Charm Decays and Spectroscopy at BABAR

Representing the *BABAR* Collaboration

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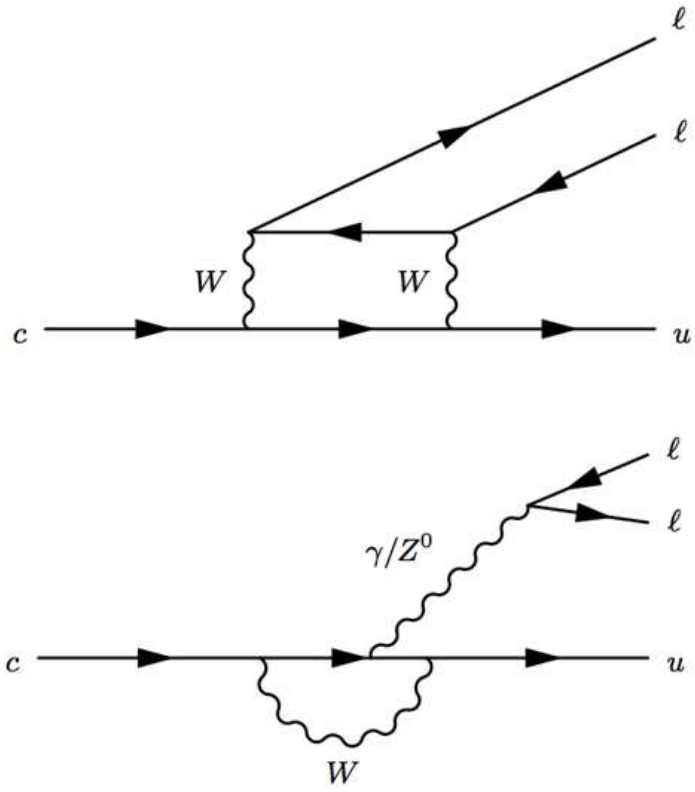
☐ SM short-distance contribution to $c \to u\ell^+\ell^-$ transition



♢ Flavor-Changing Neutral Current (FCNC)

→ very rare because they cannot occur at tree level in SM, heavily GIM suppressed

♢ Lepton-Flavor Violating (LFV) and Lepton-Number Violating (LNV) decays

→ are forbidden in Standard Model

♢ All these predictions are orders magnitude below the current experimental sensitivity

♢ In New Physics (NP), FCNC can be enhanced by many orders of magnitude:

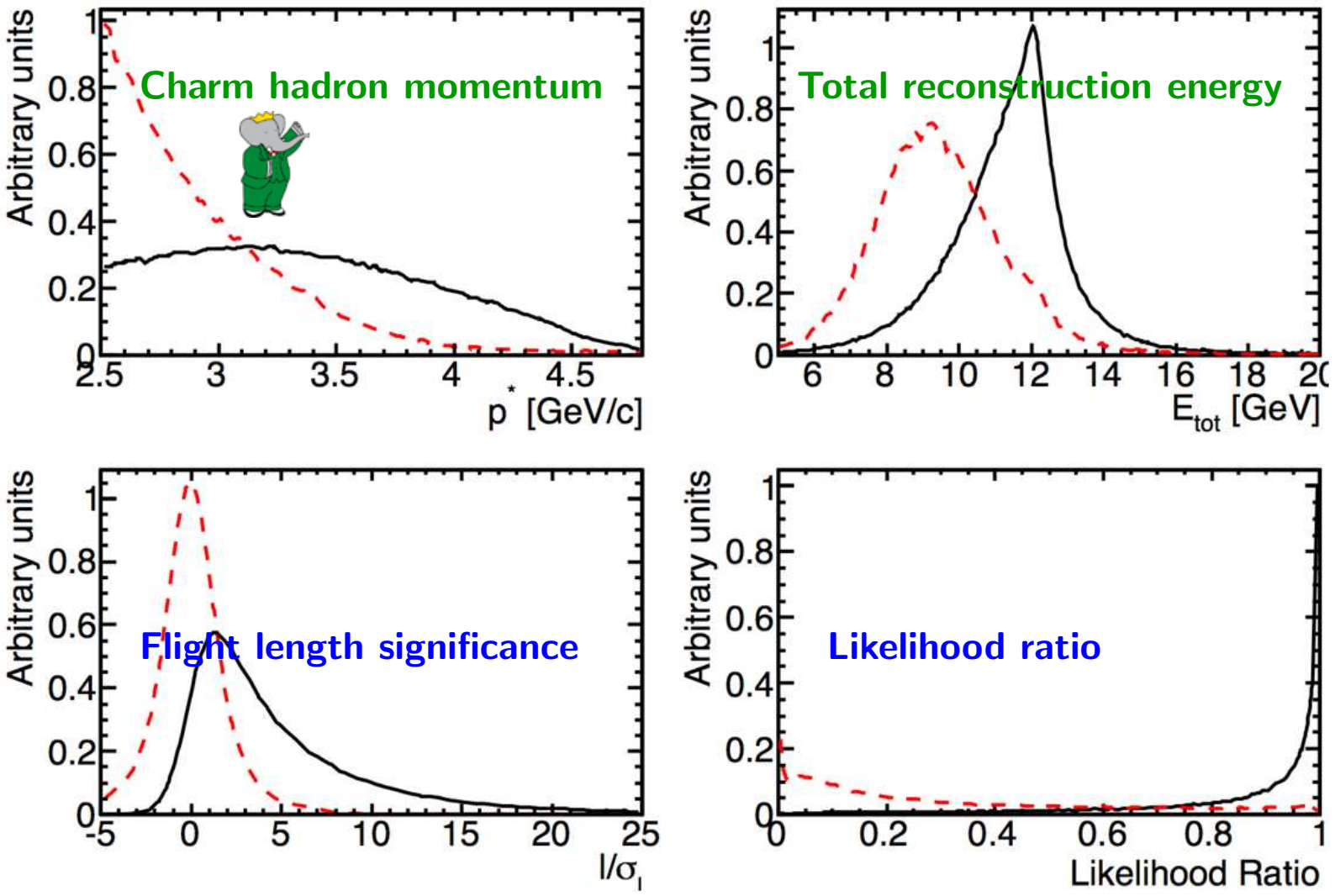
- Recent $D^0 - \bar{D}^0$ mixing observation
- R-parity violating supersymmetry (based on R-parity violating couplings)

NP scenario predicts signals within experimental sensitivity $\mathcal{O}(10^{-5})$

Search for $X_c^+ \to h^\pm \ell^\mp \ell^{(\prime)\pm}$ PRD 84, 072006, 2011

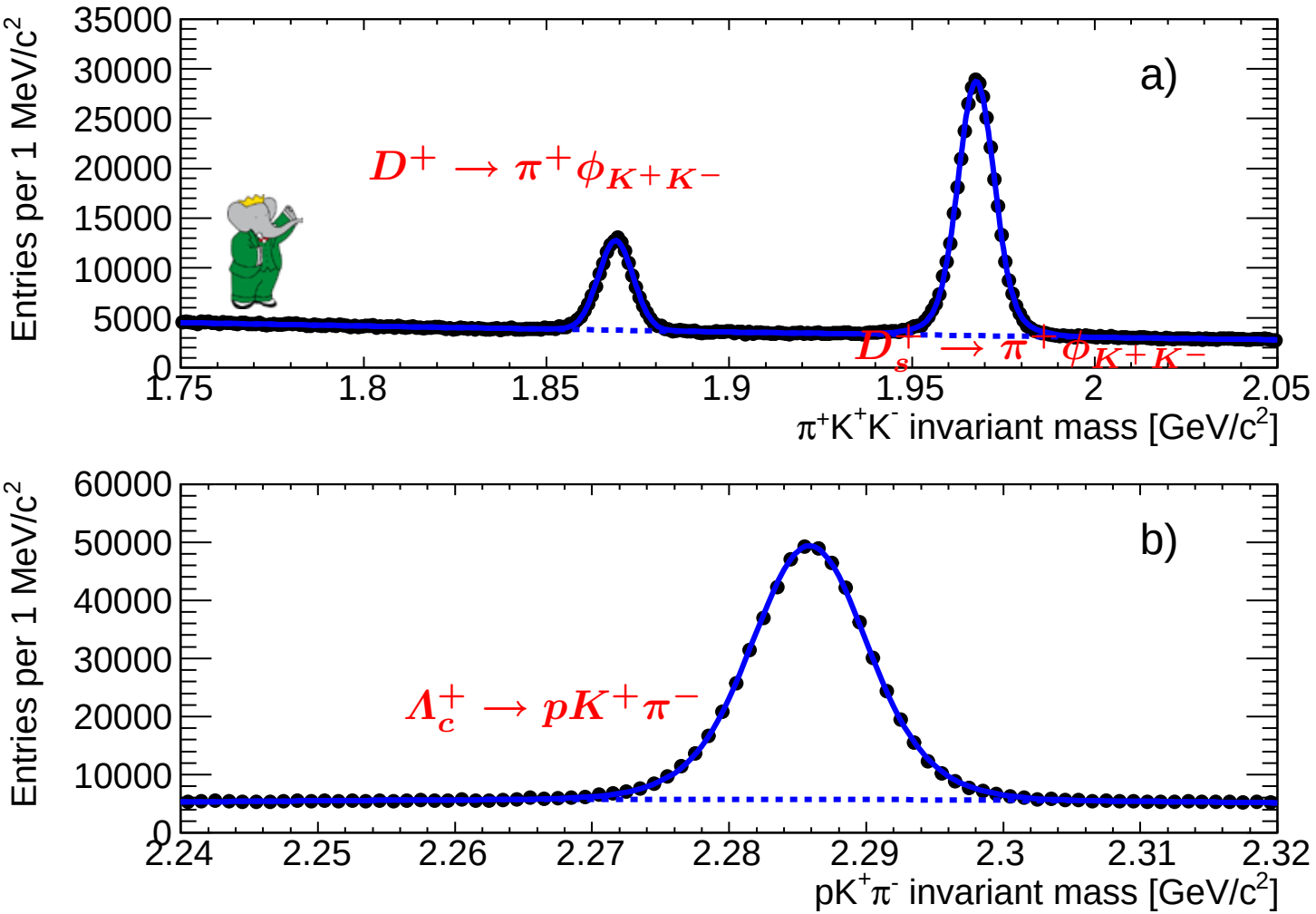
- Data: 384 fb^{-1} at $\Upsilon(4S)$ on-resonance and 37 fb^{-1} at $\Upsilon(4S)$ off-resonance
- X_c^+ is charm hadron $\to$ D^+, D_s^+ or Λ_c^+
- $\ell^{(\prime)\pm}$ is an electron or muon
- For D^+ and D_s^+ modes: $h^\pm$ can be $\pi^\pm$ or $K^\pm$; For Λ_c^+ modes: $h^\pm$ is a proton
- Lepton: Search for all combination of e and μ including Lepton-Flavor Violating (LFV) and Lepton Number Violating (LNV)
- To suppress QED backgrounds $\to$ at least 5 tracks in event
- To suppress combinatoric backgrounds $\to$ p^* of $X_c > 2.5$ GeV
- Mass $M_{e^+e^-} > 200$ MeV to reject photon conversion and π^0 decays
- For $D_{(s)} \to \pi\ell\ell^{(\prime)} \to$ the ϕ resonance in dilepton invariant mass is excluded

- Combinatoric background Vs. Signal



- Red is combinatoric background from sideband data
- Black solid curve is signal MC of $D^+ \to \pi^+ e^+ e^-$

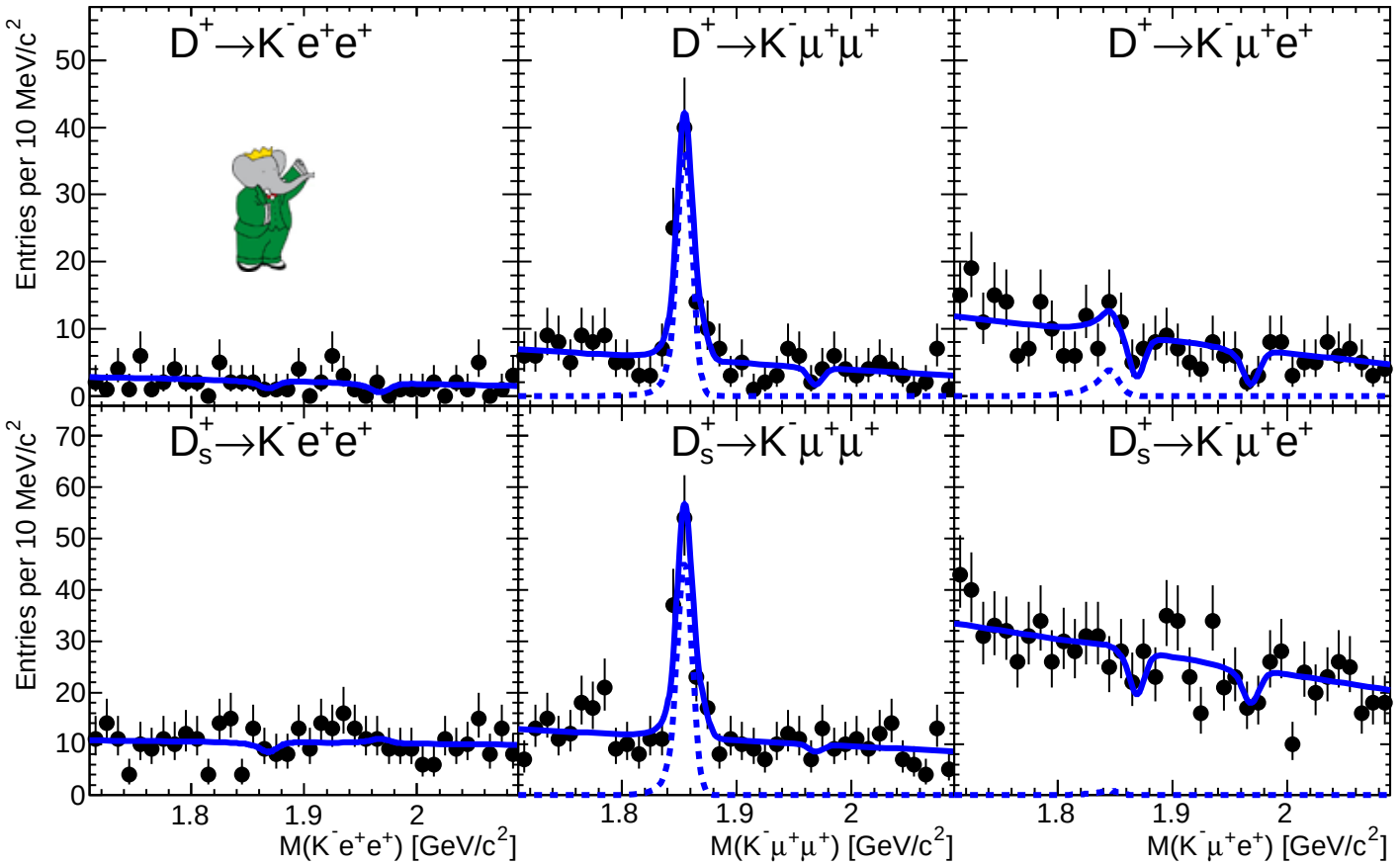
- Measured signal yields are converted into BR by normalizing them to the yields of known charm decays



- Solid line = fits to double-Gaussian for signal

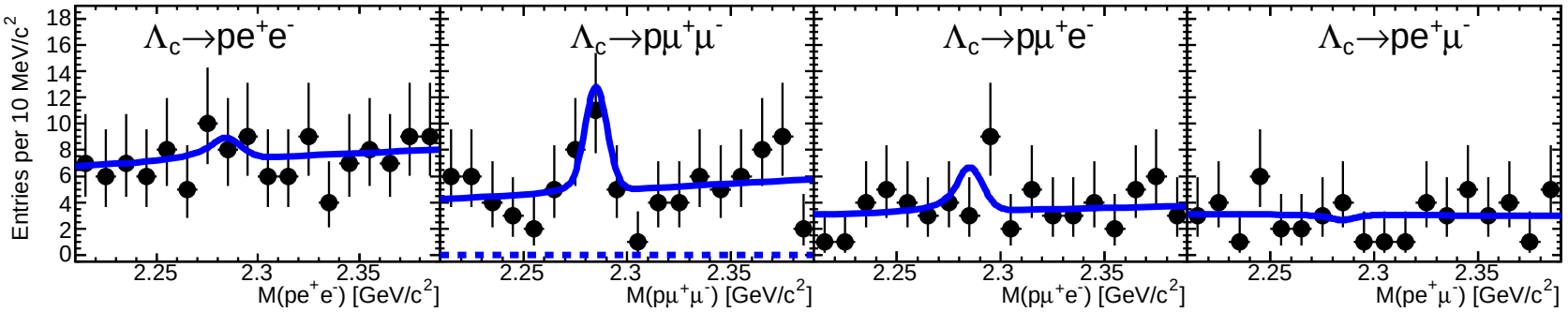
  Dash line = second-order polynomial for background

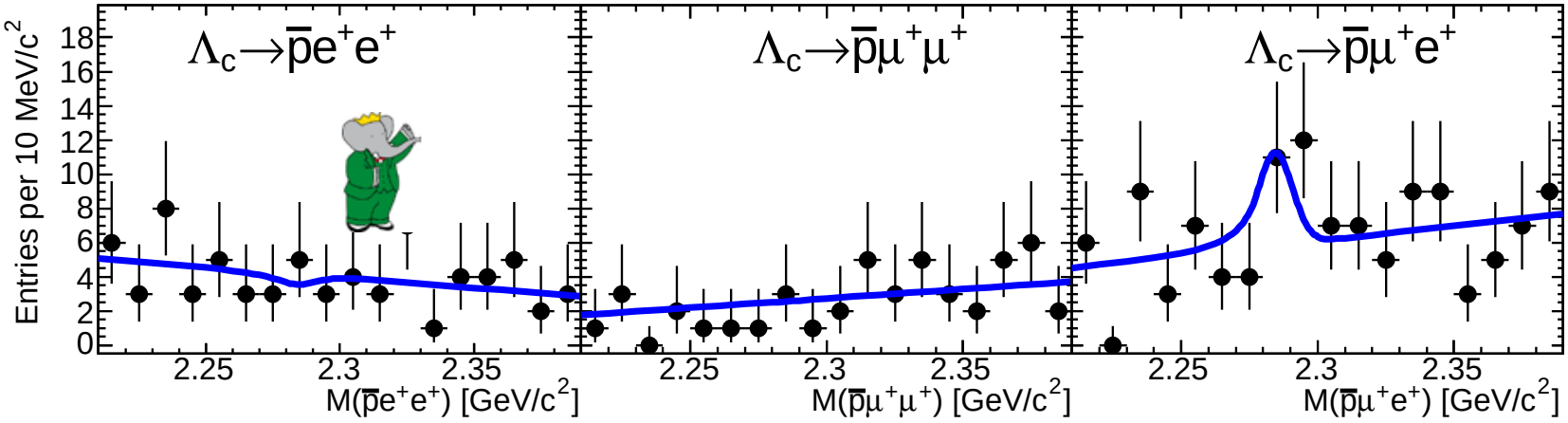
- 35 different measurements on $X_c^+ \to h^\pm \ell^\mp \ell^{(\prime)\pm}$ inv. mass distributions



- Solid lines = invariant mass for $D^+ \to K^- \ell^+ \ell^{(\prime)+}$ and $D_s^+ \to K^- \ell^+ \ell^{(\prime)+}$
- Dash lines = background component for dimuon modes and $D_{(s)}^+ \to K^- \mu^+ e^+$ from misidentified hadrons
- Peaking background: $D^+ \to K^- \pi^+ \pi^+$ and $D_{(s)}^+ \to K^+ (\phi \to K^+ K^-)$

Search for $X_c^+ \to h^\pm \ell^\mp \ell^{(\prime)\pm}$ Fit Results: $\Lambda_c^+ \to (p/\bar{p})\ell^+\ell^{(\prime)\pm}$





- $\Lambda_c^+ \to p\ell^+\ell^{(\prime)-}$ (top) and $\Lambda_c^+ \to \bar{p}\ell^+\ell^{(\prime)+}$ (bottom) inv. mass distributions
- Background component for dimuon candidates from misidentified hadrons
- The most significant signal is seen in $\Lambda_c^+ \to p\mu^+\mu^-$

Search for $X_c^+ \to h^\pm \ell^\mp \ell^{(\prime)\pm}$ PRD 84, 072006, 2011

- No signals are observed in 35 measurements: $X_c^+ = D^+, D_s^+$ or Λ_c^+
- Report upper limits between $(0.4 - 37) \times 10^{-4}$ at 90% CL on ratio of BF for the signal mode wrt that of normalization mode
- This corresponds to limits on BF between $(1 - 44) \times 10^{-6}$ at 90% CL
- The most significant signal: $\Lambda_c^+ \to p\mu^+\mu^-$:

Yields (event) $= 11.1 \pm 5.0(stat.) \pm 2.5(syst.)$ (2.6σ)

$\to BF(\Lambda_c^+ \to p\mu^+\mu^-) = 44 \times 10^{-6}$ at 90% CL

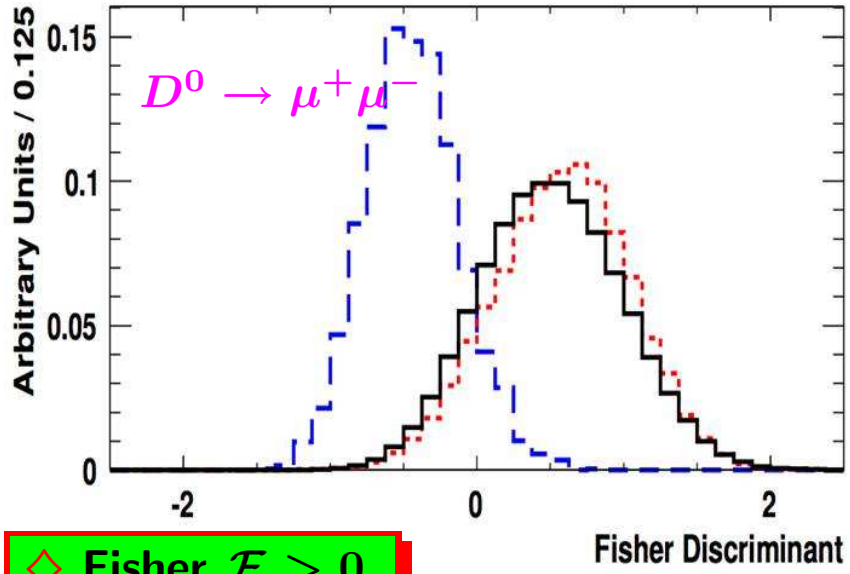
Search for $D^0 \to \ell^{\mp}\ell^{(\prime)\pm}$ Submitted to PRD: arXiv 1206.5419

- We search for all lepton flavor combinations: e^+e^-, $\mu^+\mu^-$, $e^+\mu^-$, or $e^-\mu^+$
- Data: 468 fb^{-1} at $\Upsilon(4S)$ on-resonance (BABAR full dataset)
- Combinatoric bkgs are dominated by semileptonic B and Charm decays
- To reduce the combinatoric background we required:
  - $p^*(D^0)$ of decays $D^{*+}(2010) \to D^0\pi^+ > 2.4$ GeV
  - Slow pion from D^{*+} vertex constrained to beam spot to improve resolution
- Vertex probability of D^0 and D^{*+} vertices $> 1\%$
- QED backgrounds are eliminated with the following criteria:
  - Minimum event track multiplicity: $e^+e^- \geq 5$, $\mu^+\mu^-$ and $e\mu \geq 4$
  - Event can only have at most 3 electron candidates
  - Slow pion from D^{*+} and leptons cannot be originating from photon conversion

☐ To distinguish combinatoric $B\overline{B}$ background and signal → Fisher Discriminant

Using the combination of the following variables:

- ♢ Ratio of the 2^{nd} and 0^{th} Fox-Wolfram moments
- ♢ The missing transverse momentum wrt the beam axis
- ♢ The D^0 momentum in the Center of Mass
- ♢ The measured D^0 flight length divided by its uncertainty
- ♢ $|cos\ \theta_{helicity}|$, where $\theta_{helicity}$ is the D^0 decay helicity angle



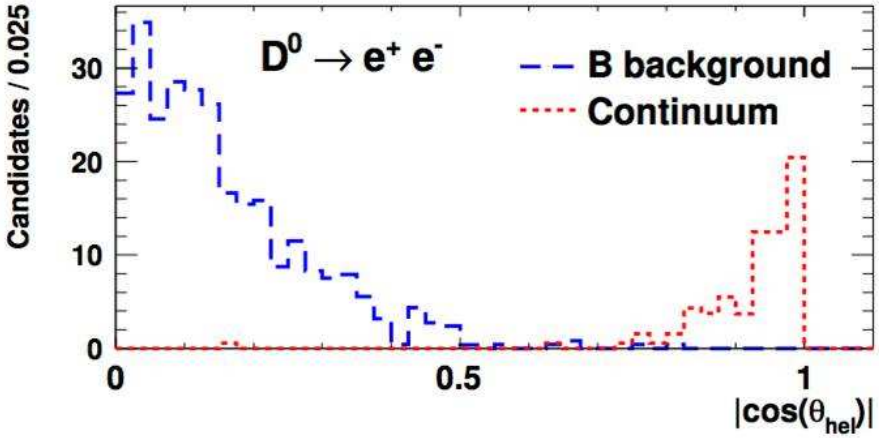
♢ Fisher $\mathcal{F} > 0$

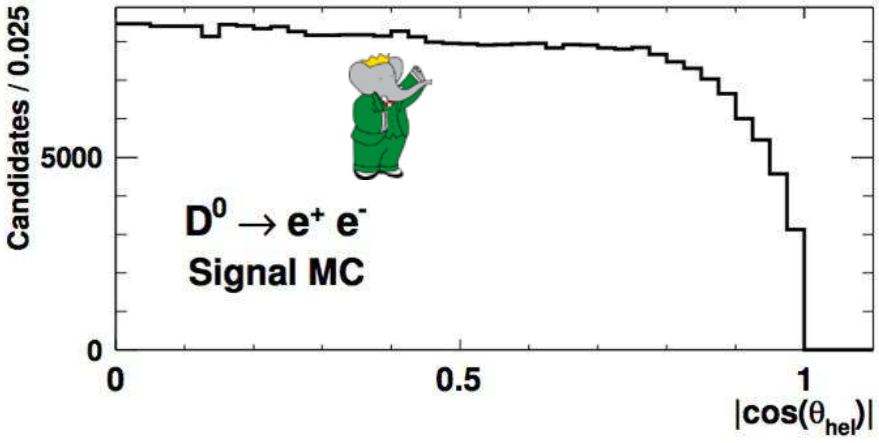
- ♢ Dashed blue → $B\overline{B}$ Monte Carlo
- ♢ Solid black → Signal MC
- ♢ Dotted red → Continuum MC

Search for $D^0 \to \ell^{\mp}\ell^{(\prime)\pm}$ Cont. Bkg Suppression: arXiv 1206.5419

☐ We use $|cos\ \theta_{helicity}|$ variable to remove continuum combinatoric background

Requirement: $|cos\ \theta_{helicity}| > 0.85$





◇ Before minimum Fisher requirement

◇ Top:

◇ Dashed blue → Combinatoric $B\overline{B}$

◇ Dotted red → Continuum Bkg

◇ Bottom:

Solid black → Signal MC with arbitrary normalization

- No statistically significant excess over the background
- Observed 1 event for $D^0 \to e^+e^-$ with expected bkg 1.0 ± 0.5
- Observed 2 events for $D^0 \to e^{\pm}\mu^{\mp}$ with expected bkg 1.4 ± 0.3
- Observed 8 events for $D^0 \to \mu^+\mu^-$ with expected bkg 3.9 ± 0.6
- Set Upper Limit on the Branching Fraction at 90% CL:

$$D^0 \to e^+e^- < 1.7 \times 10^{-7} \quad \to \quad \text{(best electron channel)}$$

$$D^0 \to e^{\pm}\mu^{\mp} < 3.3 \times 10^{-7}$$

$$D^0 \to \mu^+\mu^- = [0.6, 8.1] \times 10^{-7}$$

- LHCb: $D^0 \to \mu^+\mu^- < 1.3 \times 10^{-8}$ at 95% CL (LHCb-CONF-2012-005)

- Measurement of $\Gamma(D^{*+})$ opens an important window on the non-perturbative strong interaction of heavy quarks

- Total width in terms of the strong couplings:

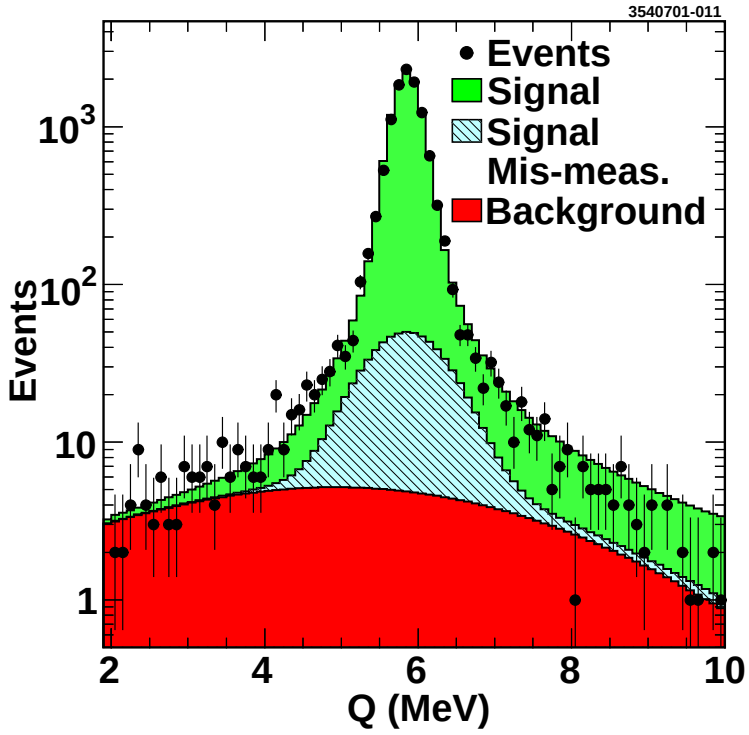
$$\Gamma(D^{*+}) = \frac{2g^2 p_\pi^3}{12\pi f_\pi^2} + \frac{g^2 p_{\pi^0}^3}{12\pi f_\pi^2} + \frac{\alpha g^2_{D^*\to D^+\gamma} p_\gamma^3}{3}$$

Where g is a universal strong coupling between heavy vector and pseudoscalar mesons and f_π is the pion decay constant

- Total width of the D^{*+} only depends on universal strong coupling g since contribution of electromagnetic decay of $D^* \to D^+\gamma$ can be neglected

- Since there is no phase space for $B^* \to B\pi$ splitting $\to g$ can also be used to calculate the coupling in B system

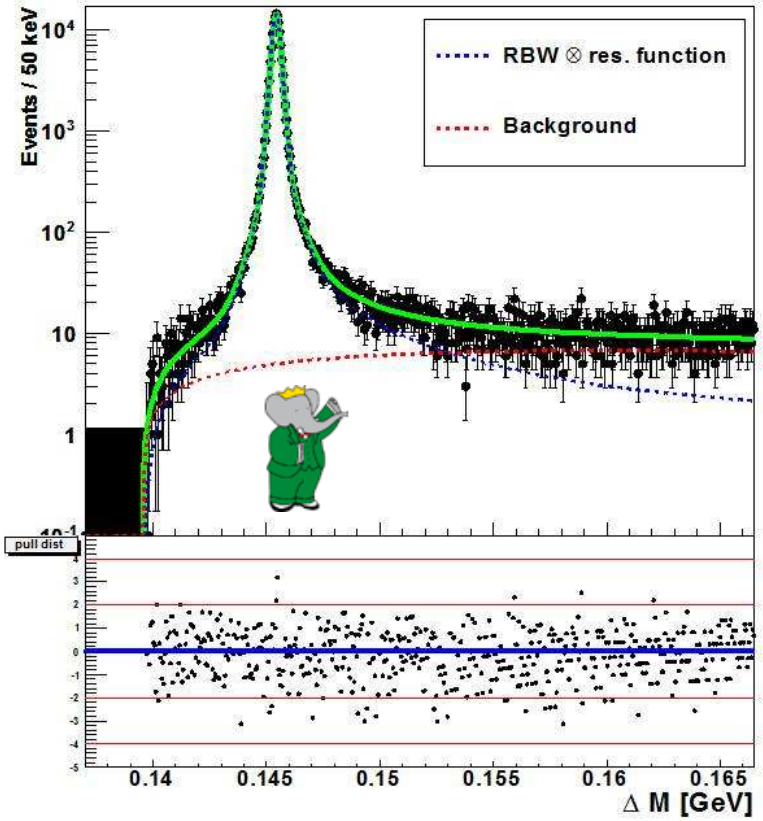
☐ Previous measurement of $\Gamma(D^{*+})$



- CLEO: PRD 65, 032003 (2002)
- $Q = M(K^-\pi^+\pi^+) - M(K^-\pi^+) - m_{\pi^+}$
- $\Gamma(D^{*+}) = (96 \pm 4 \pm 22)$ keV
- Data: 9 $fb^{-1} \rightarrow$ 11,000 $D^0 \rightarrow K^-\pi^+$

- Calculation by Pierro and Eichen (PRD 64, 114004, 2001) showed good agreement with CLEO's result where $g = 0.82 \pm 0.09$
- However, BABAR results (PRD 82, 11101, 2010) showed a disagreement in $g = 1.15 \pm 0.01$ when using $\Gamma(D_2^{*0}(2460)) = (50.5 \pm 0.9)$ MeV

☐ **BABAR Preliminary:**



- CLEO result was systematically limited
- ΔM = Mass difference of D^{*+} and D^0 where $D^0 \to K^-\pi^+$ (142,000 events)
- Blue → Signal (Breit-Wigner Lineshape) convoluted with experimental resolution function from MC (not allowed by FWHM)
- Larger BABARś sample → allowed us to do a better background study
- Green → total PDF, red → total bkg

$$\Delta M = (145,425 \pm 0.6 \pm 2.6) \text{ keV}$$

$$\Gamma(D^{*+}) = (83.5 \pm 1.7 \pm 1.2) \text{ keV} \to g = 0.76 \pm 0.01$$

Summary BABAR is still producing papers...

- Search for $X_c^+ \to h^\pm \ell^\mp \ell^{(\prime)\pm}$ (PRD 84, 072006, 2011)
  - BABAR significantly improved in most channels
  - The most significant signal: $\Lambda_c^+ \to p\mu^+\mu^-$:

Yields (event) $= 11.1 \pm 5.0(stat.) \pm 2.5(syst.)$ (2.6σ)

- Search for $D^0 \to \ell^\mp \ell^{(\prime)\pm}$: UL on BF at 90% CL (Preliminary)

$D^0 \to e^+e^- < 1.7 \times 10^{-7}$ $\to$ (best result on electron)

$D^0 \to e^\pm \mu^\mp < 3.3 \times 10^{-7}$

$D^0 \to \mu^+\mu^- = [0.6, 8.1] \times 10^{-7}$

- Most precise measurement D^{*+} total width

$\Gamma(D^{*+}) = (83.5 \pm 1.7 \pm 1.2)$ keV (Preliminary)

...

BACKUP SLIDES

BACKUP : Search for $D^0 \to \ell^{\mp}\ell^{(\prime)\pm}$ Selected Event

☐ Scatter plot of Δm Vs. m(D^0), m(D^0) projections and Δm projections