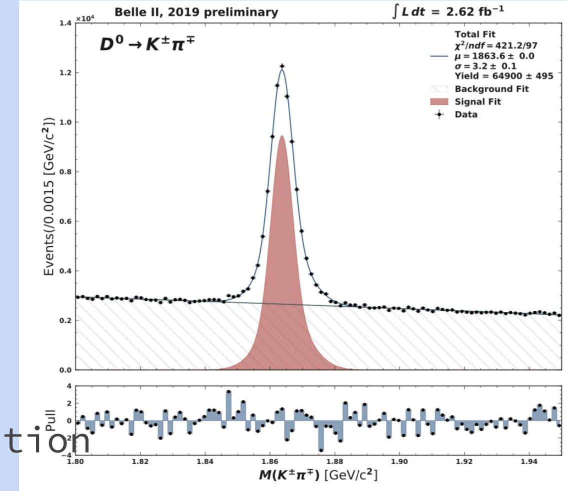
Mass peaks

Impact parameter

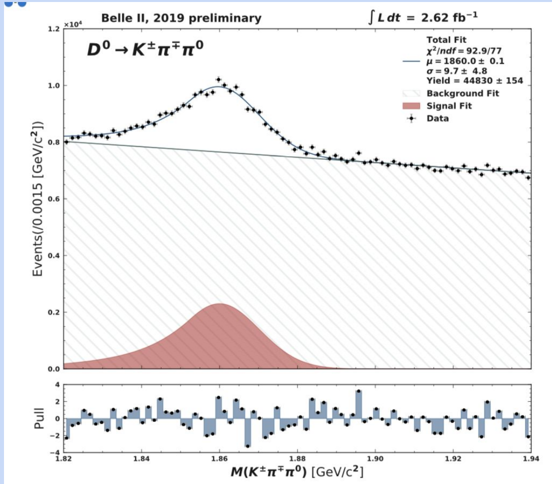
E_9/E_{21} selection

K_s optimization selection

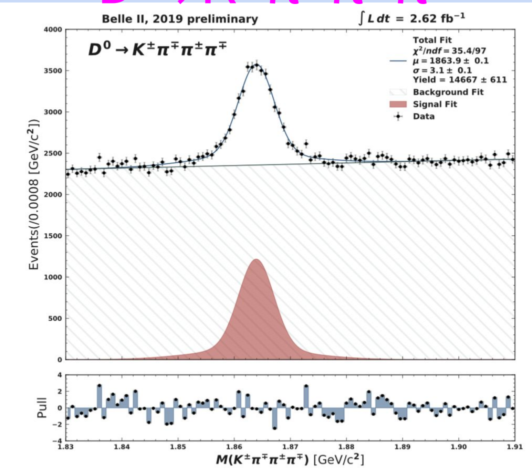
$D^0 \to K^+\pi^-$



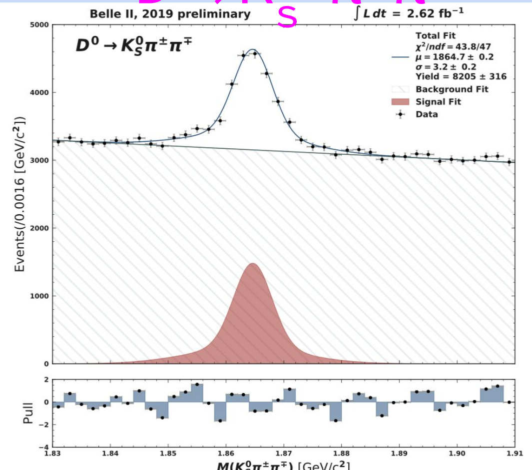
$D^0 \to K^+\pi^-\pi^0$



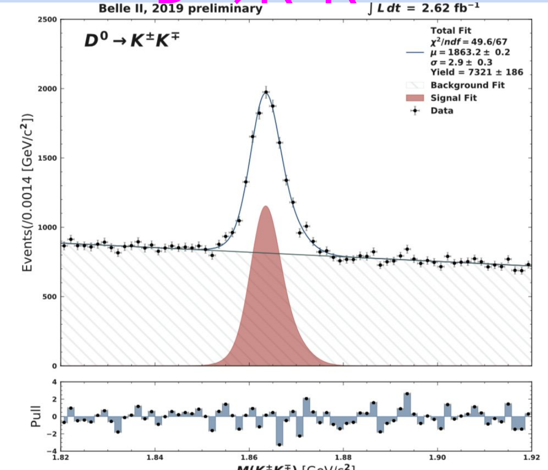
$D^0 \to K^+\pi^-\pi^+\pi^-$



$D^0 \to K_s^0\pi^+\pi^-$



$D^0 \to K^+K^-$

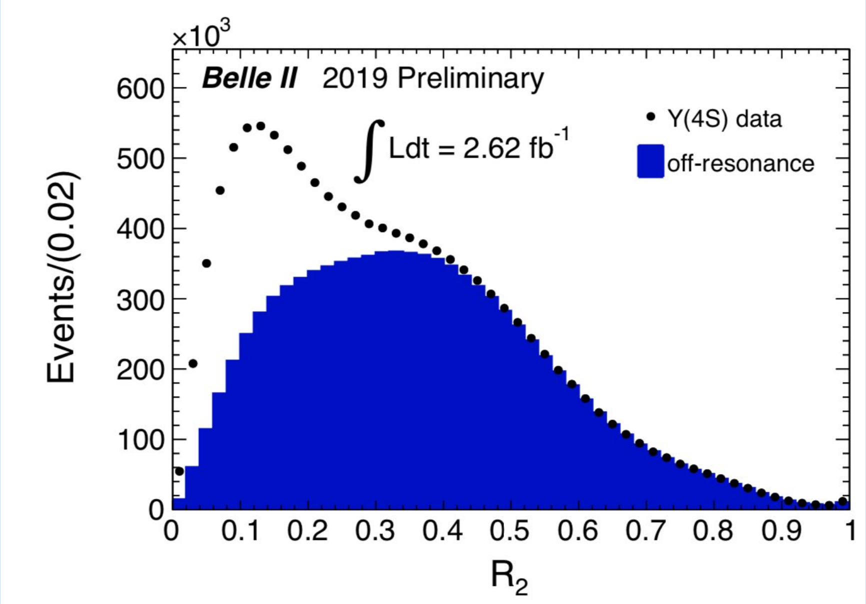


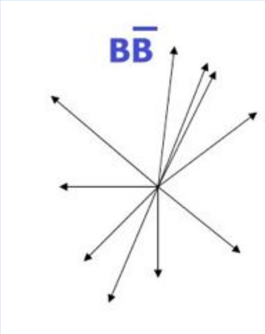
Topology of final states of B meson

Fox-Wolfram moments

$$H_l = \sum_{i,j} \frac{|P_i||P_j|}{E_j^{vis}} P_l(cos\theta_{ij})$$

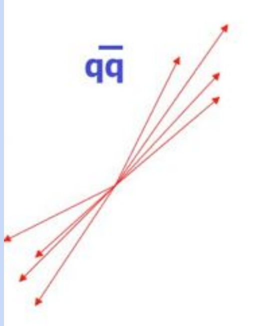
$R_2=H_2/H_0$





Spherical-like

verse



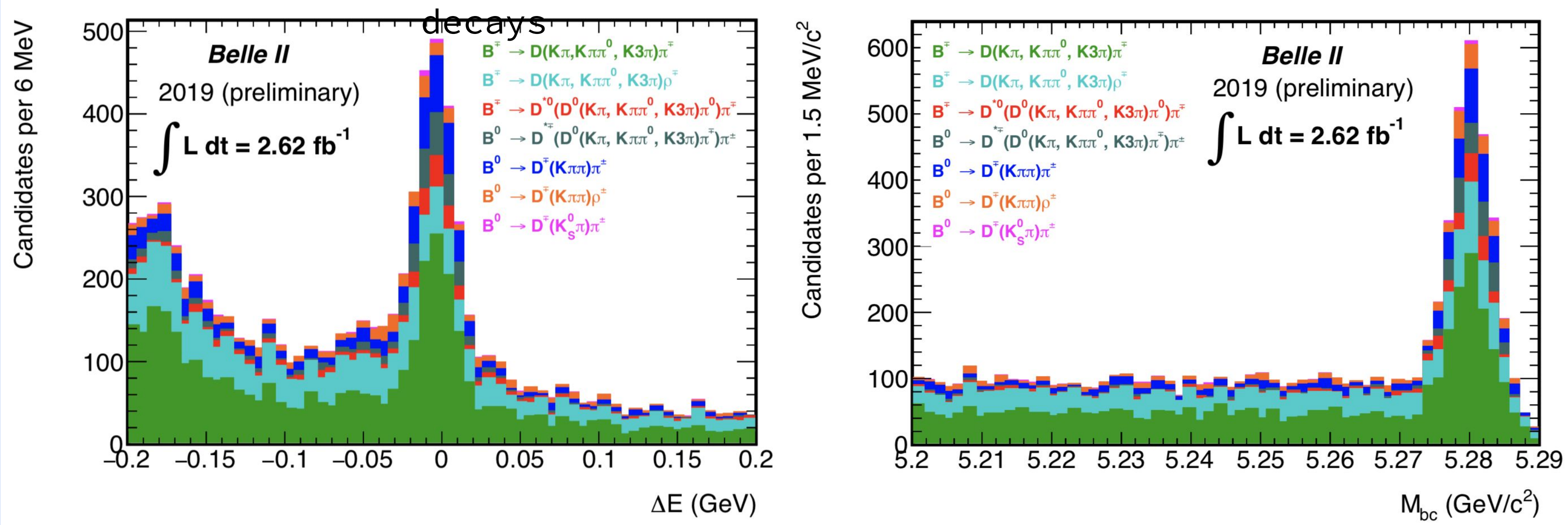
Jet-like

FW moments variables are used to separate BB pair event from qq-bar events.

Early phase 3 data are used

Re-discover B meson

Hadronic $B^{+/0} \rightarrow D^{(*)}h^{+}(h=\pi \text{ or } \rho)$ decays



Demonstration of Capabilities: Modes with neutrals, and K_s mesons are efficiently reconstructed along with all-charged final states containing kaons and pions.

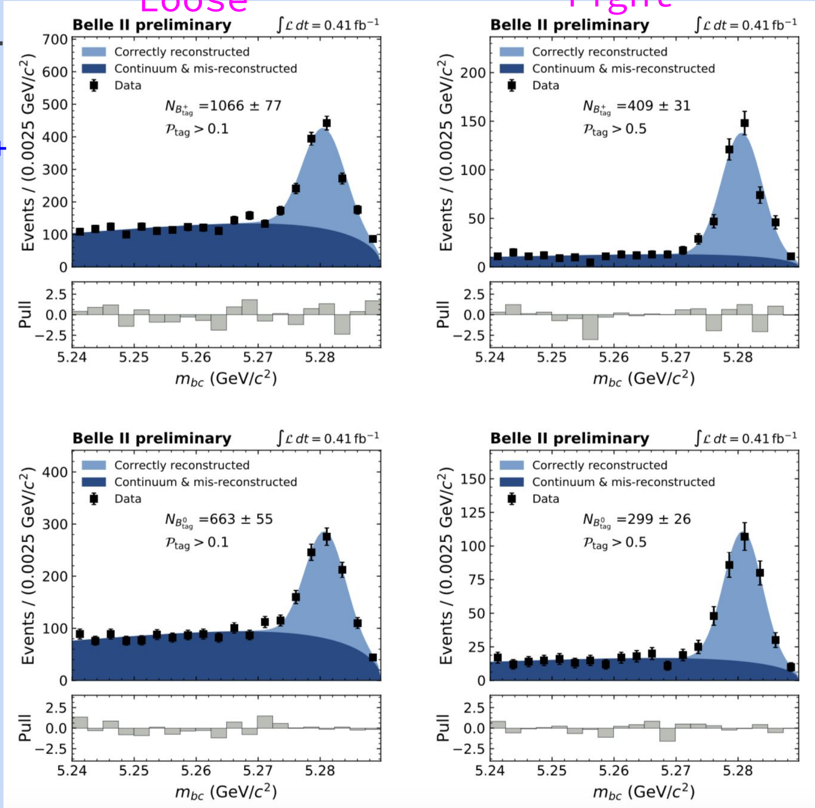
B decay mode re-discover

B_{tag} by Full Event Interpreter

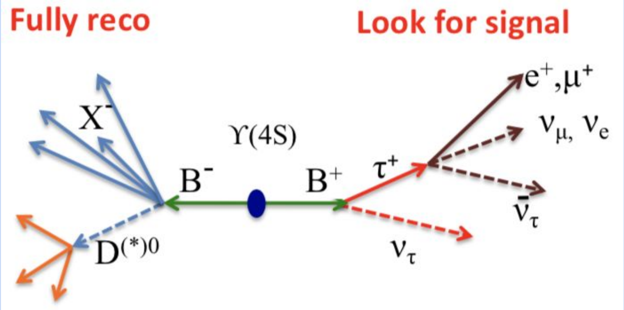
Loose Tight

B_{tag}^{+}

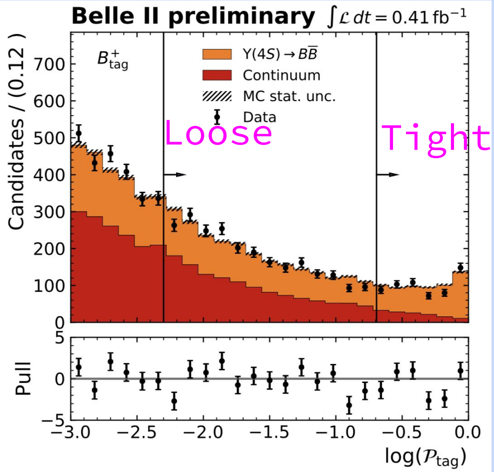
B_{tag}^{0}



B_{sig} are reconstruct from B → Xlν.



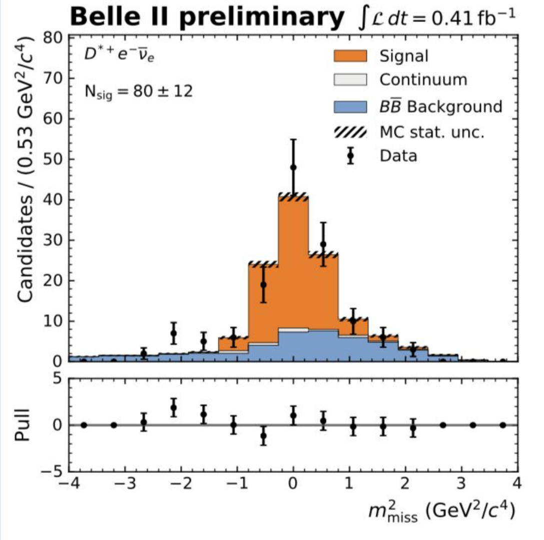
FEI: BDT (boosted decision trees) and a large number of B decay modes. Increase yields by O(X8) than FR of Belle.

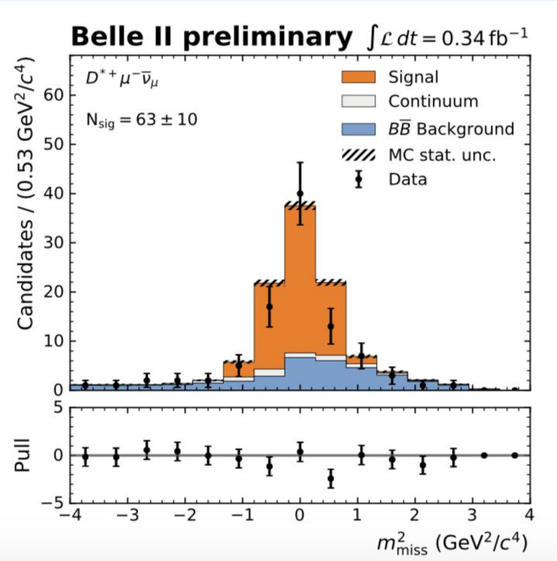


Semi-leptonic B decays

Untagged of $B^0 \to D^{*+}\ell^-\nu$ candidates in $m_{miss}{}^2$ distribution.
Clean signal can be seen in e and μ mode.

$$m^2_{miss} = (\frac{P_{ee}}{2} - P^*_{D^*l})$$

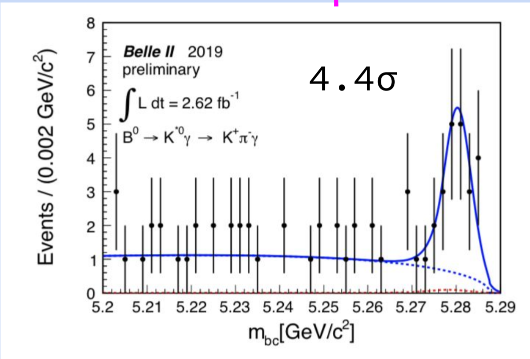




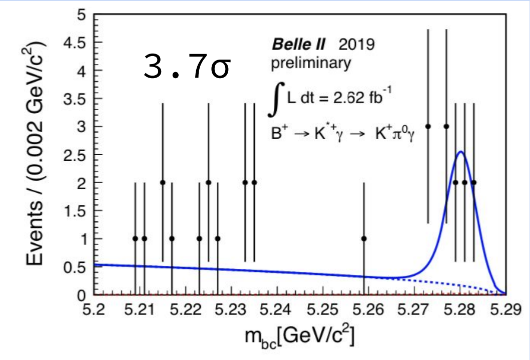
Observation of B⟶ $K^*\gamma$

First observation radiative penguin process (b→ sγ) @Belle II.

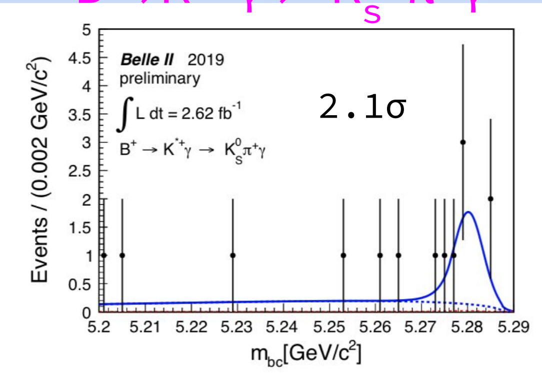
$B^0 \to K^{*0}\gamma$



$B^+ \to K^{*+}\gamma \to K^+\pi^0\gamma$



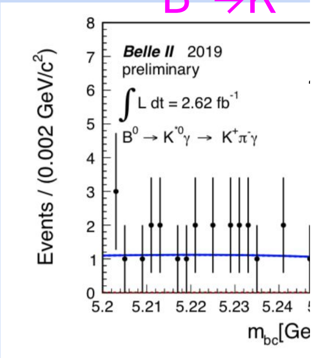
$B^+ \to K^{*+}\gamma \to K_s^0\pi^+\gamma$

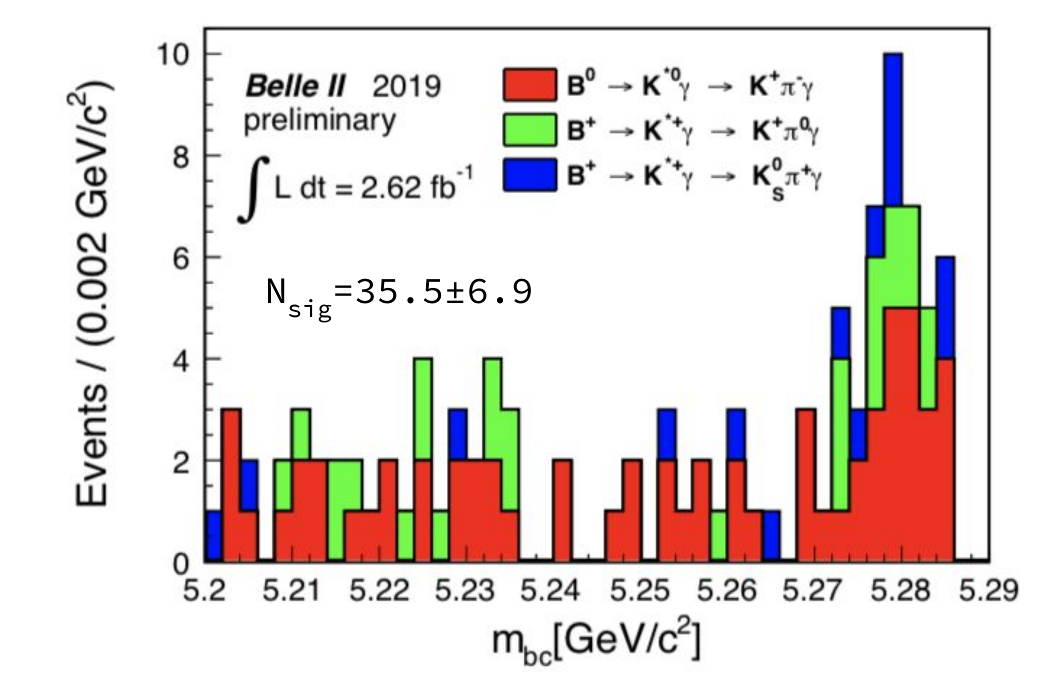


Observation of $B \to K^* \gamma$

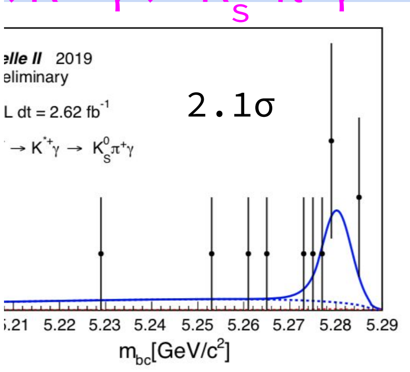
First observ … γ) @Belle II.

$B^0 \to K^{*0}$



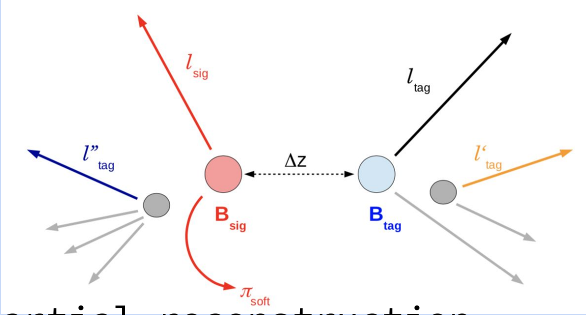


$\to K^{*+}\gamma \to K_s^0 \pi^+ \gamma$



Yields consistent with WA branching fraction

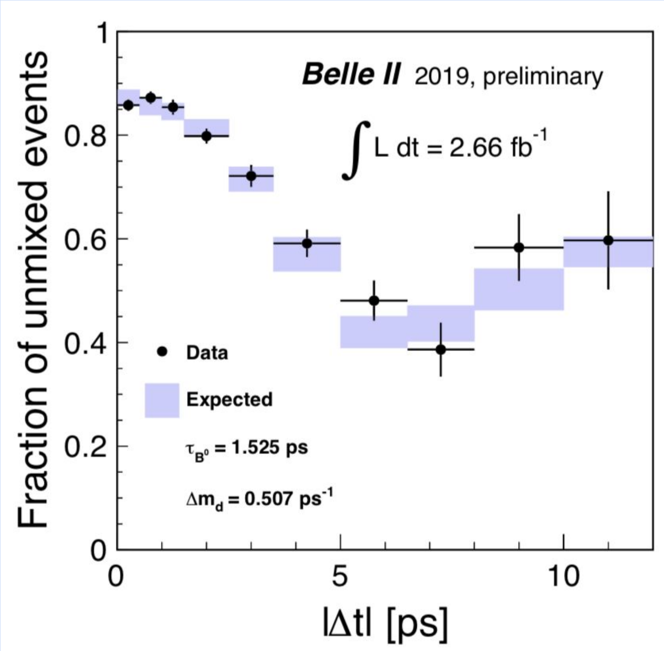
Time dependent B^0-$\overline{B^0}$ mixing signature



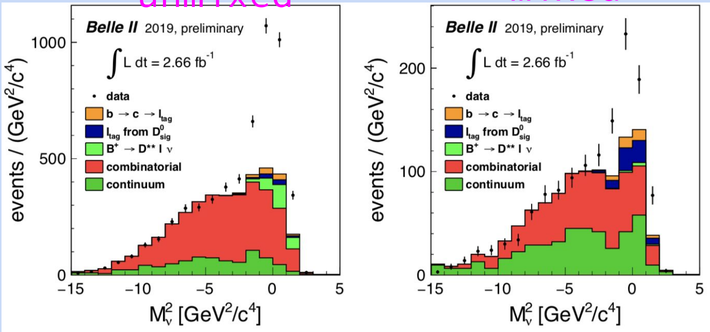
$$\bar{B}^0 \to D^{*+} l^- \nu$$

Partial reconstruction and time determination uses only Lepton tagging.

--- Oscillation observed



unmixed mixed



No mixing fraction:

$f_{unmix}(t) = K[1+\cos(\Delta m_d \Delta t)]$

Use “diff” sign of two lepton in the final state.

Verifies Belle II VXD capabilities for CP violation.

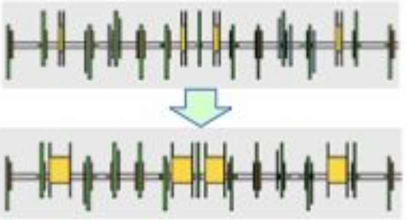
Summary

- Rich physics in Belle II experiment.
  - CP violation & rare decay of B/D decay, LFV/LNF in τ decay, pentaquark, dark sector and Quarkonium.
- The first physics run in the Super B factory mode (Phase 3) started in spring 2019. Integrated luminosity ~6.5 fb^{-1}.
- Time-dependent capabilities with VXD and particle ID with TOP are demonstrated. Many good results of re-discoveries are presented in phase 3 data.
- SuperKEKB are going through way to world’s highest luminosity accelerator. Belle II target at high efficiency data-taking rate to record more physics.
- Phase 3 resume in mid-October and continue until June 2020.

Stay tuned
Belle II will discover exciting physics soon.

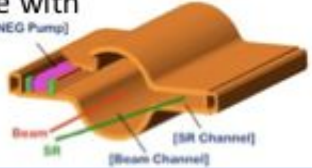
backup

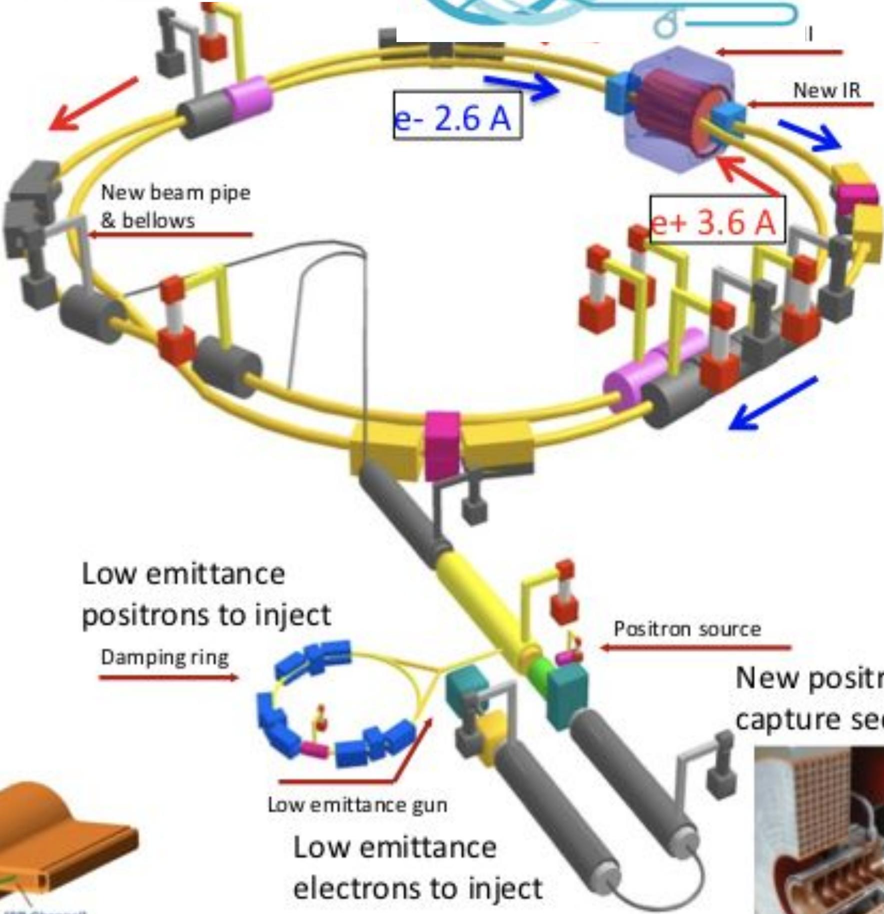
Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance

TiN-coated beam pipe with antechambers

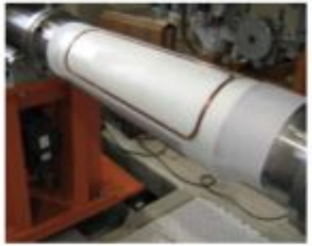




Low emittance positrons to inject

Low emittance electrons to inject

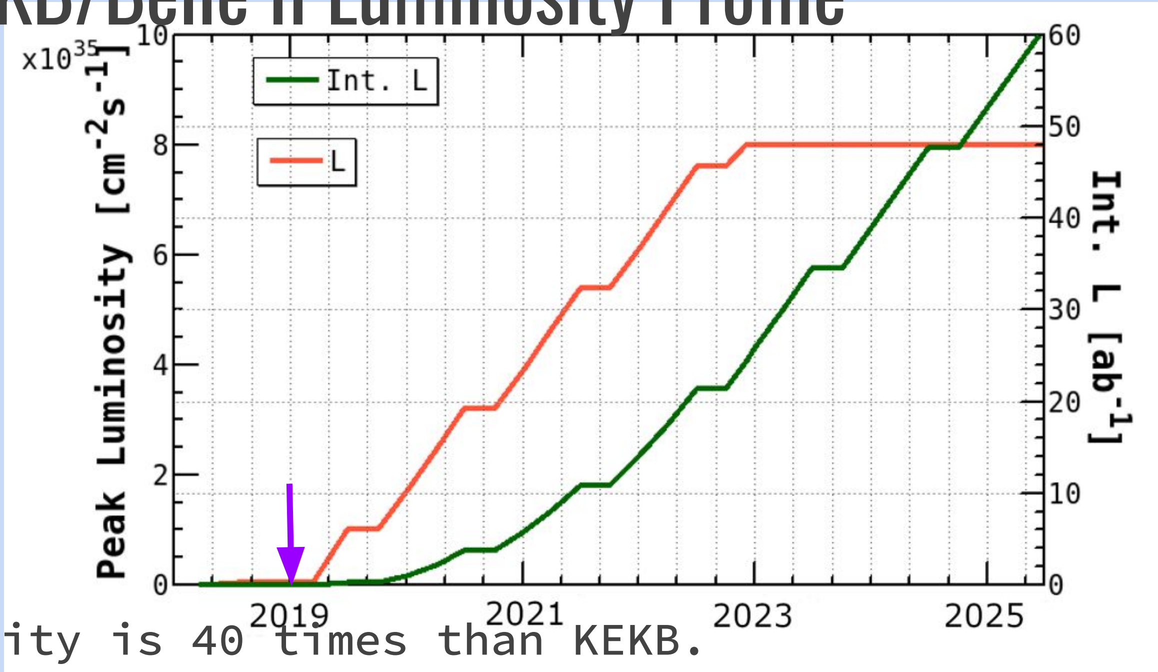
New superconducting /permanent final focusing quads near the IP



New positron target / capture section

Add / modify RF system for higher beam current

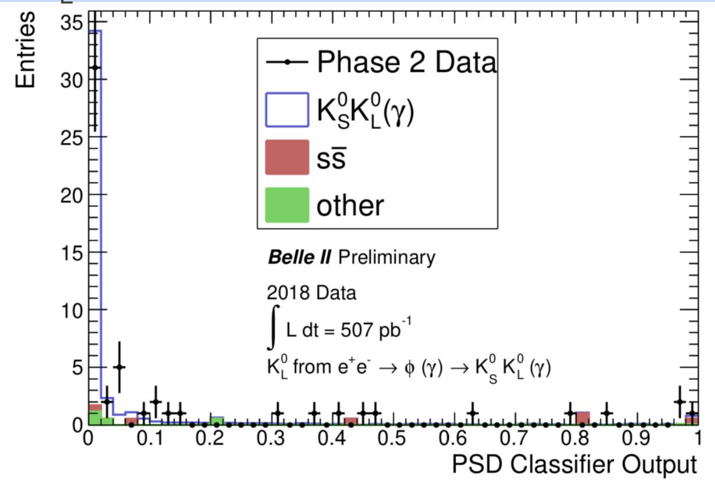
SuperKEKB/Belle II Luminosity Profile



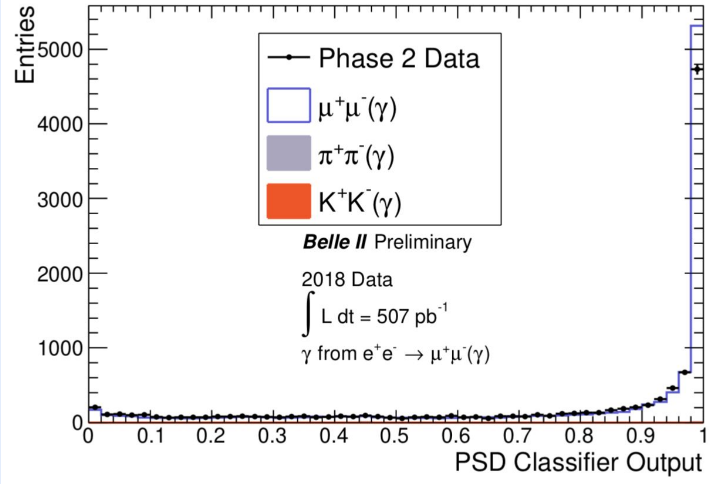
- Luminosity is 40 times than KEKB.
  - Beam profile size: y-axis 50 nm, x-axis 100 µm. (nano beam)
  - Beam current is about 2 times of KEKB.
- Belle/KEKB recorded ~1000 fb^{-1}. Now we have to change units on the y-axis to ab^{-1}

K_L identification by ECL pulse shape discriminator

New PID approach: The pulse shape parameters of ECL (electromagnetic calorimeter) can be the inputs of BDT which works as an classifier of K_L/γ.



K_L^0 candidates selected from $e^+e^- \to \phi\gamma \to K_S^0 K_L^0\gamma$ control sample in Phase 2 Data and MC.



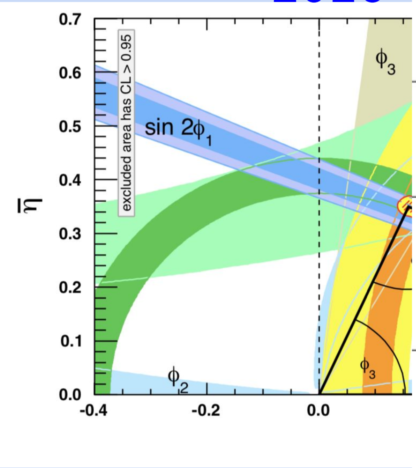
Photons candidates selected from $e^+e^- \to \mu^+\mu^-(\gamma)$ control sample in Phase 2 Data and MC.

CKM unitar

2016

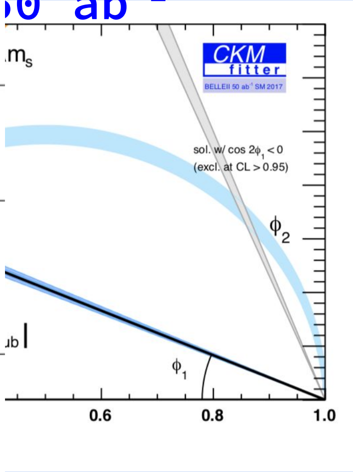
Error will depress much

Input	World average 2016	Belle II (+LHCb) 2025	SM-like Belle II (+LHCb) 2025
$\lvert V_{ub}\rvert$(semileptonic)$[10^{-3}]$	$4.01 \pm 0.08 \pm 0.22$	± 0.10	3.71 ± 0.09
$\lvert V_{cb}\rvert$(semileptonic)$[10^{-3}]$	$41.00 \pm 0.33 \pm 0.74$	± 0.57	41.80 ± 0.60
$\mathcal{B}(B \to \tau\nu)$	1.08 ± 0.21	± 0.04	0.817 ± 0.03
$\sin 2\phi_1$	0.691 ± 0.017	± 0.008	0.710 ± 0.008
$\phi_3[^\circ]$	$73.2^{+6.3}_{-7.0}$	± 1.5 (± 1.0)	67 ± 1.5 (± 1.0)
$\phi_2[^\circ]$	$87.6^{+3.5}_{-3.3}$	± 1.0	90.4 ± 1.0
Δm_d	0.510 ± 0.003	-	-
Δm_s	17.757 ± 0.021	-	-
$\mathcal{B}(B_s \to \mu\mu)$	$2.8^{+0.7}_{-0.6}$	(± 0.5)	$3.31^{+0.7}_{-0.6}$ (± 0.5)
f_{B_s}	$0.224 \pm 0.001 \pm 0.002$	0.001	-
B_{B_s}	$1.320 \pm 0.016 \pm 0.030$	0.010	-
f_{B_s}/f_{B_d}	$1.205 \pm 0.003 \pm 0.006$	0.005	-
B_{B_s}/B_{B_d}	$1.023 \pm 0.013 \pm 0.014$	0.005	-
$\lvert V_{cd}\rvert(\nu N)$	0.230 ± 0.011	-	-
$\lvert V_{cs}\rvert(W \to c\bar{s})$	$0.94^{+0.32}_{-0.26} \pm 0.13$	-	-
f_{D_s}/f_{D_d}	$1.175^{+0.001}_{-0.004}$	-	-
$\mathcal{B}(D \to \mu\nu)$	0.374 ± 0.017	± 0.010	-
ϵ_K	2.228 ± 0.011	-	-
$\lvert V_{us}\rvert f_+^{K\to\pi}(0)$	0.2163 ± 0.0005	-	0.22449 ± 0.0005
$\mathcal{B}(K \to e\nu)$	1.581 ± 0.008	-	1.5689 ± 0.008
$\mathcal{B}(K \to \mu\nu)$	0.6355 ± 0.0011	-	0.6357 ± 0.0011
$\mathcal{B}(\tau \to K\nu)$	0.6955 ± 0.0096	-	0.7170 ± 0.0096
$\lvert V_{ud}\rvert$	0.97425 ± 0.00022	-	-



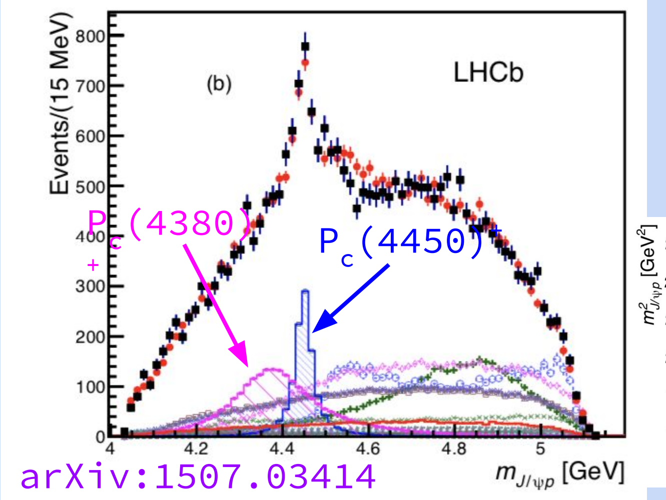
th

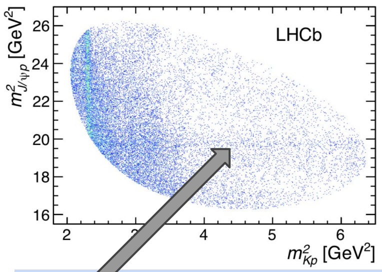
50 ab^{-1}



Pentaquark search

From $\Lambda^0_b \to J/\psi K^- p$ decay, pentaquarks $P_c(4380)^+$ and $P_c(4450)^+$ are found in LHCb.





The LHCb collaboration

$M(P_c(4380)+) = 4380 \pm 8 \pm 29$ MeV

$M(P_c(4450)+) = 4449.8 \pm 1.7 \pm 2.5$ MeV

- Candidates for strange partners of charmed XYZ states e.g. $Y(2175) \to \Phi\pi^+\pi^-$ observed at BaBar and BESIII.
- LHCb search for strange partner $P_s^+ \to \Phi p$ in $\Lambda_c \to [\Phi p]\pi^0$ at 915 fb^{-1}
  - No significant signal is found.

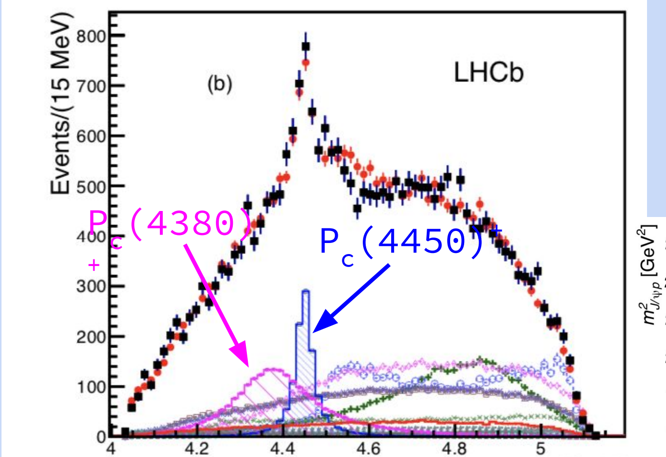
Recently, $P_c(4312)^+$ and two peaks of $P_c(4450)^+$ arXiv:1904.03947

Pentaquark search

From $\Lambda^0_b \to J/\psi K^- p$ decay, pentaquarks $P_c(4380)^+$ and $P_c(4450)^+$ are found in LHCb.

$B^0 \to J/\psi p\bar{p}$ of 5.2 fb^{-1} data at LHCb

PRL 122, 191804 (2019)

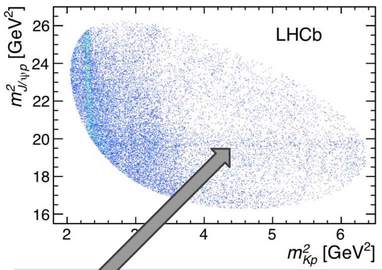


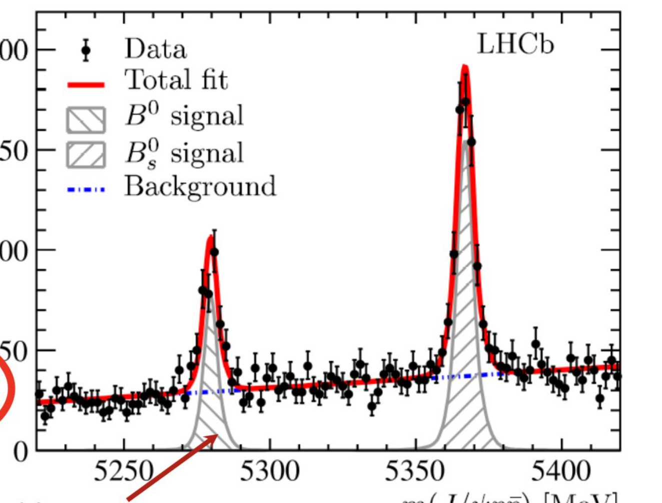
$P_c(4380)^+$

$P_c(4450)^+$

arXiv:1507.03414

The LHCb collaboration





9,500 M $B^0 \bar{B}^0$

Signal yield 256±22

$M(P_c(4380)+)=4380\pm8\pm29$ MeV

$M(P_c(4450)+)=4449.8\pm1.7\pm2.5$ MeV

$$\mathcal{B}(B^0 \to J/\psi p\bar{p}) = [4.51 \pm 0.40(\text{stat}) \pm 0.44(\text{syst})] \times 10^{-7},$$

$$\mathcal{B}(B^0_s \to J/\psi p\bar{p}) = [3.58 \pm 0.19(\text{stat}) \pm 0.39(\text{syst})] \times 10^{-6},$$

Recently, $P_c(4312)^+$ and two peaks of $P_c(4450)^+$

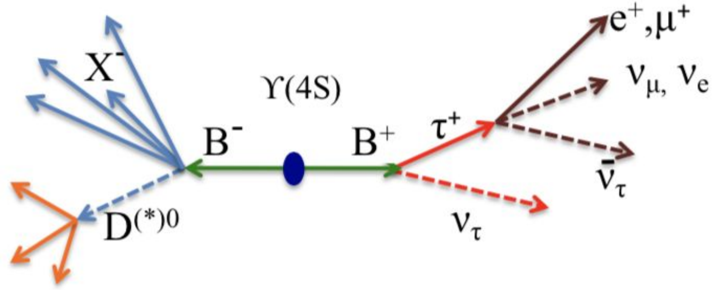
arXiv:1904.03947

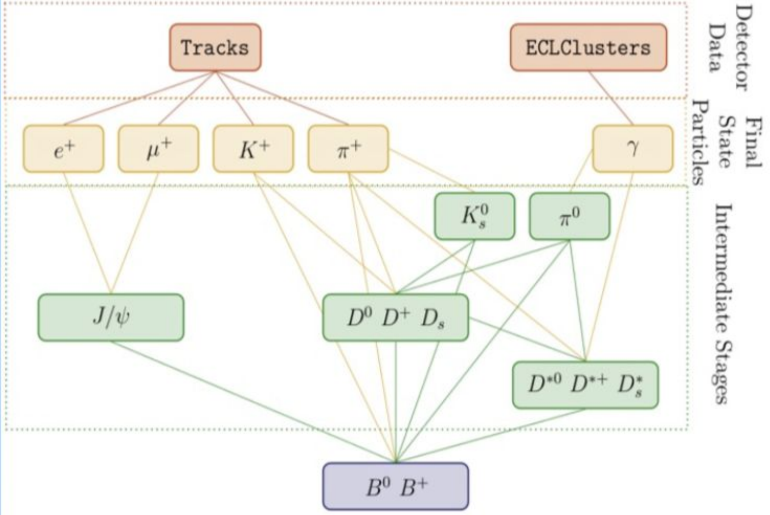
From F. Forty@ EPS

Full Event Interpretation

- Fully reconstruct B decays in many many modes to reduce backgrounds and provide tagging
- Useful for channels with weak exp. signature
  - Missing momentum (many neutrinos in the final state)
  - Inclusive analyses
- Tag with semileptonic decays
  - PRO: Higher efficiency εtag ~ 1.5%
  - CON: more background, B momentum unmeasured
- Tag with hadronic decays
  - PRO: cleaner events, B momentum reconstructed
  - CON: smaller efficiency εtag ~ 0.3%

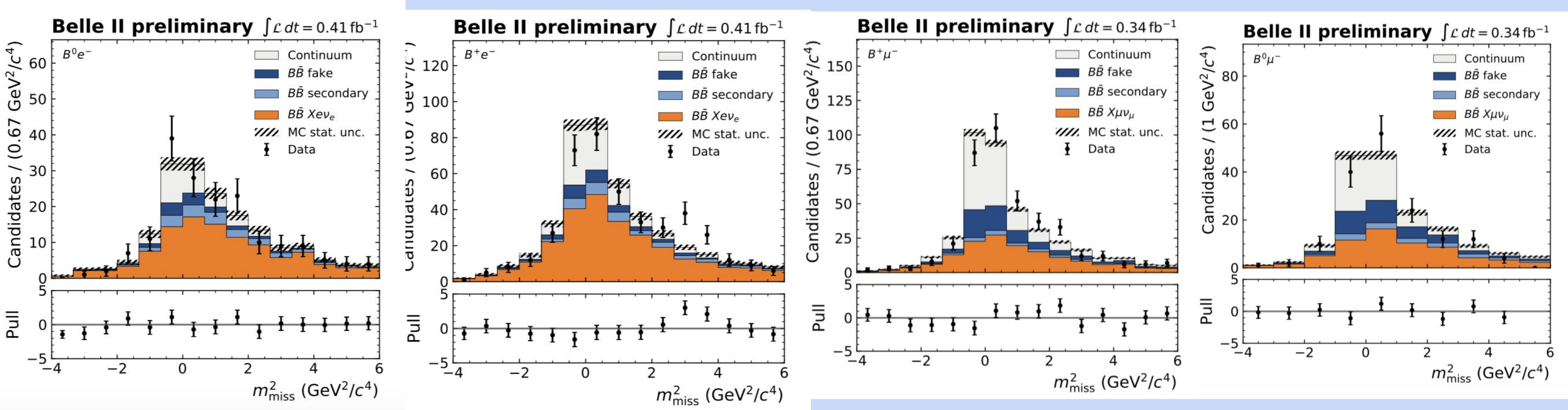
T.Keck, et al. Comput Softw Big Sci (2019) 3: 6. https://doi.org/10.1007/s41781-019-0021-8





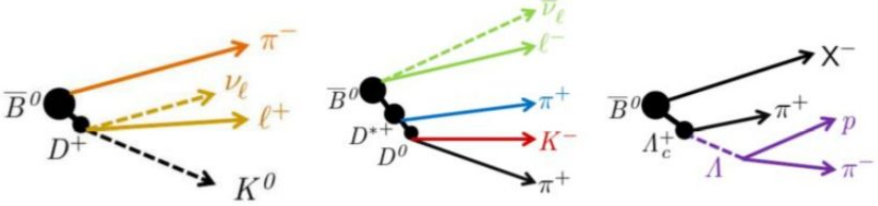
$B^{\pm/0} \to X \ell^- \nu$

FEI is used to select B_{tag}

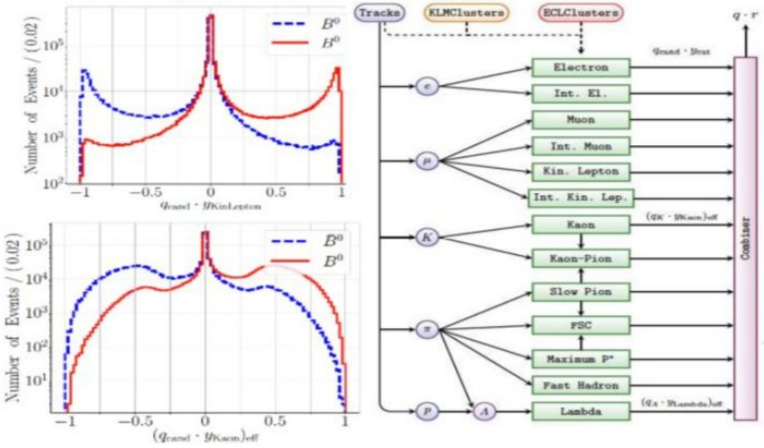


Flavor Tagger

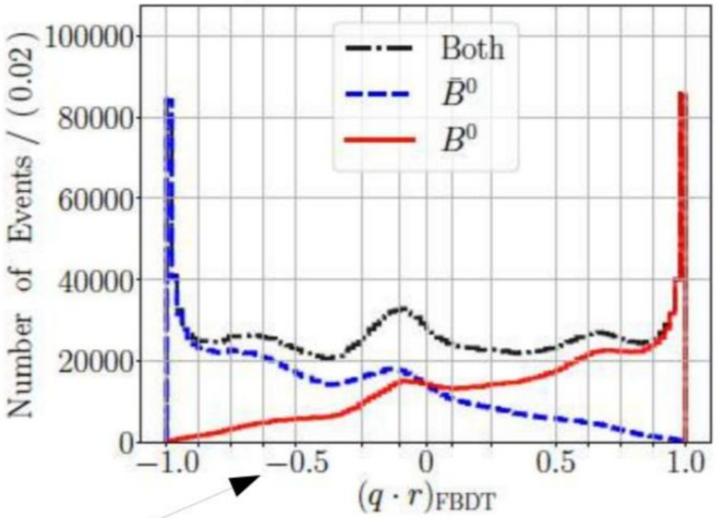
MVA – based tagger :
many sub-taggers with many input variables



Belle II Physics Book – arXiv:180810567



Belle II Physics Book – arXiv:180810567



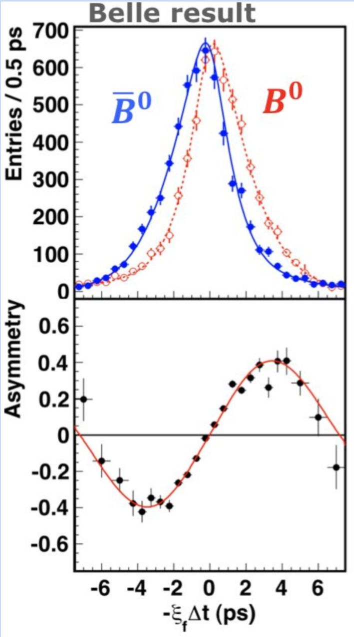
Total expected effective tagging efficiency :
37.2 % (Belle II MC)
to be compared with 30 – 33 % in BaBar and Belle

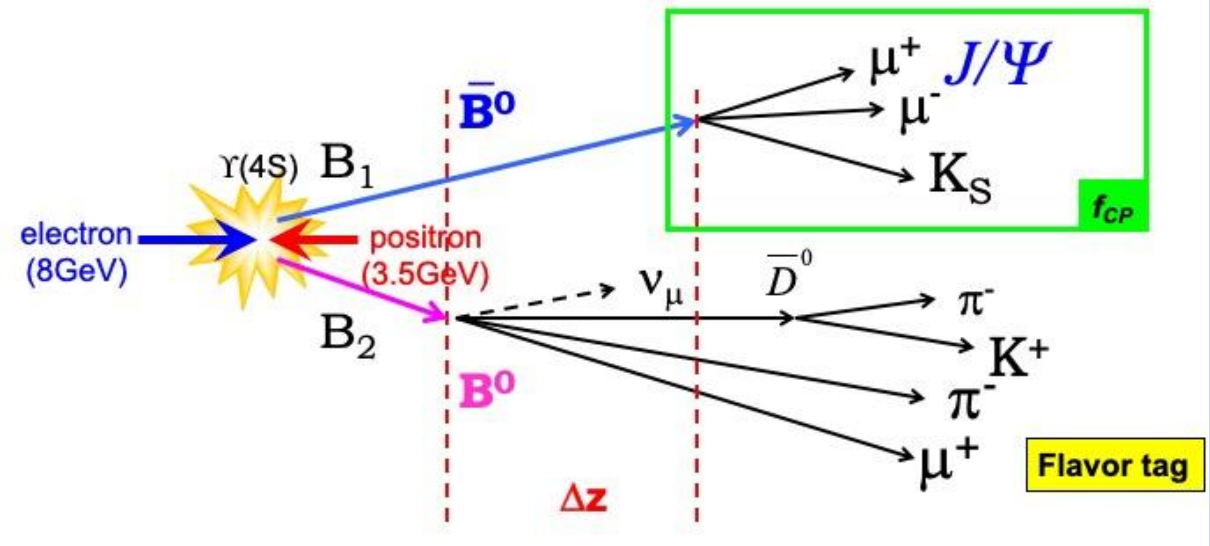
From the Belle to Belle II

- What has been changed?

- PXD, vertex resolution in z direction (beam direction) will be factor 2 better than before:
  50 μm (Belle) → 25 μm (Belle II)
- TOP: no TOF (time-of-flight) detector anymore, but TOP (time-of-propagation) will do the timing of the Cerenkov light. Time resolution ~50 ps. TOP detector surface is polished to nanometer precision for total reflection of Cerenkov light
- KLM: inner 2 layers of barrel + all layers in the endcap replaced by scintillators, because of large background
- ECL readout electronics exchanged, fast FADC sampling for identify pile-up of pulses
- Huge gain in luminosity in Belle II compared to Belle: factor x40. How?
  - factor 2 by beam current: 1.64/1.19 A (Belle) → 3.6/2.6 A for e^+(e^-) beam in Belle II
  - factor 20 by "nano-beam" principle (collision point in vertical direction will be only 59 nm)

Time CP violation measurement





$$A_{CP}(\Delta t) = \frac{\Gamma(\overline{B}^0(\Delta t) \to f_{CP}) - \Gamma(B^0(\Delta t) \to f_{CP})}{\Gamma(\overline{B}^0(\Delta t) \to f_{CP}) + \Gamma(B^0(\Delta t) \to f_{CP})}$$

$$= S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t)$$

S : mixing induced CPV

A : direct CPV

Ability to measure vertex precisely is needed in time CPV measurement