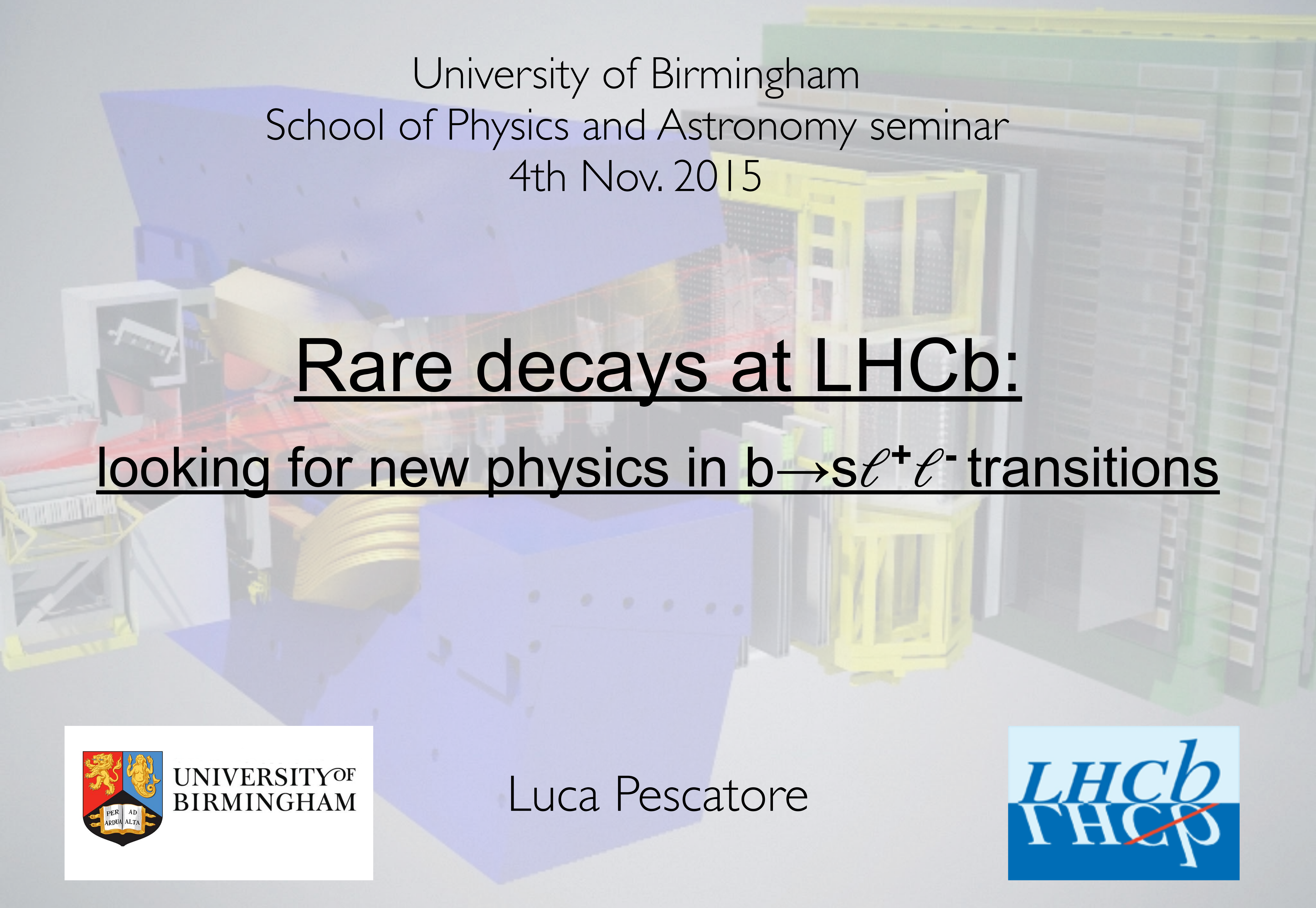


University of Birmingham
School of Physics and Astronomy seminar
4th Nov. 2015

Rare decays at LHCb:

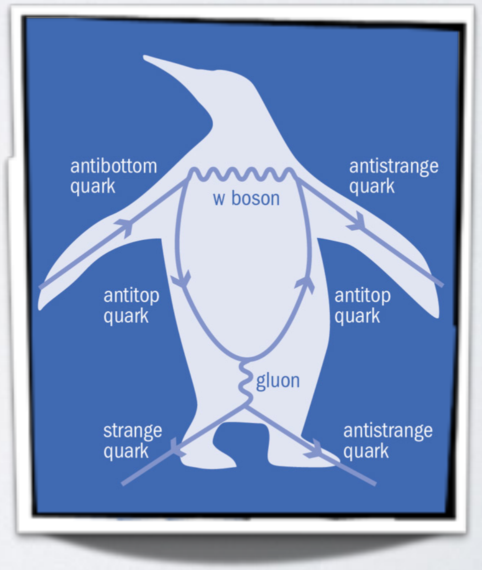
looking for new physics in $b\rightarrow s\ell^+\ell^-$ transitions

UNIVERSITY OF BIRMINGHAM

Luca Pescatore

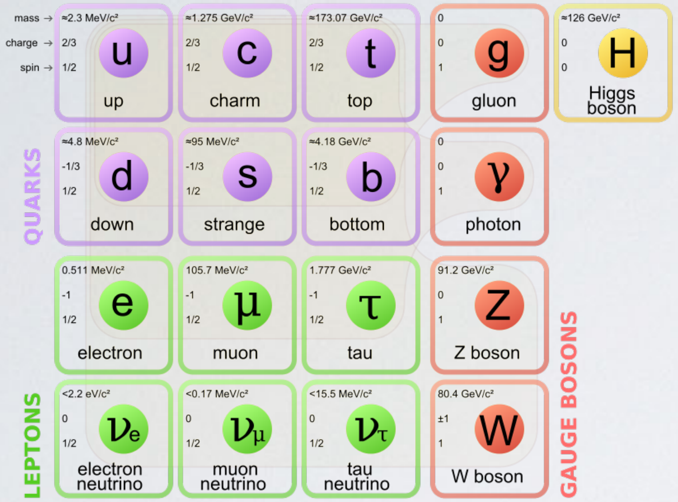
Outline

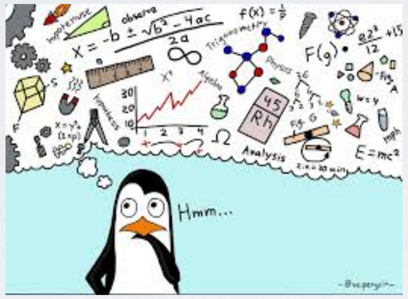
- Rare decays: a tool to search for new physics
    - Motivation
    - Theoretical framework
    - Recent results at LHCb
- An analysis of $\Lambda_b \to \Lambda^0 \mu\mu$ decays
    - Introduction
    - Differential Branching fraction measurement
    - Angular analysis
- Testing lepton universality with R_{K*0} ratio
    - R_K and R_{K*}
    - Measurement description

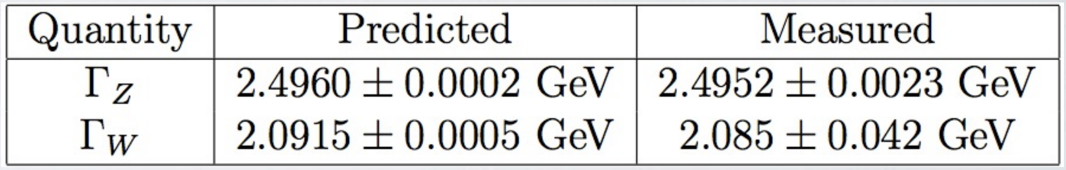


The flavour problem and the need for New Physics

The SM is a very successful theory!







Quantity	Predicted	Measured
Γ_Z	2.4960 ± 0.0002 GeV	2.4952 ± 0.0023 GeV
Γ_W	2.0915 ± 0.0005 GeV	2.085 ± 0.042 GeV

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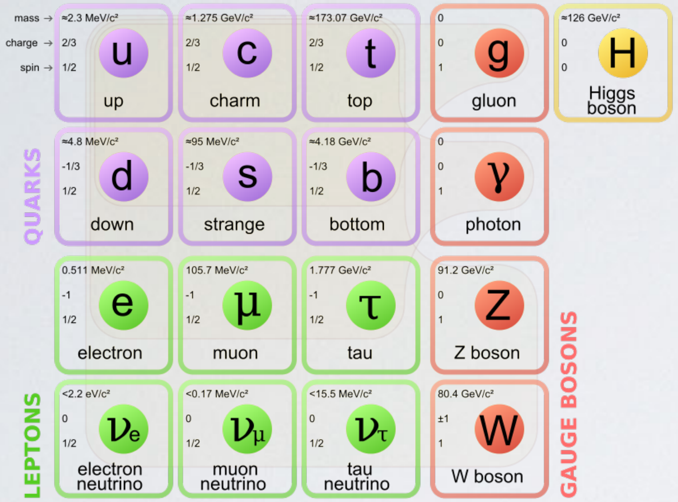
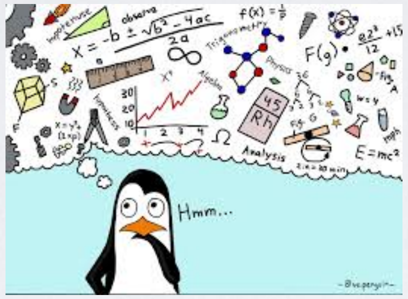
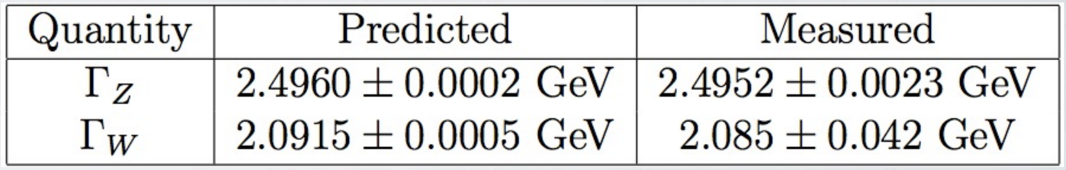






Quantity	Predicted	Measured
Γ_Z	2.4960 ± 0.0002 GeV	2.4952 ± 0.0023 GeV
Γ_W	2.0915 ± 0.0005 GeV	2.085 ± 0.042 GeV

… but still has its limits …

Dark matter?

Include gravity?

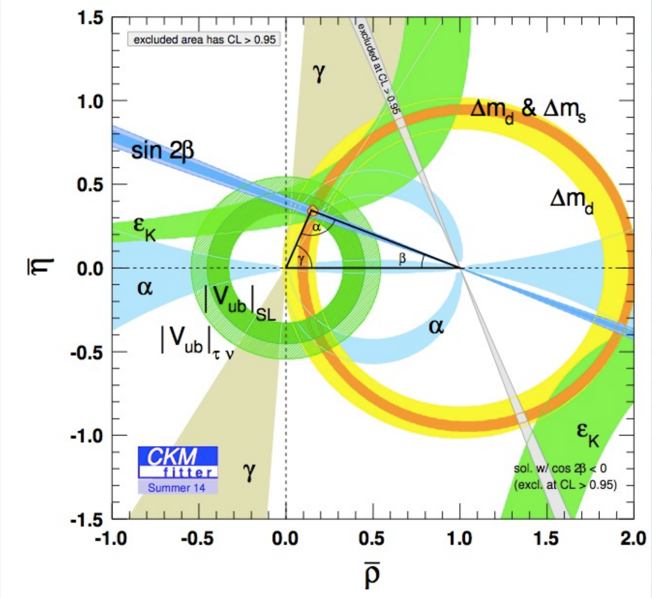
Hierarchy problem?

Matter antimatter asymmetry?

The flavour problem and the need for New Physics

Flavour: Flavour violation in the SM is ruled by the CKM matrix.

$$\begin{pmatrix} 0.97427 \pm 0.00015 & 0.22534 \pm 0.00065 & 0.00351^{+0.00015}_{-0.0014} \\ 0.22520 \pm 0.00065 & 0.97344 \pm 0.00016 & 0.00412^{+0.0011}_{-0.0005} \\ 0.00867^{+0.00029}_{-0.00031} & 0.0404^{+0.0011}_{-0.0005} & 0.999146^{+0.000021}_{-0.000046} \end{pmatrix}$$



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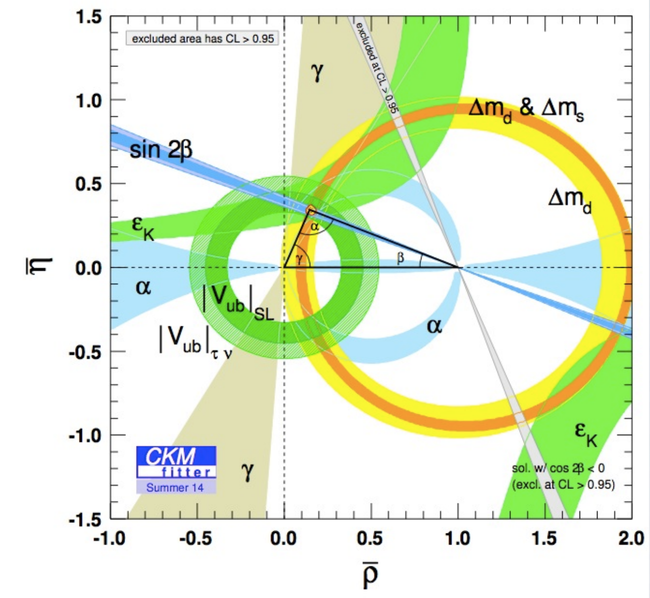
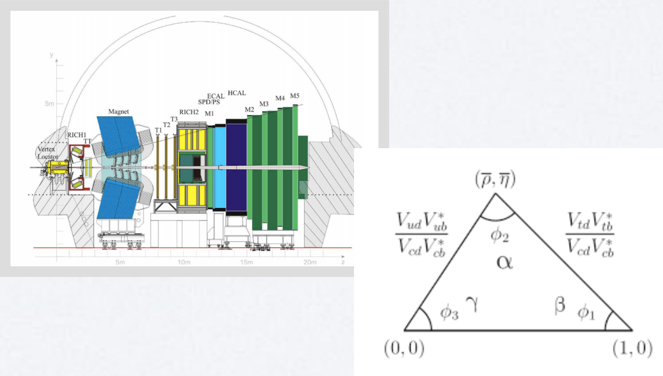


First job for LHCb: precision measurement of CKM parameters.



It needs a solid basis to go beyond.

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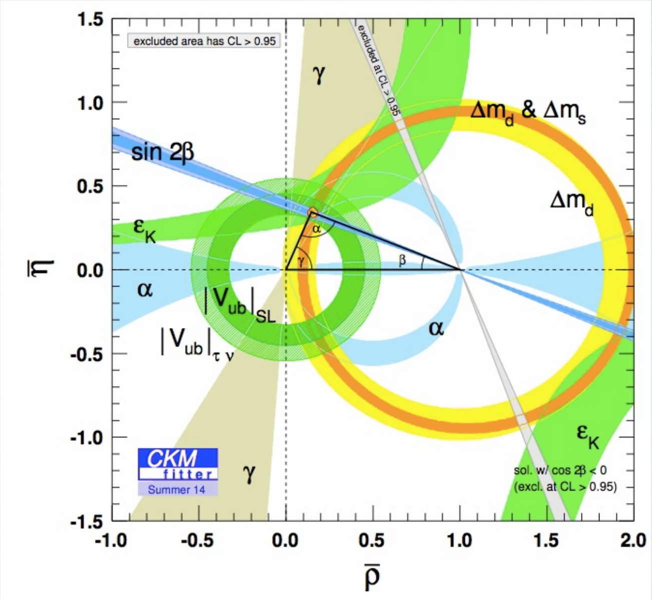

Neutrino oscillations?

Indicate flavour violation beyond the SM

… then we need beyond the SM physics (BSM)

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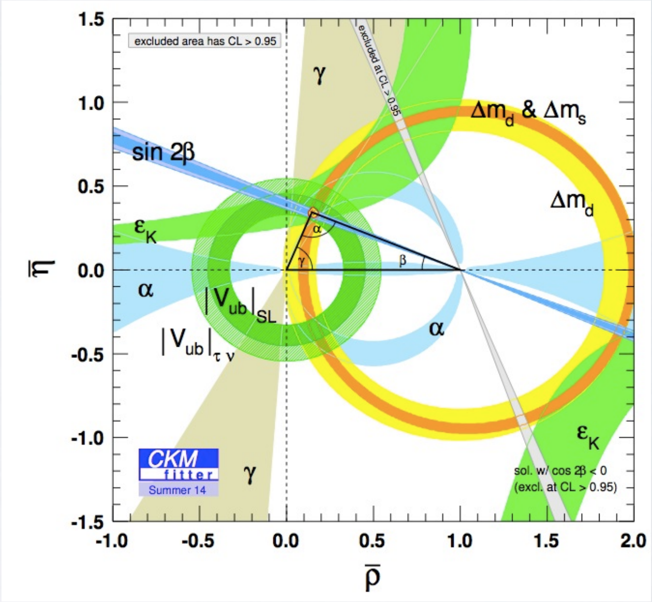

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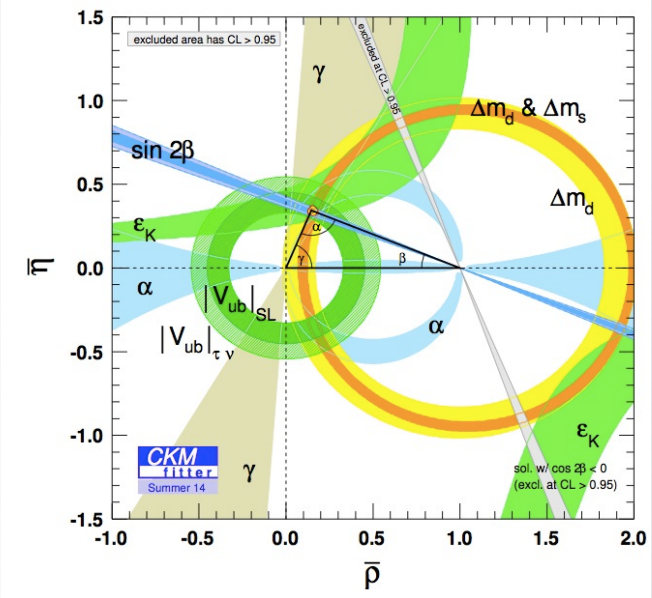

Neutrino oscillations?

Indicate flavour violation beyond the SM

Why does it have a hierarchical structure?

Why are there 3 families of quarks and leptons?

… then we need beyond the SM physics (BSM)

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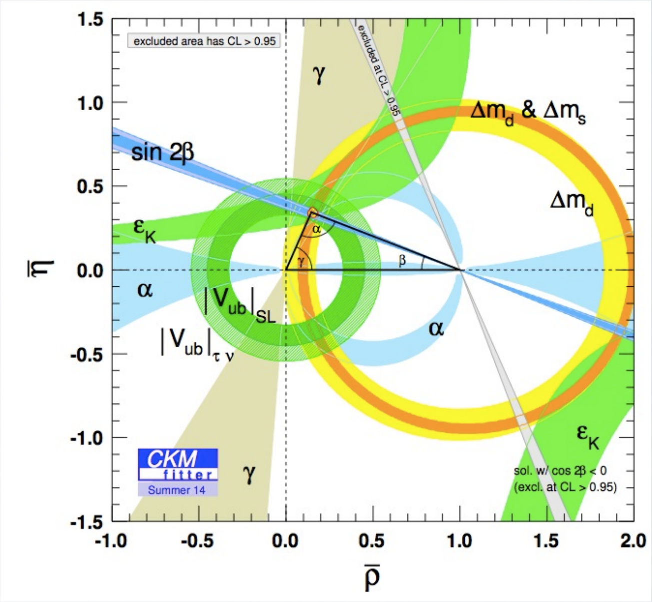
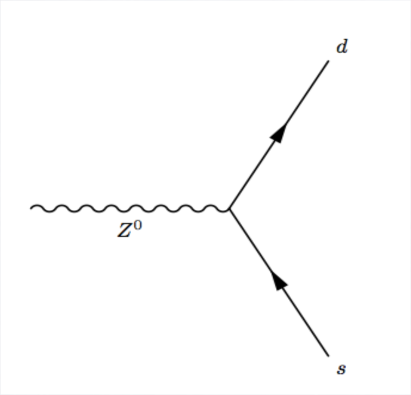
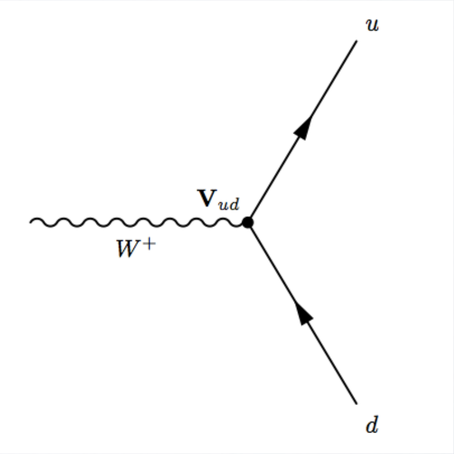


FCNCs in the SM



← Neutral currents: exchange of a Z/γ boson

Charged currents: exchange of a W boson →



Only charged currents change flavour in the SM:

FCNCs are forbidden at tree level

… but it could be different in BSM

Flavour and BSM physics

BSM models often predict different amounts of flavour violation than the SM

BSM models

Can be almost anything

as long as compatible with SM

→ need to constrain the parameter space

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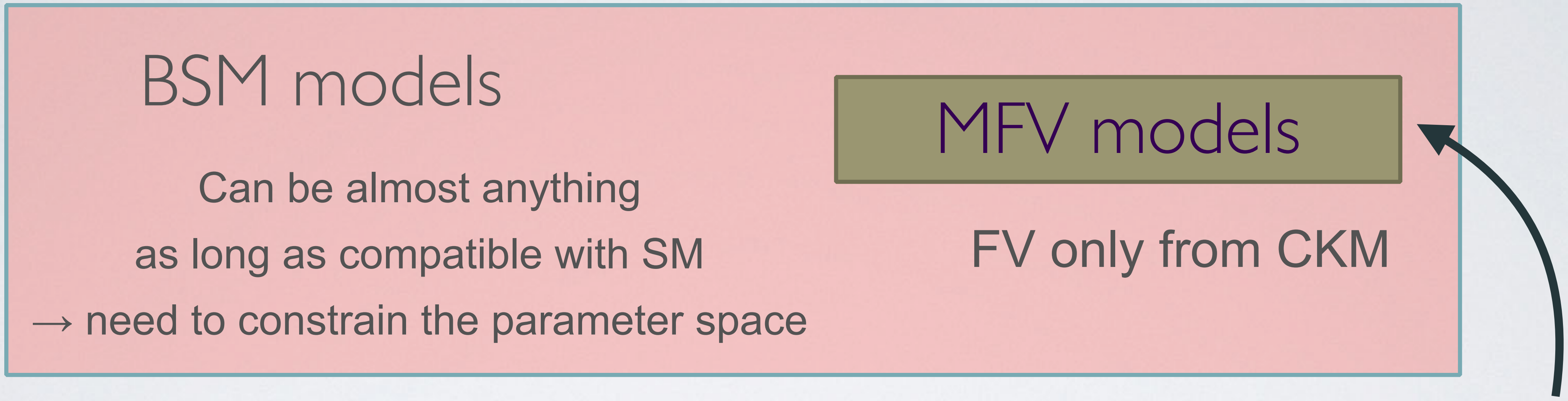

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→ need to constrain the parameter space

MFV models

FV only from CKM

Can be constrained

looking at B_d / B_s ratios

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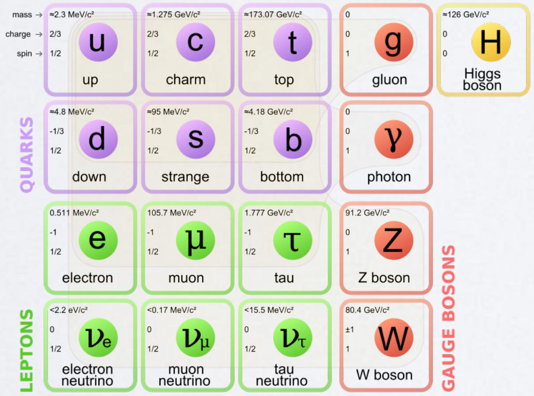
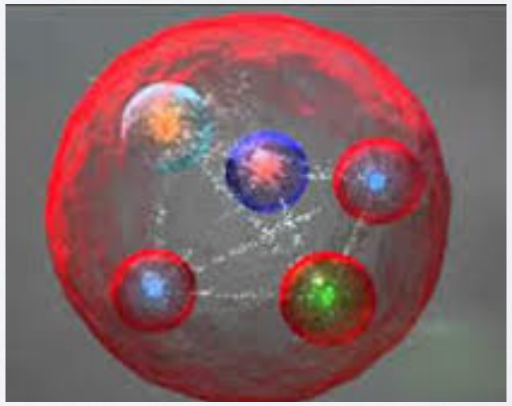
Simplified models

Mid-way model building step: can show the way.



mass → charge → spin →	≈2.3 MeV/c² 2/3 1/2 u up	≈1.275 GeV/c² 2/3 1/2 c charm	≈173.07 GeV/c² 2/3 1/2 t top	0 0 1 g gluon	≈126 GeV/c² 0 0 H Higgs boson
QUARKS	≈4.8 MeV/c² -1/3 1/2 d down	≈95 MeV/c² -1/3 1/2 s strange	≈4.18 GeV/c² -1/3 1/2 b bottom	0 0 1 γ photon	
	0.511 MeV/c² -1 1/2 e electron	105.7 MeV/c² -1 1/2 μ muon	1.777 GeV/c² -1 1/2 τ tau	91.2 GeV/c² 0 1 Z Z boson	GAUGE BOSONS
LEPTONS	<2.2 eV/c² 0 1/2 ν_e electron neutrino	<0.17 MeV/c² 0 1/2 ν_μ muon neutrino	<15.5 MeV/c² 0 1/2 ν_τ tau neutrino	80.4 GeV/c² ±1 1 W W boson	



Limited set of parameters = very predictive and easy to compare with measurement

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Z' penguins

Additional Z' bosons

from a U(1) gauge symmetry

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Z' penguins
Additional Z' bosons
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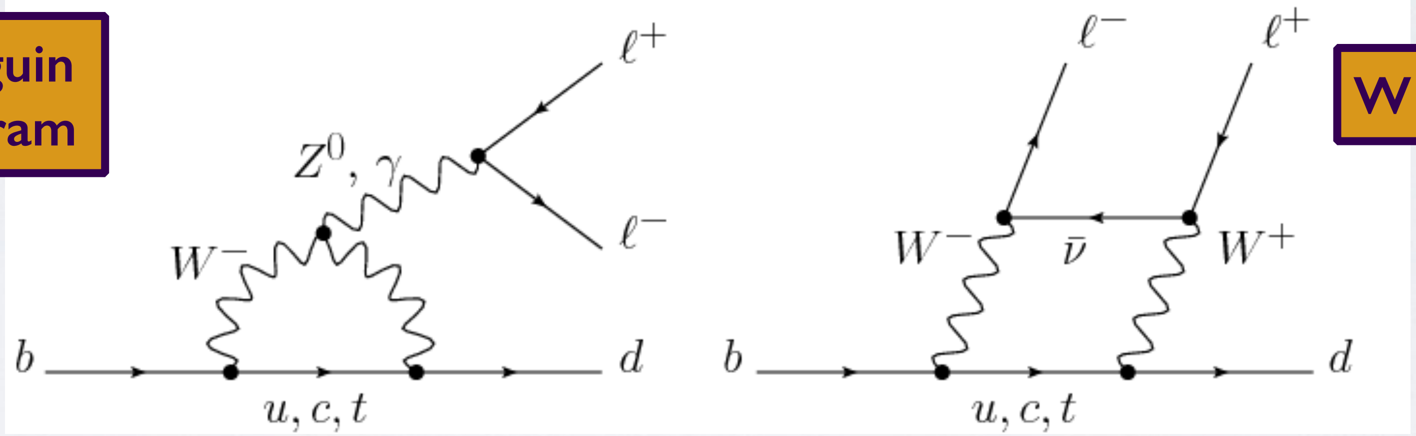
Leptoquarks
Bosonic particles that carry one lepton
and one quark quantum numbers

Limited set of parameters = very predictive and easy to compare with measurement

Rare decays

- Rare decays: processes suppressed in the SM that can happen **only at loop level**.
  - Flavour Changing Neutral Currents
    → forbidden at tree level in the SM (e.g $b \to s$ or $b \to d$ transitions)
    → branching fractions typically ~10^{-6} or less
    → today: mainly dealing with $b \to s\ell^+\ell^-$ decays

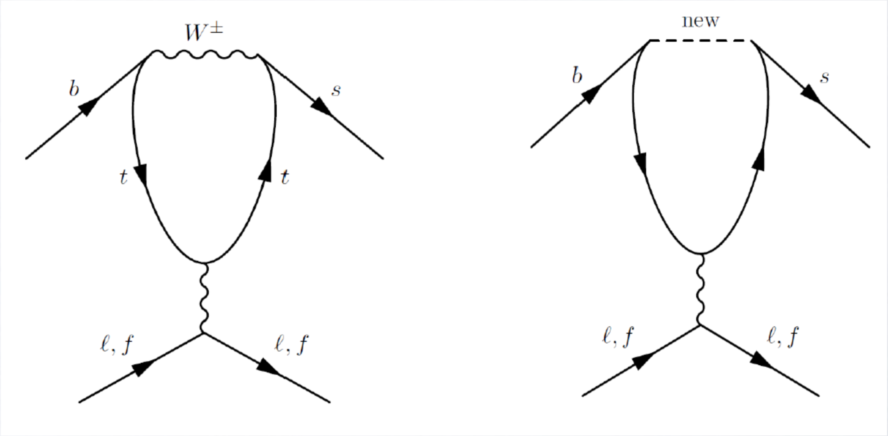
arXiv:1501.03309



Penguin diagram

W box

- **New Physics** can enter in the loops
  - Very sensitive to new physics effects
    → NP enters at the same level as SM
  - No evidence in direct searches so far
    → loops can probe **high energy scales**



Theoretical framework:

the effective Hamiltonian

- M(b) << M(W, Z, top) ⇒ an **effective theory** can be built
- Separate aptitude calculations into 2 parts:
  - "**long-distance**": below *b* mass scale (known SM physics)
  - "**short-distance**": above *b* mass scale (Z,W and top + all new physics)
  - An example of effective theory is the Fermi-theory of weak interactions

Effective theory

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Phys.Lett. B400 (1997) 206–219

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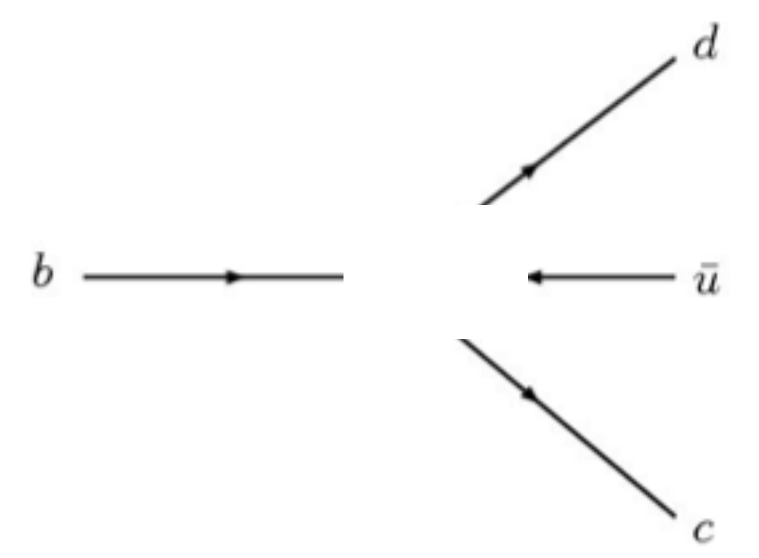

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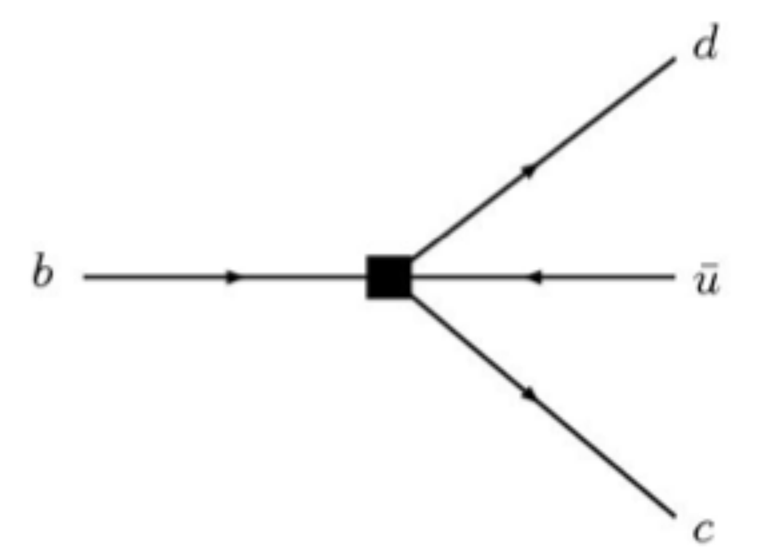

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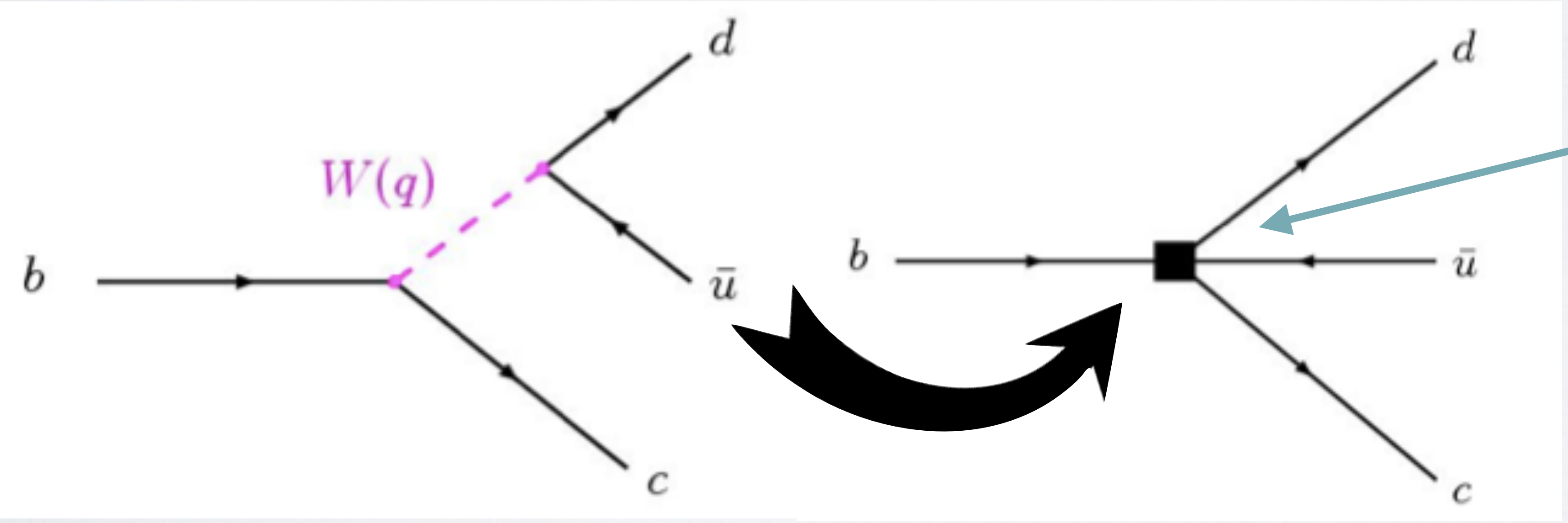

Short distance contribution associated with G_F

Full theory

Effective theory

arXiv:1501.03309

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Effective Hamiltonian for *b*→*d* and *b*→*s* transitions

$$\mathcal{H}_{eff} = \frac{-4G_F}{\sqrt{2}} \left[\lambda_q^t \sum C_i(\mu)\mathcal{O}_i(\mu) + \lambda_q^u \sum C_i(\mu)(\mathcal{O}_i(\mu) - \mathcal{O}_i^u(\mu))\right]$$

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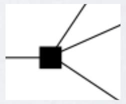

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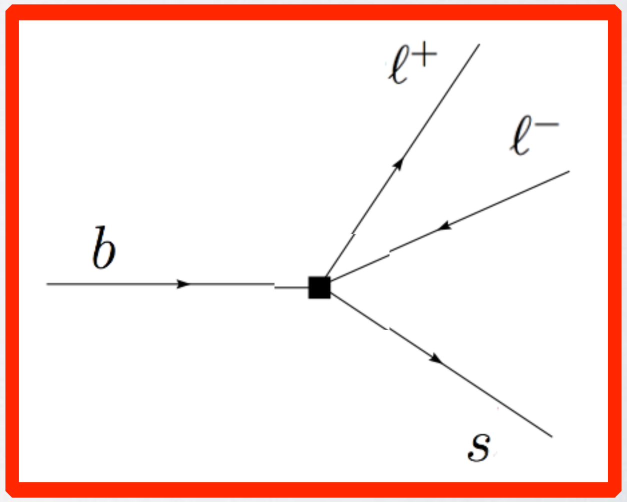

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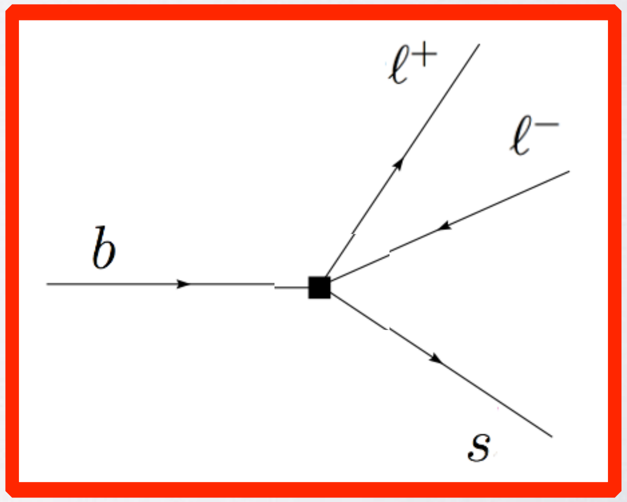
CKM factors: $\lambda_q^{q'} = V_{q'b}V_{q'q}^*$

For *b*→*s* transitions $V_{us} << V_{ts}$

⇒ the second term can be neglected



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Left-handed and right-handed

▶ $$\underline{C_i\mathcal{O}_i} + \underline{C_i'\mathcal{O}_i'}$$

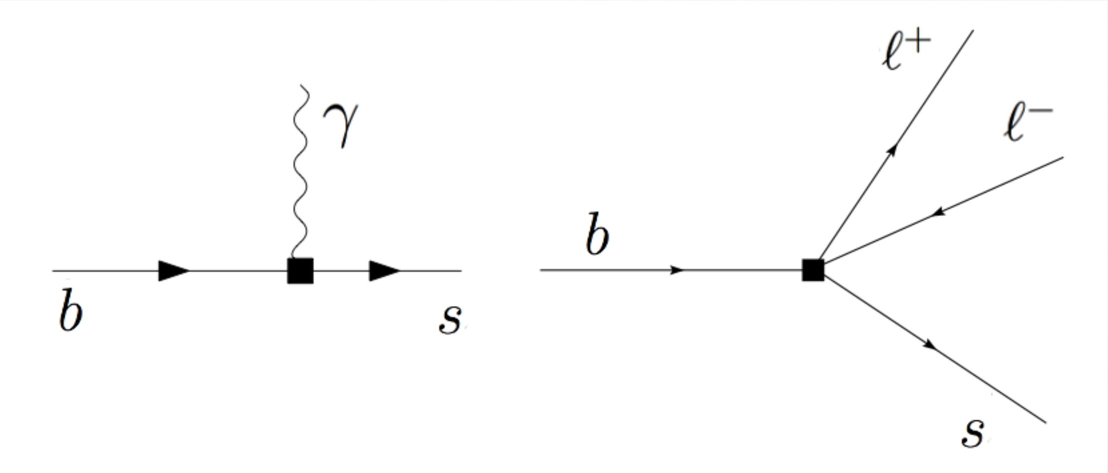
In the SM: $C' \sim m_s/m_b\, C$

Contributions to $b \to s\ell^+\ell^-$:

✓ <u>O_7 : radiative penguin</u>

✓ <u>$O_{9,10}$: semileptonic decays</u>

(Z penguin and W-box)



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Left-handed and right-handed

- $$\underline{C_i \mathcal{O}_i} + \underline{C_i' \mathcal{O}_i'}$$

In the SM: C' ~ m_s/m_b C

$$\boxed{C_7^{SM} = -0.3, \quad C_9^{SM} = 4.2, \quad C_{10}^{SM} = -4.2.}$$

$$\boxed{C_i = C_i^{NP} + C_i^{SM}}$$

Calculating exclusive decay amplitudes

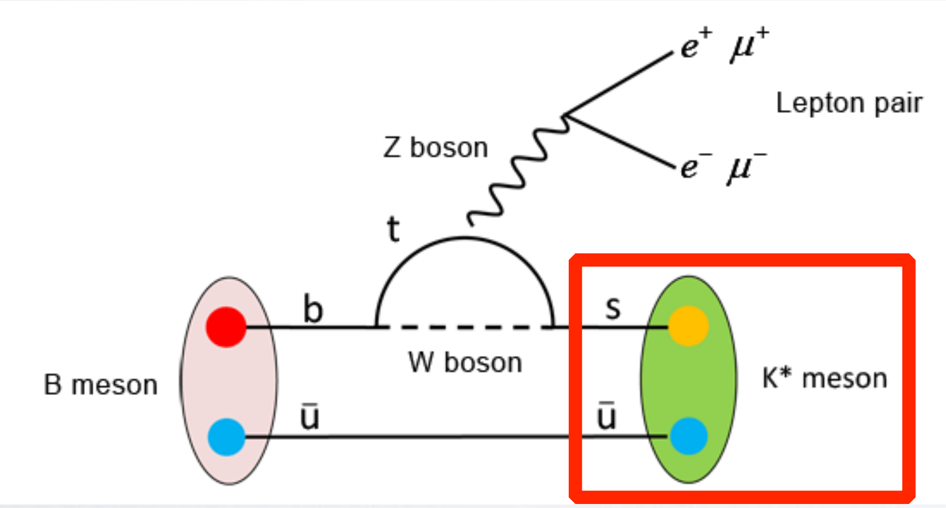
The decay amplitude of an exclusive decay

→ expectation value of H_{eff} given the initial and final states

$$A(M \to F) = \langle M|\mathcal{H}_{eff}|F\rangle =$$

$$= \frac{G_F}{\sqrt{2}} \sum V^i_{CKM} C_i(\mu) \langle M|\mathcal{O}_i(\mu)|F\rangle$$

Perturbative contribution



Hadronic matrix elements (**form factors**) describing the hadronization process. Need to be obtained with non perturbative methods e.g. Lattice QCD

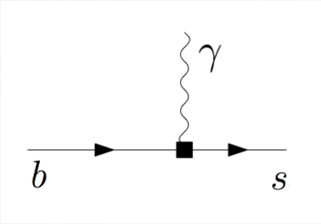
Form factors = **main source of uncertainty** in theory predictions

Phenomenology of $b \to s\ell^+\ell^-$ decays

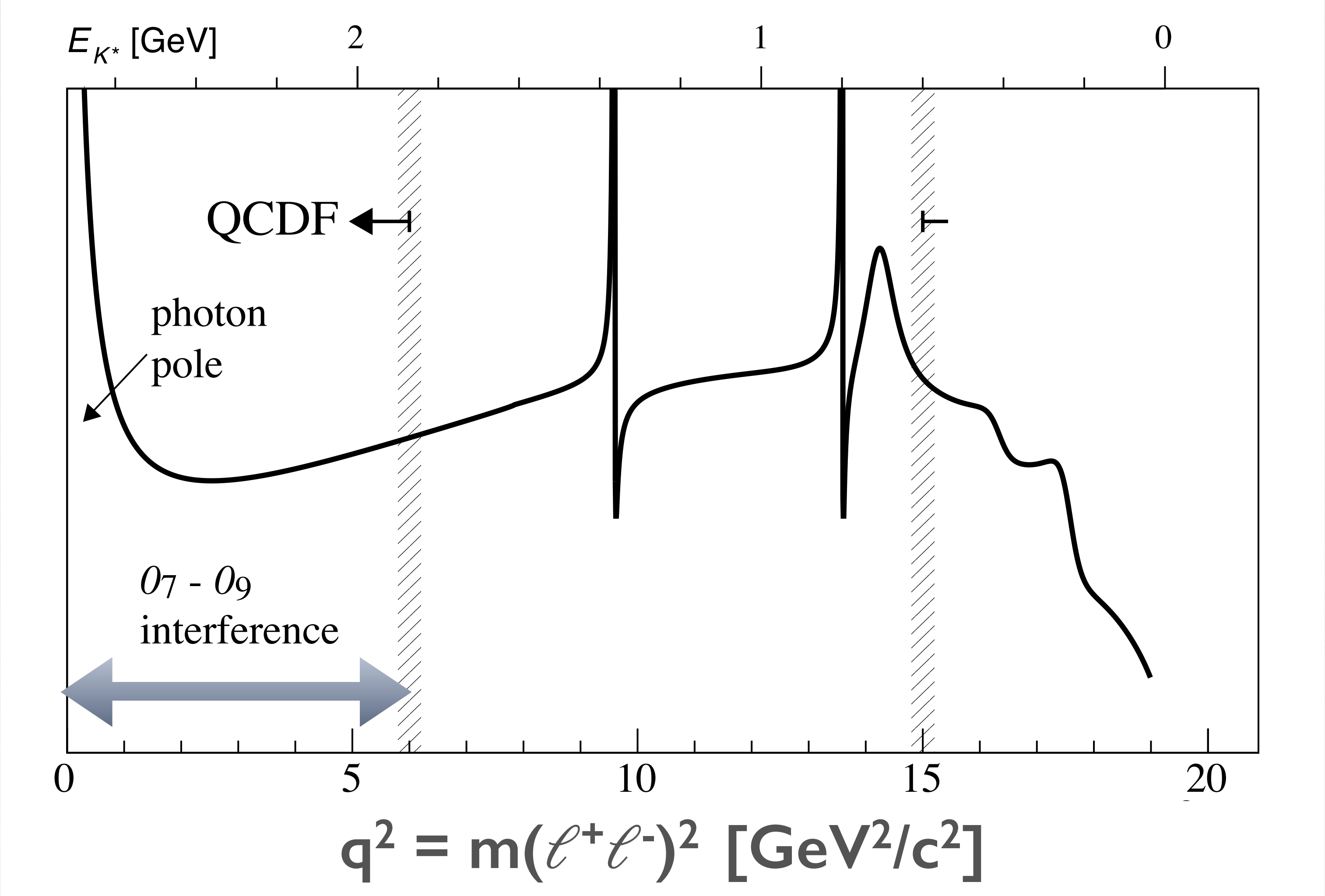
Low q^2

region of large hadron recoil

- photon pole → linked to C_7



- OPE in $1/E_h$ applies (SCET)
- up to open-charm threshold $2m_c \sim 7 \mathrm{GeV}^2/c^4$
- Interval 1-6 GeV^2/c^4 cleanest
  - ✓ Far from photon pole
  - ✓ Far from charm threshold



arXiv:1501.03309

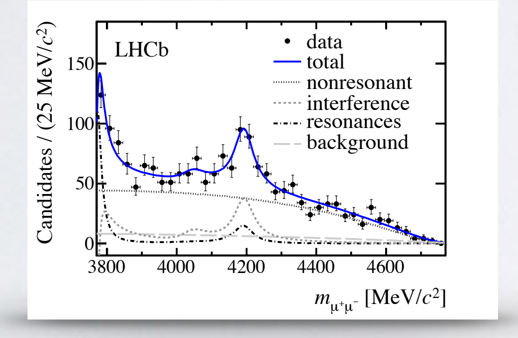
$q^2 = 0$	$E_{K^{*0}} >> \Lambda_{QCD}$	$q^2 \sim m^2_{J/\psi,\psi(2S)}$	$E_{K^{*0}} \sim \Lambda_{QCD}$	$q^2 = (m_B - m^{*0}_K)^2$
max. recoil	large recoil (SCET)	$c\bar{c}$ resonances	low recoil (HQET)	zero recoil

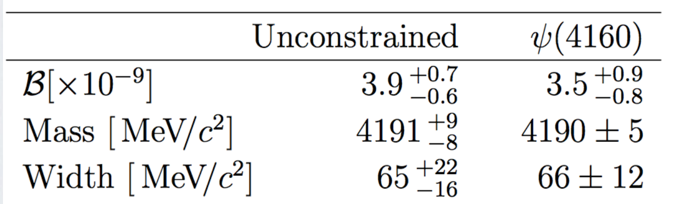
Phenomenology of b$\to s\ell^+\ell^-$ decays

High q^2

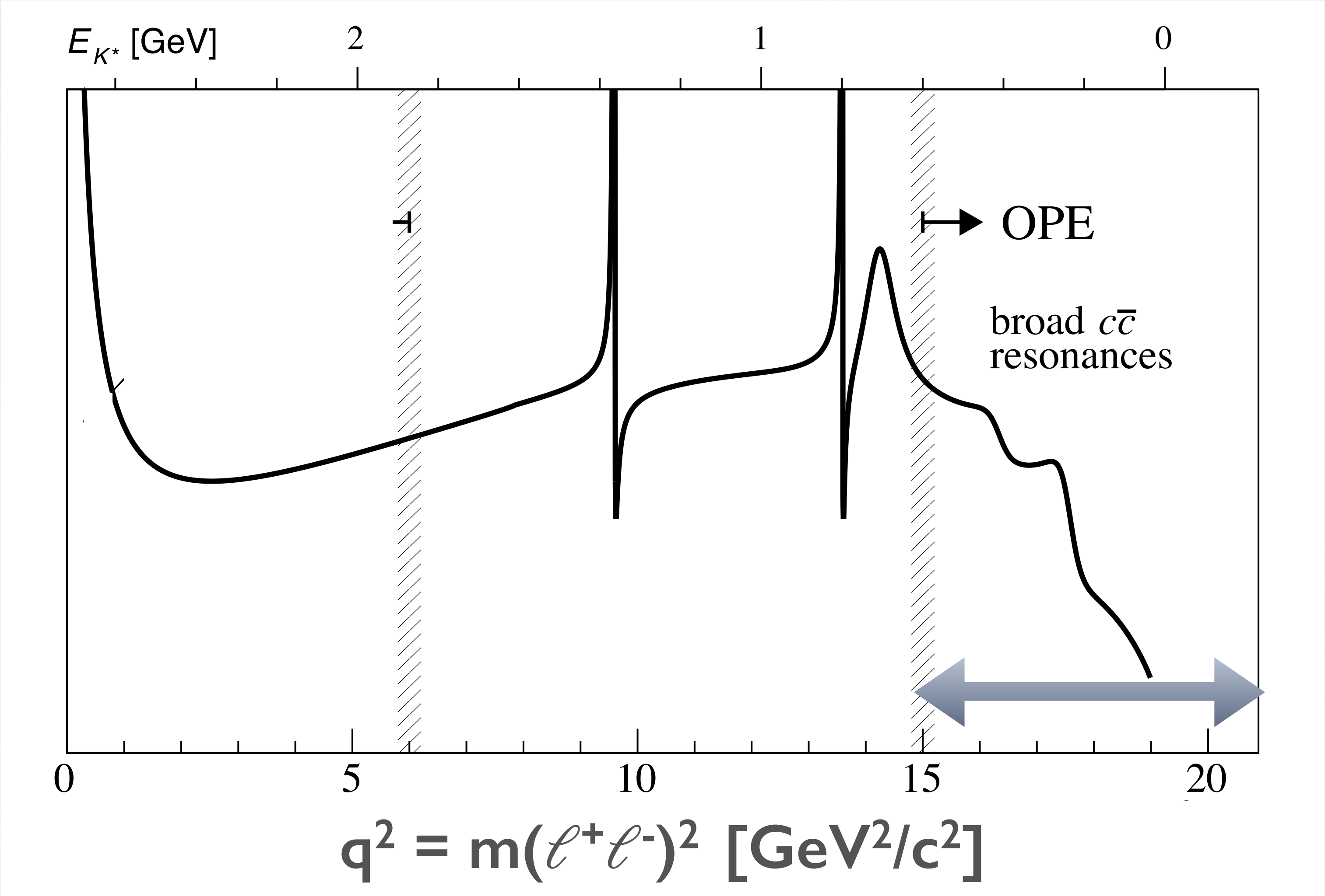
region of low hadron recoil

- can use limit $m_b \to \infty$
- OPE in $1/m_b$ applies (HQET)
- potential contribution from charm resonances





	Unconstrained	$\psi(4160)$
$\mathcal{B}[\times 10^{-9}]$	$3.9\,^{+0.7}_{-0.6}$	$3.5\,^{+0.9}_{-0.8}$
Mass [MeV/c^2]	$4191\,^{+9}_{-8}$	4190 ± 5
Width [MeV/c^2]	$65\,^{+22}_{-16}$	66 ± 12



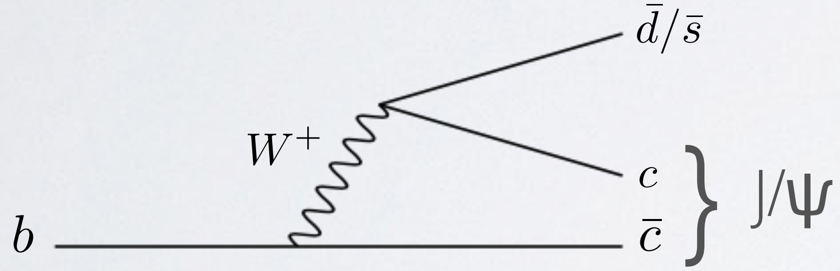
arXiv:1501.03309

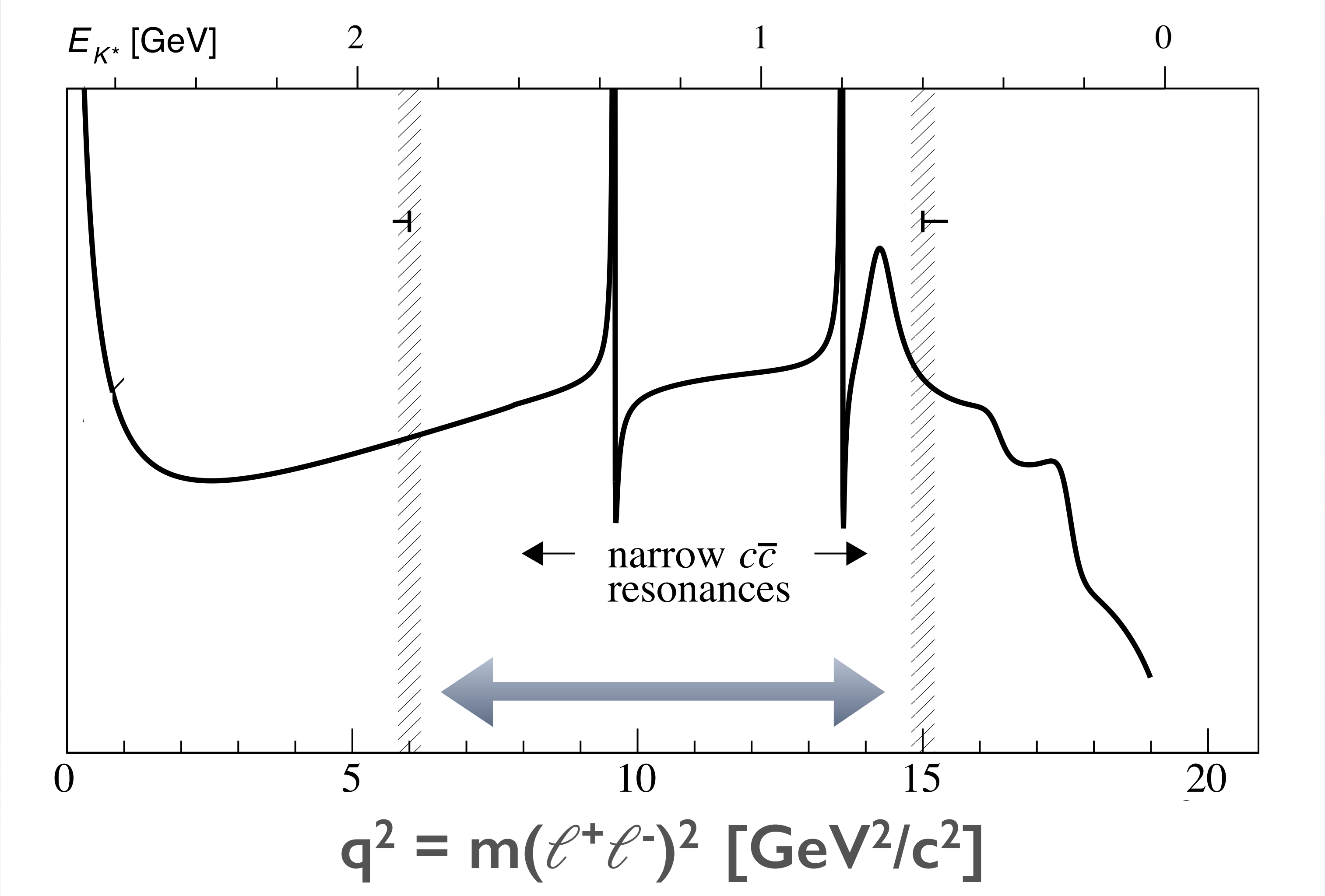
$q^2 = 0$	$E_{K^{*0}} >> \Lambda_{QCD}$	$q^2 \sim m^2_{J/\psi,\psi(2S)}$	$E_{K^{*0}} \sim \Lambda_{QCD}$	$q^2 = (m_B - m_K^{*0})^2$
max. recoil	large recoil (SCET)	$c\bar{c}$ resonances	low recoil (HQET)	zero recoil

Phenomenology of $b \to s\ell^+\ell^-$ decays

Central q^2

- Dominated by J/ψ and ψ(2S)
- Charm resonances through tree level b→scc transitions
- No predictions possible
- Vetoed experimentally





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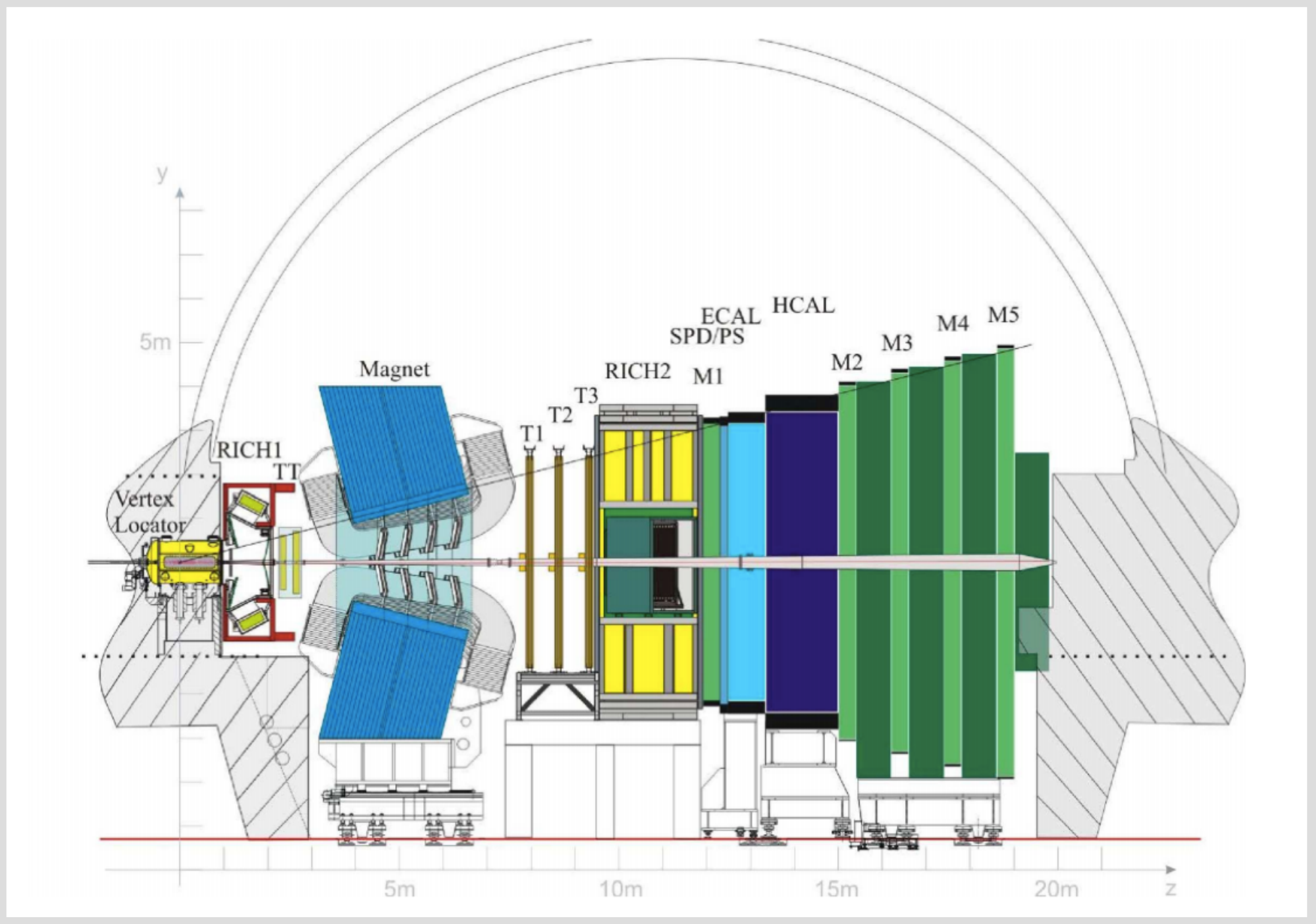
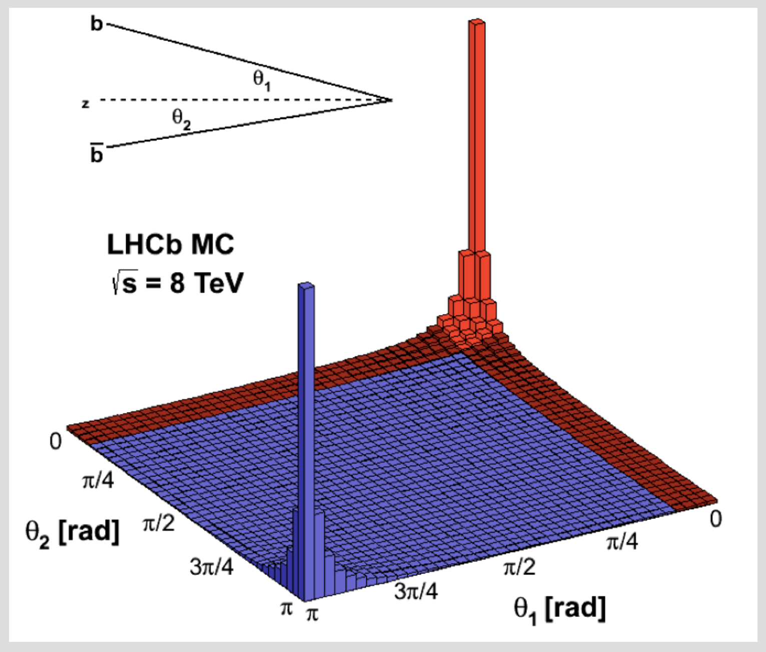
The LHCb detector





JINST 3 (2008) S08005

Forward geometry optimised for for b and c decays.

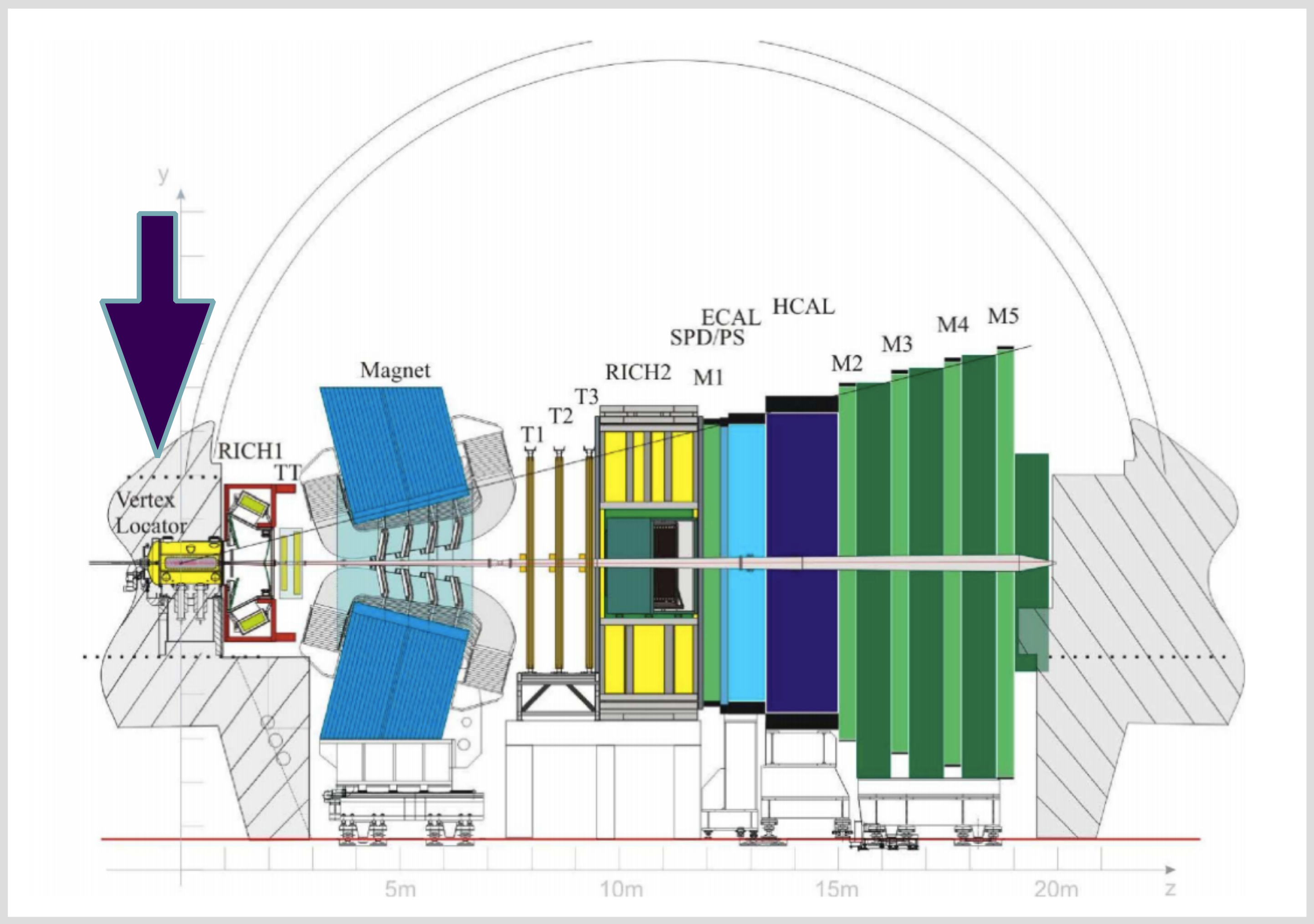
Fully instrumented in 2 < η < 5

Cleanest LHC events: <Pile-Up> ~ 2 in Run I

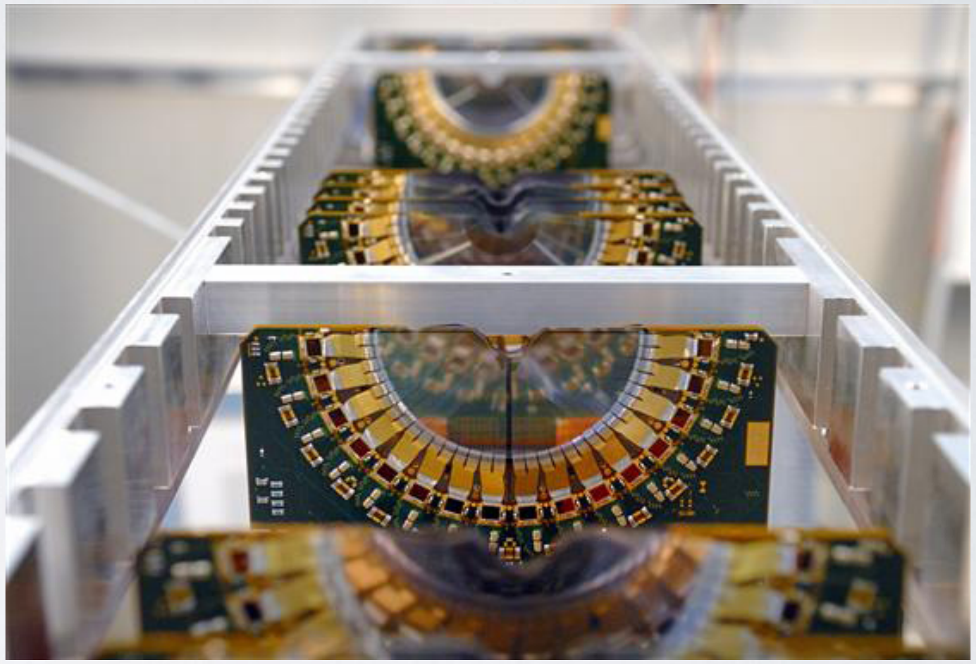
3fb^{-1} collected: 1fb^{-1} in 2011 at TeV and 2fb^{-1} in 2012 at 8TeV

The LHCb detector

JINST 3 (2008) S08005

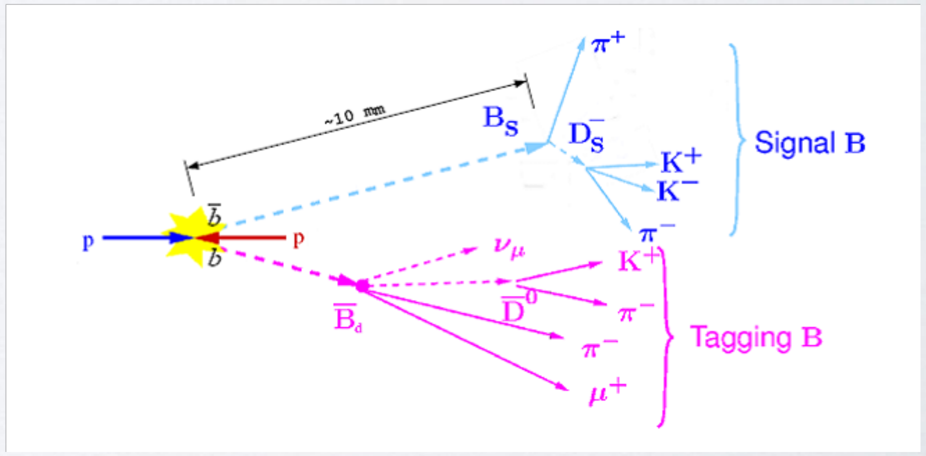


VeLo



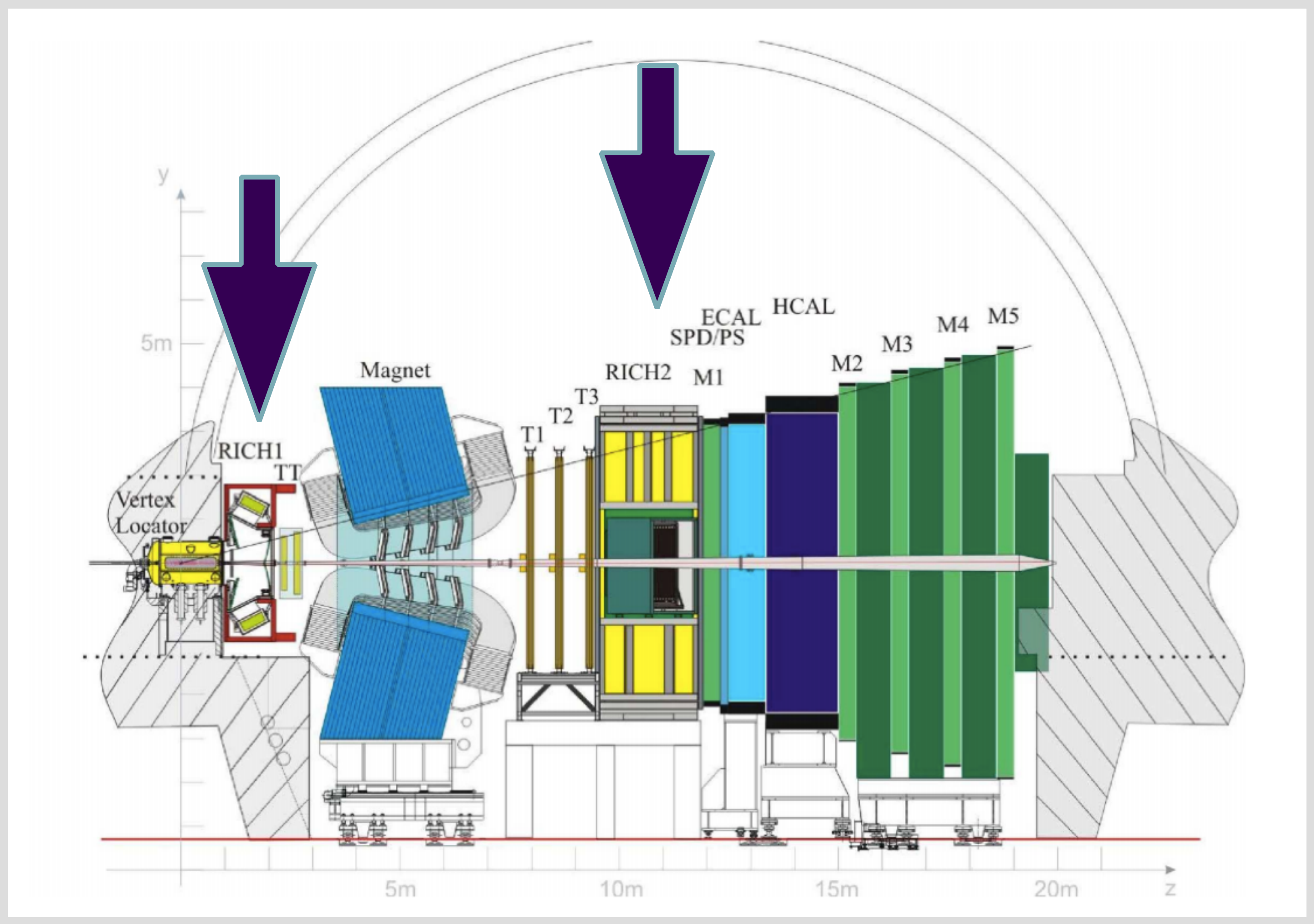
Silicon tracker → Needed for precise determination of secondary vertices

B mesons travel ~1cm into the detector. VeLo is essential to reconstruct secondary vertices of B and D hadrons.



The LHCb detector

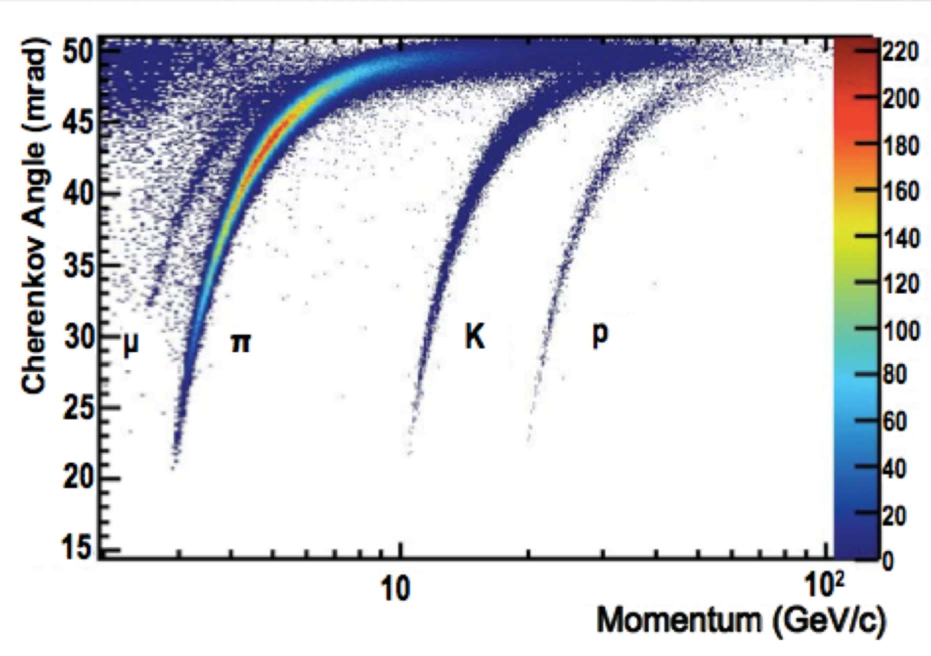
JINST 3 (2008) S08005

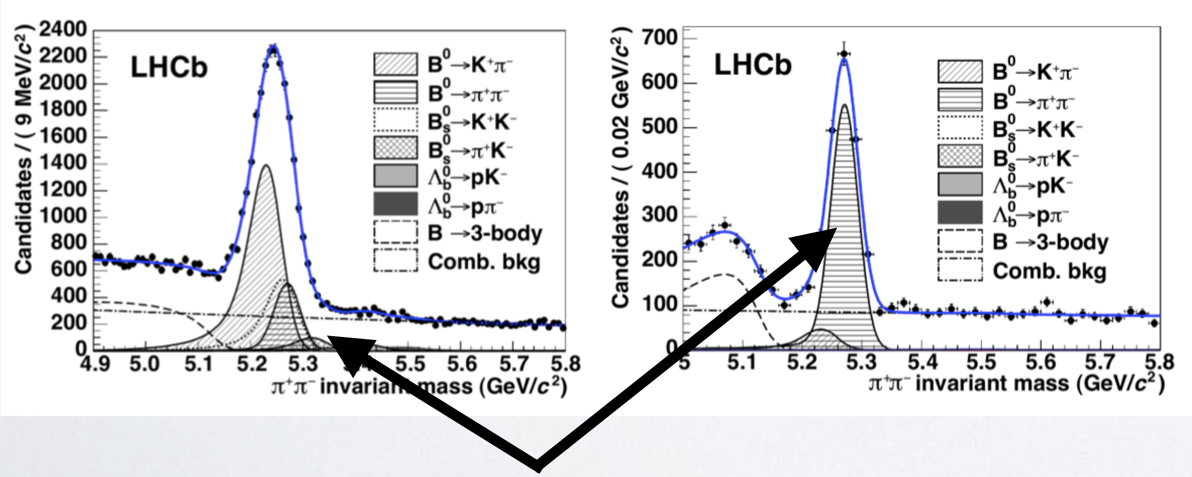


RICH

RICH I: before magnet
for 1 < p < 70 GeV/c
RICH II: before magnet
for 20 < p < 200 GeV/c

Provide particle ID

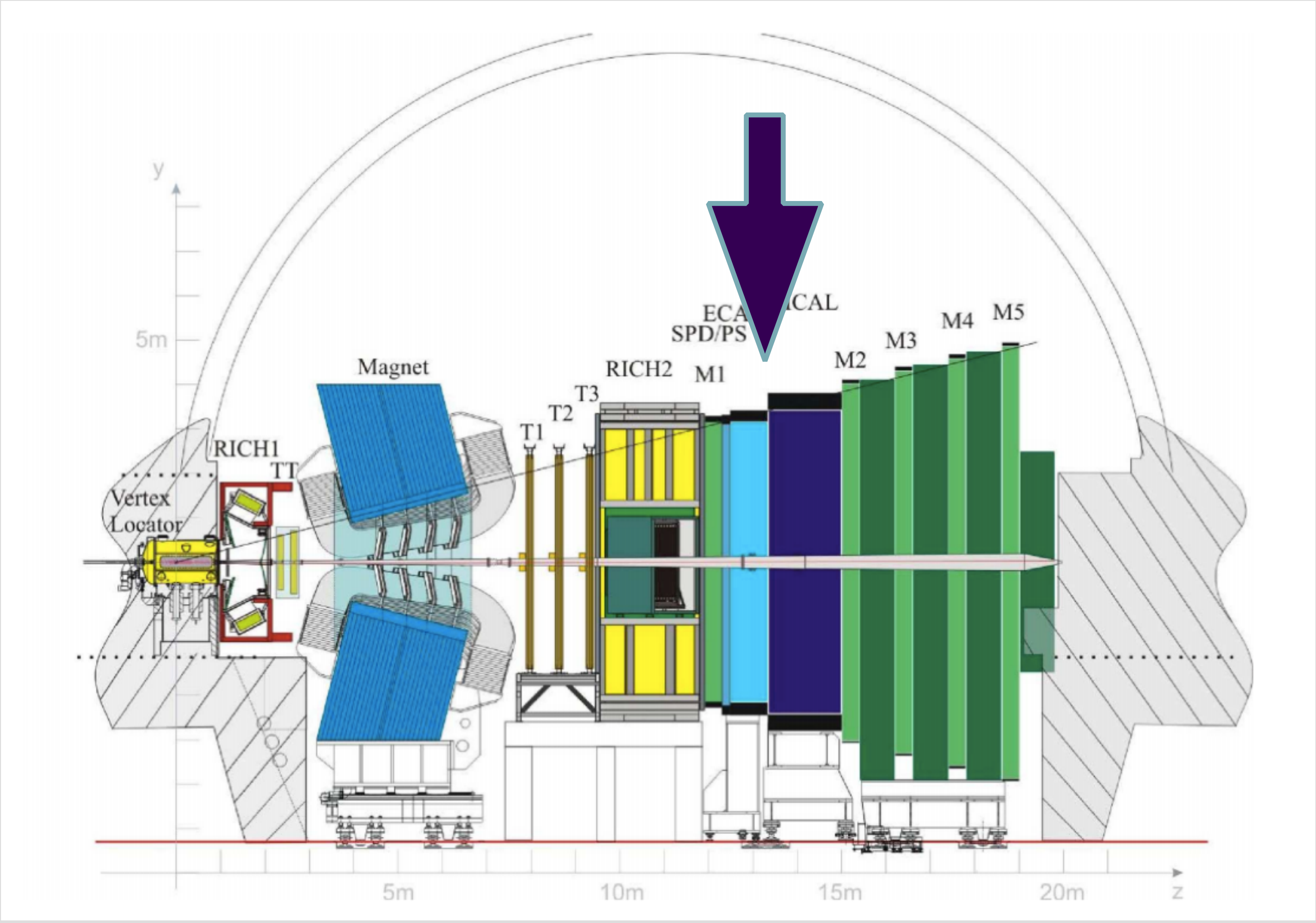




Essential to distinguish kinematically similar decays with different final states

The LHCb detector

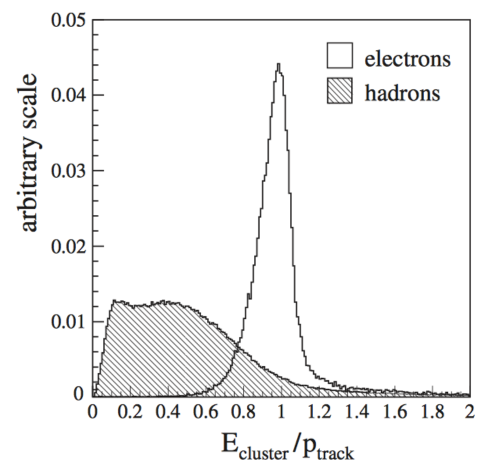
JINST 3 (2008) S08005

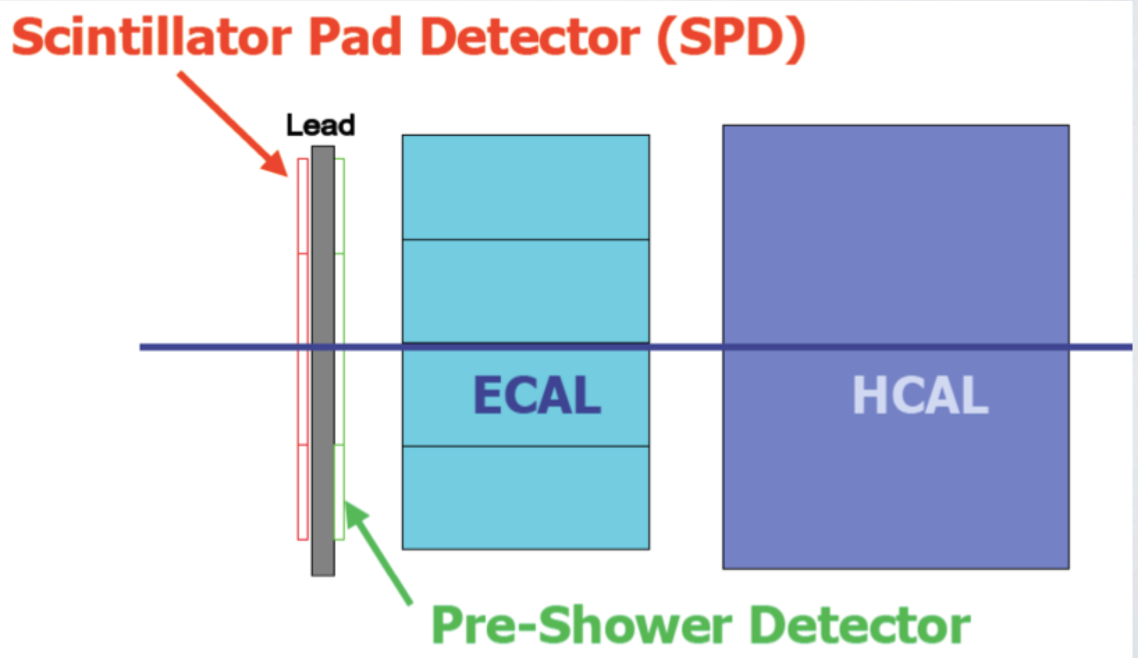


Calorimeters

PD for charged pions rejection
SPD for neutral pions rejection
ECAL fully contains electrons
HCAL for hadrons ID

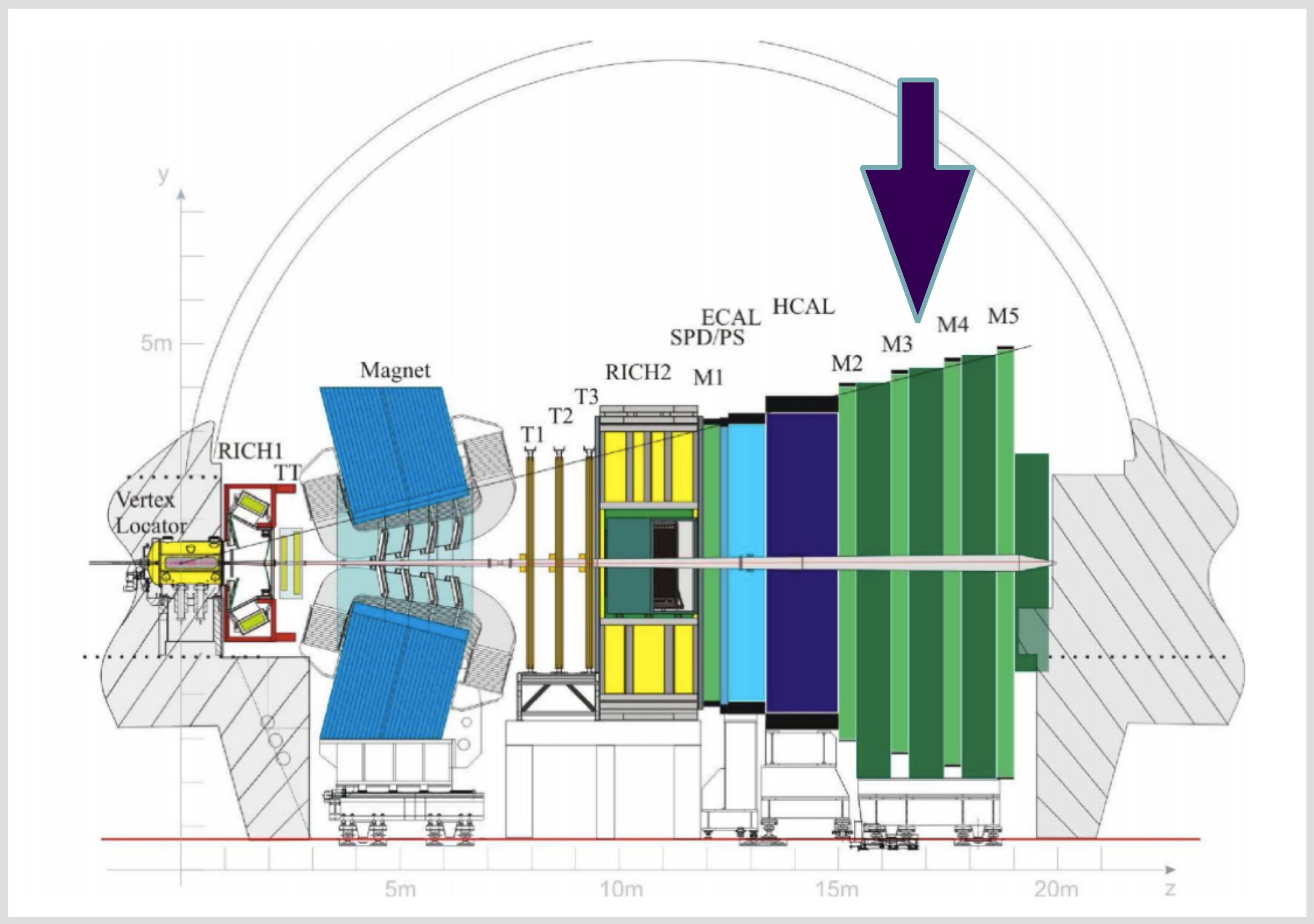
Example of e/h discrimination





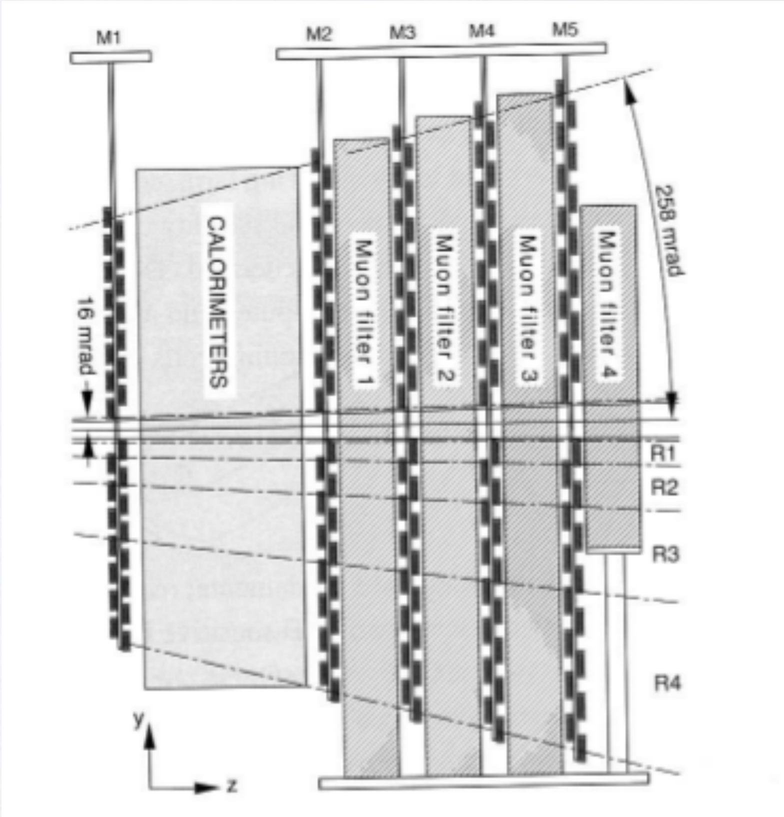
The LHCb detector

JINST 3 (2008) S08005



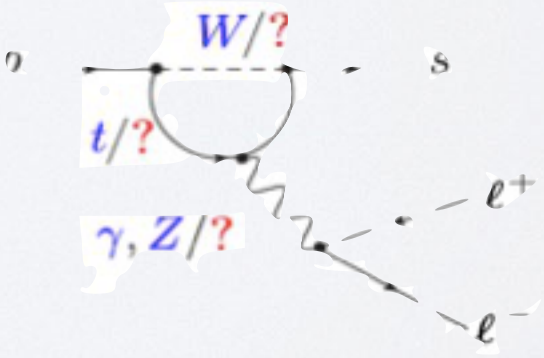
Muon detector

5 tracking station separated by iron layers
Drift tubes in the outer region
GEM in the inner region due to higher track density



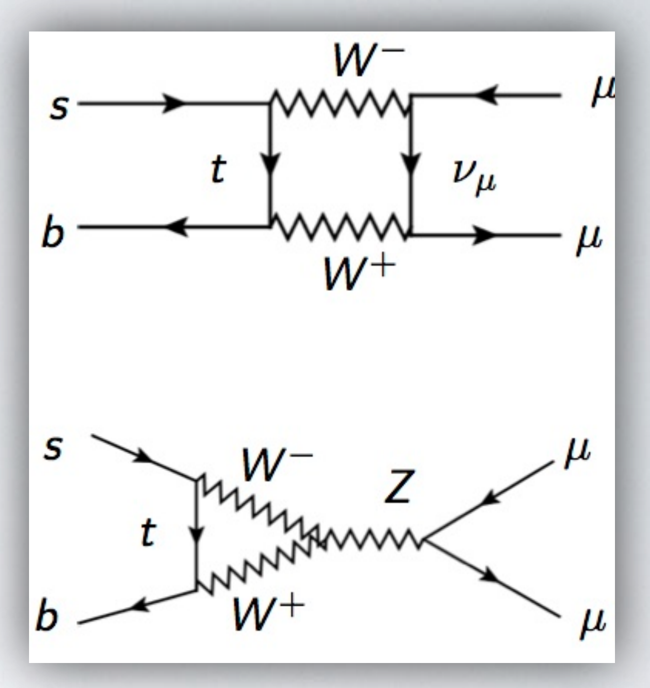
Each station has 95% efficiency.
Provides good triggering.
Only 10 GeV/c muons pass through.

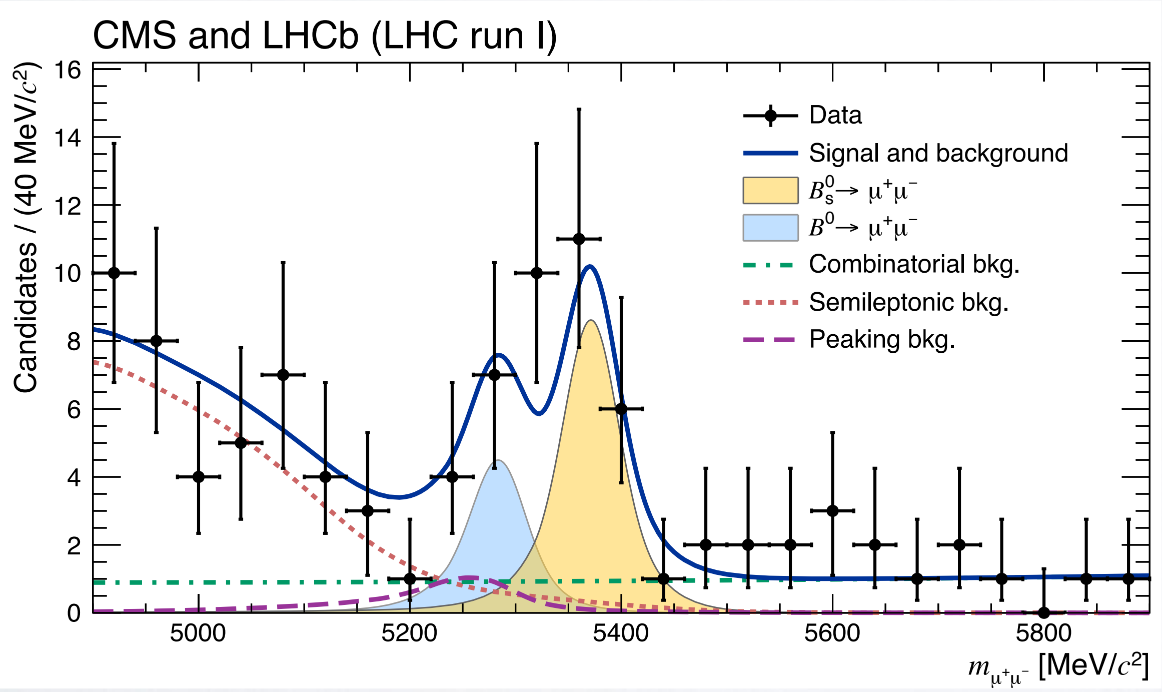
Recent results



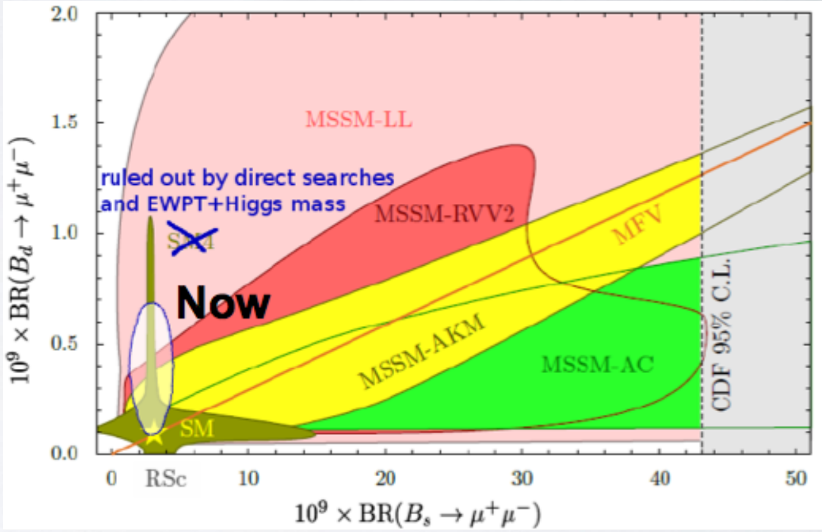
$B(B_{d/s} \rightarrow \mu^+\mu^-)$

- Highly suppressed in the SM FCNC + CKM + helicity
- Possible tree level BSM contributions ⇒ very sensitive
- Leptonic decay (no hadronic uncertainties)
  → Very well predicted $B(B_s \rightarrow \mu\mu) = (3.56 \pm 0.30) \cdot 10^{-9}$
- Combined measurement by LHCb and CMS





Nature 522 (2015) 68–72, [arXiv:1411.4413].



$$\mathcal{B}(B^0_s \rightarrow \mu^+\mu^-) = (2.8^{+0.7}_{-0.6}) \times 10^{-9}$$

$$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) = (3.9^{+1.6}_{-1.4}) \times 10^{-10}$$

Compatible with the SM.
Highly constrains SUSY.

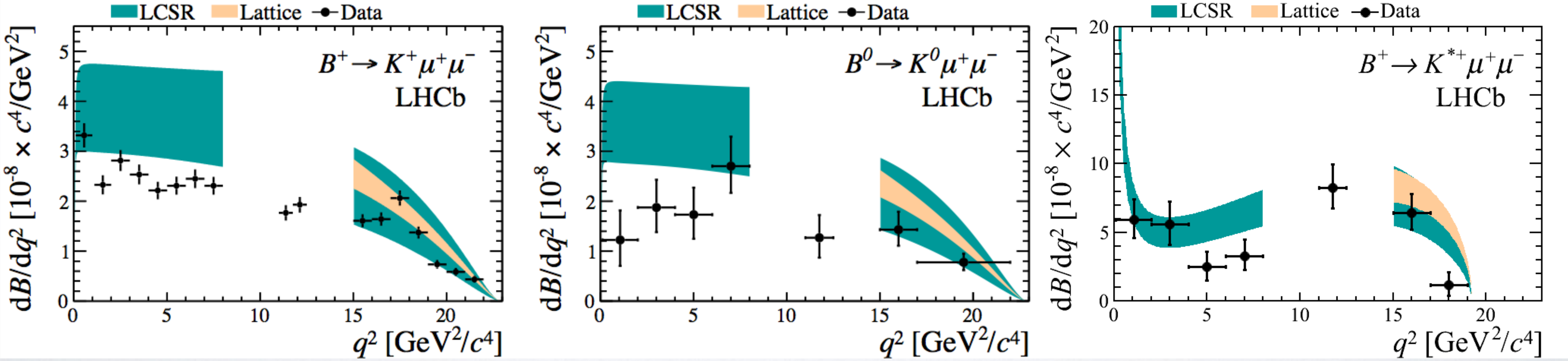
Observables in $B \to K^{(*)}\mu\mu$ decays

- Decay rates of $B \to K^{(*)}\mu\mu$ decays: sensitive to new physics entering the loops
- Single measurements more precise than current world average!
- All compatible with SM but also all slightly lower.

JHEP 06 (2014) 133,
[arXiv:1403.8044]

$$\begin{aligned}
\mathcal{B}(B^+ \to K^+\mu^+\mu^-) &= (4.29 \pm 0.07\,(\text{stat}) \pm 0.21\,(\text{syst})) \times 10^{-7},\\
\mathcal{B}(B^0 \to K^0\mu^+\mu^-) &= (3.27 \pm 0.34\,(\text{stat}) \pm 0.17\,(\text{syst})) \times 10^{-7},\\
\mathcal{B}(B^+ \to K^{*+}\mu^+\mu^-) &= (9.24 \pm 0.93\,(\text{stat}) \pm 0.67\,(\text{syst})) \times 10^{-7}.
\end{aligned}$$

Extrapolating below J/ψ assuming distribution as in PRD 61 (2000) 074024



Observables in B→K$^{(*)}$μμ decays

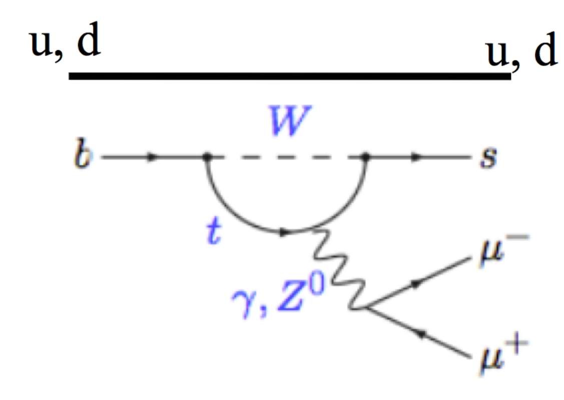
- Large uncertainties in B→K$^{(*)}$ form factors calculations affect predictions
    - ➡ to maximise sensitivity measure asymmetries and ratios where the leading form factor cancel: e.g. isospin asymmetry

JHEP 06 (2014) 133,
[arXiv:1403.8044]

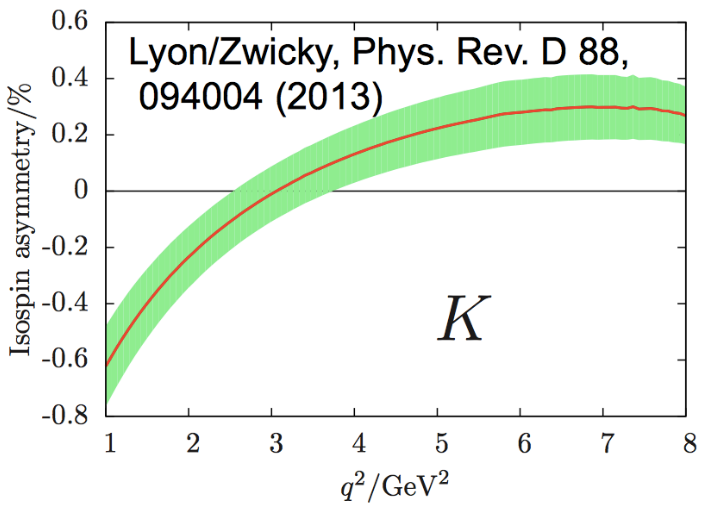
$$A_I = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - (\tau_0/\tau_+)\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + (\tau_0/\tau_+)\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

Two ratios are measured for K and K*

B^0 over B^+ lifetimes ratio



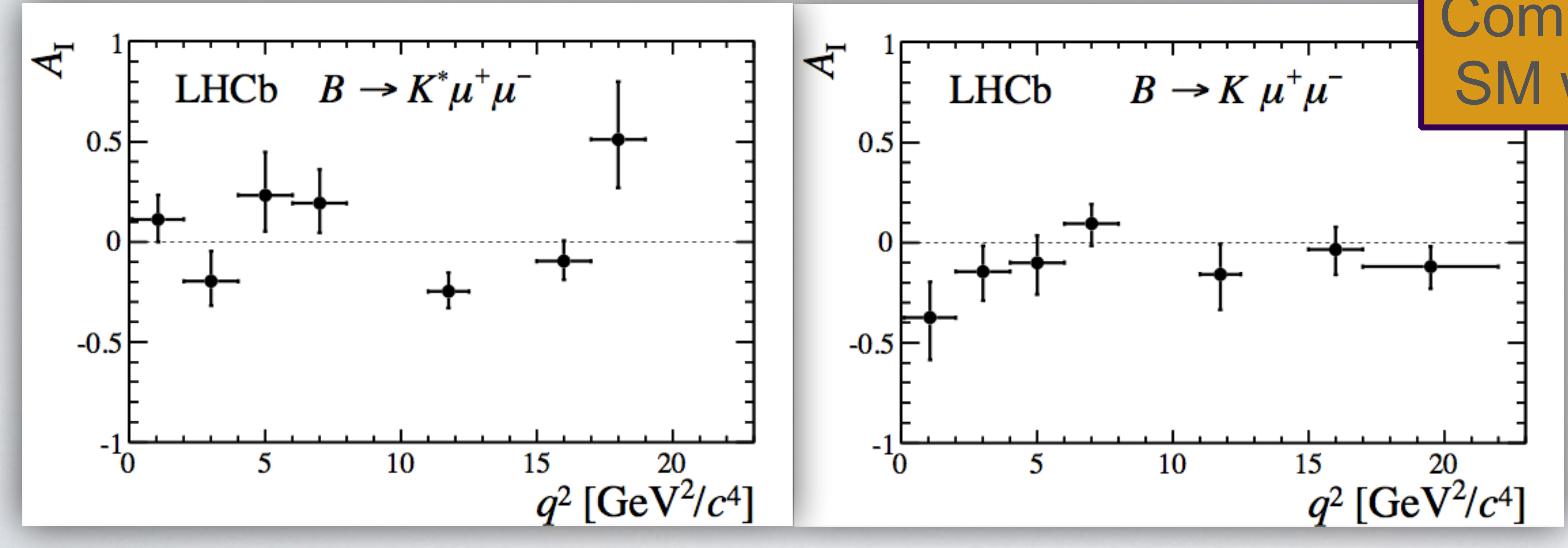
- Same quark level transition but charge different light spectator quark
- A_I ~ O(1%) in SM (≠0 for m_q/m_b corrections)


Lyon/Zwicky, Phys. Rev. D 88, 094004 (2013)

Observables in B→K$^{(*)}$μμ decays

$$\frac{B \to K^{(*)}\mu^+\mu^-}{B \to K^{(*)}(J/\psi \to \mu^+\mu^-)}$$

- B$^+$/B^0 production asymmetry can bias the result
  - B-factories assumed null B$^+$/B^0 production asymmetry
  - LHCb: J/ψ modes used for normalisation
  - J/ψ channels have same final daughters → cancellations of systematics
- A = 0 tested against simplest alternative: constant different than zero.

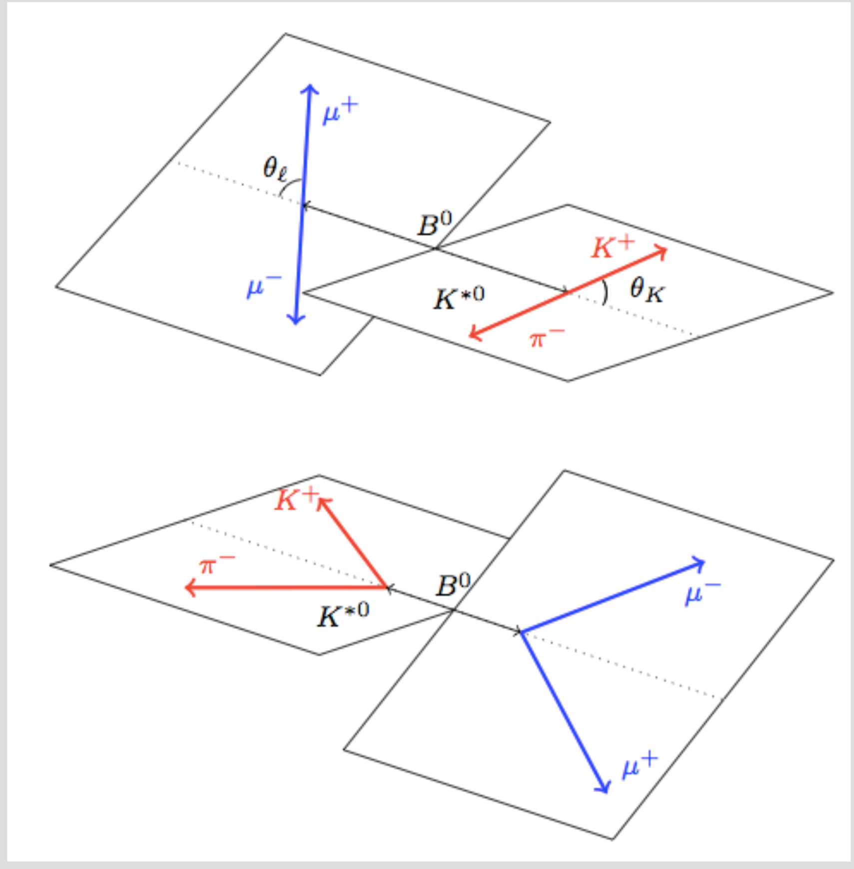


Compatible with SM within 1.5σ

JHEP 06 (2014) 133, [arXiv:1403.8044]

$B^0 \to K^{*0}\mu\mu$ angular analysis

- Angular distributions described by 3 angles: θ_l, θ_K, ϕ
- Distributions depend on:
  - ✓ Wilson coefficients: sensitive to new physics :-)
  - ✓ and form factors :-(
- Measure variables with reduced form factor uncertainties (JHEP, 05, 2013, 137)



JHEP 08 (2013) 131, [arXiv:1304.6325]
Phys. Rev. Lett. 111 (2013) 191801

$$P'_{(4,5,6,8)} = \frac{S_{(4,5,7,8)}}{\sqrt{F_L(1-F_L)}}$$

F_L = fraction of longitudinally polarised dimuons

$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_l d\cos\theta_K d\phi dq^2} = \frac{9}{32\pi}[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_l$$
$$-F_L\cos^2\theta_K\cos 2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_l\cos\phi$$
$$+S_5\sin 2\theta_K\sin\theta_l\cos\phi + S_6\sin^2\theta_K\cos\theta_l + S_7\sin 2\theta_K\sin\theta_l\sin\phi$$
$$+S_8\sin 2\theta_K\sin 2\theta_l\sin\phi + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi]$$

$B^0 \to K^{*0}\mu\mu$ angular analysis

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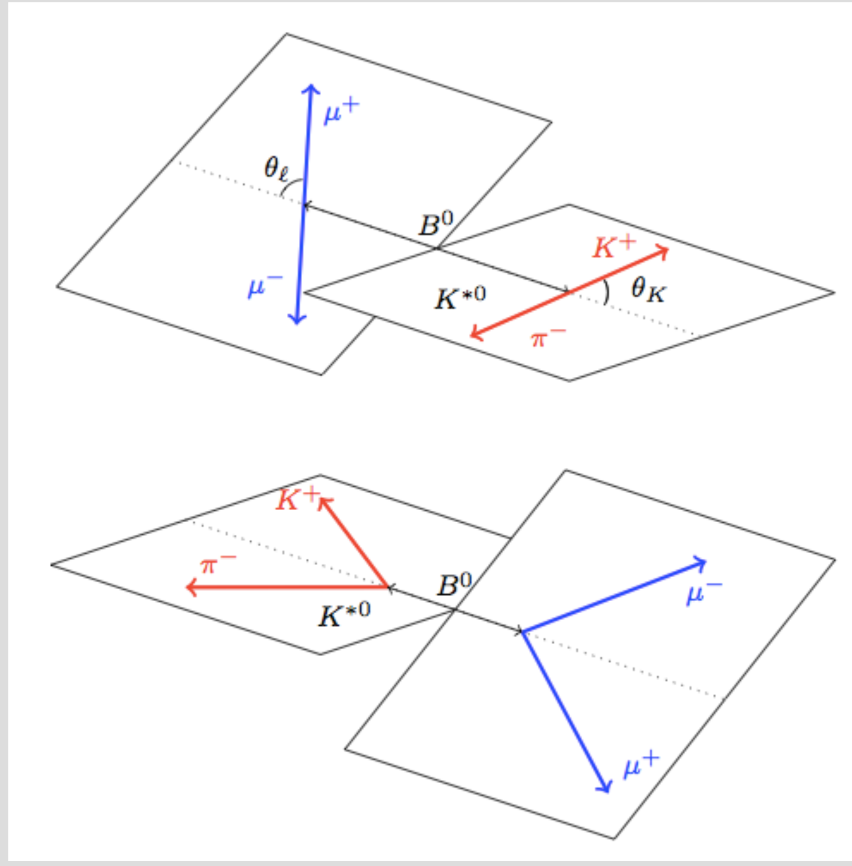

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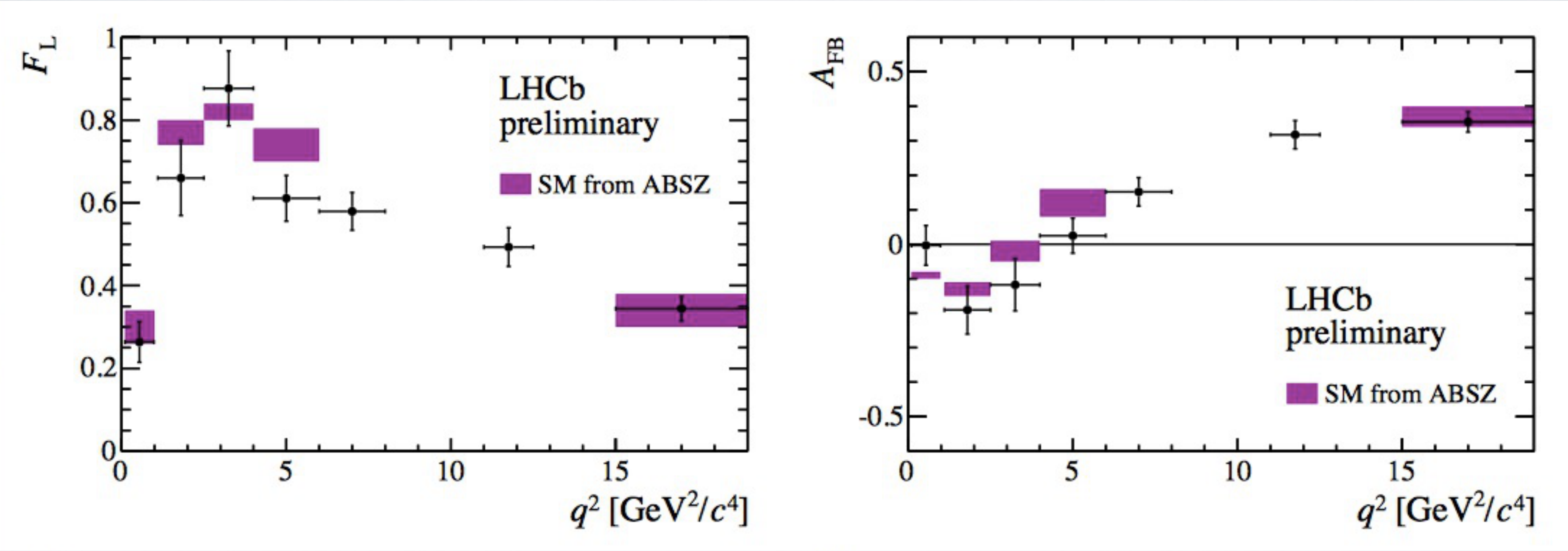
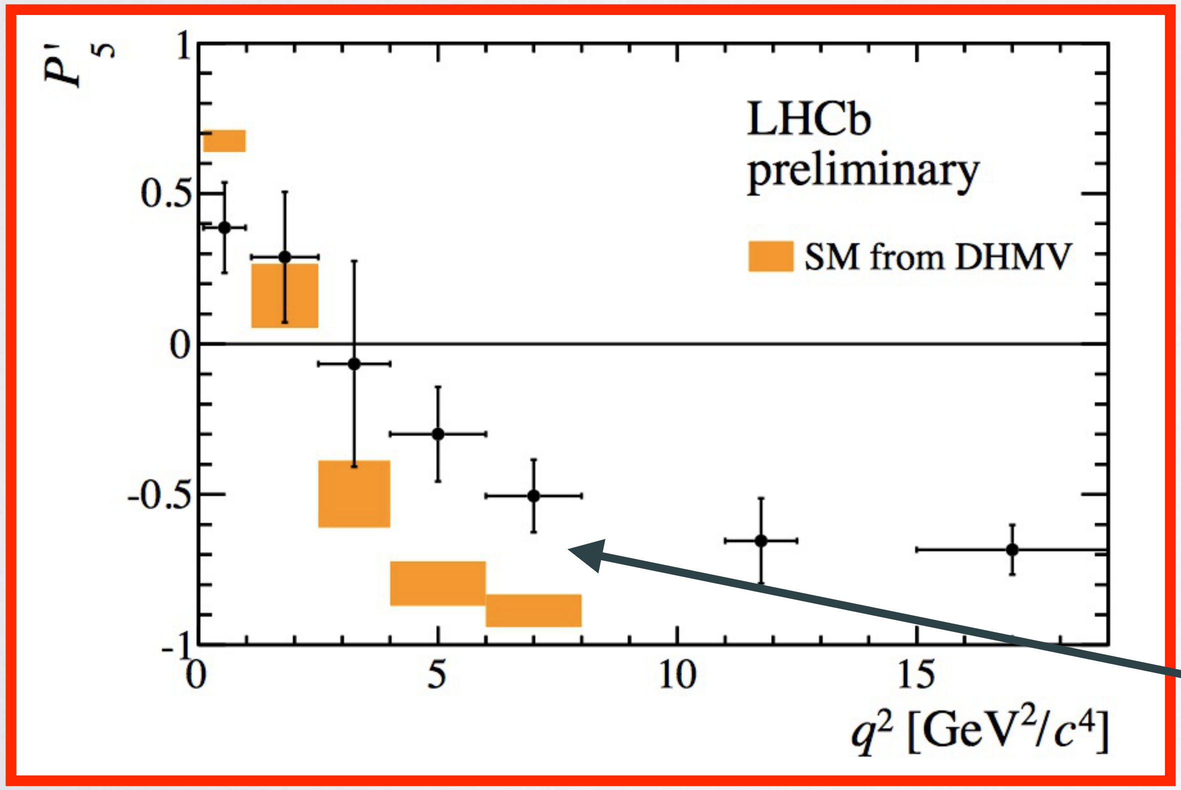
$$-F_L\cos^2\theta_K\cos 2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_l\cos\phi$$
$$+S_5\sin 2\theta_K\sin\theta_l\cos\phi + S_6\sin^2\theta_K\cos\theta_l + S_7\sin 2\theta_K\sin\theta_l\sin\phi$$
$$+S_8\sin 2\theta_K\sin 2\theta_l\sin\phi + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big]$$

$B^0 \to K^{*0}\mu\mu$ angular analysis



JHEP 08 (2013) 131, [arXiv:1304.6325]
LHCb-CONF-2015-002



Many observables found to be in agreement with the SM predictions

BUT

Local 3.7σ deviation on P'_5 found on 2011 data and confirmed on 2012.

Lepton Universality and R_H

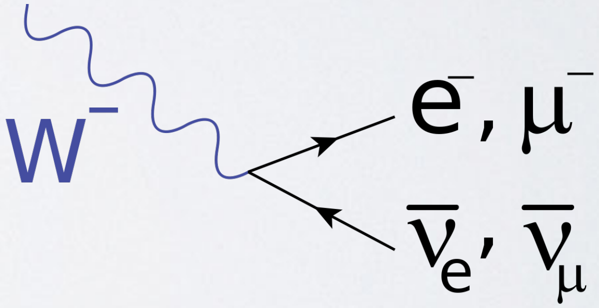
- **Lepton universality**: equality of the EW couplings for leptons
- Idea: test it using suppressed decays, where there is space for new physics

PhysRevLett.113.151601
arXiv:1406.6482

$$R_H = \frac{\int_{4m_\mu^2}^{m_b} \frac{d\mathcal{B}(B\to H\mu^+\mu^-)}{dq^2}}{\int_{4m_\mu^2}^{m_b} \frac{d\mathcal{B}(B\to He^+e^-)}{dq^2}} dq^2$$

$$q^2_{max} \sim m_b^2$$
$$q^2_{min} \sim 4m_\mu^2$$
$$H = K, K^{*0}, \phi, \ldots$$

- Universality → $R_K \sim 1$ with $o((m_\mu/m_b)^2)$ corrections (JHEP 12 (2007) 040)
- Hadronic uncertainties cancel in the ratio
  - ➡ precisely predicted: $R_K = 1.0 \pm 0.0001$

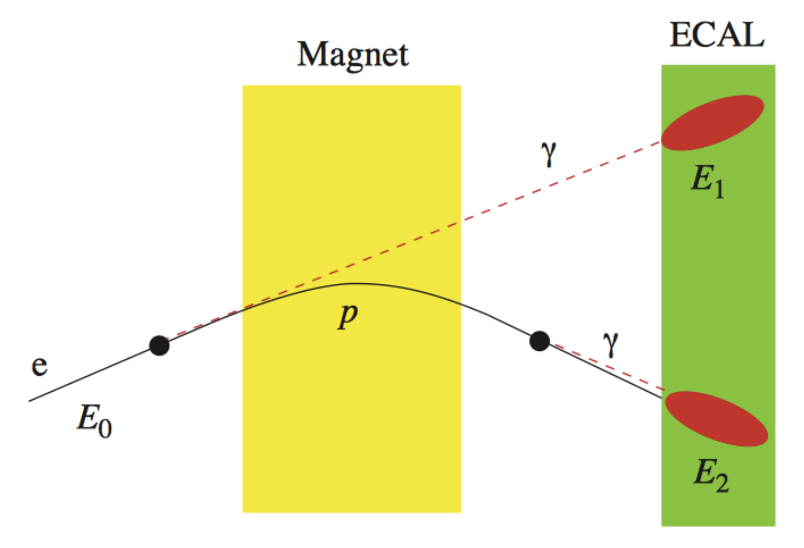


Belle ⇒ $R_K = 0.74^{+0.46}_{-0.37}$ PRL 103 (2009) 171801

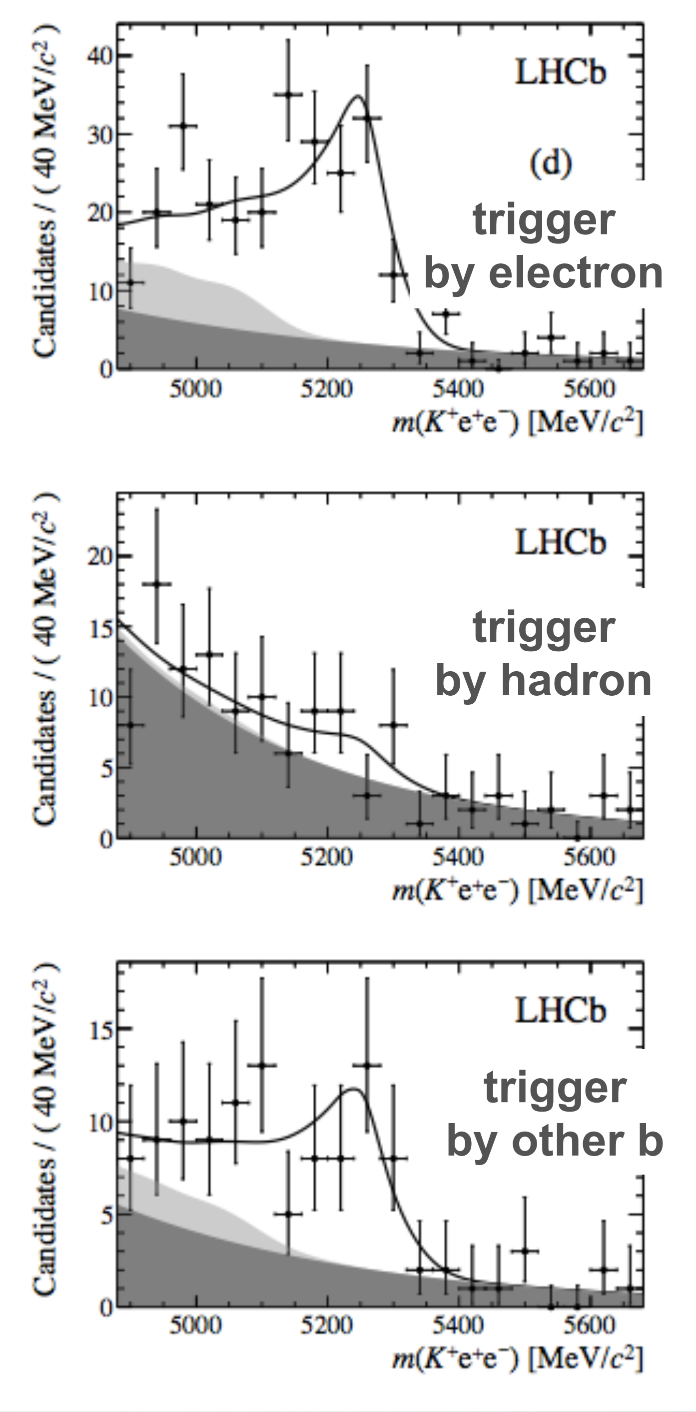
BaBar ⇒ $R_K = 1.03 \pm 0.25$ PRD 86 (2012) 032012

The R_K measurement

- The ee channels are the challenge in this analysis:
  - **Bremsstrahlung** affects the e momentum
    → energy recovered looking at calorimeter hits



PhysRevLett.113.151601
arXiv:1406.6482



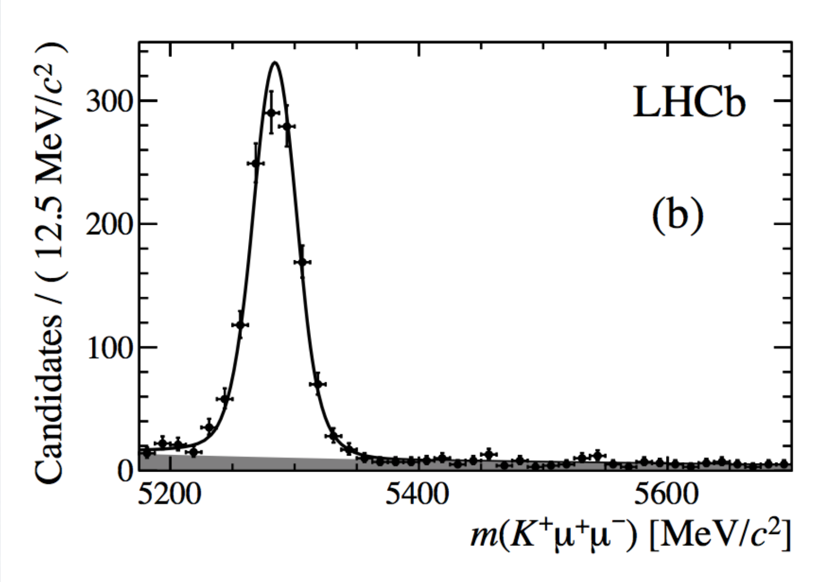
trigger
by electron

trigger
by hadron

trigger
by other b

  - **Low trigger efficiency**
    → Use events triggered by the electrons, by the hadrons and by other particles in the event

The R_K measurement

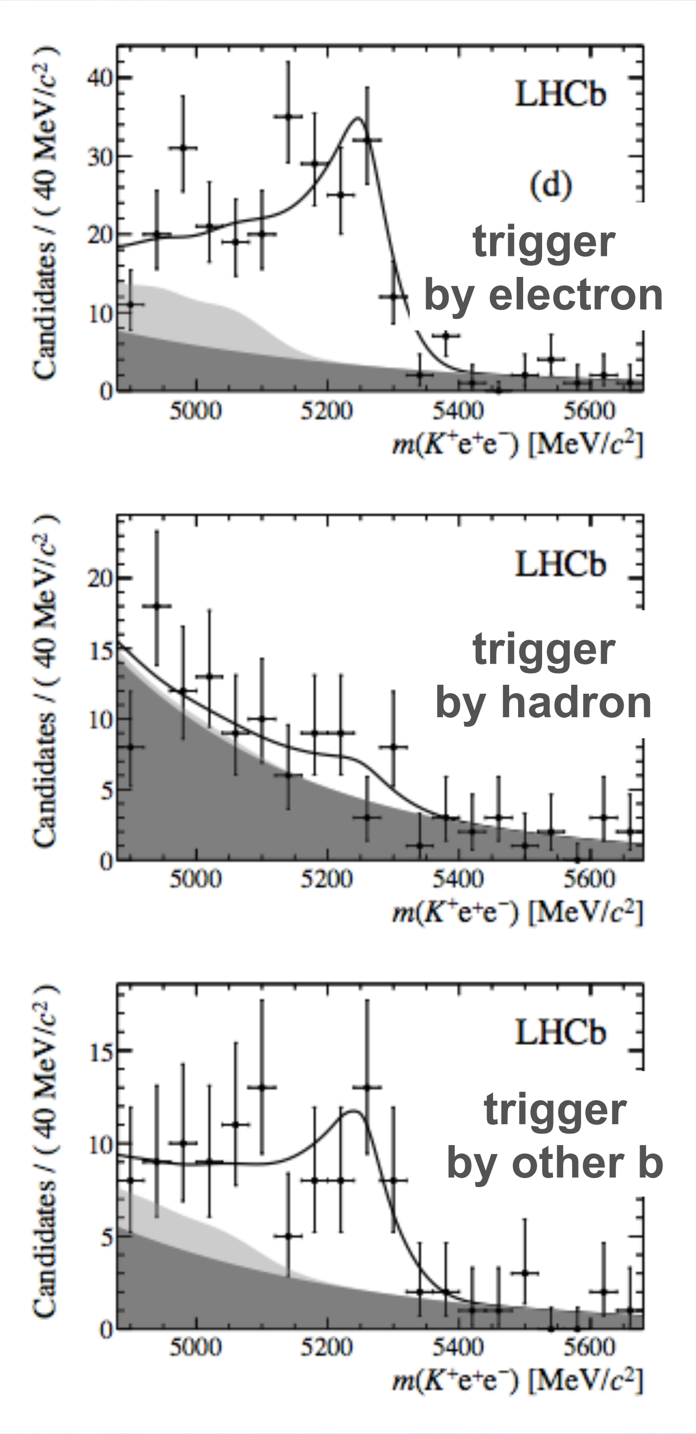


← **Kμμ** triggered by muons

1266 ± 41 evts

Kee in 3 categories →

172 + 20 + 62 evts



trigger by electron

trigger by hadron

trigger by other b

$$R_K = 0.745^{+0.090}_{-0.074}\,(\text{stat})\,^{+0.036}_{-0.036}\,(\text{syst}),$$

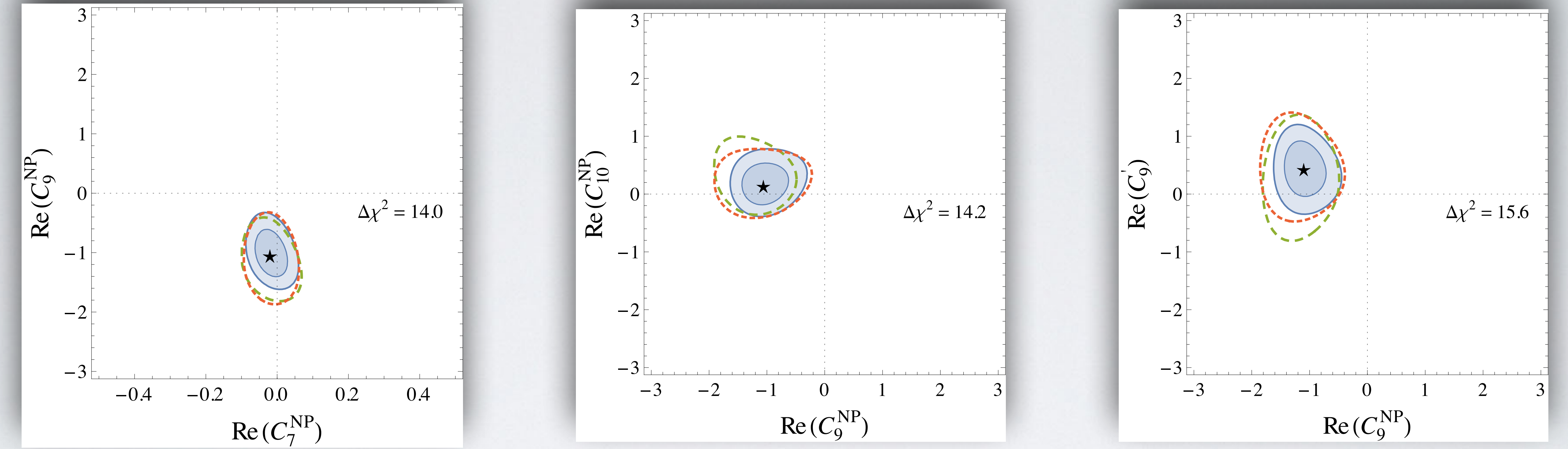
2.6σ from the SM

PhysRevLett.113.151601
arXiv:1406.6482

The *ee* BR is also reported:

$$B(B^+ \to K^+e^+e^-) = (1.56\,^{+0.19}_{-0.15}\,^{+0.06}_{-0.04}) \times 10^{-7}\ ,$$

Global fits



Coefficient	Best fit	1σ	3σ	Pull_{SM}
$\mathcal{C}_9^{\text{NP}}$	−1.13	[−1.33, −0.91]	[−1.72, −0.42]	**4.6**

Presented at moriond 2015

- Global fits including information from many results combining many observables.

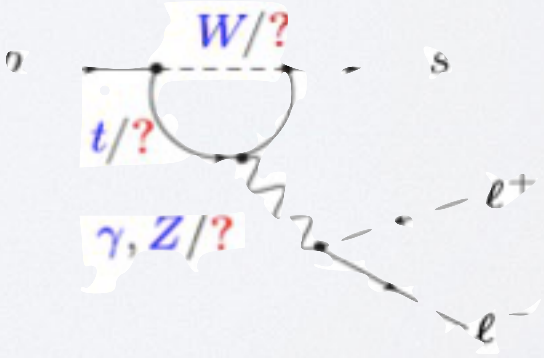
[S. Descotes-Genon et al. PRD 88, 074002] [Altmannshofer et al. arxiv:1411.3161] [Beaujean et al. EPJC 74 2897]

  - A consistent picture can be built putting most results in agreement
  - Possible explanation with Z’ bosons.
  - Based on assumptions

    → we need more data to be sure

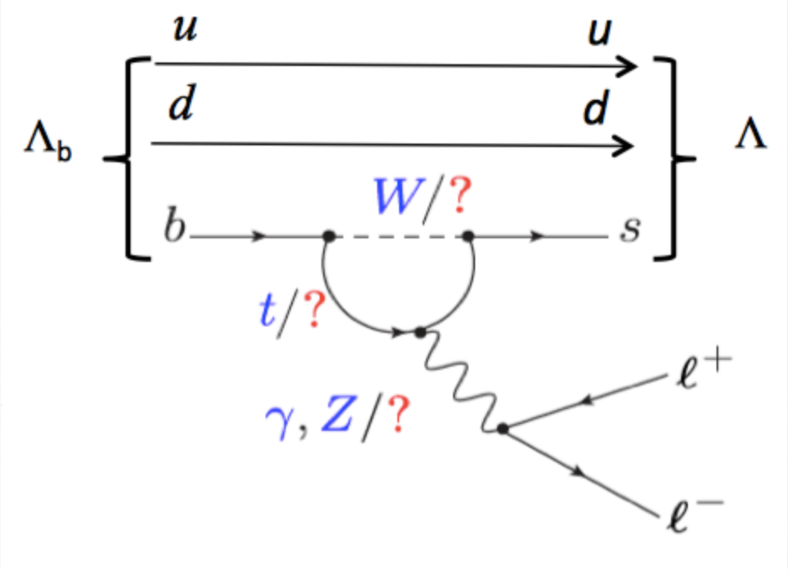
A shift of C_9 by -1 is favoured with respect to the SM

The analysis of the rare $\Lambda_b \rightarrow \Lambda^0 \mu\mu$ decay



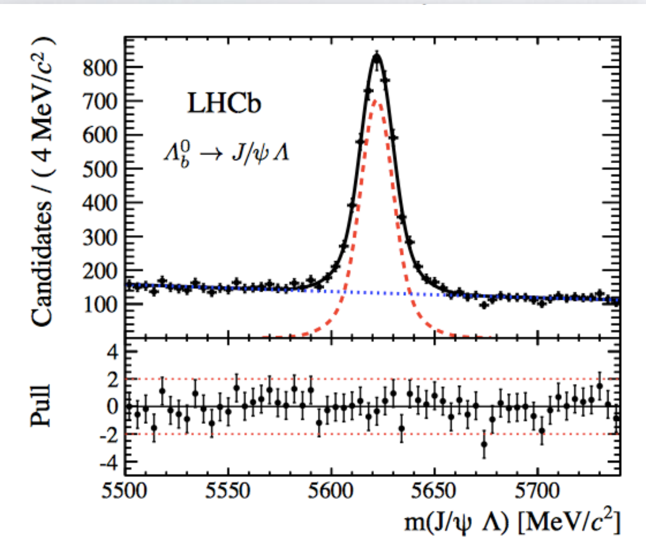
Rare decays and $\Lambda_b \to \Lambda^0 \mu\mu$

- Λ_b has non-zero spin:
  → complementary wrt B mesons
- Particular hadronic physics (heavy quark + diquark)
  → independent form factors



T. Gutsche et al., PRD87 (2013) 074031

$\Lambda_b \to \Lambda^0 \mu\mu$ is a FCNC
$b \to s$ transition: rare decay

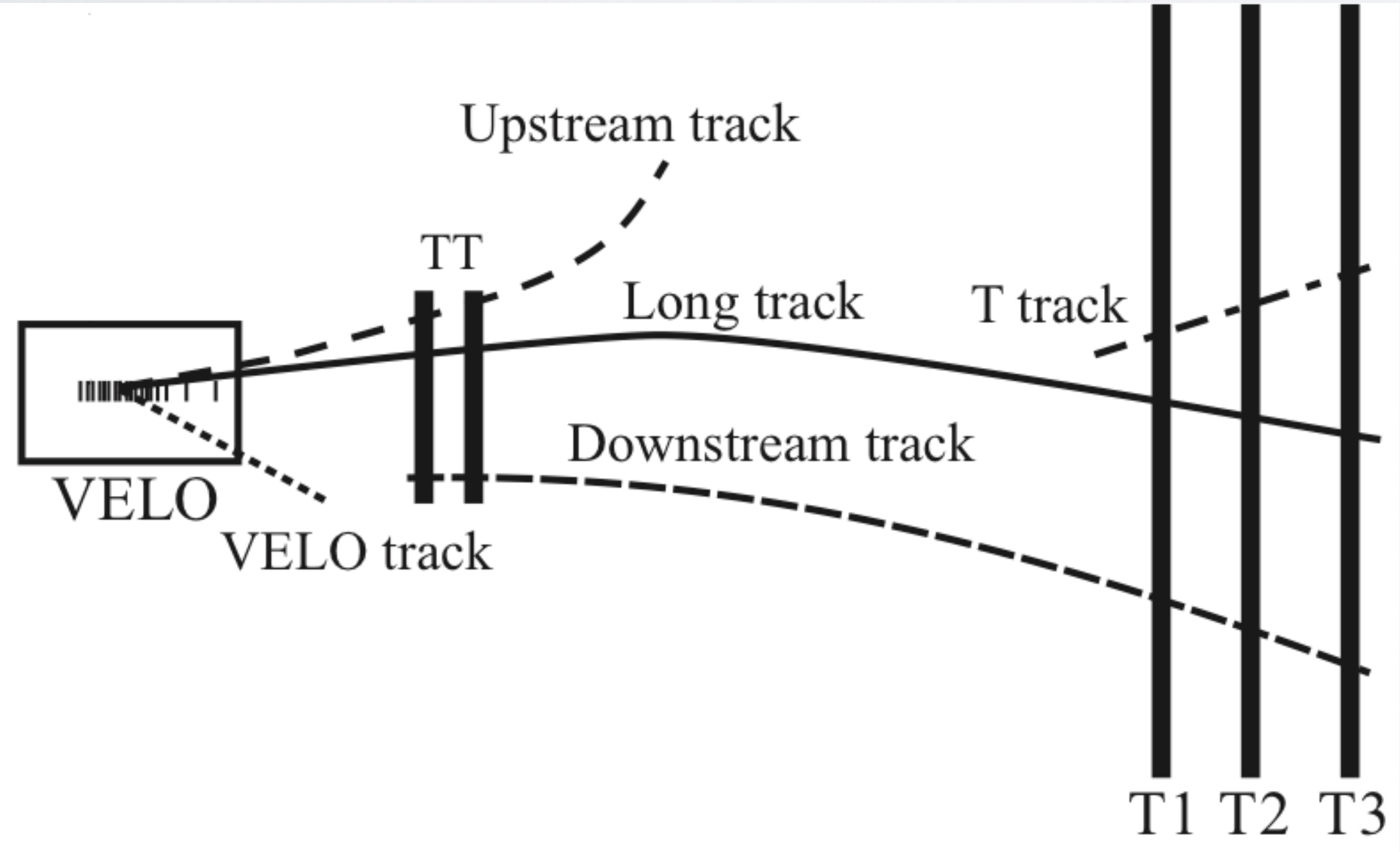


So why bother?

- Can give complementary results → angular analysis
- Can give independent verifications of results in B physics

Reconstructing Λ^0 in LHCb

- Decay reconstructed using the $\Lambda^0 \rightarrow p\pi$ mode
- **Λ^0 is a long-lived** particle and can fly a few meters into the detector
- Can be reconstructed from 2 types of tracks: long and downstream
- Characterised by different resolution and decay kinematics



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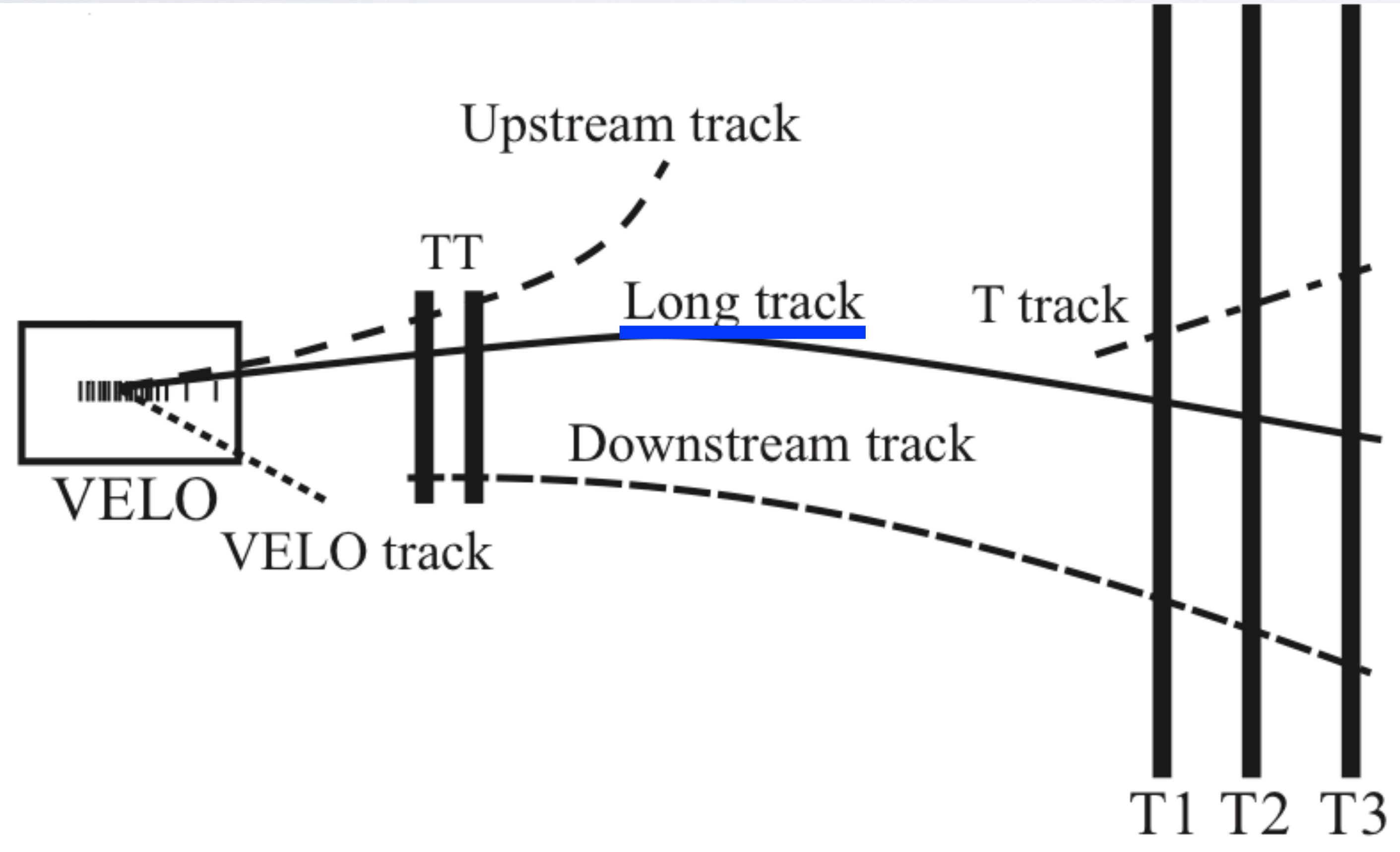
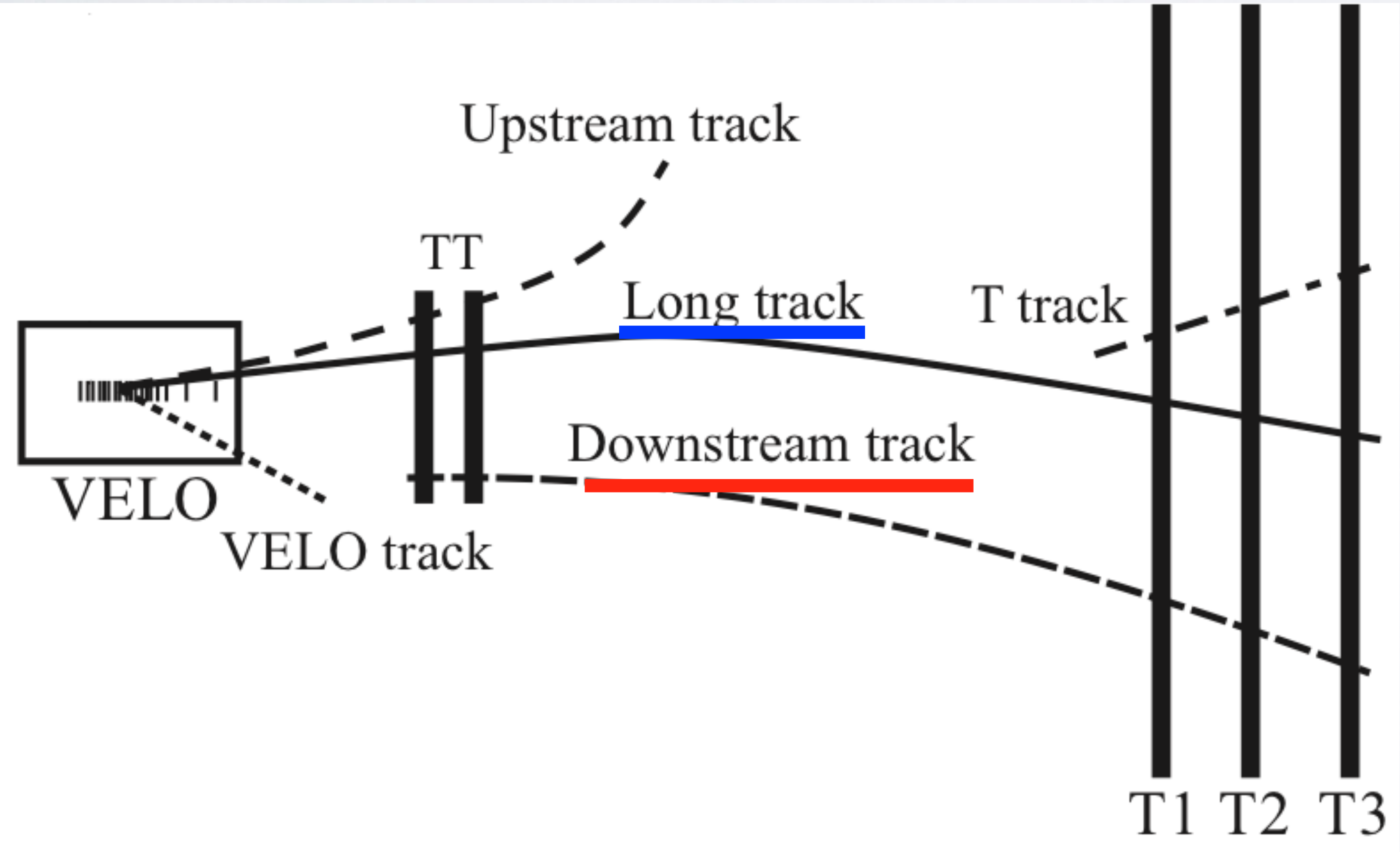


✓ **Long tracks**
with hits in the VELO

Reconstructing Λ^0 in LHCb

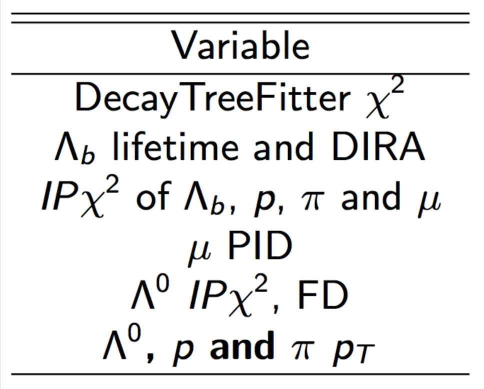
- Decay reconstructed using the $\Lambda^0 \rightarrow p\pi$ mode
- **Λ^0 is a long-lived** particle and can fly a few meters into the detector
- Can be reconstructed from 2 types of tracks: long and downstream
- Characterised by different resolution and decay kinematics



✓ **Long tracks**
with hits in the VELO

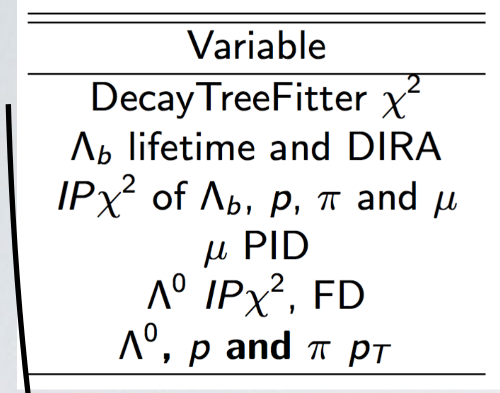
✓ **Downstream tracks**
without hits in the VELO

Selection



Variable
DecayTreeFitter χ^2
Λ_b lifetime and DIRA
$IP\chi^2$ of Λ_b, p, π and μ
μ PID
Λ^0 $IP\chi^2$, FD
Λ^0**,** p **and** π p_T

Selection



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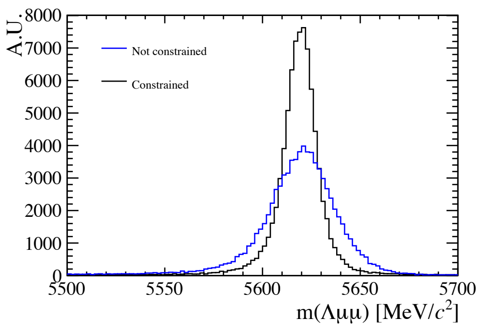

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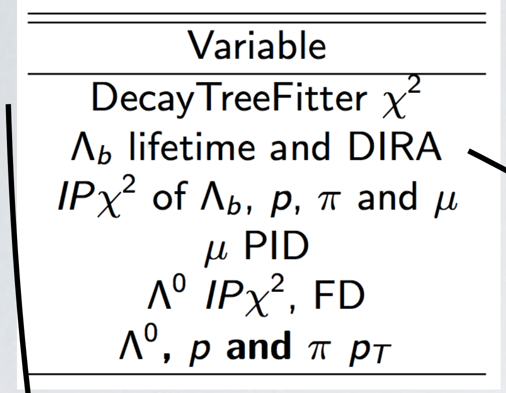

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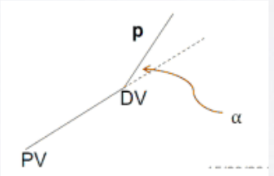

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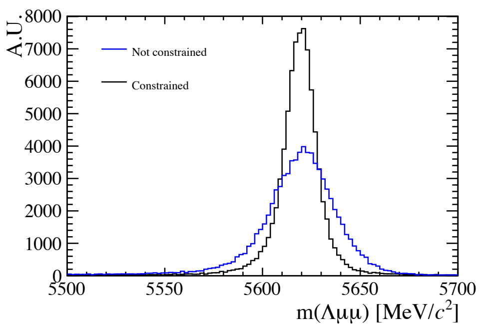

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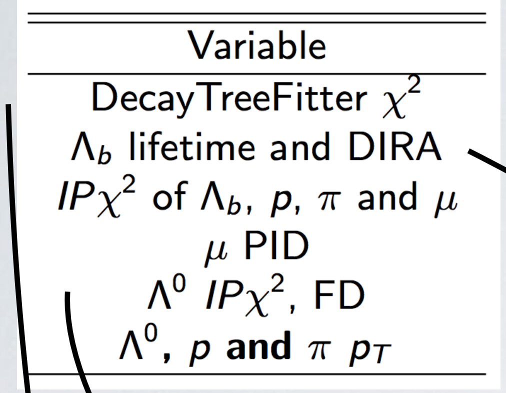

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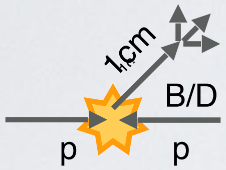

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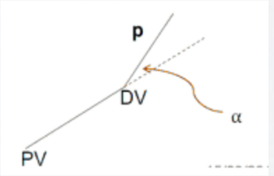

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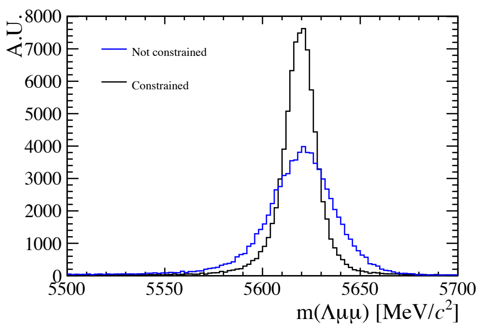

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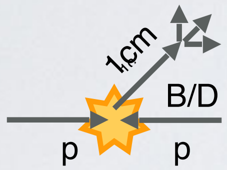

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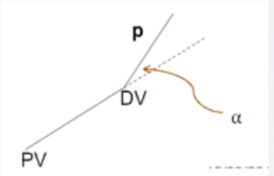

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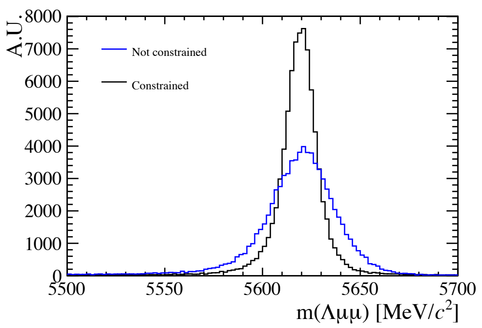

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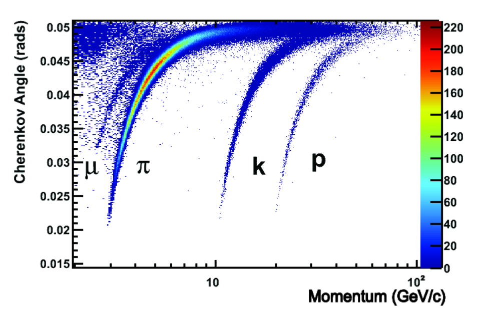

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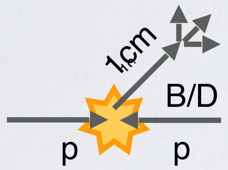

Momenta
help distinguishing combinatorial

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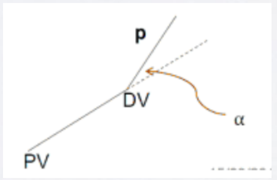

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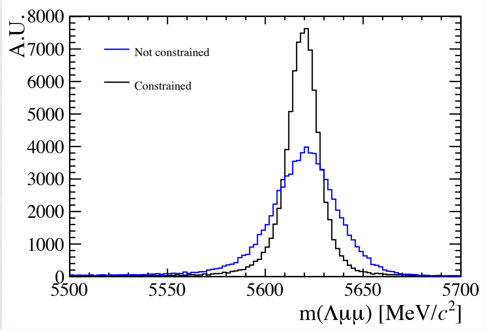

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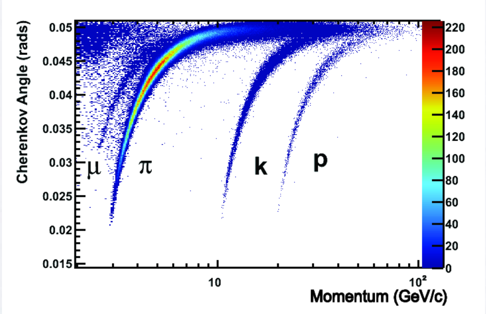

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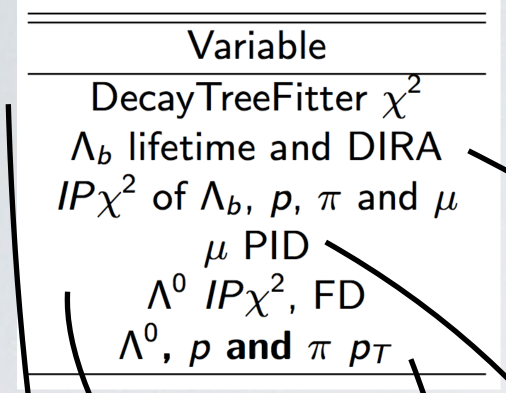

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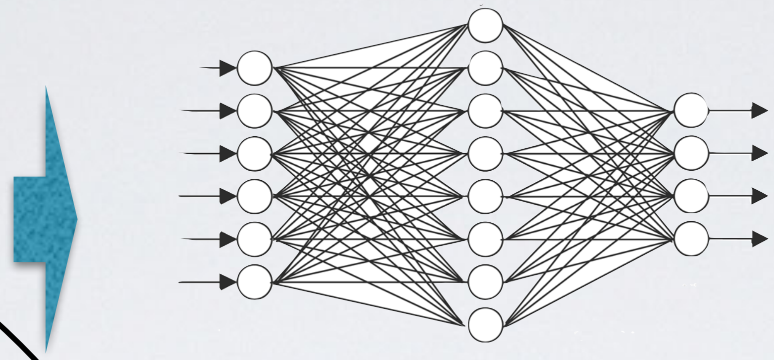

Neural Network: NeuroBayes
Training: signal MC and
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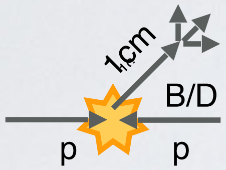

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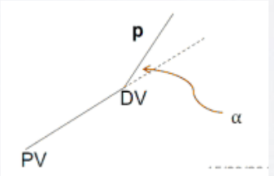

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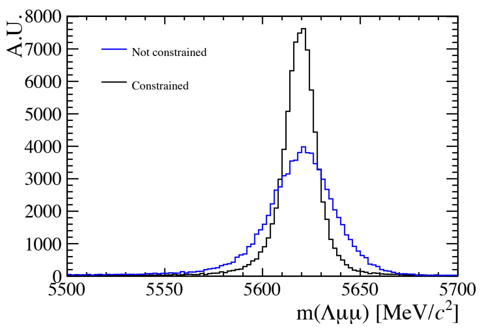

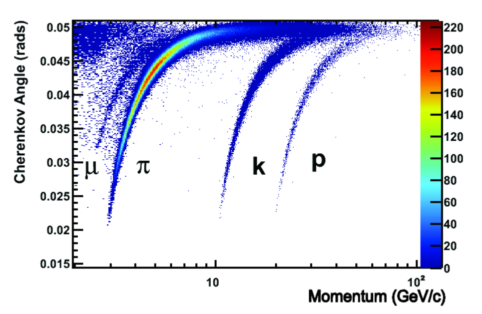

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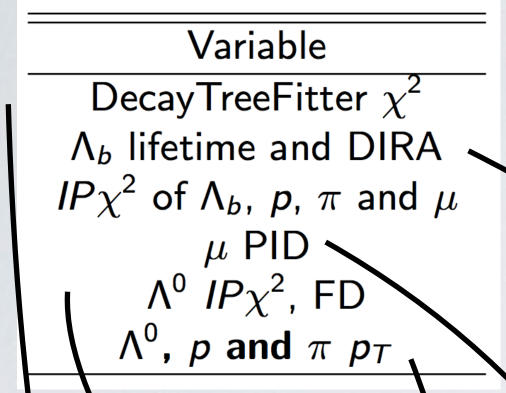

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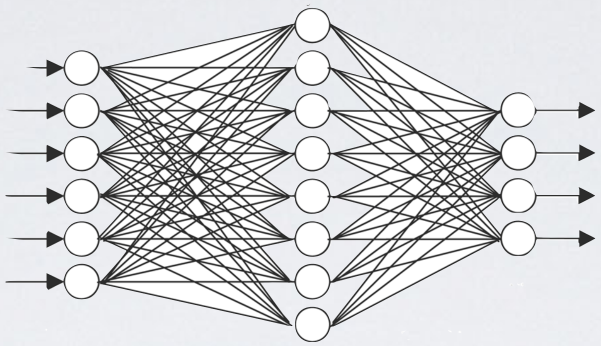

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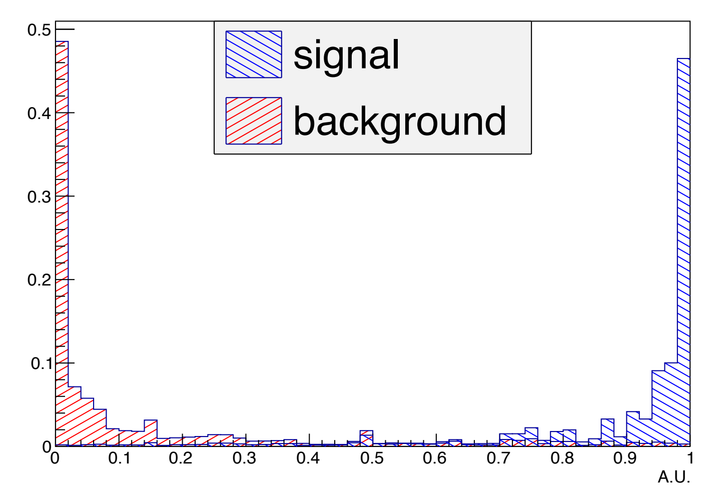

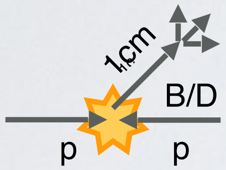

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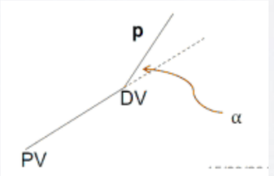

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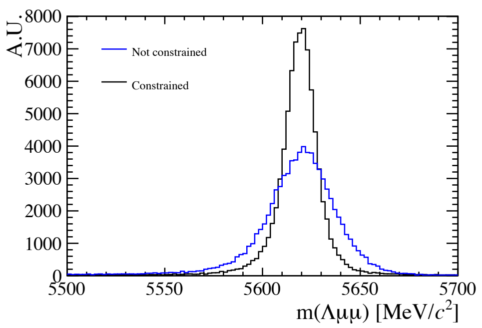

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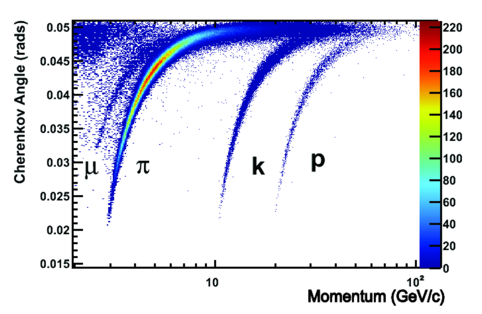

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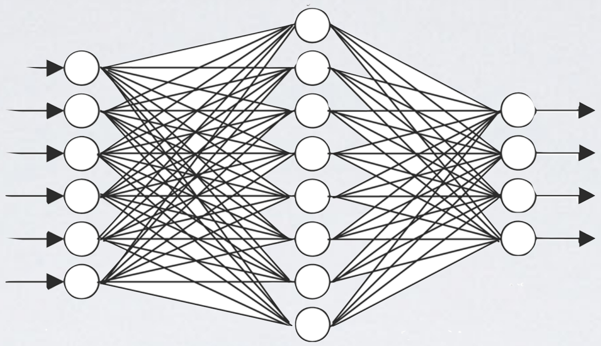

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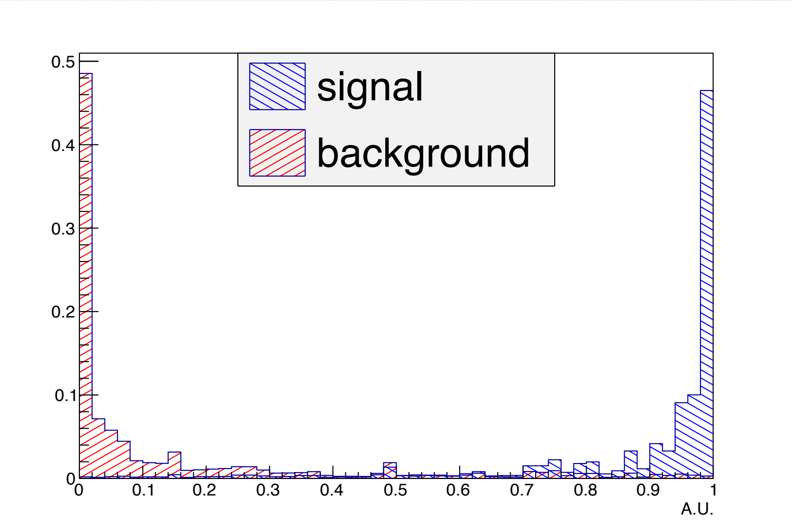

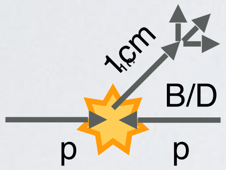

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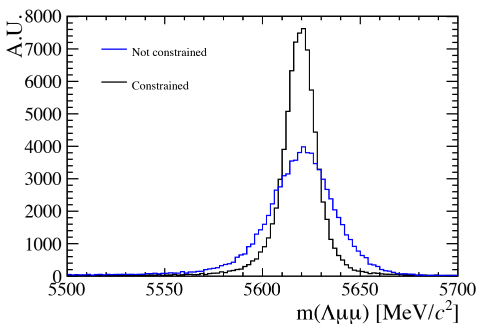

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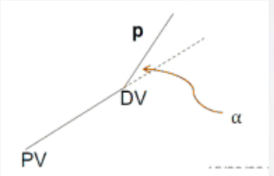

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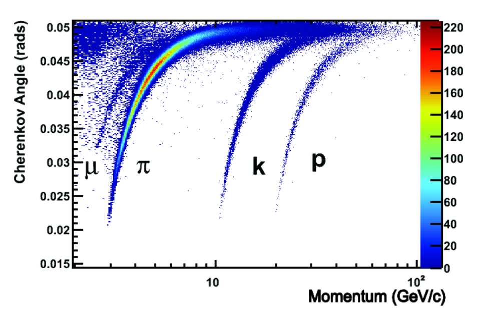
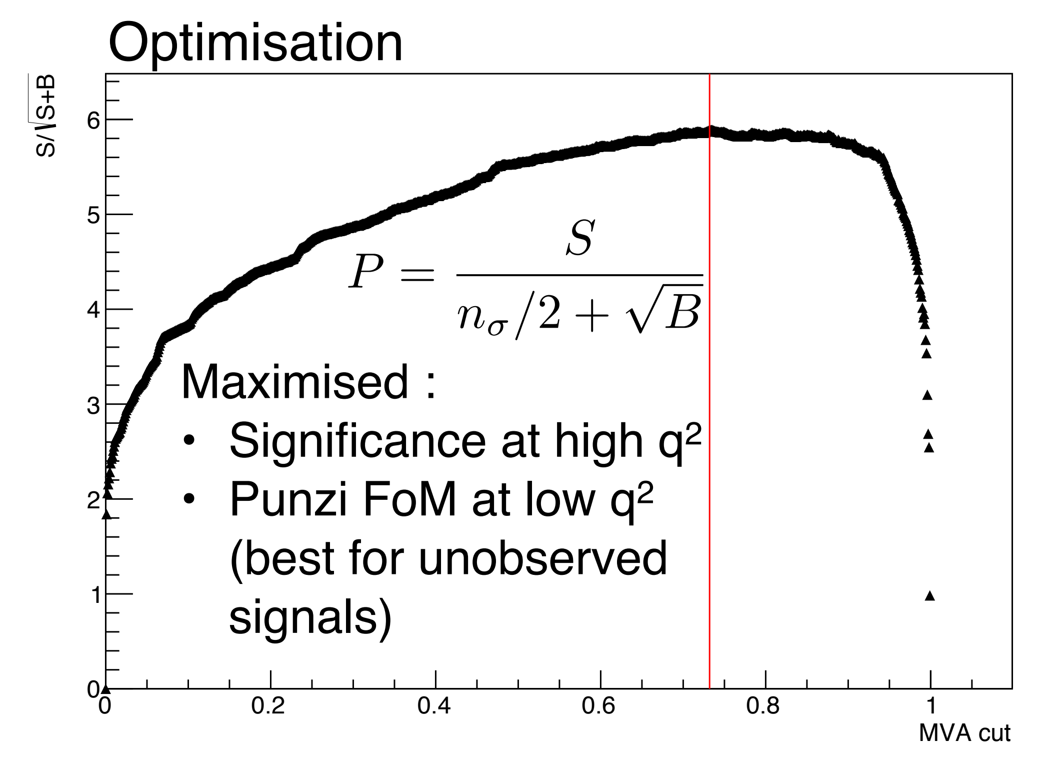


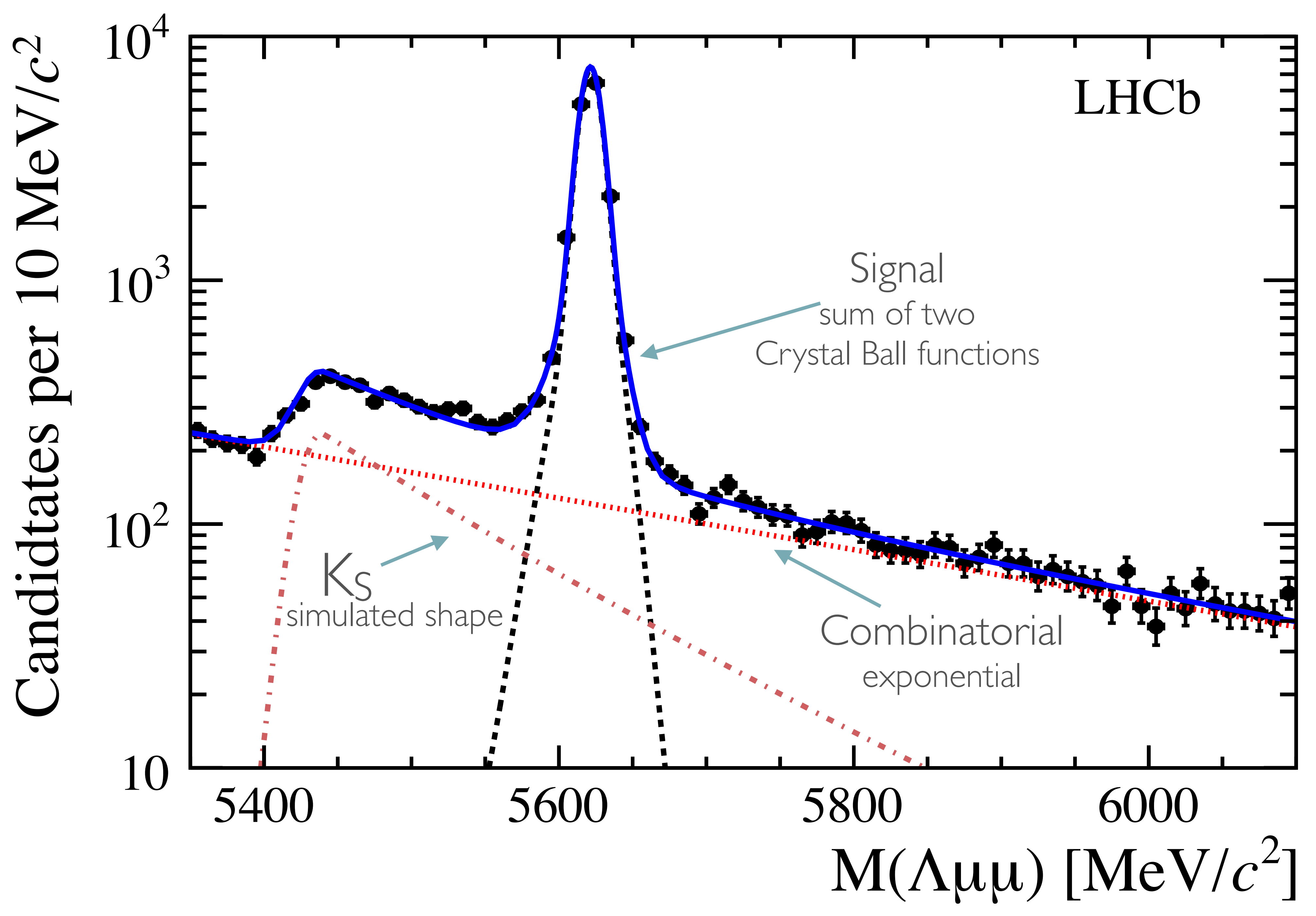
Optimisation



$$P = \frac{S}{n_\sigma/2 + \sqrt{B}}$$

Maximised :
- Significance at high q²
- Punzi FoM at low q² (best for unobserved signals)

Mass fits: $\Lambda_b \to \Lambda^0(J/\psi \to \mu\mu)$



Signal
sum of two
Crystal Ball functions

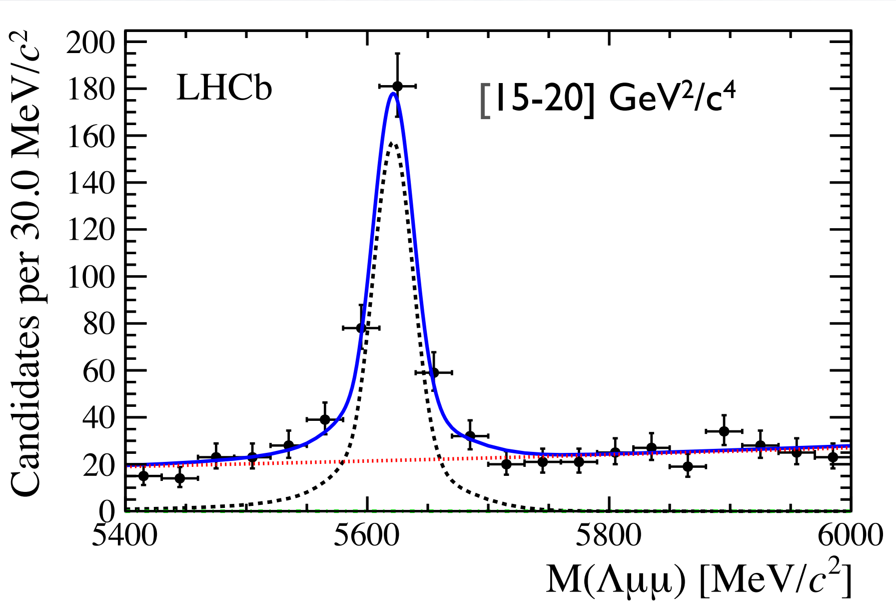
K_S
simulated shape

Combinatorial
exponential

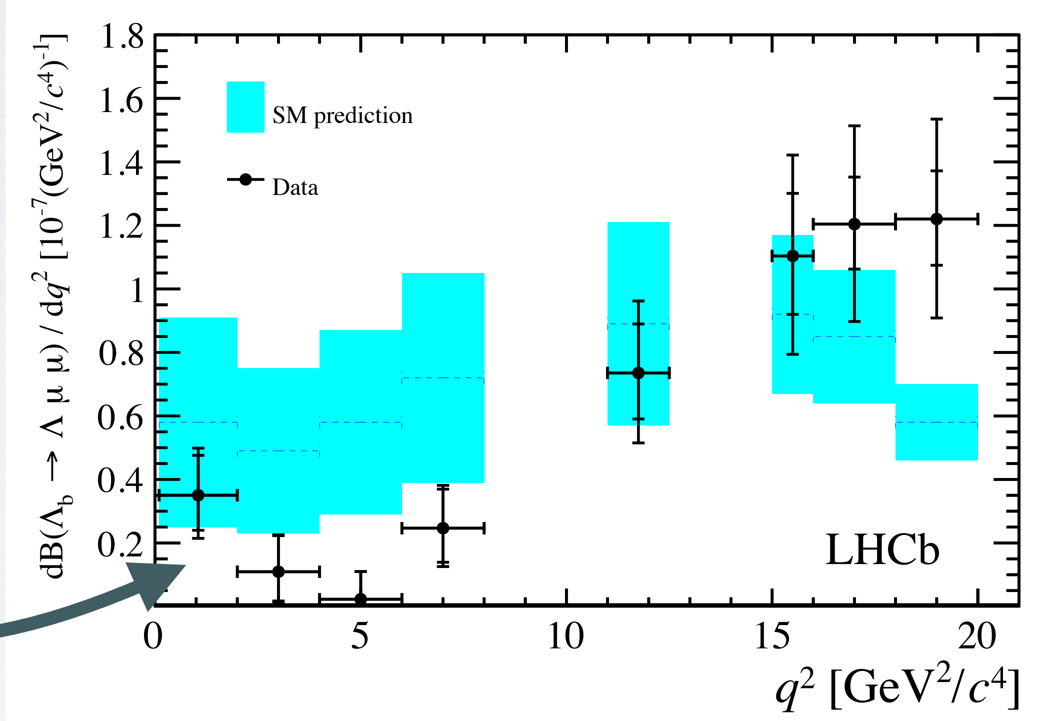
Same signal shape used for rare and resonant channels

$\Lambda_b \to \Lambda^0 \mu\mu$ branching fraction

- Already observed at CDF (PRL 107 2011 201802) and LHCb (PLB725 2013 25) but only in the high q^2 region, above $\psi(2S)$
- Analysis on 3fb^{-1}: ~300 observed events



First observation at 3σ level at low q^2



Prediction: PRD 87 (2013) 074502

Branching ratio:

$$
\begin{array}{ll}
1.1 < q^2 < 6.0 & 0.09 \, {}^{+0.06}_{-0.05} \, (\text{stat}) \, {}^{+0.01}_{-0.01} \, (\text{syst}) \, {}^{+0.02}_{-0.02} \, (\text{norm}) \\
15.0 < q^2 < 20.0 & 1.18 \, {}^{+0.09}_{-0.08} \, (\text{stat}) \, {}^{+0.03}_{-0.03} \, (\text{syst}) \, {}^{+0.27}_{-0.27} \, (\text{norm})
\end{array}
$$

JHEP 1506 (2015) 115, [arXiv:1503.07138]

Inner error: stati + syst

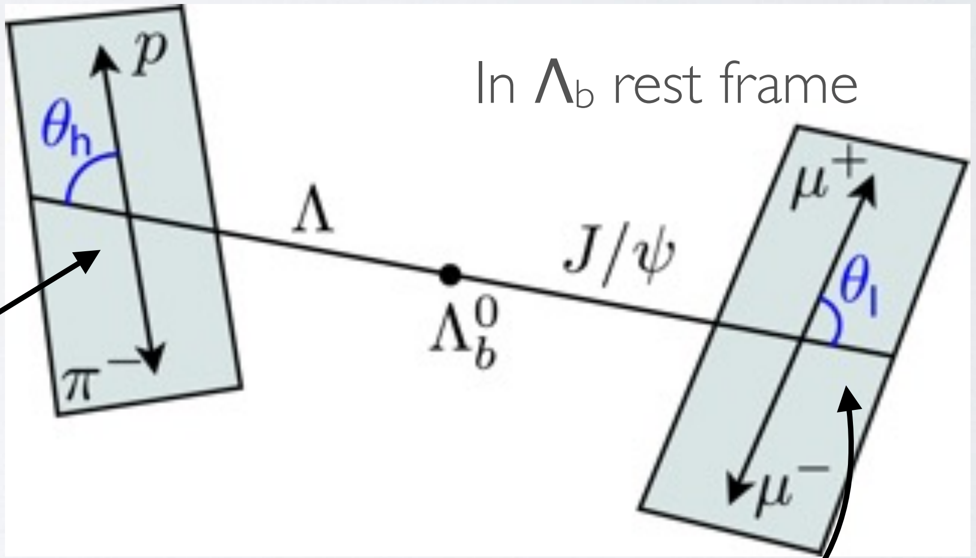
Outer error:
including normalisation (dominant)

Angular analysis

New!

- First measurement of angular observables for this decay
- In $\Lambda_b \to \Lambda^0 \mu\mu$ the Λ^0 decays weakly (v/s in $B \to K^*\mu\mu$ the K^* decays strongly) → the hadronic side asymmetry is also interesting
- Fit one-dimensional angular distributions

$$A^h_{\mathrm{FB}} = \frac{1}{2}\alpha_\Lambda P^\Lambda_z(q^2)$$



In Λ_b rest frame

Differential rates as a function of the angles

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_h} \propto (1 + 2A^h_{\mathrm{FB}}\cos\theta_h)$$

$$\frac{d\Gamma}{dq^2 d\cos\theta_\ell} \propto \frac{3}{8}(1+\cos\theta_\ell)(1-f_L) + A^\ell_{FB}\cos\theta_\ell + \frac{3}{4}f_L\sin^2\theta_\ell$$

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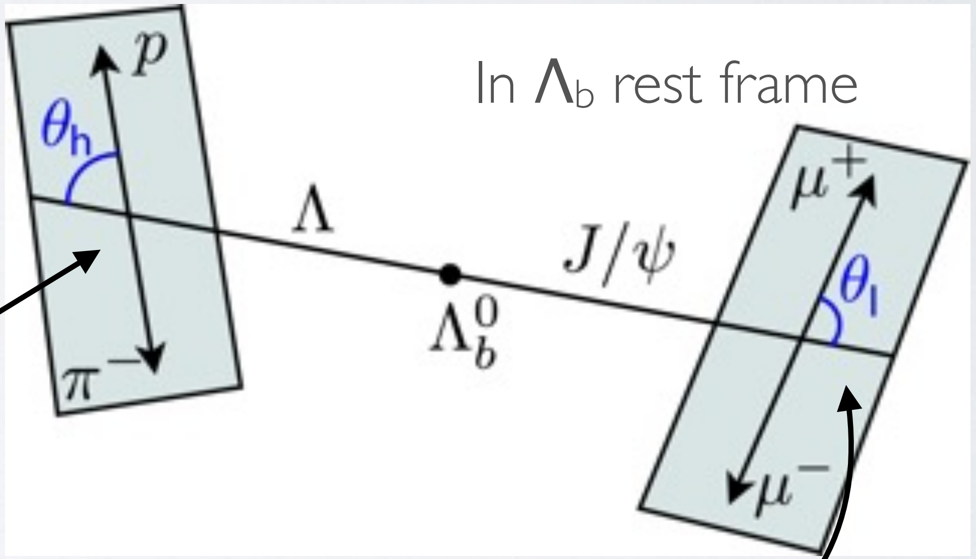

Forward-backward asymmetry in the dimuon system

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_h} \propto (1 + 2A^h_{\mathrm{FB}}\cos\theta_h)$$

$$\frac{d\Gamma}{dq^2 d\cos\theta_\ell} \propto \frac{3}{8}(1+\cos\theta_\ell)(1-f_L) + \boxed{A^\ell_{FB}}\cos\theta_\ell + \frac{3}{4}f_L\sin^2\theta_\ell$$

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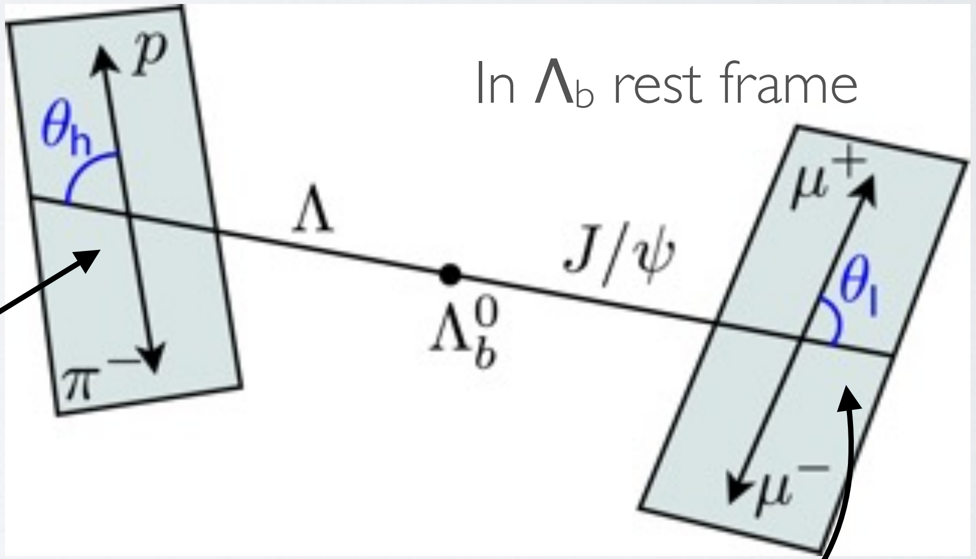

Fraction of longitudinally polarised dimuons

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_h} \propto (1 + 2A^h_{\mathrm{FB}}\cos\theta_h)$$

$$\frac{d\Gamma}{dq^2 d\cos\theta_\ell} \propto \frac{3}{8}(1+\cos\theta_\ell)(1-f_L) + A^\ell_{FB}\cos\theta_\ell + \frac{3}{4}f_L\sin^2\theta_\ell$$

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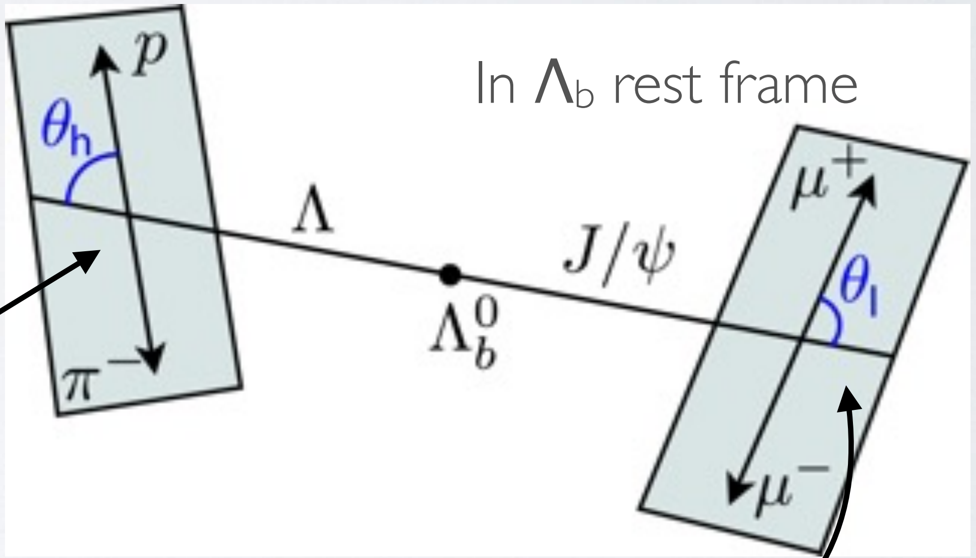

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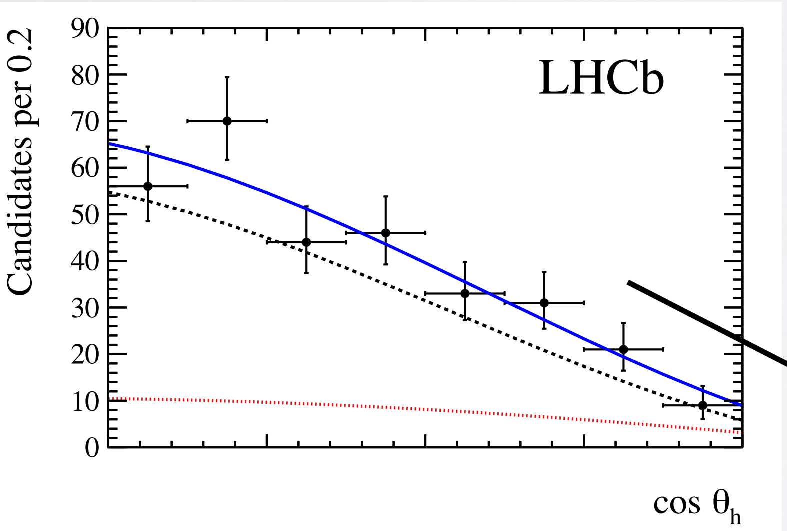
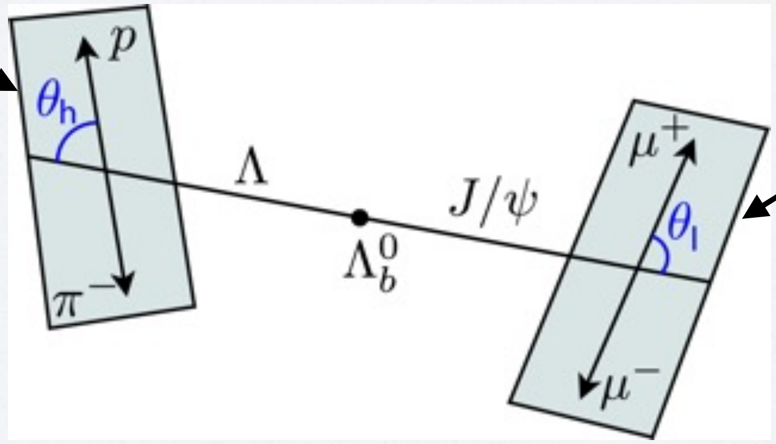
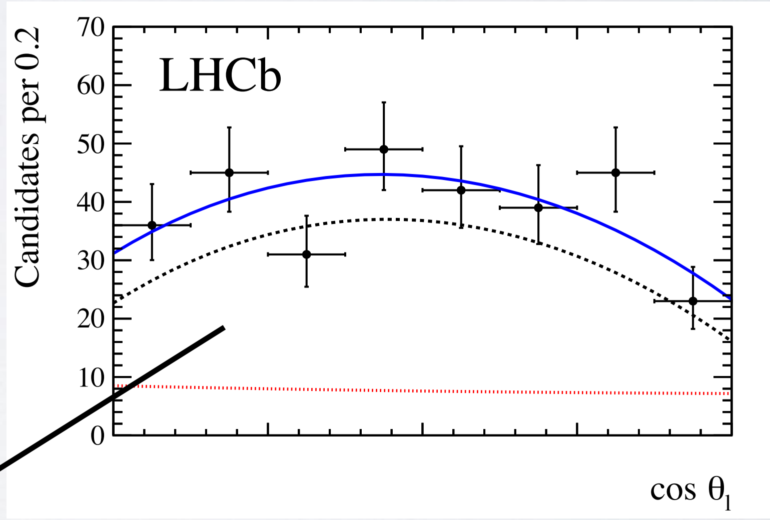
$$PDF^{tot}(\cos\theta_i) = [f^{theory}(\cos\theta_i) + f^{bkg}(\cos\theta_i)] \times \varepsilon(\cos\theta_i)$$



15 < q² < 20 GeV²/c⁴





Hadronic system

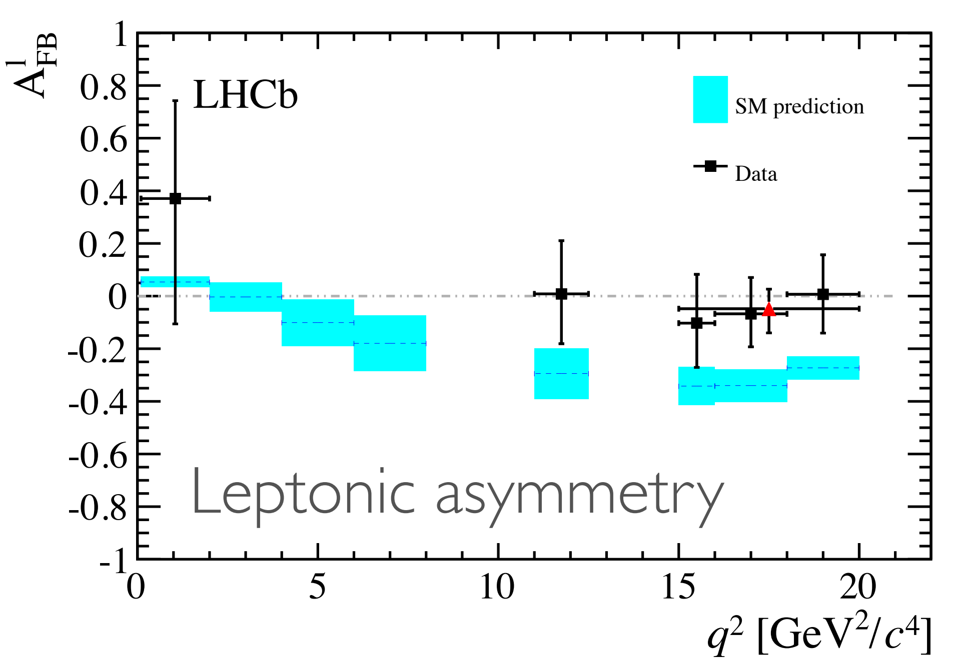
Dimuon system

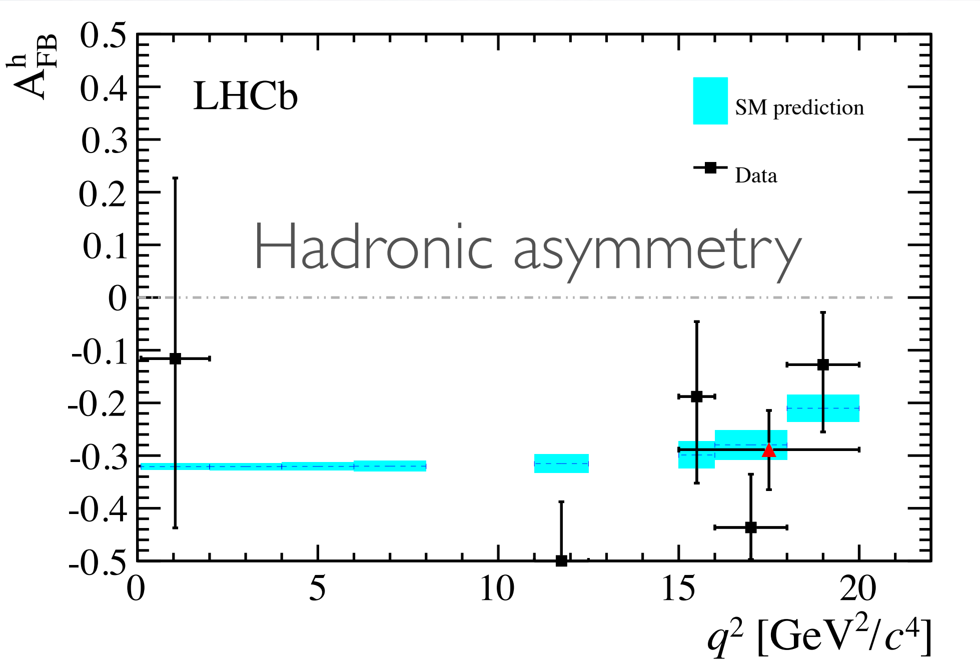
Most challenging due to asymmetric acceptance.

JHEP 1506 (2015) 115, [arXiv:1503.07138]

Angular analysis: results

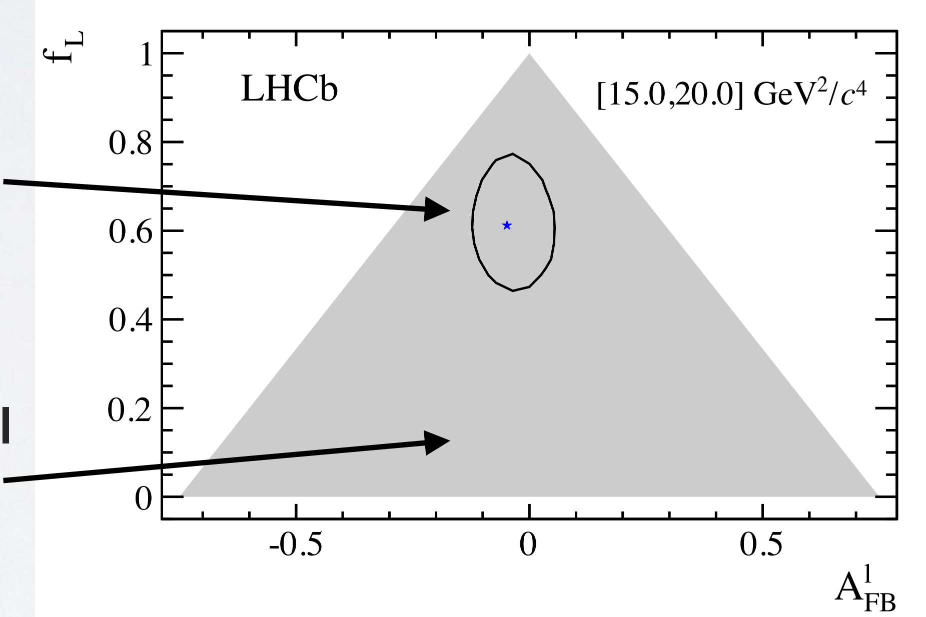
New!





JHEP 1506 (2015) 115, [arXiv:1503.07138]
Theory: arXiv:1401.2685

- Only where the signal significance is above 3σ
- Physical boundaries in the parameter-space:
  → using Feldman-Cousins inspired "plug-in" method



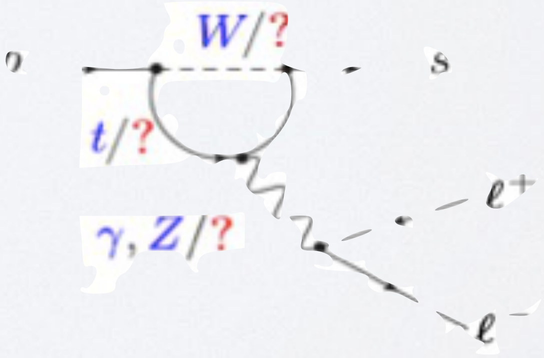
Two-dimensional 68% CL region

Physical region

- A^{h}_{FB} is in good agreement with SM prediction
- A^{l}_{FB} is compatible within 2 sigma but consistently above the prediction

  → Could be due large $c\bar{c}$ contributions.

Testing lepton universality: R_{K^*}



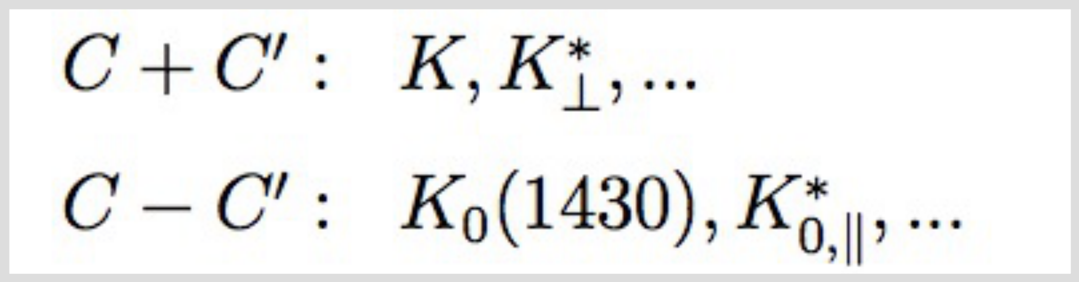
R_{K^*}: making R_K stronger and more

$$R_H = \frac{\int_{4m_\mu^2}^{m_b} \frac{d\mathcal{B}(B\to H\mu^+\mu^-)}{dq^2}}{\int_{4m_\mu^2}^{m_b} \frac{d\mathcal{B}(B\to He^+e^-)}{dq^2}} dq^2$$

$$\boxed{H = K^{*0}}$$

- Amplitudes for different B→H$\ell\ell$ are described by different combinations of left- and right-handed (C and C') Wilson coefficients
- Therefore sensitive to different kind of new physics

JHEP 1502 (2015) 055
[arXiv:1411.4773]



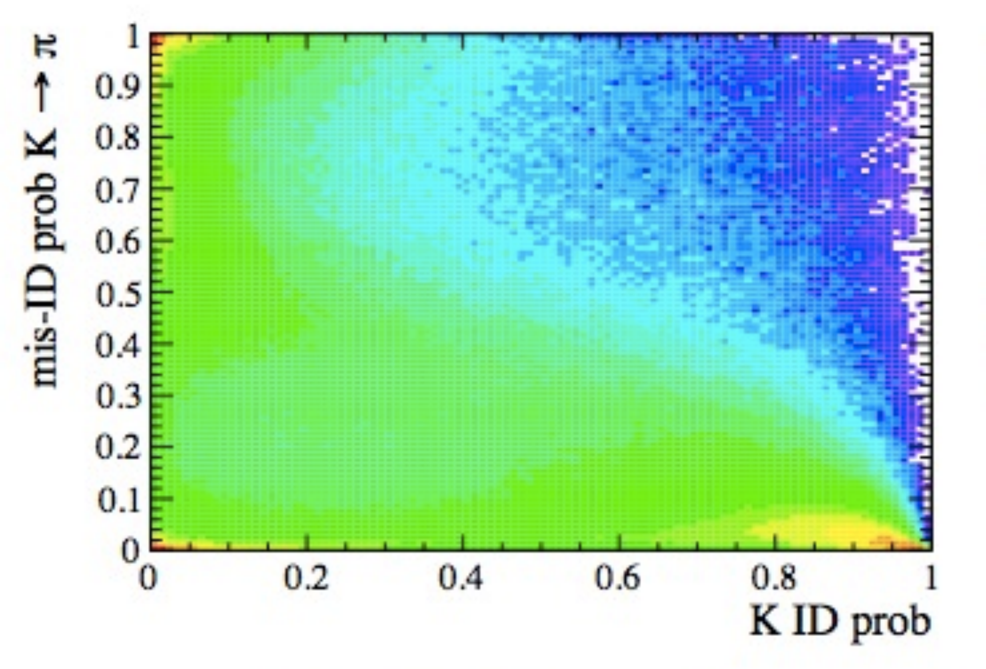
$$C + C' : \quad K, K^*_\perp, \ldots$$

$$C - C' : \quad K_0(1430), K^*_{0,\|}, \ldots$$

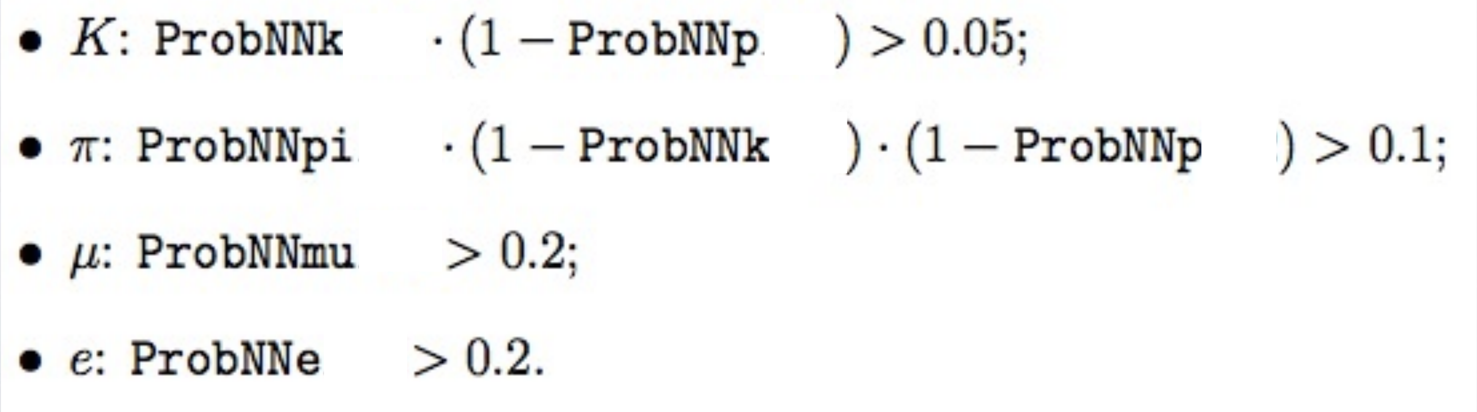
R_K and R_{K^*} give complementary information!

Selection for R_{K^*}

- Neural Network (similarly to $\Lambda_b \to \Lambda^0 \mu\mu$)
- **PID** from variables combining information from RICH, calorimeters, muon detector and tracking



Kaon ID efficiency:
~ 95 % for ~ 5 % π→K mis-id probability
Muon ID efficiency:
~ 97 % for 1-3 % π→μ mis-id probability



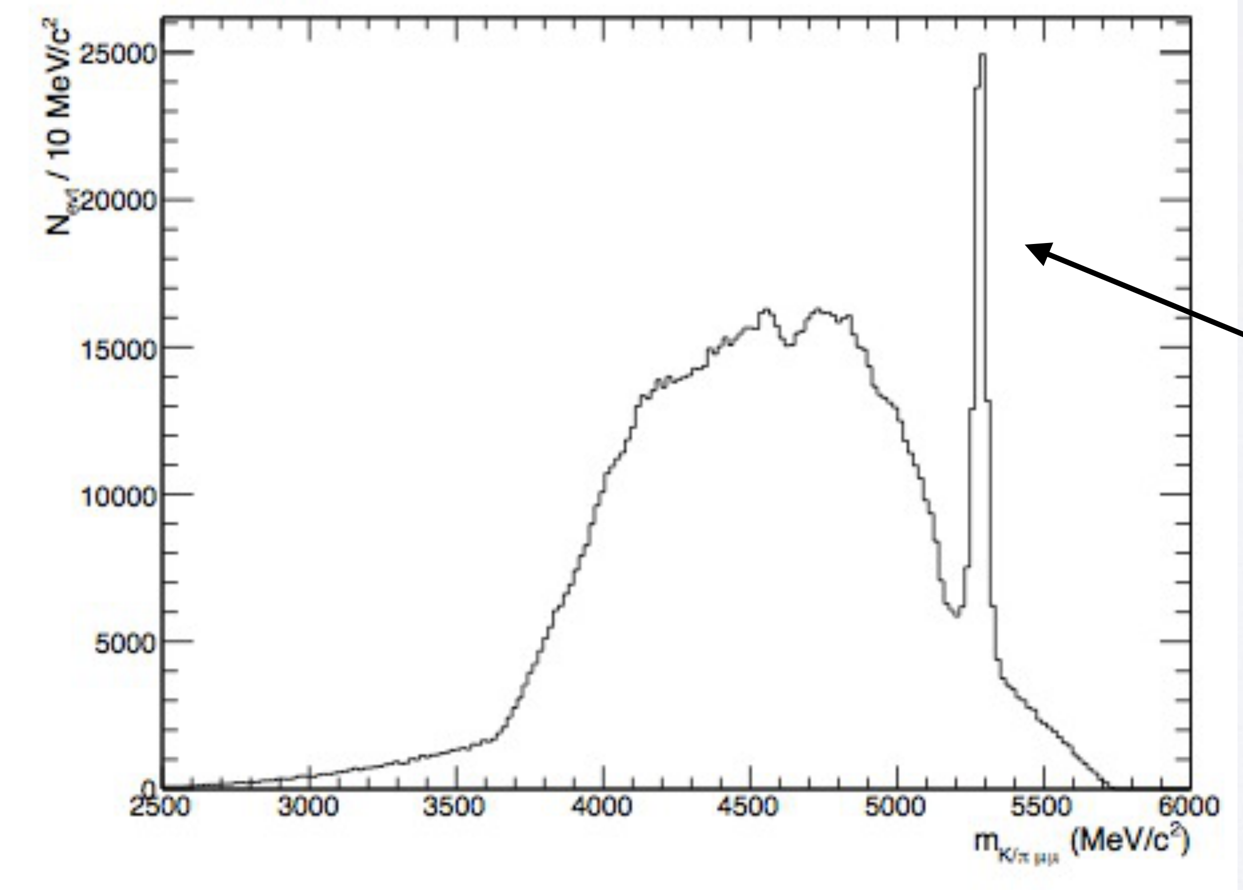
- K: `ProbNNk` $\cdot\,(1 -$ `ProbNNp` $) > 0.05$;
- π: `ProbNNpi` $\cdot\,(1 -$ `ProbNNk` $)\cdot(1 -$ `ProbNNp` $) > 0.1$;
- μ: `ProbNNmu` > 0.2;
- e: `ProbNNe` > 0.2.

Cuts on combinations of correct ID and mis-ID variables to exploit the full PID power.

Peaking backgrounds

Other decays may mimic the decays of interest:

- ✓ $B^+ \to K^+ \mu\mu$ plus a random pion
- ✓ $B_s \to \phi\mu\mu$ with $\phi \to KK$ and a K misidentified as a π
- ✓ Λ_b decays with misidentified or misreconstructed particles
  - Not peaking: need to be modelled in the fit



3-body $K\mu\mu$ invariant mass shows a narrow B^+ peak easy to remove

Peaking backgrounds

Other decays may mimic the decays of interest:

- ✓ $B^+ \to K^+\mu\mu$ plus a random pion
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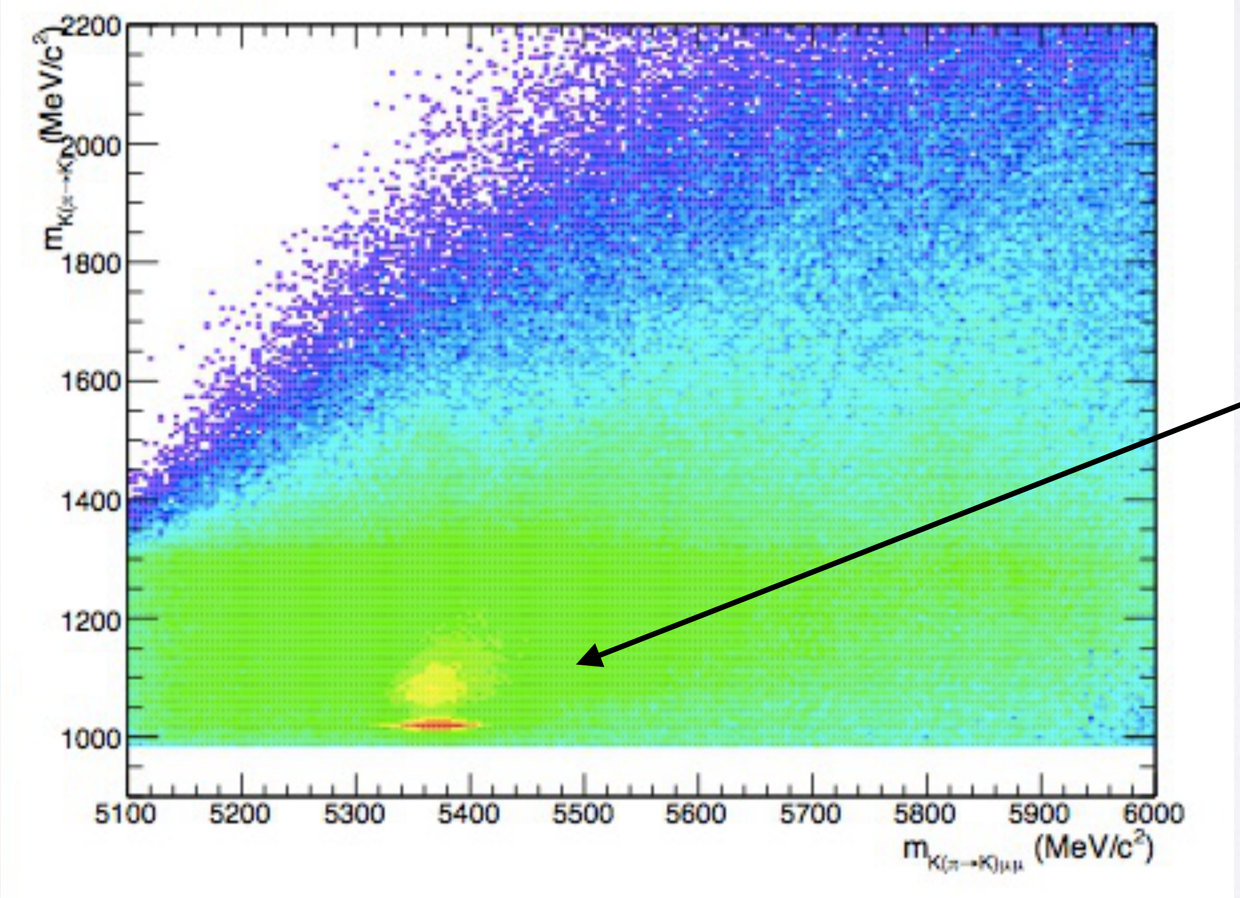
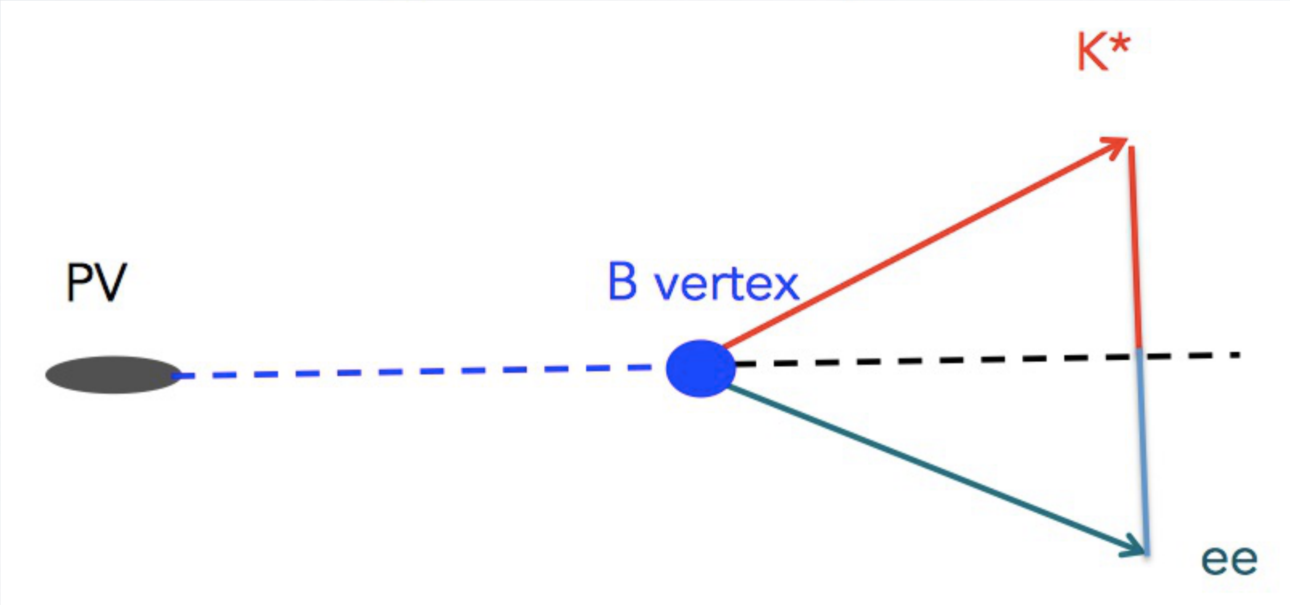


We give the identify of a K to the pion and recalculate the mass. A peak is present in a limited region of the plane

The HOP cut for electrons

Correct electron momentum assuming the energy is lost due to bremsstrahlung

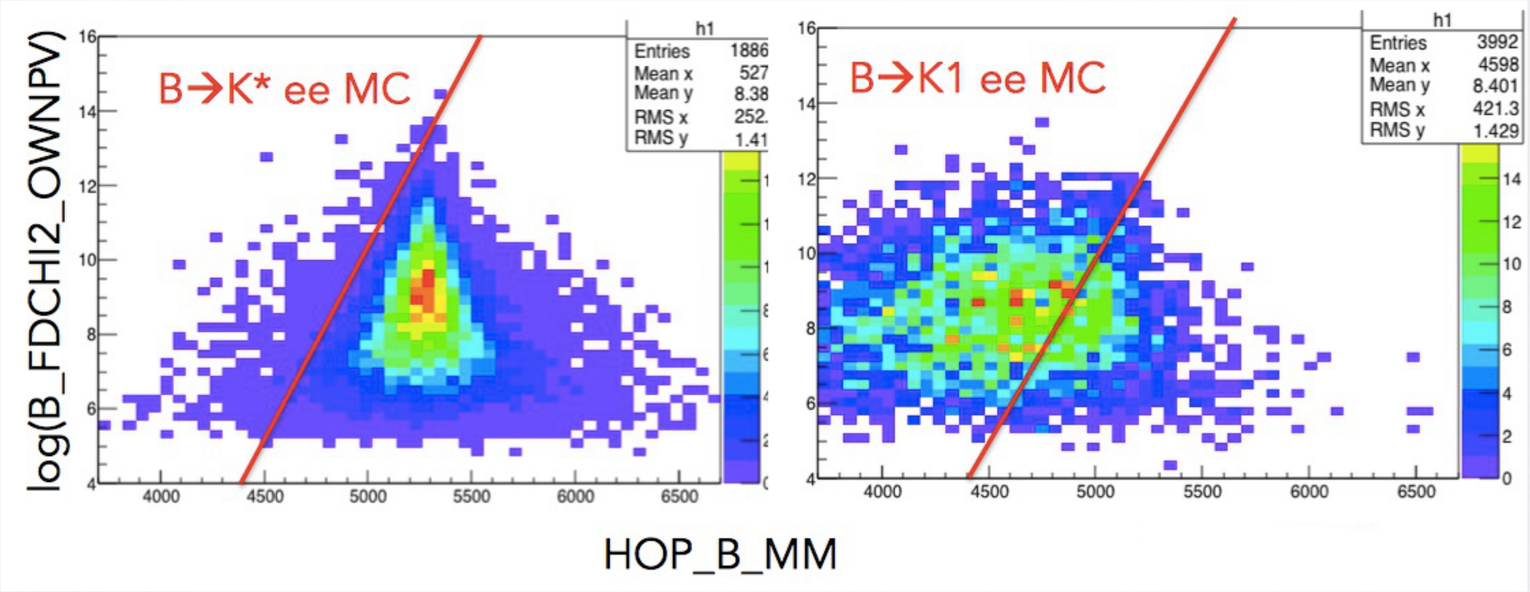


$$p_T^{K^{*0}} = -p_T^{ee}$$

▼

$$p^{corr}_{x,y,x} = \left(\frac{p_T^{K^{*0}}}{p_T^{ee}}\right) p^{meas}_{x,y,z}$$

then recompute the 4-body mass

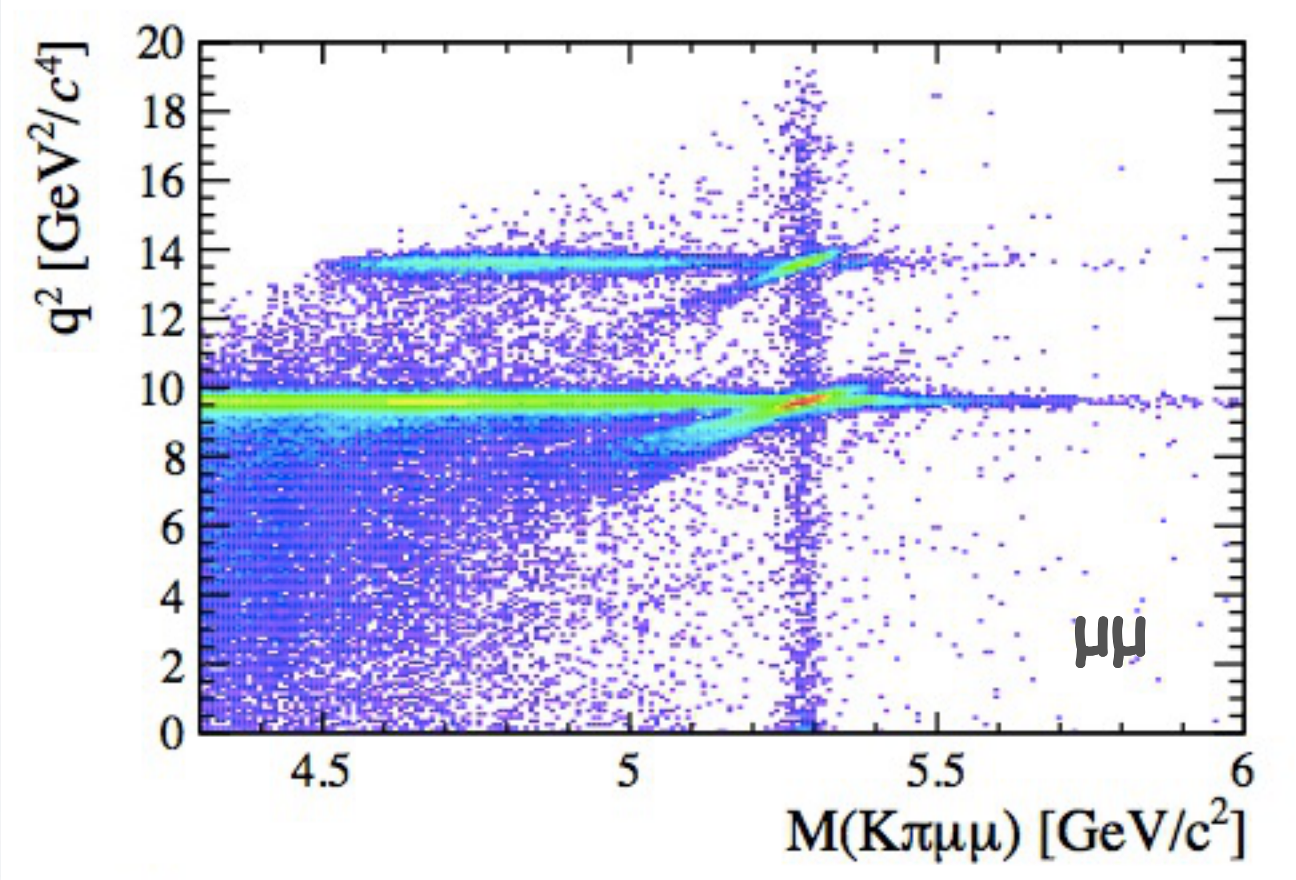


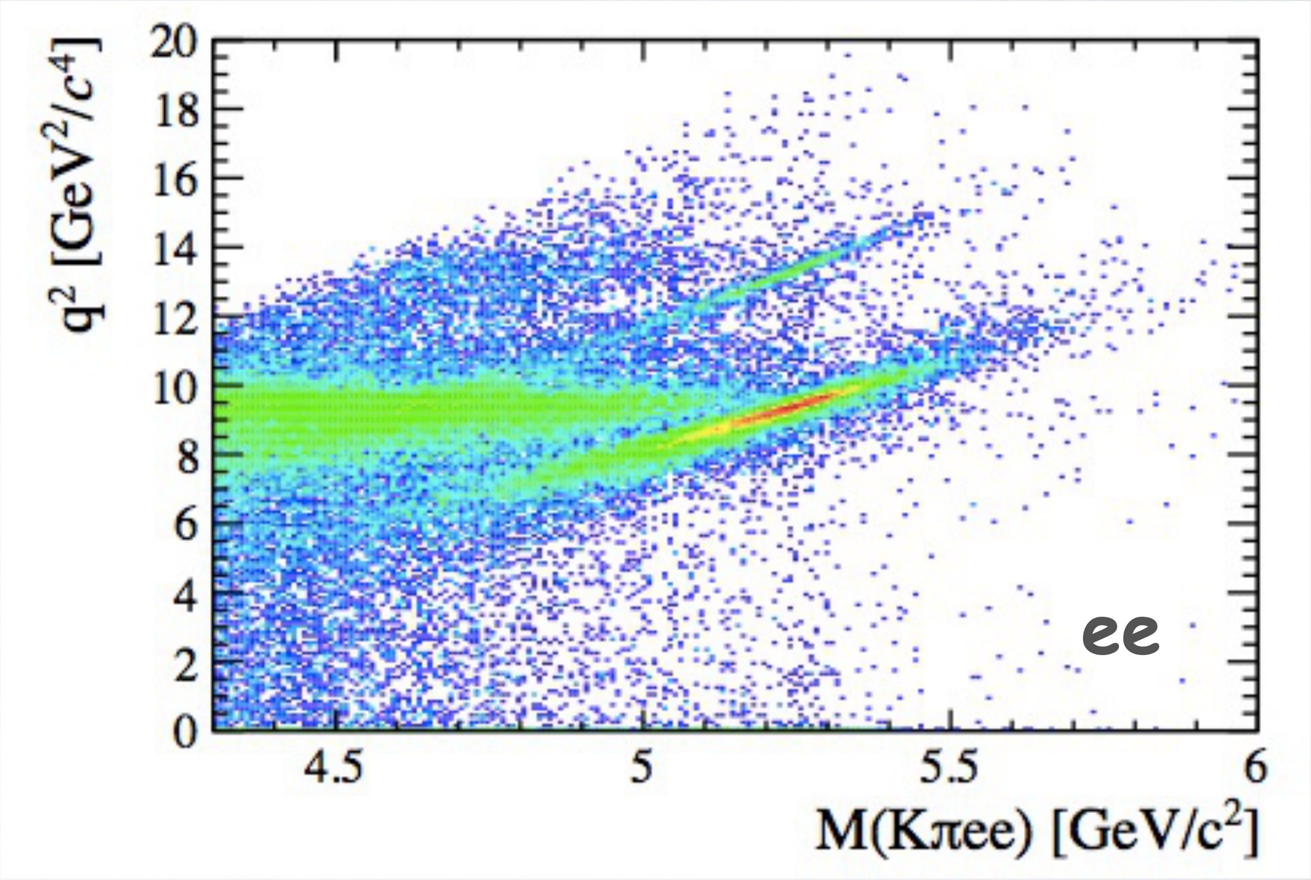
Backgrounds have low values of corrected masses which allows to separate the signal.

Charmonium channels

- Charmonium channels $B \to K^*(J/\psi \to \ell\ell)$ peak in the q^2 spectrum.
- Naturally distinguished from the rare channels by the q^2 binning

[0.1,1,1,2,4,6,8] - J/ψ - [11,12.5] - $\psi(2S)$ - [15,16,18,20]





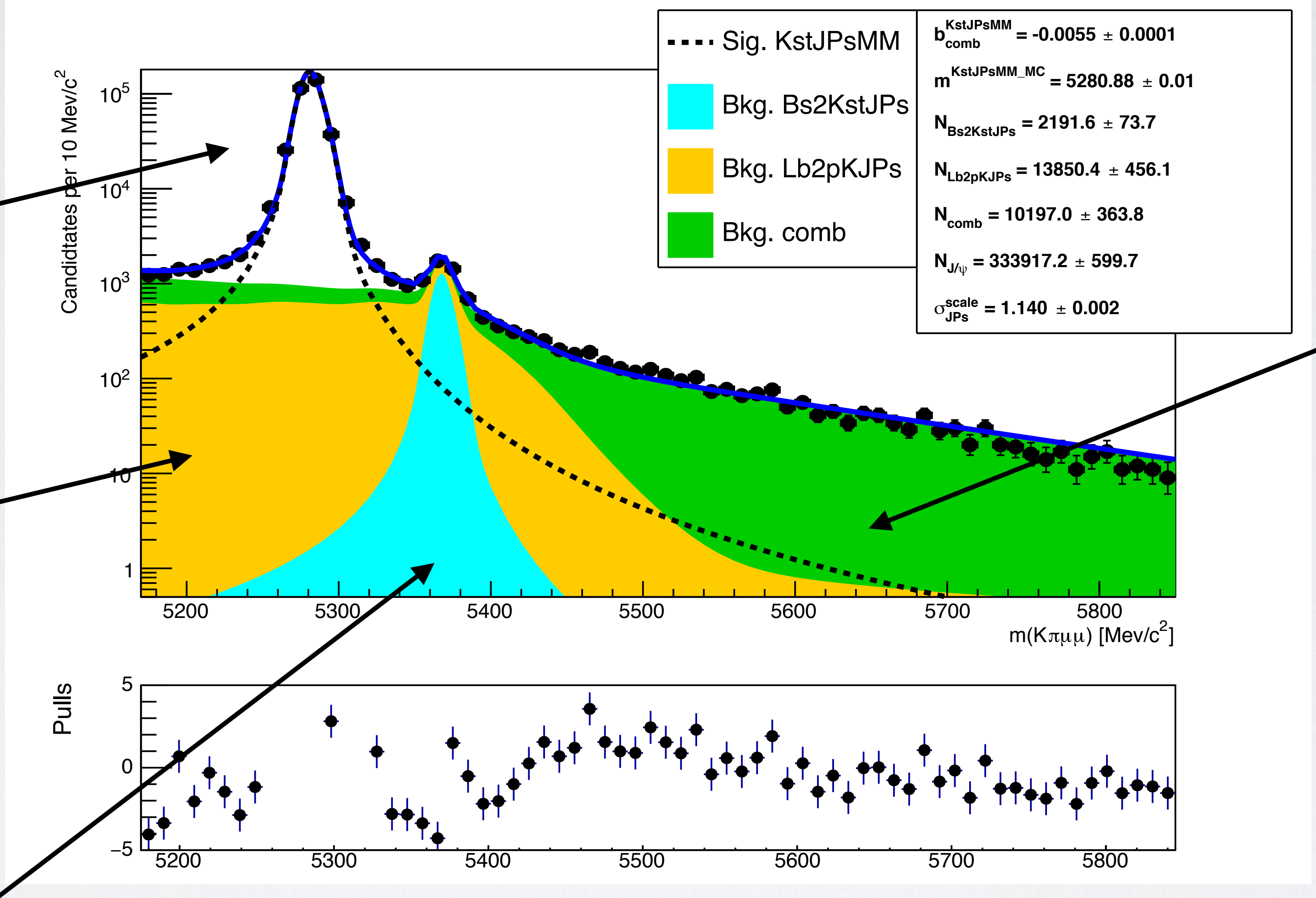
Resonant samples used as high statistics control samples.

Mass fits: $B^0 \to K^{*0}(J/\psi \to \mu\mu)$

- Resonant and rare samples fit simultaneously → some shape parameters shared

Signal:
sum of two
Crystal Ball functions

Λ_b decays:
modelled with
a simulated shape



Combinatorial:
exponential

Bs→K*μμ:
same shape as signal
but shifted in mass

- A kinematic fit is used to constrain the Jpsi mass improving the B0 mass resolution

Electron channels: trigger

- The trigger categories (with different mass shapes and efficiencies)
  - ✓ L0E ⇒ triggered by the electron
  - ✓ L0H ⇒ triggered by the hadron and not the electron
  - ✓ L0I ⇒ triggered by other particles in the event (and not the first two)
- Yields parameterised as a function of a common parameter:

$$N_{\ell\ell} = N_{J/\psi\,(\ell\ell)} \cdot \frac{\varepsilon^{\ell\ell}}{\varepsilon^{J/\psi\,(\ell\ell)}} \cdot R_{\ell\ell},$$

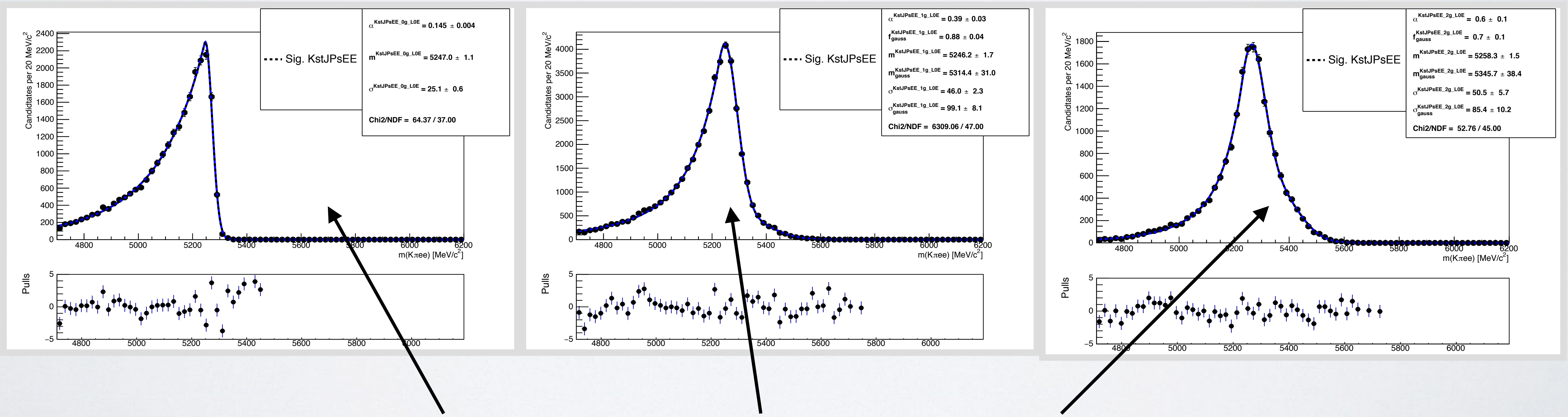
Simultaneous fit to the three trigger categories

➡ Allows to get a combined result directly out of the fit

➡ More stable fit as it gathers information form 3 samples at once

Electron channels: signal description

- Mass shapes depend on how many bremsstrahlung photons are recovered
  - ✓ Fit simulation split in brem categories
  - ✓ Take from simulated fractions of 0, 1 and 2 γ
  - ✓ Build a combined PDF

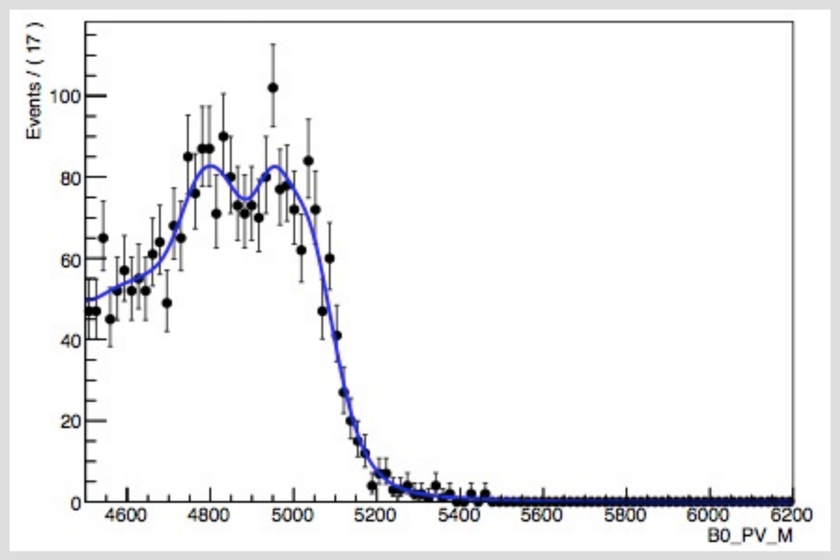


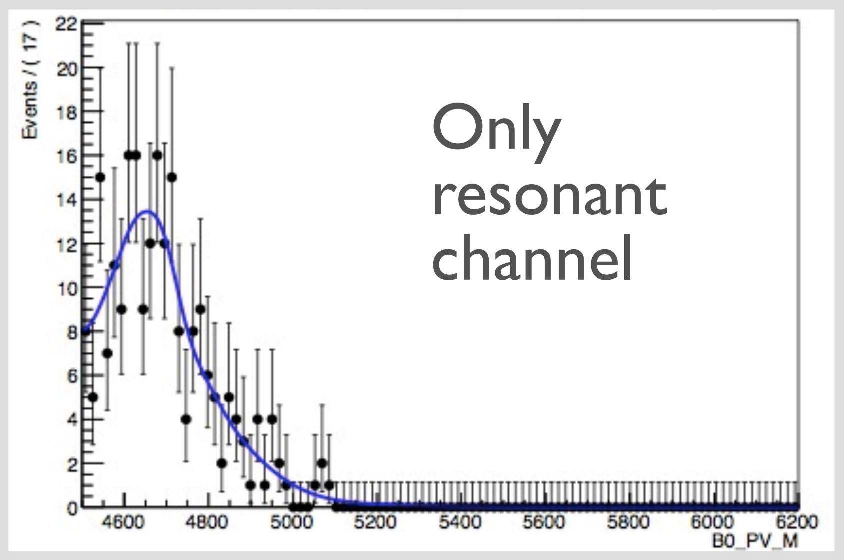
0γ: simple CB 1γ: CB+gauss 2γ: CB+gauss

Electron channels: background description

- Combinatorial: exponential
- Background from higher hadronic and leptonic resonances
- Leak of the J/ψ and ψ(2S) tails into the rare intervals

$B\to(Y\to K\pi X)(J/\psi\to ee)$ $B\to(K^*\to K\pi)(Y\text{->}J/\psi\to ee)$

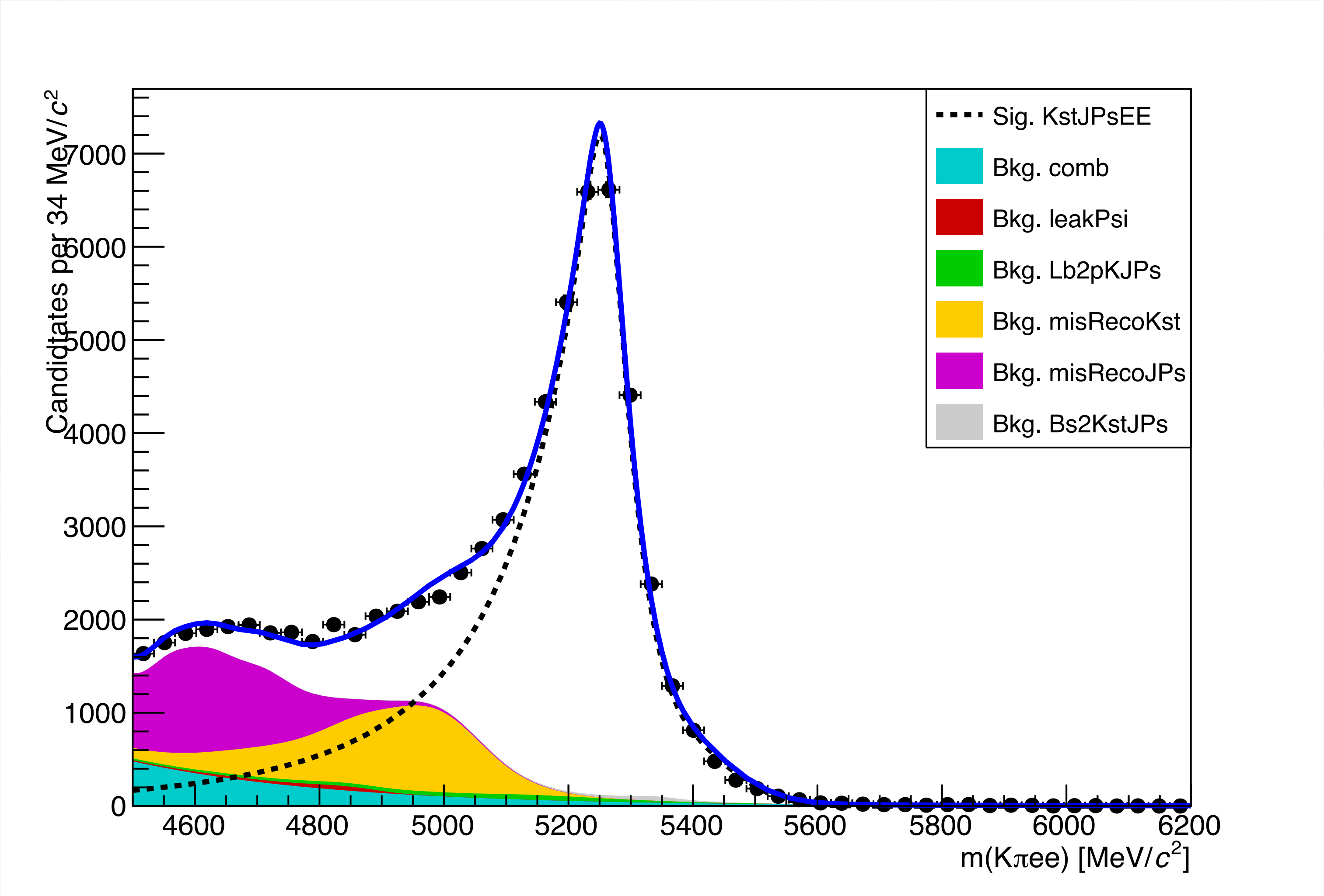




Only
resonant
channel

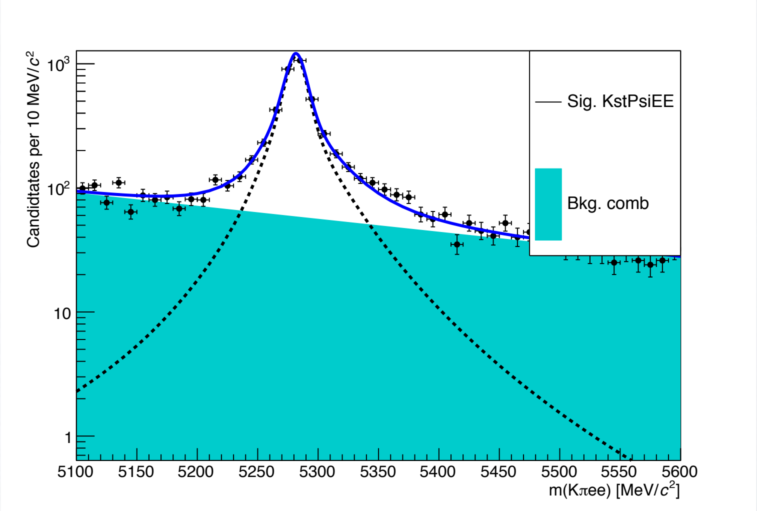
Modelled with simulated distributions

Mass fits: $B^0 \rightarrow K^{*0}(J/\psi \rightarrow ee)$



Simultaneous fit to the three trigger categories, resonant and rate samples: shape parameters are shared.

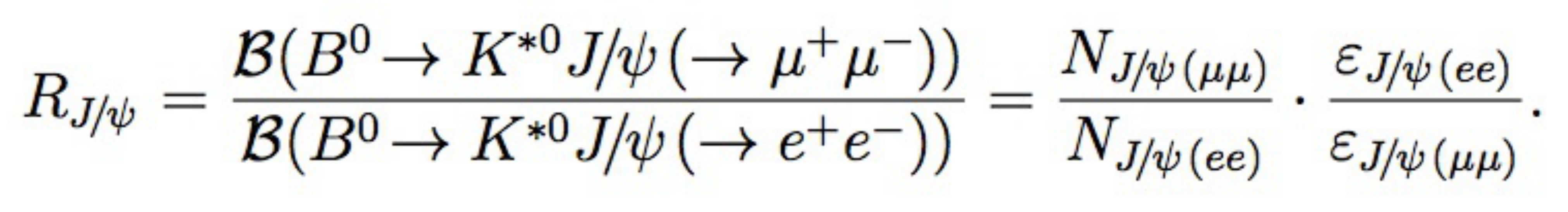
Fitting also ψ(2S) events as they can leak into the high q^2 rare interval.



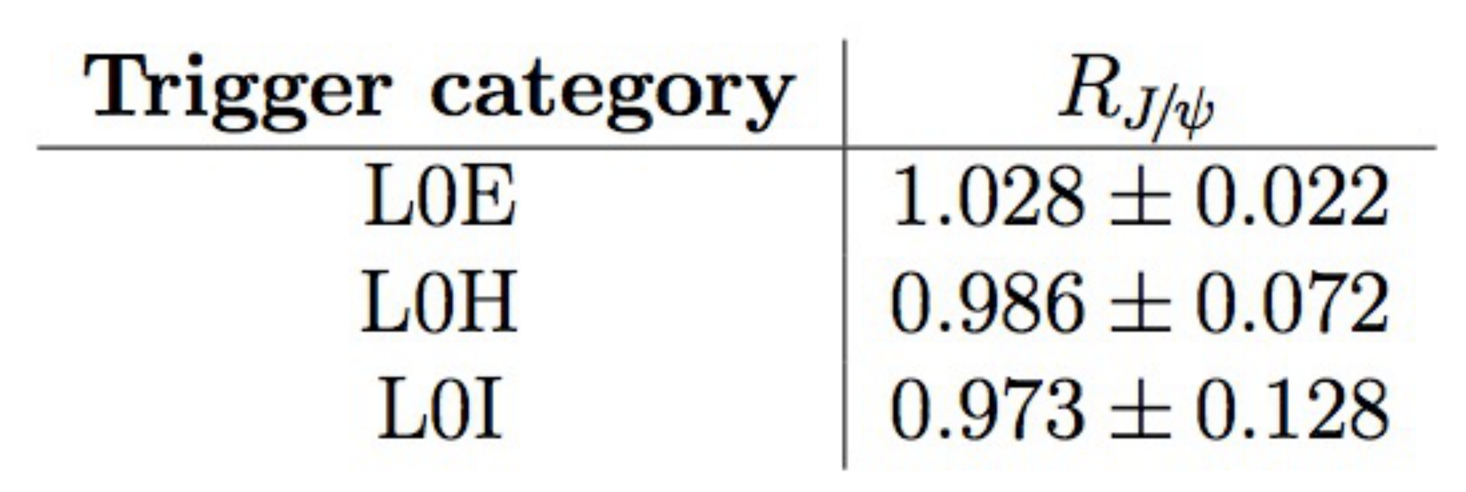
J/ψ sanity check

No new physics expected in the resonant channels

→ Ratio between them corrected for efficiency should be 1



$$R_{J/\psi} = \frac{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to \mu^+\mu^-))}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to e^+e^-))} = \frac{N_{J/\psi(\mu\mu)}}{N_{J/\psi(ee)}} \cdot \frac{\varepsilon_{J/\psi(ee)}}{\varepsilon_{J/\psi(\mu\mu)}}.$$



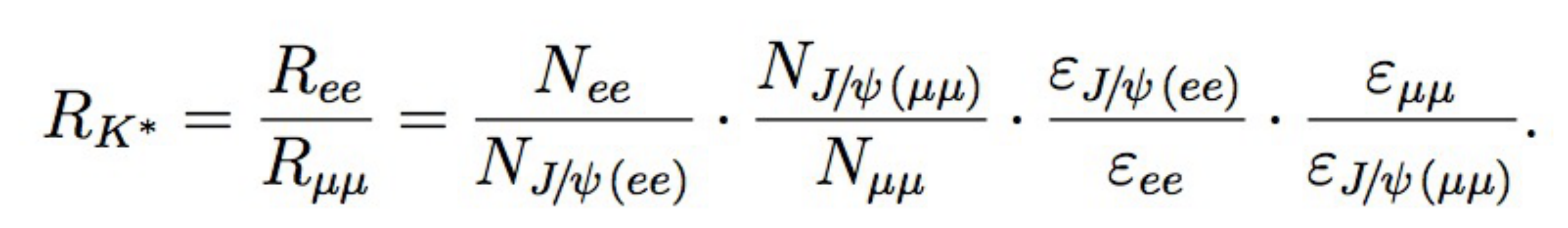
Trigger category	$R_{J/\psi}$
L0E	1.028 ± 0.022
L0H	0.986 ± 0.072
L0I	0.973 ± 0.128

Good agreement is found → almost ready to get the results out!

Result and systematics

Result as a double ratio over the resonant channels

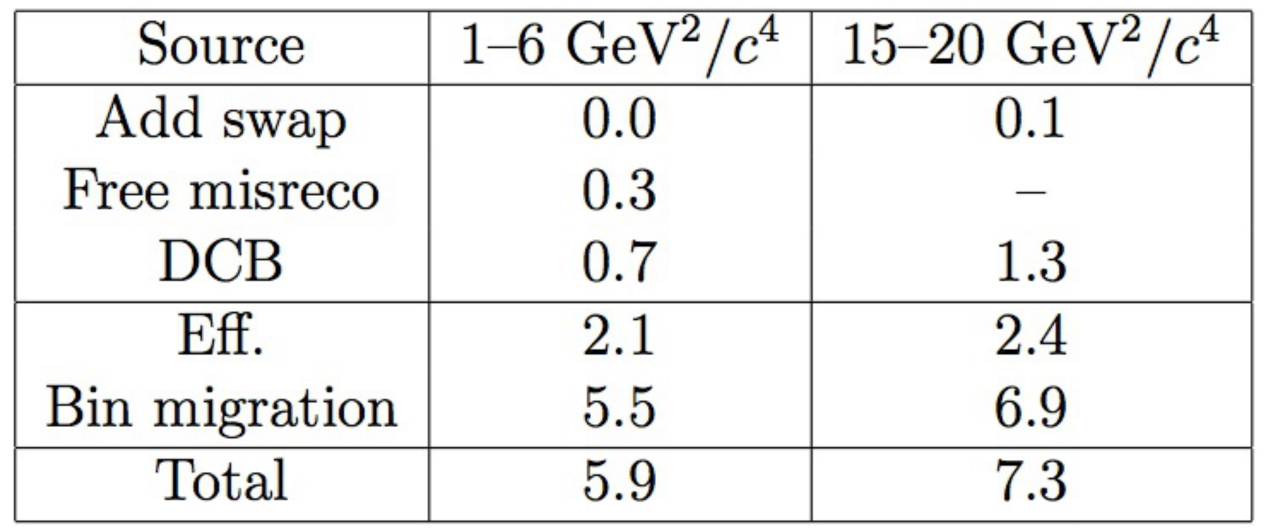
→ similar kinematics cancels systematic uncertainties in efficiency determination



$$R_{K^*} = \frac{R_{ee}}{R_{\mu\mu}} = \frac{N_{ee}}{N_{J/\psi\,(ee)}} \cdot \frac{N_{J/\psi\,(\mu\mu)}}{N_{\mu\mu}} \cdot \frac{\varepsilon_{J/\psi\,(ee)}}{\varepsilon_{ee}} \cdot \frac{\varepsilon_{\mu\mu}}{\varepsilon_{J/\psi\,(\mu\mu)}}.$$

Results not approved yet, but soon!

Systematics



Source	1–6 GeV^2/c^4	15–20 GeV^2/c^4
Add swap	0.0	0.1
Free misreco	0.3	–
DCB	0.7	1.3
Eff.	2.1	2.4
Bin migration	5.5	6.9
Total	5.9	7.3

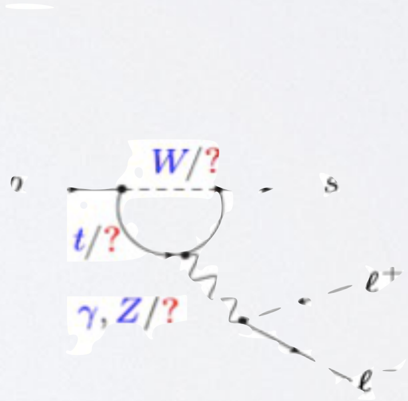
- Choice of signal and background PDFs
- Bin migration modelling
- …

Summary

- Many interesting results from the RD group at LHCb

- Updated B($\Lambda_b \rightarrow \Lambda^0 \mu\mu$): uncertainties improved by a factor of ~3
- First evidence of signal al low q^2
- First measurement of angular observables

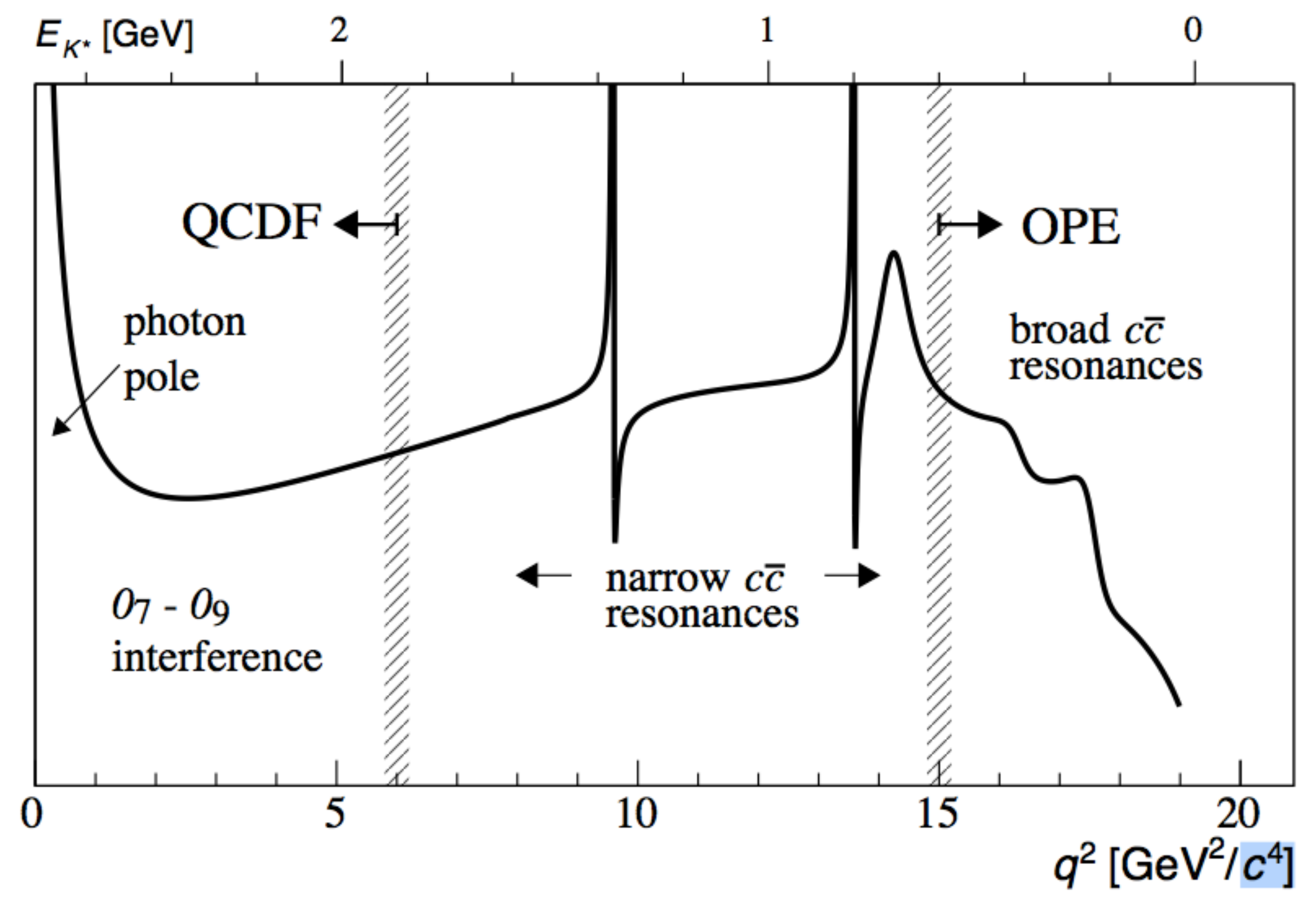
- Testing Lepton Universality with RK*
- Results coming soon!



Thank you for listening!

Backup

q^2 spectrum DNA



Blake, Gershon & Hiller: arXiv:1501.03309v1

Angular analysis: uncertainties

Statistical uncertainties treated with likelihood ordering method

- Lepton side PDF has physical boundaries → can bias the uncertainties
- Nuisance parameters treated with the plug-in method (arXiv:1109.0714)
  - ✓ Based on toy experiments
  - ✓ Well defined frequentist coverage

Dark area: region of the parameter space where the PDF is positive.

Systematics:

- Effect of a non-flat efficiency on the integration of the full 5D angular PDF
- Data-MC discrepancies (MC used for most of the efficiencies)
- Particular choice of background parameterisation
- Effect of finite angular resolution → asymmetric bin migration

Feldman-Cousins method

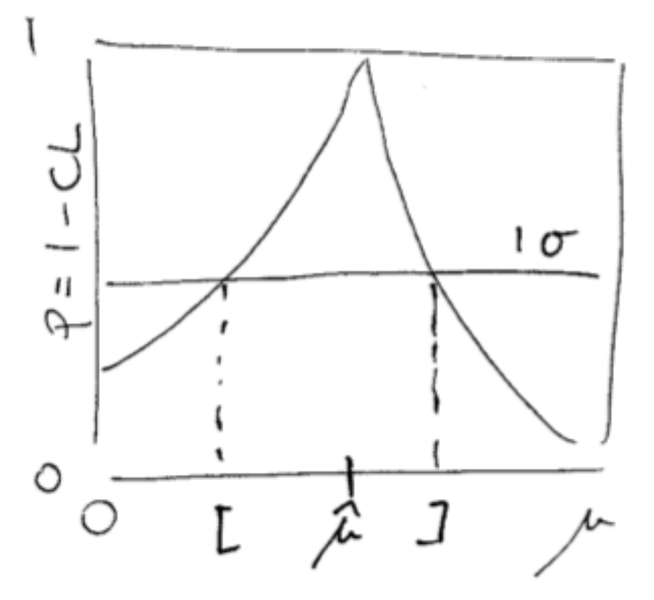
arXiv:physics/9711021

- Feldman-Cousins method plug-in method to extract confidence bands
  - Choose Parameters of Interest (PoI) and fit data with PoI free and fixed
  - Generate toys with PoI fixed to tested values and nuisance parameters (all other parameters) from fixed fit on data.
  - Fit toys with free and fixed PoI
  - Look how may times log likelihood ratio in data is smaller than MC
  - Scan values to look for 68%, 95% etc.

$$\left(\frac{logL_{free}}{logL_{fixed}}\right)_{data} < \left(\frac{logL_{free}}{logL_{fixed}}\right)_{MC}$$

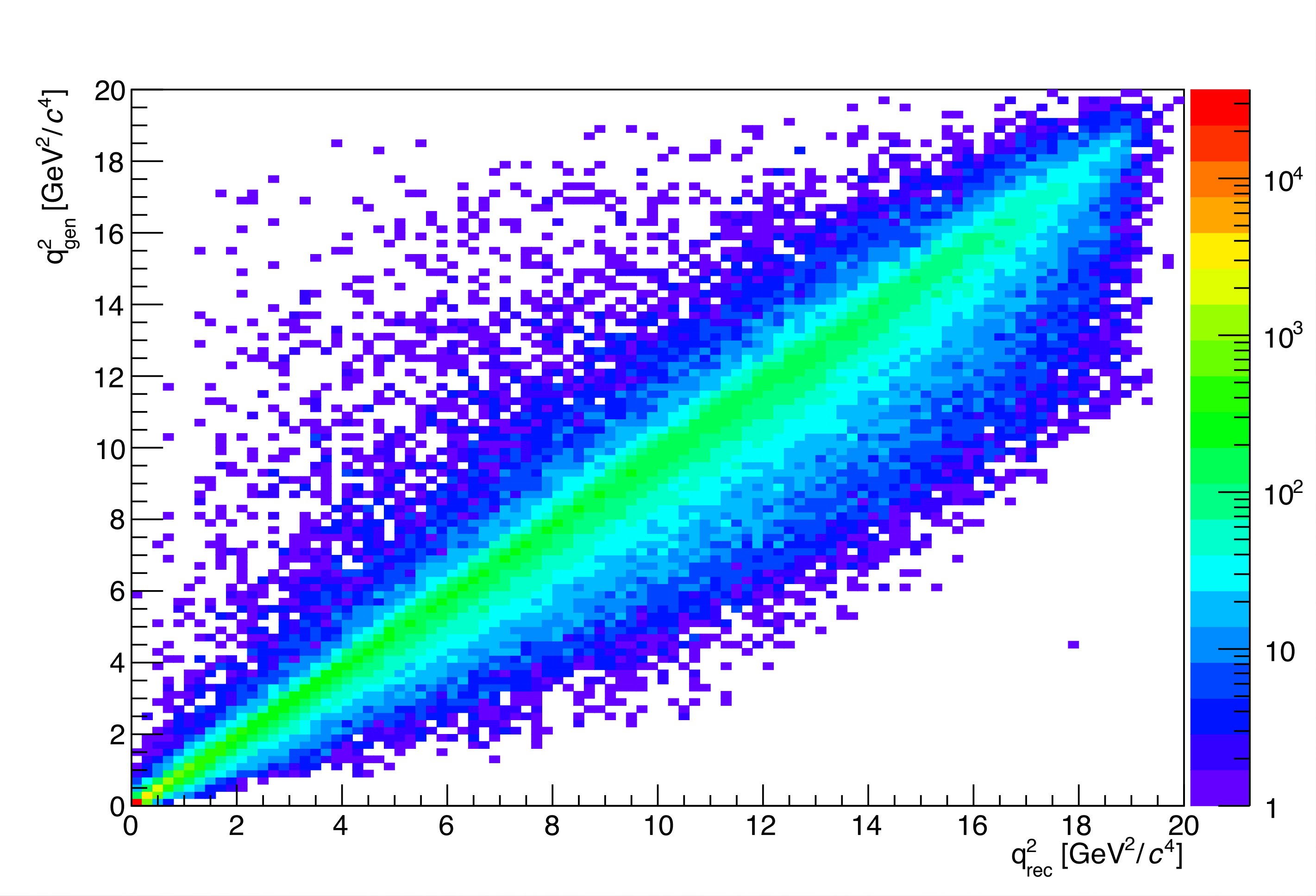
Statistica Sinica 19 (2009) 301

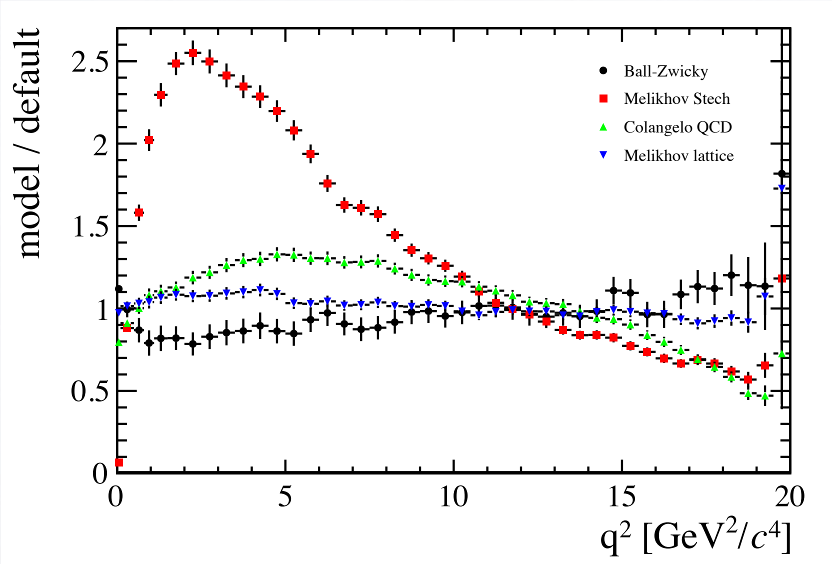
arXiv:1109.0714v1



- Starts to be widely used in LHCb
- Allows to consider nuisance parameters: no confidence belt
- Guarantees full coverage
- Returns 2-side intervals and upper limits in a unified approach

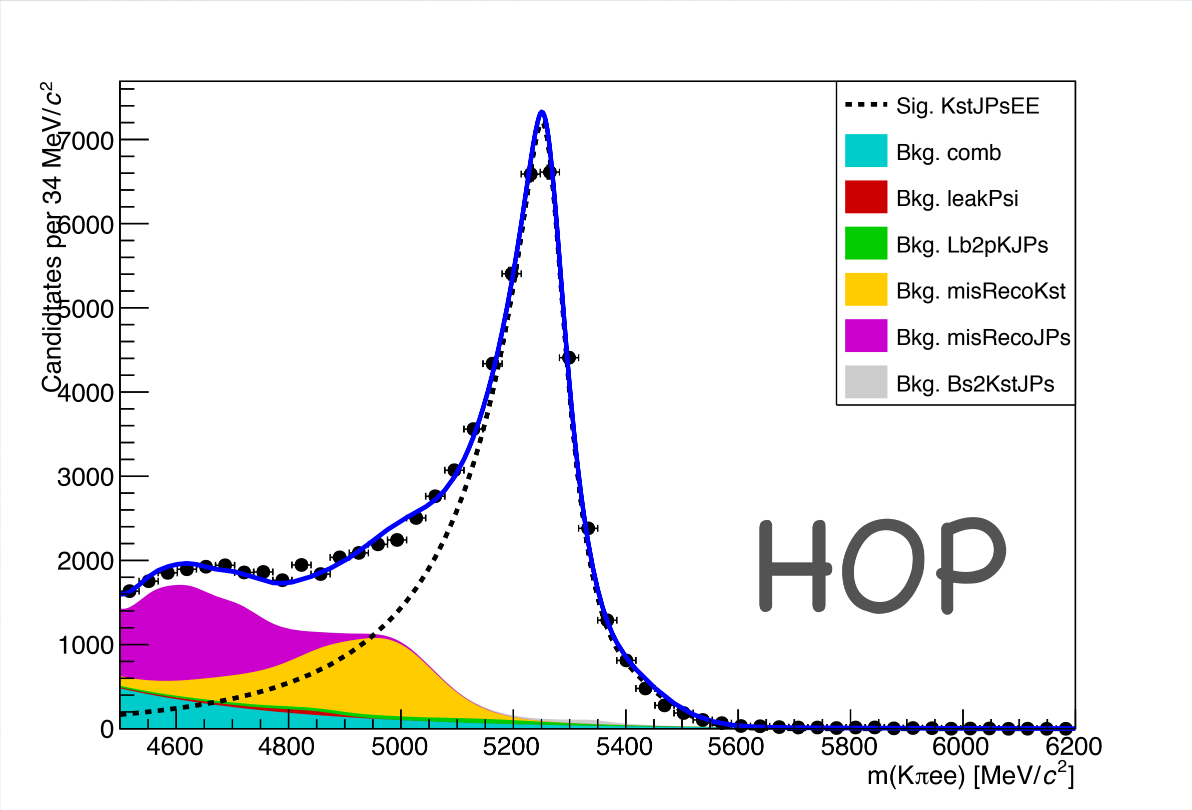
Bin migration

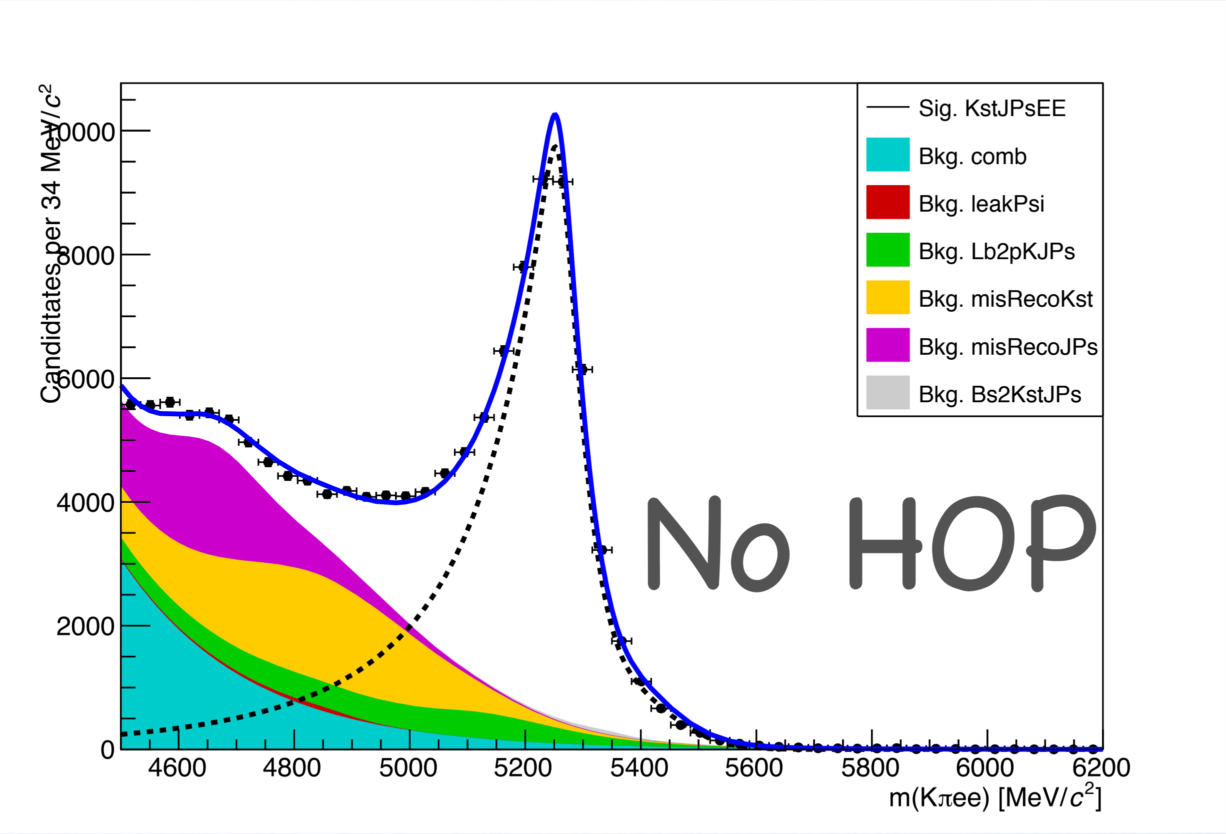




- Events generated in a q^2 can be reconstructed in an other.
- E.g. Due to bremsstrahlung
- Can cause bias is the migration of events is asymmetric
- We generate events with different models to verify how much we are sensitive to this

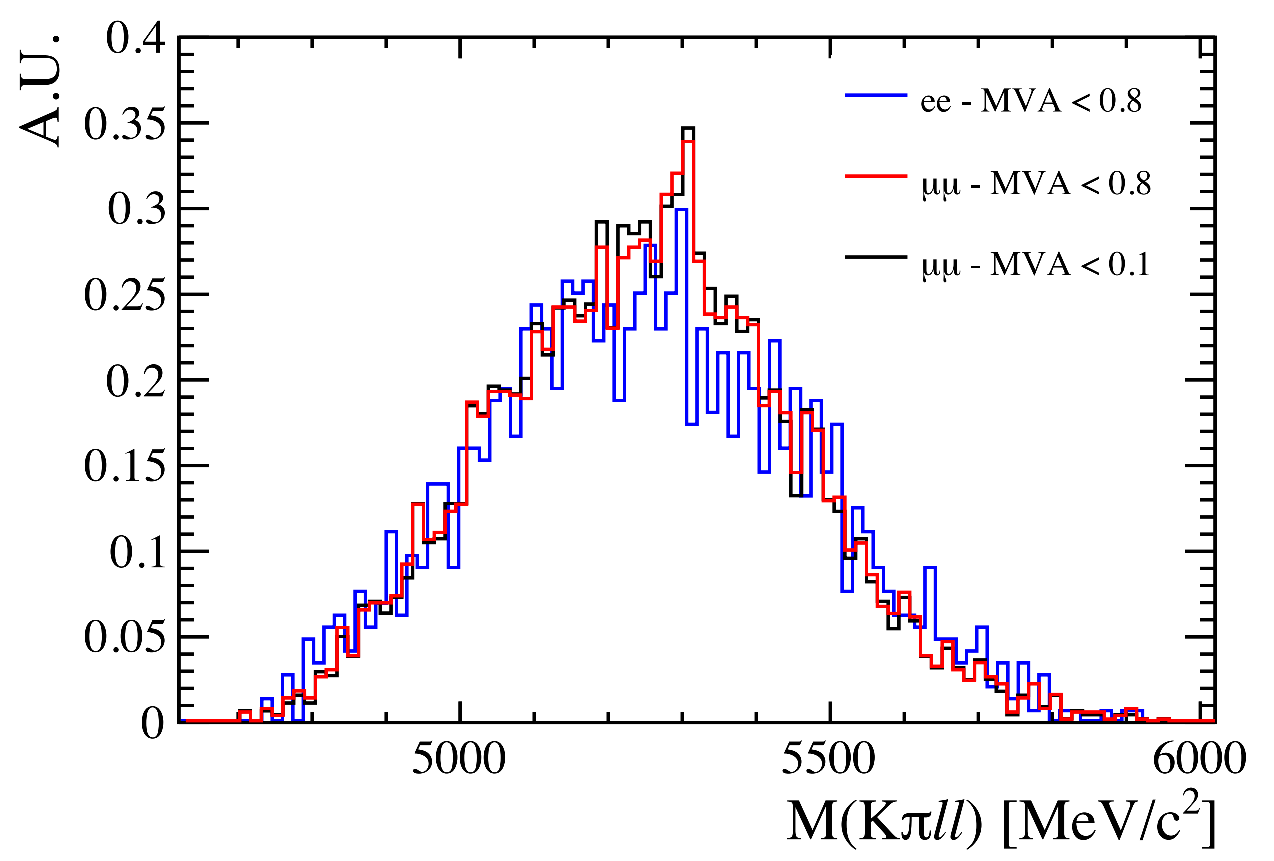
HOP cut effect





Combinatorial background for high q^2

In the high q^2 region - above $\psi(2S)$ - due to threshold effect the combinatorial is not exponential



By inverting the MVA cut one selects only combinatorial background!

The flavour problem and the need for New Physics

Flavour:

Assumed to be conserved in all SM interactions due to experimental evidence

$\mu \to eee$

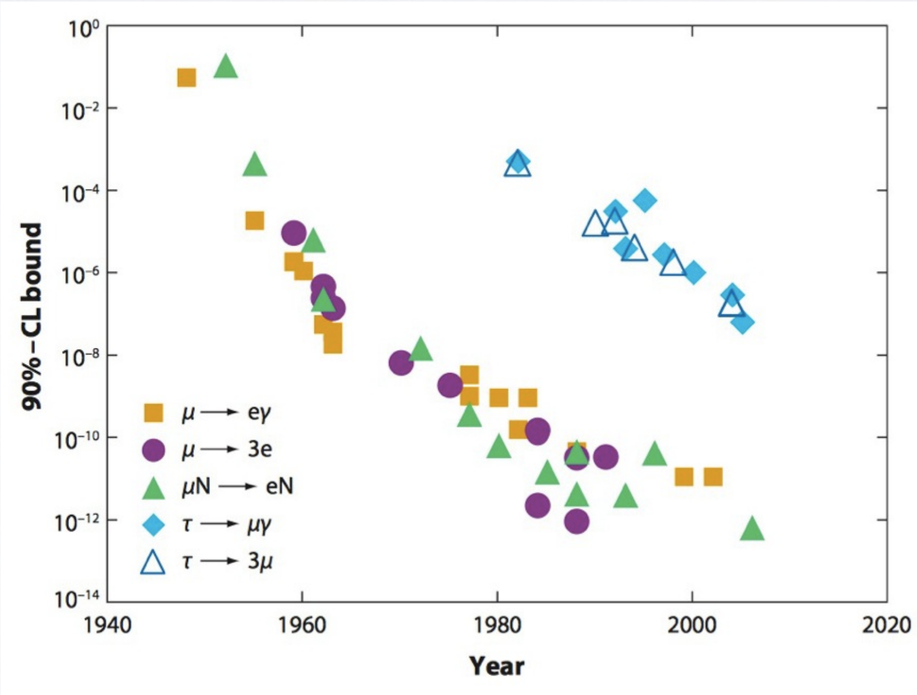
BR < 1.2×10^{-11}

Nucl.Phys. B299 (1988) 1

$\mu \to e\gamma$

BR < 1.0×10^{-12}

Phys.Rev. D65 (2002) 112002 [hep-ex/0111030]



Ann.Rev.Nucl.Part.Sci. 58 (2008) 315–341

Wilson coefficients

The effective theory matched with the full SM calculation at the EW scale (μ_W)

$$\boxed{C_7^{SM} = -0.3, \quad C_9^{SM} = 4.2, \quad C_{10}^{SM} = -4.2.}$$

Renormalization equations allow to evolve to different scales.

Any particle above the *b* mass, including Z, W and t, affects at least one coefficient.

New physics enters into Wilson coefficients as additive factors.

$$\boxed{C_i = C_i^{NP} + C_i^{SM}}$$

hep-ph/9806471.

Operators

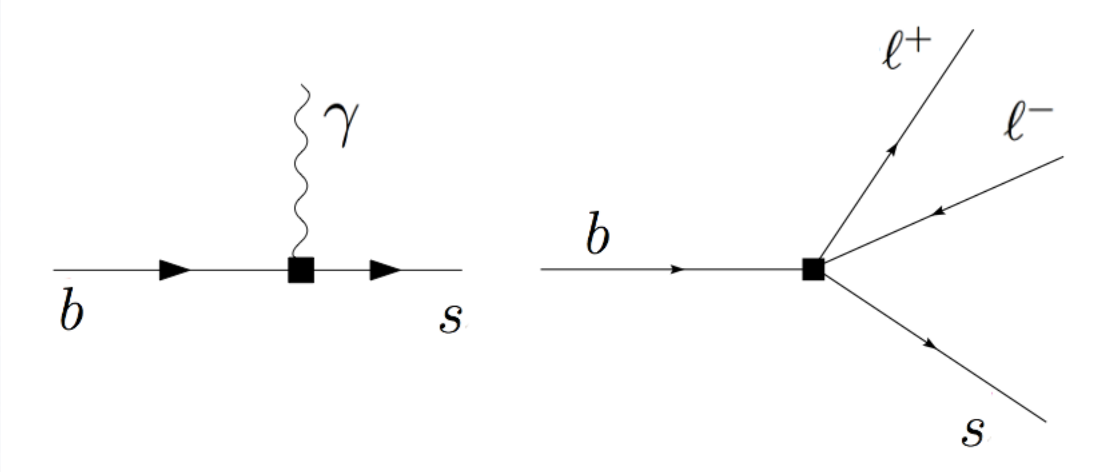
Separating left-handed and right-handed components:

$$\mathcal{H}_{eff} = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \frac{\alpha_e}{4\pi} \sum_{i=1}^{10} [\underline{C_i \mathcal{O}_i} + \underline{C_i' \mathcal{O}_i'}]$$

Suppressed
C' ~ m_s/m_b C

A complete basis is given by:

- ✓ $O_{1,2}$: tree level
- ✓ $O_{3\text{-}6}$ and O_8 : mediated by gluons
- ✓ O_7 : radiative penguin
- ✓ $O_{9,10}$: semileptonic decays
  (Z penguin and W-box)



arXiv:1501.03309

$$\mathcal{O}_7 = \frac{m_b}{e} (\bar{s}\sigma^{\mu\nu} P_R b) F_{\mu\nu}$$
$$\mathcal{O}_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell),$$
$$\mathcal{O}_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

Right-handed operators can be obtained swapping P_R and P_L

Operators

Separating left-handed and right-handed components:

$$\mathcal{H}_{eff} = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \frac{\alpha_e}{4\pi} \sum_{i=1}^{10} [\underline{C_i \mathcal{O}_i} + \underline{C_i' \mathcal{O}_i'}]$$

→ **Suppressed**
C' ~ m_s/m_b C

A complete basis is given by:

- ✓ $O_{1,2}$: tree level
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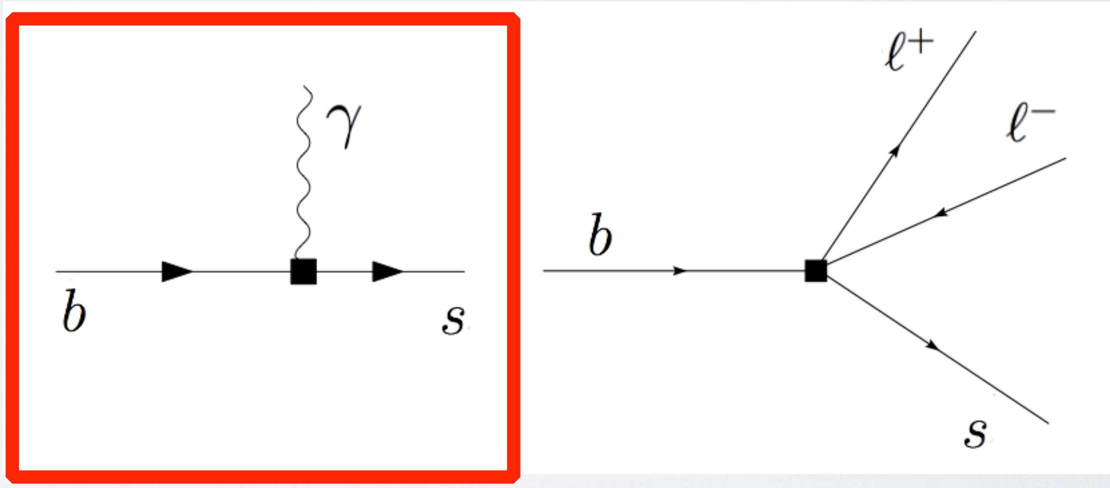
  (Z penguin and W-box)



arXiv:1501.03309

$$\boxed{\mathcal{O}_7 = \frac{m_b}{e}(\bar{s}\sigma^{\mu\nu}P_R b)F_{\mu\nu}}$$
$$\mathcal{O}_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell),$$
$$\mathcal{O}_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

Right-handed operators can be obtained swapping P_R and P_L

Operators

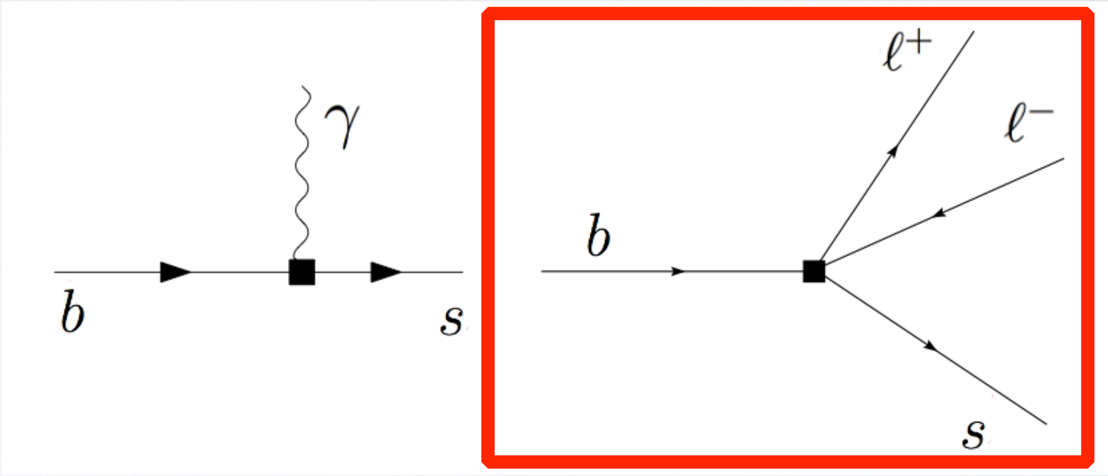
Separating left-handed and right-handed components:

$$\mathcal{H}_{eff} = \frac{4G_F}{\sqrt{2}} V_{tb} V^*_{ts} \frac{\alpha_e}{4\pi} \sum_{i=1}^{10} [\underline{C_i \mathcal{O}_i} + \underline{C'_i \mathcal{O}'_i}]$$

Suppressed
C' ~ m_s/m_b C

A complete basis is given by:

- ✓ $O_{1,2}$: tree level
- ✓ $O_{3\text{-}6}$ and O_8 : mediated by gluons
- ✓ O_7 : radiative penguin
- ✓ $O_{9,10}$: semileptonic decays
  (Z penguin and W-box)



arXiv:1501.03309

$$\mathcal{O}_7 = \frac{m_b}{e}(\bar{s}\sigma^{\mu\nu} P_R b) F_{\mu\nu},$$
$$\boxed{\begin{aligned}\mathcal{O}_9 &= (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell),\\ \mathcal{O}_{10} &= (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\end{aligned}}$$

Right-handed operators can be obtained swapping P_R and P_L

… and a lot more from RDWG

Analysis semileptonic B_s decays e.g. $B_s \rightarrow \varphi\, \mu\mu$

JHEP 07 (2013) 084, [arXiv:1305.2168]

arXiv:1506.08777

Majorana neutrino and

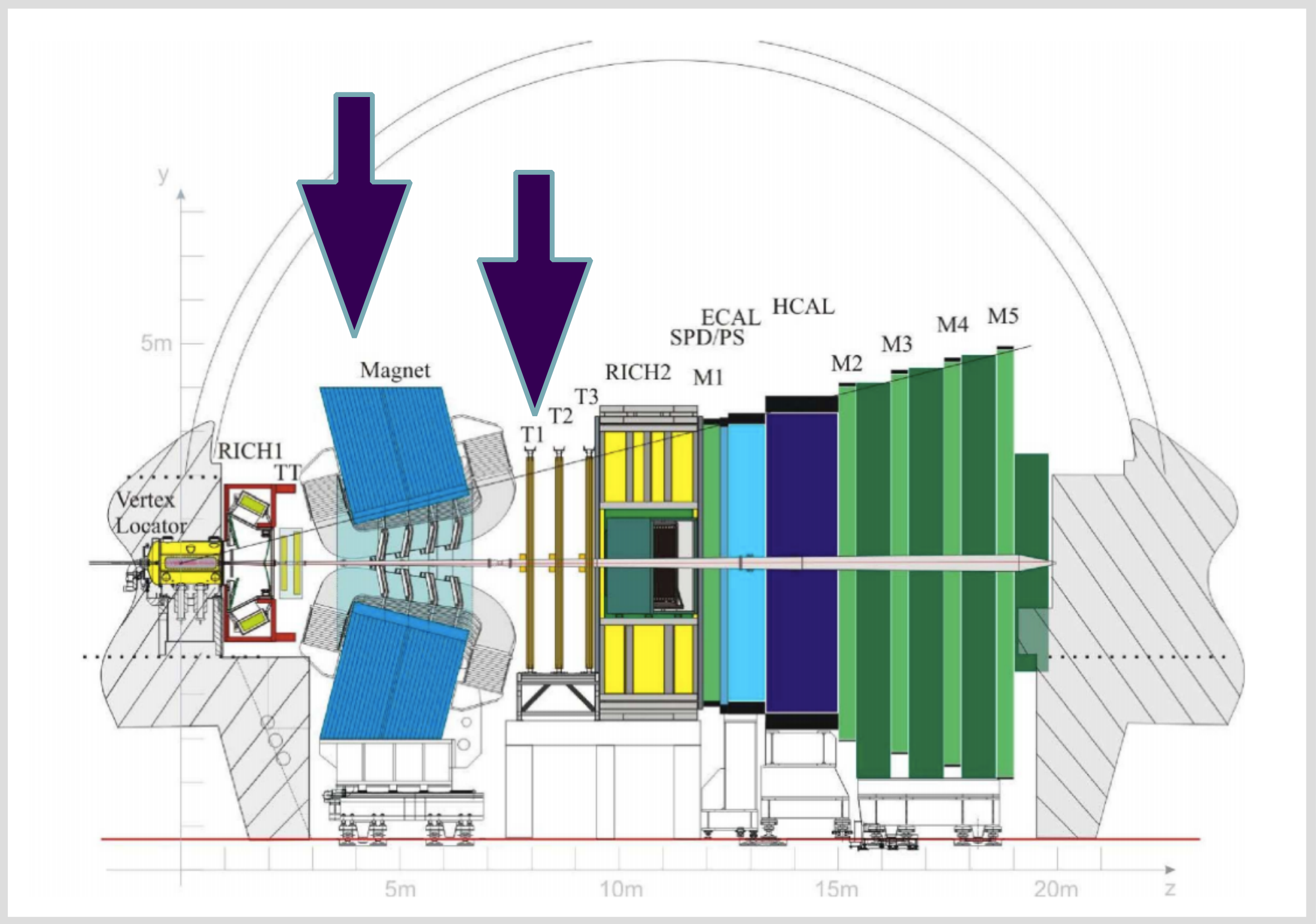
PRL 112 (2014) 131802

lepton flavour violation searches

PRL 111 (2013) 141801 PRL. 111 (2013) 141801

The LHCb detector

JINST 3 (2008) S08005



Magnet

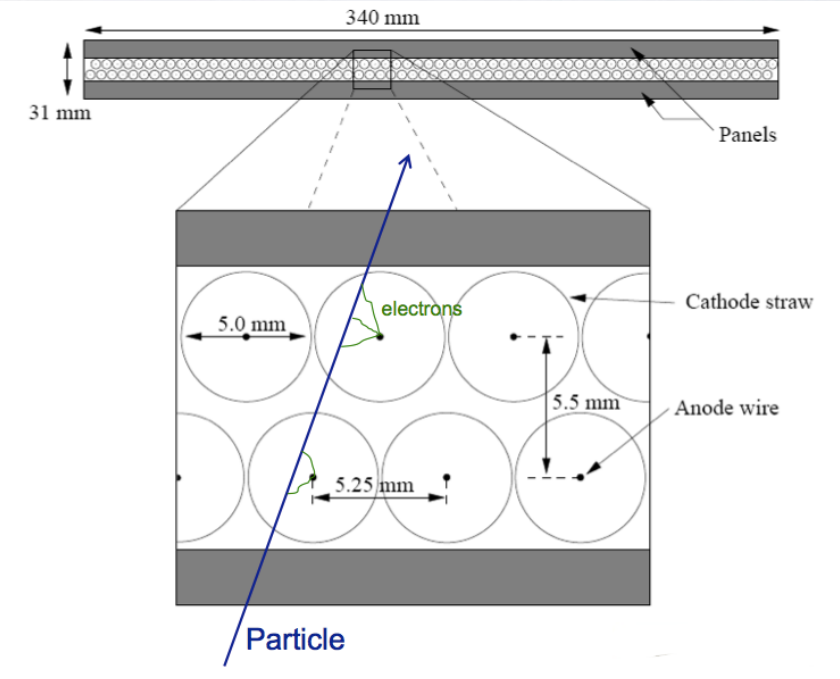
Power: 4 Tm
Polarity periodically reversed
to reduce systematics

Tracking system

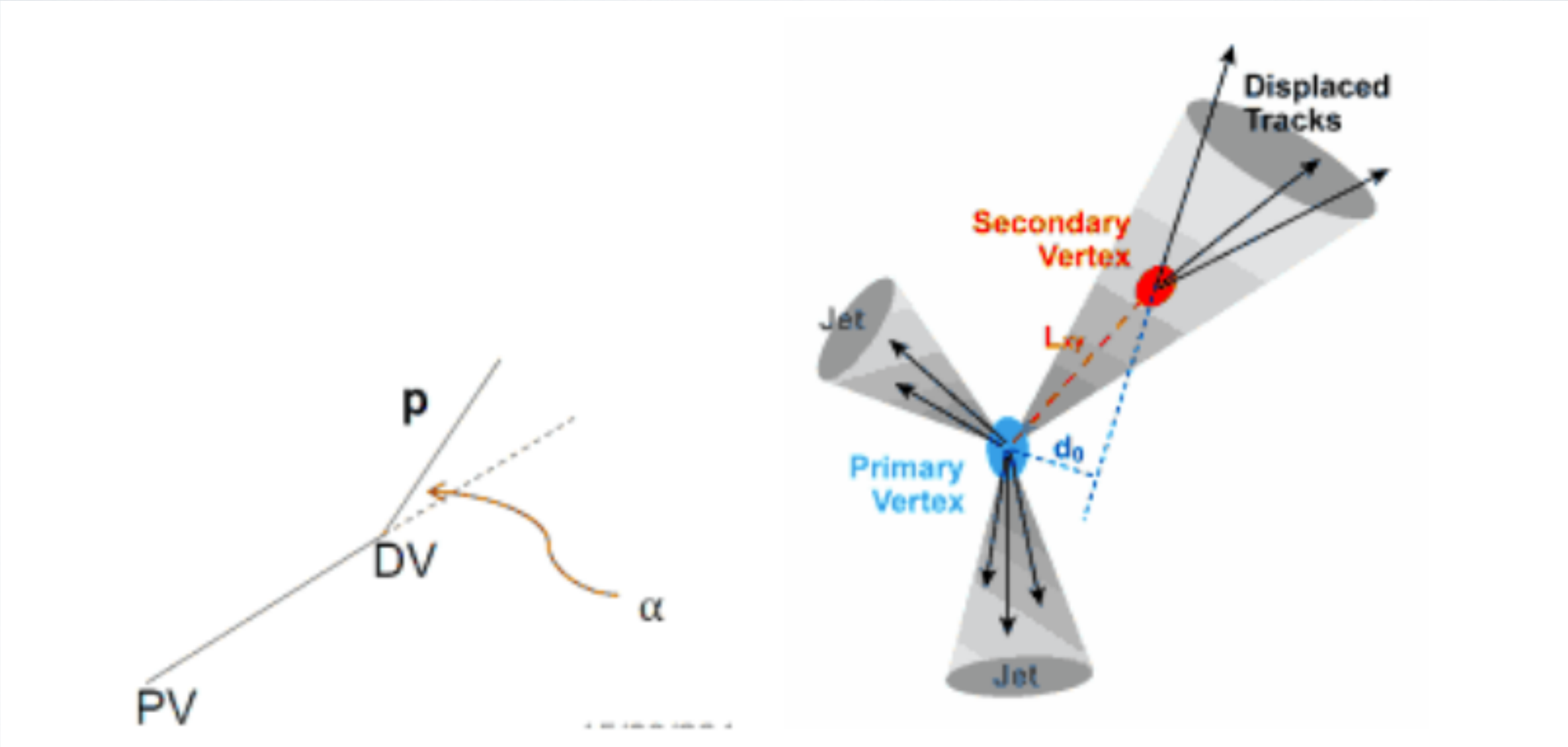
TT → before magnet
OT → after magnet

Precision:
0.4% at 5 GeV/c
1% at 200 GeV/c

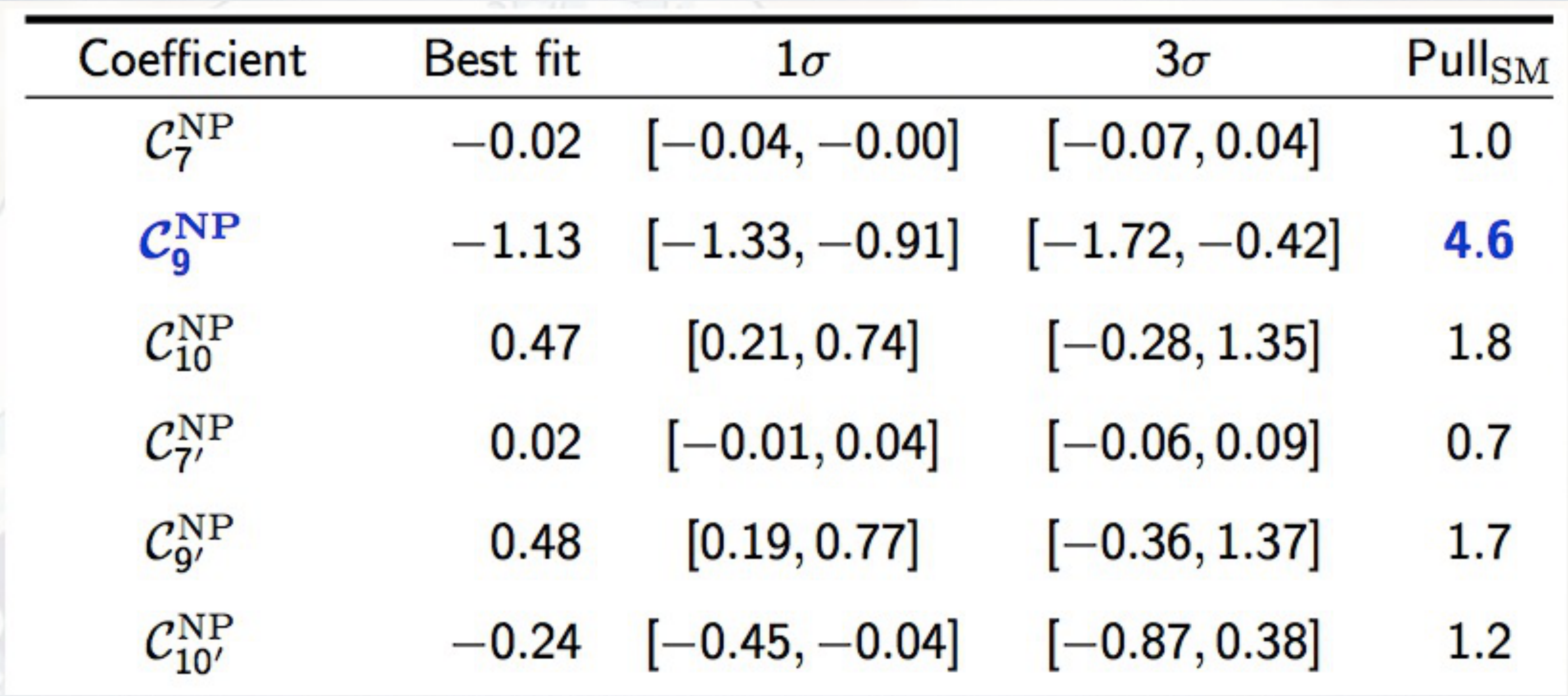
Silicon strip and drift chambers



IPχ^2 and DIRA

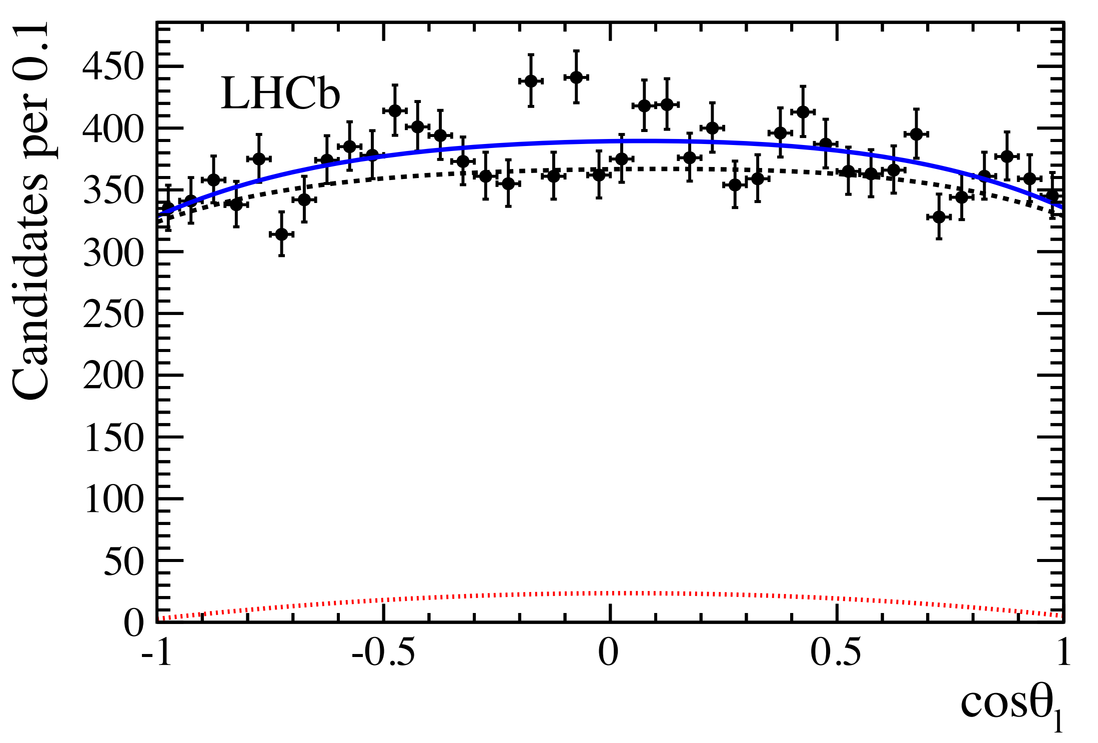


Global fit results



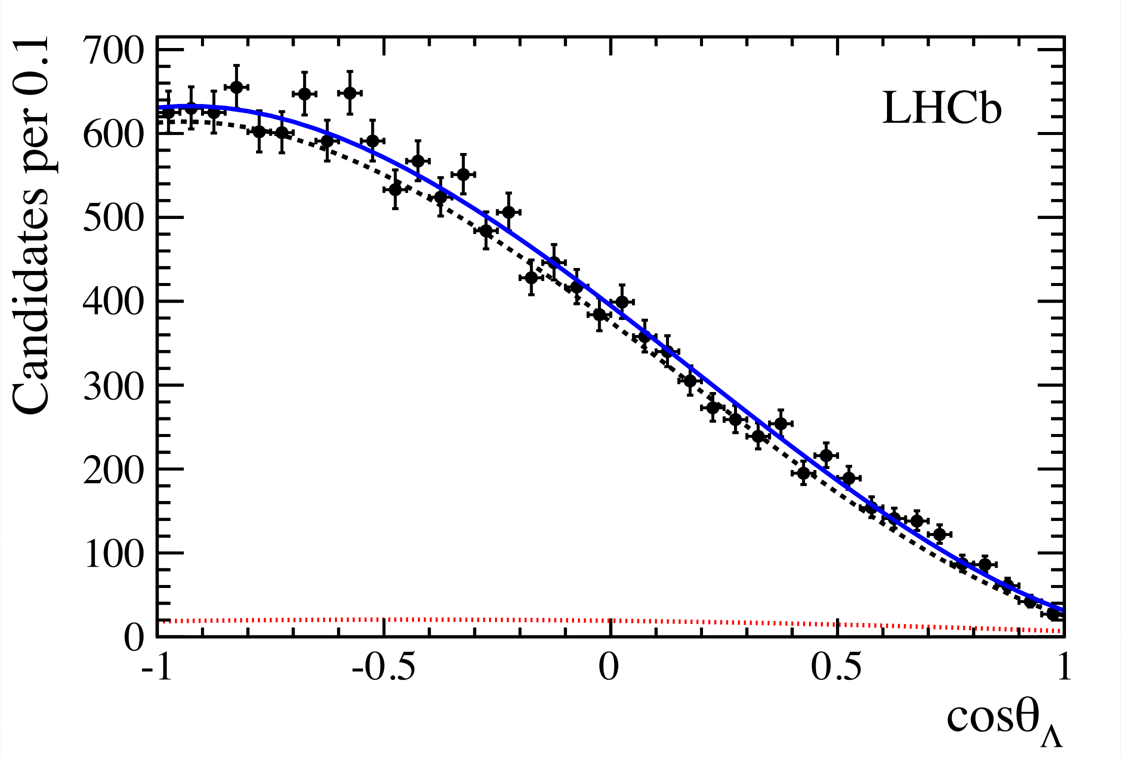
Coefficient	Best fit	1σ	3σ	$\mathrm{Pull}_{\mathrm{SM}}$
$\mathcal{C}_7^{\mathrm{NP}}$	−0.02	[−0.04, −0.00]	[−0.07, 0.04]	1.0
$\boldsymbol{\mathcal{C}_9^{\mathrm{NP}}}$	−1.13	[−1.33, −0.91]	[−1.72, −0.42]	**4.6**
$\mathcal{C}_{10}^{\mathrm{NP}}$	0.47	[0.21, 0.74]	[−0.28, 1.35]	1.8
$\mathcal{C}_{7'}^{\mathrm{NP}}$	0.02	[−0.01, 0.04]	[−0.06, 0.09]	0.7
$\mathcal{C}_{9'}^{\mathrm{NP}}$	0.48	[0.19, 0.77]	[−0.36, 1.37]	1.7
$\mathcal{C}_{10'}^{\mathrm{NP}}$	−0.24	[−0.45, −0.04]	[−0.87, 0.38]	1.2

Using J/ψΛ for cross-check



Leptonic angle

Hadronic angle



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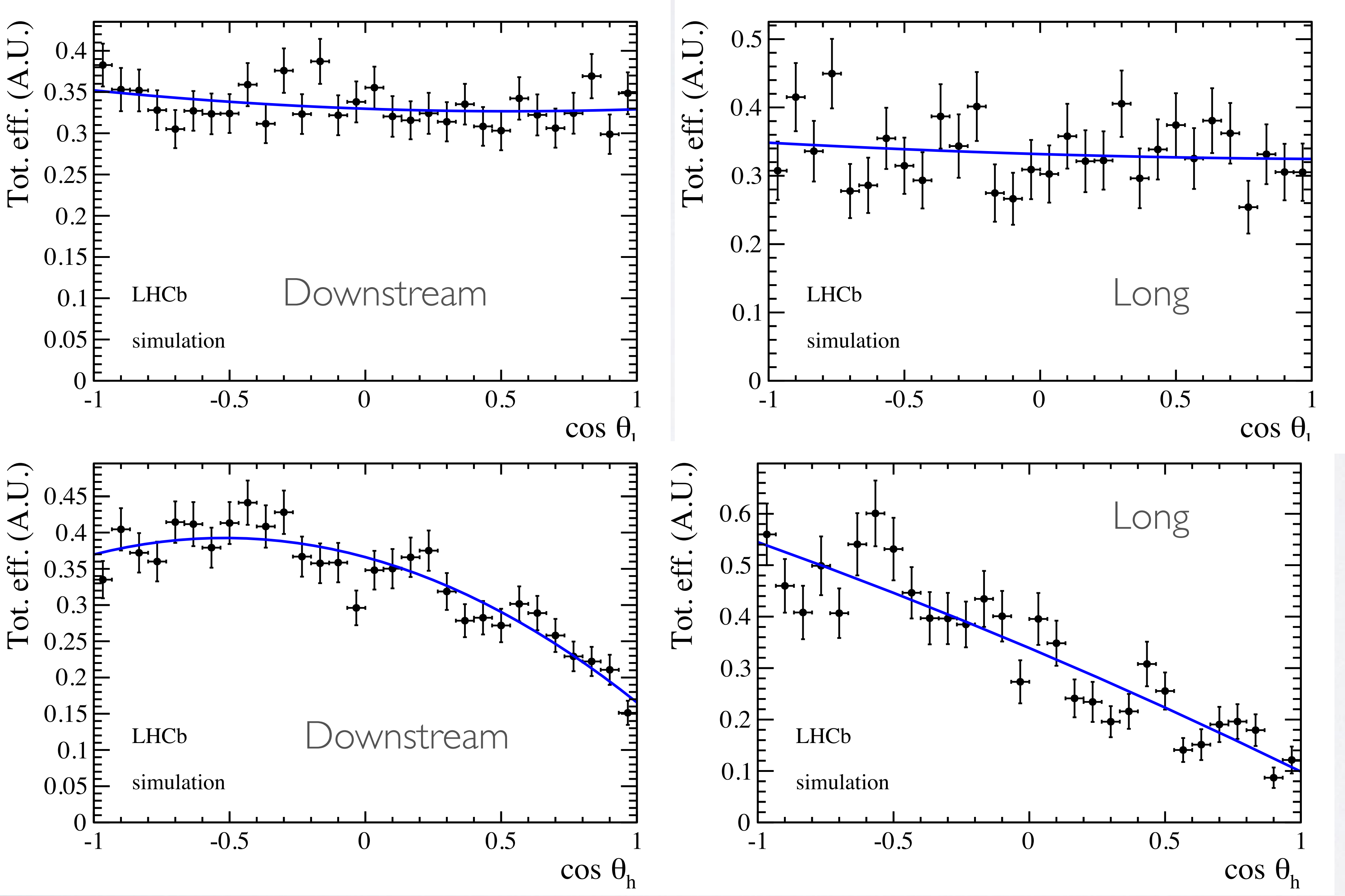
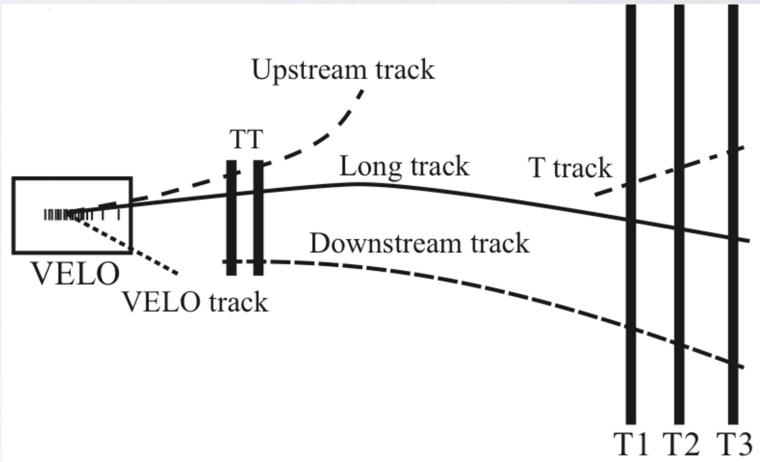
Angular acceptances

In LHCb long-lived particles, like Λ^0, can be reconstructed with hits in the VELO (log) or without hits in the VELO (downstream).

- Up- and down-stream events are characterised by different efficiency and resolution
- A simultaneous fit is performed on the two categories





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Results tables

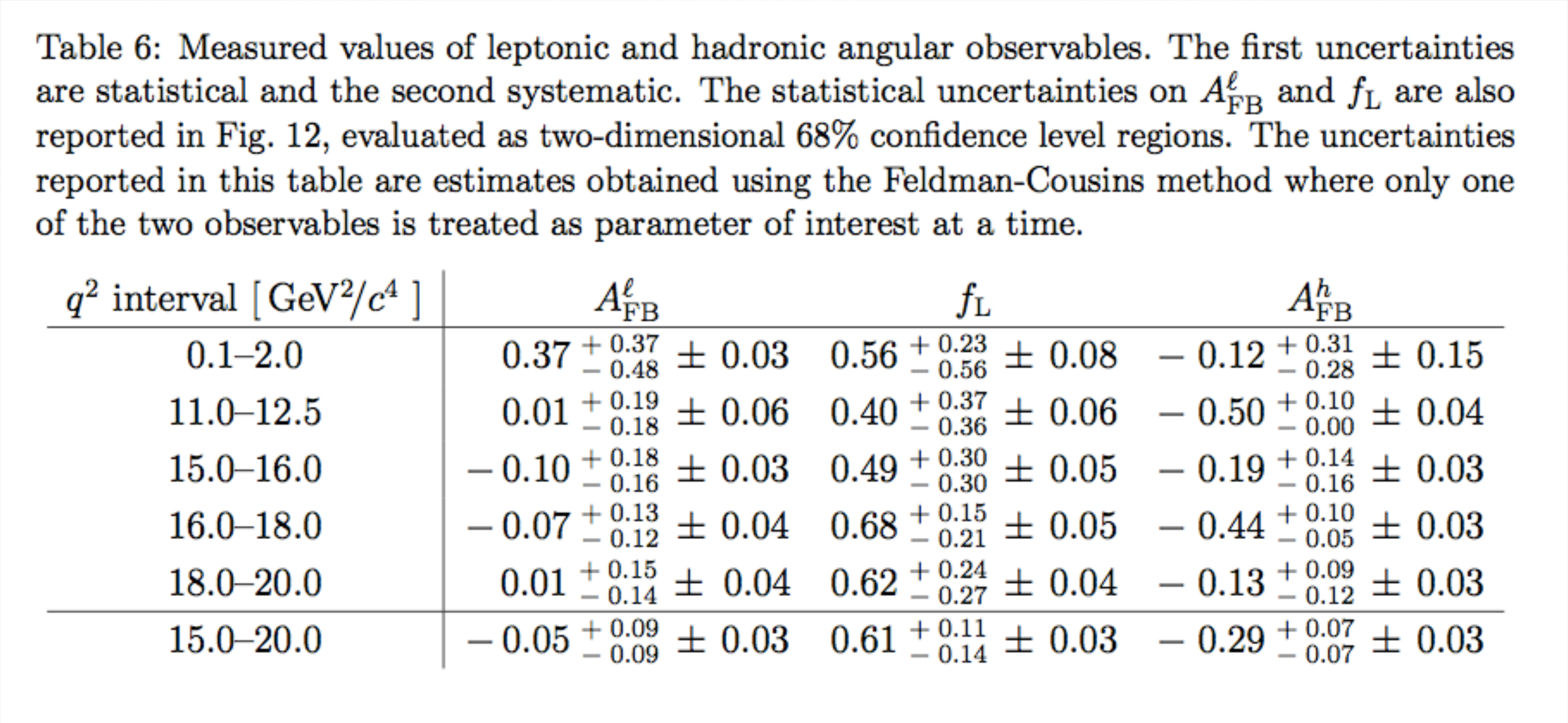

Table 6: Measured values of leptonic and hadronic angular observables. The first uncertainties are statistical and the second systematic. The statistical uncertainties on A^{ℓ}_{FB} and f_{L} are also reported in Fig. 12, evaluated as two-dimensional 68% confidence level regions. The uncertainties reported in this table are estimates obtained using the Feldman-Cousins method where only one of the two observables is treated as parameter of interest at a time.

q^2 interval $[\,\mathrm{GeV}^2/c^4\,]$	A^{ℓ}_{FB}	f_{L}	A^{h}_{FB}
0.1–2.0	$0.37\,^{+\,0.37}_{-\,0.48} \pm 0.03$	$0.56\,^{+\,0.23}_{-\,0.56} \pm 0.08$	$-\,0.12\,^{+\,0.31}_{-\,0.28} \pm 0.15$
11.0–12.5	$0.01\,^{+\,0.19}_{-\,0.18} \pm 0.06$	$0.40\,^{+\,0.37}_{-\,0.36} \pm 0.06$	$-\,0.50\,^{+\,0.10}_{-\,0.00} \pm 0.04$
15.0–16.0	$-\,0.10\,^{+\,0.18}_{-\,0.16} \pm 0.03$	$0.49\,^{+\,0.30}_{-\,0.30} \pm 0.05$	$-\,0.19\,^{+\,0.14}_{-\,0.16} \pm 0.03$
16.0–18.0	$-\,0.07\,^{+\,0.13}_{-\,0.12} \pm 0.04$	$0.68\,^{+\,0.15}_{-\,0.21} \pm 0.05$	$-\,0.44\,^{+\,0.10}_{-\,0.05} \pm 0.03$
18.0–20.0	$0.01\,^{+\,0.15}_{-\,0.14} \pm 0.04$	$0.62\,^{+\,0.24}_{-\,0.27} \pm 0.04$	$-\,0.13\,^{+\,0.09}_{-\,0.12} \pm 0.03$
15.0–20.0	$-\,0.05\,^{+\,0.09}_{-\,0.09} \pm 0.03$	$0.61\,^{+\,0.11}_{-\,0.14} \pm 0.03$	$-\,0.29\,^{+\,0.07}_{-\,0.07} \pm 0.03$

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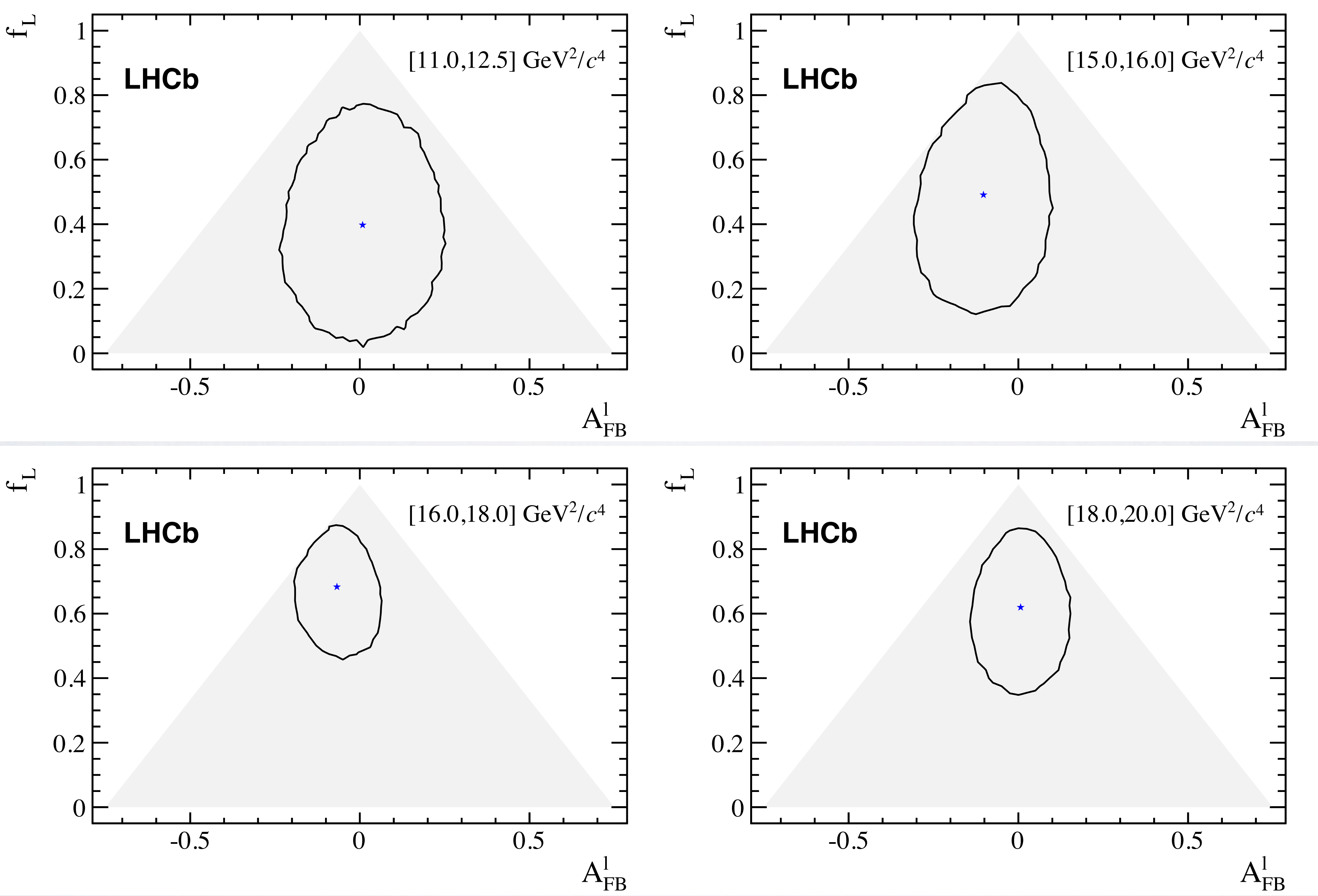
Confidence regions



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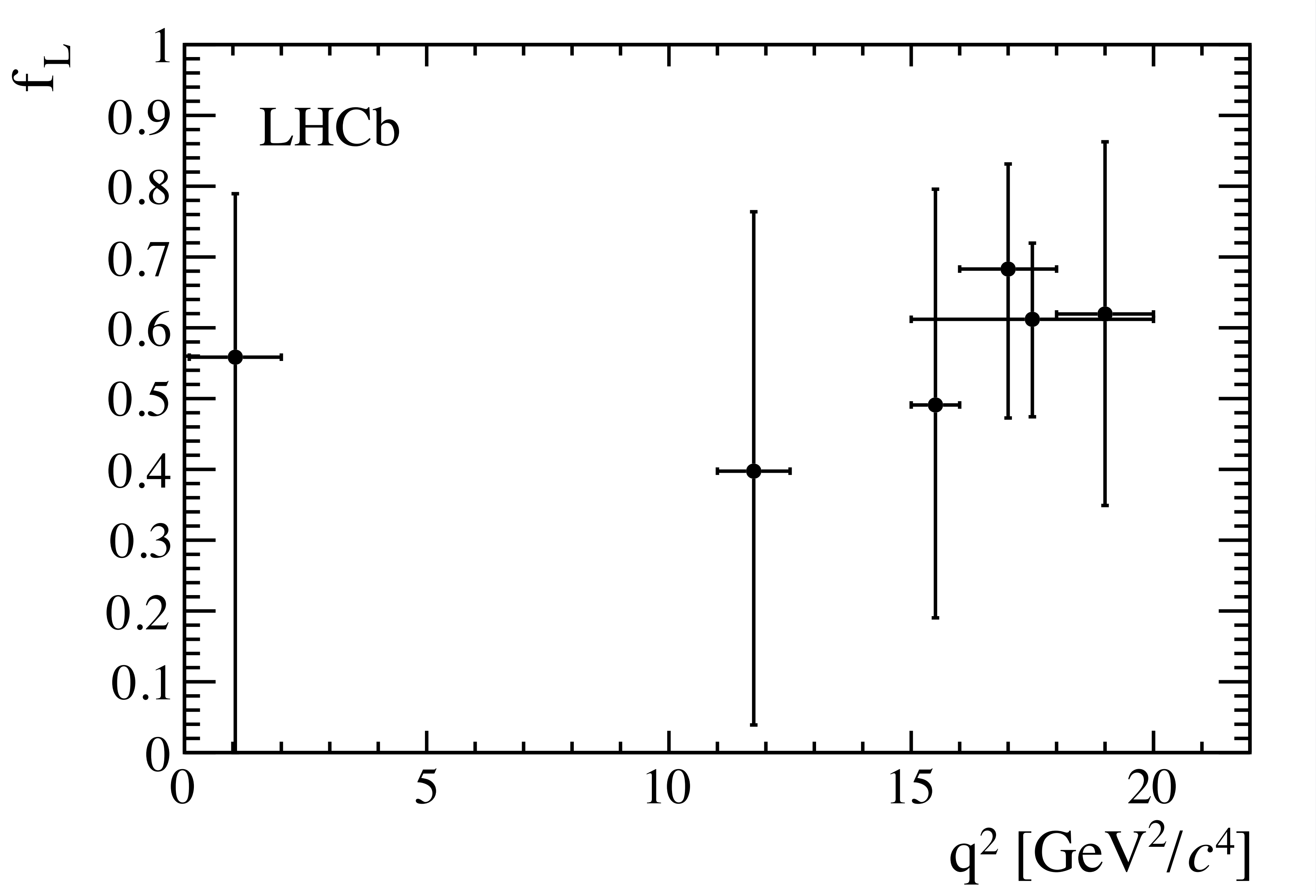
fL values



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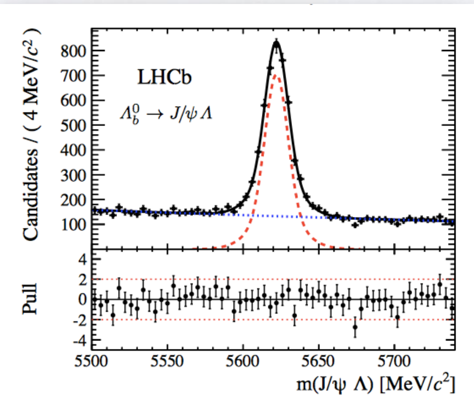
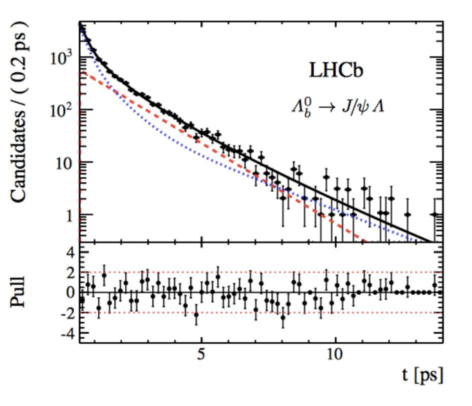
Progress with Λ_b

- Young but growing sector. Recent measurements at LHCb:
  - Lifetime: 1.482 ± 0.021 ps (PRL 111 (2013) 102003)
  - Polarisation: 0.06 ± 0.09 (PLB 724 (2013) 27)
  - Mass: 5619.44 ± 0.51 (PRL 110 (2013) 182001)
  - Hadronization fraction: (PRD 85 (2012) 032008)
    $f_{\Lambda}/f_d = (0.387 \pm 0.043) + (0.067 \pm 0.017)(\eta - 3{,}198)$



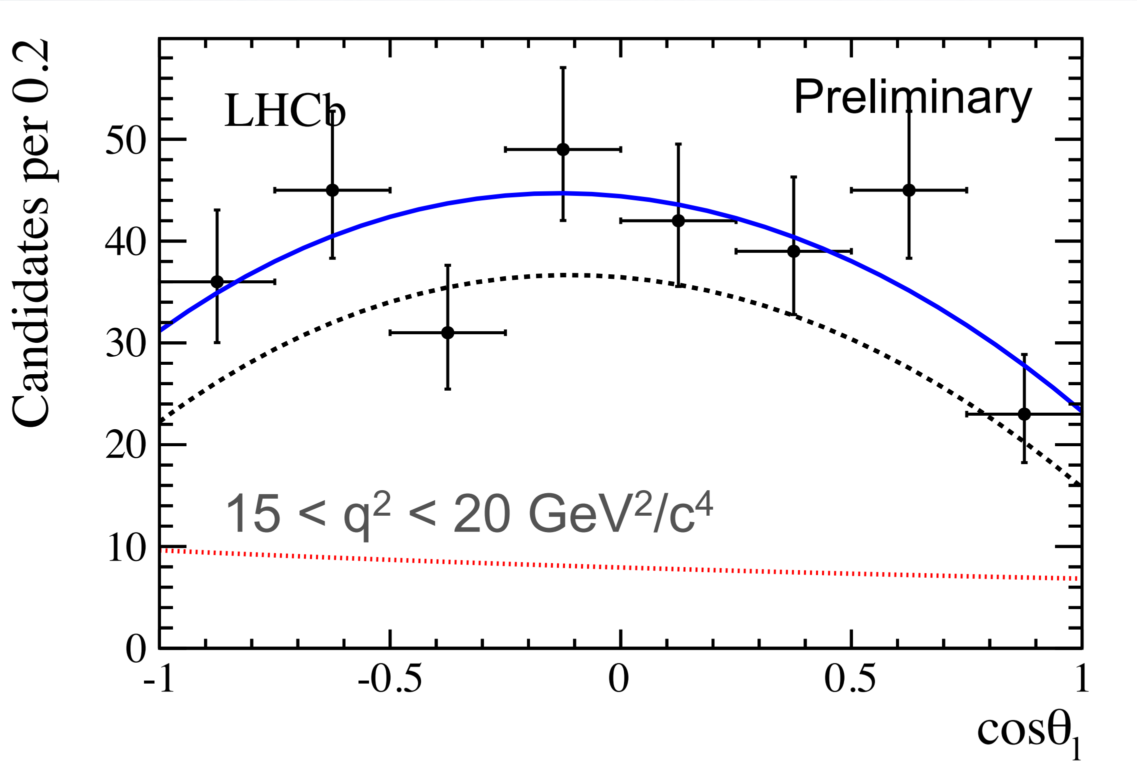


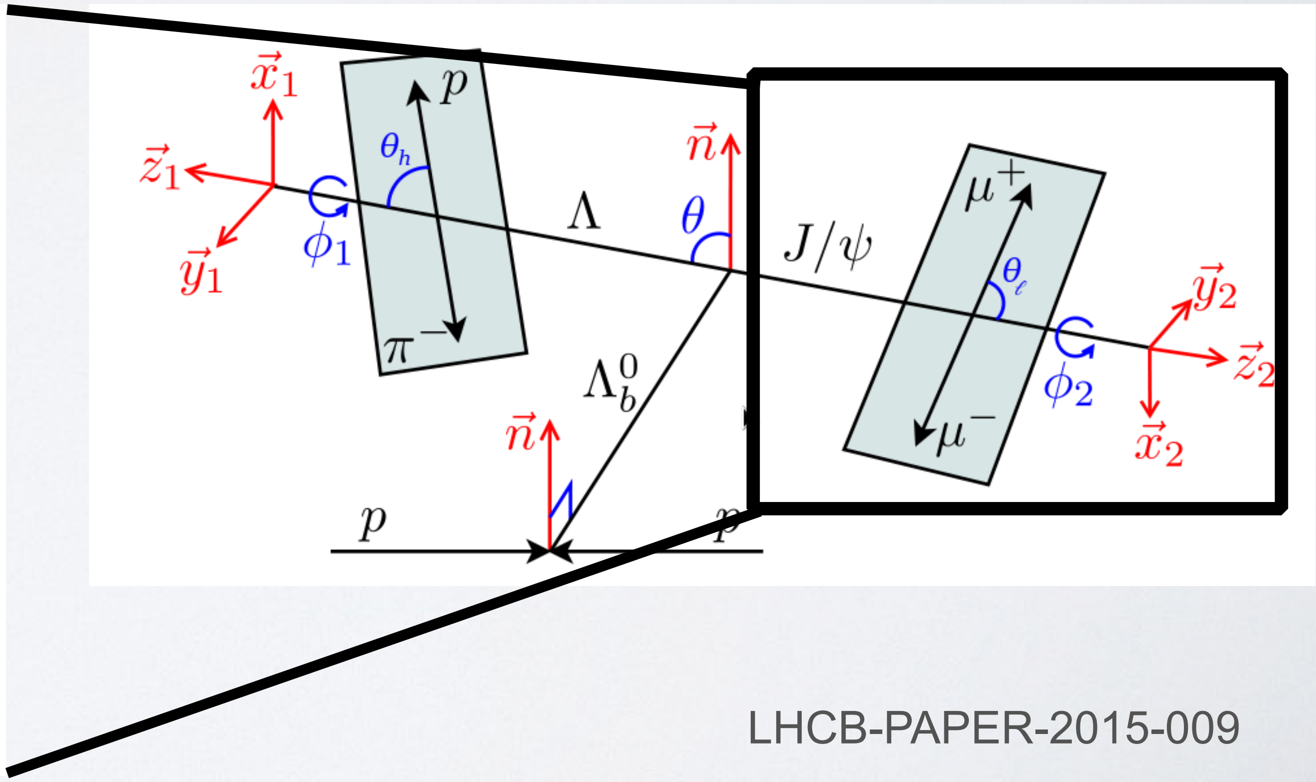
Angular analysis

New!

- In $\Lambda_b \to \Lambda^0 \mu\mu$ the Λ^0 decays weakly
  → unlike for B decays the hadronic side asymmetry is also interesting
- Measure two forward-backward asymmetries: in dimuon and Λ^0 system
- Selection based on a Neural Network using the NeuroBayes package
- Fit one-dimensional angular distributions

$$PDF^{tot}(\cos\theta_i) = [f^{theory}(\cos\theta_i) + f^{bkg}(\cos\theta_i)] \times \varepsilon(\cos\theta_i)$$





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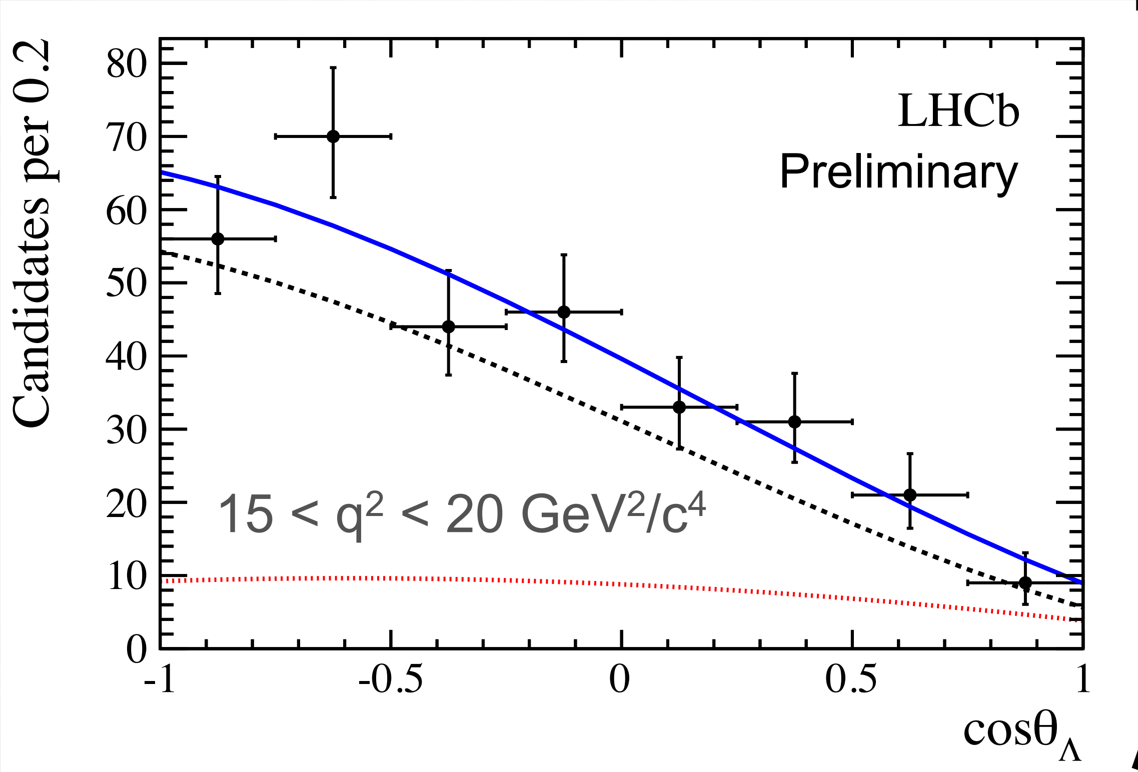

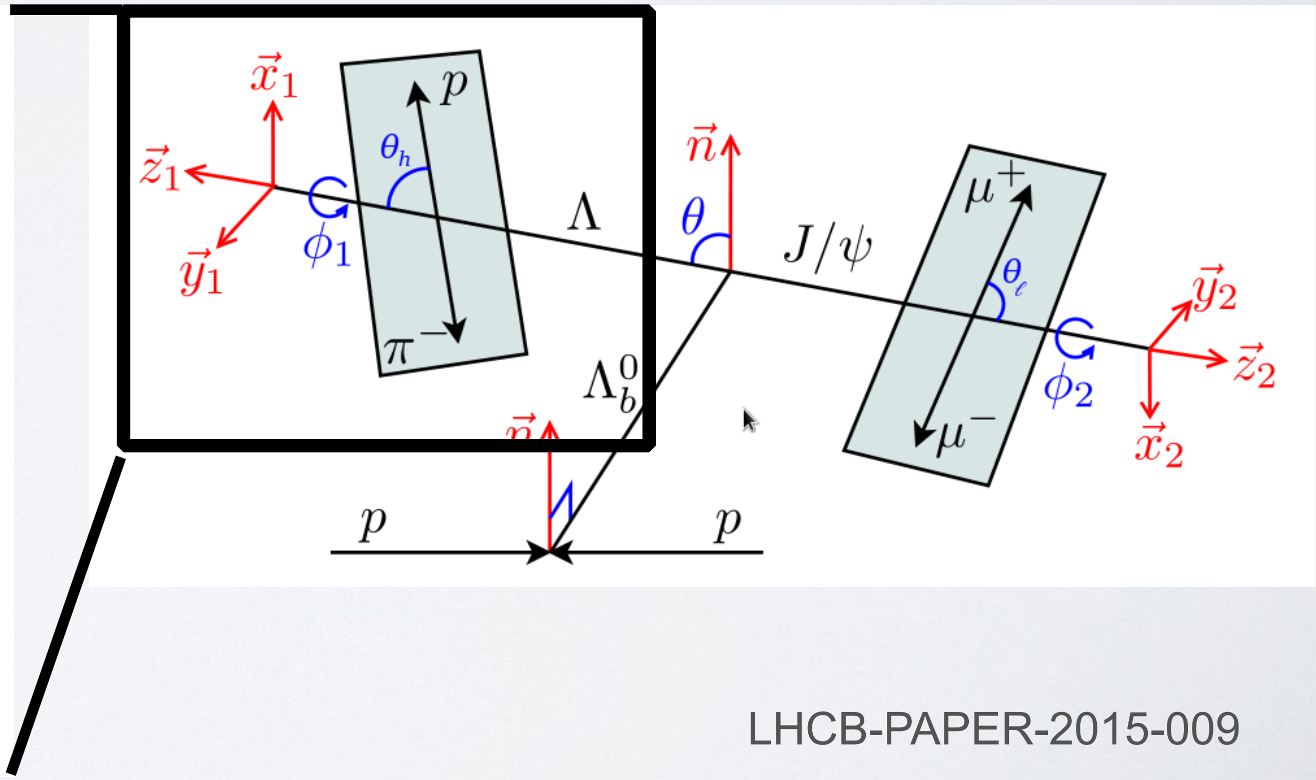

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$\Lambda_b \to \Lambda^0 \mu\mu$ branching ratio

- Already observed at CDF (PRL 107 2011 201802) and LHCb (PLB725 2013 25) but only in the low q^2 region
- Reconstructed using the $\Lambda \to p\pi$ mode
- $J/\psi\Lambda$ as normalisation to limit systematics
- Analysis on 3fb^{-1}: ~300 observed events
- Peaking background from $B \to K_S$ decays modelled in fit.

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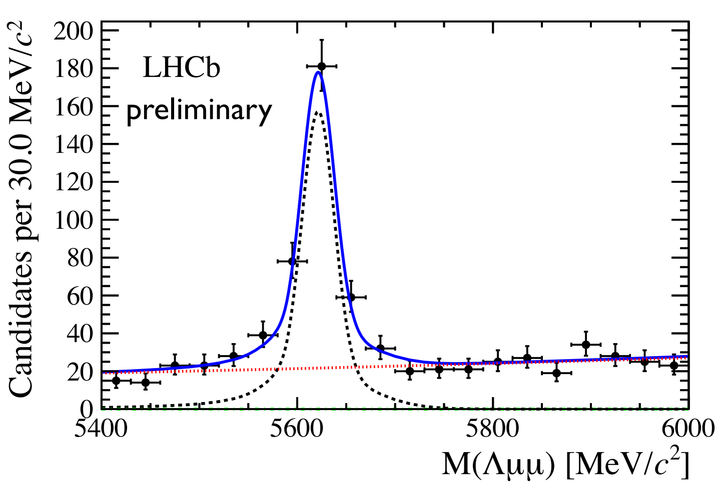
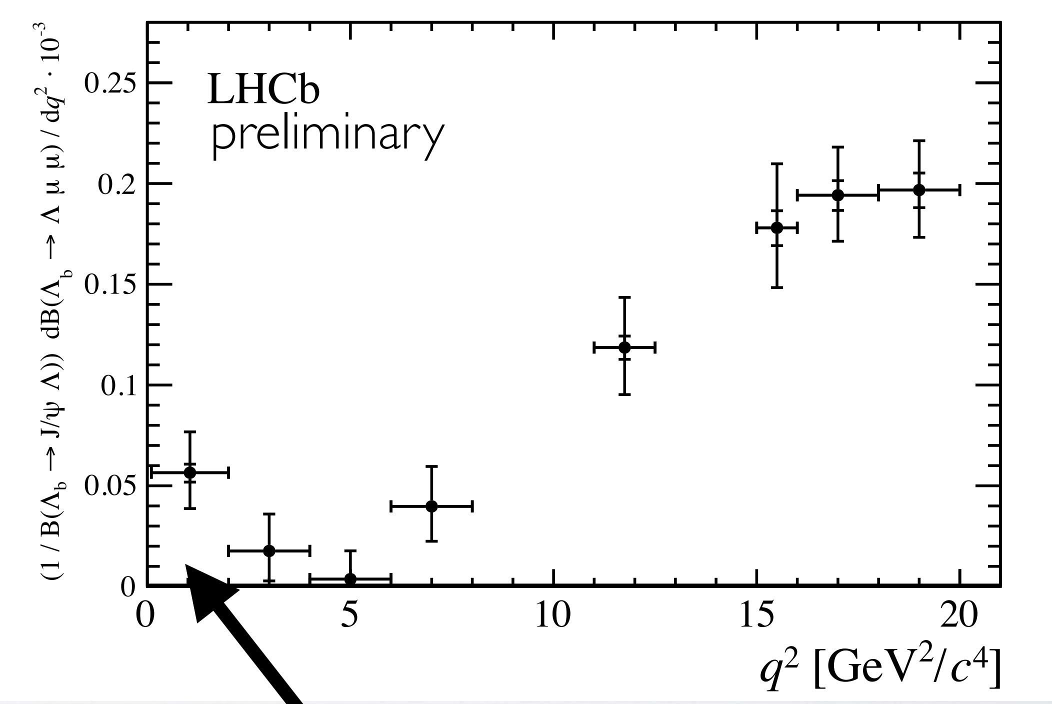
to be submitted to JHEP



Relative branching fraction



First observation

at 3σ level at low q^2

Branching ratio:

$$\begin{array}{ll} 1.1 < q^2 < 6.0 & 0.09\,^{+0.06}_{-0.05}\,(\text{stat})\,^{+0.01}_{-0.01}\,(\text{syst})\,^{+0.02}_{-0.02}\,(\text{norm}) \\ 15.0 < q^2 < 20.0 & 1.18\,^{+0.09}_{-0.08}\,(\text{stat})\,^{+0.03}_{-0.03}\,(\text{syst})\,^{+0.27}_{-0.27}\,(\text{norm}) \end{array}$$

Inner error: total systematic

Outer error: statistical (dominant)

$\Lambda_b \rightarrow \Lambda^0 \mu\mu$ branching ratio

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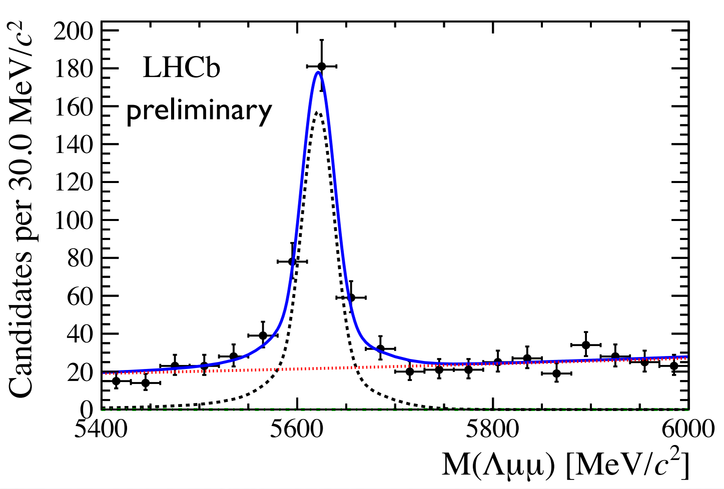
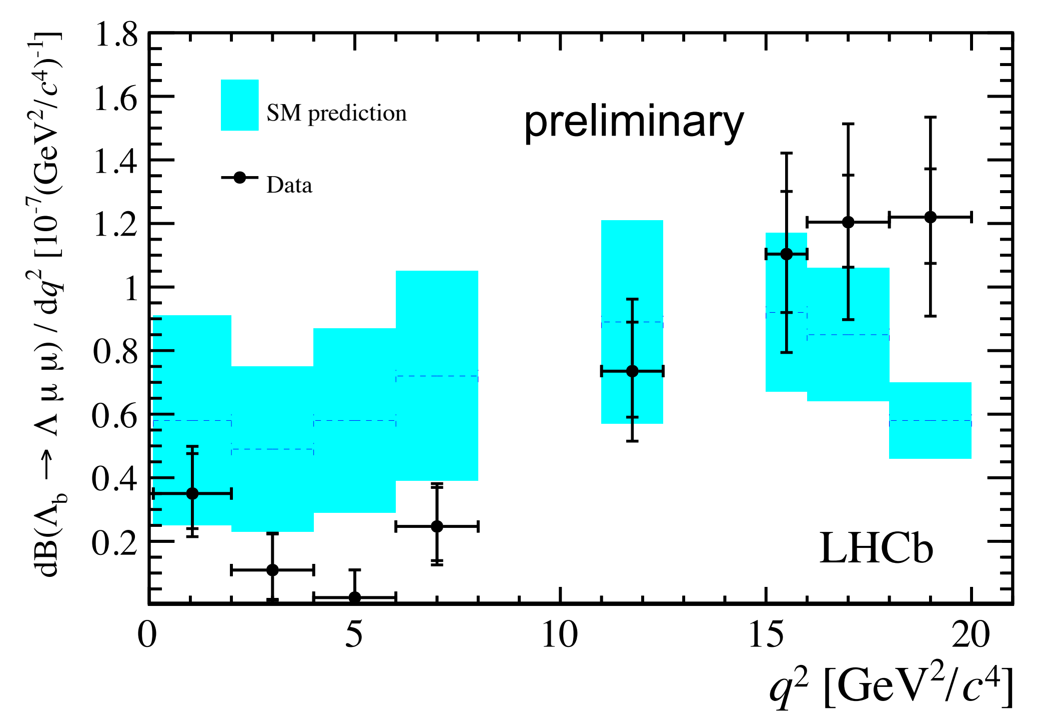


Absolute branching fraction



Compatible with the SM within 1.5σ.

Prediction: PRD 87 (2013) 074502

Branching ratio:

$$\boxed{\begin{array}{ll} 1.1 < q^2 < 6.0 & 0.09\,^{+0.06}_{-0.05}\,(\text{stat})\,^{+0.01}_{-0.01}\,(\text{syst})\,^{+0.02}_{-0.02}\,(\text{norm}) \\ 15.0 < q^2 < 20.0 & 1.18\,^{+0.09}_{-0.08}\,(\text{stat})\,^{+0.03}_{-0.03}\,(\text{syst})\,^{+0.27}_{-0.27}\,(\text{norm}) \end{array}}$$

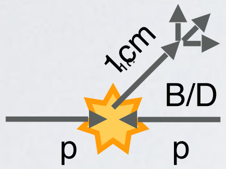
Inner error: stati + syst

Outer error:
including normalisation (dominant)

Selection

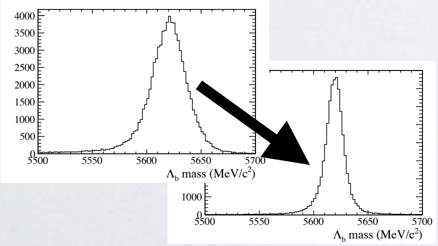
Variable
DecayTreeFitter χ^2
Λ_b lifetime and DIRA
$IP\chi^2$ of Λ_b, p, π and μ
μ PID
Λ^0 $IP\chi^2$, FD
Λ^0, p and π p_T

Flight distance

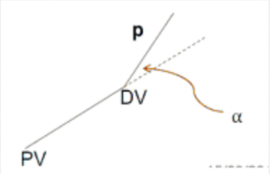


Momenta
help distinguishing combinatorial

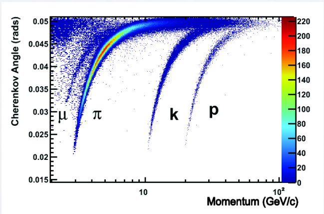
DecayTreeFitter:
χ^2 of a kinematically constrained refit



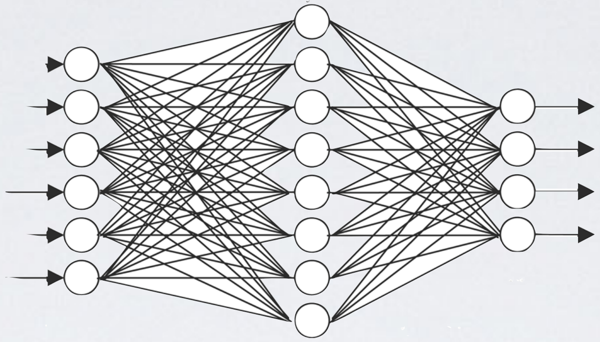
DIRA



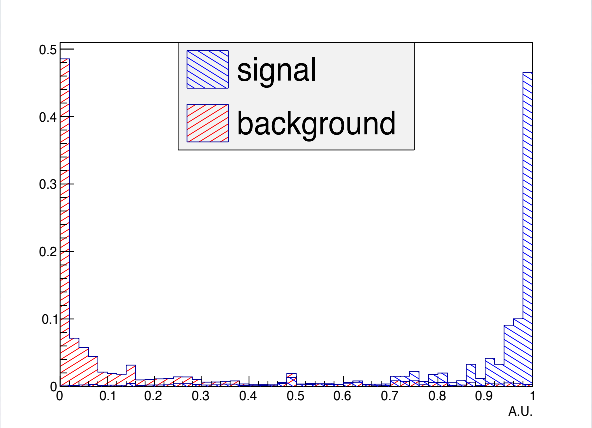
PID
using information from RICH and muon detector

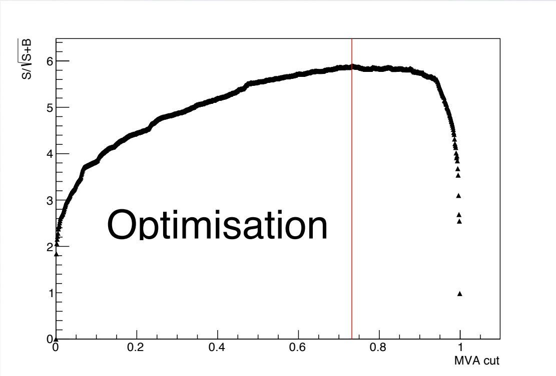


arXiv:1211.6759



Training: signal MC and sideband background

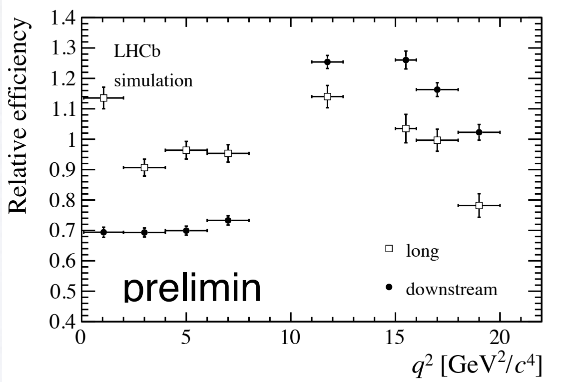




Maximised :

- Significance at high q²
- Punzi FoM at low q² (best for unobserved signals)

$$P = \frac{S}{n_\sigma/2 + \sqrt{B}}$$



Efficiency evaluated

(LHCB-PAPER-2015-009)