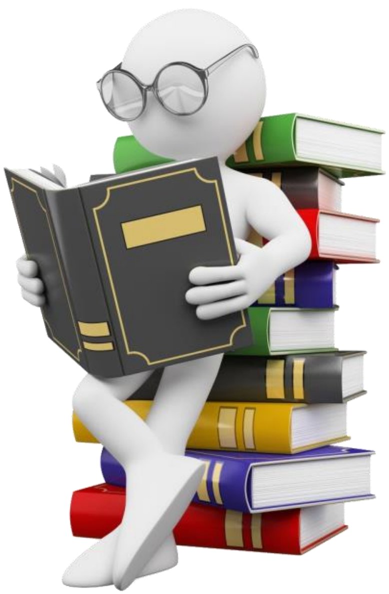
FUDAN UNIVERSITY

The prospect of Belle II

Chengping Shen shencp@fudan.edu.cn

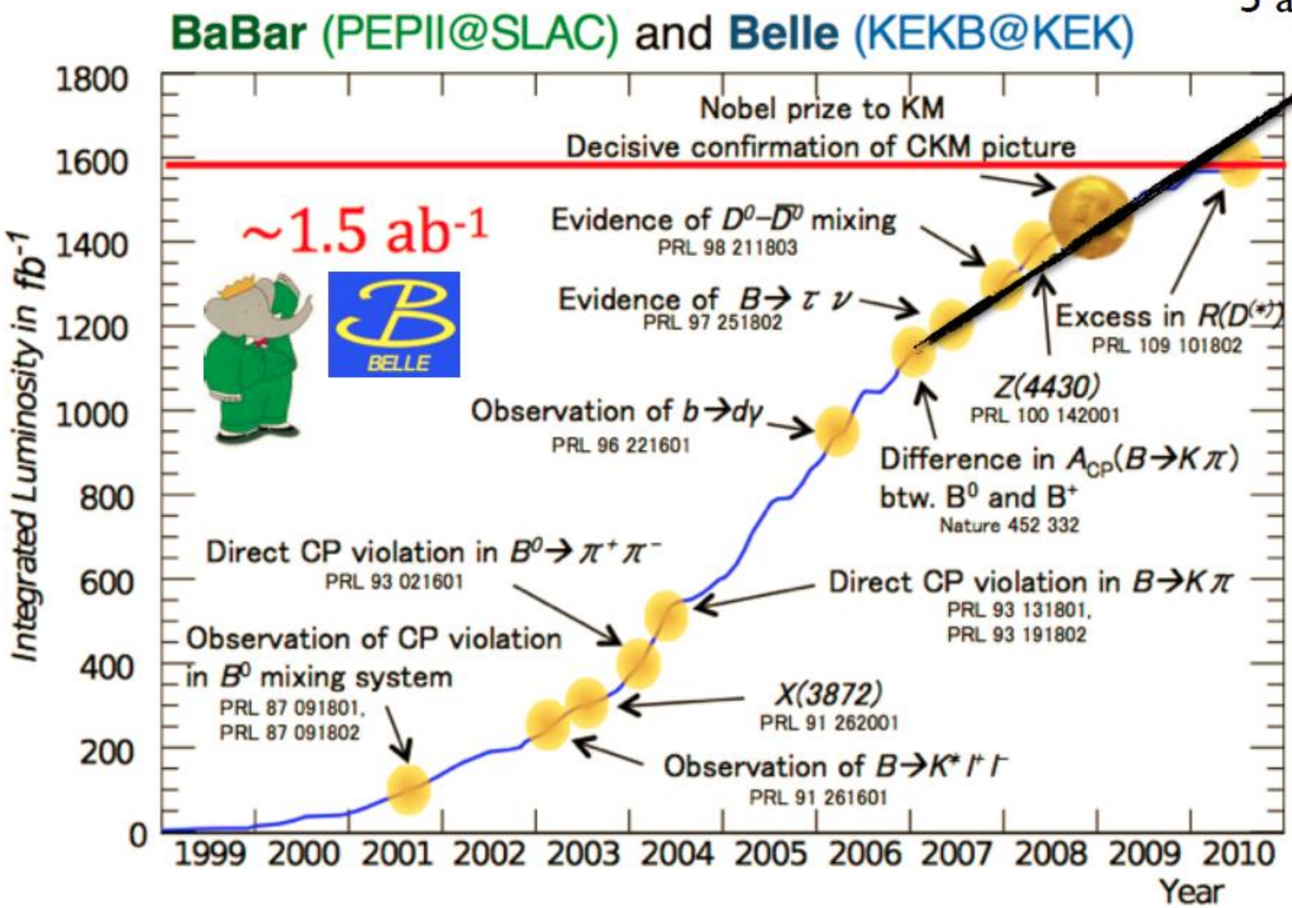
Outline

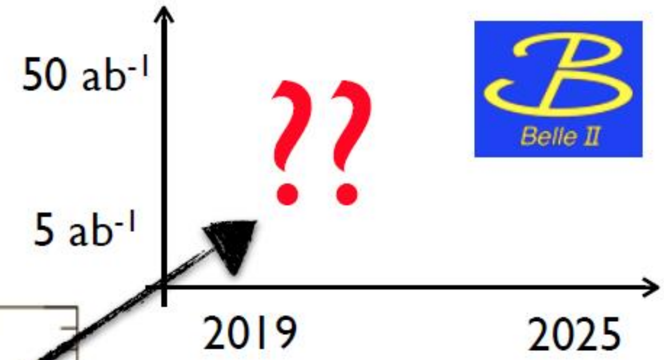


- The status of Belle II accelerator/dector
- Belle II luminosity projection
- B signals in Phase 2 data
- Advantage in Belle II physics analysis
- Prospect in various physics topics including: CKM, Test Lepton Universality; LFV τ Decays; Hadron Spectroscopy; ….

Due to rich physics, here I just selected a few topics as examples. For more details, please refer to Belle II physics book: arXiv:1808.10567

B-factories in the last decade





- Belle and BaBar have a produced a large number of important results, since the beginning of their data taking
- Competition between the two experiments has helped in pulling out the best from the two datasets

The Physics of B factories EPJC 74, 3026 (2018)

Belle II will provide a significantly larger data sample (x50 Belle) that will allow to continue the investigation with a much more powerful instrument

arXiv:1808.10567

SuperKEKB/Belle II

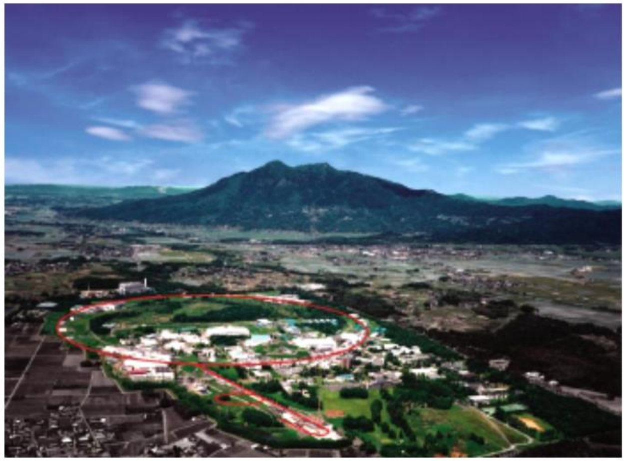
New intensity frontier facility at KEK

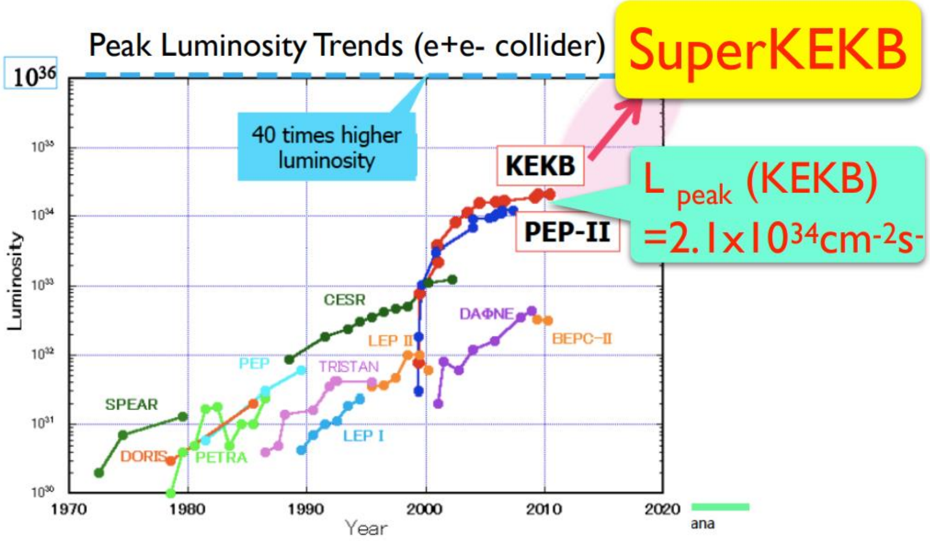
- Target luminosity ; $L_{peak} = 8 \times 10^{35} cm^{-2}s^{-1}$

  $\Rightarrow \sim 10^{10}\ B\bar{B}, \tau^+\tau^-$ and charms per year !

  $L_{int} > 50\ ab^{-1}$

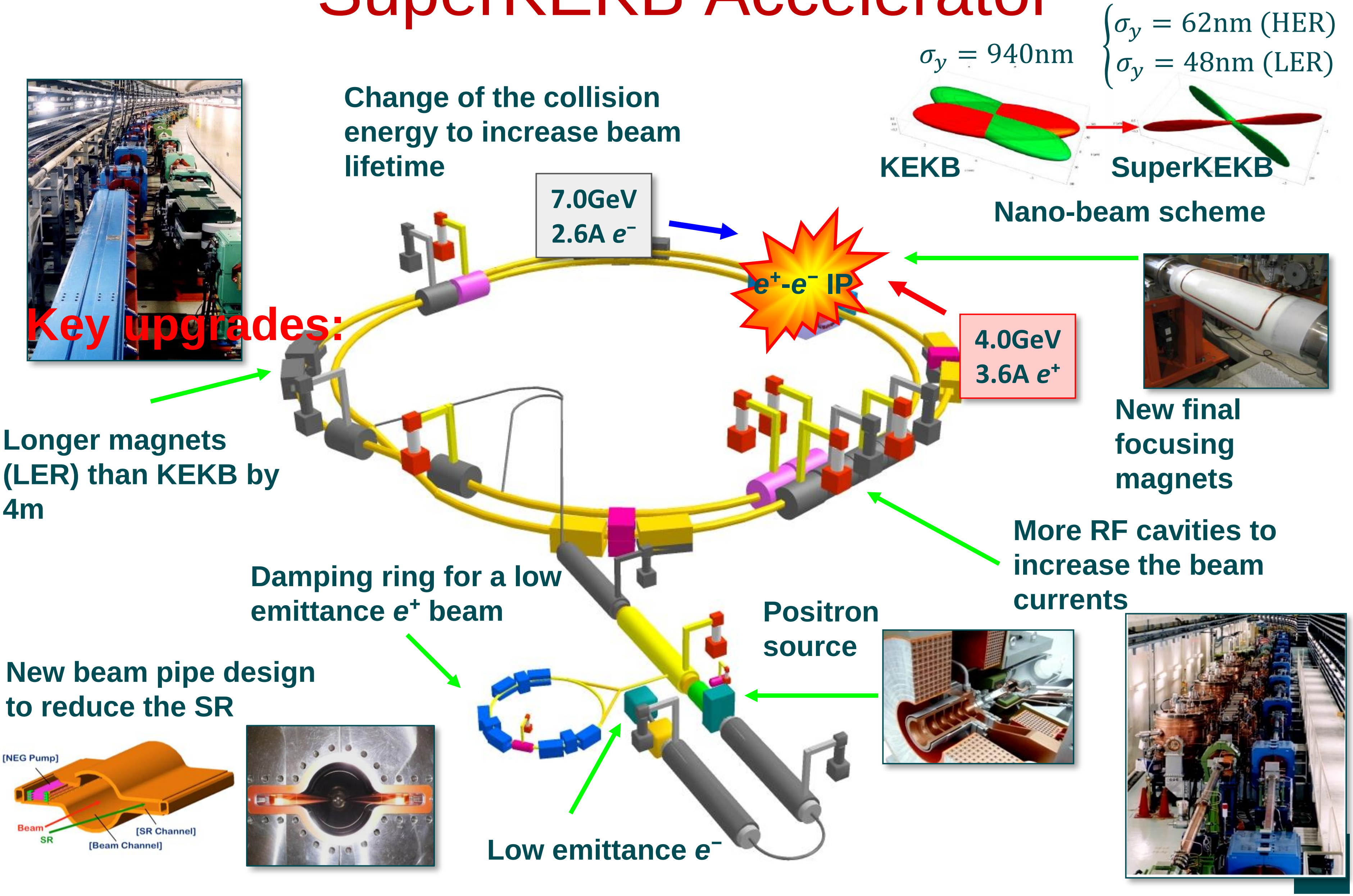
- Rich physics program
  - Search for New Physics through processes sensitive to virtual heavy particles.
  - New QCD phenomena (XYZ, new states including heavy flavors)   + more





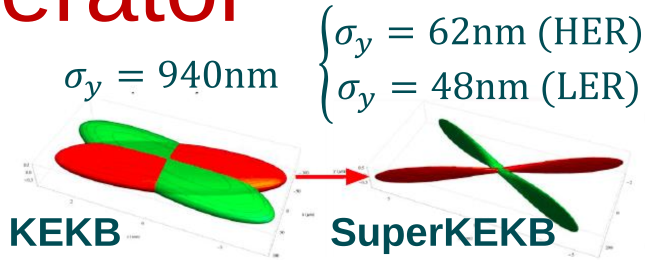
The first particle collider after the LHC !

SuperKEKB Accelerator



SuperKEKB Accelerator

Change of the collision energy to increase beam lifetime



-beam scheme

Key upgrades:

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

	KEKB (HER/LER)	SuperKEKB (HER/LER)	
β_y^* (mm)	5.9/5.9	0.30/0.27	x20
I_{beam} (A)	1.19/1.64	2.6/3.6	x2
$\mathcal{L}$ ($cm^{-2}s^{-1}$)	2.11×10^{34}	80×10^{34}	x40
$\int \mathcal{L}dt$ (ab^{-1})	1	50	x50

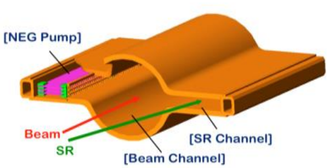
New final focusing magnets

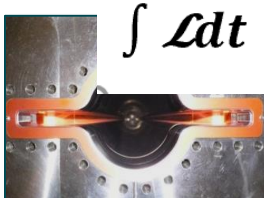
Longer magnets (LER) than KEKB by 4m

Dam
emit

-e RF cavities to
-rease the beam
-rents

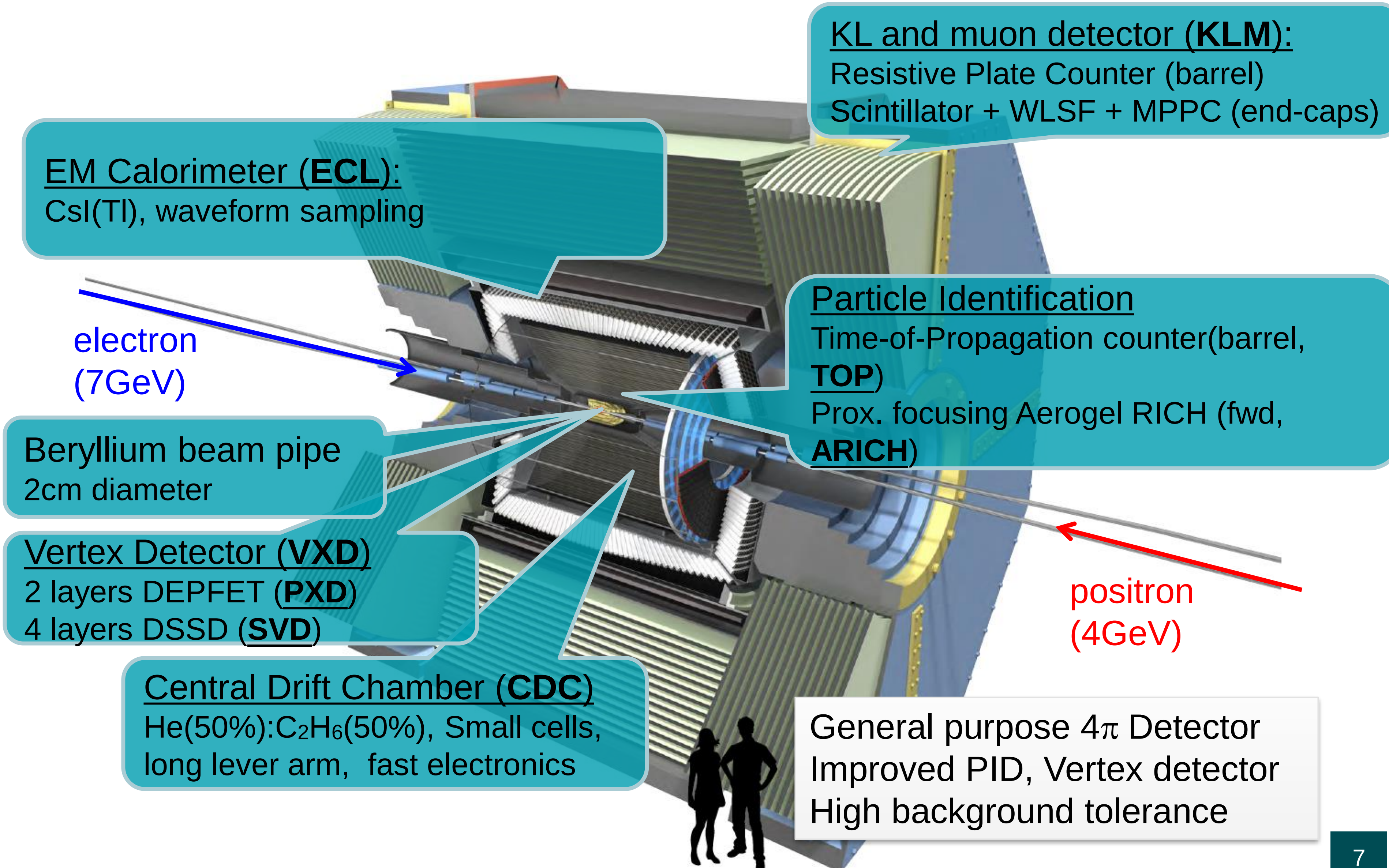
New beam pipe design to reduce the SR





Low emittance e^-

Belle II Detector



General purpose 4π Detector
Improved PID, Vertex detector
High background tolerance

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)

Belle II and SuperKEKB Upgrade History

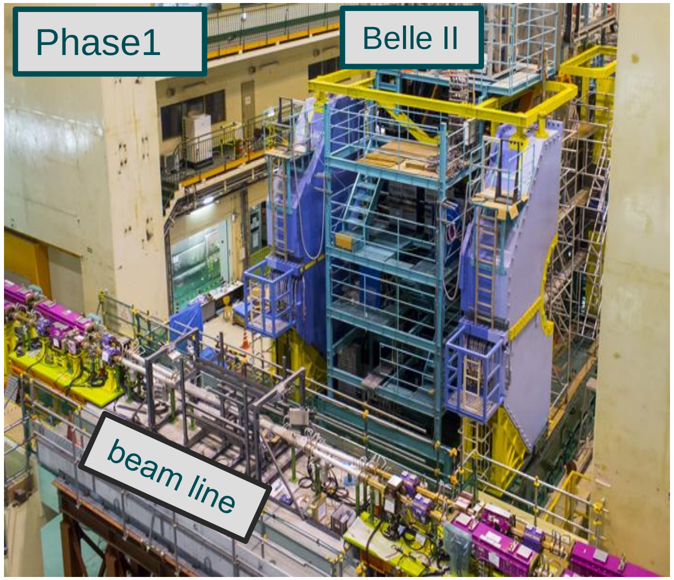
- 2010, Belle and KEKB operation completed
  - Started upgrade to Belle II and SuperKEKB

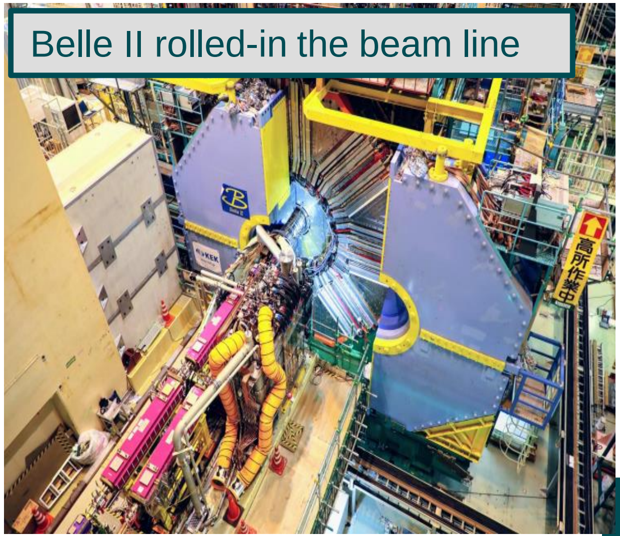
- **2016 Phase 1 Commissioning**
  - SuperKEKB single beams
  - no collisions, without Belle II

- 2017 Belle II Detector rolled-in to the beam line

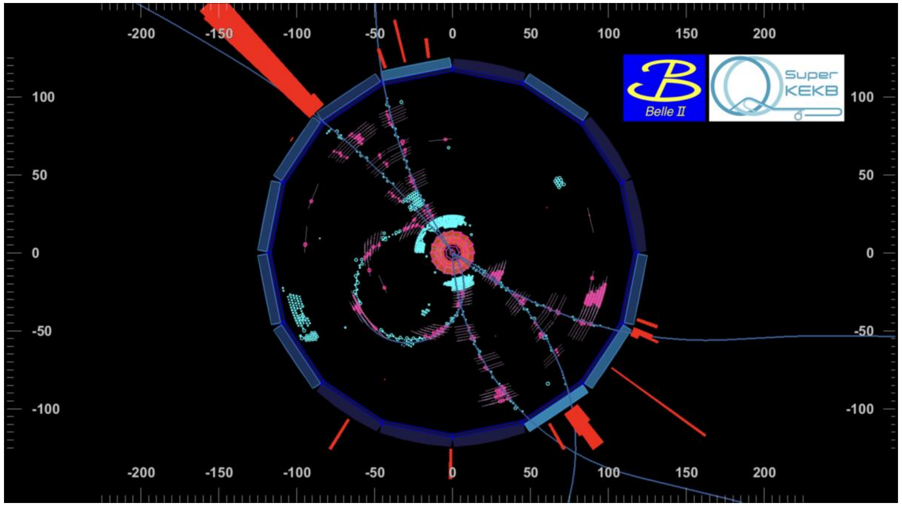
- **2018 March-July Phase 2 Commissioning**
  - First e+e- collisions at SuperKEKB
    - Confirm the nano-beam scheme
  - **Data taking with Belle II Detector (w/o VXD, but background detectors (BEASTII)**
    - Confirm the background condition for final VXD

- **2019 March- Phase 3 Operation**
  - **Physics run with the full Belle Detectors with the VXD (PXD+SVD) installed**
  - **Aim at the design luminosity $8x10^{35}$ /cm^2/s**
  - **Search for the new physics**

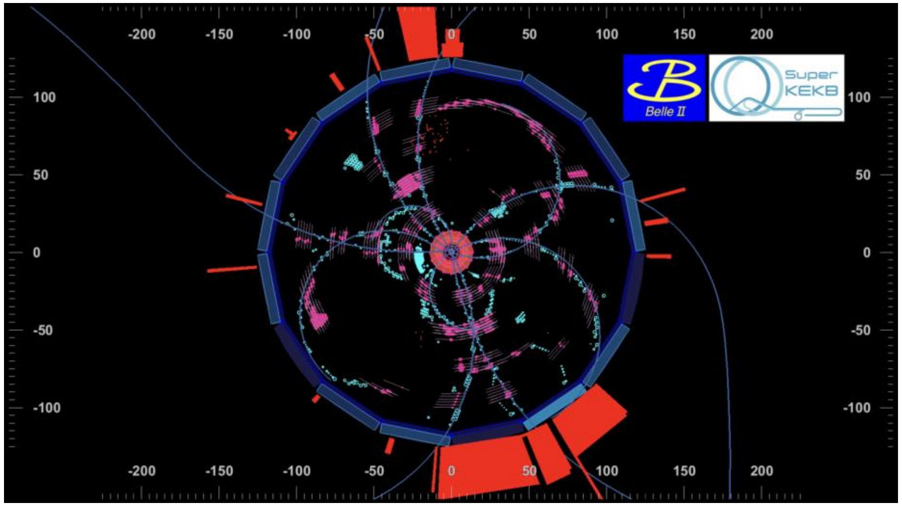




Kick-off of the Belle II Phase 3 Physics Run



The first hadronic event in the Belle II Phase3 physics run



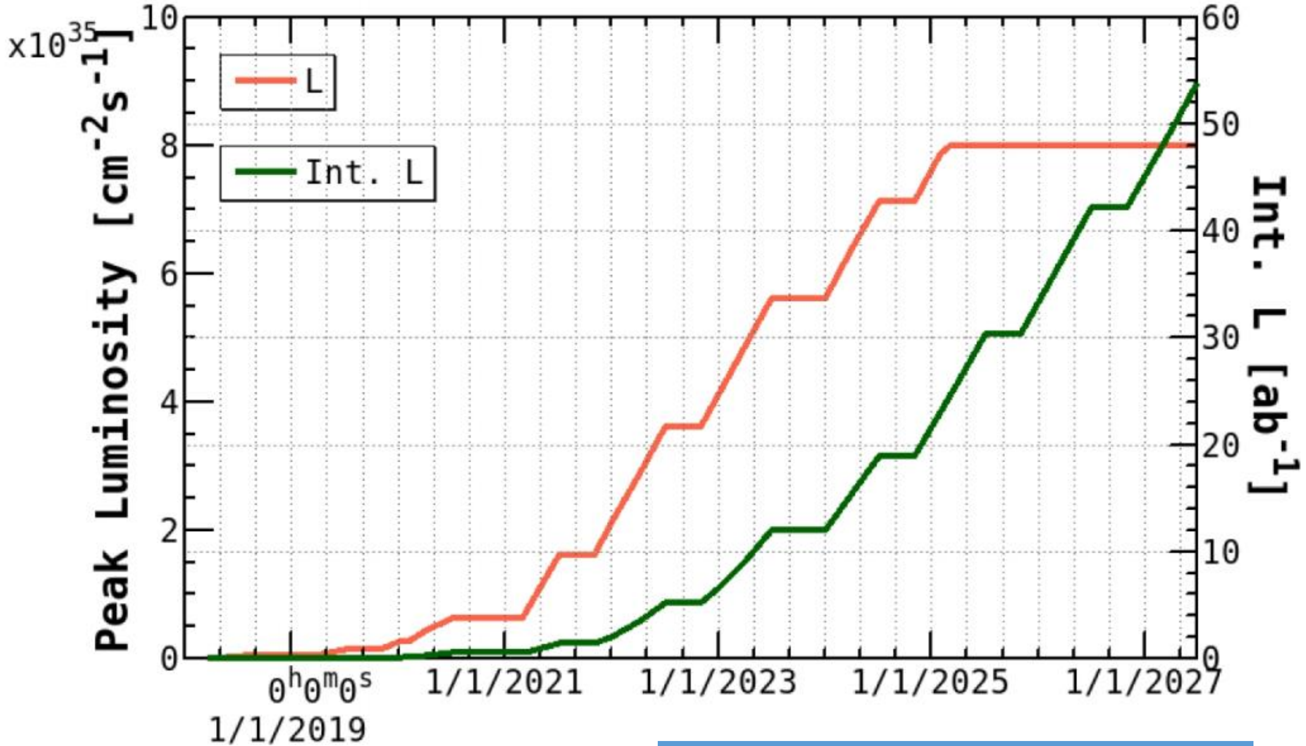
The first “B - anti-B like” event in the Belle II Phase3 physics run

On March 25 19:44 (JST), 2019, electron-positron collisions have restarted at the SuperKEKB collider, and the Belle II experiment has now kicked off its physics data taking.

Belle II will perform a broad range of extremely high precision and fundamental measurements in flavor physics, particularly of properties of the bottom quark, charm quark, and tau lepton. In recent years, there has been a great deal of excitement worldwide about a number of intriguing hints of new physics in the decays of B mesons, particles which contain bottom quarks.

SuperKEKB Luminosity Projection

Plan of instantaneous and integrated luminosity at SuperKEKB.



Phase 3 (w/ full detector)

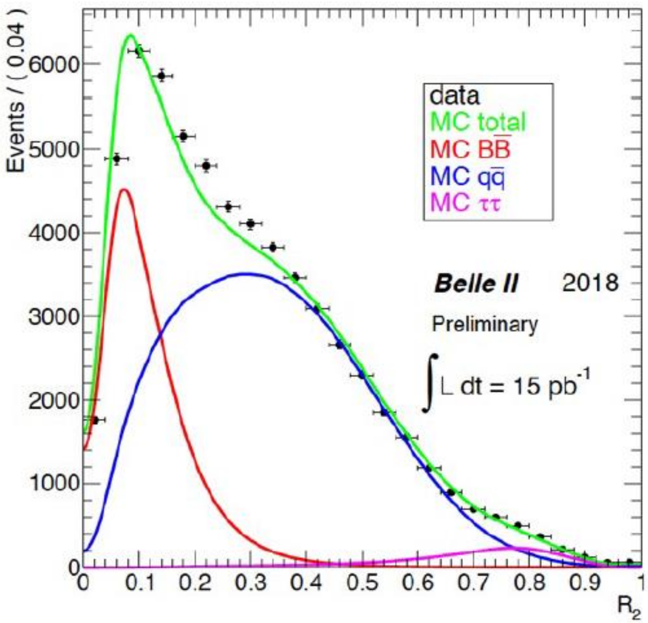
- $1ab^{-1}$ after 1 year
- $5ab^{-1}$ by ~2022
- $50ab^{-1}$ by ~2027

Process	σ (nb)
bb	1.1
cc	1.3
Light quark qq	~2.1
$\tau^+\tau^-$	0.9
e^+e^-	~40

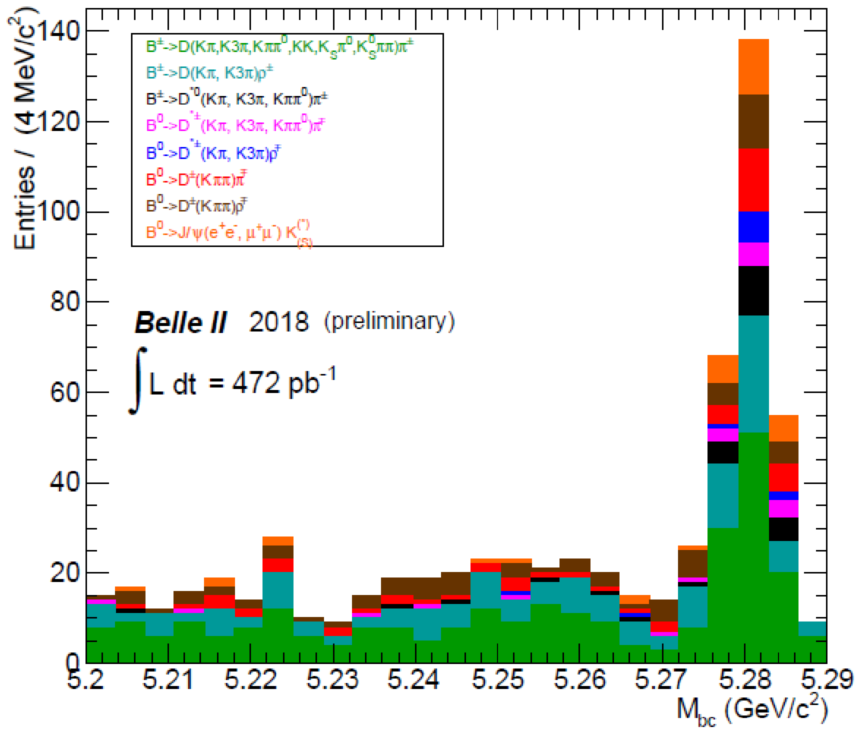
Rediscovery of B mesons

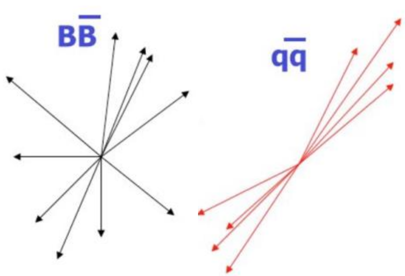
Event Shape Distribution
(Fox-Wolfram R2)

$$M_{bc} = \sqrt{(E_{cm}/2)^2 - p^2_{recon}}$$



Spherical R_2 Jet-like





- Clearly observed the excess of $B\bar{B}$ events in early phase 2 Data
- "Rediscovered" reconstructed B mesons.

Full reconstruction analysis chain is working well.

Physics at Belle II

Ultimate precision, 50 ab^{-1}

Observables	Expected the. accuracy		Expected exp. uncertainty	Facility (2027)
UT angles & sides				
ϕ_1 [°]	***	CKM	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				
$S(B \to \phi K^0)$	***	CPV	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		(Semi)		
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**	LEPTONIC	3%	Belle II
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	LFUV	7%	Belle II
$R(B \to D\tau\nu)$	***		3%	Belle II
$R(B \to D^*\tau\nu)$	***		2%	Belle II/LHCb

QUARKONIUM

DARK SECTOR

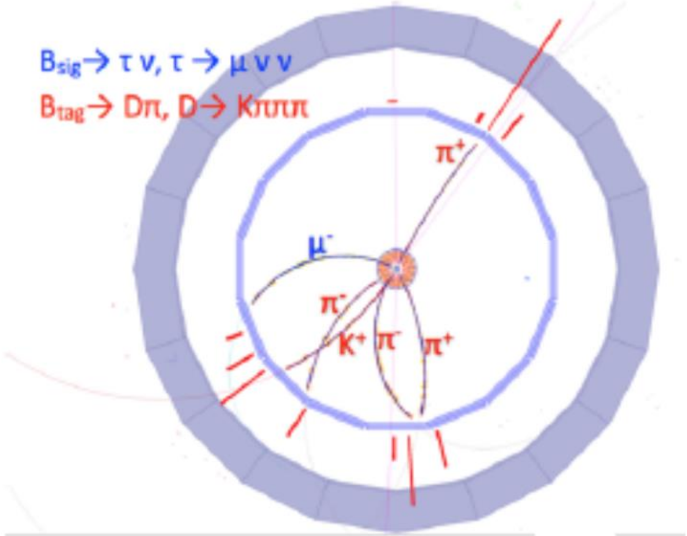
Very Rich Physics Program!

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
$S(B \to \rho\gamma)$	**	EWP	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
$\mathcal{B}(D_s \to \tau\nu)$	***	CHARM	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
$\tau \to e\gamma$ $[10^{-10}]$	***	TAU	< 100	Belle II
$\tau \to \mu\mu\mu$ $[10^{-10}]$	***		< 3	Belle II/LHCb

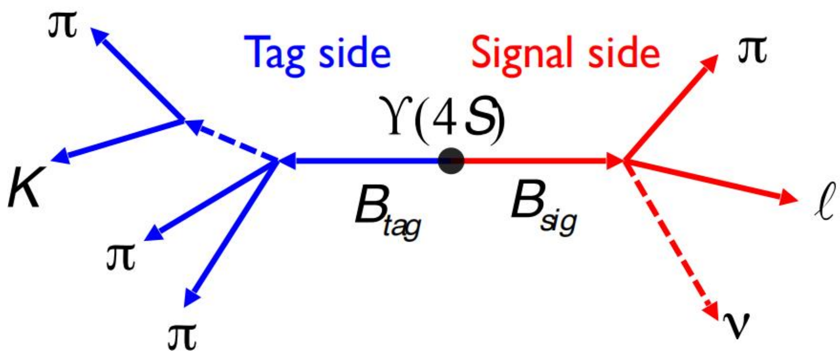
E. Kou, P. Urquijo et al.
Belle II Physics book,
arXiv: 1808.10567
(Accepted to PTEP)

Advantage of e^+e^- Flavor Factory

- Clean environment
  - Efficient detection of neutrals (γ, π^0, η, ...)
- Quantum correlated $B^0\bar{B}^0$ pairs
  - High effective flavor tagging efficiency :
  ~34%(Belle II) ⟷ ~3% (LHCb)
- Large sample of τ leptons
  - Search for LFV τ decays at $O(10^{-9})$



- Full reconstruction tagging possible
  - A powerful tool to measure;
    - $b \to u$ semileptonic decays (CKM)
    - decays with large missing energy



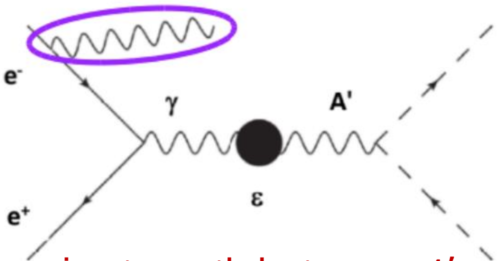
- Systematics different from LHCb
  - Two experiments are required to establish NP

$B \to \pi l \nu$
$B \to \tau\nu, D\tau\nu$
$B \to K\nu\nu$

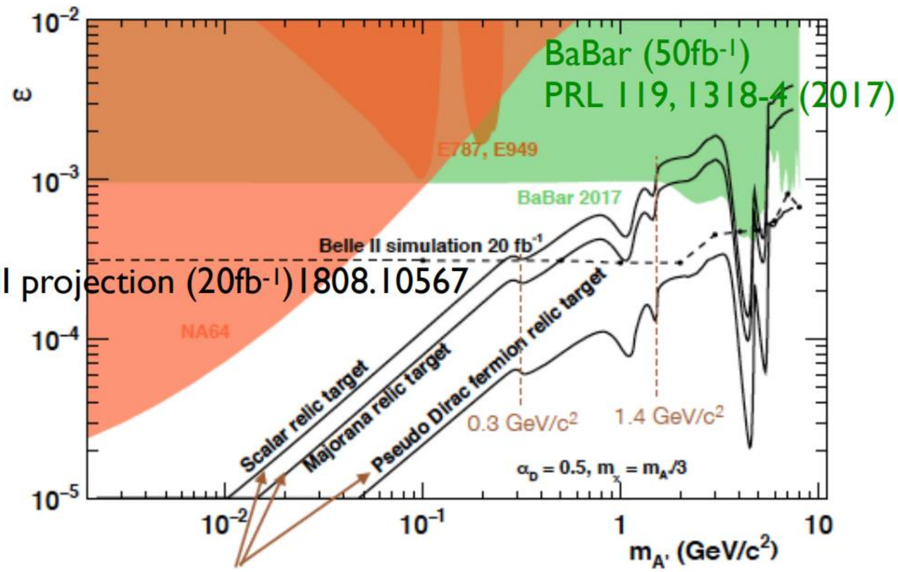
Dark Sector Physics at Belle II

Search for the direct production of low-mass new particles will be highlights in early running period of Belle II

- Dark photon → invisible
  - A single, monochromatic high energy ISR photon. $E^*_\gamma = E^*_{\text{beam}} - \dfrac{m^2_{A'}}{4E^*_{\text{beam}}}$
  - Background from e+e-→γγ(γ), e+e-γ→γ(γ) due to finite acceptance & imperfect detector
  - Dedicated single photon trigger.



ε: mix strength between A' with ordinary photon

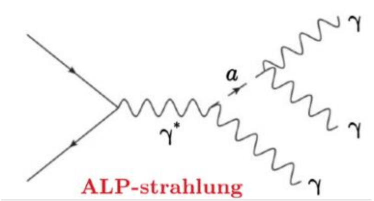


If astronomical dark matter is due to the dark sector, parameters will lie along one of these lines. Derived from E. Izaguirre, G. Krnjaic, P. Schuster, N. Toro, Phys. Rev. Lett. 115, 251301 (2015)

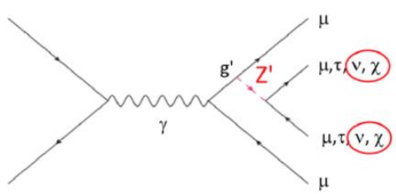
* New result from NA62 [JHEP 05, 182 (2019)]

- Anticipated results also for

Axion Like Particle



Z' → invisible



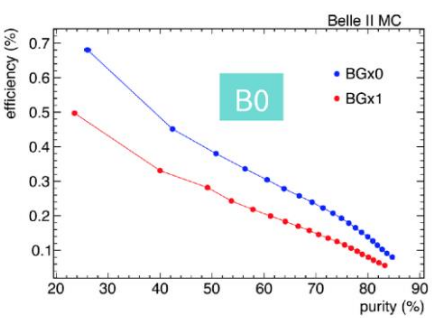
Belle II Full Event Interpretation

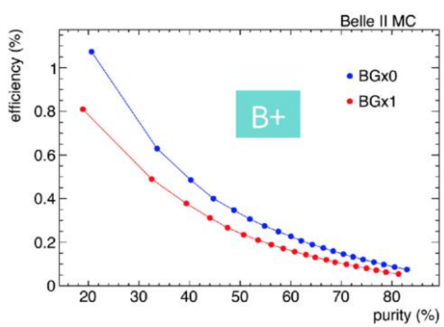
- Belle II has developed a new "Full Event Interpretation" tool based on fast BDT.

Number of decay modes used in tagging (Belle → Belle II)

- B^+: 17→29, B^0: 14→26
- $D^+/D^{*+}/D_s^+$: 18→26, D^0/D^{*0}: 12→17

Tag algorithm date	MVA	Efficiency	Purity
Belle v1 (2004)	Cut-based (Vcb)	-	-
Belle v3 (2007)	Cut-based	0.1	0.25
Belle NB (2011)	**Neurobayes**	**0.2**	**0.25**
Belle II FEI (2017)	Fast BoostedDecisionTree	0.5	0.25





- + NEW FEI method based on semileptonic tag Fast BDT tag in B → D(*) l ν + B → D(*)π l ν.

More recent update: 1807.08680

B^+ modes	B^0 modes
$B^+ \to \overline{D}^0\pi^+$	$B^0 \to D^-\pi^+$
$B^+ \to \overline{D}^0\pi^+\pi^0$	$B^0 \to D^-\pi^+\pi^0$
$B^+ \to \overline{D}^0\pi^+\pi^0\pi^0$	$B^0 \to D^-\pi^+\pi^+\pi^-$
$B^+ \to \overline{D}^0\pi^+\pi^+\pi^-$	$B^0 \to D_s^+D^-$
$B^+ \to D_s^+\overline{D}^0$	$B^0 \to D^{*-}\pi^+$
$B^+ \to \overline{D}^{*0}\pi^+$	$B^0 \to D^{*-}\pi^+\pi^0$
$B^+ \to \overline{D}^{*0}\pi^+\pi^0$	$B^0 \to D^{*-}\pi^+\pi^+\pi^-$
$B^+ \to \overline{D}^{*0}\pi^+\pi^+\pi^-$	$B^0 \to D^{*-}\pi^+\pi^+\pi^-\pi^0$
$B^+ \to \overline{D}^{*0}\pi^+\pi^+\pi^-\pi^0$	$B^0 \to D_s^{*+}D^-$
$B^+ \to D_s^{*+}\overline{D}^0$	$B^0 \to D_s^+D^{*-}$
$B^+ \to D_s^+\overline{D}^{*0}$	$B^0 \to D_s^{*+}D^{*-}$
$B^+ \to \overline{D}^0K^+$	$B^0 \to J/\psi K_s^0$
$B^+ \to D^-\pi^+\pi^+$	$B^0 \to J/\psi K^+\pi^+$
$B^+ \to J/\psi K^+$	$B^0 \to J/\psi K_s^0\pi^+\pi^-$
$B^+ \to J/\psi K^+\pi^+\pi^-$	
$B^+ \to J/\psi K^+\pi^0$	
$B^+ \to J/\psi K_s^0\pi^+$	

$B^+ \to D^-\pi^+\pi^+\pi^0$	$B^0 \to D^-\pi^+\pi^0\pi^0$
$B^+ \to \overline{D}^0\pi^+\pi^+\pi^-\pi^0$	$B^0 \to D^-\pi^+\pi^+\pi^-\pi^0$
$B^+ \to \overline{D}^0D^+$	$B^0 \to \overline{D}^0\pi^+\pi^-$
$B^+ \to \overline{D}^0D^+K_s^0$	$B^0 \to D^-D^0K^+$
$B^+ \to \overline{D}^{*0}D^+K_s^0$	$B^0 \to D^-D^{*0}K^+$
$B^+ \to \overline{D}^0D^{*+}K_s^0$	$B^0 \to D^{*-}D^0K^+$
$B^+ \to \overline{D}^{*0}D^{*+}K_s^0$	$B^0 \to D^{*-}D^{*0}K^+$
$B^+ \to \overline{D}^0D^0K^+$	$B^0 \to D^-D^+K_s^0$
$B^+ \to \overline{D}^{*0}D^0K^+$	$B^0 \to D^{*-}D^+K_s^0$
$B^+ \to \overline{D}^0D^{*0}K^+$	$B^0 \to D^-D^{*+}K_s^0$
$B^+ \to \overline{D}^{*0}D^{*0}K^+$	$B^0 \to D^{*-}D^{*+}K_s^0$
$B^+ \to \overline{D}^{*0}\pi^+\pi^0\pi^0$	$B^0 \to D^{*-}\pi^+\pi^0\pi^0$

D^+,D^{*+},D_s^+ modes	D^0,D^{*0} modes
$D^+ \to K^-\pi^+\pi^+$	$D^0 \to K^-\pi^+$
$D^+ \to K^-\pi^+\pi^+\pi^0$	$D^0 \to K^-\pi^+\pi^0$
$D^+ \to K^-K^+\pi^+$	$D^0 \to K^-\pi^+\pi^+\pi^-$
$D^+ \to K^-K^+\pi^+\pi^0$	$D^0 \to \pi^-\pi^+$
$D^+ \to K_s^0\pi^+$	$D^0 \to \pi^-\pi^+\pi^0$
$D^+ \to K_s^0\pi^+\pi^0$	$D^0 \to K_s^0\pi^0$
$D^+ \to K_s^0\pi^+\pi^+\pi^-$	$D^0 \to K_s^0\pi^+\pi^-$
$D^{*+} \to D^0\pi^+$	$D^0 \to K_s^0\pi^+\pi^-\pi^0$
$D^{*+} \to D^+\pi^0$	$D^0 \to K^-K^+$
$D_s^+ \to K^+K_s^0$	$D^0 \to K^-K^+K_s^0$
$D_s^+ \to K^+\pi^+\pi^-$	$D^{*0} \to D^0\pi^0$
$D_s^+ \to K^+K^-\pi^+$	$D^{*0} \to D^0\gamma$
$D_s^+ \to K^+K^-\pi^+\pi^0$	
$D_s^+ \to K^+K_s^0\pi^+\pi^-$	
$D_s^+ \to K^-K_s^0\pi^+\pi^+$	
$D_s^+ \to K^+K^-\pi^+\pi^+\pi^-$	
$D_s^+ \to \pi^+\pi^+\pi^-$	
$D_s^{*+} \to D_s^+\pi^0$	

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

- Below line: not used in Belle NB tag.

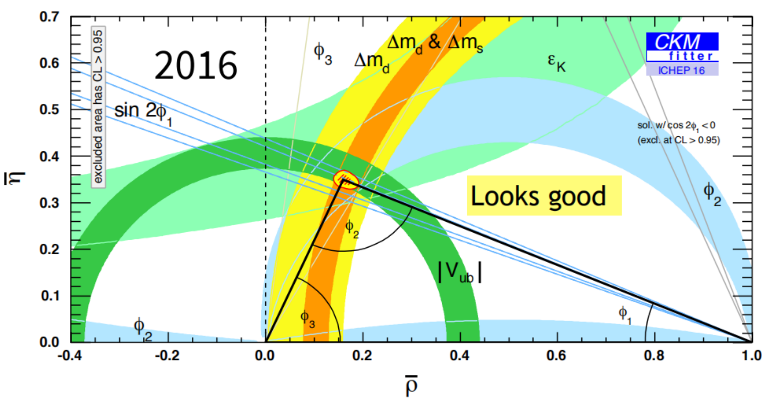
CKM fit with Belle II + LHCb

Input	Current WA	SM value Belle II	SM value Belle II+LHCb
A	$0.8227^{+0.0066}_{-0.0136}$	$^{+0.0025}_{-0.0027}$	$^{+0.0024}_{-0.0028}$
λ	$0.22543^{+0.00042}_{-0.00031}$	$^{0.00036}_{-0.00030}$	$^{0.00035}_{-0.00030}$
$\bar{\rho}$	$0.1504^{+0.0121}_{-0.0062}$	$^{+0.0054}_{-0.0044}$	$^{+0.0042}_{-0.0040}$
$\bar{\eta}$	$0.3540^{+0.00069}_{-0.0076}$	$^{+0.0037}_{-0.00040}$	$^{+0.0036}_{-0.00037}$

1808.10567

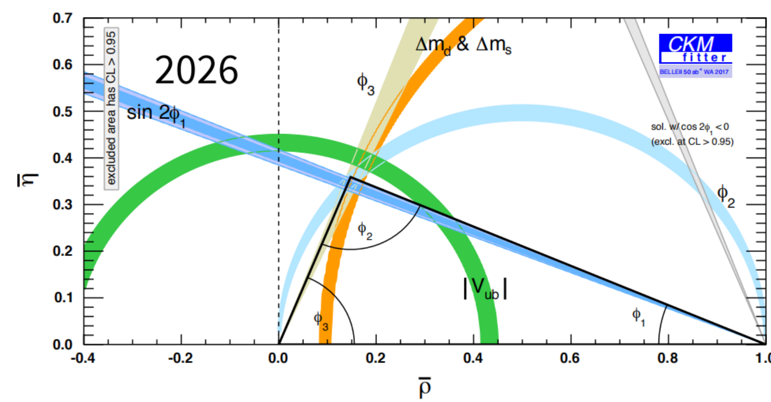
- Precision improvements require improved uncertainties and resolved tensions, e.g. $|V_{ub}|$ inc.-excl.

E. Kou, PU et al. arXiv: 1808.10567



Φ_3 ~ 1-1.5º at LHCb & Belle II

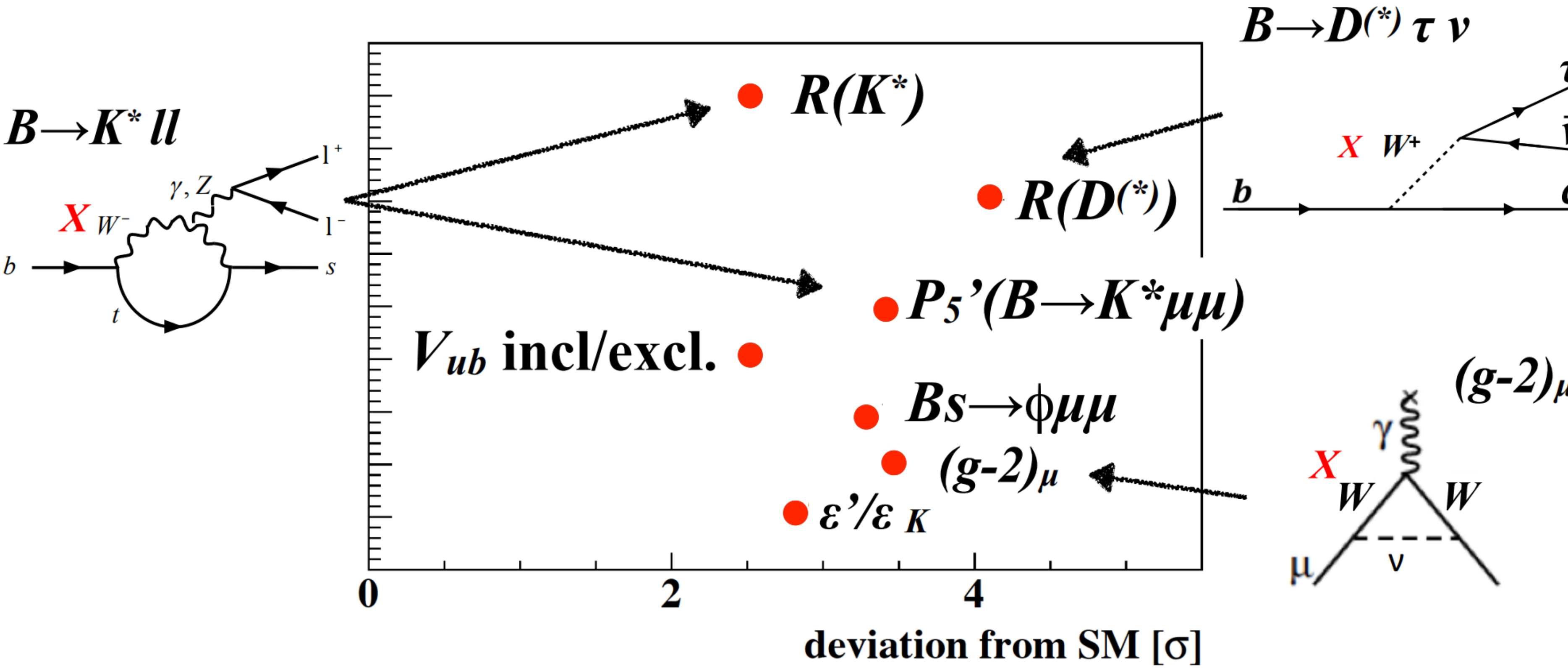
$|V_{ub}|$ ~ 1.2% Belle II



Test Lepton Universality

Observed deviation from SM

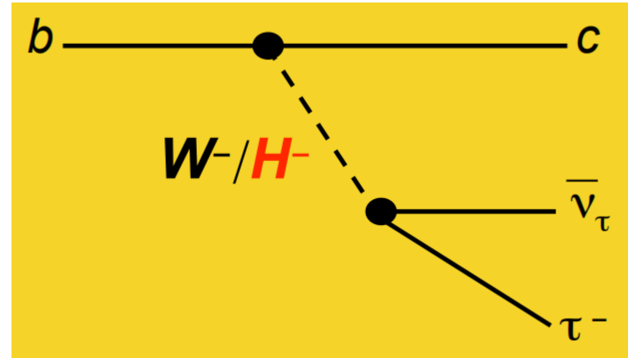
(as of Spring 2018)



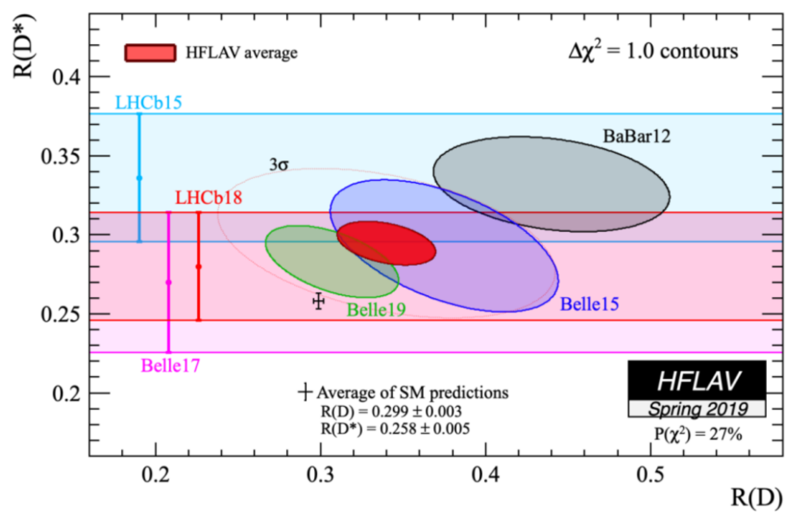
It is important to test lepton universality precisely.

$B \to D(*) \tau \upsilon$

- New Physics may appear at tree level.
- 3rd generation quark (b) and lepton (τ) involved.
  - large masses → sensitivity to NP
  - Charged Higgs, Leptoquark, …
- $B \to D^{(*)} \tau \nu$ and $B \to \tau \nu$ are complementary
- Quantities of interest
  - Lepton Flavor Universality :
    - R(D), R(D*)
  - Polarization: P_τ, P_{D^*}
  - q^2 distribution etc.



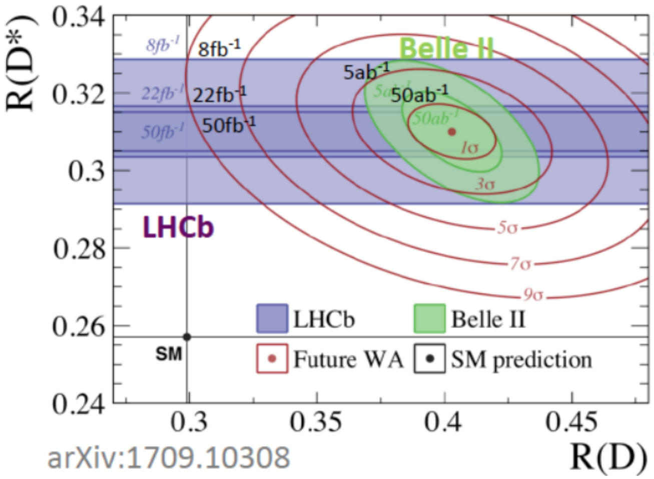
Spring 2019 update

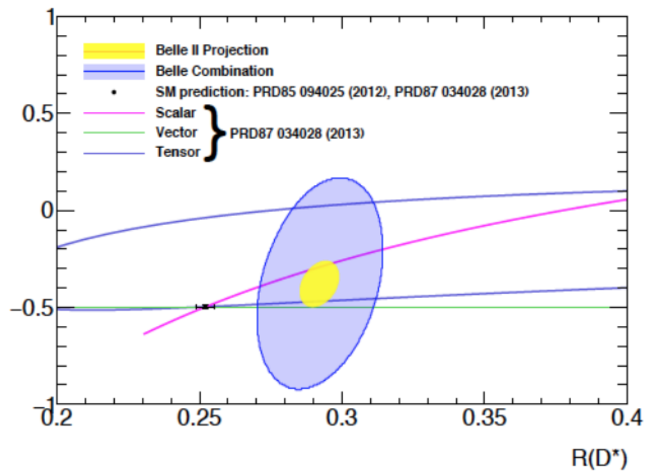


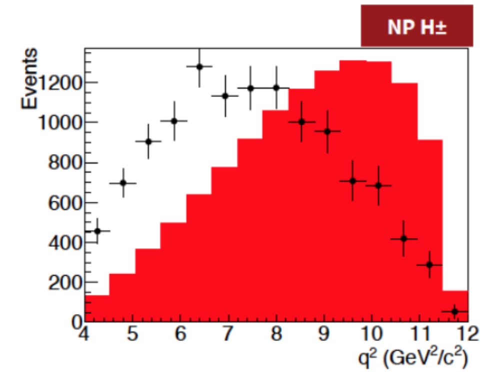
3.1σ deviation from SM

Belle II sensitivity

- Lepton universality violation may be established even with $5ab^{-1}$ (2020).
- High statistics data will provide more detailed information, such as τ polarization, q^2 distribution, to discriminate type of NP.







50 ab-1 projection of the subtracted q^2 spectrum in $B \to D^* \tau \nu$ (HT)

	ΔR(D) [%]			ΔR(D*) [%]		
	Stat	Sys	Total	Stat	Sys	Total
Belle 0.7 ab^{-1}	14	6	16	6	3	7
Belle II 5 ab^{-1}	5	3	6	2	2	3
Belle II 50 ab^{-1}	2	3	3	1	2	2

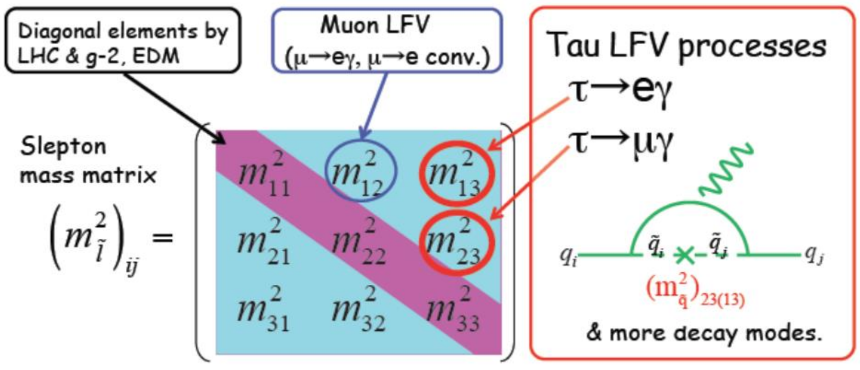
Will soon hit the systematic limit !

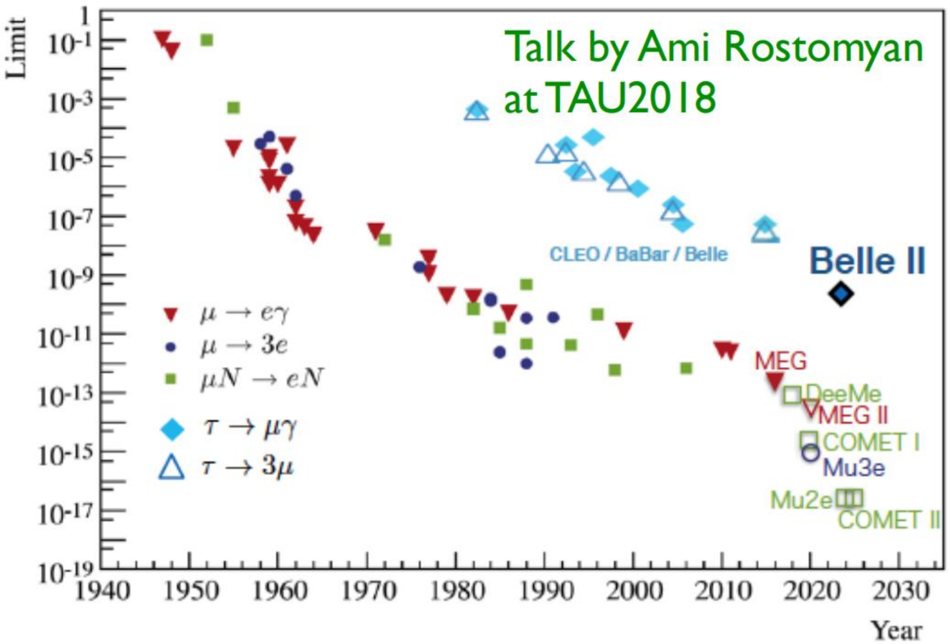
- More observables (distributions) !
  - P(τ), P(D*)
  - $d\Gamma/dq^2$, $d\Gamma/dp_{D(*)}$, $d\Gamma/dp_e$, …
- More modes !
  - $B \to \pi \tau \nu$,
  - $B_s \to D_s \tau \nu$ (at 5S runs) , …

LFV τ Decays

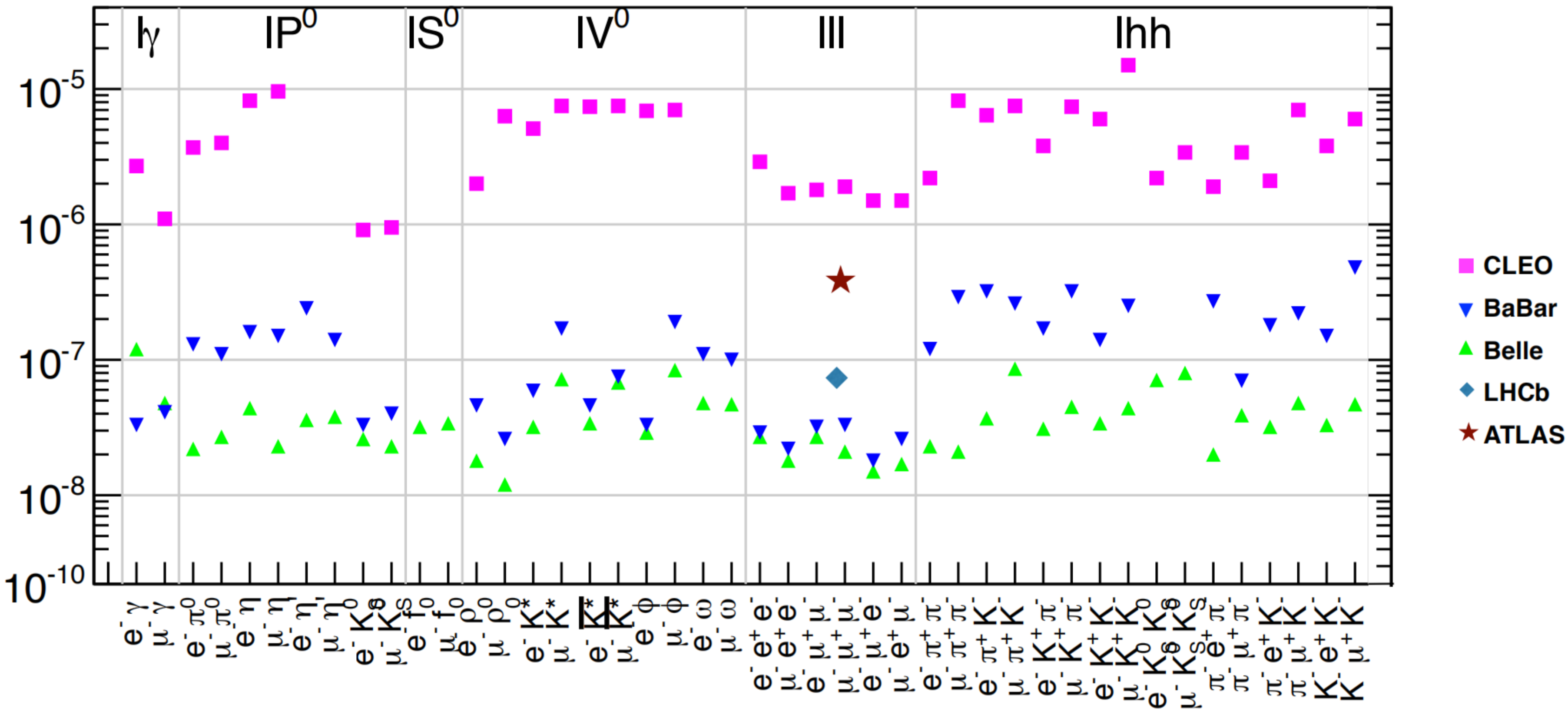
SuperKEKB provides $N(\tau^+\tau^-) \sim N(B\bar{B})$

- Lepton flavor violated in the neutrino sector.
- Some NP models predict LFV to be observed in 'near' future experiments.
- τ is the heaviest charged lepton, sensitive to NP.
- τ LFV complementary to muon programs
  - μ→eγ, eee
  - μ→e conversion



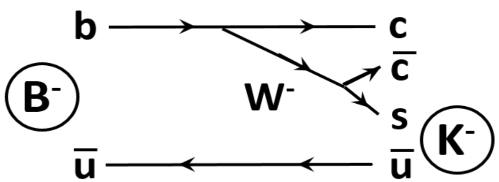


Prospect on LFV τ Decays at Belle II



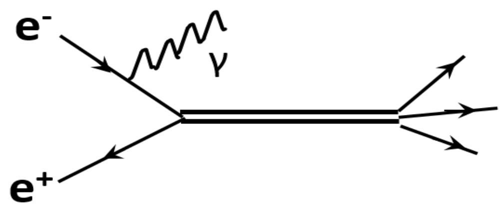
- Belle II will push down the current bounds further by more than an order of magnitude.
- Trying to increase sensitivity by improved analysis technique.

B-factory = hadron factory!



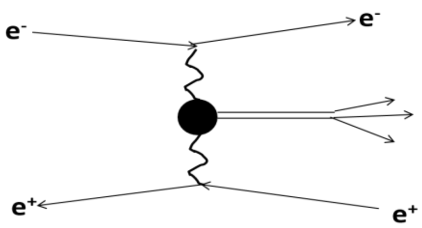
B meson decay

- 1^+, $0^{-/+}$ ….
- X(3872), Z(4430)….
- Open charm hadrons



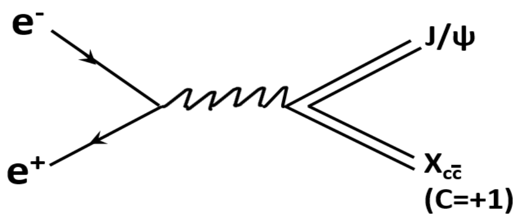
Initial state radiation

- $J^{PC}=1^{--}$
- Y(4260)



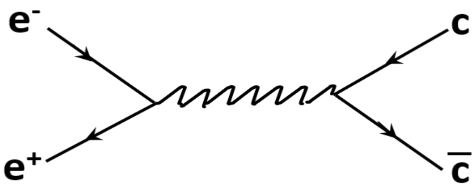
Two photon collision

- $J^{PC}=0^{++}$, 2^{++}….
- Extract two photon width



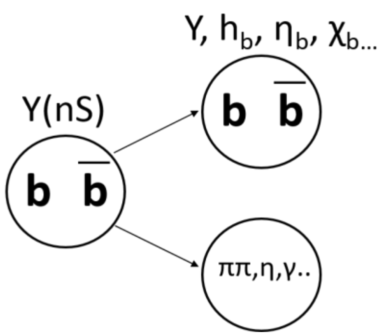
Double charmonium

- C-even charmonium



$e^+e^- \to c\bar{c}$

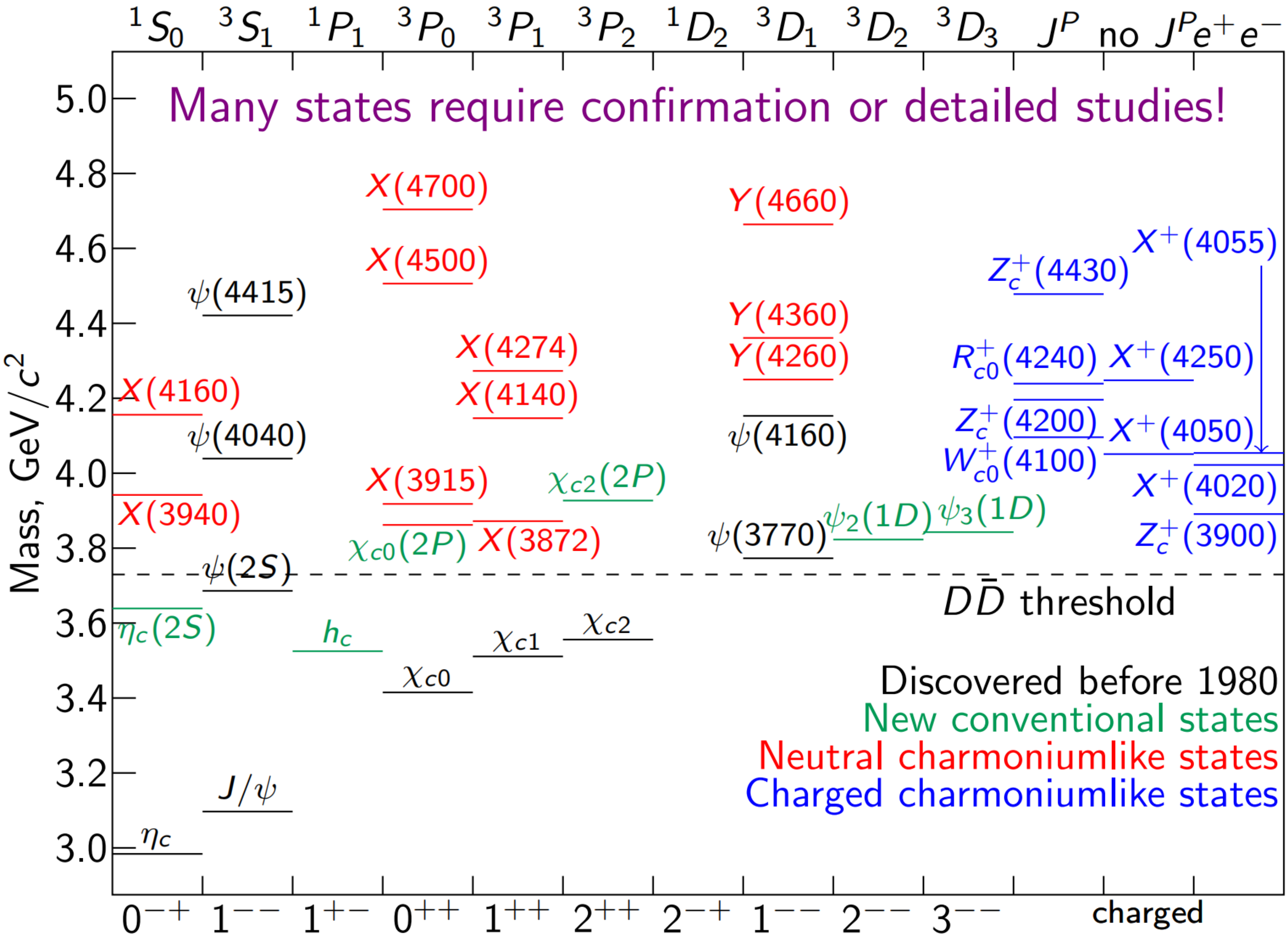
Charm,mesons/baryons



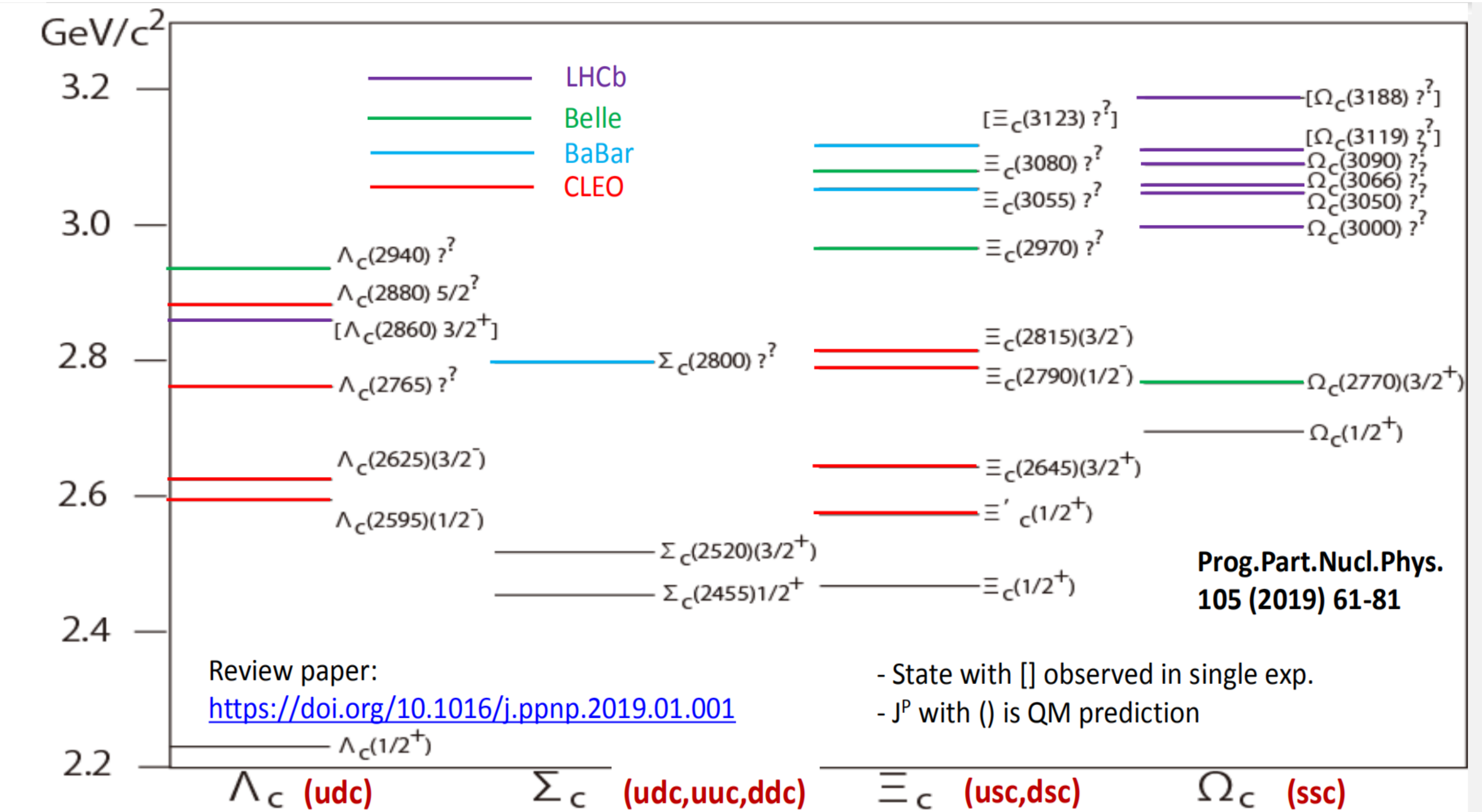
Bottomonium transition

Z_b states

Hadron Spectroscopy



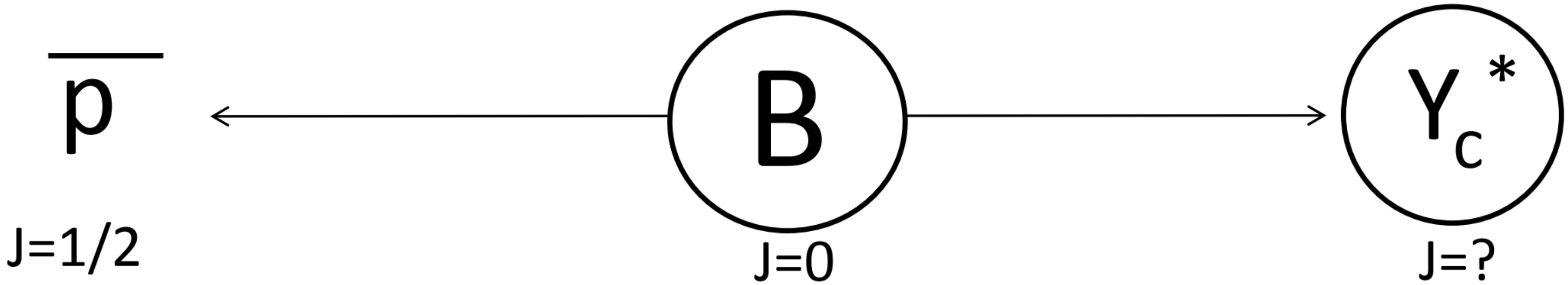
Observed charmed baryons



J^P determination at Belle II

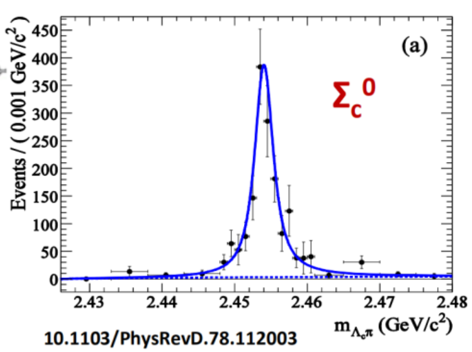
- B-meson two body decay constrains the helicity to be ½
  as B meson has spin zero and proton has spin ½. This largely reduce uncertainty

- Statistics at current B-factory is not good enough for higher excited states.



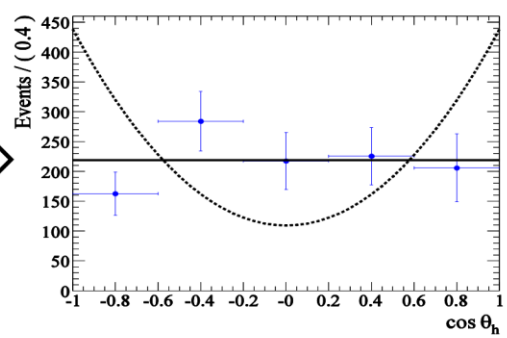
Example

$B \to \Sigma_c^0\, p^{bar}$, $\Sigma_c \to \Lambda_c^+ \pi^-$



10.1103/PhysRevD.78.112003

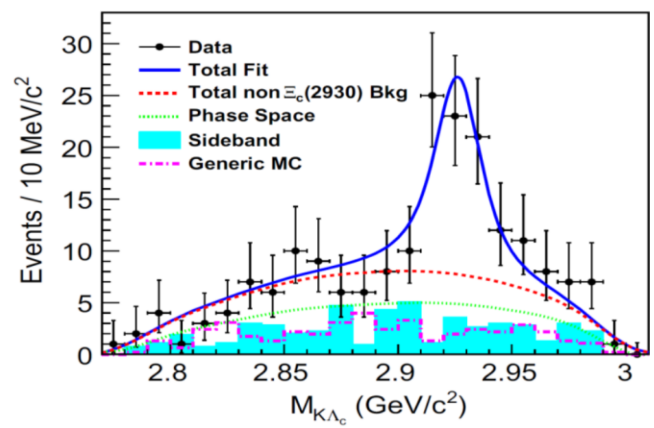
$\Lambda_c^+\pi^-$ angular distribution



S=1/2, exclude 3/2 by ~4σ

Higher excited states observed!

$B \to \Xi_c(2930)\Lambda_c$, $\Xi_c(2930) \to K\Lambda_c$



Eur. Phys. J. C (2018) 78: 252.

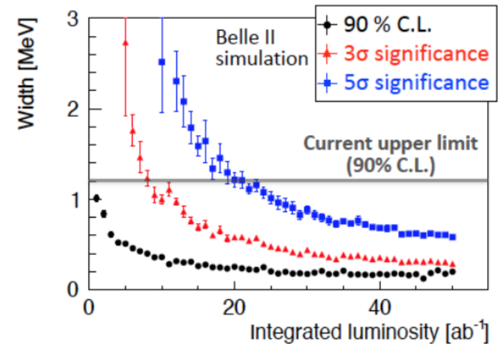
Hadron Spectroscopy at Belle II

- High statistics data at Belle II enables us to do
  - Search for new states near thresholds
  - Amplitude analyses to determine J^{PC}
  - Precise determination of resonance parameters

    e.x.: X(3872) width

    The current 90% C.L. UL is 1.2 MeV

State	Production and Decay	N
X(3872)	$B \to K X(3872)$, $X(3872) \to J/\psi \pi^+ \pi^-$	$\simeq$14400
Y(4260)	ISR, $Y(4260) \to J/\psi \pi^+ \pi^-$	$\simeq$29600
Z(4430)	$B \to K^{\mp} Z(4430)$, $Z(4430) \to J/\psi \pi^{\pm}$	$\simeq$10200



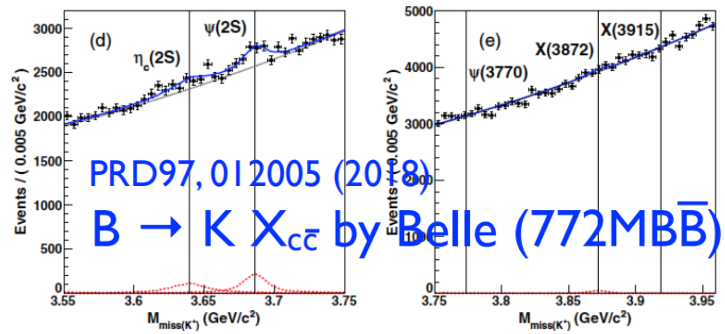
$X(3872) \to D\bar{D}\pi^0$

[90% C.L.] ~ 180 keV

[3σ significance] ~ 280 keV

[5σ significant] ~ 570 keV

- Variety of approaches
  - B decays
  - ISR → study XYZ at threshold
    - $>1 fb^{-1}/10 MeV$ at $E_{cm} \sim 4 GeV$
  - Recoil mass → measure absolute branching fraction
  - b sector by running on ϒ(5S) …



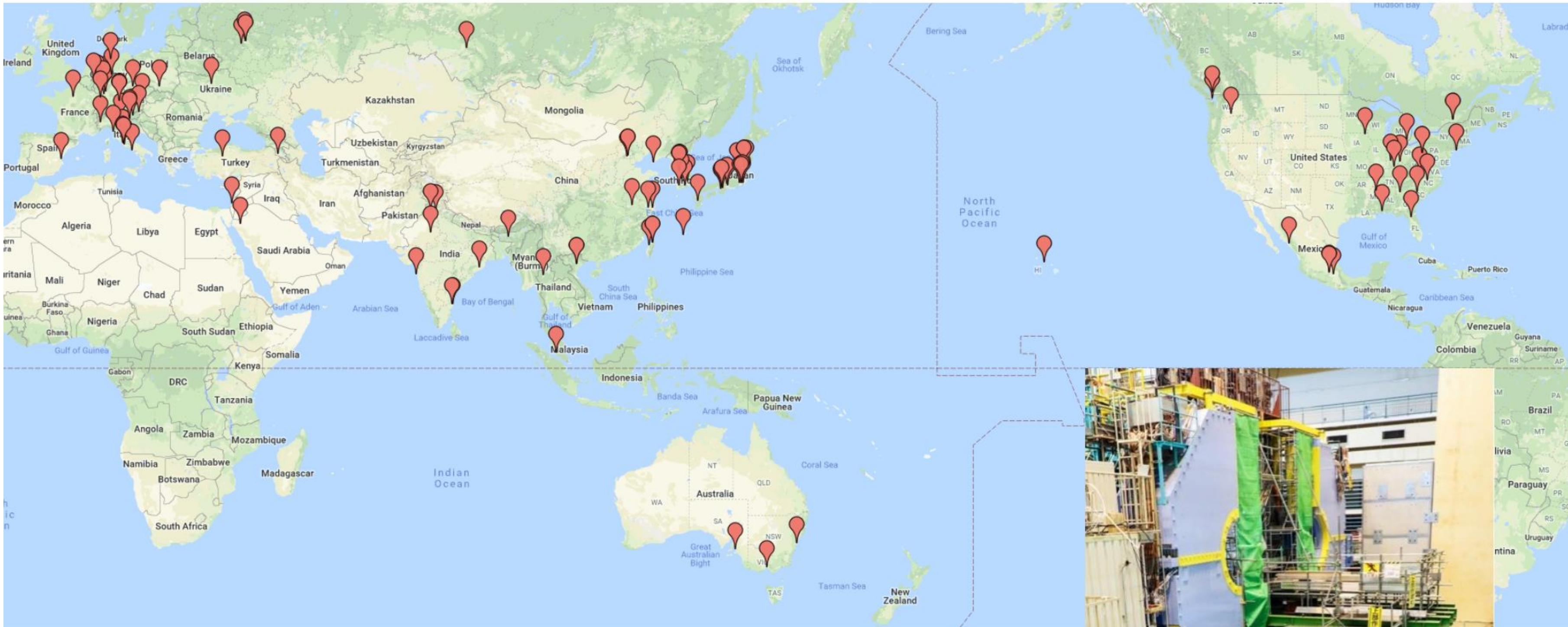
PRD97, 012005 (2018)

$B \to K X_{c\bar{c}}$ by Belle (772M$B\bar{B}$)

Br[B→KX(3872)] can be measured at Belle II

Also spectroscopies of non exotic quarkonium and baryons.

The Belle II Collaboration



- Belle II has now grown to ~ 1000 researchers from 112 institutions in 26 countries.
- Large international collaboration hosted by KEK, Japan

Summary

- Belle II has successfully concluded the phase 2 physics run
- Phase 3 run started in March 2019: there is much better vertexing, particle ID than in Belle; and full reconstruction on tag side is notably improved over Belle/BaBar.
- Belle II aims to explore NP in the flavor sector with $50ab^{-1}$ with ultimate precision measurement (a few % typically) of heavy flavor decays.
- Variety of subjects (including low-energy QCD, dark photon, exotic states, mesons/baryons, …)
- **We expect many exciting results in the coming years !**

Belle II physics book (arXiv:1808.10567):
https://confluence.desy.de/display/BI/B2TiP+ReportStatus

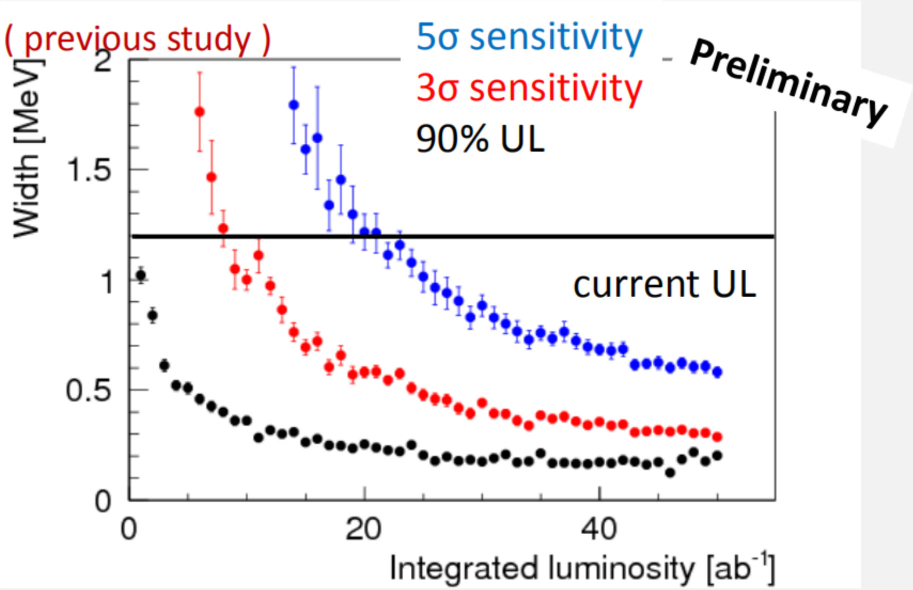
Total width with X(3872)→D$\bar{D}$π⁰ decay mode

- In general, the mass resolution is better for smaller mass difference.
- The mass difference is smallest in D$\bar{D}\pi^0$ mode.

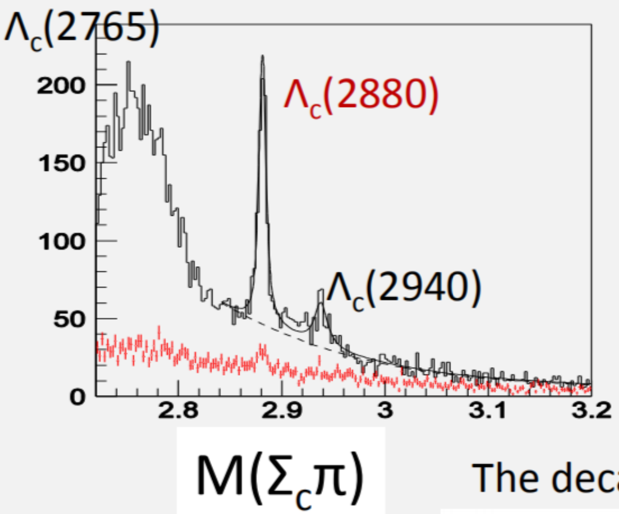
Decay	Mass difference (MeV/c^2)
$J/\psi\pi^+\pi^-$	~500
$DD\pi^0$	7

- The mass resolution is **680 keV: ~3 times better than $J/\psi\pi^+\pi^-$ mode**.
  - No width measurement at Belle (1) due to poor statistics
- No bias seen up to O(100 keV) in the simulation.
- The expected 90% UL is 180 keV.

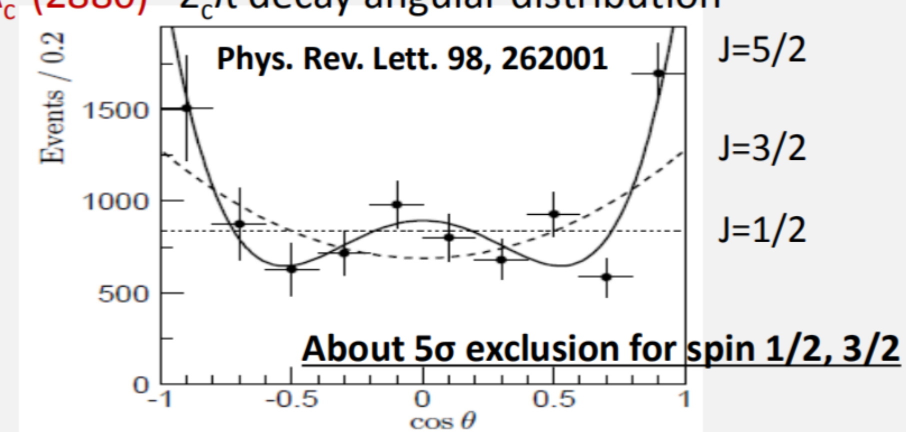
Total width (previous study)



J^P determination at Belle



$\Lambda_c^+(2880)$ $\Sigma_c\pi$ decay angular distribution



The decay angular distribution for spin 5/2.

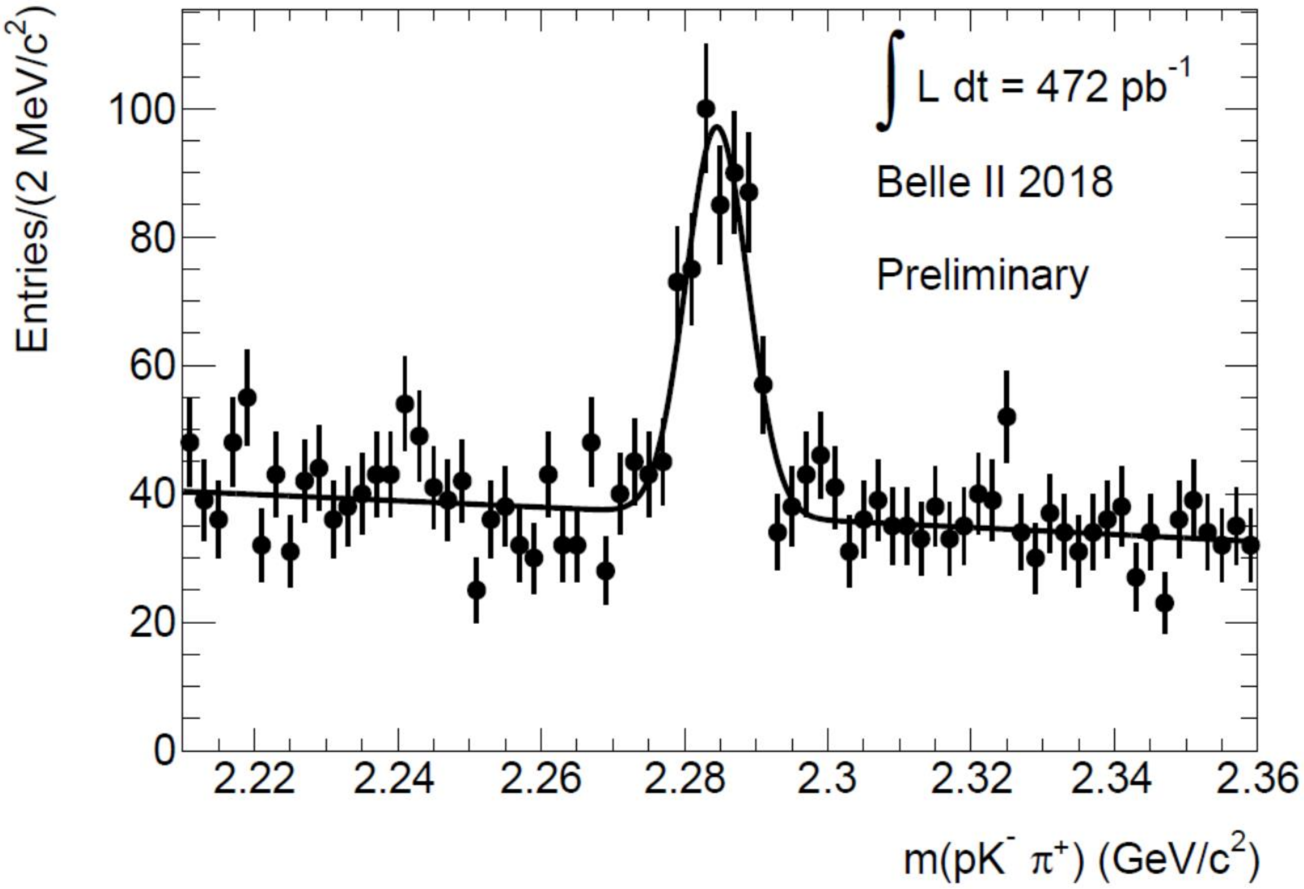
$$W_{5/2} = \frac{3}{8}[\rho_{55}2(5\cos^4\theta - 2\cos^2\theta + 1) + \rho_{33}(-15\cos^4\theta + 14\cos^2\theta + 1) + \rho_{11}5(1-\cos^2\theta)^2]$$

- Decay angular distribution depends on helicity fraction (ρ_{ii}).
  Difficult to predict ρ_{ii} in continuum production.

- If a charm baryon is not polarized (ρ_{ii} have same value), angular distribution becomes flat.
  → It is difficult to distinguish spin 1/2 and no polarization.

- J^P determination is essential.

Λ_c^+ in Belle II phase2 data!



Prospect for CKM

- For $|V_{xb}|$, Belle II is able to perform both inclusive and exclusive measurements with B tagging, including
  - detailed studies of exclusive decays to understand the difference, which is presently seen.
- Interplay with theoretical studies is important.

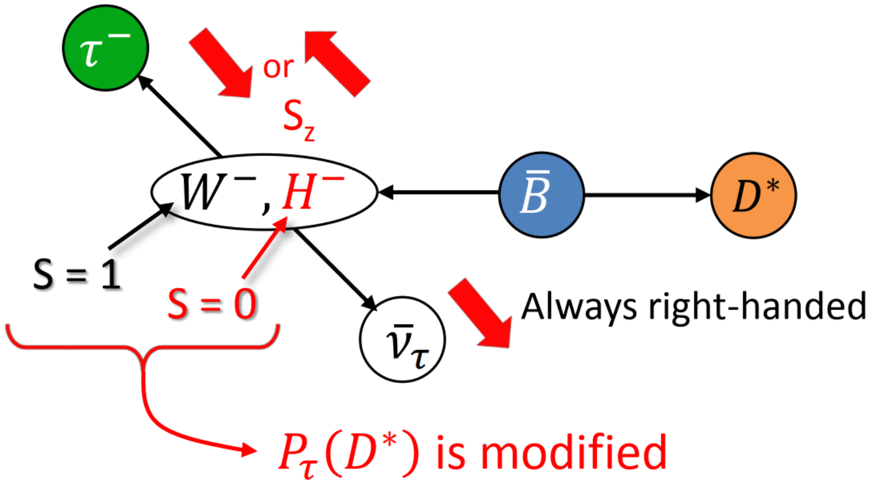
1808.10567

Belle II prospect for $|V_{xb}|$

% uncertainties	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory Lattice projections	Total
$\|V_{ub}\|$ exclusive (had. tagged)					
711 fb^{-1}	3.0	(2.3, 1.0)	3.8	7.0	8.0
5 ab^{-1}	1.1	(0.9, 1.0)	1.8	1.7	3.2
50 ab^{-1}	0.4	(0.3, 1.0)	1.2	0.9	1.7
$\|V_{ub}\|$ exclusive (untagged)					
605 fb^{-1}	1.4	(2.1, 0.8)	2.7	7.0	7.5
5 ab^{-1}	1.0	(0.8, 0.8)	1.2	1.7	2.1
50 ab^{-1}	0.3	(0.3, 0.8)	0.9	0.9	1.3
$\|V_{ub}\|$ inclusive					
605 fb^{-1} (old B tag)	4.5	(3.7, 1.6)	6.0	2.5–4.5	6.5–7.5
5 ab^{-1}	1.1	(1.3, 1.6)	2.3	2.5–4.5	3.4–5.1
50 ab^{-1}	0.4	(0.4, 1.6)	1.7	2.5–4.5	3.0–4.8

Polarizations in $B \to D^* \tau \nu$

- $R(D^{(*)})$ deviations from SM (by ~3.8σ as of 2018) motivates further study
- Detailed kinematic information of the final-state particles, e.g. angular observables, can provide a good clue for NP signature (*if there is any*!)



$$\mathcal{P}_\tau^{\rm SM} = -0.497 \pm 0.014$$

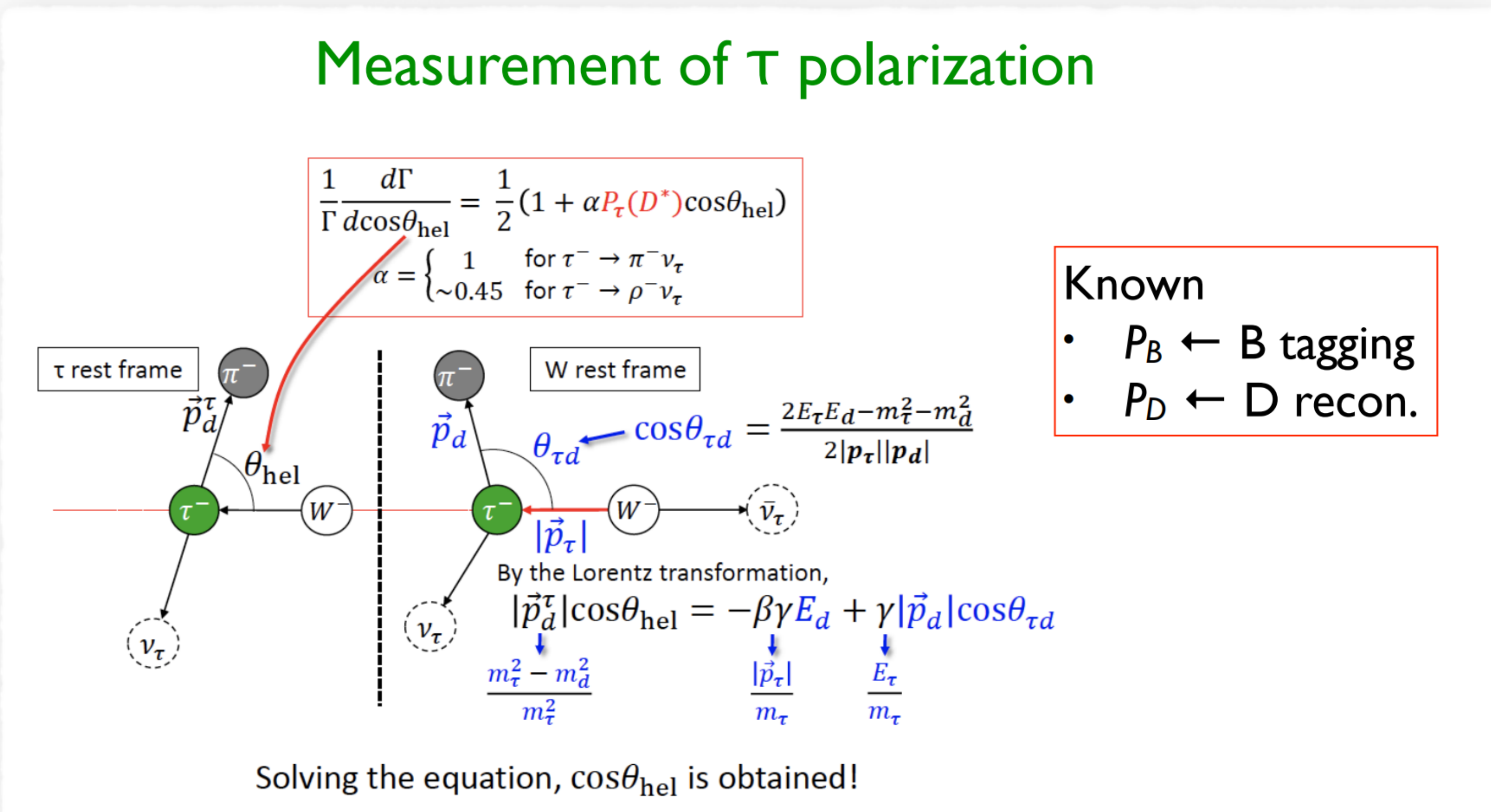
by M. Tanaka & R. Watanabe, PRD 87, 034028 (2013)

- In 2017, Belle has reported world-first measurement of P_τ in B ➔ D* τν

$$\mathcal{P}_\tau(D^*) = -0.38 \pm 0.51^{+0.21}_{-0.16}$$

Measurement of τ polarization

- Belle II will be able to measure distributions; such as τ polarization, q^2 distribution, to discriminate type of NP.

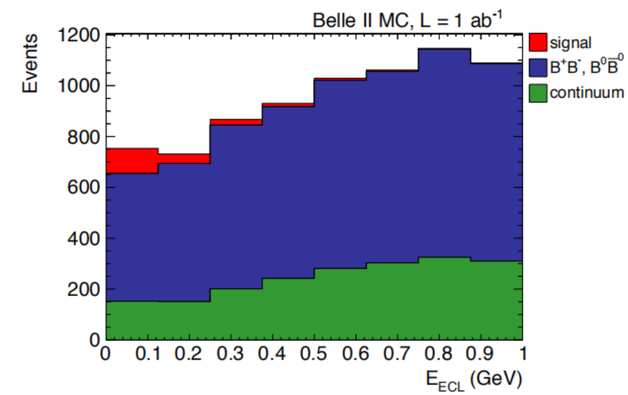


$B \to \tau\nu, l\nu$ at Belle II

1808.10567

$B \to \tau\nu$

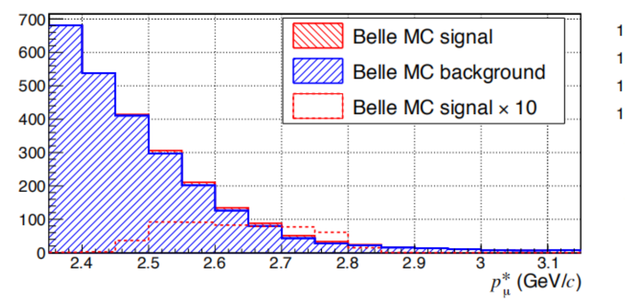
- Exploits high efficiency of the hadronic tag method through the Full Event Interpretation (FEI).
- Selection of photon candidates is important to cope with machine background in Belle II (x20 w.r.t. Belle)
  - Cluster energy, timing, shape (E9/E25)
- Multivariate continuum suppression



E_{ECL}		< 1 GeV	< 0.25 GeV
without background	Background yield [events]	12835	2062
	Signal yield [events]	332	238
	Signal efficiency (‰)	3.8	2.7
with background	Background yield [events]	7420	1348
	Signal yield [events]	188	136
	Signal efficiency (‰)	2.2	1.6

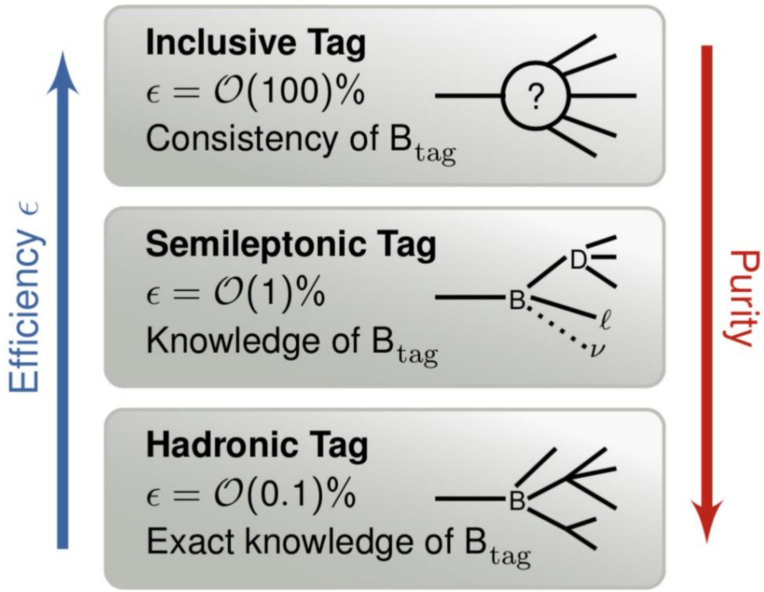
$B \to \mu\nu$

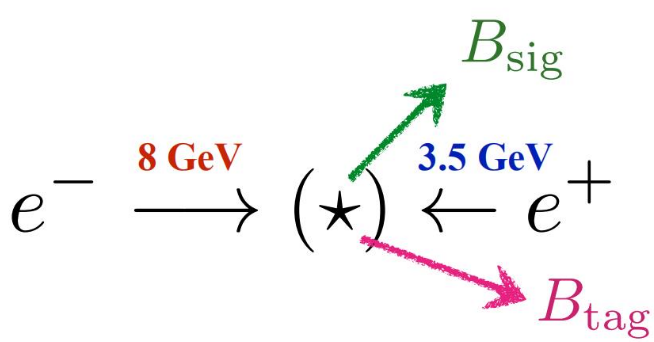
- Tagged searches are possible, but efficiency is too low
- Extrapolation from Belle to Belle II
  - Branching fraction error : 7%(stat.) at 50ab^{-1}
  - 5σ observation at 6 ab^{-1}



Experiment	Upper limit @ 90% C.L.	Comment
Belle [225]	2.7×10^{-6}	Fully reconstructed hadronic tag, 711 fb^{-1}
Belle [226]	1.1×10^{-6}	Untagged analysis, 711 fb^{-1}
BaBar [222]	1.0×10^{-6}	Untagged analysis, 468×10^6 $B\bar{B}$ pairs

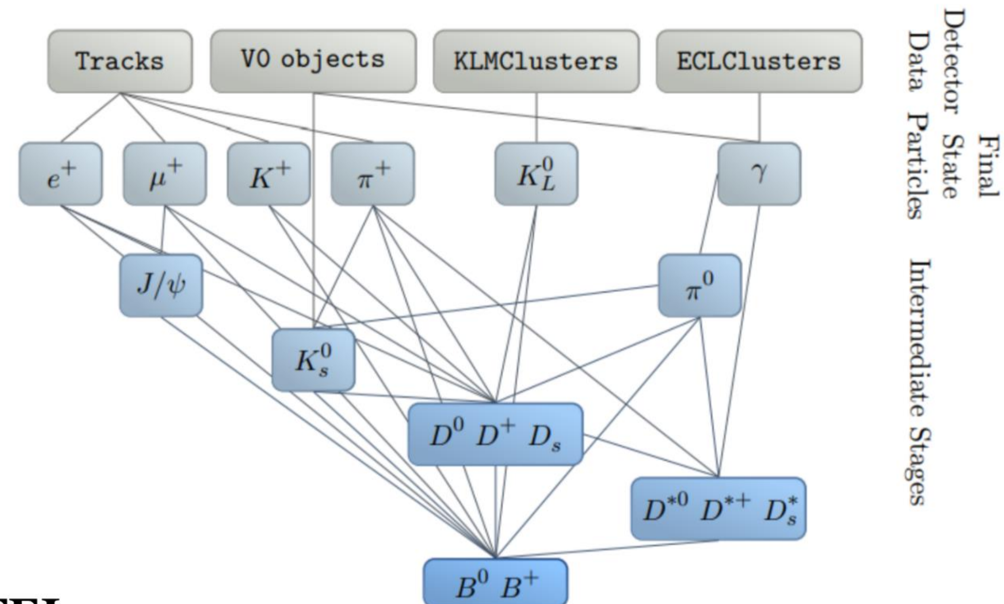
B-tagging and FEI





Exclusive Tagging:
The Full Event Interpretation (FEI)

Keck, T., et al. Comput Softw Big Sci (2019)



FEI

- the most evolved version of B-tagging S/W
- developed for Belle II; used in several Belle studies
  - O(200) decay chains with BDT trained for each
  - O(10k) decay chains in 6 stages
  - ×3 high MC efficiency than existing Belle algorithm