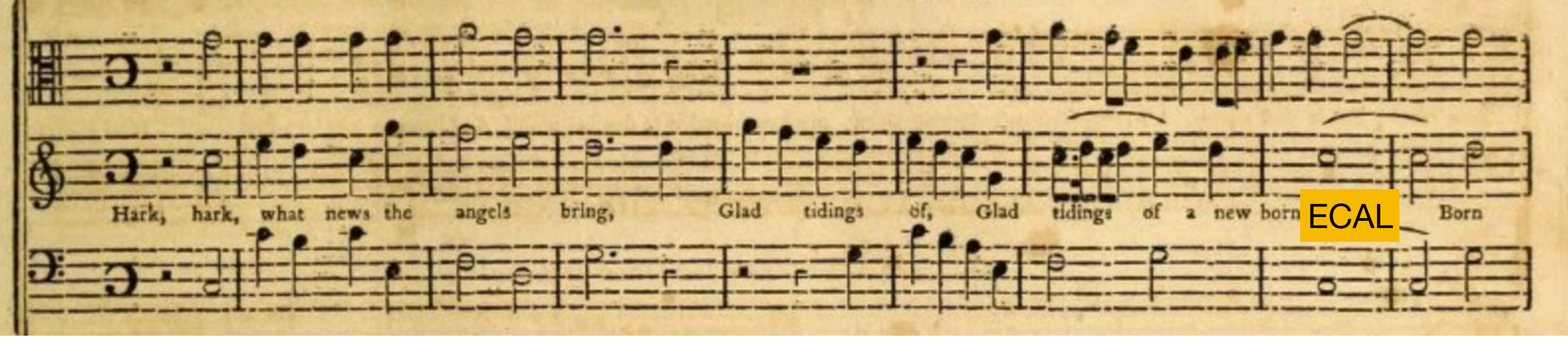


Physics with an upgraded ECAL

Yasmine Amhis & Patrick Robbe

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Thanks to : M. Vesterinen, O. Lupton, S.Monteil, C.Fitzpatrick, M.Borsato
F. Polci, M.Winn, M.-H Schune, J. Lefrançois, for the discussions

LHCb

Terminology

γ, $e^{\pm}$, π^0

but also in jets…

Theatre of Dreams: Beyond the LHCb Phase 1 Upgrade

Working with calo objects

... but statistically a small percentage of analyses is done with calo:

Statement from a WG:
"So far the X WG has not taken full advantage of analyses that involve calo objects since those without are plentiful. "
Could be re-read as:
"So far the X WG has not taken full advantage of analyses that involve calo objects since those with them are painful. "

- Whenever there is a π^0 instead of a π^+ or a e instead of a μ: typically a factor 20 less signal yield
- Trigger intrinsically more difficult to understand
- Worse mass resolutions (hence higher backgrounds)

What has been the sociology of the collaboration with the ECAL ?

Total number of papers in LHCb 474

Measurement of the ratio of branching fractions BR($B0\to K{*}0\gamma$)/BR ($B0s\to\phi\gamma$) [2012]

Measurement of the ratio of prompt χc to J/ψ production in pp collisions at $s\sqrt{}=7$ TeV [2012]

Evidence for the decay $B0\to J/\psi\omega$ and measurement of the relative branching fractions of B0s meson decays to $J/\psi\eta$ and $J/\psi\ \eta'$ [2012]

Measurement of the cross-section for $Z\to e+e-$ production in pp collisions at $s\sqrt{}=7$ TeV [2012]

Measurement of the $B0\to K{*}0e+e-$ branching fraction at low dilepton mass

Measurement of the relative rate of prompt $\chi c0$, $\chi c1$ and $\chi c2$ production at $s\sqrt{}=7$TeV [2013]

Study of forward Z+jet production in pp collisions at $s\sqrt{}=7$TeV [2013]

Observation of photon polarization in the $b\to s\gamma$ transition [2014]

Evidence for the decay $X(3872)\to\psi(2S)\gamma$ [2014]

Test of lepton universality with $B\to$ K ll [2014]

Measurement of the $\chi b(3P)$ $\chi b(3\ P)$ mass and of the relative rate of $\chi b1$ (1P) $\chi b1$ (1 P) and χ b2 (1P) χ b2(1P) [2014]

Search for CP violation in $D0\to\pi-\pi+\pi0$ decays with the energy test [2014]

Angular analysis of the $B0\to K{*}0e+e-$ decay in the low-q2 region [2014]

Study of χb meson production in pp collisions at $s\sqrt{}=7$ and 8TeV and observation of the decay $\chi b(3P)\to\Upsilon(3S)\gamma$ [2014]

Observation of the $B0s\to\eta'\eta'$ decay [2015]

A study of CP violation in $B\mp\to Dh\mp$ (h=K,π) with the modes $D\to K\mp\pi\pm\pi0$, $D\to\pi+\pi-\pi0$ and $D\to K+K-\pi0$ [2015]

Search for the $\Lambda0b\to\Lambda\eta'$ and $\Lambda0b\to\Lambda\eta$ decays with the LHCb detector [2015]

Study of W boson production in association with beauty and charm[2015]

Search for the rare decays $B0\to J/\psi\gamma$ and $B0s\to J/\psi\gamma$ [2015]

\Search for the lepton-flavour violating decay $D0\to e\pm\mu\mp$ [2015]

Measurement of the $B0s\to J/\psi\eta$ lifetime [2016]

First experimental study of photon polarization in radiative B0s decays [2016]

Measurement of forward $t\bar{t}$, $W+b\bar{b}$ and $W+c\bar{c}$ production in pp collisions at $s\sqrt{}=8$ TeV [2016]

Search for the $B0s\to\eta'\phi$ decay [2017]

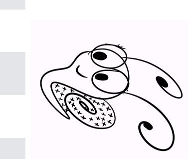
Test of lepton universality with $B0\to K{*}0\ell+\ell-$ decays [2017]

Measurement of CP violation in $B0\to J/\psi K0S$ and $B0\to\psi(2S)K0S$ decays [2017]

Search for the lepton-flavour violating decays $B0(s)\to e\pm\mu\mp$ [2017]

Search for lepton-universality violation in $B+\to K+\ell+\ell-$ decays [2019]

Many more to come



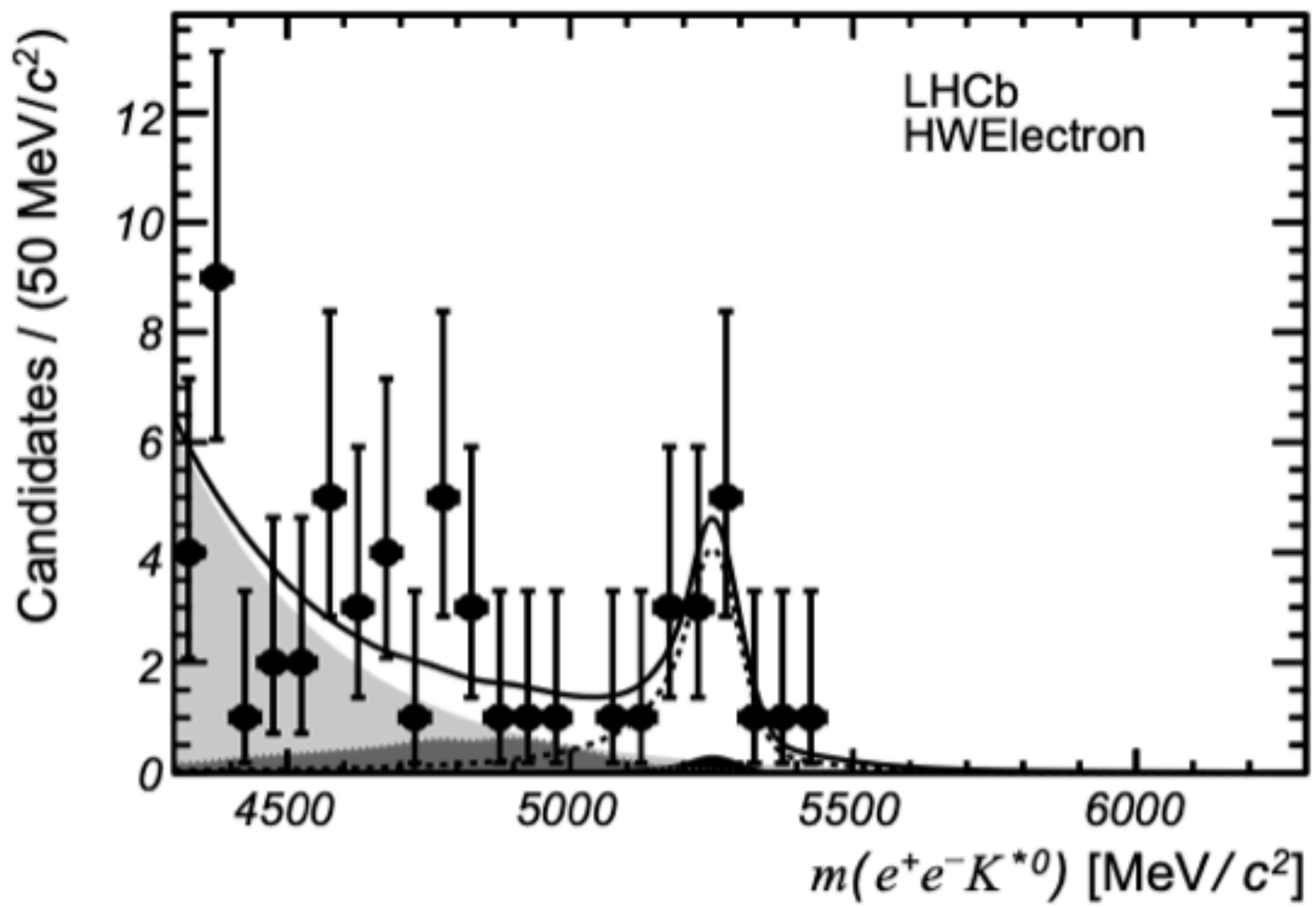
“It’s just 10 %” peanuts vs gold

These particles are powerful when we explore their specificities

Outline

- Decays where ECAL is mandatory: photons and electrons
- Dreams decays where ECAL is mandatory
- Decays where reconstruction of π^0 can bring necessary increase of statistics
- Other fields in LHCb

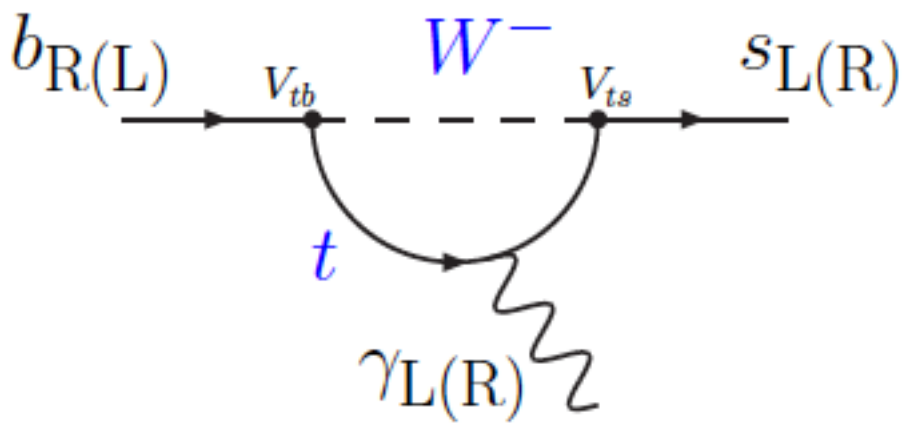
Where muons can't go…



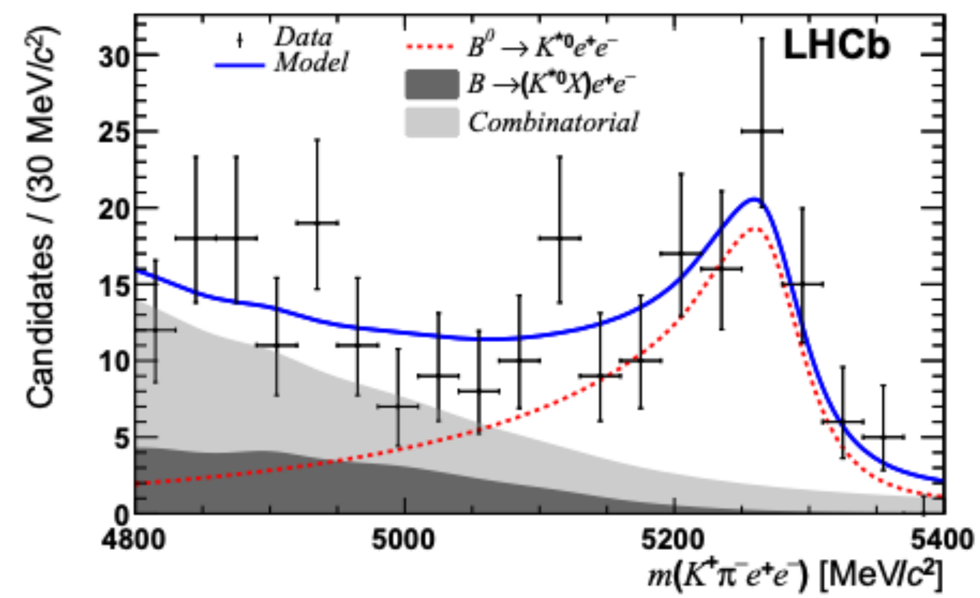
Photon polarisation

[arXiv:1304.3035]

$$b \to s\gamma \ \left(C_7^{(\prime)}\right)$$



arXiv:1501.03038



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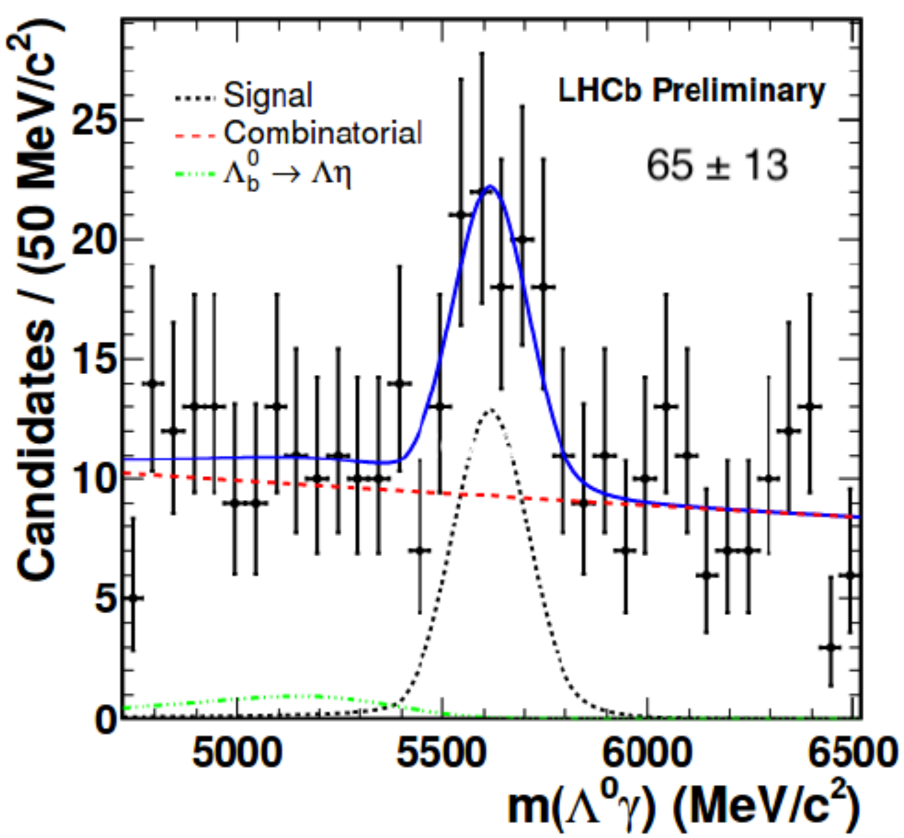
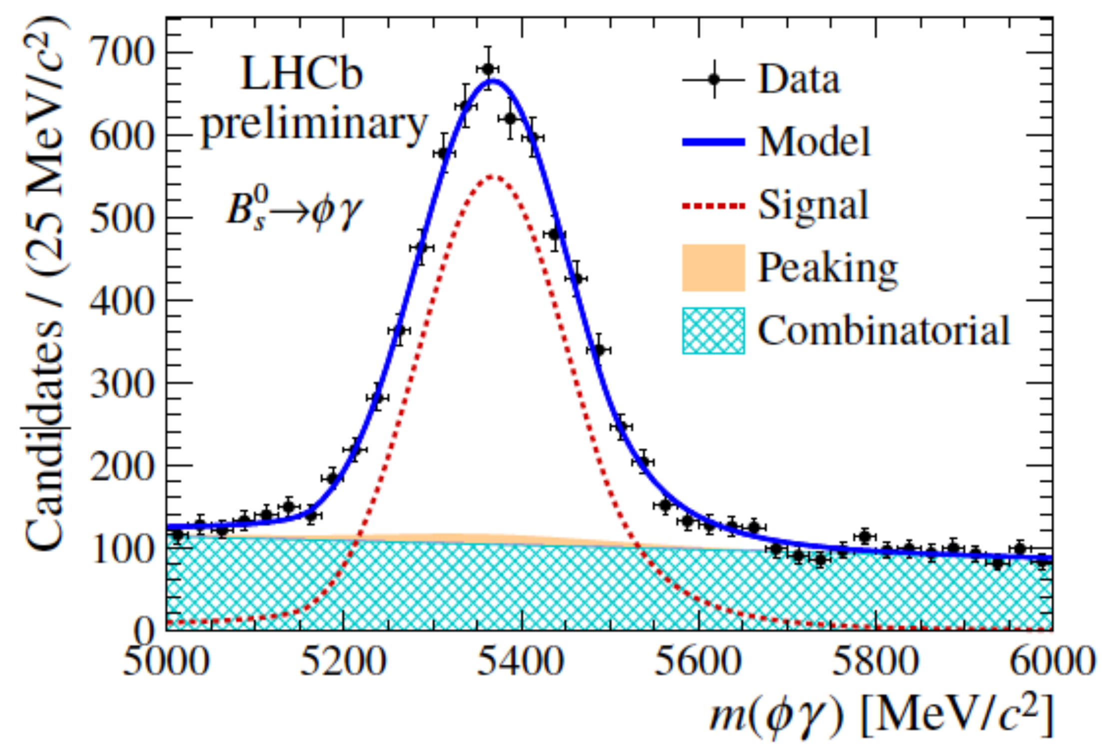


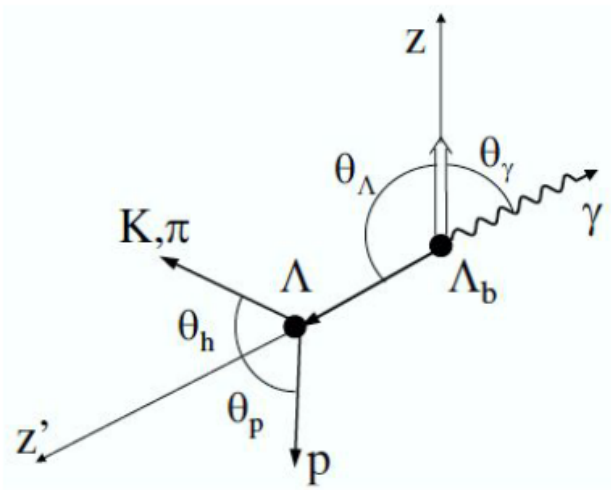
$$\mathcal{B}(\Lambda_b \to \Lambda\gamma) = (7.1 \pm 1.5 \pm 0.7 \pm 0.6) \times 10^{-6}$$

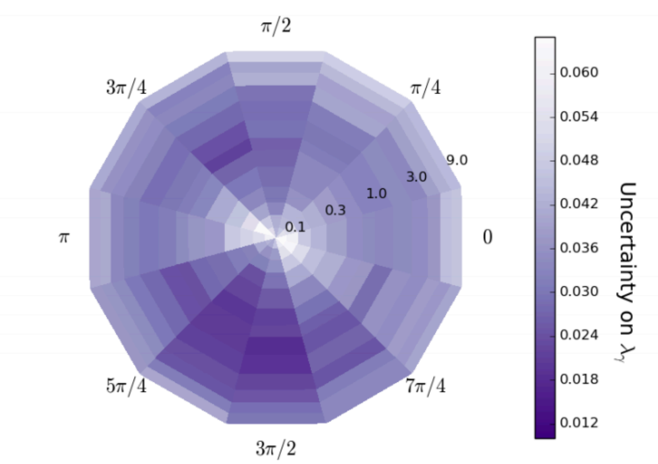
LHCB-PAPER-2019-015

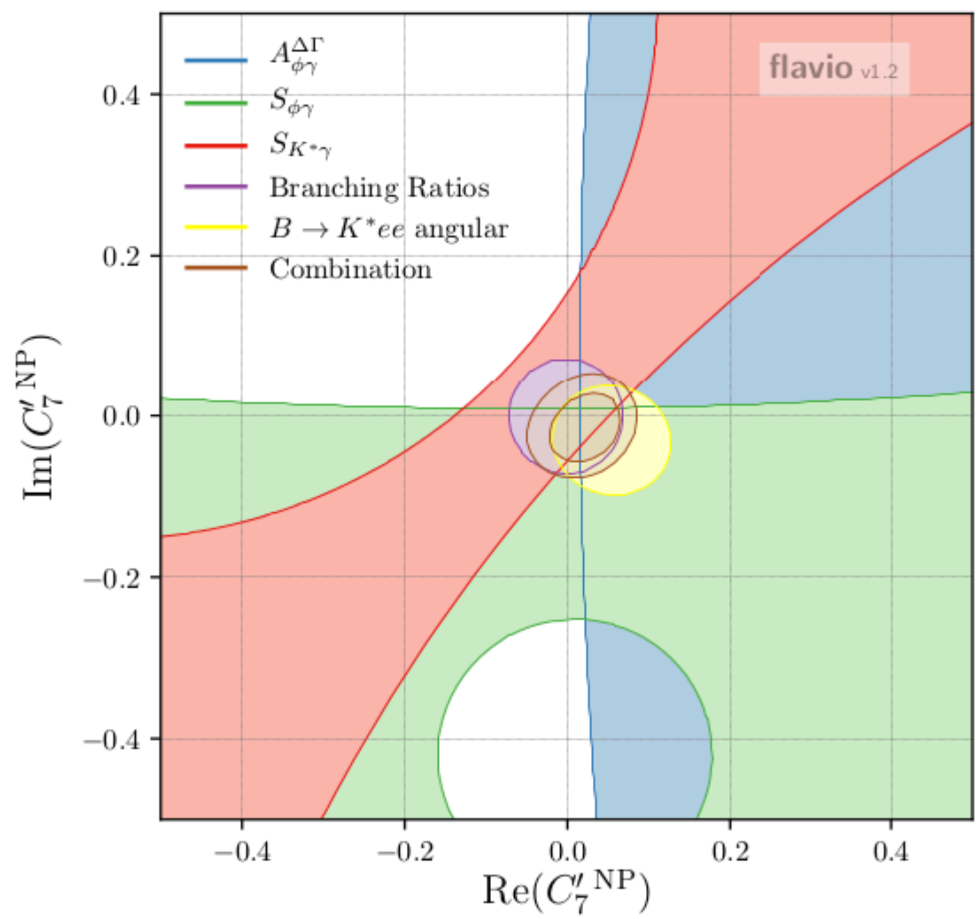


$$S_{\phi\gamma} = 0.43 \pm 0.30 \pm 0.11,$$
$$C_{\phi\gamma} = 0.11 \pm 0.29 \pm 0.11,$$
$$\mathcal{A}^{\Delta}_{\phi\gamma} = -0.67\,^{+0.37}_{-0.41} \pm 0.17$$

What to look forward to ?







radiative constrains on b-baryon not included

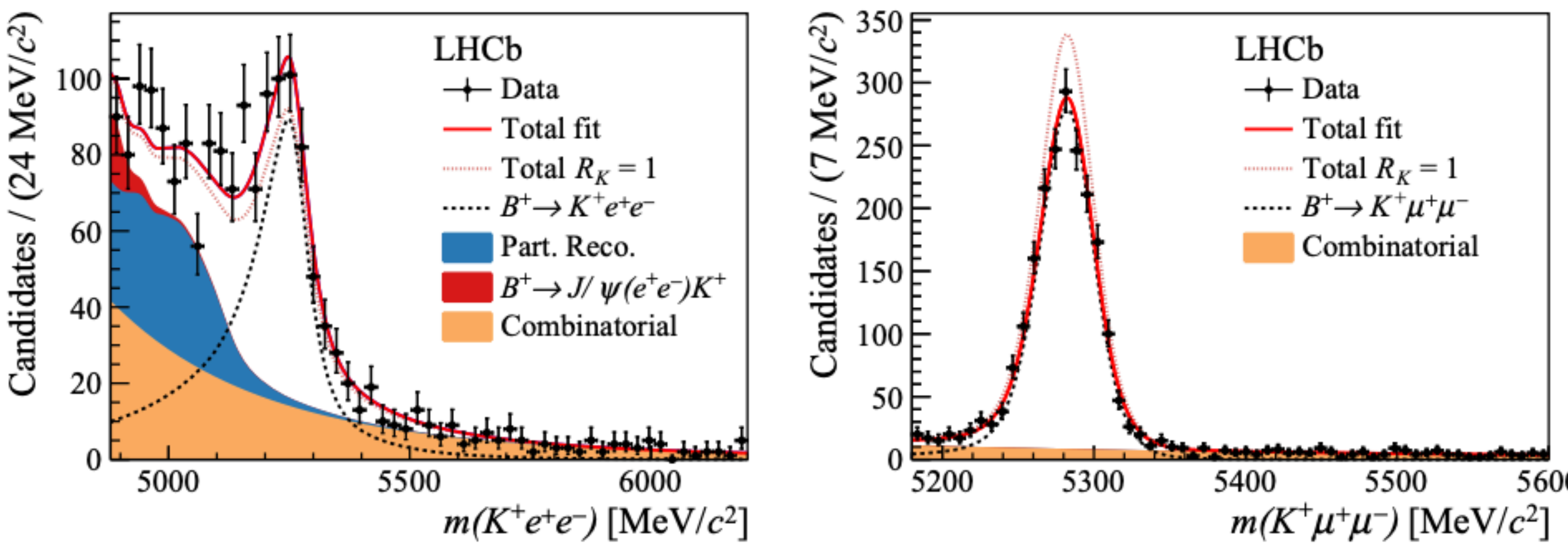
[arXiv:1902.04870]

Open a window on charm radiative decays as well D→ Vɣ where branching fraction O(10^{-5}).
Use also B_c mesons ($B_c \to D_s^* \gamma$) or charm baryons $\Lambda_c \to p^{(*)} \gamma$
CP asymmetries contribute to null tests [arXiv:1701.06392].

Wishlist for the photon reconstruction :

Keep the detector light for all the photons not to convert in the material.

Where both muons and electrons can/should go



Decay Mode	Event Yield
$B^+ \to K^+ e^+ e^-$	766 ± 48
$B^+ \to K^+ \mu^+ \mu^-$	$1\,943 \pm 49$
$B^+ \to J/\psi\,(\to e^+ e^-) K^+$	$344\,100 \pm 610$
$B^+ \to J/\psi\,(\to \mu^+ \mu^-) K^+$	$1\,161\,800 \pm 1\,100$

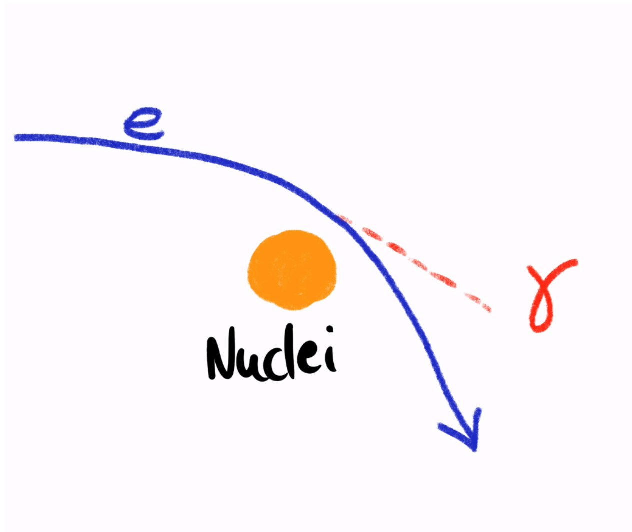
Limitations from L0 Trigger will go away.

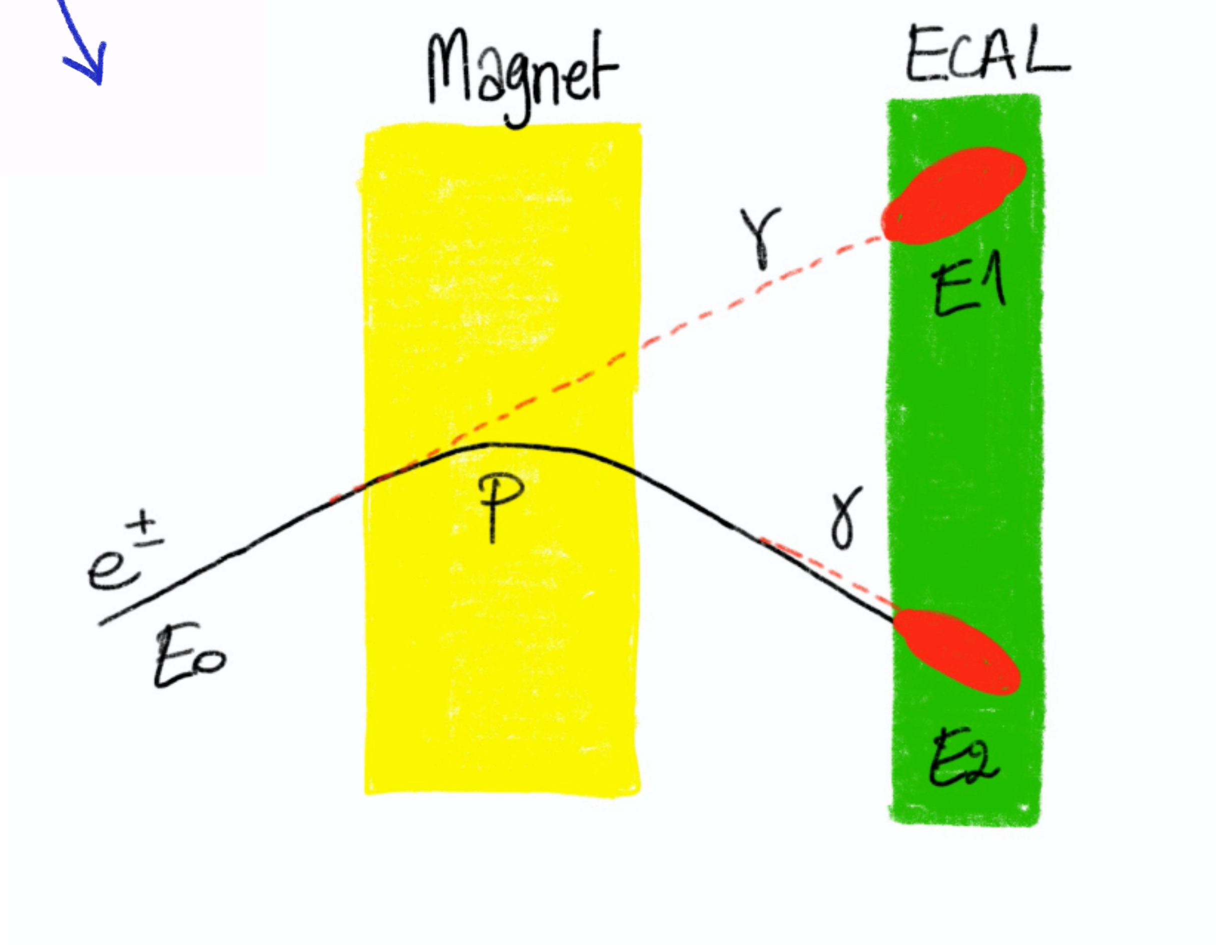
Bremsstrahlung

$\sigma \propto 1/m_l^2$

Energy loss $\propto E_e$

Energy loss $\propto$ material

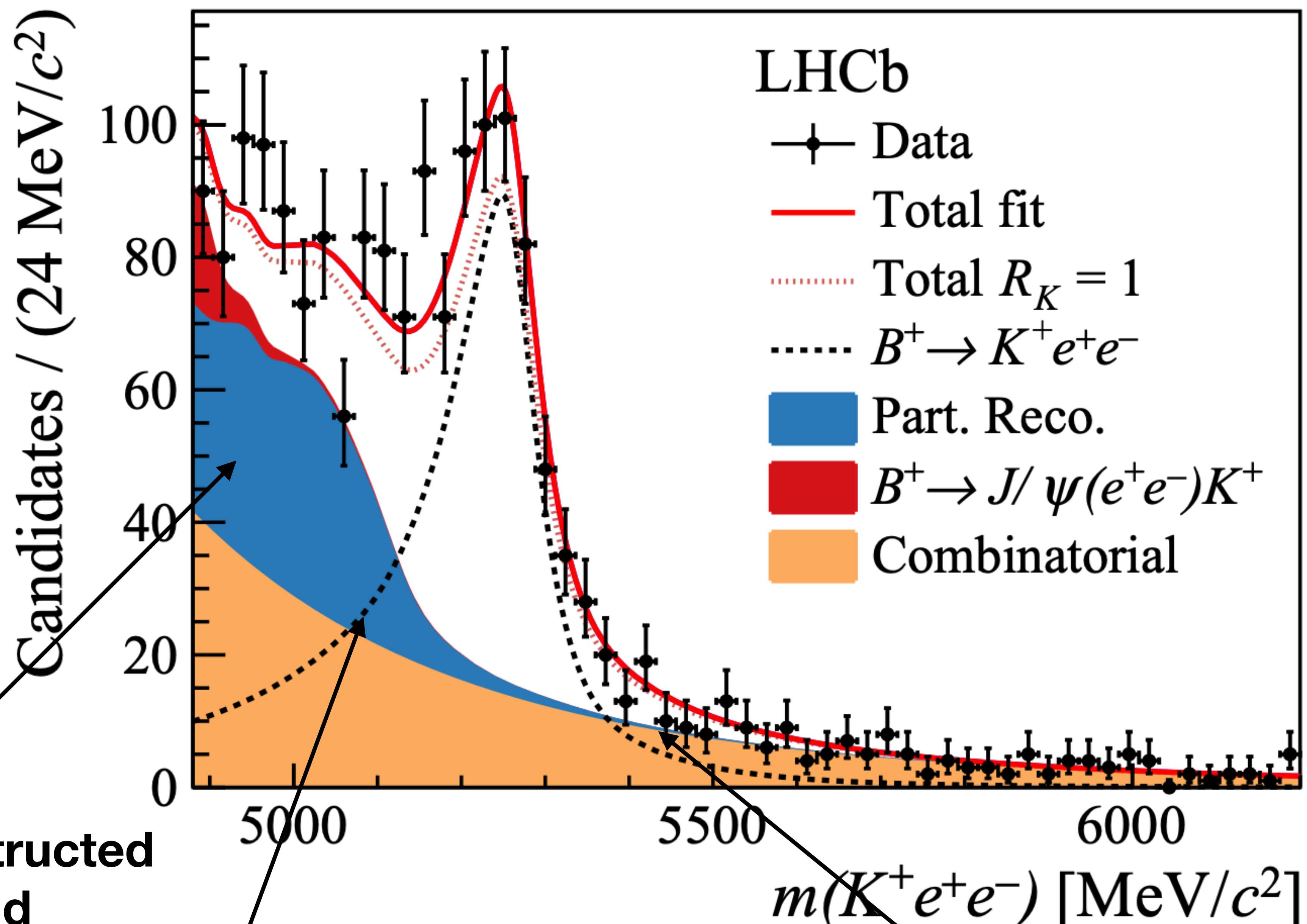




Wishlist

Important to keep a light detector and to be able to reconstructed the bremsstrahlung photons.
Could we improve/rethink the identification of bremsstrahlung photons using “timing” ?

Where both muons and electrons can/should go



Partially reconstructed background

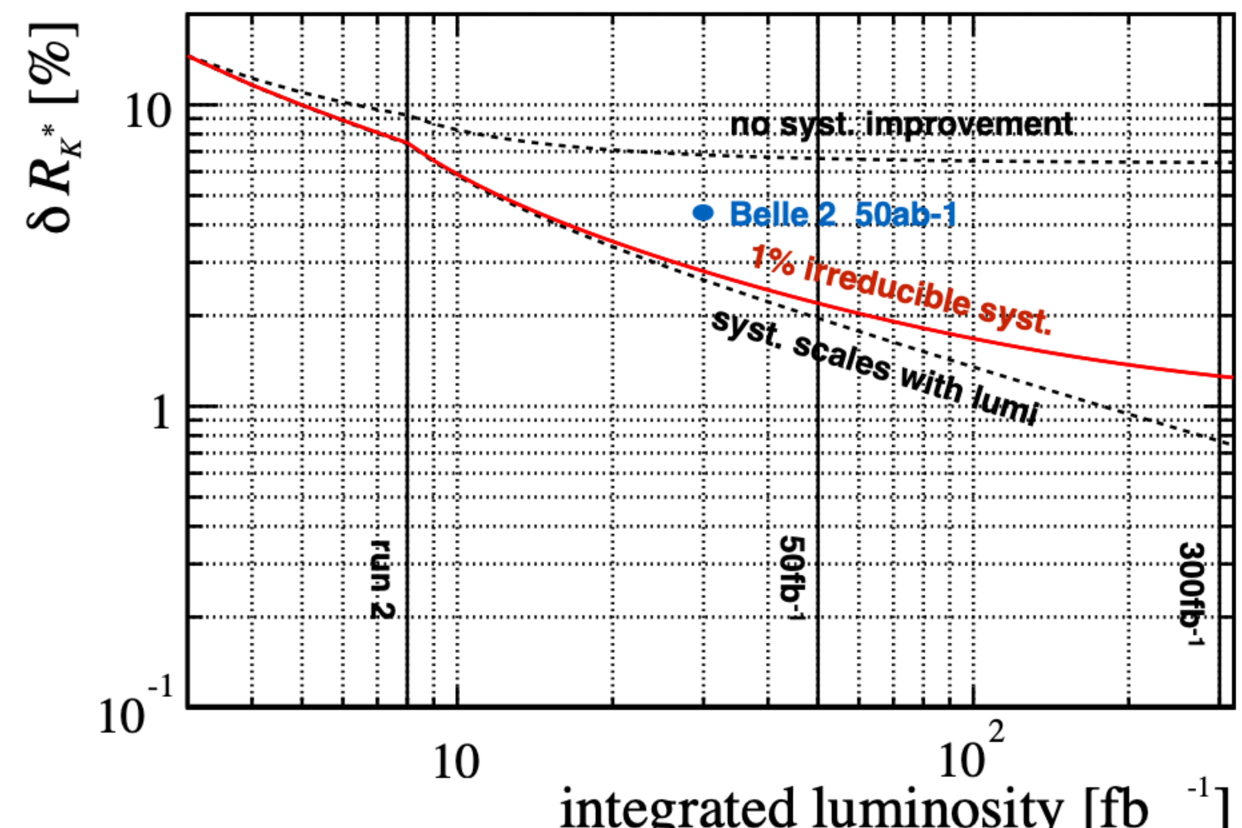
non trivial signal shape from simulation

When bremsstrahlung photons are added.

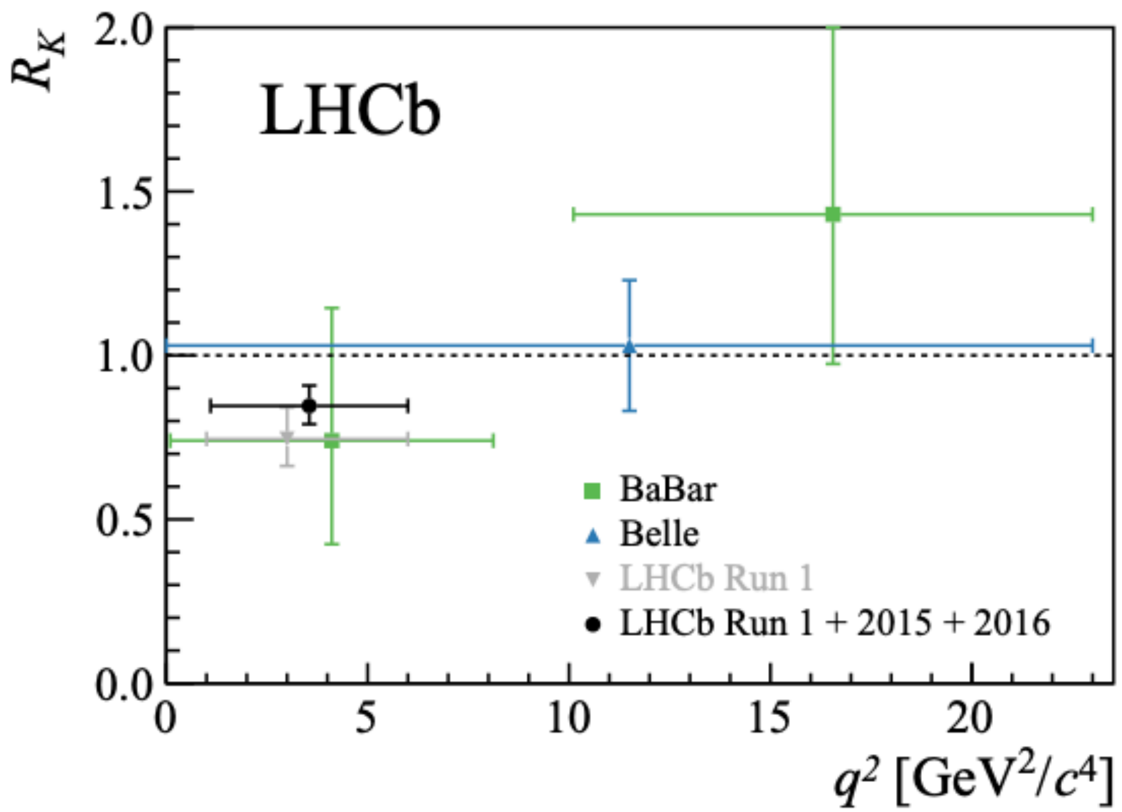
Let’s not forget the systematics

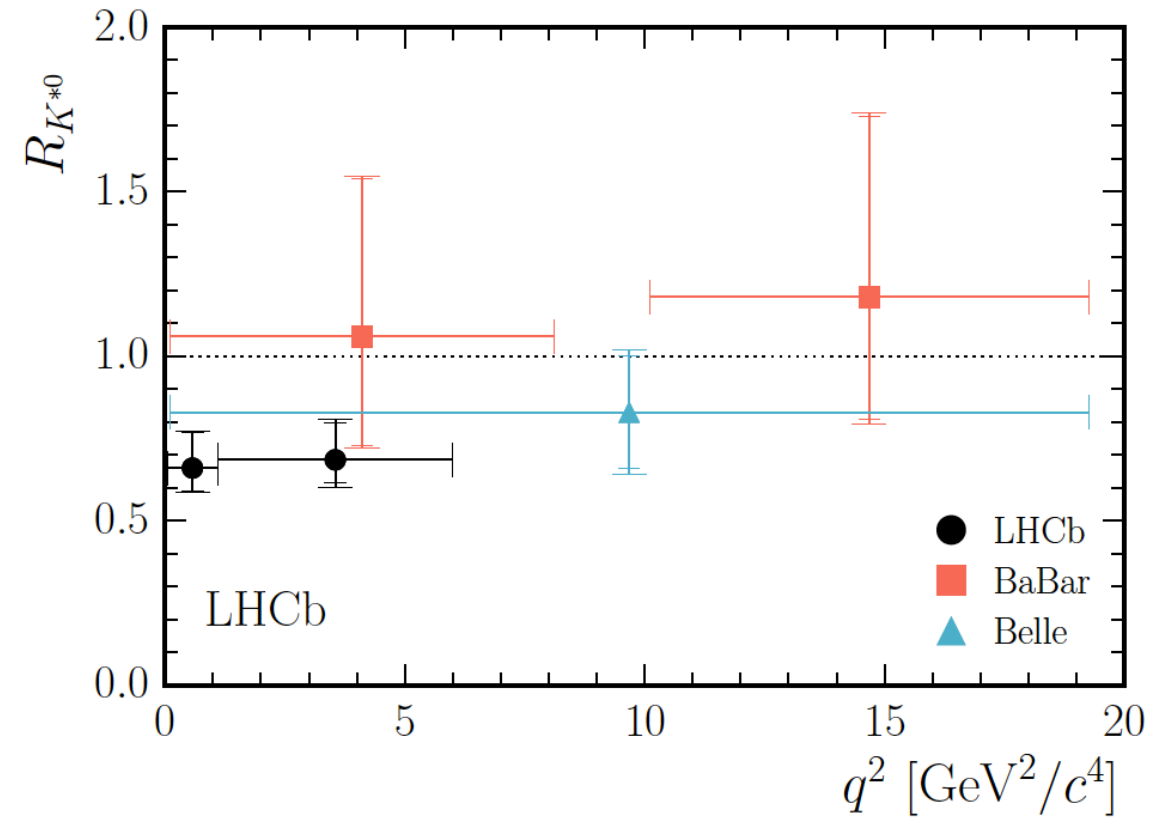
	$\Delta R_{K^{*0}}/R_{K^{*0}}$ [%]						
	low-q^2			central-q^2			
Trigger category	L0E	L0H	L0I	L0E	L0H	L0I	
Corrections to simulation	2.5	4.8	3.9	2.2	4.2	3.4	scales with the luminosity. L0H dropped.
~~Trigger~~	~~0.1~~	~~1.2~~	~~0.1~~	~~0.2~~	~~0.8~~	~~0.2~~	
• PID	0.2	0.4	0.3	0.2	1.0	0.5	scales with the luminosity.
• Kinematic selection	2.1	2.1	2.1	2.1	2.1	2.1	description of the Brem tail of the Jpsi. Could be much much smaller.
• Residual background	–	–	–	5.0	5.0	5.0	Handling of pion misidentified as electrons
Mass fits	1.4	2.1	2.5	2.0	0.9	1.0	Will scale with lumi
Bin migration	1.0	1.0	1.0	1.6	1.6	1.6	Could be very much reduced with a B mass constraint cut (and negligible according to RK paper)
$r_{J/\psi}$ ratio	1.6	1.4	1.7	0.7	2.1	0.7	scales with lumi
Total	4.0	6.1	5.5	6.4	7.5	6.7	

- Calo plays an important role



Putting it all together





[arXiv:1903.0952]

[arXiv:1705.05802]

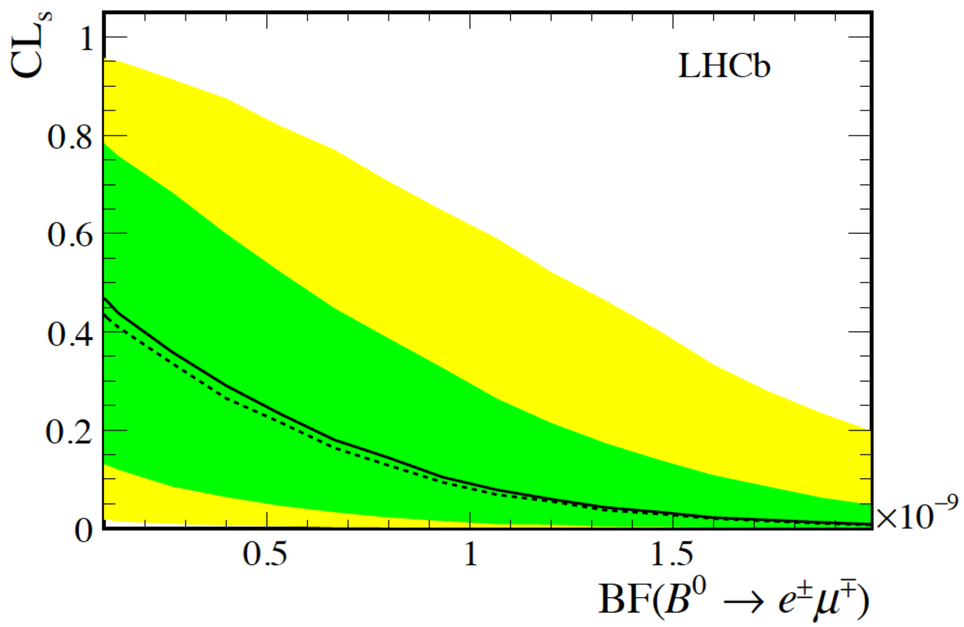
and their friends: R_{pK}, R_{ϕ}, $R_{K\pi\pi}$, R_{Λ} etc.
We should not forget b→ c l nv.
Also, test of LU in charm decays.

What can we look forward to ?

only at
LHCb

Yield	Run 1 result	$9\,\text{fb}^{-1}$	$23\,\text{fb}^{-1}$	$50\,\text{fb}^{-1}$	$300\,\text{fb}^{-1}$
$B^+ \to K^+e^+e^-$	254 ± 29 [274]	1 120	3 300	7 500	46 000
$B^0 \to K^{*0}e^+e^-$	111 ± 14 [275]	490	1 400	3 300	20 000
$B^0_s \to \phi e^+e^-$	–	80	230	530	3 300
$\Lambda^0_b \to pKe^+e^-$	–	120	360	820	5 000
$B^+ \to \pi^+e^+e^-$	–	20	70	150	900
R_X precision	**Run 1 result**	**$9\,\text{fb}^{-1}$**	**$23\,\text{fb}^{-1}$**	**$50\,\text{fb}^{-1}$**	**$300\,\text{fb}^{-1}$**
R_K	$0.745 \pm 0.090 \pm 0.036$ [274]	0.043	0.025	0.017	0.007
$R_{K^{*0}}$	$0.69 \pm 0.11 \pm 0.05$ [275]	0.052	0.031	0.020	0.008
R_ϕ	–	0.130	0.076	0.050	0.020
R_{pK}	–	0.105	0.061	0.041	0.016
R_π	–	0.302	0.176	0.117	0.047

Search for LFV



$$B^0_{(s)} \to e\mu, e\tau, \mu\tau$$

[arXiv:1710.04111]

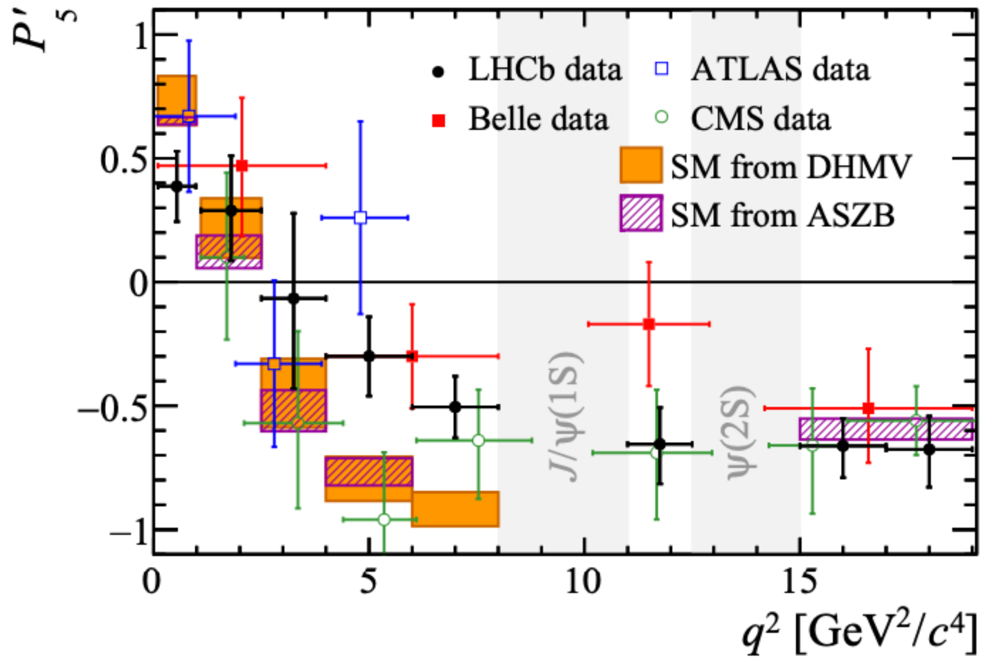
$$B \to K^{(*)}e\mu, K^{(*)}e\tau, K^{(*)}\mu\tau$$

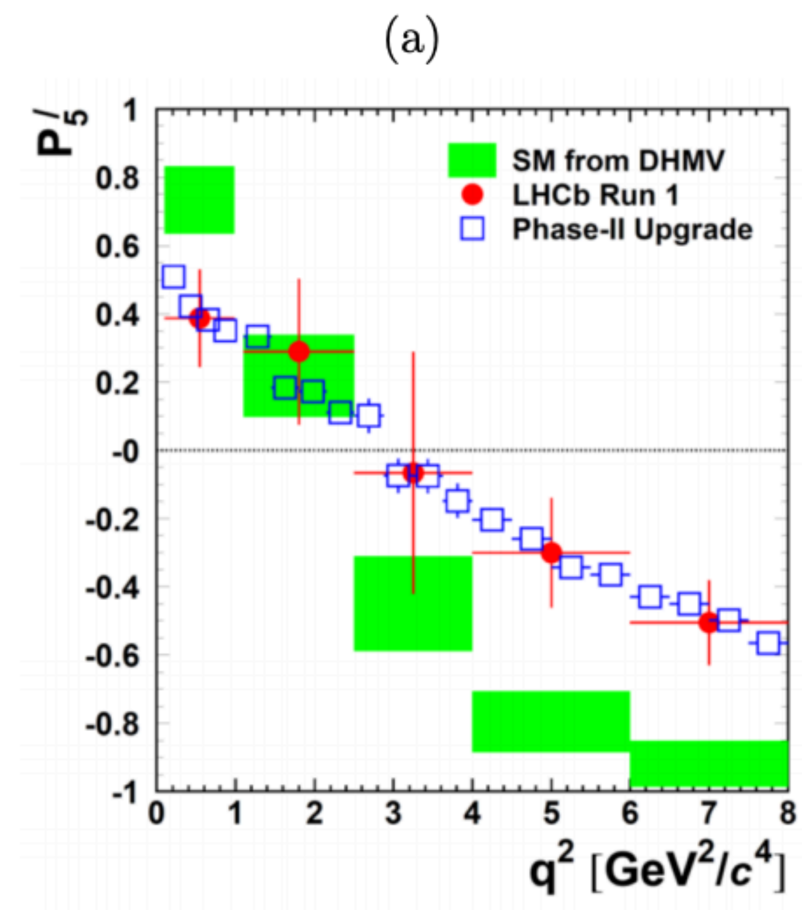
in case of discovery, study of the coupling

$$\mathcal{B}(B^+ \to K^+\mu^\pm e^\mp) \cong 2\rho_{NP}^2 \left|\frac{U^\ell_{L31}}{U^\ell_{L32}}\right|^2 \mathcal{B}(B^+ \to K^+\mu^+\mu^-) = \left(2.16^{+2.54}_{-1.50}\right) \left|\frac{U^\ell_{L31}}{U^\ell_{L32}}\right|^2 \times 10^{-8}$$

[arXiv:1411.0565]

What about P'$_5$?





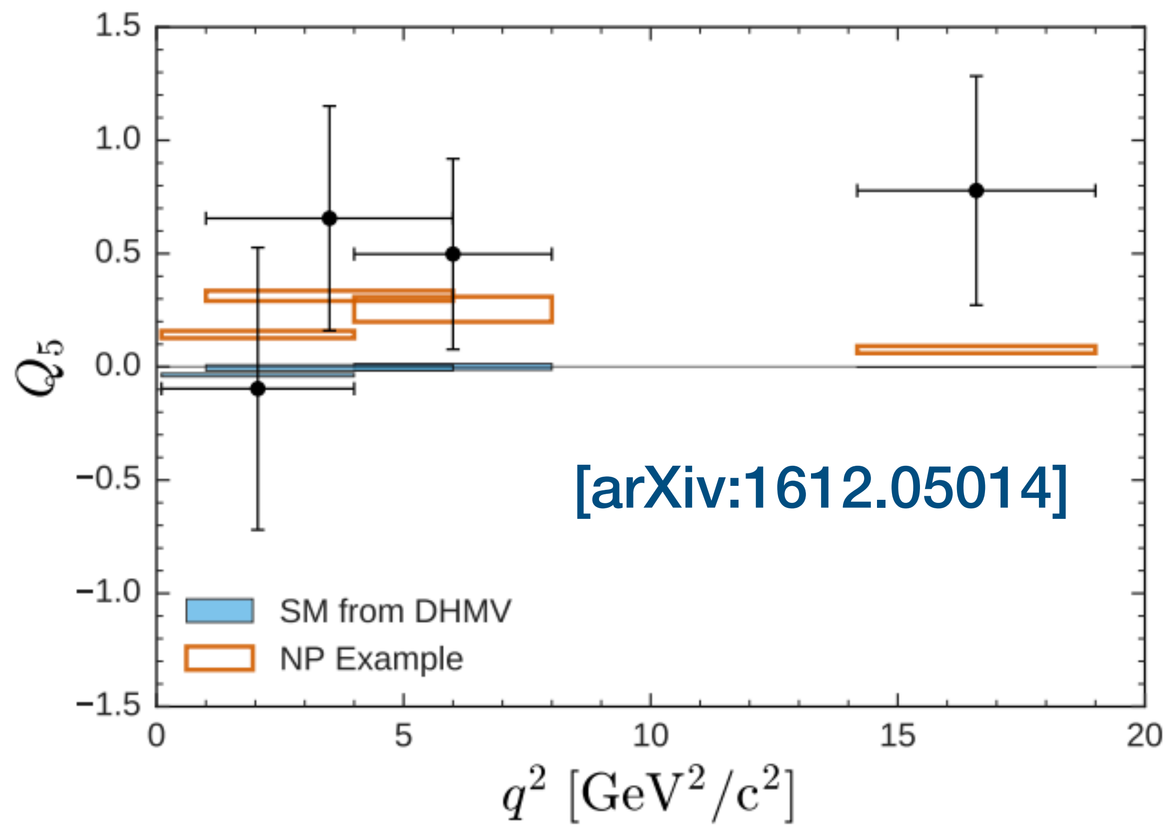
Coeff.	Dirac structure	best fit	1σ	pull
$C_9^{bs\mu\mu}$	$L \otimes V$	-0.95	$[-1.10, -0.79]$	5.8σ
$C_9^{\prime bs\mu\mu}$	$R \otimes V$	$+0.09$	$[-0.07, +0.24]$	0.5σ
$C_{10}^{bs\mu\mu}$	$L \otimes A$	$+0.73$	$[+0.59, +0.87]$	5.6σ
$C_{10}^{\prime bs\mu\mu}$	$R \otimes A$	-0.19	$[-0.30, -0.07]$	1.6σ
$C_9^{bs\mu\mu} = C_{10}^{bs\mu\mu}$	$L \otimes R$	$+0.20$	$[+0.05, +0.35]$	1.4σ
$C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$	$L \otimes L$	-0.53	$[-0.62, -0.45]$	6.5σ

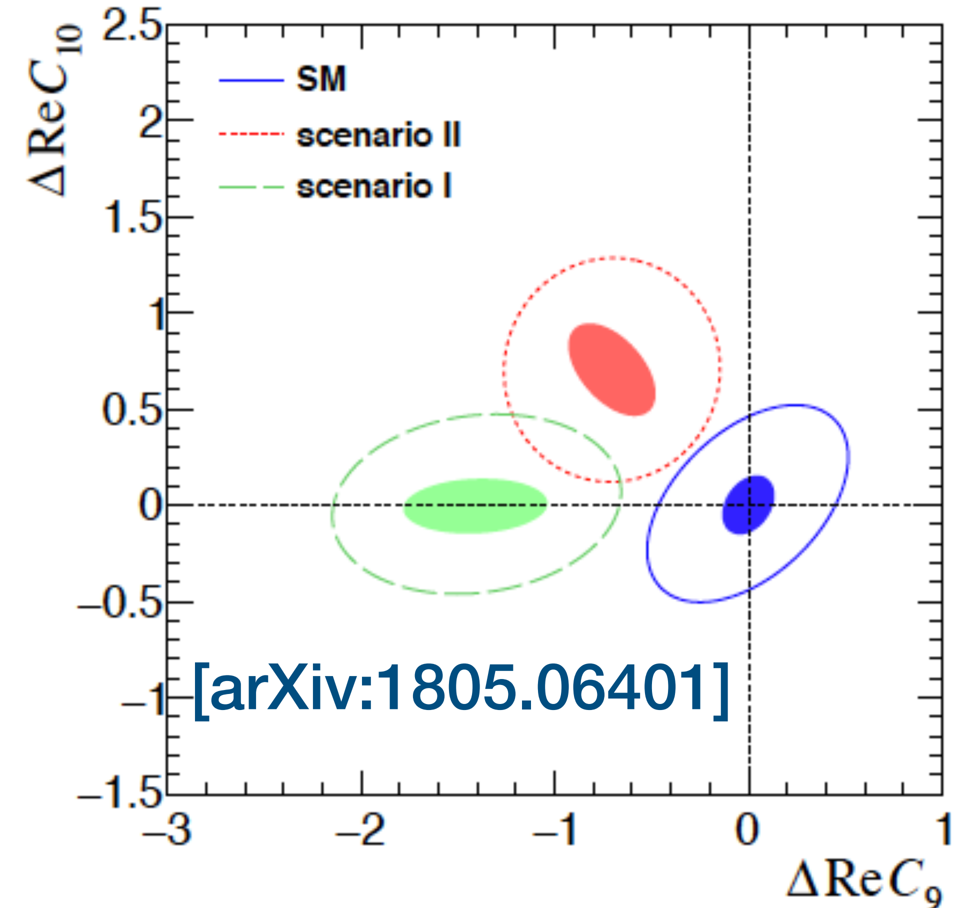
D.Straub
Moriond EW

[arXiv:1903.10434]

After measuring P'$_5$ with muons the next natural step is doing this with electrons…

Angular analyses with electrons





$$Q_i = P_i^\mu - P_i^e$$

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

Crucial to control and understand the q² distribution.

What about τ ?

$\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ INSPIRE search

$\Gamma(\tau^- \to \pi^-\pi^+\pi^-\nu_\tau)/\Gamma_{\text{total}}$ Γ_{67}/Γ

$\Gamma_{67}/\Gamma = (0.34598\Gamma_{36} + \Gamma_{70} + 0.01535\Gamma_{176})/\Gamma$

VALUE (%)	
9.31 ± 0.05	**OUR FIT**

References:

see fit info

$\tau^- \to h^-h^-h^+\pi^0\nu_\tau$ INSPIRE search

expand all datablocks

$\Gamma(\tau^- \to h^-\rho\pi^0\nu_\tau)/\Gamma(\tau^- \to h^-h^-h^+\pi^0\nu_\tau)$ Γ_{79}/Γ_{73}

$\Gamma(\tau^- \to h^-\rho^+h^-\nu_\tau)/\Gamma(\tau^- \to h^-h^-h^+\pi^0\nu_\tau)$ Γ_{80}/Γ_{73}

$\Gamma(\tau^- \to h^-\rho^-h^+\nu_\tau)/\Gamma(\tau^- \to h^-h^-h^+\pi^0\nu_\tau)$ Γ_{81}/Γ_{73}

$\Gamma(\tau^- \to h^-h^-h^+\pi^0\nu_\tau)/\Gamma_{\text{total}}$ Γ_{73}/Γ

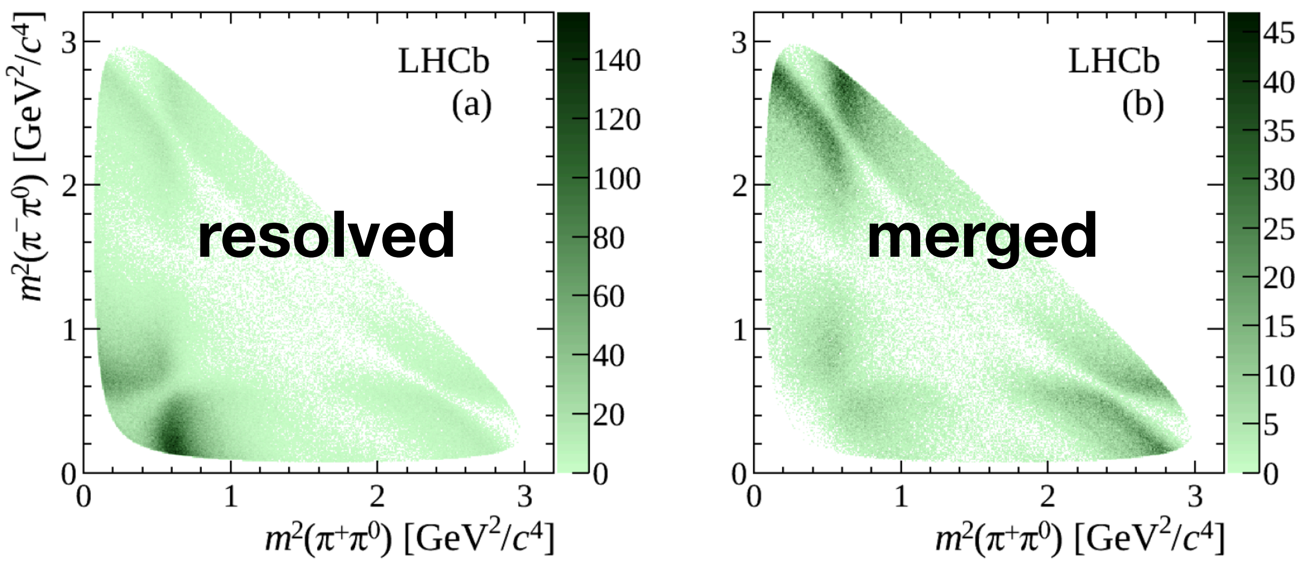
$\Gamma_{73}/\Gamma = (0.34598\Gamma_{41} + 0.34598\Gamma_{43} + \Gamma_{78} + \Gamma_{103} + \Gamma_{107} + 0.22915\Gamma_{150} + 0.89245\Gamma_{176} + 0.89245\Gamma_{177} + 0.01535\Gamma_{178})/\Gamma$

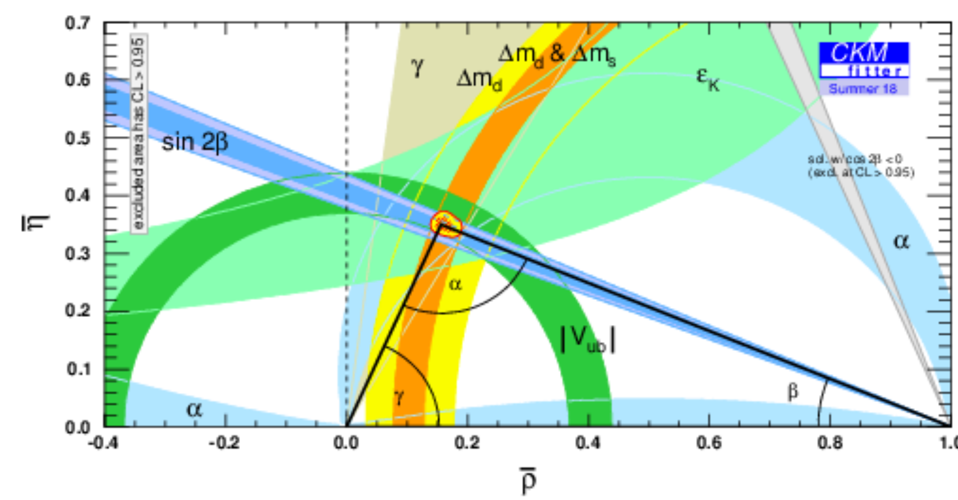
VALUE (%)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
4.76 ± 0.05	**OUR FIT**			

ECAL performance important either if we reconstruct these neutral pions to add statistics
or
“just” want to control them as a background.

Fully hadronic decays

1410.4170





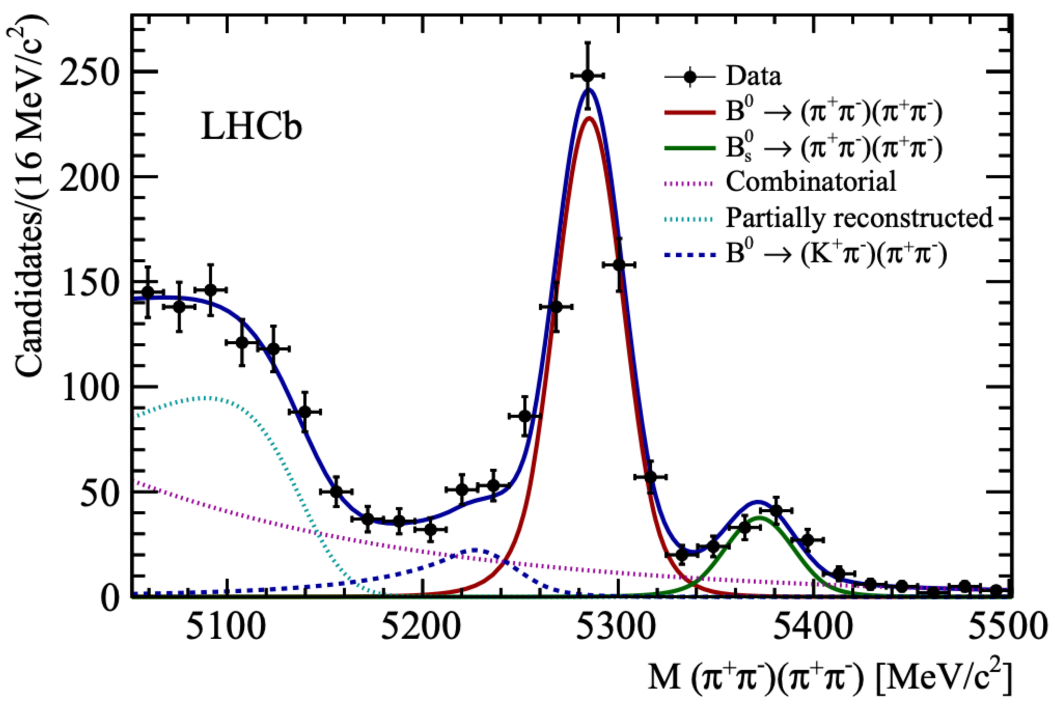
➡ **D→ πππ^0 contribute to gamma measurement B →DK.**

➡ **D→ ππ^0 enhanced CPV → Isospin violating NP.**

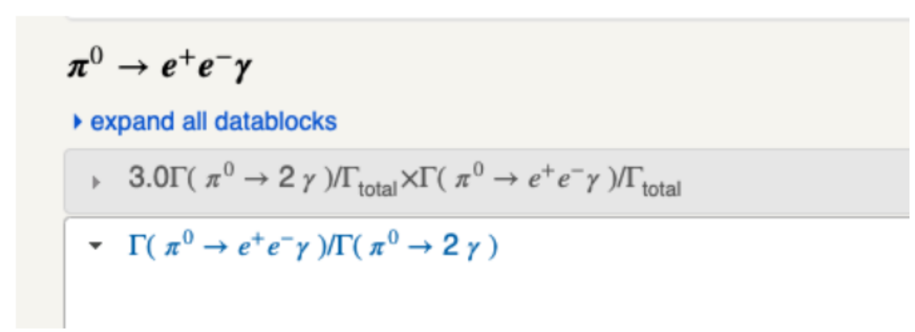
➡ **D→ π^{0}π^0 search for CP violation.**

Measurement of α

[arXiv:1503.07770]



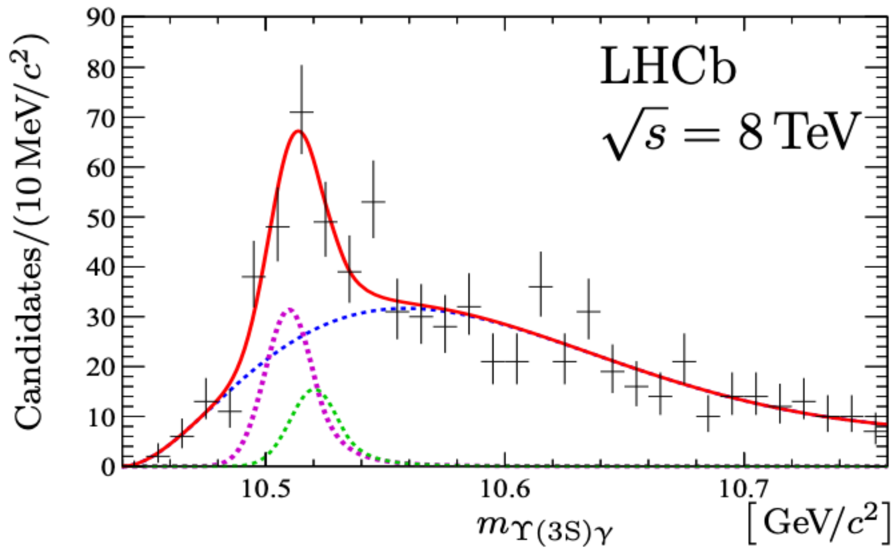
$$B \to \rho^+(\pi^+\pi^0)\rho^-(\pi^-\pi^0)$$

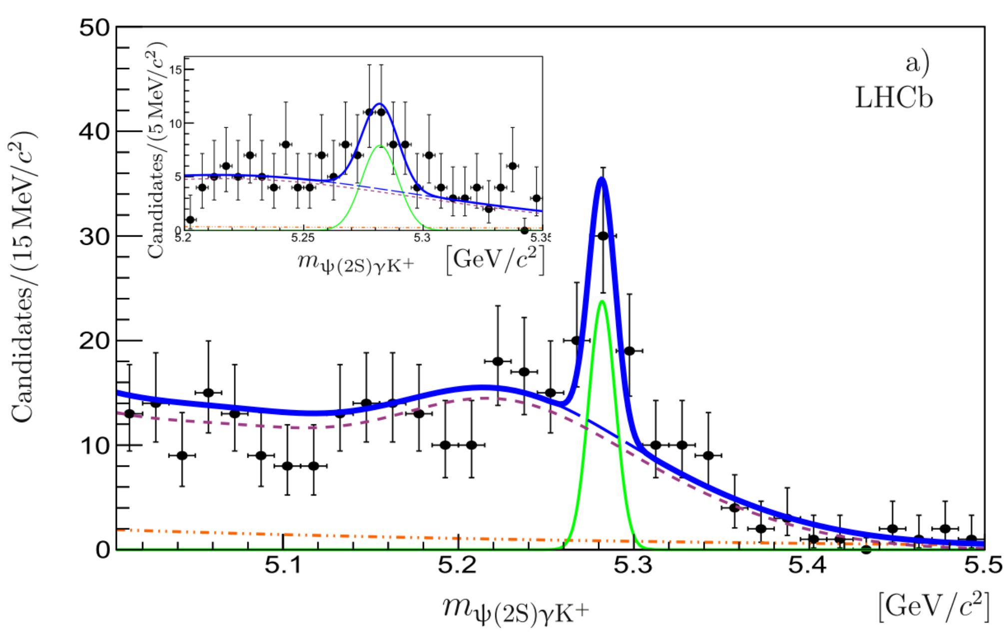


In order to use B→ππ decays to obtain α, need to measure $B \to \pi^0\pi^0$.
Using Dalitz decays of one π^0, $\pi^0 \to \gamma e^+e^-$, possibility to use vertex information, but large statistics needed because of small π^0 decay branching fraction

Spectroscopy

[arXiv:1407.7734]



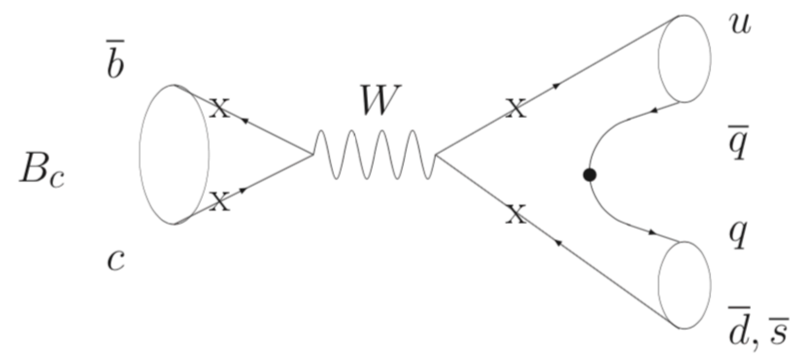


[arXiv:1404.0275]

Conversions could be useful to identify near by resonances

States/structures	Channels	Observables	Further comments
$D_{s0}^*(2317)$	$D_s\pi^0$, $D_s^*\gamma$	Width upper limit; branching fractions	π^0 is difficult
$D_{s1}^*(2460)$	$D_s^{*+}\pi^0$, $D_s^+\pi^+\pi^-$, $D_s^{(*)+}\gamma(\to \mu^+\mu^-)$	see above	May use the Dalitz decay to probe photons
Broad D_0^*, D_1 structures	$\bar{B} \to D^{(*)}\pi^-\pi^-$, $D_s^{(*)}\bar{K}\pi$, $D_s^{(*)}\bar{K}\bar{K}$, $\bar{B}_s \to D^{(*)}\bar{K}\pi$	$D^{(*)}\pi$ angular moments; $D_s^{(*)}\bar{K}$ invariant mass distribution	$\langle P_1\rangle - \frac{14}{9}\langle P_3\rangle$ is particularly sensitive to the $D^{(*)}\pi$ S-wave; possible enhancement above $D_s\bar{K}$ threshold
B_{s0}^* (?)	$B_s\pi^0$, $B_s^*\gamma$		$M \sim 5.72$ GeV; not seen yet
B_{s1} (?)	$B_s^*\pi^0$, $B_s\pi^+\pi^-$, $B_s^{(*)}\gamma$		$M \sim 5.77$ GeV, lower than $B_{s1}(5810)$; not seen yet
Excited single-heavy baryons			A whole SU(3) family; determination of spin and parity
$X(3872)$	$D^0\bar{D}^0\pi^0$, $D\bar{D}\gamma$, $J/\psi\pi^+\pi^-$, $J/\psi 3\pi$, $J/\psi\gamma$, $\psi'\gamma$	Line shapes; decay width; production rates	
X_2 (?)	$D\bar{D}$, $D\bar{D}^*$ + c.c., $J/\psi\omega$		$J^{PC} = 2^{++}$, $M \sim 4$ GeV, $\Gamma \lesssim 50$ MeV; existence unknown
$\chi_{c1}(2P)$ (?)	$D\bar{D}^*$ + c.c., $J/\psi\omega$		$M \sim 3.9$ GeV, broad; existence unknown
$h_c(2P)$ (?)	$D\bar{D}^*$ + c.c., $J/\psi\eta$, $\eta_c\omega$		$M \sim 3.9$ GeV, broad; not seen yet
X_b (?)	$\Upsilon\omega$, $\chi_{bJ}\pi^+\pi^-$, $B\bar{B}\gamma$, $\Upsilon\gamma$		Bottom analogue of $X(3872)$; existence unknown
X_{b2} (?)	$B\bar{B}$, $\Upsilon\omega$		Bottom analogue of X_2; existence unknown
Z_c structures	$(c\bar{c})\pi^\pm$, $(D^{(*)}\bar{D}^{(*)})^\pm$	Line shapes; production rates; Argand plots	Sensitivity to kinematics
Z_{cs} (?)	$(c\bar{c})K$, $D_s^{(*)}\bar{D}^{(*)}$		Existence unknown
Z_b structures	$(b\bar{b})\pi^\pm$, $(B^{(*)}\bar{B}^{(*)})^\pm$	Line shapes	Not seen at LHC yet
W_{bJ} (?)	$\Upsilon\pi^+\pi^-$, $\Upsilon\gamma$		$I^G(J^{PC}) = 1^-(J^{++})$, possible spin partners of Z_b states; existence unknown
P_c and relatives	$J/\psi p$, $\chi_{cJ}p$, $\Lambda_c\bar{D}^{(*)}$, $\Sigma_c\bar{D}^{(*)}$		Hidden-charm pentaquarks
Doubly-heavy baryons			Displaced B_c as an inclusive signature of weakly decaying double-beauty hadrons
$\bar{b}\bar{b}ud$ (?); $\bar{b}\bar{b}qs$ ($q = u, d$) (?)	$B^+\bar{D}^0$, $J/\psi B^+K^0$; $B\bar{D}_s$, $B_s\bar{D}$, $J/\psi B\phi$, $J/\psi B_sK$		Ground states likely stable against strong decays; not seen
$cc\bar{c}\bar{c}$ (?); $bb\bar{b}\bar{b}$ (?)	$H_Q\bar{H}_Q$+anything, $J/\psi(\Upsilon)\mu^+\mu^-$, $\mu^+\mu^-$, 4μ		Widths: tens of MeV if below double-$(Q\bar{Q})$ thresholds; H_Q denotes any heavy hadron; existence unknown

B_c: pure annihilation decays

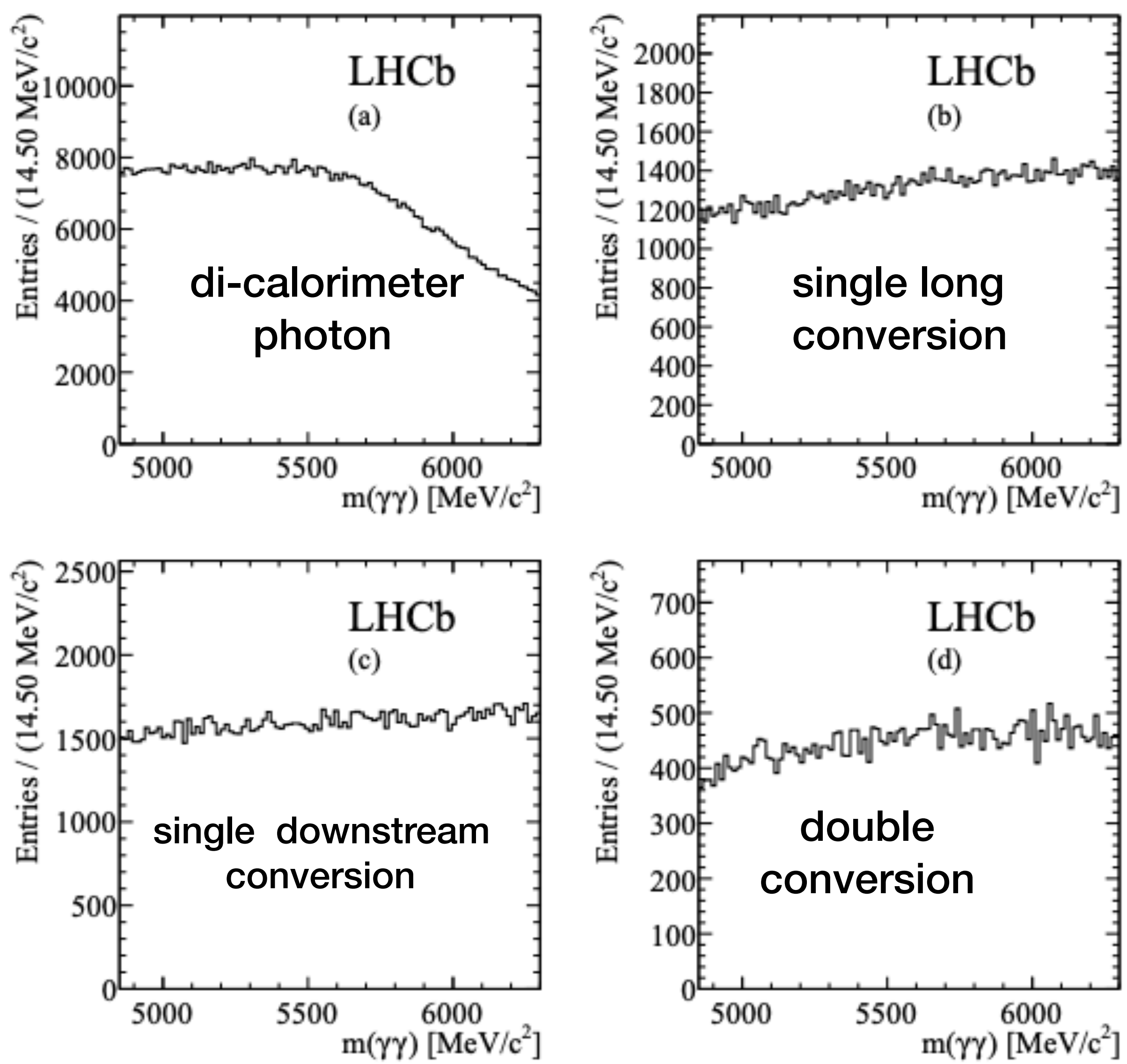


- Decays where the c and b quarks annihilate, such as $B_c \to K^+ \pi^0$, …
- Small production cross-section of B_c: addition of modes with π^0 can make the difference.

[arXiv:0907.2256]

Towards $B_s \to \gamma\gamma$

Described by annihilation topologies, could be enhanced by NP ex top' [arXiv:0302177]

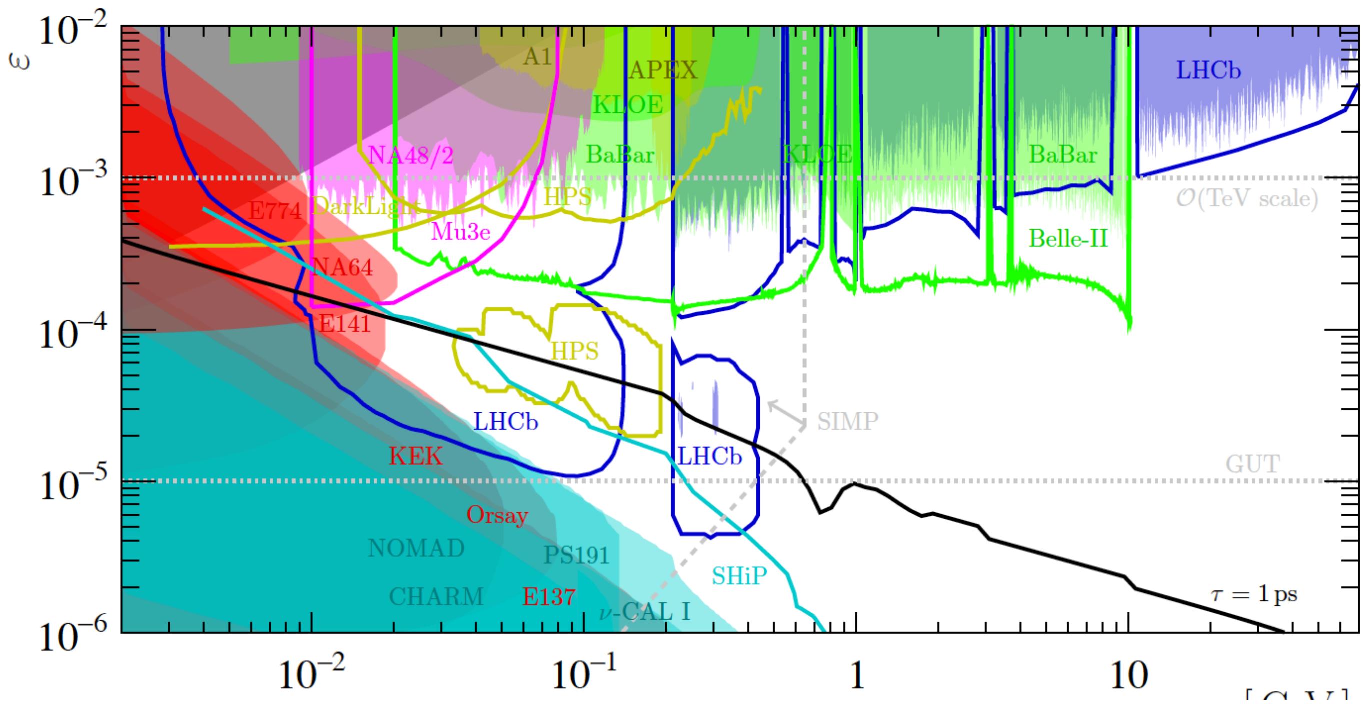


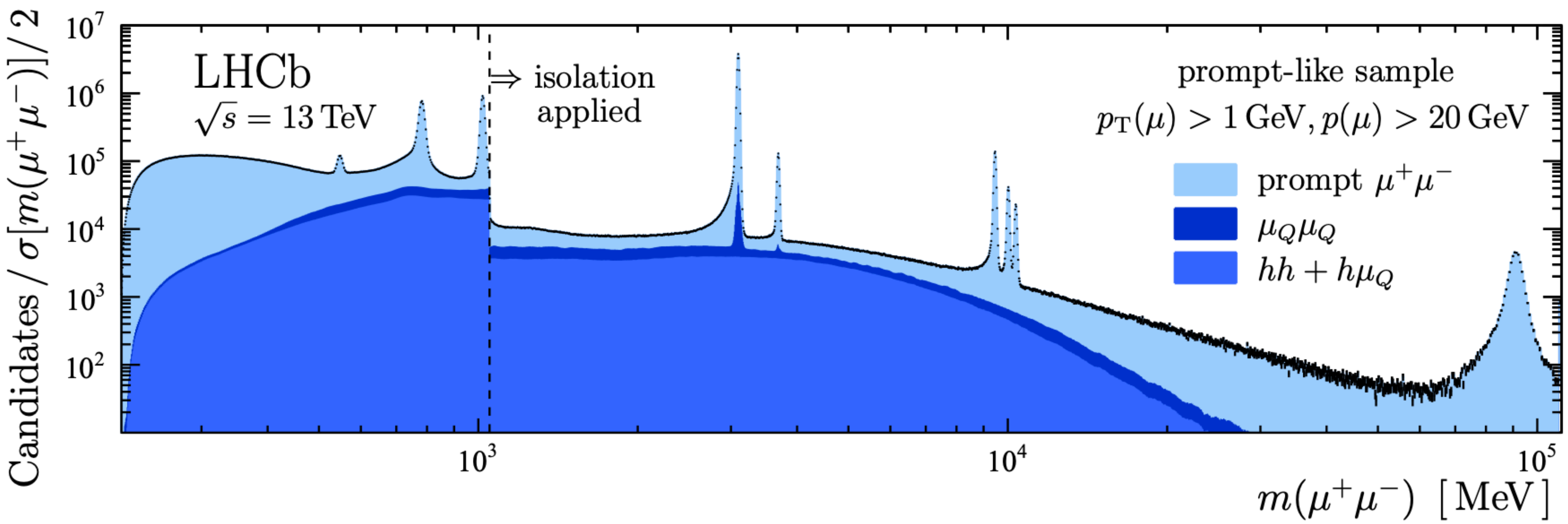
LHCb-PUB-2018-006

Dedicated triggers were added to be able to reconstruct these challenging modes.
This opens opportunities to Axion Like Particles searches.

Direct searches

$$\mathcal{L} \supset -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m^2_{A'}A'_\mu A'^\mu + \epsilon e A'_\mu J^\mu_{\rm EM}. \qquad D^{*0} \to D^0 A', \quad A' \to e^+e^-$$

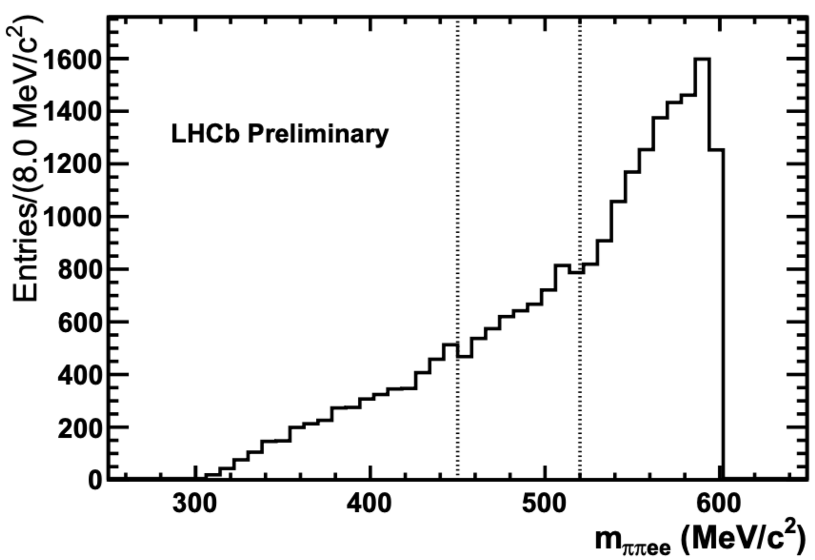




[arXiv:1710.02867]

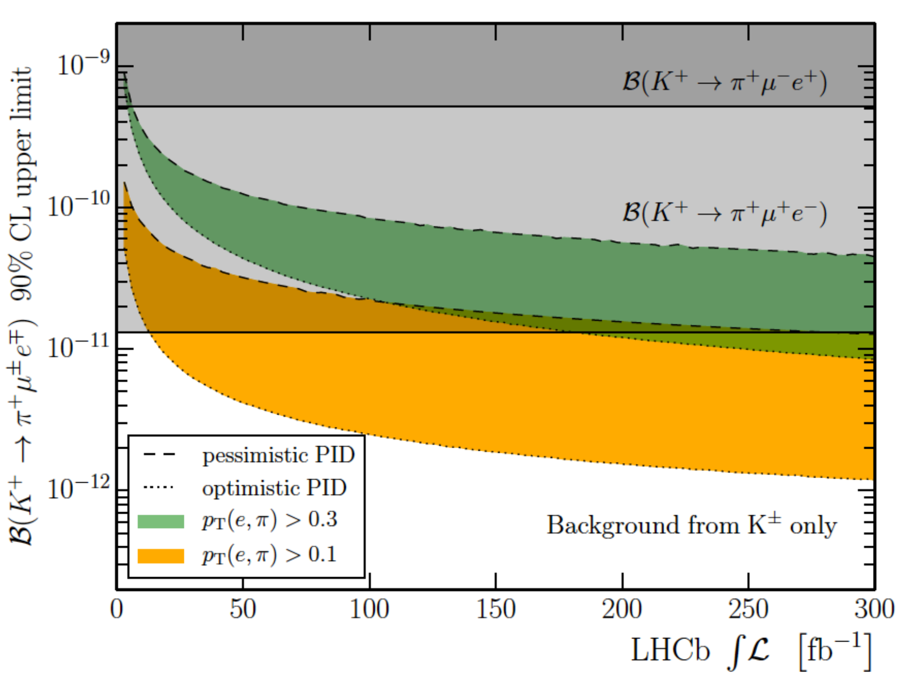
Rare kaon physics

LHCb-PUB-2016-016



Channel	$\mathcal{R}$	ϵ_L	ϵ_D	$\sigma_L(\mathrm{MeV}/c^2)$	$\sigma_D(\mathrm{MeV}/c^2)$
$K^0_{\mathrm{S}} \to \pi^+\pi^-e^+e^-$	1	1.0 (0.18)	2.83 (1.1)	~ 2.0	~ 10
$K^0_{\mathrm{S}} \to \mu^+\mu^-e^+e^-$	1	1.18 (0.48)	2.93 (1.4)	~ 2.0	~ 11
$K^+ \to \pi^+e^+e^-$	~ 2	0.04 (0.01)	0.17 (0.06)	~ 3.0	~ 13
$\Sigma^+ \to pe^+e^-$	~ 0.13	1.76 (0.56)	3.2 (1.3)	~ 3.5	~ 11
$\Lambda \to p\pi^-e^+e^-$	~ 0.45	$< 2.2 \times 10^{-4}$	$\sim 17\ (< 2.2)\ \times 10^{-4}$	–	–

[arXiv:1808.03477]

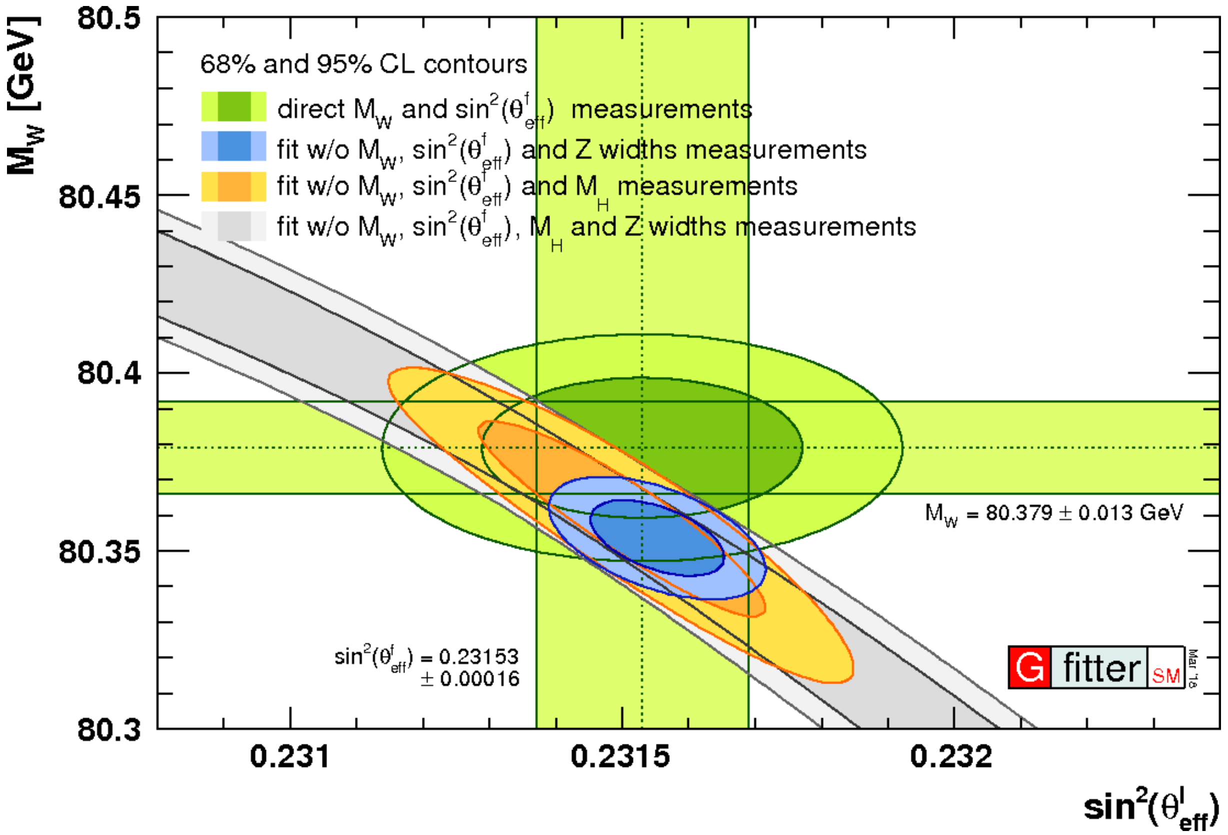


Chiral perturbative Theory tests.

LFV searches

[arXiv:1808.02006]

EW physics



So far Electroweak studies done with muons only in LHCb.
Can electrons be included ?

sub-detector	ECAL
number of channels	5952
overall lateral dimension in x,y	6.3 m×7.8 m
depth in z	835 mm, 25 X_0, 1.1 λ_I
basic requirements	$\sigma(E)/E = 10\%/\sqrt{E} \oplus 1.5\%$
dynamic range	0-10 GeV E_T 12 bits

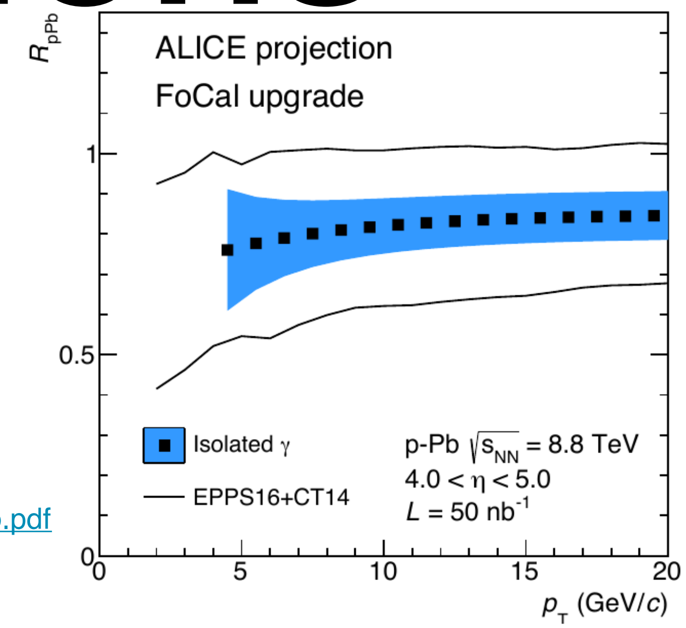
Calorimeters TDR

Wishlist :

- Need to minimise the non-linearities.
- Increase longitudinal segmentation for energy measurement
- Need to improve the constant term for the resolution.

[arXiv:1508.06954]

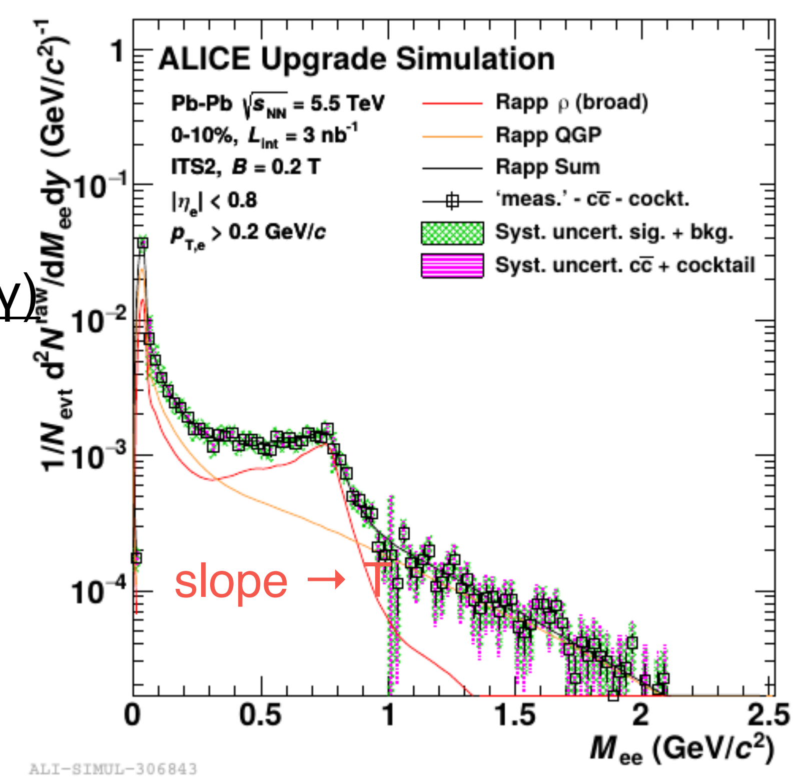
Heavy ions



1) <u>Prompt photon and di-photon production in *p*A collisions</u>:
Constrain nuclear PDF and probe of saturation [Focal YR]:
so far unexploited: E_T range 2-15 GeV
FOCal ALICE LS3 project (not yet approved, but likely this summer) competition:
https://indico.cern.ch/event/783989/contributions/3332201/attachments/1808470/2952550/20190307_FOCAL_intro.pdf

2) <u>Thermal prompt photons and di-electrons in AA collisions</u>:
ALICE Run 1 [arXiv:1509.0723]:
→ direct QGP temperature from virtual di-electrons (1-3 GeV)
and from real photon spectra: very large error bars even with ALICE Run 3/4
→ space-time evolution (never done): E_T range: as low as possible, 0.5-5.0 GeV

3) <u>P-wave quarkonia/other heavy-flavour in AA with soft photon (eg: $\chi_c \to J/\psi\ \gamma$)</u>
direct probe of de-confinement, never done in AA, even in ALICE/CMS
because it is very difficult/impossible to see low p_T photons.
E_T range as low as possible



<u>Requirements</u>

→ π^0 background rejection to select isolated photons (good spatial/energy resolution & low material budget)
→ excellent granularity and very good energy resolution at low E
→ timing will not help here ! (in *p*A and AA, there is almost no pileup)

See also [arXiv:1812.06772], [arXiv:1902.01211]

A great competitor of U2 is the actual upgrade.

Type	Observable	Current precision	LHCb 2018	**Upgrade** ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s$ ($B_s^0 \to J/\psi\ \phi$)	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\ f_0(980)$)	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\mathrm{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\,A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [16]	8 %	2.5 %	~ 10 %
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	γ ($B \to D^{(*)}K^{(*)}$)	~ 10–$12°$ [19, 20]	4°	0.9°	negligible
	γ ($B_s^0 \to D_sK$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\,K_S^0$)	0.8° [18]	0.6°	0.2°	negligible
Charm CP violation	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

Table 1: Statistical sensitivities of the LHCb upgrade to key observables. For each observable the current sensitivity is compared to that which will be achieved by LHCb before the upgrade, and that which will be achieved with $50\,\mathrm{fb}^{-1}$ by the upgraded experiment. Systematic uncertainties are expected to be non-negligible for the most precisely measured quantities.

A few benchmark numbers

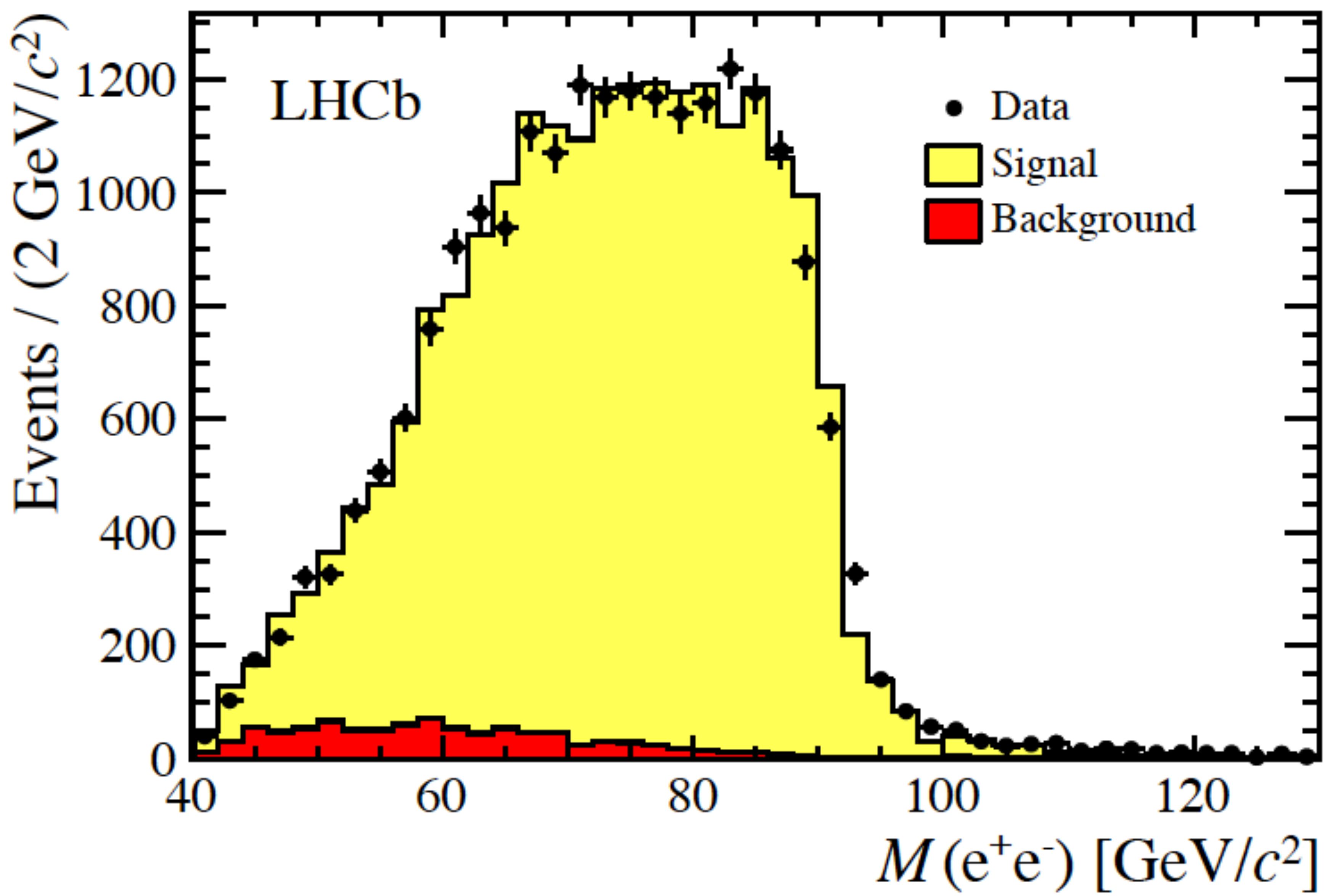
Table 2.1: Summary of prospects for Phase-II measurements of selected flavour observables.

Topics and observables	Experimental reach	Remarks
EW Penguins		
Global tests in many $b \to s\mu^+\mu^-$ modes with full set of precision observables; lepton universality tests; $b \to dl^+l^-$ studies	*e.g.* 440k $B^0 \to K^*\mu^+\mu^-$ & 70k $\Lambda_b^0 \to \Lambda\mu^+\mu^-$; Phase-II $b \to d\mu^+\mu^- \approx$ Run-1 $b \to s\mu^+\mu^-$ sensitivity.	Phase-II ECAL required for lepton universality tests.
Photon polarisation		
$\mathcal{A}^\Delta$ in $B_s^0 \to \phi\gamma$; $B^0 \to K^*e^+e^-$; baryonic modes	Uncertainty on $\mathcal{A}^\Delta \approx 0.02$; $\sim 10k$ $\Lambda_b^0 \to \Lambda\gamma$, $\Xi_b \to \Xi\gamma$, $\Omega_b^- \to \Omega\gamma$	Strongly dependent on performance of ECAL.
$b \to cl^-\bar{\nu}_l$ lepton-universality tests		
Polarisation studies with $B \to D^{(*)}\tau^-\bar{\nu}_\tau$; τ^-/μ^- ratios with B_s^0, Λ_b^0 and B_c^+ modes	*e.g.* 8M $B \to D^*\tau^-\bar{\nu}_\tau$, $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$ & $\sim 100k$ $\tau^- \to \pi^-\pi^+\pi^-(\pi^0)\nu_\tau$	Additional sensitivity expected from low-p tracking.
$B_s^0, B^0 \to \mu^+\mu^-$		
$R \equiv \mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$; $\tau_{B_s^0 \to \mu^+\mu^-}$; CP asymmetry	Uncertainty on $R \approx 20\%$ Uncertainty on $\tau_{B_s^0 \to \mu^+\mu^-} \approx 0.03$ ps	
LFV τ decays		
$\tau^- \to \mu^+\mu^-\mu^-$, $\tau^- \to h^+\mu^-\mu^-$, $\tau^- \to \phi\mu^-$	Sensitive to $\tau^- \to \mu^+\mu^-\mu^-$ at 10^{-9}	Phase-II ECAL valuable for background suppression.
CKM tests		
γ with $B^- \to DK^-$, $B_s^0 \to D_s^+K^-$ *etc.*	Uncertainty on $\gamma \approx 0.4°$	Additional sensitivity expected
ϕ_s with $B_s^0 \to J/\psi K^+K^-$, $J/\psi\pi^+\pi^-$	Uncertainty on $\phi_s \approx 3$ mrad	in CP observables from Phase-II
$\phi_s^{s\bar{s}s}$ with $B_s^0 \to \phi\phi$	Uncertainty on $\phi_s^{s\bar{s}s} \approx 8$ mrad	ECAL and low-p tracking.
$\Delta\Gamma_d/\Gamma_d$	Uncertainty on $\Delta\Gamma_d/\Gamma_d \sim 10^{-3}$	Approach SM value.
Semileptonic asymmetries $a_{\rm sl}^{d,s}$	Uncertainties on $a_{\rm sl}^{d,s} \sim 10^{-4}$	Approach SM value for $a_{\rm sl}^d$.
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ with Λ_b^0, B_s^0 and B_c^+ modes	*e.g.* 120k $B_c^+ \to D^0\mu^-\bar{\nu}_\mu$	Significant gains achievable from thinning or removing RF-foil.
Charm		
CP-violation studies with $D^0 \to h^+h^-$, $D^0 \to K_S^0\pi^+\pi^-$ and $D^0 \to K^\mp\pi^\pm\pi^+\pi^-$	*e.g.* 4×10^9 $D^0 \to K^+K^-$; Uncertainty on $A_\Gamma \sim 10^{-5}$	Access CP violation at SM values.
Strange		
Rare decay searches	Sensitive to $K_S^0 \to \mu^+\mu^-$ at 10^{-12}	Additional sensitivity possible with downstream trigger enhancements.

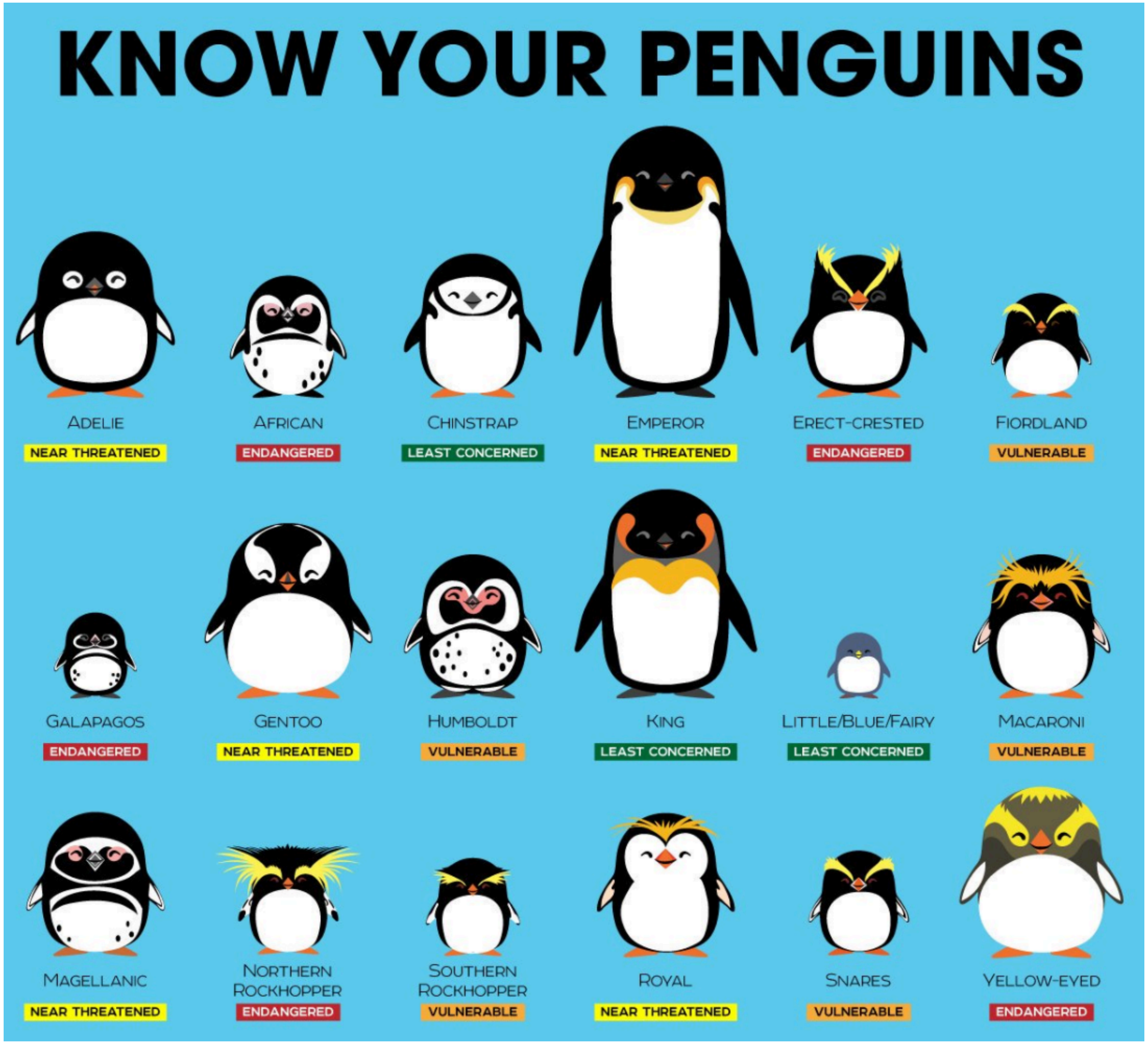
Conclusion

- An Upgraded ECAL @ HL-LHC will offer the possibility to do many interesting and unique physics analyses (1812.07638, CERN-LHCC-2018-027).
- Realistically, with the expected occupancy and pile-up this won't be a trivial exercice.
- But, but…. in case of surprises in LUV, LFV, more CPV, dark photons, it's important to have the possibility to get the maximum out of the HL data.

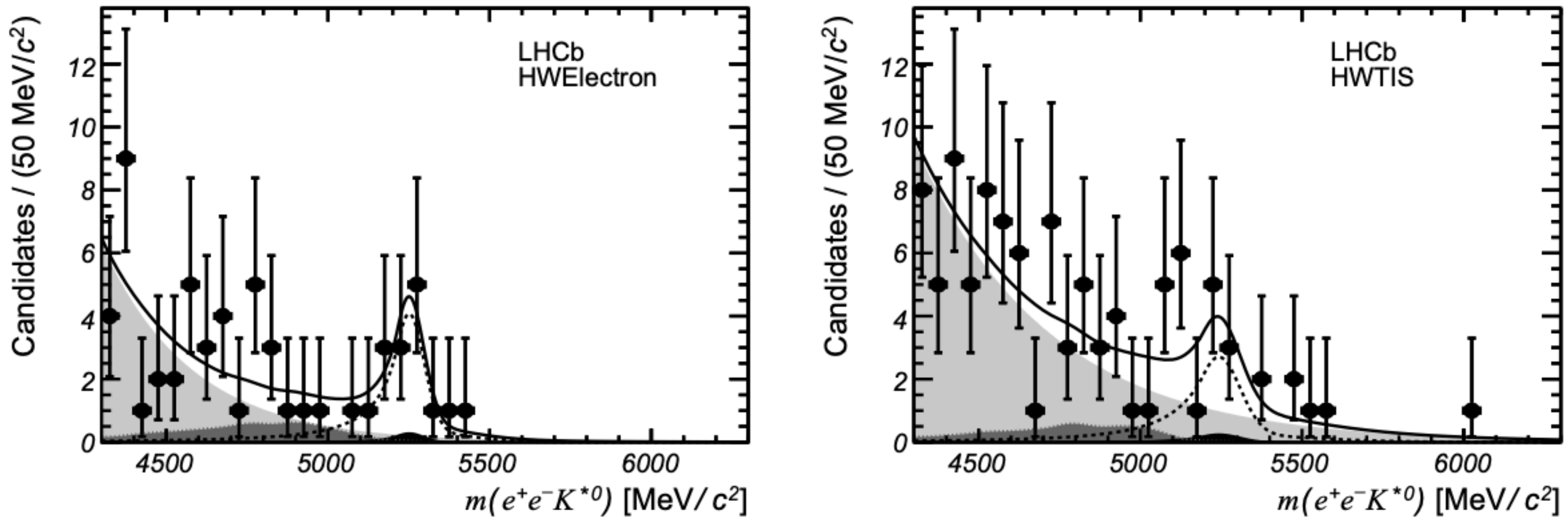
1212.4620v2



LHCb
Data
Signal
Background
Events / (2 GeV/c^2)
M(e$^+$e$^-$) [GeV/c^2]
0
200
400
600
800
1000
1200
40
60
80
100
120


KNOW YOUR PENGUINS
ADELIE
NEAR THREATENED
AFRICAN
ENDANGERED
CHINSTRAP
LEAST CONCERNED
EMPEROR
NEAR THREATENED
ERECT-CRESTED
ENDANGERED
FIORDLAND
VULNERABLE
GALAPAGOS
ENDANGERED
GENTOO
NEAR THREATENED
HUMBOLDT
VULNERABLE
KING
LEAST CONCERNED
LITTLE/BLUE/FAIRY
LEAST CONCERNED
MACARONI
VULNERABLE
MAGELLANIC
NEAR THREATENED
NORTHERN ROCKHOPPER
ENDANGERED
SOUTHERN ROCKHOPPER
VULNERABLE
ROYAL
NEAR THREATENED
SNARES
VULNERABLE
YELLOW-EYED
ENDANGERED

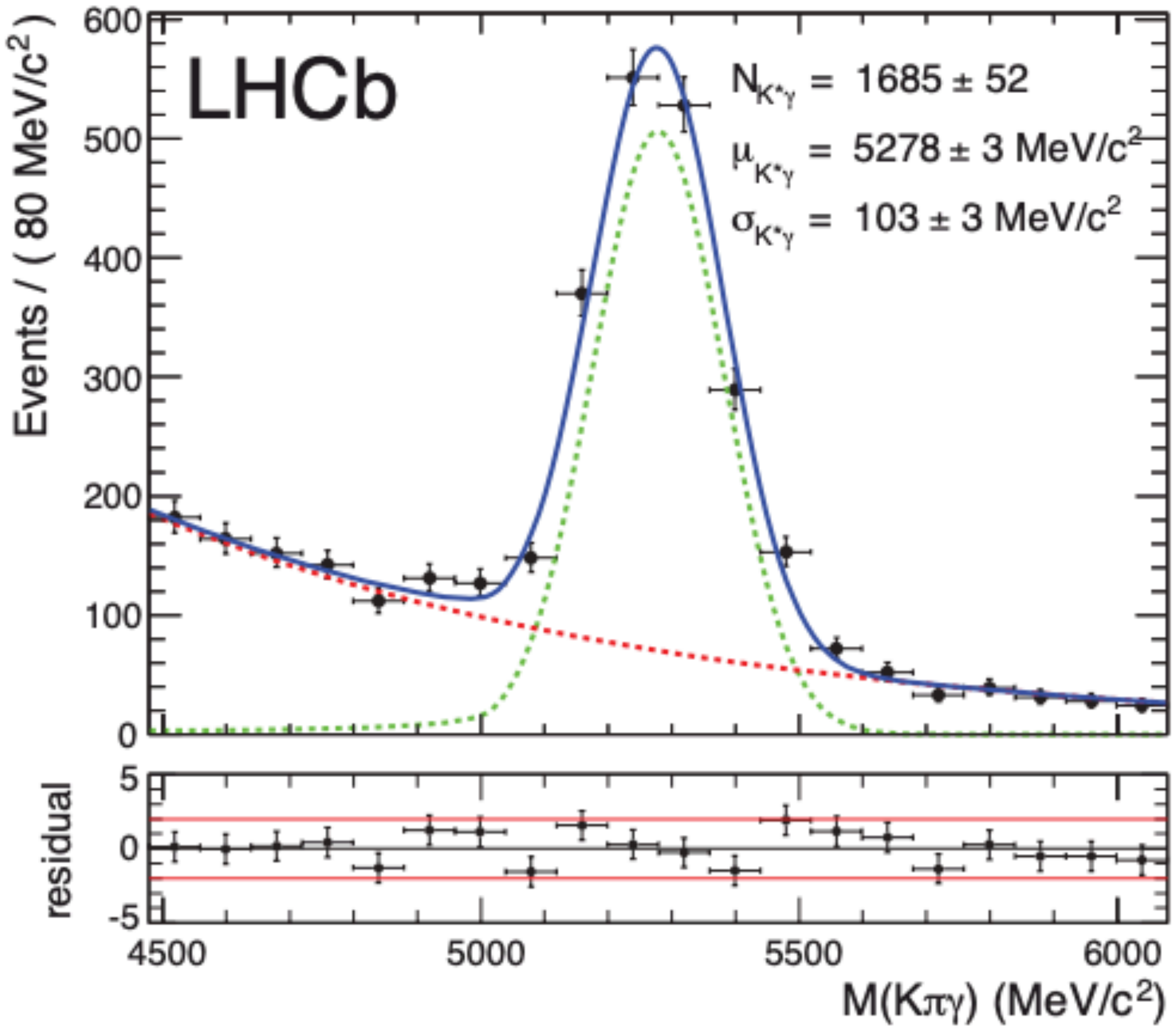
1304.3035

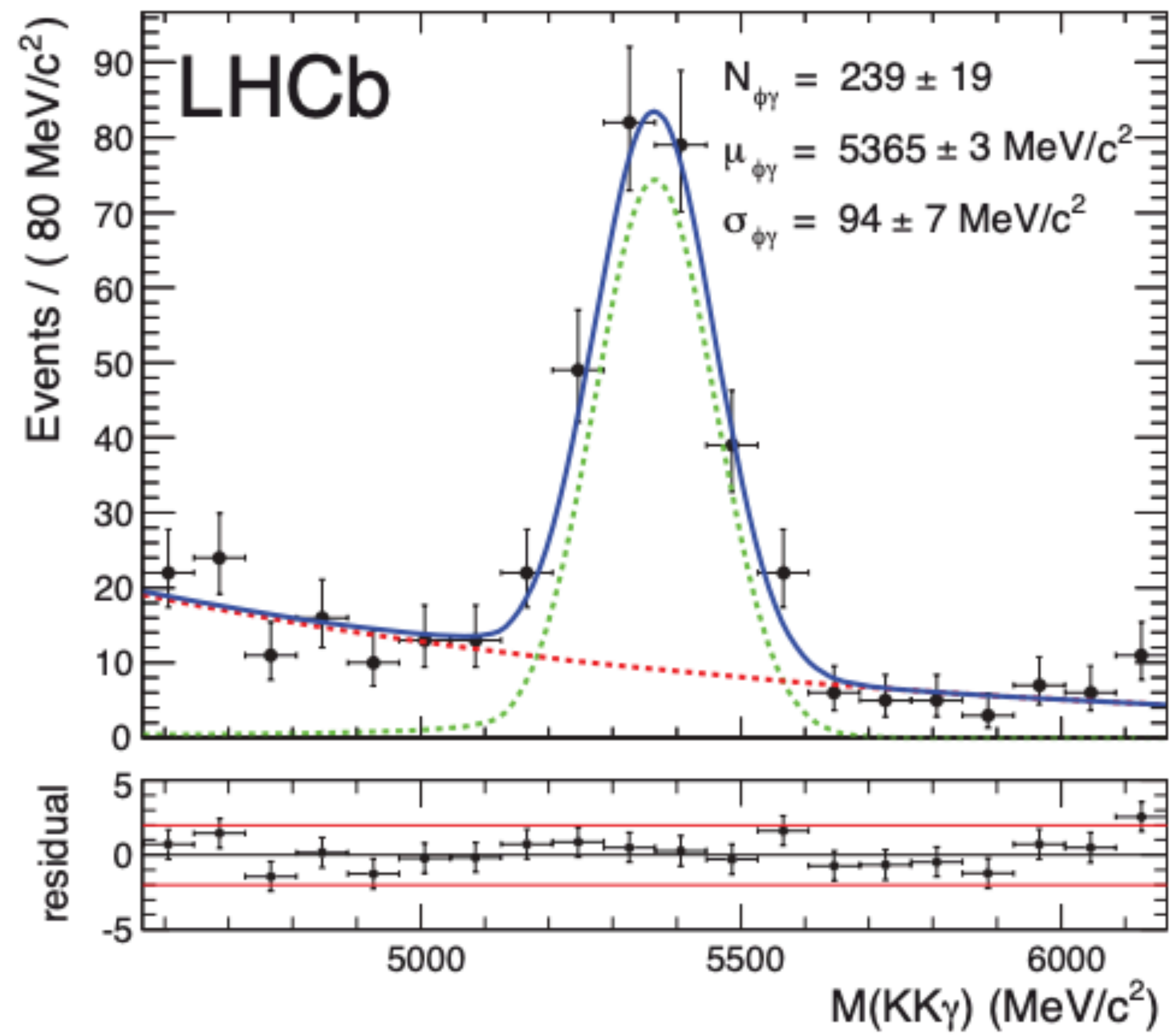


$$A_{\mathrm{T}}^{(2)}(q^2 \to 0) = \frac{2\mathcal{R}e(\mathcal{C}_7\mathcal{C}_7^{\prime *})}{|\mathcal{C}_7|^2 + |\mathcal{C}_7^{\prime}|^2} \quad \text{and} \quad A_{\mathrm{T}}^{\mathrm{Im}}(q^2 \to 0) = \frac{2\mathcal{I}m(\mathcal{C}_7\mathcal{C}_7^{\prime *})}{|\mathcal{C}_7|^2 + |\mathcal{C}_7^{\prime}|^2}.$$

$$\begin{aligned} F_{\mathrm{L}} &= 0.16 \pm 0.06 \pm 0.03 \\ A_{\mathrm{T}}^{(2)} &= -0.23 \pm 0.23 \pm 0.05 \\ A_{\mathrm{T}}^{\mathrm{Im}} &= +0.14 \pm 0.22 \pm 0.05 \\ A_{\mathrm{T}}^{\mathrm{Re}} &= +0.10 \pm 0.18 \pm 0.05, \end{aligned}$$

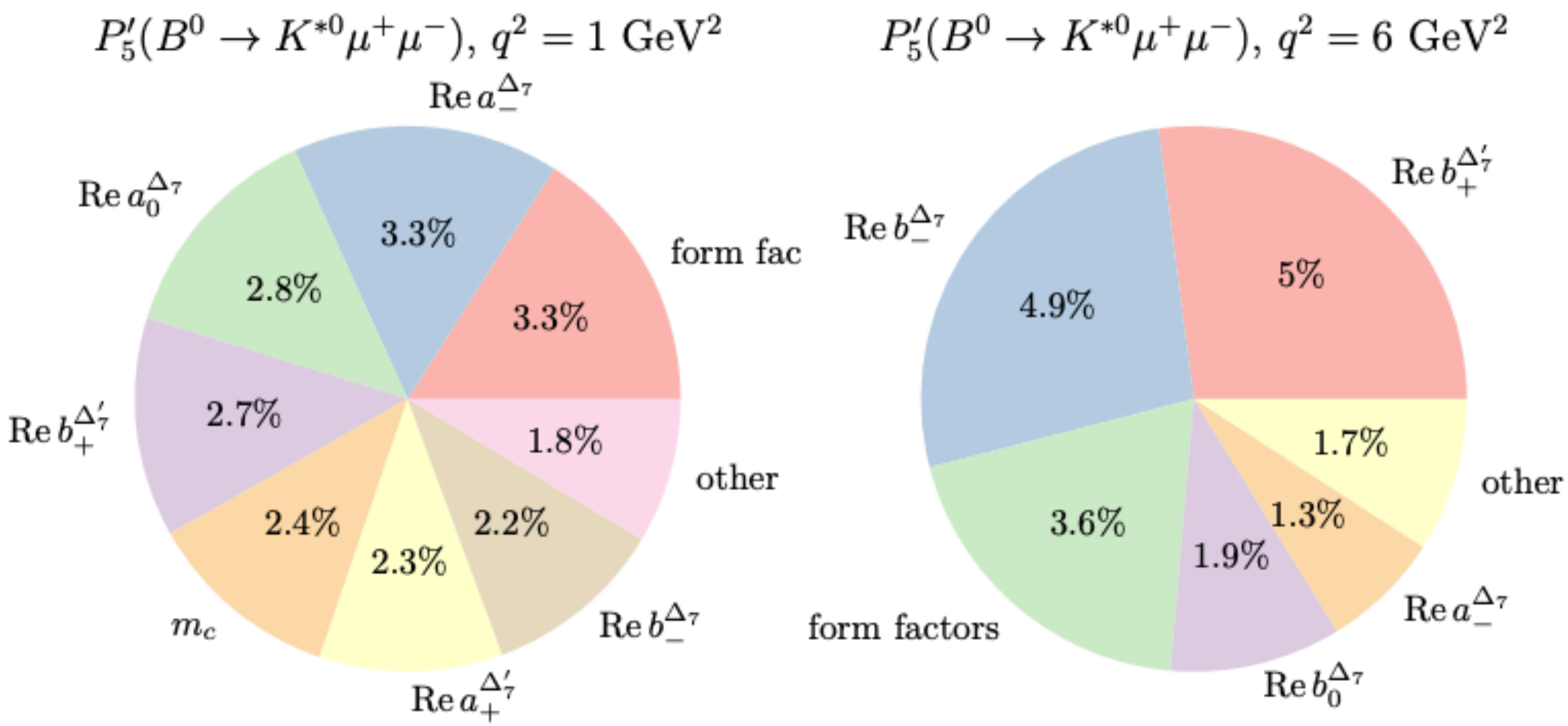
1501.03038


LHCb
N K*γ = 1685 ± 52
μ K*γ = 5278 ± 3 MeV/c2
σ K*γ = 103 ± 3 MeV/c2
Events / (80 MeV/c2)
residual
M(Kπγ) (MeV/c2)


LHCb
N φγ = 239 ± 19
μ φγ = 5365 ± 3 MeV/c2
σ φγ = 94 ± 7 MeV/c2
Events / (80 MeV/c2)
residual
M(KKγ) (MeV/c2)

1202.6267

SM error budgets: examples



$a_x^{\Delta_i}, b_x^{\Delta_i}, c_x^{\Delta_i}$: parametrisation of non-factorisable hadronic effects

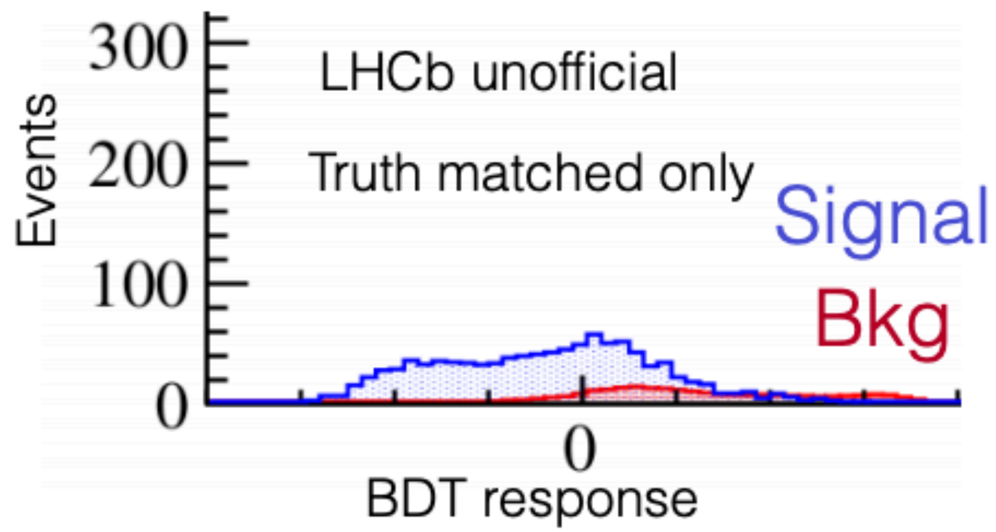
P.Owen

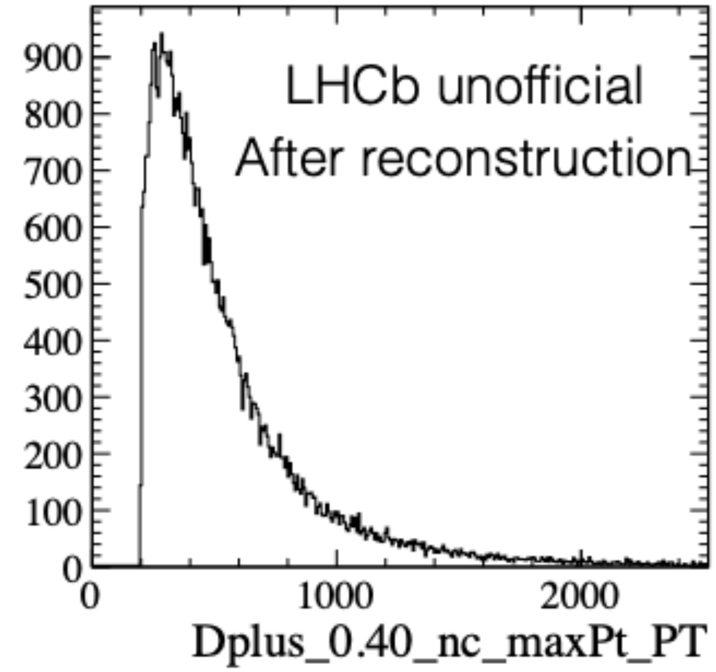
Neutral isolation

- Take example from R(D^+) analysis: Try to reject $D^{*+} \to D^+\pi^0$.

Study by Julian Garcia Pardinas

- Truth match photons in a cone to come from D^{*+} as background.





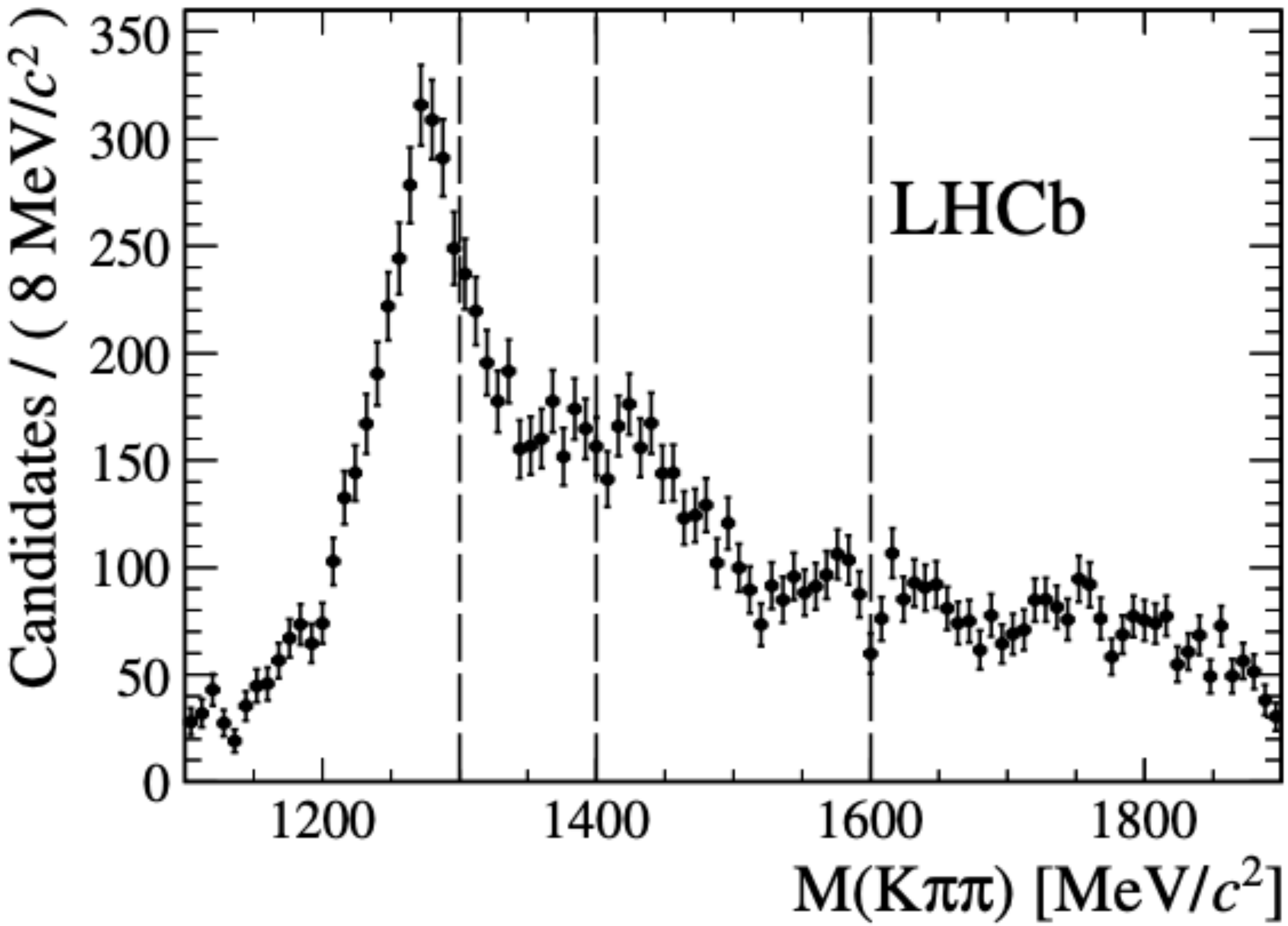
- Matching a photon in a very large cone is only 15% efficient.
- Performance good once you've reconstructed the right photon.
- These are very soft photons.

Reducing the correlation

P.Owen

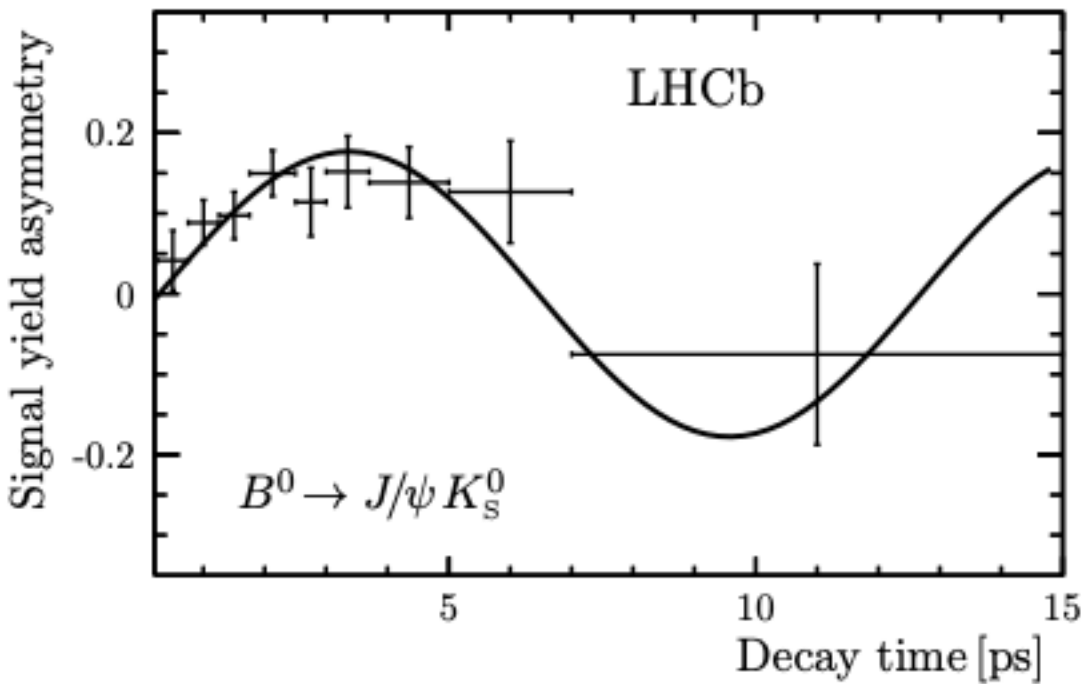
- Due to feed-down, get a large negative correlation between $R(X_c^*)$ and $R(X_c)$.
- Improving isolation can reduce this correlation by:
  - With an upgraded calorimeter can reduce feed-down from e.g. neutral $D^{*0} \longrightarrow D^0\pi^0$ signatures.
  - Better vertex resolution can improve performance of rejecting additional charged tracks.
  - Additional tracking stations on the magnet faces improves acceptance (->rejection) of slow pions.
- This is all important for figuring out if the NP enhancement to $R(D^*)$ and $R(D)$ is the same.

1402.6852

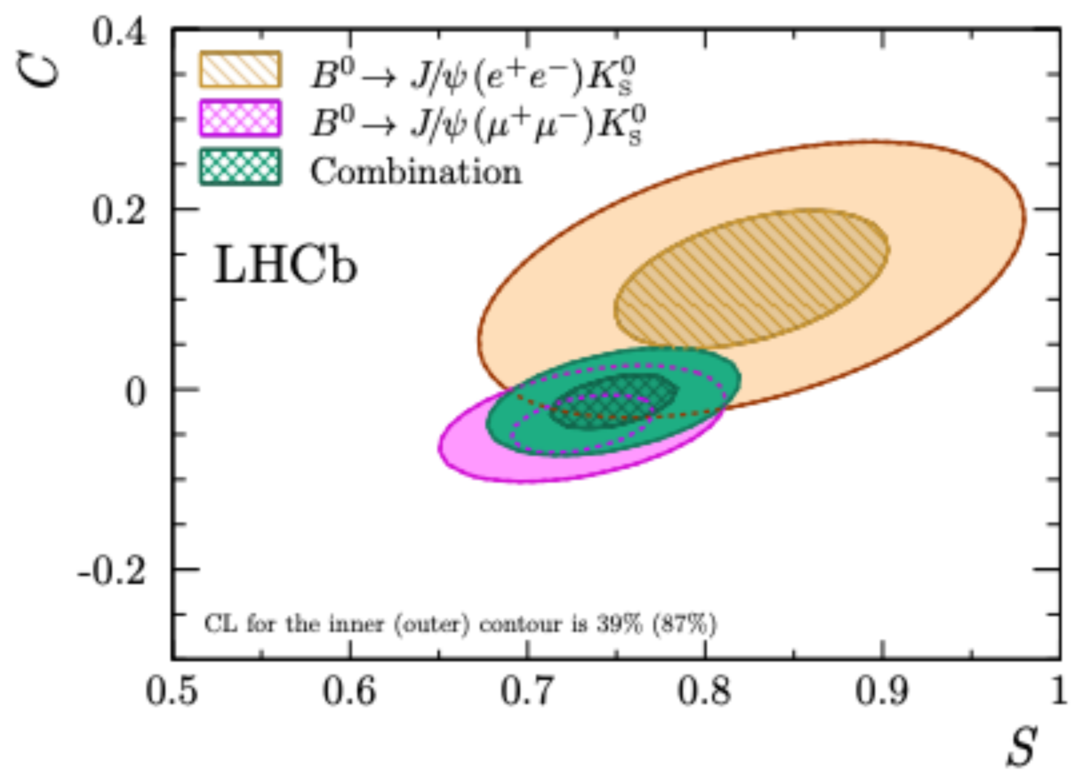


Candidates / (8 MeV/c^2)
350
300
250
200
150
100
50
0
1200
1400
1600
1800
M(Kππ) [MeV/c^2]
LHCb

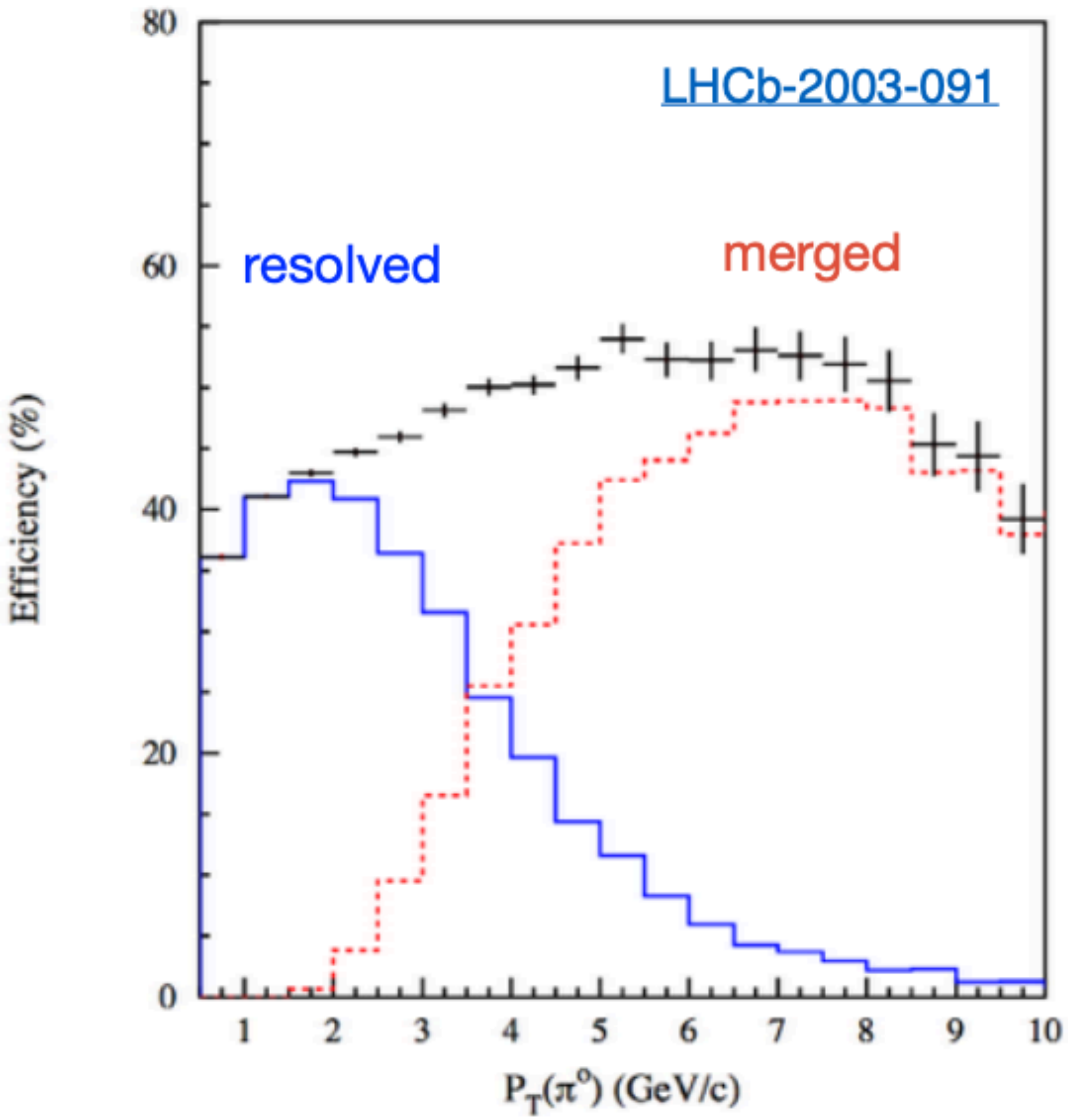
TD measurements with electrons



$$C(B^0 \to J/\psi K^0_S) = 0.12 \pm 0.07 \pm 0.02\,,$$
$$S(B^0 \to J/\psi K^0_S) = 0.83 \pm 0.08 \pm 0.01\,,$$



π^0 efficiency



LAPTH-025/17
ZU-TH 23/17
CP3-Origins-2017-030 DNRF90

$B_s^0 \to \ell^+\ell^-\gamma$ as a Test of Lepton Flavor Universality

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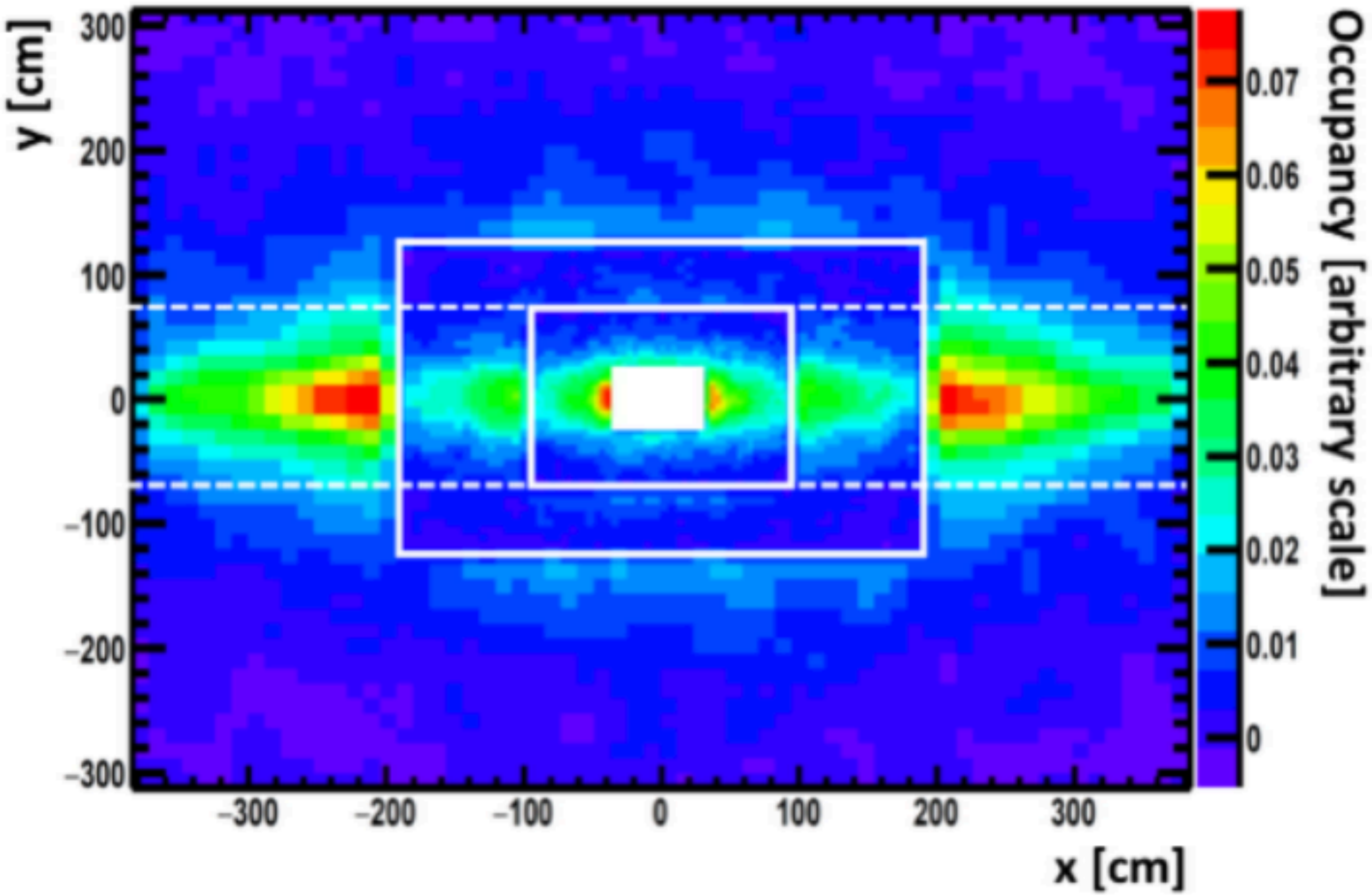
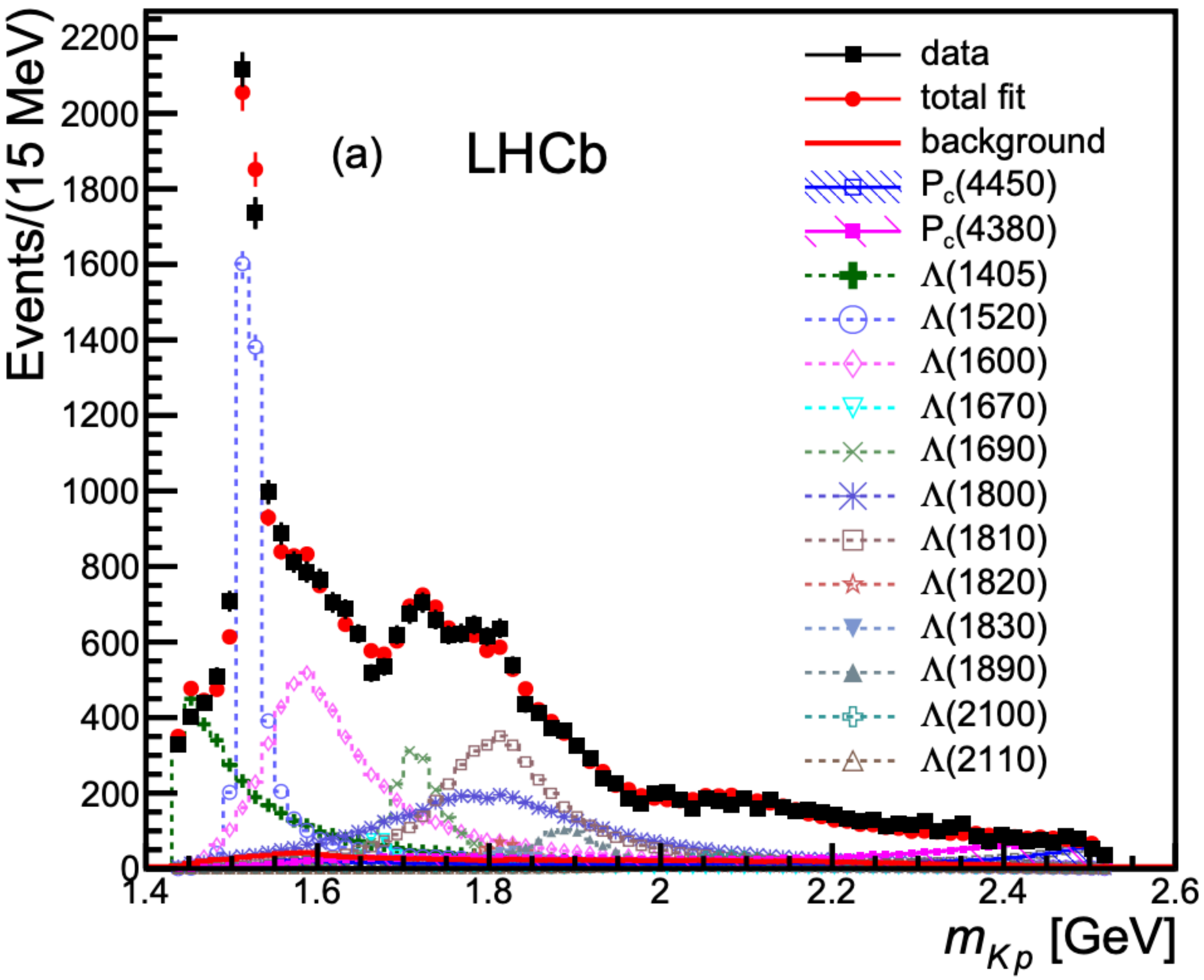
We discuss a number of strategies to reduce the $\mathcal{B}(B_s^0 \to \ell^+\ell^-\gamma)$ theoretical error, and make such a measurement a new probe of the interactions that are interesting in the light of present-day flavor discrepancies. In particular, for low di-lepton invariant mass we propose to exploit the close parenthood between $\mathcal{B}(B_s^0 \to \ell^+\ell^-\gamma)$ and the measured $\mathcal{B}(B_s^0 \to \phi(\to K^+K^-)\gamma)$. For high q^2, conversely, we exploit the fact that the decay is dominated by two form-factor combinations, plus contributions from broad charmonium that we model accordingly. We construct the ratio R_γ, akin to R_K and likewise sensitive to lepton-universality violation. Provided the two rates in this ratio are integrated in a suitable region that minimises bremsstrahlung contributions while maximising statistics, the ratio is very close to unity and the form-factor dependence cancels to an extent that makes it a new valuable probe of lepton-universality violating contributions in the effective Hamiltonian. We finally speculate on additional ideas to extract short-distance information from resonance regions, which are theoretically interesting but statistically limited at present.

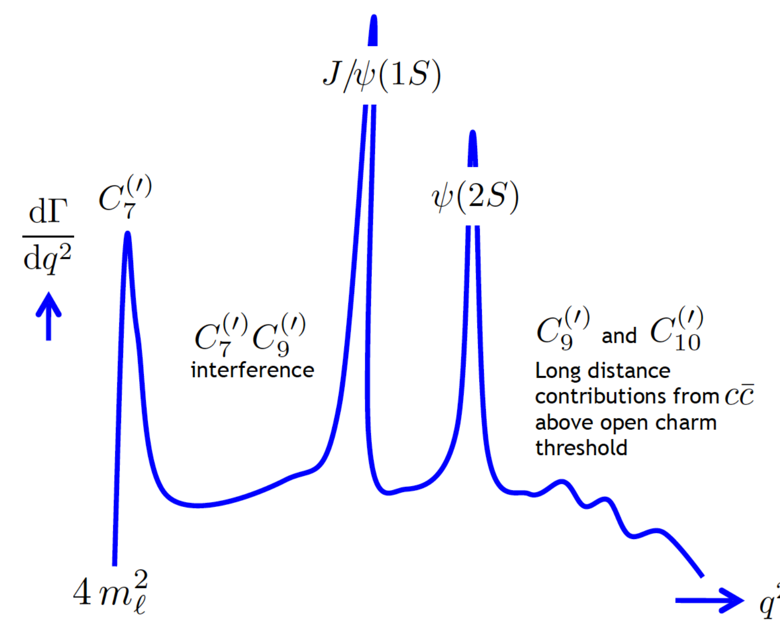
Contents

Occupancy in the ECAL



Amplitude analysis of $\Lambda_b \to pK\gamma$



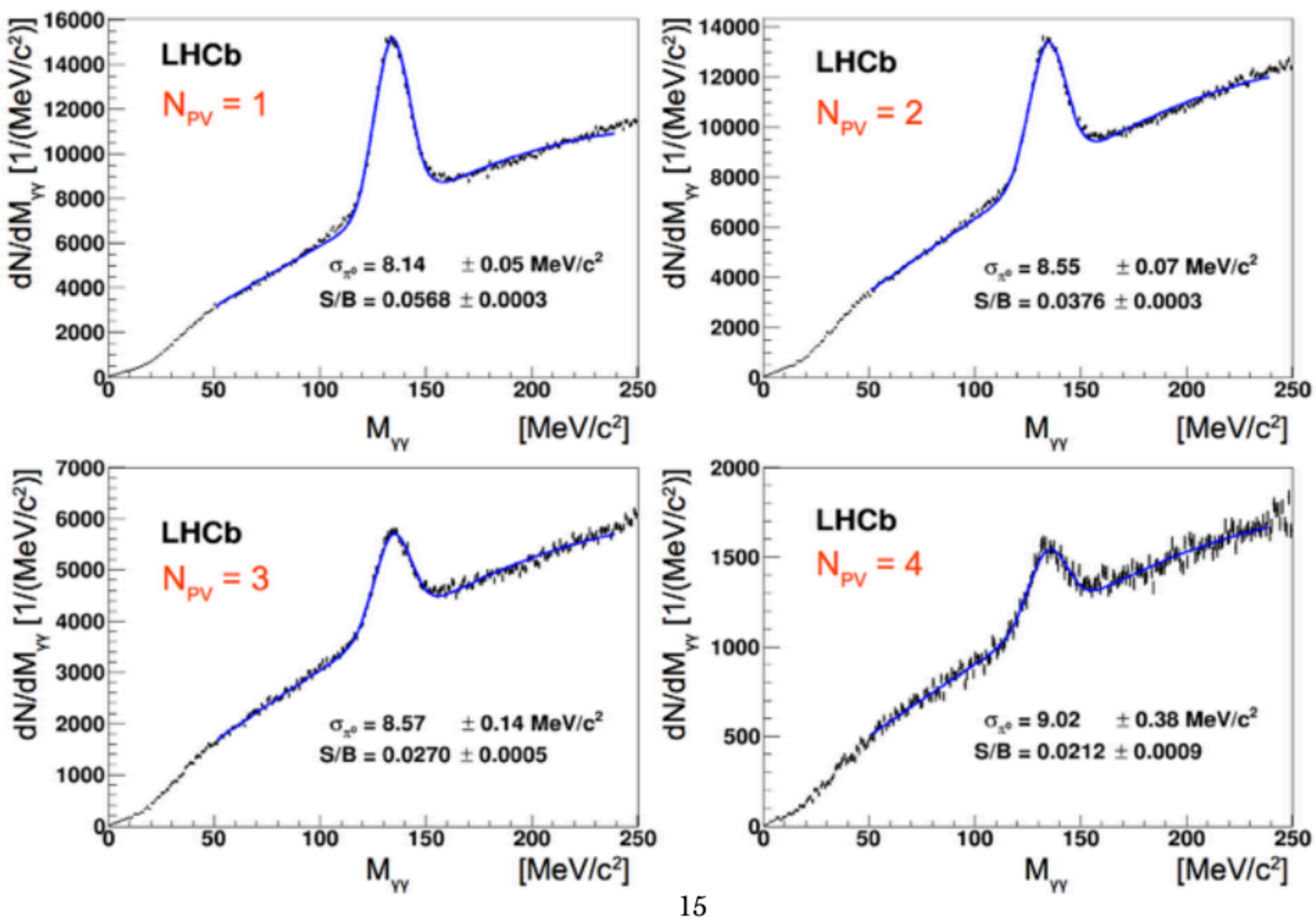


4.2.2. $B^0 \to K^+\pi^-\pi^0\gamma$ decays

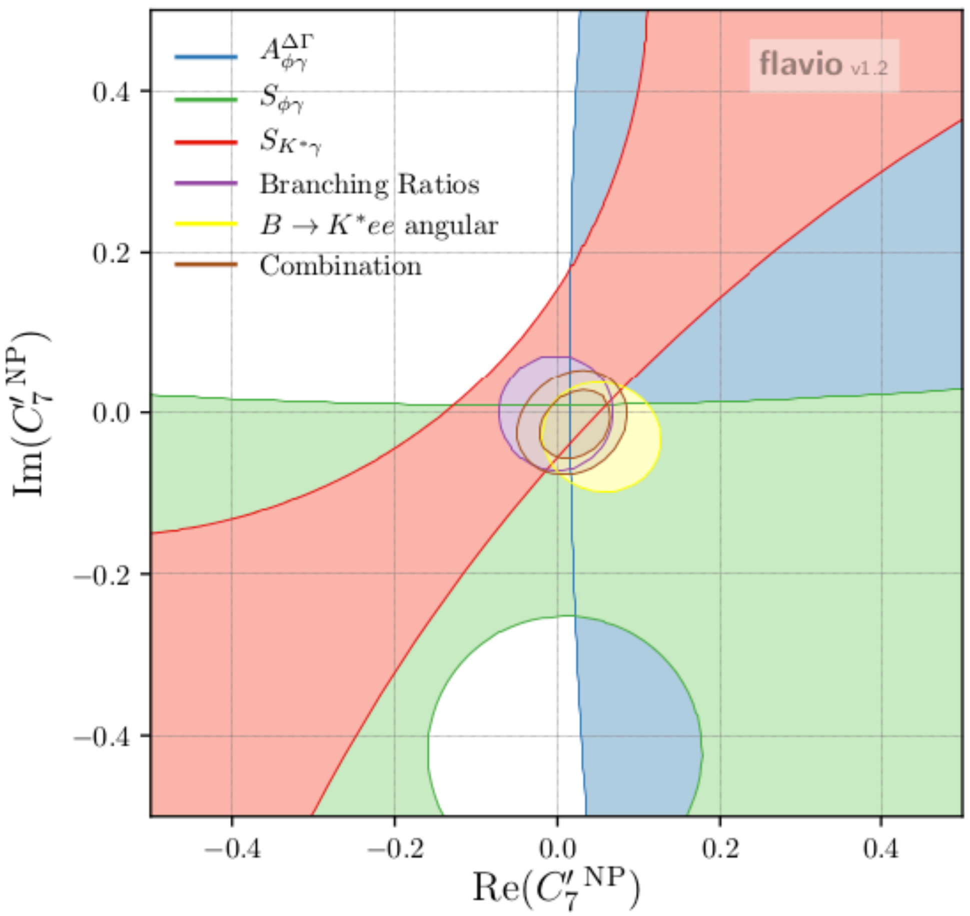
As discussed in Sec. 4.1, $B^0 \to K^+\pi^-\pi^0\gamma$ decays can also be used for a measurement of the photon polarisation parameter. The main difference with the $B^+ \to K^+\pi^-\pi^+\gamma$ decays used above is that the hadronic part of the decays is a priori more complex due to an additional source of interference involving $K^*(892)^0\pi^0$ and $K^*(892)^+\pi^-$ intermediate states in the decays of the heavy kaonic resonances $K_{\mathrm{res}} \to K^+\pi^-\pi^0$.

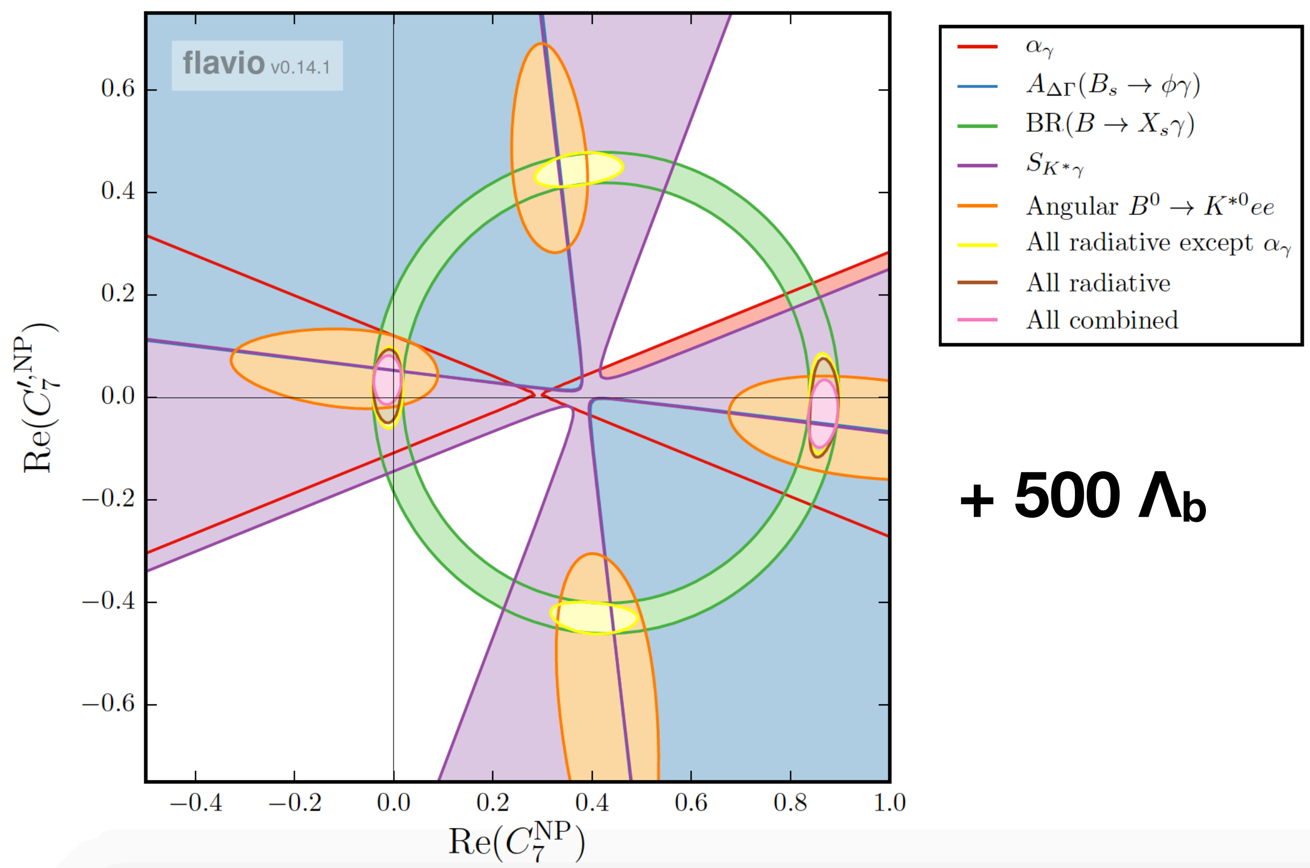
In order to evaluate the sensitivity of a measurement of the photon polarisation parameter using $B^0 \to K^+\pi^-\pi^0\gamma$ decays, samples of 10 000 simulated signal events (corresponding to the number of expected $B^0 \to K^+\pi^-\pi^0\gamma$ decays to be reconstructed by Belle II with 5 ab^{-1} of integrated luminosity) are used. As little is known about the hadronic system in such decays, a model of the $K\pi\pi$ system is obtained from the model used for the charged modes, assuming the relative magnitudes and phases of all allowed decay modes without a $K^*(892)\pi$

π^0 resolution in bins of number of reconstructed primary vertices



Global fits of $C_7^{(\prime)}$





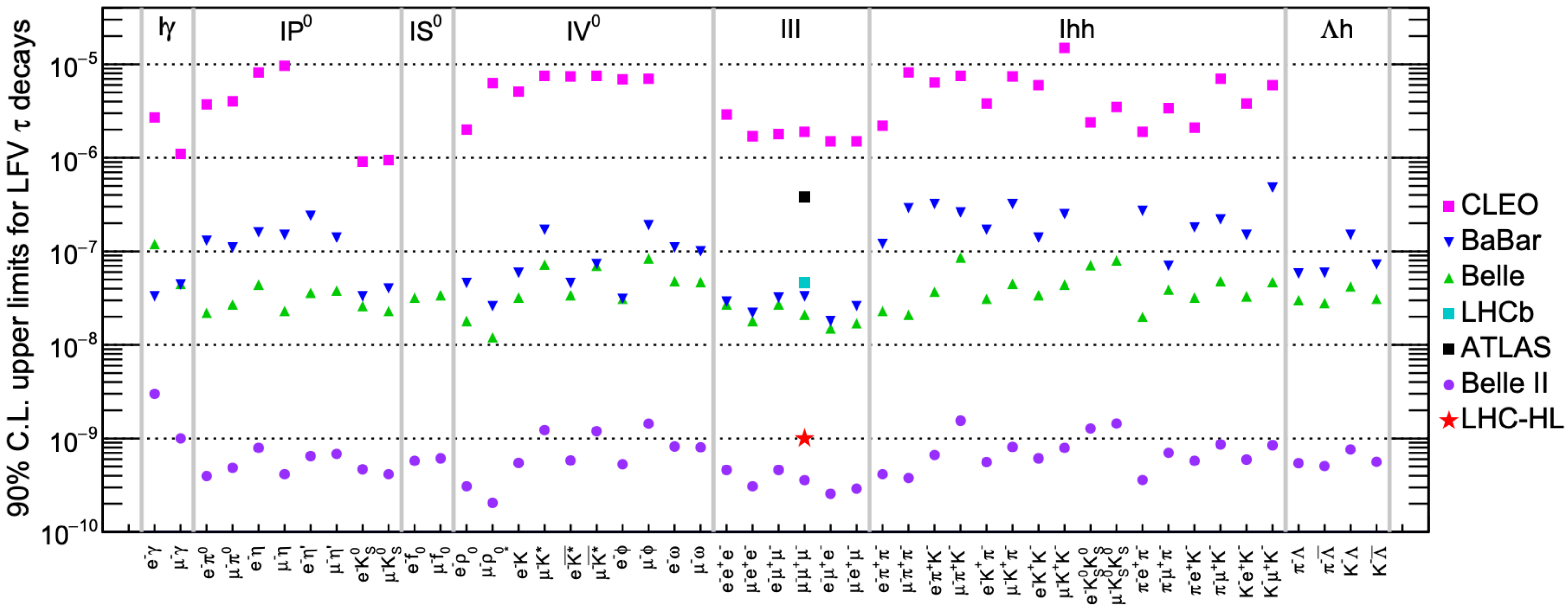
+ 500 Λ_b

Mode	Amplitude	Mode	Amplitude
$K^+\pi^0$	$\sqrt{\frac{3}{10}}S^{PP}$	$\pi^+\pi^0$	0
$K^0\pi^+$	$\sqrt{\frac{3}{5}}S^{PP}$	$K^+\bar{K}^0$	$\sqrt{\frac{3}{5}}S^{PP}$
$K^+\eta$	$-\frac{2}{3\sqrt{5}}S^{PP}+\frac{\sqrt{2}}{3}I^{PP}$	$\pi^+\eta$	$\frac{4}{3\sqrt{5}}S^{PP}+\frac{\sqrt{2}}{3}I^{PP}$
$K^+\eta'$	$\frac{1}{3\sqrt{10}}S^{PP}+\frac{4}{3}I^{PP}$	$\pi^+\eta'$	$-\frac{1}{3}\sqrt{\frac{2}{5}}S^{PP}+\frac{4}{3}I^{PP}$

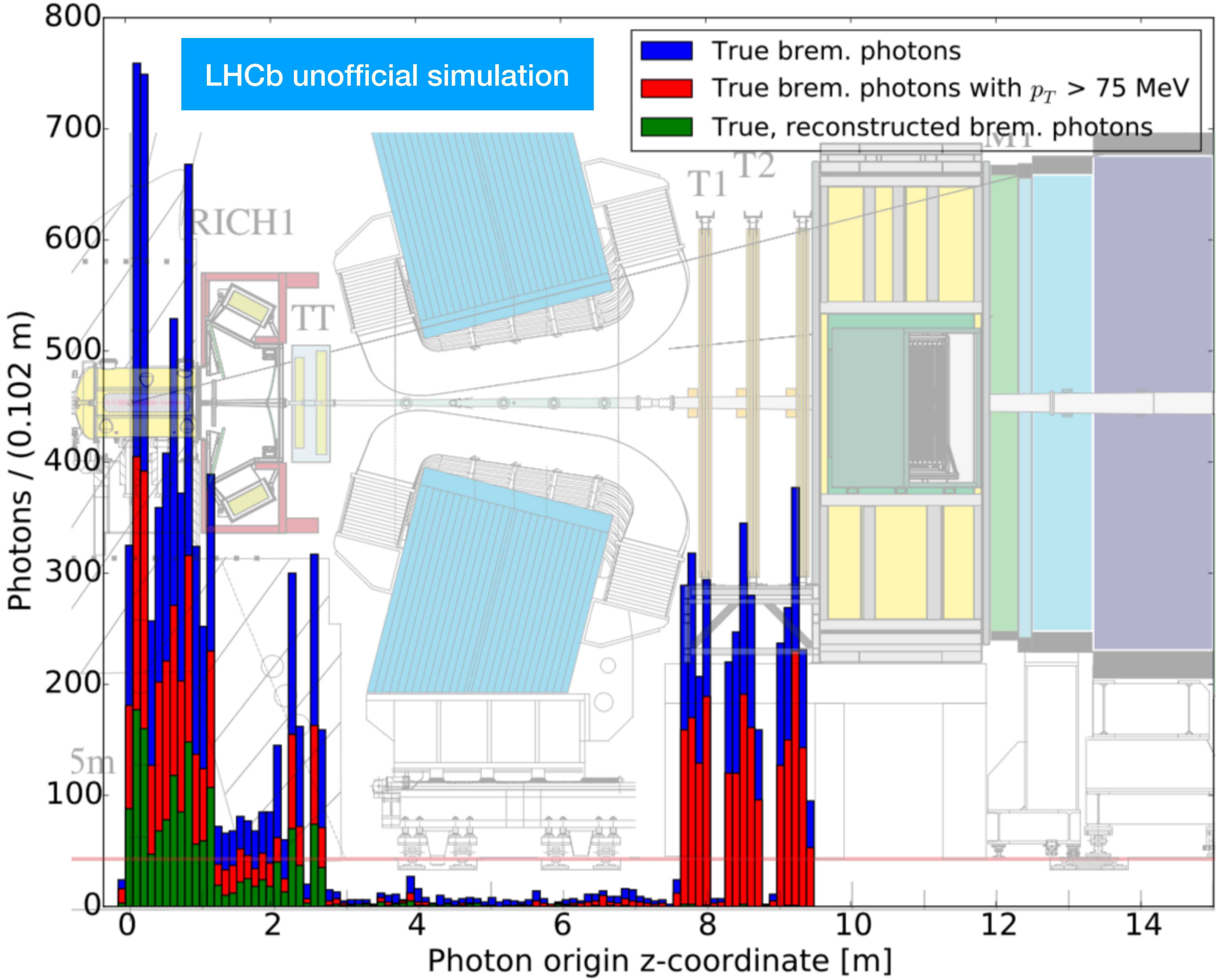
$$A(B_c^+ \to K^0\pi^+) = \sqrt{2}A(B_c^+ \to K^+\pi^0) = \hat{\lambda}A(B_c^+ \to K^+\bar{K}^0)$$

Nevertheless, good performances are achieved when considering decays with at least two charged particles in the final states, such as $D^0 \to \pi^+\pi^-\pi^0$, since the charged particles help to identify the displaced decay vertex of the charm meson. In only $2\,\text{fb}^{-1}$ of data, collected during 2012, LHCb has reconstructed about 660,000 $D^0 \to \pi^+\pi^-\pi^0$ decays [195], i.e., about five times more than Babar from its full data set [291], with comparable purity. Preliminary estimates for Run 2 data, give about 500 000 signal decays per fb^{-1}, making future CP-violation searches in this channel very promising. Similarly, large samples of $D^+_{(s)} \to \eta^{(\prime)}\pi^+$ decays, with $\eta^{(\prime)} \to \pi^+\pi^-\gamma$, or $D^+ \to \pi^+\pi^0$ decays, with $\pi^0 \to e^+e^-\gamma$, are already possible with the current detector. The $D^+_{(s)} \to \eta'\pi^+$ mode, as an example, has been used by LHCb during Run 1 to perform the most precise measurement of CP asymmetries in these channels to date, with uncertainties below the 1% level [292].

More challenging final states consisting only of neutral particles, such as $\pi^0\pi^0$ or $\eta\eta$, can still be reconstructed with $\pi^0 \to \gamma\gamma$ or $\eta \to \gamma\gamma$ candidates made of photons which, after interacting with the detector material, have converted into an e^+e^- pair. Such conversions must occur before the tracking system to have electron tracks reconstructed. Although the reconstruction efficiency of these "early" converted photons in the current detector reaches only a few percent of the calorimetric photon efficiency, their purity is much higher. This approach may become interesting only with the large data sets that are expected to be collected by the end of Upgrade II. The η decays can also be reconstructed through the $\pi^+\pi^-\gamma$ final state.



90% C.L. upper limits for LFV τ decays
lγ
lP0
lS0
lV0
lll
lhh
Λh
CLEO
BaBar
Belle
LHCb
ATLAS
Belle II
LHC-HL



LHCb unofficial simulation
True brem. photons
True brem. photons with p_T > 75 MeV
True, reconstructed brem. photons
RICH1
TT
T1
T2
M1
5m
Photons / (0.102 m)
Photon origin z-coordinate [m]

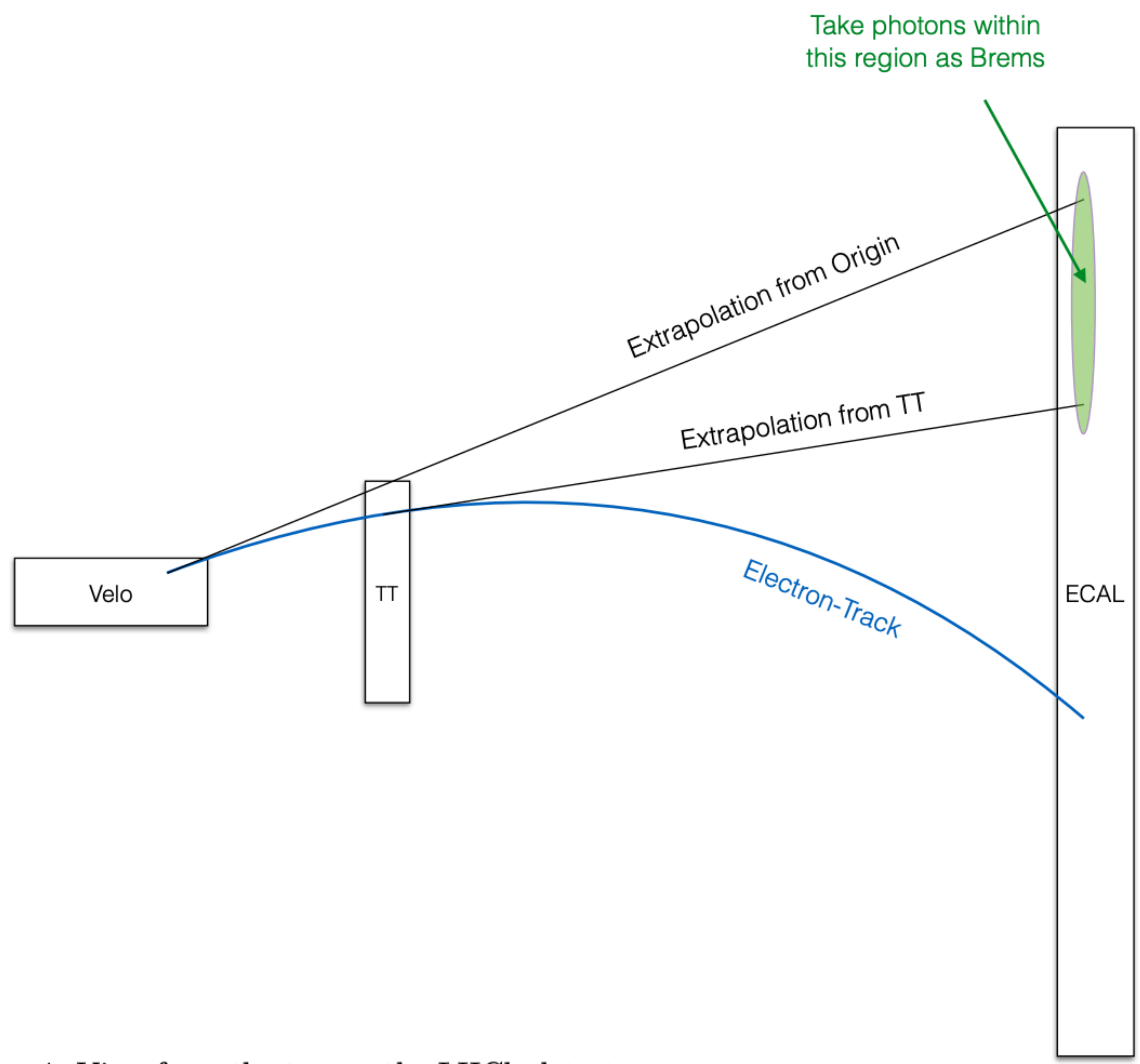
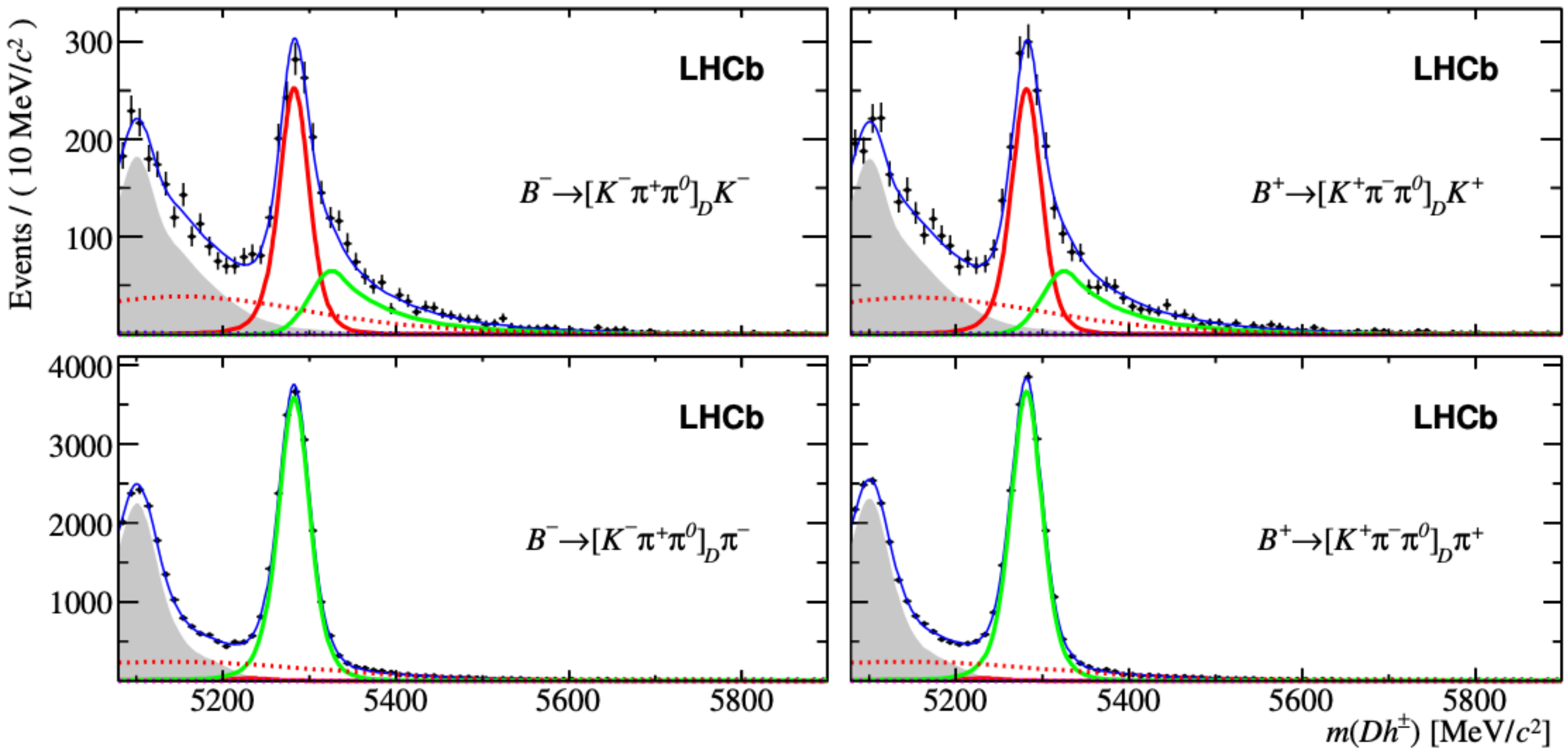


Figure 4: View from the top on the LHCb-detector:
Schematic illustration of the current method to deal with emitted bremsstrahlung

Measurement of γ

Reconstruction of π^0 is important increase number of decay modes studies



Praeludium in Organo pleno, pedale di Joh. Seb. Bach