XXX-th International Workshop on High Energy Physics,
Protvino, 23-28 June 2014

Rare decays at LHCb

Luca Pescatore
on behalf of the LHCb collaboration

UNIVERSITY OF BIRMINGHAM

OUTLINE

- The LHCb detector and how we use it
- Rare decays results at LHCb:
  - $B_{s,d} \to \mu\mu$: just a reminder
  - EW penguins
    1. Isospin asymmetry in $B^0 \to K^{(*)}\mu\mu$
    2. Angular analysis of $B^0 \to K^{(*)}\mu\mu$ decays
    3. Testing lepton universality in R_K
    4. Radiative decays: photon polarisation in $b \to s\gamma$
  - Lepton-flavour violation searches
    1. Search for Majorana neutrino in $B \to \pi\mu\mu$
    2. Search for LFV in $\tau \to \mu\mu\mu$

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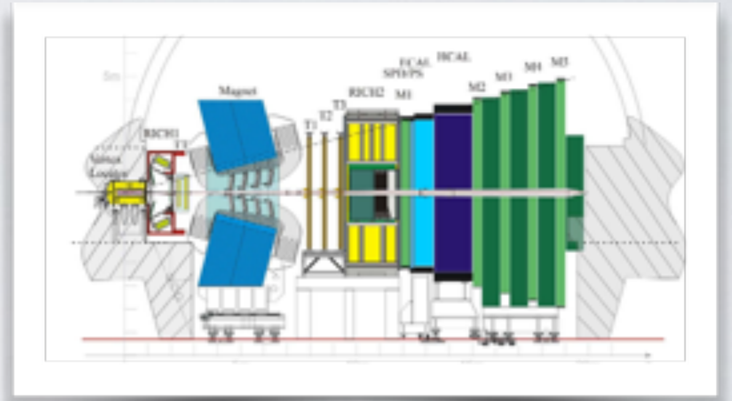

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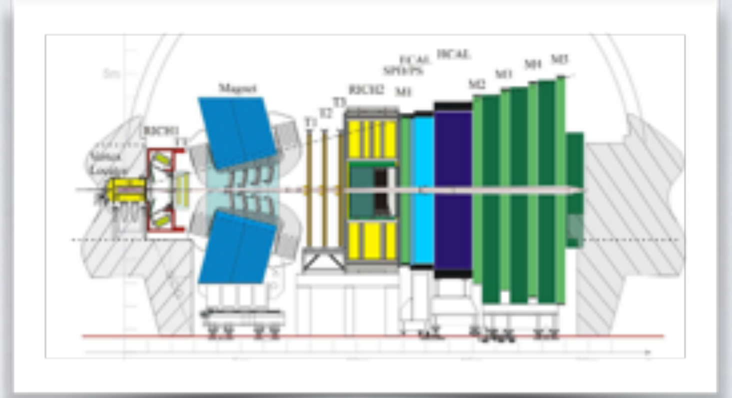

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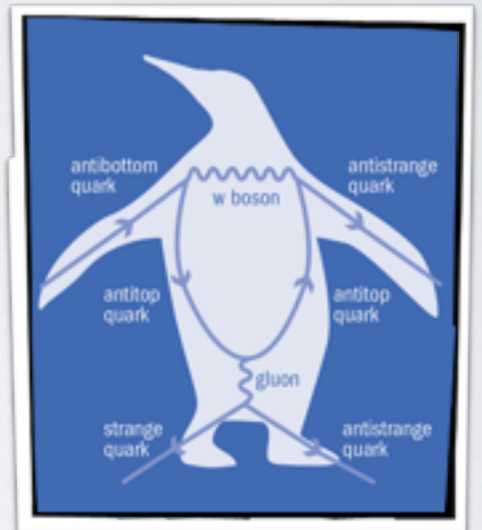

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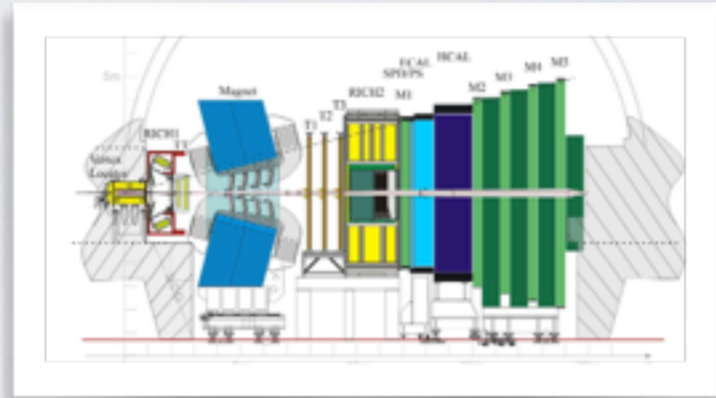

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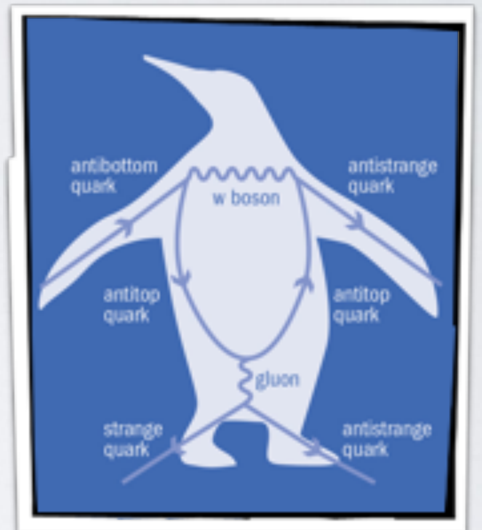

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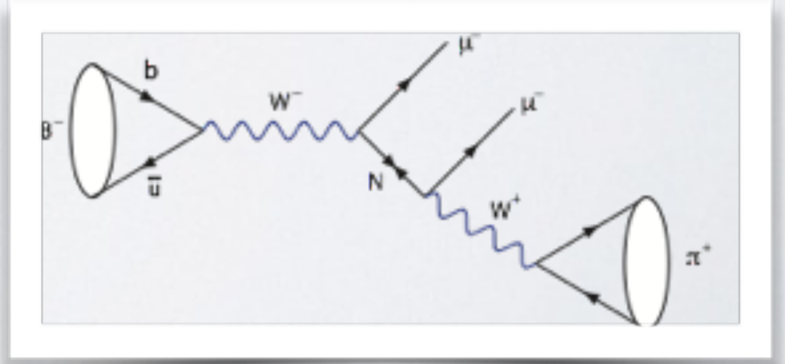


The LHCb experiment

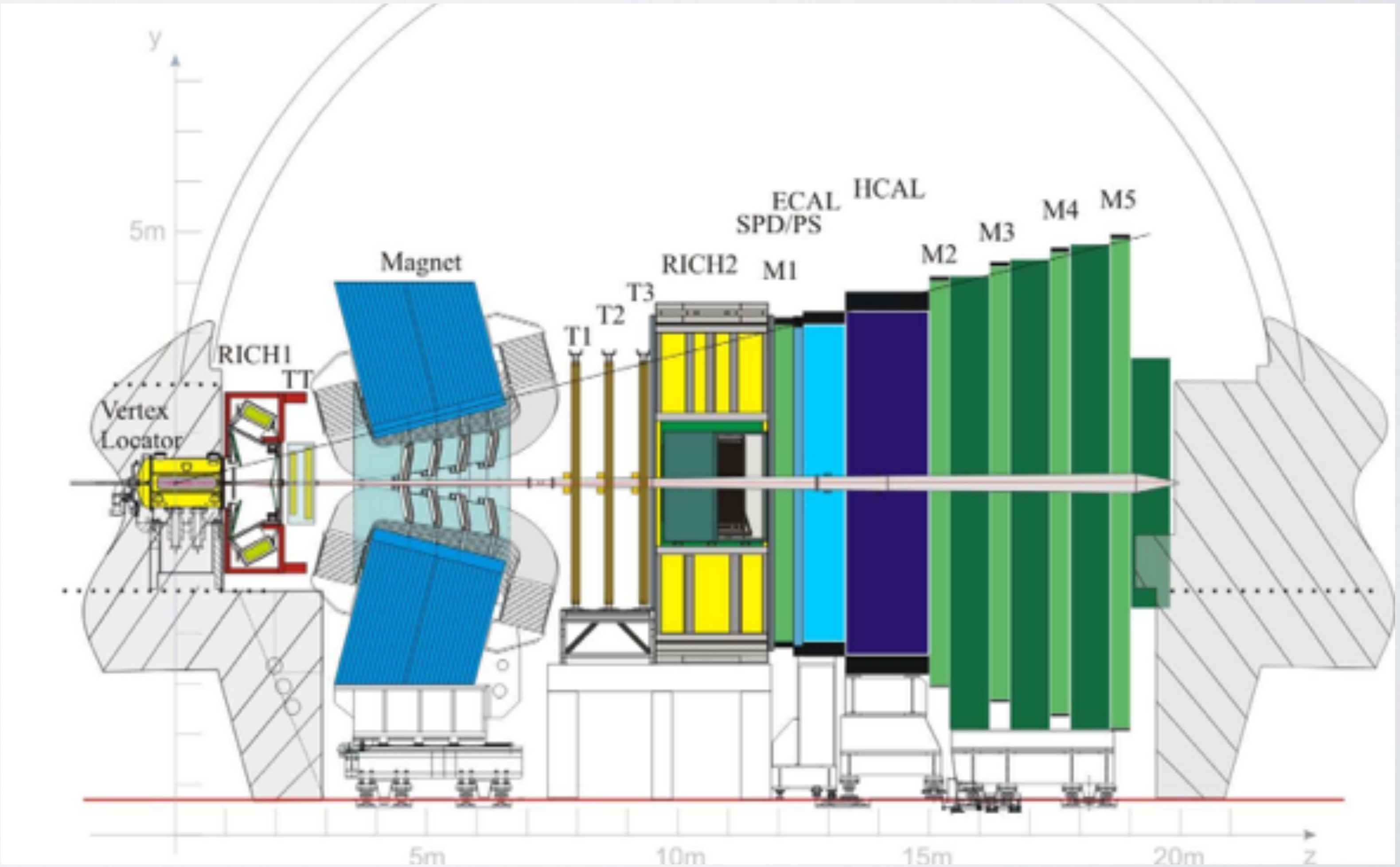
- Precise vertex reconstruction: σ(IP) ~20μm
- Good PID (RICH): $\varepsilon_{PID}(K)$ = 95% for MisID(π→K) = 5%

- Excellent mass resolution δp/p~0.5%
- Very clean muon ID for trigger ~97%

Forward spectrometer fully instrumented in $2 < \eta < 5$

Flexible 2-level trigger:

- Hardware level → on muons, hadrons, electrons and photons
- Software level (HLT) → using partial reconstruction



JINST 3 (2008) S08005

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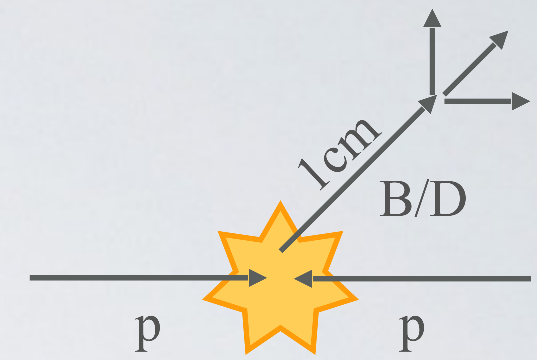

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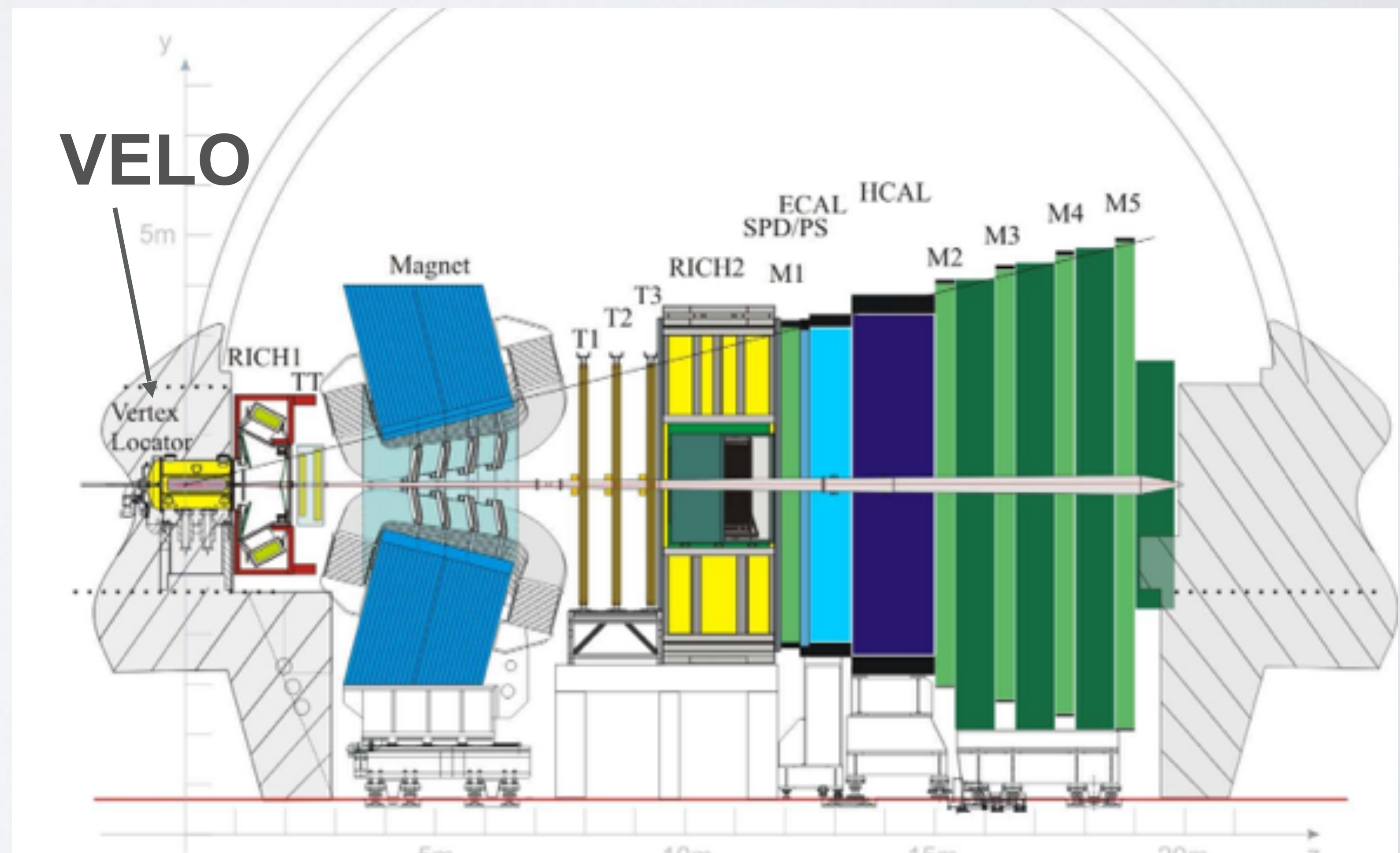

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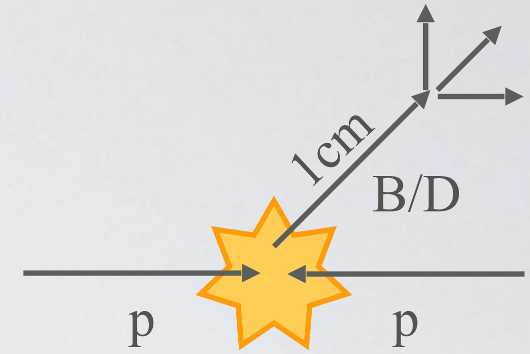

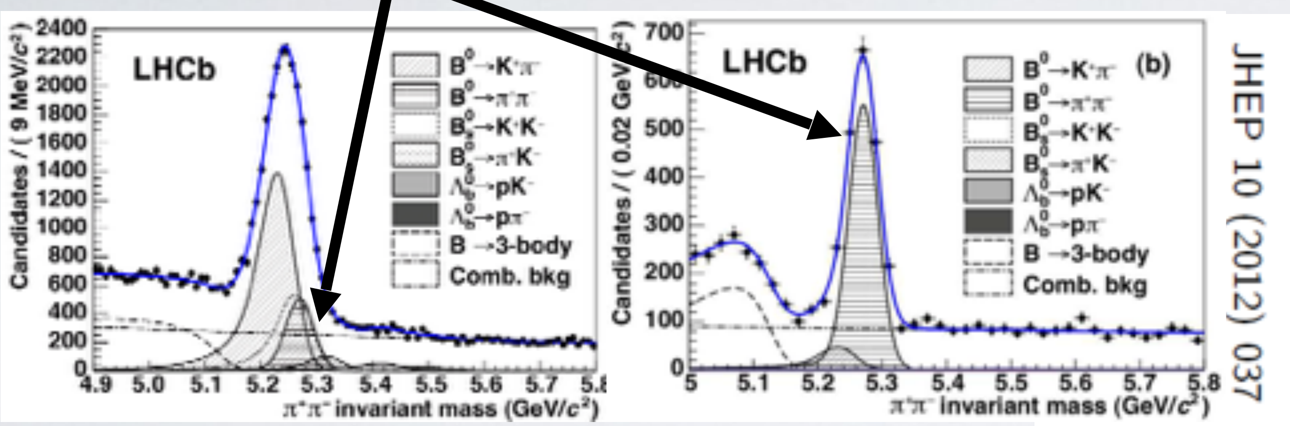

JHEP 10 (2012) 037

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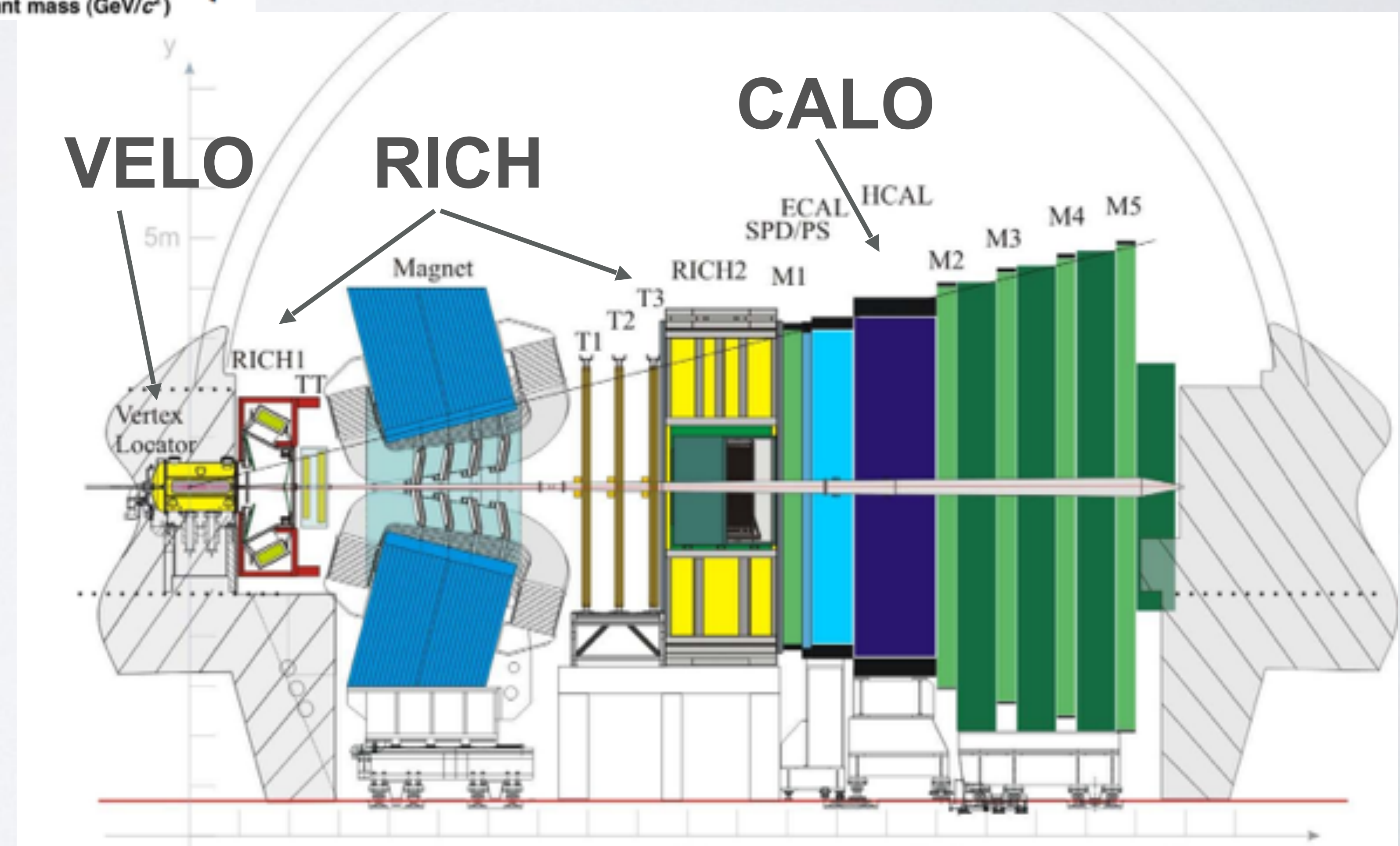

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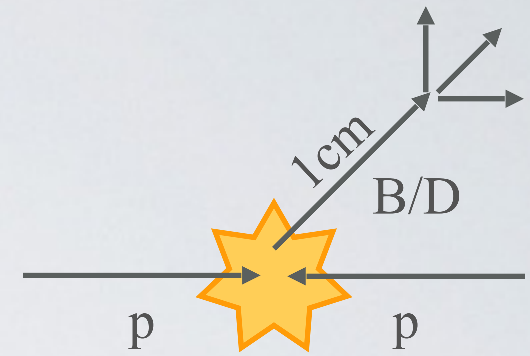

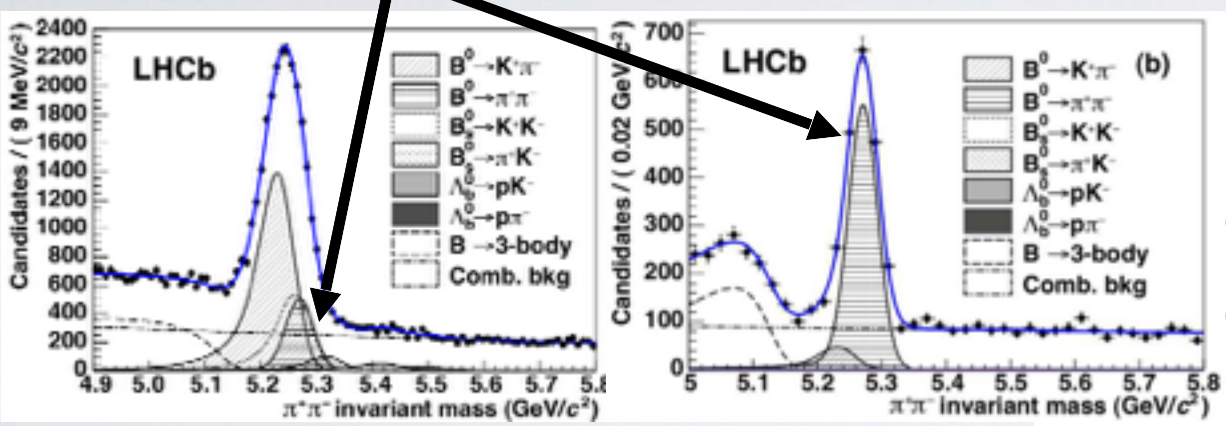

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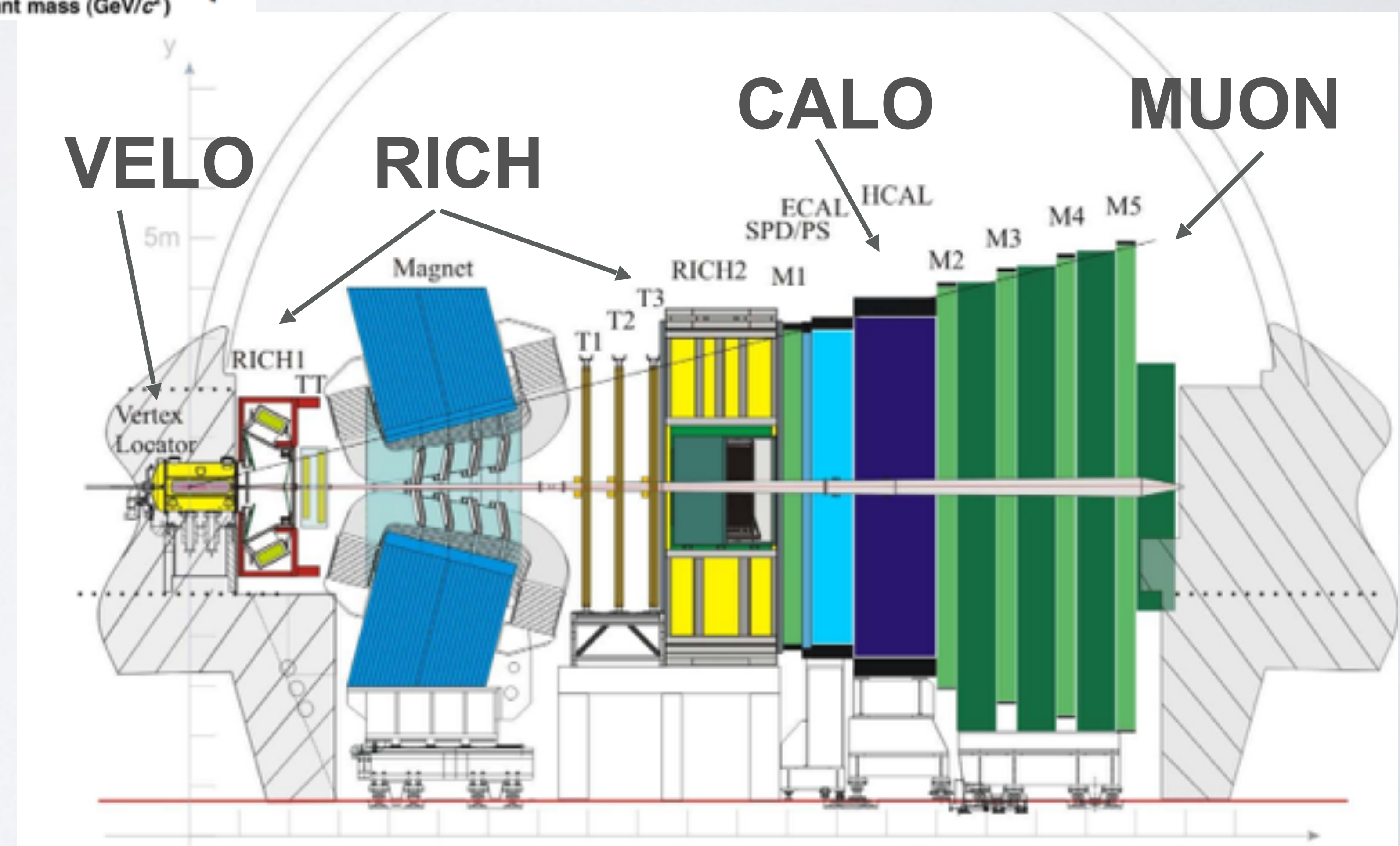

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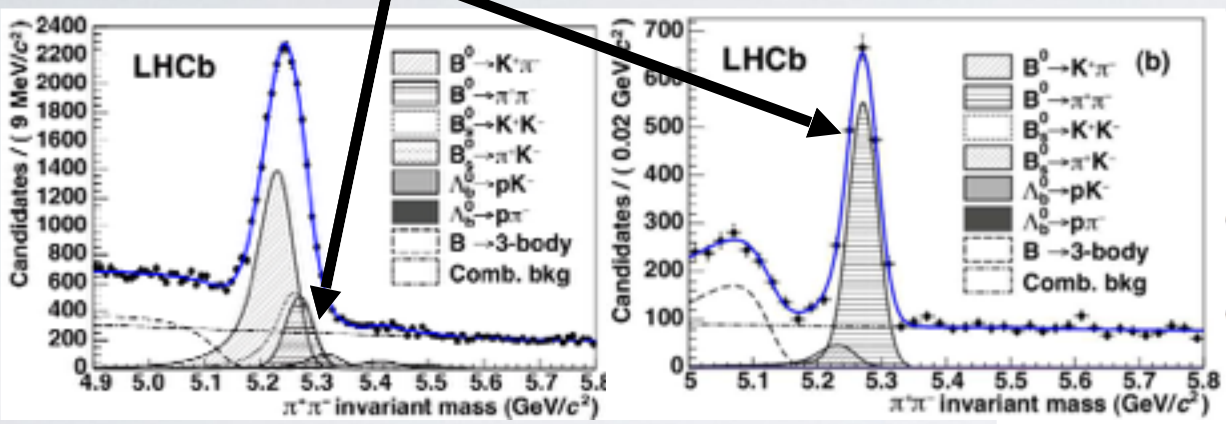

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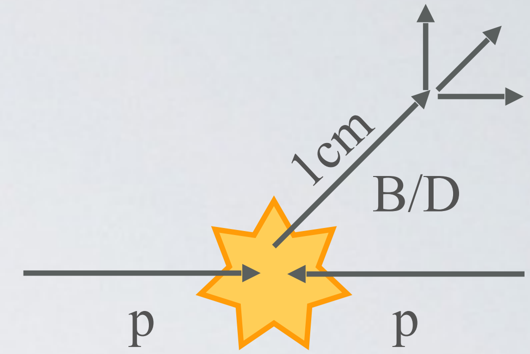

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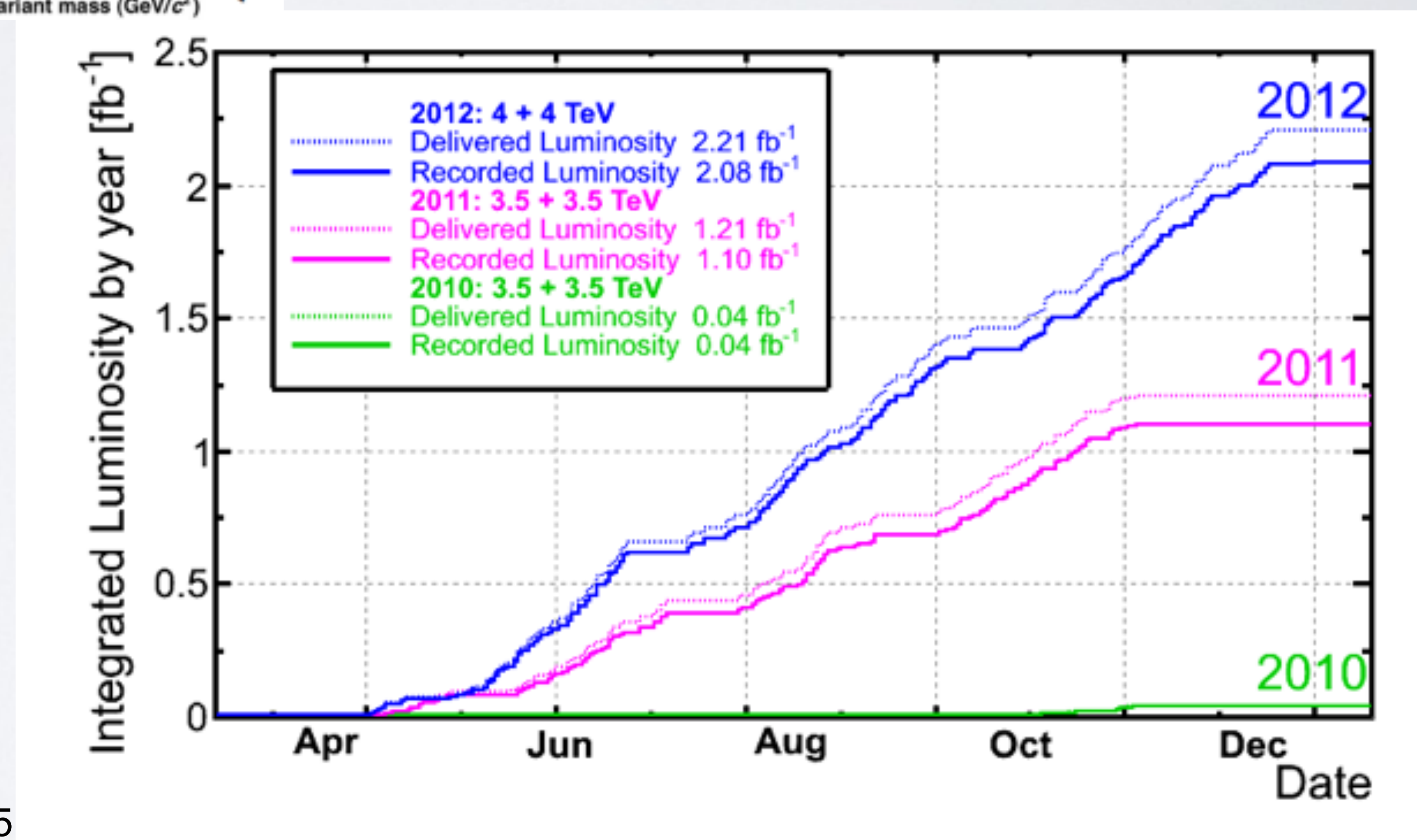
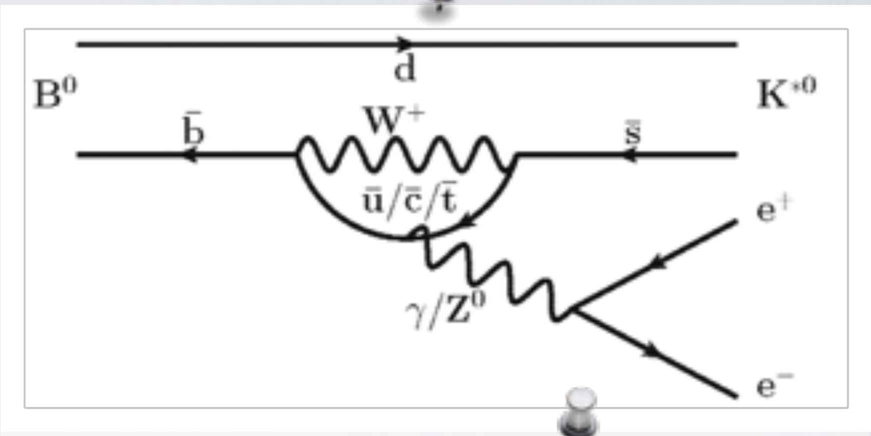


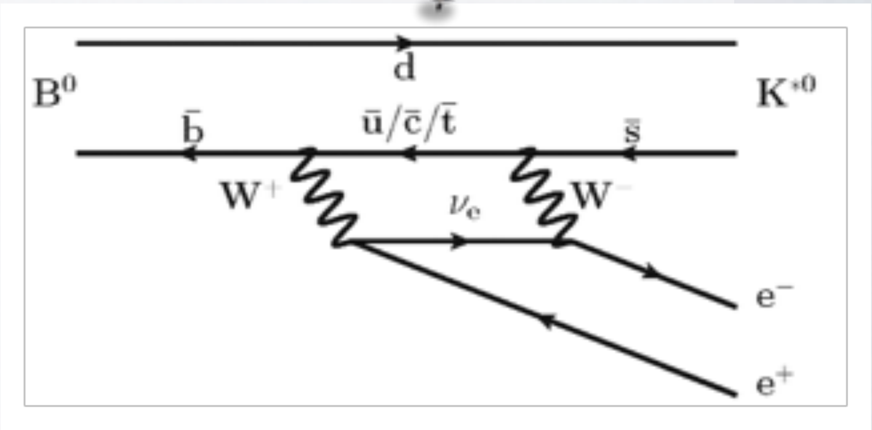
3 fb^{-1} of data on tape:
1fb^{-1} @ 7TeV 2011
2fb^{-1} @ 8 TeV 2012

JINST 3 (2008) S08005

Is New Physics in my loops?

- Rare decays are decays suppressed in the SM happening at **loop level** only (penguin/box).
  - FCNC decays (like b→s transitions) forbidden at tree level in the SM





- New Physics can enter in the loop
  - Very sensitive to NP effects since SM component is small: BR typically ~10^{-6} or less
  - No evidence in direct searches so far
  - Complementary: can probe **high energy scales**

- Large number of observables:
  - Branching fractions, angular distributions, asymmetries.

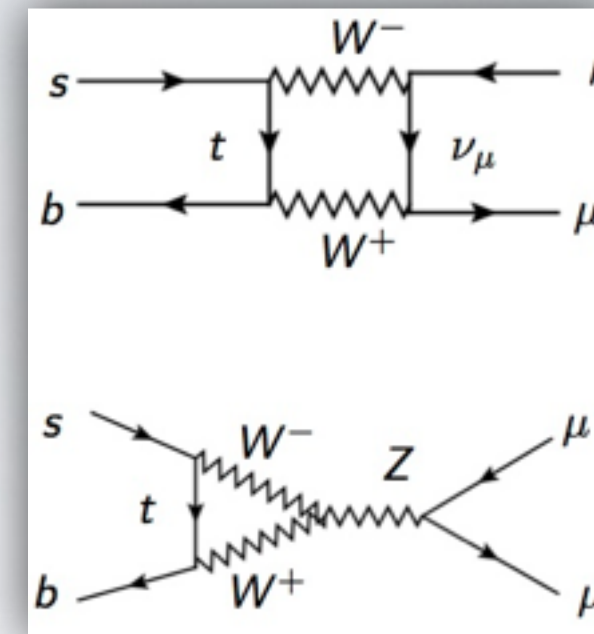
$B_{d,s} \to \mu\mu$ reminder

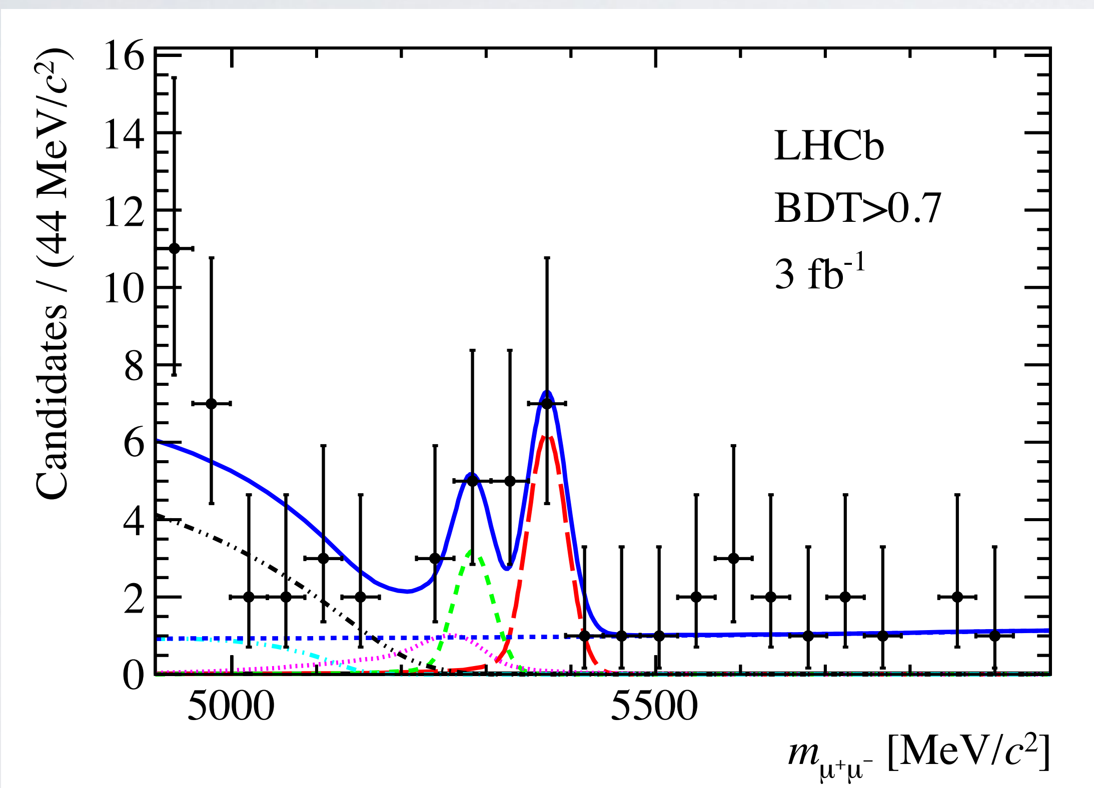
- Highly suppressed in the SM by GIM + helicity
- Possible tree level BSM contributions ⇒ very sensitive

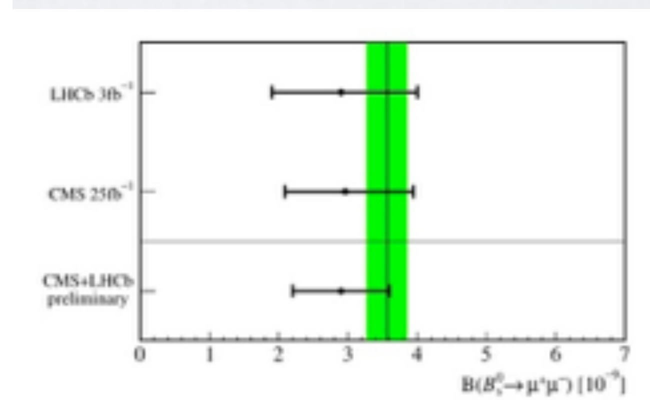
- Very well known in the SM $\mathcal{B}(B_s \to \mu\mu) = (3.56 \pm 0.30) \cdot 10^{-9}$
- Excess was seen by Tevatron

HFAG arXiv:1207.1158

- BR measured at LHCb and CMS highly constrains SUSY

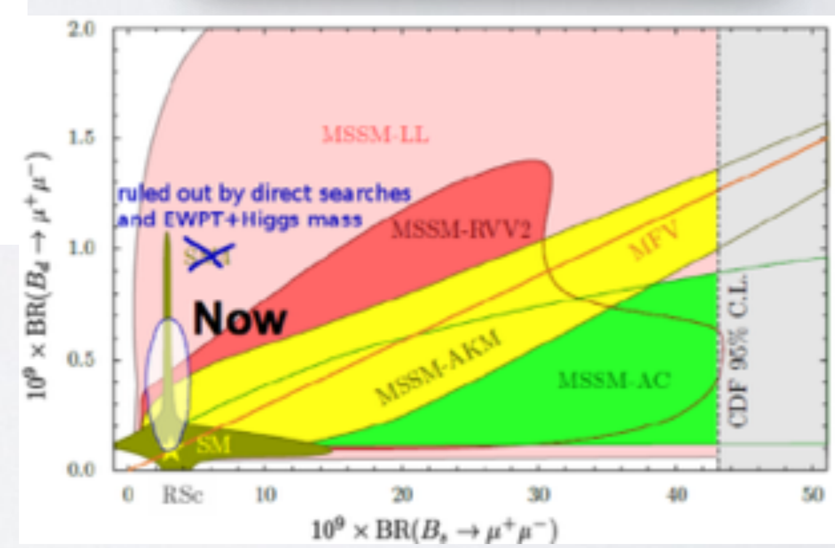






CERN-LHCb-CONF-2013-012

On 3fb^{-1}
full dataset



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.9\,^{+1.1}_{-1.0}\,(\text{stat})\,^{+0.3}_{-0.1}\,(\text{syst})) \times 10^{-9}\,,$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.7\,^{+2.4}_{-2.1}\,(\text{stat})\,^{+0.6}_{-0.4}\,(\text{syst})) \times 10^{-10}\,.$$

Compatible with the SM.

PRL111(2013)101805

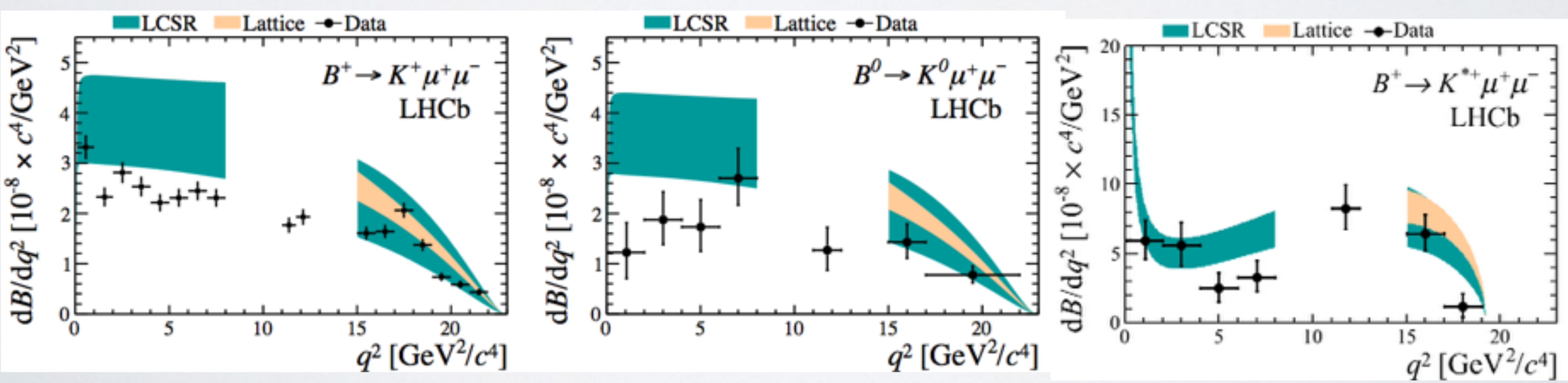
$B \to K^{(*)}\mu\mu$ Branching Ratios

- Decay rates of $B \to K^{(*)}\mu\mu$ decays are highly sensitive to NP entering the loops
- Decays considered are $K^{*+} \to K^0_S\pi$, $K^{*0} \to K^+\pi^-$ and $K^0_S \to \pi\pi$. Modes with K^0_L and π^0 are not considered.
- Using $3\,fb^{-1}$: full dataset
- Single measurements more precise than current world average!
- All compatible with SM but also all slightly lower.

arXiv:1403.8044v2
Submitted to JHEP

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

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



Isospin asymmetry in B→K$^{(*)}$μμ

- Large uncertainties in B→K$^{(*)}$ form factors calculations affect predictions
- To maximise sensitivity: measure asymmetries and ratios where the leading form factor cancel ⇒ Isospin asymmetry

arXiv:1403.8044v2
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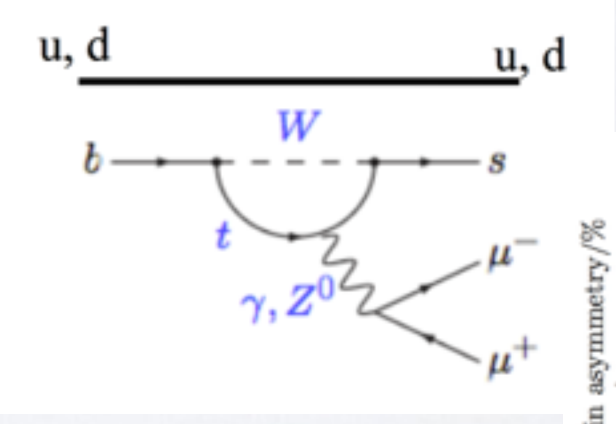
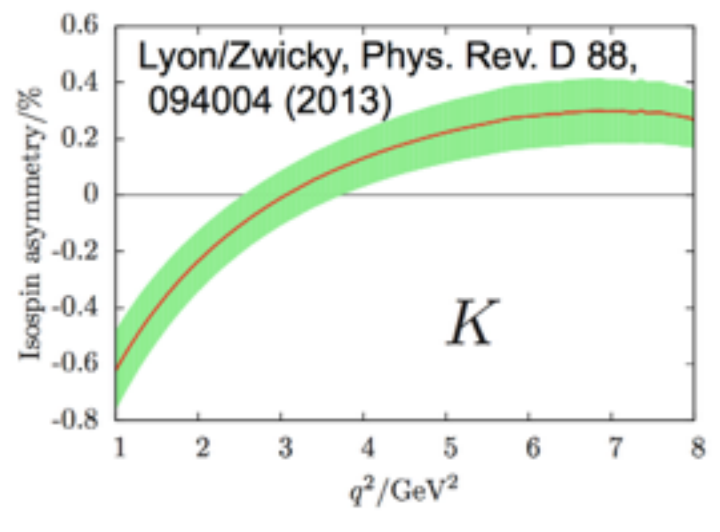
$$A_I = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - (\tau_0/\tau_+)\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + (\tau_0/\tau_+)\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

Two ratios are measured for K and K*

B^0 over B^+ lifetimes ratio

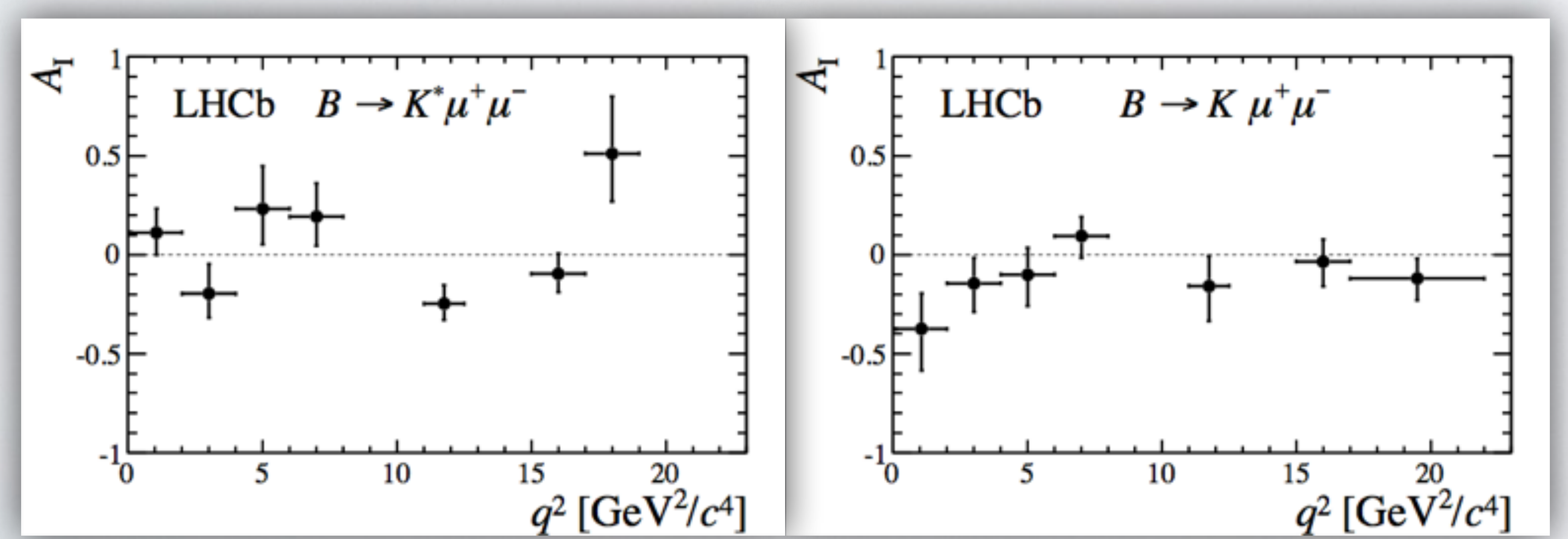




- Decays in the ratio differ only by the charge of the light spectator quark
  ⇒ A_I ~ O(1%) in SM (≠0 for m_q/m_b corrections)

Isospin asymmetries

- B^+/B^0 production asymmetry can bias or dilute the result
  - B-factories assumed instead null B^+/B^0 production asymmetry
  - LHCb: J/ψ modes used for normalisation → assuming null isospin asymmetry
  - Also J/ψ channels have same final daughters → cancellations of systematics
- A_I=0 hypothesis tested against simplest alternative: constant ≠ 0
- Is now compatible with SM within 1.5σ
- Compatible with BaBar and LHCb result on $1fb^{-1}$ which showed evidence for $A_I \neq 0$



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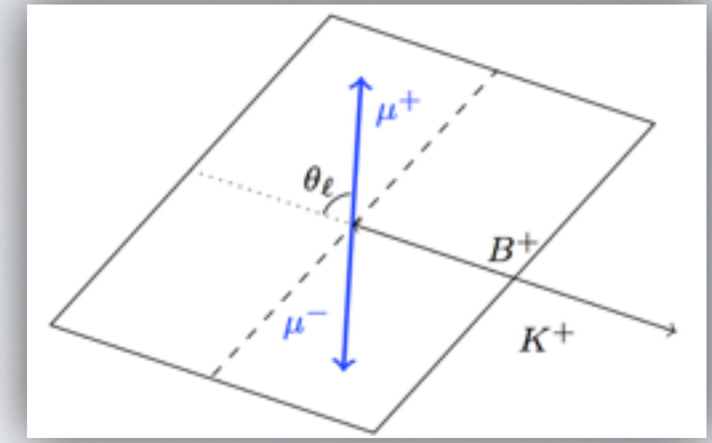
On $3fb^{-1}$ full dataset

$B \rightarrow K\mu\mu$ angular analysis



- Angular distribution of $B^+ \rightarrow K^+\mu\mu$, $B^0 \rightarrow K^0_S\mu\mu$
- As a function of $\cos\theta_l$, where θ_l is the angle between the K and the muon of opposite sign.

Fractional contribution of pseudo scalar and tensor amplitudes

Forward-backward asymmetry

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_l} = \frac{3}{4}(1 - F_H)(1 - \cos^2\theta_l) + \frac{1}{2}F_H + A_{FB}\cos\theta_l$$

- Both B^0 and $\overline{B}^0$ can decay in $K^0_S\mu\mu$ ⇒ not possible to distinguish without tagging the B at production
  - Use $|\cos\theta_l|$ to cancel any asymmetry (depends only on F_H)

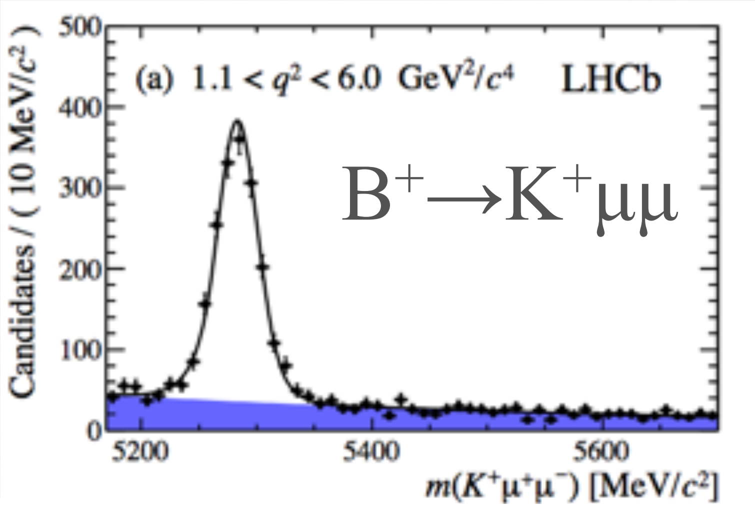
$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_l} = \frac{3}{2}(1 - F_H)(1 - |\cos\theta_l|^2) + F_H$$

- A_{FB} and F_H expected to be small in the SM.

JHEP 05 (2014) 082

$B \to K\mu\mu$ angular analysis

- Unbinned max likelihood fit is performed on m(Kμμ) and $\cos\theta_l$
- Acceptance is included modelled with a even polynomial (any asymmetries in reconstruction cancel combining B and $\overline{B}$)
- For charged $B \to D^0(\to K\pi)\pi$ decays are vetoed
- Done on $3 fb^{-1}$ 2011+2012 data sets
- 4746 ± 81 charged B events
- 176 ± 17 neutral B events.



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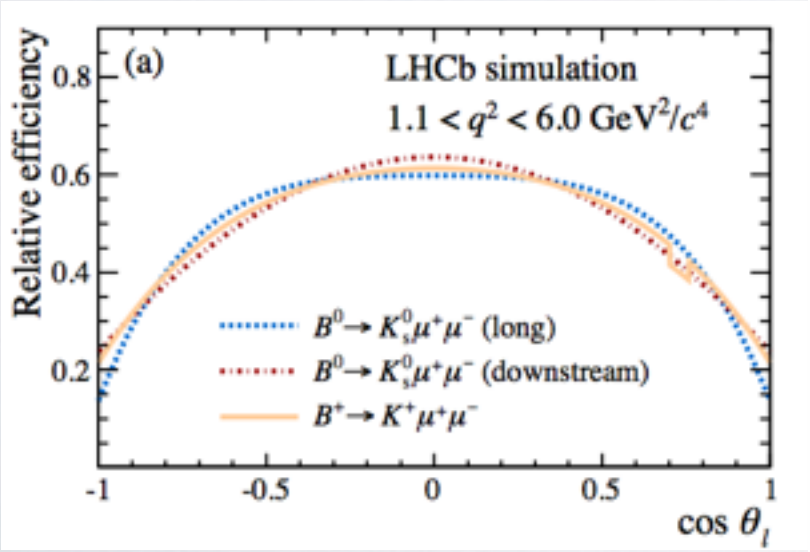
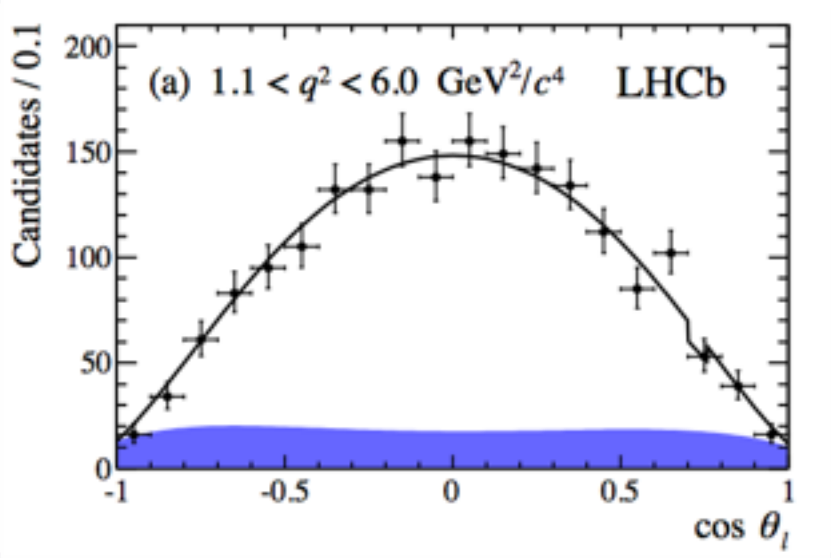
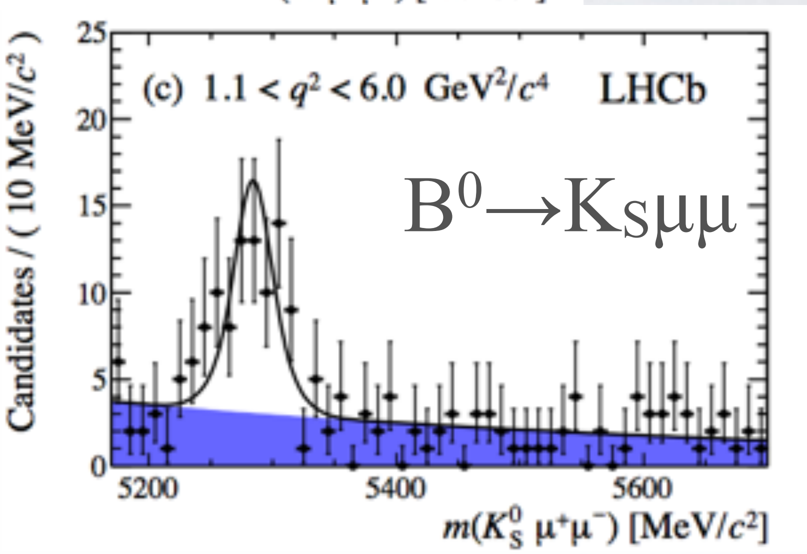
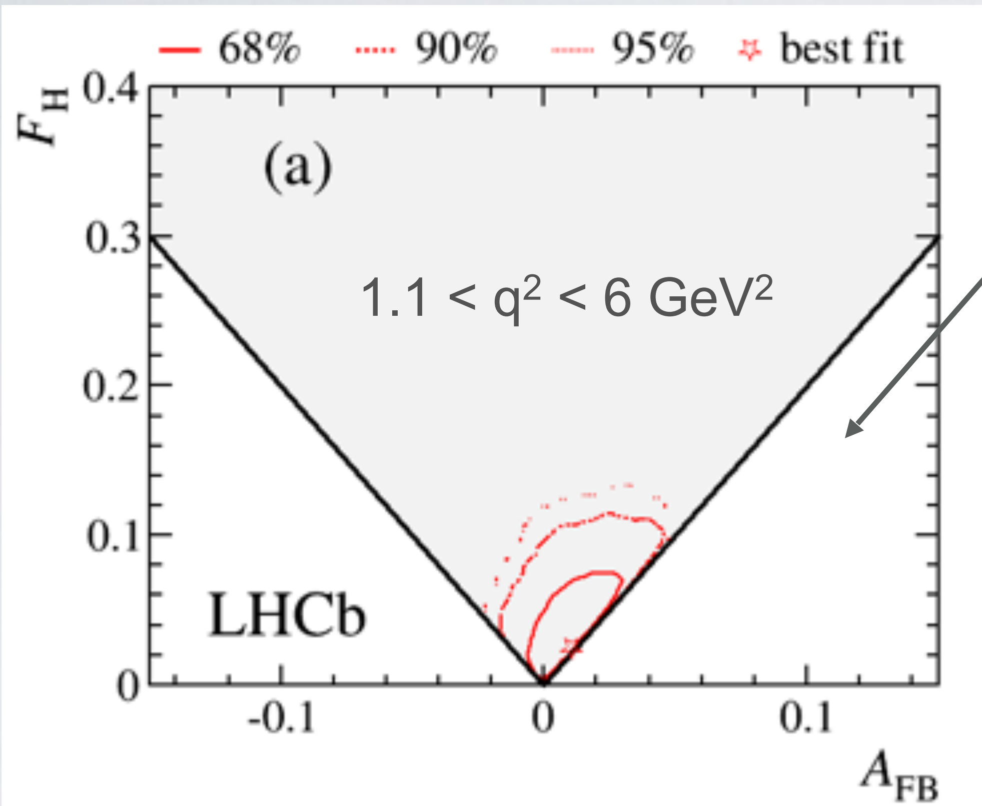
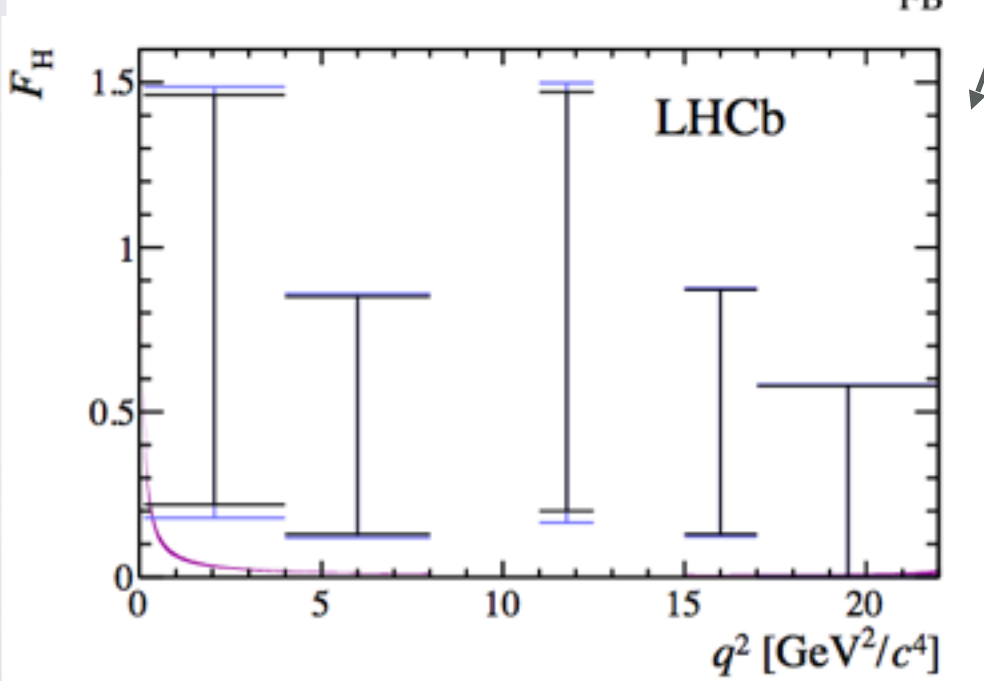






$B\to K\mu\mu$ angular analysis: results





- 2-dimensional A_{FB} vs F_H confidence regions for $B^+\to K^+\mu\mu$ using Feldman-Cousins plug-in method

arXiv:1109.0714v1

- 1-dimensional for $B^0\to K^0_S\mu\mu$ (only F_H)

A_{FB} and F_H consistent with SM predictions at 95%CL

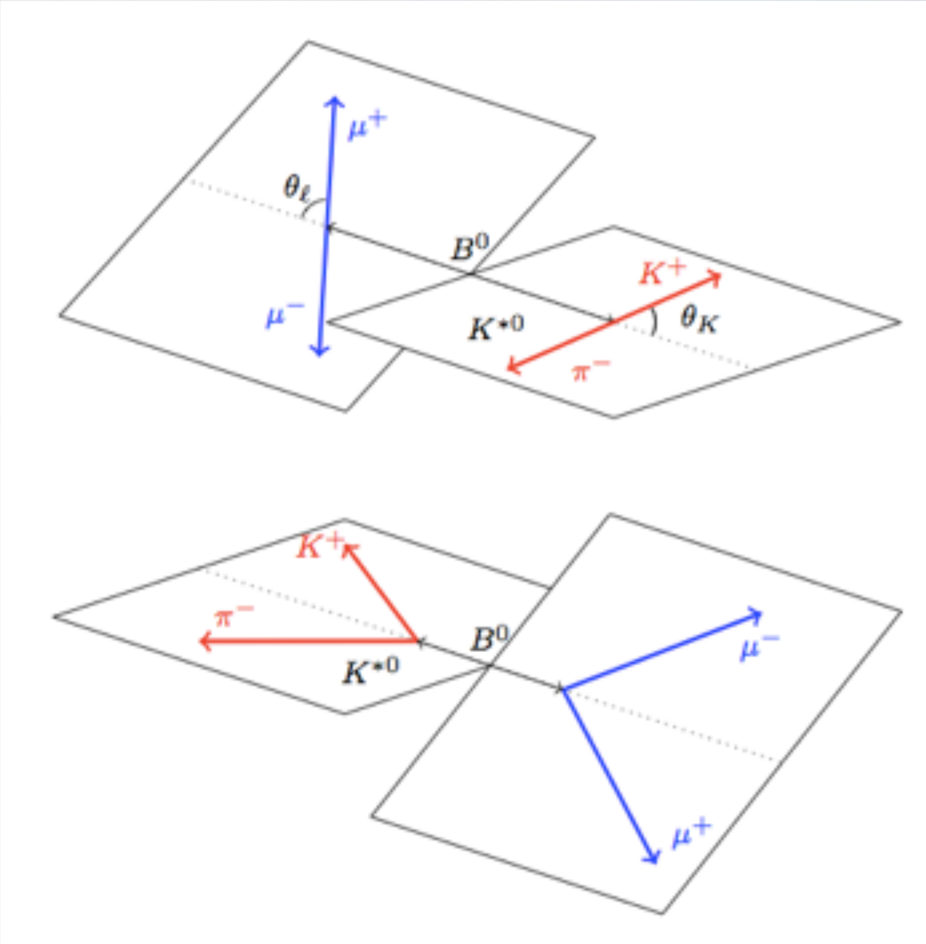
JHEP 05 (2014) 082

- F_H consistent in charged and neutral B decays
- Measurement available in 17 q^2 bins also for charged B case thanks to the higher statistics.
- (Pseudo)Scalar amplitudes already constrained by $B_s\to\mu\mu$. This result also rules out large accidental cancellations between left and right handed couplings

Angular observables in B→K*μμ

- Angular distributions described by 3 angles: θ_l, θ_K, ϕ
- Depends on Wilson coefficients (short distance) and form factors (long distance)
- Study variables which reduce form factor uncertainties (JHEP, 05, 2013, 137)

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



PRL 111 (2013) 191801

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

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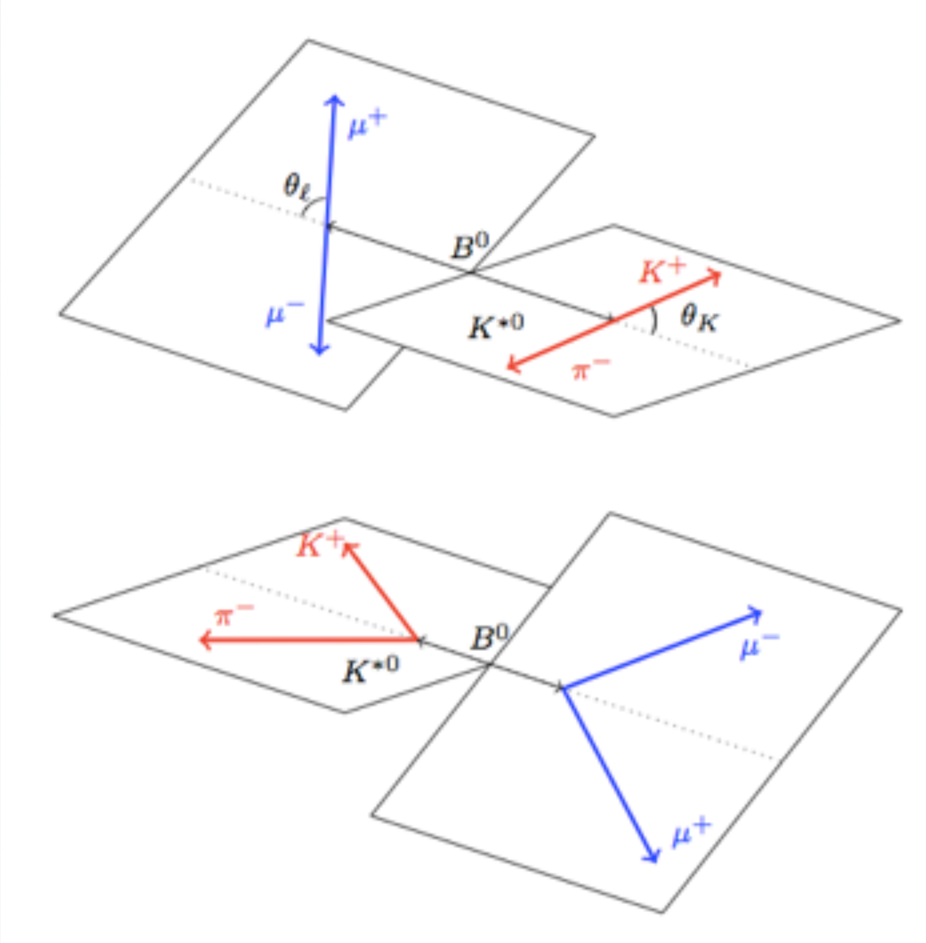

PRL 111 (2013) 191801

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

Angular observables in B→K*μμ

- On 1 fb^{-1}: update to 3fb^{-1} in progress
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- Many quantities are in good agreement with SM
- But 3.7σ local tension in P'_5
- Possible interpretation with NP contribution to Wilson coefficient C_9
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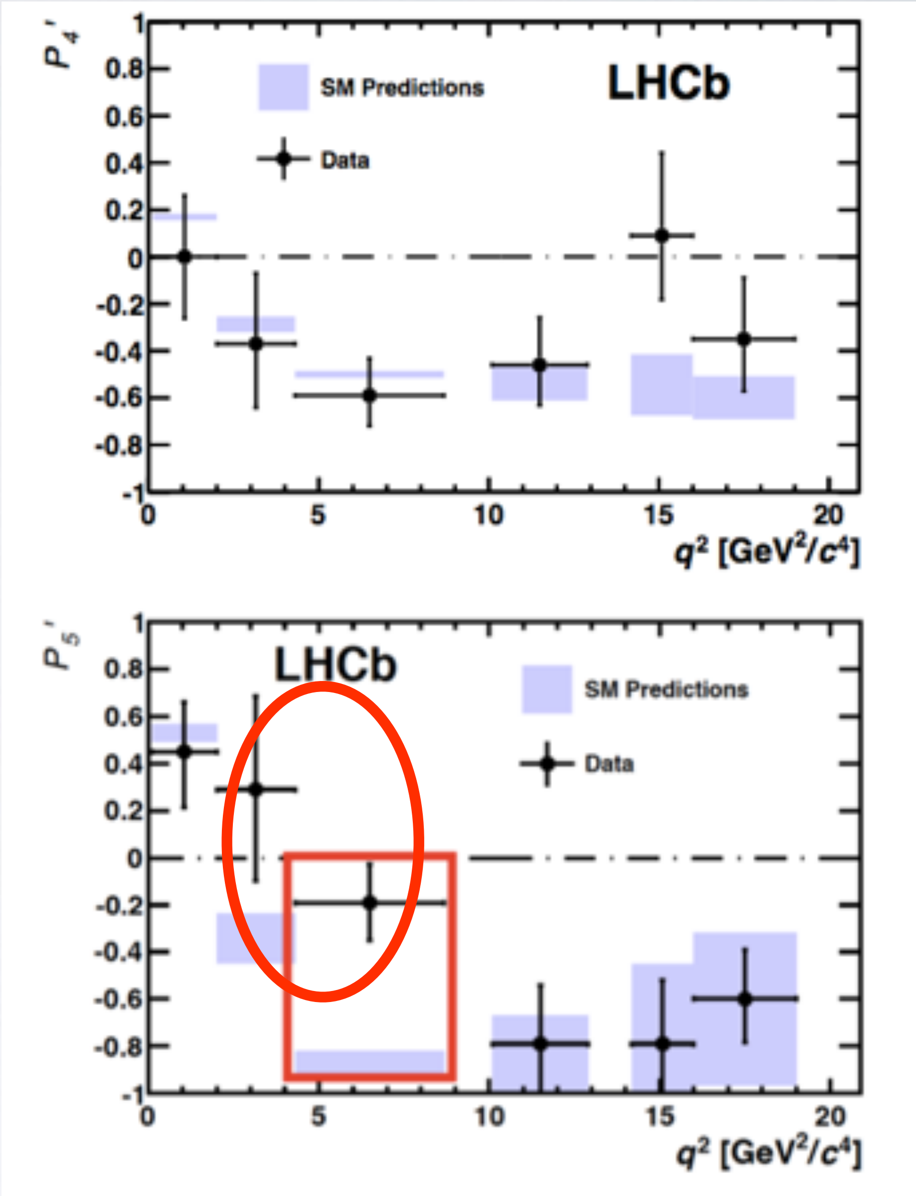

PRL 111 (2013) 191801

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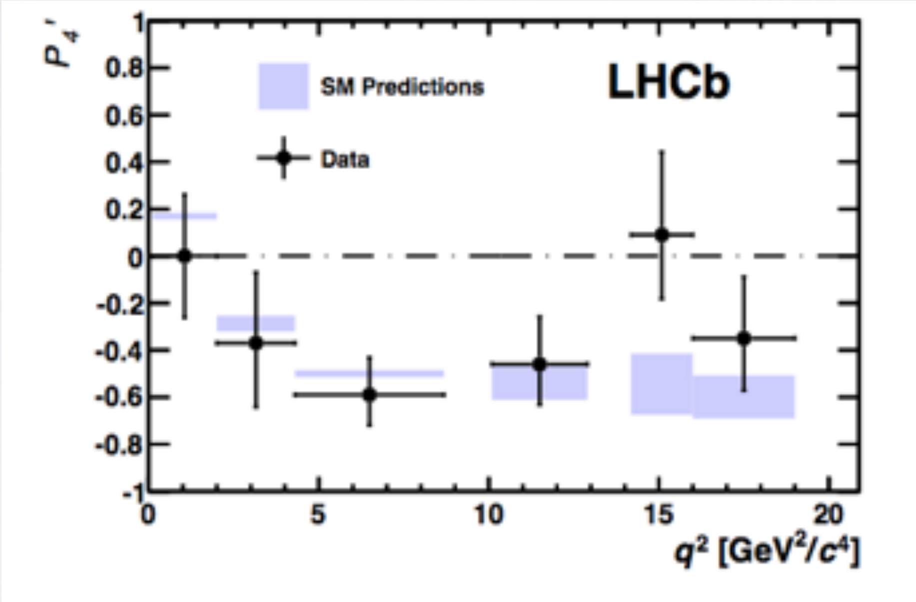
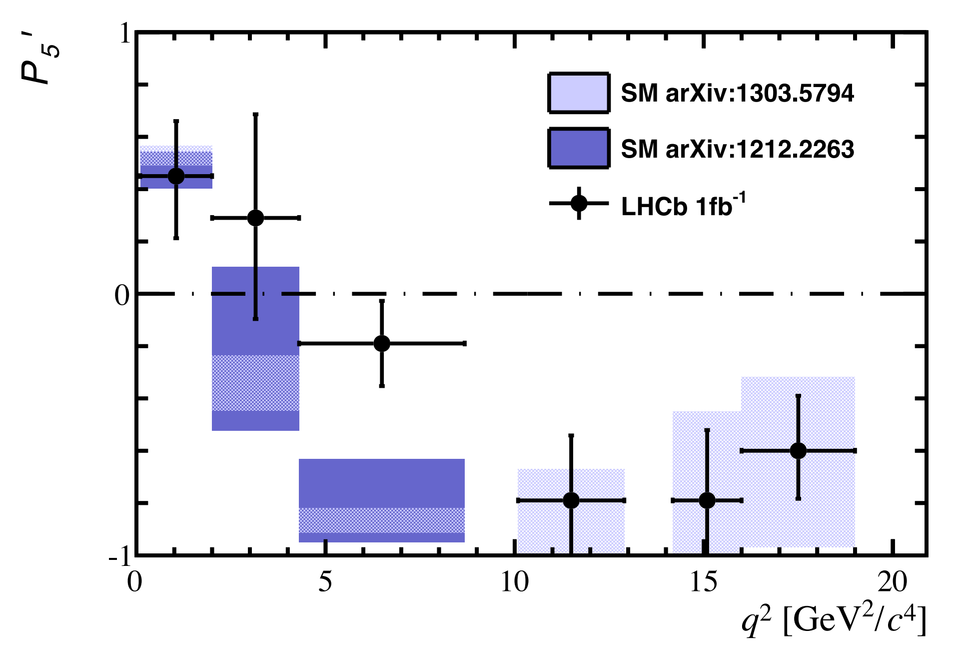




PRL 111 (2013) 191801

Testing lepton universality

- The equality of the EW couplings of *e* and *μ* in the SM is called **lepton universality**
- Idea: use highly suppressed rare decays, where there is space for NP to test it
  - Universality → $R_K \sim 1$ with $o((m_\mu/m_b)^2)$ corrections (JHEP 12 (2007) 040)

$$R_K = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(B^+ \to K^+ ee)}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(B^+ \to K^+ \mu\mu)}{dq^2} dq^2}$$

$$q^2_{max} \sim m_b^2$$
$$q^2_{min} \sim 4m_\mu^2$$

- Precisely predicted $R_K = 1.0 \pm 0.0001$
- q^2 bin [1,6] GeV^2 is theoretically favoured for NP
- Double ratio with J/ψ channels is measured to cancel systematics

LHCb-PAPER-2014-024, in preparation

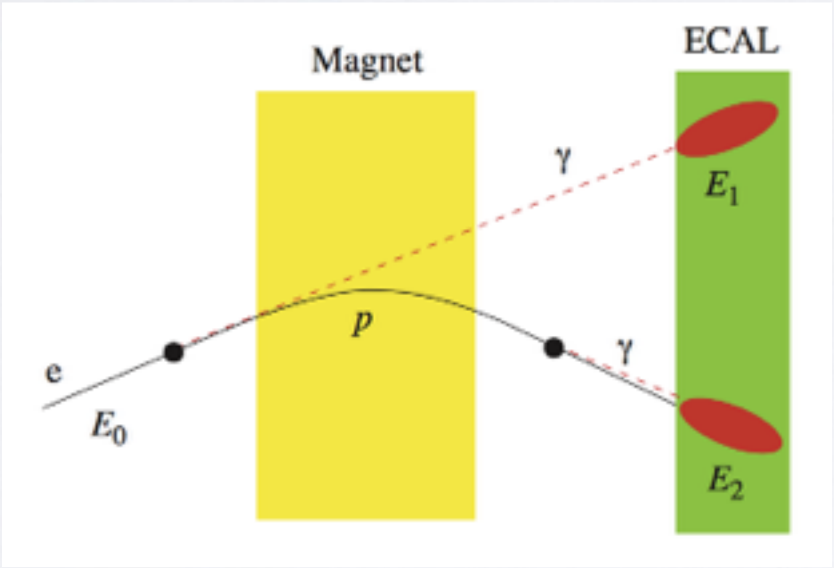
Belle ⇒ RK = $0.74^{+0.46}_{-0.37}$ PRL 103 (2009) 171801

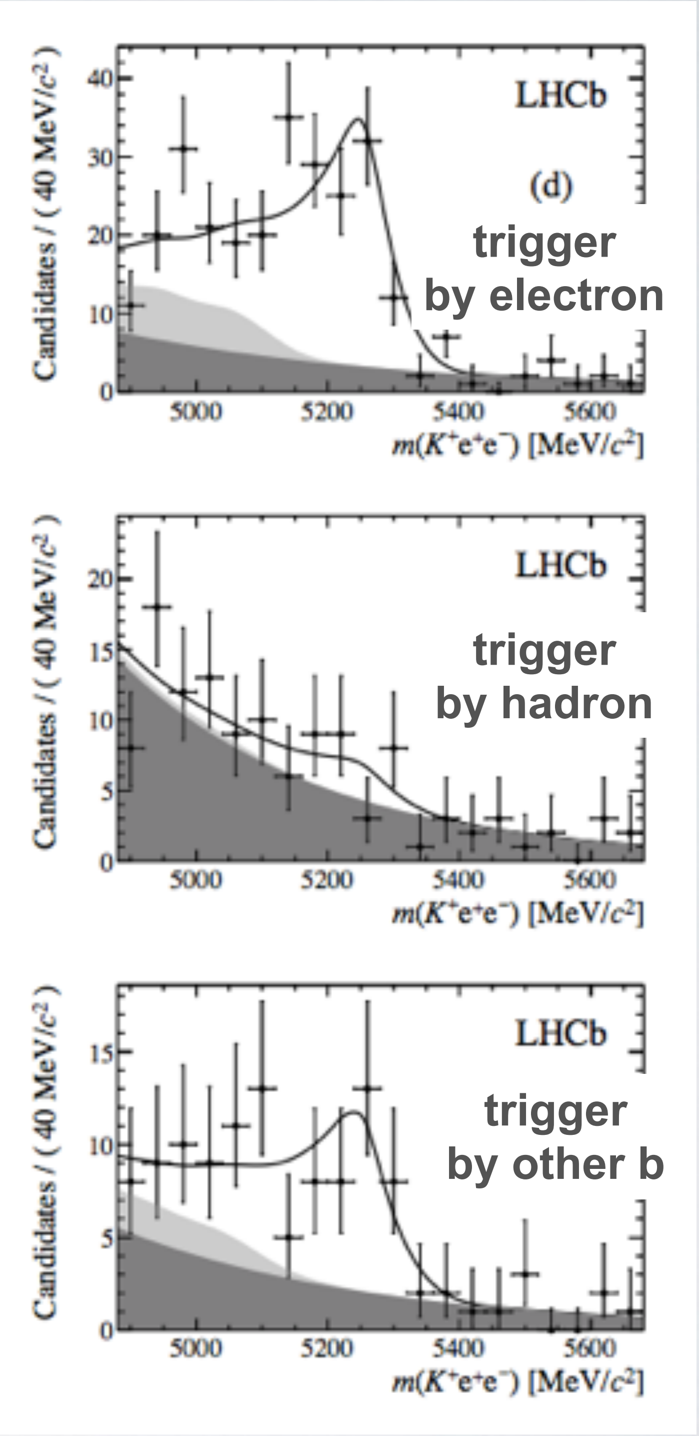
BaBar ⇒ RK = 1.03 ± 0.25 PRD 86 (2012) 032012

Now done in LHCb with **3fb^{-1}** of data

Electrons in LHCb

- The *ee* channels are the challenge in this analysis
  - Bremsstrahlung can affect the *e* momentum
    → energy recovered looking at calorimeter hits
  - Fit in 0, 1, 2 bremsstrahlung photons categories
    → to better handle resolutions and backgrounds



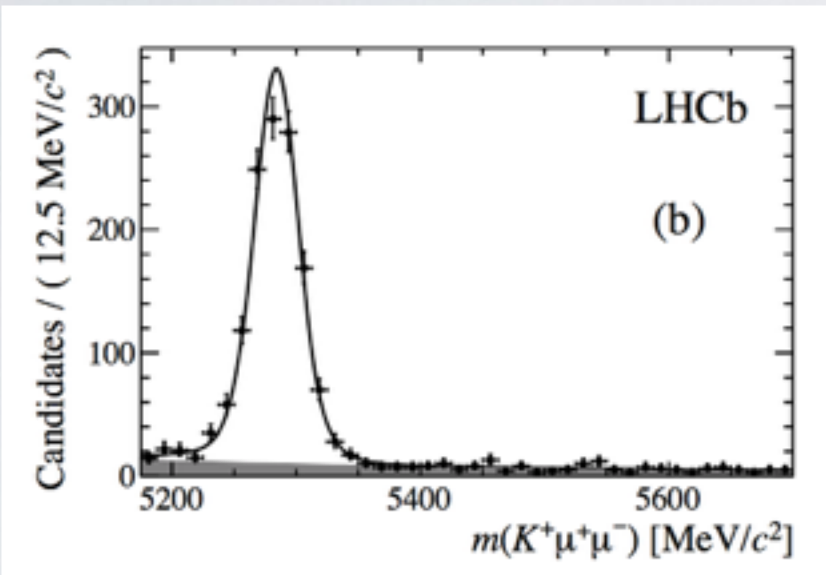


- Three trigger categories considered to maximise the yield
  - Trigger on the electron, hadrons and on on other b in the event

LHCb-PAPER-2014-024, in preparation

R_K results

- Very recent result: on arXive by the end of the week

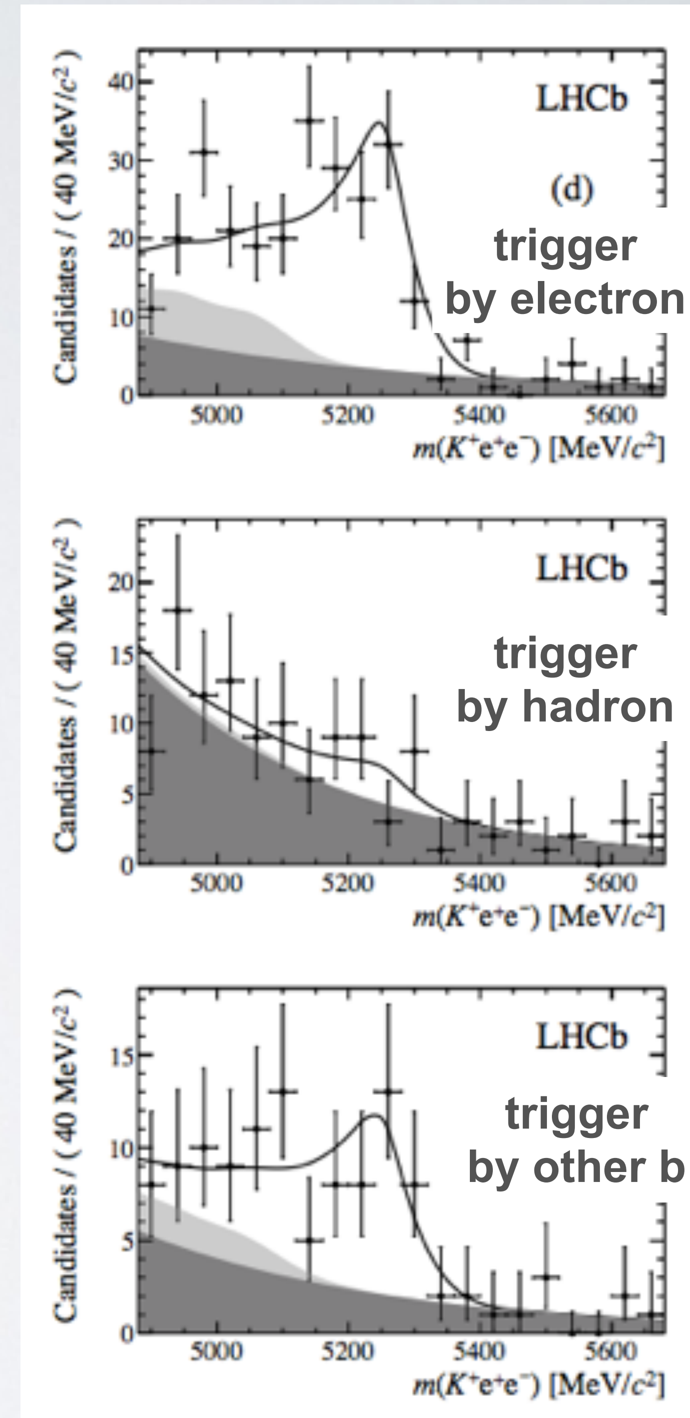


← **Kμμ** triggered by muons

1266 ± 41 evts

Kee using 3 different trigger → categories to maximise the yield

172 + 20 + 62 evts



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

- 2.6 deviations from the SM
- The *ee* BR is also reported

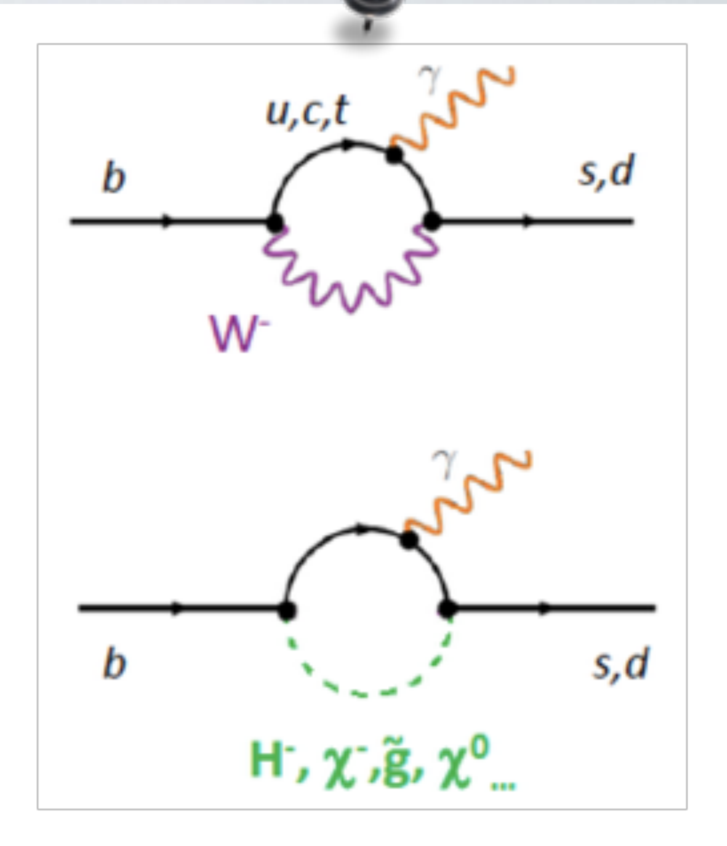
LHCb-PAPER-2014-024, in preparation

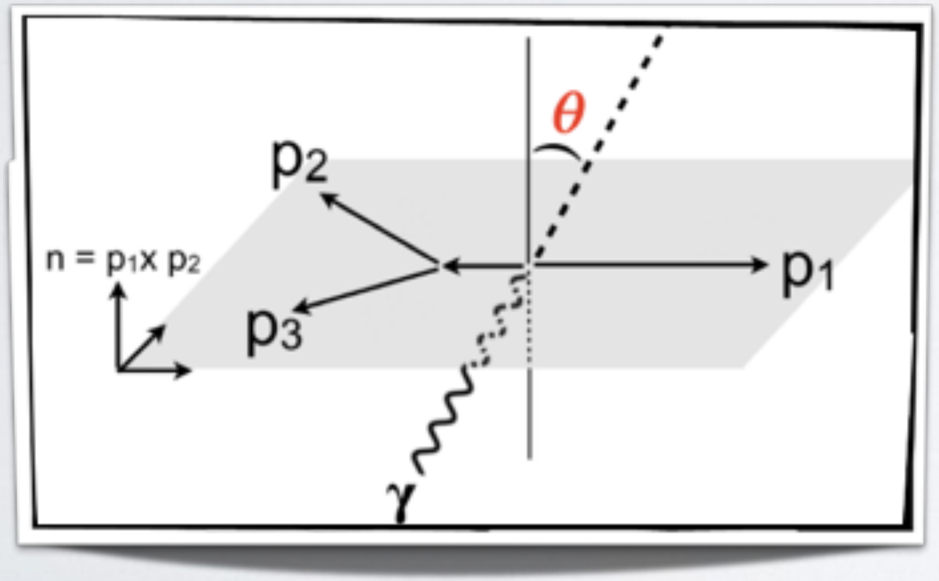
$$B(B^+ \to K^+e^+e^-) = (1.56\,^{+0.19}_{-0.15}\,^{+0.06}_{-0.04}) \times 10^{-7}\,,$$

- Same ratio with K* in place of K is also being analysed

Photon polarisation in $B \to K\pi\pi\gamma$

- $b \to s\gamma$ transitions are EW loops in SM
- W boson couples only with left-handed fermions
  → photon dominantly left-handed (right-handed $\sim m_s/m_b$)
- In BSM significant right-handed component expected due to exchange of heavy fermions





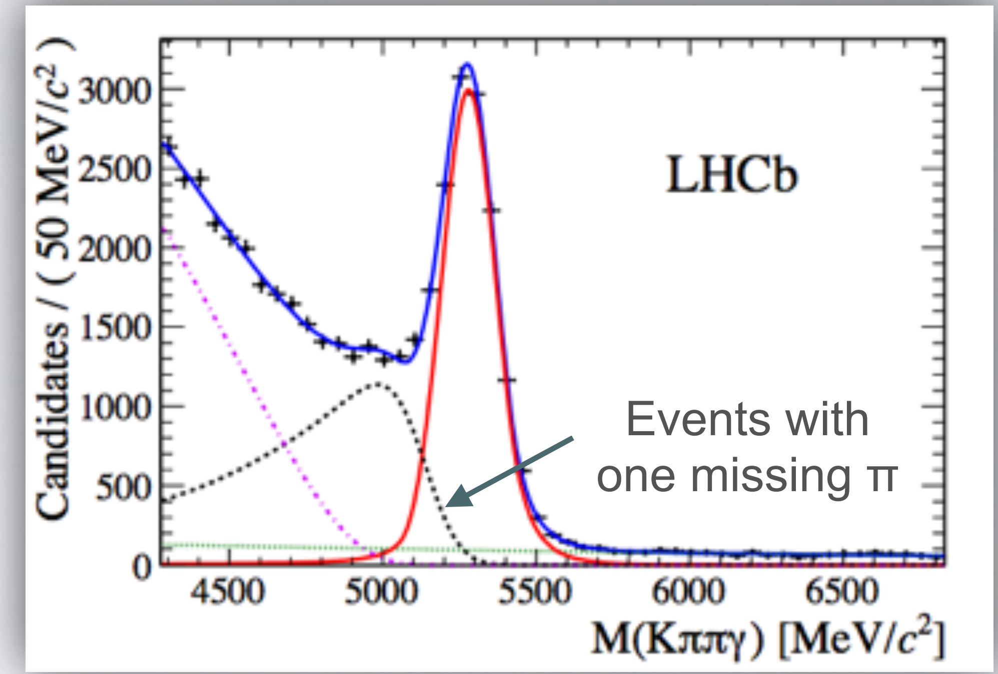
PRL **112 (2014)** 161801

- Using the photon angular distribution wrt the plane of the 3 hadrons in their CoM frame
- Measure up-down asymmetry, A_{UD}, proportional to photon polarisation λ_γ
- Conceptually similar to the historic Mrs Wu's P-violation experiment

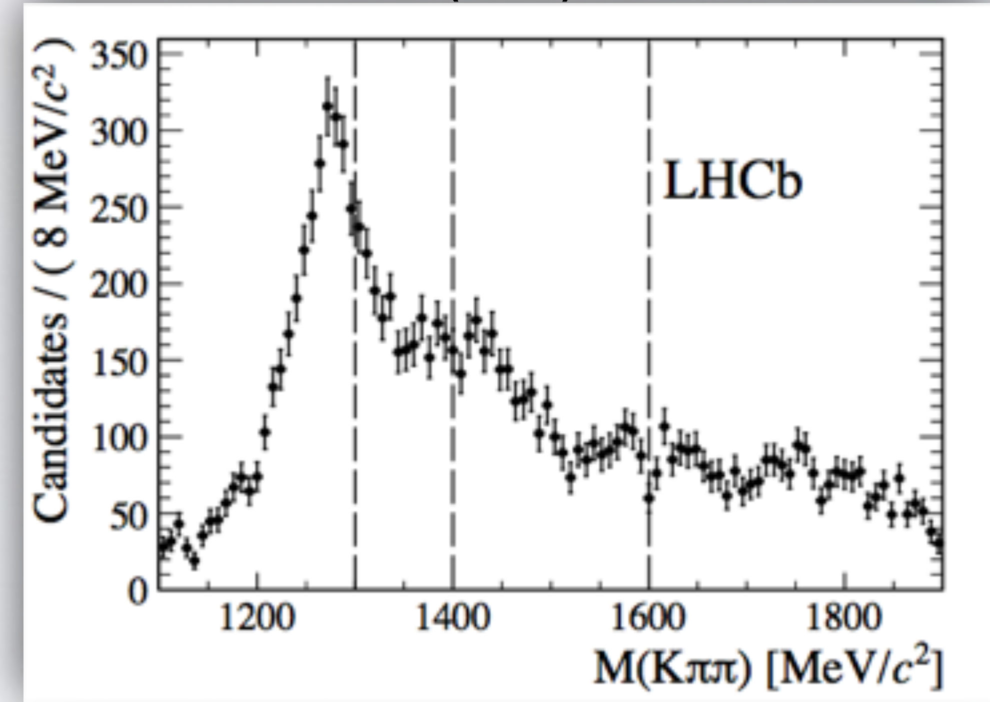
Photon polarisation in B→Kππγ

- Using $3fb^{-1}$ full data set:
  13876 ± 153 signal events
- Limited knowledge of Kππ invariant mass doesn't allow a straightforward interpretation
  → main resonances K(1270) and K(1400)
  → extraction of polarisation needs theory input
  → study done in 4 Kππ mass bins
- Method:
  - Fit of B mass in bins of cosθ
  - Correct for selection/reconstruction efficiency
  - Fit angular distribution to extract A_{UD}

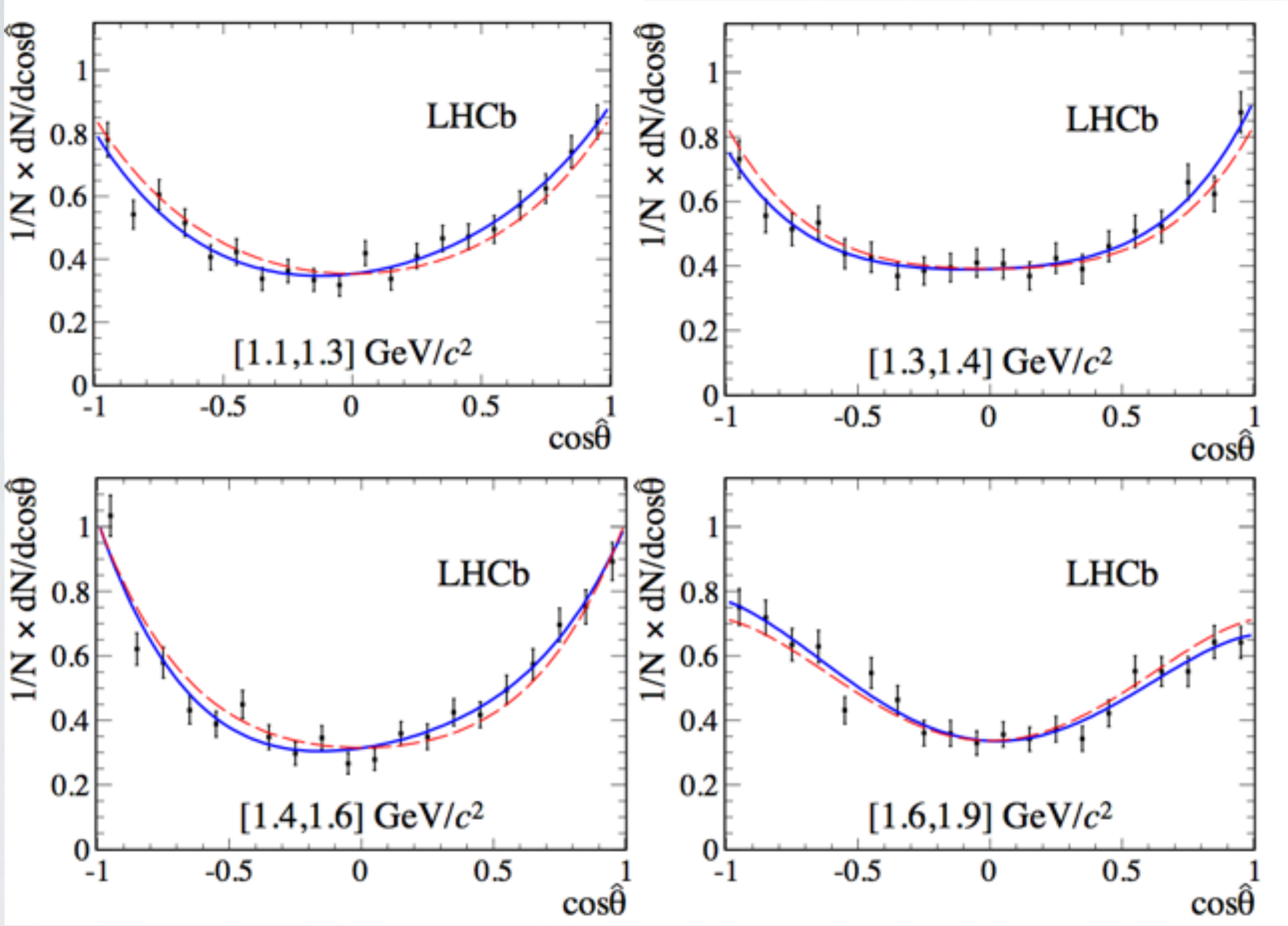
$$A_{ud} = \frac{\int_0^1 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta} - \int_{-1}^0 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta}}{\int_{-1}^1 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta}}$$



PRL **112 (2014)** 161801



Photon polarisation in $B \to K\pi\pi\gamma$: results



Blue solid:
including λ_γ term

Red dashed:
forbidding λ_γ term
(λ_γ=0)

PRL 112 (2014) 161801

First observation of a parity-violating photon polarisation at 5.2σ (for A_{UD})

$$\sum_{i=0,2,4} a_i(s, s_{13}, s_{23}) \cos^i\theta + \lambda_\gamma \sum_{j=1,3} a_j(s, s_{13}, s_{23}) \cos^j\theta$$

N.B.: non-zero A_{UD} implies non-zero λ_γ

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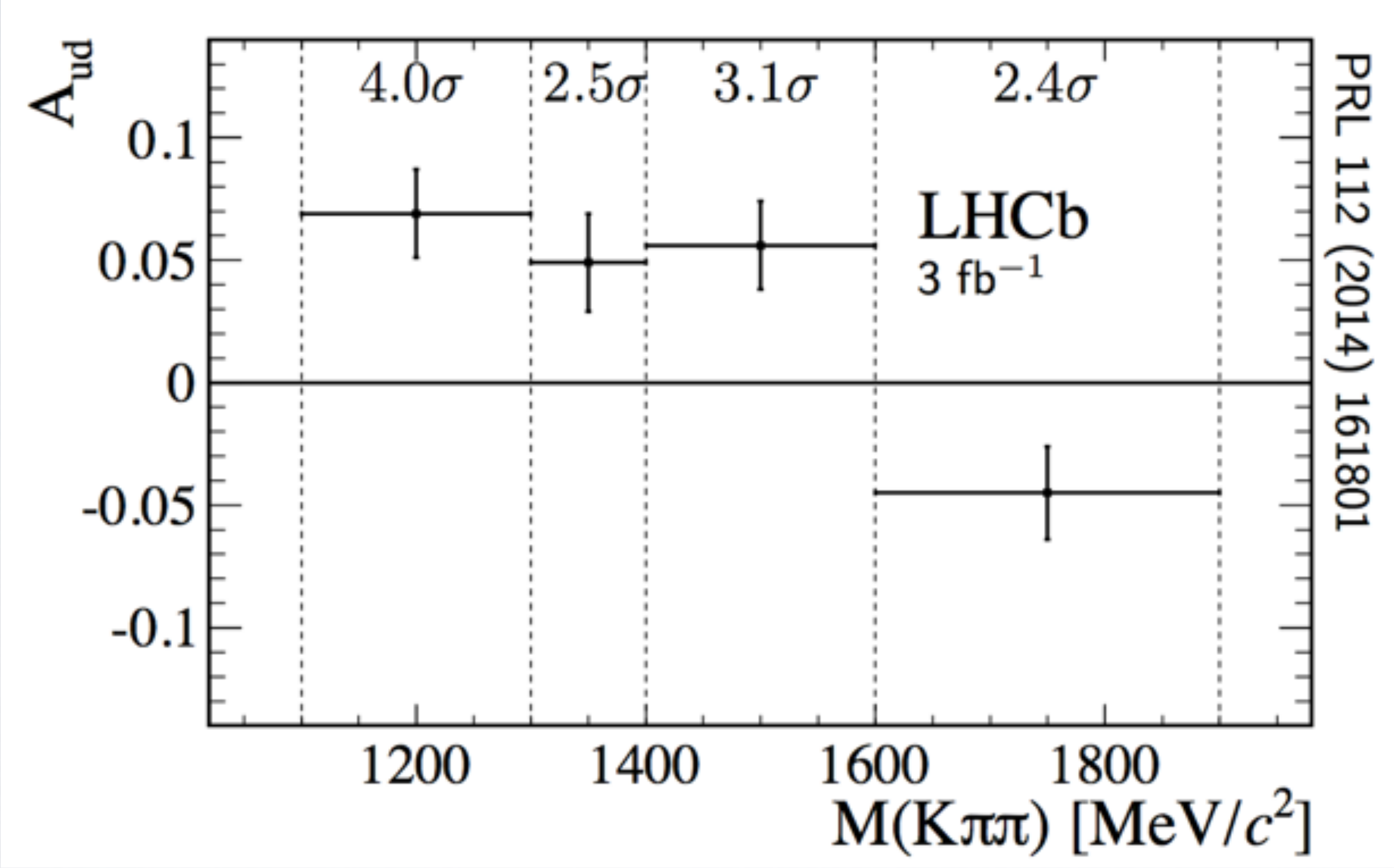

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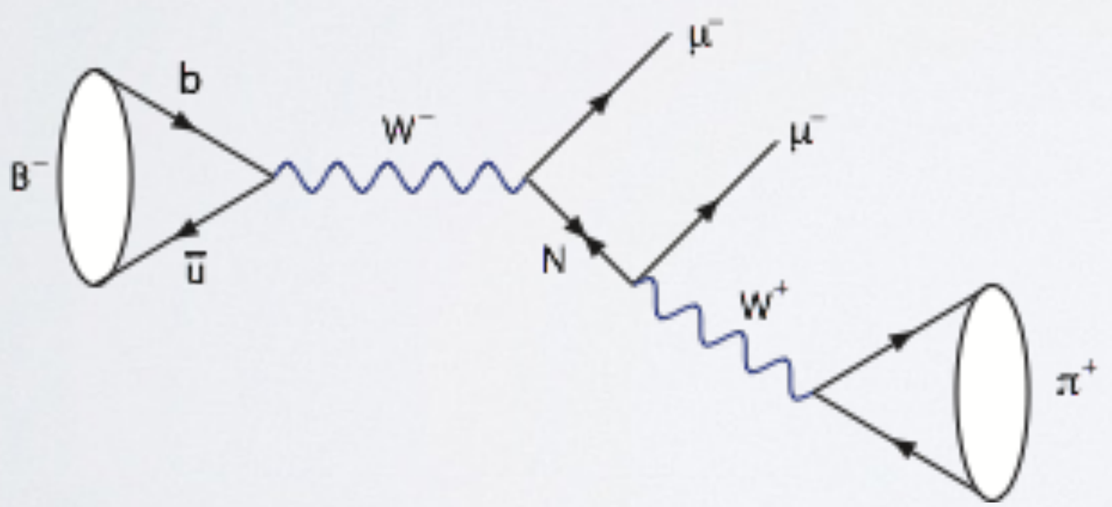
N.B.: non-zero A_{UD} implies non-zero λ_γ

Majorana neutrino search

- Neutrinos can be **Majorana** ($\nu = \overline{\nu}$), **or Dirac fermions**.
  - Searches done using neutrino-less 2β decay found no signal yet
- $B^- \rightarrow \pi^+ \mu^- \mu^-$ is a lepton number violating decay, forbidden in the SM: can happen by exchange of a Majorana neutrino
- Sensitive to 250-5000 MeV neutrino mass (m_N) range and up to 1000 ps neutrino lifetime (τ_N)



PRL 112 (2014) 131802

CLEO ⇒ BR < 1400 x 10^{-9} @ 90% CL

PRD 65(2002) 111102

BaBar ⇒ BR < 107 x 10^{-9} @ 90% CL

PRD 85(2012) 071103

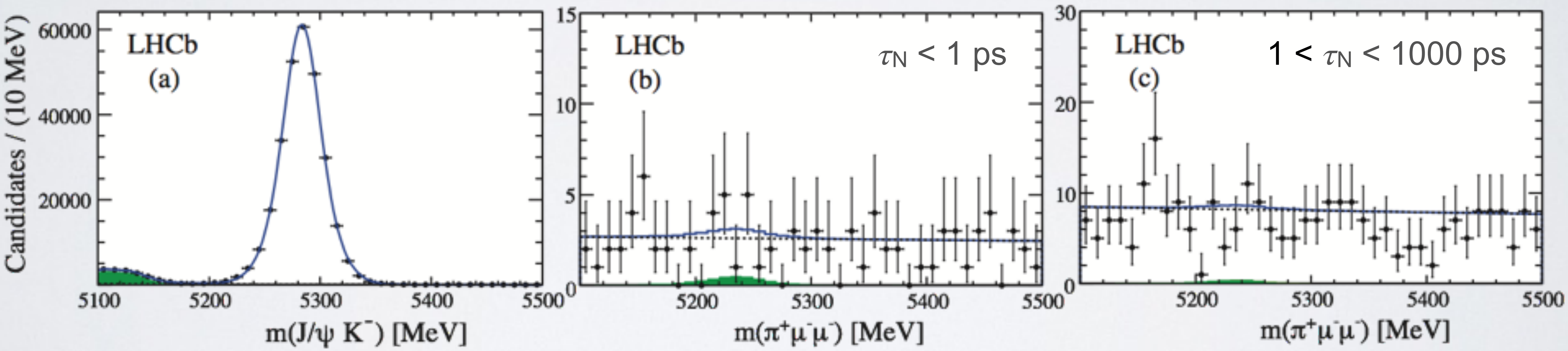
LHCb (0.41fb^{-1}) ⇒ BR < 13 x 10^{-9} @ 95% CL

PRD 81(2012) 112004

Now using 3fb^{-1}: full data set

Majorana neutrino search

- Use $B \to J/\psi(\to \mu\mu)K$ as normalisation channel
- Two selections optimised for long and short neutrino lifetime:
  - τ_N < 1 ps: the neutrino is considered as coming from the B vertex
  - τ_N > 1 ps: the information from the displaced vertex is used
- No signal found → Limits set using CLs method. Nucl.Instrum.Meth. A434 (1999)

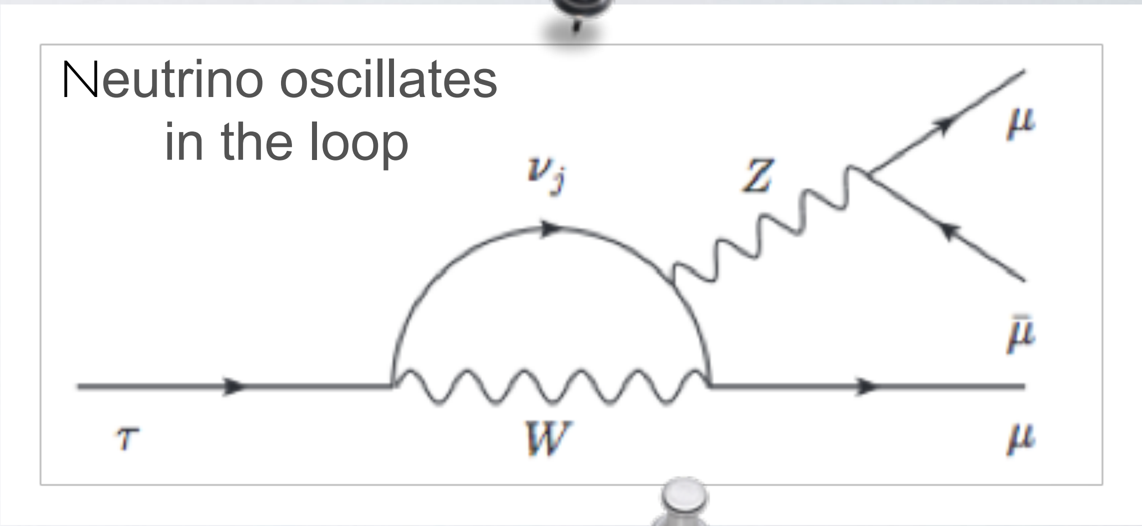


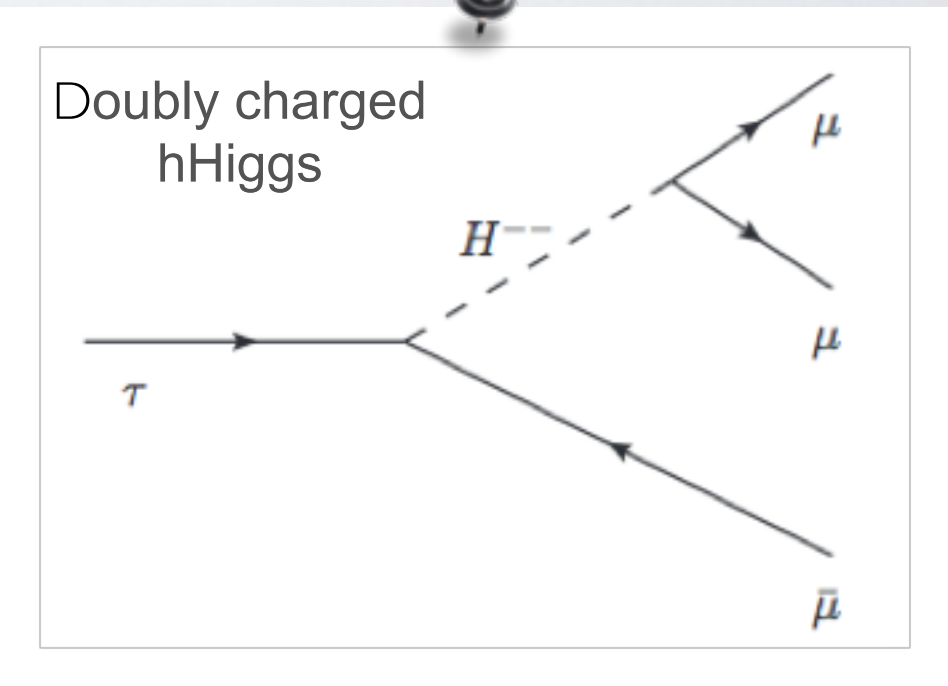
$\mathcal{B}(B \to \pi\mu\mu) < 4 \times 10^{-9}$ at 95% CL for τ_N < 1 ps

PRL 112 (2014) 131802

LFV in $\tau \to \mu\mu\mu$

- Forbidden in SM due to lepton flavour conservation
  - Well established (e.g. $\mu \to e\gamma$) but not supported by strong theoretical reasons
- Observation of neutrino oscillation makes LFV possible via loops (BR < 10^{-40})
- NP (e.g. doubly charged Higgs) can enhance up to BR ~ 10^{-7}





PLB724(2013)036045

Belle ⇒ BR < 2.1 x 10^{-8} @ 90% CL
PLB 687(2010) 139

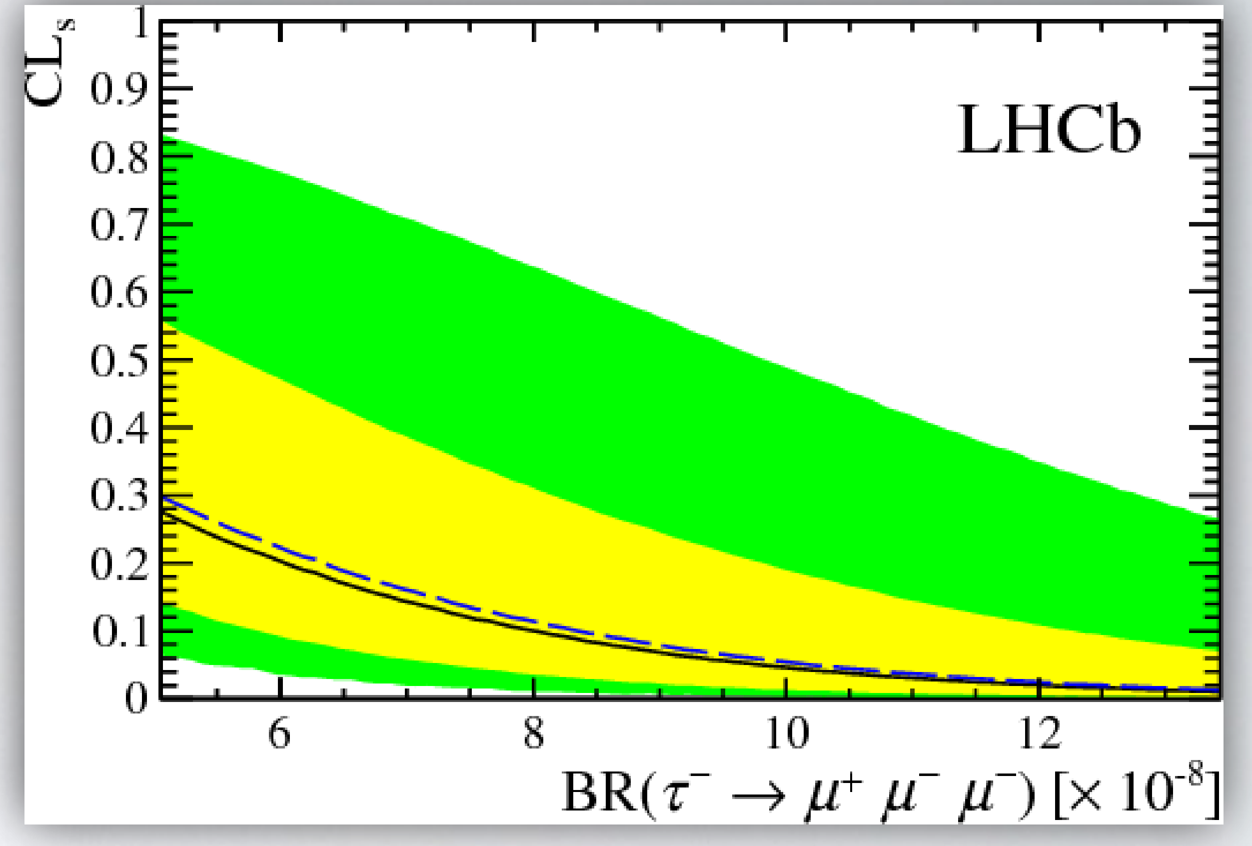
BaBar ⇒ BR < 3,3 x 10^{-8} @ 90% CL
PRD 81(2010) 111101

$\tau \rightarrow \mu\mu\mu$ results

- Using 1fb^{-1} of data
- Number of signal compatible with number of number of background events ⇒ upper limit set

$$\mathcal{B}(\tau^- \to \mu^-\mu^+\mu^-) \;<\; 8.0\ (9.8) \times 10^{-8}$$

@90(95)% CL



- First limit at an hadron collider!
- Result compatible with Belle and BaBar limits
- Will be updated to 3fb^{-1} very soon
- Also limits set on other decays using 1fb^{-1}

PLB724(2013)036045

$$\mathcal{B}(\tau^- \to \bar{p}\mu^+\mu^-) \;<\; 3.3\ (4.3) \times 10^{-7}$$
$$\mathcal{B}(\tau^- \to p\mu^-\mu^-) \;<\; 4.4\ (5.7) \times 10^{-7}$$

} @90(95)% CL

Summary and a look at the future

- The Rare Decay group at LHCb has produced good results last year!
  - ➡ Measurement of a wealth of observables in $B \to K^{(*)}\mu\mu$ decays
  - ➡ Measurement of R_K testing **lepton universality**
  - ➡ First observation of **photon polarisation** in $b \to s\gamma$ transitions
  - ➡ World limit on $B^+ \to \pi^+\mu^-\mu^-$ going through **Majorana neutrino**
  - ➡ Competing limits **LFV** in $\tau \to \mu\mu\mu$ ($B \to e\mu$, …)

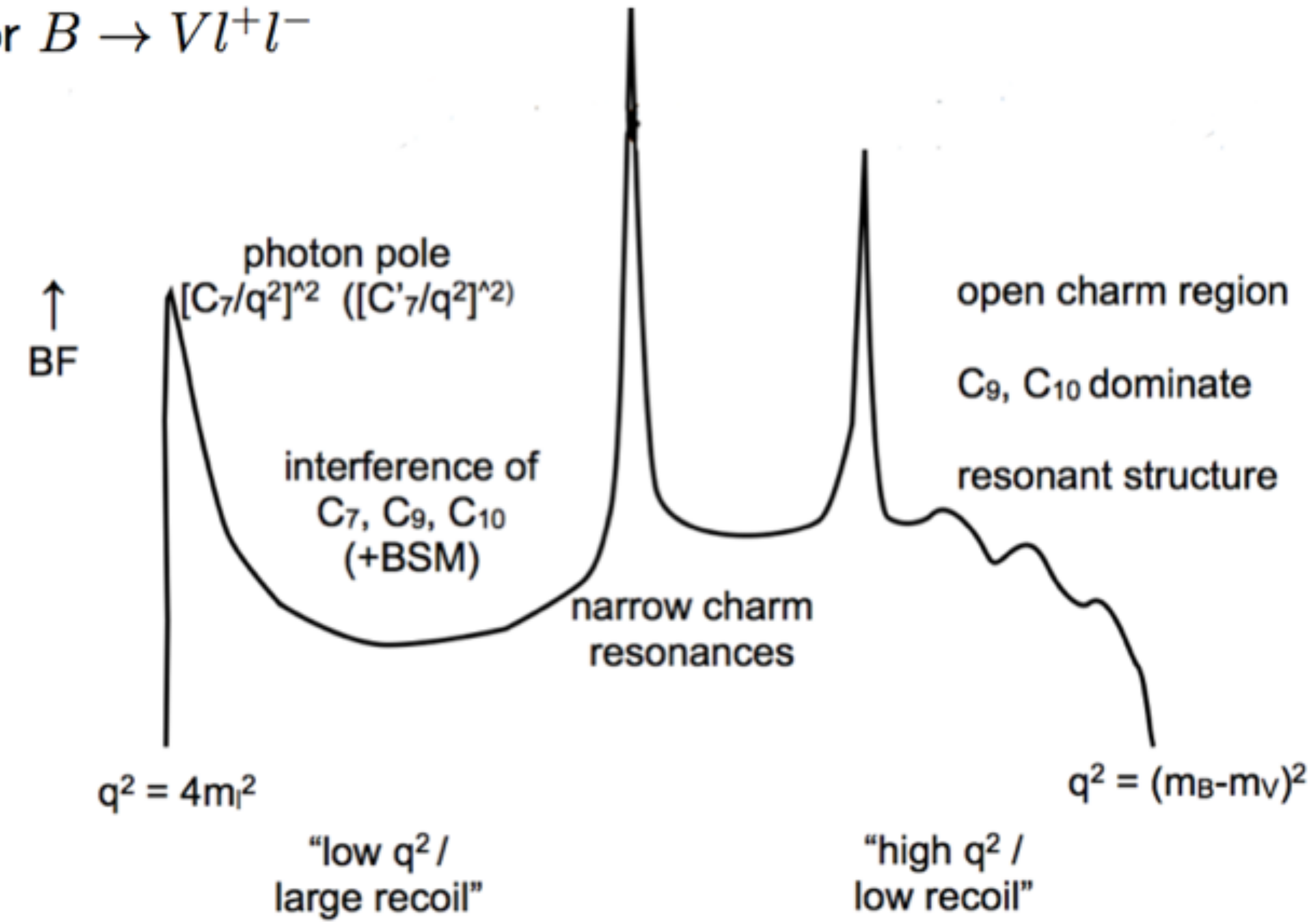
- And you can expect more in the next year:
  - ➡ All analysis are being updated to $3fb^{-1}$ ($K^*\mu\mu$ angular analysis very soon)
  - ➡ Analysis of **Λ_b decays**: $\Lambda_b \to \Lambda\mu\mu$ and $\Lambda_b \to pK\mu\mu$
  - ➡ $B \to K^*ee$ angular analysis and much more…

- Also remember **2015 is close** and new data is coming!

Backup

Typical q^2 spectrum

Valid for $B \to V l^+ l^-$

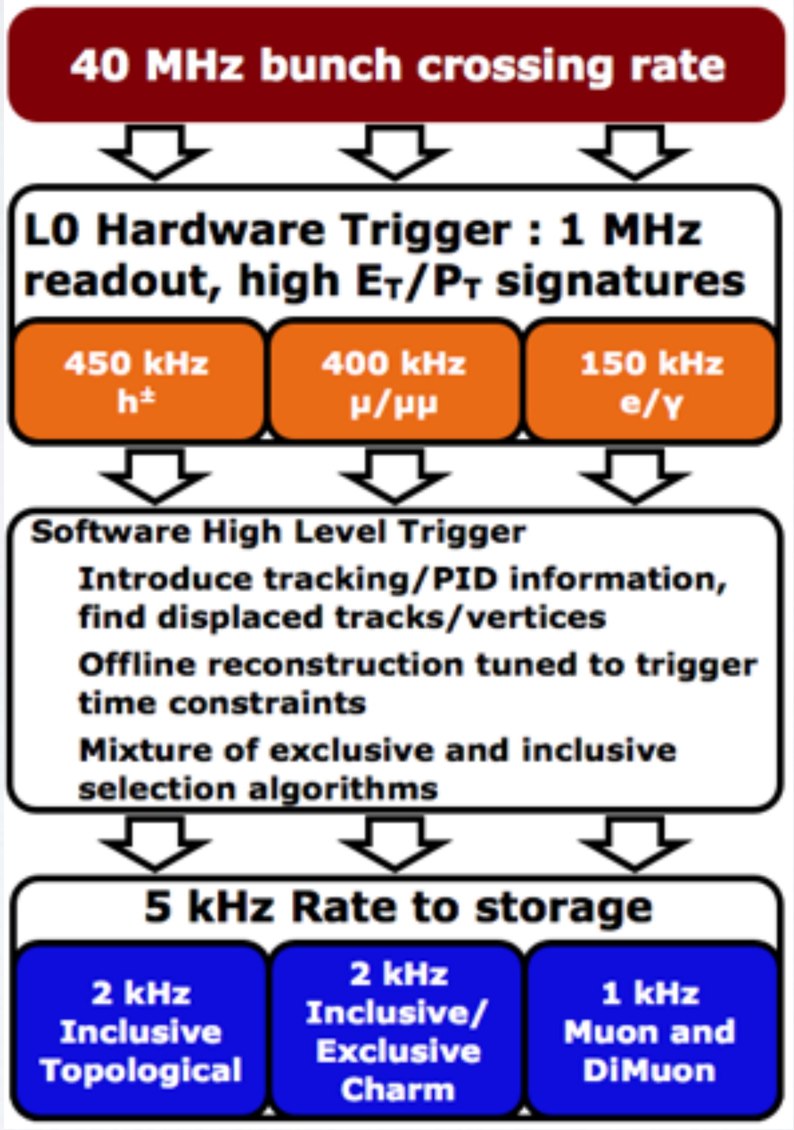


Different q^2 region sensitive to different contributions

From S. Jäger at Workshop on $b \to sll$ processes, 1-3 April 2014

Selection in LHCb

- **Trigger:** can't save everything on tape!
  - L0 trigger mainly looking for hits in muon detector or hadronic clusters
  - 2 level HLT trigger: confirming L0 decision with partial reconstruction



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  - B/D meson **flight distance** and **pointing angle**
  - Hadron **PID** information from RICH
  - Cuts to remove specific **peaking background**
- Kinematic refit of the decay chain constraining PV and masses of intermediate resonances $\Rightarrow$ yields to a better resolution
- Long-lived particles (mostly Λ and K_S) can be reconstructed with **long or downstream tracks**
- **MVA analysis** to remove combinatorial combining any variables (p, p_T, quality variables): most common is BDT from TMVA

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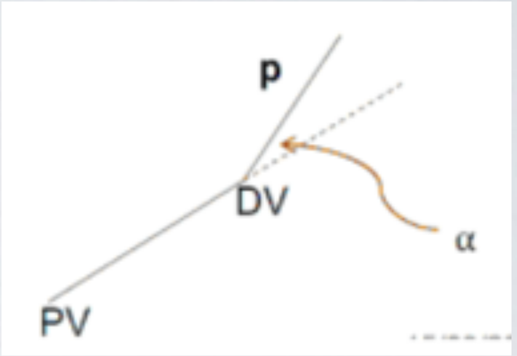

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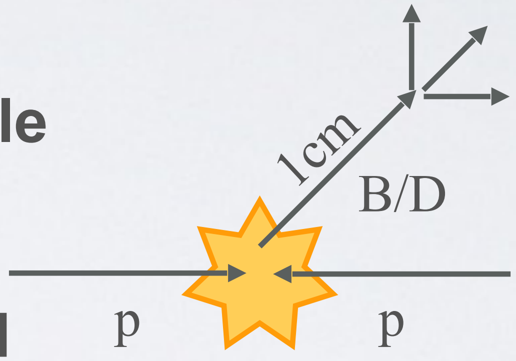

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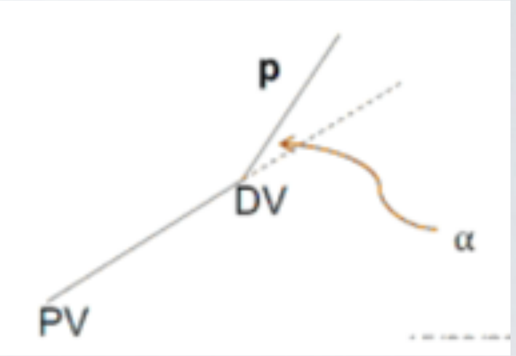

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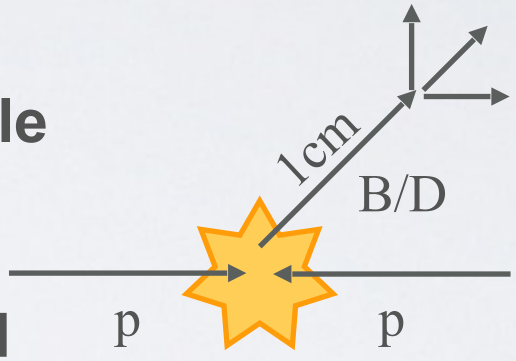

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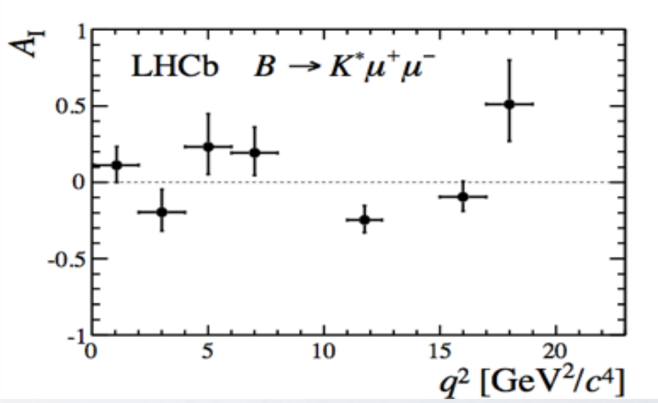

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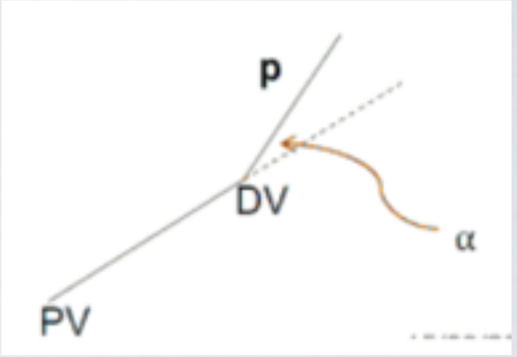

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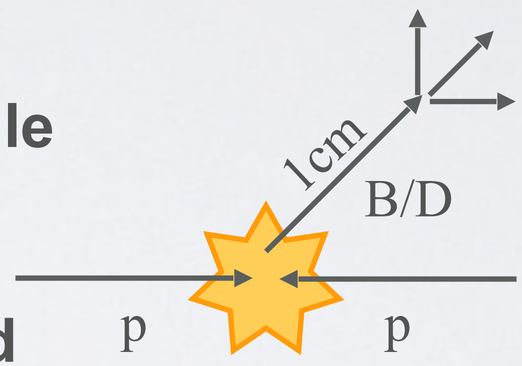

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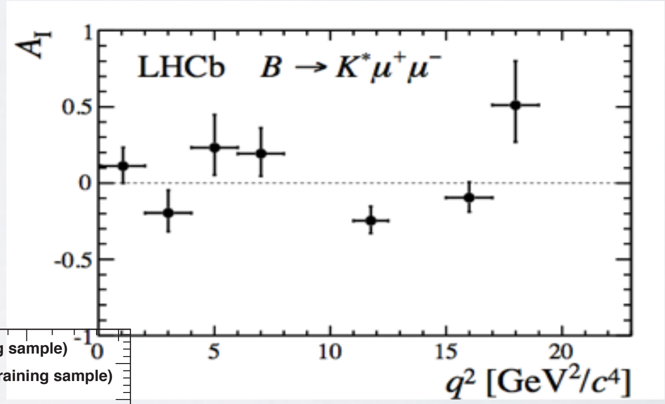

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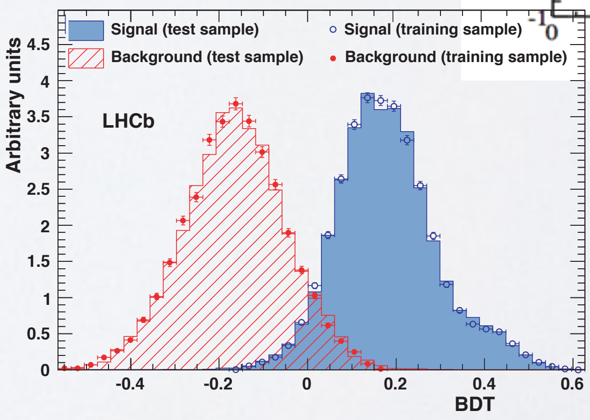


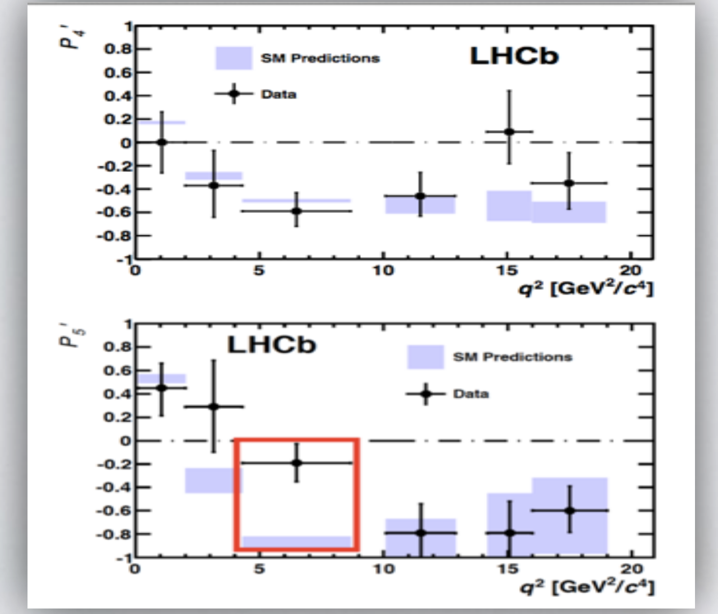
Feldman-Cousins method

- 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

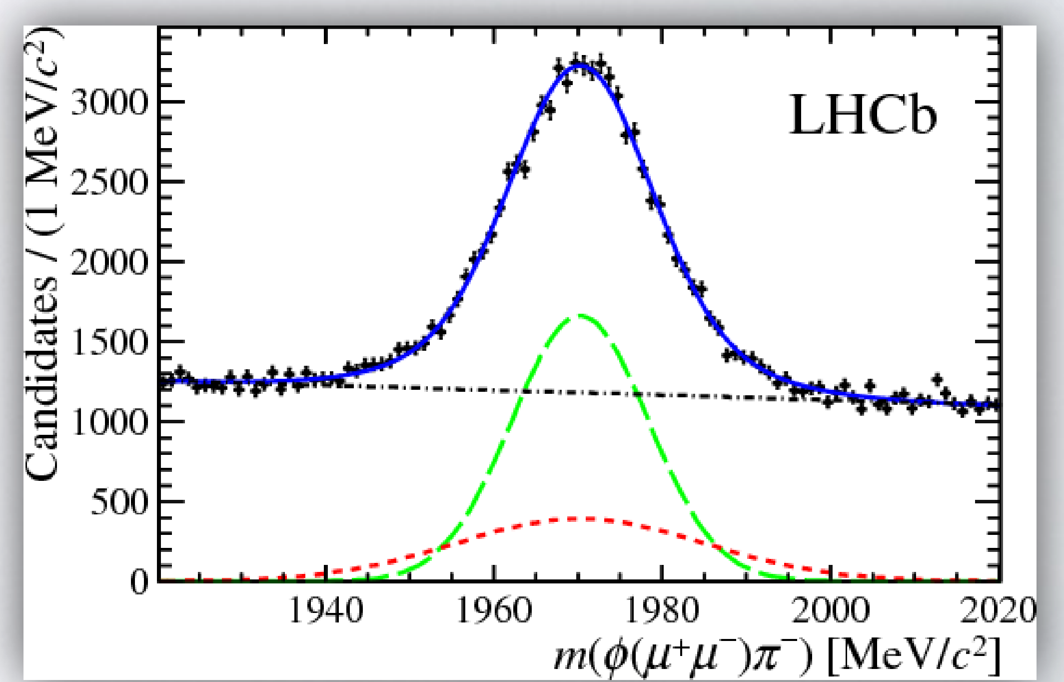
arXiv:1109.0714v1



- 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

$\tau \rightarrow \mu\mu\mu$ analysis method

- Study events in 3D binned space:
  - Likelihood variable based on event topology (BDT): including vertex quality and displacement
  - Likelihood of muon identification (Neural Networks): including information from RICH, calorimeters, muon stations, kinematics
  - Invariant mass of τ candidate
- Using $1fb^{-1}$ collected at 7 TeV
- $D_s \rightarrow \phi(\rightarrow \mu\mu)\pi$ for normalisation



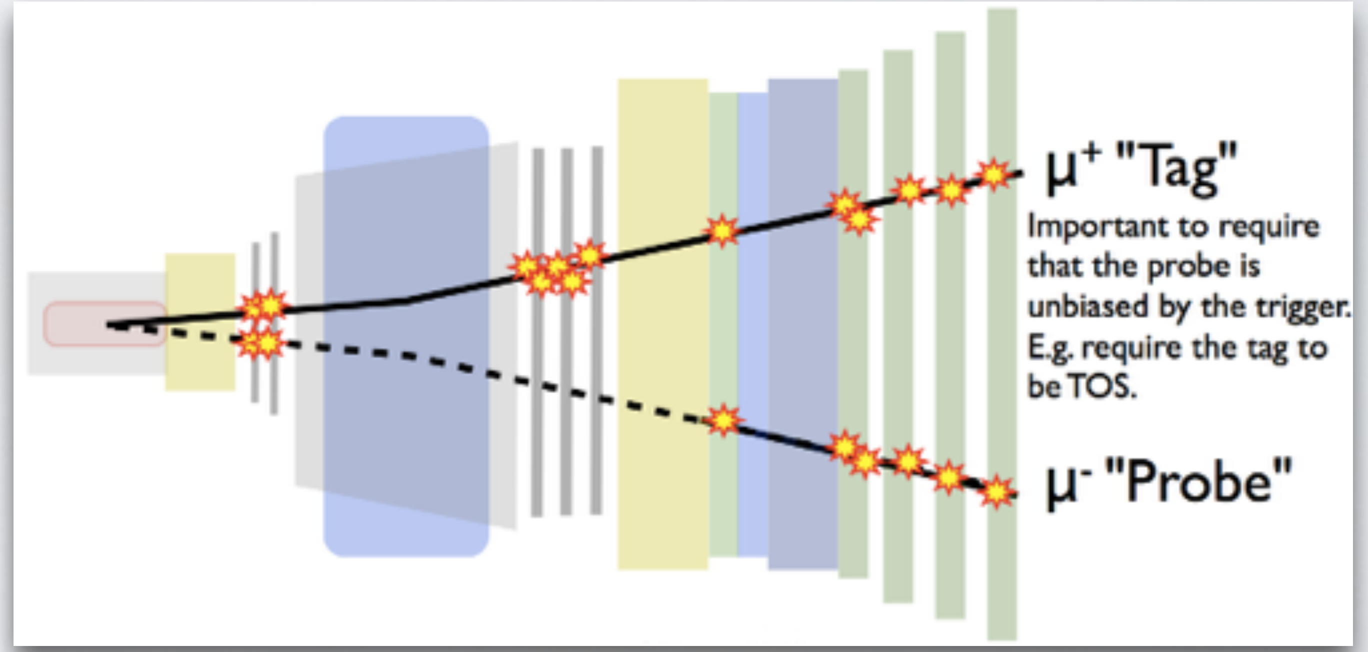
Normalisation channel

PLB724(2013)036045

Measuring detection asymmetry

- Attempts were done to measure various detection asymmetry in LHCb and some have been used in CPV measurements

1. Use tag-and probe method:
    - easy for muons, easy for PID → not so easy for hadron reconstruction



3. In some case is possible to measure detection asymmetries from yields ratios
    - Often polluted by non-zero production asymmetry and nuclear interactions

e.g.

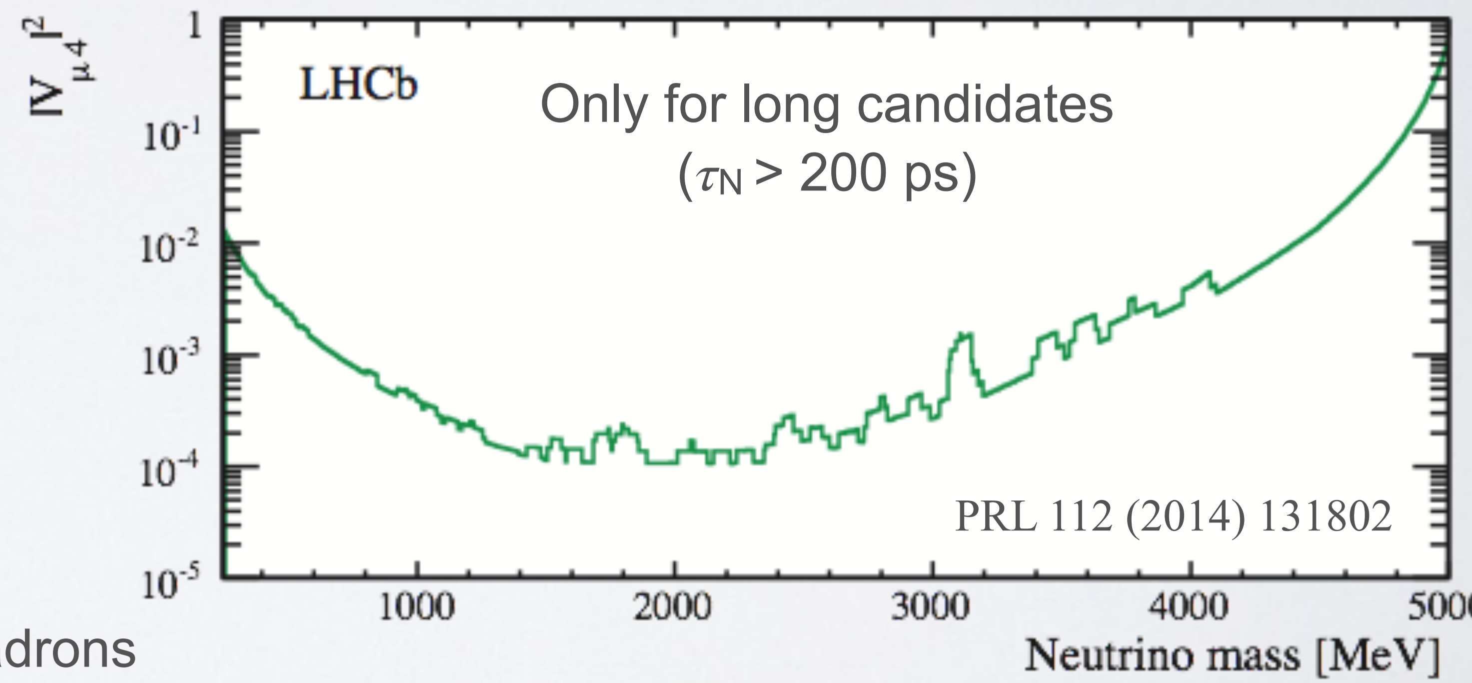
$$\frac{\epsilon(K^+\pi^-)}{\epsilon(K^-\pi^+)} = \frac{N(D^- \to K^+\pi^-\pi^-)}{N(D^+ \to K^-\pi^+\pi^+)} \times \frac{N(D^+ \to K^0_s\pi^+)}{N(D^- \to K^0_s\pi^-)}$$

Majorana neutrino: upper limits

- Since no signal found a model dependent upper limit on coupling with a fourth generation ($|V_{\mu 4}|$) is also reported as a function of m_N

$$B(B^- \to \pi^+\mu^+\mu^-) = \frac{G_F f_B^2 f_\pi^2 m_B^5}{128\pi^2\hbar}|V_{ub}V_{ud}|^2\tau_B\left(1-\frac{m_N^2}{m_B^2}\right)\frac{m_N}{\Gamma_N}|V_{\mu 4}|^4$$

- For each m_N a value of $|V_{\mu 4}|$ is assumed
- Then Γ_N can be calculated which allows to determine the τ_N dependent efficiency

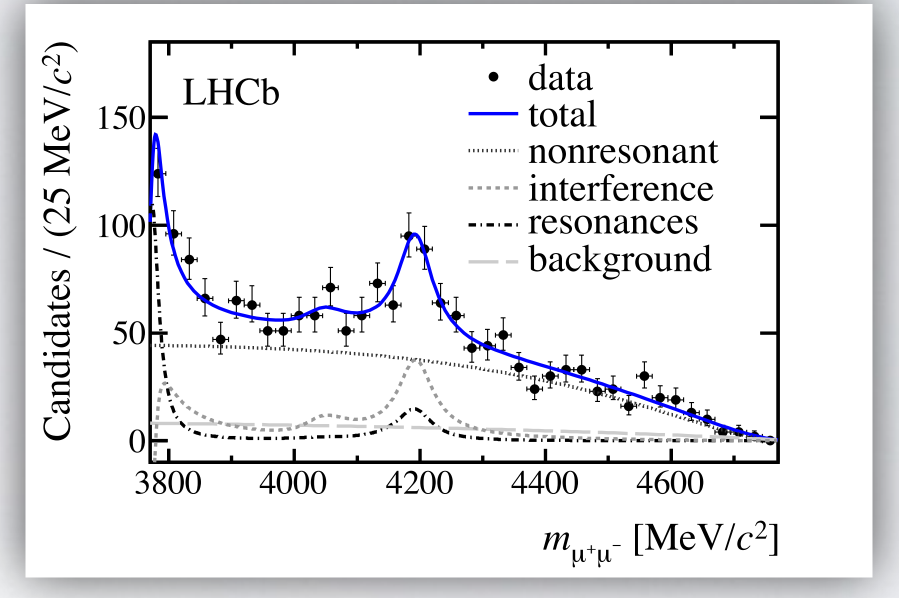


Fully leptonic decays — One lepton + hadrons

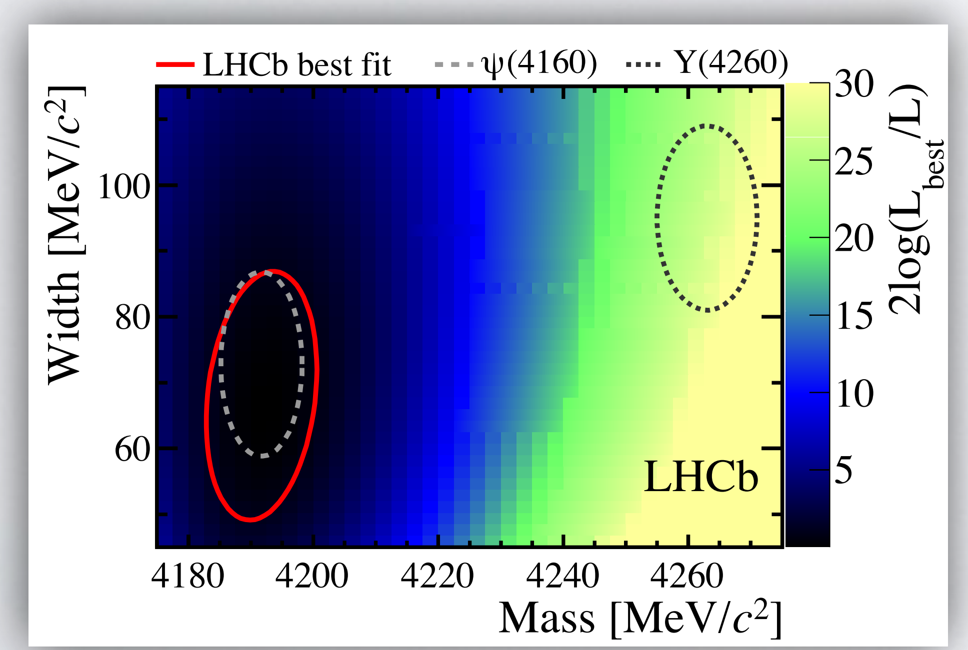
$$\Gamma_N = \left[3.95 m_N^3 + 2.00 m_N^5 (1.44 m_N^3 + 1.14)\right] 10^{-13}|V_{\mu 4}|^2,$$

Observation of a resonance in $B^+ \to K^+ \mu\mu$

- $B^+ \to K^+ \mu\mu$ has been discovered by Belle in 2001 (PRL 88 2001 021801)
- Resonance found in high q2 region, where K has low recoil
- Two resonance visible:
  - ψ(3770) at low edge
  - Newly observed resonance corresponding at ψ(4160)
    ψ(4260) rejected at > 4σ



Using 3fb^{-1} of data



Fits performed constraining to ψ(4160) and unconstraint

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

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