Quarkonium and Charm

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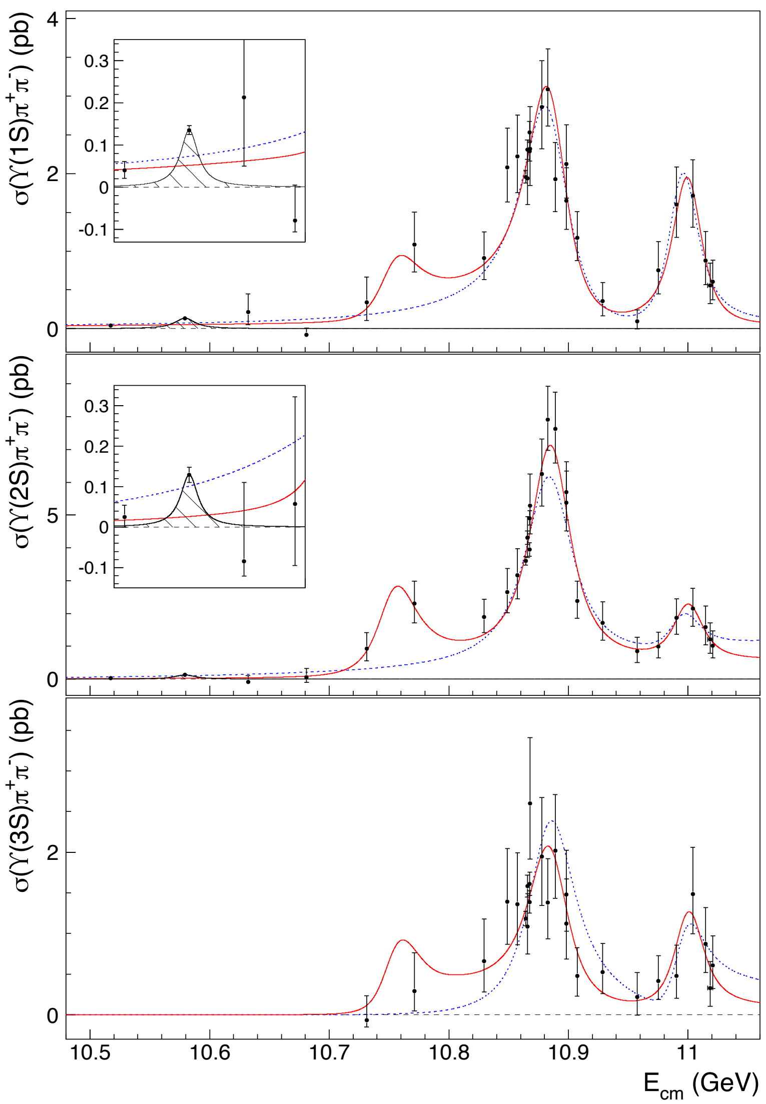
57th Rencontres de Moriond QCD - 03/27/23

Belle II

Intro

- heavy quarkonium to study non-perturbative QCD
- bottomonium states above $B\bar{B}$ have unexpected properties (e.g. $\Upsilon(10753)$)



JHEP10(2019)220

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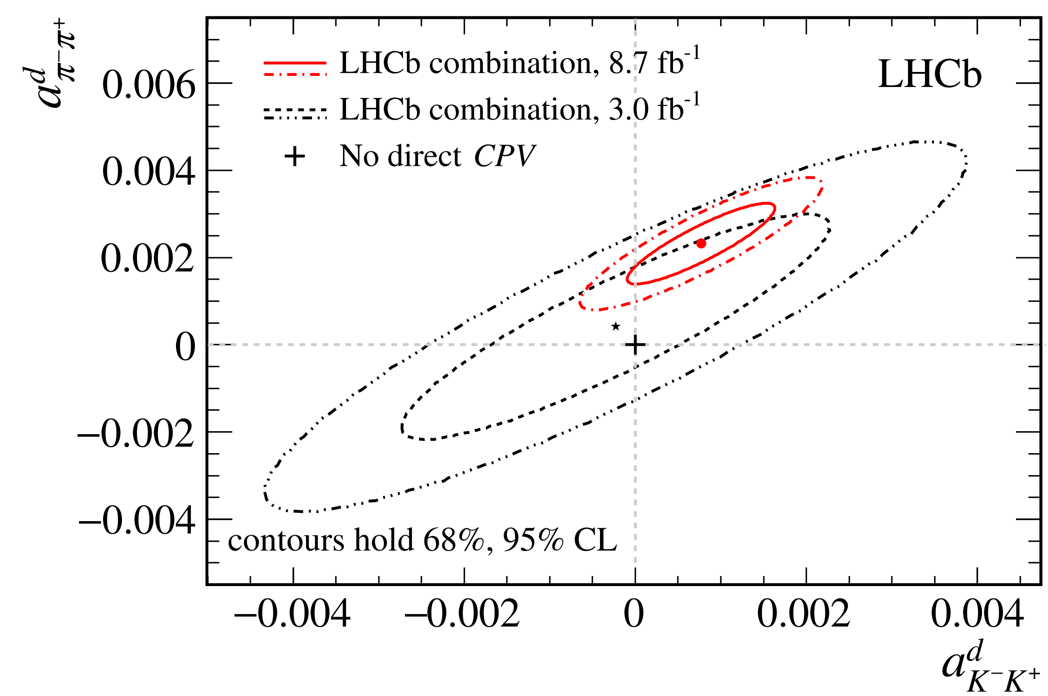
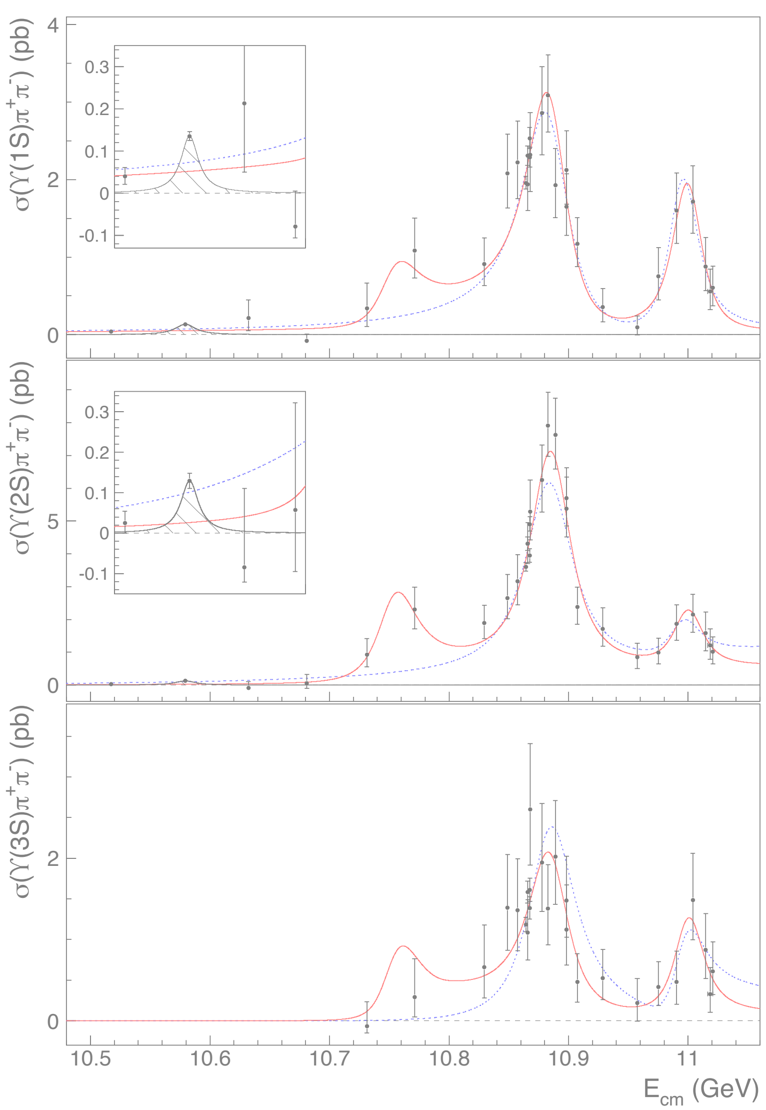
arXiv:2209.03179





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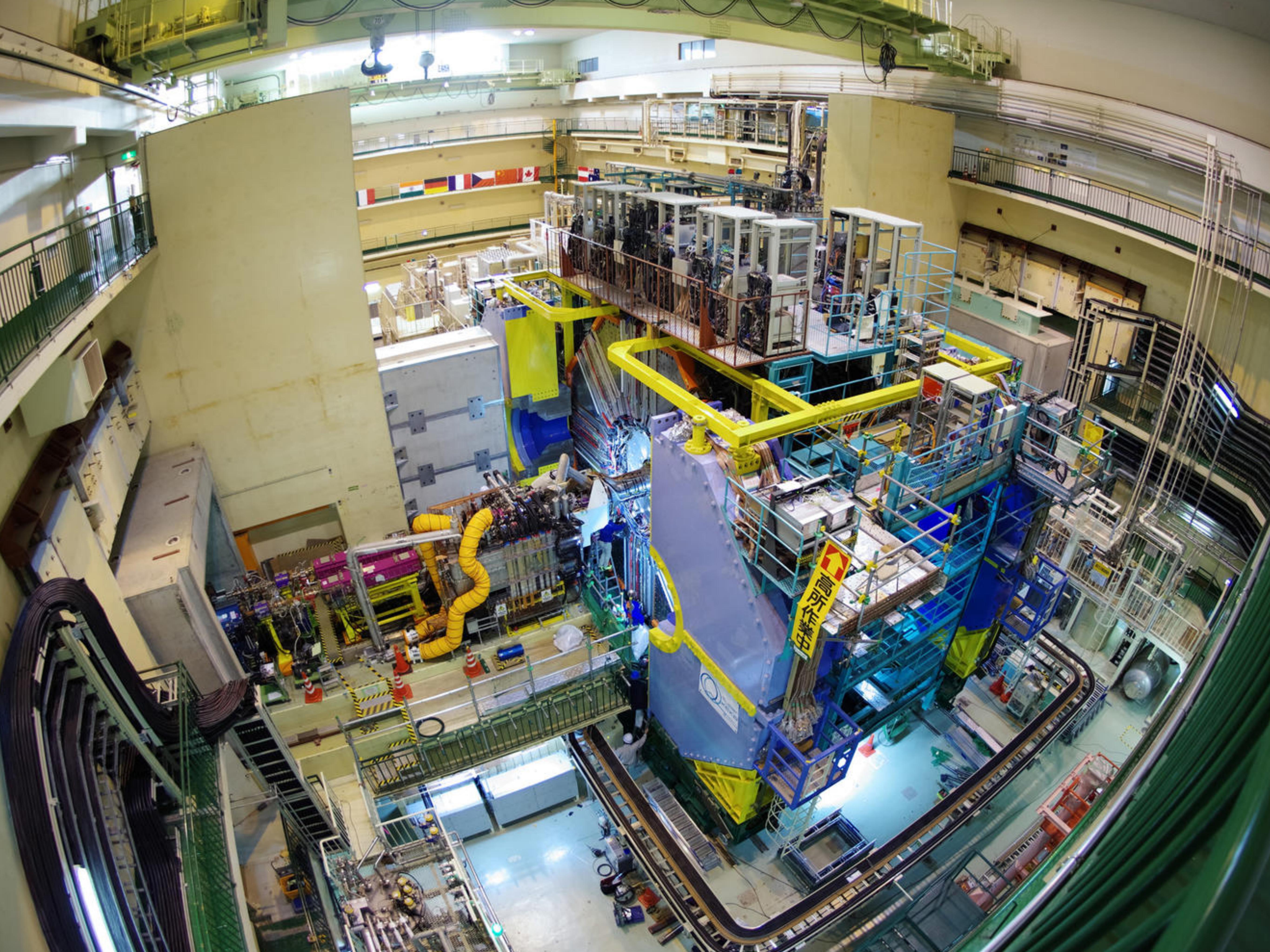
- charm is unique to search for CPV in up-type quark sector
- ongoing debate whether value is consistent with SM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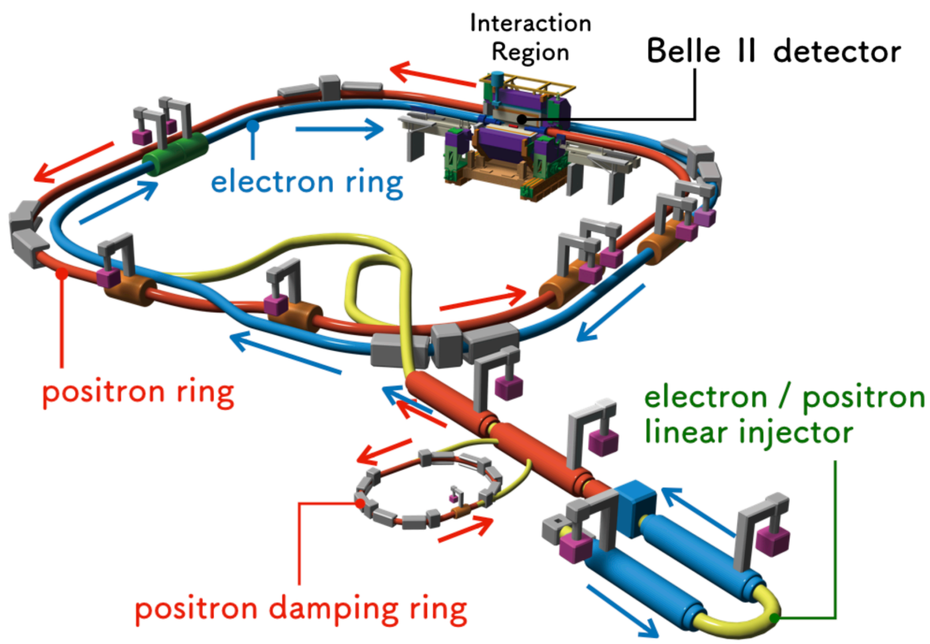
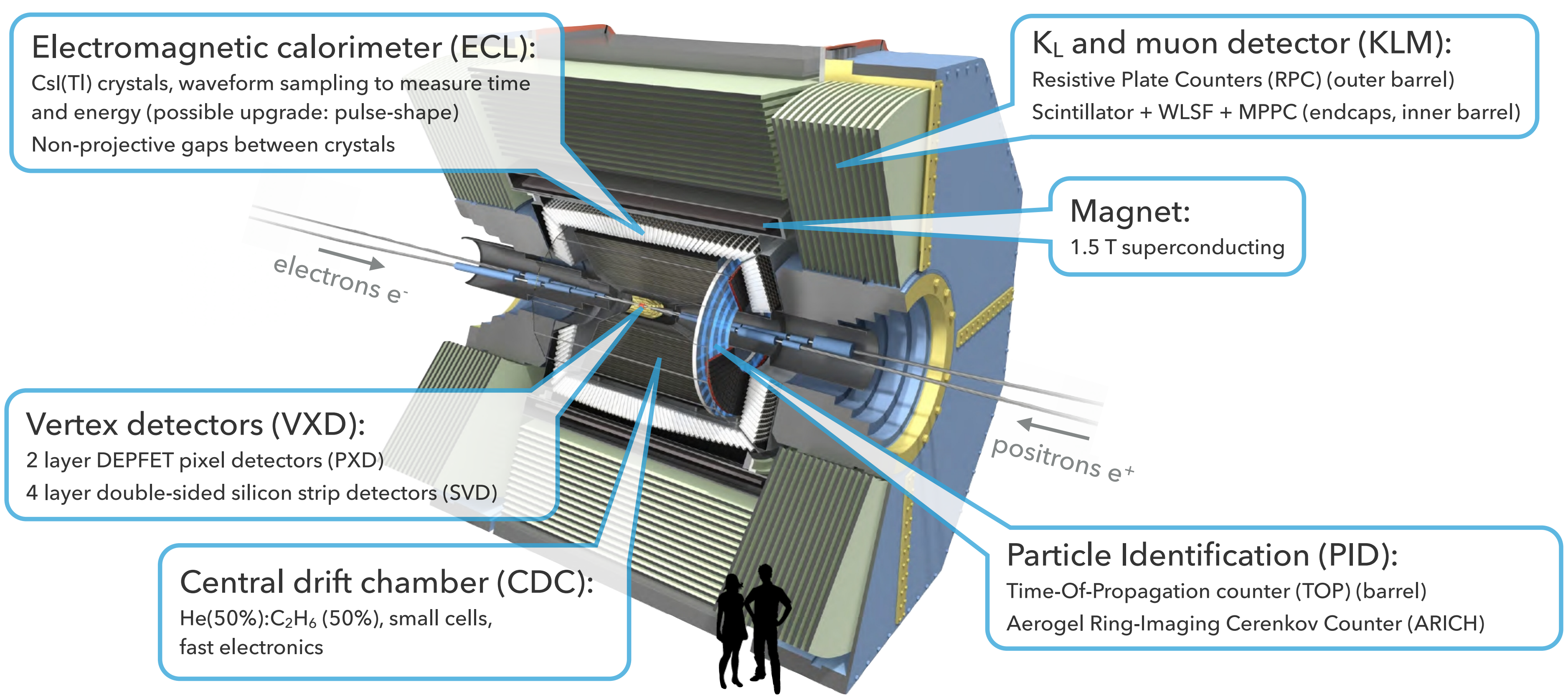
SuperKEKB and Belle II

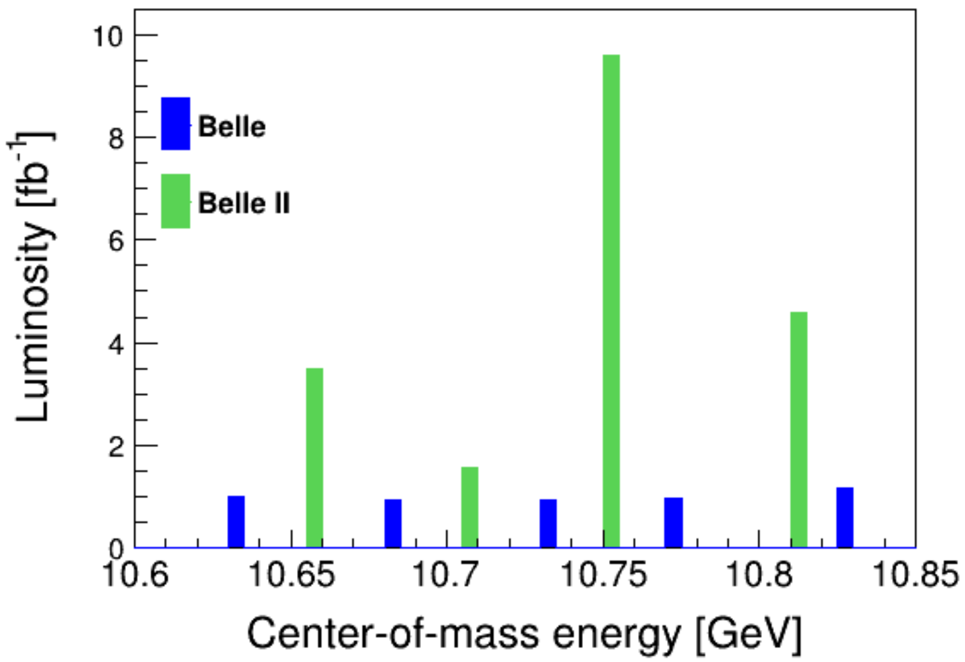


- *SuperKEKB*
  - asymmetric e^+e^- collider in Tsukuba, Japan
  - nano-beam interaction point
  - $\mathscr{L}$=4.7 × 10^{34}cm^{-2}s^{-1} (record)
  - tunable E_{cm} around $\Upsilon(4S)$ mass
- *Belle II*
  - 4π spectrometer with optimal vertexing, tracking, PID and calorimetry capabilities
  - 424fb^{-1} collected up to now
  - rich physics program: B and D physics, quarkonium, tau, low mass dark sector



SuperKEKB and Belle II

- collected data at four different E_{cm} above $\Upsilon(4S)$:
  - total of 20fb-1
  - unique data set to explore uncharted regions



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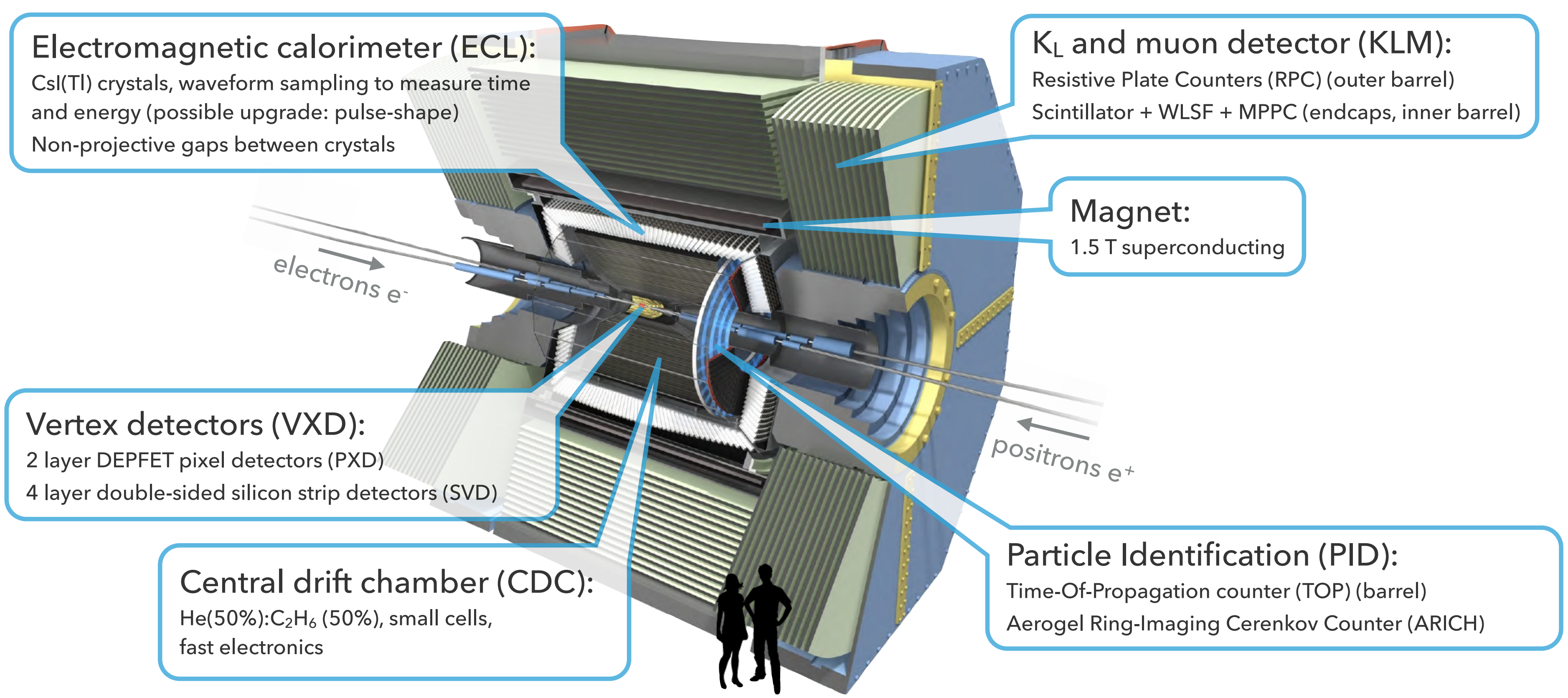
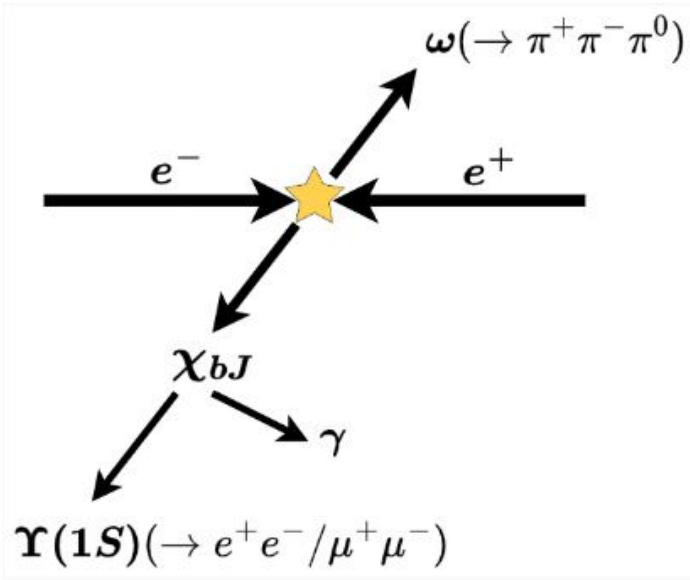


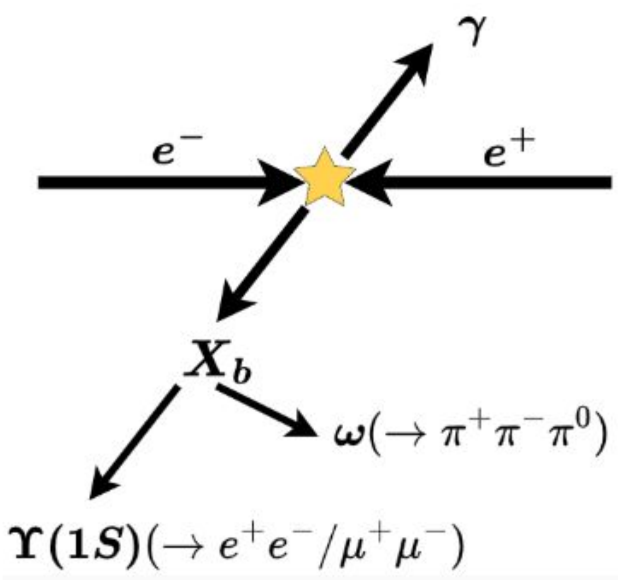
Observation of $e^+e^- \to \omega\chi_{bJ}(1P)$ and search for $X_b \to \omega\Upsilon(1S)$ at $\sqrt{s}$ near 10.75 GeV

PRL 130, 091902

Motivation

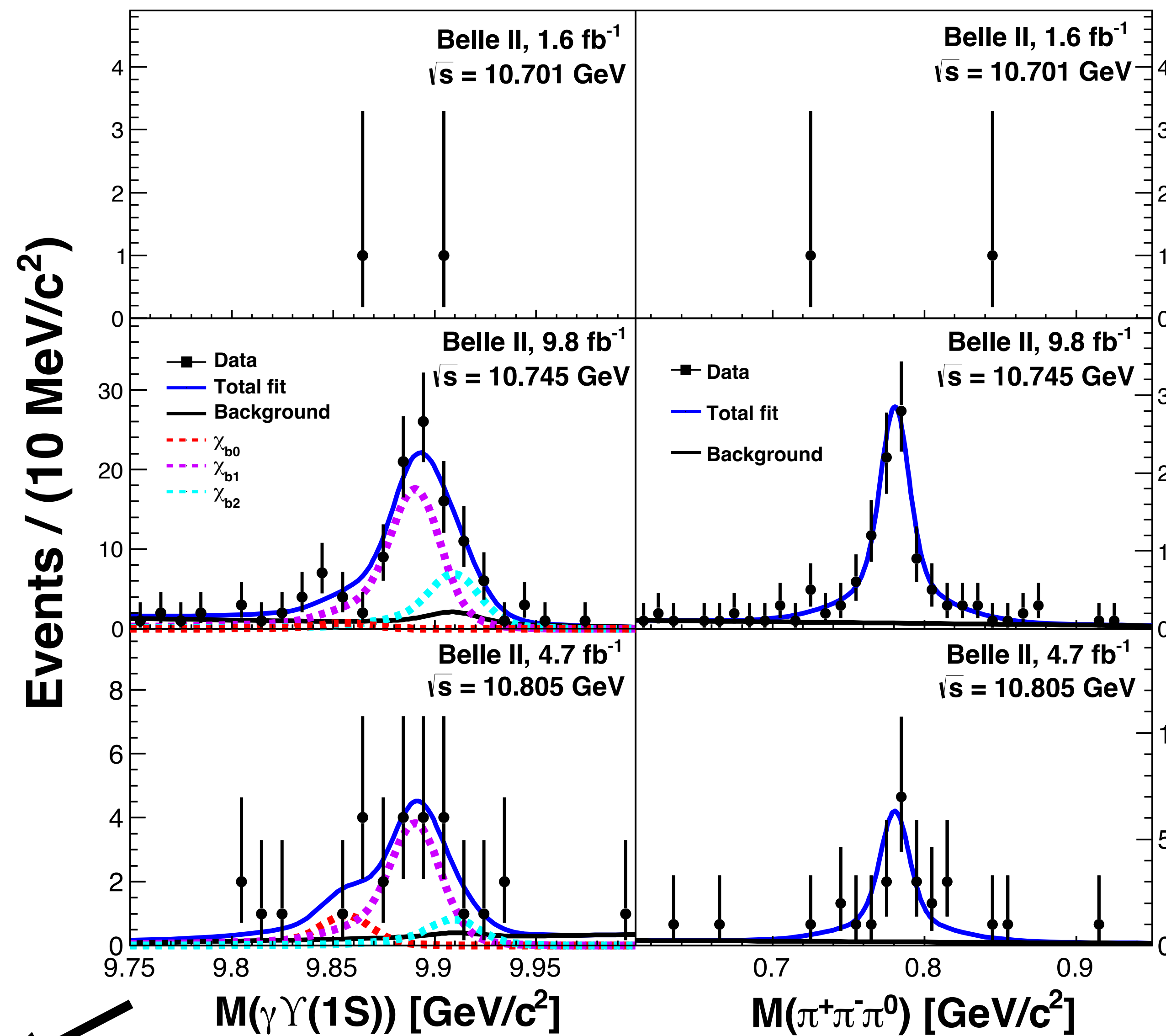
- study $\Upsilon(10753)$
  - not a conventional $b\bar{b}$ state
  - prediction for $\Upsilon(4S) - \Upsilon(3D)$ mixing :
    - $\mathscr{B}[\Upsilon(10753) \to \omega\chi_{bJ}(1P)] \sim 10^{-3}$
    - *(PRD 104,034036)*
- search for X_b
  - analog of $X(3872)$?
    - BESIII: $Y(4220) \to \pi\pi J/\psi, \gamma X(3872), \omega\chi_{c0}(1P)$
    - (*PRD 99, 091103*)
- same final state for both studies:
  - events with at least 4 tracks
  - exclusive final state -> low background

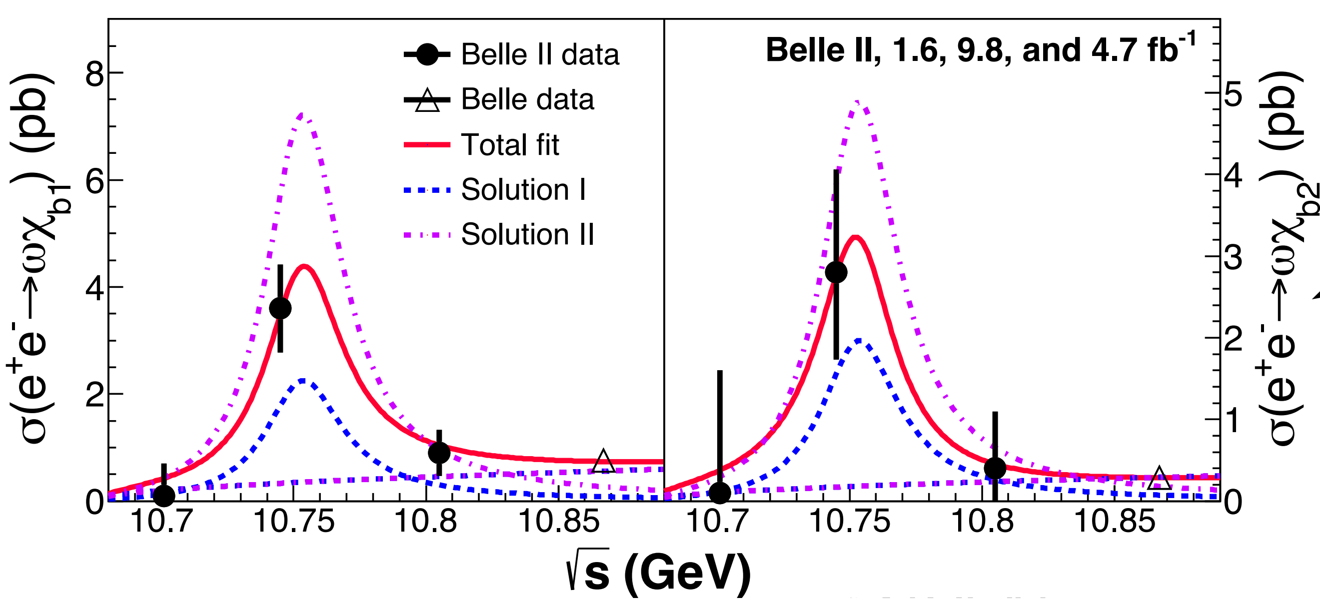




Results

- study $\Upsilon(10753)$
  - 2D fit to $M(\gamma\Upsilon(1S))$ vs. $M(\pi^+\pi^-\pi^0)$
    - 11σ (4.5σ) at 10.745 (10.805) GeV
  - Born cross section from signal yields

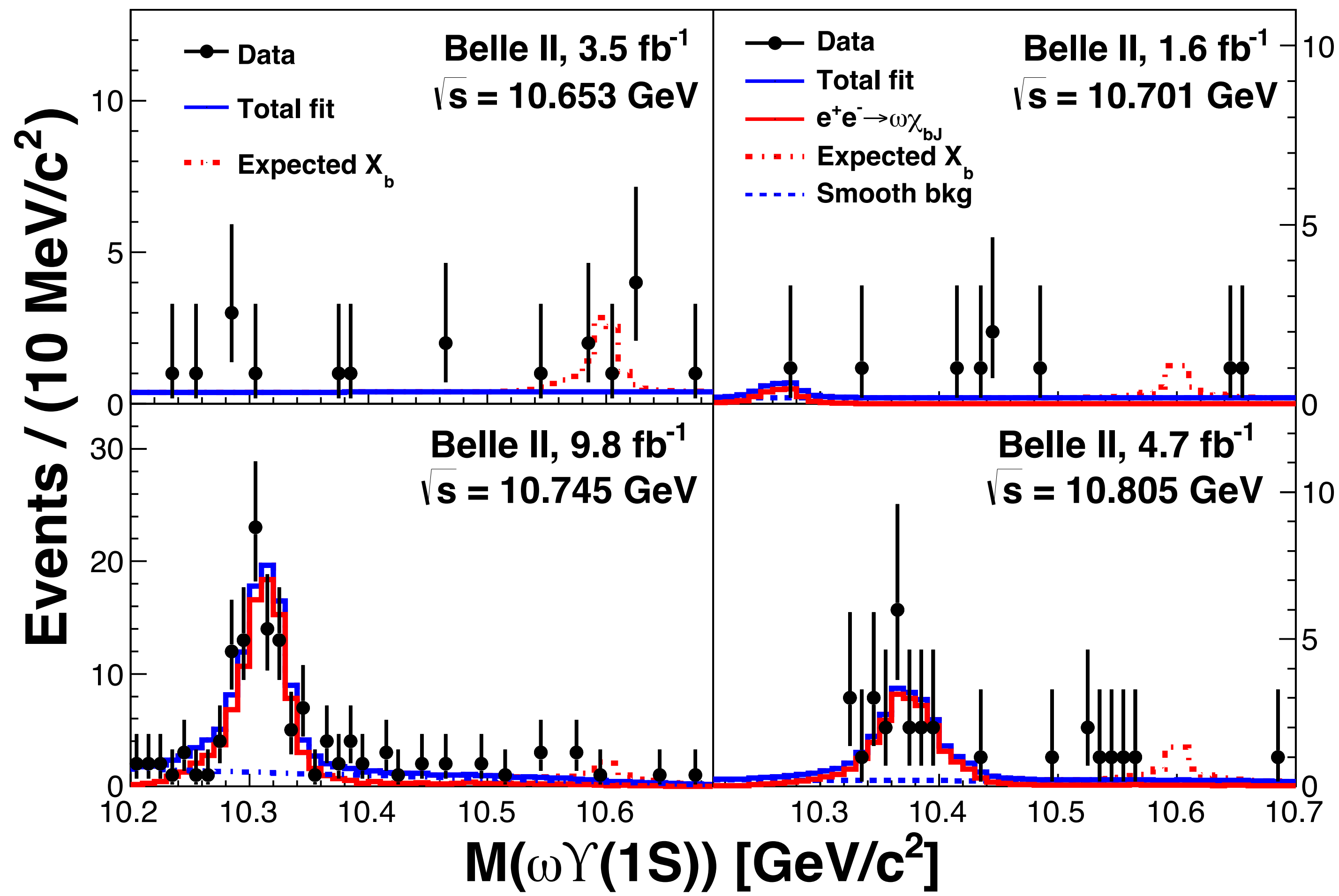




first observation of $\Upsilon(10753) \to \omega\chi_{bJ}(1P)$!

Results

- search for X_b
  - search for resonances in $M(\omega\Upsilon(1S))$
  - reflection from $\Upsilon(10753) \to \omega\chi_{bJ}(1P)$
  - no evidence for signal
    - compute upper limit on σ_{X_b}



$\sqrt{s}$ (GeV/c^2)	M_{X_b} (GeV/c^2)	$\sigma^{UL}_{X_b}$ (pb)
10.653	10.59	0.55
10.701	10.45	0.84
10.745	10.45	0.14
10.805	10.53	0.37

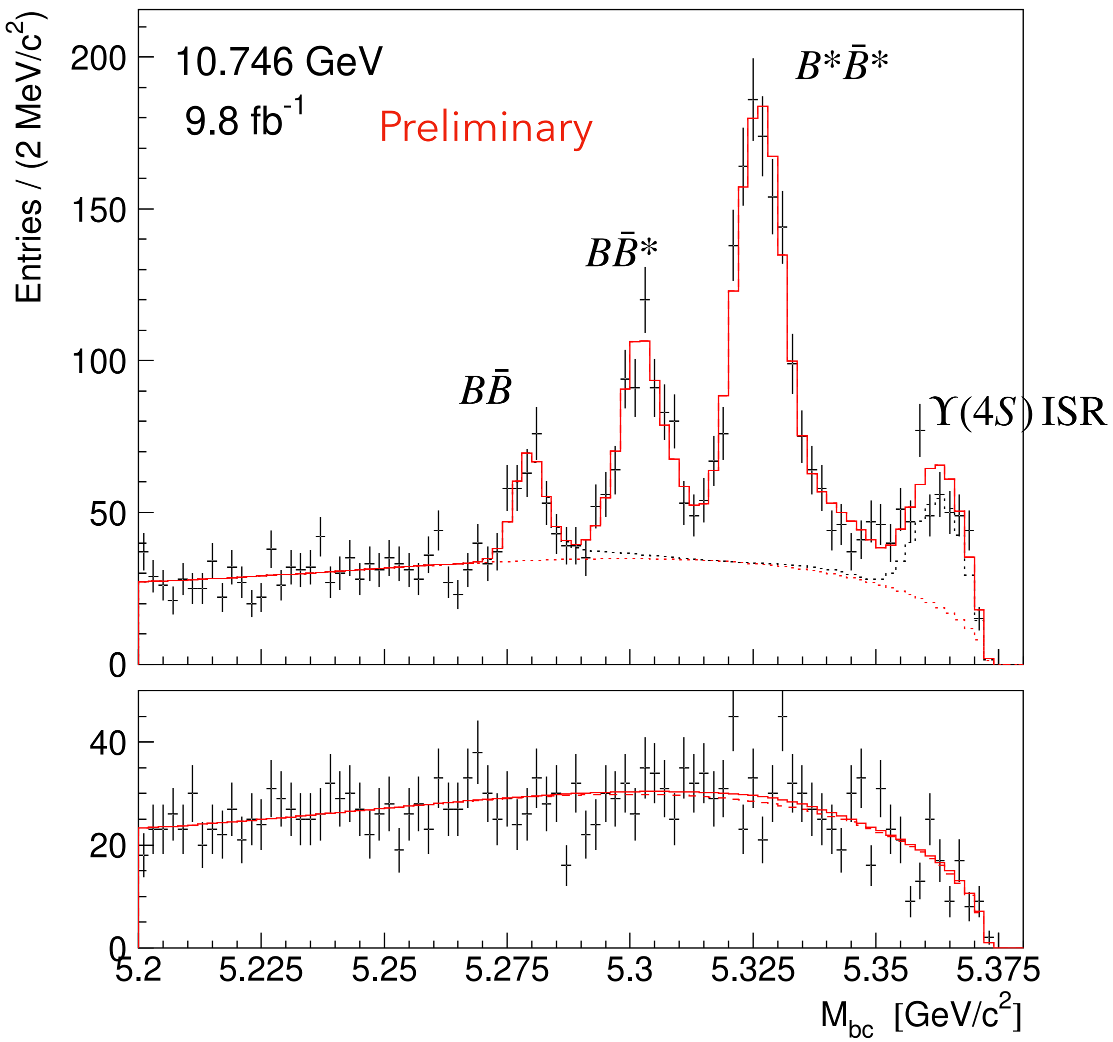
NEW for Moriond!

Measurement of the energy dependence of the $e^+e^- \to B\bar{B}, B\bar{B}^*$ and $B^*\bar{B}^*$ cross sections

Motivation

NEW for Moriond!

- further investigate heavy bottomonium
  - $\Upsilon(10753)$ also observed in fits to $e^+e^- \to b\bar{b}$ cross section
  - need more scan points to improve understanding
- method
  - fully reconstruct one B in hadronic decays
  - identify different signals with $M_{\rm bc}$



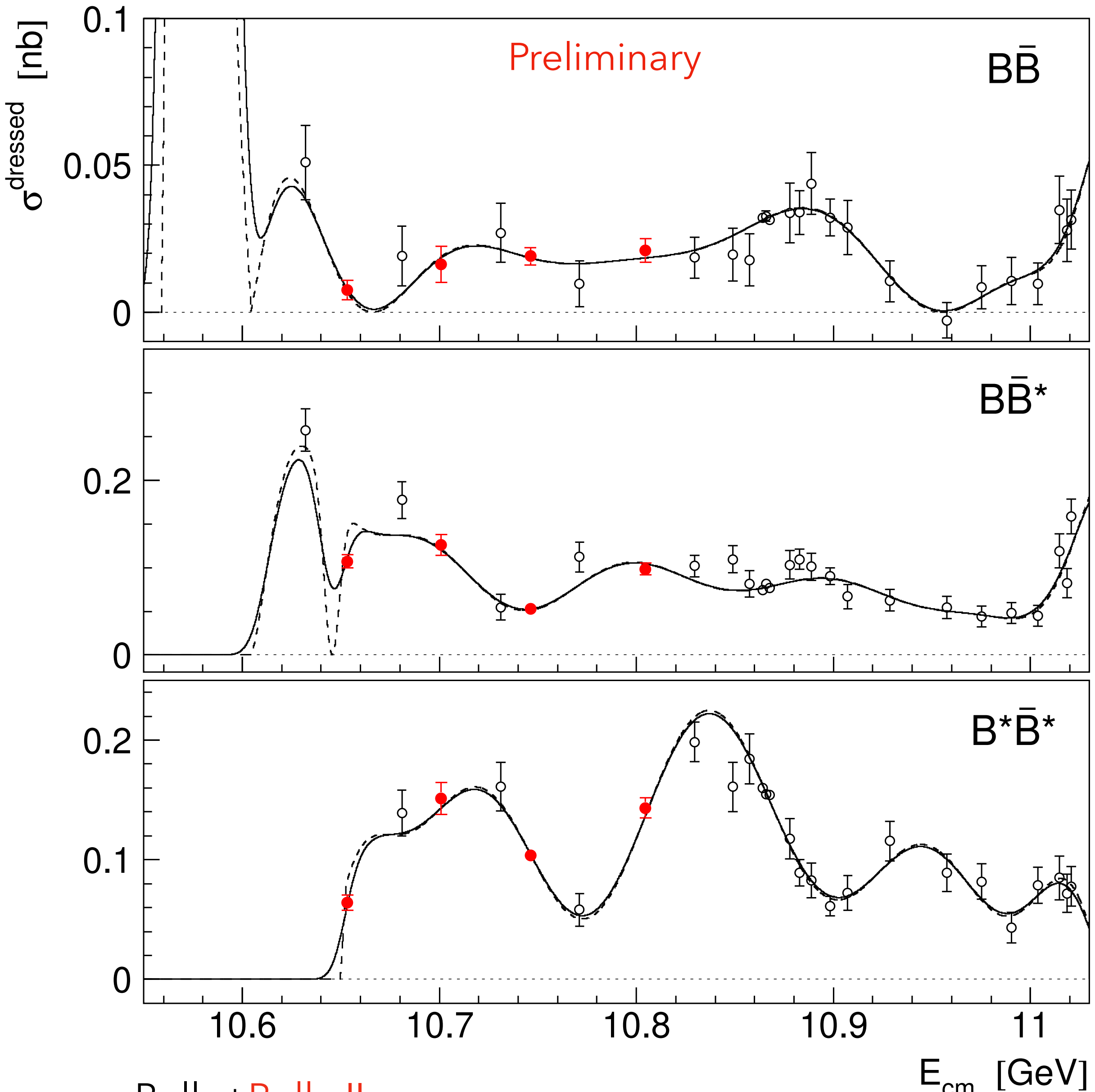
$$M_{\rm bc} = \sqrt{(E_{\rm cm}/2)^2 - p_B^2}$$

Invariant mass of the B meson, where the energy has been replaced with half the $E_{\rm cm}$

Results

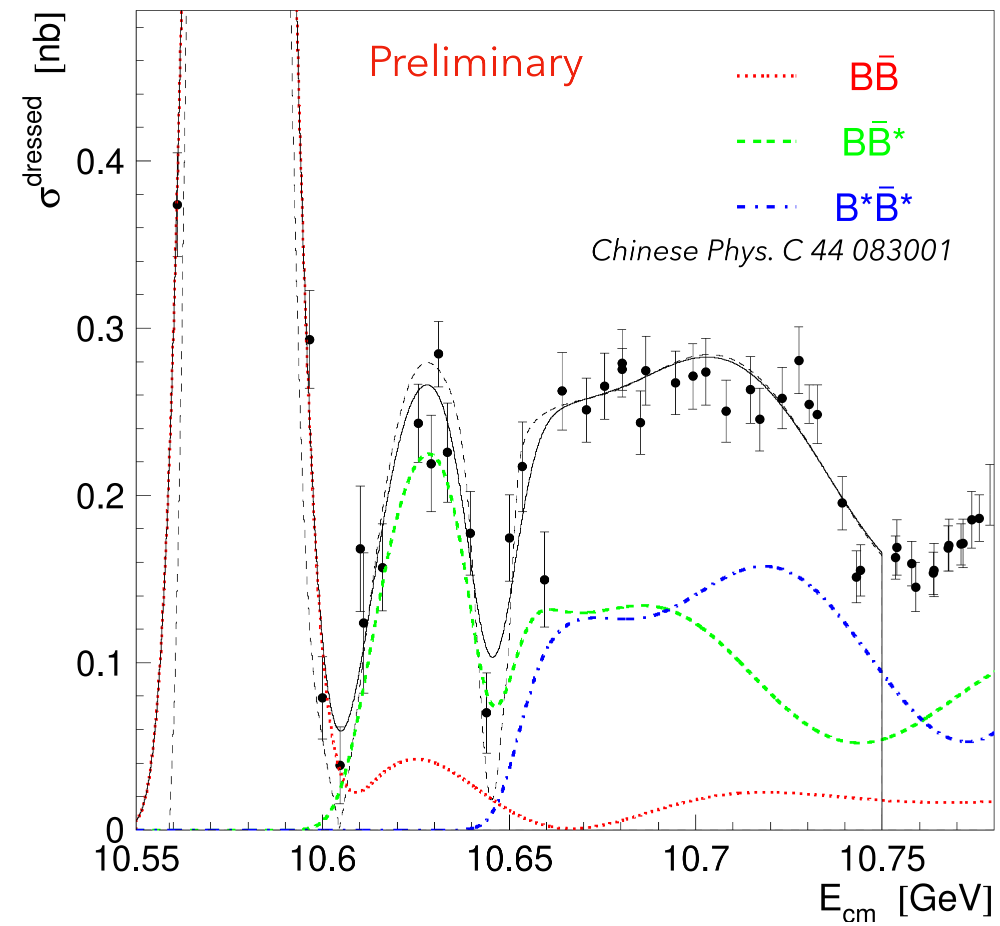
NEW for Moriond!

exclusive cross-section



Belle+Belle II

total cross-section

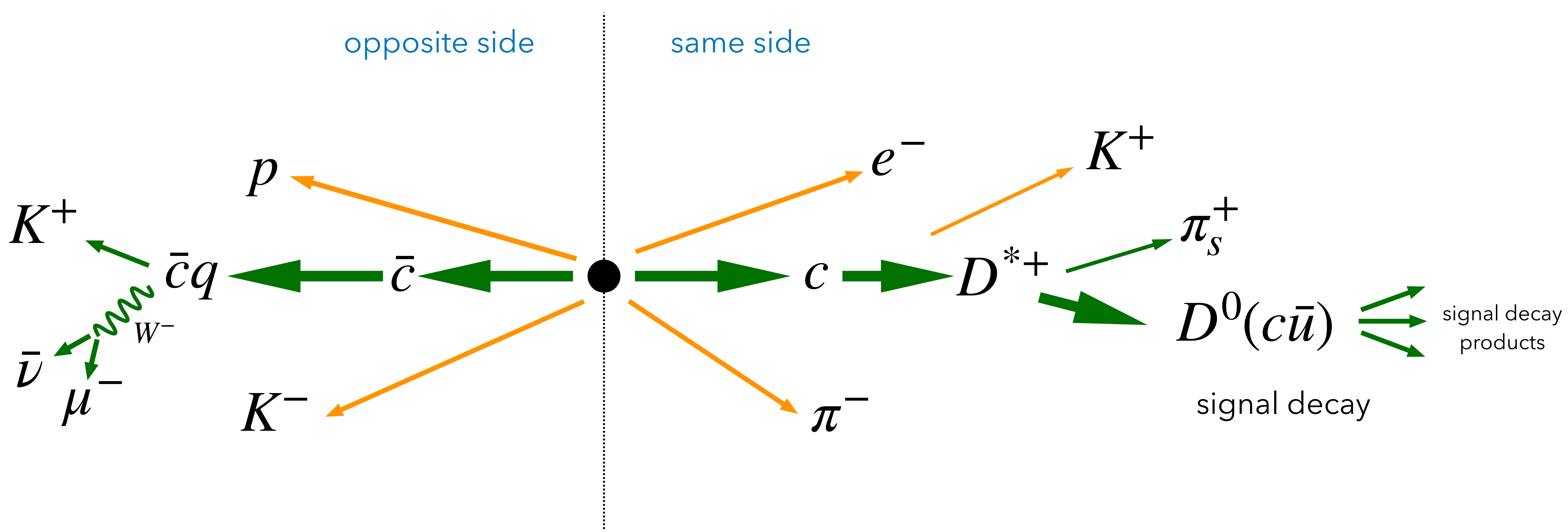


- simultaneous fit to exclusive and total cross sections
- combine Belle I + II

sharp increase at $B^*\bar{B}^*$ threshold hints at possible resonance

What about charm?

A charm event is different



- $e^+e^- \rightarrow$ two charm hadrons + fragmentation
  - no entanglement, inaccessible strong phase
- one of main ingredients to any CPV/mixing measurement is **flavor tagging**
  - standard approach: **exclusive reconstruction** of strong decay $D^{*+} \rightarrow D^0\pi_s^+$

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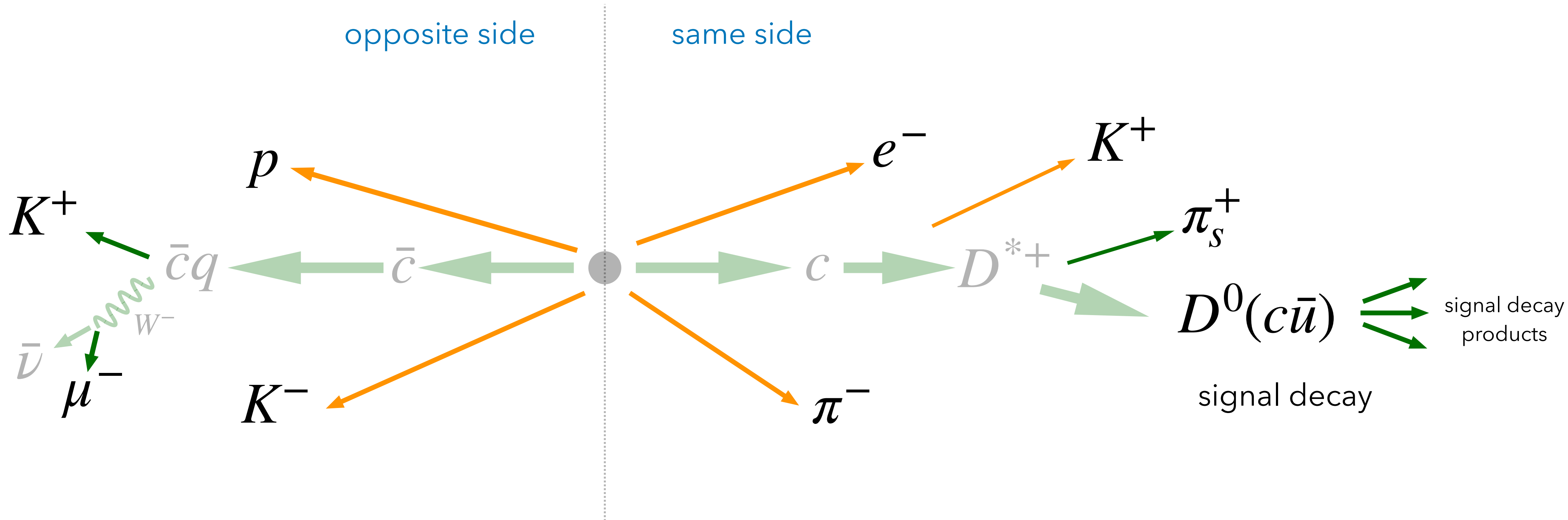

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- one of main ingredients to any CPV/mixing measurement is **flavor tagging**
  - standard approach: **exclusive reconstruction** of strong decay $D^{*+} \rightarrow D^0\pi_s^+$
  - a new **more inclusive** method is desirable to exploit correlation between signal flavor and charge of tagging particles

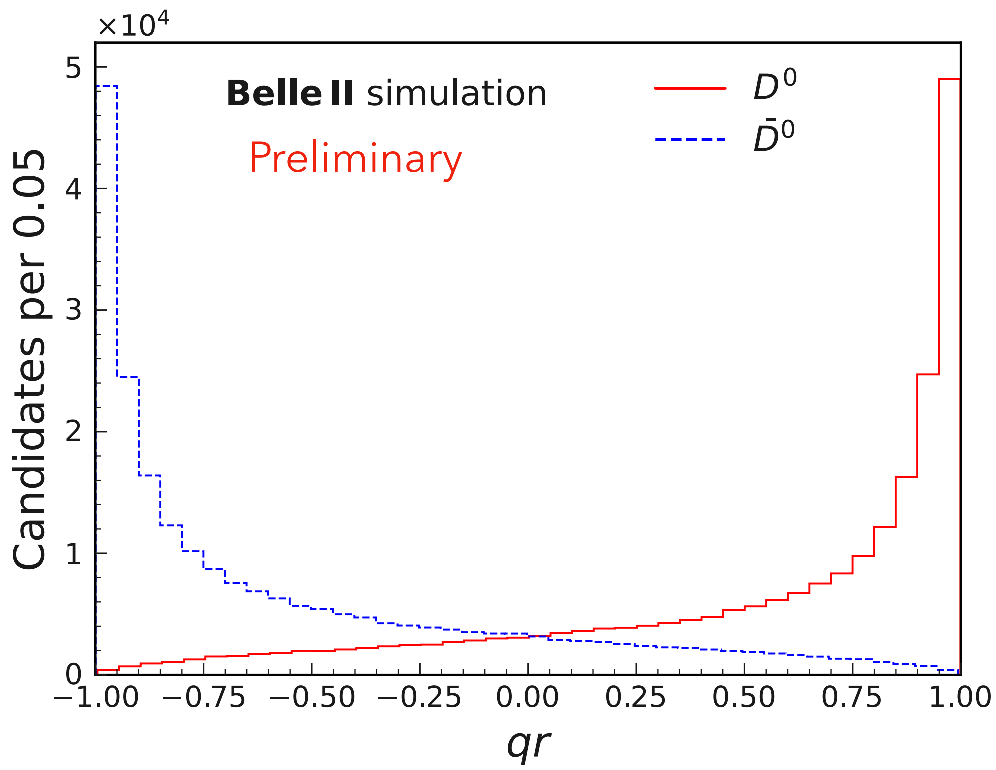
first usage of opposite-tagging in charm decays

Novel method for the identification of neutral charmed mesons

The Charm Flavor Tagger (CFT)

NEW for Moriond!

- reconstruct particles most collinear with signal meson
- uses **kinematic features** (ΔR, recoiling mass) and **PID** of tagging particles
- based on BDT, **predicts** qr (tagging decision q and dilution r)
- trained using simulation and calibrated with Belle II data



q=+1 for D^0 and -1 for $\bar{D}^0$

r=1 perfect prediction, r=0 random guessing

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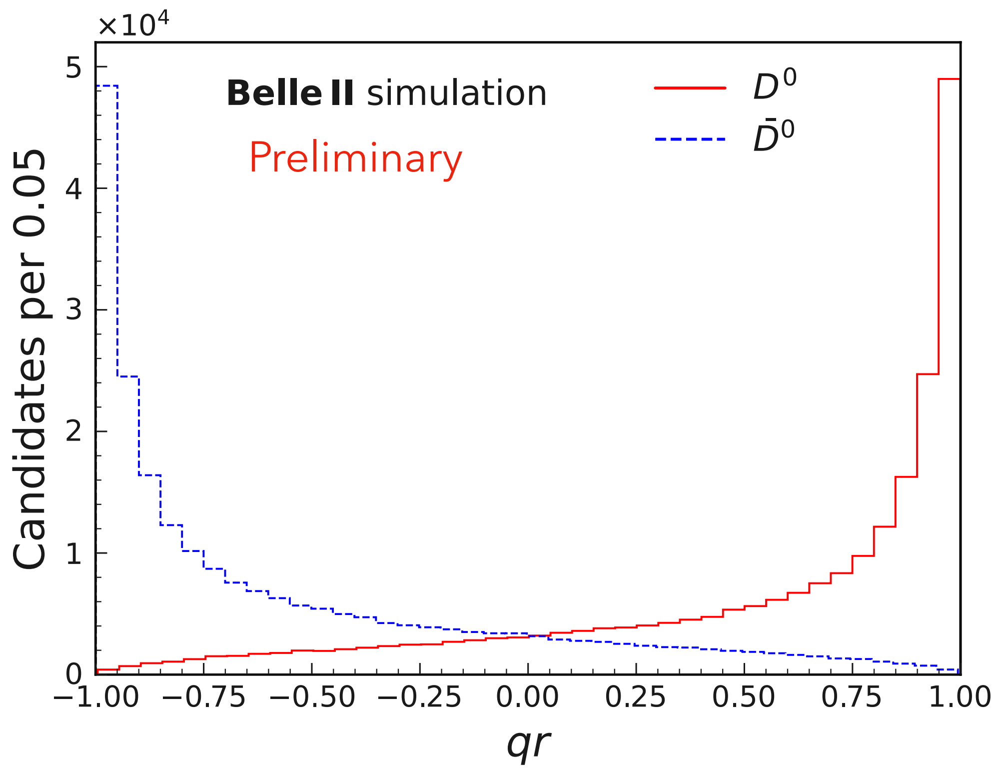
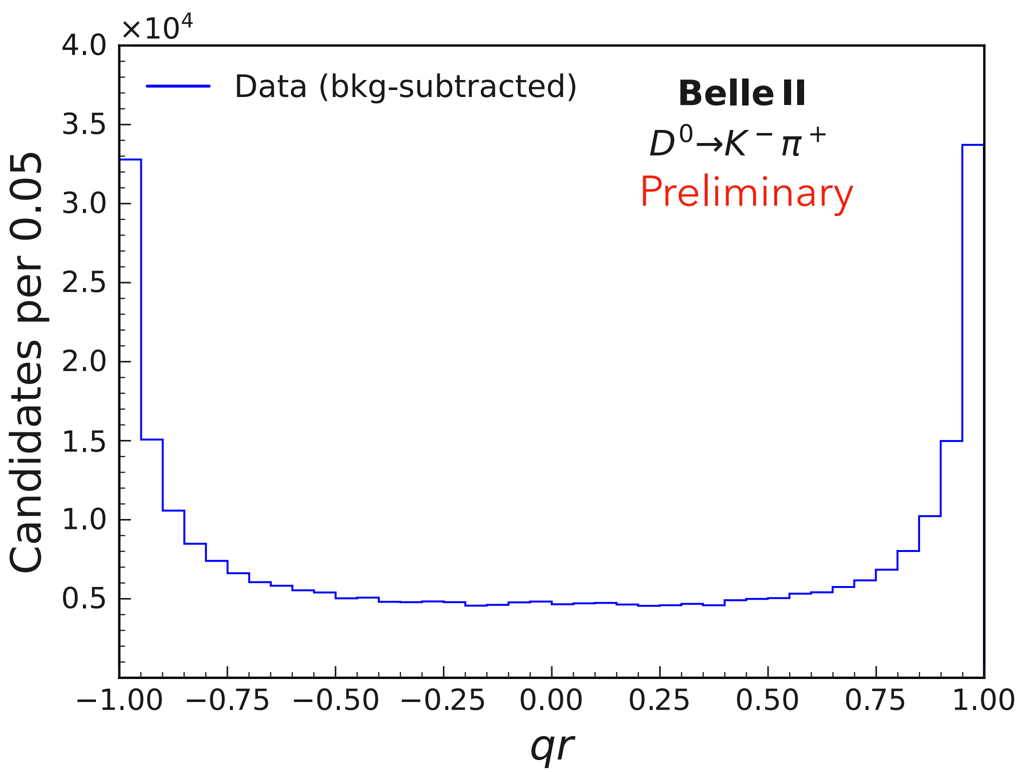




q=+1 for D^0 and -1 for $\bar{D}^0$

r=1 perfect prediction, r=0 random guessing

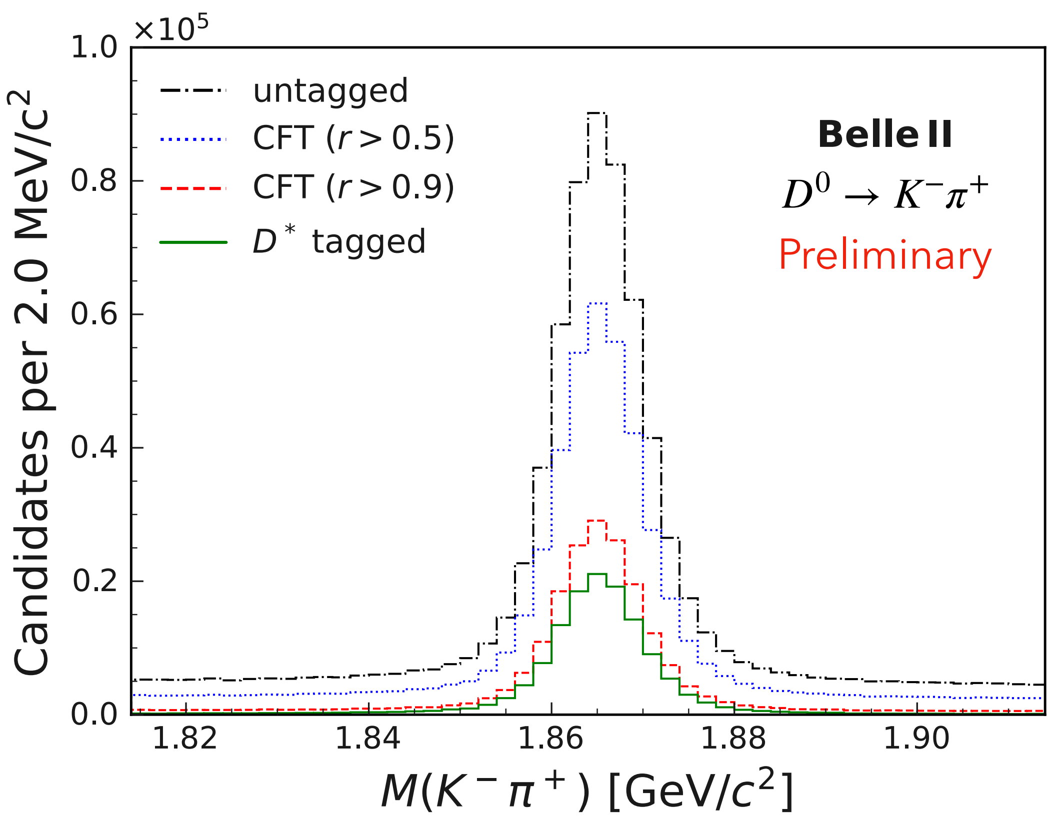
$$\epsilon_{\rm tag}^{\rm eff} = (47.91 \pm 0.07({\rm stat.}) \pm 0.51({\rm syst.}))\ \%$$

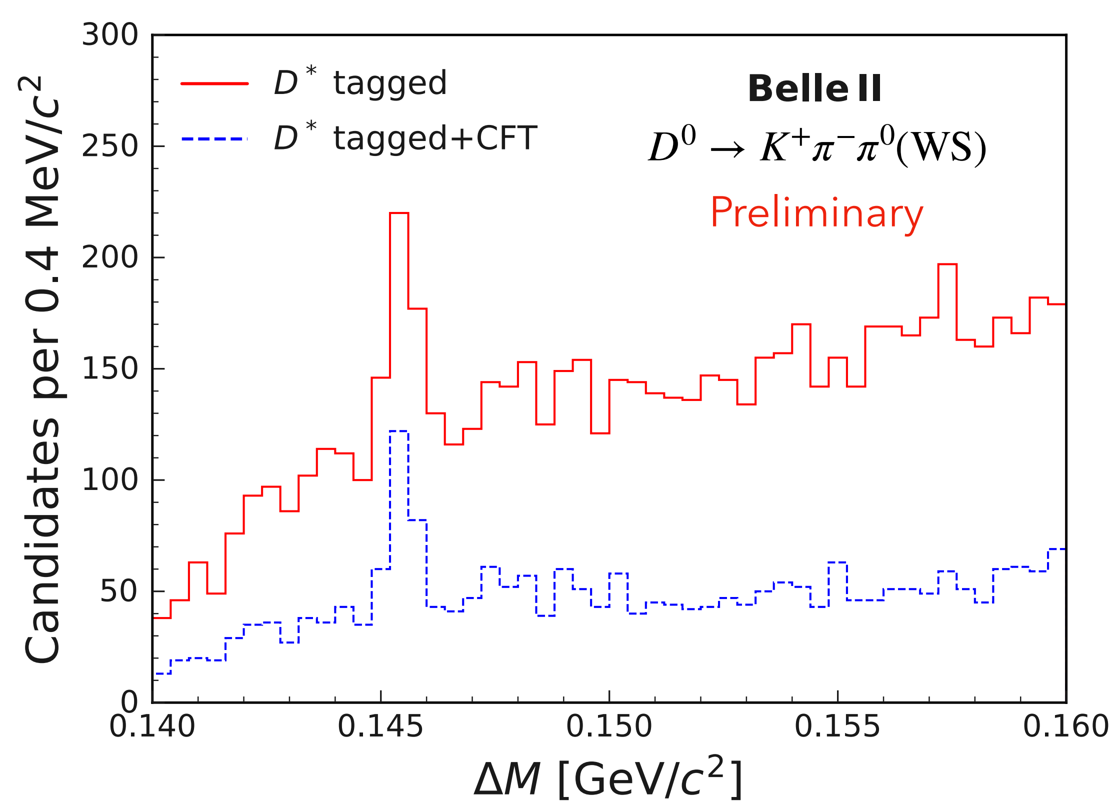
tagging power: $\epsilon_{\rm tag}^{\rm eff} = \epsilon_{\rm tag}\langle r^2 \rangle$

The Charm Flavor Tagger (CFT)

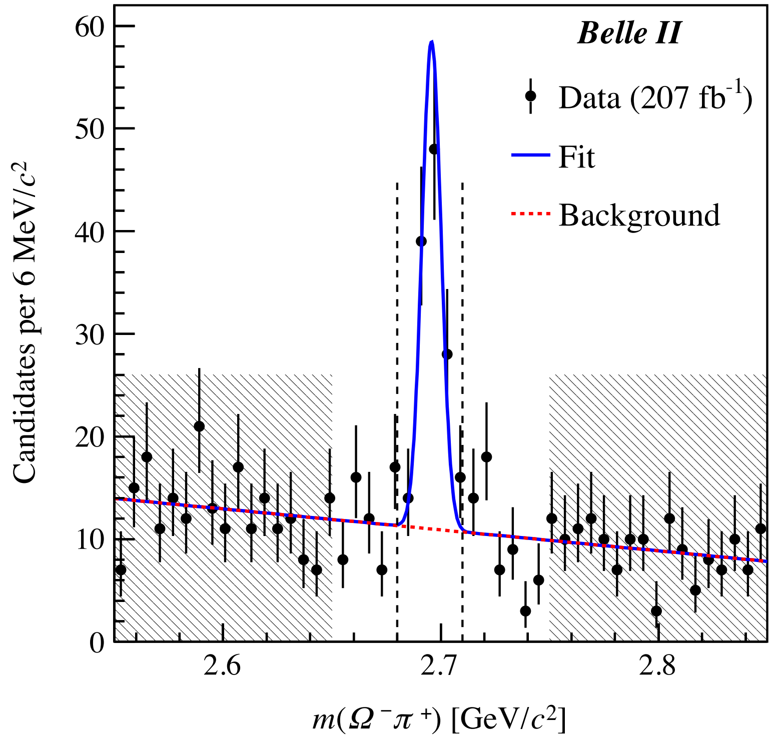
NEW for Moriond!

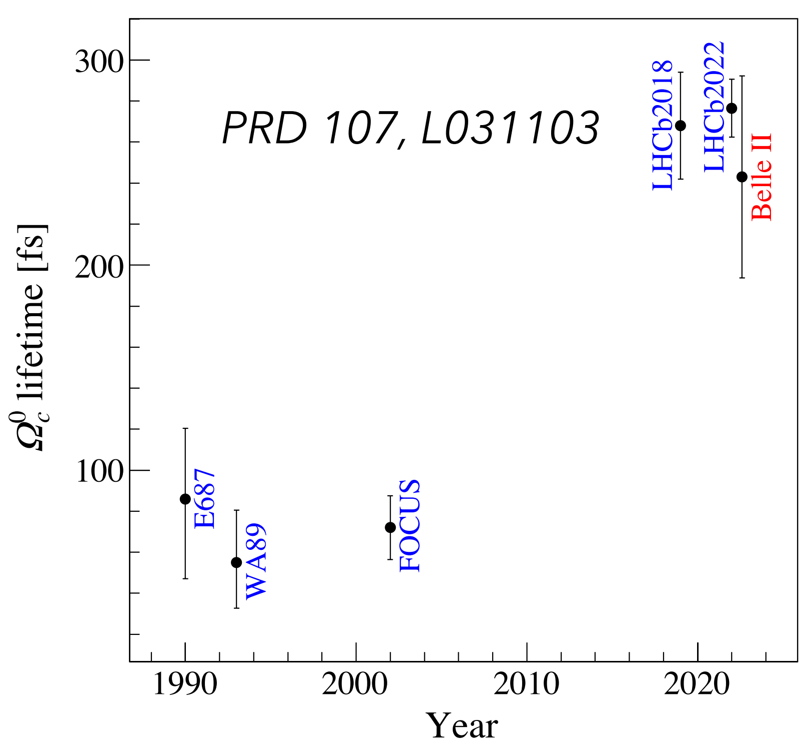
- **double** the sample **size** w.r.t D^{*+}-tagged events
- provide discrimination between signal and background
- CFT will increase sensitivity for many charm decays:
  - $D^0 \to \pi^0\pi^0, K_S^0K_S^0, K\pi\pi^0, \pi\pi\pi^0 \ldots$





One more lifetime





$$\tau(\Omega_c^0) = (243 \pm 48(\text{stat.}) \pm 11(\text{syst.}))\ \text{fs}$$

new lifetime hierarchy :

$$\tau(\Xi_c^0) < \tau(\Lambda_c^+) < \tau(\Omega_c^0) < \tau(\Xi_c^+)$$

- Ω_c^0 was believed to be the shortest-lived charmed baryon
- confirmed LHCb Ω_c lifetime that challenged earlier determinations and HQE expectations
- independent measurement from Belle II
- another confirmation of excellent performance and alignment of vertex detector

Conclusion

- beginning of a rich quarkonium physics program
  - unique data near E_{cm} ~ 10.75 GeV
  - $\Upsilon(10753) \to \omega\chi_{bJ}(1P)$ observed for the first time
  - $B\bar{B}$, $B\bar{B}^*$, $B^*\bar{B}^*$ cross section hint at possible resonance
- Charm Flavor Tagger
  - new inclusive algorithm that exploits correlation between signal flavor and charge of tagging particles
  - significantly enlarge the available sample size
- Measurement of Ω_c^0 lifetime confirms new hierarchy for lifetime of charmed baryons

Backup

Long-shutdown activity and plans

Belle II stopped taking data in Summer 2022 for a long shutdown

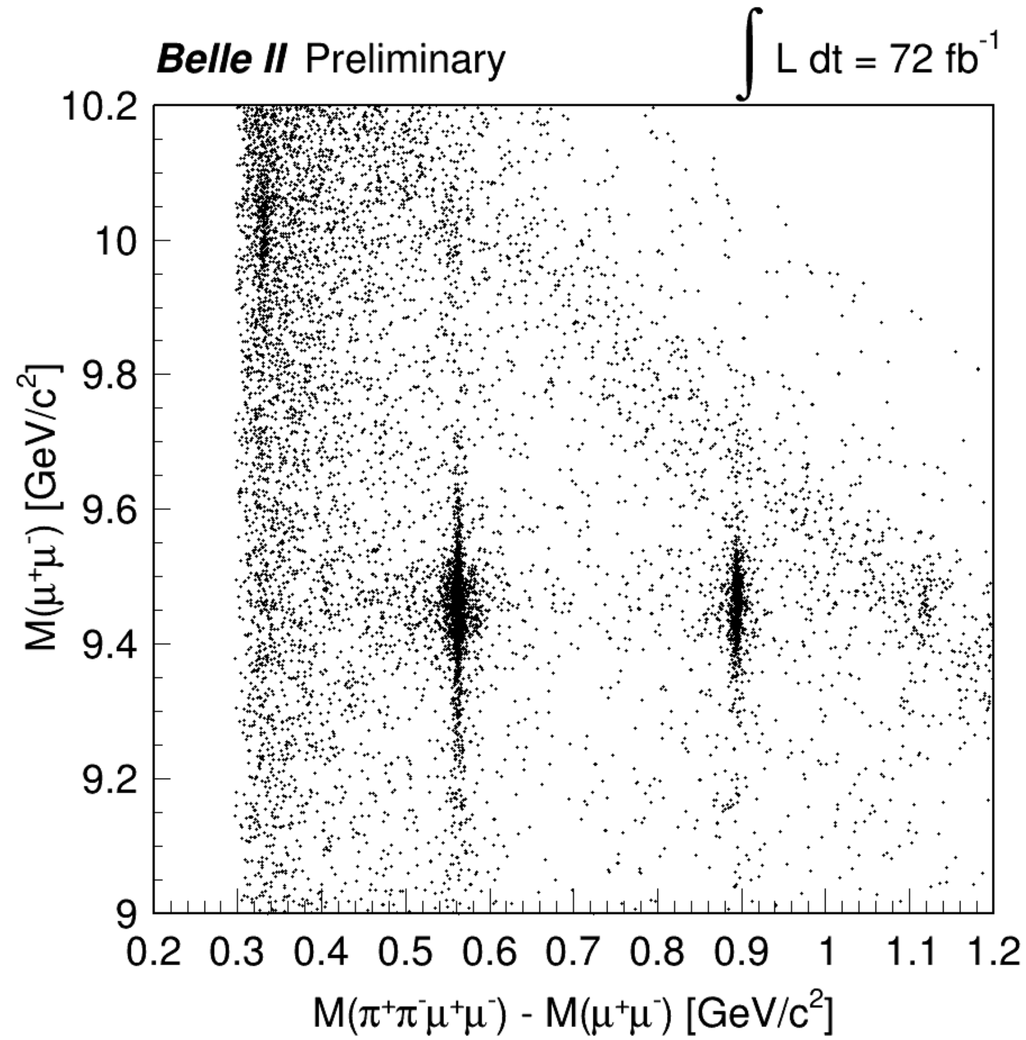
- replacement of beam pipe
- replacement of photomultipliers of the central PID detector (TOP)
- installation of 2-layered pixel vertex detector
- improved data-quality monitoring and alarm system
- complete transition to new DAQ boards (PCIe40)
- replacement of aging components
- additional shielding and increased resilience against beam backgrounds

Currently working on pixel detector installation:

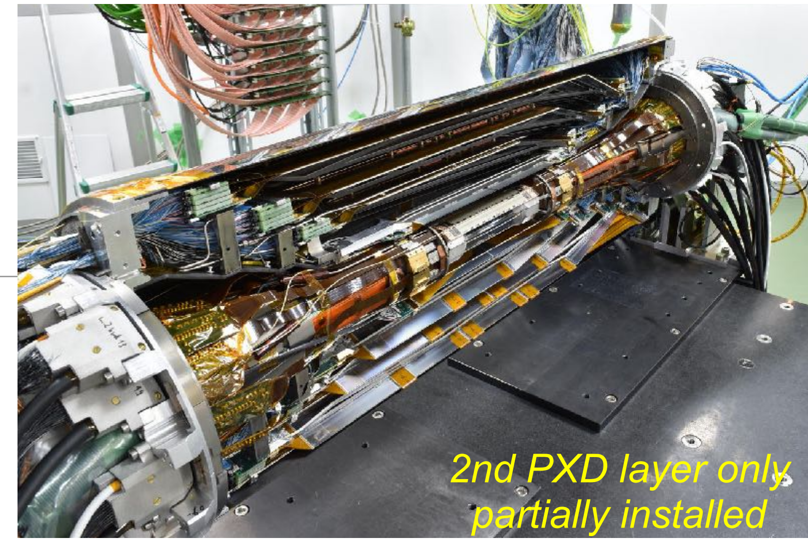
- shipping to KEK in mid March
- final test at KEK scheduled in April

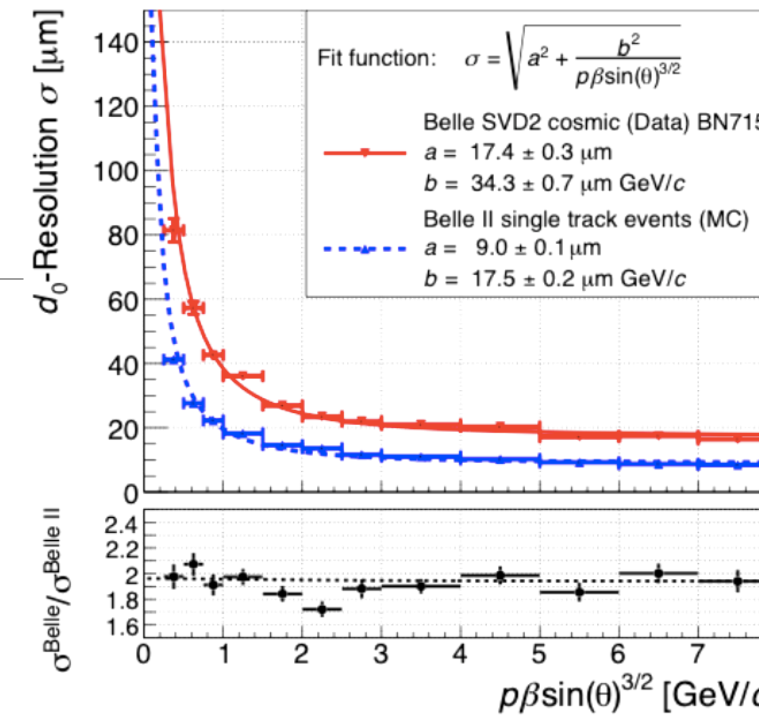
Additional bottomonium searches

- additional searches with $\Upsilon(10750)$ scan data
  - di-pion transitions $e^+e^- \to \pi^+\pi^-\Upsilon(nS)$
  - inclusive search for $e^+e^- \to \omega\eta_b(1S)$
  - $e^+e^- \to \eta\Upsilon(nS)$ and search for γX_b



High-precision vertexing





- Silicon vertex detector
  - 2-layer pixel detector (PXD)
  - 4-layer double-sided strip detector (SVD)
- PXD
  - Innermost layer is only 1.4 cm from the interaction region (×2 closer than in Belle)
  - Very low material thickness (0.1% X_0/layer for perpendicular tracks)
  - Excellent hit position resolution
- ×2 better impact parameter resolution than Belle/BaBar shows up in decay-time distribution