# Recent Results from Belle II experiments

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**On behalf of the Belle II collaboration**

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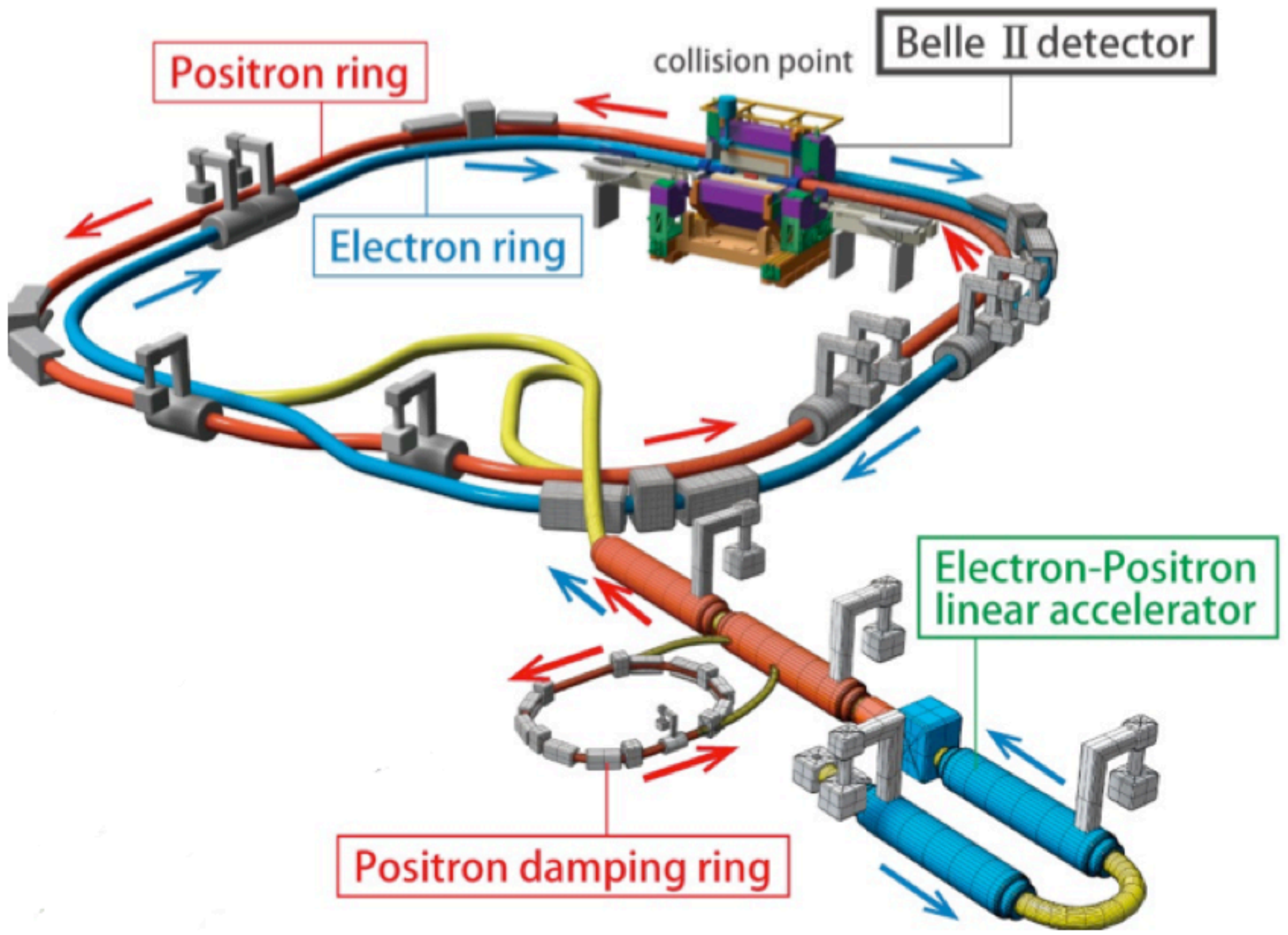
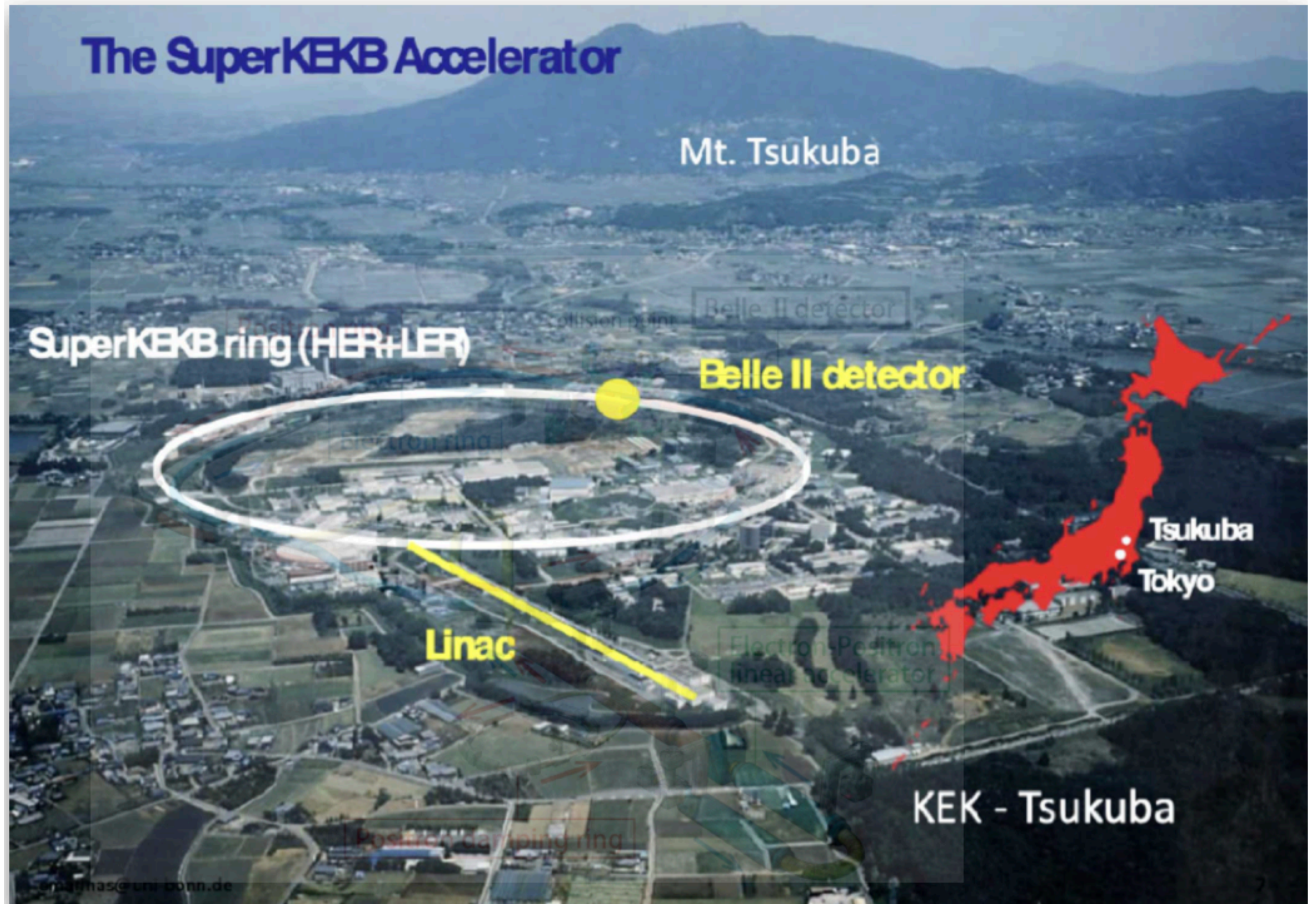
Workshop on HighLumi-LHC and Hadron Colliders
Frascati, 01-04 October 2024

# Belle II experiment: SUPERKEKB complex

- Asymmetric $e^+e^-$ colliders
- Collisions mainly at 10.58 GeV , i.e at $\Upsilon(4S)$ resonance




**SuperKEKB**

2019-current

- $e^+$ (4 GeV) $e^-$(7 GeV)

**Target:**

$$\int Ldt = 50 \ \ ab^{-1}$$

$$L_{peak} = 6 \times 10^{35} \ \ cm^{-2}s^{-1}$$

**Achieved**:

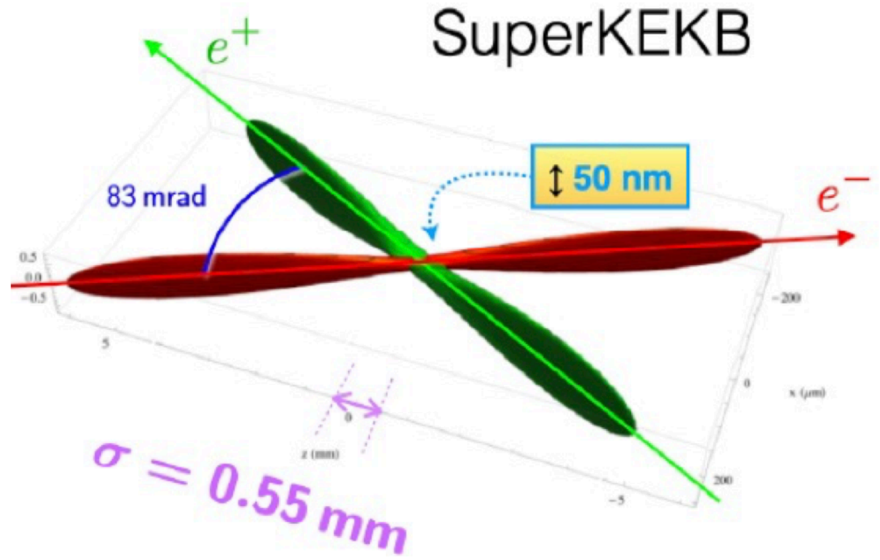
$$\int Ldt > 530 \ \ fb^{-1}$$

$$L_{peak} = 4.7 \times 10^{34} \ \ cm^{-2}s^{-1}$$

***Current world record***

New **nano-beam** scheme

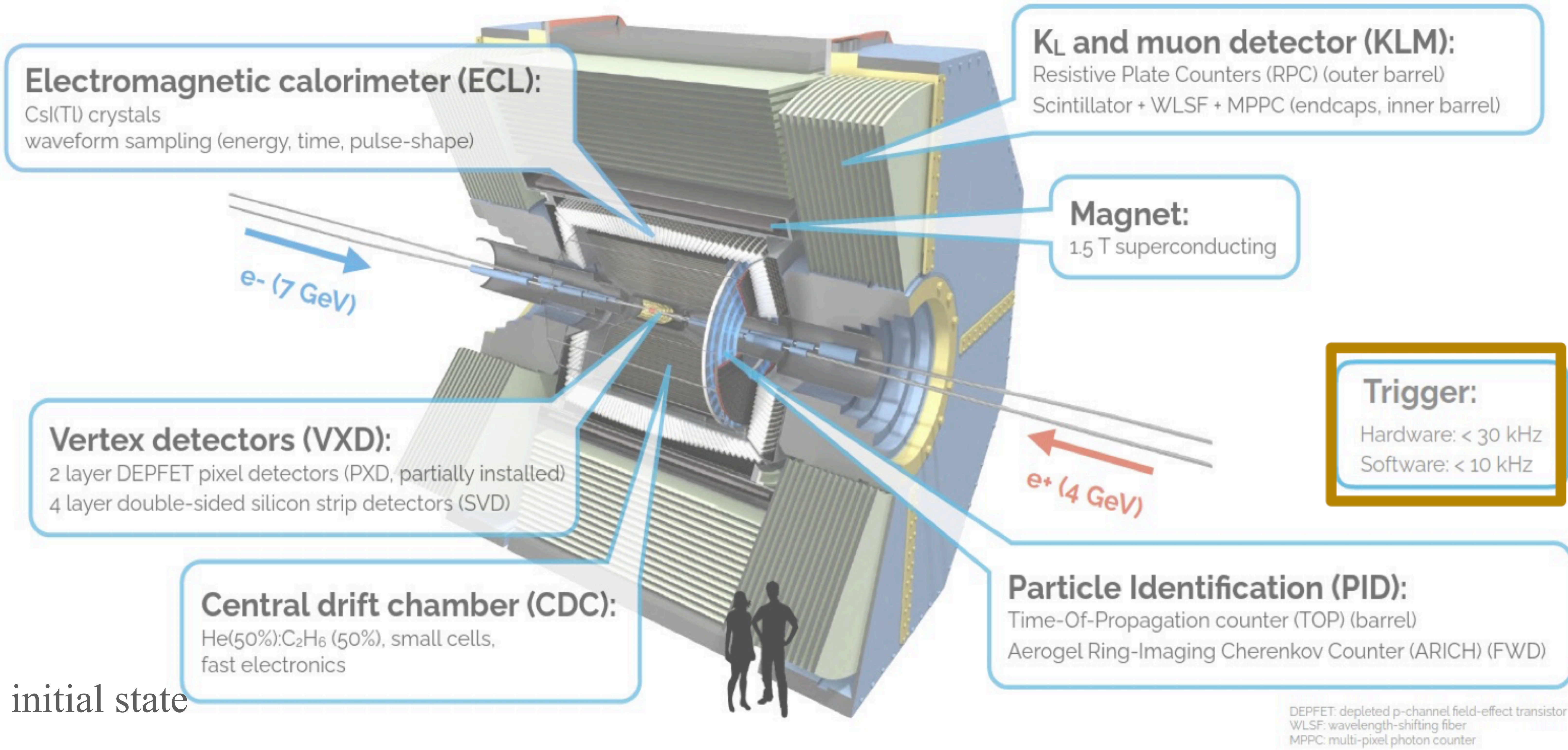
- $\beta_y^* \sim 0.284$



# Belle II experiment: detector

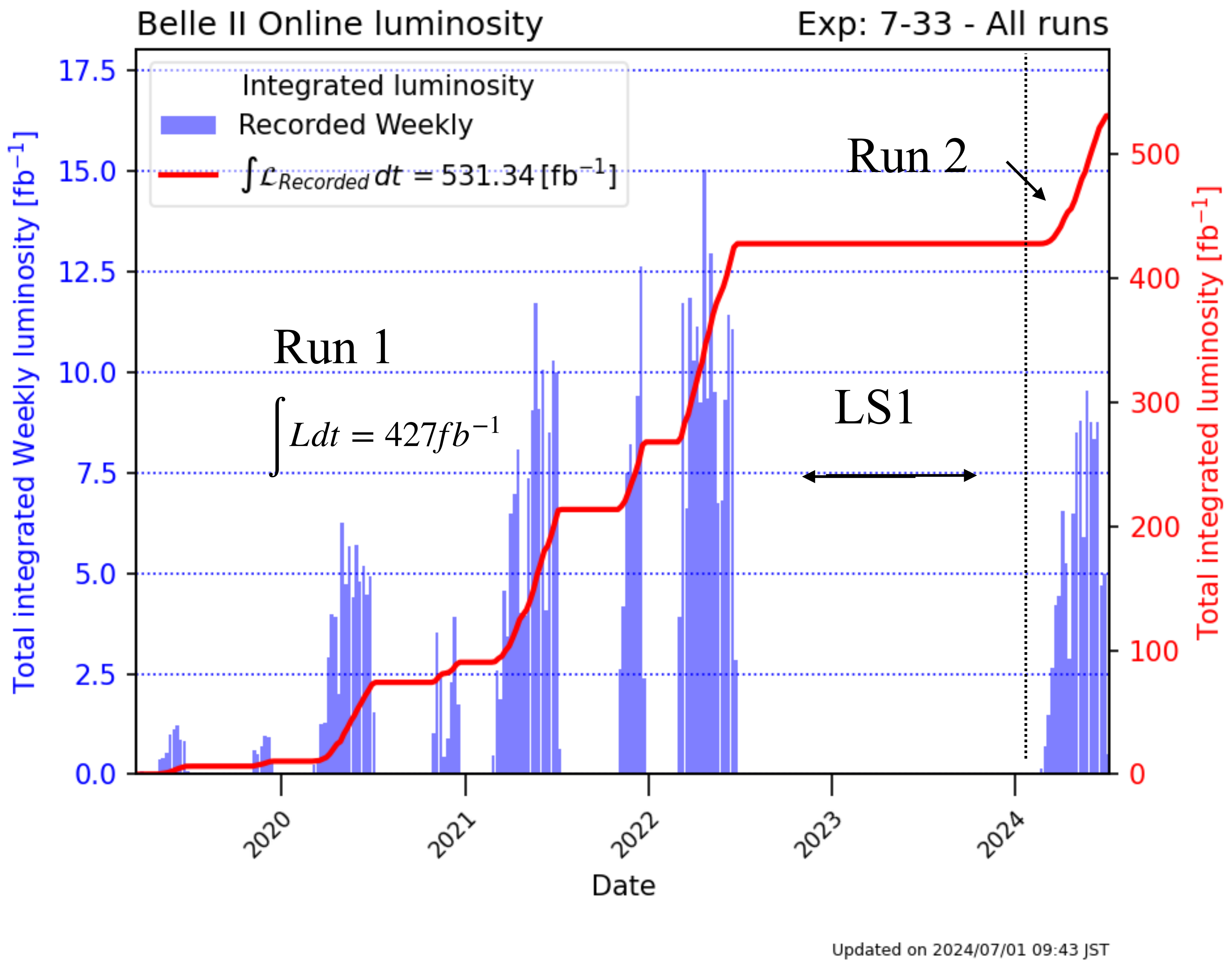
Benefits from **clean environment** at lepton colliders + **hermetic detector**

- Excellent overtaxing and tracking performances




- Running mainly $\sqrt{s} = 10.58$ GeV, very **well-known** initial state
- Multipurpose detector with cylindrical symmetry
- Efficient reconstruction of **neutrals** $(\pi^0, \eta)$
- Specific **low-multiplicity triggers:** single track, /muon / photon (previously not available at Belle and BaBar)
- Excellent particle identification system

# Belle II data -taking




July 2022: First LS1 to allow the installation of two layers PXD detector

February 2024: start of RUN2

We are suffering from **sudden beam loss events**, with large doses at the interaction region.

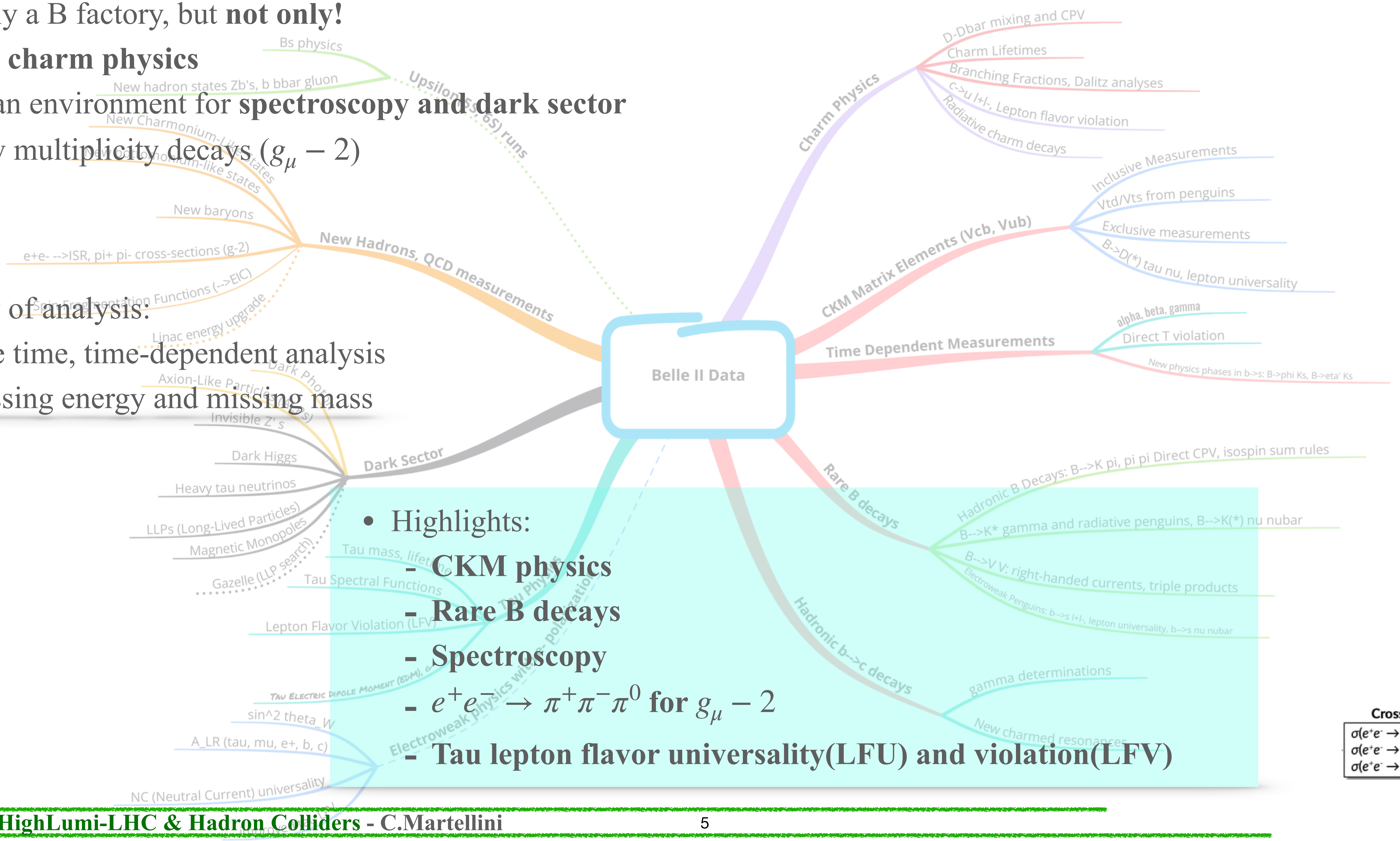
In a couple of them two channels of **PXD were damaged**

- as a precaution, it has been decided to **keep PXD off** while investigating the sources of the sudden beam loss and implement countermeasures to stabilize the beam operation

# Belle II Physics Program

- Primarly a B factory, but **not only!**
  - **tau, charm physics**
  - Clean environment for **spectroscopy and dark sector**
  - Low multiplicity decays ($g_\mu - 2$)

- Variety of analysis:
  - Life time, time-dependent analysis
  - Missing energy and missing mass




- Highlights:
  - **CKM physics**
  - **Rare B decays**
  - **Spectroscopy**
  - $e^+e^- \to \pi^+\pi^-\pi^0$ **for** $g_\mu - 2$
  - **Tau lepton flavor universality(LFU) and violation(LFV)**

**Cross sections**

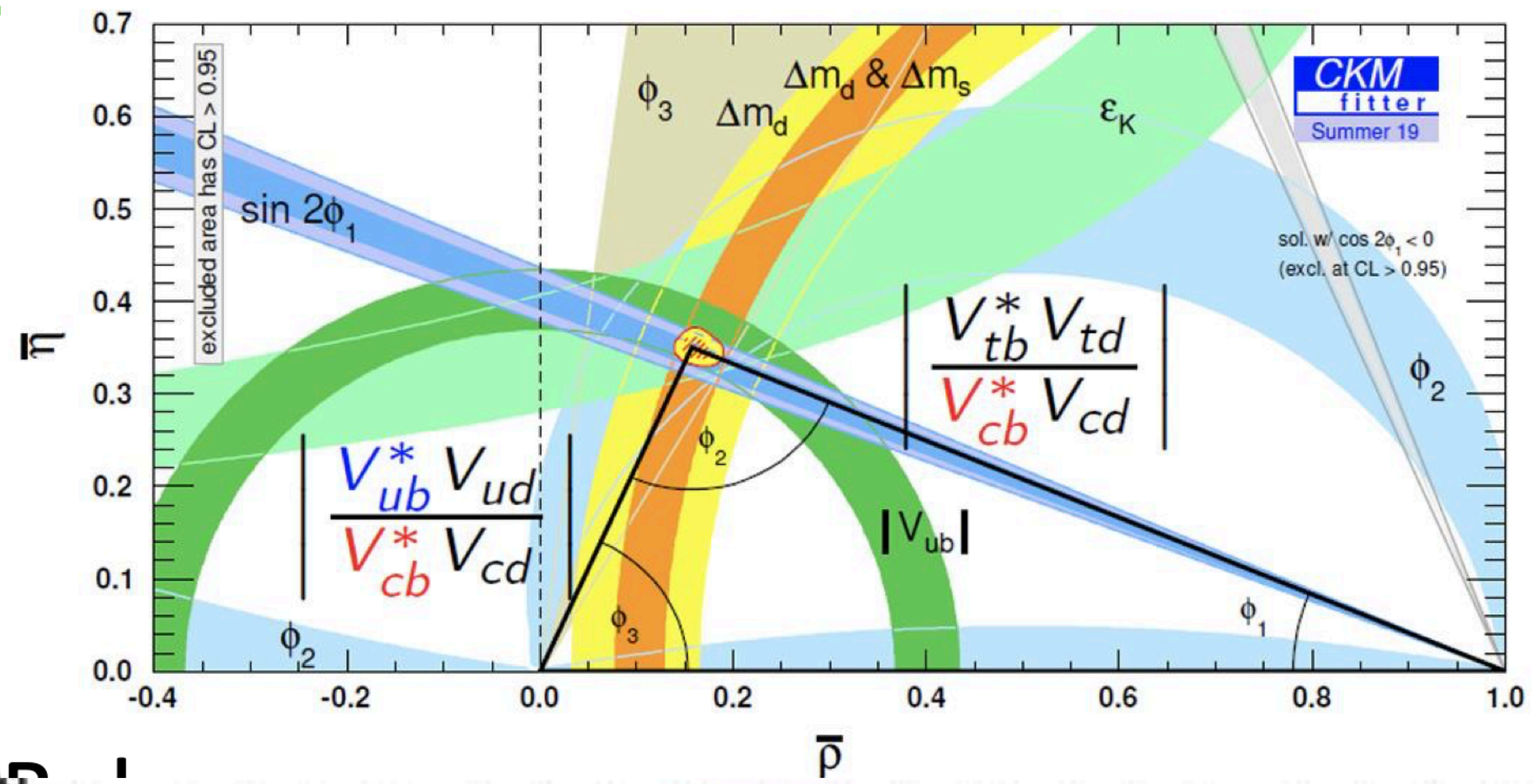
$\sigma(e^+e^- \to b\bar{b}) \simeq 1.1$ nb
$\sigma(e^+e^- \to c\bar{c}) \simeq 1.3$ nb
$\sigma(e^+e^- \to \tau^+\tau^-) \simeq 0.9$ nb

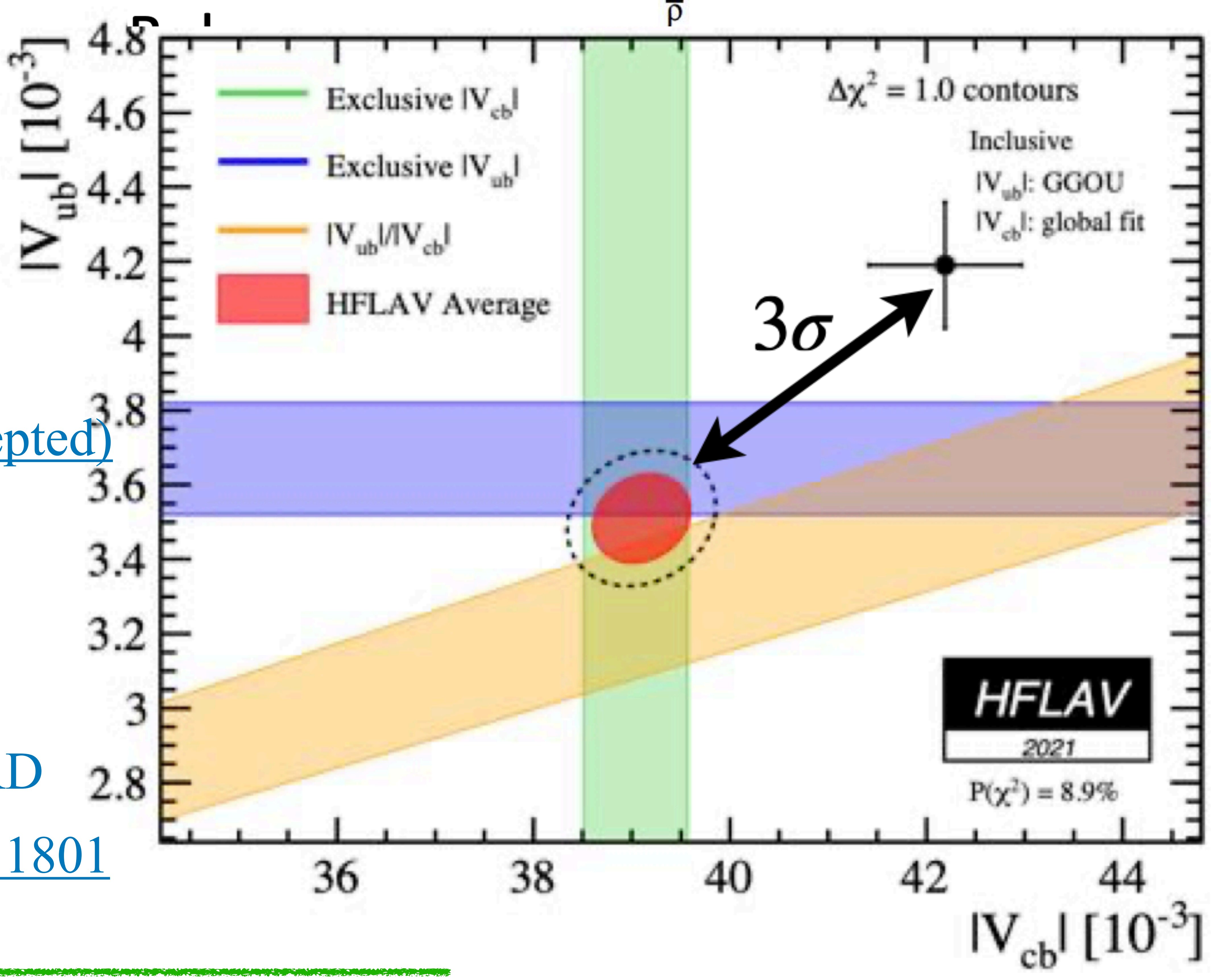
# CKM matrix - elements $|V_{cb}|$ and $|V_{ub}|$

- Determine the $|V_{xb}|$:

**Exclusive :** $B \rightarrow \pi l \nu, B \rightarrow D^{(*)} l \nu$ , etc

**Inclusive :** $B \rightarrow X_u l \nu, B \rightarrow X_c l \nu$




Different measures carried out by Belle and Belle II

- $|V_{cb}|$ angular coefficient of $B \rightarrow D^* l \nu$ Belle arXiv.2310.20286 (PRL accepted)

- $|V_{ub}|$
  - a. from $B \rightarrow (\pi/\rho) l \nu$ simultaneous analysis arXiv.2407.17403 submitted to PRD
  - b. Simultaneous inclusive and exclusive $|V_{ub}|$ Belle PRL.131.211801

arXiv.2407.17403

submitted to PRD

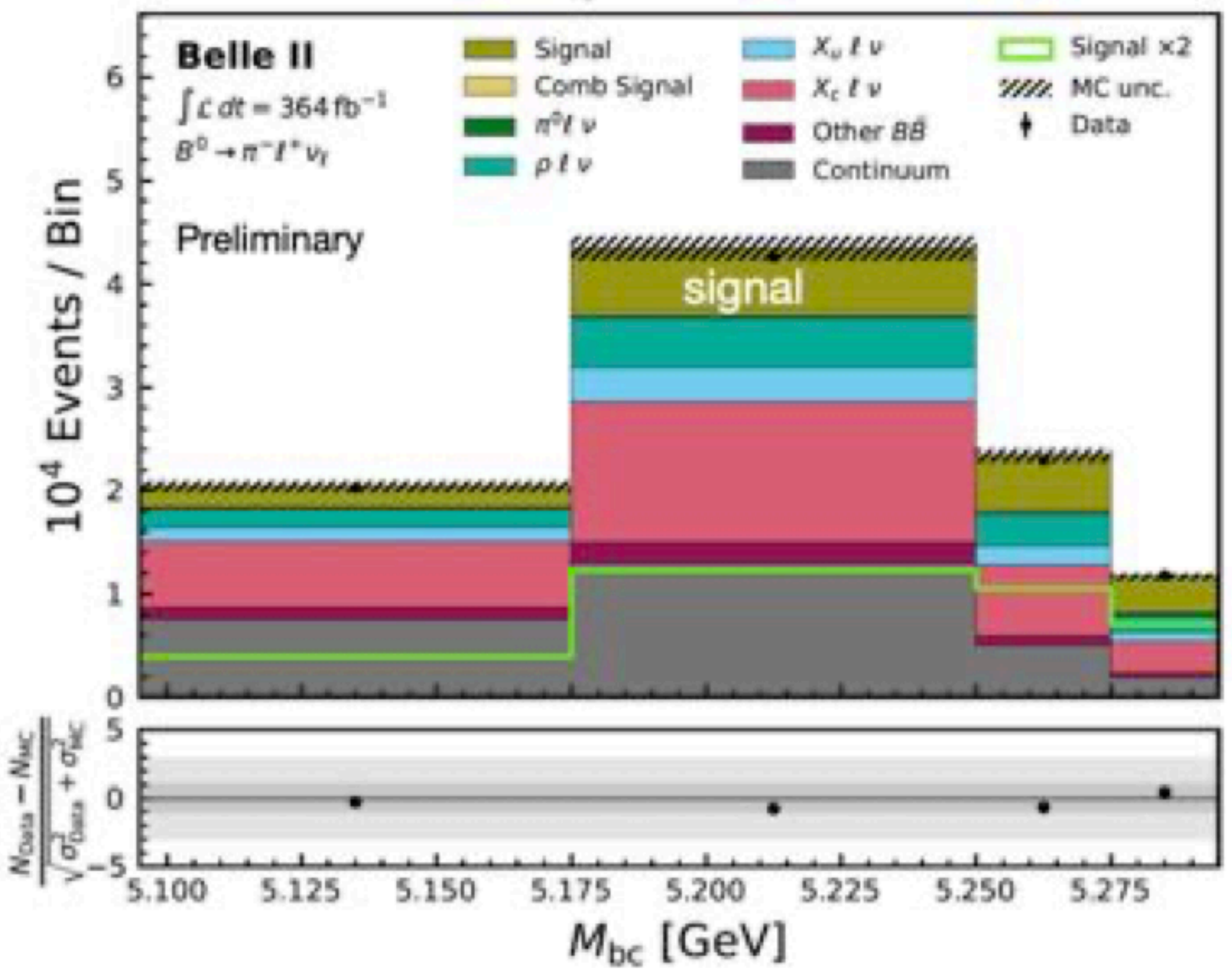
## New measurements from Belle II

Full Run1 data of 364 $fb^{-1}$ with inclusive tagging strategy

- Extract signal yield by combined fit of $M_{bc}$ and $\Delta E$ for each bin of $q^2$:
  - 13 bins for $\pi$-mode
  - 10 bins of $\rho$-mode
  - Build up BDT discriminator to suppress $B \to X_c l \nu$ and continuum

$$M_{bc} = \sqrt{E^{*2} - |\overrightarrow{p_B}|^2}$$

$$\Delta E = E_B^* - E_{beam}^*$$

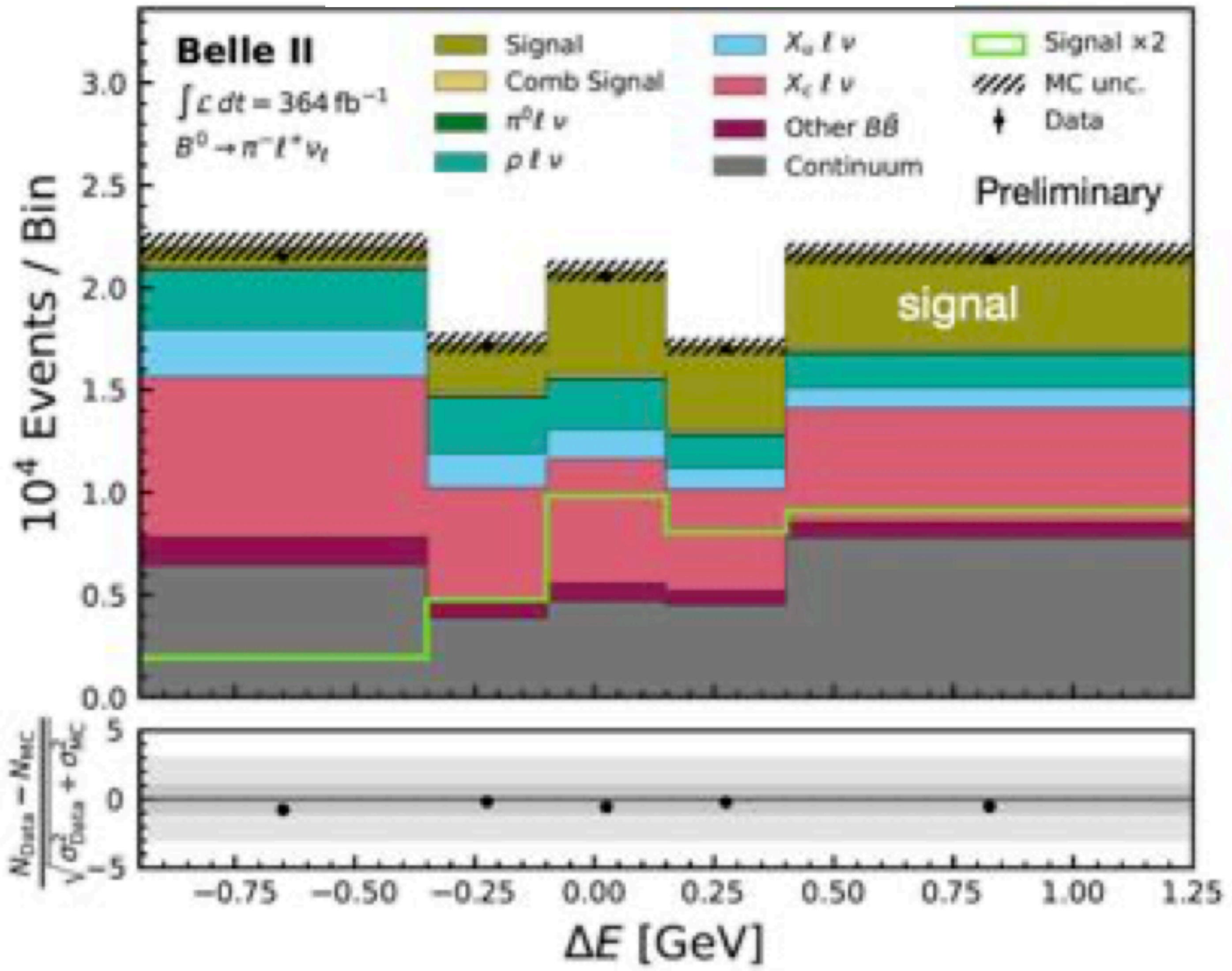



$$\mathscr{B}(B^0 \to \pi^- l \nu_l) = (1.516 \pm 0.042(stat) \pm 0.059(sys)) \times 10^{-4}$$

$$\mathscr{B}(B^0 \to \rho^0 l^+ \nu_l) = (1.625 \pm 0.079(stat) \pm 0.180(sys)) \times 10^{-4}$$

**Consistent with World Average**

**Compatible precision w.r.t. Belle and BaBar**

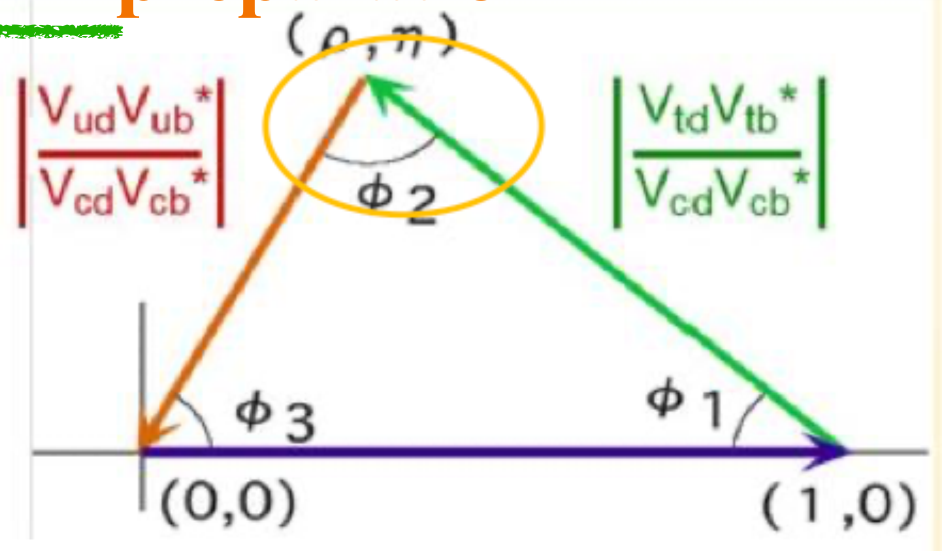



$$|V_{ub}|_{B \to \pi l \nu} = (3.73 \pm 0.07(stat) \pm 0.07(sys) \pm 0.16(theo)) \times 10^{-3}$$

$$|V_{ub}|_{B \to \rho l \nu} = (3.19 \pm 0.12(stat) \pm 0.17(sys) \pm 0.26(theo)) \times 10^{-3}$$

# $B^0 \to \pi^0\pi^0$ at Belle II : overview

Preliminary, paper in preparation




Tree level $b \to u$ **processes** allow extraction of $\phi_2$ ( or $\alpha$) (least precise CKM angle)

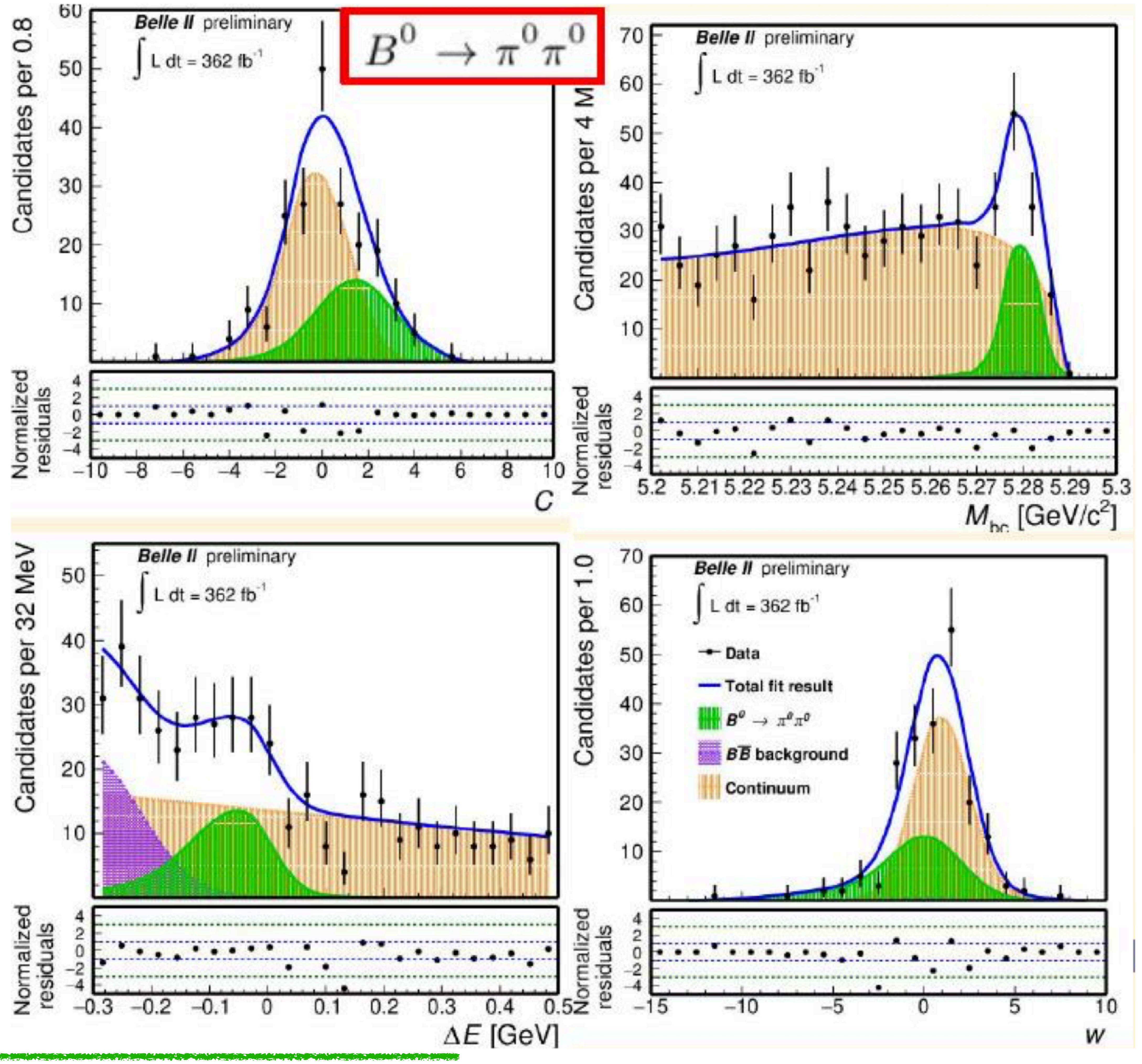
Build upon previous Belle II effort and extend to full **RUN1 data sample with improvements:**

- Improved photon selection
- Bkg mostly from continuum and $B^+ \to \rho^+\pi^0; B^0 \to K_s\pi^0$

- Statistical and systematic uncertainty reduced by 10% and 50% respectively on BF and absolute uncertainty on $A_{CP}$
- Simultaneous fit to $M_{bc}, \Delta E, C, w$ : - where C is the continuum variable
  - and w is the wrong tag probability

$$\mathscr{B}(B^0 \to \pi^0\pi^0) = (1.26 \pm 0.20 \pm 0.12) \times 10^{-6}$$

$$\mathscr{A}_{CP}(B^0 \to \pi^0\pi^0) = (0.06 \pm 0.30 \pm 0.05)$$

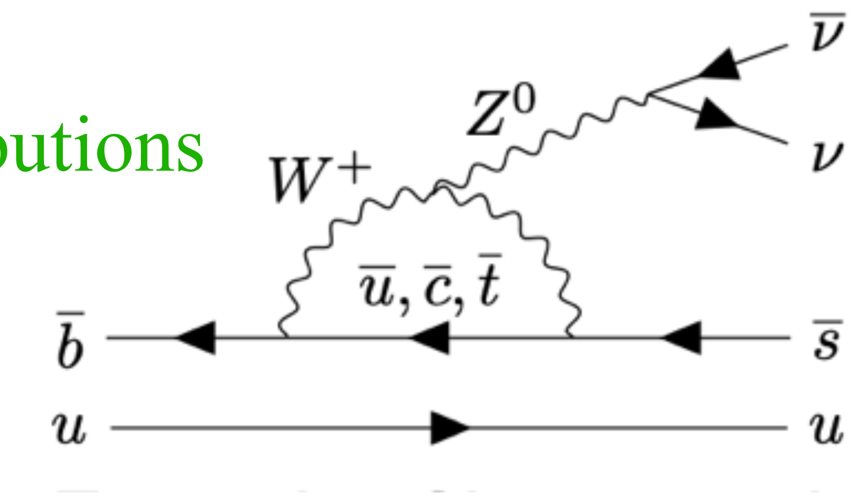



- Agreement with previous measurements
- Comparable precision with world best result from BaBar

# Rare Decays : $B^+ \to K^+\nu\bar{\nu}$ motivation

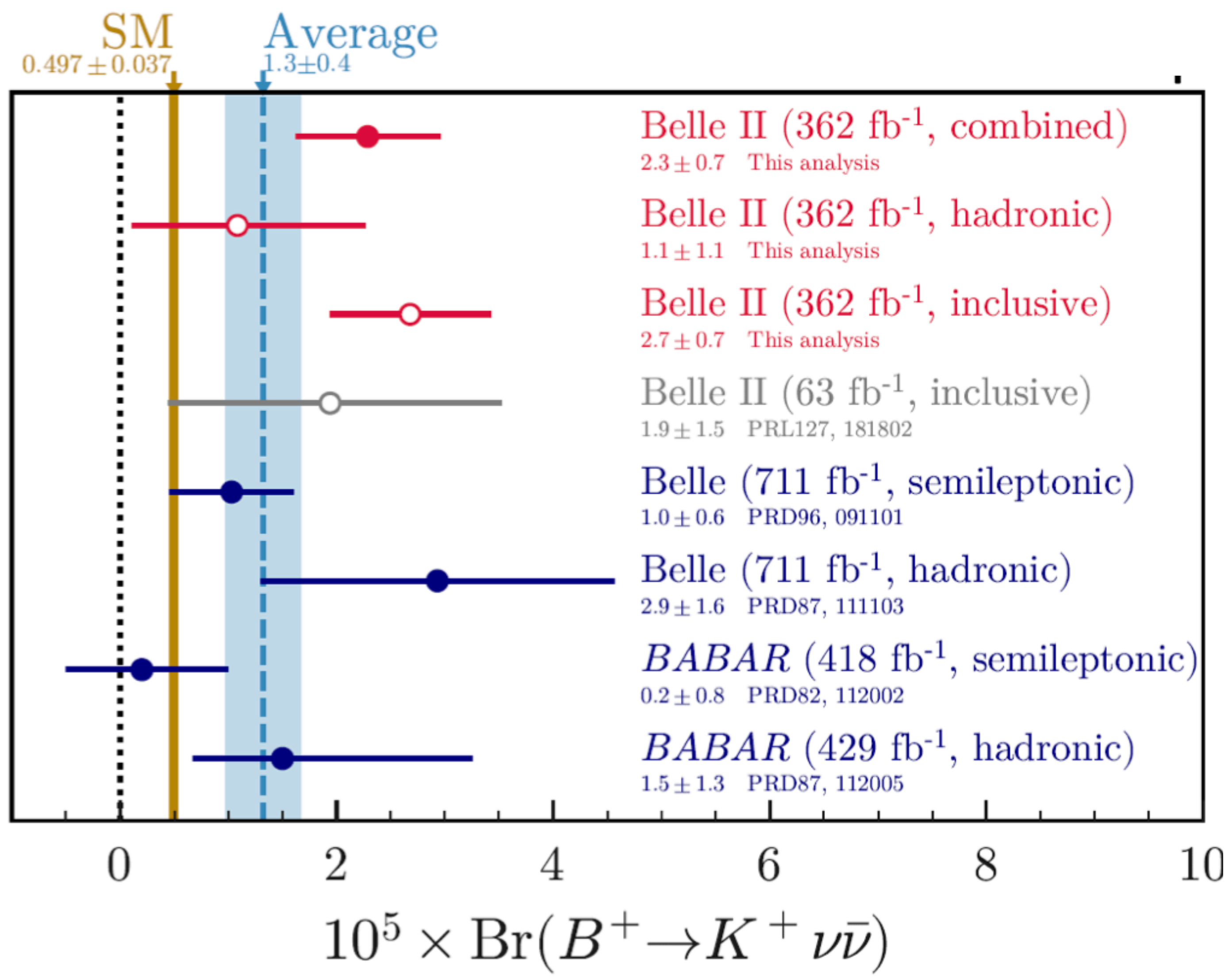
PhysRevD.109.112006

- $b \to s\nu\bar{\nu}$ are highly ***suppressed*** in the SM Highly sensitive to non-SM contributions



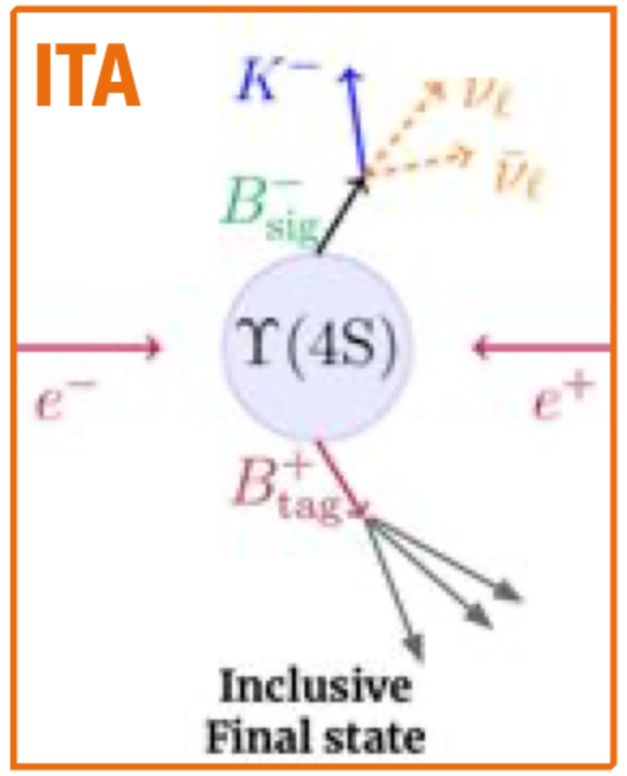

- Precise prediction in the SM: $\mathscr{B}(B^+ \to K^+\nu\bar{\nu}) = (5.6 \pm 0.4) \times 10^{-6}$ arXiv 2207.13371
  - Leading theoretical uncertainties from hadronic form factors

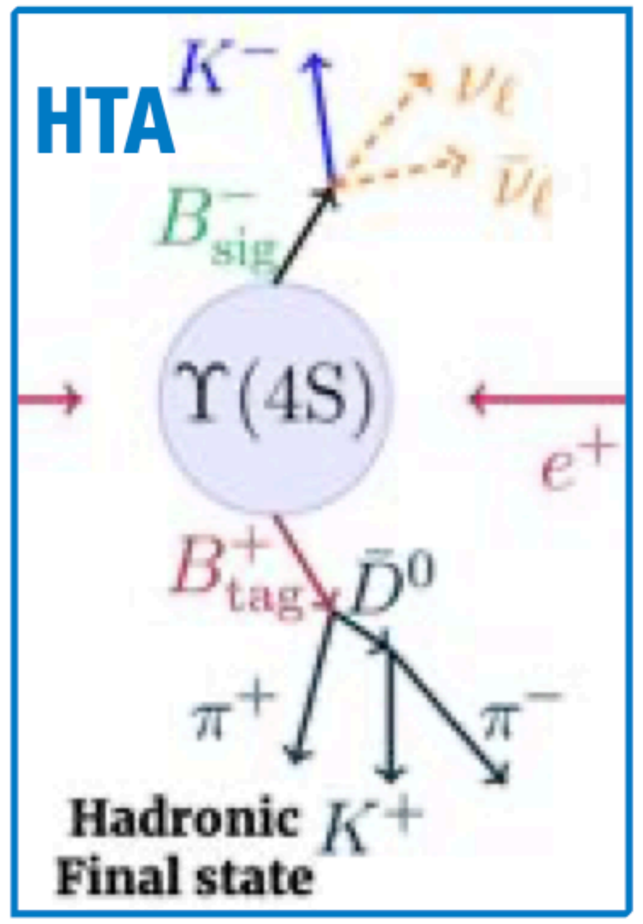
- Existing results are from BaBar (PhysRevD.87.112005) and first analysis with Belle II (Phys.Rev.Lett.127.181802)




**Belle reports upper limits only; branching fractions are estimated using published number of events and efficiency**

- Experimental challenges: **Low BF with 2 neutrinos in the final state and high bkg contamination mainly from continuum**
  - **Used to complementary B tag approach** : **low purity-high efficiency** (0.8%-8%) **and its opposite** (3.5%-0.4%)
  - Signal selection combines kaon , event topology and the rest of the event properties in MVA classifiers
  - Bkg validation : from semileptonic B-decays: $(B^+ \to K^+ n\bar{n}, B^+ \to K^+K^0\bar{K}^0)$
- **Inclusive method validated by** closure test by measuring. $\mathscr{B}(B^+ \to \pi^+K^0)$



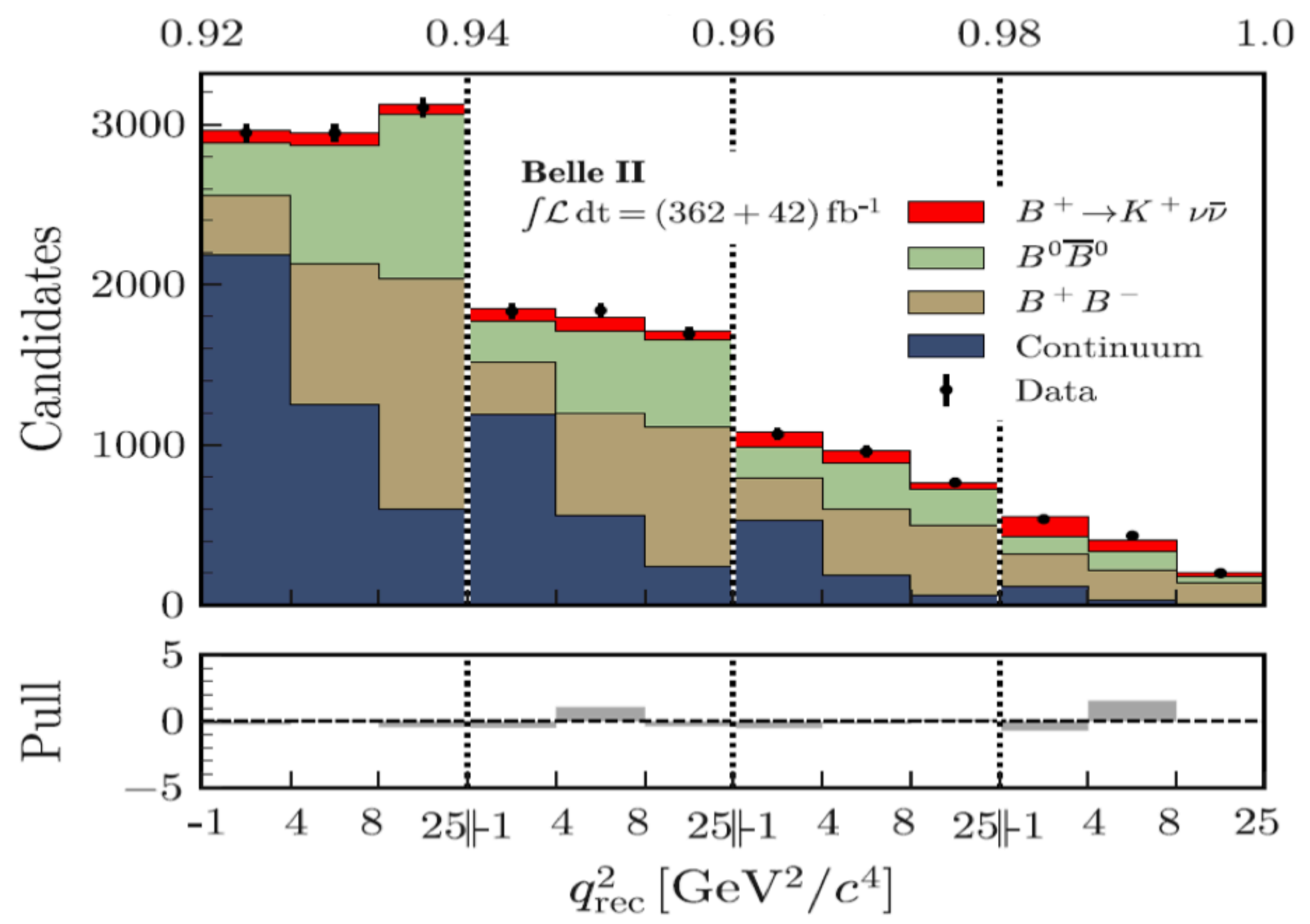
- Parameter of interest: $\mu = \dfrac{\mathscr{B}(B^+ \to K^+\nu\bar{\nu})}{\mathscr{B}_{\mathscr{SM}}(B^+ \to K^+\nu\bar{\nu})}$

- **Binned fit** to extract $\mu$:
  - ITA : 2D fit on a classifier output $[\eta(BDT_2)]$ bins and $q^2$ bins
  - HTA: fit on a classifier output $\eta(BDT_h)$

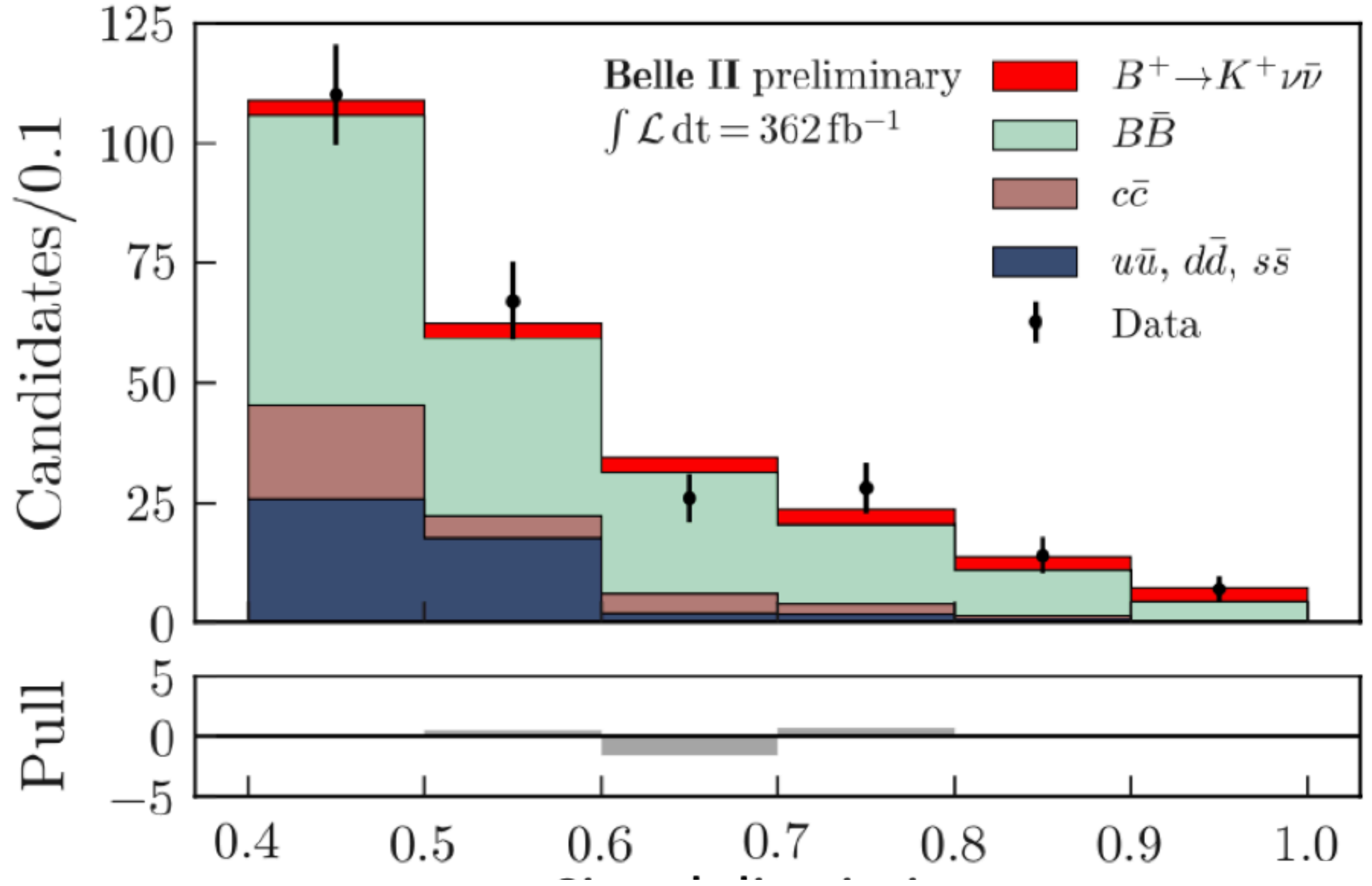
- **Combining ITA & HTA** we have a 10% increase in precision w.r.t ITA alone

**First evidence of $B^+ \to K^+\nu\bar{\nu}$ process**

ITA




HTA



# Rare Decays : $B^0 \to K^{*0}\tau^+\tau^-$ motivation

Preliminary, paper in preparation

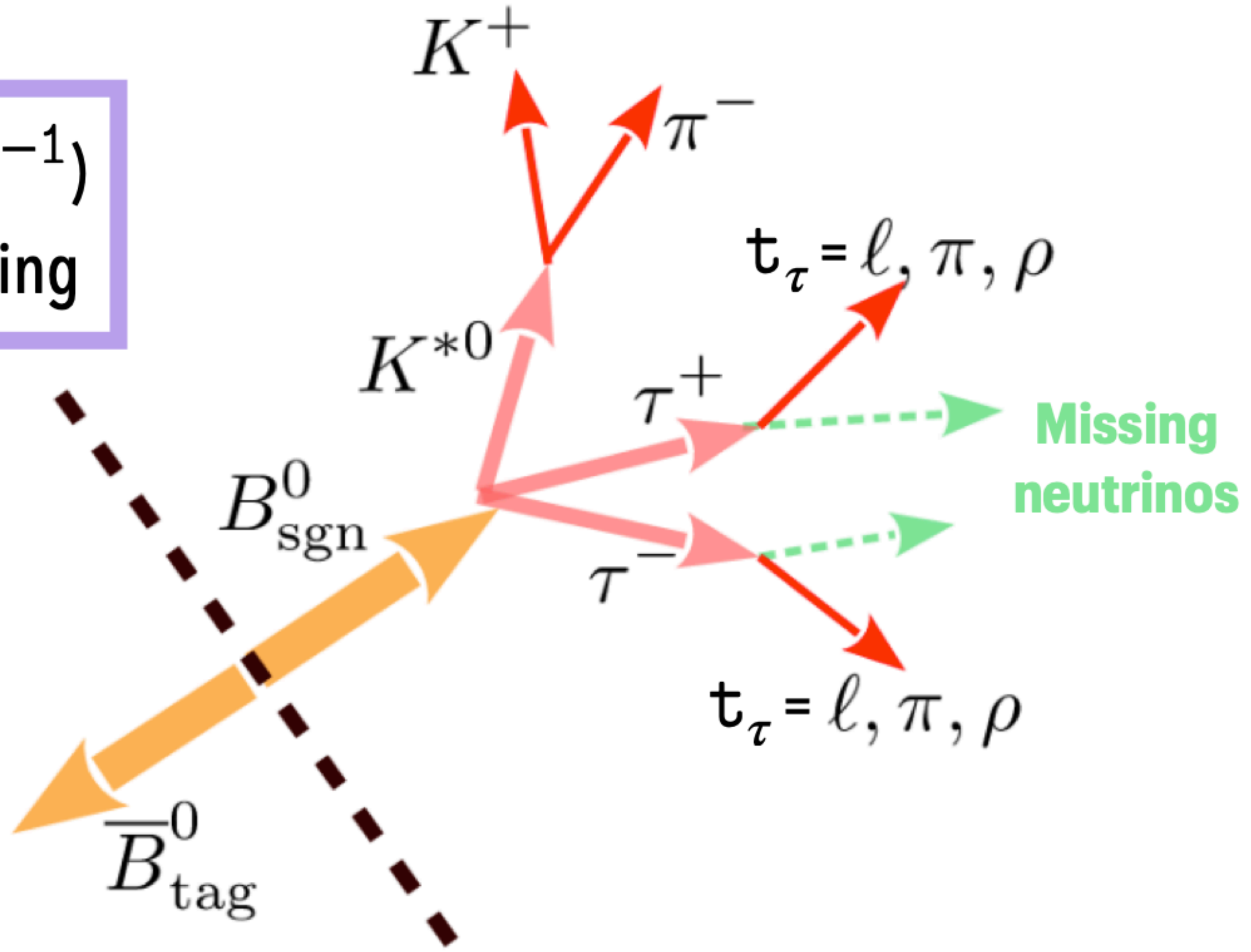
- These processes are suppressed in the SM and occur only a loop level

$$\mathscr{B}_{SM} = (0.98 \pm 0.10) \times 10^{-7}$$

- Sensitive to new physics models accommodating the $b \to c\tau\nu$ anomalies
  - Might correlate with enhanced $b \to s\tau\tau$ decay rates

- **Belle (711 fb$^{-1}$) :** $\mathscr{B}(B^0 \to K^{*0}\tau^+\tau^-) < 3.1 \times 10^{-3}$ **@ 90% C.L.**

**Belle II** (364 fb$^{-1}$)
hadronic B-tagging




**Experimental challenges:**

- Low branching fraction
- No signal peaking kinematic observable
- Large background + more than 3 prompt tracks
- Up to 4 neutrinos originating from $\tau$

- $K^{*0}$ has low momentum due to the phase space

# Rare Decays : $B^0 \to K^{*0}\tau^+\tau^-$ strategy and results

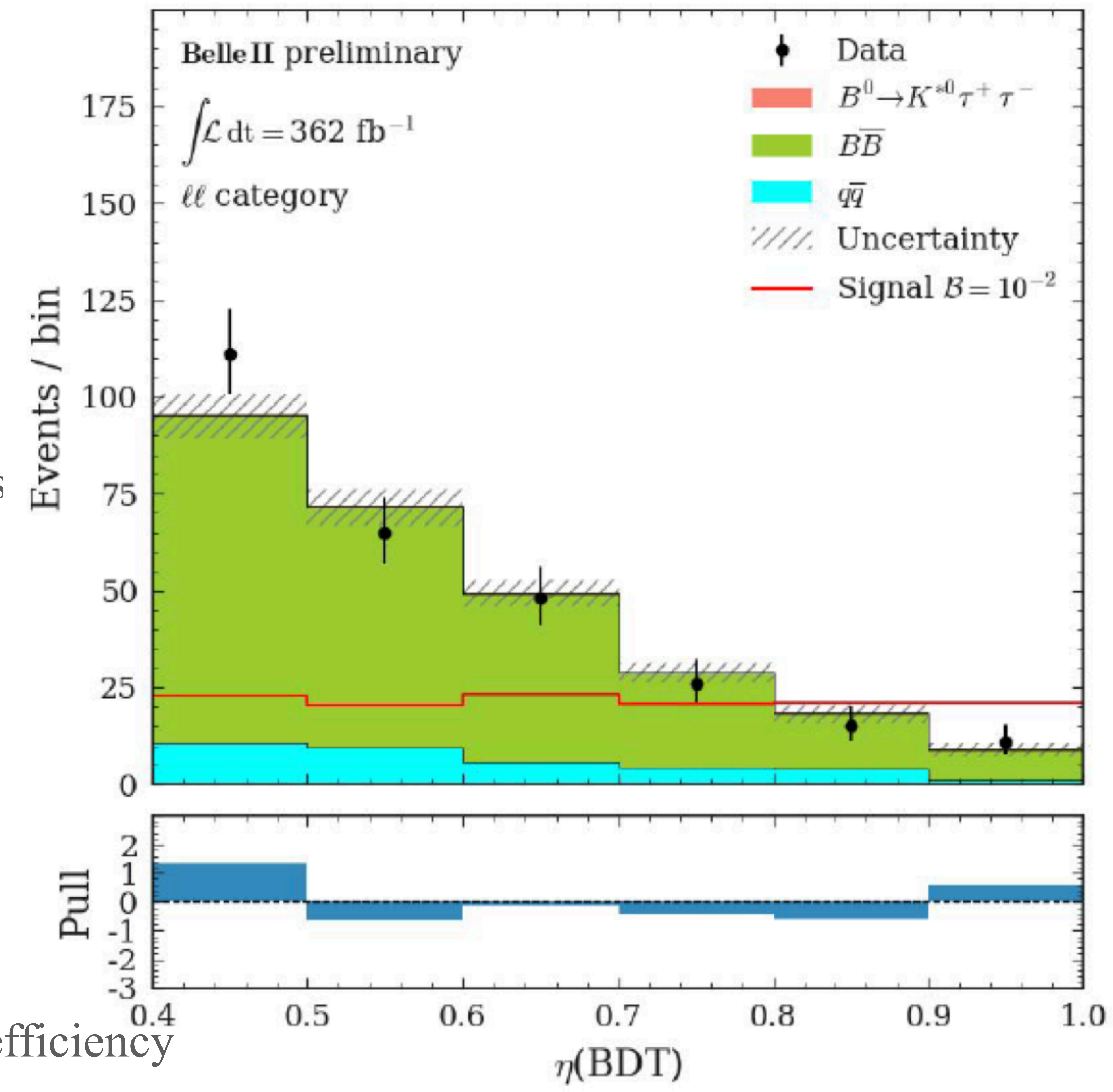
- Combination of charged particle from $\tau$ decay lead to 4 categories:

$$ll, l\pi, \pi\pi, \rho X$$

- **BDT** is trained using missing energy, extra cluster energy in EM calorimeter, $M(K^{*0}t_\tau)$, $q^2$,etc

- BDT output $\eta(BDT)$ is used to extract the signal yield with simultaneous fit to 4 categories

$$\mathscr{B}(B^0 \to K^{*0}\tau^+\tau^-) = 1.8 \times 10^{-3} \quad @\ 90\%\ \text{C.L}$$



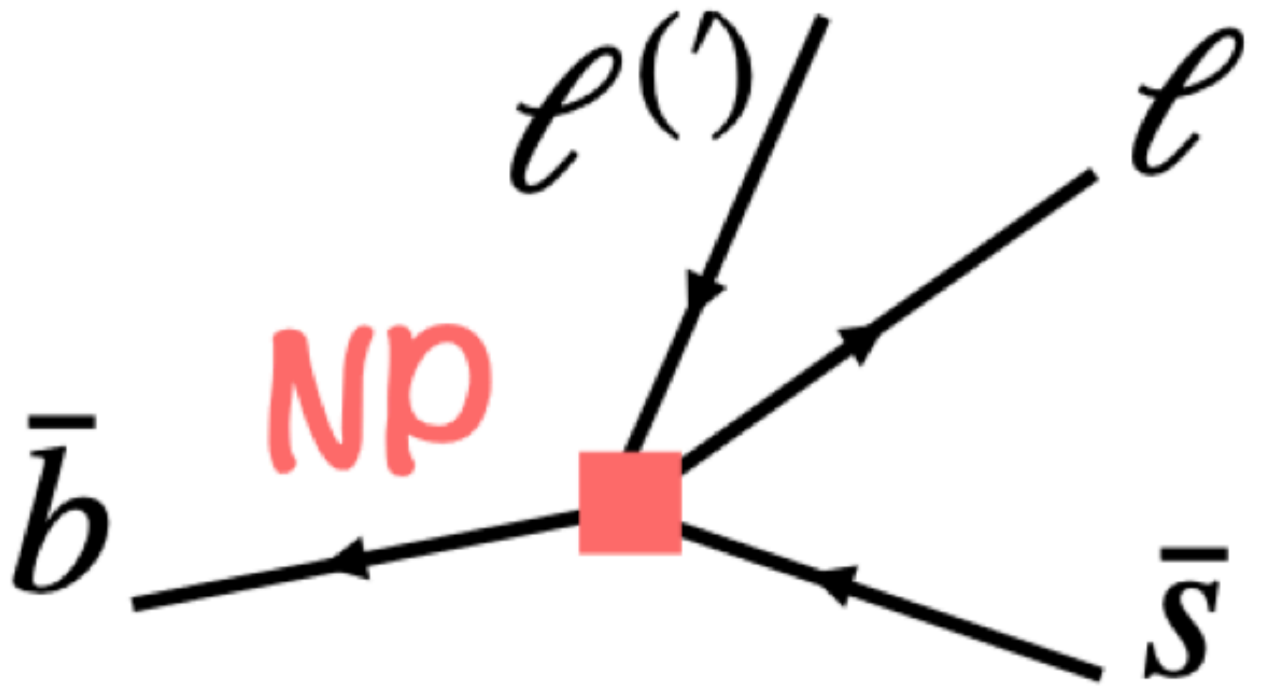

- **Twice better with only half sample w.r.t Belle :** better tagging & signal efficiency

- **The most stringent limit on the $B^0 \to K^{*0}\tau^+\tau^-$ decay and in general on $b \to s\tau\tau$ transition**

# Rare Decays : $B^0 \to K_S^0 \tau^\pm l^\mp$ motivation

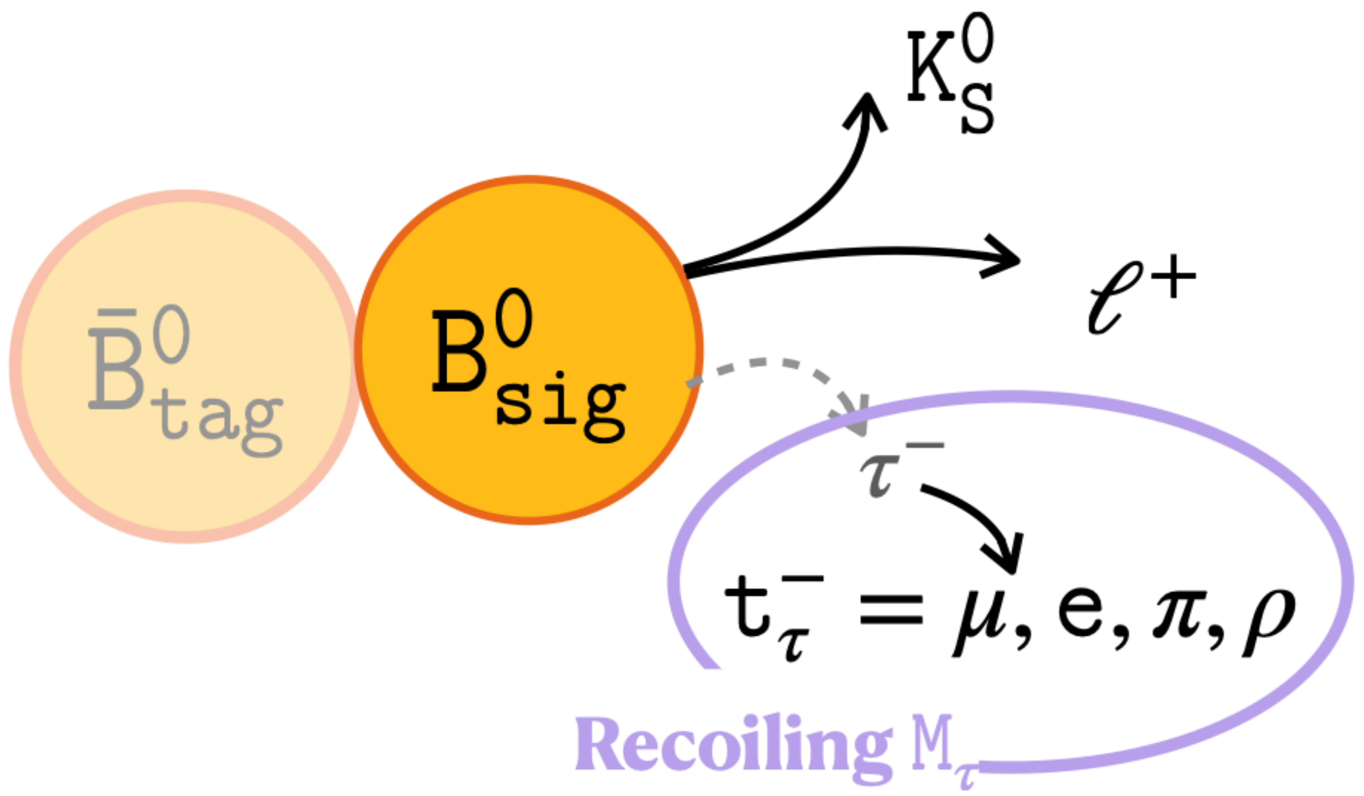
**Preliminary, paper in preparation**

- New heavy particles might accommodate the $\mathscr{B}(B^\pm \to K^\pm \bar{\nu}\nu)$ excess and $b \to c\tau\nu$ anomalies
  - new physics coupling preferentially to 2nd and 3rd generation leptons could result in observable decays to $b \to s\tau l$ (Lepton Flavor Violation-LFV)




- BaBar (428 $\text{fb}^{-1}$) : $B^+ \to K^+\tau^\pm l^\mp$ PRD.86.012004
- LHCb (9 $\text{fb}^{-1}$) : $B^+ \to K^+\tau^+\mu^-$ , $B^0 \to K^{*0}\tau^\pm\mu^\mp$ JHEP.06.129, arXiv.2209.09846
- Belle (711 $\text{fb}^{-1}$) : $B^+ \to K^+\tau^\pm l^\mp$ PRL.130.261802

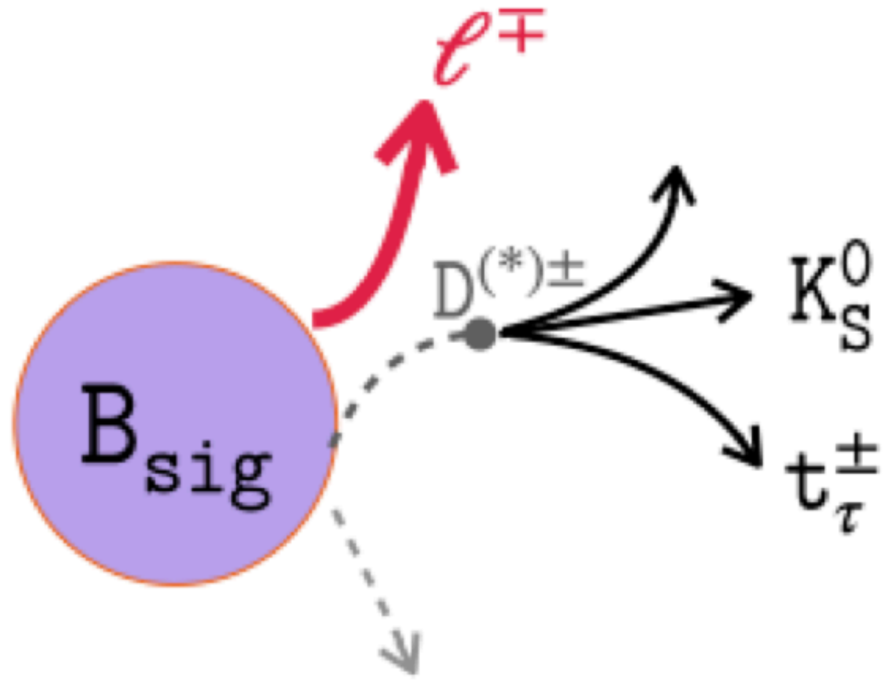
**Most stringent UL**




- **First search in $B^0 \to K_s^0 \tau^\pm l^\mp$**

- Belle + Belle II (711+364 $\text{fb}^{-1}$) + hadronic B-tagging

# Rare Decays :$B^0 \to K_S^0 \tau^{\pm} l^{\mp}$ strategy and results




- Final states involving **presence of neutrinos** ⟶ **can compute recoil mass of $\tau$**
- $K_S^0$ reconstructed from a pair of opposite charged pions ⟶ after selections more than **98% purity**
- Semileptonic B decays are primarily **background**
- The remaining background is treated with the use of a **BDT**

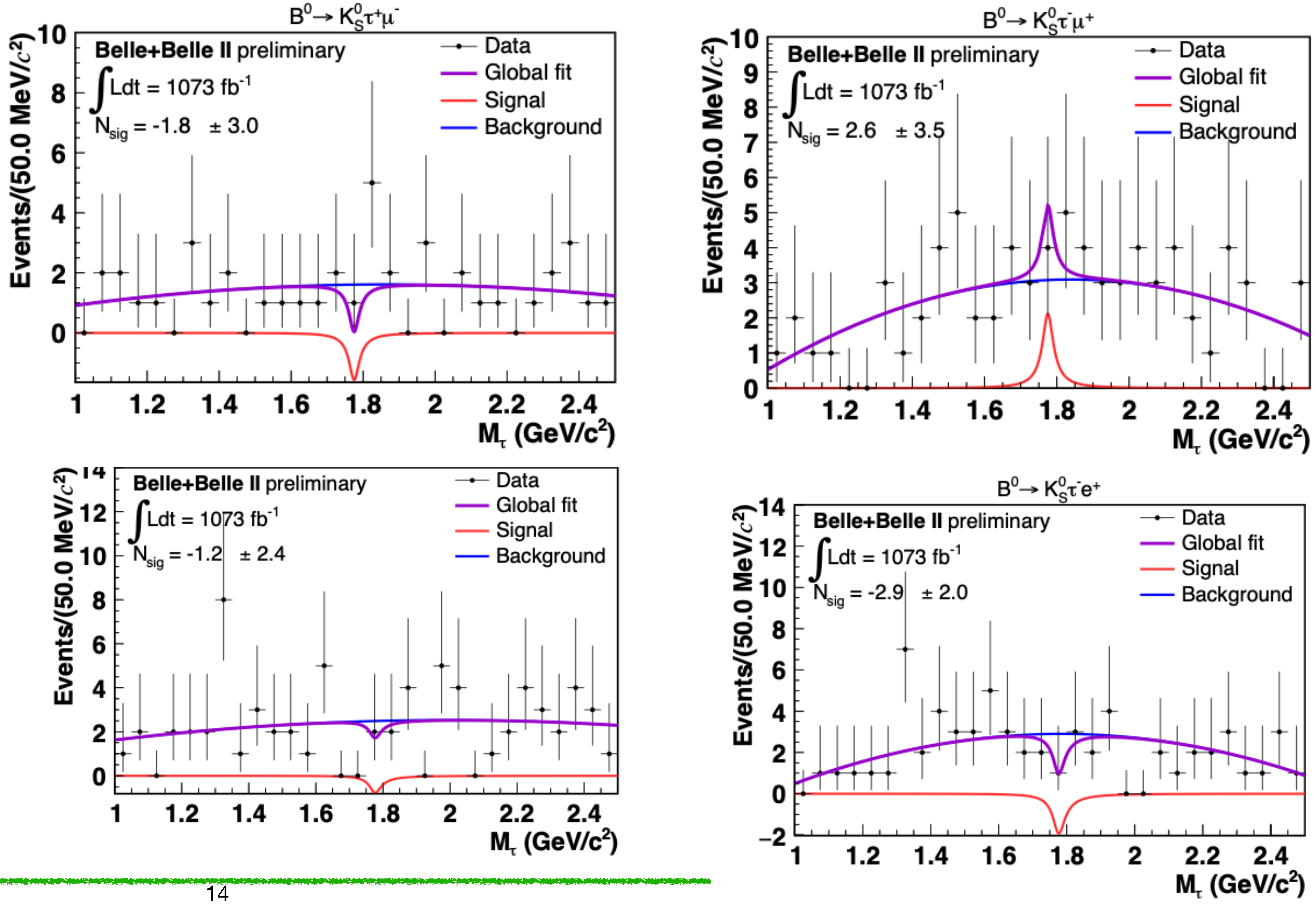
**90% U.L.** are derived:

$$\mathscr{B}(B^0 \to K_S^0 \tau^+ \mu^-) < 1.1 \times 10^{-5}$$

$$\mathscr{B}(B^0 \to K_S^0 \tau^- \mu^+) < 3.6 \times 10^{-5}$$

$$\mathscr{B}(B^0 \to K_S^0 \tau^+ e^-) < 1.5 \times 10^{-5}$$

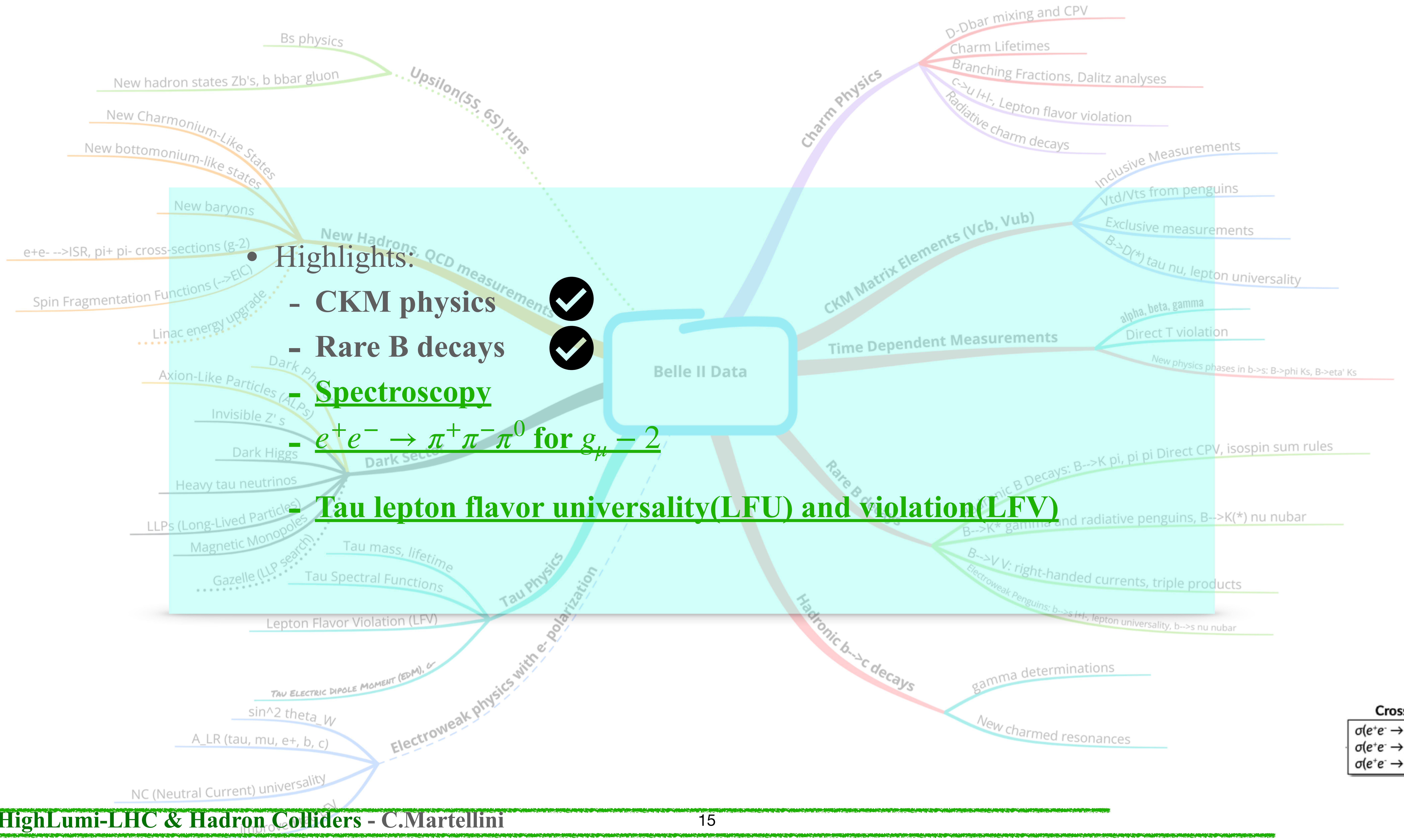
$$\mathscr{B}(B^0 \to K_S^0 \tau^- e^+) < 0.8 \times 10^{-5}$$




**The results are among the most stringent limits**

# Belle II Physics Programs

- Highlights:
  - CKM physics ✔
  - Rare B decays ✔
  - **Spectroscopy**
  - $e^+e^- \to \pi^+\pi^-\pi^0$ for $g_\mu - 2$
  - **Tau lepton flavor universality(LFU) and violation(LFV)**




| Cross sections |
|---|
| $\sigma(e^+e^- \to b\bar{b}) \simeq 1.1$ nb |
| $\sigma(e^+e^- \to c\bar{c}) \simeq 1.3$ nb |
| $\sigma(e^+e^- \to \tau^+\tau^-) \simeq 0.9$ nb |

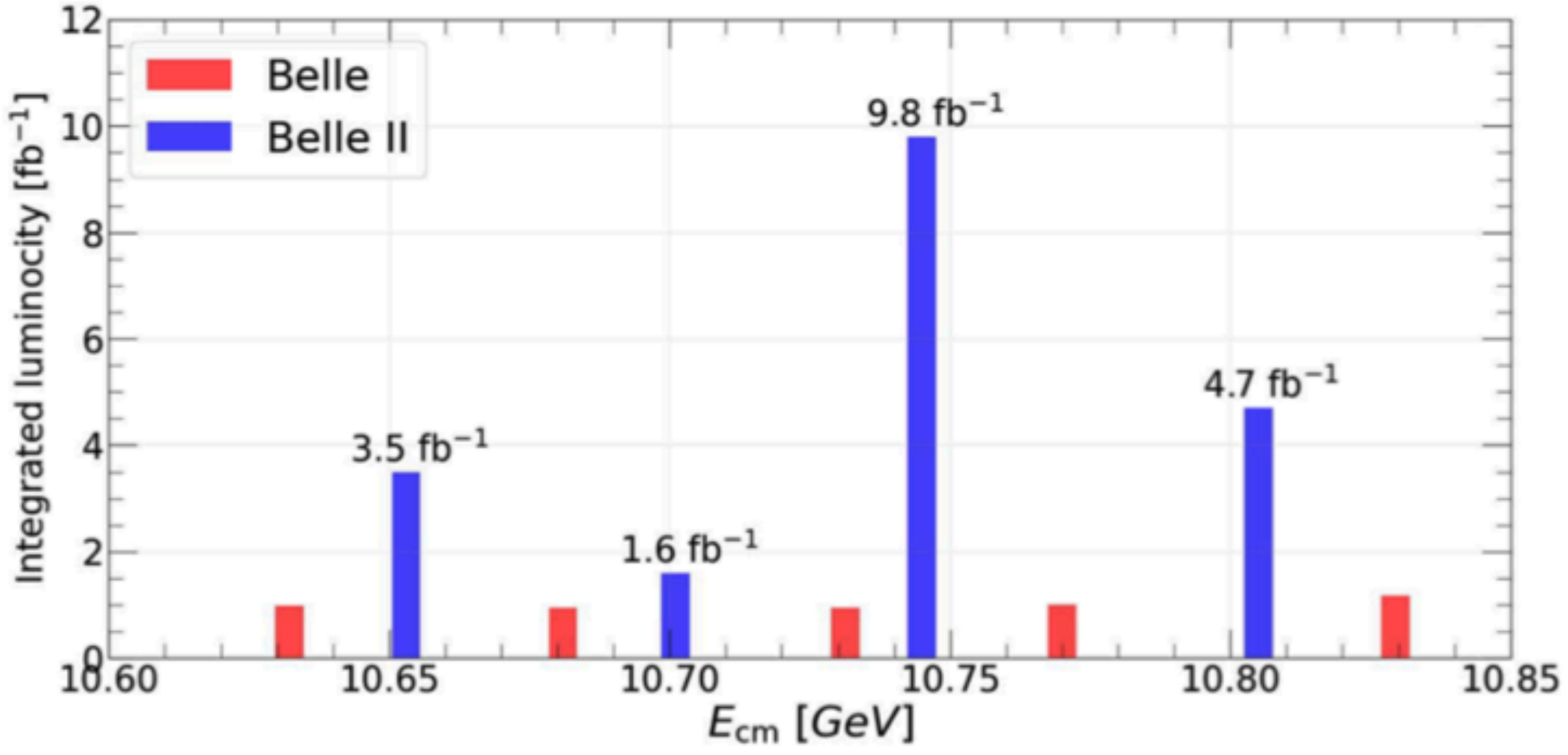
# Spectroscopy: Improved measurements of $\Upsilon(10753)$ at Belle II

[arXiv.2401.12021](arXiv.2401.12021)

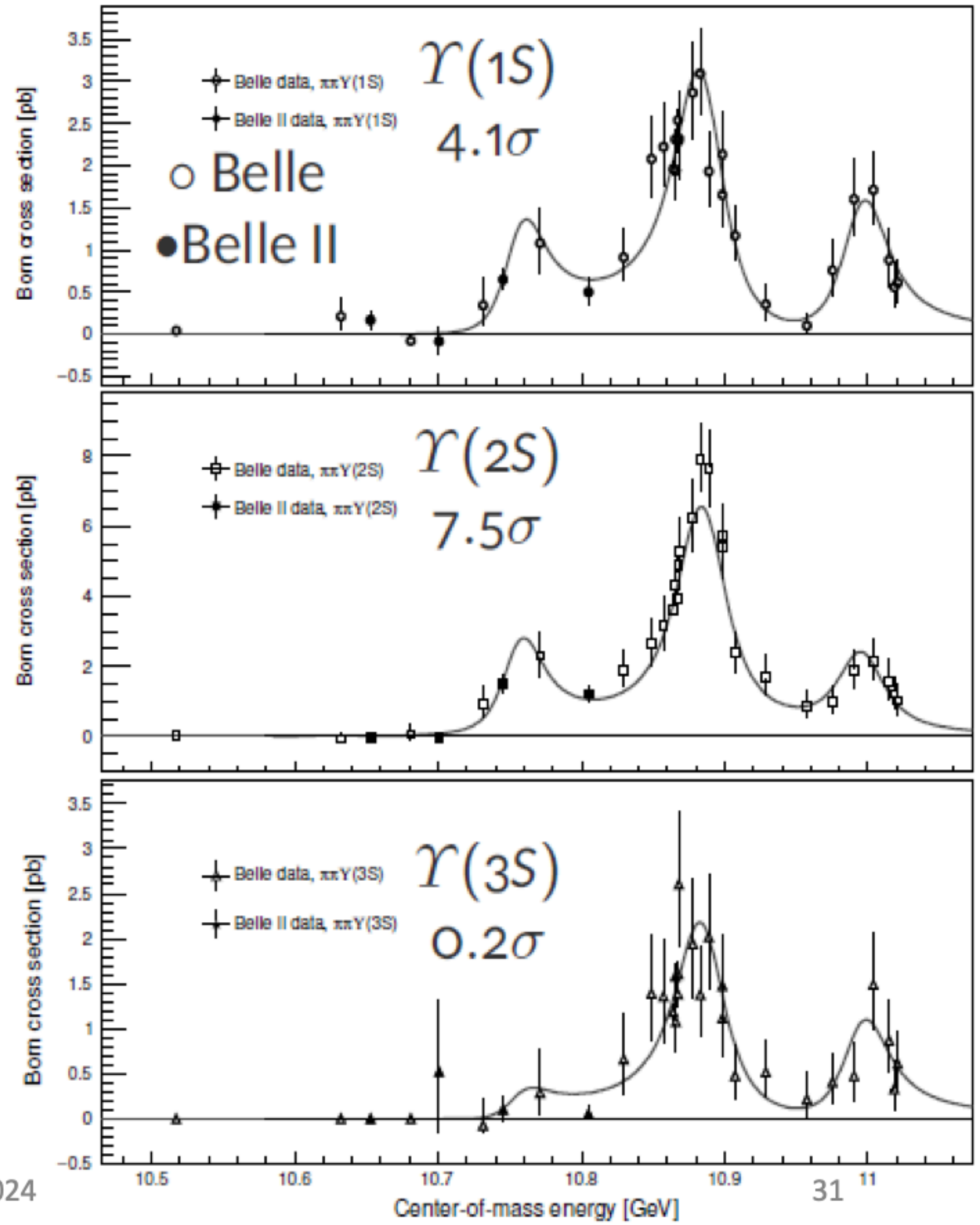
Accepted by JHEP

- New energy scan performed by **Belle II** to fill in the gaps of Belle scan

For a total integrated luminosity of 19 $fb^{-1}$




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




- ***Observation of $\Upsilon(10753)$ in agreement with Belle results***

$$M(\Upsilon(10753)) = 10756.6 \pm 2.7 \pm 0.9\ \mathrm{MeV}/c^2$$

$$\Gamma(\Upsilon(10753)) = 29.0 \pm 8.8 \pm 1.2\ \mathrm{MeV}/c^2$$

*No signal of intermediate $Z_b^+$ (10610/10650) observed*

: 2024 31

# Spectroscopy: Search for $\Upsilon(10753) \to \omega\eta_b(1S)/\chi_{b_0}(1P)$ at Belle II

PRD,109.072013

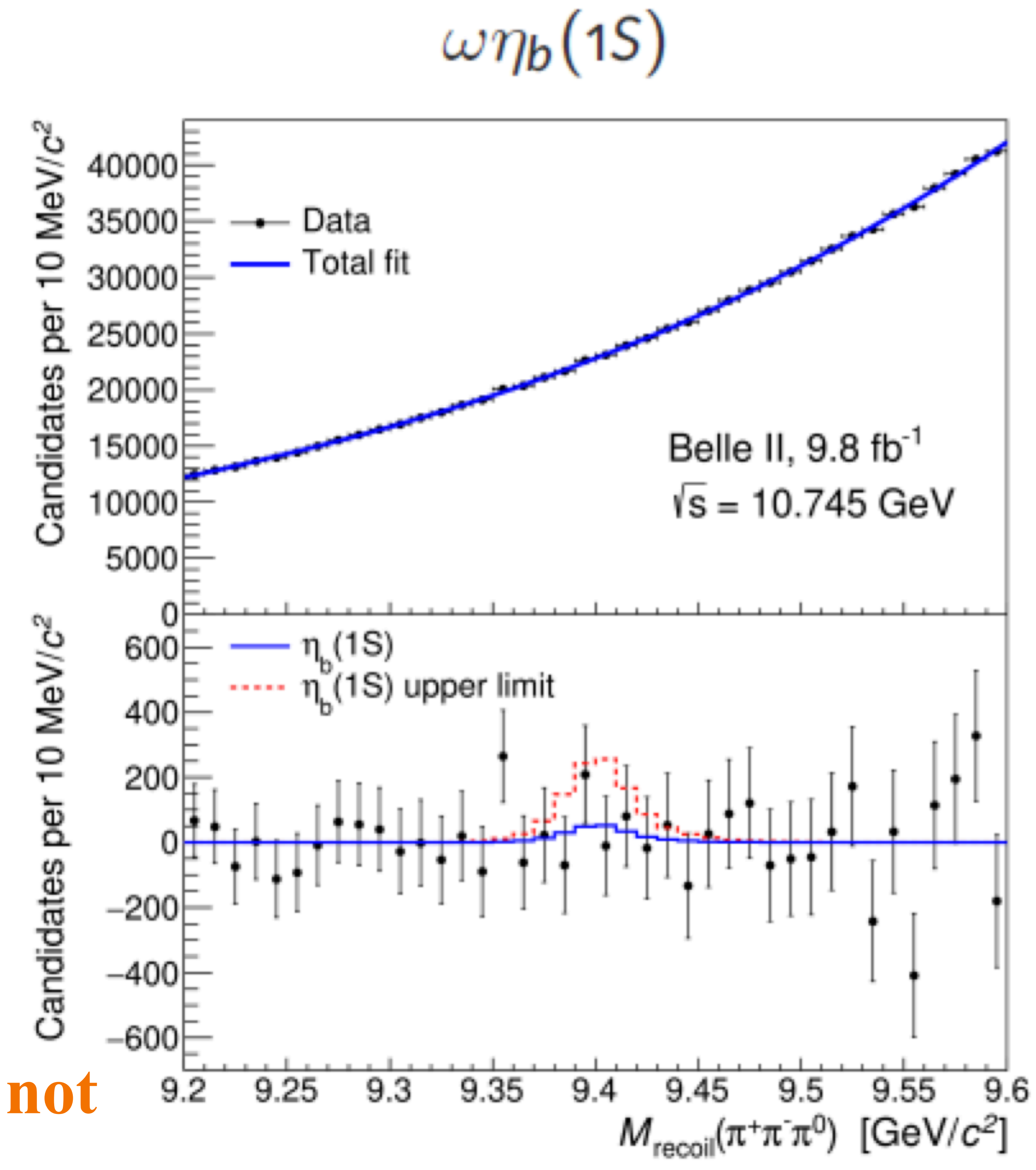
- $\Upsilon(10753)$ tetraquark interpretation predicts a strong transition to $\omega\eta_b(1S)$

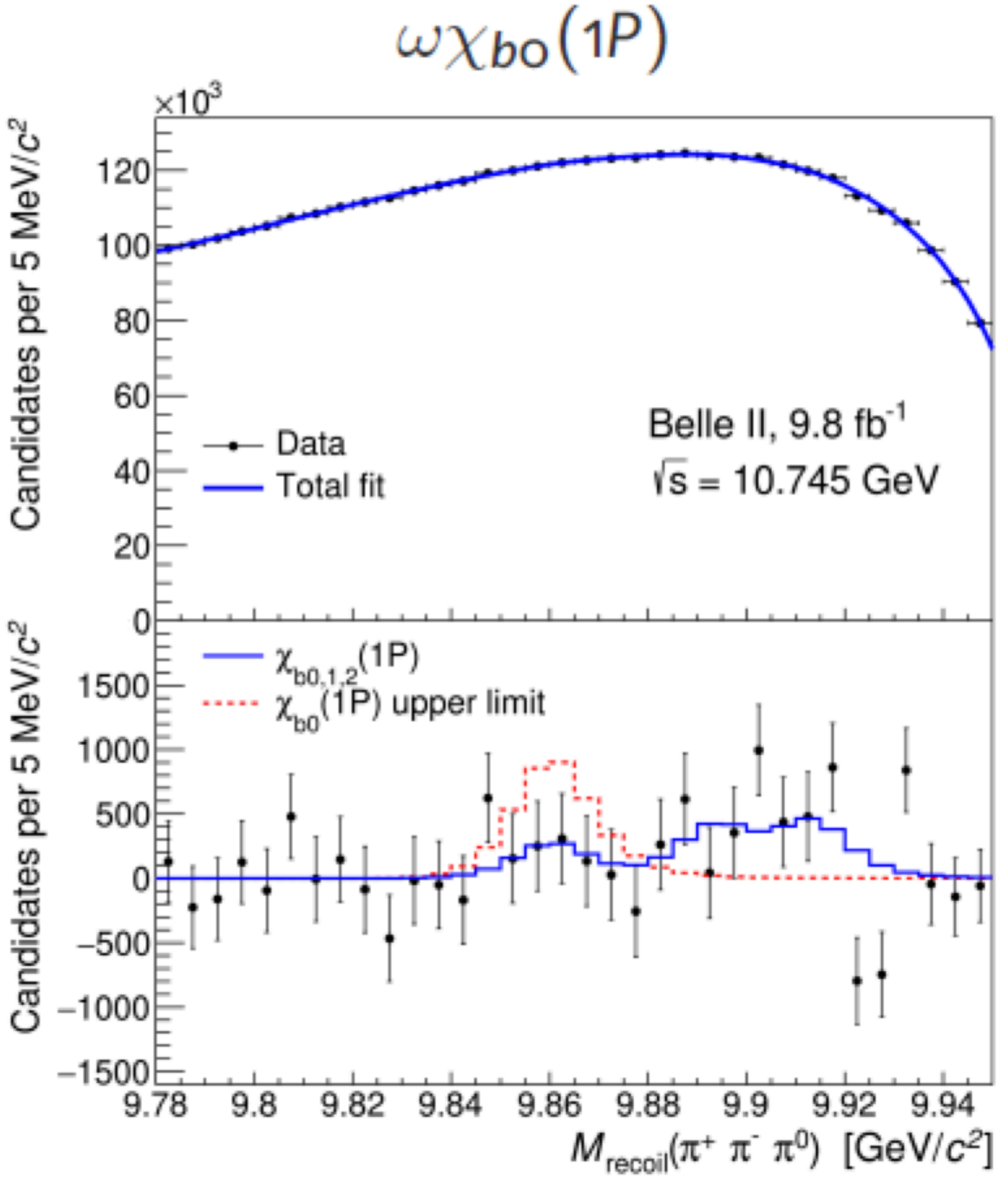
Compared to $\pi^+\pi^-\Upsilon(nS)$

- Validate the model with reconstruction of $\omega \to \pi^+\pi^-\pi^0$ and look for a peak in the recoil mass distribution

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

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




No significant signal observed → **Tetraquark model not supported**

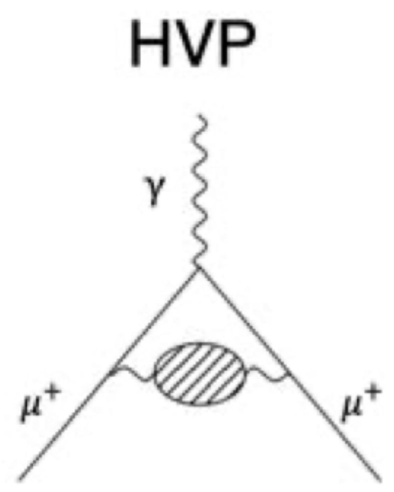
(*)obtained by averaging the result of this analysis with the previously published one Phys. Rev. Lett. 130, 091902

# Measurement of $e^+e^- \to \pi^+\pi^-\pi^0$ cross section at Belle II

**Preliminary**

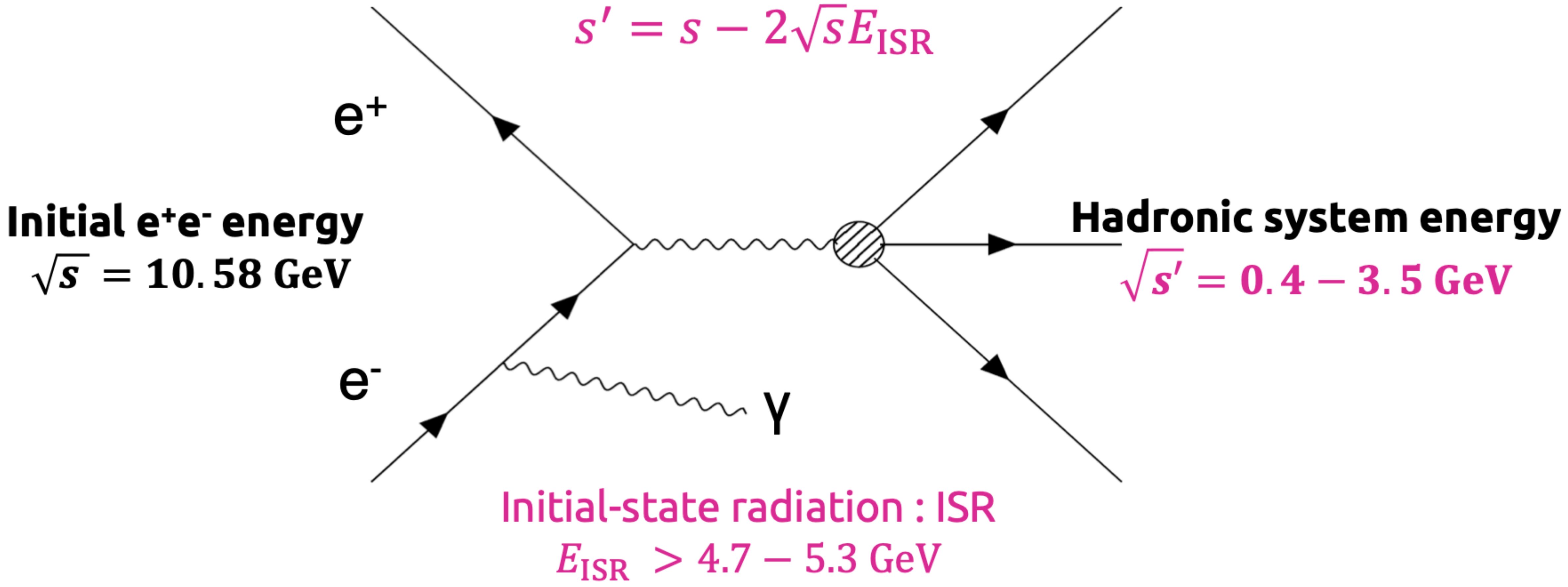
arXiv.2404.04915

- Motivation:
  - Non-negligible uncertainty in the theoretical predictions
  - **hadron vacuum polarisation** produces the largest uncertainty in the dispersive prediction of $(g-2)_\mu$ (HVP, 82%)
  - Cross section $e^+e^- \to hadrons$ is an **input to the dispersive calculation and gives largest uncertainty**




Perform the measurement in the energy range from 0.62 GeV to 3.50 GeV

- Initial-state radiation (ISR) method




Measured at Belle II exploiting $e^+e^- \to \pi^+\pi^-\pi^0\gamma_{ISR}$
$\to$ Scan region $0.7 < \sqrt{s} < 3.5$ GeV by $\gamma_{ISR}$ reconstruction

Allows to scan a wide range of $M(\pi\pi)$ rather than having to scan the c.m energy

Used 191 $\mathrm{fb}^{-1}$ of Belle II data @ $\Upsilon(4S)$

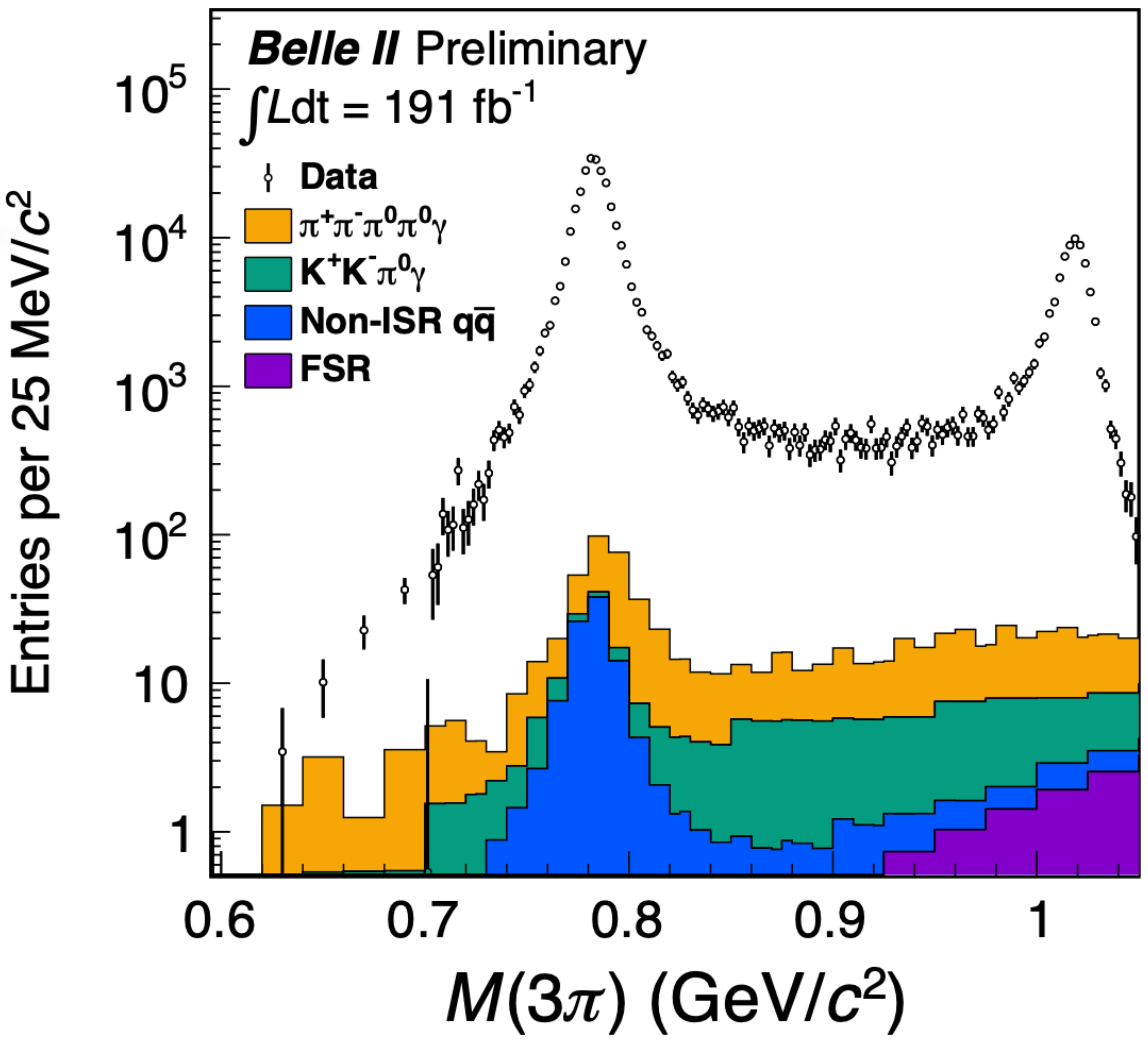
Recent predictions of LQCD show $2-3\sigma$ differences from values based on dispersion relations $\to$ **new experimental measures are important**

# Measurement of $e^+e^- \to \pi^+\pi^-\pi^0$ cross section at Belle II

arXiv.2404.04915

**Measured at Belle II with Signal process :**
$e^+e^- \to \gamma_{ISR}\pi^+\pi^-\pi^0(\to\gamma\gamma)$

- **Signal extracted** by fitting M($\gamma\gamma$) in each M($3\pi$) bin
- Signal efficiency and DATA/MC corrections:
  - Tracking efficiency
  - $\pi^0$ detection efficiency
  - High energy photon detection efficiency
- Systematic uncertainty dominates: modelling of higher-order corrections and efficiency




Integrated over $3\pi$ cross section from 0.62 - 1.8 GeV

$$a_\mu^{LO,HVP,3\pi}(0.62 - 1.8GeV) = (48.91 \pm 0.25_{stat} \pm 1.07_{syst}) \times 10^{-10}$$

6.7% or 2.5 $\sigma$ higher than current global average from BaBar, CMD-2 and SND

# LFU tests - Light lepton universality in $\tau$ decays

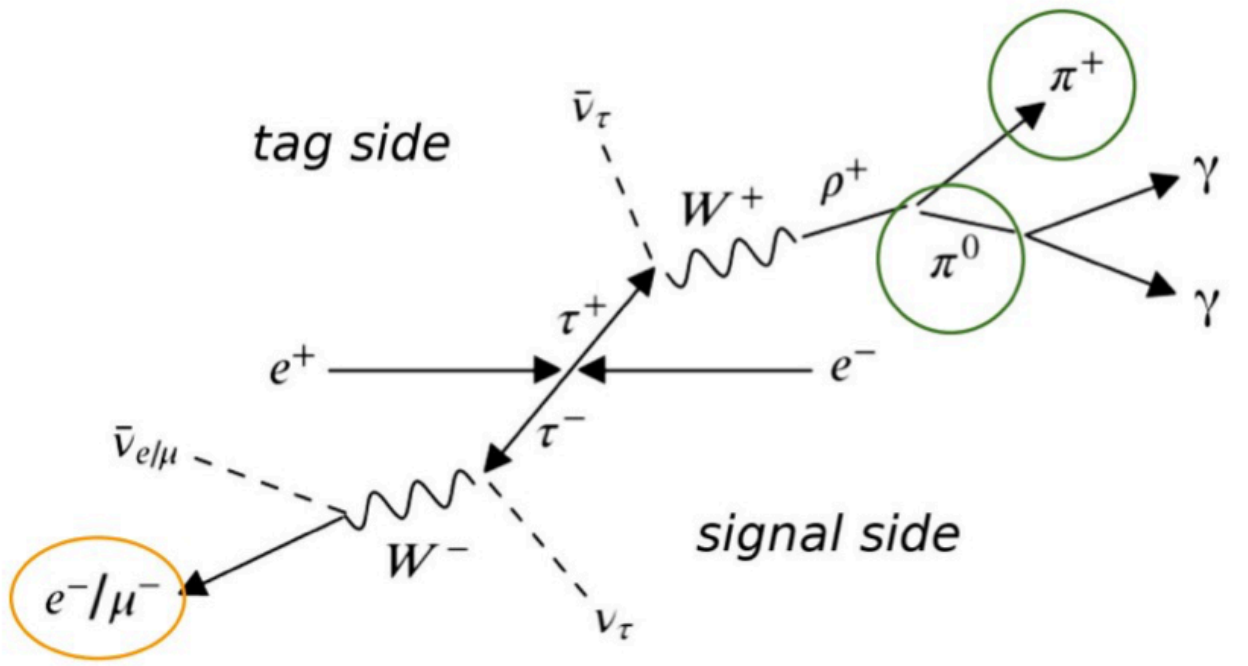
[JHEP.10.1007]

In the SM all charged leptons have equal coupling strength (gℓ) to the W boson: LFU → may be violated by new forces [1]

**For each $B\bar{B}$ event we get ~ a $\tau\tau$ pair**
**→ Belle II optimal for $\tau$ physics too**

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

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




- **Test of $\mu/e$ universality in $\tau$ decays**
  - In the $e^+e^- \to \tau^+\tau^-$ one can separate the event in two hemispheres: tag $\tau$, and signal $\tau$

Purity 96% and 92% for electron and muon channels

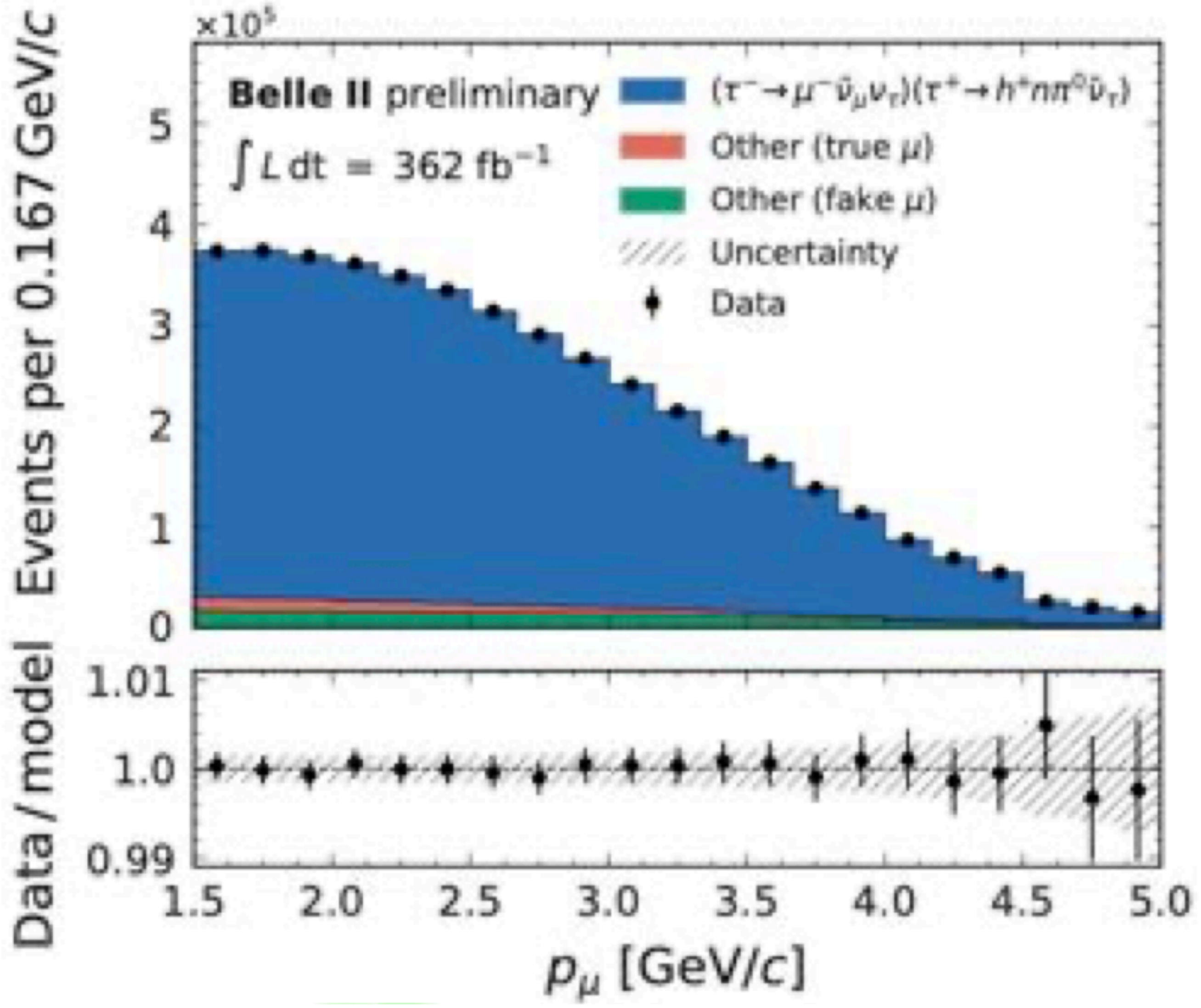
Full Belle II RUN1 data sample 364 fb$^{-1}$

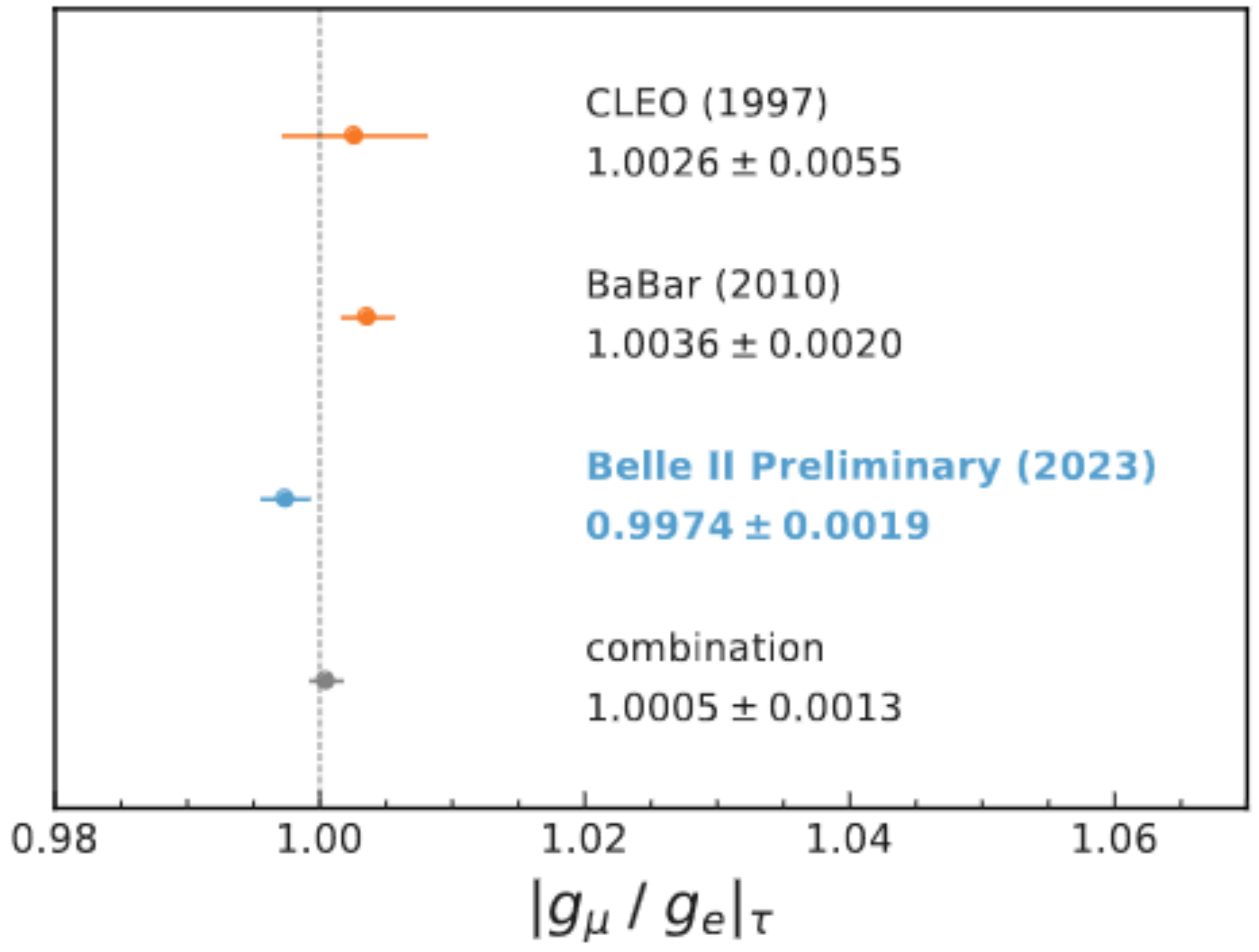
-Signal side: e or $\mu$

-Tag side: 1 charged hadron + $\geq 1\pi^0$

- Background suppression using a Neural Network
- Systematics dominated by eID and trigger

**$R_\mu$ obtain by binned maximum likelihood fit on momentum spectra on $\mu/e$**




**Most precise test of light lepton universality in $\tau$ decays**

$$R_\mu = 0.9675 \pm 0.0007(stat) \pm 0.0036(sys)$$

$$g_\mu/g_e = 0.9974 \pm 0.0019$$

# Search for LFV decays: $\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm$

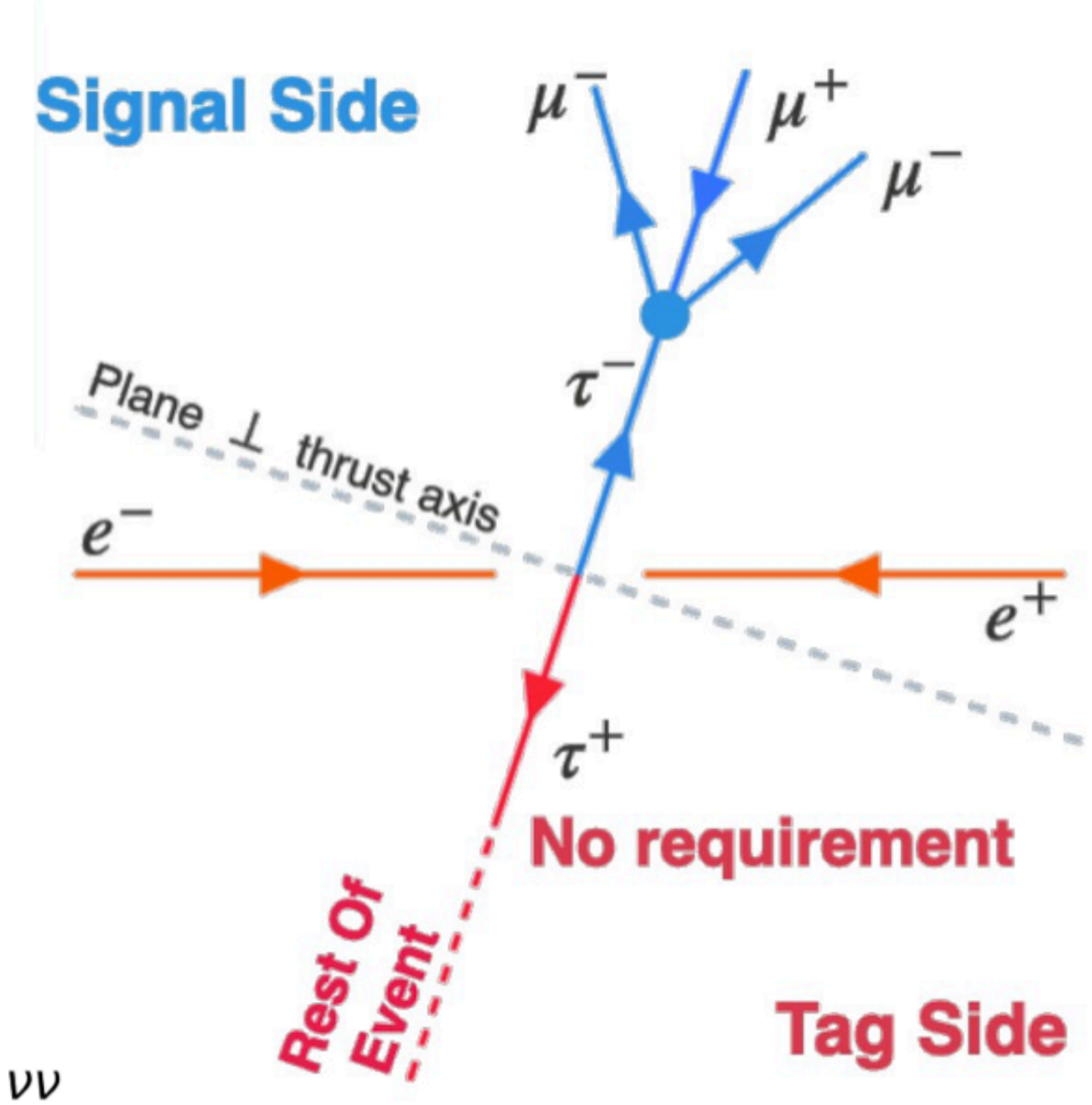
arXiv:2405.07386
Accepted by JHEP

$\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm$:

- Almost free from SM background
- Very good resolution on the energy and momentum
- Can also be probe by LHC experiments

A lot of interest in LFV decays at $e^+e^-$ colliders, with ~ 50 modes: $\tau \to l\gamma, \tau \to l\phi, \tau \to lll$

These are rare decays : it's all about **maximising the statistics!**



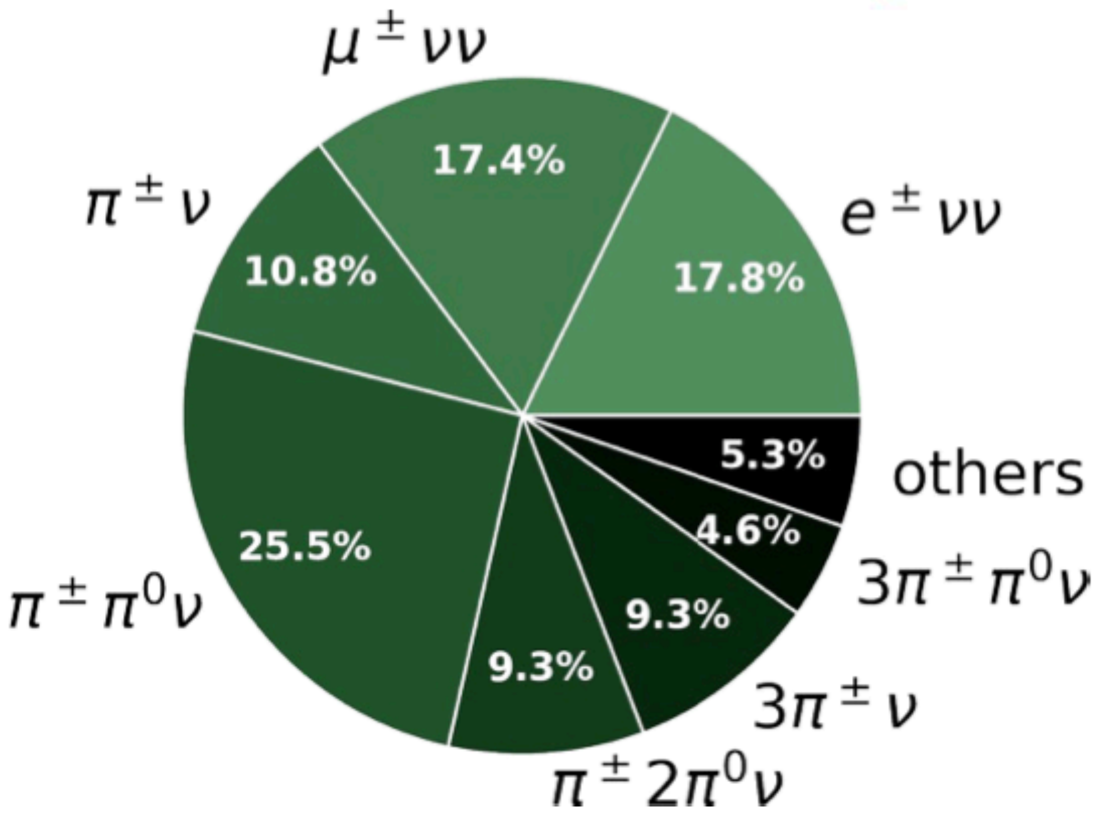

- Existing measurements : $2.1 \times 10^{-8}$ by Belle ( Phys.Lett.B687)

  $2.9 \times 10^{-8}$ by CMS ( Phys.Lett.B853)

**Untagged event selection:**

- We reconstruct signal candidate by combining three muons
- **No explicit reconstruction** of the other $\tau$: everything that is not the signal candidate is **combined in an unique object called Rest of the Event** (ROE)

- Allows to target all the 1 and 3 prong* decays of the other $\tau$




*prong = Number of charged particles

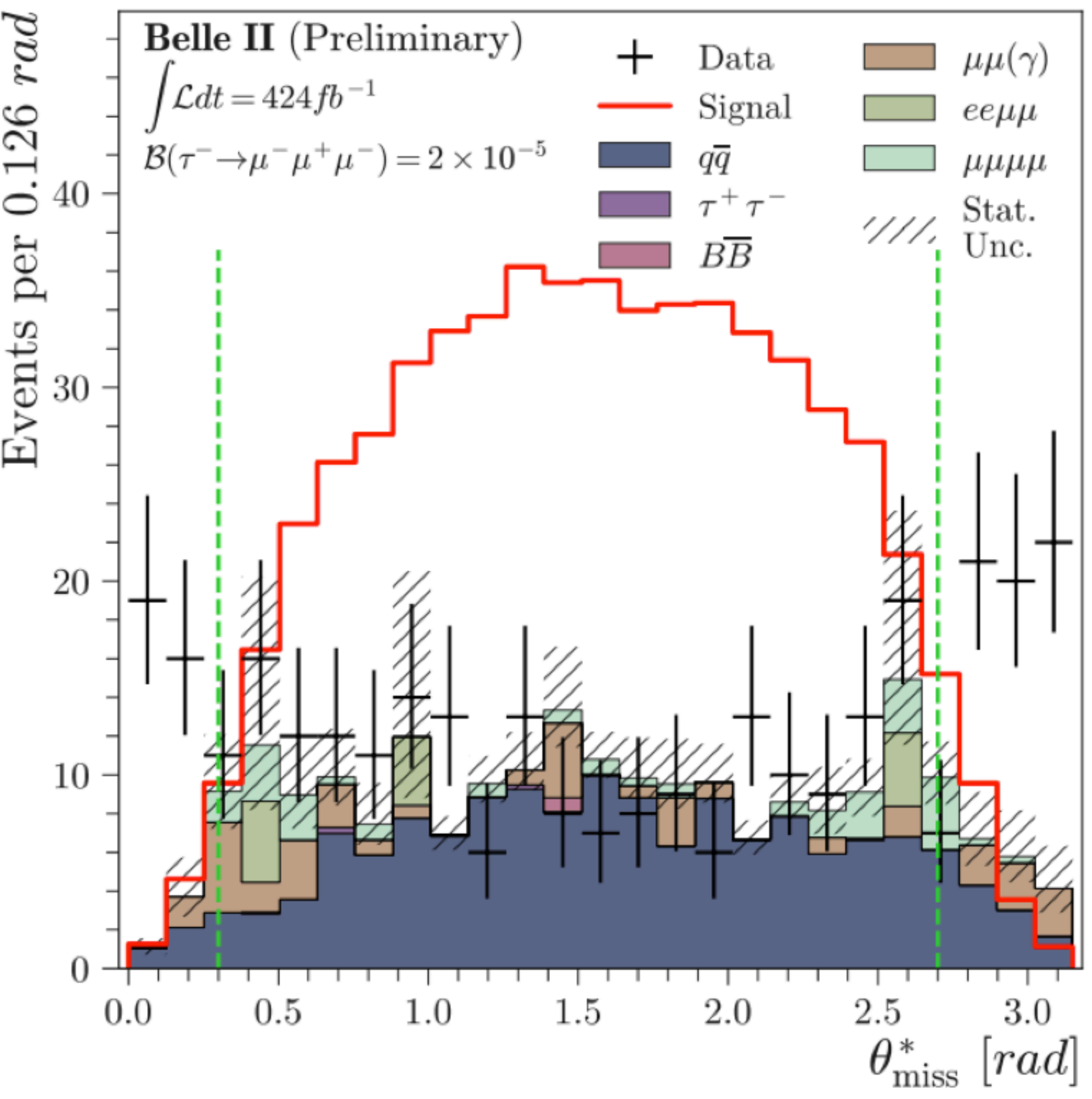
# $\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm$ : background suppression

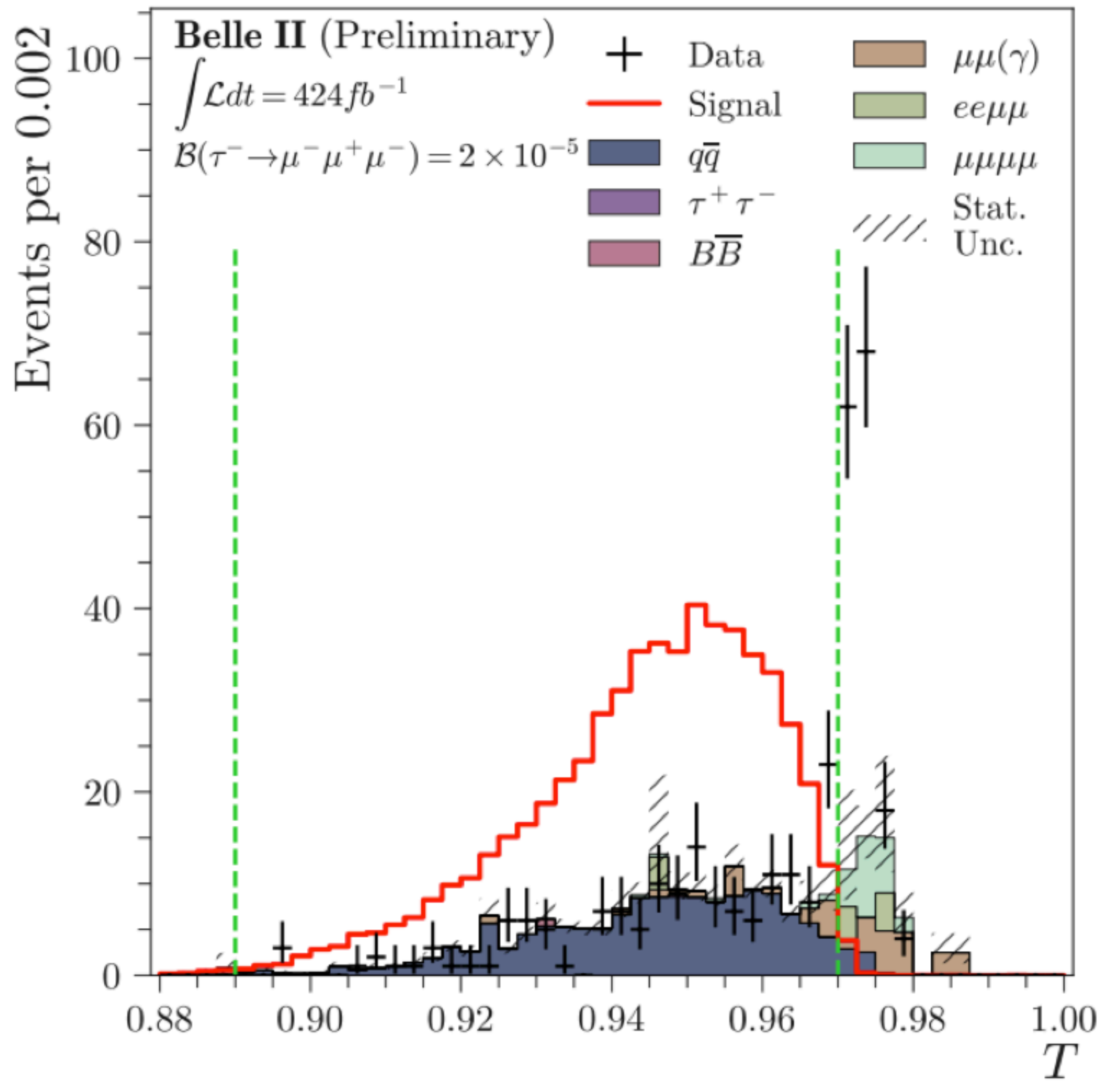
Background suppression

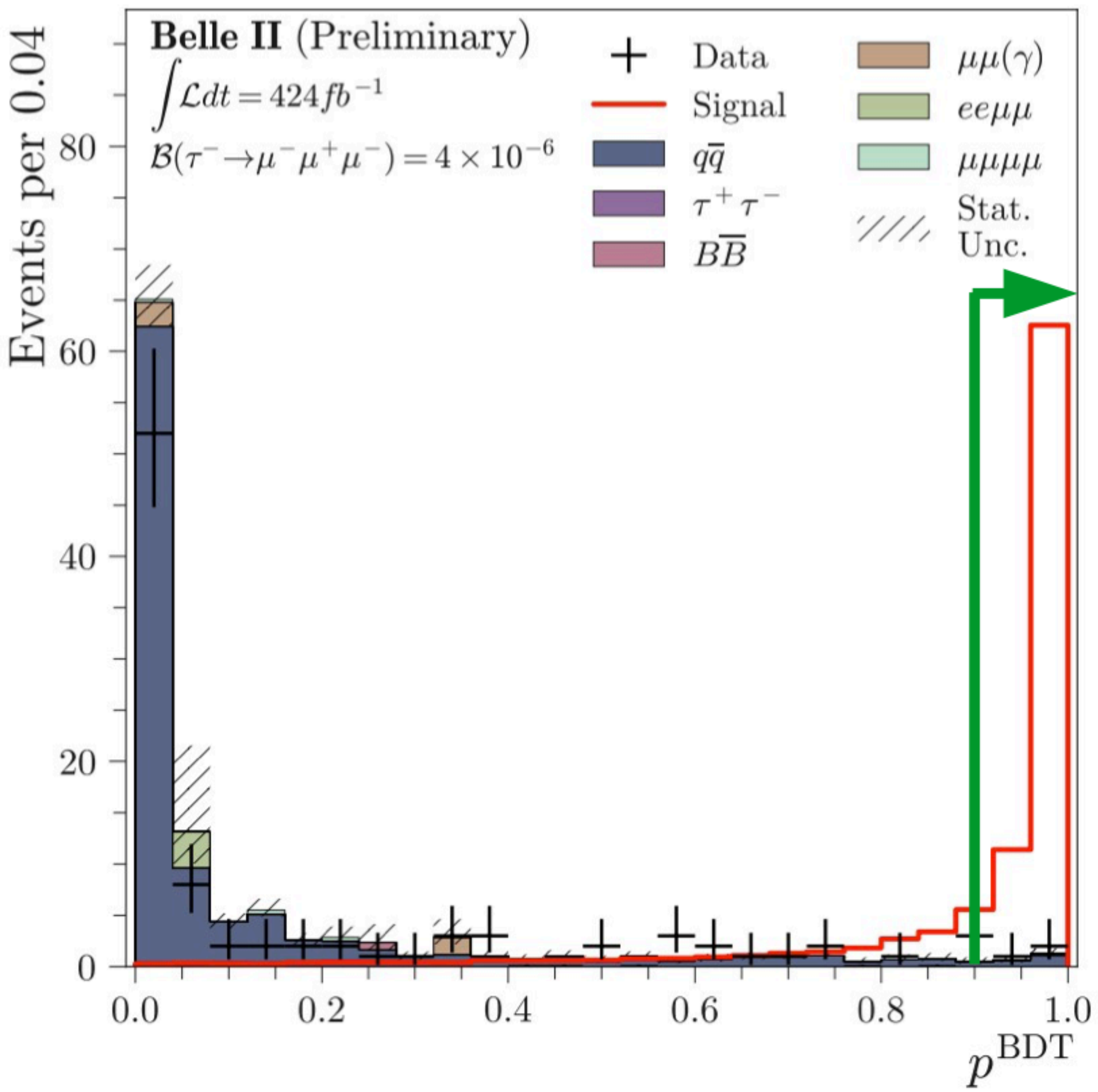
- With a set of selection cuts to remove low multiplicity QED processes, mis-modelled background

A **BDT classifier** with k-folding to reject $e^+e^- \to q\bar{q}$ events

- Rest of Events kinematics, signal candidate, missing momentum informations




**Final signal efficiency : 20.4%**

(3 times higher than Belle's efficiency )

# $\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm$ : results

arXiv:2405.07386

Accepted by JHEP

Signal yield is extracted with a poisson counting experiment

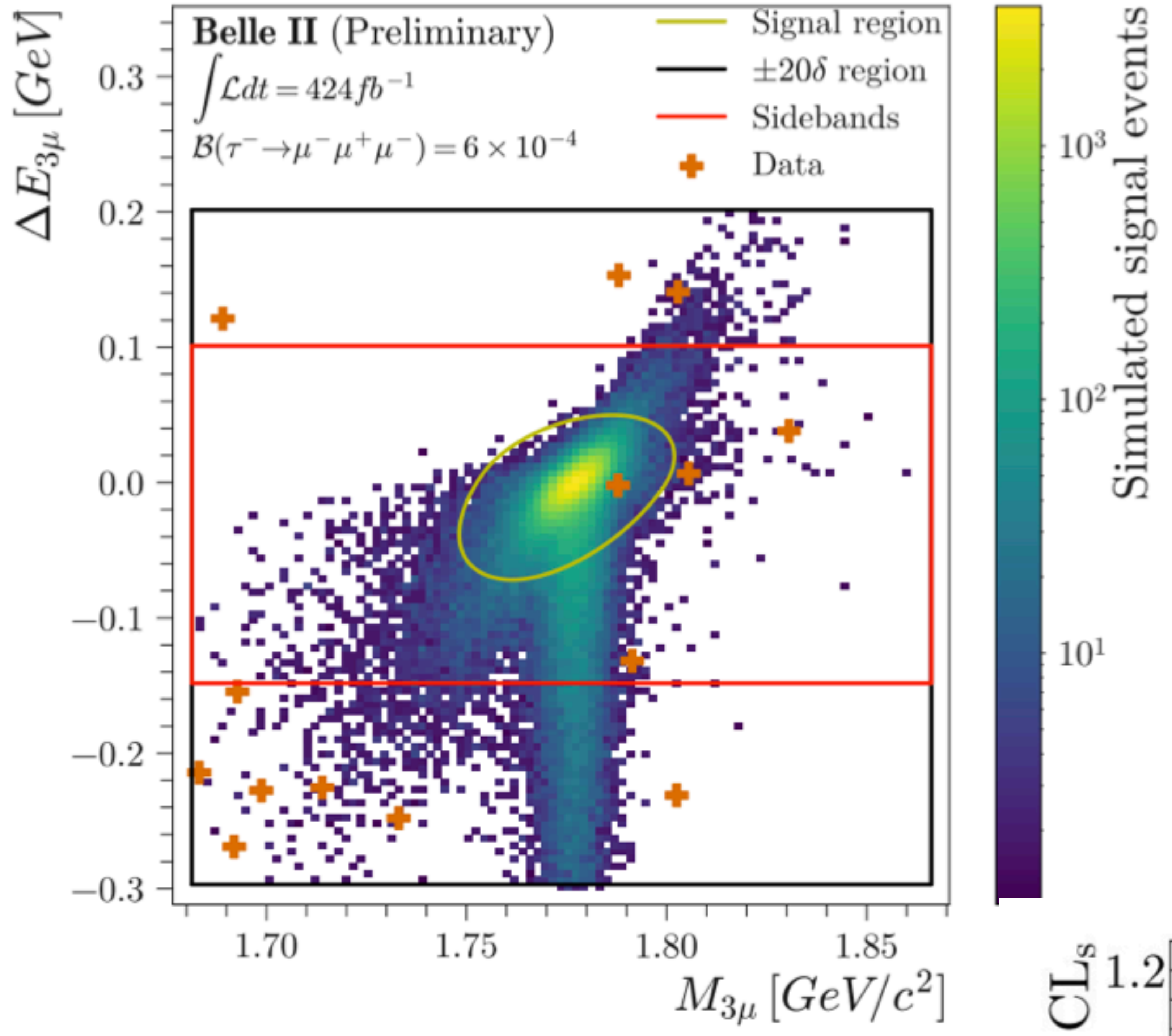
- Signal region defined as an ellipse in the 2D plane ( $M_{3\mu}$, $\Delta E_{3\mu}$)

$$(\Delta E_{3\mu} = \frac{E_{beam}}{2} - E_{3\mu})$$

$$\mathscr{B}(\tau \to \mu\mu\mu) = \frac{N_{obs} - N_{exp}}{2\sigma_{\tau\bar{\tau}} \cdot \mathscr{L} \cdot \epsilon_{3\mu}}$$

Number of expected background $N_{exp} = 0.7^{+0.6}_{-0.5} \pm 0.01$

Obtained by rescaling the yields from **the sidebands** data in the signal region



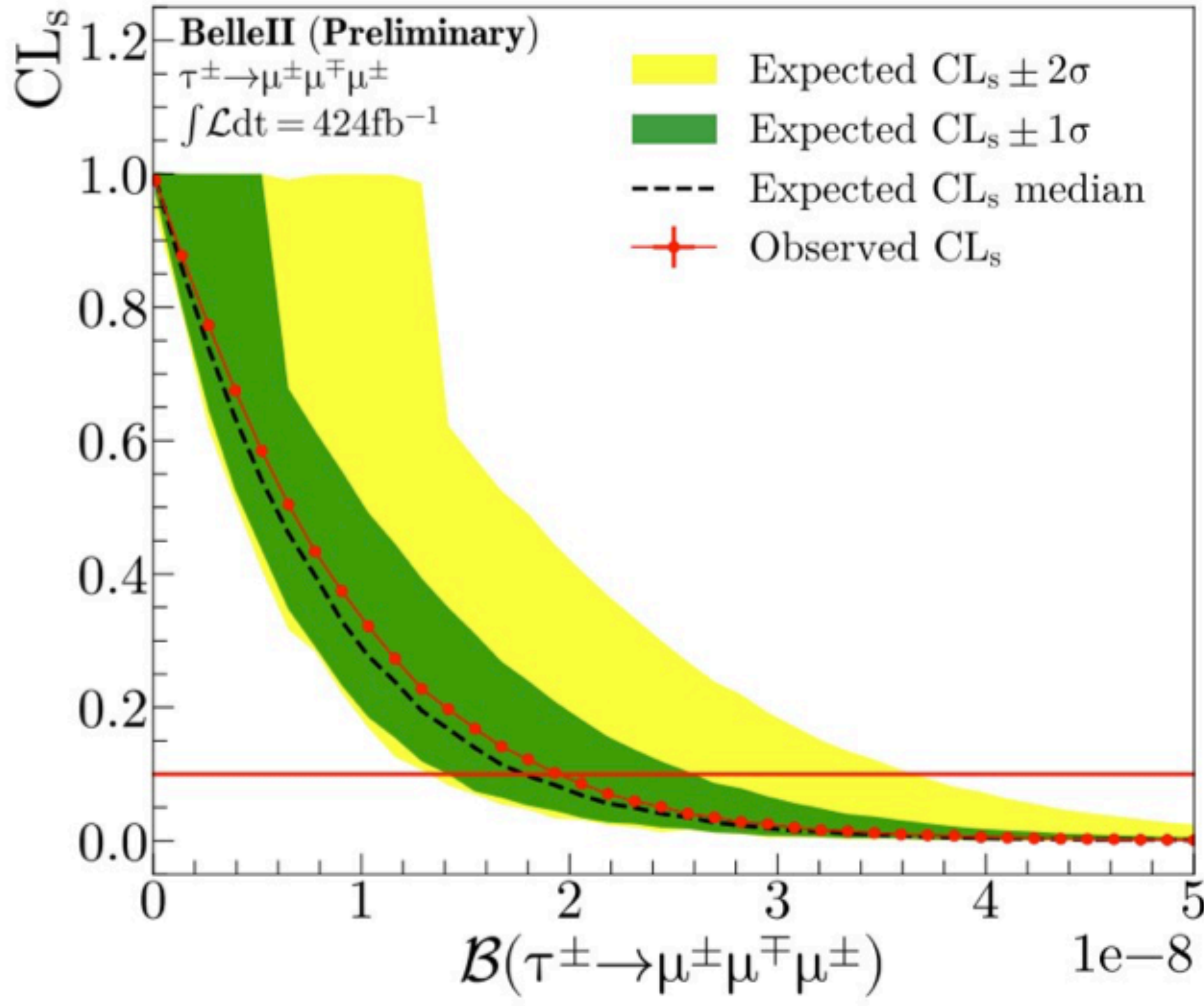

**Main uncertainty is statistical!**

90% CL upper limit on Branching Fraction

$$\mathscr{B}(\tau \to \mu\mu\mu) < 1.9 \times 10^{-8}$$

**World's best limit!!!**

No excess is found!



# Conclusions

- Belle and Belle II have been and will continue to collect excellent data for various physics programs
- Many more measurements are in progress
- You can find more on our public publications page : https://www.belle2.org/research/physics/publications
- Only a small fraction of the exciting results are included in this talk
- Belle II has restarted collecting data from its Run2, aiming to significantly increase its data sample in the next few years

- Looking forward to more data in the coming years

Thank you for your attention

# Back up slides

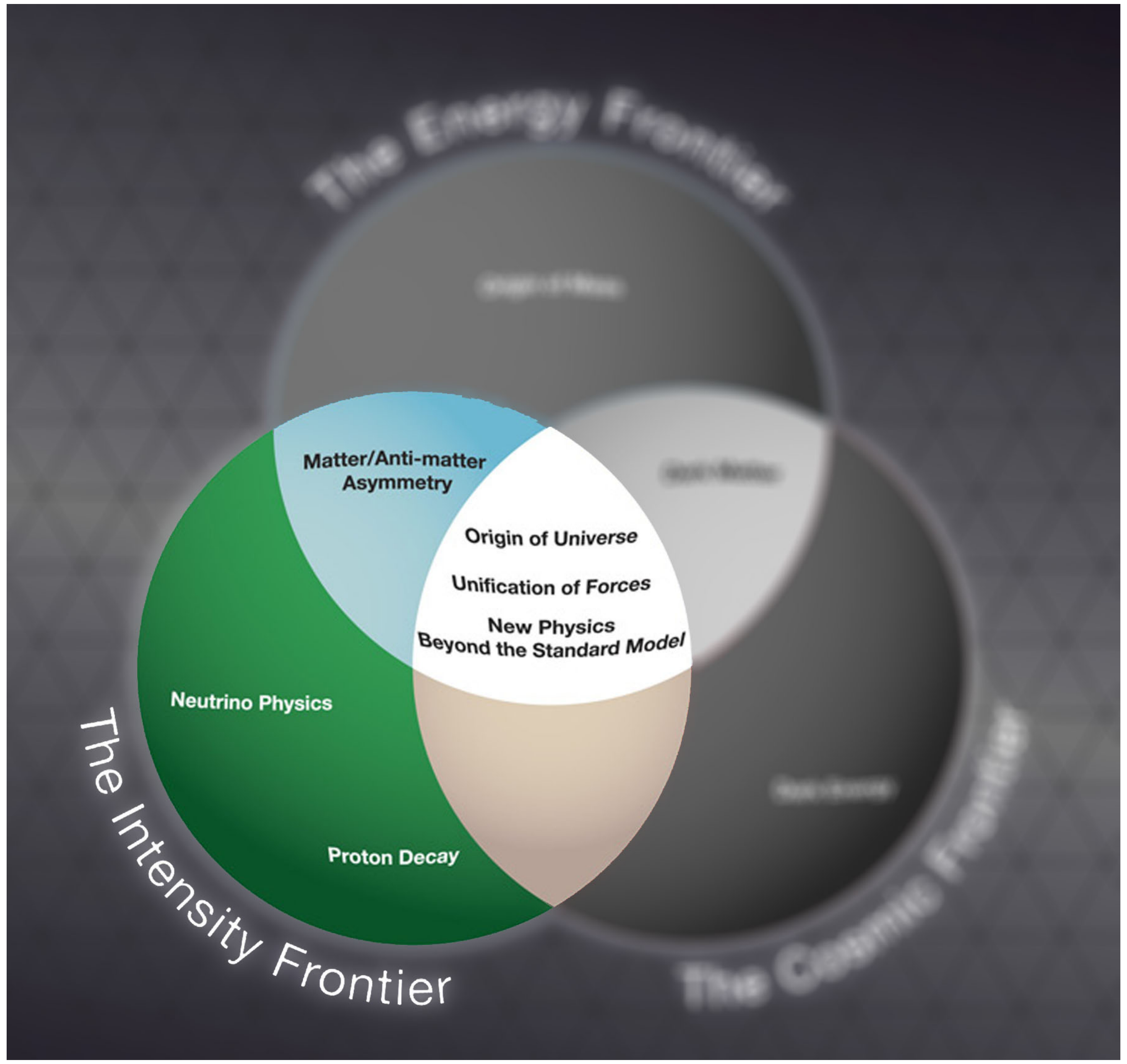
# Beyond the SM physics

*Open question unexplained by SM → New Physics beyond the SM*

*Belle & Belle II operates at the "Intensity Frontier"*

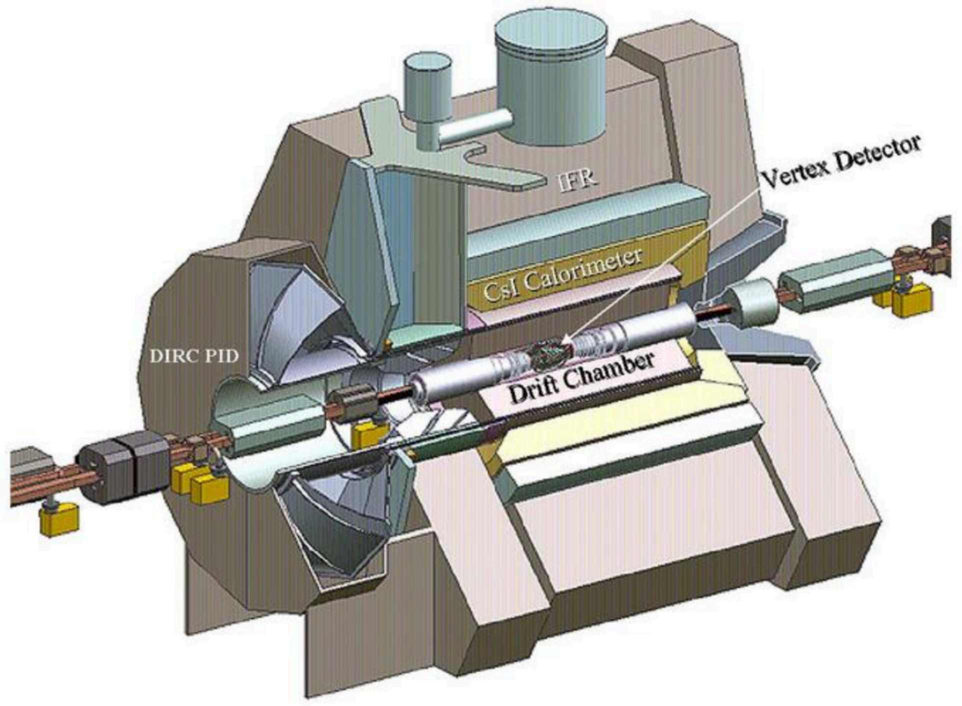
High precision measurements , probing SM indirectly

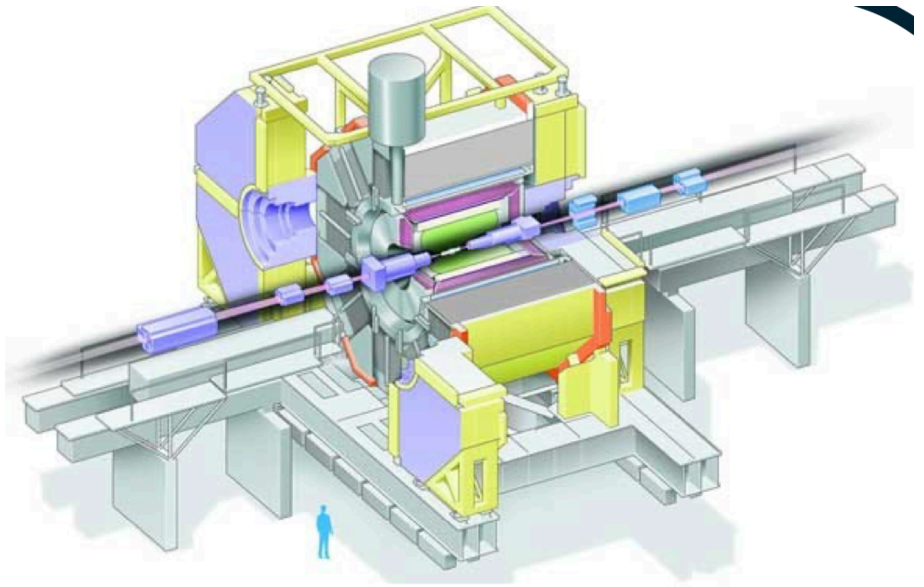
- as measurements of the SM-forbidden or suppressed process

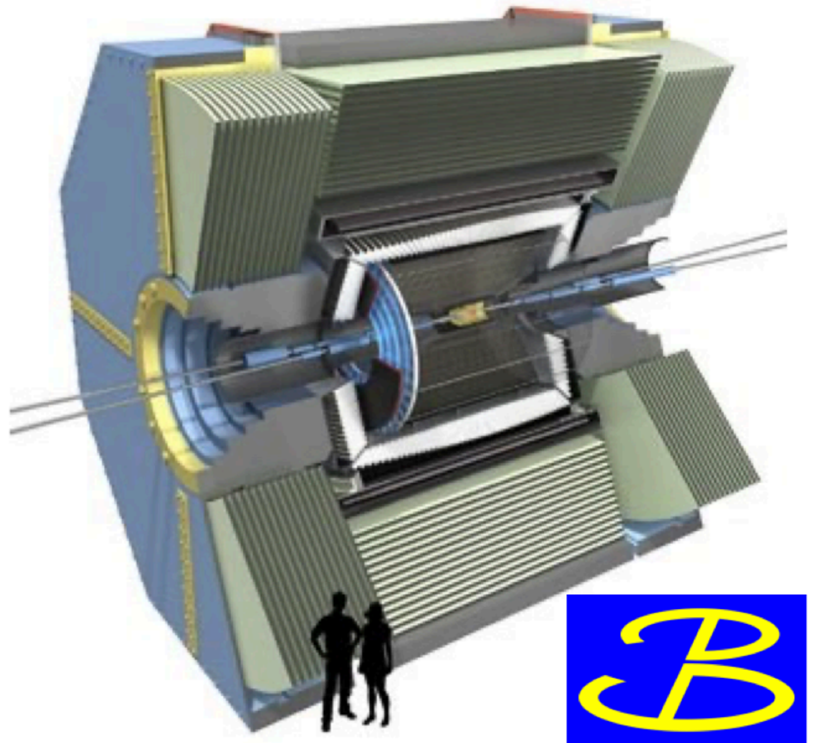



B-factories:

$e^+e^-$ collider @ $\Upsilon(4S) \to B\bar{B}$





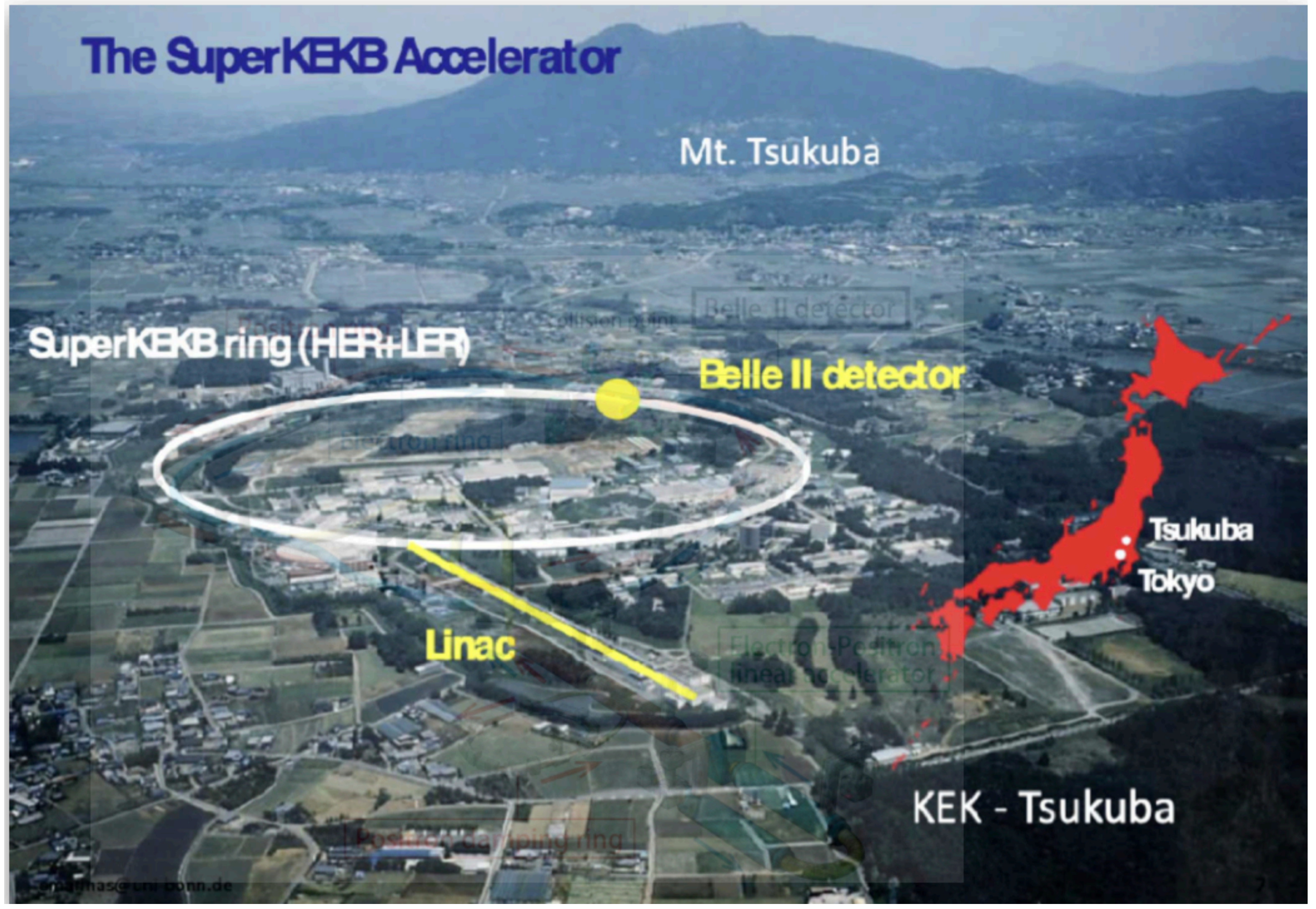
BABAR SLAC-PEP II collider : 462 $fb^{-1}$ @ $\Upsilon(4S)$ [1999-2008]

BELLE KEKB collider : 711 $fb^{-1}$ @ $\Upsilon(4S)$ [1999-2010]

Belle II SuperKEKB collider : 530 $fb^{-1}$ @ $\Upsilon(4S)$ [2019-current]

# KEK-SUPERKEKB complex

- Asymmetric $e^+e^-$ colliders
- Collisions mainly at 10.58 GeV , i.e at $\Upsilon(4S)$ resonance




## KEKB

1999-2010

- $e^+$ (3.5 GeV) $e^-$(8 GeV)
- $L_{peak}$: $2.1 \times 10^{34}\ cm^{-2}s^{-1}$ [achieved]

## SuperKEKB

2019-current

- $e^+$ (4 GeV) $e^-$(7 GeV)

**Target:**

$$\int Ldt = 50\ \ ab^{-1}$$

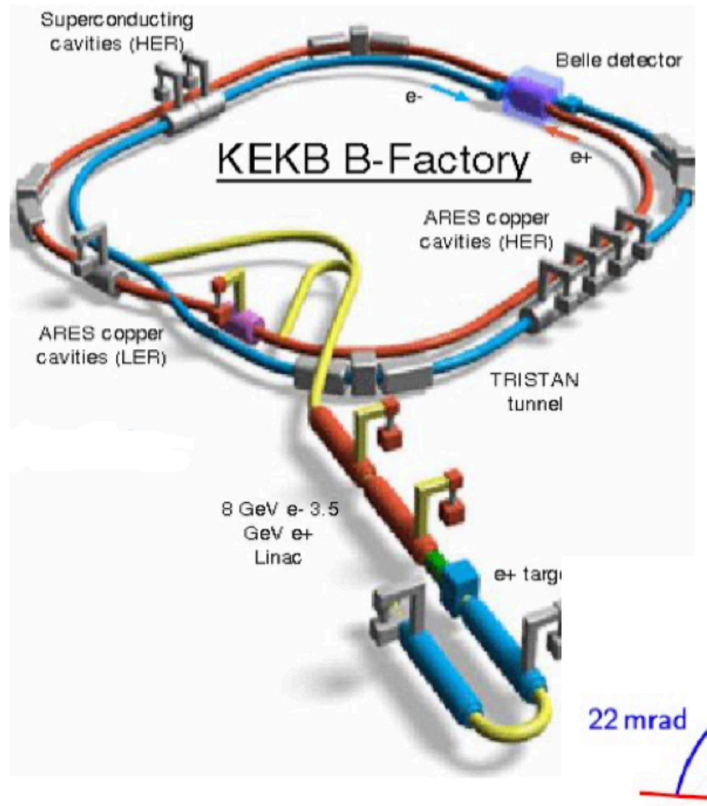
$$L_{peak} = 6 \times 10^{35}\ \ cm^{-2}s^{-1}$$

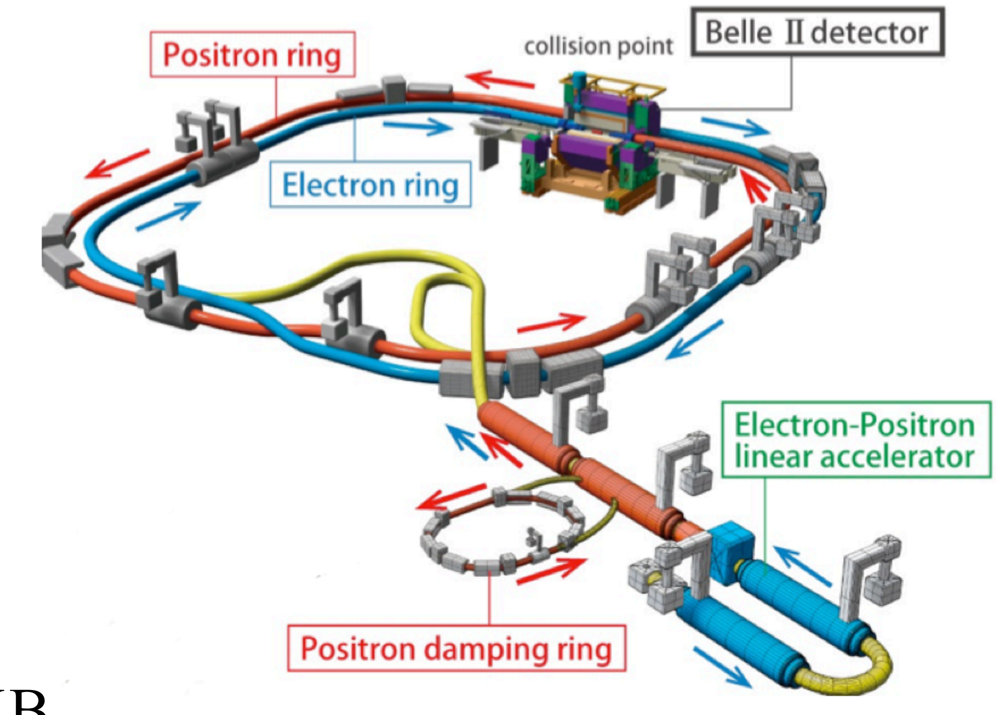
**Achieved**:

$$\int Ldt > 530\ \ fb^{-1}$$

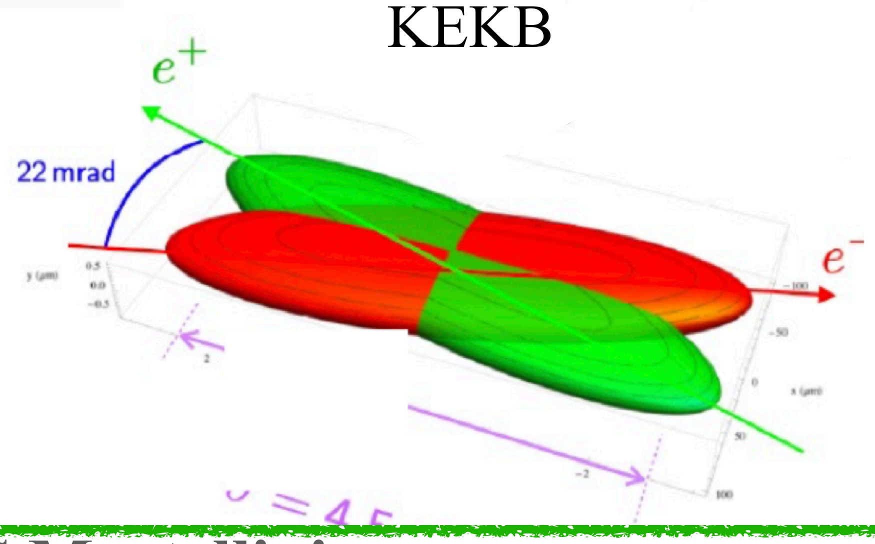
$$L_{peak} = 4.7 \times 10^{34}\ \ cm^{-2}s^{-1}$$

***Current world record***

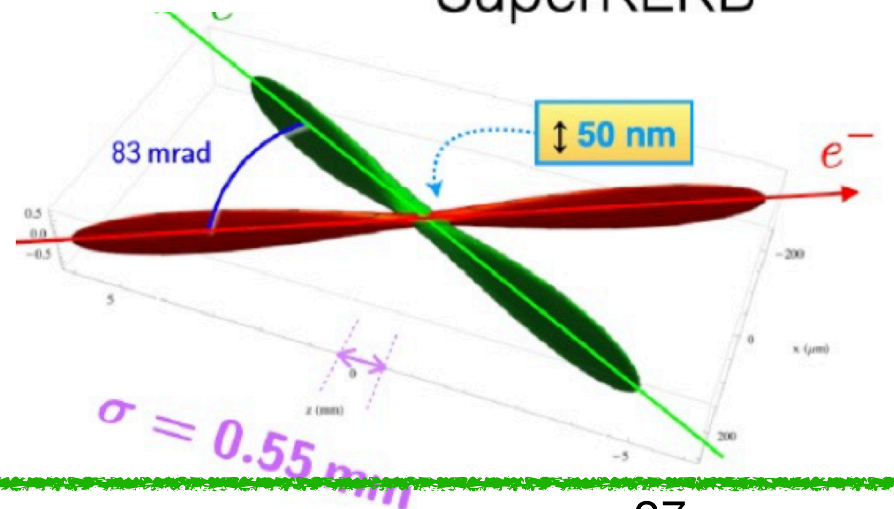



KEKB




SuperKEKB



# Belle & Belle II detectors

Belle II

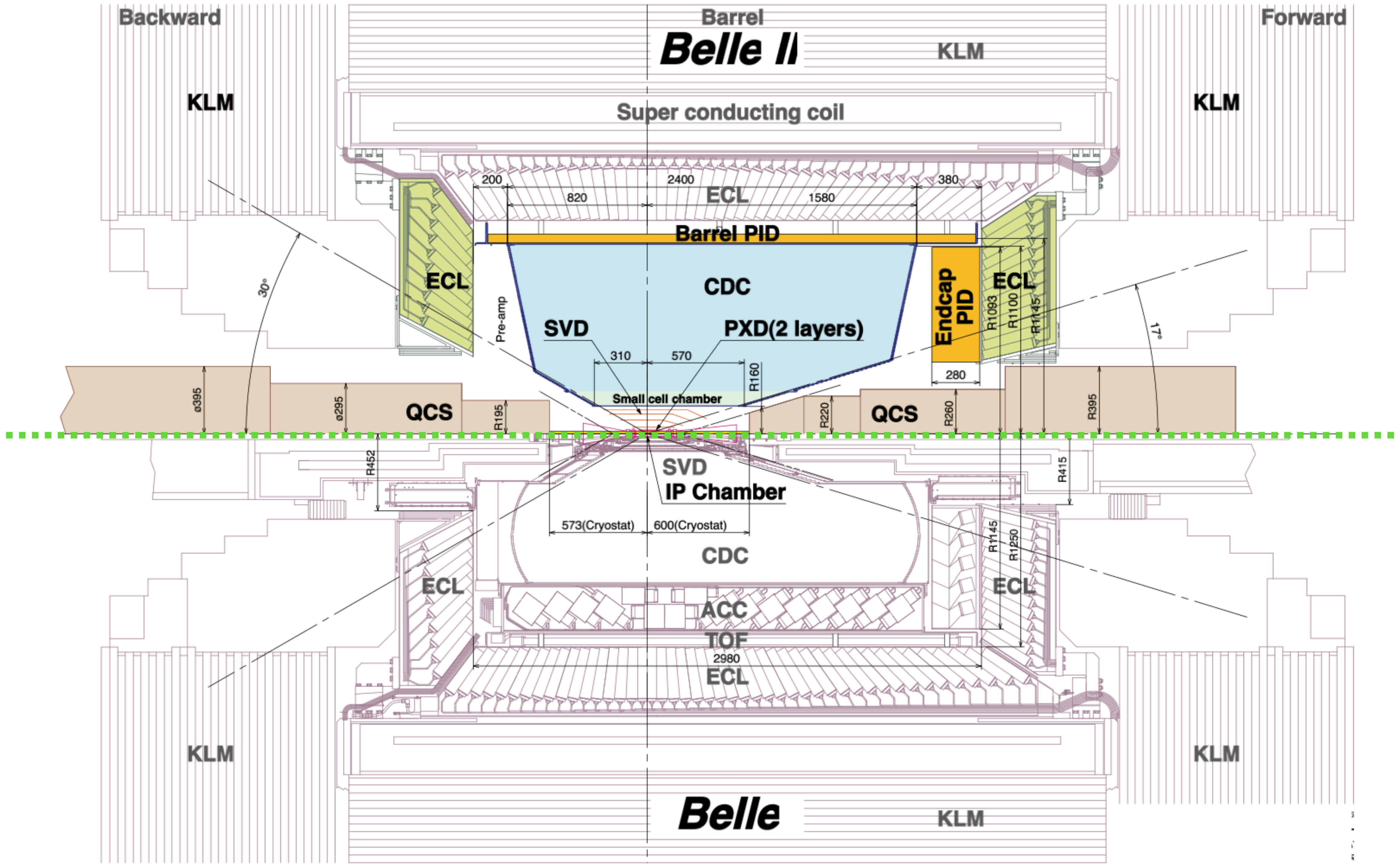
**ECL** (electromagnetic calorimeter): Updated electronics

**PID** (Particle Identification): Better $K/\pi$ separation under higher bkg level

**CDC** (Central drift chamber): larger volume, smaller drift cells and faster electronics

**VTX**: + 2 layers PXD (pixel detector)
+ 4 layers SVD (Silicon vertex detector)

BELLE



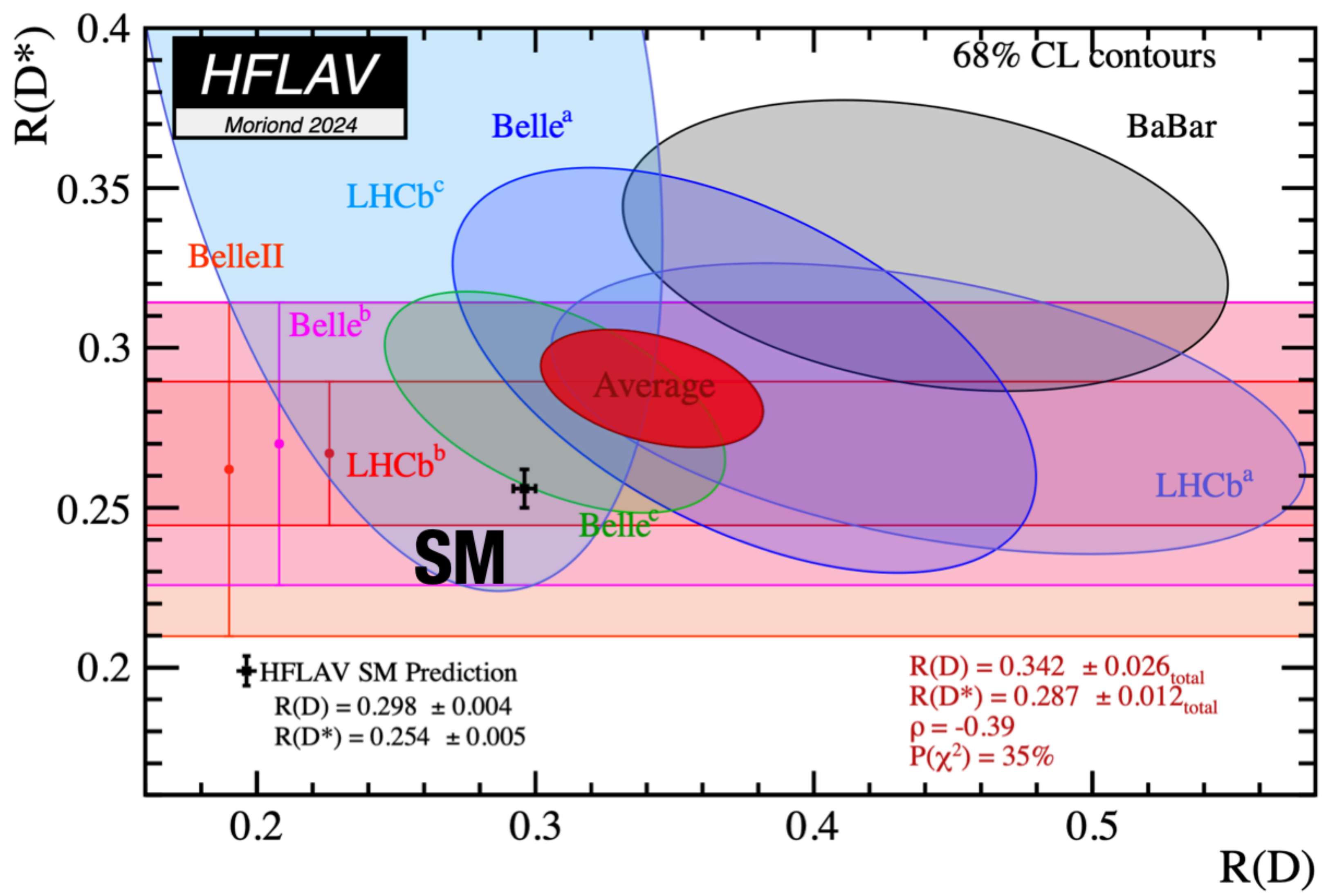

[Belle II TDR]

- Well-known **initial state** condition
- Benefits from **clean environment**
- Efficient reconstruction of **neutrals**
- Boosted center of mass that allows for time-dependent measurements
- Hermetic detectors ⟶ ideal for studying neutral or invisible decays

# LFU tests - Measurement of R($X_{\tau/l}$)

[Phy.Rev.Lett.132.211804]

- **LFU:** SM expects lepton coupling to EW gauge boson to be **flavour-universal**
- **Ratio** of the branching-fraction of senile-tonic decays

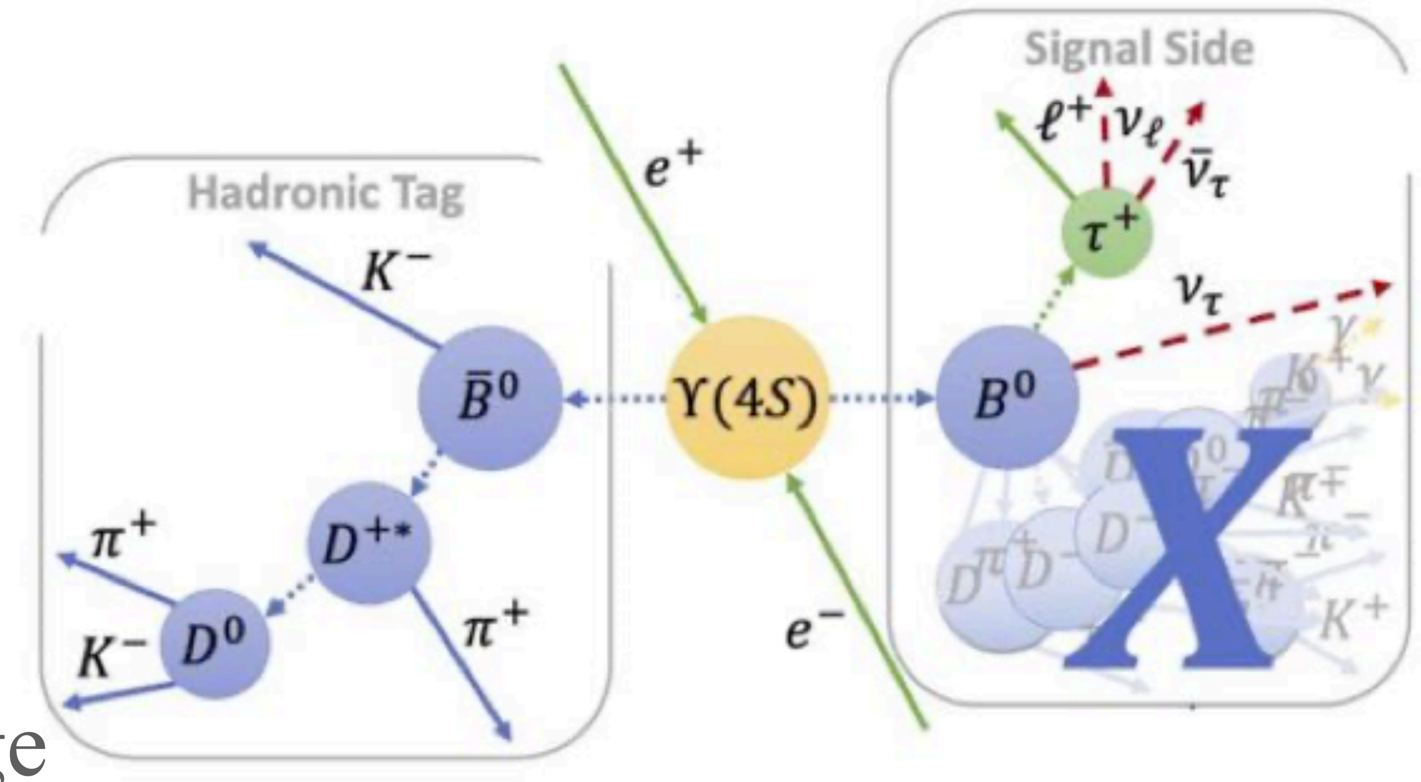



$$R(H_{\tau/l}) = \frac{Br(B \to H\tau\nu_\tau)}{Br(B \to Hl\nu_l)}$$

Where H = D,D*, X, $\pi$ … and l= e, $\mu$

New

- Measurement of R($X_{\tau/l}$) has been carried out with 189 $fb^{-1}$ of Belle II data
  - Reconstruction of $B \to X\tau\nu_\tau$ and $B \to Xl\nu_l$:
    - Hadronic tag: tagged B reconstructed in its hadronic decay modes (using **Full Event Interpretation (FEI)**)
    - Signal : $B \to X\tau\nu_\tau$ with leptonic decays ($\tau \to e\bar{\nu}_e\nu_\tau / \mu\bar{\nu}_\mu\nu_\tau$)
    - Normalisation: $B \to Xl\nu_l$ (with l= e, $\mu$)




Background contamination and modeling of many decay channels in signal side is the challenge

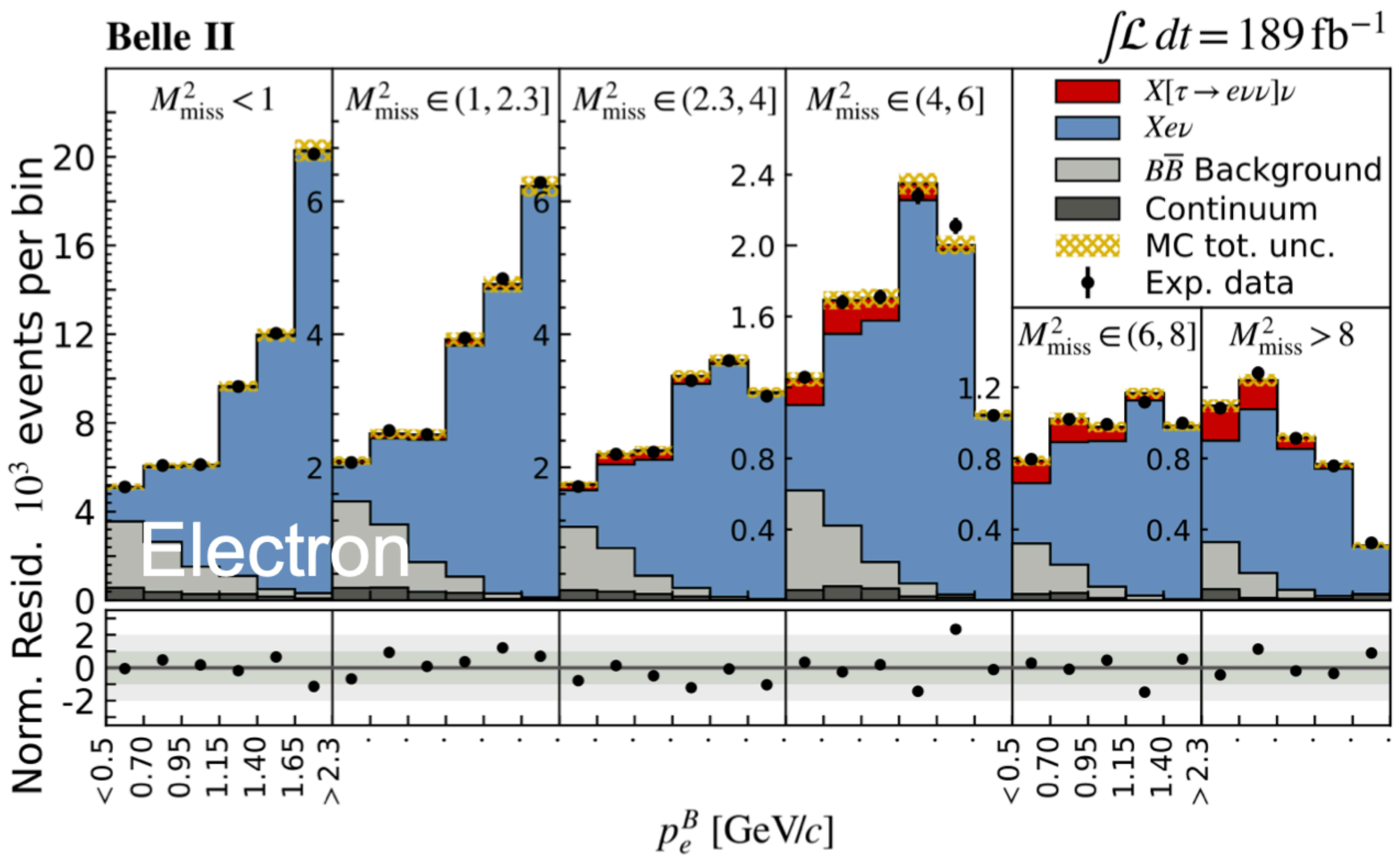
# LFU tests - Measurement of R($X_{\tau/l}$)

- **Signal extraction:**

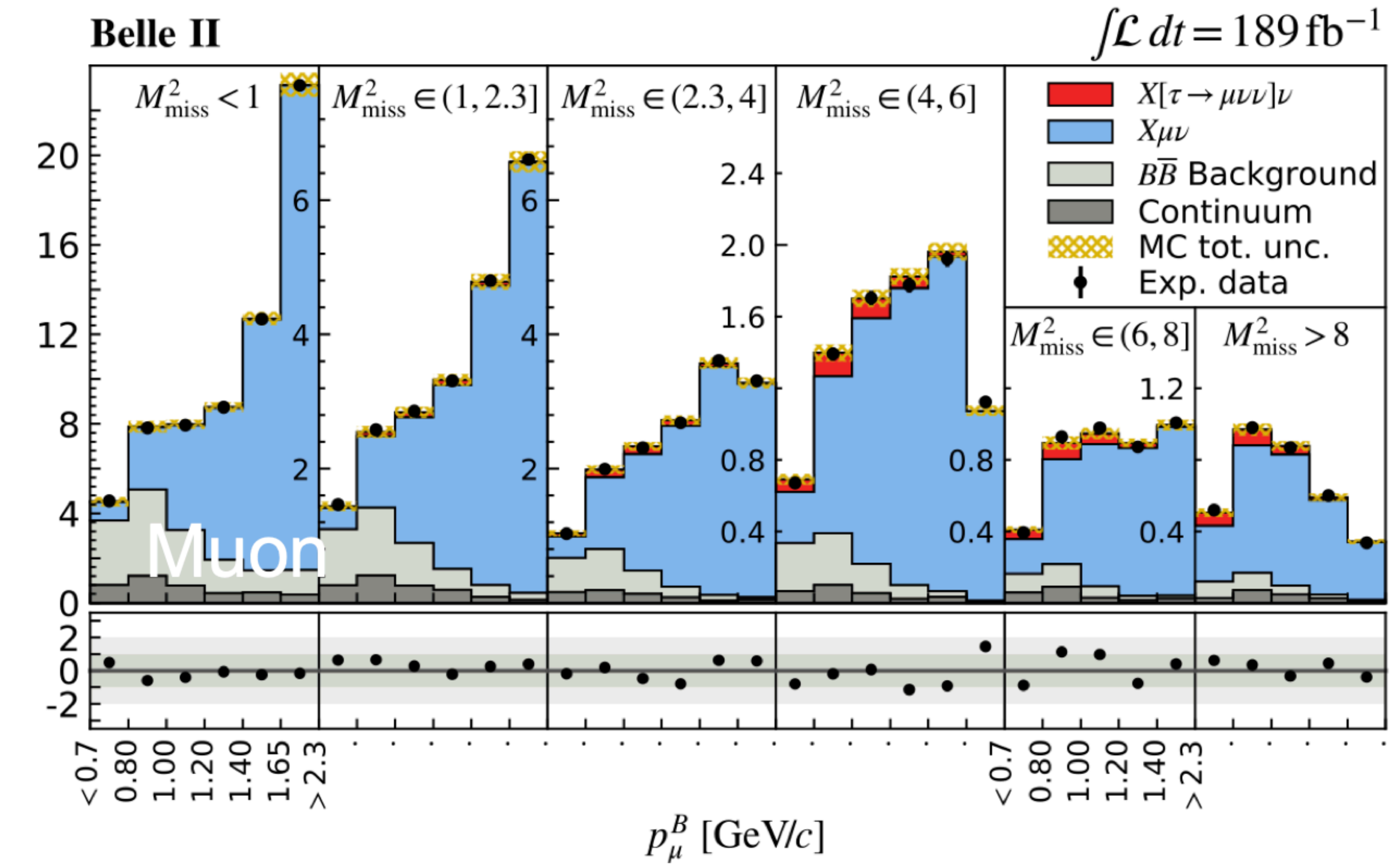
Phy.Rev.Lett.132.211804

- 2D binned maximum likelihood fit to extract the **signal** and **normalization** yields for both electrons and muons modes simultaneously
  - In bins of $p_l^B$ and $M_{miss}^2$
    - e channel: $R(X_{\tau/e}) = 0.232 \pm 0.020(stat) \pm 0.037(syst)$
    - $\mu$ channel: $R(X_{\tau/\mu}) = 0.222 \pm 0.027(stat) \pm 0.050(syst)$

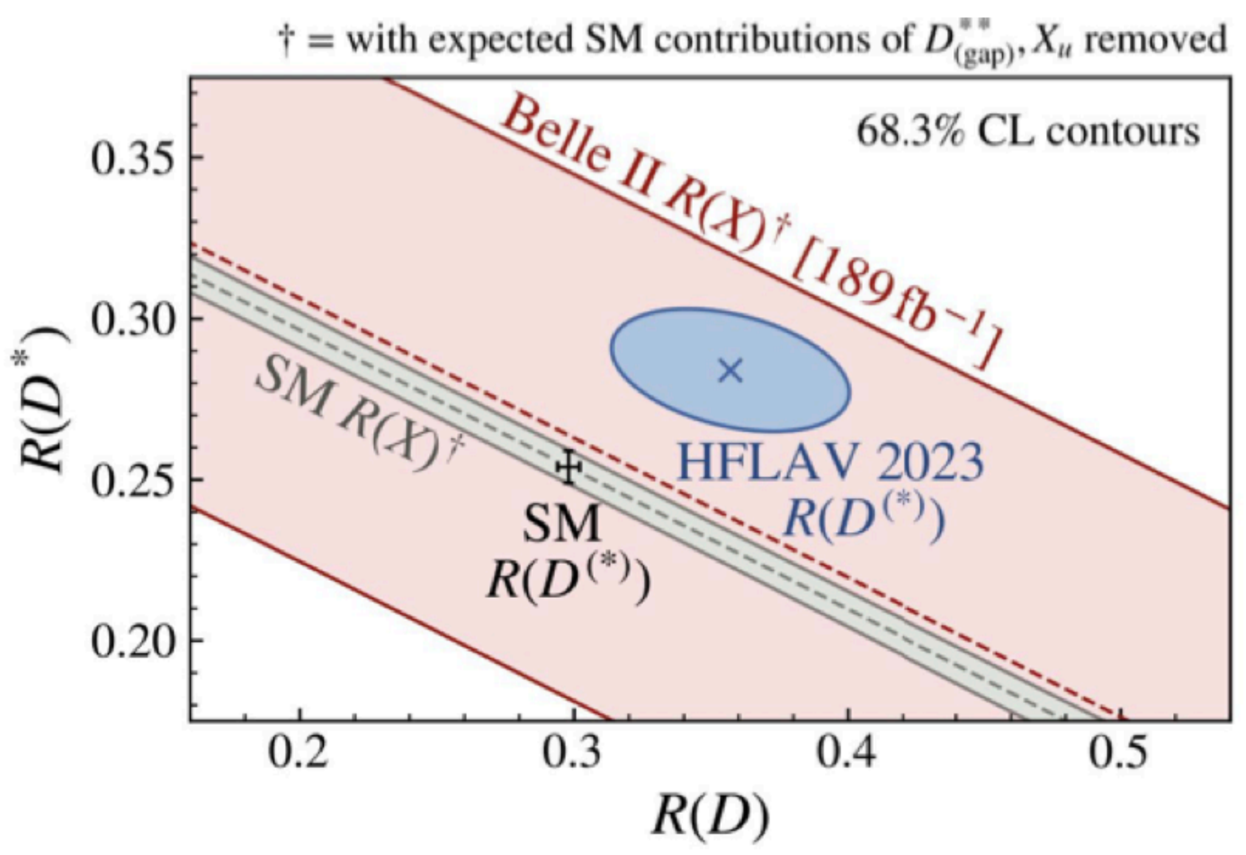
$$R(X_{\tau/l}) = 0.228 \pm 0.016(stat) \pm 0.036(syst)$$

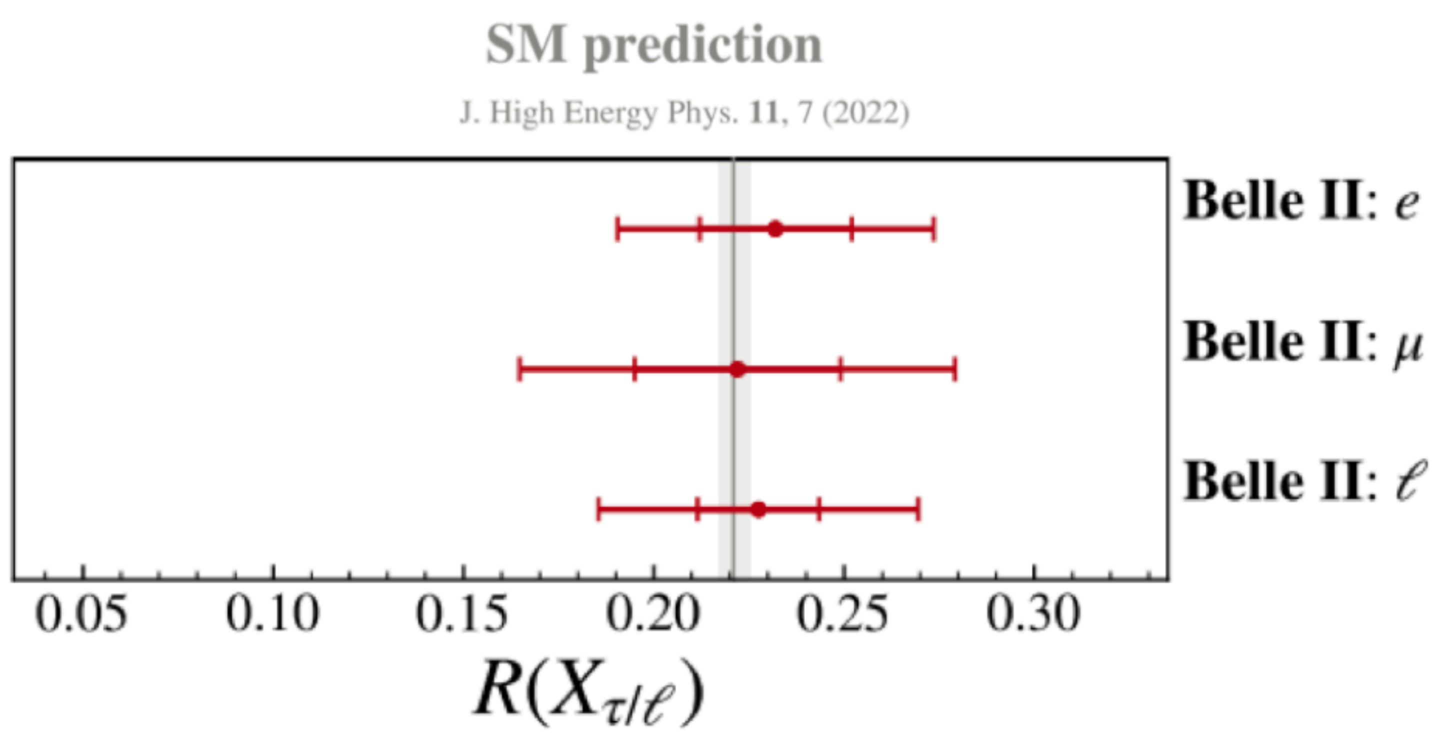



Agreement between the e and $\mu$ channel measurements




Consistent with SM prediction ($0.221 \pm 0.004$) and $R(D^*)$ anomalies



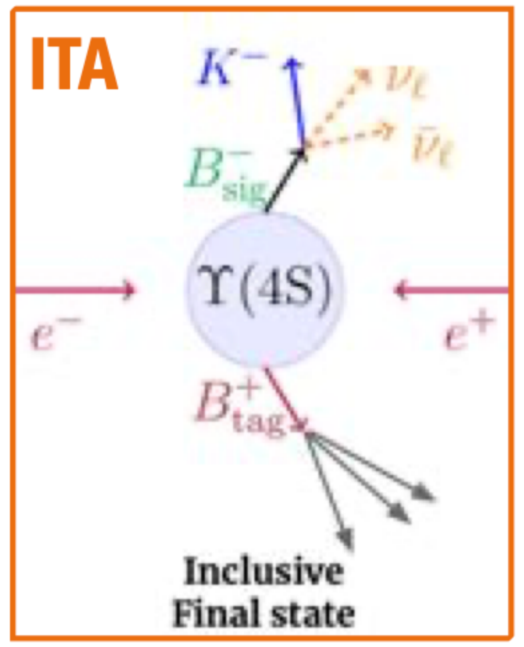
# Rare Decays : $B^+ \to K^+ \nu \bar{\nu}$ validation and corrections

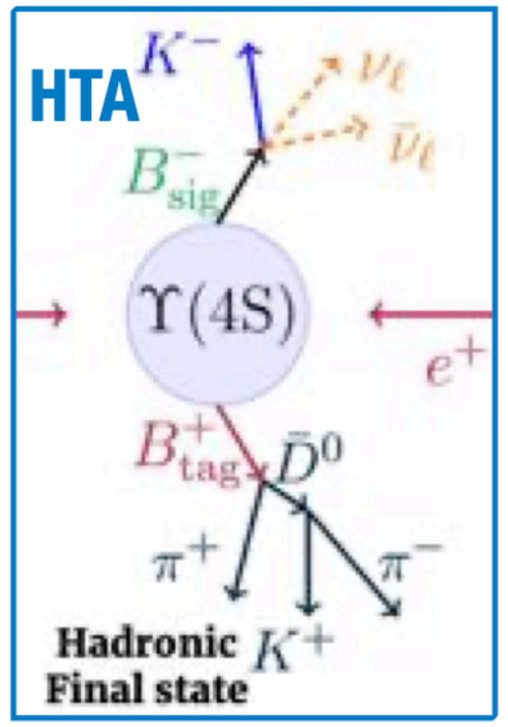
PhysRevD.109.112006

- Used to complementary B tag approach : **low purity-high efficiency** (0.8%-8%) **and its opposite** (3.5%-0.4%)

- **Signal validation:** event selection by combining signal Kaon, event topology, rest of the event in the MVA classifiers

- **Full Belle II Run1 data sample (362 $fb^{-1}$ )**




- **Background validation:** background from continuum
  Semileptonic B decays
  $B^+ \to K^+ n\bar{n}$
  $B^+ \to K^+ K^0 \bar{K}^0$
  $B \to K^+ D( \to K_L X)$
  pions fake

- **Inclusive method validation**:
  - Closing test by measuring $\mathscr{B}(B^+ \to \pi^+ K^0)$

# Rare Decays : double radiative $B^0 \to \gamma\gamma$ at Belle and Belle II

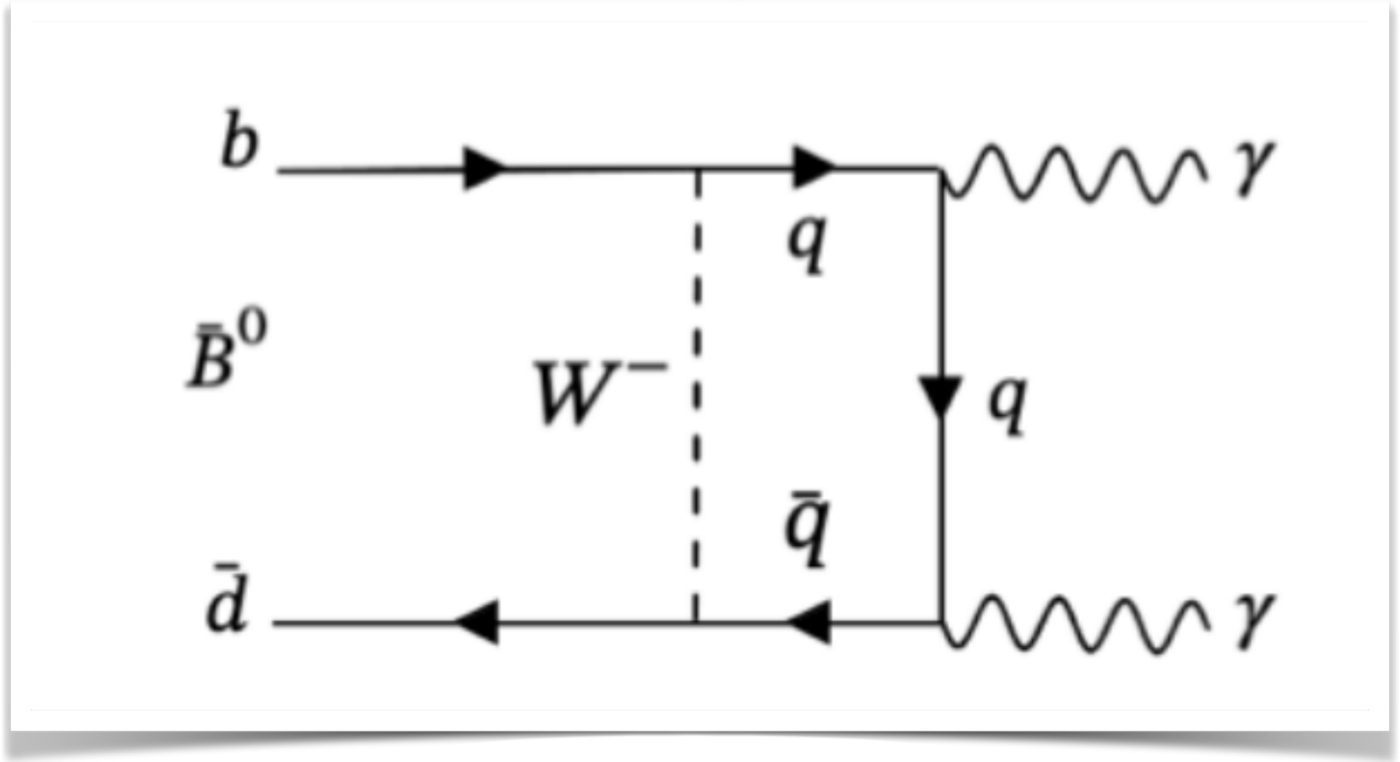
**Preliminary**

arXiv:2405.19734

Accepted by PRDL

- Flavor-changing Neutral Current (FCNC) b→d decay with $\mathscr{B}(SM) = 1.4^{+1.4}_{-0.8} \times 10^{-8}$

  Highly suppressed in the SM , sensitive to New physics




- Two photons in the final states makes it experimentally challenging
  - Previous measurements only set upper limits

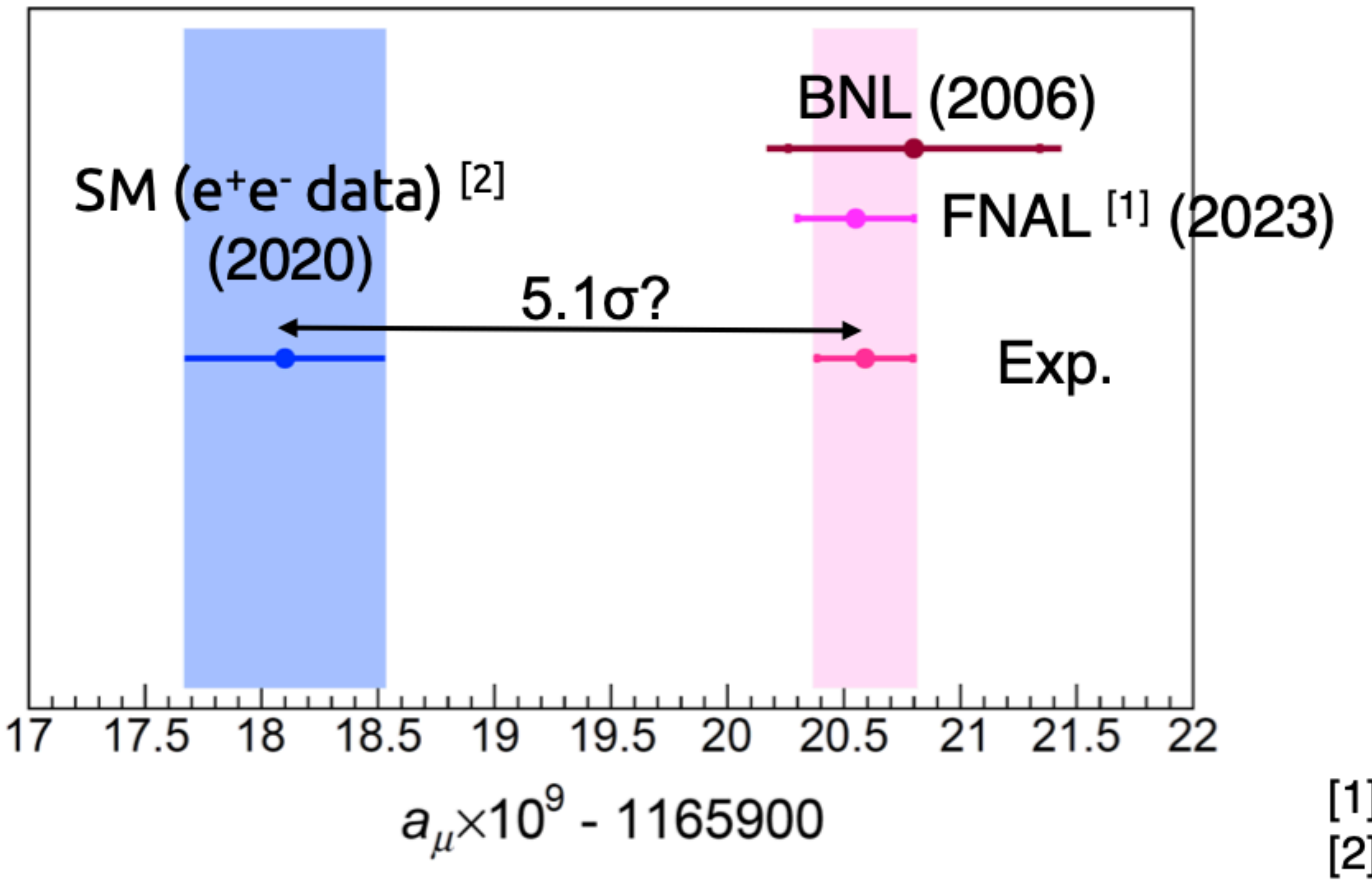
| Experiment | $\int \mathscr{L} dt$ | Limits @ 90 C.L |
|---|---|---|
| L3 | 73 $pb^{-1}$ | $3.9 \times 10^{-5}$ |
| Belle | 104 $fb^{-1}$ | $6.2 \times 10^{-7}$ |
| Babar | 426 $fb^{-1}$ | $3.2 \times 10^{-7}$ |

Phys.Lett.B363 137
Phys.Rev.D.73.051107
Phys.Rev.D.83.032006

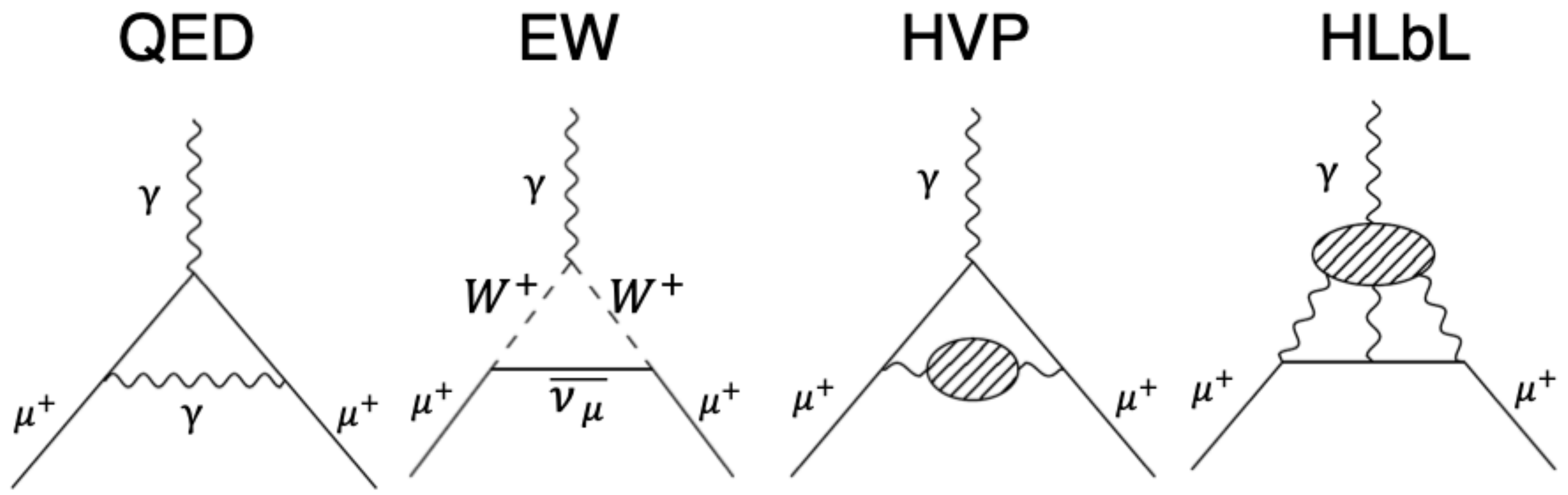
- Improve with larger statistics: Belle (694 $fb^{-1}$) + Belle II Run1 data (362 $fb^{-1}$)

# Recent situation in muon g-2 anomaly

- 5σ significance through new direct measurements from Fermilab
- Non-negligible uncertainty in theoretical predictions




$$a_\mu^{\mathrm{SM}} = \frac{g_\mu - 2}{2} = a_\mu^{\mathrm{QED}} + a_\mu^{\mathrm{EW}} + a_\mu^{\mathrm{HVP}} + a_\mu^{\mathrm{HLbL}}$$





[1] DPRL 131 161802 (2023)
[2] Phys. Rept. 887, 1 (2020)

# Rare Decays : double radiative $B^0 \to \gamma\gamma$ at Belle and Belle II

**Preliminary**

arXiv:2405.19734

Accepted by PRDL

- 3D fit to $\Delta E, M_{bc}$
- Belle (694 $fb^{-1}$ ) + Belle II Run1 data (362 $fb^{-1}$)

$$\mathcal{B}(B^0 \to \gamma\gamma) = (3.7^{+2.2}_{-1.8}(stat) \pm 0.7(sys)) \times 10^{-8}$$

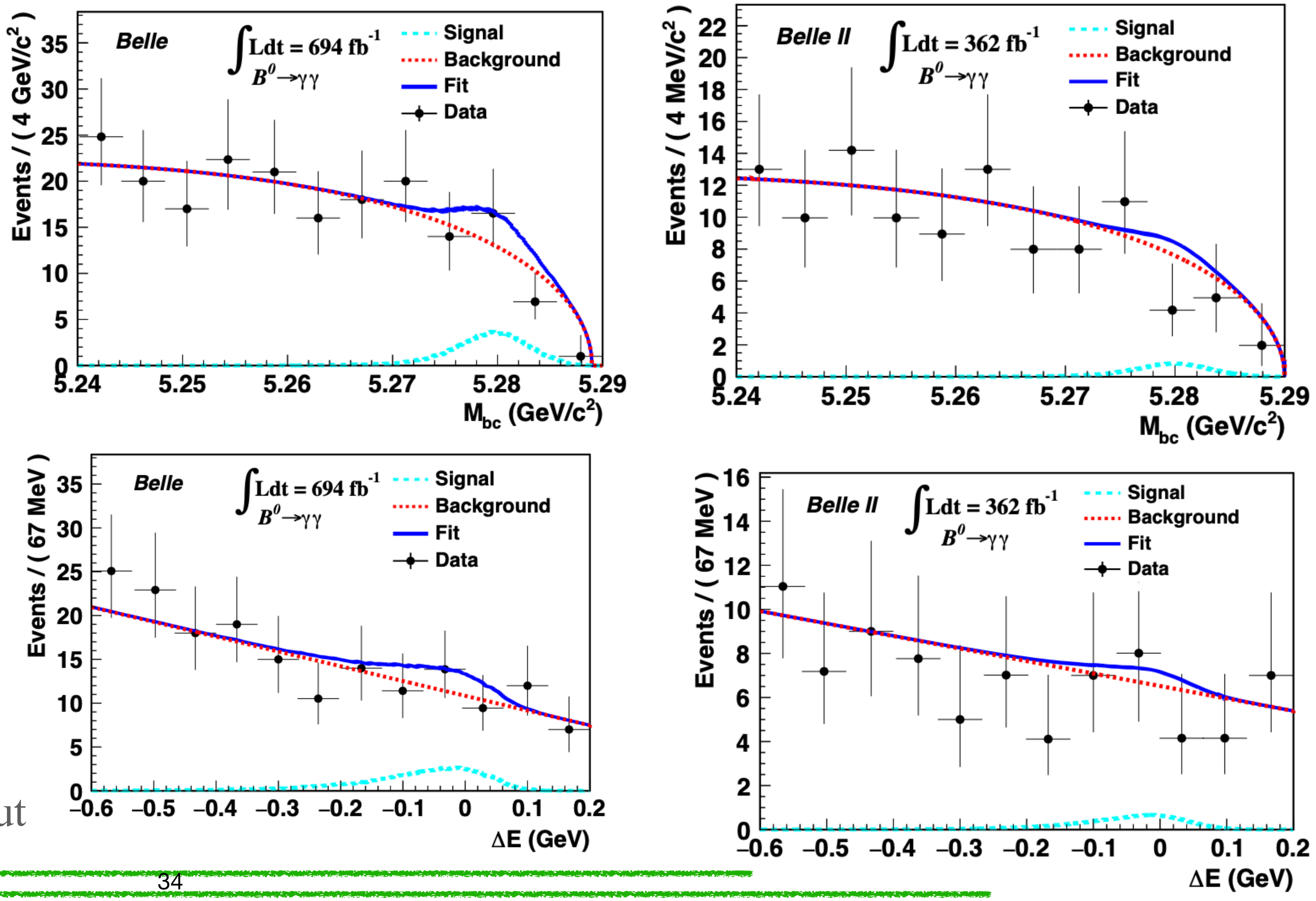
***Combined***

$$\mathcal{B}(B^0 \to \gamma\gamma) = (5.4^{+3.3}_{-2.6}(stat) \pm 0.5(sys)) \times 10^{-8}$$

$$\mathcal{B}(B^0 \to \gamma\gamma) = (1.7^{+3.7}_{-2.4}(stat) \pm 0.3(sys)) \times 10^{-8}$$

**World best Upper Limit:**

U.L $< 6.4 \times 10^{-8}$ @ 90% C.L




Fit projections on $M_{bc}$ transformed continuum BDT output

# $\tau^\pm \to \mu^\pm\mu^\mp\mu^\pm$ : results

arXiv:2405.07386

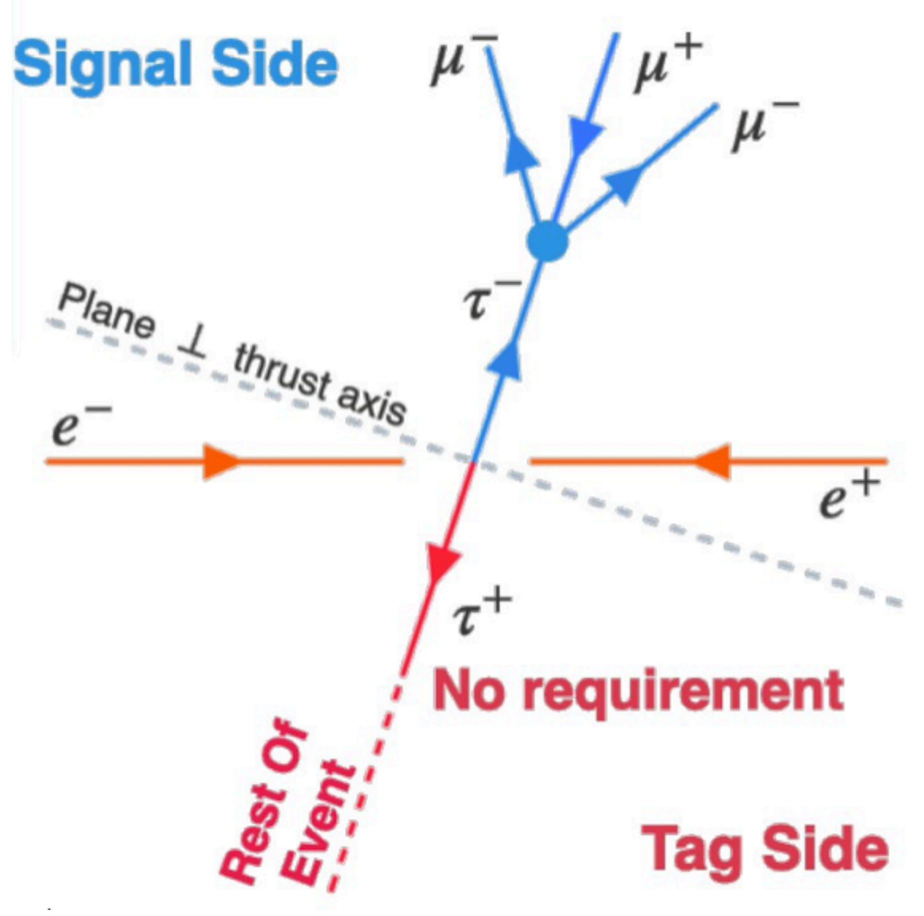
Accepted by JHEP

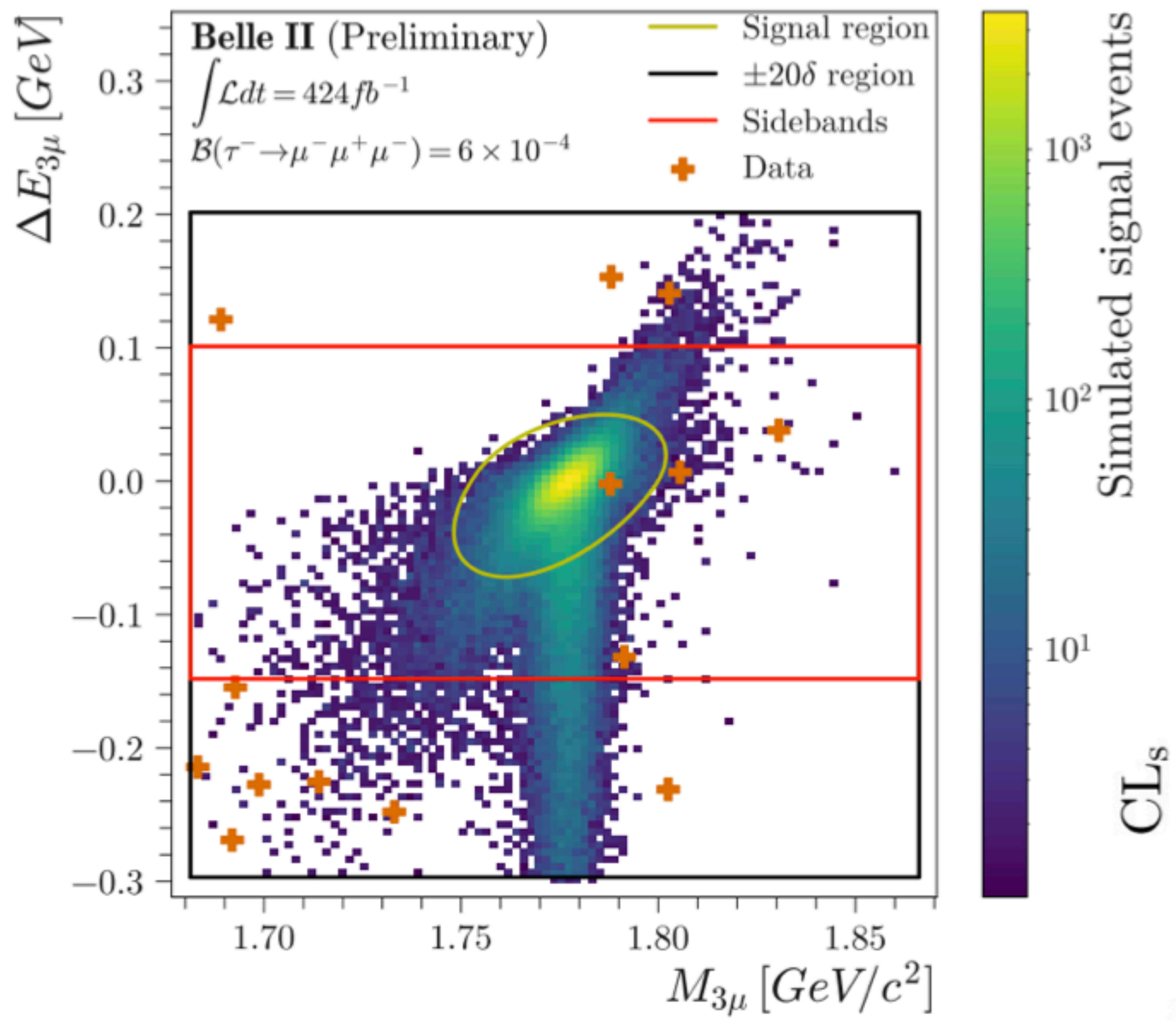
Talk by A.Thaller

A lot of interest in LFV decays at $e^+e^-$ colliders, with ~ 50 modes: $\tau \to l\gamma, \tau \to l\phi, \tau \to lll$

These are rare decays : it's all about **maximising the statistics!**

- Almost free from SM background
- Very good resolution on the energy and the momentum




**Signal:**

- reconstruction of signal candidate by combining three muons

**Background:**

- Selections to remove low-multiplicity events
- BDT to reject $q\bar{q}$ events

90% CL upper limit on Branching Fraction

$$\mathcal{B}(\tau \to \mu\mu\mu) < 1.9 \times 10^{-8}$$

**World's best limit!!!**

No excess is found!