# BelleII @ PG

I have stolen pictures, drawings, etc from several people

# BelleII Collaboration

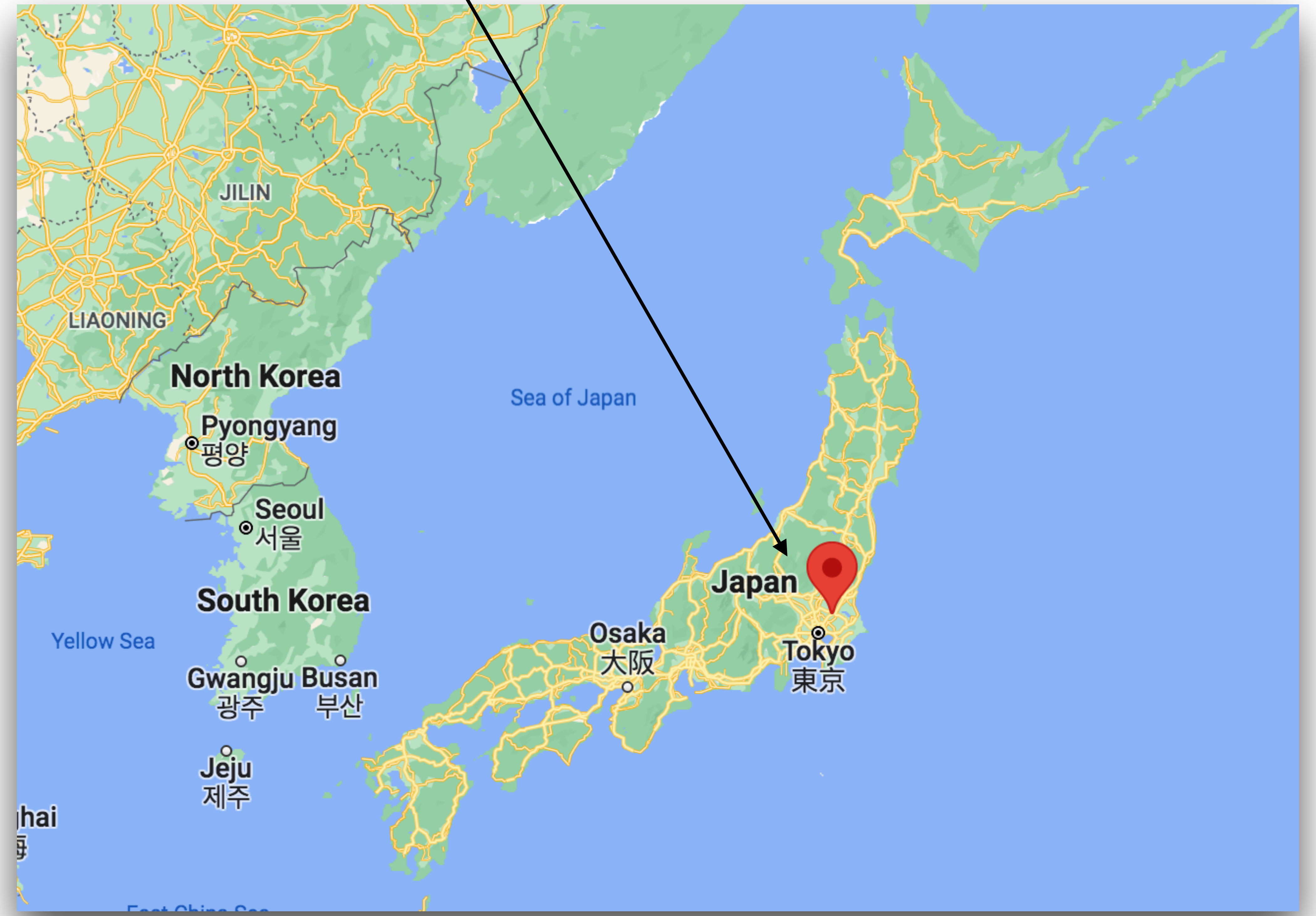

**≈1100 researchers**

**>123 institutions**

**≈26 nations**

# Belle2 experiment is at KEK, Japan

**Tsukuba, Ibaraki, Japan**





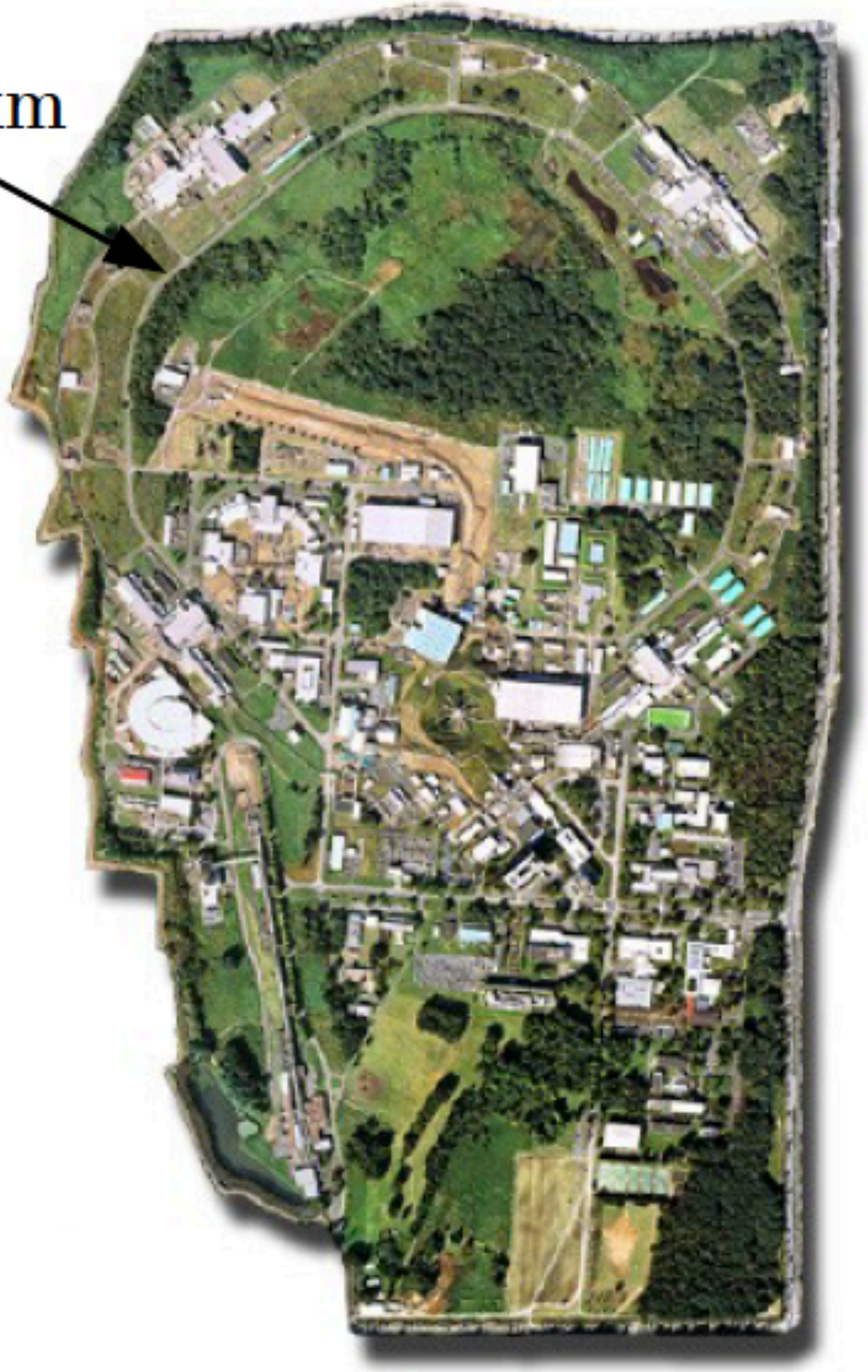
- **Tsukuba Campus**: 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
- **Tokai Campus**: 2-4 Shirane Shirakata, Tokai-mura, Naka-gun, Ibaraki 319-1195, Japan

# KEK

High Energy Accelerator Research Organization

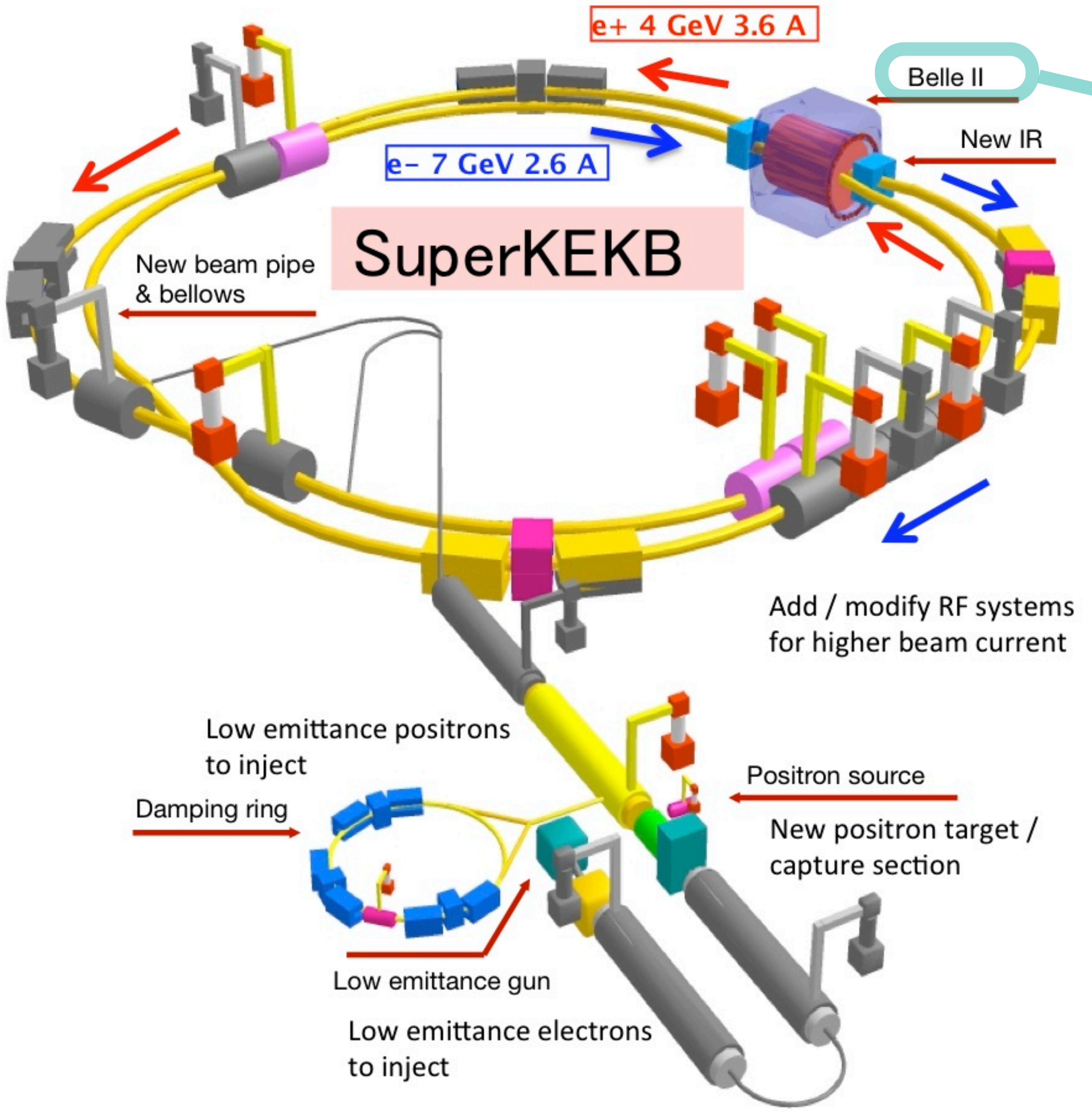
KEK Inter-University Research Institute Corporation
High Energy Accelerator Research Organization

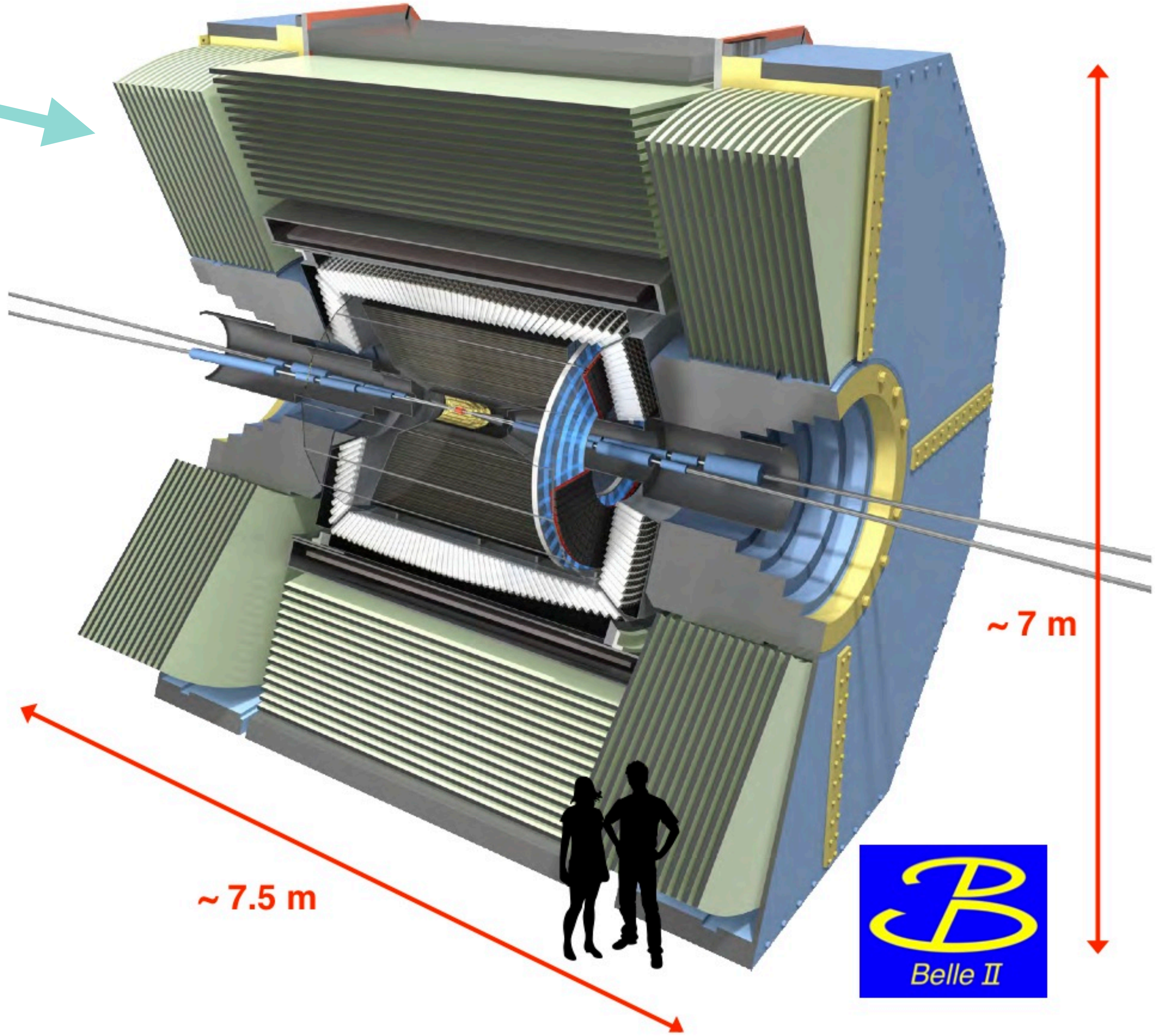

Accelerator circumference 3 km



First collisions: 26 April 2018

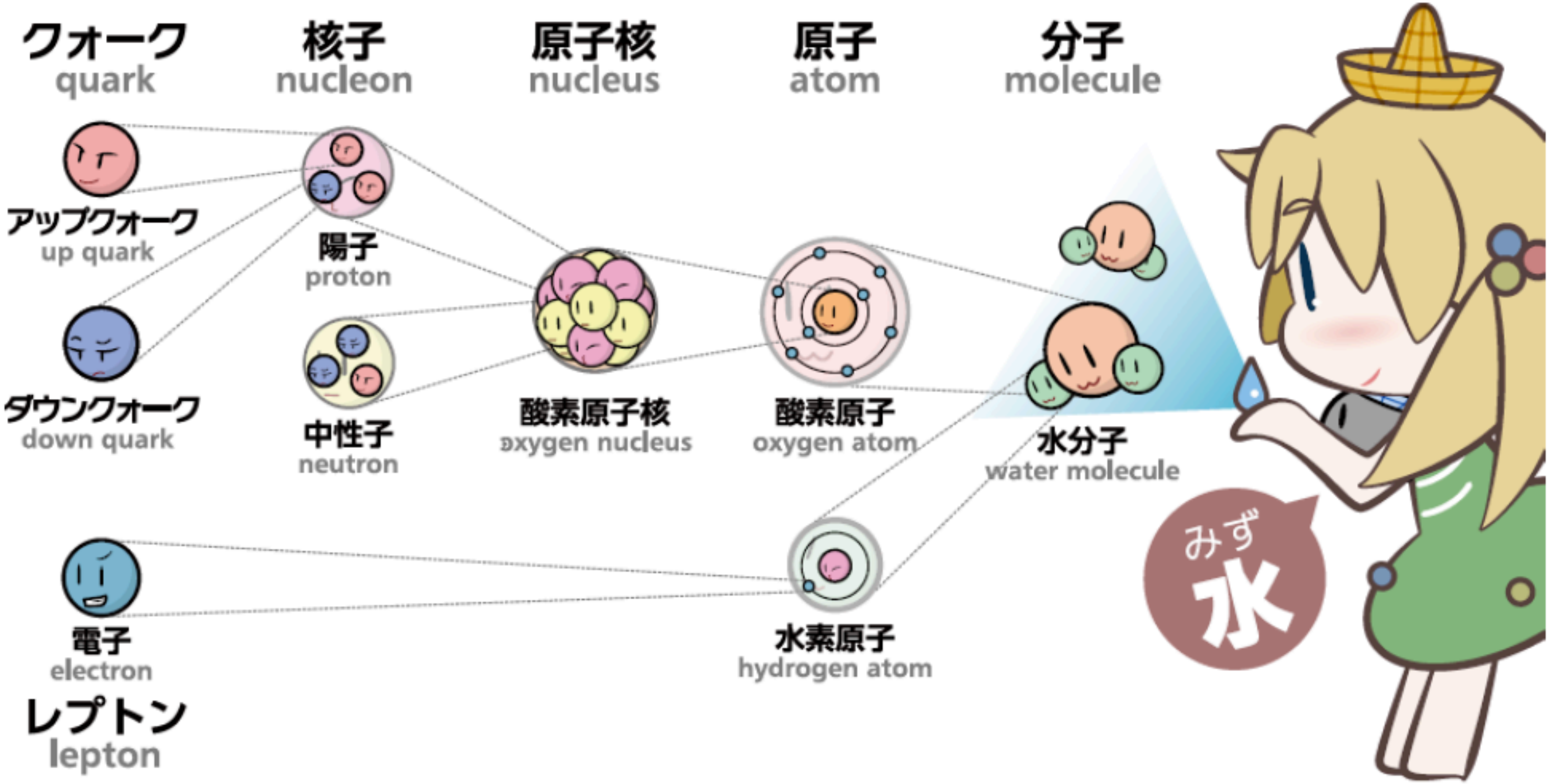
# BelleII experiment at SuperKEKB



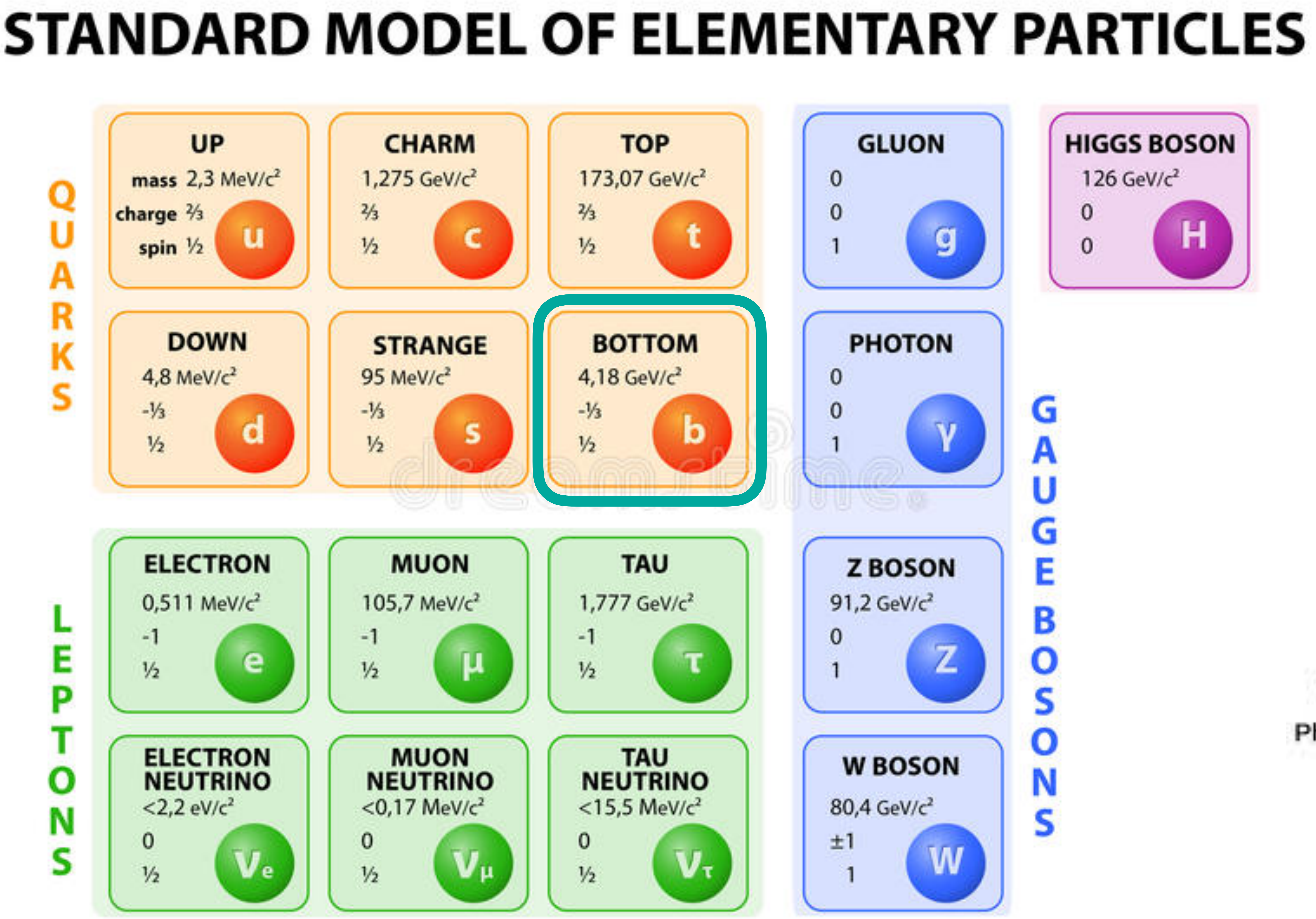



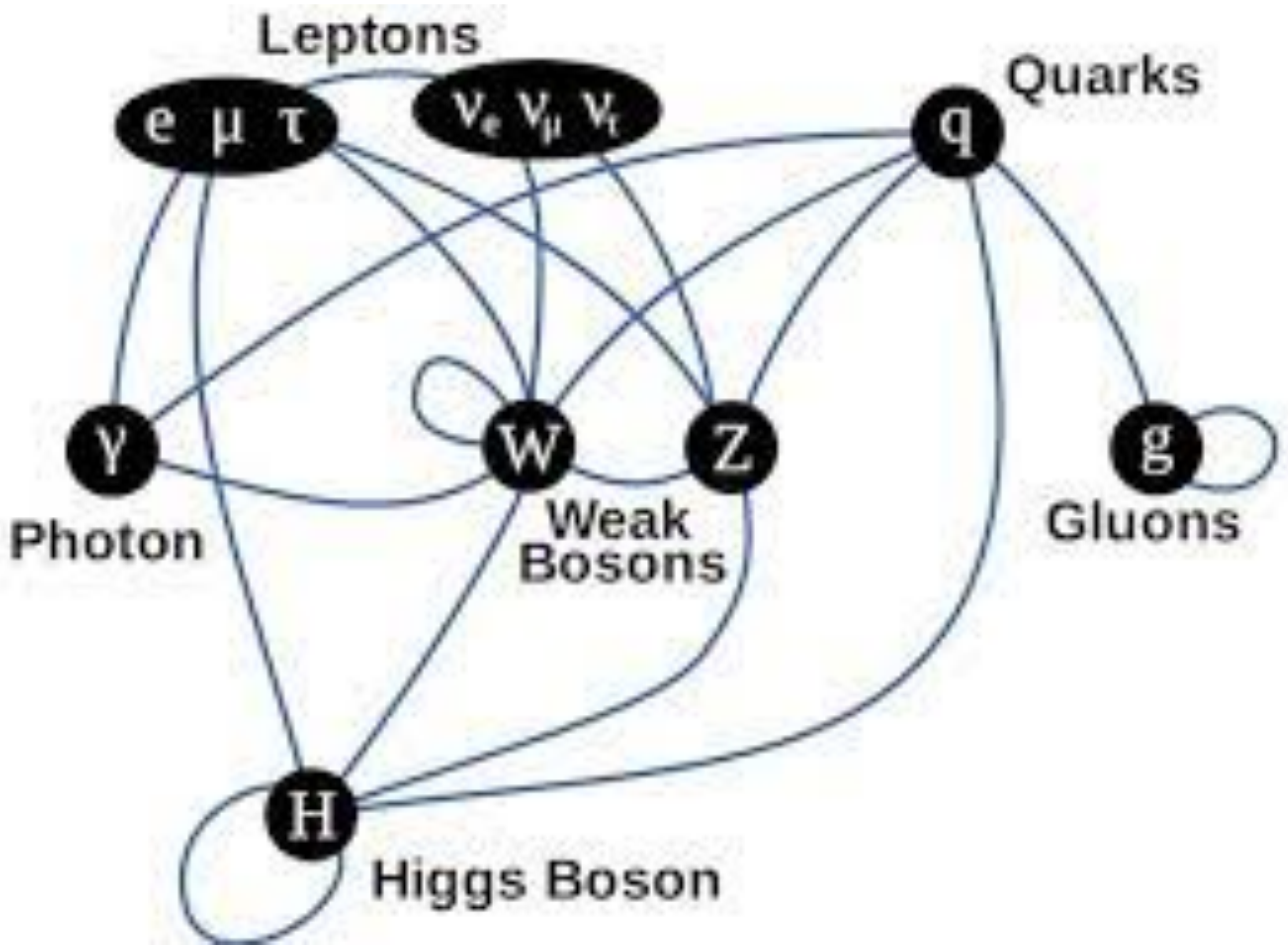
# What is matter made of?

## Ordinary matter, for example water:



# SM


STANDARD MODEL OF ELEMENTARY PARTICLES
QUARKS
UP
mass 2,3 MeV/c²
charge ⅔
spin ½
u
CHARM
1,275 GeV/c²
⅔
½
c
TOP
173,07 GeV/c²
⅔
½
t
DOWN
4,8 MeV/c²
-⅓
½
d
STRANGE
95 MeV/c²
-⅓
½
s
BOTTOM
4,18 GeV/c²
-⅓
½
b
LEPTONS
ELECTRON
0,511 MeV/c²
-1
½
e
MUON
105,7 MeV/c²
-1
½
μ
TAU
1,777 GeV/c²
-1
½
τ
ELECTRON NEUTRINO
<2,2 eV/c²
0
½
νe
MUON NEUTRINO
<0,17 MeV/c²
0
½
νμ
TAU NEUTRINO
<15,5 MeV/c²
0
½
ντ
GLUON
0
0
1
g
PHOTON
0
0
1
γ
Z BOSON
91,2 GeV/c²
0
1
Z
W BOSON
80,4 GeV/c²
±1
1
W
GAUGE BOSONS
HIGGS BOSON
126 GeV/c²
0
0
H


Leptons
e μ τ
νe νμ ντ
Quarks
q
γ
Photon
W
Z
Weak Bosons
g
Gluons
H
Higgs Boson

# SM issues:

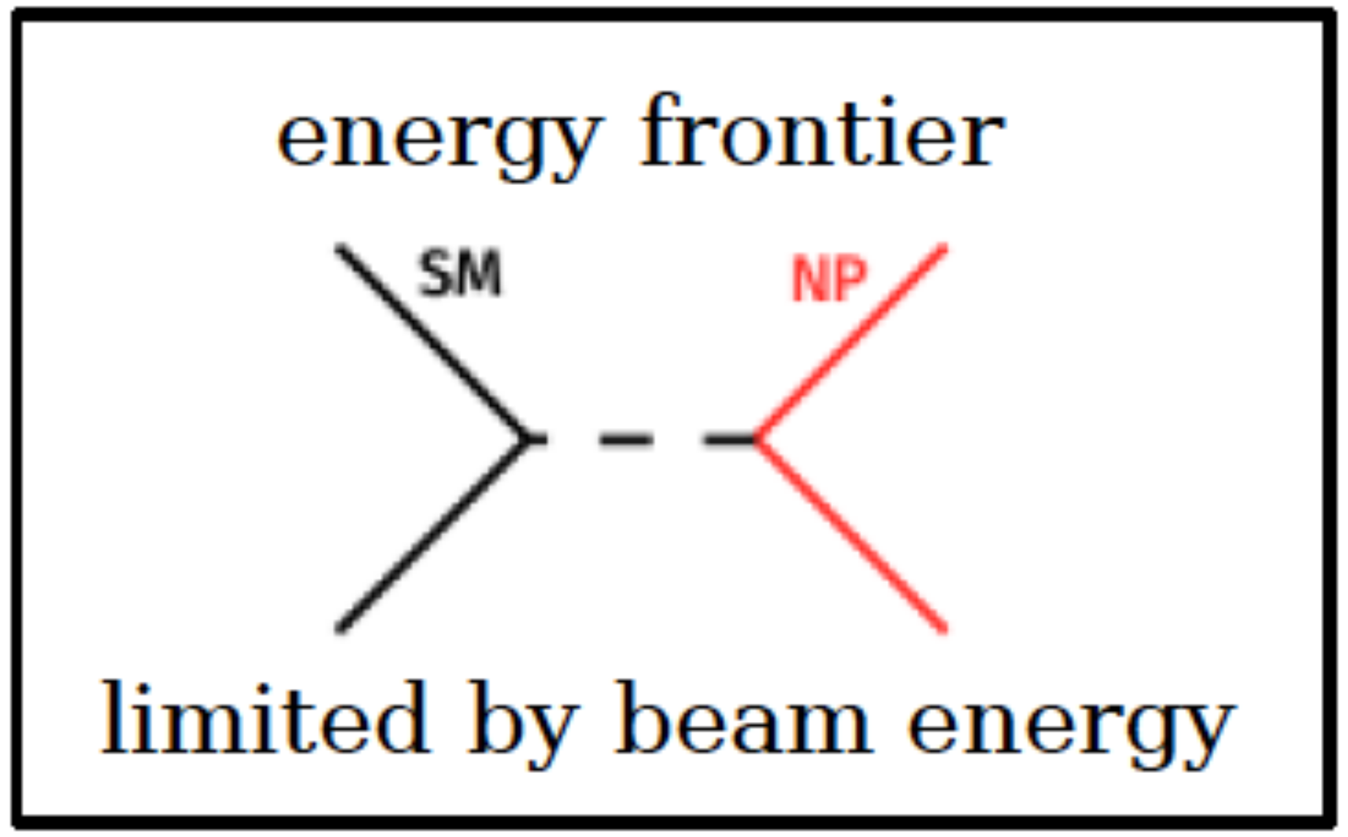
Issues which can be investigated at BelleII

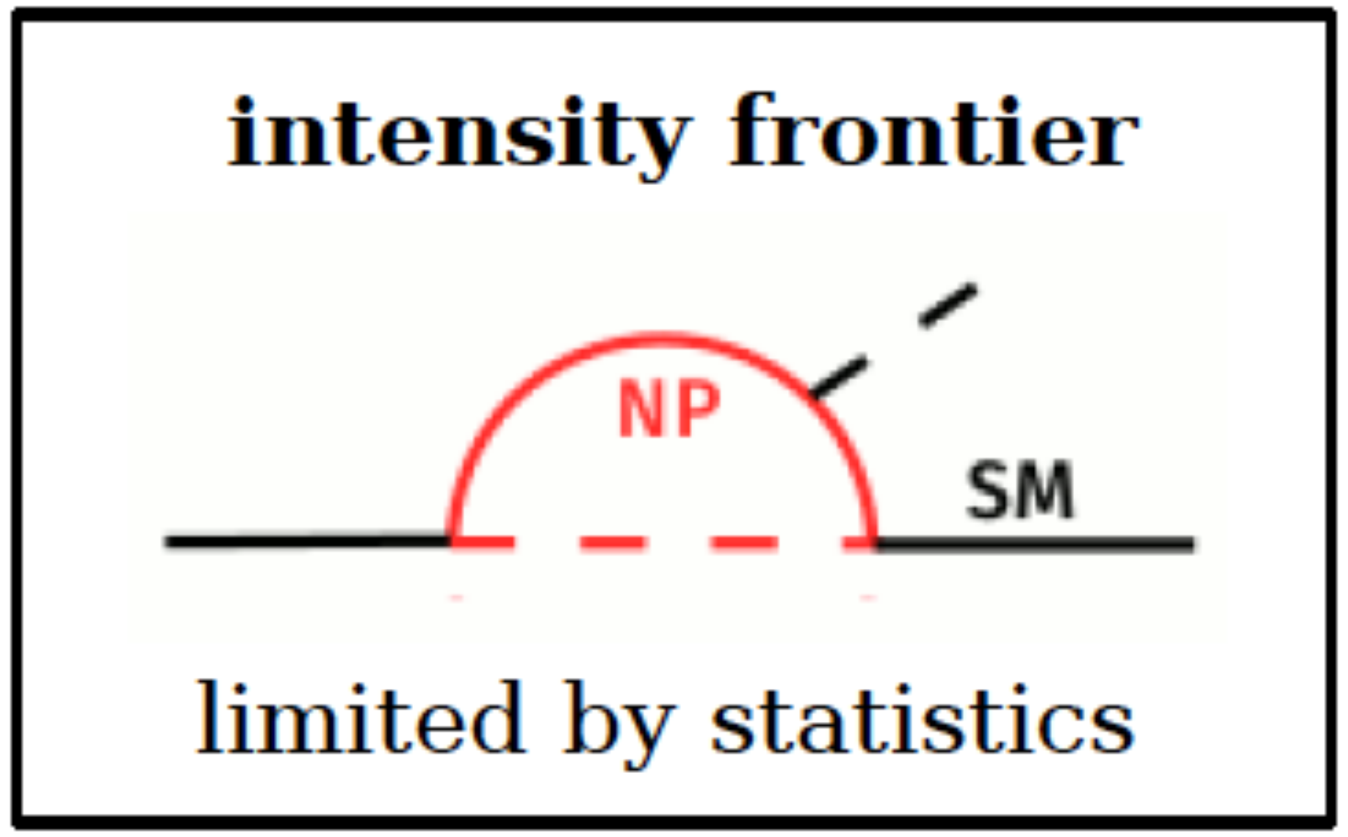
- Why do neutrinos have mass?
- What is dark matter?
- Why is there so much matter in the universe?
- Why is the expansion of the universe accelerating?
- Is there a particle associated with the force of gravity?

# B physics

- <u>Why do neutrinos have mass?</u>
- <u>What is dark matter?</u> *Light invisible particles*
- <u>**Why is there so much matter in the universe?**</u> *Matter-antimatter asymmetry can be explained with the CP violation (Sakharov conditions)*

Indirect searches for new physics: SM anomalies



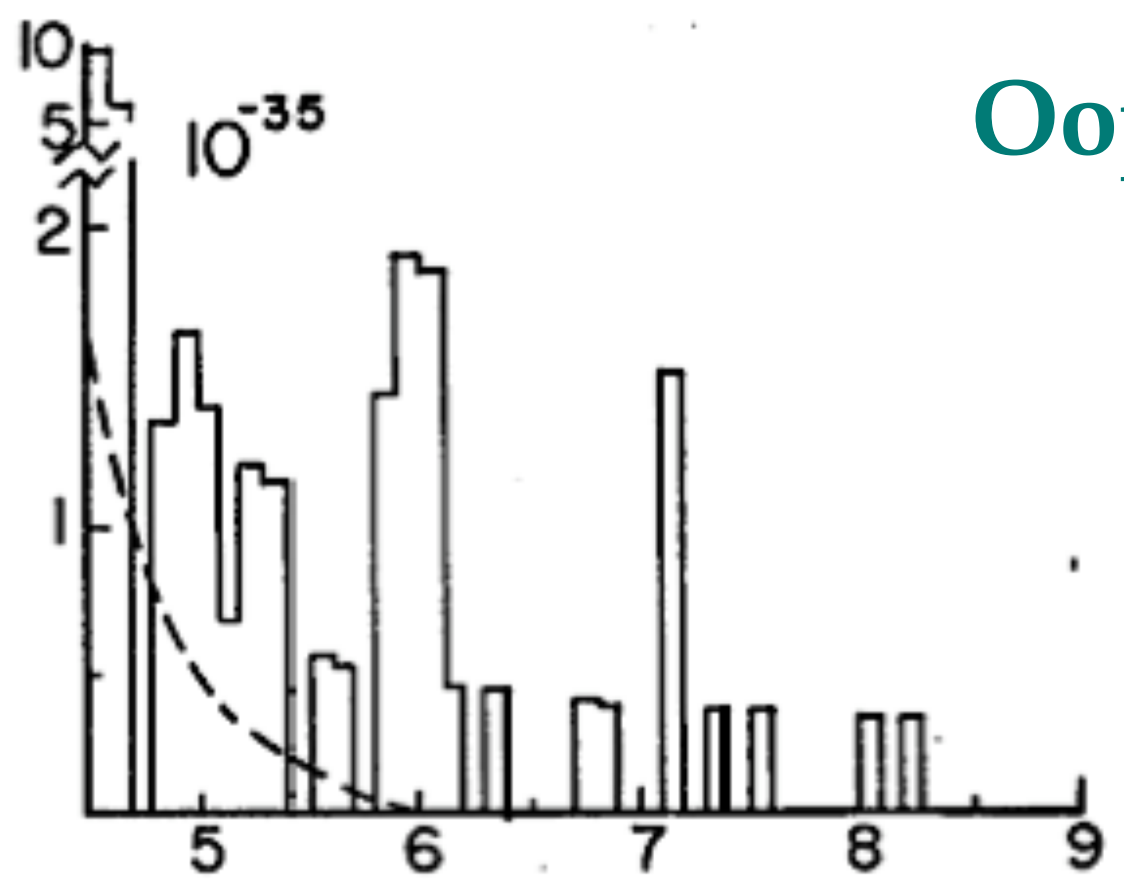




probe new physics at multi-TeV scale in a indirect way

Very massive particles produced in loops

# Discovery of Υ(4S)

## Bound state $\bar{b}b$




Oops-Leon

https://en.wikipedia.org/wiki/Oops-Leon

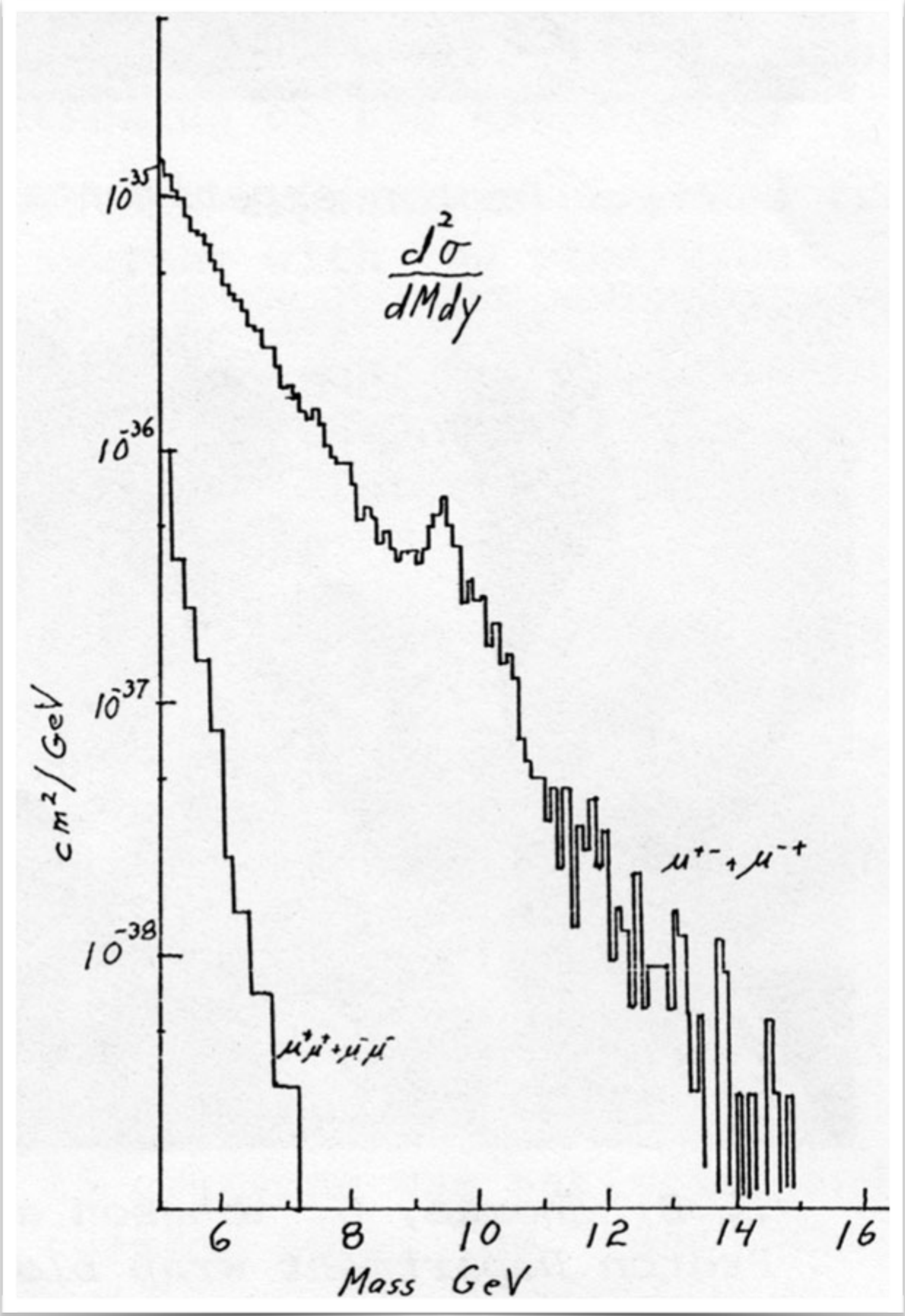
1976 E288 Experiment, Leon Lederman claimed a new particle with m~ 6 GeV, and named it Υ

After collecting more data the peak disappeared

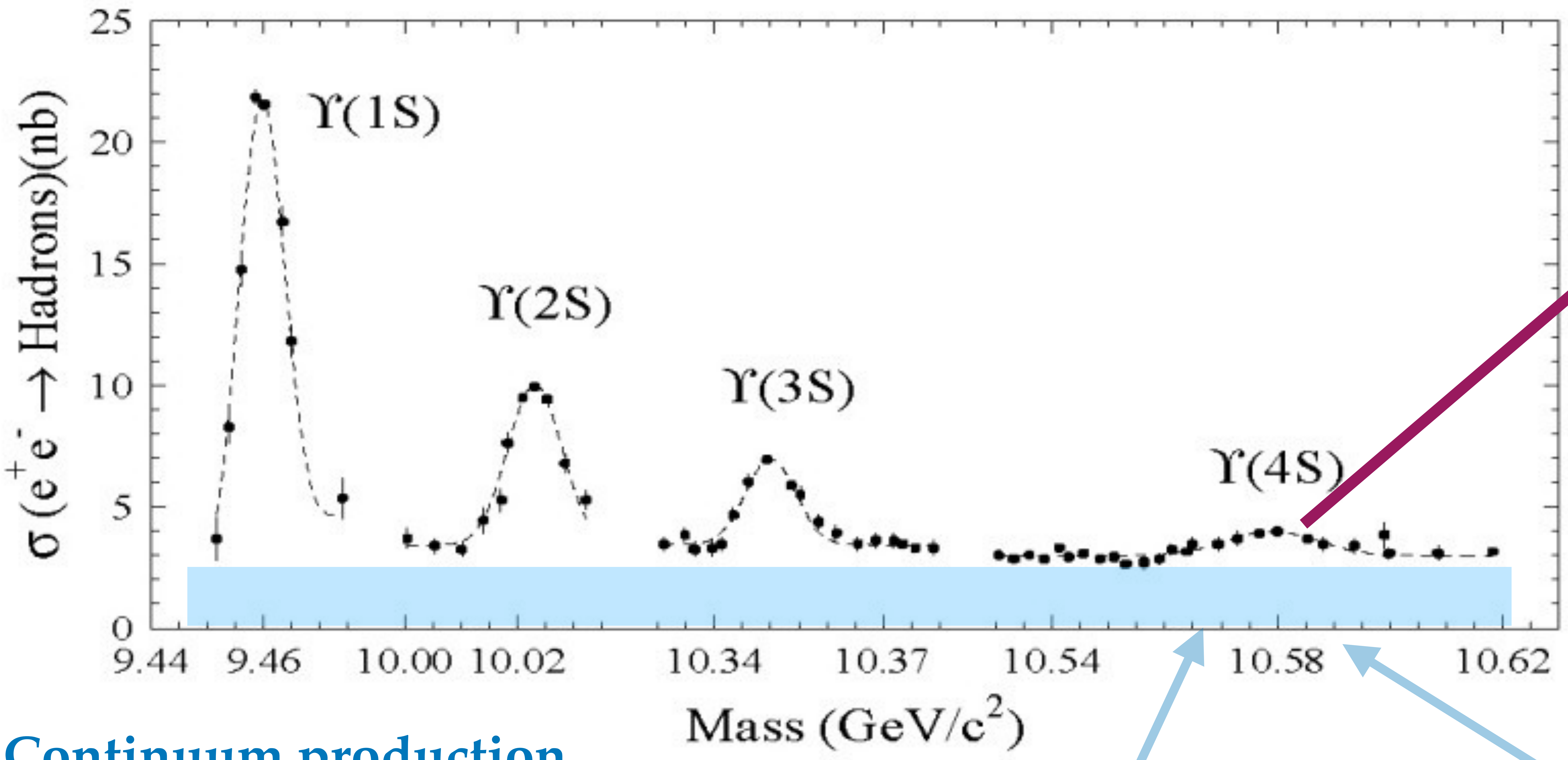
In 1977 a new peak appeared at ~ 9.5 GeV. The name Υ was used again

**Leon Lederman:**

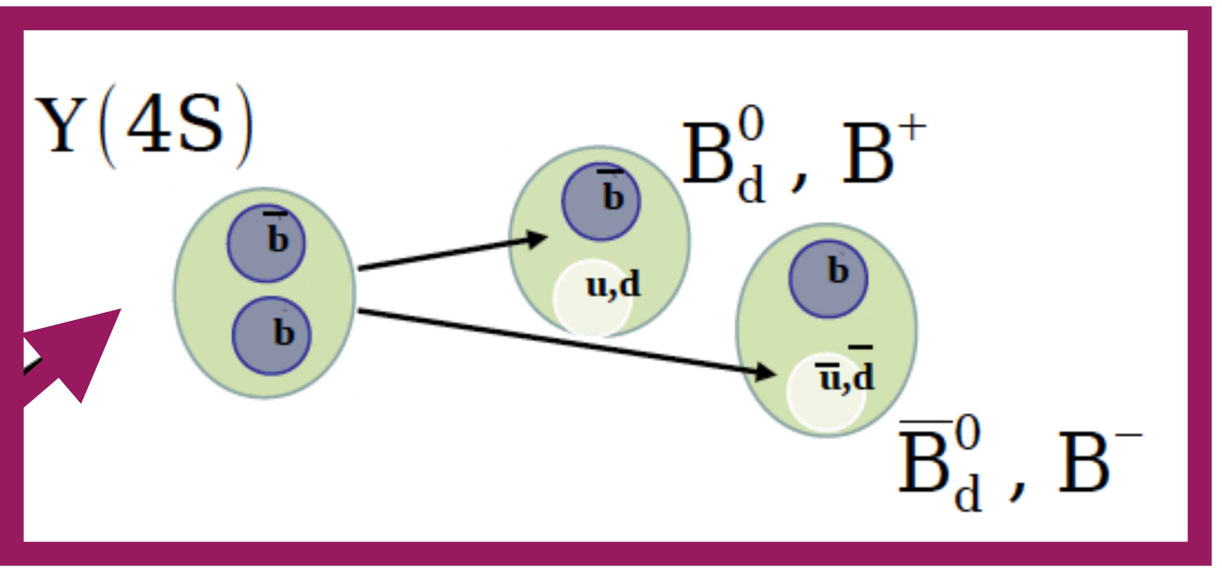
*The Upsilon fits very nicely into the picture of a super-atom consisting of the bound state of a bottom quark and antiquark*

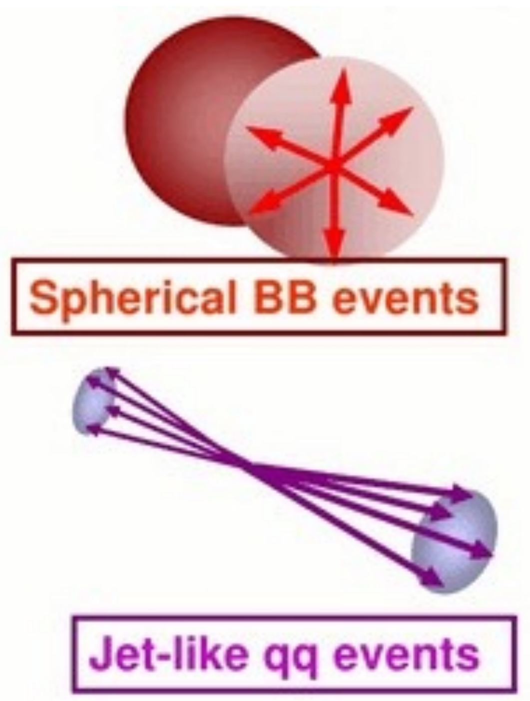


# Υ(4S)

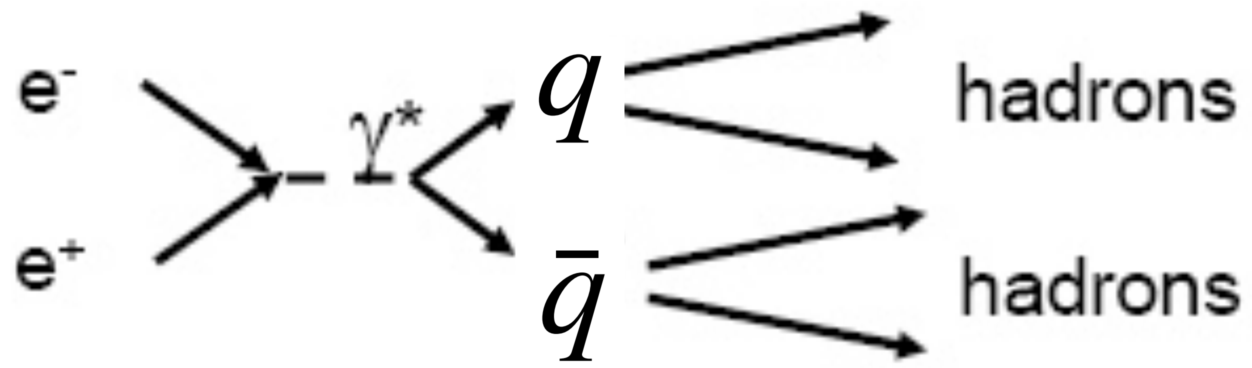



## On-resonance production




## Continuum production

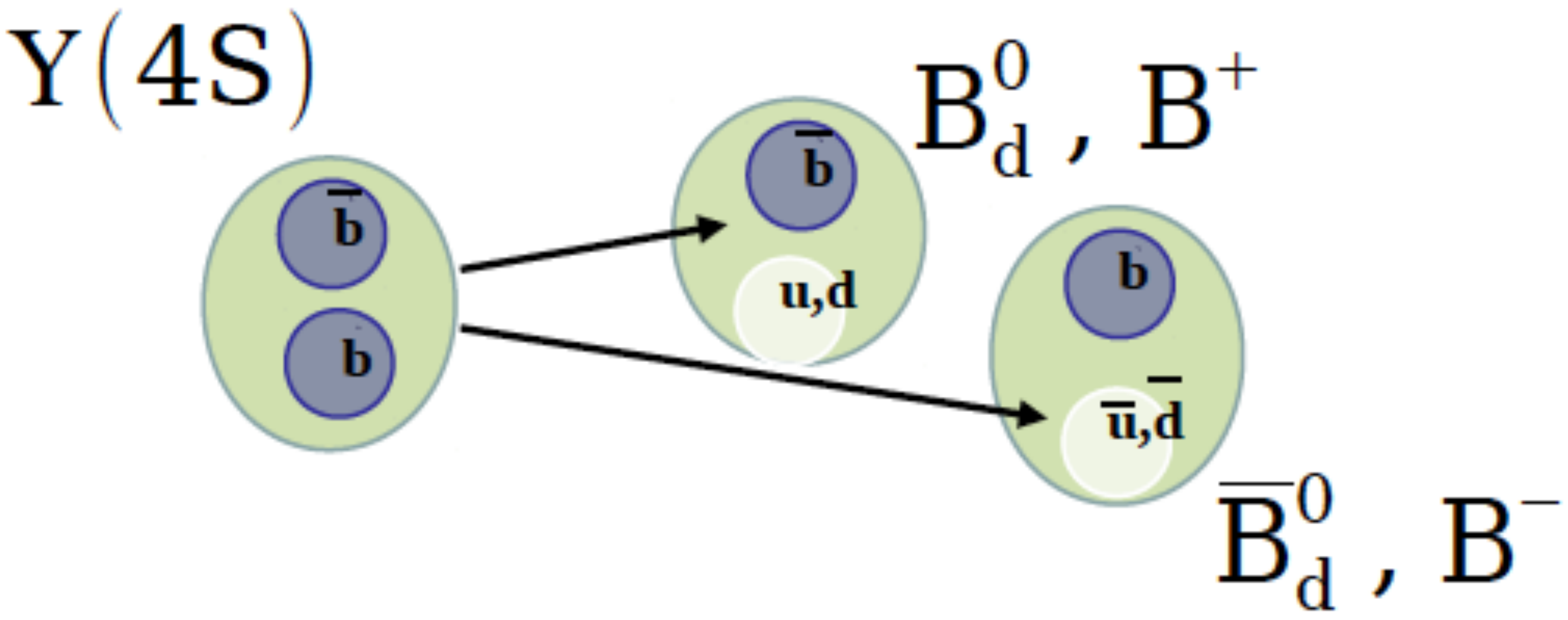



$\sigma(e^+e^- \to c\bar{c}) = 1.3$ **nb**
$\sigma(e^+e^- \to s\bar{s}) = 0.4$ **nb**
$\sigma(e^+e^- \to u\bar{u}) = 1.6$ **nb**
$\sigma(e^+e^- \to d\bar{d}) = 0.4$ **nb**

$\sigma(e^+e^- \to \tau^+\tau^-) = 1$ **nb**
$\sigma(e^+e^- \to \mu^+\mu^-) = 1$ **nb** **(calibration)**
$\sigma(e^+e^- \to e^+e^-) \sim 100$ **nb** **(luminosity)**

# $\Upsilon(4S)$= Y(10580): B factory

## On-resonance production




$$e^+e^- \rightarrow Y(4S) \rightarrow B_d^0\bar{B}_d^0, B^+B^-$$

$$\sigma(e^+e^- \rightarrow B\bar{B}) \sim 1.1 \text{ nb}$$

at $\Upsilon(4S)$ energies

- ☑ **2 B mesons and nothing else**
- ☑ **The 2 Bs are created simultaneously in a L=1 coherent status:**
  This makes it easier than in hadron collisions to infer the charge state of one B meson from observation of the other

# Why do we need high luminosity?

1 barn = $10^{24}cm^2$

Number of collision events per second = Luminosity × Cross section of the reaction

Example: Integrated luminosity: $1\ fb^{-1} = 10^{15} b^{-1} = 10^{6} nb^{-1}$ Cross section: $\sigma = 1 nb = 10^{-6} fb$ → N= 1M

Number of decay events per second = Luminosity × Cross section of the reaction × Branching ratio Of the decay

For rare decays this is very small

# BelleII Luminosity

**Peak luminosity**

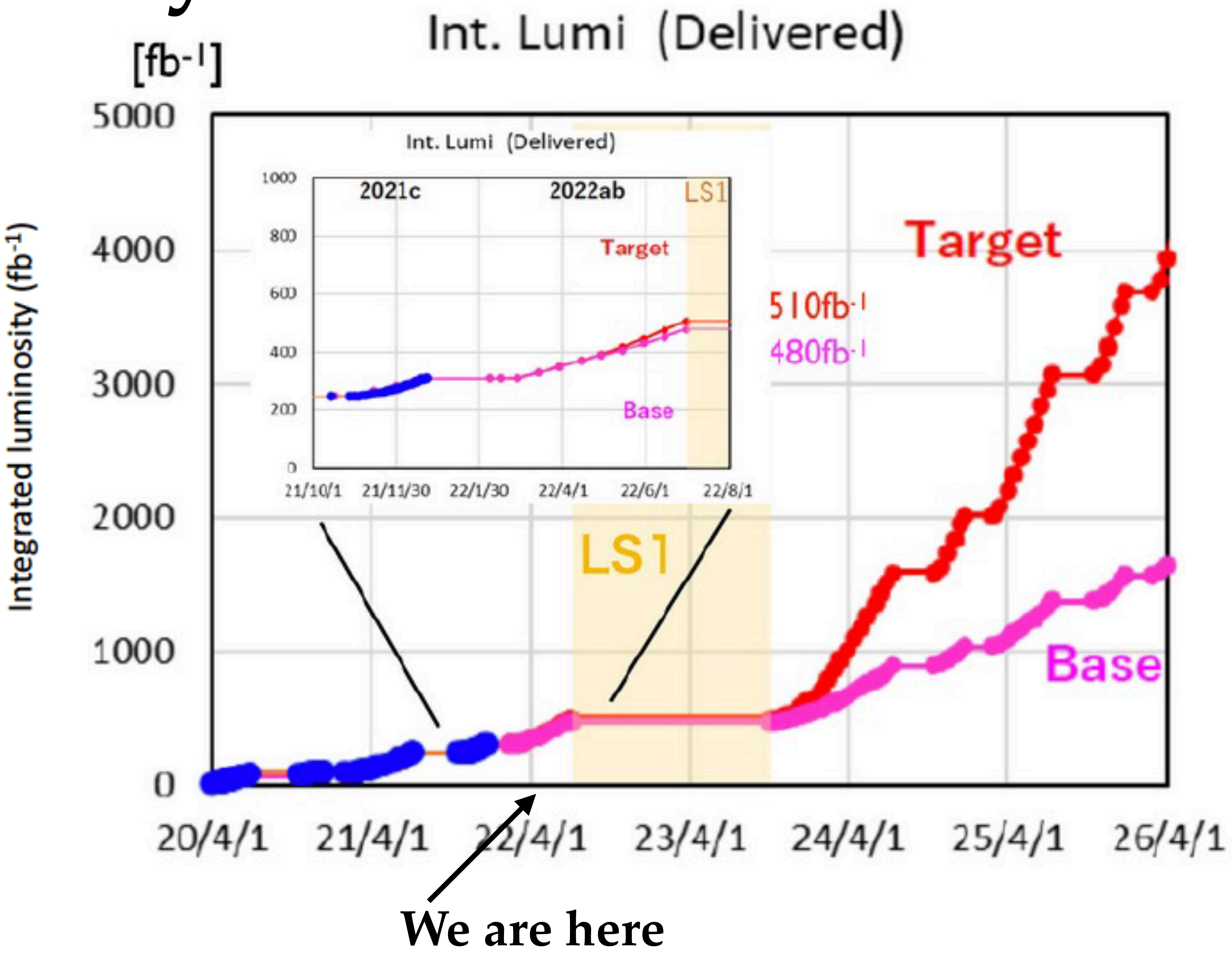
$$\mathscr{L}_{peak} = 3.81 \times 10^{34} cm^{-2} s^{-1}$$

**December 2021**

$$\mathscr{L}^{expected}_{peak} \sim 2 \times 10^{35} cm^{-2} s^{-1}$$

**Long Shutdown 1 (LS1)**

**July 2022- Oct 2023**

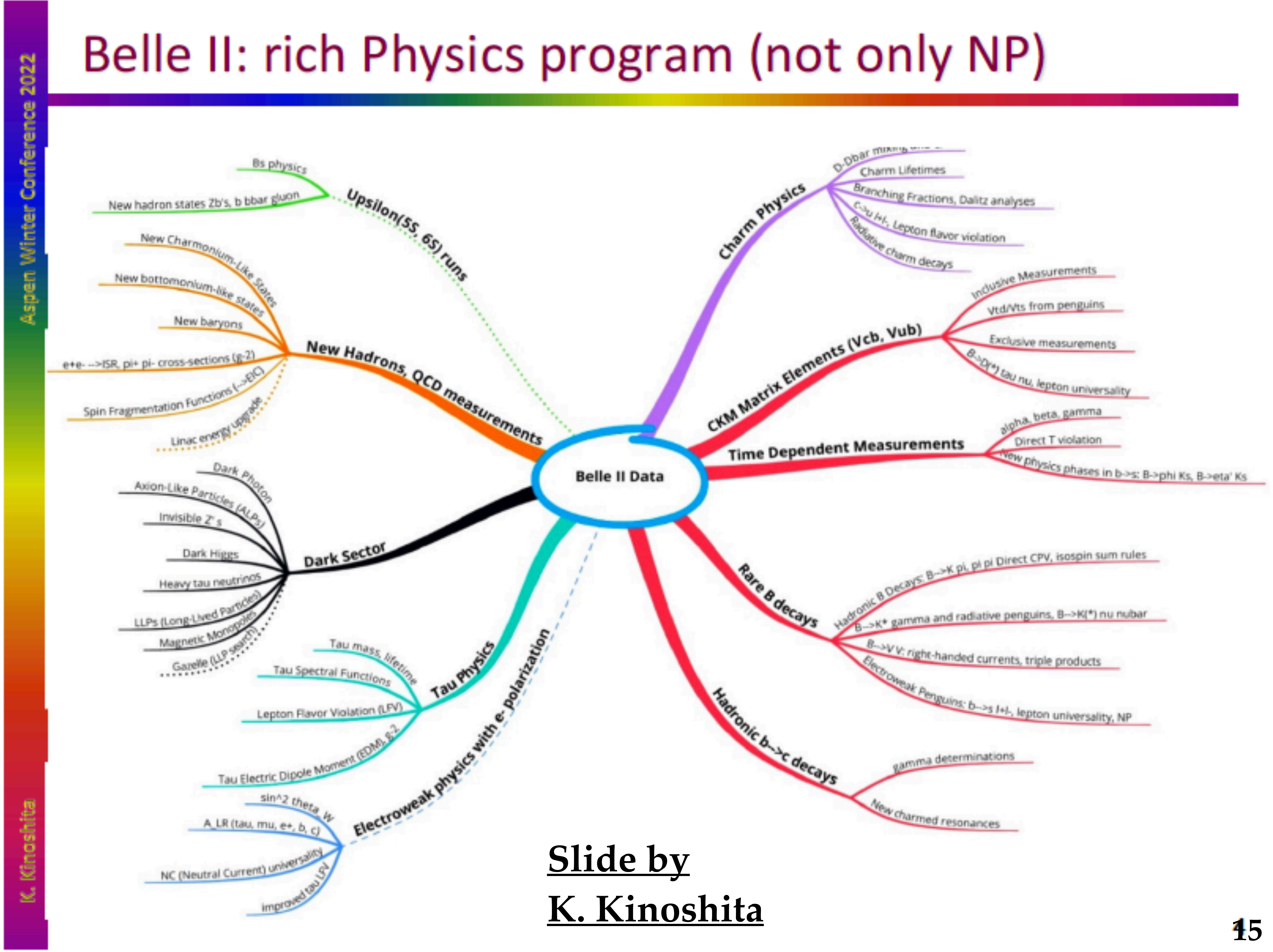


**Main motivation of B-physics**

- Origin of the generations and role of the flavor
- CP violation and baryon asymmetry

Indirect searches for new physics: SM anomalies

BelleII will probe new physics at multi-TeV scale in a indirect way



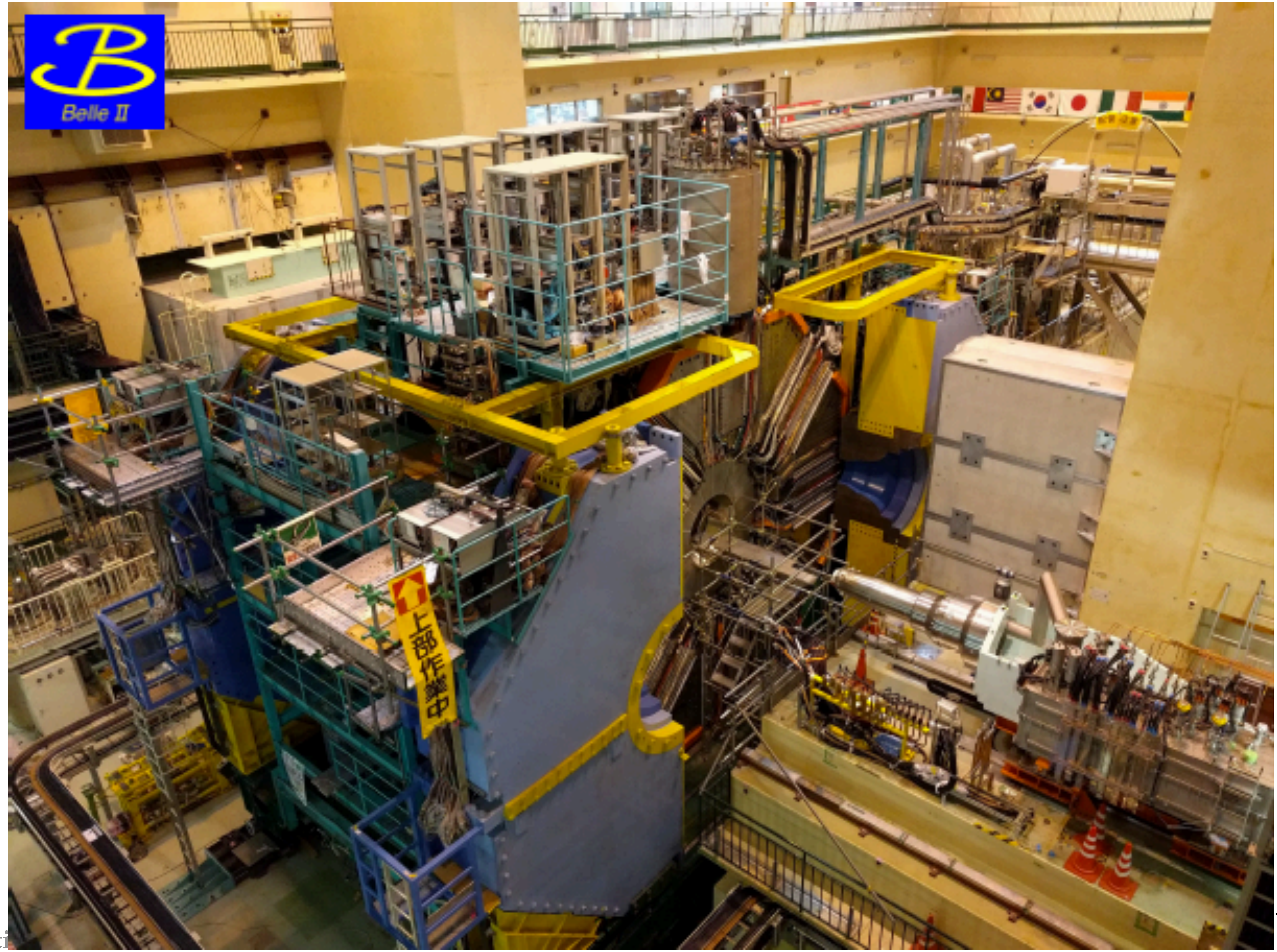

**Slide by K. Kinoshita**

# BelleII physics

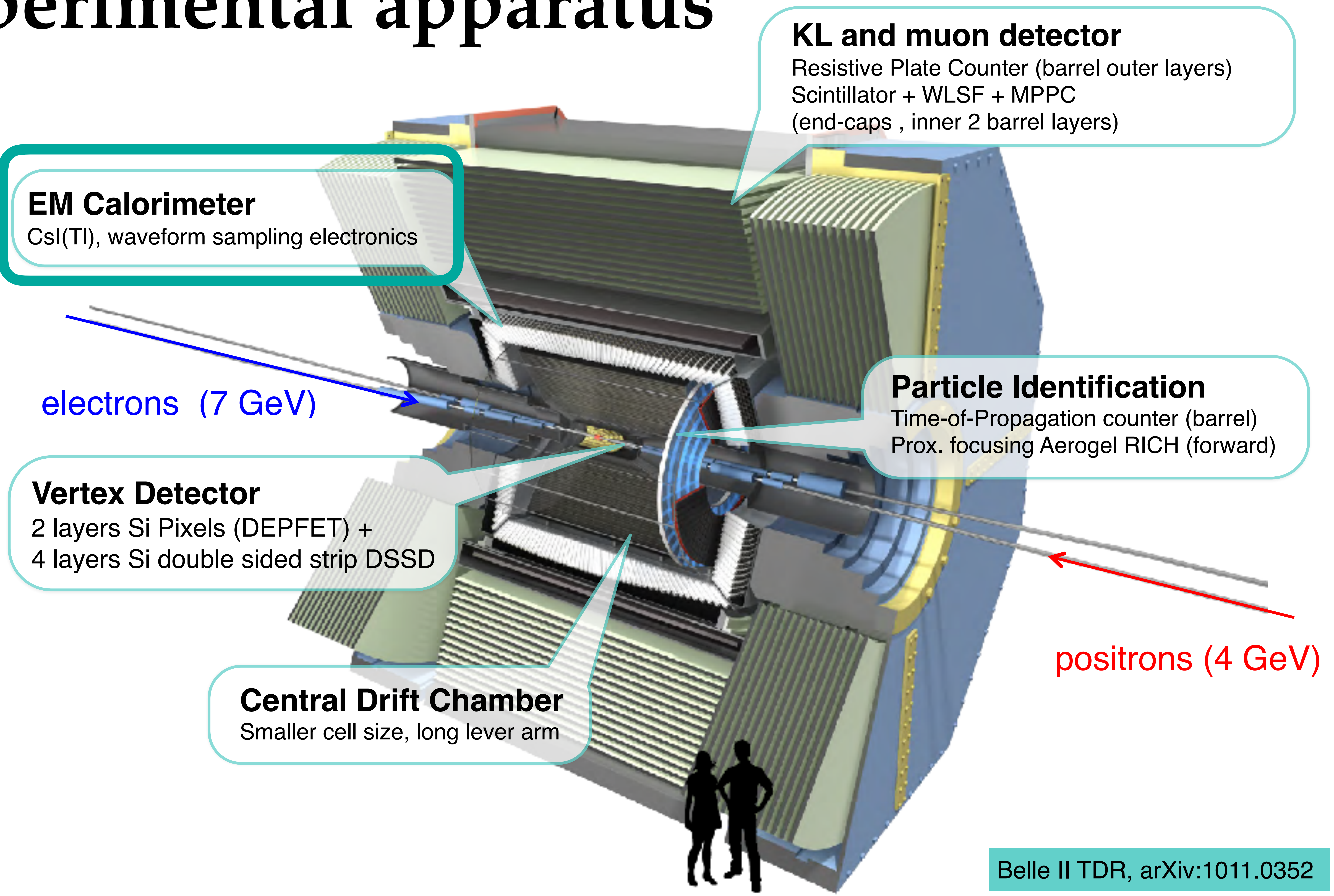
- Belle II (2019- )
  - 189.3 $fb^{-1}$ ≈190M **Public results to date**
  - to date: ≈290 M collected; ultimate goal = 50G (>100X)
  - published /submitted physics results so far
    - Integrated luminosity [Chinese Physics C 44, 021001 (2020)]
    - search for invisible Z' [PRL 124, 141801 (2020)]
    - search for Axion-like [PRL 125, 161806 (2020)]
    - search for $K\nu\bar{\nu}$ [PRL 127, 181802 (2021)] **(Inclusive tag)**
    - $D^0$ and $D^+$ lifetimes [PRL 127, 211801 (2021)]
    - Belle+Belle II, CKM angle $\varphi_3$ [JHEP 02 2022, 063 (2022)]

→ **Already nice results on the hidden sector**

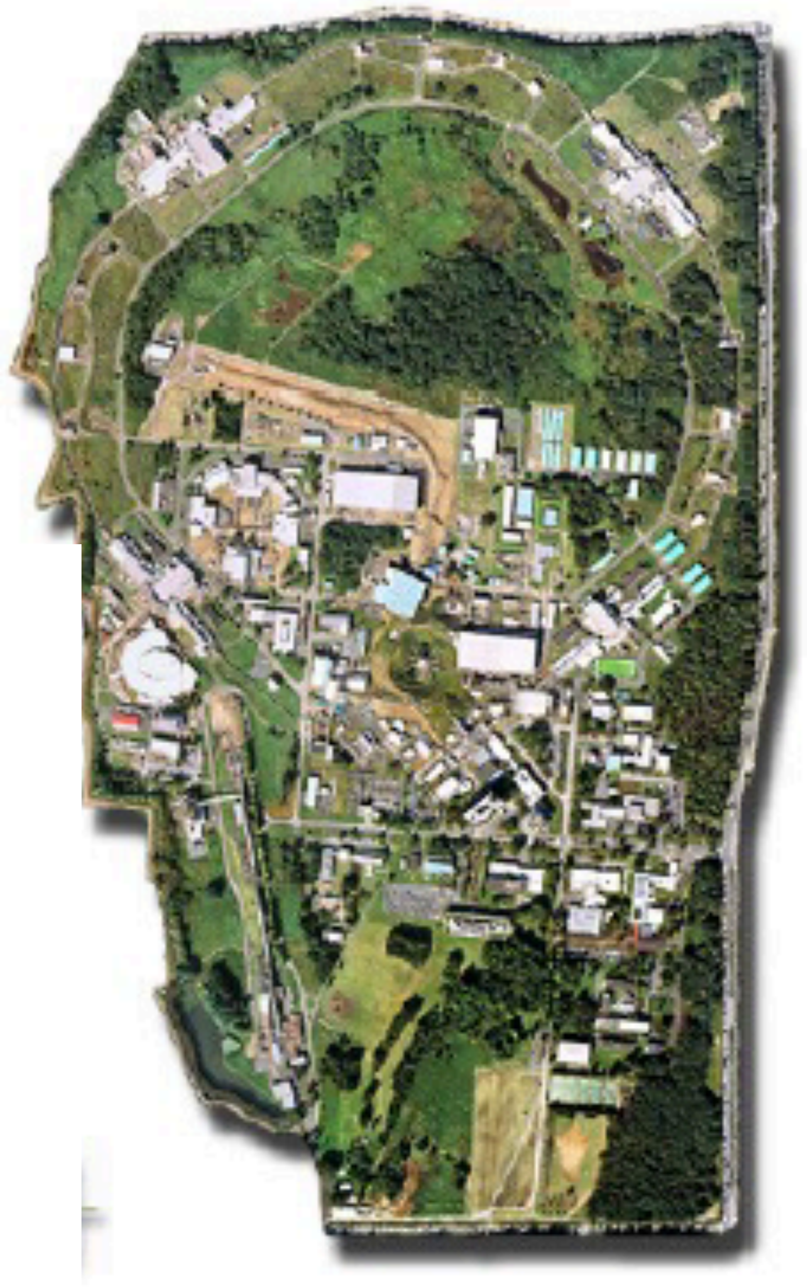
# BelleII



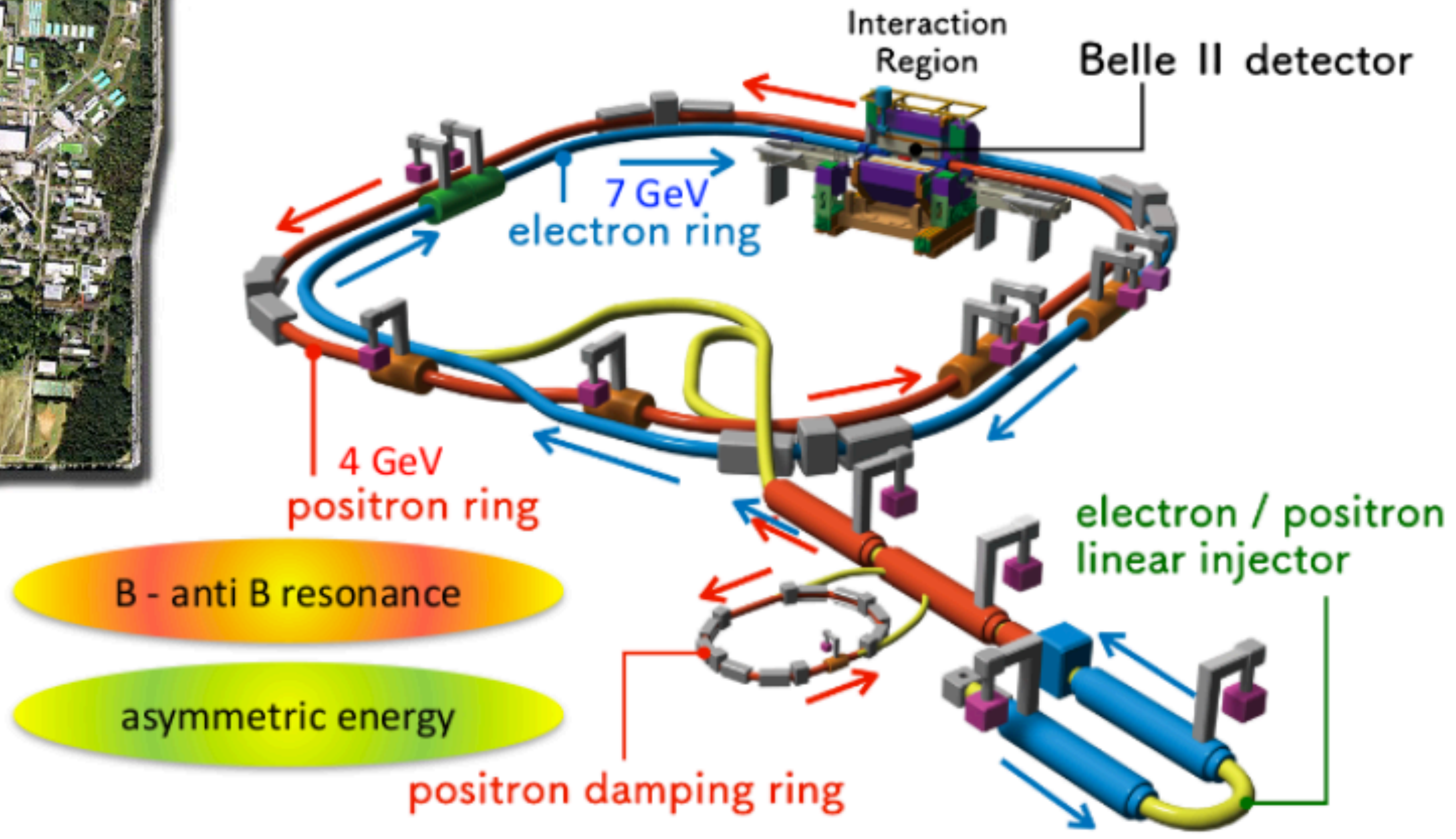
# BelleII experimental apparatus



# $e^+e^-$ collisions



SuperKEKB accelerator complex

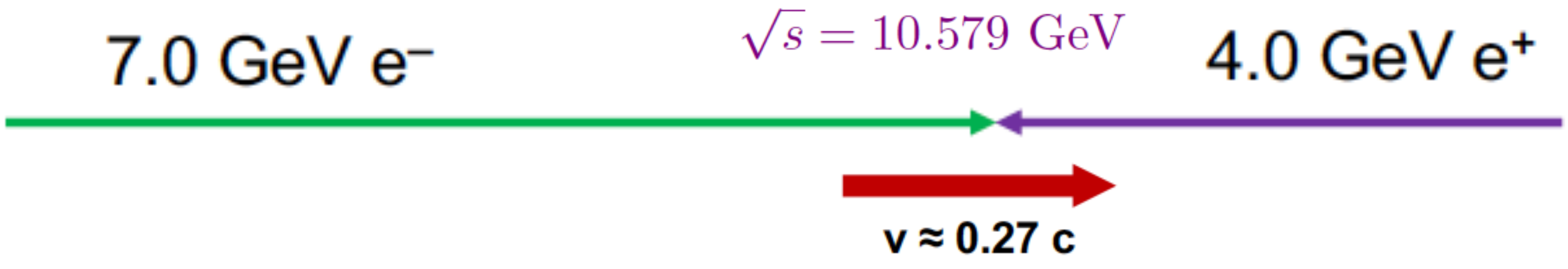



The B are very slow in the $\Upsilon(4S)$ rest frame
A boost is needed to give momentum to the decay products to allow time-dependent measurements that are crucial for the study of CP violation

**Asymmetric beams**

$KEKB : \beta\gamma = 0.43$

$SuperKEKB : \beta\gamma = 0.28$



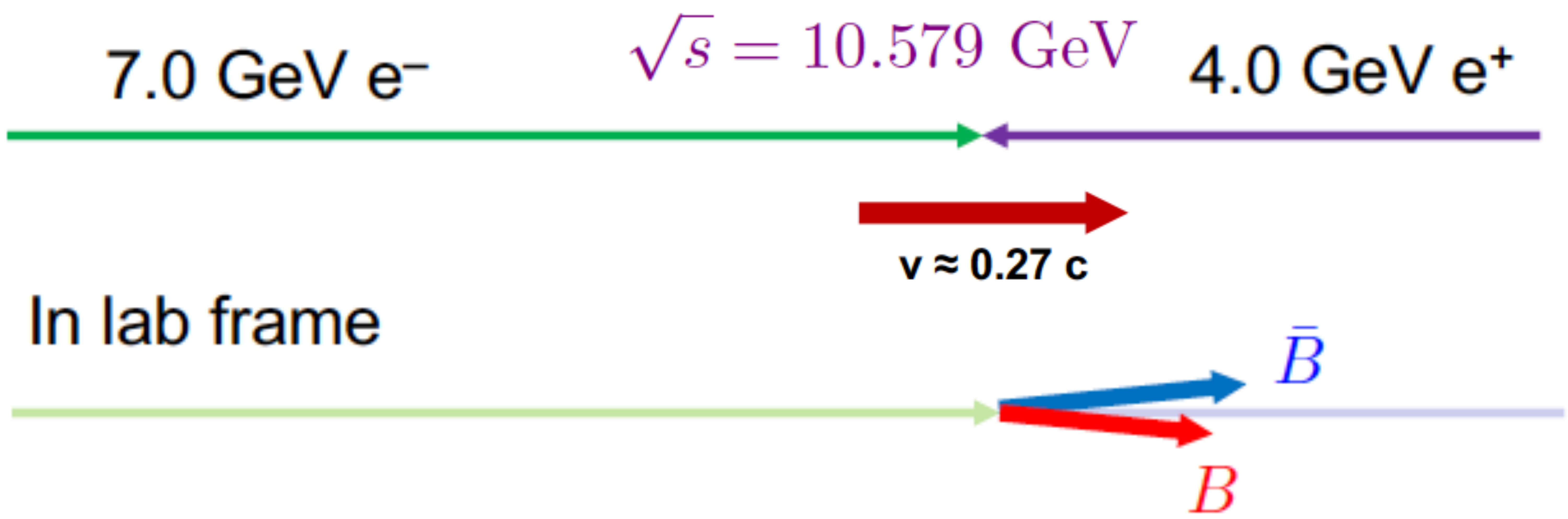
# Thousands of possible decay chains

**$K$ or $K^*$ modes**

| | | | |
|---|---|---|---|
| $K^0\pi^+$ | $(2.37 \pm 0.08)\times10^{-5}$ | | 2614 |
| $K^+\pi^0$ | $(1.29 \pm 0.05)\times10^{-5}$ | | 2615 |
| $\eta' K^+$ | $(7.04 \pm 0.25)\times10^{-5}$ | | 2528 |
| $\eta' K^*(892)^+$ | $(4.8\ ^{+1.8}_{-1.6})\times10^{-6}$ | | 2472 |
| $\eta' K_0^*(1430)^+$ | $(5.2 \pm 2.1)\times10^{-6}$ | | – |
| $\eta' K_2^*(1430)^+$ | $(2.8 \pm 0.5)\times10^{-5}$ | | 2346 |
| $\eta K^+$ | $(2.4 \pm 0.4)\times10^{-6}$ | S=1.7 | 2588 |
| $\eta K$ | | | |
| $\eta K$ | | | |
| $\eta K$ | | | |
| $\eta($ | | | |
| $\eta($ | | | |

**Light unflavored meson modes**

| | | | |
|---|---|---|---|
| $\rho^+\gamma$ | $(9.8 \pm 2.5)\times10^{-7}$ | | 2583 |
| $\pi^+\pi^0$ | $(5.5 \pm 0.4)\times10^{-6}$ | S=1.2 | 2636 |
| $\pi^+\pi^+\pi^-$ | $(1.52 \pm 0.14)\times10^{-5}$ | | 2630 |
| $\rho^0\pi^+$ | $(8.3 \pm 1.2)\times10^{-6}$ | | 2581 |
| $\pi^+ f_0(980),\ f_0 \to \pi^+\pi^-$ | $< 1.5\times10^{-6}$ | CL=90% | 2545 |
| $\pi^+ f_2(1270)$ | $(2.2\ ^{+0.7}_{-0.4})\times10^{-6}$ | | 2484 |
| $\rho(1450)^0\pi^+,\ \rho^0 \to \pi^+\pi^-$ | $(1.4\ ^{+0.6}_{-0.9})\times10^{-6}$ | | 2434 |




**$D$, $D^*$, or $D_s$ modes**

| | | | | |
|---|---|---|---|---|
| $\overline{D}^0\pi^+$ | | $(4.68 \pm 0.13)\times10^{-3}$ | | 2308 |
| $D_{CP(+1)}\pi^+$ | [nnn] | $(2.05 \pm 0.18)\times10^{-3}$ | | – |
| $D_{CP(-1)}\pi^+$ | [nnn] | $(2.0 \pm 0.4)\times10^{-3}$ | | – |
| $\overline{D}^0\rho^+$ | | $(1.34 \pm 0.18)$ % | | 2237 |
| $\overline{D}^0 K^+$ | | $(3.63 \pm 0.12)\times10^{-4}$ | | 2281 |
| $D_{CP(+1)}K^+$ | [nnn] | $(1.80 \pm 0.07)\times10^{-4}$ | | – |
| $D_{CP(-1)}K^+$ | [nnn] | $(1.96 \pm 0.18)\times10^{-4}$ | | – |
| $D^0 K^+$ | | $(3.57 \pm 0.35)\times10^{-6}$ | | 2281 |
| $[K^-\pi^+]_D K^+$ | [ooo] | $< 2.8\times10^{-7}$ | CL=90% | – |
| $[K^+\pi^-]_D K^+$ | [ooo] | $< 1.5\times10^{-5}$ | CL=90% | – |
| $[K^-\pi^+]_D \pi^+$ | [ooo] | $(6.3 \pm 1.1)\times10^{-7}$ | | – |
| $[K^+\pi^-]_D \pi^+$ | | $(1.78 \pm 0.32)\times10^{-4}$ | | – |
| $[\pi^+\pi^-\pi^0]_D K^-$ | | $(4.6 \pm 0.9)\times10^{-6}$ | | – |
| $\overline{D}^0 K^*(892)^+$ | | $(5.3 \pm 0.4)\times10^{-4}$ | | 2213 |
| $D_{CP(-1)}K^*(892)^+$ | [nnn] | $(2.7 \pm 0.8)\times10^{-4}$ | | – |
| $D_{CP(+1)}K^*(892)^+$ | [nnn] | $(6.2 \pm 0.7)\times10^{-4}$ | | – |
| $D^0 K^*(892)^+$ | | $(3.1 \pm 1.6)\times10^{-6}$ | | 2213 |
| $\overline{D}^0 K^+\pi^+\pi^-$ | | $(5.2 \pm 2.1)\times10^{-4}$ | | 2237 |
| $\overline{D}^0 K^+\overline{K}^0$ | | $(5.5 \pm 1.6)\times10^{-4}$ | | 2189 |

**Charmonium modes**

| | | | |
|---|---|---|---|
| $\eta_c K^+$ | $(1.06 \pm 0.09)\times10^{-3}$ | S=1.2 | 1751 |
| $\eta_c K^+,\ \eta_c \to K_S^0 K^\mp\pi^\pm$ | $(2.7 \pm 0.6)\times10^{-5}$ | | – |
| $\eta_c K^*(892)^+$ | $(1.1\ ^{+0.5}_{-0.4})\times10^{-3}$ | | 1646 |
| $\eta_c K^+\pi^+\pi^-$ | $< 3.9\times10^{-4}$ | CL=90% | 1684 |
| $\eta_c K^+\omega(782)$ | $< 5.3\times10^{-4}$ | CL=90% | 1475 |
| $\eta_c K^+\eta$ | $< 2.2\times10^{-4}$ | CL=90% | 1588 |
| $\eta_c K^+\pi^0$ | $< 6.2\times10^{-5}$ | CL=90% | 1723 |
| $\eta_c(2S)K^+$ | $(4.4 \pm 1.0)\times10^{-4}$ | | 1320 |
| $\eta_c(2S)K^+,\ \eta_c \to p\overline{p}$ | $(3.5 \pm 0.8)\times10^{-8}$ | | – |
| $\eta_c(2S)K^+,\ \eta_c \to K_S^0 K^\mp\pi^\pm$ | $(3.4\ ^{+2.3}_{-1.6})\times10^{-6}$ | | – |
| $\eta_c(2S)K^+,\ \eta_c \to p\overline{p}\pi^+\pi^-$ | $(1.12 \pm 0.18)\times10^{-6}$ | | – |
| $h_c(1P)K^+,\ h_c \to J/\psi\pi^+\pi^-$ | $< 3.4\times10^{-6}$ | CL=90% | 1401 |
| $X(3730)^0 K^+,\ X^0 \to \eta_c\eta$ | $< 4.6\times10^{-5}$ | CL=90% | – |
| $X(3730)^0 K^+,\ X^0 \to \eta_c\pi^0$ | $< 5.7\times10^{-6}$ | CL=90% | – |
| $\chi_{c1}(3872)K^+$ | $< 2.6\times10^{-4}$ | CL=90% | 1141 |
| $\chi_{c1}(3872)K^+,\ \chi_{c1} \to p\overline{p}$ | $< 5\times10^{-9}$ | CL=95% | – |
| $\chi_{c1}(3872)K^+,\ \chi_{c1} \to J/\psi\pi^+\pi^-$ | $(8.6 \pm 0.8)\times10^{-6}$ | | 1141 |
| $\chi_{c1}(3872)K^+,\ \chi_{c1} \to J/\psi\gamma$ | $(2.1 \pm 0.4)\times10^{-6}$ | S=1.1 | 1141 |

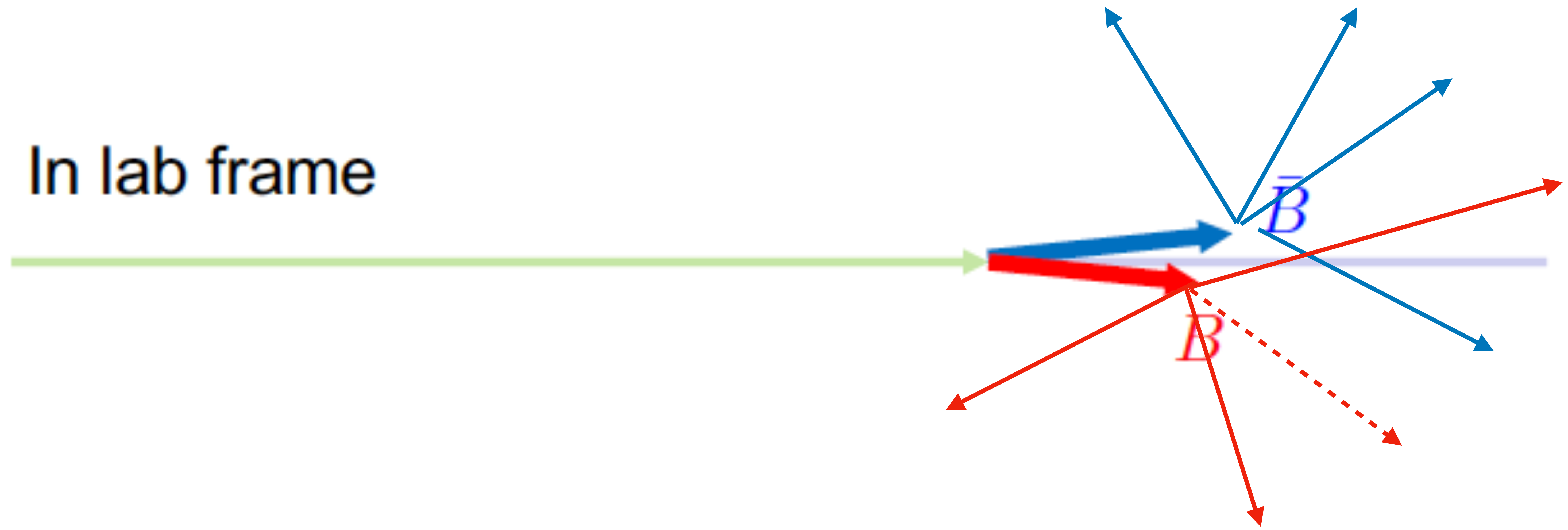
**$B^+$ DECAY MODES**

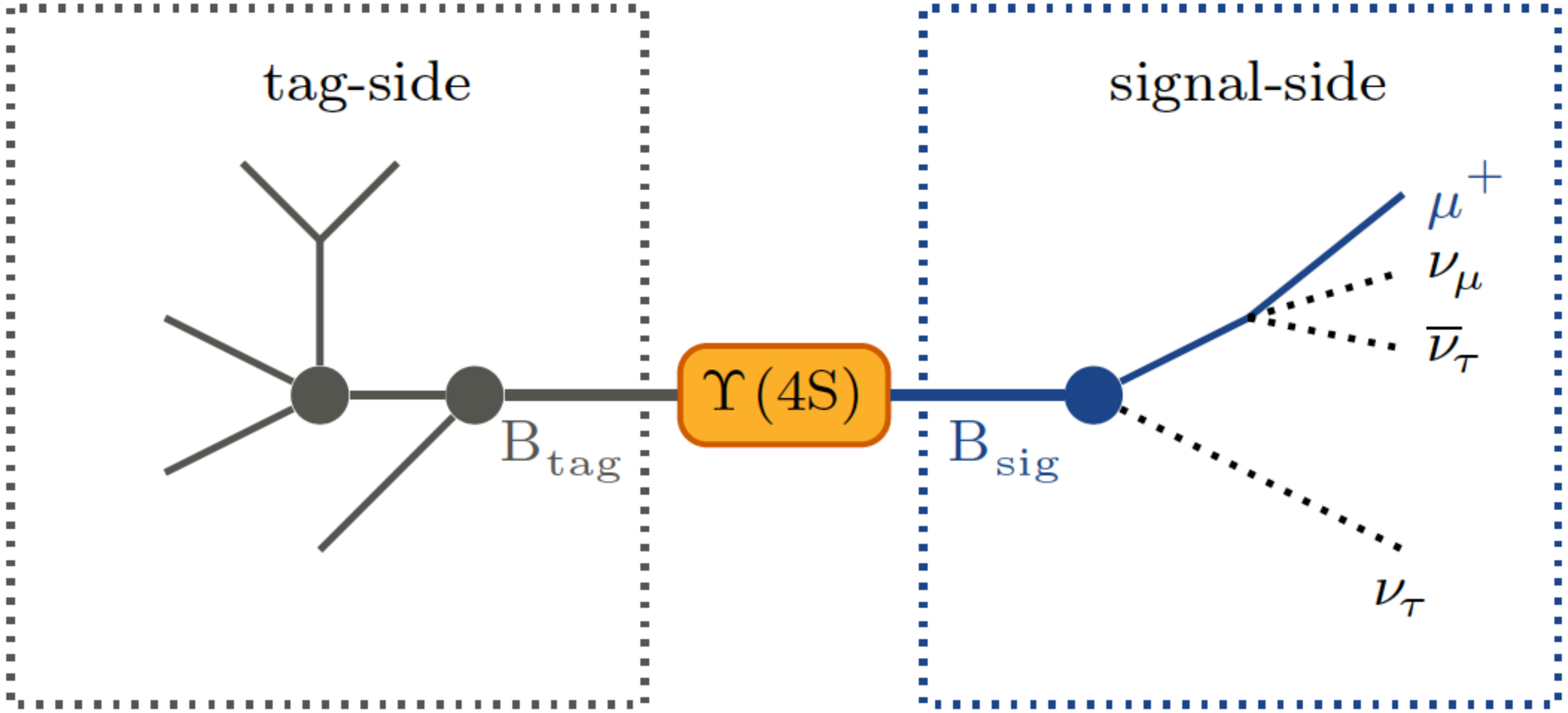
**Semileptonic and leptonic modes**

| Mode | | Fraction $(\Gamma_i/\Gamma)$ | Scale factor/ Confidence level | $p$ (MeV/c) |
|---|---|---|---|---|
| $\ell^+\nu_\ell X$ | [lll] | $(10.99 \pm 0.28)$ % | | – |
| $e^+\nu_e X_c$ | | $(10.8 \pm 0.4)$ % | | – |
| $D\ell^+\nu_\ell X$ | | $(9.7 \pm 0.7)$ % | | – |
| $\overline{D}^0\ell^+\nu_\ell$ | [lll] | $(2.35 \pm 0.09)$ % | | 2310 |
| $\overline{D}^0\tau^+\nu_\tau$ | | $(7.7 \pm 2.5)\times10^{-3}$ | | 1911 |
| $\overline{D}^*(2007)^0\ell^+\nu_\ell$ | [lll] | $(5.66 \pm 0.22)$ % | | 2258 |
| $\overline{D}^*(2007)^0\tau^+\nu_\tau$ | | $(1.88 \pm 0.20)$ % | | 1839 |
| $D^-\pi^+\ell^+\nu_\ell$ | | $(4.4 \pm 0.4)\times10^{-3}$ | | 2306 |
| $\overline{D}_0^*(2420)^0\ell^+\nu_\ell,\ \overline{D}_0^{*0} \to D^-\pi^+$ | | $(2.5 \pm 0.5)\times10^{-3}$ | | – |
| $\overline{D}_2^*(2460)^0\ell^+\nu_\ell,\ \overline{D}_2^{*0} \to D^-\pi^+$ | | $(1.53 \pm 0.16)\times10^{-3}$ | | 2065 |
| $D^{(*)}n\pi\ell^+\nu_\ell (n \geq 1)$ | | $(1.88 \pm 0.25)$ % | | – |
| $D^{*-}\pi^+\ell^+\nu_\ell$ | | $(6.0 \pm 0.4)\times10^{-3}$ | | 2254 |
| $\overline{D}_1(2420)^0\ell^+\nu_\ell,\ \overline{D}_1^0 \to D^{*-}\pi^+$ | | $(3.03 \pm 0.20)\times10^{-3}$ | | 2084 |
| $\overline{D}_1'(2430)^0\ell^+\nu_\ell,\ \overline{D}_1'^0 \to D^{*-}\pi^+$ | | $(2.7 \pm 0.6)\times10^{-3}$ | | – |
| $\overline{D}_2^*(2460)^0\ell^+\nu_\ell,\ \overline{D}_2^{*0} \to D^{*-}\pi^+$ | | $(1.01 \pm 0.24)\times10^{-3}$ | S=2.0 | 2065 |
| $\overline{D}^0\pi^+\pi^-\ell^+\nu_\ell$ | | $(1.7 \pm 0.4)\times10^{-3}$ | | 2301 |
| $\overline{D}^{*0}\pi^+\pi^-\ell^+\nu_\ell$ | | $(8 \pm 5)\times10^{-4}$ | | 2248 |
| $D_s^{(*)-}K^+\ell^+\nu_\ell$ | | $(6.1 \pm 1.0)\times10^{-4}$ | | – |
| $D_s^-K^+\ell^+\nu_\ell$ | | $(3.0\ ^{+1.4}_{-1.2})\times10^{-4}$ | | 2242 |
| $D_s^{*-}K^+\ell^+\nu_\ell$ | | $(2.9 \pm 1.9)\times10^{-4}$ | | 2185 |
| $\pi^0\ell^+\nu_\ell$ | | $(7.80 \pm 0.27)\times10^{-5}$ | | 2638 |
| $\eta\ell^+\nu_\ell$ | | $(3.9 \pm 0.5)\times10^{-5}$ | | 2611 |
| $\eta'\ell^+\nu_\ell$ | | $(2.3 \pm 0.8)\times10^{-5}$ | | 2553 |
| $\omega\ell^+\nu_\ell$ | [lll] | $(1.19 \pm 0.09)\times10^{-4}$ | | 2582 |
| $\rho^0\ell^+\nu_\ell$ | [lll] | $(1.58 \pm 0.11)\times10^{-4}$ | | 2583 |
| $p\overline{p}\ell^+\nu_\ell$ | | $(5.8\ ^{+2.6}_{-2.3})\times10^{-6}$ | | 2467 |
| $p\overline{p}\mu^+\nu_\mu$ | | $< 8.5\times10^{-6}$ | CL=90% | 2446 |
| $p\overline{p}e^+\nu_e$ | | $(8.2\ ^{+4.0}_{-3.3})\times10^{-6}$ | | 2467 |
| $e^+\nu_e$ | | $< 9.8\times10^{-7}$ | CL=90% | 2640 |
| $\mu^+\nu_\mu$ | | $2.90\times10^{-07}$ to $1.07\times10^{-06}$ | CL=90% | 2639 |
| $\tau^+\nu_\tau$ | | $(1.09 \pm 0.24)\times10^{-4}$ | S=1.2 | 2341 |
| $\ell^+\nu_\ell\gamma$ | | $< 3.0\times10^{-6}$ | CL=90% | 2640 |
| $e^+\nu_e\gamma$ | | $< 4.3\times10^{-6}$ | CL=90% | 2640 |
| $\mu^+\nu_\mu\gamma$ | | $< 3.4\times10^{-6}$ | CL=90% | 2639 |
| $\mu^+\mu^-\mu^+\nu_\mu$ | | $< 1.6\times10^{-8}$ | CL=95% | 2634 |

……. ……. …….

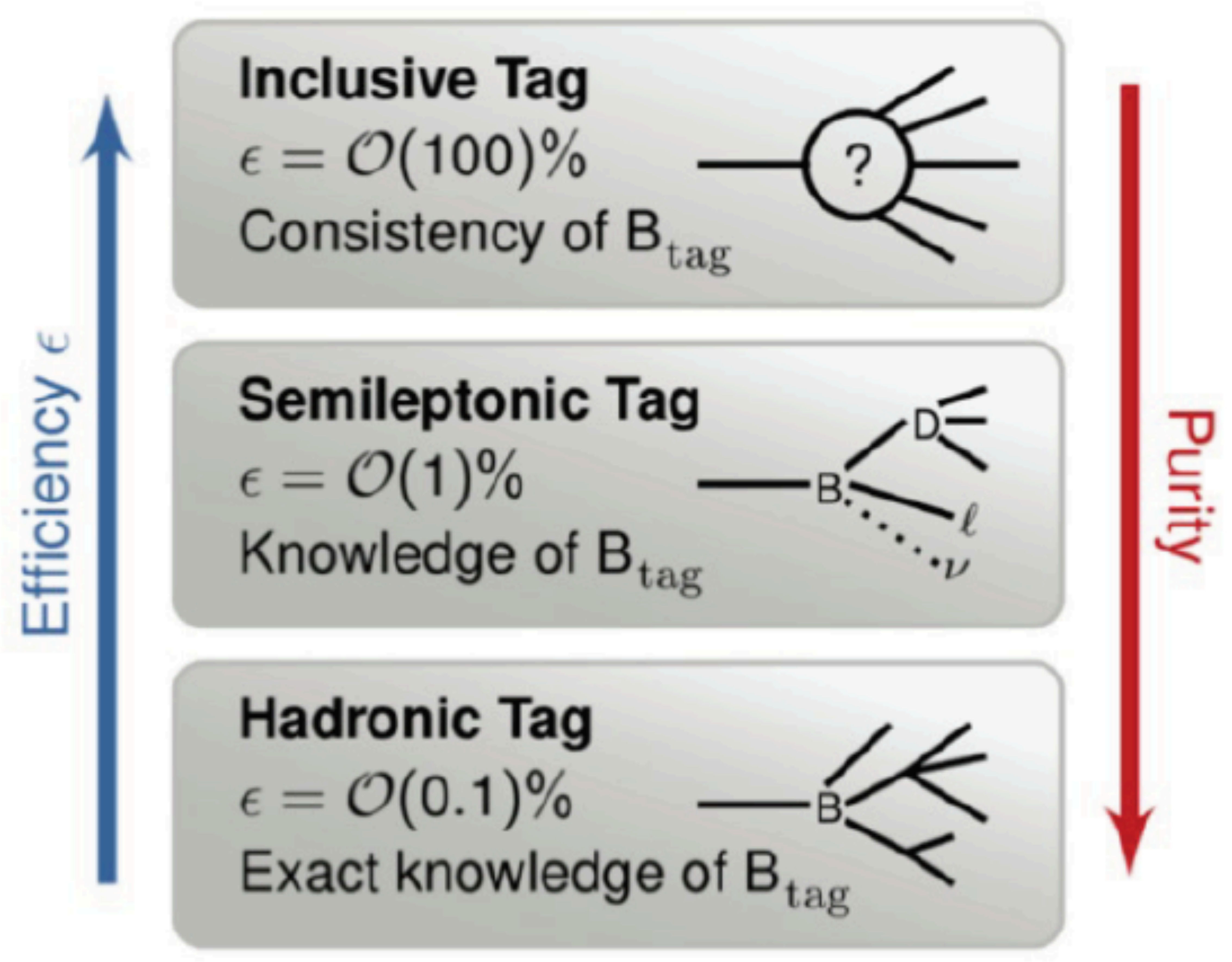
# Tagging strategy




**A precise knowledge of the energy momentum of one B (tagging B) allows to deduce the properties of the other B (signal B)**

# Tagging strategy




**In the CMS frame**

$$E_{\text{tag}} = \sum_{i,\text{tag}} E_i = E_{\text{beam}}$$

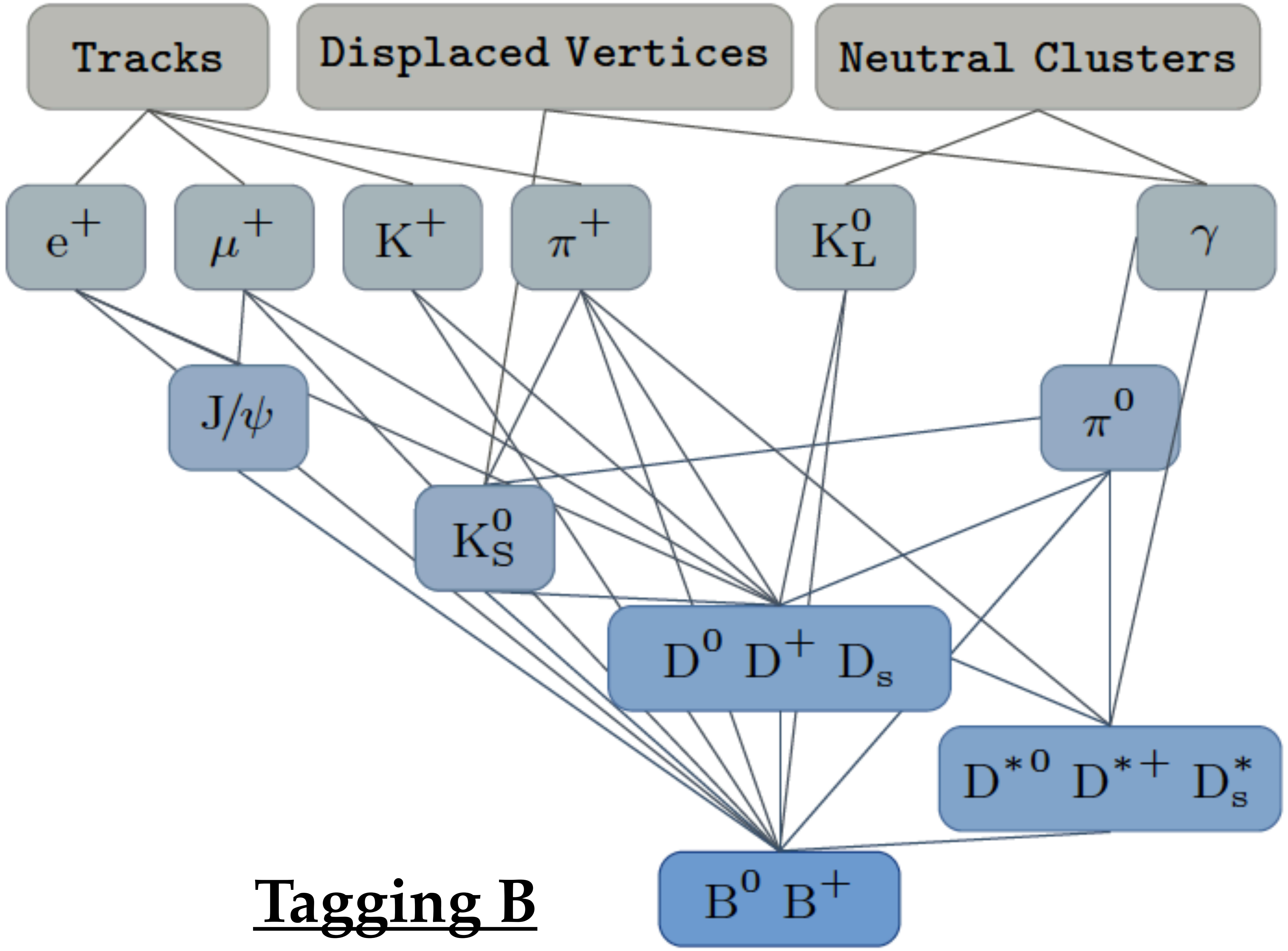
$$\vec{p}_{\text{tag}} = \sum_{i,\text{tag}} \vec{p}_i$$

→ Beam-constrained mass

$$M_{\text{bc}} = \sqrt{E^2_{\text{beam}} - \vec{p}^{\,2}_{\text{tag}}}$$

# Use of MVA

example from:
The Full Event Interpretation -
An exclusive tagging algorithm for the Belle II experiment
[arXiv:1807.08680](arXiv:1807.08680) [10.1007/s41781-019-0021-8](10.1007/s41781-019-0021-8)




**Tagging B**

Hadronic modes (examples)

**$D$, $D^*$, or $D_s$ modes**

| | | | | |
|---|---|---|---|---|
| $\overline{D}^0\pi^+$ | | $(4.68 \pm 0.13)\times10^{-3}$ | | 2308 |
| $D_{CP(+1)}\pi^+$ | [nnn] | $(2.05 \pm 0.18)\times10^{-3}$ | | – |
| $D_{CP(-1)}\pi^+$ | [nnn] | $(2.0 \pm 0.4)\times10^{-3}$ | | – |
| $\overline{D}^0\rho^+$ | | $(1.34 \pm 0.18)\%$ | | 2237 |
| $\overline{D}^0K^+$ | | $(3.63 \pm 0.12)\times10^{-4}$ | | 2281 |
| $D_{CP(+1)}K^+$ | [nnn] | $(1.80 \pm 0.07)\times10^{-4}$ | | – |
| $D_{CP(-1)}K^+$ | [nnn] | $(1.96 \pm 0.18)\times10^{-4}$ | | – |
| $D^0K^+$ | | $(3.57 \pm 0.35)\times10^{-6}$ | | 2281 |
| $[K^-\pi^+]_D K^+$ | [ooo] | $< 2.8 \times10^{-7}$ | CL=90% | – |
| $[K^+\pi^-]_D K^+$ | [ooo] | $< 1.5 \times10^{-5}$ | CL=90% | – |
| $[K^-\pi^+]_D \pi^+$ | [ooo] | $(6.3 \pm 1.1)\times10^{-7}$ | | – |
| $[K^+\pi^-]_D \pi^+$ | | $(1.78 \pm 0.32)\times10^{-4}$ | | – |
| $[\pi^+\pi^-\pi^0]_D K^-$ | | $(4.6 \pm 0.9)\times10^{-6}$ | | – |
| $\overline{D}^0K^*(892)^+$ | | $(5.3 \pm 0.4)\times10^{-4}$ | | 2213 |
| $D_{CP(-1)}K^*(892)^+$ | [nnn] | $(2.7 \pm 0.8)\times10^{-4}$ | | – |
| $D_{CP(+1)}K^*(892)^+$ | [nnn] | $(6.2 \pm 0.7)\times10^{-4}$ | | – |
| $D^0K^*(892)^+$ | | $(3.1 \pm 1.6)\times10^{-6}$ | | 2213 |
| $\overline{D}^0K^+\pi^+\pi^-$ | | $(5.2 \pm 2.1)\times10^{-4}$ | | 2237 |
| $\overline{D}^0K^+\overline{K}^0$ | | $(5.5 \pm 1.6)\times10^{-4}$ | | 2189 |
| $\overline{D}^0K^+\overline{K}^*(892)^0$ | | $(7.5 \pm 1.7)\times10^{-4}$ | | 2072 |
| $\overline{D}^0\pi^+\pi^+\pi^-$ | | $(5.6 \pm 2.1)\times10^{-3}$ | S=3.6 | 2289 |
| $\overline{D}^0\pi^+\pi^+\pi^-$ nonresonant | | $(5 \pm 4)\times10^{-3}$ | | 2289 |
| $\overline{D}^0\pi^+\rho^0$ | | $(4.2 \pm 3.0)\times10^{-3}$ | | 2208 |
| $\overline{D}^0 a_1(1260)^+$ | | $(4 \pm 4)\times10^{-3}$ | | 2123 |

- **Fully reconstruct the decay (Hadronic modes)**
- **Partially reconstruct the decay (Semileptonic modes)**

It reconstructs O(200) hadronic and semileptonic decay channels

# Perugia activities

- **Coordination of a physics group: Radiative and electroweak penguin B decays (Elisa Manoni)**

- **Data analysis**

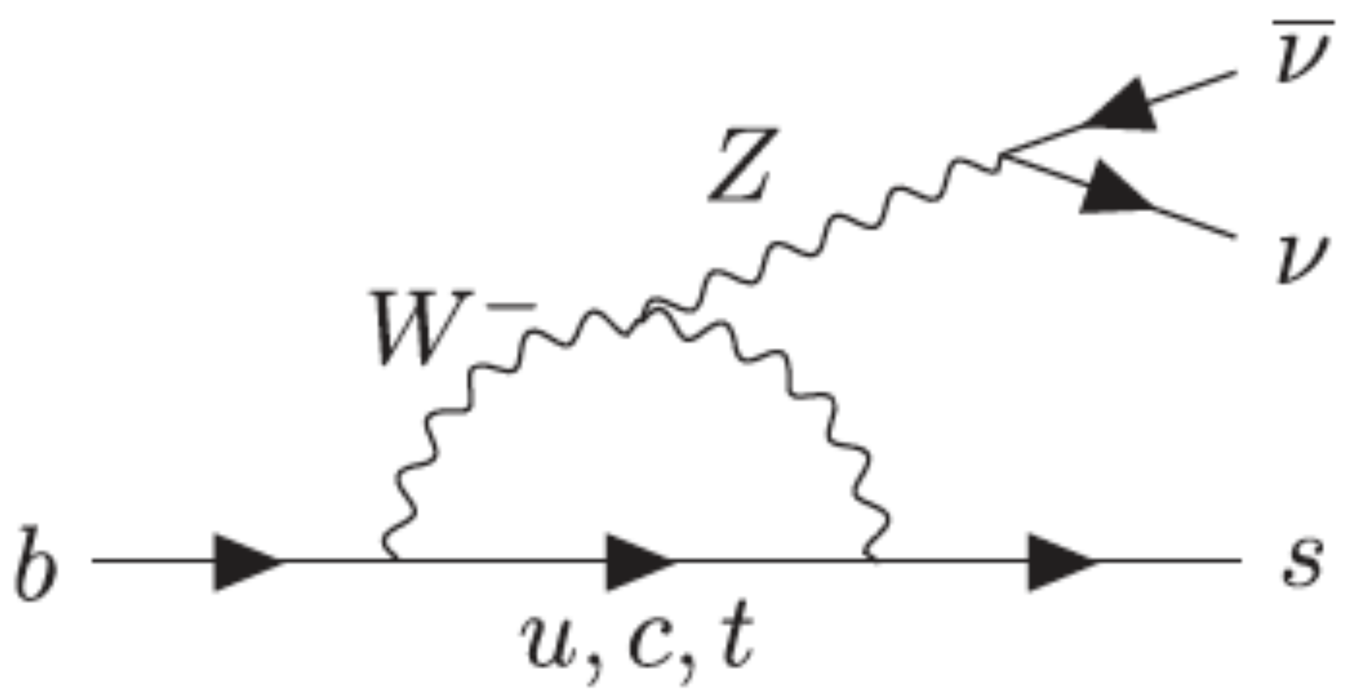
$$B \to K^{(*)}\nu\bar{\nu}$$

$$B \to K^{(*)}\tau^+\tau^-$$

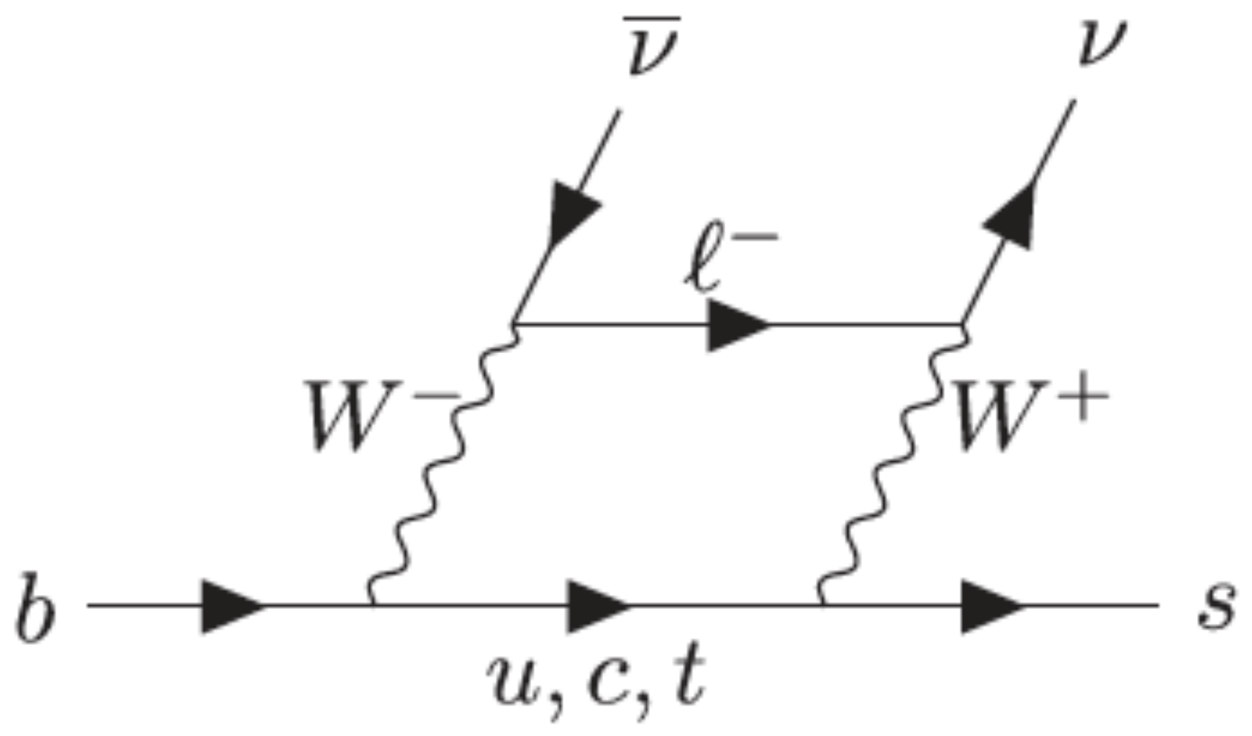
- **Coordination of the ECL upgrade (Prof. Claudia Cecchi)**
- **ECL upgrade: laboratory activity in Perugia**
- **Performance of ECL, b-counting,..**

# $B \to K^{(*)}\nu\bar{\nu}$

## Penguin diagram

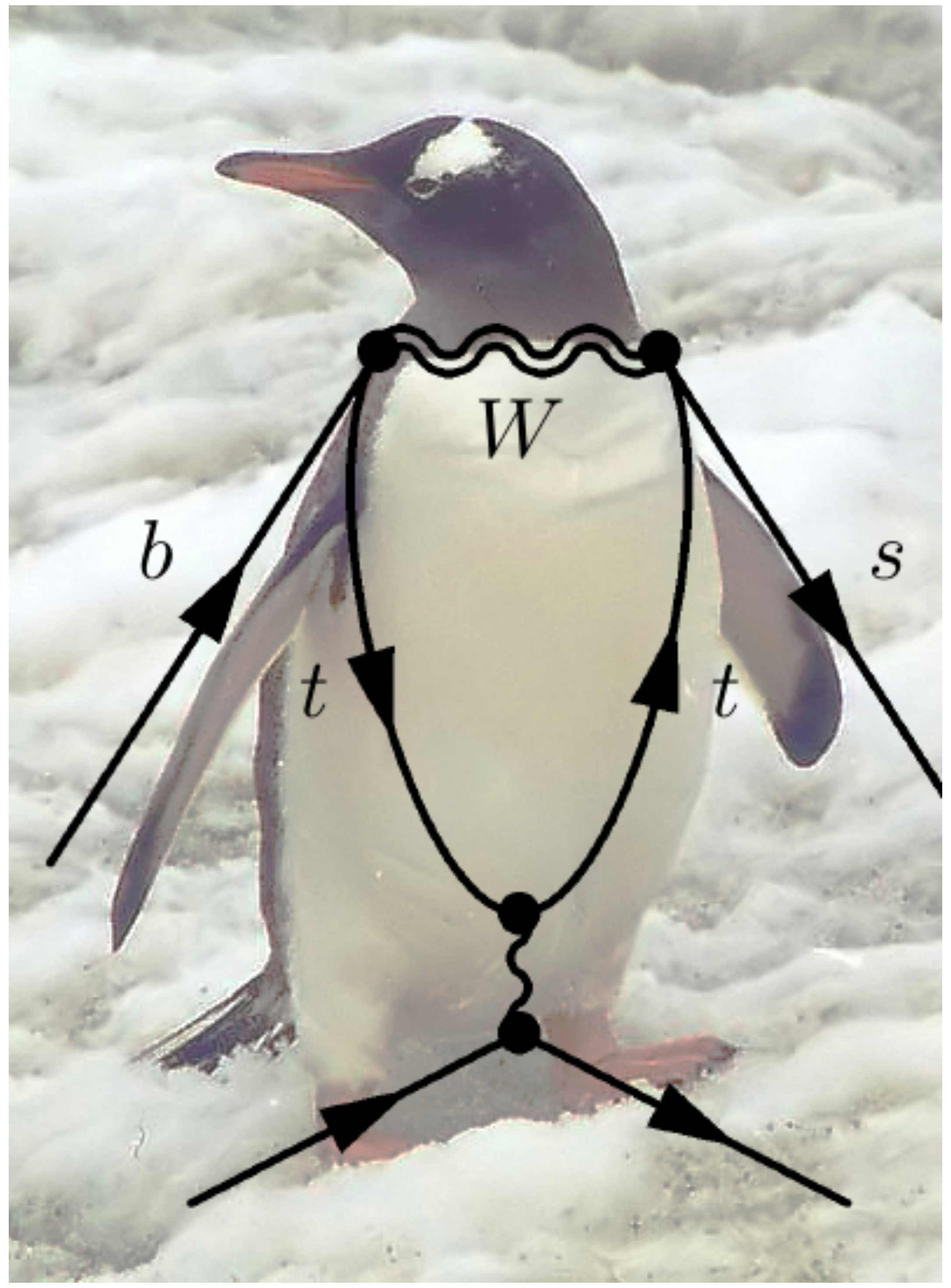



## Box diagram




## Origin of the name

https://en.wikipedia.org/wiki/Penguin_diagram




$B \to K^{(*)}\nu\bar{\nu}$

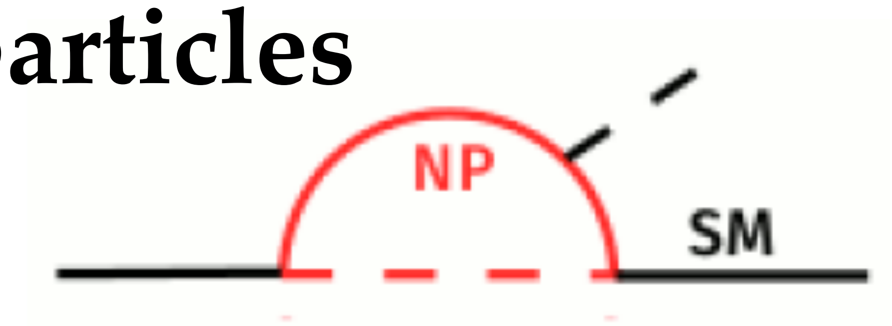
**Flavor changing neutral current (FCNF) decays are strongly suppressed in SM: loops and GIM mechanism**

**<u>Very rare decays predicted with good precision by the SM</u>**
**If BR larger than the SM expectation => New physics**

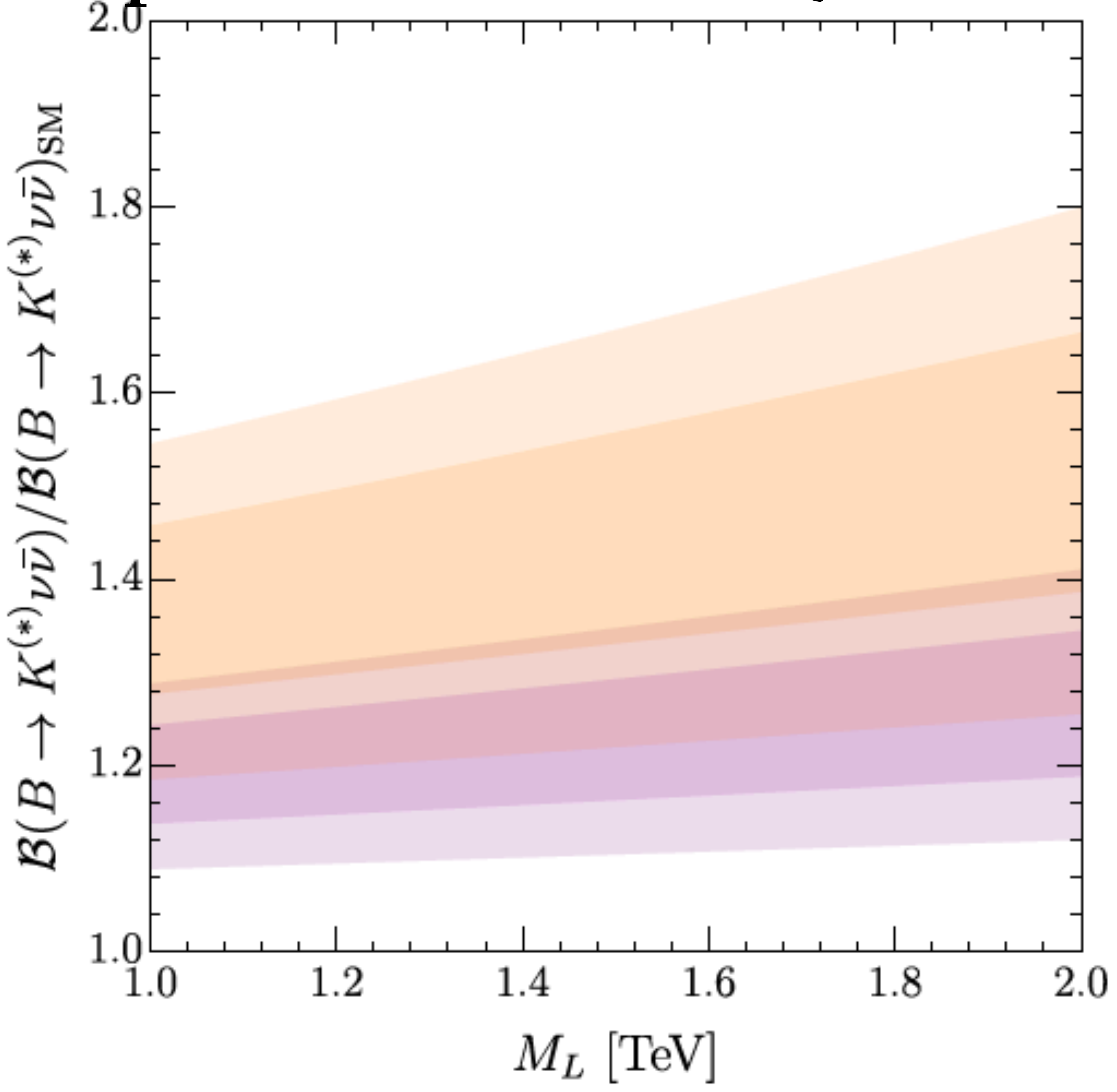
These decays offer complementary probes of non-SM physics scenarios proposed to explain the anomalies observed in b → $s\ell^+\ell^-$ transitions

# $B \to K^{(*)}\nu\bar{\nu}$

**Indirect search for heavy particles (Lepto-Quark, Z′,…)**




**example: Models with LQ:**

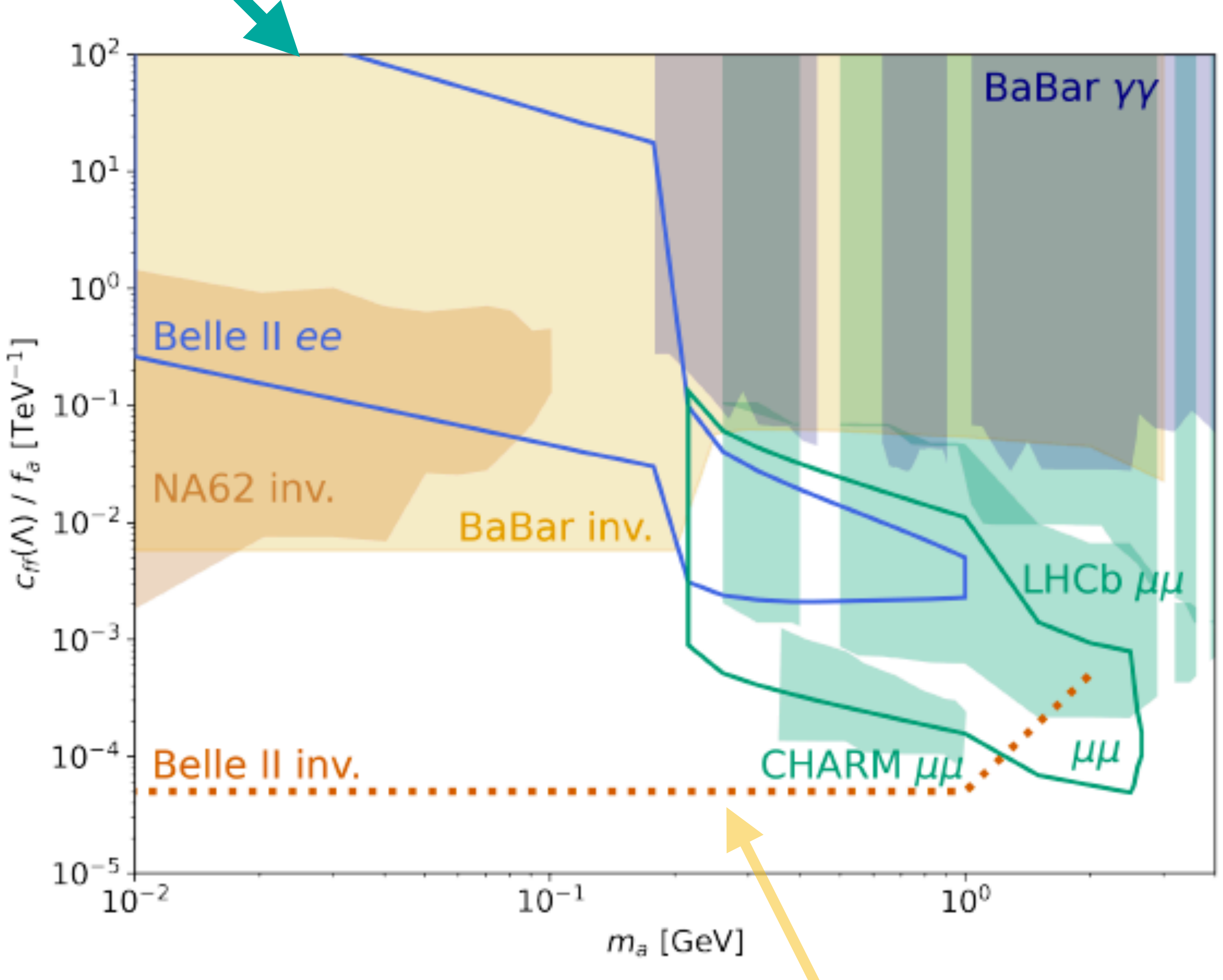



**Cornella et al** 2103.16558 [hep-ph] 10.1007/JHEP08(2021)050

**Direct search for invisible light particles**

$B \to KX, X \to inv$

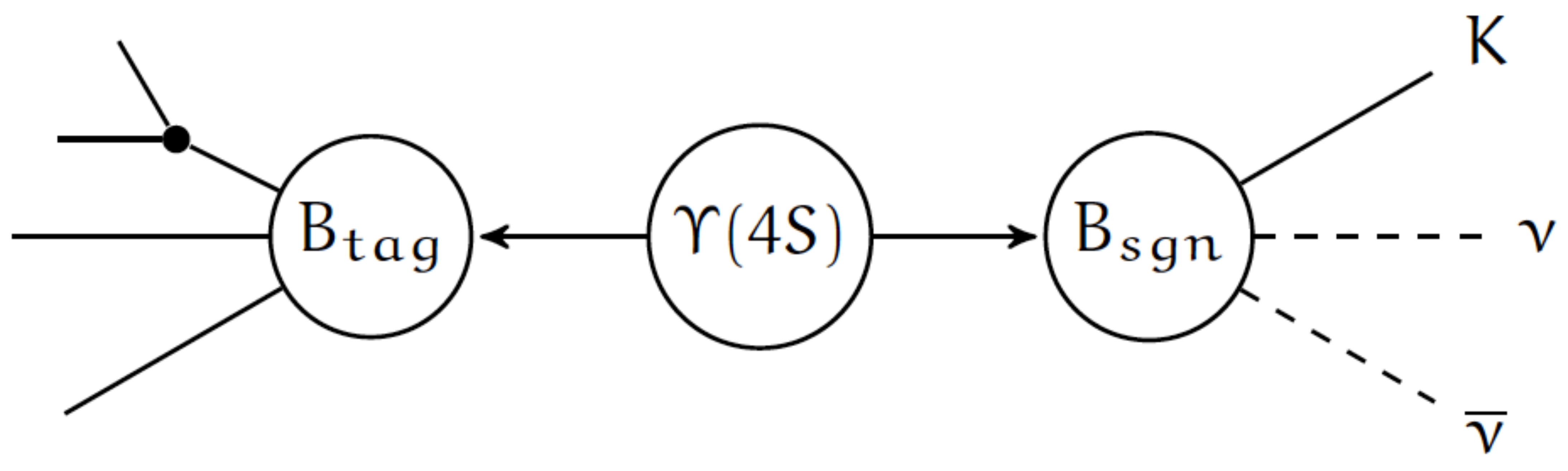
$B \to Ka \qquad B \to K^{(*)}S$




**Ferber et al.** arXiv:2201.06580

**$L = 50 ab^{-1}$**
**Assuming 0 background**

# $B \to K^{(*)}\nu\bar{\nu}$




| Topic | Who |
|---|---|
| **B→K*νν** using feiHadronicB0, feiHadronicBplus feiSLB0 feiSLBplus | @Guglielmo De Nardo, @Mario Merola (Napoli); @Claudia Cecchi, @Elisa Manoni, @Volpe, Roberta (PG); @Giulio Dujany, @Isabelle Ripp-Baudot, @Lucas Martel, @Jacopo Cerasoli (Strasbourg) |

## Tagging B

- Fully reconstruct the decay (Hadronic modes)
- Partially reconstruct the decay (Semileptonic modes)

## Signal B

$B^+ \to K^+\nu\bar{\nu}$
$B^0 \to K^0\nu\bar{\nu}\ (K_S^0 \to \pi^+\pi^-)$
$B \to K\nu\bar{\nu}$ using $\mathcal{B}(B^+ \to K^+\nu\bar{\nu})/\mathcal{B}(B^0 \to K^0\nu\bar{\nu}) = \tau_{B^+}/\tau_{B^0}$
$B^+ \to K^{*+}\nu\bar{\nu}\ (K^+\pi^0)$
$B^+ \to K^{*+}\nu\bar{\nu}\ (K_S^0\pi^+)$
$B^+ \to K^{*+}\nu\bar{\nu}$
$B^0 \to K^{*0}\nu\bar{\nu}\ (K^+\pi^-)$
$B \to K^*\nu\bar{\nu}$ using $\mathcal{B}(B^+ \to K^{*+}\nu\bar{\nu})/\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu}) = \tau_{B^+}/\tau_{B^0}$

**Not only 1 analysis!**

# $B \to K^{(*)}\tau^+\tau^-$

B→K*ττ **PG** Stefano Moneta (Rahul Tiwary) **PhD thesis**

**SM prediction:**

$$BR(B^0 \to K^{*0}\tau^+\tau^-) \sim 10^{-7}$$

**Belle Collaboration recently published this result:**

$$BR(B^0 \to K^{*0}\tau^+\tau^-) < 2.0 \times 10^{-3} @ 90\,\%\,CL$$

**Anomalies in B decays**

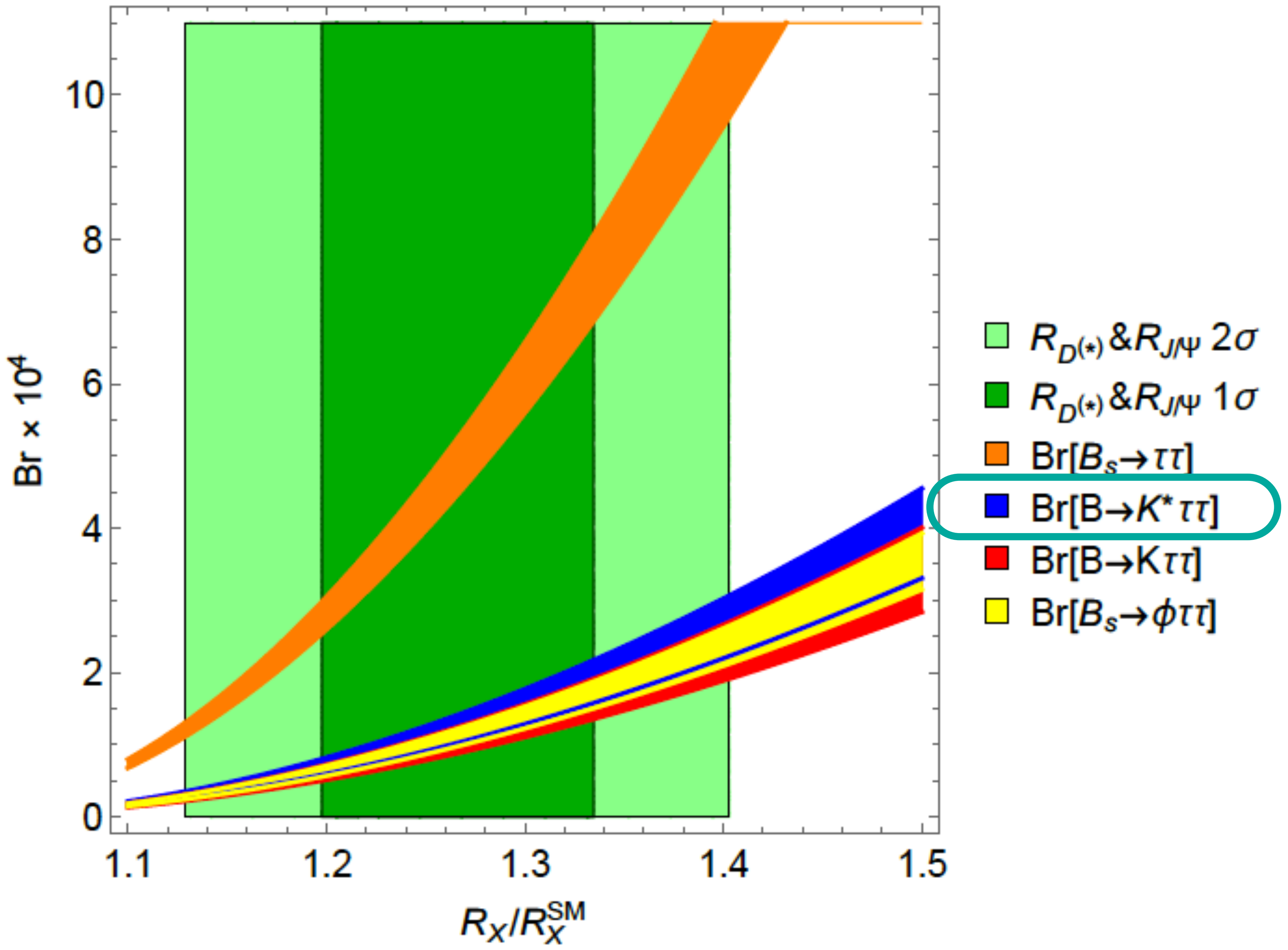
violation of Lepton Flavour Universality (LFU)

LHCb Measurements of $R_K$ and $R_D$

$b \to s l^+ l^-$ $\quad b \to c l^- \bar{\nu}$

LFU violation should affect also $b \to s\tau^+\tau^-$

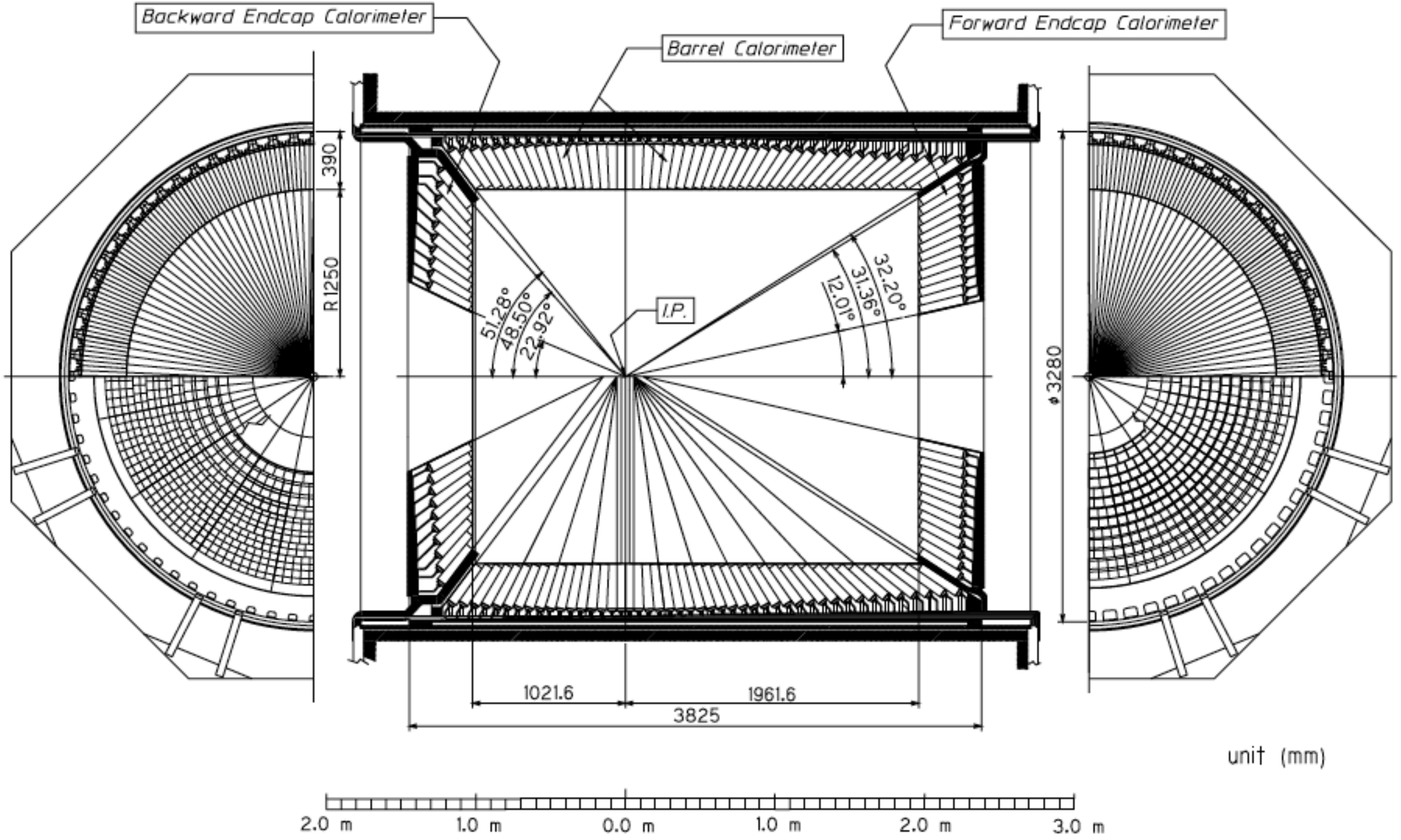
By assuming a New Physics scenario which accommodates the B anomalies, an enhancement of $BR(b \to s\tau^+\tau^-)$ is expected




Phys. Rev. Lett. 120, 181802 (2018) arXiv:1712.01919v1

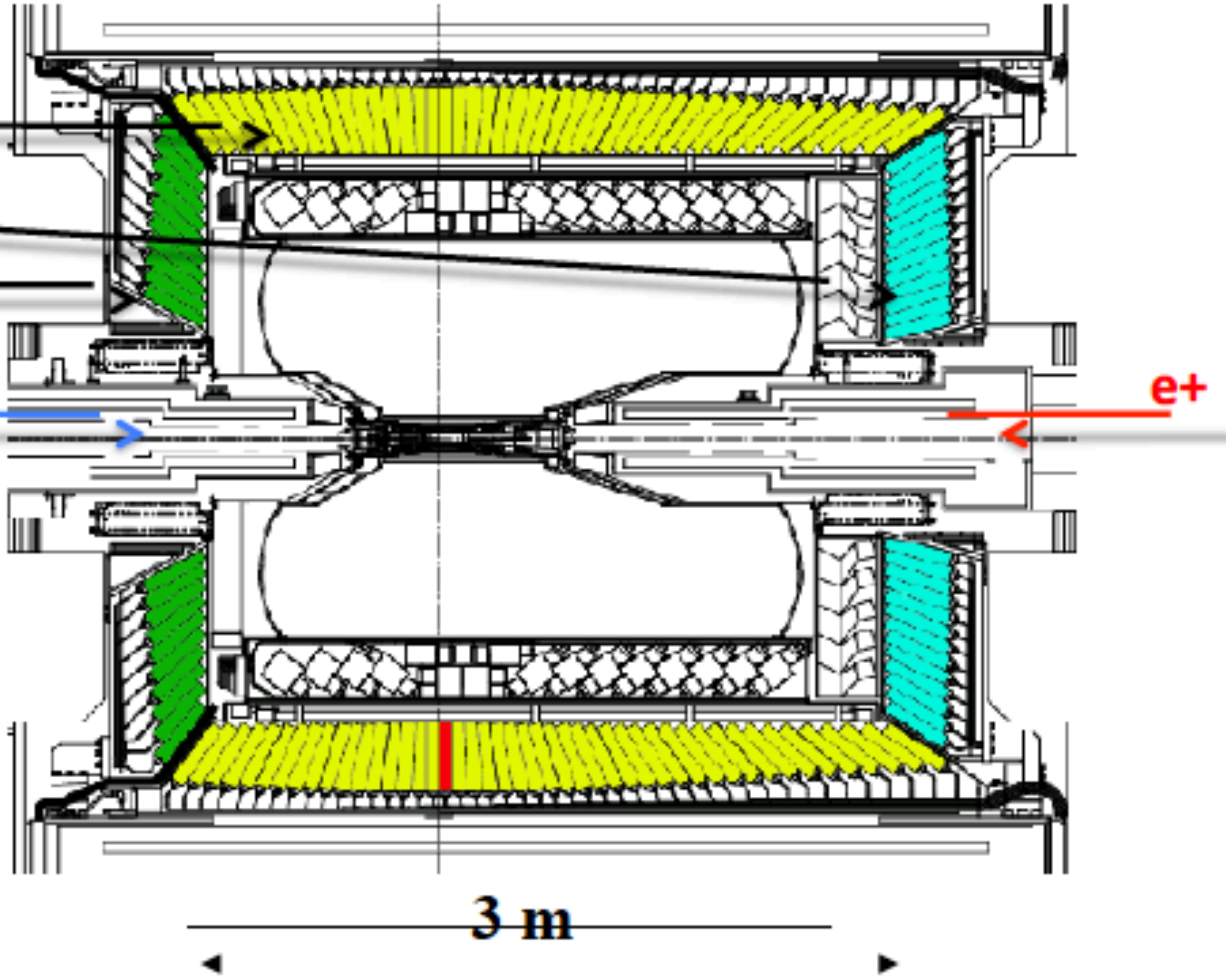
# ECL (Electromagnetic calorimeter)

- detection of photons with high efficiency
- precise determination of the photon energy and angular coordinates
- electron identification
- generation of the proper signal for trigger
- on-line and off-line luminosity measurement
- $K^0_L$ detection together with the KLM .

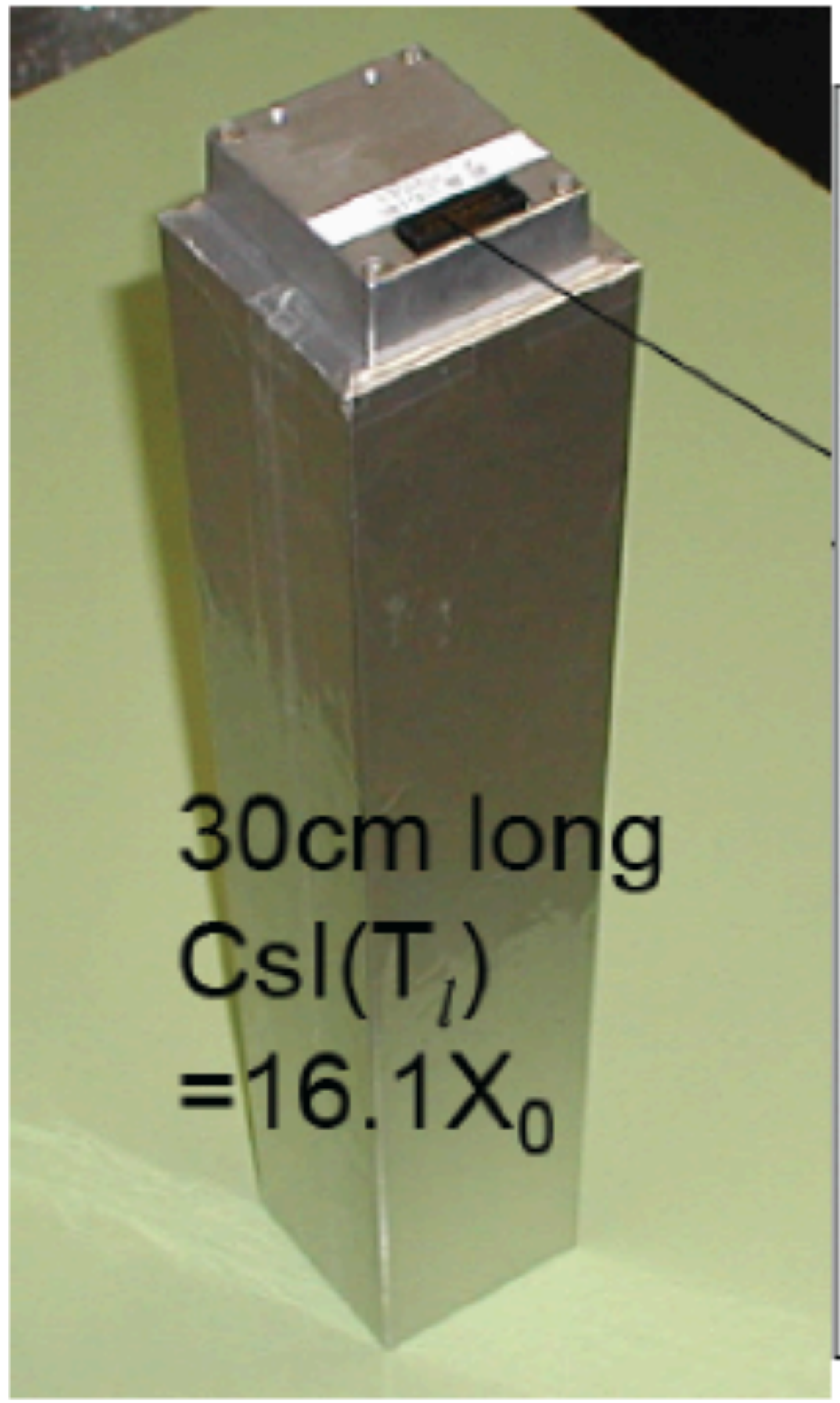


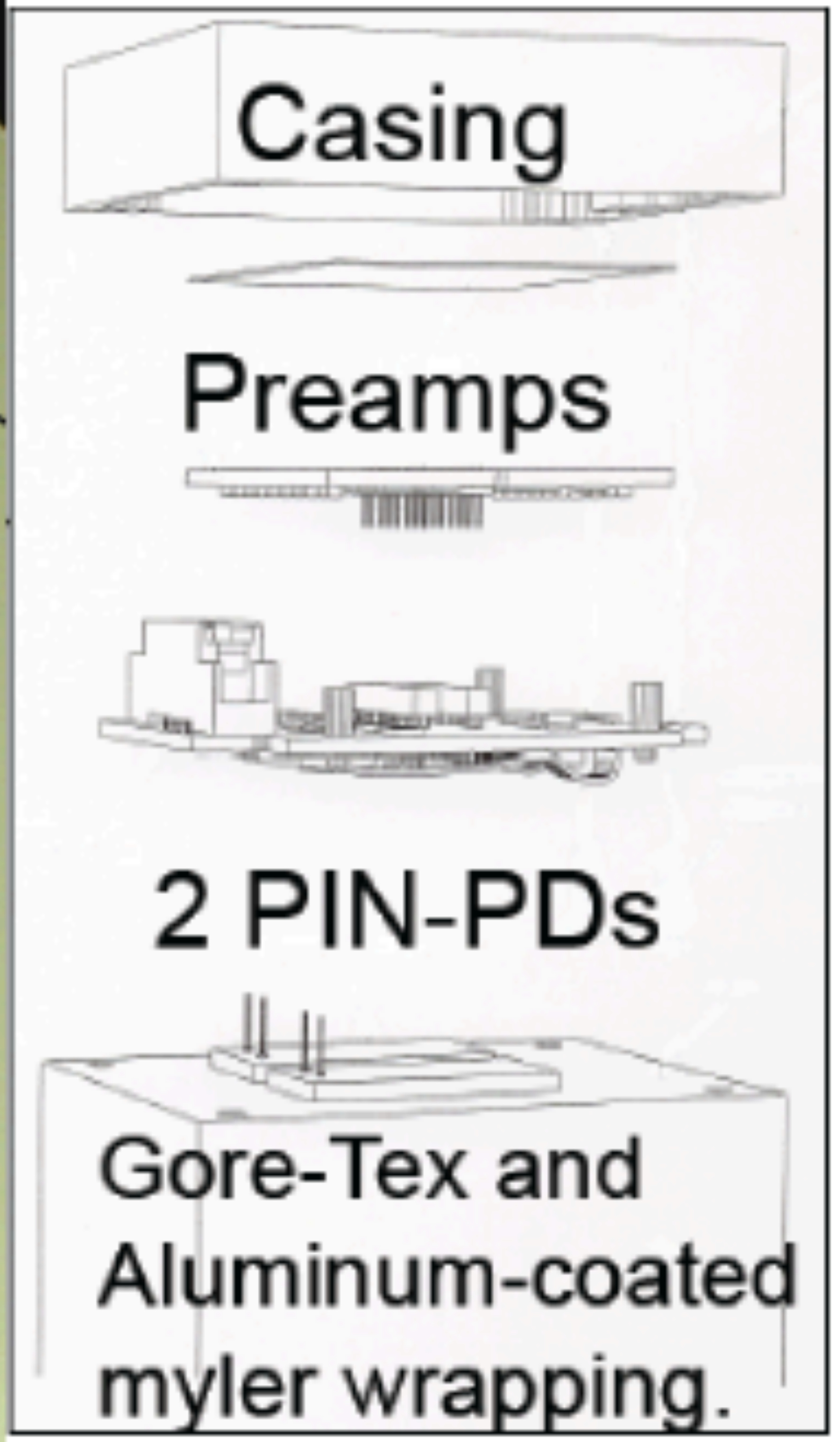
# ECL

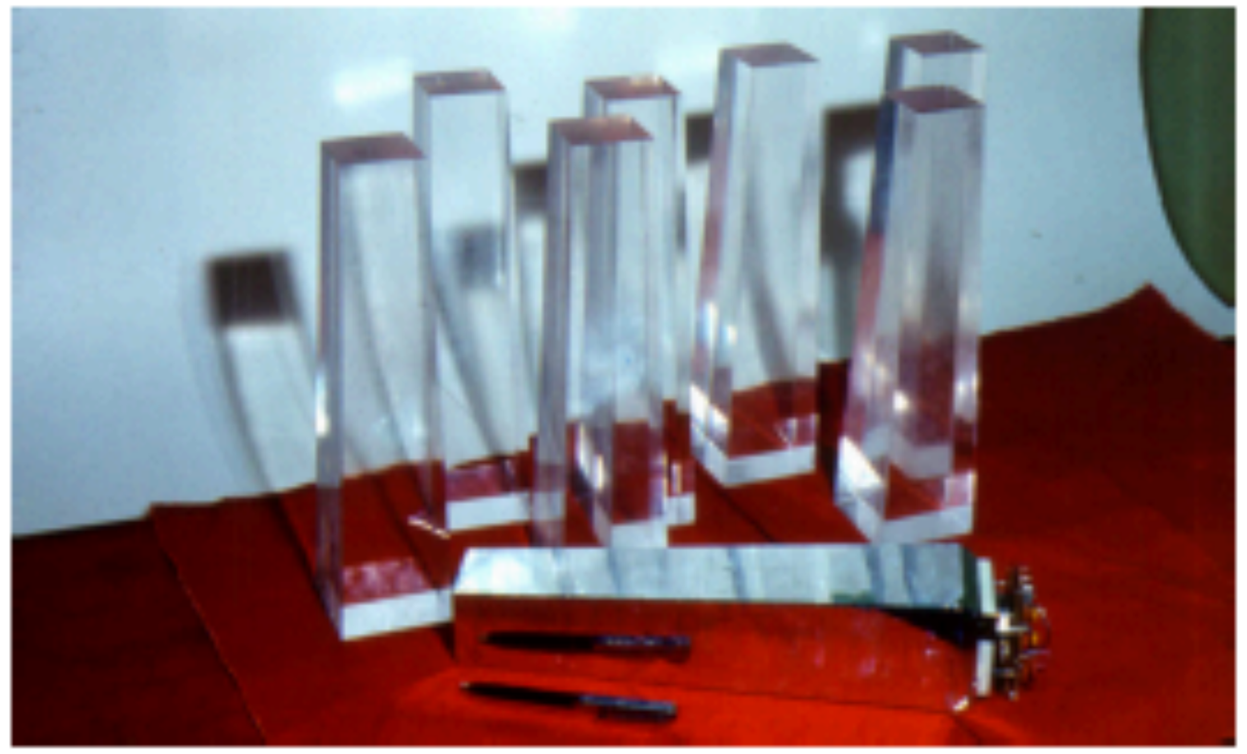
8736 CsI(Tl) crystals
- 6624 Barrel
- 1152 Fwd. Endcap
- 960 Bwd. Endcap




PERUGIA activities concentrated on ECL



C. cchi $L_{cr}$ = 30 cm = 16.2$X_0$

**Light output – 5000 ph.el./MeV**

**electronics noise σ~200 keV**

# ECL upgrade

**BelleII long shutdowns (LSs)**

**Short term:** Long Shutdown 1 (LS1) is planned for approximately 15 months starting in July 2022, to install a complete pixel detector (PXD).

**Medium term:** approximately year 2026-27.
Long Shutdown 2 (LS2) will probably be needed for the upgrade of the interaction region to reach L(peak)= $6.5 \times 10^{35} cm^{-2} s^{-1}$.

**Long term:** years > 2032.
Studies have started to explore upgrades beyond the currently planned program, such as beam polarization and ultra-high luminosity

| | | | |
|---|---|---|---|
| ECL | $\gamma$, $e$ ID | add pre-shower detector in front of ECL | long-term |
| | | Replace ECL PiN diodes with APDs **(Avalance PhotoDiode)** | long-term |
| | | Replace CsI(Tl) with pure CsI crystals | long-term |

**The performance of the ECL will degrade with higher background rates without future upgrades. At nominal luminosity, the efficiency may decrease by around 50% for $\pi^0$ reconstruction and discrimination techniques will degrade in performance.**

# Argomenti di tesi

Principalmente in laboratorio:

Misure in laboratorio su cristalli di CsI puro con diversi fotorivelatori

Principalmente software:

Studio delle performance del calorimetro di Belle-II con i dati

Studio nell'ambito di un'analisi di fisica

$$B \to K^{(*)}\tau^+\tau^-$$

$$B \to K^{(*)}\nu\bar{\nu}$$

**possibilita` di soggiorno a KEK (Pandemic-dependent)**

Molte altre possibilita`, contattateci per i dettagli

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