Phase I: A Proposal for R&D Work on a Trigger for $D^{*\pm} \rightarrow D^0\pi^\pm \rightarrow h_1^+ h_2^- \pi^\pm$ Decays Using the *HERA-B* Detector

Phase II: An Experiment to Study CP Violation and Mixing in the D^0-$\overline{D}^0$ System via $D^0 \rightarrow K^+\pi^-/K^+K^-/\pi^+\pi^-$ Decays

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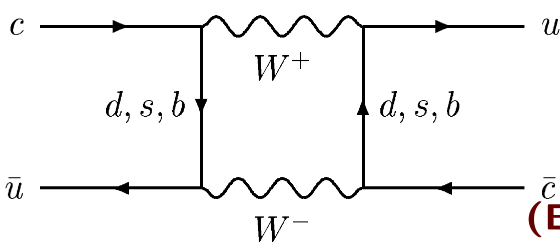
- mixing in the D^0-$\overline{D}^0$ system
- trigger scheme for *HERA-B*
- MC study of acceptance
- estimate of sensitivity to x'^2
- conclusion

Mixing in the D^0-$\overline{D}^0$ System

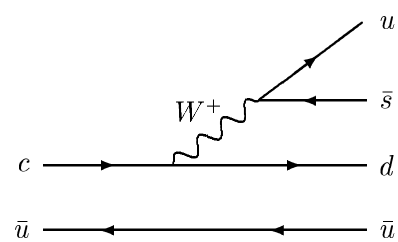


$$r \equiv \frac{\Gamma(D^0 \to \overline{D}^0 \to \bar{f})}{\Gamma(D^0 \to f)} \sim 10^{-6}$$

(Bigi and Uraltsev, hep-ph/0005089)

Flavor of D^0 at $t=0$ is tagged via $D^{*+} \to D^0\pi^+$;
Flavor at $t_{\rm decay}$ is tagged via $D^0 \to K^+\pi^-$ or $K^-\pi^+$

$\Rightarrow$ contamination from DCS decays:



Separate mixing and DCS amplitudes via decay time dependence:

$$\frac{dN_{K^+\pi^-}}{dt} \propto \left[R + \sqrt{R}\,y'\left(\frac{t}{\tau}\right) + \frac{1}{4}\left(x'^2 + y'^2\right)\left(\frac{t}{\tau}\right)^2\right] e^{-\Gamma t}$$

where

$$\begin{aligned} R &= \Gamma(D^0 \to K^+\pi^-)/\Gamma(D^0 \to K^-\pi^+) \\ x' &= x\cos\delta + y\sin\delta \\ y' &= y\cos\delta - x\sin\delta \end{aligned}$$

and

$x = \Delta m/\Gamma \qquad y = \Delta\Gamma/2\Gamma$

$\delta =$ strong phase shift between DCS, CF modes

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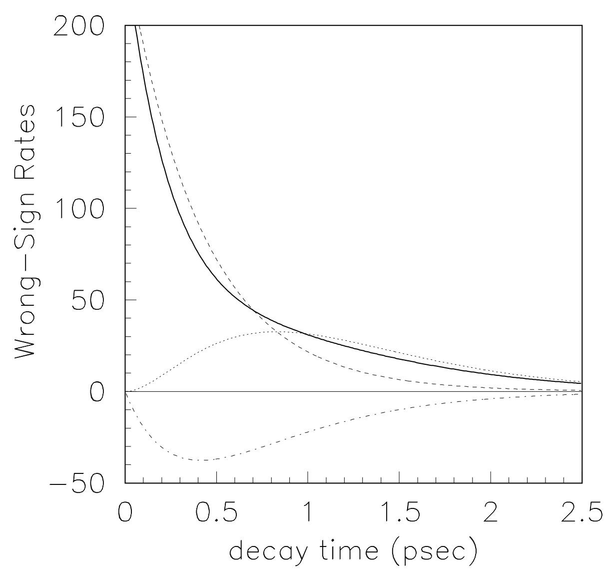
$x = \Delta m/\Gamma \qquad y = \Delta\Gamma/2\Gamma$

$\delta =$ strong phase difference



Previous Results

- CLEO 2000:
  45 ± 10 WS events, $x' = (0.0 \pm 1.5)\%$, $y' = (-2.3^{+1.3}_{-1.4})\%$
  (stat. errors only)

- BaBar 2003: 430 WS events (57 fb^{-1})
  $x'^2 < 0.002$ or 0.0022 (95% C.L.), $y' = 0.008^{+0.014}_{-0.035}$ (95% C.L.)

A Trigger for $D^{*+} \to D^0\pi^+ \to K^+\pi^-\pi^+$

- Conservation of 4-momentum: $P_\pi + P_{D^0} = P_{D^*}$
  Squaring both sides gives:
  $2P_\pi \cdot P_{D^0} = m^2_{D^*} - m^2_\pi - m^2_{D^0} = 0.544\ (\mathrm{GeV}/c^2)^2$

  or: $P_\pi \cdot P_{D^0} = 0.272\ (\mathrm{GeV}/c^2)^2$

- since the D^0 and π^+ resulting from the D^{*+} have very small momentum in the D^{*+} rest frame, the ratio of their momenta in the lab frame is:
  $\gamma(p^*_{D^0} + \beta E^*_{D^0})/\gamma(p^*_\pi + \beta E^*_\pi) \approx \gamma\beta E^*_{D^0}/\gamma\beta E^*_\pi \approx m_{D^0}/m_\pi$

  This ratio is large: $1.865/0.139 = 13.4$

All information needed is available to the FLT.
Minimum bias data (December 2002 run):

	N	Fraction relative	Fraction absolute
Events read	10000	1.	1.
2 RSEGs in PC region, both accepted by iHPT or oHPT, $(q_1 \cdot q_2) = -1$, $\lvert p_{asym}\rvert < 0.70$	6812	0.681	0.681
kaon accepted by TC1	6703	0.984	0.670
$1.820 < m_{K\pi} < 2.010$ GeV/c^2	1837	0.274	0.184
$10.0 < p_{rat} < 19.0$	1538	0.837	0.154
$p_{dot} < 0.32$	526	0.342	0.053
π_s : $\lvert x_{swm}\rvert < 18$ cm, $\lvert y_{swm}\rvert < 18$ cm	378	0.719	0.719
$\lvert m_{K\pi} - m_{D^0}\rvert < 60$ MeV/c^2 (RTRA)	45	0.119	0.086
$10 < p_{rat} < 19$ (RTRA)	42	0.933	0.080
$p_{dot} < 0.32$ (RTRA)	37	0.881	0.070

Trigger Cont'd

Summary:

- FLT rejection is 20 (1 MHz→ 50 kHz)
- SLT rejection is 14.2 (50 kHz→ 3.5 kHz)

Current event logging rate: $\sim$200 Hz. Can this be increased to 1 kHz? If so, then SLT would need only another factor of 3.5

$\Rightarrow$ use impact parameter trigger a la FNAL SELEX (600 GeV Σ^- beam on Cu, C. $IR \approx 4$ kHz):

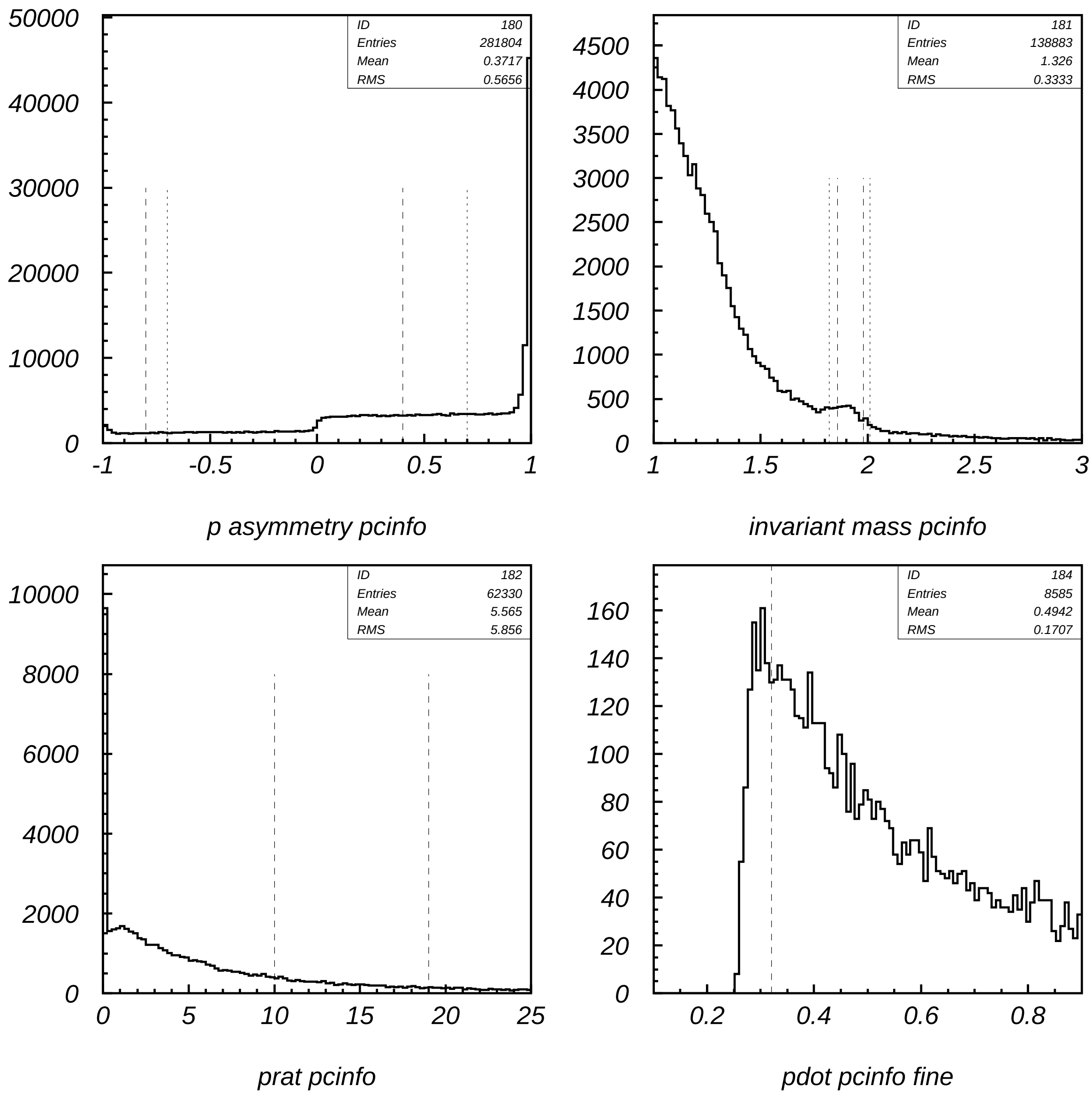
- trigger finds tracks in PWC's, extrapolates them upstream into silicon vertex detector.
- hits found in the vertex detector are used to reconstruct (straight) silicon tracks, which are fit to a common primary vertex. If fit has reasonable χ^2, and all tracks are included, event is rejected. If χ^2 is large, event is kept.

  Minimum bias rejection factor: 8
  Typical charm decay efficiency: 0.5

$\Rightarrow$ we assume the SLT could make an impact parameter cut to obtain factor of 3.5 rejection; further study needed. Assume $\varepsilon_{i.p.} = 0.5$

Trigger Cont'd

Minimum bias, RSEG quantities:



MC Acceptance + Efficiencies

Calculate efficiencies in "reverse" order:

- Require fully reconstructed $D^{*+} \to D^0\pi^+ \to K^+\pi^-\pi^+$ decays passing p_{asym}, $m_{K\pi}$, p_{rat}, p_{dot} cuts with RTRA quantities. Note: π_s uses PC RSEG + `rgauxsmv`
- From this sample require SLT-level requirements: π_s track is swum back through the magnetic field, and $|x_{(z=0)}| < 18$ cm, $|y_{(z=0)}| < 18$ cm.
- From this sample require FLT-level requirements: all three tracks accepted by PC (+ HPT chambers), K accepted by TC1, $K + \pi$ pass p_{asym}, $m_{K\pi}$, p_{rat}, p_{dot} cuts calculated using PC RSEGs plus formula:

$$\frac{q}{p} \approx -\frac{(x - z\cdot\theta_x)\sqrt{1+\theta_x^2}}{(2200 \cdot 0.00029975 \cdot 450)\sqrt{1+\theta_x^2+\theta_y^2}}$$

(RECONSTRUCTION)	N	Fraction relative	Fraction absolute
Events generated	10000		
Number $D^{*+} \to D^0\pi^+ \to K^+\pi^-\pi^+$	12671	1.	1.
K^- track reconstructed (in RTRA)	3988	0.315	0.399
π^+ track reconstructed (in RTRA)	1488	0.373	0.149
π_{slow} segment reconstructed (in RSEG)	1176	0.790	0.118
$\lvert m_{K\pi} - m_{D^0}\rvert < 60$ MeV/c^2	1030	0.876	0.103
$10.0 < p_{rat} < 19.0$	978	0.950	0.098
$p_{dot} < 0.32$	888	0.908	0.089

MC Efficiencies Cont'd

(TRIGGERING)	N	Fraction relative	Fraction absolute
Reconstructed $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^+\pi^-\pi^+$	888		
π_s $\lvert x_{swm}\rvert < 18$ cm, $\lvert y_{swm}\rvert < 18$ cm	861	0.970	1.0
K^- track accepted by PC1-PC4 and TC1	632	0.734	
π^+ track accepted by PC1-PC4	681	0.791	
π_{slow} track accepted by PC1-PC4	839	0.974	
all 3 tracks accepted (FLT tracking)	502	0.583	0.583
K^- track accepted by inner/outer HPT1–3	466	0.928	
π^+ track accepted by inner/outer HPT1–3	458	0.912	
π_{slow} track accepted by inner/outer HPT1–3	351	0.699	
all 3 tracks accepted (HPT pretrigger)	304	0.606	0.353
RSEGs satisfy $\lvert p_{asym}\rvert < 0.70$	281	0.924	0.326
$1.820 < m_{K\pi} < 2.010$ GeV/c^2	225	0.801	0.261
$10 < p_{rat} < 19$	214	0.951	0.249
$p_{dot} < 0.32$	204	0.953	0.237

Other factors:

- SLT impact parameter requirement: 0.50
- SLT tracking efficiency: $(0.90)^3 = 0.73$
- FLT tracking efficiency: $(0.70)^3 = 0.34$
- requiring hits in PC2 and PC3: $(0.95)^3 = 0.74$
- HPT chambers: $(0.95)^9 = 0.63$
- HPT optical links, pretrigger algorithm: 0.50
- offline analysis cuts: 0.27

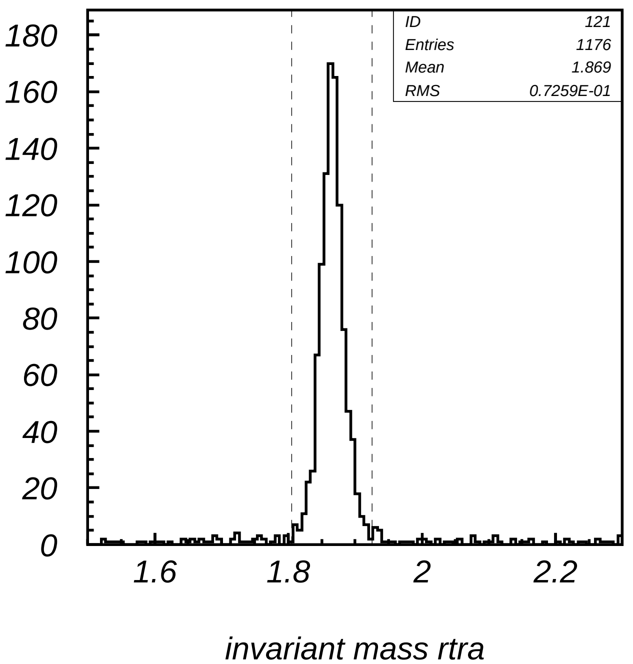
  lifetime cut (0.7), RICH PID (0.7),

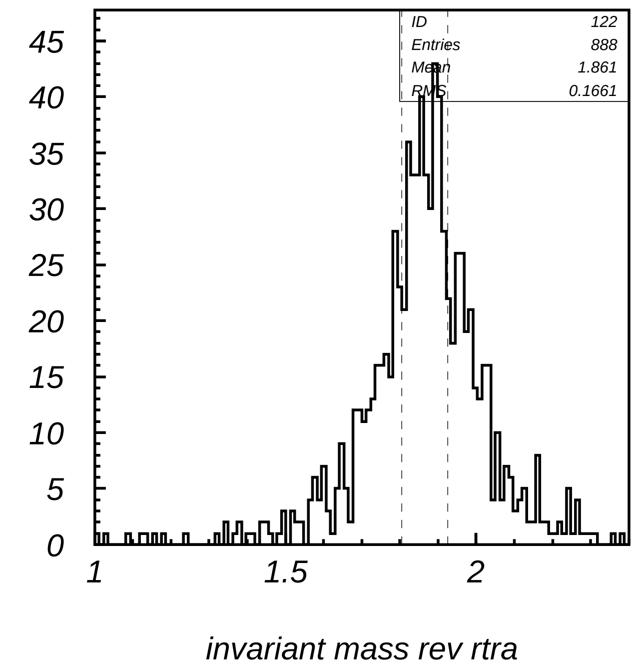
  track quality/point-back (0.8),

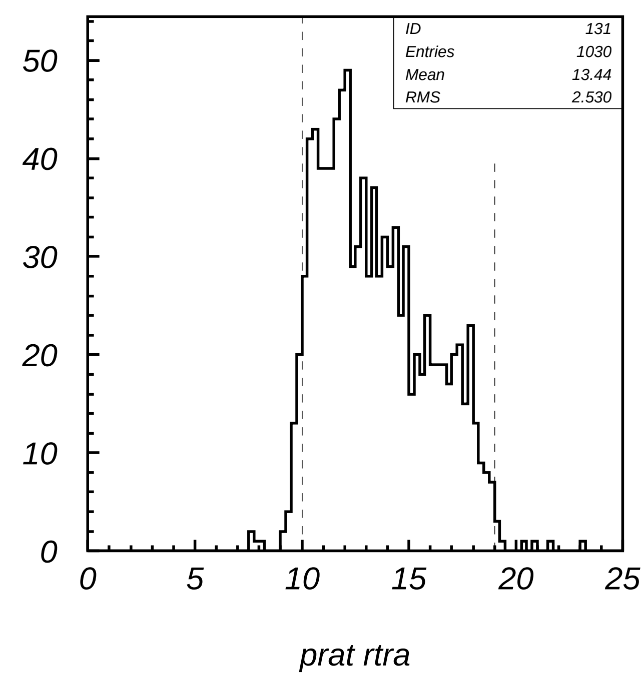
  vertex quality/misc (0.7)

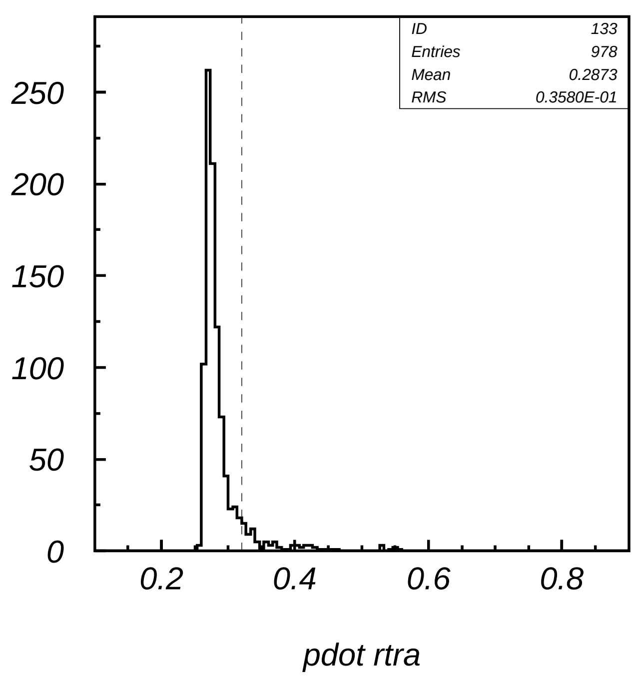
MC Efficiencies Cont'd

MC $D^{*+} \to D^0\pi^+ \to K^+\pi^-\pi^+$, RTRA quantities:



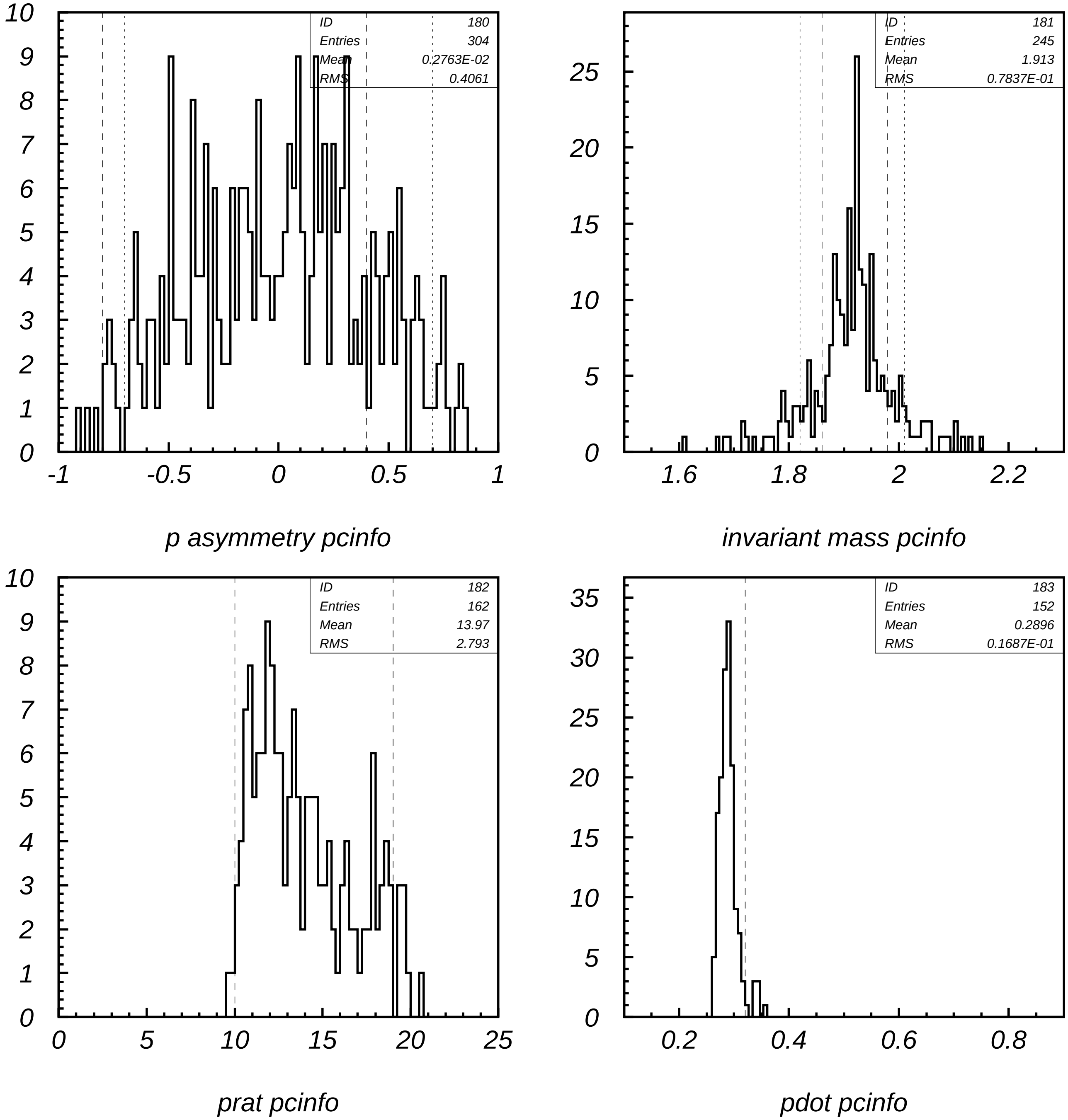






MC Efficiencies Cont'd

MC $D^{*+} \to D^0\pi^+ \to K^+\pi^-\pi^+$, RSEG quantities:



Estimated Event Yield

- $$\frac{\sigma(pN \to D^{*+}X)}{\sigma(pp)_{inel}} = \frac{158 \pm 63\,^{+25}_{-32}\ \mu\text{b (A. Gorisek)}}{34\text{ mb (PDG)}} = 4.7 \times 10^{-3}$$

- Multiply by: $$\left\{ \begin{array}{lcl} A^{1/3} & = & 2.3\ \text{(C)} \\ B_{D^{*+} \to D^0\pi^+} & = & 0.683 \\ IR & = & 10^6\ \text{Hz} \end{array} \right\}$$

- Multiply by the following efficiencies:
  - acceptance + reconstruction: 0.0888
  - SLT: $0.97 \times 0.5 \times (0.90)^3 = 0.35$
  - FLT: $0.583 \times 0.606 \times 0.671 \times (0.70)^3 \times 0.74 = 0.060$
  - HPT: $(0.95)^9 \times 0.5 = 0.32$
  - Offline: $0.7 \times 0.7 \times 0.8 \times 0.7 = 0.27$

Mode	Branching fraction (%)	Yield (2 years)	Est. BaBar/Belle yield (350 fb^{-1})
$D^0 \to K^-\pi^+$	3.85	0.91×10^6	1.01×10^6
$D^0 \to K^+K^-$	0.412	98 000	97 000
$D^0 \to \pi^+\pi^-$	0.143	34 000	43 000
$D^0 \to K^+\pi^-$	0.0138	3300	3020

(Old) Toy MC Study

- Generate 6000 events with a lifetime distribution

$$dN/dt \;=\; \left[R + \sqrt{R}\, y' \left(\frac{t}{\tau}\right) + \frac{1}{4}\left(x'^2 + y'^2\right)\left(\frac{t}{\tau}\right)^2\right] e^{-\Gamma t}$$

  and smear by resolution $\sigma \approx 120$ fs.

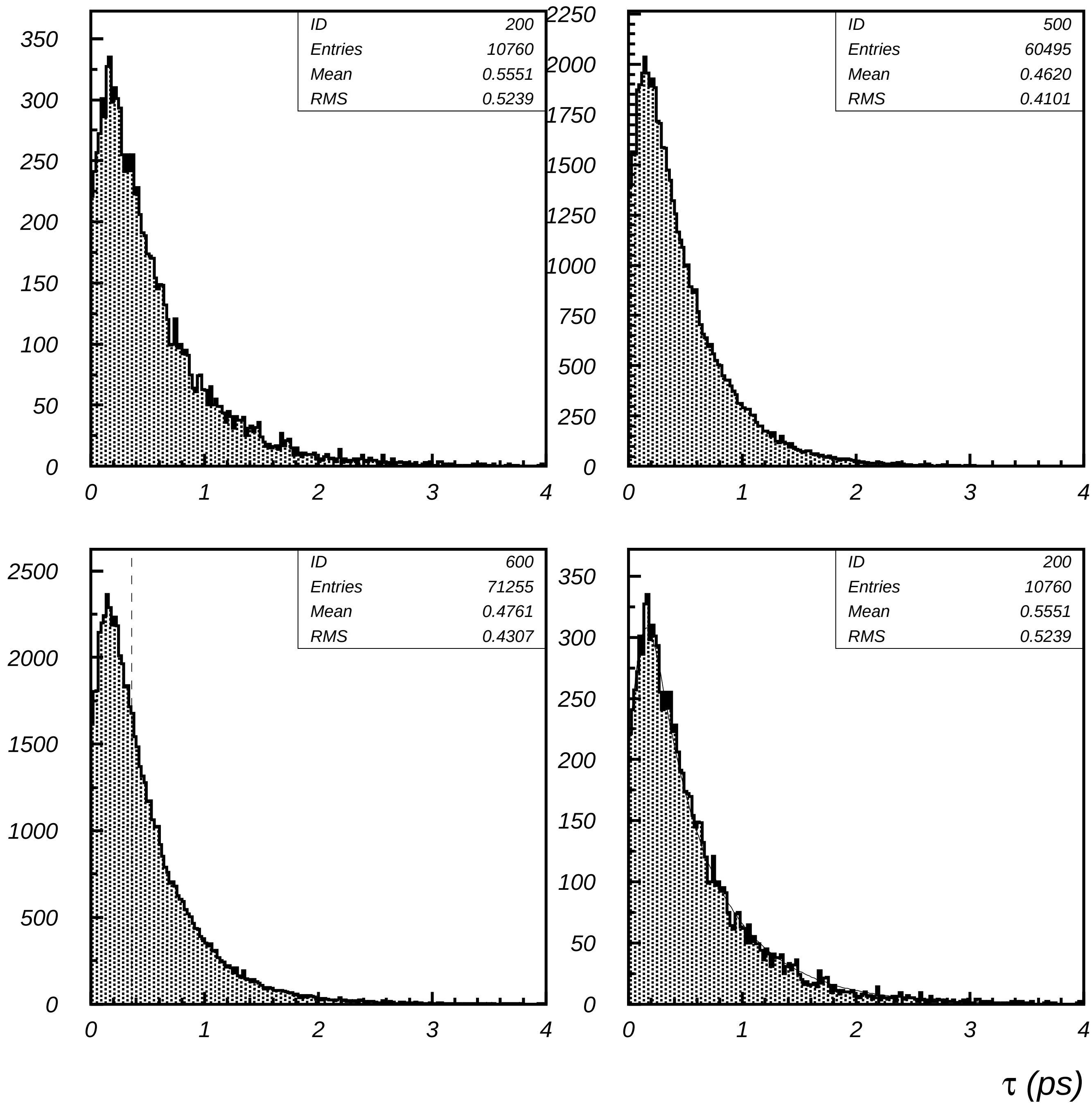
- Generate background events with a lifetime distribution $dN/dt = e^{-t/\tau_{D^0}}$ (since main backgrounds are D^0 double-mis-ID and $D^0 +$ random π^+) and smear by resolution σ. Take $S/B = 0.20$ (similar to FNAL E791).

- combine background and signal samples, make lifetime cut (360 fs), and do an unbinned ML fit for x'^2. Plot likelihood function and take points where $-\ln(\mathcal{L})$ rises by 0.5 as 1σ errors

- repeat for "Babar sample" of 1920 events with $\sigma = 220$ fs, $S/B = 3$: do ML fit and find $1\,\sigma$ errors.

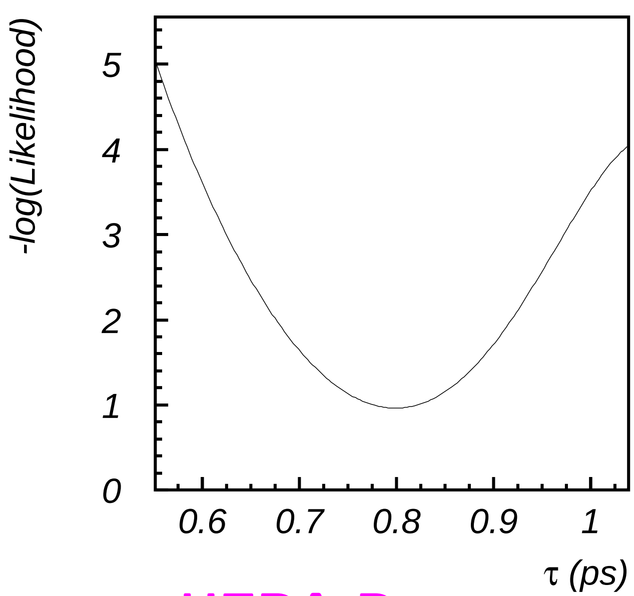
Toy MC Study Cont'd

$x'^2 = 0.001$, $N_s = 6000$, $S/B = 0.20$, $\sigma = 120$ fs, $\tau_{cut} = 0.36$ ps:

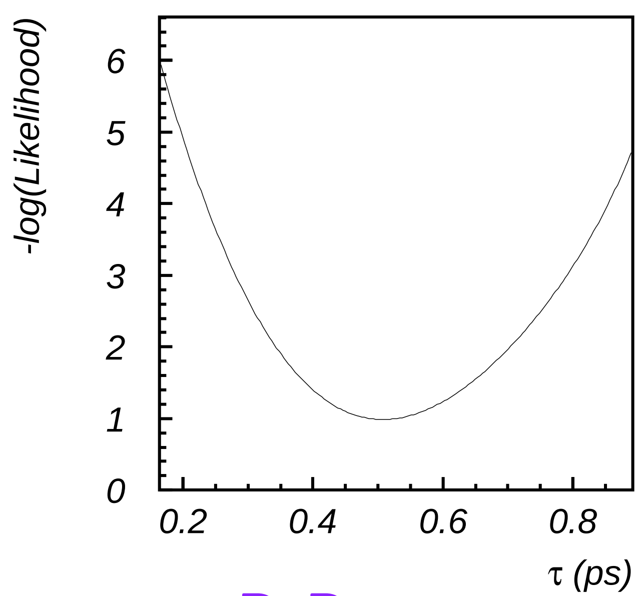


Results for x'^2

Generated x'^2 ($\times 10^{-3}$)	Fit result for *HERA-B* sample	Fit result for BaBar sample
0.4	0.67 ± 0.08	$0.33^{+0.11}_{-0.10}$
0.6	0.80 ± 0.08	$0.51^{+0.13}_{-0.12}$
0.8	$0.93^{+0.10}_{-0.09}$	$0.70^{+0.15}_{-0.14}$
1.0	1.06 ± 0.10	$0.89^{+0.17}_{-0.15}$
1.2	1.19 ± 0.11	$1.09^{+0.17}_{-0.16}$
1.4	$1.35^{+0.12}_{-0.11}$	1.31 ± 0.18



HERA-B



BaBar

$\Rightarrow$ further study needed

Conclusions

- The *HERA-B* detector could be used to collect a competitive sample of tagged SCS $D^0 \to K^+K^-/\pi^+\pi^-$ and DCS $D^0 \to K^+\pi^-$ decays. These would be used to measure/constrain the mixing parameters x', y', y and search for CP violation in the D^0-$\overline{D}^0$ system. CLEO-c cannot do this measurement; CDF/D0 probably cannot due to marginal PID.

- The statistical errors obtained for x' and y' would be substantially smaller than the current errors (Babar, hep-ex/0304007)

- The sensitivity to x' and y' would be comparable to theoretical predictions (hep-ph/0005089); i.e, the experiment could possibly *observe* mixing.

- The statistical errors for $S/B = 1/5$ would be similar to those obtained by Belle/Babar in 2005. Systematic errors would be different.

- Technical needs:
  - new FLT TDU board needed
  - new HPT pretrigger coincidence board probably needed
  - event-logging rate must be increased to $\sim$1 kHz.