Experimental prospects for V_{ud}, V_{us}, V_{cd}, V_{cs} and (semi-)leptonic D decays at LHCb

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On behalf of the LHCb Collaboration

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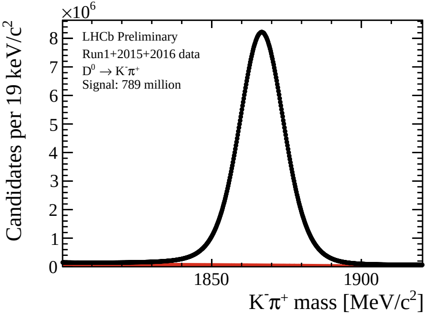
LHCb

Int. J. Mod. Phys. A 30, 1530022 (2015)

- LHCb acceptance: $2 < \eta < 5$
- Reconstructed $\mathcal{O}(2\text{ billion})$ charm hadron decays in 2011-2016
- With more on the way!



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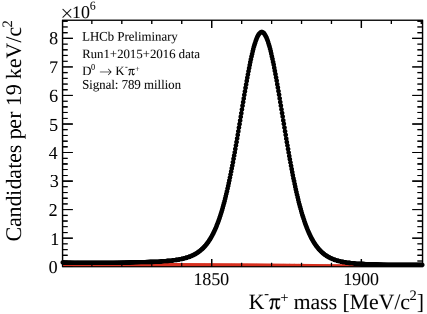

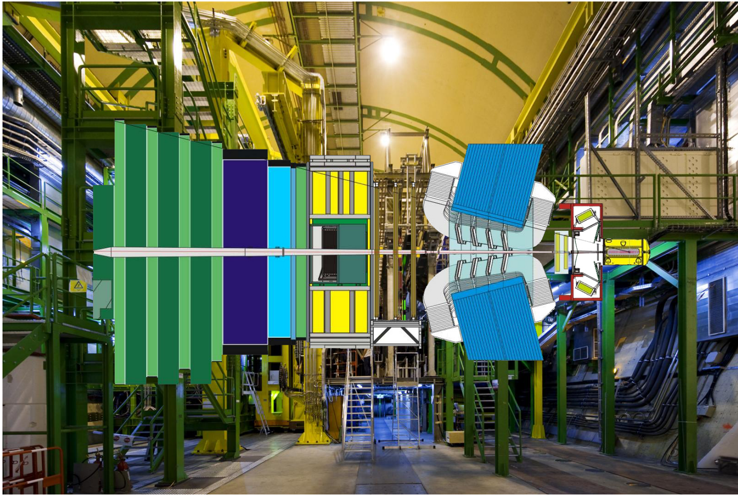

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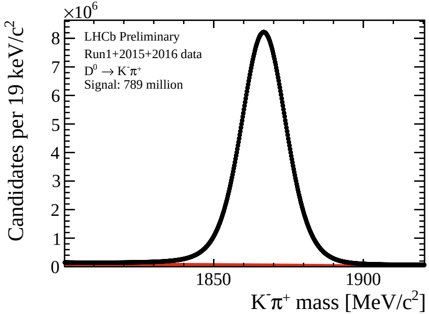

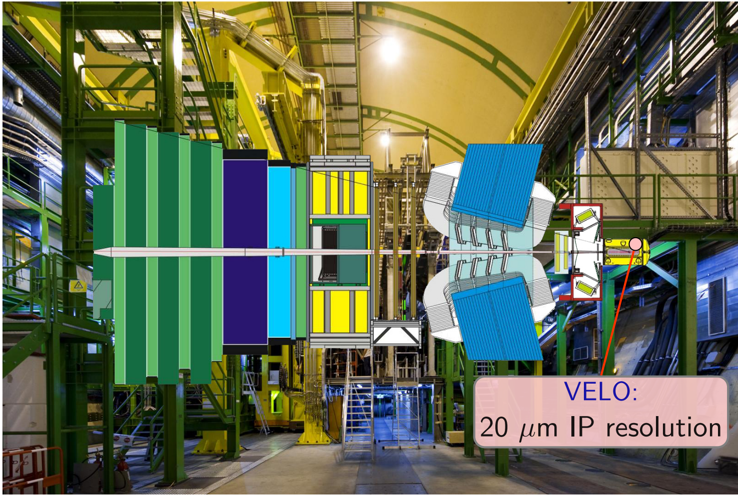

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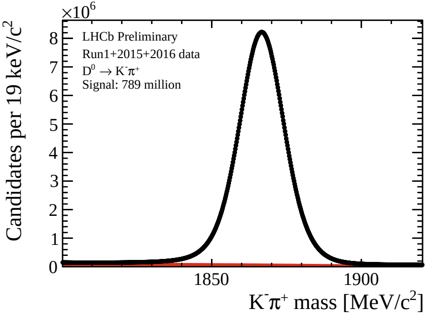

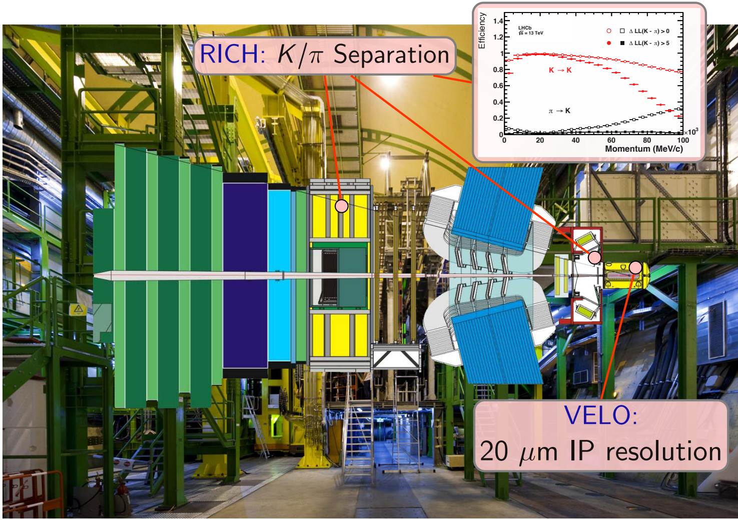

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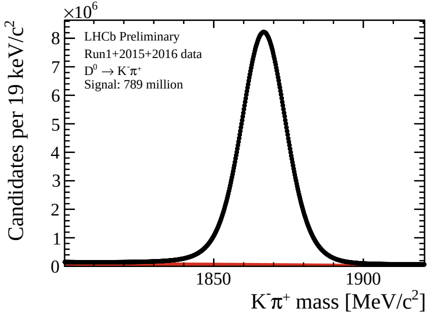

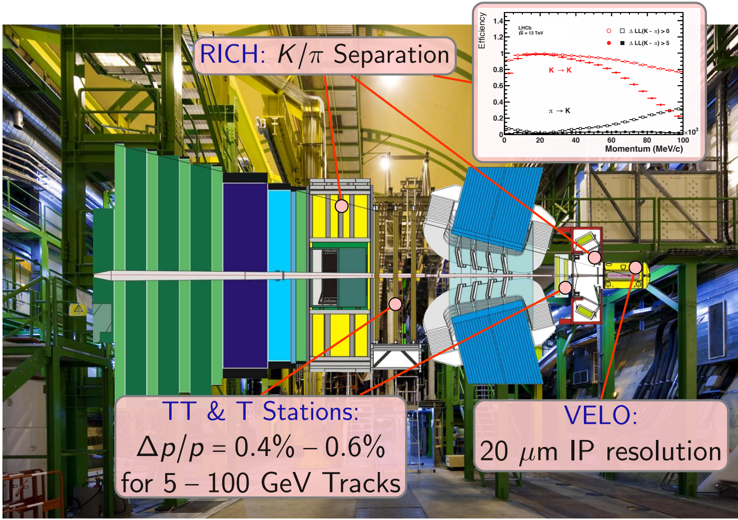

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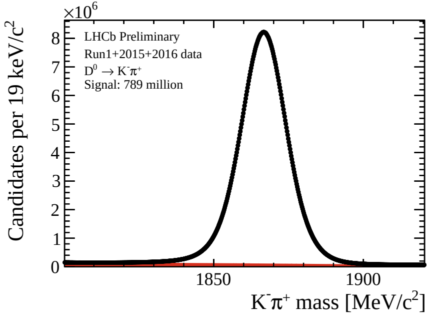

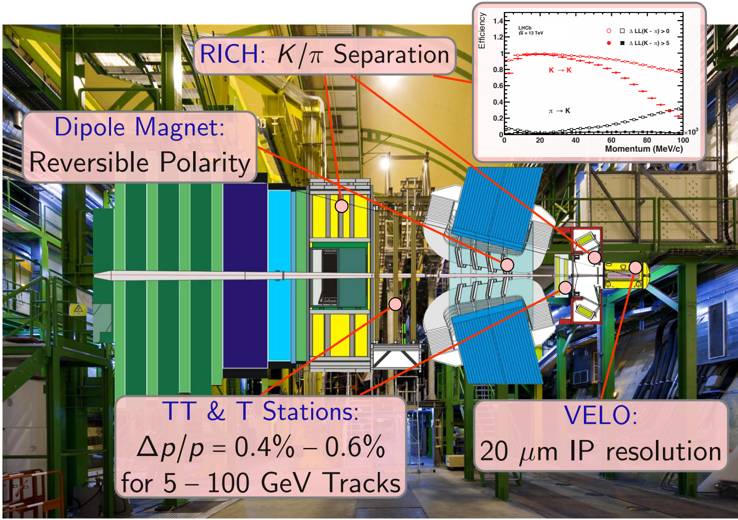

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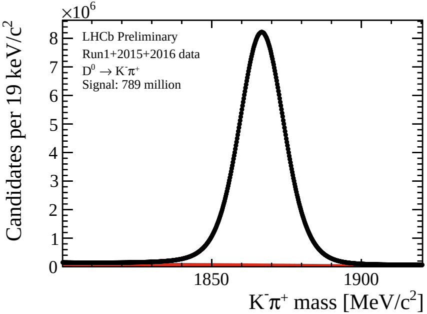

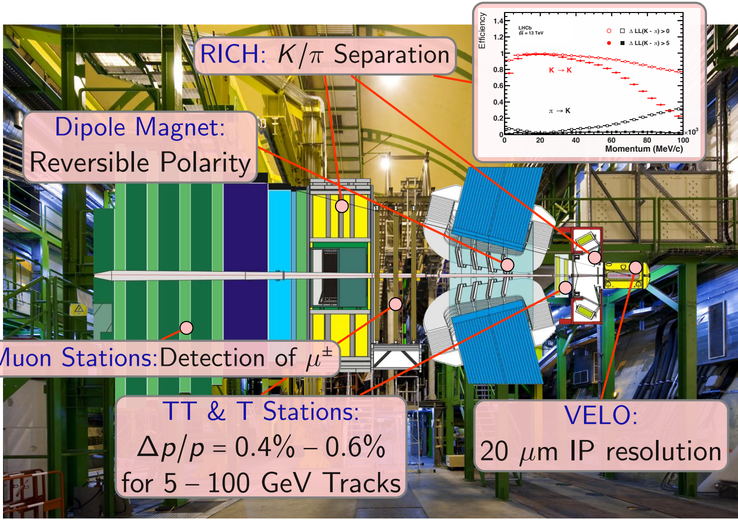

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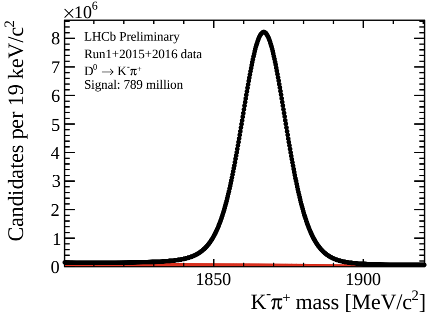

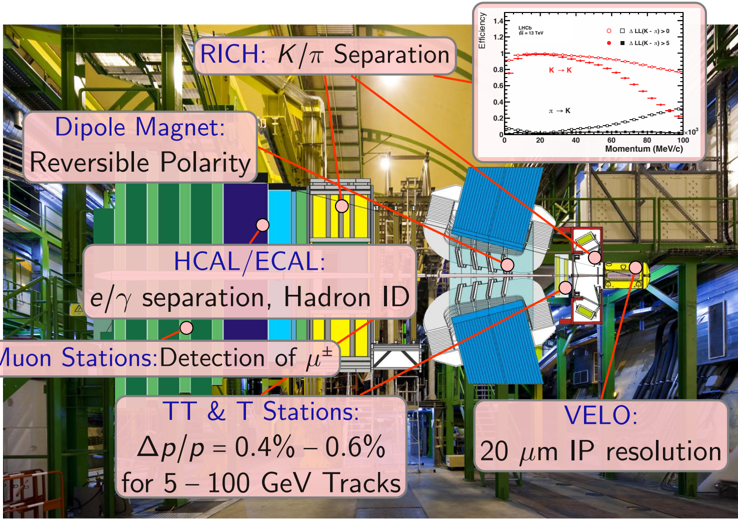

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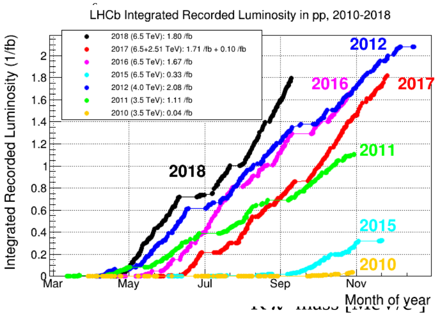
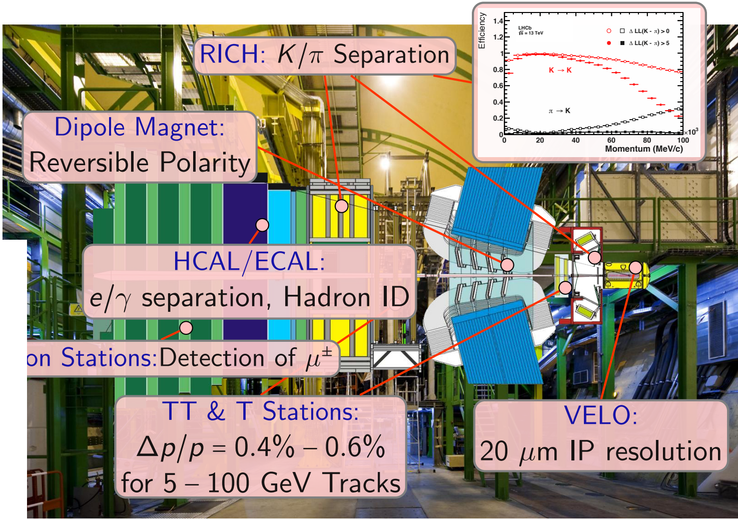
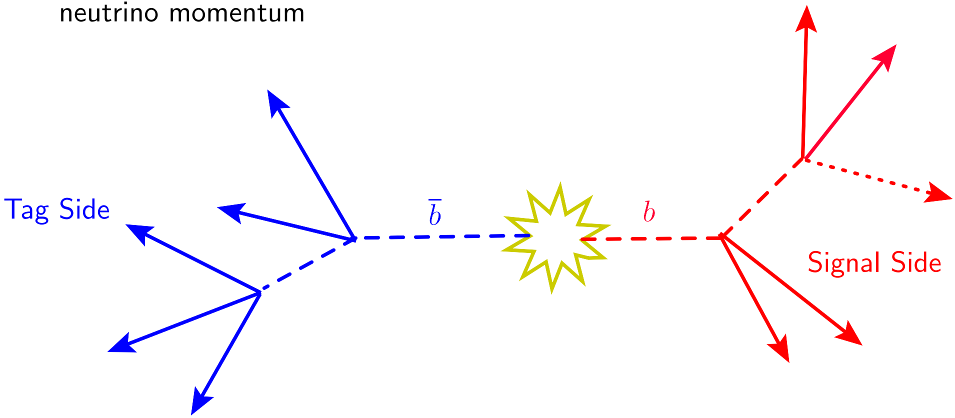




Challenges of Hadron Collider Environment: Neutrino Reconstruction

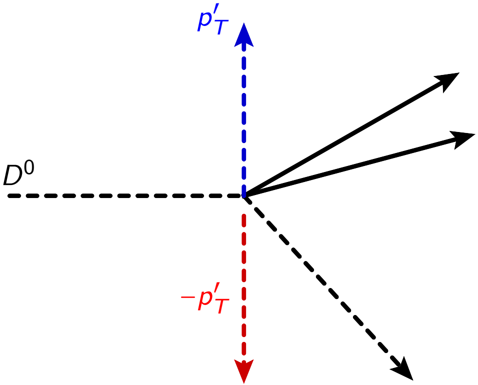
- Challenge: Only partially reconstructed final state
- For e^+e^- machines, use the other side of the event and beam energy to constrain neutrino momentum



- Not possible at a hadron collider

Challenges of a Hadron Environment: Neutrino Reconstruction

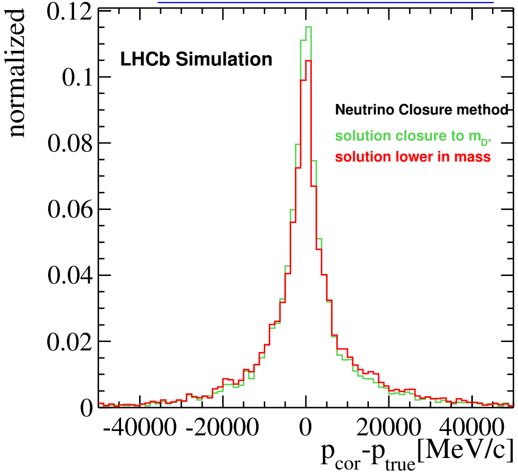
- We would like to solve for the missing neutrino momentum to
  - Be able to reconstruct a narrow mass peak
  - Accurately reproduce q^2
- Can reconstruct neutrino momentum without any additional information up to two-fold ambiguity



- Given the origin and end vertices of the D^0, neutrino momentum perpendicular to flight direction is known
- Direction of $p_{||}(\nu)$ has quadratic ambiguity

- How to get the right answer?
  - Choose a solution with some requirement

From D. Mitzel Master Thesis



Methods of Reconstruction

- How to get the right answer?
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  - k factor method $p(K\ell\nu) = \frac{p(K\ell)}{k(m(K\ell))}$

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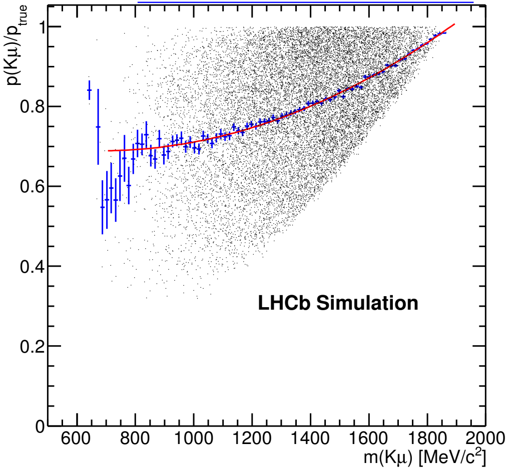

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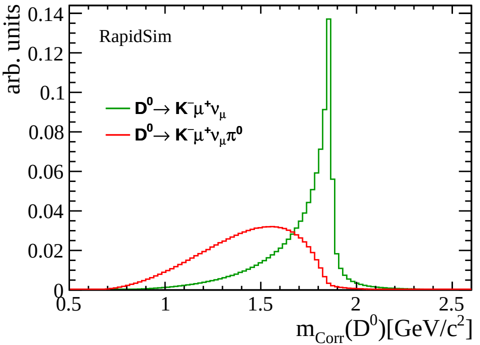
$$m_{corrected} = \sqrt{p_T'^2 + m^2(K\ell)} + |p_T'|$$

Computer Physics Communications 214C (2017) pp. 239-246



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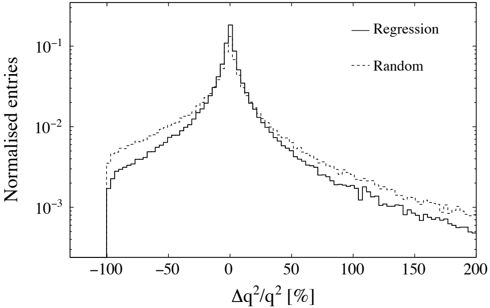
  - Use Multivariate Regression (JHEP(2017) 2017:21)

$B_s^0 \to K\mu\nu$, from JHEP(2017) 2017:21



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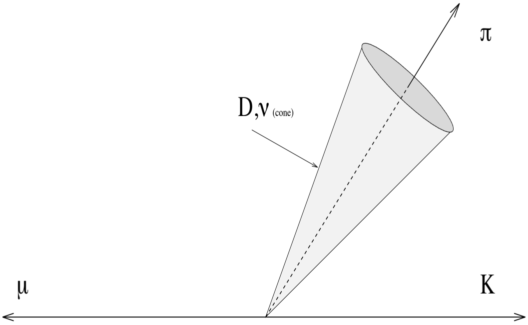
  - Use Multivariate Regression (JHEP(2017) 2017:21)
  - Use two external mass constraints: $D^{*+} \rightarrow D^0\pi_s^+ \rightarrow$ cone closure
  - Can work for any excited decay, e.g. $\overline{B}_{s2}^{*0} \rightarrow B^- K^+, B^- \rightarrow D^{(**)^0}\mu\nu$

from Johns, FERMILAB-THESIS-1995-05,UMI-96-02371



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- Caveats
  - Can have failures due to detector resolution effects
  - Missing massive particles can shift distributions → discrimination power

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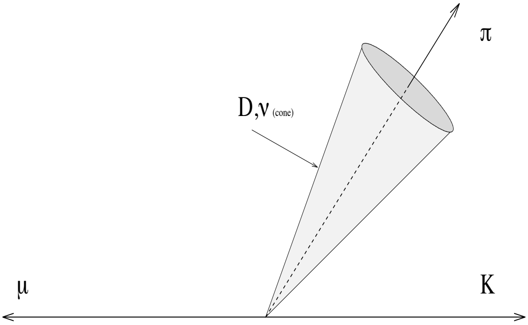

CKM Elements: The "Usual" Ways

- Taken largely from PDG Review of CKM Matrix

V_{ud}

- Nuclear β decay
- Neutron β decay
- $\pi^+ \to \pi^0 e^+ \nu_e$ ($\mathcal{B} \simeq 10^{-8}$)

V_{us}

- $K_L^0 \to \pi^- e^+ \nu_e$
- $K_L^0 \to \pi^- \mu^+ \nu_\mu$
- $K^+ \to \pi^0 e^+ \nu_e$
- $K_s^0 \to \pi^+ e \nu_e$
- $\frac{K^+ \to \mu^+ \nu_\mu \gamma}{\pi^+ \to \mu^+ \nu_\mu \gamma}$ assuming $|V_{ud}|$, limited by f_K/f_π

V_{cd}

- $H_c \to H_d^- \ell^+ \nu_\ell$
- $D^+ \to \ell^+ \nu_\ell$
- Neutrino Scattering

V_{cs}

- $H_c \to H_s^- \ell^+ \nu_\ell$
- $D_s^+ \to \ell^+ \nu_\ell$
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The Not-So Usual Ways

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- $\Lambda \to p\mu\nu$
- $K_s^0 \to \pi\mu\nu$

- Taps into s-hadron physics program possible at LHCb
- As-of yet unobserved $K_s^0 \to \pi\mu\nu$ reachable 1808.03477
- Interesting in LNU searches alone

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- $B_c^+ \to B^0\pi^+$
- $B_c^+ \to B^0\mu^+\nu_\mu$

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- New explorations into the B_c physics program of LHCb LHCb-PUB-2018-009
- Limited currently by hadronization fractions, statistics
- Possible unique measurement using ratio with SL D decays?

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Something to watch for in the future!

$|V_{cd}|/|V_{cs}|$

- Use BFs to access FF×CKM elements

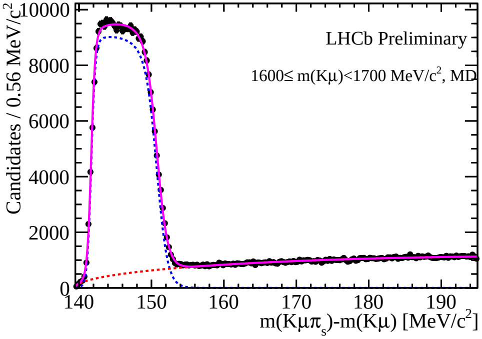
$$\frac{d\mathcal{B}(D^0 \to \pi^-\mu^+\nu)/dq^2}{d\mathcal{B}(D^0 \to K^-\mu^+\nu)/dq^2} \propto \frac{|V_{cd}|^2}{|V_{cs}|^2}\frac{|f^{D\to\pi}(q^2)|^2}{|f^{D\to K}(q^2)|^2}$$

- Analogous to measurement of $|V_{ub}|$ from $\Lambda_b \to p\mu\nu$ (Nature Physics 10 (2015) 1038)
- Experimental advantages:
  - Use $D^{*+} \to D^0\pi_s^+ \to$ gives access to Δm for background rejection, q^2 constraint
  - μ, π_s detection efficiencies cancel in ratio
  - K, π detection efficiencies known well from CP measurements
  - Use $M_{corr}, \Delta m_{visible}$ to reduce multibody/neutral backgrounds

$|V_{cd}|/|V_{cs}|$

- a_{sl}^s(PRL 117, 061803 (2016)), used $D^* \to D^0\pi_s$, $D^0 \to K\mu\nu$ to cross check detection efficiencies.
- Triggering on the μ at L0, and further on the K candidate gives $\sim 5M$ signal candidates
- This study was done with Run I data (3 fb^{-1})
- Increase in cross section + $\sqrt{\mathcal{L}}$ scaling gives roughly factor of 3 more stats → 15M
- Using $\mathcal{B}(D^0 \to \pi\mu\nu) \simeq \frac{1}{15}\mathcal{B}(D^0 \to K^-\mu^+\nu)$, expect $\simeq$ 1M $D \to \pi^-\mu^+\nu$
- Expect relative error on ratio to be 0.1% statistical
- Current relative error on $f_+^{D\to\pi}(0)$ is 4%, 2.5% for $f_+^{D\to K}(0)$
- Will be limited by form factor calculation from lattice

PoS CKM2016 (2017) 025

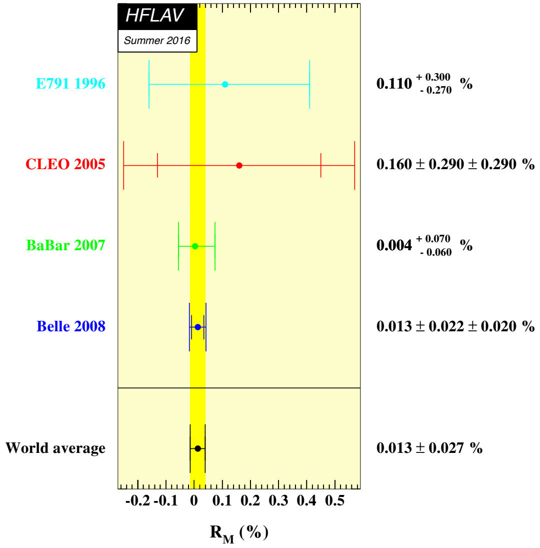


CPV/Mixing from $D^0 \to K\mu\nu$

- Similar to $D^0 \to K\pi$ mixing and CPV, look at $\frac{\mathcal{B}(D^0 \to K^+\mu^-\nu_\mu)}{\mathcal{B}(D^0 \to K^-\mu^+\nu_\mu)}$
- RS decay dominated by CF decay
- WS decay occurs only through mixing

$$\frac{\mathcal{P}(D^0 \to K^+\mu^-\nu_\mu)}{\mathcal{P}(D^0 \to K^-\mu^+\nu_\mu)} \propto \frac{x^2+y^2}{4}\left(\frac{t}{\tau}\right)^2 \to \frac{x^2+y^2}{2}$$

- With the current values from HFLAV, and using 5M RS decays, expect roughly 700 WS decays (From D. Mitzel Master Thesis)
- Estimated statistical precision on R_M using pseudoexperiments $\sim 0.01\%$



Lepton Non-Universality in Charm

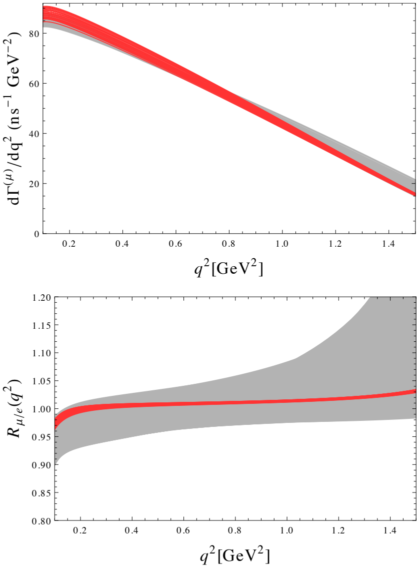
- In the SM, the only difference between e,μ and τ are their masses
- See differences in the b sector
- Are there any other places we can look? How about in the D sector?

$$R^{\mu/e} = \frac{\mathcal{B}(D^0 \to h^- \mu^+ \nu_\mu)}{\mathcal{B}(D^0 \to h^- e^+ \nu_e)}$$

$$h = K, \pi, K^* ...$$

- Why? Differences in b vs c vs s could point to possible flavor hierarchy
- Measure vs q^2 to probe possible new physics effects

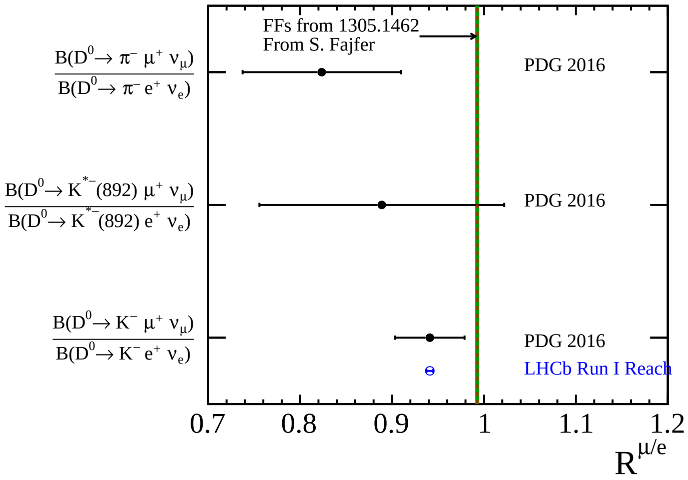
PhysRevD.91.094009



Status

- Since the last time I presented this plot, a lot of progress has been made!

adapted from PoS CKM2016 (2017) 025



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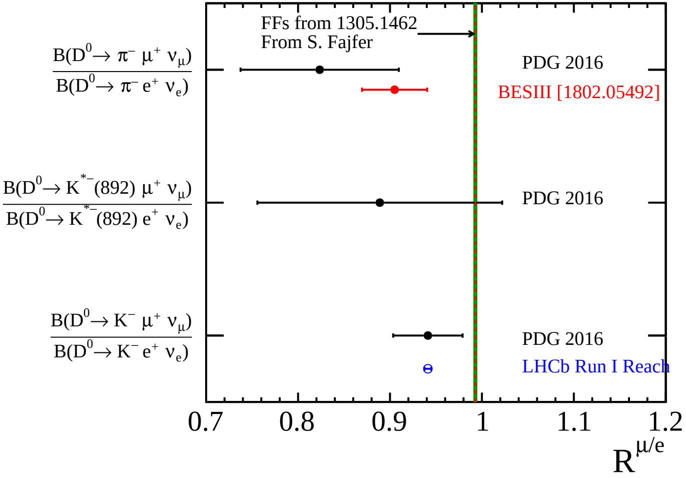

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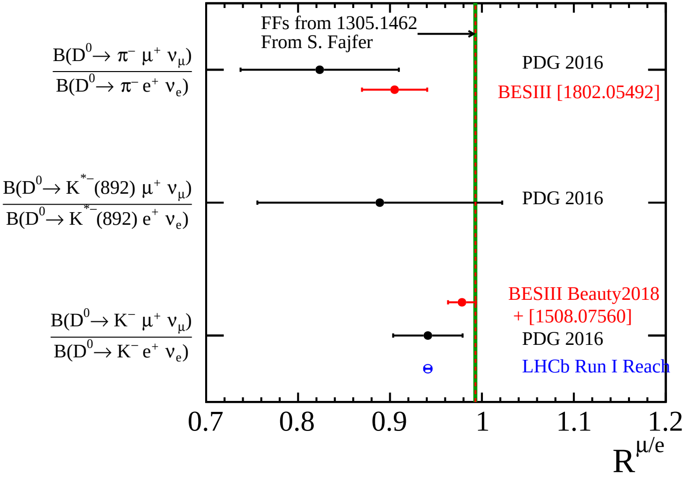

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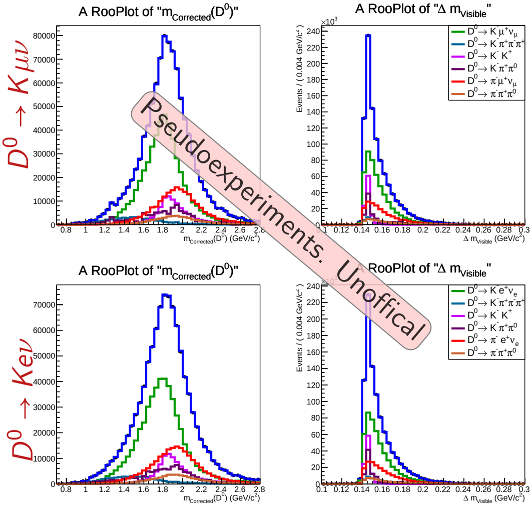
LHCb Measurement

- MC Template fit to
  - $\Delta m_{visible}$ vs $M_{corr}(D^0)$
  - $m(D^*)$ from decay-chain kinematic fit vs $m(K\ell)$
- Reconstruct q^2 using cone-closure
- Use template shapes for physics backgrounds
- Psuedoexperiment studies confirm projections



Conclusions

- LHCb is a charm factory. Should exploit this to its fullest
- Huge statistics→ low statistical uncertainties
- Many new and interesting ideas on how to access these quantities
- While hadron environment is difficult, it is not impossible
- Stay tuned

Thank you!

Backup Slides