D Hadronic Analyses at CLEO-c

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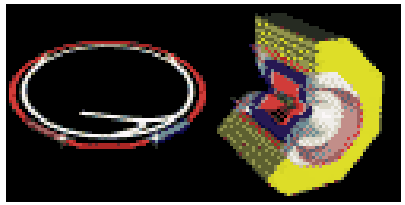
CLEO Collaboration

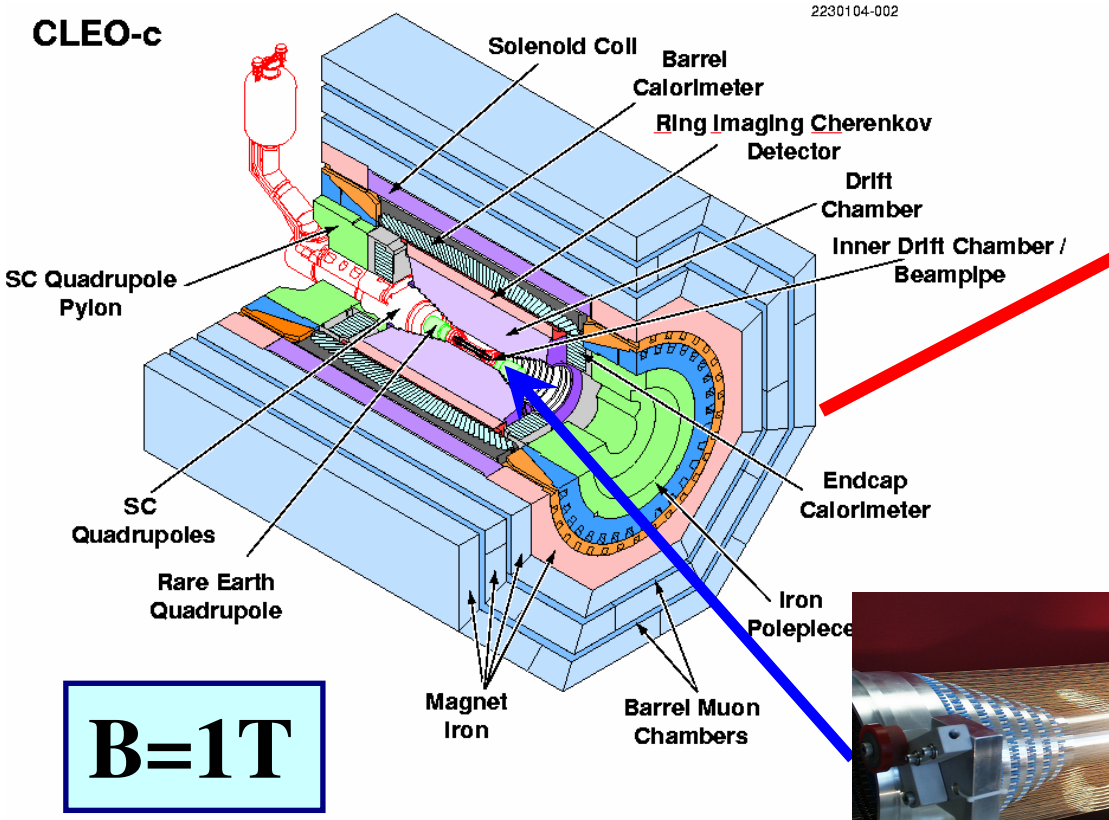
CORNELL UNIVERSITY LEPP
LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS

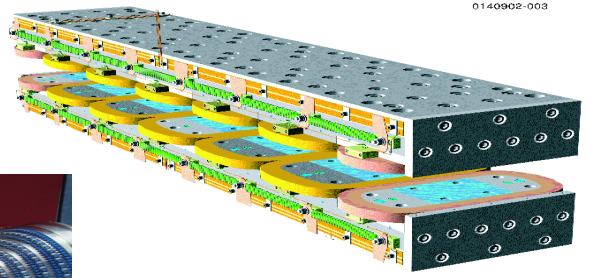


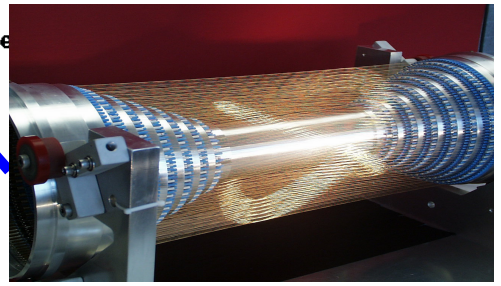
Moriond QCD 2007, March 18

CLEO-c at CESR

- CLEO-c universal detector at Cornell Electron-positron Storage Ring



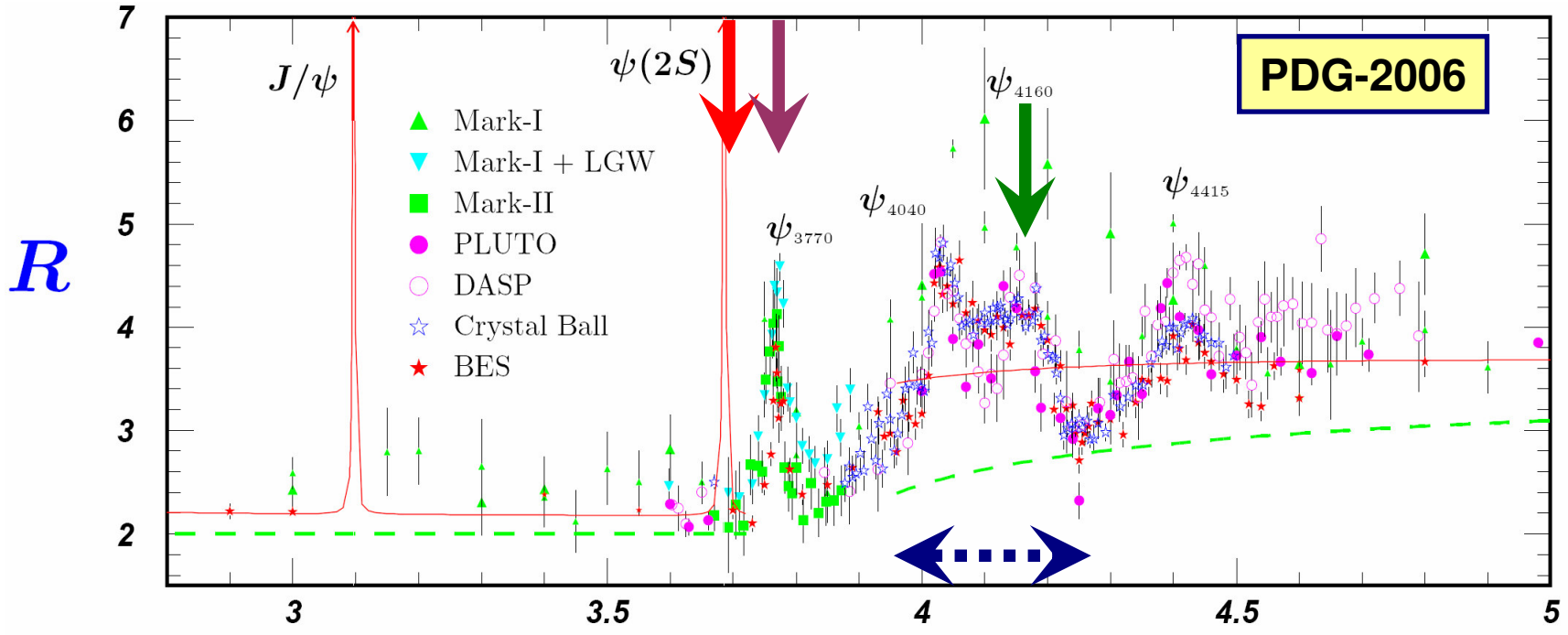




12 superconducting wigglers for stable running at low energy

CLEO-c data samples

- CLEO-c: Oct.2003 – Apr.2008
- √s=3100MeV, J/ψ is excluded from CLEO-c run plan
- **3686MeV**, 54pb^{-1}, N(ψ(2S))≈29M (in talk of R. Mitchell), $e^+e^- \to \psi(2S) \to \pi\pi$ J/ψ, $\gamma\chi_{cJ}$,etc
- **3773MeV**, 281pb^{-1} processed, → 560pb^{-1}, $e^+e^- \to \psi(3770) \to D\underline{D}$ **≈4M**
- **4170MeV**, 195pb^{-1} → 314pb^{-1} →more→ ~750pb^{-1}, $D_{(s)}^{(*)}\underline{D}_{(s)}^{(*)}$
- **3970–4260MeV** energy scan, 60pb^{-1} in12 points



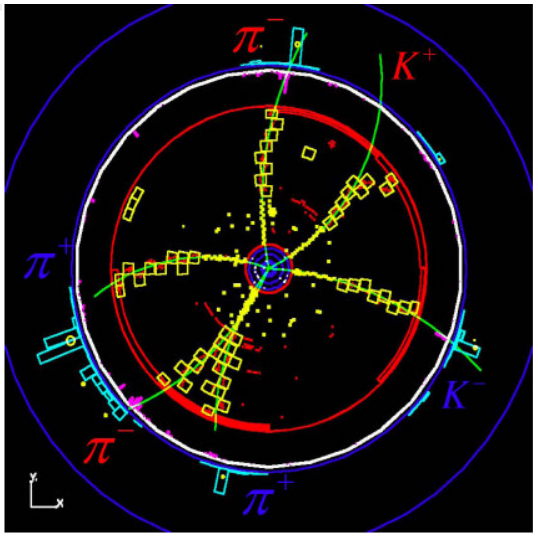
Recent D hadronic results

- Absolute D^0, D^+ hadronic $\mathcal{B}$'s
- $e^+e^- \rightarrow D_{(s)}^{(*)}\underline{D}_{(\underline{s})}^{(*)}$ Production Cross Section
- Absolute D_s hadronic $\mathcal{B}$'s
- D^0 / D^+ / $D_s \rightarrow (\eta,\eta',\varphi)X$, inclusive $\mathcal{B}$'s
- D^0 mass measurement

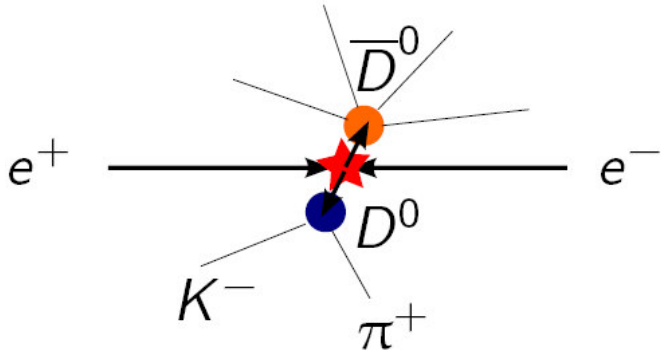
Absolute hadronic $\mathcal{B}$'s of D^0 and D^+

- PRL 95, 121801 (2005) **for 56pb^{-1}**
- Now, update **for 281pb^{-1}**
- Technique pioneered by MARK III, using
  - Single Tag yields $D \to i$ and $\bar{D} \to X \quad N_i = N_{D\bar{D}}\mathcal{B}_i\varepsilon_i$
  - Double Tag yields $D \to i$ and $\bar{D} \to \bar{j} \quad N_{i\bar{j}} = N_{D\bar{D}}\mathcal{B}_i\mathcal{B}_{\bar{j}}\varepsilon_{i\bar{j}}$
  - Compute:

$$\mathcal{B}_i = \frac{N_{i\bar{j}}}{N_{\bar{j}}}\frac{\varepsilon_{\bar{j}}}{\varepsilon_{i\bar{j}}} \text{ and } N_{D\bar{D}} = \frac{N_i N_{\bar{j}}}{N_{i\bar{j}}}\frac{\varepsilon_{i\bar{j}}}{\varepsilon_i\varepsilon_{\bar{j}}}$$



  - Use χ^2 fit to extract $\mathcal{B}_i$ and $\mathbf{N_{D\bar{D}}}$



- Signal variables:

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

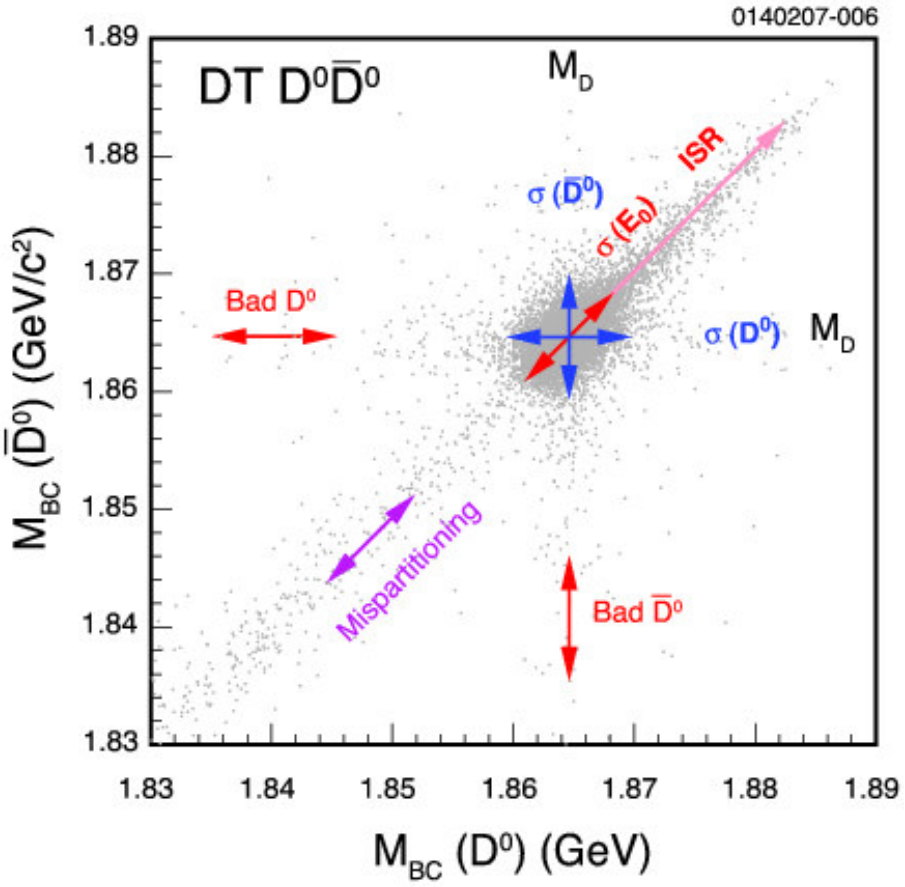
$$M_{BC} = \sqrt{E_{beam}^2 - p_D^{\,2}}$$

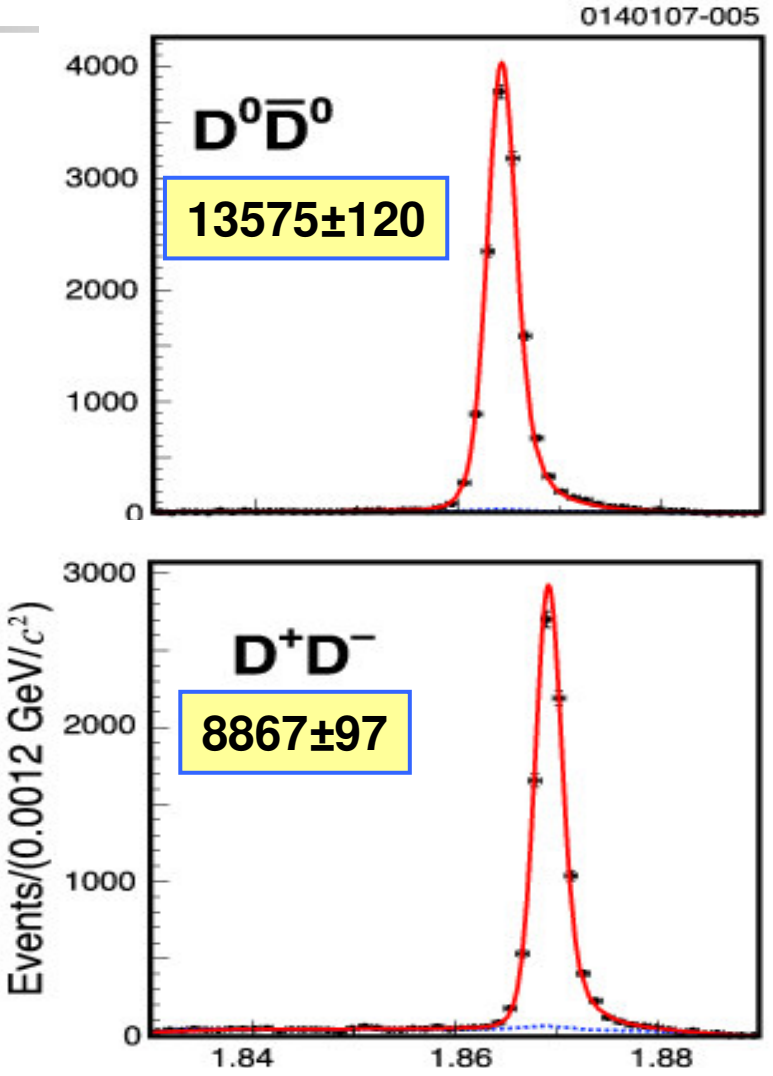
$\sigma(\Delta E)$ ~ 7—10 MeV, ×2 with π^0

$\sigma(M_{BC})$ ~ 1.3 MeV, ×2 with π^0

Absolute hadronic $\mathcal{B}$'s of D^0 and D^+

- Double Tag yields from 2D, $M_{BC}(D)$ vs $M_{BC}(\underline{D})$ fit:



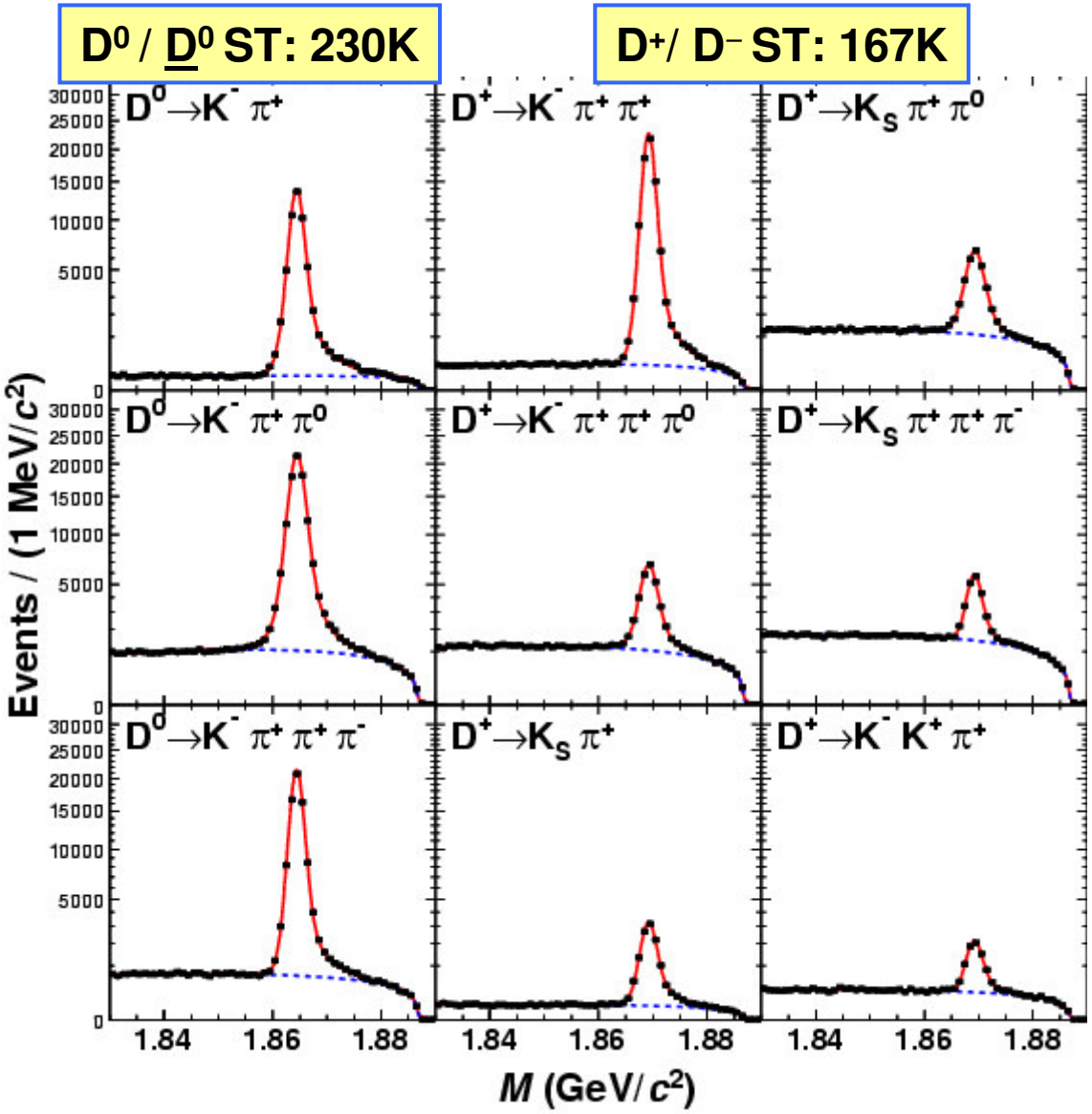


$$M_{BC} = \sqrt{E_{beam}^2 - p_D^{\,2}}$$

Absolute hadronic $\mathcal{B}$'s of D^0 and D^+

- Single Tag yields
- Fit to:
  - ARGUS for bkg.
  - "First principles" for signal:
    - M_{BC} resolution
    - ISR
    - ψ(3770) BW

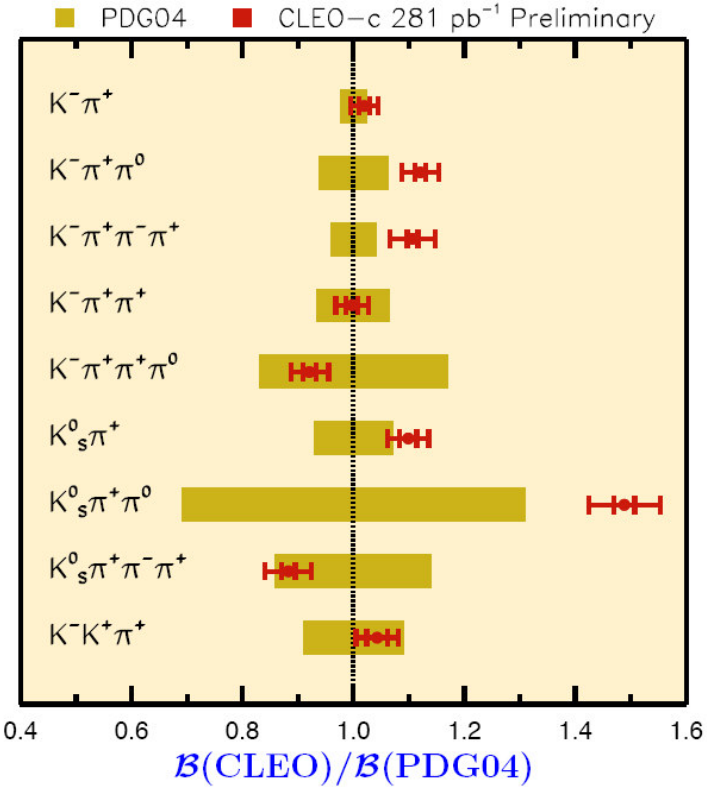
$$M_{BC} = \sqrt{E_{beam}^2 - p_D^{\ 2}}$$



Absolute hadronic $\mathcal{B}$'s of D^0 and D^+

- Preliminary for 281pb^{-1}

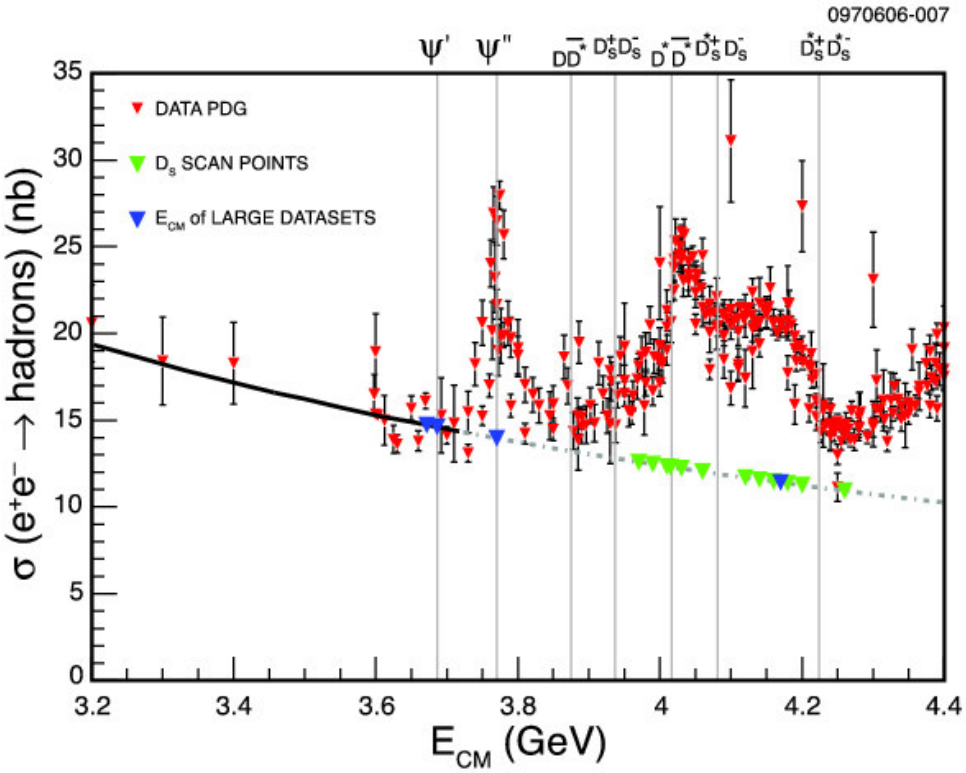
Mode	$\mathcal{B}$ (%)
$D^0 \to K^-\pi^+$	$3.87 \pm 0.04 \pm 0.08$
$D^0 \to K^-\pi^+\pi^0$	$14.6 \pm 0.1 \pm 0.4$
$D^0 \to K^-\pi^+\pi^+\pi^-$	$8.3 \pm 0.1 \pm 0.3$
$D^+ \to K^-\pi^+\pi^+$	$9.2 \pm 0.1 \pm 0.2$
$D^+ \to K^-\pi^+\pi^+\pi^0$	$6.0 \pm 0.1 \pm 0.2$
$D^+ \to K^0_S\pi^+$	$1.55 \pm 0.02 \pm 0.05$
$D^+ \to K^0_S\pi^+\pi^0$	$7.2 \pm 0.1 \pm 0.3$
$D^+ \to K^0_S\pi^+\pi^+\pi^-$	$3.13 \pm 0.05 \pm 0.14$
$D^+ \to K^+K^-\pi^+$	$0.93 \pm 0.02 \pm 0.03$

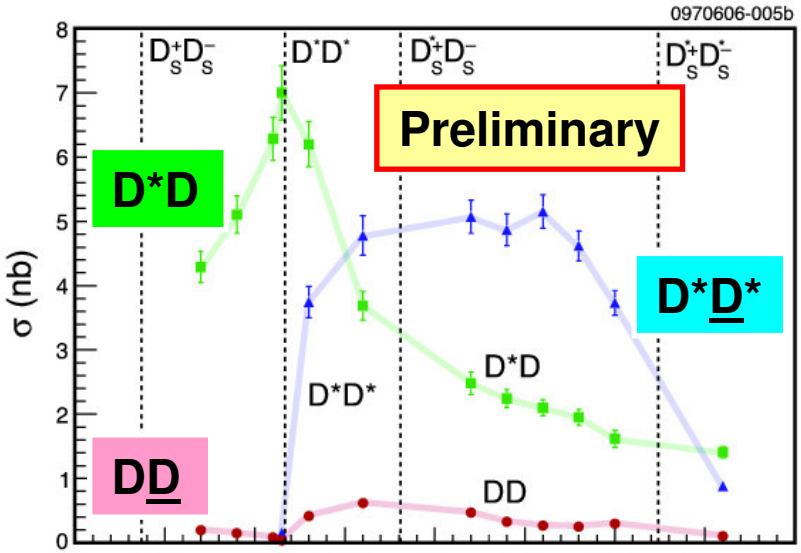


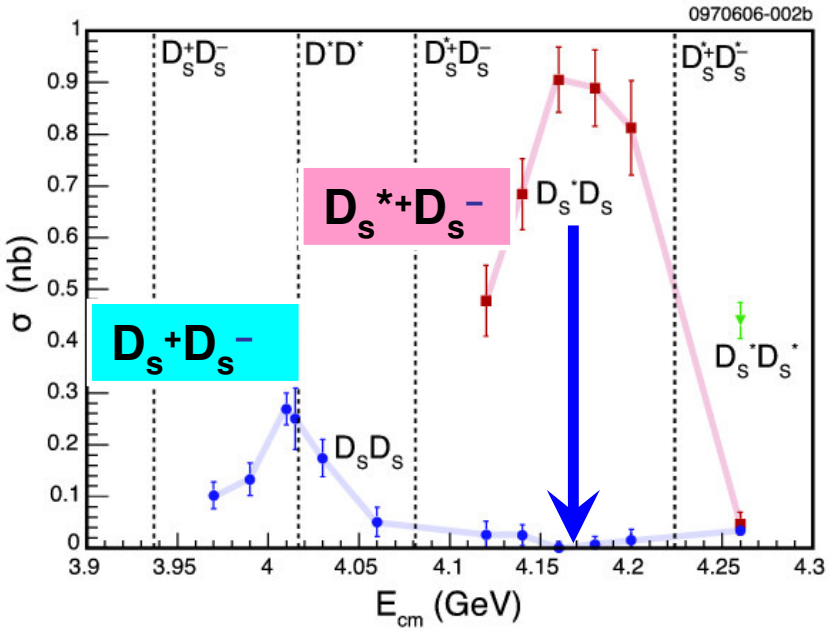
- Little change from 56pb^{-1} results to 281pb^{-1}
  - Systematic errors dominate now
- Final State Radiation included in efficiency
  - Without FSR in MC $\mathcal{B}$'s decrease ≤ 2%

D_s Production Cross Section

- Little was known about components of $\sigma(e^+e^- \to \text{hadrons})$ @ $E_{cm} > M[\psi(3770)]$
- CLEO scan 60pb^{-1} in12 points 3.97-4.26GeV
- + large stat at 4.17GeV, 314pb^{-1}
- Total cross section is saturated by 5 measured $D_{(s)}^{(*)}\underline{D}_{(s)}^{(*)}$ components







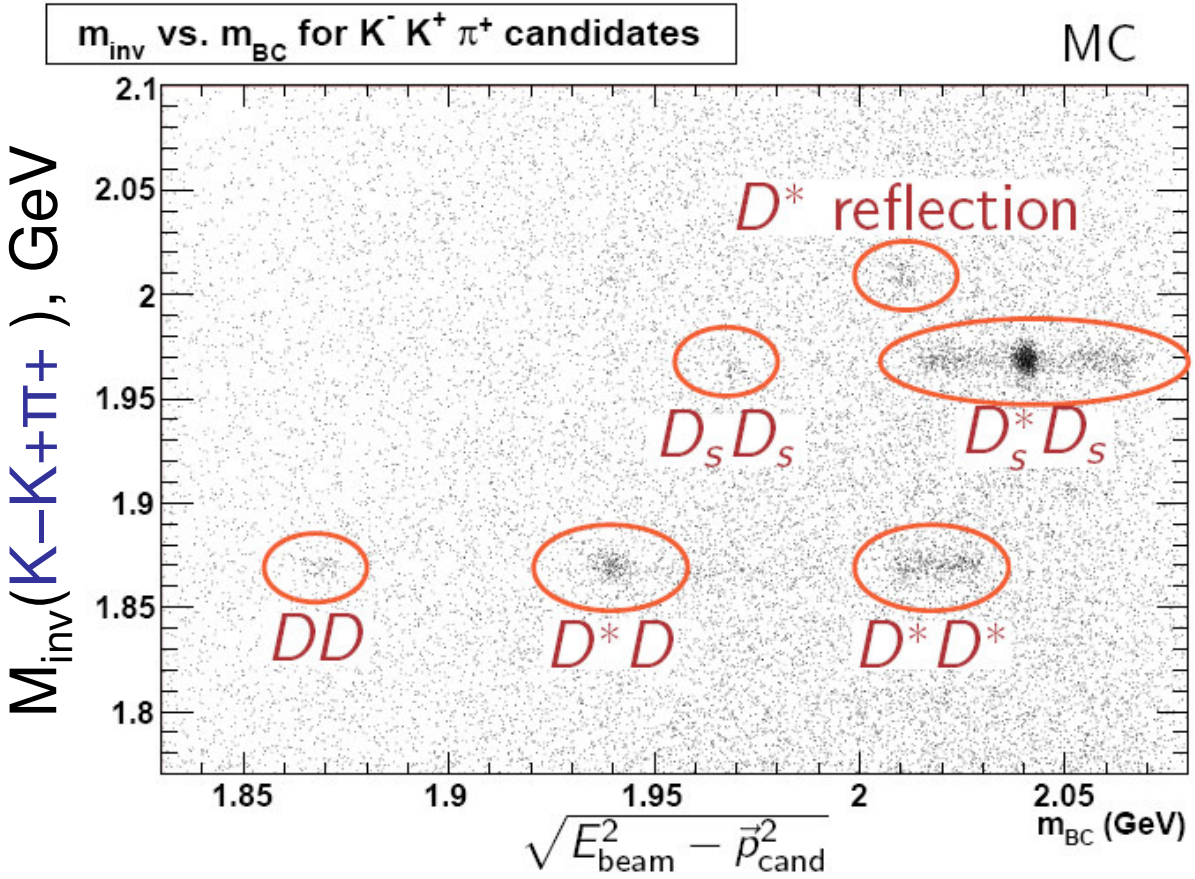
Absolute D_s hadronic $\mathcal{B}$'s: selection

$$e^+e^- \to D_s^{*\pm} D_s^{\mp}$$

$$D_s^{*\pm} \to D_s^{\pm}\gamma \text{ or } D_s^{\pm}\pi^0$$

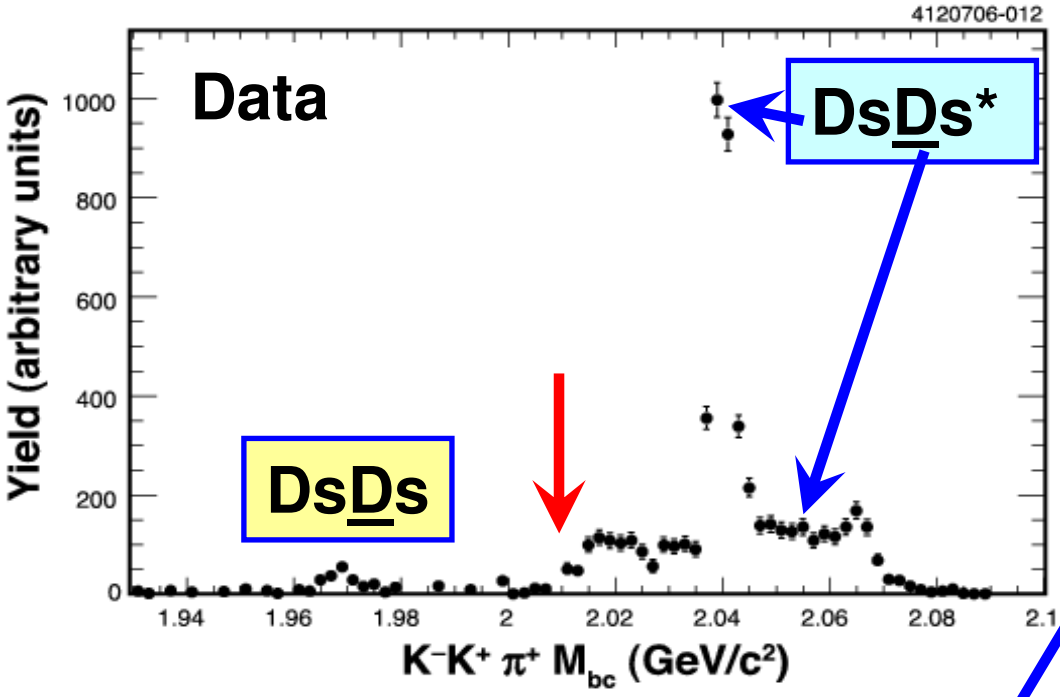
- Ignoring γ or π^0 from D_s^*
- Select events using:

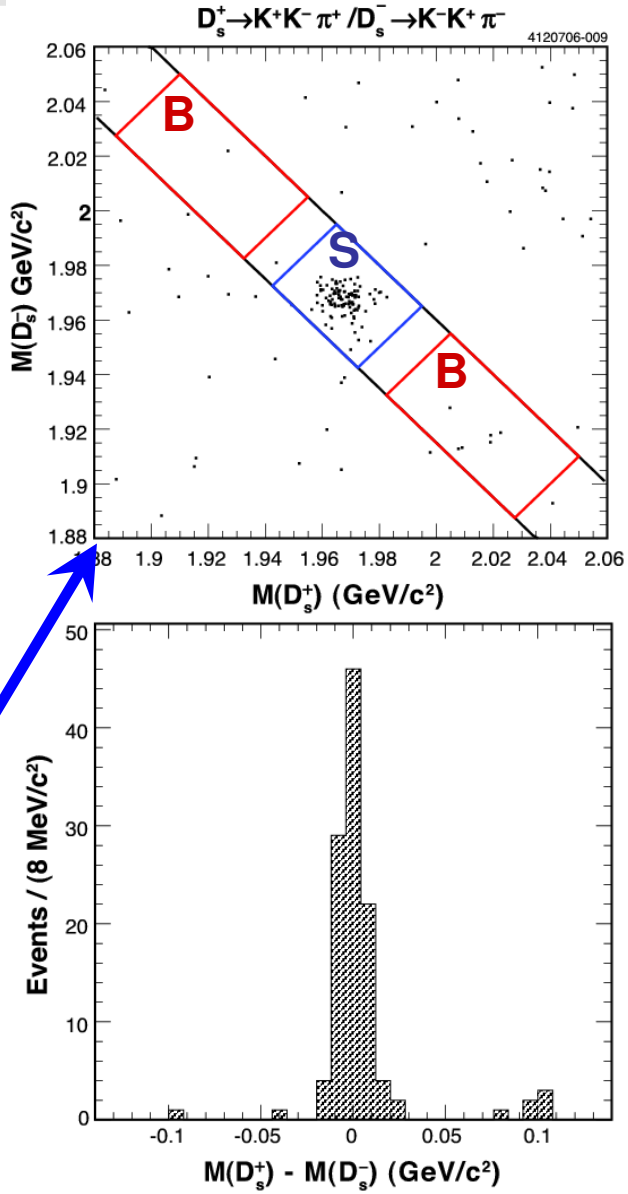
- Good kinematical separation between modes



Absolute D_s hadronic $\mathcal{B}$'s

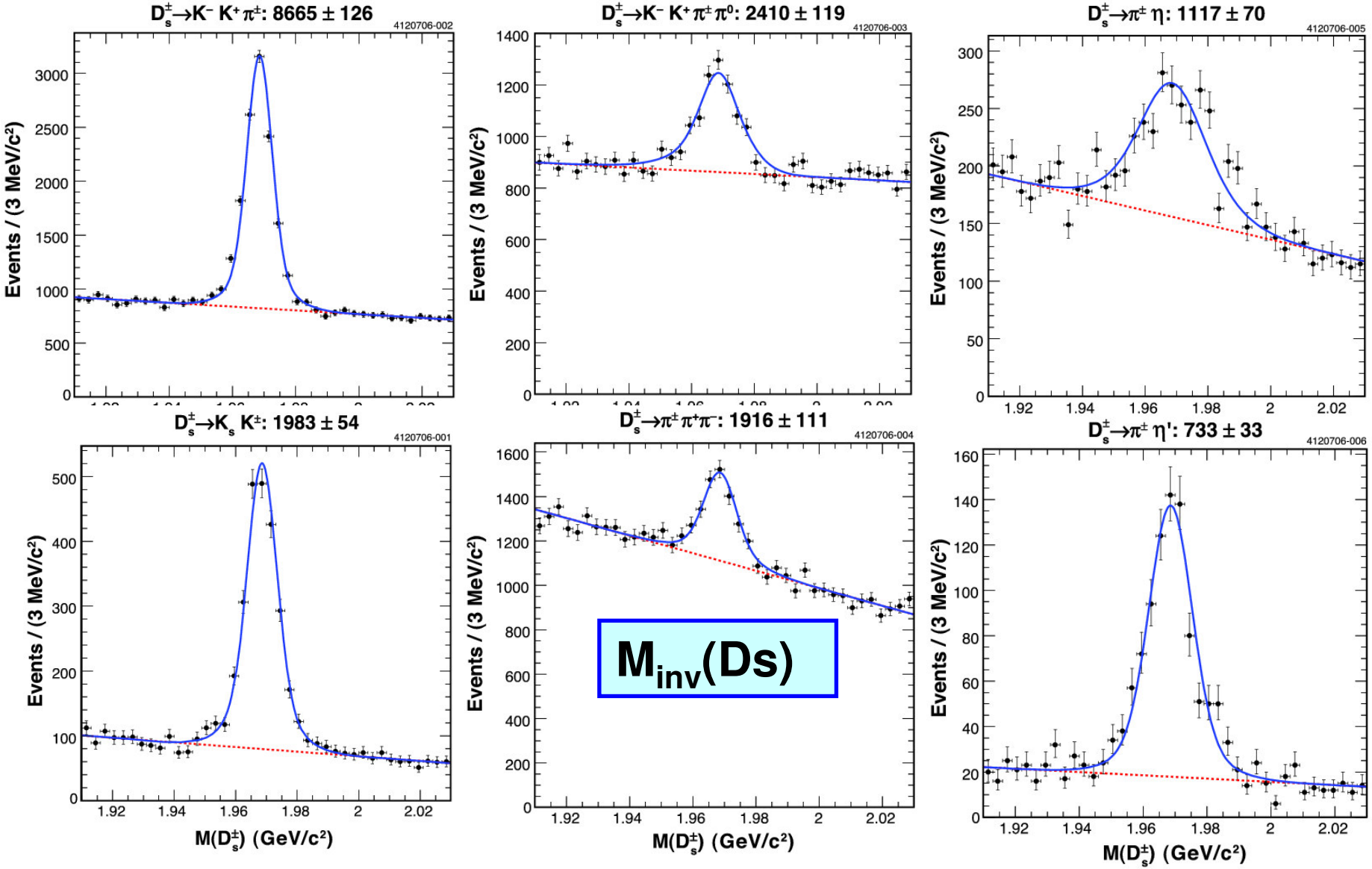
- Measure ST and DT yields:
  - Require M_{BC}>2.01GeV





  - DT yields: Cut and count in $M(D_s^+)$ vs $M(D_s^-)$

Absolute D_s hadronic $\mathcal{B}$'s, ST yields:

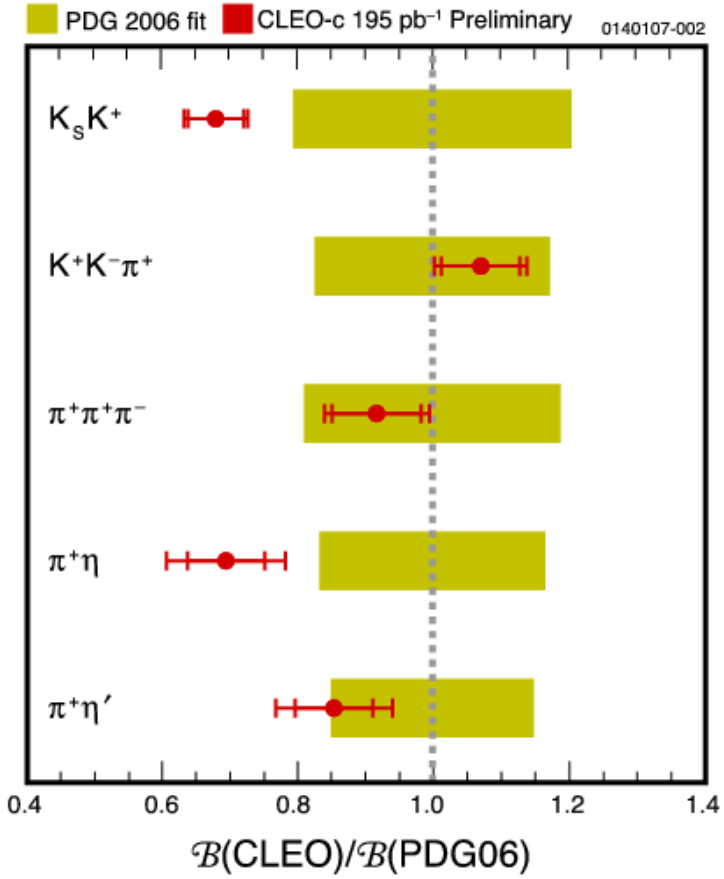


Absolute D_s hadronic $\mathcal{B}$'s

- CLEO-c, 4170MeV, 195pb^{-1}

Preliminary

D_s^+ Mode	$\mathcal{B}$ (%)
$K_S K^+$	$1.50 \pm 0.09 \pm 0.05$
$K^- K^+ \pi^+$	$5.57 \pm 0.30 \pm 0.19$
$K^- K^+ \pi^+ \pi^0$	$5.62 \pm 0.33 \pm 0.51$
$\pi^+ \pi^+ \pi^-$	$1.12 \pm 0.08 \pm 0.05$
$\pi^+ \eta$	$1.47 \pm 0.12 \pm 0.14$
$\pi^+ \eta'$	$4.02 \pm 0.27 \pm 0.30$



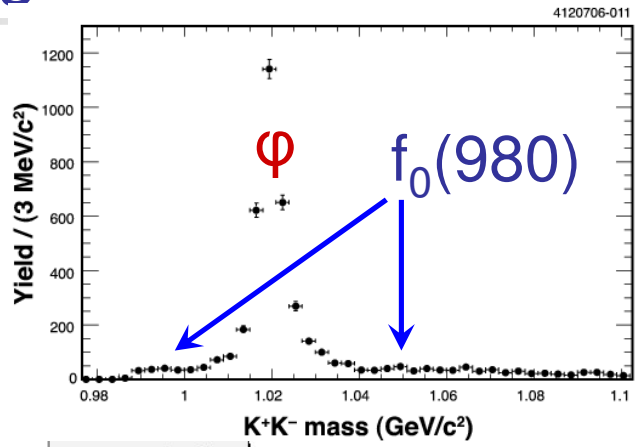
The $\varphi\pi^+$ problem in $D_s \to K^-K^+\pi^+$

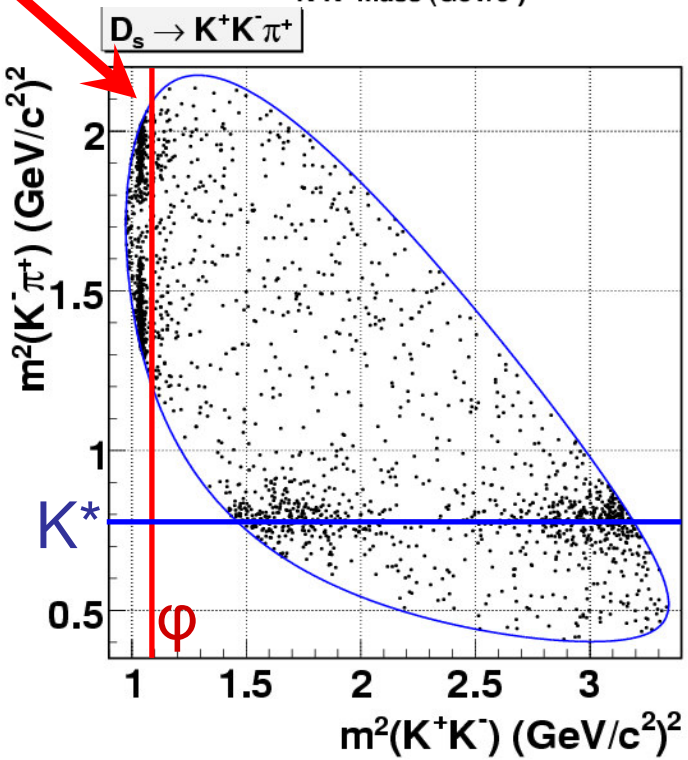
- Historically $D_s \to \varphi\pi^+$ used for normalization
- The process $f_0(980) \to K^-K^+$ contribute to any $\varphi \to K^-K^+$ mass region
- Correction depends on experiment's mass window, resolution, angular distribution requirements
- We produce partial $K^-K^+\pi^+$ branching for 10 and 20 MeV mass windows on each side of the φ mass:

BF	Result (%)
$\mathcal{B}_{10}$	$1.98 \pm 0.12 \pm 0.09$
$\mathcal{B}_{20}$	$2.25 \pm 0.13 \pm 0.12$

  - 14% difference

- Amplitude analysis is most appropriate to disentangle this problem…



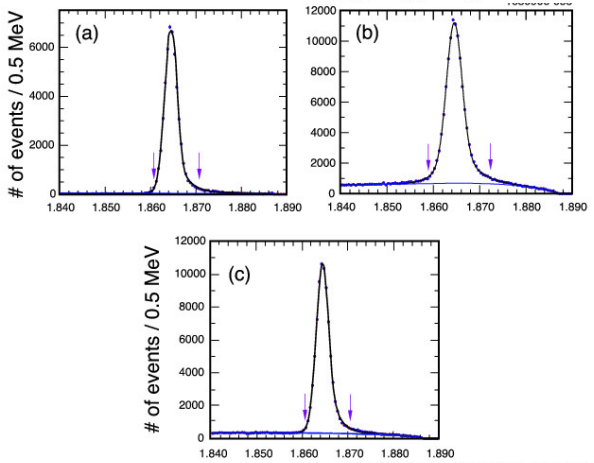


D^0 / D^+ / $D_s \rightarrow (\eta,\eta',\phi)X$

- PR D74,112005 (2006)
  - 281pb^{-1} @ ψ(3770)
  - 195pb^{-1} @ 4170MeV
- Tag side:

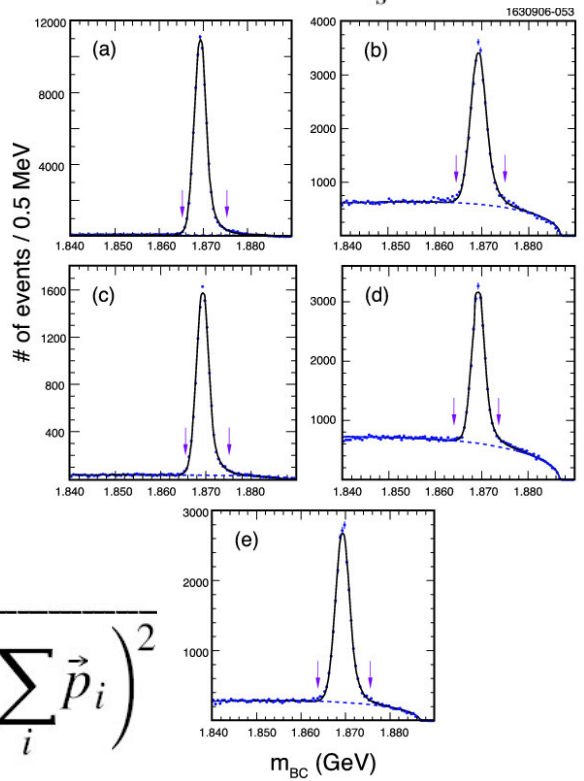
D^0

$K^+\pi^-$
$K^+\pi^-\pi^0$
$K^+\pi^-\pi^+\pi^-$



D^+

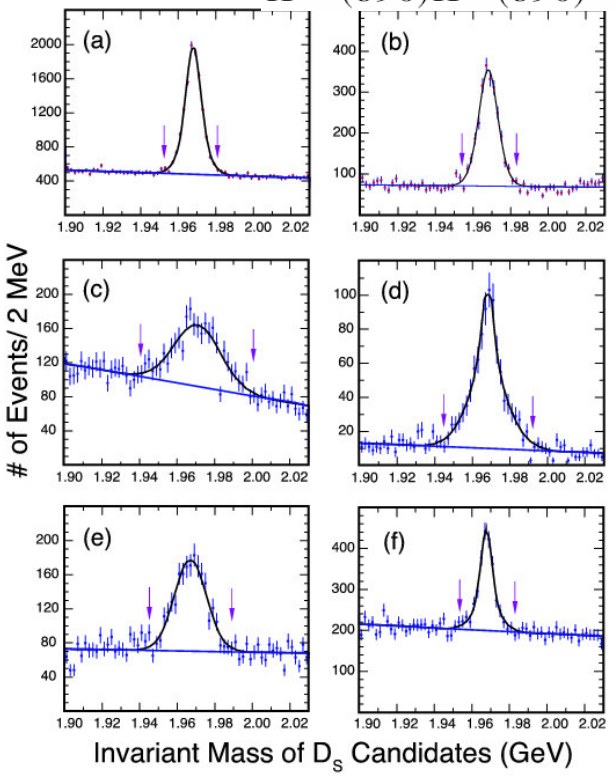
$K^+\pi^-\pi^-$
$K^+\pi^-\pi^-\pi^0$
$K_s\pi^-$
$K_s\pi^-\pi^-\pi^+$
$K_s\pi^-\pi^0$



$$m_{\mathrm{BC}} = \sqrt{E^2_{\mathrm{beam}} - \left(\sum_i \vec{p}_i\right)^2}$$

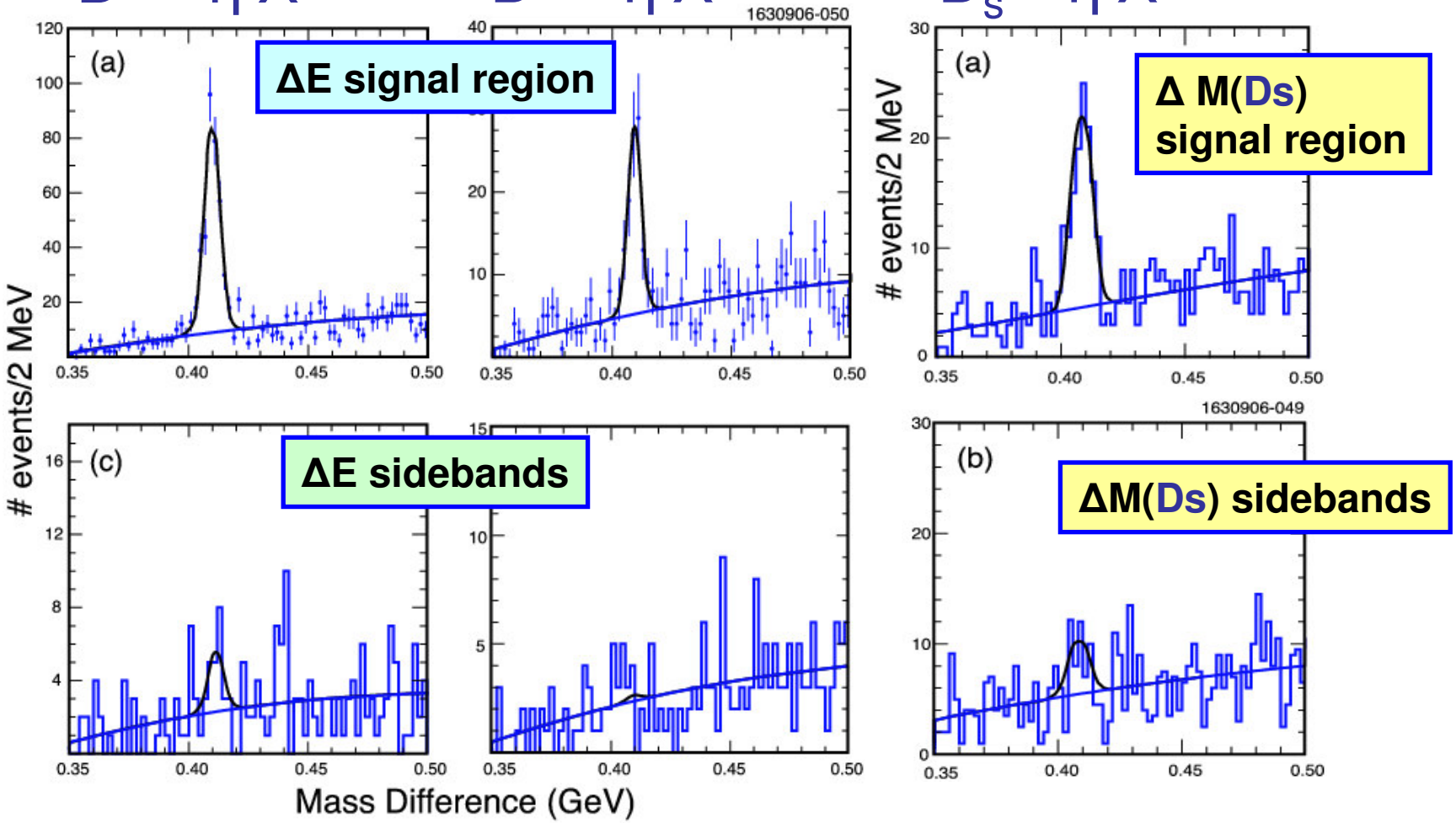
D_s

$K^+K^-\pi^-$
$K_sK^-(K_s \rightarrow \pi^+\pi^-)$
$\eta\pi^-$
$\eta'\pi^-$
$\phi\rho^-$
$K^{*+}(890)K^{*0}(890)$



D^0 / D^+ / $D_s \rightarrow (\eta,\eta',\varphi)X$

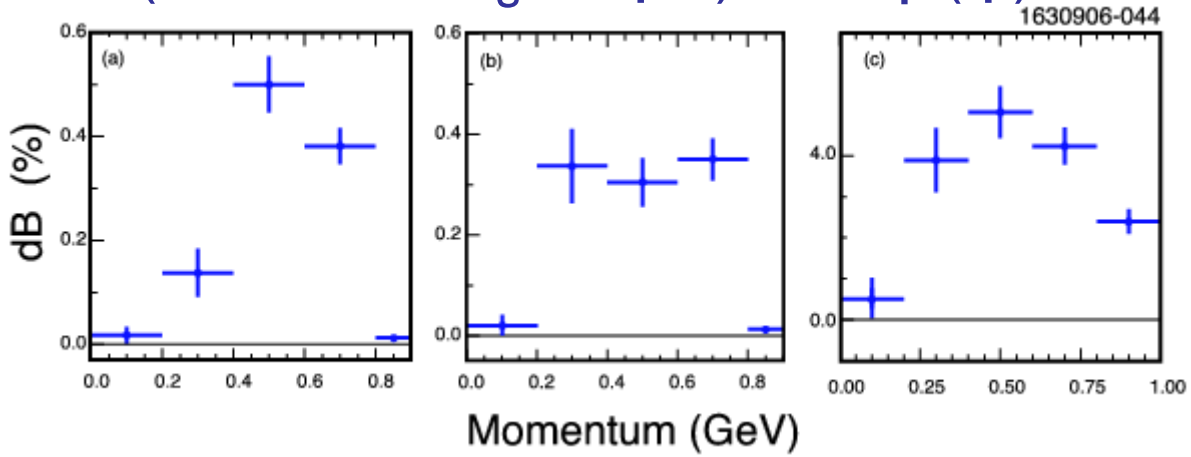
- η' yields, use **M(η') – M(η)** : $\eta' \to \pi^+\pi^-\eta,\ \eta \to \gamma\gamma, \quad \phi \to K^+K^-$



D^0 / D^+ / $D_s \rightarrow$ (η,η',φ)X

- Momentum dependence:

$\mathcal{B}$ (D^0 / D^+ / $D_s \rightarrow \varphi X$) vs p($\varphi$)



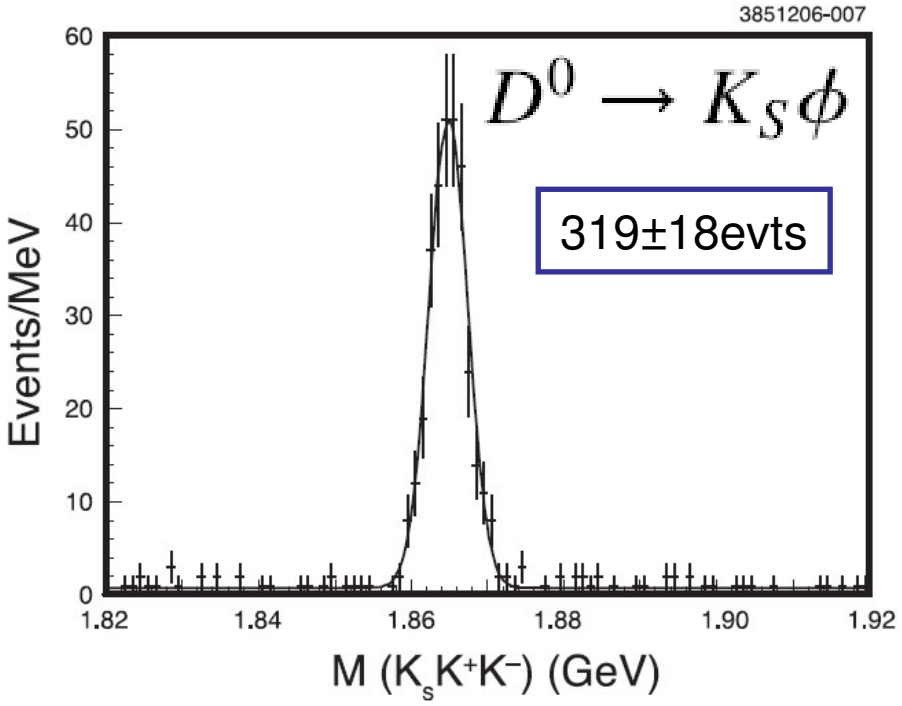
- Inclusive $\mathcal{B}$ and their ratios depends on ss quark content:

Mode	D^0 (%)		D^+ (%)		D_s^+ (%)	
	Our result	PDG	Our result	PDG	Our result	PDG
ηX	$9.5 \pm 0.4 \pm 0.8$	<13	$6.3 \pm 0.5 \pm 0.5$	<13	$23.5 \pm 3.1 \pm 2.0$	···
$\eta' X$	$2.48 \pm 0.17 \pm 0.21$	···	$1.04 \pm 0.16 \pm 0.09$	···	$8.7 \pm 1.9 \pm 0.8$	···
ϕX	$1.05 \pm 0.08 \pm 0.07$	1.7 ± 0.8	$1.03 \pm 0.10 \pm 0.07$	<1.8	$16.1 \pm 1.2 \pm 1.1$	···

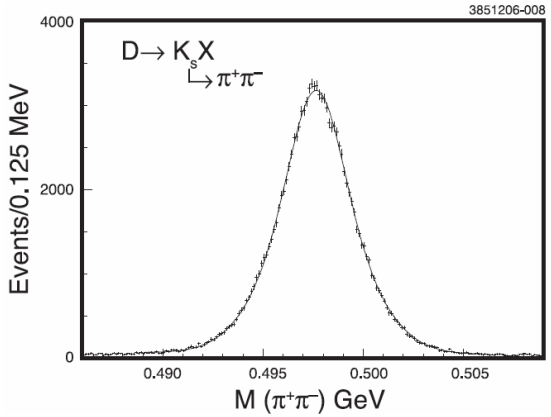
Ratio	η	η'	ϕ
D_s^+/D^0	$2.47 \pm 0.34 \pm 0.18$	$3.51 \pm 0.80 \pm 0.27$	$15.3 \pm 1.6 \pm 0.8$
D_s^+/D^+	$3.73 \pm 0.57 \pm 0.27$	$8.37 \pm 2.23 \pm 0.64$	$15.6 \pm 1.9 \pm 0.8$

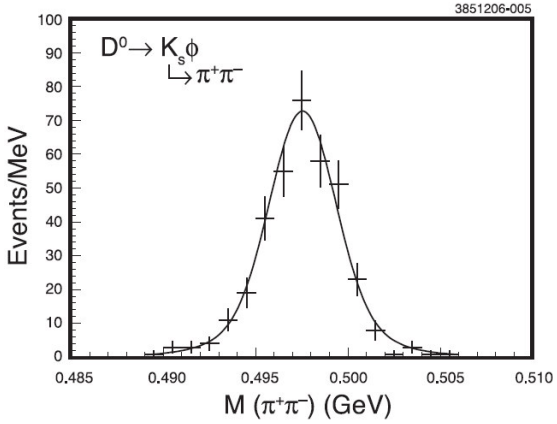
D^0 mass measurement

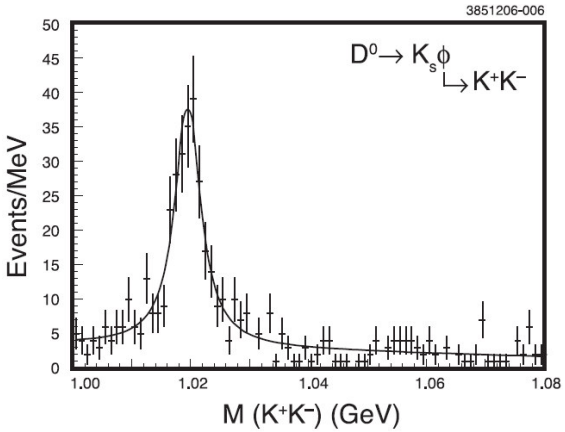
- PRL 98,092002 (2007)
- PDG: M(D0)=1864.5±0.4MeV
  - average of LGW, MARK II, NA32
  - Measured in $D^0 \to K\pi$, $K\pi\pi\pi$
- CLEO-c, 281pb^{-1}, use $D^0 \to K_S\varphi$:
  - $M(D^0)-M(\varphi)-M(K_S)$=347MeV
  - p(K), p(π) <600MeV range
- p calibration: $M(K_S \to \pi^+\pi^-)$ in $D^0 \to K_S X$: max vars cosθ and p for π's
- B calibration: $M(J/\Psi \to \mu^+\mu^-)$
- Cross-check: $M(\Psi(2S) \to \pi^+\pi^- J/\Psi)$



$$M(D^0) = 1864.847 \pm 0.150(\text{stat}) \pm 0.095(\text{syst})\ \text{MeV}$$







Non covered D hadronic results and analyses

- Recently published
  - PRD 74, 071102, 2006, *Branching fraction for the DCSD* $D^+ \to K^+\pi^0$
  - PRD 74, 031108, 2006, *Measurement of Interfering* $K^{*+}K^-$ *and* $K^{*-}K^+$ *Amplitudes in the Decay* $D^0 \to K^-K^+\pi^0$

- In progress
  - D^0 / D^+ / D_s hadronic branchings for SCSD and DCSD
  - The Quantum correlation analysis of the D^0 $\underline{D^0}$ decays
  - Dalitz plot analyses $D^+ \to \pi^-\pi^+\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D_s^+ \to K^-K^+\pi^+$, $D^0 \to K^0_{(S,L)}\pi^+\pi^-$, $D^0 \to K^0_S\pi^0\pi^0$, etc… with and without CP and flavor tags

Summary

- CLEO-c experiment: Oct.2003 – Apr.2008
  successfully taking data:
  - **3686MeV**, N(ψ(2S))≈29M, done
  - **3773MeV**, ψ(3770), N(ψ(3770)→D$\underline{D}$)≈4M, done
  - **4170MeV**, $D_{(s)}^{(*)}\underline{D}_{(s)}^{(*)}$ 195pb^{-1}→314pb^{-1}→ get more

- Selected published and preliminary results on D^0 / D^+ / D_s production and hadronic decays are presented in this talk

- CLEO plan:
  - Collect more statistics @ 4170MeV
  - Process all data
  - Get more published results