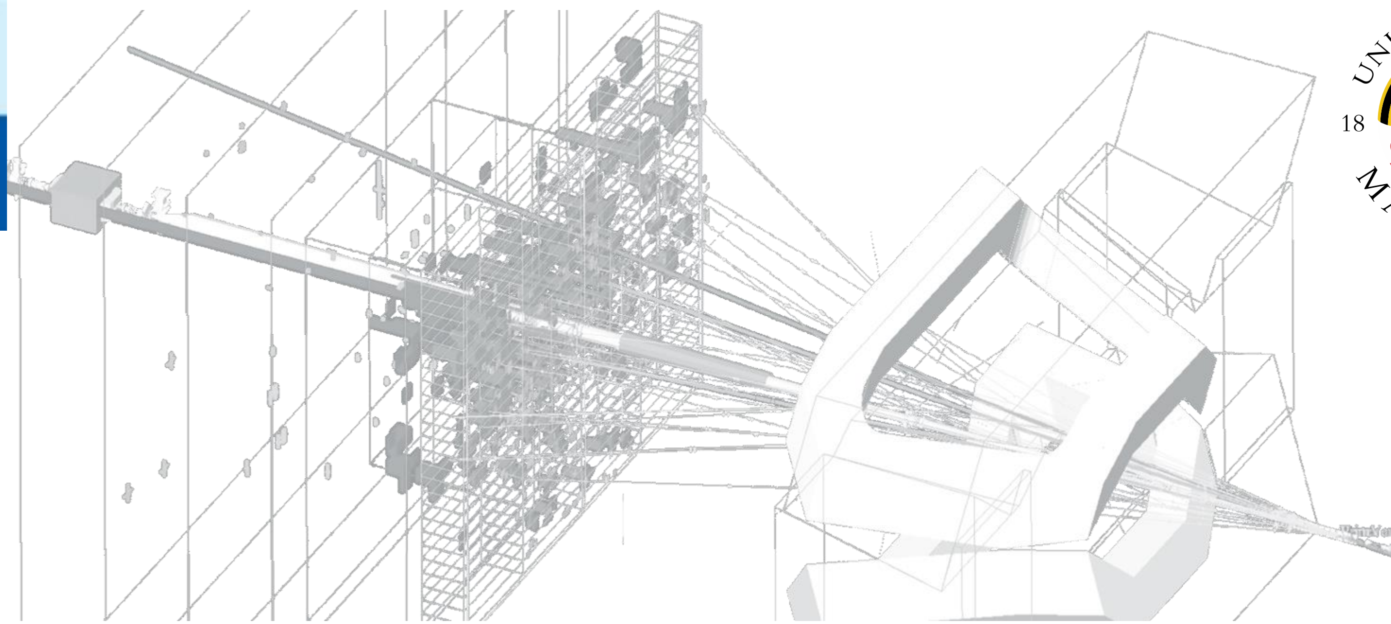


MEASUREMENT OF THE SEMITAUONIC DECAY $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$ AT LHCb

CERN LHC SEMINAR
30 JUNE 2015

LHCb-PAPER-2015-025
arXiv:1506.08614 [hep-ex]
Submitted to Phys. Rev. Lett.

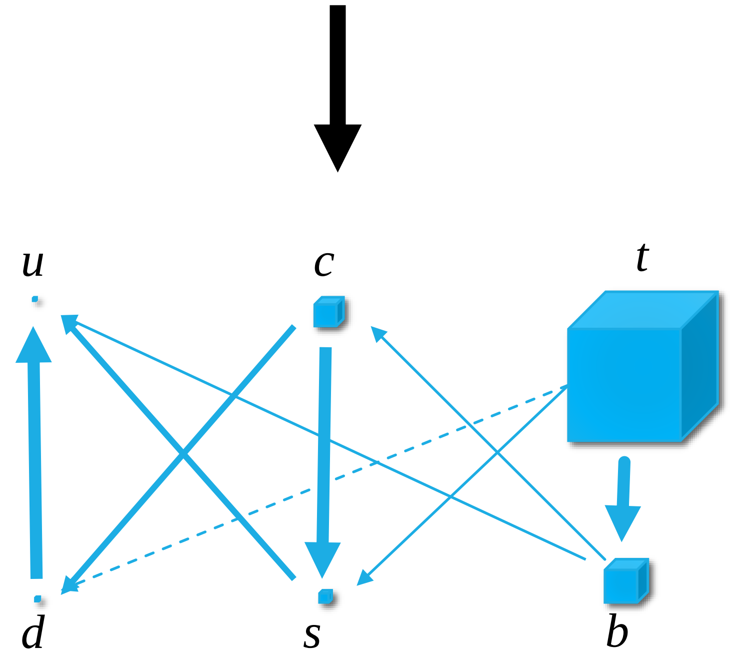
BRIAN HAMILTON
ON BEHALF OF THE LHCB COLLABORATION

B physics & lepton universality

SM flavor structure and B physics basics

- Standard model flavor structure is described by the Cabibbo-Kobayashi-Maskawa mixing matrix
- V_{CKM} hierarchical & nearly diagonal
  - Quark flavor transitions mixing different generations suppressed
  - 3rd generation especially "isolated"
- This leads to suppression of all tree-level b quark decay amplitudes
  - $|V_{cb}|$~0.04
  - Makes B physics quite sensitive to NP generically misaligned with CKM
- Also leads to long b quark lifetime: $c\tau_B \sim 400\mu m$! (= about 2x charm lifetime)
  - Very Important for hadron collider b tagging/reconstruction
  - Allows access to time-dependent phenomena

$$\begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$



Moving from left…

$$\bar{B}^0 \rightarrow D^{*+}\tau^-\bar{\nu}_\tau$$

… to right

$$\bar{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}_\tau$$

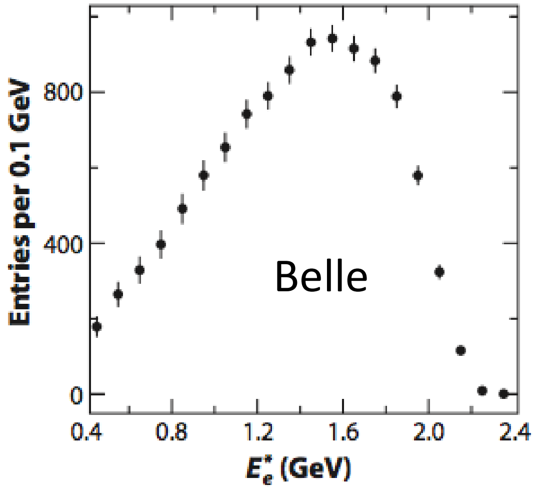
Lepton universality

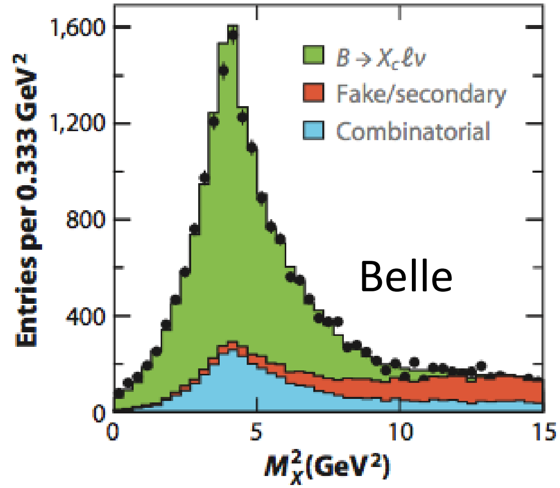
- In SM, charged lepton flavors are ***identical copies*** of one another
  - Electroweak couplings forced to be the same for all three generations by construction, only masses are different
  - Amplitudes for processes involving e, μ, τ must all be identical up to effects depending on lepton mass (which can be large!)
    - Examples:
      - $\mathcal{B}(Z \to e^+e^-) = \mathcal{B}(Z \to \mu^+\mu^-) = \mathcal{B}(Z \to \tau^+\tau^-)$
      - $\mathcal{B}(\psi(2S) \to e^+e^-) = \mathcal{B}(\psi(2S) \to \mu^+\mu^-) = \mathcal{B}(\psi(2S) \to \tau^+\tau^-)/0.3885$

- ->Observation of violations of lepton universality would be a clear sign for physics beyond the standard model
  - Searches have been underway for violations in a number of different systems
    - $Z \to \ell\ell, W \to \ell\nu, \tau \to \ell\nu\bar{\nu}, \pi \to \ell\nu$, etc...
  - Recent interest generated by LHCb in $b \to s\ell\ell$ channels:
    - $\frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)}(1 \leq q^2 \leq 6\ GeV^2) = 0.745^{+0.090}_{-0.074} \pm 0.036$ PRL 113 1510601 (2014)
  - No definitive deviations observed yet

Semileptonics & physics beyond the Standard Model

Semileptonic B decays





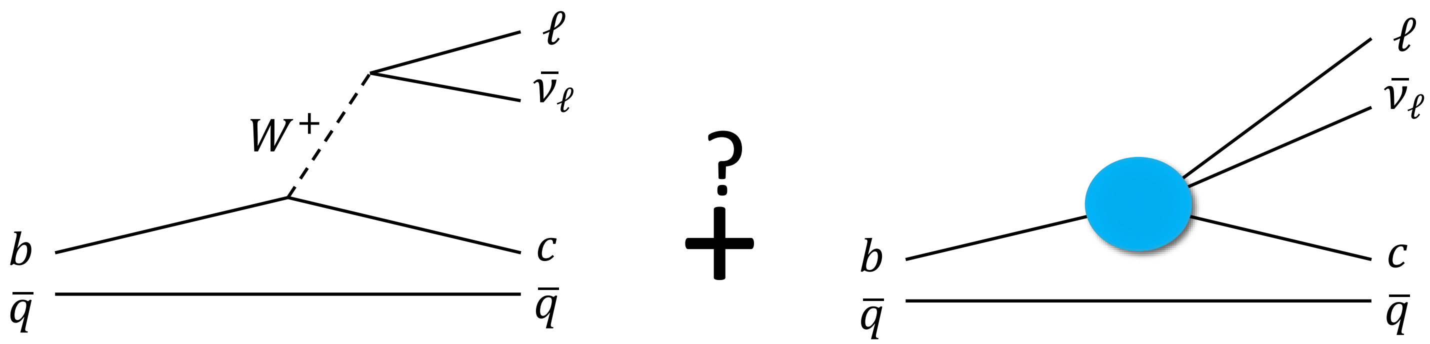
Luth, V.G. Annual Review of Nuclear Science, **61** (2011) 119-148

- "Beta decay" of B hadrons – signature is lepton (μ or e (or τ!)) , recoiling hadronic system, and missing momentum

- Theoretically well-understood in the SM
  - Tree level virtual W emission – strong V-A structure
  - No QCD interaction between the lepton-neutrino system and the recoiling hadron(s)
    - $\bar{B} \to W^{*\pm} D^{(*)}$ half of the decay still needs non-perturbative input

- Charged lepton universality implies branching fractions for semileptonic decays to e, μ, τ differ only phase space and helicity-suppressed contributions

New Physics in Tree-level decays?



- Semileptonic decay rates to e or μ extensively studied in B-factory data, but many unexplored avenues remain.
  - In particular, Decays to third generation (τ) remain less well-measured (10% relative uncertainty on branching fractions, c.f. 2% on decays to μ)

- In general, room for non-universal tree-level physics to contribute still, especially if there is preferential coupling to 3rd generation

Why expect NP with strong coupling to τ?

- What couples preferentially to 3rd generation?
  - Higgs!

- Recall, SM scalar sector:

$$\mathcal{L}_\phi = |D_\mu \phi|^2 - \mu^2 \phi^\dagger \phi - \lambda(\phi^\dagger \phi)^2 - \lambda^L_{ij} L_{ia} \phi_a E_j - \lambda^D_{ij} Q_{ia} \phi_a D_j - \lambda^U_{ij} Q_{ia} \left[\epsilon^{ab} \phi^\dagger_b\right] U_j$$

This setup is *minimal* to break EW symmetry and induce all fermion mass terms

- Generically, more than one doublet is possible instead, or even more complicated structures
- Anything more complicated (e.g. a second doublet) can introduce new charged Higgs bosons which can mediate new charged currents

Prototypical $H^{\pm}$ scenario

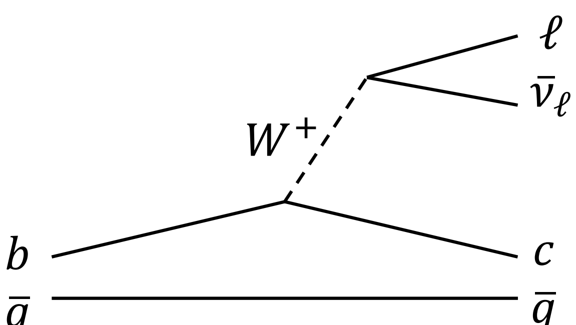
- Prototypical new physics we all know and love: MSSM
  - Simplest SU(2) doublet Higgs sector of the Standard Model isn't workable in MSSM
    - Why? SM Quark Yukawa terms are problematic in SUSY:

$$\mathcal{L}_Q = -\lambda^D_{ij} Q_{ia}\phi_a D_j - \lambda^U_{ij} Q_{ia}\left[\epsilon^{ab}\phi^\dagger_b\right] U_j$$

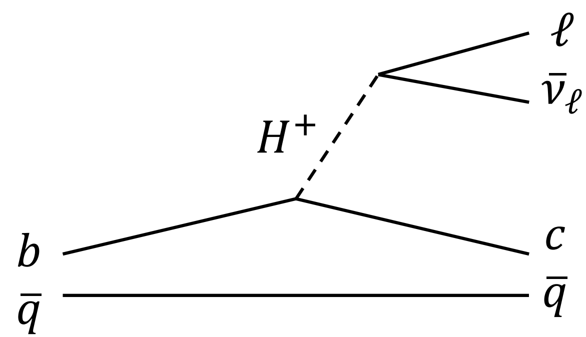
    - The bracketed (red) term has no SUSY-invariant equivalent
  - Instead, MSSM introduces up- and down- Higgs doublets

$$y^D_{ij} Q_i H_d D_j + y^U_{ij} Q_i H_u U_j$$

  - One linear combination acts as SM would-be goldstone bosons, while the other combination mediates new charged current interactions
- Separate doublets for up and down known generally as "Type-II 2-Higgs doublet model" (caveat: MSSM itself only type-II at tree level)



$$\sim \frac{G_F}{\sqrt{2}} m_B^2$$



$$\sim \frac{G_F}{\sqrt{2}} m_\ell m_B \frac{\tan^2\beta}{m_{H^+}^2}$$

Aside: more general 2HDM

- Abandoning for the moment the the MSSM motivation, generically each of the two Higgs doubles may couple to both up and down-type fermions
- Requires some finesse to avoid flavor bounds from, e.g. neutral K mixing. Bad terms look like:

$$\xi_{ij} \bar{D}^i H_2^0 D_R^j$$

(and similar for U, L)

  - Popular choice (due to Cheng and Sher) is to take ξ to be proportional to the geometric mean $m_i m_j$

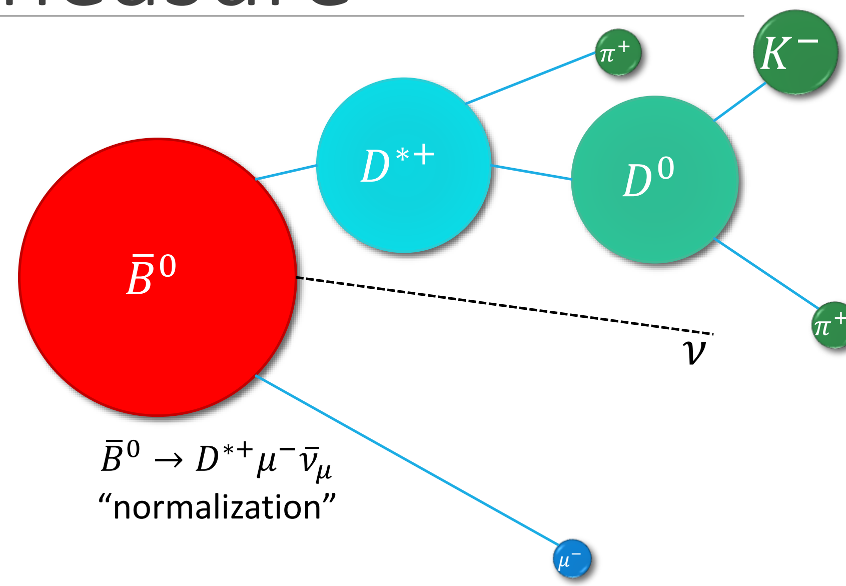
- Generally known as Type-III 2HDM
- Less well-motivated (depending on whom you ask) but with more "knobs"
- Other NP structures of course also possible, so long as couplings to light leptons are somehow suppressed

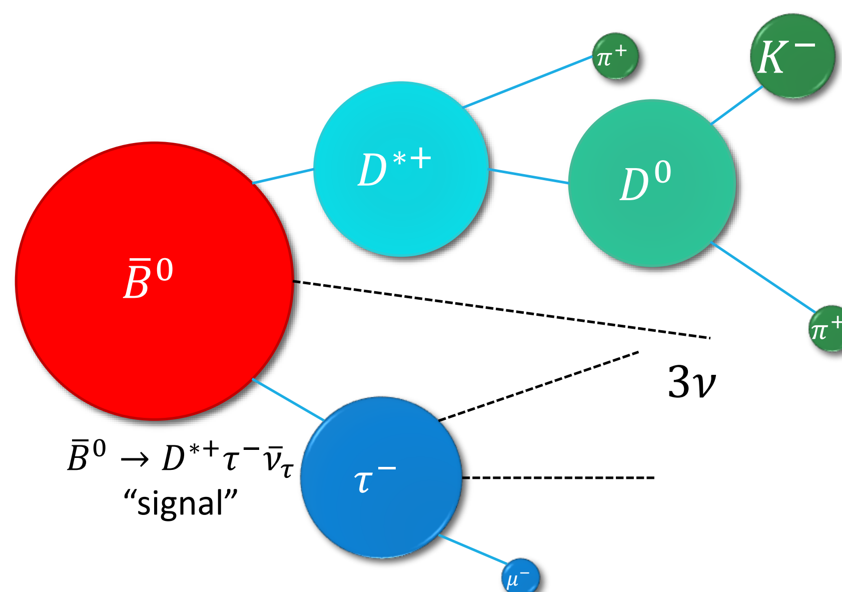
Measuring semitauonic B decays

What we want to measure

$$R(D^*) \equiv \frac{\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)}$$

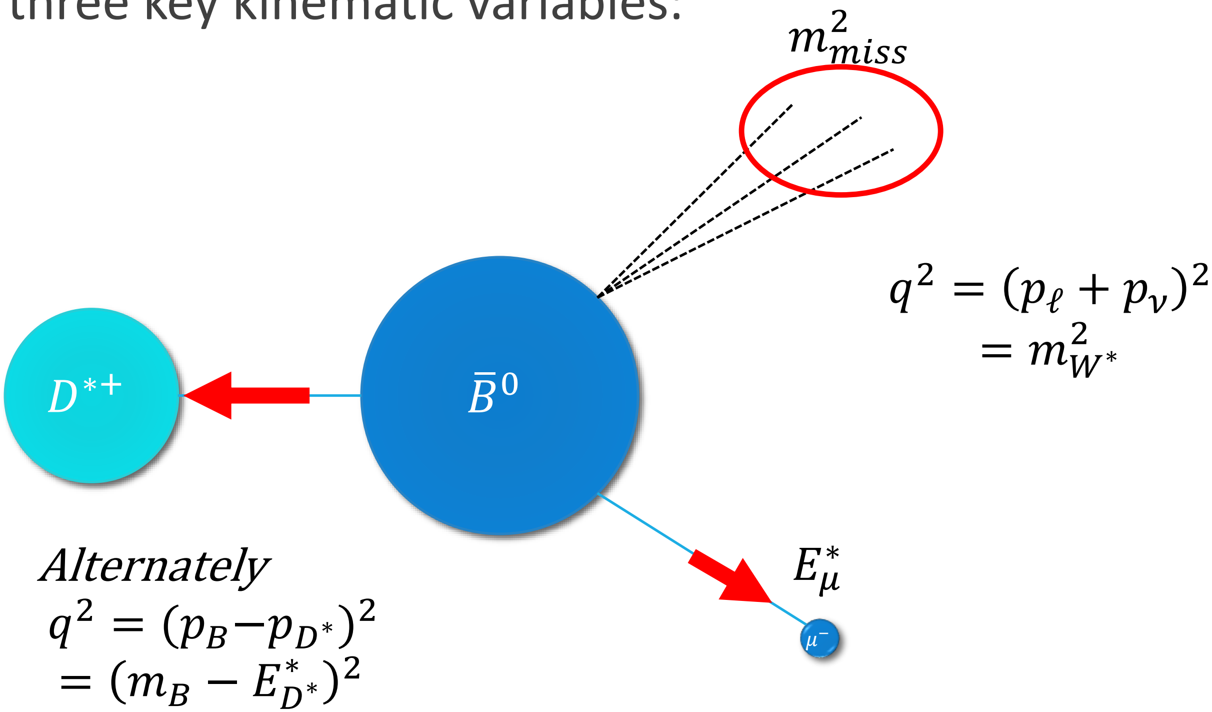
- **Theoretically clean** due to cancellation of form factor uncertainties
  - Poorly-measured helicity suppressed amplitudes give dominant uncertainty
  - SM: $R(D^*) = 0.252(3)$
    PRD **85** 094025 (2012)
- **Experimentally nice with $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$**
  - Results in identical (visible) final state
  - large, well-measured BF:
    $\mathcal{B}\left(\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau\right) = (17.41 \pm 0.04)\%$
    - Expected (signal)/(normalization)=0.439%
  - Disentangle from $\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu$ using invariant mass of invisible system, lepton energy spectrum





Distinguishing $b \to c\tau(\to \mu\nu\nu)\nu$ from $b \to c\mu\nu$

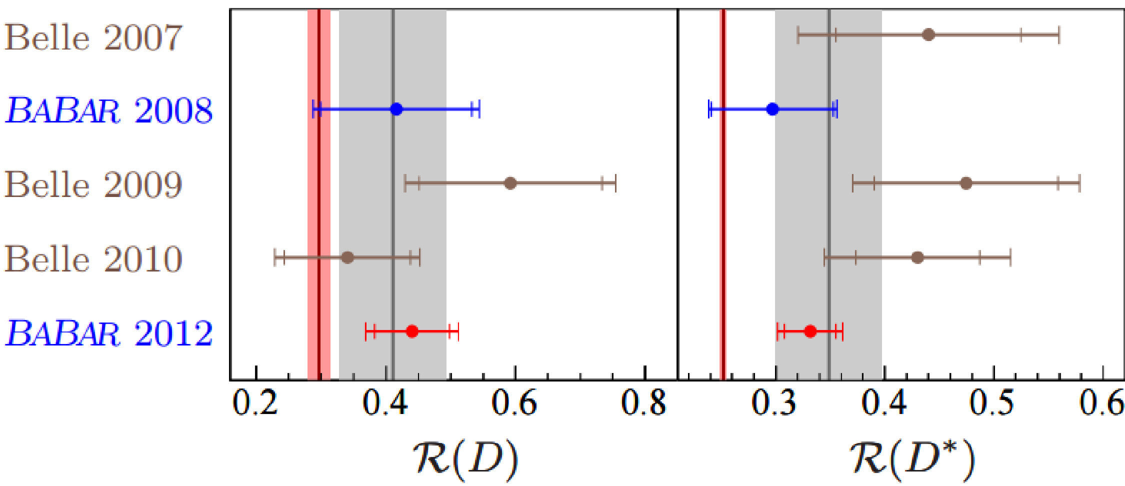
- In B rest frame, three key kinematic variables:

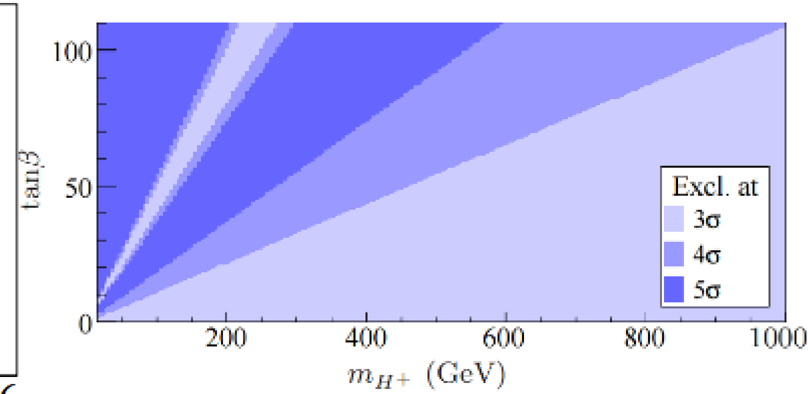


$\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}$	$\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}$
$m^2_{miss} > 0$	$m^2_{miss} = 0$
E^*_l spectrum is soft	E^*_l spectrum is hard
$\mathrm{m}^2_\tau \leq q^2 \leq 10.6\ \mathrm{GeV}^2$	$0 \leq q^2 \leq 10.6\ \mathrm{GeV}^2$

BaBar results

Figures from PRD 88, 072012 (2013)





- In 2012/2013, BaBar presented the most precise measurement yet of

$$R\left(D^{(*)}\right) \equiv \frac{\mathcal{B}\left(\bar{B} \to D^{(*)}\tau^-(\to \ell^-\bar{\nu}\nu)\bar{\nu}_\tau\right)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^-\bar{\nu})}, \ell = e \text{ or } \mu$$

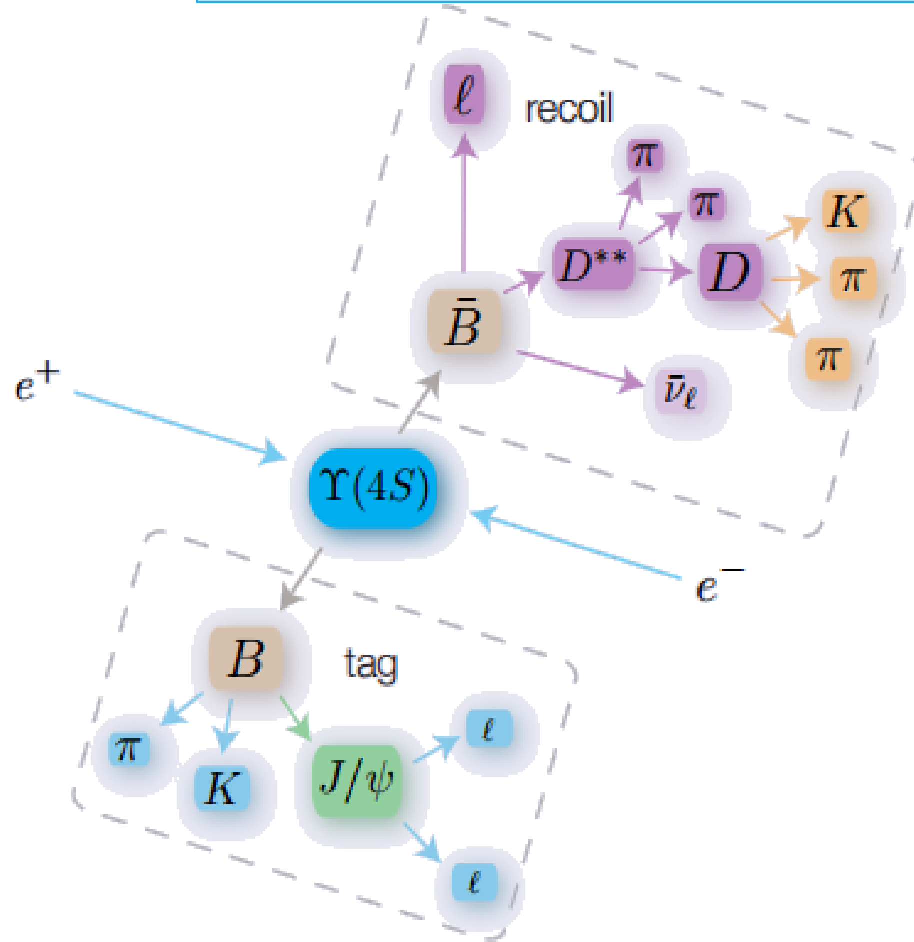
  - Including anticorrelation between D and D^* gives 3.2σ above SM expectation
    - Anticorrelation induced by feed-down from D^* decay into D samples
  - Strongly in tension with type-II 2HDM as well
- Earlier measurements from Belle and BaBar consistently above SM
- Follow-up measurements have badly needed since

B-factory measurements

- B-factory measurements exploit the simple kinematics of the $e^+e^- \to \Upsilon(4S) \to B\bar{B}$ reaction
  - Small Q-value means no additional hadrons produced

- "Hadronically-tagged" analyses preferred in channels with multiple neutrinos
  - Reconstruct 2nd B meson in decay mode with no missing particles
  - Provides precise knowledge of kinematics of missing system
  - Reduces backgrounds from $e^+e^- \to c\bar{c}$ and from background partially-reconstructed B decays
  - Efficiency of few 10^{-3} -- costly!

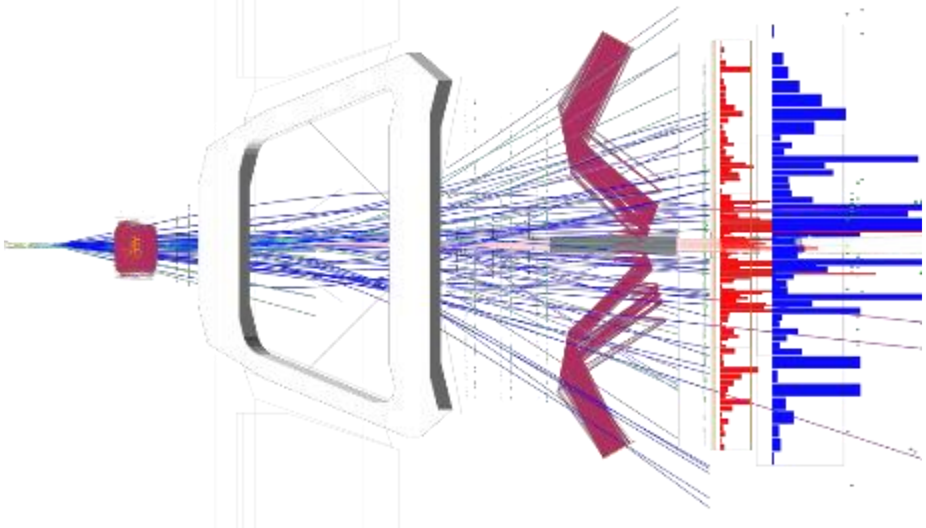
Figure from T. Lück's talk at ICHEP 2014



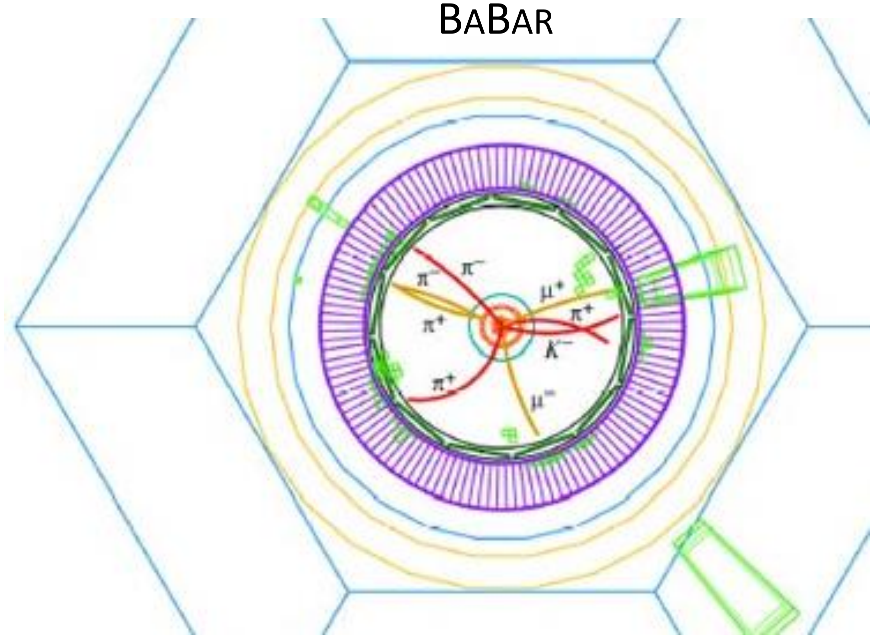
Example of hadronic-tagging technique for $\bar{B} \to D^{**}(\to D\pi\pi)\ell\nu$ analysis

Following up using LHC data

LHCb



BABAR

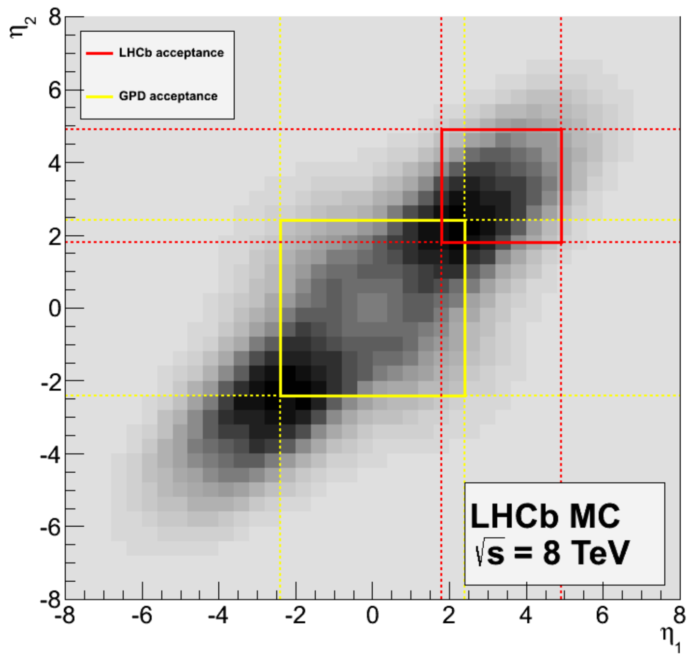


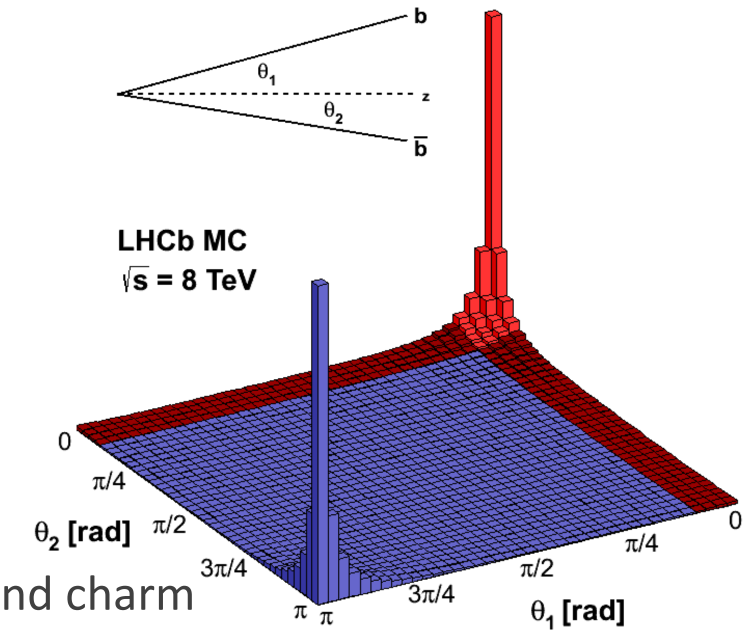
- In hadron collisions, things are not nearly as “nice” as in $\Upsilon(4S)$ decay
  - Unknown CM frame for $gg \to b\bar{b}$ production
  - Lots of additional particles in the event (showering, MPI etc)
- Different handles are needed to deal with (1) missing neutrinos and underconstrained kinematics as well as (2) large backgrounds from partially-reconstructed B decays

The LHCb experiment

HEAVY FLAVOR AT LHC

Heavy Flavor at LHC



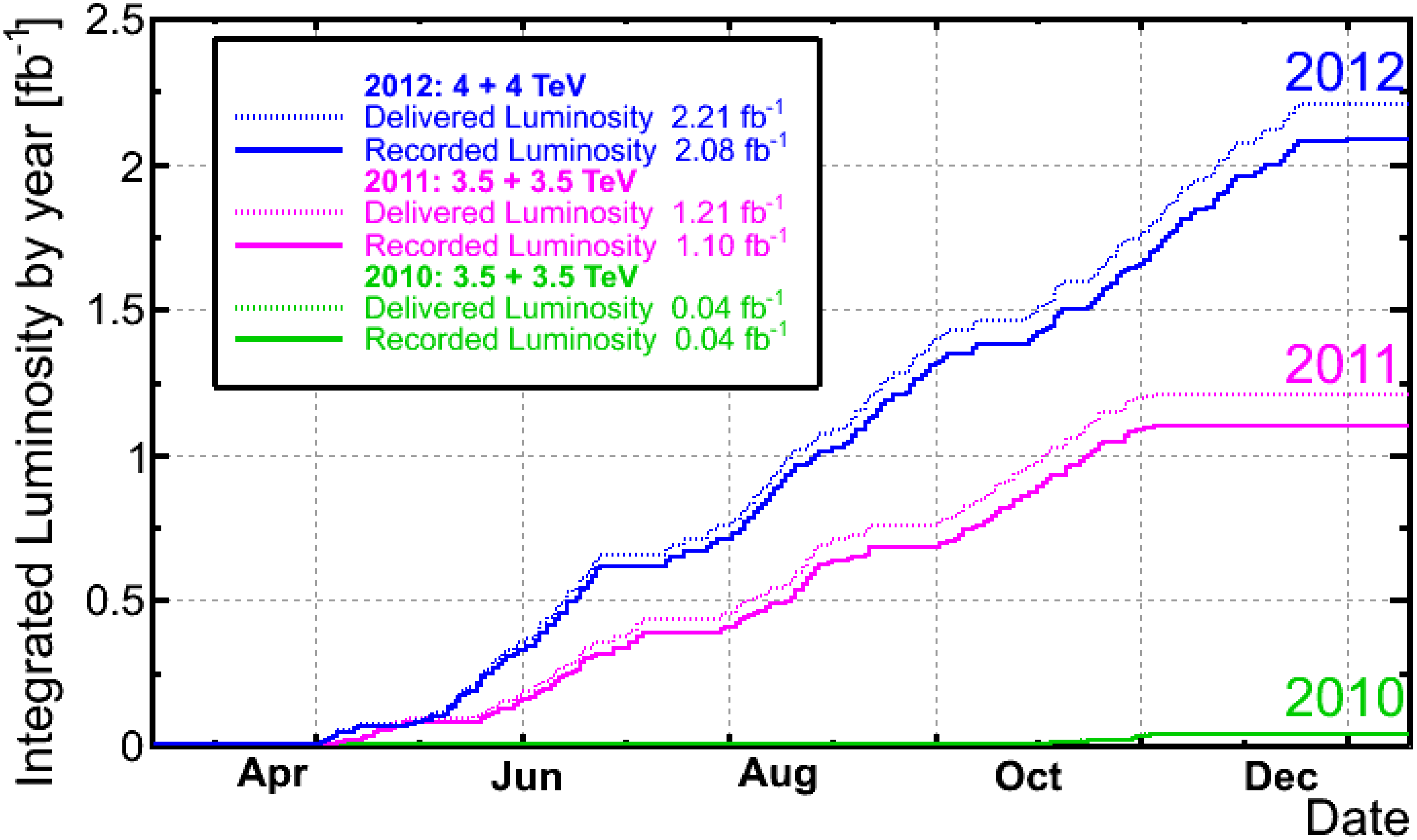


- LHC collisions produce copious amounts of beauty and charm
  - At 7 TeV: $\sigma_{c\bar{c}}$ ~ 6 mb
    $\sigma_{b\bar{b}}$ ~ 280 μb
  - Production dominantly occurs at high η with highly-boosted CM frame

- Central detector ($|\eta| < 2.5$) scheme covers only 52% (45%) of b quark (pair) production despite surrounding >98% of the solid angle

- Alternate approach: focus on forward direction: cover 27% (25%) of (pair) production while instrumenting < 3% of the solid angle

Run 1 Dataset

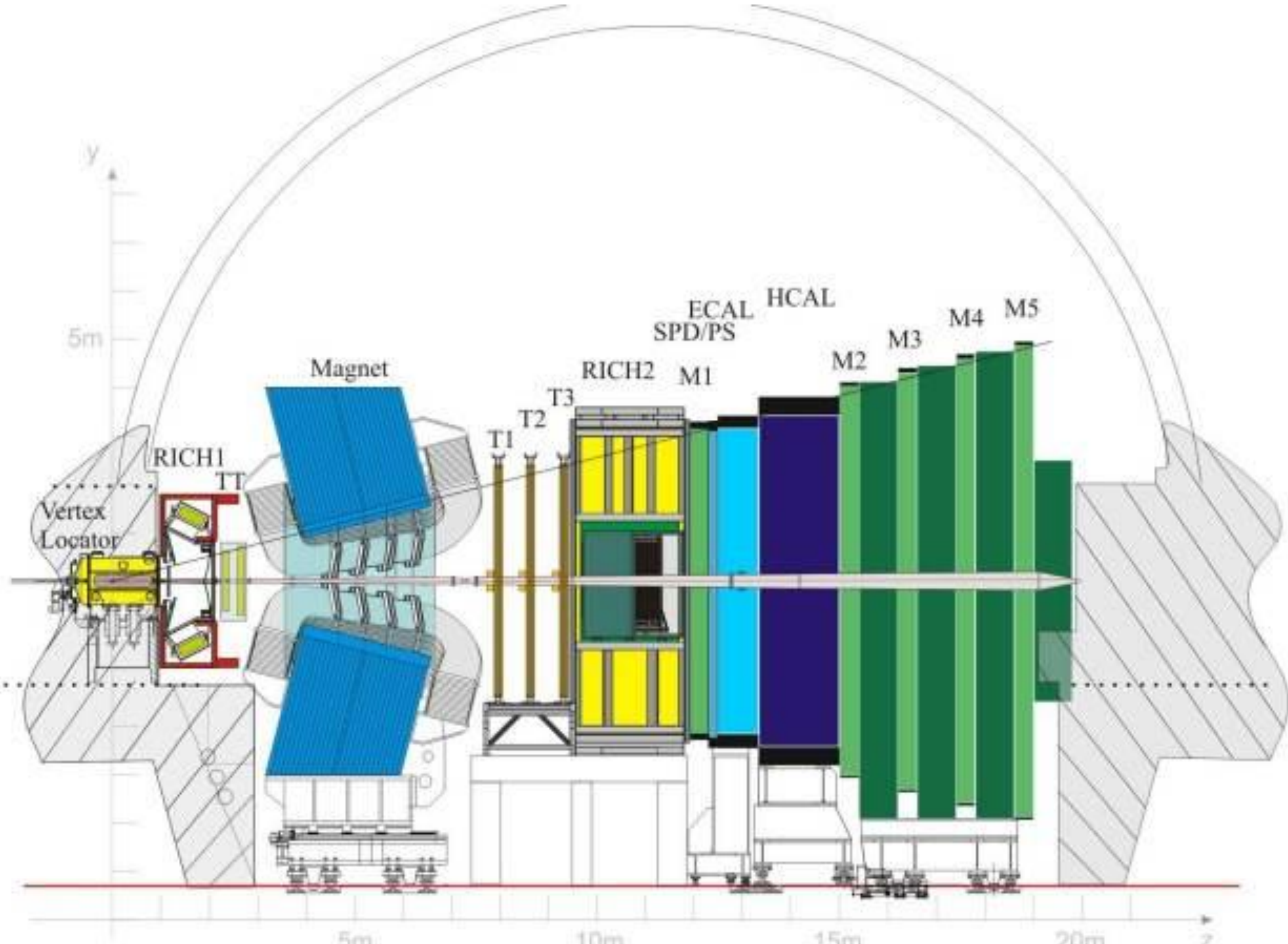


- >90% data taking efficiency with >99% of collected data good for analyses
- Lumi collected: 1 fb^{-1} @ 7 TeV 2 fb^{-1} @ 8 TeV

The LHCb Detector

- Single-arm forward spectrometer covering approximately $1.9 < \eta < 4.9$ (~15-300 mrad) optimized for flavor physics studies at LHC point 8

The LHCb Detector



The LHCb Detector

Vertex Locator (VELO) and tracking stations give > 96% tracking efficiency for charged particles traversing the whole detector

VELO provides 20μm resolution on impact parameter,
45 fs decay time resolution on b hadron decays

Dipole (warm) electromagnet - $\int Bdl = 4\,Tm$ ($\delta p/p = (0.4 - 0.6)\%$)

VELO Performance Paper:
JINST 9 (2014) P09007

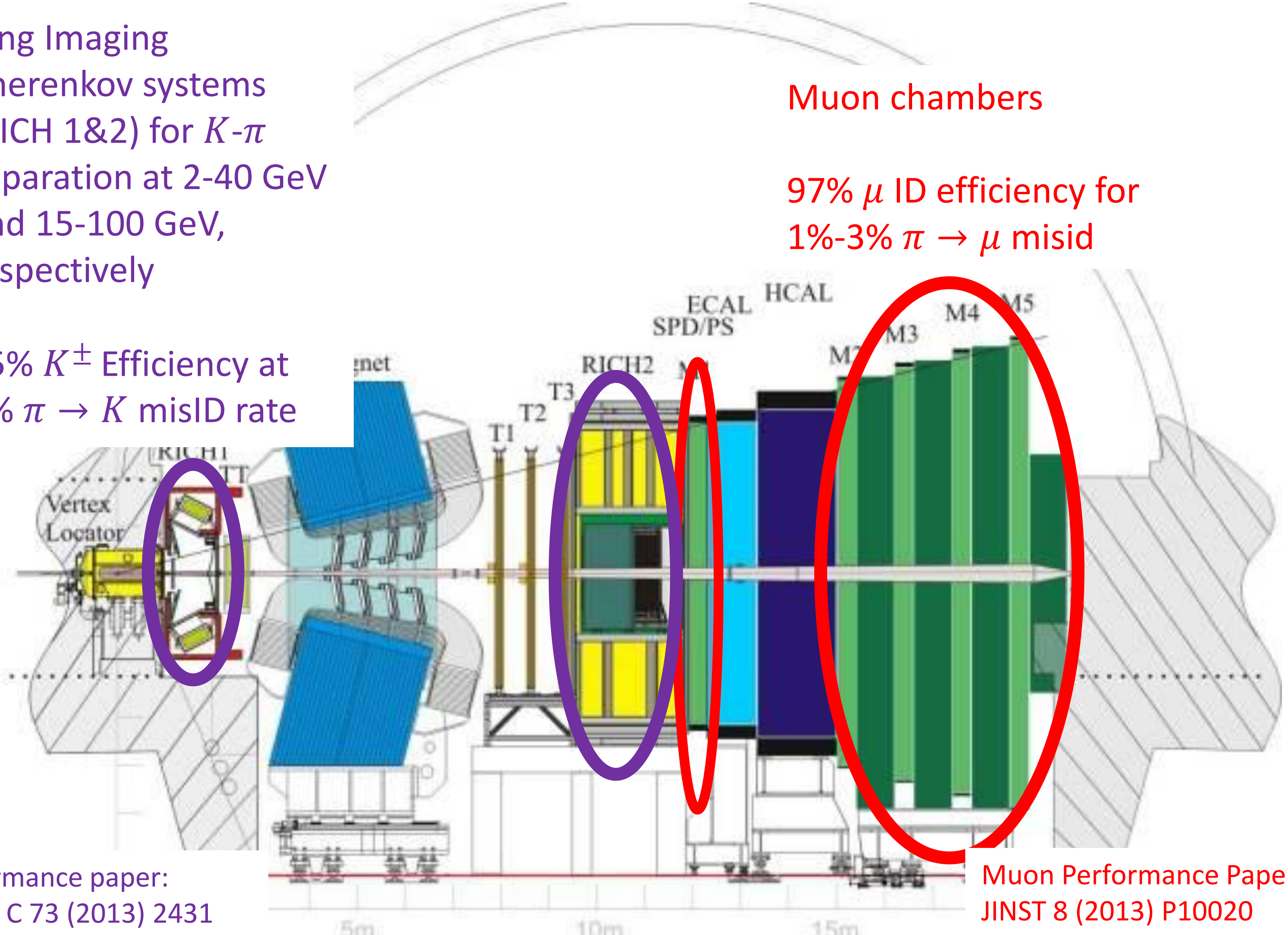
The LHCb Detector

Ring Imaging Cherenkov systems (RICH 1&2) for K-π separation at 2-40 GeV and 15-100 GeV, respectively

95% $K^{\pm}$ Efficiency at 5% $\pi \rightarrow K$ misID rate

Muon chambers

97% μ ID efficiency for 1%-3% $\pi \rightarrow \mu$ misid



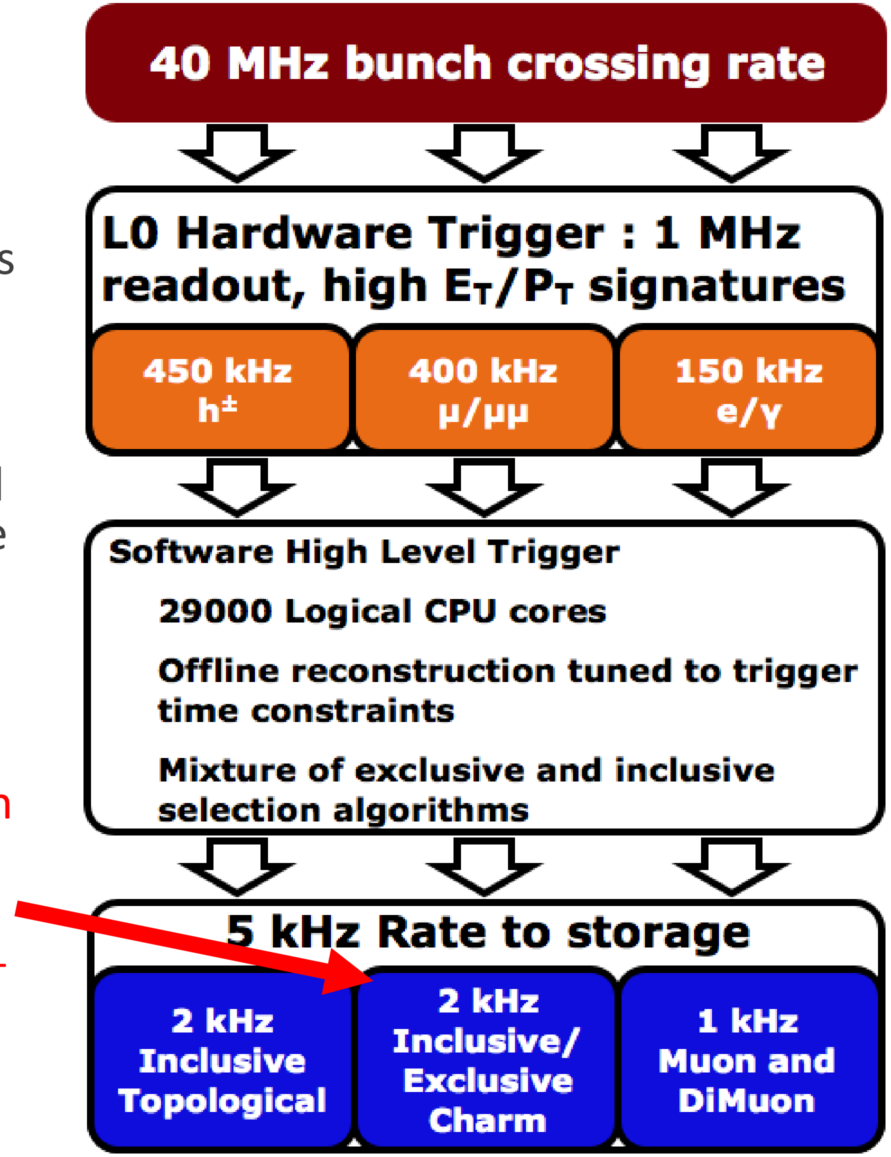
RICH Performance paper:
Eur. Phys. J. C 73 (2013) 2431

Muon Performance Paper:
JINST 8 (2013) P10020

Triggering

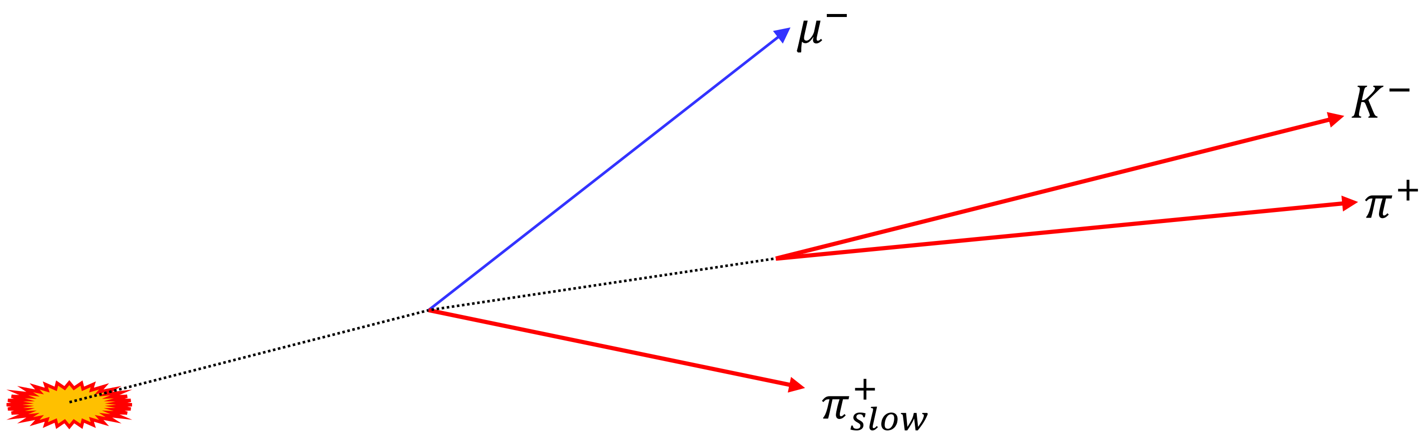
Performance paper:
JINST 8 P04022 (2013)

- Large cross section for heavy flavor production means a robust triggering system is needed
  - Triggering inclusively as possible is *essential* in order to not limit the physics program
  - Hardware trigger relies on muon and calorimetery
  - Software high-level trigger performs full event reconstruction for all tracks above 300 MeV of p_T



- For this measurement:
  - Trigger signal and normalization through the exclusive charm trigger path in software
    - Moderately high p_T $D^0 \to K^-\pi^+$ with well-separated vertex that loosely points to a PV in the event
  - No hardware muon trigger requirement

Event Selection

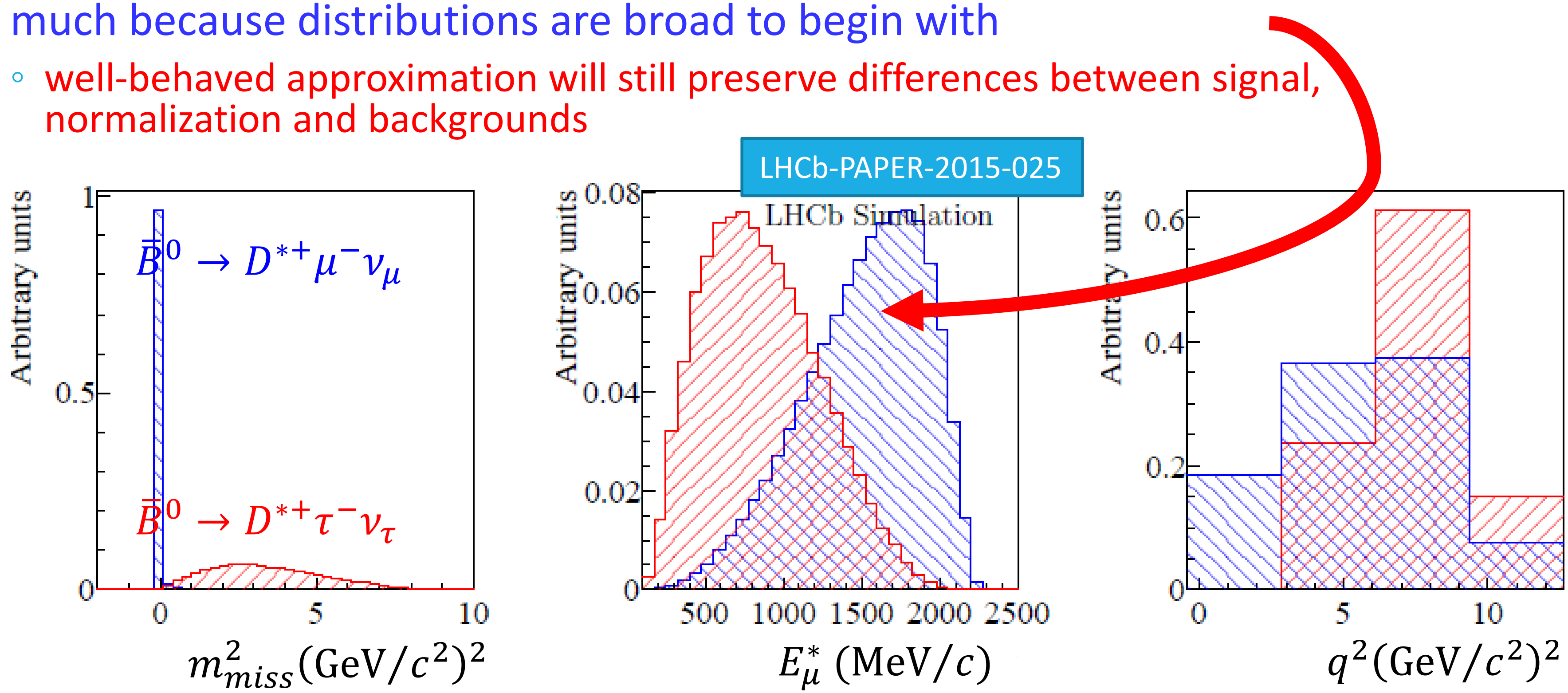


- Combine $D^0 \to K^-\pi^+$ candidate passing charm trigger with μ^- and π^+_{slow}
  - Require $D^0 \to K^-\pi^+$ decay vertex well-separated from PV
  - Require $\mu^-, K^-\pi^+$all to have significant impact parameter with respect to PV
  - Remove prompt charm background with impact parameter requirements on $D^0 \to K^-\pi^+$ (main background killed by full event reco at B-factories)

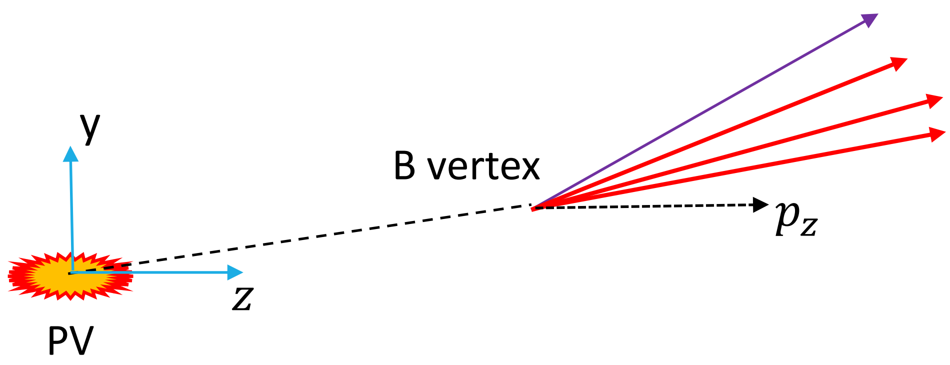
Rest-frame kinematics at LHCb

- How to compute the rest frame of the B in hadron collisions?
  - B flight direction is well-measured, but only provides enough constraints (with B mass) to solve for B momentum with single missing particle
    - Even then, 2-fold ambiguity remains
    - Exact solution impossible without more information
  - Important observation: resolution on rest frame variables doesn't matter much because distributions are broad to begin with
    - well-behaved approximation will still preserve differences between signal, normalization and backgrounds

True (simulated) disgtributions
For selected events



Rest-frame approximation at LHCb

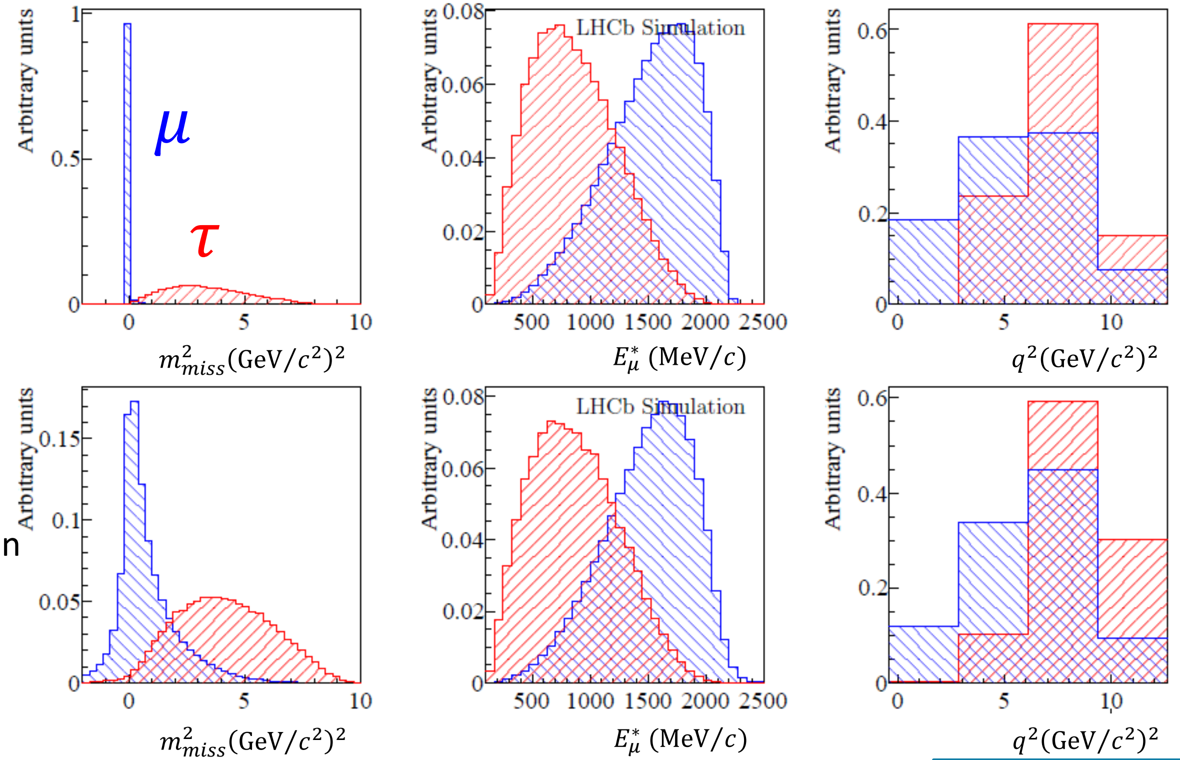


- Take $(\gamma\beta_z)_{\bar{B}} = (\gamma\beta_z)_{D^*\mu} \quad \Longrightarrow \quad (p_z)_{\bar{B}} = \frac{m_B}{m(D^*\mu)}(p_z)_{D^*\mu}$
  - Inspiration: B boost along z >> boost of decay products in B frame
  - Equivalent to choosing a decay axis in the rest frame – approximation is independent of B momentum
    - Small momentum dependence due to momentum dependence of resolution on flight direction

Reconstructed fit variables

MC Truth

Our Approximation



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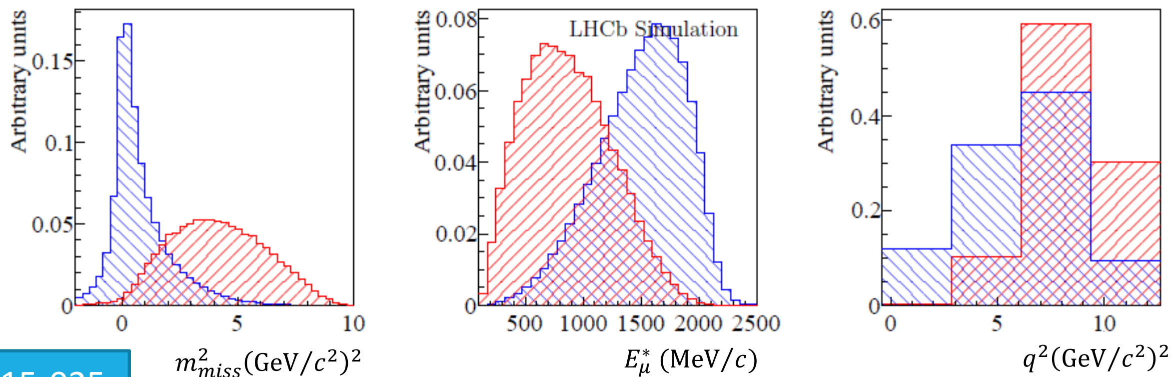
- 18% resolution on B momentum approximation gives excellent shapes to use for fit

Fit

- Using rest frame approximation, construct 3D "template" histograms for each process contributing to $D^{*+}\mu^-$
  - Signal, normalization, and partially reconstructed backgrounds use simulated events, other backgrounds use control data
  - Templates are functions of any relevant model parameters via interpolation between histograms generated with different fixed values of those parameters

- These templates are then used as PDFs for a maximum likelihood fit to data

- -> distributions shown previously directly translate to one-dimensional projections of the 3D templates for signal and normalization



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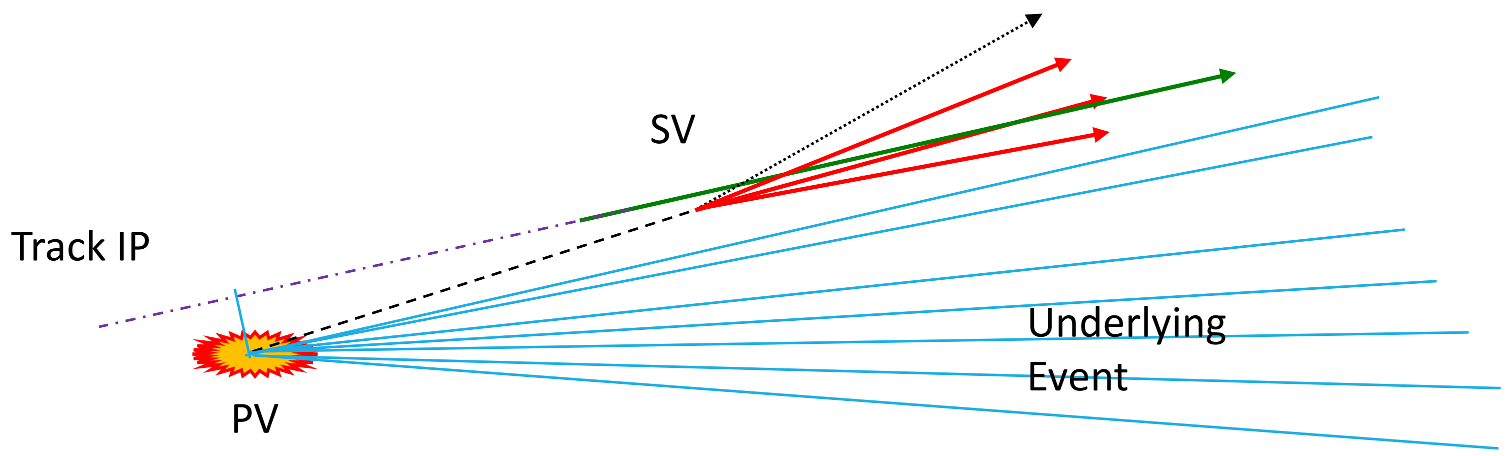
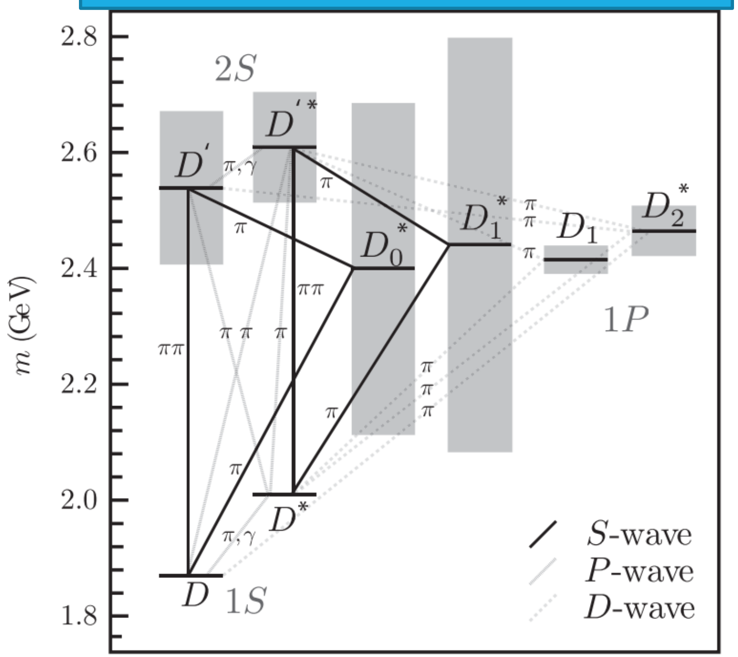
Reducing partially reconstructed backgrounds



- Make use of superb tracking system
  - Scan over every reconstructed track and compare against $D^{*+}\mu^-$ vertex
    - Check for vertex quality with PV and SV, change in displacement of SV, p_T, alignment of track and $D^{*+}\mu^-$ momenta
- Each track receives BDT score as “SV-like” (high) vs “PV-like” (low)
  - Cut on most SV-like track below threshold: get signal sample enriched in exclusive decays. Rejects 70% of events with 1 additional slow pion
  - Cut on most SV-like track(s) being above threshold: get control samples enriched in interesting backgrounds

Semileptonic Backgrounds

Bernlochner et al, PRD 85 094033 (2012)



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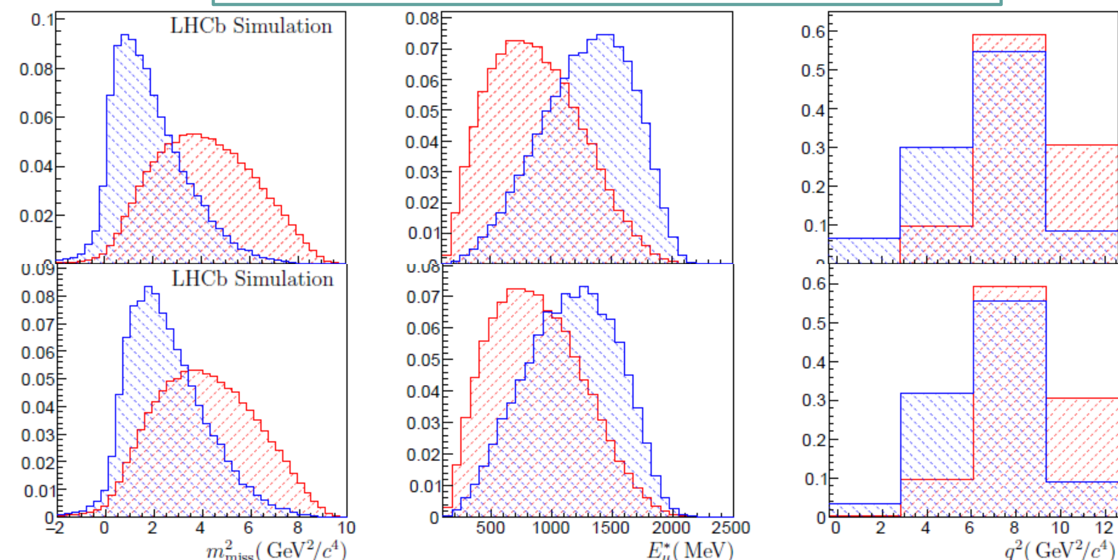
$\bar{B}^0 \to D_1^+(2420)\mu^-\bar{\nu}_\mu$ vs $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$



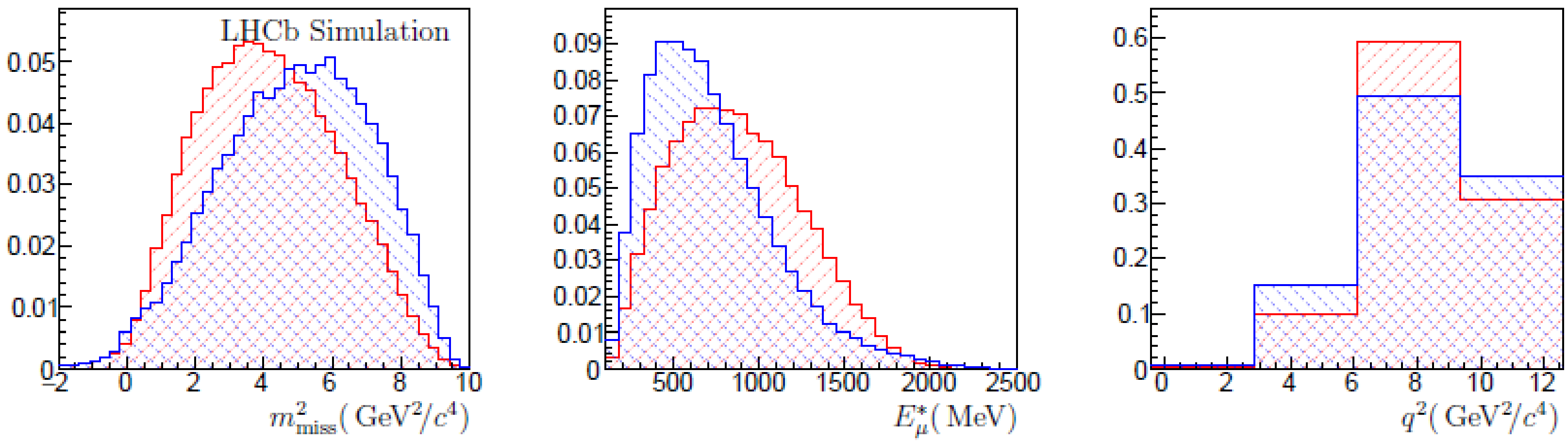
$\bar{B}^0 \to D^{**+}(\to D^{*+}\pi\pi)\mu^-\bar{\nu}_\mu$ vs $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$

- Contributions of excited charm states in the $B^{\pm,0} \to (c\bar{q})\mu\nu$ transition are large
  - 1P states decaying as $D^*\pi$ known and reasonably well-described by theory (HQET)
    - $D^{*+}\mu^-\pi^-$ control sample sets nonperturbative shape parameters for input to signal fit
  - States decaying as $D^*\pi\pi$ less well-understood, fit insensitive to exact composition.
    - $D^{*+}\mu^-\pi^+\pi^-$ control sample used to correct q^2 spectrum to match data
- Distinguishable by "edge" at missing mass $\approx (2)m_\pi$

$B \to D^{*+} H_c(\to \mu\nu X')X$ background

- $b \to c\bar{c}q$ decays can lead to very similar shapes to the semitauonic decay (e.g. $\bar{B}^0 \to D^{*+} D_s^-(\to \phi\mu\nu)$ +many others)
- Branching fractions well-cataloged, but detailed descriptions of the $D^* D K(n \geq 0\ \pi)$ final states are not well-simulated
  - Dedicated $D^{*+}\mu^- K^\pm$ control sample used to improve the template to match data

$\bar{B}^0 \to D^{*+} H_c(\to \mu\nu X')X$ vs $\bar{B}^0 \to D^{*+}\tau^-\nu_\tau$



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Big picture

$\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu$ (normalization)

$\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$
(signal)

$\bar{B}^0 \to D^{**+}\mu^-\bar{\nu}_\mu + \bar{B}^0 \to D^{**+}\tau^-\bar{\nu}_\tau$
$\bar{B}^- \to D^{**0}\mu^-\bar{\nu}_\mu + \bar{B}^- \to D^{**0}\tau^-\bar{\nu}_\tau$
$D^{**} \to D^{*+}\pi$ (3 states each, 6 PDFs)

$\bar{B}^0_s \to D_s^{**+}\mu^-\bar{\nu}_\mu$
$D_s^{**+} \to D^{*+}K_S^0$, (2 states, 1 free param)

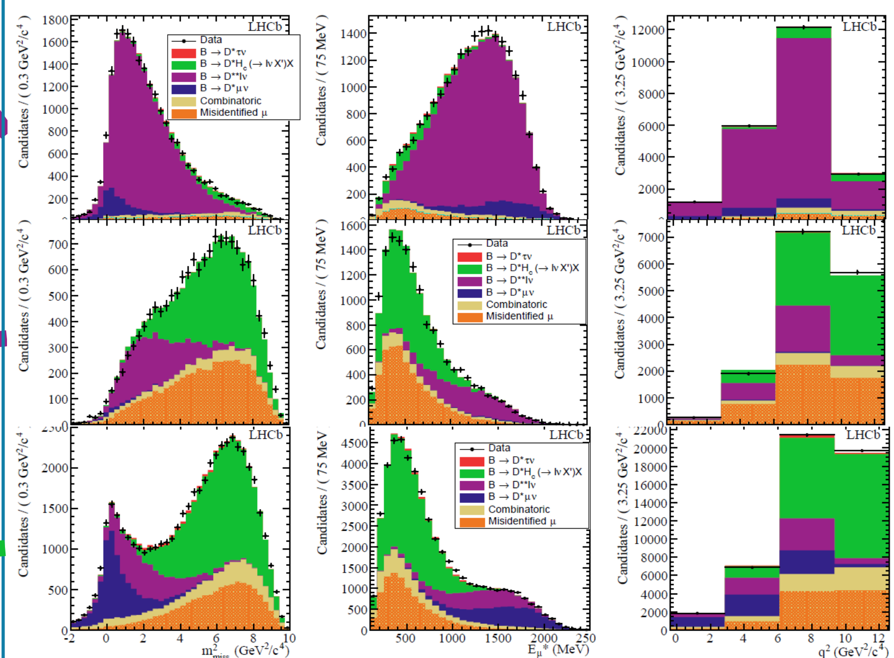
$B^{+,0} \to \bar{D}^{**}\mu^+\nu_\mu$
$\bar{D}^{**} \to D^{*-}\pi\pi$, (cocktail)

$\bar{B} \to D^{*+}H_c(\to \mu\nu X')X$
$+\bar{B} \to D^{*+}D_s^-(\to \tau^-\bar{\nu}_\tau)X$

combinatorial D^{*+}
combinatorial $D^{*+}\mu^-$

$h \to \mu$ misidentification

Control sample fits to constrain shapes



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Signal Fit Results

Fit Result – Full projections

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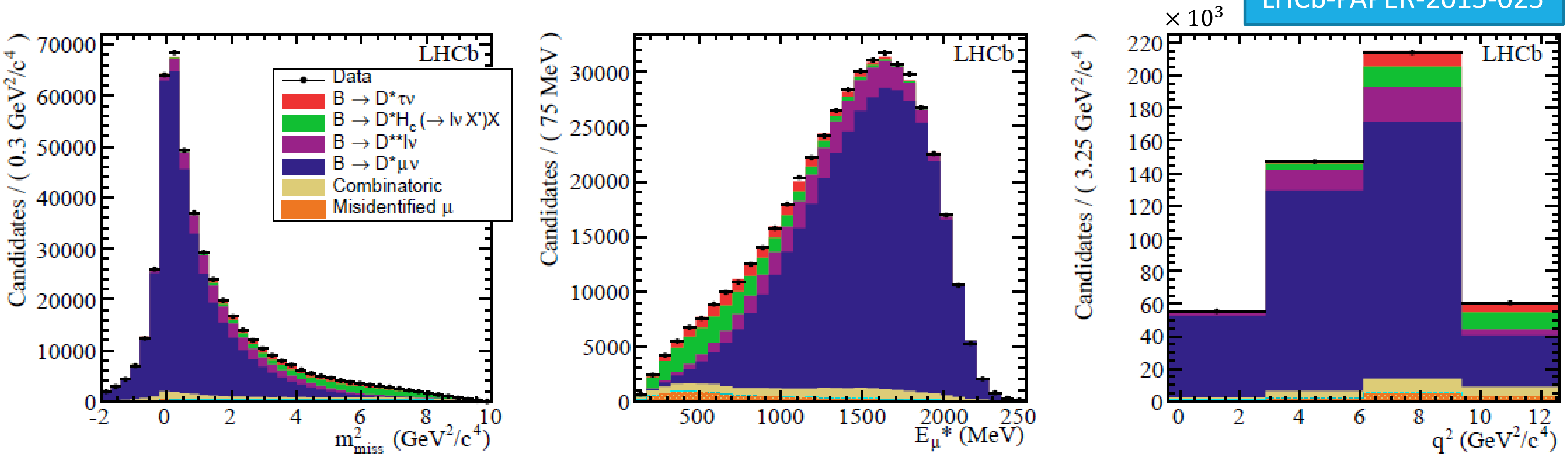
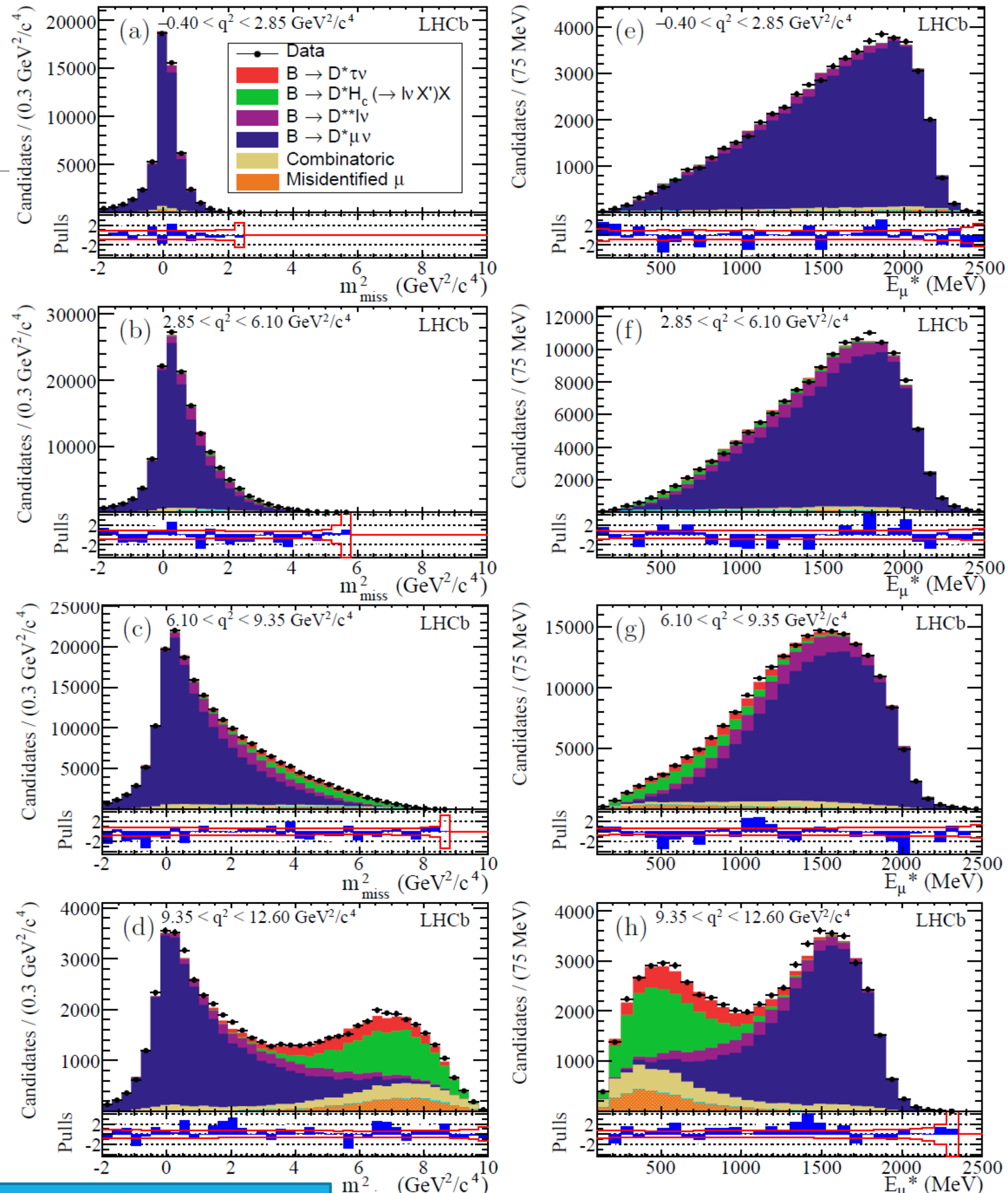


- Projections of (left) m_{miss}^2 and (middle) E_μ^* and (right) q^2
- Signal clearly much smaller than normalization, as expected from phase-space suppression combined with $\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) \cong 17\%$

Detailed fit projections

- Projections of (left) m^2_{miss} and (right) E^*_μ in bins of increasing q^2 from top to bottom

- Signal more clearly visible here in highest q^2 bin
  - Note different y scales, most signal actually in second-highest q^2 bin



arXiv:1506.08614 [hep-ex]

Systematics

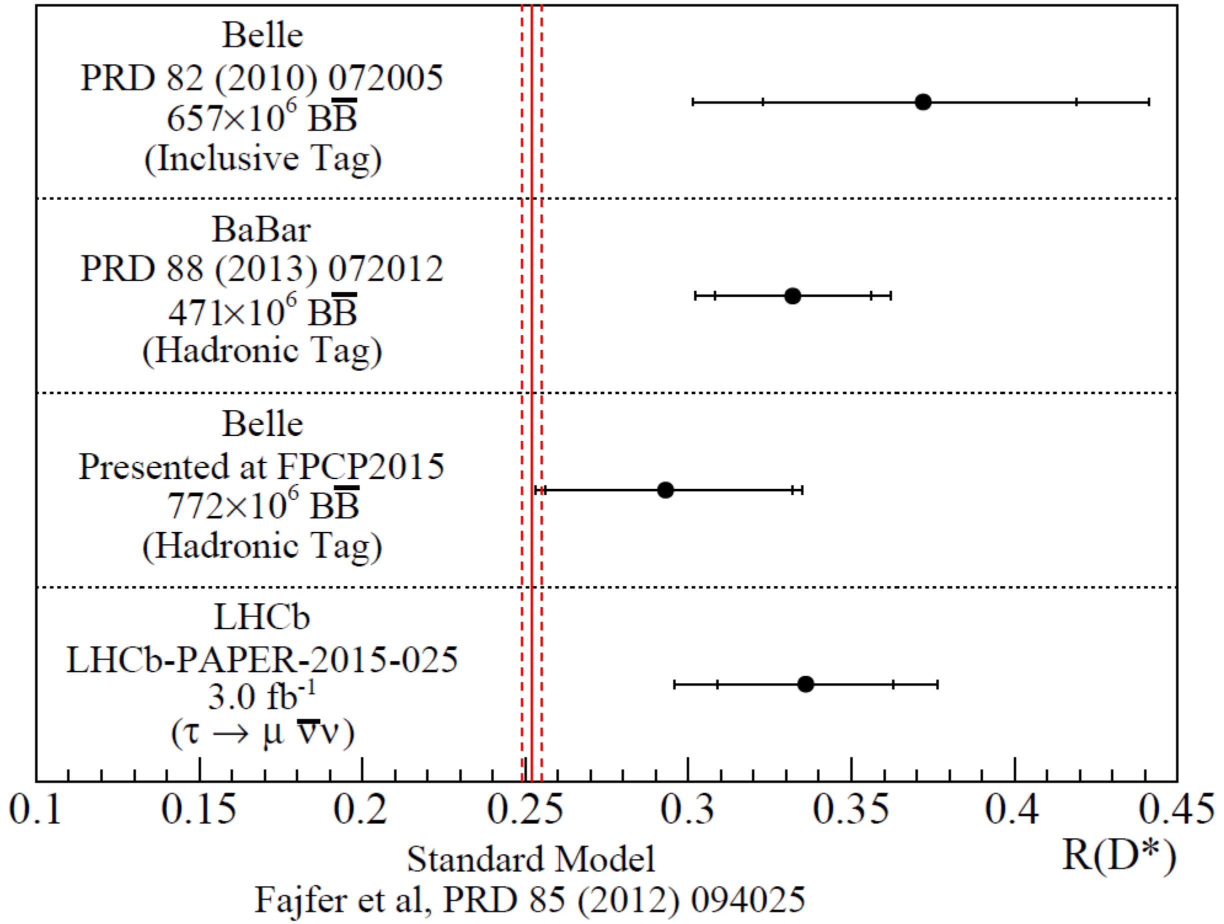
Model uncertainties	Absolute size ($\times 10^{-2}$)
Simulated sample size	2.0
Misidentified μ template shape	1.6
$\overline{B}^0 \to D^{*+}(\tau^-/\mu^-)\overline{\nu}$ form factors	0.6
$\overline{B} \to D^{*+}H_c(\to \mu\nu X')X$ shape corrections	0.5
$\mathcal{B}(\overline{B} \to D^{**}\tau^-\overline{\nu}_\tau)/\mathcal{B}(\overline{B} \to D^{**}\mu^-\overline{\nu}_\mu)$	0.5
$\overline{B} \to D^{**}(\to D^*\pi\pi)\mu\nu$ shape corrections	0.4
Corrections to simulation	0.4
Combinatorial background shape	0.3
$\overline{B} \to D^{**}(\to D^{*+}\pi)\mu^-\overline{\nu}_\mu$ form factors	0.3
$\overline{B} \to D^{*+}(D_s \to \tau\nu)X$ fraction	0.1
Total model uncertainty	**2.8**
Normalization uncertainties	**Absolute size ($\times 10^{-2}$)**
Simulated sample size	0.6
Hardware trigger efficiency	0.6
Particle identification efficiencies	0.3
Form-factors	0.2
$\mathcal{B}(\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau)$	< 0.1
Total normalization uncertainty	**0.9**
Total systematic uncertainty	**3.0**

Expected to be reduced

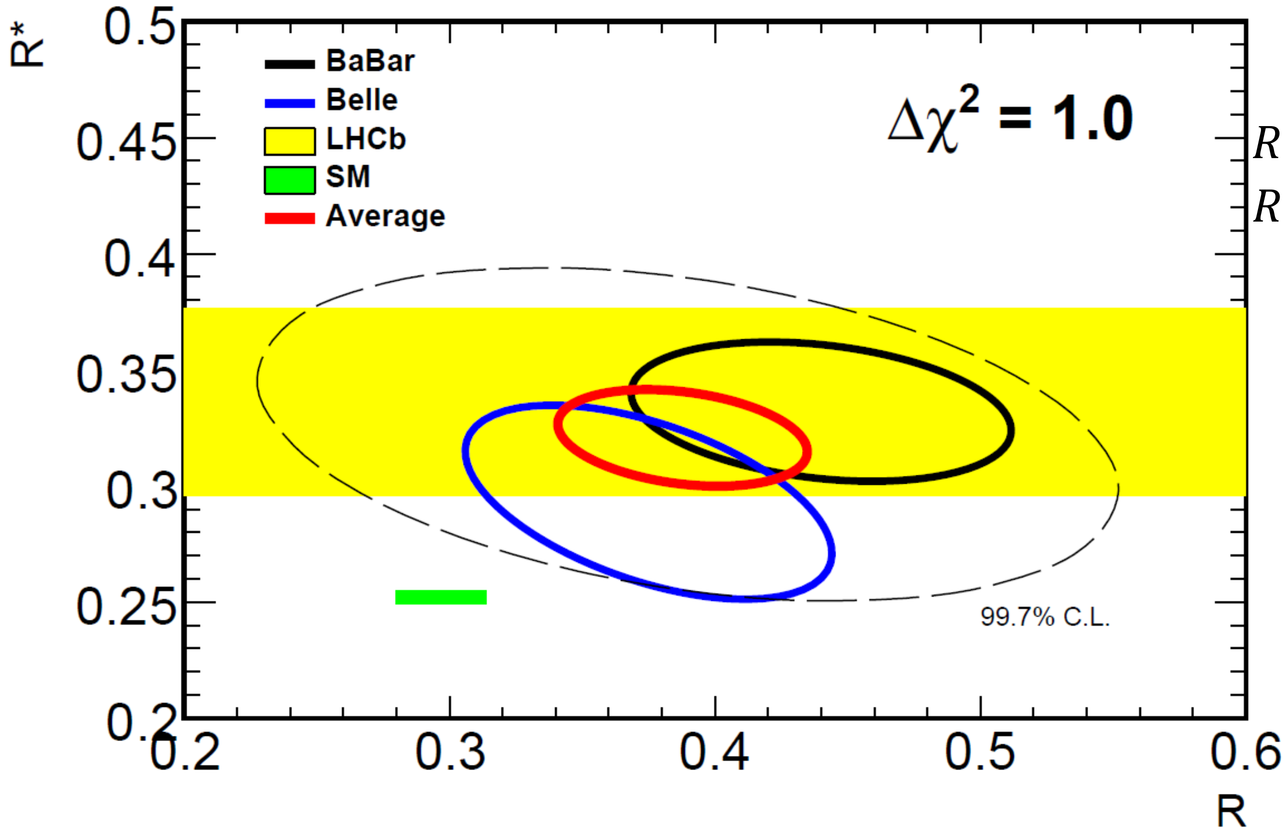
Will scale down with more data

Result

- Full result:
  $R(D^*) = 0.336 \pm 0.027 \pm 0.030$
  - Close agreement with BaBar result
  - 2.1σ from SM. Not significant alone, but tantalizing given history of high results in this channel



A global look



$$R(D^*)_{avg} = 0.322 \pm 0.021$$
$$R(D)_{avg} = 0.390 \pm 0.047$$
$$\rho = -0.34$$

- WARNING: Average shown is the naïve weighted average with no correlations or use of fit likelihoods!
- Plot and average courtesy of M. Rotondo

Summary

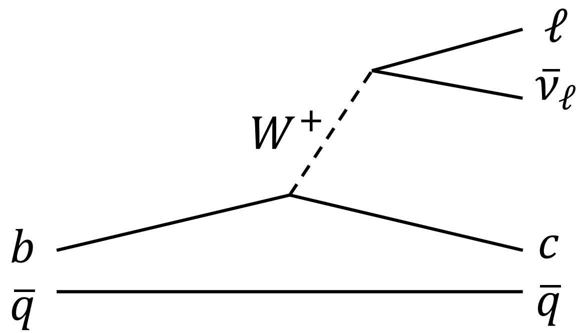
- LHCb has produced a competitive measurement of the ratio of semileptonic branching fractions $R(D^*) \equiv \frac{\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)}$
  - Result: $R(D^*) = 0.336 \pm 0.027 \pm 0.030$
    - Good agreement with similar measurements at the B-factories
  - Plans for simultaneous measurement of $R(D)$ and $R(D^*)$ with existing data, as well as analogous measurement in other b hadron decays
  - Prospects for Run2 and beyond very good, with most systematics expected to scale with size of (control) data

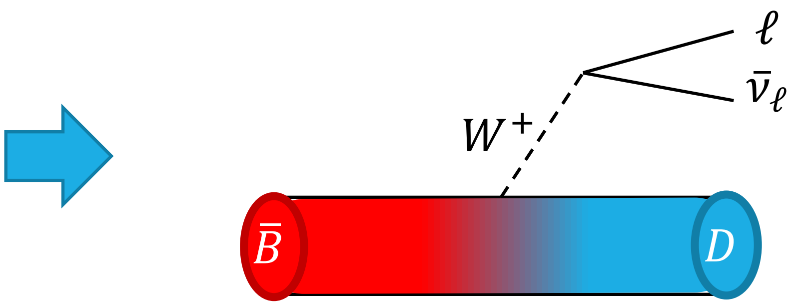
- $\bar{B}^0 \to D^{*+}\tau^-(\to \pi^+\pi^-\pi^+\nu_\tau)\bar{\nu}_\tau$ using Run1 data underway
  - Will provide complimentary information via different systematic uncertainties

- “Real” main result: semitauonic B decays are still very interesting, and will remain so for the foreseeable future

Backup

Aside: nonperturbative factors





- Know the general form $|\mathcal{M}|^2 = L^{\alpha\beta} H_{\alpha\beta}$
  - $L^{\alpha\beta}$ describes $W^{*\pm} \to \ell^\pm \nu$ and is completely calculable (messy spinor algebra)
  - $H_{\alpha\beta}$ describes $\bar{B} \to W^{*\pm} D^{(*)}$, and is non-perturbative
    - BUT it can only depend on the 4-velocities of the $\bar{B}$ and $D^{(*)}$, as well as m_{W^*} and the D^* polarization (if D^*)
      - *Finite number of Lorentz-covariant combinations of the 4-vectors*
      - Each combination is multiplied by a scalar function of $m_{W^*}^2 = q^2$-> “form factors”

Efficiency Ratio

From fit

Known (~17%)

$$R(D^*) = \frac{N(\bar{B}^0 \to D^{*+}\tau^-(\to \mu^-\bar{\nu}\nu)\bar{\nu})}{N(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu})} \times \frac{1}{\mathcal{B}(\tau^- \to \mu^-\bar{\nu}\nu)} \times \frac{\epsilon_n}{\epsilon_s}$$

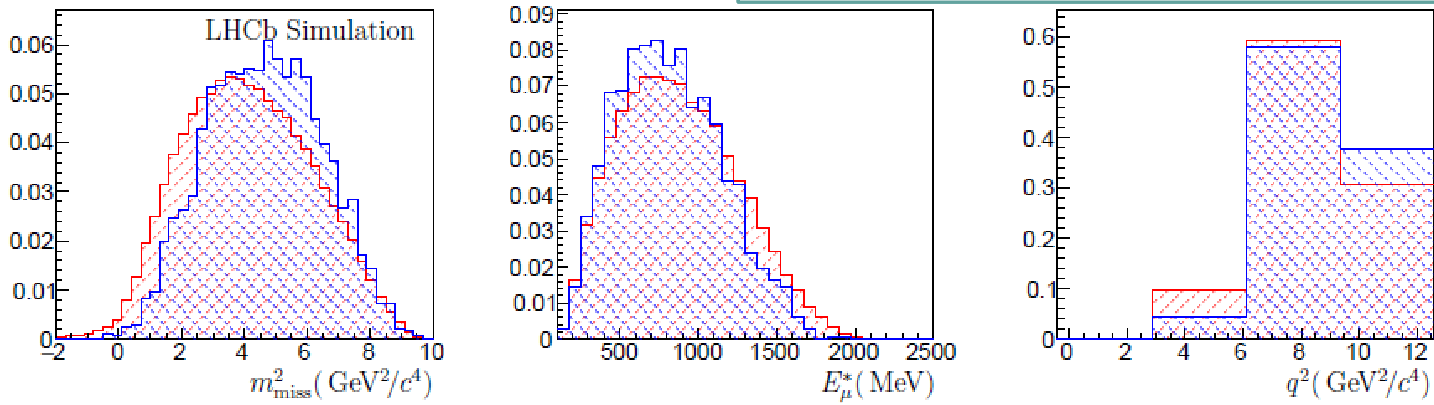
Computed in simulation (with corrections)

$$\frac{\epsilon_s}{\epsilon_n} = (77.6 \pm 1.4)\%$$

Deviation from 100% due to τ flight and lower Muon ID efficiency at low p_T

Tau backgrounds

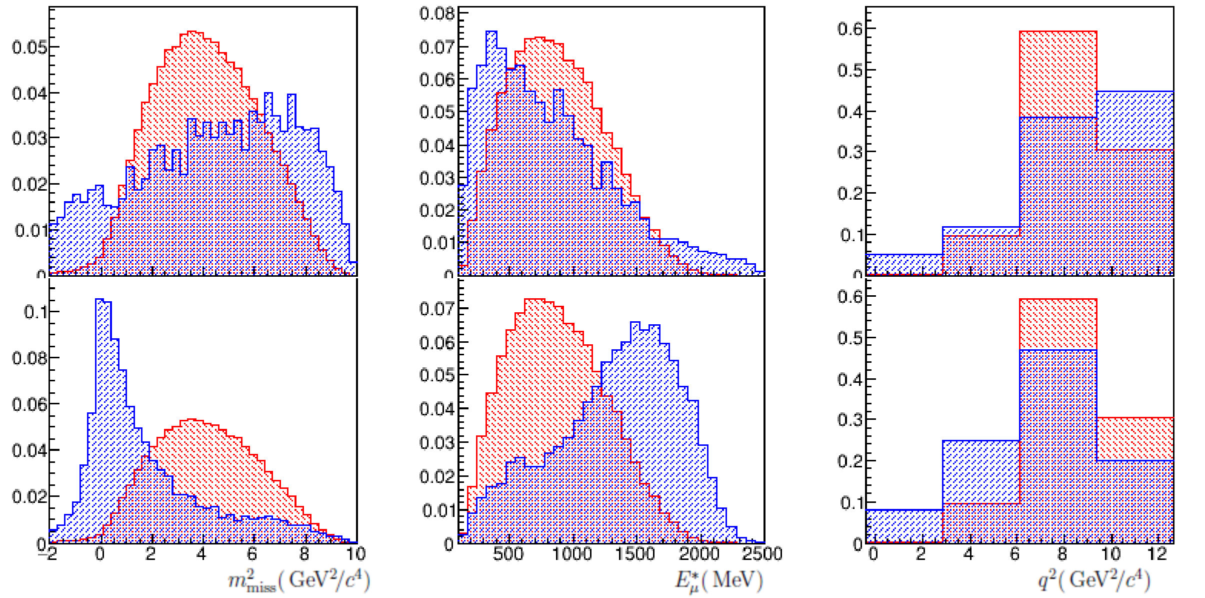
$\bar{B}^0 \to D_2^{*+}(2460)\tau^-\bar{\nu}_\tau$ vs $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$



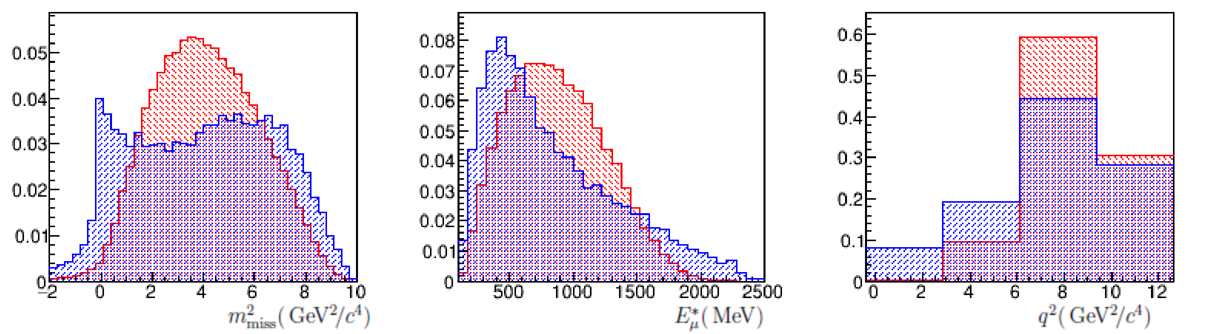
- All backgrounds with real $\tau \to \mu\bar{\nu}\nu$ decays are an order of magnitude (at least) smaller than the signal
  - Background contributions from $\bar{B} \to D^{**}\tau^-\bar{\nu}_\tau$ are considered to be fixed relative to the corresponding decay modes to muons
    - Very small component, varying this contribution by 50% only moves R(D*) by 0.005
  - Similarly, $\bar{B} \to D^{*+}D_s^-(\to \tau^-\nu)X$ are fixed to a known fraction of the $\bar{B} \to D^{*+}H_c(\to \mu\nu X')X$ background
    - Again, these have a negligible effect on R(D*)

Other backgrounds

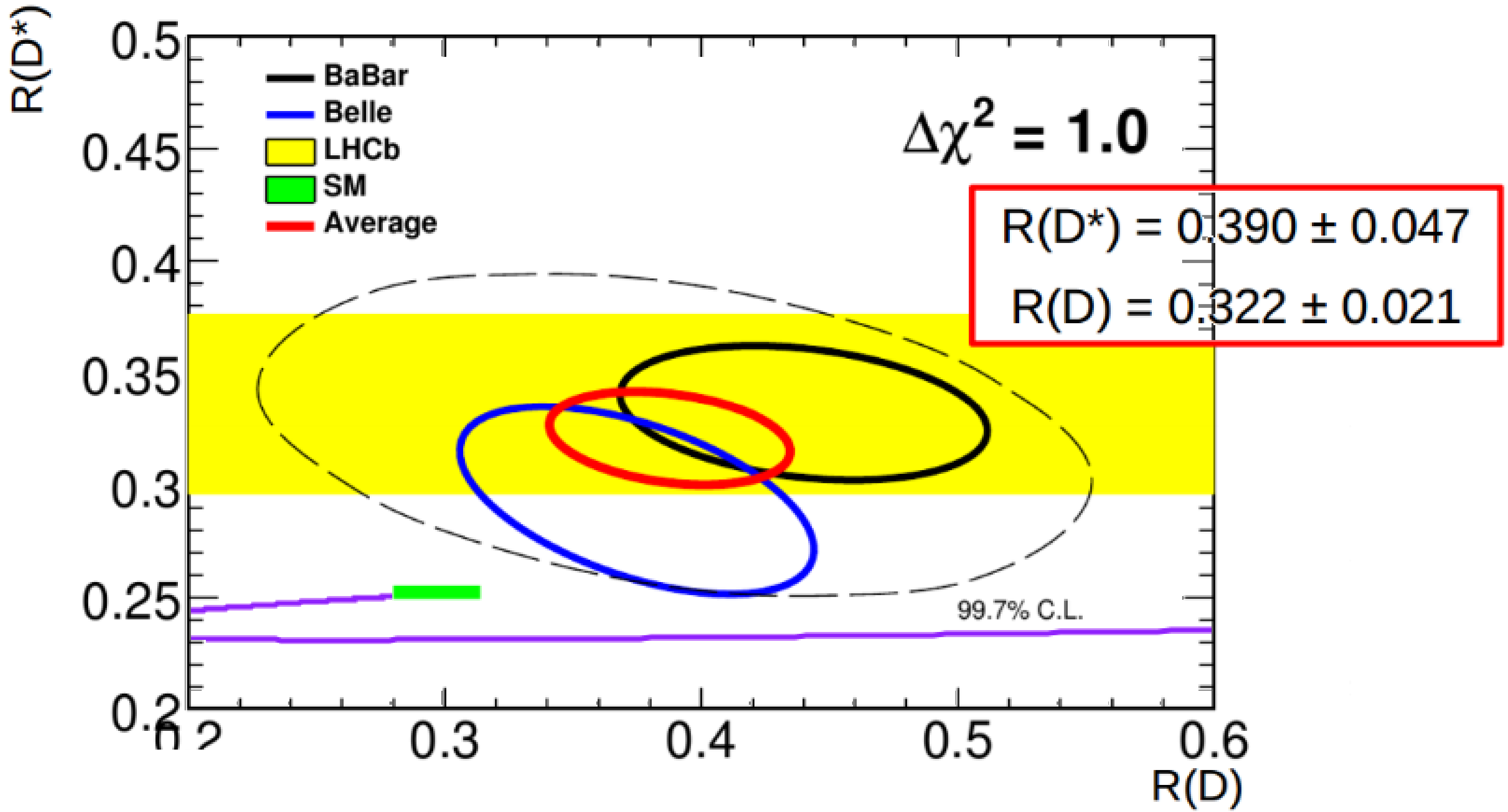
- Other backgrounds from "junk" reconstructed as $D^{*+}\mu^-$
  - combinatorial (top), fake D^{*+} candidates (middle), hadrons misidentified as muons (bottom), all derived from control samples



- Misidentification background particularly troublesome due to ambiguities in deriving fit shapes from the control sample



A global look



- WARNING: Average shown is the simple weighted average -- no correlations or likelihood combinations (yet)!

- Purple: sketch of 2HDM central value plotted for $0 < \frac{\tan\beta}{m_H} < 1$ just to show shape
  - General punchline: 0^+ contributions interfere destructively with SM to suppress R(D*), some other Lorentz structure needed…