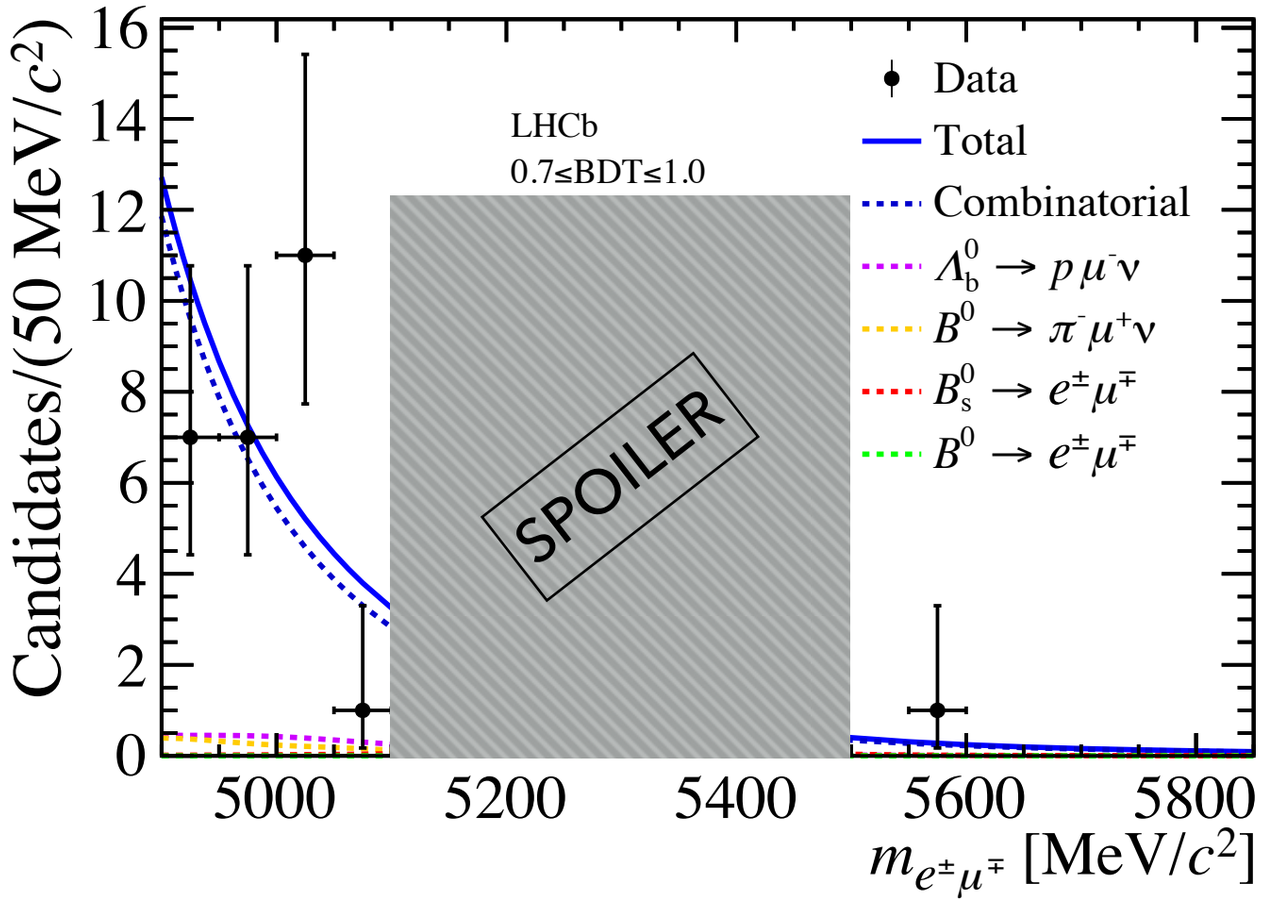
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE



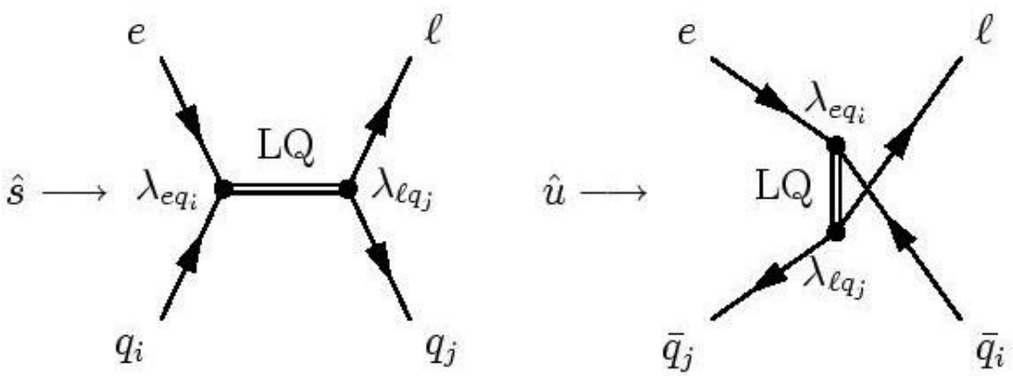
LHCb

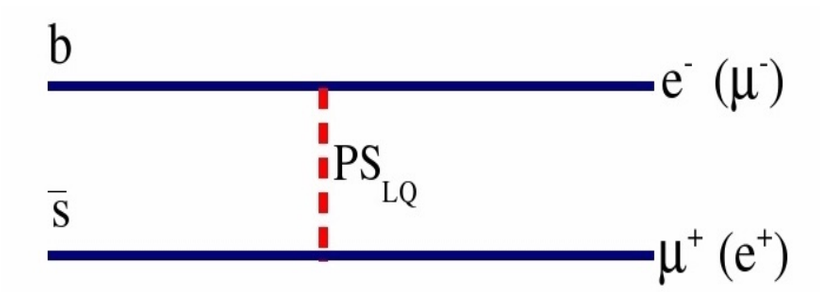
GUIDO ANDREASSI

SEARCH FOR THE LEPTON FLAVOUR VIOLATING DECAY B → eμ

MOTIVATIONS

- Processes that are strongly suppressed (forbidden) in the SM might be enhanced by new mediating particles
- LFV predicted by a large variety of alternative models (Lepto-Quarks, new gauge Z'...)
- Such particles can enter SM diagrams as virtual particles ⇒ can indirectly observe mediators unaccessible to direct searches





EXPERIMENTAL SCENARIO

[1] Phys. Rev. Lett. 115, 111803
[2] JHEP 08 (2017) 055
[3] Phys. Rev. Lett. 113, 151601
[4] arXiv: 1609.08895v2
[5] Phys. Rev. Lett. 114, 091801
[6] Phys.Rev.Lett. 111, 141801

- Recent hints of LNU effects [1,2,3] open to new scenarios
- Potential links between LNU and LFV [4,5] entail a renewed interest on the subject

$$\mathcal{B}(B \to K\mu^{\pm}e^{\mp}) \sim 3 \cdot 10^{-8} \left(\frac{1-R_K}{0.23}\right)^2, \; \mathcal{B}(B \to K(e^{\pm},\mu^{\pm})\tau^{\mp}) \sim 2 \cdot 10^{-8} \left(\frac{1-R_K}{0.23}\right)^2$$

$$\frac{\mathcal{B}(B_s \to \mu^+ e^-)}{\mathcal{B}(B_s \to \mu^+\mu^-)_{\rm SM}} \sim 0.01 \left(\frac{1-R_K}{0.23}\right)^2, \quad \frac{\mathcal{B}(B_s \to \tau^+(e^-,\mu^-))}{\mathcal{B}(B_s \to \mu^+\mu^-)_{\rm SM}} \sim 4 \left(\frac{1-R_K}{0.23}\right)^2.$$

[arXiv: 1609.08895v2]

- Previous best limits are from LHCb, with 2011 (1 fb^{-1}) data, published in 2013 [6]:

$$\mathcal{B}(B^0 \to e^{\pm}\mu^{\mp}) < 2.8(3.7) \times 10^{-9} @ 90\%(95\%) C.L$$

$$\mathcal{B}(B_s^0 \to e^{\pm}\mu^{\mp}) < 1.1(1.4) \times 10^{-8} @ 90\%(95\%) C.L$$

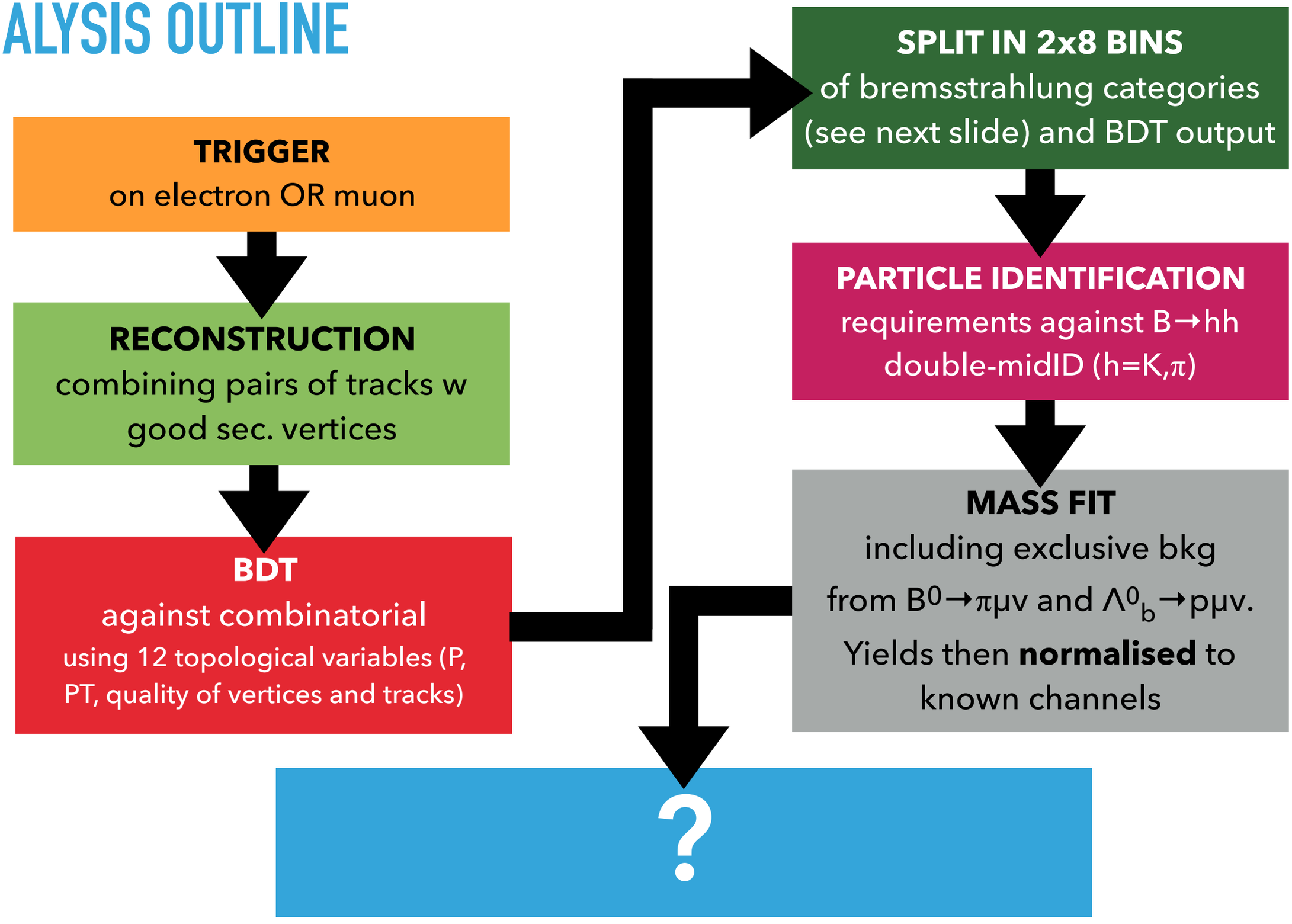
OUR ANALYSIS

- Search for both B^0_s and B^0_d mesons decaying to an electron and a muon with opposite charge
- B mass region [5100, 5500] MeV blind until the analysis strategy was finalised

WITH RESPECT TO THE PREVIOUS PUBLICATION FROM LHCB:

- Present analysis on Run1 data (2011+2012, 3 fb^{-1})
- Improved candidate selection strategy and invariant mass fit
- Benefits from improved reconstruction of electrons

ANALYSIS OUTLINE



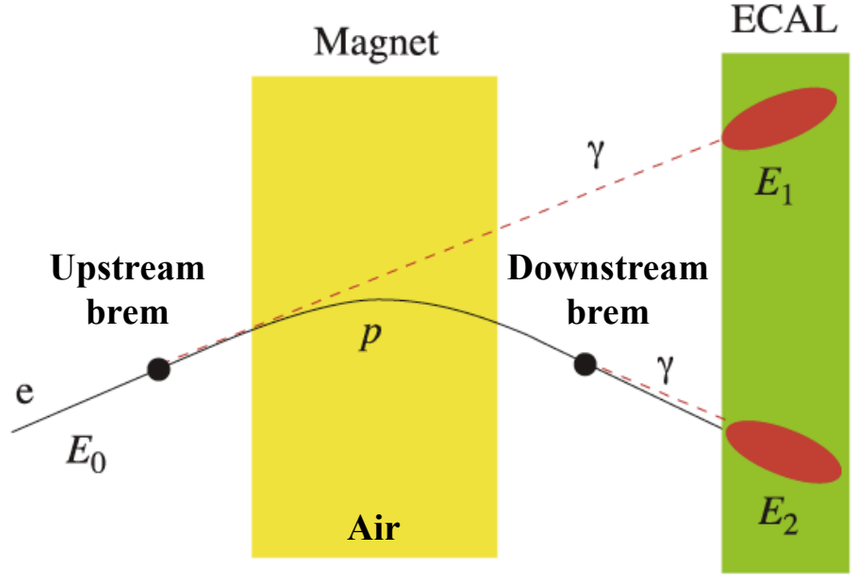
BREMSSTRAHLUNG

The emission of bremsstrahlung photons by electrons has sizeable fallouts on some aspects of the analysis.

Ideally, brem photons clusters in the ECAL are identified and their energy is *recovered* by assigning it back to the parent electron.

In practice:

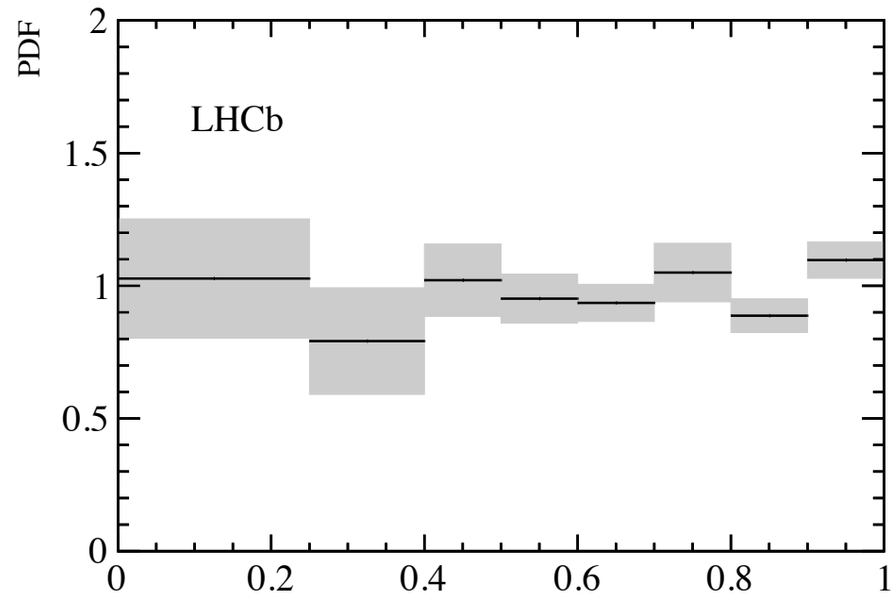
- some real γ are missed, some *wrong* γ are added
- resolution on the energy of the γ affects electron's P, PT quality of the vertices...



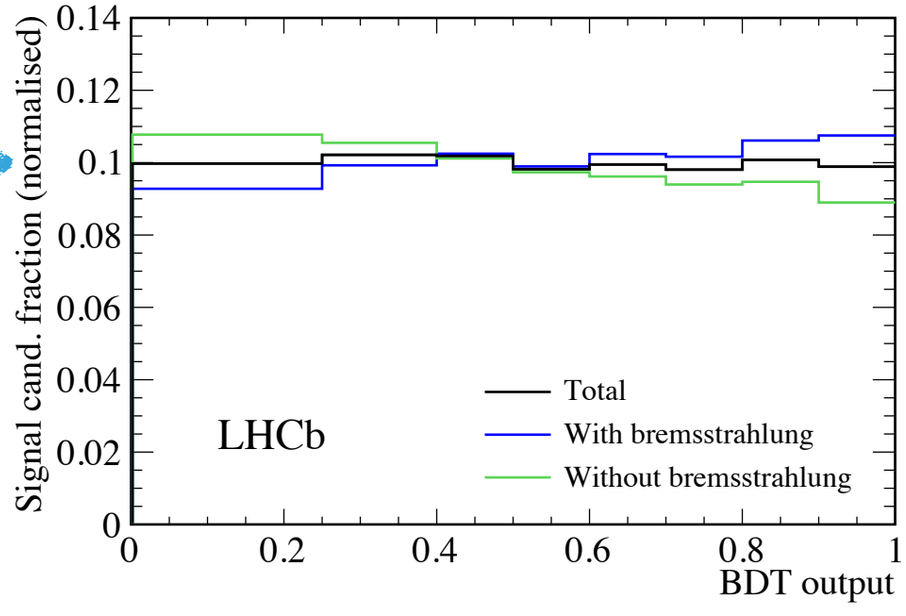
Selection efficiencies and mass shapes depend on whether or not a brem photon was added to the electron in the reconstruction (brem categories)

SELECTION

plots from JHEP03 (2018) 078]



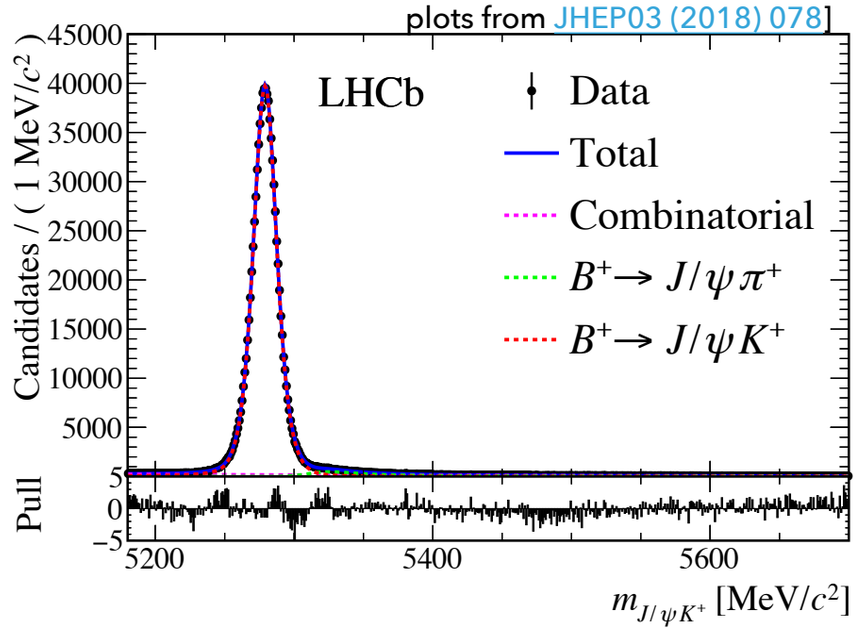
- Trigger efficiencies in brem categories
- BDT response modelled to be flat on signal (MC) (and peaked on zero for bkg)
- Response on data evaluated on $B^0 \to K\pi$, as a proxy channel
  - Unbiased for trigger selection
  - Corrected for PID selection efficiency
  - Corrected for brem category
- Analysis binned in 8 BDT bins
- PID efficiencies split in these bins and in brem category

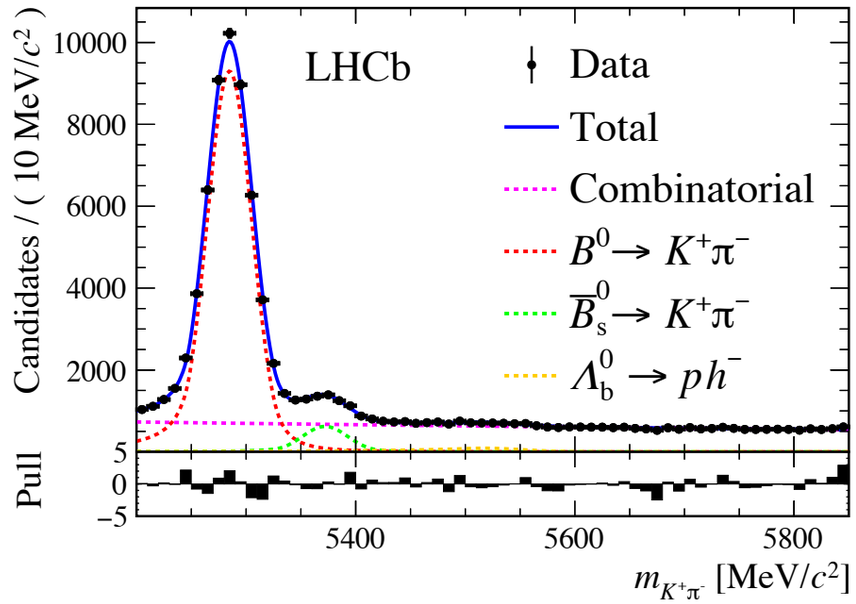


NORMALISATION

- Normalise simultaneously to two channels:
  - $B^+ \to J/\psi(\to \mu\mu)K^+$, chosen for the large yield, allowing a precise fit
  - $B^0 \to K^+\pi^-$, chosen for the similar topology to the signal (i.e. similar reco efficiencies)

plots from JHEP03 (2018) 078]





- Average with inverse of error:

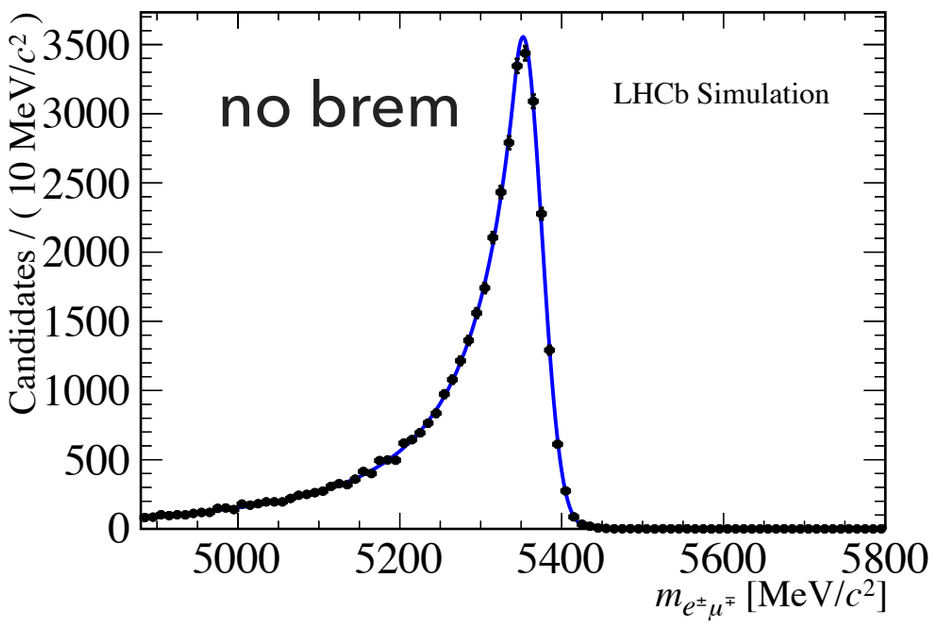
$$\mathcal{B}(B^0_{(s)} \to e^\pm\mu^\mp) = \sum_i w^i \frac{\mathcal{B}^i_{\rm norm}}{N^i_{\rm norm}} \frac{\varepsilon^i_{\rm norm}}{\varepsilon_{\rm sig}} \frac{f_q}{f_{d(s)}} \frac{\mathcal{L}^i_{\rm norm}}{\mathcal{L}_{\rm sig}} \times N_{B^0_{(s)}\to e^\pm\mu^\mp}$$

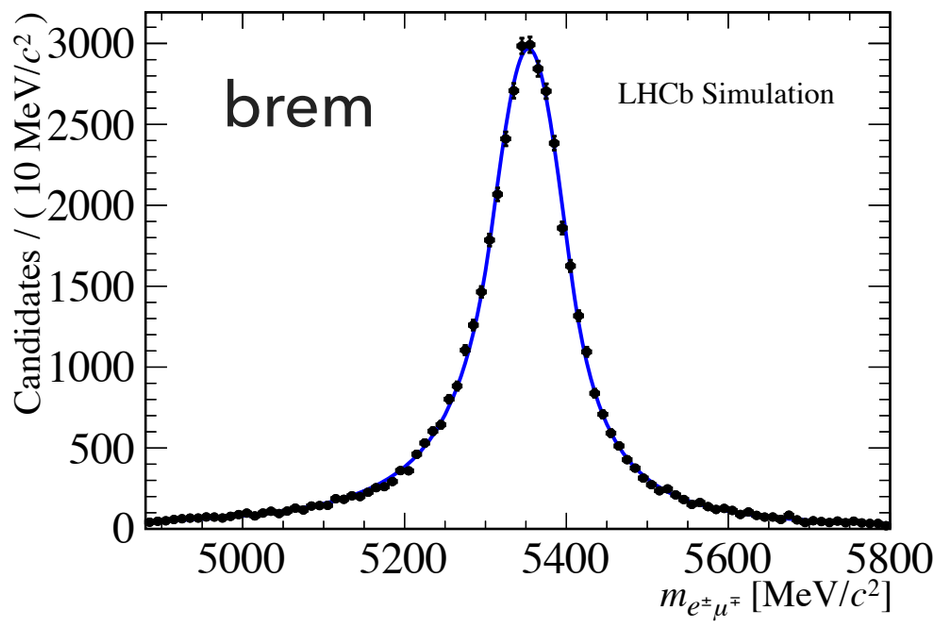
- Ratio of the two measured BF found in excellent agreement with PDG

$$R_{\rm norm} = \frac{N_{B^0\to K^+\pi^-} \times \varepsilon_{B^+\to J/\psi K^+}}{N_{B^+\to J/\psi K^+} \times \varepsilon_{B^0\to K^+\pi^-}} = 0.332 \pm 0.002\,({\rm stat}) \pm 0.020\,({\rm syst})$$

MASS FIT

- Mass shape of B_d and B_s from simulation
  - PDF: double-sided Crystal Ball





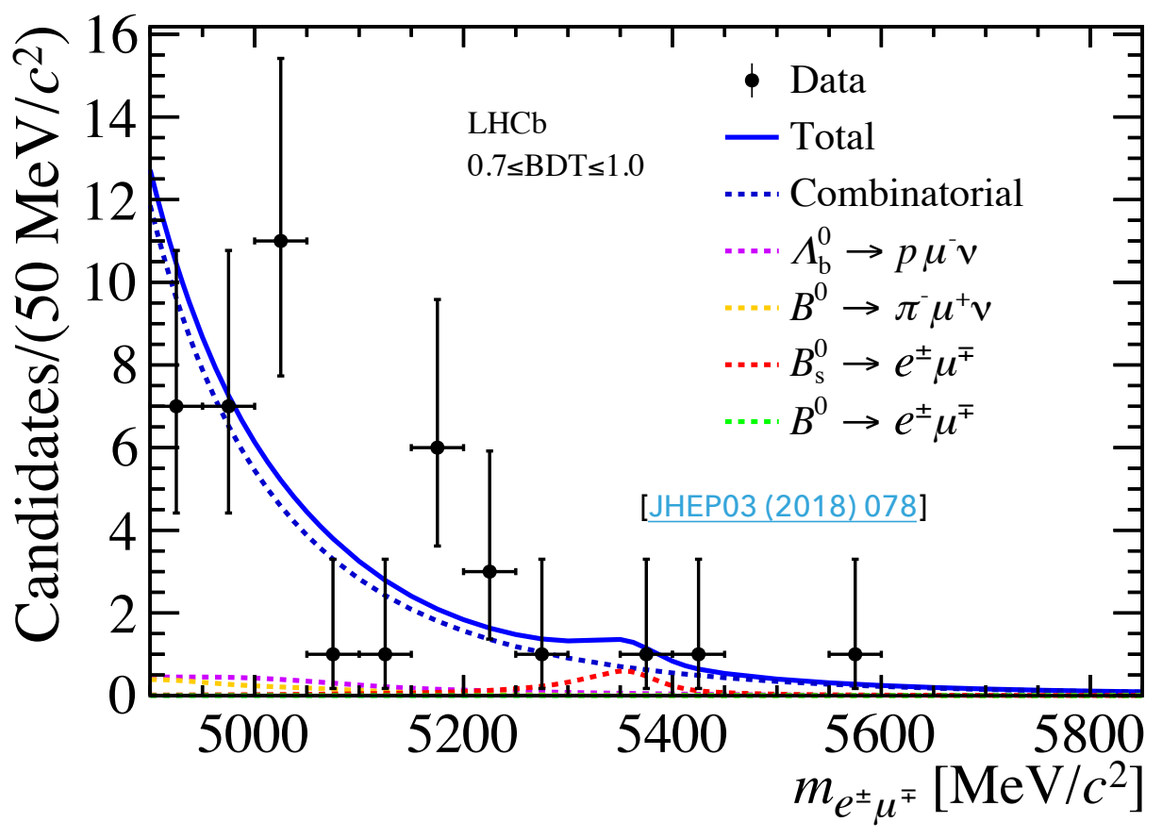
- Correct the core width of the distribution for data/MC differences using J/ψ→ee and J/ψ→μμ appropriately combined to reproduce eμ final state

MASS FIT (2)

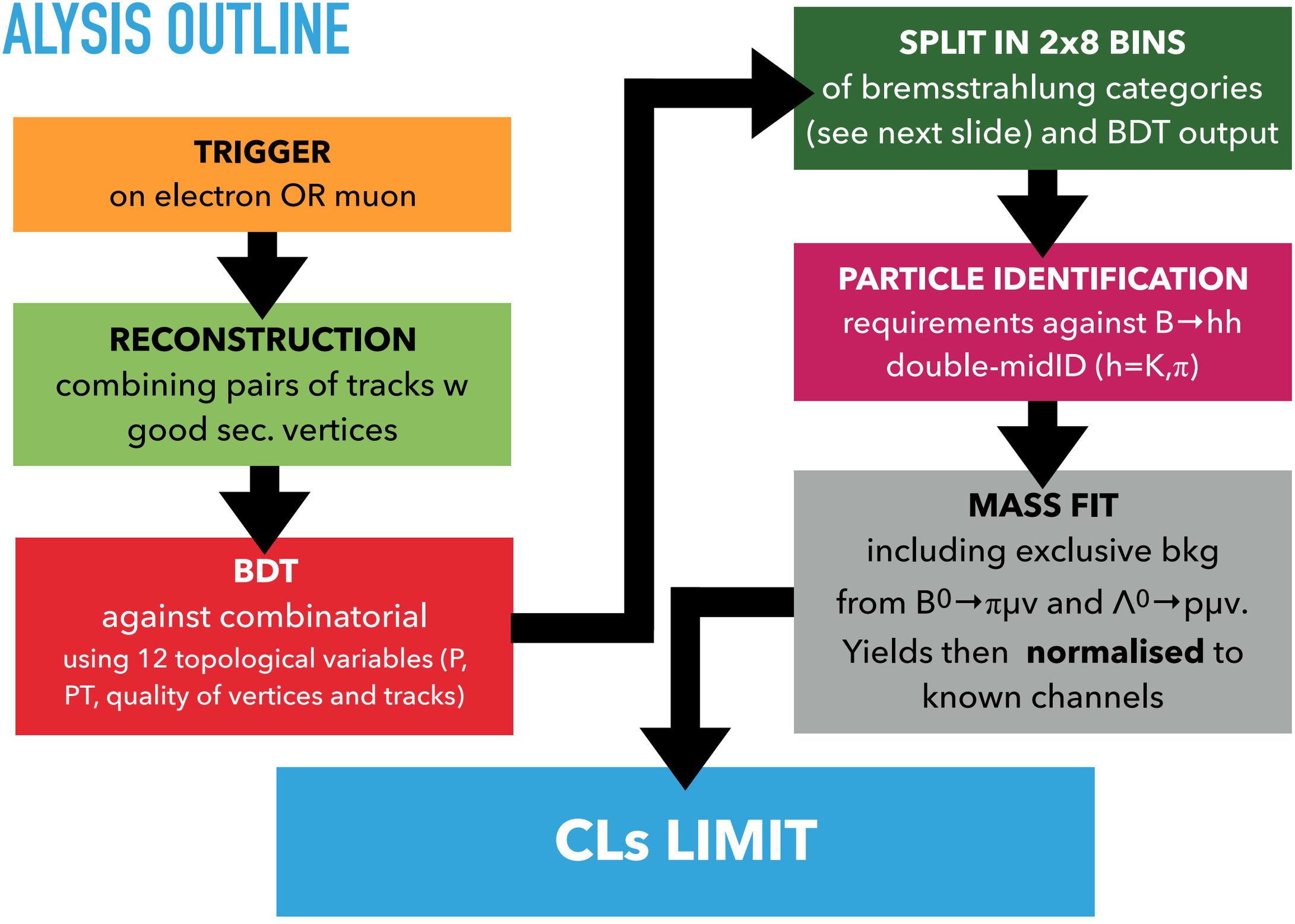
- Combinatorial: exponential pdf
- Exclusive backgrounds ($B^0 \to \pi\mu\nu$ and $\Lambda_b^0 \to p\mu\nu$): nonparametric functions from simulation, with total yields constrained to expected
- Simultaneous fit in 7x2 bins (most background-like BDT bin is excluded)
- No significant excess observed

Systematics mostly from PDF parametrisations, yields of the backgrounds, shape of BDT response, selection efficiencies.
Overall impact on the limit <5%

This is not an independent fit, just the sum of the last 3 bins.



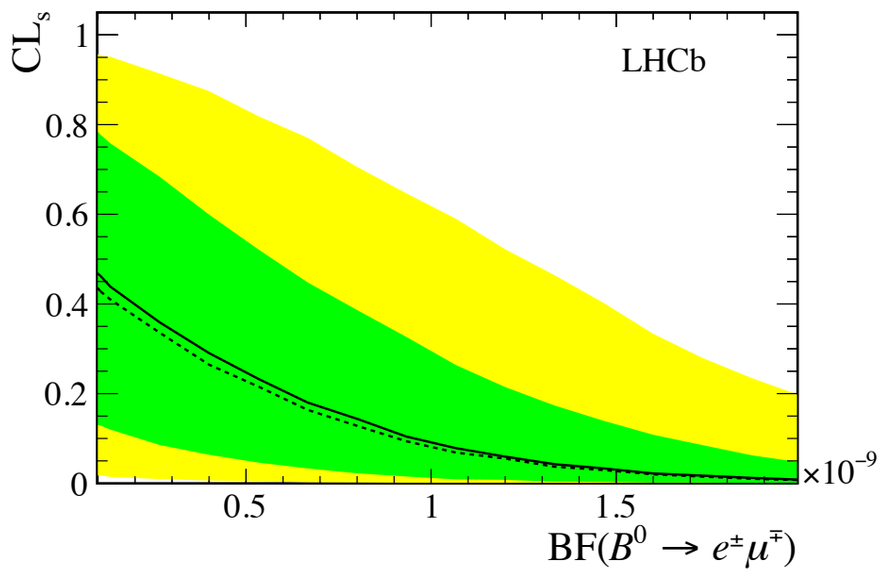
ANALYSIS OUTLINE

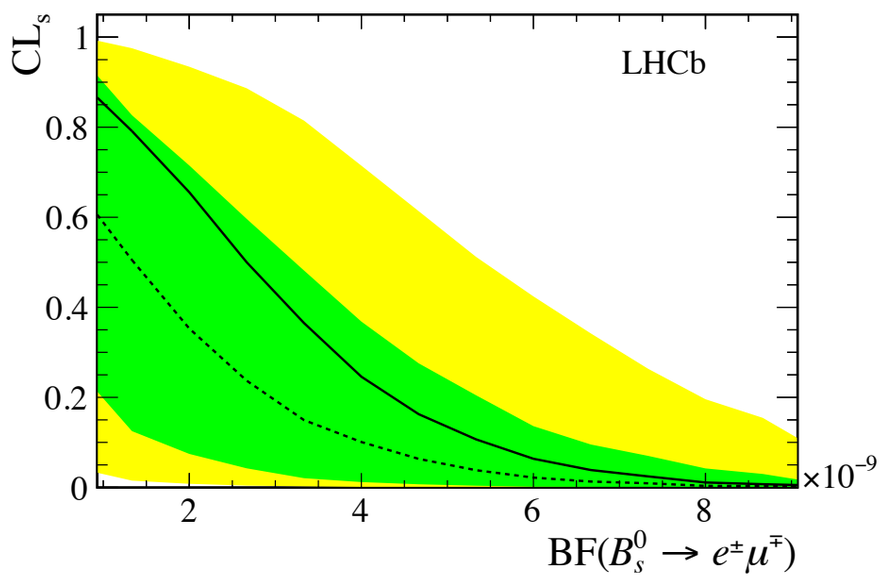


LIMIT

plots from JHEP03 (2018) 078]

- Upper limits with pseudo-experiments using CLs with Likelihood ratio
- Large lifetime difference between the two B_s mass eigenstates affects efficiencies. Limit in two assumptions: 100% heavy, 100% light
- Scans performed independently on B_s and B_d, fixing each time the other yield to the best fit





channel	expected	observed
$\mathcal{B}(B_s^0 \to e^\pm\mu^\mp)$	$5.0\,(3.9) \times 10^{-9}$	$6.3\,(5.4) \times 10^{-9}$
$\mathcal{B}(B^0 \to e^\pm\mu^\mp)$	$1.2\,(0.9) \times 10^{-9}$	$1.3\,(1.0) \times 10^{-9}$

*

* for heavy eigenstate. For light: $\mathcal{B}(B_s^0 \to e^\pm\mu^\mp) < 7.2\,(6.0) \times 10^{-9}$ at 95% (90%) CL.

CONCLUSIONS & OUTLOOK

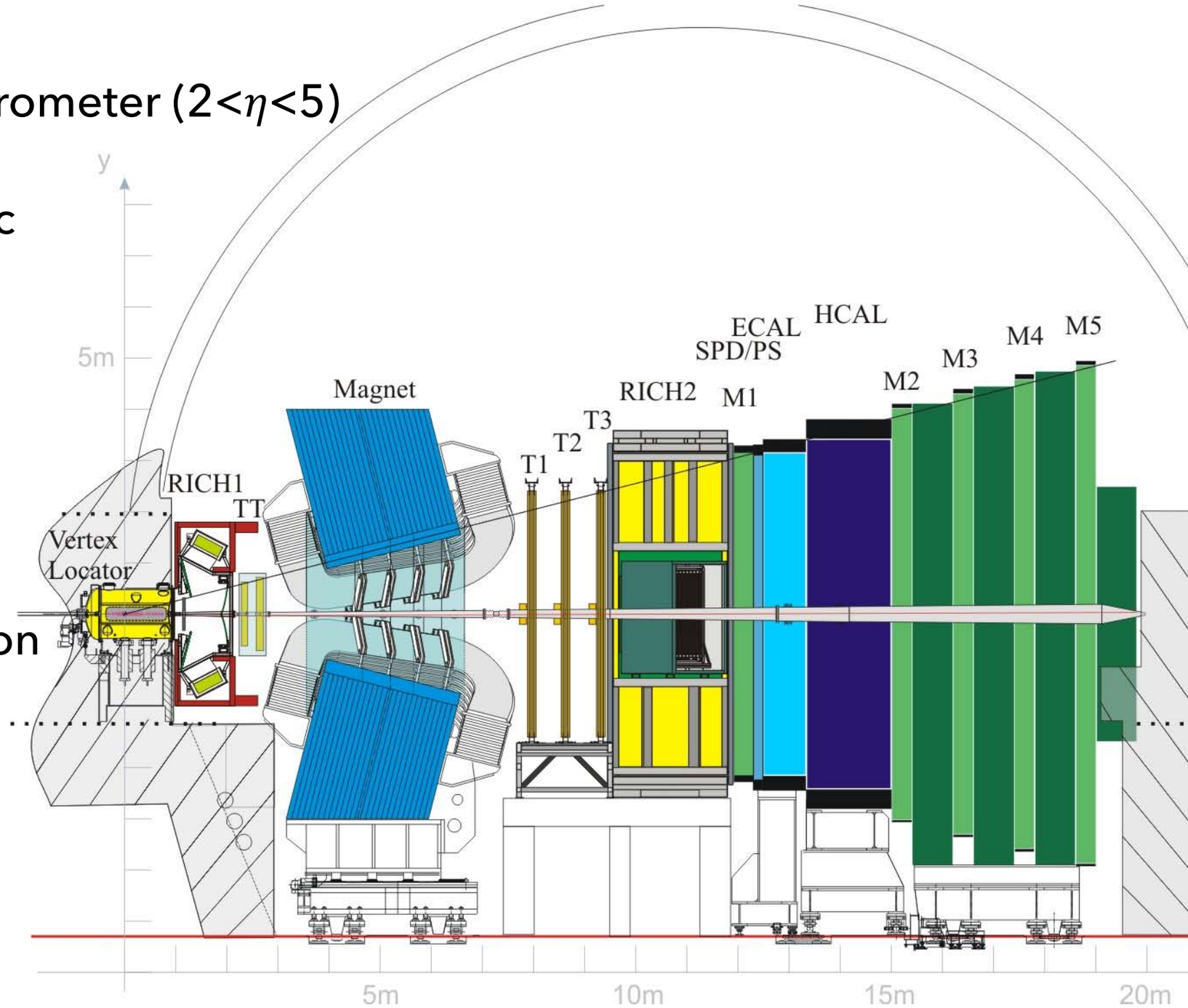
- The analysis presented here as recently been published [JHEP03 (2018) 078]
- No evidence of LFV
- New world's best UL on both $B_d \to e\mu$ and $B_s \to e\mu$
- LHC Run 2 data still to be analysed, could provide significantly stronger limits or open to new perspectives
- Even more potentially interesting data to come after the LHCb detector upgrade (Run3)!
- More LFV searches ongoing at LHCb, many results out soon!

The End

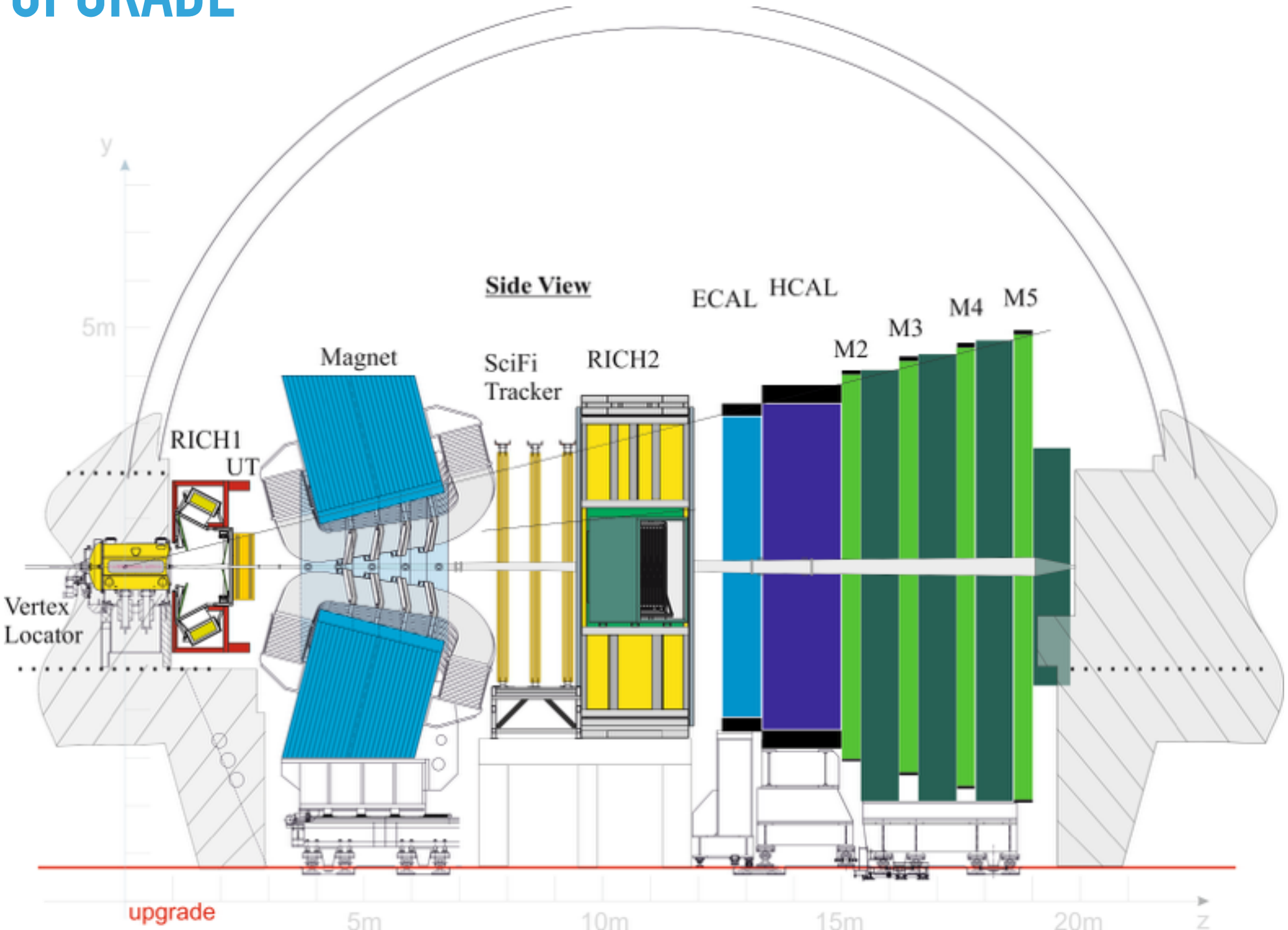
BACKUP

THE LHCB EXPERIMENT

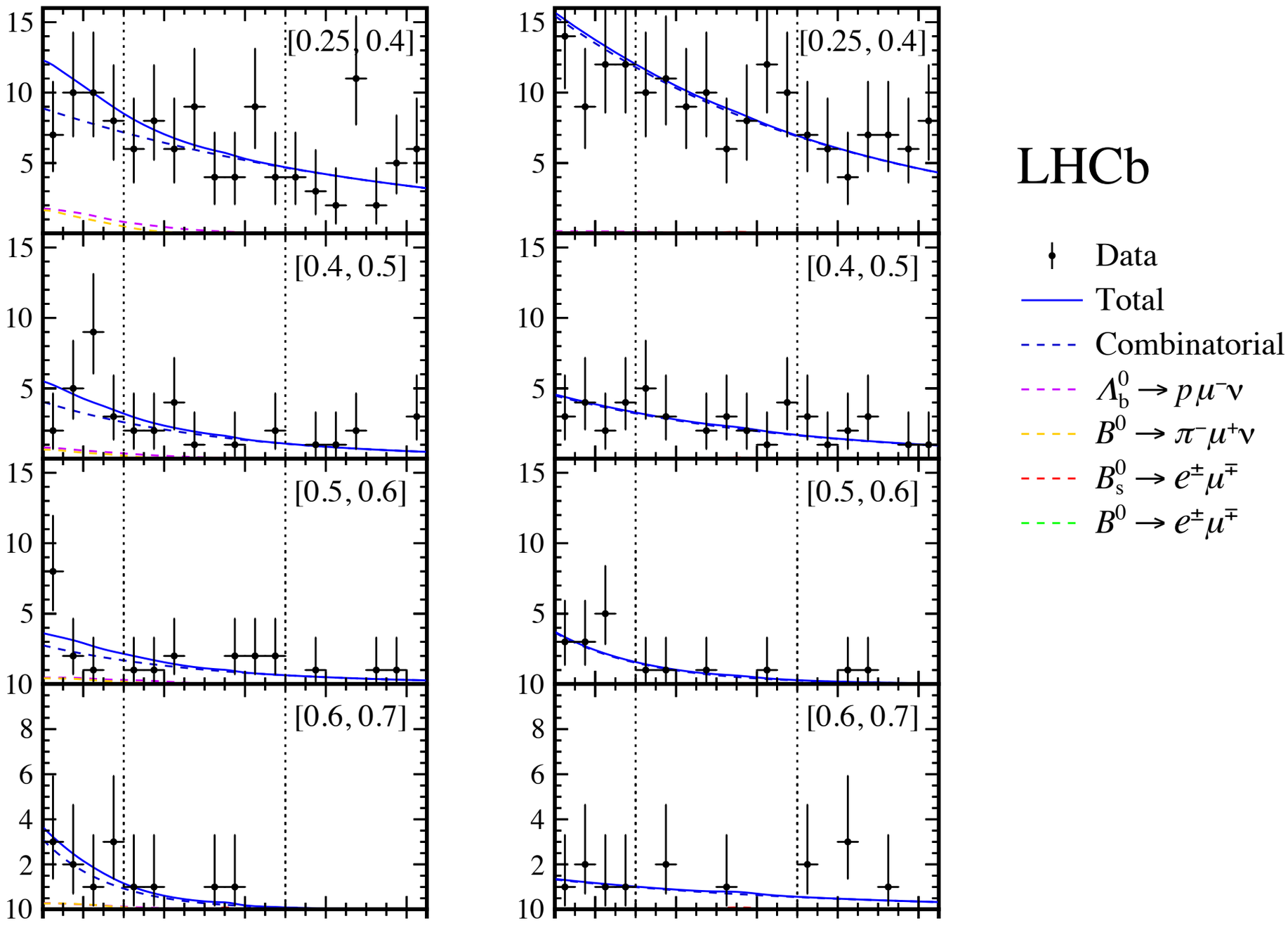
- Single-arm forward spectrometer ($2<\eta<5$)
- Designed to study b and c quarks physics
- High resolution on decay vertex of flying b hadrons and momenta
- Good particle identification



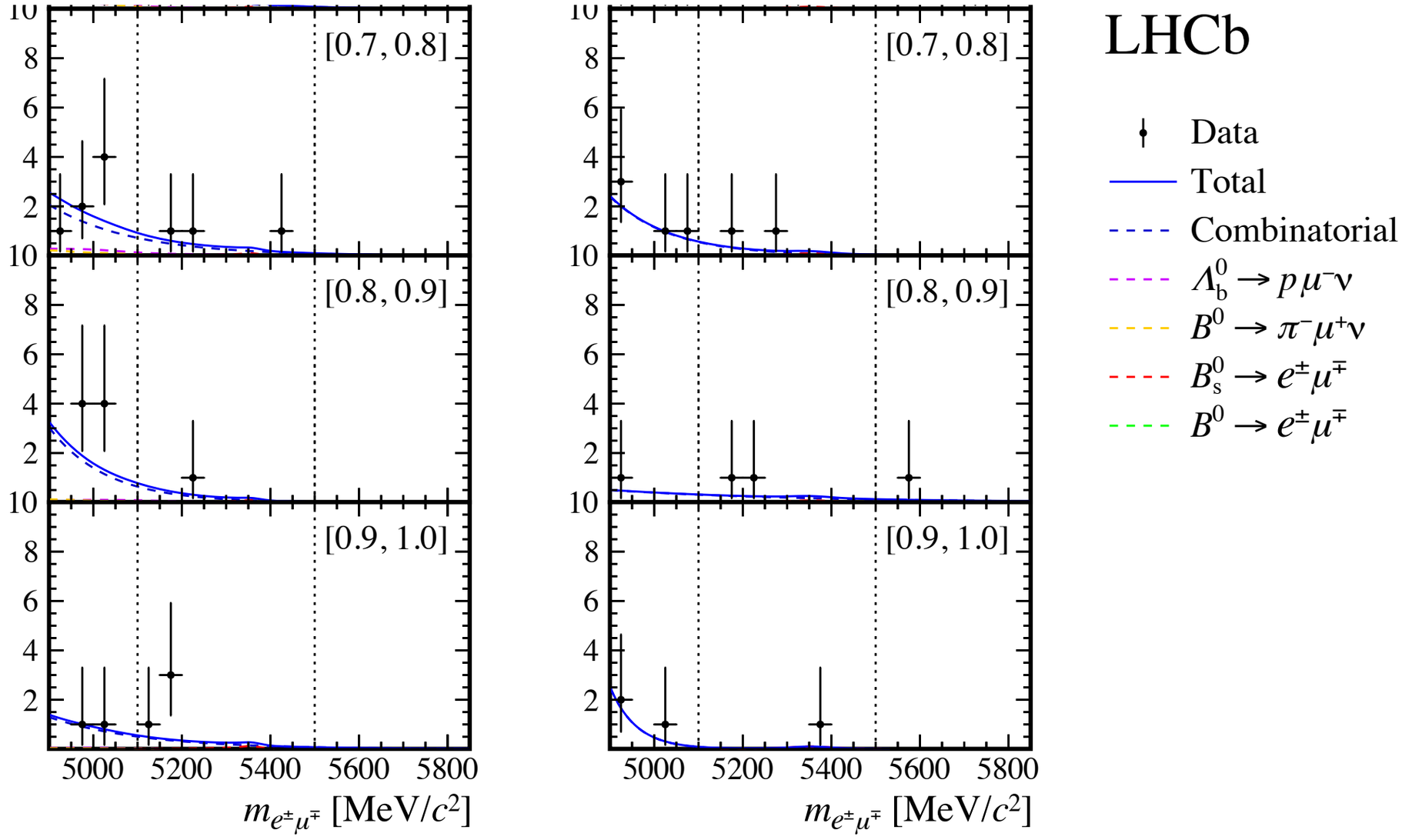
LHCB UPGRADE



MASS FITS

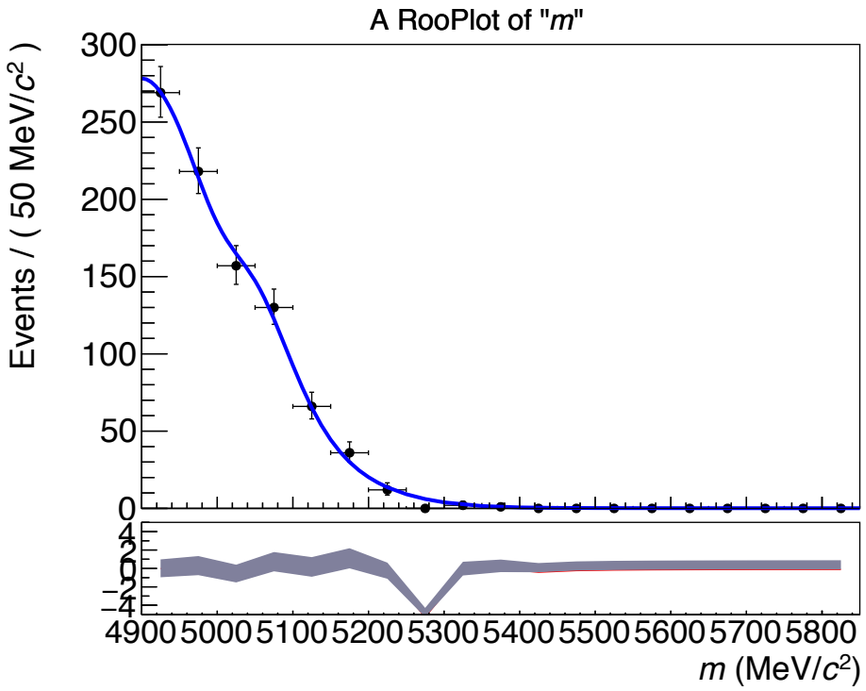

[0.25, 0.4]
[0.4, 0.5]
[0.5, 0.6]
[0.6, 0.7]
LHCb
Data
Total
Combinatorial
$\Lambda_b^0 \to p\mu^-\nu$
$B^0 \to \pi^-\mu^+\nu$
$B_s^0 \to e^\pm\mu^\mp$
$B^0 \to e^\pm\mu^\mp$

MASS FITS (2)

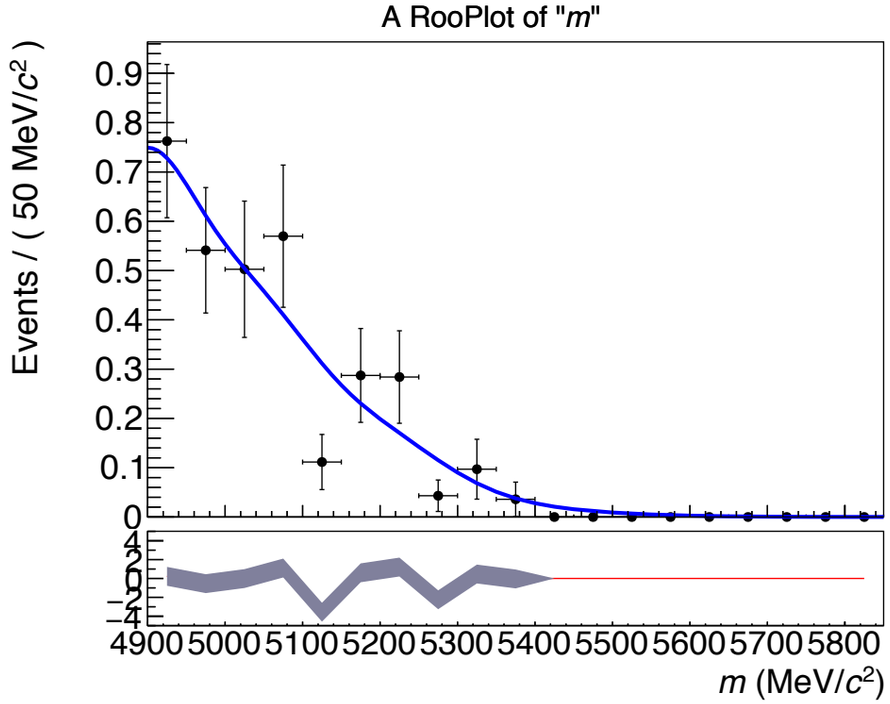

[0.7, 0.8]
[0.8, 0.9]
[0.9, 1.0]
$m_{e^\pm\mu^\mp}$ [MeV/c^2]
LHCb
Data
Total
Combinatorial
$\Lambda_b^0 \to p\mu^-\nu$
$B^0 \to \pi^-\mu^+\nu$
$B_s^0 \to e^\pm\mu^\mp$
$B^0 \to e^\pm\mu^\mp$

EXCLUSIVE BACKGROUNDS

$B^0 \to \pi\mu\nu$



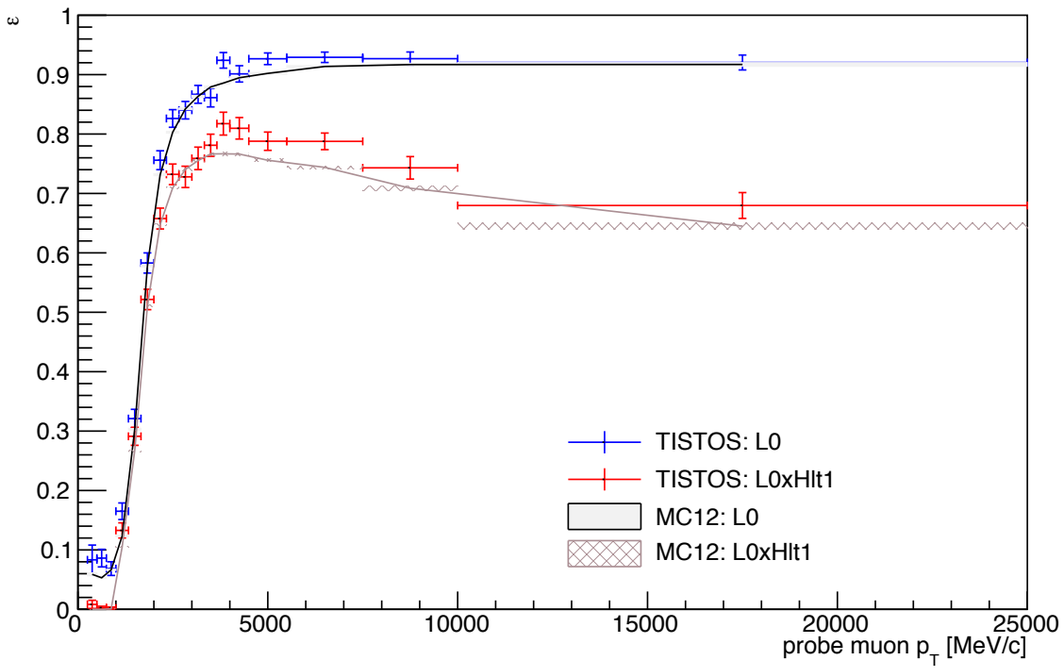
$\Lambda_b^0 \to p\mu\nu$

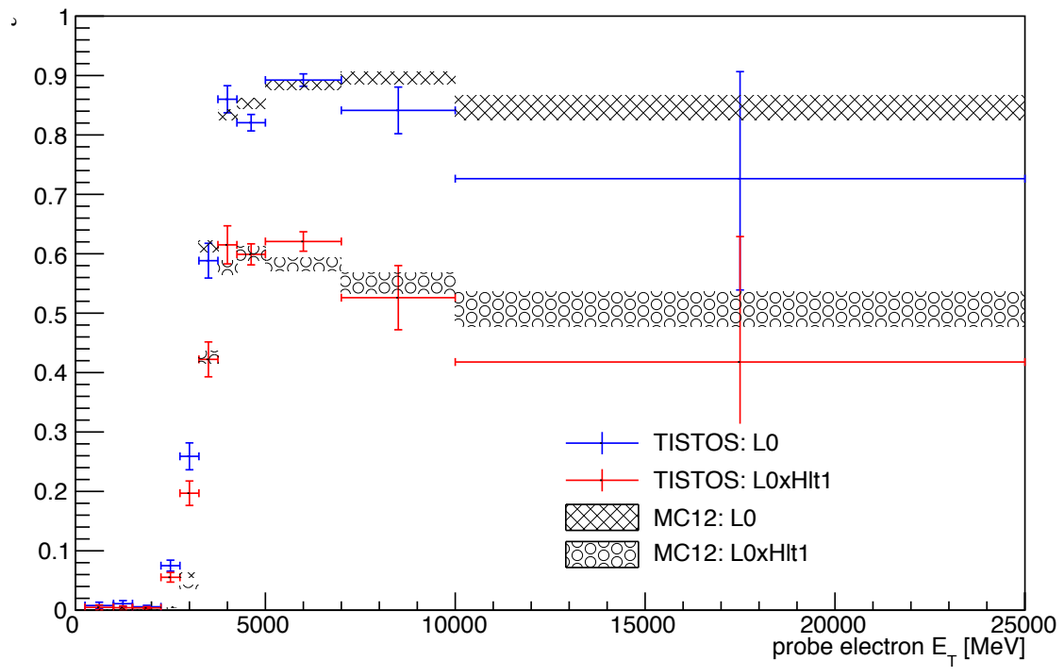


- Shapes shown are BDT bin 2 $[0.25, 0.4]$, without brem recovery

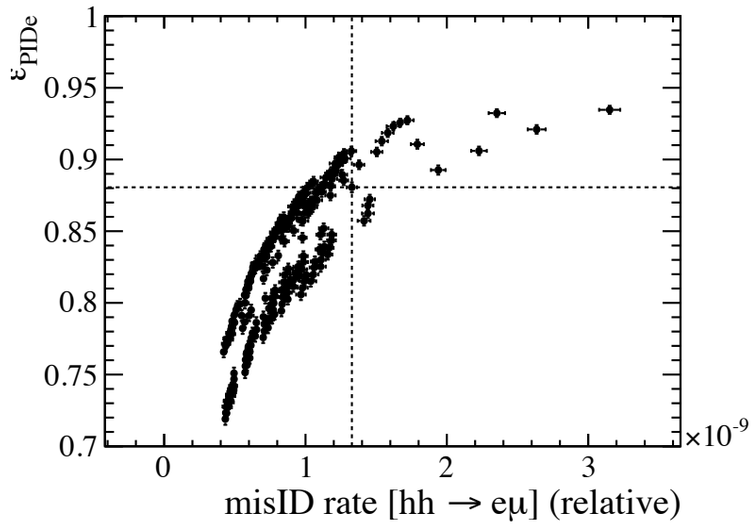
TRIGGER STRATEGY AND EFFICIENCIES

$B^0_{d,s} \to e^{\pm}\mu^{\mp}$ (HasBremAdded == 0)	$0.726 \pm 0.002\,(\mathrm{stat}) \pm 0.015\,(\mathrm{syst})$
$B^0_{d,s} \to e^{\pm}\mu^{\mp}$ (HasBremAdded == 1)	$0.621 \pm 0.002\,(\mathrm{stat}) \pm 0.015\,(\mathrm{syst})$
$B^+ \to J/\psi(\mu^+\mu^-)K^+$	0.758 ± 0.006
$B^0 \to K^+\pi^-$	0.212 ± 0.002





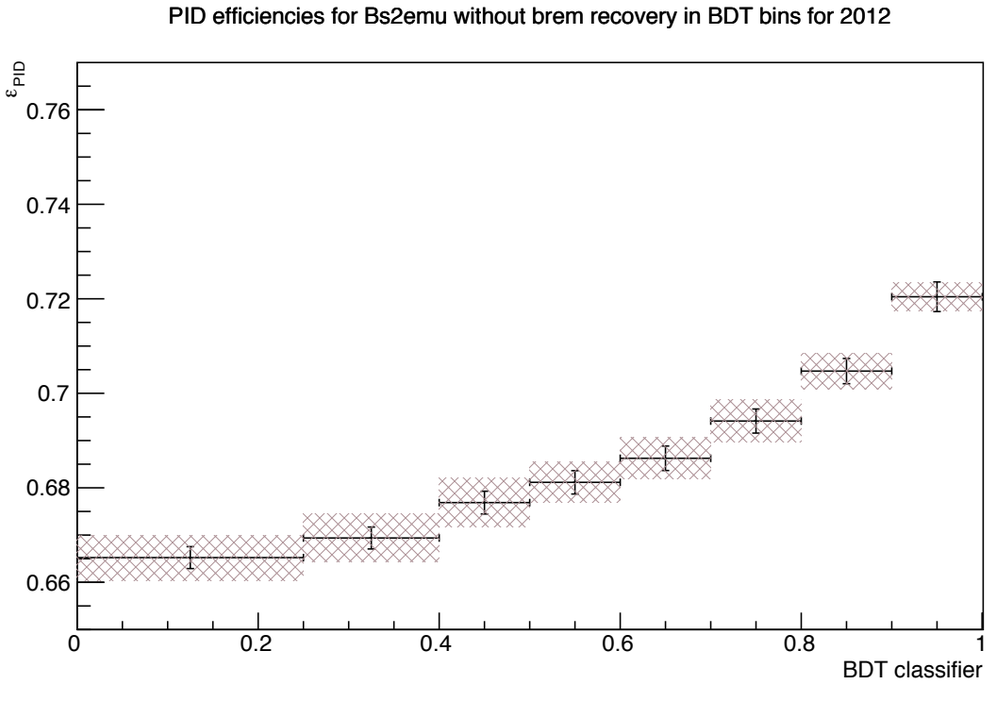
PID STRATEGY AND EFFICIENCIES

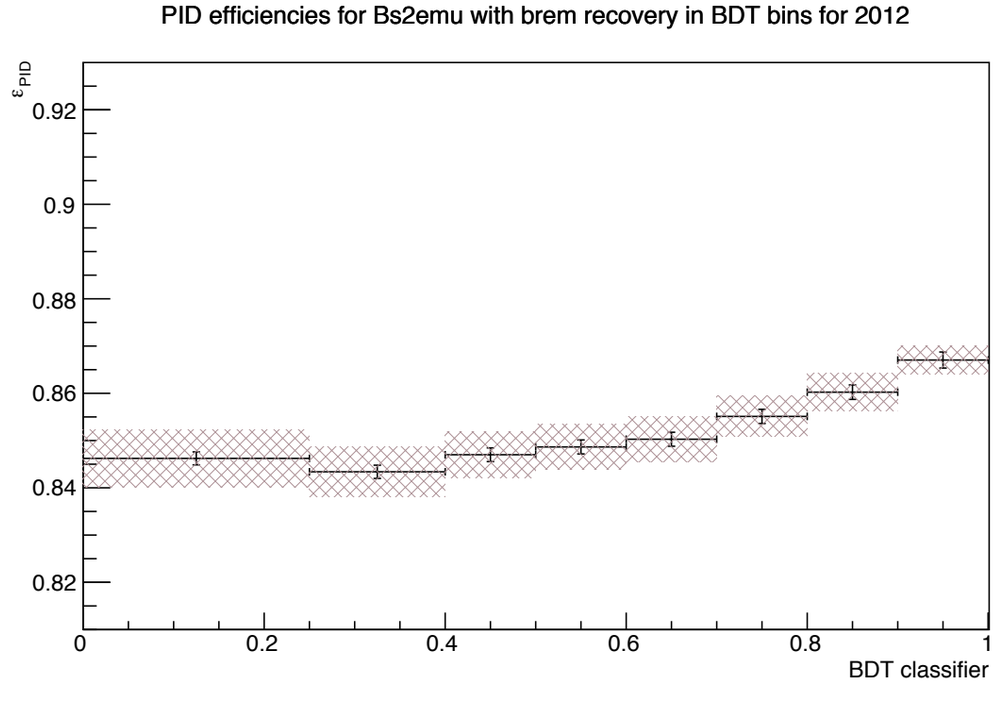


- Optimisatised with respect to $B^0_{(s)} \to h^+h^-$ double misID, with figure of merit (FOM):

$$\text{FOM} = \sum_{B^0_{d,s}\to \text{hh}} \frac{f_{d,s}}{f_d} \mathcal{B}(B^0_{d,s} \to \text{hh}) \epsilon^{\text{PID}}_{\text{hh}\to e\mu}$$

- Same signal PID efficiency (wrt old LHCb analysis) ($\simeq 80\%$), but lower misID rate





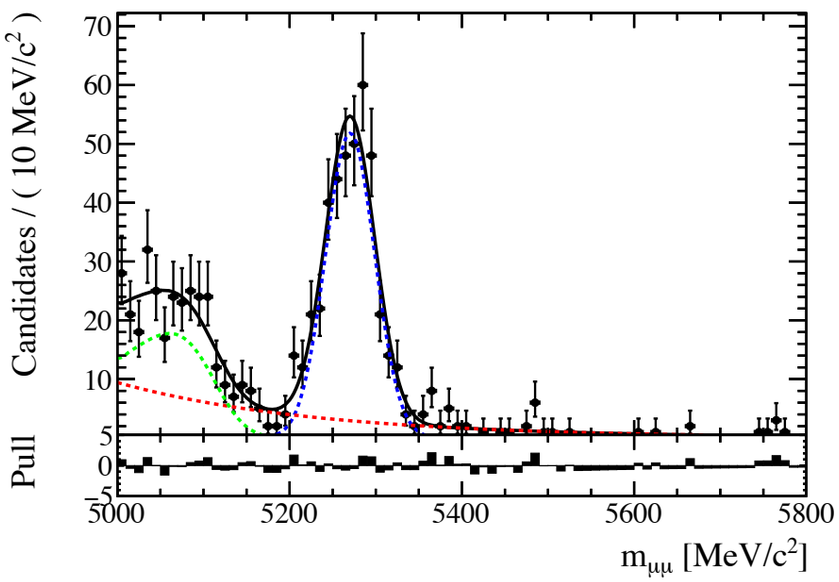
PEAKING BACKGROUNDS - B→HH

Main method

- Estimation of expected amount of $B^0_{(s)} \to h^+h^-$ is determined using $B^0_{(s)} \to h^+h^-$ MC weighted with `PIDCalib` efficiencies
- Normalise with respect to $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$
- Expected result shown here in full mass, BDT and `HasBremAdded` range and is negligible

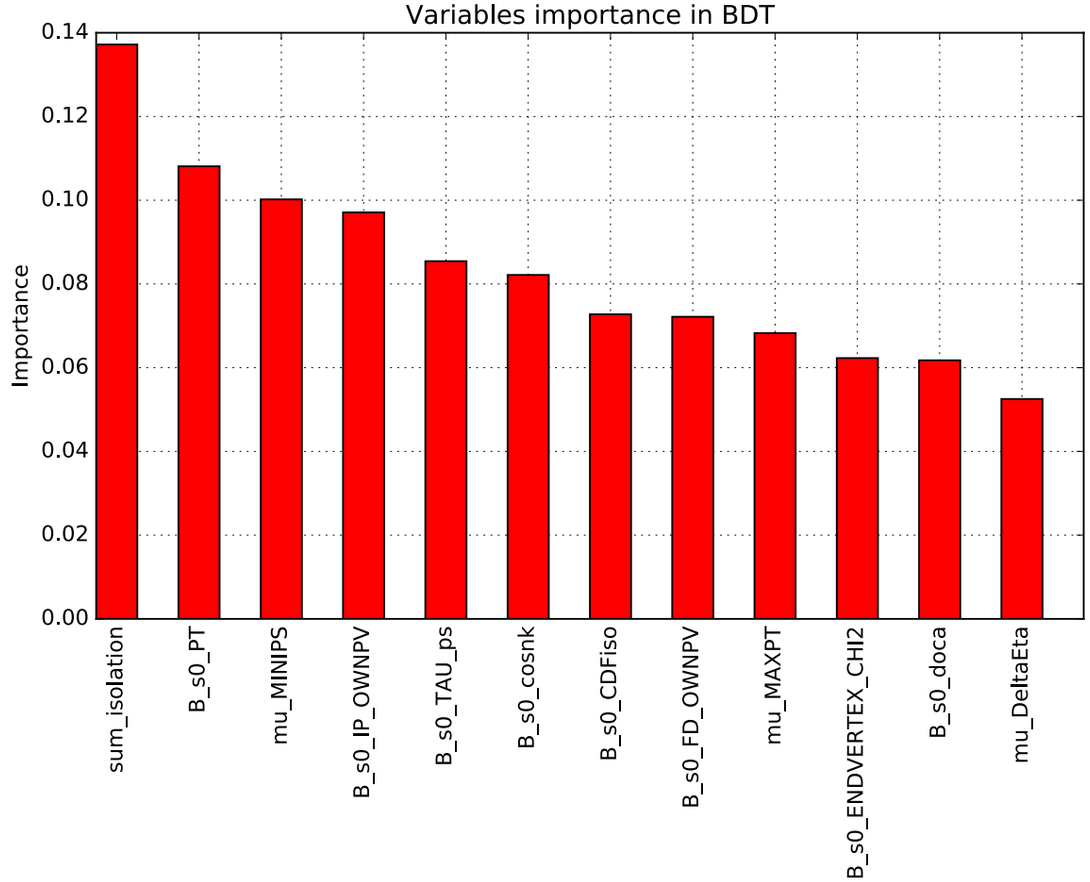
Cross-check

- Single misID determined in $B^0_{(s)} \to h^+h^-$ data
- Electron PID on one of the tracks and hadron PID on other
- Additional misID efficiency with main method
- Result compatible



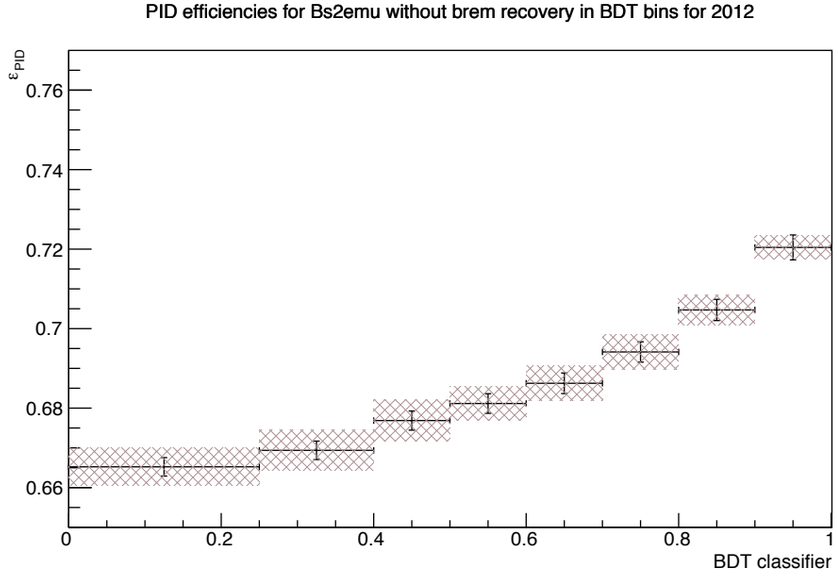
MULTIVARIATE CLASSIFIER

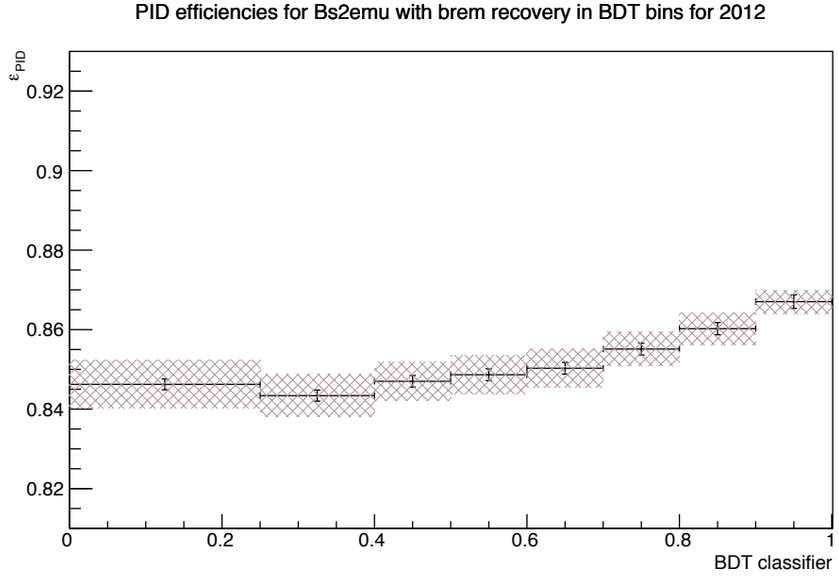
- Boosted Decision Tree (BDT) from TMVA
- Purpose: separate two-body B decay without any PID assumptions from combinatorial background
- 12 input variables, containing B kinematics and topology, vertrex quality and track isolation



EFFICIENCIES – PID

- Determined using `PIDCalib`
- Reweighting to signal MC in bins of BDT and `HasBremAdded` with track p_T, η (and nSPDHits for electron to data nSPDHits distribution)
- $B^0 \to K^+\pi^-$ uses p and η binnings

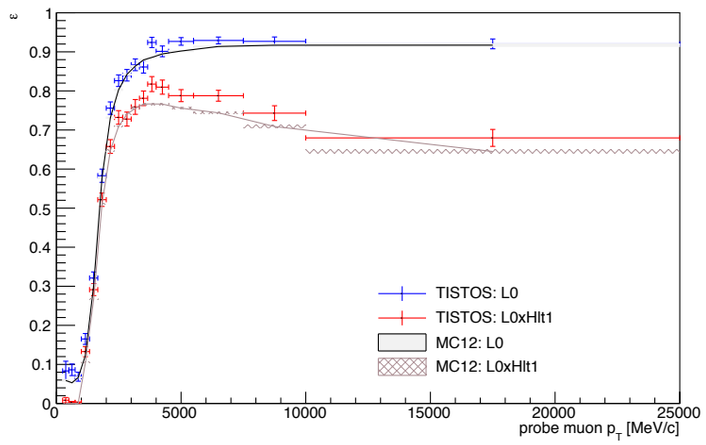


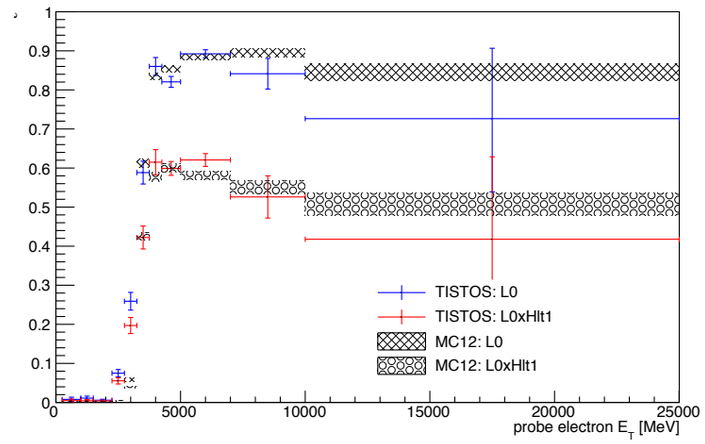


	Run 1
$B^+ \to J/\psi\ (\to\mu^+\mu^-)K^+$	$0.9781 \pm 0.0002\,(\mathrm{stat})$
$B^0 \to K^+\pi^-$	$0.3850 \pm 0.0001\,(\mathrm{stat})$

EFFICIENCIES – TRIGGER

- TISTOS for L0xHlt1
- Using TIS sample of
- Reweight efficiencies to IP and E_T (for electron) or p_T (for muon) to account for biases
- Hlt2 efficiencies from MC





- Systematics from TISTOS binning and MC reweighted for B p_T and nSPDHits

$B^0_{d,s} \to e^\pm \mu^\mp$ (HasBremAdded == 0)	$0.726 \pm 0.002\,(\mathrm{stat}) \pm 0.015\,(\mathrm{syst})$
$B^0_{d,s} \to e^\pm \mu^\mp$ (HasBremAdded == 1)	$0.621 \pm 0.002\,(\mathrm{stat}) \pm 0.015\,(\mathrm{syst})$
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