Precision D^0 Mass Measurement at CLEO-c

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Motivation

- Proximity of X(3872) mass to the $D^0\overline{D^{0*}}$ threshold:
  - $M_{X(3872)}$ =(3871.2±0.5) MeV PDG'06
  - $M_{D^0\overline{D^{0*}}} = 2M_{D^0} + \Delta M_{D^{0*}-D^0} = 2\cdot(1864.5\pm0.4)+(142.12\pm0.07)$
    $=(3871.1\pm0.8)$MeV
- Coincidental?
  - If X(3872) is a charmonium state, a hybrid or a glueball
- Consequence of its nature?
  - A threshold cusp
  - A loosely bound $D^0\overline{D^{0*}}$ molecule or other type of 4-quark state ($c\bar{c}q\bar{q}$)
- $M_{X(3872)} - M_{D^0\overline{D^{0*}}}$ becomes a key parameter for model builders
  - $M_{X(3872)} - M_{D^0\overline{D^{0*}}} = +(0.1\pm1.0)$ MeV with the error dominated by the uncertainty in the D^0 mass

PDG'06

D^0 MASS

The fit includes $D^{\pm}$, D^0, $D_s^{\pm}$, $D^{*\pm}$, D^{*0}, and $D_s^{*\pm}$ mass and mass difference measurements.

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1864.5± 0.4 OUR FIT	Error includes scale factor of 1.1.				
1864.1± 1.0 OUR AVERAGE					
1864.6± 0.3±1.0	641	BARLAG	90C	ACCM	π^- Cu 230 GeV
1852 ± 7	16	ADAMOVICH	87	EMUL	Photoproduction
1861 ± 4	144	DERRICK	84	HRS	e^+e^- 29 GeV

$m_{D^{\pm}} - m_{D^0}$

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
4.78±0.10 OUR FIT Error includes scale factor of 1.1.				
4.74±0.28 OUR AVERAGE				
4.7 ±0.3	[3] SCHINDLER	81	MRK2	e^+e^- 3.77 GeV
5.0 ±0.8	[3] PERUZZI	77	MRK1	e^+e^- 3.77 GeV

$D^{\pm}$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1869.3± 0.4 OUR FIT	Error includes scale factor of 1.1.				
1869.4± 0.5 OUR AVERAGE					
1870.0± 0.5±1.0	317	BARLAG	90C	ACCM	π^- Cu 230 GeV
1863 ± 4		DERRICK	84	HRS	e^+e^- 29 GeV
1869.4± 0.6		[1] TRILLING	81	RVUE	e^+e^- 3.77 GeV

- Based on surprisingly old data…

CLEO-c experiment

- $e^+e^- \to \psi(3770) \to D^0\overline{D^0}$ (σ = 3.6nb)
  - D^0 nearly at rest (P~0.29 GeV), thus momenta of decay products primarily reflect its mass
  - Clean low-multiplicity environment
- CLEO-c $\psi(3770)$ data sample:
  - 281pb^{-1}, 1.8M $\psi(3770)$, 1M $D^0\overline{D^0}$ pairs
  - Much larger than in previous experiments (BES <33 pb^{-1})
  - Can afford trading statistics to decrease systematical errors
- CLEO-c detector:
  - 1T field: excellent momentum resolution (~0.3% at 0.5 GeV)
  - dE/dx+RICH: excellent K/π separation
- In unique position to make a precision measurements of D^0 mass

Signal mode:

$$D^0 \rightarrow K_s\,\phi \rightarrow (\pi^+\pi^-)(K^+K^-)$$

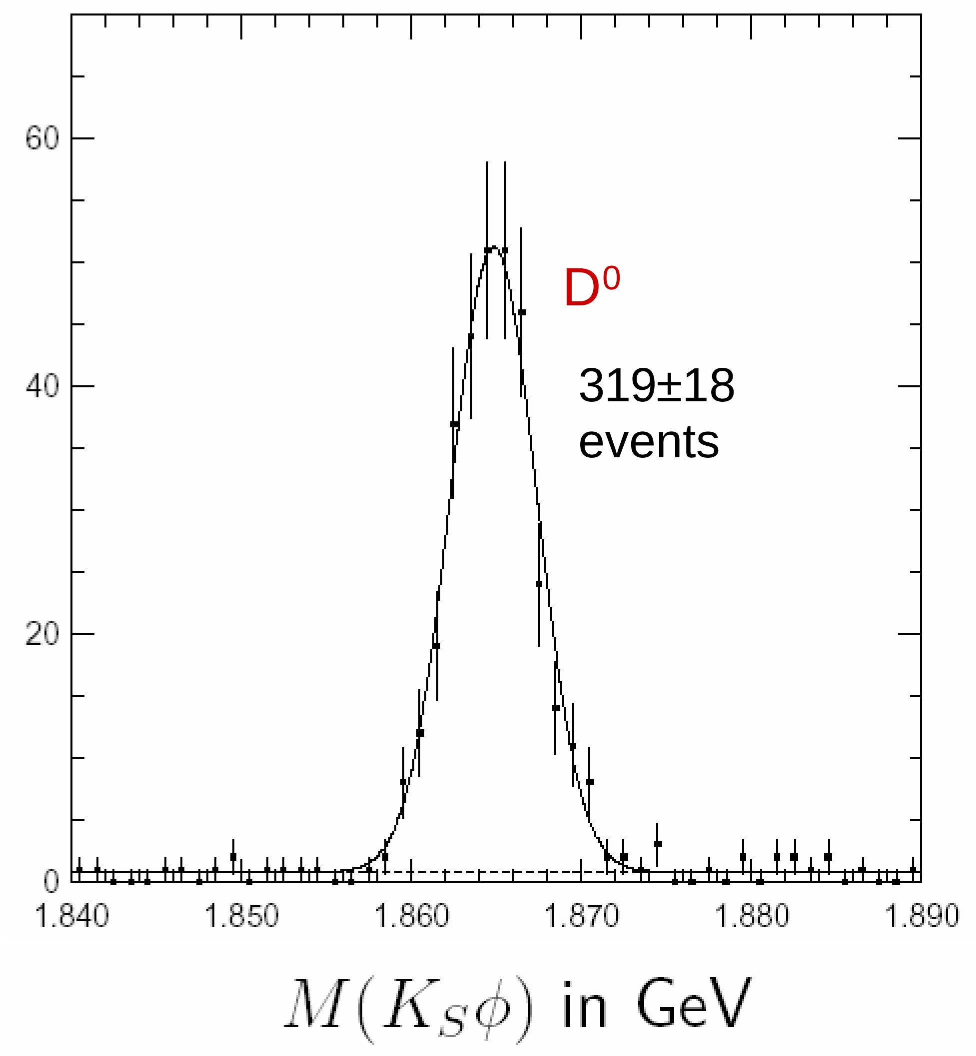
- Product BR=0.2%
  - 2k of such decays produced in our sample before selection cuts
- K_s,ϕ also relatively slow (p~0.5 GeV)
  - their well known masses (±0.02 MeV each) calibrate momentum scale
- K_s lifetime (detached vertex) and narrow ϕ width
  - excellent background suppression tools
- All decays are 2-body with well understood kinematics
  - reliable modeling of kinematics in studies of systematic effects
- Momenta of all final state particles (π's,K's) in a narrow range (0.1-0.5 GeV)
  - absolute momentum scale easier to control

Event selection

- Select $K_S K^+ K^-, K_S \to \pi^+\pi^-$ candidates:
  - dE/dx provides good K/π separation at low momenta
  - The signal tracks must be in the central part of the detector and satisfy tight track quality cuts
- K_s selection:
  - Constrain $\pi^+\pi^-$ to K_s mass and a common vertex: $\chi^2(K_s)<20$
  - >10mm flight distance, >3σ significant
- ϕ selection:
  - ±15MeV of the nominal ϕ mass
  - No constrain to the ϕ mass, since some non-resonant K^+K^- may be present within the ϕ mass window

D^0 mass fit

- Gaussian + flat background

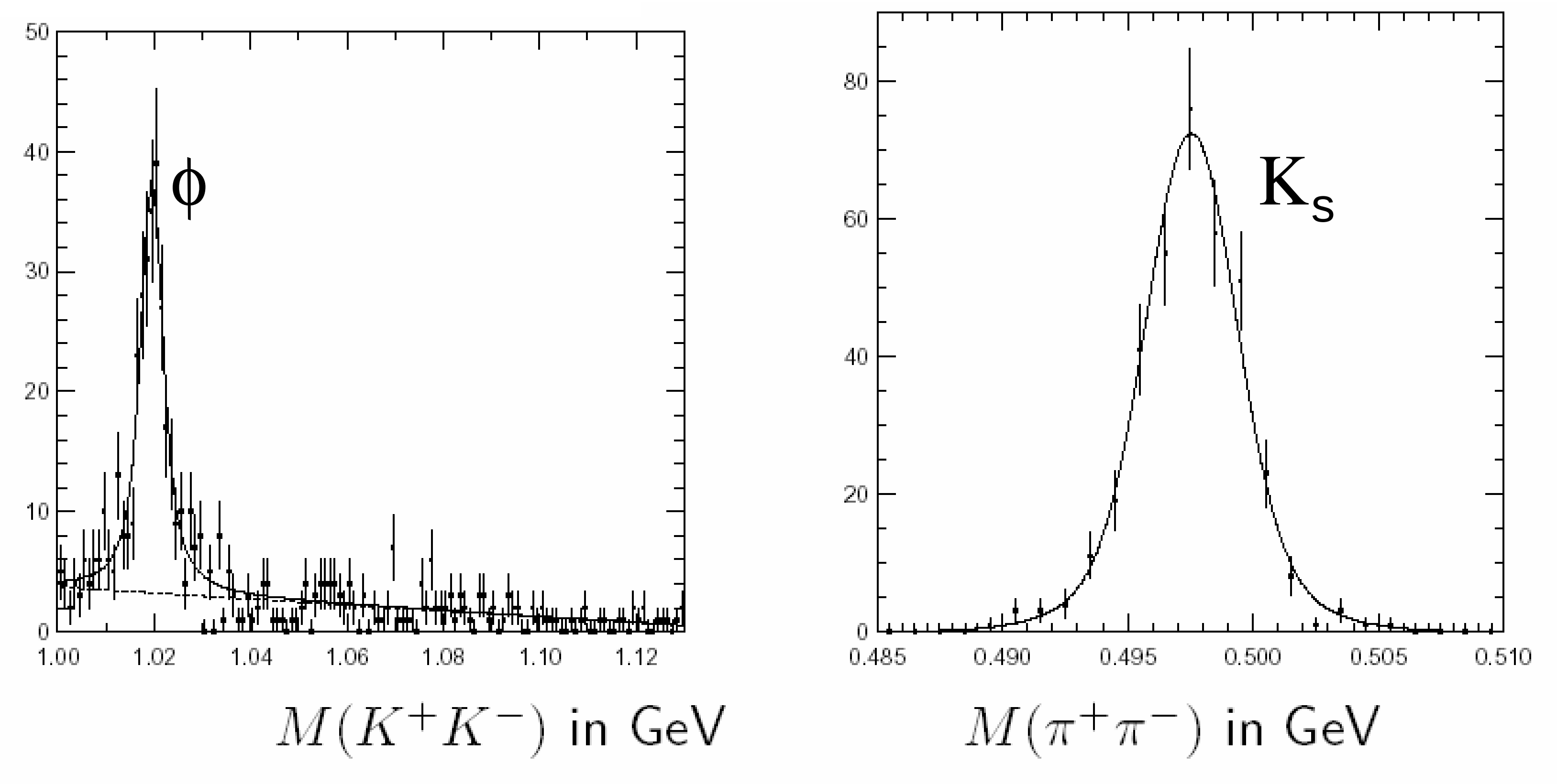


M_{D0} = 1864.85±0.15 MeV

Statistical error only

Calibration checks

- Signal sample

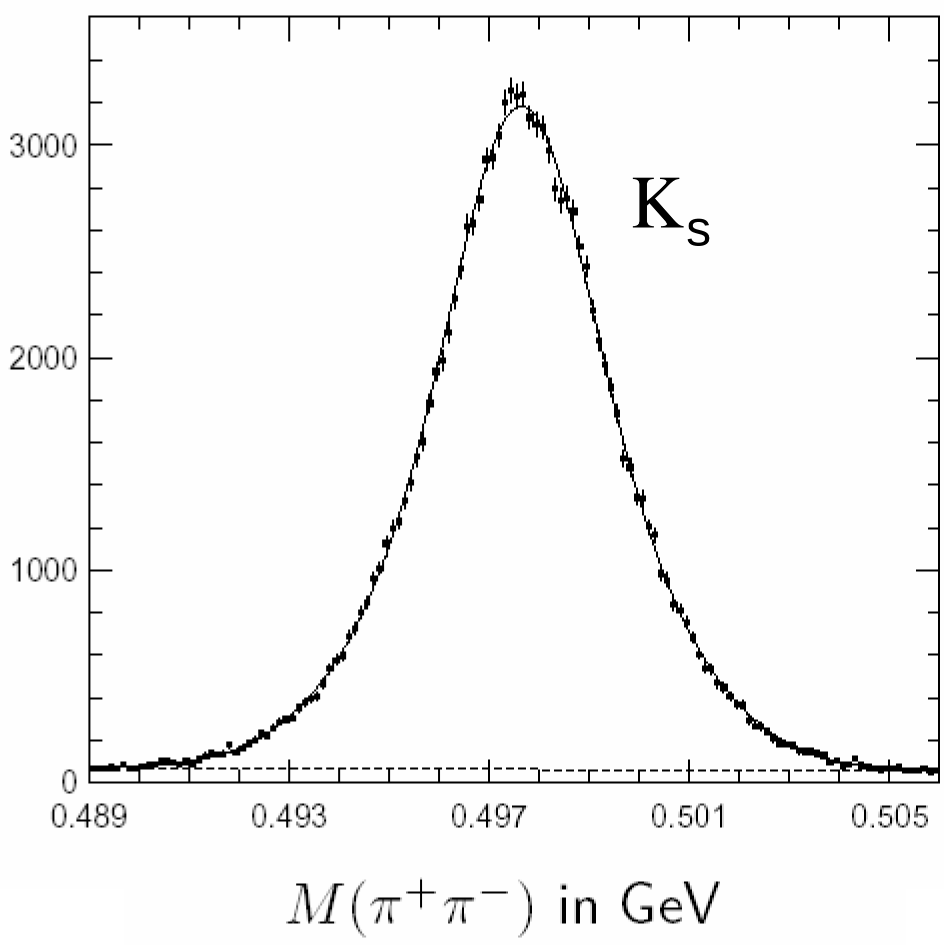


- Masses in excellent agreement with the PDG:
  - $M - M_{PDG} = +0.06 \pm 0.24$ MeV (ϕ); -0.10 ± 0.11 MeV (K_S)

Statistical errors only

Calibration checks

- Inclusive K_s in tagged D sample



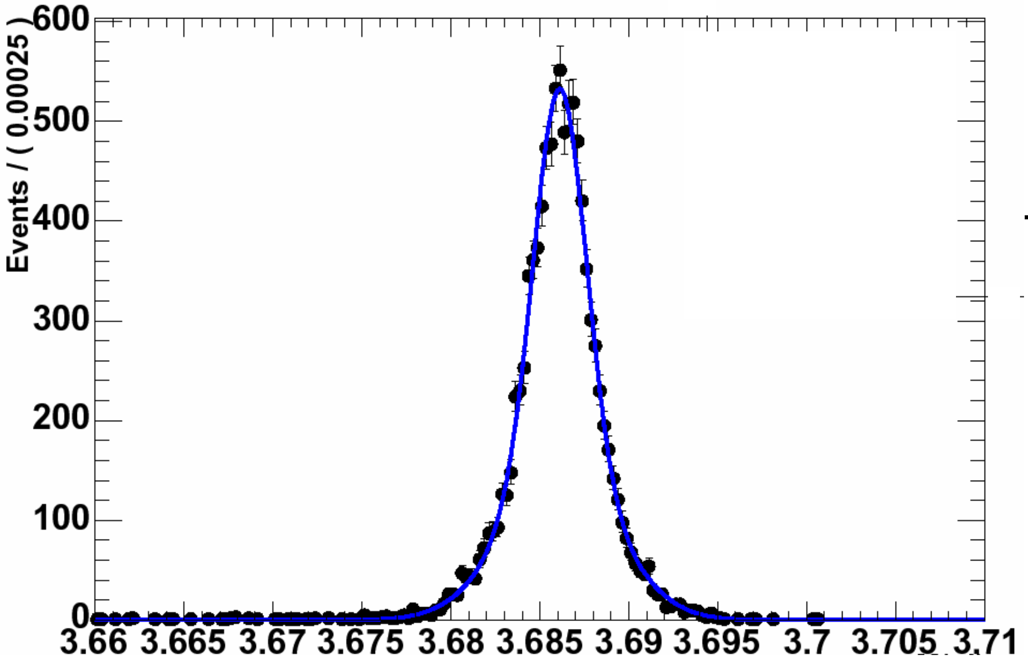
With pion momenta
in the same range as in $K_s\phi$ signal

$M_{Ks\ CLEO} - M_{Ks\ PDG} =$
$+0.000 \pm 0.007 \pm 0.043$ MeV

From MC studies and analytical calculations, a D^0 mass uncertainty is about twice the K_s mass error

Calibration checks

- $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow l^+l^-$
  - Constrain l^+l^- to the J/ψ mass.
  - Test calibration of $\pi^+\pi^-$ momenta via $\psi(2S)$ mass.



$M(\pi^+\pi^- J/\psi)$ GeV

$M_{\psi(2S)\ CLEO} - M_{\psi(2S)\ PDG} = +0.022 \pm 0.068$ MeV

D^0 mass uncertainty is about twice the $\psi(2S)$ mass error

Consistent with the D^0 mass uncertainty from the K_s study

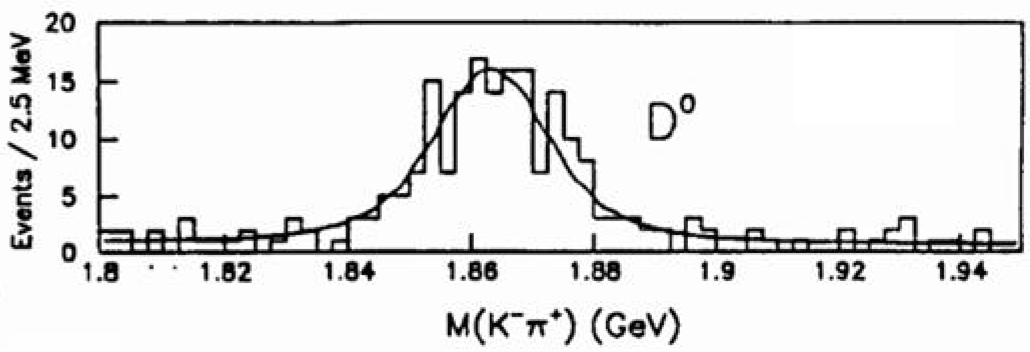
Systematical errors

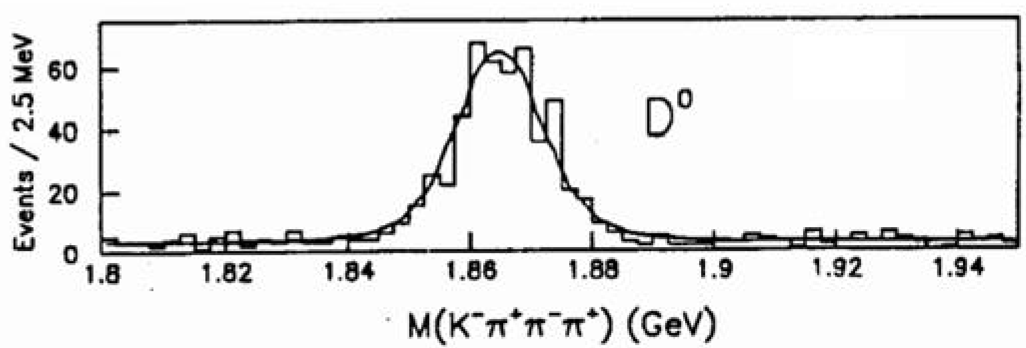
	Systematic Error in $M(D^0)$ (MeV)
Detector Calibration	± 0.090
Monte–Carlo input/output	± 0.022
Binning	± 0.016
Individual event fit	± 0.007
D^0 Peak Shape	± 0.003
Background Shape	± 0.007
Fit interval	± 0.002
Sum in Quadrature	± 0.095

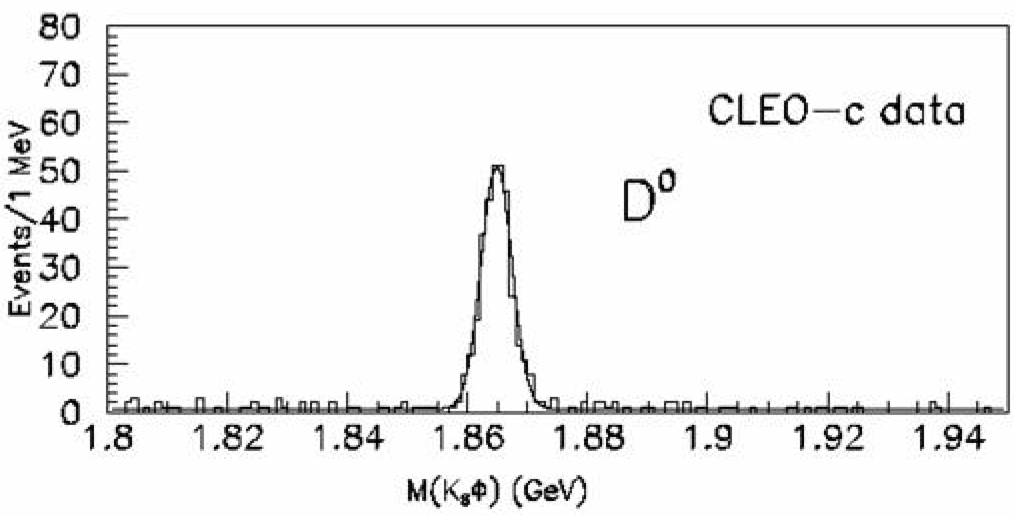
Preliminary!

- Since the systematic studies are still in progress, we are assigning a conservative error of ±0.2 MeV

Comparison to NA32







NA32

$K^-\pi^+$

M_{D0} = 1863.0±0.8±1.0 MeV

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

M_{D0} = 1865.0±0.4±1.0 MeV

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

M_{D0} = 1864.6±0.3±1.0 MeV

CLEO-c

$K_s\phi$

M_{D0} = 1864.85±0.15±0.20 MeV

= 1864.85±0.25 MeV

Preliminary!

Conclusions

- We have improved D^0 mass measurement to:
  - 1864.85±0.15±0.20 MeV PRELIMINARY
- $M_{X(3872)} - M_{D^0\overline{D}^{0*}} = M_{X(3872)} - (2M_{D^0} + \Delta M_{D^{0*}-D^0}) =$
  - +0.1±1.0 MeV PDG'06
  - -0.4±0.7 MeV PDG'06+CLEO
    - The error is now limited by the X(3872) mass measurement
- Accidental mass coincidence even less likely.
- This points to $D^0\overline{D}^{0*}$ molecule, other 4-quark state with small binding energy, or a threshold cusp interpretation.