Fixed Target Results Survey

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OVERVIEW

An overview of results recently published/announced.

- SELEX
- NUTEV
- NUSEA
- FOCUS
- DONUT
- E791
- HYPERCP
- KTEV

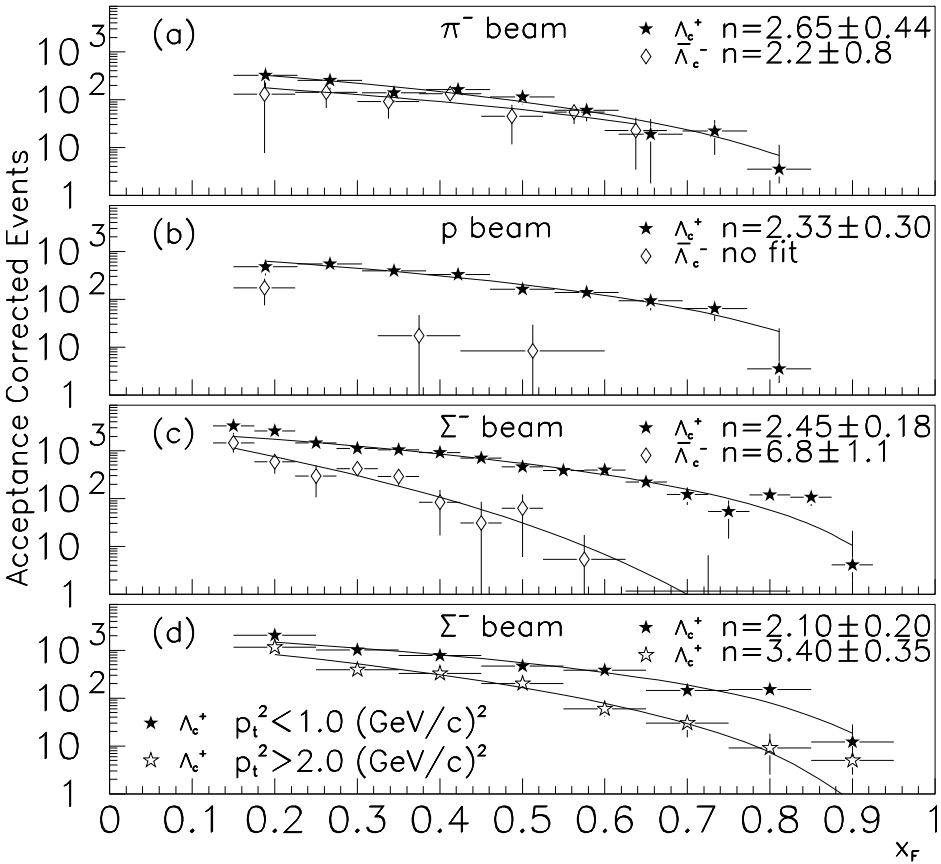
SELEX

Hadroproduction asymmetry

- Resent results on hadroproduction asymmetry of charmed baryons/charmed antibaryons
- $c\bar{c}$ production at quark level is almost symmetric
- hadroproduction asymmetries are features of hadronization process
- $leading\ charm$: charmed baryon shares a quark in common with the beam ($non\text{-}leading\ charm$: do not have a shared quark)

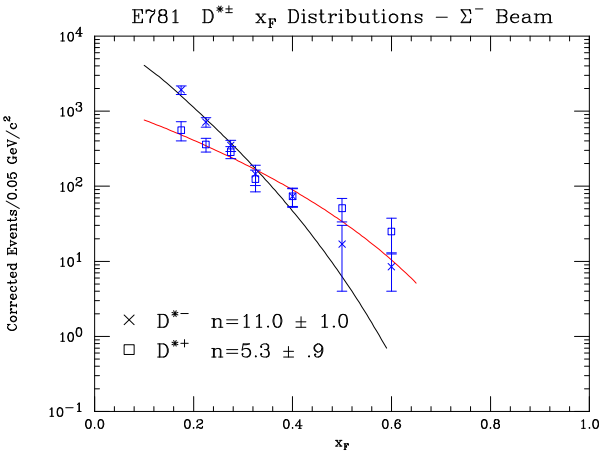
SELEX

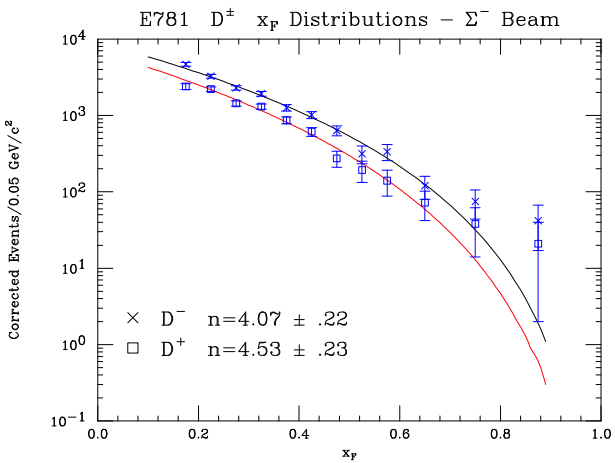
Hadroproduction of Λ_c^+ and $\bar{\Lambda}_c^-$



$D^{\pm}$ and $D^{*\pm}$ from Σ^- beam

Mesons with the same quark content are **very different!**





SELEX

- Resent results from SELEX on hadroproduction of $D^{\pm}$, $D^{\pm}$, $D_s^{*\pm}$, D^0, $\bar{D}^0$, Λ_c^+, $\bar{\Lambda}_c^-$ from π^-, p and Σ^- beams.
- Significant non-perturbative effects in x_F and p_t^2 distributions. In general agreement with hardonization models.
- Some effects do not fit simply into any present model.
- Resent results from E791 on $\Lambda_c/\bar{\Lambda}_c$ asymmetry show similar effects.

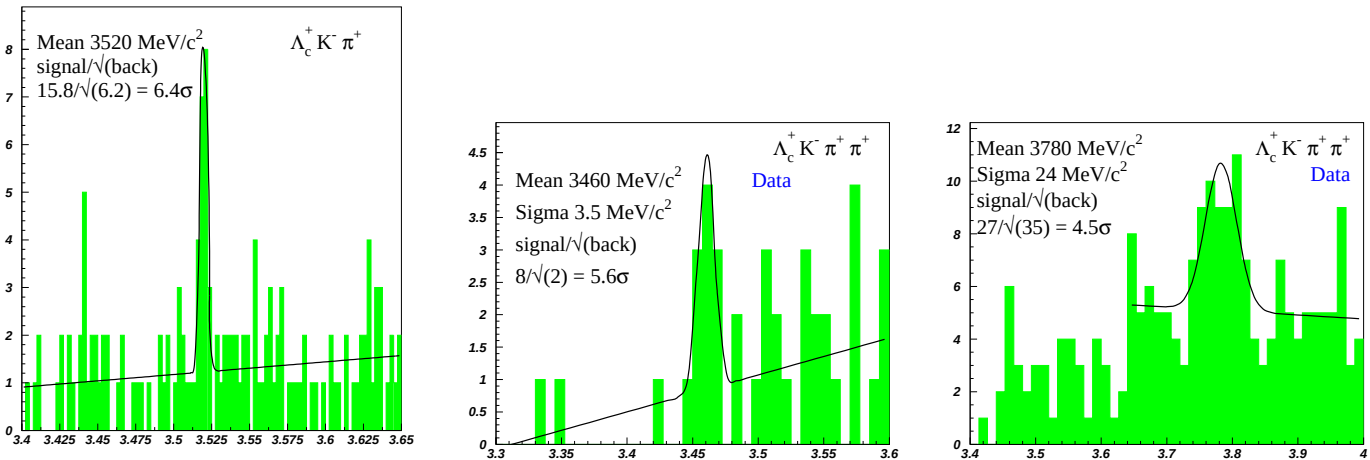
Observation of High Mass States

- Flavor-Independent QCD: Double- and Triple-Charm Baryons **must** exist
- Not observed yet
- Expected decays:
  - $ccu^{++} \longrightarrow K^-\pi^+\pi^+\Lambda_c^+$
  - $ccd^+ \longrightarrow K^-\pi^+\Lambda_c^+$
  - $ccu^{*++} \longrightarrow K^-\pi^+\pi^+\Lambda_c^+$

    $ccu^{*++} \longrightarrow ccd^+\pi^+$

SELEX

Strong Evidence for Doubly-Charmed baryons

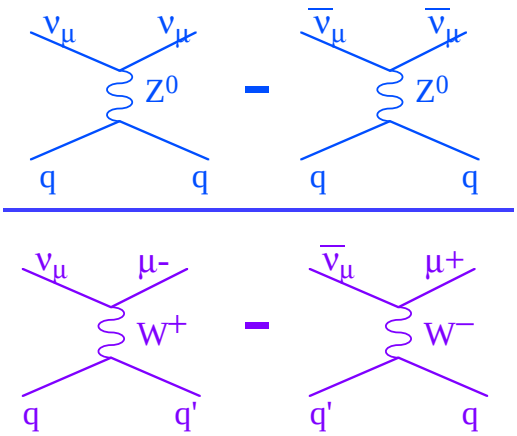


Candidates for ccd^+(3520) with lifetime in 30 fs range, ccu^{++}(3460) and ccu^{*++}(3780) states.

Measurement of $sin^2\theta_W$

Paschos-Wolfenstein Relation:

$$R^- = \frac{\sigma^{\nu}_{NC} - \sigma^{\bar{\nu}}_{NC}}{\sigma^{\nu}_{CC} - \sigma^{\bar{\nu}}_{CC}} = \rho^2 \left(\frac{1}{2} - sin^2\theta_W \right)$$

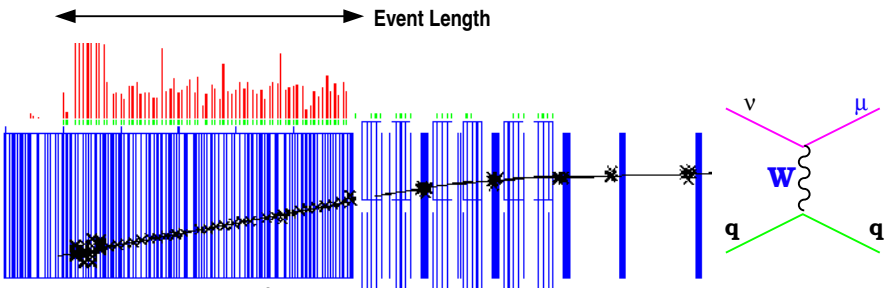


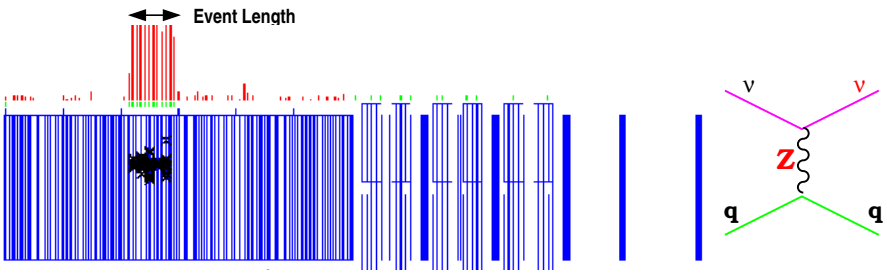
NC/CC event separation

Pure ν and $\bar{\nu}$ beams

$\bar{\nu}$ in ν: 3×10^{-4}

ν in $\bar{\nu}$: 4×10^{-3}





Result

$$
\begin{aligned}
sin^2\theta_W^{(on-shell)} &= 0.2277 \pm 0.0013(stat) \pm 0.0009(syst) \\
&- 0.00022 \cdot \left(\frac{M_{top}^2 - (175\ GeV)^2}{(50\ GeV)^2} \right) \\
&+ 0.00032 \cdot ln \left(\frac{M_{Higgs}}{150\ GeV} \right)
\end{aligned}
$$

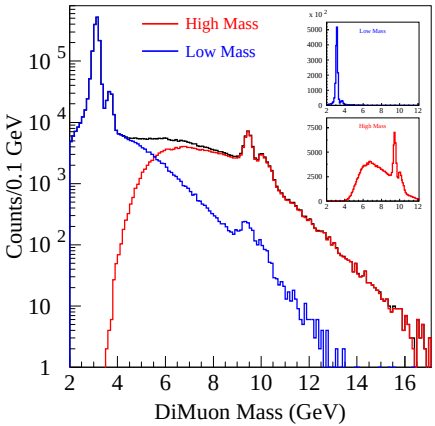
Previous νN result: 0.2277 $\pm$ 0.0031
Standard Model fit (LEPEWWG): 0.2227 $\pm$ 0.0004
A discrepancy of 3σ

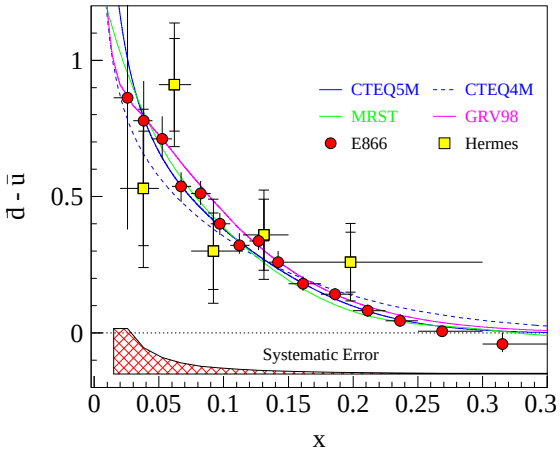
Interpretations

- Fluctuation (unlikely but possible)
- Asymmetric strange sea
- Isospin violations
- Extra Z'
- Missing physics

...A puzzle...

Quark Sea: $\bar{d}$ and $\bar{u}$





- 360,000 Drell-Yan muon pairs
- Ratio of $\bar{d}$ and $\bar{u}$ quarks in proton sea
- Wide range of x
- Most precise measurement
- Important for PDFs, tests of nonperturbative models, other experiments.

Published in Phys. Rev. D64,052002 (2001)

Search for CP violation

Mode	Yield(+)	Yield(-)
$D^{\pm} \to K_S\pi^{\pm}$	4487±96	4770±96
$D^{\pm} \to K_S K^{\pm}$	495±38	454±42
$D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$	84750±512	91520±508

CP asymmetry:

$$A_{CP} = \frac{\eta(D^+) - \eta(D^-)}{\eta(D^+) + \eta(D^-)}$$

where $\eta(D^{\pm})$ is the relative BR.

$A_{CP}(K_S\pi)$ wrt $K\pi\pi$ (-1.6±1.5±0.9)%
$A_{CP}(K_S K)$ wrt $K\pi\pi$ (+6.9±6.0±1.5)%
$A_{CP}(K_S K)$ wrt $K_S\pi$ (+7.1±6.1±1.2)%

Published in PRL 88,041602(2002)

Lifetime Mesurements

Lifetime measurements are fundamental for understanding of the heavy quark decays

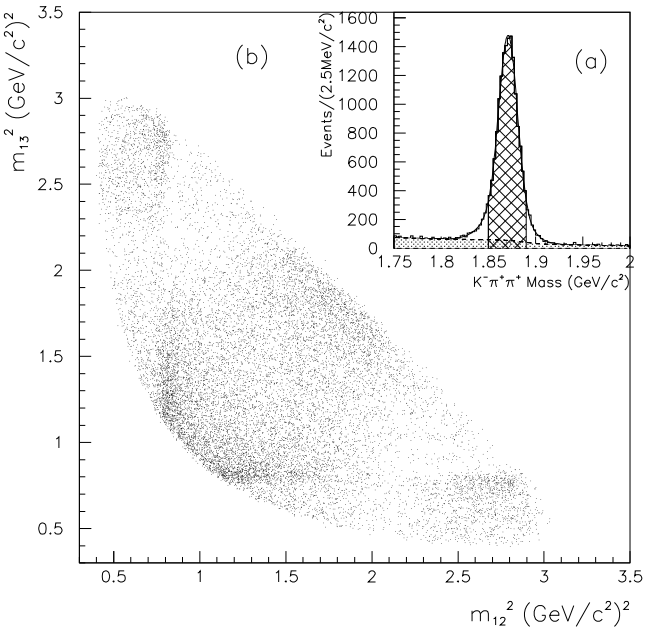
Part.	Events	Lifetime
Λ_c^+	8034±122	204.6±3.4±2.5 fs
Ξ_c^+	532±30	439±22±9 fs
Ξ_c^0	137±19	109+16-9 fs
Ω_c^0	64±14	79±12±8 fs
D^0	210K	409.6±1.1±1.5 fs
D^+	110K	1039.4±4.3±7.0 fs

Direct Observation of ν_τ

- First observation of tau neutrino interactions. 4 ν_τ events with an estimated background 0.34 events. Phys. Lett. B504,218-224(2001)
- A new upper limit for ν_τ magnetic moment $\mu_{\nu_\tau} \leq 3.9 \times 10^{-7}$ Phys. Lett. B513,23-29(2001)
- Improved Analysis (Preliminary results): 3 new ν_τ candidates (7 total). Better understanding efficiencies, backgrounds and systematics

E791

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



- 15090 events
- Best fit when include additional scalar resonance κ
  $M_\kappa = 797 \pm 19 \pm 43 \mathrm{MeV}/c^2$
  $\Gamma_\kappa = 410 \pm 43 \pm 87 \mathrm{MeV}/c^2$
- Good fit quality.
- Strong evidence for κ

More Dalitz plots

- $D_S^+ \to \pi^-\pi^+\pi^+$
- 848±44 events
- New measurements for $f_0(980)$:
  $m_0 = 975 \pm 3 \pm 2\ \mathrm{MeV}/c^2$
  $\Gamma_0 = 44 \pm 2 \pm 2\ \mathrm{MeV}/c^2$
- New measurements for $f_0(1370)$:
  $m_0 = 1434 \pm 18 \pm 9\ \mathrm{MeV}/c^2$
  $\Gamma_0 = 172 \pm 32 \pm 6\ \mathrm{MeV}/c^2$

- $D^+ \to \pi^-\pi^+\pi^+$
- 1170±65 events
- Best fit when include additional scalar resonance σ
  $M_\sigma = 478^{+24}_{-23} \pm 17\mathrm{MeV}/c^2$
  $\Gamma_\sigma = 324^{+42}_{-40} \pm 21\mathrm{MeV}/c^2$
- Good fit quality.
- Strong evidence for σ

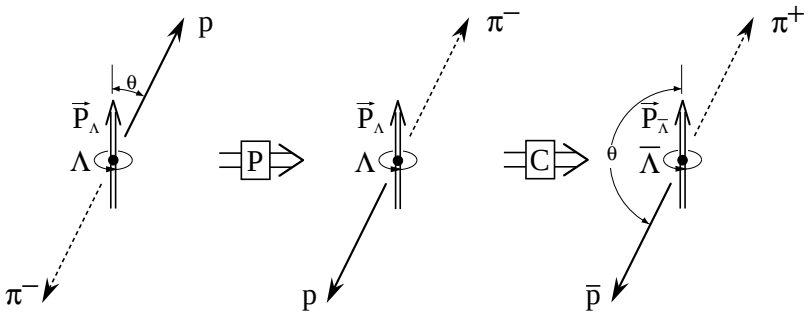
E791

Search for rare decays of D meson

- D^+, D_S^+ and D^0 mesons
- Dilepton flavor-changing neutral current, lepton-number violating, lepton familyviolating decays
- Obtained upper limits on 51 decays
- 18 limits are significant iimprovements of previously published results
- 26 of the remaining modes had no previously repored limits.

Search for CP violation

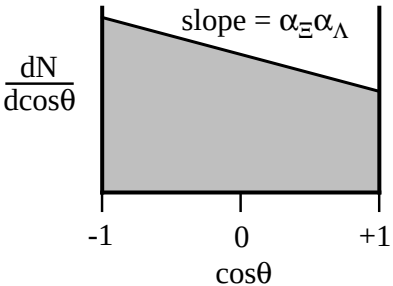
CP transformation in Λ rest frame:



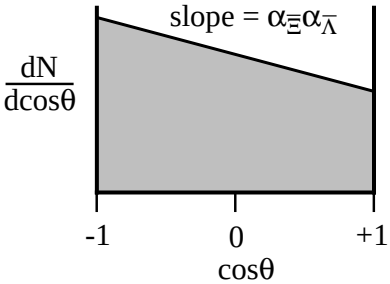
$$CP(\theta) = \pi - \theta$$

Experimentally compare

$$\Xi^- \to \Lambda\pi^- \quad \Lambda \to p\pi^-$$



$$\bar{\Xi}^+ \to \bar{\Lambda}\pi^+ \quad \bar{\Lambda} \to \bar{p}\pi^+$$



HYPERCP

Measure the the difference in slope of $cos\theta$ distributions for p and $\bar{p}$

$$A_{\Xi\Lambda} \equiv \frac{\alpha_{\Xi}\alpha_{\Lambda} - \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}}{\alpha_{\Xi}\alpha_{\Lambda} + \alpha_{\bar{\Xi}}\alpha_{\bar{\Lambda}}}$$

Previous Measurement of $A_{\Xi\Lambda}$=0.012$\pm$0.014 (E756)

Fraction of the data set, randomly selected during reconstruction
3.0×10^7 Ξ^+ and 1.5×10^7 Ξ^-

$$\alpha_{\Xi}\alpha_{\Lambda} = -0.2880 \pm 0.0004(Stat.)$$

(PDG: -0.294 $\pm$ 0.005)

CP violation asymmetry Result

A preliminary limit on CP violation asymmetry:

$$A_{\Xi\Lambda} = [-7 \pm 12(\text{stat.}) \pm 6.2(\text{sys.})] \times 10^{-4}$$

an order of magnitude better than the current limit

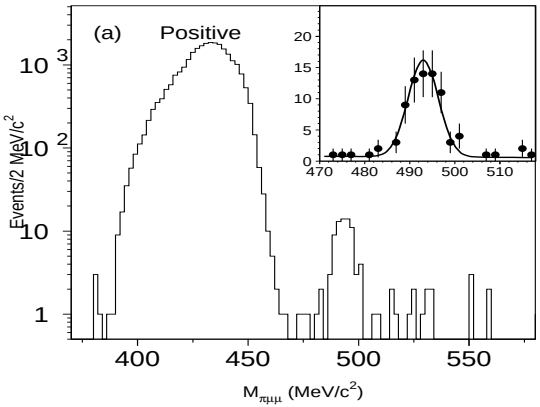
Full data of $\Xi \longrightarrow \Lambda\pi$ events reconstructed
0.46×10^9 Ξ^+ and 2.0×10^9 Ξ^-

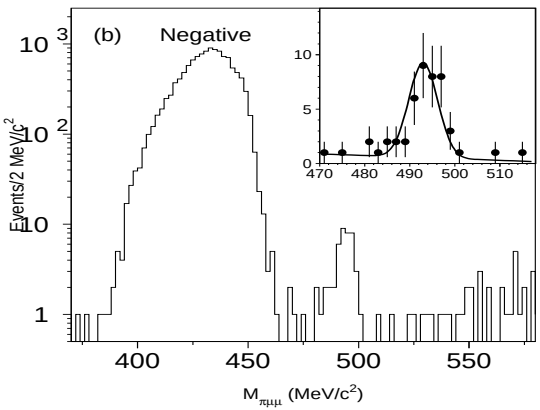
Expected statistical precision for asymmetry:

$$\delta A_{\Xi\Lambda} \approx 2 \times 10^{-4}$$

Current systematic uncertainties are expected to scale down with increased sample statistics

Measurement of $K_L^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$

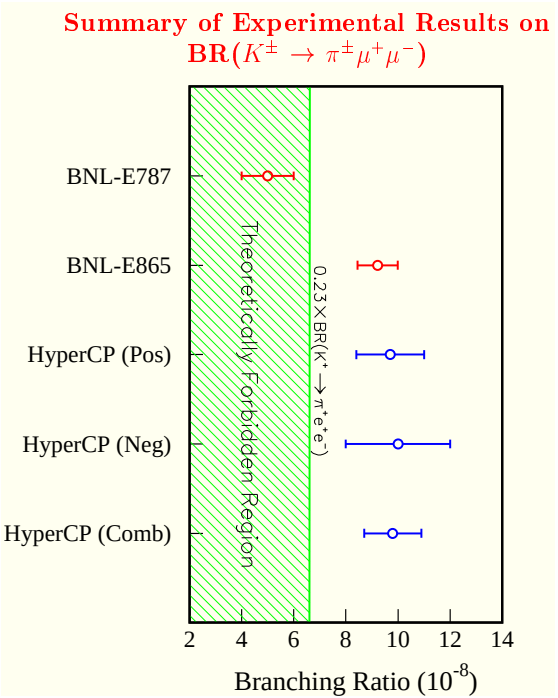




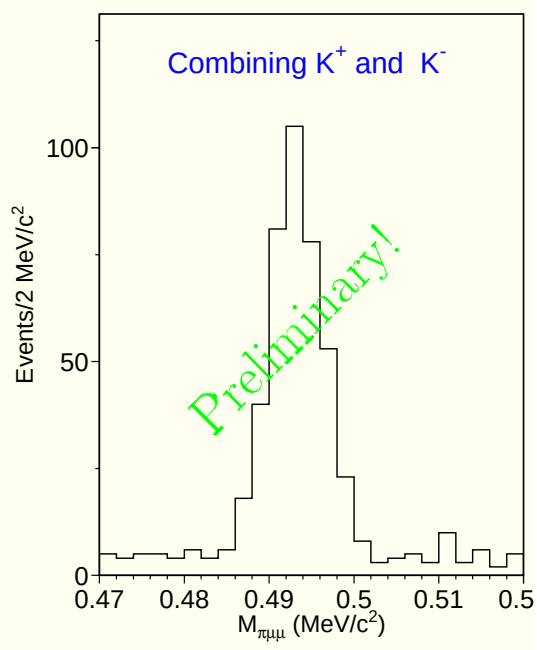
- Based on fraction of the data (1997 data only):
- 65.3±8.2 $K^{+} \to \pi^{+}\mu^{+}\mu^{-}$ events
- 35.2±6.6 $K^{-} \to \pi^{-}\mu^{+}\mu^{-}$ events (First observation)
- BR($K^{+}_{\pi\mu\mu}$)=$(9.7\pm1.2\pm0.4)\times10^{-8}$
- BR($K^{-}_{\pi\mu\mu}$)=$(10.0\pm1.9\pm0.7)\times10^{-8}$

Published in PRL 88, 111801 (2001)

HYPERCP



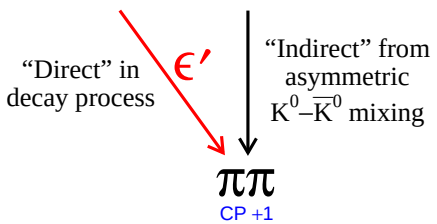
1999 data set has four times the statistics



KTEV

Direct CP violation parameter Re(ϵ'/ϵ)

$$K_L = \overset{\text{CP}-1}{K_2} + \epsilon \overset{\text{CP}+1}{K_1}$$



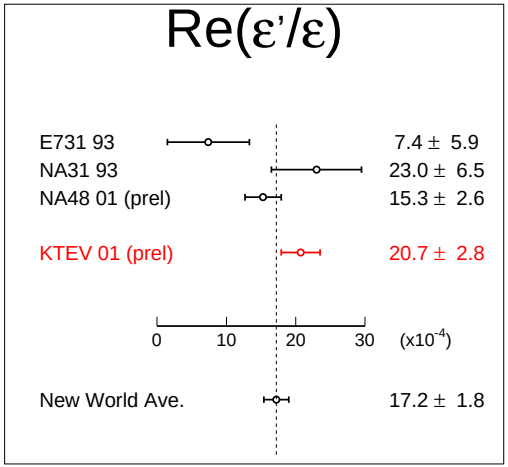
$$\eta_{+-} \equiv \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} = \epsilon + \epsilon'$$

$$\eta_{00} \equiv \frac{A(K_L \to \pi^0\pi^0)}{A(K_S \to \pi^0\pi^0)} = \epsilon - 2\epsilon'$$

$$\left|\frac{\eta_{+-}}{\eta_{00}}\right|^2 \simeq 1 + 6\mathrm{Re}\left(\frac{\epsilon'}{\epsilon}\right)$$

Preliminary result from 1996-1997 data

$\mathrm{Re}(\epsilon'/\epsilon) = [\ 20.7 \pm 1.5(\mathrm{stat}) \pm 2.4(\mathrm{syst}) \pm 0.5(\mathrm{MC\ stat})\ ] \times 10^{-4}$



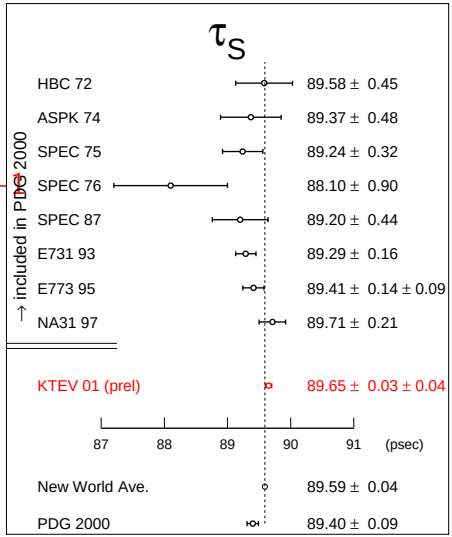
The analysis of 1999 data is in progress (equal statistics to 1996-1997)

KTEV

Kaon Sector Parameters

Preliminary:

$$\Delta m = (5262 \pm 7.7(\text{exp}) \pm 13(\text{th})) \times 10^{6} \text{hs}^{-1}$$
$$\tau_S = (8967.1 \pm 3.5(\text{exp}) \pm 4(\text{th})) \times 10^{-14} \text{s}$$
$$\Phi_{+-} = 44.11 \pm 0.72(\text{stat}) \pm 1.1(\text{syst})$$
$$\Delta\Phi = 0.41^{\circ} \pm 0.22^{\circ}(\text{stat}) \pm 0.53^{\circ}(\text{syst})$$



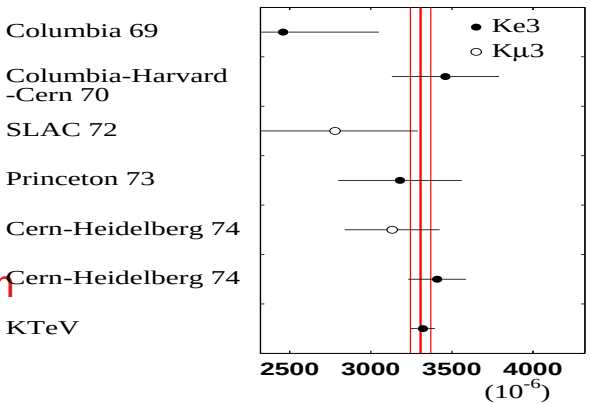
KTEV

CP violation in $K_L \to \pi^{\pm} e^{\mp} \nu$

$$\delta_L = \frac{\mathrm{BR}(K_L \to \pi^- e^+ \nu) - \mathrm{BR}(K_L \to \pi^+ e^- \nu)}{\mathrm{BR}(K_L \to \pi^- e^+ \nu) + \mathrm{BR}(K_L \to \pi^+ e^- \nu)}$$

Related to indirect CP violation
298 million Ke3 decays analyzed.
Result [PRL 88,181601(2002)]:

$\delta_L = 3322 \pm 58(\mathrm{stat}) \pm 47(\mathrm{syst})\mathrm{ppm}$



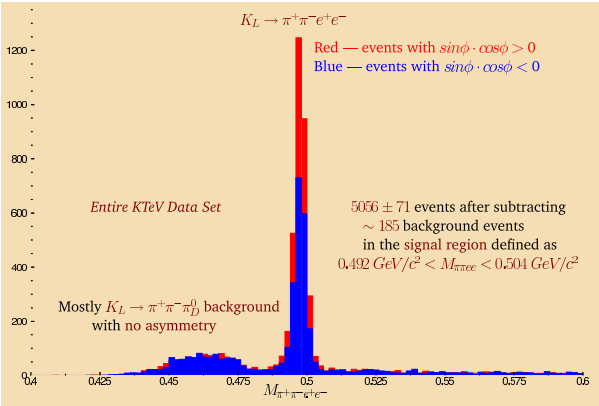
KTEV

CP violation in $K_L \to \pi^+\pi^-e^+e^-$

CP-odd and T-odd angle ϕ between $\pi^+\pi^-$ and e^+e^- planes in Kaon rest frame

Asymmetry

$$A(\phi) = \frac{N_{\sin\phi\cos\phi>0} - N_{\sin\phi\cos\phi<0}}{N_{\sin\phi\cos\phi>0} + N_{\sin\phi\cos\phi<0}}$$



BR($K_L \to \pi^+\pi^-e^+e^-$) = [3.63 $\pm$ 0.11 $\pm$ 0.14] $\times 10^{-7}$ (Preliminary)

Total KTeV sample: 5056$\pm$71 events

$$A(\phi) = 13.3 \pm 1.4 \pm 1.0\% \text{(Preliminary)}$$

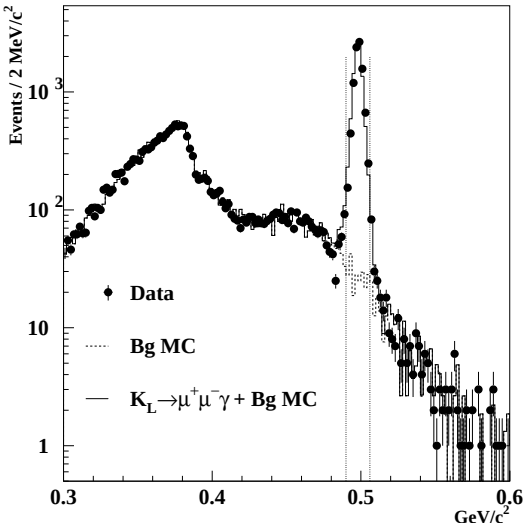
Previously published measurements: $A(\phi) = 13.6 \pm 2.5 \pm 1.2\%$ (KTEV)

Theory: $\sim 14\%$

KTEV

α_{K*} form factor in $K_L \to l^+l^-\gamma$

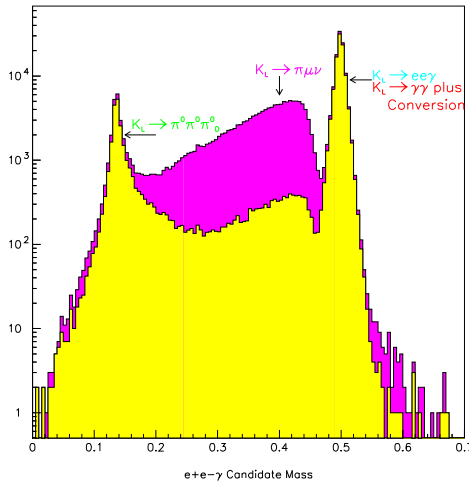
The form factor from $K_L \to l^+l^-\gamma$ needed to estimate "short-distance" in $K_L \to \mu^+\mu^-$ (V_{td}).



$K_L \to \mu\mu\gamma$

BR=[3.62±0.04±0.08]$\times 10^{-7}$

PRL 87,071801 (2001)

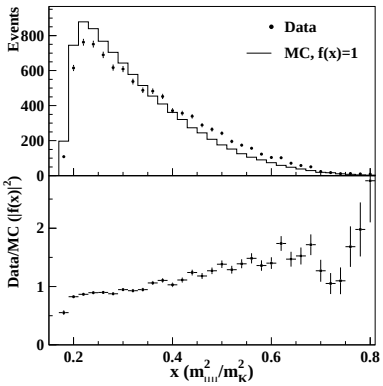


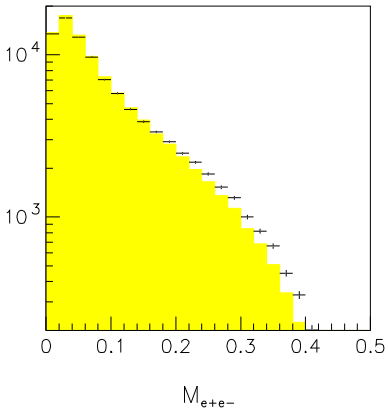
$K_L \to ee\gamma$

BR=[10.13±0.04±0.06 ±0.29(ext syst)]$\times 10^{-6}$ (Preliminary)

KTEV

α_{K*} form factor in $K_L \to l^+ l^- \gamma$





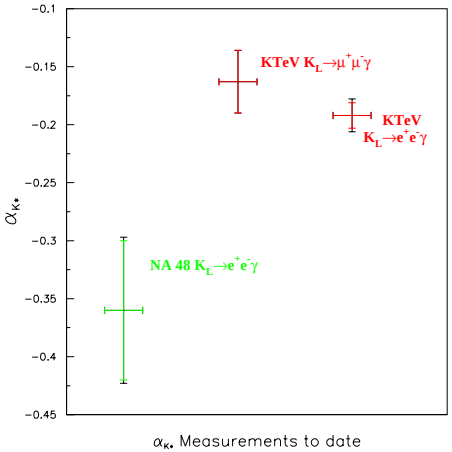
$K_L \to \mu\mu\gamma$[PRL 87,071801(2001)]:

$$\alpha_{K*} = -0.160^{+0.026}_{-0.028}$$

$K_L \to ee\gamma$: [Preliminary]

$$\alpha_{K*} = -0.192 \pm 0.011 \pm 0.008$$

Agreement between electron and muon modes!



KTEV

Rare decays

Mode	Phys.	Events	BR	Published
$K_L \to \pi^0 e^+ e^-$	Direct CPV		$\leq 5.1 \times 10^{-10}$	2001
$K_L \to \pi^0 \mu^+ \mu^-$	Direct CPV		$\leq 3.8 \times 10^{-10}$	2000
$K_L \to \pi^0 \nu \bar{\nu}$	Direct CPV		$\leq 5.9 \times 10^{-7}$	2000
$K_L \to \pi^+ \pi^- \gamma$	Indirect CPV	8,669	20.8×10^{-3}	2001
$/BR(K_L \to \pi^+ \pi^-)$				
$K_L \to \pi^+ \pi^- e^+ e^-$	Indirect CPV	5,056	3.6×10^{-7}	Prelim
$K_L \to e^+ e^- \mu^+ \mu^-$	$K\gamma^*\gamma^*$	133	2.61×10^{-9}	Prelim.
$K_L \to e^+ e^- e^+ e^-$	$K\gamma^*\gamma^*$	441	3.72×10^{-8}	2001
$K_L \to e^+ e^- \gamma$	$K\gamma\gamma^*$	93K	10.13×10^{-6}	Prelim.
$K_L \to \mu^+ mu^- \gamma$	$K\gamma\gamma^*$	9,327	3.6×10^{-7}	2001
$K_L \to \pi^0 \mu^\pm e^\mp$	LFV		$\leq 3.31 \times 10^{-10}$	Prelim.
$K_L \to e^\pm e^\pm \mu^\mp \mu^\mp$	LFV		$\leq 4.12 \times 10^{-11}$	Prelim.
$K_L \to \pi^0 \gamma \gamma$	χPT,VDM	884	1.66×10^{-6}	1999
$K_L \to \pi^0 e^+ e^- \gamma$	χPT,VDM	48	2.3×10^{-8}	2001
$K_L \to \pi^0 \pi^0 e^+ e^-$	χPT,VDM		$\leq 5.4 \times 10^{-9}$	Prelim

SUMMARY

- High statistics charm experiments (SELEX,E791,FOCUS)
  - Presicion test of hadroproduction
  - High sensitivity for rare and forbidden processes
- Constraining PDFs, quark sea (NUSEA, NUTEV ...)
- Standard Model (Electroweak parameter-NUTEV, ν_τ-DONUT)
- Precision measurement of direct and indirect CP violation in Kaon system (KTEV). Search for CP violation in D meson (E791) and Λ (HYPERCP) decays. High sensitivity for rare processes. Tests of SM.