Introduction *to the B physics discovery potential of Belle II@SuperKEKB*

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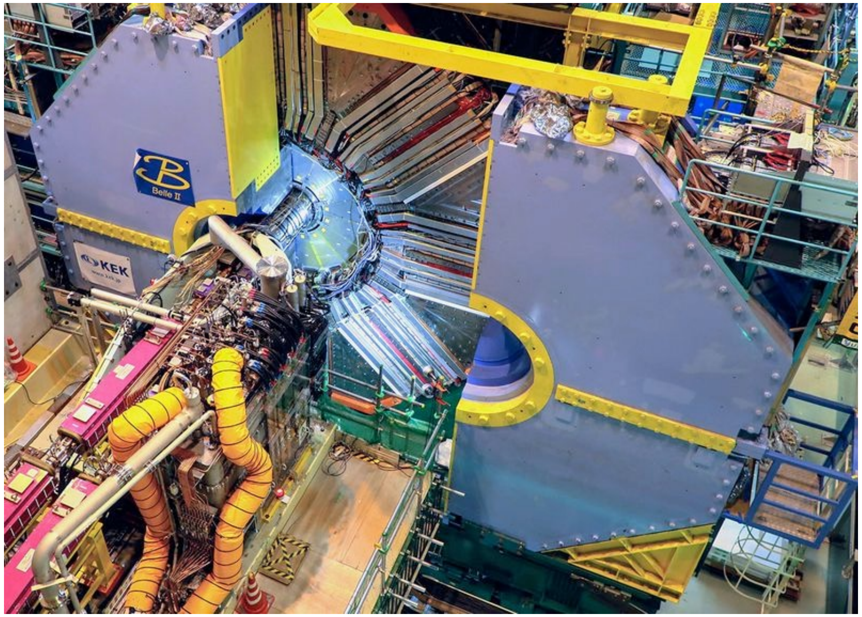
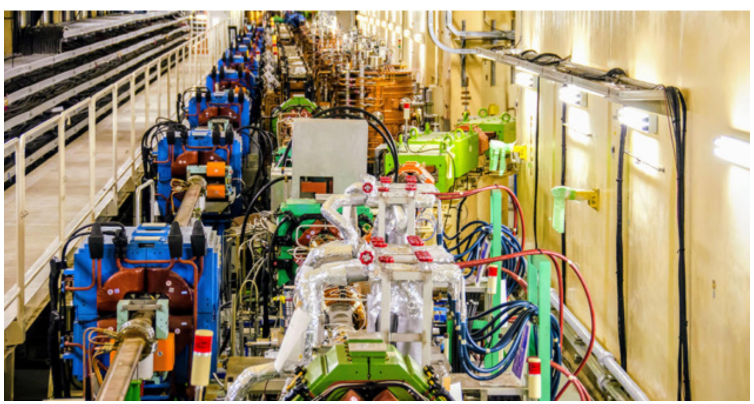
Belle II



The complex superconducting final focus is partially visible here (before closing the endcap).



Inside the SuperKEKB tunnel

Introduction to B physics

Some Basics and Fundamental Questions. (**Very simple and basic**)

Opportunities for *Beyond the Standard Model (BSM) discoveries at Belle II* and the road ahead in the next decade. **(What's new in 2023)**

Prof Soeren Prell will cover CP Violation; Prof Alan Schwartz will cover CKM matrix elements; Prof Jim Cochran will discuss Anomalies.

Belle II/SuperKEKB Snowmass White Papers:
https://confluence.desy.de/display/BI/Snowmass+2021

Snowmass 2022 (*International* Physics Rodeo)

To plan the high energy physics discoveries for the next decade.

Scenes from the actual Snowmass Rodeo in Colorado

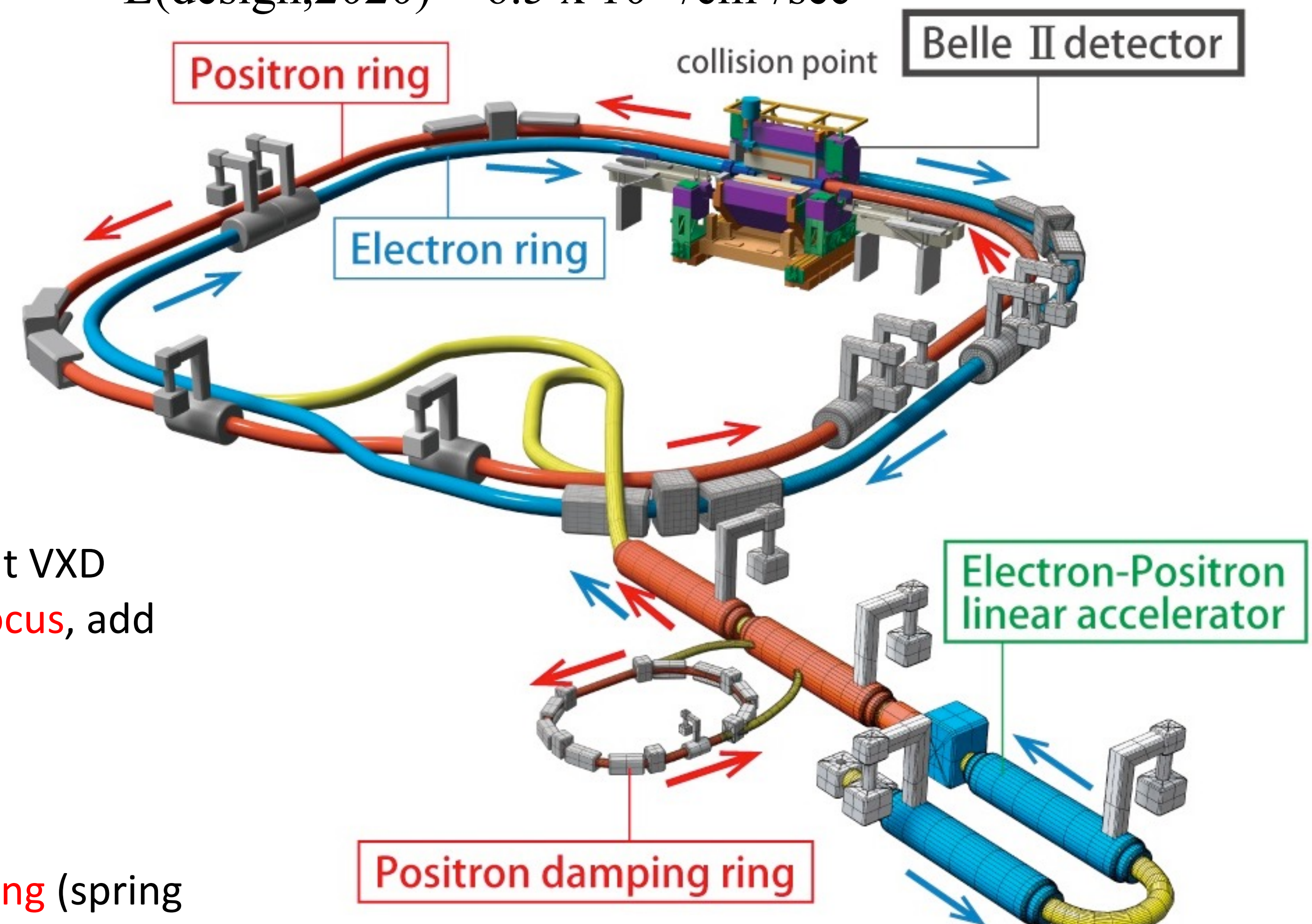
N.B. Snowmass was *held* in Seattle, Washington in summer of 2022. The last one was held in Minneapolis, Minnesota in 2013. It is unlikely that there will ever be another month-long decadal planning meeting in Snowmass, Colorado.

Historical note: Young(ish) Scientist Pier Oddone (originally from Peru/Italy) introduced the concept and first proposal for an asymmetric energy B-factory to the broad HEP community at a Snowmass in 1988.

SuperKEKB, the first new collider in particle physics since the LHC in 2008 (electron-positron (e^+e^-) rather than proton-proton (pp)). Operates on the *Upsilon(4S) resonance* with 7 GeV(e-) on 4 GeV(e+) beams.

Super KEKB

$L(design,2020) = 6.5 \times 10^{35}/cm^2/sec$



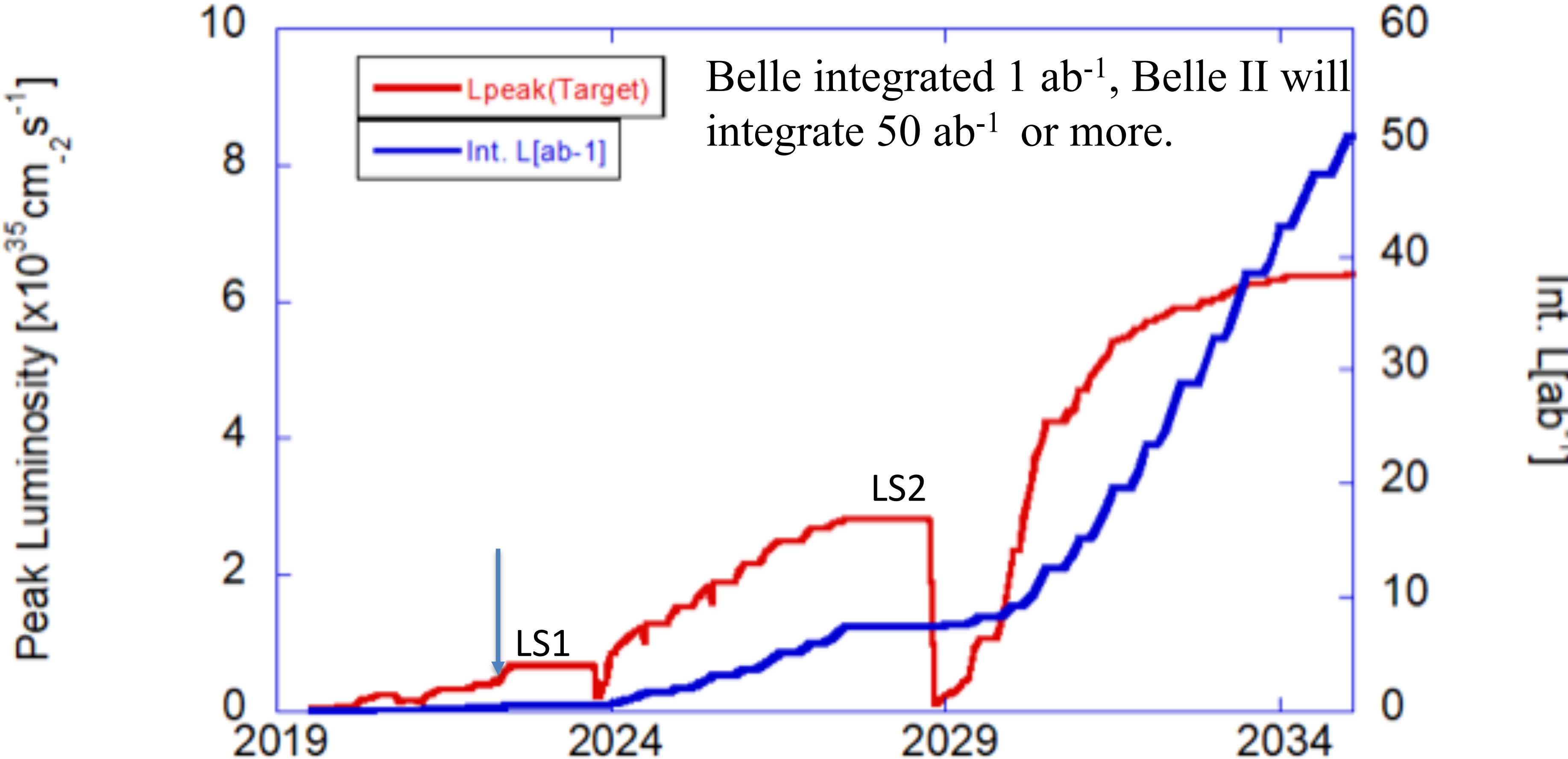
Phase 1:
Background, Optics Commissioning Feb-June 2016.
Brand new 3 km positron ring.

Phase 2: Pilot run without VXD
Superconducting Final Focus, add positron damping ring,
First Collisions (0.5 fb^{-1}).
April 27-July 17, 2018

Phase 3: → Physics running (spring 2019 to present).
Have integrated 428 fb^{-1} so far.

Accelerator innovations: nano-beams and crab waist optics (*rather than large beam currents*)

An innovative machine and a plan for the next decade and beyond

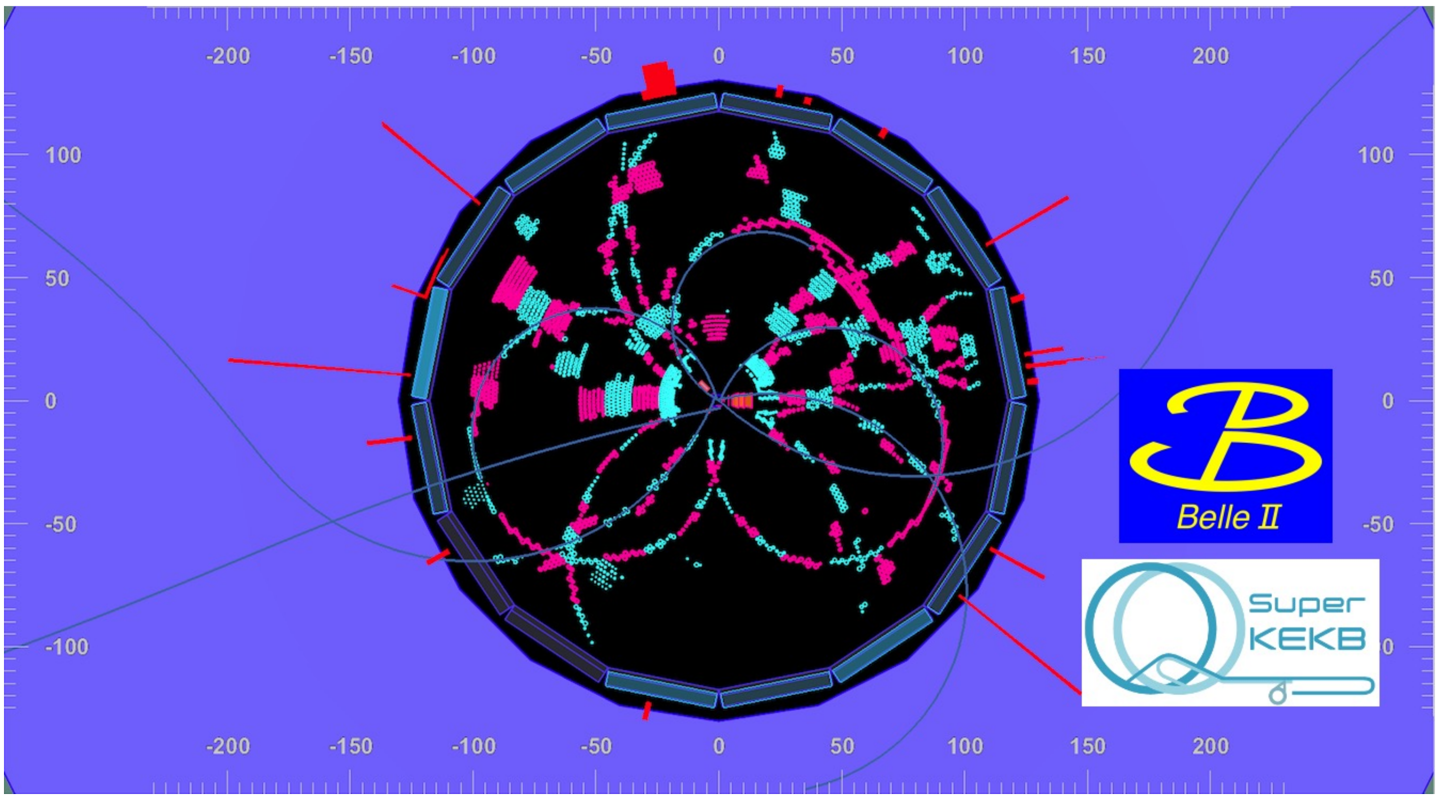


Needs international accelerator cooperation: CERN, DESY, BNL, SLAC, Cornell, ESRF, IHEP, BINP.

We now realize that SuperKEKB is a "test bed" for FCC-ee, a 100 km circumference machine planned at CERN

Matter-antimatter annihilation in Tsukuba: An event from Belle II's first evening in 2019

$$e^{+}e^{-} \rightarrow \gamma^{*} \rightarrow B\overline{B}$$



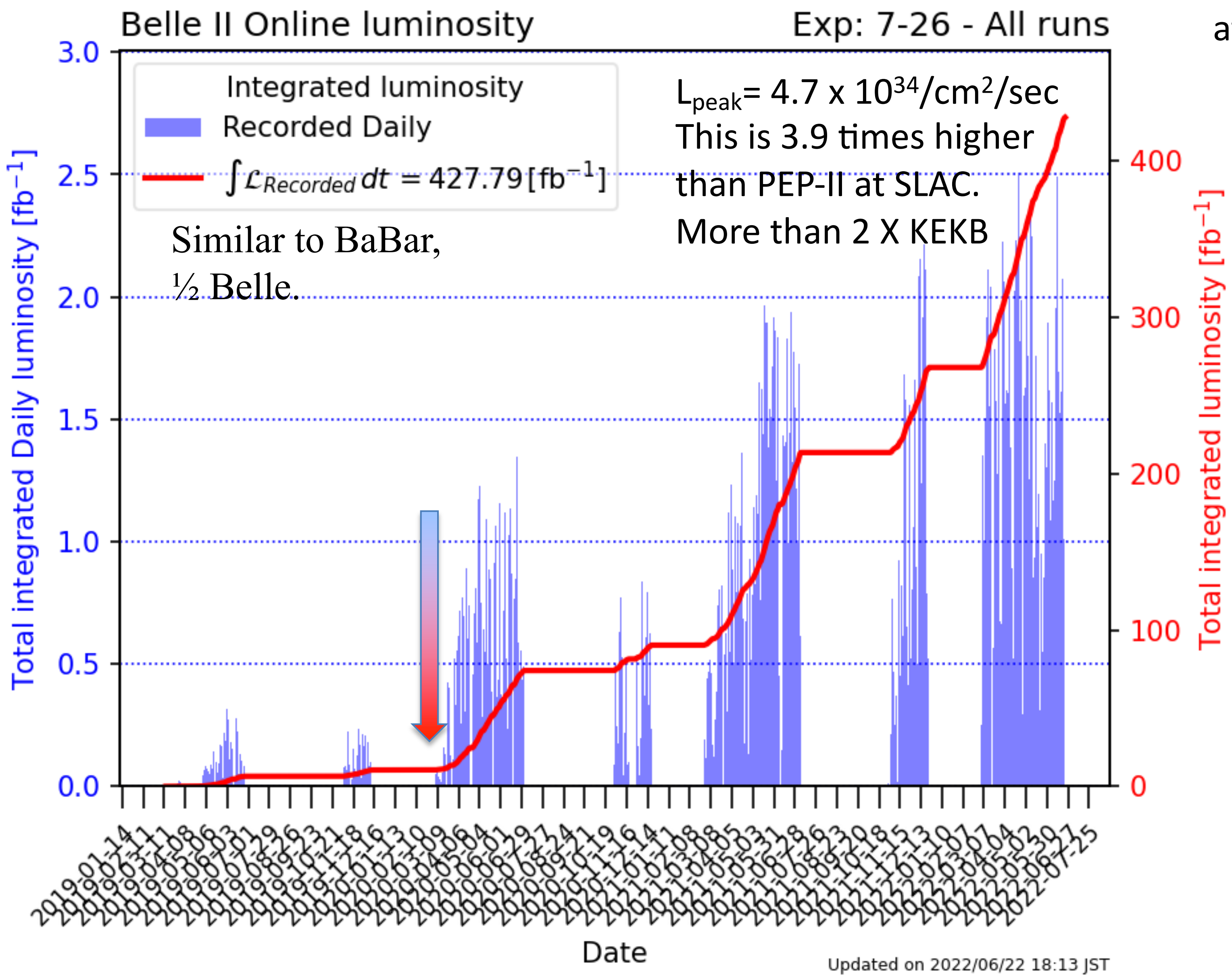
An e+ e- →B anti-B candidate

The experimental control room in Tsukuba Hall B3 (Spring 2019)

This was scientific history in the making: SuperKEKB/Belle II joined DORIS/ARGUS, CESR/CLEO, and PEP-II/BaBar and KEKB/Belle

Ran Belle II and SuperKEKB *through the global pandemic*.
Broke many accelerator world records for luminosity.

Int(L dt)/day
=2.5 fb^{-1}
>>0.9 fb^{-1}/day
at PEP-II

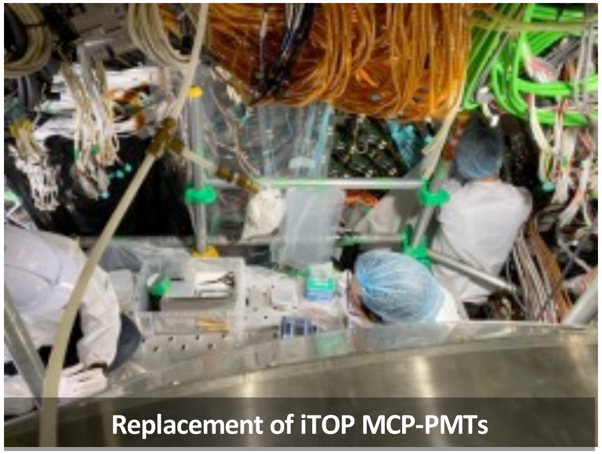


Current state of Belle II

Detector and *accelerator upgrades* during Long Shutdown I (LS1) and preparing to restart SuperKEKB in mid-December with collisions in Feb 2024.


Installation of the upgraded PXD2


Replacement of CDC HV bias resistor


Replacement of iTOP MCP-PMTs

Let's go back in time a bit, take a break from the technical parts and think for a moment about some basic questions in high energy physics (HEP):

1) "What is particle-antiparticle mixing" ?

2) "What is the fundamental importance of "matter-antimatter asymmetry" (or CP violation) to the mystery of *why we exist* ?"

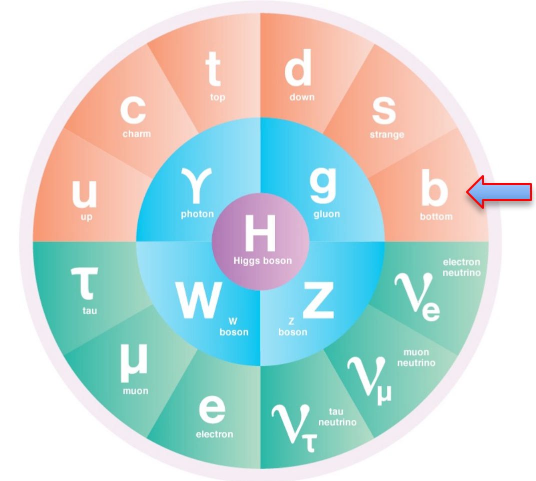
3) "Why are there three generations of quarks and leptons ? " i.e. (u, d, e, ν_e), (c, s, μ, ν_μ), (t, b, τ, ν_τ)

4) "How are B physics and flavor physics connected to these fundamental questions ?"

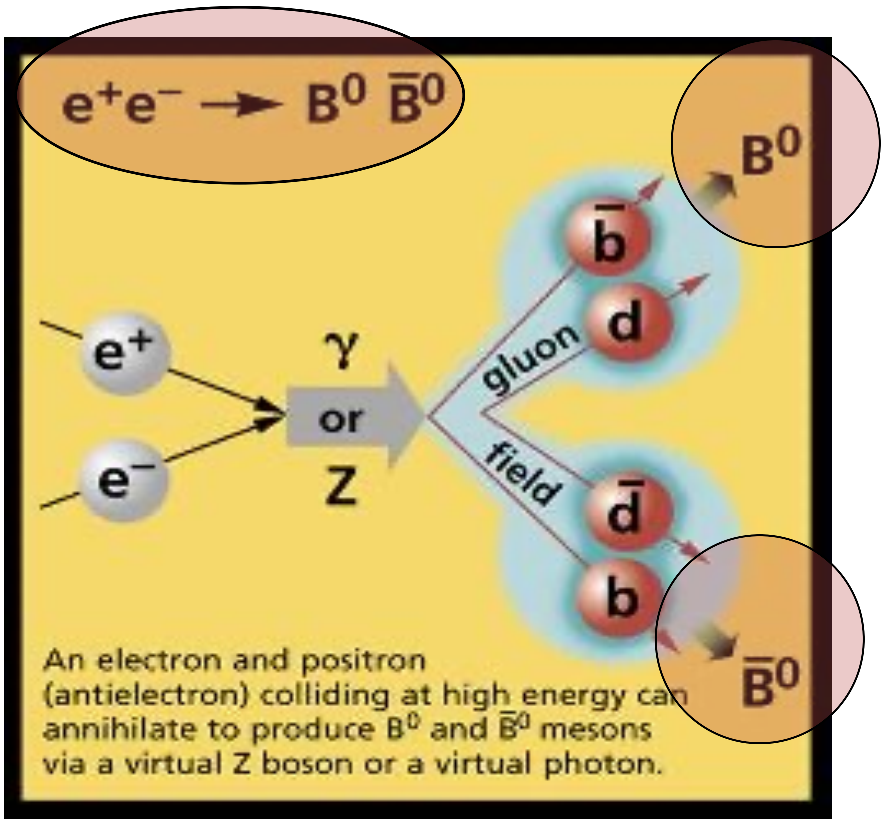
Do you already know the answers to these questions ?

B mesons:
"Laboratory rats of the weak interaction"

"Breed large numbers and watch them die"



At the ϒ(4S), B Bbar pairs are produced with NO additional particles.



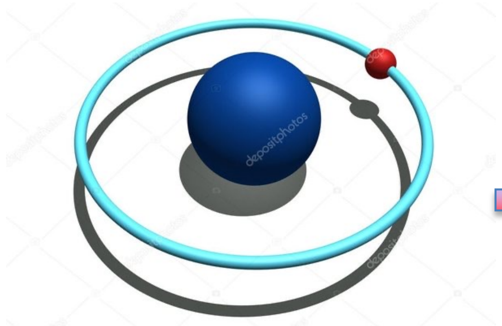
Exotic bound state of matter and antimatter (hydrogen-like)
b quark mass
~ 5 x proton mass

Lifetime ~ 1.5ps

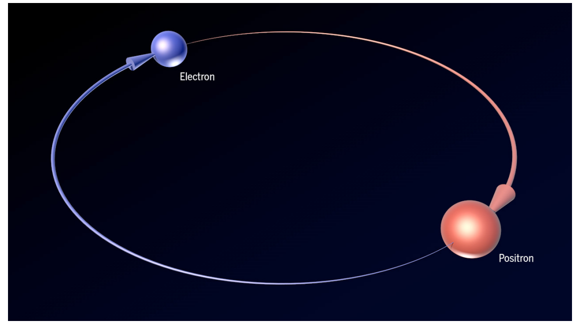
$$c \leftarrow \begin{pmatrix} t \\ b \end{pmatrix}$$

More on this in a moment

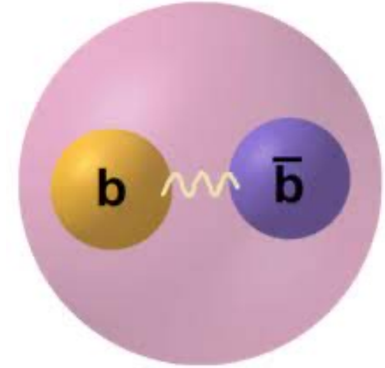
1987: ARGUS@DESY found that the neutral B meson can transform into its *anti-particle*, "B-Bbar mixing"



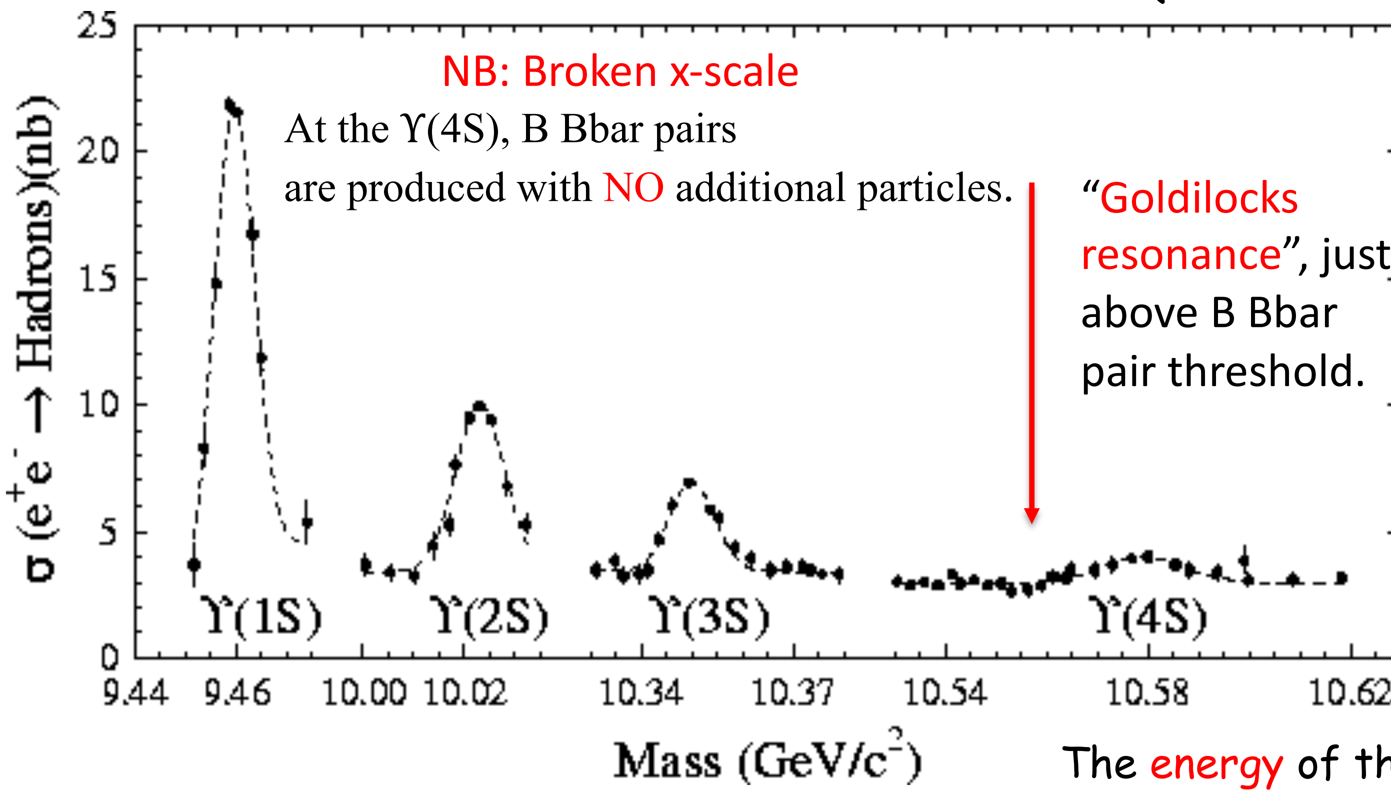
Hydrogen (p and electron bound state)



Positronium (e+e- bound state)



Bottomonium (b bar bound state), QCD instead of QED.



The energy of the e+e- machine is tuned to the Υ(4S)resonance

Particle-Antiparticle Mixing

Start with a B^0 (wait a while, a few x 10^{-12} sec)

There is a large probability it will turn into its anti-particle, an anti-B^0 i.e.

$$B^0 \rightarrow \bar{B}^0$$

$$\begin{cases} x_d = 0.769 \pm 0.004 & (B_d^0\text{–}\overline{B}_d^0 \text{ system}) \\ x_s = 26.89 \pm 0.07 & (B_s^0\text{–}\overline{B}_s^0 \text{ system}) \end{cases},$$

This also happens with K^0 's (strange quarks) and D^0 (charm quark) particles

x (%)	$0.50^{+0.18}_{-0.14}$
y (%)	0.62 ± 0.07

Particle-AntiParticle Mixing;
Now let's add in QM Interference

Quantum Mechanical Interference

"We choose to examine a phenomenon which is impossible, <u>absolutely</u> *impossible,* to explain in any classical way, and which has in it the heart of quantum mechanics. In reality, it contains the *only* mystery."

--Richard P. Feynman

Physicist and Bongo drummer

Recall even single electrons *interfere* in a two-slit experiment !

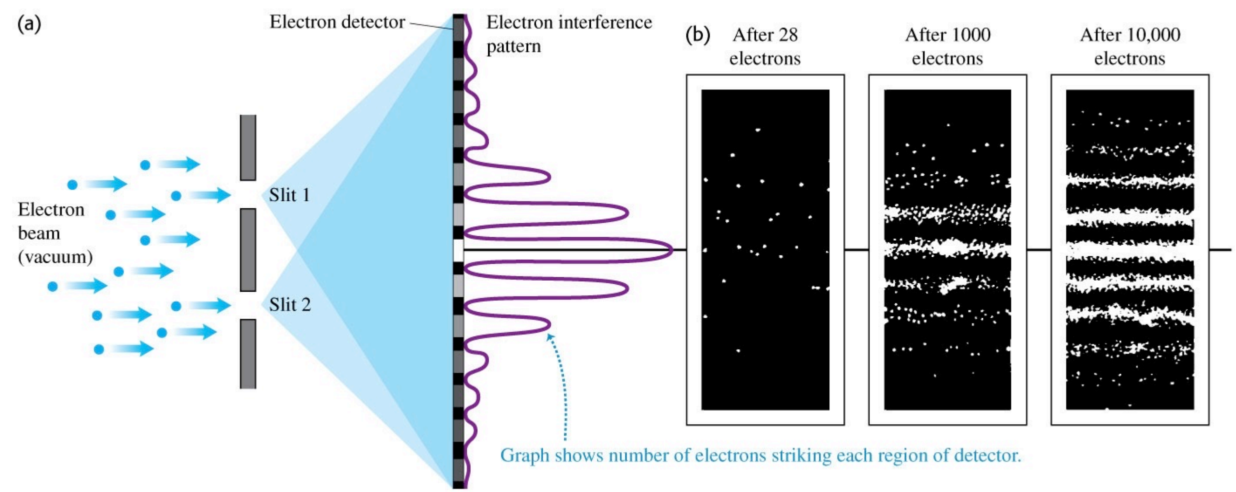
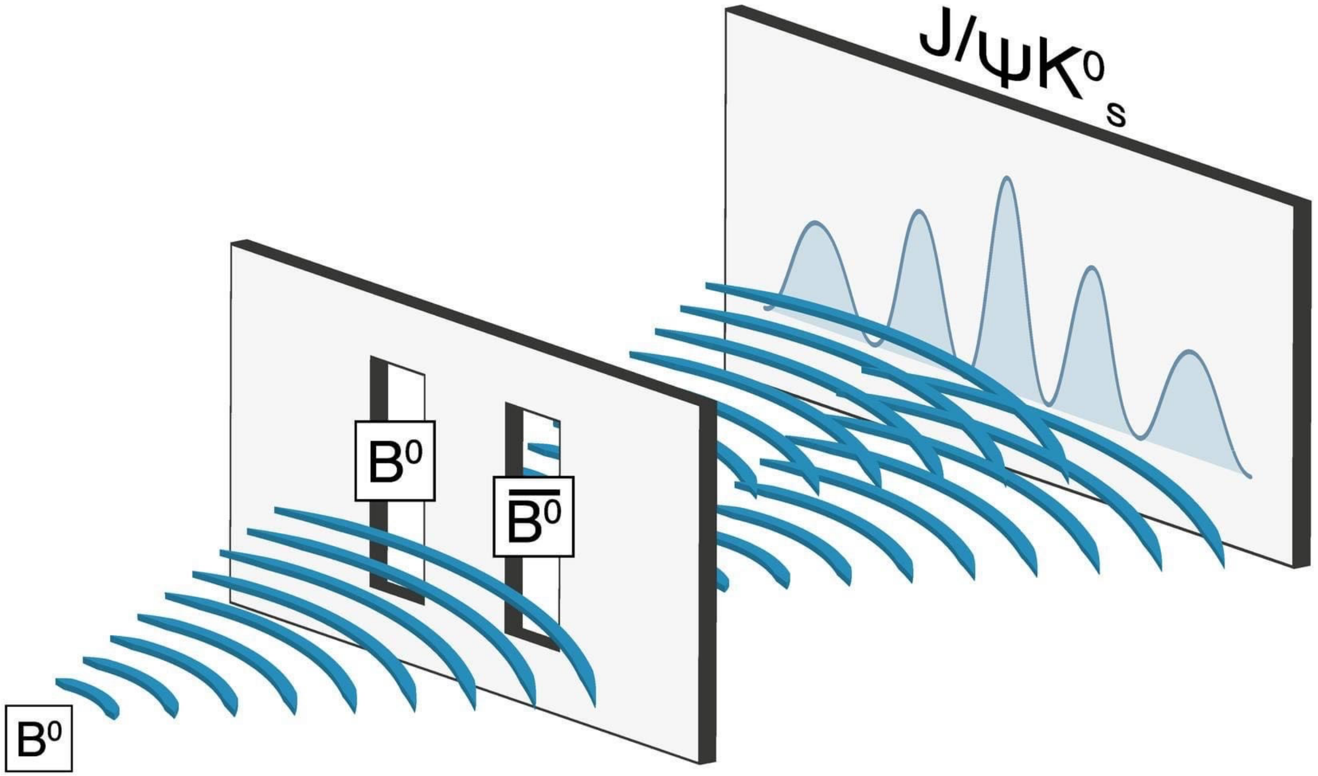


Figure from CERN LHCb outreach (also see Hazumi 2001)

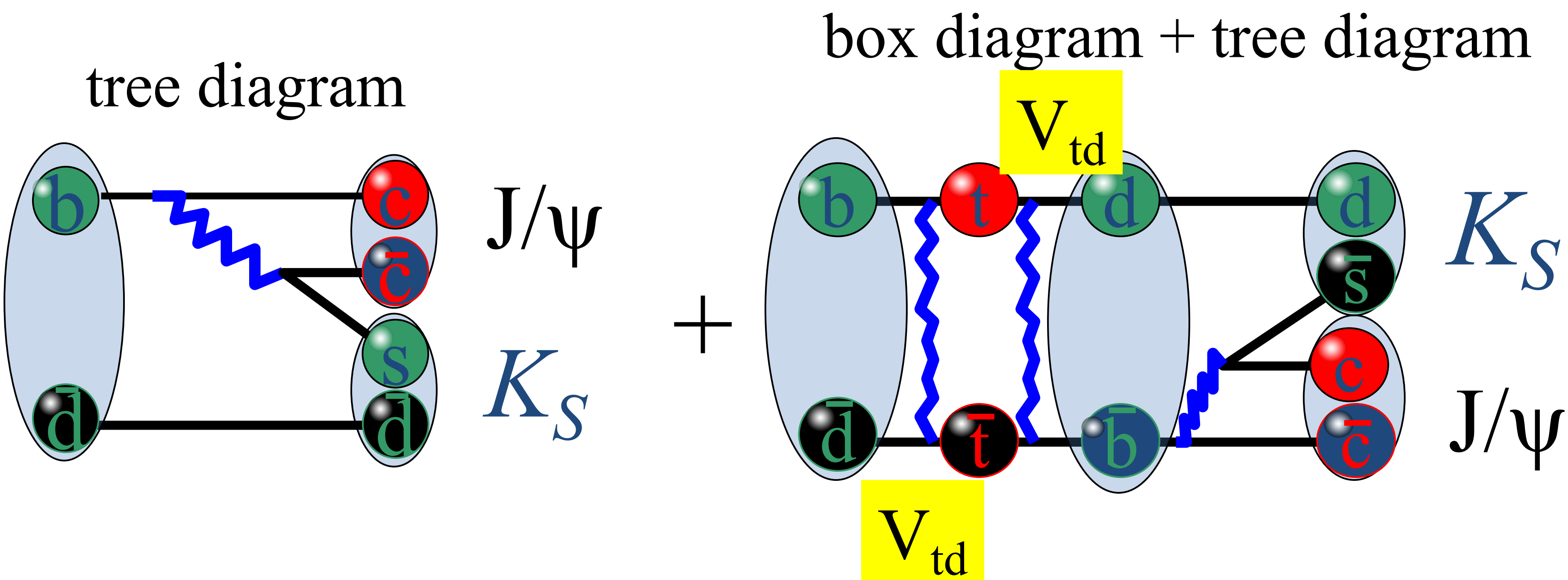


Q: How can we get a phase difference between the two paths (so that there is an interference pattern on the screen) ?

Time-dependent *CP* violation is

"*A Double-Slit experiment*" with particles and antiparticles

QM interference between two diagrams



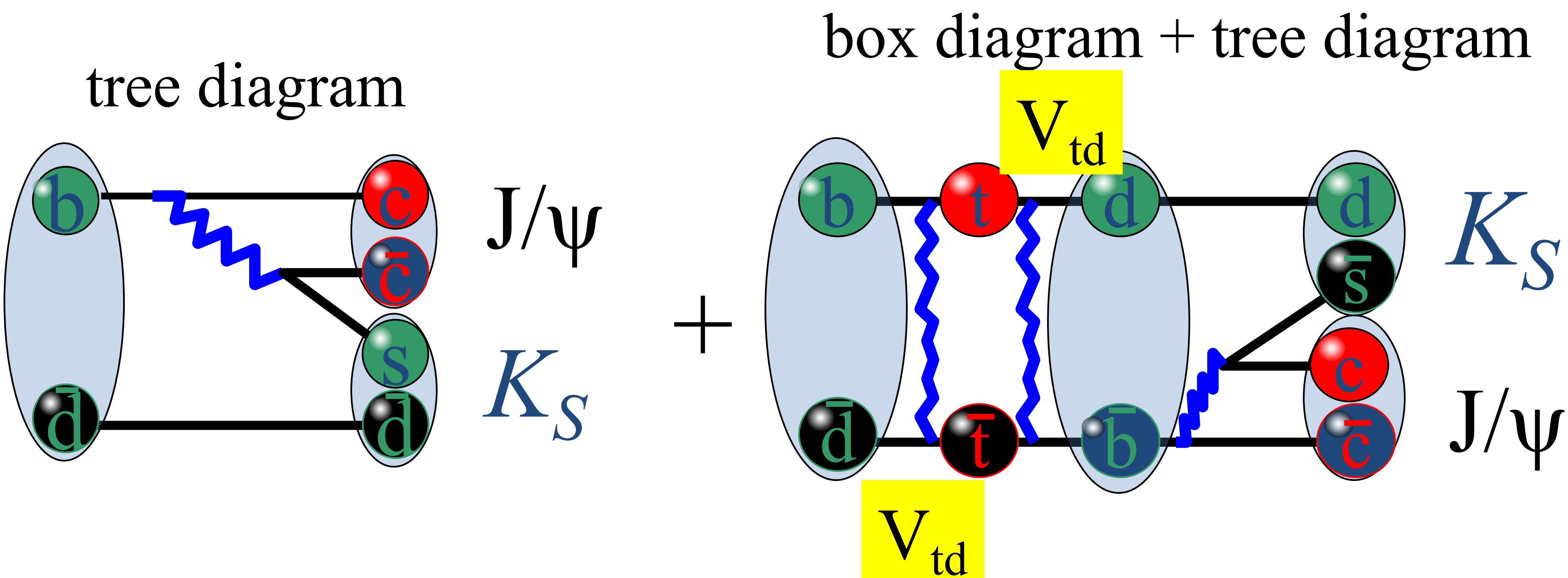
Two interfering amplitudes with a phase difference

Quantum Mechanical Interference between Diagrams for the same final state with a phase difference.

Time-dependent *CP* violation is

"*A Double-Slit experiment*" with particles and antiparticles

QM interference between two diagrams



Measures the *phase* *of* V_{td} *or equivalently the* *phase* *of* B_d*–anti* B_d *mixing.*

Some history: Summer of 2001

Belle:

VOLUME 87, NUMBER 9 PHYSICAL REVIEW LETTERS 27 AUGUST 2001

Observation of Large *CP* Violation in the Neutral *B* Meson System

We present a measurement of the standard model CP violation parameter $\sin 2\phi_1$ based on a 29.1 fb^{-1} data sample collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. One neutral B meson is fully reconstructed as a $J/\psi K_S$, $\psi(2S)K_S$, $\chi_{c1}K_S$, $\eta_c K_S$, $J/\psi K_L$, or $J/\psi K^{*0}$ decay and the flavor of the accompanying B meson is identified from its decay products. From the asymmetry in the distribution of the time intervals between the two B meson decay points, we determine $\sin 2\phi_1 = 0.99 \pm 0.14(\text{stat}) \pm 0.06(\text{syst})$. We conclude that we have observed CP violation in the neutral B meson system.

BaBar:

VOLUME 87, NUMBER 9 PHYSICAL REVIEW LETTERS 27 AUGUST 2001

Observation of *CP* Violation in the B^0 Meson System

We present an updated measurement of time-dependent CP-violating asymmetries in neutral B decays with the *BABAR* detector at the PEP-II asymmetric B Factory at SLAC. This result uses an additional sample of $\Upsilon(4S)$ decays collected in 2001, bringing the data available to 32×10^6 $B\overline{B}$ pairs. We select events in which one neutral B meson is fully reconstructed in a final state containing charmonium and the flavor of the other neutral B meson is determined from its decay products. The amplitude of the CP-violating asymmetry, which in the standard model is proportional to $\sin 2\beta$, is derived from the decay time distributions in such events. The result $\sin 2\beta = 0.59 \pm 0.14(\text{stat}) \pm 0.05(\text{syst})$ establishes CP violation in the B^0 meson system. We also determine $|\lambda| = 0.93 \pm 0.09(\text{stat}) \pm 0.03(\text{syst})$, consistent with no direct CP violation.

The first example of CP Violation outside of the kaon (strange quark) system. CP Violating Effects of O(1) rather than O(10^{-3})

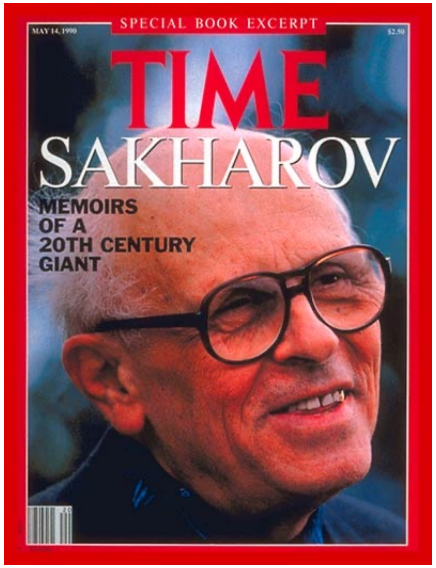
2008:

Critical Role of the B factories in Japan (KEK) and the US (SLAC) in the verification of the Kobayashi-Maskawa hypothesis was recognized and cited by the Nobel Foundation

A single irreducible complex phase accounts for all the matter-antimatter asymmetries in particle physics.

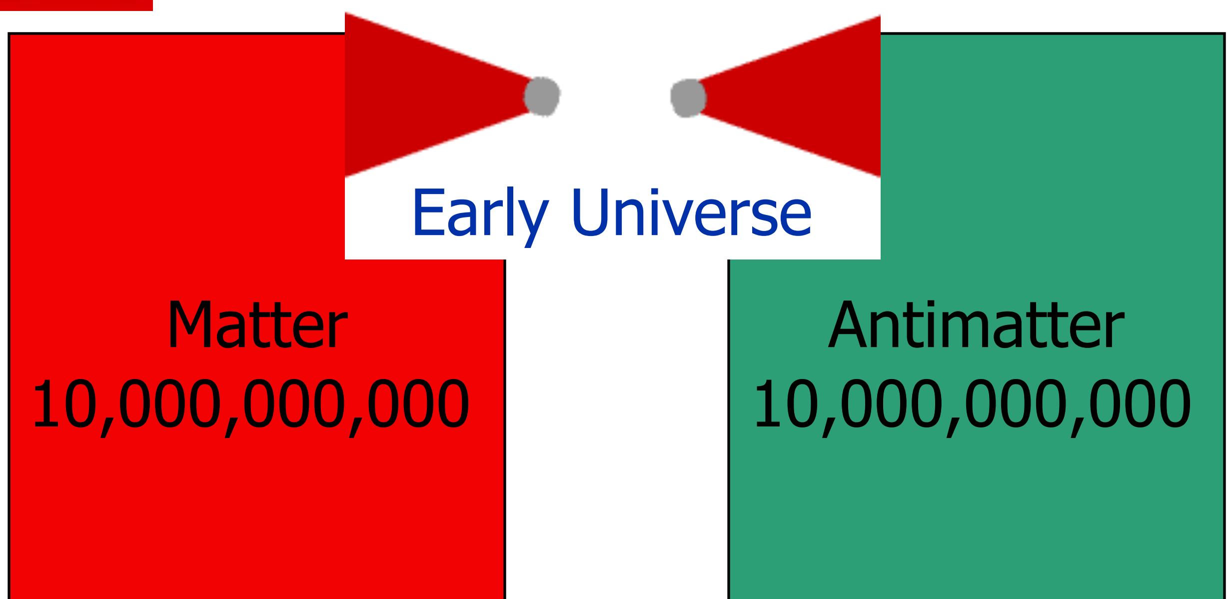
CP violating effects in the B sector are O(1) rather than O(10^{-3}) as in the kaon system.

Why is CP Violation Interesting ?



- *1967: Andrei Sakharov (brilliant Russian physicist and dissident): the cosmic connection linking particle physics with the existence of the Universe. CP violation (discovered in 1964 in neutral kaons) is the key.*

One of the three ingredients needed.



"Tsukuba, we have a Problem"

(with deep apologies to Tom Hanks and Apollo 13)

KEK DG Yamauchi

WMAP data

$$\eta \equiv \frac{n_b - n_{\bar{b}}}{n_\gamma} = (6.21 \pm 0.16) \times 10^{-10}$$

KM Theoretical prediction

$$\left(\frac{n_b}{n_\gamma}\right)^{\mathrm{SM}} \propto \frac{J_{CP}}{T_c^{12}} \sim 10^{-20}$$

What does this mean ?

The CP Violation (matter-antimatter asymmetry) predicted by Kobayashi and Maskawa is too small by *~10 orders of magnitude* in the Standard Model.

Physics Beyond the SM + Discoveries ahead in HEP.

Going back to our basic questions in high energy physics (HEP):

✓ 1) "What is particle-antiparticle mixing"

✓ 2) "What is the fundamental importance of "matter-antimatter asymmetry" (or CP violation) to the mystery of *why we exist*?"

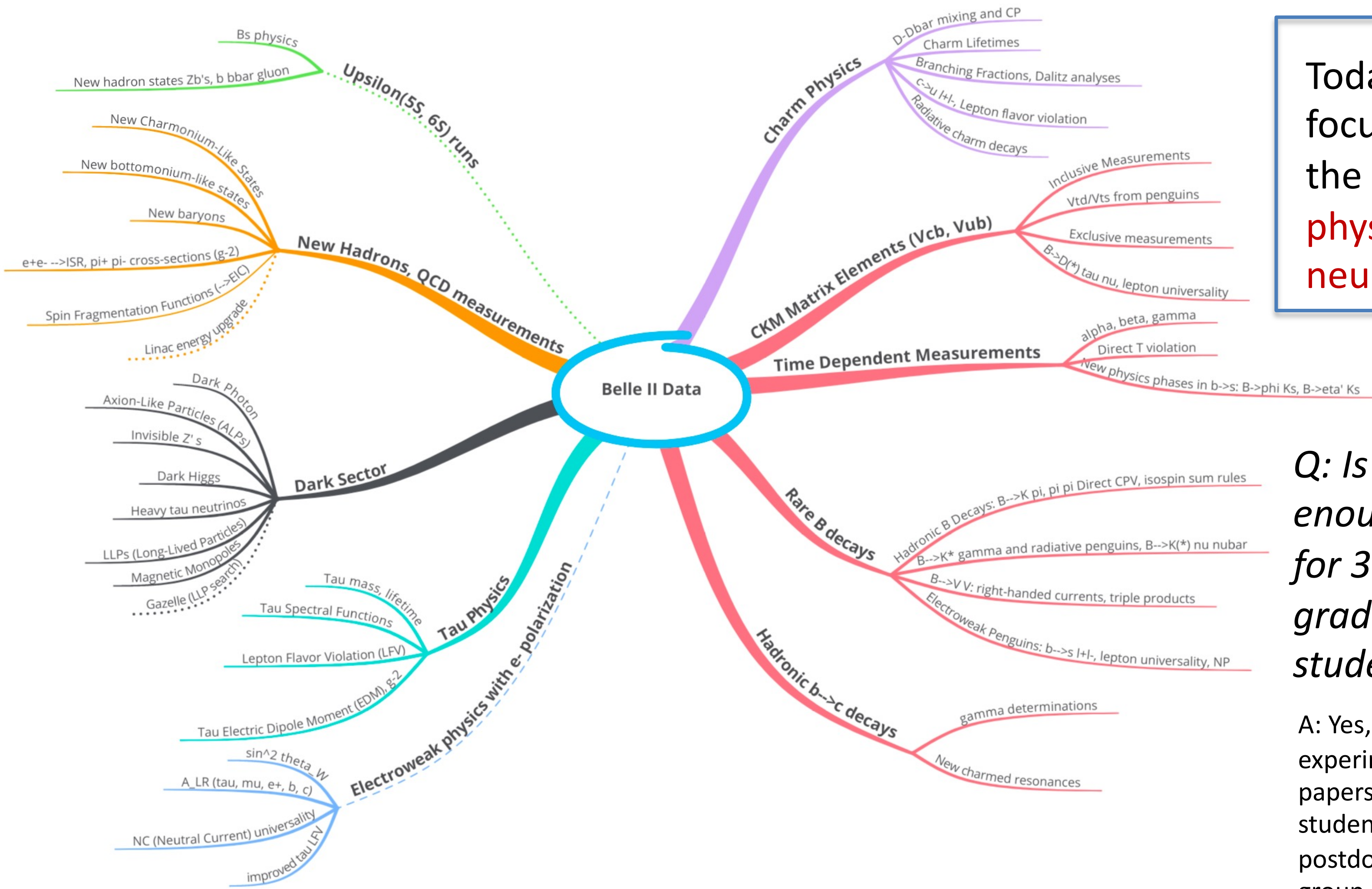
? 3) "Why are there three generations of quarks and leptons: " i.e. (u, d, e, ν_e), (c, s, μ, ν_μ), (t, b, τ, ν_τ)

4) "How are B physics and flavor physics connected to these fundamental questions ?"

Questions 3) and 4) are at the core of high energy physics.

Belle II Physics "Mind Map" for Snowmass 2022

Wealth of new physics possibilities in different domains of HEP (weak, strong, electroweak interactions). Many opportunities for *initiatives* by young scientists.



Today, we focus on the B physics neurons.

Q: Is there really enough physics for 300 graduate students ?

A: Yes, c.f. B factory experiments, >500 papers. Most by Phd student/advisor, postdoc or small group.

Dashed lines indicate extensions to SuperKEKB/Belle II that can enhance the physics reach of the facility. WP's https://confluence.desy.de/display/BI/Snowmass+2021

Revisionist History and Paradigm Shift

The B factory experiments, Belle and BaBar, discovered large CP violation in the B system in 2001, compatible with the SM and provided a large range of CKM measurements. These provided the experimental foundation for the 2008 Nobel Prize to Kobayashi and Maskawa.

In the meantime, the LHC was constructed in 2008, ATLAS and CMS *completely changed* the nature of high energy physics. Of particular importance was the landmark discovery in 2012 of the Higgs boson.

This discovery was recognized by the 2013 Physics Nobel Prize to Englert and Higgs.

In addition, the high pT experiments, established tight constraints on direct production of high mass particles (e.g. M(Z'), M(W')>3 TeV, vector-like fermions > 800 GeV) and limits on SUSY. This *noble search* continues with the high luminosity LHC.

Paradigm shift: inspired by intriguing results from B factories, LHCb and the potential of Belle II, the possibility of finding new physics in flavor has emerged as a *alternate* route to going beyond the SM.

Younger theorists: Dark Sector may be another path.

At Snowmass in 2022, we explored the "Vision Thing" for Belle II/SuperKEKB

What happens at 50 ab^{-1} and beyond ?

Belle II
Higher sensitivity to decays with photons and neutrinos (e.g. $B \to K\nu\nu$, $\mu\nu$), inclusive decays, time dependent CPV in B_d, τ physics.

LHCb
Higher production rates for ultra rare B, D, & K decays, access to all b-hadron flavours (e.g. Λ_b), high boost for fast B_s oscillations.

Overlap in various key areas to verify discoveries.

Upgrades
Most key channels will be stats. limited (not theory or syst.).

Observable	2022 Belle(II), BaBar	2022 LHCb	Belle-II 5 ab^{-1}	Belle-II 50 ab^{-1}	LHCb 50 fb^{-1}	Belle-II 250 ab^{-1}	LHCb 300 fb^{-1}
$\sin 2\beta/\phi_1$	0.03	0.04	0.012	0.005	0.011	0.002	0.003
γ/ϕ_3	11°	4°	4.7°	1.5°	1°	0.8°	0.35°
α/ϕ_2	4°	–	2°	0.6°	–	0.3°	–
$\|V_{ub}\|/\|V_{cb}\|$	4.5%	6%	2%	1%	2%	< 1%	1%
$S_{CP}(B \to \eta' K^0_S)$	0.08	–	0.03	0.015	–	0.007	–
$A_{CP}(B \to \pi^0 K^0_S)$	0.15	–	0.07	0.04	–	0.018	–
$S_{CP}(B \to K^{*0}\gamma)$	0.32	–	0.11	0.035	–	0.015	–
$R(B \to K^* \ell^+ \ell^-)^\dagger$	0.26	0.12	0.09	0.03	0.022	0.01	0.009
$R(B \to D^* \tau\nu)$	0.018	0.026	0.009	0.0045	0.0072	<0.003	<0.003
$R(B \to D \tau\nu)$	0.034	–	0.016	0.008	–	<0.003	–
$\mathcal{B}(B \to \tau\nu)$	24%	–	9%	4%	–	2%	–
$\mathcal{B}(B \to K^* \nu\bar{\nu})$	–	–	25%	9%	–	4%	–
$\mathcal{B}(\tau \to e\gamma)$ UL	42×10^{-9}	–	22×10^{-9}	6.9×10^{-9}	–	3.1×10^{-9}	–
$\mathcal{B}(\tau \to \mu\mu\mu)$ UL	21×10^{-9}	46×10^{-9}	3.6×10^{-9}	0.36×10^{-9}	1.1×10^{-9}	0.07×10^{-9}	5×10^{-9}

The dagger refers to a measurement in the range $1 < q^2 < 6$ GeV^2/c^2

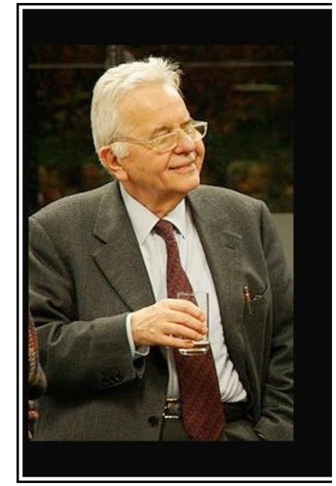
JAHEP report to Snowmass: Arxiv 2203:13979

Consideration of further luminosity upgrade and electron polarization capability of SuperKEKB are started for ultimate new physics searches with heavy flavor quarks and leptons including τ lepton $g-2$ in the light of muon $g-2$ anomaly [28].

Backup slides on e- polarization and electroweak measurements.

Preliminaries:

The Cabibbo matrix



$$\begin{pmatrix} d' \\ s' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} \\ V_{cd} & V_{cs} \end{pmatrix} \begin{pmatrix} d \\ s \end{pmatrix}$$

This is a simple rotation matrix.

$$\begin{pmatrix} d' \\ s' \end{pmatrix} = \begin{pmatrix} \cos\theta_c & \sin\theta_c \\ -\sin\theta_c & \cos\theta_c \end{pmatrix} \begin{pmatrix} d \\ s \end{pmatrix}$$

The rotation angle is the Cabibbo angle, $\sin\theta_c \sim 0.22$

CKM weak interaction exercise

There are no free quarks. Need to work with hadrons.

Estimate the following ratios

$$1)\frac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to \pi^+K^-)};$$

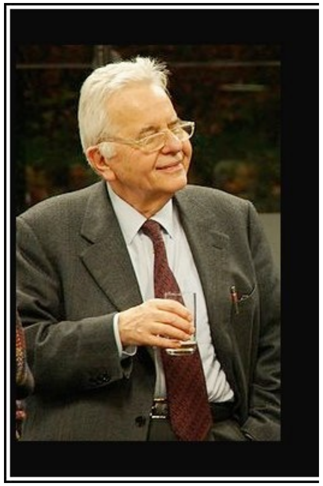
$$2)\frac{\Gamma(D^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to \pi^+K^-)};$$

$$3)\frac{\Gamma(D^0 \to K^+\pi^-)}{\Gamma(D^0 \to \pi^+K^-)}$$

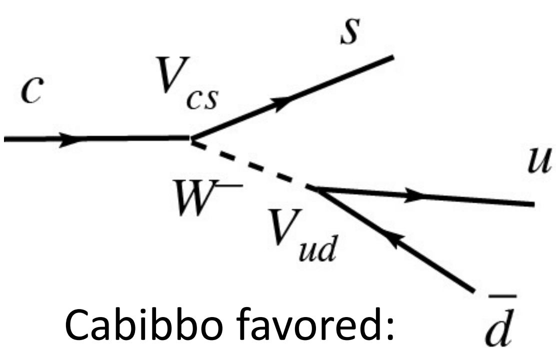
The first two are “singly Cabibbo suppressed”.

The last one is “doubly Cabibbo suppressed.”

Weak interaction example

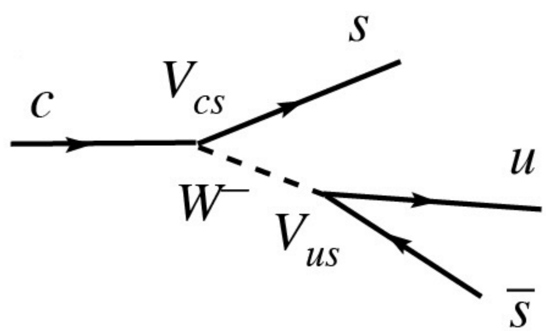


a)



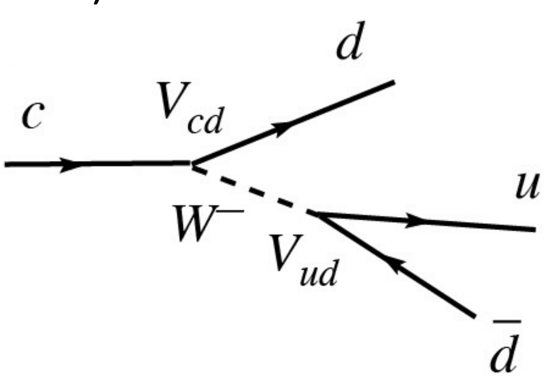
Cabibbo favored:
$V_{cs}V_{ud}$ (~1)

b)



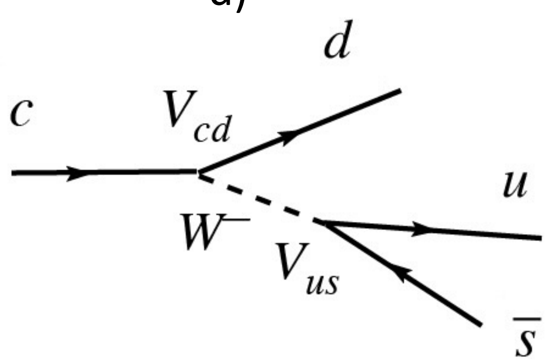
Singly Cabibbo suppressed: $V_{cs}V_{us}$ ($\sin\theta_c$)

c)



Singly Cabibbo suppressed: $V_{cd}V_{ud}$ ($\sin\theta_c$)

d)



Doubly Cabibbo suppressed: $V_{cd}V_{us}$ ($\sin^2\theta_c$)

Let's count Cabibbo factors.

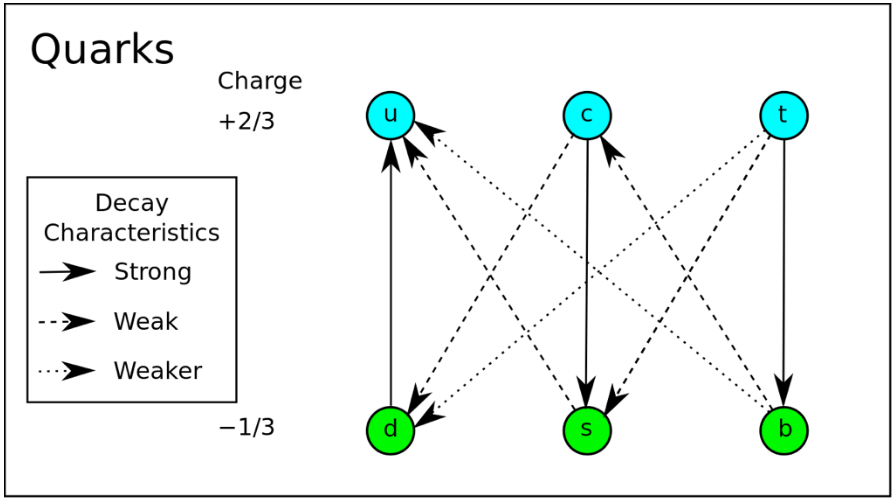
A review of a few weak interaction fundamentals that you and I need to know for Belle II Physics.

Q: What is a rare decay of a B meson ?

Ans 1: A decay that is suppressed.

But compared to what ?

Ans: **Suppressed compared to a decay involving a b→c transition**, which is dominant (since b is a “d-type quark”).



Q: So which transitions give rise to rare decays ?

Ans 1: *Decays that involve a jump in generations.*

Ans 2: b→u decays

Q: But what about b→s or b→d transitions, why aren’t they shown here ?

Spoiler Alert: Do not occur at 1st order in the weak interaction.

Weak Interaction Coupling Constants

$$\begin{pmatrix} d' \\ s' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} \\ V_{cd} & V_{cs} \end{pmatrix} \begin{pmatrix} d \\ s \end{pmatrix}$$

The full CKM (Cabibbo Kobayashi Maskawa) matrix

Schwartz, Prell

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

3 X 3 unitary matrix with a single irreducible complex phase

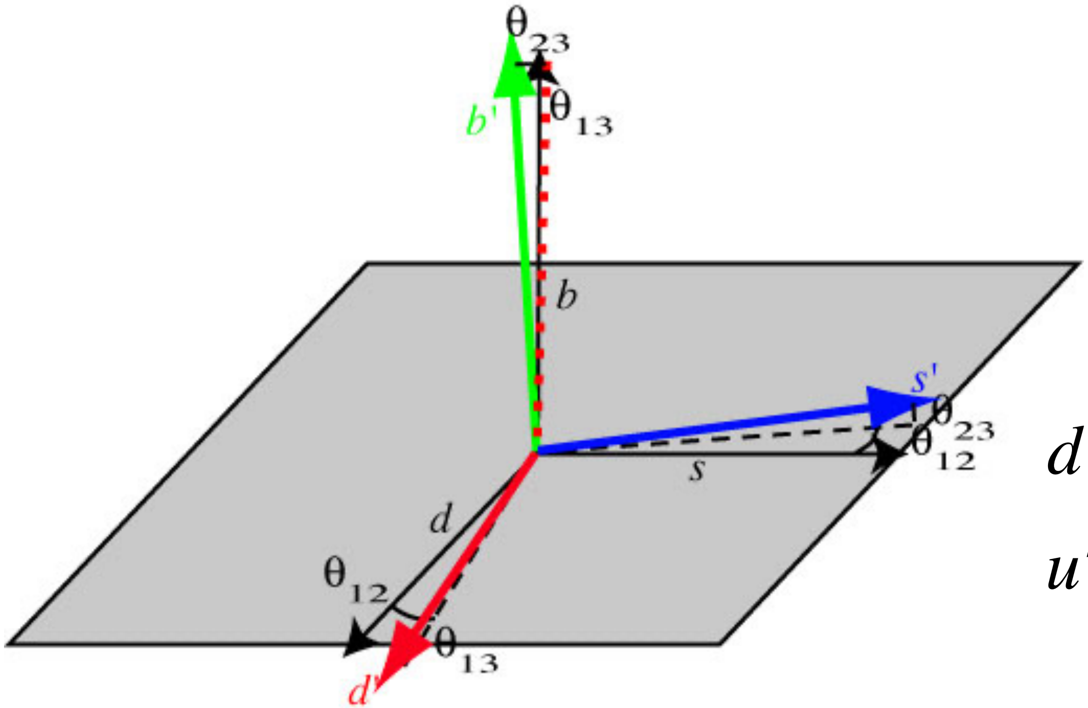
$$\begin{pmatrix} 0.9739 \text{ to } 0.9751 & 0.221 \text{ to } 0.227 & 0.0029 \text{ to } 0.0045 \\ 0.221 \text{ to } 0.227 & 0.9730 \text{ to } 0.9744 & 0.039 \text{ to } 0.044 \\ 0.0048 \text{ to } 0.014 & 0.037 \text{ to } 0.043 & 0.9990 \text{ to } 0.9992 \end{pmatrix}$$

Notice the pattern along and off the diagonal of the matrix of the magnitudes.

Measurement of CKM matrix element in Schwartz's talk

The CKM rotation matrix

Prell, Schwartz



Parameter counting: a complex 3 x 3 unitarity matrix has 9 independent elements.

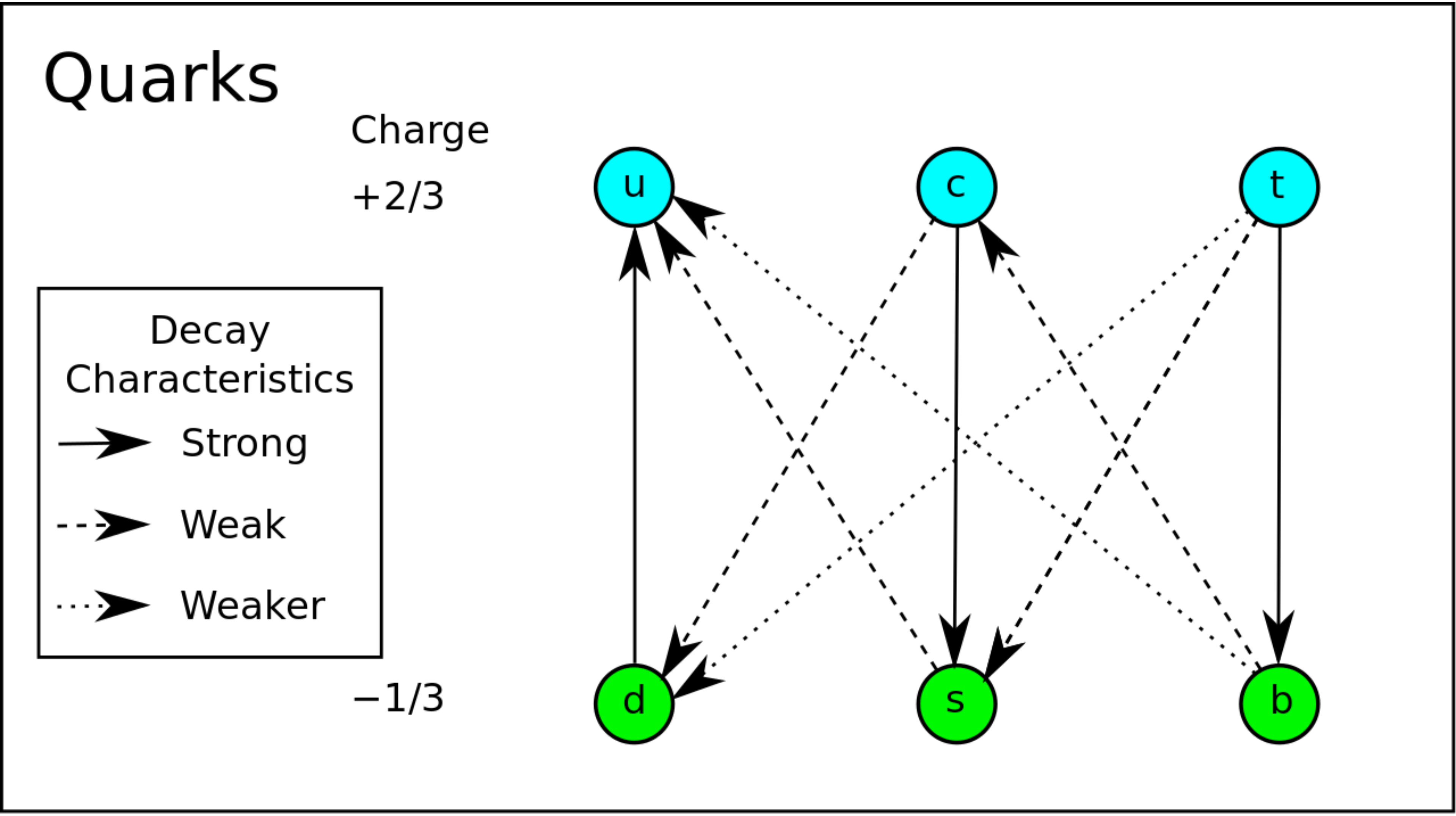
Rephasing invariance

$$d^k \rightarrow e^{i\theta_k} d^k \quad V_{ik} \rightarrow e^{-i\theta_k} \quad \text{or}$$

$$u^k \rightarrow e^{i\theta_k} u^k \quad V_{ik} \rightarrow e^{-i\theta_k}$$

$$\begin{pmatrix} \bar{u} & \bar{c} & \bar{t} \end{pmatrix} \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

In the end, there are three rotation angles and one irreducible complex phase factor $e^{i\delta}$



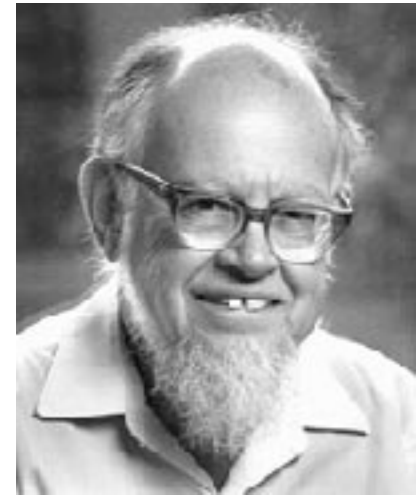
Jumping generations is highly suppressed.

The b quark is a "d-type" lower generation quark [but the c quark is a "u-type" quark]

And remember the strong interaction does NOT change flavor

Things are quite clear in the Wolfenstein parameterization of the CKM matrix.

$$\begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$



Lincoln Wolfenstein

In the end, there are three rotation angles and one complex phase factor $e^{i\delta}$

Question: What are the three real parameters and phase in the Wolfenstein parameterization ?

Ans: A, λ, ρ and η

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Weak Interaction Review question/quiz:

Find the valence quark composition, dependence on CKM matrix elements and relative rates of the following processes (order them by strength).

$$1)\ B^0 \to D^- \pi^+$$

$$2)\ B^0 \to \pi^- \pi^+$$

$$3)\ B^0 \to \pi^- K^+$$

$$4)\ B^0 \to D^- K^+$$

Hint: B^0 = bbar d or anti-B^0= b dbar

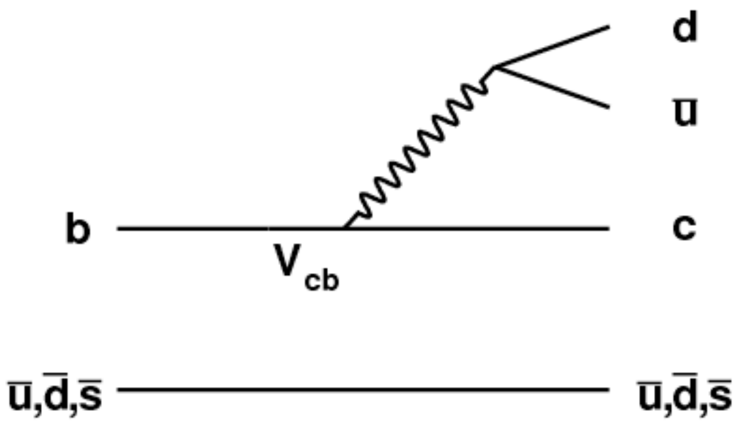
$$1)\ B^0 \to D^- \pi^+$$

$$2)\ B^0 \to \pi^- \pi^+$$

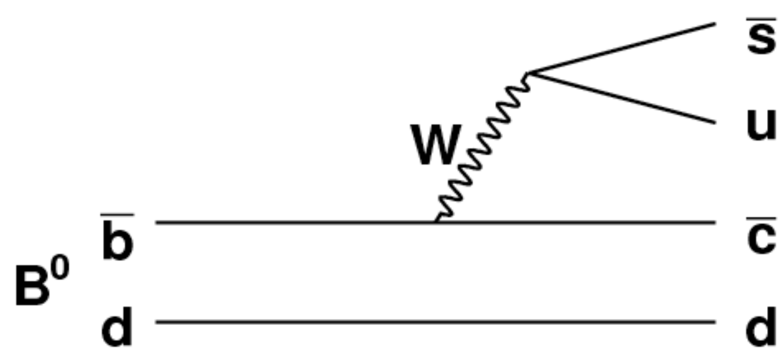
$$3)\ B^0 \to \pi^- K^+$$

$$4)\ B^0 \to D^- K^+$$

Feynman diagram for process 1)



Can you draw the Feynman diagram for process 4) ? (Hint: it is Cabibbo suppressed).



Trees and Penguins

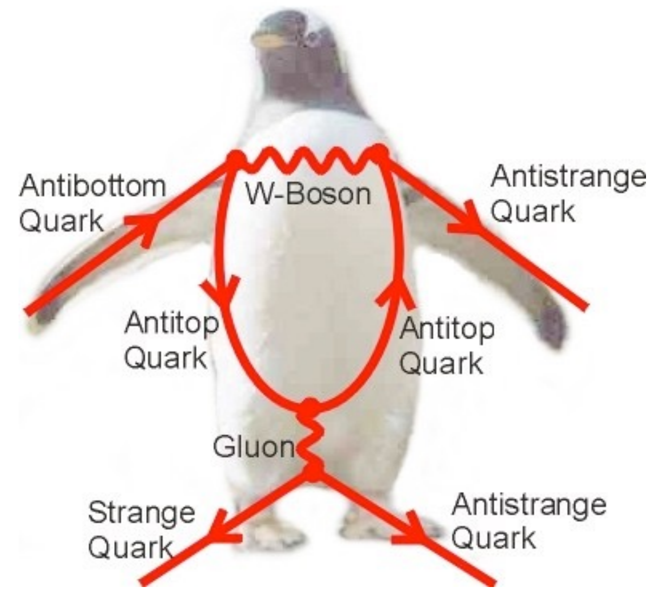
1) $B^0 \rightarrow D^-\pi^+$

2) $B^0 \rightarrow \pi^-\pi^+$

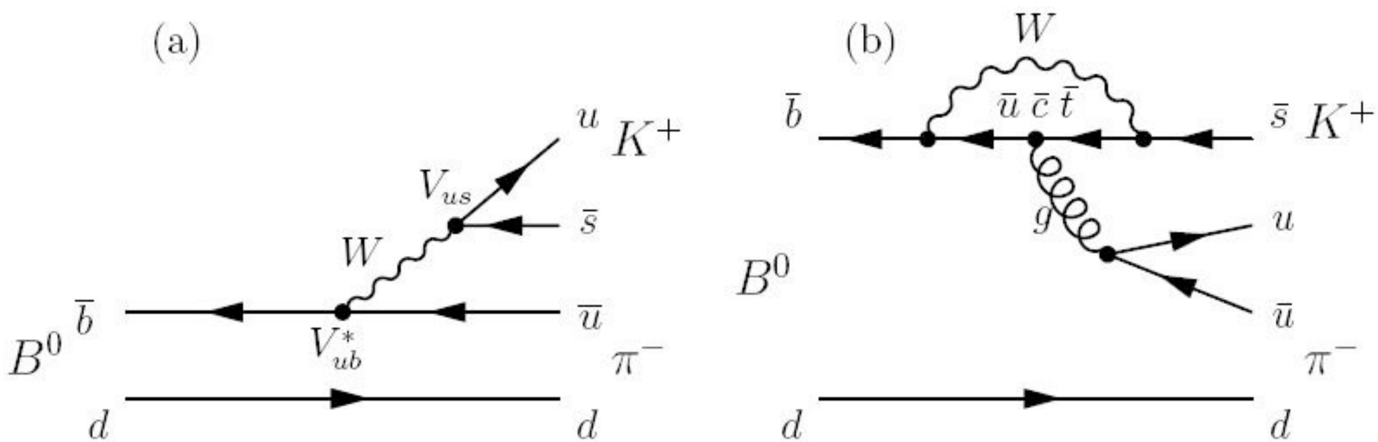
3) $B^0 \rightarrow \pi^-K^+$

4) $B^0 \rightarrow D^-K^+$

Rare Decay Mascot



Feynman diagrams for process 3)



Feynman tree (a) and penguin (b) diagrams for the $B_d^0 \rightarrow K^+\pi^-$ decay

Both amplitudes contribute, Penguin is larger.

Trees and Penguins

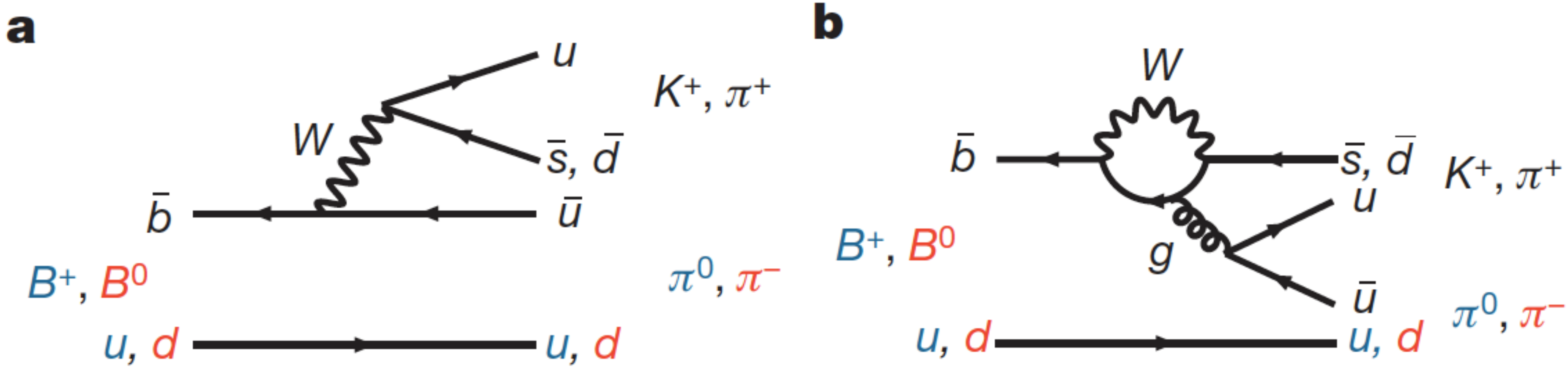
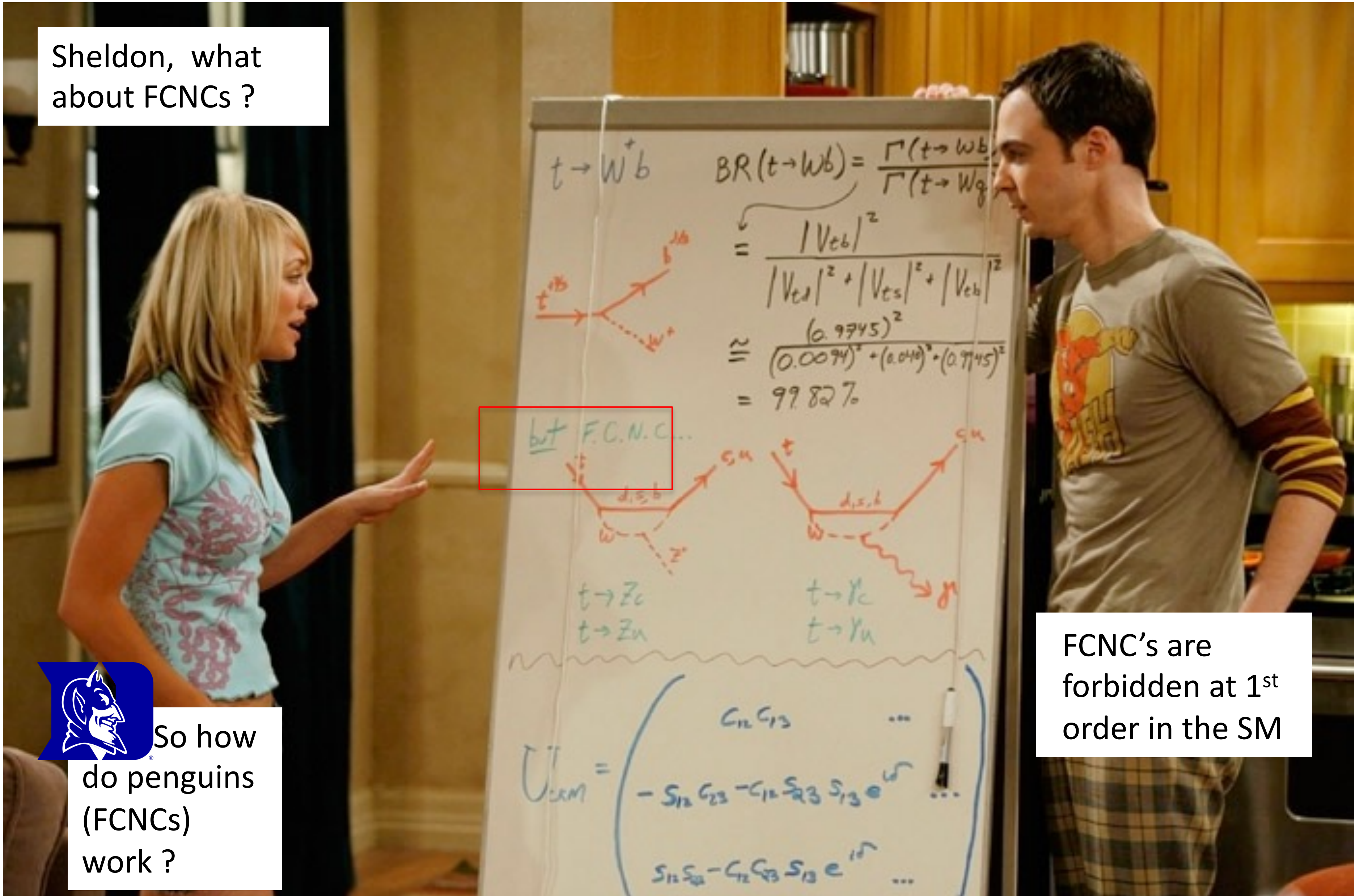


Figure 17.4.4. The dominant Tree-level (a) and Penguin-loop (b) Feynman diagrams in the two-body decays $B \to K\pi$ and $B \to \pi\pi$ (Lin, 2008).

Q: How do the penguin and contributions compare in these two cases (i.e. K pi, pi pi) ?

Of course it is also possible to have three or four-body rare decays....Three body decays can be studied by fitting their Dalitz plots, taking quantum mechanical interference into account. Amplitude analyses needed for 4-body decays.

US TV Show, Big Bang Theory Episode (FCNCs)



Sheldon, what about FCNCs ?

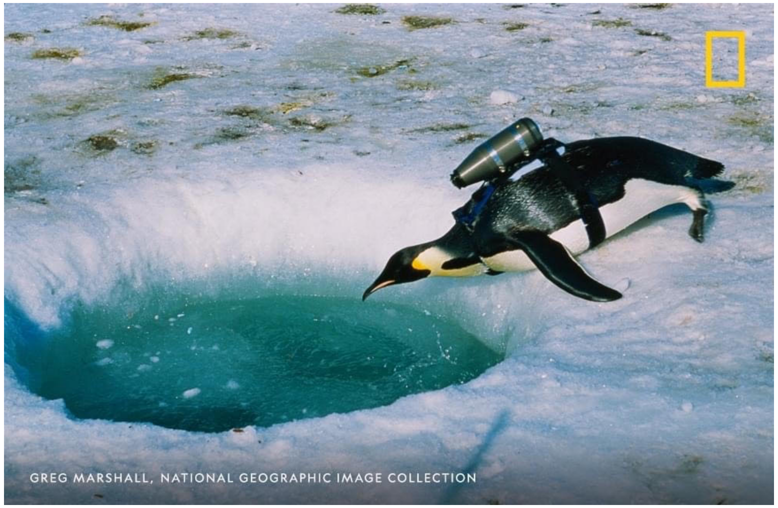
So how do penguins (FCNCs) work ?

FCNC's are forbidden at 1st order in the SM

At Snowmass 2023 we considered how Belle II might discover physics Beyond the SM (BSM)

Research penguin

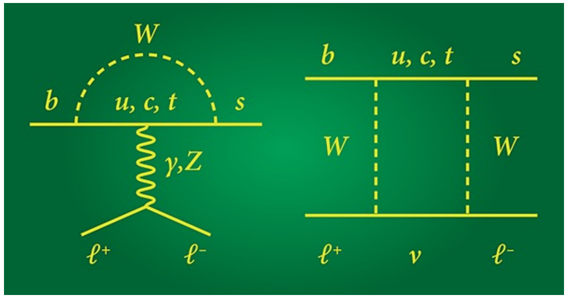
Photo Credit: National Geographic

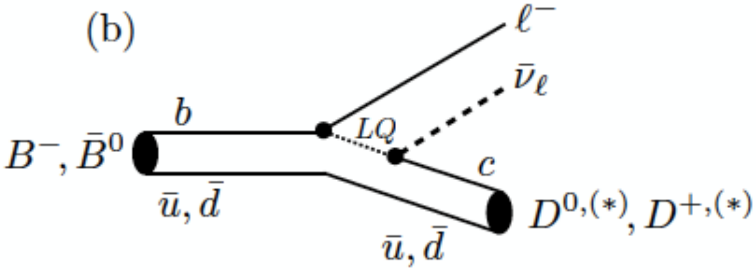


Sequoia National Forest

Exploring the unknown with b→s "electroweak penguins": (weak neutral current or FCNC)

Discovering NP with b→c l ν "trees": (weak charged current)





2019

Re-discovery of Radiative Penguins at Belle II

1975: Vainshtein, Zakharov and Shifman

Examine the following b→s γ decay modes in the Belle II Phase 3 dataset.

$$B^0 \to K^{*0}\gamma \to K^+\pi^-\gamma$$

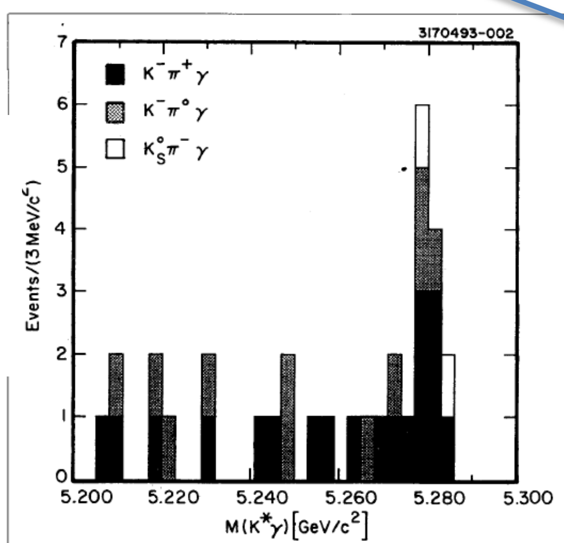
$$B^+ \to K^{*+}\gamma \to K^+\pi^0\gamma$$

$$B^+ \to K^{*+}\gamma \to K_S^0\pi^+\gamma$$

1993 CERN Courier:

CORNELL CLEO discovers B meson penguins

N.B. Using 1.5 x 10^6 B meson pairs



John Ellis, the CERN theorist who coined the name "Penguin" (a type of FCNC).

Ed Thorndike, Rochester, CLEO

Belle II's CsI(Tl) calorimeter (~Belle with improved waveform sampling and timing). 8736 crystals covering 90% of the solid angle.

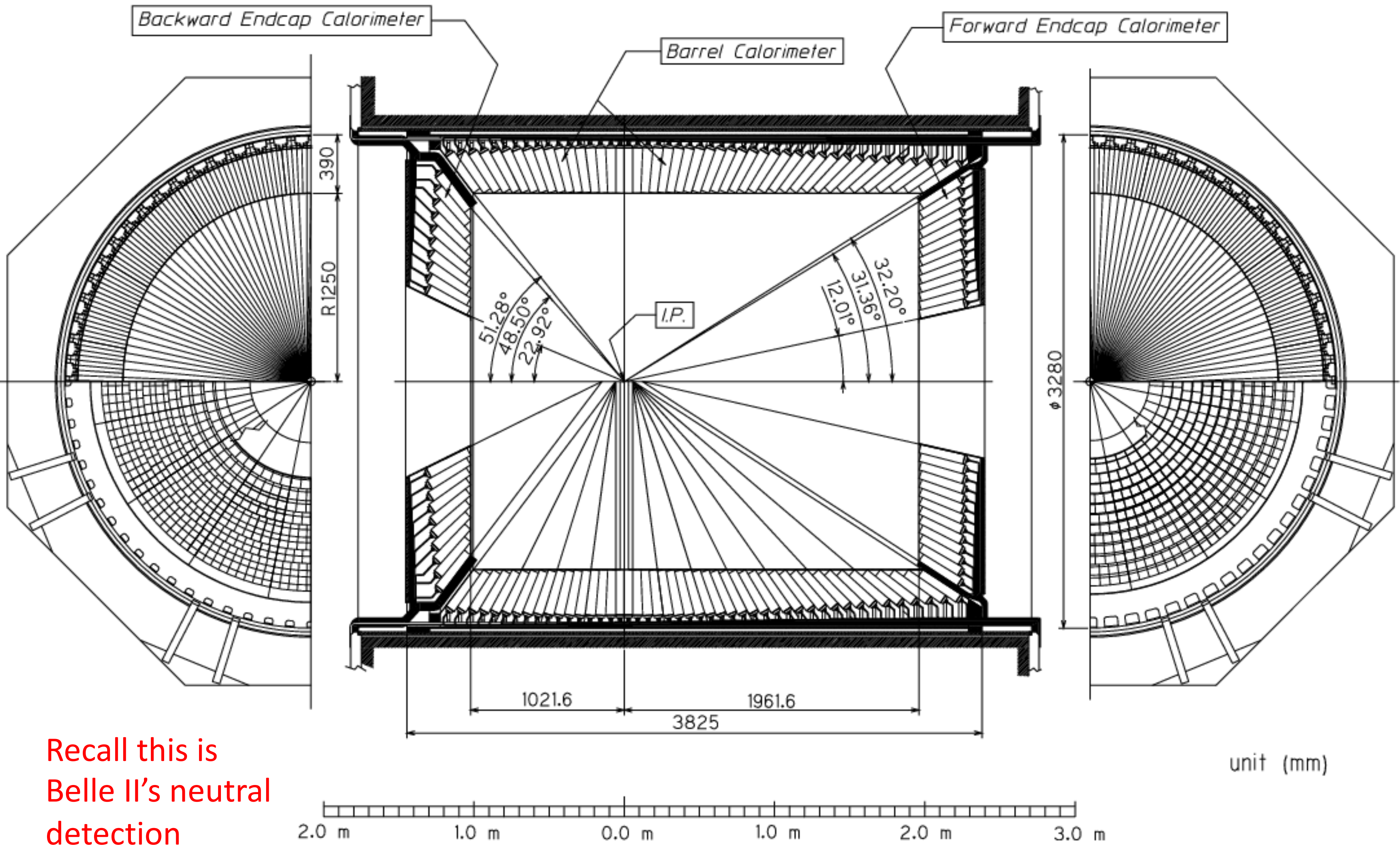


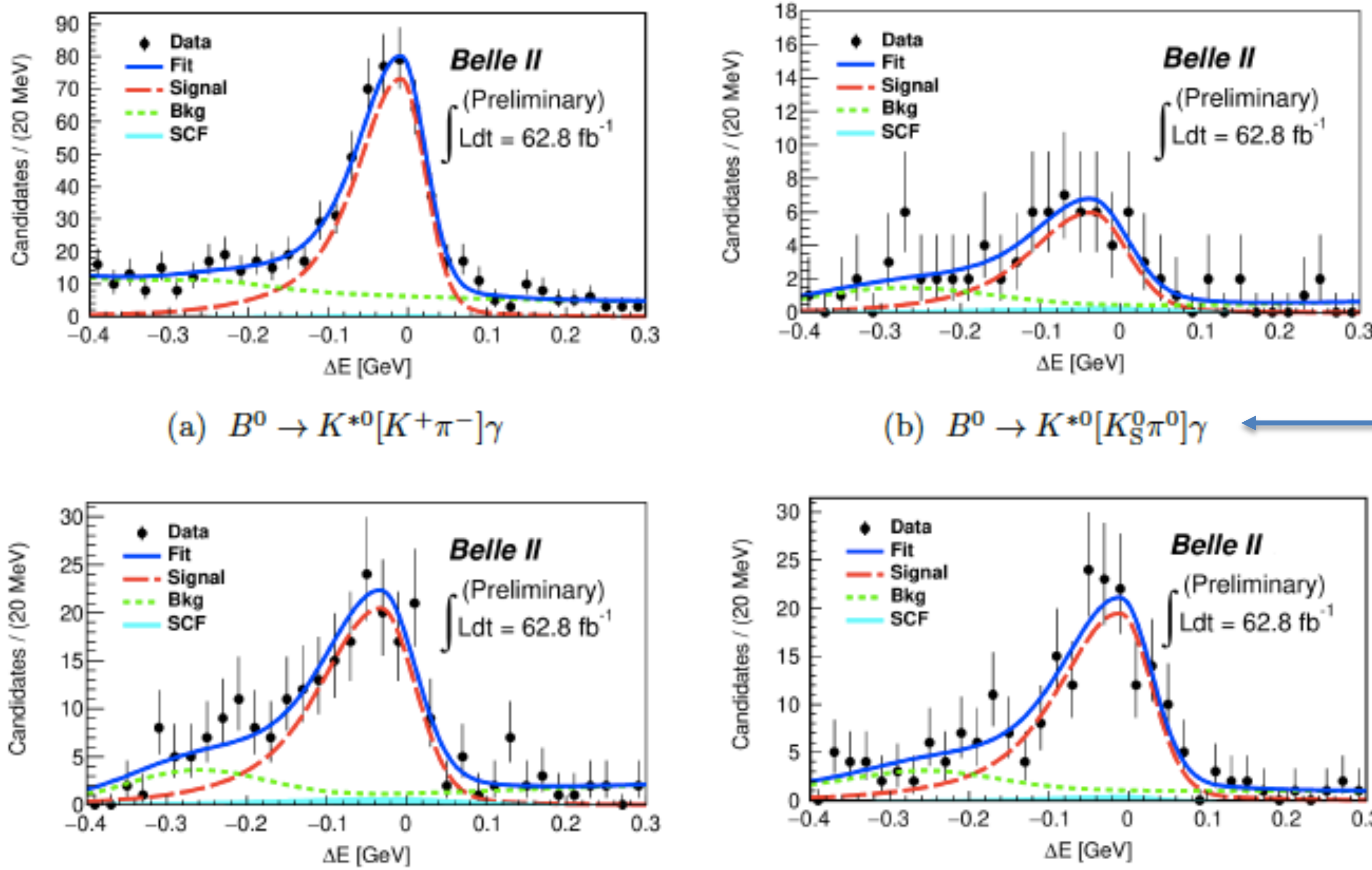
Fig. 69. Overall configuration of ECL.

Recall this is Belle II's neutral detection superpower

Belle II, 2021

$$\Delta E = E_{recon} - E_{beam}$$

BELLE2-CONF-2021-028, Radiative Penguin Status



(a) $B^0 \to K^{*0}[K^+\pi^-]\gamma$

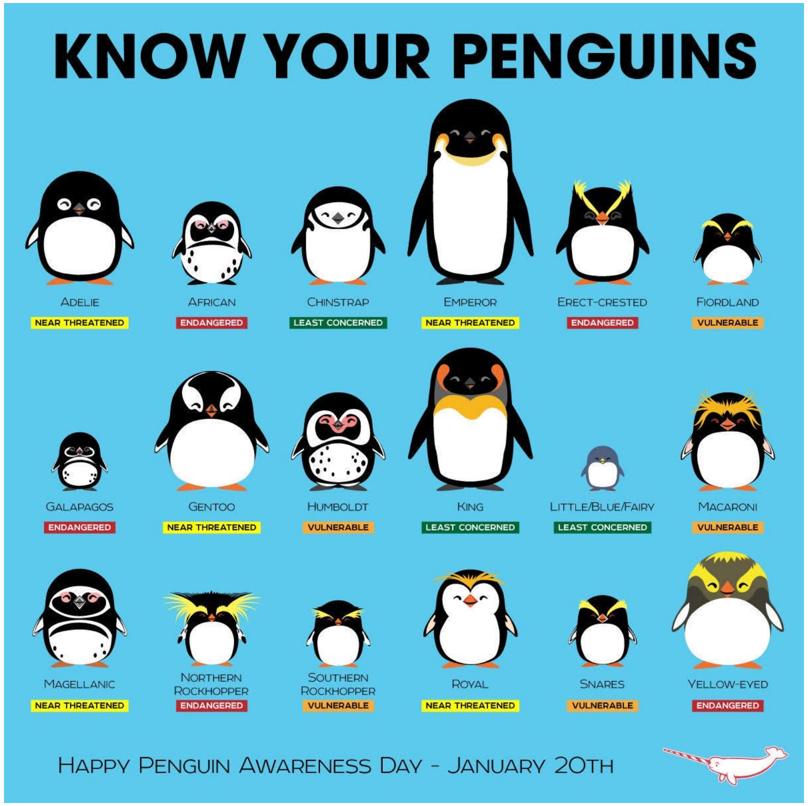
(b) $B^0 \to K^{*0}[K^0_S\pi^0]\gamma$

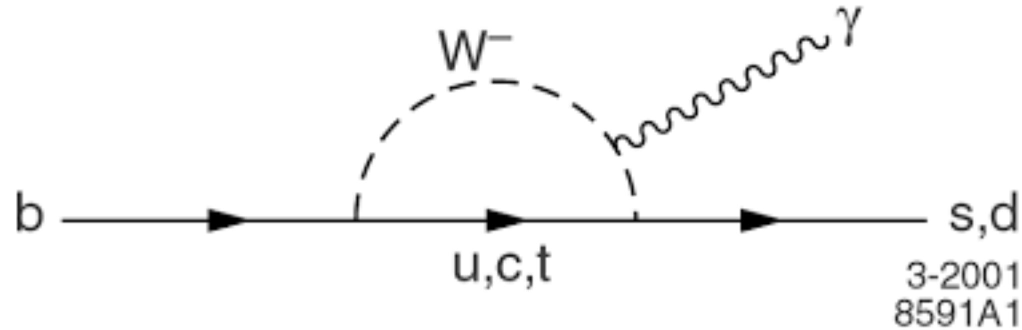
(c) $B^+ \to K^{*+}[K^+\pi^0]\gamma$

(d) $B^+ \to K^{*+}[K^0_S\pi^+]\gamma$

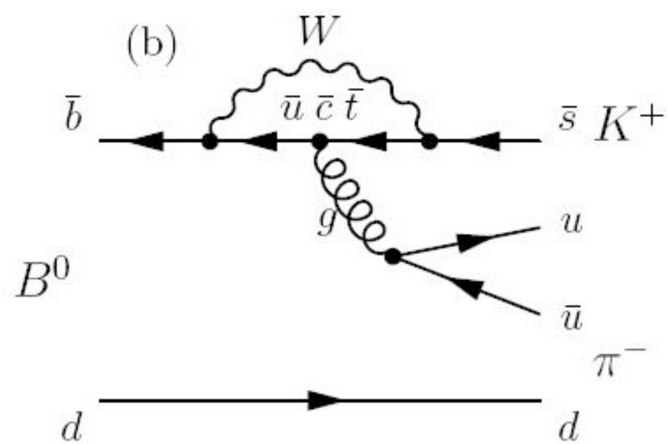
Figure 2. ΔE distributions for each $B \to K^*\gamma$ mode with the fit result superimposed. The black dots with error bars denote the data, the blue curve denotes the total fit, the dashed red curve is the signal component, the dotted green curve is the background component, and the filled cyan region is the misreconstructed signal component.

Recap:





"Radiative Penguin"
(b-->s photon)



"Gluonic Penguin"
(b->s gluon)

Q: But there is one more in our penguin taxonomy. Do you remember what it is?

A. Electroweak penguins.
(e.g. b-->s l+ l-)

nature Vol 452|20 March 2008|doi:10.1038/nature06827

An old anomaly:

LETTERS

In 2008, "the K pi puzzle" appeared in Nature.
Charged and neutral A(CP's) for B→Kπ penguins differ.
Is this a sign of new physics ? *How do we tell ?*

Difference in direct charge-parity violation between charged and neutral *B* meson decays

The Belle Collaboration*

Also confirmed by BaBar

$\mathcal{A}_{CP}$			
Mode	BaBar	Belle	LHCb
$K^+\pi^-$	$-0.107 \pm 0.016^{+0.006}_{-0.004}$	$-0.069 \pm 0.014 \pm 0.007$	$-0.080 \pm 0.007 \pm 0.003$
$K^+\pi^0$	$0.030 \pm 0.039 \pm 0.010$	$0.043 \pm 0.024 \pm 0.002$	0.025+-0.015+0.006
$K^0\pi^+$	$-0.029 \pm 0.039 \pm 0.010$	$-0.011 \pm 0.021 \pm 0.006$	$-0.022 \pm 0.025 \pm 0.010$
$K^0\pi^0$	$-0.13 \pm 0.13 \pm 0.03$	$0.14 \pm 0.13 \pm 0.06$	

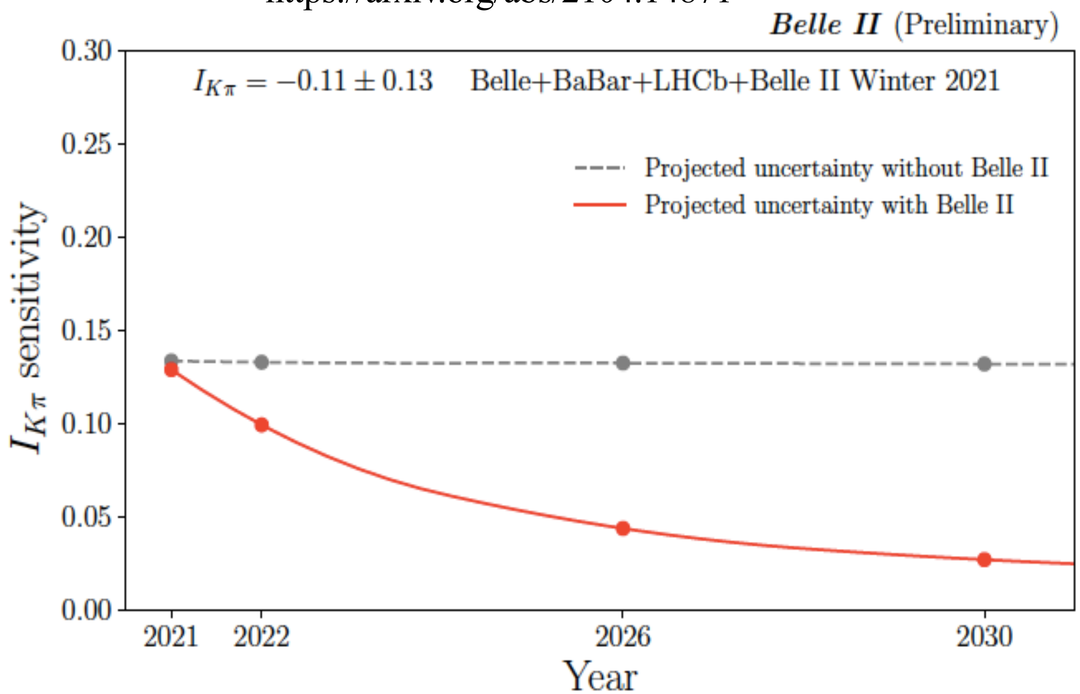
In summary, we have measured the CP asymmetries for $B \to K^\pm\pi^\mp$, $K^\pm\pi^0$ and $\pi^\pm\pi^0$ using 535 million $B\bar{B}$ pairs. Direct CP violation in $B^\pm \to K^\pm\pi^\mp$ is observed, accompanied by a large deviation between $\mathcal{A}_{K^\pm\pi^\mp}$ and $\mathcal{A}_{K^\pm\pi^0}$. Although this deviation could be due to our limited understanding of the strong interaction, the difference in direct CP asymmetries for charged versus neutral B decays may be an indication of new sources of CP violation beyond the standard model of particle physics.

The isospin sum rule in the next decade.

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

Michael Gronau

https://arxiv.org/abs/2104.14871



The isospin sum rule detects enhanced NP electroweak penguins in B→K π

With Belle II@250 ab^{-1} , expect a sensitivity of ~0.018

Requires neutrals *and* flavor tagging.

Without Belle II measurements of $A_{CP}(B^0 \rightarrow K^0 \pi^0)$, we are stuck.

FIG. 4. The projected uncertainty on $I_{K\pi}$ with and without Belle II inputs. The inputs for $I_{K\pi}$ are averages of the estimated updates from ongoing LHCb and Belle II experiments with current world averages [10]. The red curve shows a projection when updates on the complete set of $K\pi$ measurements are considered, and the grey curve is the case if only $A_{K^+\pi^-}, A_{K^+\pi^0}, A_{K^0\pi^+}$ are updated by LHCb. The projection corresponds to the luminosity plans from LHCb and Belle II.

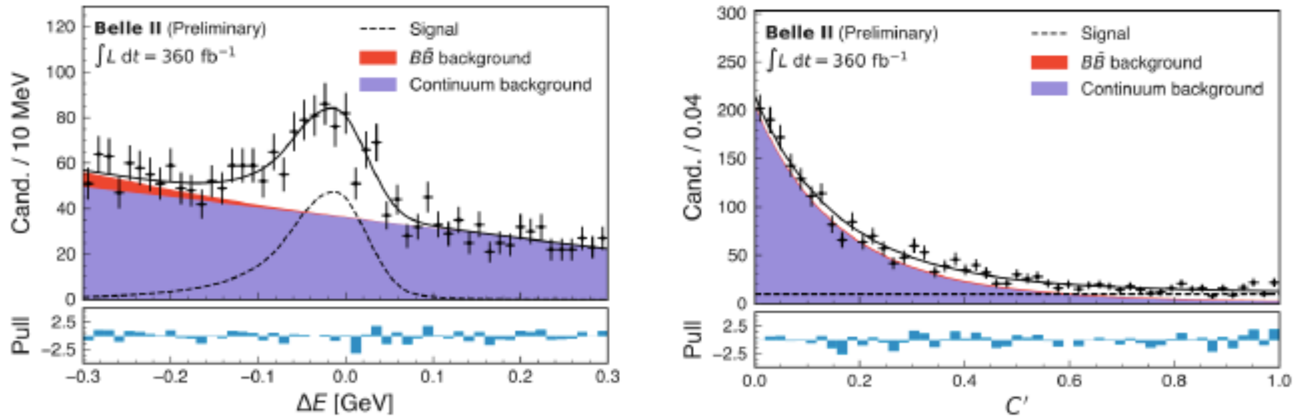
LaThuile/Moriond 2023: Belle II reported a new result on the B-->h h isospin sum rule.

Skio details: A_CP(Ks pi^0) can be measured at Belle II

Isospin sum rule: $K^0\pi^0$ time-integrated asymmetry

- Complementary measurement of $A_{K^0\pi^0}$ using time-integrated analysis
- Requires flavor tagging to tag $B^0/\bar{B}^0$, $\epsilon_{tag} = 30.0 \pm 1.2\%$
- $P_{sig}(q) = \frac{1}{2}.(1 + q.(1 - 2w_r).(1 - 2.\chi_d).A_{K^0\pi^0})$, where q : flavor of the B meson, w_r : wrong-tag fraction and χ_d : B^0 mixing parameter

New for Moriond



Signal yield=502 ± 32

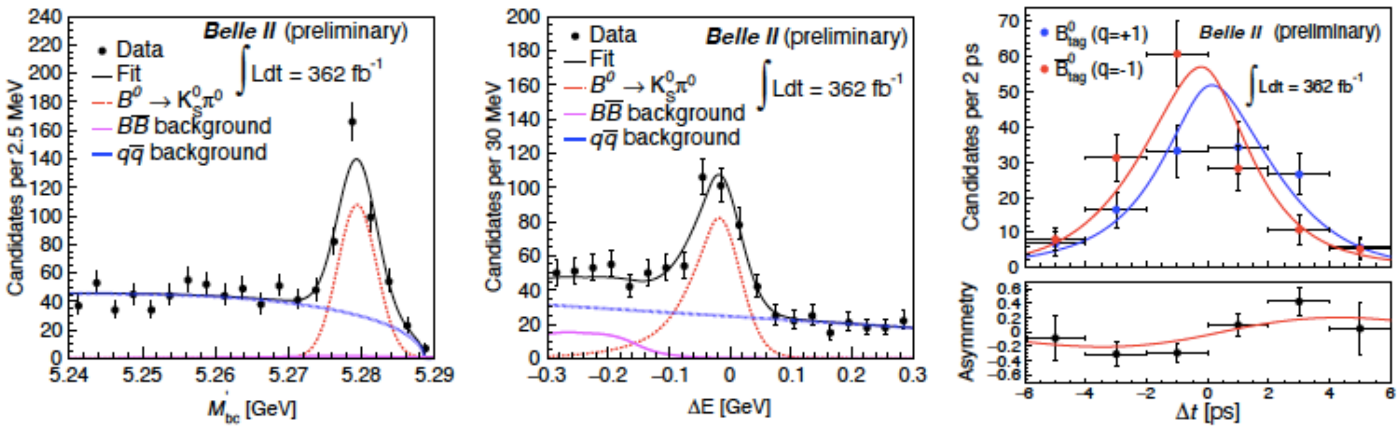
$$\mathscr{B}(B^0 \to K^0\pi^0) = [10.2 \pm 0.6(stat) \pm 0.6(syst)] \times 10^{-6}$$

$$A_{K^0\pi^0} = -0.06 \pm 0.15(stat) \pm 0.05(syst)$$

Skip details

Isospin sum rule: $K^0\pi^0$ time-dependent asymmetry

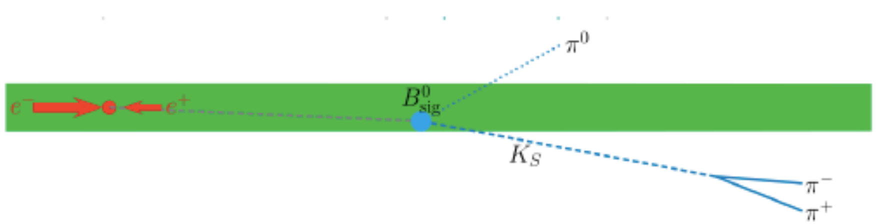
New for Moriond



Signal yield $=415 \pm 25$

$A_{CP} = 0.04 \pm 0.15(stat) \pm 0.05(syst)$, $S_{CP} = 0.75^{+0.20}_{-0.23}(stat) \pm 0.04(syst)$

Idea: Ks vertexing in the silicon.

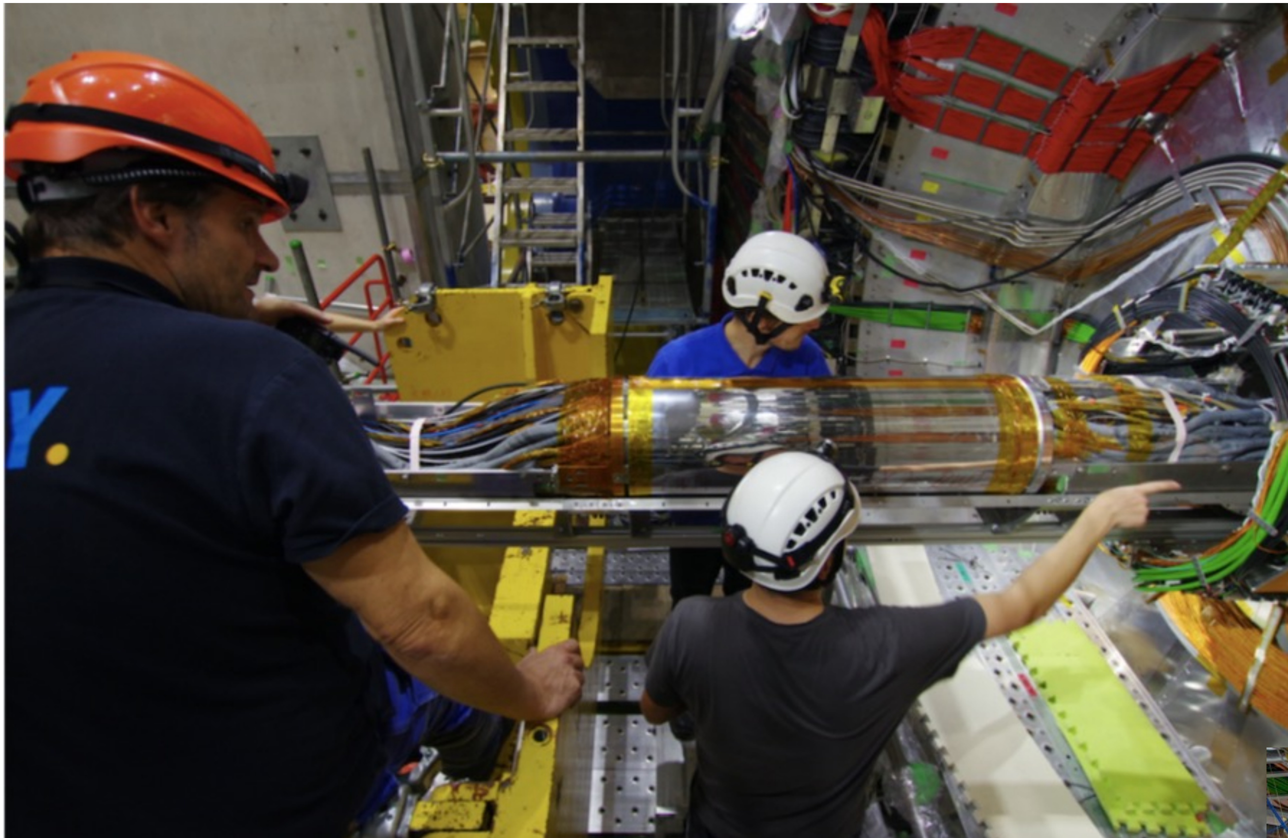


- Putting all together, we obtain an overall Belle II isospin test:
  $I_{K\pi} = -0.03 \pm 0.13(stat) \pm 0.05(syst)$

Time Dependent Measurements at Belle II

"Pain et beurre" (i.e .bread and butter) for the B factories.

"misoshiro and gohan" ?



Belle II VXD installed on Nov 21, 2018. (PXD L1 and two ladders of L2. and the SVD (4 layers))

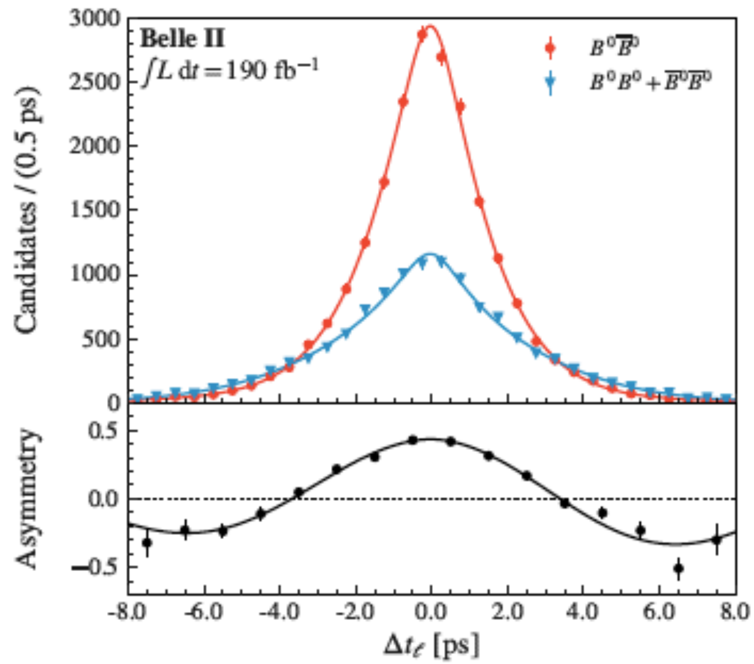
LS1: A VXD upgrade is in progress

Recent time-dependent measurements from Belle II:
https://arxiv.org/abs/2302.12898 (CPV in b-->c cbar s)
https://arxiv.org/abs/2302.12791 (B-Bbar mixing)
More time-dependent papers on CPV in B→ϕ Ks, Ks π0, Ks Ks Ks at LaThuile/Moriond 2023. (to be discussed in Prell's talk).

Skip, this will be covered in Prof Prell's talk.

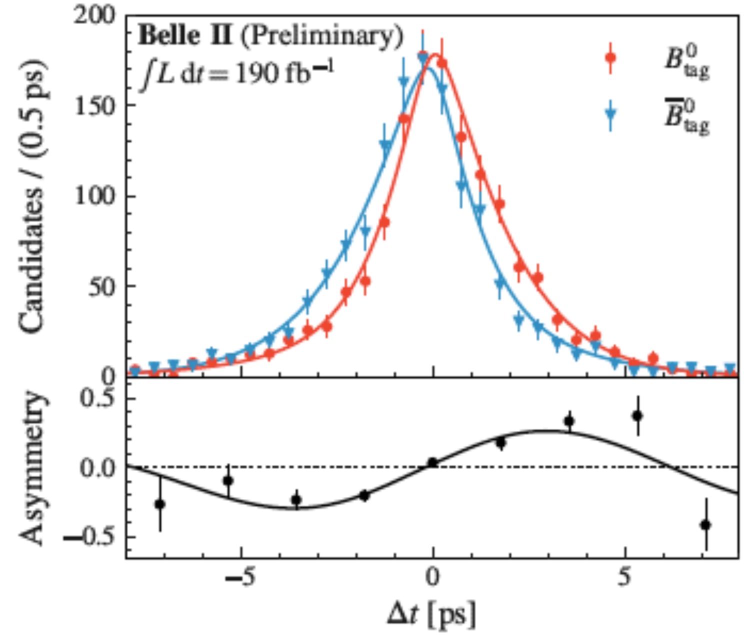
Verification of B-Bbar mixing in Belle II data

$$\Delta m_d = (0.516 \pm 0.008 \pm 0.005)\text{ps}^{-1}$$



https://arxiv.org/abs/2302.12791

Verification of mixing induced CP Violation in Belle II data



https://arxiv.org/abs/2302.12898

Figure 1 – Projections of the Δt fit on the $B^0 \to D^{(*)-}\pi^+$ (left) and $B^0 \to J/\psi K^0_S$ (right) samples.

$$N_{SF/OF} \sim \frac{\exp(-|\Delta t|/\tau)}{4\tau}[1 \pm (1-2w)\cos(\Delta m_d \Delta t)] \otimes R(\Delta t)$$

$$N_{+/-} \sim \frac{\exp(-|\Delta t|/\tau)}{4\tau}\{1 \pm (1-2w)\sin(2\phi_1)\sin(\Delta m_d \Delta t)\} \otimes R(\Delta t)$$

$$\sin(2\phi_1)[\sin(2\beta] = 0.720 \pm 0.062(stat) \pm 0.016(sys)$$

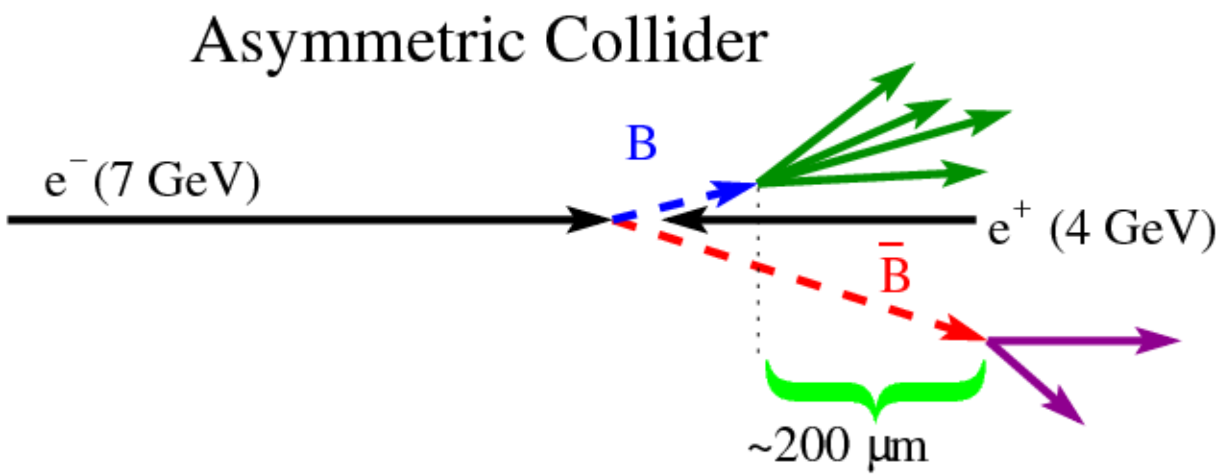
The B^0-anti B^0 meson pairs at the Upsilon(4S) are produced in a <u>coherent</u>, *entangled* **quantum mechanical state**.

(Exercise: why is there a minus sign ?)

$$|\Psi >=| B^0(t_1,f_1)\overline{B^0}(t_2,f_2)> - | B^0(t_2,f_2)\overline{B^0}(t_1,f_1)>$$

Need to measure decay times to observe CP violation (particle-antiparticle asymmetry).

One B decays →collapses the flavor wavefunction of the other anti-B. (N.B. One B must decay before the other can mix) [*exercise: explain*]



Not to scale

<u>The beam energies are asymmetric (7 on 4 GeV)</u>

<u>The decay distance is increased by around a factor ~7</u>

Reminder: Quantum Mechanical Entanglement

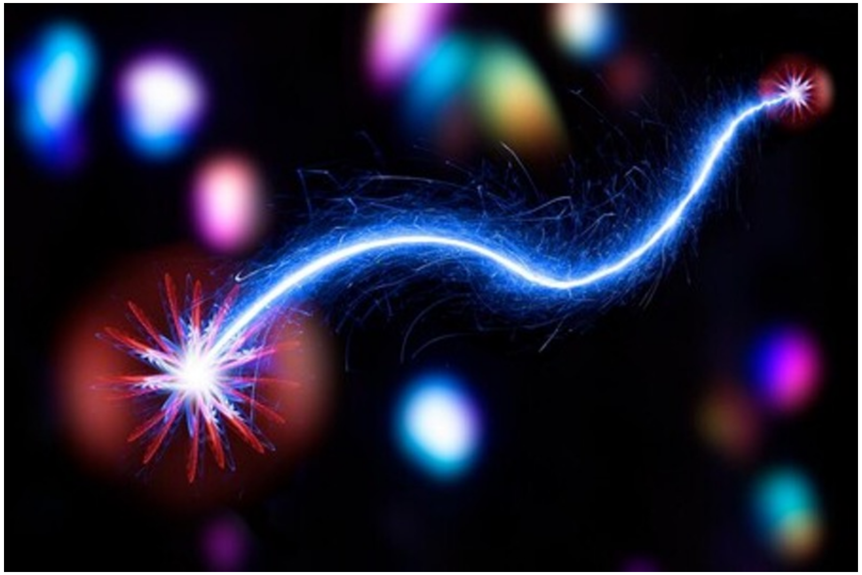
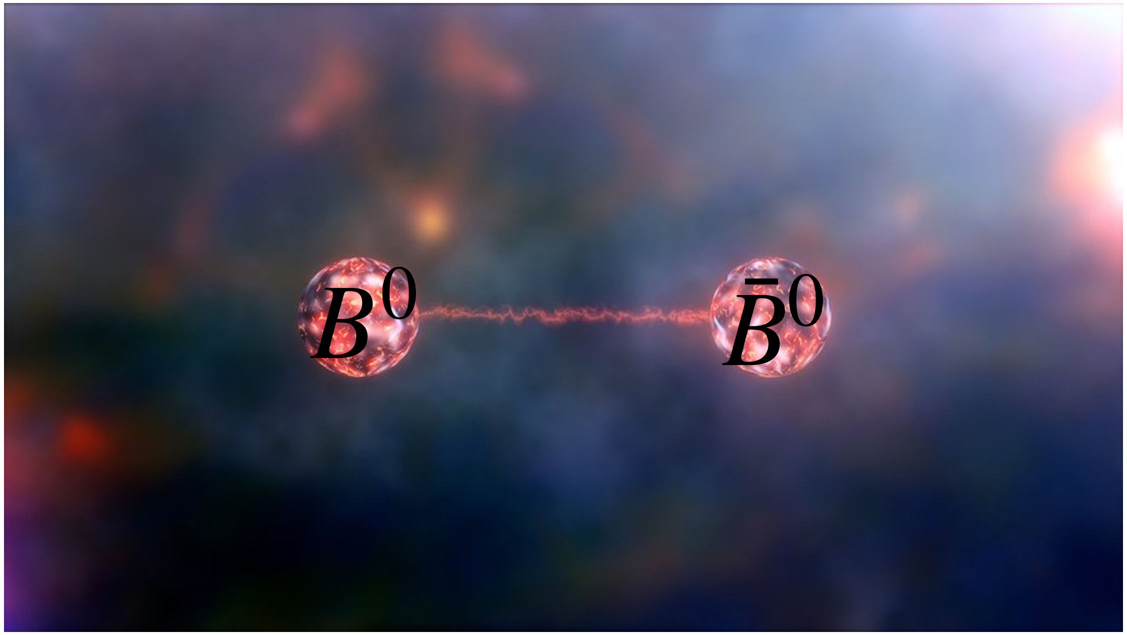


Figure credit: V. de Schwanberg/sciencesource.com



Original from Caltech outreach

The B^0-anti B^0 meson pairs at the Upsilon(4S) are produced in a coherent, *entangled* **quantum mechanical state.**

$$|\Psi> = |B^0(t_1, f_1)\overline{B^0}(t_2, f_2)> - |B^0(t_2, f_2)\overline{B^0}(t_1, f_1)>$$

Ans: C=-1

Need to measure decay times to observe CP violation (particle-antiparticle asymmetry).

One B decays →collapses the flavor wavefunction of the other anti-B. (N.B. One B must decay before the other can mix) [Ans: otherwise the overall wavefunction is zero]

The Nobel Prize in Physics 2022

Ill. Niklas Elmehed © Nobel Prize Outreach
Alain Aspect
Prize share: 1/3

Ill. Niklas Elmehed © Nobel Prize Outreach
John F. Clauser
Prize share: 1/3

Ill. Niklas Elmehed © Nobel Prize Outreach
Anton Zeilinger
Prize share: 1/3

Nobel Prize for "QM Entanglement"

Each B^0-anti B^0 pair is an Einstein-Podolsky-Rosen (EPR) experiment.

Belle checked for the breakdown of QM in https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.99.131802
https://arxiv.org/abs/quant-ph/0702267

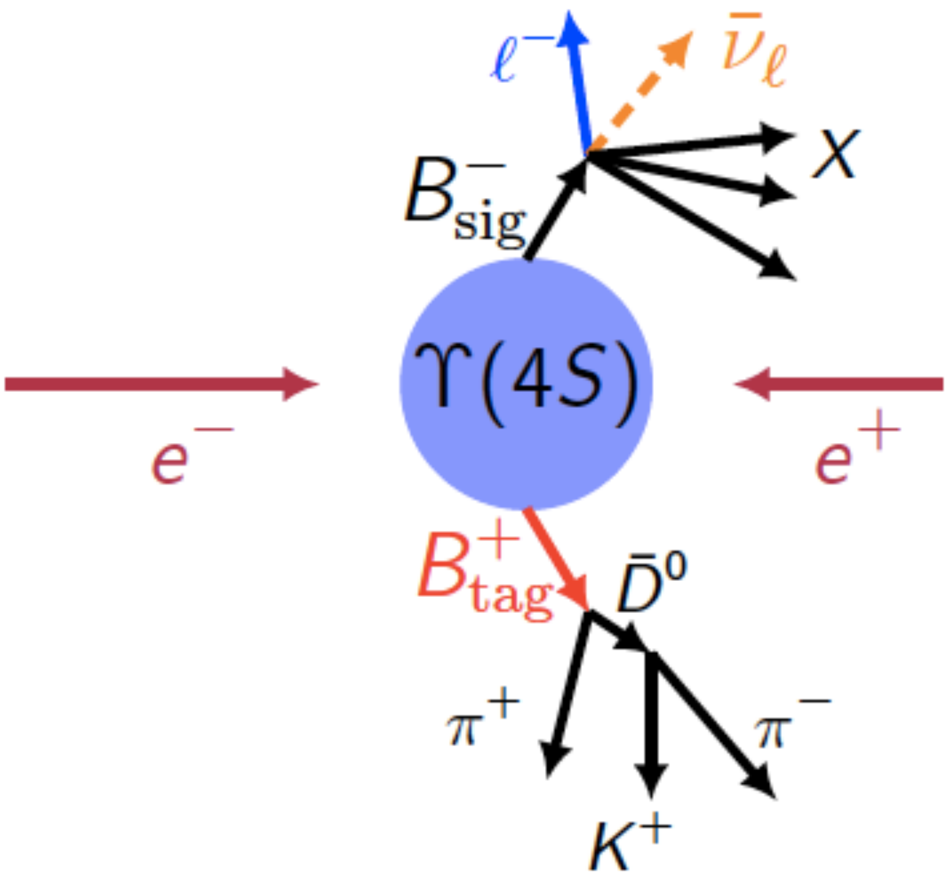
Q: Can Belle II do more on QM entanglement ?

Let's now briefly review Belle II capabilities for flavor (B) physics

Full and equally strong capabilities for electrons and muons

Photons, K_S's with excellent resolution and efficiency

Neutrinos via "missing energy" and missing momentum. Hermeticity.



https://arxiv.org/abs/2008.06096

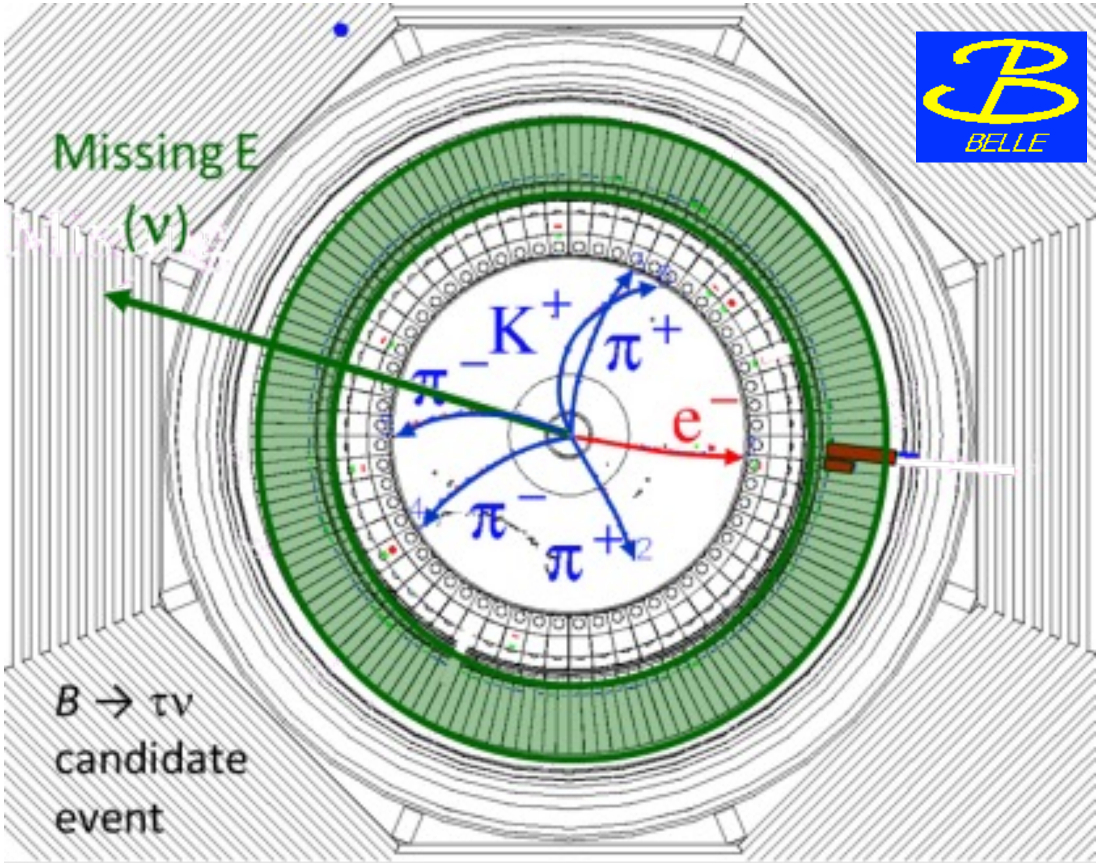
This is now called FEI "Full Event Interpretation" and uses large numbers of tag modes via a BDT (Boosted Decision Tree).

Clean but efficiency $\varepsilon \sim 0.5\%$

T. Keck et al., Comput. Softw. Big Sci. 3, 6 (2019), arXiv:1807.08680 [hep-ex].

Example of a Missing Energy Decay (B→τν) *in old Belle Data*
(recorded before 2010)

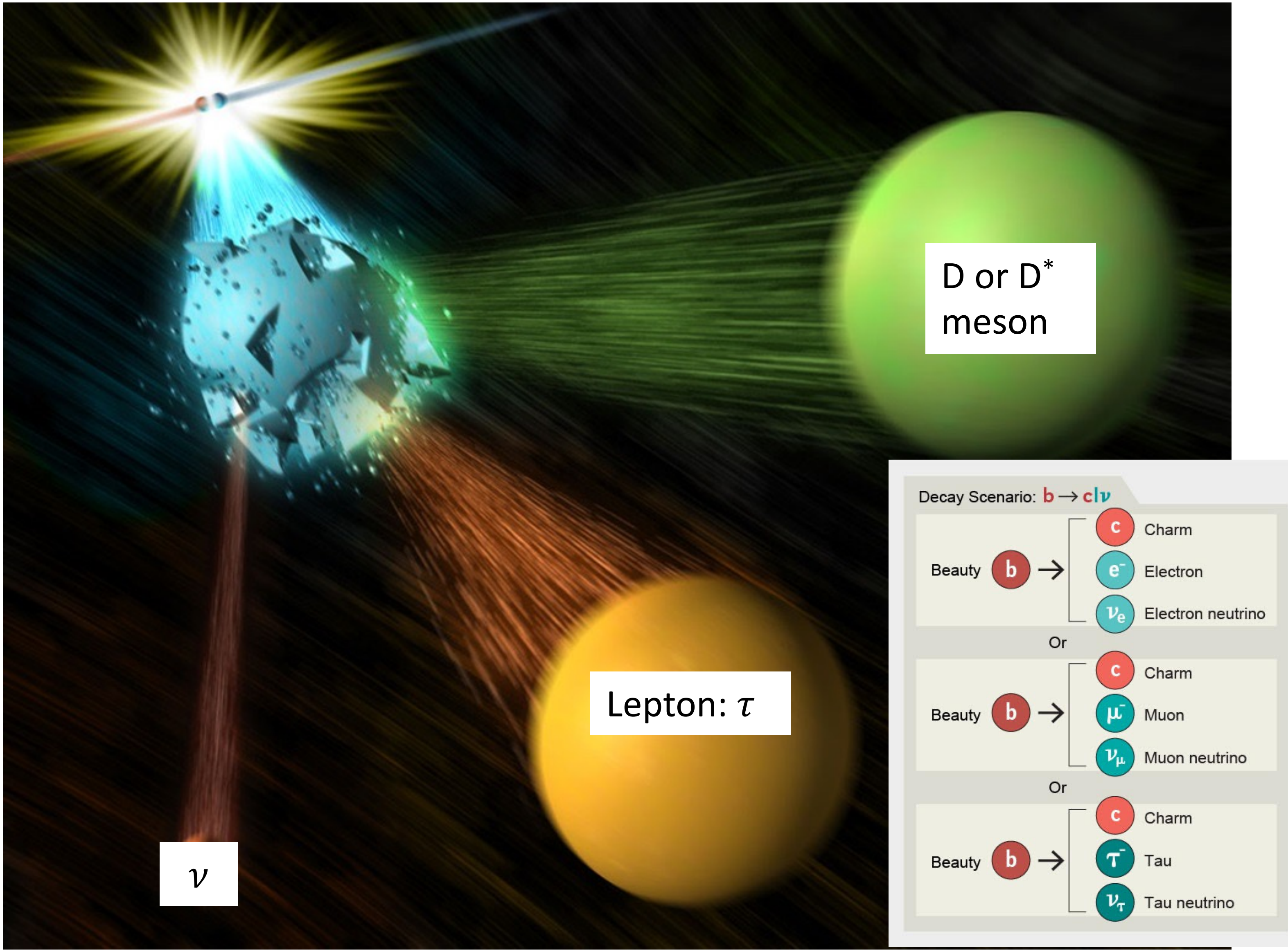
$$B^+ \to \overline{D}^0\pi^+$$
$$(\to K\pi^-\pi^+\pi^-)$$
$$B^- \to \tau(\to e\nu\bar{\nu})\nu$$



The clean e^+e^- environment (and the CsI(Tl) crystal calorimeter) makes this possible.

SLAC
Outreach

Possible breakdown of lepton universality in $B \rightarrow D^{(*)} \tau \upsilon$

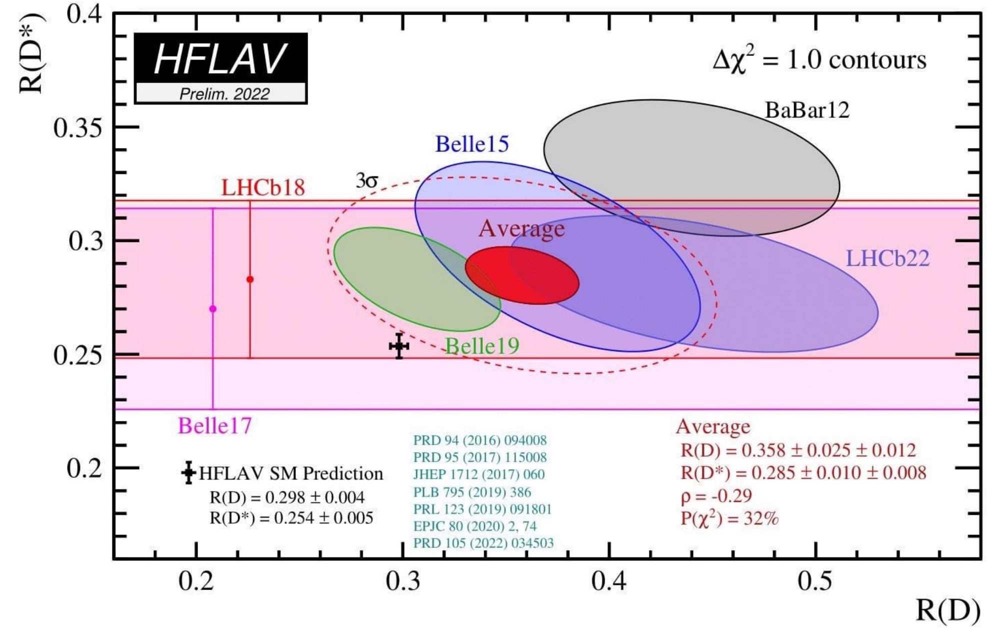


Let's try to understand this picture of the production process (EM) and a weak decay

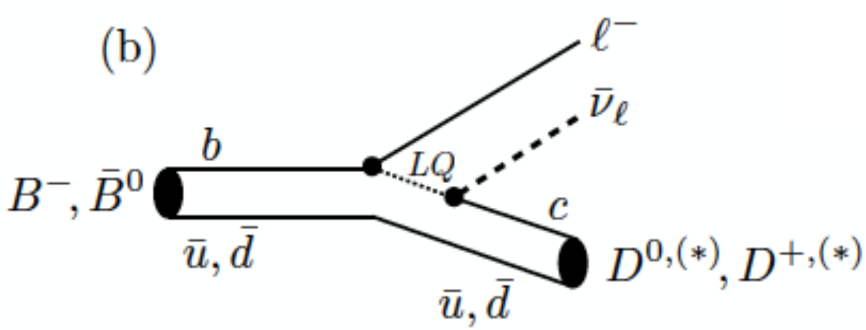
B→D$^{(*)}$ τ υ, possible breakdown of lepton universality

$$R_D^{(*)} = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\nu_\ell)}$$

This may be BSM in the weak b→c charged current



Normally mediated by virtual W charged current.
Some BSM physics possibilities (leptoquarks (LQ), charged Higgs type 3 etc..):



Belle, BaBar, LHCb combined: Evidence of lepton universality breakdown in semileptonic B decays with τ leptons. Last Belle measurement (2019) with semileptonic tags brought down the WA discrepancy from 4→3.4σ
LHCb update(2022, 2023)→3.2σ→ 3.0σ

	$5\ \mathrm{ab}^{-1}$	$50\ \mathrm{ab}^{-1}$
R_D	$(\pm 6.0 \pm 3.9)\%$	$(\pm 2.0 \pm 2.5)\%$
R_{D^*}	$(\pm 3.0 \pm 2.5)\%$	$(\pm 1.0 \pm 2.0)\%$
$P_\tau(D^*)$	$\pm 0.18 \pm 0.08$	$\pm 0.06 \pm 0.04$

Belle II

Future: Look at q^2, angular distributions

Lepton Universality Tests in b→s l+ l- transitions

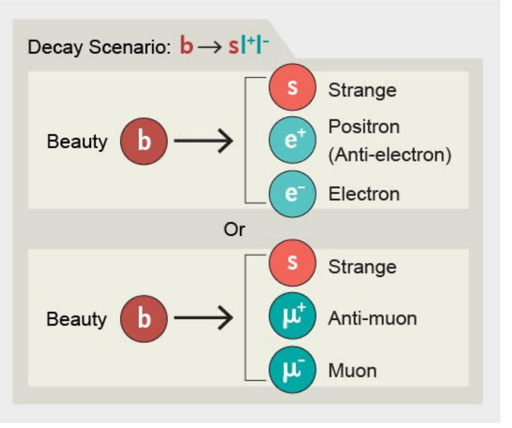
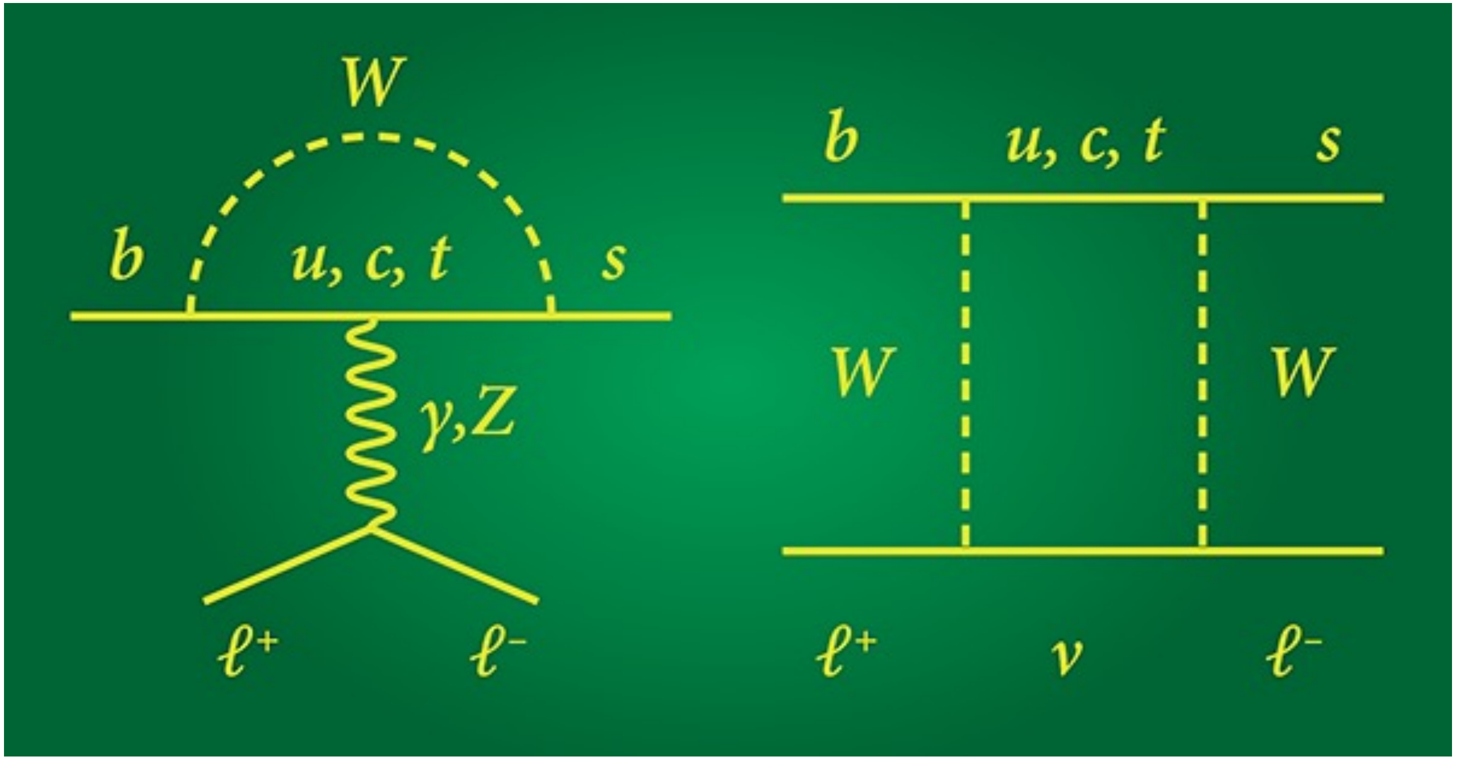


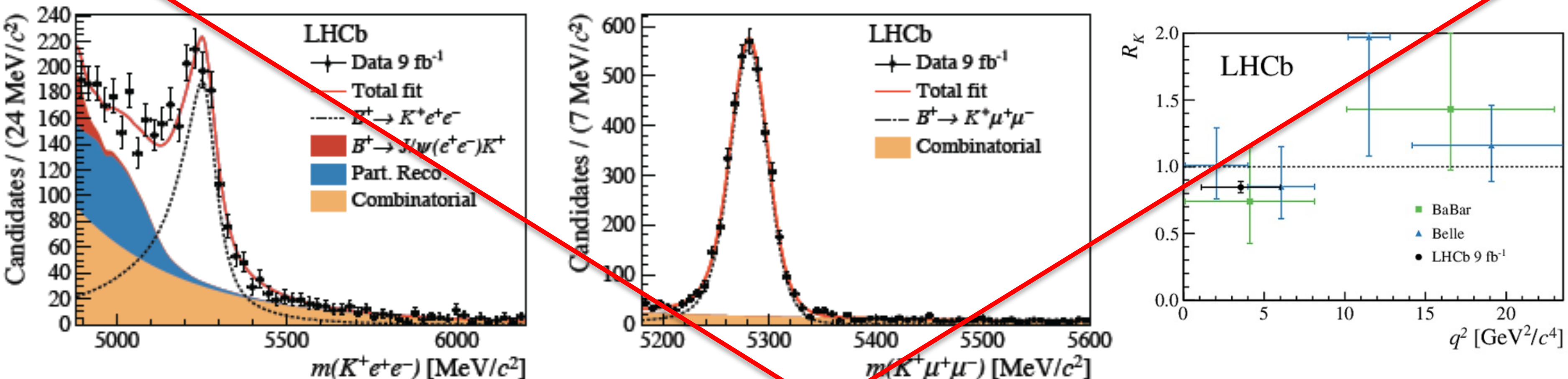
Figure credit: Scientific American



"Electroweak Penguin" "Box"

Possible breakdown of Lepton Universality in b→s l+ l- transitions by the LHCb experiment at CERN, reported in 2021.

https://arxiv.org/abs/2103.11769, published in Nature



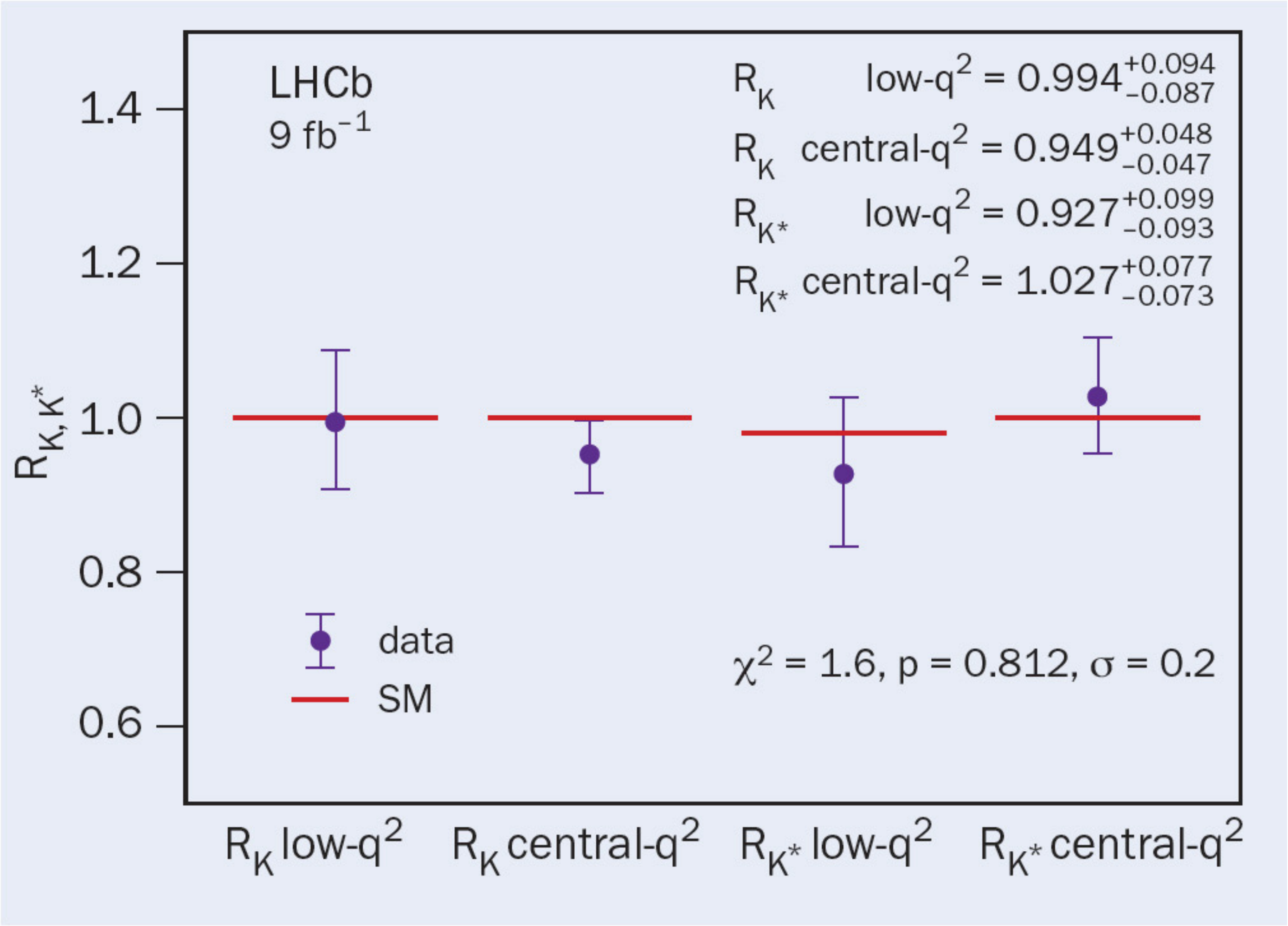
$$R_K = \frac{BF(B^+ \to K^+\mu^+\mu^-)}{BF(B^+ \to J/\psi(\to \mu^+\mu^-)K^+} \Big/ \frac{BF(B^+ \to K^+e^+e^-)}{BF(B^+ \to J/\psi(\to e^+e^-)K^+}$$

$$R_K(1.1 < q^2 < 6.0\ \mathrm{GeV}^2/\mathrm{c}^4) = 0.846^{+0.042+0.013}_{-0.039-0.012}$$

<1 (lepton universality prediction)

And thus this *might indicate* the breakdown of the Standard Model of Particle Physics (3.1 σ)

Note: $q^2 = M^2(l^+\ l^-)$



Details in
https://arxiv.org/abs/2212.09153

"Although a component of this shift can be attributed to statistical effects, it is understood that this change is primarily due to systematic effects," explains LHCb spokesperson Chris Parkes of the University of Manchester. "The systematic shift in R(K) in the central q^2 region compared to the 2021 result stems from an improved understanding of misidentified hadronic backgrounds to electrons, due to an underestimation of such backgrounds and the description of the distribution of these components in the fit. New datasets will allow us to further research this interesting topic, along with other key measurements relevant to the flavour anomalies." –CERN Courier Dec 2021

More in Jim Cochran's talk

Time for a shift in thinking:

Look for lepton universality violation in $B \to K^* l^+ l^-$ (and $B \to D^* l \nu$) angular distributions.

Use "Delta" Δ observables (comparing electron and muon angular distributions) to fit for BSM Wilson coefficient contributions
https://arxiv.org/abs/2203.06827

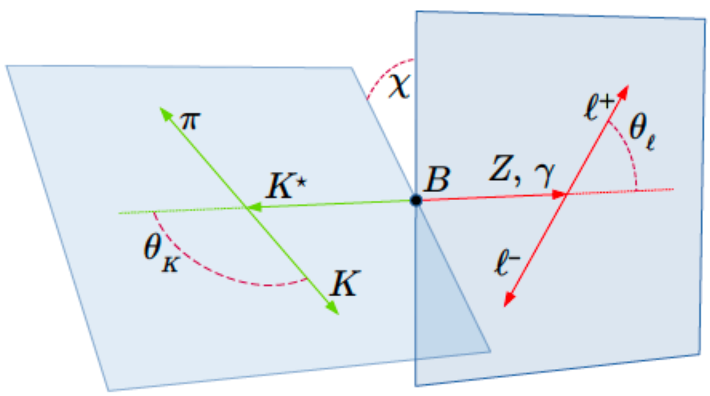


FIG. 1. The $B \to K^* \ell^+ \ell^-$ decay and the subsequent $K^* \to K\pi$ decay kinematic parameters.

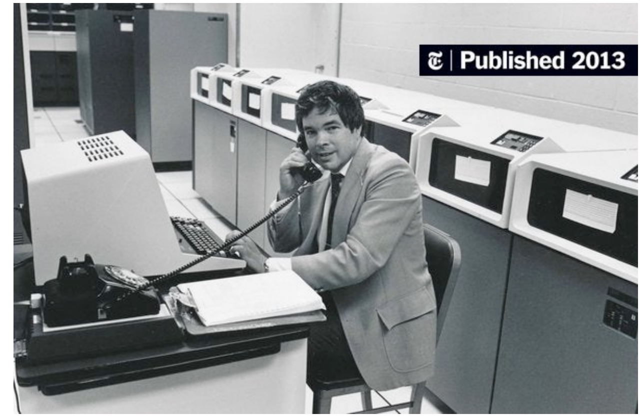
Belle II

Equally strong detection capabilities for electrons and muons. Already publishing a number of lepton universality tests. Ideally suited for this mission.

Feynman Diagrams and Model Building

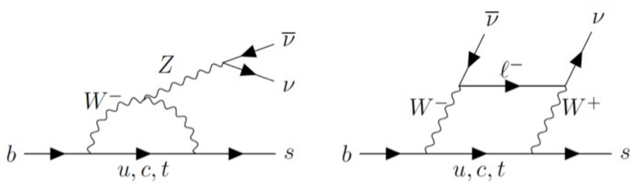
Effective Field Theory →Wilson Coefficients

Paradigm shift



Feynman family and diagrams

Ken Wilson ("Wilson coefficients")



(a) Penguin diagram (b) Box diagram

C_7, C_9, C_{10}

New Physics/BSM Couplings in b→s

The effective Hamiltonian for $b \to s$ transitions can be written as

$$\mathcal{H}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i (C_i O_i + C_i' O_i') + \text{h.c.}$$

and we consider NP effects in the following set of dimension-6 operators,

$$O_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,, \qquad O_9' = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)\,,$$

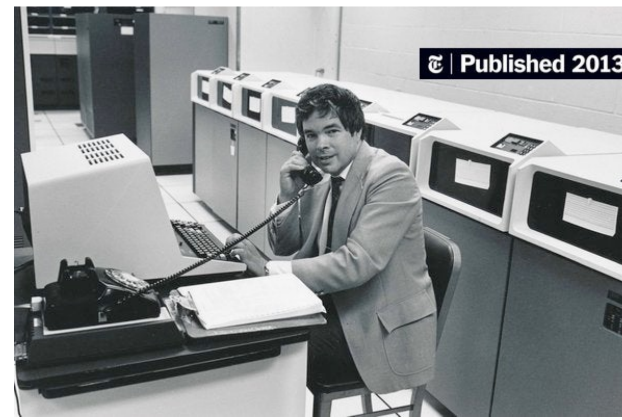
$$O_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, \qquad O_{10}' = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,.$$

The primes are NP right-handed couplings.

We need new tools to explore BSM physics couplings

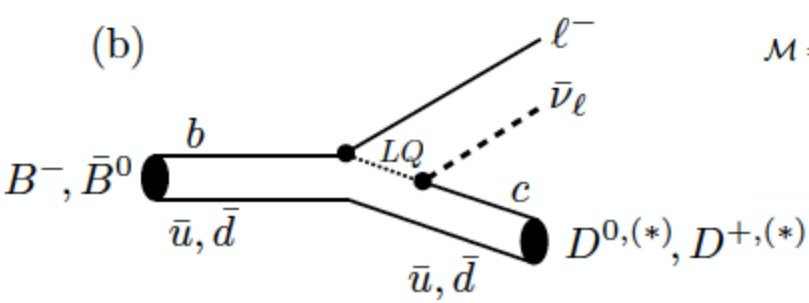
Monte Carlo Generators for B→D* l nu and B→K* l+ l- that allow for SM and BSM physics in Wilson coefficients.
This will allow for new and powerful experimental analyses of angular dependences.

Paradigm shift



Feynman and his diagrams

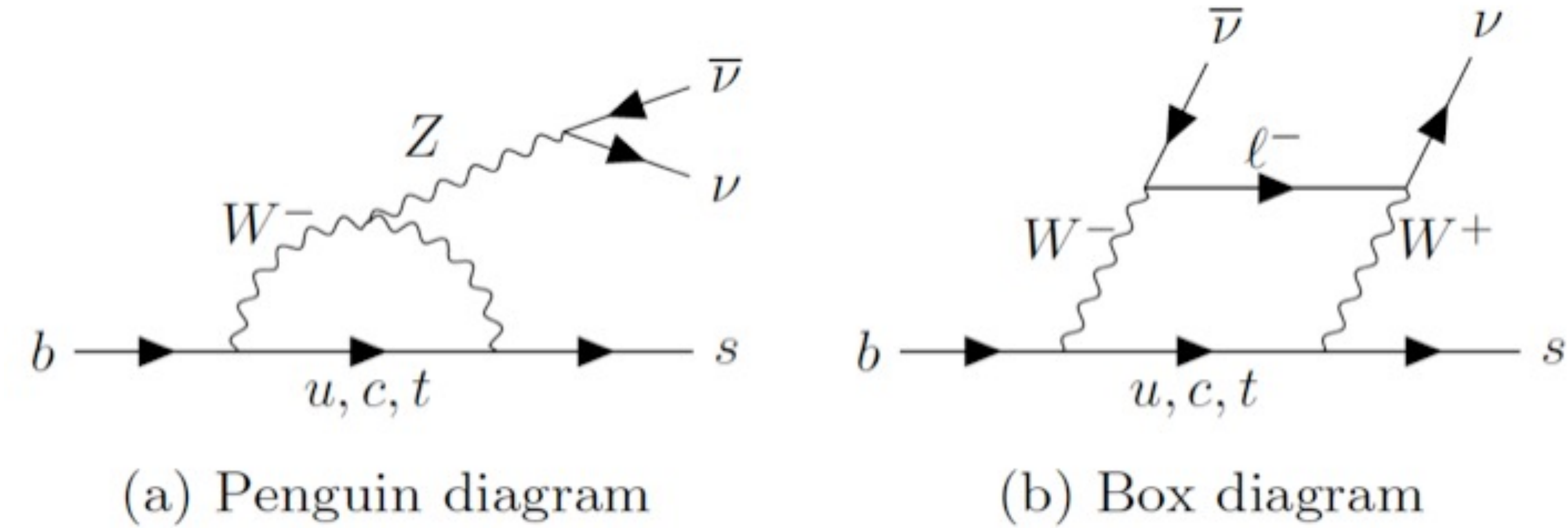
Wilson and his Coefficients in Effective Field Theories

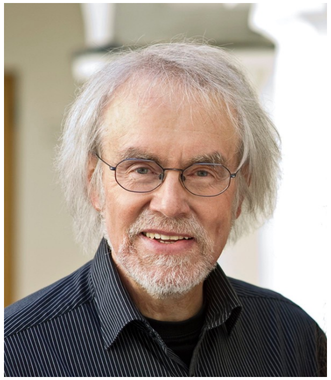


$$\mathcal{M} = \frac{4 G_F V_{cb}}{\sqrt{2}} \Big\{ \langle D\pi | \bar{c}\gamma^\mu \left[(1+g_L)P_L + g_R P_R\right] b | \overline{B} \rangle (\bar{\ell}\gamma_\mu P_L \nu) + \langle D\pi | \bar{c}(g_{S_L} P_L + g_{S_R} P_R) b | \overline{B} \rangle (\bar{\ell} P_L \nu) + g_T \langle D\pi | \bar{c}\sigma^{\mu\nu} b | \overline{B} \rangle (\bar{\ell}\sigma_{\mu\nu} P_L \nu) \Big\}$$

Can MC this matrix element for any value of g_L, g_R, g_{SL}, g_{SR}

$B \to K\nu\bar{\nu}$: NP without hadronic uncertainties





Andrezj Buras

Note that in contrast to $B \to K^{(*)}\, l^+\, l^-$ angular asymmetries, there are NO “dirty” long distance (charm annihilation) contributions from $B \to J/\psi\ K^{(*)}$ and $B \to \psi(2S)\ K^{(*)}$

For example, https://arxiv.org/abs/1409.4557

The $B \to K^{(*)}$ nu nubar missing energy modes are accessible to Belle II (and Belle), but might be difficult at a hadron experiment.

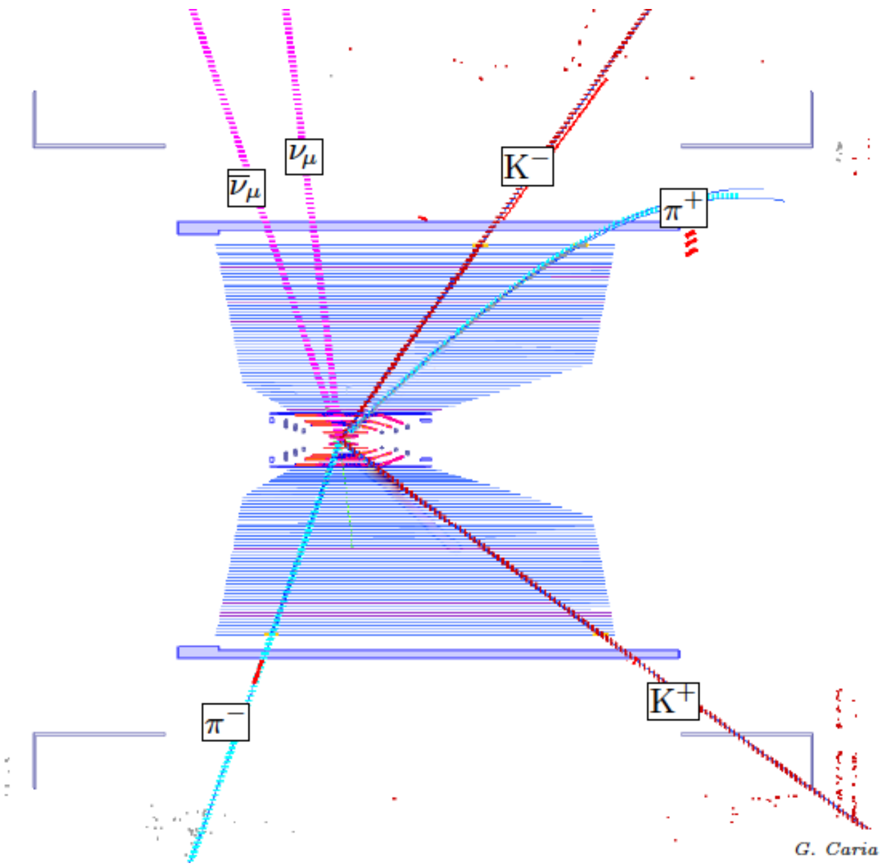
Realizing "Buras' clean dream" in Belle II ?

"Missing Energy Decay" in a Belle II GEANT4 MC simulation

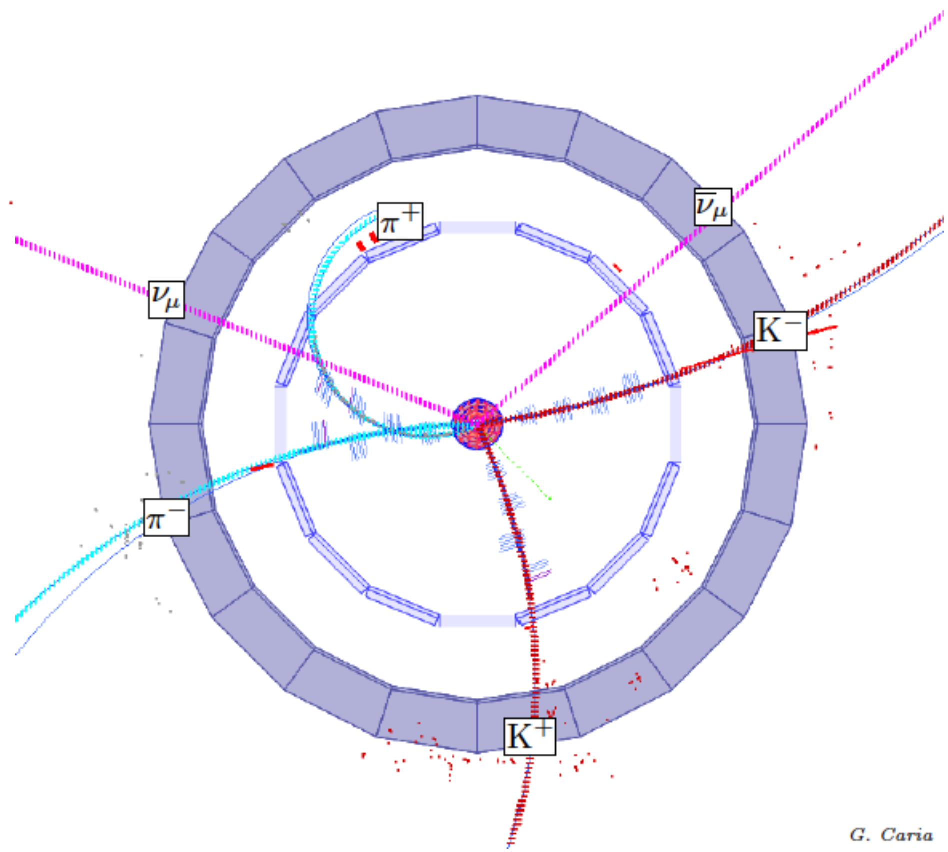
Signal: B→K ν ν

tag mode: B→Dπ; D→Kπ

View in r-z



Zoomed view of the vertex region in r--phi



B→K ν νbar: NP without hadronic uncertainties

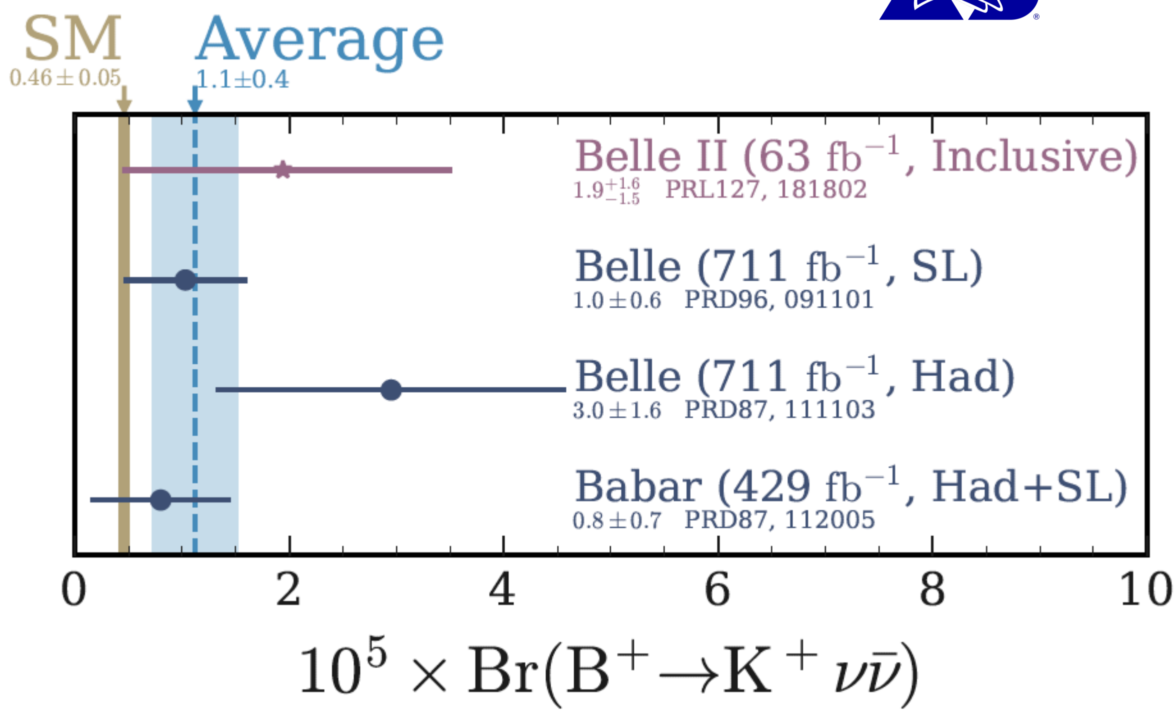
An emerging anomaly ???

$B \to K\nu\bar{\nu}$

<u>New Technique</u> from Belle II with inclusive ROE (Rest of the Event) tagging.

Phys. Rev. Lett. 127, 181802, (2021)

Now apply to new Belle II and old Belle data. Stay tuned (EPS2023 ?)



It is quite possible that NP shows up in b→s nu nubar and not b→s l+ l- or vice-versa

<u>Dark matter</u> could also play a major role.

>>>This is one way that Belle II could discover BSM Physics soon <<<

More details in this theory paper (TEB, N. Deshpande, R. Mandal, R. Sinha): https://arxiv.org/abs/2107.01080, published as Phys. Rev. D. 104, 053007 (2021)

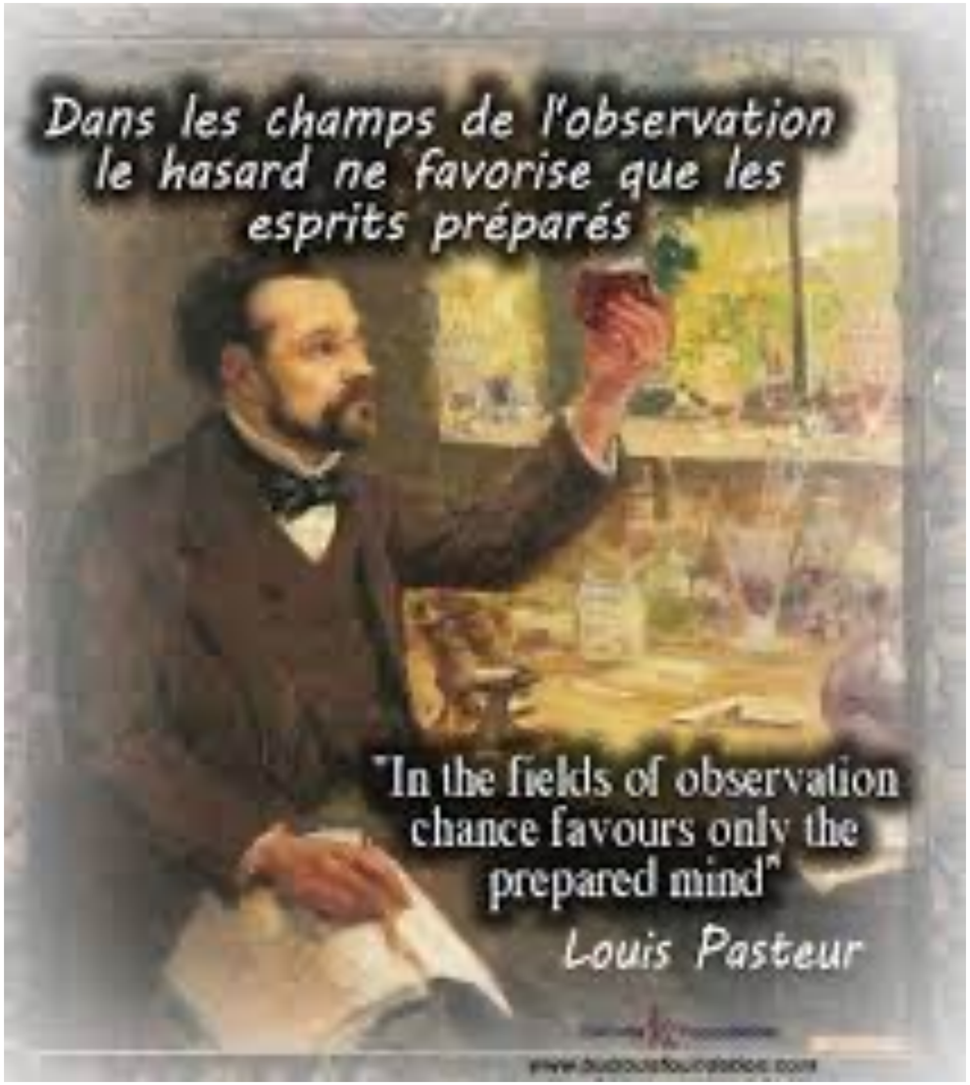
Opportunities for BSM Physics Discoveries with Belle II@SuperKEKB

- Quantum mechanics, entanglement, symmetry and *symmetry breaking* are at the heart of the particle physics in Belle II
- Belle II is exploring BSM Physics on the Luminosity or Intensity Frontier. *This is different from the LHC high pT program*
- *Will BSM physics appear in angular asymmetries in $B \to D^* l \nu$ or $B \to K^* l^+ l^-$ and/or perhaps in $B \to K^{(*)} \nu \bar{\nu}$?*

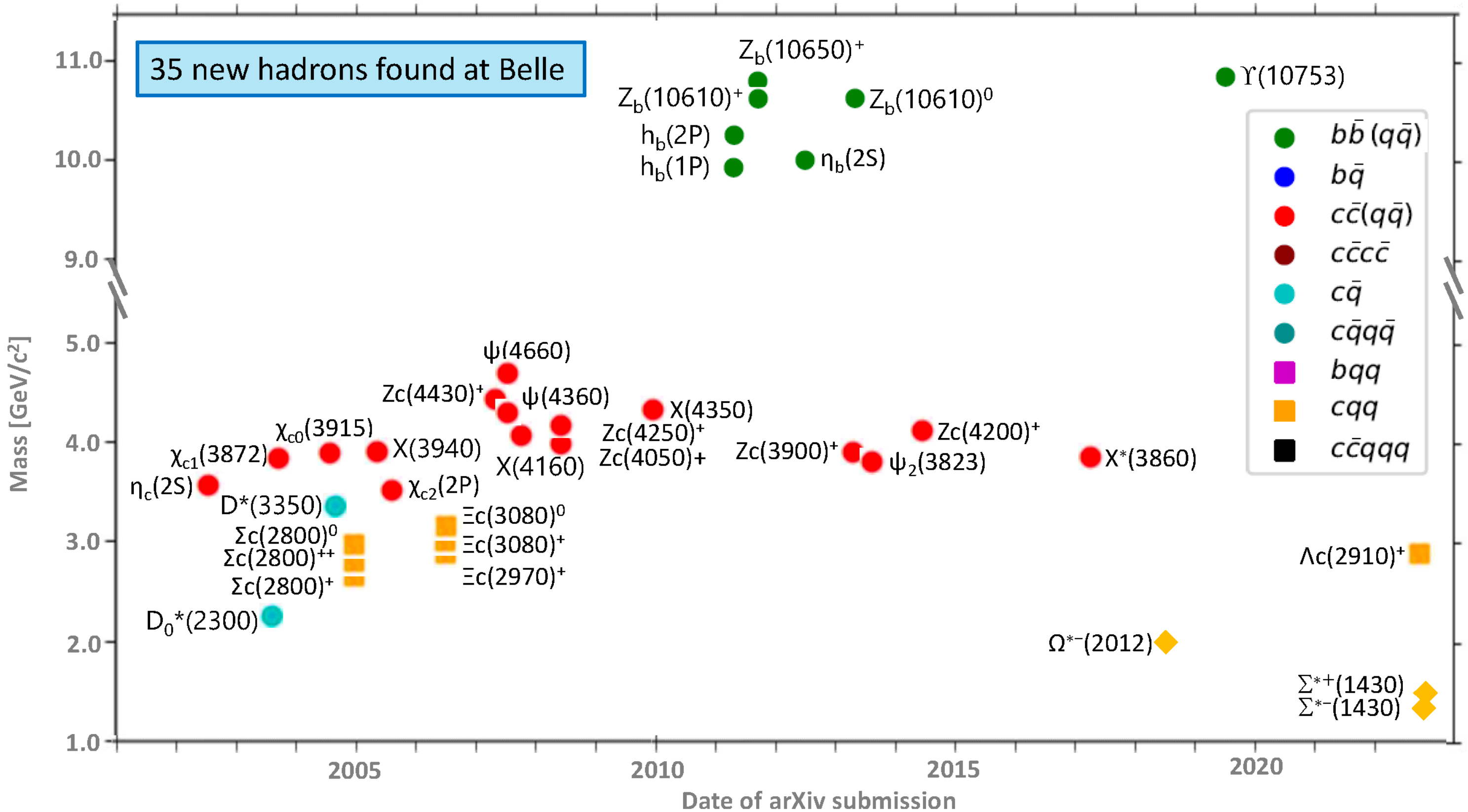
Belle II Executive Summary for Snowmass (high energy physics for the next decade) https://arxiv.org/abs/2203.10203

Some new ideas for BSM discoveries at Belle II
https://arxiv.org/abs/2107.01080 (PRD)
https://arxiv.org/abs/2203.06827 (submitted to PRD)
https://arxiv.org/abs/2206.11283 (PRD)

Backup slides



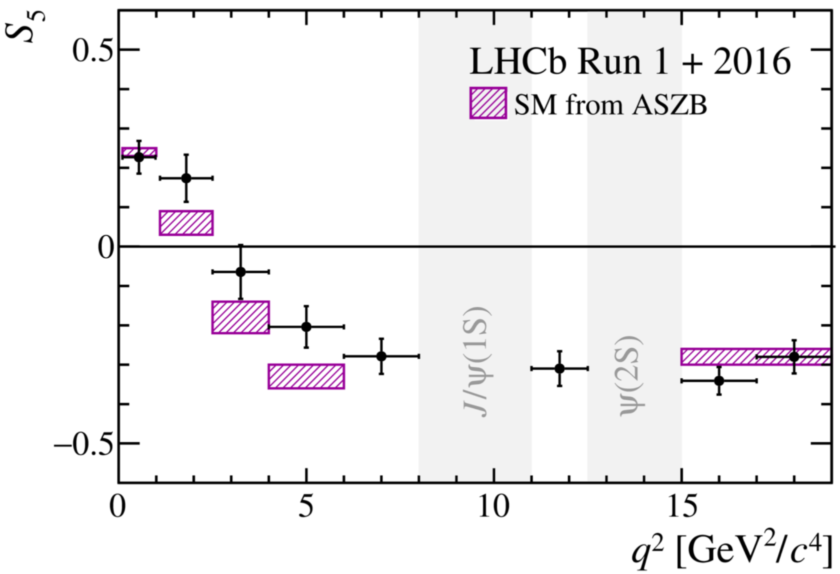
New Particles at Belle (and being investigated at Belle II)



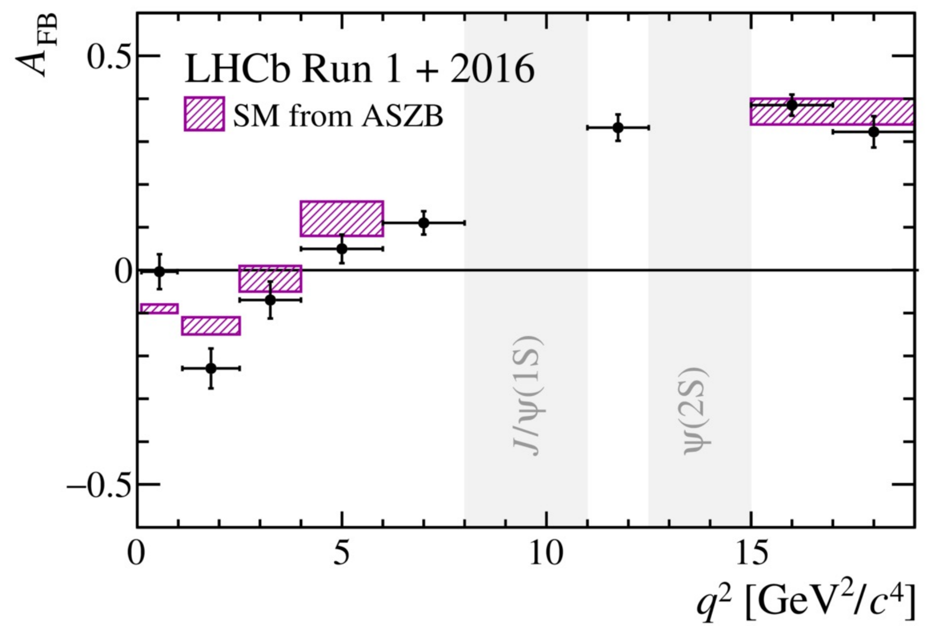
35 new hadrons were found at Belle. 10 of these are "exotic" and cannot be explained in the conventional quark model while the nature of 8 of them are still under investigation. The remaining 17 states are consistent with the quark model. Measurements of all these states will provide critical insights for QCD.

Published LHCb 5 fb^{-1} results on $B \rightarrow K^* \mu^+\mu^- (q^2)$

A different angular asymmetry, involving χ

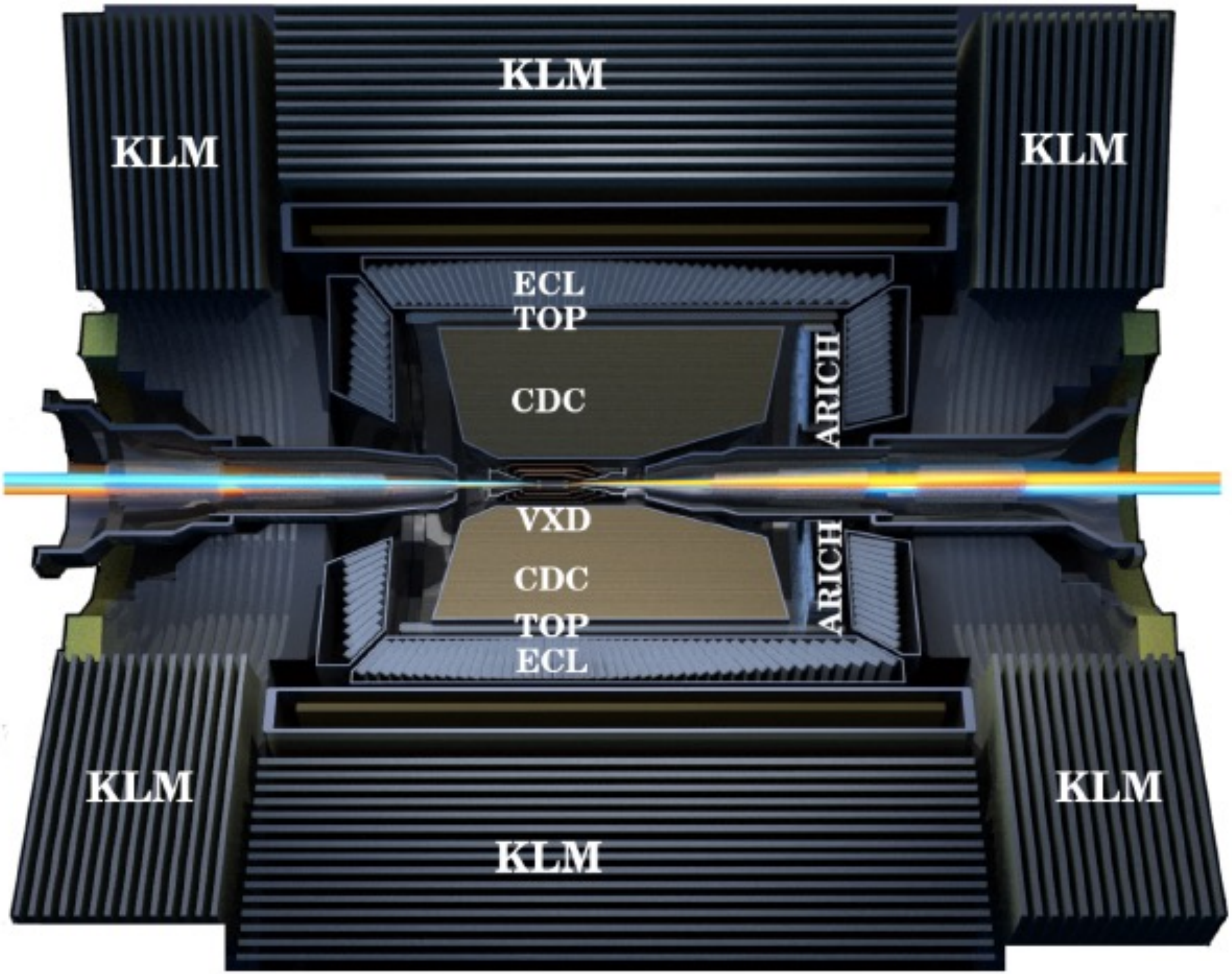


Forward-backwards asymmetry



"The P_5' measurements are only compatible with the SM prediction at a level of 3.7σ…..A mild tension can also be seen in the A_{FB} distribution, where the measurements are systematically <=1σ below the SM prediction in the region $1.1<q^2< 6.0$ GeV^2" (LHCb 2015 conference paper)

These angular asymmetries persist in 2023


KLM
KLM
KLM
ECL
TOP
CDC
ARICH
VXD
ARICH
CDC
TOP
ECL
KLM
KLM
KLM

Upgrading SuperKEB with Polarized Electron Beams: "Chiral Belle" uses Belle II with L-R polarized SuperKEKB

- Goal is ~70% polarization with 80% polarized source (SLC had 75% polarization at the experiment)
- Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode (similar to SLC source)
- Inject vertically polarized electrons into the High Energy Ring (HER) - needs low enough emittance source to be able to inject.
- Rotate spin to longitudinal before IP, and then back to vertical after IP using solenoidal and dipole fields – recent studies have demonstrated feasibility
- Use Compton polarimeter to monitor longitudinal polarization with <1% absolute precision, higher for relative measurements (arXiv:1009.6178) - needed for real time polarimetry – similar to HERA and EIC technologies.
- Use tau decays to obtain absolute average polarization at IP – *BaBar* analysis demonstrates 0.5% precision (see C. Miller, Lake Louise Winter Institute 2022)

“Chiral Belle II” -> Left-Right Asymmetries

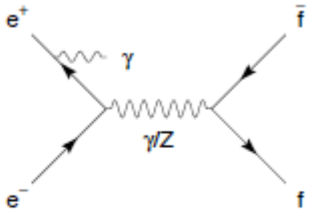
•Measure *difference* between cross-sections with left-handed beam electrons and right-handed beam electrons

•Same technique as SLD A_{LR} measurement at the Z-pole giving single most precise measurement of :

$$\sin^2\theta_{eff}^{lepton} = 0.23098 \pm 0.00026$$

•At 10.58 GeV, polarized e^- beam yields product of the neutral axial-vector coupling of the electron and vector coupling of the final-state fermion via Z-γ interference:

(for s-channel Born)



$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}}\left(\frac{G_F s}{4\pi\alpha Q_f}\right) g_A^e g_V^f \langle Pol \rangle$$

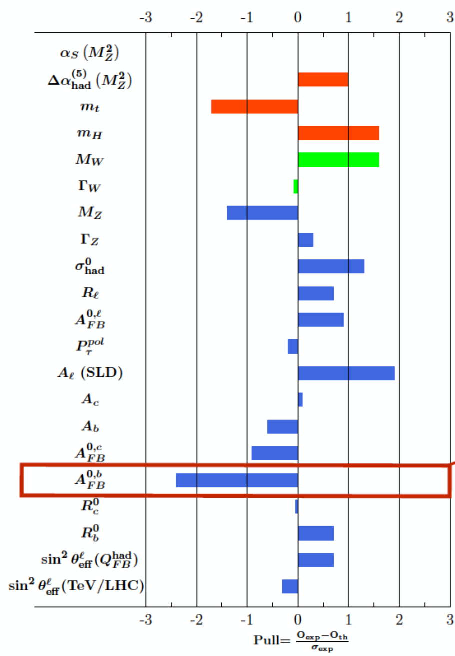
$$\propto T_3^f - 2Q_f \sin^2\theta_W$$

Belle II/SuperKEKB with a polarized e^- beam can address this long-standing electroweak discrepancy and hint of NP

Warning: Does not include CDF 2022 W mass update.

SM fit results: Predictions for EWPO

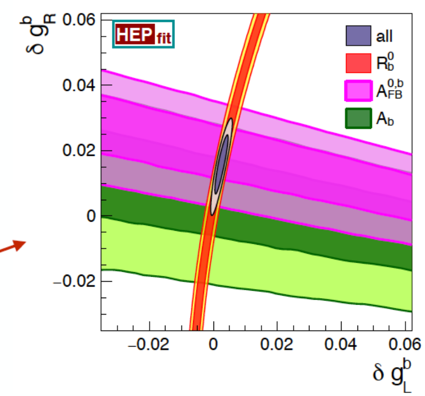
Also good agreement between indirect determination of EWPO and experimental measurements, **with one notable exception**



~2.5 σ discrepancy in forward-fackward asymmetry of the b quark

Requires modifications of (right-handed) *Zbb* couplings

$$g^b_{L,R} = g^{b\,\rm SM}_{L,R} + \delta g^b_{L,R}$$

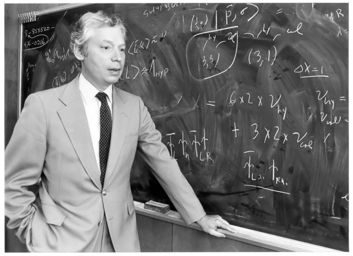


	Fit result	Correlations	
δg^b_R	0.017±0.007	1.00	
δg^b_L	0.003±0.001	0.89	1.00

29th International Symposium on Lepton Photon Interactions at High Energies
Toronto, August 6, 2019
19
Jorge de Blas
INFN - University of Padova

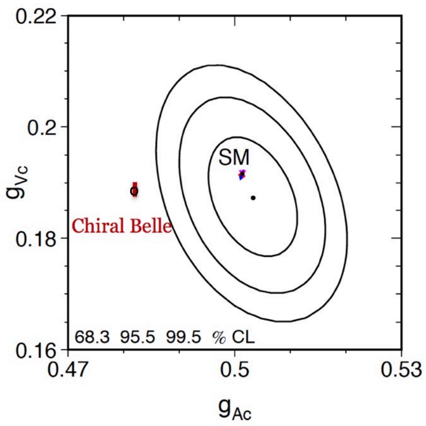
A New Path for Belle II Discovery in a *Precision Neutral Current Electroweak Program* with Heavy Quarks

- Left-Right Asymmetries (A_{LR}) yield high precision measurements of the *neutral current vector couplings* (g_V) to each of accessible fermion flavor, f :
  - beauty (D-type) (as well as for 3 charged leptons and light quarks)
  - charm (U-type)

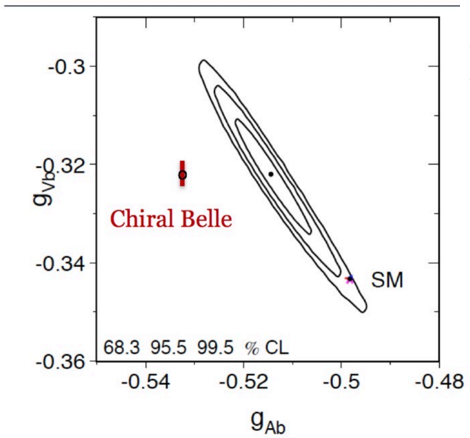


Steve Weinberg

c-quark:
Chiral Belle ~7 times more precise



b-quark:
Chiral Belle ~4 times more precise
with 20 ab^{-1}



$$\text{Recall: } g_V^f \text{ gives } \theta_W \text{ in SM} \begin{cases} g_A^f = T_3^f \\ g_V^f = T_3^f - 2Q_f \sin^2\theta_W \end{cases}$$

T_3 = -0.5 for charged leptons and D-type quarks
+0.5 for neutrinos and U-type quarks

Unique Access to New Physics in bottom-to-charm Neutral Current Vector Coupling Universality Ratio via A_{LR} (b-bbar)/ A_{LR} (c-cbar)

Projections of b-quark and c-quark Neutral Current Vector Coupling Sensitivities with 70% polarized e^- beam

UNPRECEDENTED PRECISION

Final State Fermion	SM	World Average[1]	Chiral Belle 20 ab^{-1}	Chiral Belle 50 ab^{-1}	Chiral Belle 250 ab^{-1}
	$g_V^f (M_Z)$	$g_V^f (M_Z)$	$\sigma (g_V^f)$ or $\sigma(g_V^b/ g_V^c)$	$\sigma (g_V^f)$ or $\sigma(g_V^b/ g_V^c)$	$\sigma (g_V^f)$ or $\sigma(g_V^b/ g_V^c)$
b-quark	-0.3437	-0.322	±0.0003(stat) ±0.0017(sys)	±0.0002(stat) ±0.0017(sys)	±0.00009(stat) ±0.0017(sys)
(eff.=0.3)	± .00049	±0.0077	±0.0017(total)	±0.0017(total)	±0.0017(total)
		2.8σ tension	**Improves x 4**	Improves x 4	Improves x 4
c-quark	0.192	0.1873	±0.0006(stat) ±0.0009(sys)	±0.00035(stat) ±0.0009(sys)	±0.00016(stat) ±0.0009(sys)
(eff.=0.3)	± .0002	±0.0070	±0.0011(total)	±0.0010(total)	±0.0009(total)
			Improves x 7	Improves x 7	Improves x 8
g_V^b / g_V^c	-1.7901	-1.719	±0.0058 (stat ~ total)	±0.0034 (stat ~ total)	±0.00015 (stat ~ total)
Ratio	± .0005	± .082	**Improve x 14**	**Improve x 24**	**Improve x 53**
Relative error:	0.18%	4.8%	**0.32%**	**0.19%**	**0.09%**

Get stuck at ~20 ab^{-1}

Use the ratio

bottom-to-charm UNIVERSALITY RATIO Beam Polarization (dominant systematic) cancels in the ratio

$\sin^2 \Theta_W$ - all LEP+SLD measurements combined WA = 0.23153 ± 0.00016

$\sin^2 \Theta_W$ - Chiral Belle combined leptons with 40 ab^{-1} have error ~current WA