Charm semileptonic decays at LHCb

A prospects talk

Adam Davis
On behalf of the LHCb Collaboration

29 November, 2016

Some Theory

- In the most general form, the decay rate of the D meson can be written as

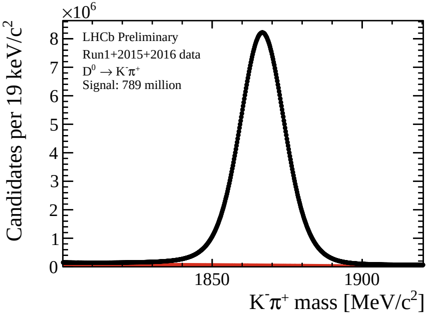
$$\frac{d\Gamma^{(\ell)}}{dq^2} = (\text{Constants}) \times \left|V_{q_i q_j}\right|^2 \times (\text{F'n of form factors}(q^2, m_\ell))$$

- Things we can do:
  1. Assuming known form factor dependence, measure $\left|V_{q_i q_j}\right|$
  2. Measure $\mathcal{B}$ dependence on q^2, use known CKM elements to understand form factors
  3. Something completely different
- In any case, dependence on q^2 is a key ingredient

LHCb

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

- LHCb acceptance: $2 < \eta < 5$
- Reconstructed 1.8 billion charm hadron decays in 2011-2016



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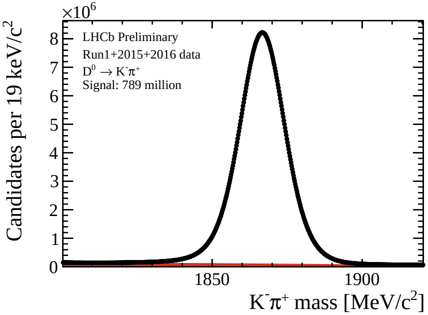

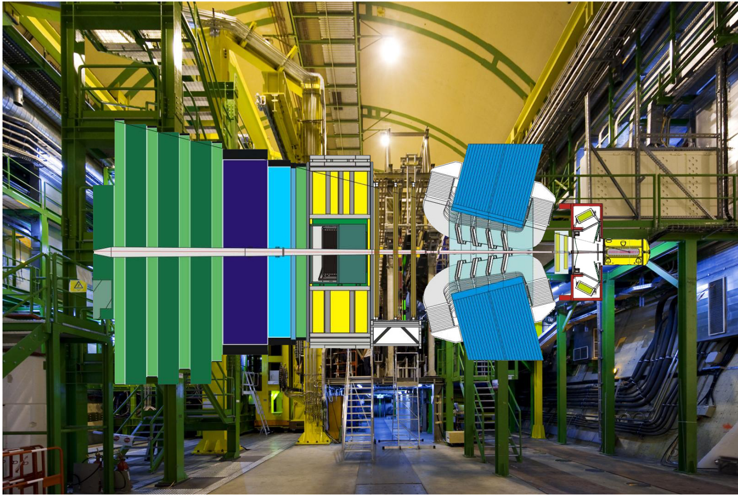

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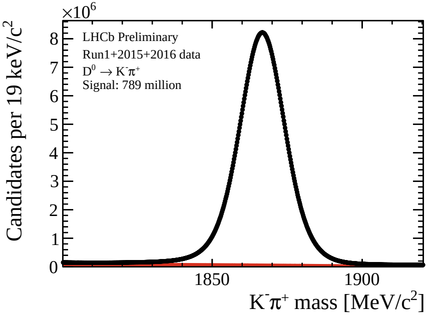

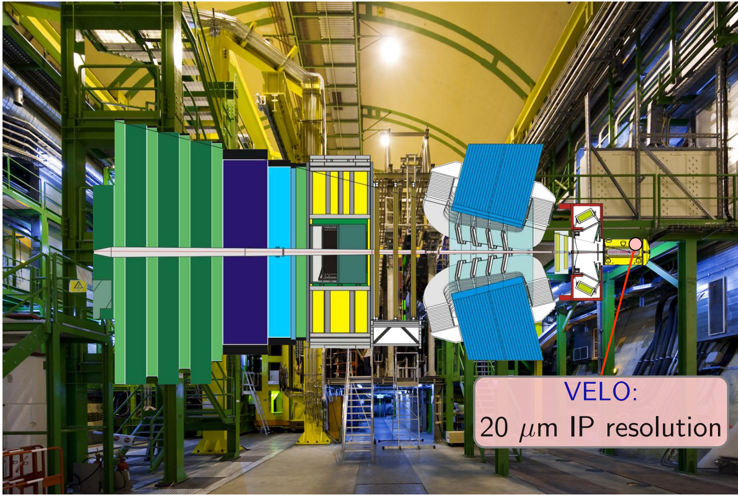

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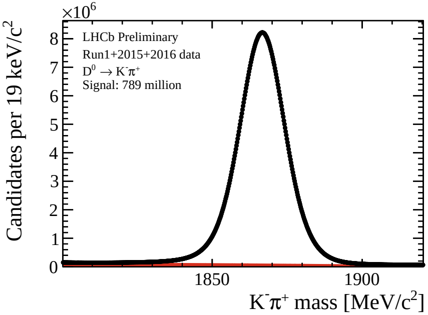

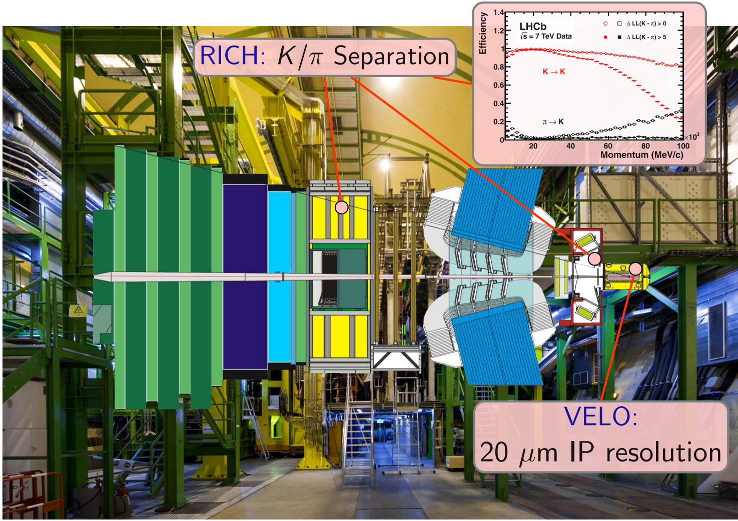

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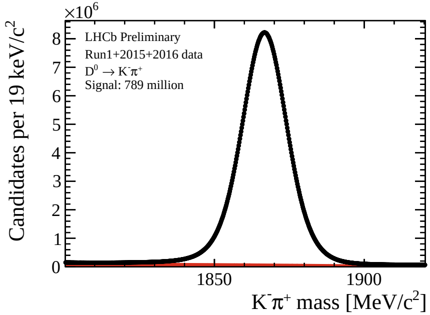

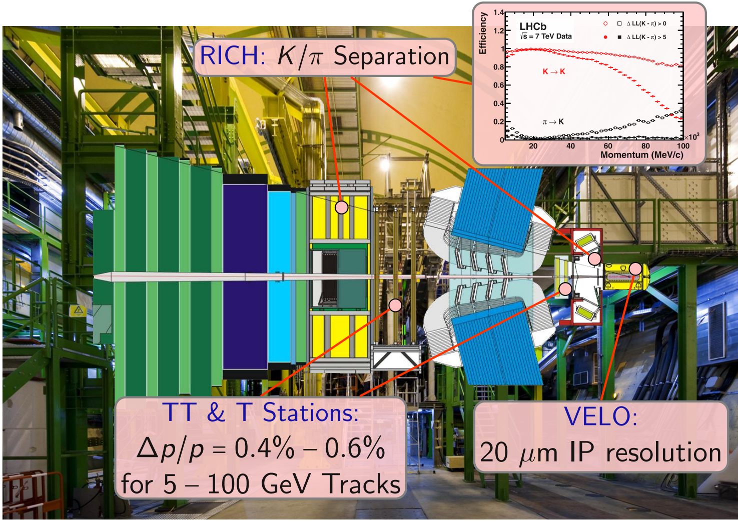

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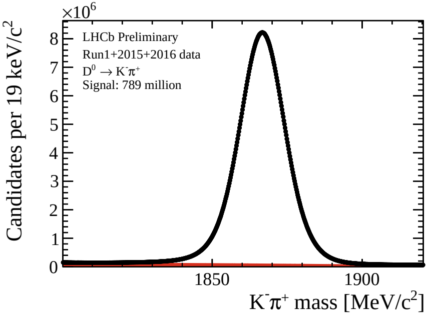

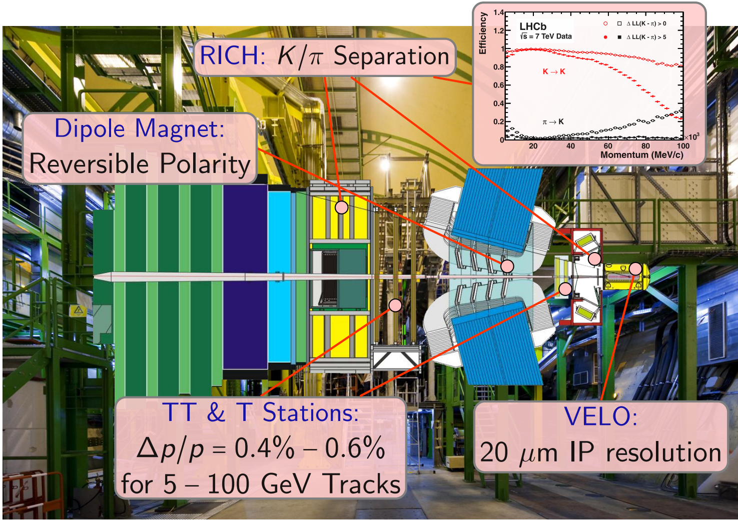

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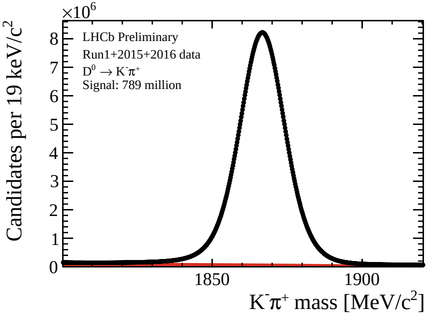

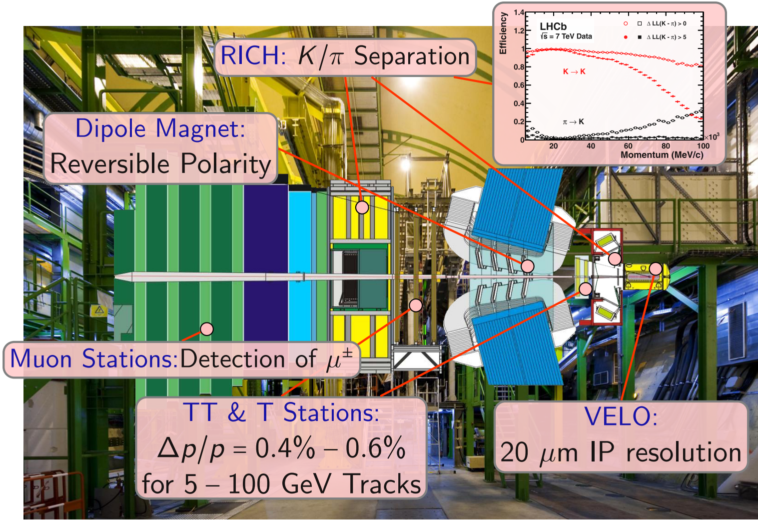

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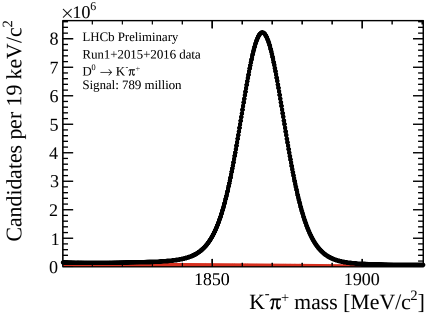
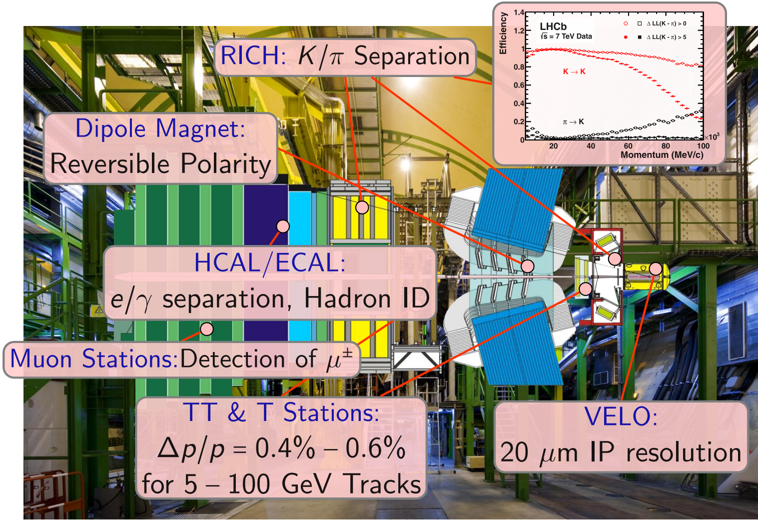
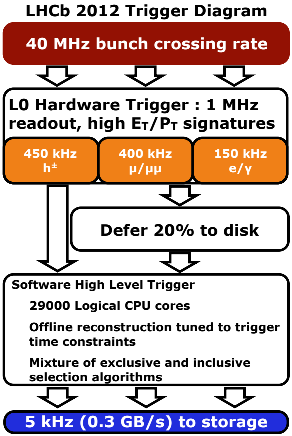
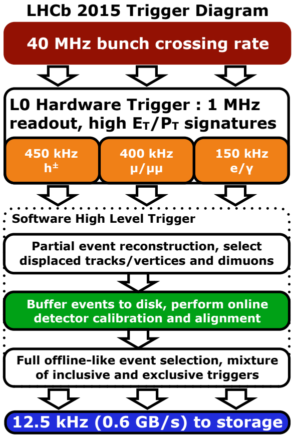


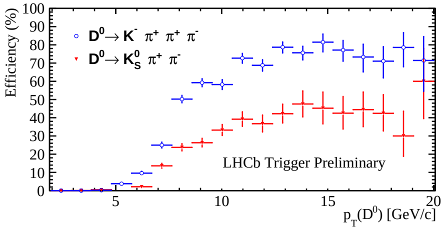


The Trigger



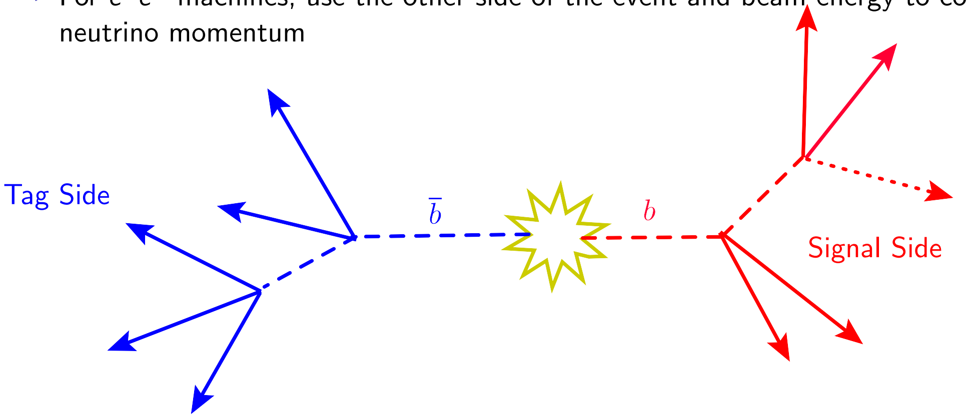


- Selection of hardware and software triggers requires care
- Depending on the physics analysis, one may be more optimal than another
- Software trigger for charm has both exclusive selections, and inclusive based on MVA trainings



Neutrino Reconstruction

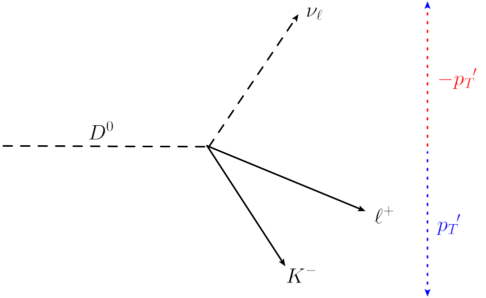
- Challenge: Only partially reconstructed final state
- For e^+e^- machines, use the other side of the event and beam energy to constrain neutrino momentum



- Not possible at a hadron collider

Neutrino Reconstruction

- Use flight direction of the D to constrain p'_T



- Leaves two-fold ambiguity for total neutrino momentum

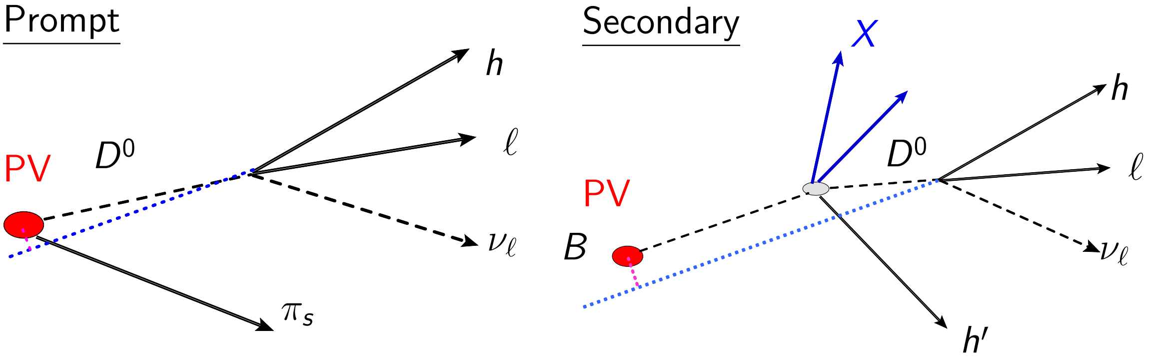
- Relies on D mass constraint
- Solutions can be imaginary due to detector effects
- Choosing a solution will bias q^2 distributions
- Many methods of dealing with this already exist:
- k factor: $p_{true} = p(K\ell)/k$
- If only missing one massless particle, can use

$$M_{corr} = \sqrt{m(K\ell)^2 + p'^2_T} + p'_T$$

- Using $D^{*+} \to D^0\pi_s^+$ decays can break this two fold ambiguity by using D^* mass constraint (Cone Closure)

Experimental Strategies

- Topology choices are key
- Prompt D^* decay is most similar to what has been previously used



- Can use hadronic B decay with SL D decay

Experimental Challenges

- Lots of places to induce bias (trigger, ν reconstruction, selection)

→ Fits will be templated

- Production/detection efficiencies requires carefully chosen control channels

$$N_{measured} = N_{physics} \times \epsilon_{trigger} \times \epsilon_{reconstruction} \times \epsilon_{PID} \times \epsilon_{selection}$$

- Some, but not all, of these can be measured in a data driven way
- q^2 resolution: Depends heavily on decay kinematics, final state, and statistics
- Muons are good, electrons are a bit more difficult

An example measurement

- Measure

$$\frac{|V_{cs}|^2}{|V_{cd}|^2} \text{ using } \frac{\mathcal{B}(D \to K\mu\nu)}{\mathcal{B}(D \to \pi\mu\nu)}$$

- 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
  - μ easily detectable
  - Use M_{corr} to reduce multibody/neutral backgrounds
- The hard parts
  - Trigger on the inclusive D event $\to$ possible biases vs q^2 depending on data-taking conditions
  - MC statistics will be a limiting factor
  - $f_+^K(q^2), f_+^\pi(q^2)$ knowledge will play a large role in the extraction

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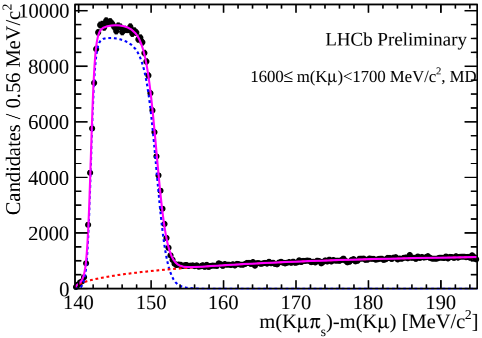
- $B(D \to \pi \mu \nu) \simeq 1/15 B(D \to K \mu \nu) \to 0.2\%$ relative uncertainty on ratio
- 10 bins of q^2 still leaves about 0.5% relative uncertainty
- Using values from CKM Fitter, q^2 integrated would be at the same level as world average

How close did we come?

- Back of the envelope calculation gives $\sim$ 4.4M signal $D \to K\mu\nu$ candidates
- a^s_{sl}(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
- Todo: understand the q^2 resolution and biases therein
- Run II will only bring more statistics



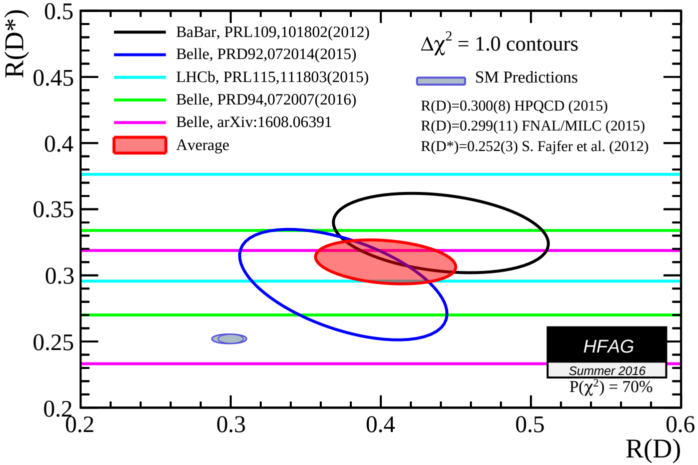
Other measurements we could think about

$\underline{D^0}$		$\underline{D^+}$		$\underline{D_s}$	
$D^0 \to \pi\mu\nu$	$(\mathcal{B} = 0.238 \pm 0.024\%)$	$D^+ \to K\pi\mu\nu$	$(\mathcal{B} = 3.9 \pm 0.4\%)$	$D_s^+ \to \phi\mu\nu$	$(\mathcal{B} =\sim 2\%)$
$D^0 \to K\mu\nu$	$(\mathcal{B} = 3.3 \pm 0.13\%)$	$D^+ \to K^0\mu\nu$	$(\mathcal{B} = 9.3 \pm 0.7\%)$	$D_s^+ \to K^0\mu\nu$	$(\mathcal{B} =\sim 0.3\%)$
$D^0 \to K^*(892)^-\mu\nu$	$(\mathcal{B} = 1.92 \pm 0.25\%)$	$D^+ \to K^{*0}\mu\nu$	$(\mathcal{B} = 5.3 \pm 0.15\%)$	$D_s^+ \to \eta^{(\prime)}\mu\nu$	$(\mathcal{B} =\sim 3\%)$
		$D^+ \to \eta\mu\nu$	$(\mathcal{B} =\sim 1\%)$		

- Items in red are unlikely
- Considerations: need a control channel for each
- Resonant vs non-resonant will be challenging
- $D^+_{(s)}$ would be possible from B decay first
- $\eta^{(\prime)} \to \pi^+\pi^-\gamma$ is a possibility (see LHCb-PAPER-2016-041 (in prep.), presented at CHARM 2016)
- Λ_c? lifetime $\sim 0.5\tau(D^0)$, final state neutrons are a no-go

And now for something completely different

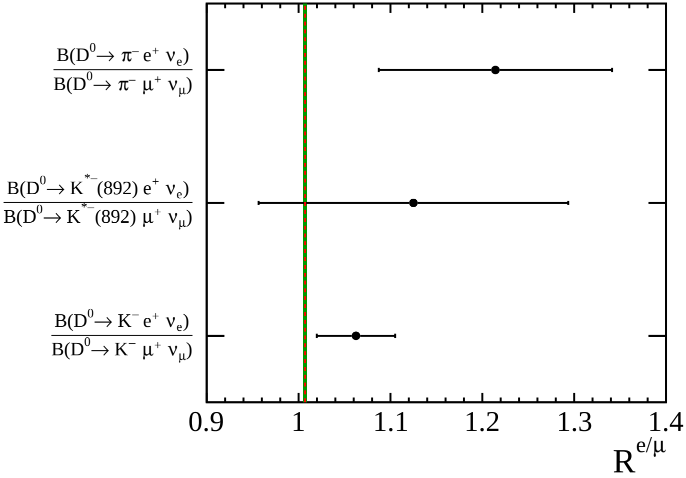
Measurements of $B \to D^{*}\tau\nu$



- Why am I even showing you this?

LNU in $D \to h\ell\nu_\ell$

- Make ratio of individual branching fractions in *D* system from PDG



Expectations and Experimental Concerns

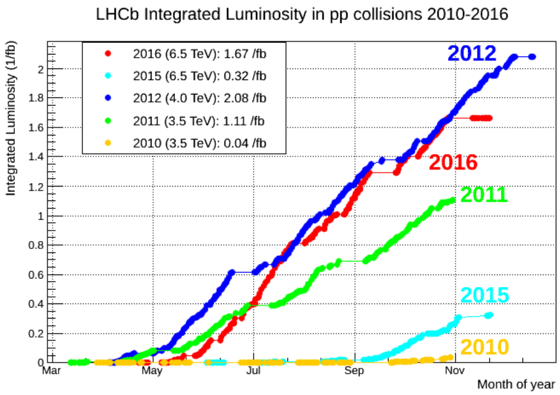
- Theoretically clean: form factors cancel to a large degree
- Expect $> 1M$ $D \to K\ell\nu_\ell$ events in Run I
- Stat error: $< 0.1\%$, would reduce error on the ratio by an order of magnitude
- Systematic uncertainties are harder to project
- Efficiencies which do not cancel in the ratio are then ϵ_μ/ϵ_e
- Bremsstrahlung recovery is difficult, but not impossible, e.g. $B \to K^* ee$,(JHEP04(2015)064) $D^0 \to e\mu$(PLB 754 (2016) 167)
- Neutral background rejection: use Δm, M_{corr}
- Use cone closure to solve for $p(\nu)$
- Run II is already bringing more statistics

Conclusions

- LHCb is a charm factory just as much as a b factory
- Muon ID gives a good foothold into CKM element measurements and form factor measurements
- Downsides: Neutrino reconstruction, MC statistics
- q^2 resolution and understanding of biases will always be key
- LNU measurements are a new field in charm. LHCb is pursuing this and we hope others will as well
- Take home point: We should measure
  - $\mathcal{B}(D^0 \to h\mu\nu)$, CKM elements, q^2 dependence
  - LNU in charm, using K, π and K^*

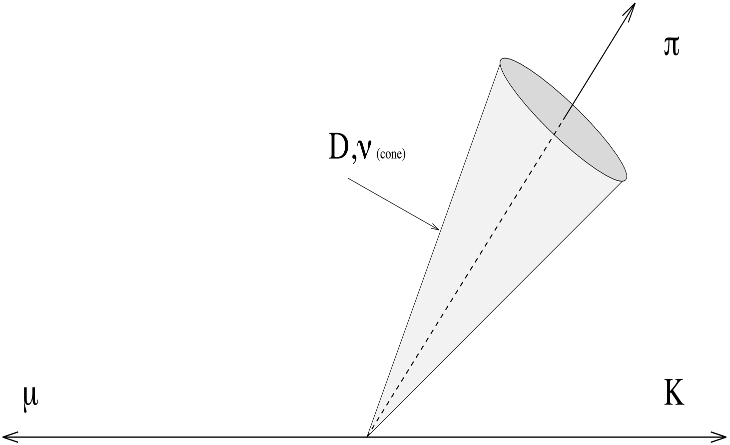
The future

- 2016 *pp* run has just finished
- LHCb has collected $\sim 1.67\ \text{fb}^{-1}$
- 2017 running to resume *pp* collisions ~May (fingers crossed)
- The fun is just beginning



Backup Slides

Cone Closure



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