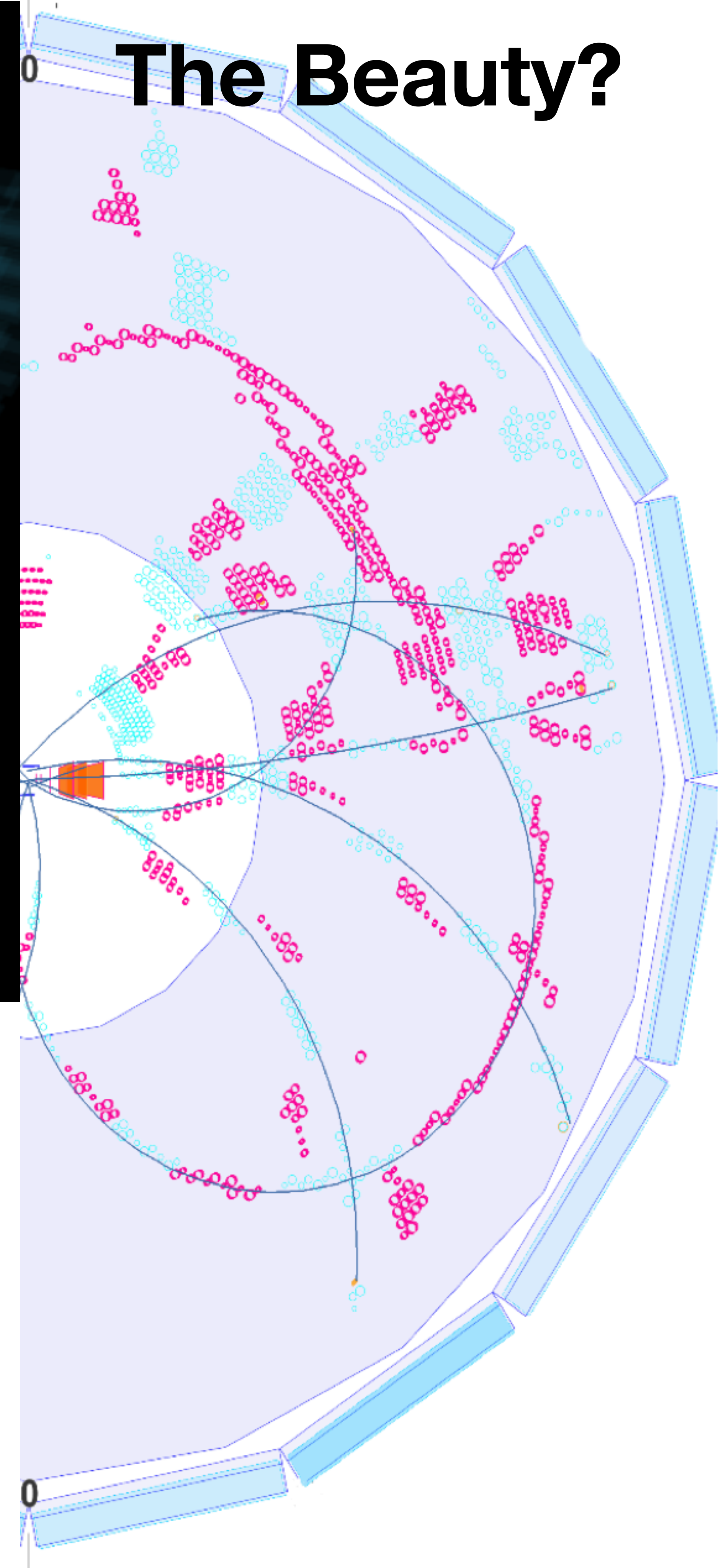
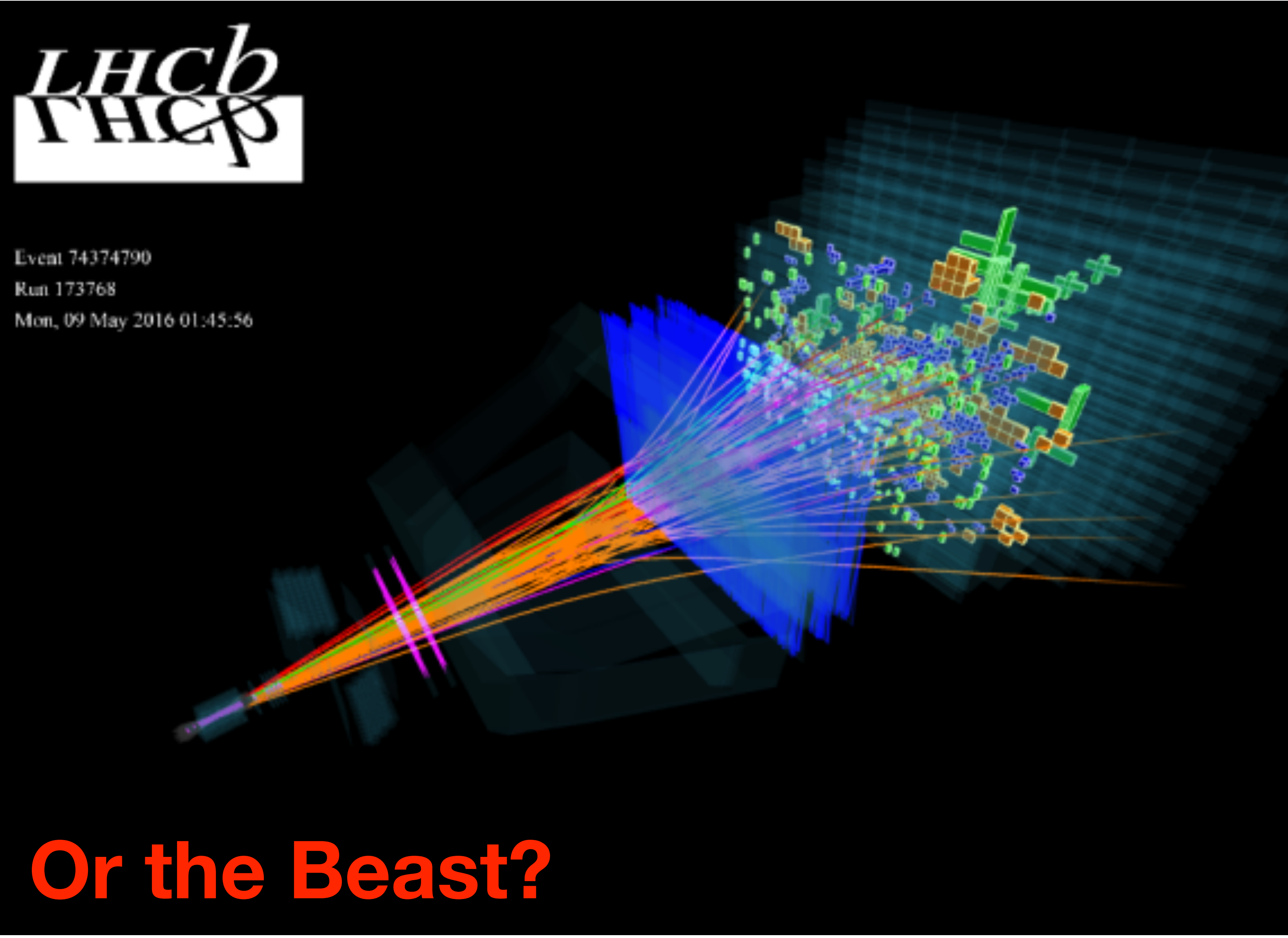
The Beauty?





Or the Beast?

Diego Tonelli — INFN Trieste

German Belle II Academy
March 26, 2021

This is a difficult talk

I could offer you a detailed list of topics where LHCb has an edge, and my own roadmap of “important topics” where Belle II is expected to have impact.

Not a very useful exercise.

It’s been done already, and better than I alone would
(https://confluence.desy.de/display/BI/Physics+WebHome?preview=/34028558/196231333/High_Priority_Belle_II_Analyses.pdf)

It would be biased (importance is subjective blah blah…).

It could be unnecessarily worrisome for those of you who might find your thesis topic on the wrong side of my list ;)

Most importantly, it would be short sighted.

This is physics. It ain’t engineering. One cannot rely too much on “expectations” or “guaranteed performance”.

Surprises, for the good or for the bad, are an intrinsic part of the game — and they actually happen. That’s why we do it, after all.

This might be a useful talk

LHCb and Belle II: could be the last large collider experiments dedicated to flavor.

We better be ready to exploit the opportunity maximally.

Understanding early (and following up in time) the potential, limitations, opportunities for synergy is essential.

We learn a lot from our Belle and Babar predecessors. Comparing with them offers precious insight on how to improve, refine, and measure our preparedness.

However, since >5 years now, the bâton has been passing in LHCb's hands for many topics central to our program.

LHCb is the reference to gauge our ambitions.

(And CMS and ATLAS are joining the party too)

Today

Discuss some aspects of the experimental capabilities of the two experiments with a (slightly provocative) spin targeted at questioning conventional wisdom.

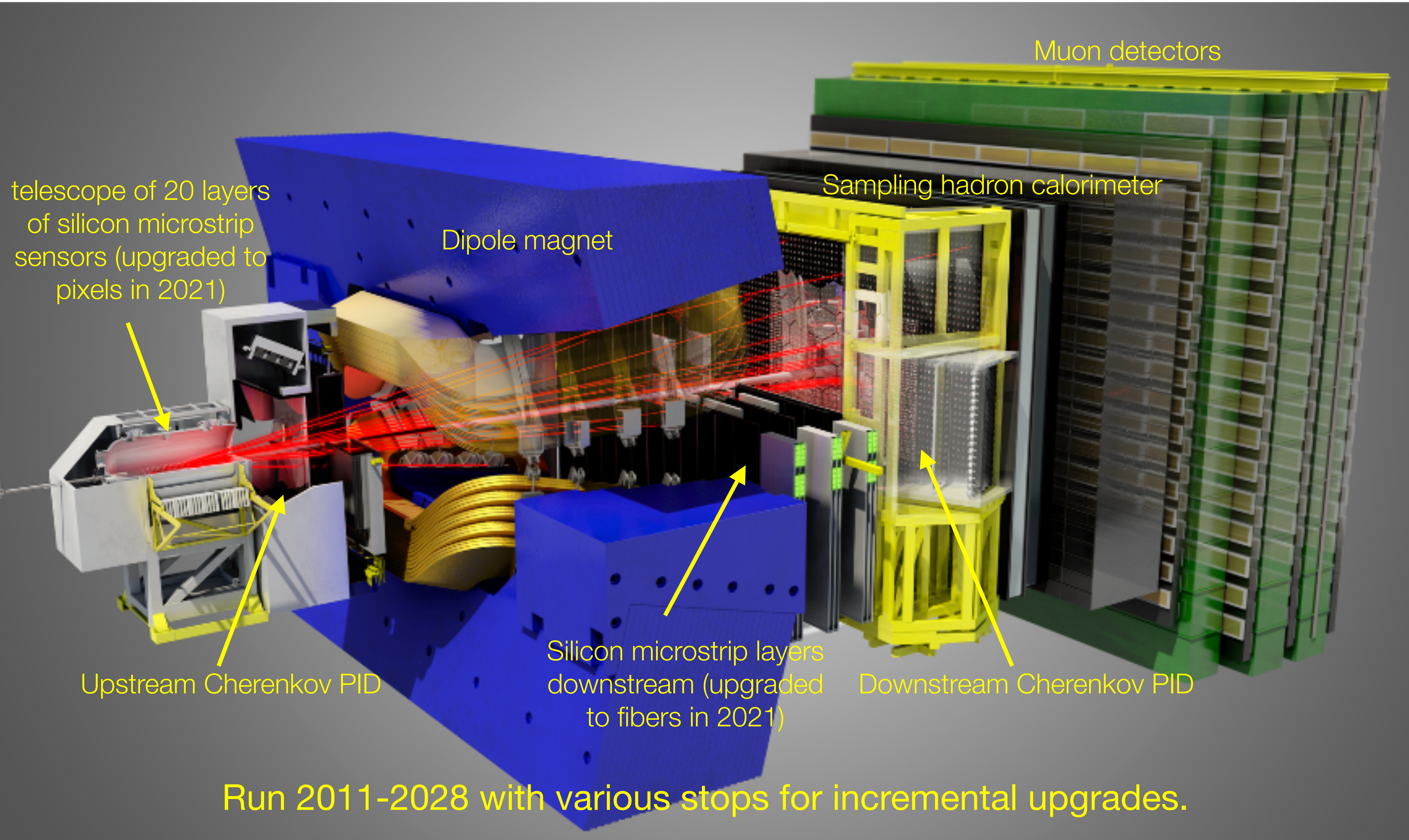
I hope you will learn something about LHCb. Or about Belle II.

Or, most importantly, about the exciting enterprise that is to be a student in an experiment that is just starting physics.

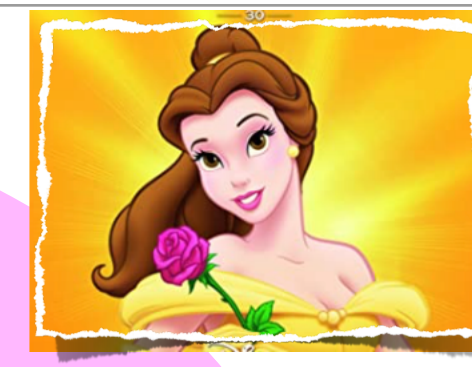
The ultimate goal is provide information and inspiration to form your own opinion on what will be your best opportunities (and hopefully identify/generate new ones).

Disclaimer: discussions/examples very much biased toward *B*/*D* physics. Just because that's my principal expertise — not a statement of priority.

The Beast: (perhaps the) ultimate hadron-collision flavor instrument



The physics



Heavy LLP

B^0_s, B^+_c and b-baryon dynamics

Select EWK physics

Select QCD physics

Select nuclear physics

B and D dynamics

Charmonium

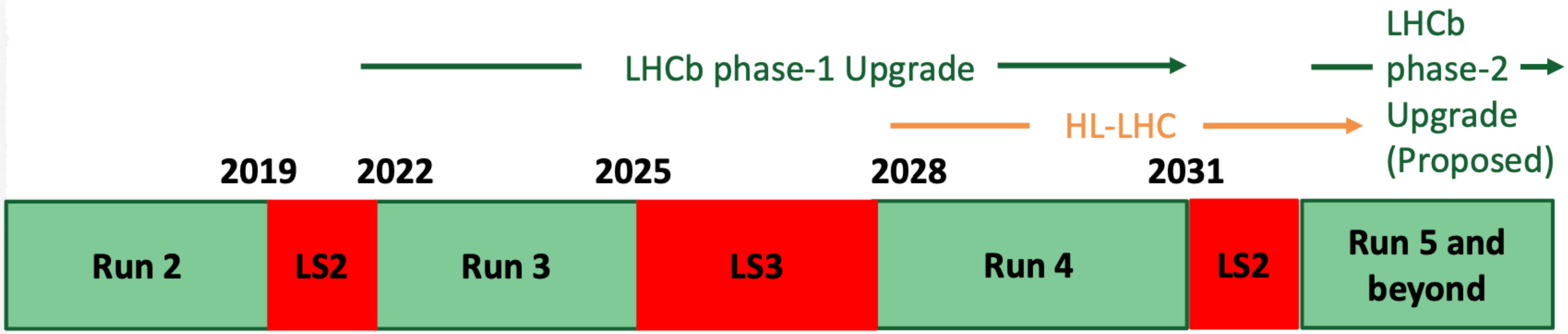
More B and D dynamics

Dark sector physics

τ-physics

Bottomonium

The timeline



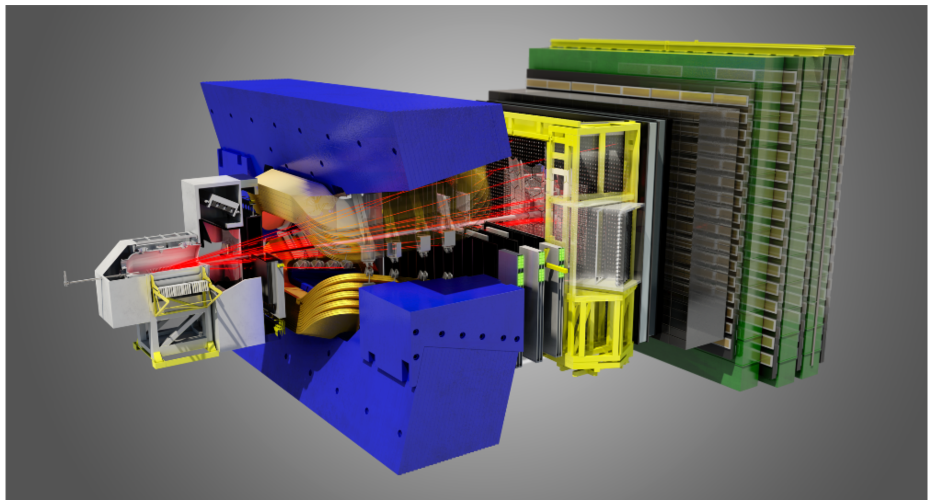
$\mathcal{L} = 4 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

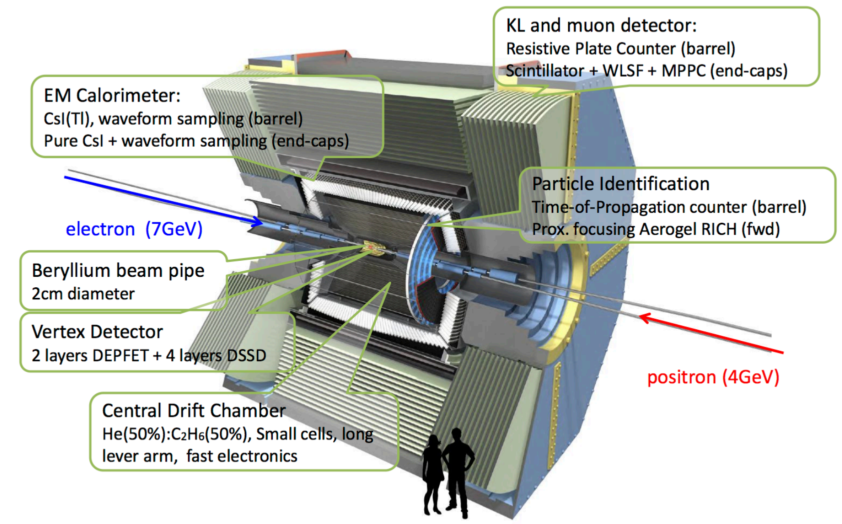
9 fb^{-1} integrated luminosity

- $\mathcal{L} = 2 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- 50 fb^{-1} integrated luminosity
- Introducing software-only trigger
- Replacing tracking detectors and detector electronics

- $\mathcal{L} = 2 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- 300 fb^{-1} integrated luminosity
- Adding fast timing
- Replacing VELO, calorimeter
- Still in development, many possible upgrades

What you already know (the conventional wisdom)



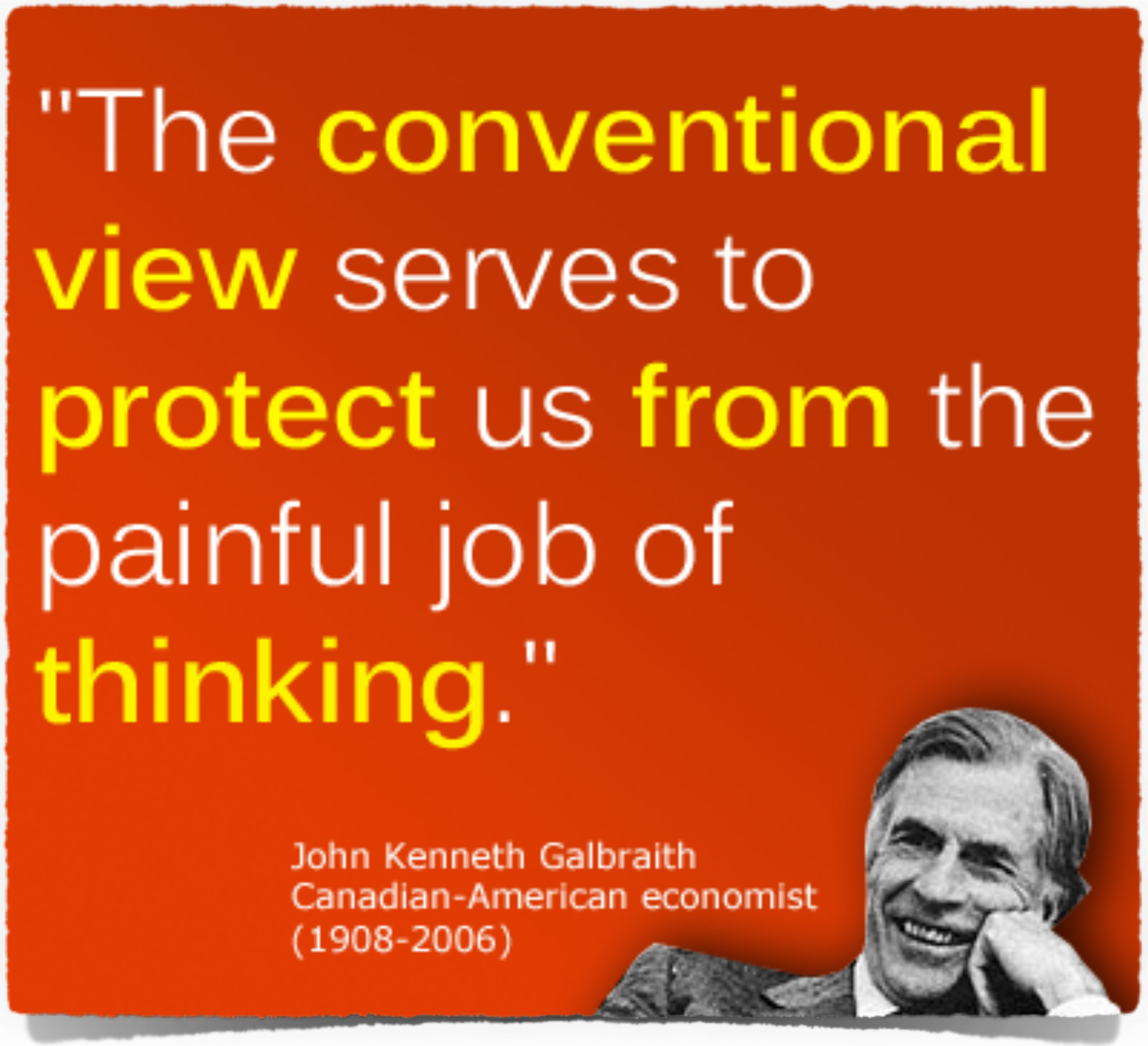


- Superb signal yield for *all types* of b hadrons
- Outstanding reach on final states with only tracks

- Superior/unique on decays into neutrals
- Superior for partially reco'd final states thanks to beam-energy constraints (superb semileptonics and τ physics)

$1\ fb^{-1} = 1\ ab^{-1}$

Beyond the conventional wisdom



Performance drivers

Need many B mesons: luminosity, trigger

Need to know whether the B was a particle or an antiparticle at t = 0

Need low-background signals: use precise particle reconstruction and kinematic constraints (when available)

$$\mathcal{A}_{CP}(t) = \frac{N(\overline{B^0}(t) \to J/\psi K_s) - N(B^0(t) \to J/\psi K_s)}{N(\overline{B^0}(t) \to J/\psi K_s) + N(B^0(t) \to J/\psi K_s)} = \sin 2\beta \sin \Delta m t$$

Need a precise determination of the decay time: fully reconstructed signal and good vertex detector

For a fruitful program in *B* and *D* physics — need to

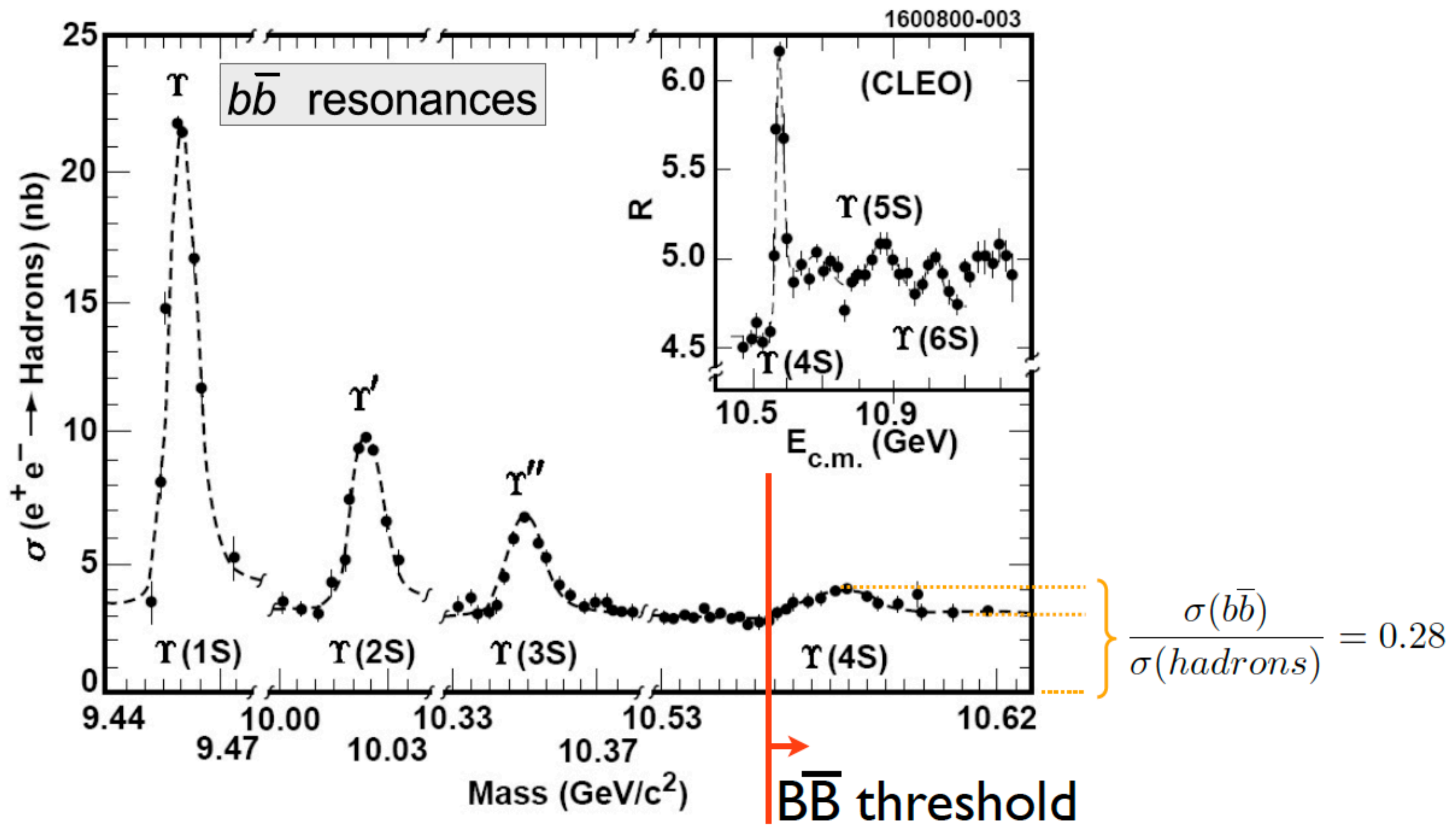
- Produce large and low-background samples of *B* and *D* hadrons
- Reconstruct precisely many *B* and *D* decays with good *S/B*
- Reconstruct precisely *B* and *D* decay time
- Identify if a particle (*B, D*) or antiparticle (anti-*B*, anti-*D*) was produced

Produce. Lots.
Of signal

B factories

At ~1 nb,Y(4S) makes up for 30% of the x-section.

Y(4S) mass lies just above the B-Bbar kinematic threshold: 96% of Y(4S) decay into B^0anti-B^0 or B^+B^- pairs (and nothing else — can't locate the production vertex.



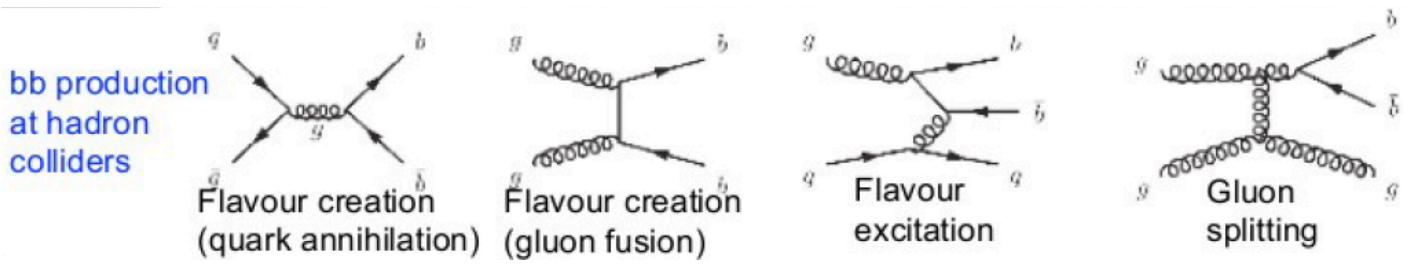
Coherence: Y(4S) is spin-1. B mesons are spin-0, hence L=1 (antisymmetric two-particle state) to conserve angular momentum. Simultaneous B or Bbar pair forbidden (identical bosons in antisymmetric state violate Bose). B and Bbar evolve as a particle-antiparticle pair until one decays.

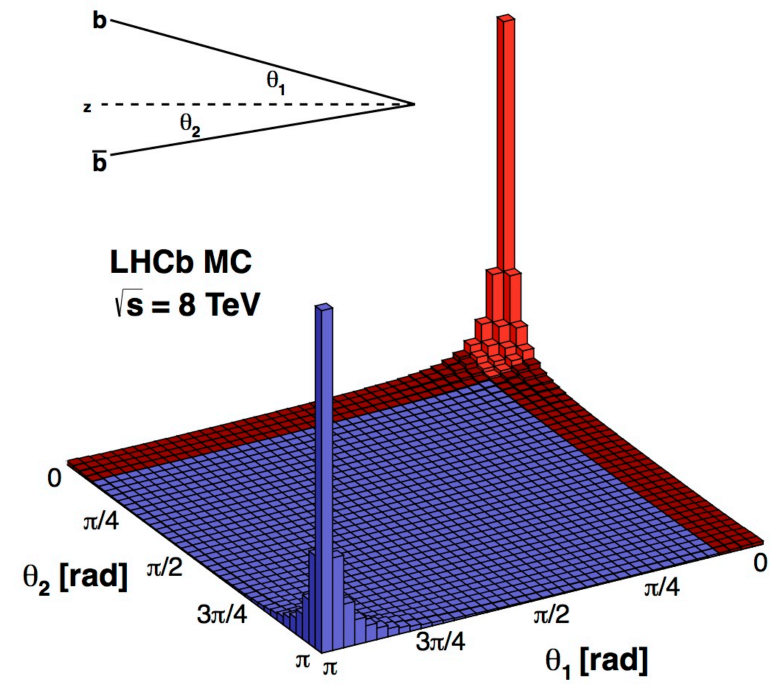
Low-background production of 100-1000 B^0*anti-*B^0 or B^+B^- pairs per second

Production of B^0_s B^+_c b-baryons energetically forbidden (but B^0_s *possible at Y(5S)*)

Hadron colliders

High-energy *pp:* O(10-100) μb x-sections for *B (D)* hadrons. 1000×–100000× higher than at *Y(4S)*. Enhanced in the “forward region” collinear to the beams.





All kind of bottom hadrons (B^0_s, B^+_c, *b*-baryons) produced

Total inelastic cross sections are O(1000) times higher: production S/B is 1/1000, due to lots of light-quark background.

Composite nature of the colliding hadrons and large extra energy available after the collision yields many particles that (i) escape undetected at small deflections, preventing to constrain p_z (ii) complicate event reconstruction.

Incoherent production of 10^5-10^6 *b*-hadrons (of any species) per second

Hadron colliders

白鵬

But high backgrounds…

…but high backgrounds…

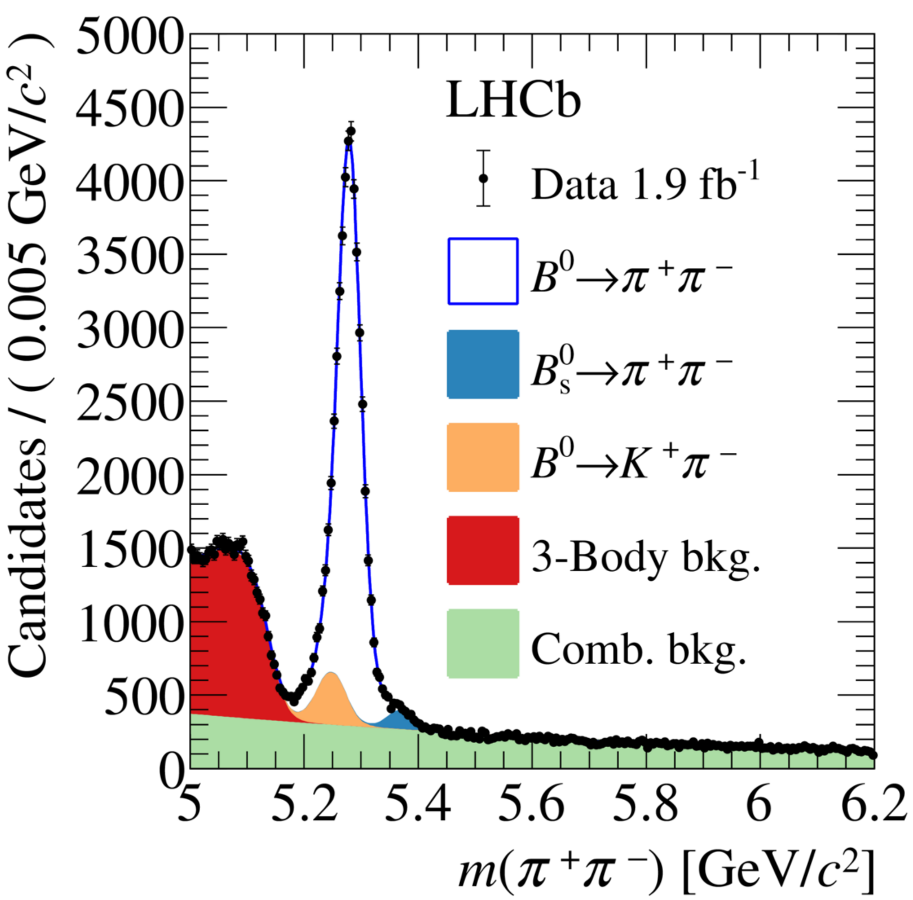
At production, background in Υ(4S) is only 4 times more abundant than signal.

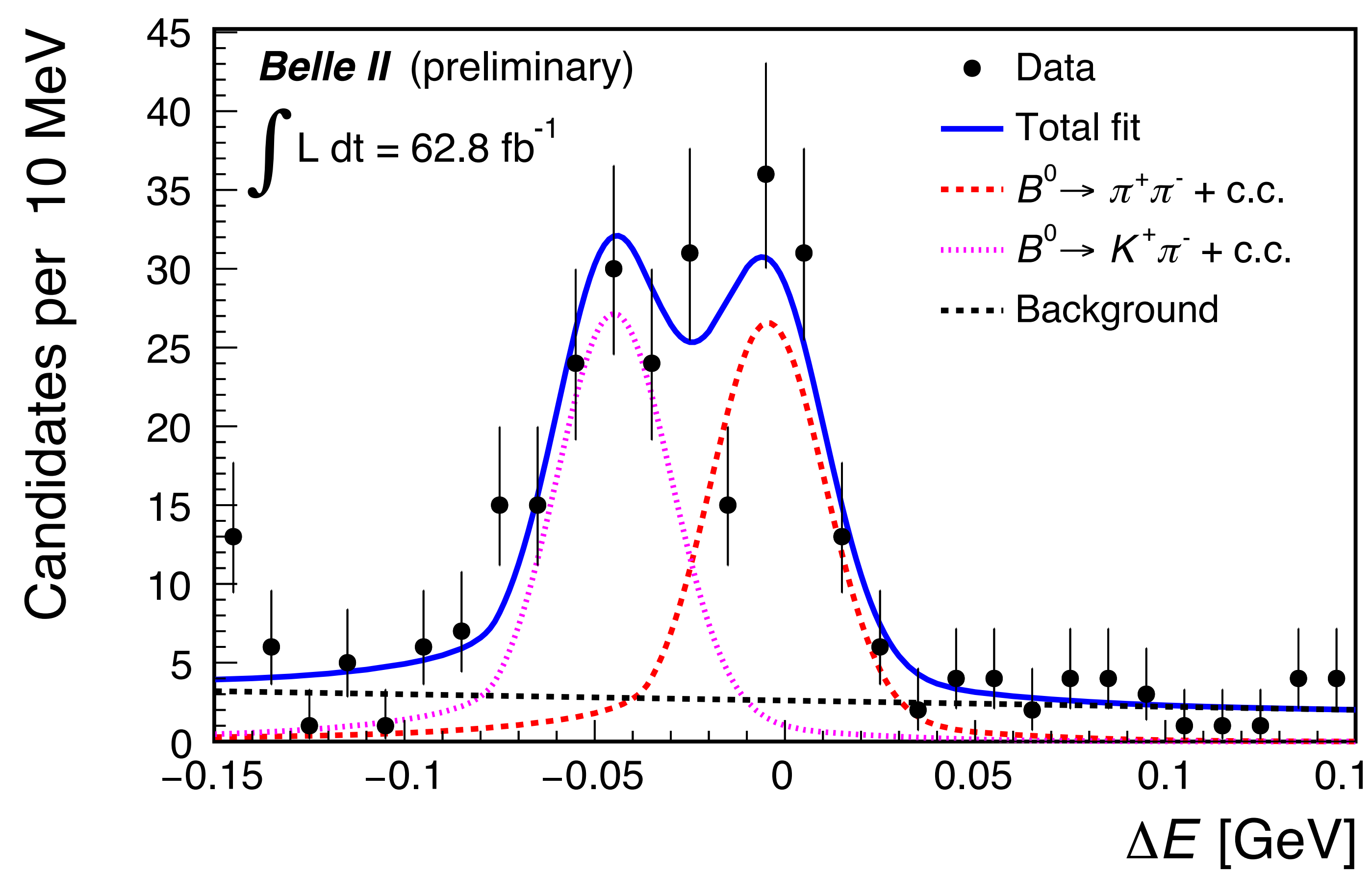
In hadron collisions the penalty looks like ~1000.

Life looks even harder than that: combinatorial background (which impacts cluster- or track-finding efficiency in inner layers, slows down track fitting, increases calo/muon occupancy etc) scales worse than linearly with cross section.

In addition, Υ(4S) benefits from stringent kinematic constraints from point-like nature of colliding particles that aid discrimination.

…but high backgrounds? Not really…

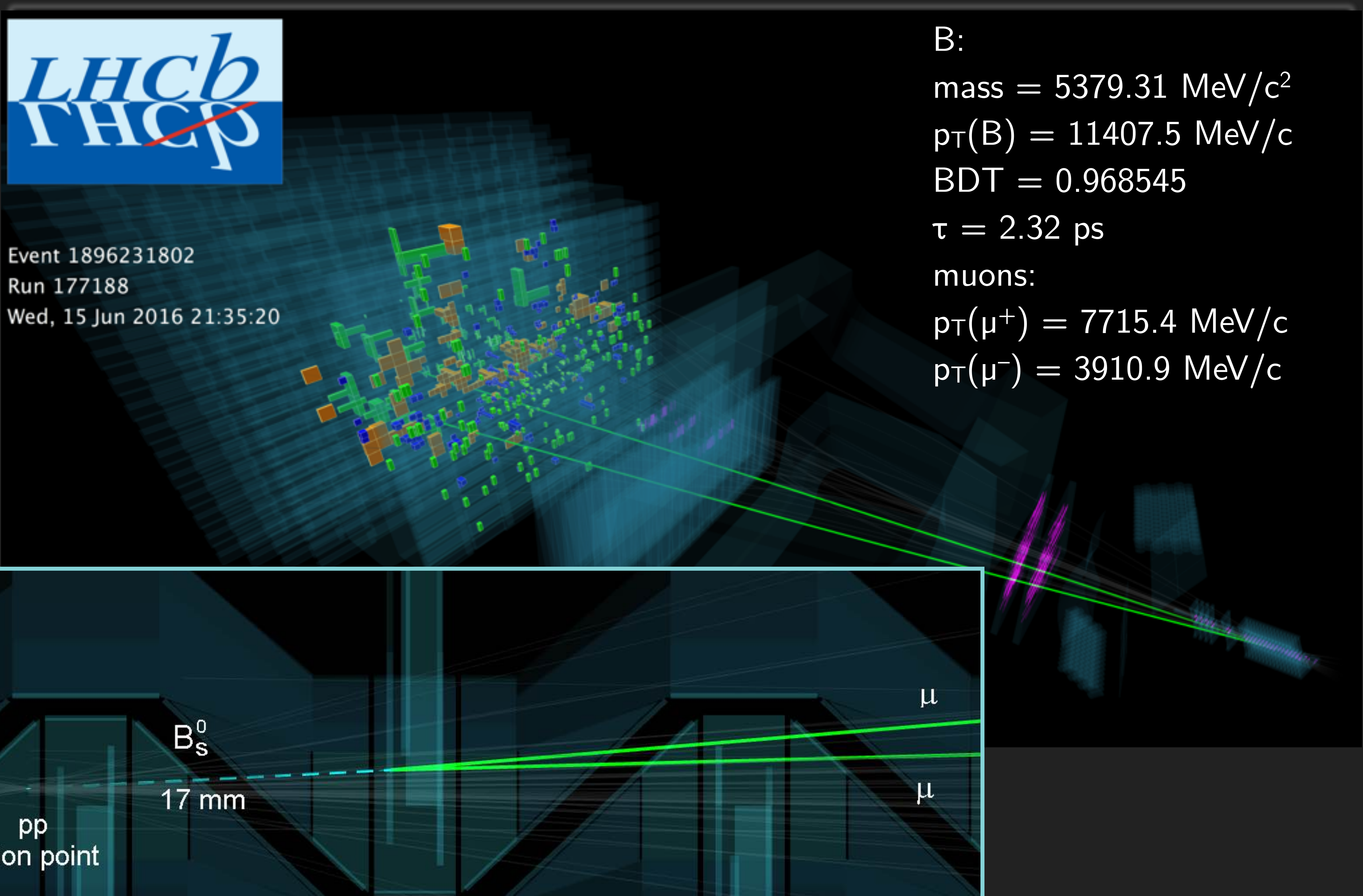




In hadron collisions, large boosts (you are using only 10 GeV (two b-quarks) of various TeV of available energy) result in large displacements of long-lived particle daughters. Even more so in the forward region where LHCb sits due to longitudinal momentum

Natural “clean up” of a large fraction of the the most annoying backgrounds.


Interaction point
Far and forward:
heavy flavor



LHCb
Event 1896231802
Run 177188
Wed, 15 Jun 2016 21:35:20
B:
mass = 5379.31 MeV/c^2
p_T(B) = 11407.5 MeV/c
BDT = 0.968545
τ = 2.32 ps
muons:
$p_T(\mu^+)$ = 7715.4 MeV/c
$p_T(\mu^-)$ = 3910.9 MeV/c
μ
B_s^0
17 mm
μ
pp
on point

Aside: a lesson associated with high yields

Producing and processing simulation of data-grade quality of adequate size (~10x data) poses difficult challenges.

"MC simulation sample size" a major systematic uncertainty in many LHCb measurements.

Typically analyses relying on fits based on MC-templates (semileptonic, R(D*), R(J/ψ)..)

PRL **115**, 111803 (2015) PHYSICAL REVIEW LETTERS week ending 11 SEPTEMBER 2015

Measurement of the Ratio of Branching Fractions $\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)$

R. Aaij *et al.**
(LHCb Collaboration)

Table 1: Systematic uncertainties in the extraction of $\mathcal{R}(D^*)$.

Model uncertainties	**Absolute size ($\times 10^{-2}$)**
Simulated sample size	2.0
Misidentified μ template shape	1.6
$\bar{B}^0 \to D^{*+}(\tau^-/\mu^-)\bar{\nu}$ form factors	0.6
$\bar{B} \to D^{*+}H_c(\to \mu\nu X')X$ shape corrections	0.5
$\mathcal{B}(\bar{B} \to D^{**}\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B} \to D^{**}\mu^-\bar{\nu}_\mu)$	0.5
$\bar{B} \to D^{**}(\to D^*\pi\pi)\mu\nu$ shape corrections	0.4
Corrections to simulation	0.4
Combinatorial background shape	0.3
$\bar{B} \to D^{**}(\to D^{*+}\pi)\mu^-\bar{\nu}_\mu$ form factors	0.3
$\bar{B} \to D^{*+}(D_s \to \tau\nu)X$ fraction	0.1
Total model uncertainty	**2.8**
Normalization uncertainties	**Absolute size ($\times 10^{-2}$)**
Simulated sample size	0.6
Hardware trigger efficiency	0.6
Particle identification efficiencies	0.3
Form-factors	0.2
$\mathcal{B}(\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau)$	< 0.1
Total normalization uncertainty	**0.9**
Total systematic uncertainty	**3.0**

An opportunity for Belle II to learn LHCb's lesson and plan accordingly?

You want (experimental requirements)

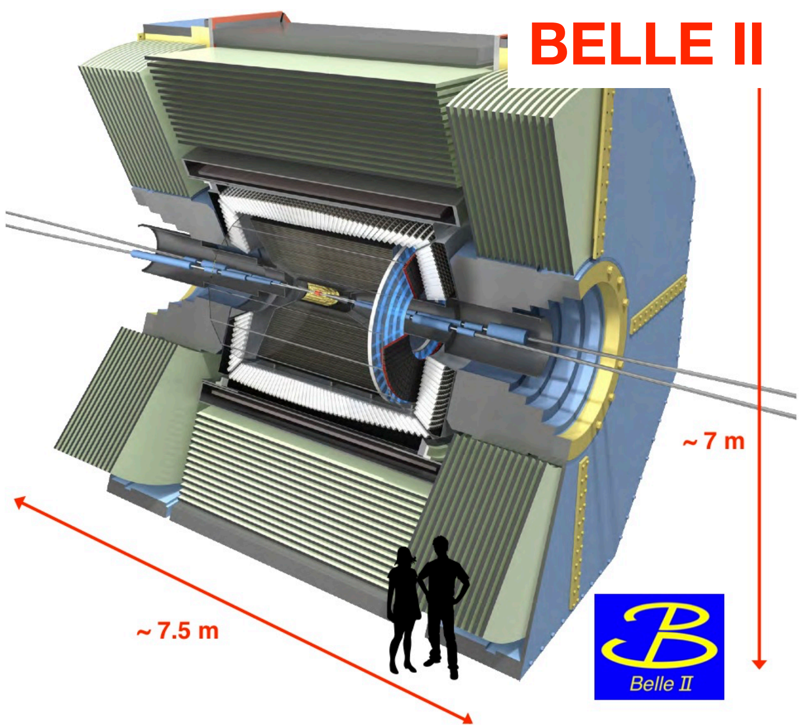
- [x] Produce large and low-background samples of *B* and *D* hadrons
- [ ] Reconstruct precisely many *B* and *D* decays with good S/B
- [ ] Reconstruct precisely *B* and *D* decay time
- [ ] Identify if a particle (*B*, *D*) or antiparticle ($\bar{B}$, $\bar{D}$) was produced
- [ ] Control tightly instrumental charge asymmetries

Reconstruct it

Reconstruction — detector coverage

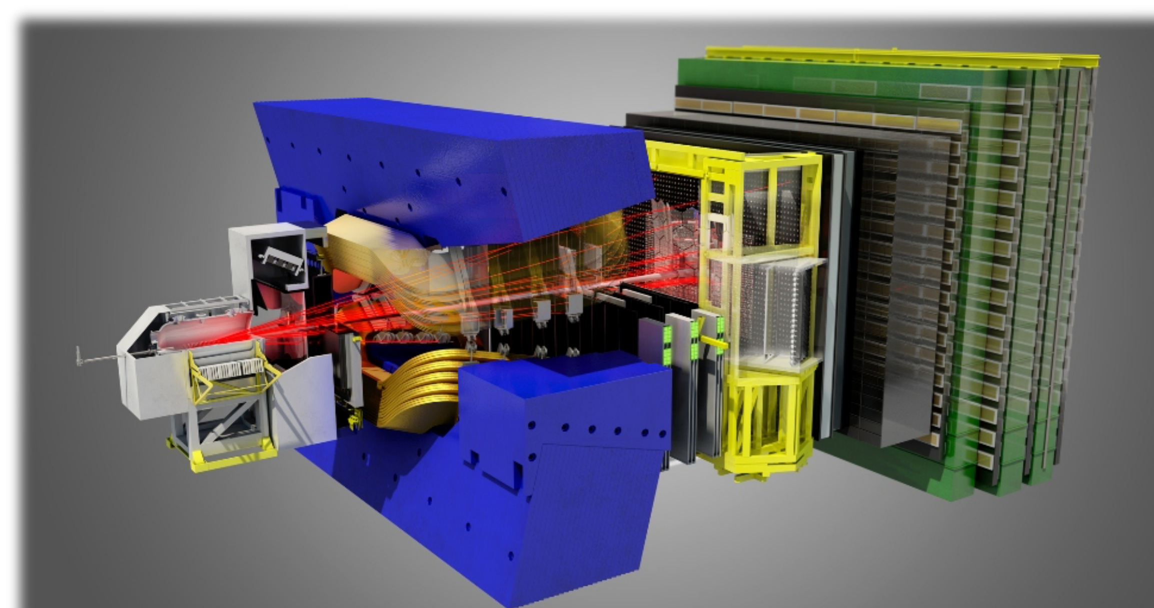
First requirement is obviously to instrument the volume surrounding the interaction region where *B/D* hadrons fly and decay and so do their decay products

BELLE II



Classic: barrel-shaped solenoidal magnetic spectrometer. High hermeticity. High acceptance. Polar asymmetry to mirror com boost.

LHCb



Novel concept: single-arm forward spectrometer. Exploits large forward cross section, but gives up to all heavy flavors produced “on the other side”

Production asymmetries

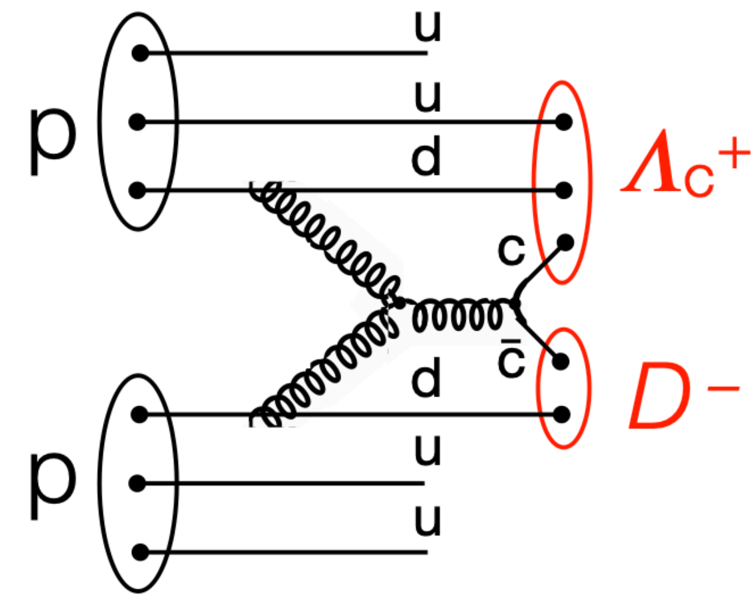
Any **particle-antiparticle asymmetry in production rates** is a potential source of bias in measuring decay-rate asymmetries

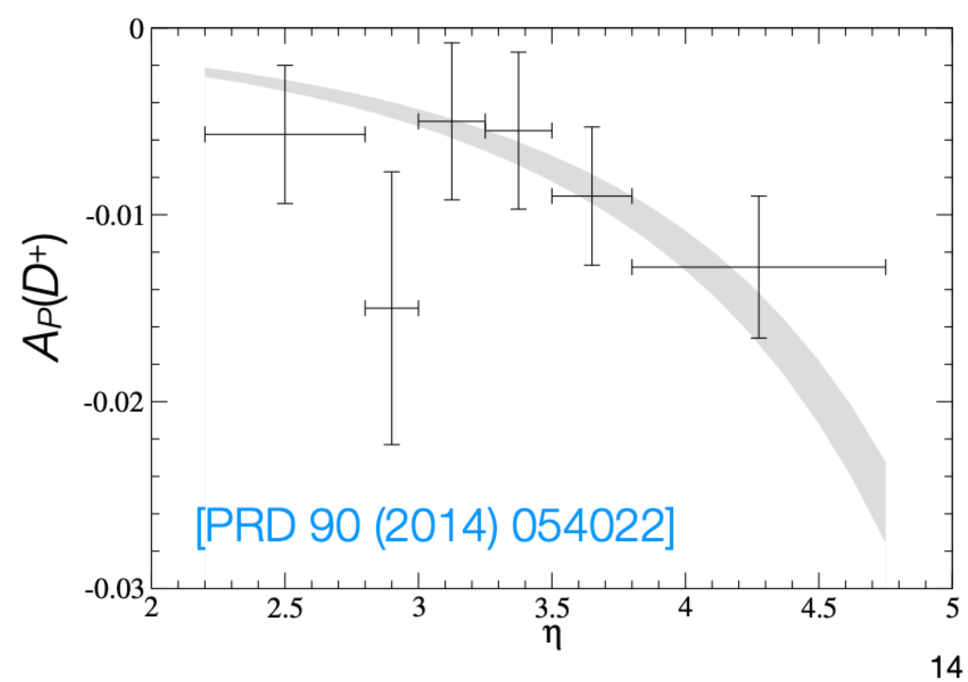
Not an issue in *B*-factories or hadron collisions recorded with symmetric detectors.

A concern at LHCb (asymmetric acceptance).

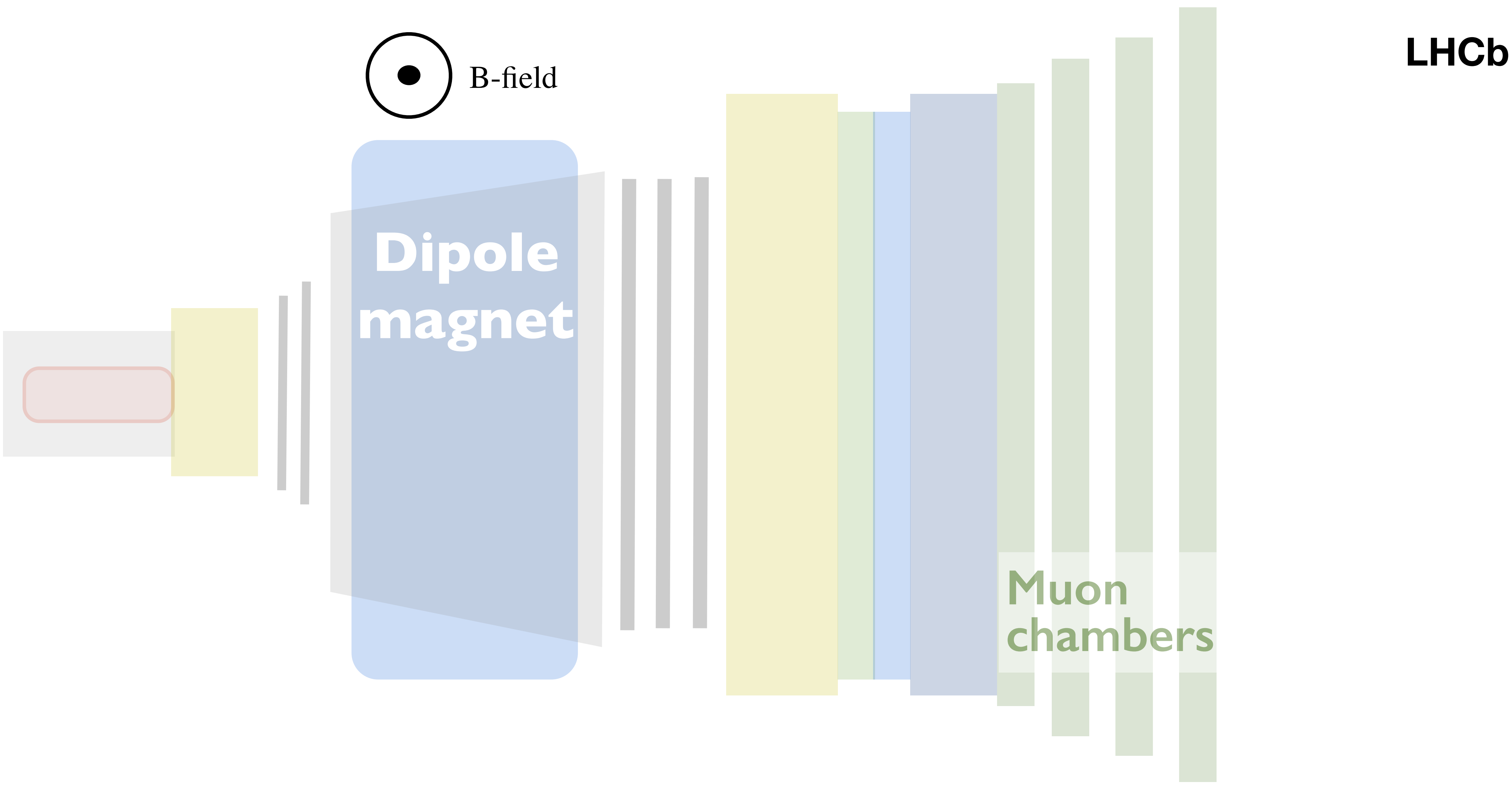
Null net flavor conserved in the strong *pp* interaction *over the whole phase space.* Not necessarily over detector acceptance.

Recombination/color interference between the heavy-quark and the proton's valence quarks ("beam drag") may generate local asymmetries in production rates of heavy mesons, that are particularly enhanced in the forward region (~collinear with beam remnants)





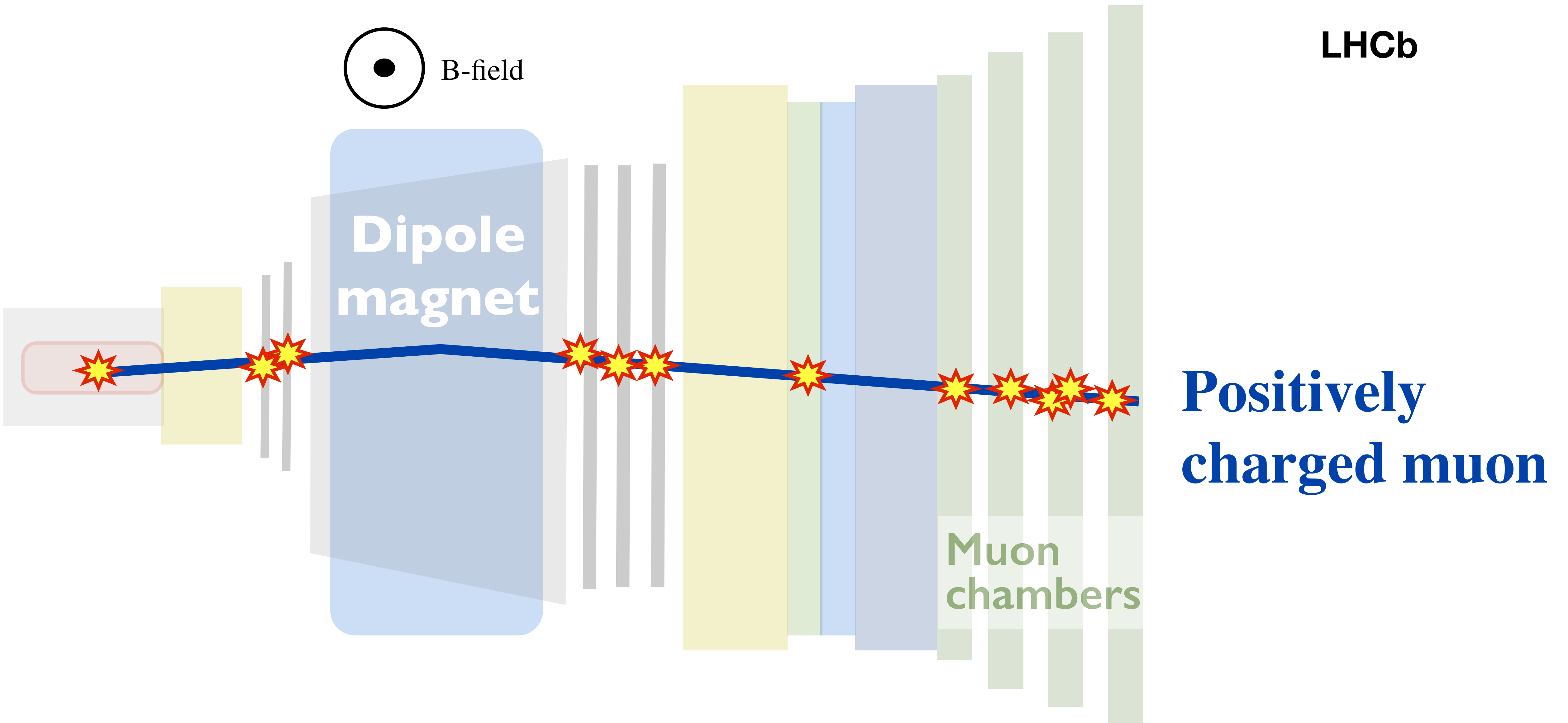
Instrumental asymmetries



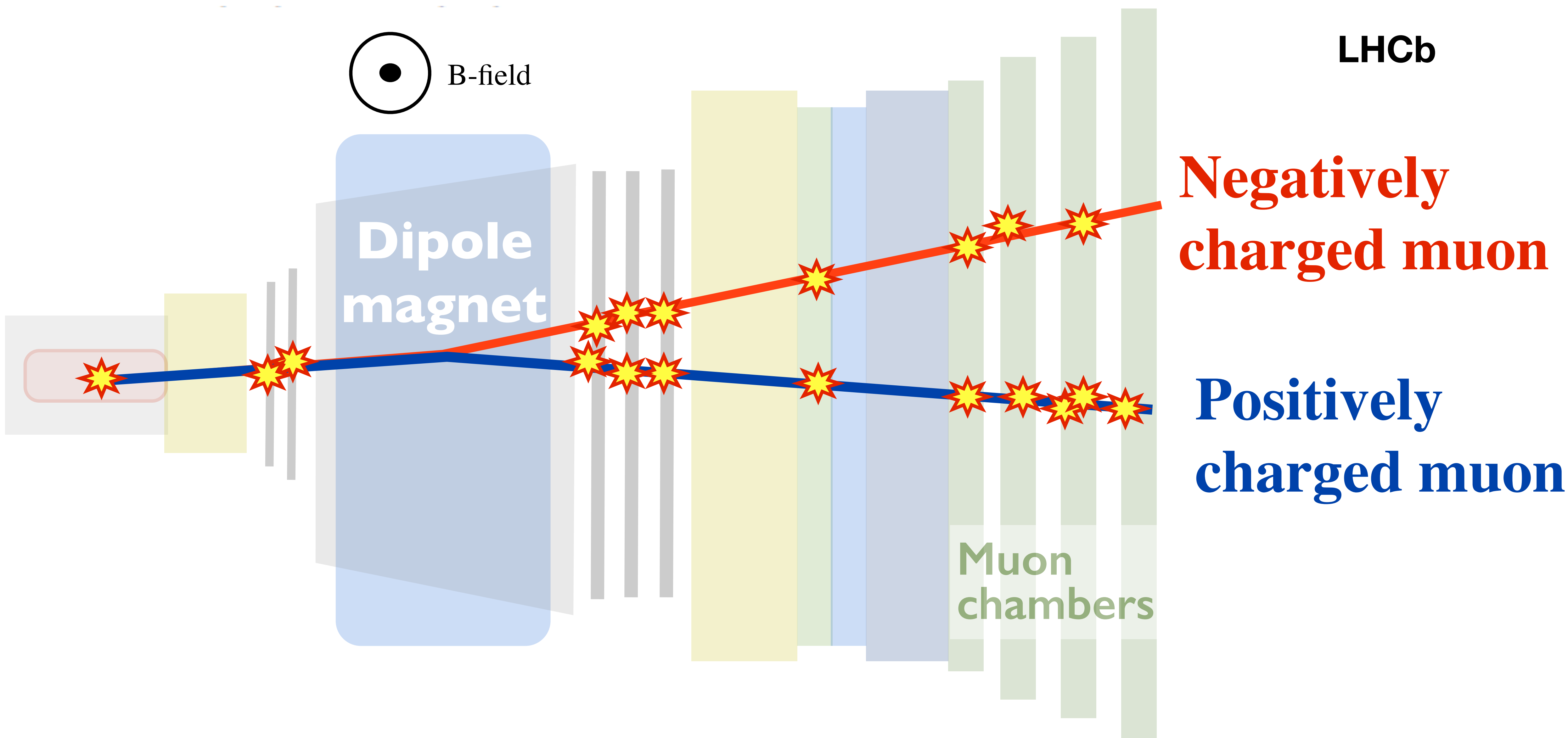
Any **particle-antiparticle asymmetry in reconstruction rates** is a potential source of bias in measuring decay-rate asymmetries. An issue in any detector.

Especially in a dipole-magnet geometry, where different regions of the detector are preferentially illuminated by particles of different charge

Instrumental asymmetries

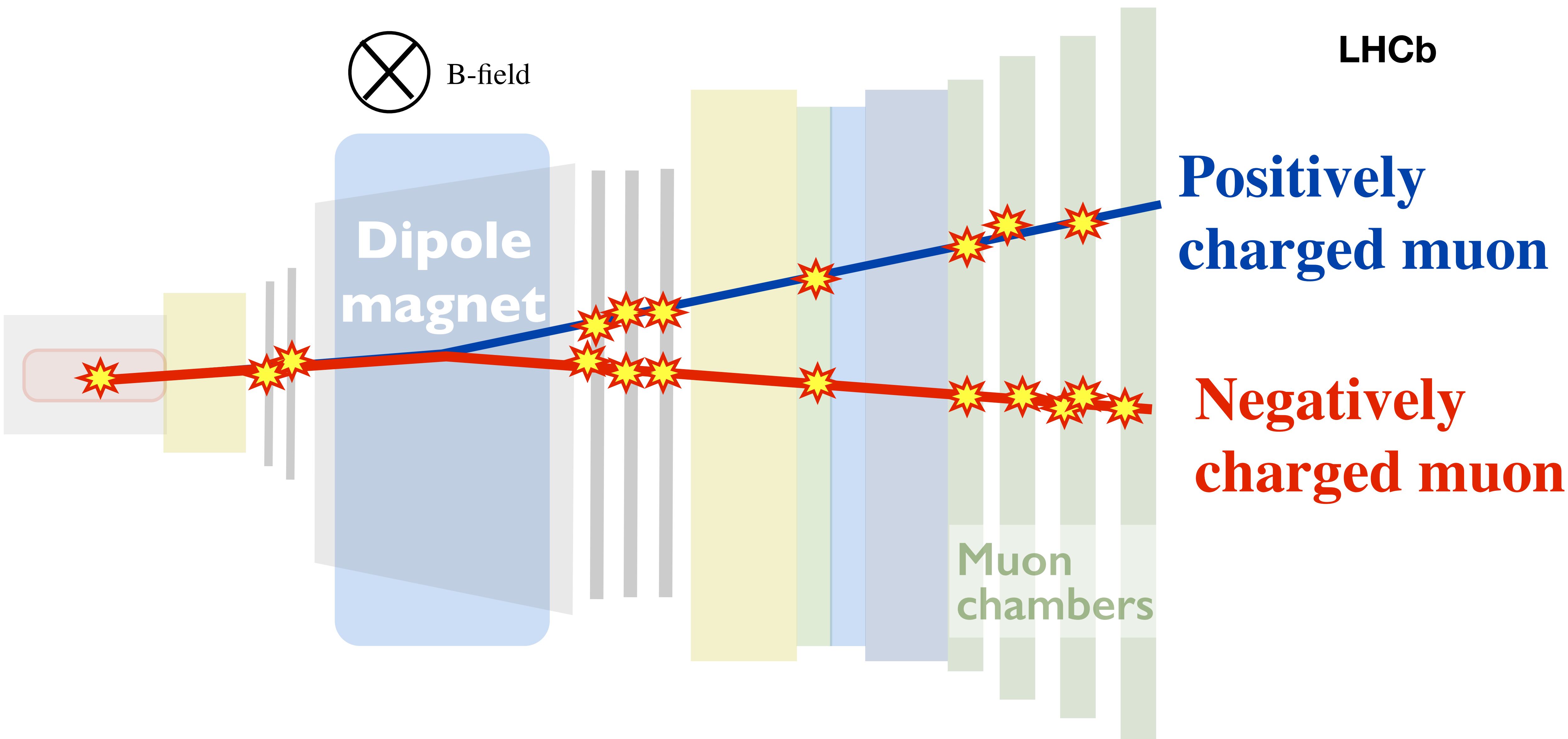


Instrumental asymmetries



Any left-right asymmetry in the material of the detector may potentially induce asymmetries in detection efficiency between positive and negative charged particles

Instrumental asymmetries

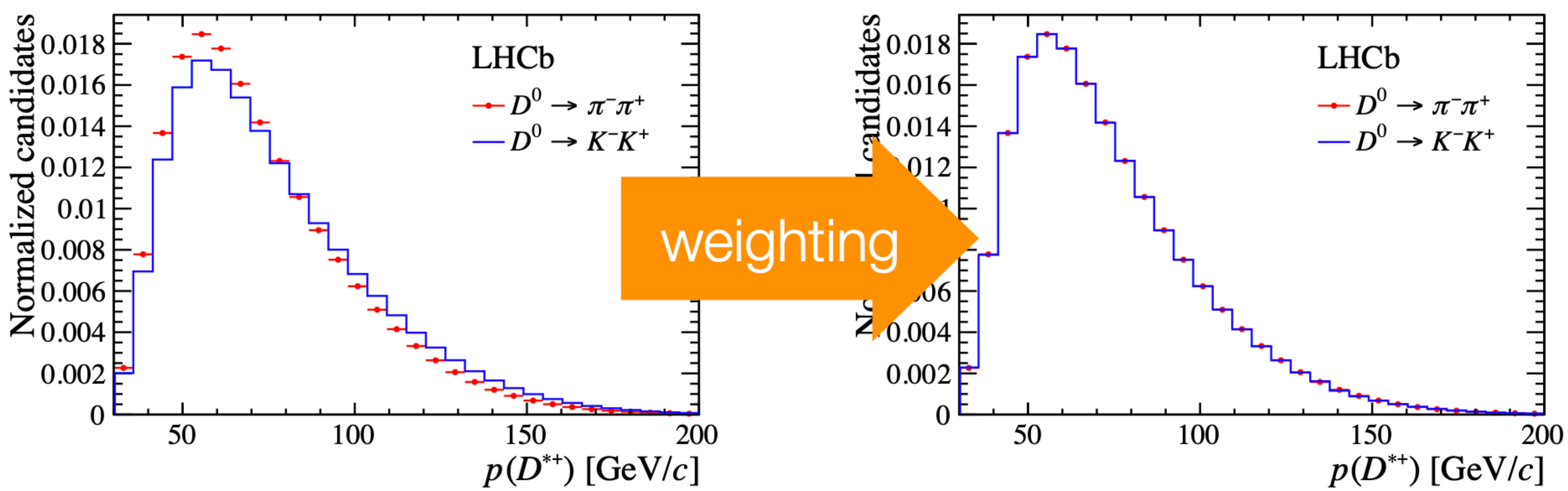


Periodic inversion of magnet polarity and average of measurements based on data sets at opposite polarities reduces instrumental asymmetries. Correct for residual effects using control samples of data

Correcting for production/instrumental asymmetries

Subtract the observed raw asymmetries of the spurious production/instrumental effects extracted from independent measurements in data.

Reweight kinematics as the spurious asymmetries depend on kinematics



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Or use the expected modulation with decay time (when dealing with neutral B) to single-out the production offsets.

Effectively very difficult to conceive time-integrated measurements of **absolute CPV** without assumptions on CPV of control modes

Correcting for production/instrumental asymmetries

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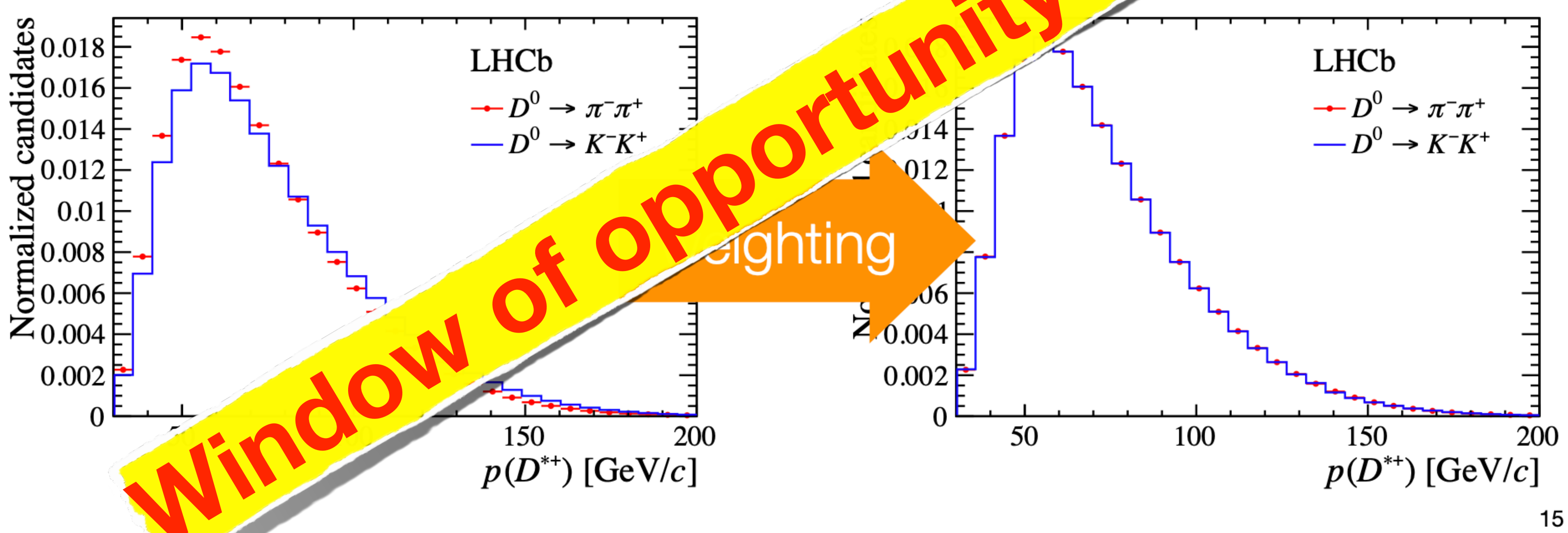


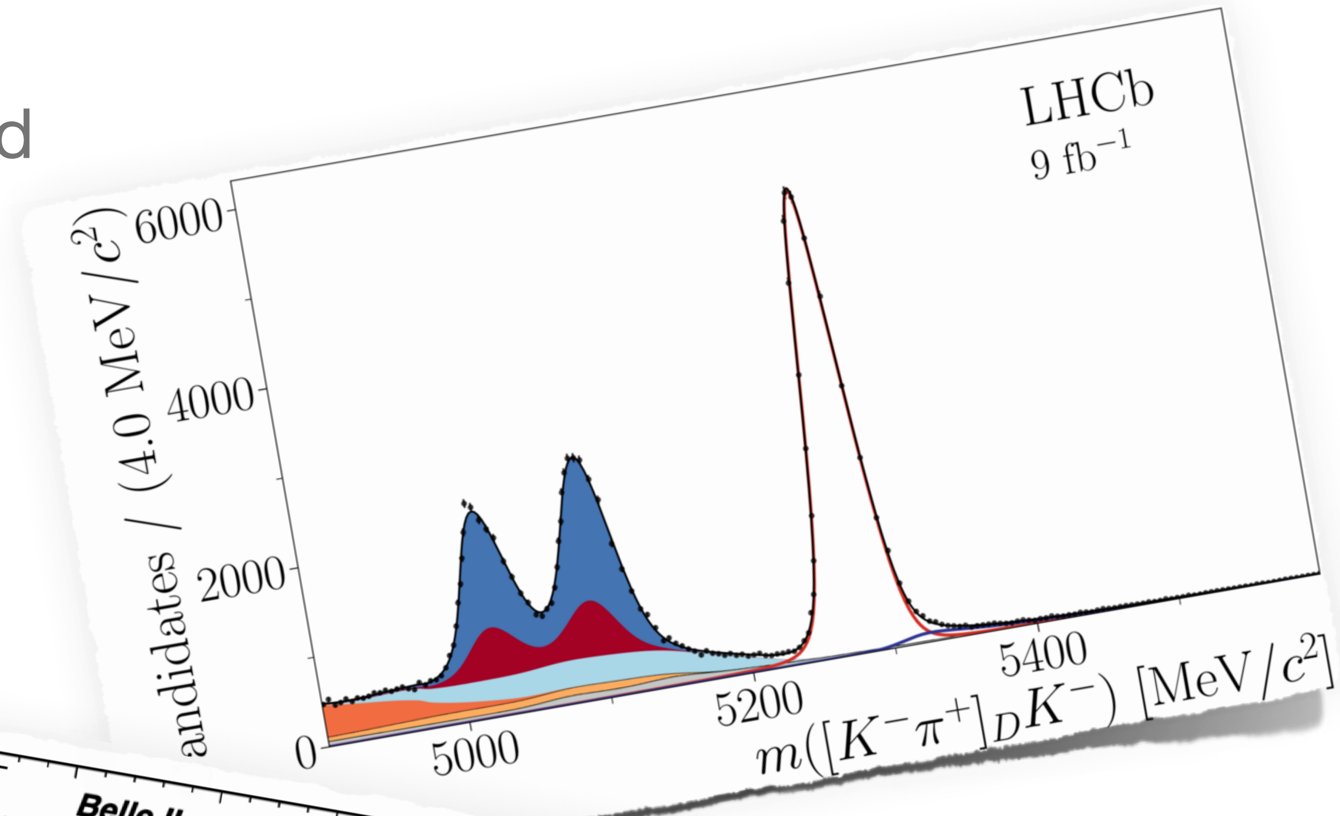
Window of opportunity for Belle II?

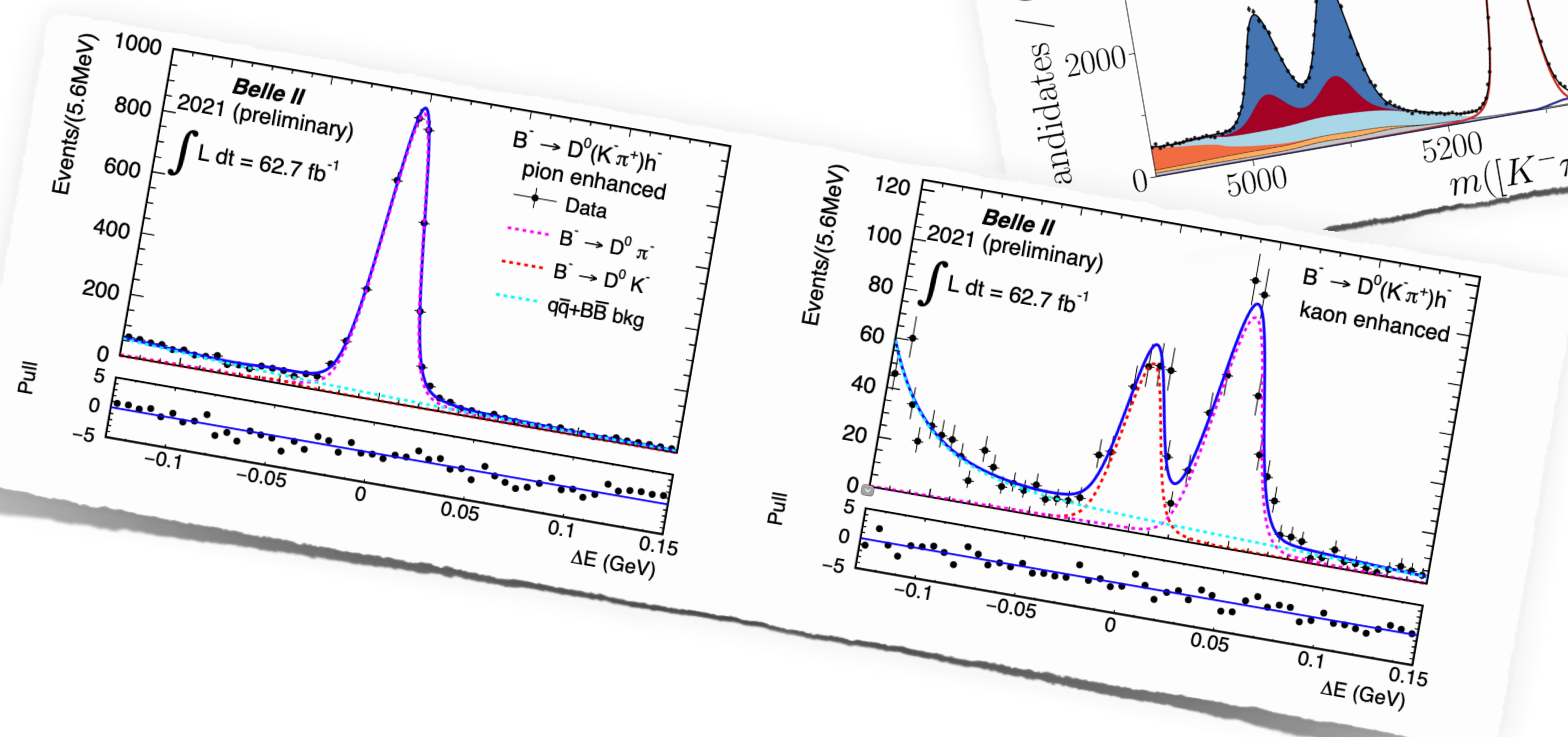
Or use the expected modulation with decay time (when dealing with neutral B) to single-out the production offsets.

Effectively very difficult to conceive time-integrated measurements of **absolute CPV** without assumptions on CPV of control modes

Charged particles

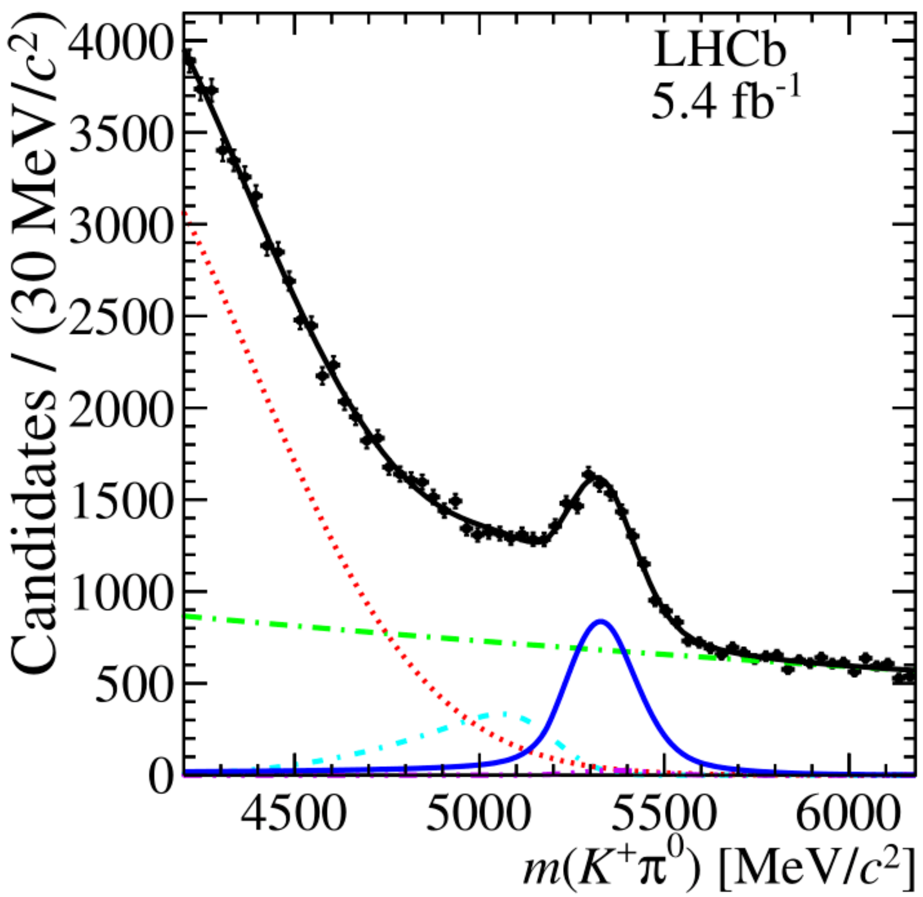
Won't spend time on this as reconstruction performance of tracks and muons are approximately equivalent

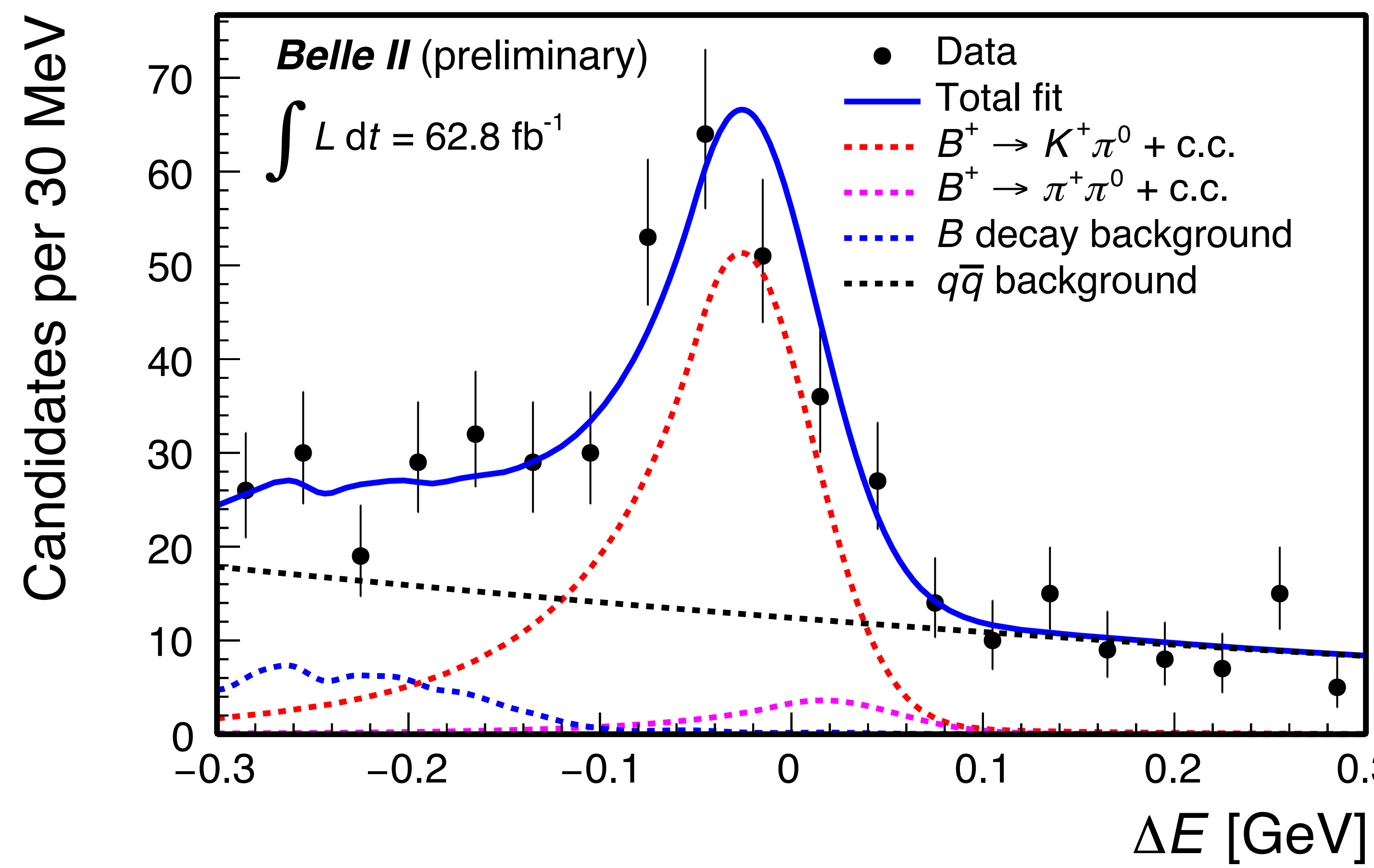




Neutral pions

First one-track B decay fully reconstructed in hadron collisions



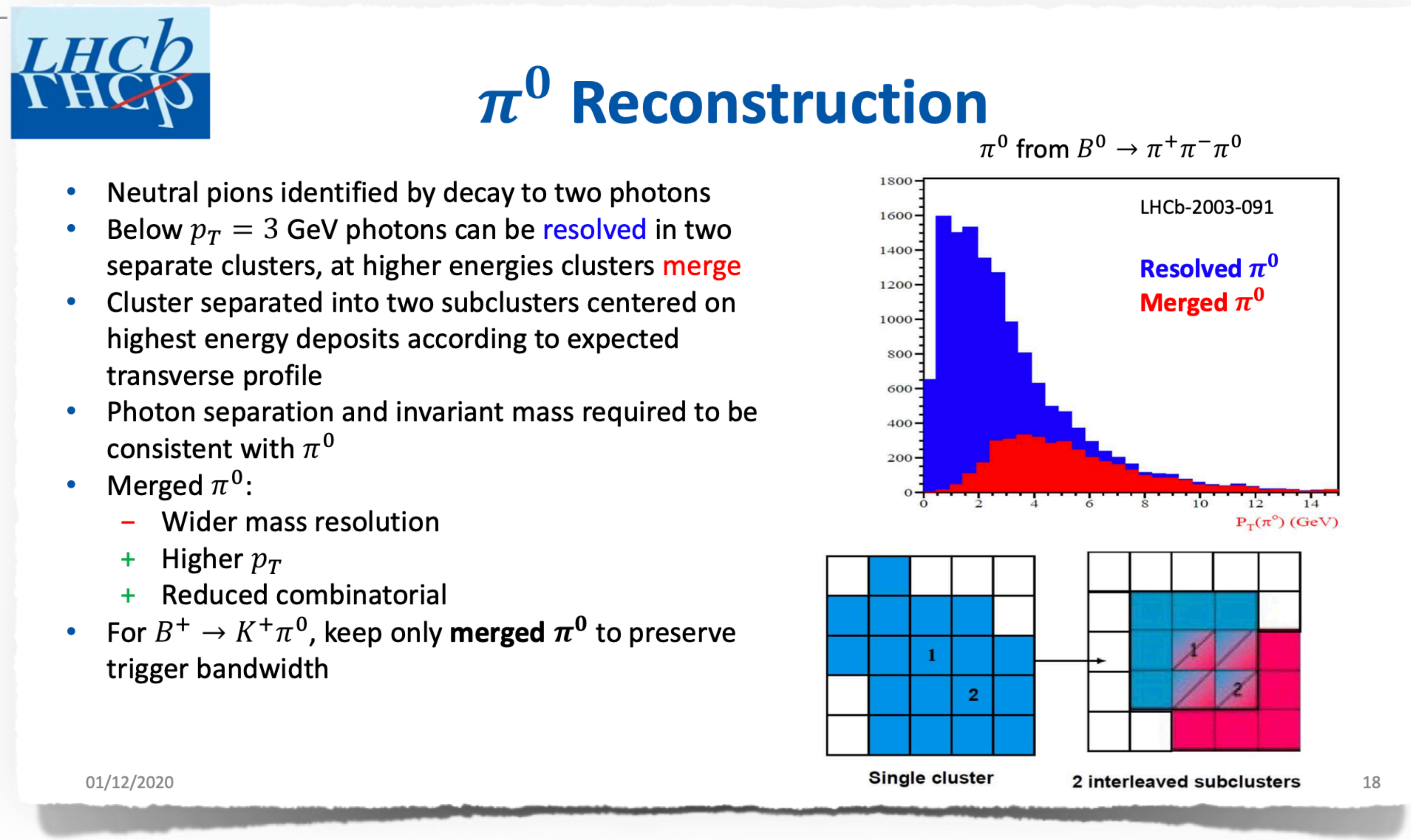


LHCb pays background b/c no secondary vertex, but signal yield makes up for that.

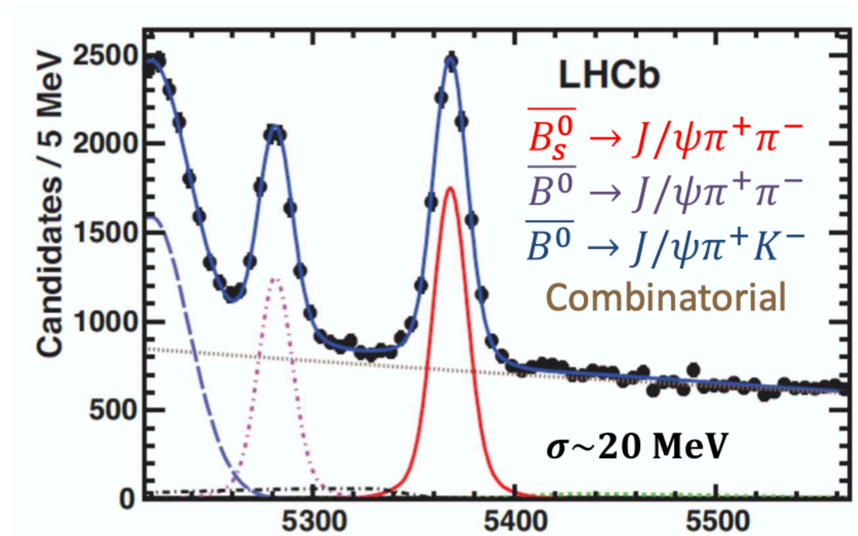
Unexpected competition on channels with one π^0.

Belle II unicity remains in final states with π^0 accompanied by γ/π^0, ν, or K^0_S.

Neutral pions in hadron collision - if you are curious



tracks only



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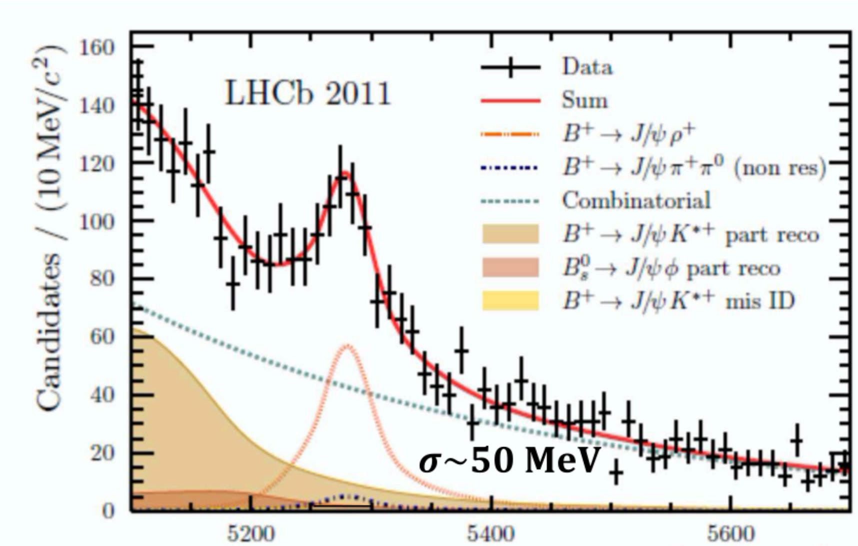
tracks + π^0



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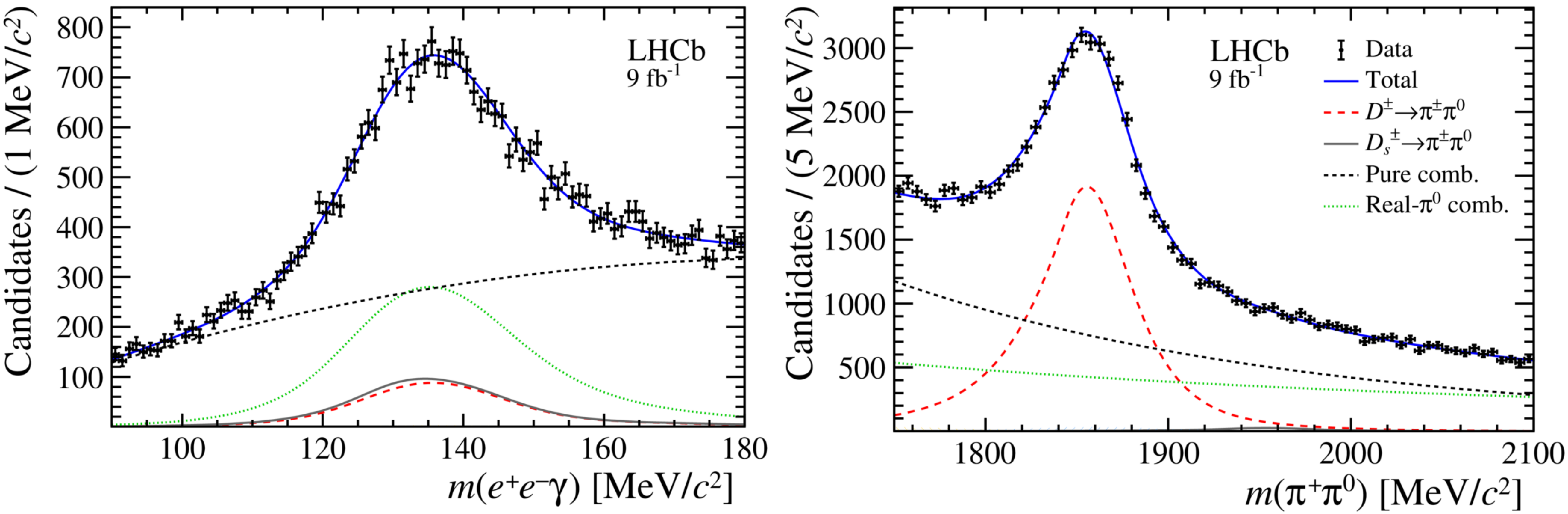
Lower efficiency, broader peaks…but feasible

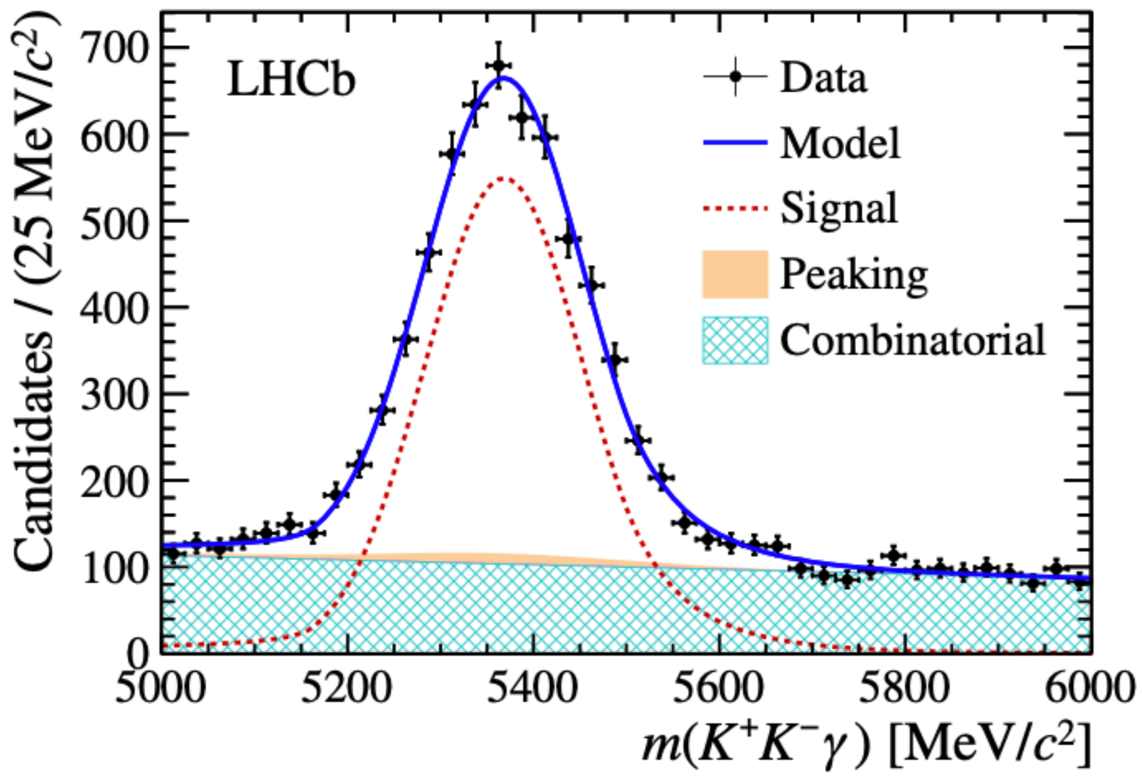
Not only $\pi^0 \to \gamma\gamma$

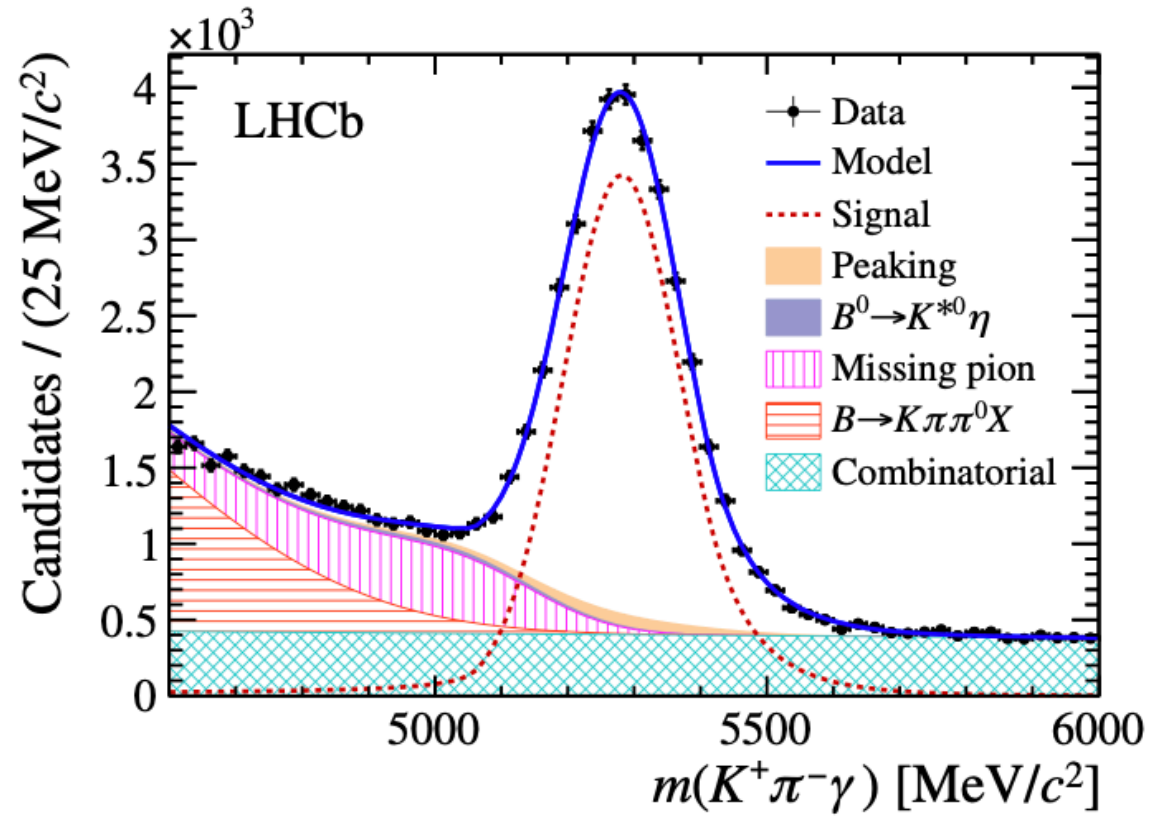


LHCb starts becoming competitive with $\pi^0 \to e^+e^-\gamma$ too.

Belle II unicity remains in final states with π^0 accompanied by γ/π^0, ν, or K^0_S.

Similar considerations for photons



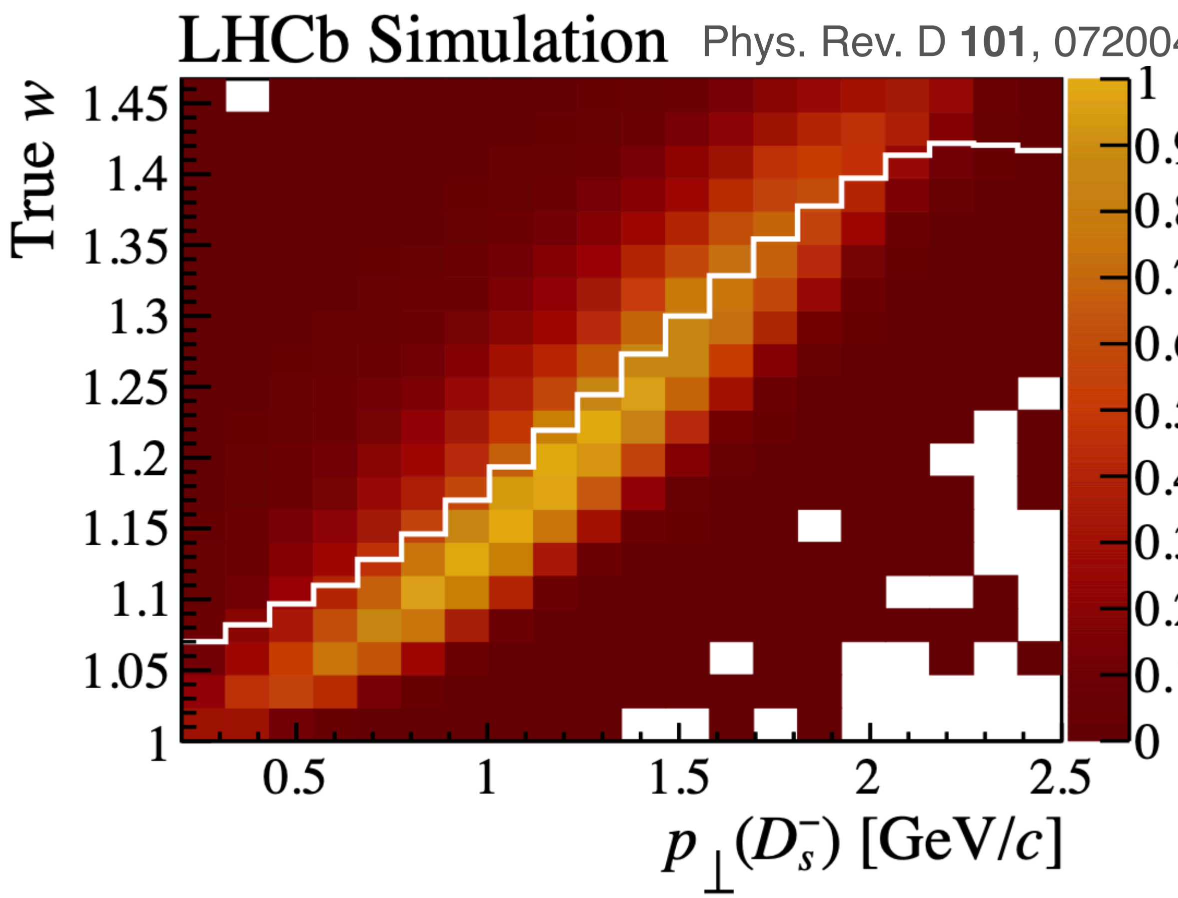


Neutrinos

Belle II benefits from production-kinematics constraints in reconstruction of semileptonic decays

However, large sample size and the ingenuity of LHCb colleagues who invented clever approaches to approximate poorly determine kinematic quantiies fills the gap.

True (unobservable) recoil vs observable Ds momentum perpendicular to Bs flight in Bs -> D*mu nu



LHCb approximations may expose shortcomings once more sophisticated quantities will be measured (angular analyses, etc).

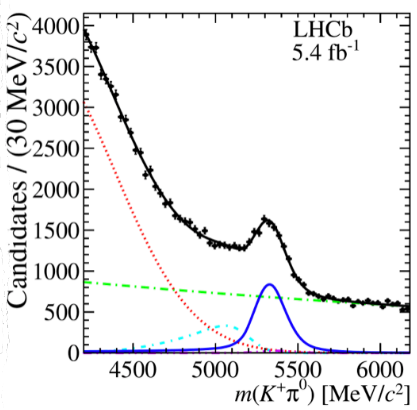
Many semileptonic measurements still need BF inputs from Belle II.

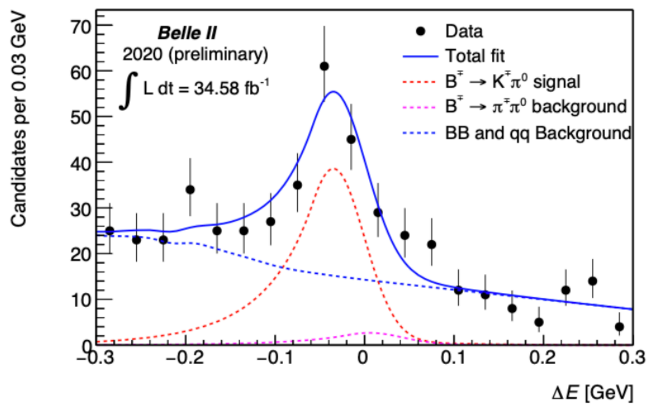
Belle II unicity remains in final states with multiple neutrinos or neutrinos accompanied by pi0/gamma/Ks.

Neutrals

Neutral pions

First one-track B decay fully reconstructed in hadron collisions



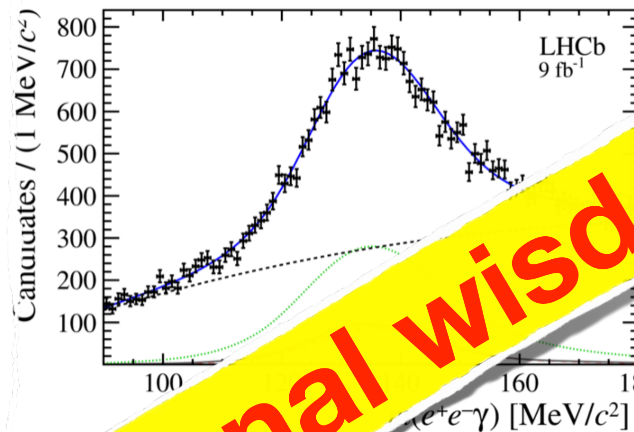


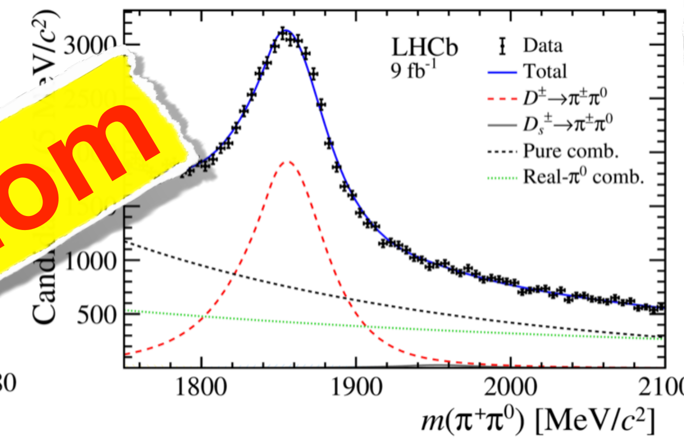
LHCb pays background b/c no secondary vertex, but signal yield makes up for that.

Unexpected competition on channels with one π^0.

Belle II unicity remains in final states with π^0 accompanied by γ/π^0, ν, or K⁰

Not only $\pi^0 \to \gamma\gamma$





...ecoming competitive with $\pi^0 \to$ e+e-γ too.

...I unicity remains in final states with π^0 accompanied by γ/π^0, ν, or K^0_S.

Neutrinos

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...in reconstruction of
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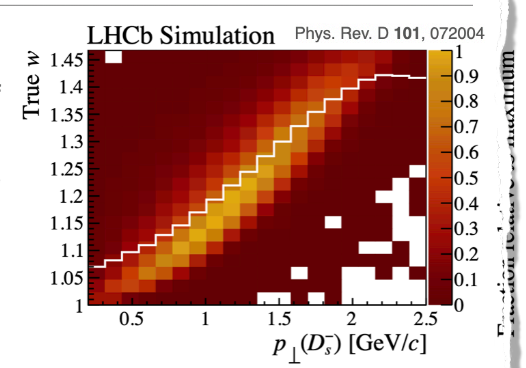
...large sample size and ingenuity
...LHCb colleagues who invented clever approximations fills the gap.



LHCb approximations may expose shortcomings once more sophisticated quantities will be measured (angular analyses etc).

Many semileptonic measurements still need BF inputs from Belle II.

Belle II unicity remains in final states with multiple neutrinos or neutrinos accompanied by pi0/gamma/Ks.

Surpassing conventional wisdom

Suppress bckg: kinematics,topology, lifetime

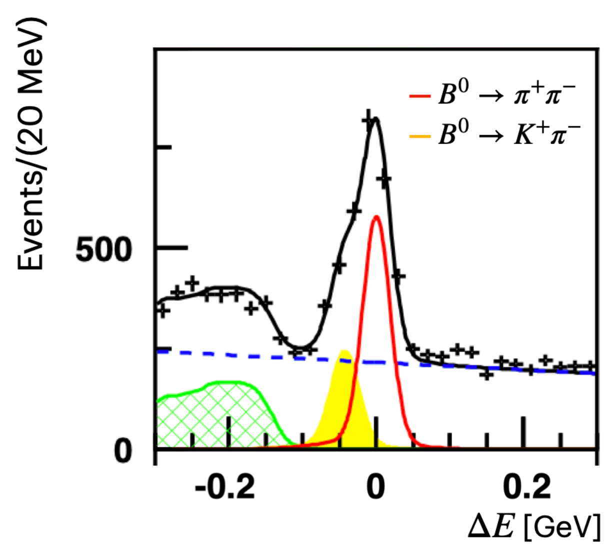
Kinematics, topology, lifetime,

Common methodologies (i) statistical learning to combine nonlinearly O(10–100) discriminating inputs into binary classifiers (ii) multidimensional fits of sample composition, possibly subjected to background subtraction (iii) control samples to validate assumptions/models

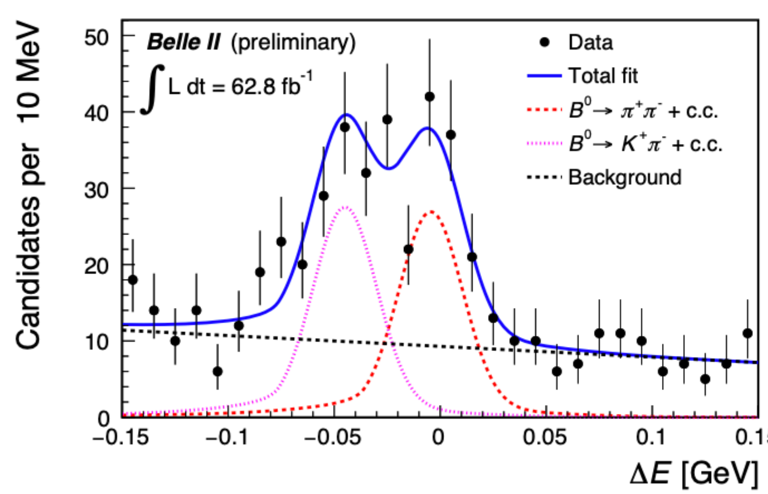
But phenomenology, environment, and tools very different. Hard to make any meaningful comparison.

My hunch is that Belle II background-suppression may still have margins of improvement.

Is the format of flavor-tagging input optimal for CS? Any gain from PID variables as inputs? Is BDT really the optimal tool for all our CS problems?



Belle '12, S/B~2.4



Belle II '21, S/B~2.6

Kinematics, topology, lifetime,

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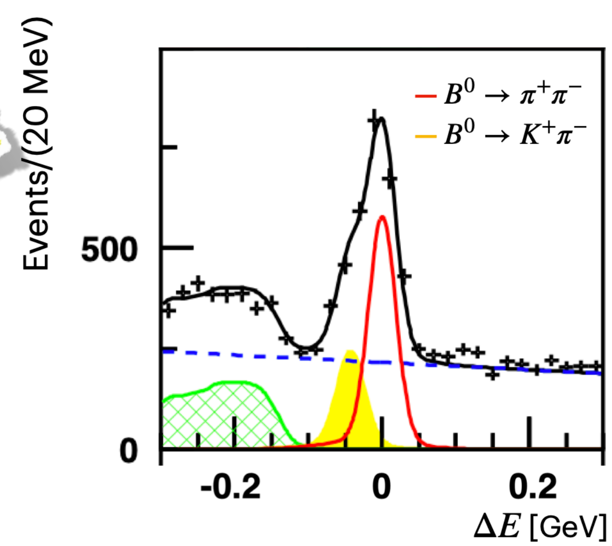
Window of opportunity?



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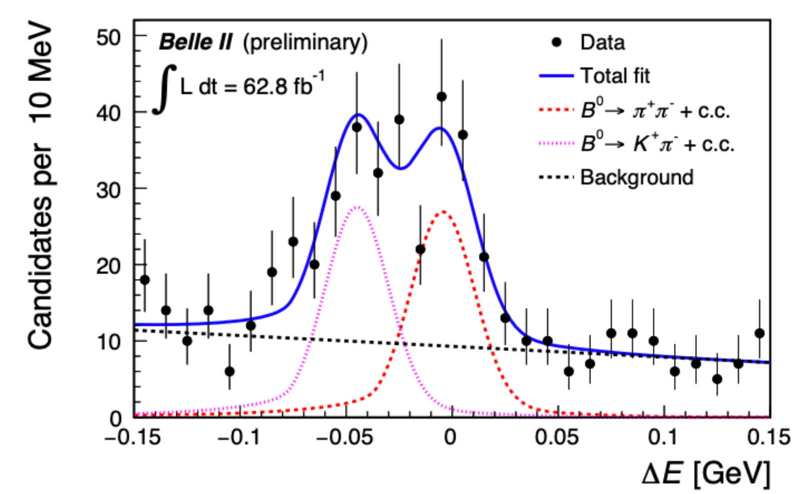
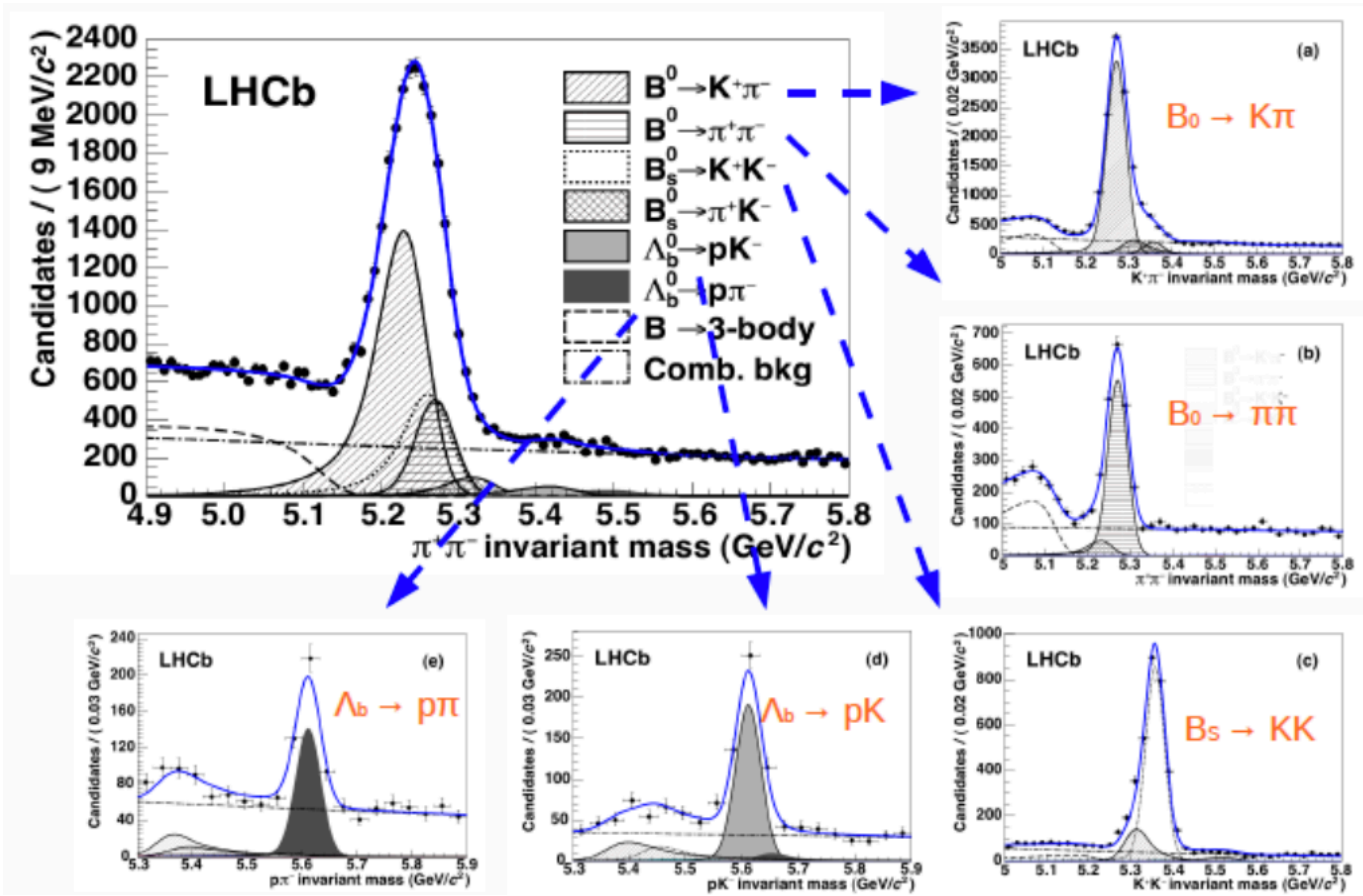


Belle II '21, S/B~2.6

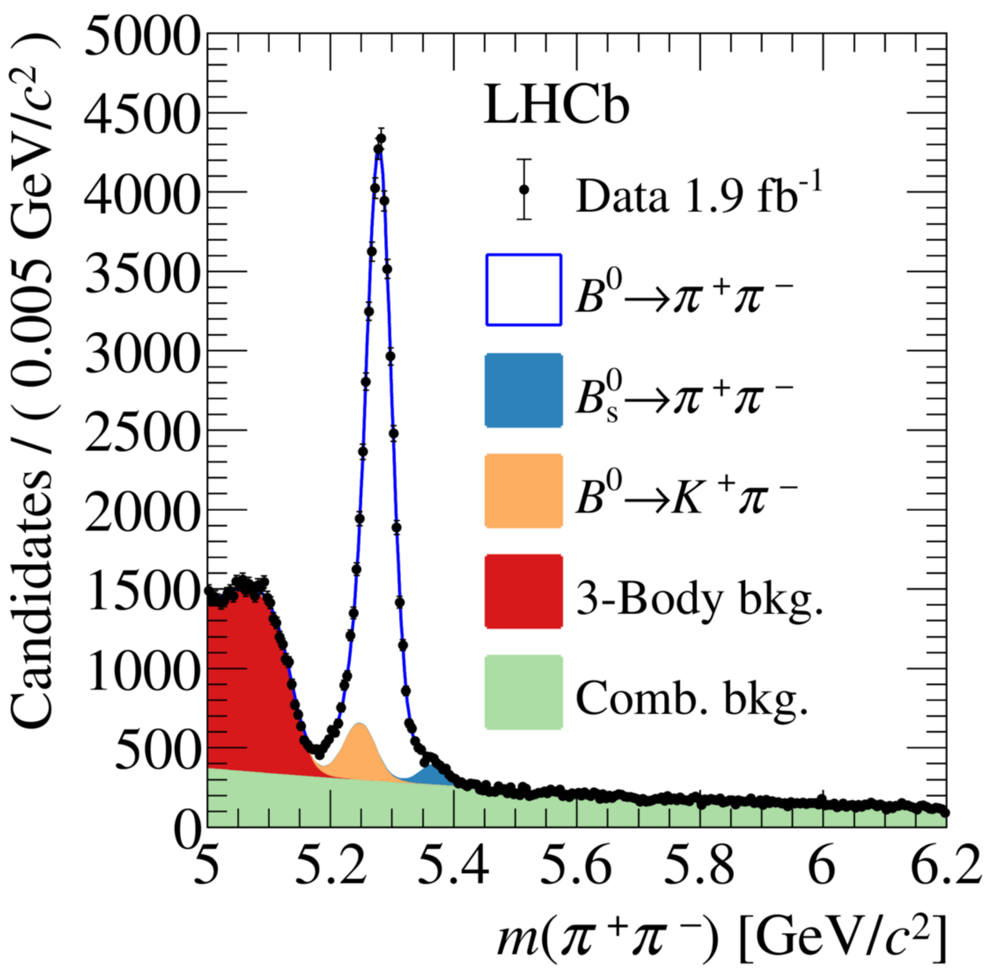
Suppress bckg: PID

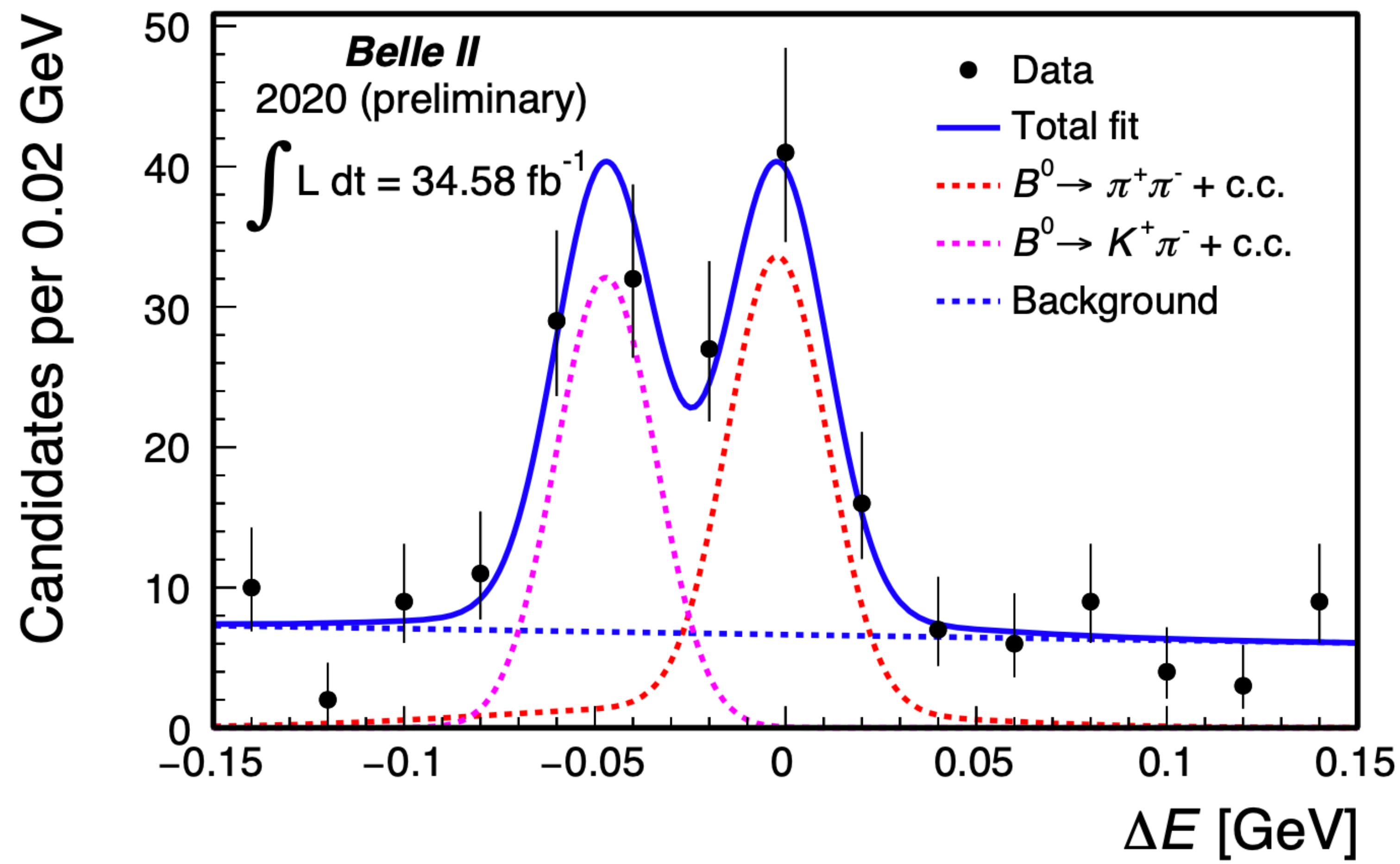
In hadron collisions PID is even more important



Has to sort out B^0_s and baryons too…

PID comparison

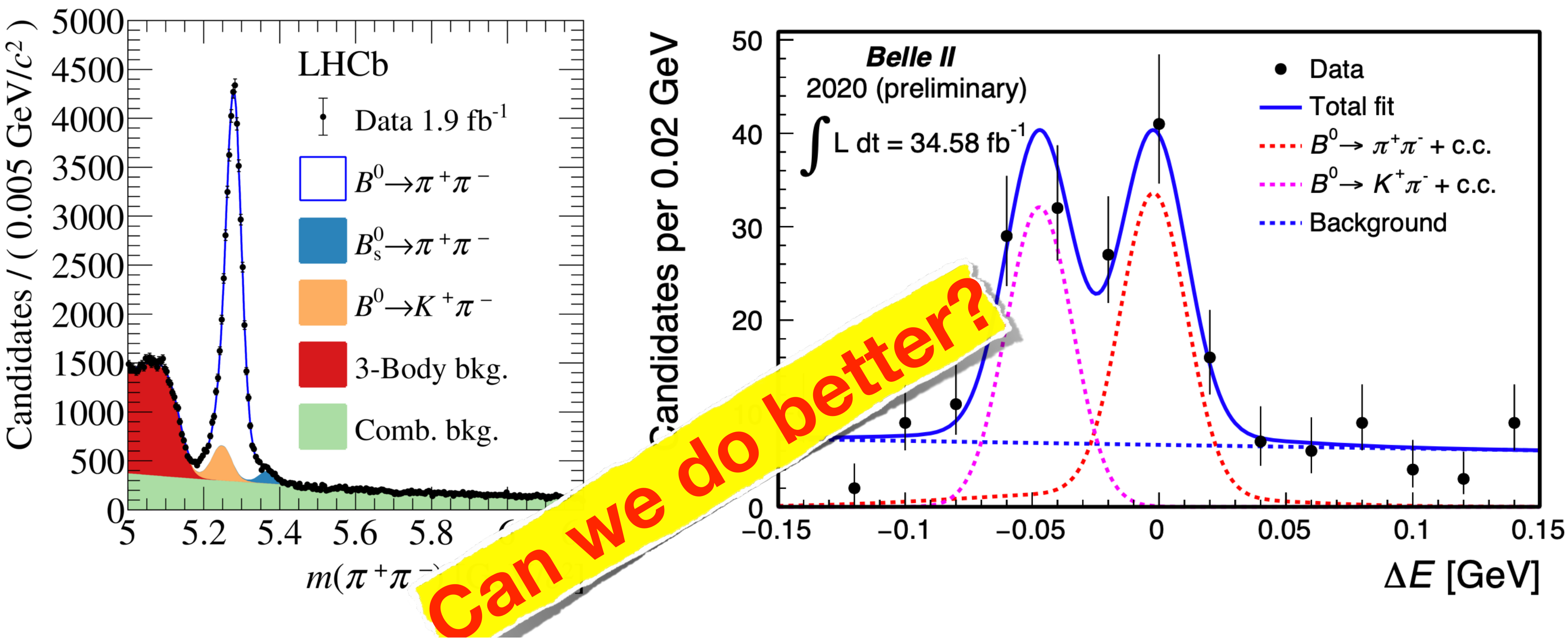




LHCb performance is impressive, even discounting the 10 years of optimization.

Belle II's advantage from larger kinematic separation between the signal and misreconstructed peak is precious.

PID comparison



LHCb performance is impressive, even discounting the 10 years of optimization.

Belle II's advantage from larger kinematic separation between the signal and misreconstructed peak is precious.

Do it online (mostly an LHCb challenge)

You want (experimental requirements)

- ☑ Produce large and low-background samples of *B* and *D* hadrons
- ☑ Reconstruct precisely many *B* and *D* decays with good S/B
    - ☐ Do it online!
- ☐ Reconstruct precisely *B* and *D* decay time
- ☐ Identify if a particle (*B*, *D*) or antiparticle ($\bar{B}$, $\bar{D}$) was produced
- ☐ Control tightly instrumental charge asymmetries

Online event selection

Current DAQ systems cannot write kB/MB-sized events at more than O(10) kHz

Less critical at *B*-factories — crossing rate is very high (MHz to GHz), but fewer interactions per crossing (10^{-5} – 10^{-4}). Detector activity following an interaction is also low (10 tracks/event), which makes it easier to process it fast by trigger algorithms.

Minimum number of tracks and an energy deposit typically sufficent to trigger most of *B*/*D* physics with high efficiency. Low-multiplicity is more challenging.

Effective triggering is **absolutely essential** in hadron collisions: MHz crossing rate with multiple interactions per crossing, each yielding O(10-100) tracks. High rates /massive combinatorial problem.

One of the reasons why LHCb has been designed to run at a ~20-fold "detuned" instantaneous luminosity with respect to what delivered by LHC.

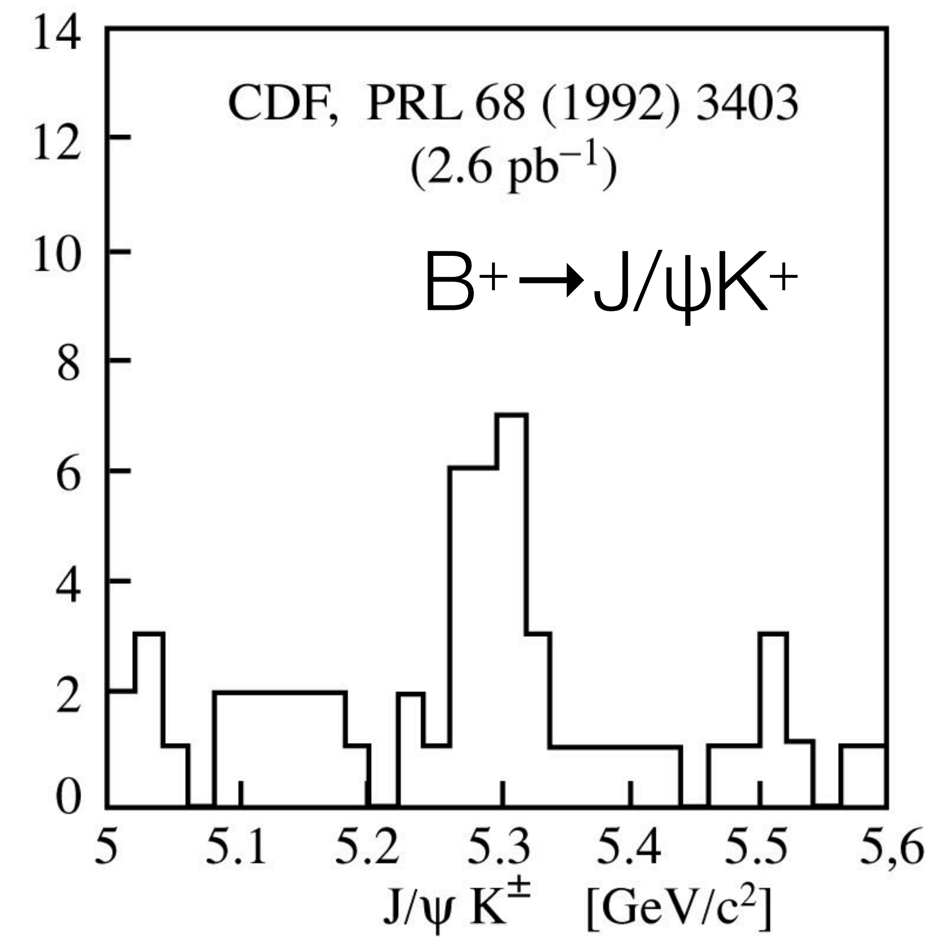
Online selection — good ol' muons..

Muons have a striking signature: charged particles that penetrate thick absorbers offering distinctive features wrt generic (mostly π) track backgrounds.

Thicker absorber reduces π punch-through but impacts kinematic acceptance: the purer the μ, the fewer.

Dimuons (from $B\to\psi X$) are best: low trigger rate, double discriminating information, and $\mu\mu$-mass restrictions around ψ further suppress background.

Electrons also distinctive, but radiate.

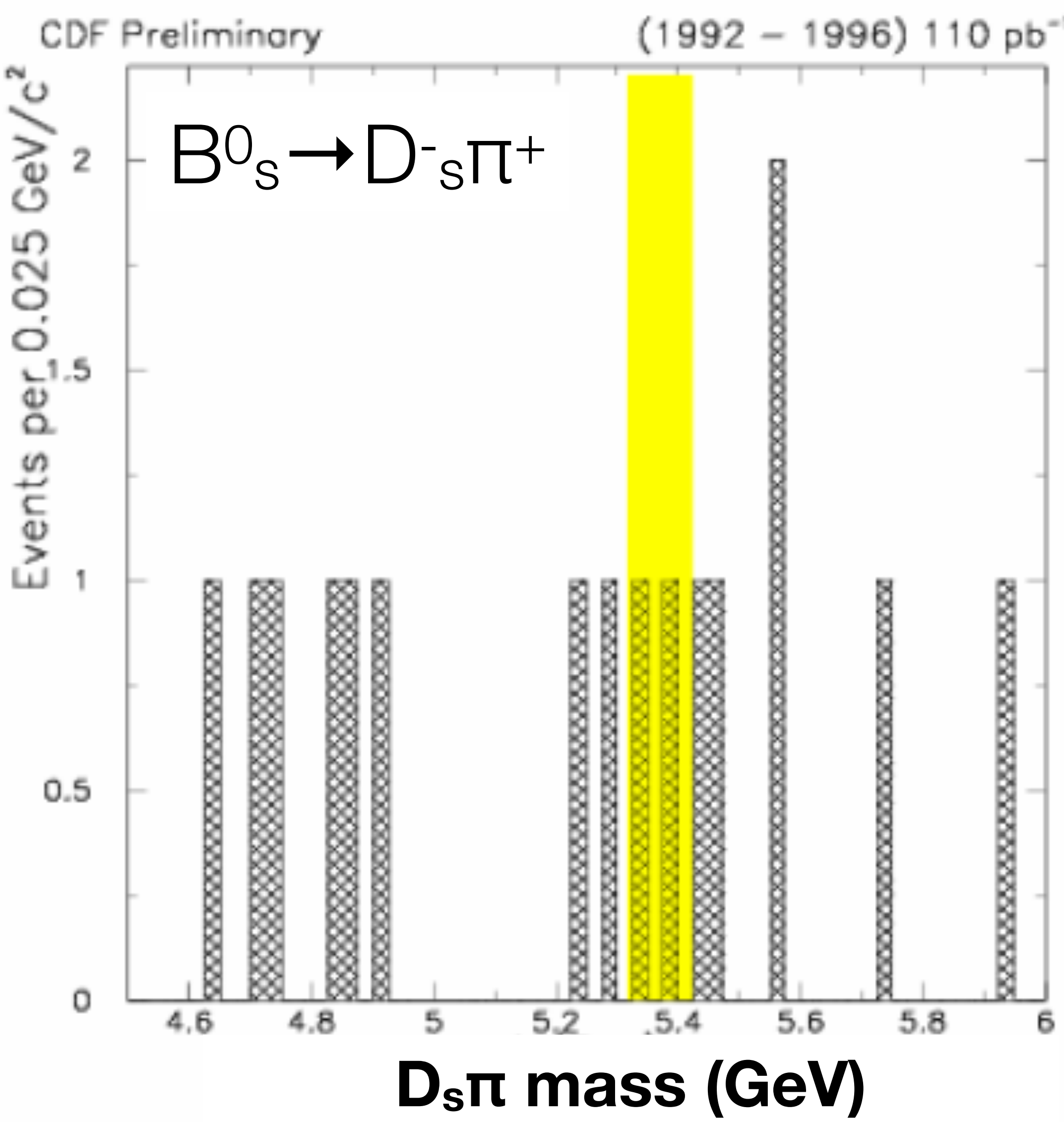


1992: first fully reconstructed *B* decay in hadron collisions — largest sample at the time. Early indication that competitive *B* physics at hadron colliders was at reach!

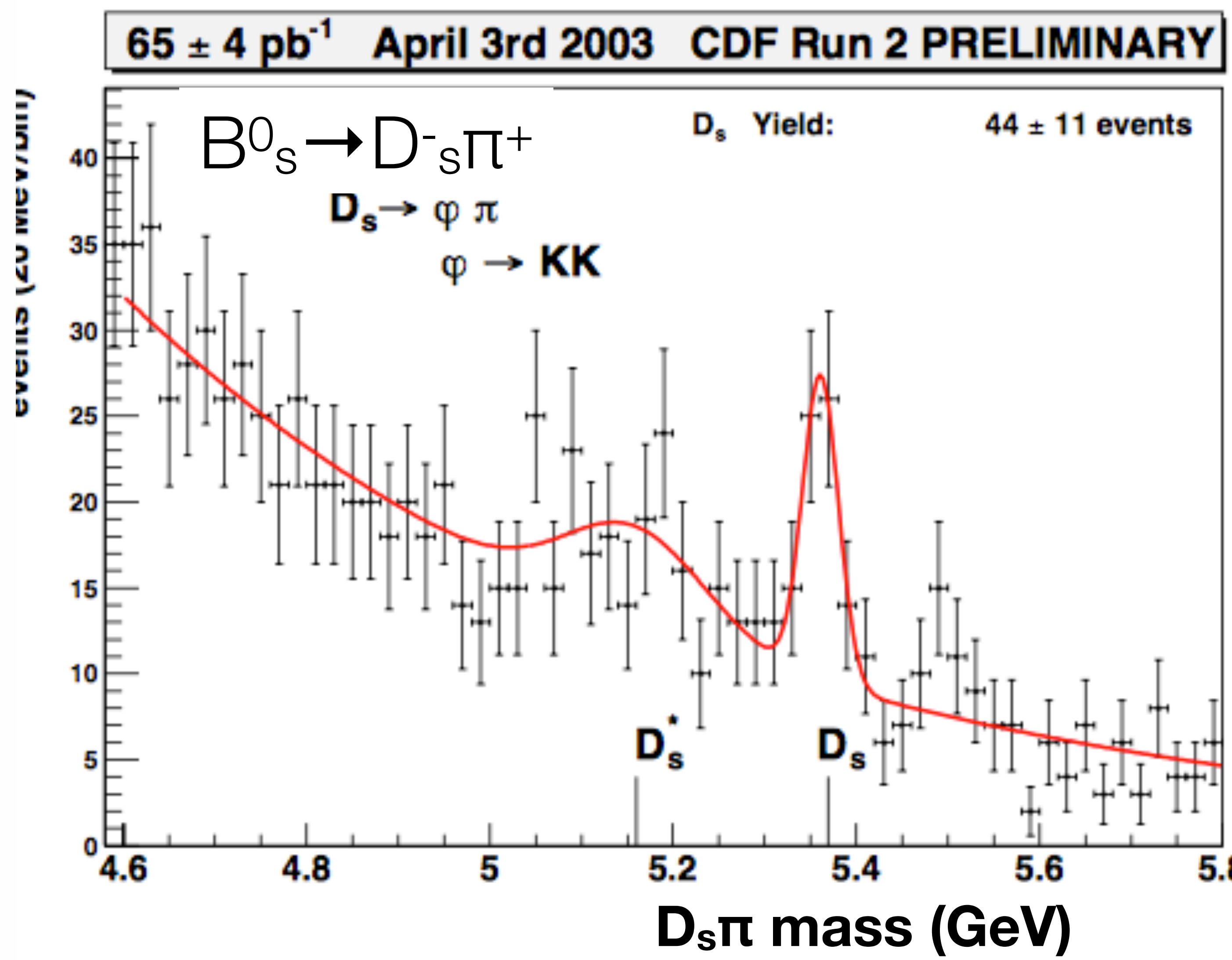
Muon triggers traditional workhorse for triggering flavor at hadron colliders (CDF, D0, LHCb, CMS, ATLAS…). But they miss out on hadronic decays.

Aside: the difference track-triggers make

without track trigger



with track trigger (and half the data!)



CDF is the only experiment to have successfully operated a track trigger for *B* physics: key enabler of the B^0_s mixing result and a major fraction of program

LHCb’s strategy

Low-level track triggering in hardware deemed too challenging

Till 2018:

- low-level calorimetric trigger (energy deposit above threshold). Straightforward to implement. Dirty/inefficient: 20-40% efficiency saturates the available 1 MHz bandwidth with background.
- higher-level track-trigger based on displacement and pT. In addition, “park” a fraction of the data “without looking at them” for subsequent analysis (something that, e.g., CMS does also)

Inefficient for hadronic decays, but huge available signal kept end result successful

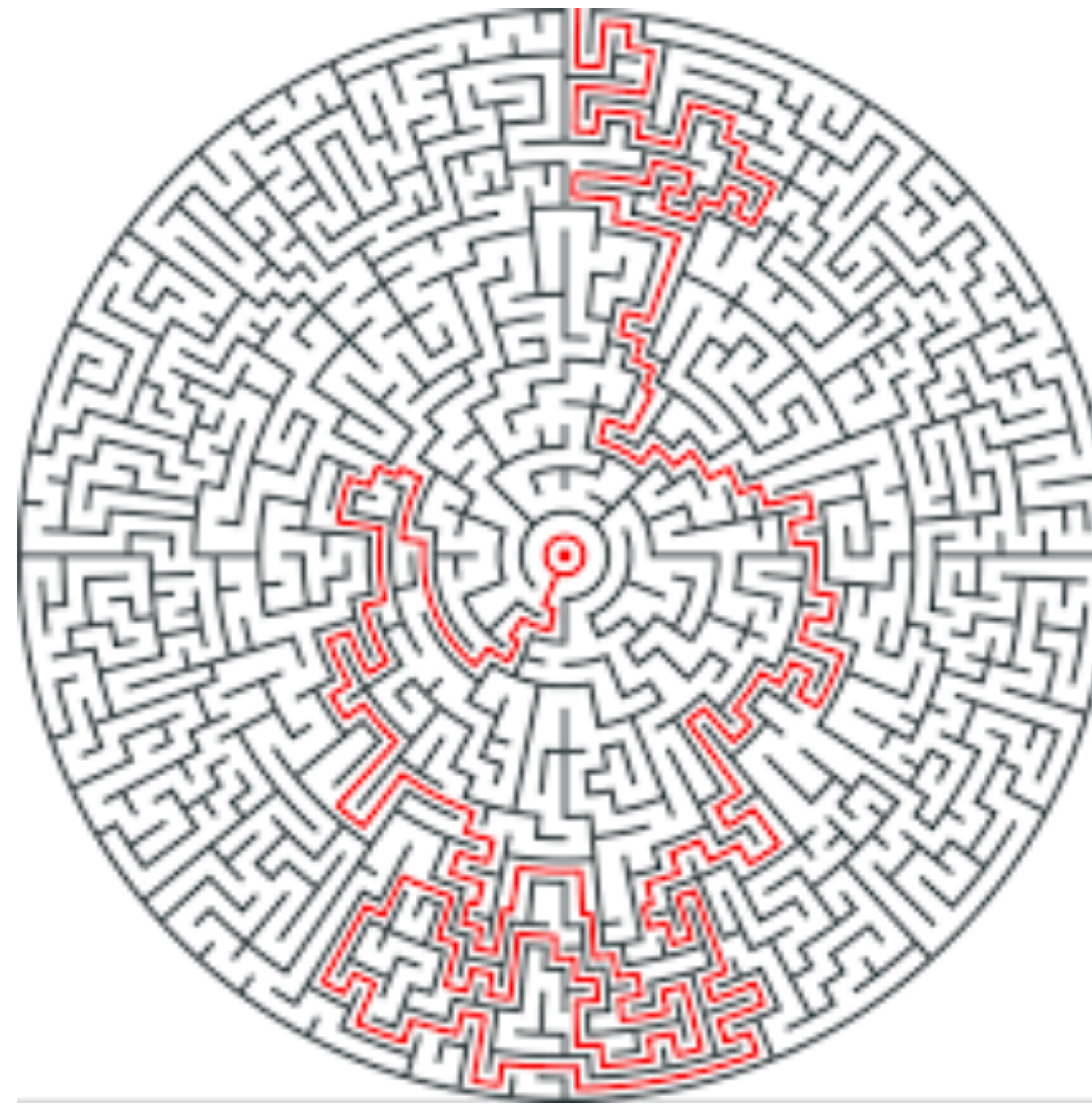
From 2022: readout detector at 40 MHz (full LHC crossing rate). Drop the calorimetric trigger. Rely on a GPU-based trigger that aims at offline-like tracking.

If successful, this brute-force approach will further boost the reach in hadronic decays (can get 3x-10x yield/lumi with respect to previous figures)

However….

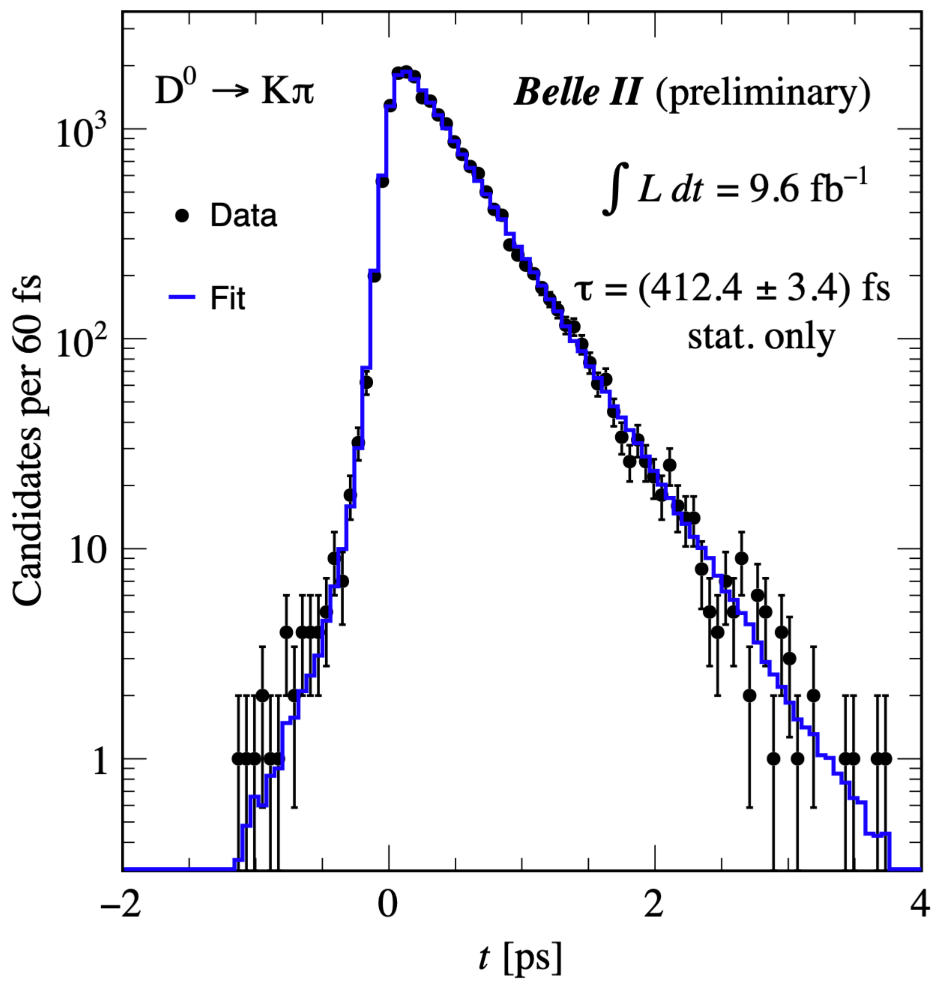
Stringent discriminating requirements needed online to reduce >1000x larger backgrounds acting on a very complicated experimental environment.

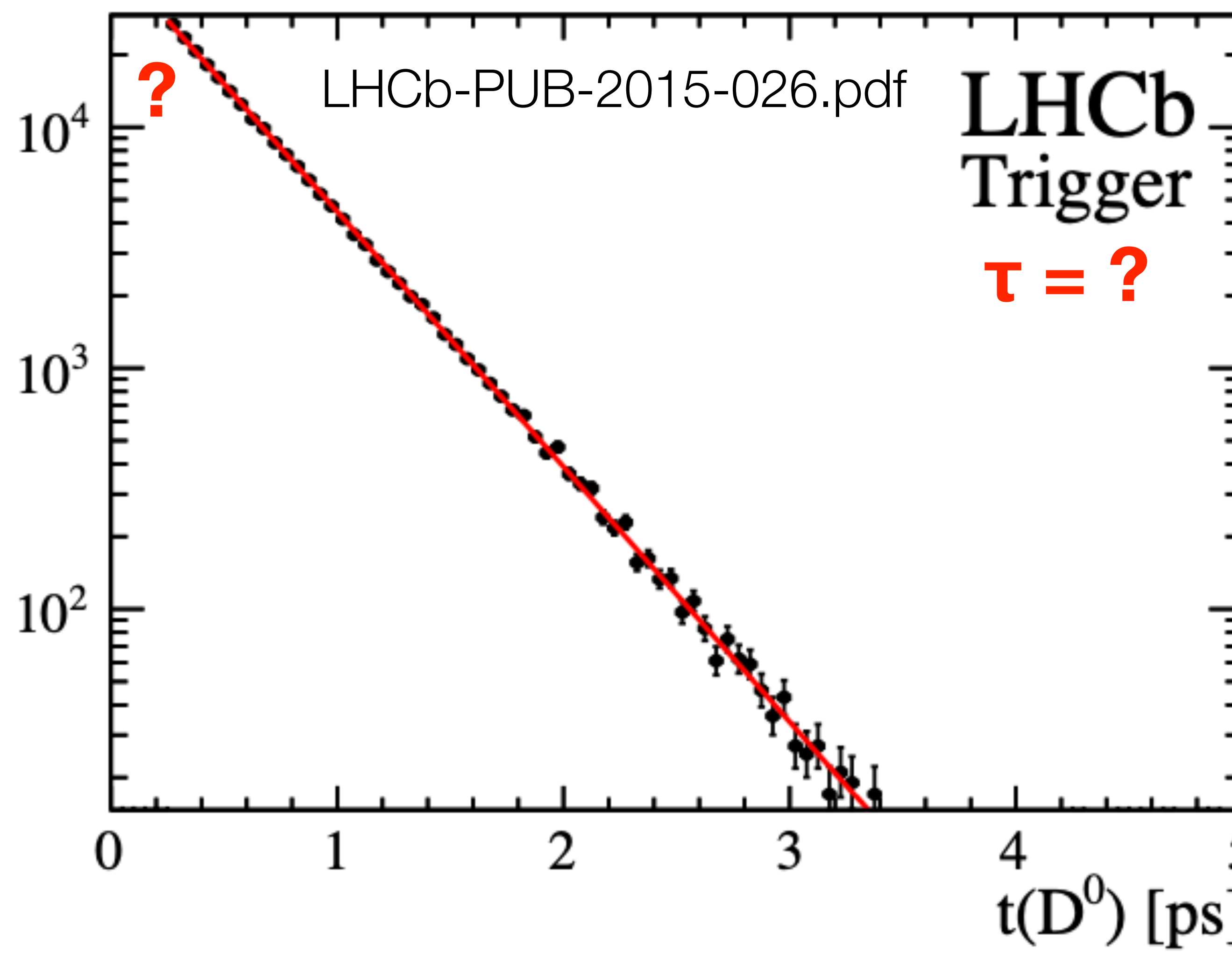
Introduce high complexity in basic quantities needed for analysis.



An example: lifetimes from hadronic decays

Lifetime-biasing and kinematic trigger requirements + reconstruction algorithms fold together decay-length, uncertainty, and kinematics in a unsimulable way.



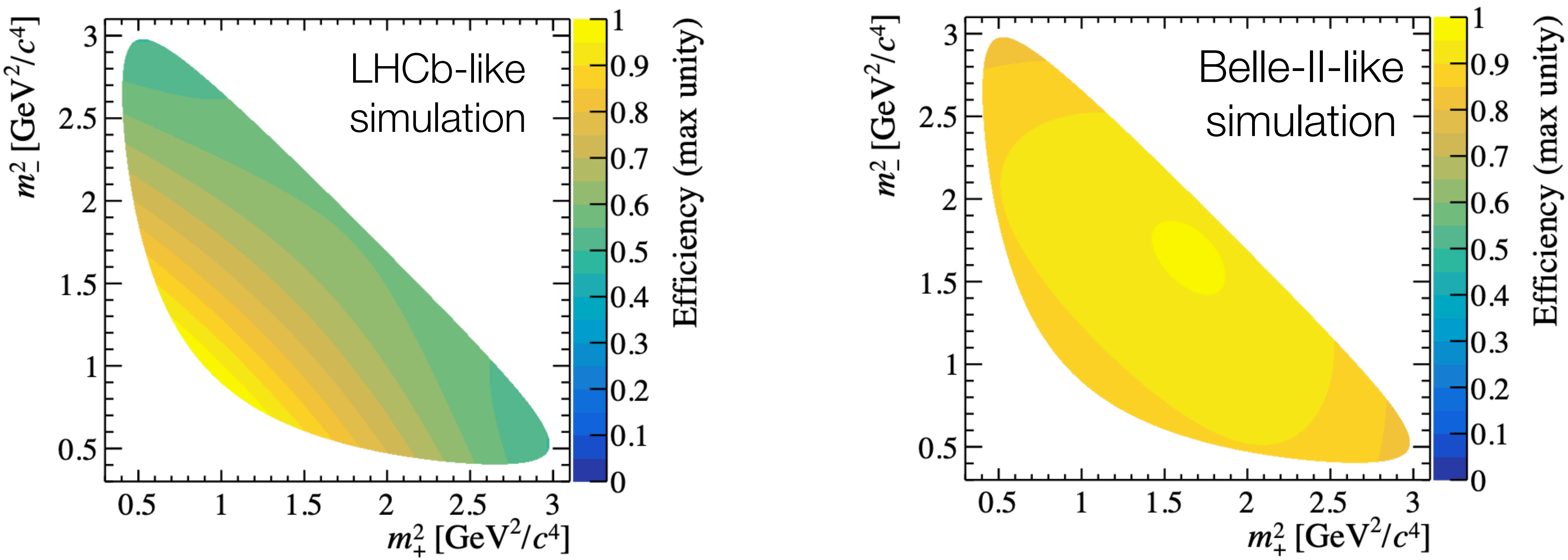


Lifetimes in hadronic decays impossible so far in LHCb's track-triggered sample.

Attempts to use a dedicated unbiased trigger, thus simulating post-2022 conditions proved intractable anyways.

Another example: Dalitz-plot analyses

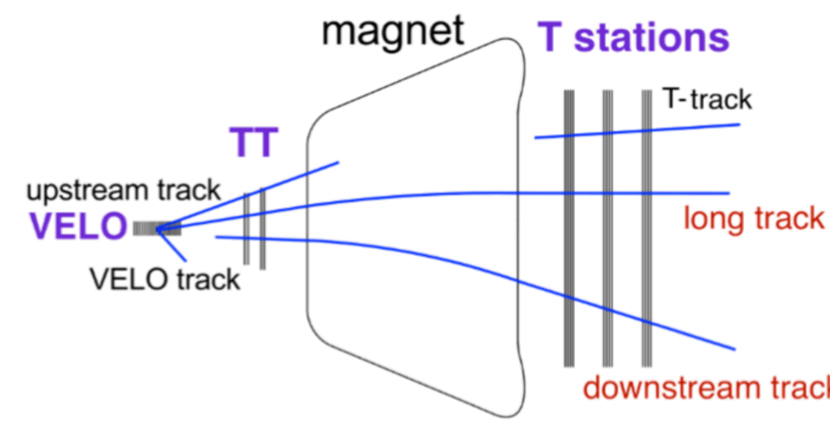
Lifetime-biasing + kinematic trigger requirements and detector geometry and reconstruction algorithms introduce nontrivial kinematic-dependent efficiencies that introduce hard-to-simulate biases in the Dalitz plots.



Dalitz-plot sculpting may become important limitation in various key measurements.

Yet another example: triggering long-lived particles

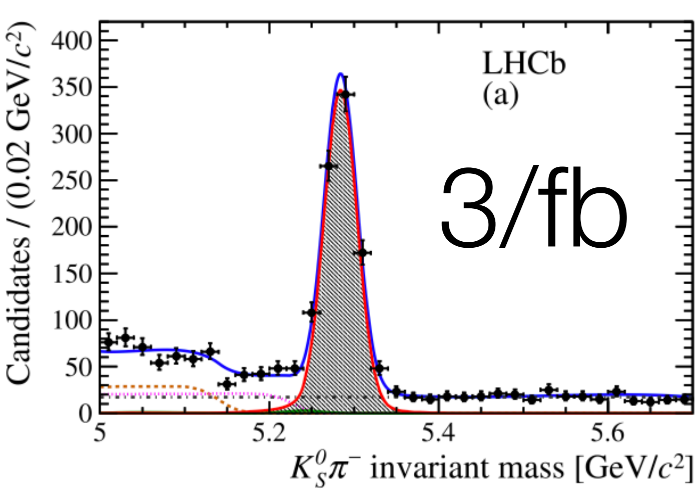
Long-lived particles decay at the end, or after, the vertex detector (“downstream”) producing tracks invisible to the earlier stage of online tracking algorithms.

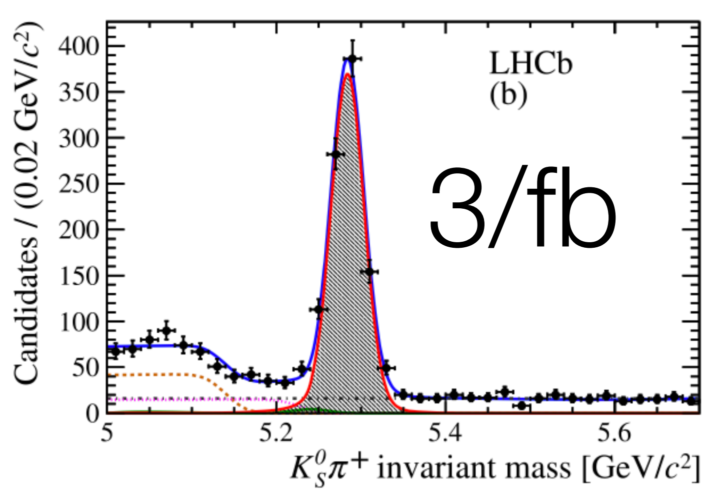


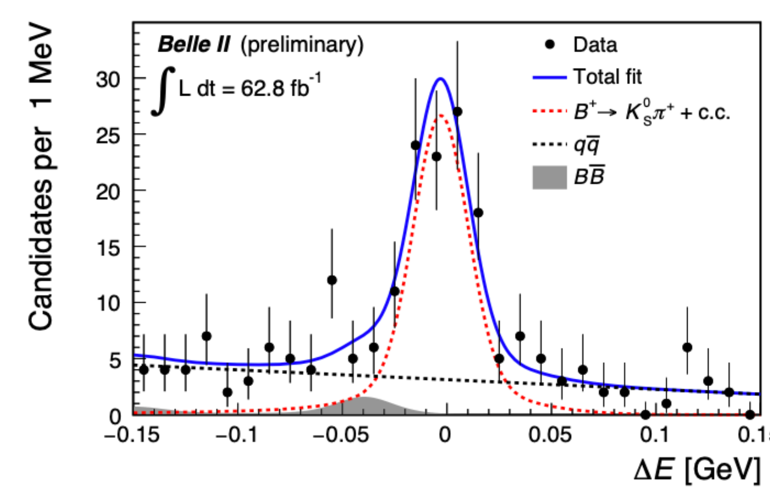
LLP at LHCb = 3 cm to 300 cm decay length

Impacts strange-particle reconstruction efficiency.

LHCb results in final states including K^0_S have been less incisive than others.







Impacts reach of generic LLP searches too.

(To my knowledge) this limitation is still present in the default trigger plan for 2022.

A general note

Complexity of the hadron collisions, and stringent selections needed: difficult to simulate and/or determine accurately **absolute** selection and reconstruction efficiencies.

~All rate measurements (BF, etc) are **relative** to reference processes.

Analyses get more laborious as suitable control samples are not always easily available and adds to the systematic uncertainty budget (limited knowledge of the references).

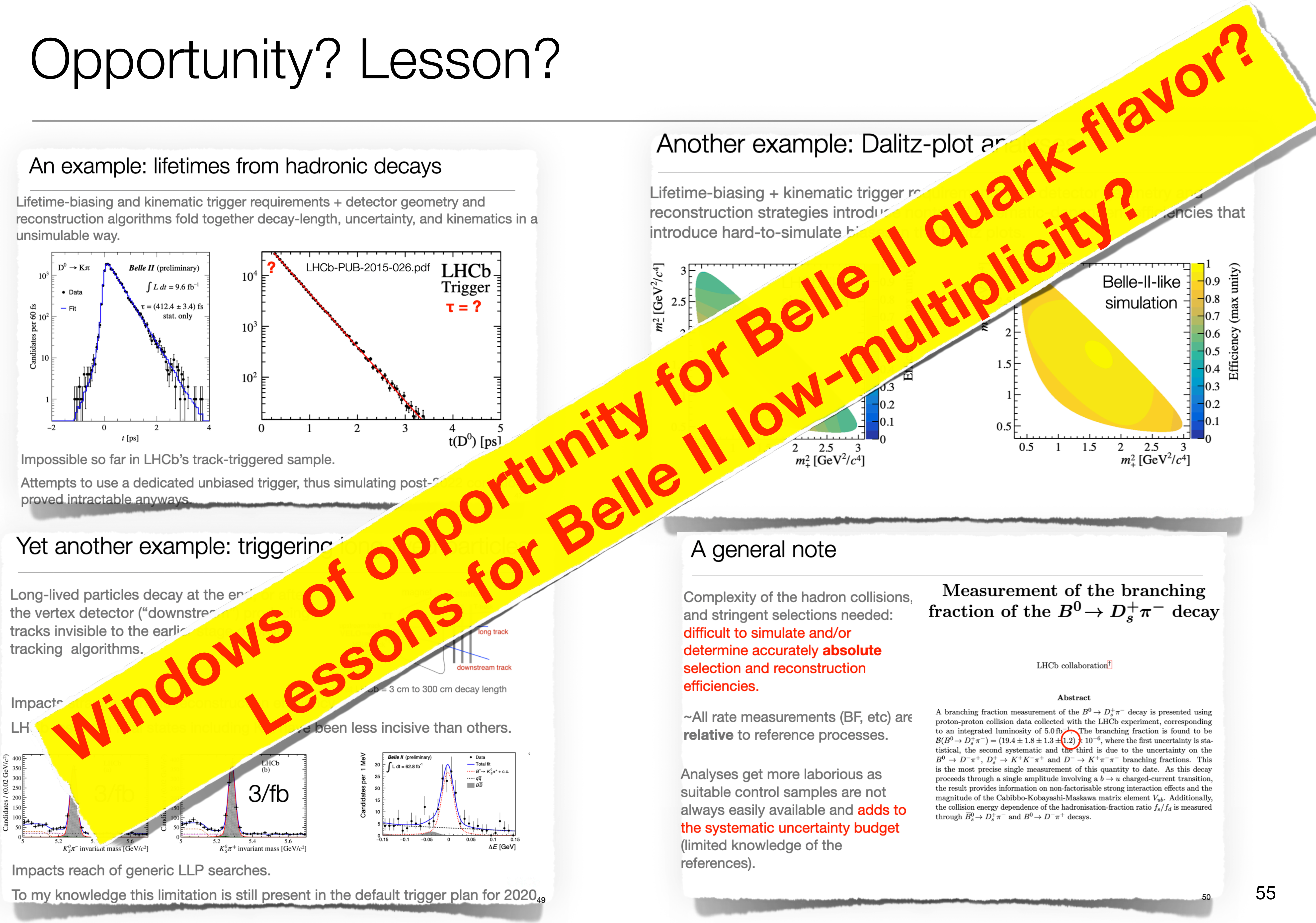
Measurement of the branching fraction of the $B^0 \to D_s^+\pi^-$ decay

LHCb collaboration[†]

Abstract

A branching fraction measurement of the $B^0 \to D_s^+\pi^-$ decay is presented using proton-proton collision data collected with the LHCb experiment, corresponding to an integrated luminosity of 5.0 fb^{-1}. The branching fraction is found to be $\mathcal{B}(B^0 \to D_s^+\pi^-) = (19.4 \pm 1.8 \pm 1.3 \pm 1.2) \times 10^{-6}$, where the first uncertainty is statistical, the second systematic and the third is due to the uncertainty on the $B^0 \to D^-\pi^+$, $D_s^+ \to K^+K^-\pi^+$ and $D^- \to K^+\pi^-\pi^-$ branching fractions. This is the most precise single measurement of this quantity to date. As this decay proceeds through a single amplitude involving a $b \to u$ charged-current transition, the result provides information on non-factorisable strong interaction effects and the magnitude of the Cabibbo-Kobayashi-Maskawa matrix element V_{ub}. Additionally, the collision energy dependence of the hadronisation-fraction ratio f_s/f_d is measured through $\bar{B}_s^0 \to D_s^+\pi^-$ and $B^0 \to D^-\pi^+$ decays.

Opportunity? Lesson?



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- ☑ Do it online!

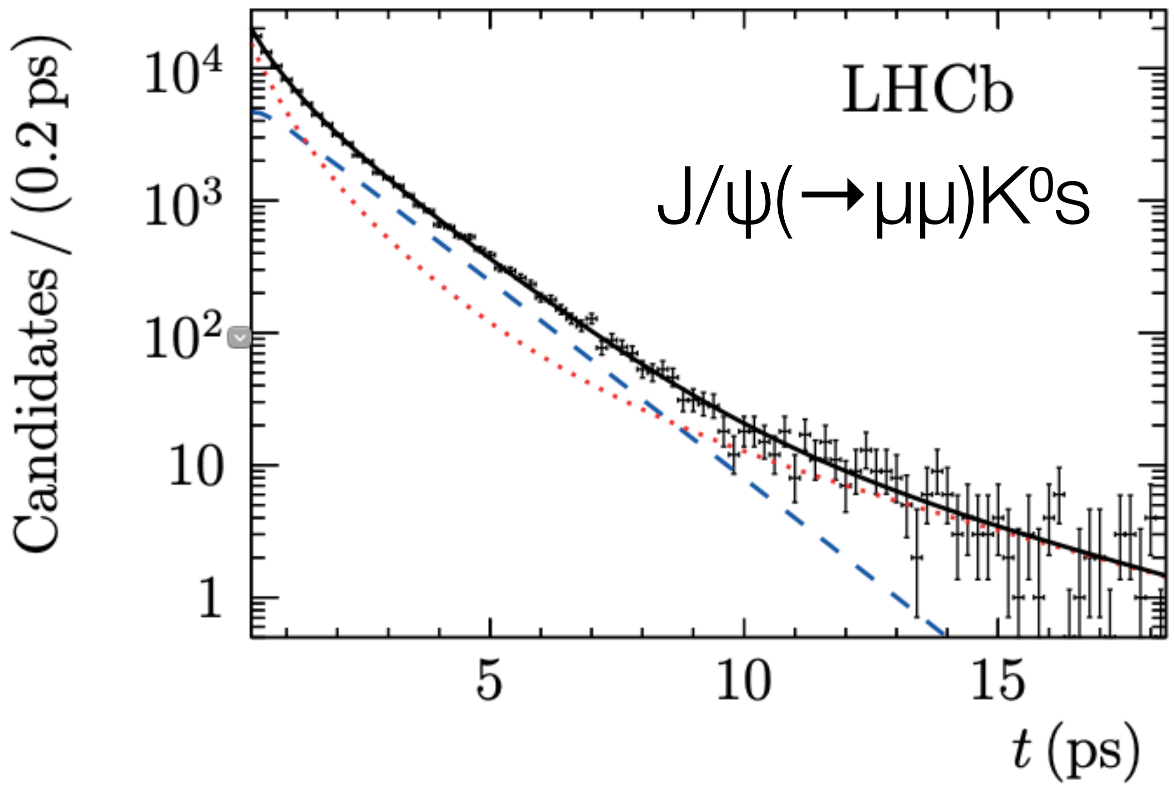
☐ Reconstruct precisely *B* and *D* decay time

☐ Identify if a particle (*B*, *D*) or antiparticle ($\bar{B}$, $\bar{D}$) was produced

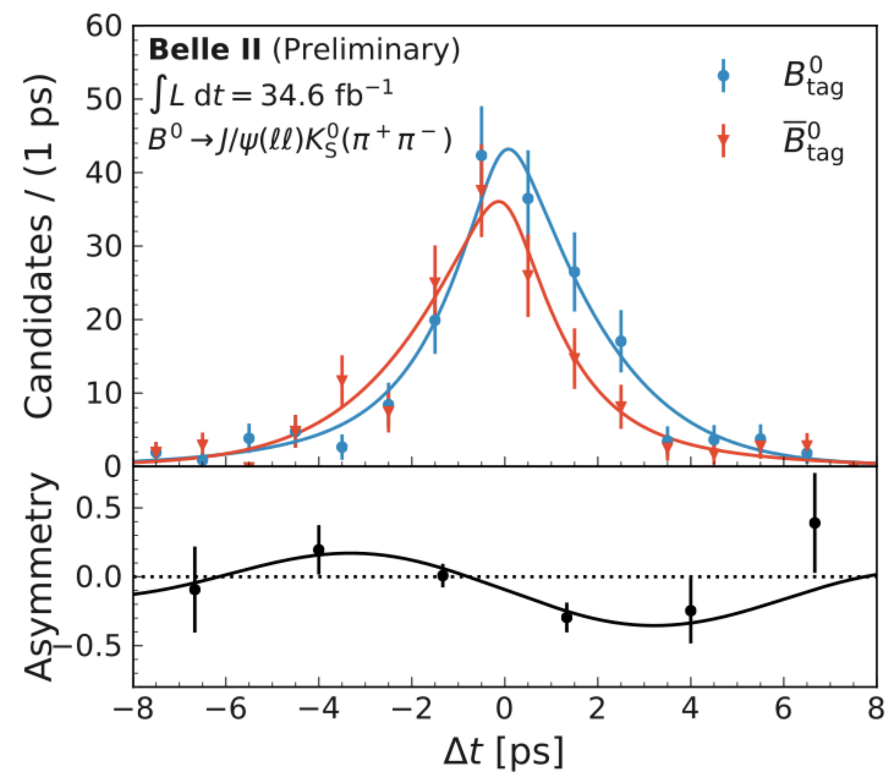
Measure decay time

Decay time

Determined from observed decay length L = βγct, sampled precisely by position sensitive detectors close to the interaction point, and momentum with βγ = p/m and ct≈cτ≈ 0.5 mm.



Resolution rms ~ 60 fs



Resolution rms is ~ 500 fs

Distance btw two secondary vertices (as opposed to LHCb's secondary from primary) and lower boost: 10x penalty for Belle II. Charm's more favorable: 2x.

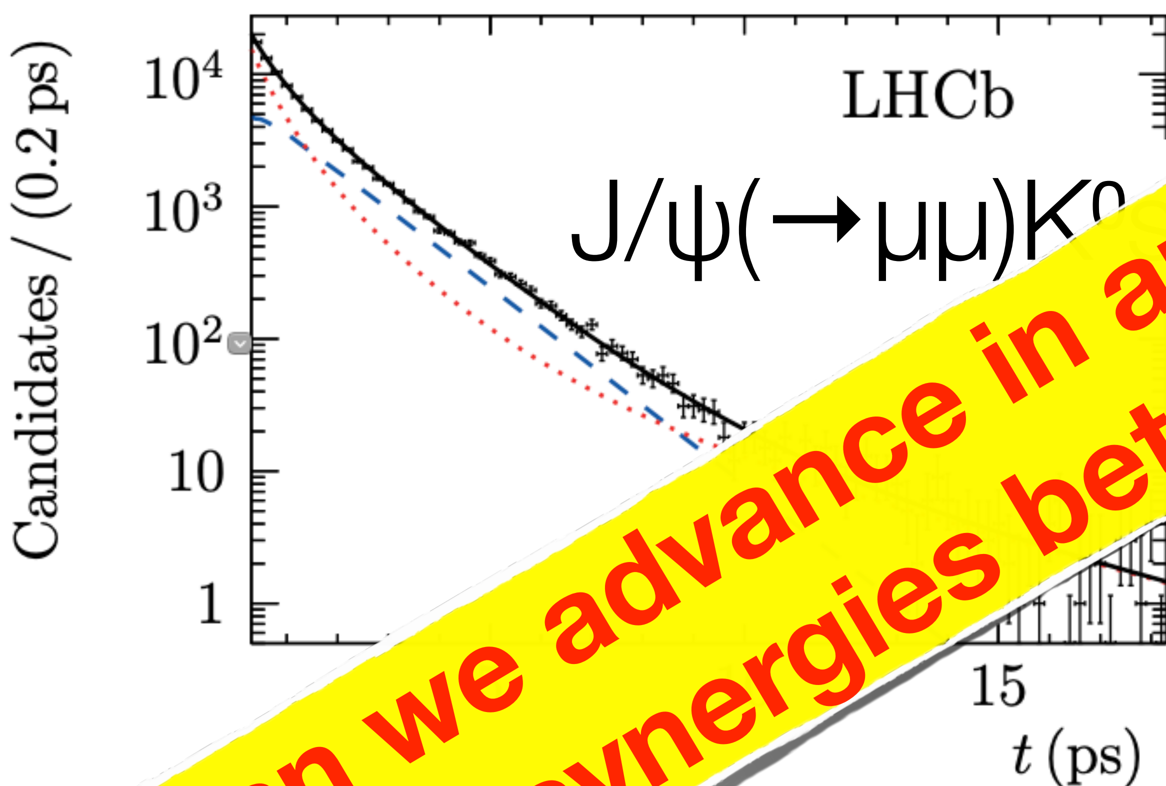
In most applications it will be the systematic uncertainties that dominate

Decay time

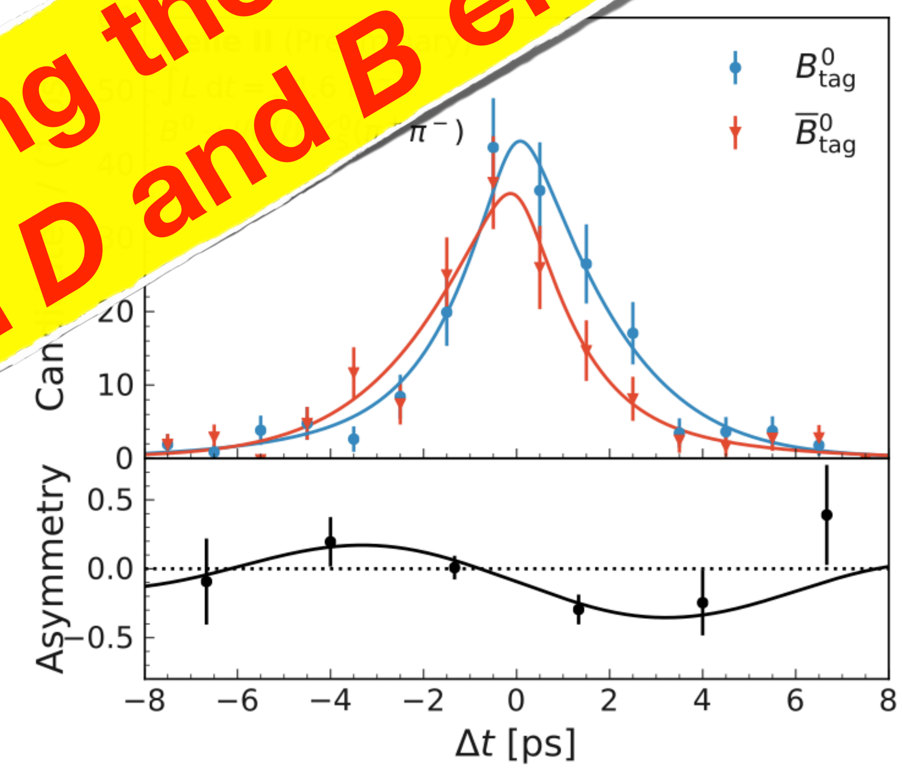
Determined from observed decay length L = βγct, sampled pr… sensitive detectors close to the interaction point, and mo… p/m and ct≈cτ≈ 0.5 mm.

Can we advance in anything these systematics?

Can synergies between D and B efforts help?



…resol… rms ~ 60 fs



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…btw two secondary vertices (as opposed to LHCb's secondary from p…ary) and lower boost: 10x penalty for Belle II. Charm's more favorable: 2x.

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Identify flavor

Was it a particle or an antiparticle at production?

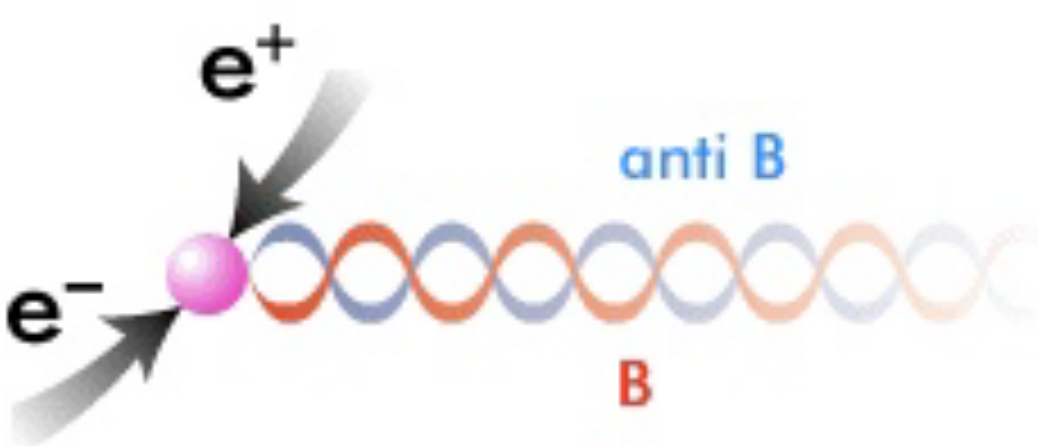
In measurements involving flavor oscillations, need to know whether oscillations occurred or not for the signal *B* meson.

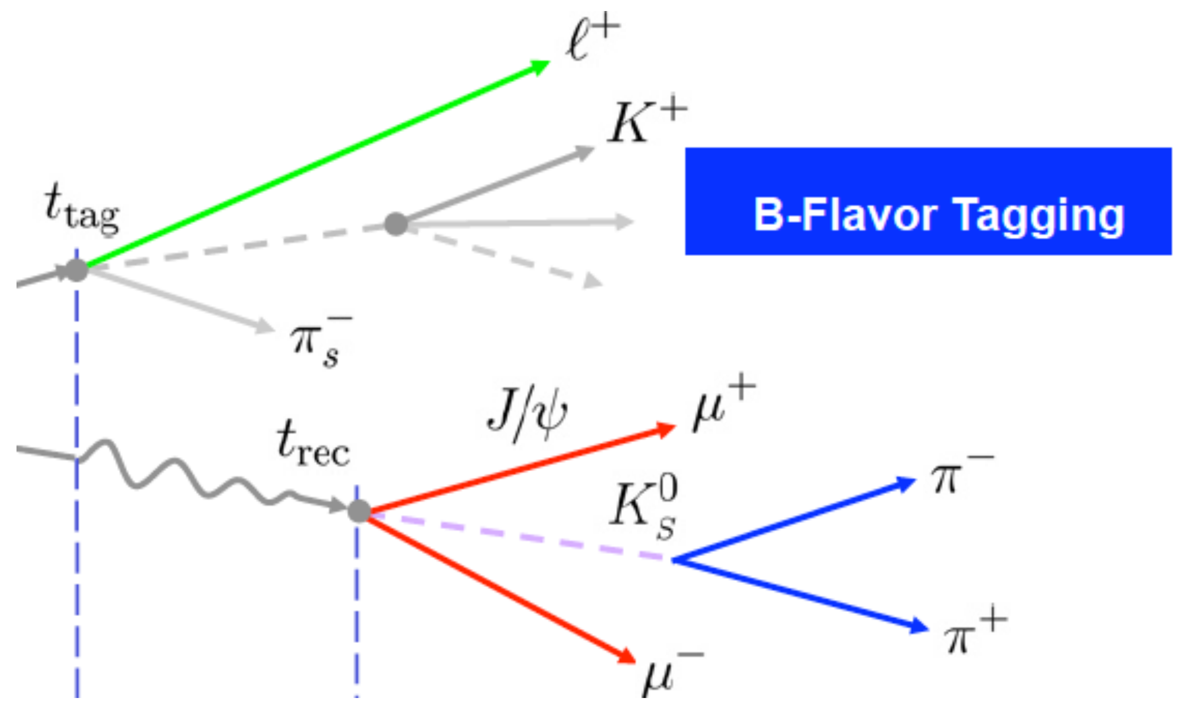
Compare the flavor at time of decay with flavor at $t = 0$ to see if an oscillation occurred.

If it was a particle when I started measuring the time and it was an antiparticle when it decayed (or viceversa) then it oscillated

Flavor tagging at B factories

B factories, exploit coherent flavor anticorrelation ofthe $B\,\bar{B}$ pair.





Two mesons evolve with opposite flavors until the first decays (which sets t = 0) and the signal *B* meson continues its evolution incoherently.

If the decay is in a final state only accessible by either particle or antiparticle, then the flavor of the decaying meson “tags” the flavor of the signal one at t = 0.

The flavor is correctly determined for 1/3 of signal *B* mesons

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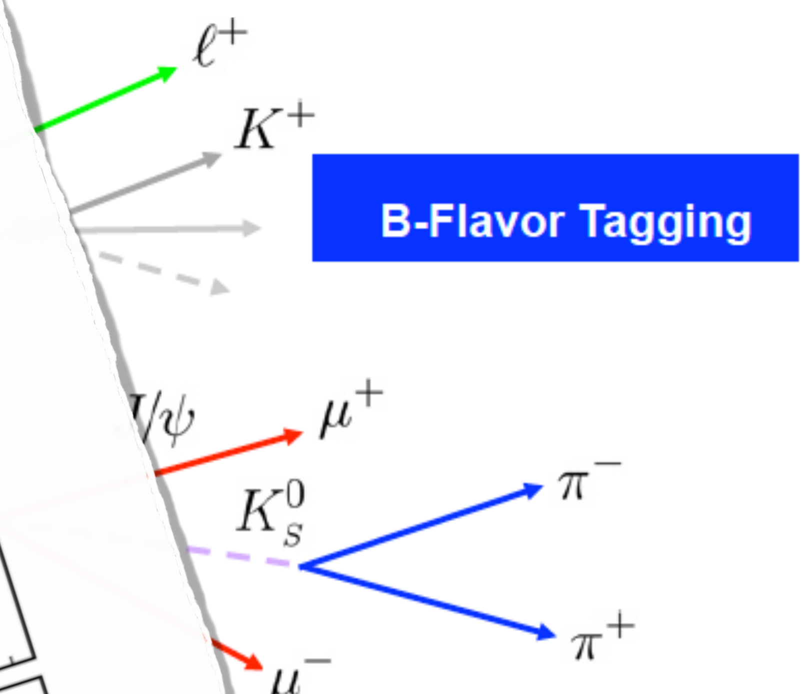
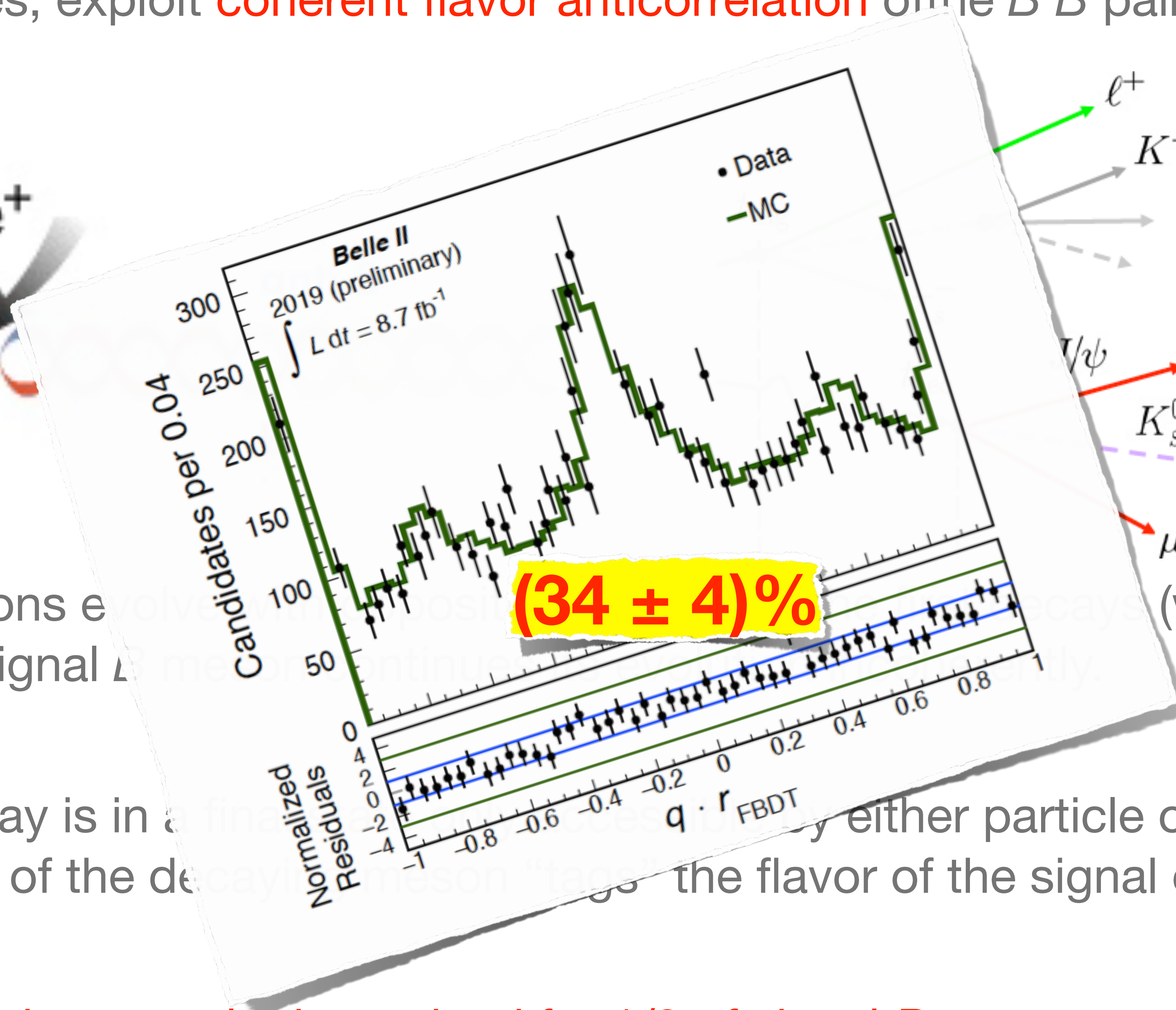


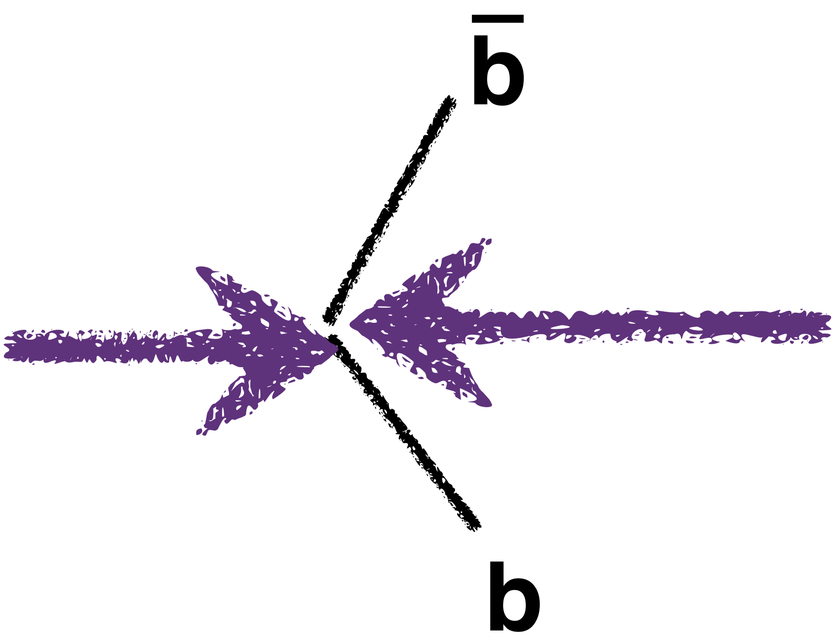


Two mesons evolve with opposite flavor until one decays (which sets t = 0) and the signal B meson continues to evolve independently.

If the decay is in a final state accessible by either particle or antiparticle, then the flavor of the decaying meson "tags" the flavor of the signal one at t = 0.

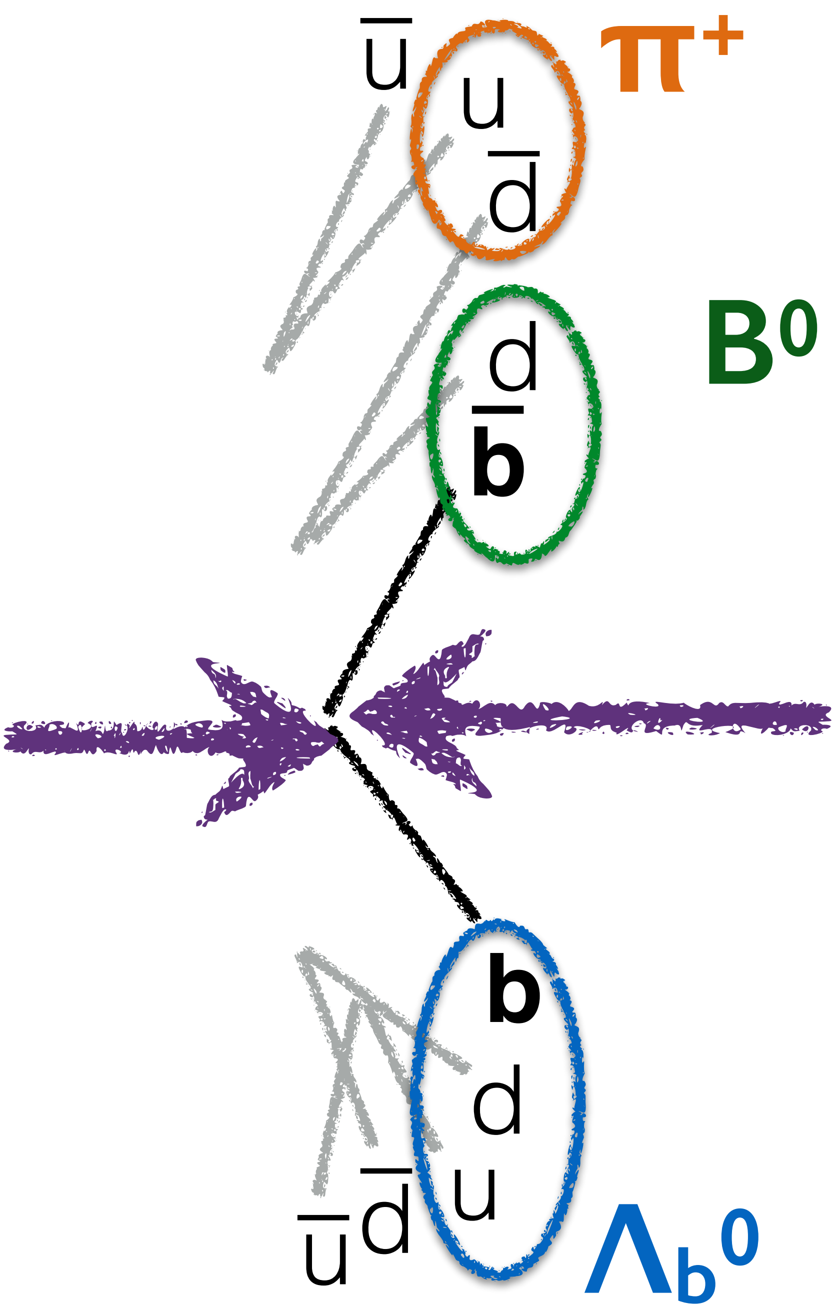
The flavor is correctly determined for 1/3 of signal *B* mesons

Flavor tagging in hadron collisions



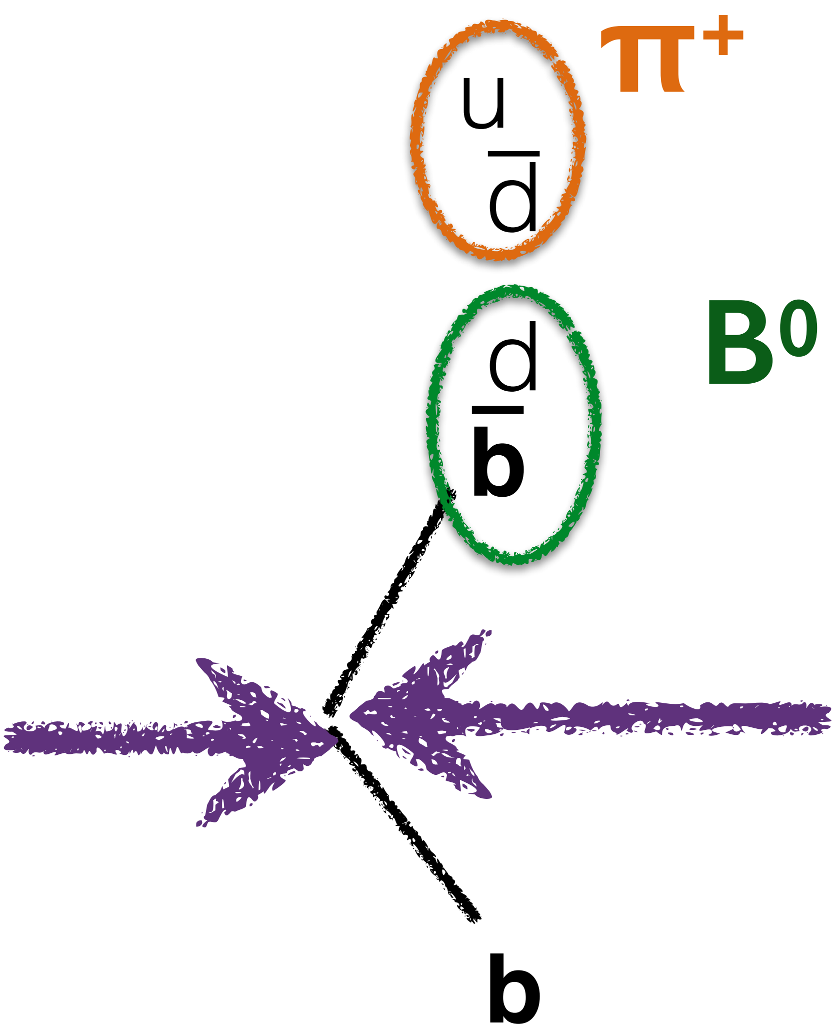
Main production mechanism of b quark
at hadron collider: b anti-b pair production

Flavor tagging in hadron collisions



The two b quarks hadronise independently into two b hadron (incoherent production)

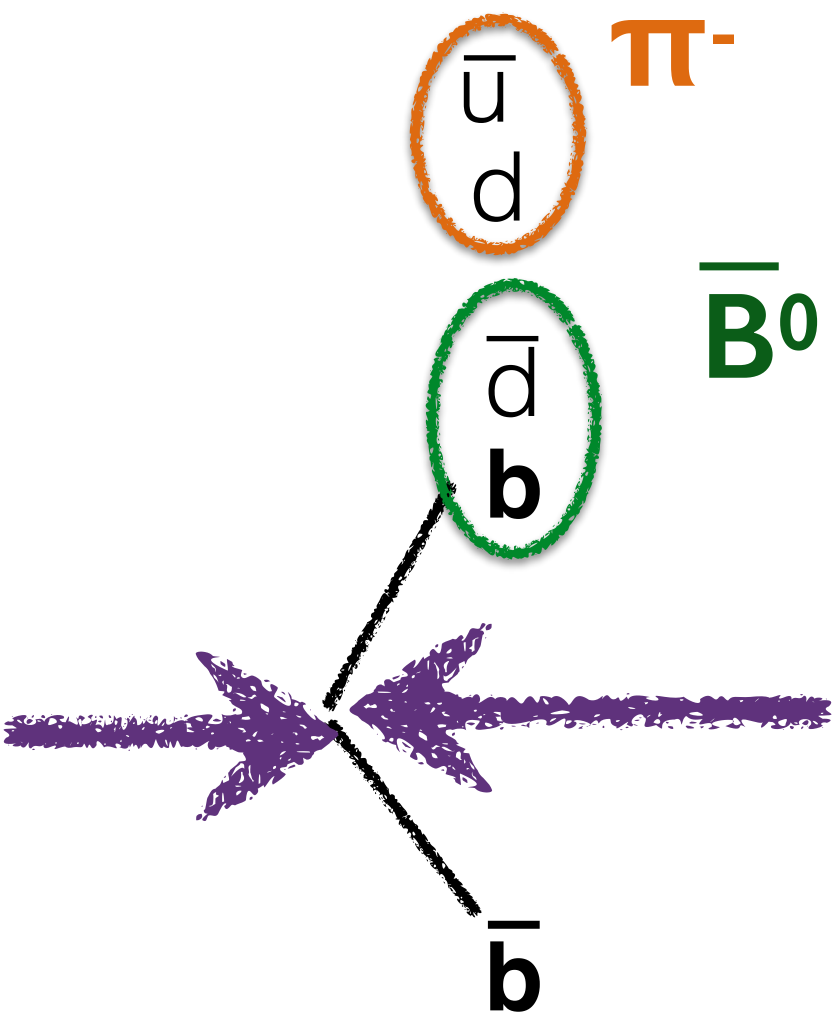
Flavor tagging in hadron collisions



The signal B^0 can be accompanied by a **charged pion** (~50% of the time): its charge gives the flavour of the B!

(**Same Side tagging**)

Flavor tagging in hadron collisions



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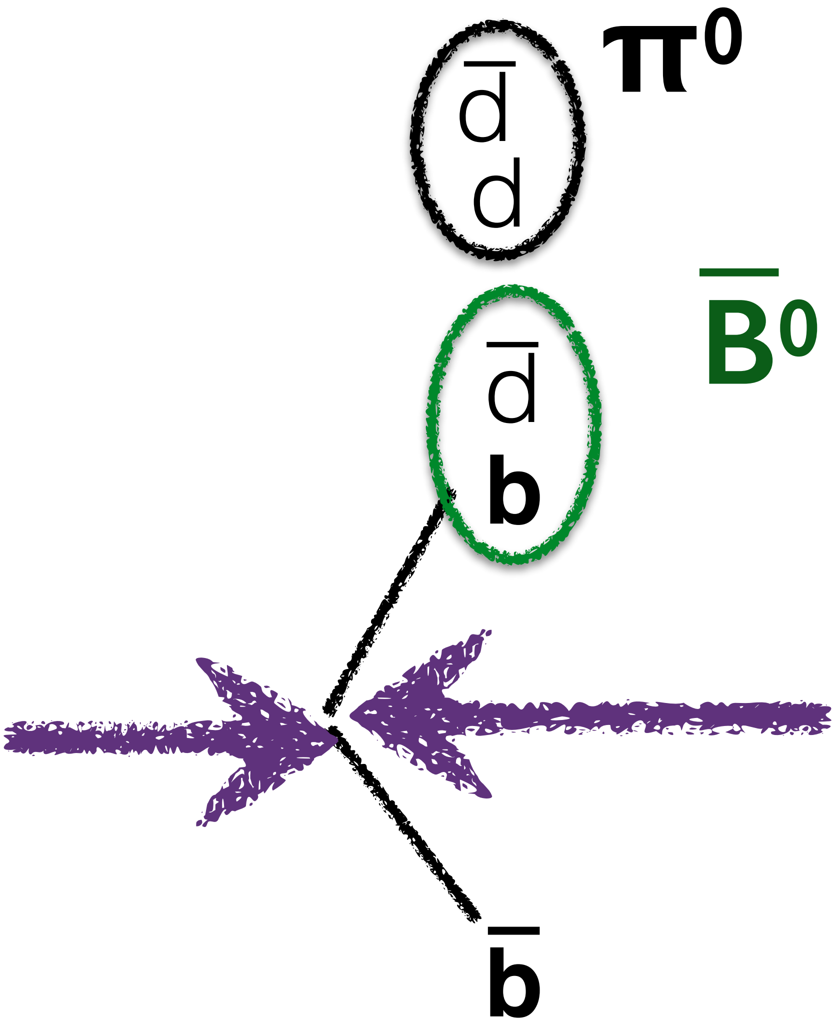
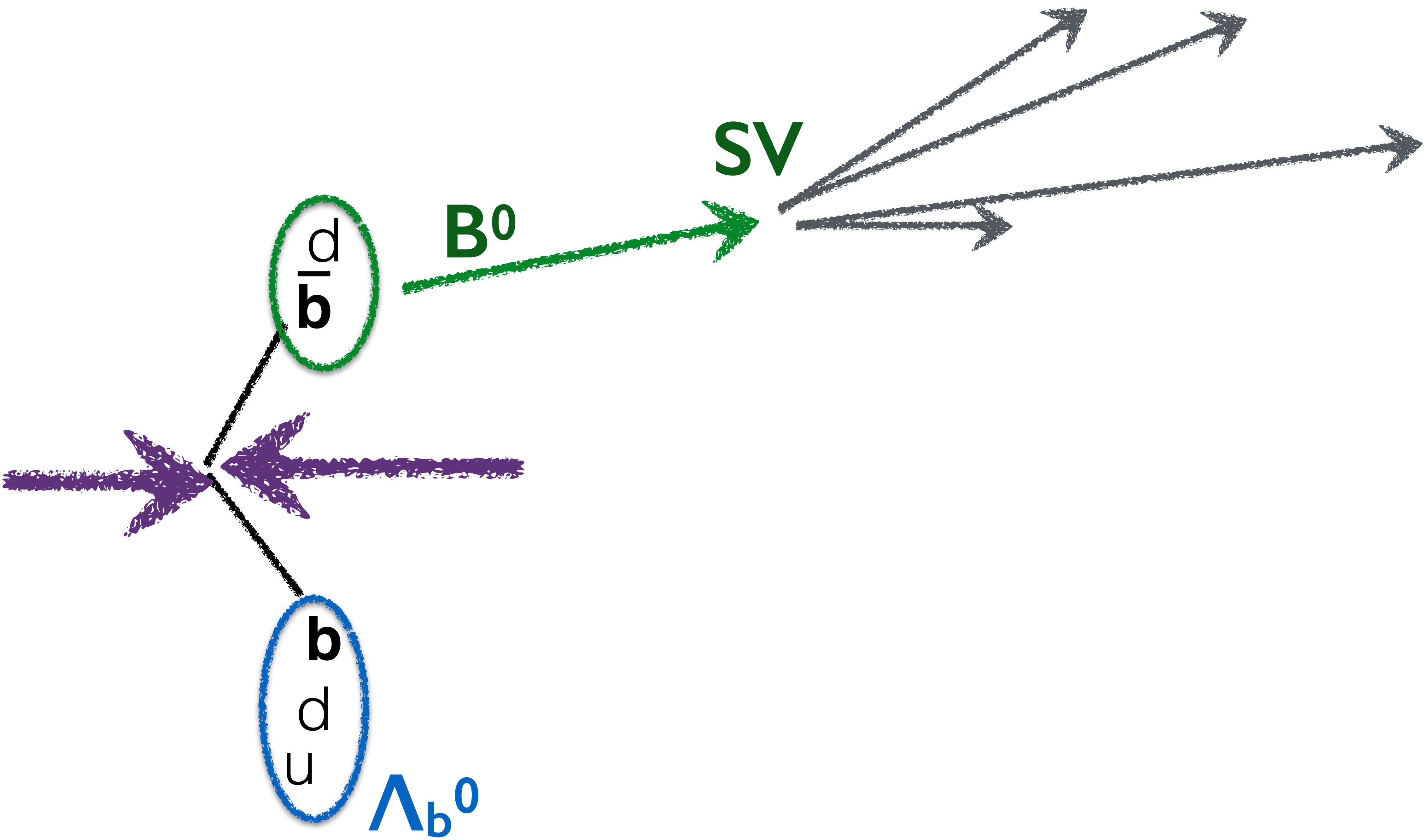
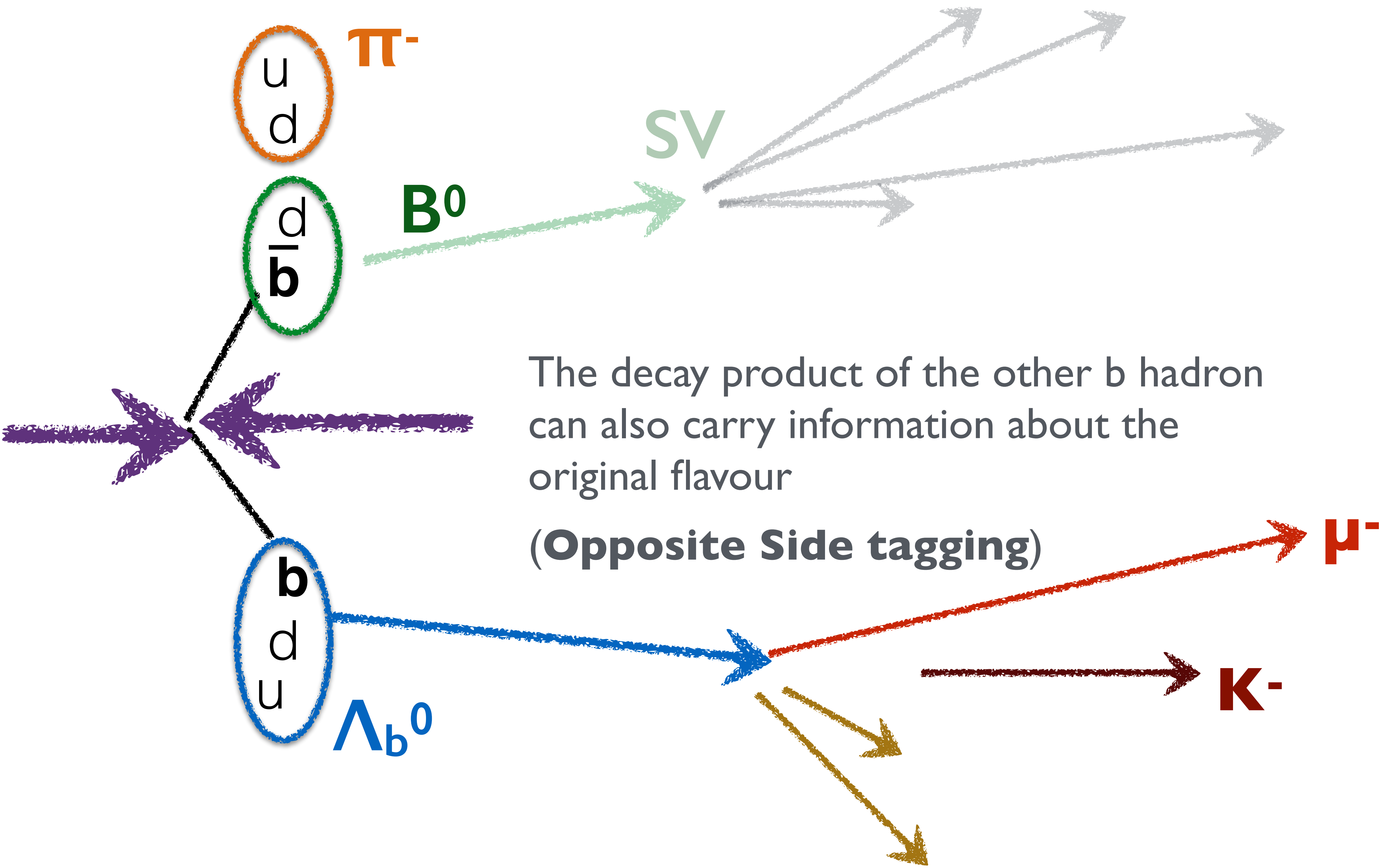


Cannot tag…

Flavor tagging in hadron collisions



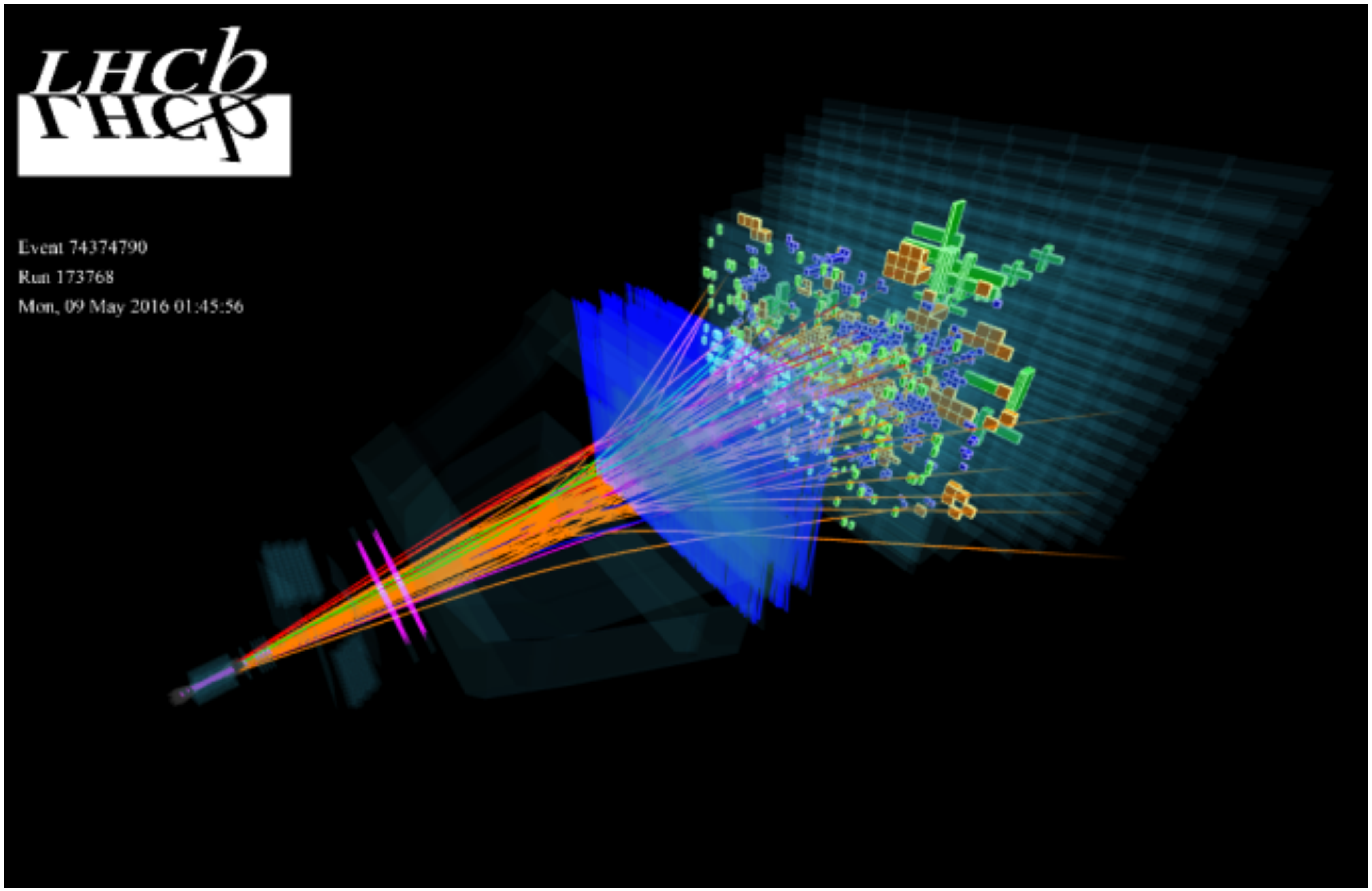
Flavor tagging in hadron collisions



The decay product of the other b hadron can also carry information about the original flavour

(**Opposite Side tagging**)

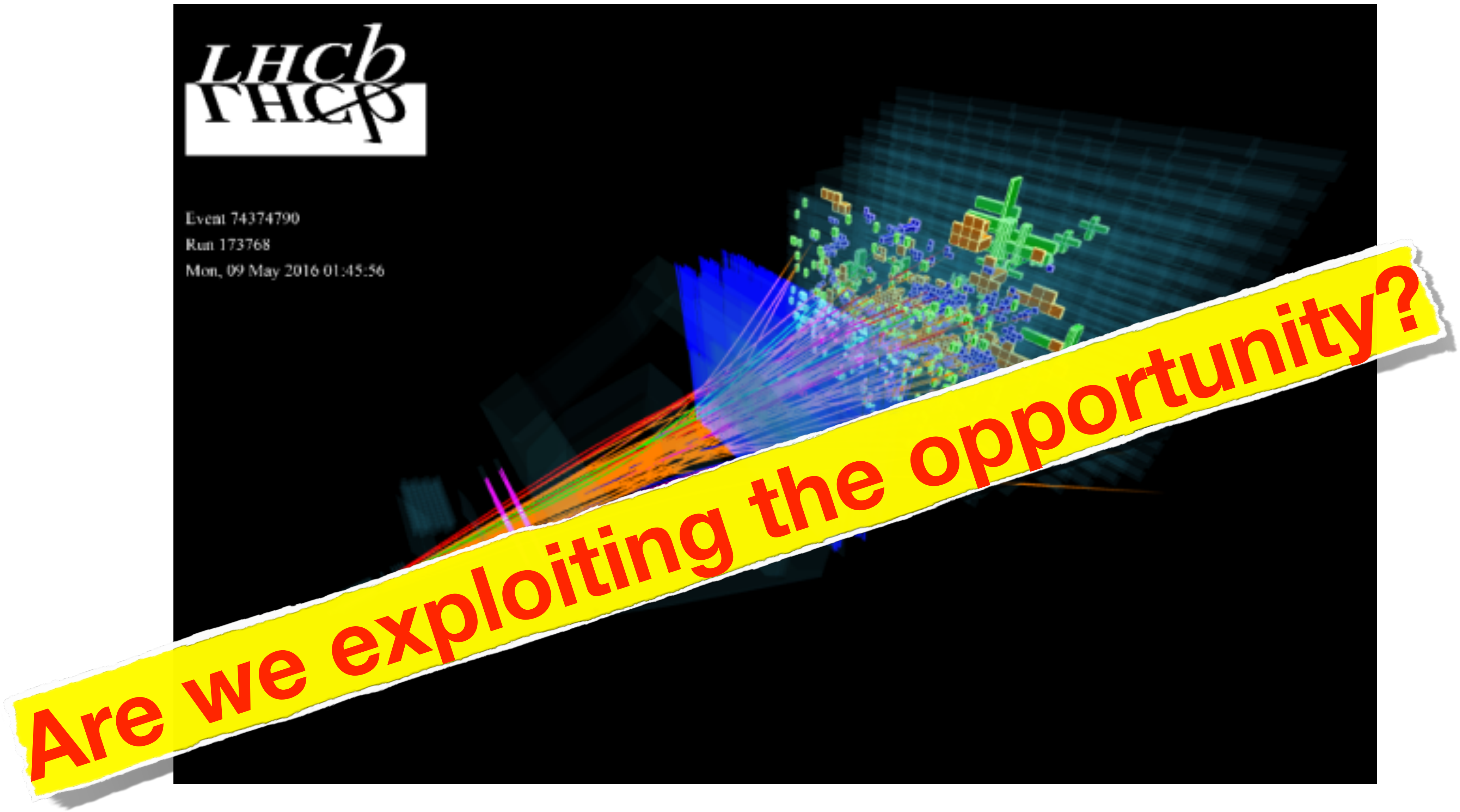
Flavor tagging in hadron collisions



The most critical aspect in many analyses associated with oscillations. Very hard, in the mess, to pick the right tracks to infer the tagging information.

The flavor is correctly determined in 1/15 to 1/30 of signal *B* mesons

Flavor tagging in hadron collisions



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  - Do it online!
- Reconstruct precisely B and D decay time
- Identify if a particle (B, D) or antiparticle ($\bar{B}$, $\bar{D}$) was produced

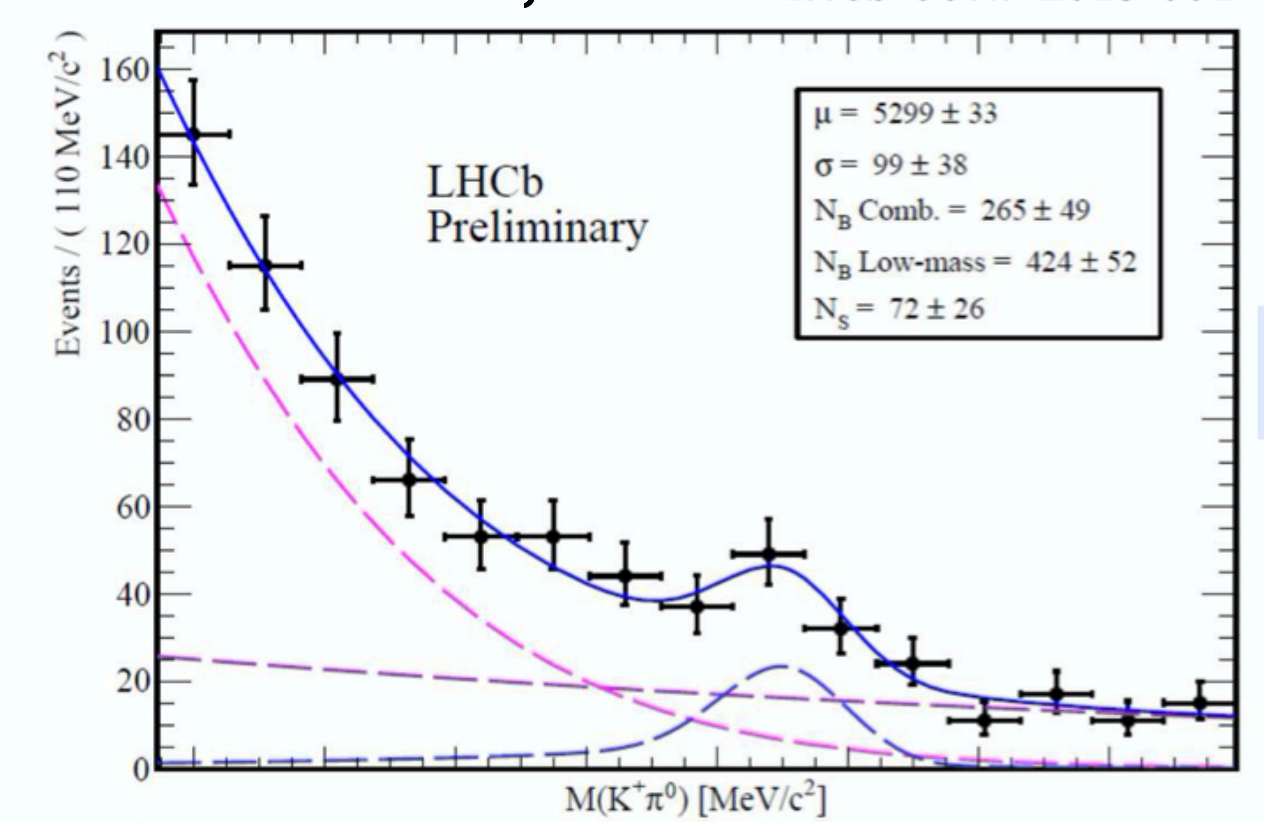
Did I get you discouraged? I haven’t been fair..

I compared the first whimpers of a newborn experiment/collaboration with the mature products of a 10-year old, well-oiled machine.

Many of the LHCb capabilities and performances shown today were not available/mature already a few years back.

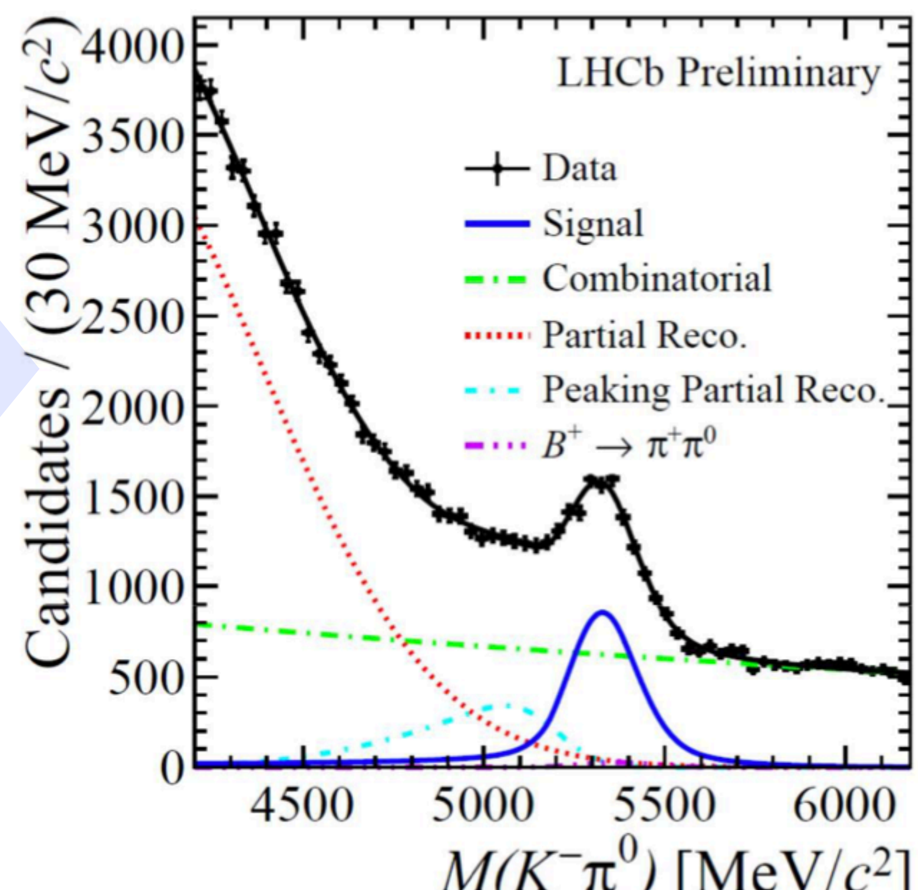
Don’t you believe me?

2015, 3/fb LHCb-CONF-2015-001



40x

2020, 6/fb



Belle II physics in 2022, 2023, 2024.. will be an entirely different business.

The intelligence of instruments

This, as many examples from the past, teach us something.

A scientific instrument (like a new detector in a new machine) when it is designed intelligently, built carefully, well understood, and operated efficiently, acquires a “scientific intelligence” on its own that enables a reach exceeding the designers’ expectations.

The unvaluable potential of talented, competent, and motivated, people like you intent in finding new ideas, approaches, techniques further enhances that

Not just physics: Ugur Sahin and Özlem Türeci had been pioneering the mRNA technique targeting cancer therapy. It took them 48 hrs to realize it could work well against covid-19 and prompt preparation of first vaccine attempts

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THE UNREASONABLE EFFECTIVENSS OF MATHEMATICS IN THE NATURAL SCIENCES

Eugene Wigner

Mathematics, rightly viewed, possesses not only truth, but supreme beauty cold and austere, like that of sculpture, without appeal to any part of our weaker nature, without the gorgeous trappings of painting or music, yet sublimely pure, and capable of a stern perfection such as only the greatest art can show. The true spirit of delight, the exaltation, the sense of being more than Man, which is the touchstone of the highest excellence, is to be found in mathematics as surely as in poetry.

- BERTRAND RUSSELL, Study of Mathematics

The (nearly miracolous) power of combining new instruments with human ingenuity in the natural sciences

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Moral of the story

We all want our work, and our experiment, to make an impact in understanding nature (while possibly having fun in the process).

Impact is not one dimensional. It's multifaceted and manifold:

- Probing something relevant noone else can probe
- Probing something relevant earlier, or with comparable/better precision, than rest
- Probing something relevant using an original approach so that the combination improves global knowledge
- Inventing an approach/technique that boost the reach of others.
- Inspiring through discussion someone else to do any of the above
- Preparing a tool that enables someone else to achieve the above
- Strive to ensure that detector and data quality/quantity are consistently at top
- Train someone that one day will achieve the above
- …

Moral of the story

We all want our work, and our experiment, to make an impact in understanding nature (while possibly having fun in the process).

Impact is not one dimensional. It's multifaceted and manifold

- Probing something relevant that no one else can probe
- Probing something relevant better, with comparable/better precision, than others
- Probing something relevant using an original approach so that the combination improves our knowledge
- Inventing an approach/technique that facilitates/boost the reach of other experiments
- Inspiring through discussion someone else to invent the above
- Preparing/optimizing a tool that enables someone else to achieve the above
- Strive to ensure that detector and data quality/quantity are consistently at top
- Train someone that one day will achieve the above
- …

Think, rather than cuddling up to conventional wisdom.
Learn from the past, challenge the present/future

Moral of the story

We all want our work, and our experiment, to make an impact in understanding nature (while possibly having fun in the process)

Impact is not one dimensional. It's multifaceted and manifold

- Probing something relevant that no one else can probe
- Probing something relevant better, or with comparable precision, than others
- Probing something relevant using an original approach, so that the combination improves our knowledge
- Inventing an approach/technique that extends the reach of other measurements
- Inspiring through discussion someone else to invent the above
- Preparing/optimizing ... that enables someone else to achieve the above
- Strive to ensure detector and data quality/quantity are consistently at top
- Train someone that one day will achieve the above
- …

Think, rather than cuddling up to conventional wisdom.
Learn from the past, challenge the present/future

And forget 1 fb^{-1} = 1 ab^{-1}
It's very much channel-, time-, and your-ideas dependent

Many among us are already doing this

PHYSICAL REVIEW LETTERS **124,** 141801 (2020)

Editors' Suggestion | Featured in Physics

Search for an Invisibly Decaying Z' Boson at Belle II in $e^+e^- \to \mu^+\mu^-(e^\pm\mu^\mp)$ Plus Missing Energy Final States

PHYSICAL REVIEW LETTERS **125,** 161806 (2020)

Search for Axionlike Particles Produced in e^+e^- Collisions at Belle II

Search for $B^+ \to K^+\nu\bar{\nu}$ decays using an inclusive tagging method at Belle II

A search for the flavor-changing neutral current decay $B^+ \to K^+\nu\bar{\nu}$ is performed with an electron-positron collision data sample corresponding to $63\,\mathrm{fb}^{-1}$ collected at the $\Upsilon(4S)$ resonance by the Belle II experiment. A novel measurement method is developed, which exploits topological properties of the decay that differ from both generic bottom-meson decays and light-quark pair-production. This inclusive tagging approach has the benefit of a higher signal efficiency compared to previous searches for this rare decay. As no significant signal is observed, an upper limit on the branching fraction of $B^+ \to K^+\nu\bar{\nu}$ of 4.4×10^{-5} is set at the 90% confidence level.

to be submitted soon

Thank you

**It's been fun to discuss physics with you.
I learned a lot in preparing this — hope you learned something in listening too**