CLEO-c *HOT* TOPICS

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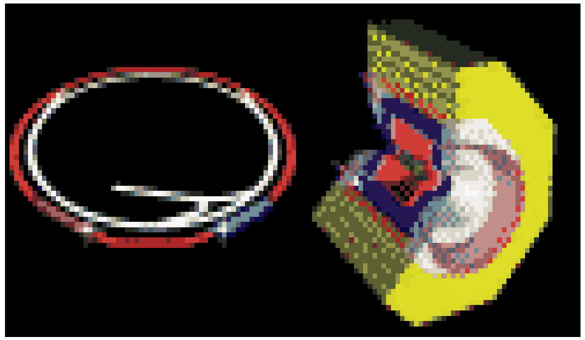
CLEO Collaboration

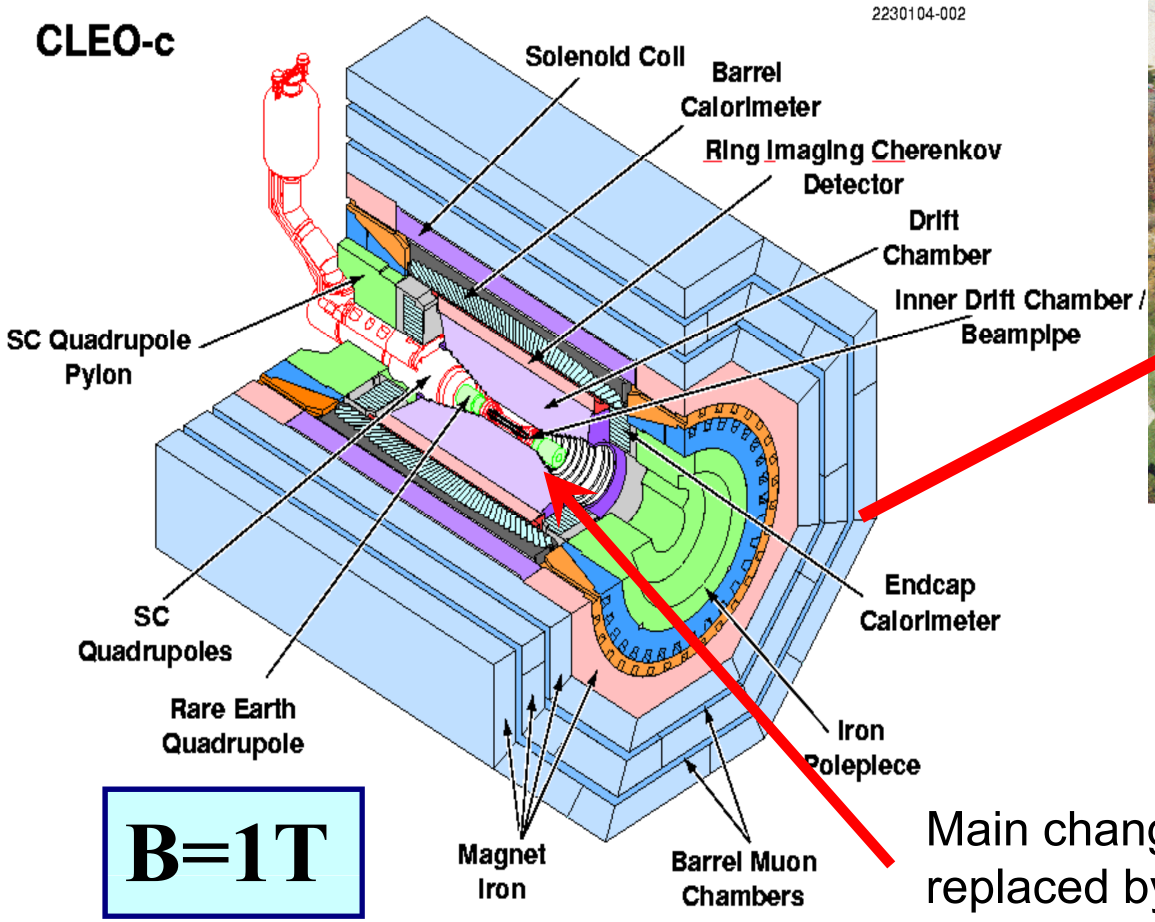
CORNELL UNIVERSITY LEPP

LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS



FPCP, Bled Slovenia, May 2007

CLEO-c at CESR



B=1T

Main change for CLEO-c, silicon detector replaced by lightweight inner drift chamber

CLEO-c data samples

CLEO-c: Oct. 2003 – Apr. 2008

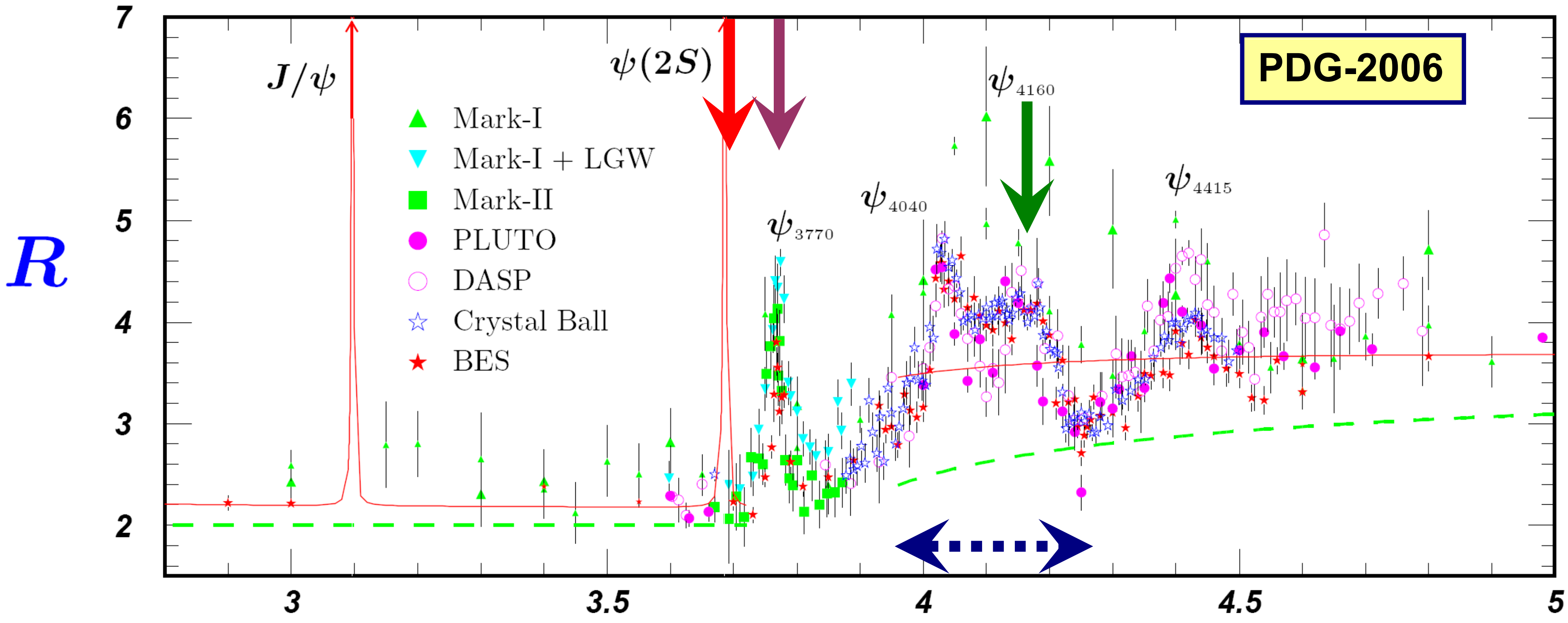
3686MeV, 54pb^{-1}, N(ψ(2S))≈27M **$e^+e^- \rightarrow$ ψ(2S) → ππ J/ψ, $\gamma\chi_c$ etc.**

3773MeV, 281pb^{-1} processed, more taken, target 670pb^{-1}, ψ(3770) →$D\overline{D}$

4170MeV, 195pb^{-1} → ~ 300pb^{-1} →more→ ~720pb^{-1}, $D_{(s)}^{(*)}\overline{D}_{(s)}^{(*)}$

3970–4260MeV energy scan, 60pb^{-1} in12 points

√s=3100MeV, J/ψ is excluded from CLEO-c run plan



Absolute D^0 and D^+ Branching Fractions

PRL 95, 121801 (2005) with 56 pb^{-1} $\psi(3770)$ data

Preliminary results with 281 pb^{-1} data now available (dataset has already doubled, and more is on the way)

Tagging technique

$D\bar{D}$ production at threshold: no extra particles, low multiplicity, very clean final state

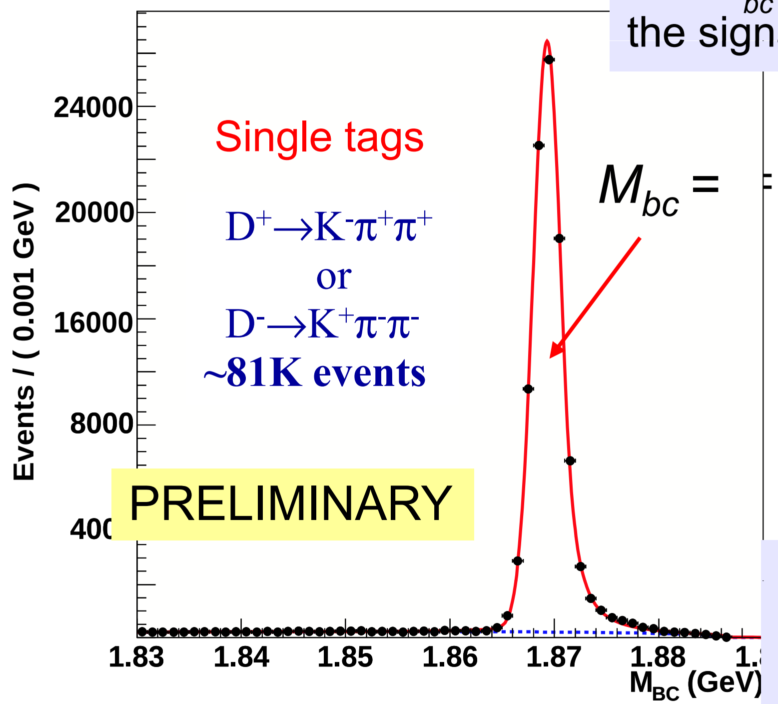
Use tagging technique (pioneered by Mark III) to fully reconstruct one (single tag) or both (double tag) D - greatly reduces combinatoric background

Variables used in the tag reconstruction:

$$\Delta E = E_{D-tag} - E_{beam} \approx 0$$

Cut on ΔE ($\pm 3\sigma$) and use M_{bc} to extract the signal by fitting

$$M_{bc} = \sqrt{E_{beam}^2 - P_{D-tag}^2} \approx M_D$$

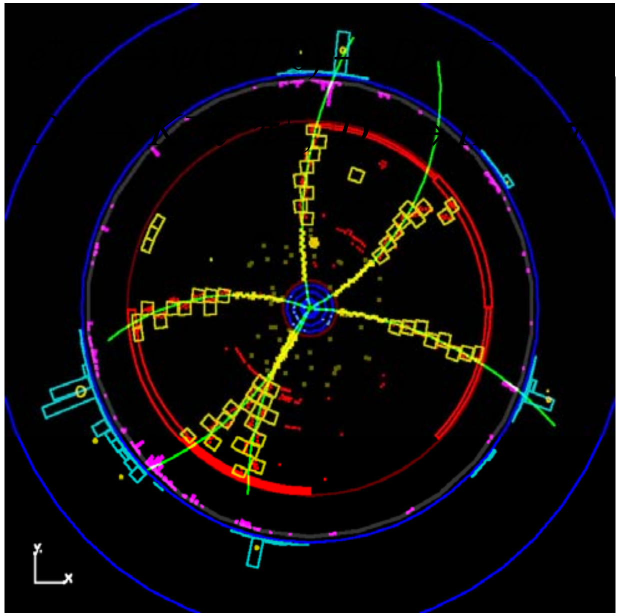


All single tags in 281 pb^{-1}:

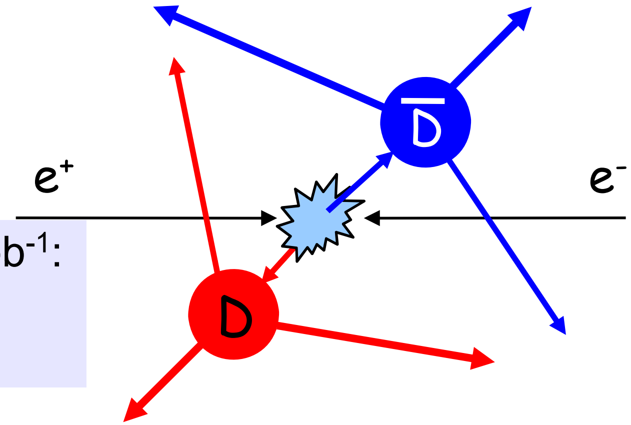
$D^0\bar{D}^0$: ~230K

D^+D^-: ~170K

$e^+e^- \to \psi(3770) \to D\bar{D}$



$D^+ \to K^- \pi^+ \pi^+$ $D^- \to K^+ \pi^- \pi^-$



D^0 and D^+ absolute BF: method

Measure 3 D^0 and 6 D^+ decay modes

single tags (ST): $n_i = N_{DD} B_i \varepsilon_i$

double tags (DT): $n_{ij} = N_{DD} B_i B_j \varepsilon_{ij}$

$$\Rightarrow B_j \approx \frac{n_{ij}}{n_j} \frac{\varepsilon_j}{\varepsilon_{ij}} \qquad N_{DD} \approx \frac{n_i n_j}{n_{ij}} \frac{\varepsilon_{ij}}{\varepsilon_i \varepsilon_j}$$

BF are independent of luminosity and cross section

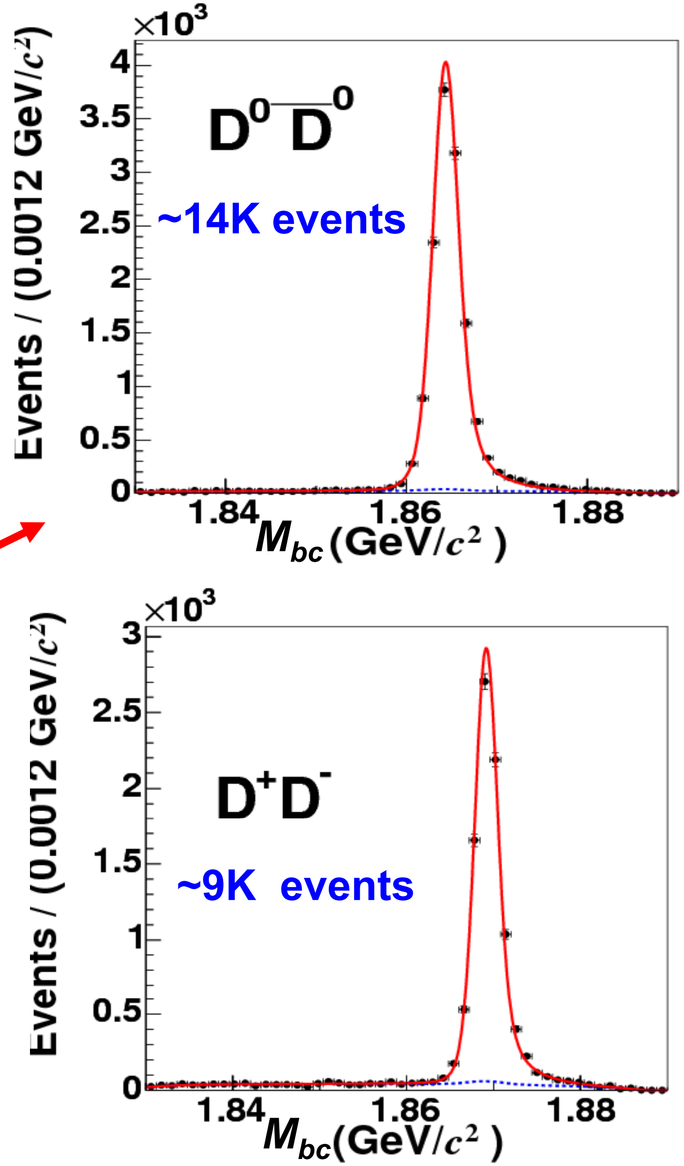
Combine ST and DT yields for all modes in χ^2 fit to get absolute BF (and N_{DD})

Scale of statistical error is set by number of total DT yield

Since $\varepsilon_{ij} \approx \varepsilon_i \varepsilon_j$ to first order

B_j are independent of tag mode efficiencies (ε_j)

Double tags in 281 pb^{-1}

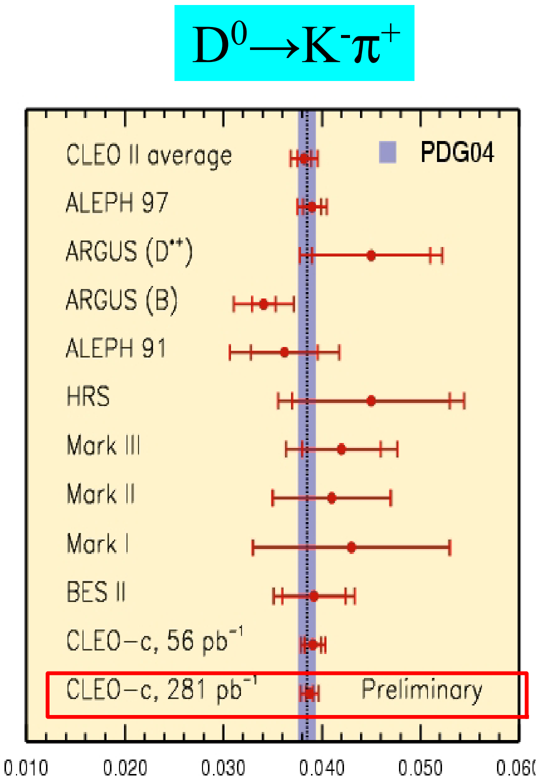


D^0 and D^+ absolute BF: results

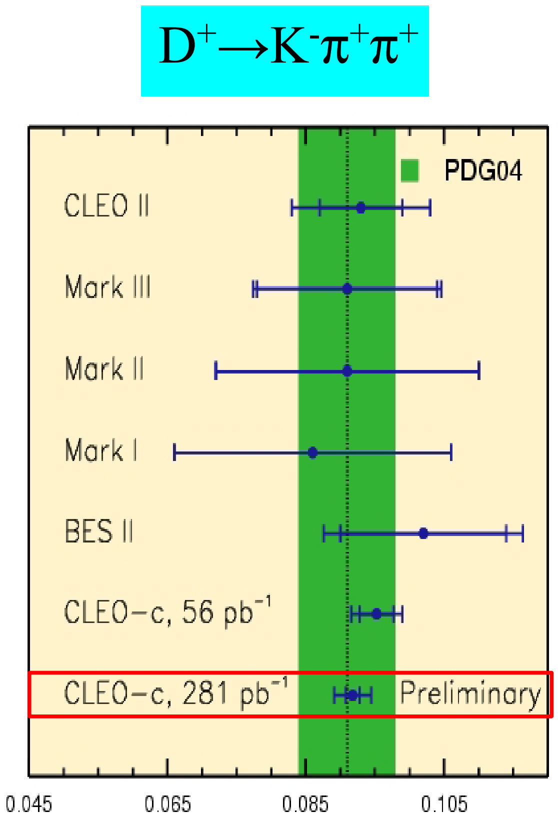
Absolute BF's based on 56 pb^{-1} data are published (and included in PDG06)

Updated the results with 281 pb^{-1} being finalized, but for now PRELIMINARY

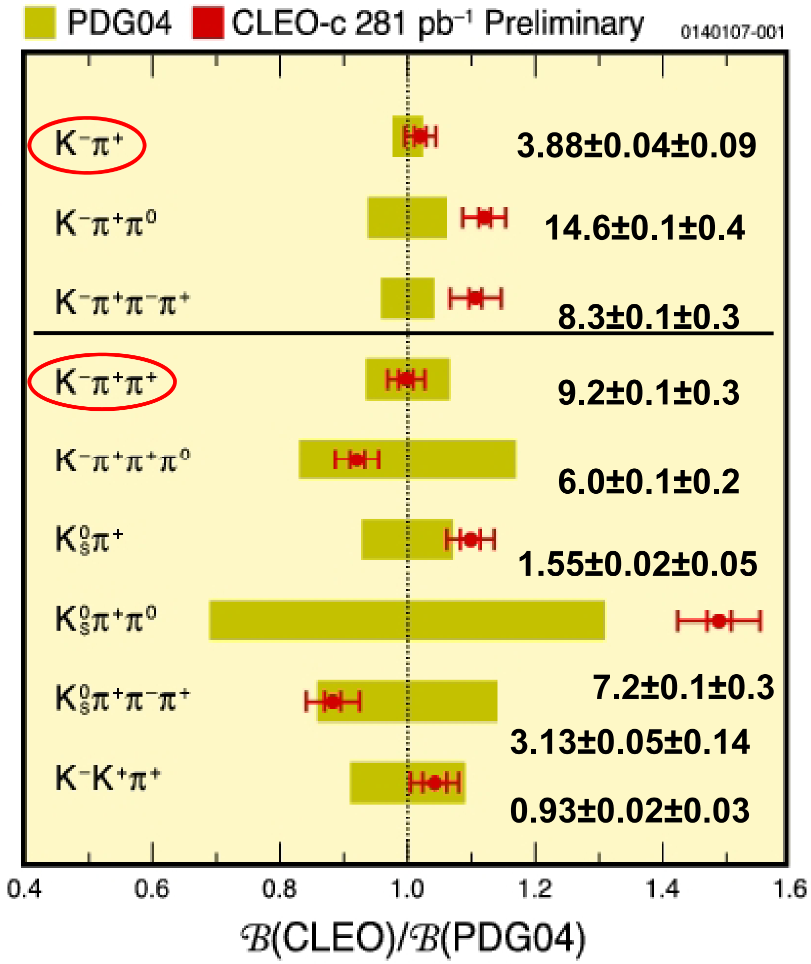
- **Statistical error ~1-2%, results are systematics limited**
- **BF corrected for FSR (~2% effect)**



$\delta B/B \approx 2.3\%$

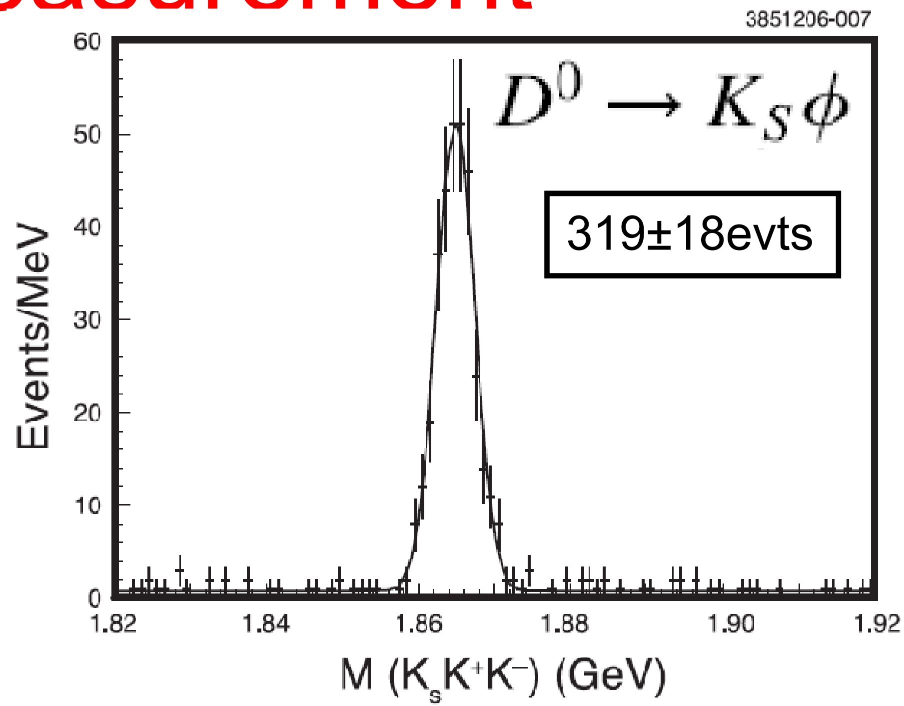


$\delta B/B \approx 2.9\%$



D^0 mass measurement

- PRL 98,092002 (2007)
- PDG: $M(D^0)=1864.5\pm0.4$MeV
  - average of LGW, MARK II, NA32
  - Measured in $D^0\to K\pi$, $K\pi\pi\pi$
- CLEO-c, 281pb^{-1}, use $D^0 \to K_S\varphi$:
  - $M(D^0)-M(\varphi)-M(K_S)=347$MeV
  - p(K), p(π) <600MeV range
- p calibration: using $M(K_S \to \pi+\pi-)$
- B calibration: $M(J/\psi\to\mu^+\mu^-)$
- Cross-check: $M(\psi(2S)\to \pi^+\pi^- J/\psi)$



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

If X(3872) is a $D^0\bar{D}^{*0}$ molecule, then $E_b=0.6\pm0.6$ MeV

D_s has been studied at CLEO for 24 Years!

CLNS 83/569
CLEO 83-05
6/18/83

EVIDENCE FOR THE F MESON AT 1970 MeV

A. Chen, M. Goldberg, N. Horwitz, A. Jawahery, P. Lipari, G. C. Moneti, C. G. Trahern, and H. Van Hecke

Syracuse University, Syracuse, New York 13210

M. S. Alam, S. E. Csorna, L. Garren, M. D. Mestayer, R. S. Panvini, and Xia Yi

Vanderbilt University, Nashville, Tennessee 37235

R. Giles, J. Hassard, M. Hempstead, K. Kinoshita, W. W. MacKay, F. M. Pipkin, and Richard Wilson

Harvard University, Cambridge, Massachusetts 02138

H. Kagan

Ohio State University, Columbus, Ohio, 43210

P. Avery, C. Bebek, K. Berkelman, D. G. Cassel, J. W. DeWire, R. Ehrlich, T. Ferguson, R. Galik, M. G. D. Gilchriese, B. Gittelman, M. Halling, D. L. Hartill, D. Herrup[a], S. Holzner, M. Ito, J. Kandaswamy, V. Kistiakowsky[b], D. L. Kreinick, Y. Kubota, N. B. Mistry, F. Morrow, E. Nordberg, M. Ogg, R. Perchonok, R. Plunkett[c], A. Silverman, P. C. Stein, S. Stone, D. Weber, and R. Wilcke

Cornell University, Ithaca, New York 14853

A. J. Sadoff

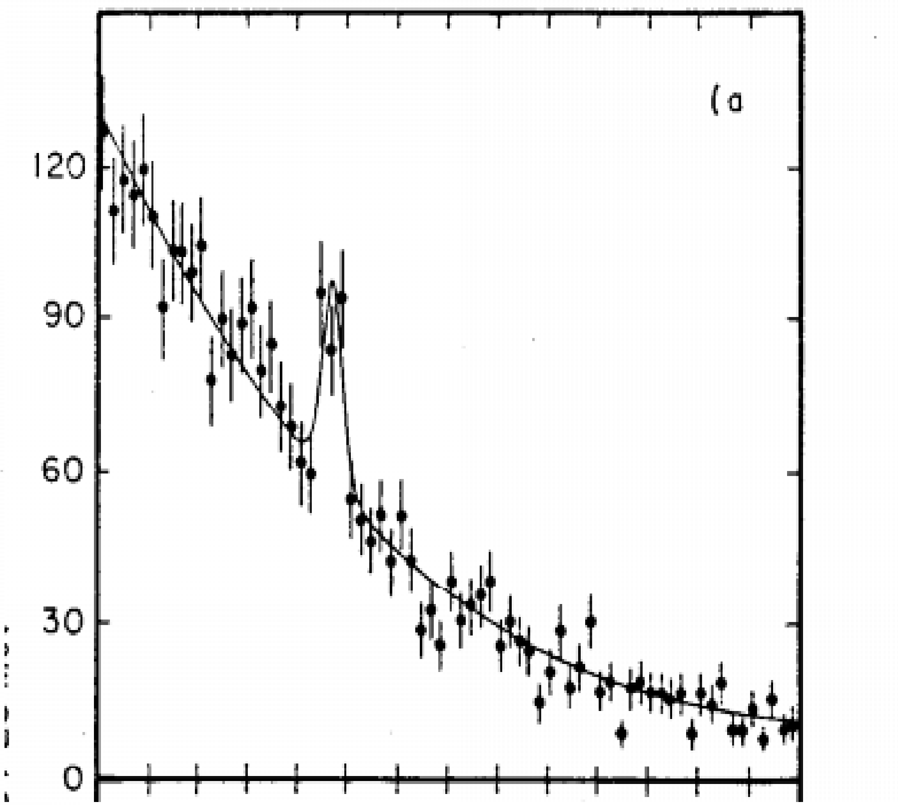
Ithaca College, Ithaca, New York 14850

S. Behrends, K. Chadwick, J. Chauveau,[d] P. Ganci[e], T. Gentile, Jan M. Guida, Joan A. Guida, R. Kass, A. C. Melissinos, S. L. Olsen, G. Parkhurst, D. Peterson, R. Poling, C. Rosenfeld, G. Rucinski[f], P. Tipton, and E. H. Thorndike

University of Rochester, Rochester, New York 14627

J. Green, R. G. Hicks, F. Sannes, P. Skubic,[g] A. Snyder, and R. Stone

Rutgers University, New Brunswick, New Jersey 08854



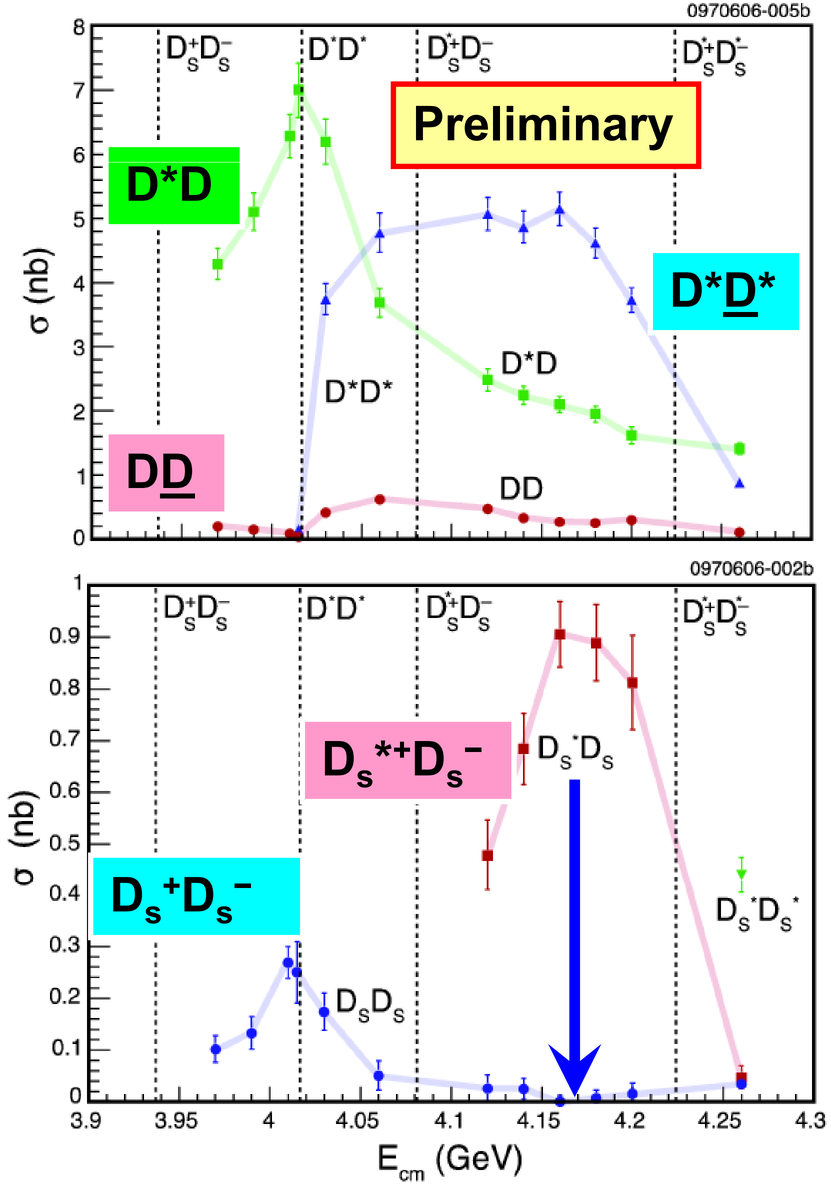
Found in 10 GeV Continuum Data

D_s Production Cross Section

Little was known about components of $\sigma(e^+e^- \rightarrow \text{hadrons})$ @ $E_{cm}>M[\psi(3770)]$

CLEO scan ($60 pb^{-1}$) in 12 points 3.97-4.26GeV

Took large statistics at 4.17GeV, $314 pb^{-1}$



At 4.17 GeV approx cross-sections:

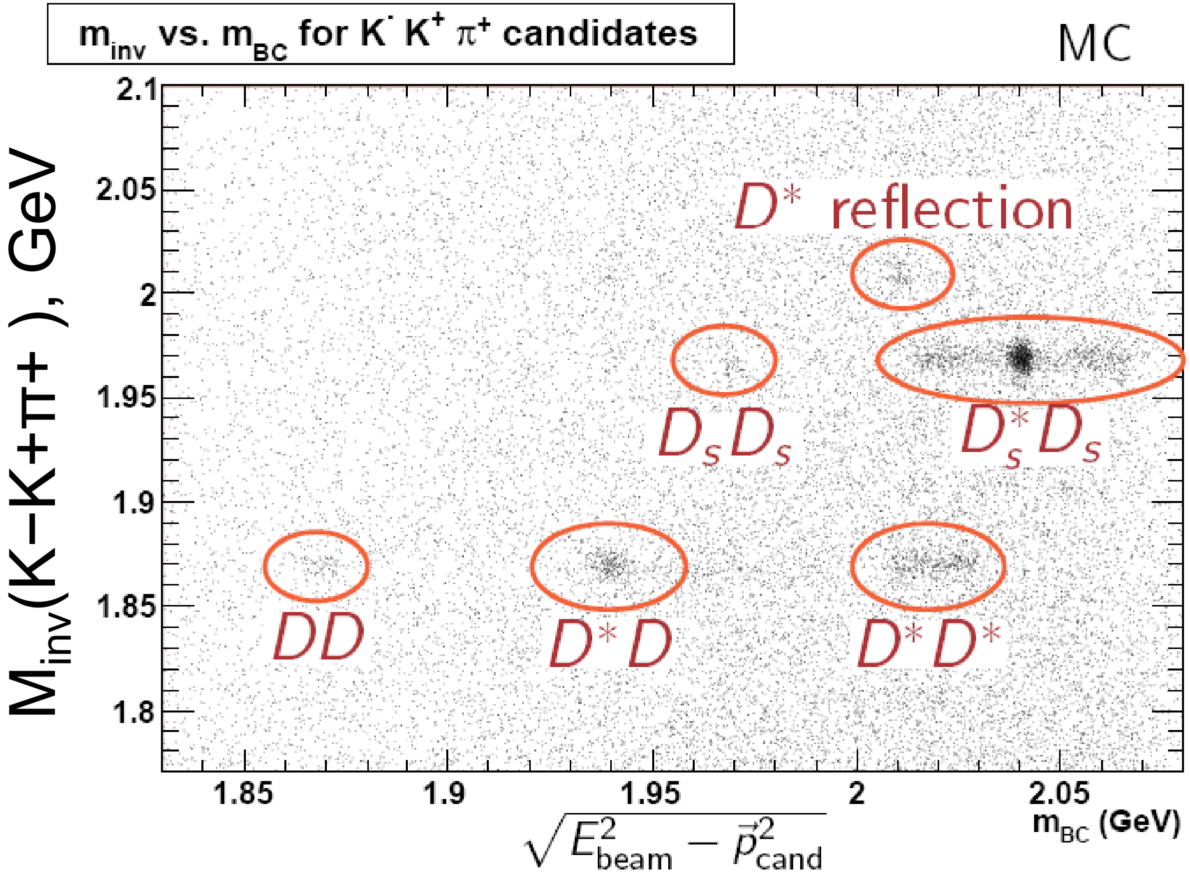
Light quarks	12 nb
$D^*\bar{D}^*$	5 nb
$D\bar{D}^*$	2 nb
$D\bar{D}$	0.2 nb
$D_s^*\bar{D}_s$	1 nb
$D_s\bar{D}_s$	0.02 nb

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:

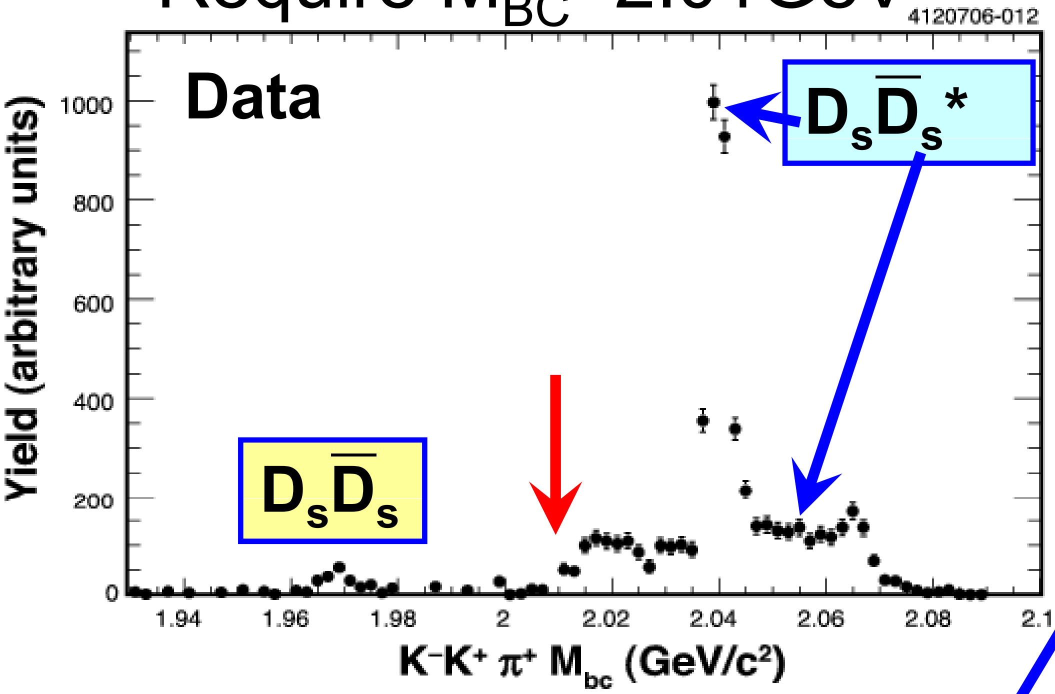


- Good kinematical separation between modes

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

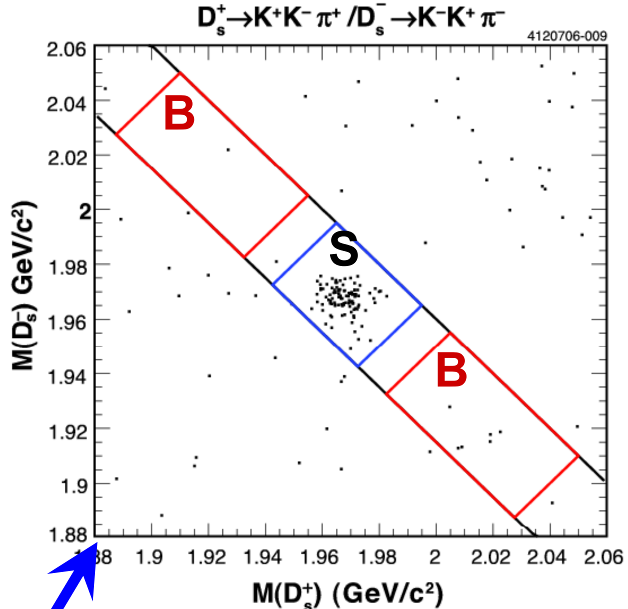
Measure ST and DT yields:

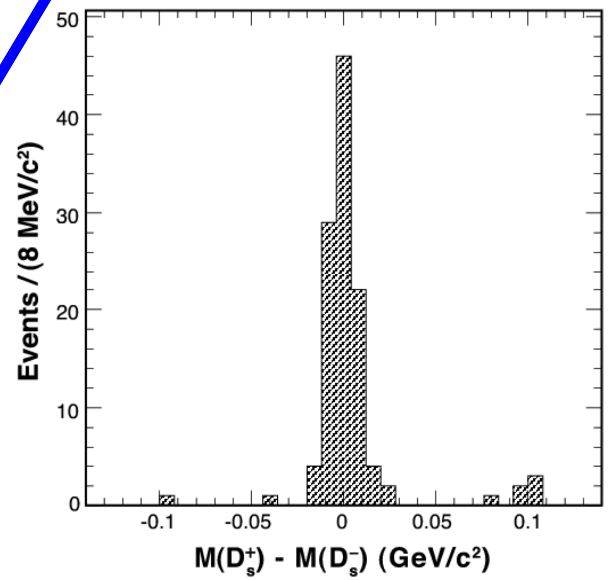
- Require M_{BC}>2.01GeV



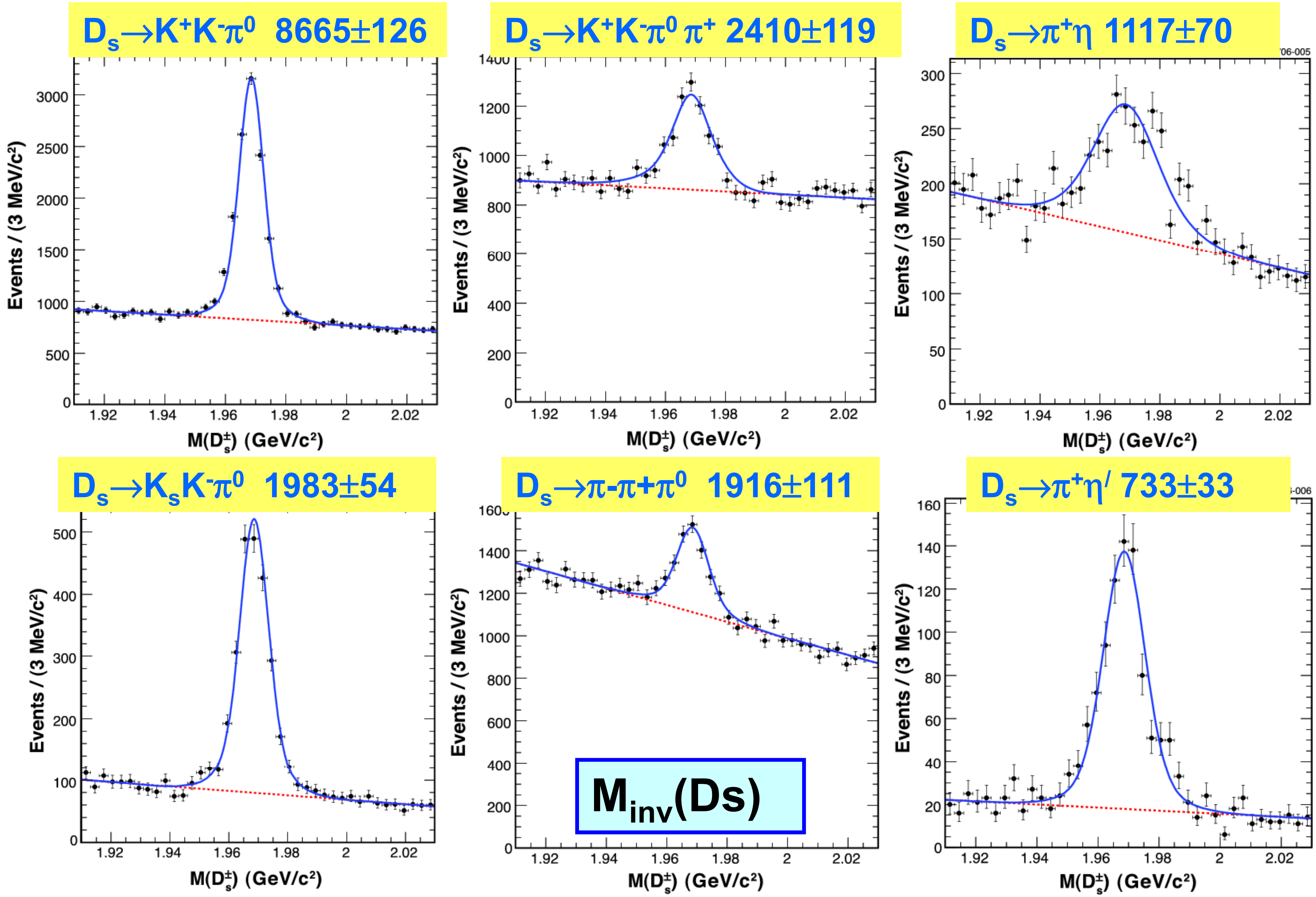
DT yields: Cut and count in $M(D_s^+)$ vs $M(D_s^-)$

PRELIMINARY 195 pb^{-1}





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

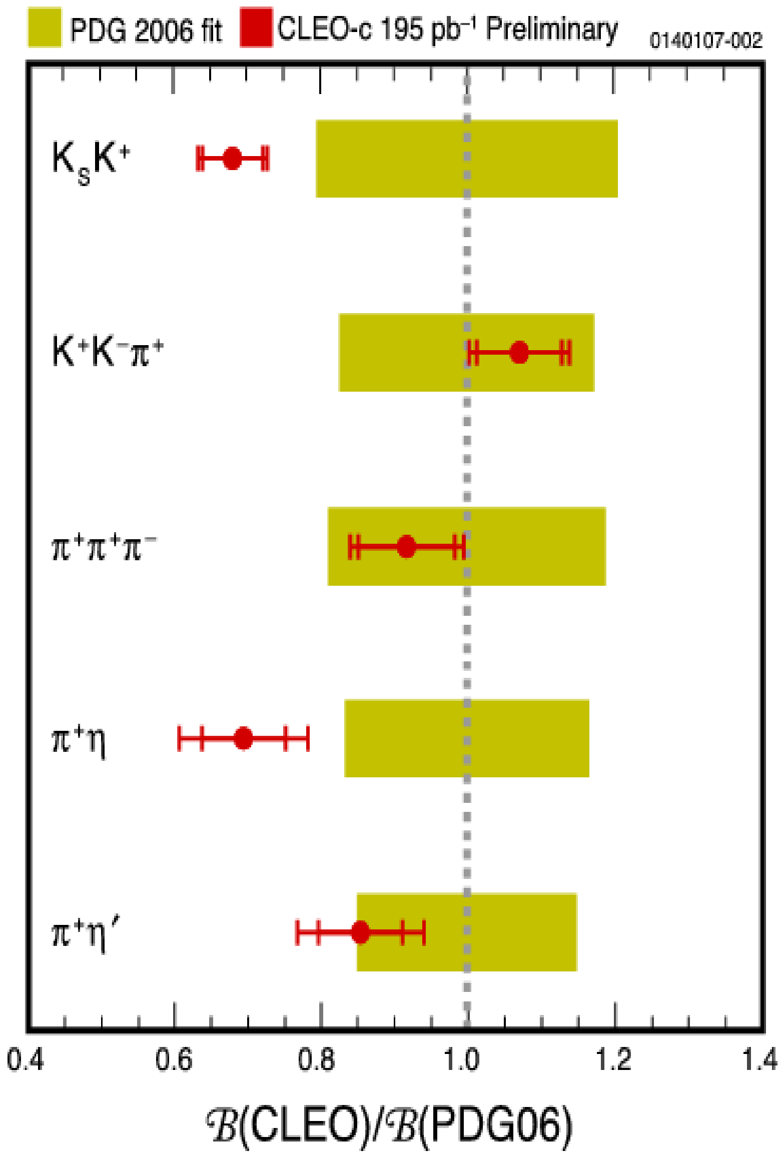


Absolute D_s hadronic $\mathcal{B}$'s

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

Preliminary

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



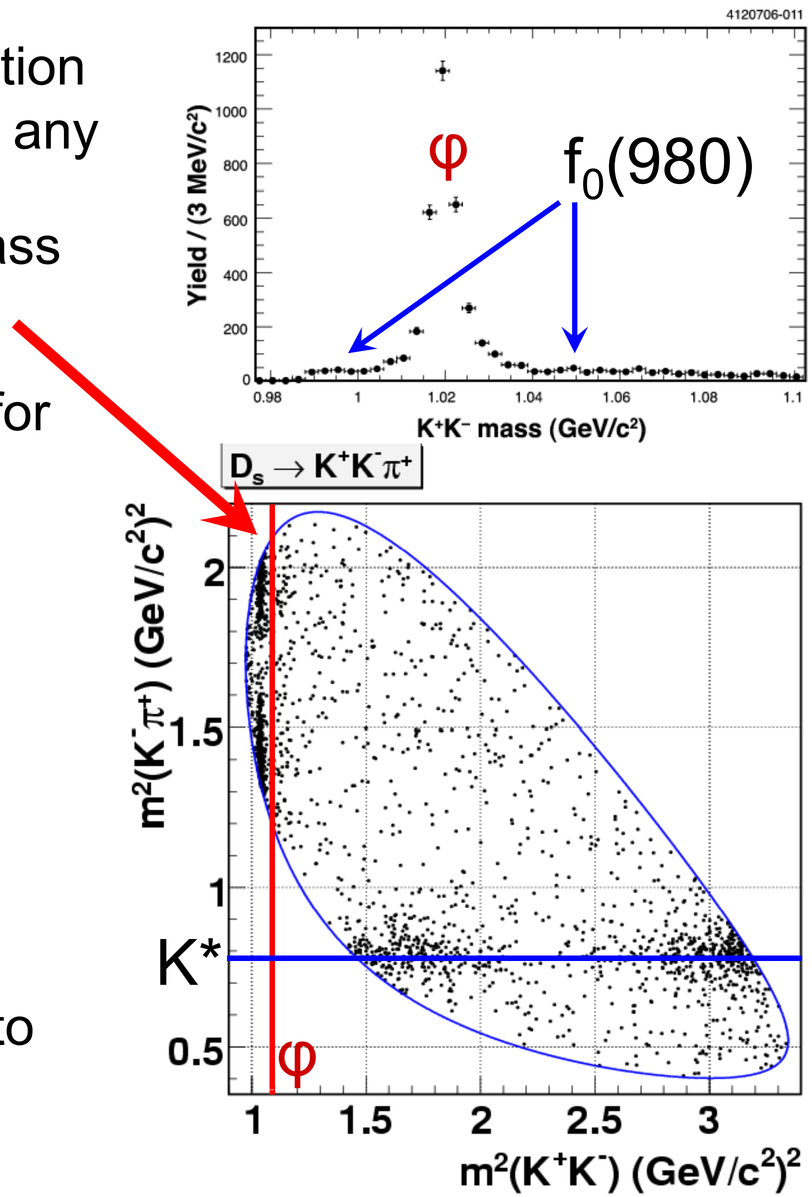
The $\varphi\pi^+$ problem in $D_s \to K^-K^+\pi^+$

- 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…



Decay Modes of the D_s into two pseudo-scalars

Search for the modes:

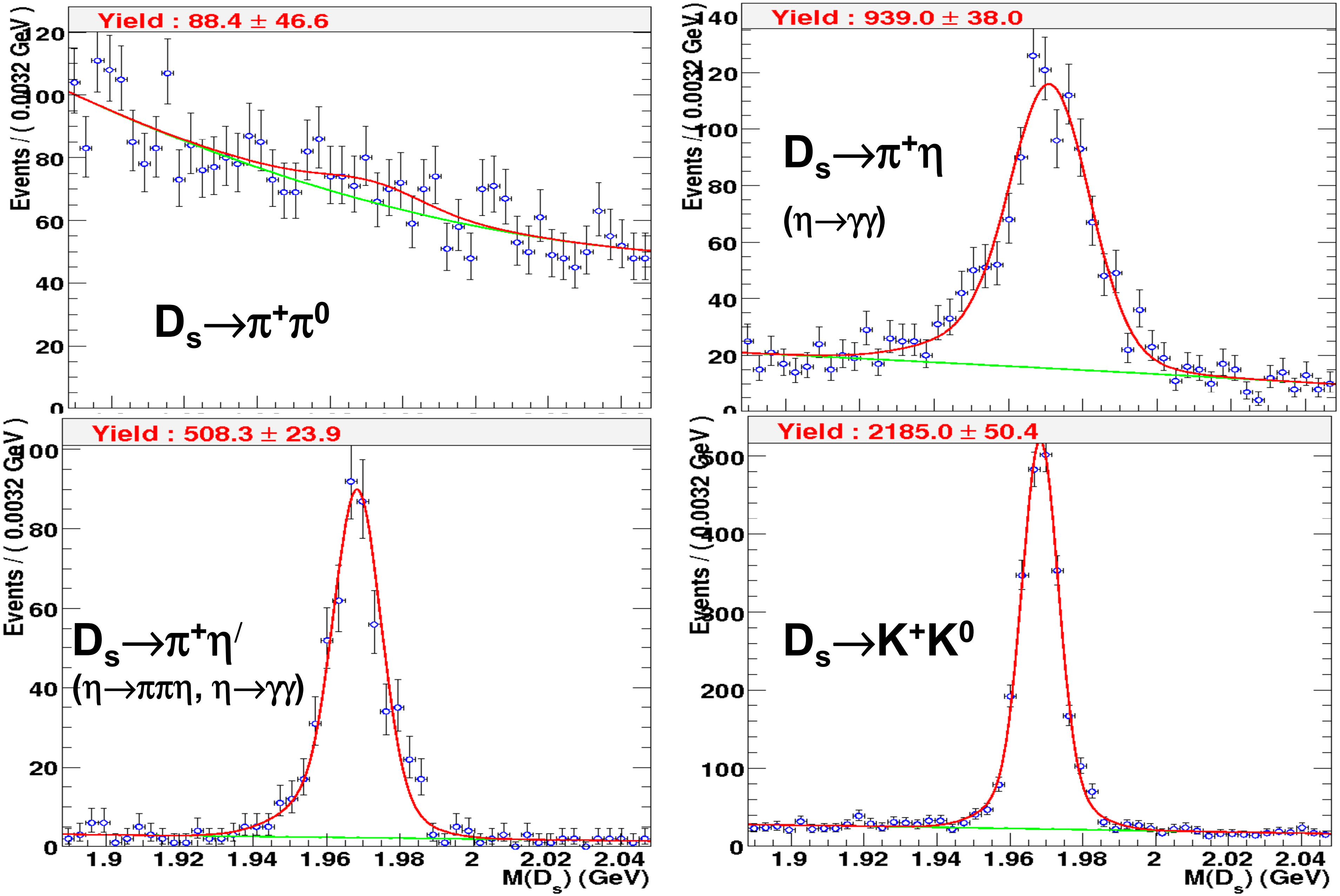
$\pi^0 K^+$
$K^+\eta$
$K^+\eta'$ Cabibbo Suppressed
$K^0\pi^+$

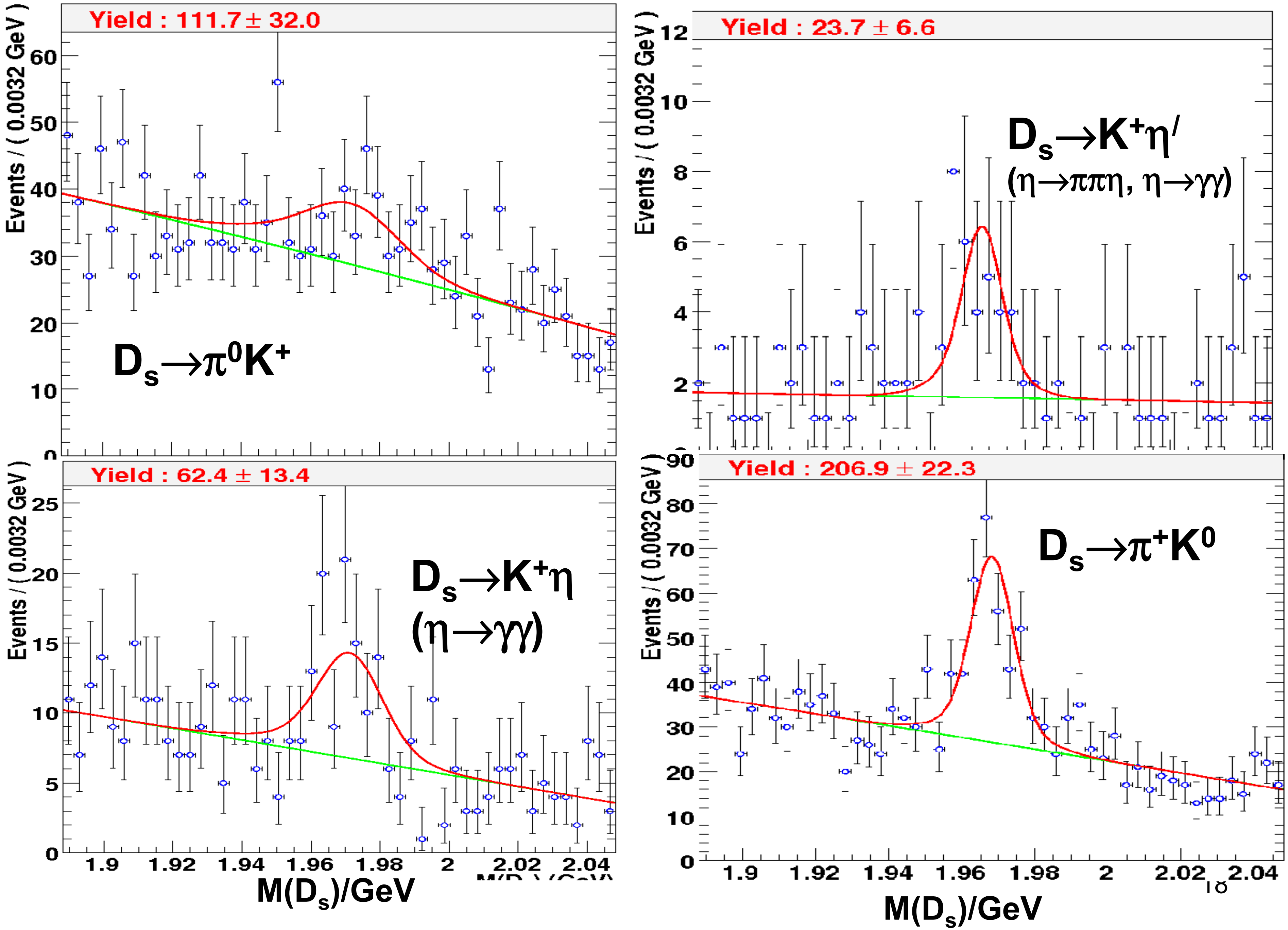
$\pi^+ \pi^0$ Forbidden

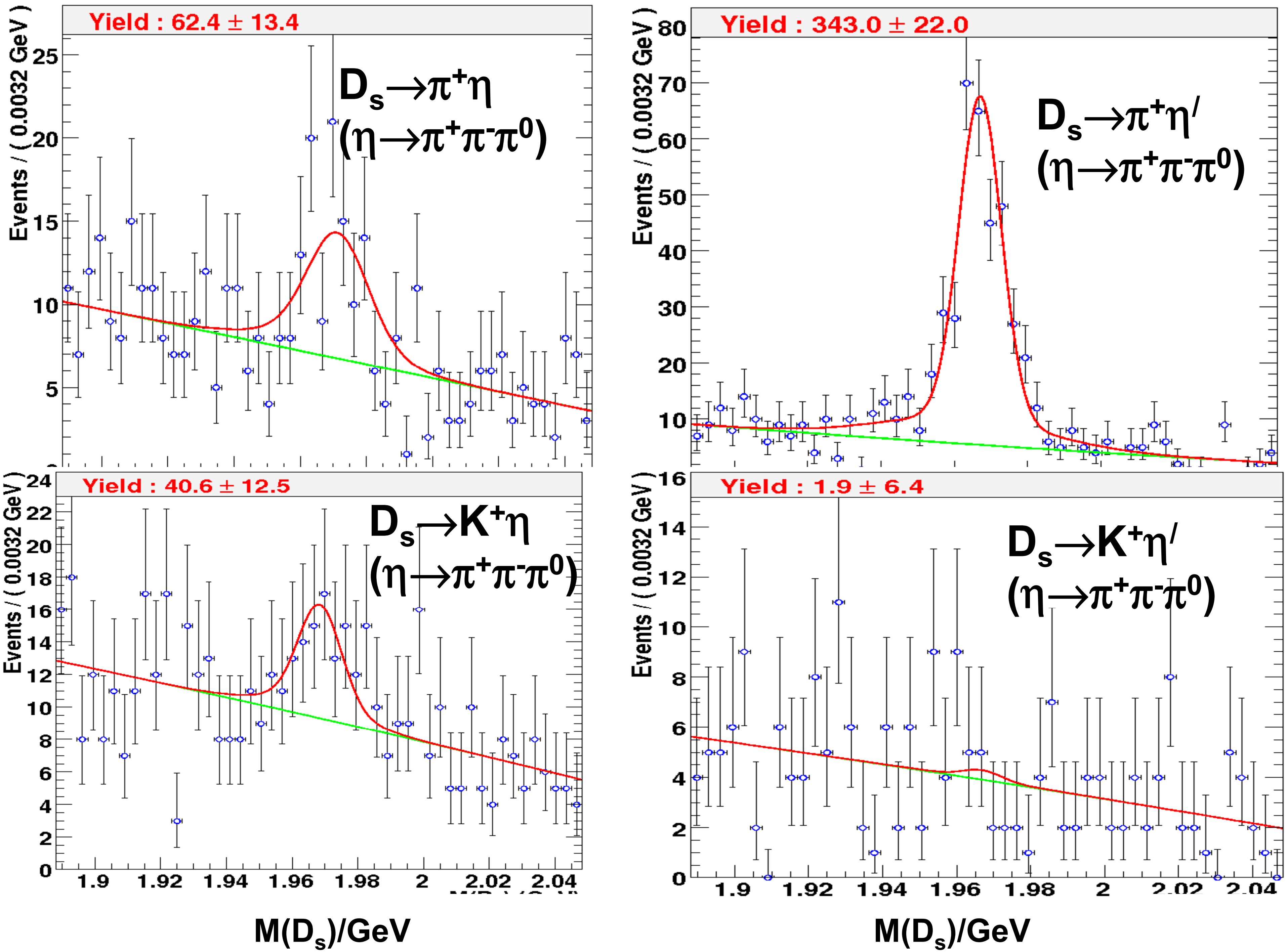
Compare with Cabibbo Allowed:

$\pi^+\eta$
$\pi^+\eta'$
K^+K^0

DATA plots (preliminary, ~300 pb^{-1})




Yield : 111.7 ± 32.0
Ds→π0K+
Yield : 23.7 ± 6.6
Ds→K+η/
(η→ππη, η→γγ)
Yield : 62.4 ± 13.4
Ds→K+η
(η→γγ)
Yield : 206.9 ± 22.3
Ds→π+K0
Events / (0.0032 GeV)
M(Ds)/GeV



Yield : 62.4 ± 13.4
Ds→π+η
(η→π+π-π0)
Yield : 343.0 ± 22.0
Ds→π+η/
(η→π+π-π0)
Yield : 40.6 ± 12.5
Ds→K+η
(η→π+π-π0)
Yield : 1.9 ± 6.4
Ds→K+η/
(η→π+π-π0)
Events / (0.0032 GeV)
M(Ds)/GeV
M(Ds)/GeV

Results (Preliminary!)

$(D_s \to K^+\eta)/(D_s \to \pi^+\eta) = 0.080 \pm 0.015$

$(D_s \to K^+\eta')/(D_s \to \pi^+\eta') = 0.039 \pm 0.013$

$(D_s \to K^0\pi^+)/(D_s \to K^+K^0) = 0.083 \pm 0.009$

$(D_s \to K^+\pi^0)/(D_s \to K^+K^0) = 0.042 \pm 0.012$

$(D_s \to \pi^+\pi^0)/(D_s \to K^+K^0) < 0.04$

Statistics Dominated – more statistics will come

D^+ and D_s leptonic decays and decay constants

$D^+ \to \mu^+\nu$ and f_D:

PRL 95, 251801 (2005): $D^+ \to \mu^+\nu$ BF and $D^+ \to e^+\nu$ (UL)

PRD 73, 112005 (2006): $D^+ \to \tau^+\nu$ (UL)

with 281 pb^{-1} $D\bar{D}$ data

$D_s \to \mu^+\nu$ and $\tau^+(\pi^+\nu)\nu$:

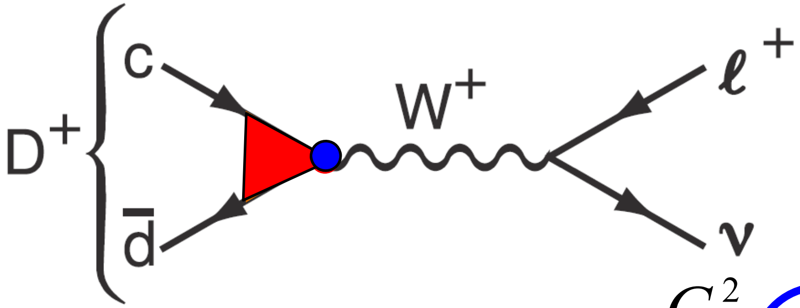
Shown in 2006 with 195 pb^{-1}

Now sent for publication with 314 pb^{-1} $D_s{}^*\bar{D}_s$ data

$D_s \to \tau^+(e^+\nu\,\nu)\nu$:

Preliminary results with 195 pb^{-1} $D_s{}^*\bar{D}_s$ data

$D_{(s)} \to \ell^+\nu$: Motivation



- **Using V_{cd} and V_{cs} , f_D and f_{Ds} can be determined from $D_{(s)} \to \ell^+\nu$ purely leptonic decays**

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

$V_{qq'}$: CKM matrix element (weak interaction)

f_P : pseudoscalar decay constant (strong interaction between quarks)

Measurement of $f_{D(s)}$ help to calibrate and validate Lattice QCD

Impact on heavy flavor physics to constrain the CKM matrix:

New physics: relative decay rate to different lepton flavors very well predicted – any deviations imply new physics.

$D^+ \to \ell^+\nu$: $\Gamma(e^+\nu) : \Gamma(\mu^+\nu) : \Gamma(\tau^+\nu) = 2.3\times10^{-5} : 1.0 : 2.7$

$D_s \to \ell^+\nu$: $\Gamma(e^+\nu) : \Gamma(\mu^+\nu) : \Gamma(\tau^+\nu) = 2.5\times10^{-5} : 1.0 : 9.7$

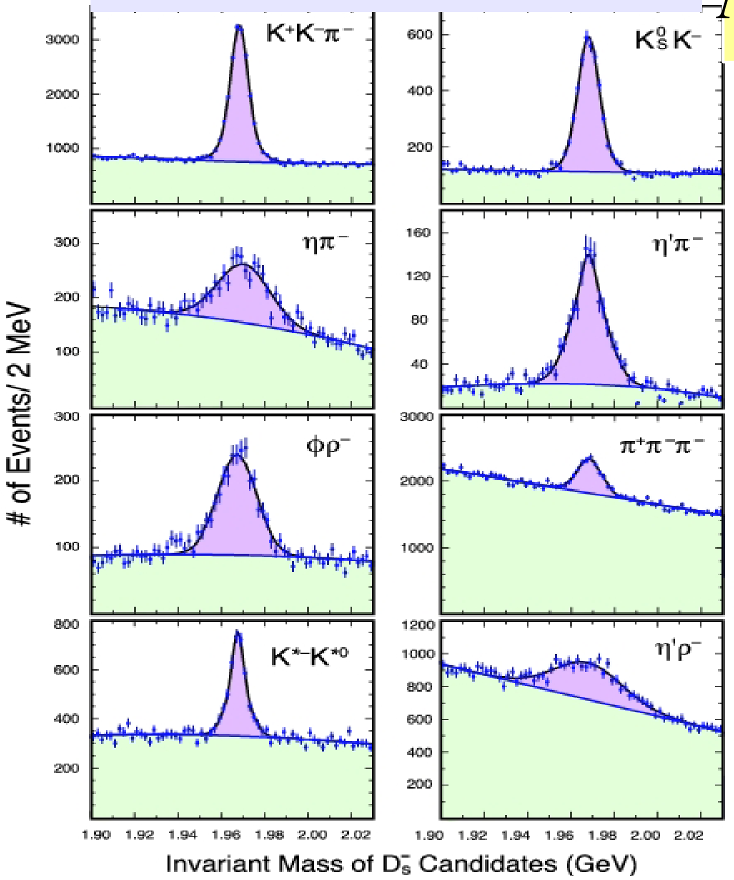
in SM

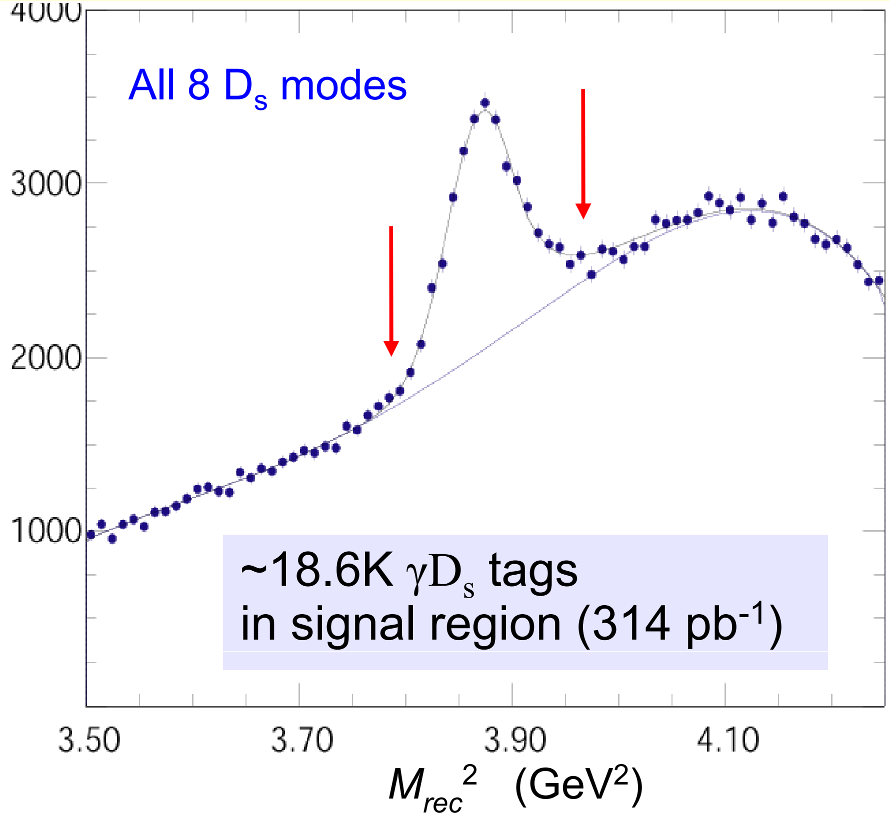
$D_s \to \mu^+\nu$ and $\tau^+(\pi^+\nu)\nu$

- **Reconstruct one D_s decaying into 8 hadronic modes (tag)**
- **Require an additional photon and calculate recoil mass against the $\gamma D_{s\text{-tag}}$**
- **(Kinematic constraints are used to improve resolutions and remove multiple combinations)**

~31.3K D_s tags in 314 pb^{-1}

$$M_{rec}^2 = (E_{CM} - E_{D_S-tag} - E_\gamma)^2 - (-\vec{p}_{D_S-tag} - \vec{p}_\gamma)^2 \approx M_{D_S}^2$$

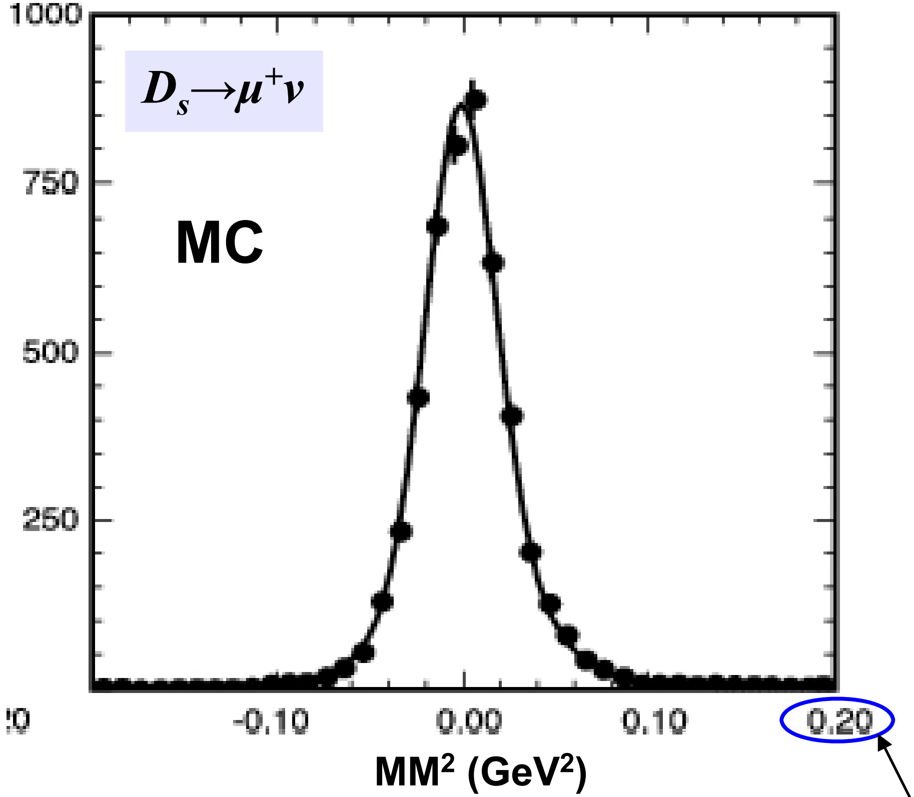


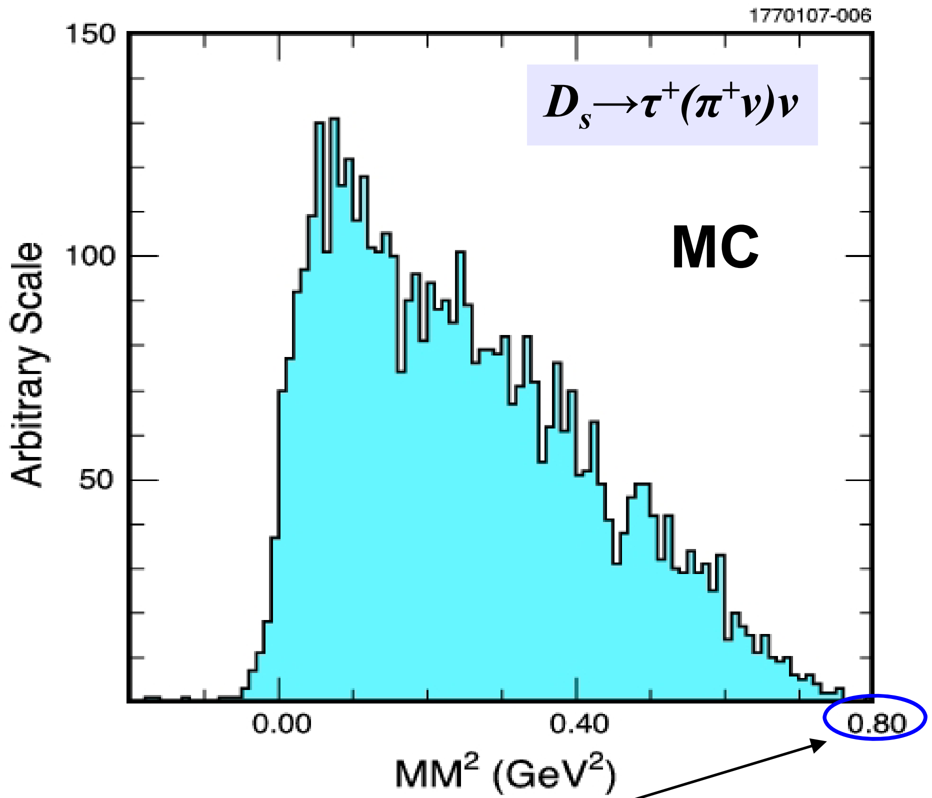


$D_s \to \mu^+ \nu$ and $\tau^+(\pi^+\nu)\nu$

- Require one additional track and no extra shower in CC with > 300 MeV
- Calculate missing mass in the event to infer the neutrino(s):

$$MM^2 = (E_{CM} - E_{D_S-tag} - E_\gamma - E_{\mu(\pi)})^2 - (-\vec{p}_{D_S-tag} - \vec{p}_\gamma - \vec{p}_\mu)^2$$





Note different scale

$D_s \to \mu^+\nu$ and $\tau^+(\pi^+\nu)\nu$

- Three cases depending on particle type:

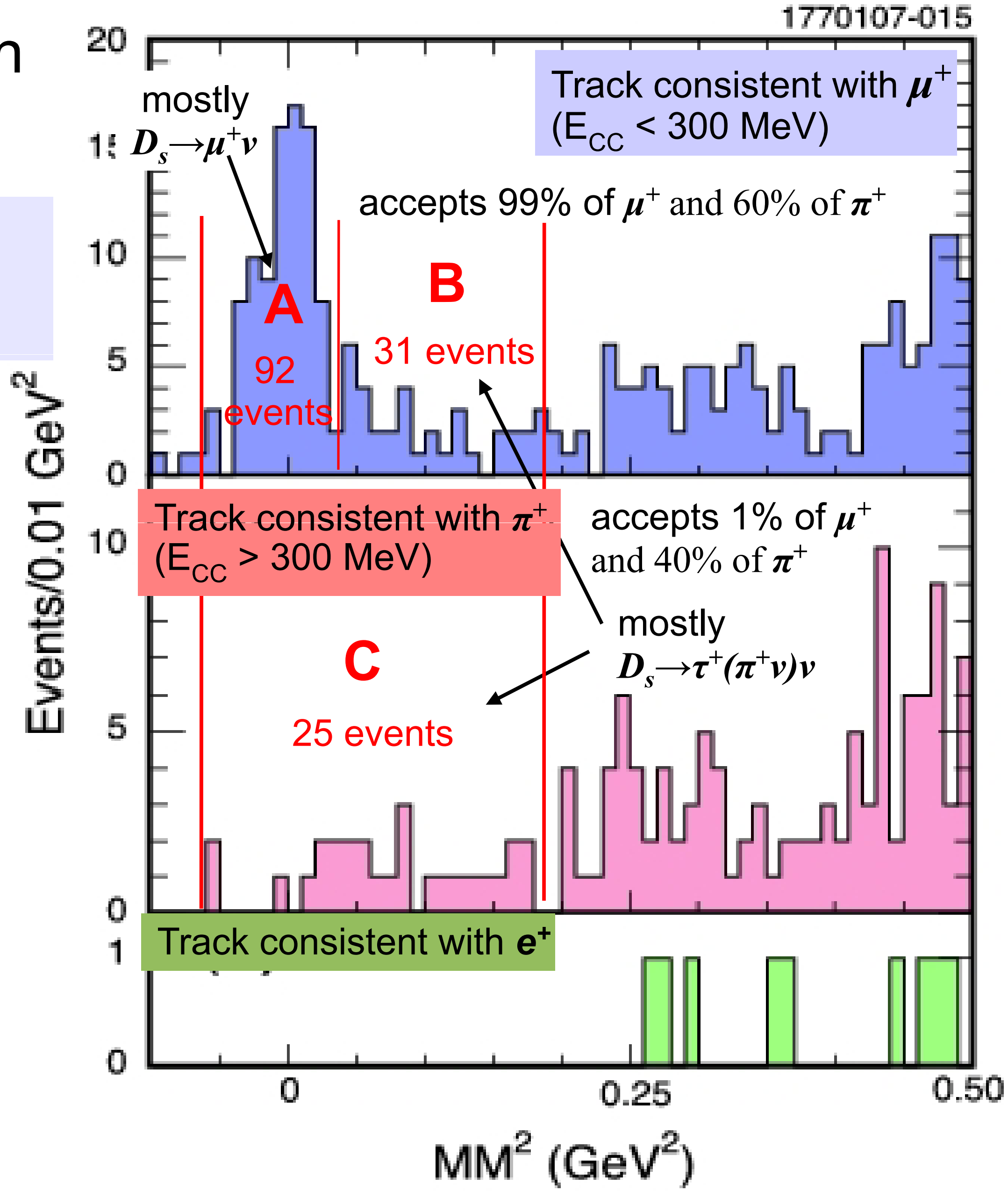
A 92 events (3.5 backg+7.4 $\tau^+(\pi^+\nu)\nu$)
using SM τ/μ ratio
$B(D_s \to \mu^+\nu)$ = **(0.594 ± 0.066 ± 0.031)%**

B+C: 31+25 events (3.5+5 backg)
$B(D_s \to \tau^+\nu)$ = **(8.0 ± 1.3 ± 0.4)%**

A+B+C: 148 events (10.7 background)
using SM τ/μ ratio
$B^{eff}(D_s \to \mu^+\nu)$ = ***(0.621 ± 0.058 ± 0.032)%***

$$f_{D_s} = (270 \pm 13 \pm 7)\ \text{MeV}$$

$B(D_s \to e^+\nu) < 1.3\times10^{-4}$



$D_s \rightarrow \tau^+(e^+\nu\nu)\nu$

- Complimentary analysis using $D_s \rightarrow \tau^+\nu$, $\tau^+ \rightarrow e^+\nu\nu$

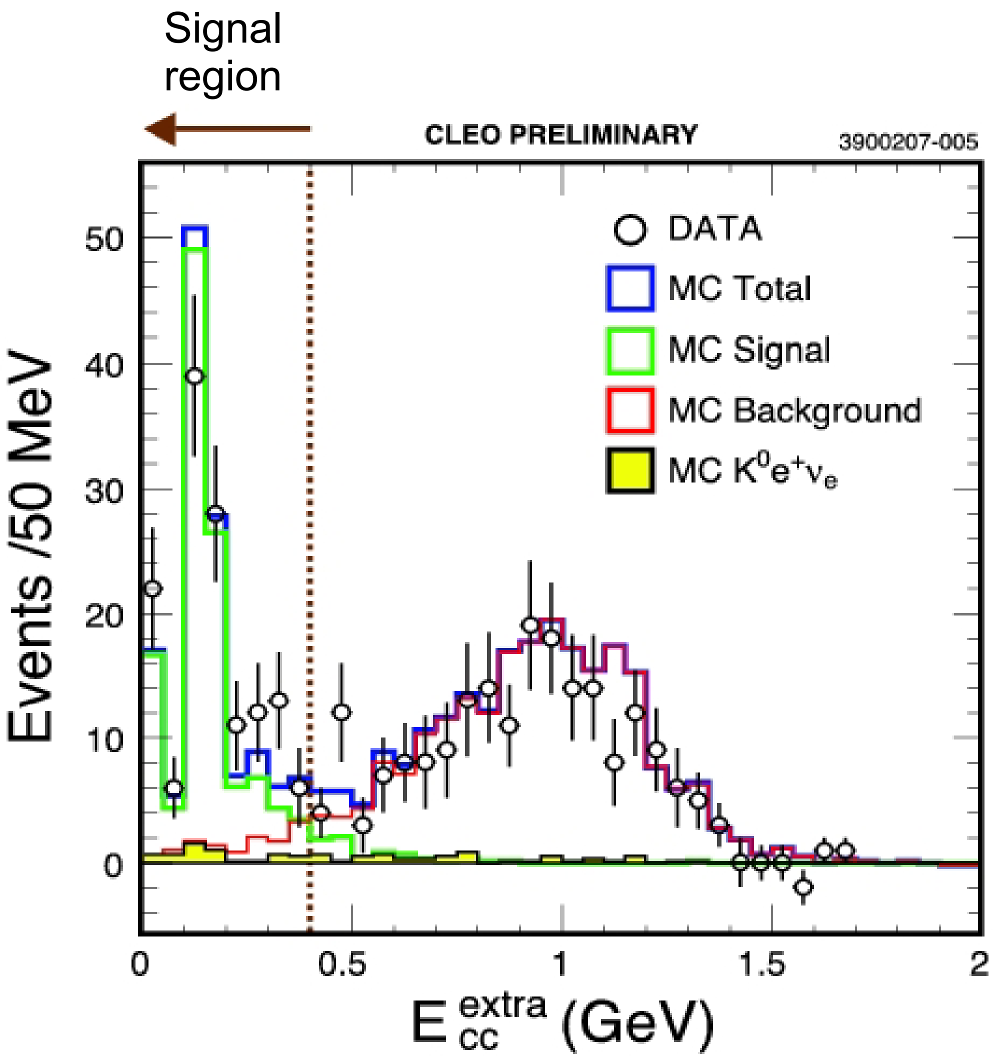
$B(D_s \rightarrow \tau^+\nu)B(\tau^+ \rightarrow e^+\nu\nu) \approx 1.3\%$ significant [compare to $B(D_s \rightarrow Xe^+\nu) \approx 8\%$]

Analysis technique:

- Find D_s^- tag and e^+ (no need to find γ from D_s^*)
- No extra track
- Extra energy in CC < 400 MeV

Results:

$B(D_s \rightarrow \tau^+\nu)$ = **(6.29 ± 0.78 ± 0.52)%**
[PDG06: $B(D_s \rightarrow \tau^+\nu)$ = (6.4 ± 1.5)%]
f_{Ds} = (278 ± 17 ± 12) MeV



f_D and f_{Ds} : comparison with theory

Summary of CLEO-c results:

f_D = (223 ± 17 ± 3) MeV

f_{Ds} = (273 ± 10 ± 5) MeV

(f_{Ds} weighted average of the two methods - syst. error is mostly uncorrelated)

f_{Ds}/f_D = 1.22 ± 0.09 ± 0.03

Consistent with most models

Statistically limited – more data is on the way!

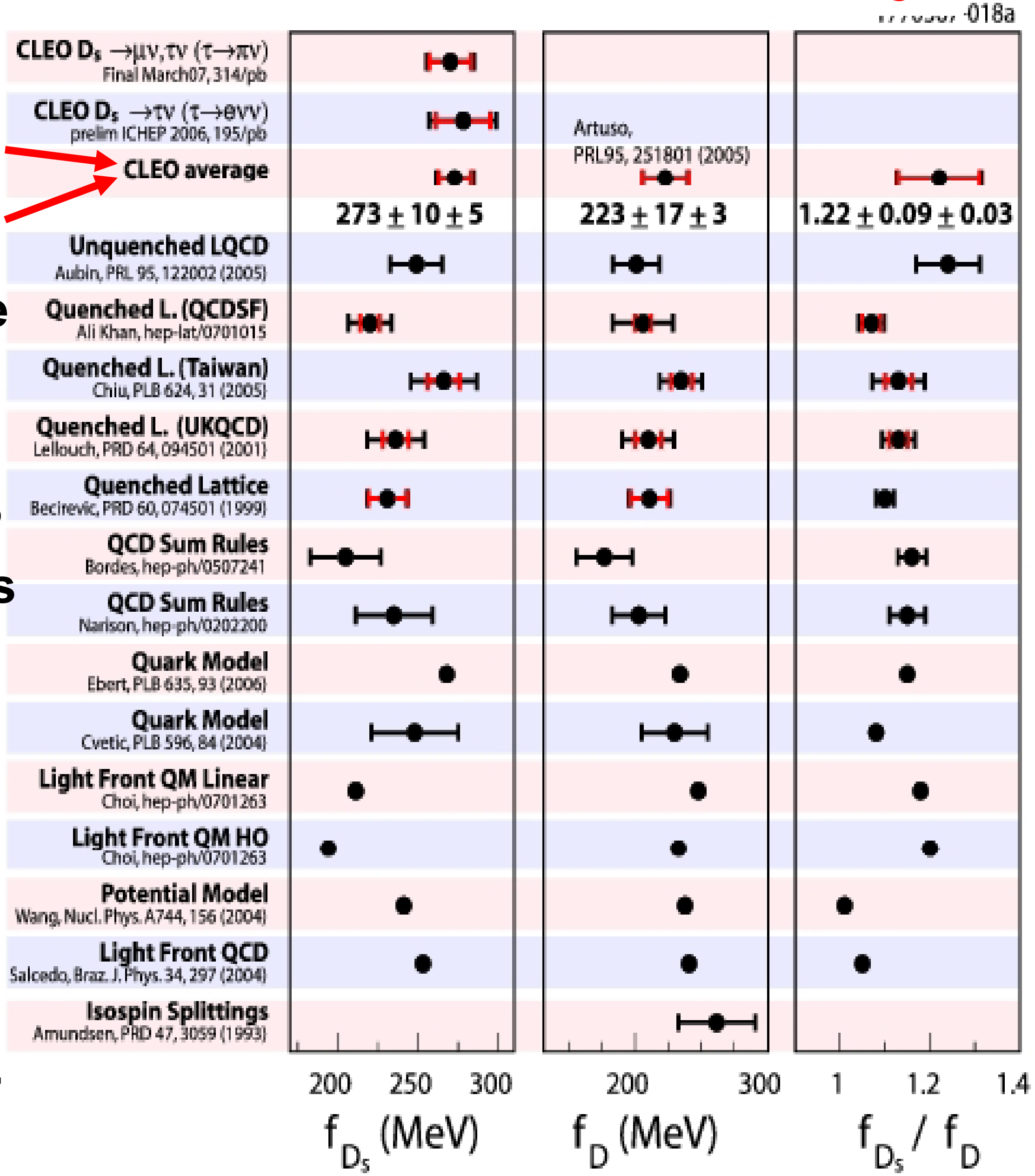
Lattice QCD (unquenched) PRL 95, 122002 (2005):

f_D = (201 ± 3 ± 17) MeV

f_{Ds} = (249 ± 3 ± 16) MeV

f_{Ds}/f_D = 1.24 ± 0.01 ± 0.07

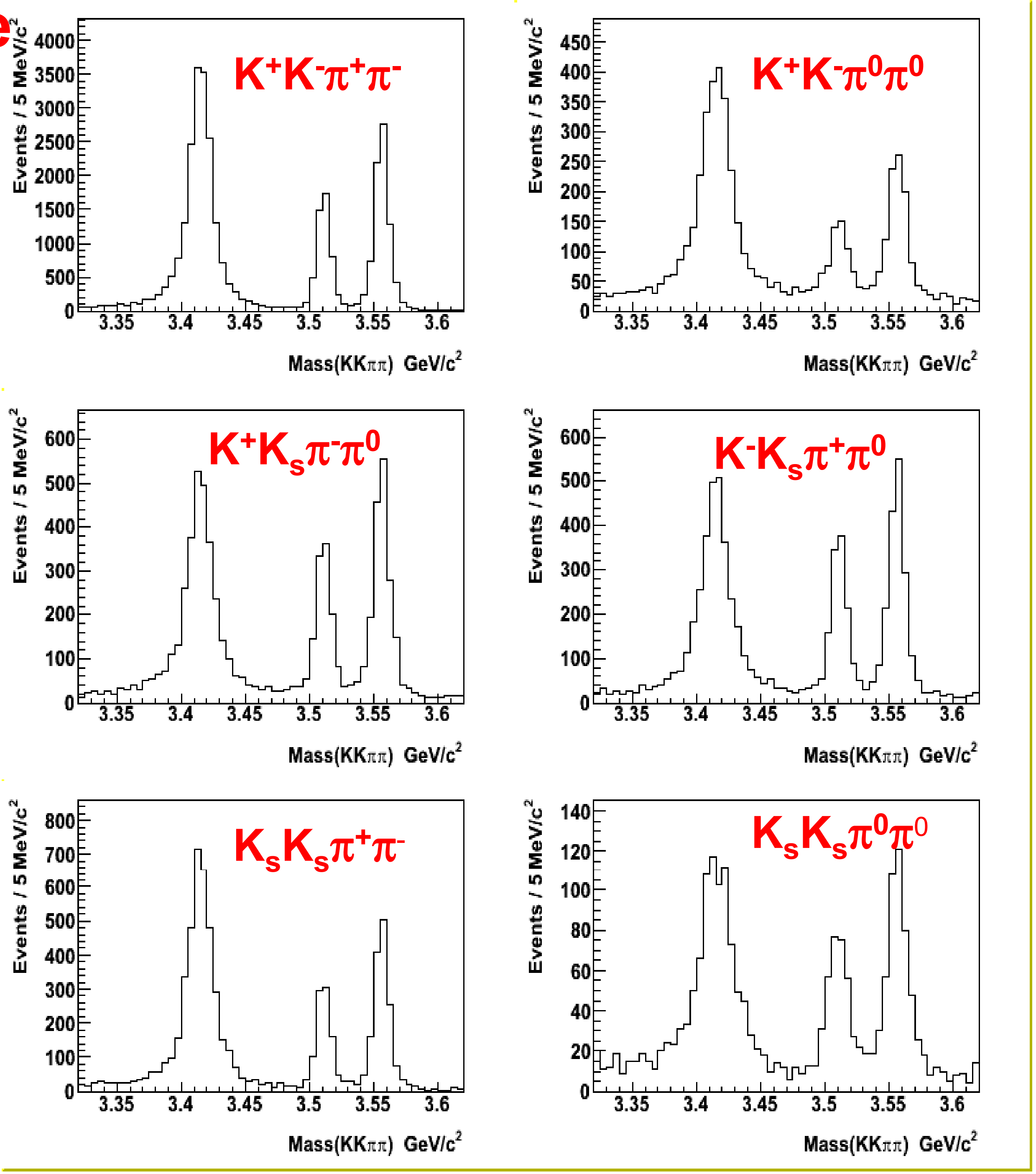
systematics limited!



A glimpse of future analyses -27M $\psi(2S)$ decays.

6 different $KK\pi\pi$ modes,
Each with 3 χ_c decay peaks.

50 other decay modes could be shown, together with h_c and η_c signals



Summary

CLEO-c experiment: Oct.2003 – Apr.2008

successfully taking data:

- **3686MeV**, N(ψ(2S))≈27M, taken, not fully analyzed
- **3770MeV**, ψ(3770), N(ψ(3770)→$D\bar{D}$)≈4M, analyzed, more collected (AND more on the way)
- **4170MeV**, $D_{(s)}^{(*)}\bar{D}_{(s)}^{(*)}$ 314pb^{-1} (more on the way)
- Selected published and preliminary results on D^0 / D^+ / D_s production and hadronic decays are presented in this talk

$D^{+/0}$ and D_s hadronic Branching Fractions,

including new $D_s \to PP$ decay results,

Important results on f_{D_s}

Much more data to be taken, MANY more results coming out soon.