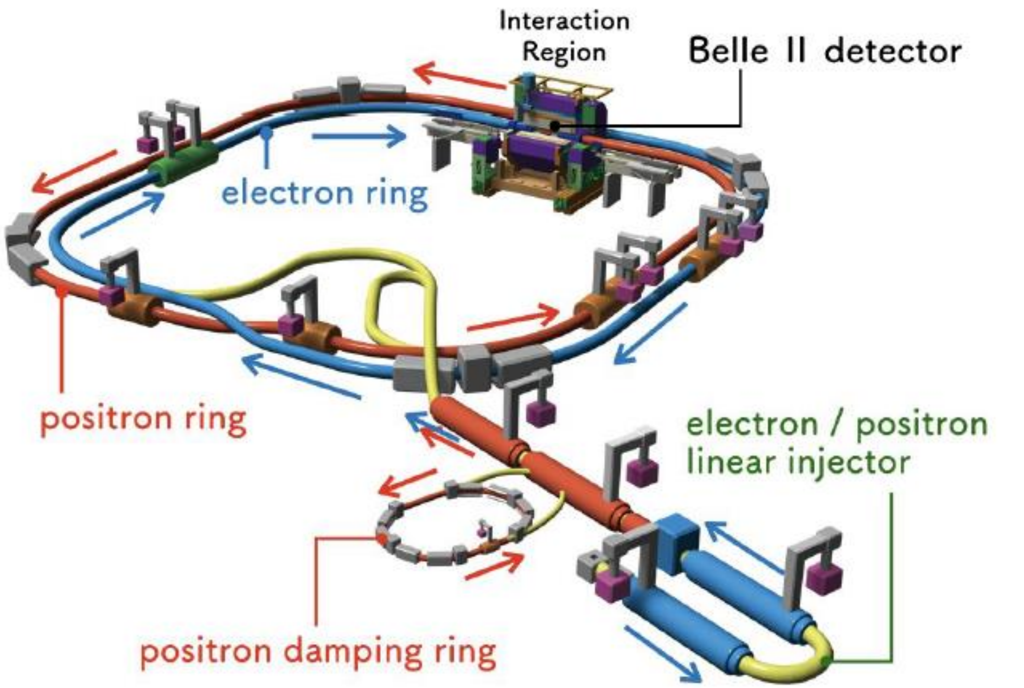
Main Results from Belle II experiment

A. Passeri, INFN Roma Tre
On behalf of the Belle and Belle II collaborations

QCD@Work – Trani 17-21 june 2024

The SuperKEKB Collider

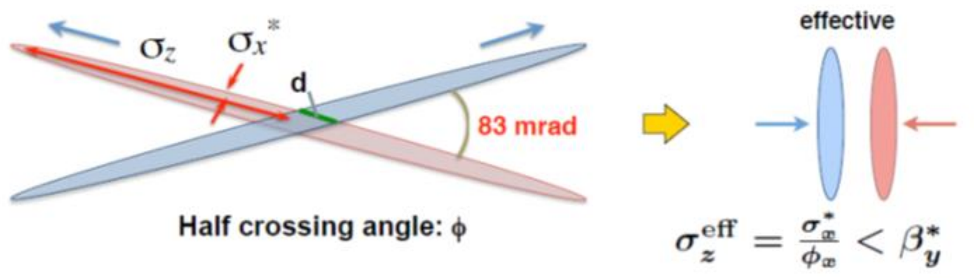


Asymmetric e^+ (4 GeV) e^- (7 GeV) collider working mainly at Y(4S) @ KEK laboratory, Tsukuba, Japan

Holds world luminosity record: 4.7×10^{34} $cm^{-2}s^{-1}$ (2022)

Aims to exceed 10^{35} and to deliver multi ab^{-1} data sample in the next few years

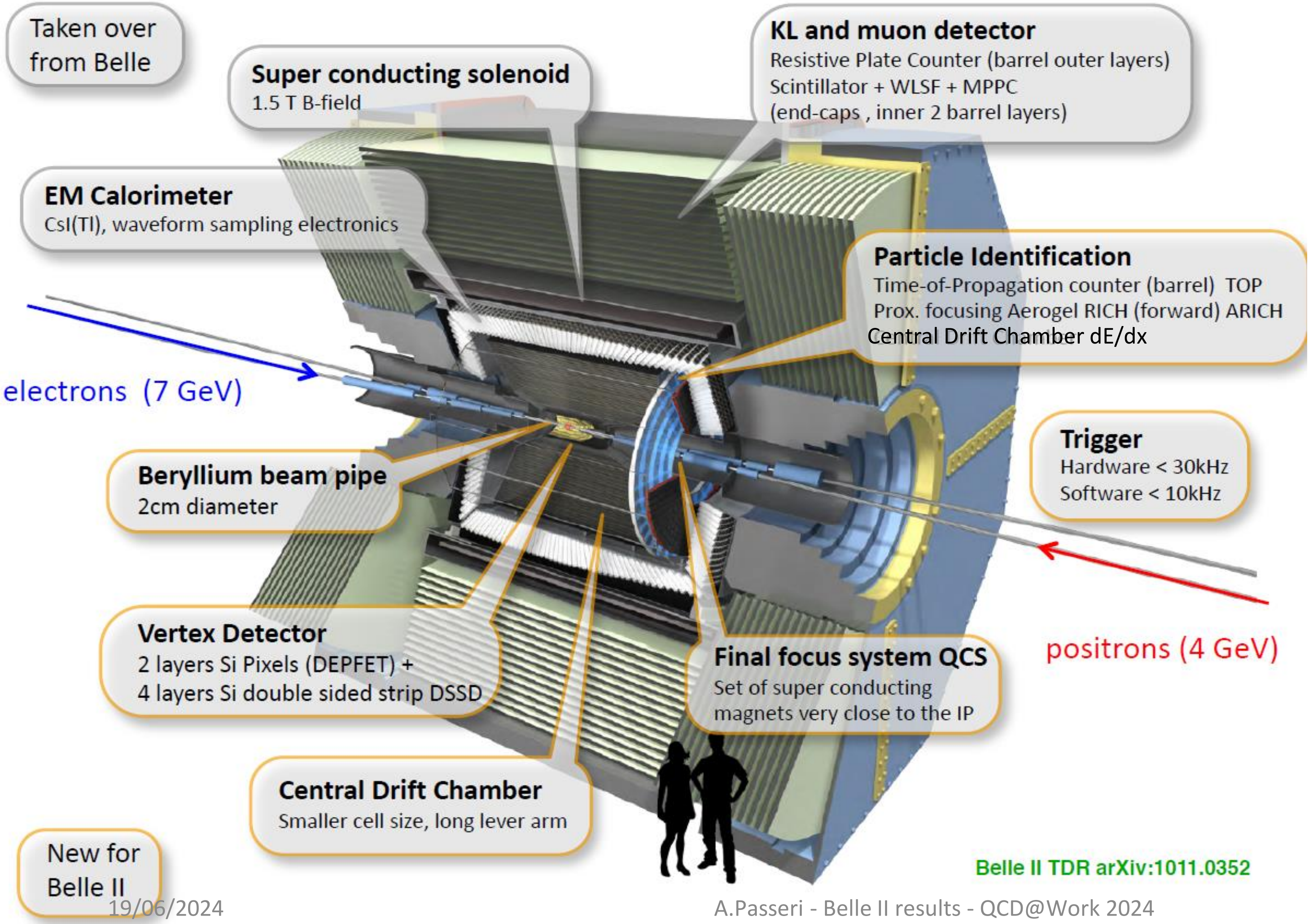
Nano-Beam scheme (P. Raimondi):
Squeeze beta function at the IP (β_x^*,β_y^*) and minimize longitudinal size of overlap region to avoid hourglass effect



Strong focusing of beams down to vertical size of ~ **50 nm** requires **very low emittance beams** and **large crossing angle (83 mrad)**
$\Rightarrow$ Need **powerful** and **sophisticated final focus** system (QCS)

- Delivered 424 fb^{-1} in Run1 (2019-22)
- Maintenance and upgrades during long shutdown 1
- Restarted collision (Run2) in Feb 2024.

The Belle II detector



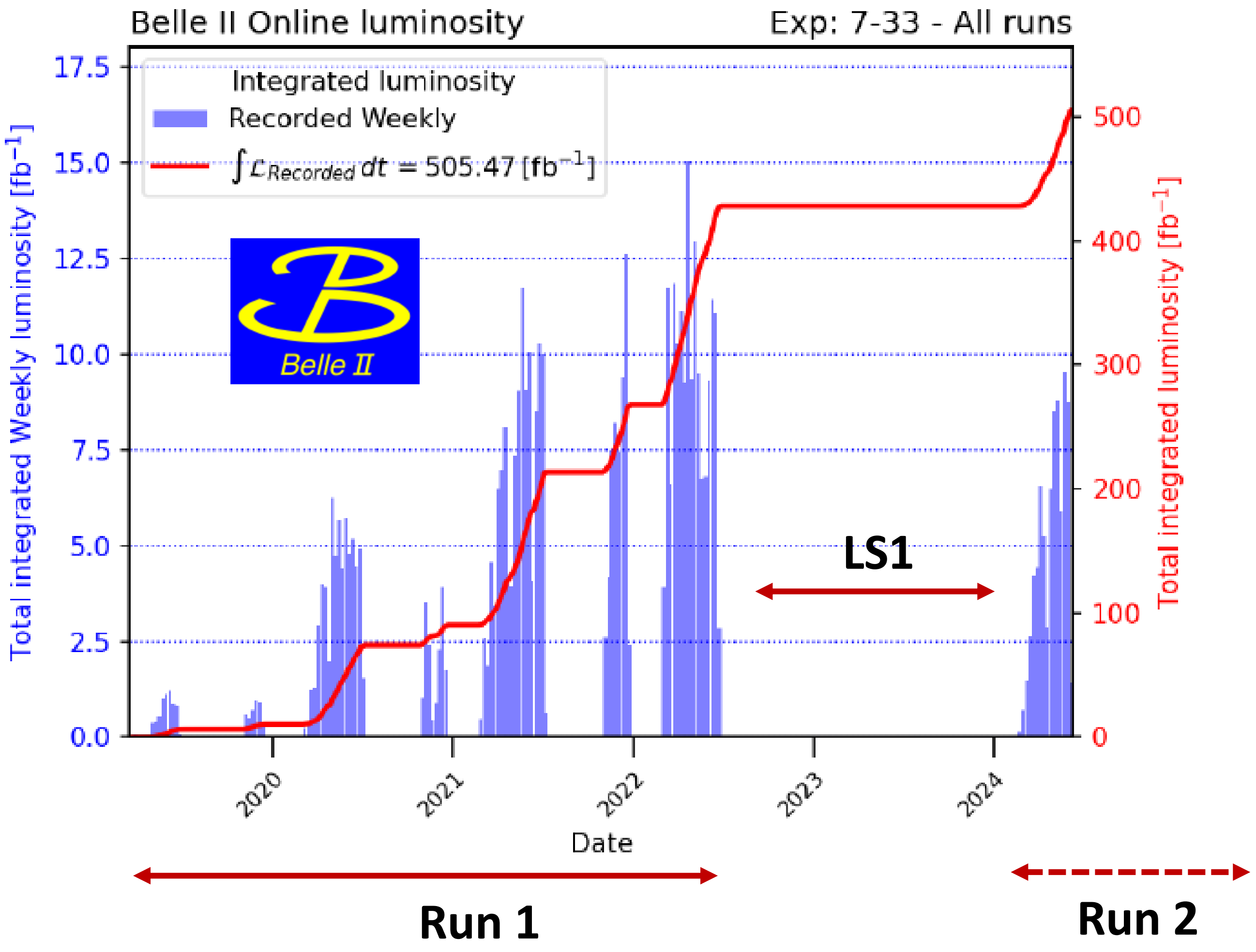
- Excellent tracking performances
- 15 μm vertex resolution
- Hermetic detector: full event reconstruction to exploit kinematics constraint
- High photon efficiency (90% above 1.5 GeV momentum)
- Very good lepton ID:

$\varepsilon(\mu)$~90% with 7% π mis-ID;
ε(e) ~86% with 0.4% π mis-ID

- Kaon ID in full momentum range:

ε(K)~90% with 6% π mis-ID

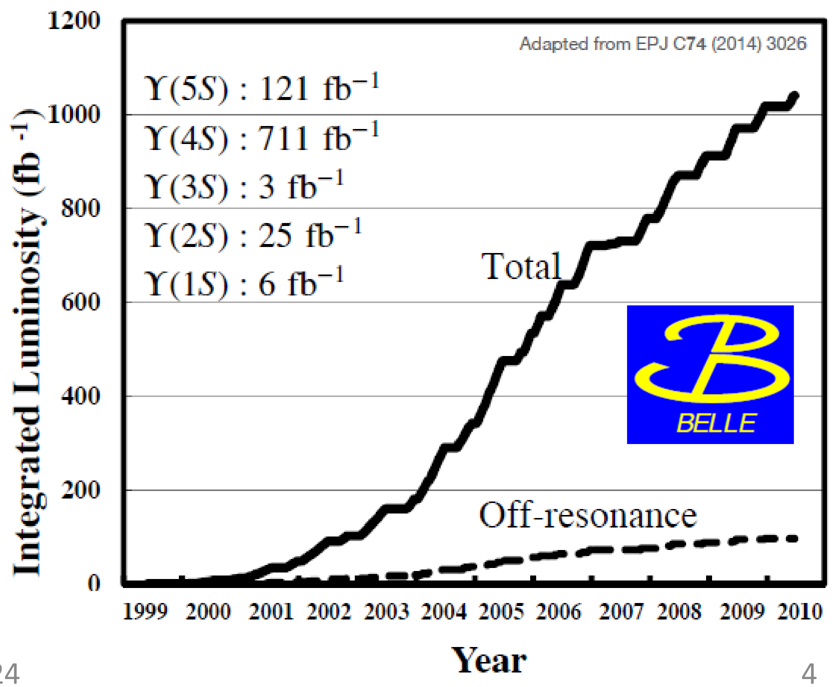
Belle II and Belle data sample



In Run 1 Belle II has collected 364 fb^{-1} @ $\Upsilon(4S)$ + 60 fb^{-1} at different c.m. energies

Equivalent to BaBar sample and about half the Belle sample

Belle data can now be analyzed in Belle II framework. Many analyses use both samples



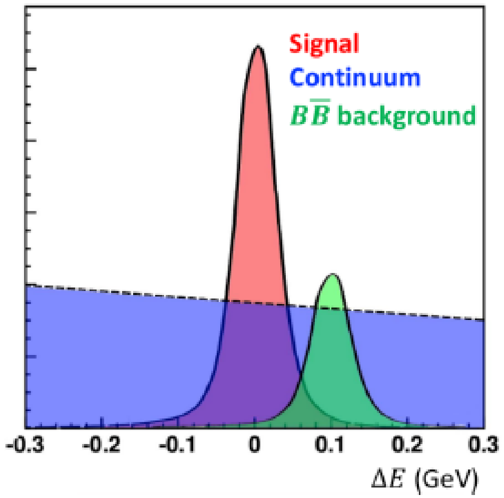
B factory basics/1

$$\sqrt{s} = m(\Upsilon(4S)) = 10.58\ GeV \cong 2m_B$$

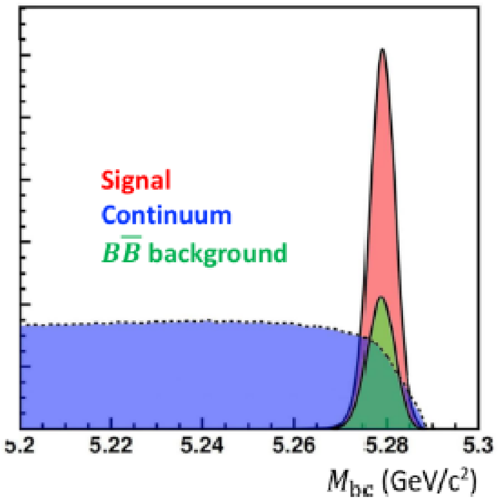
- Kinematics constraint can be exploited to separate signals and backgrounds

- $B\bar{B}$ and $q\bar{q}$ events have quite different event shapes which allow to distinguish between them

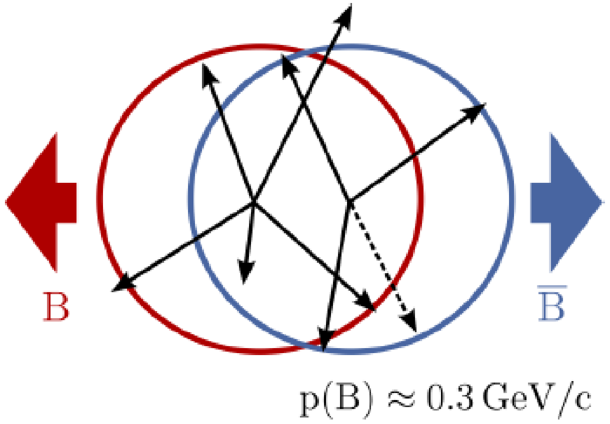
$$\Delta E = E_B^* - \sqrt{s}/2 \qquad M_{bc} = \sqrt{(\sqrt{s}/2)^2 - \vec{p}_B^{*2}}$$



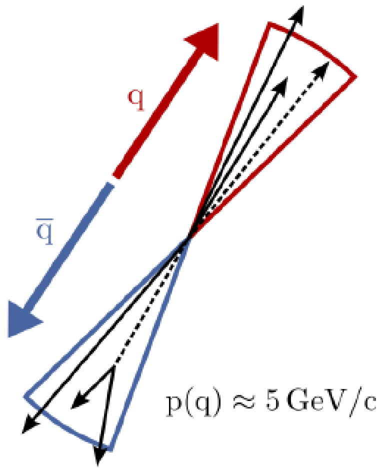
Expected $\Delta E \simeq 0$



Expected $M_{bc} \simeq m_B$



$e^+e^- \to \Upsilon(4S) \to B\overline{B}$

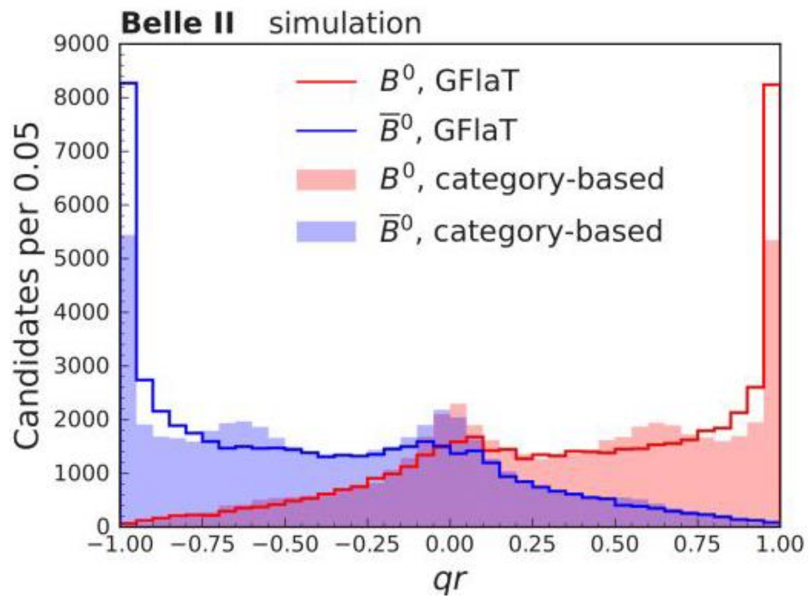


$e^+e^- \to q\overline{q} \quad (q \in \{u, d, s, c\})$

B factory basics/2

- One B meson can be used for tagging the flavour and the other as signal decay mode
- The new tag algorithm GFlaT, based on graph convolutional neural network (GNN) improves by 18% the efficiency with respect to the previous category based (CB) tag arXiv:2402.17260

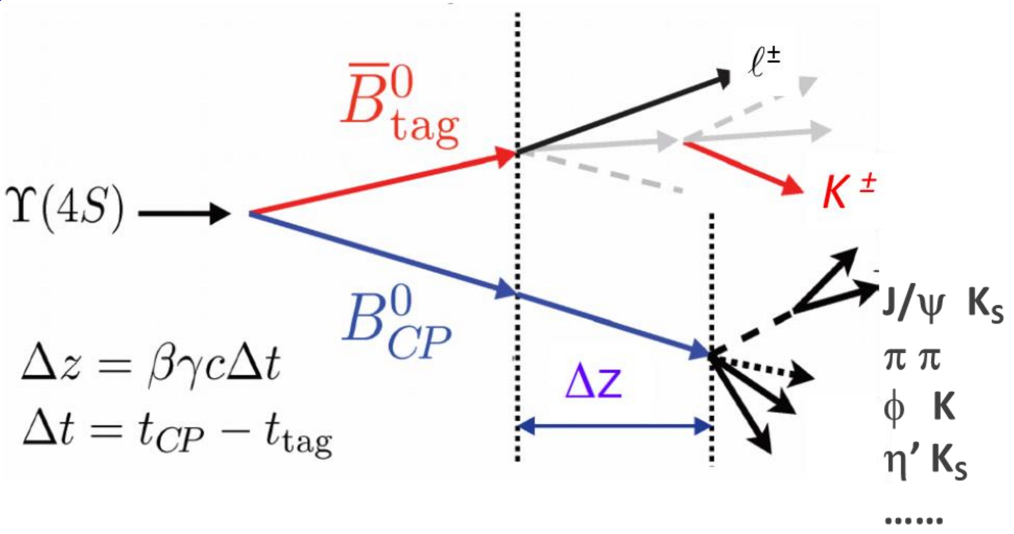
ε_{tag}(CB) = (31.7 ± 0.5 ± 0.4) %
ε_{tag}(GFlaT) = (**37.40 ± 0.43 ± 0.36**) %



- Precise vertex reconstruction of both B meson decay allows to make time dependent analysis of CP asymmetries

$$a_{CPV}(\Delta t) = \frac{\Gamma_{\overline{B}\to\bar{f}}(\Delta t) - \Gamma_{B\to f}(\Delta t)}{\Gamma_{\overline{B}\to\bar{f}}(\Delta t) + \Gamma_{B\to f}(\Delta t)} = S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)$$

S → indirect CP
C = -A → direct CP



Recent Belle II / Belle highlights

EW-radiative penguins:
- **BR, A_{CP} and Δ_{+0} of B → K* γ**
- Search for $B^0 \to \gamma\gamma$
- $b \to d\,\ell\ell$
- **Evidence of $B^+ \to K^+ \nu\bar{\nu}$**

Semileptonic decays:
- **V_{ub} untagged $B \to \pi/\rho\,\ell\,\nu$**
- **Update of $B \to D^*\,\ell\,\nu$**

low multiplicity and τ
- **$\sigma(e^+e^- \to \pi^+\pi^-\pi^0)$**
- **LFU in τ decays**
- $\tau \to \mu\mu\mu$

b, c hadronic decays:
- **BR of $B^- \to D^0\,\rho^-$**
- **BR and A_{CP} of $B^0 \to \pi^0\pi^0$**
- BR of $\Xi^0_c \to \Xi^0\pi^0, \Xi^0\eta, \Xi^0\eta'$
- **γ angle Belle+Belle II determination**

Time dependent CPV:
- **$B^0 \to \eta'\,K_S$**
- **$B^0 \to K_S\,\pi^0\,\gamma$**
- $B^0 \to J/\psi\,K_S$ using Gflat tag

Quarkonia and spectroscopy:
- **$\Upsilon(10753)$ rediscovery**
- **Search $\Upsilon(10753) \to \omega\,\eta_b(1S)/\chi_{b0}(1P)$**
- Energy dependence of $e^+e^- \to B^{(*)}\bar{B}^{(*)}$

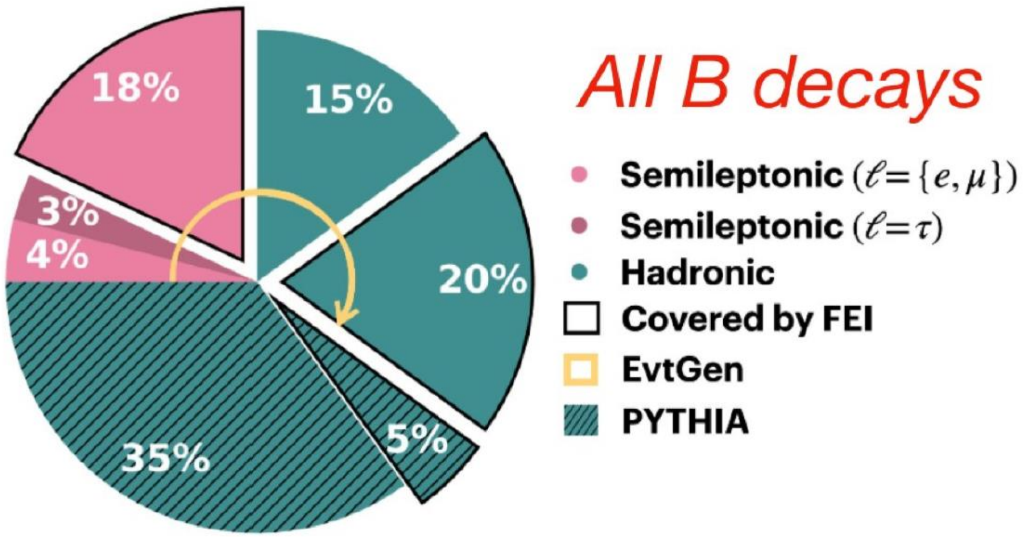
Impressive result production rate in 2023-24:

29 published or accepted journal papers + 11 submitted and being reviewed (*18 months! More than 2 paper per month on average!*)

More than 15 new results targeting ICHEP 2024 !

Will briefly present the bold typed ones

B hadronic decays



Branching fractions of B⁺→ D^0 $\rho(770)^+$

arXiv:2404.10874

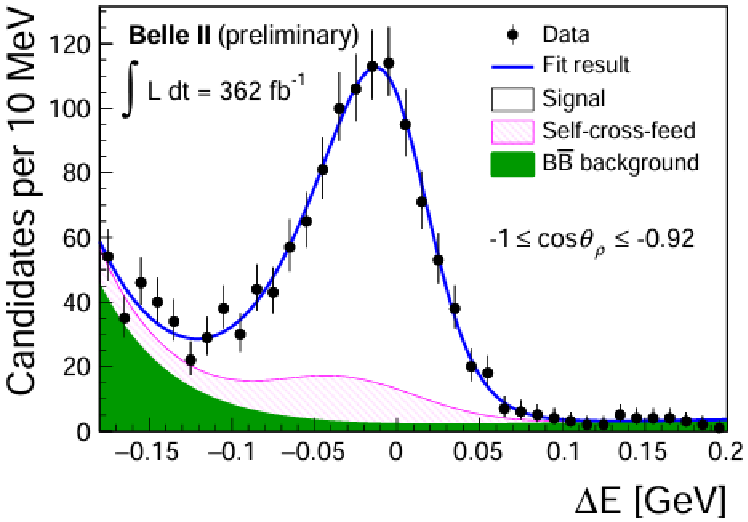
- $B^+ \to D^0\rho^+$: test heavy-quark limit and factorisation models [Nucl. Phys. B 591, 313 (2000)]
- WA BF: $(1.35 \pm 0.18)\%$; driven by old CLEO measurement [CLEO, PRD 50, 43 (1994)]
  - Very large (14 %) uncertainty
- Signal extracted from fit to ΔE
- **Challenge: separate $B \to D^0\rho(\to \pi^+\pi^0)$ and non-resonant $B \to D^0\pi^+\pi^0$ component**
  - Fit performed in bins of helicity angle ($\cos\theta_\rho$)

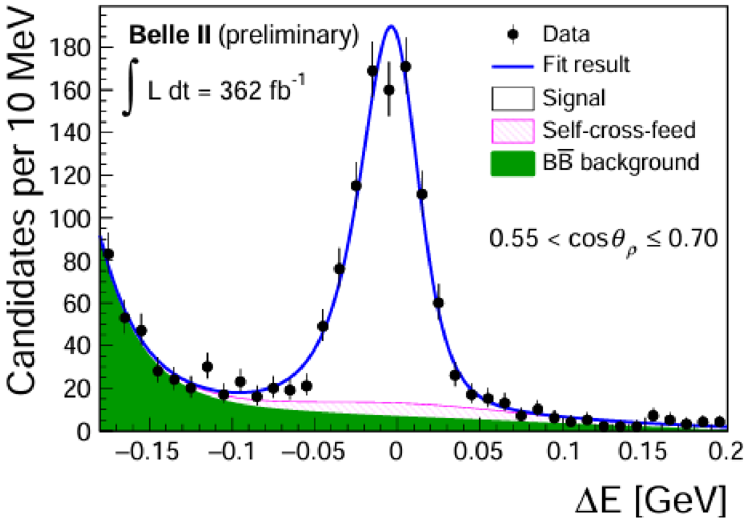
$$\boxed{\mathscr{B}(B^+ \to D^0\rho^+) = (0.939 \pm 0.021 \pm 0.050)\,\%}$$

2xbetter than previous world best

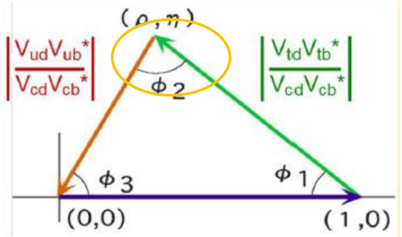
Systematically limited by π^0 efficiency accuracy

Result very useful to improve hadronic tag in missing energy channels





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

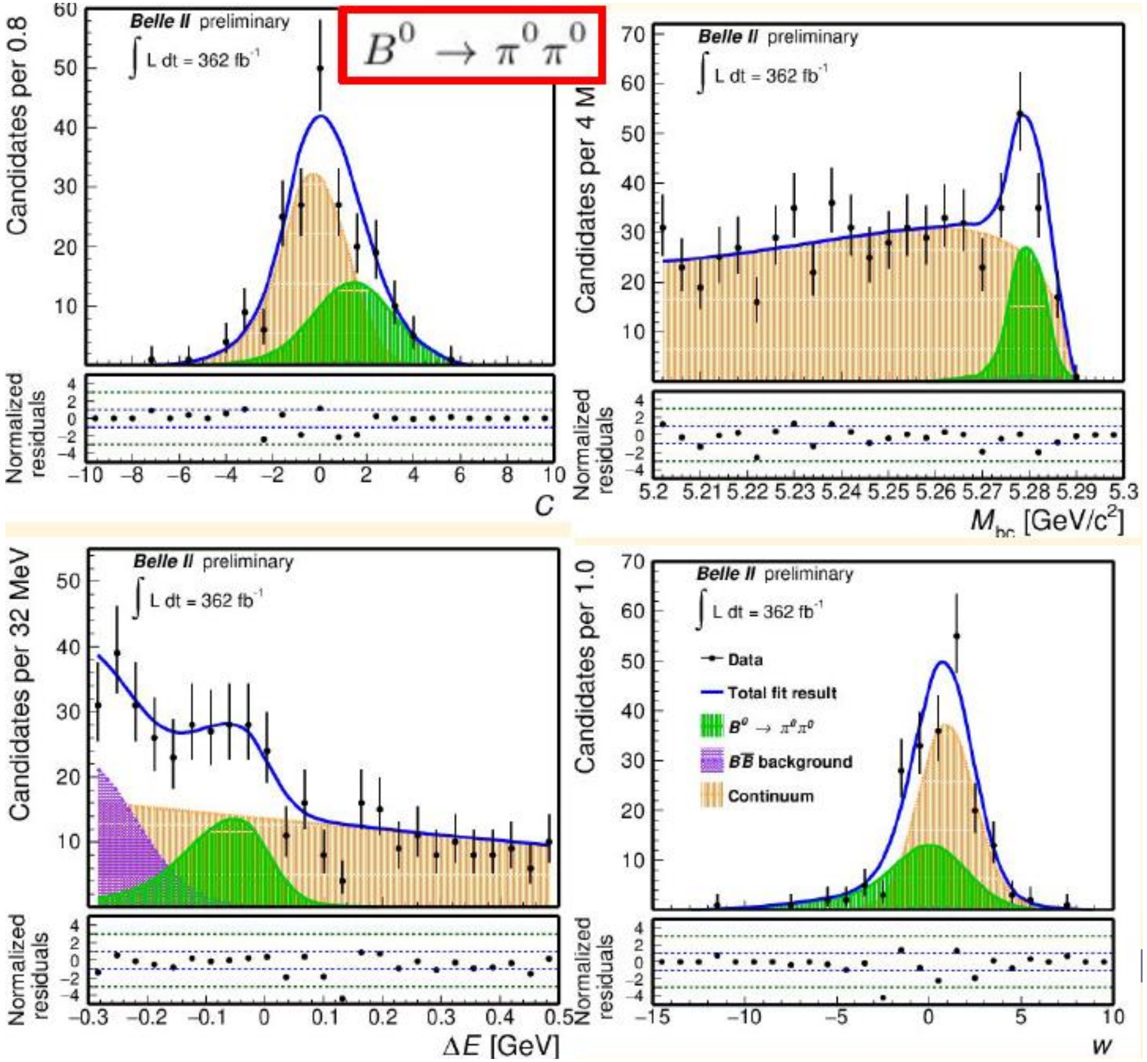


Previous result [PRD107 (2023) 112009] updated with full Run 1 statistics, new flavour tag (Gflat) and reduction of systematic uncertainties

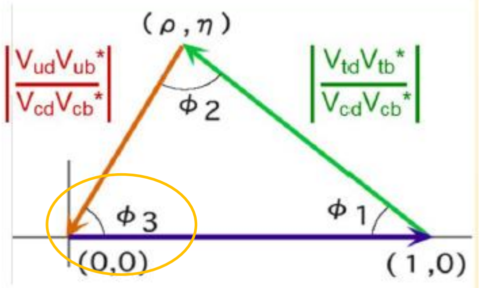
- Bkg mostly from continuum and $B^+ \to \rho^+\pi^0$; $B^0 \to K_S\pi^0$
- Photons selected with BDT, continuum suppression trained on off-resonance data
- Extract signal by simultaneous fit to ΔE, M_{bc}, continuum variable, wrong tag probability

$$BR = (1.26 \pm 0.20 \pm 0.11)\mathrm{x}10^{-6}$$
$$A_{CP} = 0.06 \pm 0.30 \pm 0.06$$

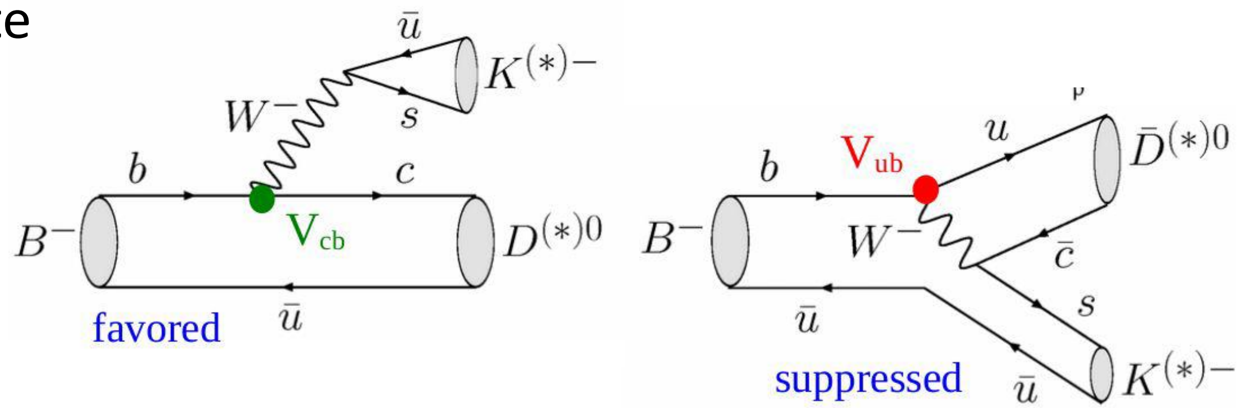
BR world best, A_{CP} same as world best



Belle + Belle II determination of ϕ_3/γ angle

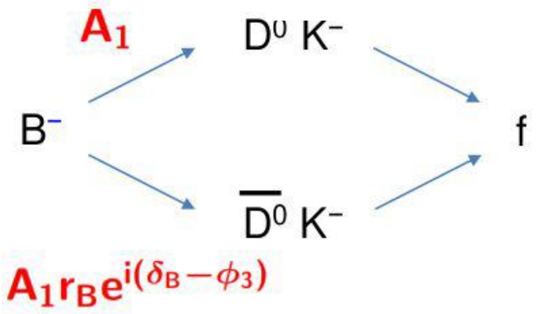


- SM benchmark: very reliably predicted (10^{-7} relative)
- Tree level decays: no large BSM
- Access via interfering decays to same final state
- D decay strong phase from Cleo-c and BESIII



Several methods used:

- GLW $B^{\pm} \rightarrow D^0_{CP}K^{\pm}$ arXiv:2308.05048 [hep-ex]
  Use CP eigenstate of D meson
- ADS PRL 78 (1997) 3257
  Enhancement of CP violation by using doubly Cabibbo suppressed decays.
- BPGGSZ $D^0 \rightarrow K_S h^+ h^-$ JHEP 2022(2022), 63
  Different amplitude and strong phase in different region of Dalitz plot.
- GLS $D^0 \rightarrow K_S K\pi$ JHEP 09(2023)146



r_B and δ_B are mode dependent

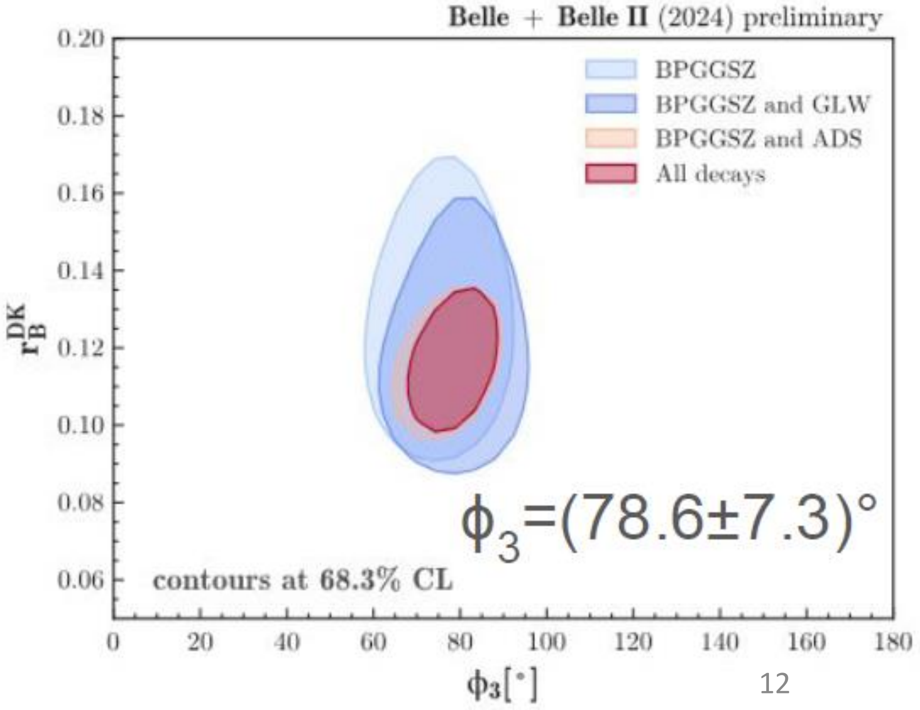
Belle + Belle II determination of ϕ_3/γ angle

arXiv [2404.12817]

B decay	D decay	Method	Data set (Belle + Belle II)[fb^{-1}]	
$B^+ \to Dh^+$	$D \to K_S^0 h^- h^+$	BPGGSZ	$711 + 128$	[JHEP 02 063 (2022)]
$B^+ \to Dh^+$	$D \to K_S^0 \pi^- \pi^+ \pi^0$	BPGGSZ	$711 + 0$	[JHEP 10 178 (2019)]
$B^+ \to Dh^+$	$D \to K_S^0 \pi^0, K^- K^+$	GLW	$711 + 189$	[arxiv:2308.05048]
$B^+ \to Dh^+$	$D \to K^+ \pi^-, K^+ \pi^- \pi^0$	ADS	$711 + 0$	[PRL 106 231803 (2011)]
$B^+ \to Dh^+$	$D \to K_S^0 K^- \pi^+$	GLS	$711 + 362$	[JHEP 09 (2023) 146]
$B^+ \to D^* K^+$	$D \to K_S^0 \pi^- \pi^+$	BPGGSZ	$605 + 0$	[PRD 81 112002 (2010)]
$B^+ \to D^* K^+$	$D \to K_S^0 \pi^0, K_S^0 \phi, K_S^0 \omega, K^- K^+, \pi^- \pi^+$	GLW	210+0	[PRD 73 051106 (2006)]

First combination of all Belle+ Belle II ϕ_3 measurements:

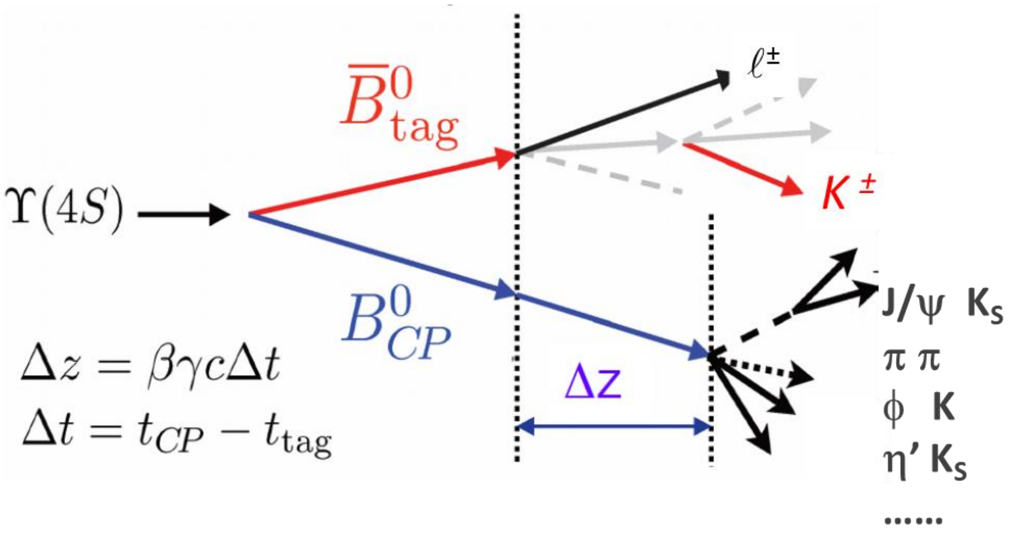
Likelihood with 60 input observables, including 15 auxiliary inputs (D-decay), 16 free parameters

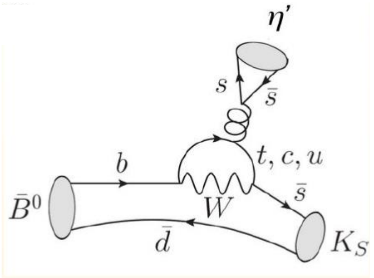


Result compatible with HFLAV WA: ϕ_3/γ (°) = $66.2^{+3.4}_{-3.6}$

Valuable single experiment determination.

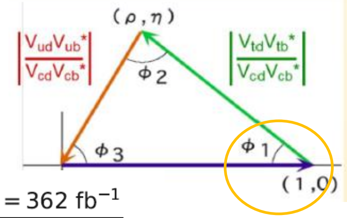
Time dependent CP violation





A gluonic penguin: $B^0 \rightarrow \eta' K_S$

arXiv:2402.03713



Two η' decay modes are reconstructed:

$\eta' \rightarrow \eta\pi\pi$ ($\eta \rightarrow \gamma\gamma$) and $\eta' \rightarrow \rho\gamma$

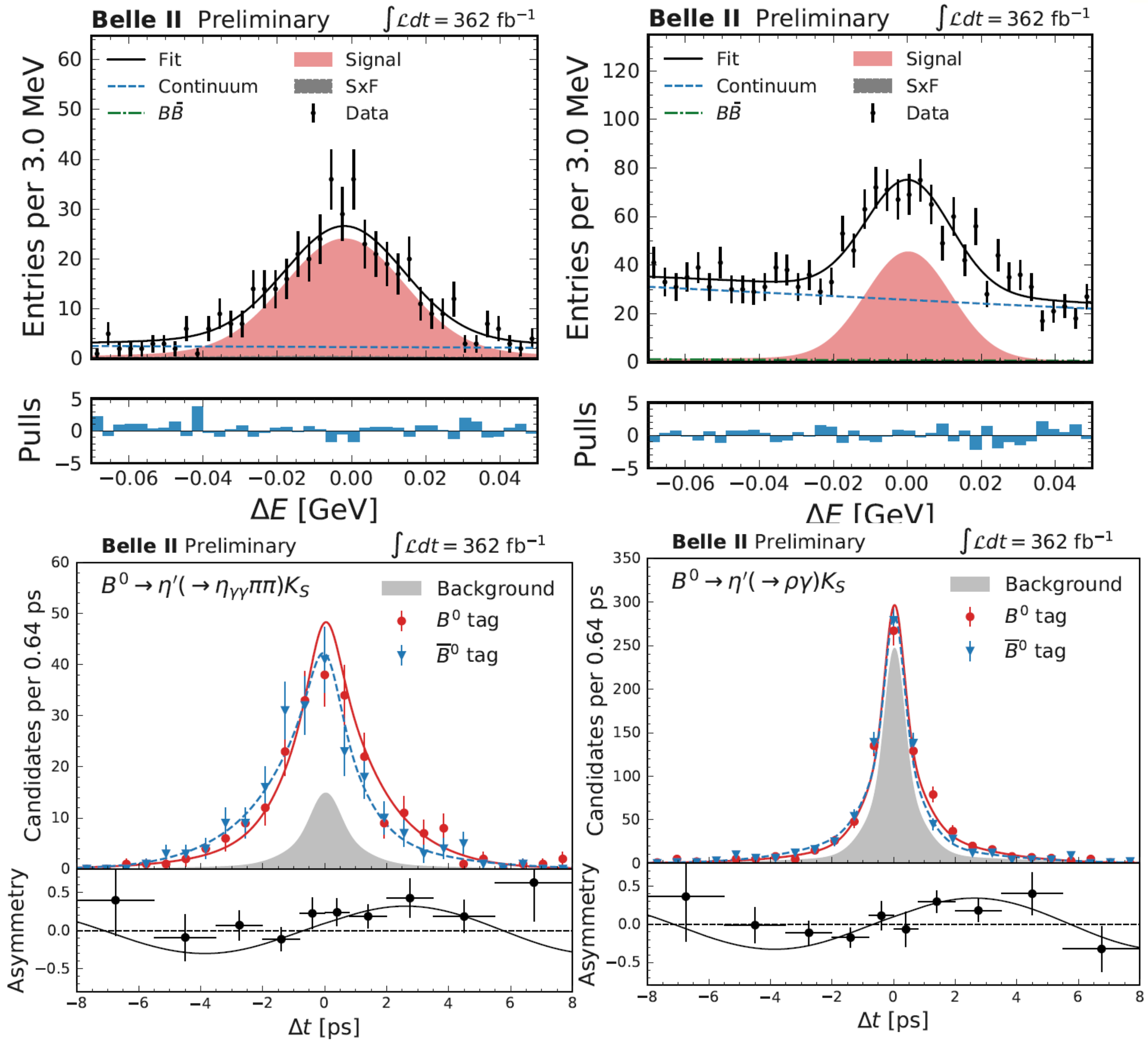
Signal extracted via fit to ΔE, M_{bc} and continuum suppression BDT output

- Bkg Δt shape from sidebands
- BKG asymmetry included in the fit
- Validation on control sample $B^+ \rightarrow \eta' K^+$

S= 0.67 ± 0.20 ± 0.04
C= -0.19 ± 0.08 ± 0.03

HFLAV: S= 0.63±0.06, C=-0.05 ± 0.04

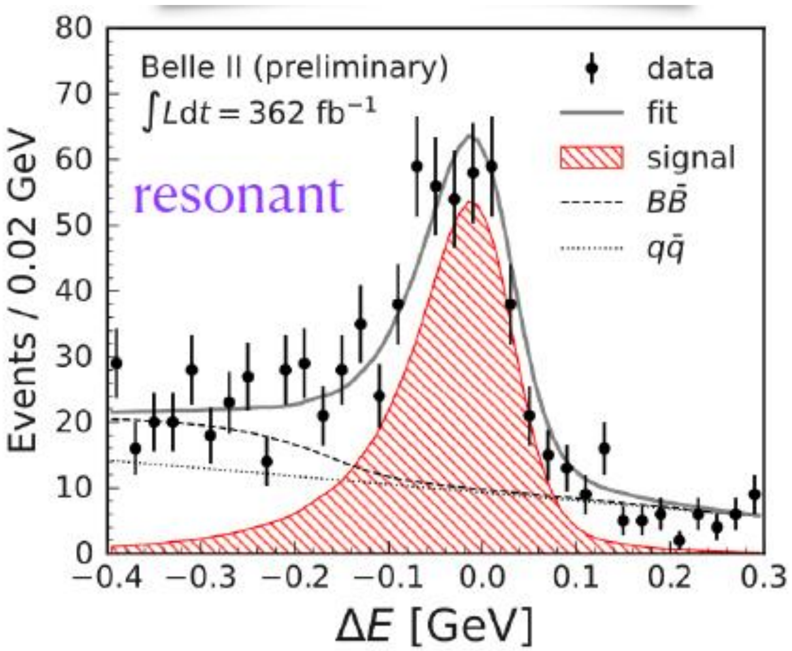
Precision comparable with Belle/BaBar

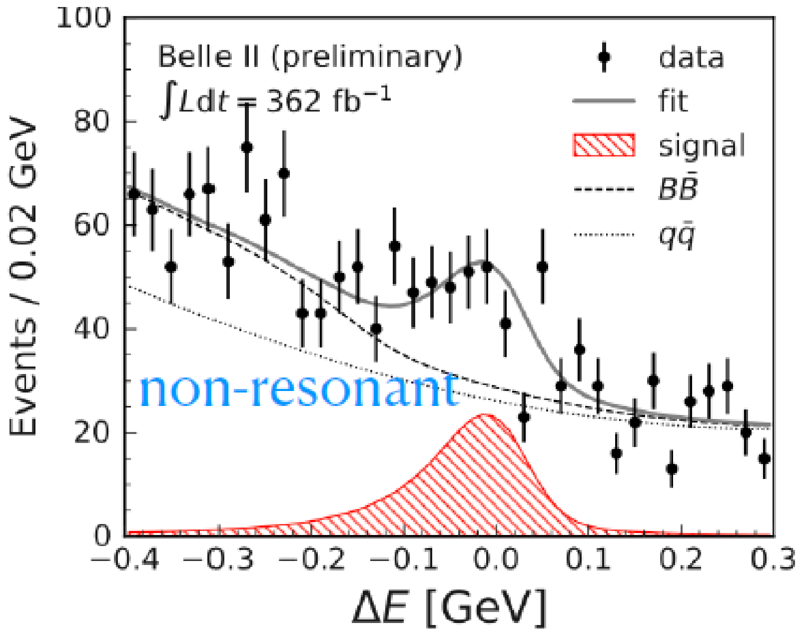


$B^0 \rightarrow K_S \pi^0 \gamma$

Expected to have small mixing induced CPV in SM, due to helicity suppression of $b \rightarrow s \gamma_R$
($b \rightarrow s\gamma_L$ and $\bar{b} \rightarrow s\gamma_R$) → Sensitive to NP

- B vertex with no prompt tracks reconstructed from $K_S \rightarrow \pi^+\pi^-$ with beam spot constraint
- Recontructed separately for resonant channel $K^{*0} \rightarrow K_S\pi^0$ and non resonant $K_S\pi^0$
- Signal extraction from combined fit to ΔE and M_{bc}

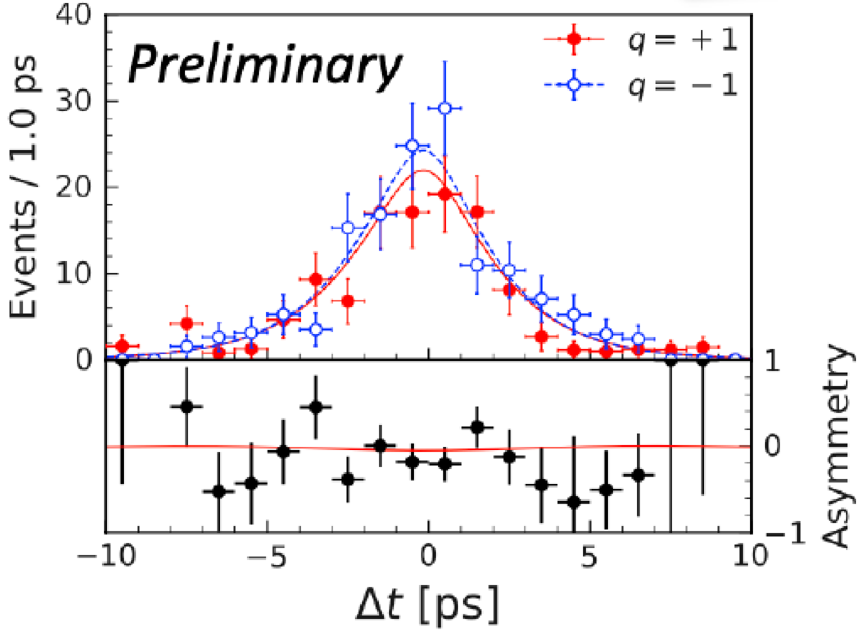




$B^0 \rightarrow K_S \pi^0 \gamma$

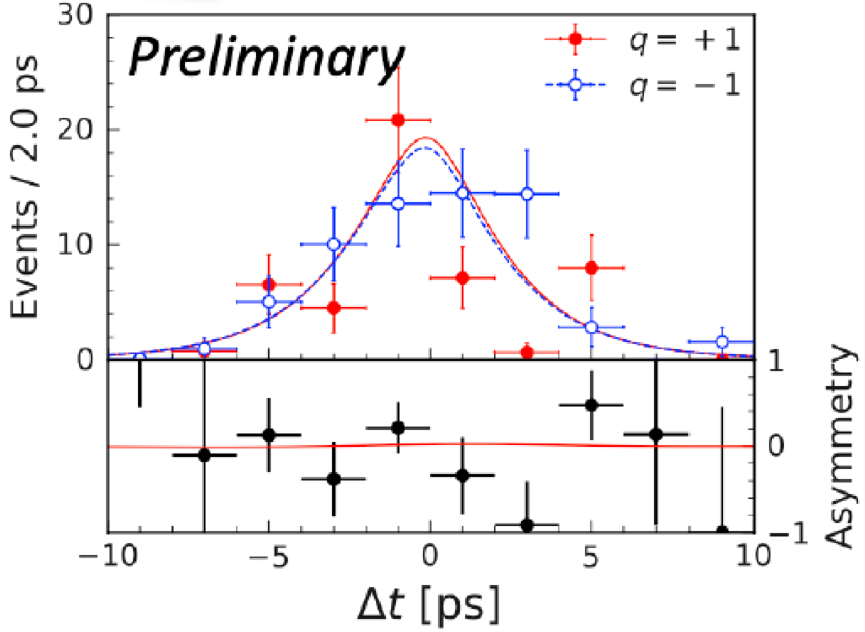
Time dependent fit:

resonant



$$S = 0.00^{+0.27+0.03}_{-0.26-0.04}$$
$$C = 0.10 \pm 0.13 \pm 0.03$$

non resonant



$$S = 0.04^{+0.45}_{-0.44} \pm 0.10$$
$$C = -0.06 \pm 0.25 \pm 0.07$$

World's best result depite lower statistics, thanks to better acceptance and bkg suppression

B semileptonic decays

$|V_{ub}|$ from $B^0 \to \pi \ell \nu$ and $B^+ \to \rho^0 \ell^+ \nu$

Untagged reconstruction with full Run 1 statistics

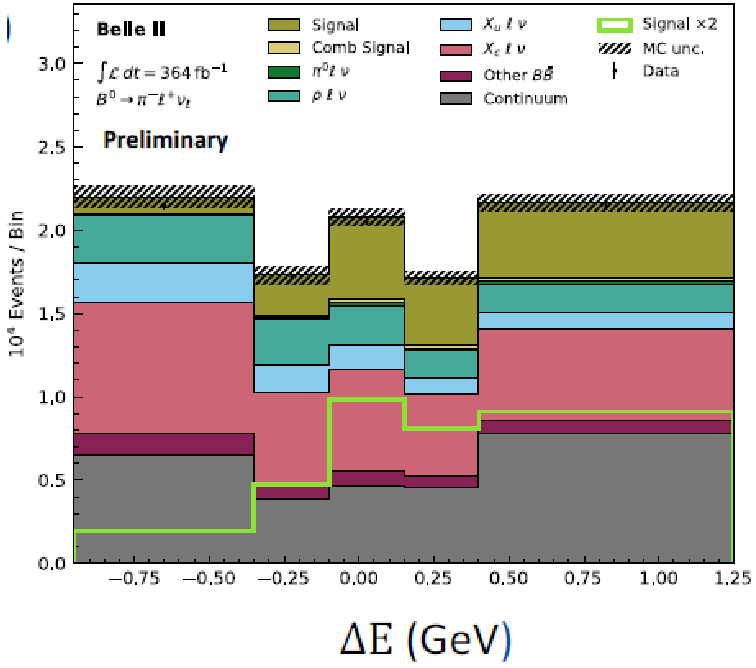
- Build up BDT discriminator to suppress $B \to X_c \ell \nu$ and continuum
- Require kinematical consistency of rest of event with B decay
- Require $p_l^* \ (\pi) > 1$ GeV and $p_l^* \ (\rho) > 1.4$ GeV

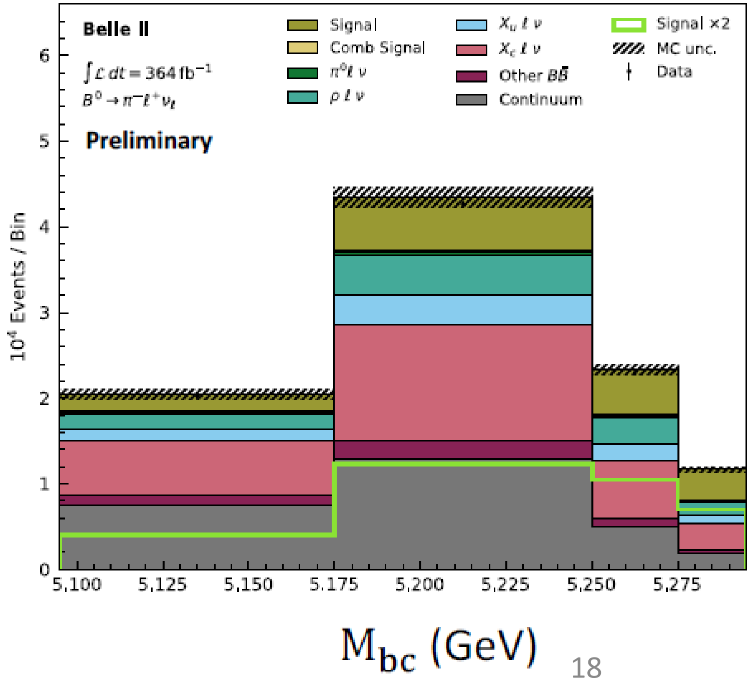
Extract signal yields by combined fit to ΔE, M_{bc} in 13 bins (π mode) + 10 bins (ρ mode) of q^2 *(defined as $(p_B - p_{\pi,\rho})^2$)*

Consistent with WA

$$\mathcal{B}(B^0 \to \pi^+ l\nu) = (1.516 \pm 0.042 \pm 0.059)\times 10^{-4}$$
$$\mathcal{B}(B^+ \to \rho^0 l\nu) = (1.625 \pm 0.079 \pm 0.180)\times 10^{-4}$$

Leading systematic are the modelling of continuum and non-resonant $B \to X_u \ell \nu$ decays

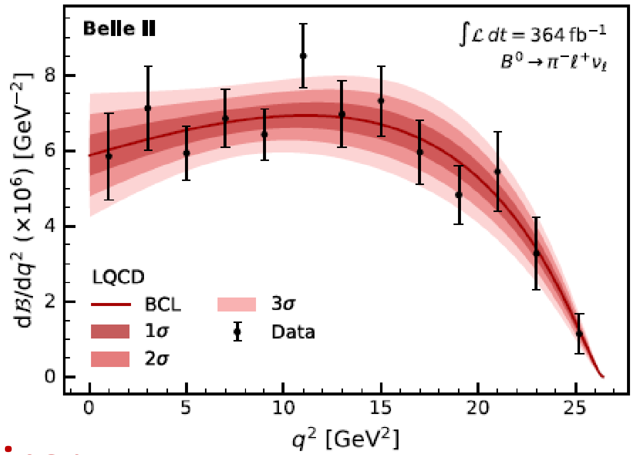




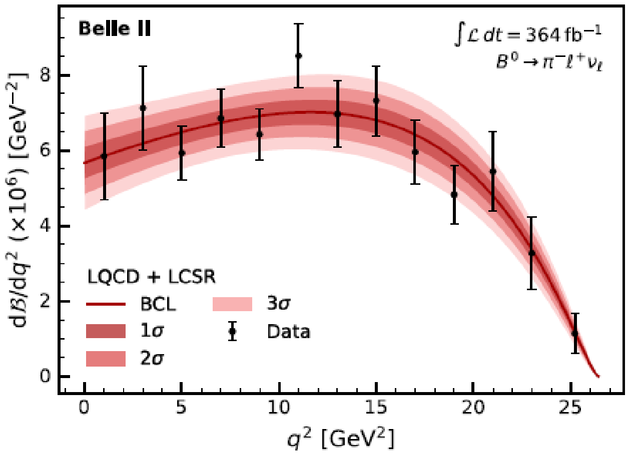
$|V_{ub}|$ from $B^0 \rightarrow \pi \ell \nu$ and $B^+ \rightarrow \rho^0 \ell^+ \nu$

$|V_{ub}|$ extracted by fitting BR(q^2) assuming FF parametrization (BCL for π, BSZ for ρ) and lattice or light cone sum rules calculations (*)

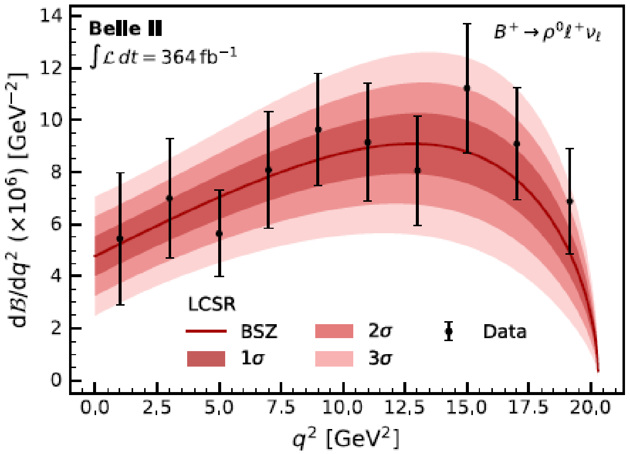
$B^0 \rightarrow \pi^+ l\nu \; d\mathcal{B}/dq^2$ with LCQD



$B^0 \rightarrow \pi^+ l\nu \; d\mathcal{B}/dq^2$ with LCQD+LCSR



$B^+ \rightarrow \rho^0 l\nu \; d\mathcal{B}/dq^2$ with LCSR



Preliminary

$$|V_{ub}|_{B\rightarrow\pi\ell\nu_\ell} = (3.93 \pm 0.09 \pm 0.13 \pm 0.19) \times 10^{-3}$$

stat syst theo

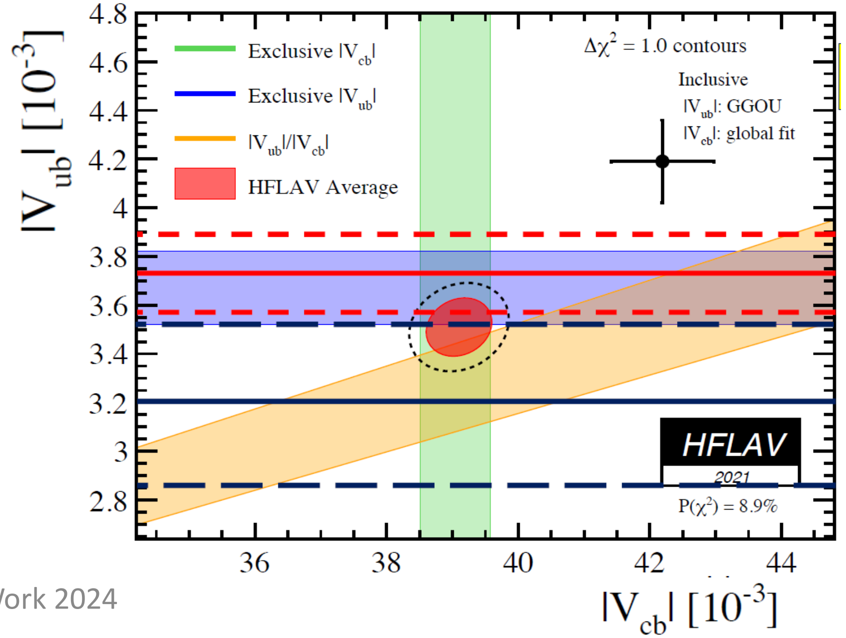
LQCD

$$|V_{ub}|_{B\rightarrow\pi\ell\nu_\ell} = (3.73 \pm 0.07 \pm 0.07 \pm 0.16) \times 10^{-3}$$

LQCD+LCSR

$$|V_{ub}|_{B\rightarrow\rho\ell\nu_\ell} = (3.19 \pm 0.12 \pm 0.17 \pm 0.26) \times 10^{-3}$$

LCSR



π channel

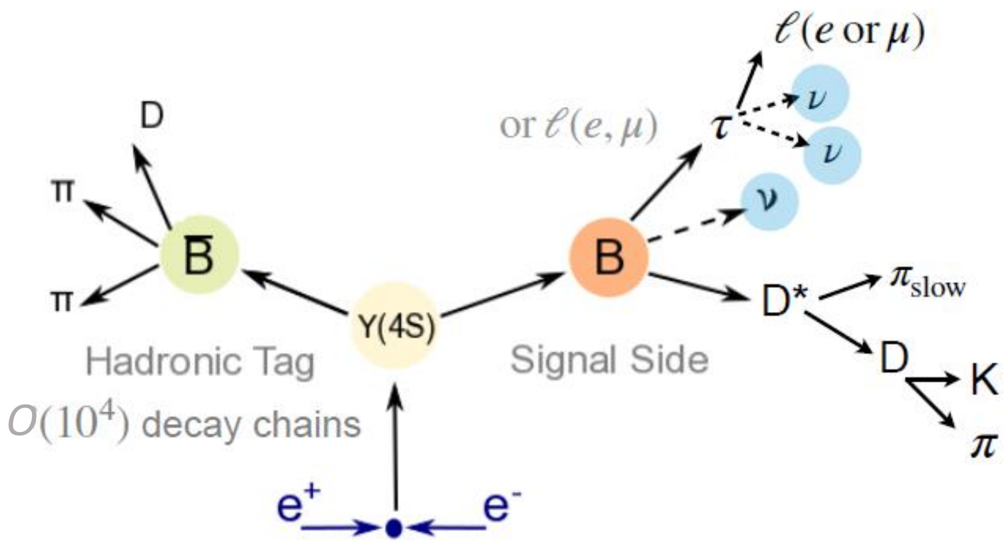
ρ channel

(*) *References in the backup material*

New LFU limits: R(D*)

[arXiv:2401.02840]

$$R(D^*_{\tau/\ell}) = \frac{\mathcal{B}(B \to D^*\tau\nu)}{\mathcal{B}(B \to D^*\ell\nu)}$$

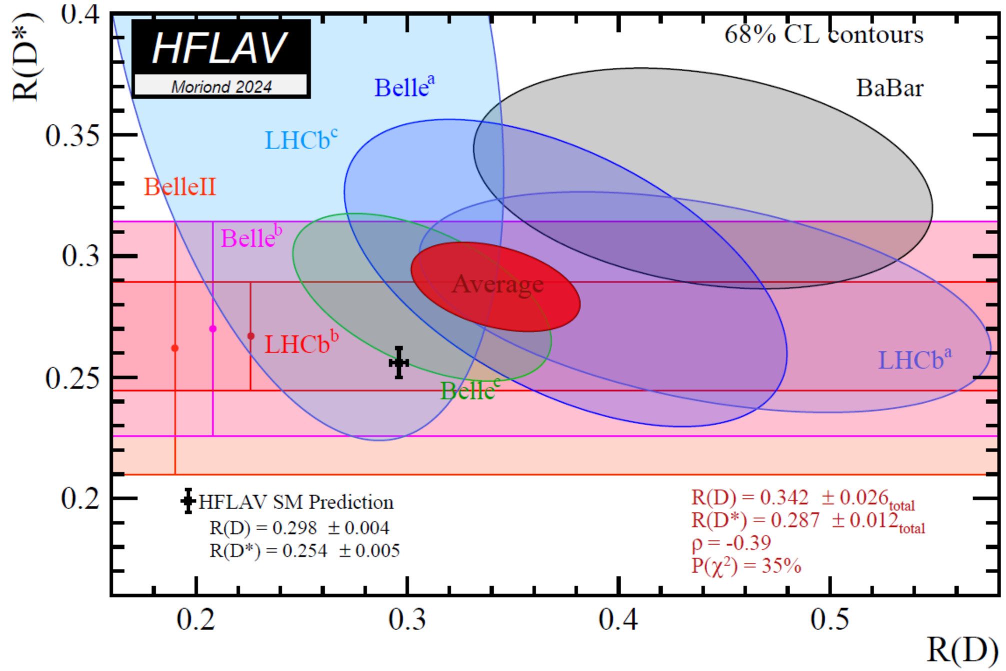


Use 189 fb^{-1} with hadronic tagging: *Full Event Interpretation* algorithm, [Comput Softw Big Sci 3, 6 (2019)]

Extract R(D*) from 2D fit to missing mass squared and residual energy in ECL

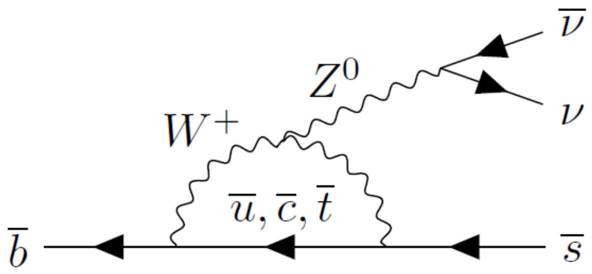
Preliminary

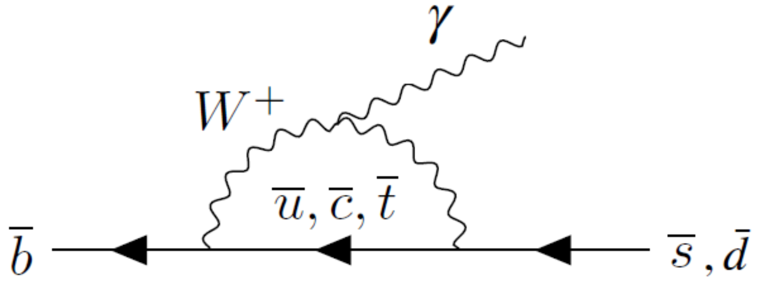
$$R(D^*) = 0.262\ ^{+0.041}_{-0.039}(\text{stat})\ ^{+0.035}_{-0.032}(\text{syst})$$



- Result consistent both with SM and WA
- Statistical error comparable to Belle. Systematics dominated by MC stat and PDF shapes
- Analysis to be extended to full Run 1 dataset. R(D) analysis also ongoing

Electroweak and radiative penguins



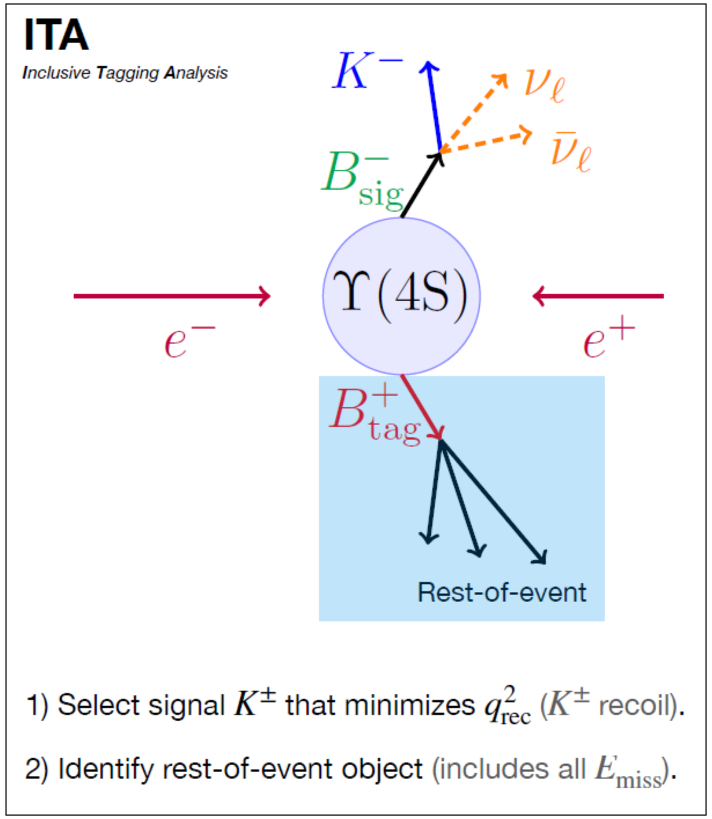


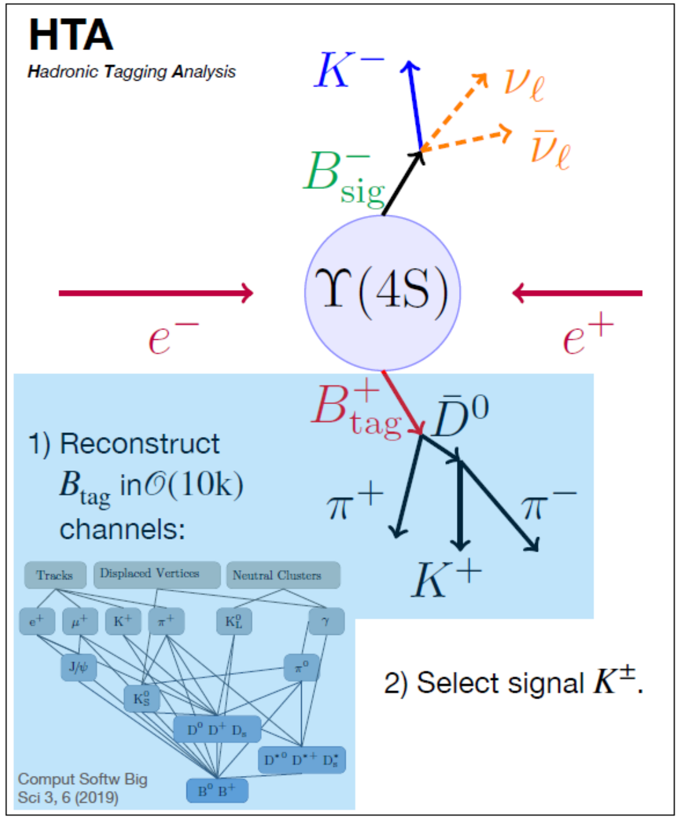
Evidence for $B^+ \to K^+ \nu \nu$

Phys. Rev. D 109, 112006

- Reliable SM prediction, never observed before, possibly affected by NP (ALPs, dark scalars, Z', leptoquarks…)
- Experimentally challenging for the 2 neutrinos in the final state
- Use two complementary B tag approach: low purity-high efficiency (0.8% - 8%) and its opposite (3.5% - 0.4%)

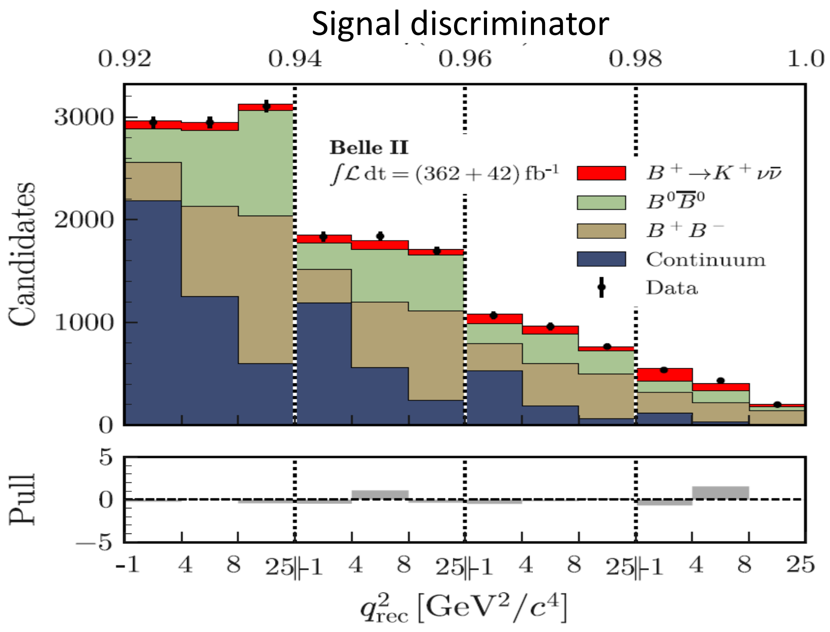
- Event selection by combining signal kaon, event topology, rest-of-event info in MVA classifiers
- Background from continuum, semileptonic B decays, $B^+ \to K^+ n\bar{n}$, $B^+ \to K^+ K^0 \bar{K}^0$,pion fakes, $B \to X_c(\to K_L + X)$
- Signal efficiency and bkg estimation corrected and validated using a variety of control channels
- Closure test by measuring BF($B^+ \to \pi^+ K^0$)



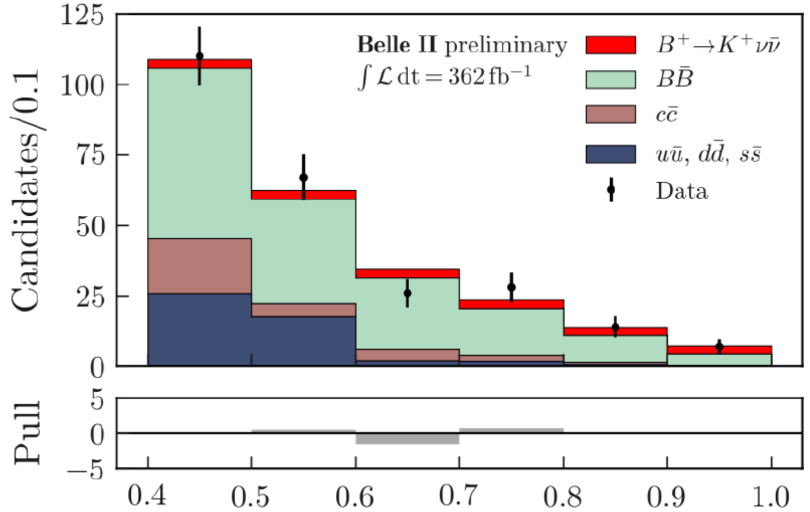


Evidence for $B^+ \rightarrow K^+ \nu \nu$

ITA



HTA



Perform binned maximum likelihood fit

- Inclusive tag: in bins of q^2 and classifier output
- Hadronic tag: in bins of classifier output

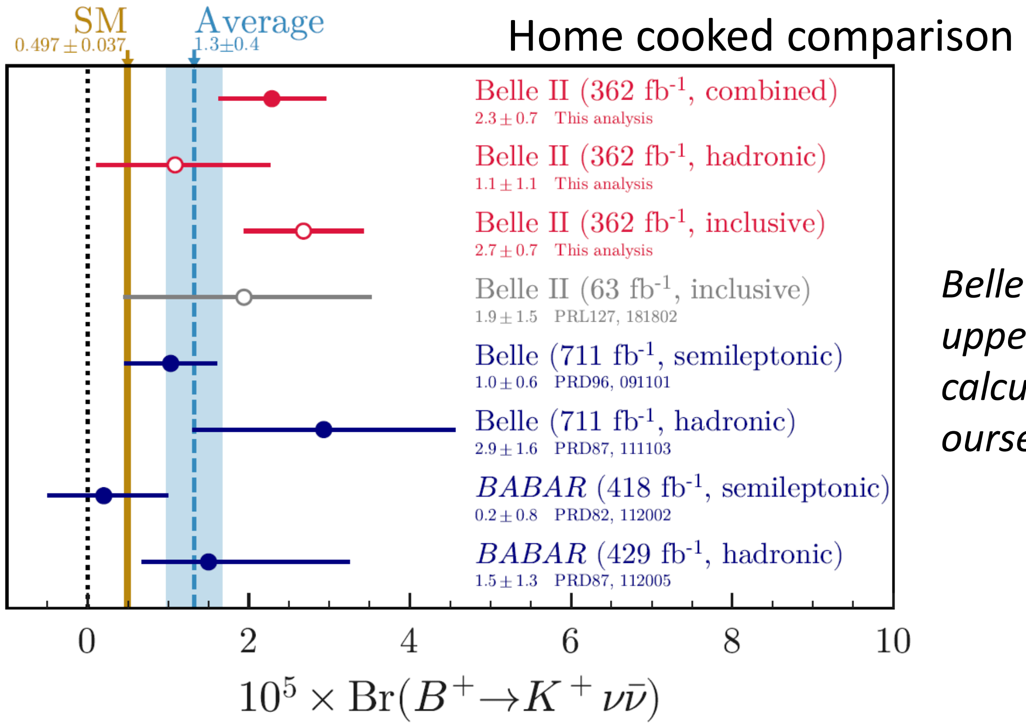
ITA: $BF = (2.7 \pm 0.5 \pm 0.5) \times 10^{-5}$

HTA: $BF = (1.1^{+0.9+0.8}_{-0.8-0.5}) \times 10^{-5}$

Combined: $BF = (2.3 \pm 0.5^{+0.5}_{-0.4}) \times 10^{-5}$

3.5 σ excess, 2.7 σ from SM

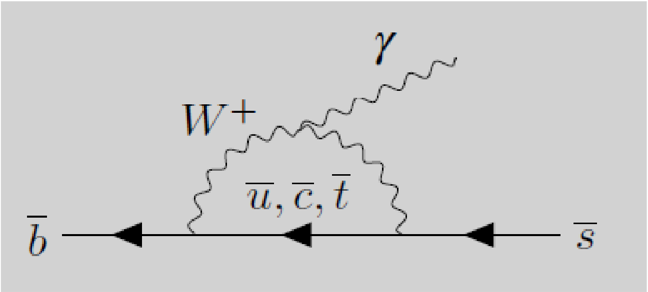
Home cooked comparison

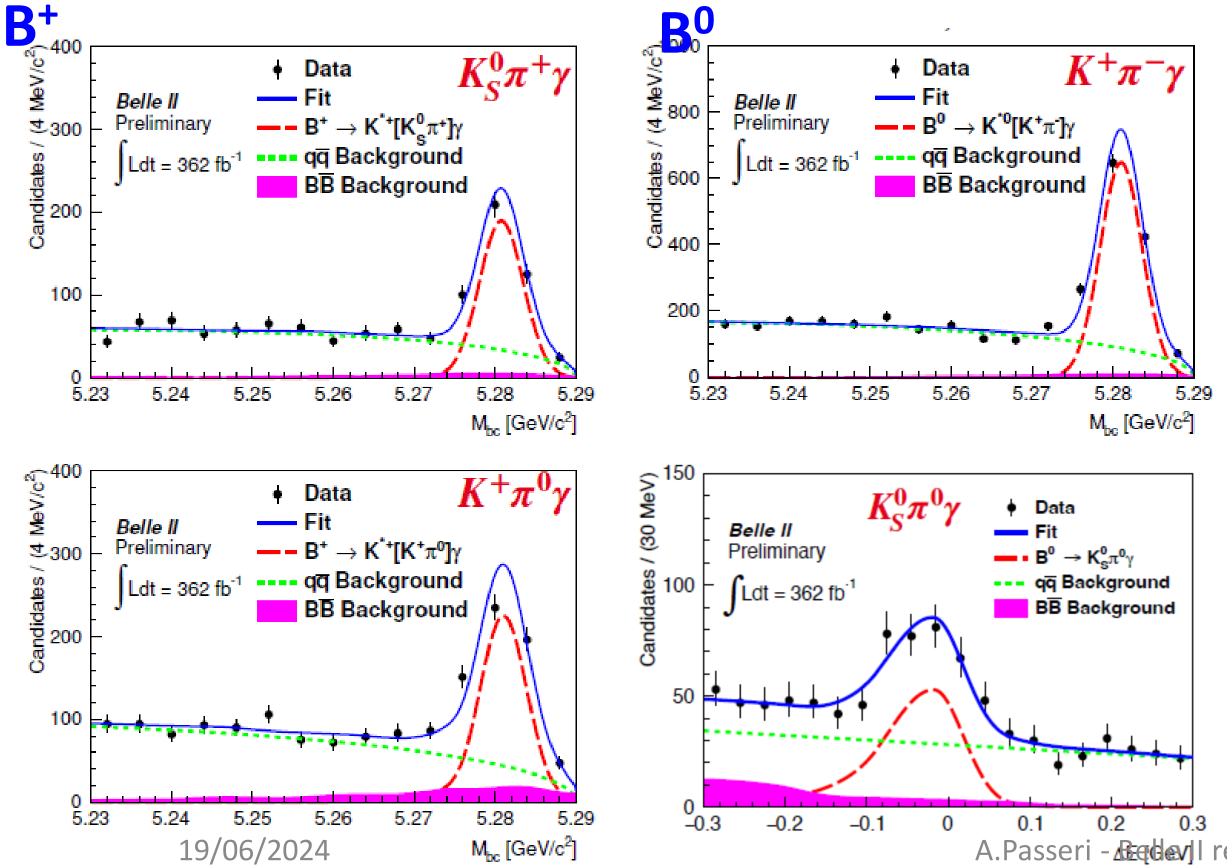


Belle quotes only upper limits: we calculated BF ourselves

A radiative penguin: $B^{(0,+)} \rightarrow K^{*(0,+)}\gamma$

- Reconstruct $K^* \to K^+\pi^-, K^0_S\pi^0, K^+\pi^0, K^0_S\pi^+$
- Classifiers to reject boosted photons from asymmetric $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ decays, and continuum events
- Fit to $M_{\rm bc}$ and ΔE to extract yields





$$\mathcal{B}[B^0 \to K^{*0}\gamma] = (4.16 \pm 0.10 \pm 0.11) \times 10^{-5},$$

$$\mathcal{B}[B^+ \to K^{*+}\gamma] = (4.04 \pm 0.13 \pm 0.13) \times 10^{-5},$$

$$\mathcal{A}_{CP}[B^0 \to K^{*0}\gamma] = (-3.2 \pm 2.4 \pm 0.4)\%,$$

$$\mathcal{A}_{CP}[B^+ \to K^{*+}\gamma] = (-1.0 \pm 3.0 \pm 0.6)\%,$$

$$\Delta\mathcal{A}_{CP} = (2.2 \pm 3.8 \pm 0.7)\%, \text{ and}$$

$$\Delta_{0+} = (5.1 \pm 2.0 \pm 1.5)\%,$$

- Consistent with WA and SM
- Similar sensitivity as Belle despite smaller sample (thanks mainly to improved ΔE resolution, K^0_S efficiency and continuum suppression)
- Asymmetries statistically limited

Tau physics and low multiplicity

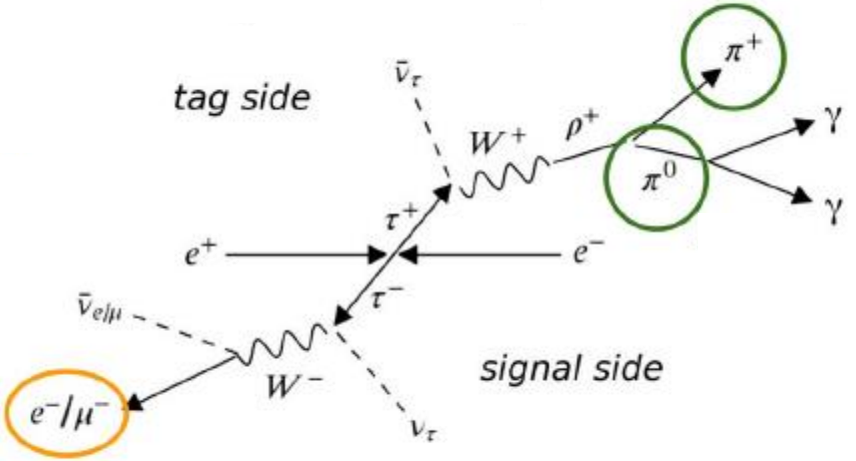
New LFU limits: R_μ

arXiv:2405.14625

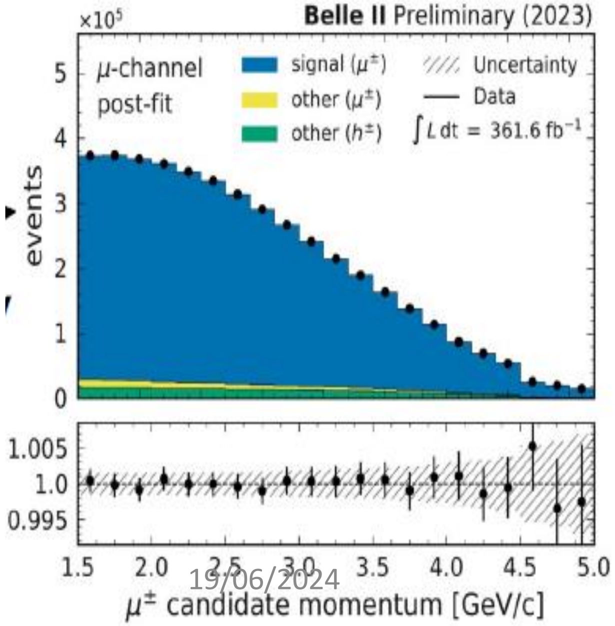
$$R_\mu = \frac{\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}$$

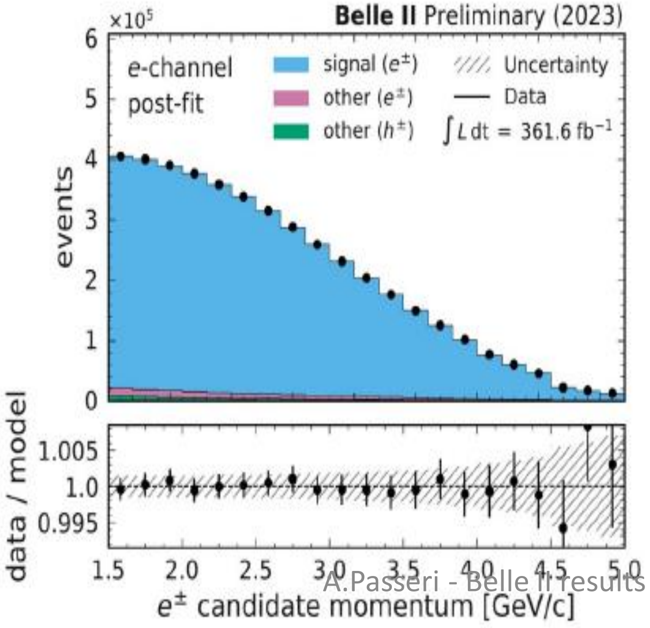
$$\left(\frac{g_\mu}{g_e}\right)_\tau = \sqrt{R_\mu \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}}$$

- Signal side: e or μ
- Tag side: 1 charged hadron + ≥1 π^0
- Background suppression via NN
- 94% purity, 9.6% efficiency



R_μ obtained by binned ML fit to lepton momentum distribution.
Main systematics from PID (0.32%) and trigger (0.10%)





- R_μ = 0.9675 ± 0.0007 (stat.) ± 0.0036 (sys.) and $|g_\mu/g_e|_\tau$ = 0.9974 ± 0.0019
  - → **Most precise** test of μ-e universality in τ decays
  - → Consistent with SM at 1.4σ

Limit on $\tau \rightarrow \mu\mu\mu$

arXiv:2405.07386

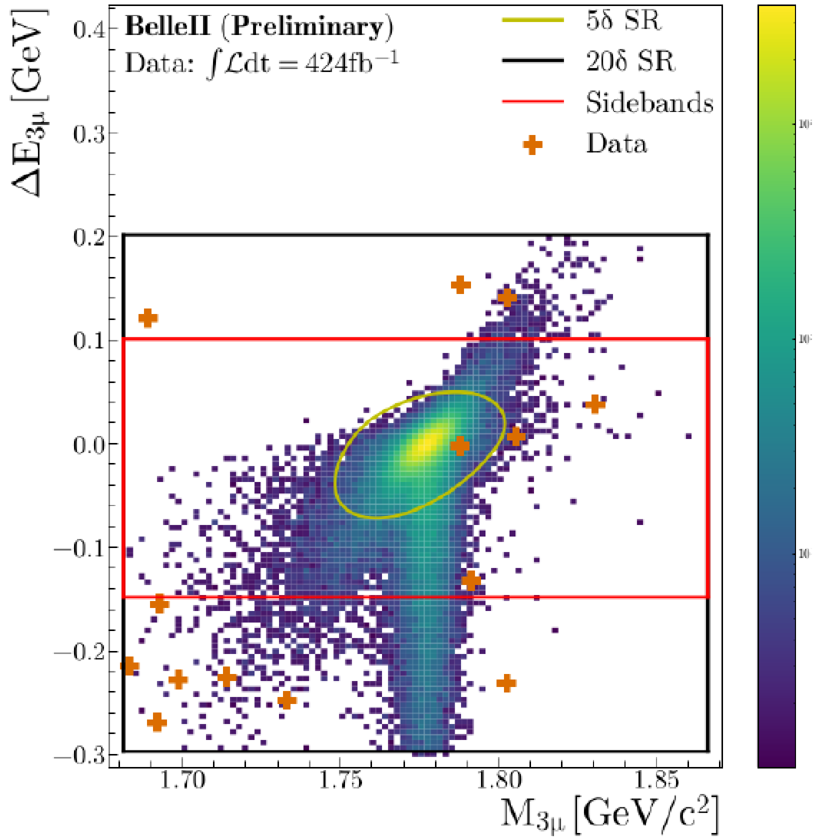
Signal side: 3 muons

Tag side: up to 3 tracks

- Background reduction by BDT
- 2D signal region: ε = 20.42% x3 larger than Belle
- Expected Bckgr 0.5 events (estimated from sidebands)

→ 1 event observed in signal region.

$\Delta E_{3\mu} = E_{\tau,\,sig} - E_{beam}$ vs $M_{3\mu}$



- **No significant excess found in 424 fb^{-1} data sample**
- **Most stringent limit** on BR(t→ μμμ) at 90% CL: 1.9 x 10^{-8}

Better limit with smaller dataset thanks to the more inclusive tag technique (includes 3-prong vs only 1-prong)

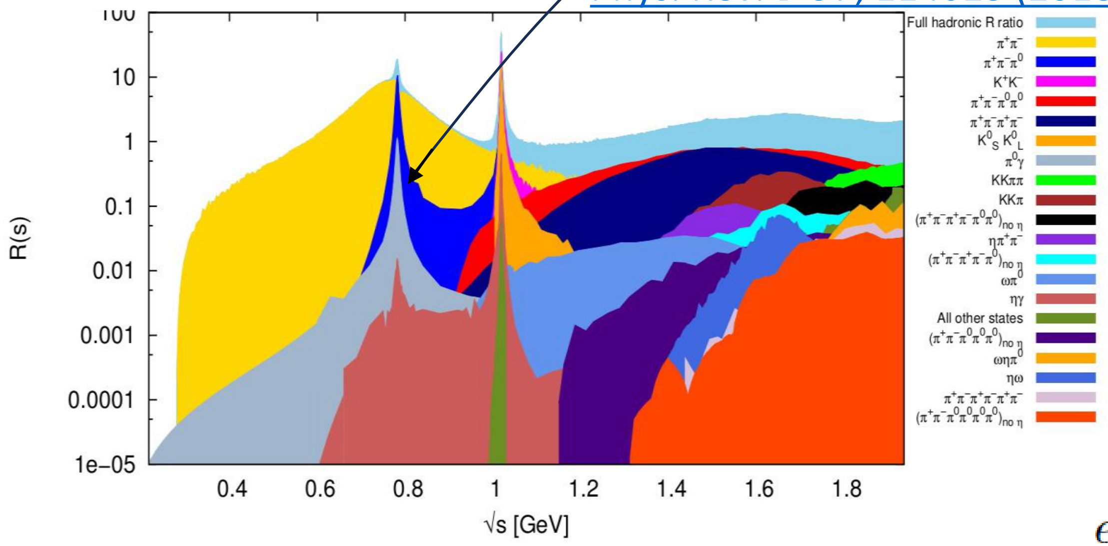
	UL at 90% CL on $B(\tau \to 3\mu)$
Belle	2.1×10^{-8} ($\mathcal{L}_{int} = 782\text{fb}^{-1}$)
BaBar	3.3×10^{-8} ($\mathcal{L}_{int} = 468\text{fb}^{-1}$)
CMS	2.9×10^{-8} ($\mathcal{L}_{int} = 131\text{fb}^{-1}$)
LHCb	4.6×10^{-8} ($\mathcal{L}_{int} = 2.0\text{fb}^{-1}$)
Belle II	1.9×10^{-8} ($\mathcal{L}_{int} = 424\text{fb}^{-1}$)

σ (e^+e^- → $\pi^+ \pi^- \pi^0$)

arXiv:2404.04915

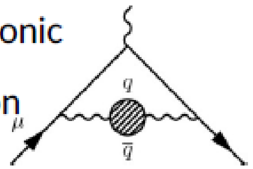
$$R(s) = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

Phys. Rev. D 97, 114025 (2018)



Is the second largest contribution to HVP below 1 GeV.

HVP: hadronic vacuum polarization



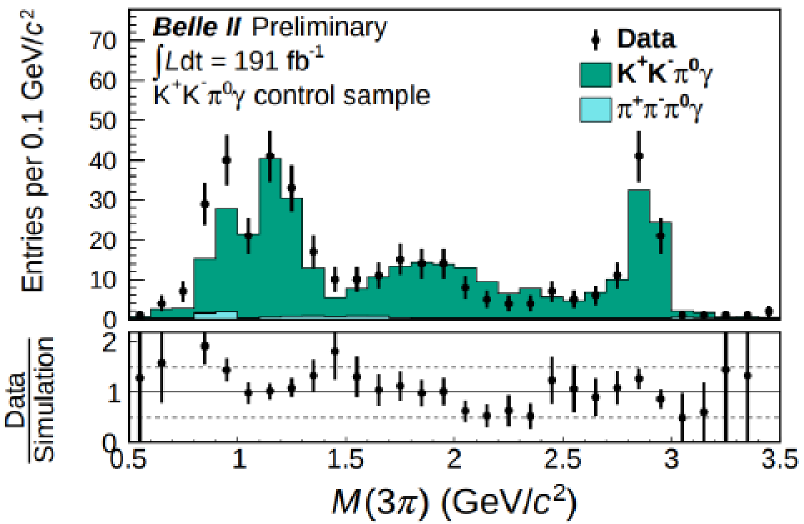
HVP produces the largest uncertainty in the prediction of the muon (g-2)

Measured at Belle II exploiting $e^+e^- \to \pi^+\pi^-\pi^0\gamma_{ISR}$

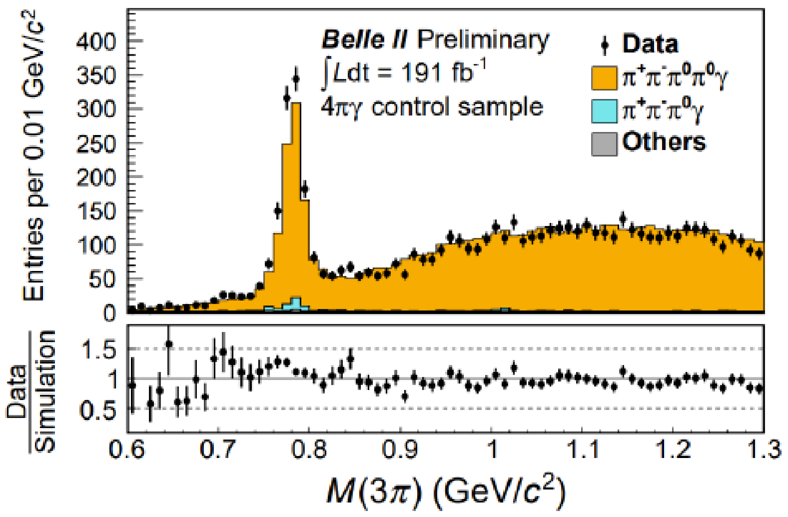
→ Scan the region 0.7 < $\sqrt{s}$ < 3.5 GeV by γ_{ISR} reconstruction

- Used a 191 fb^{-1} sample
- Kinematic fit with beam momentum constraint to suppress background
- Signal efficiency from 9.2% (low energy) to 6.3% (high energy)
- Control samples to measure residual background

$$e^+e^- \to K^+K^-\pi^0\gamma$$



$$e^+e^- \to \pi^+\pi^-\pi^0\pi^0\gamma$$

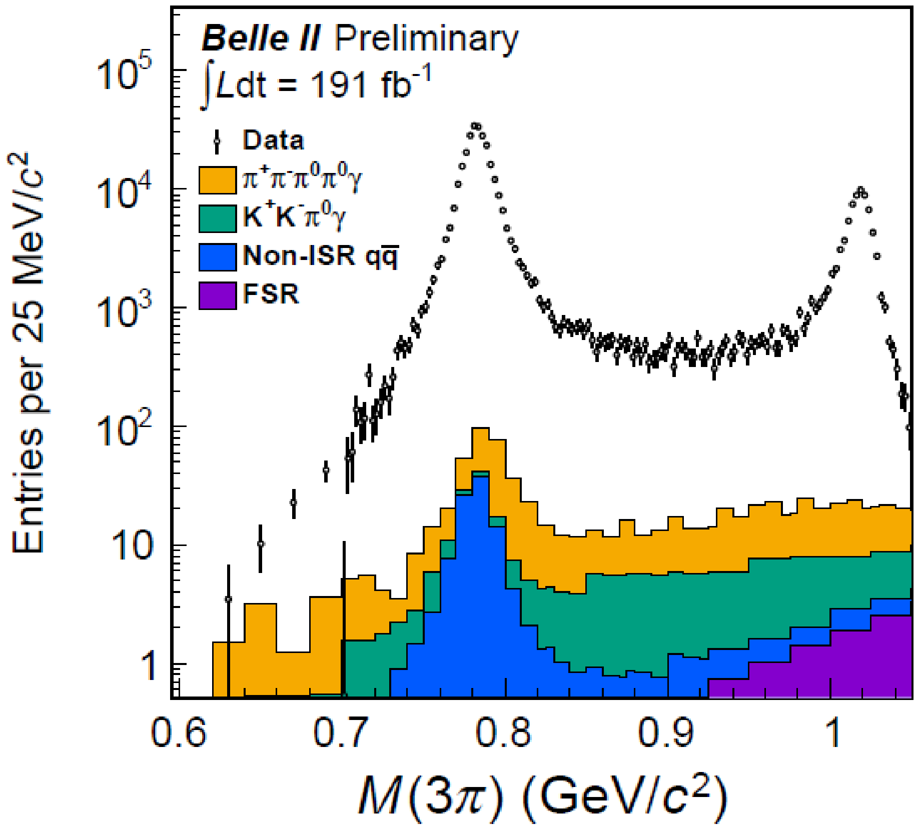


$\sigma\ (e^+e^- \rightarrow \pi^+\pi^-\pi^0)$

π^0 reconstruction efficiency measured from ω resonance decays

$$\varepsilon_{\pi^0} = \frac{N(\text{Full reconstruction of } \gamma_{ISR}\ \pi^+\pi^-\pi^0)}{N(\text{Partial reconstruction of } \gamma_{ISR}\ \pi^+\pi^-)}$$

1% accuracy reached
Main contribution to the systematics.
Not yet competitive with BaBar



Integrate over 3π cross section from $0.62 - 1.8$ GeV (Preliminary):

$$a_{\mu,0.62\text{-}1.8}^{3\pi} \times 10^{10} = 48.91 \pm 0.23_{\text{stat.}} \pm 1.07_{\text{syst.}}$$

6.7% or 2.5σ higher than current global average, obtained from BABAR, CMD-2 and SND

→ Slighlty smaller a_μ anomaly

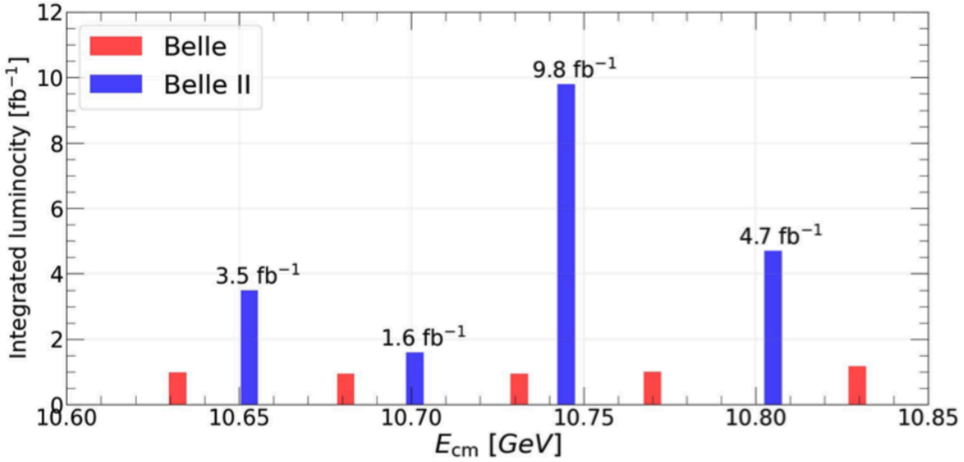
Leading systematics are π^0 efficiency and missing NNLO in generator

Quarkonium and spectroscopy

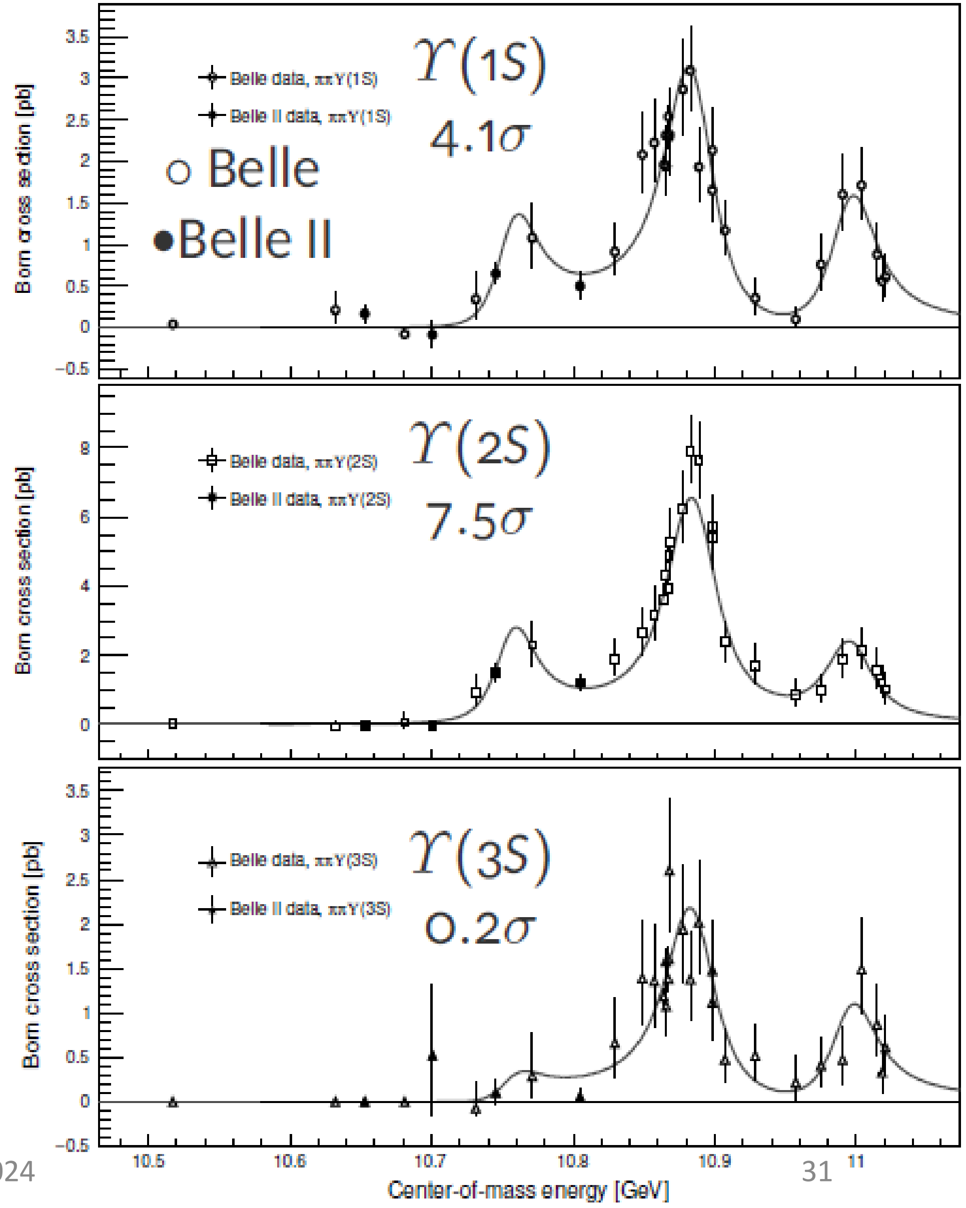
Rediscovery of Y(10753)

arxiv:2401.12021

A new energy scan performed by Belle II to fill gaps in previous Belle scan, for a total integrated luminosity of 19 fb^{-1}



Reconstruct $e^+e^- \rightarrow \pi^+\pi^-\Upsilon(nS)(\rightarrow \mu^-\mu^+)$



Observation of *Y*(10753) in agreement with Belle results

M(*Y*(10753)) = 10756.6 ± 2.7 ± 0.9 MeV/c^2
Γ(*Y*(10753)) = 29.0 ± 8.8 ± 1.2 MeV/c^2

No signals of intermediate Z_b^+ (10610/10650) resonances observed

Search for $\Upsilon(10753) \to \omega\, \eta_b(1S)/\chi_{b0}(1P)$

arxiv:2312.13043

$\Upsilon(10753)$ tetraquark interpretation predicts a strong transition to $\omega\, \eta_b(1S)$ compared to those into $\Upsilon\pi^+\pi^-$ [Chin. Phys. C 43, 123102 (2019)]

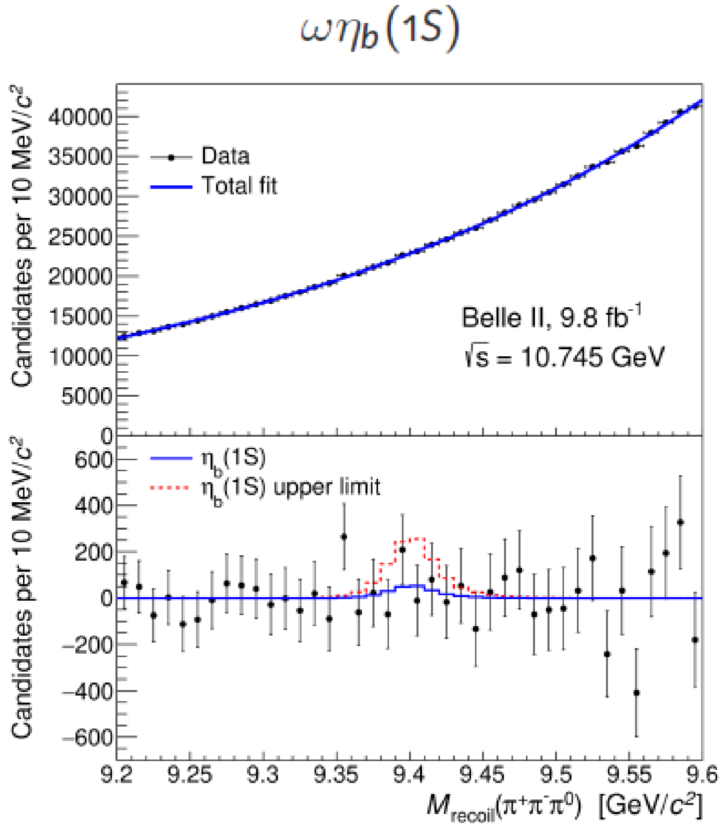
Reconstruct $\omega \to \pi^+\pi^-\pi^0$ and look for a peak in the recoil mass distribution

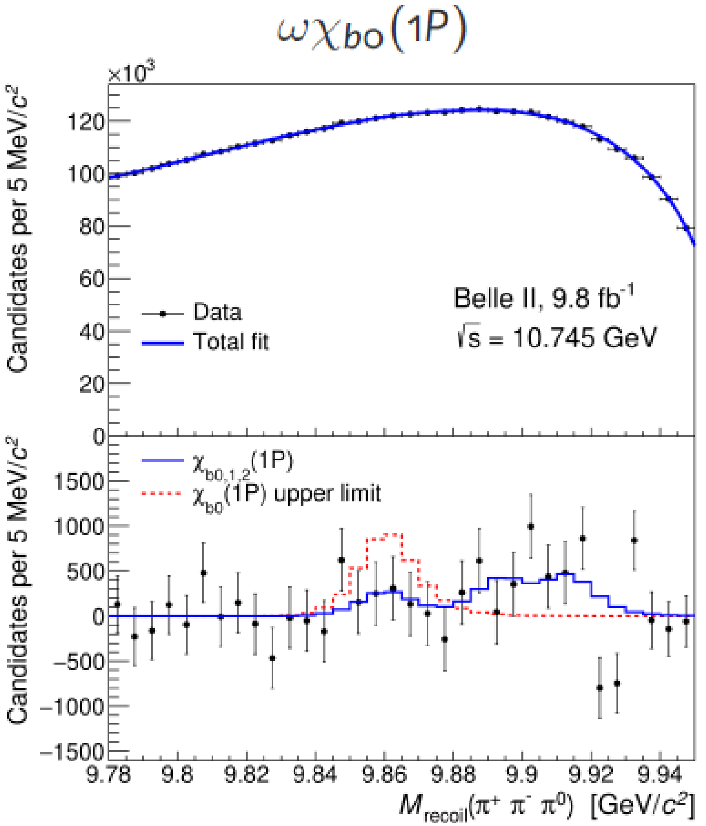
$$\sigma(e^+e^- \to \omega\chi_{b0}(1S) < 7.8\, pb \text{ (*)}$$
$$\sigma(e^+e^- \to \omega\eta_b(1S) < 2.5\ pb$$

No significant signals observed

→ Tetraquark model is not supported

(*) *obtained by averaging the result of this analysis with the previously published one Phys. Rev. Lett. 130, 091902*





Conclusions

Belle II and Belle hold a unique data sample from which a number of interesting measurement has been already performed in different fields, such as:

Evidence for $B^+ \rightarrow K^+ \nu \nu$, test of μ-e universality in τ decays, new limit on $\tau \rightarrow \mu\mu\mu$ decays, $|V_{ub}|$ exclusive measurement, $B \rightarrow \pi^0 \pi^0$ decay.

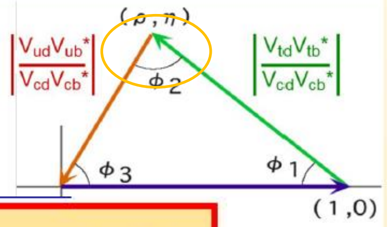
Many more measurement are in progress.

Belle II has restarted collecting data for its Run 2, in close collaboration with the SuperKEKB team, aiming to significative increase of its data sample in the next few years.

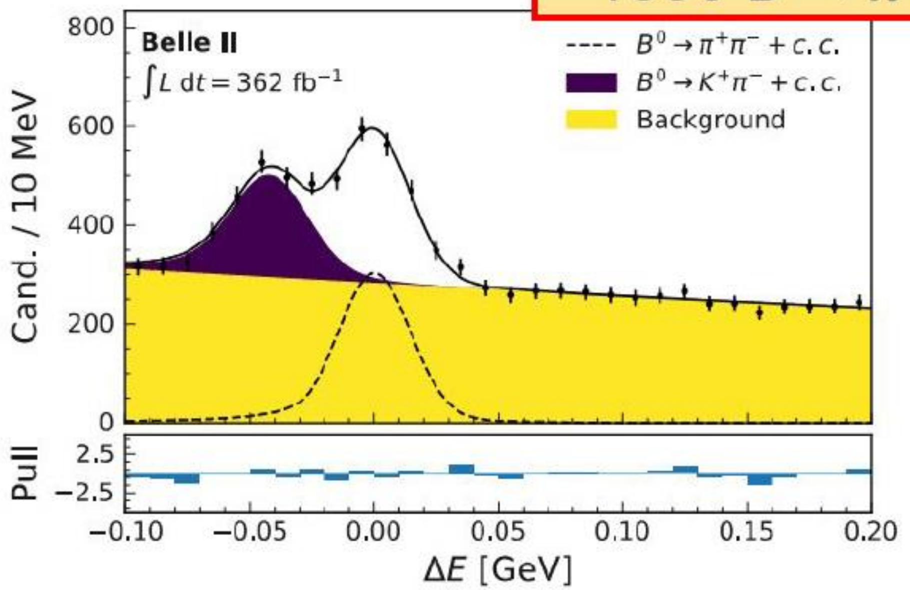
SPARES

PRD 109, 012001 (2024)

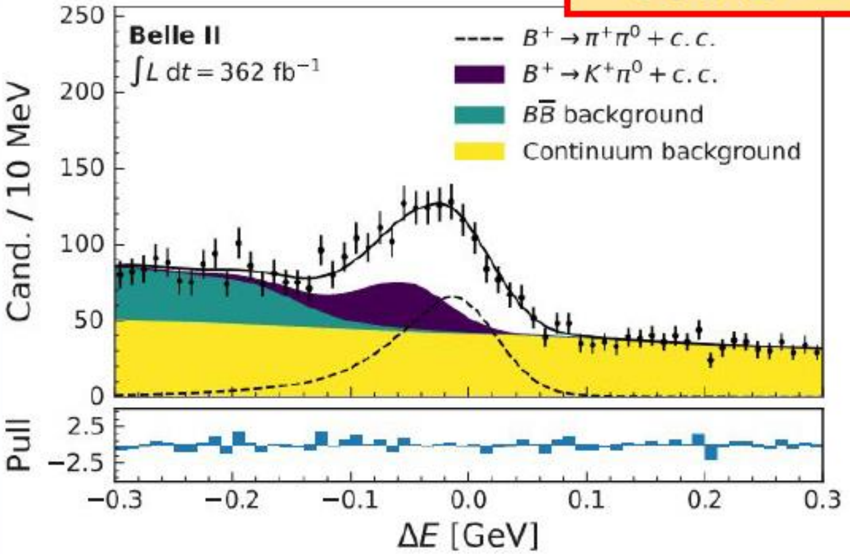
B→ $\pi\pi$



~1500 $B^0 \rightarrow \pi^+\pi^-$



~900 $B^+ \rightarrow \pi^+\pi^0$



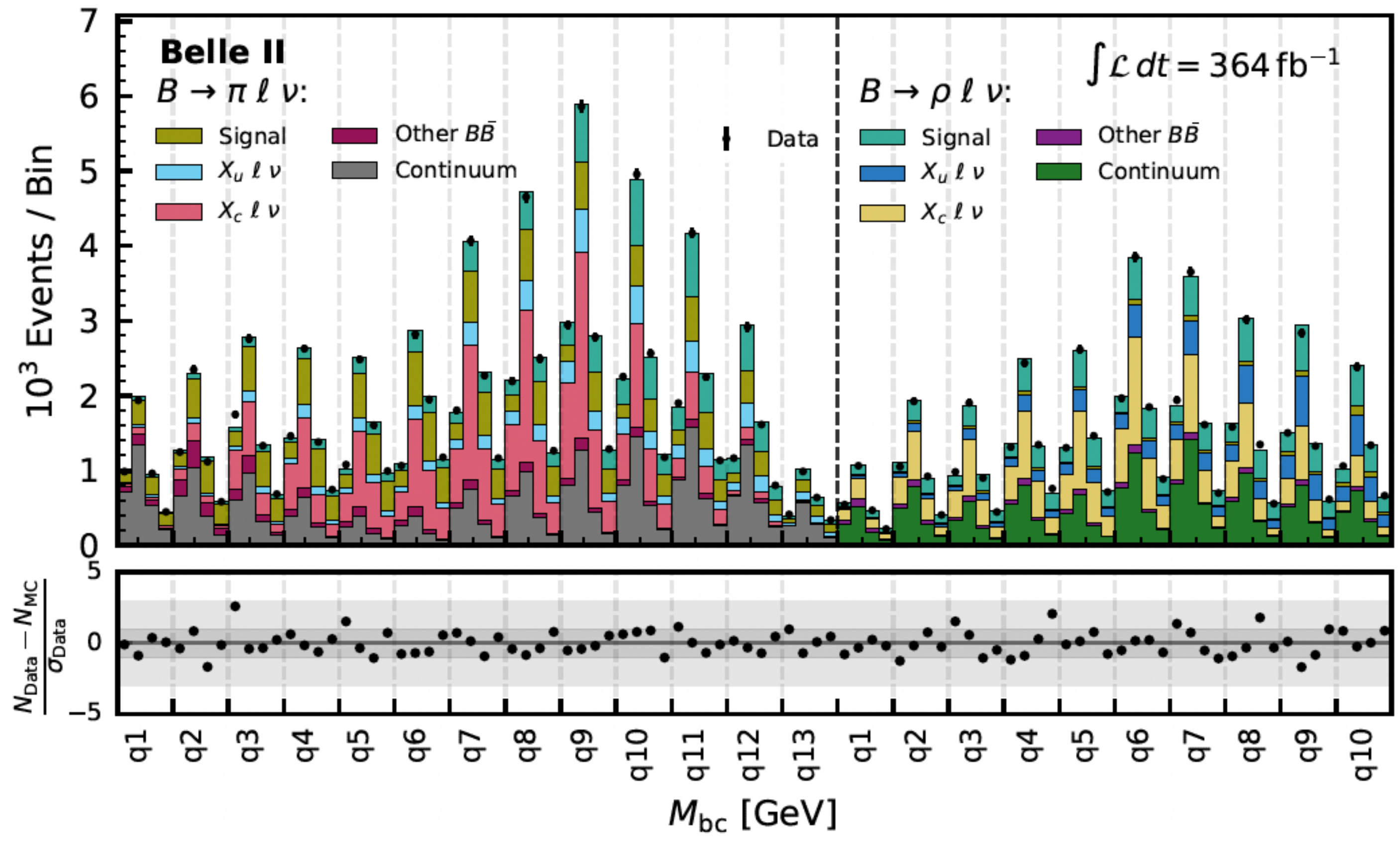
$\mathcal{B}(B^0 \rightarrow \pi^+\pi^-) = (5.83 \pm 0.22 \pm 0.17) \times 10^{-6}$

world's best

$\mathcal{B}(\pi^+\pi^0) = (5.10 \pm 0.29 \pm 0.32) \times 10^{-6}$
$A_{CP}(\pi^+\pi^0) = -0.081 \pm 0.054 \pm 0.008$

- Compatible and competitive with WA
- Modes with π^0 limited by π^0 systematics: will be reduced with more data

Simultaneously extract signals in 2D grid of beam-constrained mass and energy difference **for each bin of** : **13** bins for mode, **10** bins for mode



- Cross-feed signals are linked in two modes
- Dominant backgrounds are from B-> X_c l ν decays and continuum

Form Factor parametrization and theory inputs for $|V_{ub}|$ extraction

	$B^0 \to \pi^+ l^- \bar{\nu}_l$	$B^- \to \rho^0 l^- \bar{\nu}_l$
Form factor param.	Bourrely-Caprini-Lellouch (BCL) Phys. Rev. D **82**, 099902	Bharucha-Straub-Zwicky (BSZ) JHEP (2016) 98
Theory prediction	LQCD Eur. Phys. J. C **82** (2022) 869	LCSR JHEP (2016) 98
	LQCD + LCSR JHEP (2021) 36	

Energy dependence of $e^+e^- \to B^{(*)}\bar{B}^{(*)}$

- The obtained cross sections at four energies are consistent with the Belle results.
- $\sigma(e^+e^- \to B^*\bar{B}^*)$ increases rapidly above $B^*\bar{B}^*$ threshold
  - Similar phenomenon was observed near $D^*\bar{D}^*$ threshold.
  - **Possible interpretation:** resonance or bound state ($B^*\bar{B}^*$ or $b\bar{b}$) near $B^*\bar{B}^*$ threshold
  - Inelastic channels $[\pi^+\pi^-\Upsilon(nS)$ and $\eta h_b(1P)]$ could also be enhanced. Need more data to study these transitions.