CHARM MESON DECAYS AT CESR

- year 2000 -

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Tau-charm workshop
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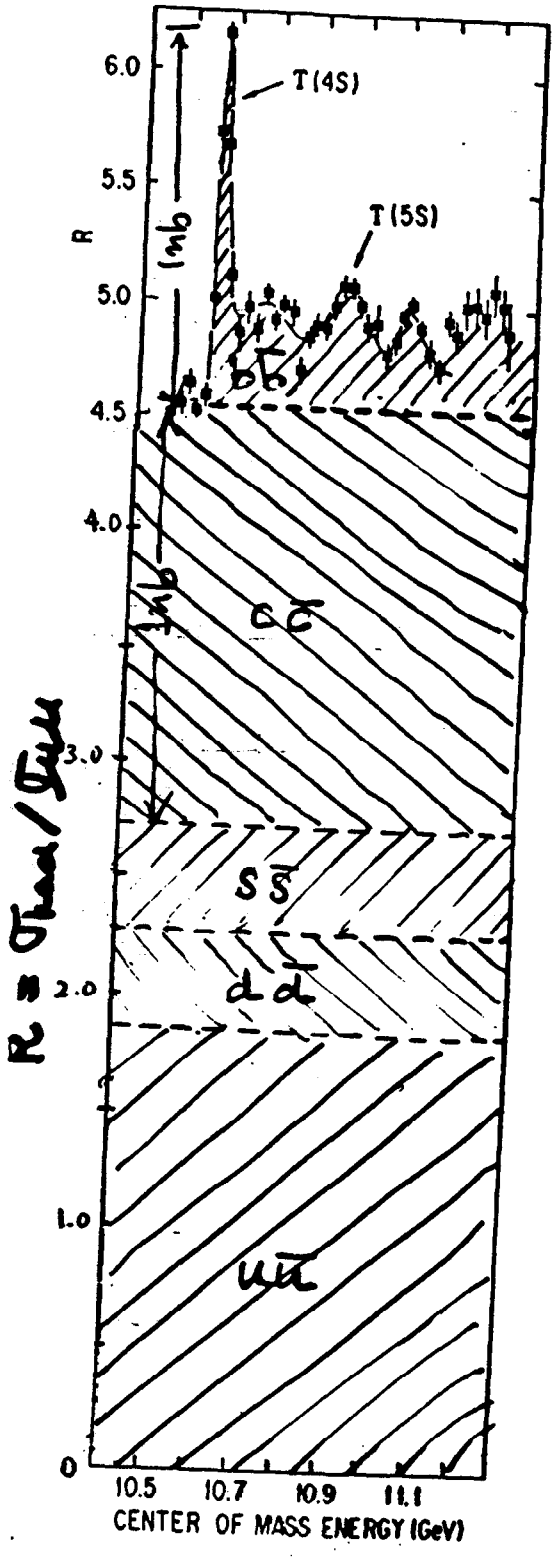
1. CESR in 2000
   Luminosity, Detector

2. Semileptonic Decays
   D^0, D^+, D_s, Cabbibo-favored/suppressed

3. Hadoronic Decays
   Cabbibo-favored/suppressed, rare decays,
   Mixing, CP violations

4. Tau-charm facotry: windows of opportunity
   CESR vs LEP, CESR vs B-factory
   - what can be learned -



CESR/CLEO

Cross Sections

On $\Upsilon(4S)$:

$\sigma_{b\bar{b}} \sim \sigma_{c\bar{c}} \sim 1\,nb.$

$(\sigma_{\mu\mu} = 0.78\,nb)$

$1\,fb^{-1} \rightarrow \begin{cases} 10^6\ B\bar{B}\ \text{pairs} \\ 10^6\ c\bar{c}\ \text{pairs} \end{cases}$

Most recent analyses based on
$\sim 2\,fb^{-1}$
i.e. $\sim 2\times10^6\ c\bar{c}$'s

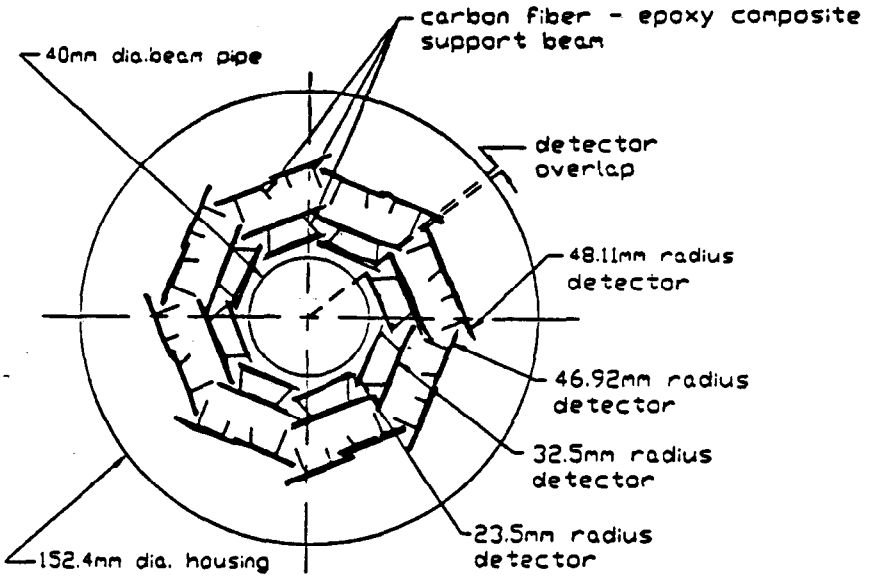
[e.g. B-factory
$\#B\bar{B}$'s $\sim 10^8$
$\Rightarrow \#c\bar{c}$'s $\sim 10^8$]

$\#c\bar{c}$ (B-factory) $\approx$ $\#c\bar{c}$ (CCF)
$\Rightarrow$ needs good systematics advantage.
(incl. BKG)

CESR/CLEO Upgrade Plan.

Phase	[machine]	[detector]
'94 I	$\mathcal{L}_{max} = 3\times10^{32}$ $\int \mathcal{L}\,dt \simeq 4\,fb^{-1}$	$\boxed{\text{CLEO-II}}$ (CsI. Cal etc..)
'95 '96 II. '97	• Multi-bunch train (3 bunch × 9 train) $\mathcal{L}_{max} = 8\times10^{32}$ $\int \mathcal{L}\,dt \cong 15\,fb^{-1}$	CLEO-II + • SVX 3 lyr, 2-sided • New IR
'98 '99 III.	• 5 bunch × 9 train • Smaller σ_z, β^* $\mathcal{L}_{max} > 1\times10^{33}$ $\int \mathcal{L}\,dt \cong \boxed{30\,fb^{-1}}$	All new except CsI. Cal • (hopefully) $\check{C}$ - particle ID • SVX $\boxed{\text{CLEO-III}}$
2000	$\mathcal{L}_{max} \sim 3\times10^{33}$	

Silicon Vertex Detector (SVX)



- 3 layers, each double-sided
- Point resolutions $\sigma_{xy} \sim 13\mu$ $\sigma_z \sim 30\mu$
  ($\times 3$ and $\times 15$ improvement)
- Dramatic improvements in charm detections

  $D^{*+} \to D^0 \pi_b^+$: $\sigma_{\delta m}$ $\times 3$ improvement
  (π_b^+ resolution & efficiency $\uparrow$)

  $D^+, D^0 \ldots$: Combinatoric background reduction

  charm $\to$ bottom

CESR ≈ 2000 Bottom-line.

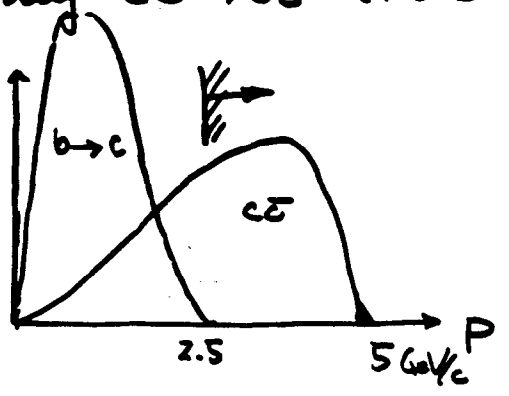
- 30~50M $c\bar{c}$ pairs (30~50 fb^{-1}) ↗ Rare decay ~ 10^{-7}
- SVX + (possibly K/π sep up to 4 GeV)
- $P_{(charmed\ hadron)} \sim 4$ GeV/c
- D^0, D^+, D_s, Λ_c^+ (cud), $\Xi_c^{0,+}$ (csd, csu), Ω_c ...

(τ-C-F:
needs special runs other than $D^{+,0}$
& lower yield than $\psi'' \to D\bar{D}$)

Charm Meson Study at $\Upsilon(4S)$ (CESR)

1. Bkg suppression → $P_{\text{charm meson}} \gtrsim 2.5$ GeV/c

→ Mostly $e^+e^- \to c\bar{c}$ (no $b \to c$)



→ 2-jet events

- c & $\bar{c}$ well separated

  { reduction in combinatorics
  { good for correlation expts.
  ($D_s \to \phi e \nu$)

- Charm meson flight direction
  ~ Thrust axis of event.
  ($\sigma \sim 0.15$ rad)
  ⇒ reconstruction of kinematic variables in S.L. decays.
  (1^{ν} —)

2. D^* Tags

	yield	mode	Br	to tag
D^{*+}	1	$D^0\pi^+$	2/3	$\leftarrow D^0$
		$D^+\pi^0$	1/3	$\leftarrow D^+$ (5 : 2 isospin)
		$D^+\gamma$	~ 0	
D^{*0}	1	$D^0\pi^0$	2/3	($\leftarrow D^0$)
		$D^0\gamma$	1/2	
D_s^{*+}	$\sim \frac{1}{3}$	$D_s^+\gamma$	1	$\leftarrow D_s^+$ ($D_s^{+*} \not\to D_s^+\pi^0$ isospin)

$$D^* \to D\pi^{(\gamma)} \quad \text{low Q-value.}$$
$$\hookrightarrow X$$

$$\delta m \equiv M_{X\pi} - M_X$$

- powerful bkg rejection
- charm sign tag (for $D^{*+} \to D^0\pi^+$)
  - $\to$ DCSD, Mixing
- additional kinematical constraint for S.L. decays.
  (extraction of q^2 etc.)

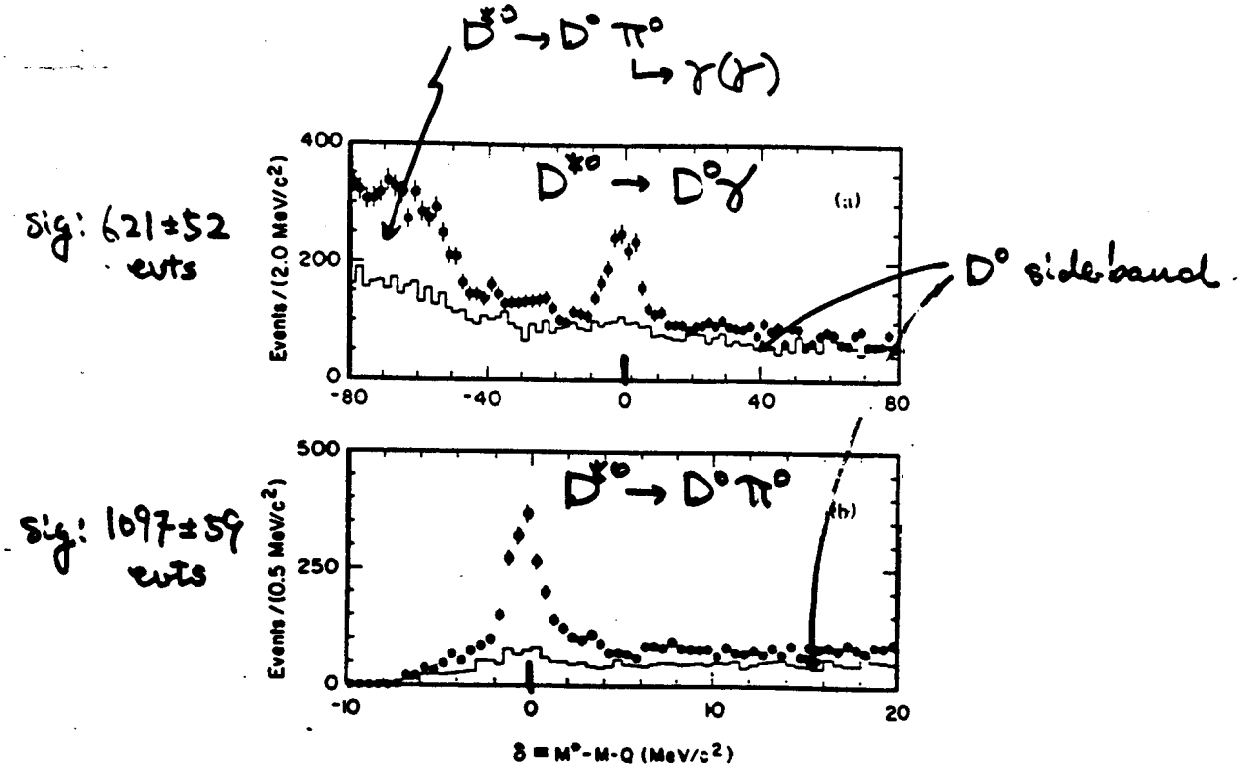
$D^{*0} \to D^0\gamma\ ,\ D^0\pi^0$ (1992) (0.8 fb^{-1})

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

$\delta m = M_{D^0\gamma(\pi^0)} - M_{D^0}$

$\delta \equiv \delta m - Q_{nom}$ (=0 for signal)

$$\frac{Br(D^{*0} \to D^0\gamma)}{Br(D^{*0} \to D^0\pi^0)} = 0.572 \pm 0.057 \pm 0.081$$



$\delta \equiv \delta m - Q_{nom}$. (MeV)

$D^{*+} \to D^+\gamma \,,\; D^+\pi^0$

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

$$\frac{Br(D^{*+} \to D^+\gamma)}{Br(D^{*+} \to D^+\pi^0)} = 0.035 \pm 0.047 \pm 0.052$$

$D_s^{*+} \to D_s\gamma$

$\hookrightarrow K^-K^+\pi^+$

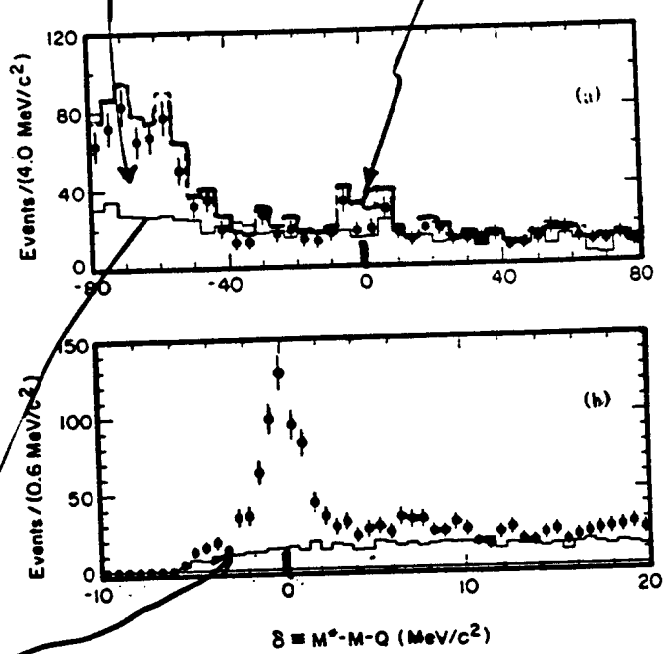
$\pi^+ \to K^+$ mis id.

$D^{*+} \to D^+\pi^0$

$\hookrightarrow \gamma(\gamma)$

ϕ: after D_s^{*+} veto

19.8 ± 12.3 ± 0.6 evts



410 ± 29 evts

π^0 side band.

$\delta \equiv \delta M - Q_{nom}$ (MeV)

		Br (%) OLD PDG	CLEO II
$D^{*+} \to$	• $D^+\gamma$	18 ± 4	$1.1 \pm 1.4 \pm 1.6$
	• $D^+\pi^0$	27.2 ± 2.5	$30.8 \pm 0.4 \pm 0.8$
	$D^0\pi^+$	55 ± 4	$68.1 \pm 1.0 \pm 1.3$
$D^{*0} \to$	• $D^0\gamma$	45 ± 6	$36.4 \pm 2.3 \pm 3.3$
	• $D^0\pi^0$	55 ± 6	$63.6 \pm 2.3 \pm 3.3$

• measured here.

Used • Σ Br's $= 1$ for D^{*+}, D^{*0} each.

• $\dfrac{Br(D^{*+} \to D^0\pi^+)}{Br(D^{*+} \to D^+\pi^0)} = 2.21 \pm 0.07$ (Theory, isosp'n)

⇨ Critical element: <u>γ-detection</u>

$$D^{*+,0} \to D^{+,0}\,(\gamma \text{ or } \pi^0)$$
$$\hookrightarrow \gamma\gamma$$

CsI → $\frac{\sigma_E}{E}$ $\begin{cases} \sim 2\% \text{ @ } 2.5\,\text{GeV} \\ \sim 5\% \text{ @ } 0.1\,\text{GeV} \end{cases}$

BTW. Using $\Gamma(D^{*+} \to D^+\pi^0) = \Gamma(D^{*0} \to D^0\pi^0)$ (isospin)

$$\to \frac{\Gamma(D^{*+} \to D^+\gamma)}{\Gamma(D^{*0} \to D^0\gamma)} < 0.17 \quad (90\%\ \text{C.L.})$$

It is good if we can observe $D^+\gamma$.

• <u>Even better</u> if we can measure $\Gamma(D^{*+,0} \to D^{+,0}\gamma)$. $\sigma_{SM} \sim 0.1\,\mu\text{b}$ needed?

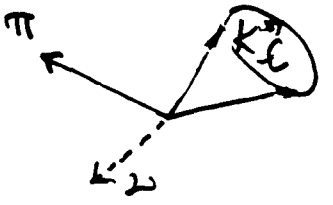
Semileptonic Decay $D \to K^{(*)} \ell \nu$

D^{*+} tag: ν missing $\to$ Calculate $\underline{\delta M \equiv M_{(K^{(*)}\ell)\pi} - M_{K^{(*)}\ell}}$

'pseudo mass diff.'

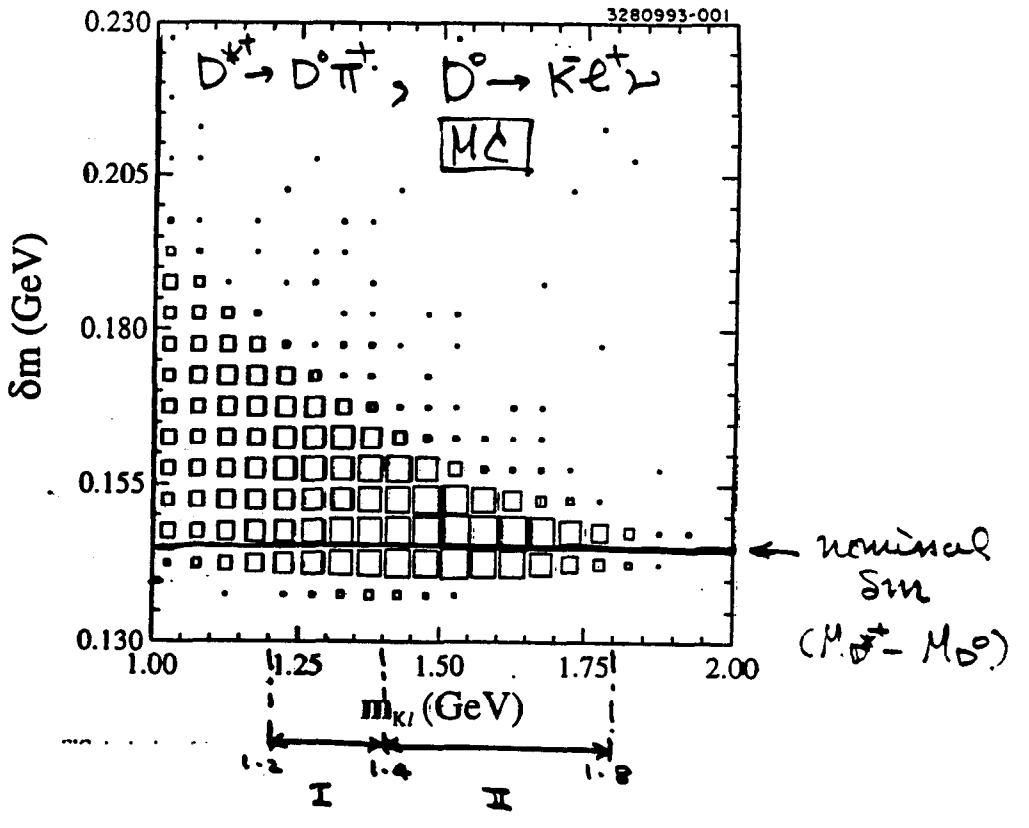
$$D^{*+} \to D^0 \pi^+$$
$$\hookrightarrow K^{(*)-} \ell^+ \nu$$

D frame



$$E_\nu = \frac{M_D^2 - M_{K^{(*)}\ell}^2}{2 M_D}$$

The smaller the E_ν, the better the pseudo-mass diff. method works.



Data: 1.7 fb^{-1} $\quad D^{*+} \to \begin{cases} D^+\pi^0 \\ D^0\pi^+ \end{cases}$ $\quad D^+ \to \bar{K}^0 \ell^+ \nu,\ \bar{K}^{*0}\ell^+\nu$

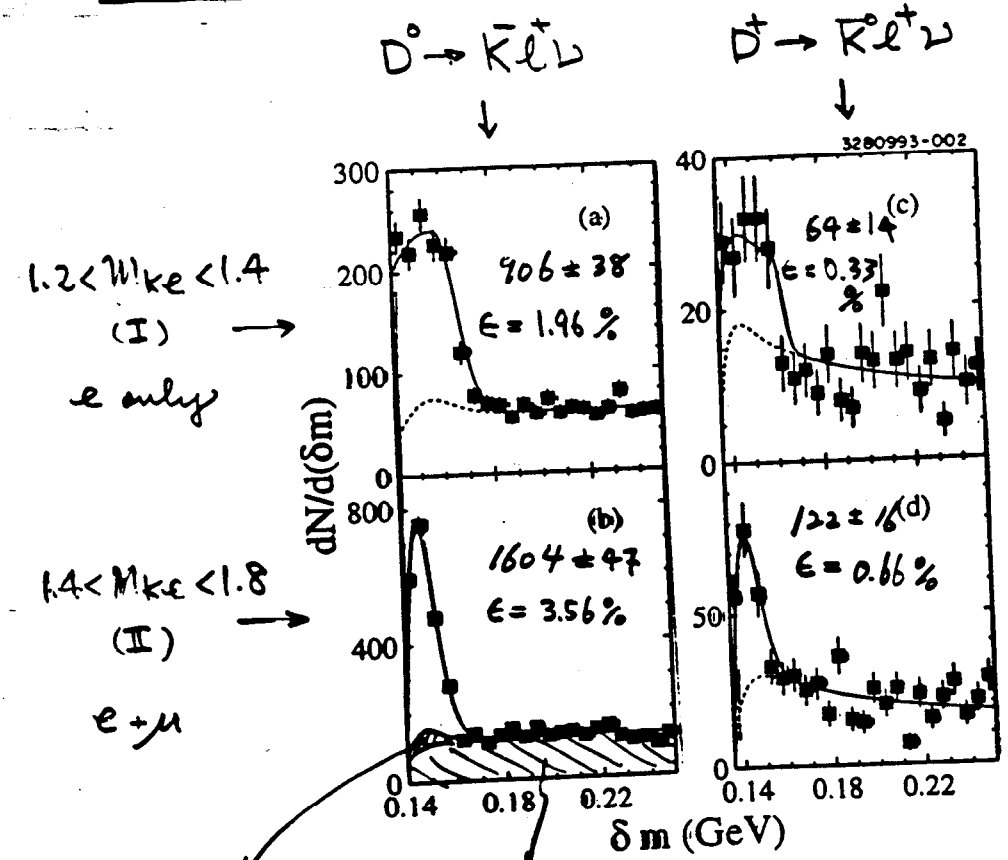
$D^0 \to \bar{K}\ell^+\nu,\ K^{*-}\ell^+\nu$

$(K^{*0} \to K^-\pi^+,\ K^{*-} \to K_S\pi^-)$

	P_{min}	Eff.	$\pi \to \ell$ fake
e	0.7 GeV	0.94	0.3%
μ	1.4 GeV	0.93	1.4%

$P_{D^*} > 2.4$ GeV/c

$D \to K\ell\nu$



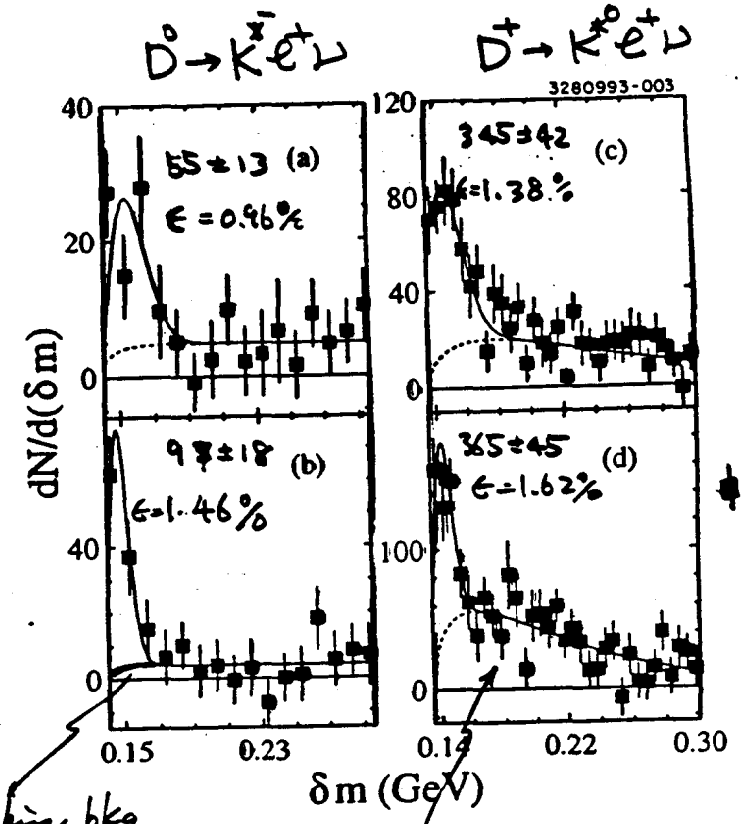
$\epsilon : \dfrac{\text{accepted}}{\text{all s.l. decays } (e+\mu)}$

(Do not include Br's)

$D \to K^* e \nu$'s

$1.2 < M_{K^* e} < 1.4$
(I)
μ

$1.7 < M_{Ke} < 1.8$
(II)
$e + \mu$



: each point is a K^* yield by fit in each δm bin.

peaking bkg negligible.

random combinatorics (true $K^* + e$) $+ \pi$

$D \to K^{(*)} e \nu$

K	D^0	$Br(\bar{K} e^+ \nu)/Br(K^- \pi^+) = 0.978 \pm 0.027 \pm 0.044$
	D^+	$Br(\bar{K}^0 e^+ \nu)/Br(\bar{K}^0 \pi^+) = 2.60 \pm 0.35 \pm 0.26$
K^*	D^0	$Br(K^{*-} e^+ \nu)/Br(K^- \pi^+ \pi^-) = 0.38 \pm 0.06 \pm 0.03$
	D^+	$Br(\bar{K}^{*0} e^+ \nu)/Br(K^- \pi^+ \pi^+) = 0.67 \pm 0.09 \pm 0.07$

Using $\begin{cases} \Gamma(D^0 \to K^{*-} e^+ \nu) = \Gamma(D^+ \to \bar{K}^{*0} e^+ \nu) \\ \Gamma(D^0 \to K^- e^+ \nu) = \Gamma(D^+ \to \bar{K}^0 e^+ \nu) \end{cases}$ (isospin)

we get

$$\boxed{\frac{\Gamma(D \to K^* e \nu)}{\Gamma(D \to K e \nu)} = 0.62 \pm 0.08}$$

(~ 1 for most theoretical models)

Also, we obtain

$$\Gamma(D \to (K + K^*) e \nu) = (14.8 \pm 1.3) \times 10^{10}\ s^{-1}$$

Comparing with the PDG inclusive rate

$$\Gamma(D \to X e \nu) = (16.7 \pm 1.5) \times 10^{10}\ s^{-1}$$

$\to D \to \begin{cases} (K + K^*) e \nu \\ (\pi + \rho, \omega) e \nu \end{cases}$ seem to <u>saturate $Xe\nu$</u>.

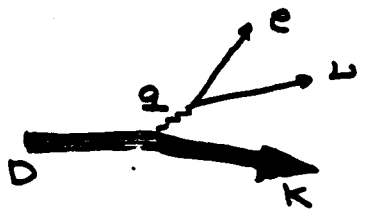
$\approx 8\%$ of K, K^*

(There exist also limits on $K^* \pi e \nu$)
E691, E653

Measurement of Formfactor in $D^0 \to K^- e^+ \nu$

$$\frac{dT}{dq^2} = \frac{G_F^2 |V_{cs}|^2}{24\pi^3} P_K^2(q^2) |f_+(q^2)|^2 \qquad (m_e \sim 0)$$

$$q^2 \equiv m^2_{e\nu}$$



K : pseudoscalar

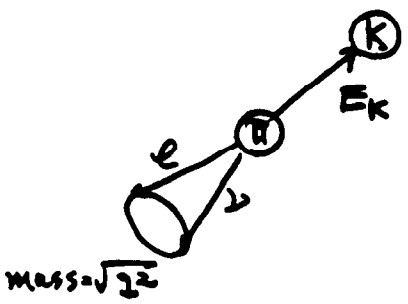
→ only 1 formfactor ($m_e = 0$)

$f_+(q^2)$

⇒ need to reconstruct q^2

- D moving, ν missing but still possible.

Suppose $\delta m \equiv 0$, and go to π^+ rest frame.
(in $D^{*+} \to D^0 \pi^+$) (or D^{*0} or D : same)
↳ $Ke\nu$



Inv. mass of $K\pi$ is

$$\underbrace{M_{K\pi}^2}_{\text{measurable}} = \underbrace{m_K^2 + m_\pi^2}_{\text{known}} + 2E_K m_\pi \Rightarrow E_K$$

q^2 can be extracted from E_K by

$$q^2 = M_D^2 + m_K^2 - 2M_D E_K$$

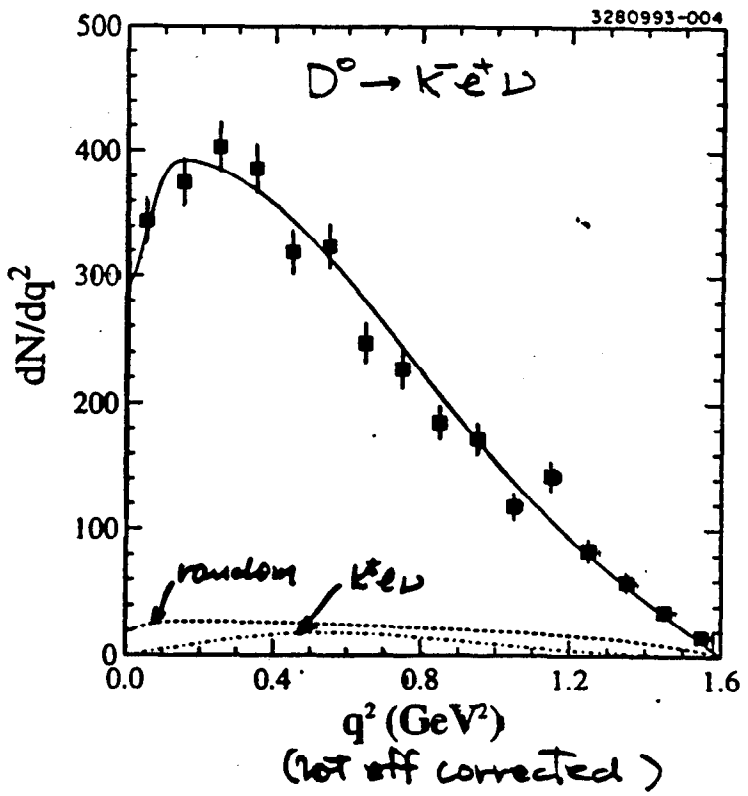
One can do slightly better by taking into account angular correlations in actual sample.

$$\sigma_{q^2} \sim 0.24 \text{ GeV}^2 \qquad (0 < q^2 < 1.9 \text{ GeV}^2)$$

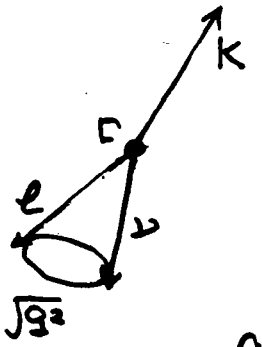
Fit the shape

$$f_+(q^2) = f_+(0)\, e^{\alpha q^2}$$

$$\boxed{\begin{array}{l} f_+(0) = 0.77 \pm 0.01 \pm 0.04 \\ \alpha = 0.29 \pm 0.04 \pm 0.06 \ \text{GeV}^{-2} \end{array}}$$



- q^2 reconstruction in <u>τCF.</u> (Back of envelop est.)
  better with other info. e.g. P_e (MKIII should know)



$$P_D = \begin{cases} 240\ \text{MeV} & (D^+) \\ 280\ \text{MeV} & (D^0) \end{cases}$$

$\alpha\ \gamma\beta \sim 0.13$

Assume D is at rest, then

$$q^2 = M_D^2 + m_K^2 - 2M_D \underbrace{E_K}_{E_K \text{ in lab.}}$$

Dis moving → $\sigma_{q^2} \cong \begin{cases} 0.12\ \text{GeV}^2 \ @\ q^2 = 0 \\ 0.05\ \text{GeV}^2 \ @\ q^2 = 1.5 \end{cases}$

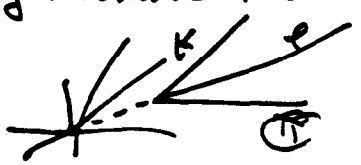
(direction unknown)

(Compare, 0.24 GeV² of CLEO)

- <u>CESR 2000</u> (x 20 data)

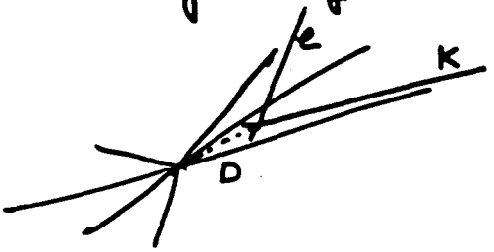
  1. SVX → dramatic reduction of random background.

     Also, another way to remove $K^* e \nu \to K e \nu$ feed down.



  2. Č ID → Remove $\pi e \nu$.

     But σ_{q^2} ~ the same, unless D direction can be given by vertex better than event axis.

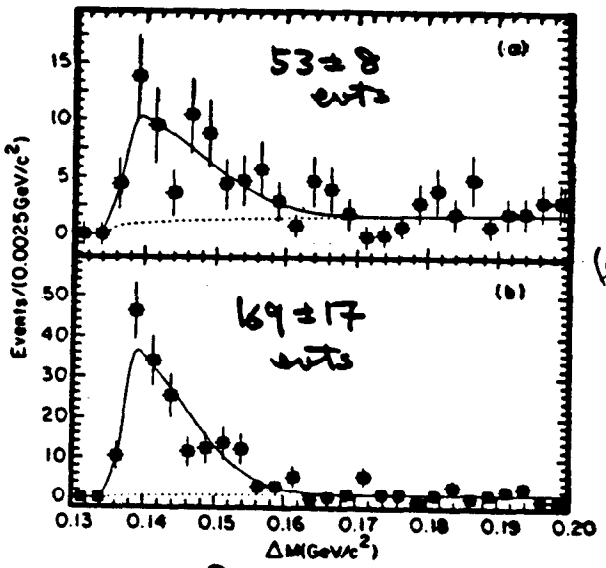


$Br(D^+ \to \pi^0 e^+ \nu) / Br(D^+ \to \bar{K}_0 e^+ \nu)$ $\quad$ 1.8 fb^{-1}

$D^{*+} \to D^0 \pi^+_s$

$\quad \hookrightarrow (\pi^0 \text{ or } \bar{K}_0) e^+ \nu \qquad (\bar{K}_0 \to K_s \to \pi^+\pi^-)$

- $1.3 < M_{(\pi \text{ or } K)e} < 1.8$ GeV.
- $P_{(\pi \text{ or } K)e} > 2.5$ GeV/c



$\pi^0 e^+ \nu$

(leptons fake subtracted)

$\bar{K}^0 e^+ \nu$
$\hookrightarrow \pi^+\pi^-$

δm (GeV/c²)

The main bkg: $D^0 \to \bar{K}_0 e^+ \nu$ looking like $\pi^0 e^+ \nu$
$\pi^0 e \nu$ $\quad \hookrightarrow \pi^0(\pi^0)$

23 out of 53 $\pi^0 e \nu$ candidates are $\bar{K} e^+ \nu$ feed down.

$$\Rightarrow \boxed{\frac{Br(D^+ \to \pi^0 e \nu)}{Br(D^+ \to \bar{K} e \nu)} = 8.5 \pm 2.7 \pm 14\ \%}$$

$$= \frac{|V_{cd}|^2 f_+^\pi(0)}{|V_{cs}|^2 f_+^K(0)}$$

$$\to \frac{f_+^\pi(0)}{f_+^K(0)} = 1.29 \pm 0.21 \pm 0.11$$

CESR 2000 $\quad \times\sqrt{20}$ improvement $\quad$ (SUX no help)

$D_s^+ \to \phi e^+ \nu$ (1.7 fb^{-1})

By ϕ-ℓ correlation (No D_s^{*+} tag) $\to D_s^+ \gamma$
(same jet) – no other sources

$\phi \to K^+ K^-$, ℓ : e & μ

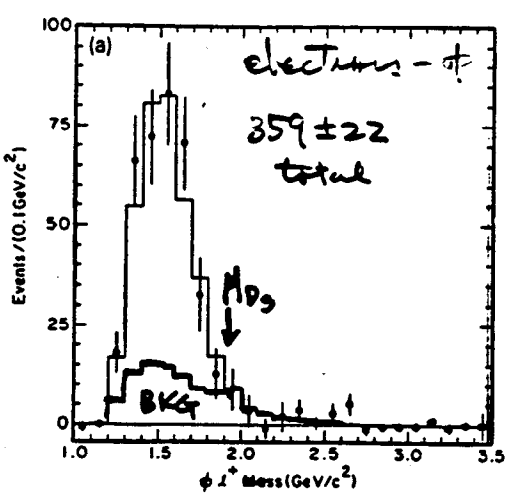
$P_{\phi e} > 2.4$ GeV/c

Background:

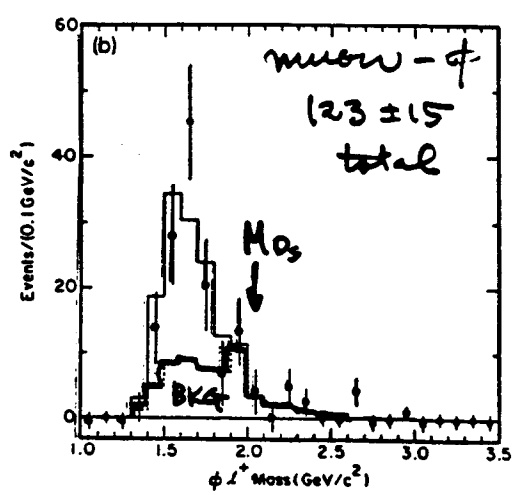
ϕ + fake ℓ 46 ± 14 (e) 27 ± 8 (μ)

ϕ + ℓ (true) $\begin{cases} c\bar{c}: & 12 \pm 8 \text{ (e)} \quad 1.8 \pm 1.2 \text{ } (\mu) \\ B\bar{B}: & 19 \pm 2 \text{ (e)} \quad 9 \pm 1 \text{ } (\mu) \end{cases}$

$D_s \to \phi \bar{K}^0 \ell \nu$, $\phi \eta \ell \nu$, $\phi \pi \pi \ell \nu$ } negligible.



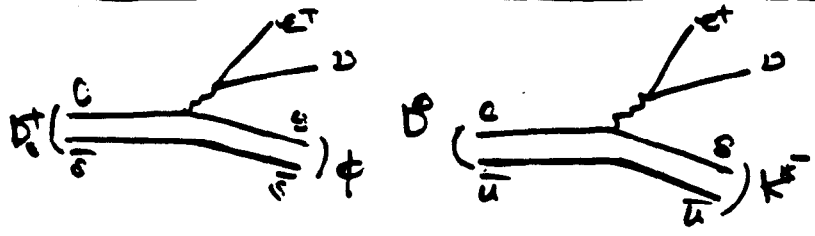
$M_{\phi e}$



$M_{\phi\mu}$

$$\boxed{\frac{Br(D_s^+ \to \phi e^+ \nu)}{Br(D_s^+ \to \phi \pi^+)} = 0.54 \pm 0.05 \pm 0.04} \quad (*)$$

If we <u>assume $\Gamma(D_s^+ \to \phi \ell^+ \nu) = \Gamma(D^0 \to K^{*-} e^+ \nu)$</u>



Then, independent of the measurement,

$$Br(D_s^+ \to \phi e^+ \nu) = \frac{\Gamma(D_s^+ \to \phi e^+ \nu)}{\Gamma_{D_s}} = \frac{\Gamma(D^0 \to K^{*-} e^+ \nu)}{\Gamma_{D_s}}$$

$$= 2.74 \pm 0.36\ \%$$

Plugging ~~this~~ in (*),

$$Br(D_s^+ \to \phi \pi^+) = 5.1 \pm 0.4 \pm 0.4 \pm \underset{\uparrow \atop \delta Br(D_s^+ \to \phi e^+ \nu)}{0.7}\ \%$$

('92 PDG: $Br(D_s^+ \to \phi \pi^+) = 2.8 \pm 0.5\%$)

<u>2.2σ</u>

CESR 2000: Can $D_s^{*+} \to (D_s^+)\gamma$ be used to tag D_s^+ by γ only? $\to$ $Br(D_s^+ \to \phi \pi^+)$ abs. meas.

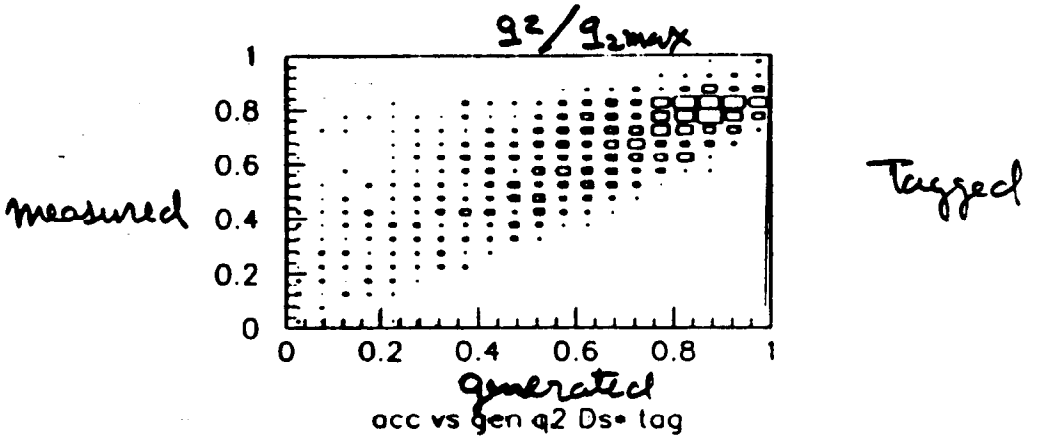
problem: <u>$D^{0*} \to D^0 \gamma$</u> (require K in the same jet?)

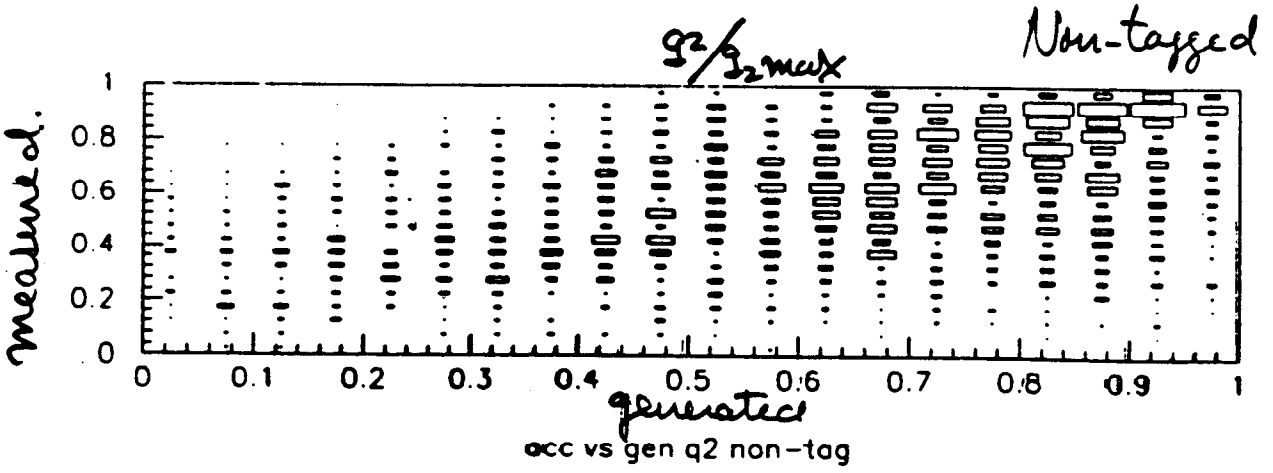
Form Factors in $D_s^+ \to \phi l \nu$

D_s^{*+}-tag + Non-tagged.

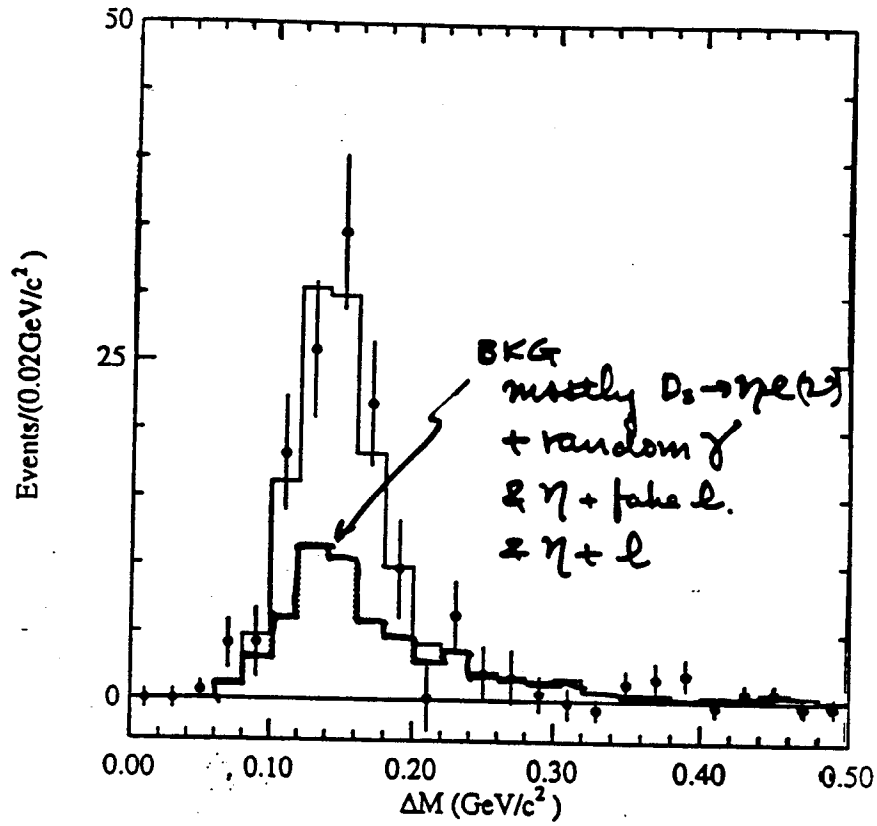
$$\sigma_{q^2} \sim \begin{cases} 0.16\ \mathrm{GeV}^2 & \text{(tag)} \\ 0.25\ \mathrm{GeV}^2 & \text{(Non-tag)} \end{cases} \qquad (0 \le q^2 \le 0.9\ \mathrm{GeV}^2)$$

$$\Rightarrow \begin{cases} \dfrac{A_2(0)}{A_1(0)} = 0.4 \pm 0.7 \pm 0.3 \\[2ex] \dfrac{V(0)}{A_1(0)} = 2.9 \pm 1.2 \pm 1.3 \end{cases}$$





$D_s^+ \to \eta \ell^+ \nu$ (2.35 fb^{-1})



δm (GeV)

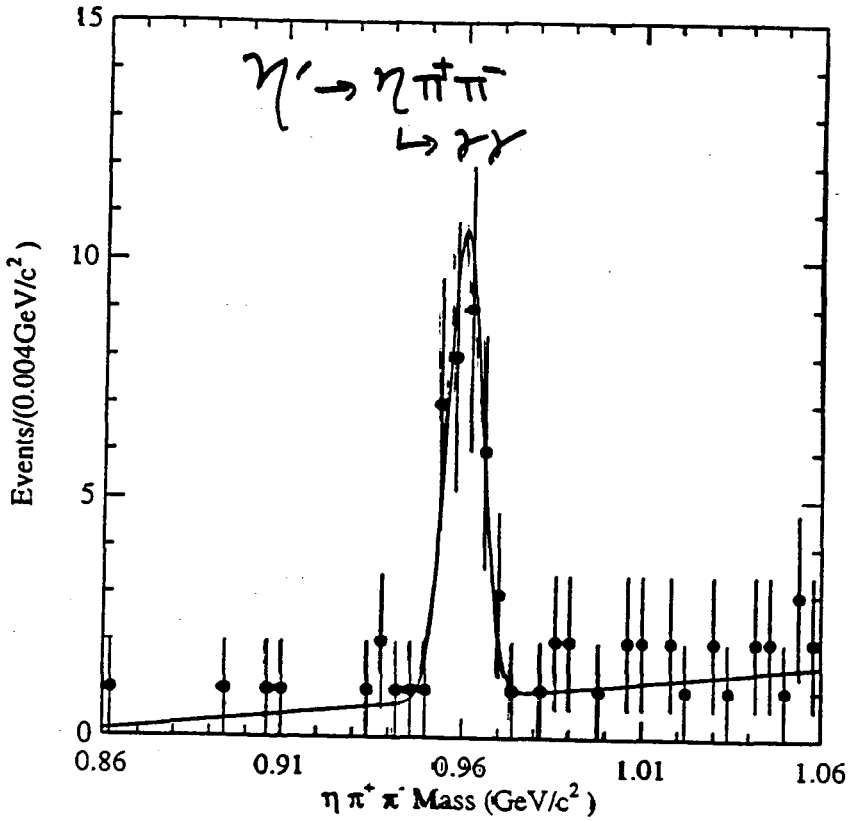
$D_s^{*+} \to D_s^+ \gamma$ $\quad 1.2 < M_{\eta\ell} < 1.9$ GeV

$\hookrightarrow \eta \ell^+ \nu$ $\quad P_{D_s} > 2.8$ GeV/c

$\hookrightarrow \gamma\gamma$

$$\frac{B(D_s^+ \to \eta e^+ \nu)}{B(D_s^+ \to \phi e^+ \nu)} = 1.74 \pm 0.34 \pm 0.24$$

$D_s^+ \to \eta' e^+ \nu$ (same way as $\eta e^+ \nu$)



$M_{\eta\pi^+\pi^-}$

$29^{+6.2}_{-5.6}$ events (incl. 9 bkg)

$$\frac{B(D_s^+ \to \eta' e^+ \nu)}{B(D_s^+ \to \phi e^+ \nu)} = 0.71^{+0.19+0.08}_{-0.18-0.10}$$

$D_s^+ \to (\eta \text{ or } \eta') e \nu$ will be bkg & systematics dominated in CESR 2000.

Absolute Meas. of $Br(D^0 \to K^-\pi^+)$

$(1.8\ fb^{-1})$

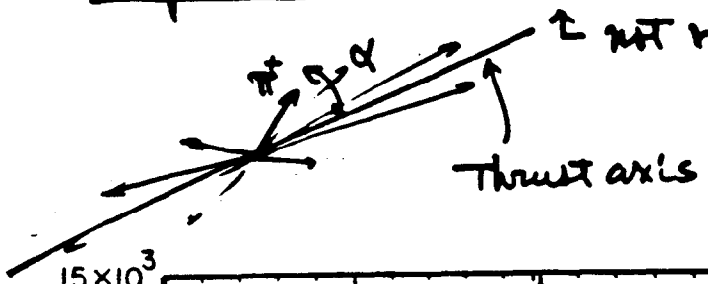
$$Br(D^0 \to K^-\pi^+) = \frac{\#(D^0 \to K^-\pi^+)}{\# D^0}$$

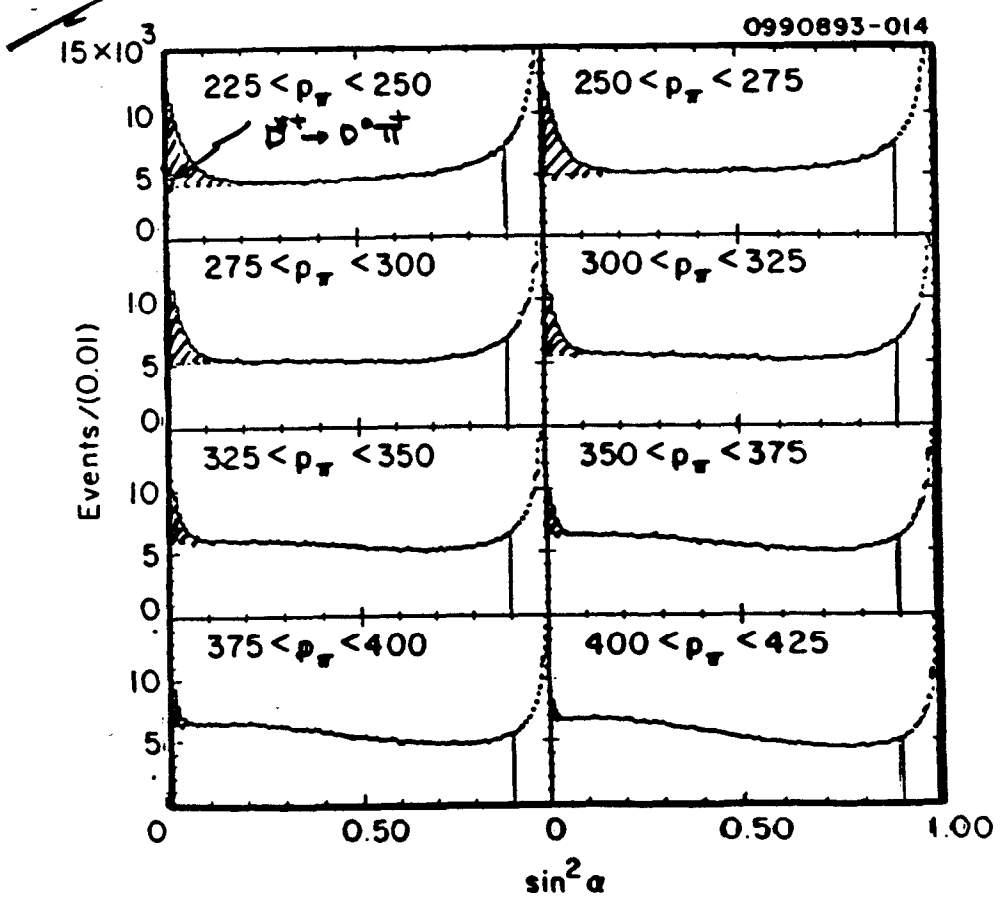
use $D^{*+} \to (D^0)\pi^+$

Soft π^+ that peak in the middle of jet:

<u>only source</u> = $D^{*+} \to (D^0)\pi^+$

↑ not reconstructed.



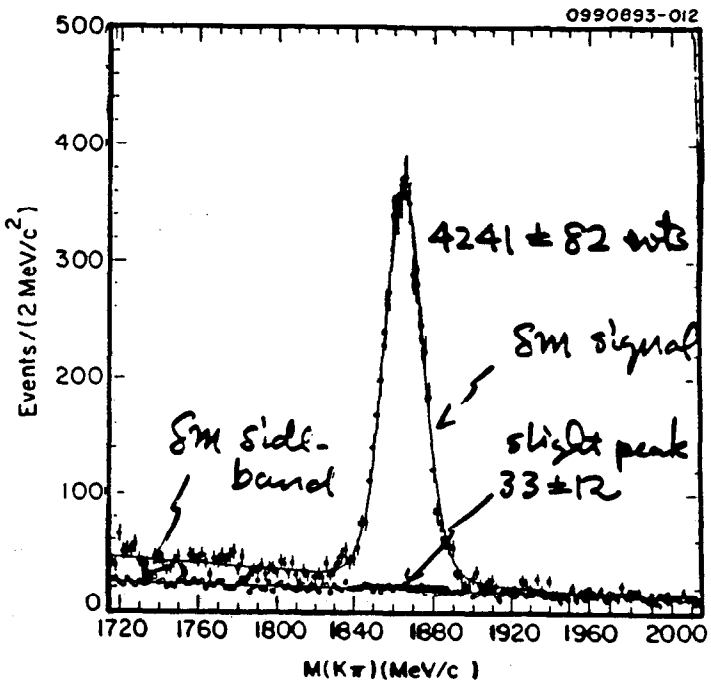


$\sin^2\alpha$.

Combine π^+ with a $K^-\pi^+$ candidate → δm

<u>Plot $M_{K\pi}$</u> for δm within 5σ of nominal.

Subtract <u>true D^0 + random π^+</u> bkg. by δm side-band fit of $M_{K\pi}$. (only 33 ± 12 evts).



$M_{K\pi}$ (MeV)

$$Br(D^0 \to K^-\pi^+) = \frac{\#(K^-\pi^+)/\text{Eff.}}{\#(D^0)} = 3.91 \pm 0.08 \pm 0.17\ \%$$

(Radiative γ energy $\lesssim 10$ MeV)

~5% measurement.

$Br(D^+ \to K^-\pi^+\pi^+)$ (1.79 fb^{-1})

$D^{*+} \to D^0\pi^+_s,\ D^0 \to K^-\pi^+$

$\searrow D^+\pi^0_s,\ D^+ \to K^-\pi^+\pi^+$

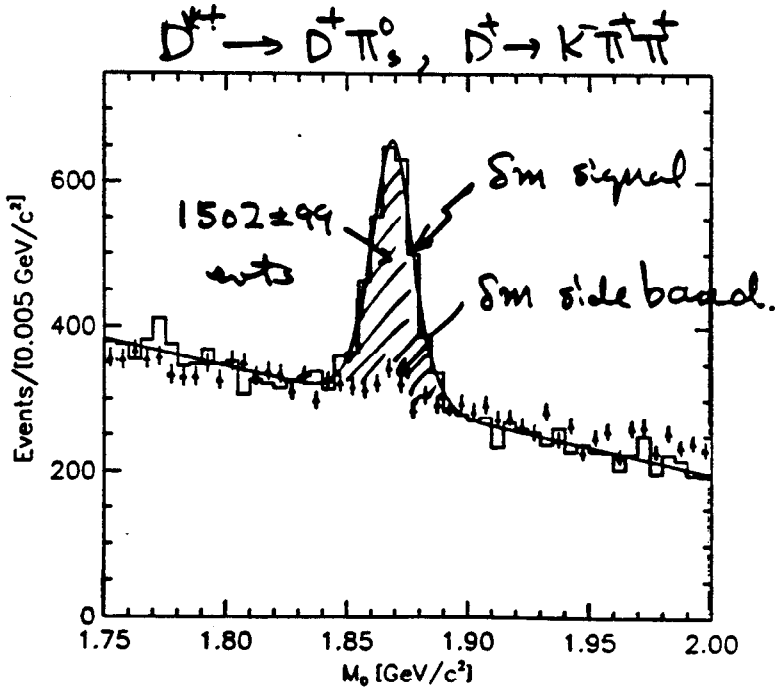
just measured

$$\frac{\#((K^-\pi^+)\pi^+_s)}{\#((K^-\pi^+\pi^+)\pi^0_s)} = \frac{Br(D^{*+}\to D^0\pi^+_s)}{Br(D^{*+}\to D^+\pi^0_s)} \cdot \frac{Br(D^0\to K^-\pi^+)}{Br(D^+\to K^-\pi^+\pi^+)} \cdot \frac{\epsilon((K^-\pi^+)\pi^+_s)}{\epsilon((K^-\pi^+\pi^+)\pi^0_s)}$$

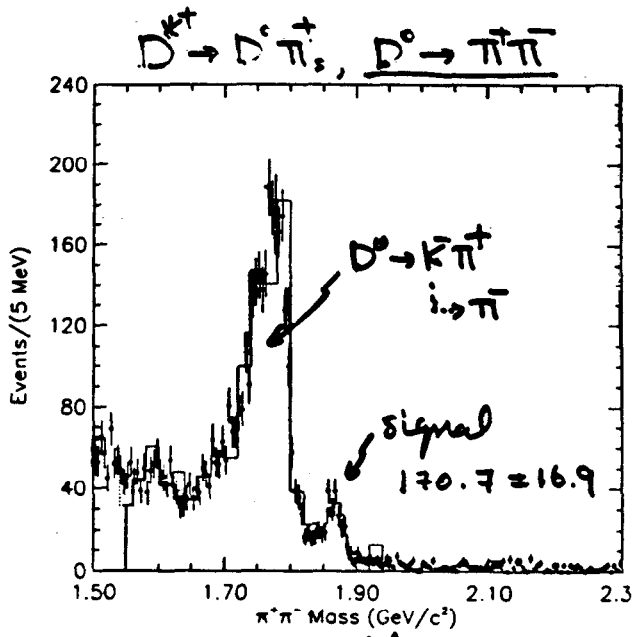
observed — 2.21 ± 0.07 (isospin & phase-space) — we want — MC & data

$$Br(D^+ \to K^-\pi^+\pi^+) = 9.3 \pm 0.6 \pm 0.8\ \%$$

FIGURES

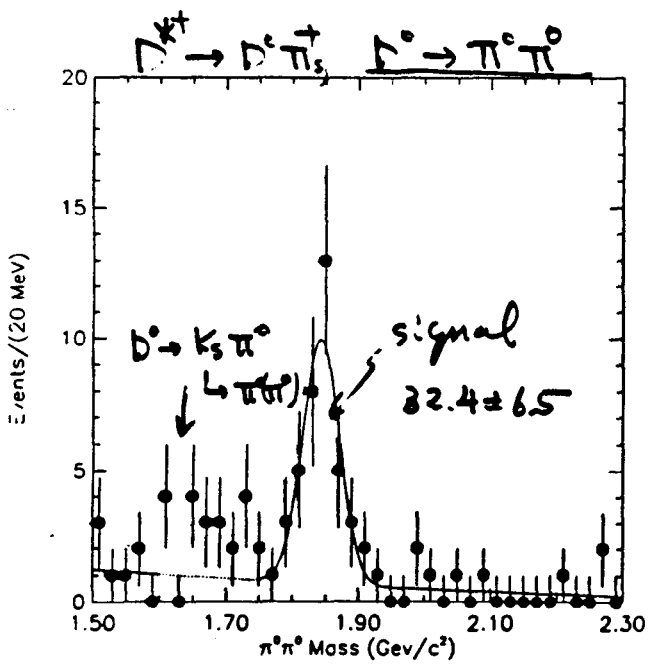


$D \to \pi\pi$ (0.93 fb^{-1})



after δm cut

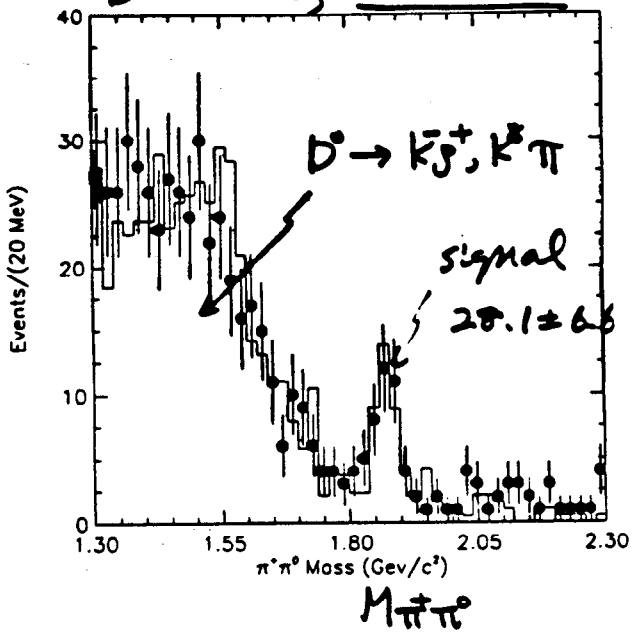
Figure 4 $M_{\pi^+\pi^-}$



after δm cut.

Figure 5 $M_{\pi^0\pi^0}$

$D^{*+} \to D^+\pi^0_s$, $D^+ \to \pi^+\pi^0$



$$\begin{cases} Br(D^0 \to \pi^+\pi^-) = 0.142 \pm 0.014 \pm 0.019\ \% \\ Br(D^0 \to \pi^0\pi^0) = 0.091 \pm 0.018 \pm 0.015\ \% \\ Br(D^+ \to \pi^+\pi^0) = 0.28 \pm 0.07 \pm 0.07\ \% \end{cases}$$

$$\begin{cases} A(D^0 \to \pi^+\pi^-) = \sqrt{\tfrac{1}{3}}\, A_2 + \sqrt{\tfrac{2}{3}}\, A_0 \\ A(D^0 \to \pi^0\pi^0) = \sqrt{\tfrac{2}{3}}\, A_2 - \sqrt{\tfrac{1}{3}}\, A_0 \\ A(D^+ \to \pi^+\pi^0) = \sqrt{\tfrac{1}{2}}\, A_2 \end{cases}$$

($A_{2,0}$: isospin 2, 0 amps)

3 params: $|A_0|$, $|A_2|$, $\arg A_2 - \arg A_0 \equiv \delta$

3 meas. : $I_{\pi^+\pi^-}$, $I_{\pi^0\pi^0}$, $I_{\pi^+\pi^0}$

→ solve.

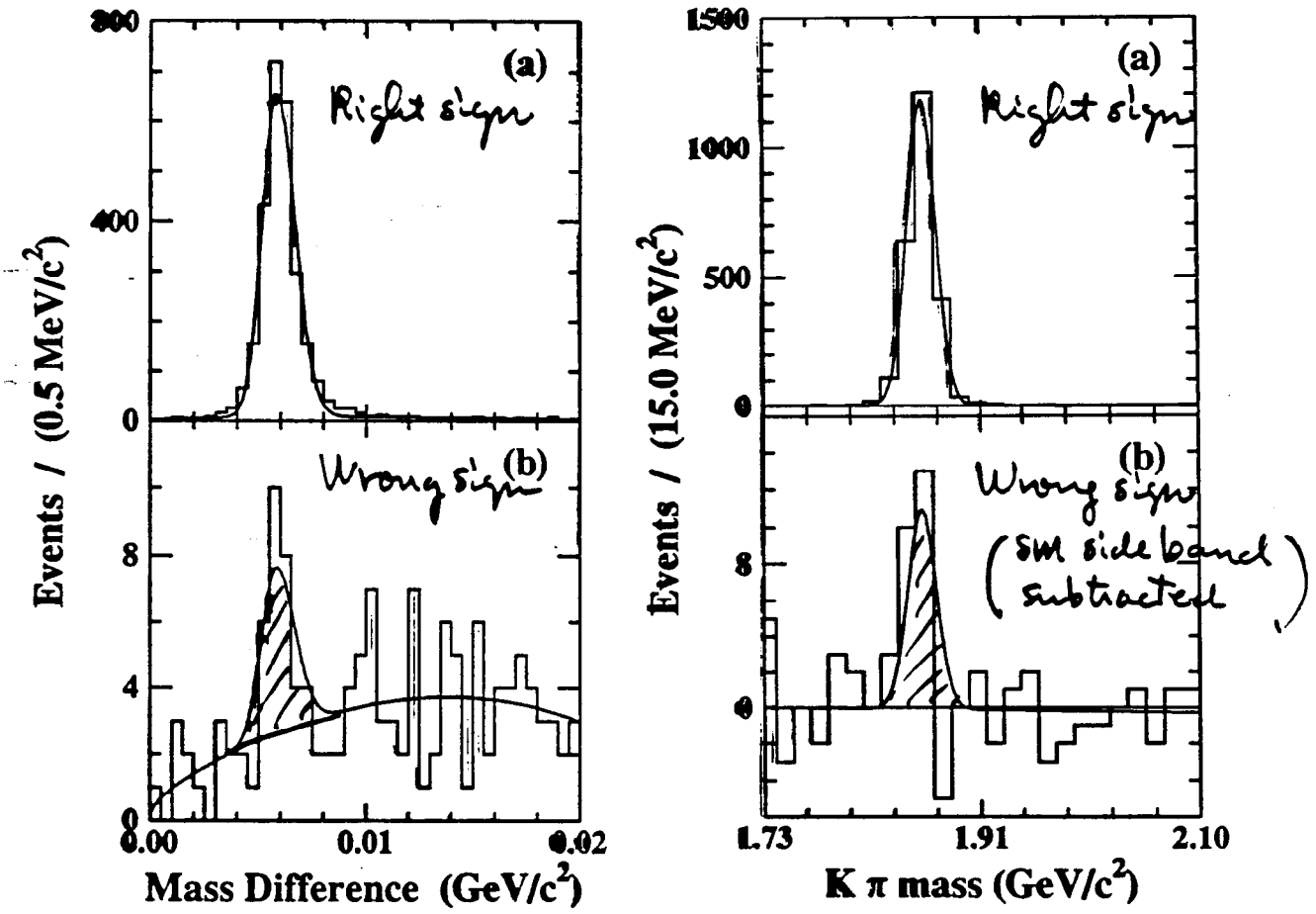
$\left|\frac{A_2}{A_0}\right| = 0.72 \pm 0.19$. $\cos(\delta) = 0.13 \pm 0.18$

large $\Delta I = \frac{3}{2}$. large FSI ($\delta \neq 0$)

$D^0 \to K^+\pi^-$ (wrong sign)

$D^{*+} \to D^0 \pi_s^+$ (wrong-sign)
$\hookrightarrow K^+\pi^-$

- Veto $D^0 \to K^-\pi^+$ (right sign) by kinematics ($K \leftrightarrow \pi$) & particle ID (dE/dx, TOF) — primary mean
- Sharp peak both in δM, $M_{K\pi}$



$$R = \frac{Br(D^0 \to K^+\pi^-)}{Br(D^0 \to K^-\pi^+)} = 0.077 \pm 0.0025 \pm 0.0025$$

- R is a mixture of mixing & DCSD

$$R = R_{mix} + R_{DCSD} + \sqrt{2 R_{mix} R_{DCSD}} \cos\phi .$$

$$R_{mix} = \frac{\#(D^0 \to \bar{D}^0)}{\#(D^0 \to D^0)} , \quad R_{DCSD} = \left| \frac{Amp(\bar{D}^0 \to K^- \pi^+)}{Amp(D^0 \to K^- \pi^+)} \right|^2$$

- <u>CESR 2000.</u>
  - R to ~8%
  - SVX will separate mixing & DCSD <u>to some extent</u>.

    $\gamma\beta c\tau \sim 250\mu m$ $\quad \sigma_{Vtx} \sim 50\mu m$.

    should be OK

- <u>TCF</u>
  - D at rest $\to P_K \sim P_\pi \to$ cannot remove $D^0 \to K^- \pi^+$ kinematically.

    ($K \leftrightarrow \pi$ gives the same $M_{K\pi}$)

    <u>Serious Problem</u>

  - Mixing can be separated from DCSD by quantum correlation.

    $$(K^- \pi^+) \leftarrow \psi'' \to (K^- \pi^+)$$

    $$\frac{\#[(K^-\pi^+)(K^-\pi^+)]}{\#[(K^-\pi^+)(K^-\pi^+)]} = R_{mix} \quad (\text{regardless of } R_{DCSD})$$

$A(D^0 \to K^-\pi^+) \equiv a, \quad A(\bar{D}^0 \to K^-\pi^+) \equiv b.$

$$\begin{cases} D_1 = \frac{1}{\sqrt{2}}(D^0 + \bar{D}^0) & : CP+ \\ D_2 = \frac{1}{\sqrt{2}}(D^0 - \bar{D}^0) & : CP- \end{cases} \qquad (\bar{D}^0 \equiv CP D^0)$$

Time evolution

$$\begin{cases} D_1 \to e_1(t) D_1 \\ D_2 \to e_2(t) D_2 \end{cases}, \quad e_\pm \equiv \frac{e_1 \pm e_2}{2}$$

Then
$$\begin{cases} D^0 \to D^0(t) = e_+(t) D^0 + e_-(t) \bar{D}^0 \\ \bar{D}^0 \to \bar{D}^0(t) = e_-(t) D^0 + e_+(t) \bar{D}^0 \end{cases}$$

$\psi'' \to D^0\bar{D}^0 - \bar{D}^0 D^0$ at $t=0$ will evolve to (t @ LHS, t' @ RHS)

$$D^0(t)\bar{D}^0(t') - \bar{D}^0(t) D^0(t')$$

Then 'amplitude' for it to decay to $\begin{pmatrix} K^-\pi^+ \text{ at } t \text{ on LHS} \\ K^-\pi^+ \text{ at } t' \text{ on RHS} \end{pmatrix}$ is

$$A_W(t,t') \equiv (e_+(t)\, e_-(t') - e_-(t)\, e_+(t'))\,(a^2 - b^2)$$

and that for $\begin{pmatrix} K^-\pi^+ \text{ at } t \text{ on LHS} \\ K^+\pi^- \text{ at } t' \text{ on RHS} \end{pmatrix}$ is

$$A_R(t,t') \equiv (e_+(t)\, e_+(t') - e_-(t)\, e_-(t'))\,(a^2 - b^2)$$

Then, $$\frac{\#[(K^-\pi^+)(K^-\pi^+)]}{\#[(K^-\pi^+)(K^+\pi^-)]} = \frac{\int |A_W(t,t')|^2 dt\,dt'}{\int |A_R(t,t')|^2 dt\,dt'} \qquad [(a^2 - b^2) \text{ cancels}]$$

This is clearly independent of if b is zero or not.
(i.e. independent of DCSD)

$D_s \to \mu\nu$ (2.1 fb^{-1})

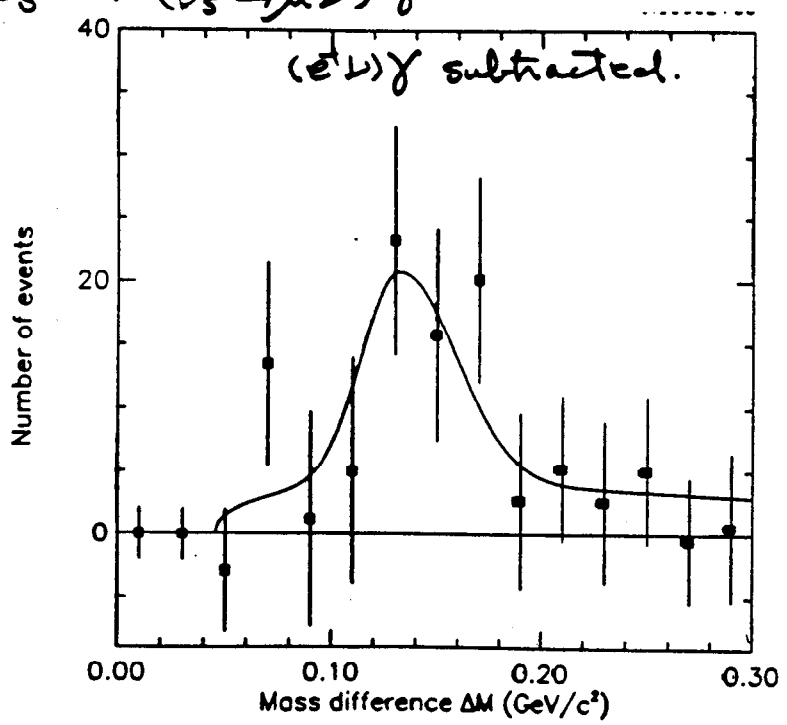
$D_s^{*+} \to D_s^+ \gamma$
$\quad\quad\quad \hookrightarrow \mu^+\nu$

$\begin{cases} E_\nu : \text{missing energy} \\ \vec{P}_\nu : \text{missing momentum} \end{cases}$

in the hemisphere

- $P_\mu > 2.4$ GeV/c.
- Use $D_s^{*+} \to D_s^+ \gamma$, $D_s^+ \to e^+\nu$ as background control sample. (with small corrections.)

$D_s^{*+} \to (D_s^+ \to \mu^+\nu)\gamma$



$$\delta M \equiv M_{(\mu\nu)\gamma} - M_{(\mu\nu)}$$

$$\rightarrow \quad \frac{\Gamma(D_s^+ \to \mu^+\nu)}{\Gamma(D_s^+ \to \phi\pi^+)} = 0.235 \pm 0.045 \pm 0.063$$

With $Br(D_s^+ \to \phi\pi^+) = 3.7 \pm 1.2\%$ (old)

$$f_{D_s} = 337 \pm 34 \pm 45 \pm 54 \text{ MeV} \qquad (\Gamma_{D_s \to \mu\nu} \propto |f_{D_s}|^2)$$

$\sigma_{Br(\phi\pi)}$

($f_{D_s} =$ 400 MeV if use 5.1% for $Br(\phi\pi)$)

- CESR 2000

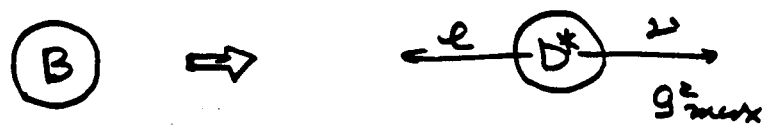
  x20 stat will help stat & sys errors.

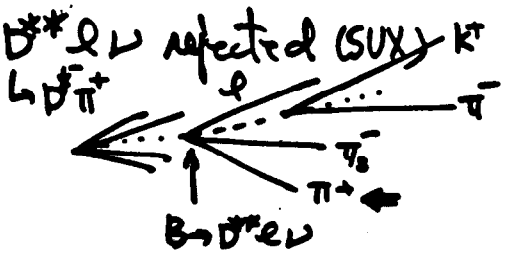
  ~x3 ?

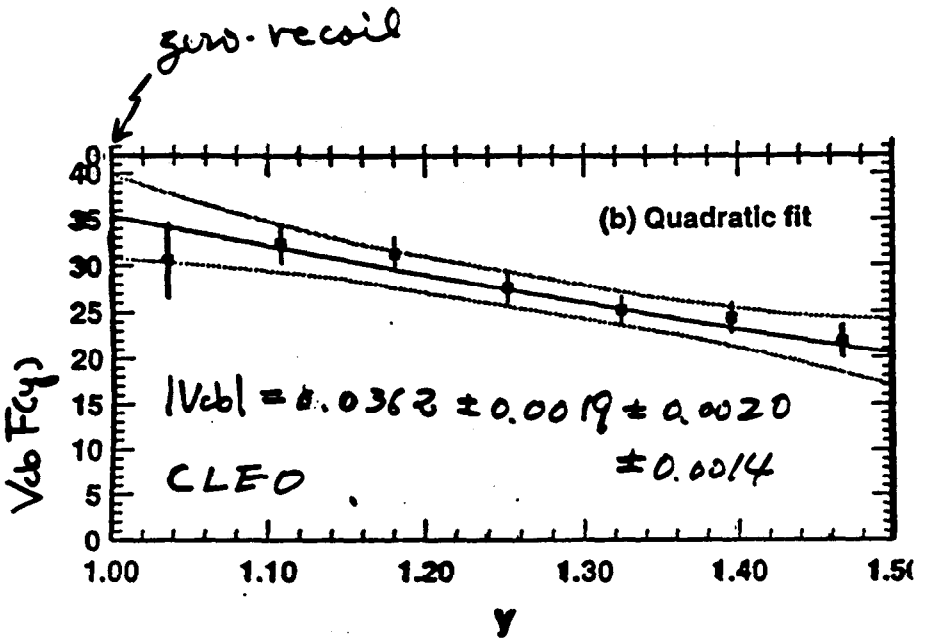
Lesson from CLEO vs LEP

Apart from B_s, Λ_b, LEP can be competitive in $B^{0,-}$ with $\sim\frac{1}{10}$ of luminosity. e.g. $|V_{cb}|$ in $D^* \ell \nu$.

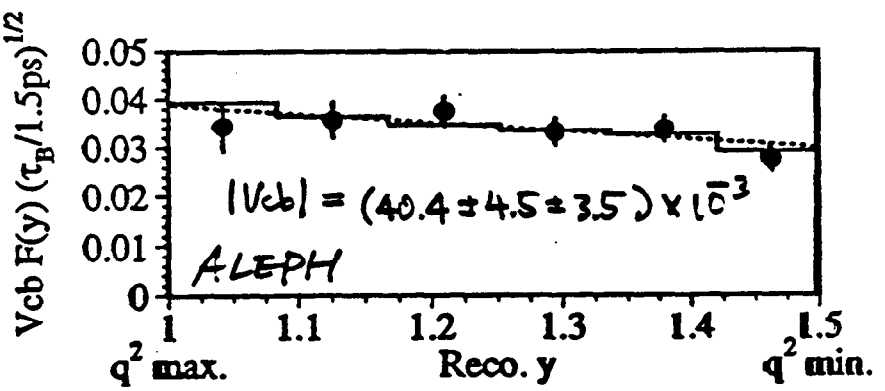
Form factor 'known' at $B \to D^*$ 0-recoil point. $\to |V_{cb}|$ (q^2_{max})



LEP	CLEO
$B\bar{B}$ separated (hermeticity → $\not{P}_\perp$) 	$B\bar{B}$ on top 
Some Non-B tracks	No non-B tracks. → M_D^2 method
Good ε @ q^2_{max}	Bad ε @ q^2_{max} (π^+_s at rest)
q^2 resolution bad (~0K)	q^2 resolution good.
$D^{**}\ell\nu$ rejected (SUX) 	$D^{**}\ell\nu$ difficult to remove.
Low stat.	High Stat.



$y \equiv v_B \cdot v_{D^*}$ (v: 4-velocity)
$= \gamma$-factor of v^* in B frame



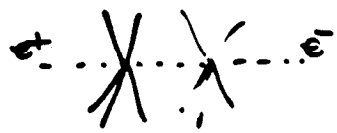
- Moving B + SVX
- Hermeticity

} critical to be competitive

Lesson 2

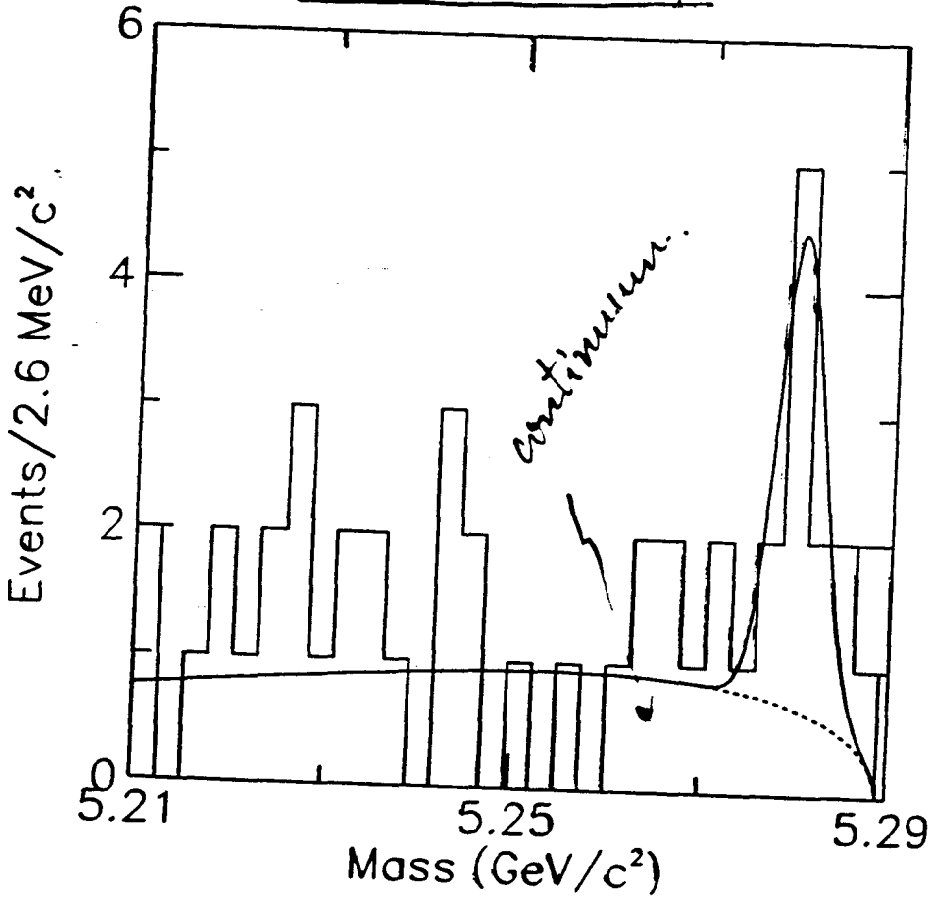
CESR vs Asymmetric B-factory

apart from CP w/mixing for B-factory

CESR 2000	Asym. B-factory
$B\bar{B}$ on top	$B\bar{B}$ separated
	
↳ large combinatorics	↳ small combinatorics
Difficult to reject continuum. event shape neural net....	Easy to reject continuum. 
critical for rare decays.	
Difficult to separate $D^{**}\ell\nu$ or $D^*\ell\nu$	Can separate $D^{**}\ell\nu$ or $D^*\ell\nu$. (à la Aleph)
Beam. constraint	Beam constraint (boost all to B frame)
High Stat?	(Low Stat?)

$B \to 2$ light particles. $P_{K,\pi} \sim 2.5$ GeV
(max B decay can give)
→ not much bkg from $B\bar{B}$
⇒ continuum bkg.

$B \to K^-\pi^+, \pi^-\pi^+$



Beam Constrained Mass
$(K\pi + \pi\pi)$

Also, $K_s\phi$, $K^*\pi$ etc swamped by continuum.

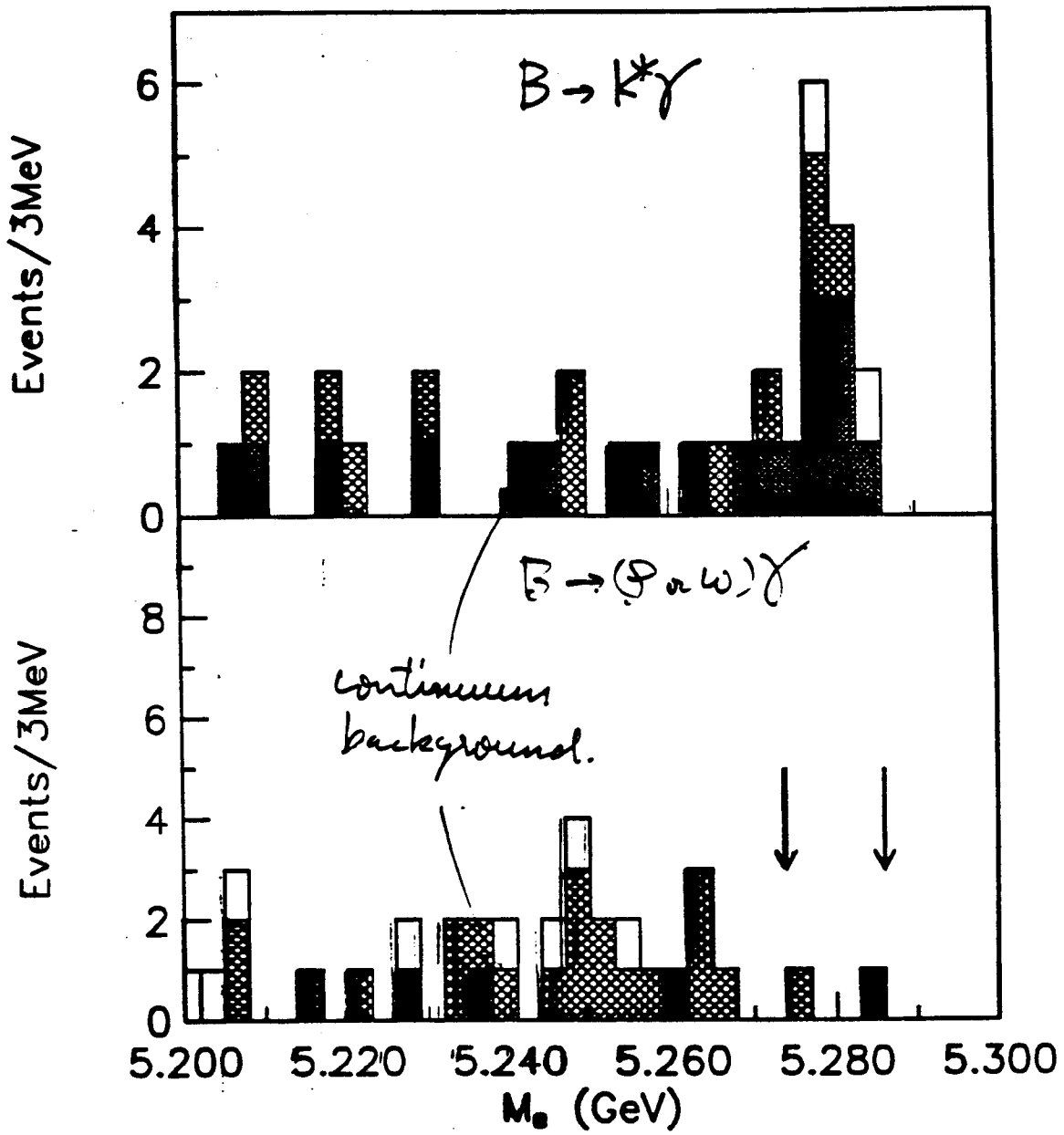


FIG. 4. The mass distributions for the B candidates for the summed $B \to K^*\gamma$ (top)[1] and $B \to (\rho,\omega)\gamma$ (bottom). The $B \to (\rho,\omega)\gamma$ plot includes 50% more luminosity than the $B \to K^*\gamma$ plot. The arrows indicate the signal region defined as $5.274 < M_B < 5.286$ GeV. The dark entries for the upper (lower) plot are the $K^-\pi^+\gamma$ ($\rho^0\gamma$) events, the cross-hatched $K^-\pi^0\gamma$ ($\rho^-\gamma$), and the white $K^0_S\pi^-\gamma$ ($\omega\gamma$).

Also, $K^{**}\gamma$'s swamped by continuum.

$b \to s\gamma$ inclusive.

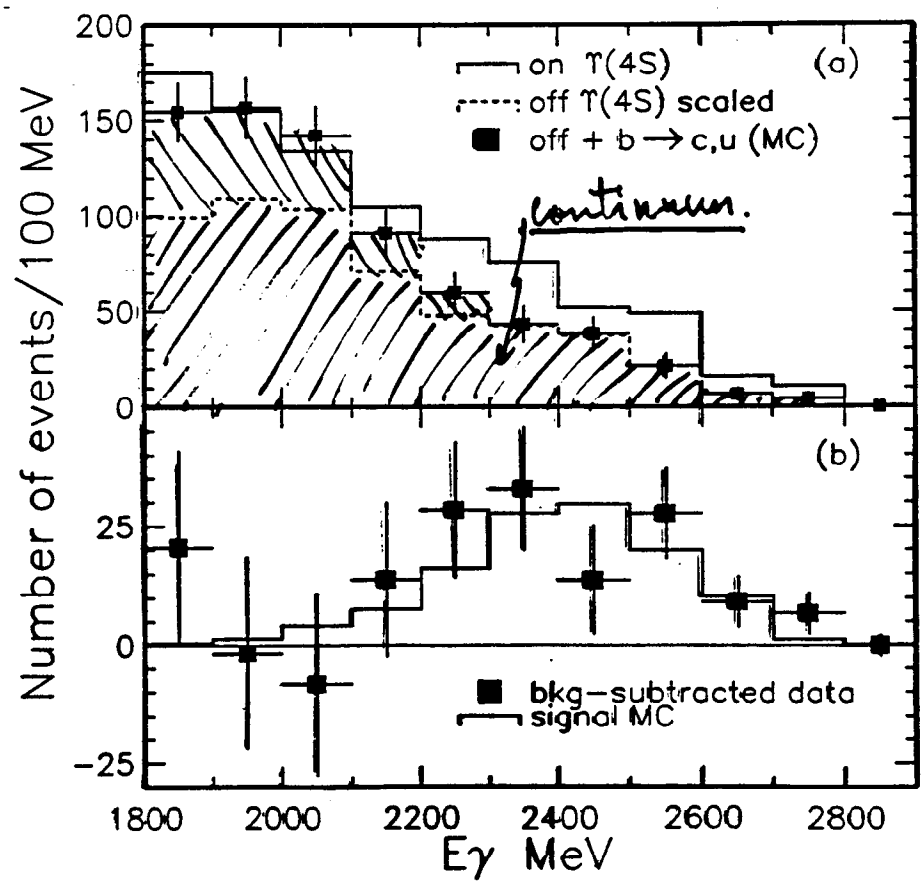
(semi-X_s reconstruction)

↓

purely inclusive mode also.

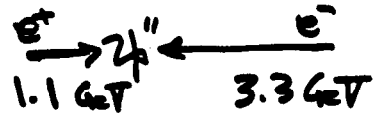
bkg is dominated by <u>continuum</u>.

$B \to \tau\nu$, $\mu\nu$, ditto.



background subtracted

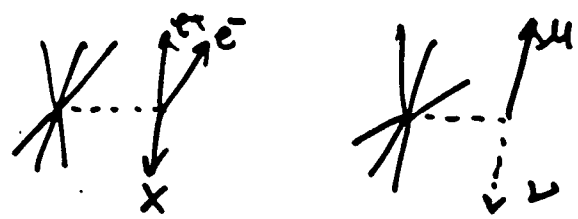
⇨ Asymmetric tau-Charm factory



AτCF will

- o Dramatically reduces combinatorics in $D\bar{D}$ events.
- o Rejects $u\bar{u}$, $d\bar{d}$, $s\bar{s}$ events critical for rare decays

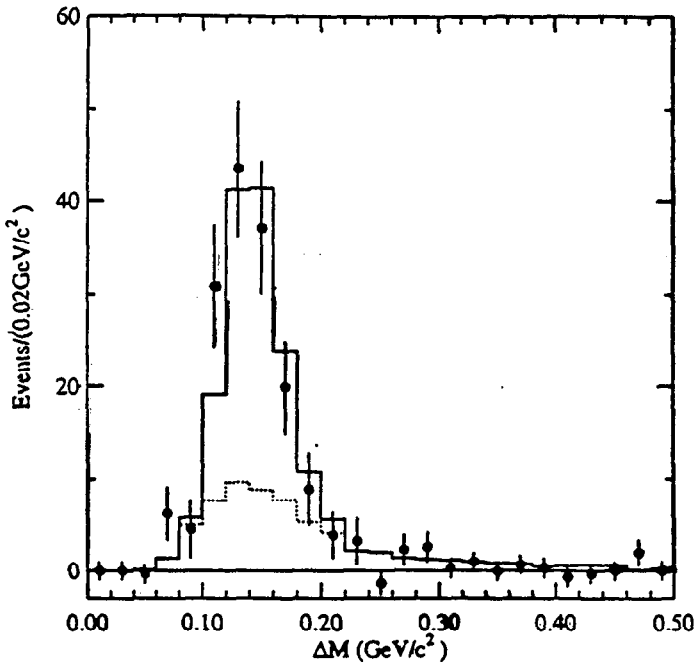
$D \to K^+ e^- X$ $\qquad$ $D \to \mu\nu$



- o Probably <u>critical</u> for D-$\bar{D}$ mixing.
  - $\dfrac{(K^-\pi^+)(K^-\pi^+)}{(K^+\pi^-)(K^+\pi^-)}$ by making $P_K \neq P_\pi$
    → <u>kinematic veto</u>.

It seem to be worth serious studies.

- SVX resolution required.
- How asymmetric?
- MC studies of bkg's.


60
40
20
0
Events/(0.02GeV/c^2)
0.00
0.10
0.20
0.30
0.40
0.50
ΔM (GeV/c^2)

$$B \to f_1 \cdots f_n$$

$$\begin{cases} \left| \sum_i^n \vec{P}_i \right| \equiv P_{tot} = P_B (330\ \text{MeV}) \\ \sum_i^n E_i \equiv E_{tot} = 5.28\ \text{GeV}\ (E_{beam}) \end{cases}$$

Historically,

$$\begin{cases} \Delta E \equiv E_{tot} - E_{beam} \\ M_B \equiv \sqrt{E_{beam}^2 - P_{tot}^2} \end{cases} \quad \text{(equiv. pair)}$$

$$dM_B = \underbrace{\frac{P_{tot}}{M_B}}_{\sim 0.06} dP_{tot} \quad : \text{good resolution}$$

$$B \to D^* e \nu$$

$$P_\nu = P_B - P_{D^* e} = \begin{pmatrix} E_B - E_{D^* e} \\ \underset{\text{ignore}}{\cancel{\vec{P}_B}} - \vec{P}_{D^* e} \end{pmatrix}$$

$P_\nu^2 \equiv M_\nu^2$ should be zero.