LHCb prospects for V_{ub} and V_{cb}

Mika Vesterinen
University of Warwick
1st October 2018

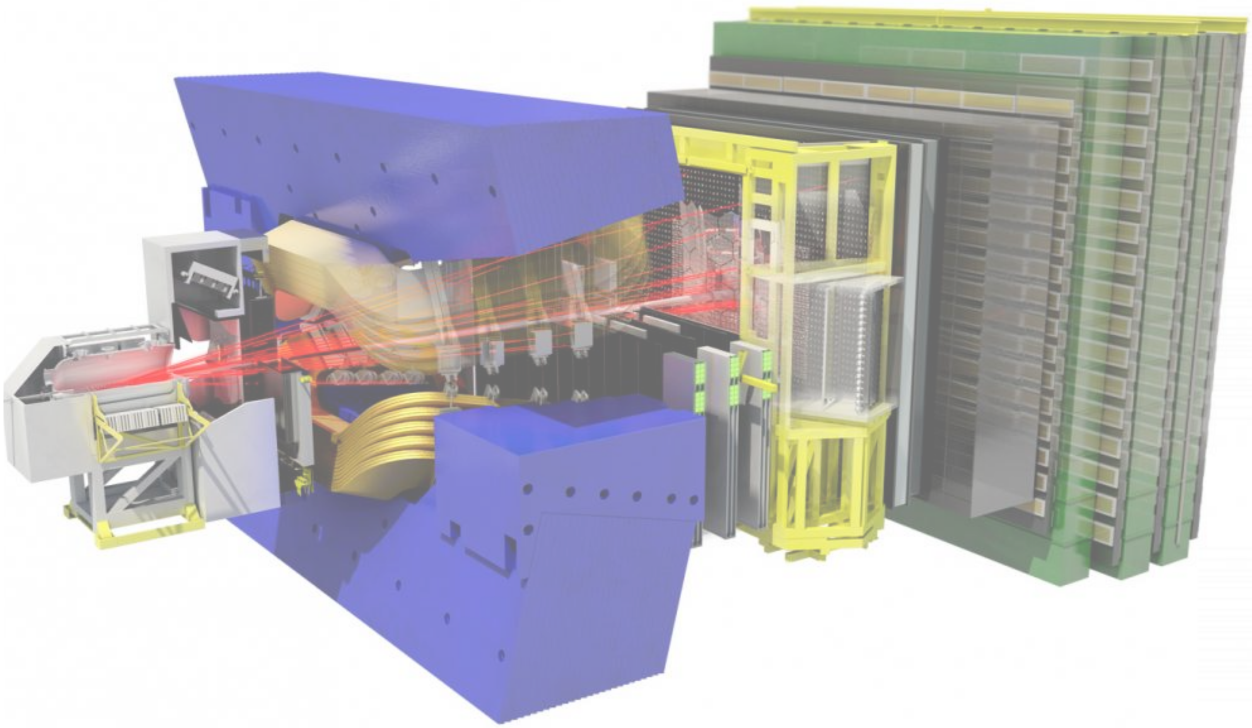
XIII Meeting on B Physics :
Synergy between LHC and SUPERKEKB
in the Quest for New Physics

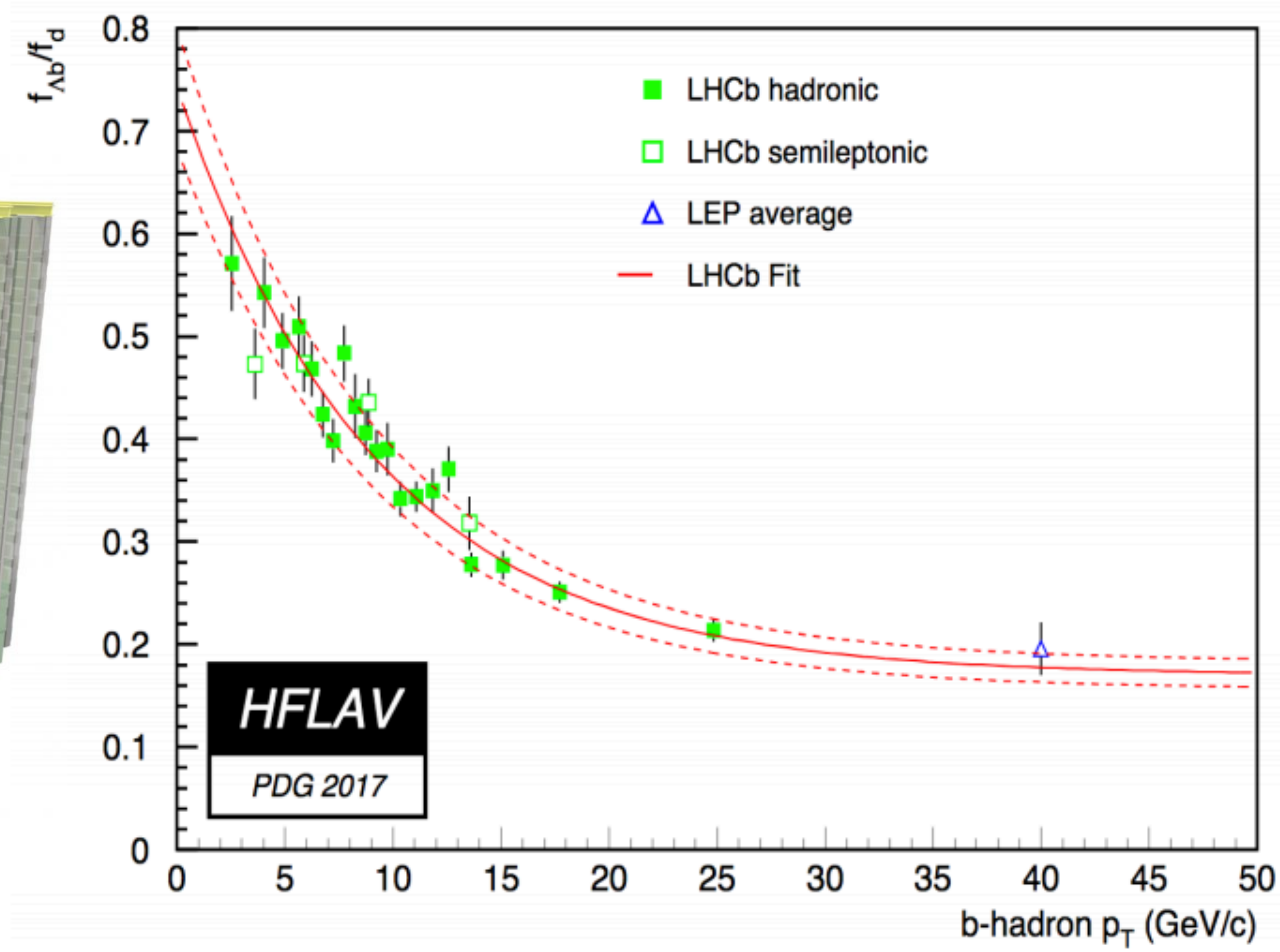
WARWICK

Outline

- Semileptonic decays at LHCb.
- Current results and analysis activities.
- Future prospects.

LHCb





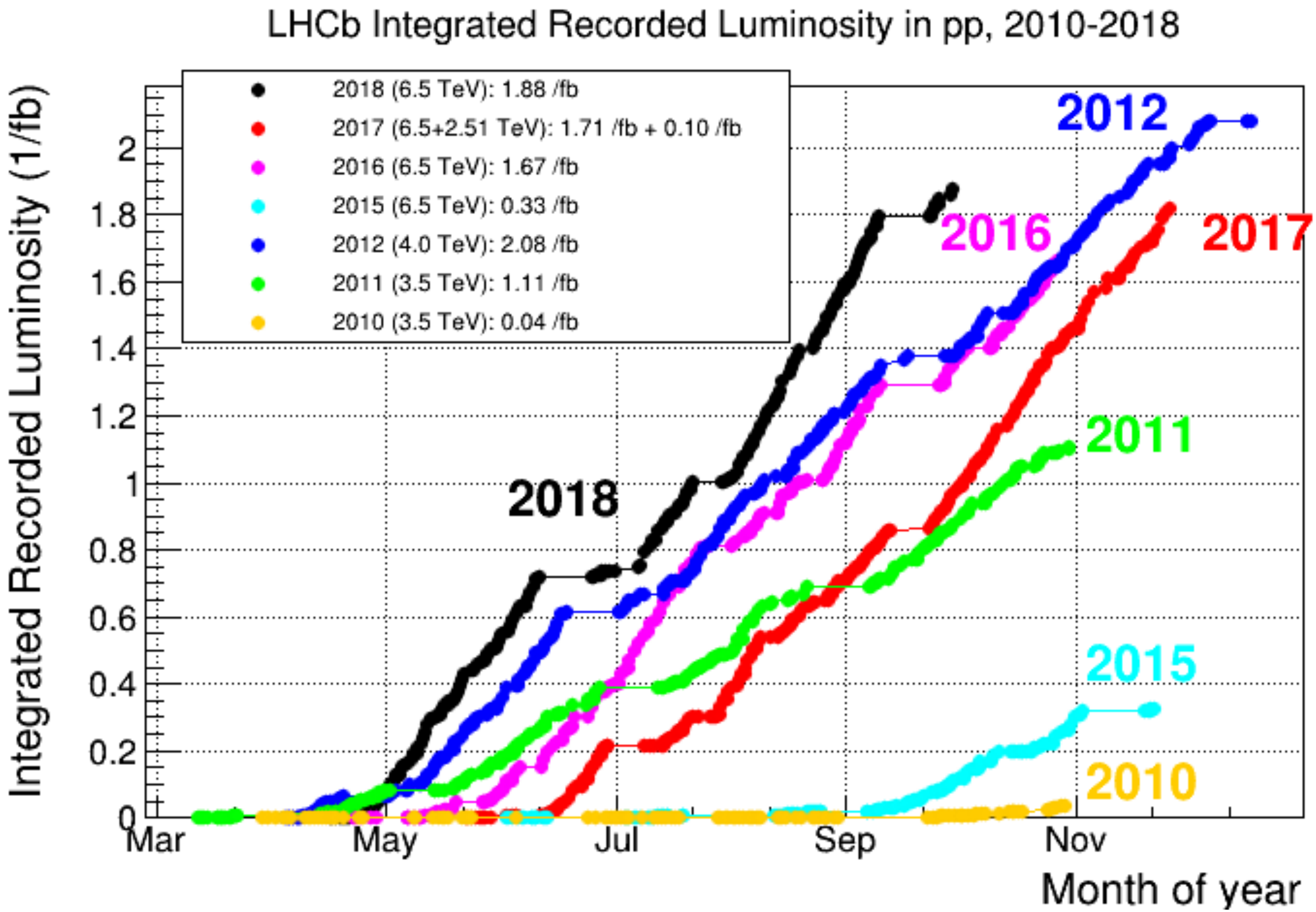
Excellent reconstruction of charged final states, while neutrals and missing energy are more challenging.

Well suited to measurements of exclusive semileptonic decays, to charged final states, of a range of b hadrons.

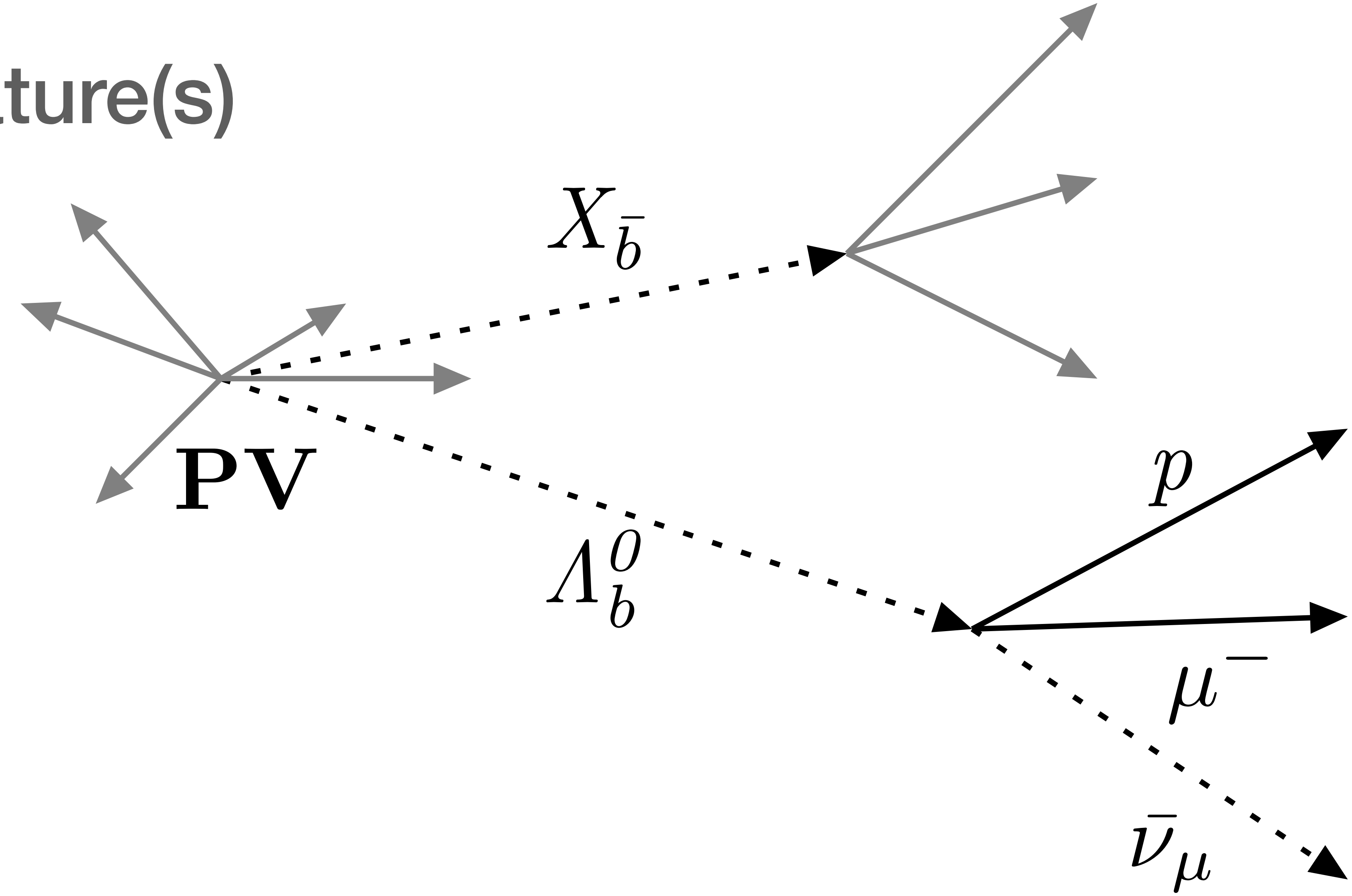
Suitable observables

- The *b* cross section isn't known.
- We can measure ratios of BFs.
- And normalised differential decay rates.

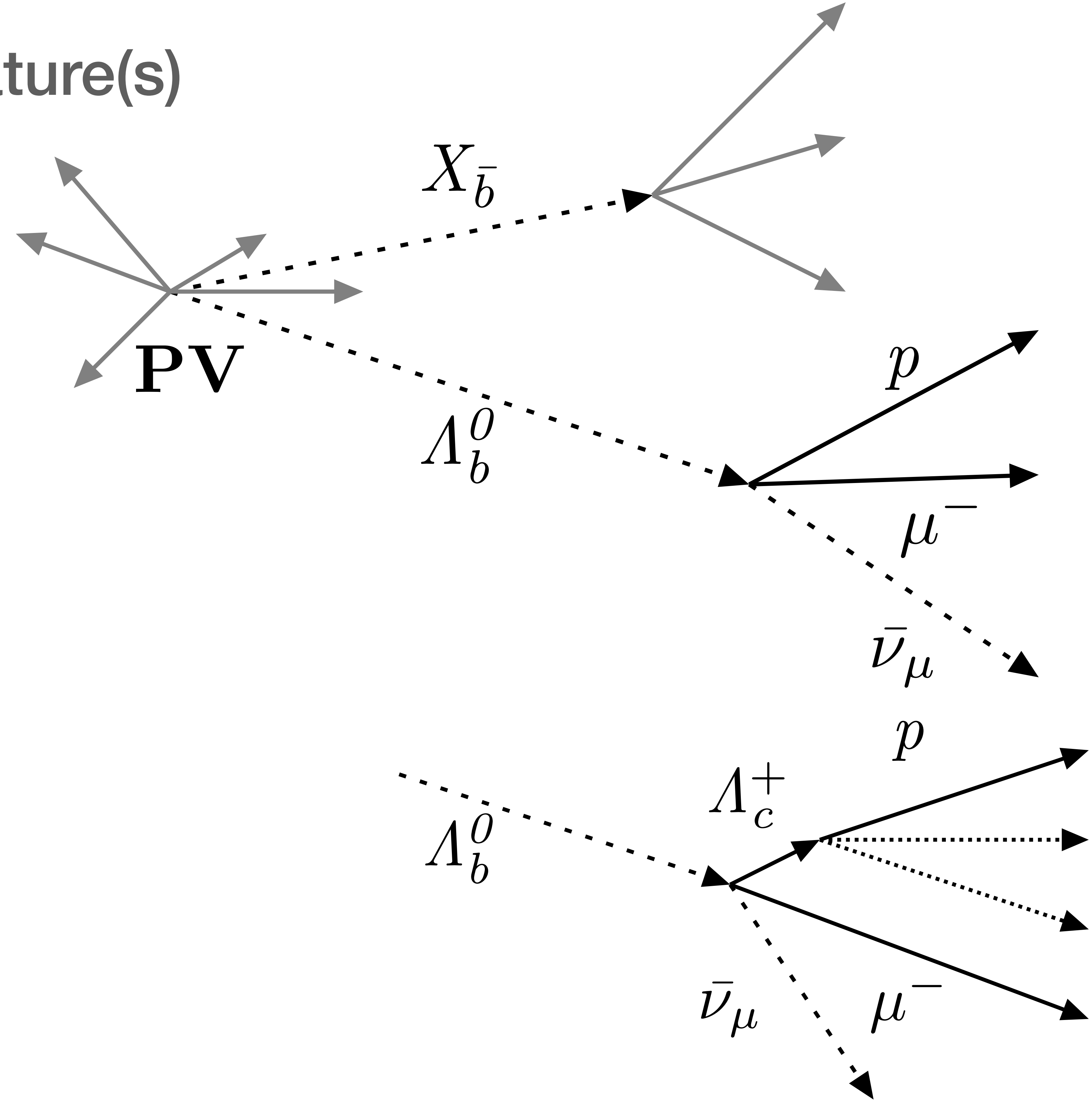
Operations


LHCb Integrated Recorded Luminosity in pp, 2010-2018
2018 (6.5 TeV): 1.88 /fb
2017 (6.5+2.51 TeV): 1.71 /fb + 0.10 /fb
2016 (6.5 TeV): 1.67 /fb
2015 (6.5 TeV): 0.33 /fb
2012 (4.0 TeV): 2.08 /fb
2011 (3.5 TeV): 1.11 /fb
2010 (3.5 TeV): 0.04 /fb
Integrated Recorded Luminosity (1/fb)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Mar
May
Jul
Sep
Nov
Month of year
2012
2016
2017
2018
2011
2015
2010

The typical signature(s)



The typical signature(s)



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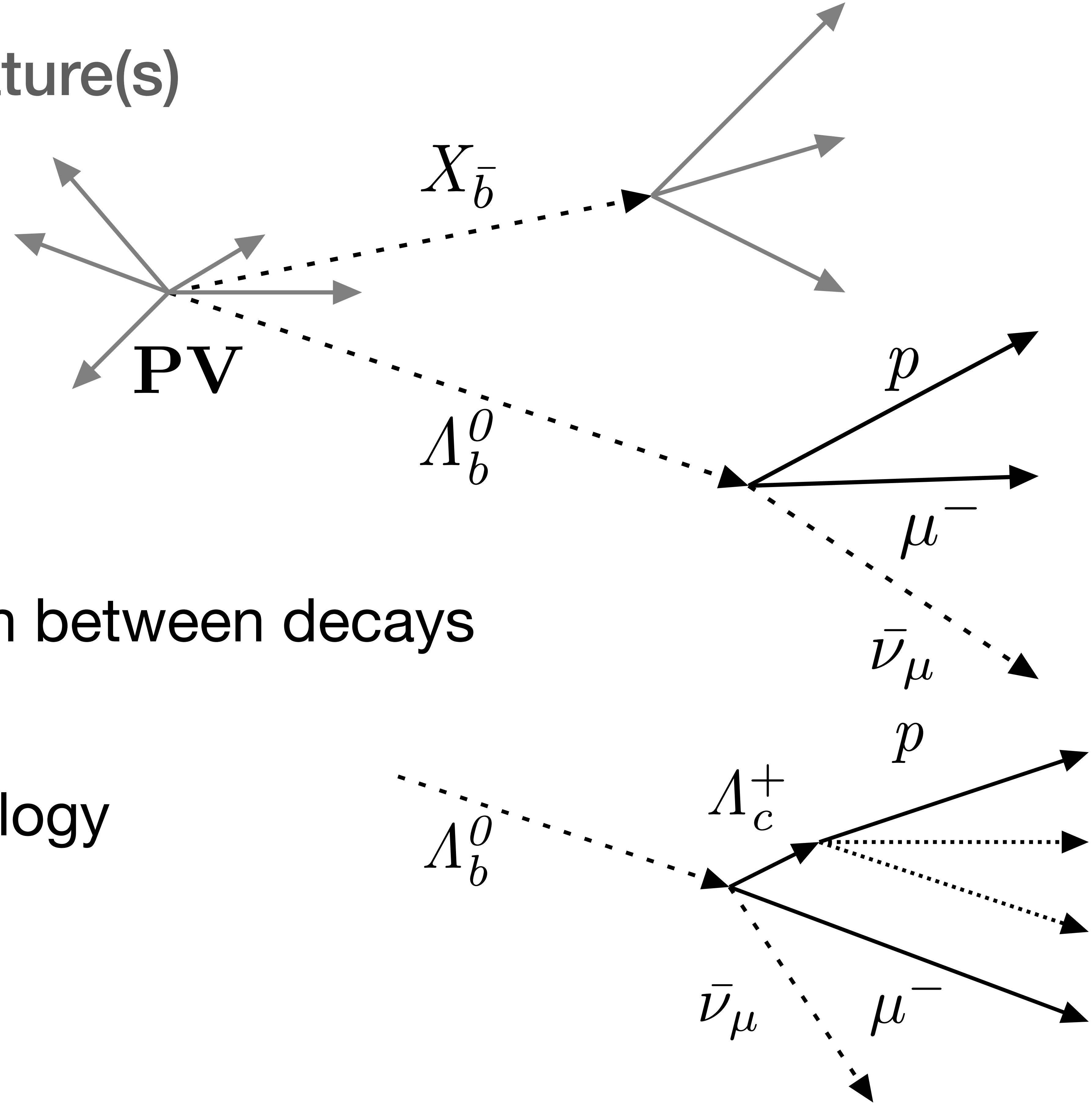
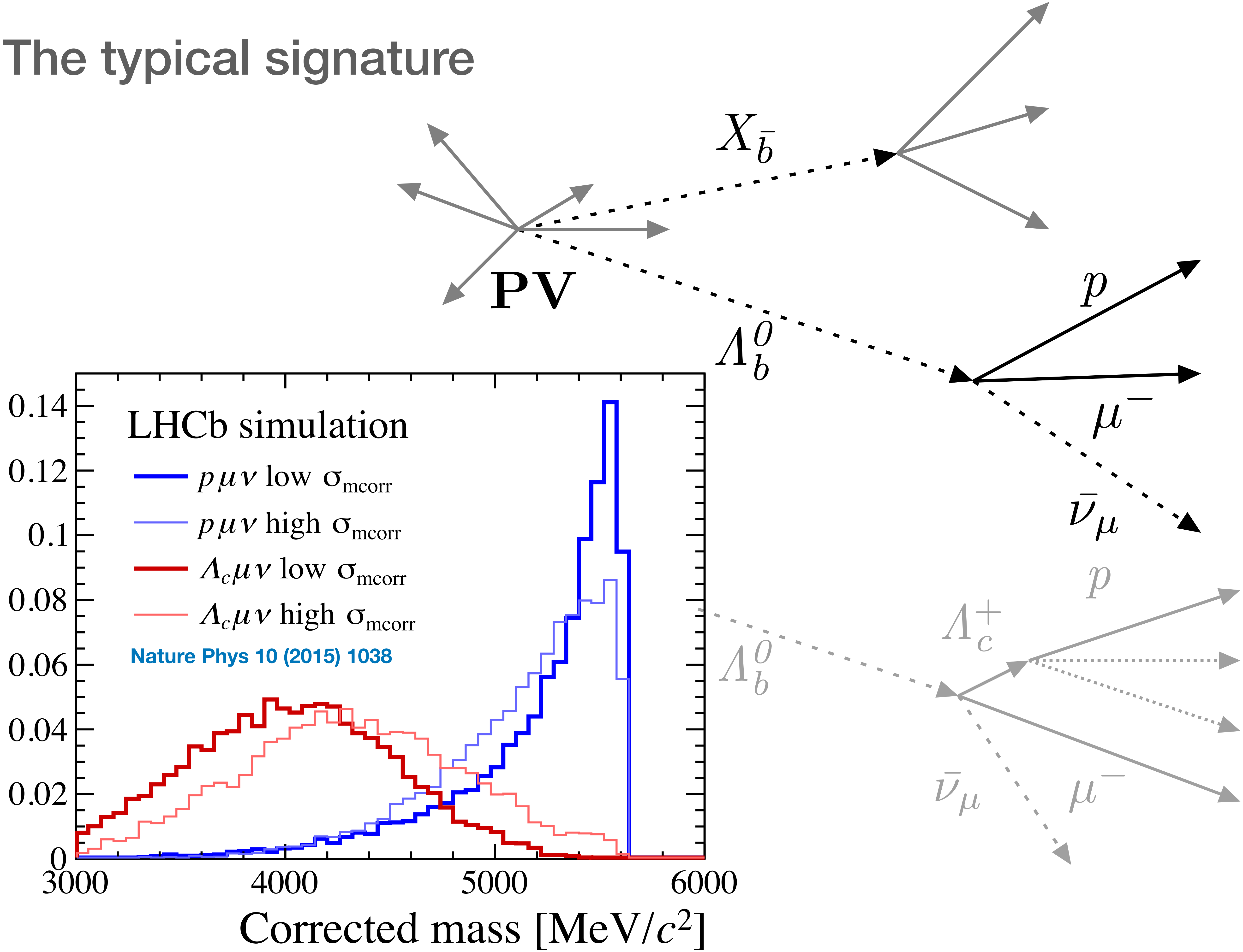


Discrimination between decays

- Isolation
- Vertex topology
- Kinematics

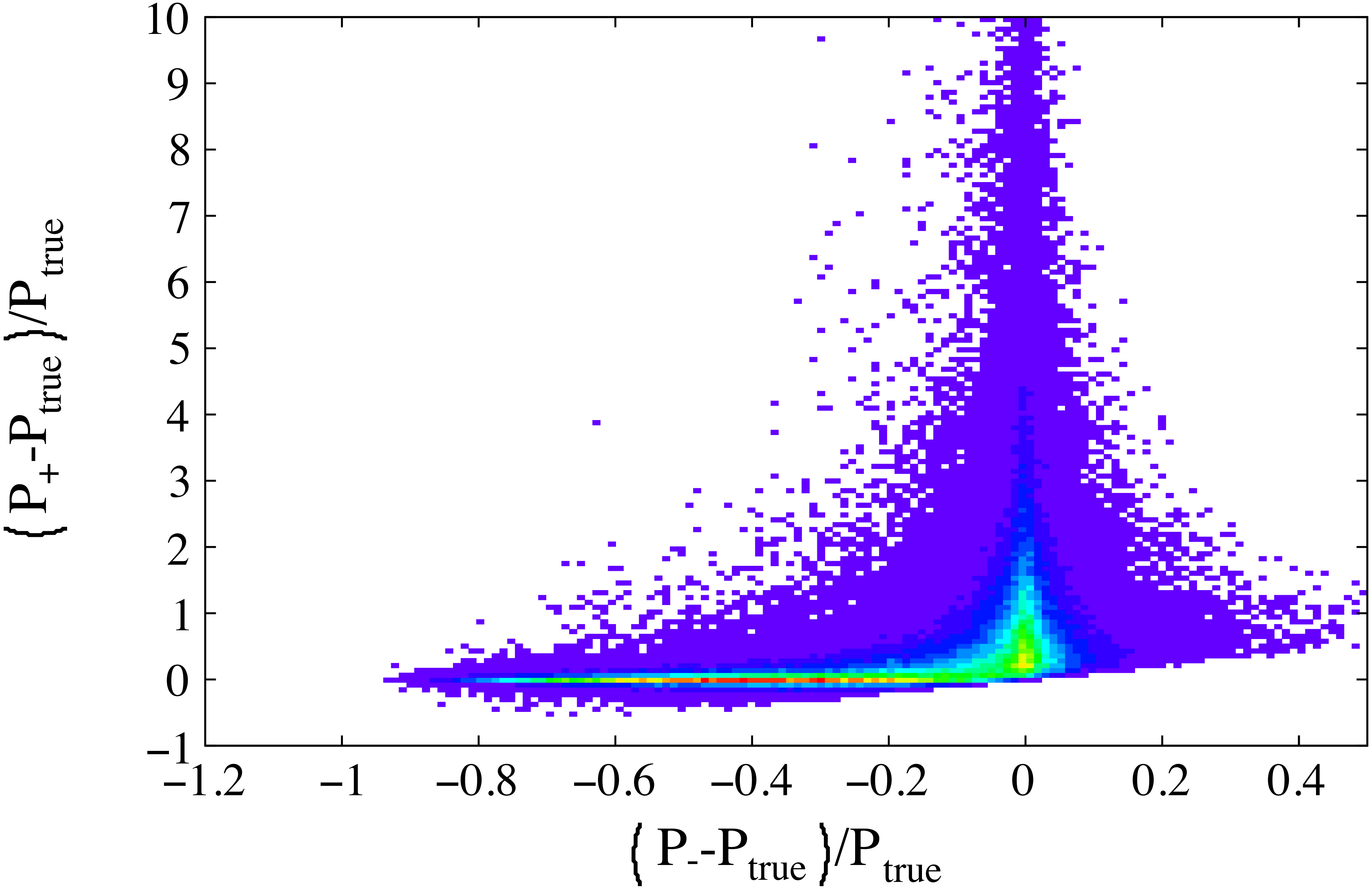
The typical signature



Kinematics

Well known formula for missing 3-momentum using topological information, but subject to quadratic ambiguity.

Dambach, Langenegger, Starodumov, NIM A569 (2006) 824



Kinematics

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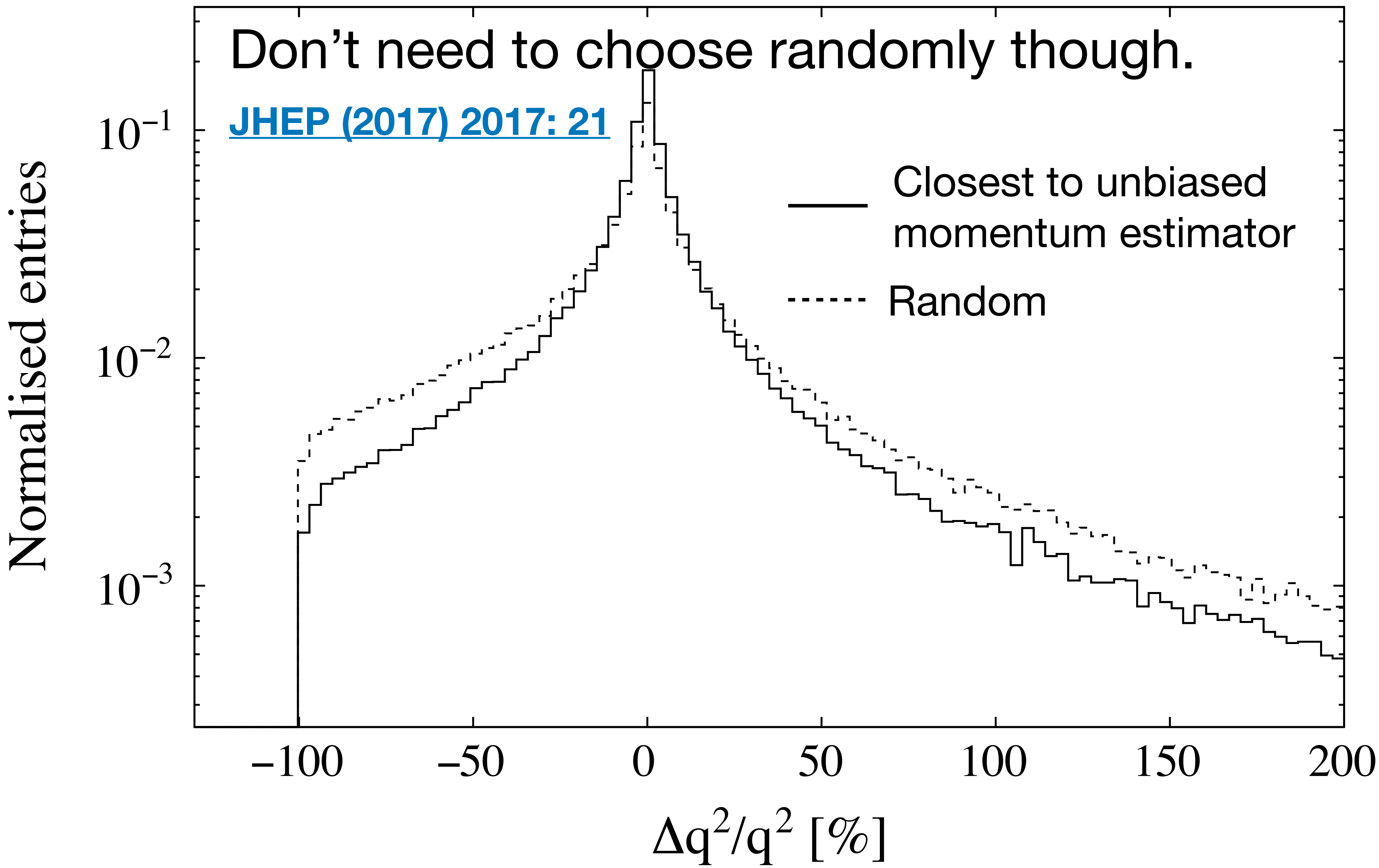
Dambach, Langenegger, Starodumov, NIM A569 (2006) 824

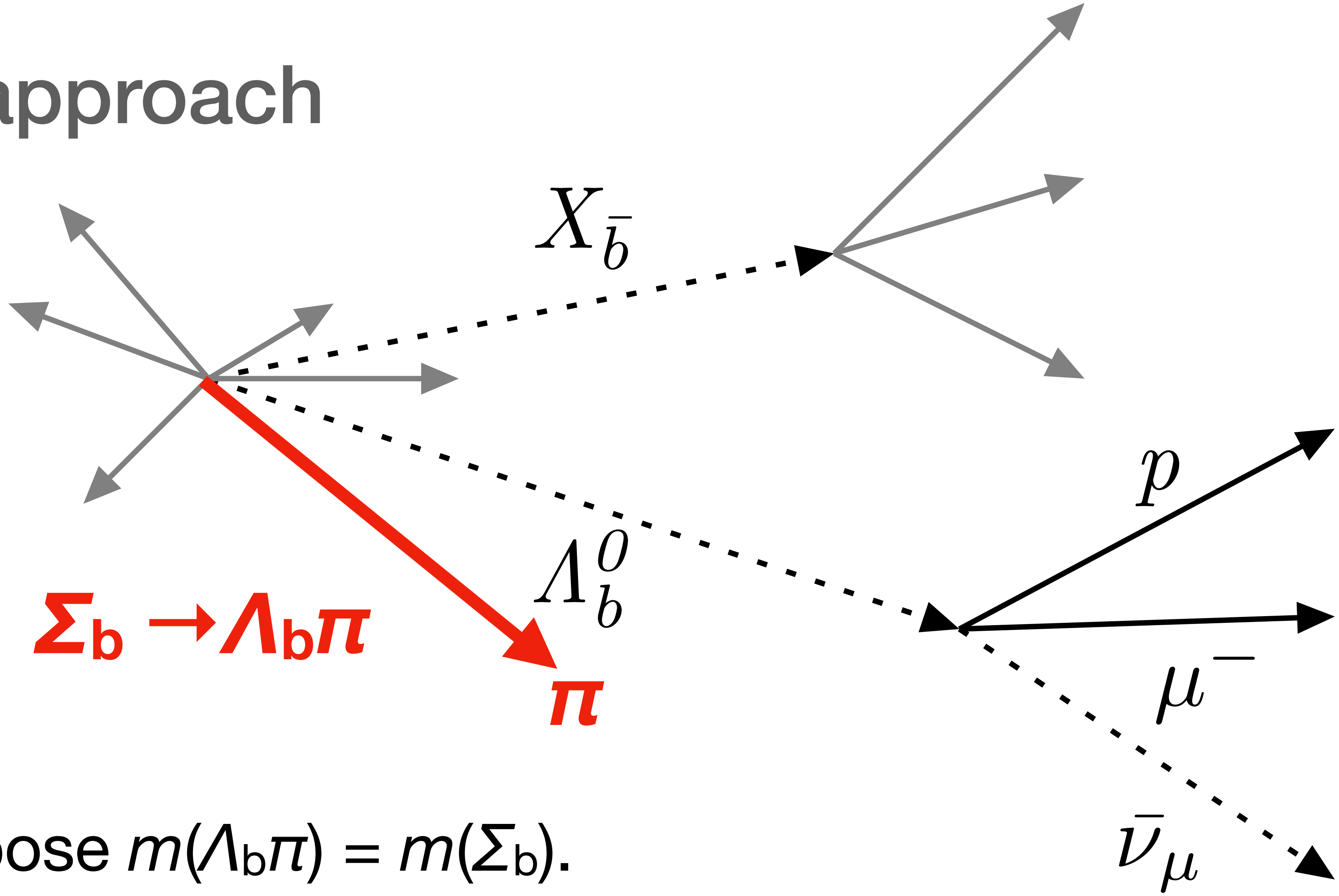
Don’t need to choose randomly though.

[JHEP (2017) 2017: 21]



Kinematic “tag” approach

Stone and Zhang,
Adv. HEP(2014) 931257,
1402.4205.



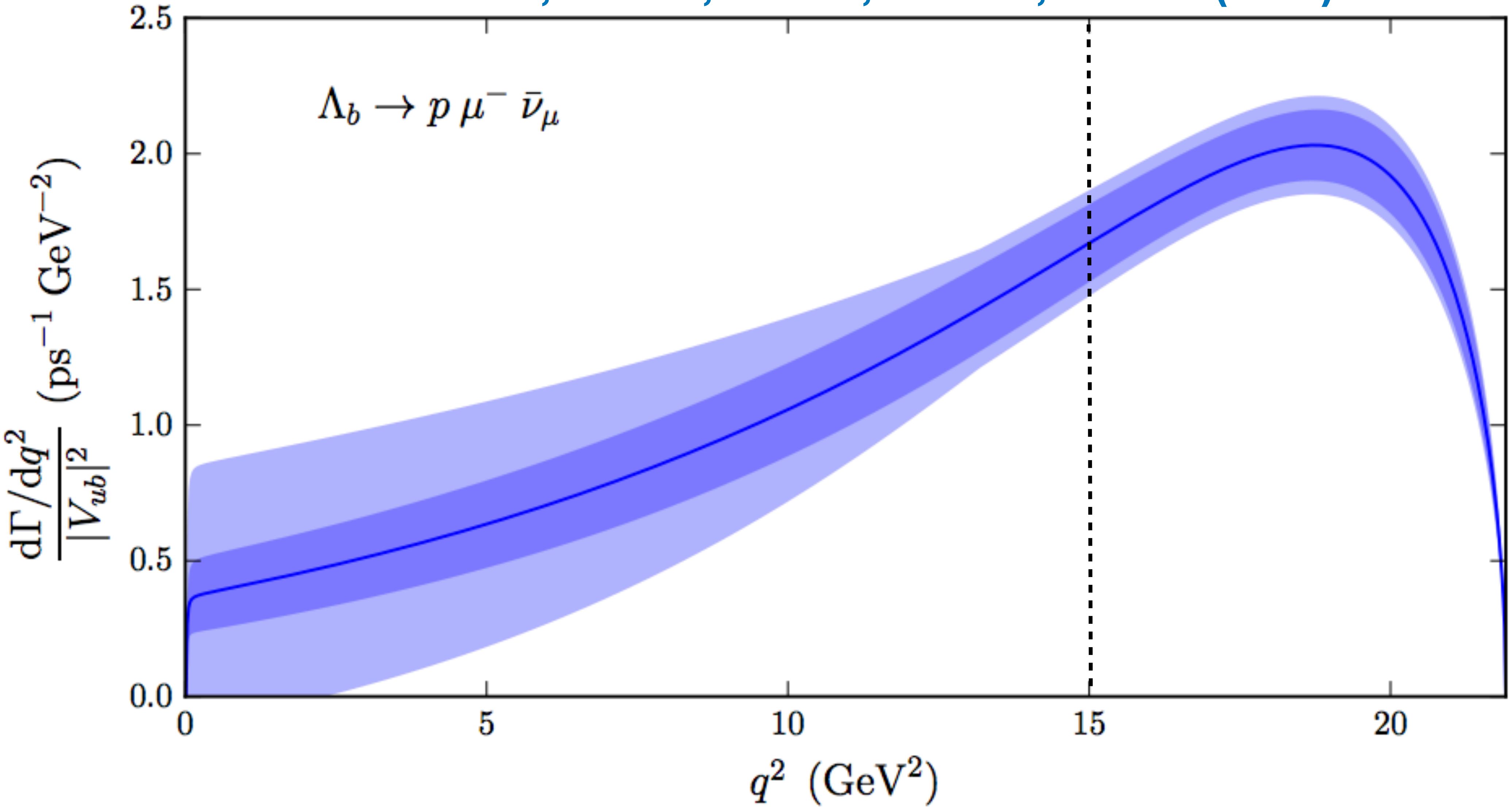
We can further impose $m(\Lambda_b\pi) = m(\Sigma_b)$.

Other possibilities, e.g. $B_s^{**} \to BK$.

Let’s see some measurements!

Ratio of V_{ub} and V_{cb} decays of the Λ_b

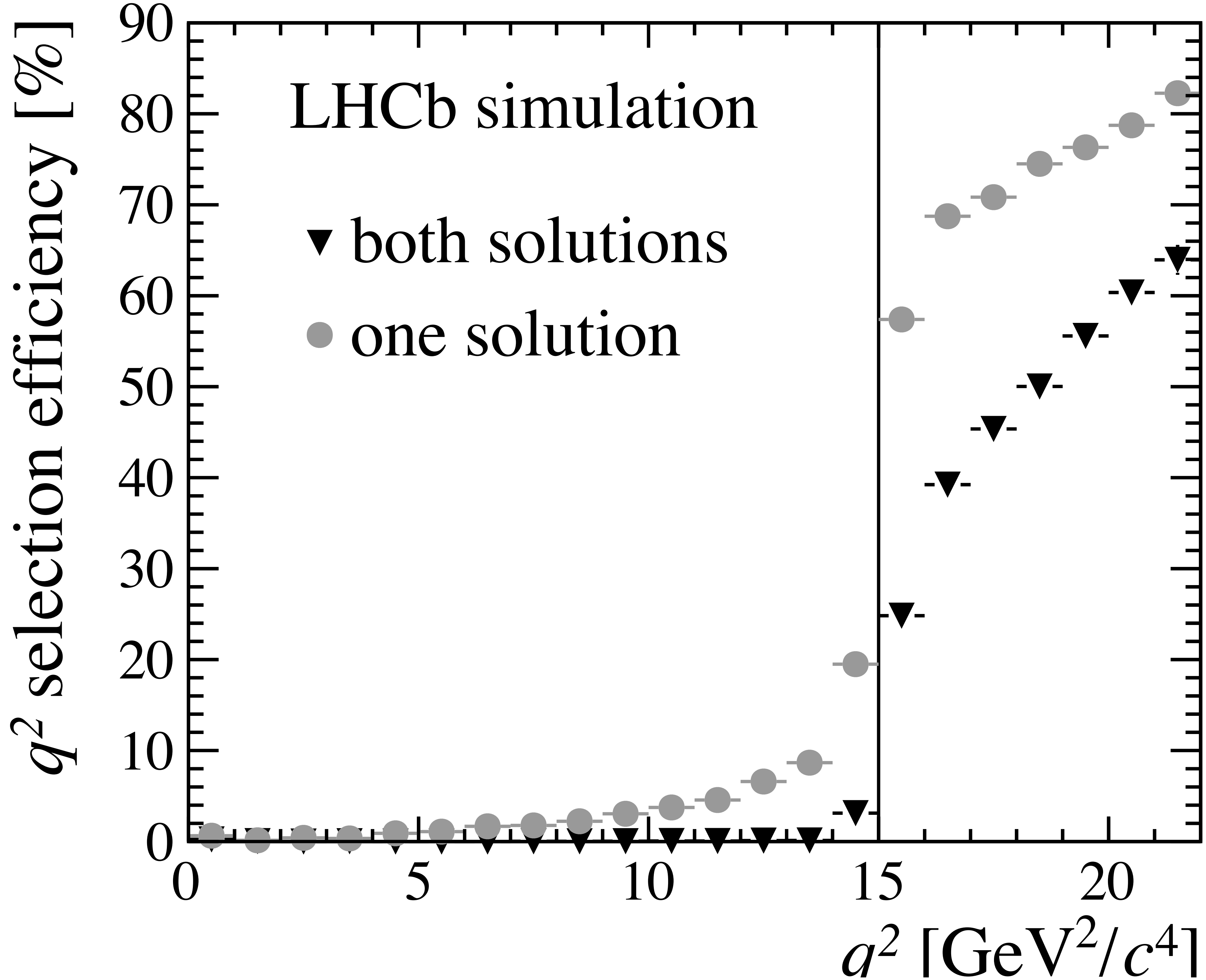
Detmold, Lehner, Meinel, PRD 92, 034503 (2015)



Motivated us to measure:

$$\frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu)_{q^2>15\,\mathrm{GeV}/c^2}}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\overline{\nu}_\mu)_{q^2>7\,\mathrm{GeV}/c^2}}$$

Ratio of V_{ub} and V_{cb} decays of the Λ_b



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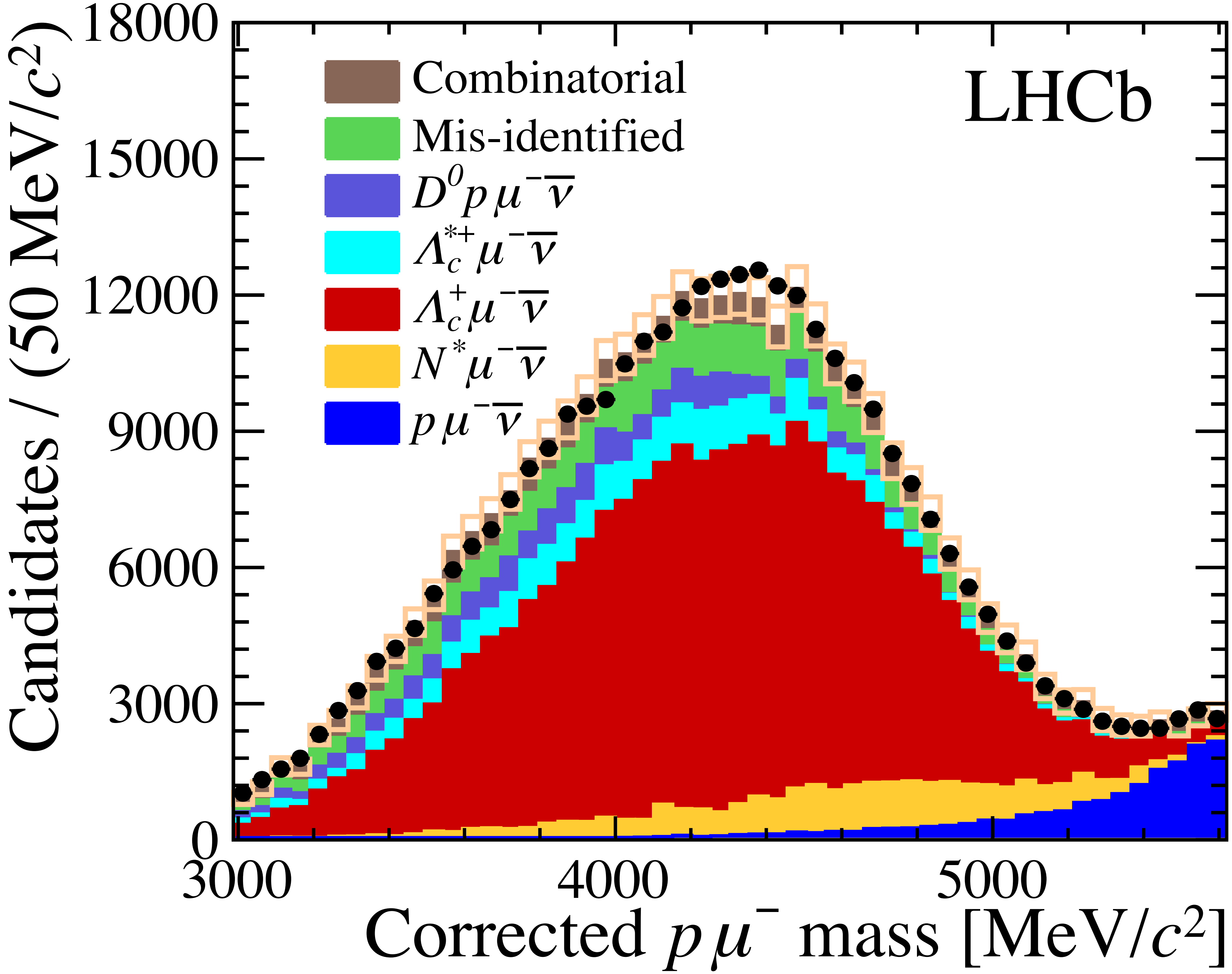


Ratio of V_{ub} and V_{cb} decays of the Λ_b

$$\frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu)_{q^2>15\,\mathrm{GeV}/c^2}}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\overline{\nu}_\mu)_{q^2>7\,\mathrm{GeV}/c^2}} = \qquad \frac{|V_{ub}|}{|V_{cb}|} = 0.083 \pm 0.004 \pm 0.004$$

$$(1.00 \pm 0.04 \pm 0.08) \times 10^{-2}$$

Source	Relative uncertainty (%)
$\mathcal{B}(\Lambda_c^+ \to pK^+\pi^-)$	$^{+4.7}_{-5.3}$
Trigger	3.2
Tracking	3.0
Λ_c^+ selection efficiency	3.0
$\Lambda_b^0 \to N^*\mu^-\overline{\nu}_\mu$ shapes	2.3
Λ_b^0 lifetime	1.5
Isolation	1.4
Form factor	1.0
Λ_b^0 kinematics	0.5
q^2 migration	0.4
PID	0.2
Total	$^{+7.8}_{-8.2}$

Form factors of $\Lambda_b \to \Lambda_c \mu \nu$

Very interesting from an HQET point of view,
but only one experimental study from Delphi. PLB 585 (2004) 63

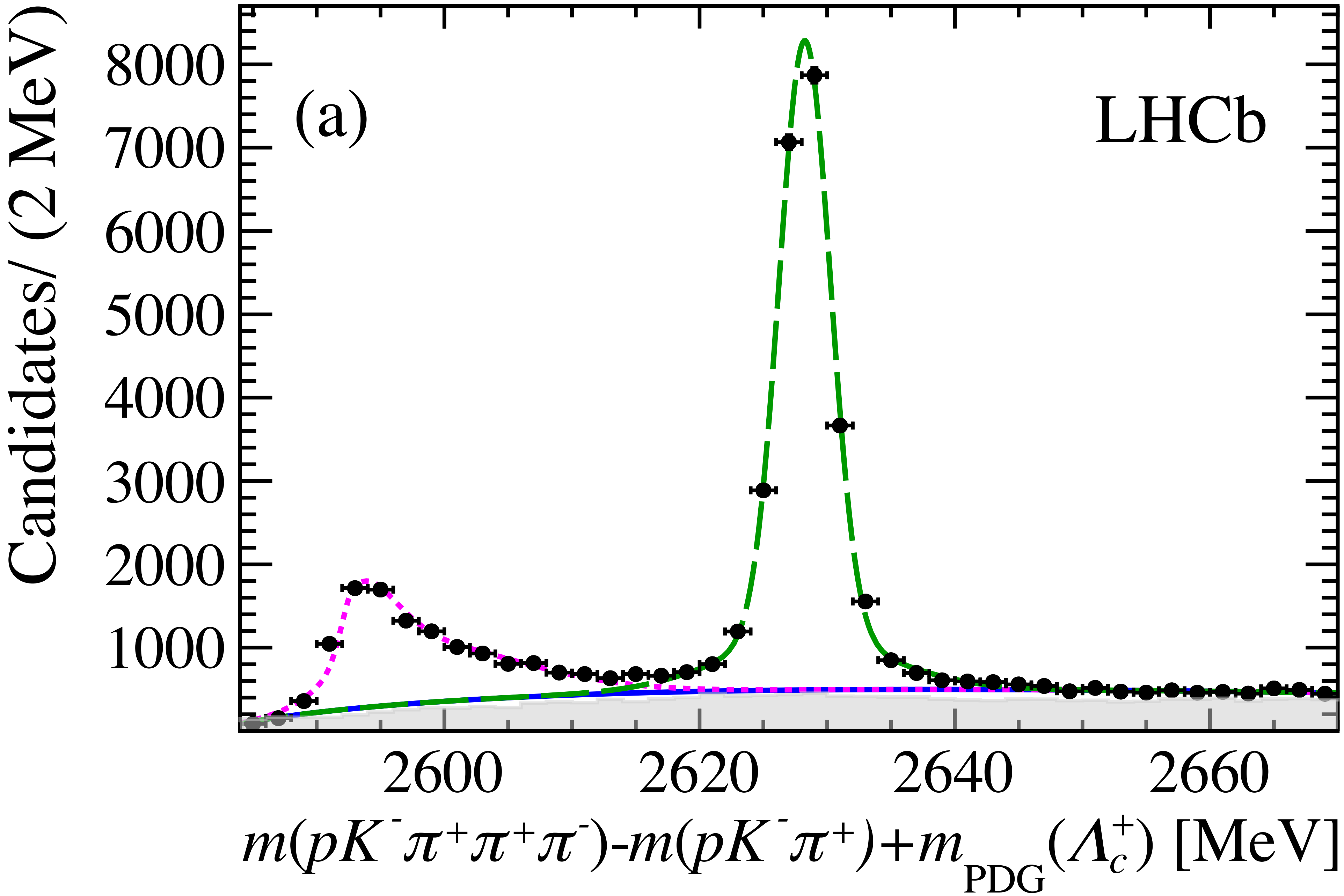
$$\frac{d\Gamma}{dw} = GK(w)\xi_B^2(w) \qquad w \equiv v_{\Lambda_b^0} \cdot v_{\Lambda_c^+}$$

Predictions of the form factor slope at zero recoil.

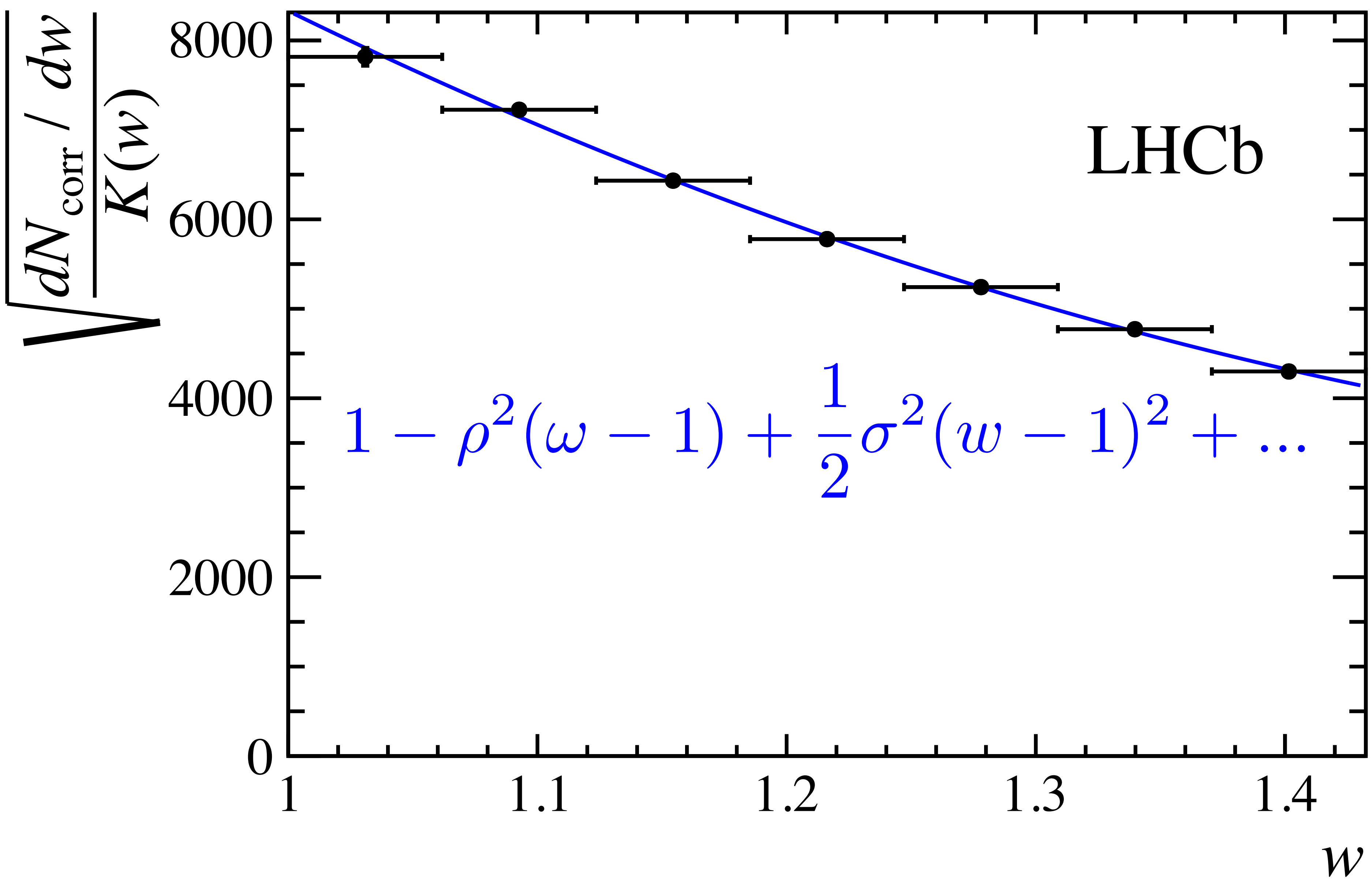
ρ^2	Approach	Reference
1.35 ± 0.13	QCD sum rules	[22]
$1.2^{+0.8}_{-1.1}$	Lattice QCD (static approximation)	[23]
1.51	HQET + Relativistic wave function	[21]

Form factors of $\Lambda_b \to \Lambda_c \mu\nu$

First challenge is to subtract $\Lambda_b \to \Lambda_c \pi\pi\mu\nu$



Form factors of $\Lambda_b \to \Lambda_c \mu \nu$



Shape	ρ^2	σ^2	correlation coefficient	χ^2/ DOF
Exponential*	1.65 ± 0.03	2.72 ± 0.10	100%	5.3/5
Dipole*	1.82 ± 0.03	4.22 ± 0.12	100%	5.3/5
Taylor series	1.63 ± 0.07	2.16 ± 0.34	97%	4.5/4

V_{cb} plans

JHEP 09 (2011) 012

Semileptonic width ratios among beauty hadrons

I.I. Bigi,[a] Th. Mannel,[b] N. Uraltsev[a,b,c]

Abstract

We present predictions based on the heavy quark expansion in QCD. We find $SU(3)$ breaking in B mesons suppressed in the framework of the HQE. B_s is expected to have the semileptonic width about 1% lower and Λ_b about 3% higher when compared to $\Gamma_{\rm sl}(B_d)$. The largest partial-rate preasymptotic effect is Pauli interference in the $b \to u\,\ell\nu$ channel in Λ_b, about +10%. We point out that the Ω_b semileptonic width is expected not to exceed that of B_d and may turn out to be the smallest among stable b hadrons despite the large mass. The underlying differences with phase-space models are briefly addressed through the heavy mass expansion.

JHEP 09 (2011) 012

V_{cb} plans

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$$\Gamma(\Lambda_b^0 \to X_c \mu\nu X) = \tau_B \times \mathcal{BF}(B \to X_c \mu\nu X)(1+\delta)$$

$$\delta = (3 \pm 1.5) \times 10^{-2}$$

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[b] Theoretische Physik 1, Fachbereich Physik, Universität Siegen
D-57068 Siegen, Germany
[c] St. Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg 188300, Russia

Abstract

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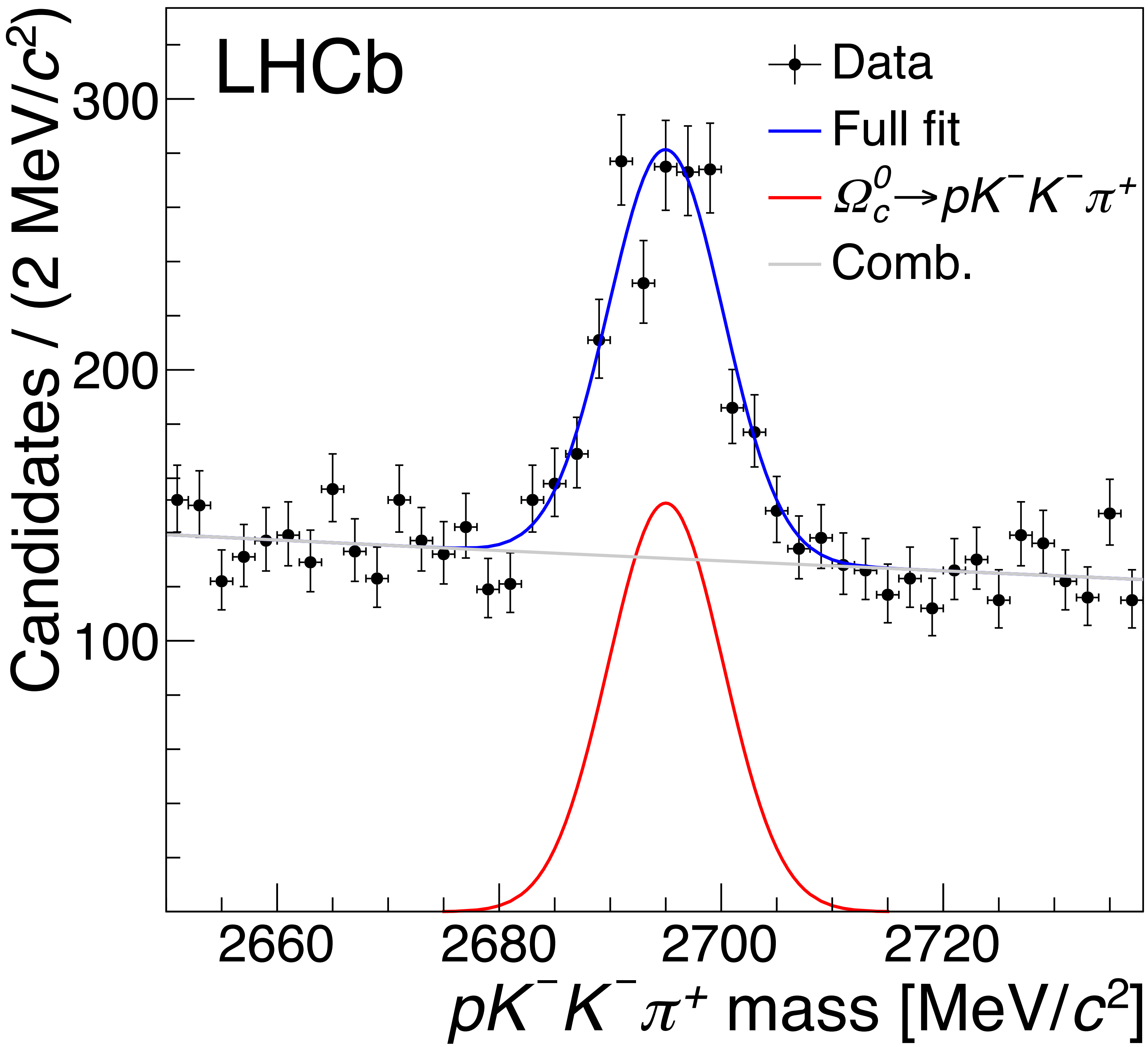
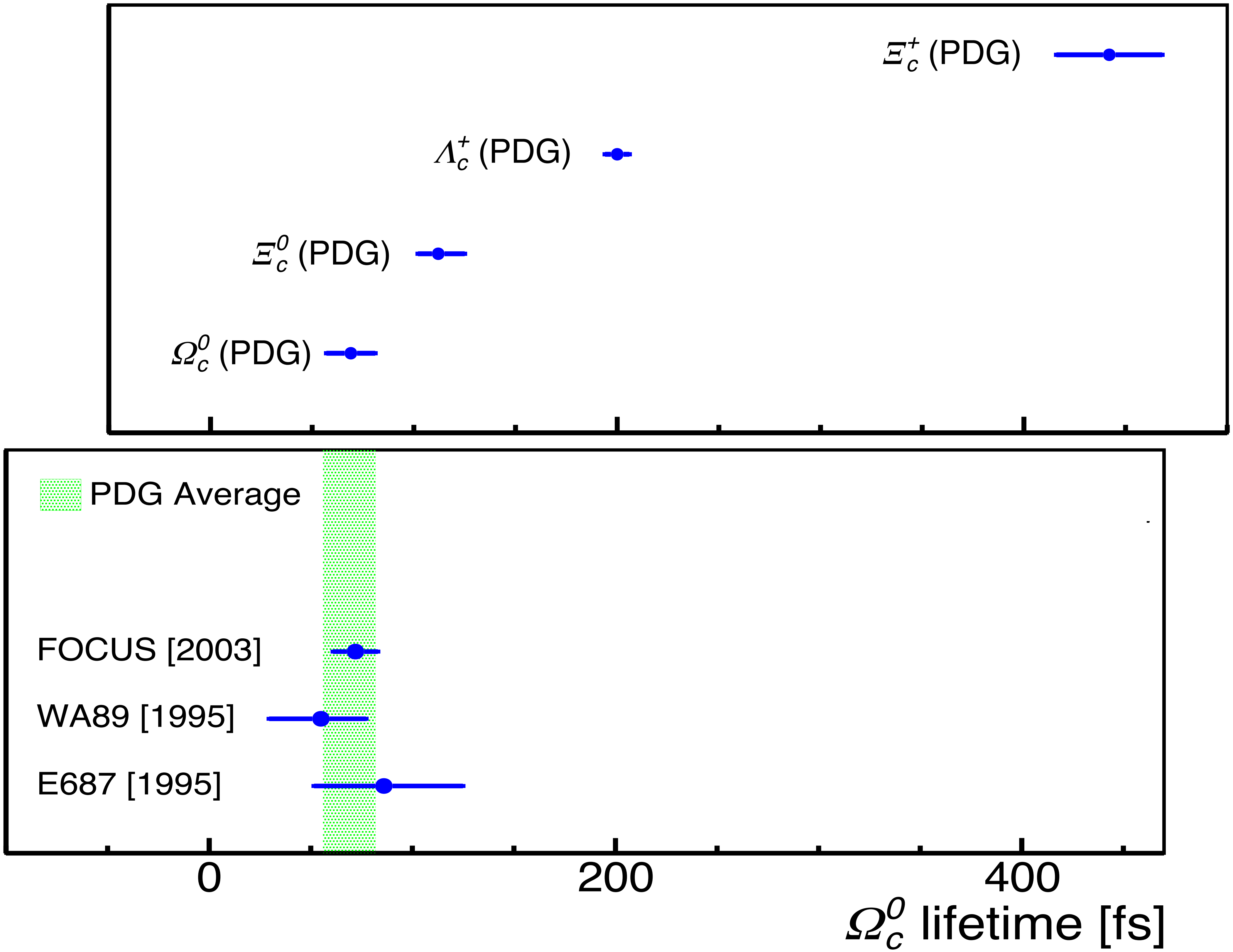
Ω_c lifetime study, with $\Omega_b \to \Omega_c \mu \nu$



Ω_c lifetime study, with $\Omega_b \rightarrow \Omega_c \mu \nu$



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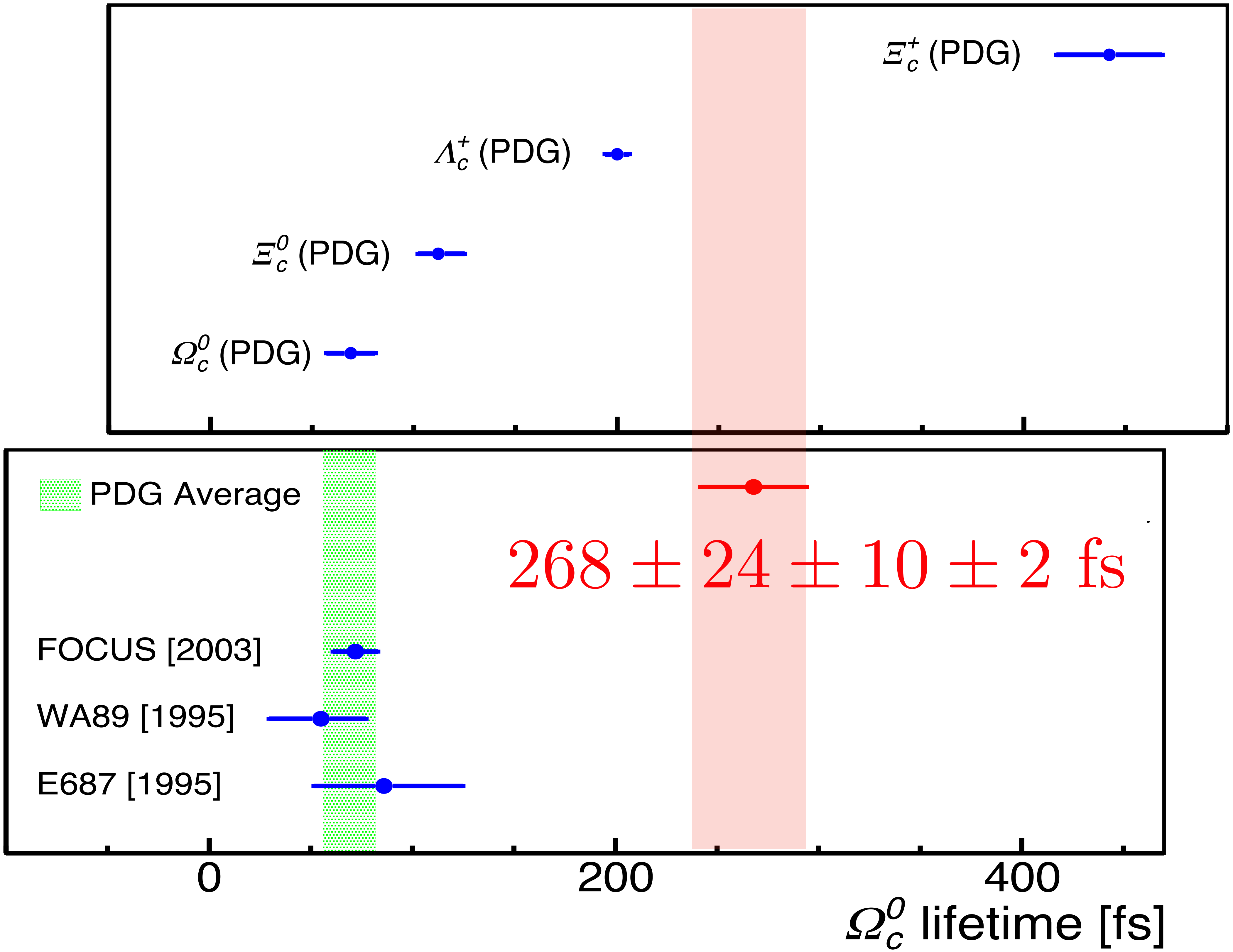


Future synergy with Belle and BES

Huge potential for LHCb to measure form-factors and $|V_{ub}|/|V_{cb}|$ ratios with a range of b hadrons.

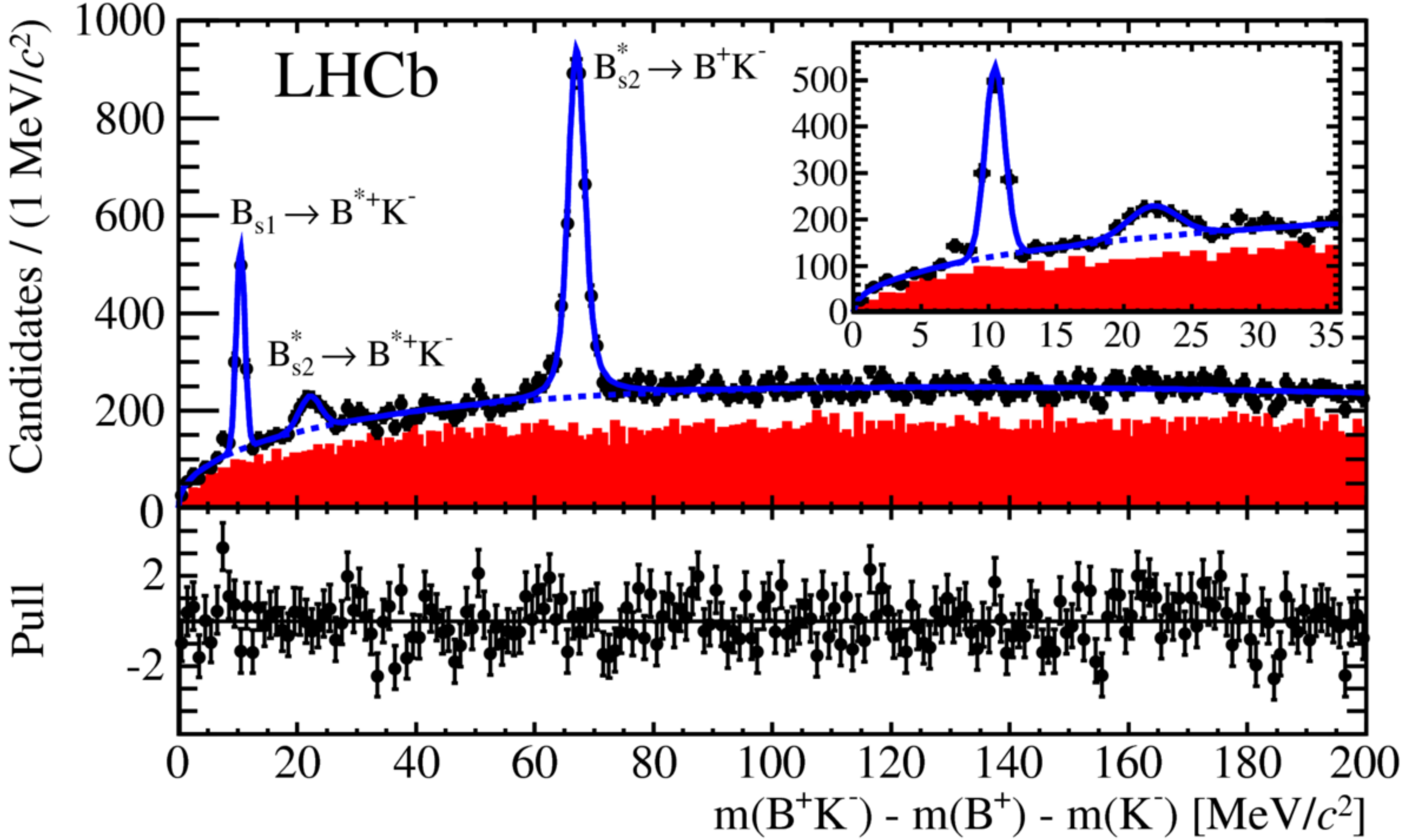
The full exploitation requires knowledge of the charm hadron branching ratios.

E.g. BF($\Lambda_c \to pK\pi$) was the dominant experimental source of uncertainty in **Nature Phys 10 (2015) 1038**

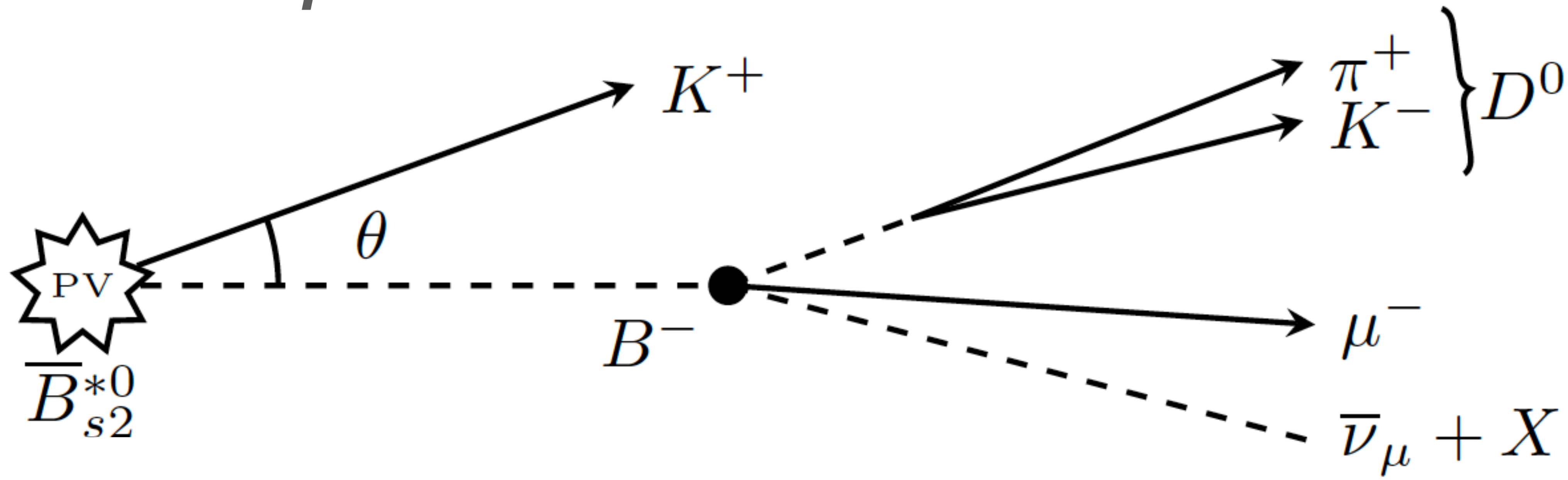
Rumours of BEPC plans to reach $\Xi_c\Xi_c$ threshold.
Hai-Ping Peng slides @ICHEP2018.

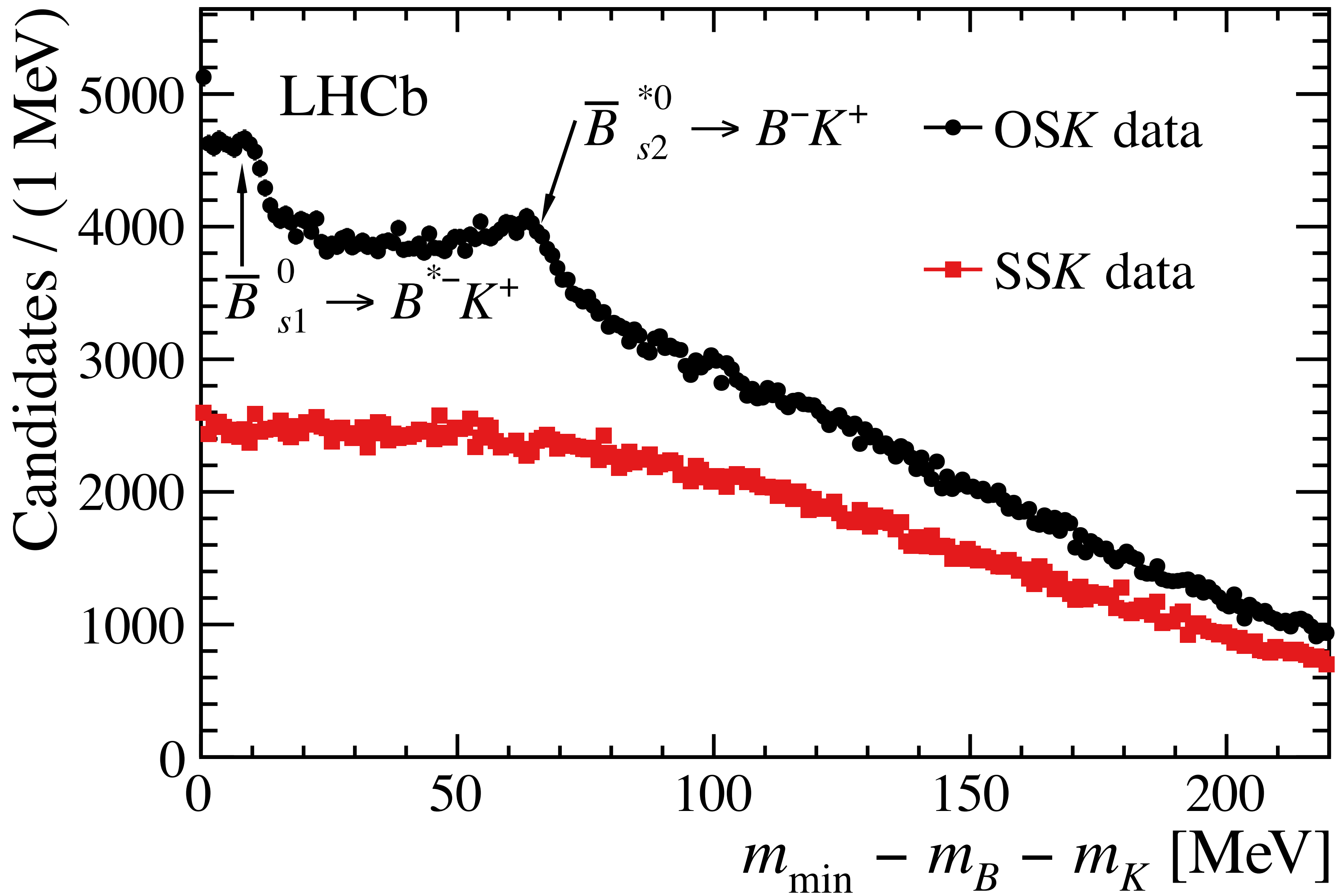
B decays with B_s^{**} tag

PRL 110, 151803 (2013)



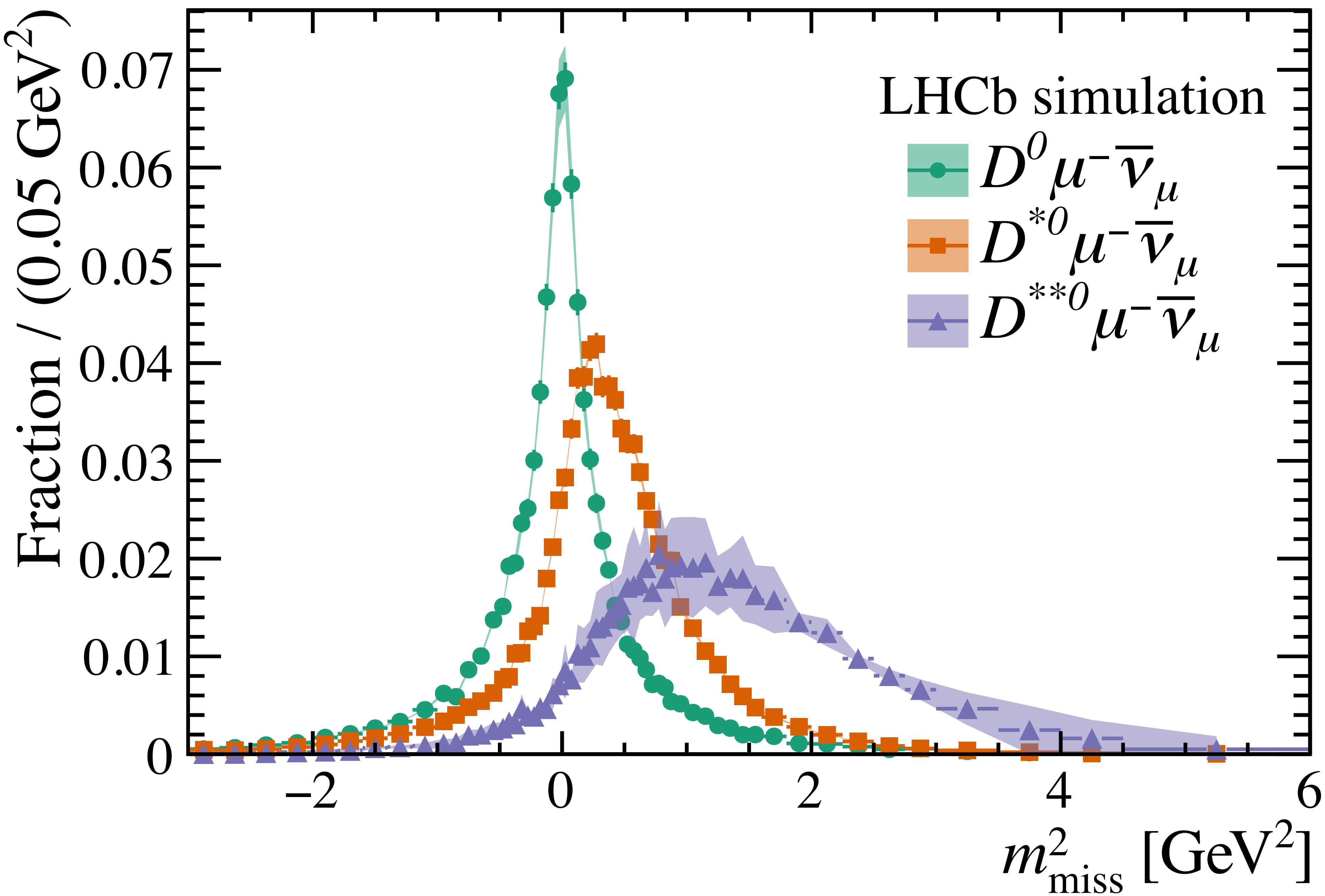
Application to $B \to D^{(*)*} \mu \nu$





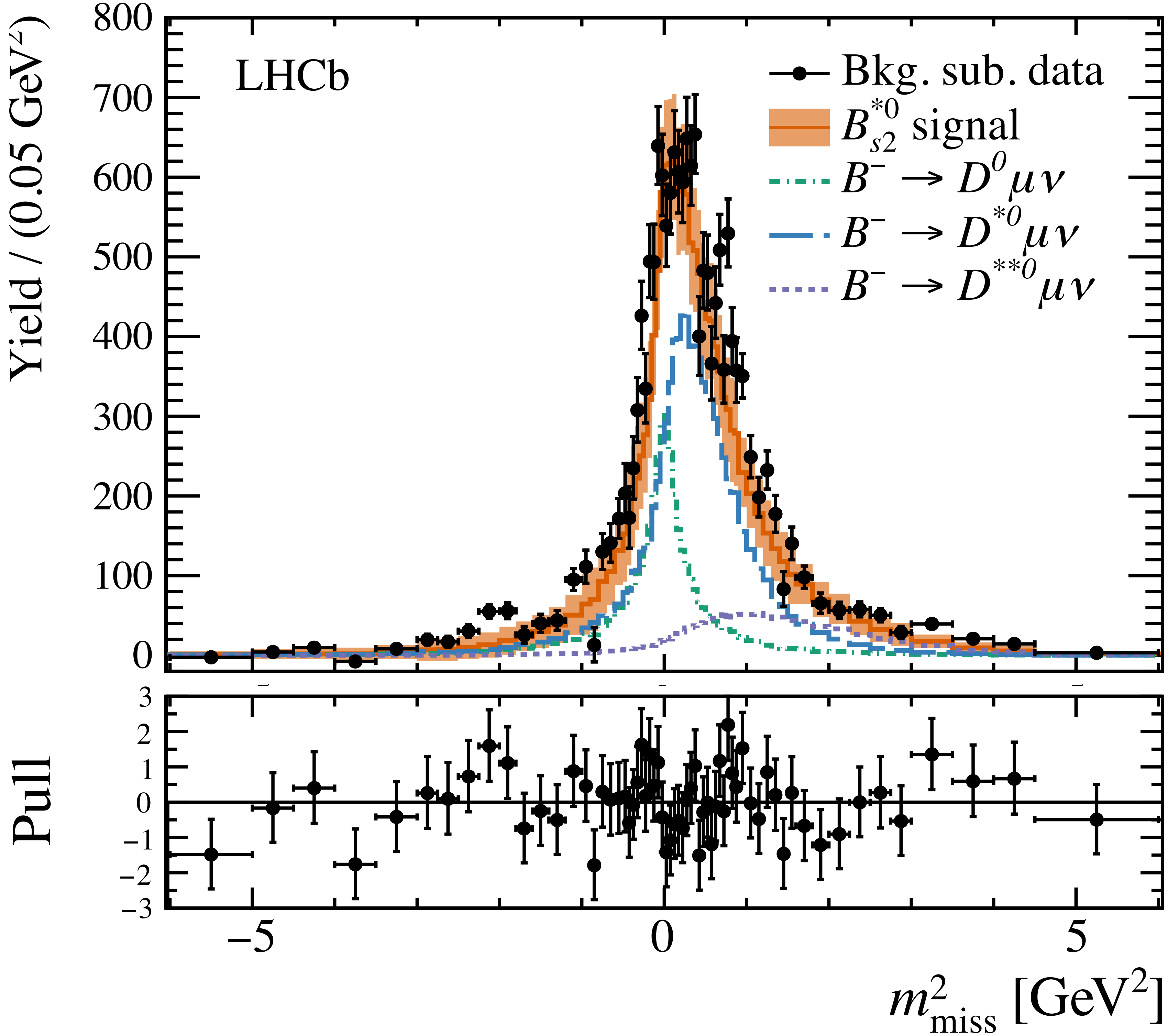
Aim for contribution to understanding of inclusive-exclusive gap puzzle…

Kinematic resolution

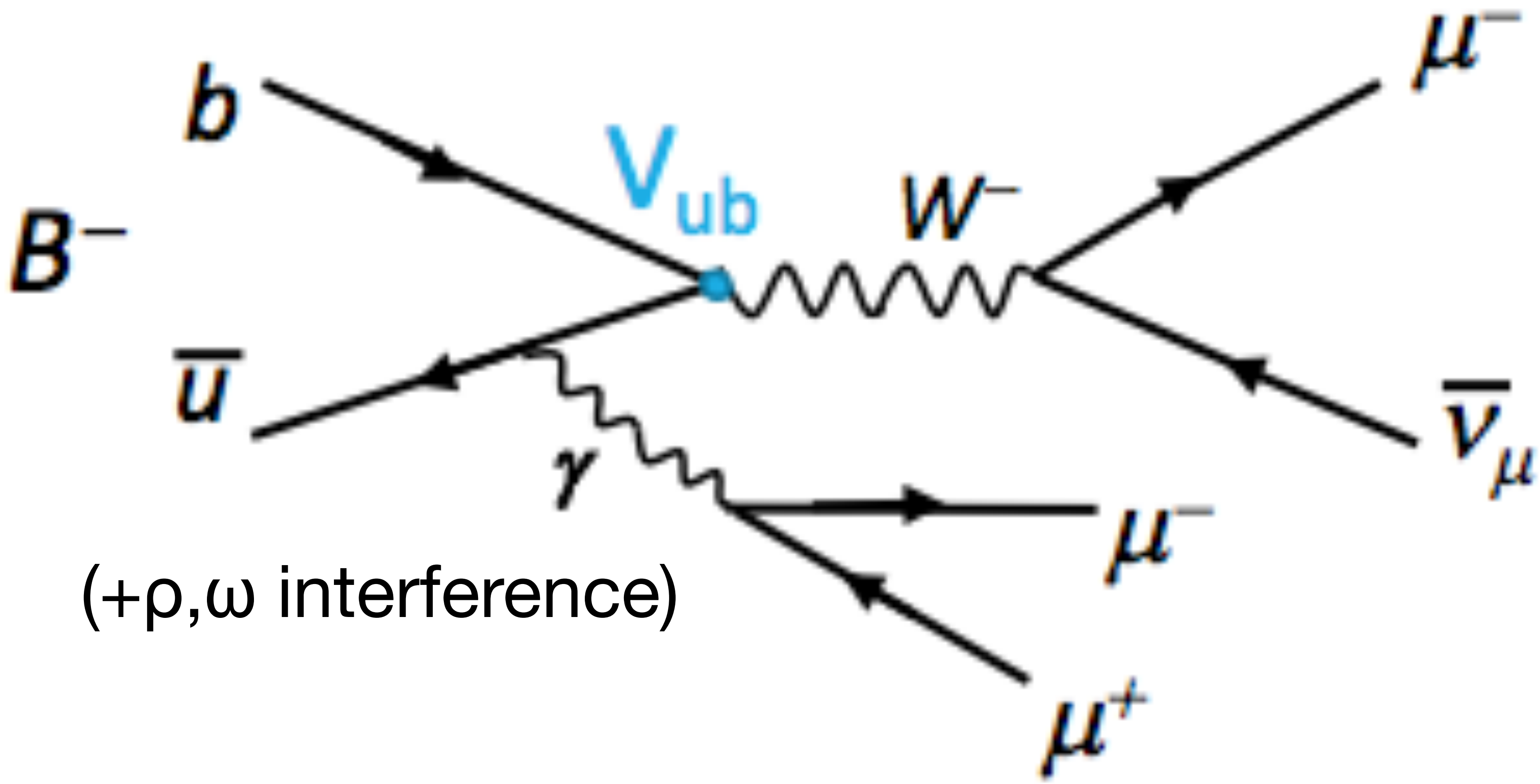


The *D* fractions fit

$$f_{D^0} = 0.25 \pm 0.06$$
$$f_{D^{**0}} = 0.21 \pm 0.07$$



Purely leptonic: $B \to \mu\mu\mu\nu$



(+ρ,ω interference)

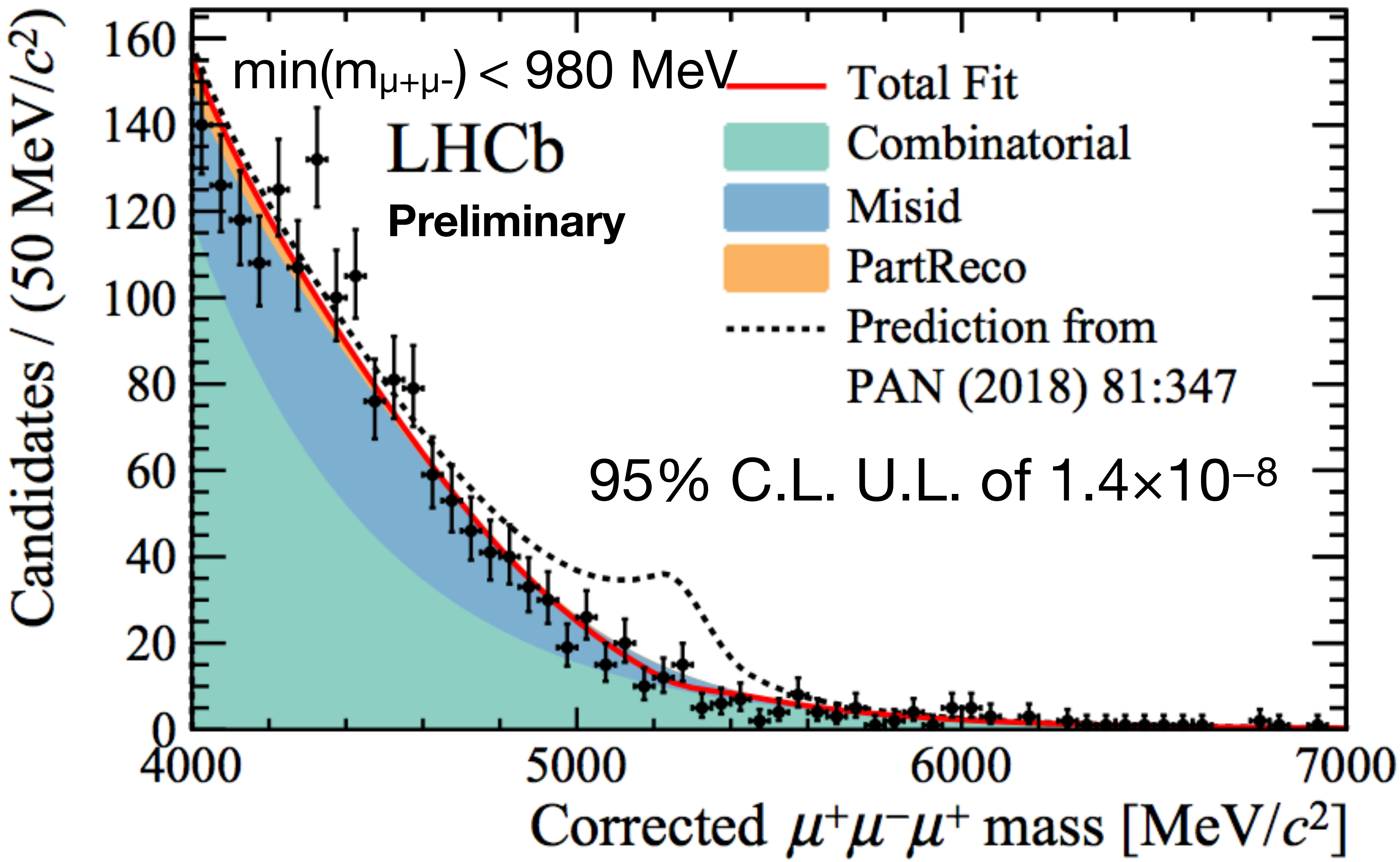
Naive expected BF ~ 10^{-8}

Vector dominance prediction of 1.3 x 10^{-7}

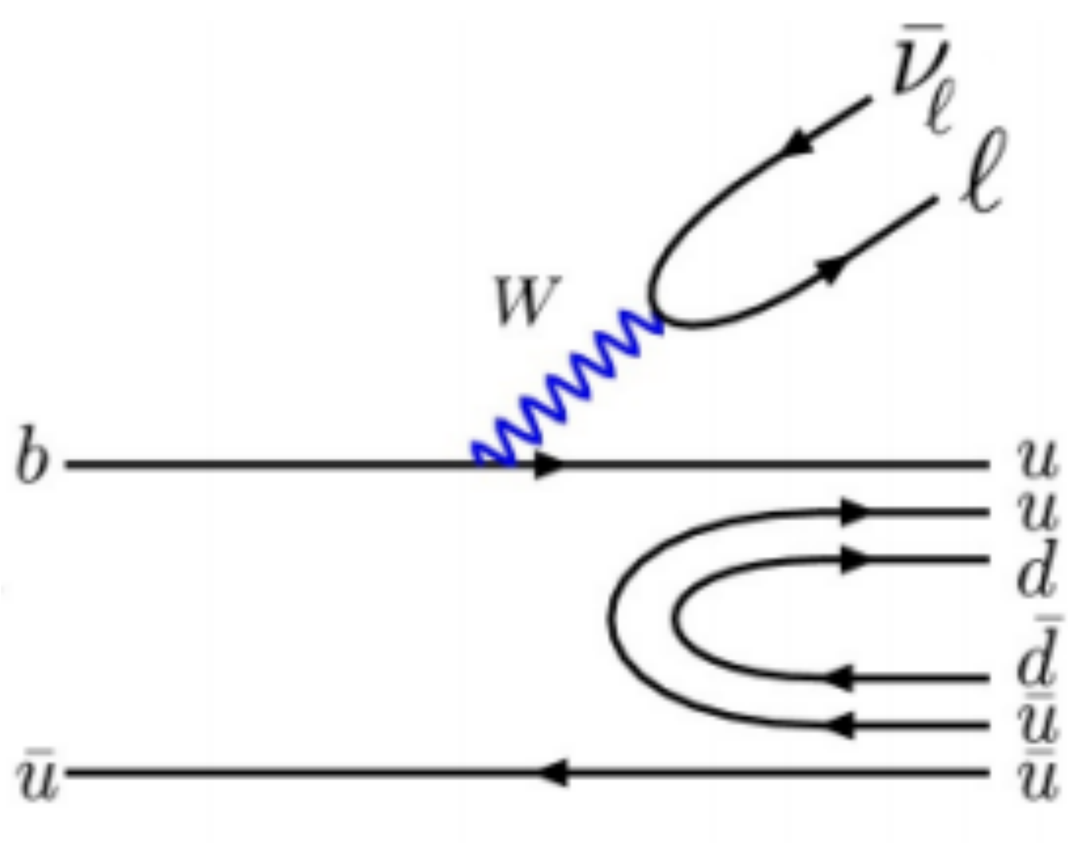
Danilina and Nikitin, Phys. Atom. Nucl. 81 (2018) 34.

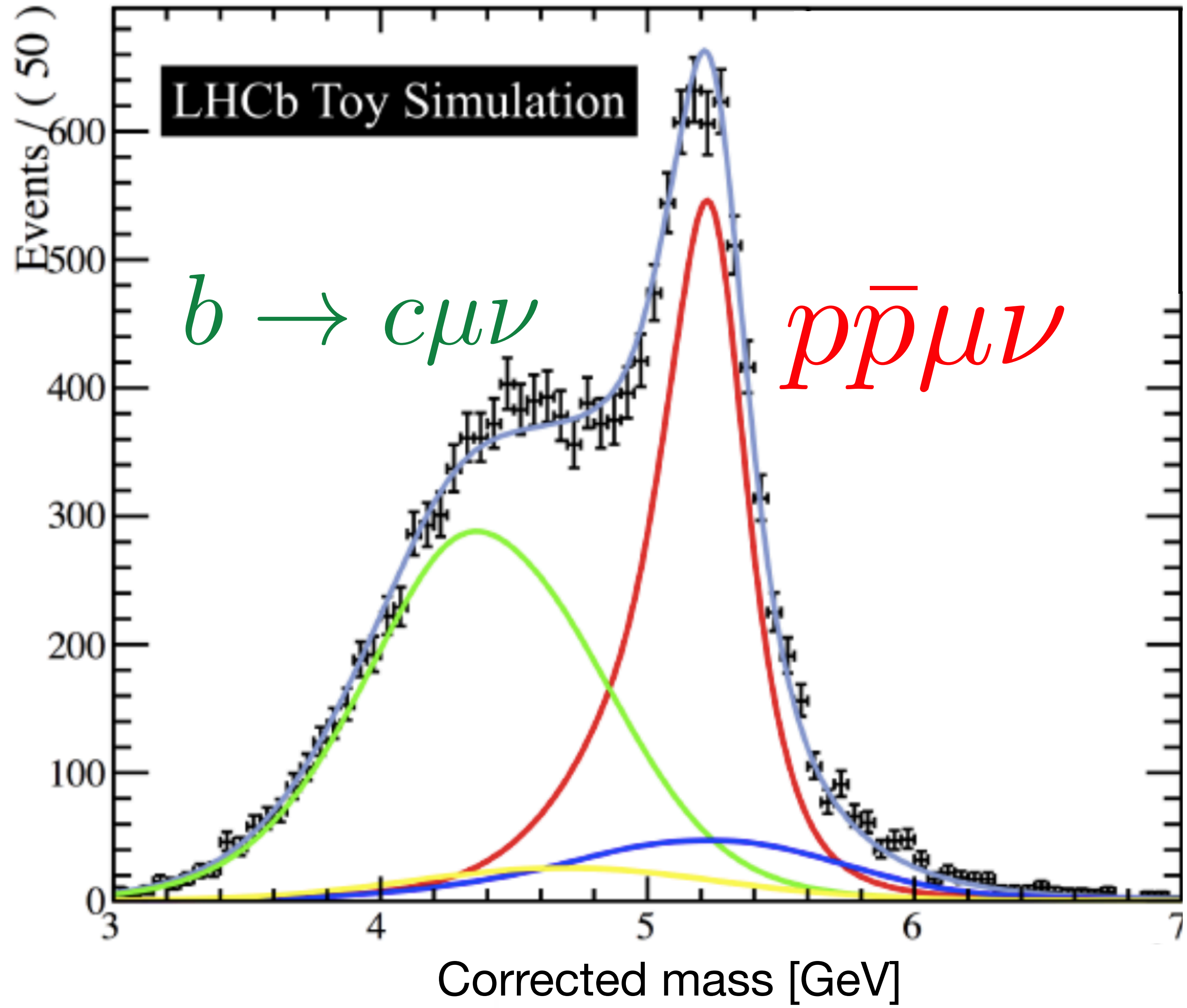
Purely leptonic: $B \to \mu\mu\mu\nu$

LHCb-PAPER-2018-037
in preparation



Plans for $B \to p\bar{p}\mu\nu$





Evidence from Belle

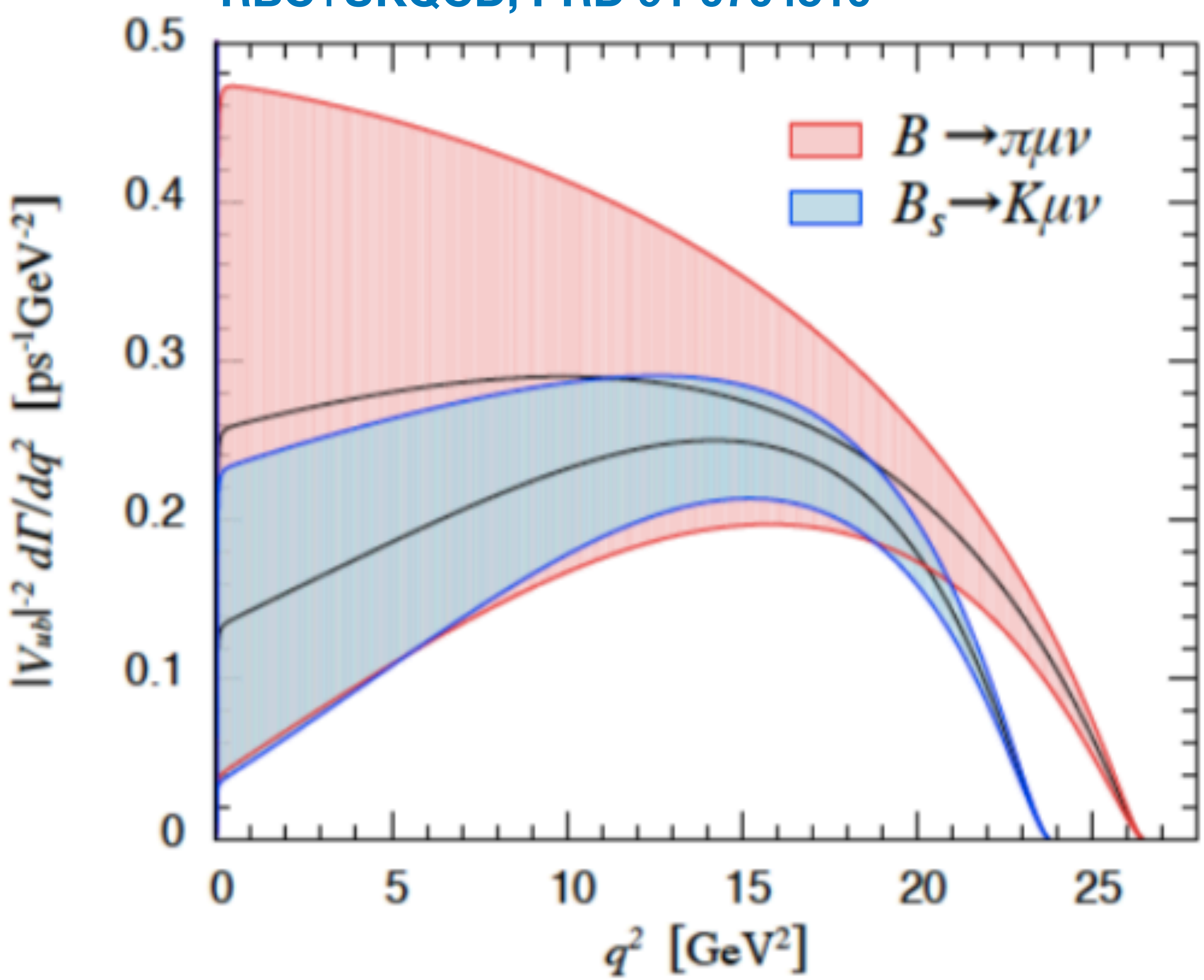
$$\mathcal{B}(B^- \to p\bar{p}\mu^-\bar{\nu}_\mu) = (3.1^{+3.1}_{-2.4} \pm 0.7) \times 10^{-6}$$

PRD 89, 011101 (2014)

B_s decays

Strong motivation from LQCD to measure $$\frac{\mathcal{B}(B_s^0 \to K^- \mu^+ \nu_\mu)}{\mathcal{B}(B_s^0 \to D_s^- \mu^+ \nu_\mu)}$$

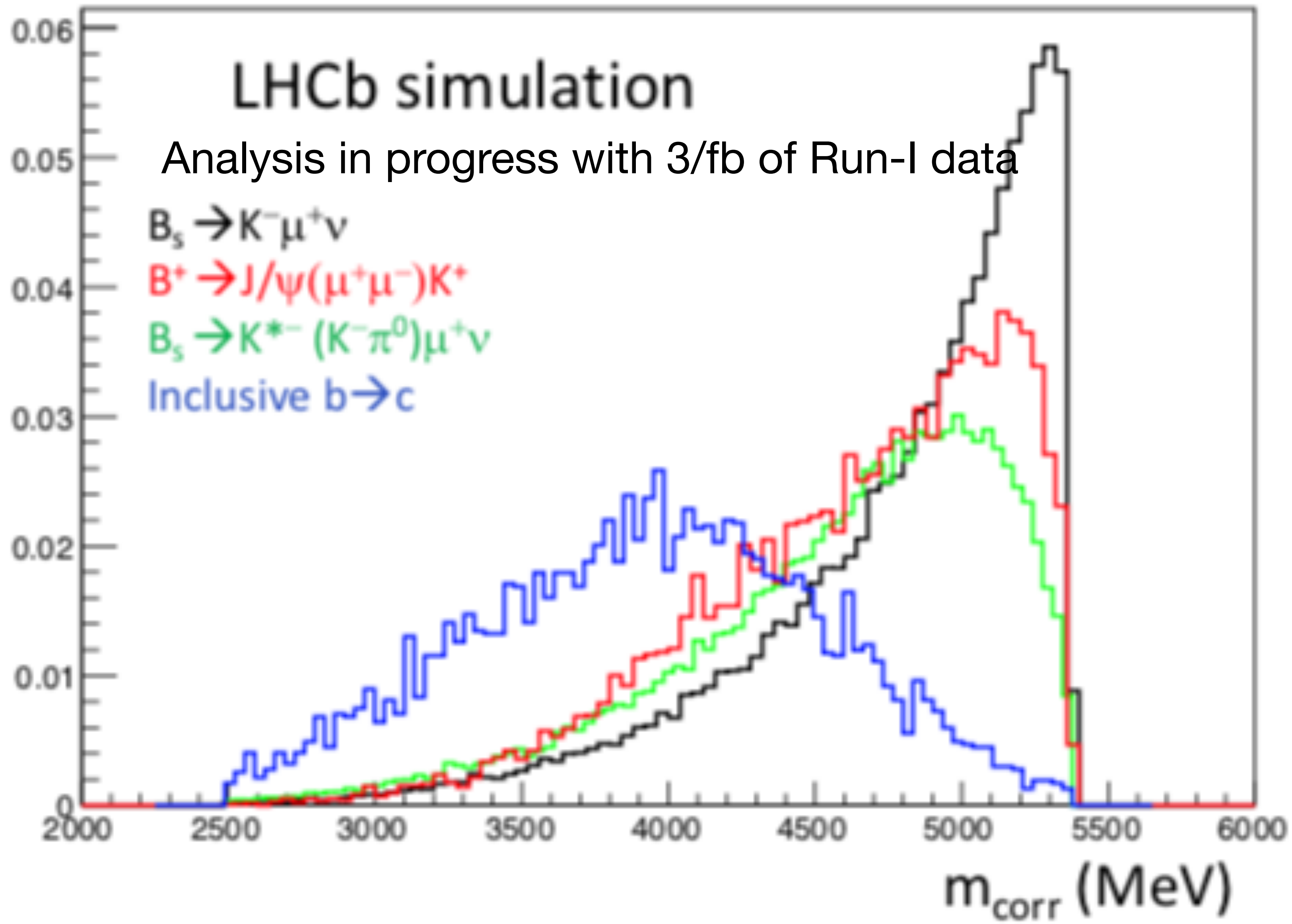
RBC+UKQCD, PRD 91 0704510



Recent dedicated study on the ratio.

Monahan et al., 1808.09285

Progress towards $B_s \to K\mu\nu / B_s \to D_s\mu\nu$

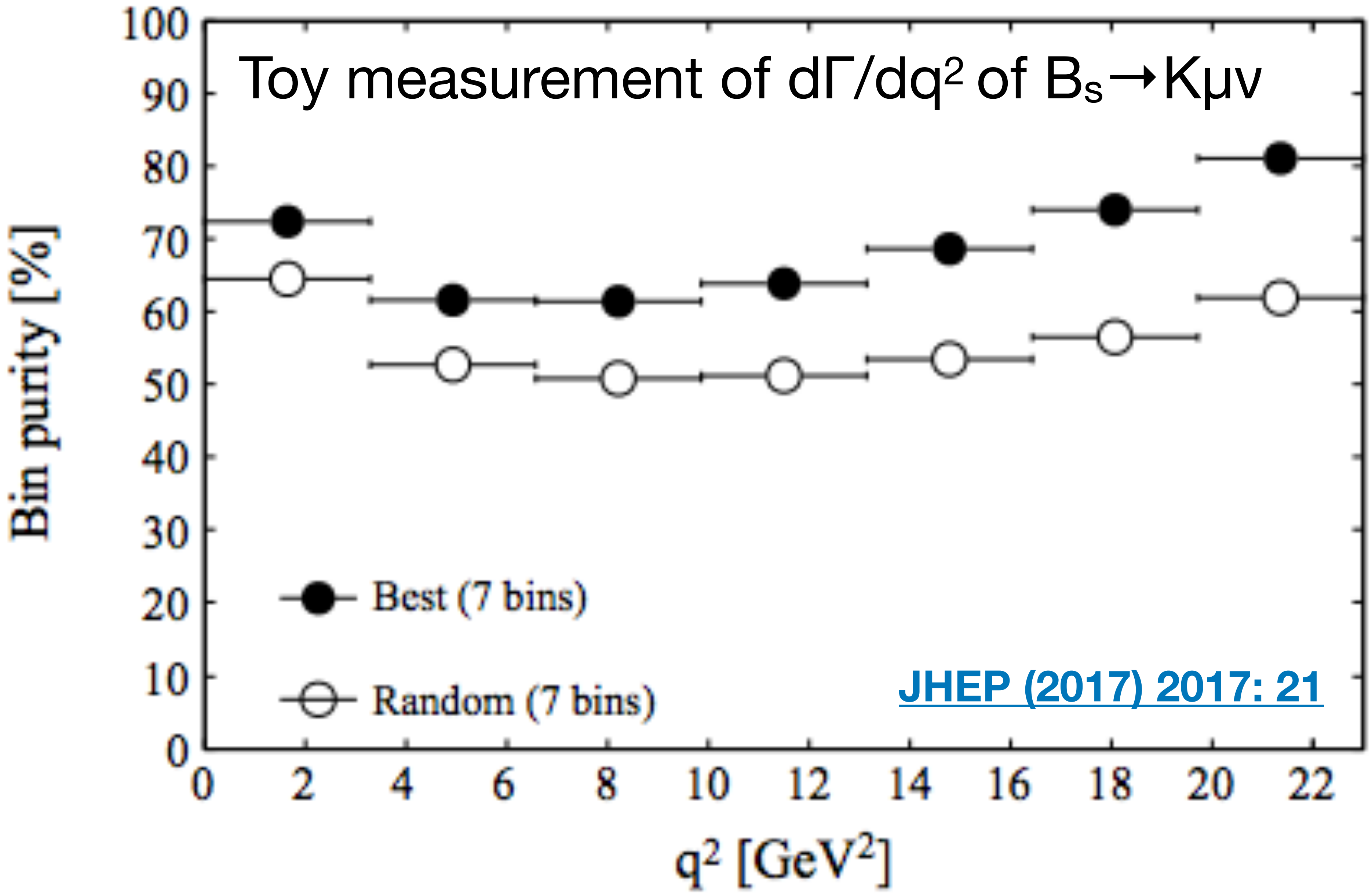


Similar idea to $p\mu\nu/\Lambda_c\mu\nu$, but backgrounds larger.

Target two q^2 bins across the full range.

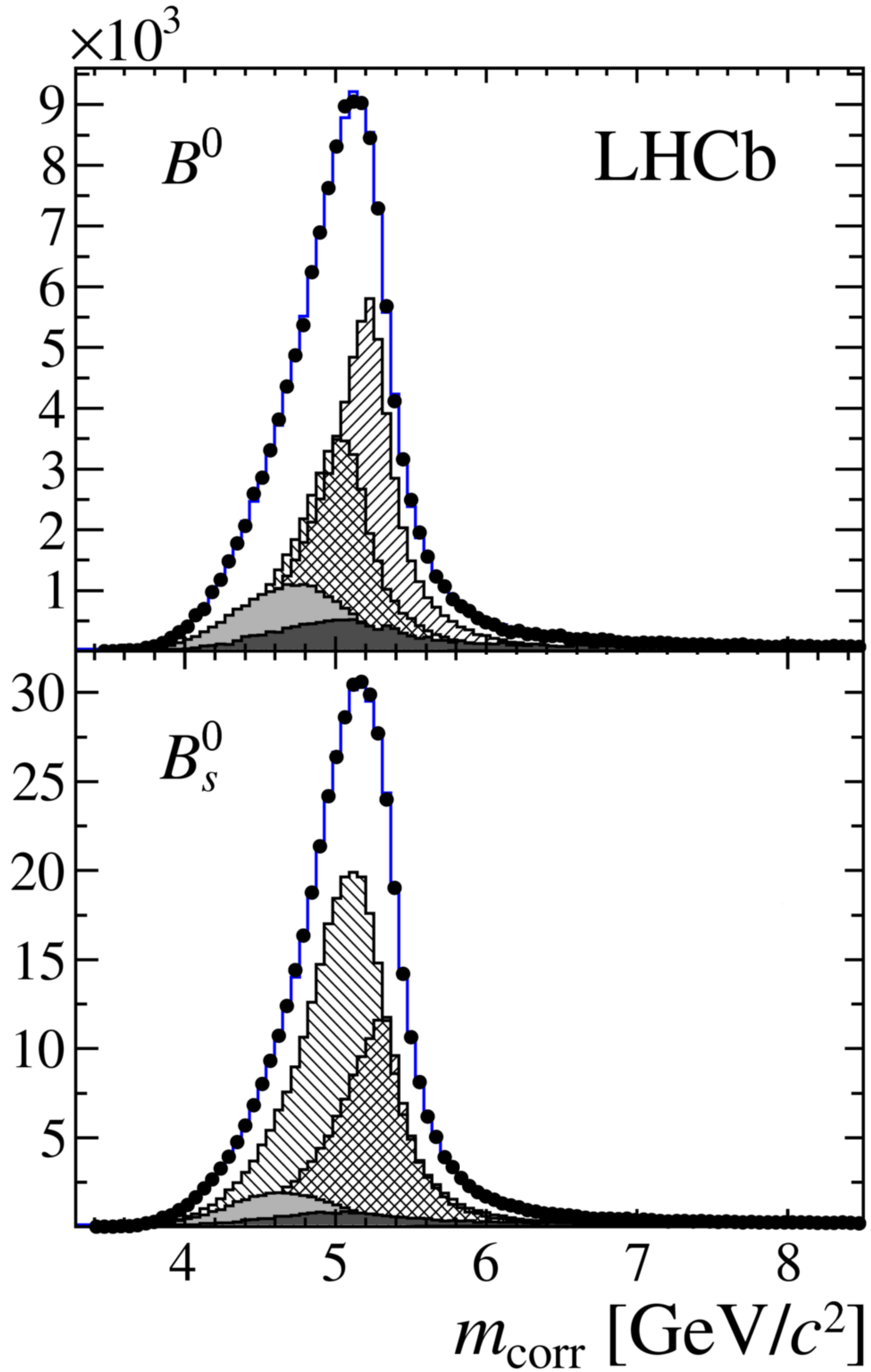
See Marta Calvi's talk at Challenges in Semileptonic B Decays

Longer term aspirations for differential measurement

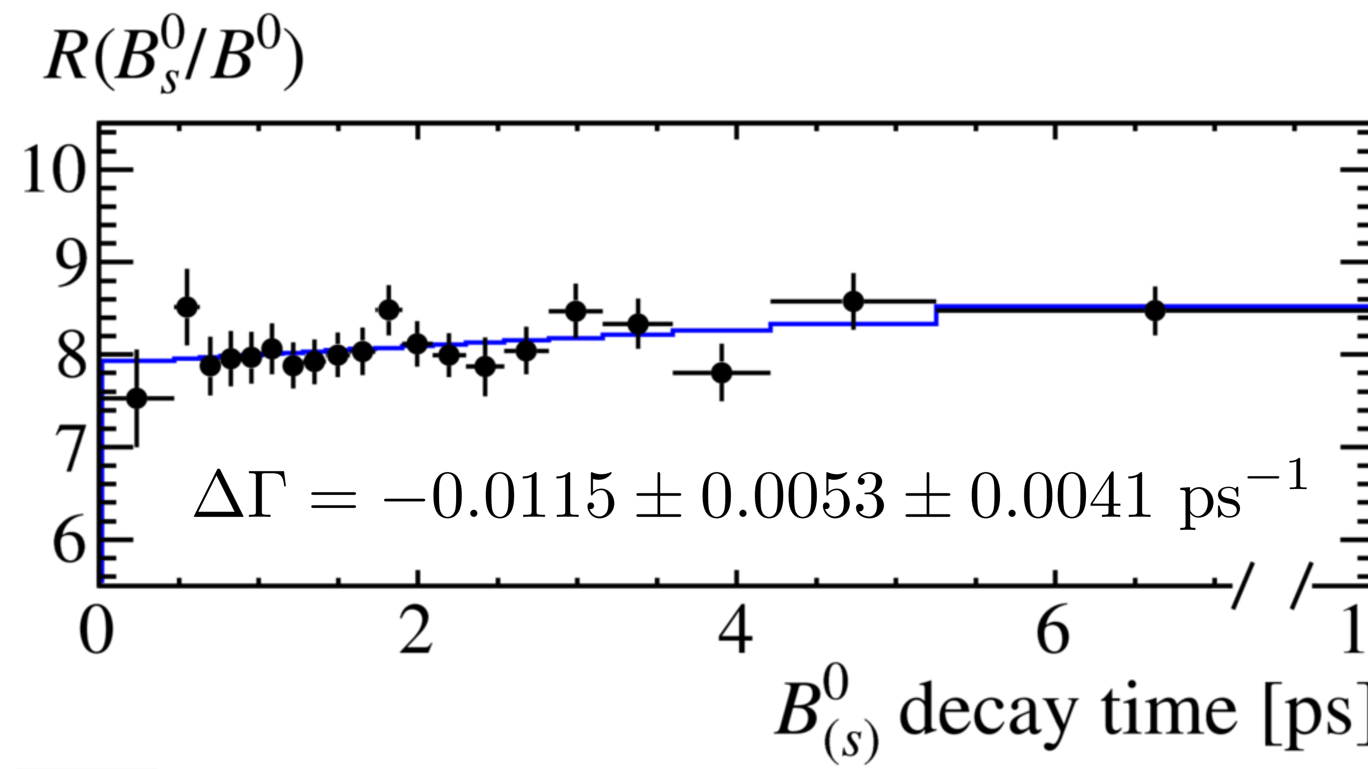


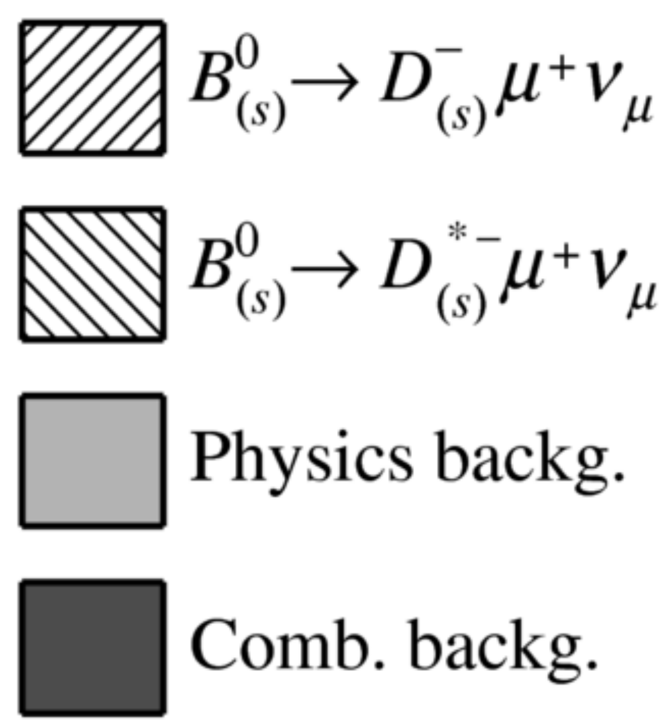
PRL 119, 101801 (2017)

Towards $B_s \to D_s^{(*)}$ form factors

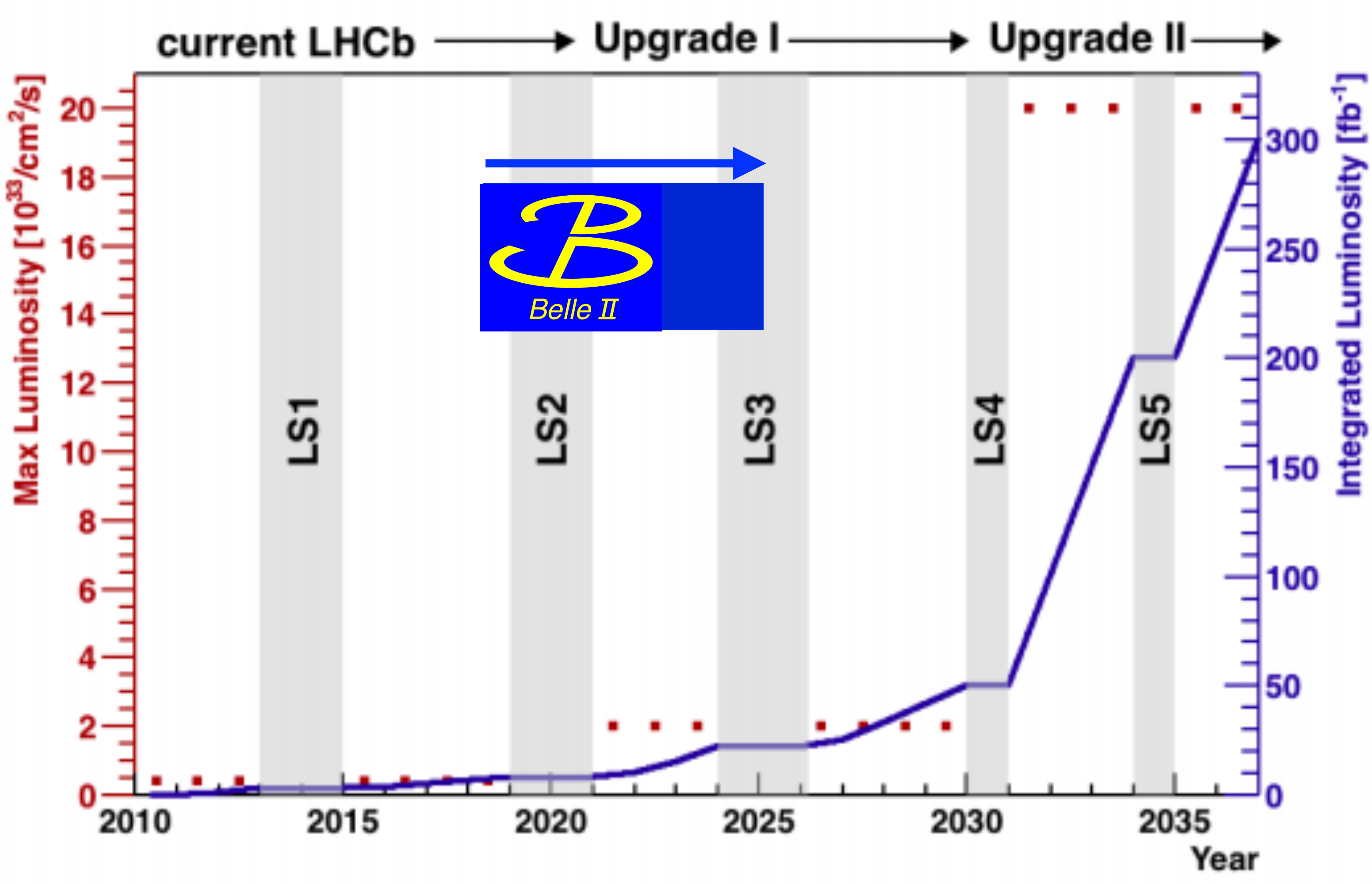


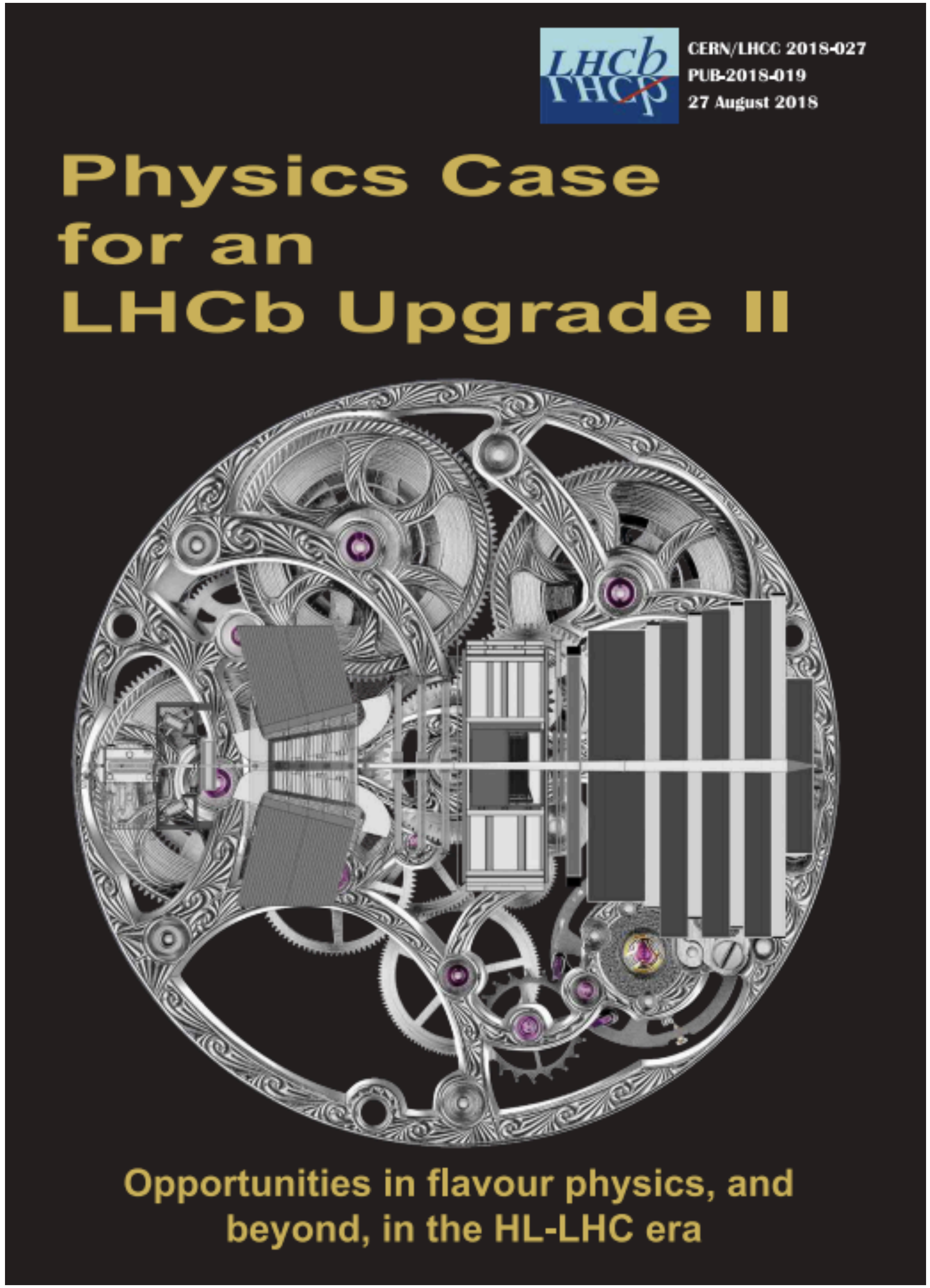
Measurement of B_s - B_d lifetime difference, and τ_{Ds}.



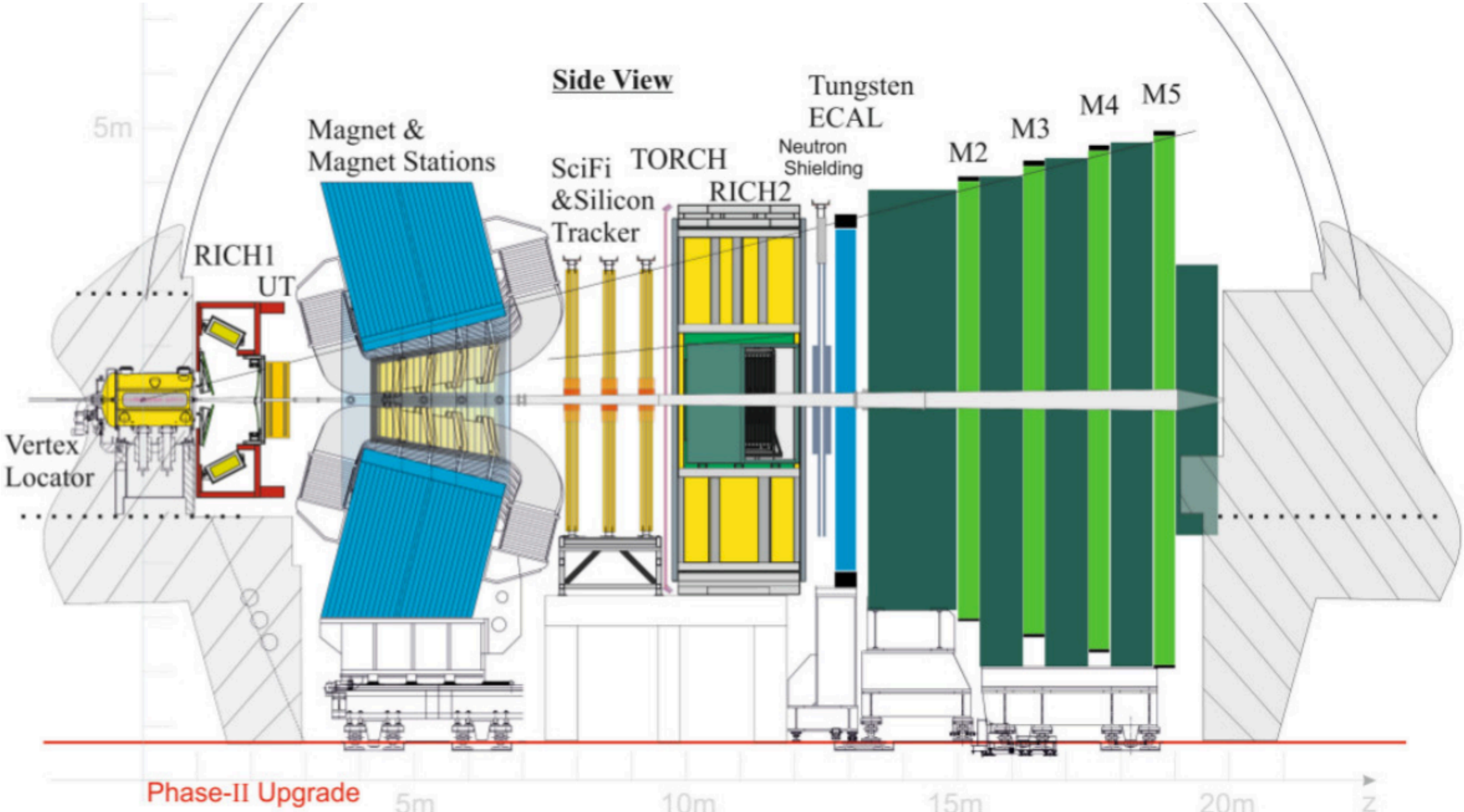


The long term future prospects



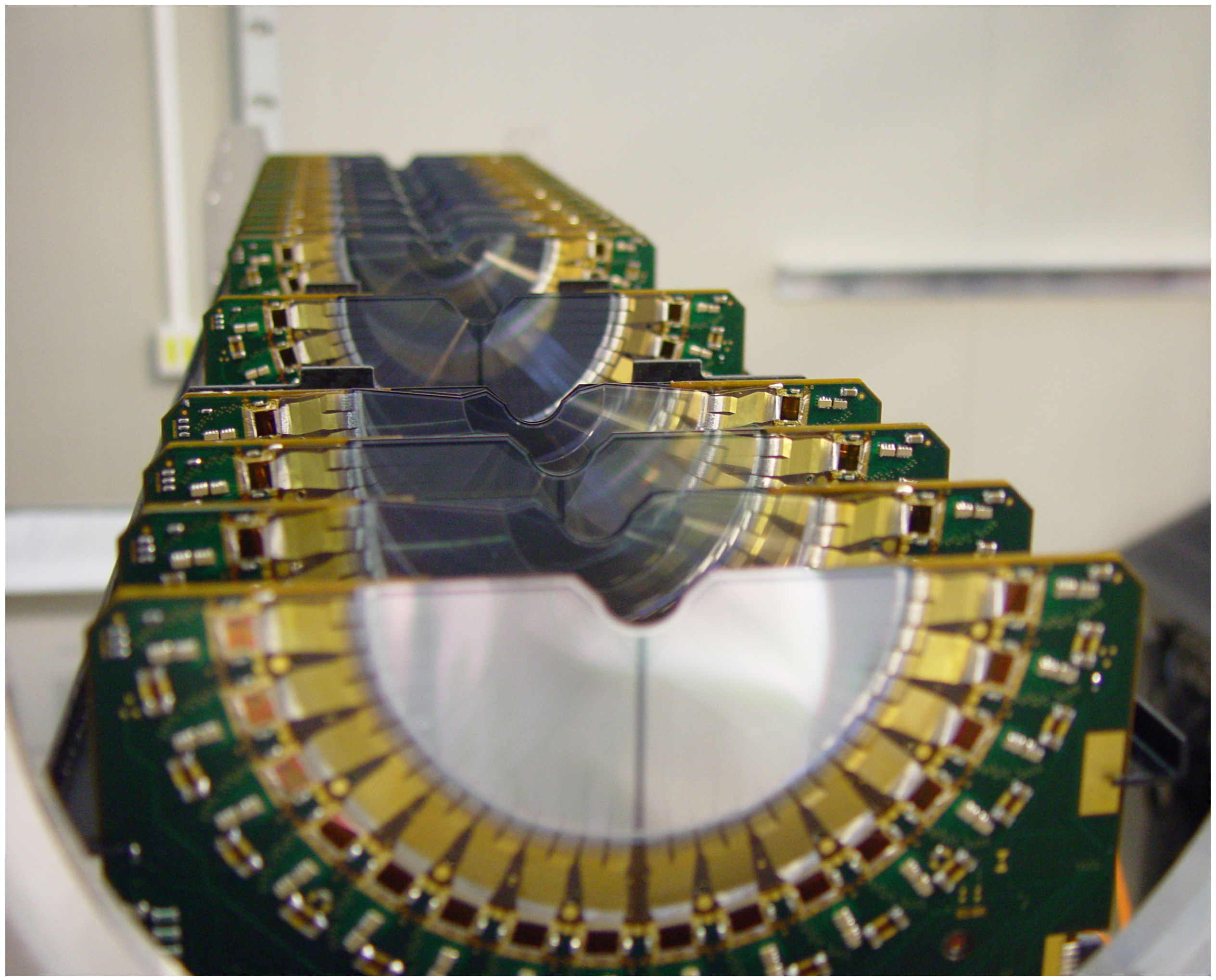

LHCb
CERN/LHCC 2018-027
PUB-2018-019
27 August 2018
Physics Case for an LHCb Upgrade II
Opportunities in flavour physics, and beyond, in the HL-LHC era

The Upgrade II detector



- Fast timing to suppress pileup.
- Higher granularity and radiation hardness.

The VELO and the RF foil



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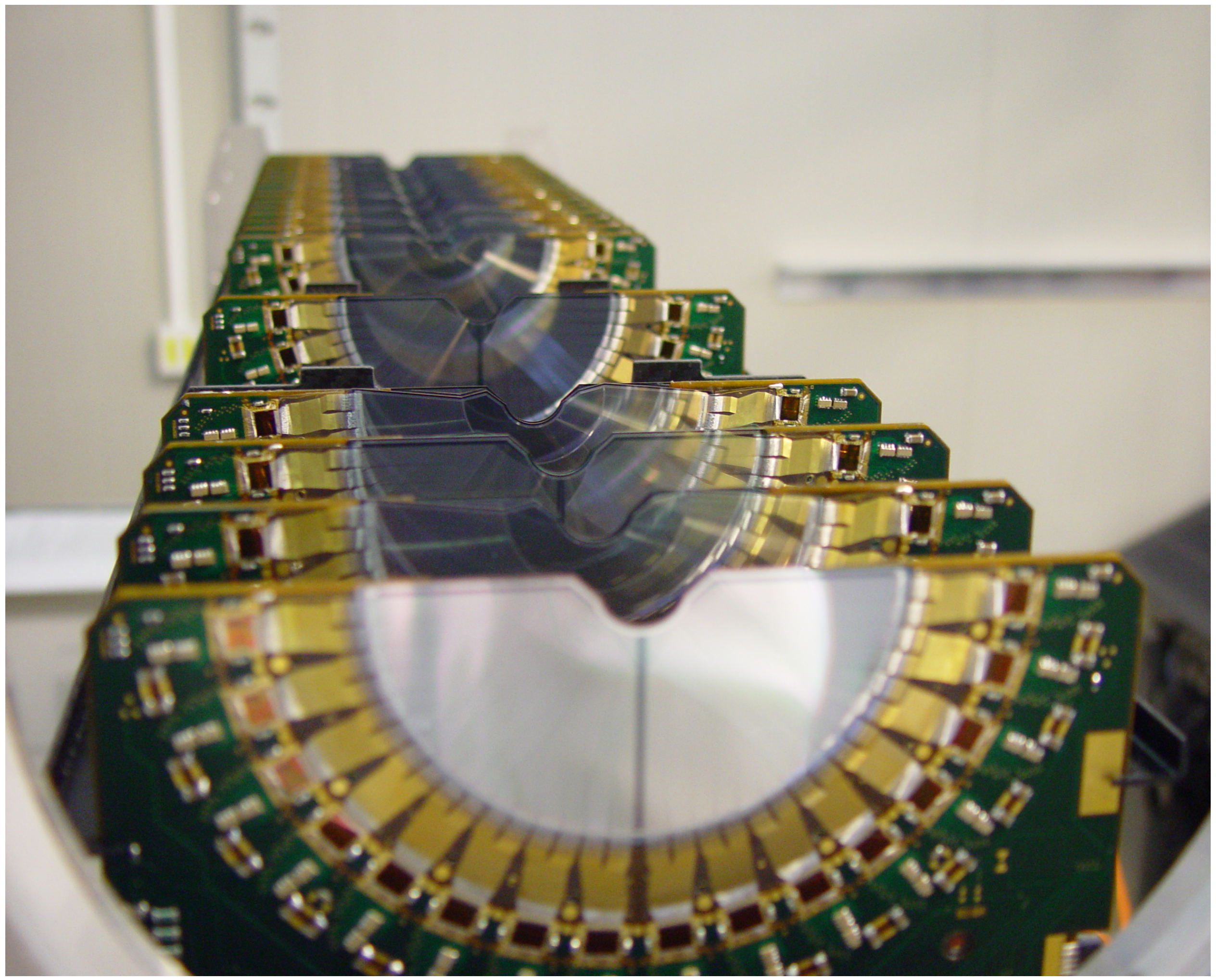
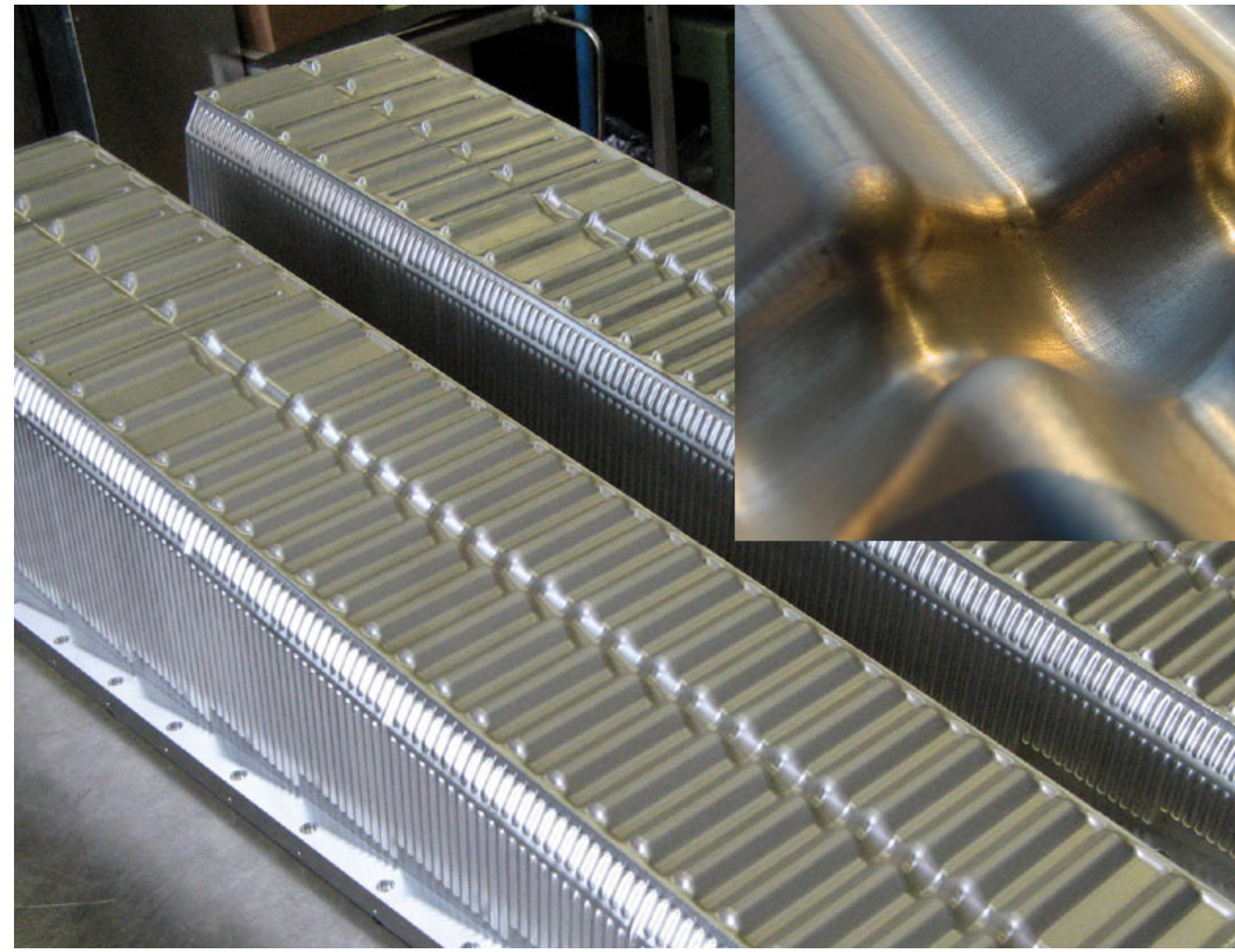
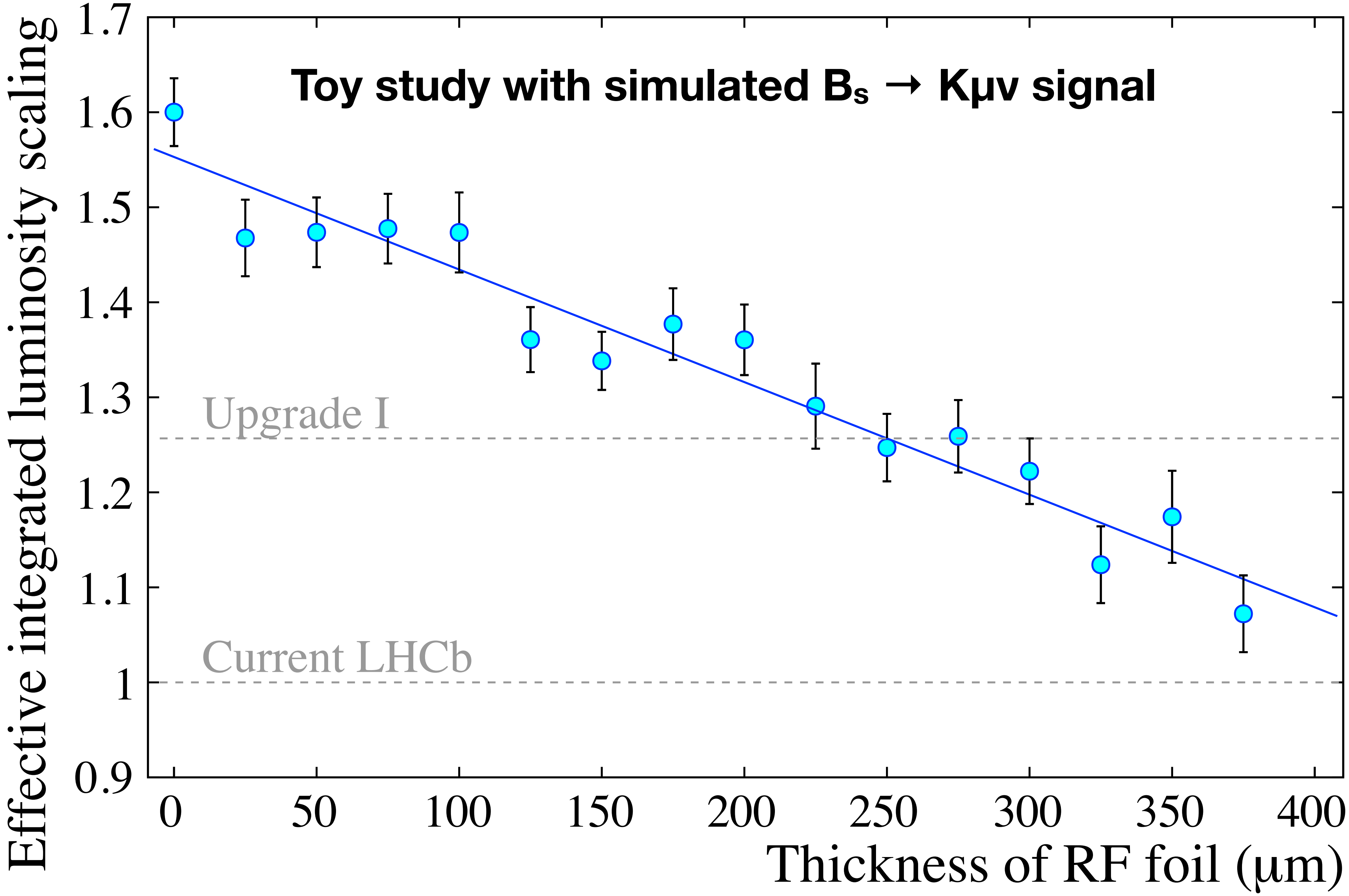


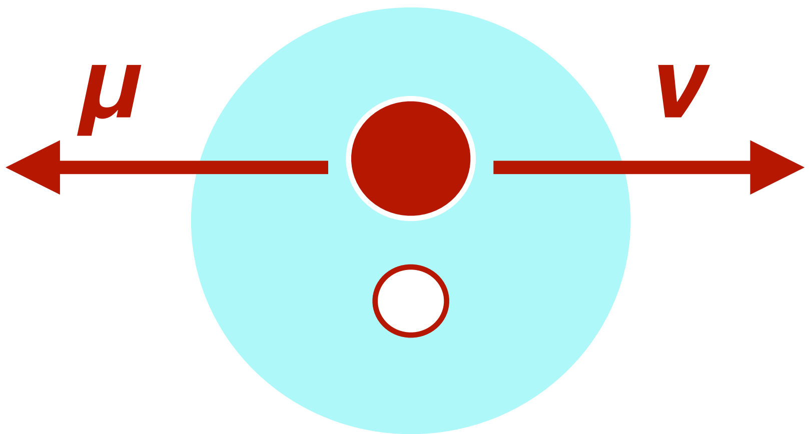


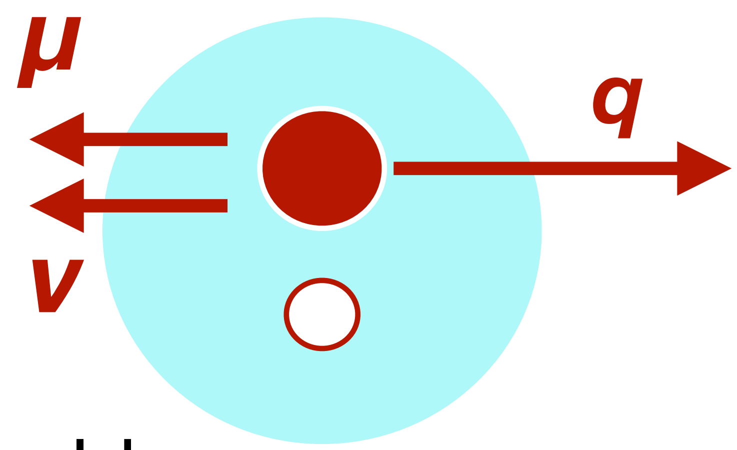
Effect of improved corrected mass resolution?



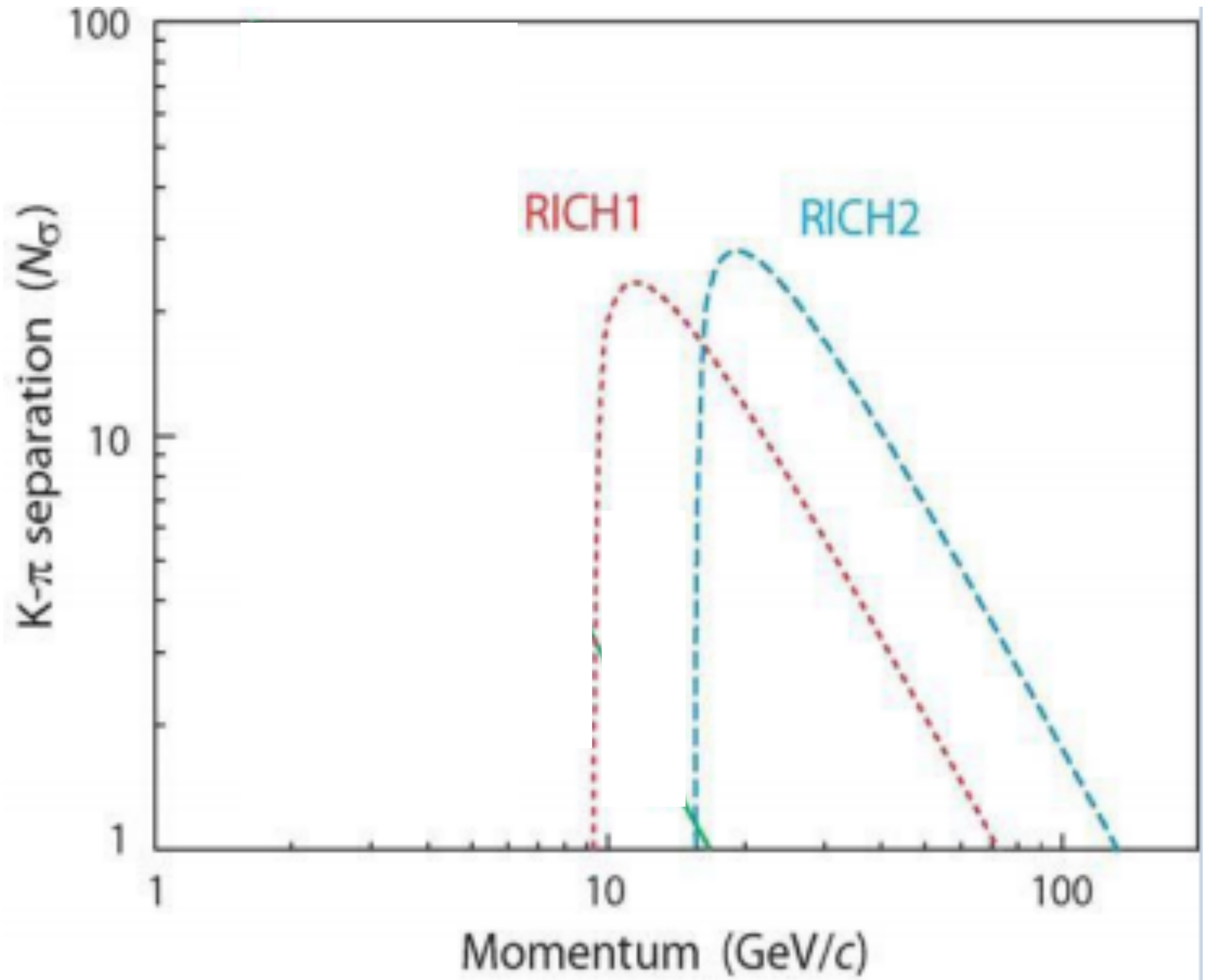
Low momentum particle ID

Smaller LQCD uncertainties at low q^2





Hadron often below the RICH PID threshold…



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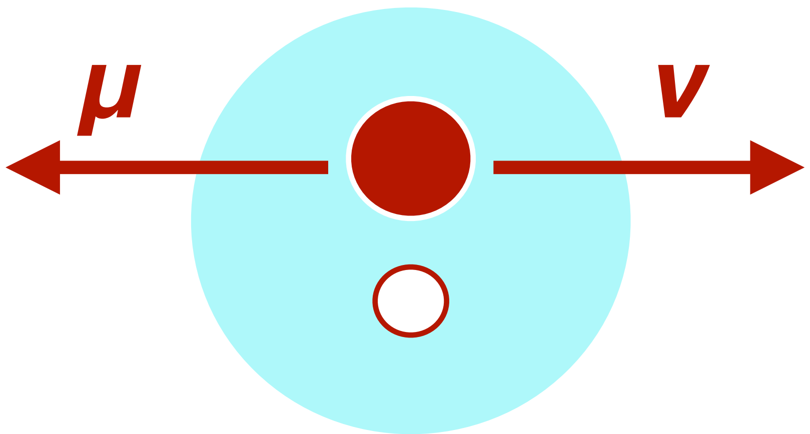

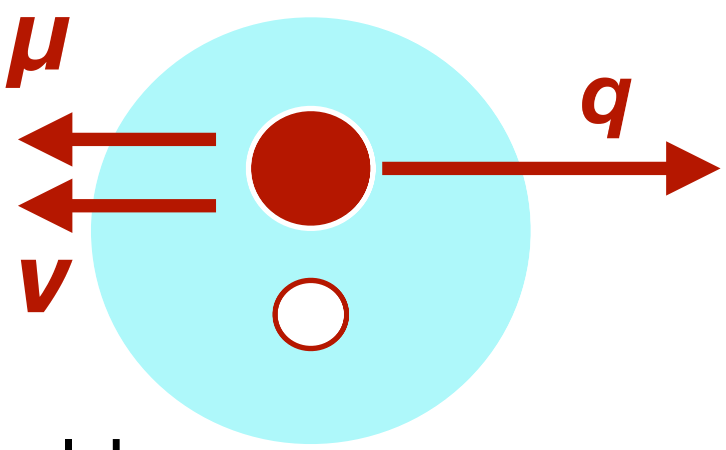

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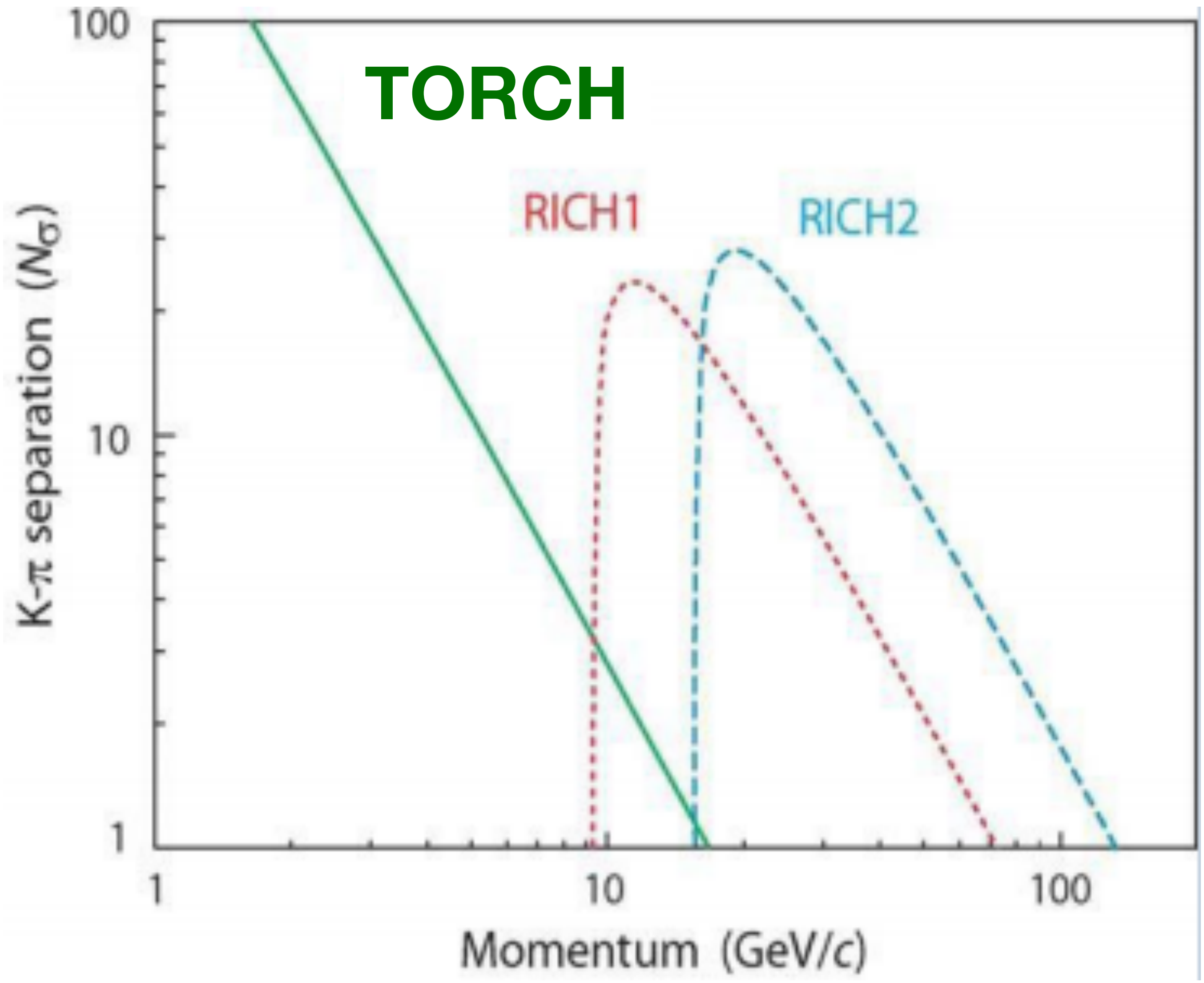
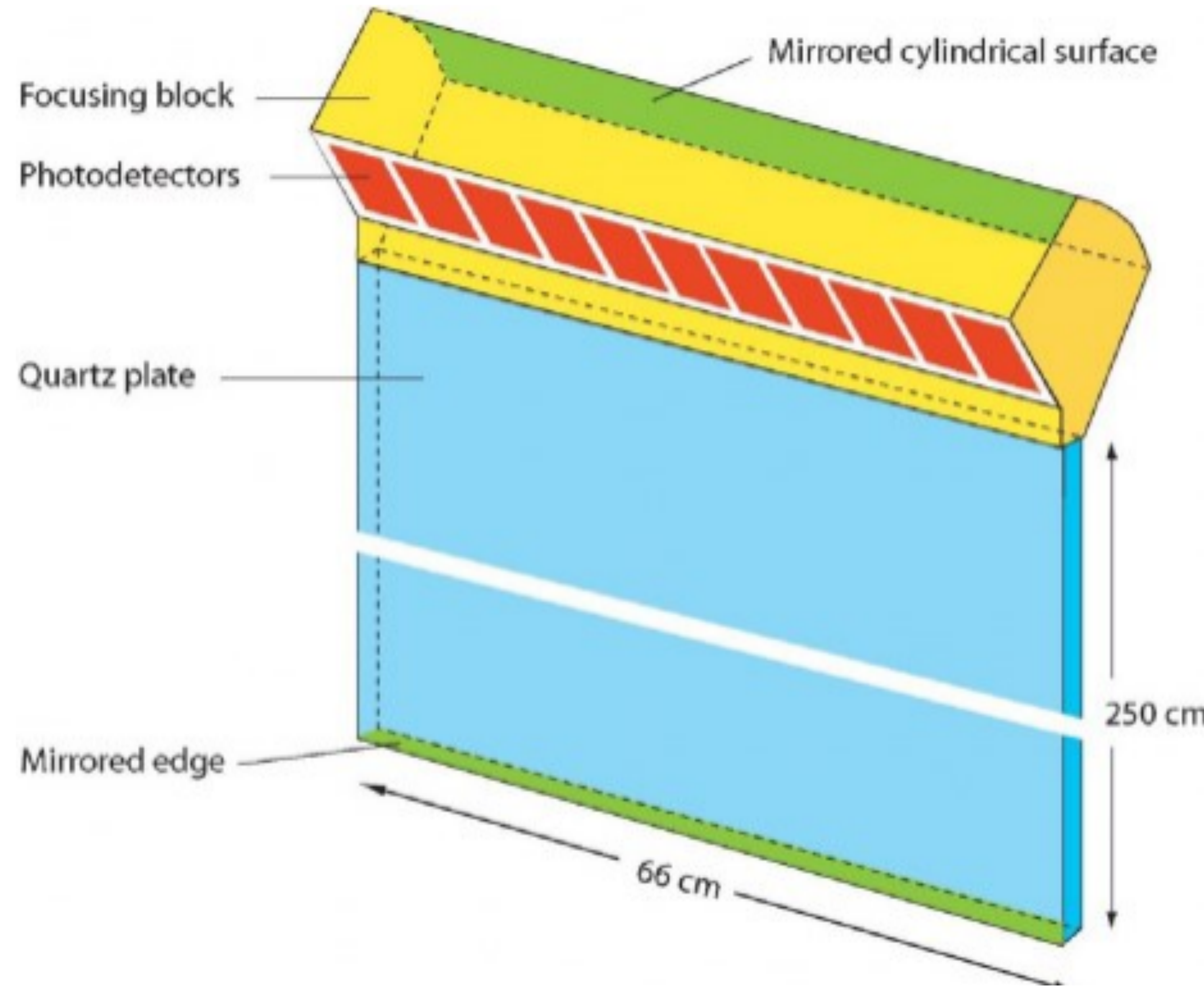
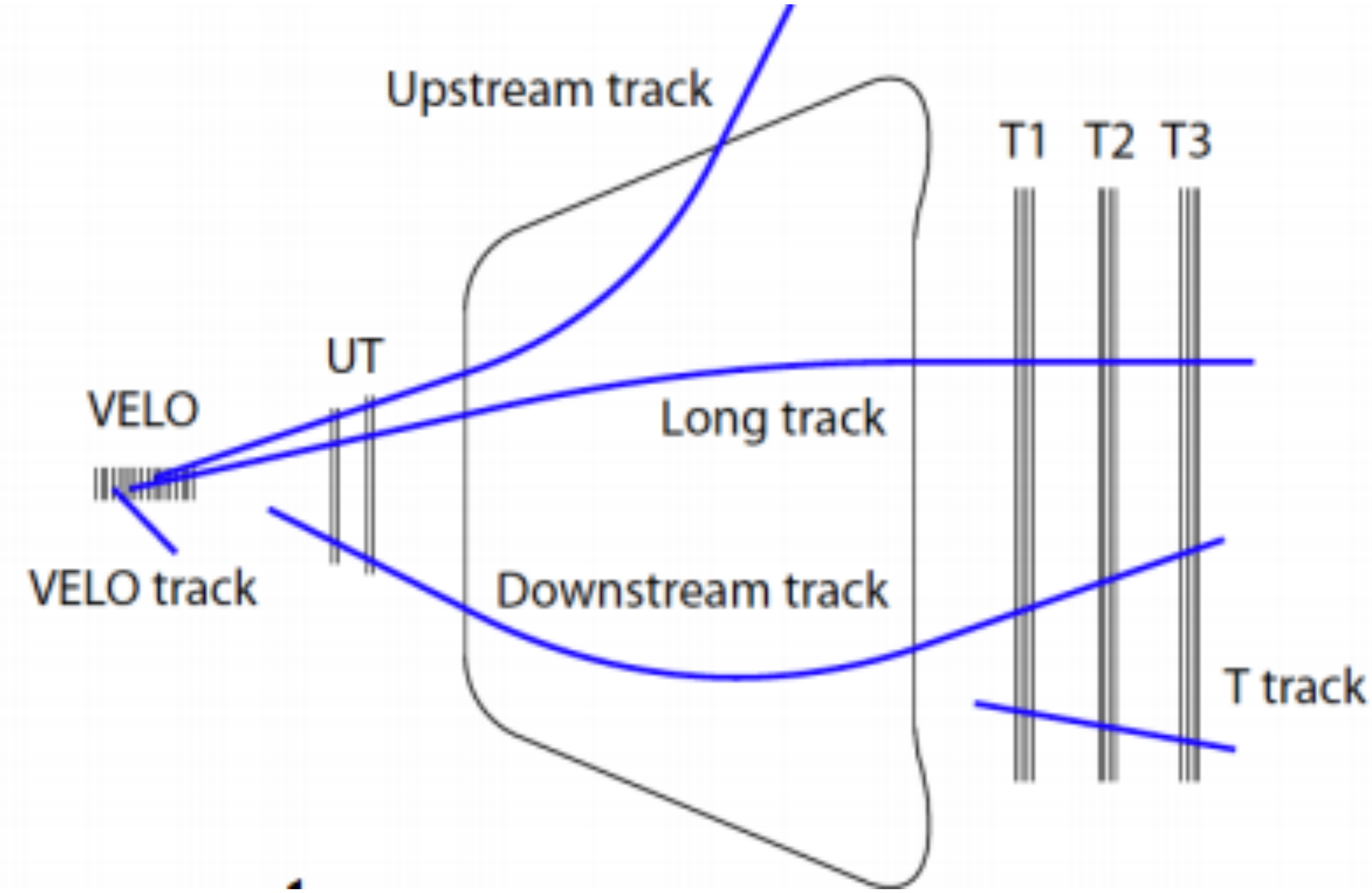
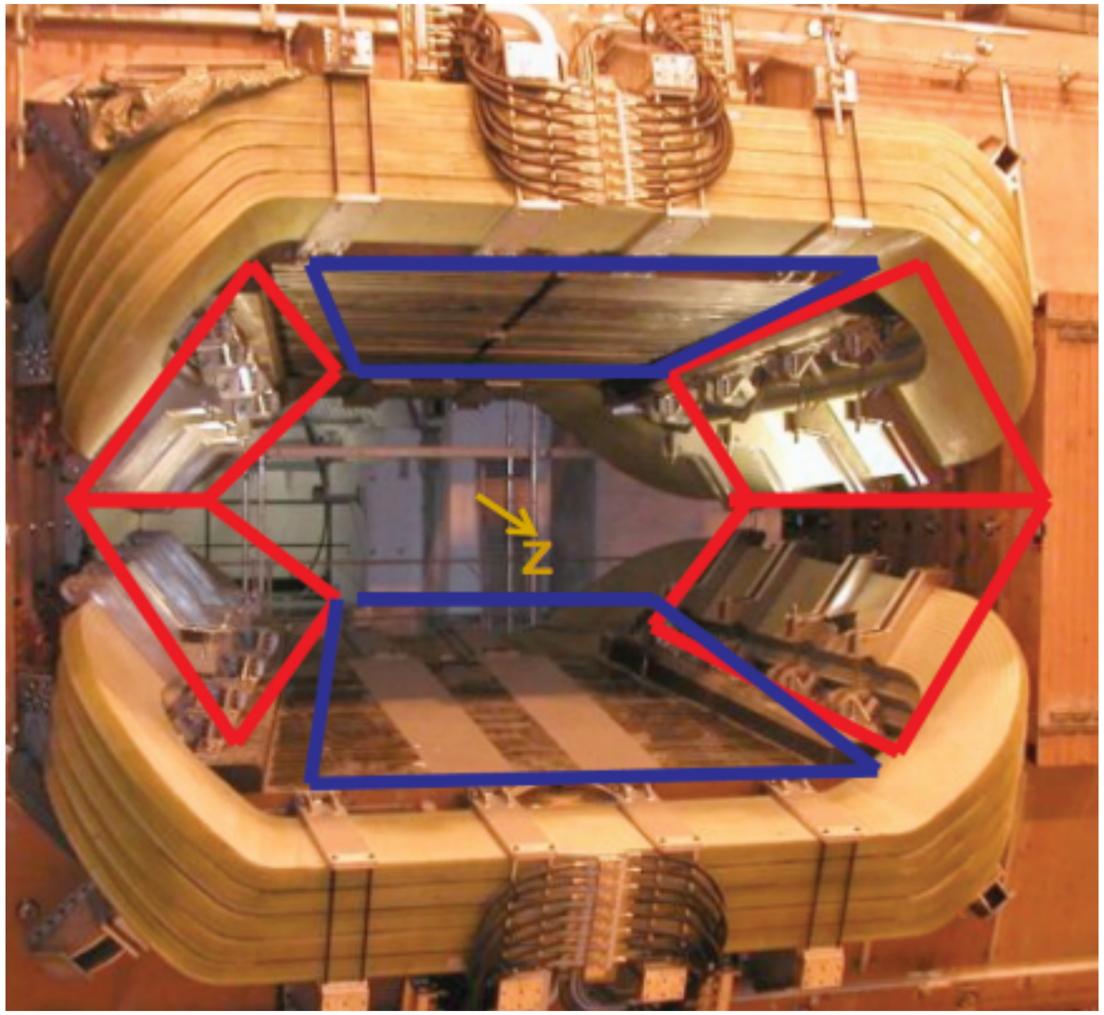




Low momentum tracking

The [$B_s^{**} \to BK$, $\Sigma_b \to \Lambda_b \pi$ etc…] approach is statistically challenging, which isn't helped by losing many tagging kaons in the magnet.



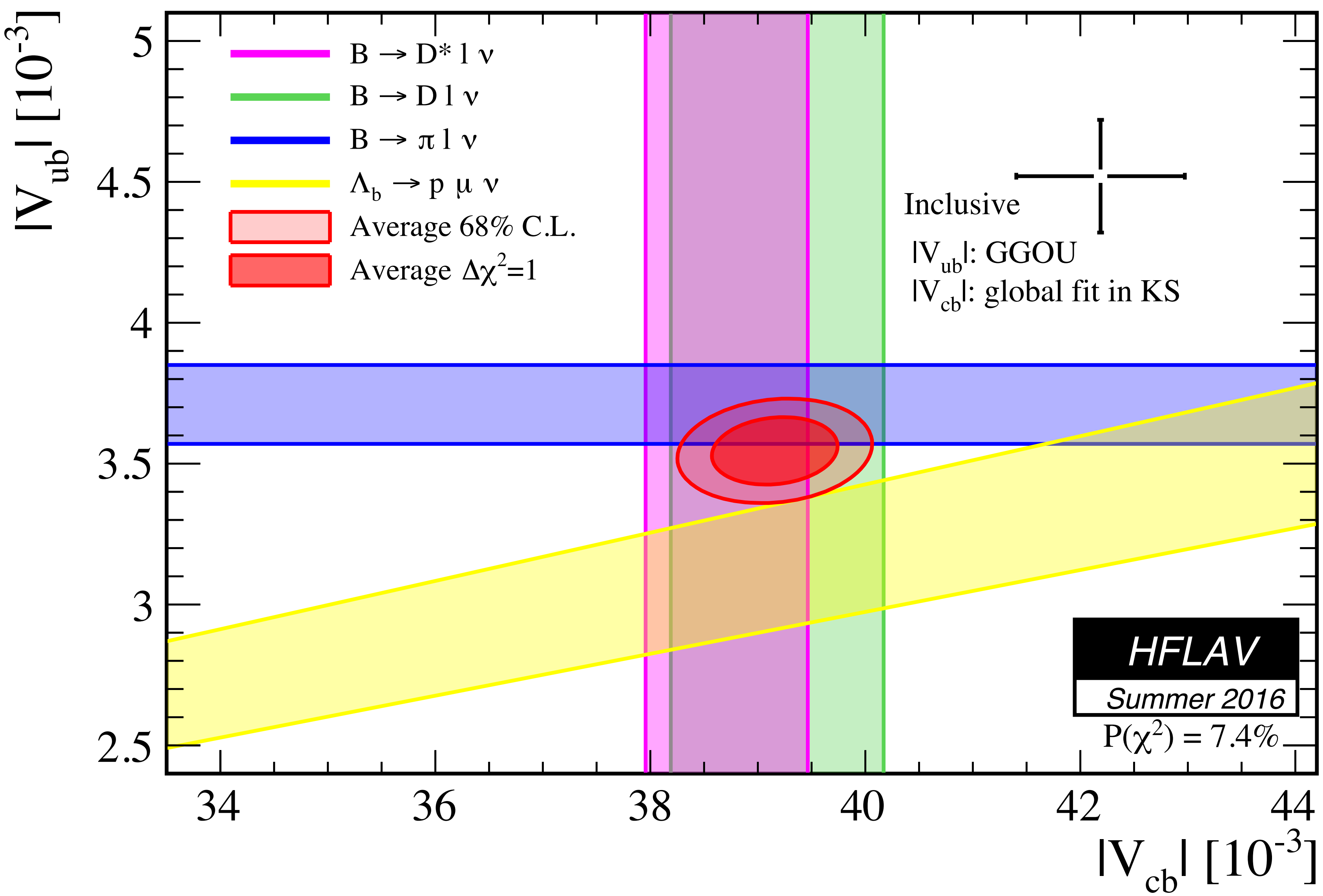


Magnet stations boost the useable acceptance by 60%.

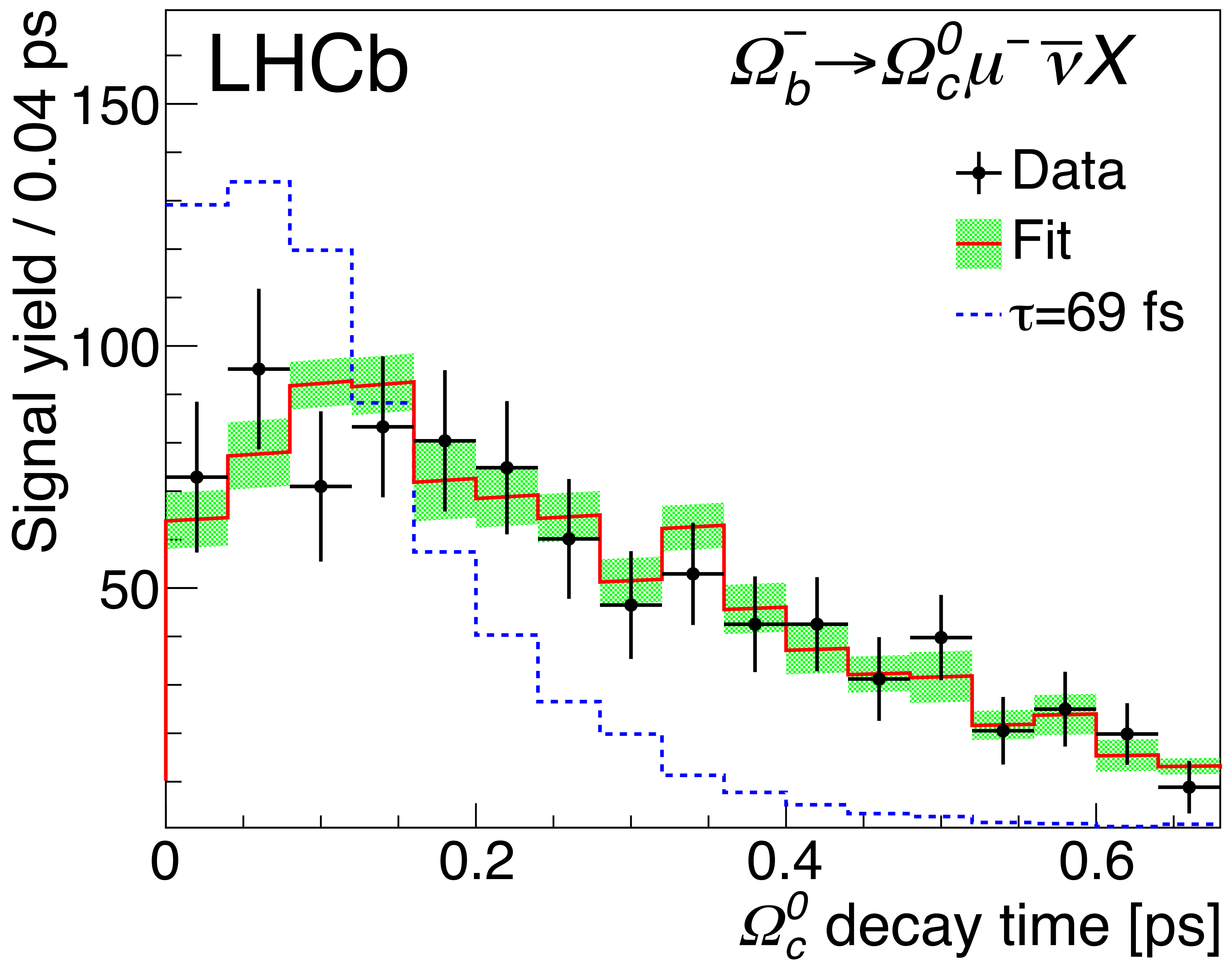
Outlook

Exclusive $b \to \{c,u\}\mu\nu$ decays are an area with really interesting synergies between LHCb with Belle(-II).

Exciting to think about all of the measurements with unexplored decays and observables that can go into future figures like this:



Backup slides follow from here…


LHCb
$\Omega_b^- \to \Omega_c^0 \mu^- \overline{\nu} X$
Data
Fit
τ=69 fs
Signal yield / 0.04 ps
150
100
50
0
0.2
0.4
0.6
Ω_c^0 decay time [ps]

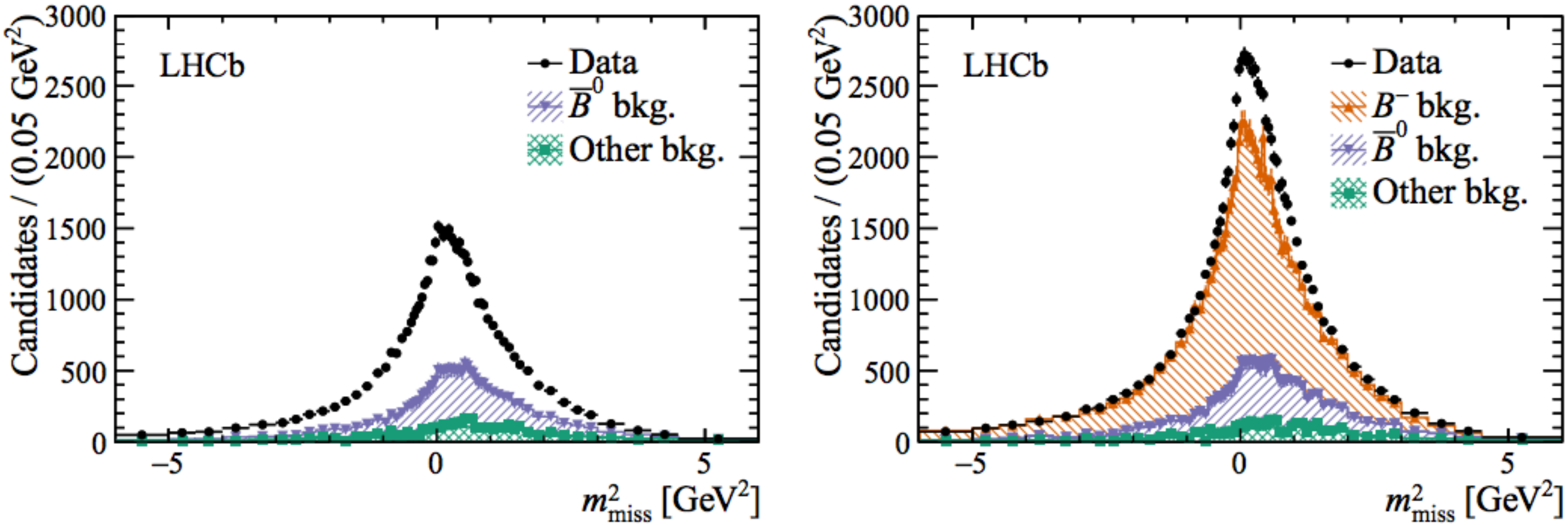
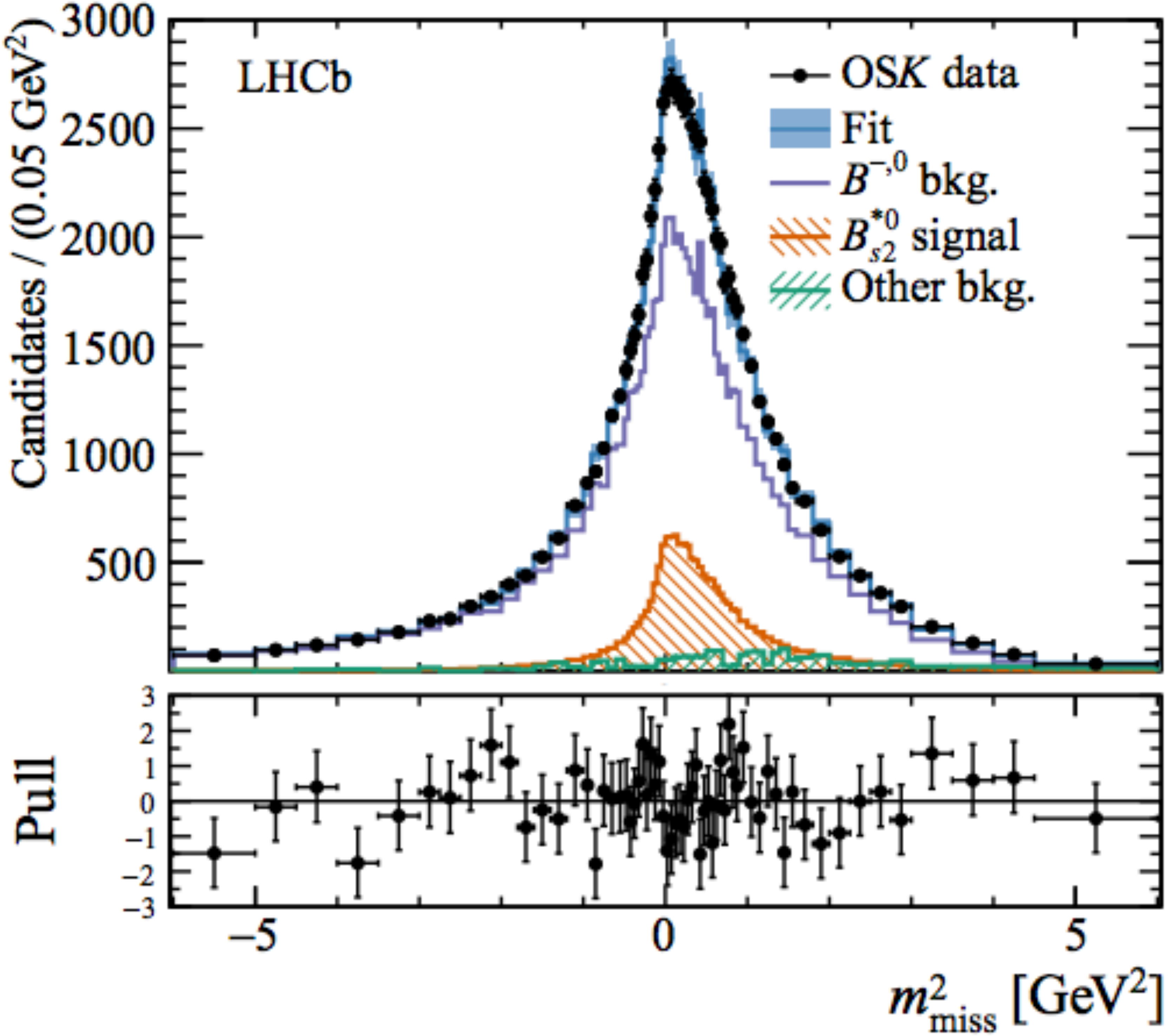
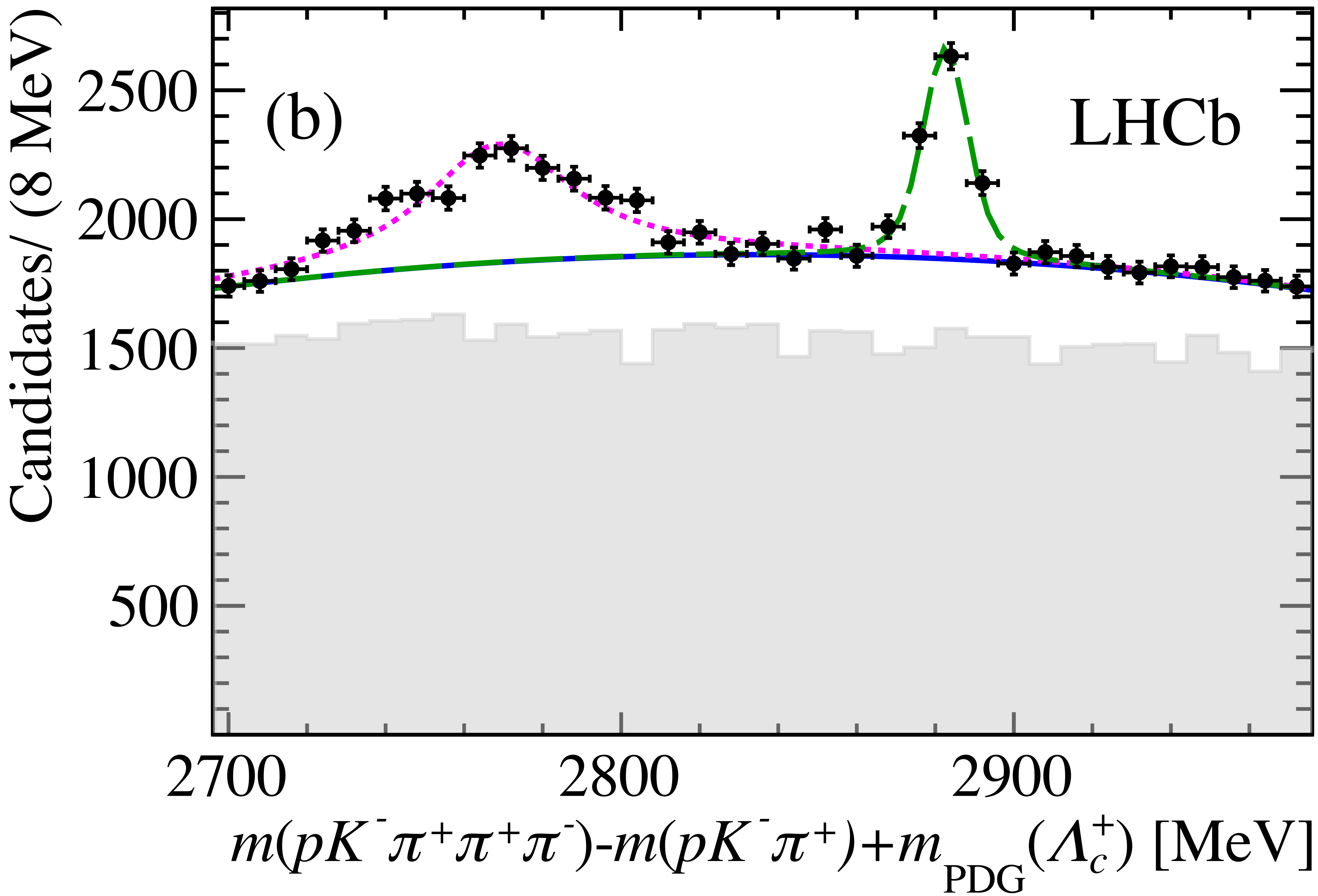
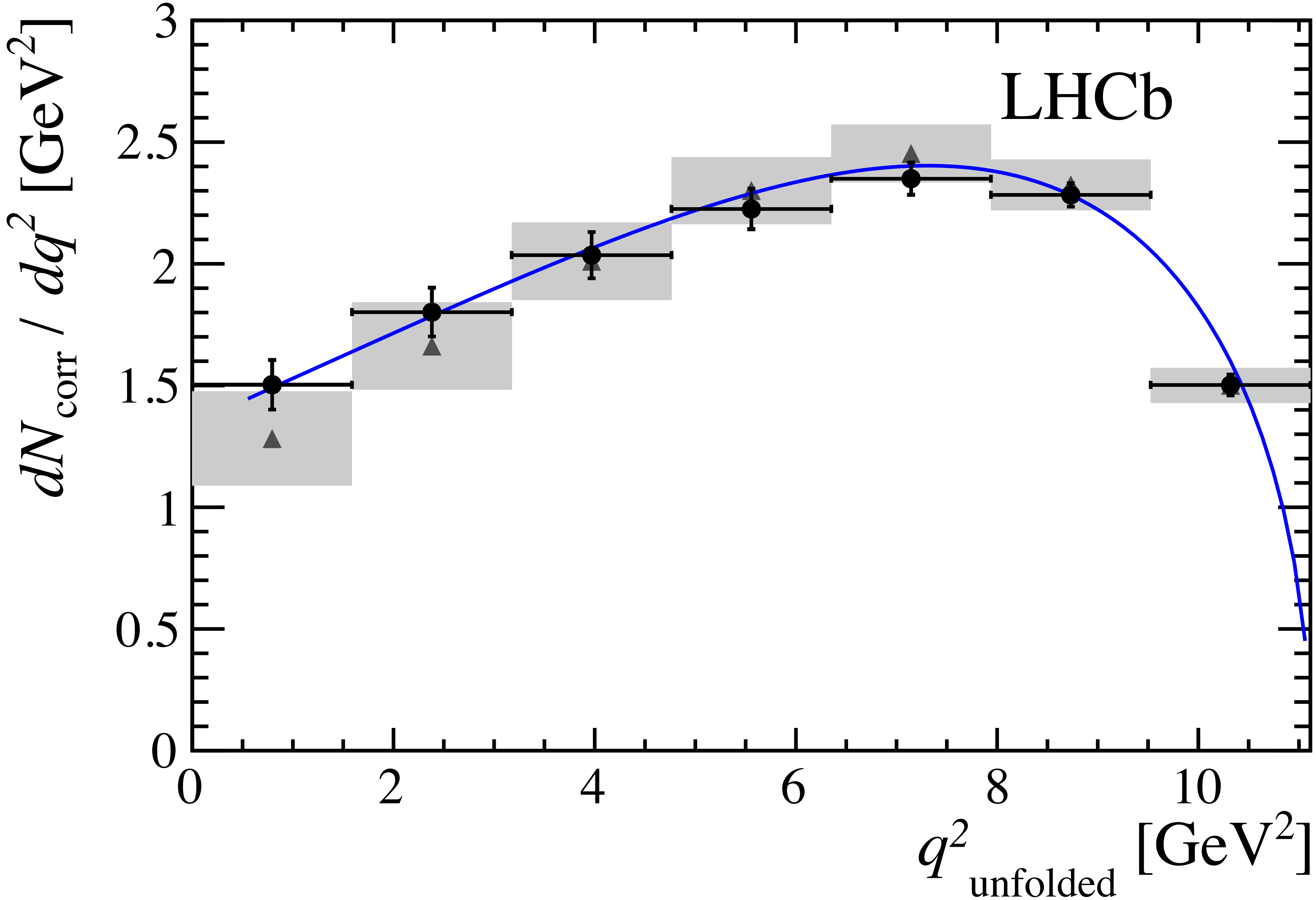


Figure 5: Missing-mass distribution for data and estimated background contributions in the (left) same-sign kaon sample and (right) opposite-sign sample. The other background decays include contributions from misreconstructed backgrounds, and semileptonic decays of $\overline{B}^0_s$ and Λ^0_b mesons. The remainder of the SSK sample not from $\overline{B}^0$ or other background decays is used to define the background contribution from B^- semileptonic decays. This is then extrapolated to the OSK sample, where the remainder is composed of signal. The background distributions are stacked.


LHCb
OSK data
Fit
$B^{-,0}$ bkg.
B_{s2}^{*0} signal
Other bkg.
Candidates / (0.05 GeV^2)
Pull
m^2_{miss} [GeV^2]



Candidates/ (8 MeV)
2500
2000
1500
1000
500
(b)
LHCb
2700
2800
2900
$m(pK^-\pi^+\pi^+\pi^-)$-$m(pK^-\pi^+)$+$m_{\rm PDG}(\Lambda_c^+)$ [MeV]



LHCb
dN_{corr} / dq^2 [GeV^2]
$q^2_{unfolded}$ [GeV^2]
0
0.5
1
1.5
2
2.5
3
0
2
4
6
8
10