Belle II

Latest *Belle II* results on beauty and charm decays

Saurabh Sandilya

(on behalf of the Belle II Collaboration)

भारतीय प्रौद्योगिकी संस्थान हैदराबाद

Indian Institute of Technology Hyderabad

Rencontres de Moriond 2021

QCD & High Energy Interactions

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SuperKEKB+Belle II : beauty and charm factory

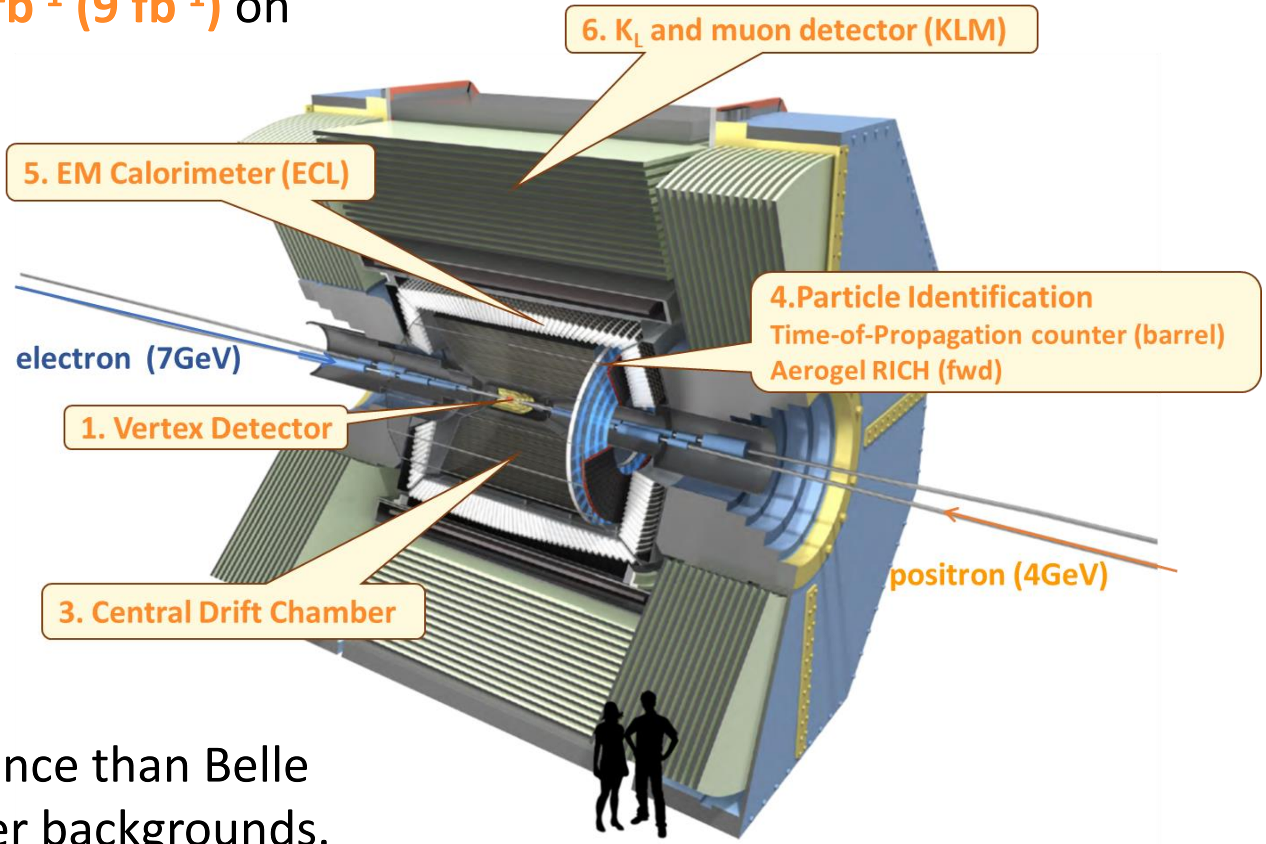
- SuperKEKB collides e^+ and e^- , with CM energy at $\Upsilon(4S)$ resonance.
- $e^+e^- \to \Upsilon(4S)$: 1.1 nb, $e^+e^- \to c\bar{c}$: 1.3 nb , $e^+e^- \to \tau^+\tau^-$: 0.92nb
- Large and clean samples of B mesons, D mesons and τ leptons.

Gianluca Inguglia (Mar 31st)

- Total data set about 105 fb^{-1}. Today's results based on up to **63 fb^{-1} (9 fb^{-1})** on (off) resonance

$\mathcal{L}_{goal} = 6.5 \times 10^{35}\ cm^{-2}s^{-1}$

$\mathcal{L}_{achieved} = 2.4 \times 10^{35}\ cm^{-2}s^{-1}$
on June 2020, world record

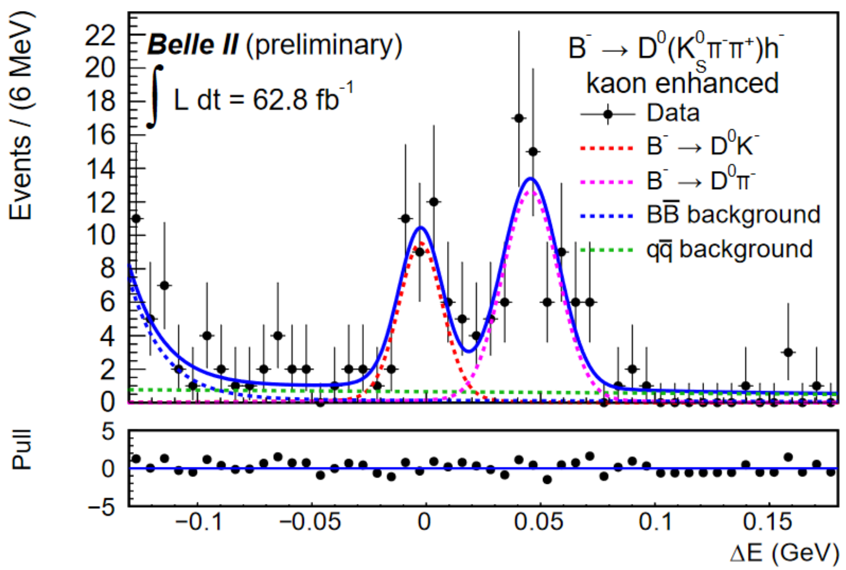


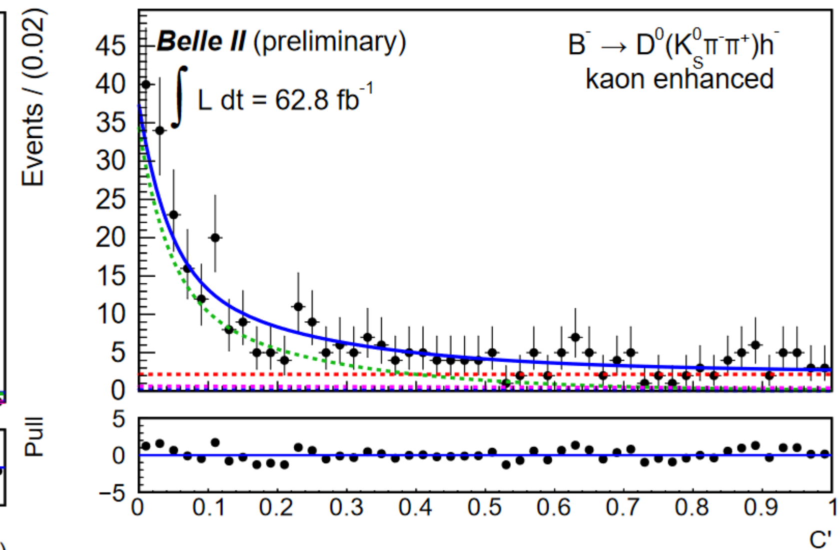
As compared to Belle :

- Better vertex resolution
- Better Ks efficiency
- Similar K/π separation.
- Similar or better performance than Belle even under 20 times higher backgrounds.

Study of $B^- \to D^{(*)}h^-$

- Decays $B^- \to D^{(*)+}K^-$ are important for precise determination CKM angle γ/ϕ_3.
- Dominant and clean decay $B^- \to D^{(*)}\pi^-$ provide good control sample.
- PID to K/π from B, signal enhanced with $M_{bc} = \sqrt{E_{beam}^2 - (\overrightarrow{P_B}c)^2}$ > 5.27 GeV/c²;
- Unbinned ML fit in ΔE (= E_B - E_{beam}) and MVA output (with event shape variables).

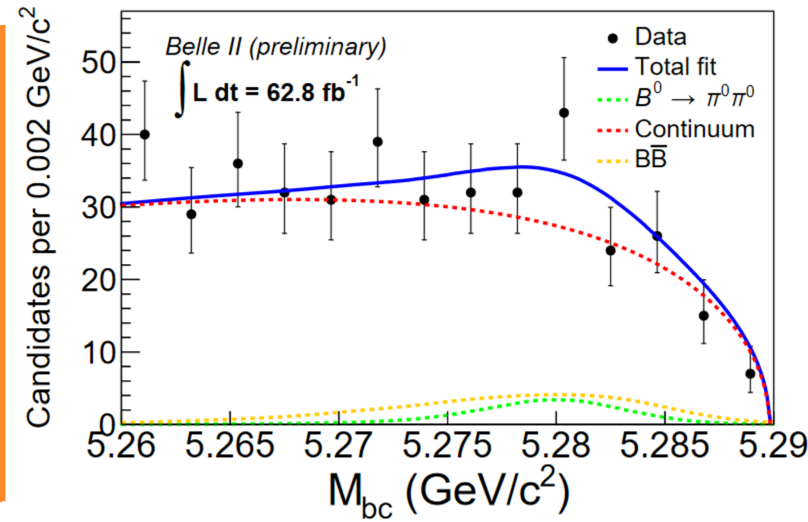




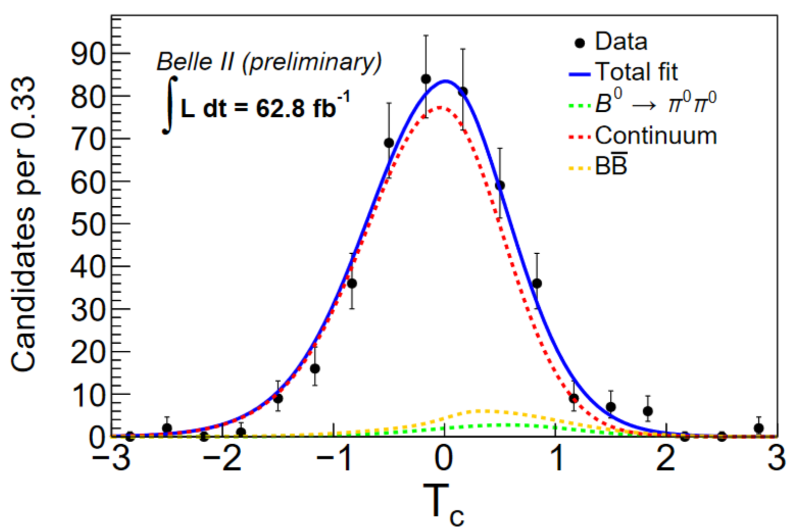
$$\frac{\Gamma(B^- \to D^0(K_S^0\pi^-\pi^+)K^-)}{\Gamma(B^- \to D^0(K_S^0\pi^-\pi^+)\pi^-)} = (6.32 \pm 0.81^{+0.09}_{-0.11}) \times 10^{-2}$$

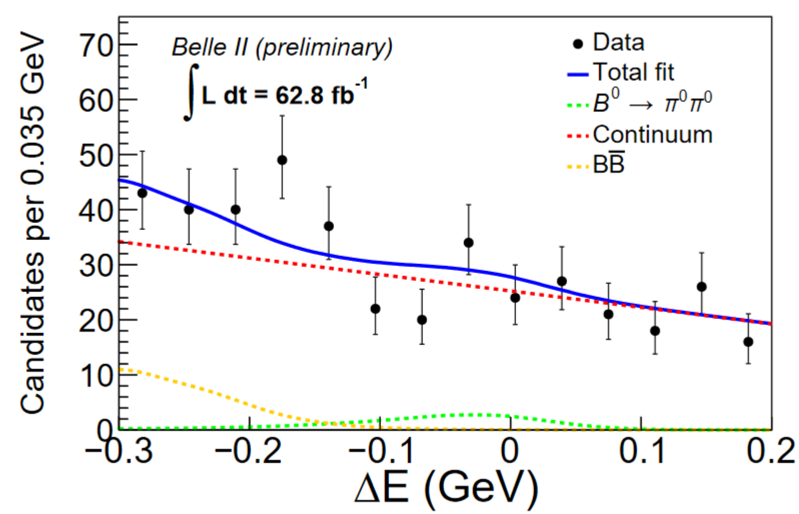
In all the 5 reconstructed modes results agree with the PDG within 2σ

- $B^0 \to \pi^0\pi^0$ limits precision of isospin relations to determine α/ϕ_2.
- Unique to Belle II : final state are just four photons.
- $B \to D(K\pi\pi^0)\pi^0$ as control channel.
- Dedicated MVA for optimized photon selection.
- Dominant bkg from continuum π^0. Suppressed with another MVA.



Unbinned ML 3D fit

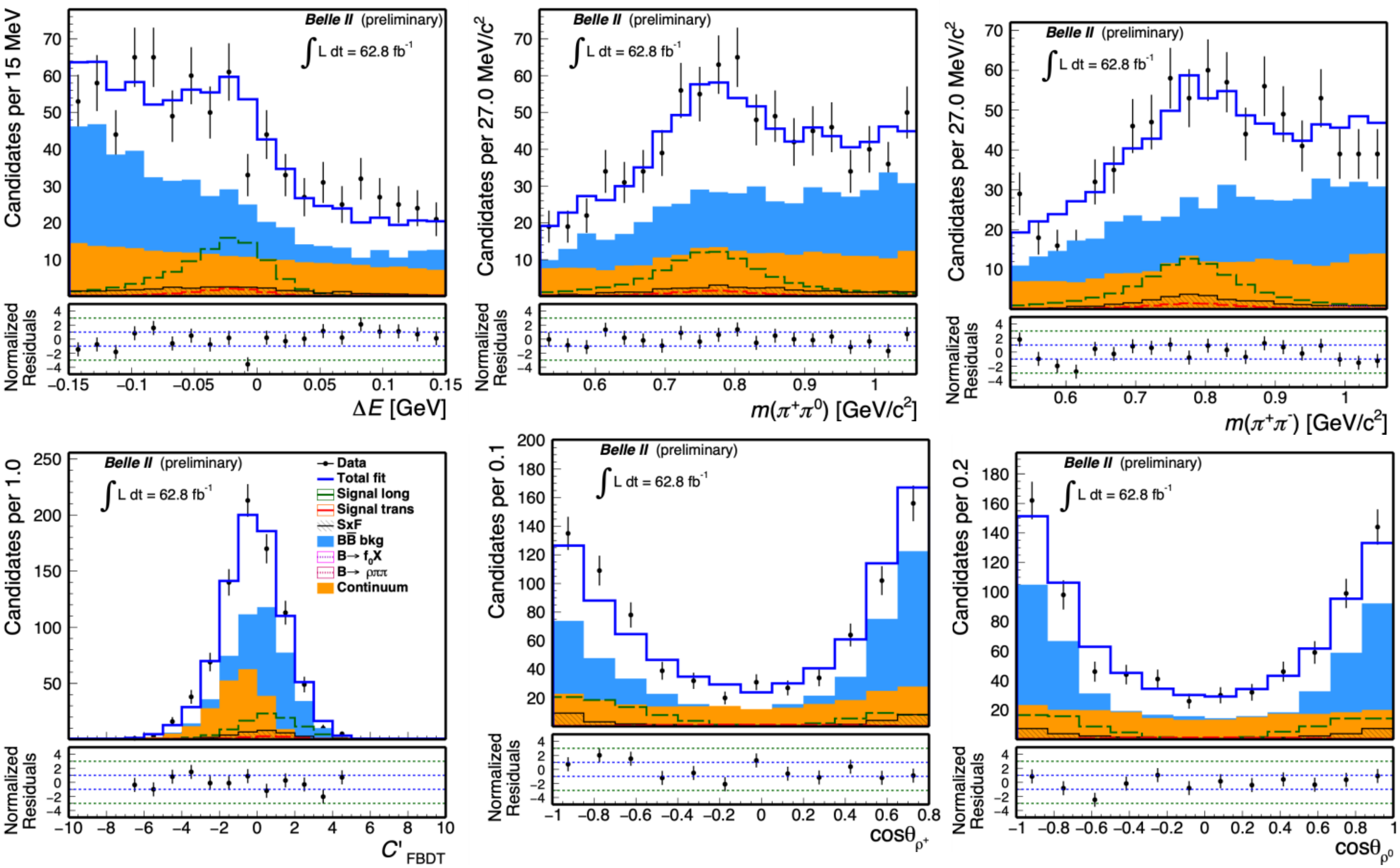




- Signal yield $14.0^{+6.8}_{-5.6}$ events, and **BF($B^0 \to \pi^0\pi^0$) = $0.98^{+0.48}_{-0.39} \pm 0.27 \times 10^{-6}$**

First Belle II analysis of $B^+ \to \rho^+\rho^0$

- pion-only $(\pi^+\pi^0)(\pi^+\pi^-)$ final state and broad ρ peak $\Rightarrow$ large bkg
- Spin-0 → spin1 + spin-1 $\Rightarrow$ angular analysis.
- 6D fit including ΔE, CS, and ρ masses to extract signal, and helicity angles to measure fraction f_L of decays with longitudinal polarization.



$N = 104 \pm 16$

$\mathcal{B} = [20.6 \pm 3.2(stat) \pm 4.0(syst)] \times 10^{-6}$

$f_L = 0.936^{+0.049}_{-0.041}(stat) \pm 0.021(syst)$

20% better precision than Belle on 78 fb^{-1} (PRL 91, 221801 (2003)).

Continuum | Generic B | Longitudinal signal | Transverse signal

First Belle II measurements of $B^0 \to K^0\pi^0$

- Stringent SM test: $B \to K\pi$ isospin sum rule ([hep-ph/0508047](hep-ph/0508047))

$$I_{K\pi} = A_{K^+\pi^-} + A_{K^0\pi^+}\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{K^+\pi^0}\frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{K^0\pi^0}\frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

Precision on $A_{K^0\pi^0}$ is the most limiting input

Challenges:

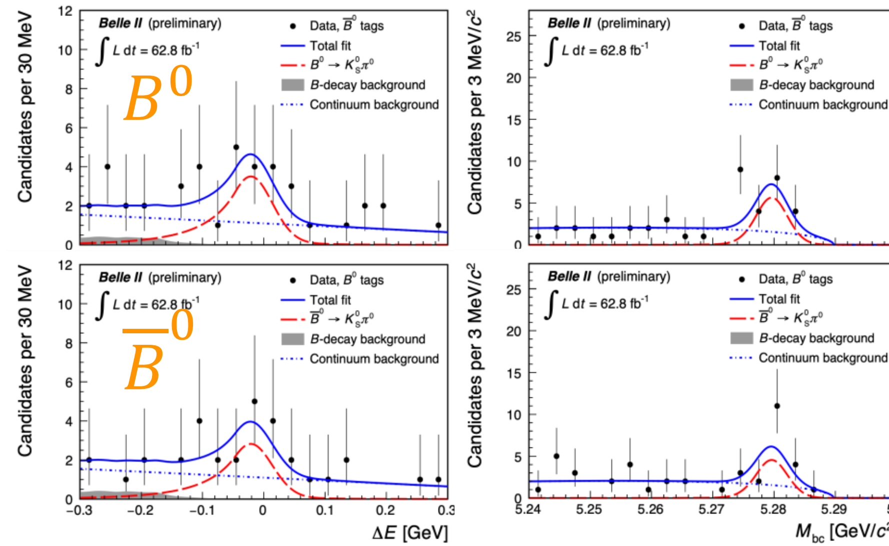
- π^0 final state ⇒ ΔE tails
- CP-eigenstate ⇒ need flavor tagging

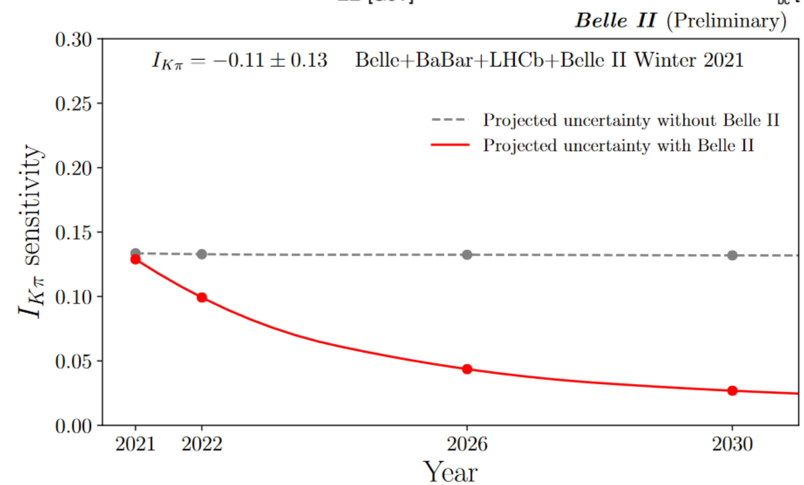
$$N(B^0 \to K_S^0\pi^0) = 45^{+9}_{-8}$$

$$\mathcal{B} = [8.5^{+1.7}_{-1.6}(\text{stat}) \pm 1.2(\text{syst})] \times 10^{-6}$$

$$A_{K^0\pi^0} = -0.40^{+0.46}_{-0.44}(\text{stat}) \pm 0.04(\text{syst})$$

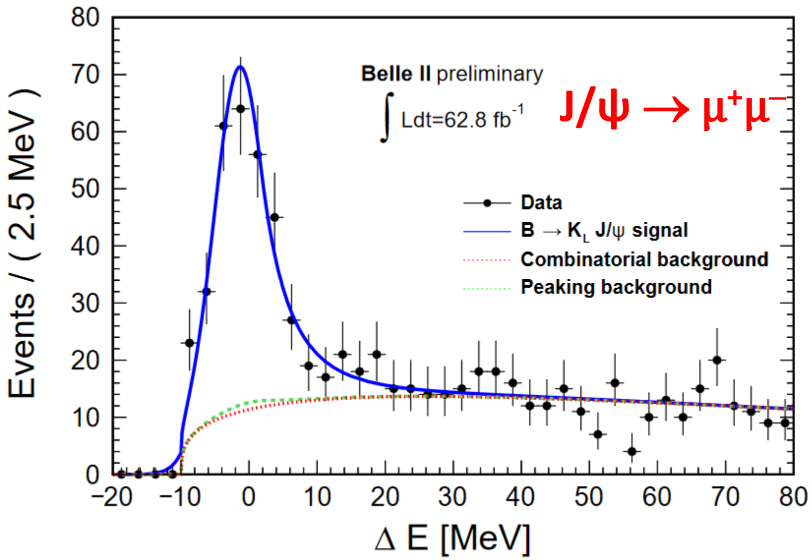
First Belle II DCPV in $K^0\pi^0$, the single most limiting input of isospin-sum-rule probing power

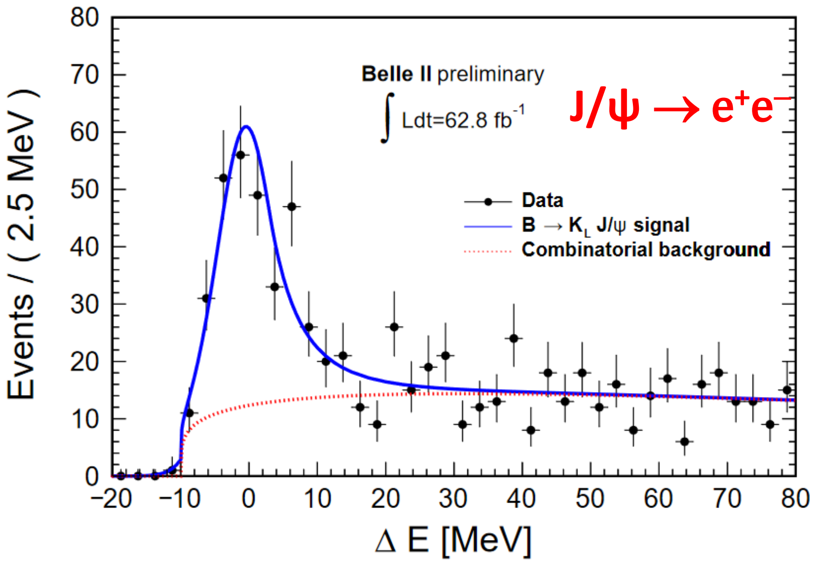




$B^0 \to J/\psi K_L^0$

- The decay $B^0 \to J/\psi K_L^0$ provides an independent measurement of $\sin(2\phi_1)$.
- $J/\psi \to e^+e^-$ or $\mu^+\mu^-$ and K_L^0 is reconstructed as a hadronic neutral cluster in K_L and μ detector (KLM).
- $p(K_L^0)$ is calculated from the direction of the cluster in KLM and reconstructed momentum of J/ψ with B^0 mass constraint.

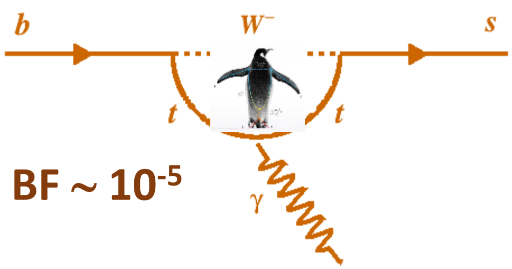




- The yield is observed with the same purity as in predecessor Belle.
- Work in progress to include neutral clusters in ECL in the path of TDCPV and $\sin(2\phi_1)$ measurements

Inclusive photon spectrum from b →sγ transition

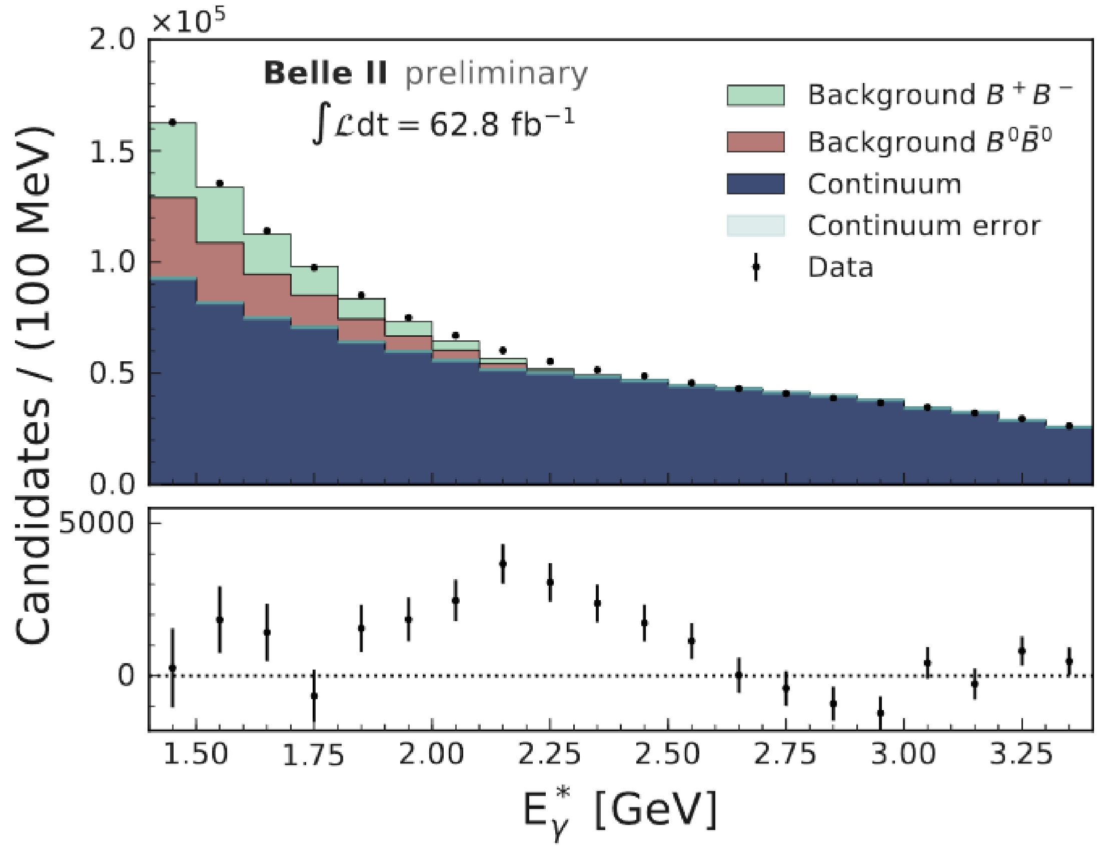
- **B-decays with b→sγ transitions:** FCNCs, suppressed at tree level and sensitive to many SM extension.



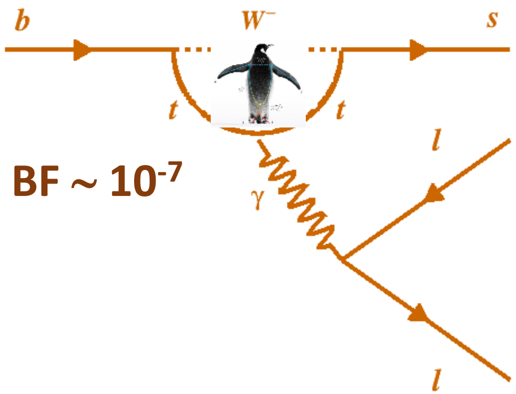
BF ~ 10^{-5}

- Monochromatic (smeared) photon energy from the two-body decay b→sγ.

- High energy photon $E_\gamma^* > 1.4$ GeV
- The γ should not be arising from a π^0 decay
- Continuum Suppression with event shape variables.
- Data driven (from off-resonance and side-bands) scaling of MC.
- Excess around expected region is clearly visible.

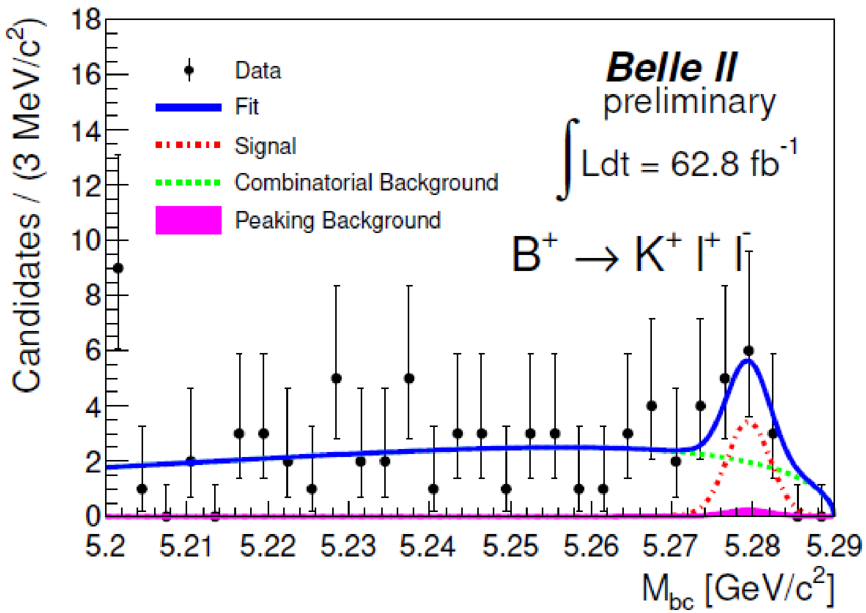


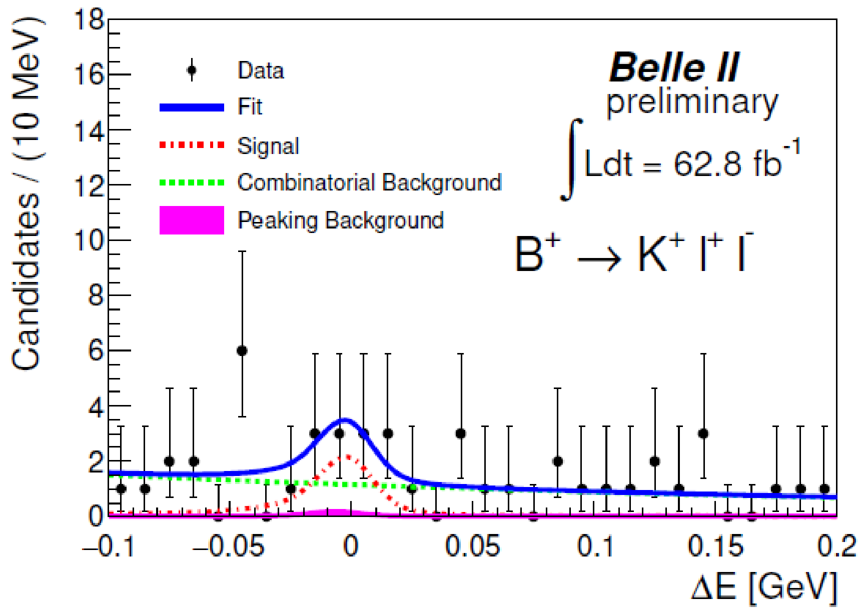
- **B-decays with $b \to s\ell\ell$ transitions:** FCNCs, suppressed at tree level and sensitive to many SM extension.

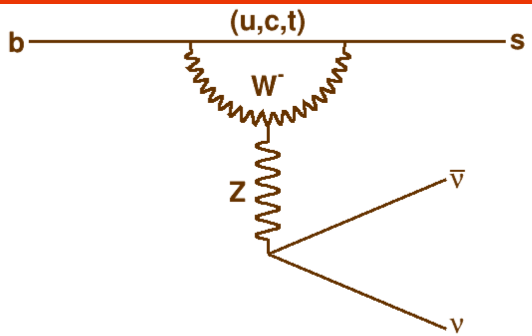


BF ~ 10^{-7}

- These decays have raised a lot of interest in the study of the LFU ratio.
- The rare decays $B^+ \to K^+\ell\ell$ (ℓ =e, μ) are seen at Belle II with just 62.8 fb^{-1}
- Signal yield : $8.6^{+4.3}_{-3.9} \pm 0.4$ (2.7σ)

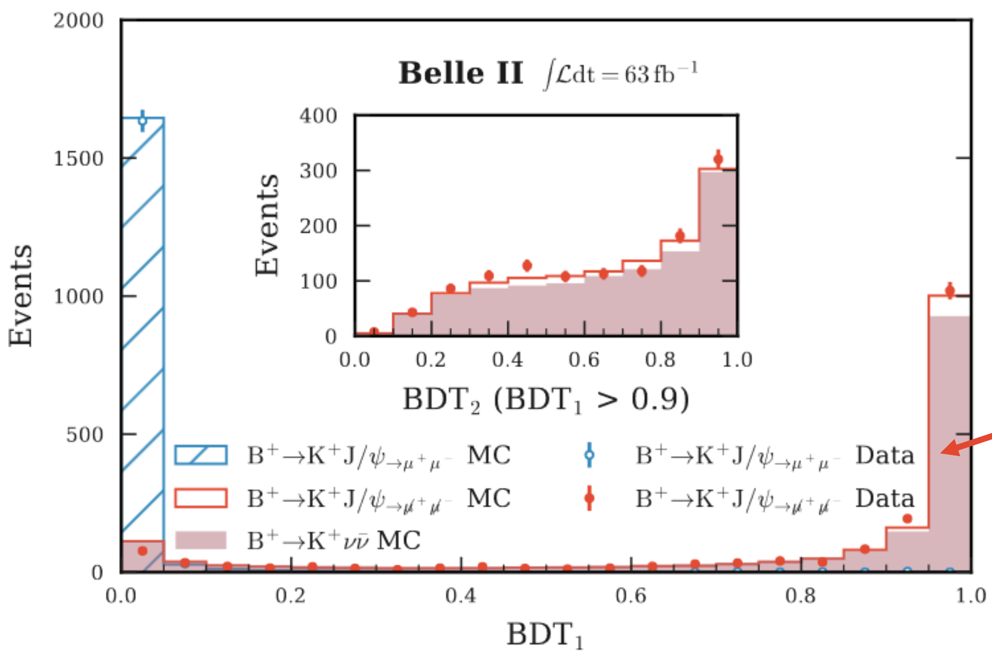






- Transition mediates by a virtual Z-boson.
- SM prediction for the **BF[$B \to K^+\nu\nu$]$_{SM}$** is **$(4.6 \pm 0.5) \times 10^{-6}$** **[B2TIP, PTEP 2019, 123C01].**

- **Inclusive tagging approach** : nested statistical-learning discriminators exploits efficiently topology allowing for sizeable signal (4%) while controlling large backgrounds.

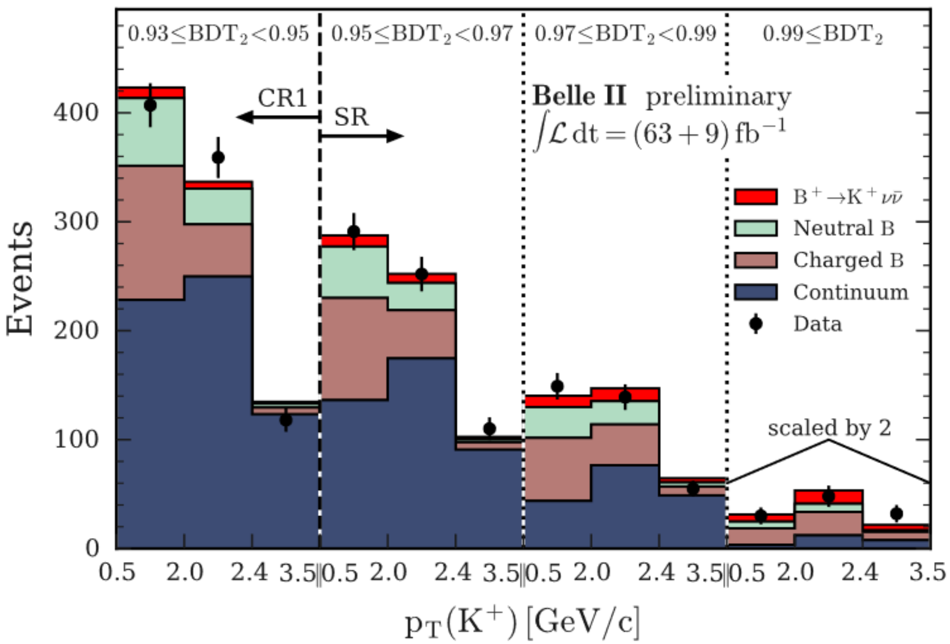


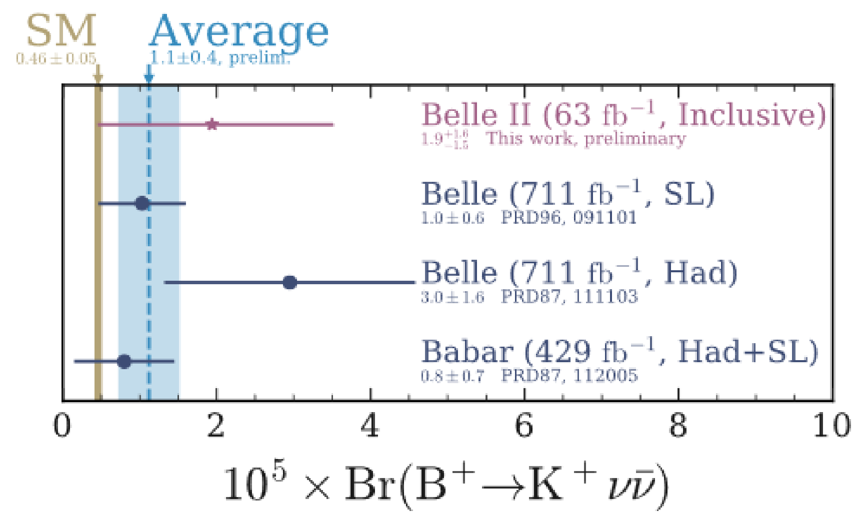
- Validate with **$B^+ \to K^+ J/\psi\ [\to\mu^+\mu^-]$**

- $\mu^+\mu^-$ ignored
- K^+ momentum modified
  2-body → 3 body

- Measured signal strenth $\mu = \mathbf{4.2^{+2.9}_{-2.9}\ {}^{+1.8}_{-1.6}} = 4.2^{+3.4}_{-3.2}$.
- Consistent with the bkg-only (SM) hypothesis at CL 1.3 σ (1 σ)
- Observed (expected) UL @90% CL **4.1×10^{-5}** (2.6×10^{-5})
- $\mathcal{B}[B \to K^+\nu\nu] = \mathbf{1.9^{+1.3}_{-1.3}\ {}^{+0.8}_{-0.7} \times 10^{-5}}$

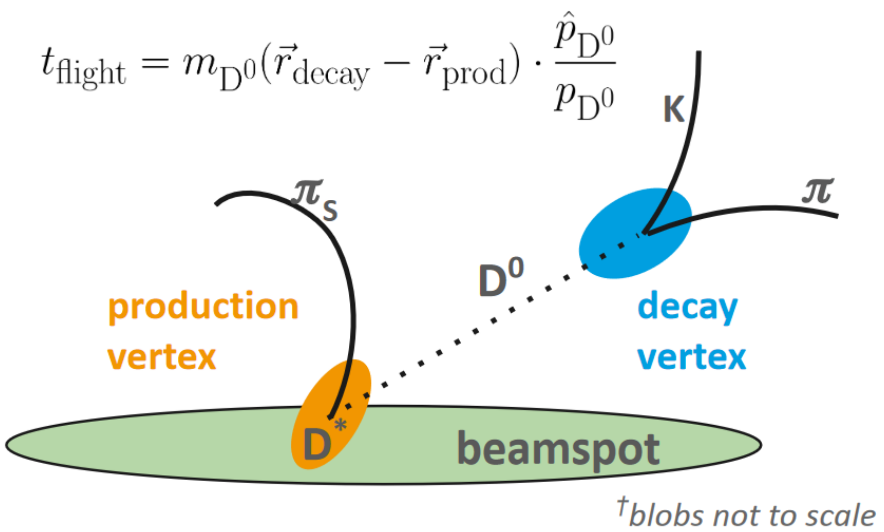
Data and post-fit predictions in the signal and control region bins

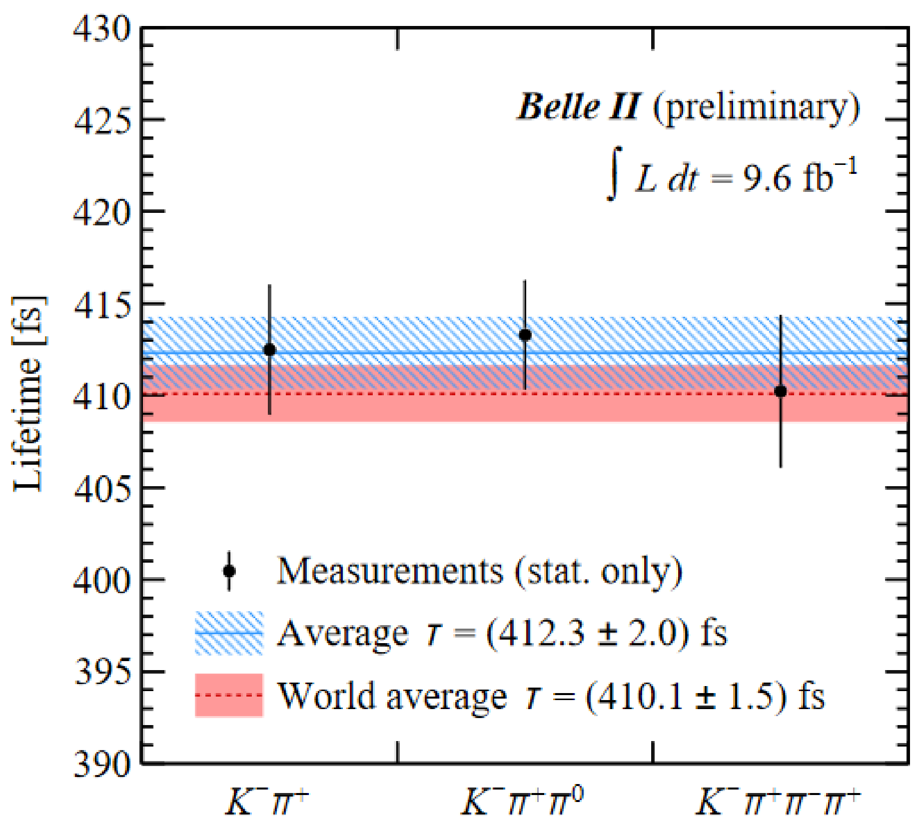




Sensitivity with just 63 fb^{-1} data is already close to previous searches with significantly large data-set.

- Reconstructed $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^0$, and $D^0 \to K^-\pi^+\pi^+\pi^-$ from $D^{*+} \to D^0\pi^+_s$ in 9.6 fb^{-1} data collected in 2019.
- D^{*+} should not be originating from a B decay ($P^*_{D^*} > 2.5$GeV).



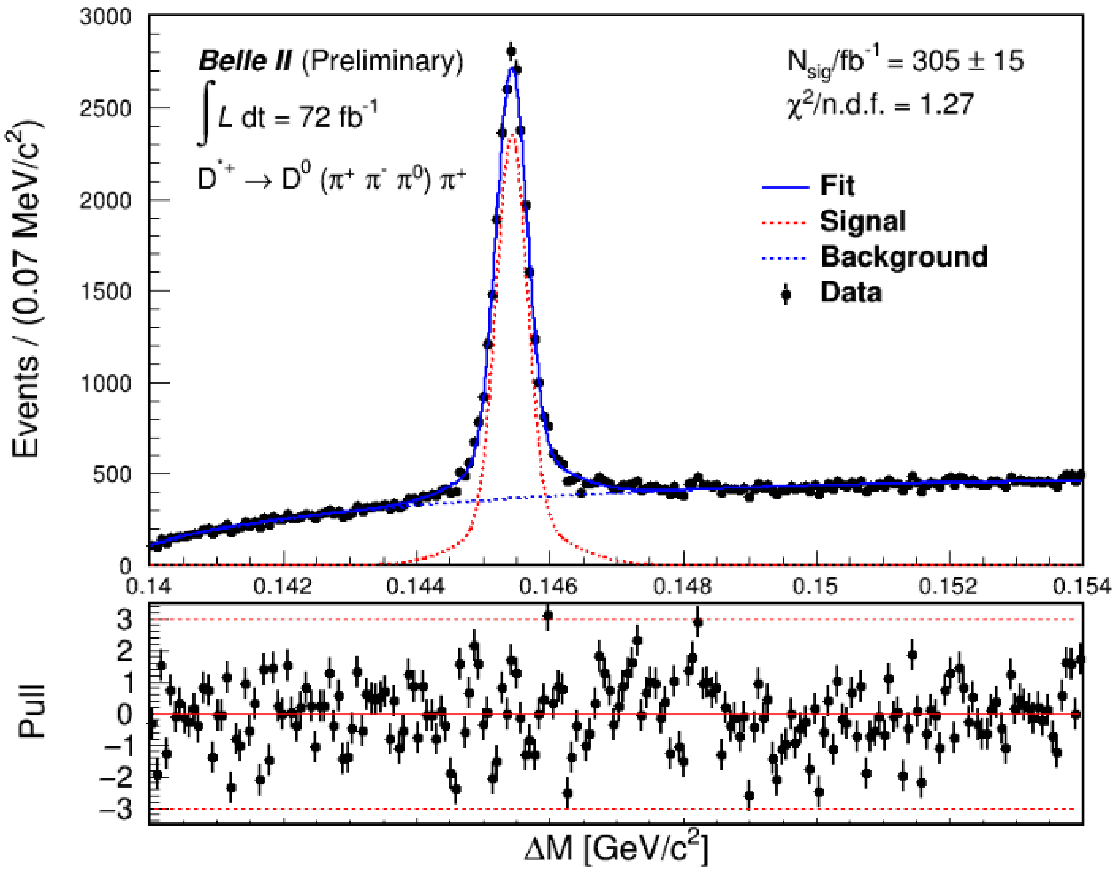


With 72 fb^{-1} Belle II life-time measurements expected to be competitive with world-averages!

- CPV in charm remains an important topic to study for the Belle II experiment.
- Preliminary study of the decay $D^{*+} \to D^0 [\pi^0\pi^+\pi^-]\pi^-$
- Ultimately to study time-averaged Dalitz analysis.

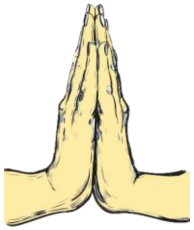
- Standard selection of π^+ and π^0
- D^{*+} should not be originating from a B-decay ($P^*_{D^*} > 2.5$GeV)

- Unbinned ML fit to $\Delta M \cong M[D^{*+}] - M[D^0]$.
- Signal (two Gaussian) Background (Threshold function).
- Signal yield (estimated)/fb^{-1} = 305 ± 15



Summary

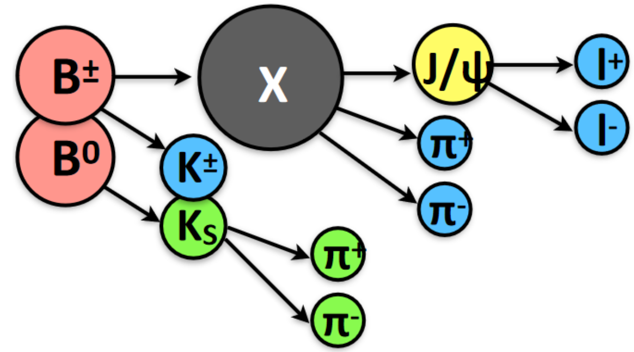
- Upcoming large and clean samples of B, D (and τ) will allow Belle II to search for NP and to improve the measurements of SM parameters.
- Improved detector and analysis methods at Belle II leads to better sensitivity.
- Results using early data demonstrates the expected performances of all the sub-detectors.
- Belle II is running well amid CoViD-19 towards its ultimate goal to record $50 ab^{-1}$.

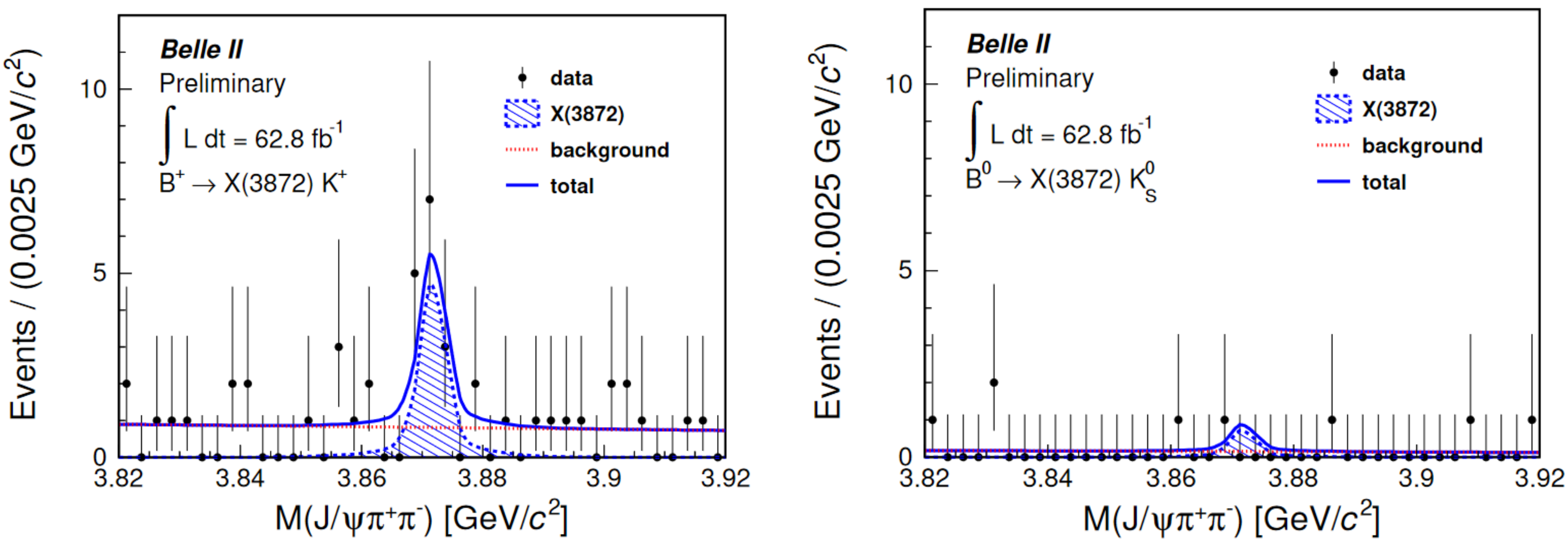


Extra Slides

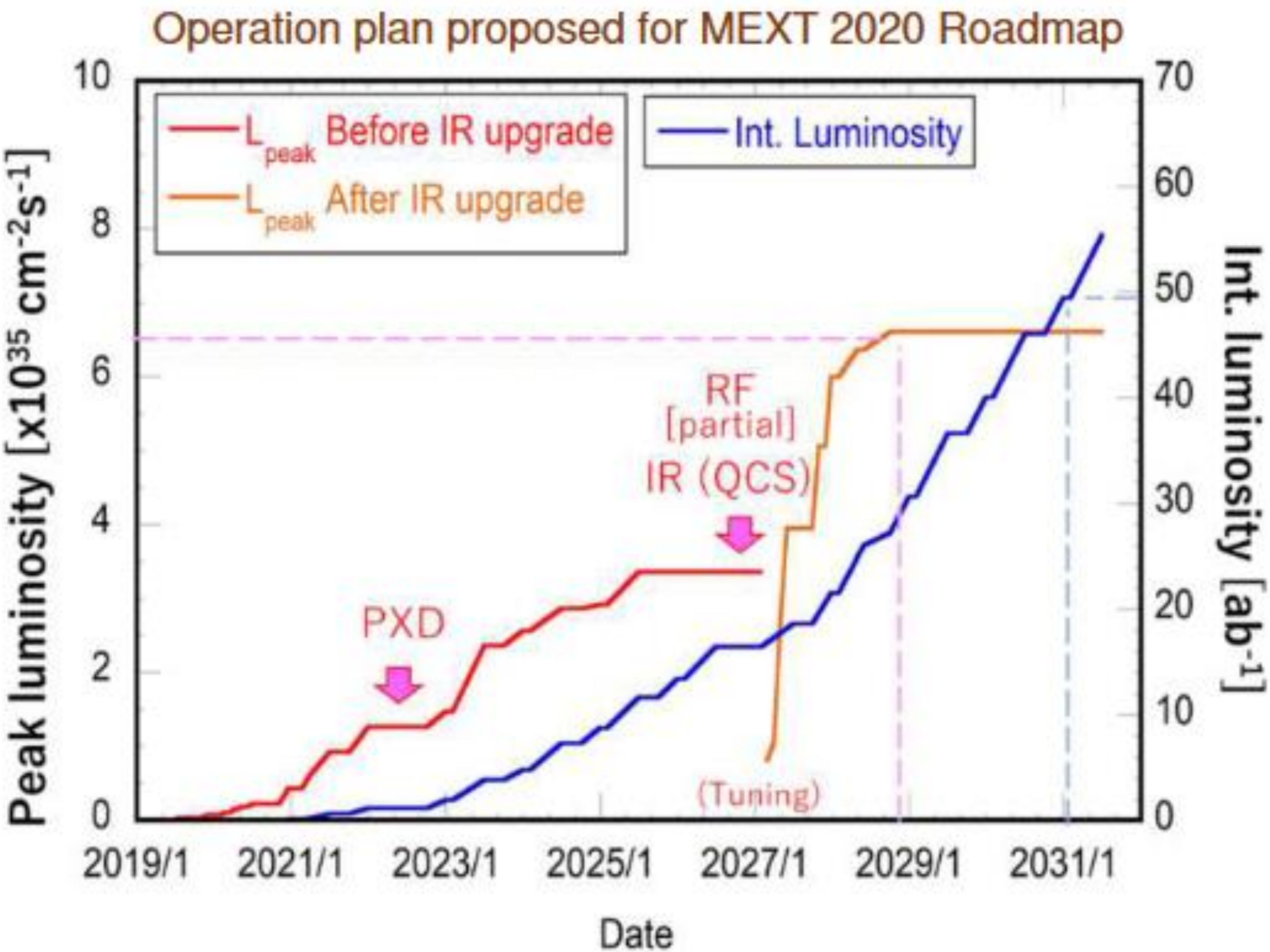
X(3872) rediscovery

- The exotic state X(3872) is searched in the B-decay:
- The decay $B \to K\psi(2S)[\to J/\psi\pi\pi]$ serves as a good control sample.
- Simultaneous fit is performed to combine the distribution from B^+ and B^0 decays.

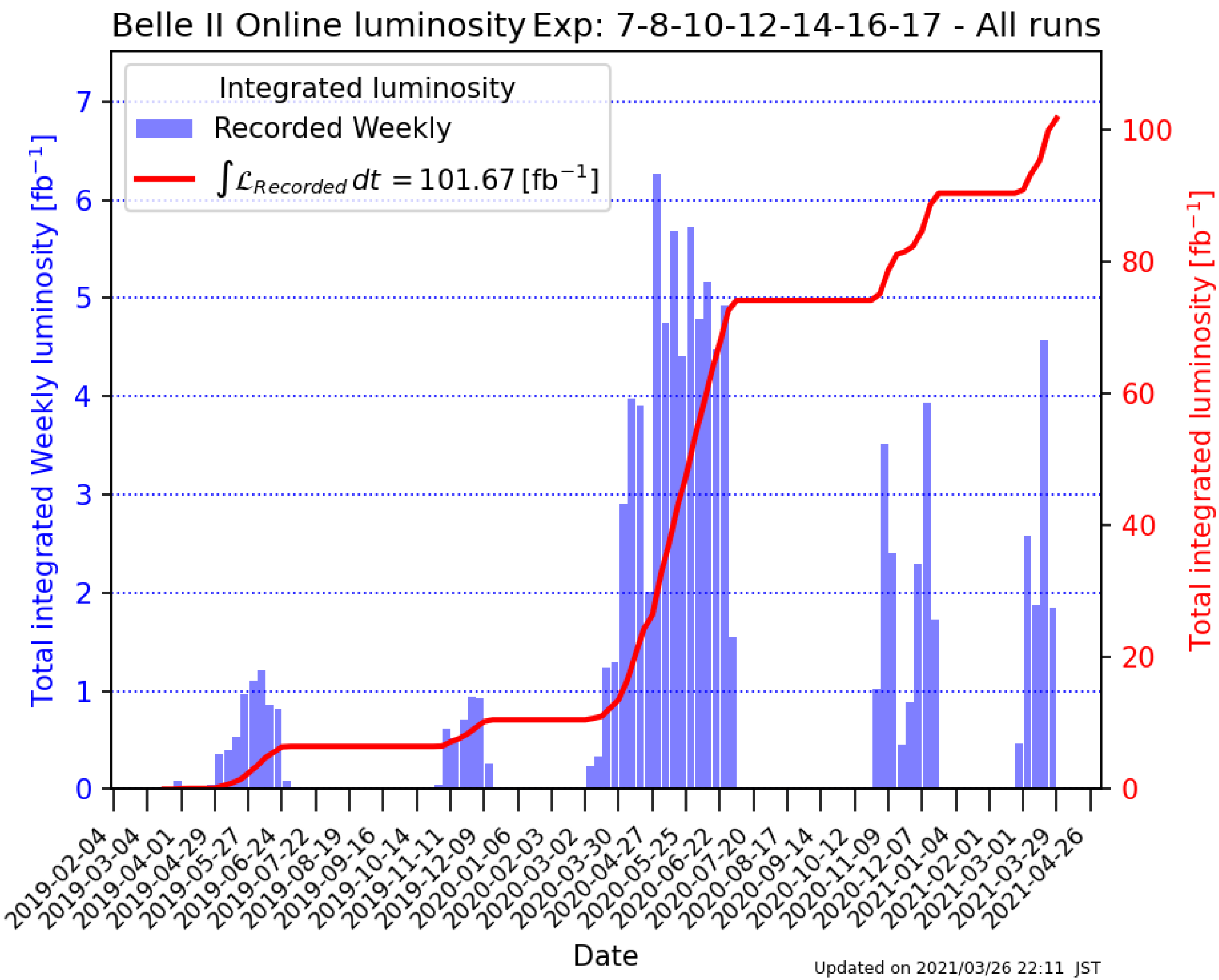




- The X(3872) signal yield is 14.4 ± 4.6 and the statistical significance is 4.6σ.
- First exotic state to be rediscovered in Belle II.


Operation plan proposed for MEXT 2020 Roadmap
L peak Before IR upgrade
L peak After IR upgrade
Int. Luminosity
Peak luminosity [x10^35 cm^-2 s^-1]
Int. luminosity [ab^-1]
PXD
RF
[partial]
IR (QCS)
(Tuning)
10
8
6
4
2
0
70
60
50
40
30
20
10
0
2019/1
2021/1
2023/1
2025/1
2027/1
2029/1
2031/1
Date

SuperKEKB Luminosity Plan



$B^0 \to K^0\pi^0$

- CP-eigenstate: flavor tagging to determine tag-side B's flavor
- Probability density function of signal-side quark flavor q:

$$P_{sig}(q) = \frac{1}{2}(1 - q \cdot \Delta w_r + q \cdot (1 - 2w_r) \cdot (1 - 2\chi_d) \cdot A_{K^0\pi^0})$$

(* integrated over B mesons' lifetime difference Δt: $P(q, \Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}[1 + q(A_f \cos(\Delta m_d \Delta t) + S_f \sin(\Delta m_d \Delta t)]$)

χ_d: time-integrated B^0 mixing probability (external input)

Assume null A_{CP}^{rare} + continuum flavor symmetric

- Simultaneous fit over 7 flavor tagging r-bins

Source	$\delta\mathcal{B}(\%)$
Tracking efficiency	1.8
K_S^0 reconstruction efficiency	3.8
π^0 reconstruction efficiency	3.2
Continuum-suppresion efficiency	2.4
N($B\bar{B}$) (as written in Eq. 3)	1.4
Signal model	<0.1
Continuum background model	1.2
Total	6.1

Source	$\delta\mathcal{A}_{K^0\pi^0}$
Flavor tagging modelling	0.03
B^0 mixing parameter χ_d	<0.01
B-decay background asymmetry	0.03
Continuum background asymmetry	0.01
Total	0.04

$$\mathcal{B} = (8.6^{+1.7}_{-1.6} \pm 0.5) \times 10^{-6}$$

$$A_{K^0\pi^0} = -0.42^{+0.46}_{-0.44} \pm 0.04$$