

Charm lifetime measurements at Belle II

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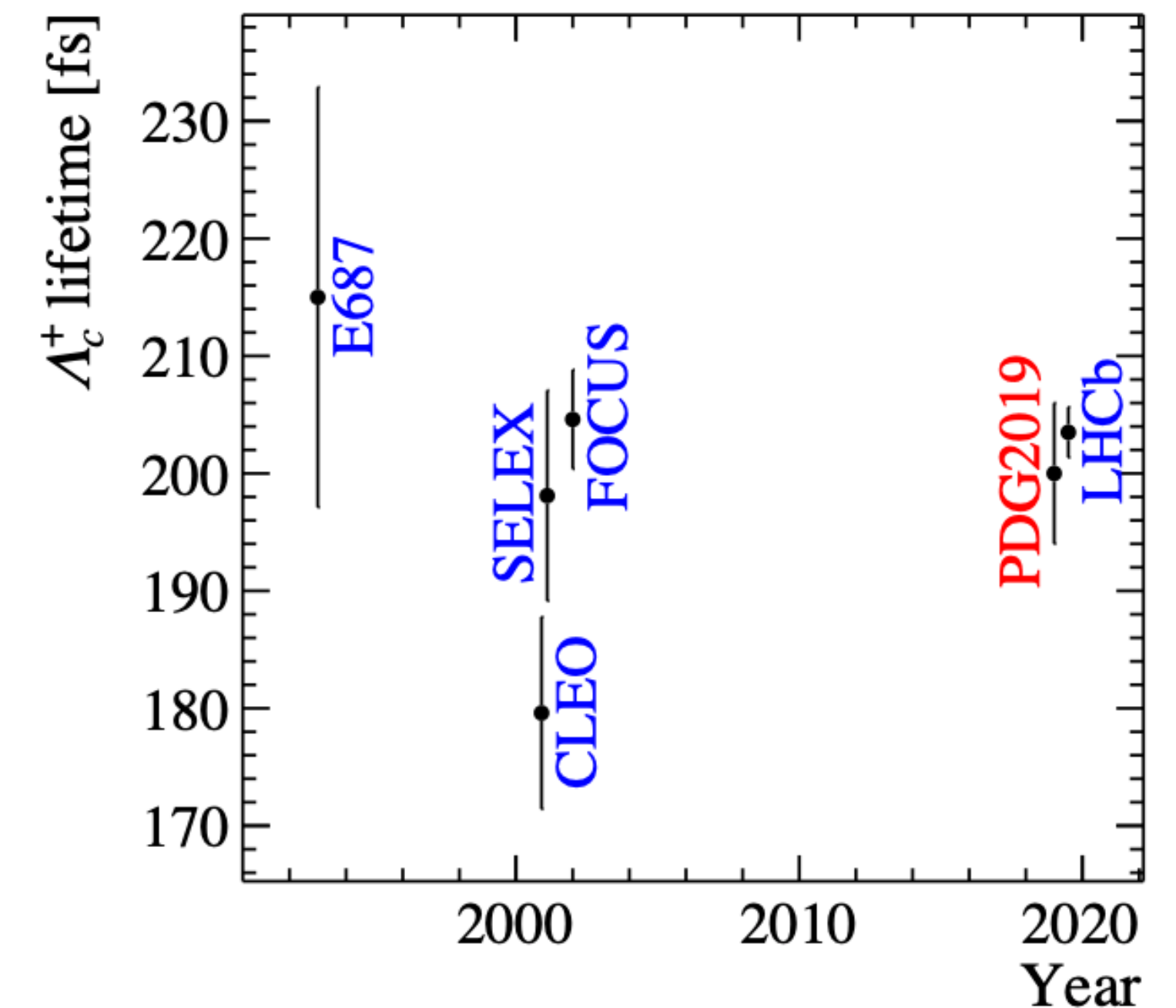
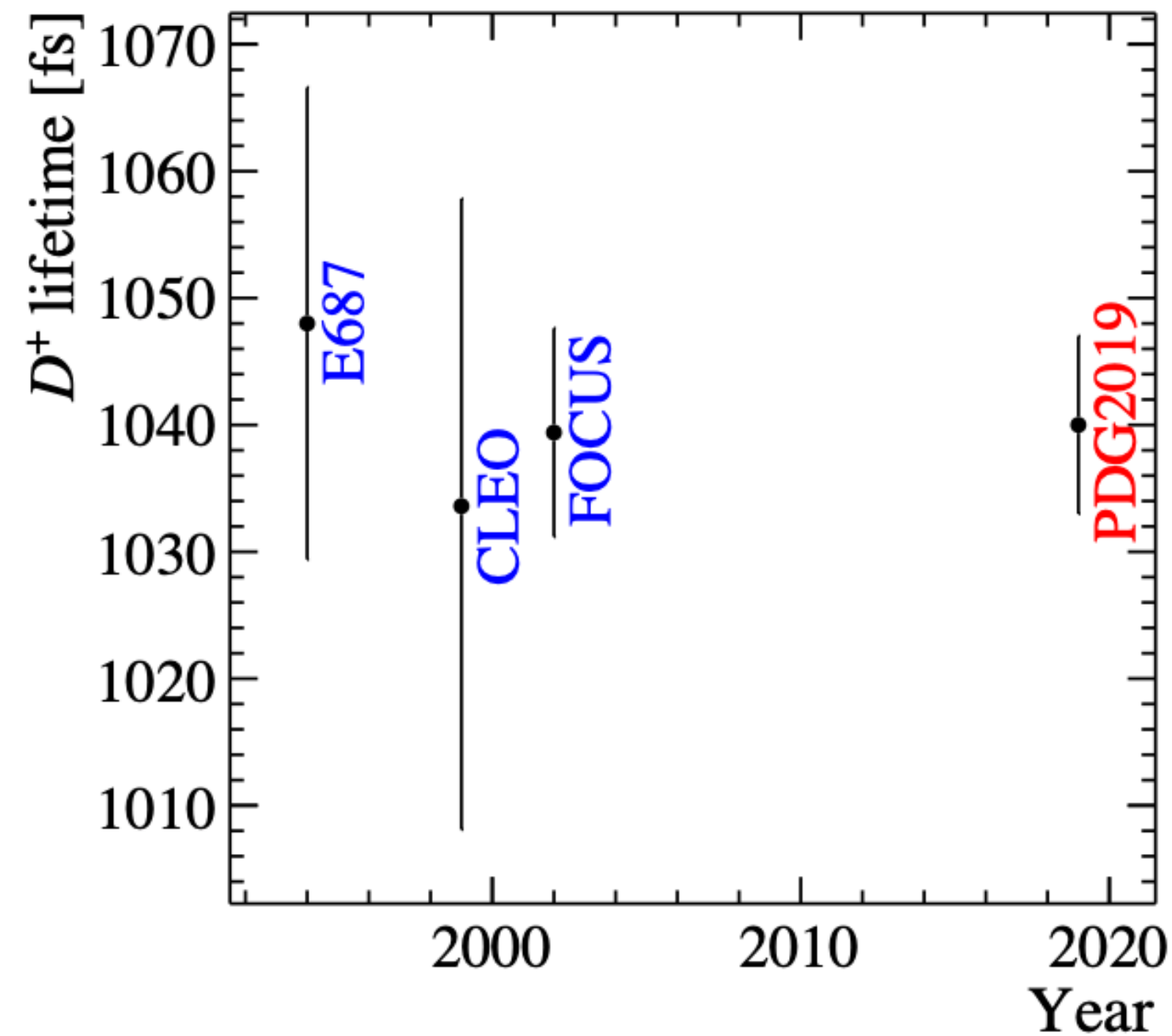
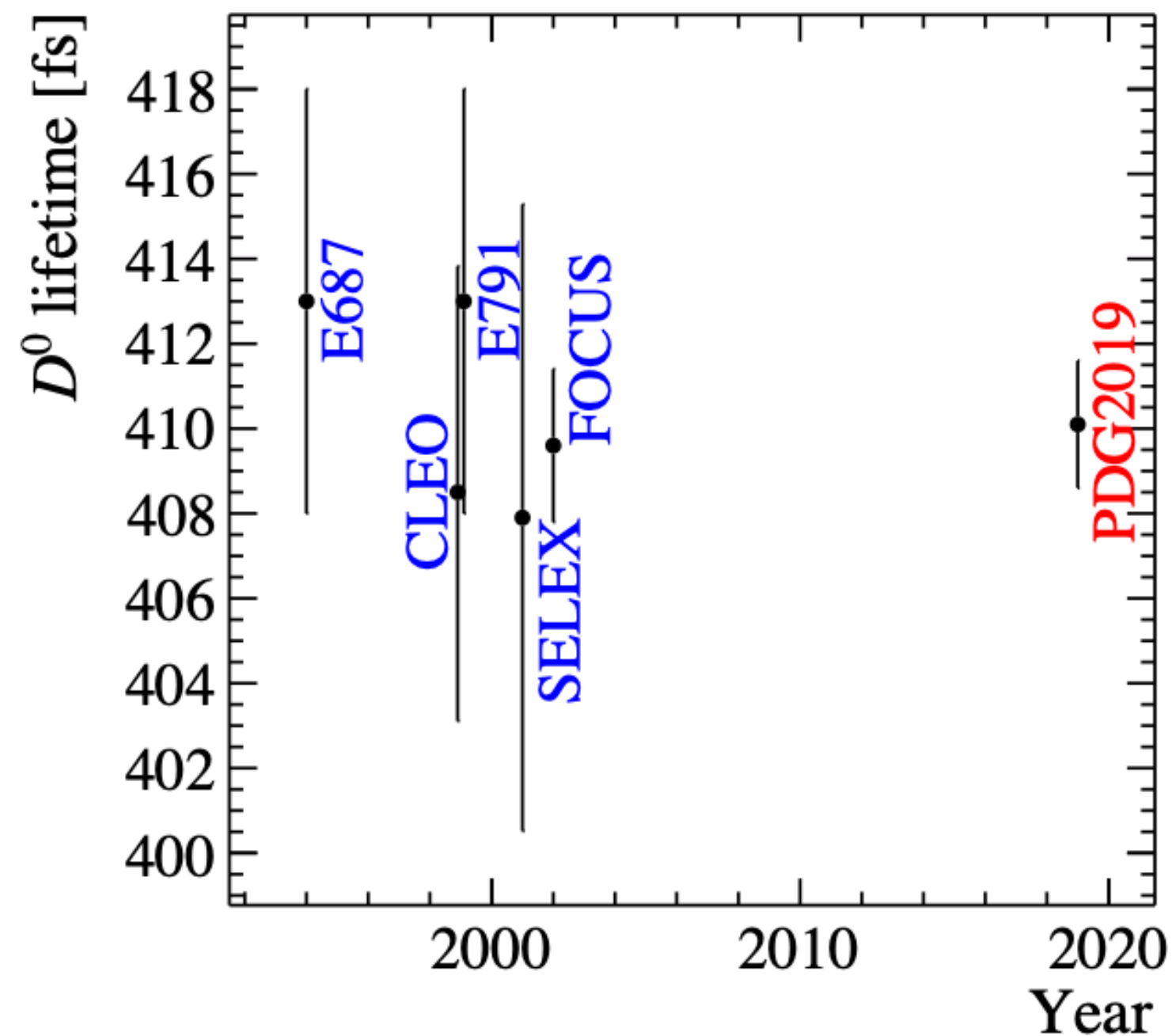
Charmed hadron lifetimes: experimental status

- D^0 and D^+ dominated by
 - FOCUS: photon beam experiment
 - SELEX: hyperon beam experiment
 - CLEO: the only e^+e^- measurements

- Other charmed hadrons dominated by LHCb
 - All relative measurements with respect to D^+

$$\tau_{\Lambda_c^+} = 203.5 \pm 1.0 \text{ (stat)} \pm 1.3 \text{ (syst)} \pm 1.4 \text{ } (\tau_{D^+}) \text{ fs}$$

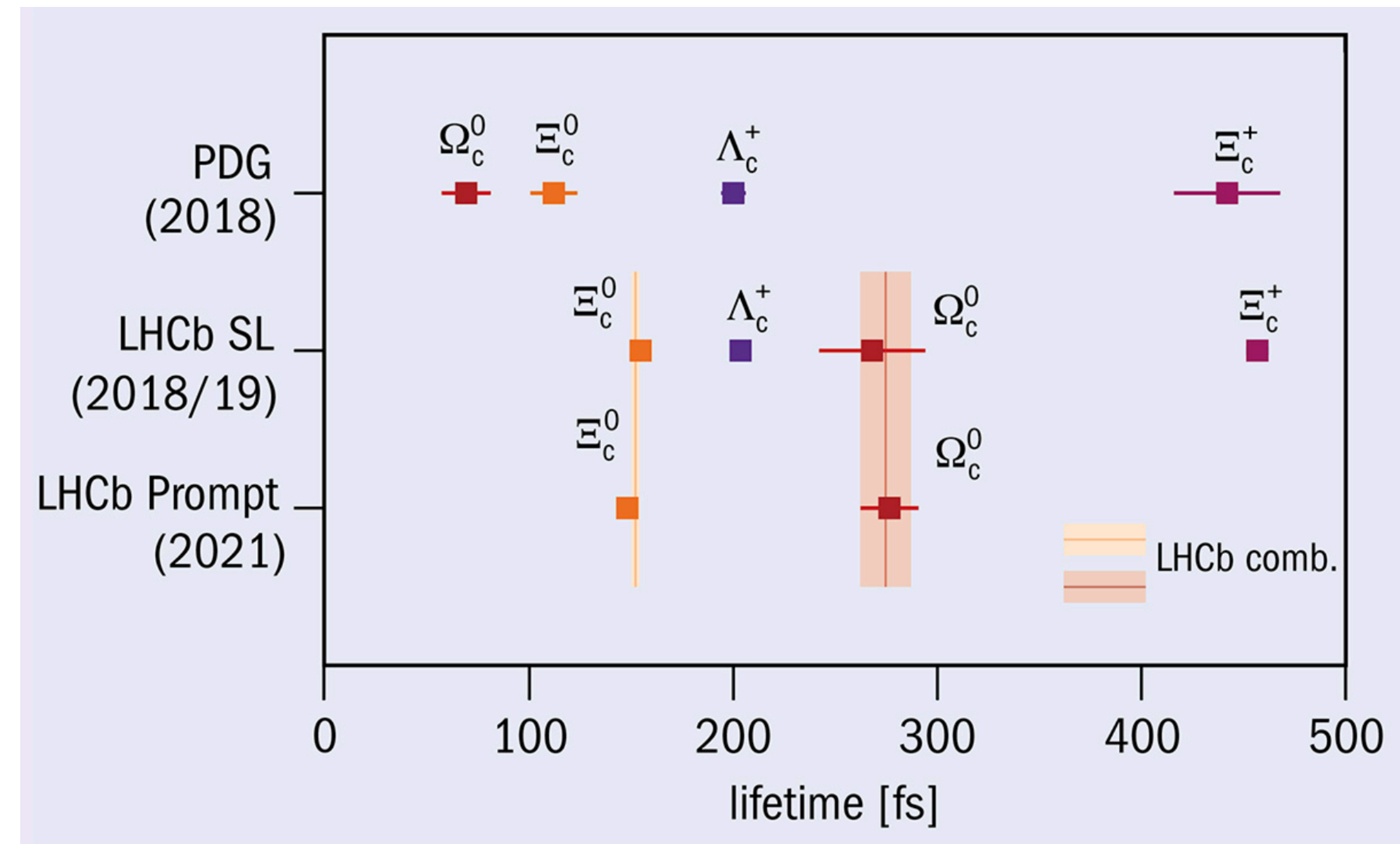
PRD 100 (2019) 032001



Charmed baryon lifetimes

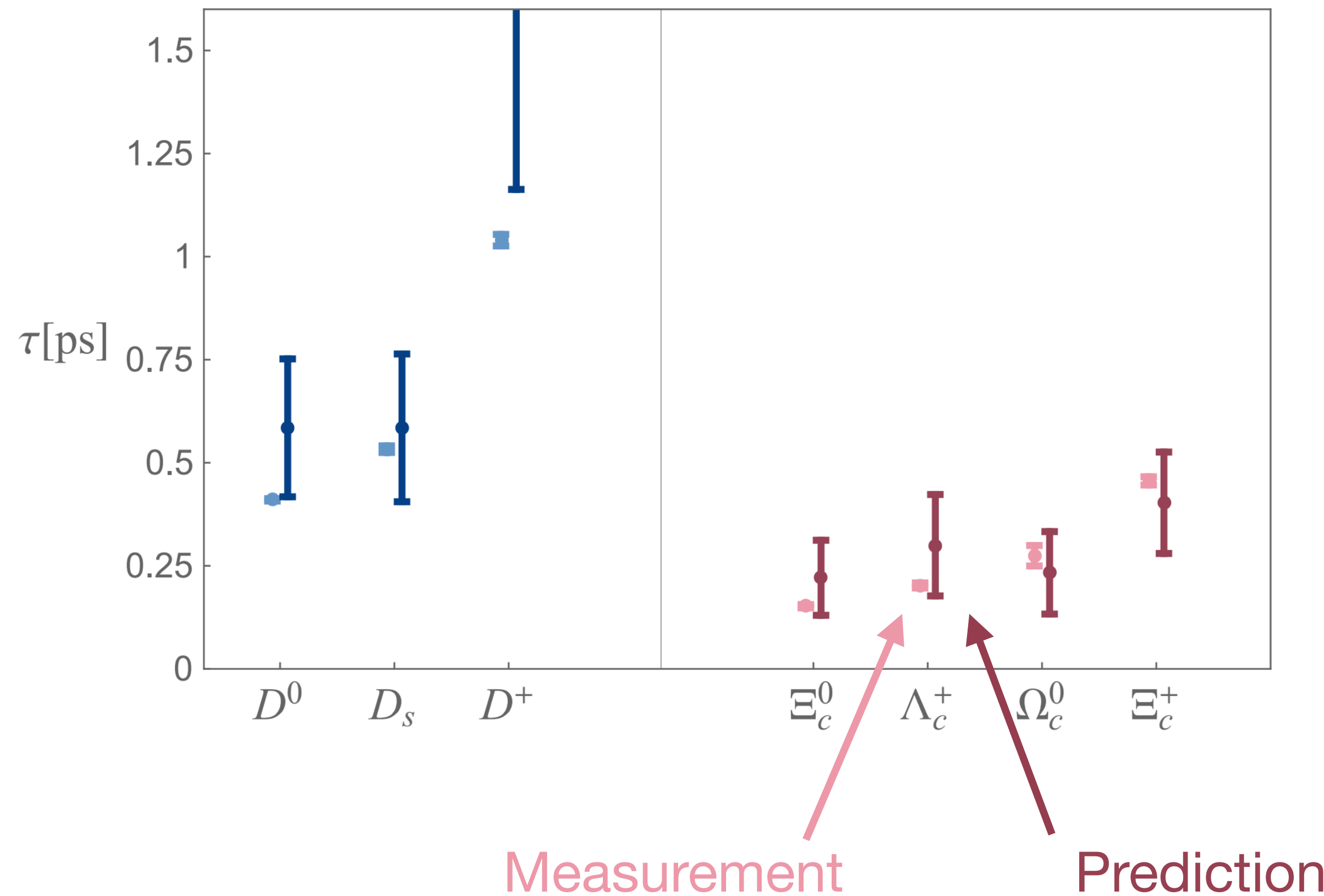
- Lifetime hierarchy of charmed baryons upended after recent measurements by LHCb
- **Searches for BSM physics rely on accurate theory descriptions of strong interactions at low energy**
 - Often rely on effective models like Heavy Quark Expansion
 - Heavy hadron lifetimes sensitive to higher order contributions
 - **Provide stringent tests of theory predictions that can be used to inform models used for BSM searches**

<https://cerncourier.com/a/new-charmed-baryon-lifetime-hierarchy-cast-in-stone>



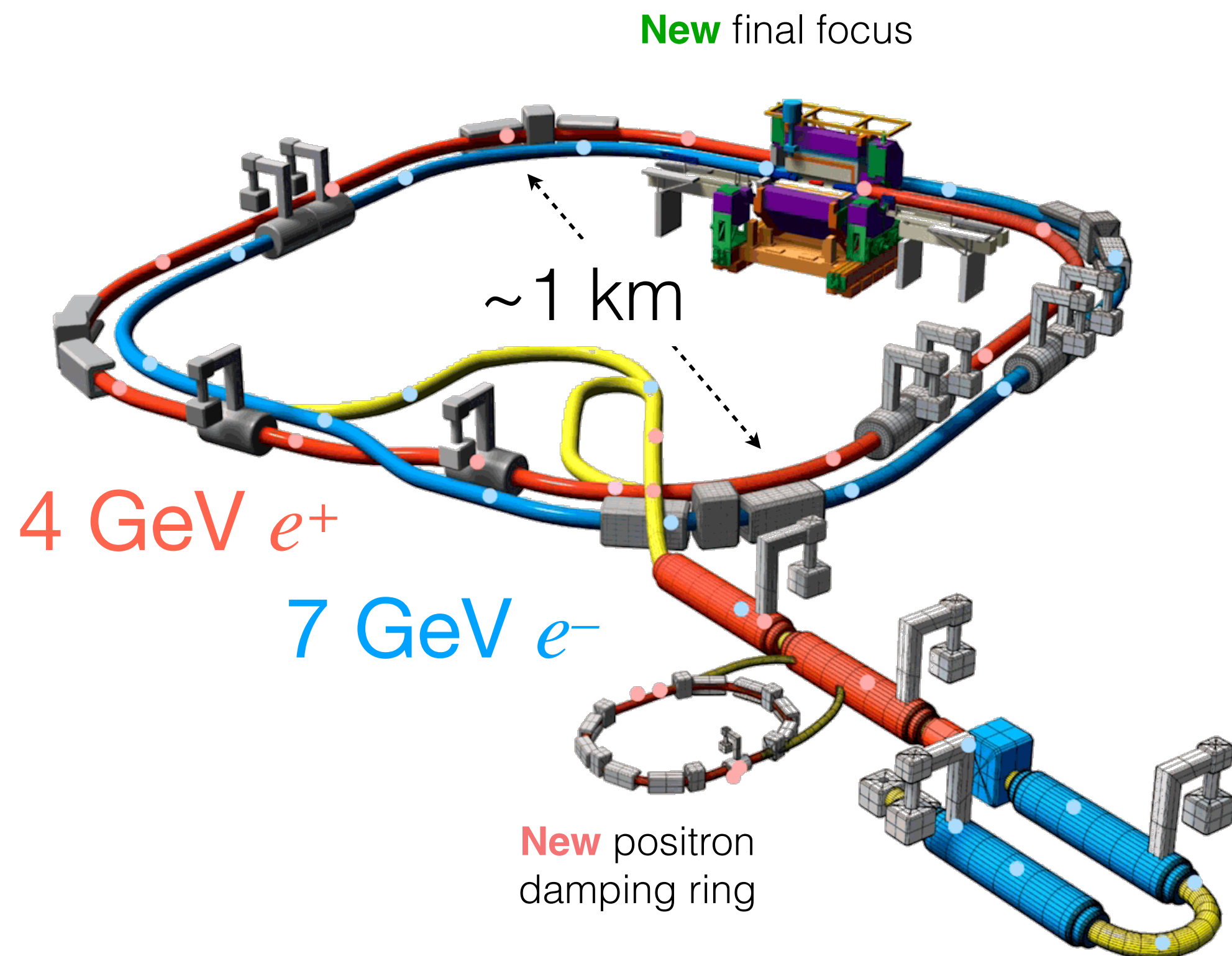
Charmed baryon lifetimes

<https://arxiv.org/abs/2204.11935> (April 2022)

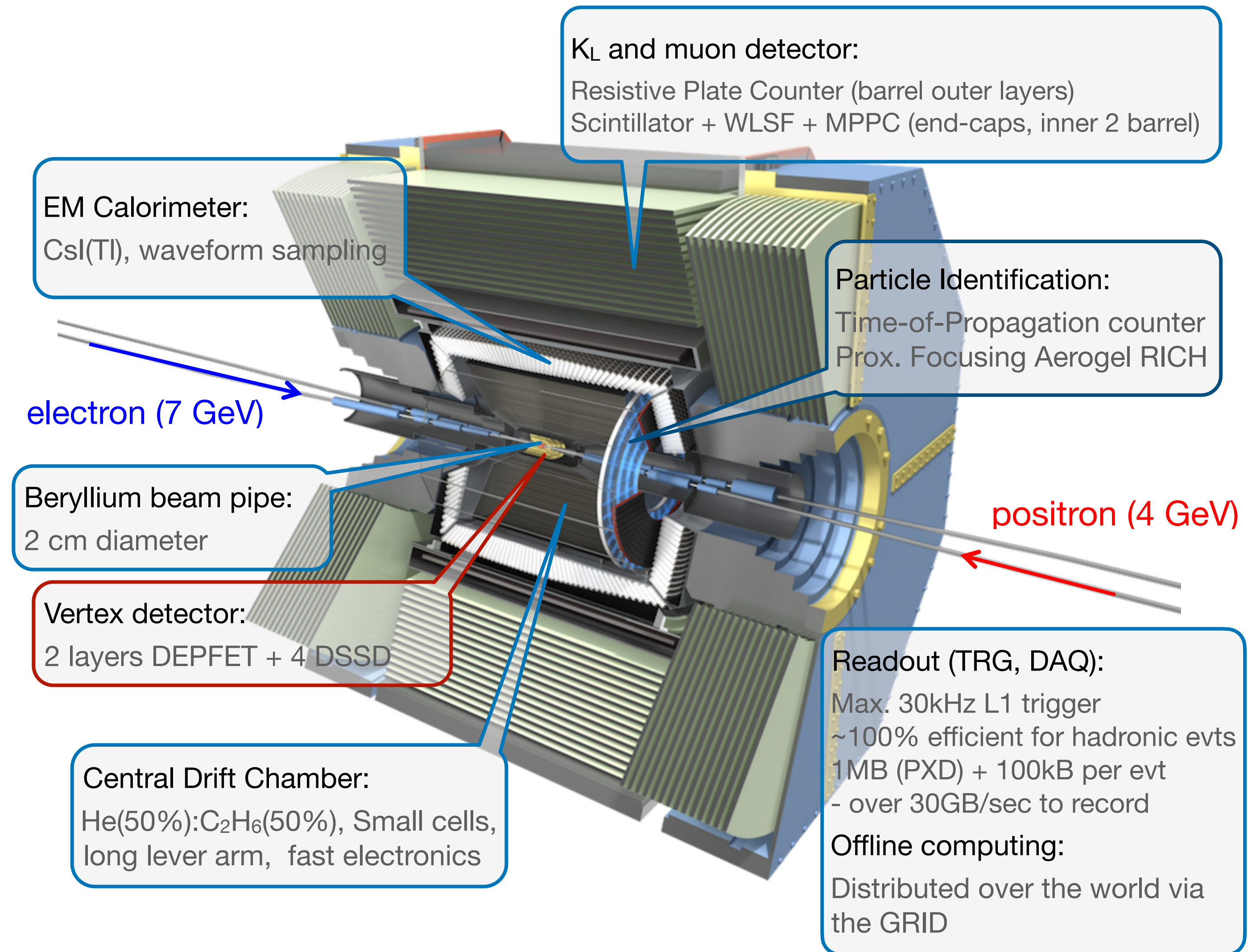


- **Charm hadrons in particular provide excellent tests**
 - Charm quark mass is much less than that of the beauty quark
 - Higher order corrections and spectator effects more significant
 - Charmed baryons are most difficult to describe due to model-dependent spectator effects like weak W -annihilation and Pauli interference

SuperKEKB and Belle II: 2nd generation “Super B Factory”



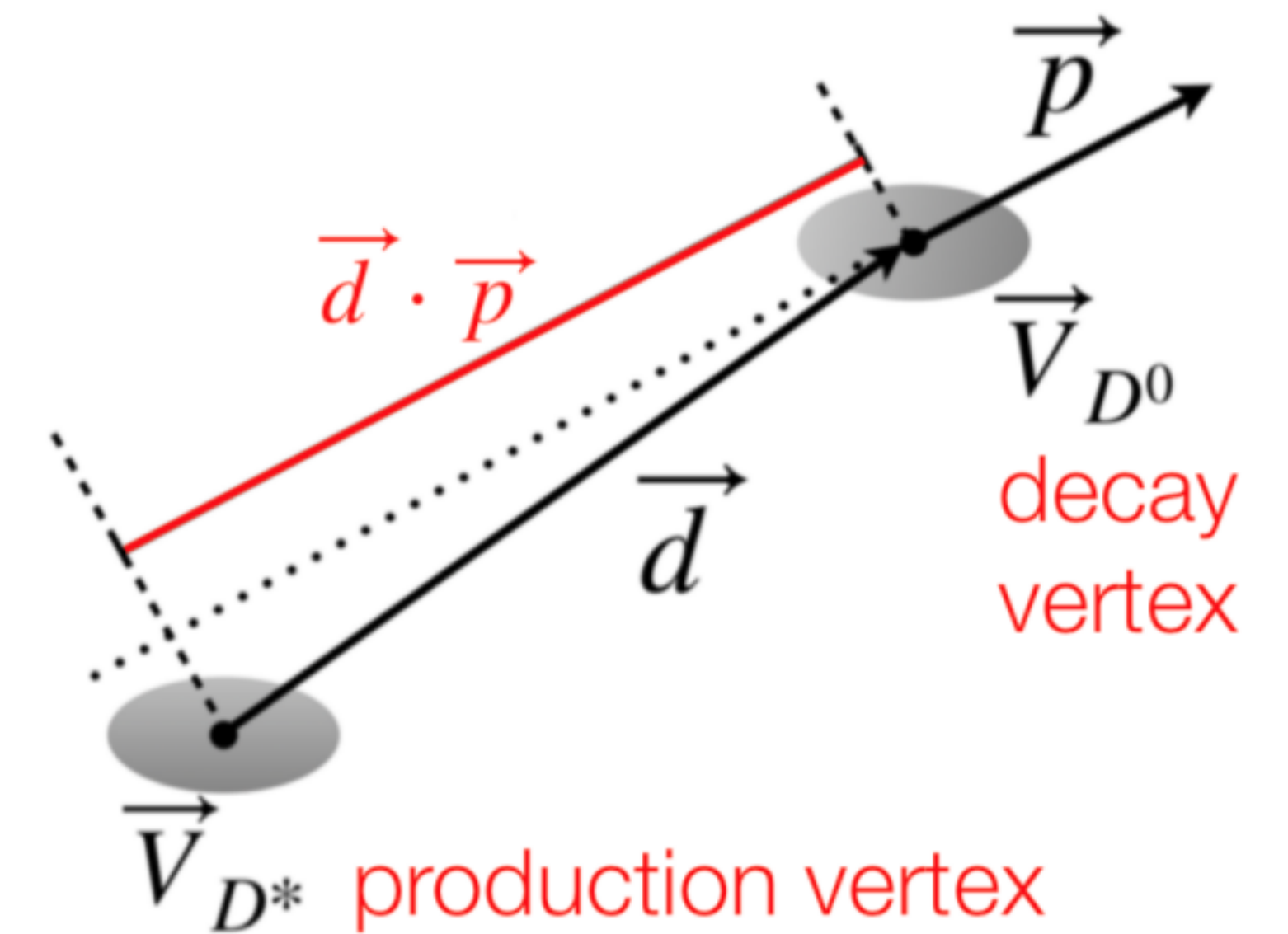
Animation © KEK



$$c\bar{c}, u\bar{u}, d\bar{d}, \ell^+ \ell^- \leftarrow e^+ e^- \rightarrow \Upsilon(nS) \rightarrow B^{(*)} \bar{B}^{(*)}$$

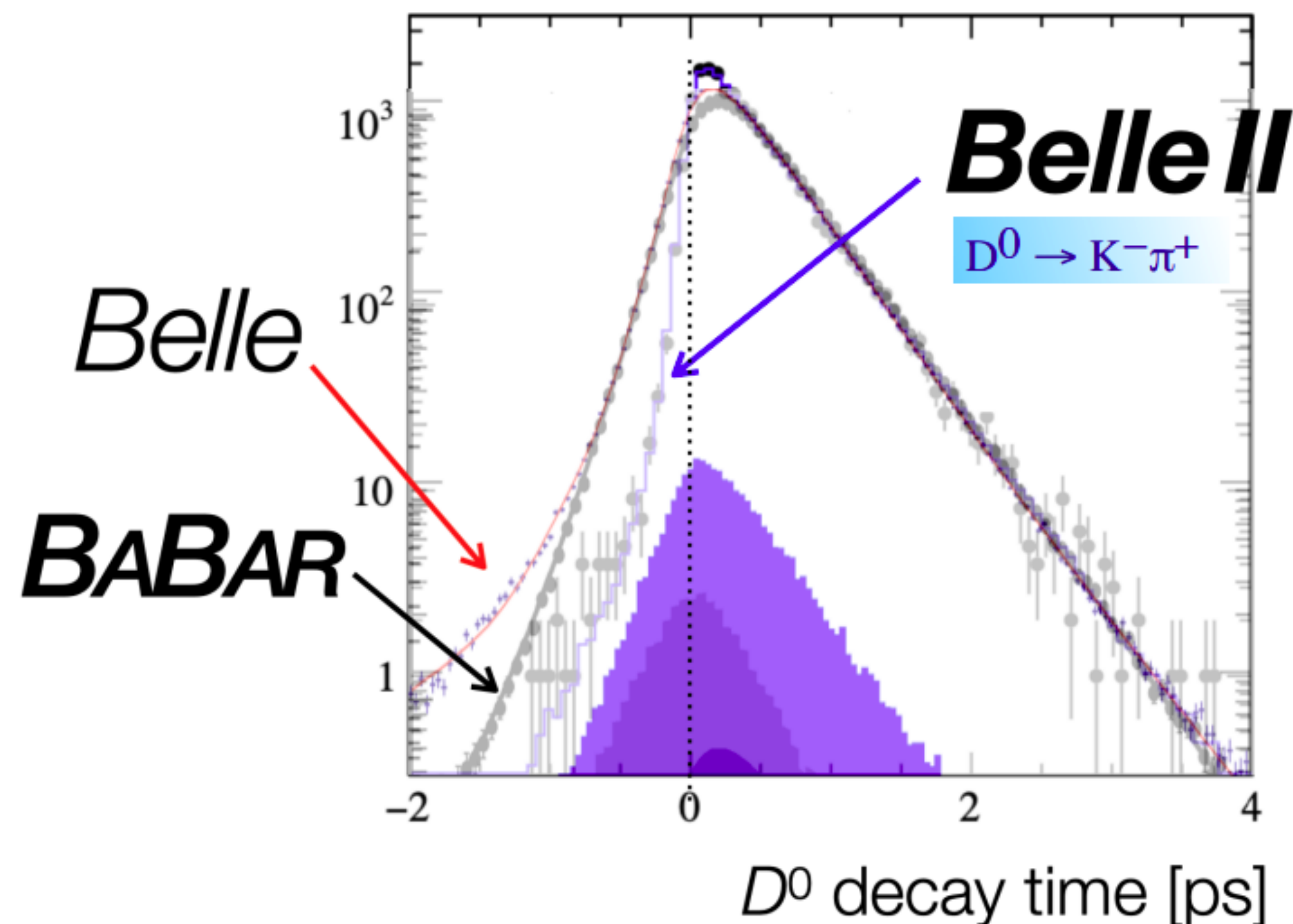
Precise lifetime measurements by Belle II

- Belle II can make precision, absolute lifetime measurements
 - Precise calibration of final state particle momenta
 - Excellent vertex detector alignment
 - Very good vertex resolution, small beam size



$$t = \frac{m_D}{p} \left(\vec{d} \cdot \hat{p} \right)$$

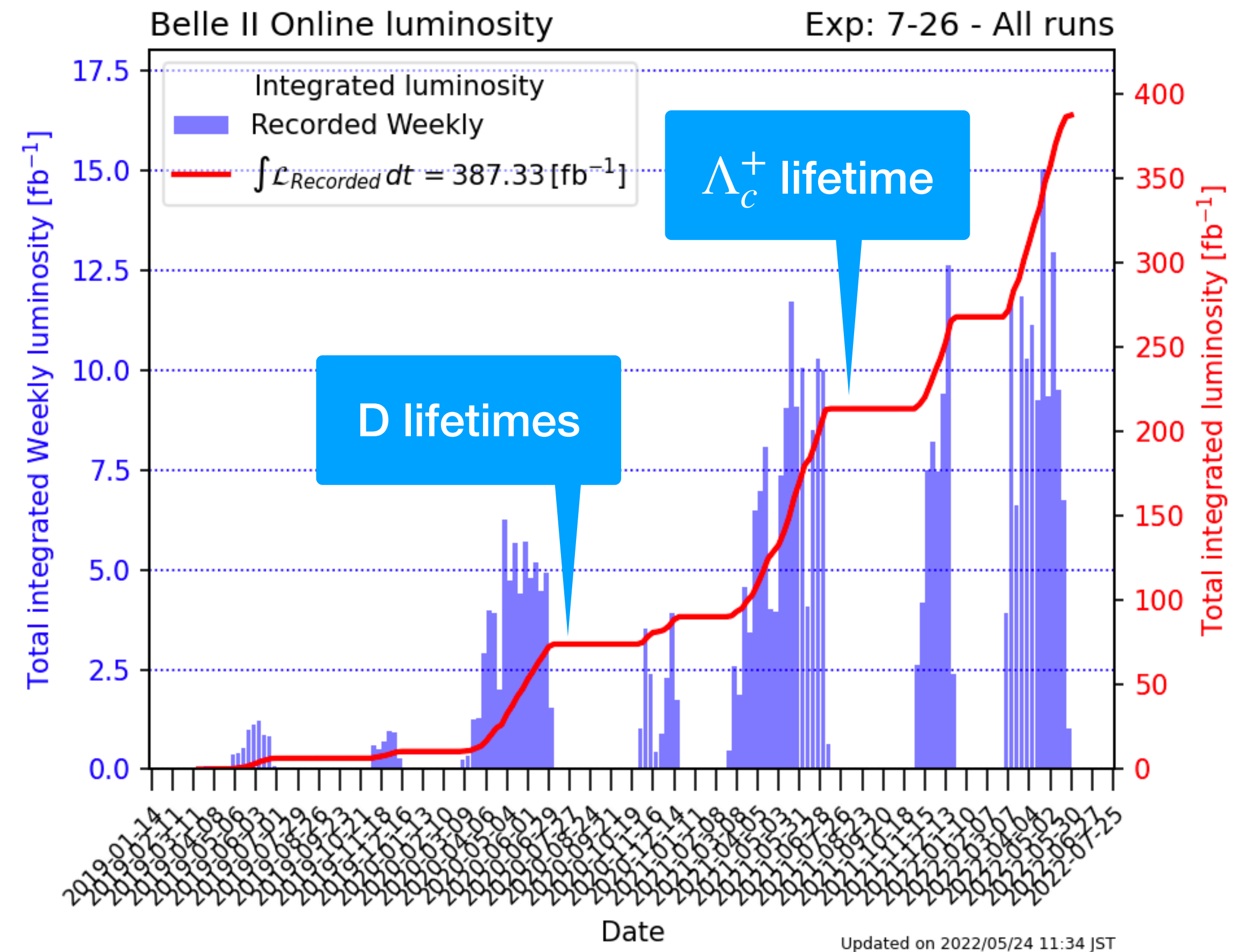
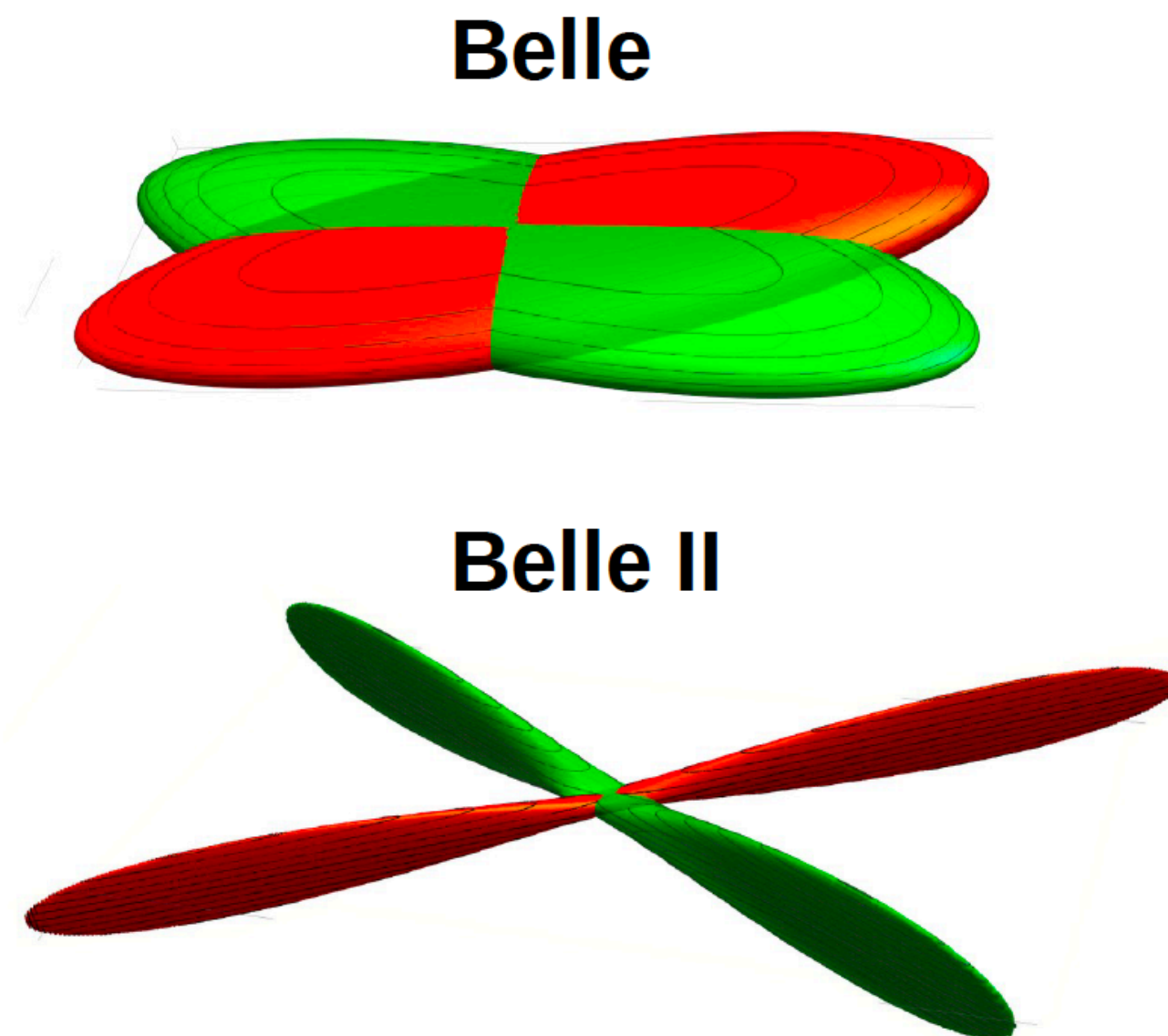
- Lifetimes calculated from distance between production and decay vertices
 - Decay times become negative due to resolution (tool to understand resolution)
 - High precision measurements probe beam spot and alignment calibration



Precise lifetime measurements by Belle II

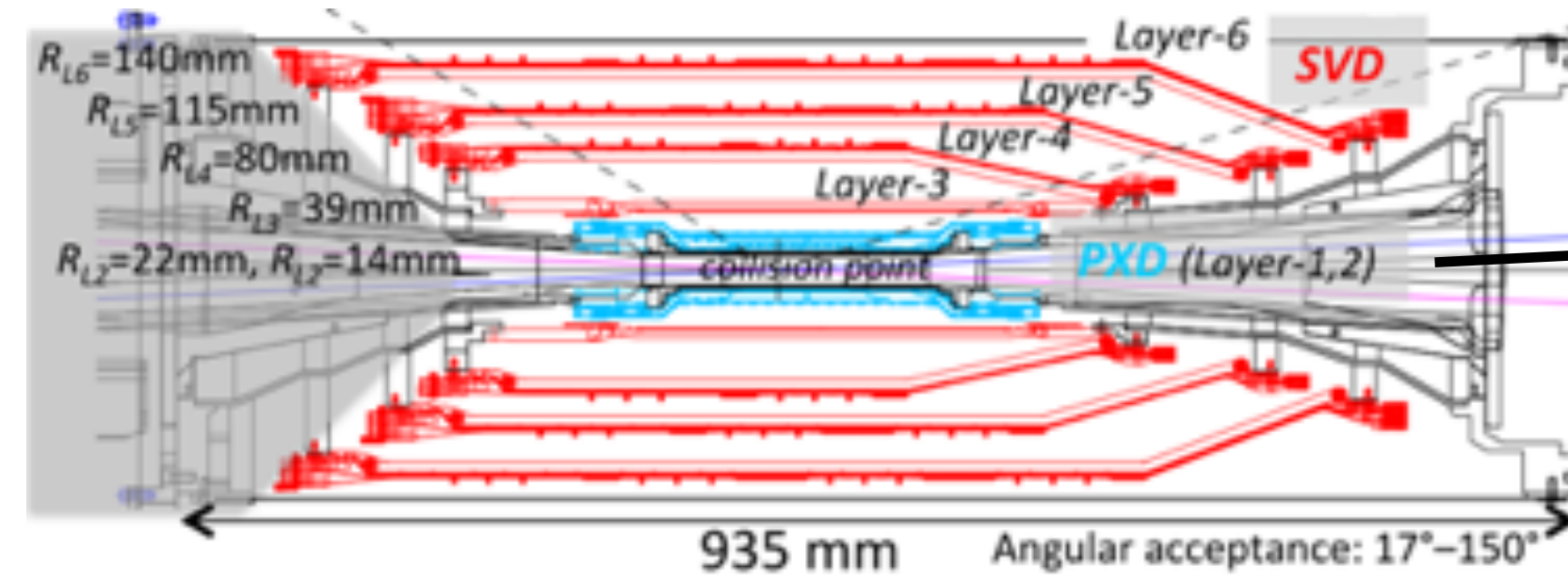
- High instantaneous luminosity via the “nano-beam” scheme
 - Small beam size better constrains event kinematics
 - Improved flight time resolution
- Beam spot calibrated continuously
 - Using $e^+e^- \rightarrow \mu^+\mu^-$ events

Integrated luminosity goal: 50 ab^{-1}
 Target luminosity: $6.5 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$
 May 17, 2022: $4.14 \times 10^{34} \text{ cm}^{-1} \text{ s}^{-1}$
World record!

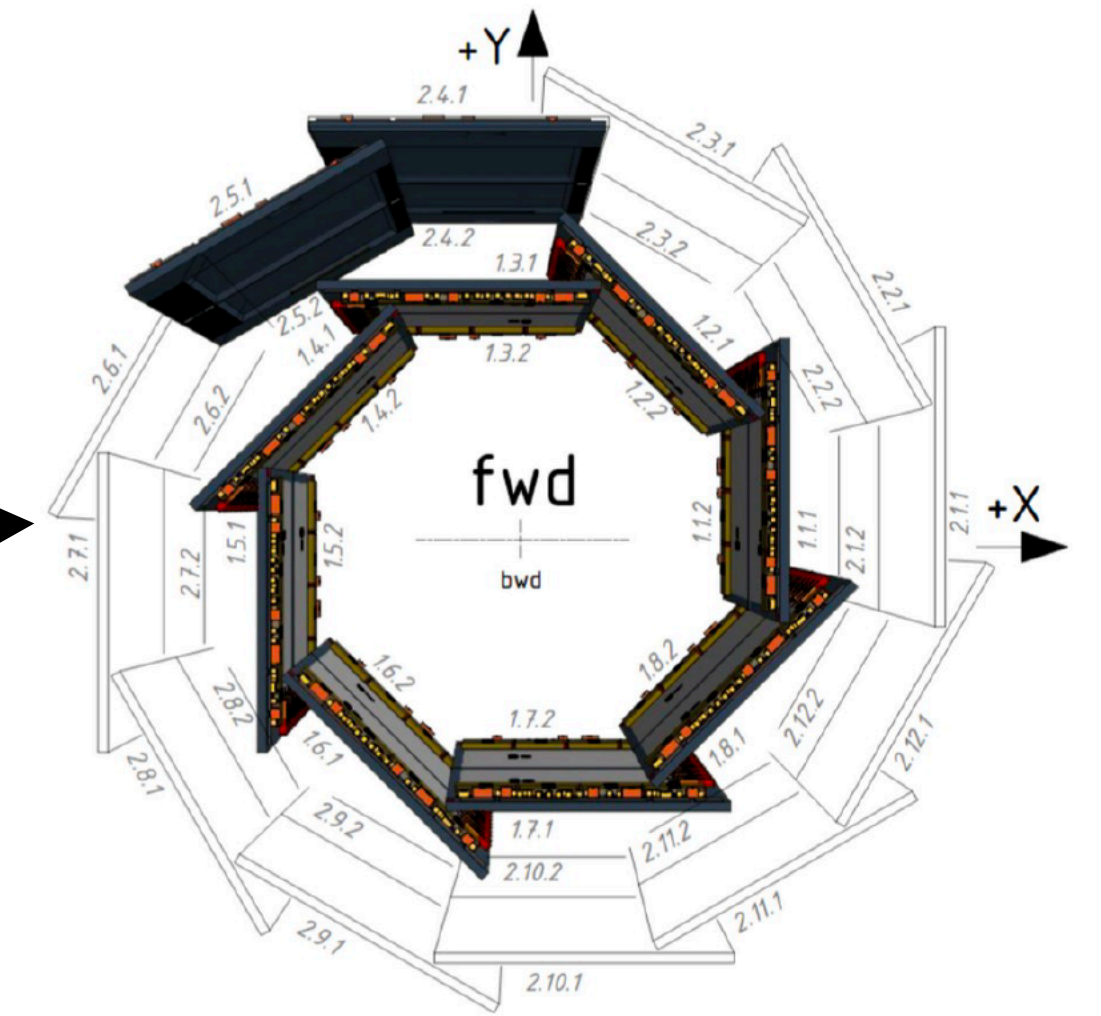


Precise lifetime measurements by Belle II

- Upgraded vertex detector
 - More robust tracking
 - Better vertex resolution

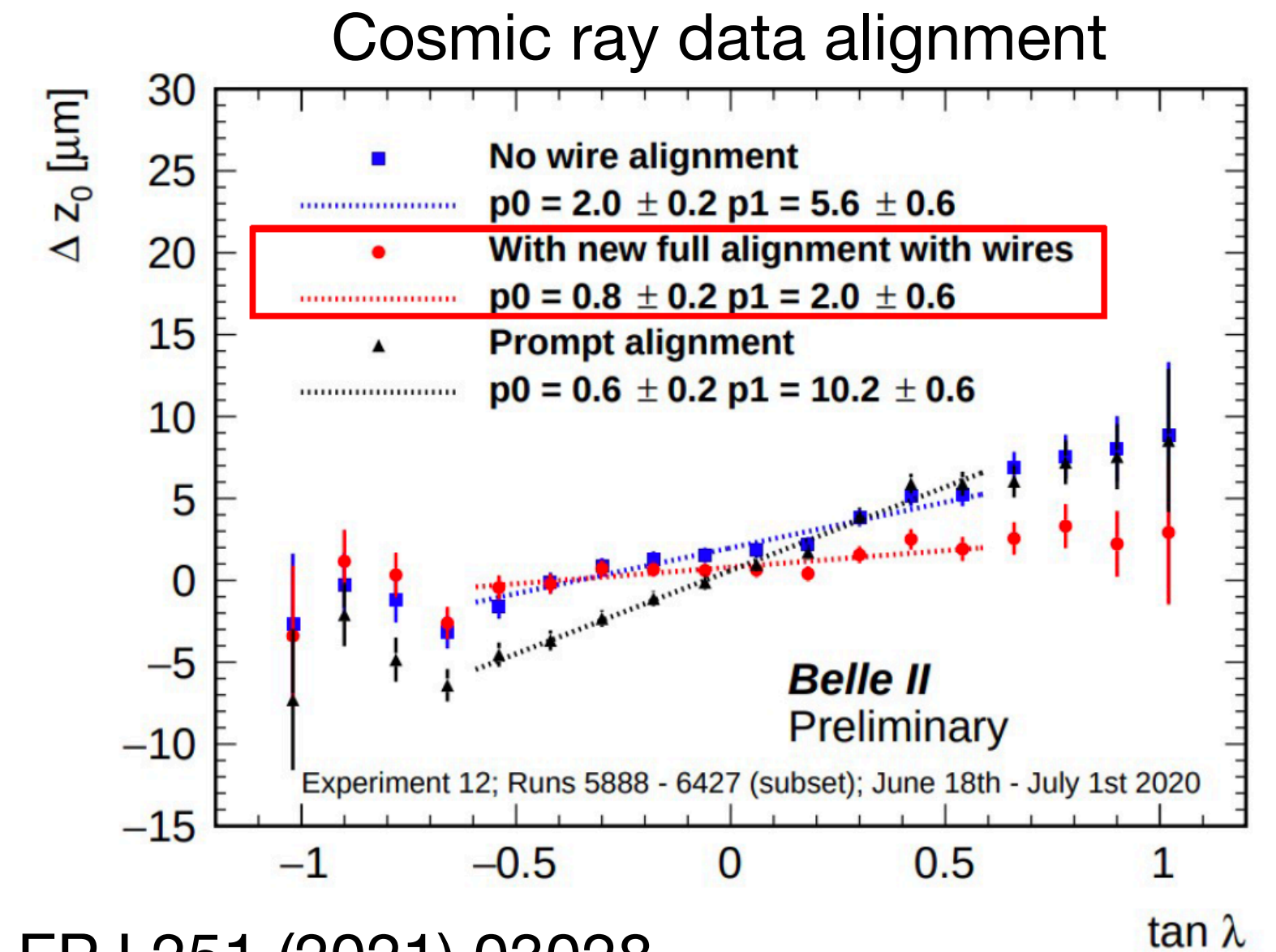
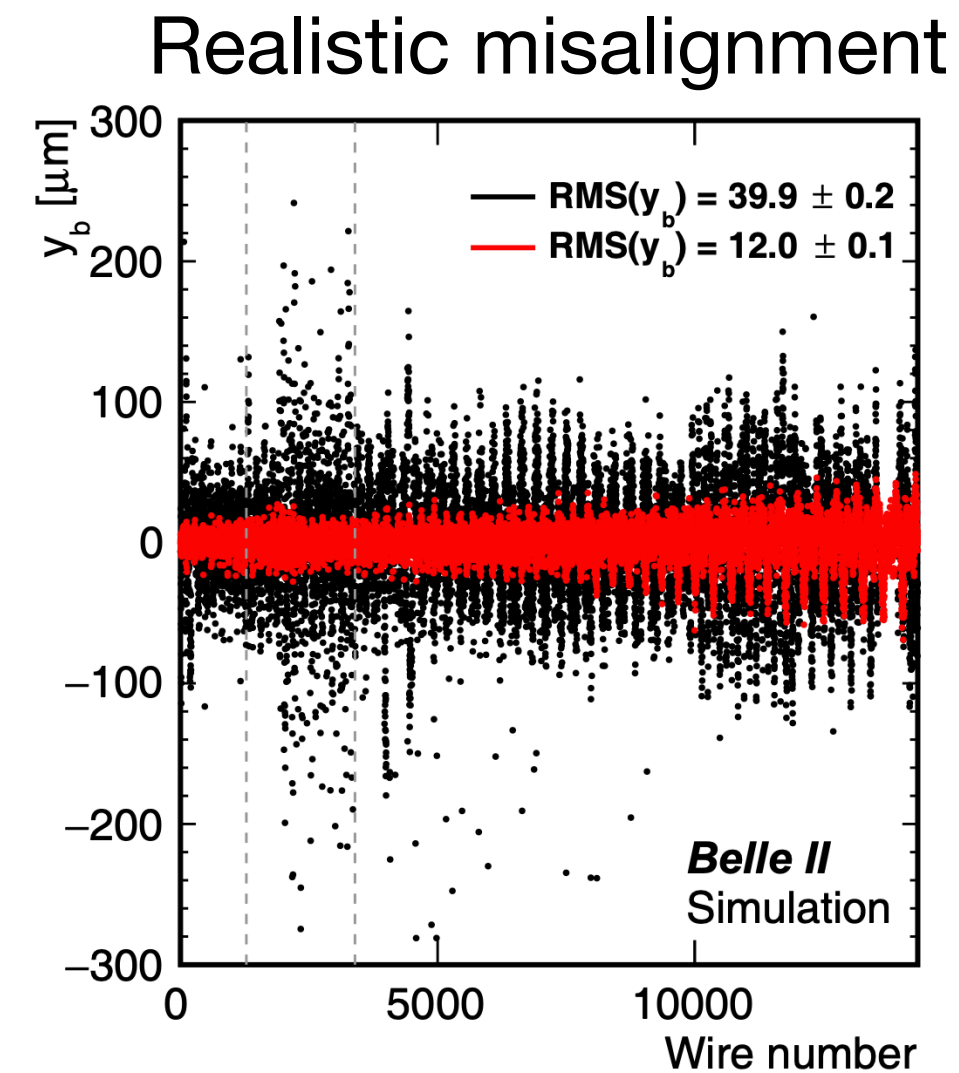
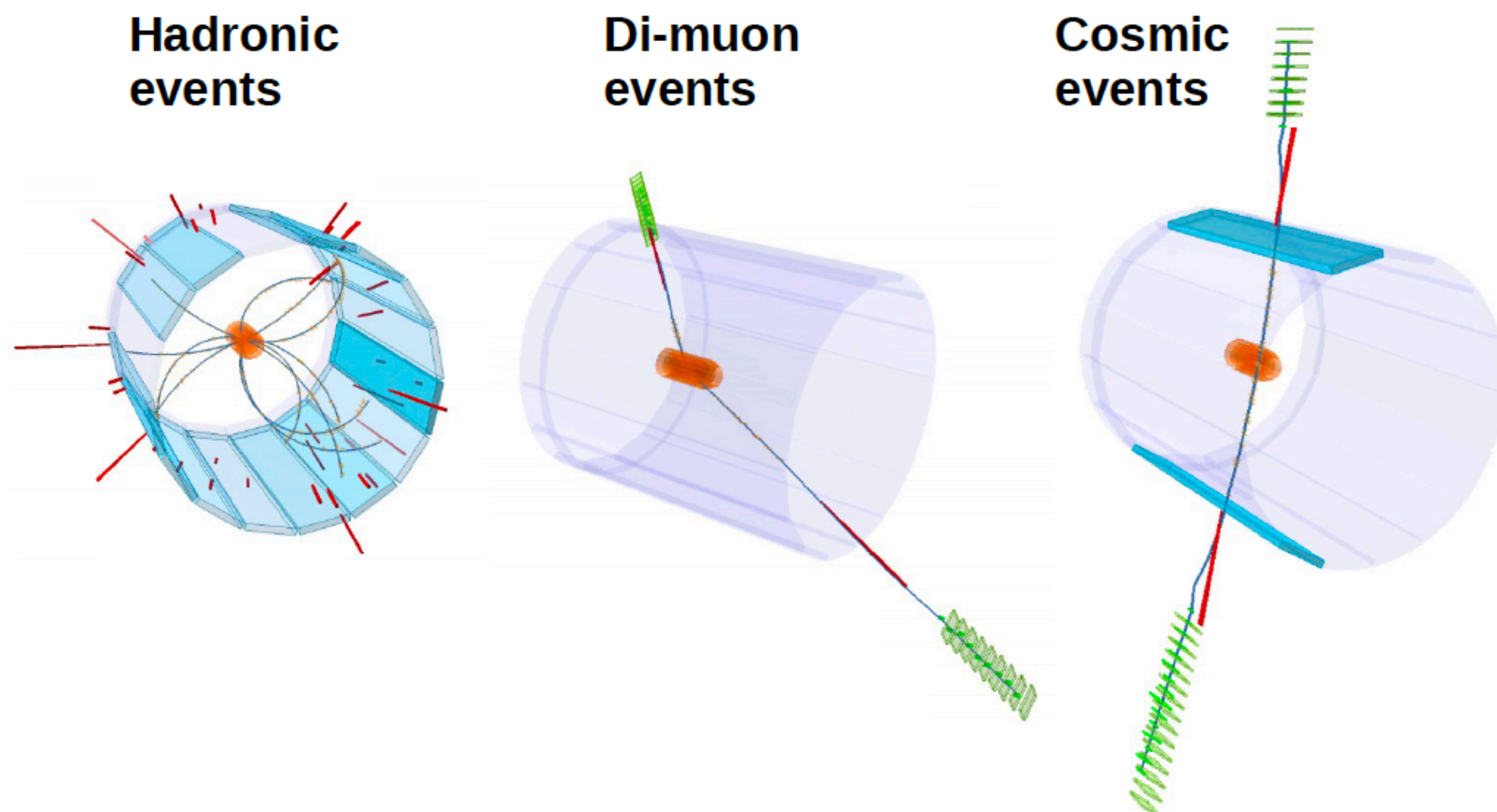


Silicon Vertex Detector (SVD)



Pixel Detector (PXD)

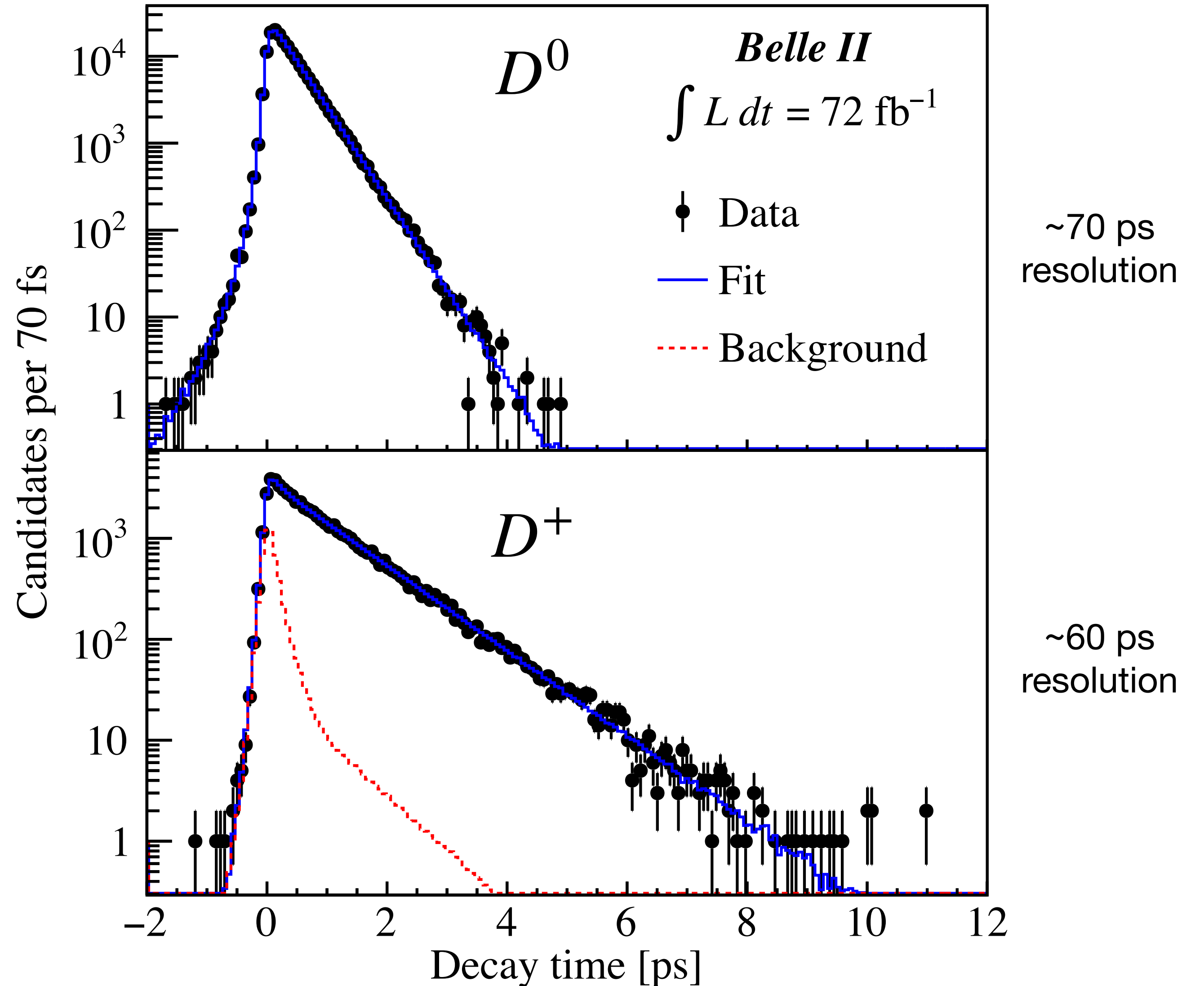
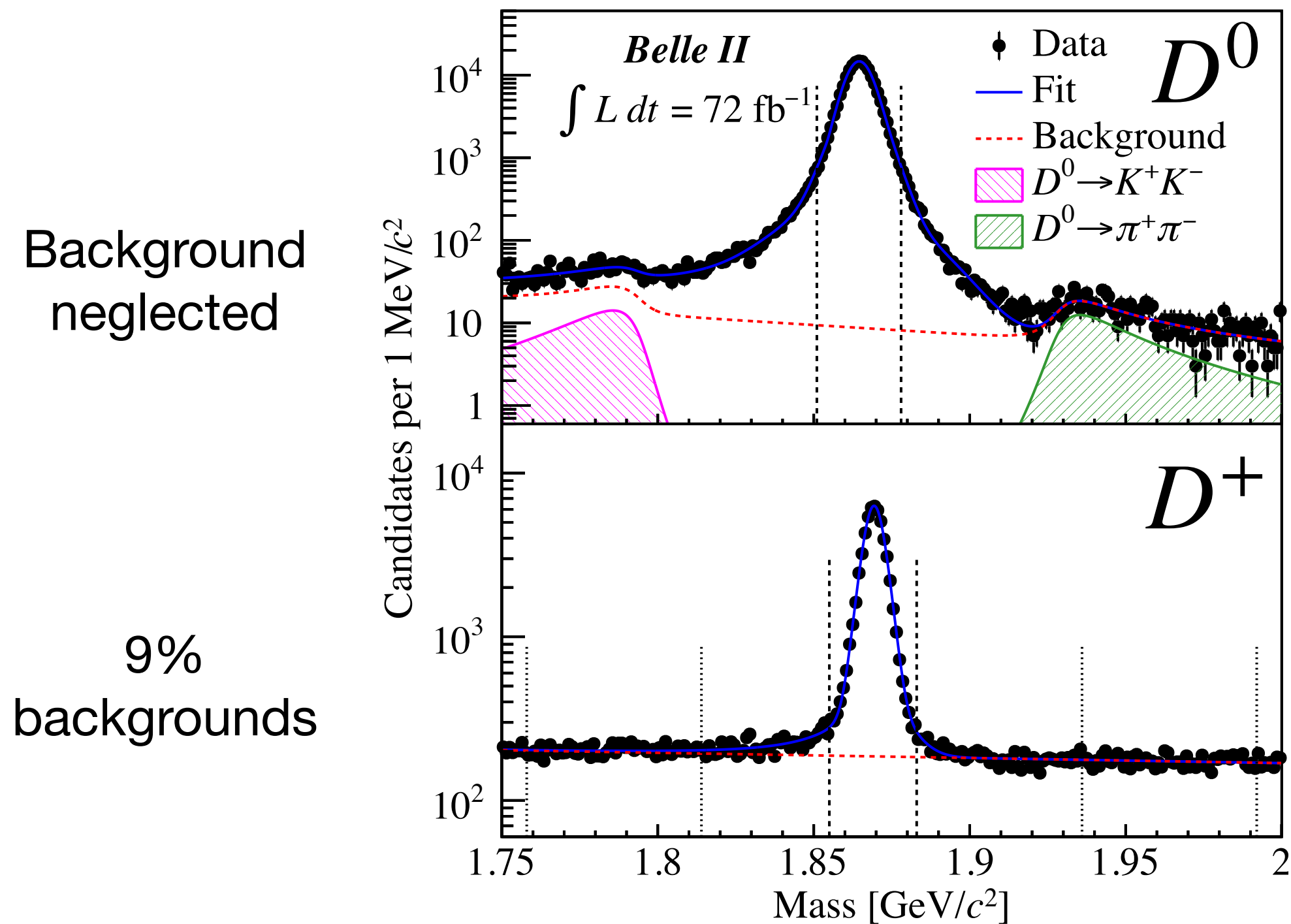
- Precise alignment crucial for precision measurements
 - Includes all 14336 wires in central drift chamber (60,000 parameters)



D⁰ and D⁺ measurements by Belle II

PRL 127 211801 (2021)

- Lifetime measured from an unbinned 2D fit to the (t, σ_t) distribution
 - Simultaneous fit to signal and sidebands
 - Background constrained from mass fit



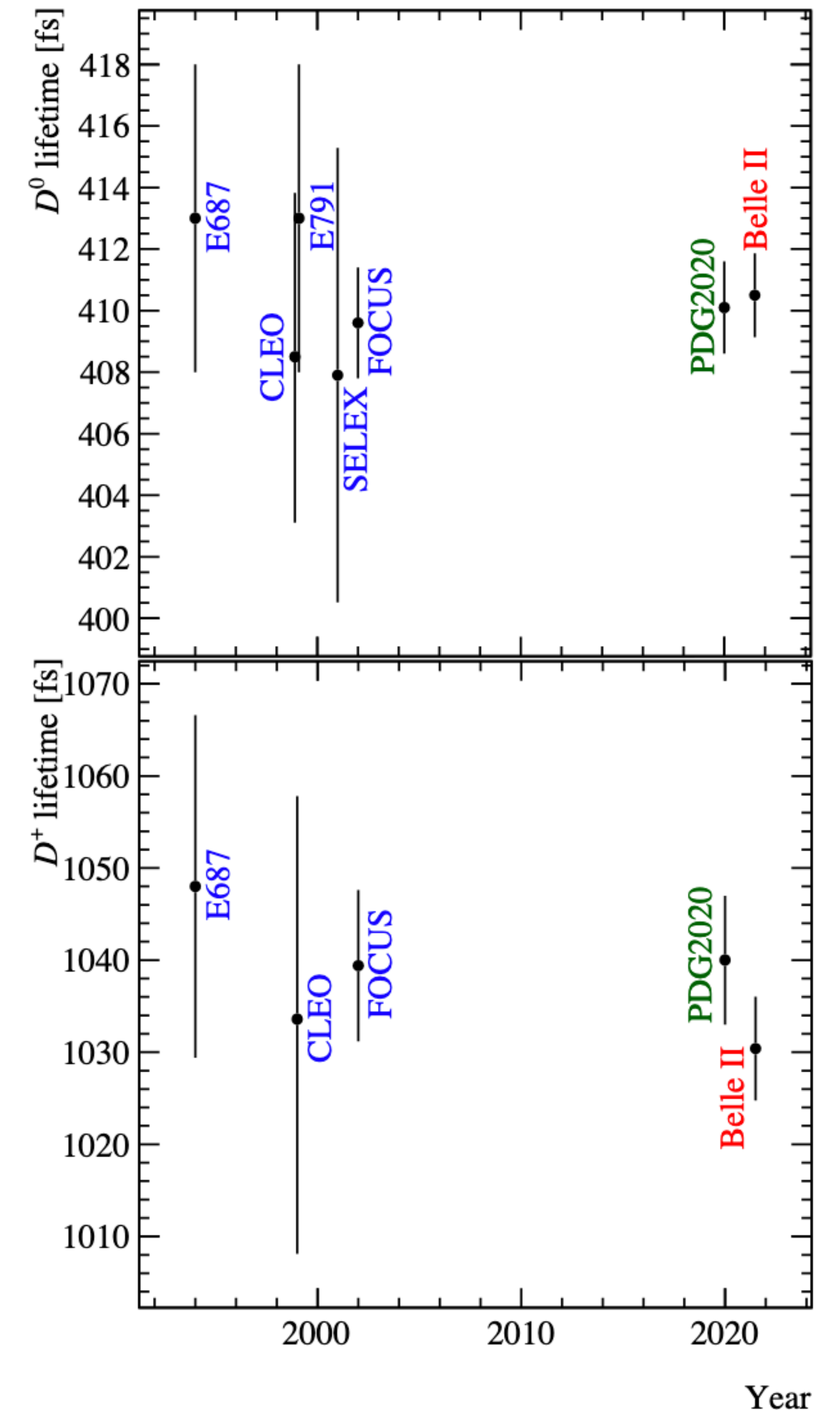
D⁰ and D⁺ measurements by Belle II

$$\tau(D^0) = 410.5 \pm 1.1 \pm 0.8 \text{ fs}$$

$$\tau(D^+) = 1030.4 \pm 4.7 \pm 3.1 \text{ fs}$$

Source	$\tau(D^0)$ [fs]	$\tau(D^+)$ [fs]
Resolution model	0.16	0.39
Backgrounds	0.24	2.52
Detector alignment	0.72	1.70
Momentum scale	0.19	0.48
Total	0.80	3.10

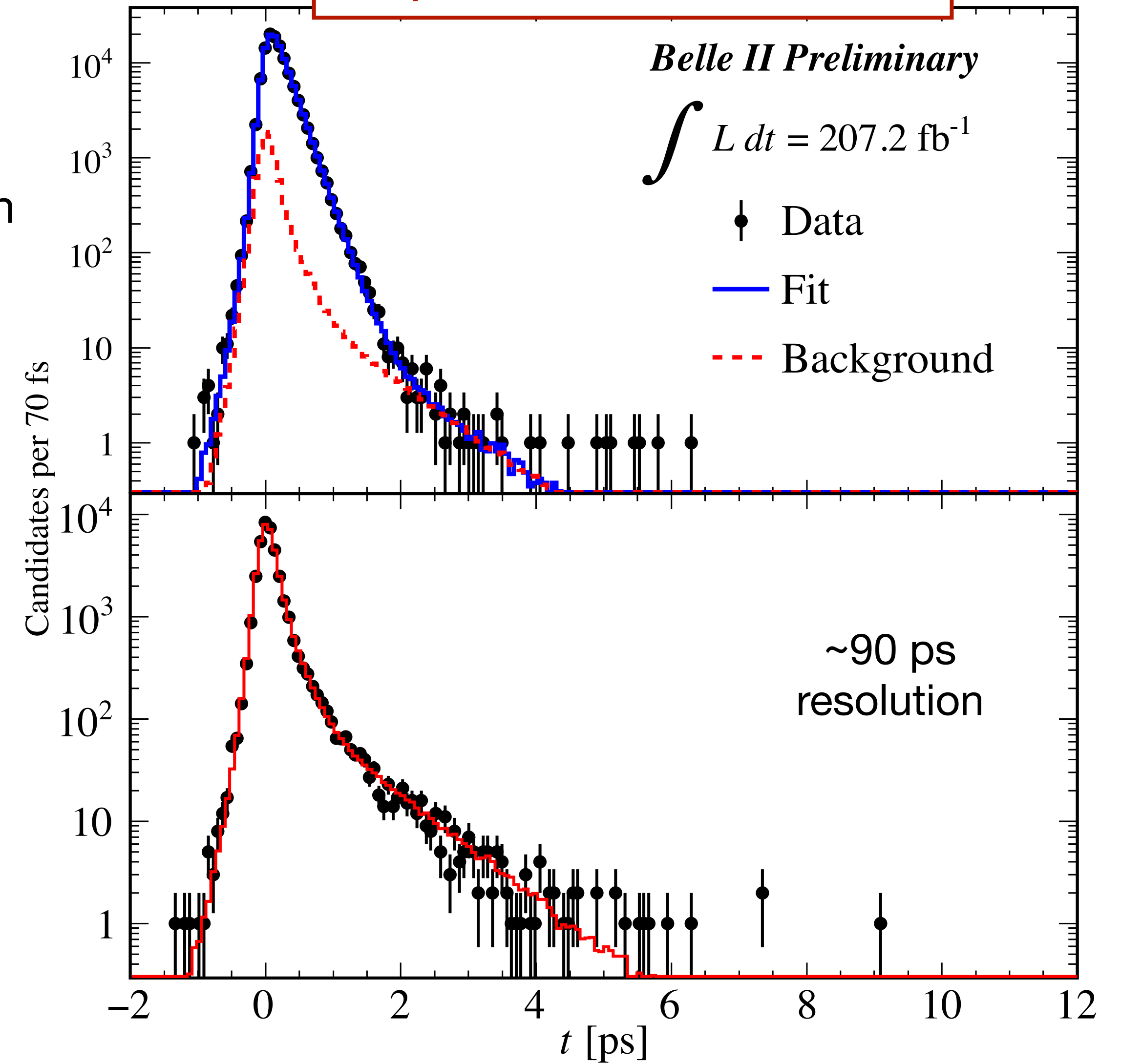
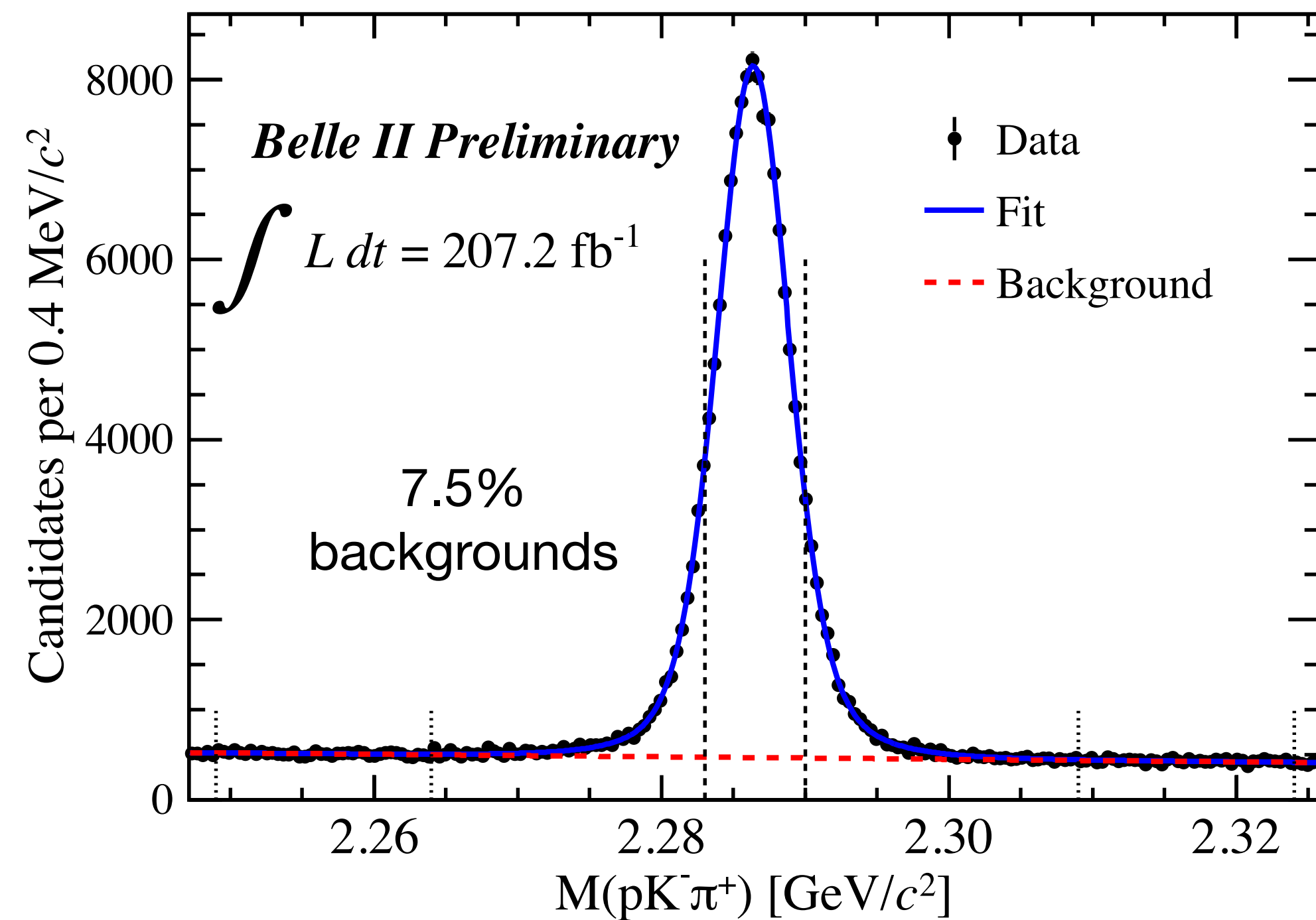
- **World's best measurements of the D⁰ and D⁺ lifetimes**
 - Consistent with current world averages
 - Sub-1% accuracy establishes excellent detector performance
 - Paves the way for additional lifetime measurements



Λ_c^+ lifetime measurement at Belle II

- Relatively clean sample of $\Lambda_c^+ \rightarrow pK^-\pi^+$ events
 - Lifetime measured from a fit to the (t, σ_t) distribution
 - Reprocessing includes improved alignment calibration
 - Potential bias due to $\Xi_c^0 \rightarrow \Lambda_c^+\pi^-$ and $\Xi_c^+ \rightarrow \Lambda_c^+\pi^0$

Updated for FPCP,
supersedes Moriond results



Ξ_c contamination

- Potentially problematic background from $\Xi_c^0 \rightarrow \Lambda_c^+ \pi^-$ and $\Xi_c^+ \rightarrow \Lambda_c^+ \pi^0$
 - Not accounted in previous Λ_c lifetime measurements
 - $BR(\Xi_c^0 \rightarrow \Lambda_c^+ \pi^-) = 0.55 \pm 0.20 \%$ (LHCb: [PhysRevD.102.071101](#))
 - $BR(\Xi_c^+ \rightarrow \Lambda_c^+ \pi^0) = 1.11 \%$ (<https://arxiv.org/pdf/2111.14111.pdf>)

Lifetimes

$$\tau(\Xi_c^0) = 153 \pm 6 \text{ fs}$$

$$\tau(\Xi_c^+) = 456 \pm 5 \text{ fs}$$

No BF measurement
(theory prediction made
after LHCb measurement
for $\Xi_c^0 \rightarrow \Lambda_c^+ \pi^-$)

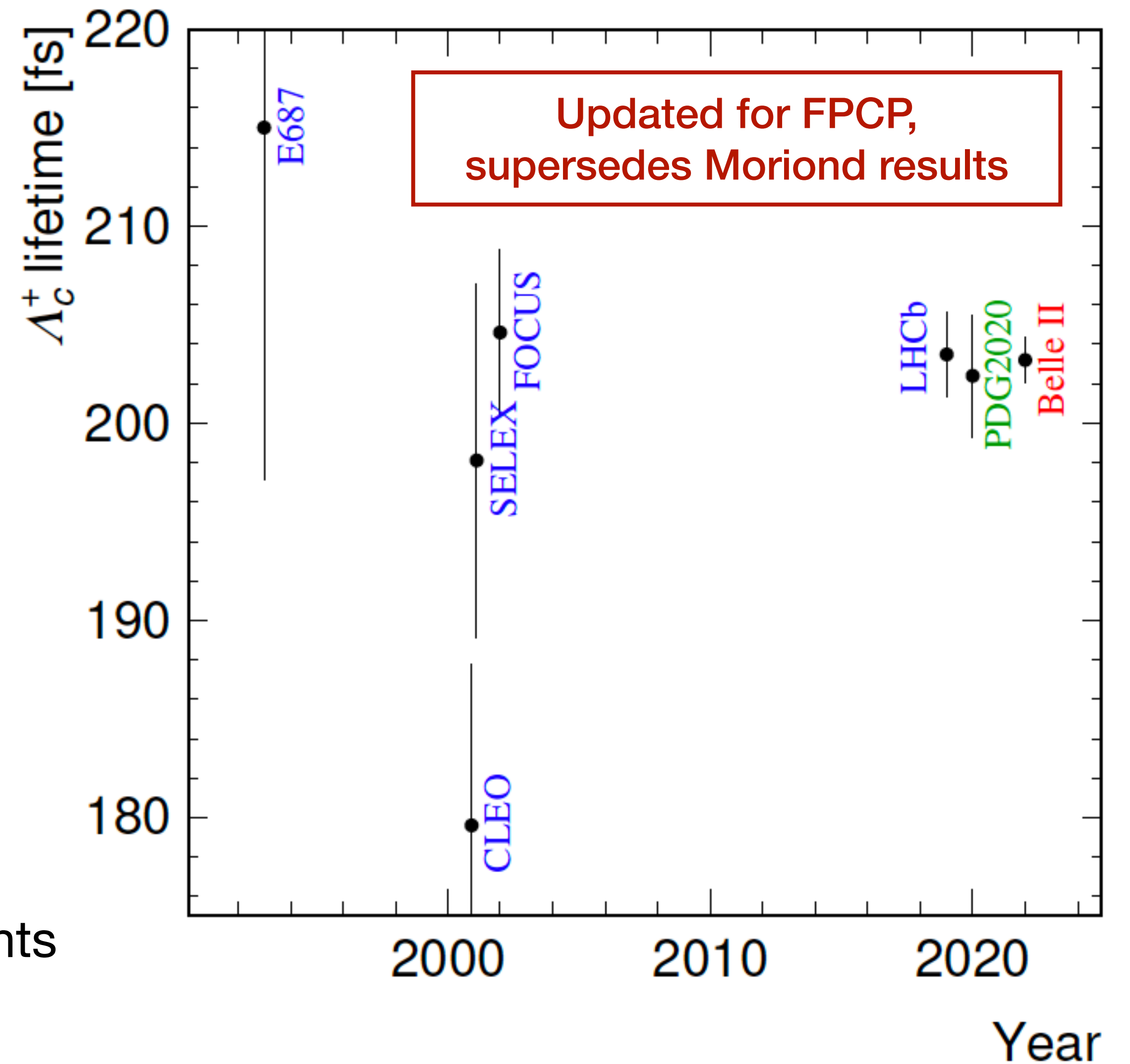
- Reduce backgrounds with veto and correct for remaining
 - Require $M(\Xi_c) - M(\Lambda_c)$ within 2σ of expected value
 - Conservative estimate determined from fit to impact parameter for Λ_c^+
 - Mix signal events with generic MC to test potential remaining bias
 - Take half the shift as correction and systematic uncertainty

Source	Uncertainty [fs]
Ξ_c contamination	0.34
Resolution model	0.46
Backgrounds	0.20
Detector alignment	0.46
Momentum scale	0.09
Total	0.77

Λ_c^+ lifetime measurement at Belle II

Experiment	Lifetime (fs)
This measurement	$203.20 \pm 0.89 \pm 0.77$
LHCb (2019)	$203.5 \pm 1.0 \pm 1.3 \pm 1.4$
FOCUS (2002)	$204.6 \pm 3.4 \pm 2.5$
SELEX (2001)	$198.1 \pm 7.0 \pm 5.6$
CLEO (2001)	$179.6 \pm 6.9 \pm 4.4$

- **World's best measurements of the Λ_c^+ lifetime**
 - Consistent with current world averages
 - Slight tension with CLEO measurement remains
 - Benchmark for future baryon lifetime measurements



Summary

- Major upgrade at KEK for the next generation B-factory
 - Many detector components and electronics replaced, software and analysis tools also improved!
 - Rich physics program, complementary to existing experiments and the energy frontier program
- **First high-precision results are here!**
 - **World's best D lifetimes, establishes excellent vertexing**
 - **World's best Λ_c lifetime, benchmark for future baryon lifetimes**
- Only 0.5% of target integrated luminosity collected so far - much more to come!