D. Tonelli (INFN Trieste) *not* on behalf of any experiment
La Thuile, Mar 13, 2019

The pre-LHC hope (or hype?)

Showing off the Atlas control room, Dr. Gianotti said that from the moment the collisions began last spring, she noticed that they were richer, with more particles coming out. That richness is only now beginning to be plumbed.

“We have been waiting so long,” she said. “Only good and beautiful things are coming.”

“The vise is closing in inexorably,” he said of the Higgs. As for dark matter, he said the CERN collider would soon exceed the Tevatron in exploring for new particles: “I can hardly contain my enthusiasm.”

Dr. Randall was followed by Dr. Kane, a self-proclaimed optimist who did try to provoke by claiming that physics was on the verge of seeing “the bottom of the iceberg.” The collider would soon discover supersymmetry, he said, allowing physicists to zero in on an explanation of almost everything about the physical world, or at least particle physics.

The wake-up call

Forbes Billionaires Innovation Leadership Money Consumer Industry

Five Years After The Higgs, What Else Has The LHC Found?

Ethan Siegel Contributor
Starts With A Bang
Apr 11, 2018, 10:00am • #WhoaScience

Yearning for New Physics at CERN, in a Post-Higgs Way

Physicists monitoring the Large Hadron Collider are seeking clues to a theory that will answer deeper questions about the cosmos. But the silence from the frontier has been ominous.

By DENNIS OVERBYE JUNE 19, 2017

“Physicists look to the future as new particle dream dies”

“Particle physics in mourning”

“The feeling in the field is at best one of confusion, and at worst depression”

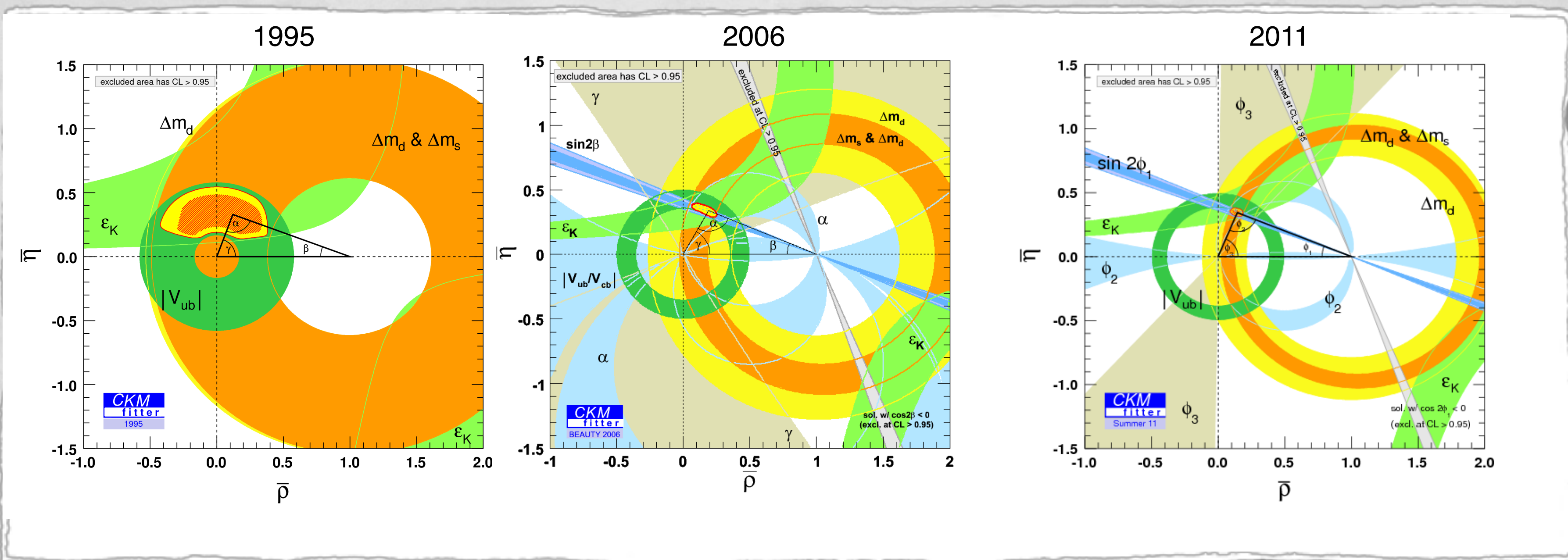
“These are difficult times [...] Our hopes seem to have been shattered. We have not found what we wanted.”

The Particle That Wasn’t

By DENNIS OVERBYE AUG. 5, 2016

We had been warned

Forewarned is forearmed



Since 2001, focus of quark-flavor shifted toward constraining non-SM dynamics.

Measurements compounded into an increasingly consistent picture of “no obvious surprise to expect at the LHC”

Didn’t want to believe it. Even invented sophisticated tricks (MFV anyone?) to circumvent the discomforting evidence.

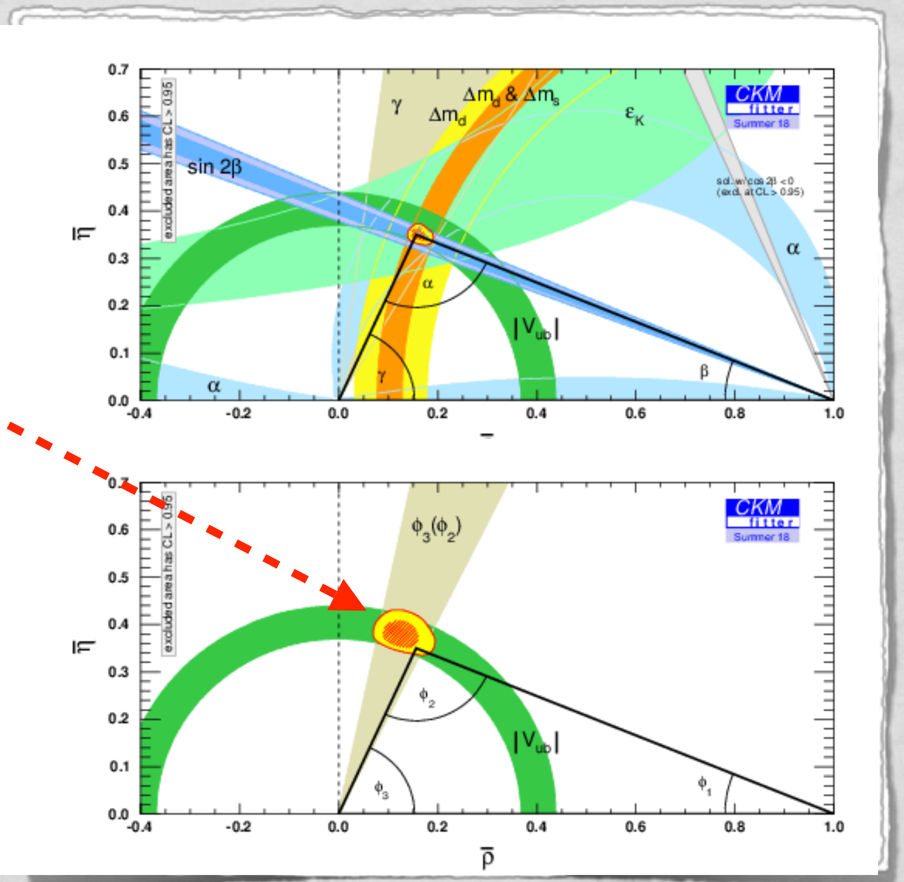
Consistency overstated?

SM is the leading source of CPV

However, wiggle room gets much larger if SM isn't assumed.

O(20%) non-SM contributions still not ruled out in most loop-mediated processes.

Go get 'em!



- Decays whose SM amplitudes are (loop-/helicity-)suppressed offer favorable non-SM/SM ratios
- Flavor oscillations: 2nd order amplitudes accept contributions from virtual nonSM particles of high mass

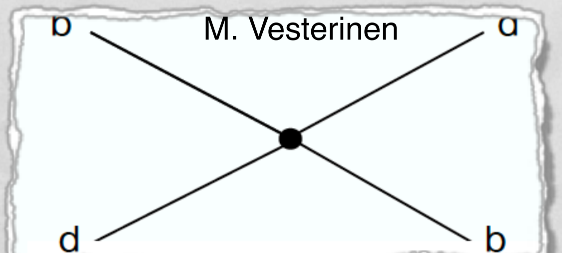
In essence

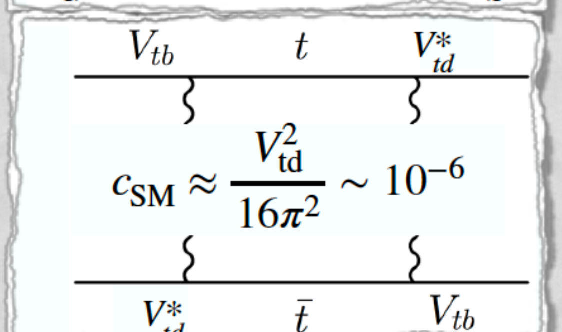
known

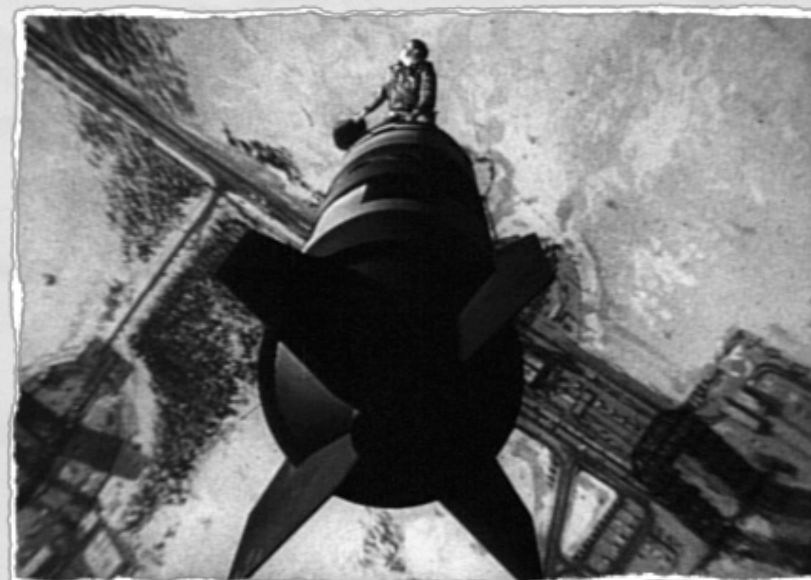
$$A = A_0\left(\frac{c_{\mathrm{SM}}}{m_W^2} + \frac{c_{\mathrm{NP}}}{\Lambda^2}\right)$$

kinematics

known







A 10% test may probe $\Lambda^2/c_{\mathrm{NP}} \approx (1000\ \mathrm{TeV})^2$.

Precision is the limit

The opportunity

We have an unique opportunity.

First time that two state-of-the-art experiments dedicated to flavor operate simultaneously in hadron collisions and @Y(4S) [*]

Our best chance for listening to any message that quark flavor may have to deliver — perhaps the last big chance.

Today: attempt at looking at what might be in store — restricting to topics showing the most reliable non-SM potential

(For the real physics, look at talks by G. Graziani, L. An, C. Cecchi, T. Pajero, C. Costa-Sobral, N. Jurik, M. Trail, J. Garcia Pardinas, and G. Inguglia)

[*] luckily enough — the last two, legendary, golden channels in K physics also getting explored— not the object of this talk.

The Belle (II) and the Beast

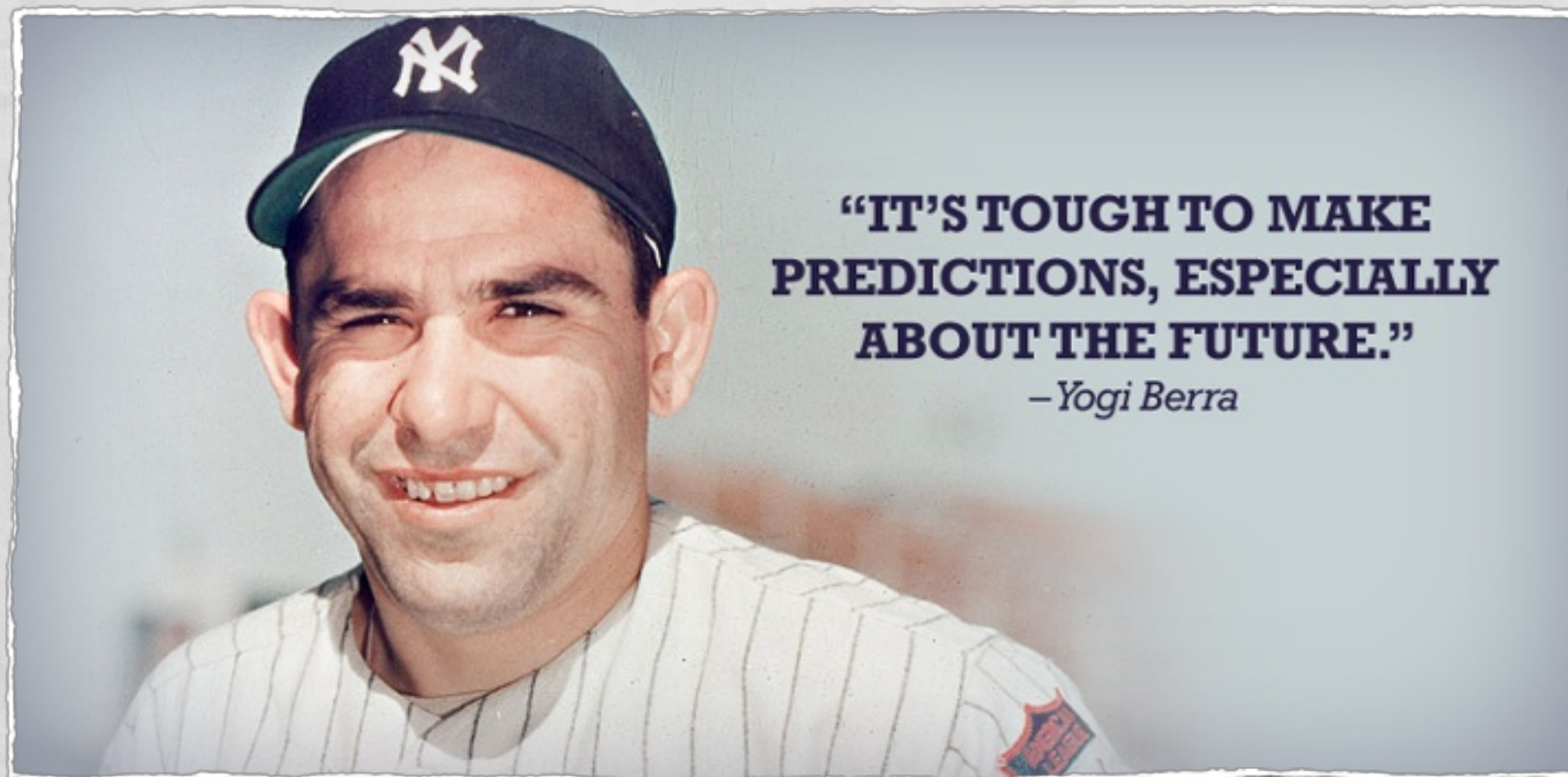
Belle II

- Low native bckg allows for more generous selections – partially offsetting rate penalty
- Stringent kinematic constraints from pointlike-colliding particles: good recostruction of final states with multiple neutrals/invisible particles. Inclusive analyses too.
- 6x flavor-tagging advantage from coherent production
- Superior efficiency for Ks/hyperons

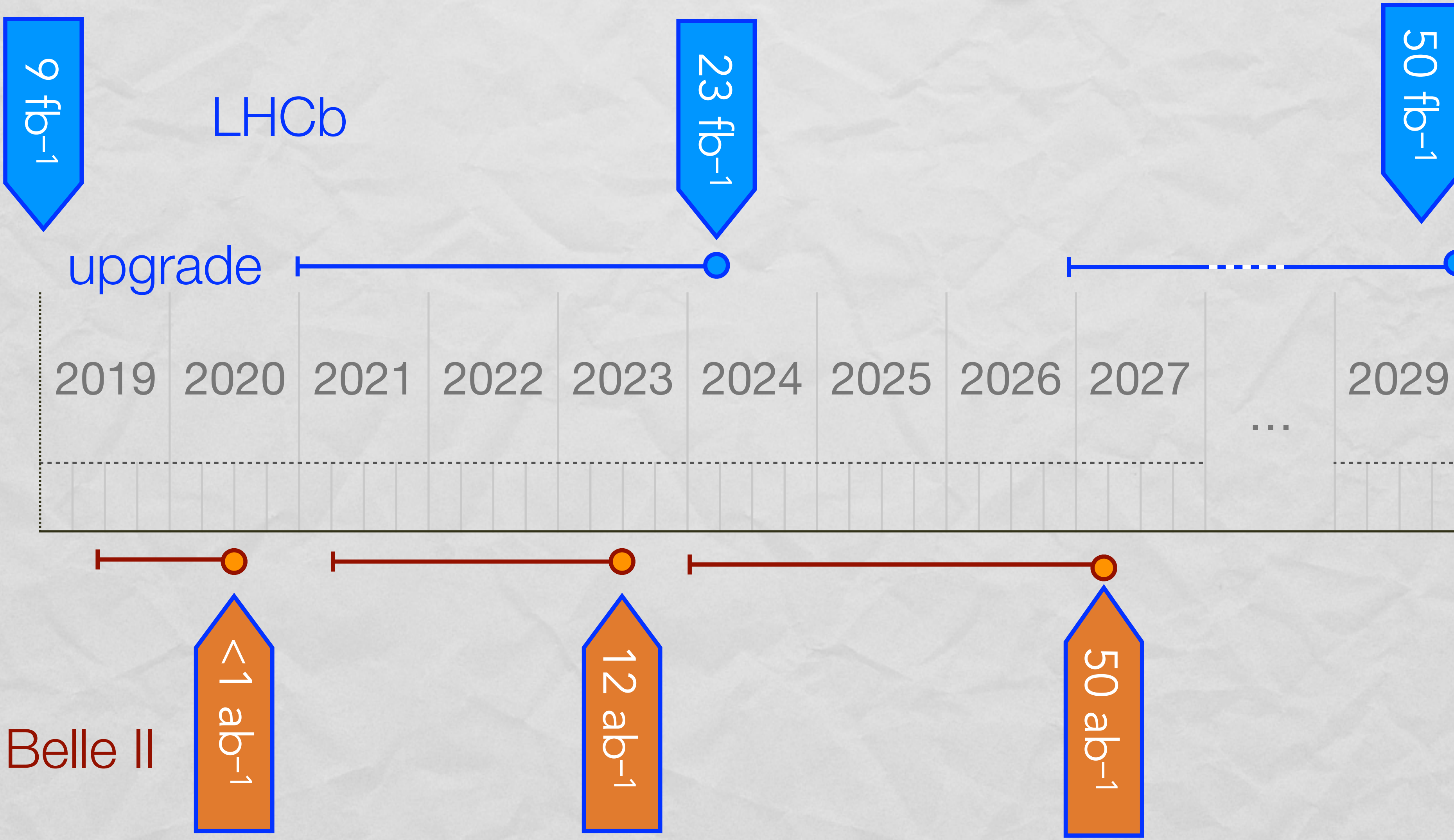
LHCb

- 500x advantage in production rate – of all kinds of flavored hadrons
- 1000x penalty in bckg-xsec * particle multiplicity => stringent online selections
- Unreachable in all-track final states (electrons 5x worse than mu)
- Superior decay-time resolution (makes a large difference in charm)
- ..but tricky decay-time acceptance

Rule of thumb: 1/fb at LHCb ≈ 1/ab at Belle II, within a (channel-dependent) factor of "few"

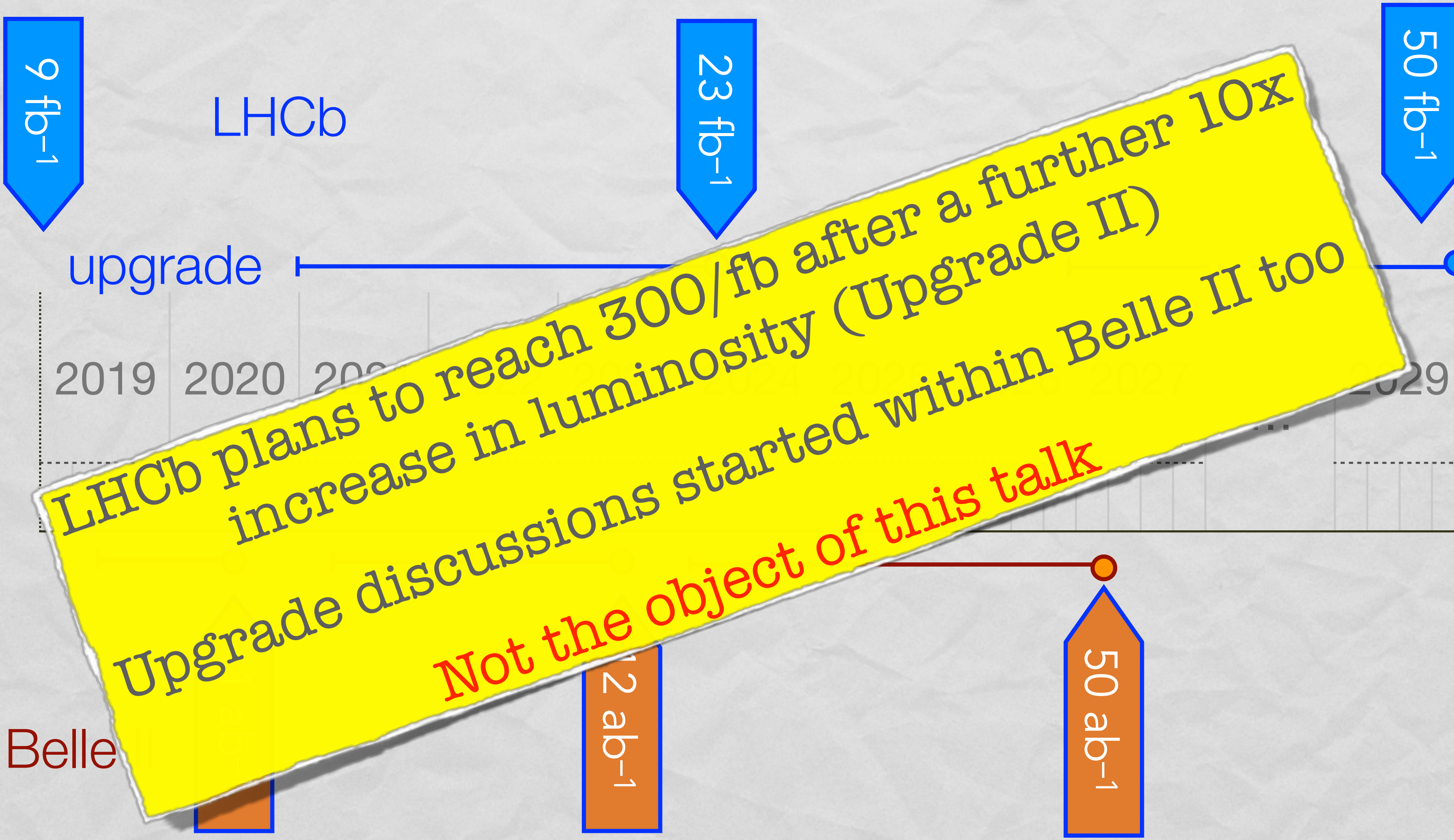

"IT'S TOUGH TO MAKE
PREDICTIONS, ESPECIALLY
ABOUT THE FUTURE."
–Yogi Berra

Official lumi targets



Physics goals: https://arxiv.org/pdf/1808.08865.pdf https://arxiv.org/abs/arXiv:1808.10567

Official lumi targets



LHCb plans to reach 300/fb after a further 10x increase in luminosity (Upgrade II)

Upgrade discussions started within Belle II too

Not the object of this talk

Physics goals: https://arxiv.org/pdf/1808.08865.pdf https://arxiv.org/abs/arXiv:1808.10567

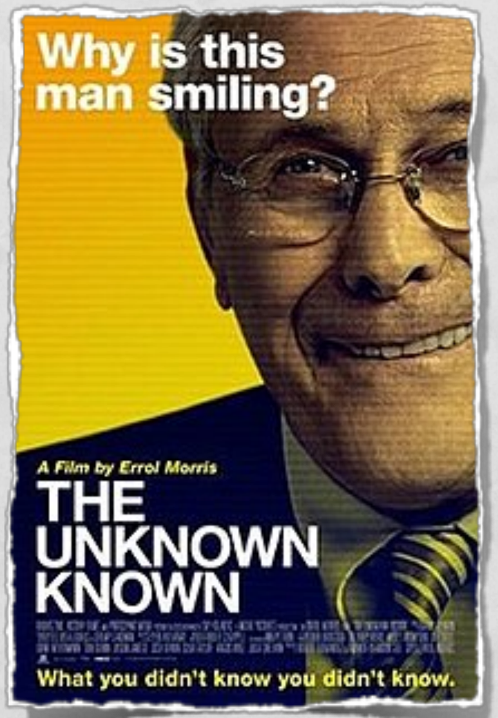
Known unknowns

LHCb-upgrade trigger

Ambitious 30x increase in input rate at 5x higher luminosity than in 2018.

Target: 2x gain in yield per unit of luminosity (that is, 10x yield per unit of time)

Challenge: real-time tracking



Luminosity & beam bckg

Ambitious SuperKEKB lumi-ramping plan.

Target: achieve a monthly increment in peak luminosity of O(max Belle lumi)

In addition, this will expose detector and DAQ to yet uncharted beam-induced backgrounds.

Challenge: get the luminosity, and get it on tape.

The "Murphy" projections

Not official. My own

Sketch a conservative scenario that accounts for pessimistic guesstimates for the unknowns.

If I manage to convince you that even that picture remains exciting I'll consider my job done.

- Lower-bound on LHCb trigger performance: assume same yield-per-luminosity in 2021–2029 as in 2018 (but remember, lumi grows 5x)

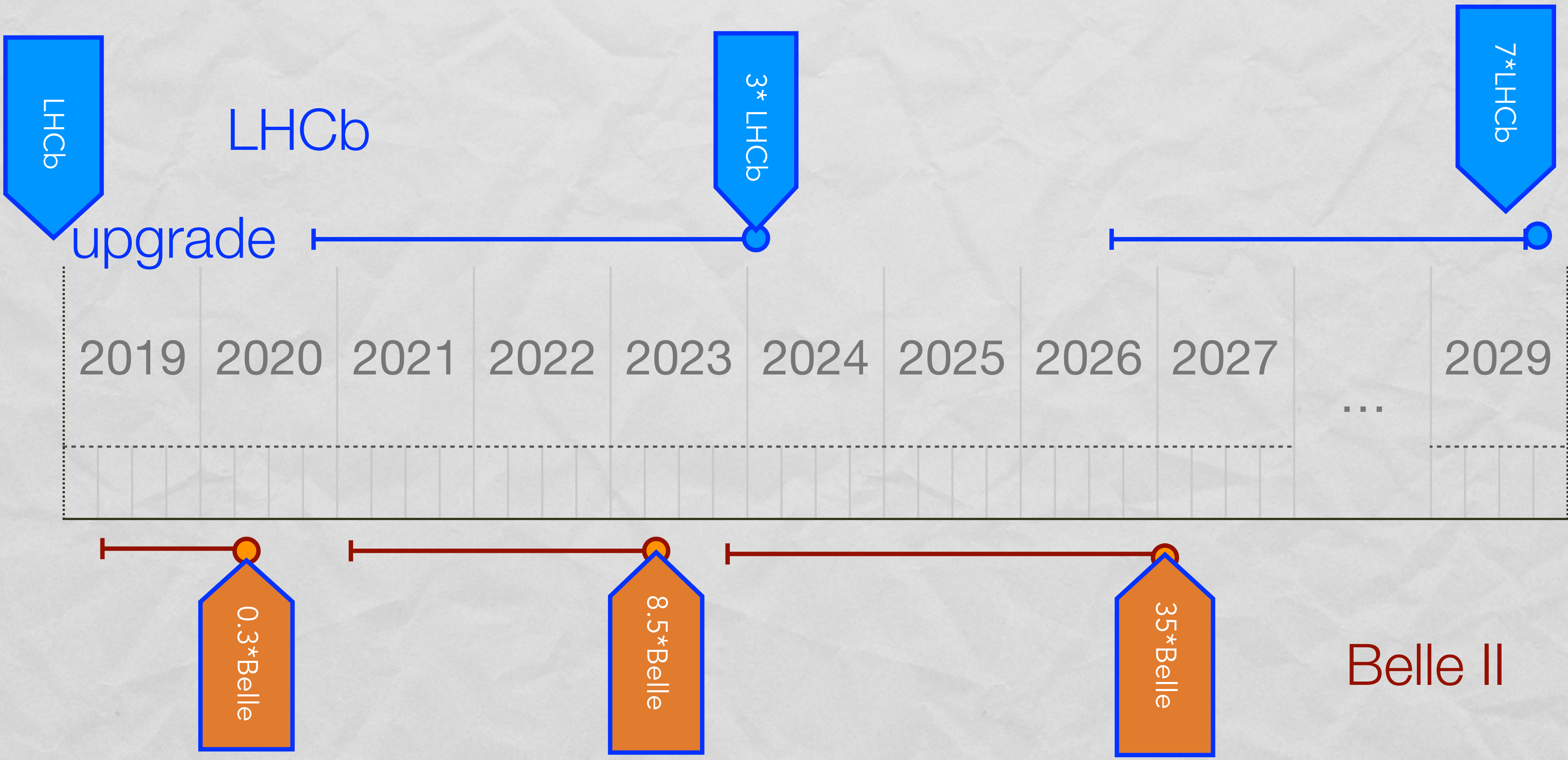
- Lower bound on SuperKEKB lumi/beam-bckg: rescale down 2x sample sizes using half-discrepancy between target and achieved lumi in pilot 2018 run

- Neglect impact of detector improvements in Belle II vs Belle (better IP resolution, PID, and K^0_S but lower boost) and upgrade LHCb vs LHCb (new vertex & tracking detectors)

Murphy samples

Not official. My own

Sample sizes in units of current LHCb and Belle samples (current LHCb sample of 9/fb scaled to 7.5/fb to account for reduced yield-per-fb-1 in 2011-12)



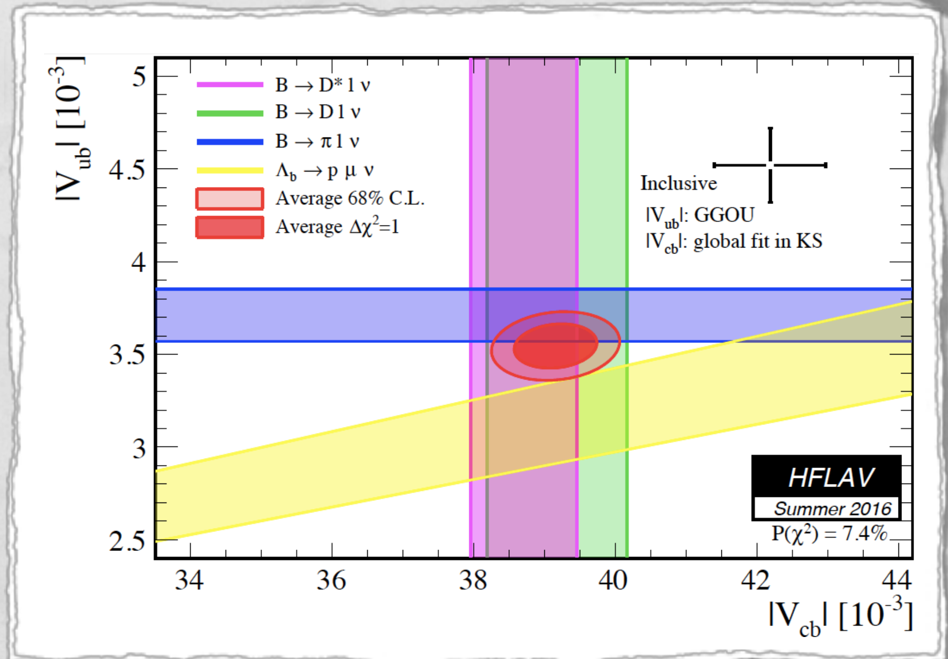
To trust any discrepancy, we need firm references

$|V_{ub}|$ and $|V_{cb}|$

Not official. My own

Traditional B-factory turf: significant impact "guaranteed" at Belle II.

In 2015, unexpected competitive LHCb results: big potential but subject to improving systematics.

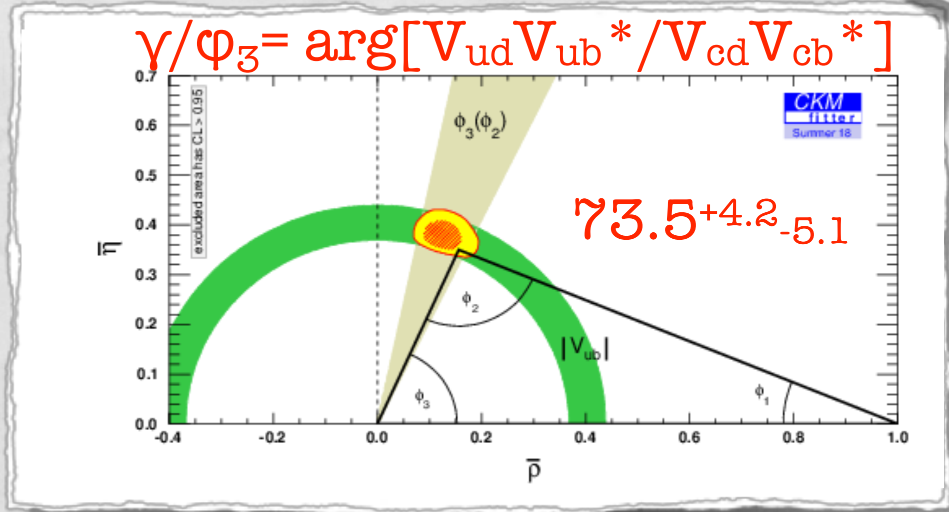


Several approaches and choices of th. inputs: hard to encapsulate gain into a single number. Realistically expect 1.5x—2x improvements over current status.

(hopefully accompanied by advancements in identifying a consistent, systematic strategy to frame the exclusive/inclusive interplay)

Everybody loves γ/φ_3

Not official. My own



Independent of top-quark couplings ==> access from tree-level B->DK decays. Very reliable predictions.

Current precision dominated by combination of several LHCb analyses.

Belle II chance to significantly contribute is time critical.

Both expts need common BESIII inputs for the most precise channel and a statistically reliable channel-combination method

1-2 deg global precision by 2030: a robust pivot to leverage in comparisons with indirect determinations


(now to my own choice of)
potential non-SM harbingers

physicstoday

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Democracy suffers a blow—in particle physics

Three independent B-meson experiments suggest that the charged leptons may not be so equal after all.

$b \to c$ anomalies

- Seen by several experiments (BaBar, LHCb, Belle)
- Three observables
- Charged current at tree level in SM
- A non-SM source must be "light"

$b \to s$ anomalies

- Seen by LHCb. Studied at Belle, BaBar, CMS, ATLAS too.
- Pattern of many observables
- Neutral-current at (CKM-suppressed) one-loop
- A non-SM source can be "heavy"

R(D) and R(D*)

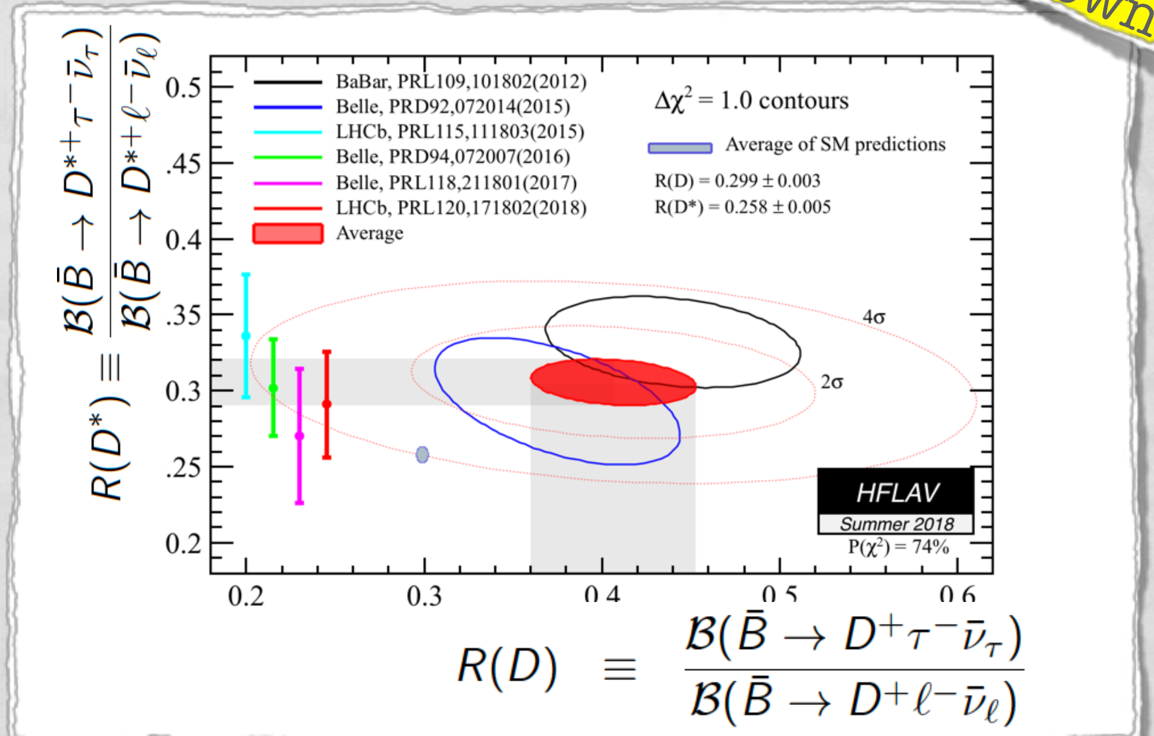
Not official. My own

3σ-ish tau excess in b → c

$$A = A_0 \left(\frac{c_{\rm SM}}{m_W^2} + \frac{c_{\rm NP}}{\Lambda^2} \right)$$

$$c_{\rm SM} \approx V_{\rm cb} \Rightarrow \frac{\Lambda^2}{c_{\rm NP}} \sim (3\ \mathrm{TeV})^2$$

We are in for an exciting race.



Belle II throws at it whole-event reco to improve reach (details of gain depends on beam-bckg mitigation). LHCb expands portfolio of observables. Both will work hard on systematics

By 2030, get 5σ-test of deviations >0.02–0.05 in R(D*) and >0.1in R(D)

R(K) and R(K*)

Not official. My own

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^-\mu^+)}{\mathcal{B}(B \to K^{(*)}e^-e^+)}$$

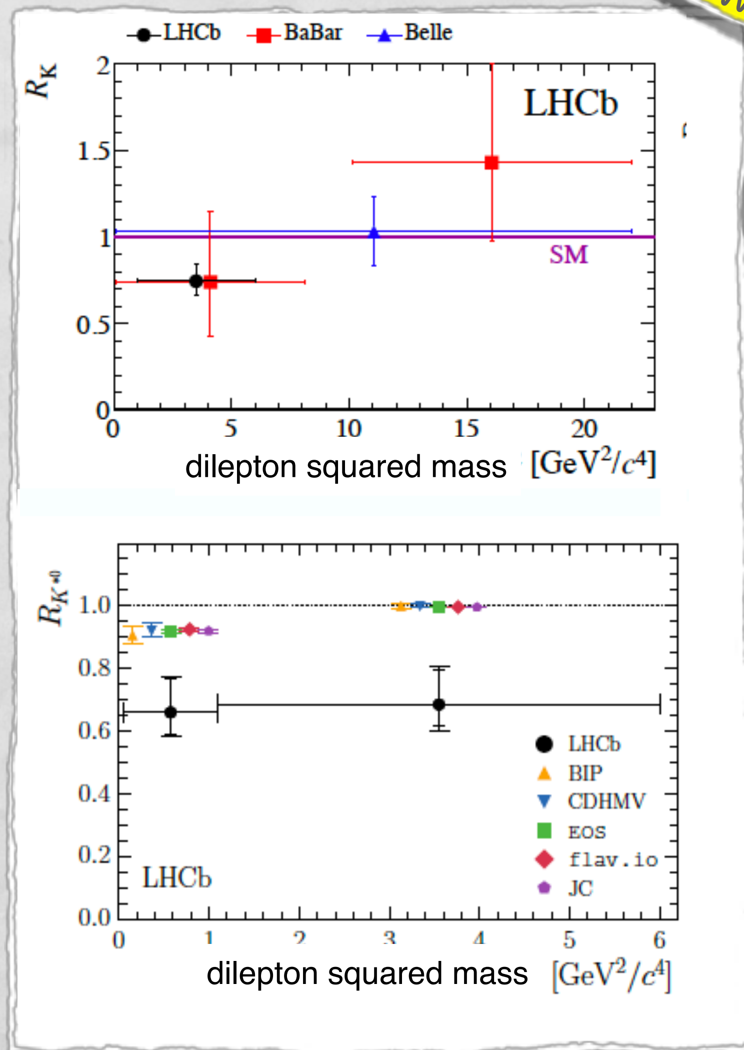
LHCb sees a muon deficit in b → s

$$A = A_0 \left(\frac{c_{\rm SM}}{m_W^2} + \frac{c_{\rm NP}}{\Lambda^2} \right)$$

$$c_{\rm SM} \approx V_{ts}/16\pi^2 \Rightarrow \frac{\Lambda^2}{c_{\rm NP}} \sim (30\ \text{TeV})^2$$

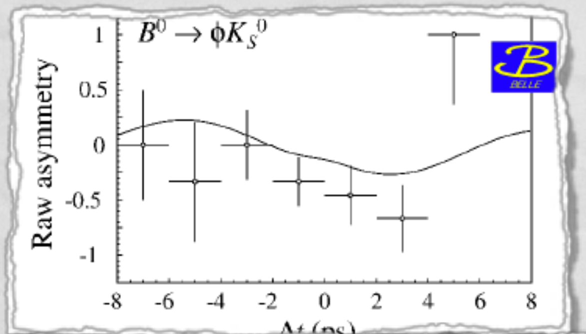
LHCb strongly nonuniversal (Efficiency for muons 5x that for electrons)

But yield advantage offers a decisive edge to LHCb: 5σ-test of deviations of 10% or more in 2030

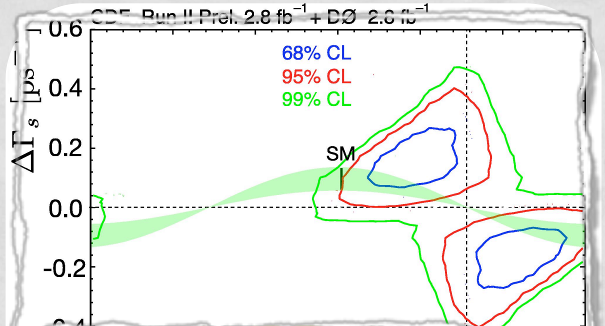


Anomalies

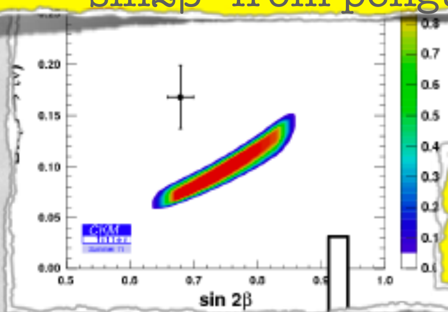
Do we really wanna get excited?



Former anomaly (circa 2003)
"sin2β" from penguins

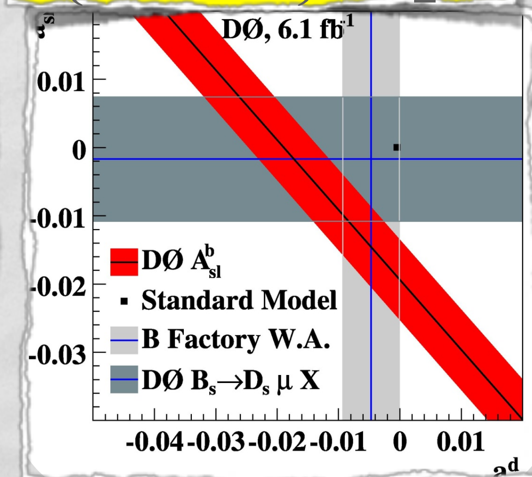


Former anomaly
(circa 2009)
sin2βs



Former anomaly
(circa 2010)
sin2β-vs-B→τν

Former (?) anomaly
(circa 2010) Asl_s



Final outcome aside, anomalies stimulate the community methabolism: push experiments to shake-up priorities and streamline the workflow and theorists to question previous biases and focus on novel directions

Not official. My own

Final-state taus

Anomalies exposed that possible 3rd-lepton-family couplings to non-SM are less strongly constrained than some thought.

Reinforced motivation for exploring processes with final-state taus. significant impact expected from Belle II

$B \to \tau\,\nu$: from single-expt observation to a % measurement

$B \to K\tau\tau$: – rarer and harder. Possible large non-SM enhancements probed

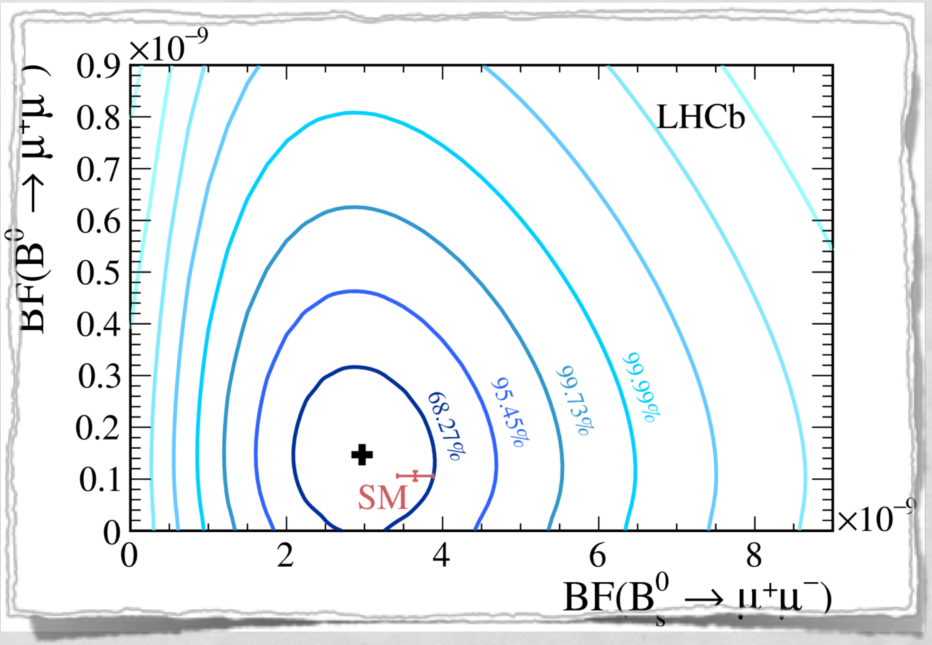
LHCb leads on $B \to \tau\tau$

Rare or medium rare?

Not official. My own

$B^0_s \to \mu\mu$ a legendary channel pursued for 30+ years has now become a solid LHC(b) workhorse.

Precision will approach (current) theory precision ($0.20 * 10^{-9}$) circa 2030.



Increasing attention on the search for the B^0 counterpart — still at LHC(b) — whose correlations with B^0_s enhance the constraining power.

B^0 & B^0_s mixing phases…

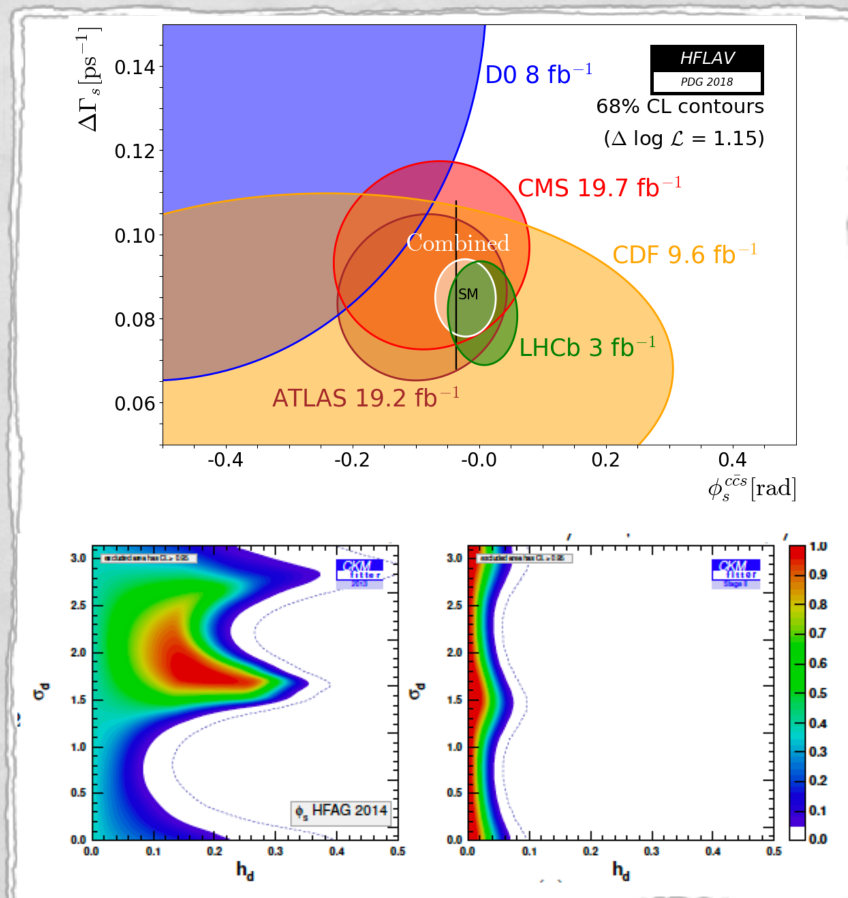
Not official. My own

A nice case of complementarity…

O(10) worse precision than that of KM expectation — driven by sample size

Belle II focuses on $\sin\beta/\varphi_1 = \sin(\arg[-V_{cb}V_{cd^*}/V_{tb}V_{tb^*}])$ from golden $B^0 \rightarrow J/\psi\ K_S$. Approach current systematic bound (0.013) in 2024. Further improvements need progress on systematics.

LHC(b) unique for βs from $B^0_s \rightarrow J/\psi[hh]$. Favorable current stat/syst ratio≈ 6 suggests 10 mrad βs uncertainty in 2030

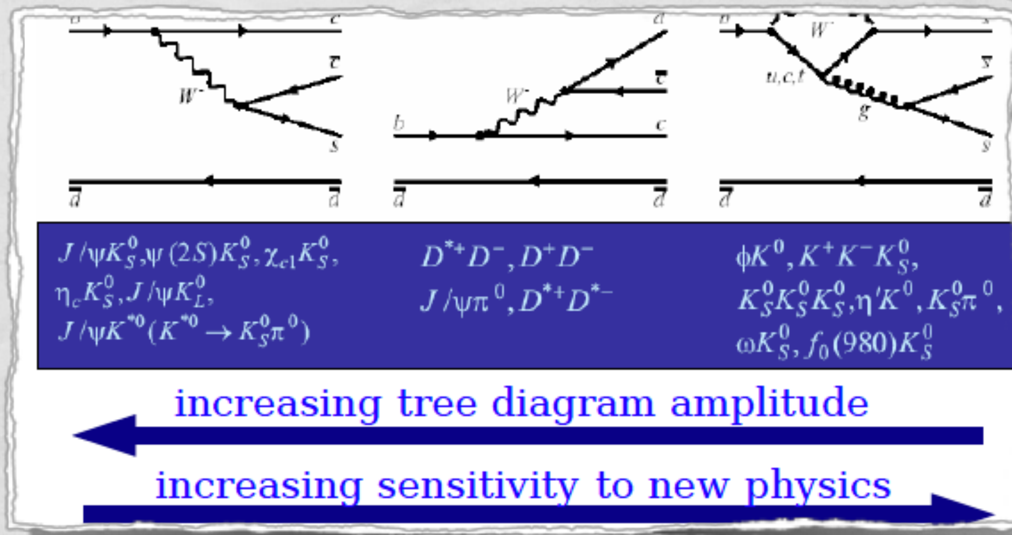


..both sweep large non-SM parameter space meanwhile

...and b → s penguins

Not official. My own

Potential enhanced by comparing tree- and penguin- determinations



Belle II: time dependent Dalitz analyses of $B^0 \to \varphi K_S$ and $B^0 \to \eta' K_S$ will be limited by sample size and reach the current tree-precision in mid-2020

Upgraded LHCb will have similar impact on $B^0_s \to \varphi\varphi$, $B^0_s \to [K\pi][K\pi]$ and asl_s.

Further penguins

Not official. My own

Probe non-SM photon polarization in $b \to s\gamma$

Belle II pursues the "killer app" $B \to K_S \pi^0 \gamma$

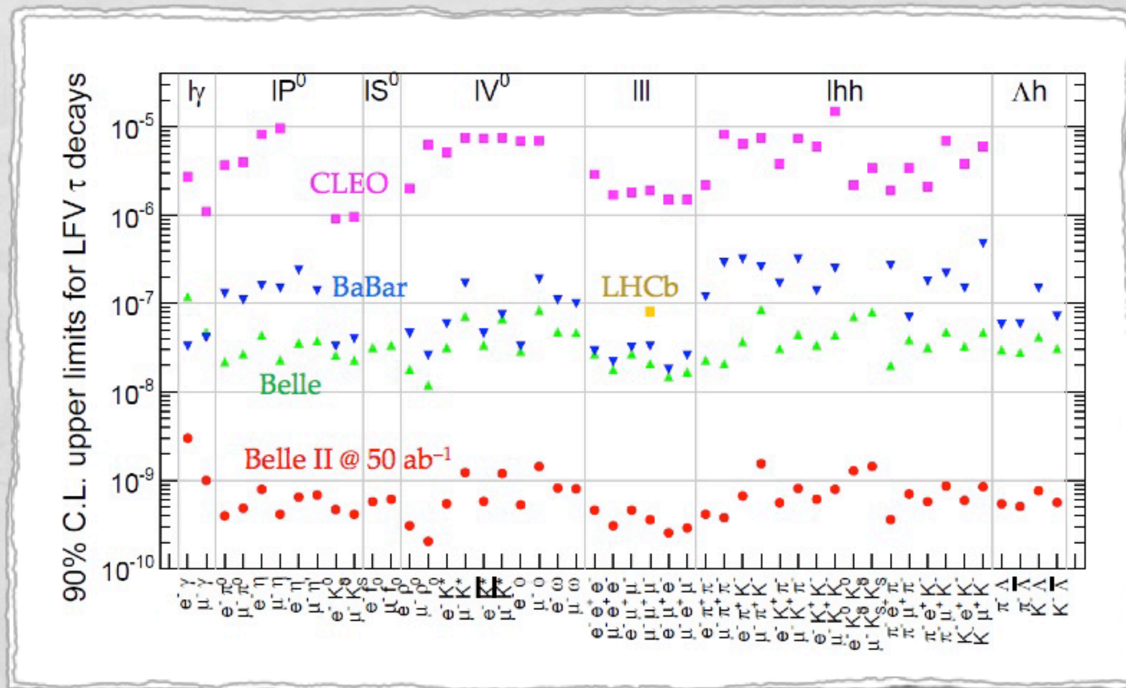
LHCb $K^* \ell\ell$ and and $B^0_s \to \varphi\gamma$

Results, suitably formatted to minimize dependences on hadronic unknowns, are fed to fits that determine global non-SM perturbations to dynamical parameters

Sample size is the limit. Expect at least 2x—5x improvements wrt current best results. Less obvious to guess how this maps into discriminating power of SM tests

Much more to that…

- Tau dynamics offers the most room for progress (and perhaps discovery potential?) — A large portion of Belle II impact



- Didn't cover charm and hadronic B decays since prediction accuracy limits reach. Any breakthrough prediction-wise would immediately open up a suite of highly precise probes since many measurements very precise already. LHCb (track-dominated f.s.) and Belle II (neutral dominated f.s.)

Summary

Two “state-of-the-art” dedicated experiments in complementary environments — an unprecedented opportunity for flavor.

(I argue that) flavor is today, and will be in this coming decade, the most promising driver of nonSM searches in collider physics.

It will be an exhausting, exciting, and exhilarating ride.

Guaranteed reward: a much sharper picture of quark dynamics — no trips to Stockolm, but essential to inform future choices.

We have no guarantee that something new will show up.

If it does, it will be beautiful (pun intended).

Otherwise, it might be time to look somewhere else — or shut up and measure with better precision ;)

Away from the energy frontier has been rewarding..

- 1927: neutrino existence (Ellis and Wooster)
- 1932: neutron discovery (could have been seen years earlier)
- 1933 proton's magnetic moment (indicated proton substructure)
- 1944 Conversi-Pancini-Piccioni difference between π and μ
- 1956 P-violation and K^0-K^0 mixing
- 1964 CP violation
- Late 60ies: solar neutrino deficit
- 1974 J/ψ (not at the ISR - the energy frontier back then)
- 1976 τ lepton
- 1977 bottom quark
- 1983 long B-meson lifetime
- 1987 B mixing (indicating heavy top)
- 1998 atmospheric neutrino mixing

(Hopefully not) The end

Thanks to Gino & organizers for inviting me, and to Karim T., Tim G., Sheldon S., Abi S., Mat C., Angelo D.C., and Mirco D. for help in improving the slides. Mistakes my own.