Measurement of $\mathcal{B}(D^+ \to \mu^+ \nu_\mu)$ and the Pseudoscalar Decay Constant f_D at CLEO

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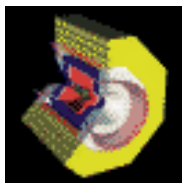


CLEO

representing the

CLEO Collaboration

CESR

1st Meeting of the APS topical Group on Hadronic Physics
Fermilab, Oct 24-26, 2004

Outline

- Motivation
- Detector and data sample
- Analysis strategy:
  - tagging technique
  - signal selection
- Background
- Summary

Motivation

Helicity suppression: $\tau : \mu : e = 3.2 : 1 : 2.4\times10^{-5}$

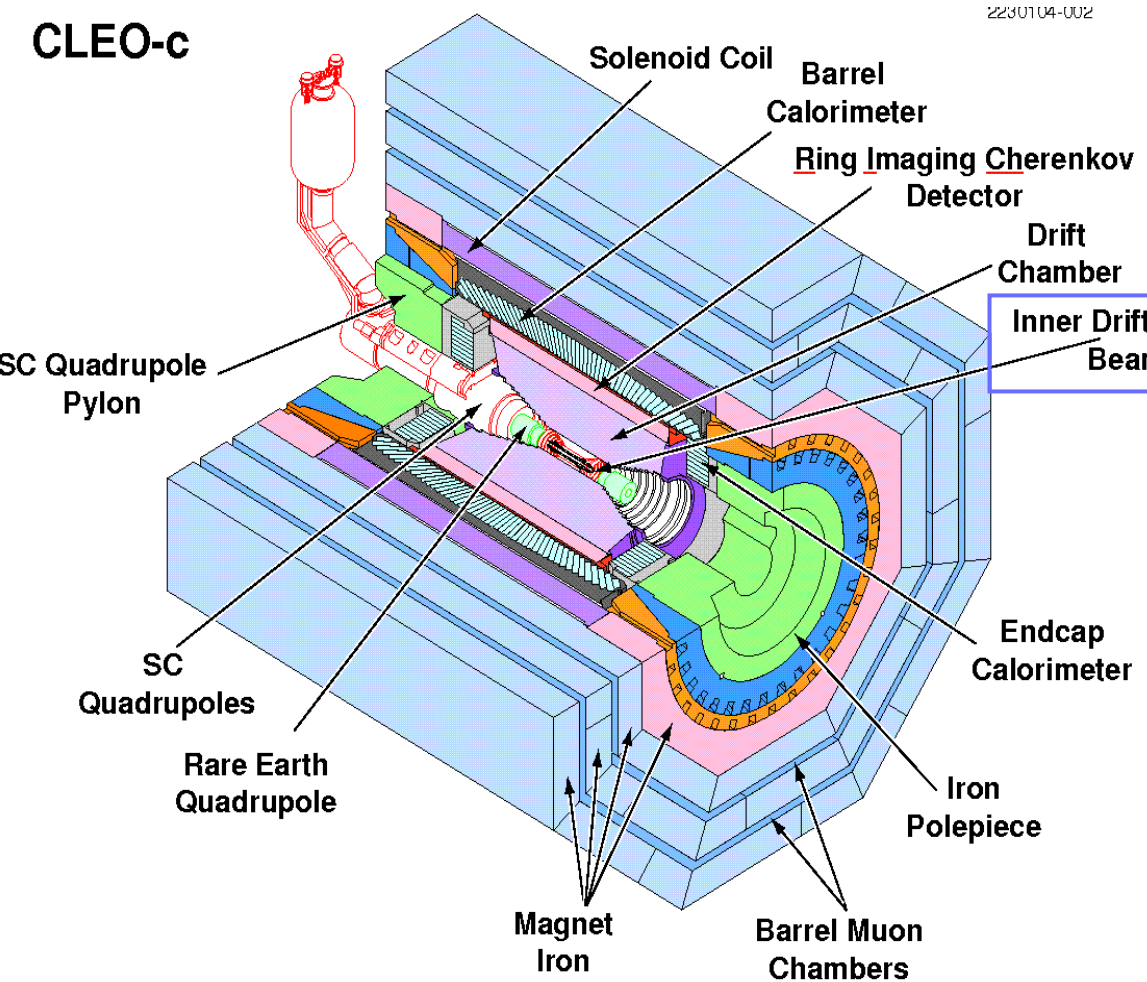
$$\Gamma(P \to \ell\nu) = \frac{G_F^2}{8\pi}\left|V_{qq'}\right|^2 f_P^2 m_\ell^2 M_P^2\left(1-\frac{m_\ell^2}{M_P^2}\right)^2$$

Pseudoscalar Decay Constant

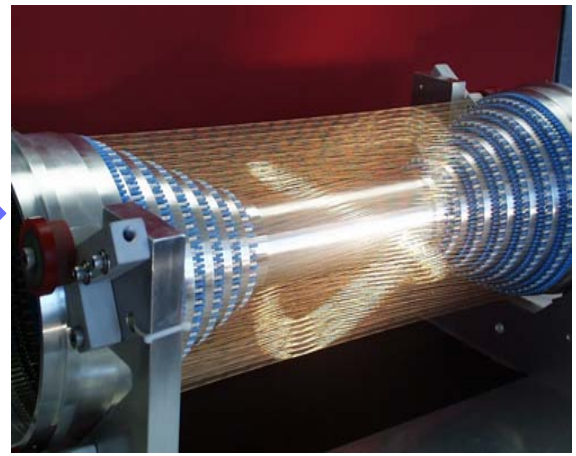
- Direct Measurement of f_D .
- Establish the accuracy of potential models and Lattice QCD computations in heavy quark sector.
- Charm measurements can be used to determine f_B which is important to determine CKM matrix elements.

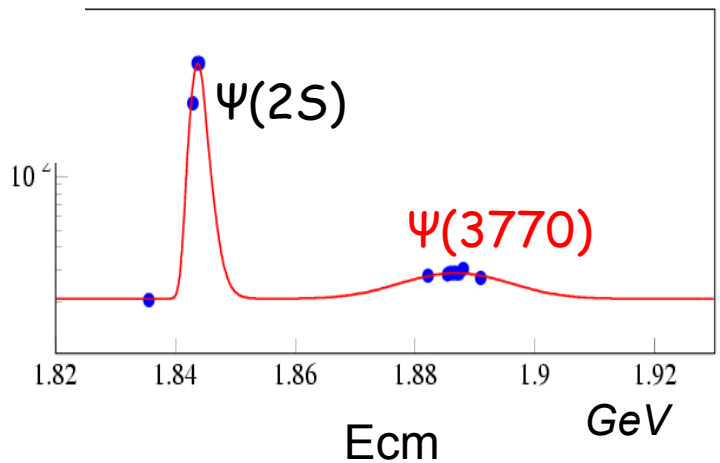
For example: precise CLEO-c f_D measurement + LQCD f_B/f_D could give a ~1% prediction for f_B

The CLEO-c detector



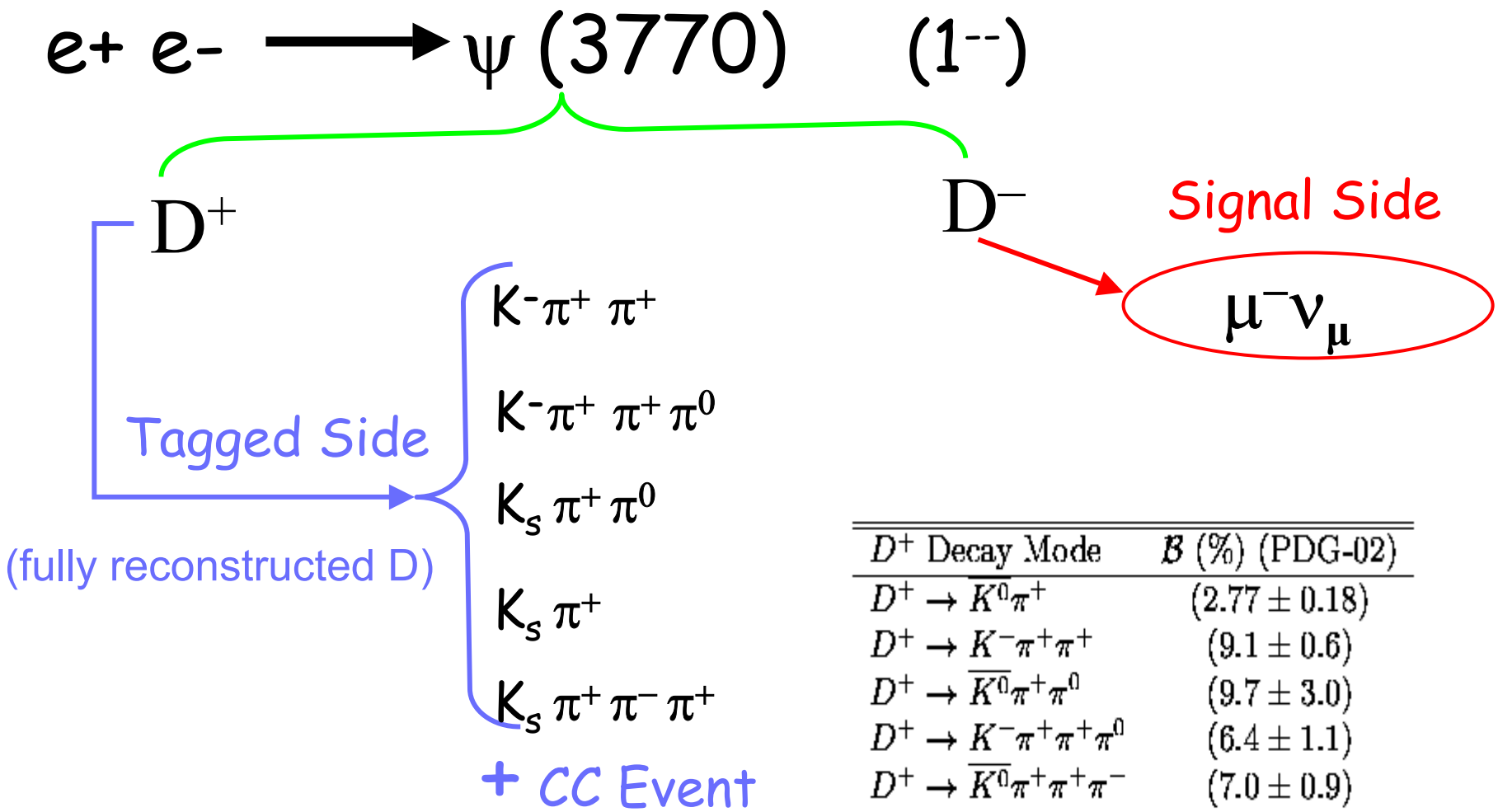
- SVX → 6-layer inner drift chamber.
- 1.5 T → 1T B field.





Data sample: ~60 pb^{-1} on the ψ(3770).

Analysis strategy



D^+ Decay Mode	$\mathcal{B}$ (%) (PDG-02)
$D^+ \to \overline{K^0}\pi^+$	(2.77 ± 0.18)
$D^+ \to K^-\pi^+\pi^+$	(9.1 ± 0.6)
$D^+ \to \overline{K^0}\pi^+\pi^0$	(9.7 ± 3.0)
$D^+ \to K^-\pi^+\pi^+\pi^0$	(6.4 ± 1.1)
$D^+ \to \overline{K^0}\pi^+\pi^+\pi^-$	(7.0 ± 0.9)

~35%

Charged D-tag Reconstruction

Preliminary!

- Two key variables:

$$\Delta E = E_{beam} - E_{candidate}$$

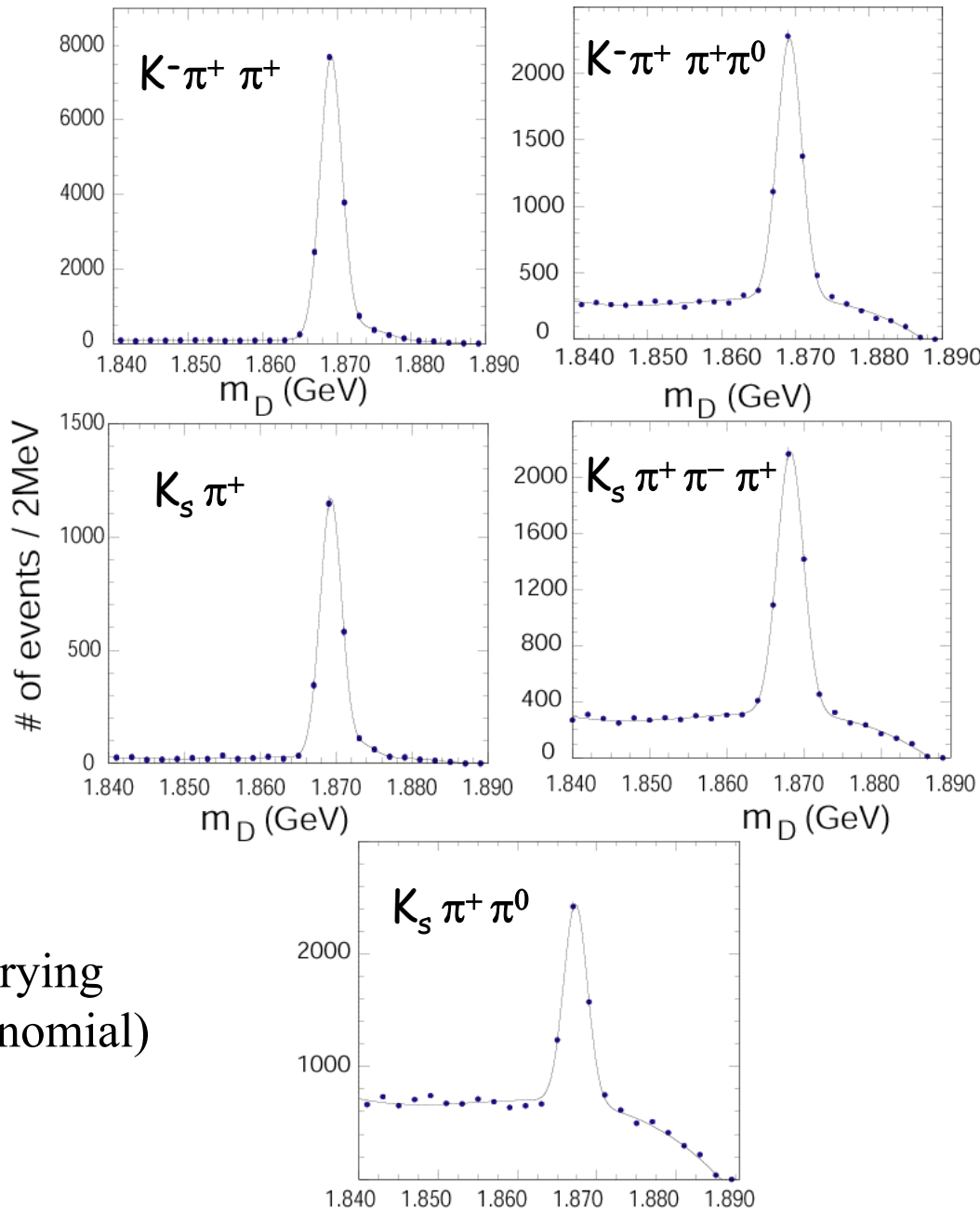
$$M_{bc} = \sqrt{E_{beam}^2 - P_{candidate}^2}$$

$|\Delta E| < 20$ MeV

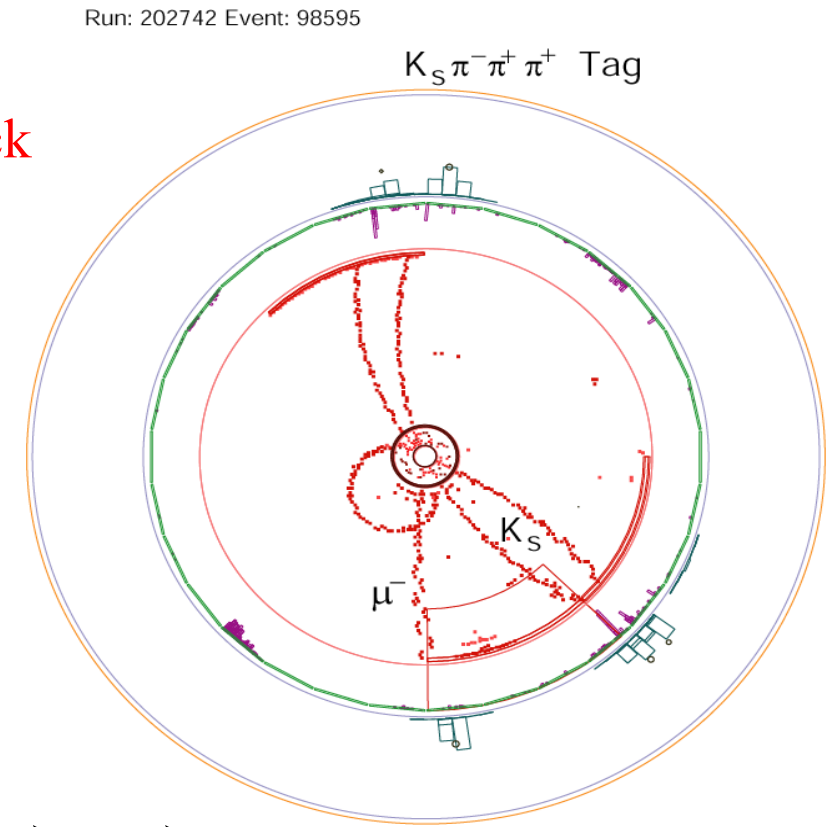
Extract the number of tags from fit to the M_{bc} distribution:

$28574 \pm 207 \pm 629$

±2.2% systematic uncertainty from varying the background shape (Argus vs. polynomial)



Signal Extraction

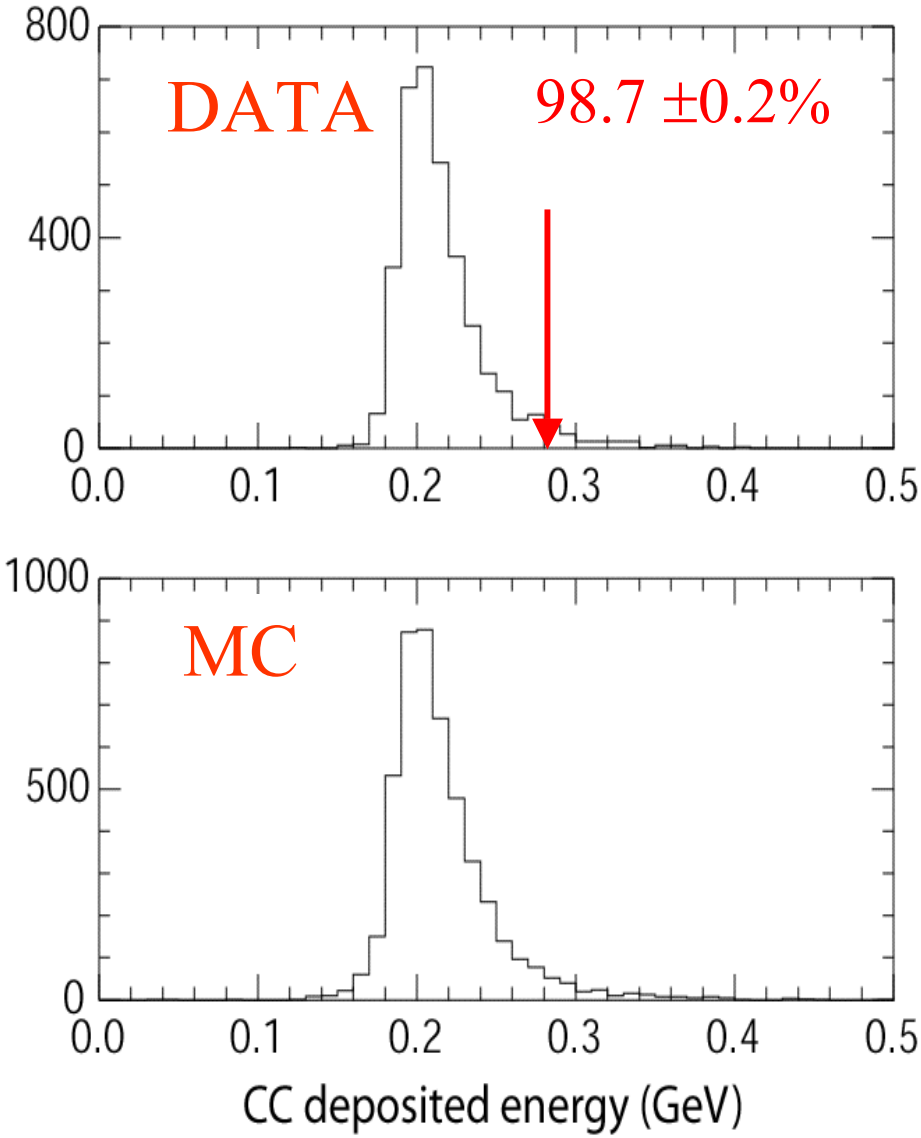


- Find events with an additional single track (beside the tagged D^+):
- No extra tracks or reconstructed K_s ($\rightarrow\pi^+\pi^-$).
- Largest extra shower < 250 MeV.
- Calculate MM^2 to separate signal from background:

$$MM^2 = (E_{beam} - E_\mu)^2 - (-\overrightarrow{P_{D^+}} - \overrightarrow{P_\mu})^2$$

- Signal peaks at $MM^2 = 0$ (neutrino mass)
- Account for the background in the signal region of MM^2 *(see later)*.

Muon candidate selection

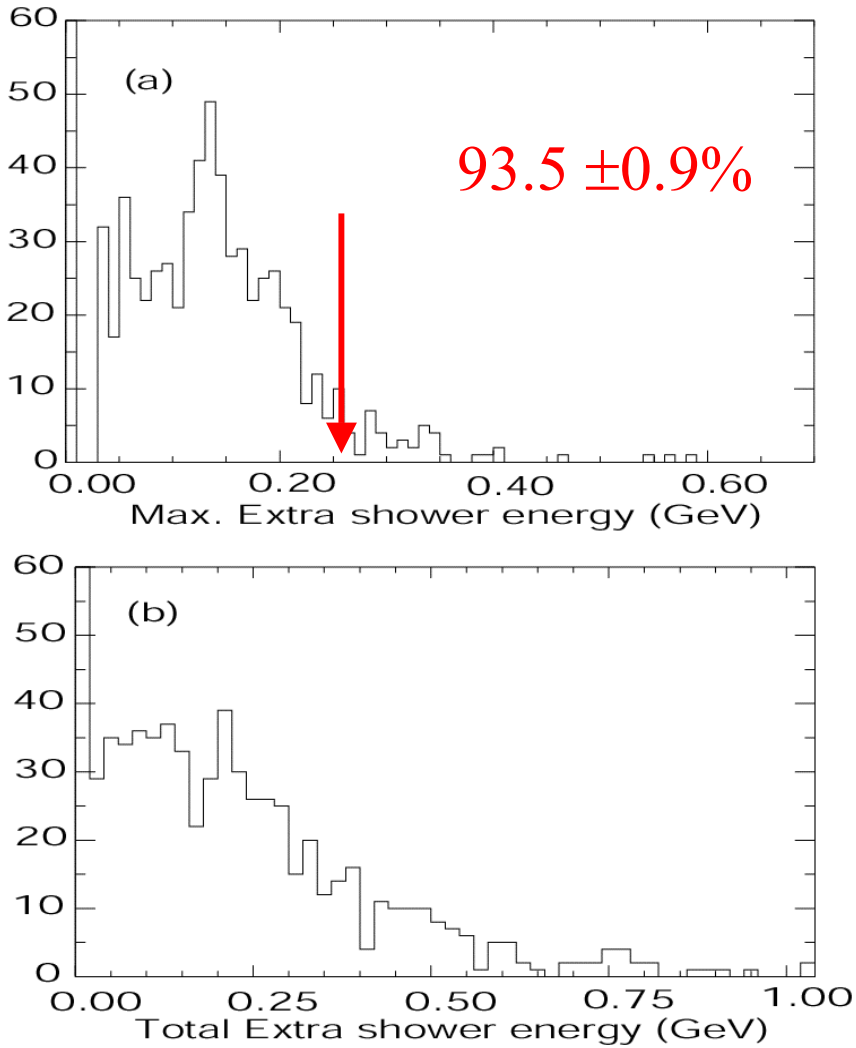


- Polar angle: $|\cos(\theta)| < 0.81$
  good resolution
  helps to suppress $D^- \rightarrow \pi^- \pi^0$ bckg.

- Consistent with minimum ionizing particle:
  deposited energy in CC
  < 300 MeV
  - ✓ Use $e^+e^- \rightarrow \mu^+\mu^-$ sample to study signature of muons.

- Not consistent with K (based on RICH info).

Extra tracks and showers



- Use double tag D^0 data sample to study extra particles and showers in the detector.

Mode 1	Mode 2	# of events
$K^-\pi^+$	$K^+\pi^-$	89
$K^+\pi^-\pi^+\pi^-$	$K^-\pi^+$	392
$K^+\pi^-\pi^+\pi^-$	$K^-\pi^+\pi^-\pi^+$	301

- No extra good tracks coming from the IP.

- Max Extra Shower energy
  < 250 MeV

  ✓ Helps to reject $D^- \to \pi^- \pi^0$ background

(Missing Mass)^2

$$MM^2 = (E_{beam} - E_\mu)^2 - (-\vec{p}_{D^+} - \vec{p}_\mu)^2$$

- Use only direction of the reconstructed D

$$MM^2 = (E_{beam} - E_\mu)^2 - (-p_0\hat{p}_{D^+} - \vec{p}_\mu)^2$$

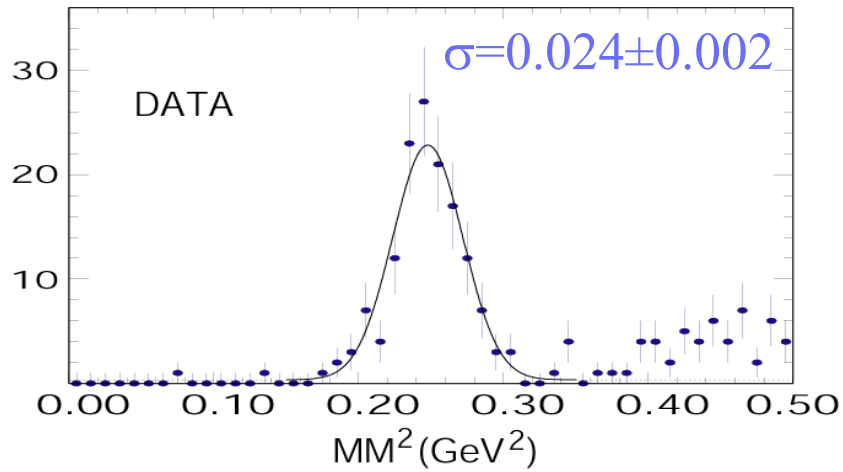
$$p_0^2 = E_{beam}^2 - M_{D^+}^2$$

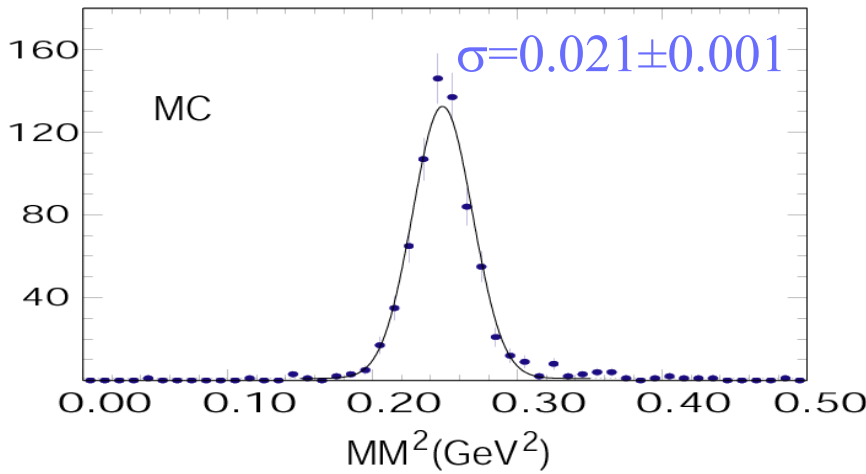
- Correct for non-zero crossing angle between e^+e^- beams (boost to CM frame).

✓ Use tagged $D^- \to K_s\pi^-$ sample to check data and MC consistency.

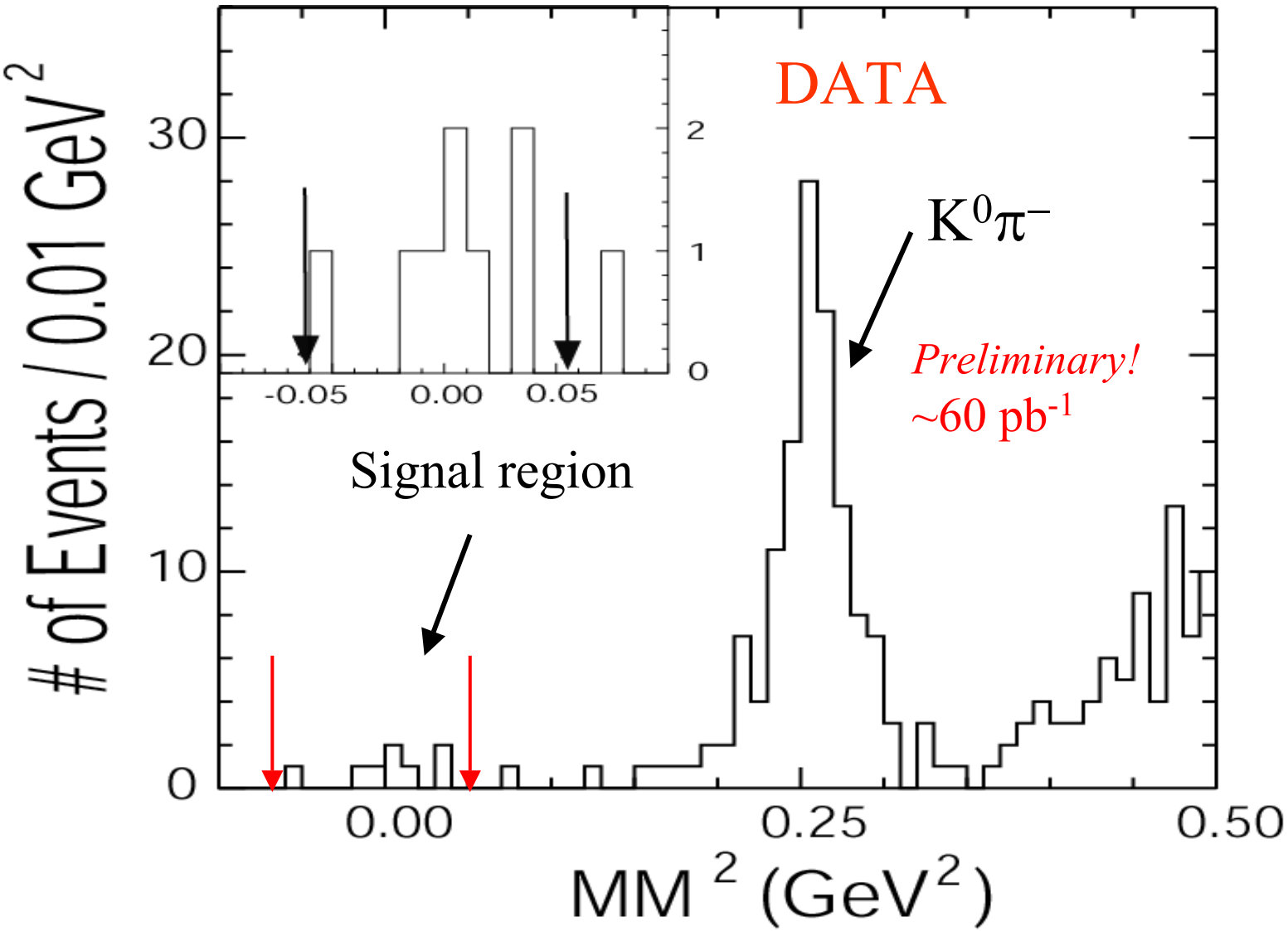
Increase MM^2 width from MC by 14% to 0.028 GeV^2.

$D^- \to K_s \pi^-$





MM^2 Distribution



Backgrounds

- $D^{\pm}$ Background:
  - ✓ $D^+ \rightarrow \pi^+\pi^0$
  - ✓ $D^+ \rightarrow \overline{K^0}\ \pi^+$
  - ✓ $D^+ \rightarrow \tau^+\ \nu$, $\tau^+ \rightarrow \pi^+\ \nu$
  - ✓ $D^+ \rightarrow \pi^0\ \mu^+\ \nu$
- $D^0\overline{D}^0$ Background:
  - ✓ $D^0\overline{D}^0$ can look like D^+D^-:
    e.g.: $D^0 \rightarrow K^-\pi^+$, $\overline{D}^0 \rightarrow \pi^+\ \mu^-\ \nu$
- Continuum Background

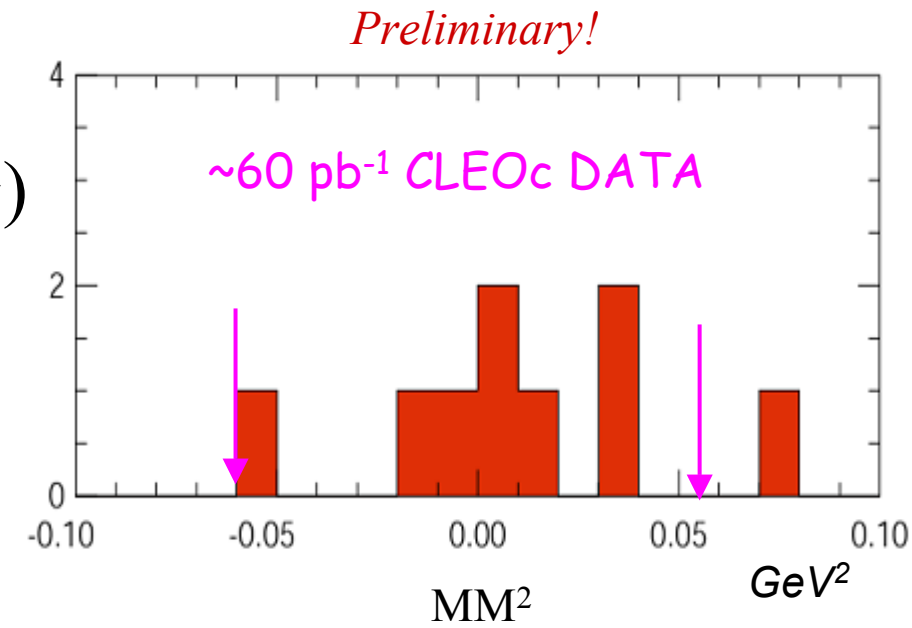
Estimated backgrounds from MC:

Mode	$\mathcal{B}$ (%)	# of events
$\pi^+\pi^o$	0.13 ± 0.02	0.31 ± 0.04
$K^o\pi^+$	2.77 ± 0.18	0.06 ± 0.05
$\tau^+\nu$	$3.2\times\ \mu^+\nu$	0.36 ± 0.08
$\pi^o\mu^+\nu$	0.31 ± 0.15	negligible
$D^o\overline{D}^o$		0.16 ± 0.16
continuum		0.17 ± 0.17
Total		1.07 ± 0.25

Assign 100% systematic uncertainty to background.

Signal

- 8 events within ±2σ
  (–0.056<MM²<0.056 GeV²)
- 1.07 ±1.07 estimated background events.
- Reconstruction efficiency: 69.9 %



$$\mathcal{B}\left(\mathcal{D}^{+} \rightarrow \mu^{+}\nu\right) = \frac{\mathcal{N}_{sig}}{\varepsilon^{\star}\,\mathcal{N}_{tag}}$$

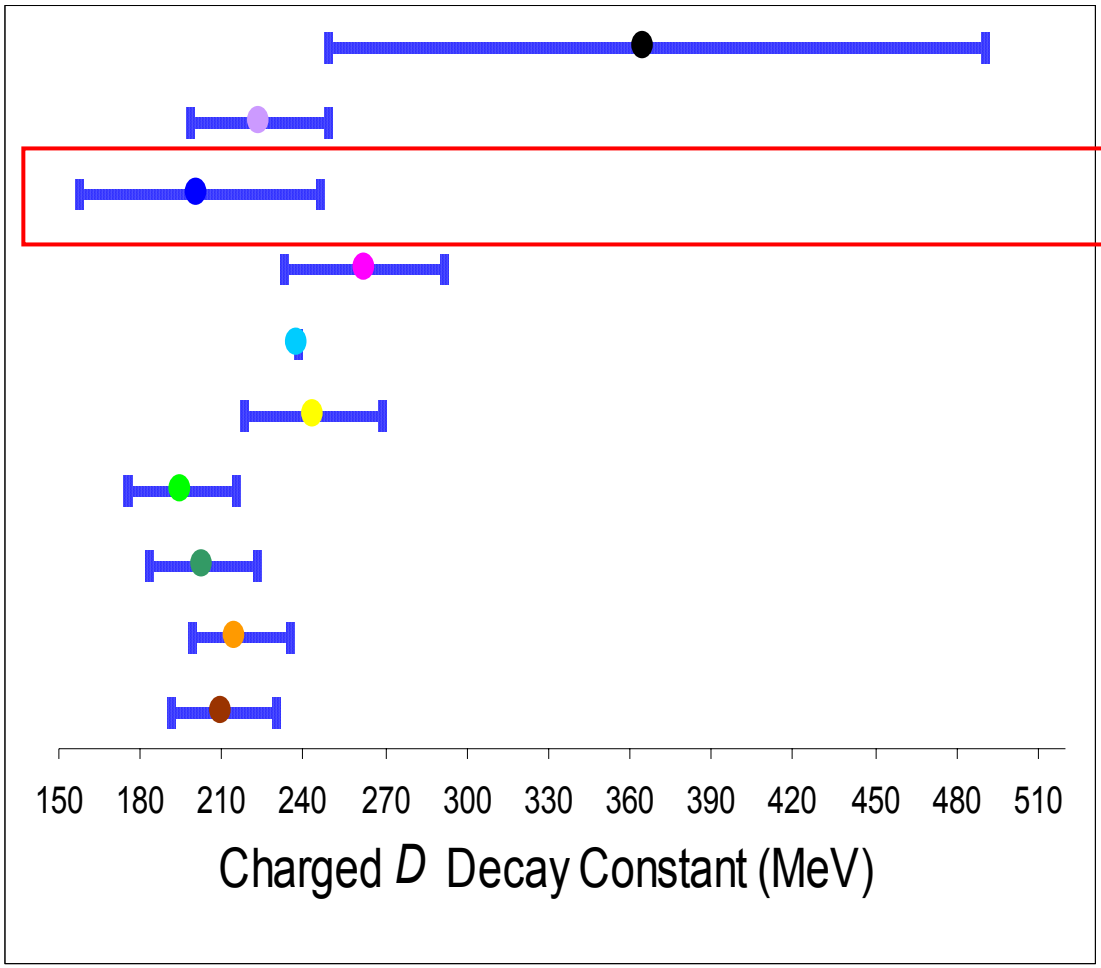
$\mathcal{B} = (3.5 \pm 1.4 \pm 0.6)\times 10^{-4}$

$f_{\mathcal{D}} = (201 \pm 41 \pm 17)\ MeV$

Preliminary!

Fractional systematic errors on $\mathcal{B}$:
a) μ detection ε (5%)
b) background, taken as 100% uncertainty (15.4%)
c) tagged sample size (2.2%)

Measurements vs. Predictions



- BES
- Lattice 2004
- CLEO-c
- Isospin Mass Splittings
- Potential Model
- Rel. Quark Model
- QCD Sum Rules
- QCD Spectral Sum Rules
- MILC
- UKQCD

Experimental uncertainty is not small enough yet to constrain theory.

Summary

- We report the first statistically compelling evidence for the decay $D^+ \rightarrow \mu^+\nu$.
- The measured branching fraction

$$\mathcal{B}(D^- \rightarrow \mu^-\nu) = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4}$$

- and *D* meson decay constant

Preliminary!

$$f_D = (201 \pm 41 \pm 17) \text{ MeV}$$

- Preliminary results presented at ICHEP 04 (hep/ex-0408071).
- To be submitted to PRD.

- Continuing work to get more data.