Thanks to Marina for the picture

A few words

Yasmine Amhis

"Our Lady of the Good Death with her shining golden robes and her smile invites us not to fear death with her as our guide, but to pray for a good death"

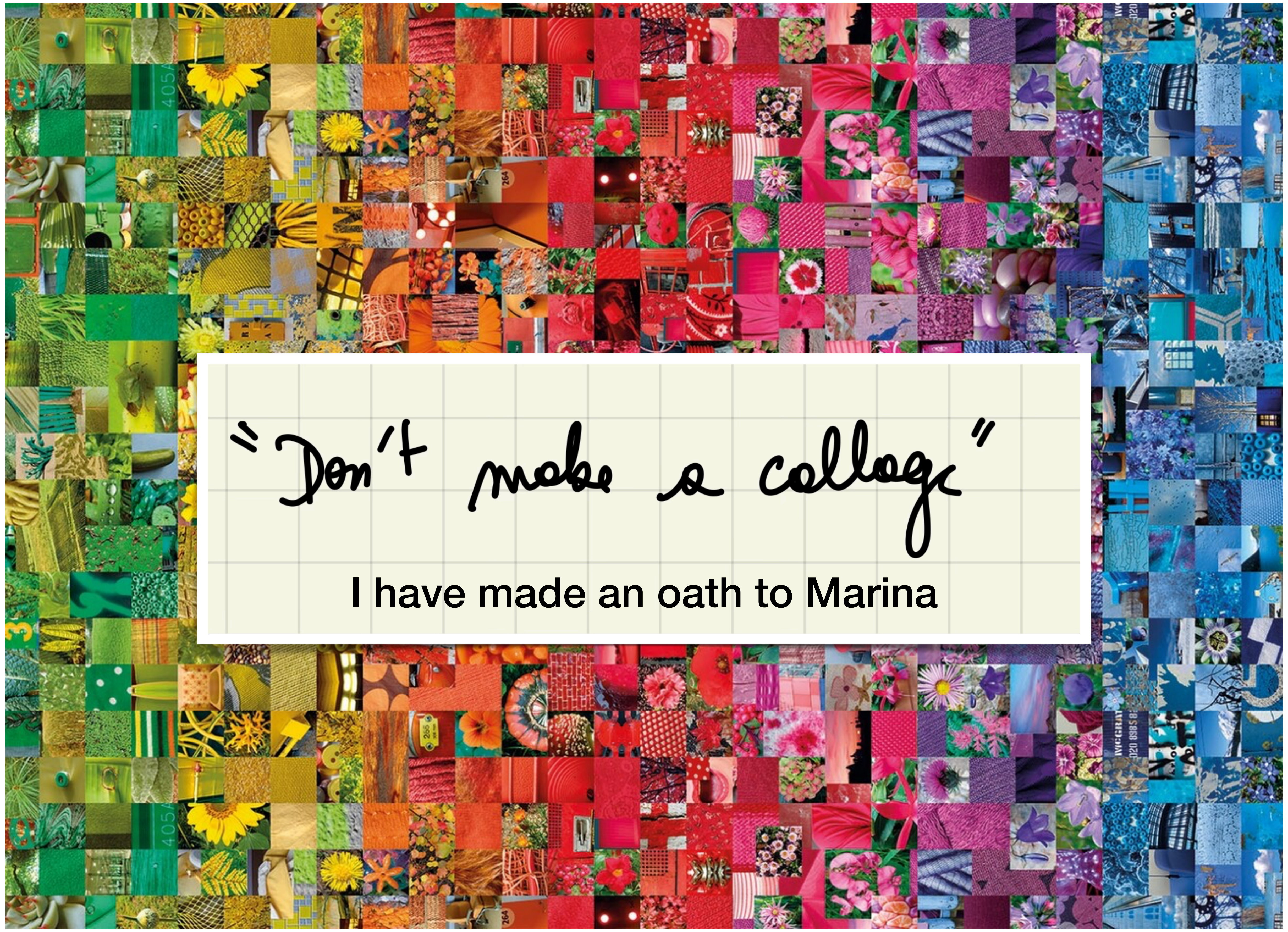
Beauty 2023 - Clermont Ferrand

A few words

Yasmine Amhis

“Don't Google Beauty 1995”

What this talk is not



Lunch recommendations: no penguin jokes, no pineapple on pizza jokes, etc.

Instead, I just listened to all of you

Quotes are anonymised but some of you may recognise themselves

If you will indulge me a personal note

I would like to thank to the organisers, it’s very humbling to be here

From my PhD 2006-2009

The channels in question

$B^0 \to D^- \rho^+(770)$ → Gamma Extraction:U-spin modes

$B^0{}_s \to D^-{}_s \rho^+$ → Bs Oscillations measurement.

You can tell I was young, I was using ComicSense

From my PhD 2006-2009

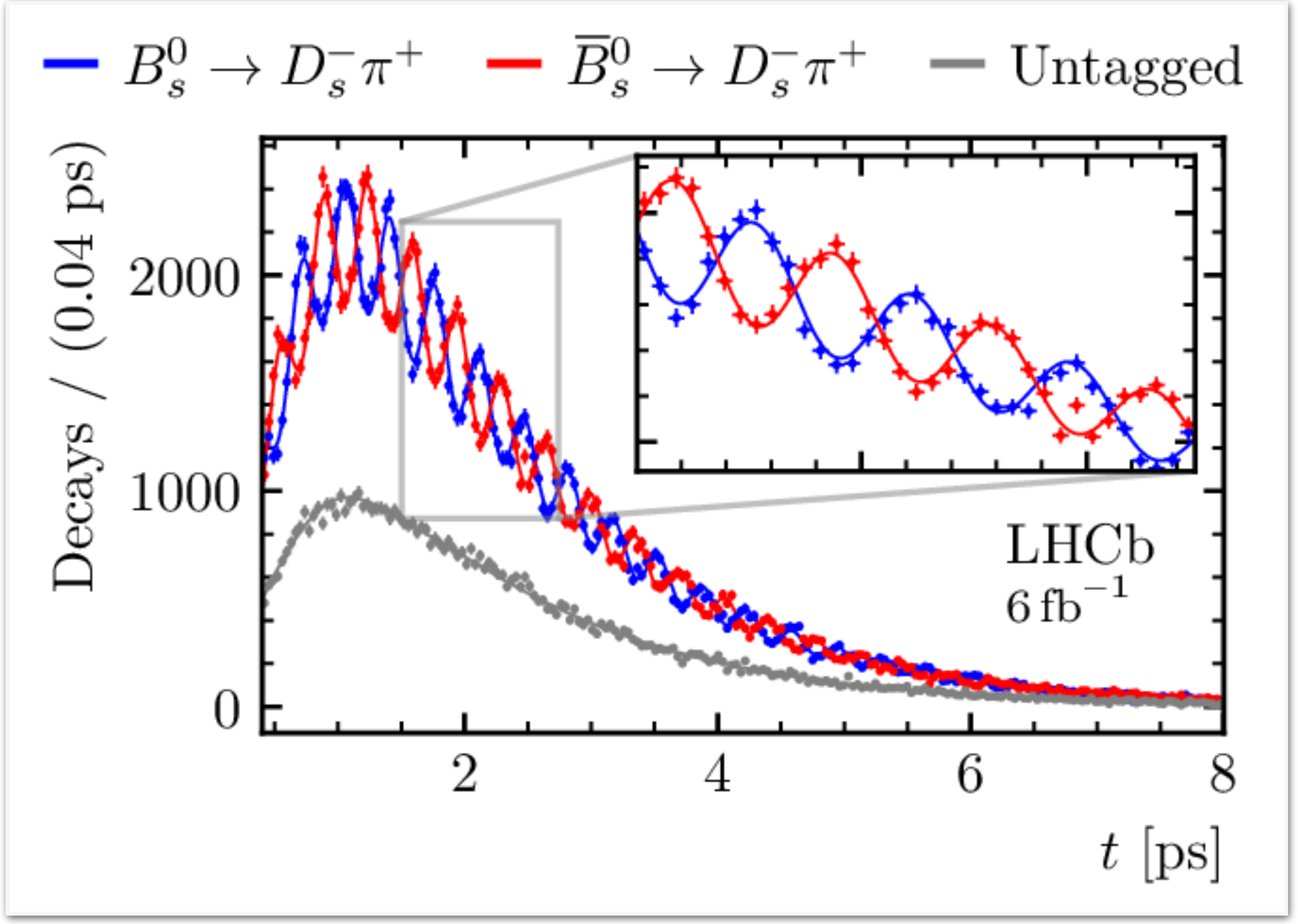
The channels in question

$B^0 \to D^- \rho^+(770)$ → Gamma Extraction:U-spin modes

$B^0_s \to D^-_s \rho^+$ → Bs Oscillations measurement.

In collaboration with S. Monteil

I thought I would be doing something like this !



From my PhD 2006-2009

The channels in question

$B^0 \rightarrow D^- \rho^+(770)$ → Gamma Extraction:U-spin modes

$B^0_s \rightarrow D^-_s \rho^+$ → Bs Oscillations measurement.

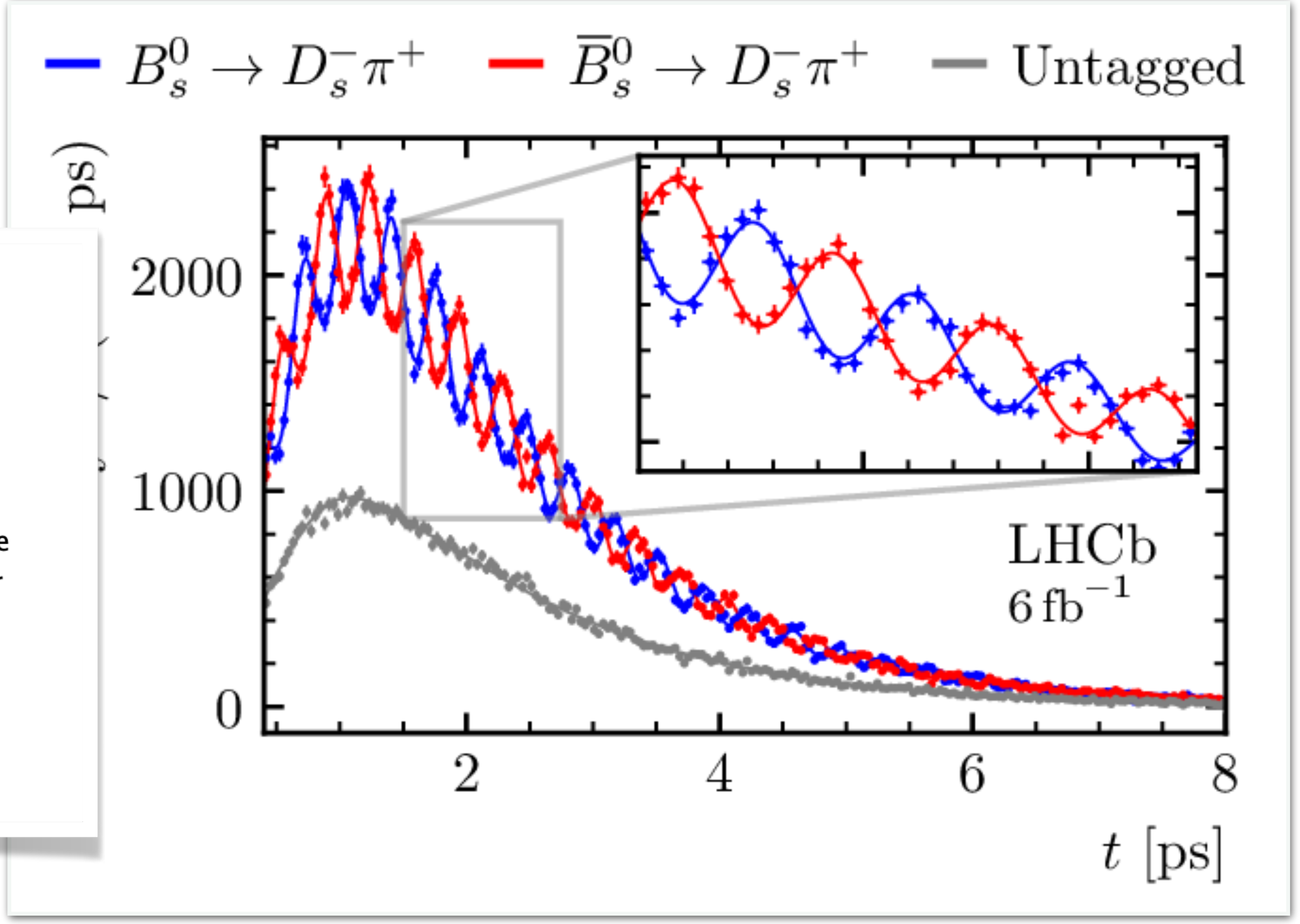
In collaboration with S. Monteil

[Submitted on 22 Sep 2006]

Observation of Bs-Bsbar Oscillations

CDF Collaboration

We report the observation of Bs-Bsbar oscillations from a time-dependent measurement of the Bs-Bsbar oscillation frequency Delta ms. Using a data sample of 1 fb^-1 of p-pbar collisions at sqrt{s}=1.96 TeV collected with the CDF II detector at the Fermilab Tevatron, we find signals of 5600 fully reconstructed hadronic Bs decays, 3100 partially reconstructed hadronic Bs decays, and 61500 partially reconstructed semileptonic Bs decays. We measure the probability as a function of proper decay time that the Bs decays with the same, or opposite, flavor as the flavor at production, and we find a signal for Bs-Bsbar oscillations. The probability that random fluctuations could produce a comparable signal is 8 X 10^-8, which exceeds 5 sigma significance. We measure
Delta ms = 17.77 +- 0.10 (stat) +- 0.07 (syst) ps^-1
and extract
|Vtd/Vts| = 0.2060 +- 0.0007 (exp) + 0.0081 - 0.0060 (theor).



22 days after the start of my thesis

From my PhD 2006-2009

The channels in question

$B^0 \rightarrow D^- \rho^+(770)$ → Gamma Extraction:U-spin modes

$B^0_s \rightarrow D^-_s \rho^+$ → Bs Oscillations measurement.

Inspired by a paper of R. Fleischer

A similar idea to a thesis of one of G. Wilkinson's students V. Gligorov I think

From my PhD 2006-2009

The channels in question

$B^0 \to D^- \rho^+(770)$ → Gamma Extraction:U-spin modes

$B^0_s \to D^-_s \rho^+$ → Bs Oscillations measurement.

Inspired by a paper of R. Fleischer

A similar idea to a thesis of one of G. Wilkinson's students, I think he was called Gligorov

CERN releases analysis of LHC incident

16 OCTOBER, 2008

Geneva, 16 October 2008. Investigations at CERN following a large helium leak into sector 3-4 of the Large Hadron Collider (LHC) tunnel have confirmed that cause of the incident was a faulty electrical connection between two of the accelerator's magnets. This resulted in mechanical damage and release of helium from the magnet cold mass into the tunnel.

One year after the start of my thesis

From my PhD 2006-2009

The channels in question

$B^0 \to D^- \rho^+(770)$ → Gamma Extraction:U-spin modes

$B^0_s \to D^-_s \rho^+$ → Bs Oscillations measurement.

Inspired by a paper of R. Fleischer

A similar idea to a thesis of one
of G. Wilkinson's students,
I think he was called Gligorov

In collaboration with S. Monteil

CERN releases analysis of LHC incident

16 OCTOBER, 2008

Geneva, 16 October 2008. Investigations at CERN following a large helium leak into sector 3-4 of the Large Hadron Collider (LHC) tunnel have confirmed that cause of the incident was a faulty electrical connection between two of the accelerator's magnets. This resulted in mechanical damage and release of helium from the magnet cold mass into the tunnel.

One year after the start of my thesis

From my PhD 2006-2009

The

$B^0 \rightarrow D^-$

$B^0_s \rightarrow$

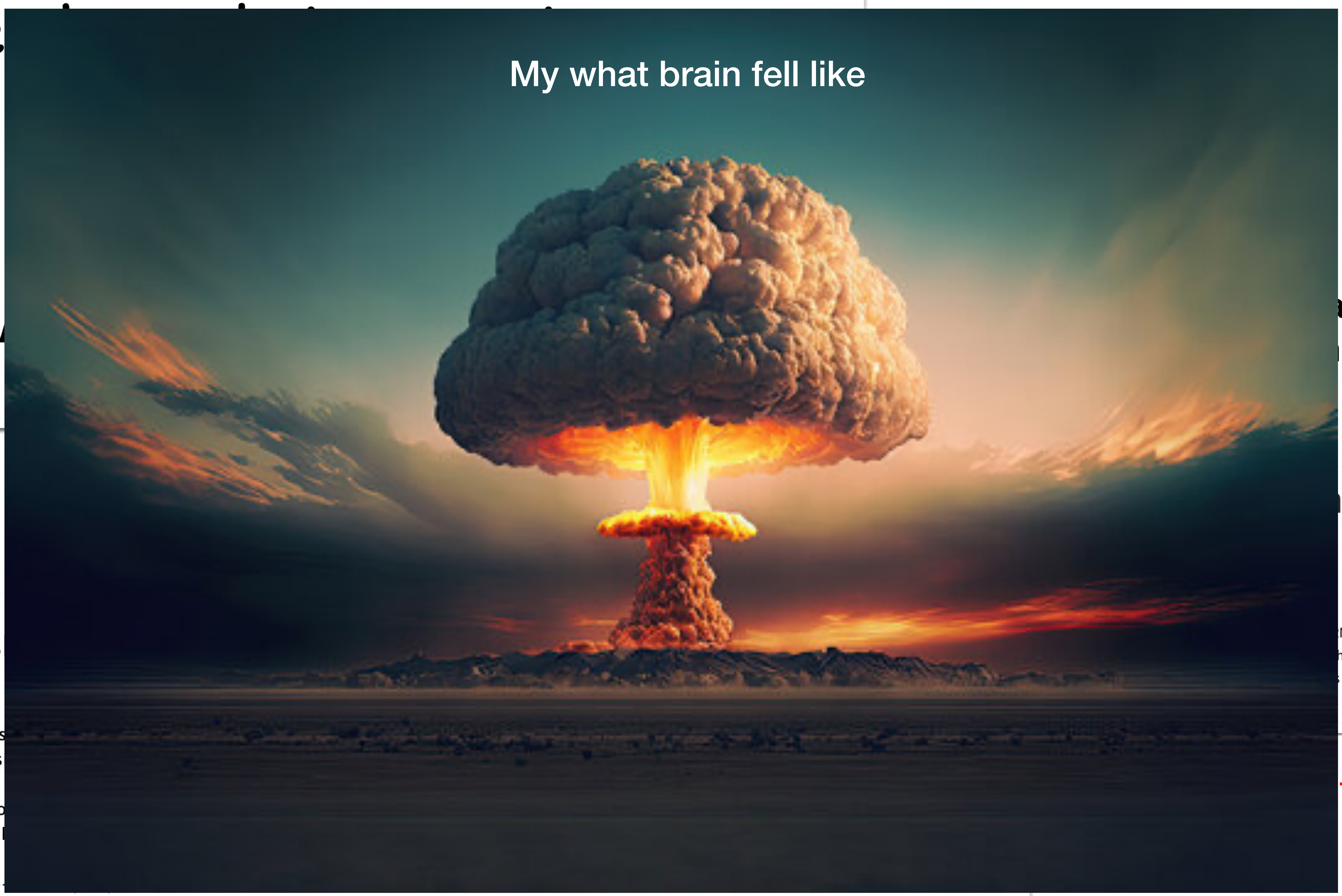
R. Fleischer

thesis of one
's students.

nalysis of LHC

N following a large helium leak into sector 3-4 of the Large
hat cause of the incident was a faulty electrical connection
resulted in mechanical damage and release of helium from the

the start of my thesis



[Submitted on 22 Sep 2006]

Observation of Bs-Bs

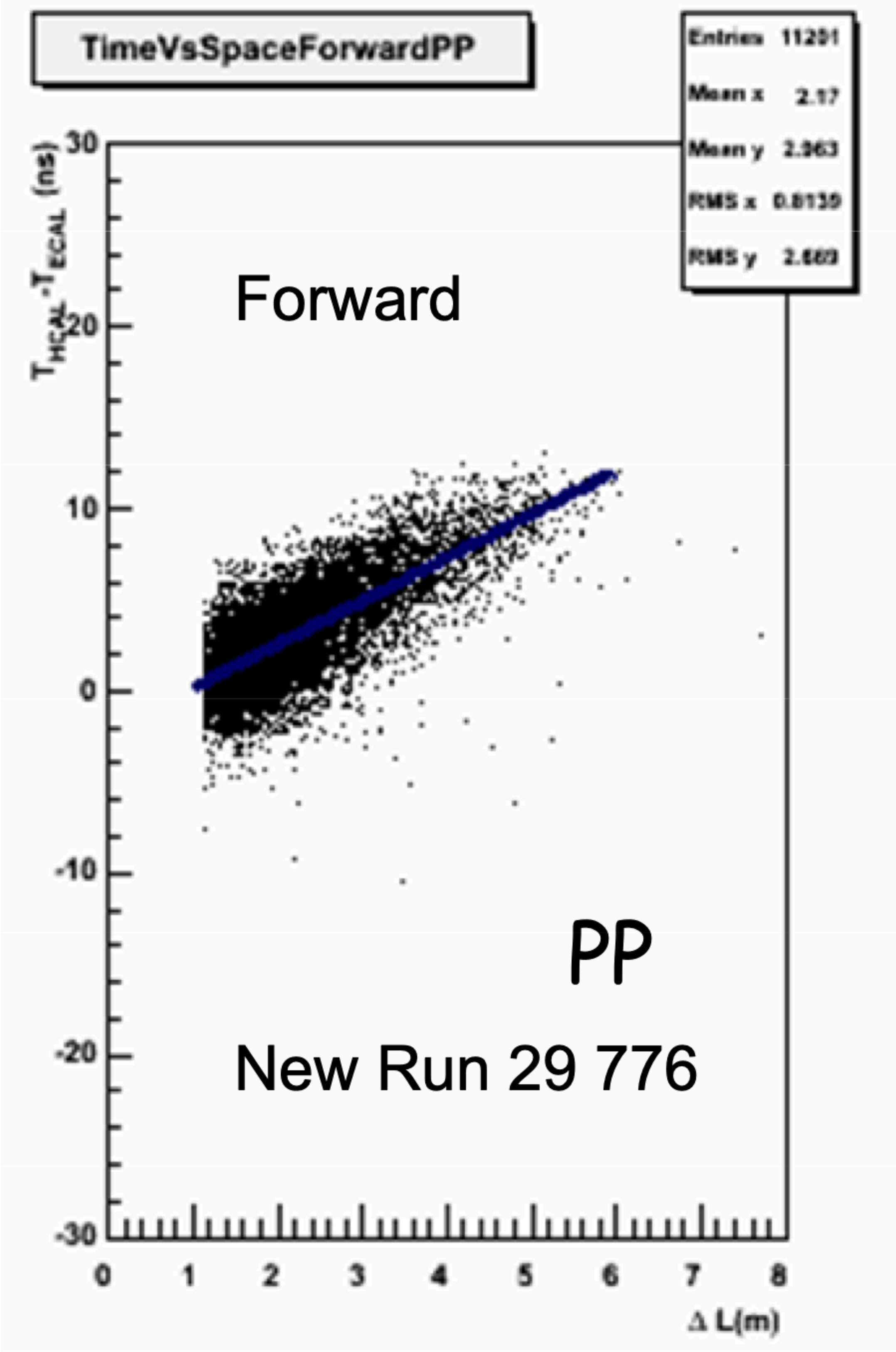
CDF Collaboration

We report the observation of Bs-Bs
sample of 1 fb^-1 of p-pbar collis
reconstructed hadronic Bs decays,
the probability as a function of pro
Bs-Bsbar oscillations. The probabil
measure
Delta ms = 17.77 +- 0.10 (stat) +
and extract
|Vtd/Vts| = 0.2060 +- 0.0007 (exp) + 0.0081 - 0.0060 (theor).

22 days after the start of my thesis

There is always hope for stubborn people

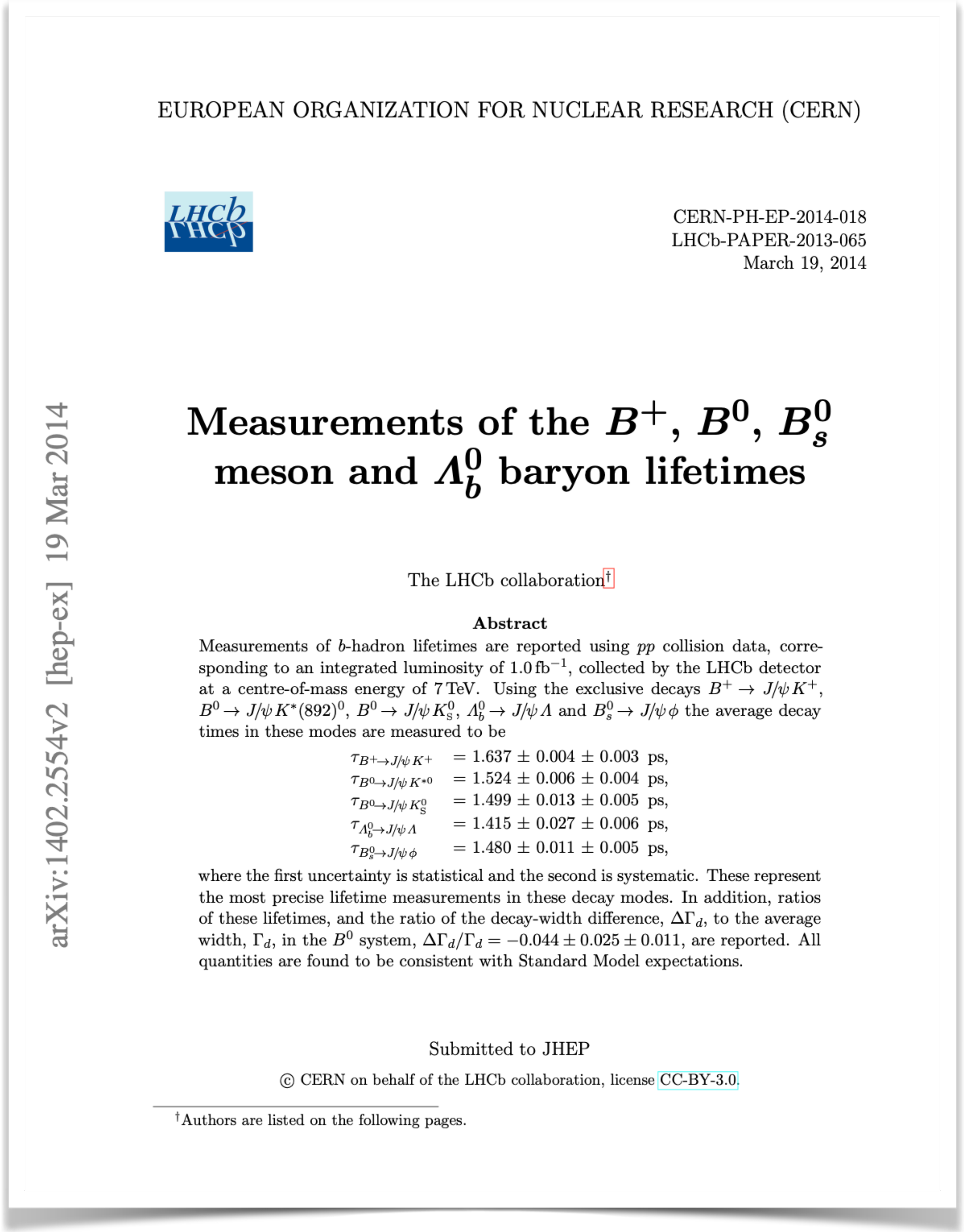
Saved by the skies & O. Deschamps



Cosmic data recorded in the ECAL
Time aligned the calorimeters 😎

With R. Lefèvre we did the Λ_b lifetime

First paper that satisfied (for a bit) my hunger for physics analyses



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2014-018
LHCb-PAPER-2013-065
March 19, 2014

arXiv:1402.2554v2 [hep-ex] 19 Mar 2014

Measurements of the B^+, B^0, B^0_s meson and Λ^0_b baryon lifetimes

The LHCb collaboration†

Abstract

Measurements of b-hadron lifetimes are reported using pp collision data, corresponding to an integrated luminosity of 1.0 fb^{-1}, collected by the LHCb detector at a centre-of-mass energy of 7 TeV. Using the exclusive decays $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^*(892)^0$, $B^0 \to J/\psi K^0_S$, $\Lambda^0_b \to J/\psi \Lambda$ and $B^0_s \to J/\psi \phi$ the average decay times in these modes are measured to be

$$\tau_{B^+\to J/\psi K^+} = 1.637 \pm 0.004 \pm 0.003 \text{ ps},$$
$$\tau_{B^0\to J/\psi K^{*0}} = 1.524 \pm 0.006 \pm 0.004 \text{ ps},$$
$$\tau_{B^0\to J/\psi K^0_S} = 1.499 \pm 0.013 \pm 0.005 \text{ ps},$$
$$\tau_{\Lambda^0_b\to J/\psi \Lambda} = 1.415 \pm 0.027 \pm 0.006 \text{ ps},$$
$$\tau_{B^0_s\to J/\psi \phi} = 1.480 \pm 0.011 \pm 0.005 \text{ ps},$$

where the first uncertainty is statistical and the second is systematic. These represent the most precise lifetime measurements in these decay modes. In addition, ratios of these lifetimes, and the ratio of the decay-width difference, $\Delta\Gamma_d$, to the average width, Γ_d, in the B^0 system, $\Delta\Gamma_d/\Gamma_d = -0.044 \pm 0.025 \pm 0.011$, are reported. All quantities are found to be consistent with Standard Model expectations.

Submitted to JHEP

© CERN on behalf of the LHCb collaboration, license CC-BY-3.0.

†Authors are listed on the following pages.

And it was received with huge enthusiasm by people like A. Lenz et al.

In 2008

B factories and Tevratron students

LHC students

These were dark days for us

Fast forward 15 years…

Monica Dunford

Yasmine Amhis

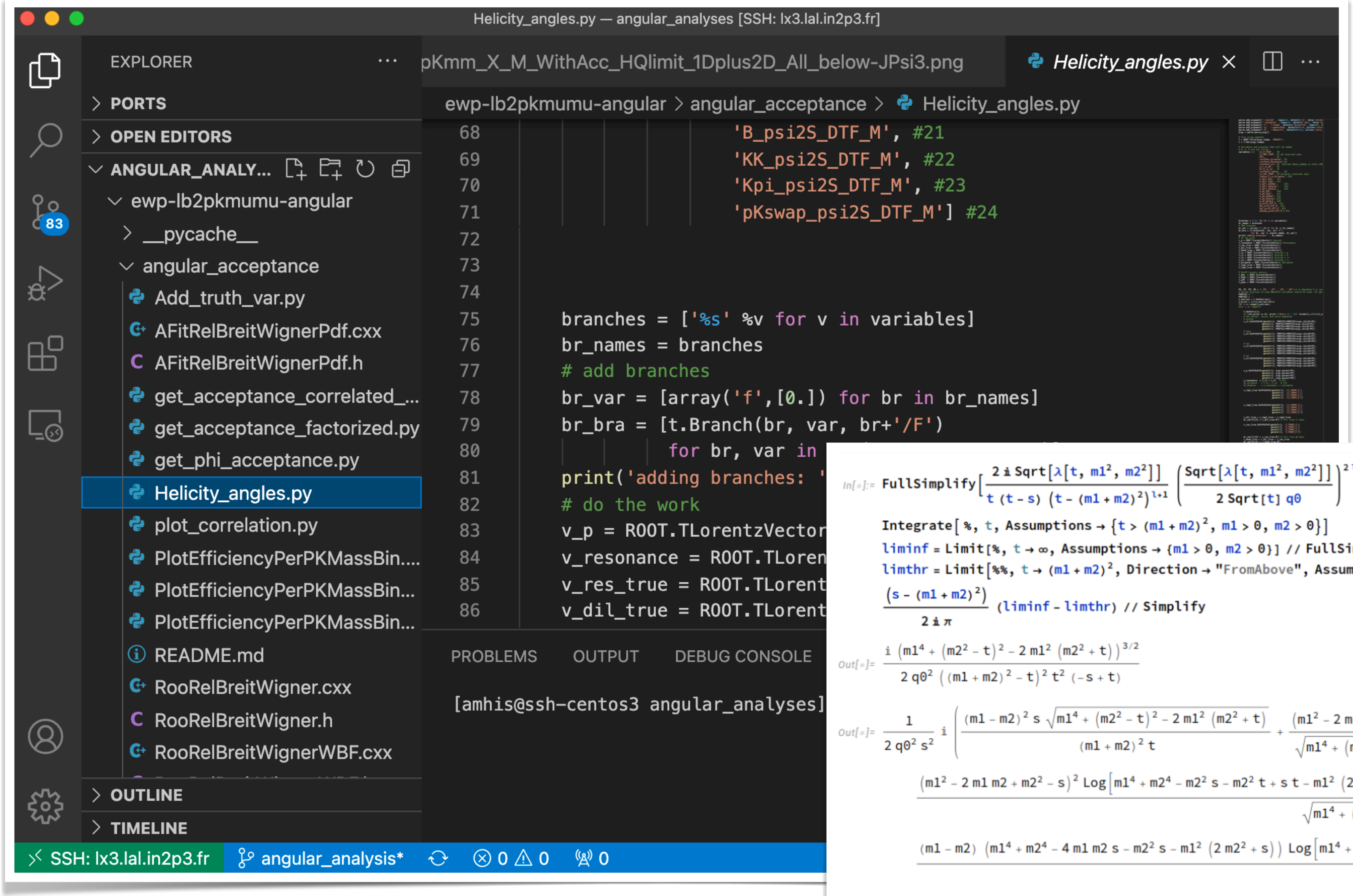
2008 kids having fun today

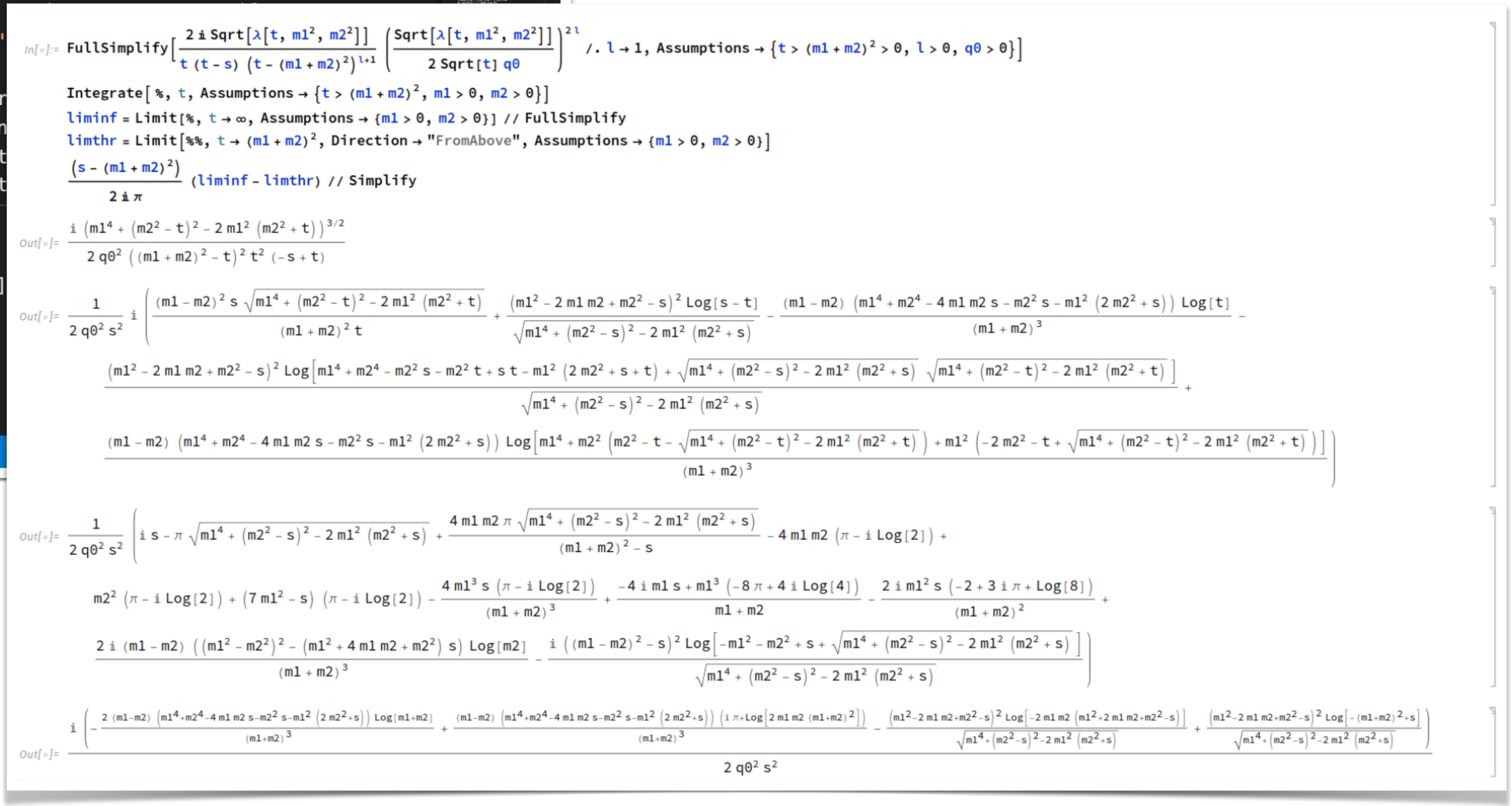
What are we doing here?

Understanding the origin of the universe

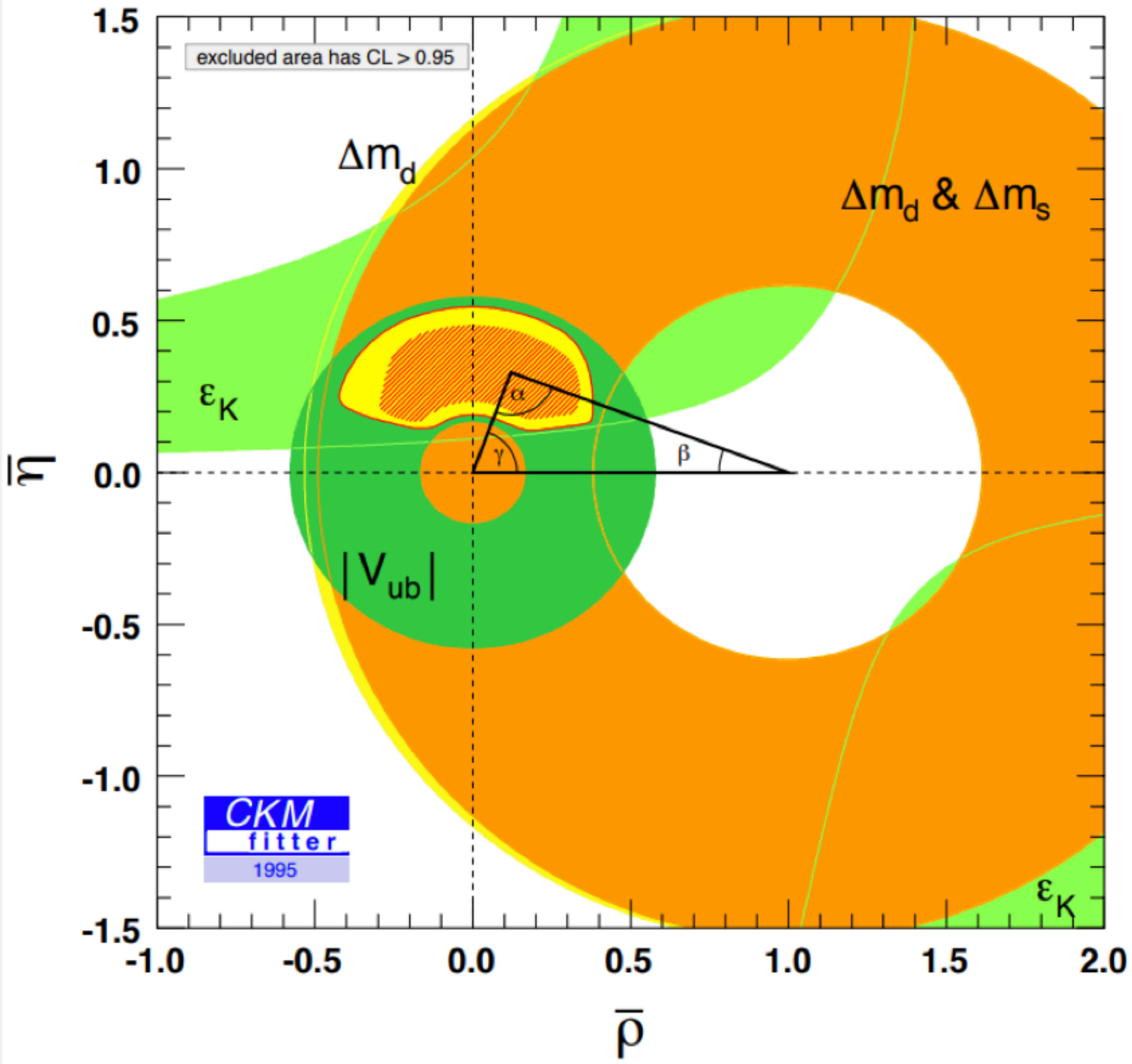
Searching for Physics Beyond the Standard Model

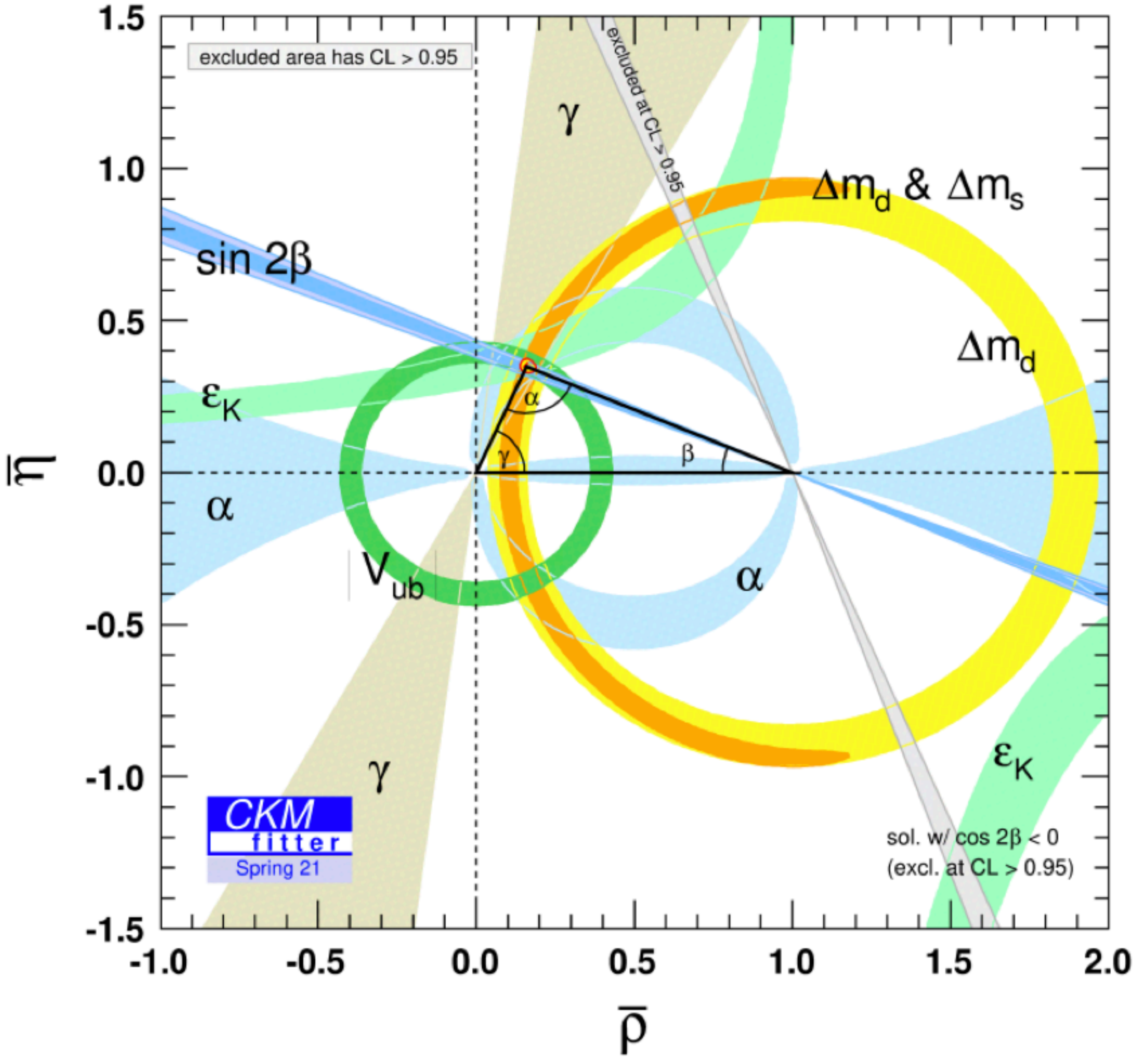
And how’s that working out for you?



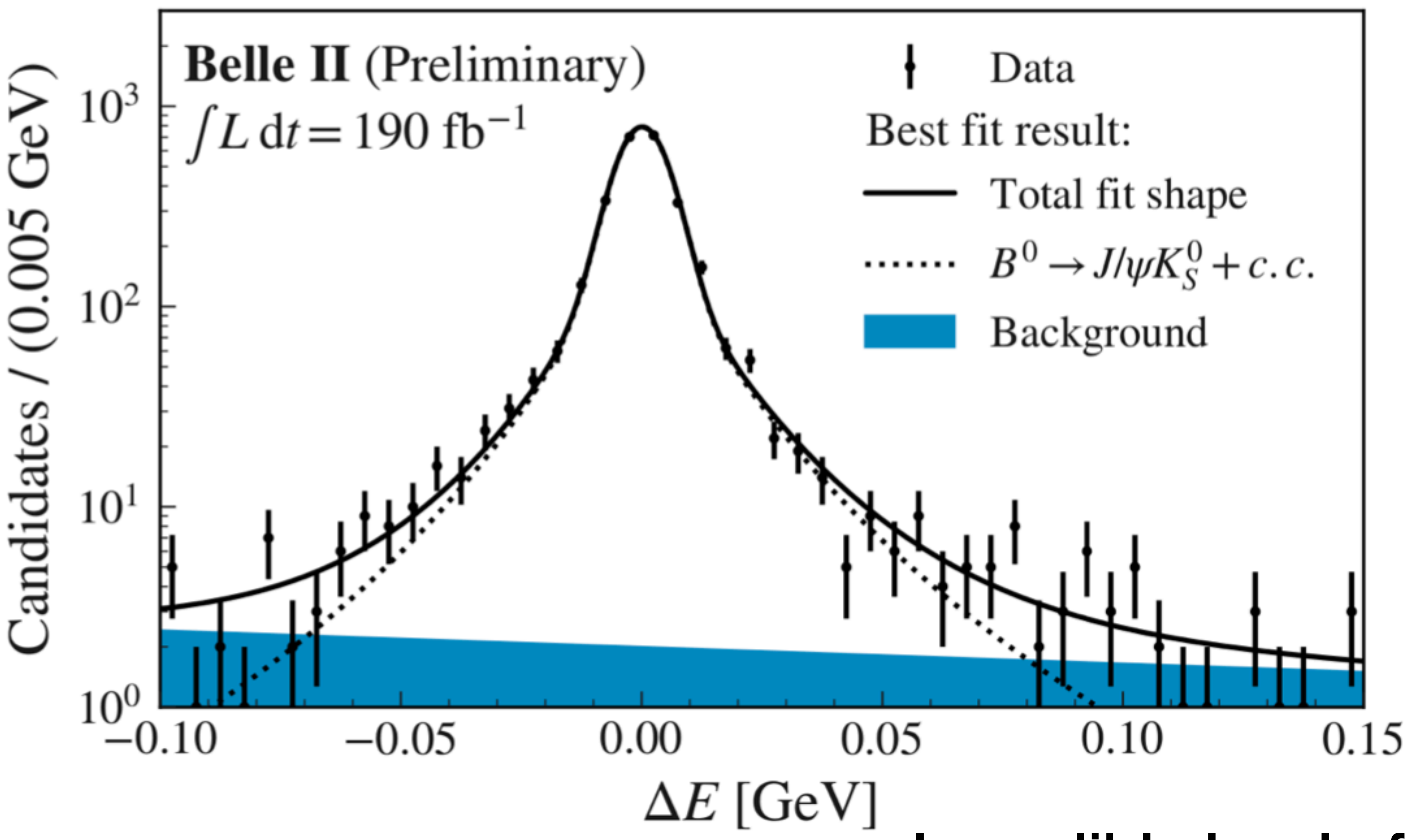


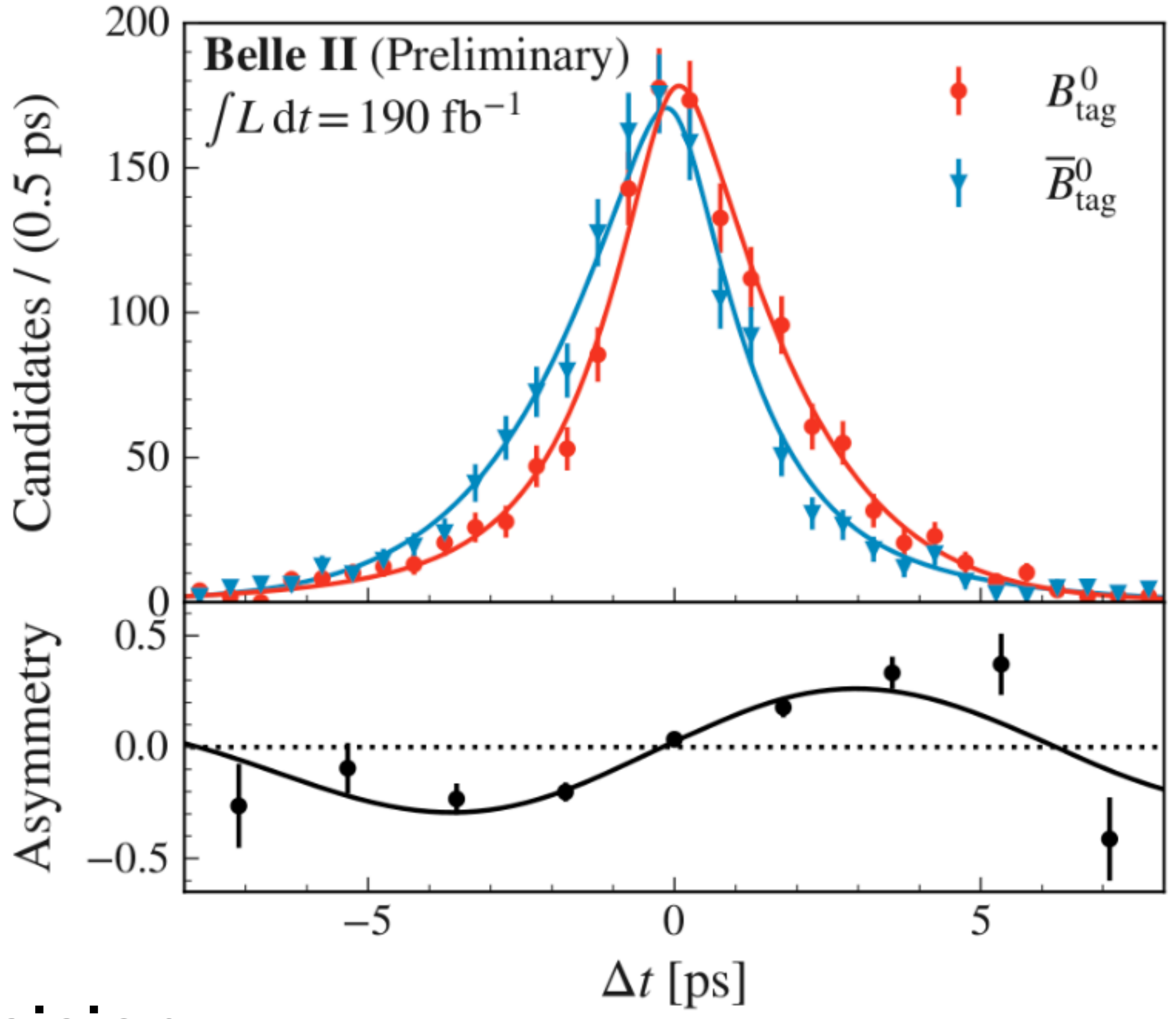
Most probably …


excluded area has CL > 0.95
Δm_d
Δm_d & Δm_s
ε_K
|V_ub|
α
β
γ
CKM fitter
1995

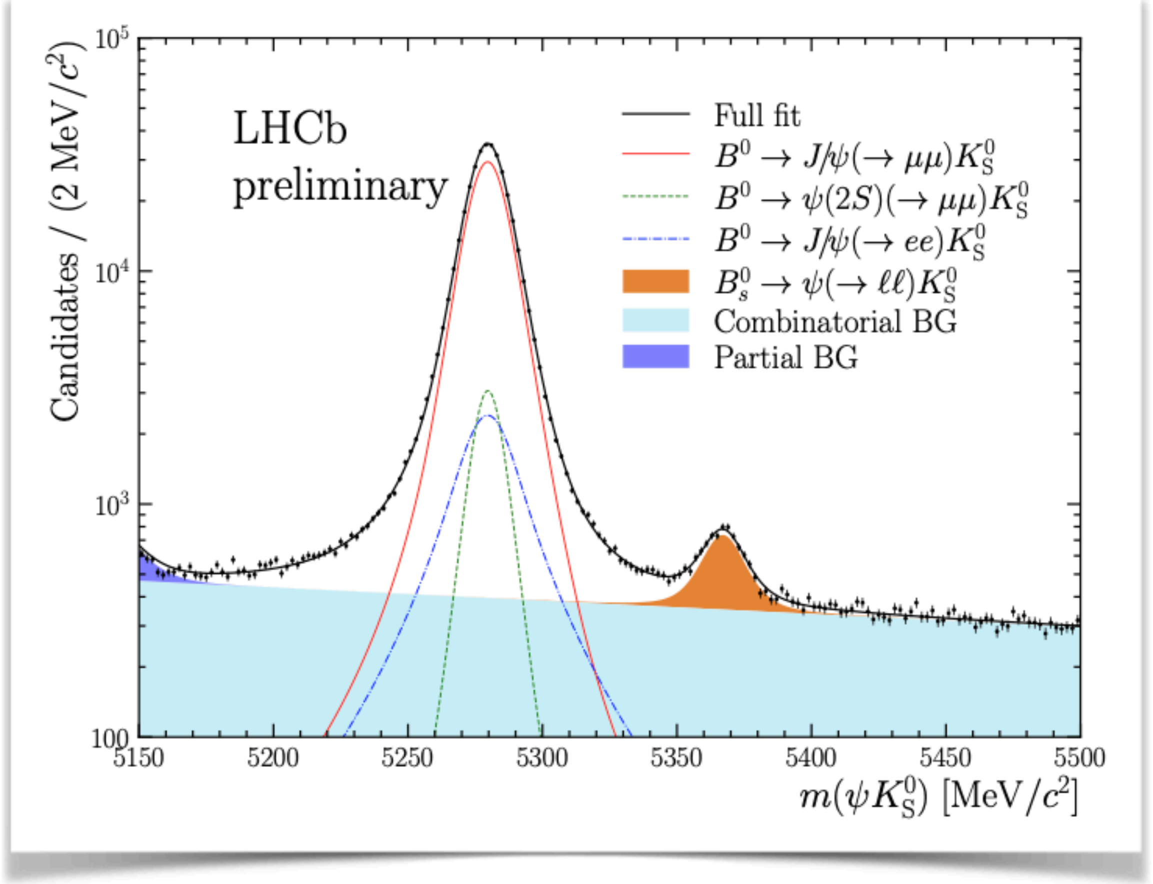

excluded area has CL > 0.95
excluded at CL > 0.95
γ
Δm_d & Δm_s
sin 2β
Δm_d
ε_K
α
V_ub
β
CKM fitter
Spring 21
sol. w/ cos 2β < 0
(excl. at CL > 0.95)

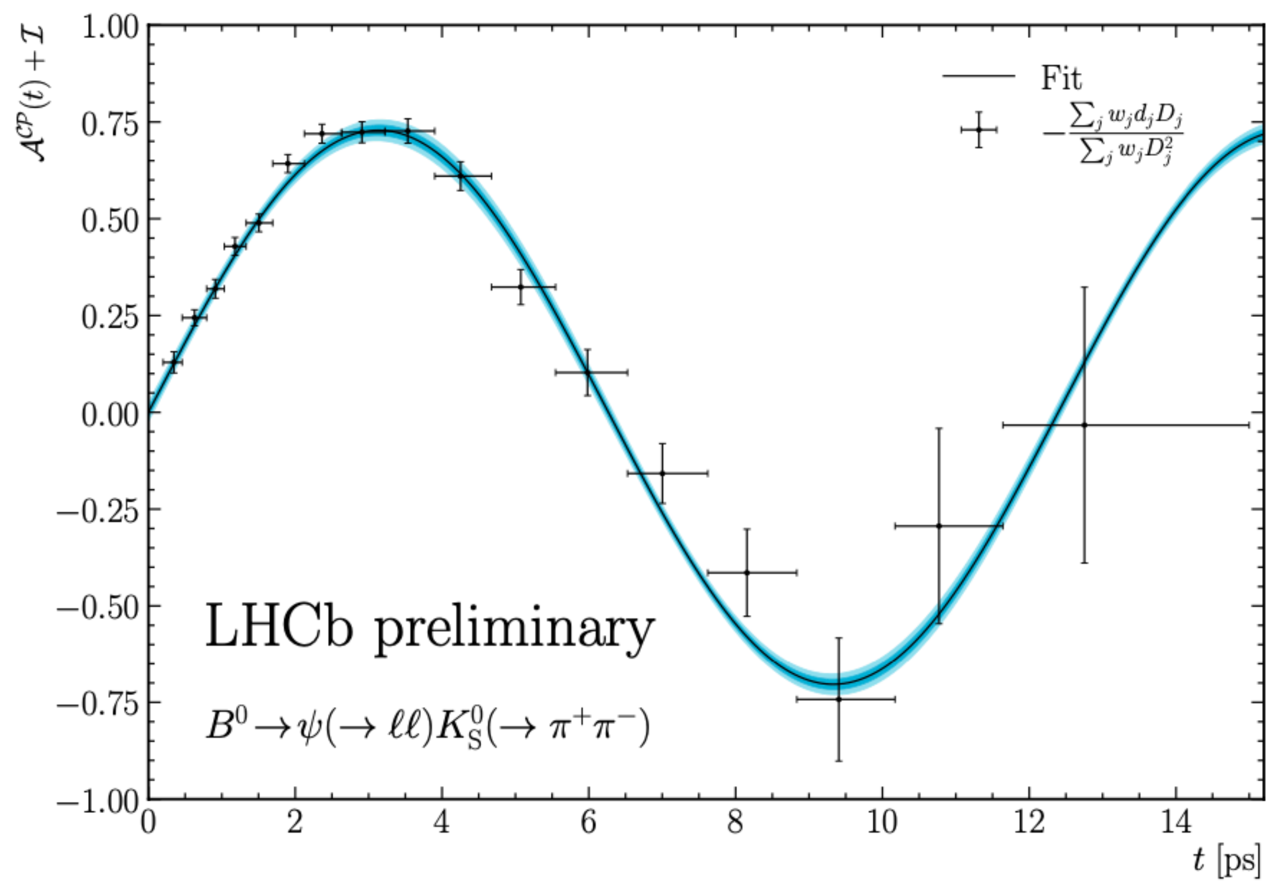
sin2β the first kid of the class





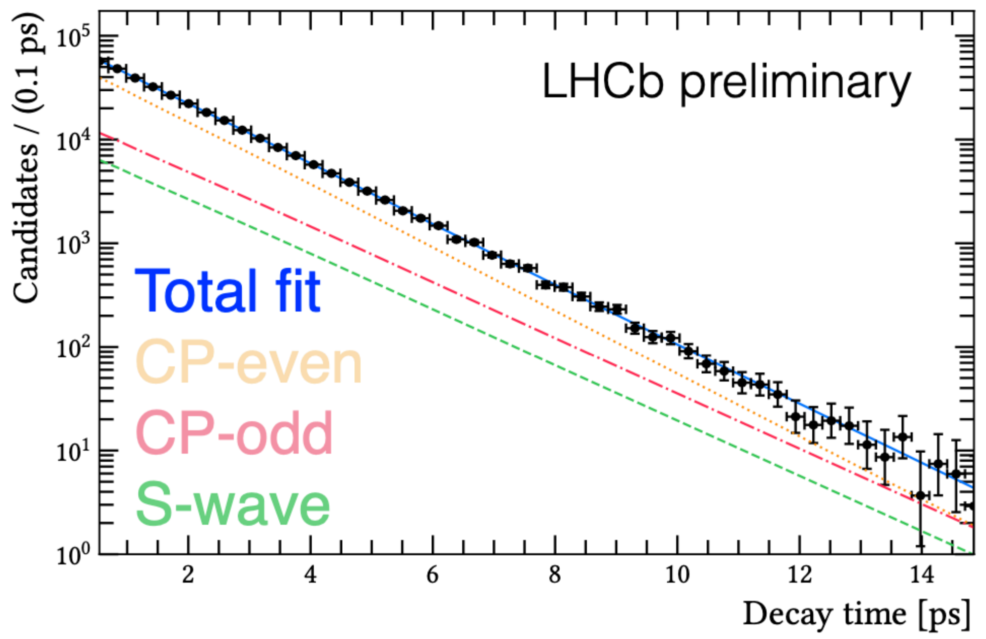
Incredible level of precision



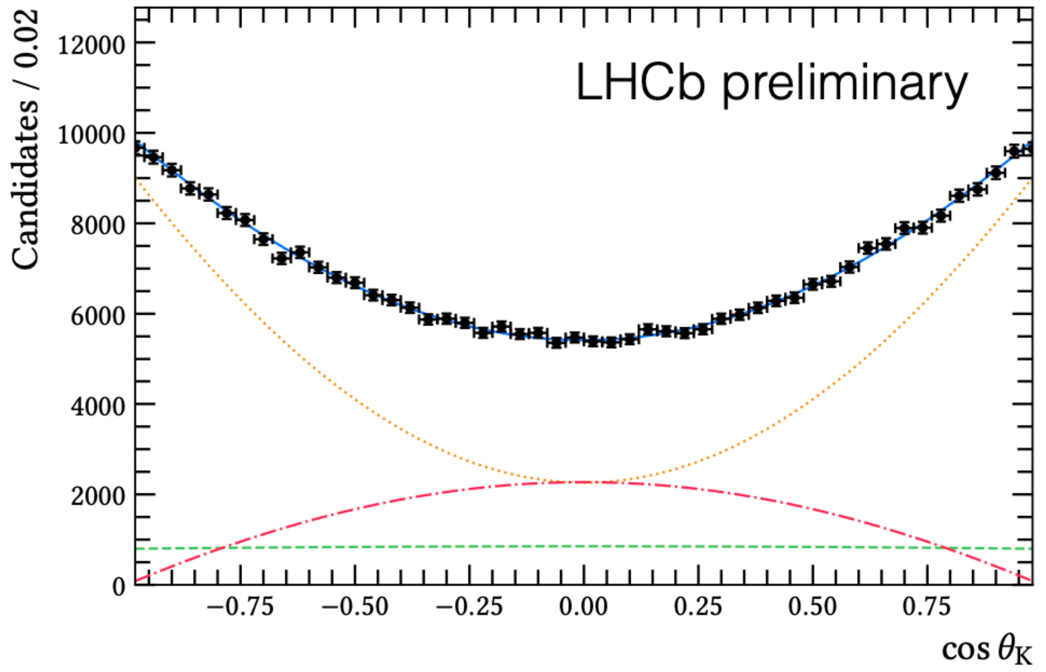


Is there still room for NP in this observable ?

ϕs



Time dependent…

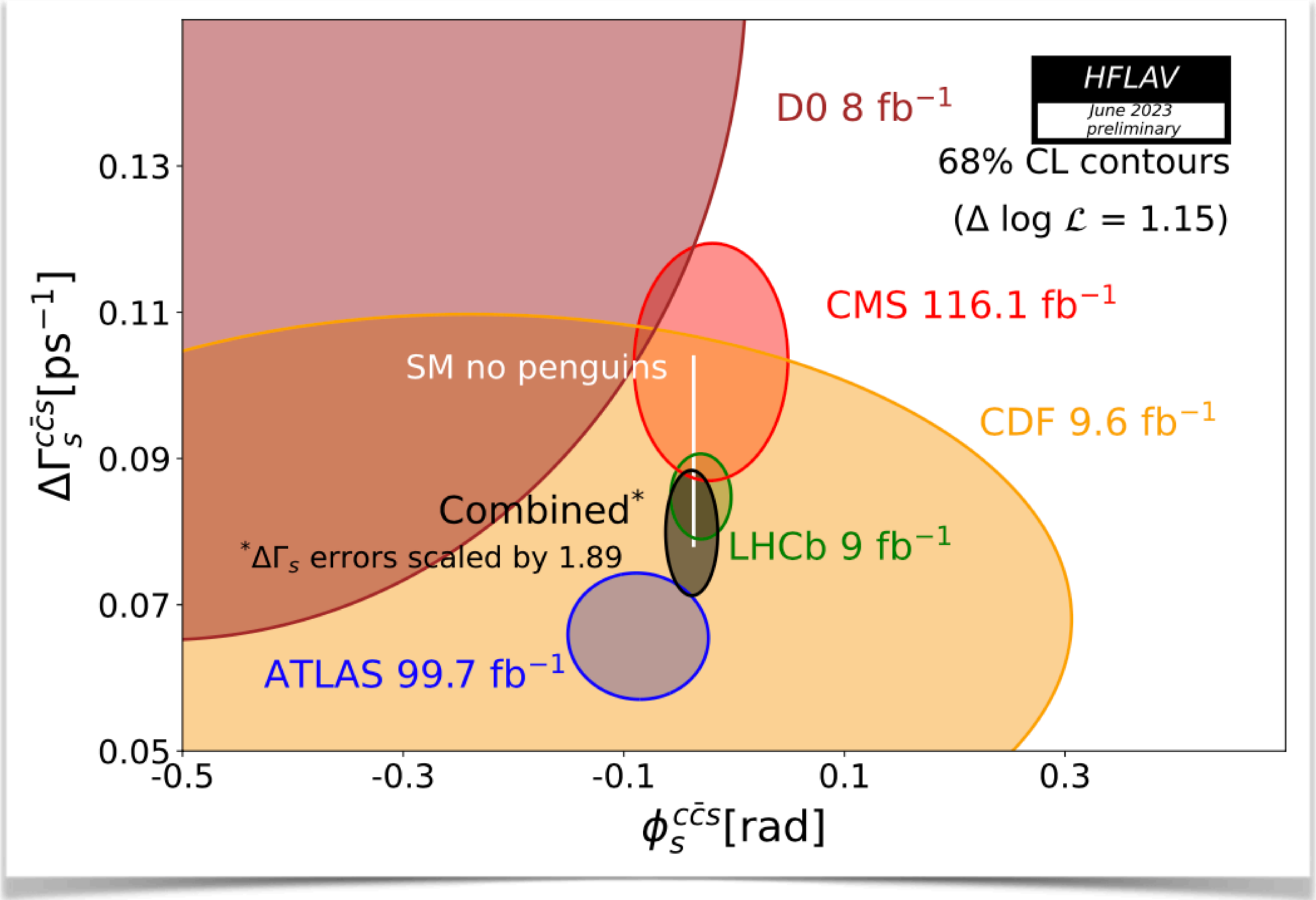


…angular analysis

Importance of Flavour Tagging
And having an excellent time resolution

The curse of precision

Parameters	Values [1]
ϕ_s [rad]	$-0.039 \pm 0.022 \pm 0.006$
$\lvert\lambda\rvert$	$1.001 \pm 0.011 \pm 0.005$
$\Gamma_s - \Gamma_d$ [ps^{-1}]	$-0.0057\,^{+0.0013}_{-0.0015} \pm 0.0014$
$\Delta\Gamma_s$ [ps^{-1}]	$0.0846 \pm 0.0044 \pm 0.0024$
Δm_s [ps^{-1}]	$17.743 \pm 0.033 \pm 0.009$
$\lvert A_\perp\rvert^2$	$0.2463 \pm 0.0023 \pm 0.0024$
$\lvert A_0\rvert^2$	$0.5179 \pm 0.0017 \pm 0.0032$
$\delta_\perp - \delta_0$ [rad]	$2.903\,^{+0.075}_{-0.074} \pm 0.048$
$\delta_\parallel - \delta_0$ [rad]	$3.146 \pm 0.060 \pm 0.052$



Looking forward to the updates from ATLAS/CMS

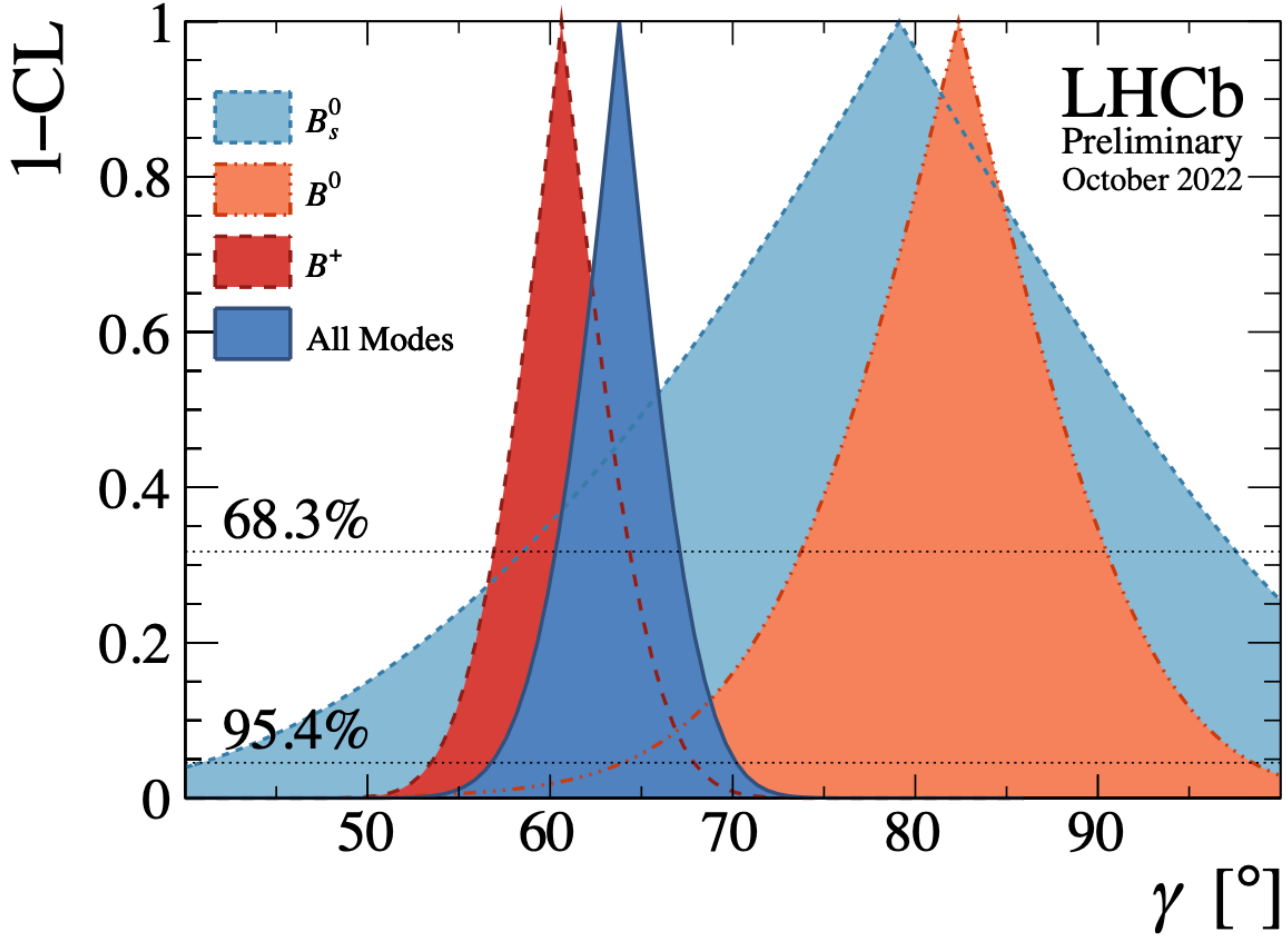
And here again the room for NP is shrinking quite dramatically…

sin 2β & ϕ_s

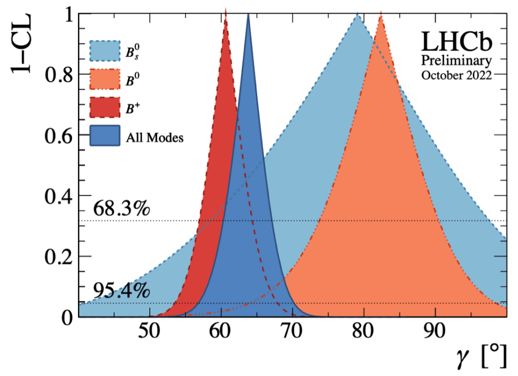
Typically dominated by
a few “Golden modes”

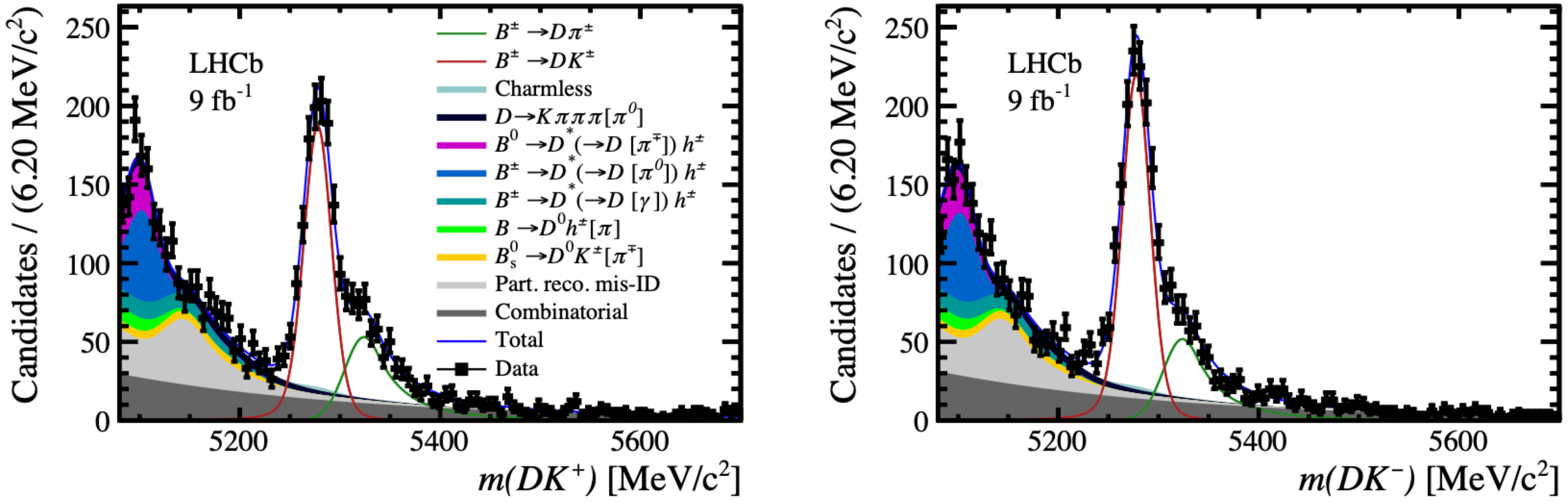
γ measurements have somewhat of a
“commune spirit ”

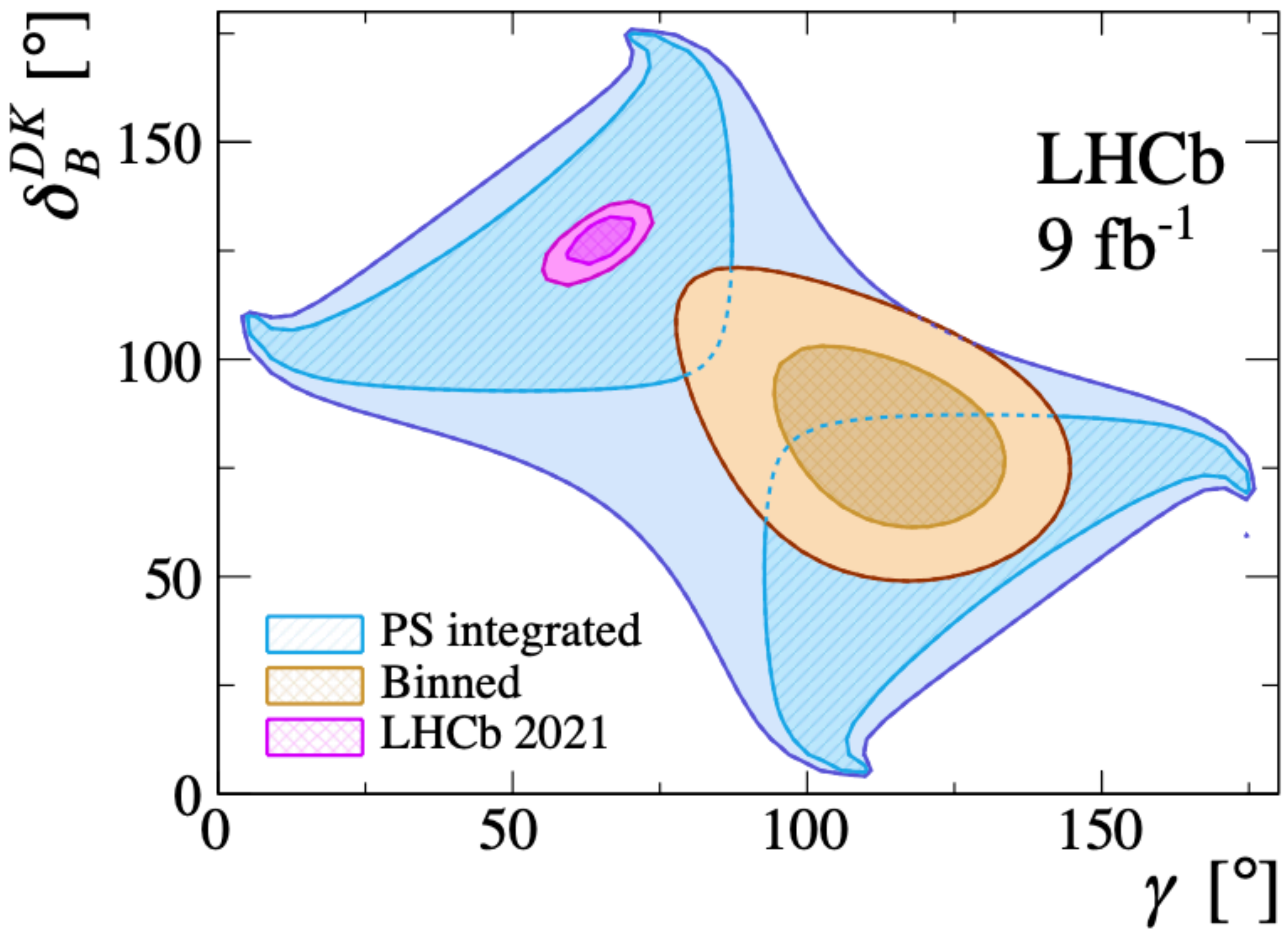
Do we have tensions in this picture?



LHCb-CONF-2022-003

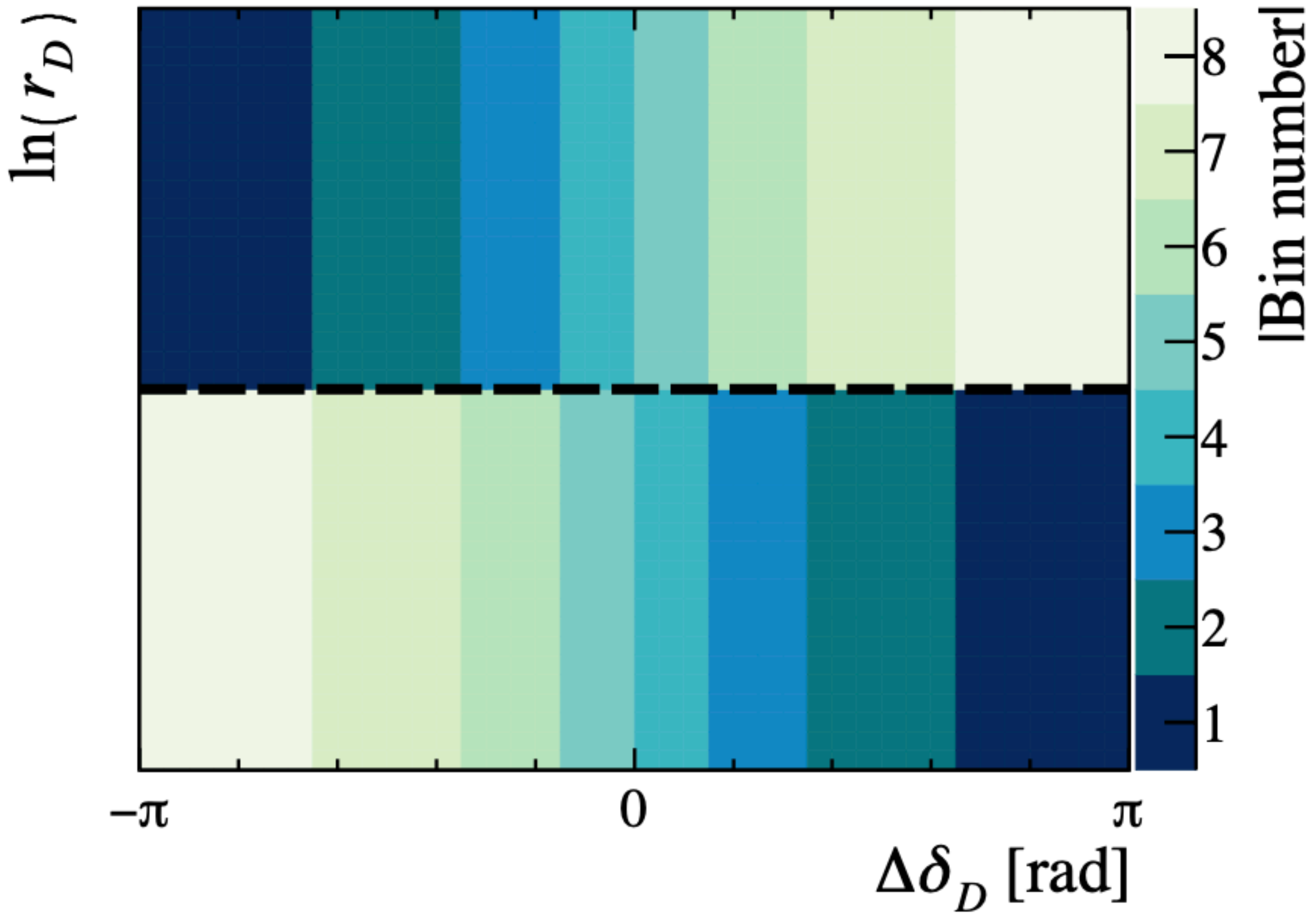






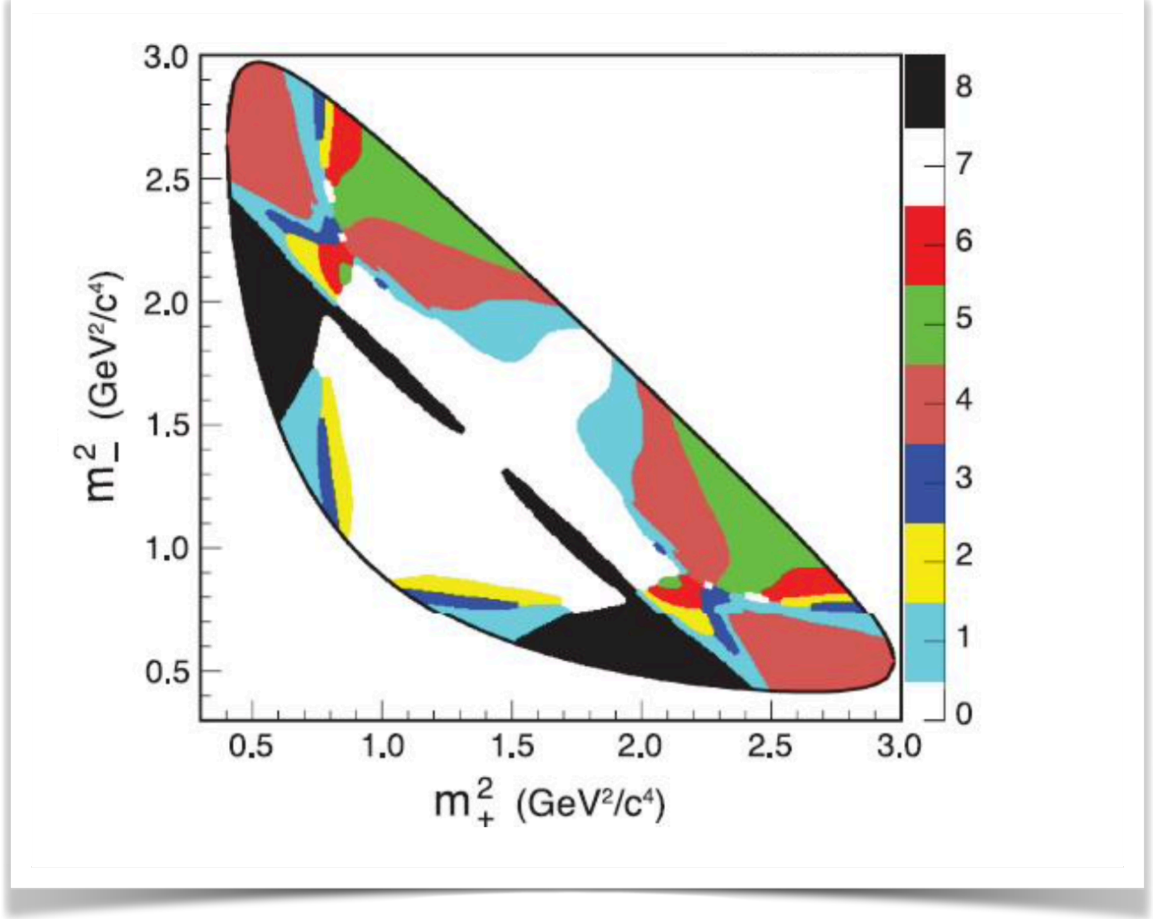
Interpretation

$$\gamma = (116^{+12}_{-14})^\circ$$



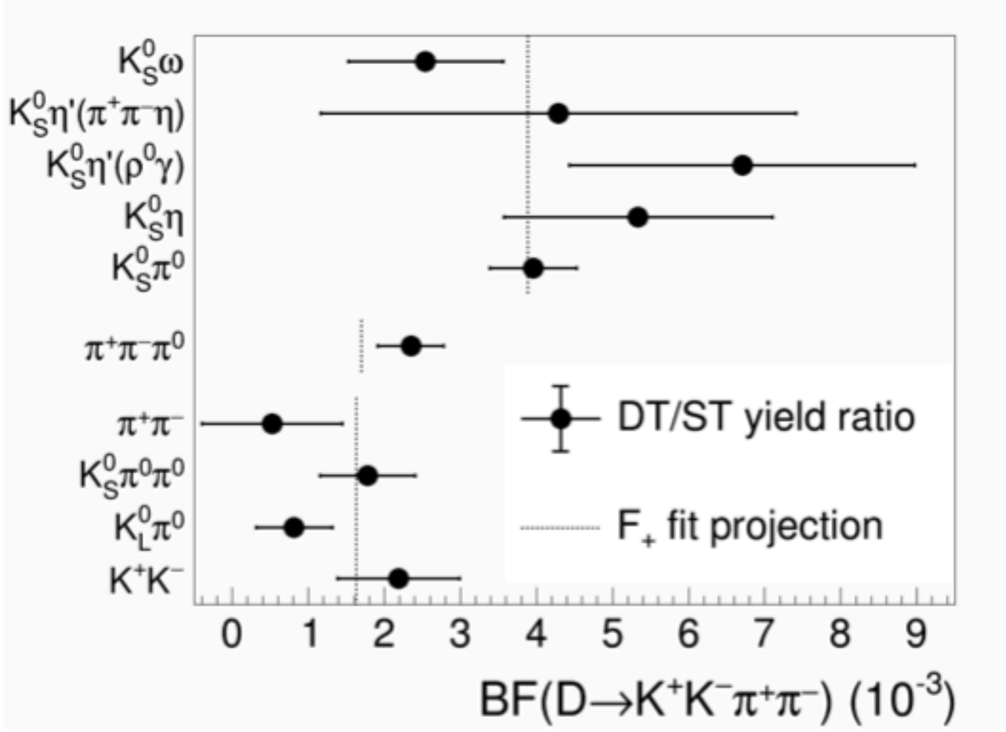
Input from BES III will be needed to understand the 4body amplitudes

Where butterflies come from

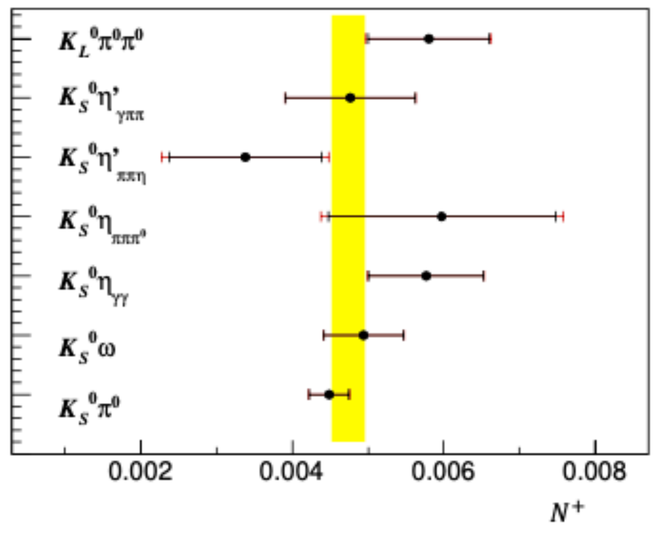


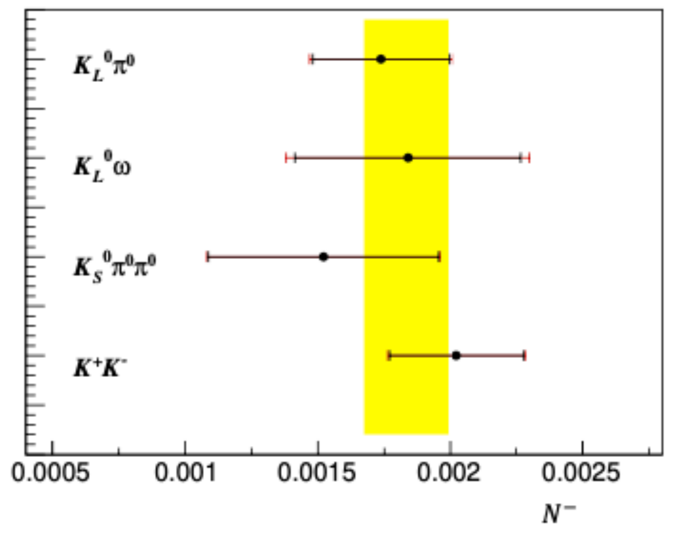
- CP-even fractions F^+ of $D^0 \to K^+K^-\pi^+\pi^-$, $D^0 \to \pi^+\pi^-\pi^+\pi^-$, and $D^0 \to K^0_S\pi^+\pi^-\pi^0$ recently measured

$K^+K^-\pi^+\pi^-$
PRD 107, 032009 (2023)

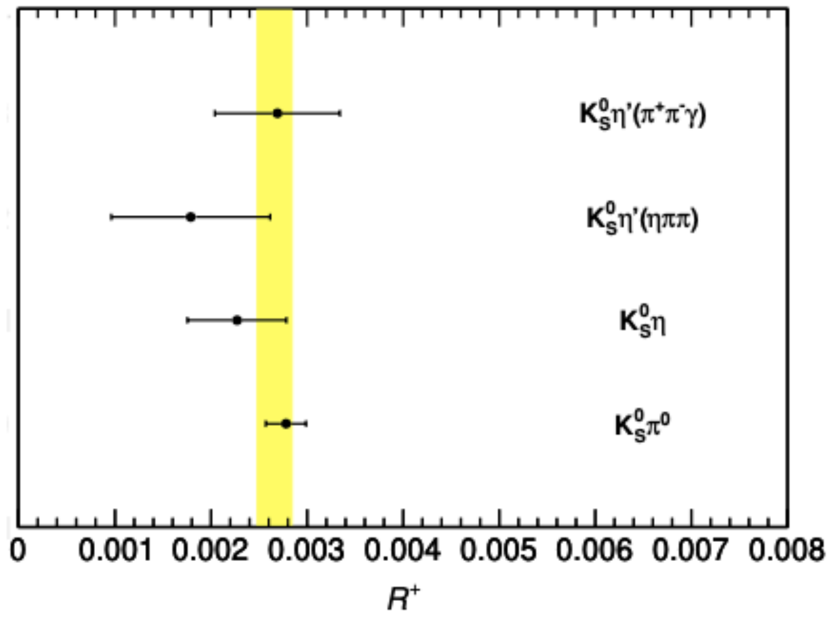


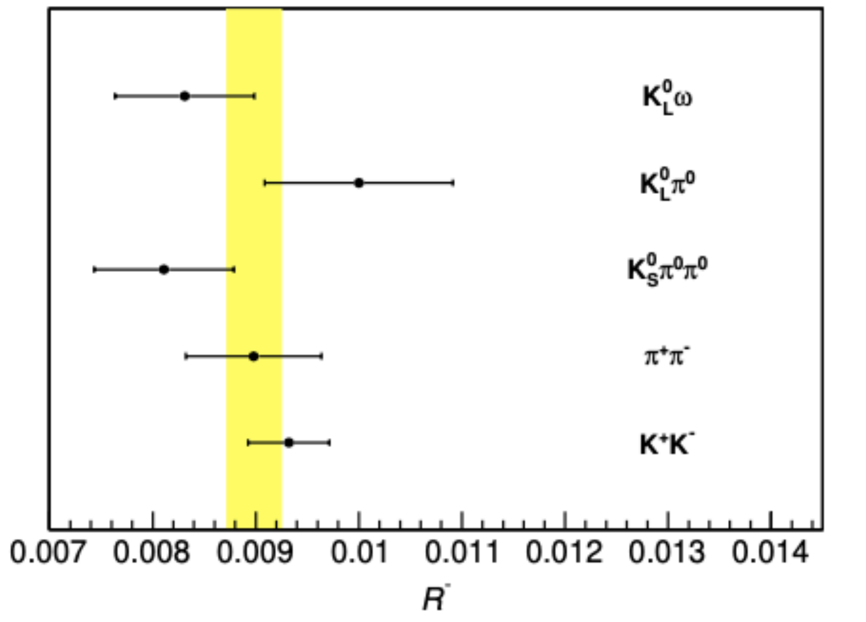
$\pi^+\pi^-\pi^+\pi^-$
PRD 106, 092004 (2022)



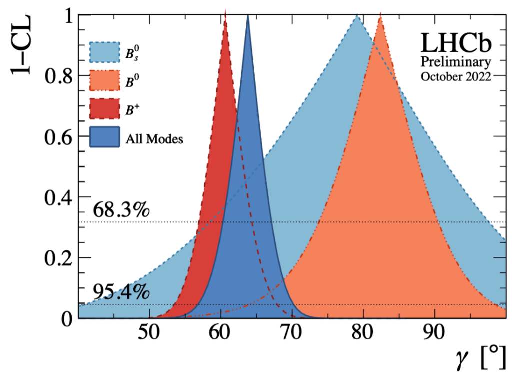


$K^0_S\pi^+\pi^-\pi^0$
arXiv:2305.03975



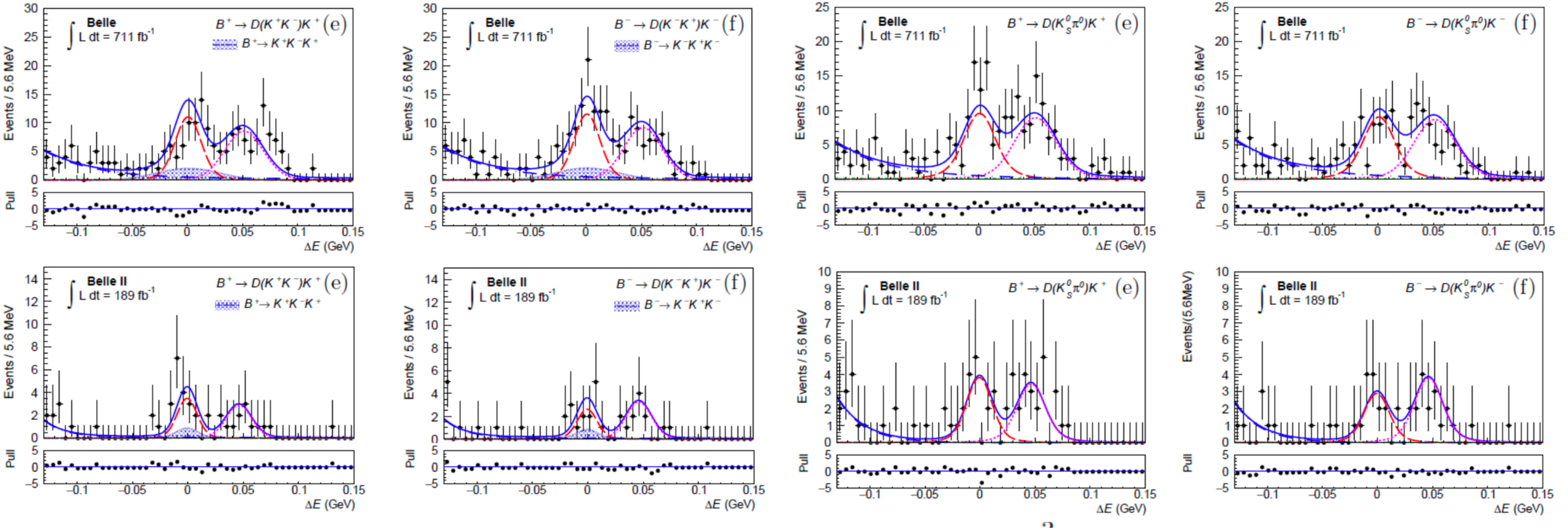


Importance of input from charm physics and complementary collaborations

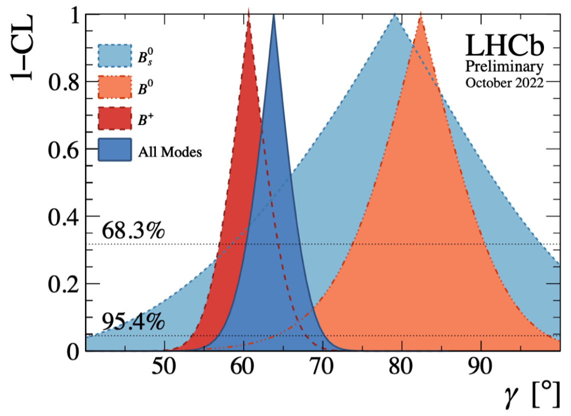


"What we do experimentally is just counting"

Fitting simultaneously the B→Dπ and DK samples, D→Kπ and… D→KK and $K^0_S\pi^0$



Having the abilities to run simultaneously on Belle and Belle 2 data is a very strong point !



Puzzle in CP Violation: $B_s^0 \to D_s^{\mp} K^{\pm}$ system

UT angle γ | Theoretically clean

tension with SM: 3σ level

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2017-315
LHCb-PAPER-2017-047
December 20, 2017

arXiv:1712.07428v3 [hep-ex] 20 Mar 2018

Measurement of CP asymmetry in $B_s^0 \to D_s^{\mp} K^{\pm}$ decays

LHCb collaboration†

Abstract

We report the measurements of the CP-violating parameters in $B_s^0 \to D_s^{\mp} K^{\pm}$ decays observed in pp collisions, using a data set corresponding to an integrated luminosity of $3.0\,\text{fb}^{-1}$ recorded with the LHCb detector. We measure $C_f = 0.73 \pm 0.14 \pm 0.05$, $A_f^{\Delta\Gamma} = 0.39 \pm 0.28 \pm 0.15$, $A_{\bar{f}}^{\Delta\Gamma} = 0.31 \pm 0.28 \pm 0.15$, $S_f = -0.52 \pm 0.20 \pm 0.07$, $S_{\bar{f}} = -0.49 \pm 0.20 \pm 0.07$, where the uncertainties are statistical and systematic, respectively. These parameters are used together with the world-average value of the B_s^0 mixing phase, $-2\beta_s$, to obtain a measurement of the CKM angle γ from $B_s^0 \to D_s^{\mp} K^{\pm}$ decays, yielding $\gamma = (128\,^{+17}_{-22})^\circ$ modulo 180°, where the uncertainty contains both statistical and systematic contributions. This corresponds to $3.8\,\sigma$ evidence for CP violation in the interference between decay and decay after mixing.

Published in JHEP 03 (2018) 059

†Authors are listed at the end of this paper.

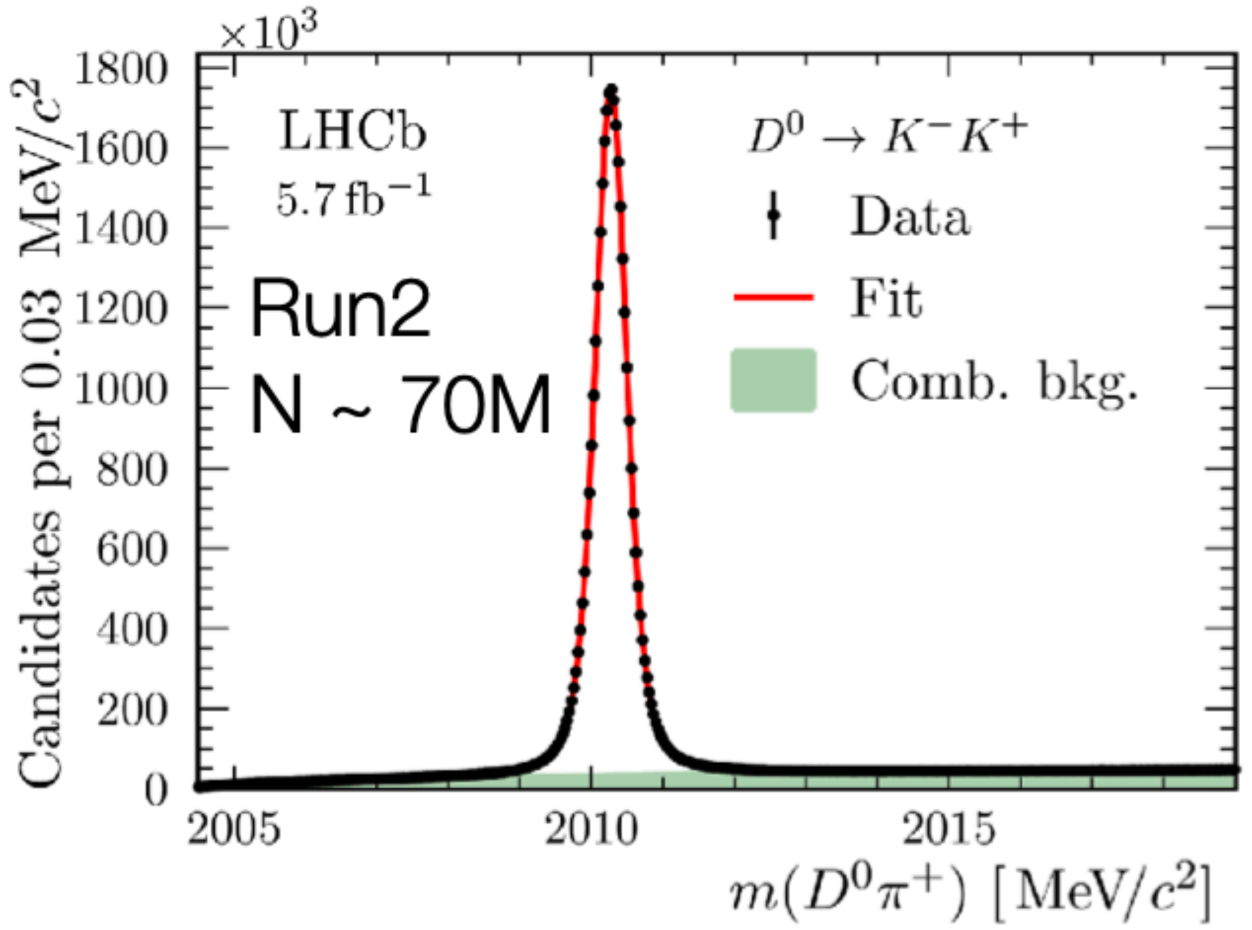
$$A^{\text{SM}}_{\bar{B}_s^0 \to D_s^+ K^-} = \frac{G_F}{\sqrt{2}} V_{us}^* V_{cb}\, f_K\, F_0^{B_s \to D_s}(m_K^2)\, (m_{B_s}^2 - m_{D_s}^2)\, a_{1\,\text{eff}}^{D_s K}$$

- decay constant (f_K)
- CKM matrix elements ($V_{us}^* V_{cb}$)
- form factor ($F_0^{B_s \to D_s}$)
- $a_{1\,\text{eff}}^{D_s K}$ → deviation from naive factorisation

Looking forward to the update of DsK

A work of art

ARXIV:2209.03179

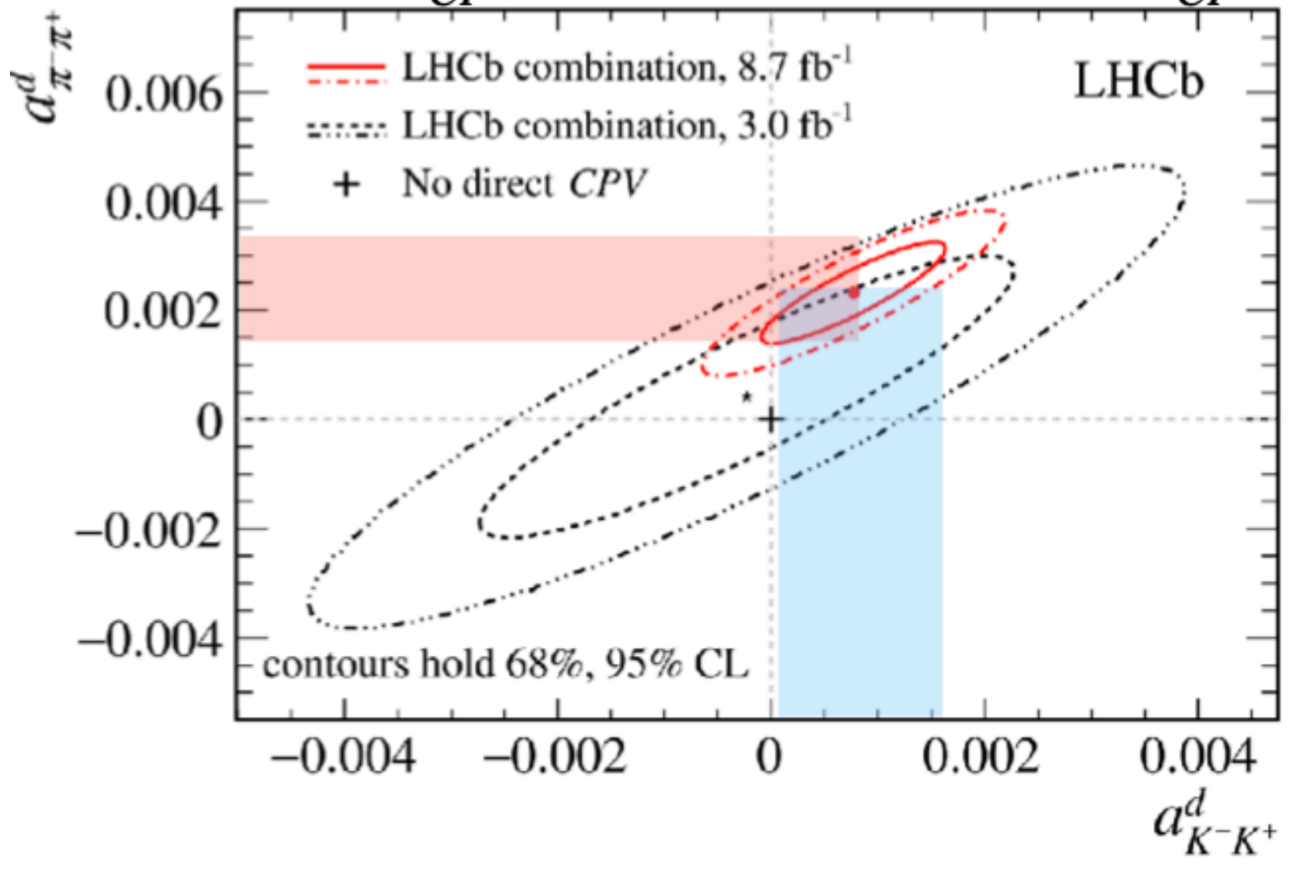


- Run 2 (5.6fb-1) data ~70M $D^0 \to K^+K^-$ candidates

> Combination of correction methods results (Run2 only):
>
> $A_{CP}(K^+K^-) = [6.8 \pm 5.4\text{(stat)} \pm 1.6\text{(sys)})] \times 10^{-4}$

- Combination with previous measurements

$A_{CP}(\pi^+\pi^-) = A(K^+K^-) - \Delta A_{CP}$



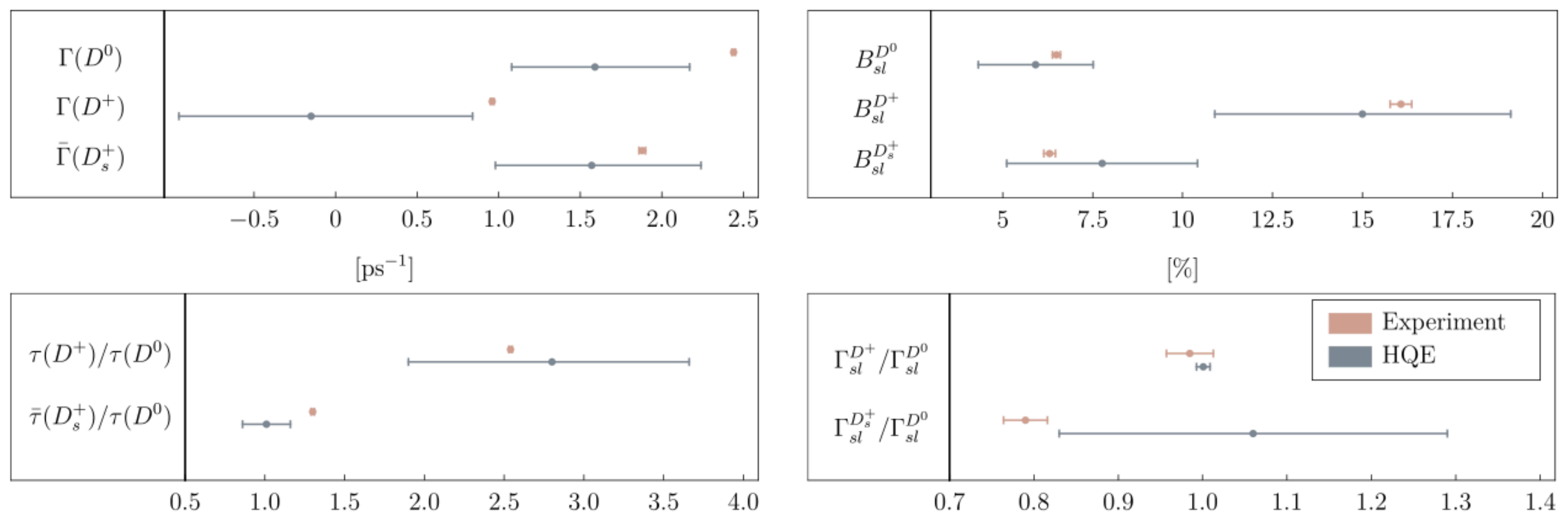
> PRL 122 (2019) 211803
>
> Run1+Run2 + combination with ΔA_{CP}
>
> $a^d_{CP}(K^+K^-) = [7.7 \pm 5.7] \times 10^{-4}$
>
> $a^d_{CP}(\pi^+\pi^-) = [23.2 \pm 6.1] \times 10^{-4}$
>
> $\rho(a^d_{KK}, a^d_{\pi\pi}) = 88\ \%$

First evidence (3.8σ) of CPV in $D^0 \to \pi^+\pi^-$!
We need to understand better!

Importance of Control modes calibration samples Closures tests.

Charm is a tricky beast

HQE worked very well for B-systems



[King, Lenz, MLP, Rauh, Rusov, Vlahos '21]

- HQE can accomodate observed pattern in D-system
- Uncertainties still very large

Mainly due to charm mass and non-perturbative inputs

I promised no jokes about penguins

Direct CP violation

- The direct CP asymmetry becomes

$$a_{CP}^{\text{dir.}}(\pi^-\pi^+) \equiv \frac{\Gamma(\bar{D}^0 \to \pi^+\pi^-) - \Gamma(D^0 \to \pi^-\pi^+)}{\Gamma(\bar{D}^0 \to \pi^+\pi^-) + \Gamma(D^0 \to \pi^-\pi^+)} \approx \underbrace{-13 \times 10^{-4}}_{-2|\lambda_b/\lambda_d|\sin\gamma} \left|\frac{P}{T}\right| \sin\phi$$

  - ∗ Sensitive to difference of weak and strong phases γ, ϕ, and to $|P/T|$

- Similarly for $a_{CP}^{\text{dir.}}(K^-K^+)$, but with opposite sign due to $\lambda_s \approx -\lambda_d$

$$\Delta a_{CP}^{\text{dir.}} \approx 13 \times 10^{-4} \left(\left|\frac{P}{T}\right|_{K^-K^+} \sin\phi_{K^-K^+} + \left|\frac{P}{T}\right|_{\pi^-\pi^+} \sin\phi_{\pi^-\pi^+} \right)$$

- From naive estimates $|P/T| \sim 0.1$

$$|\Delta a_{CP}^{\text{dir.}}| \lesssim 2.6 \times 10^{-4}$$

No theory consensus yet

- Determinations within LCSRs confirm naive expectations [Khodjamirian, Petrov '17]
  - ∗ Triggered NP interpretations e.g. [Chala, Lenz, Rusov, Scholtz '19; Dery, Nir '19; Bause, Gisbert, Golz, Hiller '20]
- Potential explanations of ΔA_{CP} within the SM
  - ∗ Using U-spin relations and SU$(3)_F$ symmetry e.g. [Grossman, Schacht '19]

    However, opposite sign for CP asymmetries, "U-spin anomaly"

    e.g. [Bause, Gisbert, Hiller et al. '22; Schacht '23], see also talk by T. Höhne
  - ∗ From analyses of topological amplitudes, or final state interactions e.g. [Li, Lü, Yu '19; Cheng, Chiang '19; Bediaga, Frederico, Megahlães '22]
- Recent study of rescattering effects using dispersive methods
  - ∗ Predictions of CP violation still below the experimental v

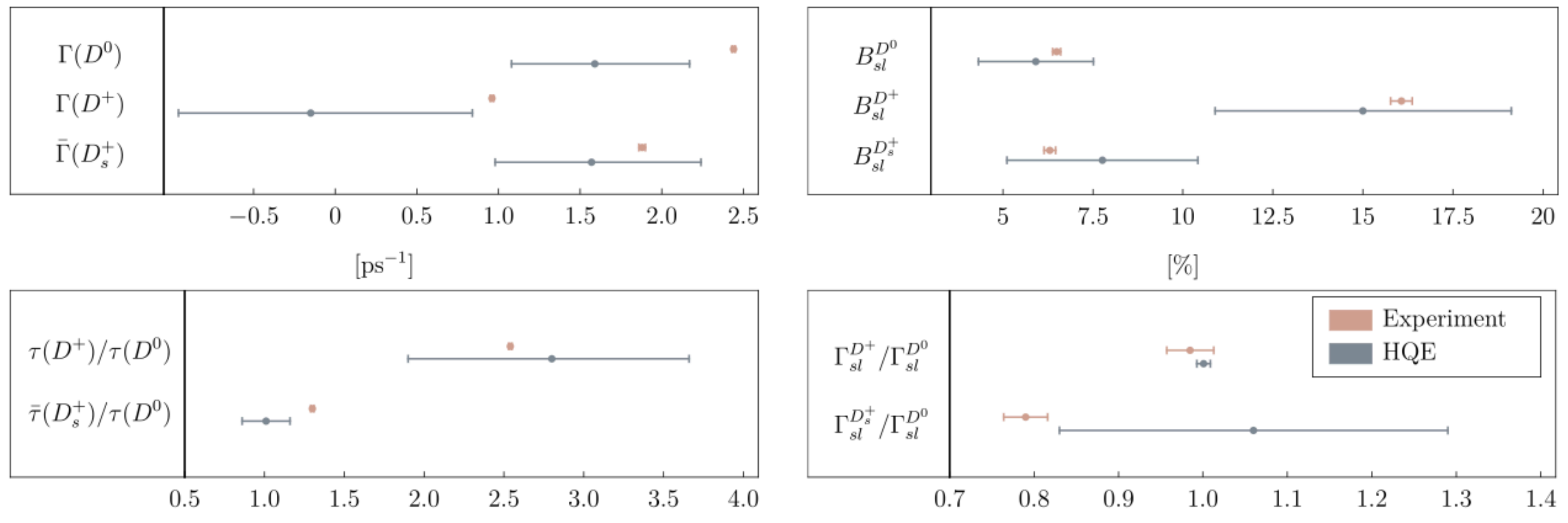
    [Pich, Solomonidi, V

Benchmark ingredients:

- generate RH ucZ'-vertex $\Rightarrow \Delta\widetilde{F}_R = \sin\theta_u(F_{u_2} - F_{u_1}) \neq 0$
- Hierarchy $a^{d,\text{exp}}_{\pi^+\pi^-} \gg a^{d,\text{exp}}_{K^+K^-}$ $\Rightarrow |F_{d_1}| \gg |F_{d_2}|$
- Avoid Kaon FCNCs $\Rightarrow F_{Q_{1,2}} = 0$
- Avoid dark photon bounds $Z' \to \ell^+\ell^-$ [LHCb'19] $\Rightarrow F_{L_{1,2},e_{1,2}} \lesssim 10^{-3} F_{d_1}$
- Anomaly cancellation $\Rightarrow$add ν_R

A nice example where we see how all the theoretical and experimental ingredients come at play

Charm is a tricky beast



[King, Lenz, MLP, Rauh, Rusov, Vlahos '21]

- HQE can accomodate observed pattern in D-system
- Uncertainties still very large

Mainly due to charm mass and non-perturbative inputs

Direct CP violation

- The direct CP asymmetry becomes

$$a_{CP}^{\mathrm{dir.}}(\pi^-\pi^+) \equiv \frac{\Gamma(\bar{D}^0 \to \pi^+\pi^-) - \Gamma(D^0 \to \pi^-\pi^+)}{\Gamma(\bar{D}^0 \to \pi^+\pi^-) + \Gamma(D^0 \to \pi^-\pi^+)} \approx \underbrace{-13 \times 10^{-4}}_{-2|\lambda_b/\lambda_d|\sin\gamma} \left|\frac{P}{T}\right| \sin\phi$$

  - Sensitive to difference of weak and strong phases γ, ϕ, and to $|P/T|$

- Similarly for $a_{CP}^{\mathrm{dir.}}(K^-K^+)$, but with opposite sign due to $\lambda_s \approx -\lambda_d$

$$\Delta a_{CP}^{\mathrm{dir.}} \approx 13 \times 10^{-4} \left(\left|\frac{P}{T}\right|_{K^-K^+} \sin\phi_{K^-K^+} + \left|\frac{P}{T}\right|_{\pi^-\pi^+} \sin\phi_{\pi^-\pi^+} \right)$$

- From naive estimates $|P/T| \sim 0.1$

$$|\Delta a_{CP}^{\mathrm{dir.}}| \lesssim 2.6 \times 10^{-4}$$

No theory consensus yet

- Determinations within LCSRs confirm naive expectations

[Khodjamirian, Petrov '17]

  - Triggered NP interpretations

'20]

'19]

öhne

ons

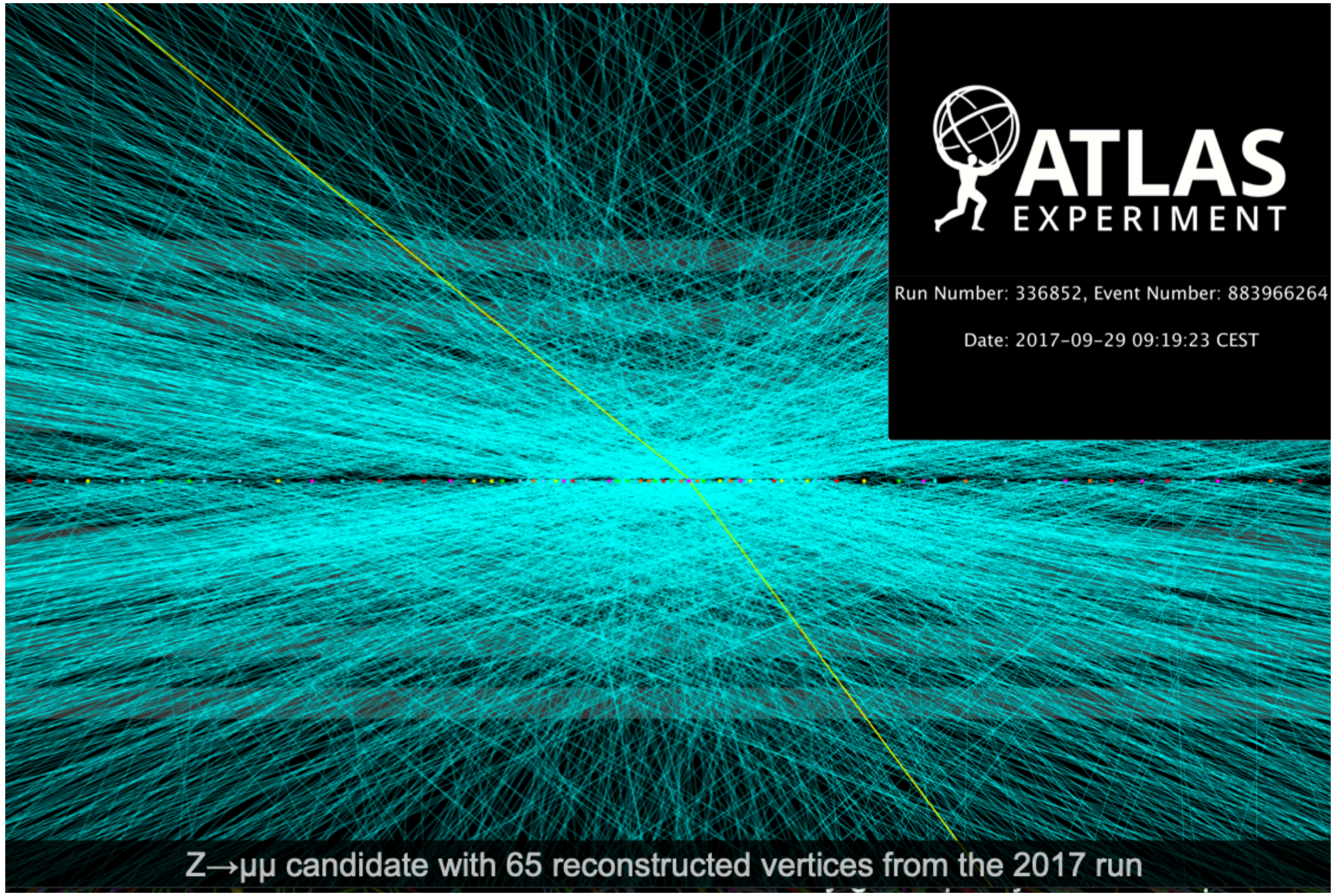
'22]

"I like these papers because they are very honest about what they can and can not do"

  - Predictions of CP violation still below the experimental values

[Pich, Solomonidi, Vale Silva '23]

Kudos to ATLAS/CMS

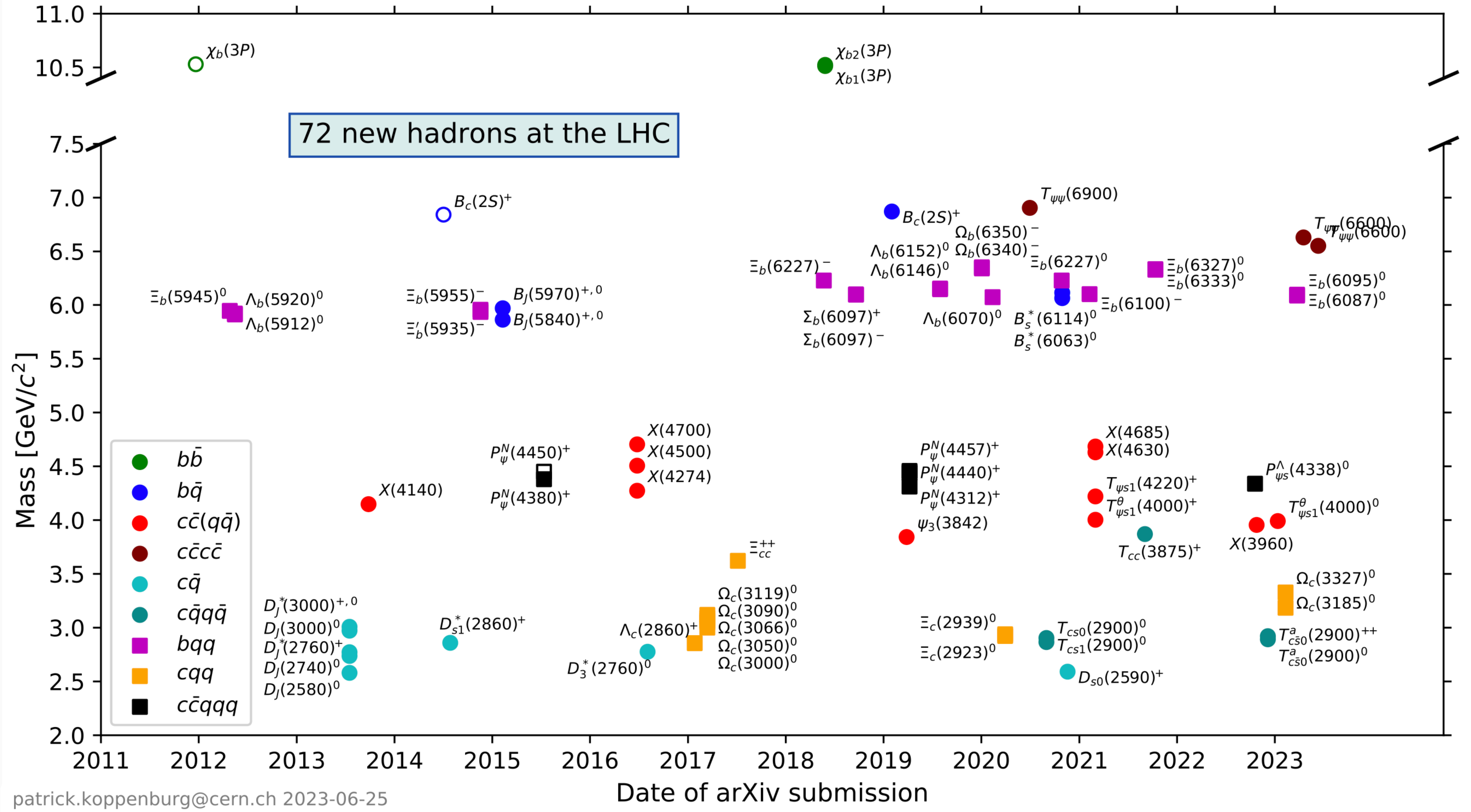


For working in these high-pile environment

Did you discover new particles at the LHC?

Announcement of the discovery of the Higgs boson in July 2012

Valiant contribution by 72 hadrons + all the one seen at Belle 2 and BES III



Some are “classical” some are “exotic” hadrons.
Often their nature is still under heavy discussion.
The knowledge of the mass, width and quantum numbers can only help shed the light.

The strength of flavour physics and indirect searches

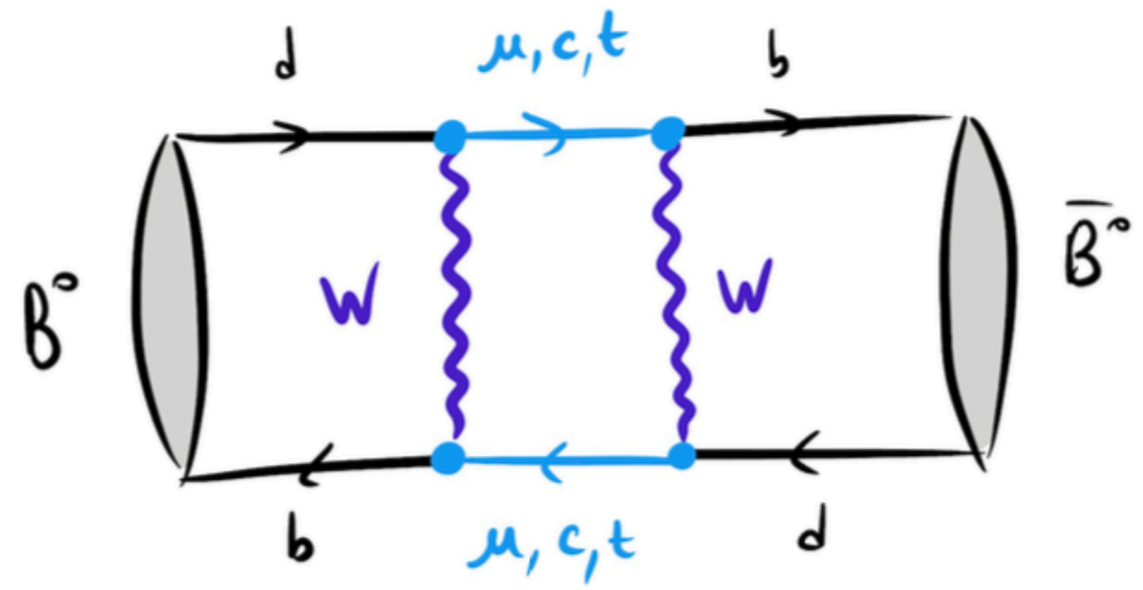
PLB 192 (1987)

OBSERVATION OF B^0–$\bar{B}^0$ MIXING

ARGUS Collaboration

In summary, the combined evidence of the investigation of B^0 meson pairs, lepton pairs and B^0 meson–lepton events on the Υ (4S) leads to the conclusion that B^0–$\bar{B}^0$ mixing has been observed and is substantial.

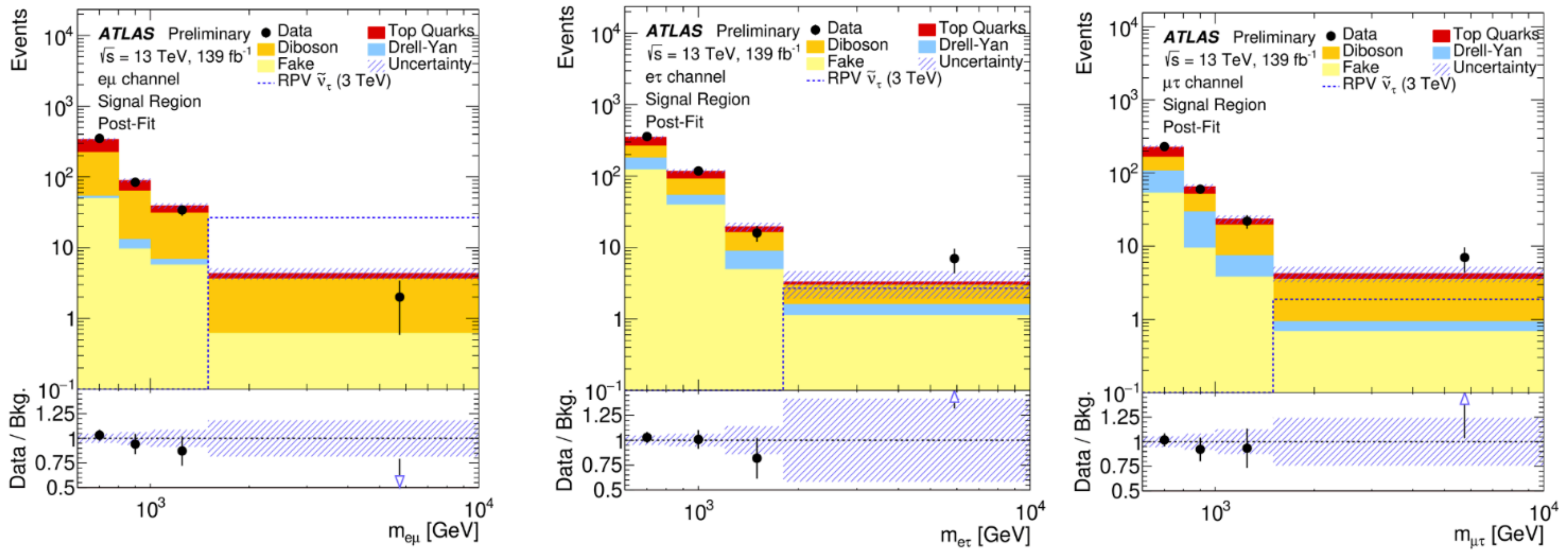
Parameters	Comments
$r > 0.09$ (90%CL)	this experiment
$x > 0.44$	this experiment
$B^{1/2} f_B \approx f_\pi < 160$ MeV	B meson (≈ pion) decay constant
$m_b < 5$ GeV/c^2	b-quark mass
$\tau < 1.4 \times 10^{-12}$s	B meson lifetime
$\lvert V_{td} \rvert < 0.018$	Kobayashi–Maskawa matrix element
$\eta_{QCD} < 0.86$	QCD correction factor [a)]
$m_t > 50$ GeV/c^2	t quark mass



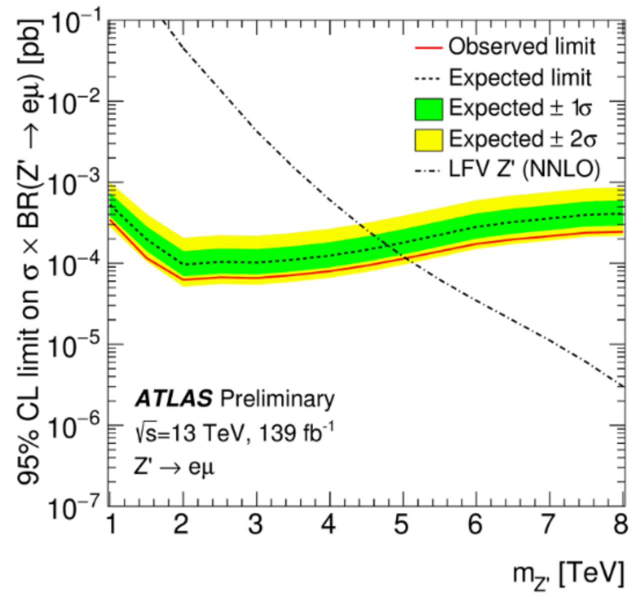
$$\mathcal{M}(B^0 - \bar{B}^0) \propto \sum_{ij} (V_{ib} V_{id}^*)(V_{jb} V_{jd}^*) F(m_{u_i}^2, m_{u_j}^2)$$

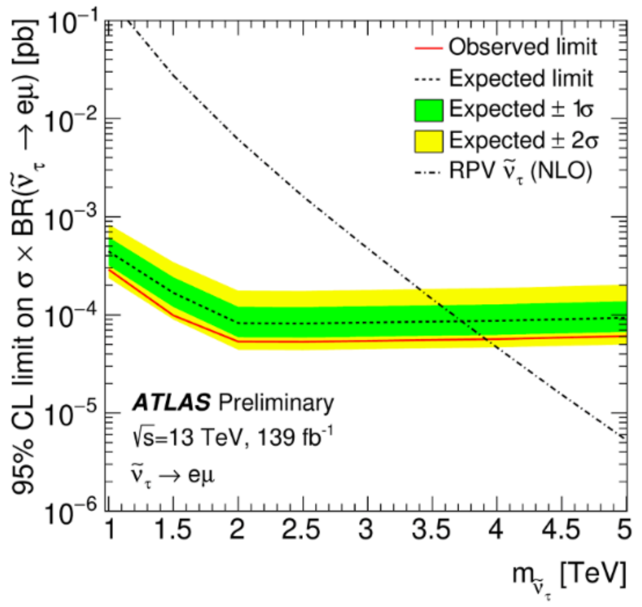
If we were to see something odd in one of the flavour observables

Heavy resonance $\rightarrow ll'$



Model	Observed (expected) 95% CL lower limit [TeV]		
	$e\mu$ channel	$e\tau$ channel	$\mu\tau$ channel
LFV Z'	5.0 (4.8)	4.0 (4.3)	3.9 (4.2)
RPV SUSY $\tilde{\nu}_\tau$	3.9 (3.7)	2.8 (3.0)	2.7 (2.9)
QBH ADD $n = 6$	5.9 (5.7)	5.2 (5.5)	5.1 (5.2)
QBH RS $n = 1$	3.8 (3.6)	3.0 (3.3)	3.0 (3.1)





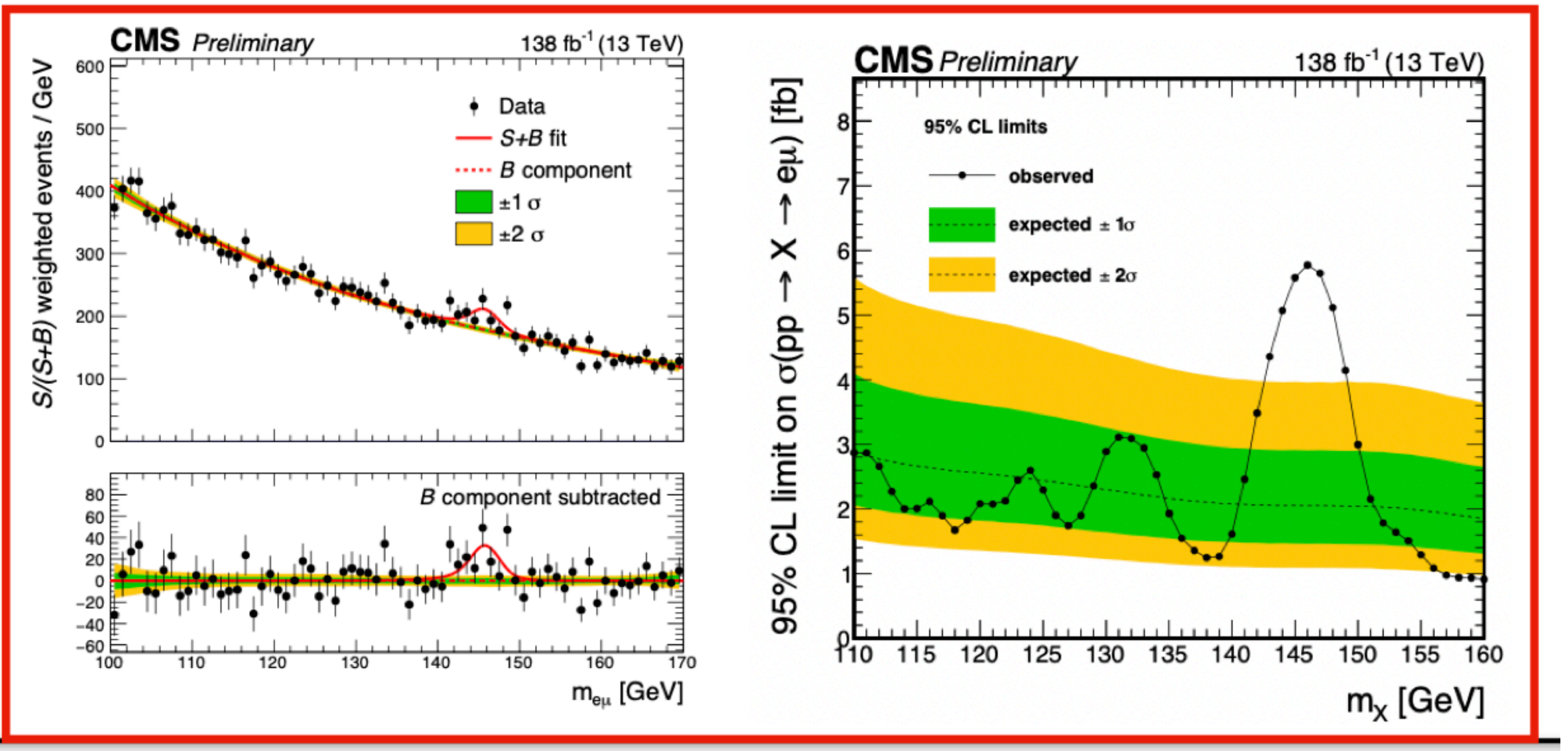
High-p_T searches (CMS and ATLAS) **can probe** the **same four-fermion operators** constrained by **flavor-physics experiments** (NA62, KOTO, BES-III, LHCb, Belle-II…).

Then we we want to see "it" too in the direct searches

"It": new resonances and/or tails of distributions

In model independent and/or model dependent cases

Example of model dependent: Z', LQ, QBH



Searching for Physics Beyond the Standard Model

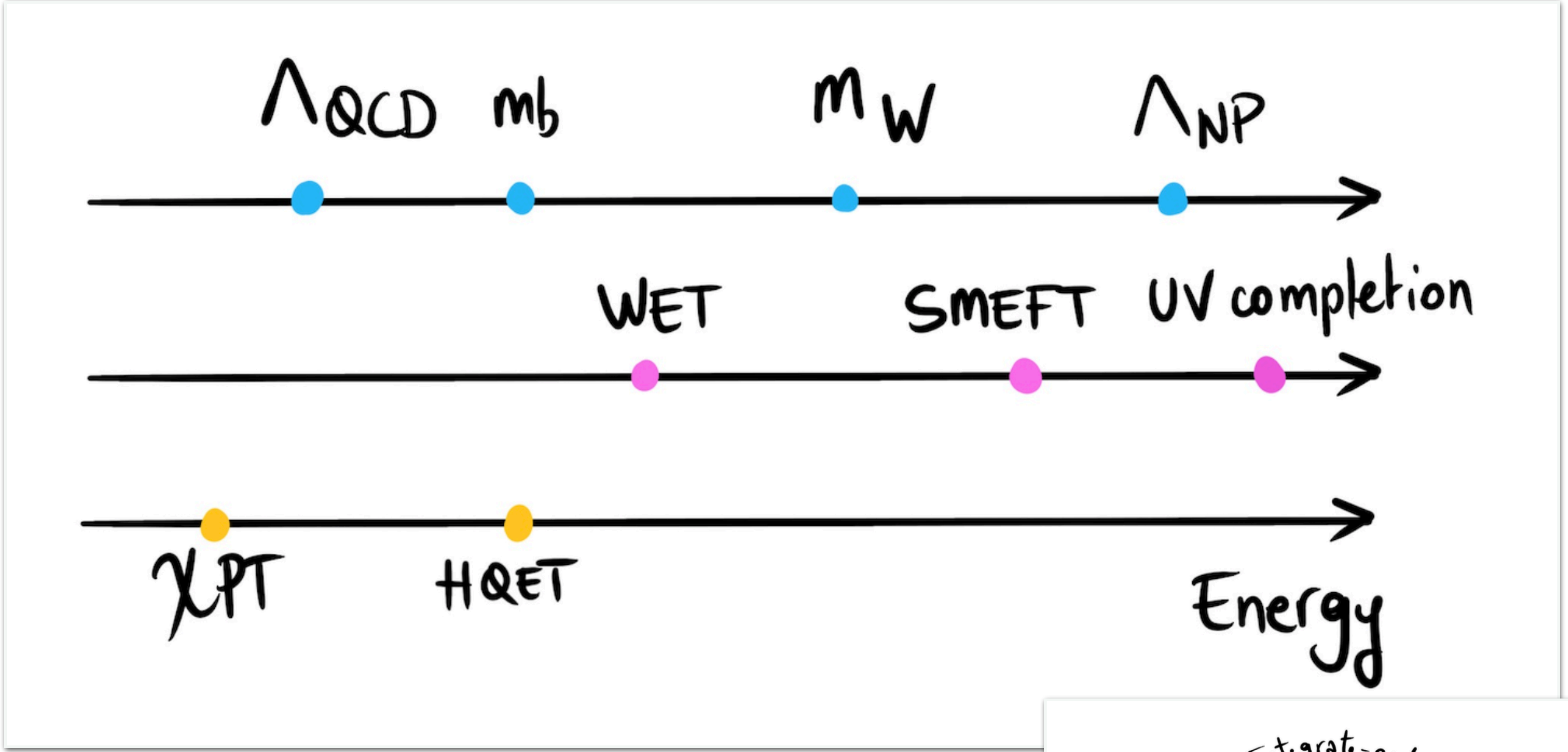
$$\mathcal{L}_{\text{NP}} = \mathcal{L}_{\text{SM}} + \sum_{d>4} \sum_{n=1}^{N_d} \frac{c_n^{(d)}}{\Lambda_{\text{NP}}^{d-4}} \mathcal{O}_n^{(d)},$$

$$\mathcal{L}_{\rm NP} = \mathcal{L}_{\rm SM} + \sum_{d>4} \sum_{n=1}^{N_d} \frac{c_n^{(d)}}{\Lambda_{\rm NP}^{d-4}} \mathcal{O}_n^{(d)},$$

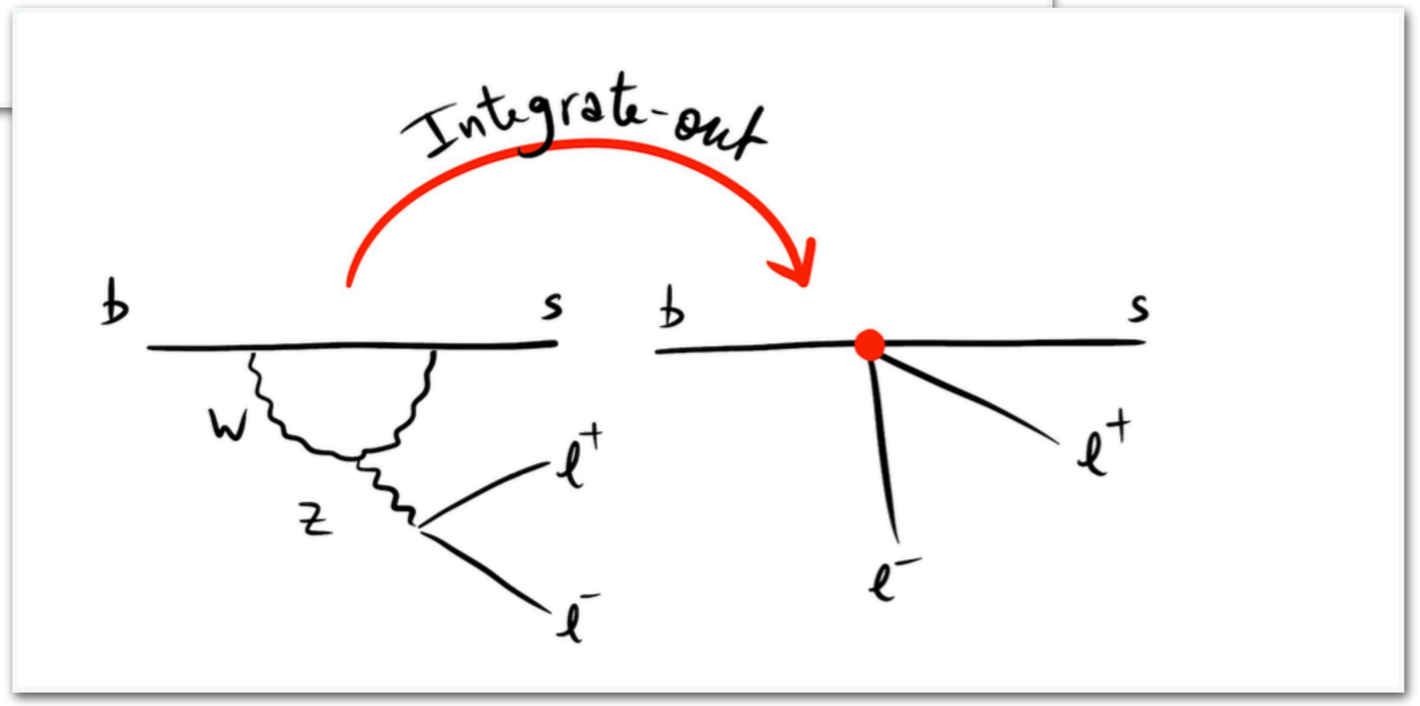
"The B-anomalies encouraged the theorists to think about Model Building in a new way."

It's bloody hard, because it's a multi-scale problem

and ultimately we all love a good Taylor Expansion

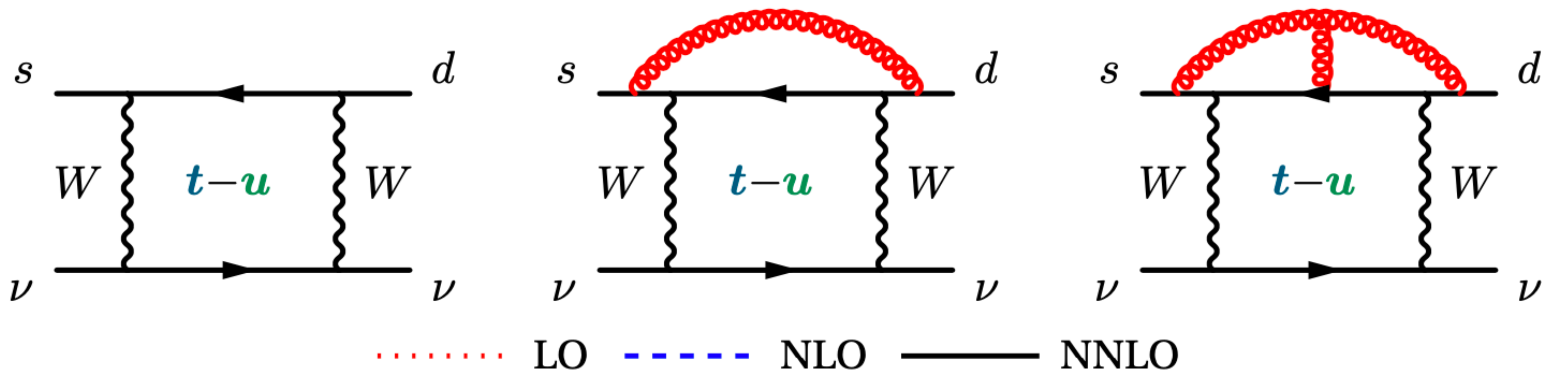


For a given scale one can absorbe heavier degrees of freedom



Kaons

"you know Kaons because B-decay into them"

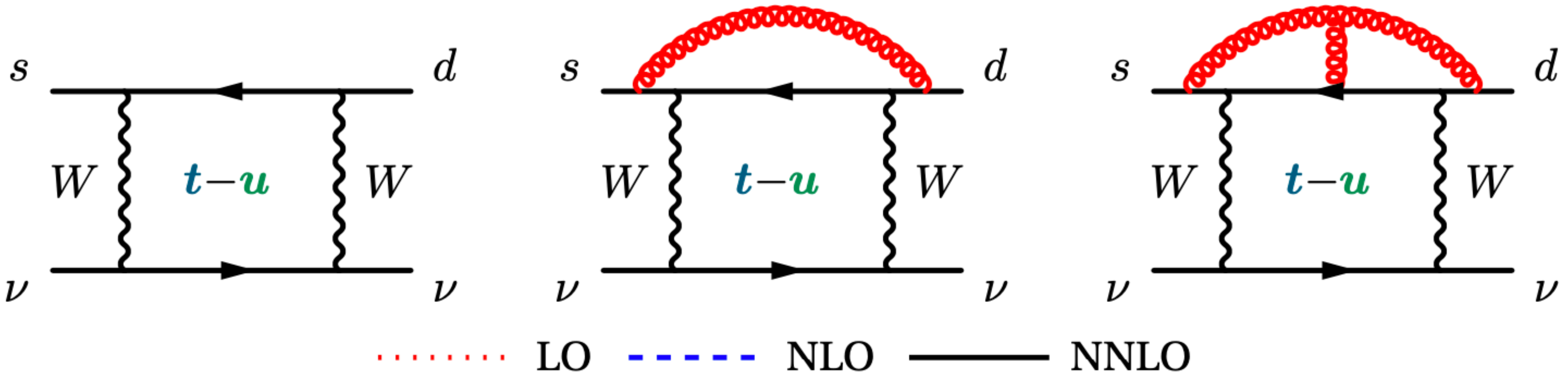


Preliminary numerics including X_t@NNLO

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu})^{\mathrm{SM}} = 8.25(11)_{\mathrm{SD}}(25)_{\mathrm{LD}}(57)_{\mathrm{para}} \times 10^{-11}$$

$$\mathrm{BR}(K_L \to \pi^0 \nu\bar{\nu})^{\mathrm{SM}} = 2.83(1)_{\mathrm{SD}}(2)_{\mathrm{LD}}(30)_{\mathrm{para}} \times 10^{-11}$$

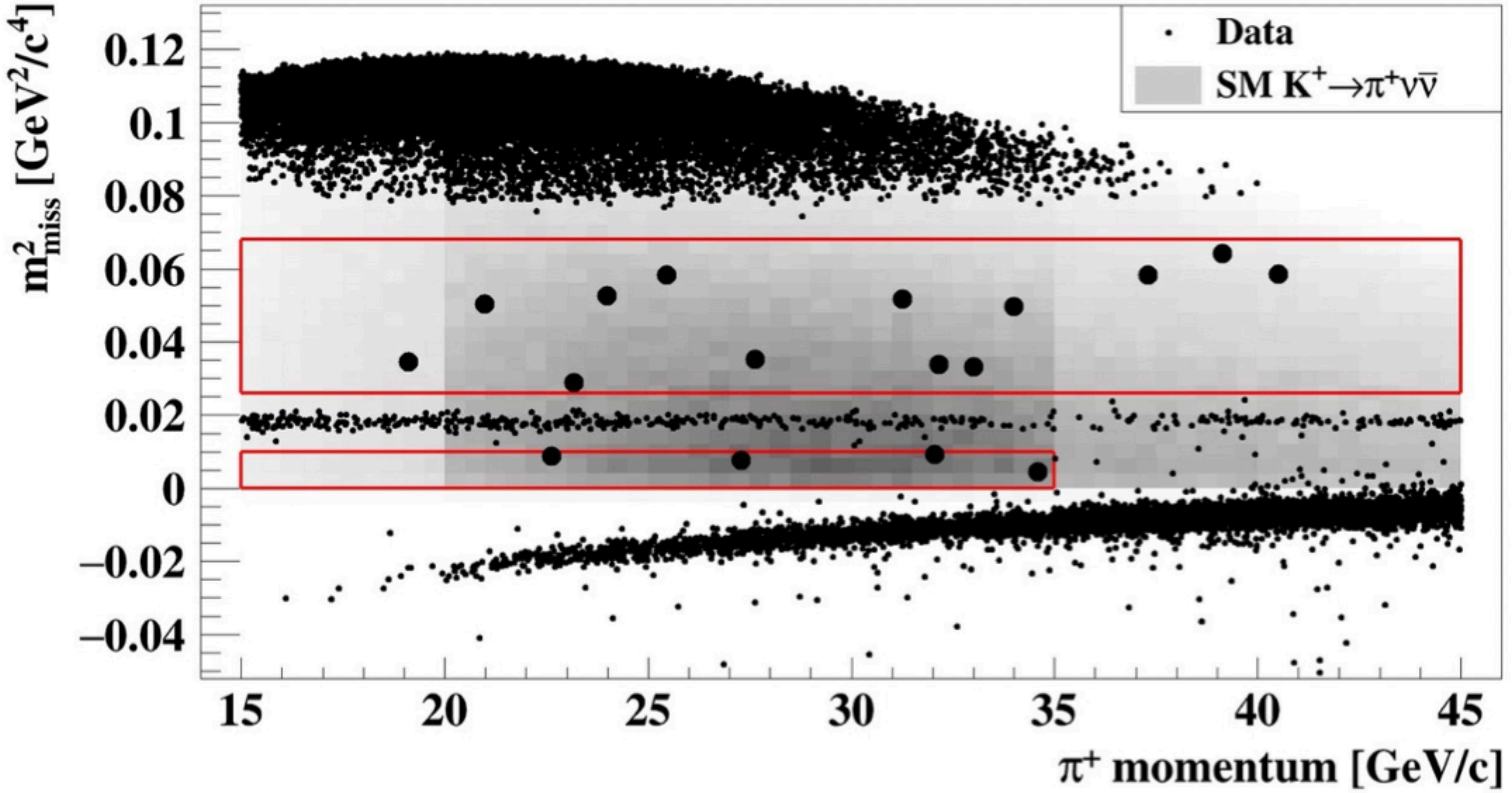
We will get back to the size of the the parametric systematic uncertainty later



Preliminary numerics including X_t@NNLO

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu})^{\mathrm{SM}} = 8.25(11)_{\mathrm{SD}}(25)_{\mathrm{LD}}(57)_{\mathrm{para}} \times 10^{-11}$$

$$\mathrm{BR}(K_L \to \pi^0 \nu\bar{\nu})^{\mathrm{SM}} = 2.83(1)_{\mathrm{SD}}(2)_{\mathrm{LD}}(30)_{\mathrm{para}} \times 10^{-11}$$



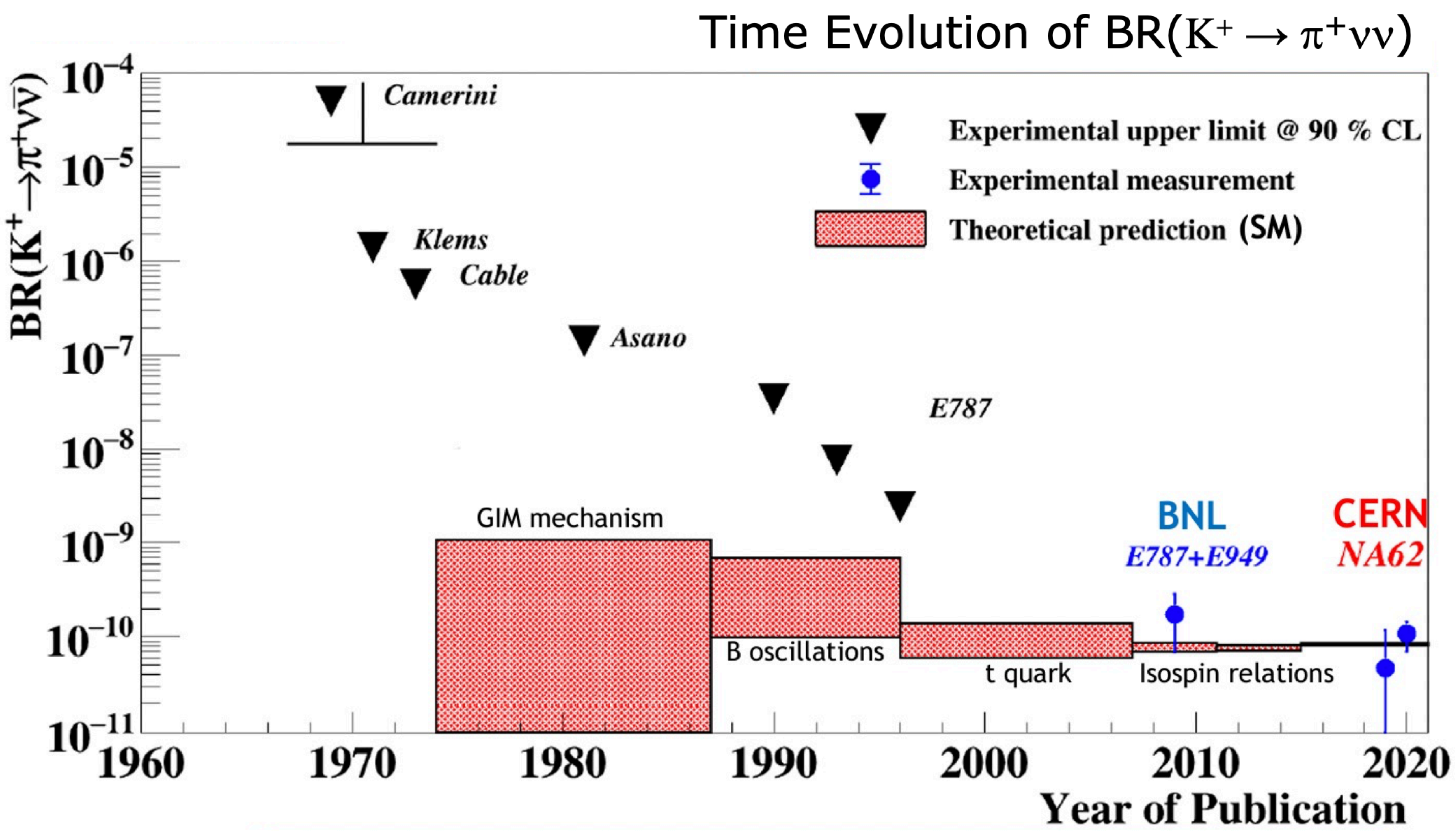
Beautiful result from NA62

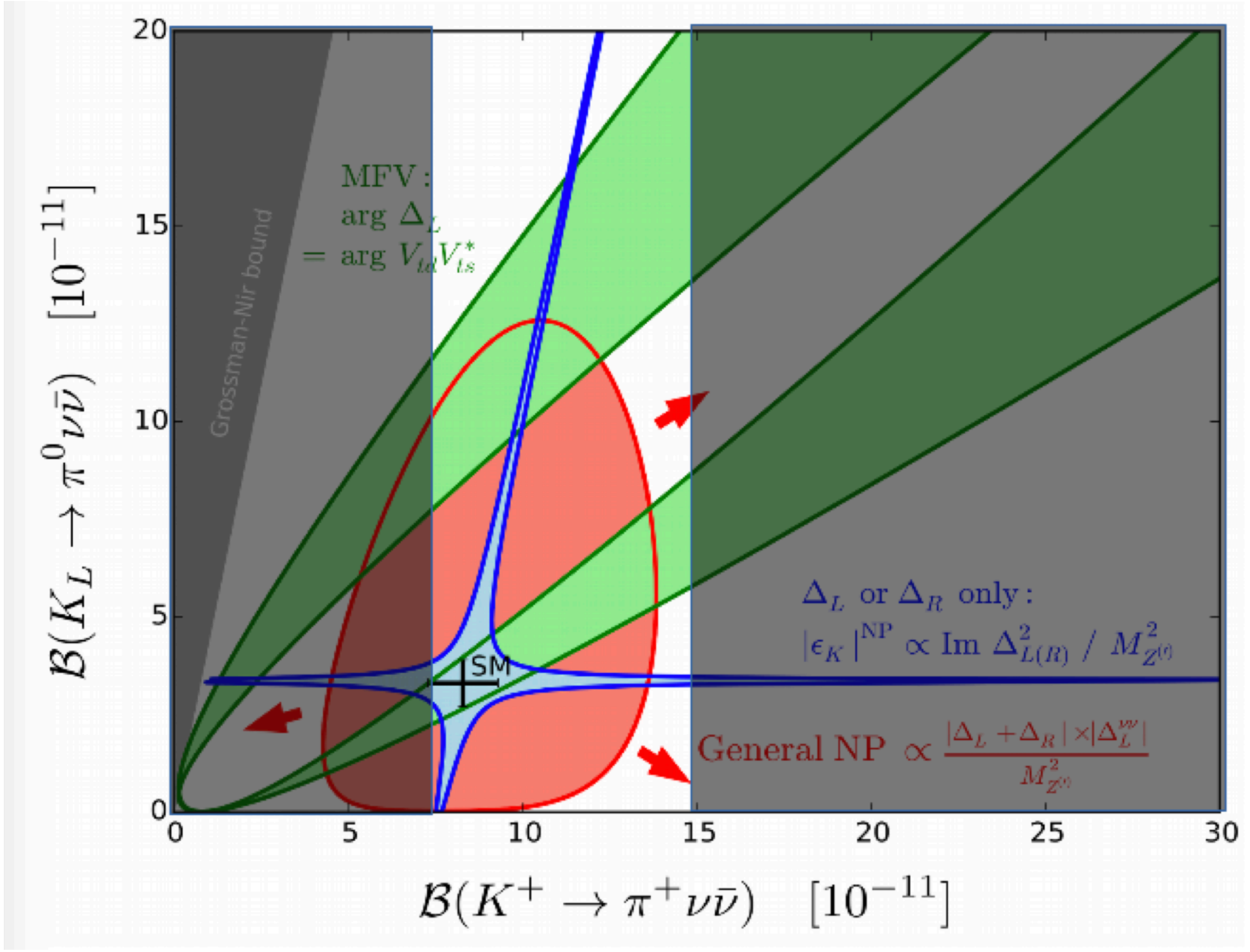
2018 Data

Exp: 7.6 signal + 5.4 background events

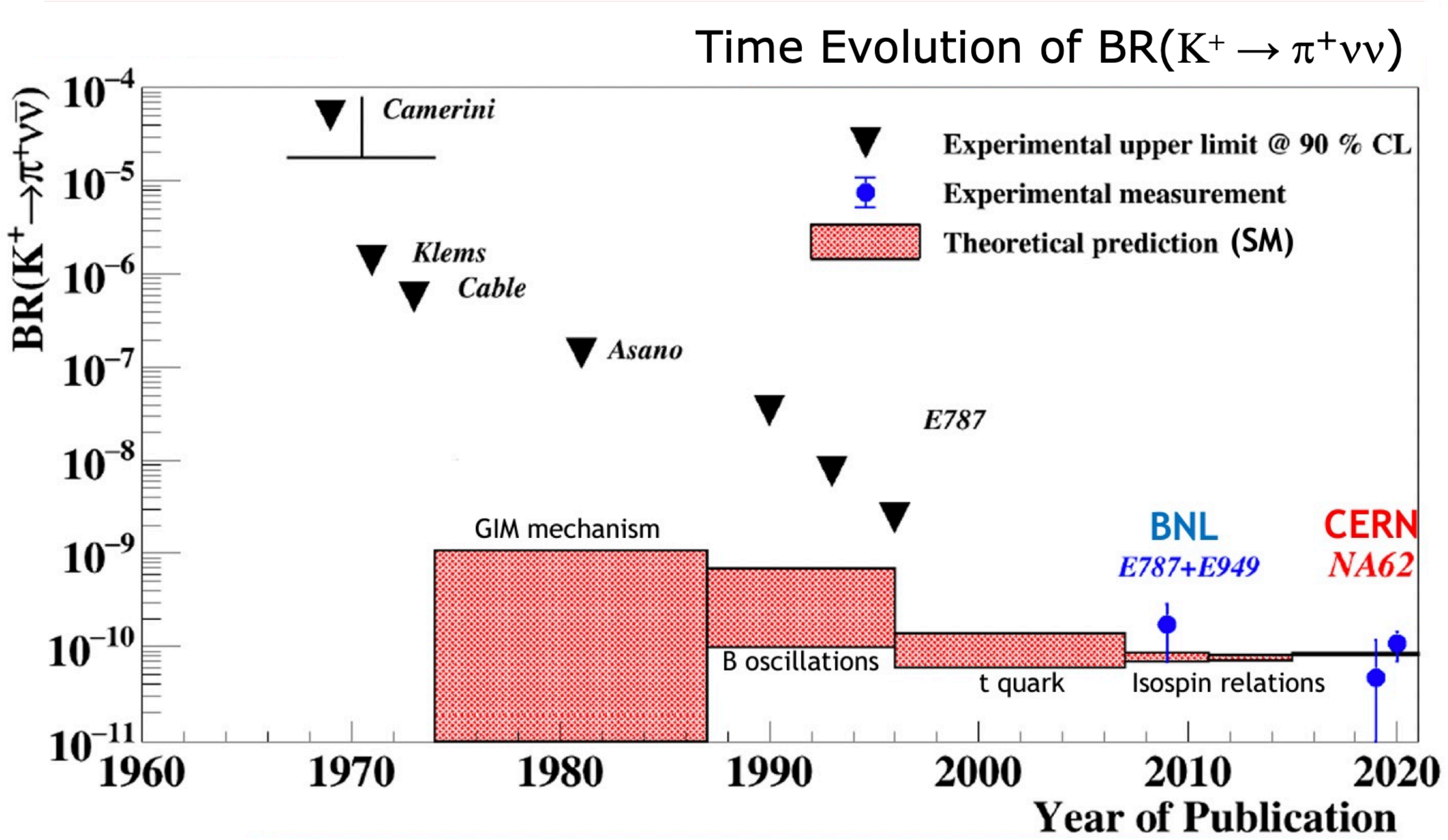
Obs: 17 $K^+ \to \pi^+\nu\bar{\nu}$ candidates

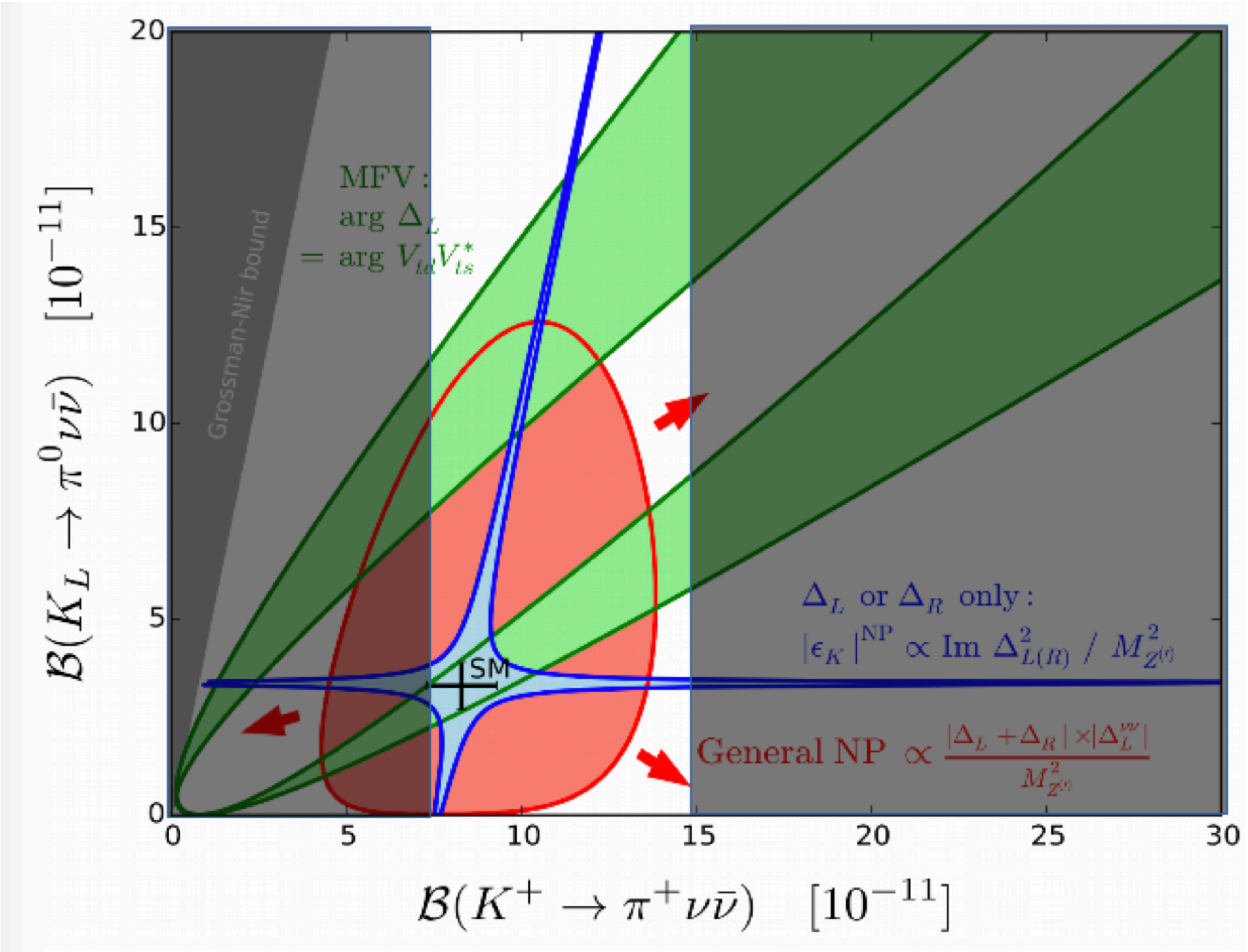
[JHEP 06 (2021) 093]

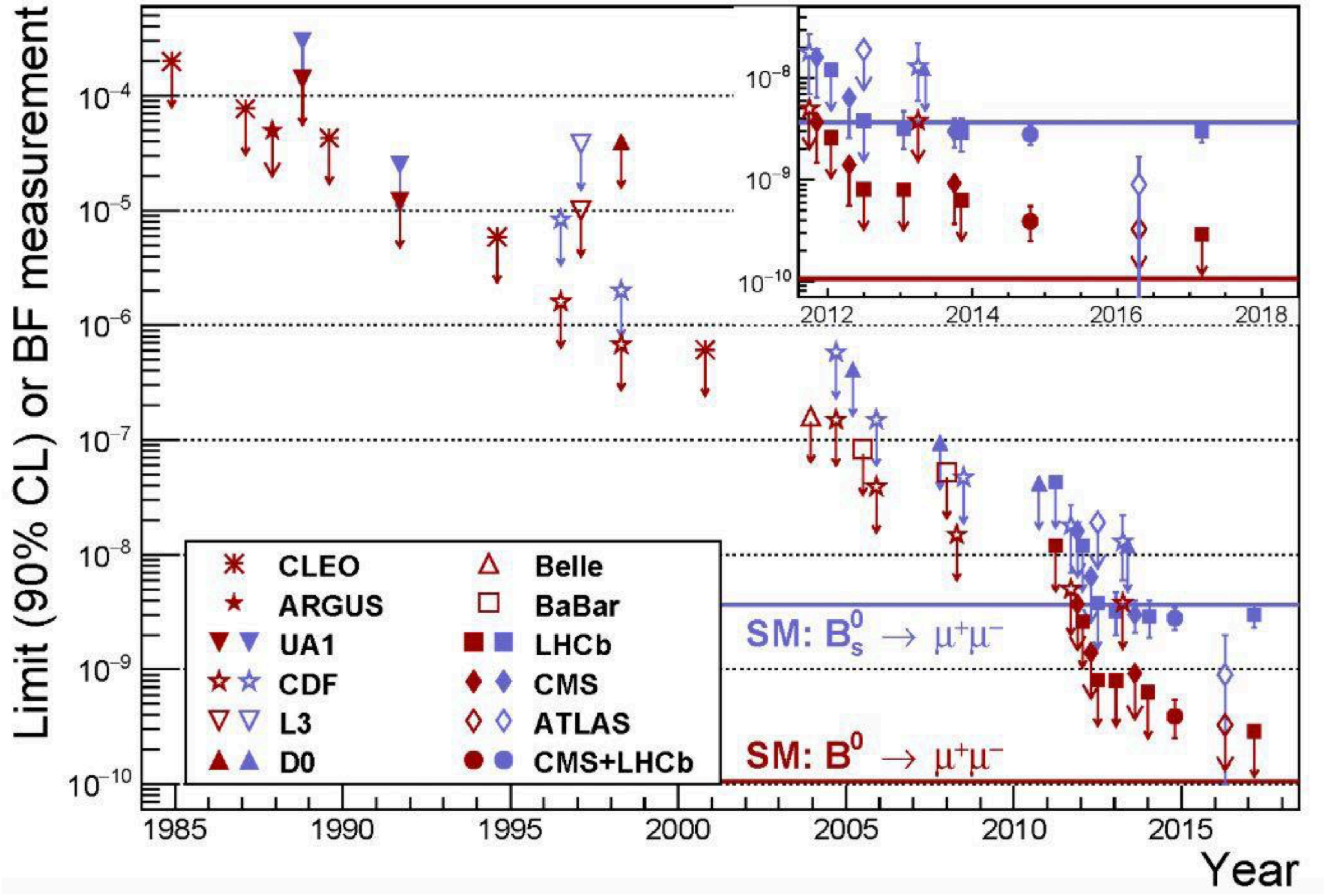


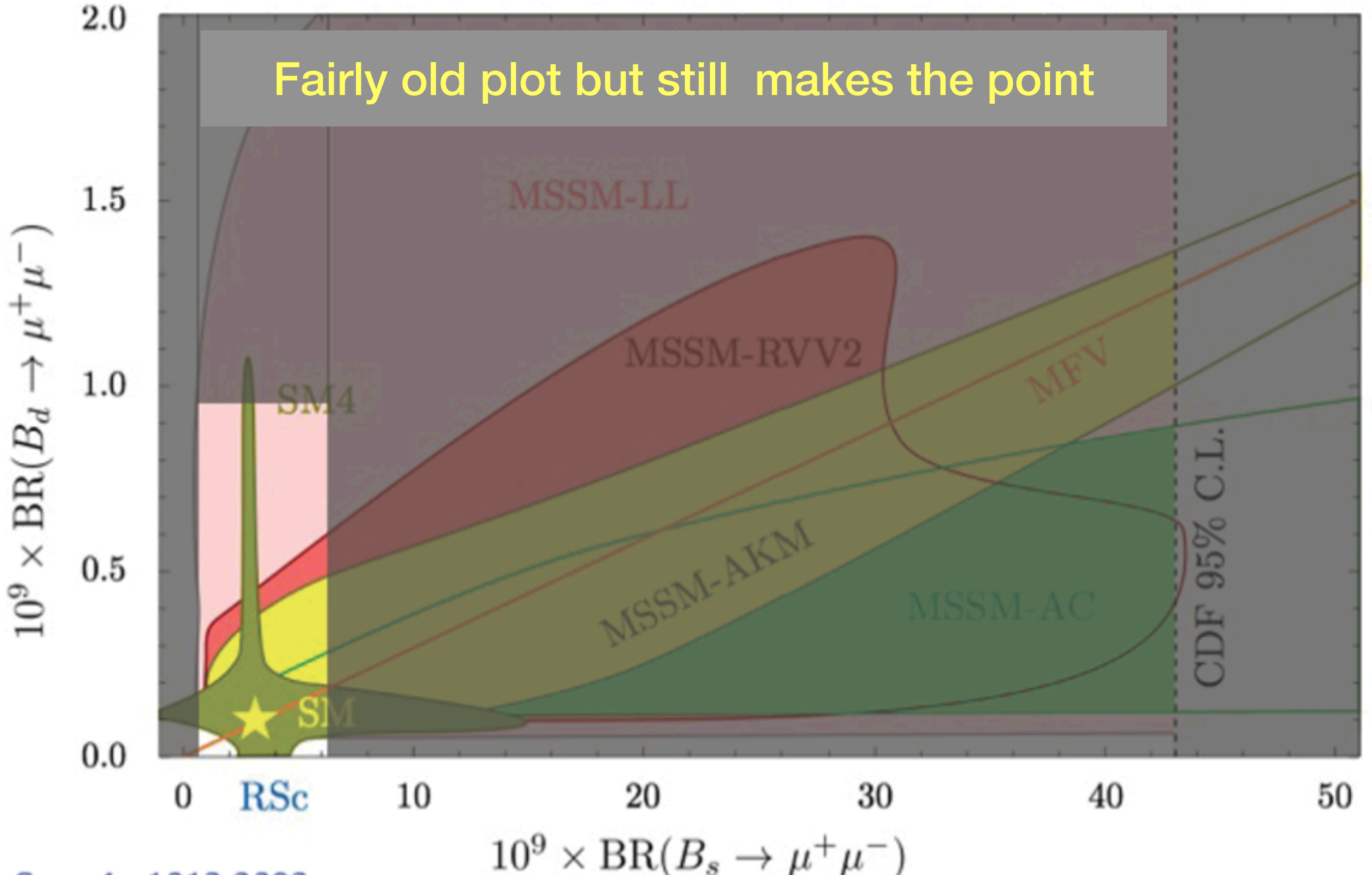


This may remind you of a picture that we have seen this week and many tears ago…





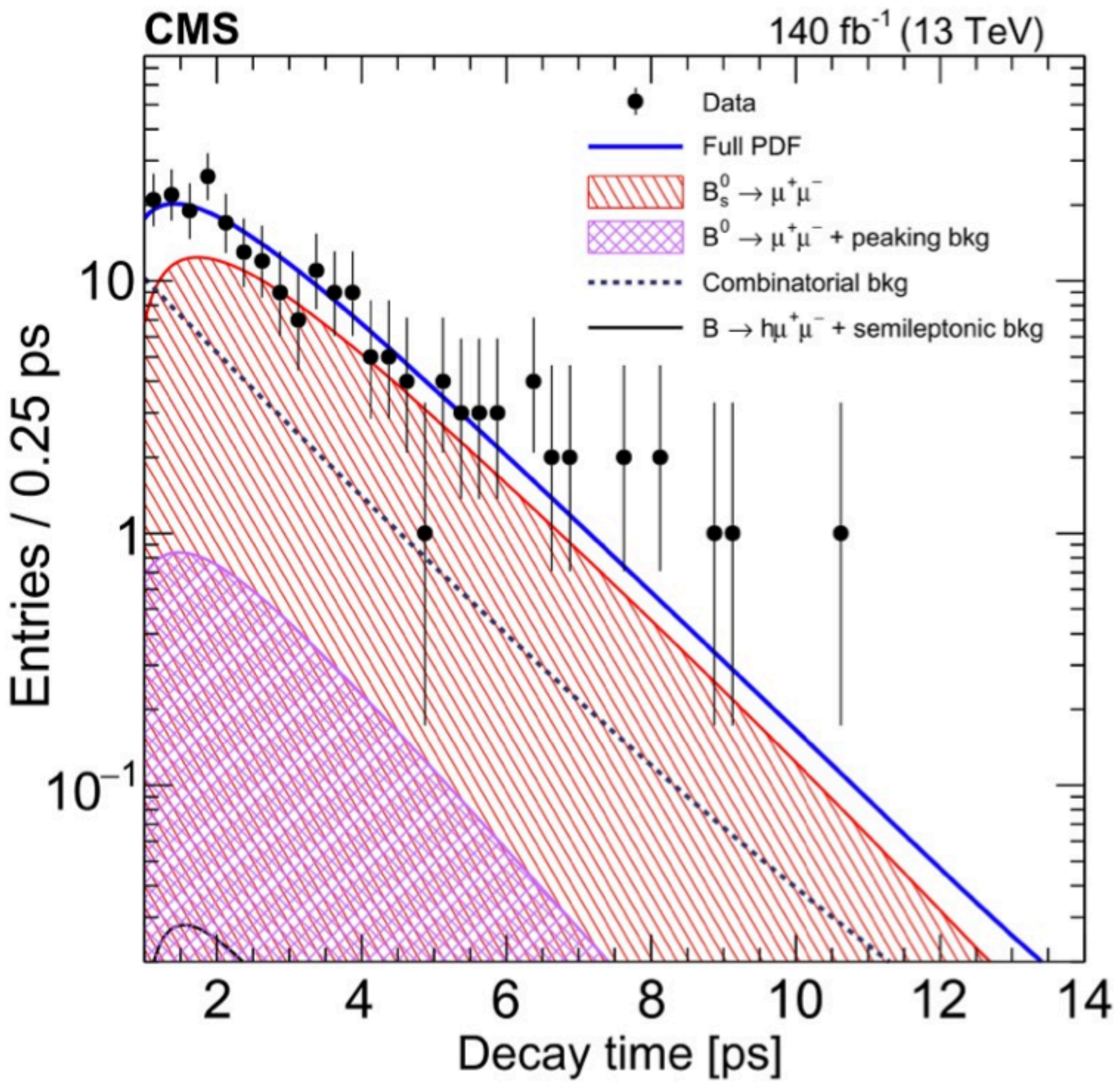


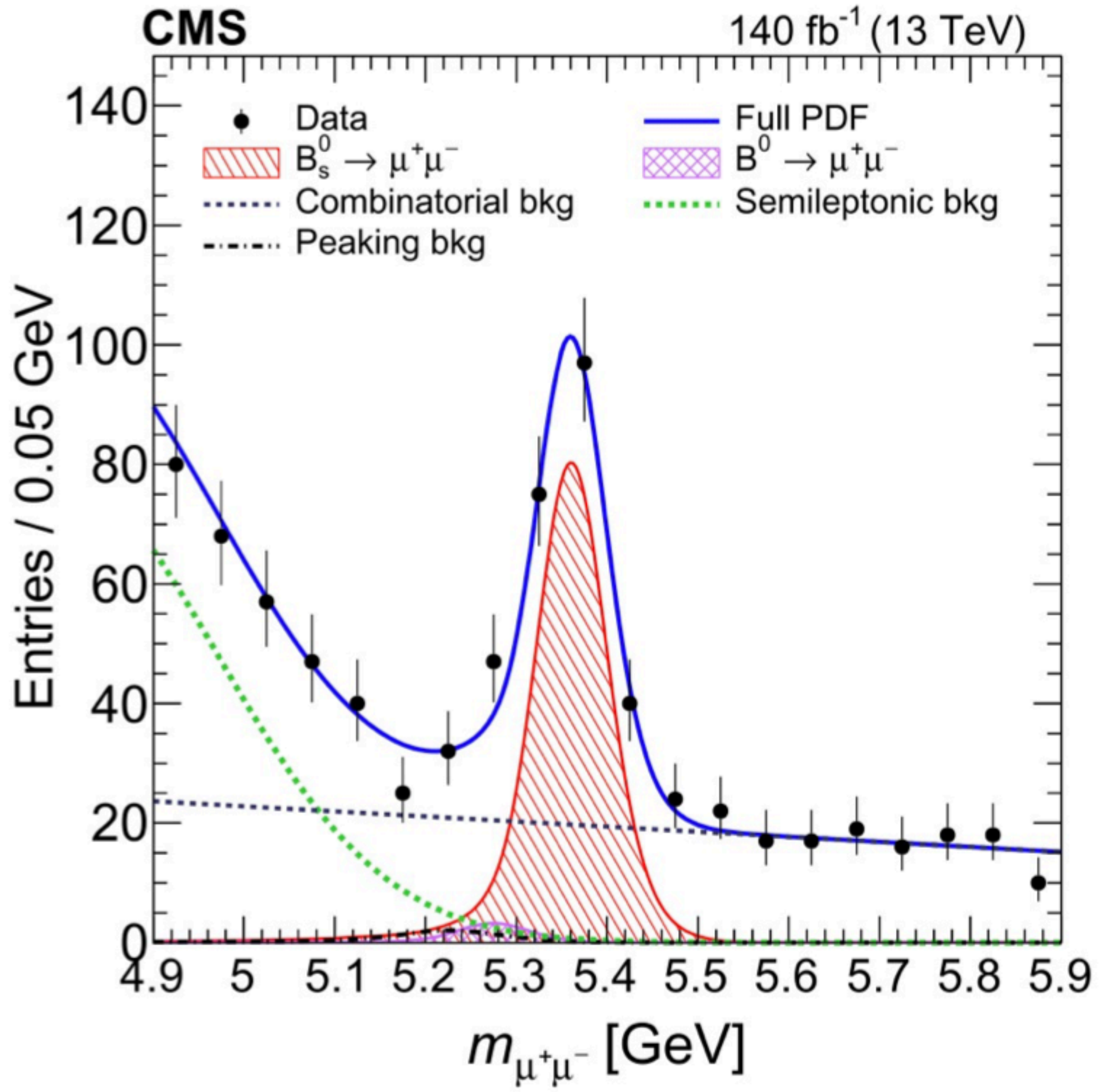


Straub, 1012.3893

Always be grateful to D.Straub for inventing Flavio

As of today



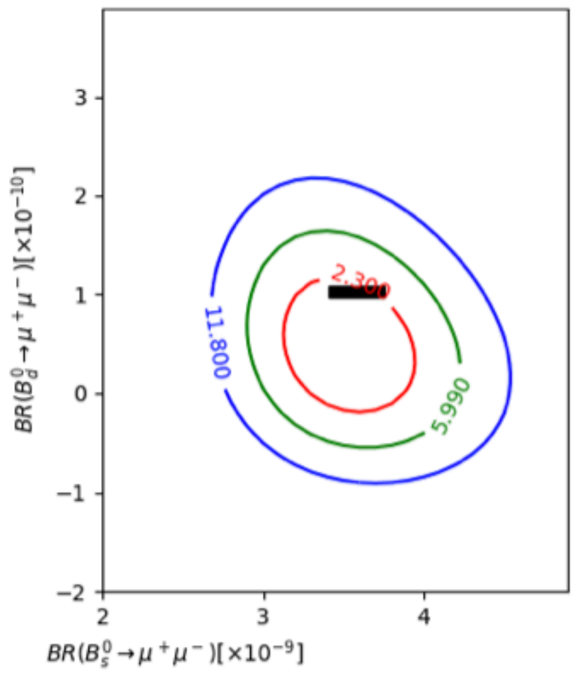


LHCb, March 2021 (PRL 128, 4, 041801, 2022)

$\mathrm{BR}(B_s \to \mu^+\mu^-)^{\mathrm{LHCb}} = (3.09^{+0.46+0.15}_{-0.43-0.11}) \times 10^{-9}$

CMS, July 2022 (CMS-PAS-BPH-21-006)

$\mathrm{BR}(B_s \to \mu^+\mu^-)^{\mathrm{CMS}} = (3.95^{+0.39+0.27+0.21}_{-0.37-0.22-0.19}) \times 10^{-9}$



Our combination using the latest measurements (LHCb, ATLAS, CMS):

$$\mathrm{BR}(B_s \to \mu^+\mu^-) = 3.52^{+0.32}_{-0.30} \times 10^{-9}$$

T. Hurth, FM, D. Martinez Santos, S. Neshatpour, 2210.07221

Need to get going soon with the combination from the LHC experiments

But before moving on too quickly

$$\mathcal{B}(B_s^0 \to \mu\mu) = \mathcal{B}(B^+ \to J/\Psi K^+) \cdot \frac{N_{B_s^0 \to \mu\mu}}{N_{B^+ \to J/\Psi K^+}} \cdot \frac{\epsilon_{B^+ \to J/\Psi K^+}}{\epsilon_{B_s^0 \to \mu\mu}} \cdot \frac{f_u}{f_s}$$

Input

$$\mathcal{B}(B_s^0 \to \mu\mu) = \mathcal{B}(B_s^0 \to J/\Psi \Phi) \cdot \frac{N_{B_s^0 \to \mu\mu}}{N_{B_s^0 \to J/\Psi\Phi}} \cdot \frac{\epsilon_{B_s^0 \to J/\Psi\Phi}}{\epsilon_{B_s^0 \to \mu\mu}}$$

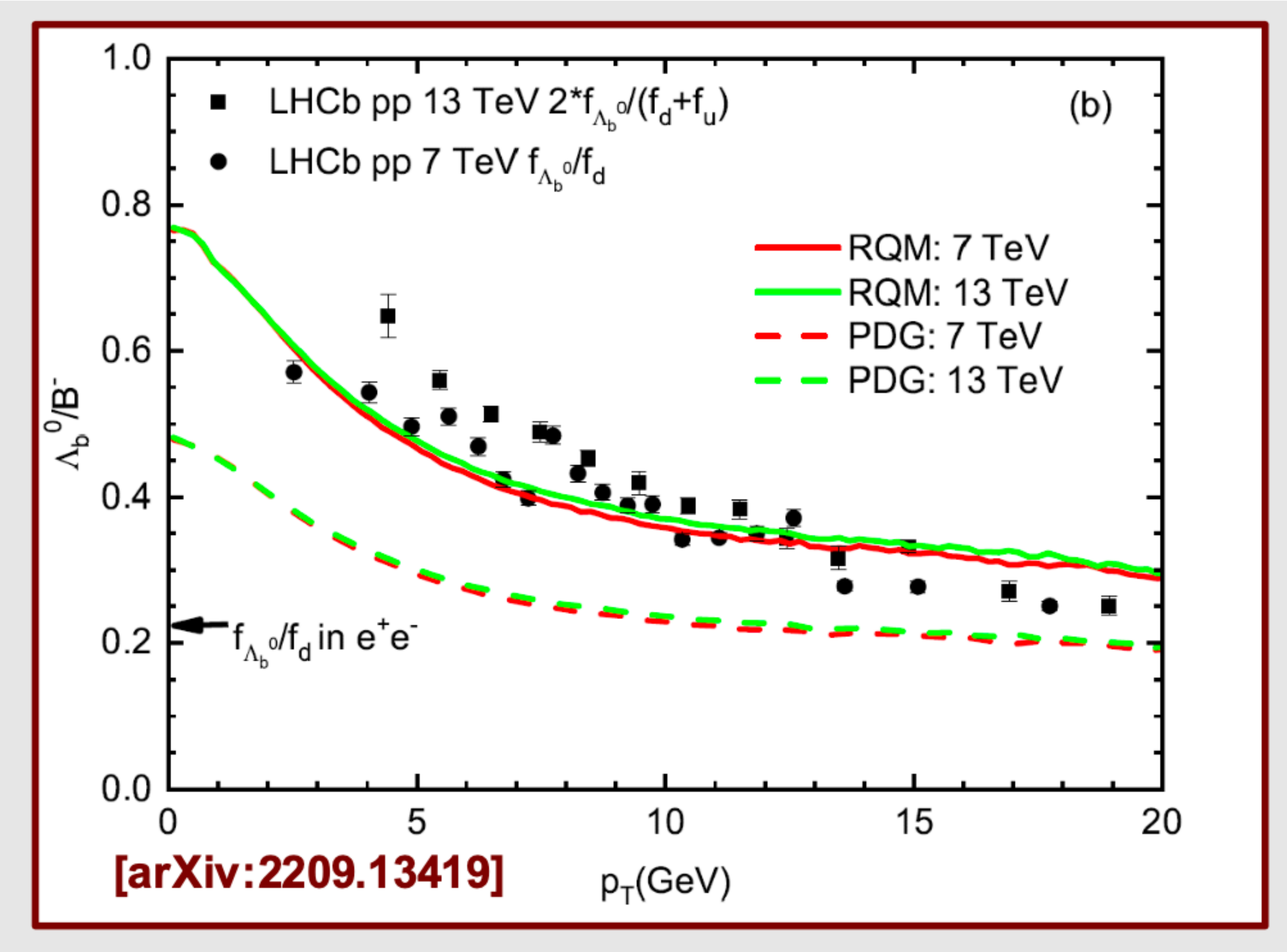
$$\mathcal{B}(B^0 \to \mu\mu) = \mathcal{B}(B^+ \to J/\Psi K^+) \cdot \frac{N_{B^0 \to \mu\mu}}{N_{B^+ \to J/\Psi K^+}} \cdot \frac{\epsilon_{B^+ \to J/\Psi K^+}}{\epsilon_{B_s^0 \to \mu\mu}} \cdot \frac{f_u}{f_d}$$

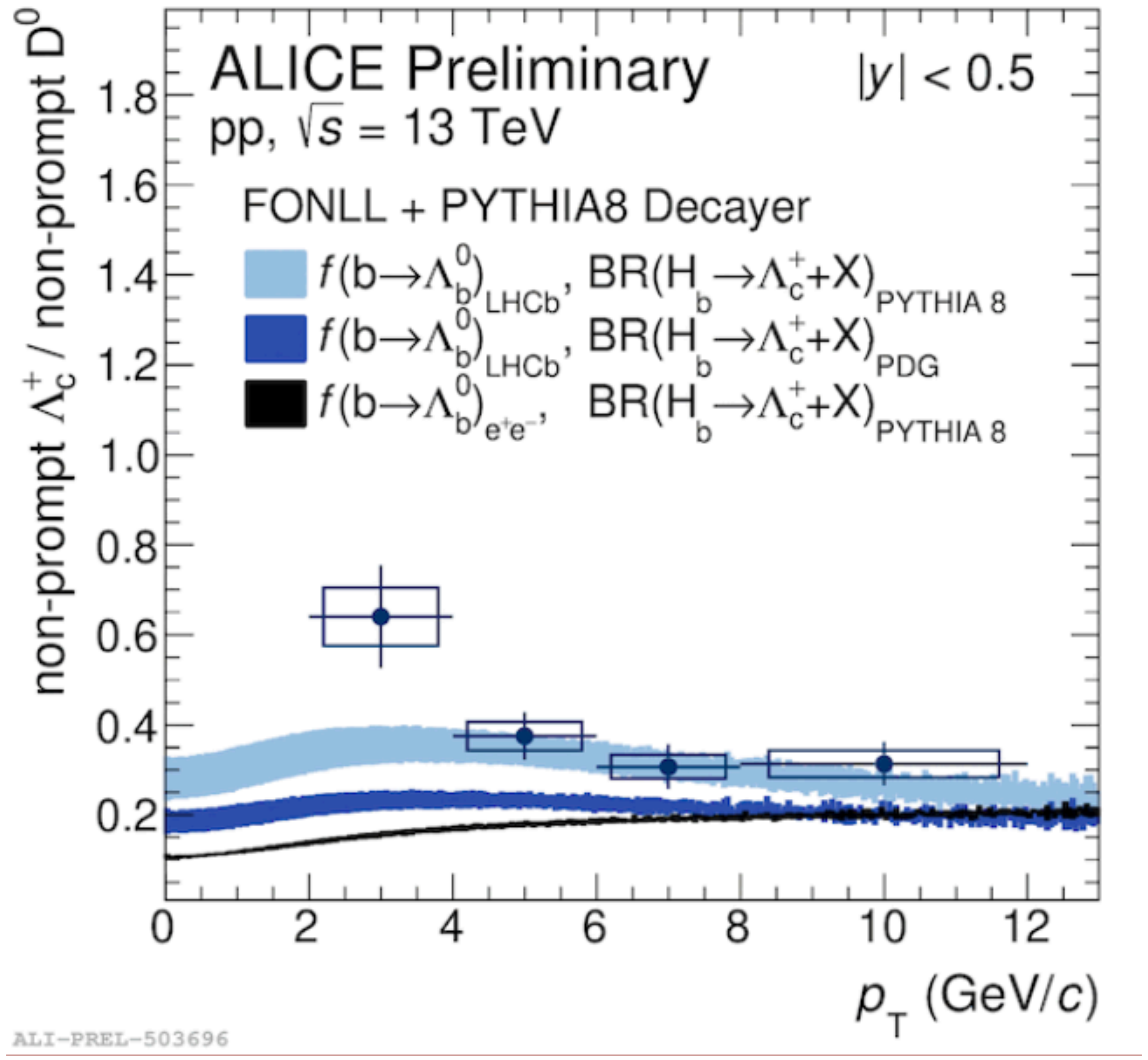
Let's not forget the B^0 and more importantly the knowledge of the fragmentation fractions

"The problem comes in when you think about reality"

As our favorite decays do not pop from vacuum.

I had a dream: mesure, tune, iterate





A very big need in the community to contribute more to our Monte Carlo generators
Many humans hours could be saved

QCD is ~~hard~~

It’s complicated

Neutral currents

$$\mathcal{L}_{\text{eff}}^{b\to s\ell\ell} = -2\sqrt{2}G_F \frac{\alpha_e}{4\pi} V_{ts}^* V_{tb} \sum_i C_i \mathcal{O}_i + \text{h.c} \qquad \text{(A1)}$$

where

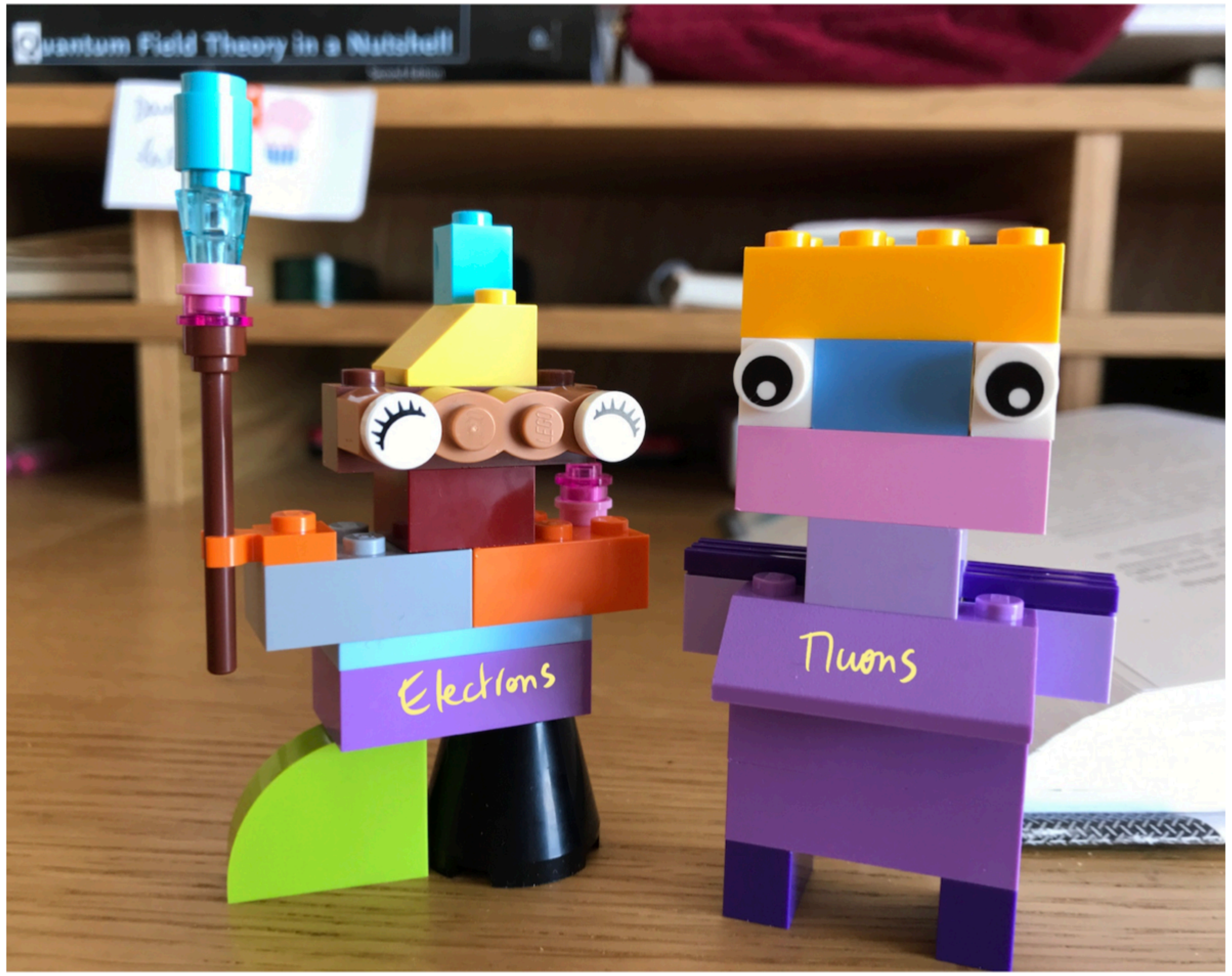
$$\begin{aligned}
\mathcal{O}_7 &= \frac{m_b}{e}(\bar{s}_L \sigma_{\mu\nu} b_R)F^{\mu\nu}, & \mathcal{O}_7' &= \frac{m_b}{e}(\bar{s}_R \sigma_{\mu\nu} b_L)F^{\mu\nu}, \\
\mathcal{O}_9^\ell &= (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \ell), & \mathcal{O}_{10}^\ell &= (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \gamma_5 \ell), \\
\mathcal{O}_9^{\ell\prime} &= (\bar{s}_R \gamma_\mu b_R)(\bar{\ell}\gamma^\mu \ell), & \mathcal{O}_{10}^{\ell\prime} &= (\bar{s}_R \gamma_\mu b_R)(\bar{\ell}\gamma^\mu \gamma_5 \ell).
\end{aligned} \qquad \text{(A2)}$$

Charged currents

$$\begin{aligned}
\mathcal{H}_{\text{eff}} = \sqrt{2}G_F V_{cb} \big[&(1+g_V)(\bar{c}\gamma_\mu b)(\bar{\ell}_L \gamma^\mu \nu_L) + (-1+g_A)(\bar{c}\gamma_\mu \gamma_5 b)(\bar{\ell}_L \gamma^\mu \nu_L) \\
&+ g_S(\bar{c}b)(\bar{\ell}_R \nu_L) + g_P(\bar{c}\gamma_5 b)(\bar{\ell}_R \nu_L) \\
&+ g_T(\bar{c}\sigma_{\mu\nu} b)(\bar{\ell}_R \sigma^{\mu\nu} \nu_L) + g_{T5}(\bar{c}\sigma_{\mu\nu}\gamma_5 b)(\bar{\ell}_R \sigma^{\mu\nu}\nu_L)\big] + \text{h.c.}
\end{aligned}$$

While Wilson coefficients encode the short distance ie the potential NP part
They always come with hadronic factors

The “Simplicity” of Lepton Universality test



Are we the same?

The "Simplicity" of Lepton Universality test

$$R_H \equiv \frac{\int \frac{d\Gamma(B\to H\mu^+\mu^-)}{dq^2}\, dq^2}{\int \frac{d\Gamma(B\to He^+e^-)}{dq^2}\, dq^2},$$

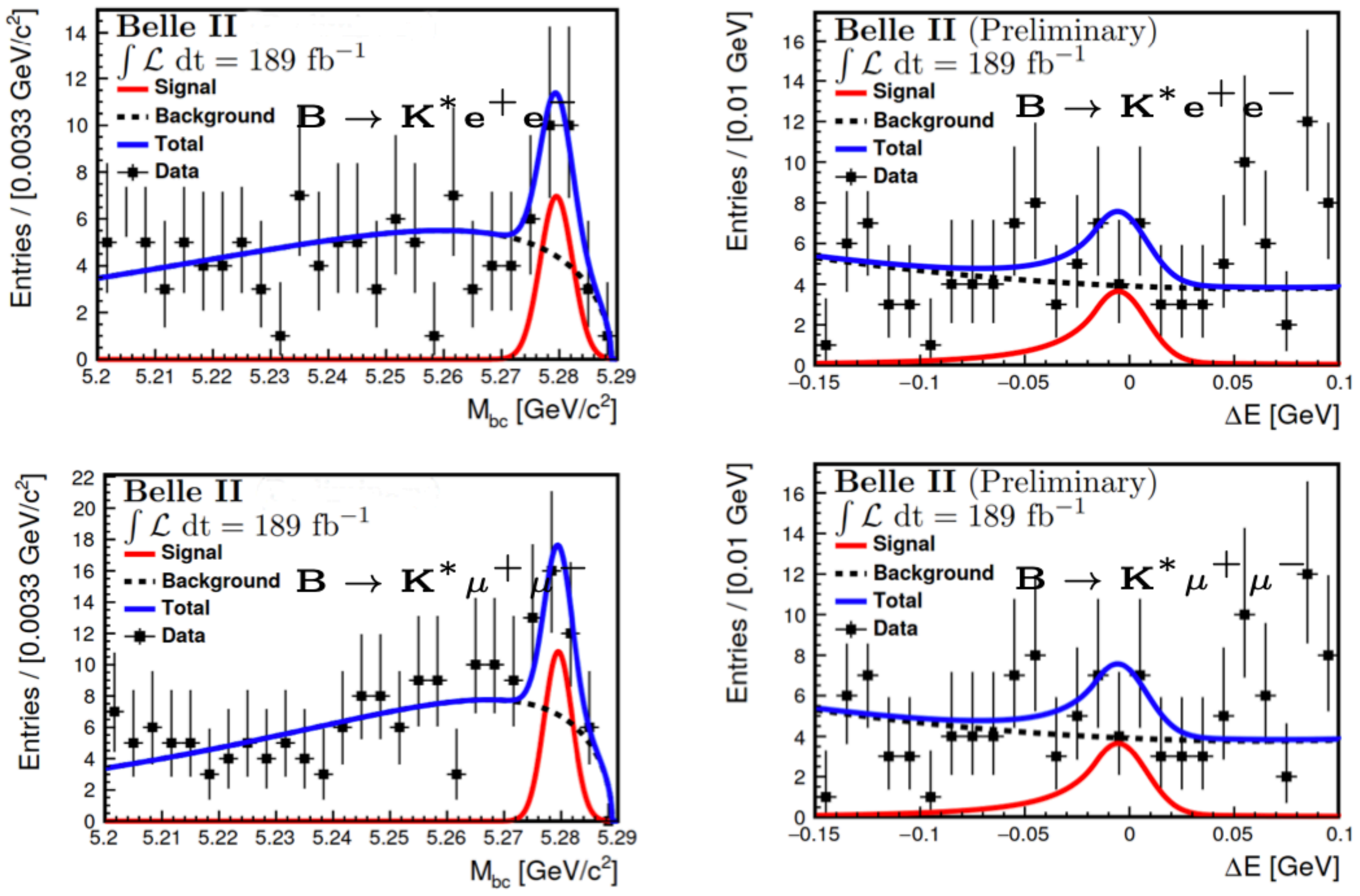
Similar observables in charged currents

$$R_{D^*}^{(\tau/\mu)}[q^2_{\rm min}] = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} dq^2 \frac{d\mathcal{B}}{dq^2}(B\to D^*\tau\bar{\nu})}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} dq^2 \frac{d\mathcal{B}}{dq^2}(B\to D^*\mu\bar{\nu})}$$

Note for future analyses:
think about aligning the cuts for τ and lighter charged leptons

Counting 1, 2, 3

Here also looking forward to seeing these measurements with (semi-) inclusive decays at Belle 2 and LHCb



And let us not forget our colleagues from ATLAS & CMS

- **R(X) LF(U)V measurements**
  - Still under review in CMS

The cold shower

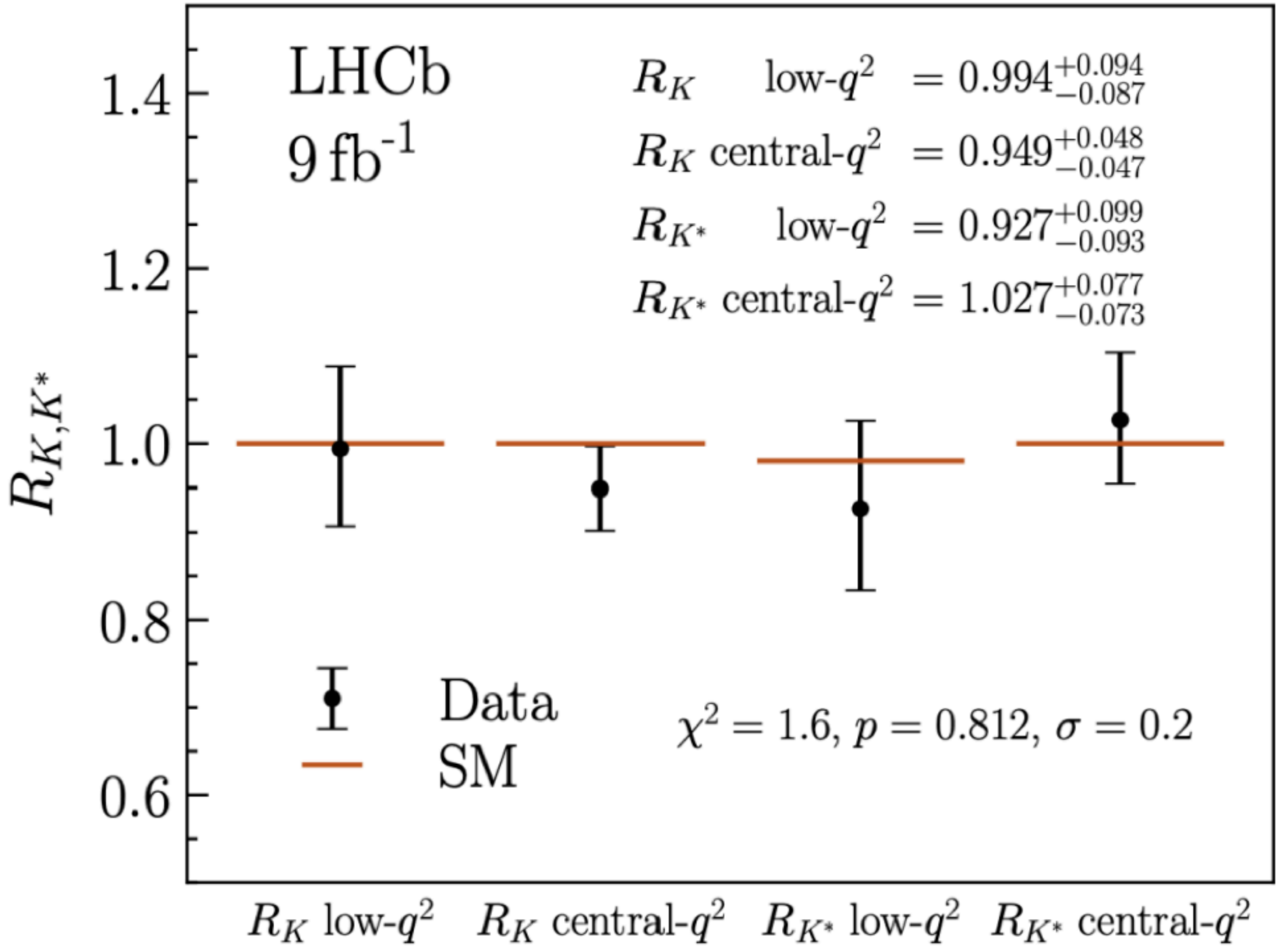
Taking a cold shower is good for your health, here's why

It's widely known that a hit of cold water can do wonders for your body. Swedish bathhouses are among an age-old Nordic healing tradition, the world's happiest people go ice swimming, and Brits swear by a jolt of cold water for a mood-boost. But when all is said and freezing, what good does a cold shower actually do? We break down four reasons why

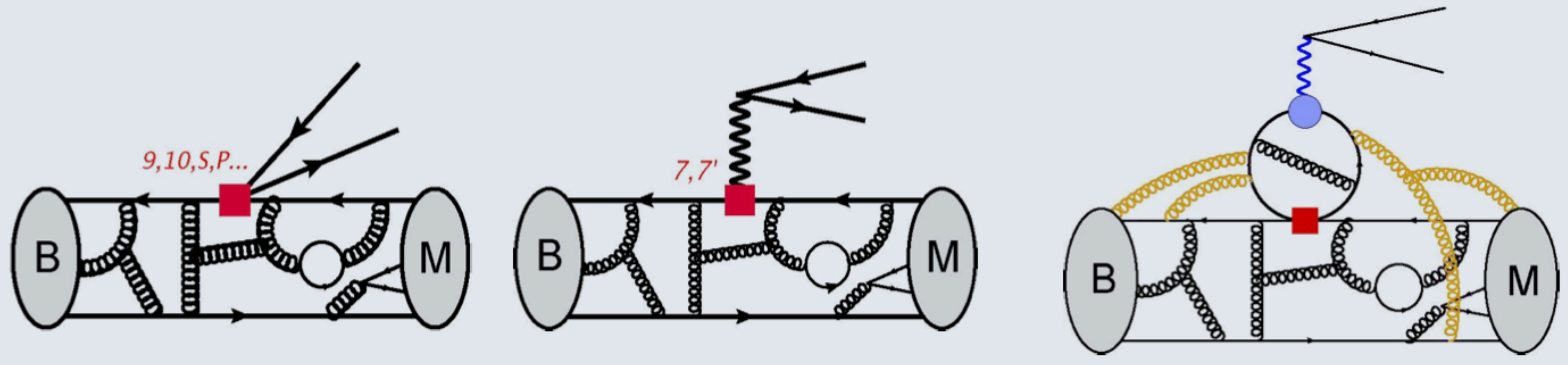
SS Sheldon L Stone <slstone@syr.edu>
To: Guy Wilkinson
Fri 10/09/2021 19:27

Thanks, but my job is to make sure RX is correct...

sheldon



The "Complexity" of these transitions



$$\mathcal{A}^{L,R}_\lambda(B \to M_\lambda \ell\ell) = \mathcal{N}_\lambda \left\{ (C_9 \mp C_{10}) \mathcal{F}_\lambda(q^2) + \frac{2 m_b M_B}{q^2} \left[C_7 \mathcal{F}^T_\lambda(q^2) - 16\pi^2 \frac{M_B}{m_b} \mathcal{H}_\lambda(q^2) \right] \right\}$$

$$\mathcal{H}_\mu(k,q) = i \int d^4x \, e^{iq\cdot x} \langle \bar{M}(k) | T\{\mathcal{J}^{\text{em}}_\mu(x), \mathcal{C}_i \mathcal{O}_i\} | \bar{B}(q+k) \rangle$$

Non-local form-factors

→ Main contributions: the **"charm-loops"** $\mathcal{O}^c_{2(1)} = (\bar{s}_L \gamma_\mu (T^a) c_L)(\bar{c}_L \gamma^\mu (T^a) b_L)$

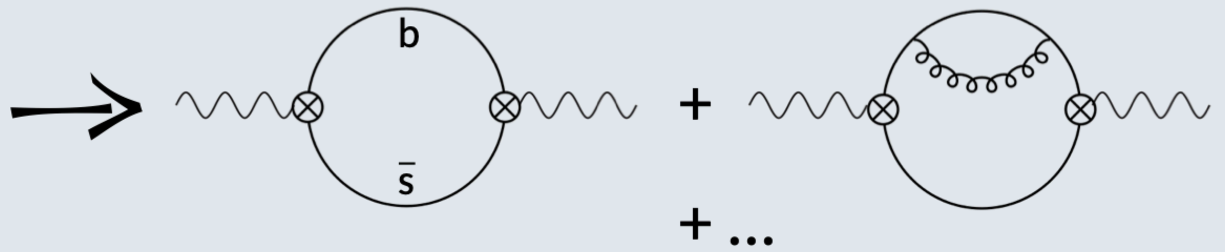
H is the nasty creature though it seems it requires the study of sad frogs

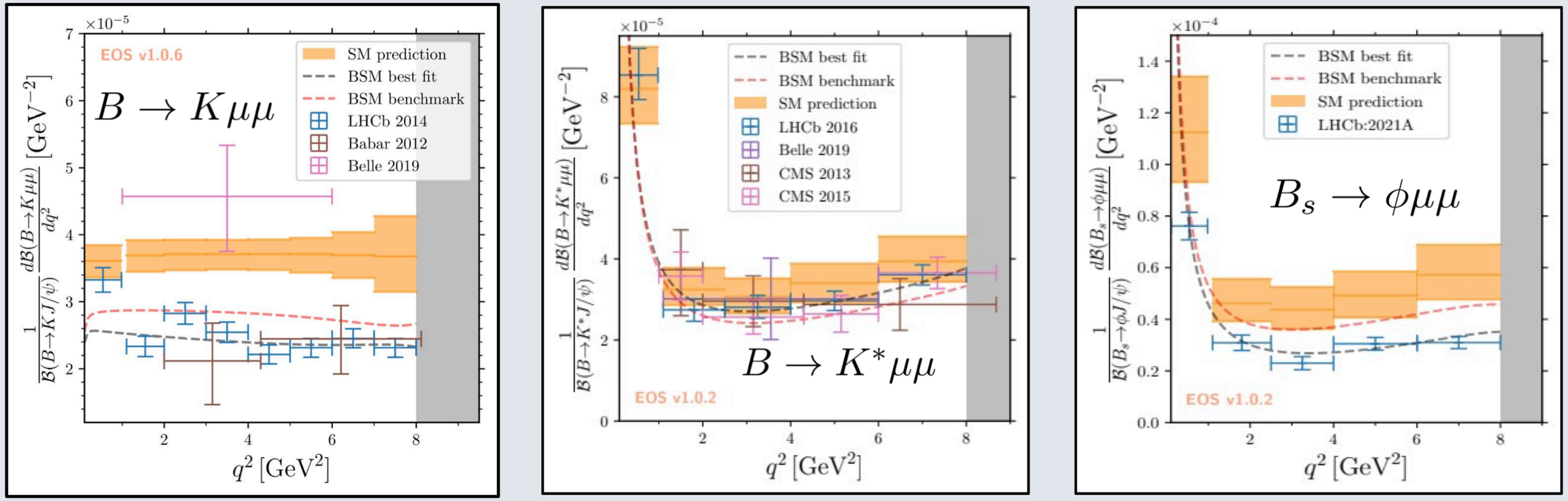
- **Main idea:** Compute the inclusive $e^+e^- \to \bar{b}s$ cross-section and relate it to the form factors [Bharucha, Feldmann, Wick '10]

$$\Pi^{\mu\nu}_\Gamma(q) \equiv i \int d^4x \, e^{iq\cdot x} \langle 0 | \mathcal{T} \left\{ J^\mu_\Gamma(x) J^{\dagger,\nu}_\Gamma(0) \right\} | 0 \rangle$$

1) Partonic calculation

Insertion of a scalar, vector or tensor current





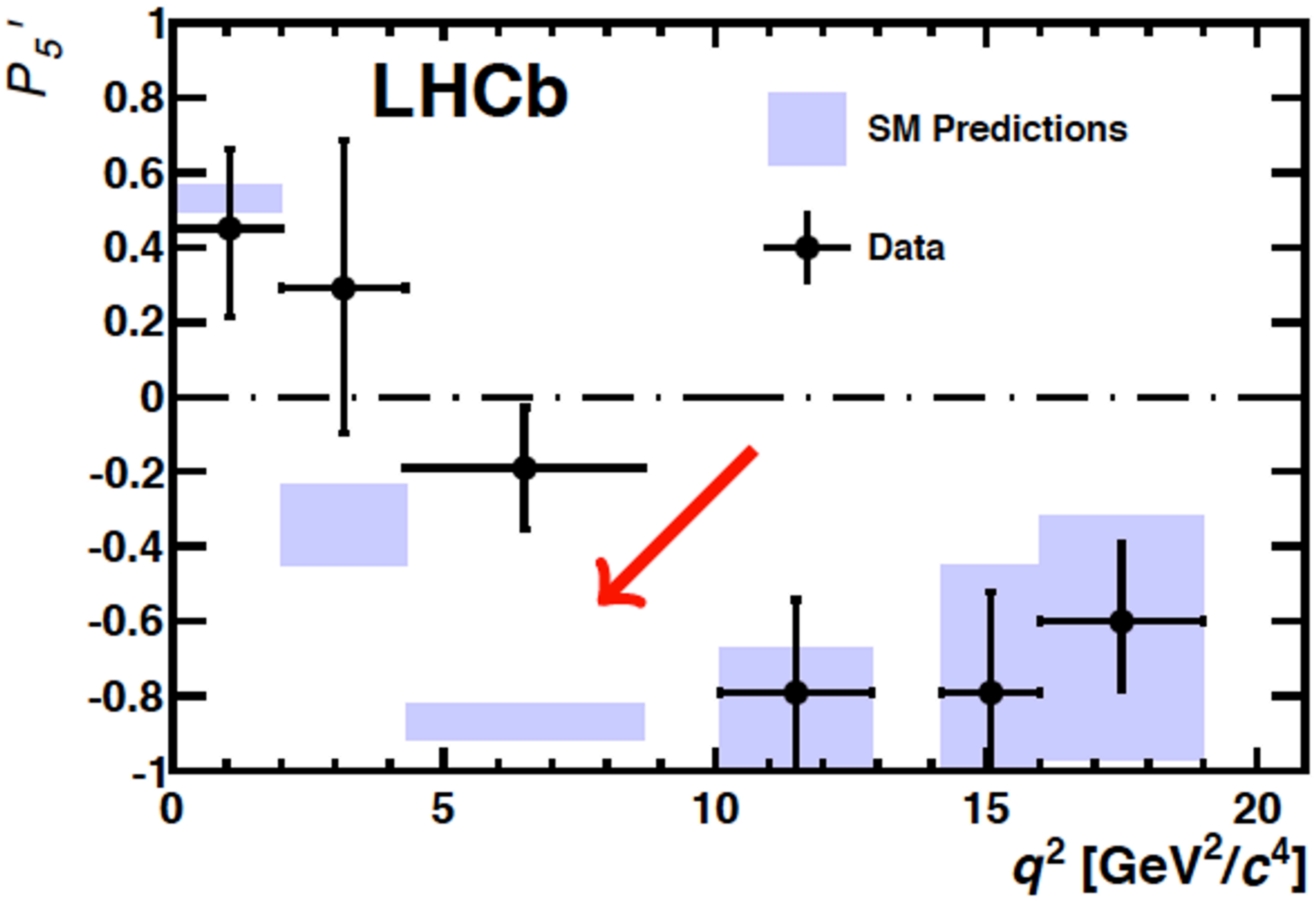
The “Complexity” of these transitions

…ugh it seems
… sad frogs

-section and relate it to the

→ Main

From a talk in 2013

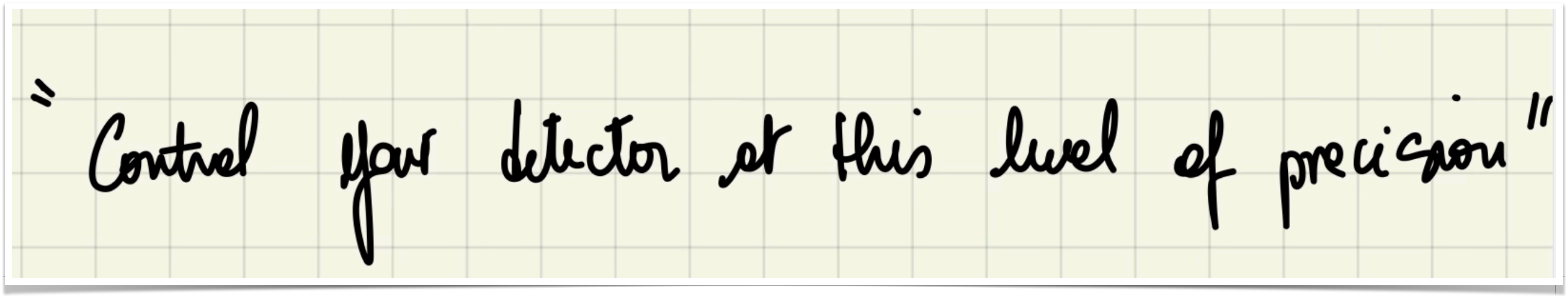


3.7 σ tension in one bin. What is happening here :

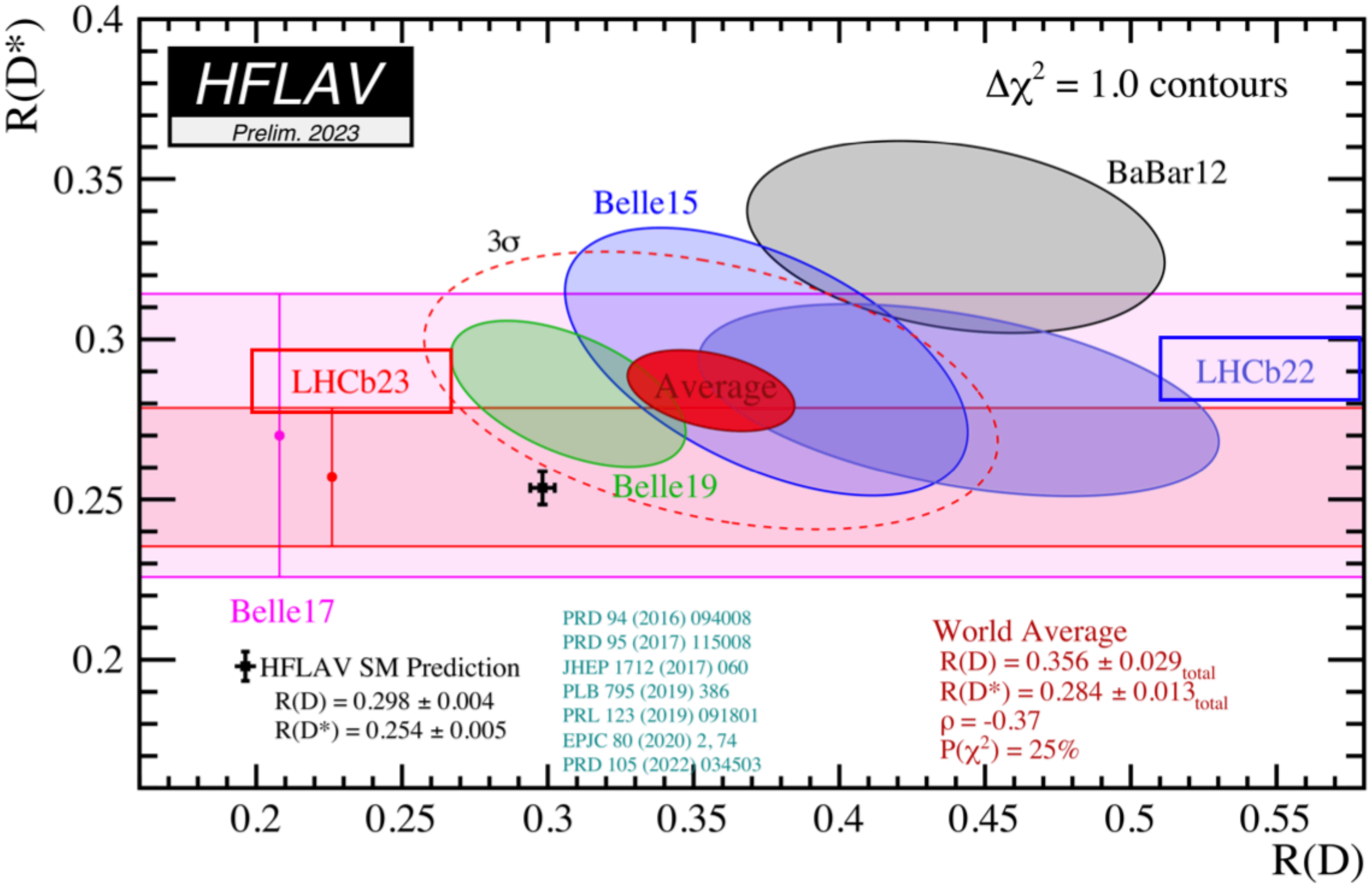
- A fluctuation ?
- How reliable is the theoretical prediction ?
- Is it a sign of New Physics ?
- Boh ! we have to understand what is happening.

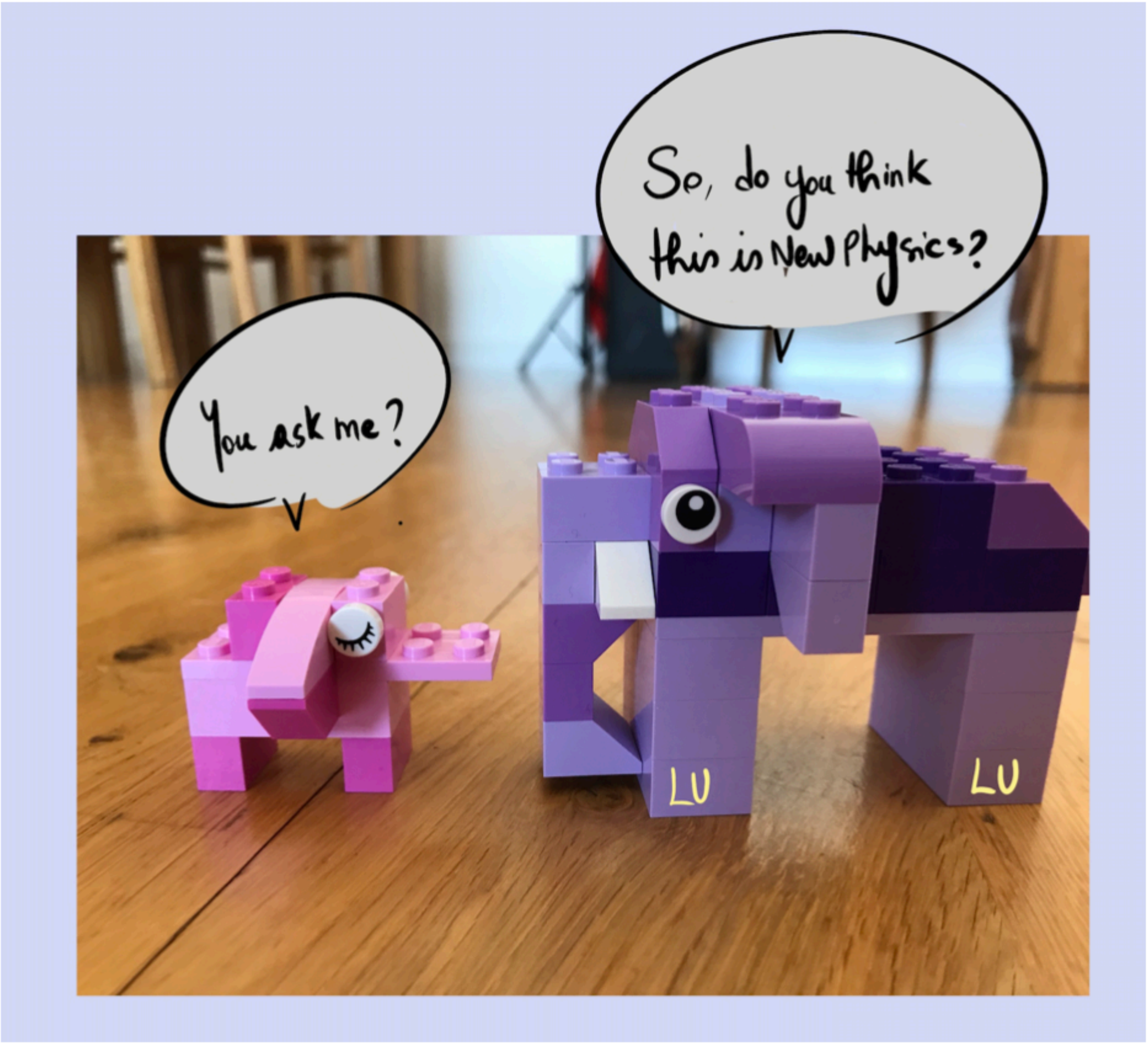
Patience required

This quote was applicable in so many places that I decided to just leave it here



Let's continue… charged currents





EFT for $b \to c\tau\bar{\nu}$

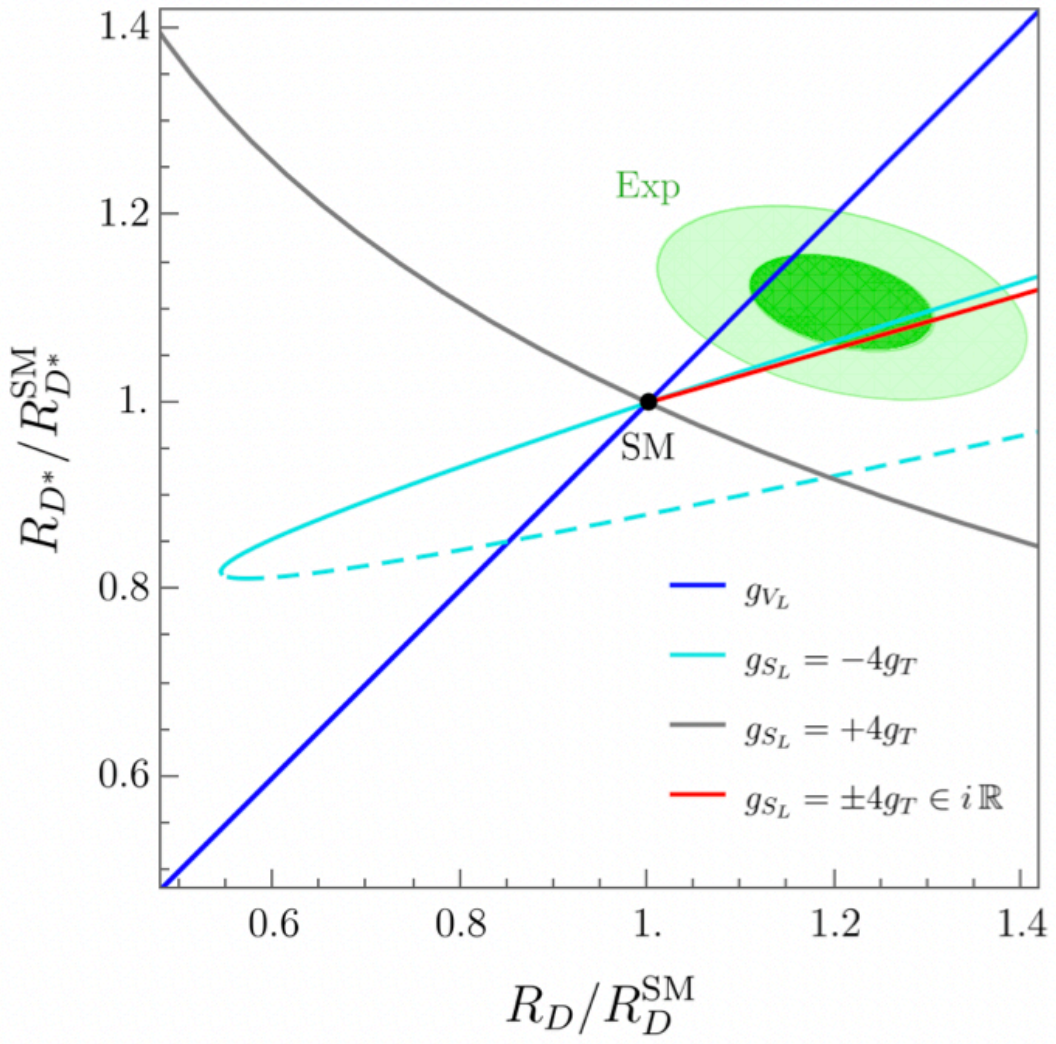
see e.g. [Angelescu, Becirevic, Faroughy, Jaffredo, **OS**, '21]

$$\mathcal{L}_{\text{eff}} = -2\sqrt{2}G_F V_{cb}\Big[(1+g_{V_L})(\bar{c}_L\gamma_\mu b_L)(\bar{\ell}_L\gamma_\mu\nu_L) + g_{V_R}(\bar{c}_R\gamma_\mu b_R)(\bar{\ell}_L\gamma_\mu\nu_L)$$
$$+ g_{S_R}(\bar{c}_L b_R)(\bar{\ell}_R\nu_L) + g_{S_L}(\bar{c}_R b_L)(\bar{\ell}_R\nu_L) + g_T(\bar{c}_R\sigma_{\mu\nu}b_L)(\bar{\ell}_R\sigma_{\mu\nu}\nu_L)\Big] + \text{h.c.}$$

- $SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge invariance implies that only g_{V_L}, g_{S_L}, g_{S_R} and g_T can break LFU at $d=6$.

- Few scenarios can accommodate data:
  - $U_1 \sim (\mathbf{3},\mathbf{1},2/3)$: g_{V_L}, g_{S_R}
  - $R_2 \sim (\mathbf{3},\mathbf{2},7/6)$: $g_{S_L} = 4g_T$
  - $S_1 \sim (\bar{\mathbf{3}},\mathbf{1},1/3)$: $g_{S_L} = -4g_T$, g_{V_L}

Only scalar/vector **leptoquarks** can **do the job**!

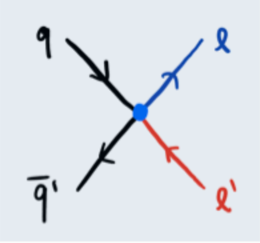


Connecting back to what happens in higher energy scales

SMEFT operators

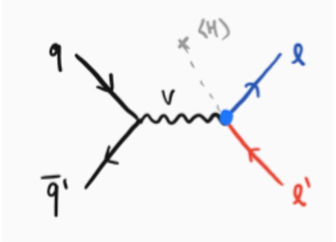
- *Warsaw* basis $d=6$: [Buchmuller, Wyler. '85], [Grzadkowski et al. '10]
- Operator classes contributing to $pp \to \ell\ell'$ at tree-level: ψ^4, $\psi^2 XH$, $\psi^2 D^2 H$

i) Four-fermion: ψ^4



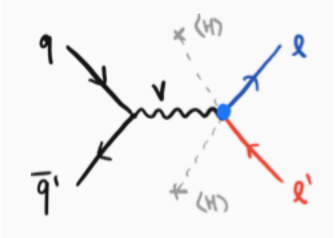
	$d=6$	ψ^4
Vector	$\mathcal{O}_{lq}^{(1)}$	$(\bar{l}_\alpha\gamma^\mu l_\beta)(\bar{q}_i\gamma_\mu q_j)$
Vector	$\mathcal{O}_{lq}^{(3)}$	$(\bar{l}_\alpha\gamma^\mu\tau^I l_\beta)(\bar{q}_i\gamma_\mu\tau^I q_j)$
Vector	$\mathcal{O}_{lu}$	$(\bar{l}_\alpha\gamma^\mu l_\beta)(\bar{u}_i\gamma_\mu u_j)$
Vector	$\mathcal{O}_{ld}$	$(\bar{l}_\alpha\gamma^\mu l_\beta)(\bar{d}_i\gamma_\mu d_j)$
Vector	$\mathcal{O}_{eq}$	$(\bar{e}_\alpha\gamma^\mu e_\beta)(\bar{q}_i\gamma_\mu q_j)$
Vector	$\mathcal{O}_{eu}$	$(\bar{e}_\alpha\gamma^\mu e_\beta)(\bar{u}_i\gamma_\mu u_j)$
Vector	$\mathcal{O}_{ed}$	$(\bar{e}_\alpha\gamma^\mu e_\beta)(\bar{d}_i\gamma_\mu d_j)$
Scalar	$\mathcal{O}_{ledq}$ + h.c.	$(\bar{l}_\alpha e_\beta)(\bar{d}_i q_j)$
Scalar	$\mathcal{O}_{lequ}^{(1)}$ + h.c.	$(\bar{l}_\alpha e_\beta)\varepsilon(\bar{q}_i u_j)$
Tensor	$\mathcal{O}_{lequ}^{(3)}$ + h.c.	$(\bar{l}_\alpha\sigma^{\mu\nu}e_\beta)\varepsilon(\bar{q}_i\sigma_{\mu\nu}u_j)$

ii) Leptonic dipoles: $\psi^2 XH$



$d=6$	$\psi^2 XH$ + h.c.
$\mathcal{O}_{eW}$	$(\bar{l}_\alpha\sigma^{\mu\nu}e_\beta)\,\tau^I H W_{\mu\nu}^I$
$\mathcal{O}_{eB}$	$(\bar{l}_\alpha\sigma^{\mu\nu}e_\beta)\,H B_{\mu\nu}$

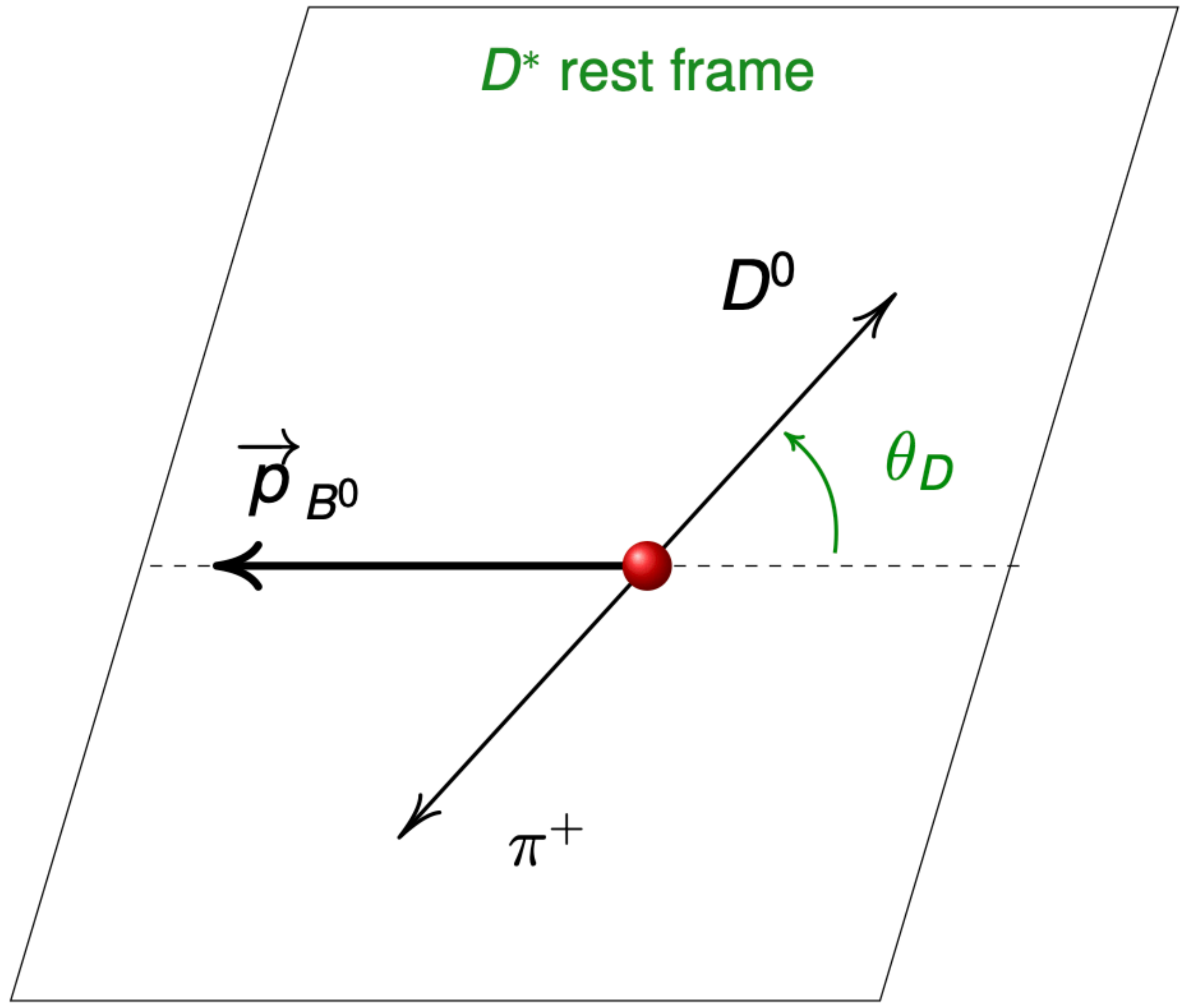
iii) Z/W-coupling modifications: $\psi^2 D^2 H$

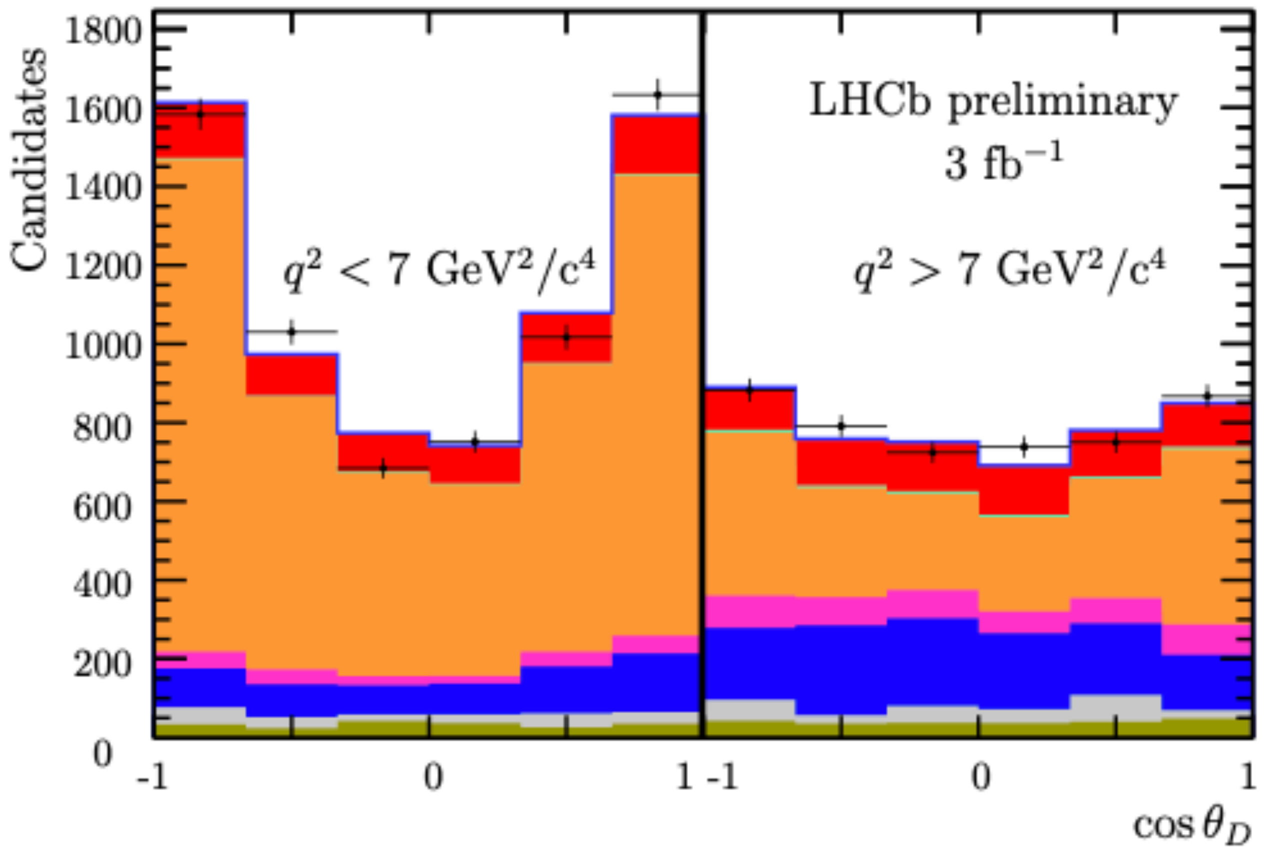


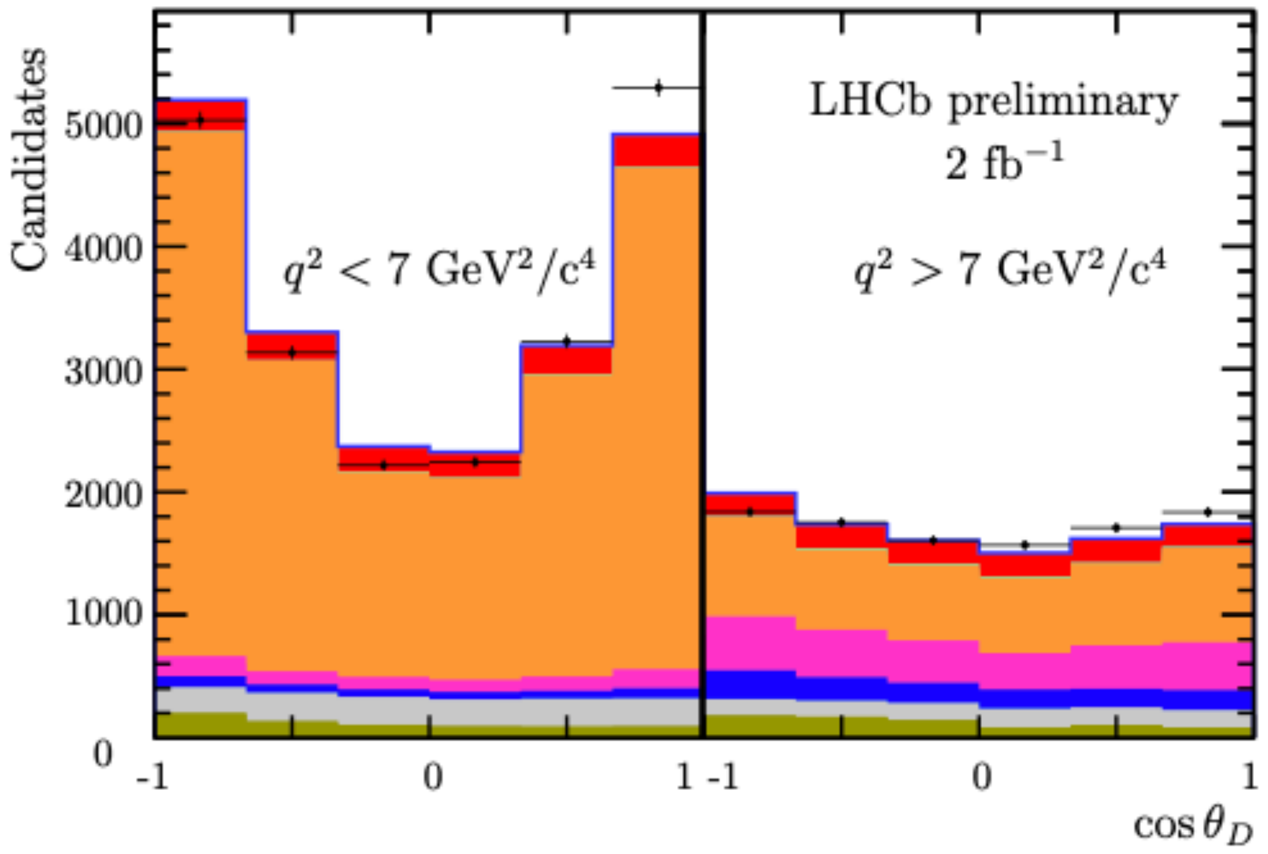
$d=6$	$\psi^2 H^2 D$
$\mathcal{O}_{Hl}^{(1)}$	$(\bar{l}_\alpha\gamma^\mu l_\beta)(H^\dagger i\overleftrightarrow{D}_\mu H)$
$\mathcal{O}_{Hl}^{(3)}$	$(\bar{l}_\alpha\gamma^\mu\tau^I l_\beta)(H^\dagger i\overleftrightarrow{D}^I_\mu H)$
$\mathcal{O}_{He}$	$(\bar{e}_\alpha\gamma^\mu e_\beta)(H^\dagger i\overleftrightarrow{D}_\mu H)$

We have seen a lot of activity in model building land in the last years.
Let's see in the future will scenario will be viable.

LHCb enters the game of semi-leptonic angular analyses







$F_L^{D^*}$ value extracted for the 3 q^2 region

$q^2 < 7\,\mathrm{GeV}^2/c^4$:	$0.51 \pm 0.07(stat) \pm 0.03(syst)$
$q^2 > 7\,\mathrm{GeV}^2/c^4$:	$0.35 \pm 0.08(stat) \pm 0.02(syst)$
q^2integrated :	$0.43 \pm 0.06(stat) \pm 0.03(syst)$

- All values are found to be compatible with the SM within 1σ

" It would be nice to have the other angular observable. "

Test on forward-backward asymmetry:

$$\mathcal{A}_{\mathrm{FB}} = \frac{\int_0^1 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell - \int_{-1}^0 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell}{\int_0^1 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell + \int_{-1}^0 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell}$$

$$\Delta\mathcal{A}_{\mathrm{FB}} = \mathcal{A}_{\mathrm{FB}}^{\mu} - \mathcal{A}_{\mathrm{FB}}^{e}$$

Preliminary

$$\mathcal{A}_{\mathrm{FB}}^{e} = 0.219 \pm 0.011 \pm 0.020\,,$$
$$\mathcal{A}_{\mathrm{FB}}^{\mu} = 0.215 \pm 0.011 \pm 0.022\,,$$
$$\boxed{\Delta\mathcal{A}_{\mathrm{FB}} = (-4 \pm 16 \pm 18) \times 10^{-3}}$$

Test on D* longitudinal polarization fraction:

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_V} = \frac{3}{2}\left(F_L \cos^2\theta_V + \frac{1-F_L}{2}\sin^2\theta_V\right)$$

$$\Delta F_L = F_L^{\mu} - F_L^{e}$$

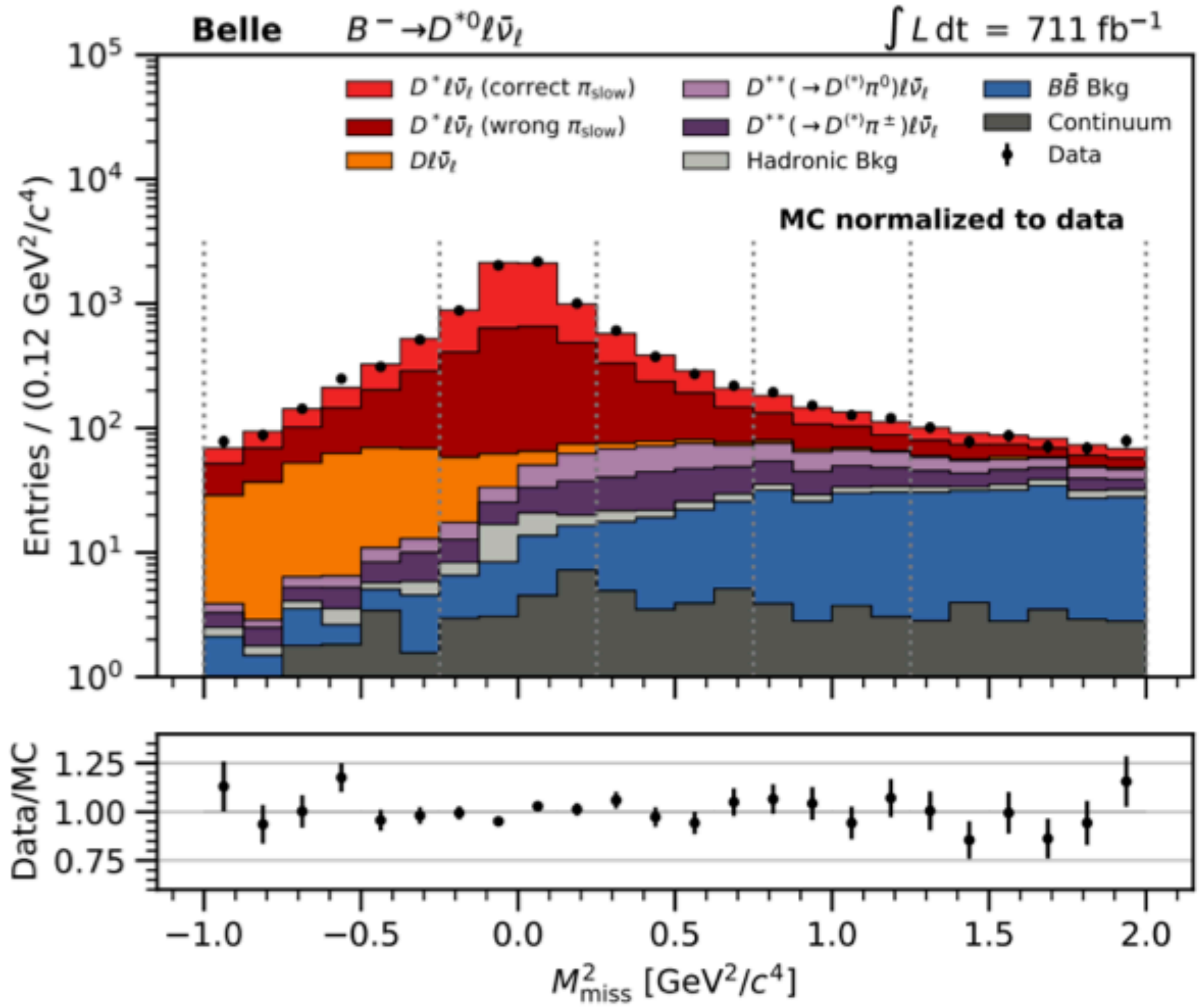
Preliminary

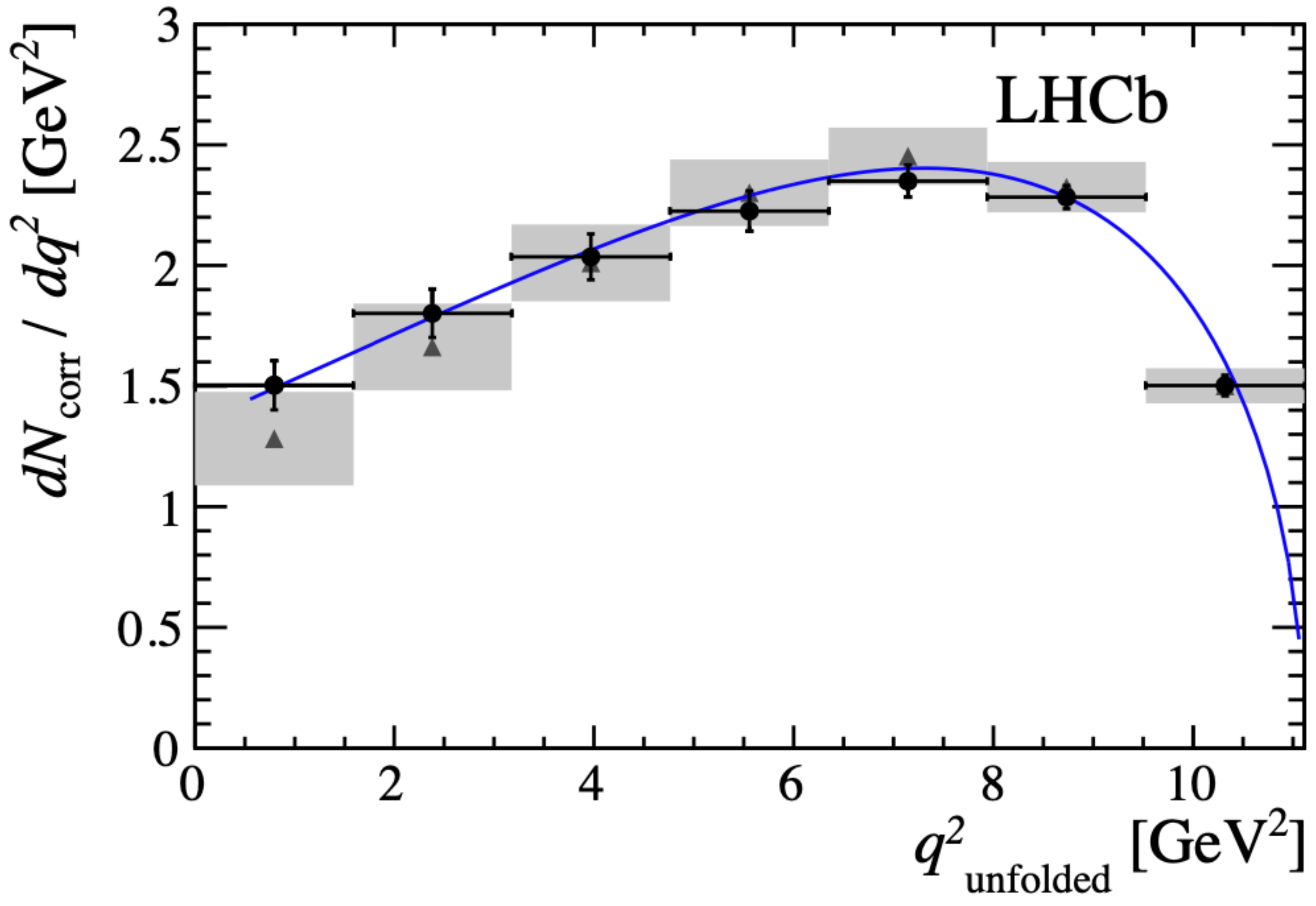
$$F_L^{e} = 0.521 \pm 0.005 \pm 0.007$$
$$F_L^{\mu} = 0.534 \pm 0.005 \pm 0.006$$
$$\boxed{\Delta F_L = 0.013 \pm 0.007 \pm 0.007}$$

6

Interesting discussions about the possibilities with Hadronic taggers @ Belle 2

What we also need to understand the differential shape of our signals together with dedicates studies of all the charm and double charm backgrounds





Remember what we had seen in kaons ?

Preliminary numerics including X_t@NNLO

$$\text{BR}(K^+ \to \pi^+ \nu\bar{\nu})^{\text{SM}} = 8.25(11)_{\text{SD}}(25)_{\text{LD}}(57)_{\text{para}} \times 10^{-11}$$
$$\text{BR}(K_L \to \pi^0 \nu\bar{\nu})^{\text{SM}} = 2.83(1)_{\text{SD}}(2)_{\text{LD}}(30)_{\text{para}} \times 10^{-11}$$

We need to know well V_{cb} and V_{ub}

$$\Gamma \propto |V_{cb}|^2 m_b^5 \Big[\Gamma_0 + \Gamma_0^{(1)}\frac{\alpha_s}{\pi} + \Gamma_0^{(2)}\left(\frac{\alpha_s}{\pi}\right)^2 + \Gamma_0^{(3)}\left(\frac{\alpha_s}{\pi}\right)^3 + \frac{\mu_\pi^2}{m_b^2}\left(\Gamma^{(\pi,0)} + \frac{\alpha_s}{\pi}\Gamma^{(\pi,1)}\right) + \frac{\mu_G^2}{m_b^2}\left(\Gamma^{(G,0)} + \frac{\alpha_s}{\pi}\Gamma^{(G,1)}\right) + \frac{\rho_D^3}{m_b^3}\left(\Gamma^{(D,0)} + \Gamma_0^{(1)}\left(\frac{\alpha_s}{\pi}\right)\right) + \mathcal{O}\left(\frac{1}{m_b^4}\right) + \cdots\Big)$$

I told you we love a Taylor Expansion

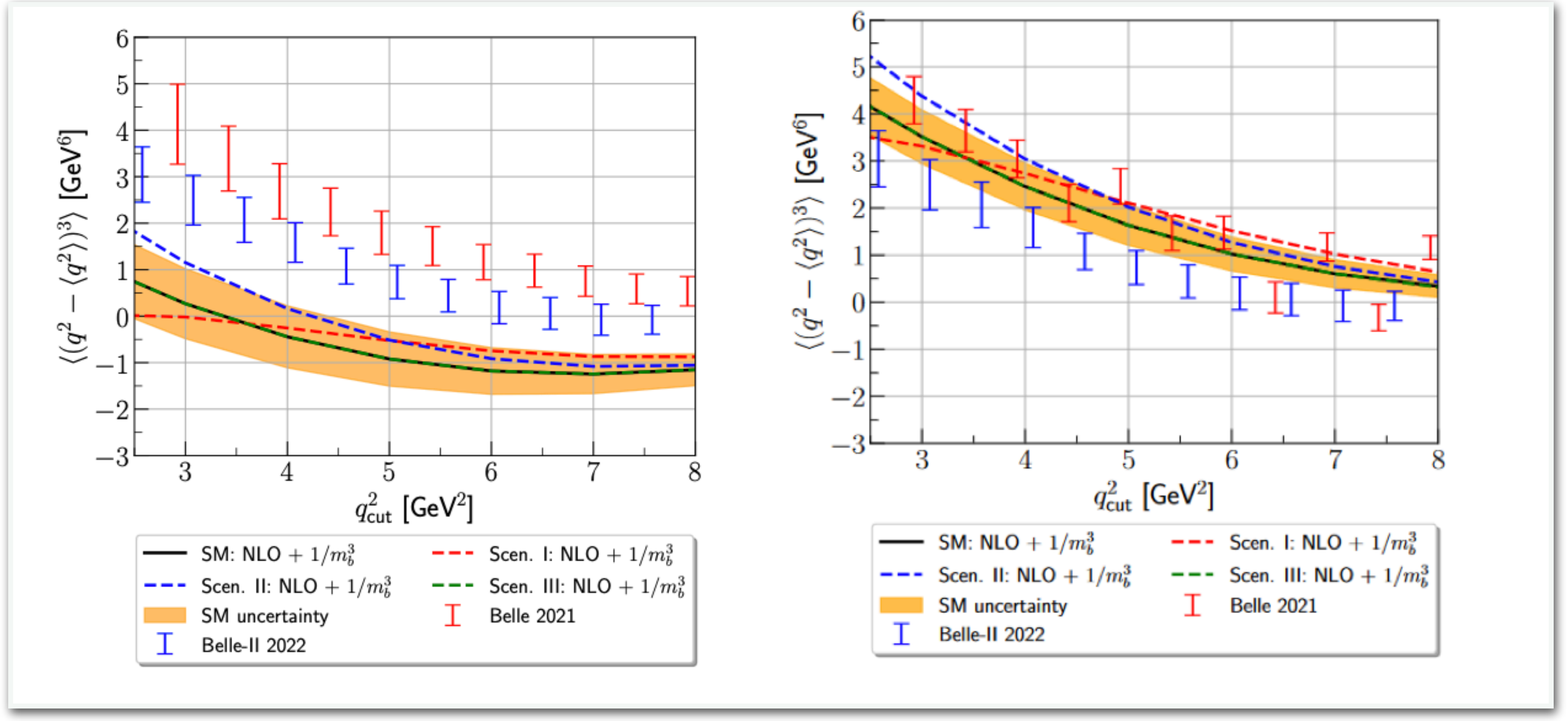
Bernlochner, Welsch, Fael, Olschewsky, Persson, van Tonder, KKV [2205.10274]

$$|V_{cb}|^{q^2}_{\text{incl}} = (41.69 \pm 0.63) \times 10^{-3}$$

- Higher order coefficients important to check convergence of the HQE

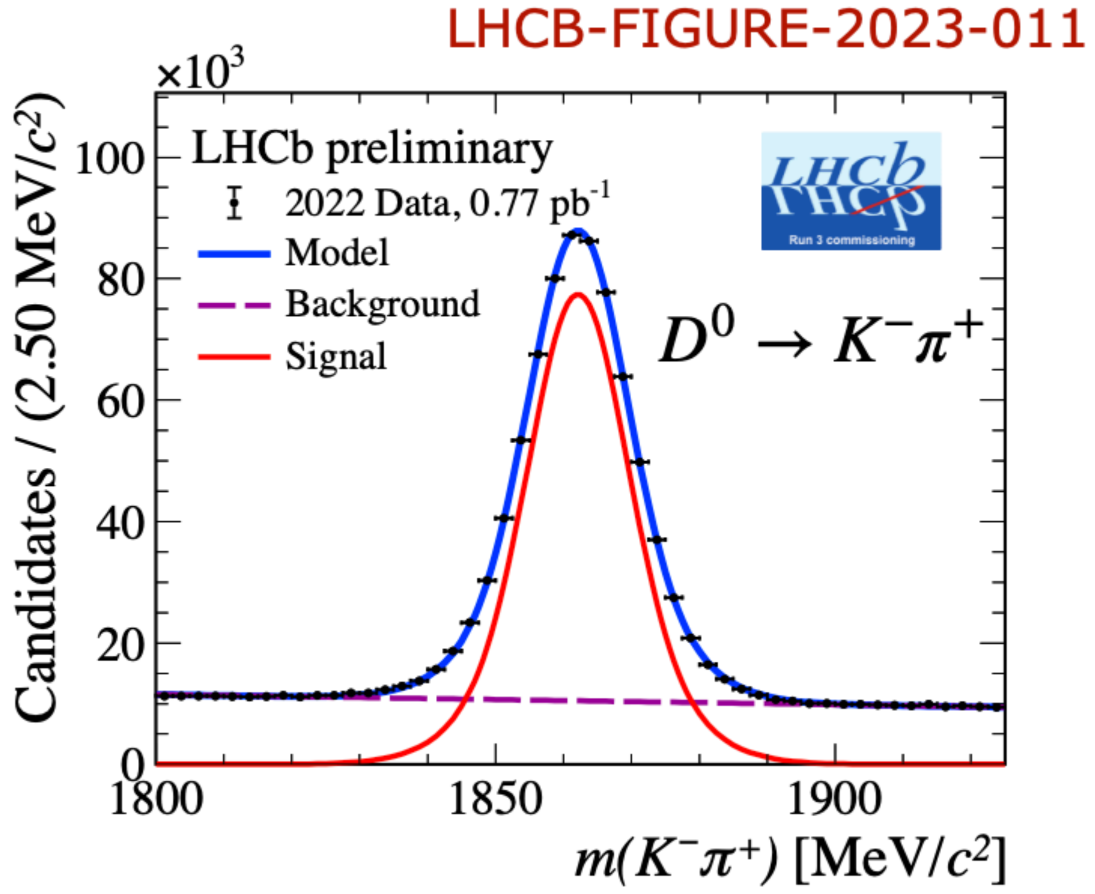
$$r_E^4 = (0.02 \pm 0.34) \cdot 10^{-1}\text{GeV}^4 \quad r_G^4 = (-0.21 \pm 0.69)\text{GeV}^4$$

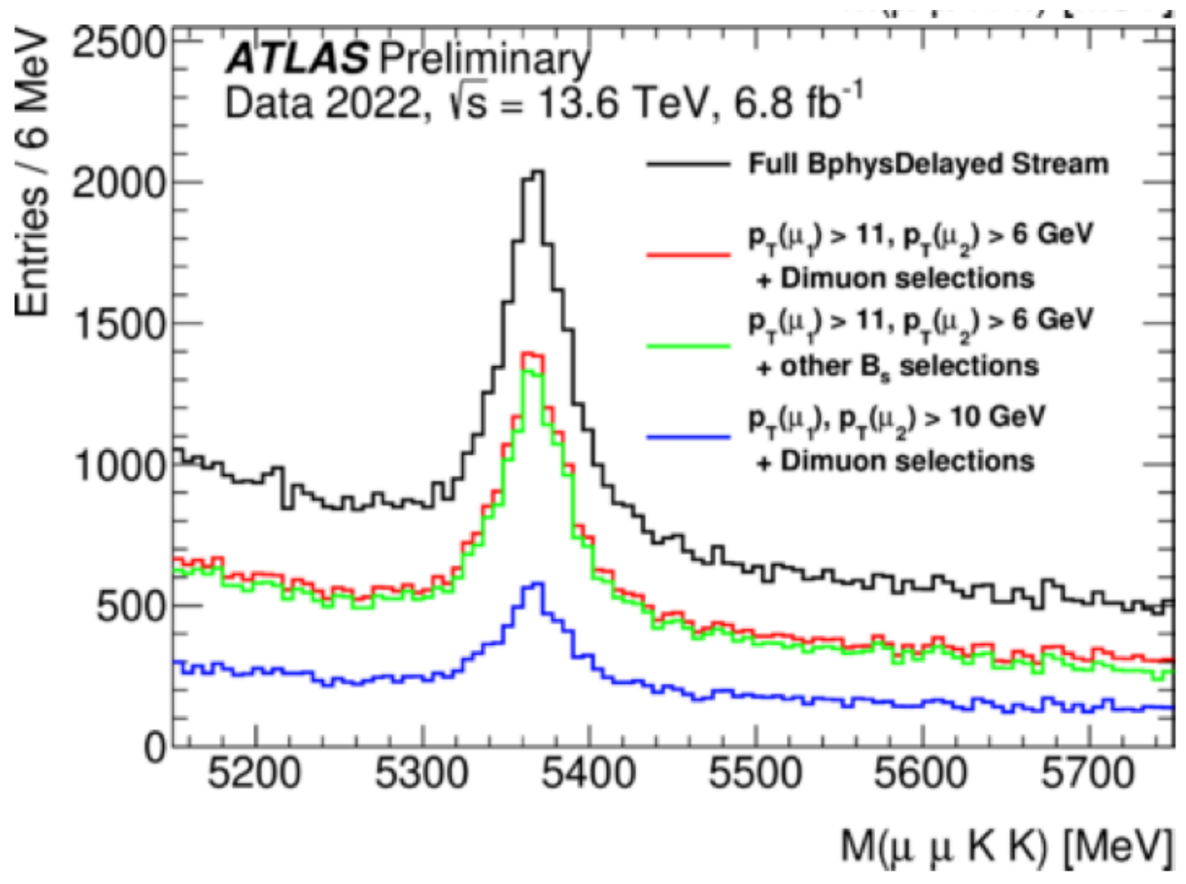
- Inputs for $B \to X_u \ell\nu$ Next, B lifetimes and $B \to X_s \ell\ell$ KKV, Huber, Lenz, Rusov, et al.
- Additional 0.23 uncertainty due to missing higher orders
- In progress: Calculation of $1/m_c^2 1/m_b^3$ terms Mannel, Mulatin, KKV [in progress]

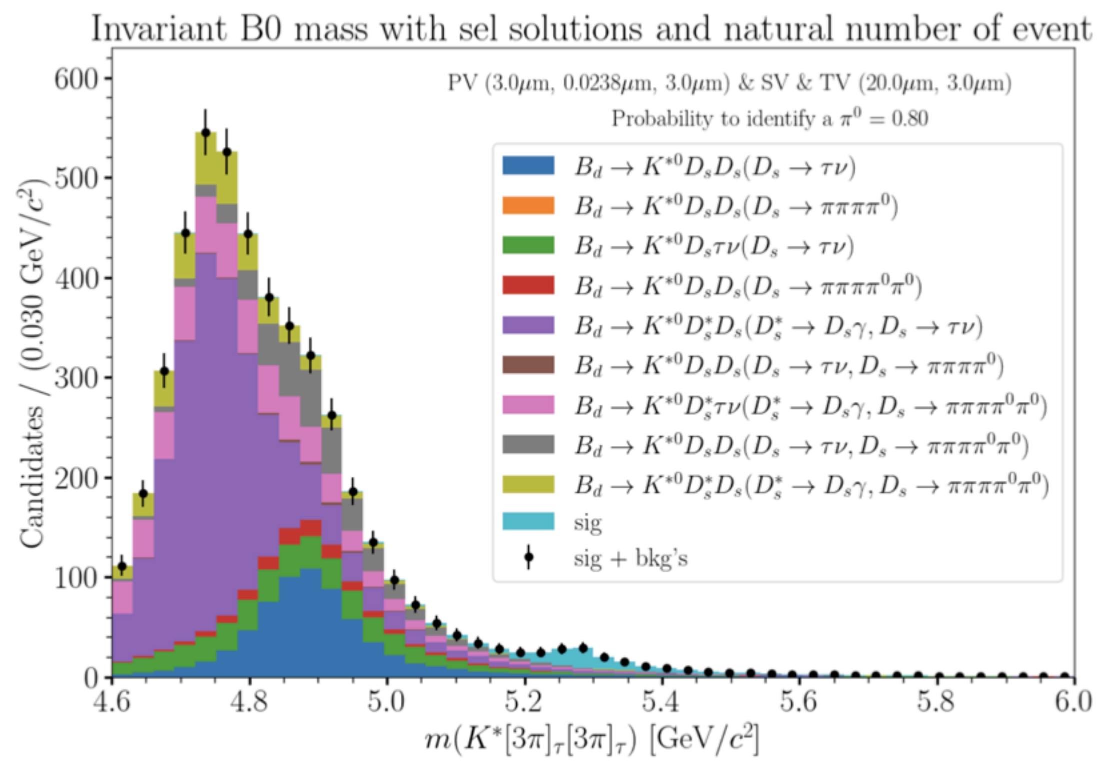


" if you have NP and you don't fit for it where would it hide?"

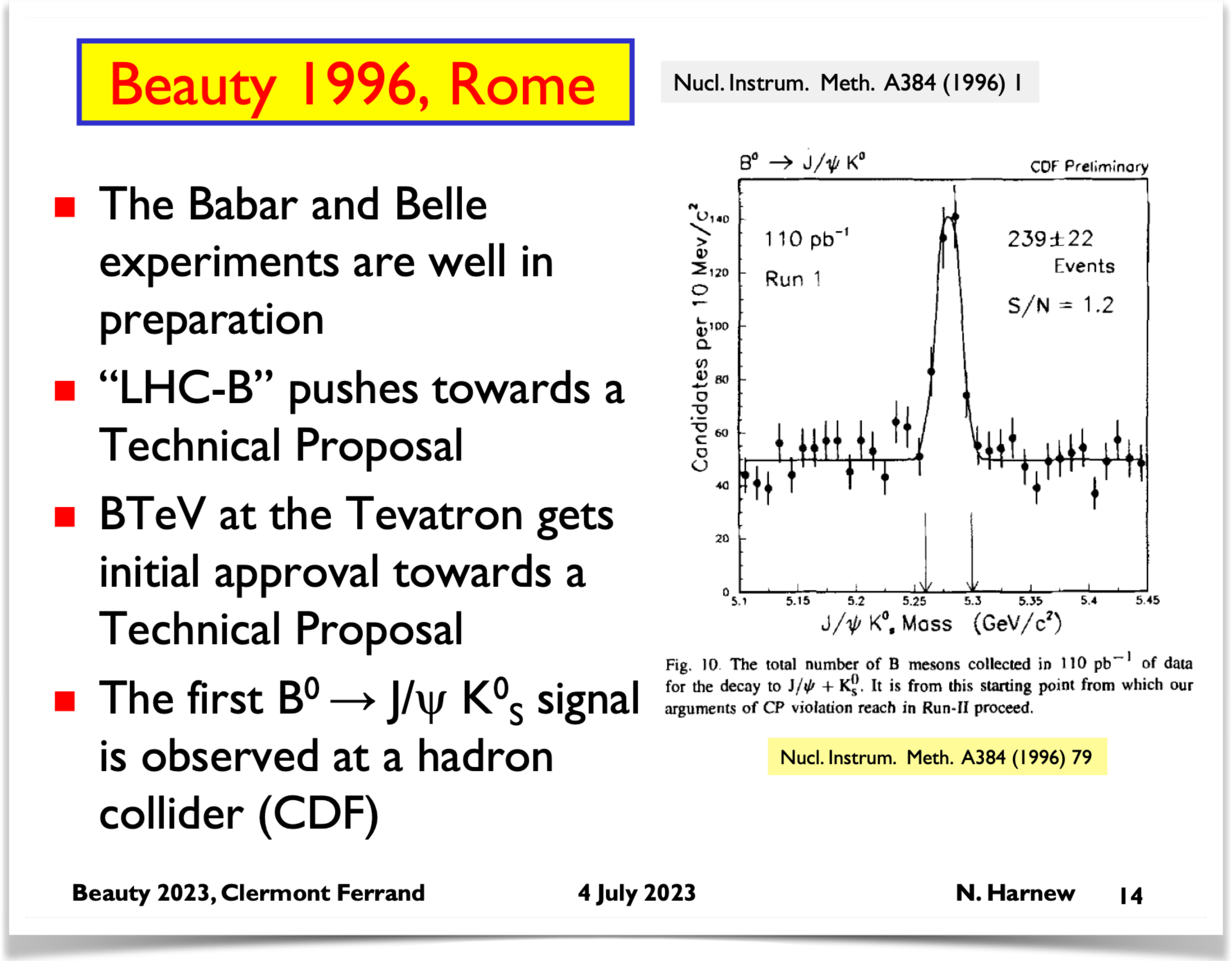
To those working on early data and/or simulations







Remember everything starts with a mass peak



History is to back you up

This is my first Beauty conference and I have enjoyed it immensely

Diversity(*) is key
theory/experiment, type of experiment, type of theory

In Surgery doctors say:

“la confiance n'exclut pas le contrôle”

Science is made by humans
so we also need a diversity in
gender, geography and everything else.

Thank you

(*) proper diversity, not just tokenism

Inspired by Ben Allanach - a shameless plug

Jul 12, 2022 · 2 min

Are there questions or comments ?

I recently attended a major conference in High Energy Physics called ICHEP. It was held in beautiful Bologna (Italy). The conference is...

[Are there questions or comments]()

…but please don't forget

"Don't Google Beauty 1995"

"I like these papers because they are very honest about what they can and can not do"