We have come a long way…

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LNF/INFN

Implications of LHCb measurements and future prospects
13th edition
CERN, 25-27 October 2023


We have come a long way...

LHCb: flavour and more!

- ~ 700 physics papers (most per author of any LHC experiment)
- Many significant discoveries
  - Rare decays
  - CP violation
  - 64 of the 72 hadronic particles discovered at the LHC
- Breadth of physics program
  - Heavy ions
  - Electroweak
  - Fixed target (He, Ne, Ar,…)…

Let us turn back the clock…

60 years of the Cabibbo angle!

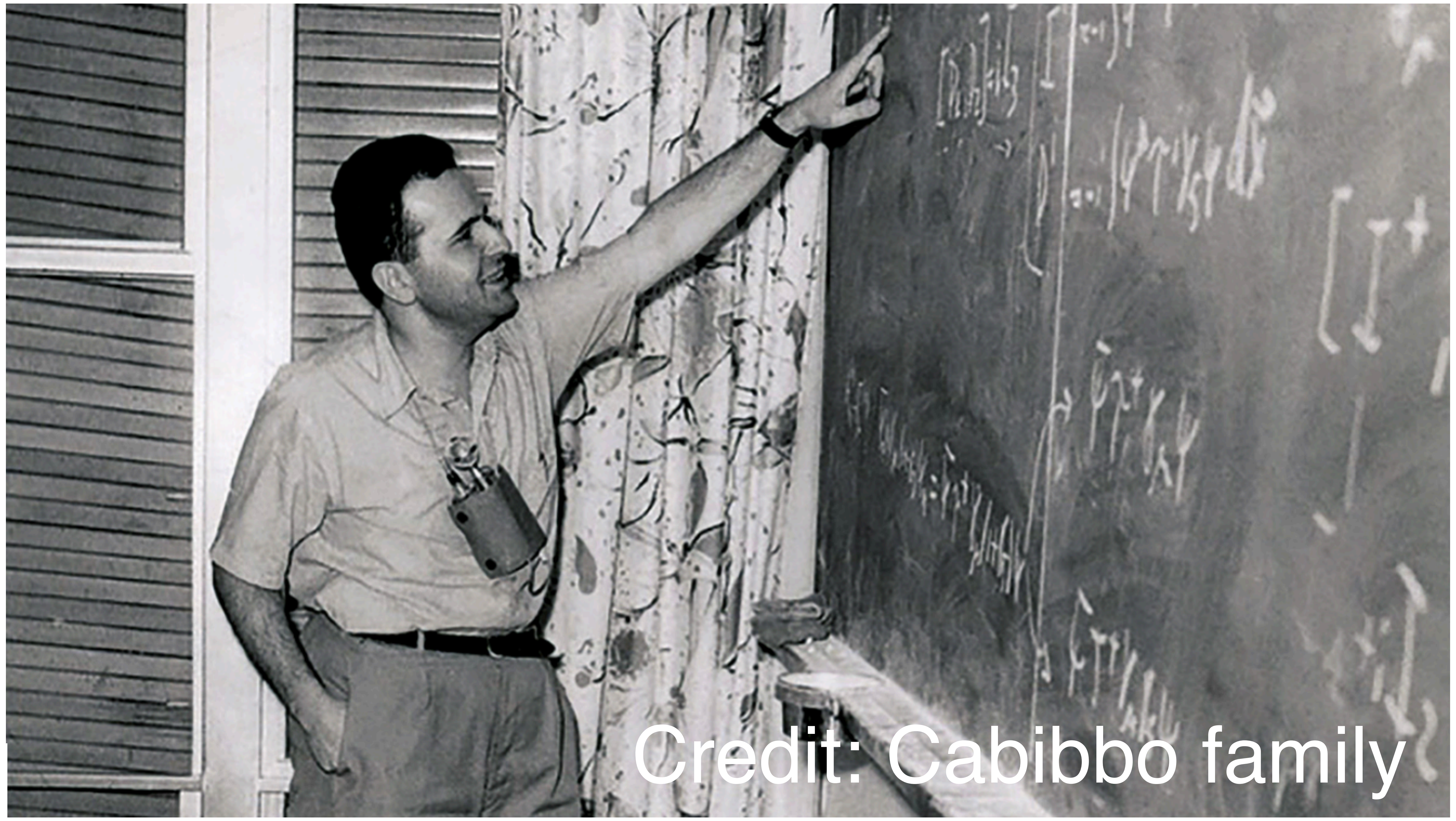
(and 50 of Kobayashi-Maskawa theory!)

- First building block of what we now call “Flavour physics” was laid down by Nicola Cabibbo in 1963 long before many of the ingredients of the SM were understood

- Cabibbo’s theory of semileptonic decays provided the first step towards a unified description of hadronic and leptonic weak interactions

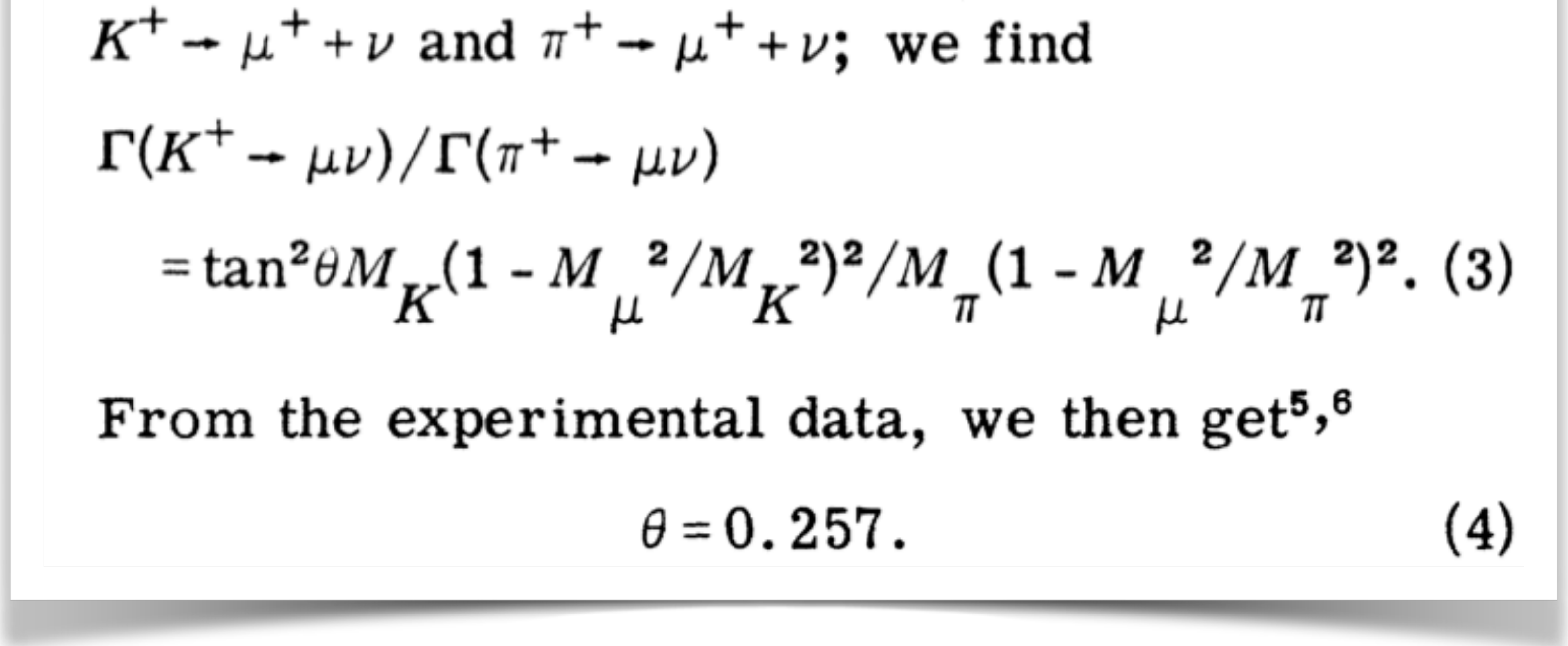
$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L, \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L, \begin{pmatrix} u \\ d' \end{pmatrix}_L = \begin{pmatrix} u \\ d\cos\theta_C + s\sin\theta_C \end{pmatrix}_L$$

- u quark is coupled by the weak interaction only to one, specific superposition of d and s, the Cabibbo combination ($d\cos\theta_c + s\sin\theta_c$)



Credit: Cabibbo family

Unitary Symmetry and Leptonic Decays
PRL 10, 531 (1963)



To determine θ, let us compare the rates for $K^+ \to \mu^+ + \nu$ and $\pi^+ \to \mu^+ + \nu$; we find

$$\Gamma(K^+ \to \mu\nu)/\Gamma(\pi^+ \to \mu\nu)$$
$$= \tan^2\theta M_K(1 - M_\mu{}^2/M_K{}^2)^2/M_\pi(1 - M_\mu{}^2/M_\pi{}^2)^2. \quad (3)$$

From the experimental data, we then get[5,6]

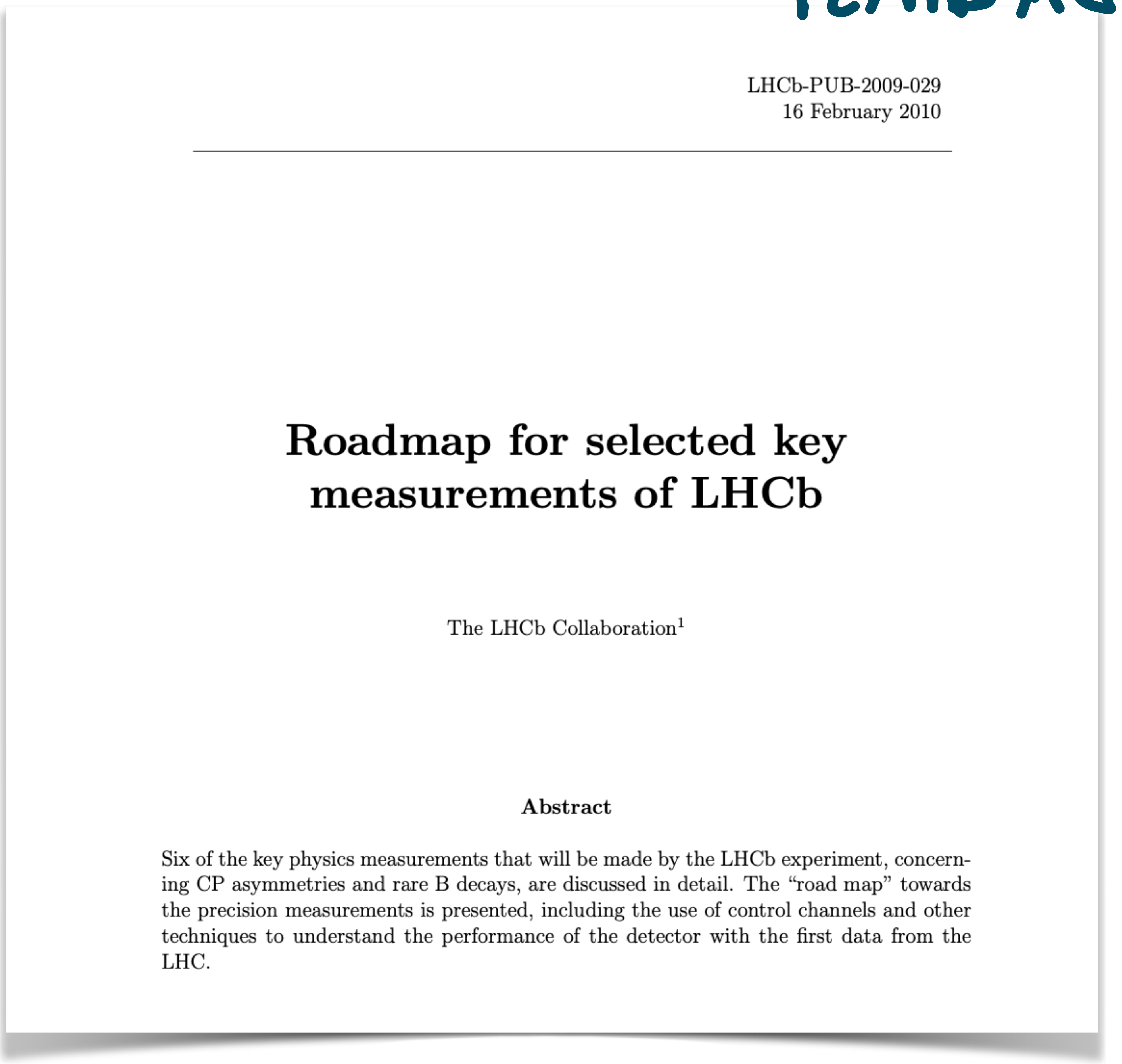
$$\theta = 0.257. \quad (4)$$

Roadmap for six selected key measurements [Feb. 2010]

13

YEARS AGO

1. The tree level determination of γ
2. Charmless charged two-body B decays
3. Measurement of mixing-induced CP violation in $B_s^0 \rightarrow J/\psi\phi$
4. Analysis of the decay $B_s^0 \rightarrow \mu^+\mu^-$
5. Analysis of the decay $B^0 \rightarrow K^{*0}\mu^+\mu^-$
6. Analysis of $B_s^0 \rightarrow \phi\gamma$ and other radiative B decays



LHCb-PUB-2009-029
16 February 2010

Roadmap for selected key measurements of LHCb

The LHCb Collaboration[1]

Abstract

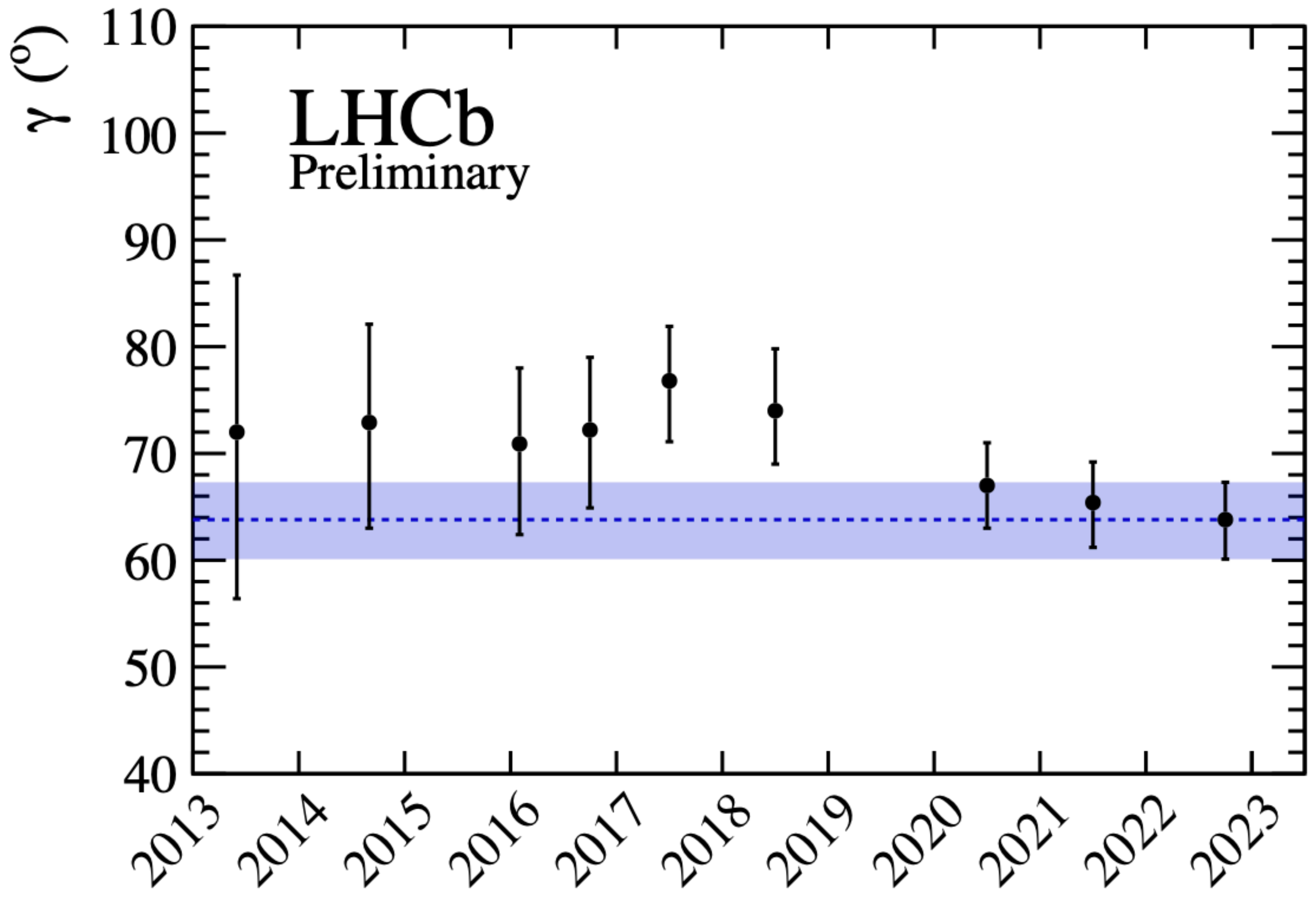
Six of the key physics measurements that will be made by the LHCb experiment, concerning CP asymmetries and rare B decays, are discussed in detail. The "road map" towards the precision measurements is presented, including the use of control channels and other techniques to understand the performance of the detector with the first data from the LHC.

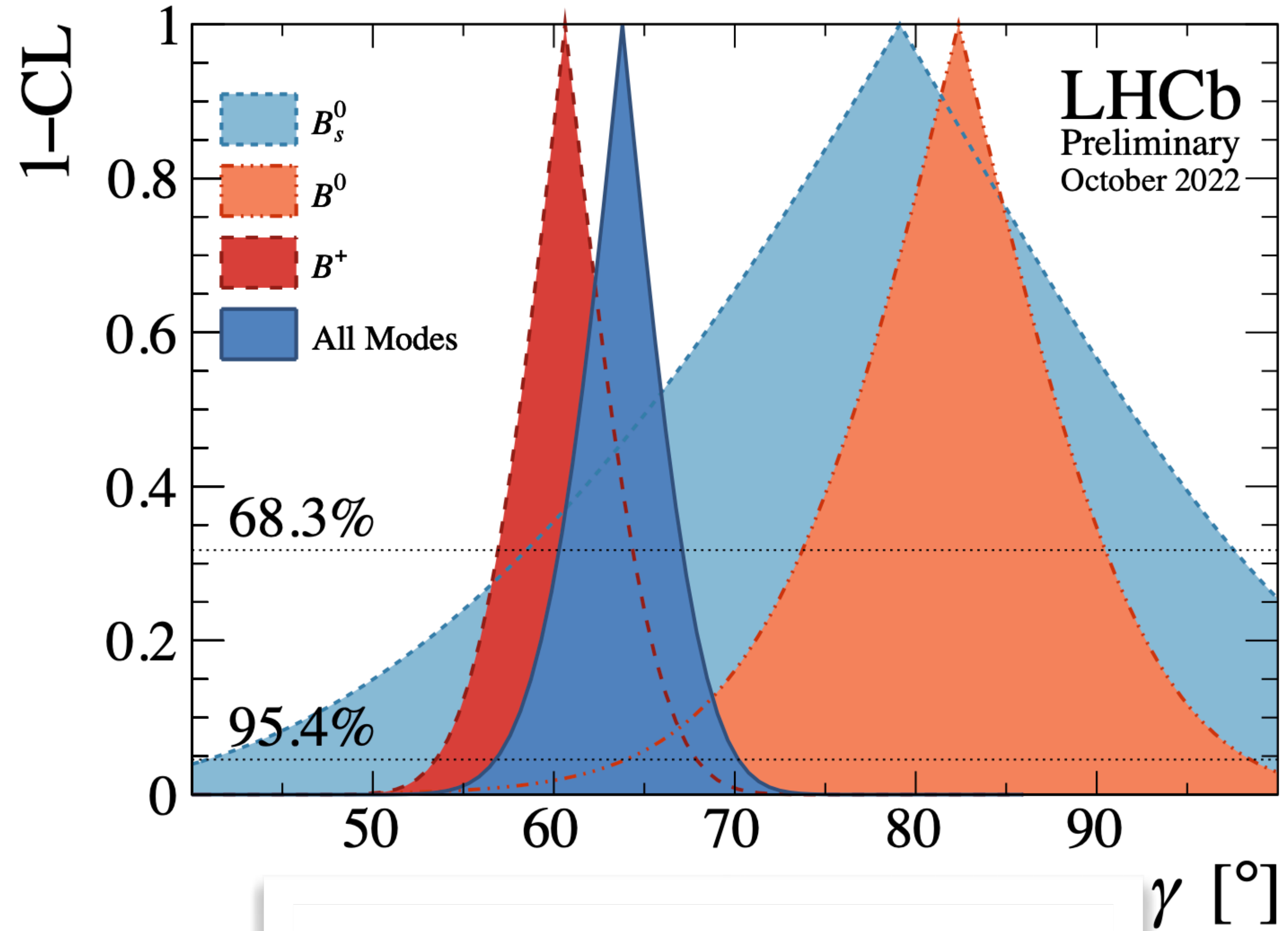
The tree level determination of γ

- The only angle that can be measured purely from tree-level decays
- We anticipated a precision of 2.5°-3° (rescaling to Run 1&2 luminosities)
- We obtained: $\gamma = \left(63.8^{+3.5}_{-3.7}\right)^\circ$ ~5% uncertainty

Uncertainty on α is $\sim 4^\circ$

- In excellent agreement with indirect CKM fit predictions $\gamma = \left(64.9 \pm 1.4\right)^\circ$ (UTfit), $\gamma = \left(65.5^{+1.1}_{-2.7}\right)^\circ$ (CKMfitter)
- Uncertainty still statistically dominated (contribution of syst. uncertainties $\sim 1.4^\circ$)





LHCB-CONF-2022-003

Measurement of mixing-induced CP violation in $B_s^0 \to J/\psi\phi$

- Tiny CP-violating phase ϕ_s arising from interference between mixing and decay amplitudes in B_s^0 decays

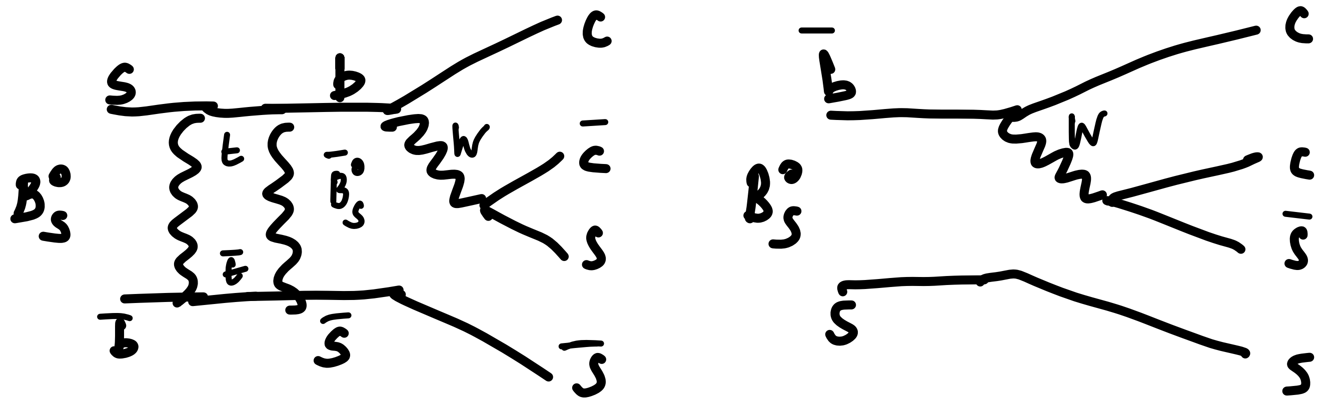
- We anticipated a tagging power $\epsilon_{\rm tag}(1-w)^2 \sim 6\,\%$, we achieved ~$4.4\,\%$

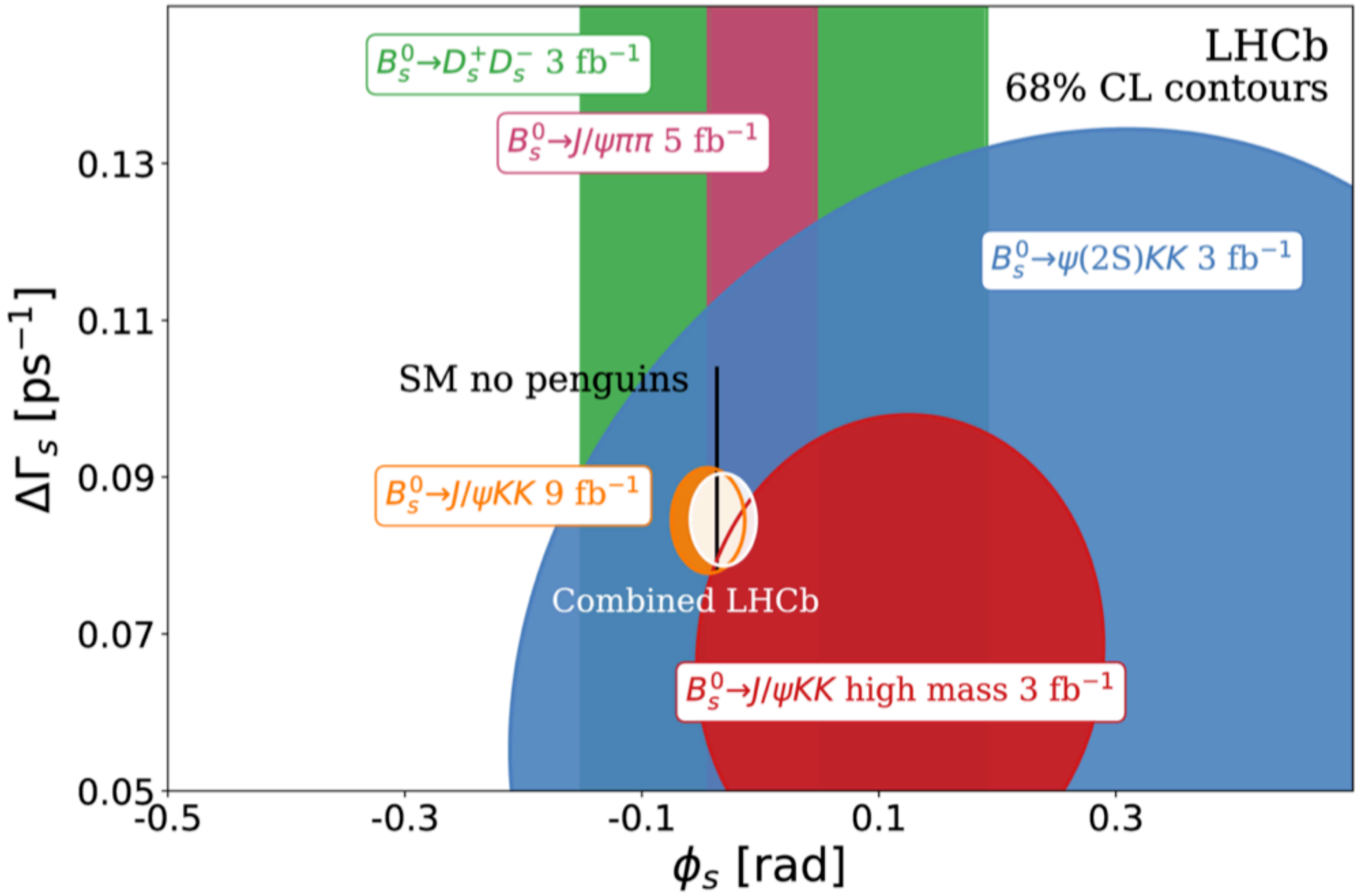
- We anticipated a proper time resolution of ~40 fs, we achieved ~42 fs

- We anticipated a statistical uncertainty of ~15 mrad; most recent result gives [6 fb^{-1}]

$$\phi_s = -0.039 \pm 0.022_{\rm stat} \pm 0.006_{\rm syst}\ \text{rad}$$

- All LHCb combined: $\phi_s = -0.031 \pm 0.018\ \text{rad}$





$\phi_s = -0.0370 \pm 0.0010$ rad (UTfitter)

Most precise measurement to date, in agreement with SM

arXiv:2308.01468

Analysis of the decay $B_s^0 \to \mu^+\mu^-$

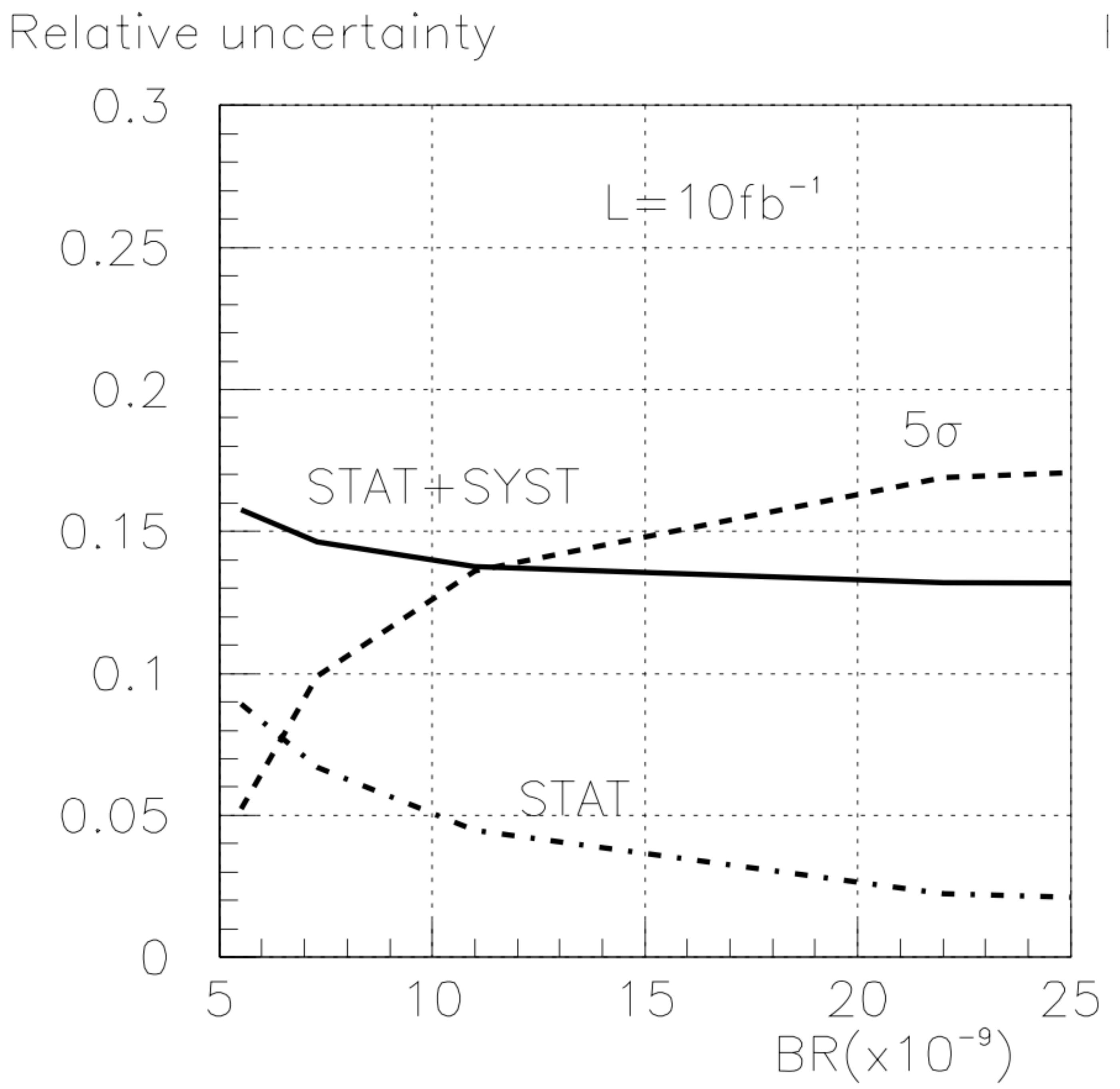
- Very suppressed in the SM (loop, $|V_{ts}|^2$, helicity ~ $\left(\frac{m_\mu}{M_B}\right)^2$), theoretically “clean”, sensitive to NP
- At the time we assumed a systematic uncertainty of ~ 13% due to the limited knowledge of the relative production rates of B_s^0 mesons compared to B^0 or B^+ mesons

f_d, f_s: probabilities for a b-quark to hadronise into a $B^{+,0}$, B_s^0

- $$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \frac{\mathcal{B}_{\text{norm}}\epsilon_{\text{norm}} f_d}{N_{\text{norm}}\epsilon_{\text{sig}} f_s} \times N_{B_s^0 \to \mu^+\mu^-}$$

$N_{norm} \leftarrow B^+ \to J/\psi K^+$
$B^0 \to K^+ \pi^-$

- LHCb measured $f_s/f_d = 0.254 \pm 0.008$ at $\sqrt{s} = 13\,\text{TeV}$
  - found a significant dependence of f_s/f_d on $\sqrt{s}$ and B-meson p_T
- This (p_T-dependent) measurement also used by CMS for their $B_s^0 \to \mu^+\mu^-$ analysis



3% measurement

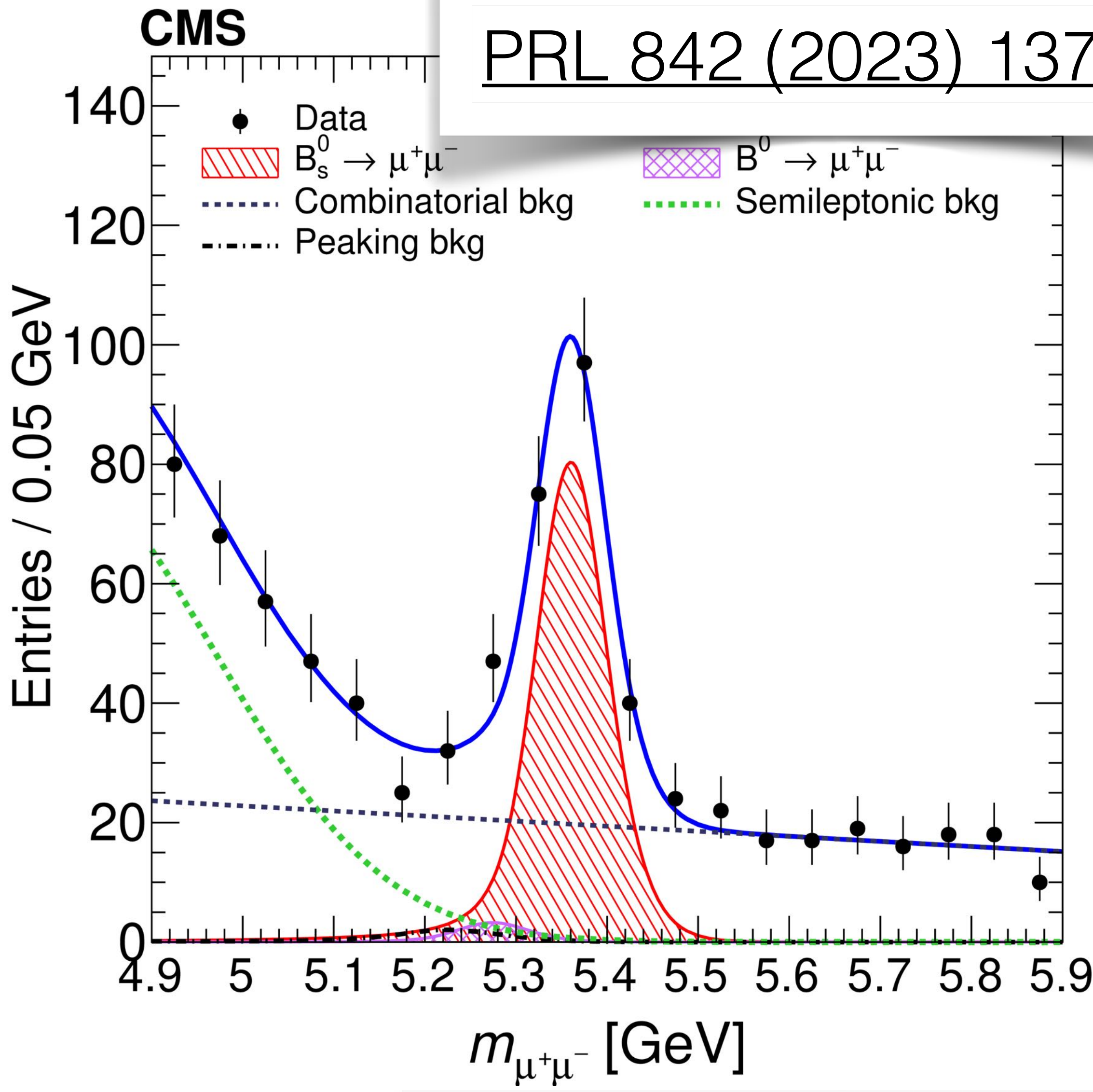
PRD 104 (2021) 032005

Most recent $B_{(s)} \to \mu^+\mu^-$ results

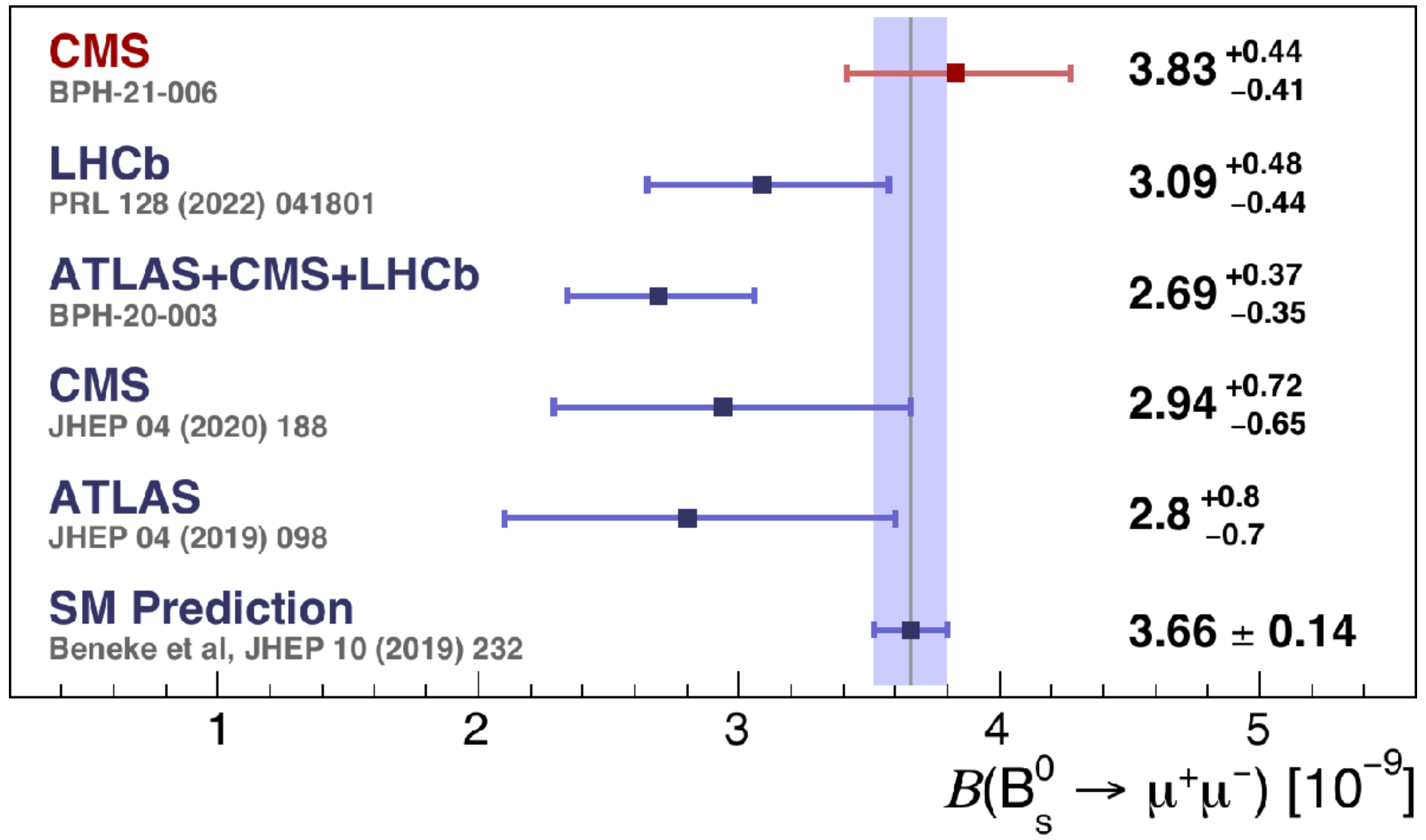
- Latest CMS measurement (140 fb^{-1}), most precise to date :

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = \left[3.83^{+0.38}_{-0.36}\ (\text{stat})\ ^{+0.19}_{-0.16}\,(\text{syst})\ ^{+0.14}_{-0.13}\,(f_s/f_u)\right] \times 10^{-9},$$

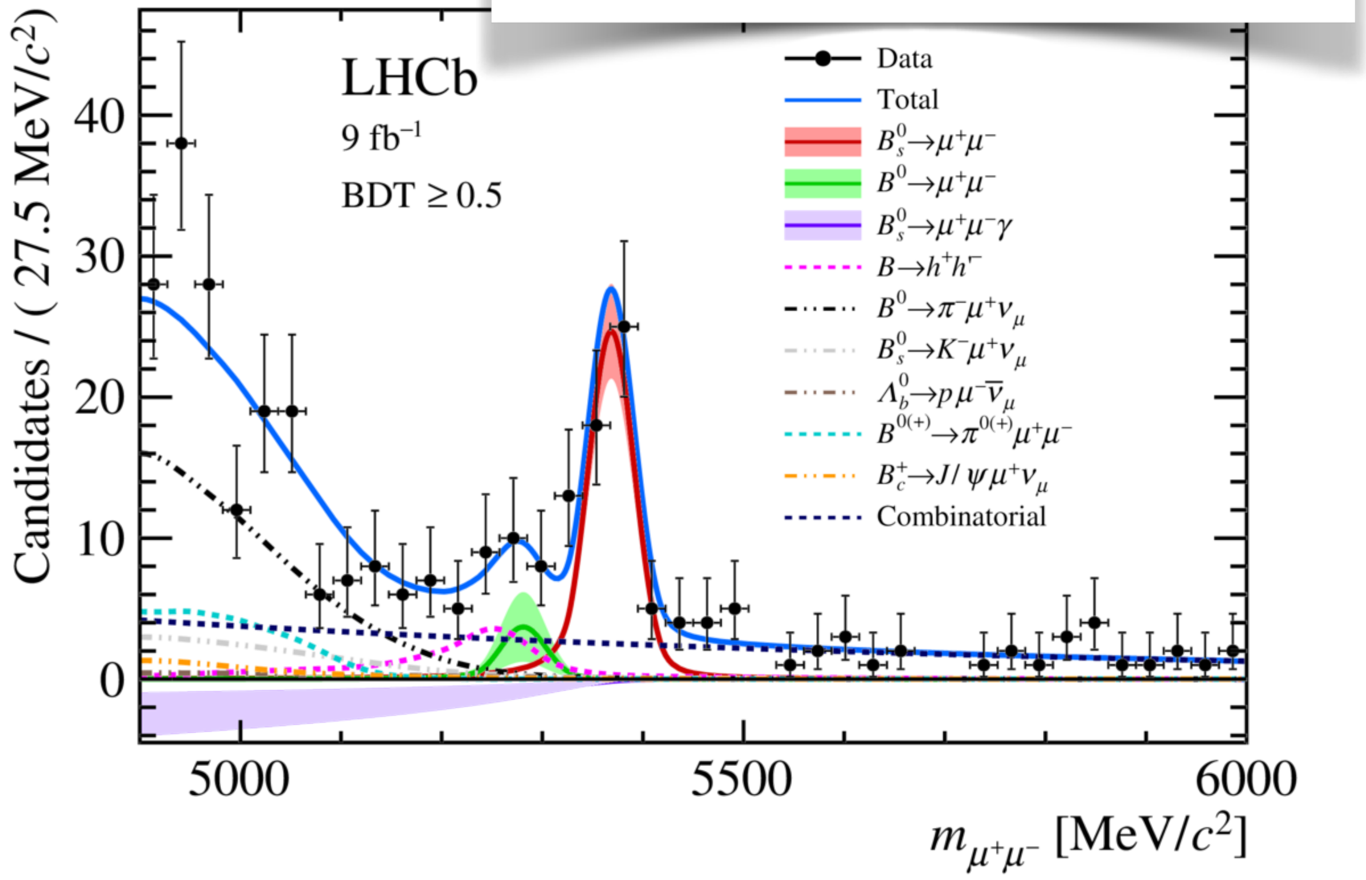
- Systematic uncertainty for $B_s \to \mu^+\mu^-$ dominated by uncertainty associated with b-quark fragmentation probability ratio f_s/f_u (~3%)
- The rarer $B^0 \to \mu^+\mu^-$ is still unobserved, but its expected ~10^{-10} rate is within reach
- These two results alone have had a major impact on constraining the parameter space of several BSM theories, in particular SUSY

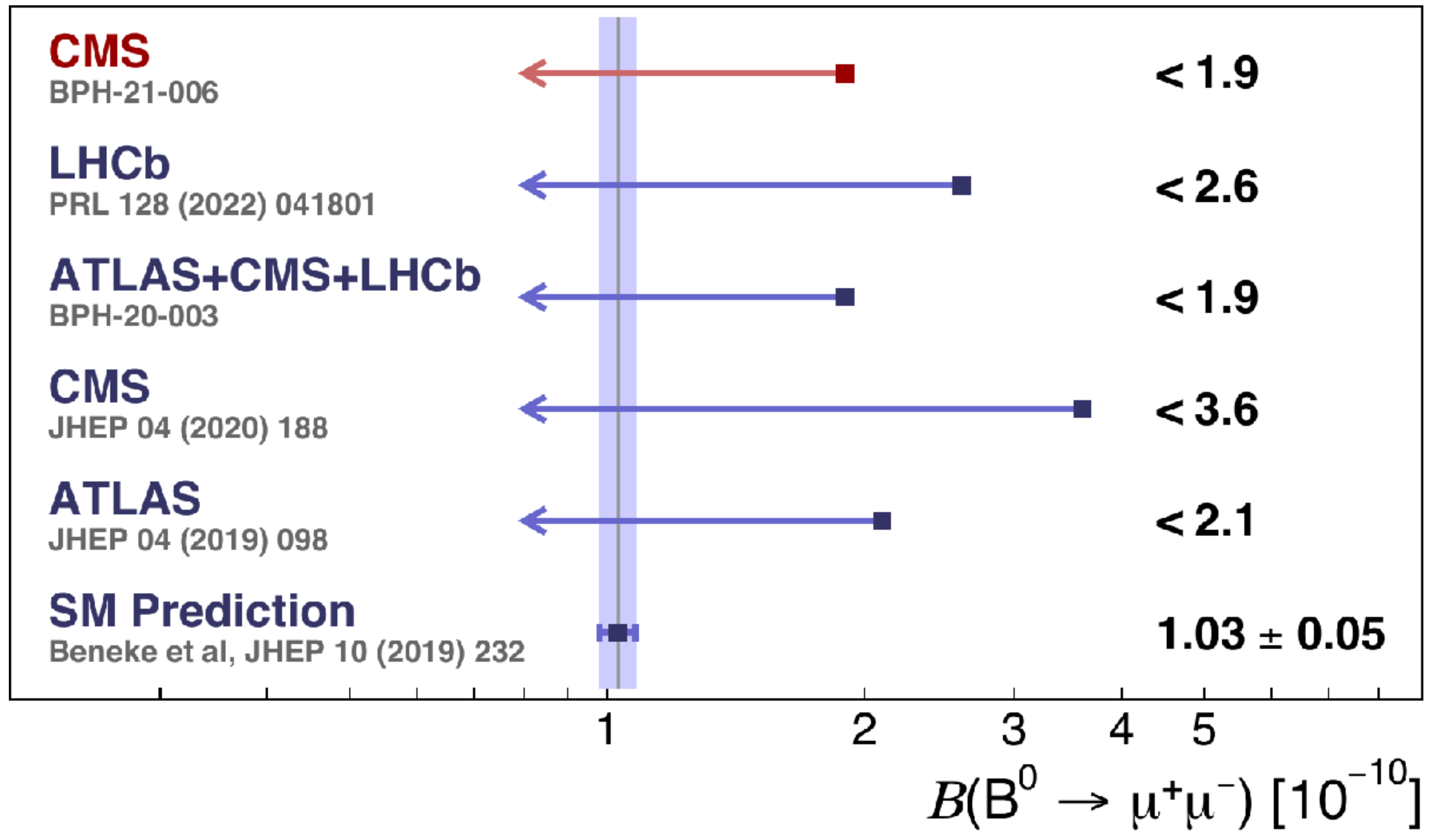


PRL 842 (2023) 137955



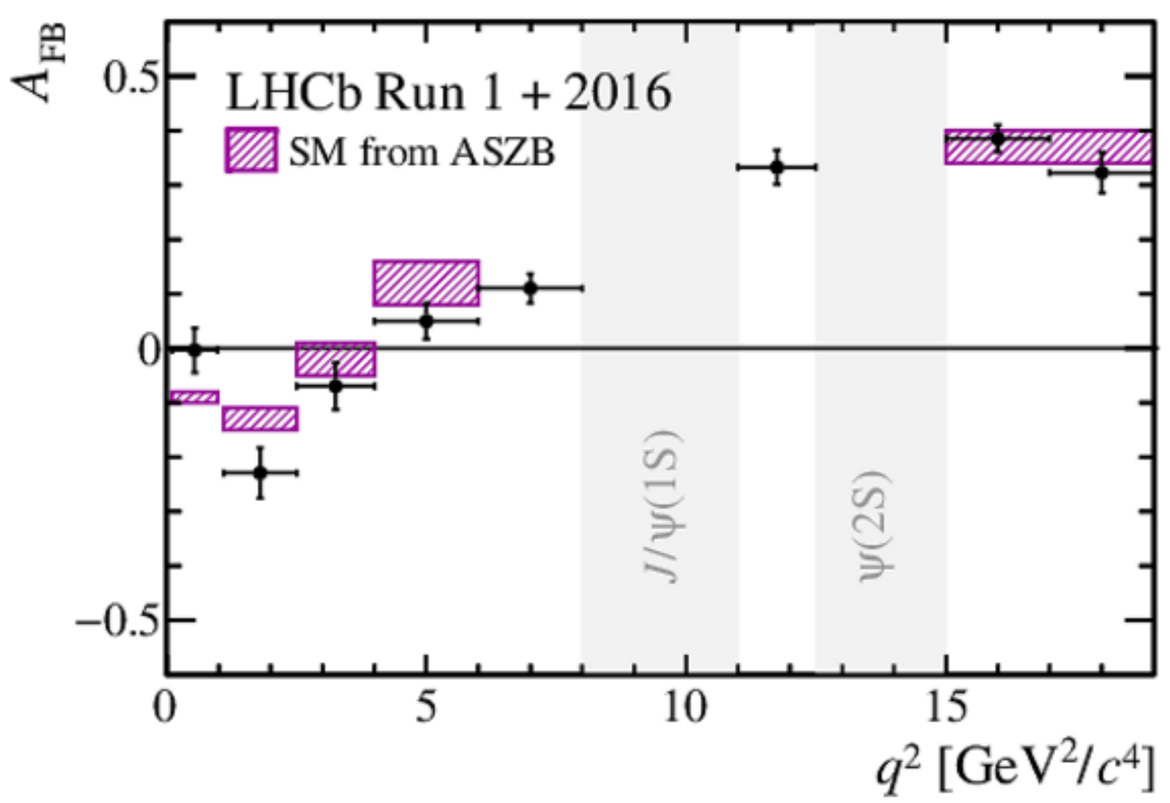
PRL 128 (2022) 041801
PRD 105 (2022) 012010

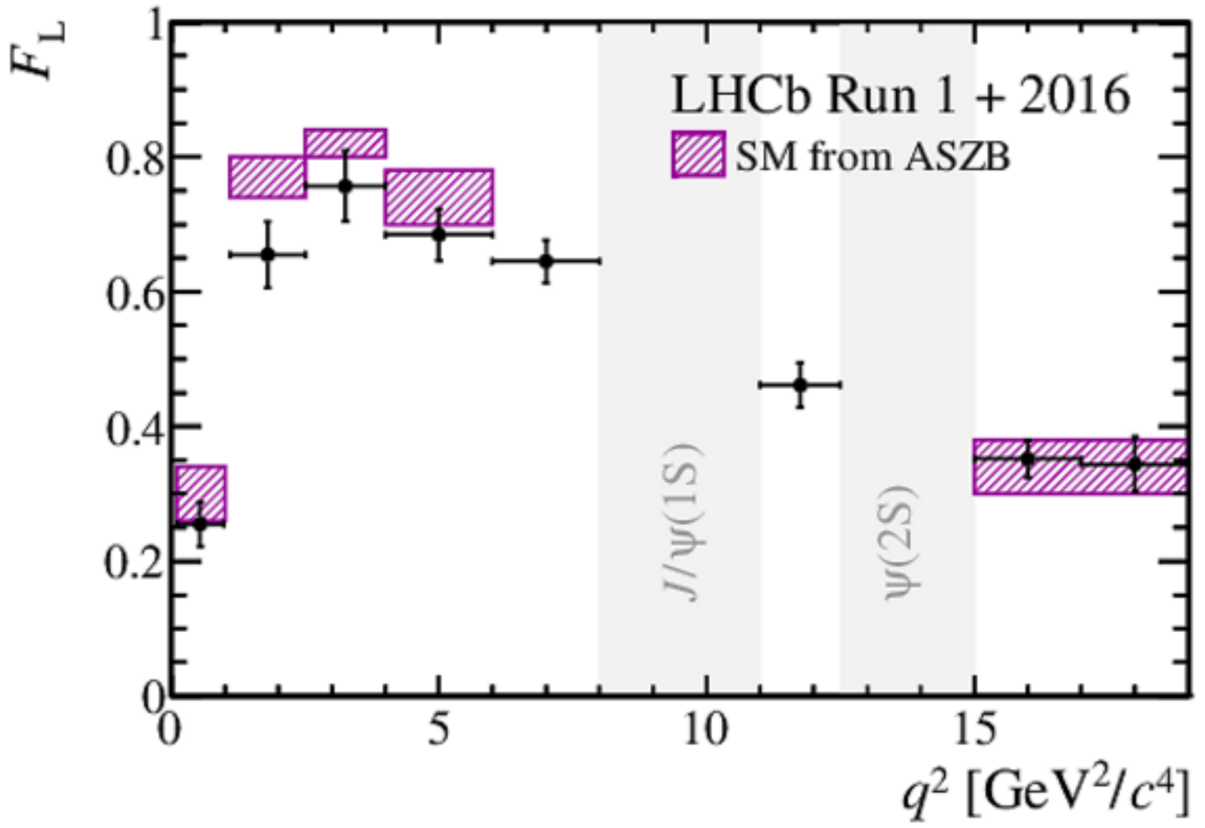




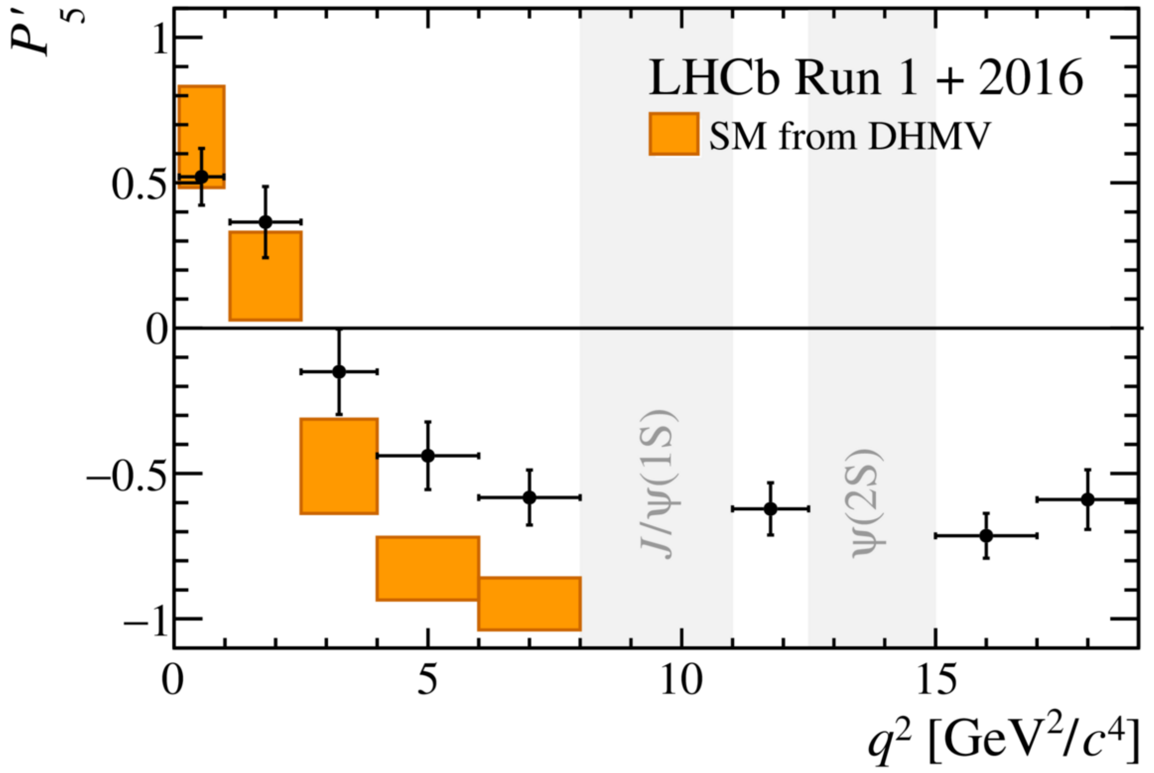
Analysis of the decay $B^0 \rightarrow K^{*0}\mu^+\mu^-$

- Another decay suitable for NP searches, as it proceeds only through EW loop diagrams
- Roadmap document: measurement of zero-crossing point of A_{FB} with a simplified analysis (counting method)
- LHCb update based on 4.7/fb (~4600 B^0events)





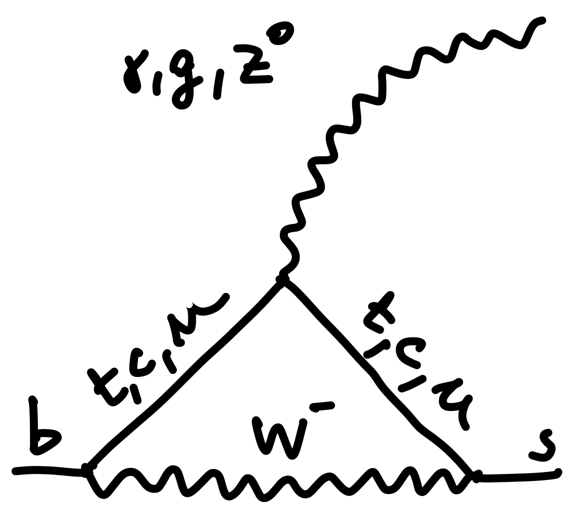
PRL 125 (2020) 011802



- $P'_5 = \frac{S_5}{\sqrt{F_{\mathrm{L}}(1-F_{\mathrm{L}})}}$, with F_{L} and S_5 combinations of K^{*0} spin amplitudes dependent on Wilson coefficients and form factors
- "Robust" to form-factor uncertainties

- P'_5: local tension of 2.5σ and 2.9σ in q^2 bins of [4.0,6.0] and [6.0,8.0] GeV^2
- Global analysis finds a deviation of $3.3\ \sigma$

$B_s^0 \to \phi\gamma$ and other radiative B decays



- $B_s^0 \to \phi\gamma$ and other radiative decays
  - $b \to s\gamma$ transition proceeds via loop diagrams, sensitive to contribution of possible NP
  - In the SM, photons are predominantly left-handed, but NP could enhance right-handed component
- $A^{\Delta}_{\phi\gamma}$ related to the ratio of right- to left-handed photon polarisation amplitudes, for which we anticipated a statistical precision of ~0.2 with 2/fb

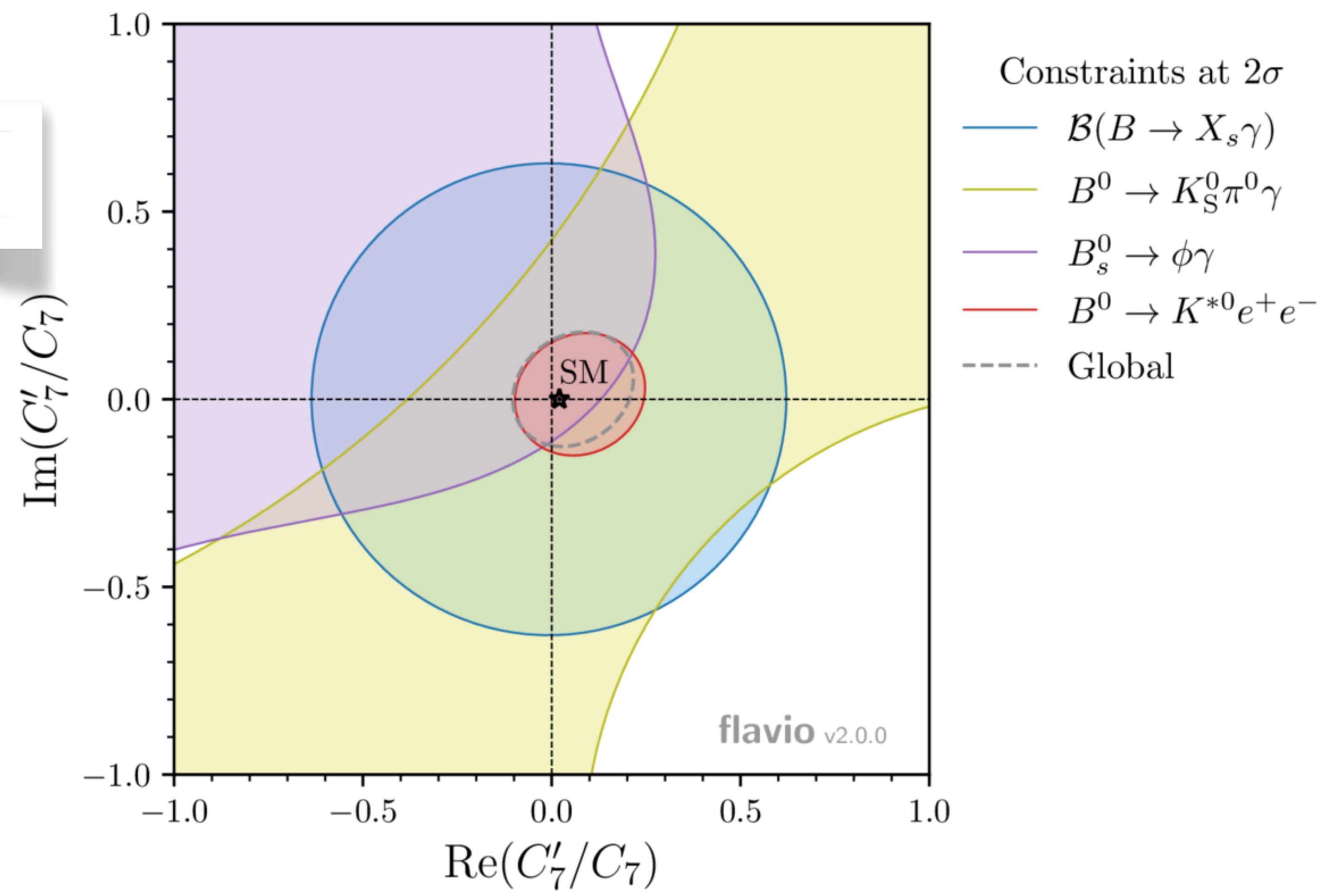
PRL 123 (2019) 081802

- We measured $A^{\Delta}_{\phi\gamma} = -0.67^{+0.37}_{-0.41} \pm 0.17$ (plus the CPV parameters $S_{\phi\gamma}$ and $C_{\phi\gamma}$) with 3/fb
- We also measured the photon polarisation in $\Lambda_b^0 \to \Lambda\gamma$ with 6/fb :
  $\alpha_\gamma \equiv \dfrac{\gamma_L - \gamma_R}{\gamma_L + \gamma_R} = 0.82^{+0.17+0.04}_{-0.26-0.13}$

PRD 105 (2022) L051104

JHEP 12 (2020) 081

- We studied $B^0 \to K^{*0}e^+e^-$ at very low q^2 [0.0008-0.257 GeV^2] where the rate is dominated by $B^0 \to K^{*0}\gamma$, to give the best constraint on the photon polarisation (5% measurement) with 9/fb
- Many radiative decay analyses still to be completed with Run 2 data



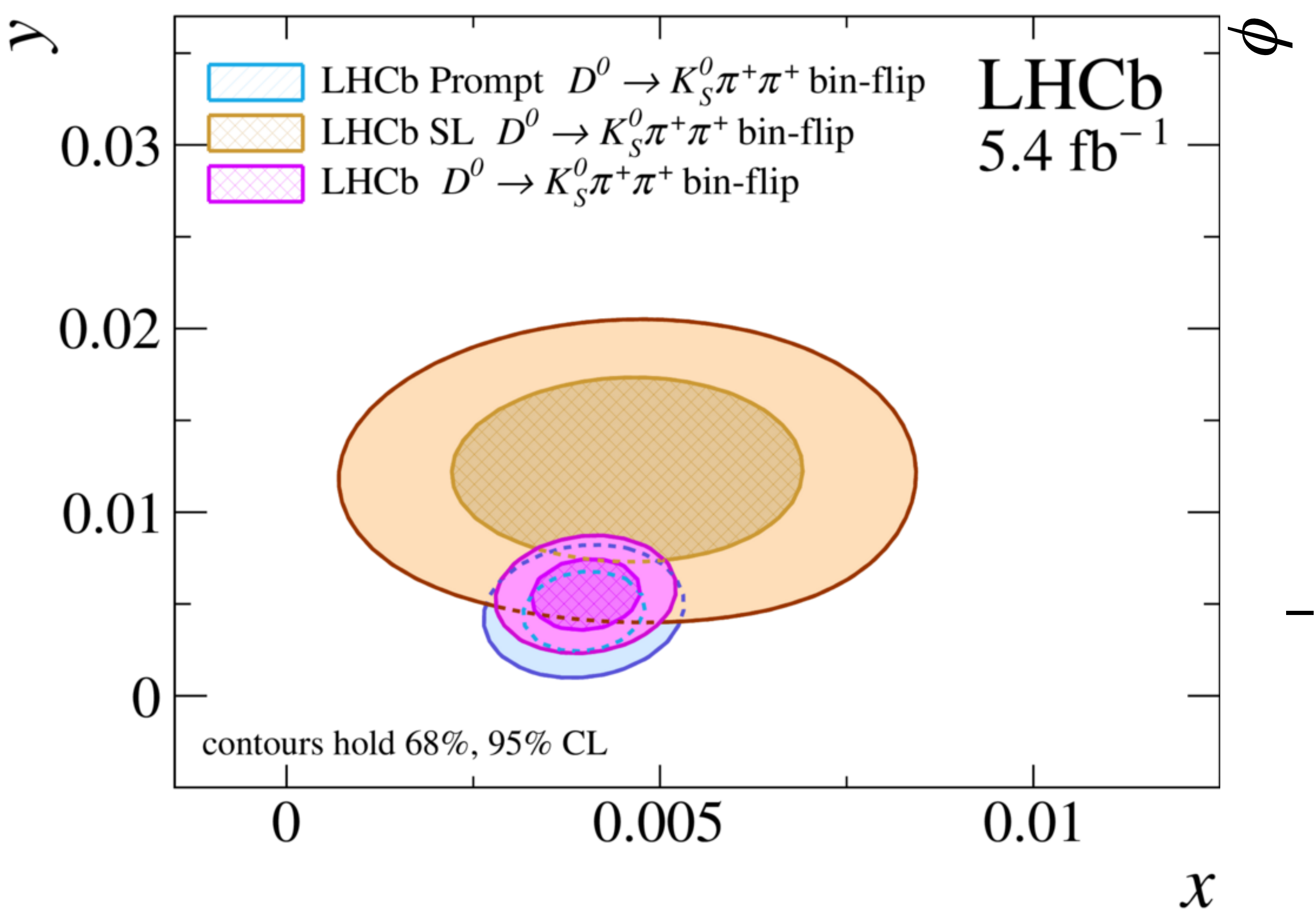
Many other results...

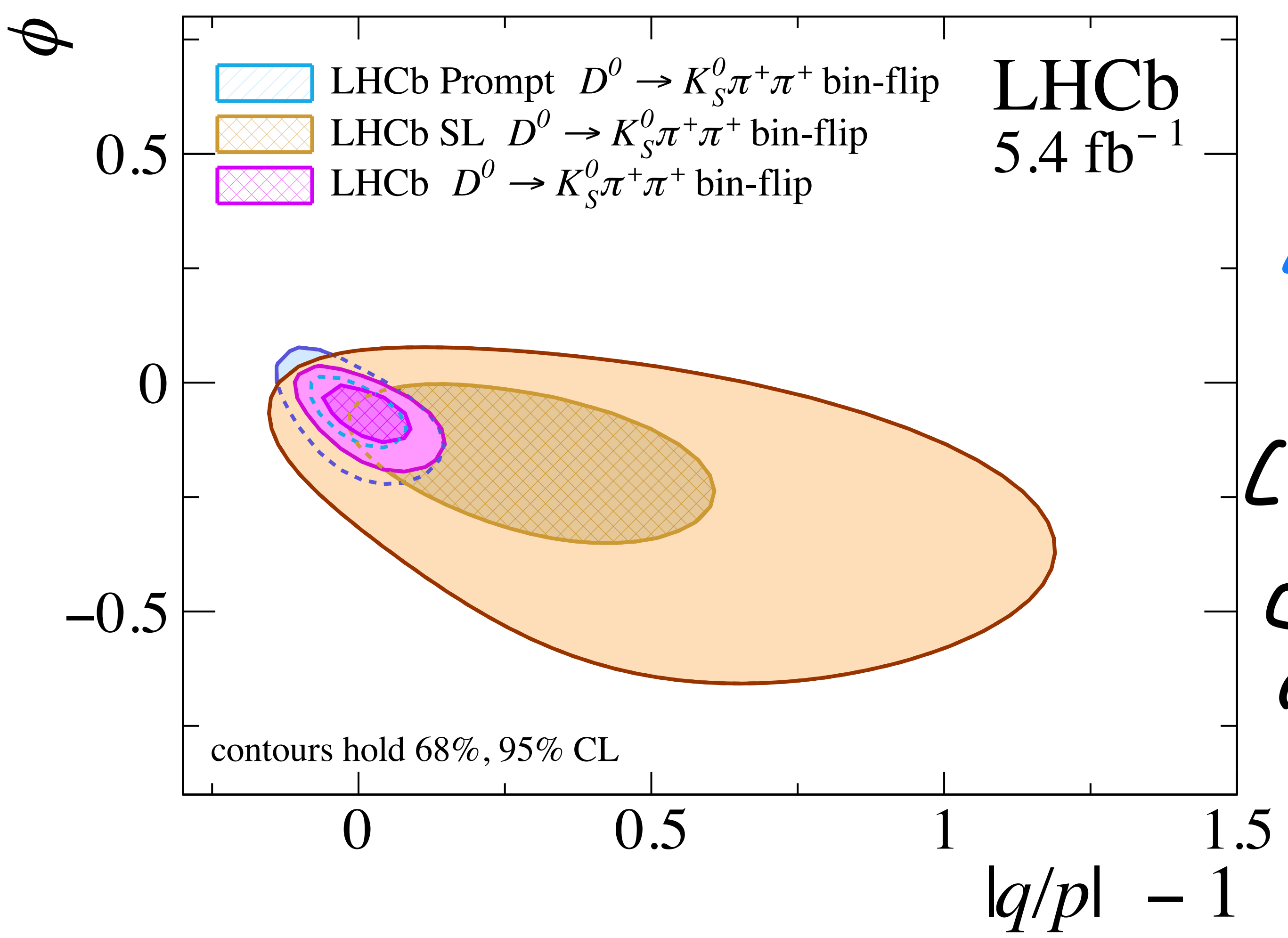
charm CPV and mixing

- Latest result on mixing parameters gives

$$x = (4.01 \pm 0.49) \times 10^{-3}$$
$$y = (\ 5.5 \pm 1.3\ ) \times 10^{-3}$$
$$|q/p| = \quad 1.012\,^{+0.050}_{-0.048}\,,$$
$$\phi = -0.061\,^{+0.037}_{-0.044}\ \text{rad.}$$

PRD 108 (2023) 052005
PRL 127 (2021) 111801





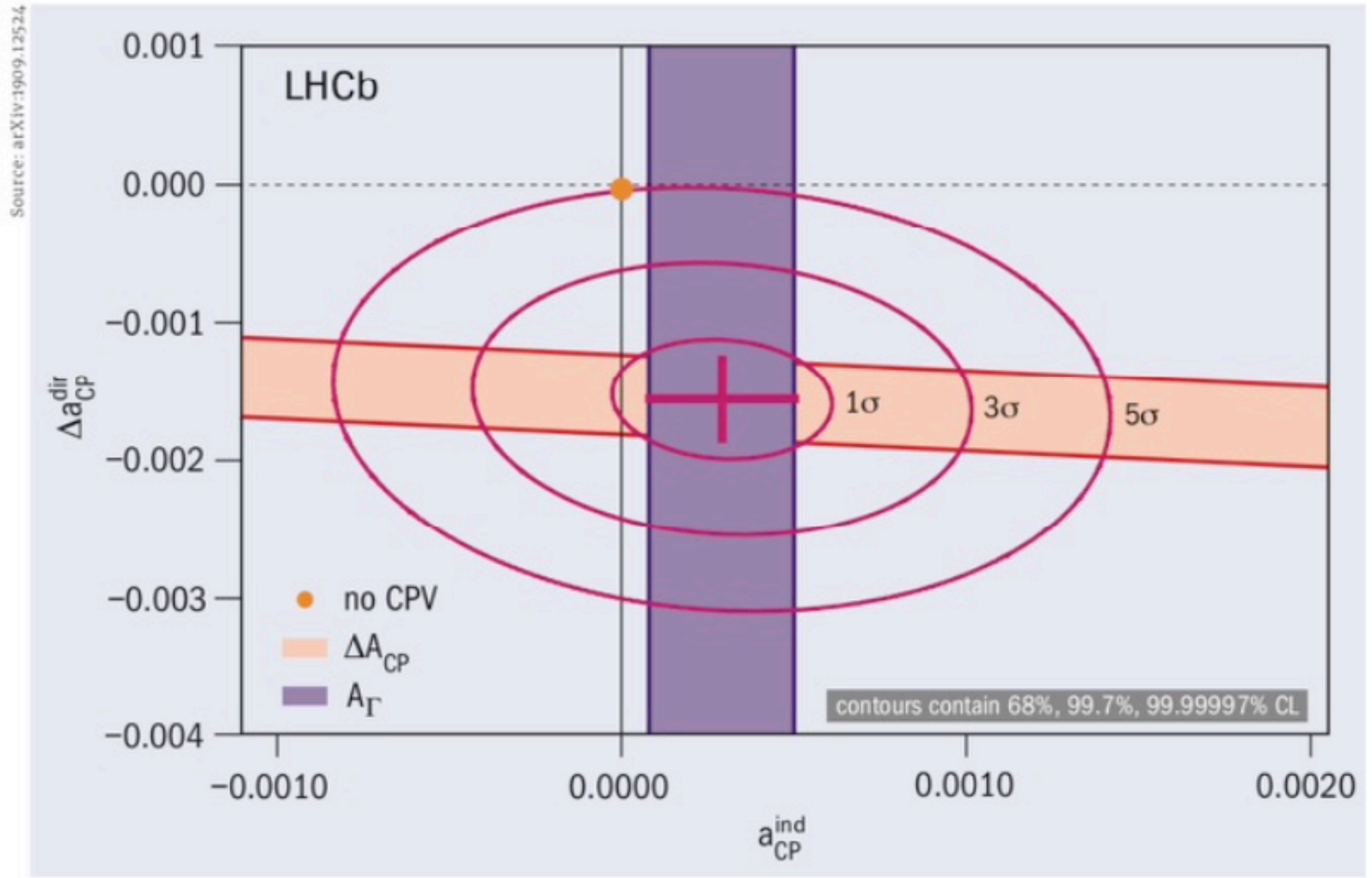
$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$$

$$x = \frac{m_2 - m_1}{\Gamma} \qquad y = \frac{\Gamma_2 - \Gamma_1}{2\Gamma}$$

CPV in mixing: $|q/p| \neq 1$

CPV in interference between mixing & decay $\phi \neq 0$

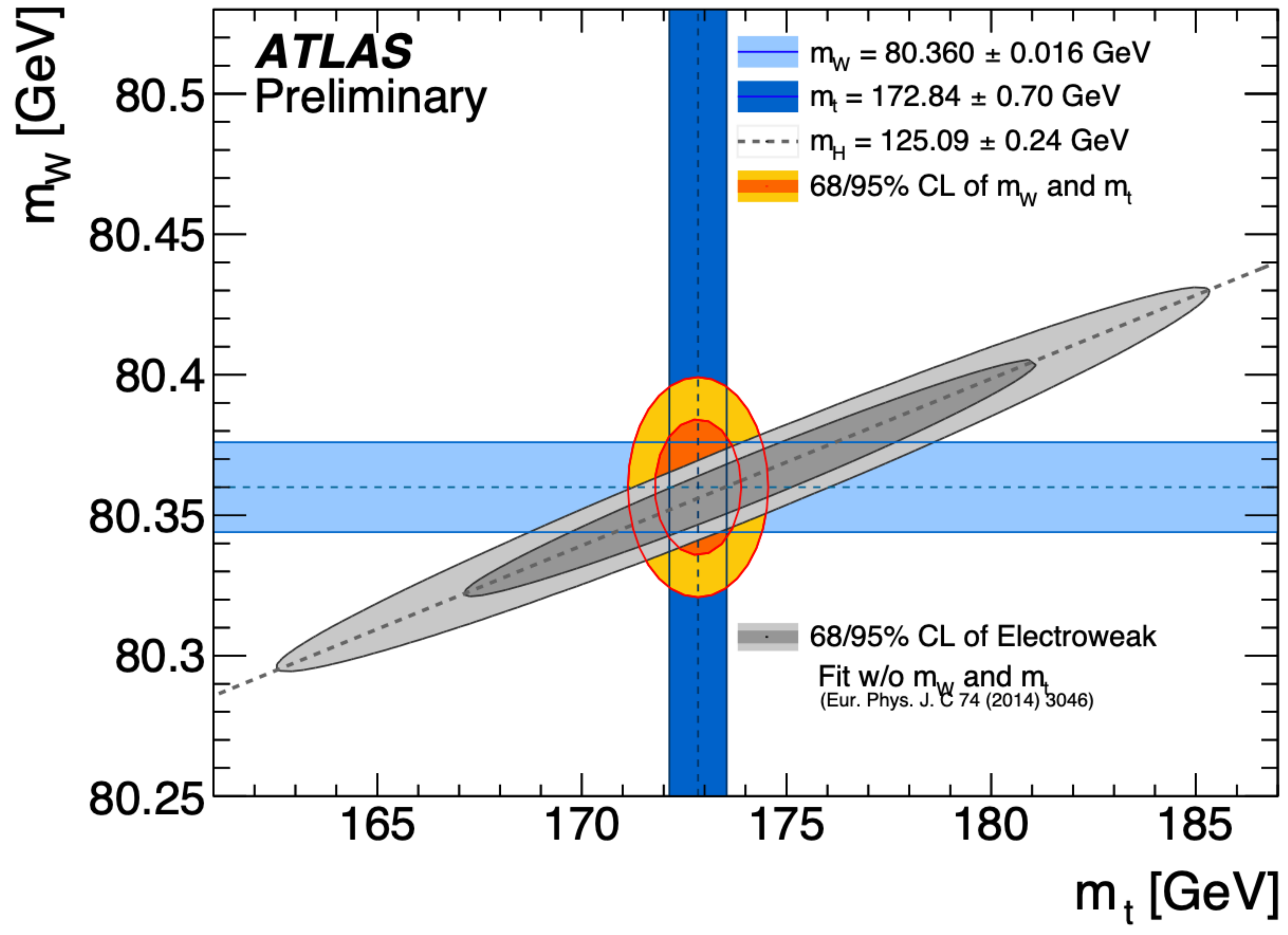
- CPV in charm decays
  - $\Delta A_{CP} = A_{\text{raw}}(K^+K^-) - A_{\text{raw}}(\pi^+\pi^-)$ difference of time-integrated CP asymmetries
  - $A_{CP}(f;t) = \dfrac{\Gamma(D^0(t) \to f) - \Gamma(\bar{D}^0(t) \to f)}{\Gamma(D^0(t) \to f) + \Gamma(\bar{D}^0(t) \to f)} f = K^+K^- \text{ or } \pi^+\pi^-$
  - $\Delta A_{CP} = (-15.4 \pm 2.9) \times 10^{-4}$
  - 5.3 σ measurement of CPV

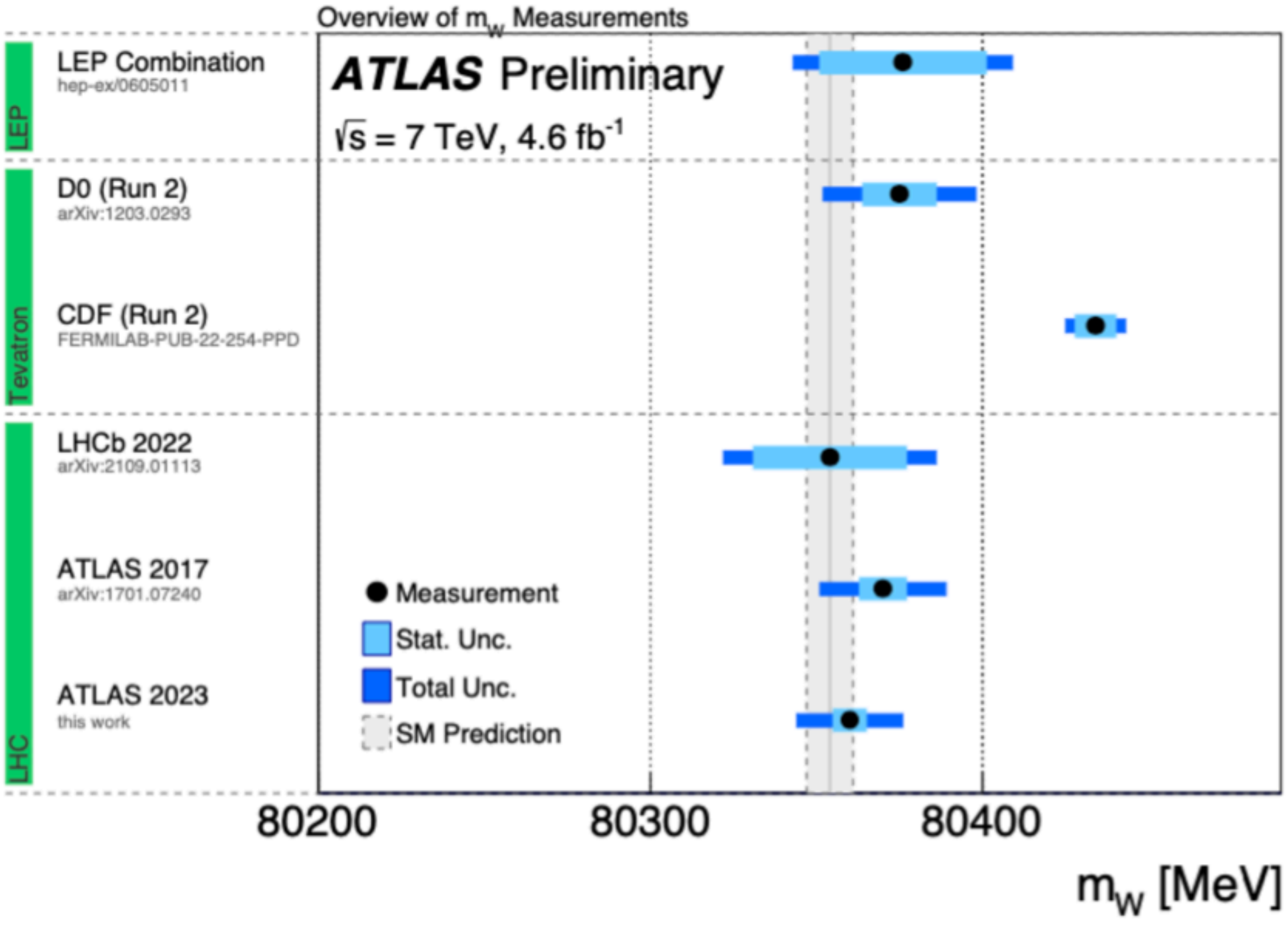


- Remarkable results, although large hadronic non-perturbative uncertainties make them particularly challenging to interprete

Some physics results not related to flavour

W mass


ATLAS
Preliminary
m_W = 80.360 ± 0.016 GeV
m_t = 172.84 ± 0.70 GeV
m_H = 125.09 ± 0.24 GeV
68/95% CL of m_W and m_t
68/95% CL of Electroweak
Fit w/o m_W and m_t
(Eur. Phys. J. C 74 (2014) 3046)
m_W [GeV]
80.5
80.45
80.4
80.35
80.3
80.25
165
170
175
180
185
m_t [GeV]


Overview of m_W Measurements
ATLAS Preliminary
√s = 7 TeV, 4.6 fb⁻¹
LEP
LEP Combination
hep-ex/0605011
Tevatron
D0 (Run 2)
arXiv:1203.0293
CDF (Run 2)
FERMILAB-PUB-22-254-PPD
LHC
LHCb 2022
arXiv:2109.01113
ATLAS 2017
arXiv:1701.07240
ATLAS 2023
this work
Measurement
Stat. Unc.
Total Unc.
SM Prediction
80200
80300
80400
m_W [MeV]

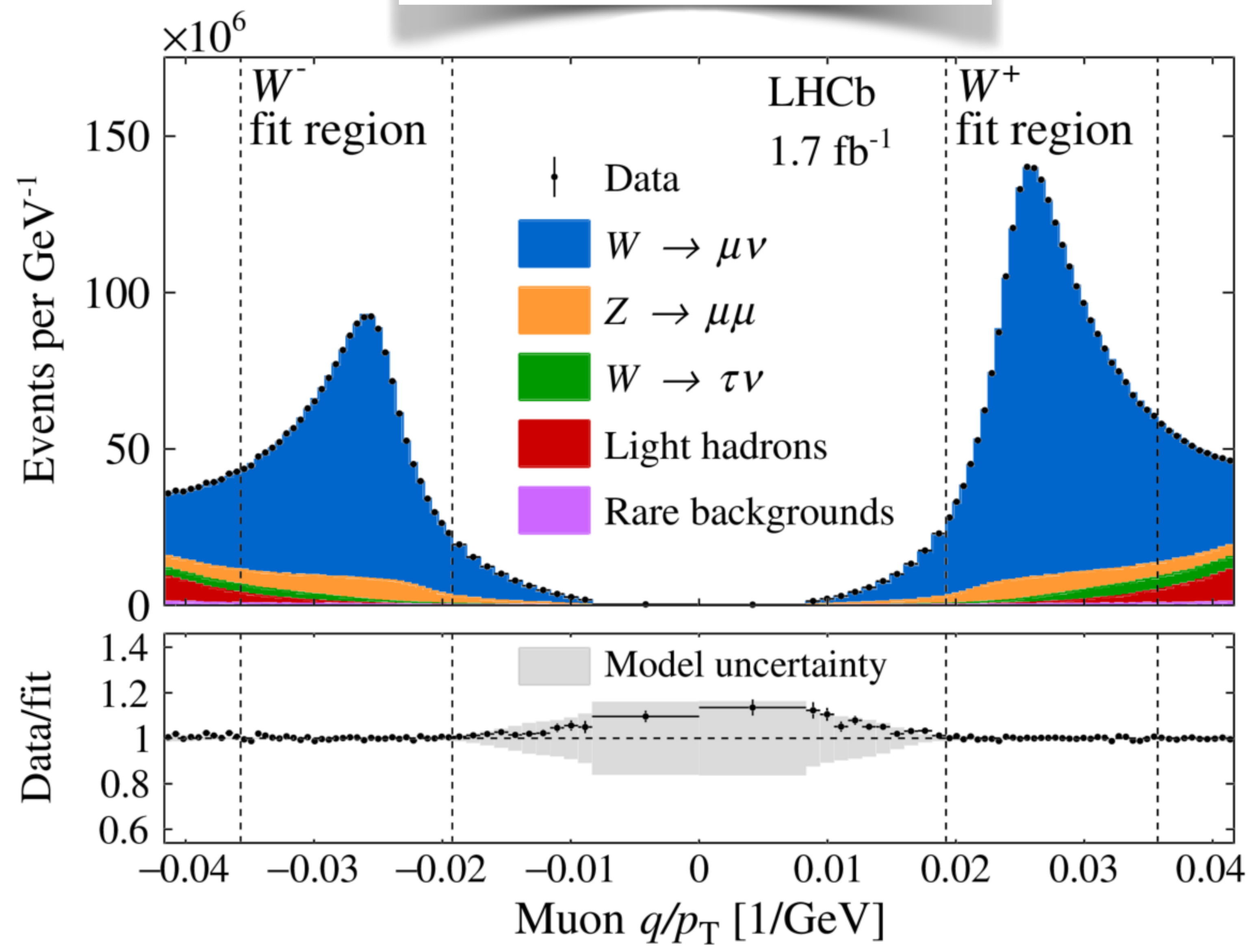
W mass @ LHCb

- Measurement based on shape of p_T distribution of muons from W decay
- Simultaneous fit of q/p_T of muons from W and of ϕ^* of $Z \to \mu\mu$

↑ Proxy of p_T^Z

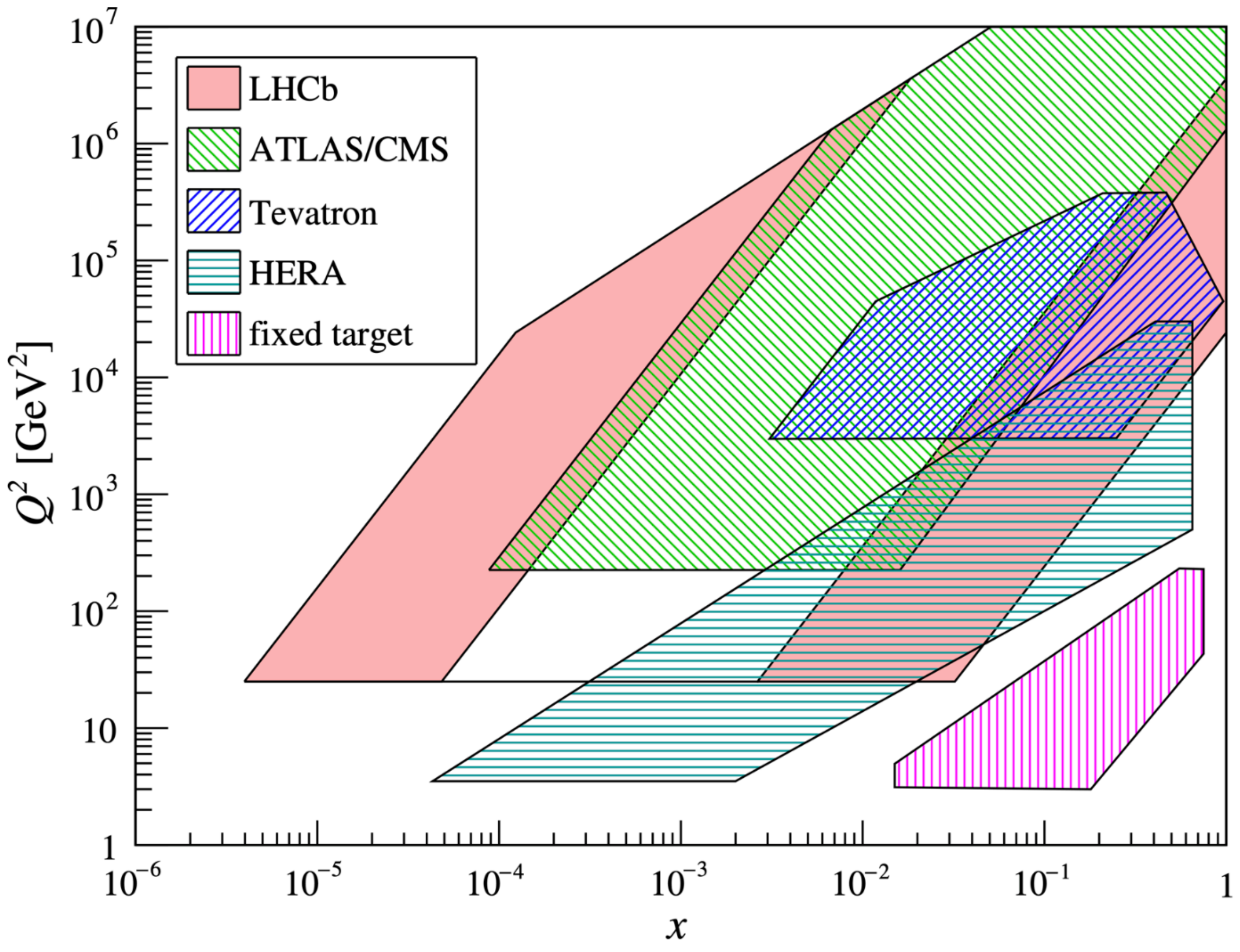
$$m_W = 80354 \pm 23_{\text{stat}} \pm 10_{\text{exp}} \pm 17_{\text{theory}} \pm 9_{\text{PDF}}\ \text{MeV}$$

[JHEP01 (2022) 036]



~32 MeV total (~20 MeV with all data)

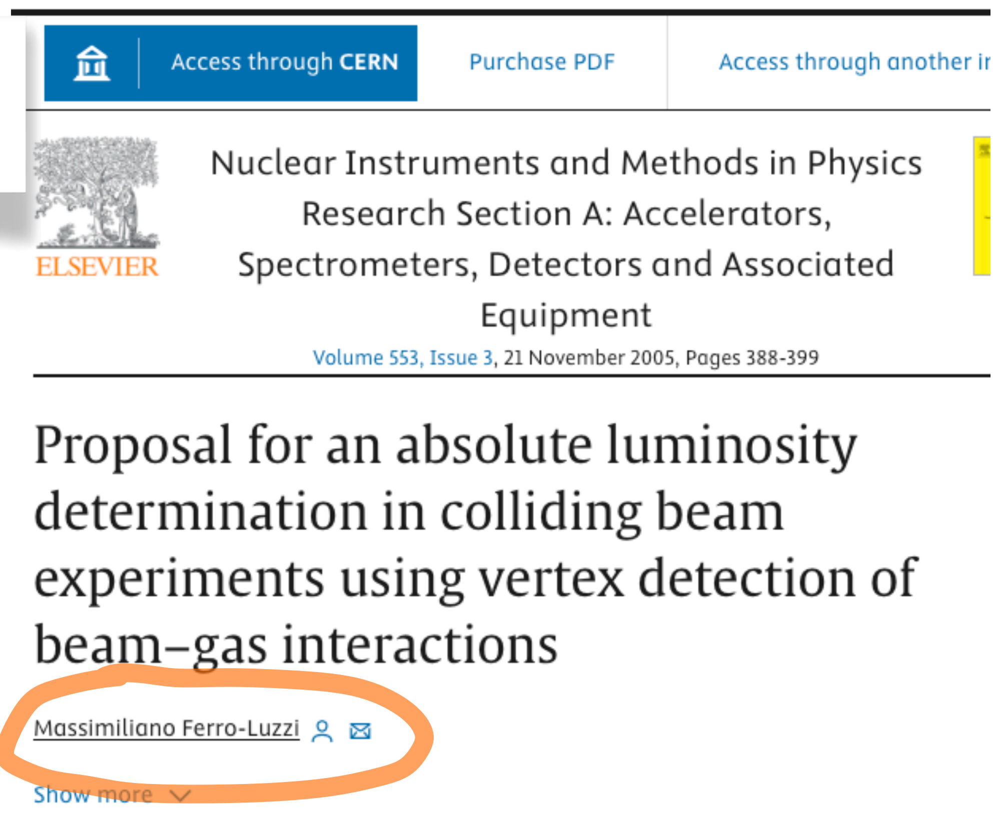
- Result based on 1.7 fb^{-1} (3x more data on tape); efforts are now being made to improve the modelling and reduce the systematic uncertainties
- Important because LHCb probes an acceptance region complementary to that of ATLAS/CMS
- Exploit anticorrelation of PDF uncertainties to partially cancel out uncertainties in M_W combination



Fixed-target experimental program

- Started with luminosity measurement for LHCb: SMOG (System to Measure Overlap with Gas)
  - Inject ~10^{-7} mbar of gas in the interaction region
  - 1.4% precision on lumi @8TeV

NIMA.2005.07.010



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Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 553, Issue 3, 21 November 2005, Pages 388-399

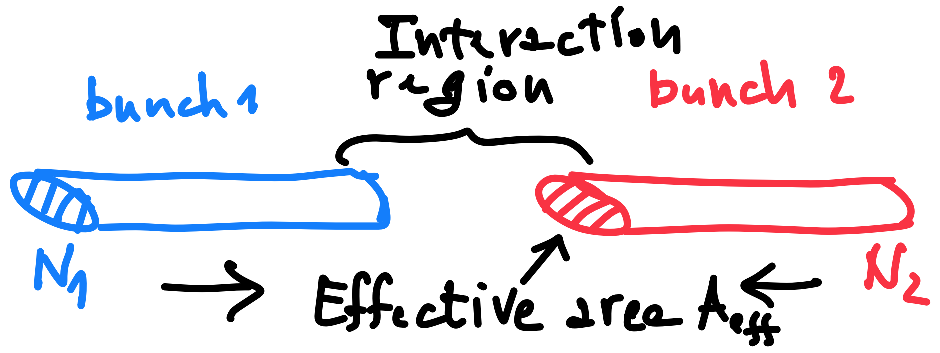
Proposal for an absolute luminosity determination in colliding beam experiments using vertex detection of beam–gas interactions

Massimiliano Ferro-Luzzi

Show more

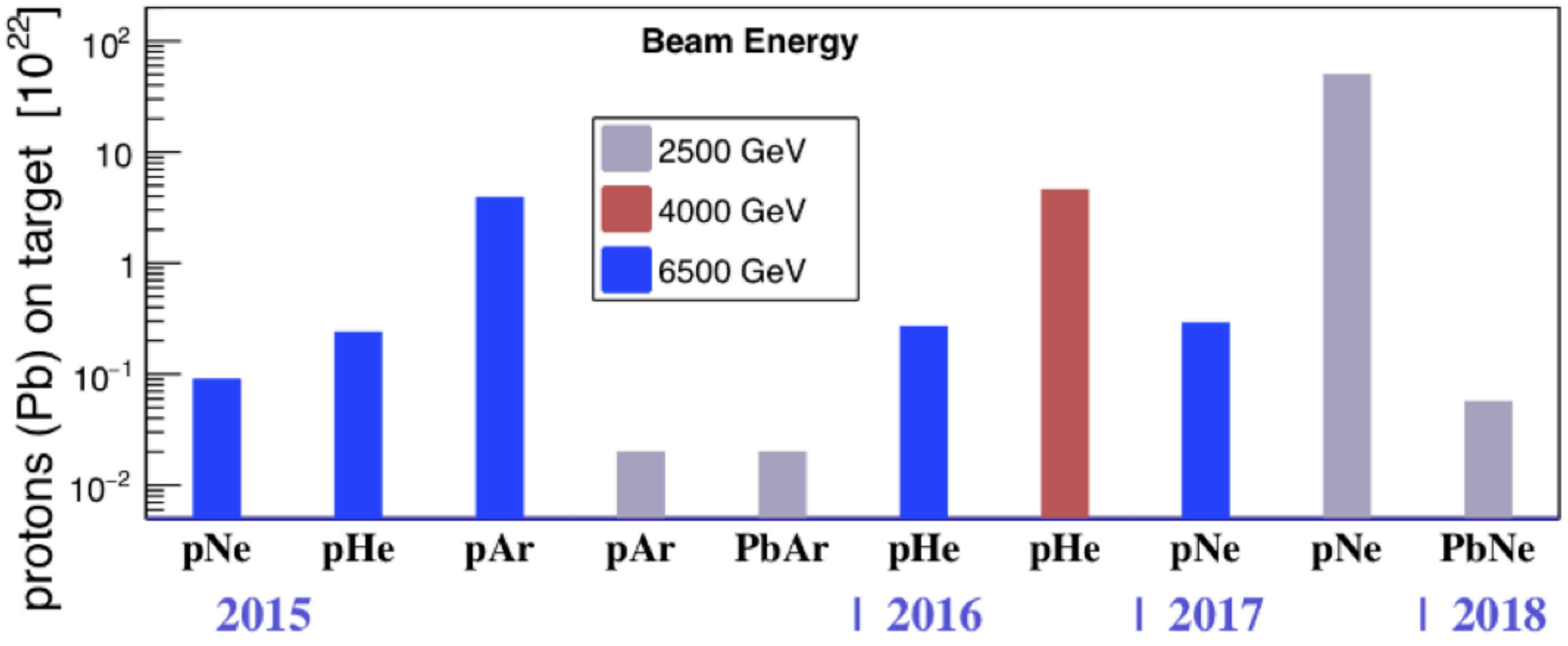
$$\mathcal{L} = \frac{N_1 N_2 f}{A_{eff}} = N_1 N_2 f \iint \rho_1(x,y)\rho_2(x,y)\,dx\,dy$$

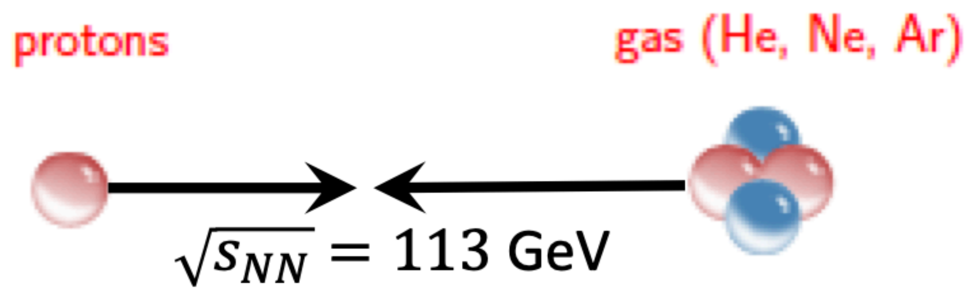
Measure ρ_1 , ρ_2 from beam-gas interactions

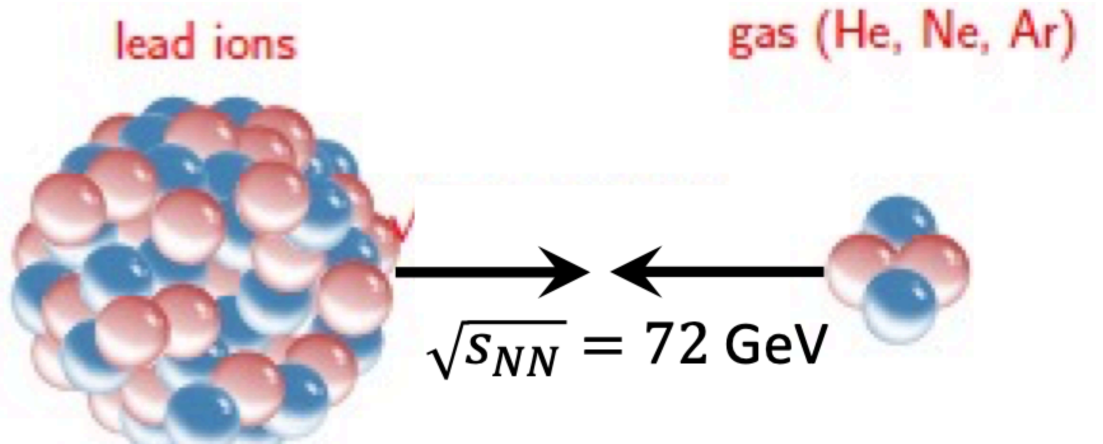


- Huge implications of this idea not so clear at the time!

- Opportunity to operate in fixed-target mode @unique energies $\sqrt{s_{NN}} \sim \sqrt{2E_N M_N} \sim$ 40-100 GeV







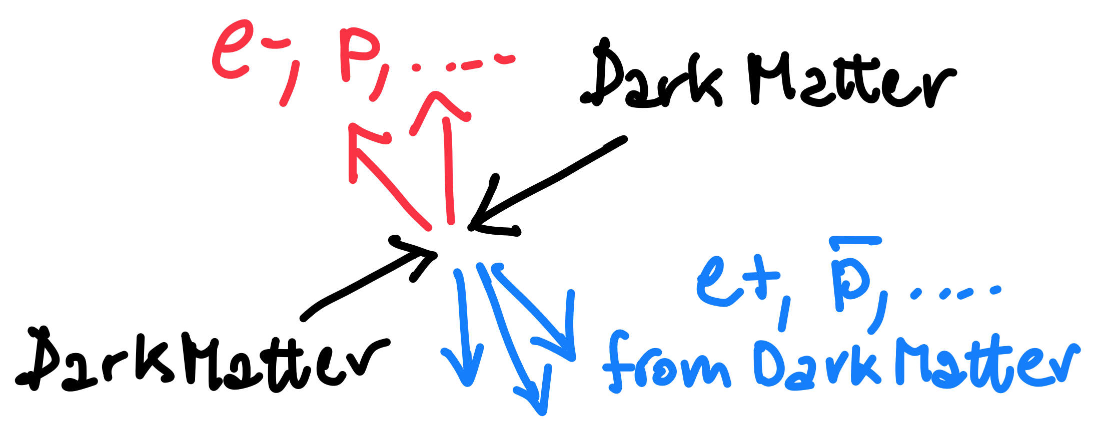
LHCb-PUB-2018-015

- SMOG2 allows simultaneous *pp* and *p*-gas data taking: the only experiment at the LHC to take data with two simultaneous interaction points at two different energies

SMOG: prompt/detached $\bar{p}$ in p-He @110 GeV

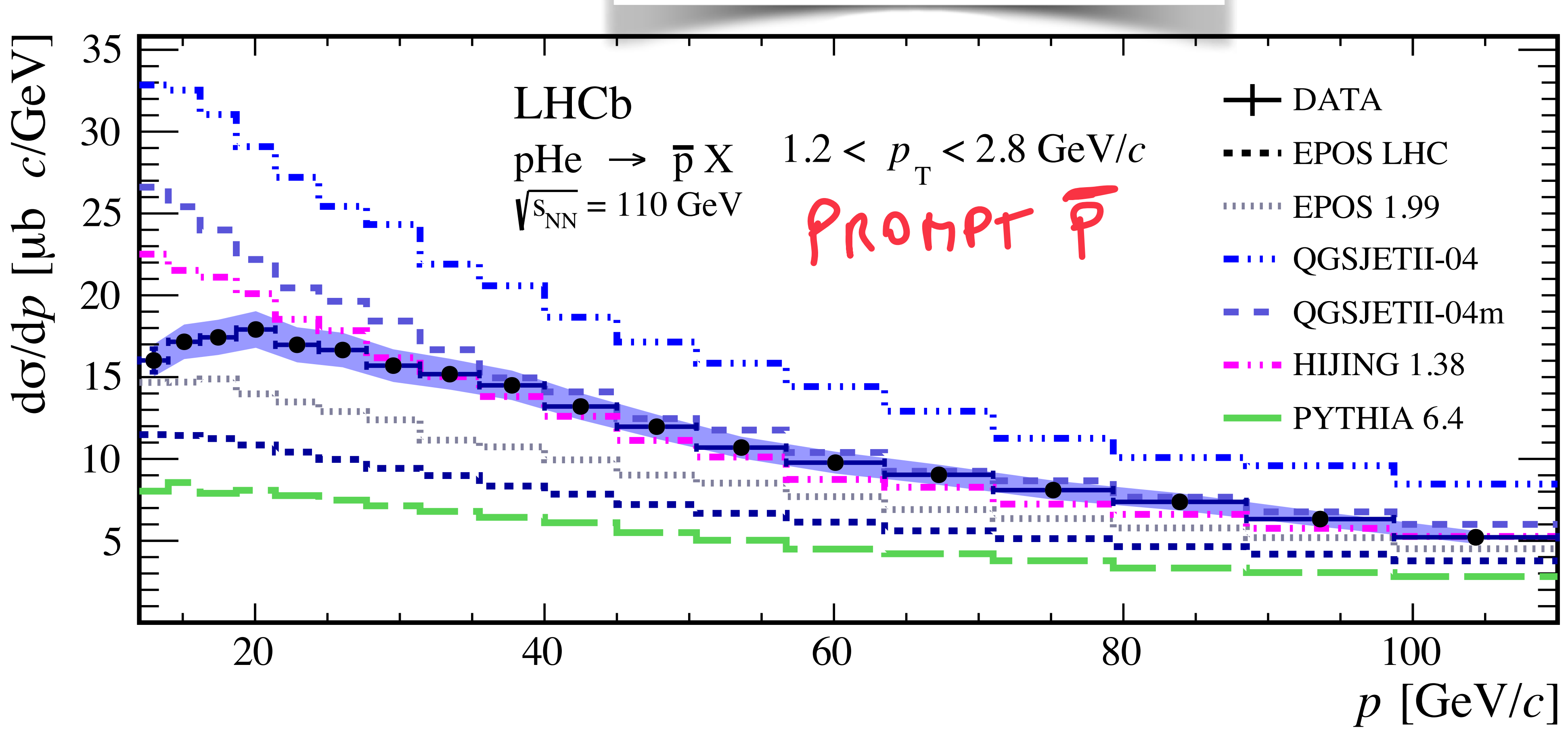
- AMS-02 has greatly improved measurements of the $\bar{p}$ abundance in cosmic rays, which is very sensitive to possible dark matter contributions

- Interesting to reduce uncertainties in $\bar{p}$ production in the interstellar medium: $p\text{He} \rightarrow \bar{p}\text{X}$ is ~40% of secondary cosmic $\bar{p}$

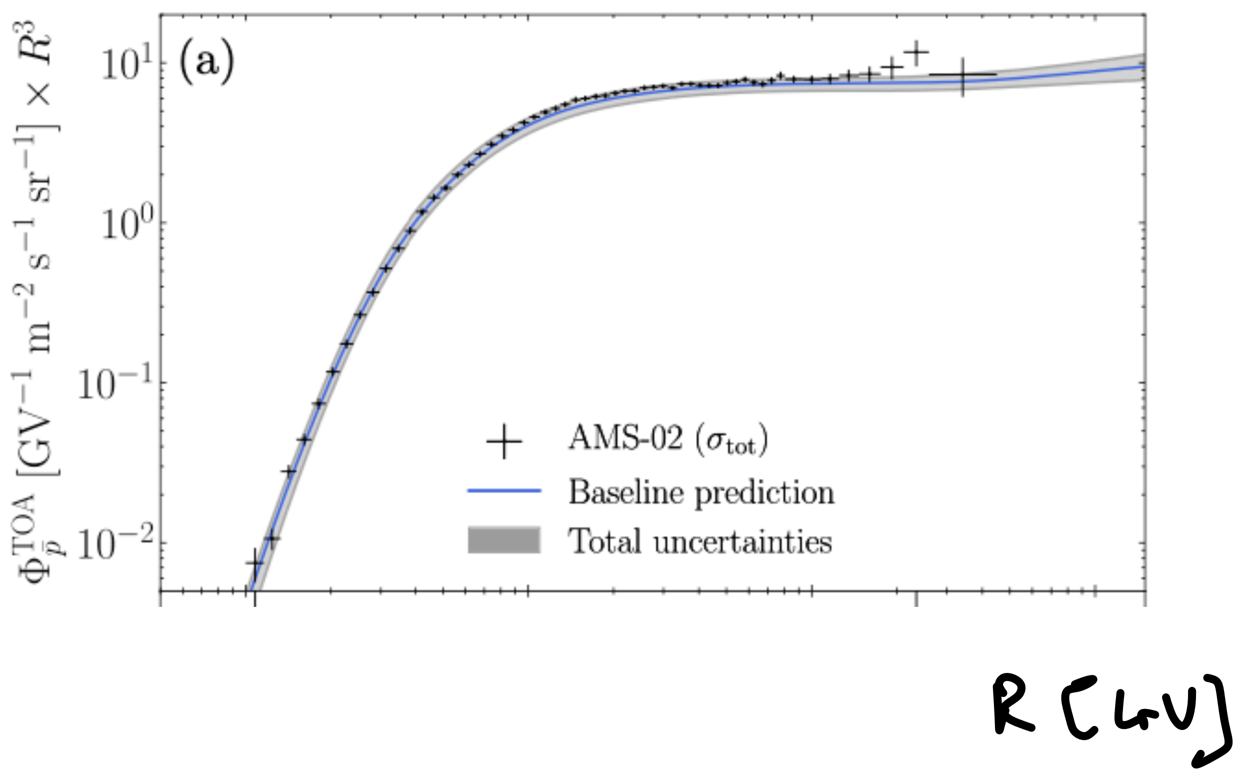


PRL121 (2018) 222001

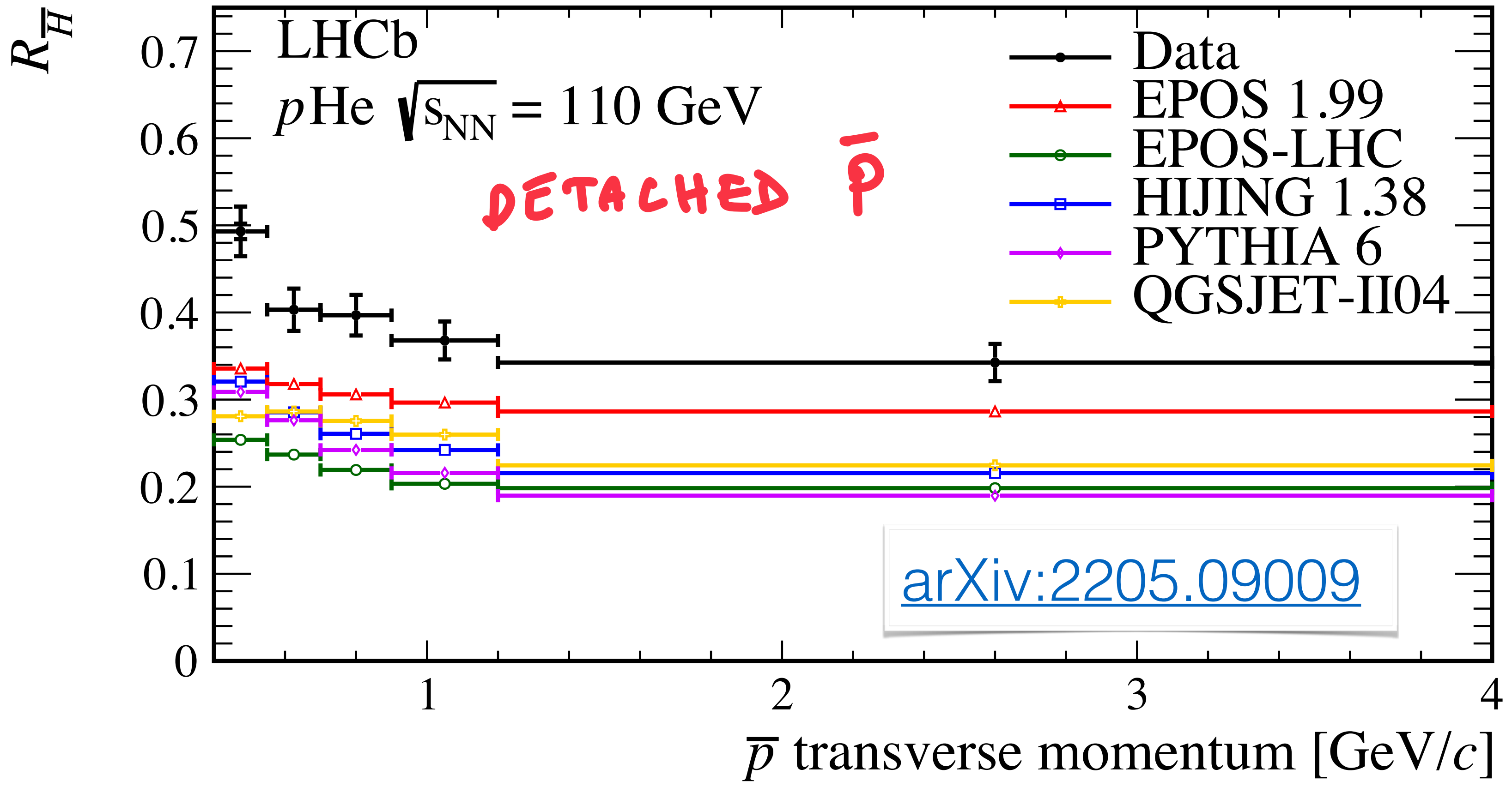
p [GeV/c]



Phys.Rev.Res 2, 023022 (2020)



AMS-02 DATA CONSISTENT WITH PURE SEC. ASTROPHYSICAL ORIGIN



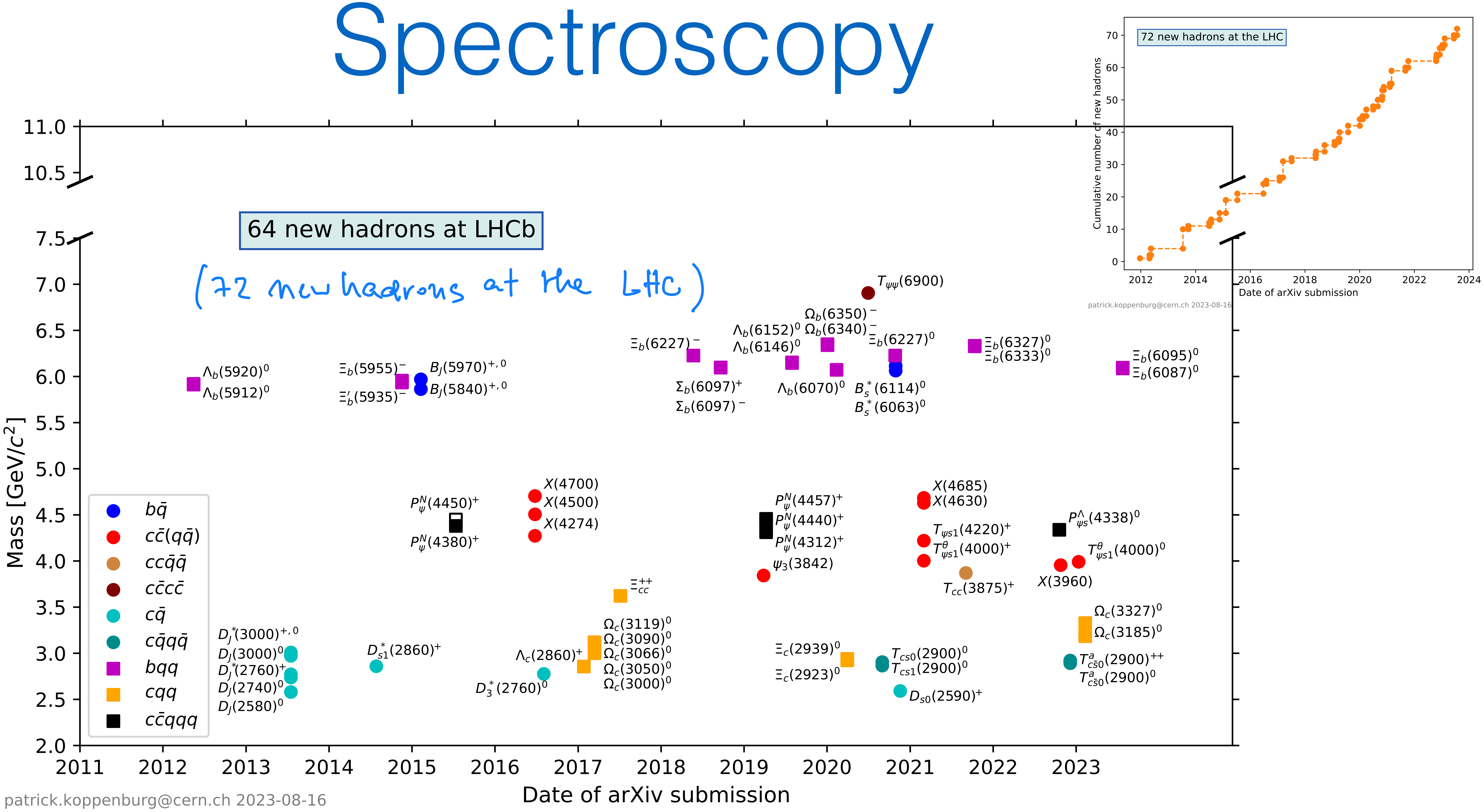
arXiv:2205.09009

- Antiprotons from Hyperon decays
  - Dominant contribution $\bar{\Lambda} \rightarrow \bar{p}\pi^+$

$$R_{\overline{H}} \equiv \frac{\sigma(p\text{He} \rightarrow \overline{H}X \rightarrow \bar{p}X)}{\sigma(p\text{He} \rightarrow \bar{p}_{\text{prompt}}X)}$$

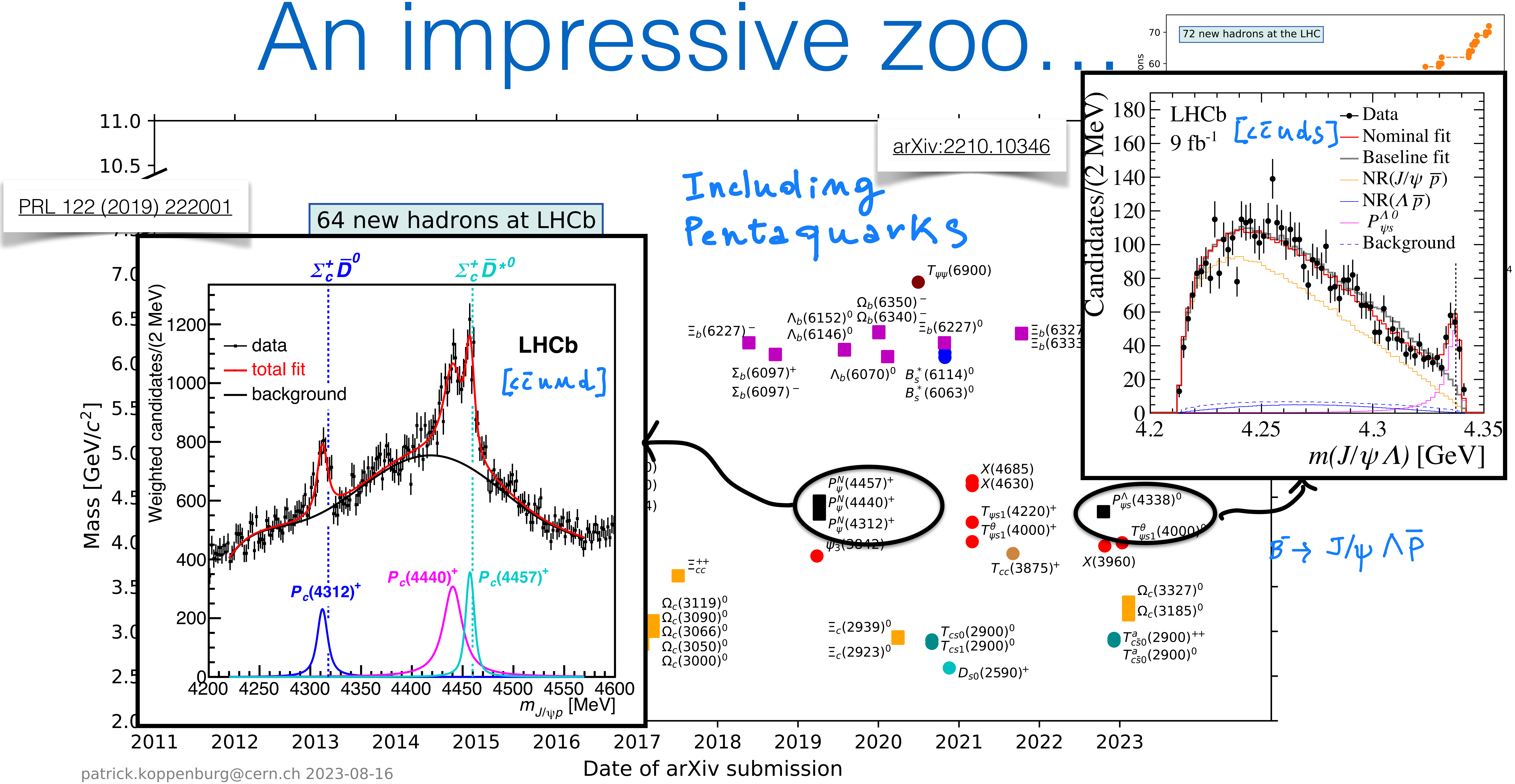
- Significantly larger than model predictions

Spectroscopy



(72 new hadrons at the LHC)

An impressive zoo…



PRL 122 (2019) 222001

arXiv:2210.10346

Including Pentaquarks

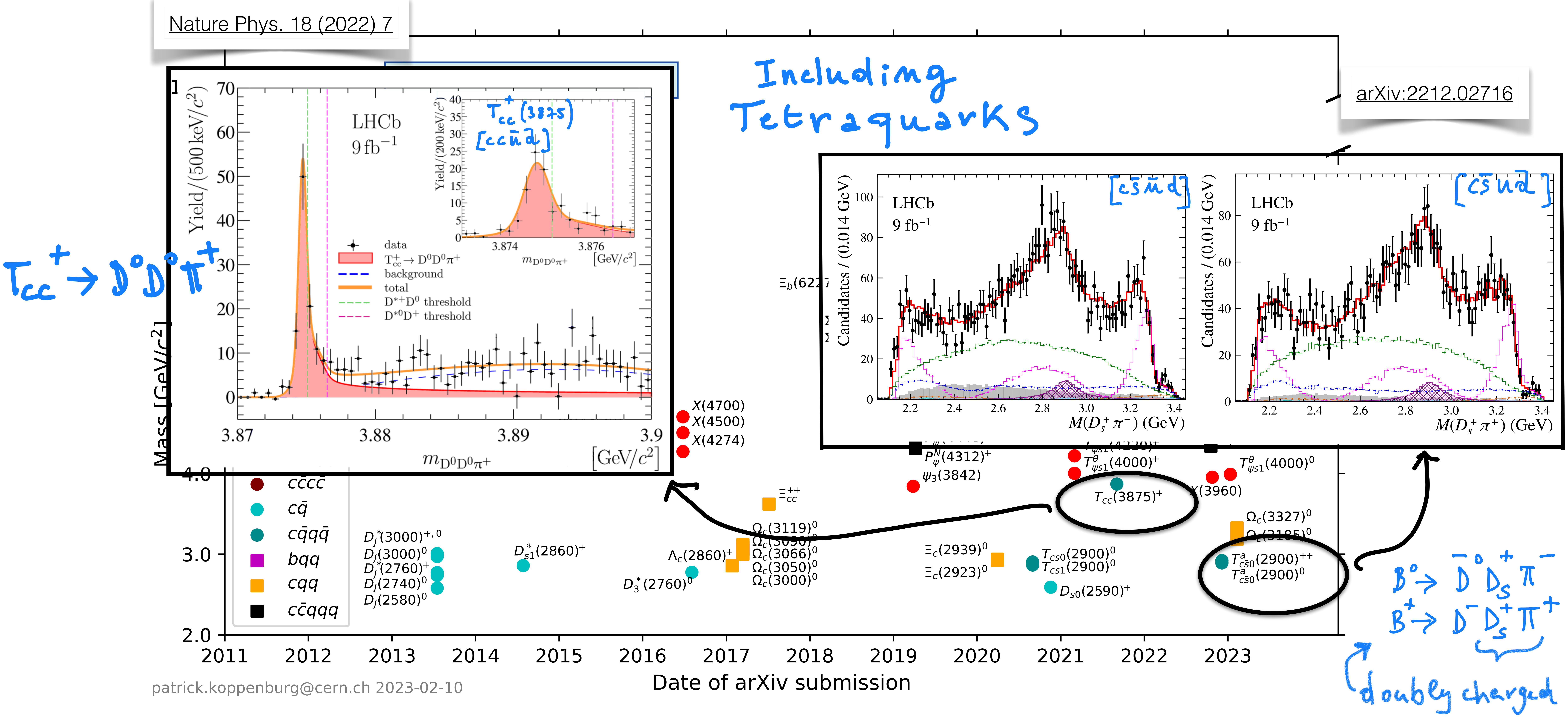
$B^- \to J/\psi\, \Lambda \bar{p}$

patrick.koppenburg@cern.ch 2023-08-16

$\Lambda_b^0 \to J/\psi\, p K^-$

An impressive zoo…

Including Tetraquarks

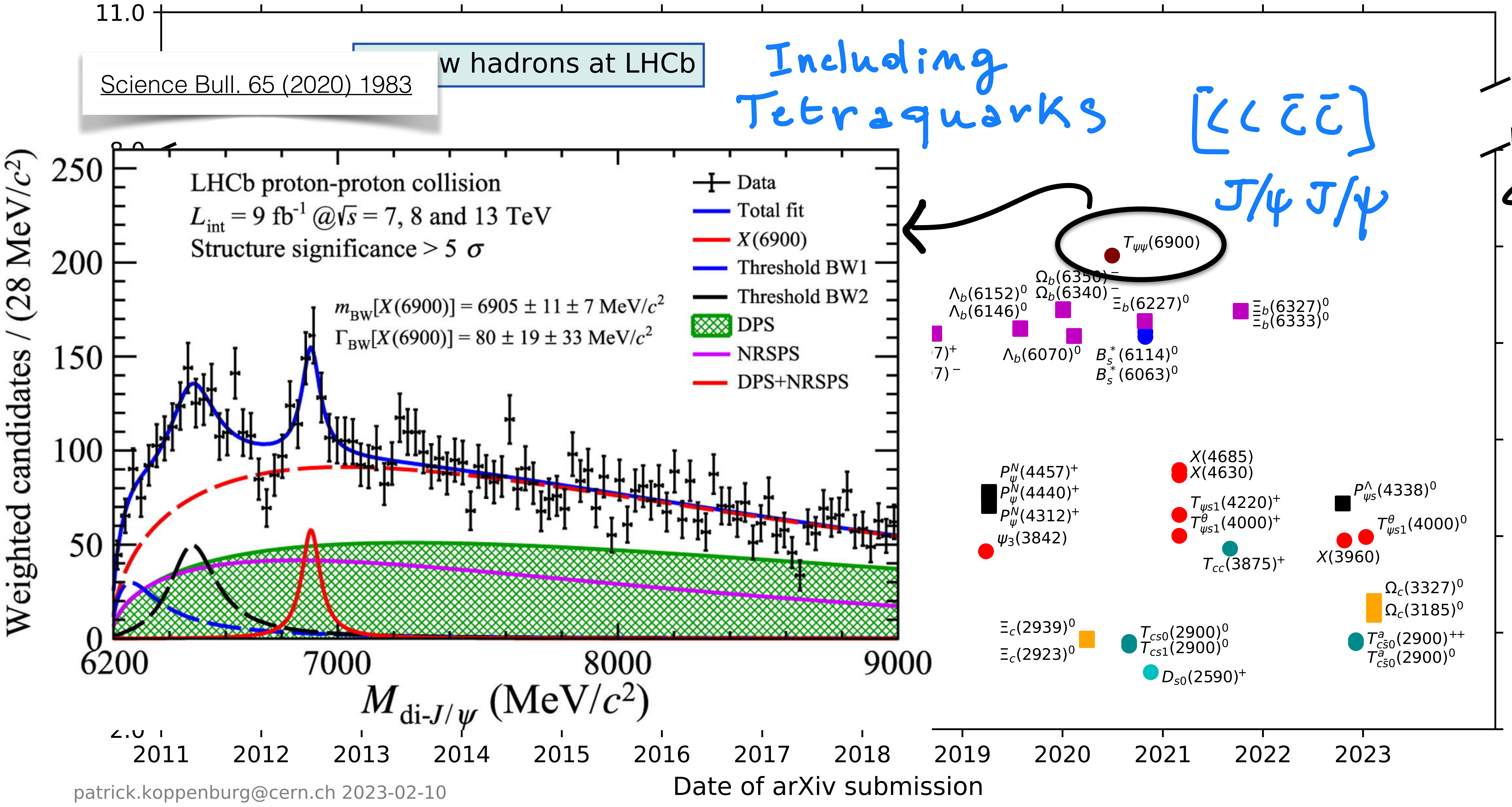


$B^0 \to \bar{D}^0 D_s^+ \pi^-$
$B^+ \to D^- \underbrace{D_s^+ \pi^+}$

doubly charged

patrick.koppenburg@cern.ch 2023-02-10

An impressive zoo…



Science Bull. 65 (2020) 1983

Including Tetraquarks $[cc\bar{c}\bar{c}]$

$J/\psi\ J/\psi$

Confirmed by ATLAS & CMS

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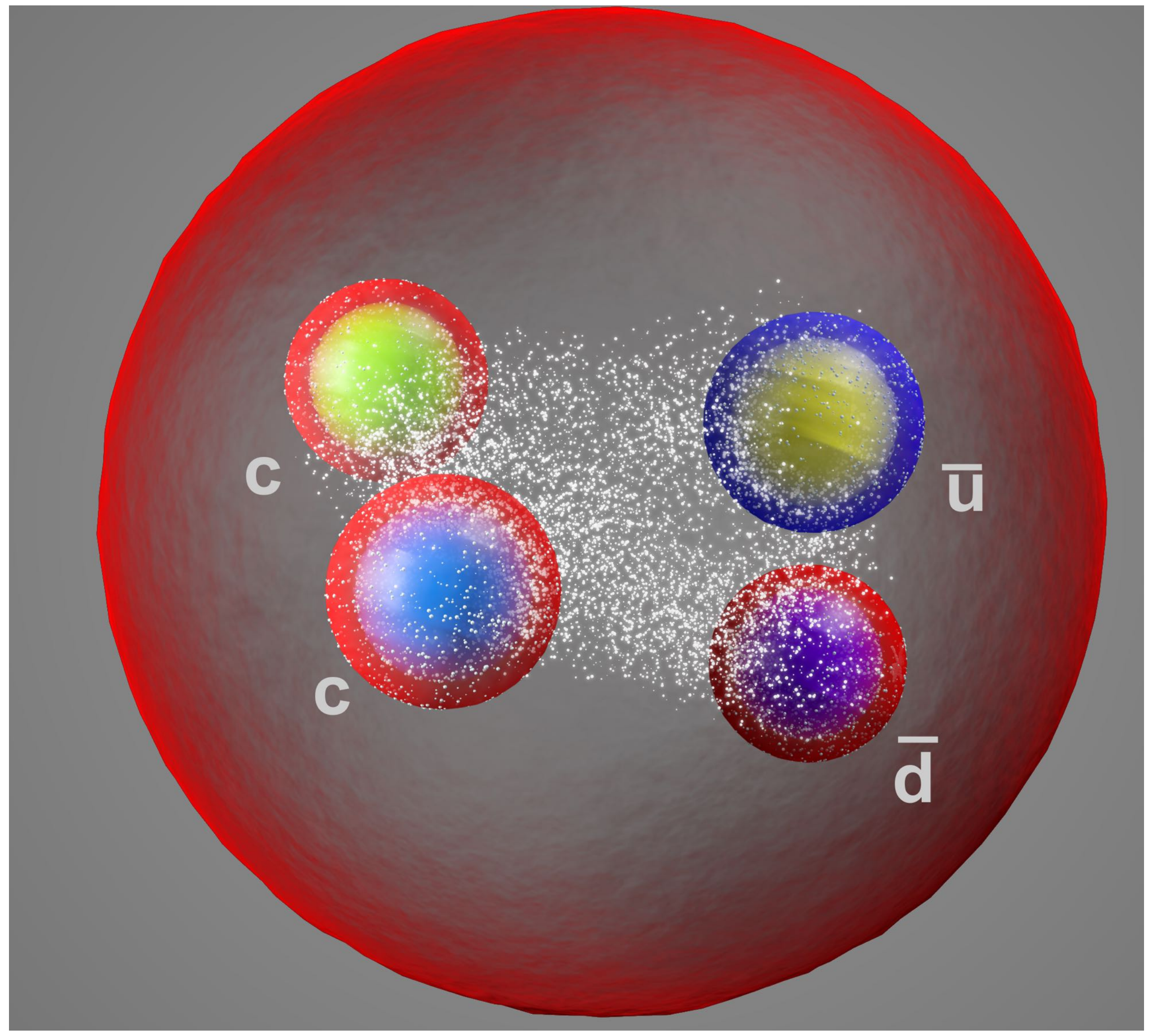
Lively debate on nature of such exotic states

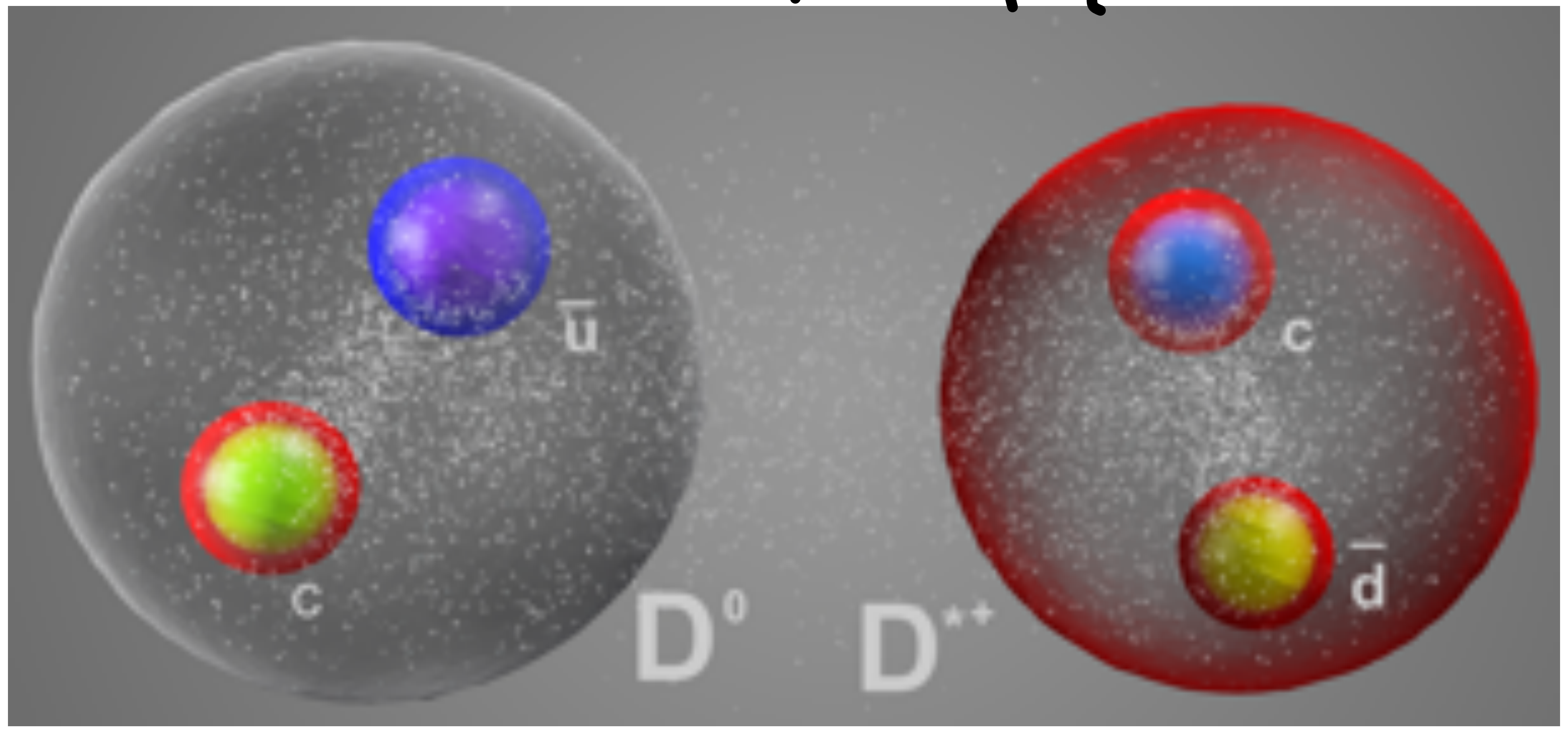
- Compact tetraquarks (pentaquarks) vs meson-meson (meson-baryon) molecules

$[(\bar{q}\bar{q})(qq)]$



$(q\bar{q}) - (q\bar{q})$

π, ρ, ω, η



- It will be difficult to explain these multi-quark states unambiguously
- The best we can probably hope for is to demonstrate the presence of different dominant binding mechanisms in different systems

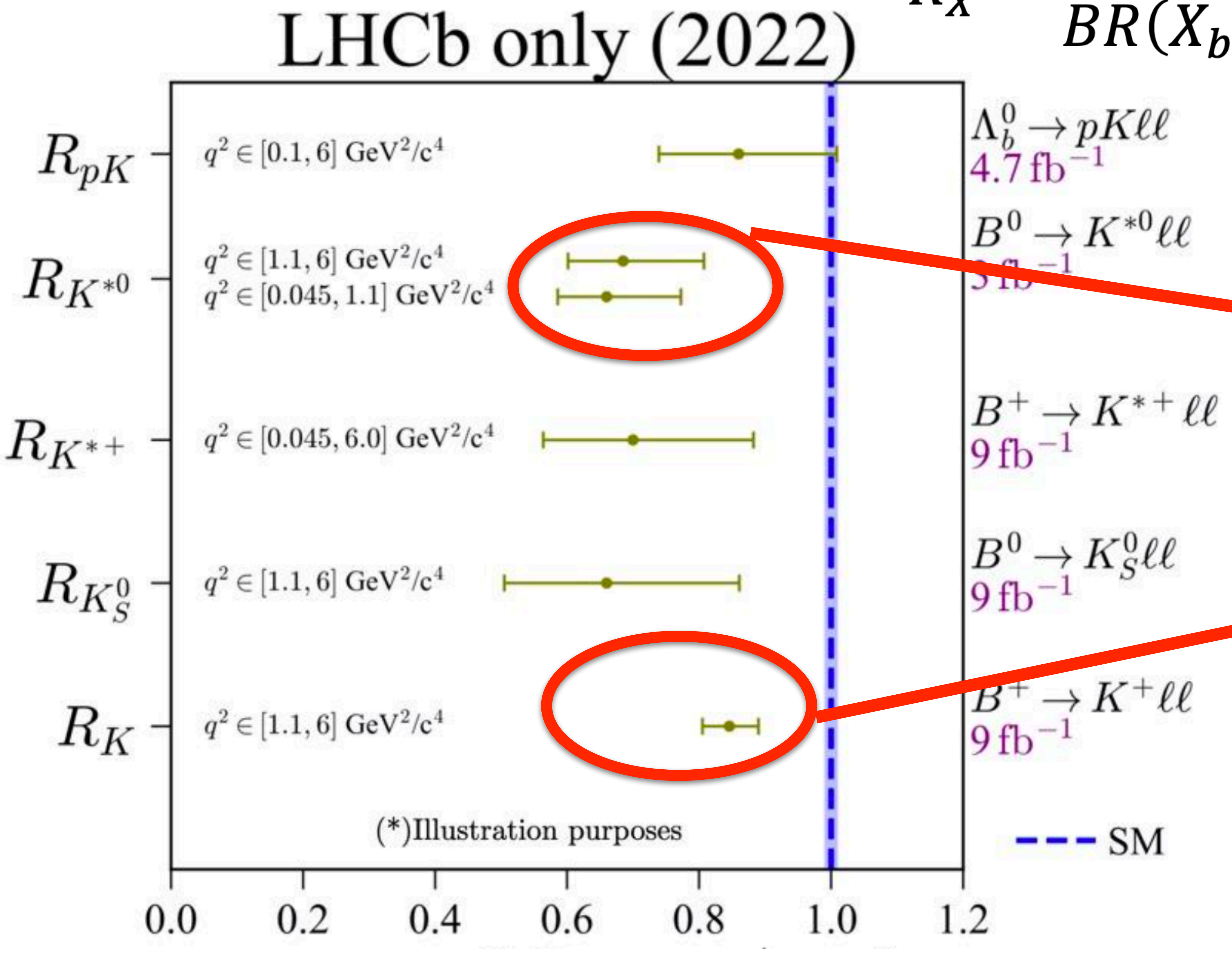
Some setbacks...

Tests of Lepton Flavour Universality

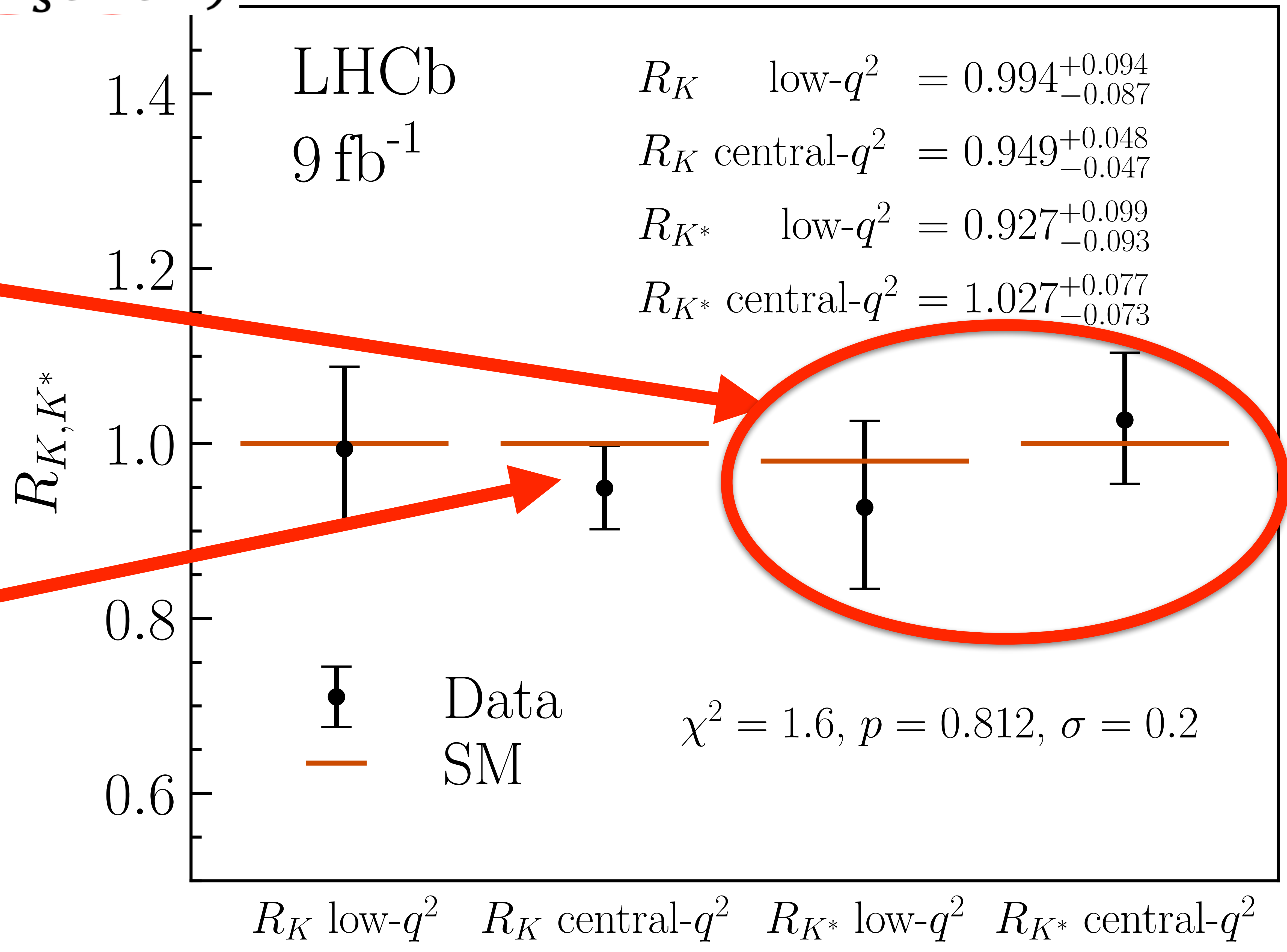
$$R_X = \frac{BR(X_b \to X_s \mu^+ \mu^-)}{BR(X_b \to X_s e^+ e^-)}$$

PRD 108 (2023) 032002
PRL 131 (2023) 051803

Pre Dec 2022



Post Dec 2022

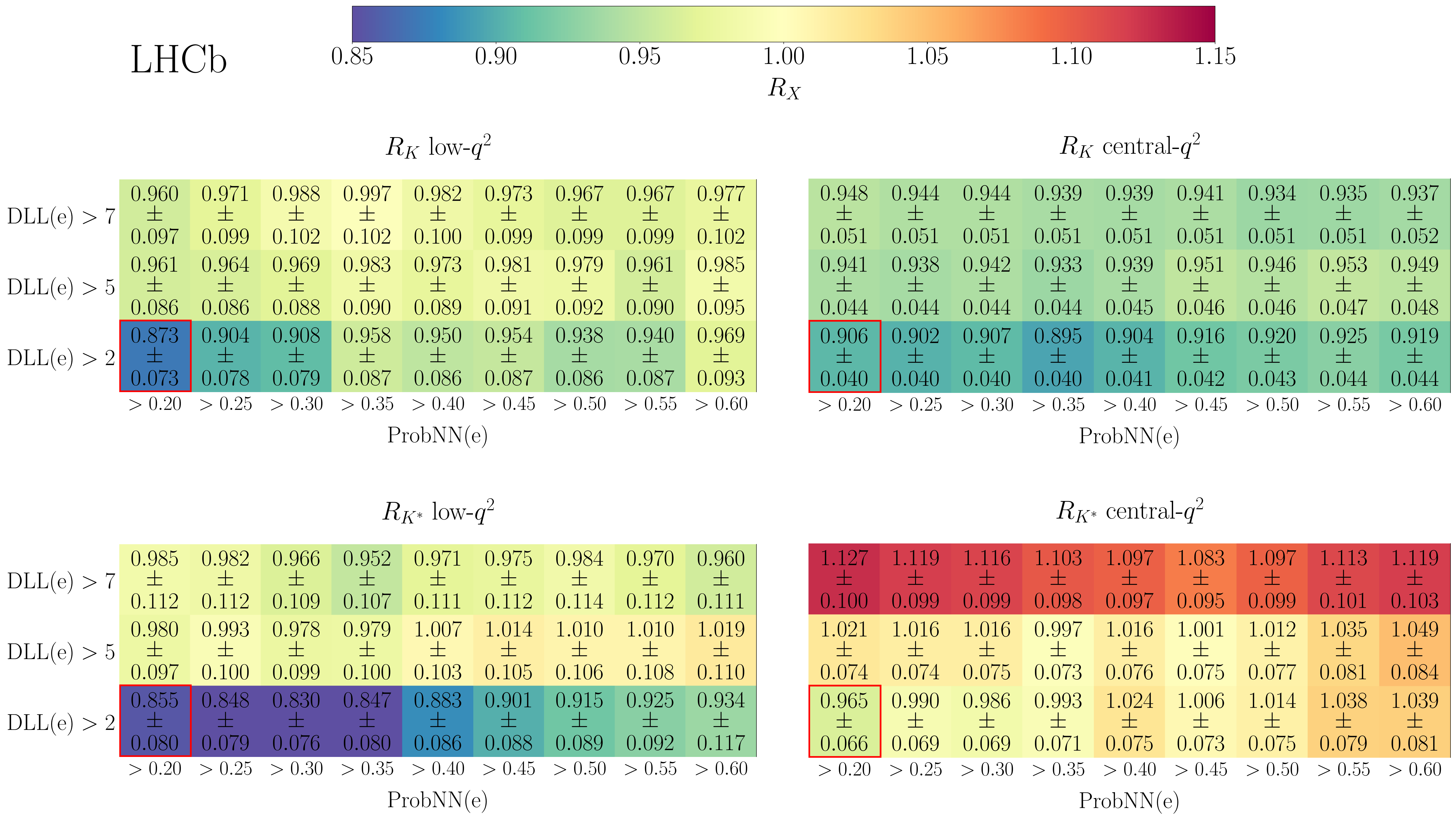


Low q^2 :
$q^2 \in [0.1, 1.1]\,\mathrm{GeV}^2/c^4$

Central q^2 :
$q^2 \in [1.1, 6.0]\,\mathrm{GeV}^2/c^4$

What happened?

- Tightening electron PID showed a coherent pattern



R_K low-q^2

	ProbNN(e) > 0.20	> 0.25	> 0.30	> 0.35	> 0.40	> 0.45	> 0.50	> 0.55	> 0.60
DLL(e) > 7	0.960 ± 0.097	0.971 ± 0.099	0.988 ± 0.102	0.997 ± 0.102	0.982 ± 0.100	0.973 ± 0.099	0.967 ± 0.099	0.967 ± 0.099	0.977 ± 0.102
DLL(e) > 5	0.961 ± 0.086	0.964 ± 0.086	0.969 ± 0.088	0.983 ± 0.090	0.973 ± 0.089	0.981 ± 0.091	0.979 ± 0.092	0.961 ± 0.090	0.985 ± 0.095
DLL(e) > 2	0.873 ± 0.073	0.904 ± 0.078	0.908 ± 0.079	0.958 ± 0.087	0.950 ± 0.086	0.954 ± 0.087	0.938 ± 0.086	0.940 ± 0.087	0.969 ± 0.093

R_K central-q^2

	ProbNN(e) > 0.20	> 0.25	> 0.30	> 0.35	> 0.40	> 0.45	> 0.50	> 0.55	> 0.60
DLL(e) > 7	0.948 ± 0.051	0.944 ± 0.051	0.944 ± 0.051	0.939 ± 0.051	0.939 ± 0.051	0.941 ± 0.051	0.934 ± 0.051	0.935 ± 0.051	0.937 ± 0.052
DLL(e) > 5	0.941 ± 0.044	0.938 ± 0.044	0.942 ± 0.044	0.933 ± 0.044	0.939 ± 0.045	0.951 ± 0.046	0.946 ± 0.046	0.953 ± 0.047	0.949 ± 0.048
DLL(e) > 2	0.906 ± 0.040	0.902 ± 0.040	0.907 ± 0.040	0.895 ± 0.040	0.904 ± 0.041	0.916 ± 0.042	0.920 ± 0.043	0.925 ± 0.044	0.919 ± 0.044

R_{K^*} low-q^2

	ProbNN(e) > 0.20	> 0.25	> 0.30	> 0.35	> 0.40	> 0.45	> 0.50	> 0.55	> 0.60
DLL(e) > 7	0.985 ± 0.112	0.982 ± 0.112	0.966 ± 0.109	0.952 ± 0.107	0.971 ± 0.111	0.975 ± 0.112	0.984 ± 0.114	0.970 ± 0.112	0.960 ± 0.111
DLL(e) > 5	0.980 ± 0.097	0.993 ± 0.100	0.978 ± 0.099	0.979 ± 0.100	1.007 ± 0.103	1.014 ± 0.105	1.010 ± 0.106	1.010 ± 0.108	1.019 ± 0.110
DLL(e) > 2	0.855 ± 0.080	0.848 ± 0.079	0.830 ± 0.076	0.847 ± 0.080	0.883 ± 0.086	0.901 ± 0.088	0.915 ± 0.089	0.925 ± 0.092	0.934 ± 0.117

R_{K^*} central-q^2

	ProbNN(e) > 0.20	> 0.25	> 0.30	> 0.35	> 0.40	> 0.45	> 0.50	> 0.55	> 0.60
DLL(e) > 7	1.127 ± 0.100	1.119 ± 0.099	1.116 ± 0.099	1.103 ± 0.098	1.097 ± 0.097	1.083 ± 0.095	1.097 ± 0.099	1.113 ± 0.101	1.119 ± 0.103
DLL(e) > 5	1.021 ± 0.074	1.016 ± 0.074	1.016 ± 0.075	0.997 ± 0.073	1.016 ± 0.076	1.001 ± 0.075	1.012 ± 0.077	1.035 ± 0.081	1.049 ± 0.084
DLL(e) > 2	0.965 ± 0.066	0.990 ± 0.069	0.986 ± 0.069	0.993 ± 0.071	1.024 ± 0.075	1.006 ± 0.073	1.014 ± 0.075	1.038 ± 0.079	1.039 ± 0.081

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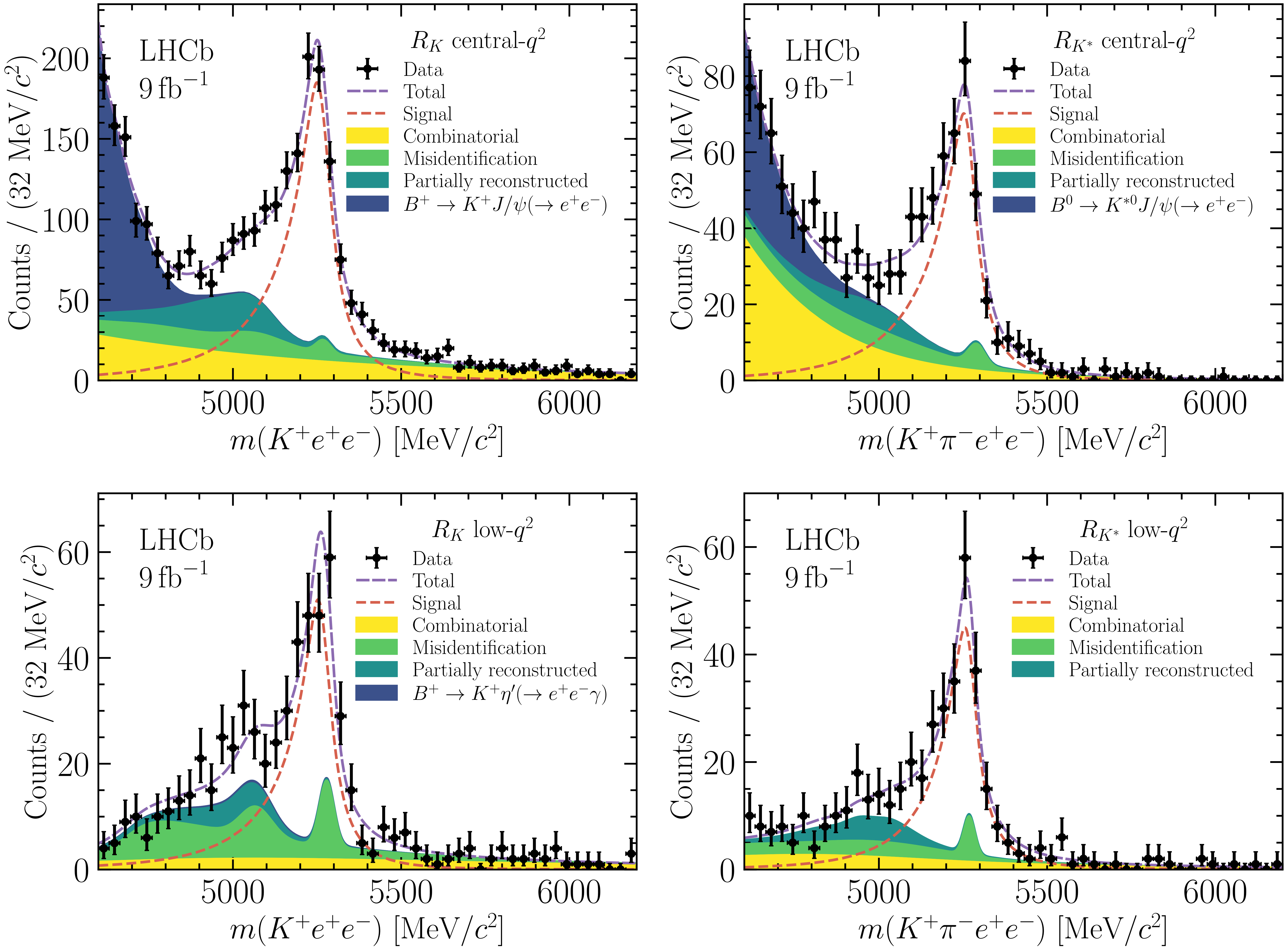
DLL(e): *combination of sub-detectors delta-log-likelihood for π/e*

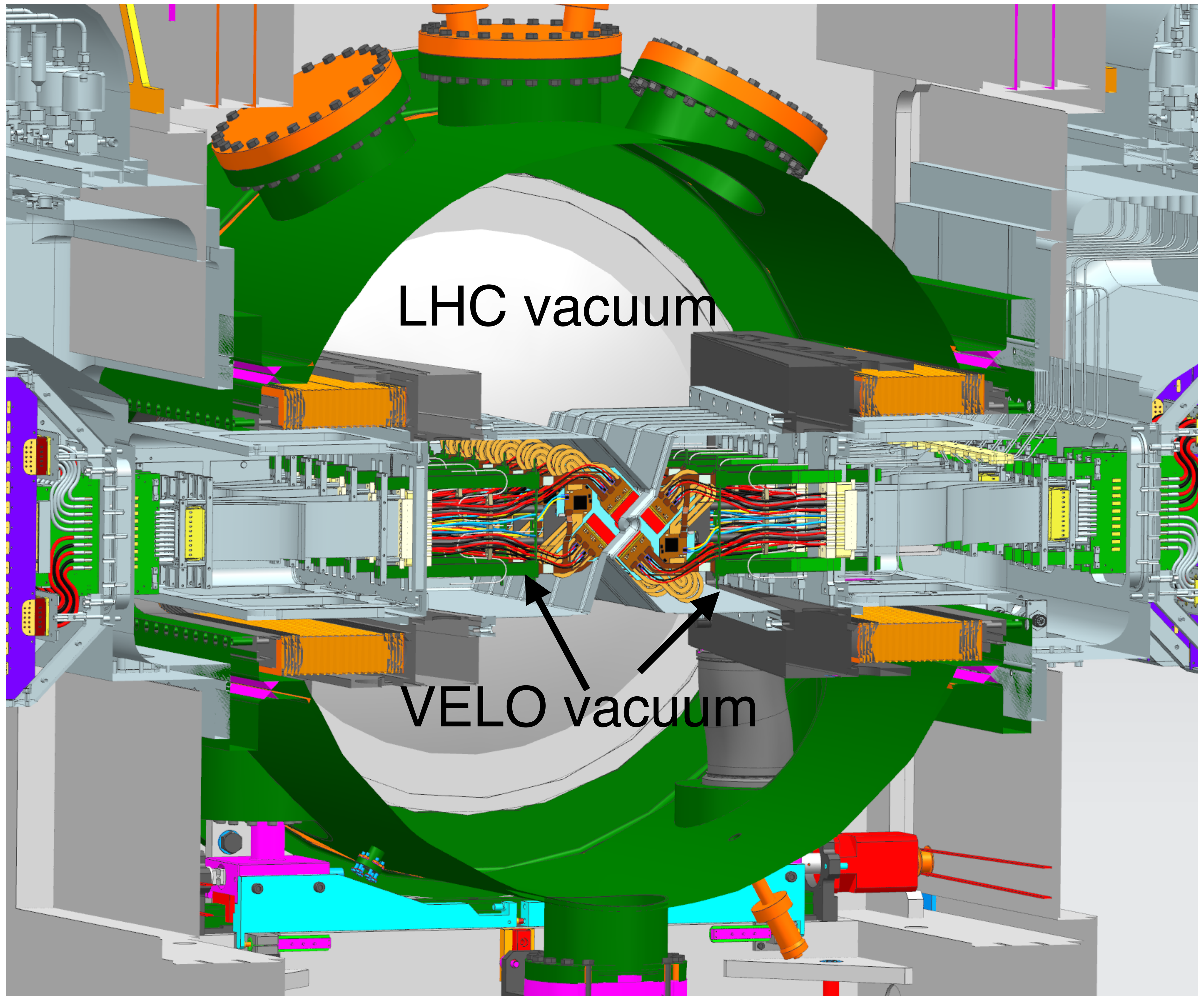
ProbNN(e): *neural-net based e-ID score*

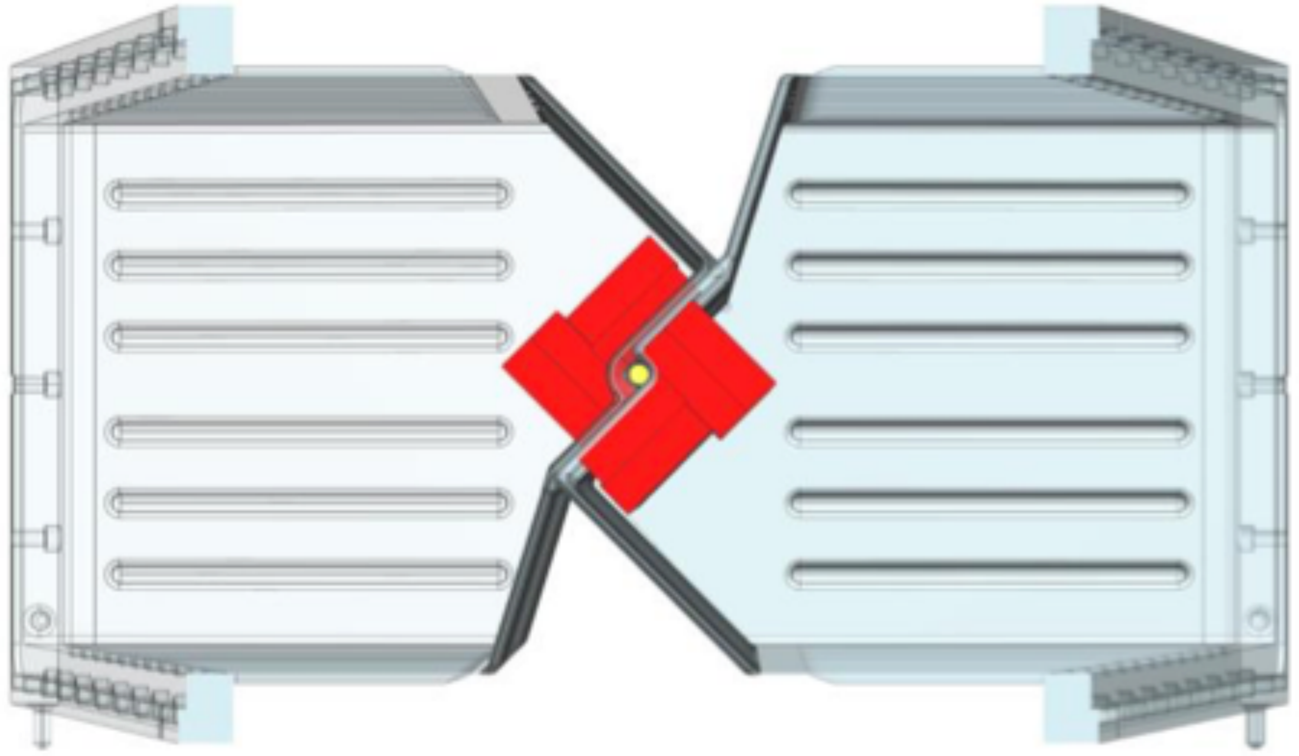
- Led to uncovering previously underestimated peaking backgrounds

Resulting mass fits in electron mode



LHC VELO vacuum control system incident

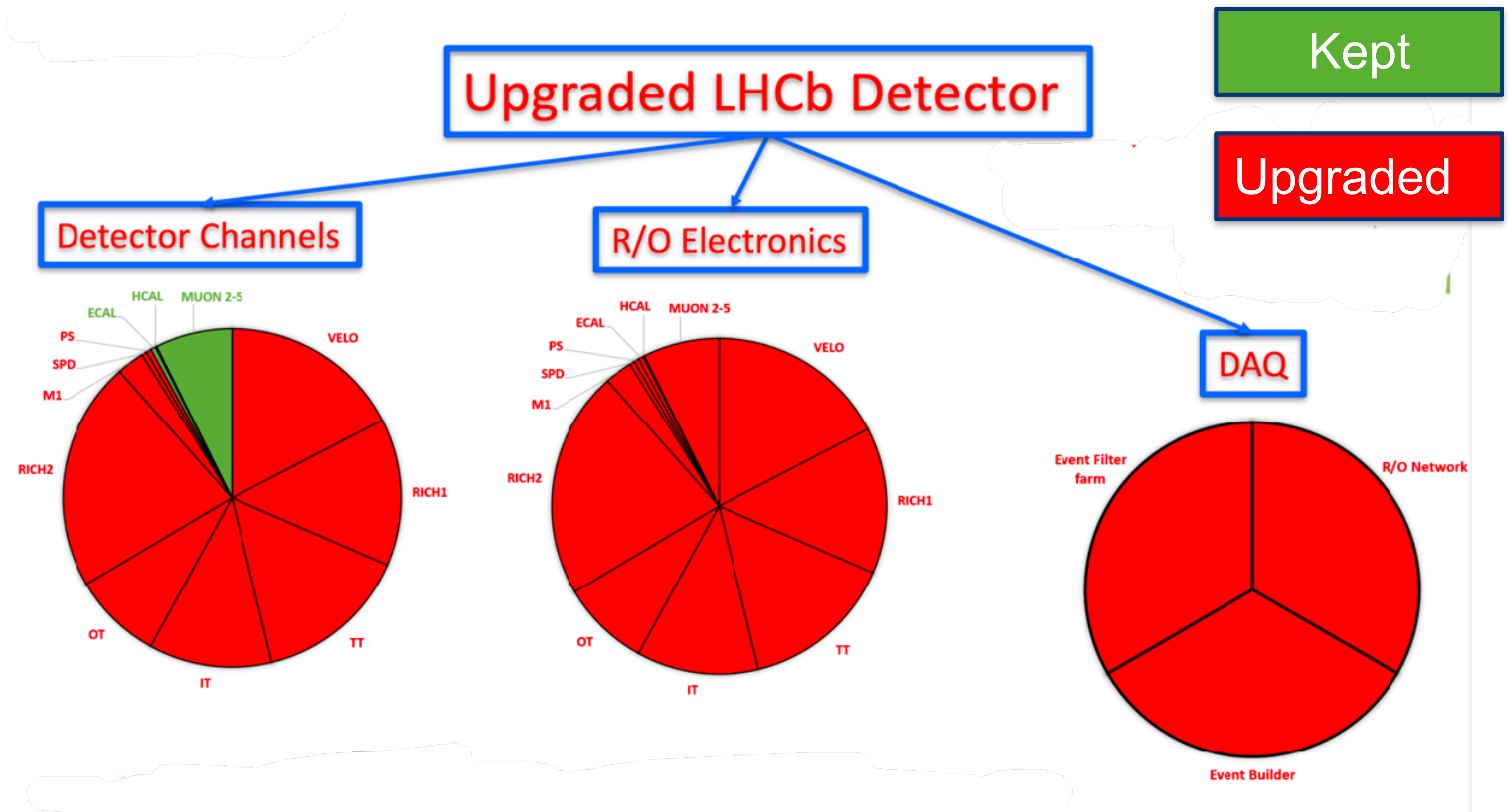




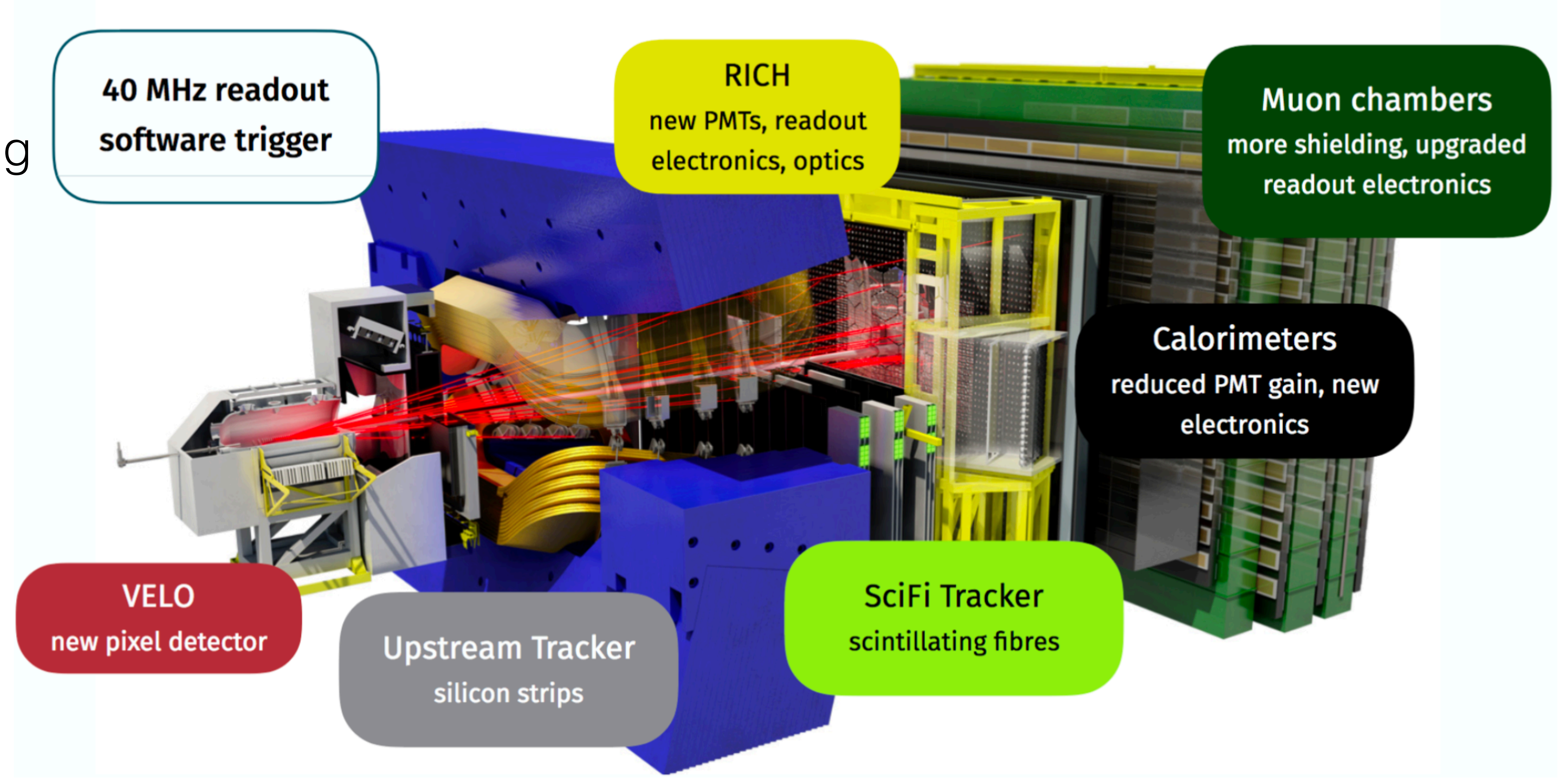
- Incident happened on 10th January 2023, during a VELO warm-up in neon.
- Very thin RF foils separating the LHC and VELO vacua, suffered a plastic deformation of up to ~15 mm towards the beam → they have to be replaced
- No damage to the detector
- Replacement of the foil in the shutdown at the end of 2023
- VELO could not be fully closed in 2023

We have upgraded our detector

- Full software trigger
- Raise $\mathscr{L}$ to 2x10^{33}cm^{-2}s^{-1}(5x Run2) maintaining the current reconstruction performance
- Major redesign of all sub-detectors and ambitious readout upgrade



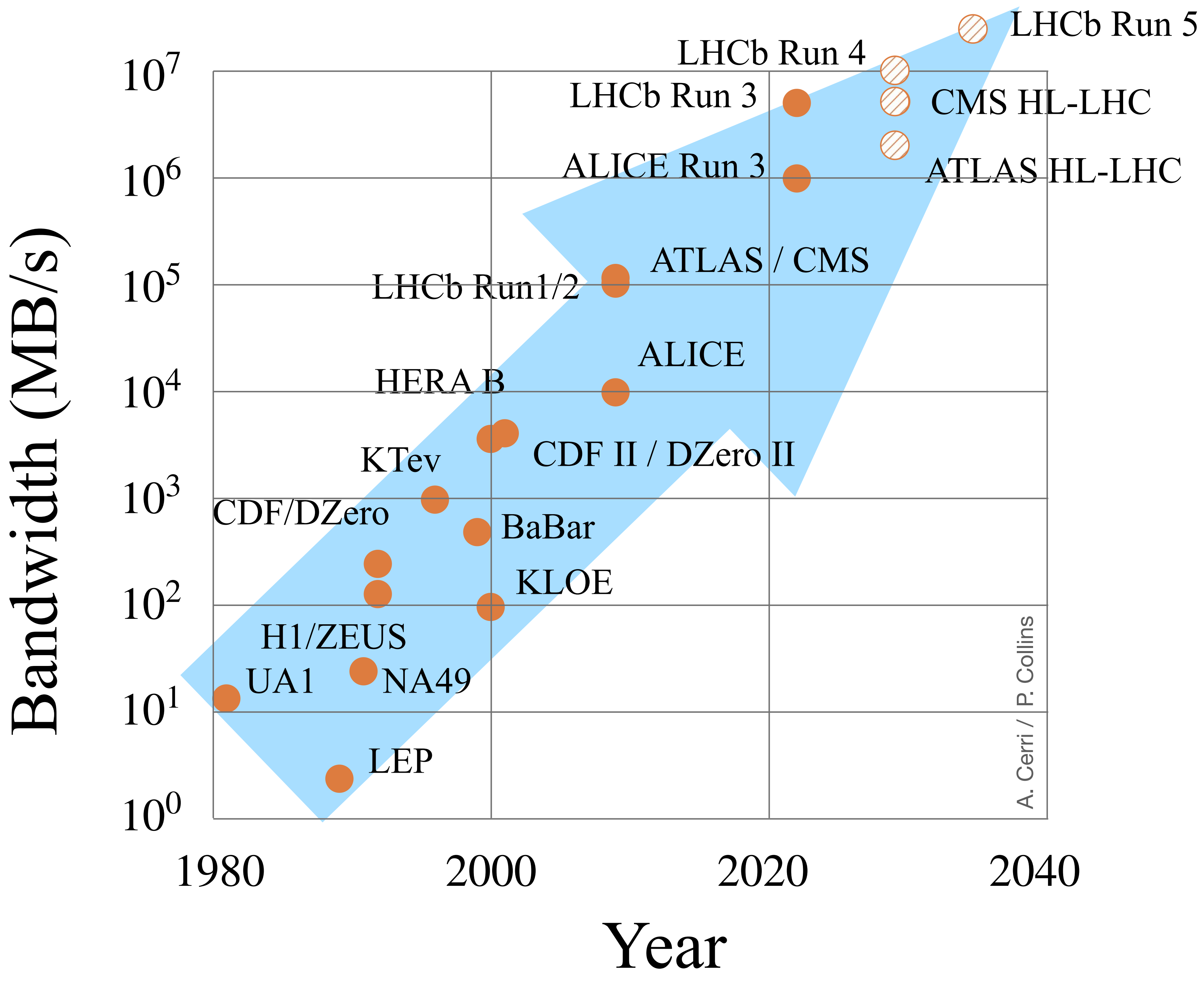
It's an all-together new detector!



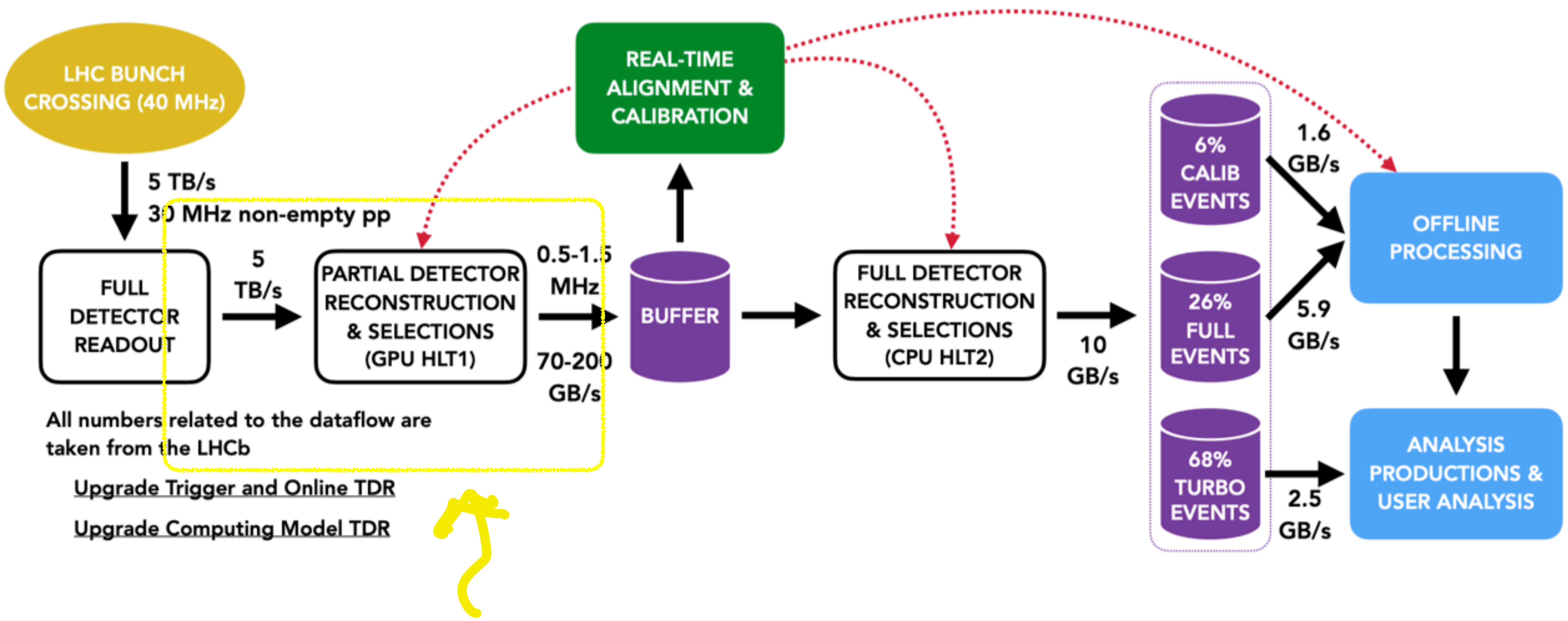
New pixel-based **VELO**
New **RICH** mechanics, optics, photodetectors
New Silicon strip upstream tracker **UT**
New **SciFi** tracker
New electronics for **MUON** and **CALO**
New luminometer **PLUME**
New **SMOG2** system for fixed target physics

A lot of signal → a lot of data to process

- Full software trigger will process 30 MHz of inelastic collisions → factor ~10 increase in hadronic yield in Run 3



[P.Collins]



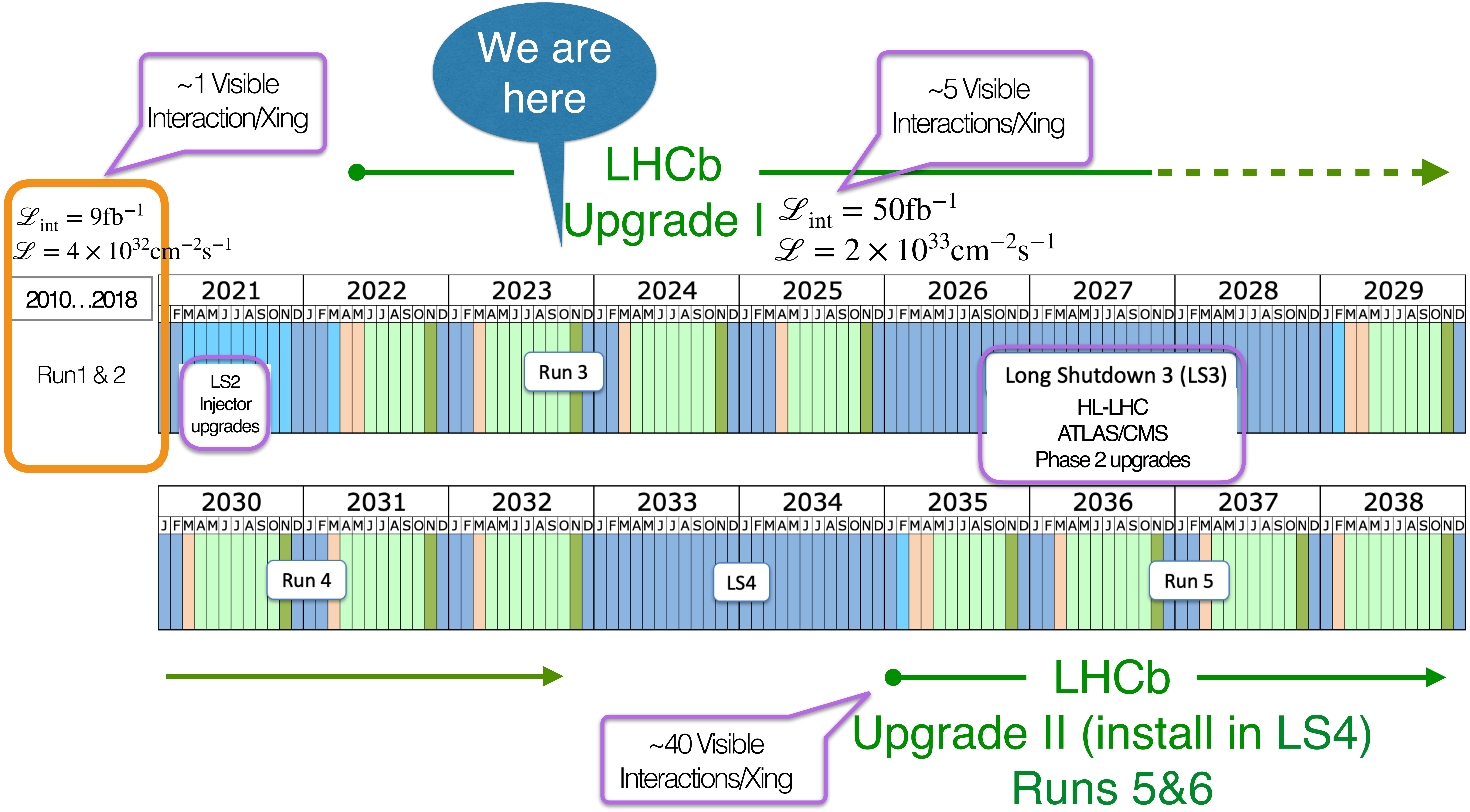
All numbers related to the dataflow are taken from the LHCb

Upgrade Trigger and Online TDR

Upgrade Computing Model TDR

First stage of all-software trigger implemented on GPU farm

LHCb upgrade program



We are here

~1 Visible Interaction/Xing

$\mathscr{L}_{\text{int}} = 9\text{fb}^{-1}$
$\mathscr{L} = 4 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$

LHCb Upgrade I

~5 Visible Interactions/Xing

$\mathscr{L}_{\text{int}} = 50\text{fb}^{-1}$
$\mathscr{L} = 2 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$

~40 Visible Interactions/Xing

LHCb Upgrade II (install in LS4)
Runs 5&6

$\mathscr{L}_{\text{int}} = 300\,\text{fb}^{-1}$
$\mathscr{L} \sim 10^{34}\text{cm}^{-2}\text{s}^{-1}$

LHCb upgrade program

Goal is to run at ~10^{34} cm^{-2} s^{-1} , and integrate ~300 fb^{-1}, which poses enormous detector challenges.

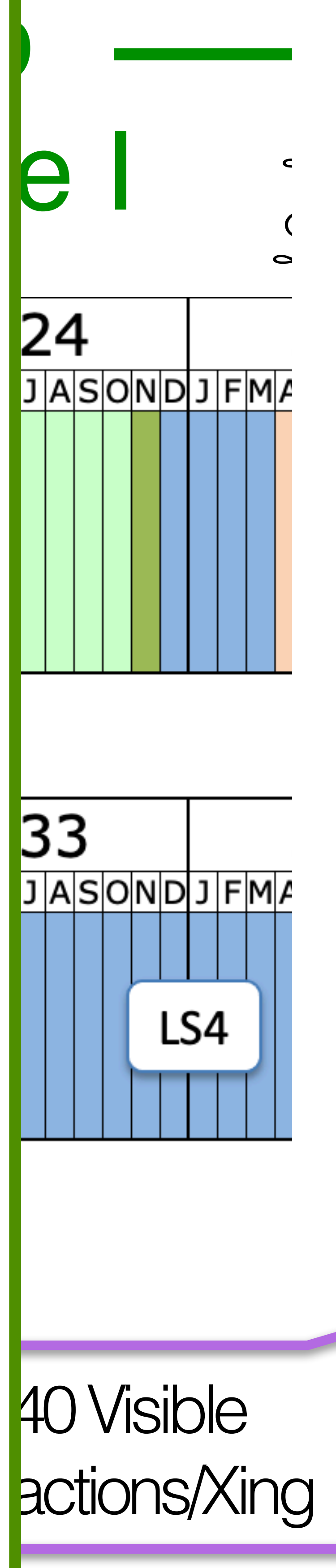
Pileup of 40 and 200 Tb/s of produced data !

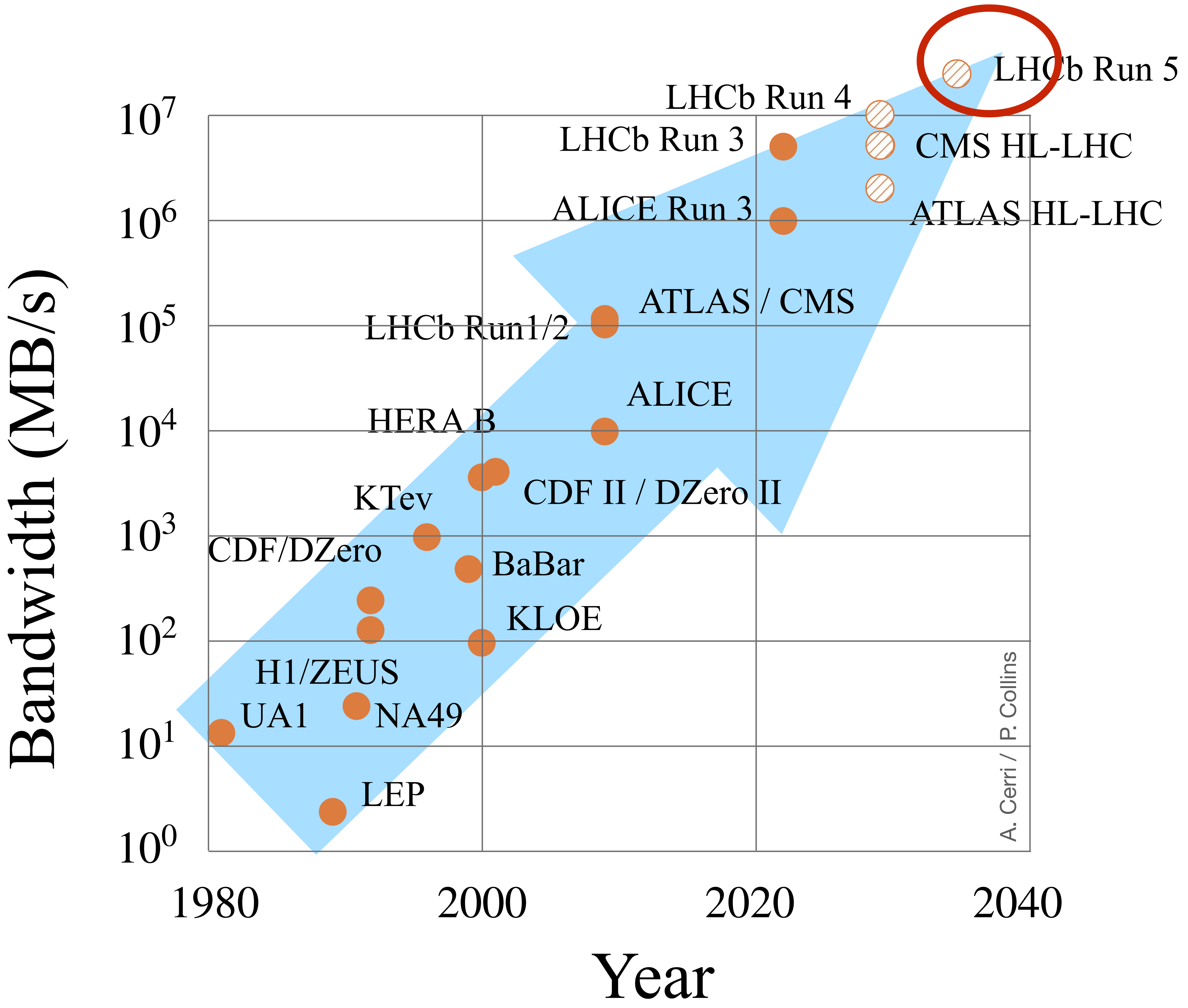
Installation in LS4, with smaller detector enhancements in LS3.

Potentially the only general purpose flavour facility in the world on this timescale.

Require excellent radiation tolerance, higher granularity and **inclusion of precise timing information** (a few 10 ps) to be able to mitigate pileup

R&D started, more groups are welcome!





Upgrade II (instal in LS4)
Runs 5&6

$$\mathscr{L}_{\text{int}} = 300\,\text{fb}^{-1}$$
$$\mathscr{L} \sim 10^{34}\text{cm}^{-2}\text{s}^{-1}$$

Concluding remarks

- LHCb has lived up to its promises and more, delivering many world record and sometimes unexpected results (exotic spectroscopy, CPV in charm,…). For some topics we have moved from exploration to precision measurements and we can still gain by increasing the sample sizes.

- Precision measurements of flavour observables provide a powerful way to search for NP effects beyond the SM, complementing direct searches for NP. This is particularly important in the absence of direct collider production of new particles.

- In general, the SM still (depressingly) in good health. We'll keep looking!

- We have upgraded our detector and implemented many innovative technological ideas.

- The precision program in flavour physics over the next 10 ÷ 15 years is, in my view, the most promising direction to make discoveries before the next accelerator (assuming NP is on the horizon).

Have a great
Implications Workshop!