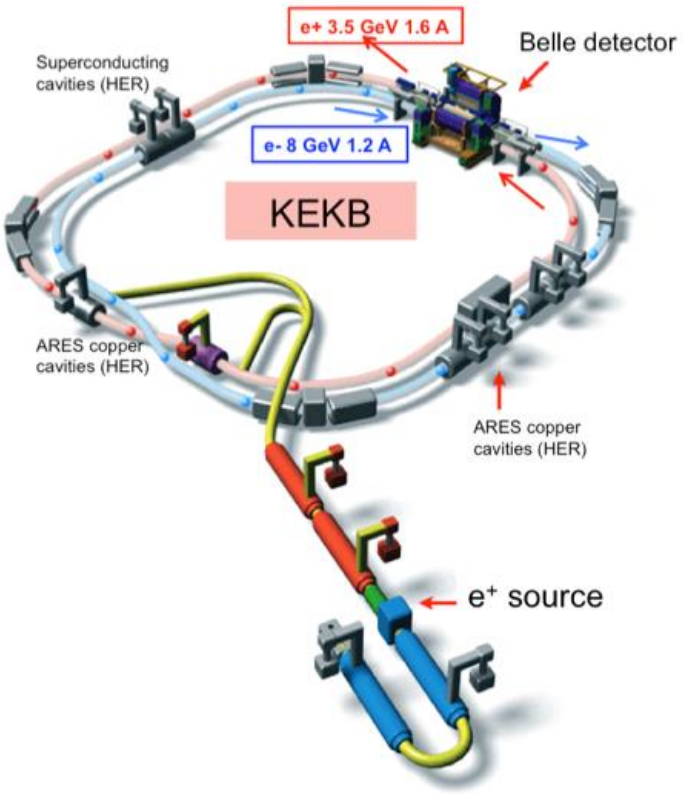
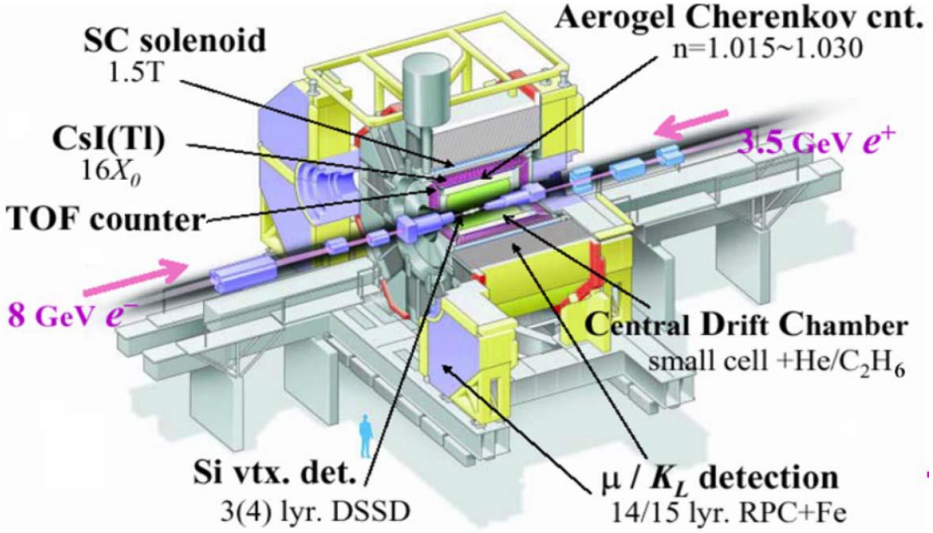
Overview of Belle and Belle II results and prospects

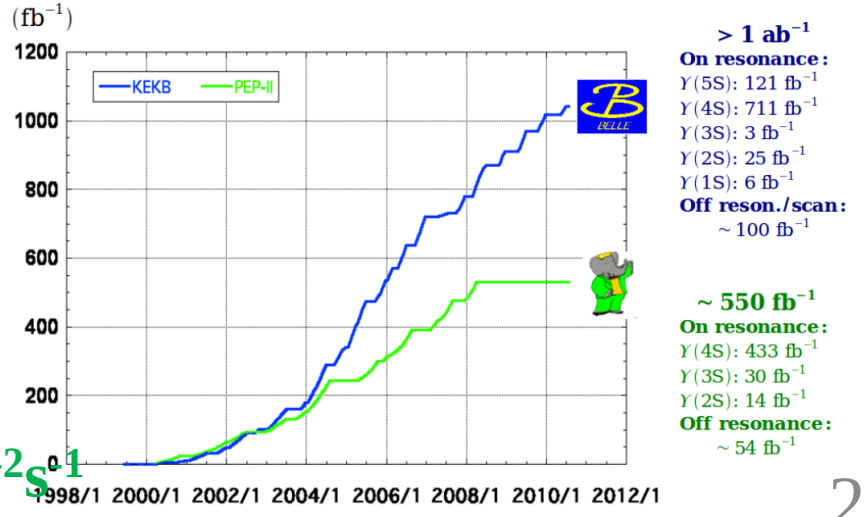
鄢文标 (中国科学技术大学)

全国第十九届重味物理和CP破坏研讨会，2022.12.9，南京

KEKB & Belle

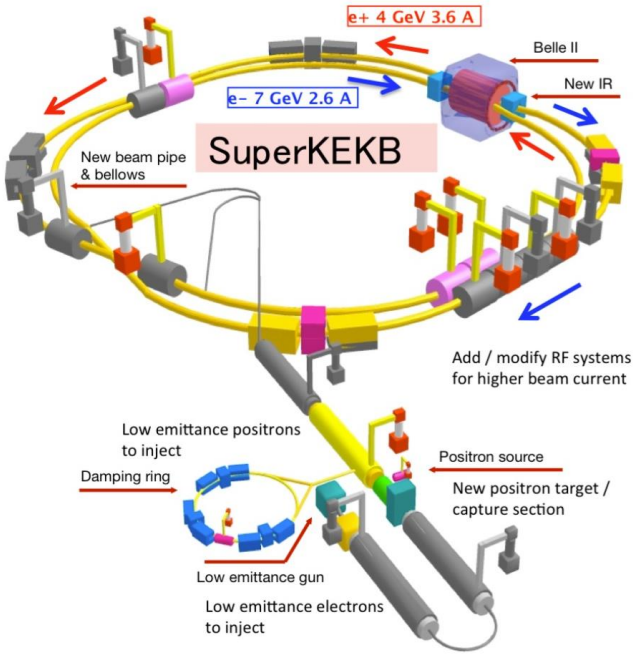


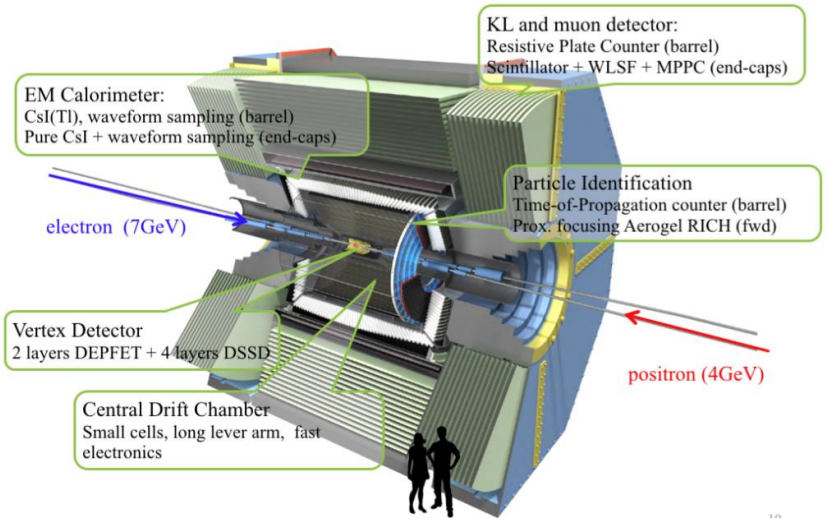




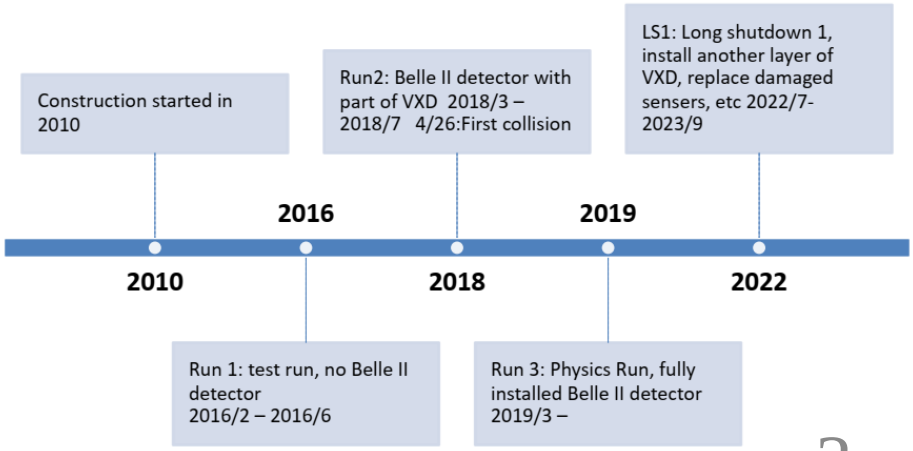
- Asymmetric e^+e^- collider
- @ Tsukuba, Japan
- Peak luminosity $2.1 \times 10^{34}\ cm^{-2}s^{-1}$

SuperKEKB & Belle II

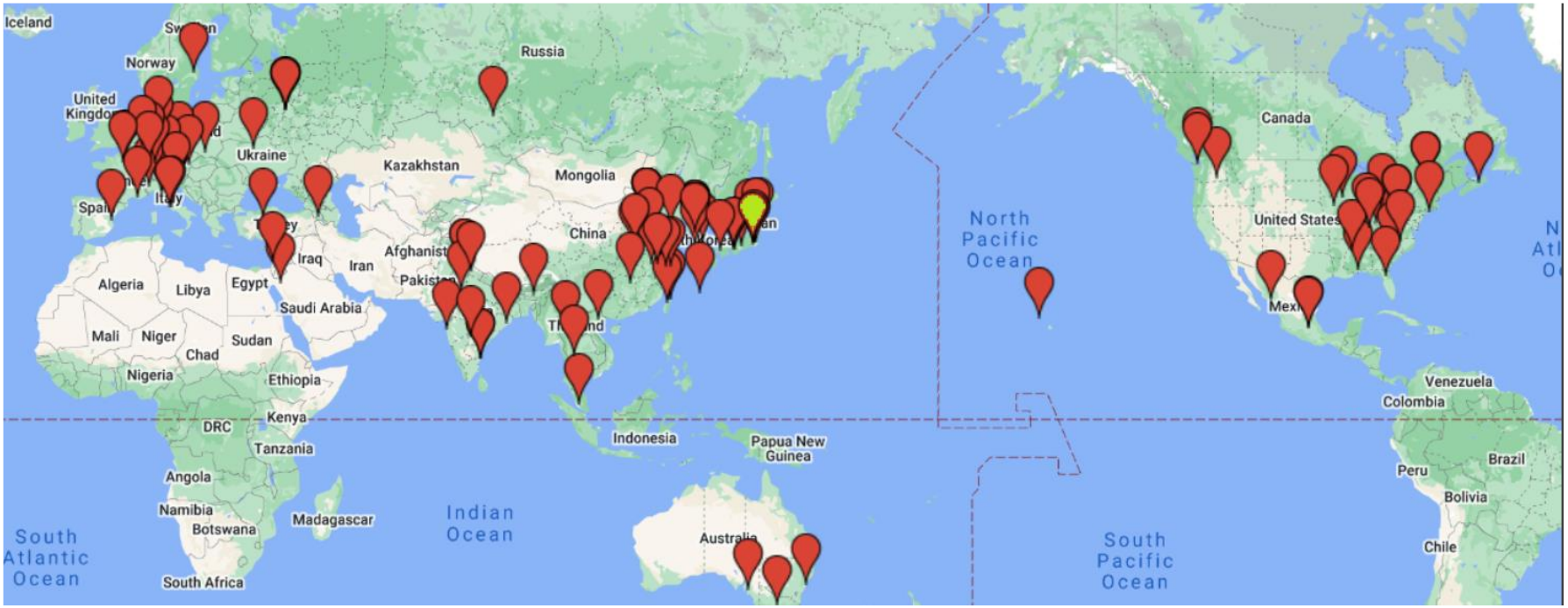




- **Peak luminosity**
  - ✓ **Record: $4.7\times10^{34}cm^{-2}s^{-1}$**
  - ✓ **Target: $6.3\times10^{35}cm^{-2}s^{-1}$**
- **Target data sample: $50\ ab^{-1}$**

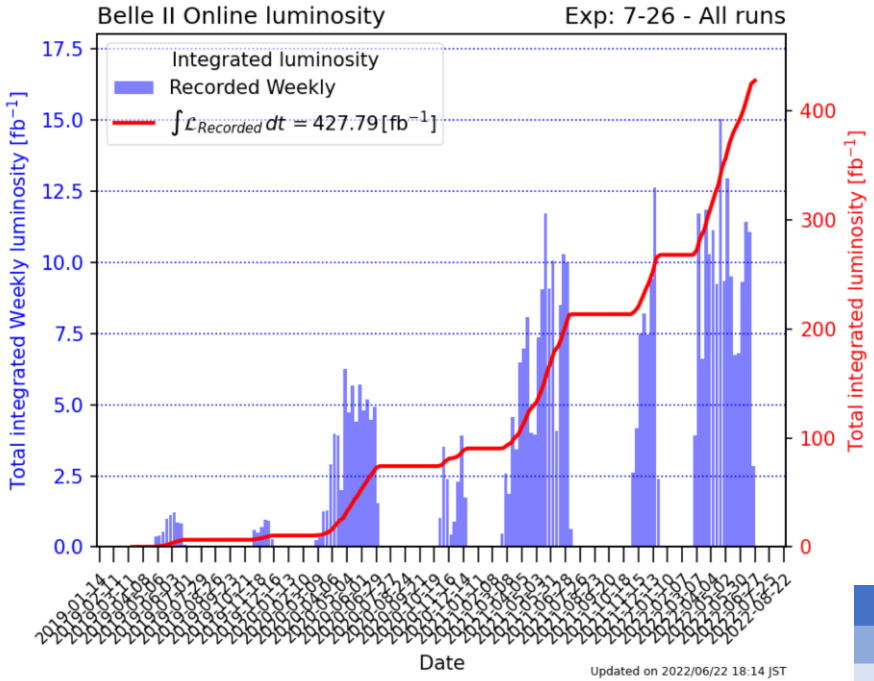


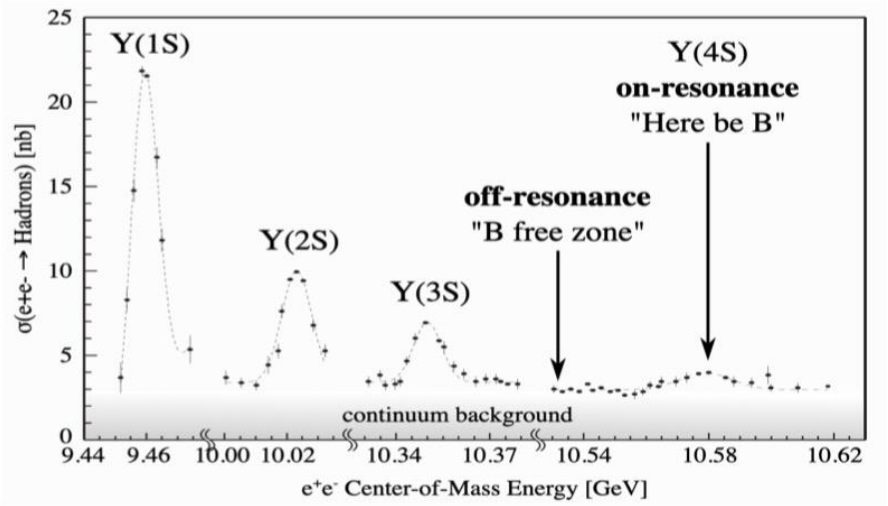
Belle II Collaboration



- **Belle II 合作组：1155个成员，130个单位，26个国家/地区**
- **(中国大陆) 15个单位：北京高能所/中国科学技术大学/北京大学/北京航空航天大学/复旦大学/苏州大学/辽宁师范大学/山东大学/南京师范大学/郑州大学/河南师范大学/湖南师范大学/(2022)东南大学/南开大学/吉林大学**

Data taking at Belle II





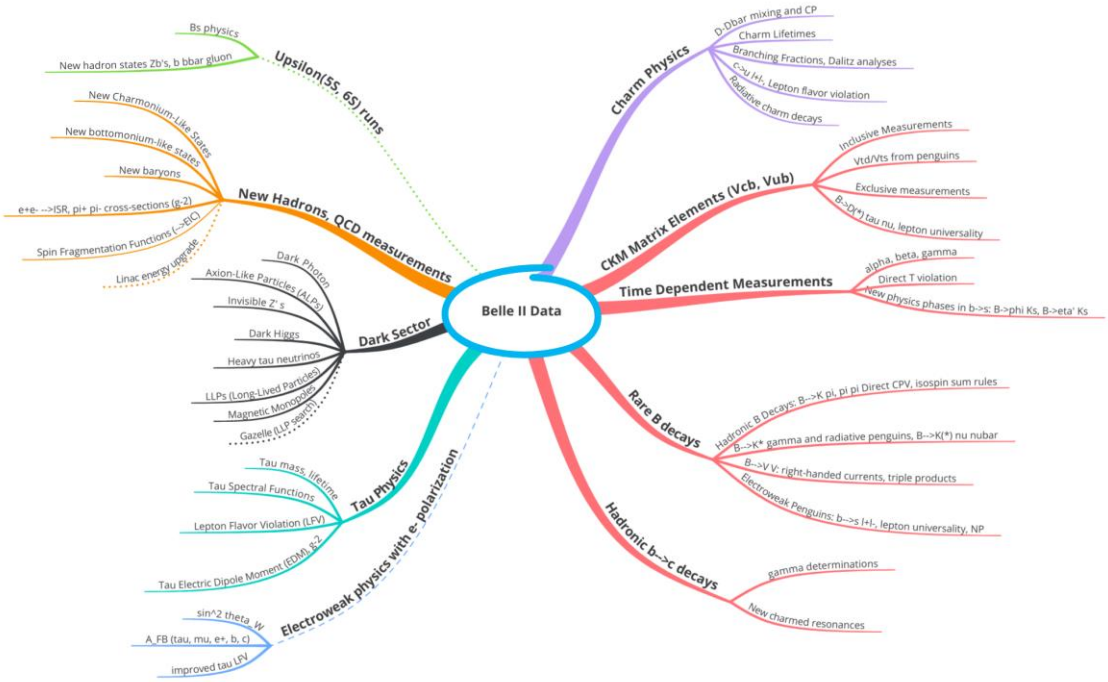
12 月 9 日 下午	报告人	报告题目	单位	主持人
Session 3 底夸克与新物理				
14:00–14:20	何吉波	LHCb 上味物理中的反常	中国科学院大学	郑阳恒
14:20–14:40	贾森	First result of scan data at around 10.75 GeV at Belle II	东南大学	

- **Integrated luminosity**
  - ➢ **~362 fb^{-1} at Y(4S)**
    - ✓ **Combine with Belle 711 fb^{-1} at Y(4S)**
  - ➢ **~42 fb^{-1} 60 MeV below Y(4S)**
  - ➢ **~19 fb^{-1} at ~10.75 GeV**

Belle II physics program

Process	σ (nb) @ Y(4S)
$b\bar{b}$	1.1
$c\bar{c}$	1.3
$q\bar{q}$ (q=u,d,s)	2.1
$\tau^+\tau^-$	0.9

B factory, also tau-charm factory



Physics potential summarized in the Belle II "Physics Book"

PTEP 2019 123C01, arXiv:1808.10567

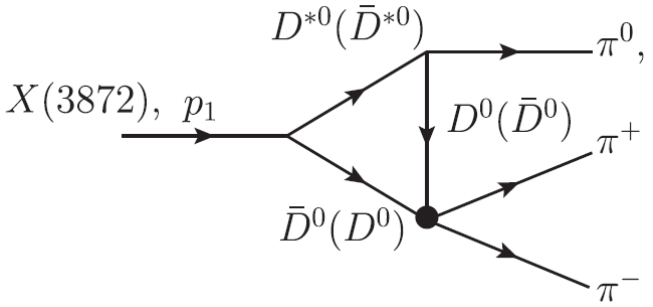
14:40-15:00(15+5)	李郁博	Recent results of charmed baryons focusing on new baryon at Belle

15:50-16:10	李龙科	Measurement of decay asymmetry parameter and CP violation in charmed baryon decays

12日10下午

X(3872) → $\pi^+ \pi^- \pi^0$

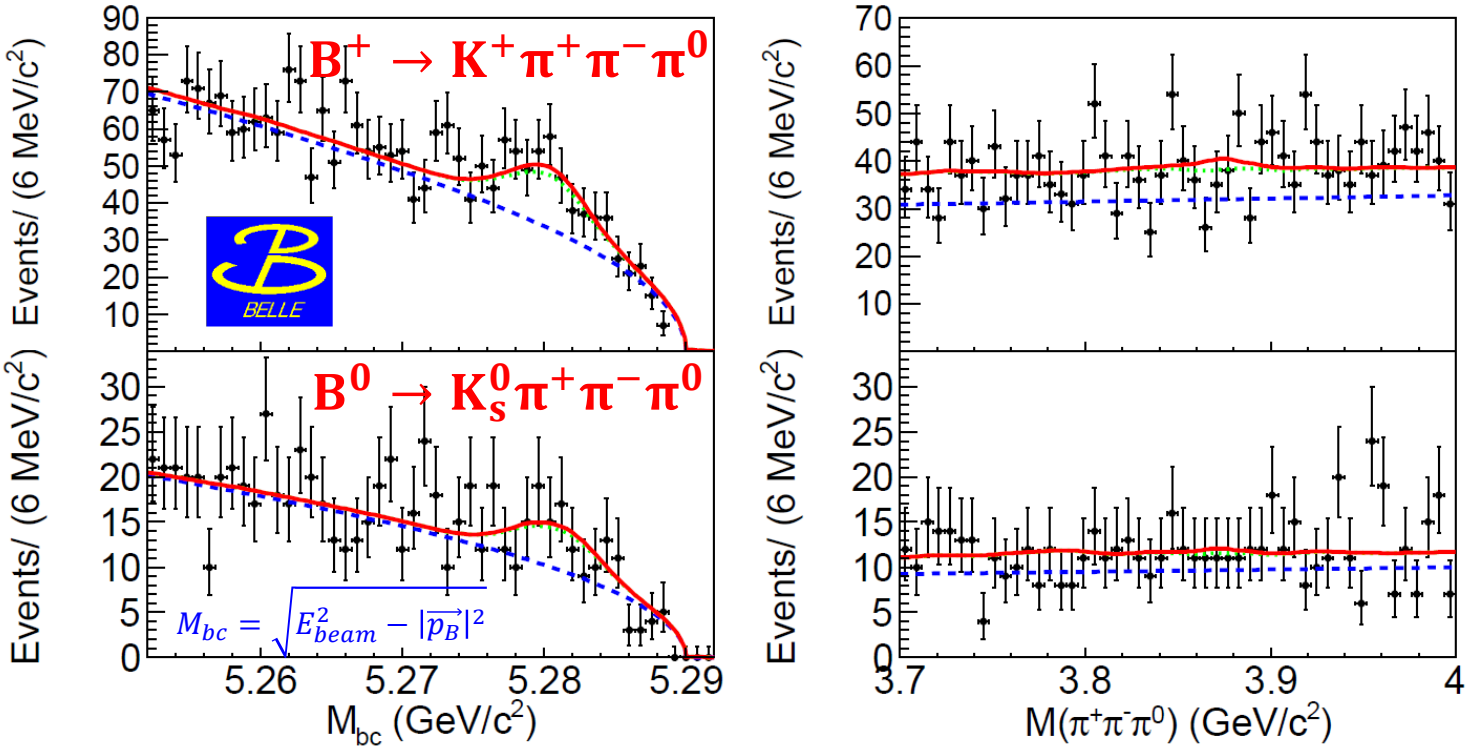
- All known X(3872) decay modes contain open charm or charmonium mesons.
- X(3872) decays into final states with light hadrons ?
- X(3872) as charmonium, significant branching fraction for gg → hadrons.
- Triangle logarithmic singularity
  - ✓ Br(X(3872) → $\pi^+ \pi^- \pi^0$) ≈ 10^{-3}- 10^{-4}.
  - ✓ A narrow interval of m($\pi\pi$) near value of $2m_D \approx 3.73$ GeV.
- Belle: (772 ± 11) × 10^6 $B\bar{B}$ events, B → K X(3872).



PRD 99 (2019) 116023

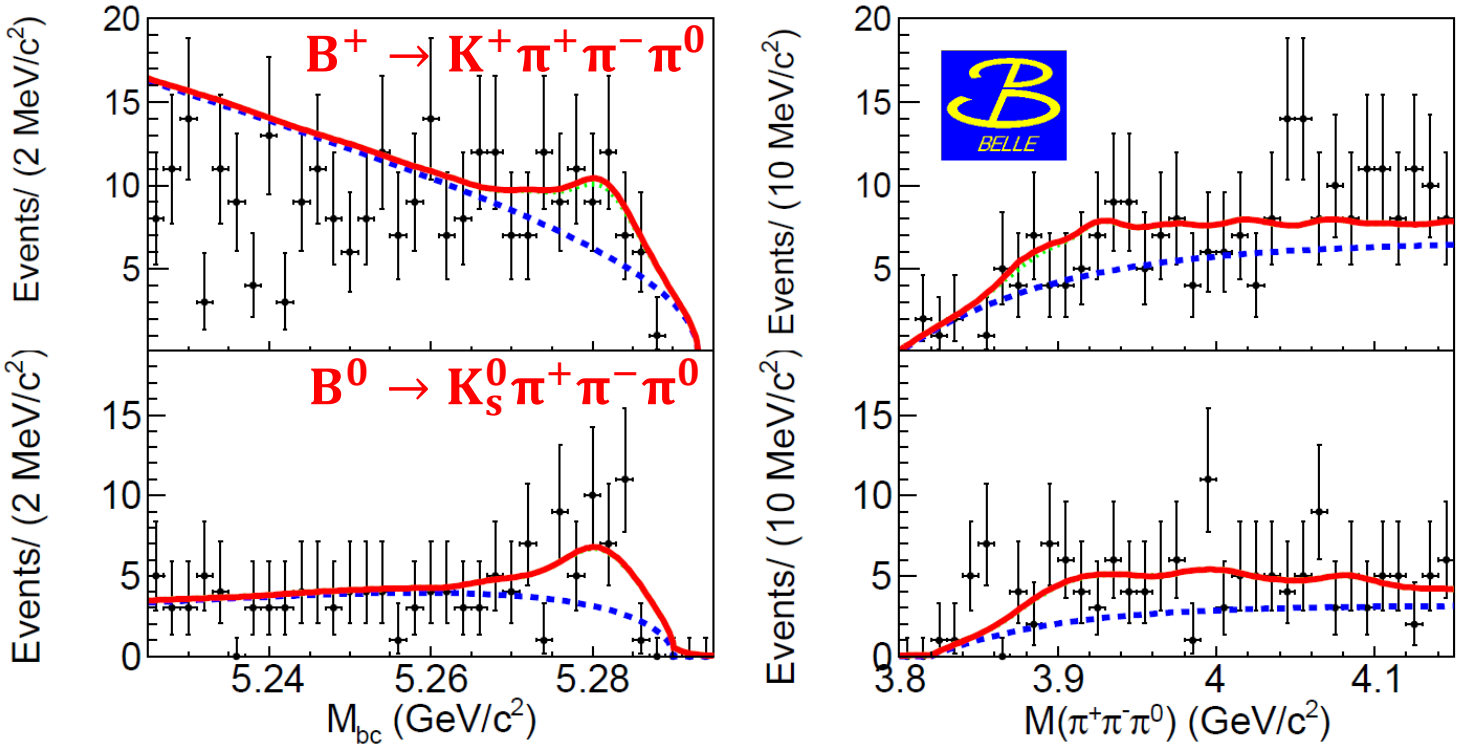
B→K X(3872) & X(3872) → $\pi^+ \pi^- \pi^0$

arXiv:2206.08592 PRD accepted



- Veto continuum background by MVA
- Veto no-B background by $\Delta E = E_{beam} - E_B$
- Same final state due to B → Dρ, K*(892) ρ by mass window cut
- Case I: X(3872) → $\pi^+ \pi^- \pi^0$ MC by Phase space
- No significant signal is found

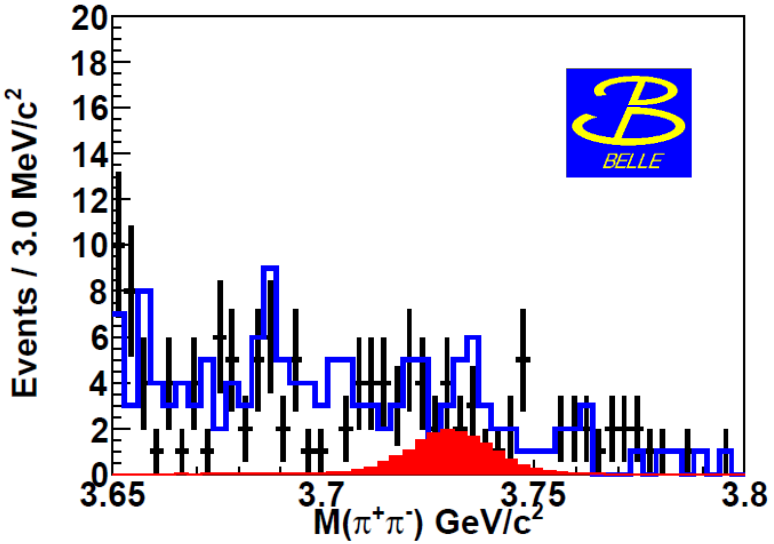
B→K X(3872) & X(3872) → $\pi^+ \pi^- \pi^0$



- Case II: X(3872) → $\pi^+ \pi^- \pi^0$ MC with PRD 99 (2019) 116023
  - ✓ $\pi^+\pi^-$ invariant mass peaks close to $2m_D \approx 3.73$ GeV
- No significant signal is found

arXiv:2206.08592 PRD accepted

B→K X(3872) & X(3872) → $\pi^+ \pi^- \pi^0$



- $\pi^+\pi^-$ invariant mass in X(3872) signal region
  - ✓ No significant enhancement near $2m_D \approx 3.73$ GeV
- More data @ Belle II ?

channel	case I	case II
$B^\pm \to K^\pm X(3872),\ X(3872) \to \pi^+\pi^-\pi^0$	$< 1.9 \times 10^{-6}$	$< 1.5 \times 10^{-7}$
$B^0 \to K^0 X(3872),\ X(3872) \to \pi^+\pi^-\pi^0$	$< 1.5 \times 10^{-6}$	$< 1.8 \times 10^{-7}$
$X(3872) \to \pi^+\pi^-\pi^0$	$< 1.3\%$	$< 1.2 \times 10^{-3}$

arXiv:2206.08592 PRD accepted

Search for tetraquark states $X_{cc\bar{s}\bar{s}}$

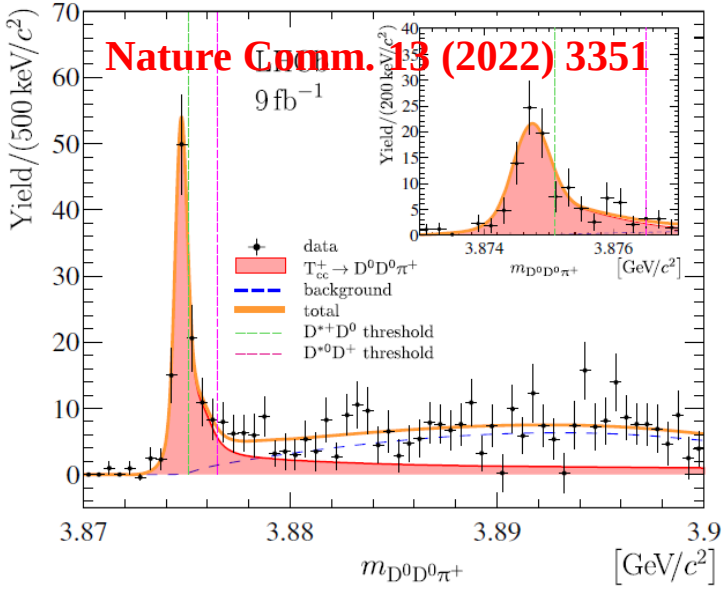


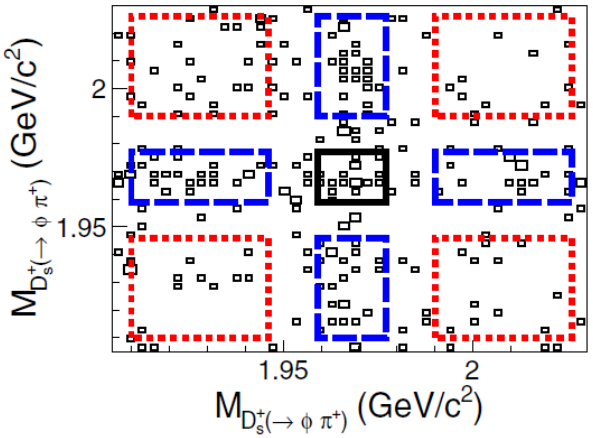
TABLE I. Predicted masses and widths for the $X_{cc\bar{s}\bar{s}}$ resonances in $D_s^+D_s^+$ and $D_s^{*+}D_s^{*+}$ final states [19].

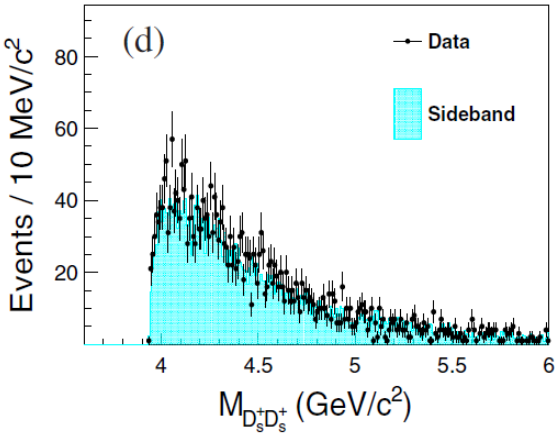
Mode	IJ^P	Mass (MeV/c^2)	Width (MeV)
$X_{cc\bar{s}\bar{s}} \to D_s^+D_s^+$	00^+	4902	3.54
$X_{cc\bar{s}\bar{s}} \to D_s^{*+}D_s^{*+}$	02^+	4821	5.58
	02^+	4846	10.68
	02^+	4775	23.26

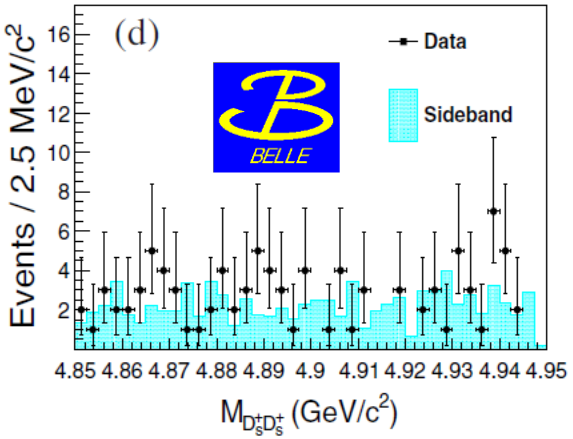
PR D 102 (2020) 054023

- **Exotic states with nonzero electric charge**
  - ✓ **LHCb: T_{cc}^+ in $D^0D^0\pi^+$ mass spectrum near threshold**
- **Search for double-heavy tetraquark candidates by $D_S^+D_S^+$ and $D_S^{*+}D_S^{*+}$ at Belle**
  - ✓ **$D_S^{*+} \to \gamma D_S^+$**
  - ✓ **$D_S^+ \to \phi(\to K^+K^-)\pi^+$ and $\bar{K}^*(892)^0(\to K^-\pi^+)K^+$**

Search for tetraquark states $X_{cc\bar{s}\bar{s}}$

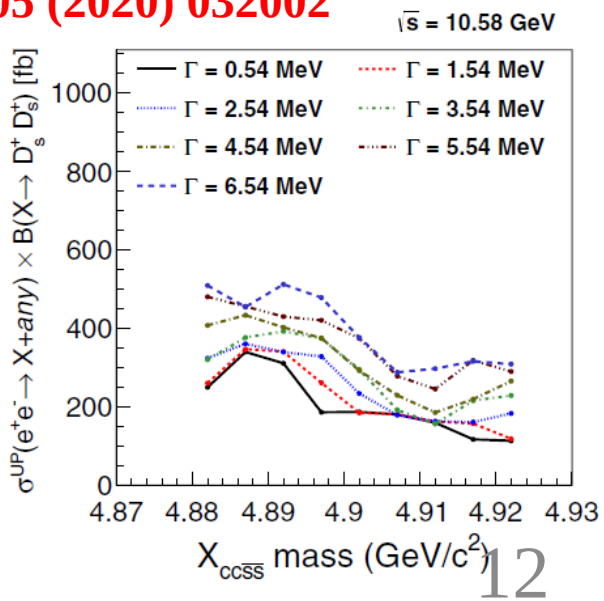






PR D 105 (2020) 032002

- **Best D_S^{*+} candidate with mass constrained fit for each D_S^+ candidate**
- **No multiple candidates after all selection**
- **Use Y(1S), Y(2S) and data $\sqrt{s}$ = 10.52, 10.58, and 10.867 GeV**
- **No clear signals are observed,**
  - ✓ **Provide 90% CL Upper limits**

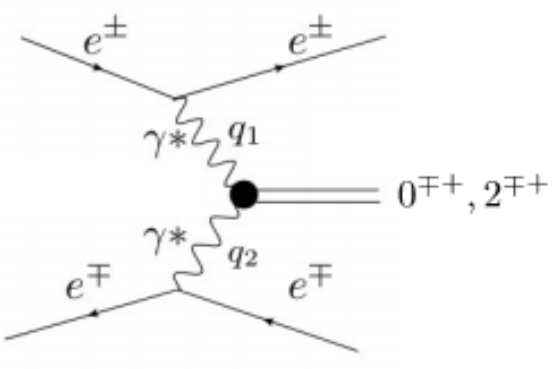


Two-photon decay width of $\chi_{c2}(1P)$

- $T_{\gamma\gamma}$ of a P-wave charmonium, whose description is at intersection between perturbative and non- perturbative QCD.
  - ✓ Theoretical calculation: between 280 eV and 930 MeV
- Two approaches: two-photon decay & two-photon production
- $\gamma\gamma \rightarrow \chi_{c2}(1P)$, $\chi_{c2}(1P) \rightarrow \gamma$ J/ψ and J/ψ $\rightarrow l^+l^-$ (l = e, μ)
  - ✓ worse results by two-photon production
- Belle: 32.6 fb^{-1} → 971 fb^{-1} data

	Approach	$T_{\gamma\gamma}$ (eV)	
CLEO-c	$\chi_{c2}(1P) \rightarrow \gamma\gamma$	$555 \pm 58 \pm 32 \pm 28$	
BESIII	$\chi_{c2}(1P) \rightarrow \gamma\gamma$	$586 \pm 16 \pm 13 \pm 29$	
Cleo III	$\gamma\gamma \rightarrow \chi_{c2}(1P)$	$582 \pm 59 \pm 50 \pm 15$	
Belle	$\gamma\gamma \rightarrow \chi_{c2}(1P)$	$596 \pm 58 \pm 48 \pm 16$	32.6 fb^{-1}

Two-photon decay width of $\chi_{c2}(1P)$



- **Cross section of R via two-photon process**
  - ✓ **W: energy of resonance R**
  - ✓ **$L_{\gamma\gamma}$(W): luminosity function**

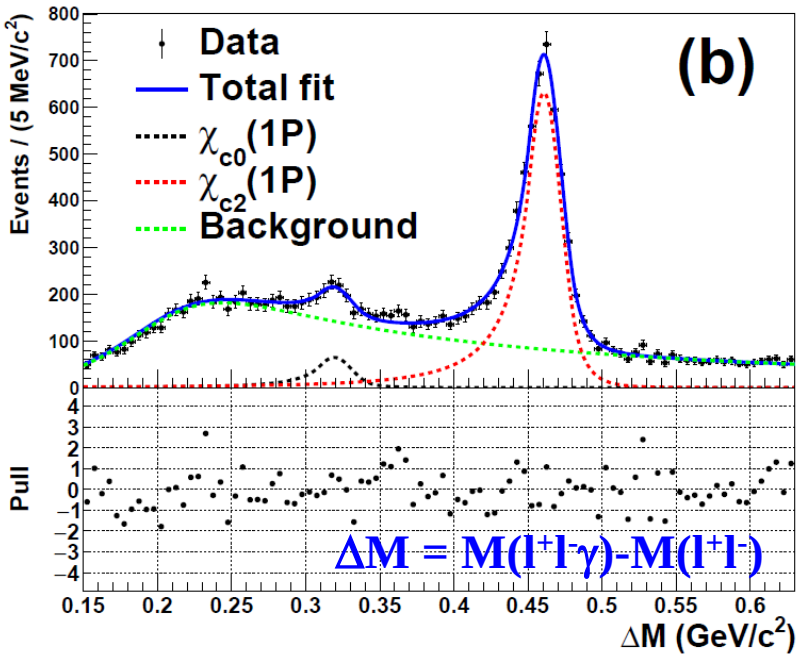
$$\sigma(e^+e^- \to e^+e^-R) = \int \sigma(\gamma\gamma \to R; W) L_{\gamma\gamma}(W) dW,$$

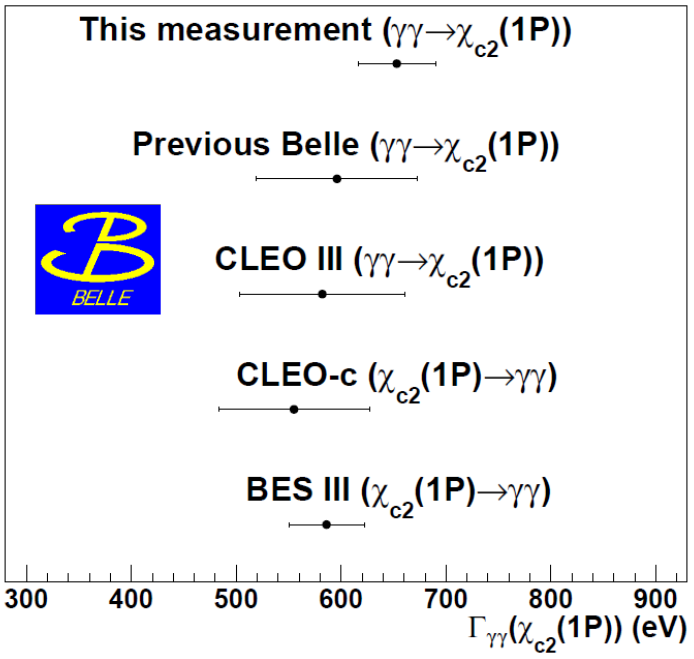
- **Total width of R is sufficiently small compared with its mass**
  - ✓ **J: spin quantum number**
  - ✓ **M_R: mass of R**

$$\sigma(e^+e^- \to e^+e^-R) = 4\pi^2(2J+1)\frac{L_{\gamma\gamma}(m_R)\Gamma^R_{\gamma\gamma}}{m_R^2},$$

- **Select quasi-real two photon collisions**
  - ✓ **Zero-tag mode**

Two-photon decay width of $\chi_{c2}(1P)$

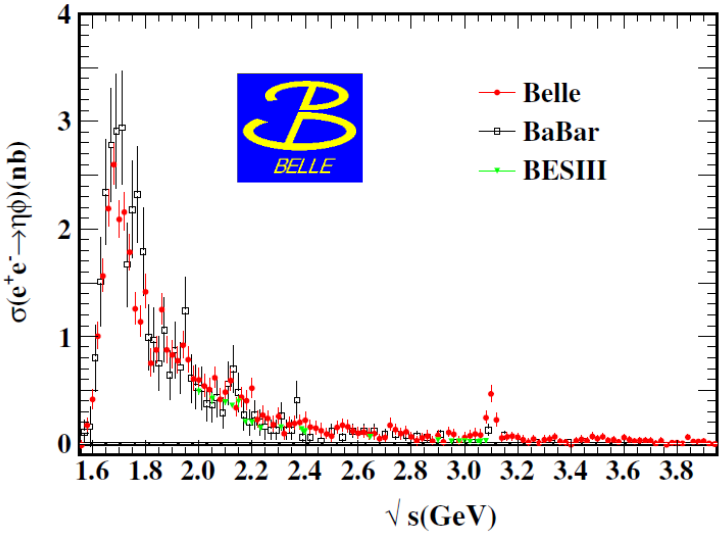




- A peaking background from e+e- → γ_{ISR} ψ(2S)
  - ✓ ψ(2S) → γ $\chi_{c2}(1P)$, $\chi_{c2}(1P)$ → γ J/ψ and J/ψ → l^+l^-
  - ✓ Subtracted by MC simulation
- Belle results is almost same as that of BESIII results

arXiv:2208.04477 JHEP accepted

$e^+e^- \to \phi\eta$ by ISR

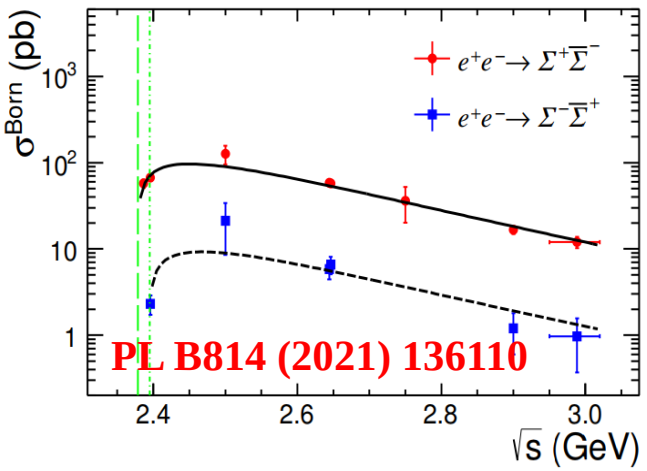


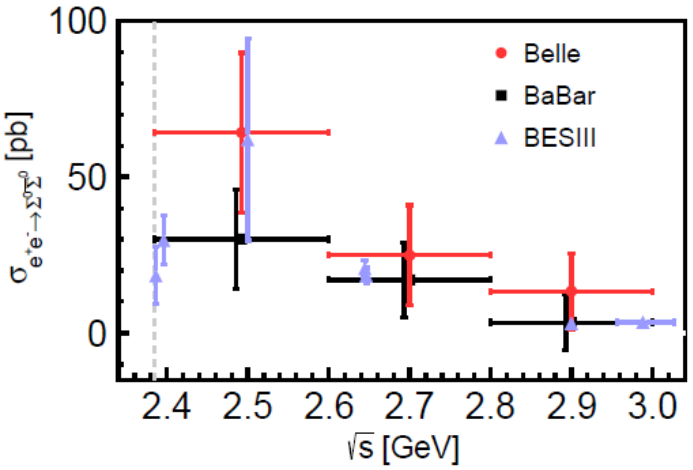
Parameters	with $\phi(2170)$				without $\phi(2170)$	
	Solution I	Solution II	Solution III	Solution IV	Solution I	Solution II
χ^2/ndf	77/56				85/60	
a_0	-4.1 ± 0.5	5.0 ± 0.7	-5.0 ± 0.5	-4.8 ± 0.2	-3.2 ± 0.7	5.0 ± 0.1
a_1	2.7 ± 0.1	2.6 ± 0.1	2.7 ± 0.1	2.6 ± 0.1	2.9 ± 0.1	2.6 ± 0.1
$\mathcal{B}^{\phi(1680)}_{\eta\phi}\Gamma^{\phi(1680)}_{e^+e^-}$(eV)	122 ± 6	219 ± 15	163 ± 11	203 ± 12	75 ± 10	207 ± 16
$M_{\phi(1680)}$(MeV/c^2)	1683 ± 7				1696 ± 8	
$\Gamma_{\phi(1680)}$(MeV)	149 ± 12				175 ± 13	
$\mathcal{B}^{\phi(1680)}_{\eta\phi}$	0.18 ± 0.02	0.19 ± 0.04	0.21 ± 0.02	0.17 ± 0.04	0.25 ± 0.12	0.23 ± 0.10
$\mathcal{B}^{\phi(2170)}_{\eta\phi}\Gamma^{\phi(2170)}_{e^+e^-}$(eV)	0.09 ± 0.05	0.06 ± 0.02	16.7 ± 1.2	17.0 ± 1.2	—	
$M_{\phi(2170)}$(MeV/c^2)	$2163.5(fixed)$				—	
$\Gamma_{\phi(2170)}$(MeV)	$31.1(fixed)$				—	
$\theta_{\phi(1680)}(^\circ)$	-89 ± 2	96 ± 6	-92 ± 1	-86 ± 7	-87 ± 15	108 ± 22
$\theta_{\phi(2170)}(^\circ)$	37 ± 14	-102 ± 11	-167 ± 6	-155 ± 5	—	

arXiv:2209.000810 JHEP accepted

- **$\phi\eta$ mode: isoscalar**
  - ✓ **ϕ* and ω* (OZI suppressed);**
  - ✓ **useful to measure ϕ*parameters.**
- **Study $\phi(1680)$ resonance parameters with Belle 980 fb^{-1} data**
- **no clear observed $\phi(2170)$ signal, but 90% C.L. is consistent with that of BESIII.**

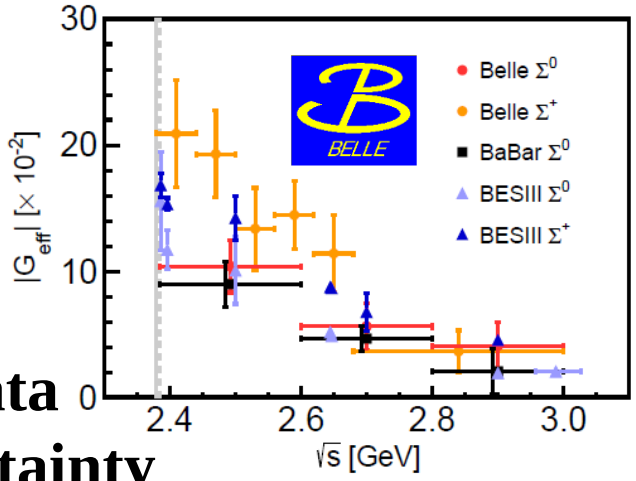
$e^+e^- \to \Sigma^+\bar{\Sigma}^-$ and $\Sigma^0\bar{\Sigma}^0$ by ISR



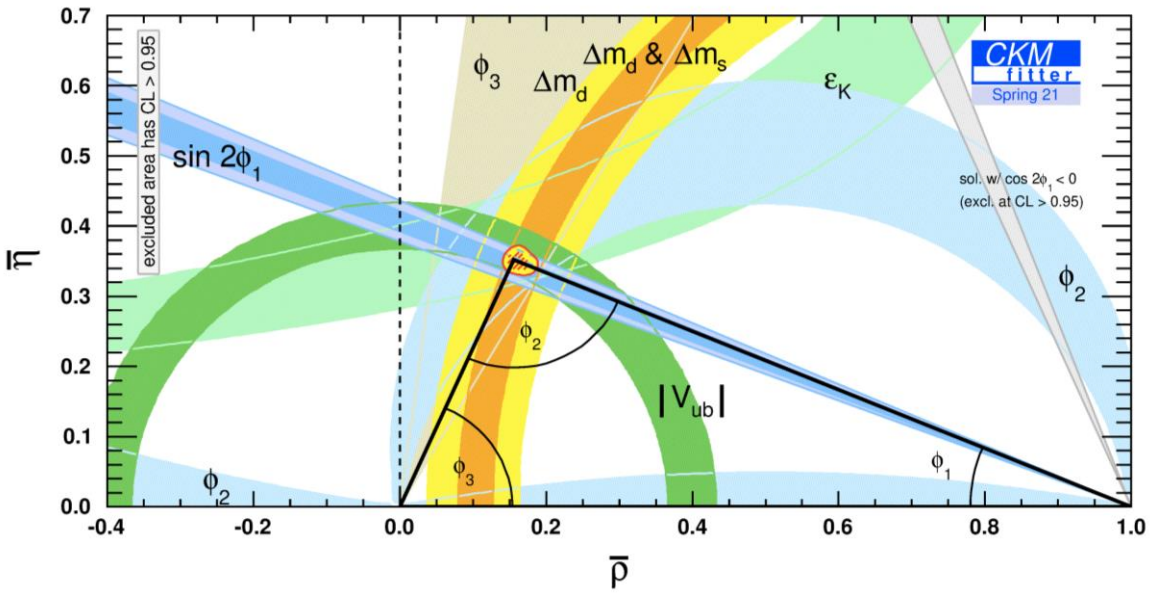


arXiv:2210.16761

- **Cross section at threshold**
  - ✓ **Charged: $\sigma \neq 0$; Neutral: $\sigma = 0$;**
  - ✓ **G_E & G_M form factor.**
- **pQCD-motivated function describe BESIII results.**
- **Study with Belle with Belle 980 fb^{-1} data**
- **All results are consistent within uncertainty**



CKM Unitarity triangle

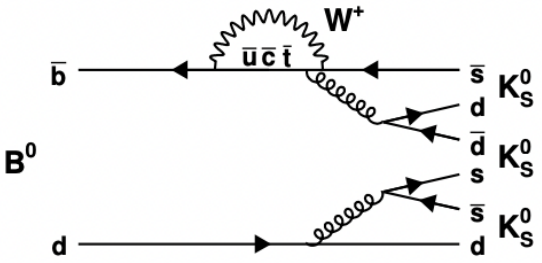


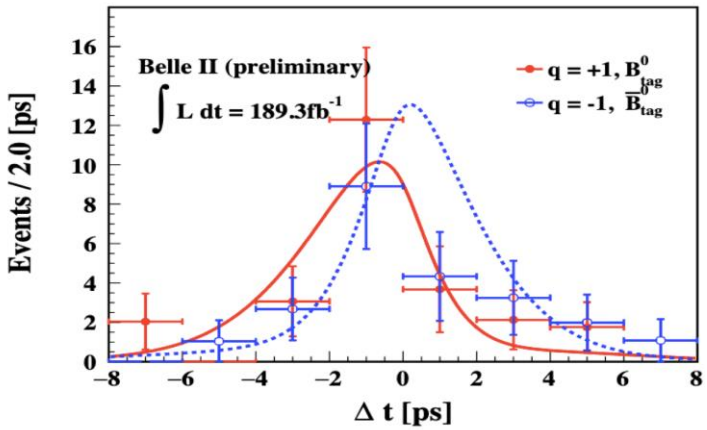
- **Tests of quark-mixing matrix unitarity**
  - ✓ **Precise measurement of unitarity triangle parameters ϕ_1, ϕ_2, ϕ_3, $|V_{cb}|$, $|V_{ub}|$**
  - ✓ **β/ϕ_1: mixing + b → $c\bar{c}s$, b → $c\bar{c}d$**
  - ✓ **α/ϕ_2: mixing + b → $u\bar{u}d$**
  - ✓ **γ/ϕ_3: b → $u\bar{c}s$, b → $c\bar{u}s$**

β/ϕ_1 @ $B^0 \to K^0_S K^0_S K^0_S$

- Target $\mathcal{B}$ and $\mathcal{A}_{CP}$ asymmetry
- Process via b → sq$\bar{q}$
- Sensitive to non-SM effects
- Important for CP asymmetry
  - ✓ $\mathcal{S}$ = -sin2ϕ_1 @ SM, mixing induced CPV
  - ✓ $\mathcal{A}$ = 0 @ SM, direct CPV
  - ✓ Deviation from SM, hint of NP !

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



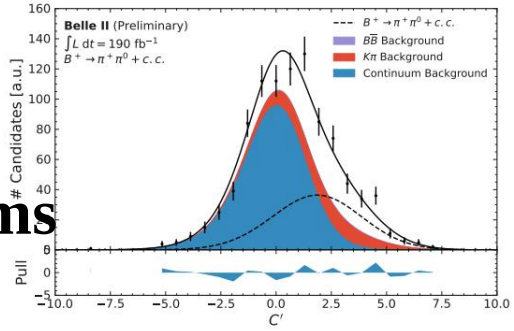


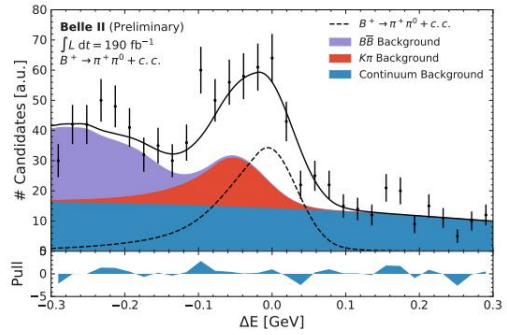
- Belle II ~190 fb^{-1} data
  - ✓ 53 ± 8 events
  - ✓ $\mathcal{S} = -1.86^{+0.91}_{-0.46} \pm 0.09$
  - ✓ $\mathcal{A} = -0.22^{+0.30}_{-0.27} \pm 0.04$
- World average
  - ✓ $\mathcal{S}$ = -0.83 $\pm$ 0.17
  - ✓ $\mathcal{A}$ = 0.15 $\pm$ 0.12

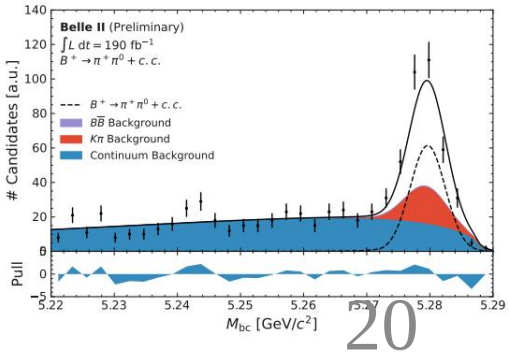
α/ϕ_2 @ $B \to \pi\pi$ & $B \to \rho\rho$

- **Measurement of $\mathcal{B}$ and $\mathcal{A}_{CP}$**
- **Process via b → u diagrams**
- **Interference between tree and penguin diagrams**
- **Belle II 190 fb^{-1} data**
  - ✓ **Multivariate analysis to suppress continuum**
  - ✓ **3D signal extraction function**
  - ✓ **Validation by $B^+ \to \bar{D}(\to K^+\pi^-\pi^0)\,\pi^+$ continuum**
- **Comparable sensitivity with ½ of data**

$B^+ \to \pi^+\pi^0$





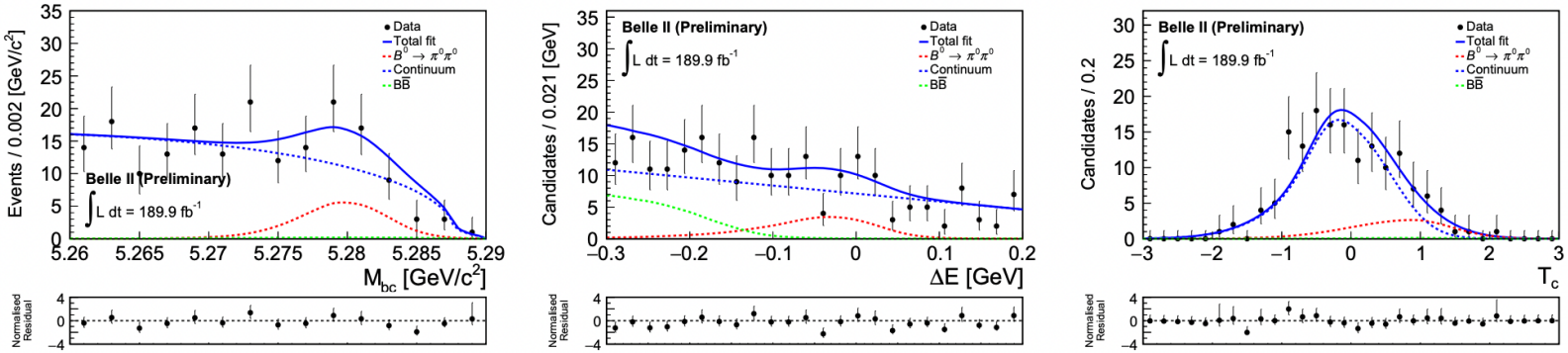


	Belle	Belle II
$B\bar{B}$ pairs	~197 M	449 M
$\mathcal{B}(\times 10^{-6})$	$6.12 \pm 0.53 \pm 0.53$	$6.5 \pm 0.4 \pm 0.4$
$\mathcal{A}_{CP}$	$-0.085 \pm 0.085 \pm 0.019$	

α/ϕ_2 @ $B^0 \to \pi^0 \pi^0$

- Very challenge, neutral final states
- All neutral suitable for Belle II
- Belle II ~190 fb^{-1} data
  - ✓ Photons by FastBDT; data driven method for background suppression
  - ✓ Belle II flavor algorithm; validation by $B^0 \to D\left(\to K^+\pi^-\pi^0\right)\pi^0$

$$\mathcal{A}_{CP} = \frac{\Gamma(\bar{B} \to \pi^0\pi^0) - \Gamma(B \to \pi^0\pi^0)}{\Gamma(\bar{B} \to \pi^0\pi^0) + \Gamma(B \to \pi^0\pi^0)}$$



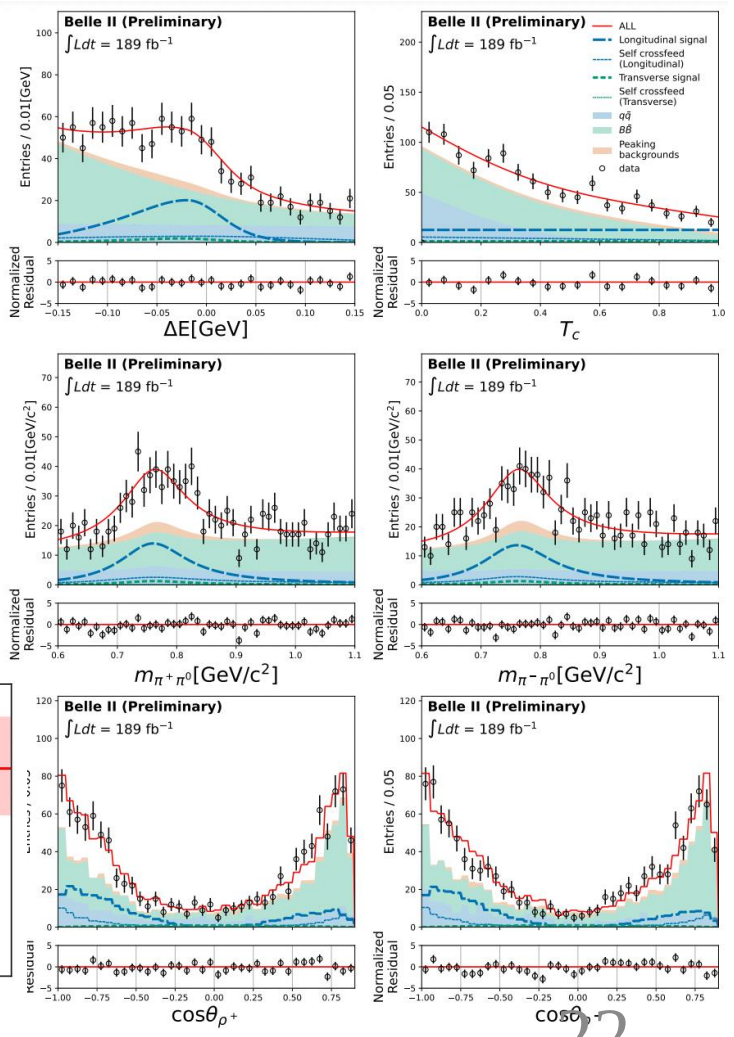
	Belle	Belle II
$B\bar{B}$ pairs	~197 M	771 M
$\mathcal{B}$ ($\times 10^{-6}$)	1.32 ± .0.25 ± 0.18	1.31 ± 0.19 ± 0.19
$\mathcal{A}_{CP}$	-0.14 ± 0.46 ± 0.07	-0.14 ± 0.36 ± 0.10

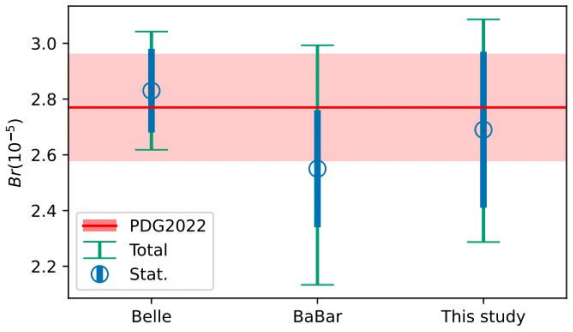
- Efficiency 35.5% @ Belle II
- Efficiency 22% @ Belle
- Comparable sensitivity with 1/4 of data

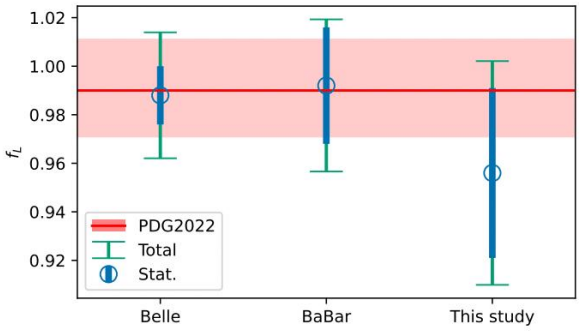
α/ϕ_2 @ $B^0 \to \rho^+\rho^-$

arXiv:2208.03554

- Golden channel for ϕ_2,
  - ✓ small contribution from penguin diagram
- Rely on neutral performance of Belle II
- Target:$\mathcal{B}$ and polarization
- Belle II ~190 fb^{-1} data
  - ✓ Continuum and peaking background (similar final states)
  - ✓ 6D fit for signal yield







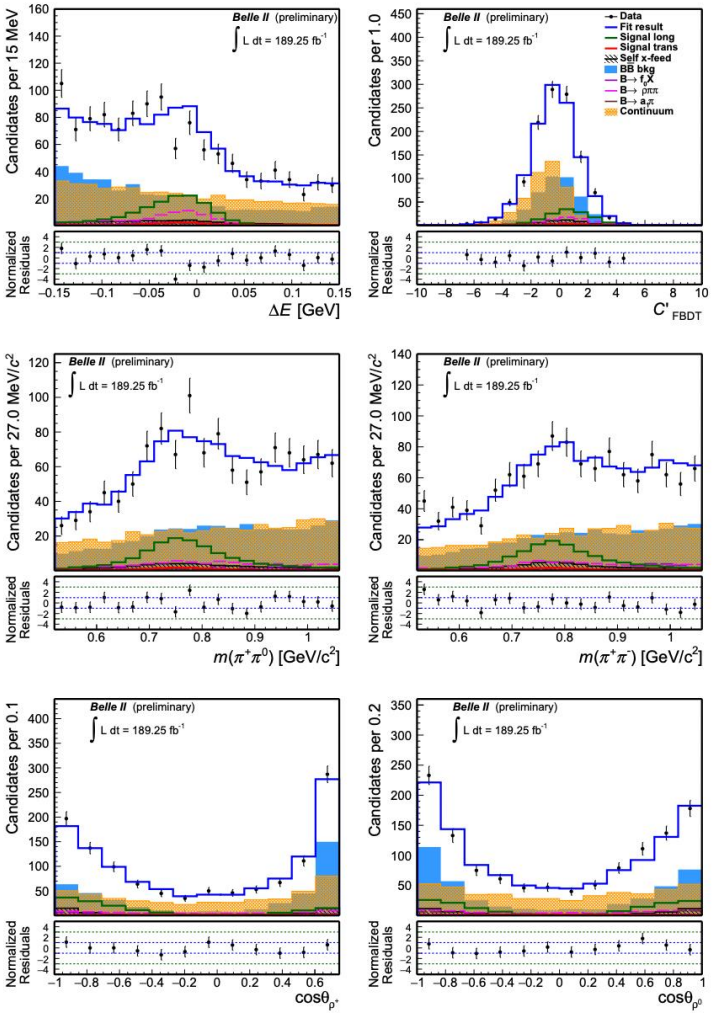
771 M **383 M** **197 M**

α/ϕ_2 @ $B^+ \to \rho^+\rho^0$

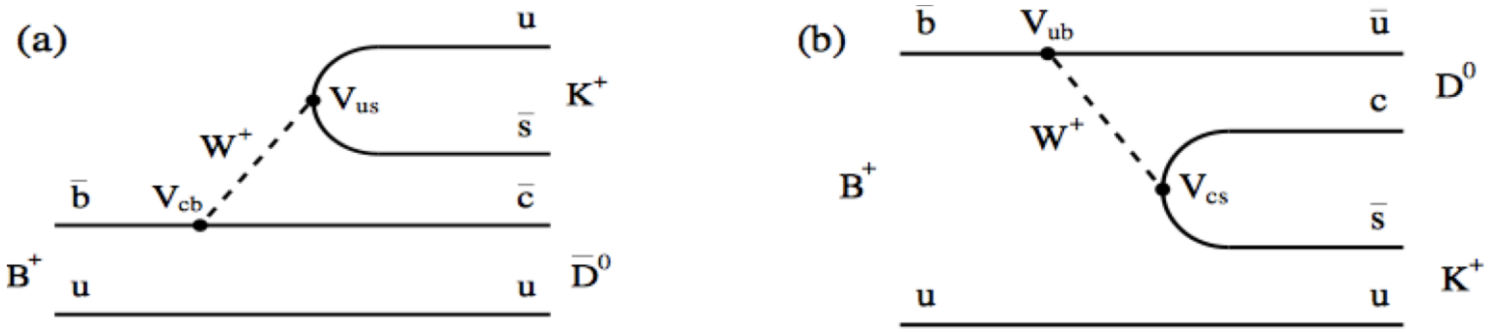
arXiv:2206.12362

- Rely on neutral performance
- Target: $\mathcal{B}$, $\mathcal{A}_{CP}$ and polarization
- Belle II ~190 fb^{-1} data
  - ✓ Continuum and peaking background (similar final states)
  - ✓ 6D fit for signal yield
- Belle II results: systematic dominated

	Values
Belle	$\mathcal{B} = (23.2^{+2.2}_{-2.1} \pm 2.7) \times 10^{-6}$
197M $B\bar{B}$	$f_L = 0.943^{+0.035}_{-0.033} \pm 0.027$
	$\mathcal{A}_{CP} = -0.069 \pm 0.068 \pm 0.060$
BaBar	$\mathcal{B} = (23.7 \pm 1.4 \pm 1.4) \times 10^{-6}$
465M $B\bar{B}$	$f_L = 0.950 \pm 0.015 \pm 0.006$
	$\mathcal{A}_{CP} = -0.054 \pm 0.055 \pm 0.010$

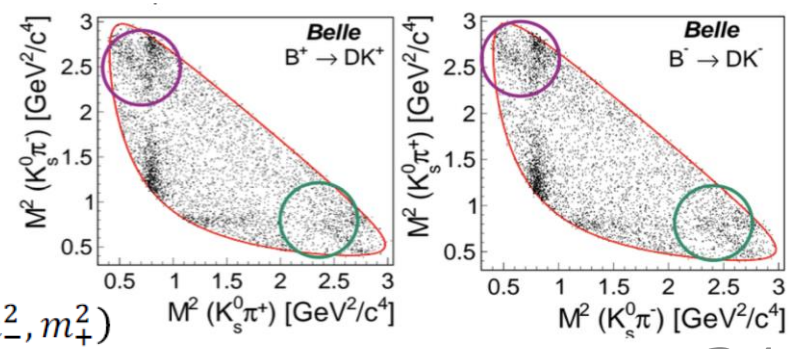


γ/ϕ_3 @ $B^+ \to D^0 (K^0_S h^+ h^-) K^+$



- **Decay rate depends on interference of two amplitudes**
  - ✓ **Sensitive to ϕ_3.**
- **ϕ_3 with r_B^{DK} and δ_B^{DK} manifests itself in the difference of dalitz distributions between B^+ and B^-**

$$\begin{aligned} m_+^2 &= m_{K^0\pi^+}^2 \\ m_-^2 &= m_{K^0\pi^-}^2 \end{aligned}$$

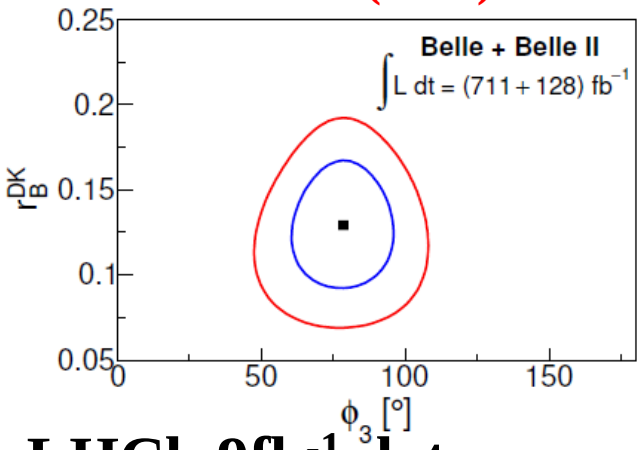


$$A_{B^+}(m_-^2, m_+^2) \propto A_{\bar{D}}(m_-^2, m_+^2) + r_B^{DK} e^{i(\delta_B^{DK} - \phi_3)} A_D(m_-^2, m_+^2)$$

γ/ϕ_3 @ $B^+ \to D^0 (K^0_S h^+ h^-) K^+$

JHEP 02 (2022) 063

- Belle + Belle II combined analysis
  - ✓ NN-based MVA for K^0_S
  - ✓ Additional statistics form h = π and K
  - ✓ Improved background rejection
- Yield increase by 40% for Belle and additional 17% statistics from Belle II



- Results @ Belle + Belle II

$$\phi_3 = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)^\circ,$$
$$r_B^{DK} = 0.129 \pm 0.024 \pm 0.001 \pm 0.002,$$
$$\delta_B^{DK} = (124.8 \pm 12.9 \pm 0.5 \pm 1.7)^\circ,$$

- LHCb 9fb^{-1} data

$$\phi_3 = \left(68.7^{+5.2}_{-5.1}\right)^\circ$$
$$r_B = 0.0904^{+0.0077}_{-0.0075}$$
$$\delta_B = \left(118.3^{+5.5}_{-5.6}\right)^\circ$$

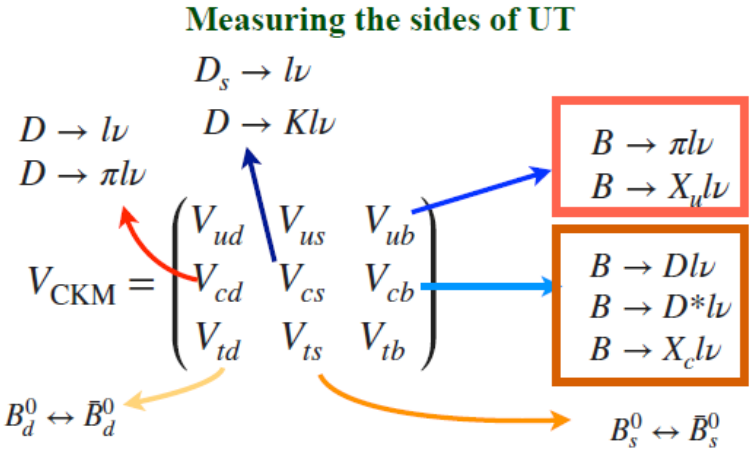
JHEP 02 (2021) 169

- Future Belle II: 1747 @ 839 fb^{-1} ~75 K @ 36 ab^{-1}
- Futrre LHCb: 13600 @ 9 fb^{-1} → ~75 K @ 50 fb^{-1}
- similar-sized event samples

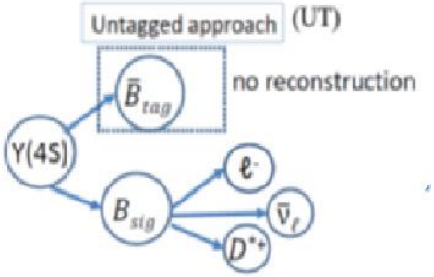
$|V_{cb}|$ and $|V_{ub}|$ measurement

- Extract $|V_{cb}|$ and $|V_{ub}|$
  - ✓ Inclusive: sum over all possible hadronic final states B → $X_{c/u}l\nu$
  - ✓ Exclusive: specific final states $B \to D/D^*/\pi l\nu$
  - ✓ Theoretically and experimentally independent
- Limitations
  - ✓ Inclusive: higher order perturbative and non-terms in HQE
  - ✓ Exclusive: hadronic form factors
- Complementary measurements: important

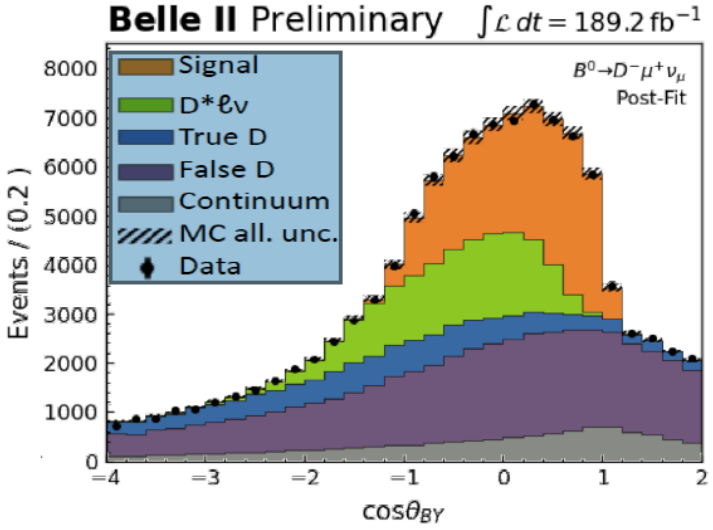
Type	V_{cb}	V_{ub}
Inclusive	$(42.19 \pm 0.78) \times 10^{-3}$	$(4.19 \pm 0.17) \times 10^{-3}$
Exclusive	$(39.10 \pm 0.50) \times 10^{-3}$	$(3.51 \pm 0.12) \times 10^{-3}$
Deviation	3.3σ	3.3σ



Untagged $|V_{cb}|$

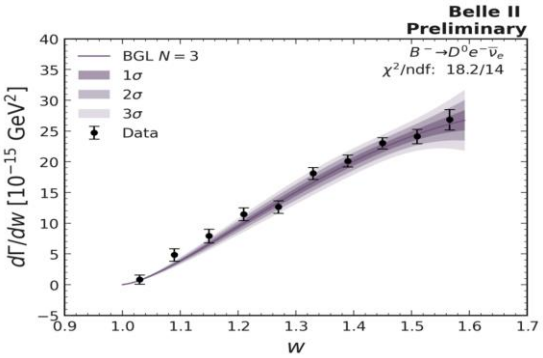


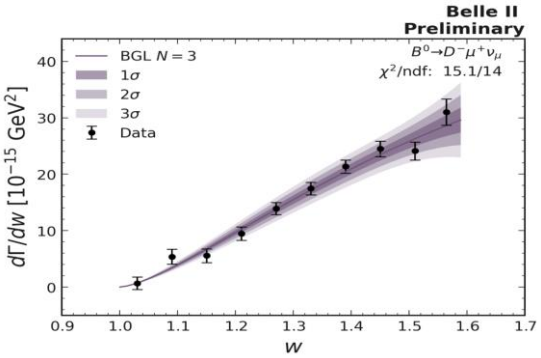
- **Event reconstruction**
  - ✓ $B^0 \to D^-(K^+\pi^-\pi^-)l^+\nu_l$
  - ✓ $B^+ \to \bar{D}^0(K^+\pi^-)l^+\nu_l$



Signal extraction with cosine angle distribution between B and (D*l*) system

- **D recoil momentum q^2 calculation**
  - ✓ **q^2 by inferring diamond-frame approach**
  - ✓ **Transfer q $\to$ $w \equiv (m_B^2 + m_D^2 - q^2)/2m_B m_D$**
  - ✓ **Split w distribution into 10 bins**





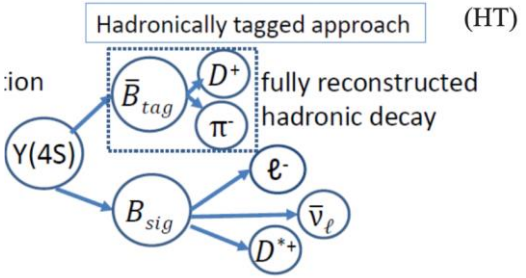
$$\frac{d\Gamma(B \to D\ell\nu_\ell)}{dw} = \frac{G_F^2 m_D^3}{48\pi^3}(m_B + m_D)^2(w^2-1)^{3/2}\eta_{EW}^2\mathcal{G}^2(w)|V_{cb}|^2$$

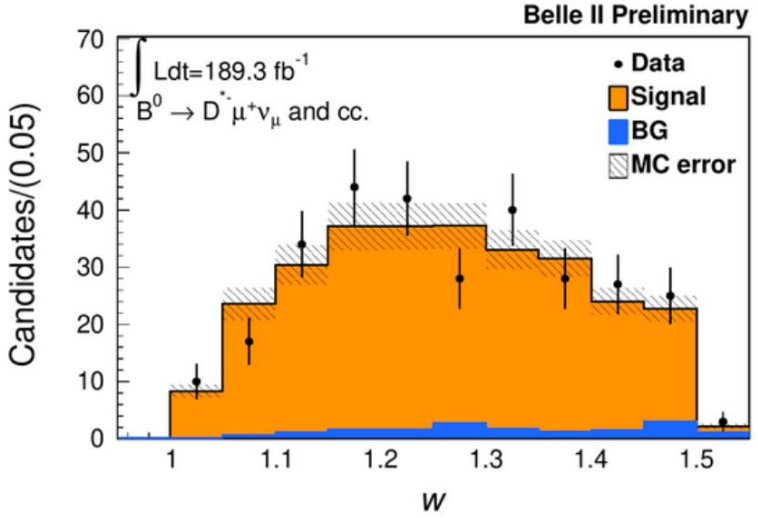
$$\eta_{EW}|V_{cb}| = (38.53 \pm 1.15) \times 10^{-3}$$

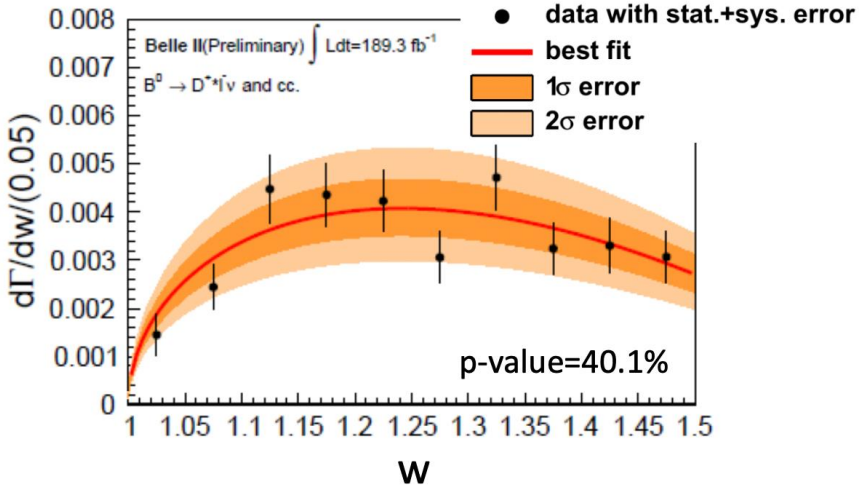
consistent with exclusive world average

tagged $|V_{cb}|$

- **Event reconstruction**
  - ✓ $B^0 \to D^{*-} l^+ \nu_l$
  - ✓ $D^{*-} \to \bar{D}^0 \pi^-$ $\bar{D}^0 \to K^+ \pi^-$ aa
  - ✓ Challenging: low momentum pion from D^{*-}
  - ✓ FEI using HT algorithm to tag B



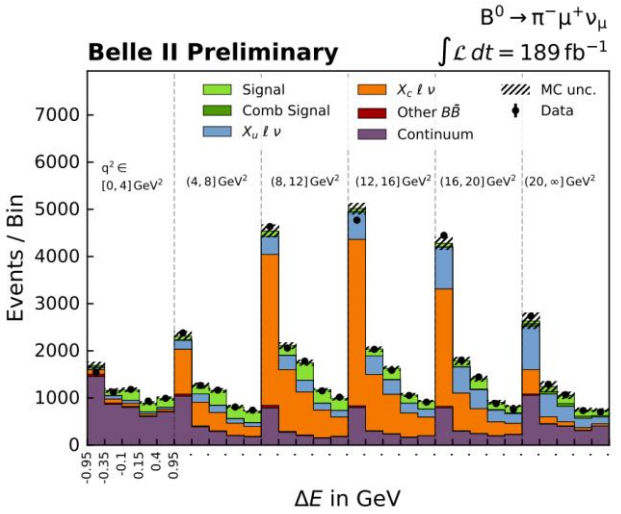


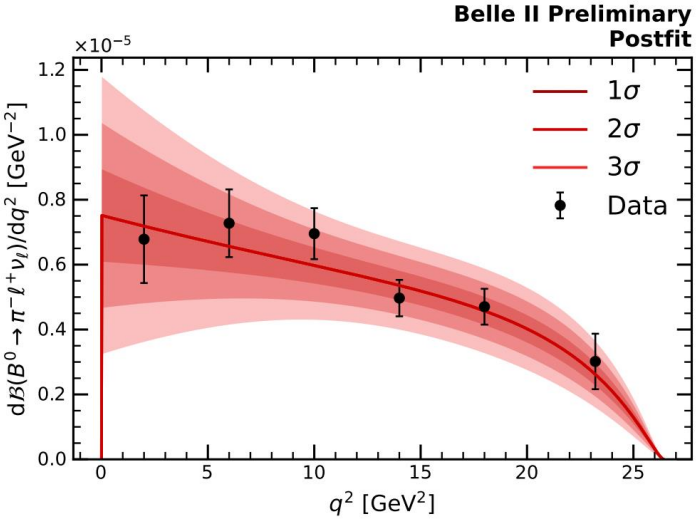


$$\frac{d\Gamma(B \to D\ell\nu_\ell)}{dw} = \frac{G_F^2 m_D^3}{48\pi^3}(m_B + m_D)^2 (w^2-1)^{3/2} \eta_{EW}^2 \mathcal{G}^2(w) |V_{cb}|^2 \quad \eta_{EW}|V_{cb}| = (38.2 \pm 2.8) \times 10^{-3}$$

Untagged $|V_{ub}|$

- **Event reconstruction**
  - ✓ $B \to \pi l \nu (B^0 \to \pi^{\pm} l^{\mp} \nu)$
  - ✓ Everything else including the other B is included as rest of events to determine p_ν
  - ✓ Signal yield by M_{bc} and ΔE distribution





$$\frac{d\Gamma(B \to \pi l \nu)}{dq^2} = \frac{G_F^2 |V_{ub}|^2}{24\pi^3} |p_\pi|^3 |f_+(q^2)|^2$$

$M(l\bar{l})$ — form factor

consistent with exclusive world average

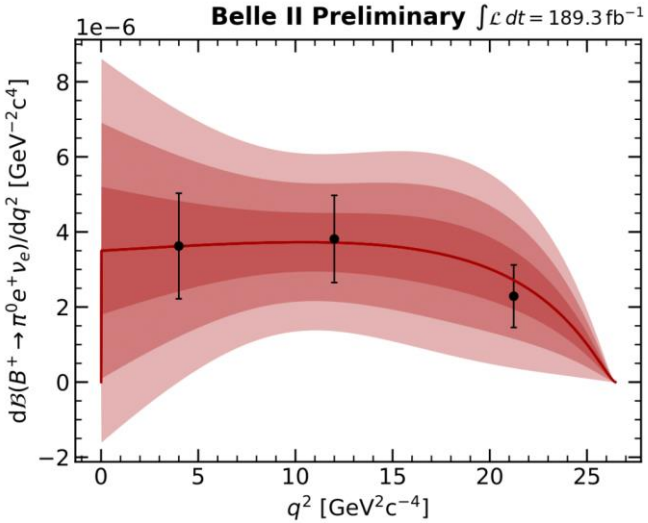
$$|V_{ub}|_{B^0 \to \pi^- l^+ \nu_l} = (3.54 \pm 0.12_{\mathrm{stat.}} \pm 0.15_{\mathrm{syst.}} \pm 0.16_{\mathrm{theo.}}) \times 10^{-3}$$

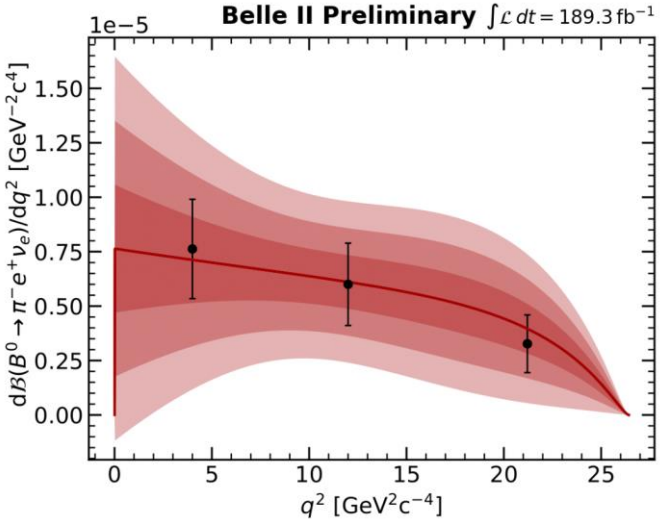
Tagged $|V_{ub}|$

- **Event reconstruction**
  - ✓ $B \to \pi e \nu$
  - ✓ $B^0 \to \pi^+ e^- \bar{\nu}_e \; B^+ \to \pi^0 e^+ \nu_e)$
  - ✓ **FEI using HT algorithm to tag B**

$$\frac{d\Gamma(B \to \pi l \nu)}{dq^2} = \frac{G_F^2 |V_{ub}|^2}{24\pi^3} |p_\pi|^3 |f_+(q^2)|^2$$

$M(l\bar{l})$ — form factor





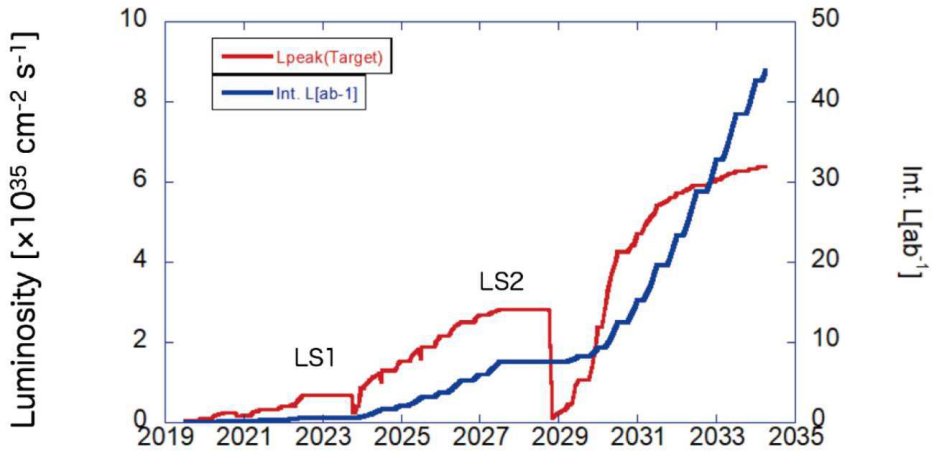
$$|V_{ub}| = (3.88 \pm 0.45) \times 10^{-3}$$

arXiv:2206.08102

consistent with exclusive world average

Prospects

- **The Belle II has taken 423 fb^{-1} of data, ~ equaling BaBar sample. Detector works well, many analysis in progress.**
- **Belle II results is directly competitive with previous B factories**
  - ✓ **Improvements in detector and trigger**
  - ✓ **Powerful analysis strategies**
  - ✓ **Fruitful results with early Belle II data**



Long shutdown #1

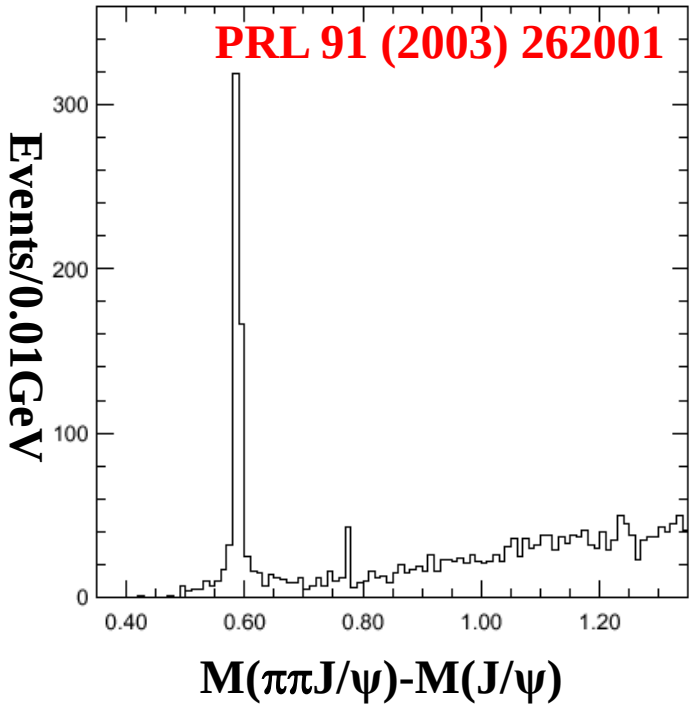
Detector upgrades:

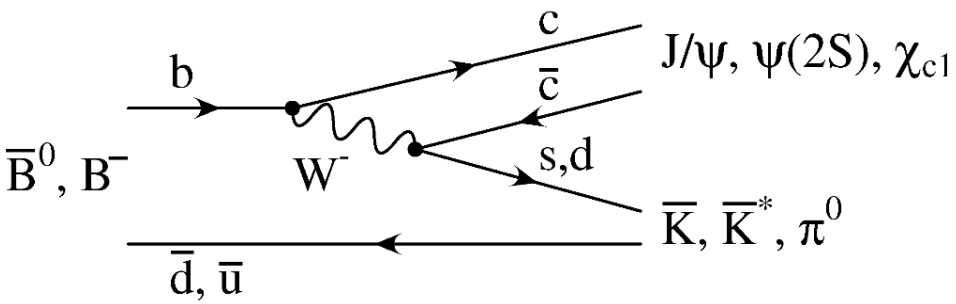
- *PXD (pixel) detector: complete 2nd layer*
- *TOP (particle ID) detector: exchange "conventional" PMTs for life-extended PMTs*
- *upgrade of back-end readout (COPPER-> PCIe40)*

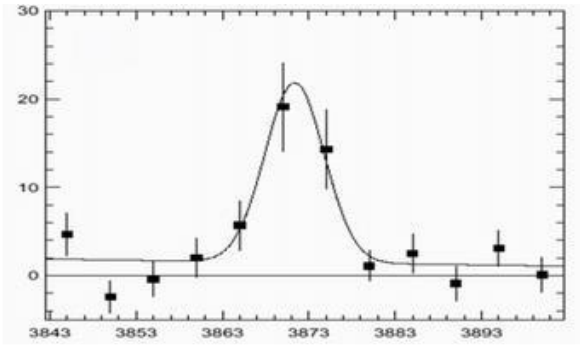
Accelerator upgrades:

- *shielding of QCS (final focusing) bellows*
- *additional neutron shielding*
- *installation of nonlinear collimator*
- *enlarged beampipe for HER injection*
- *pulse-by-pulse beam control for LINAC*

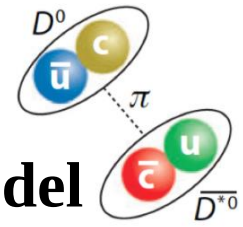
X(3872)







- **Strange X(3872)**
  - ✓ **Narrow, very close to DD* threshold**
  - ✓ **No place @ charmonium potential model**
- **Explanations of the nature**



D^0–$\overline{D^{*0}}$ "molecule"

Diquark–diantiquark