The CLEO-c Physics Program

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and

CLEO

- Run plan + Physics focus
- Why charm threshold
- Tagging + absolute Br's
- Leptonic + Semileptonic decays
- QCD probes
- Key detector elements
- Conclude

CLEO-c Proposed Run Plan

Started Nov 2001

2002: Υ(1S), Υ(2S), Υ(3S),… ~1-2 fb^{-1} each
Spectroscopy, matrix element, Γ_{ee}
10-20 X existing world's data set

CLEO-c

2003: ψ(3770) – 3 fb^{-1}
30M DD events, w/ 6M *tagged* D decays
(310 times MARK III)

2004: √s ~ 4100 MeV – 3 fb^{-1}
1.5M D_sD_s events, w/ 0.3M *tagged* D_s decays
(480 times MARK III, 130 times BES)

2005: ψ(3100) – 1 fb^{-1}
1 Billion J/ψ decays
(170 times MARK III, 15 times BES II)

CLEO-c Physics Focus

Heavy Flavor Physics: "overcome QCD roadblock"

• CLEO-c: precision charm absolute Br measurements

Leptonic decays → decay constants

Semileptonic decays →Vcd, Vcs, V_CKM unitarity check, form factors

Absolute D Br's normalize B physics

Test QCD techniques in c sector, apply to b sector
⇒ improved Vub, Vcb, Vtd, Vts

Physics beyond SM will have nonperturbative sectors

• CLEO-c: precise measurements of quarkonia spectroscopy & decay provide essential data to calibrate theory.

Physics beyond SM: where is it?

• CLEO-c: D-mixing, charm CPV, charm/tau rare decays.

CESR-c Accelerator

- Modify for low energy operation:

  w/o extra radiation damping, $L \sim E^4$ ($L \sim 1.3 \times 10^{33}$ @ Υ(4S))

  w/ wigglers (transverse cooling), $L \sim E^2$ (cost $5M)

Expected machine performance:

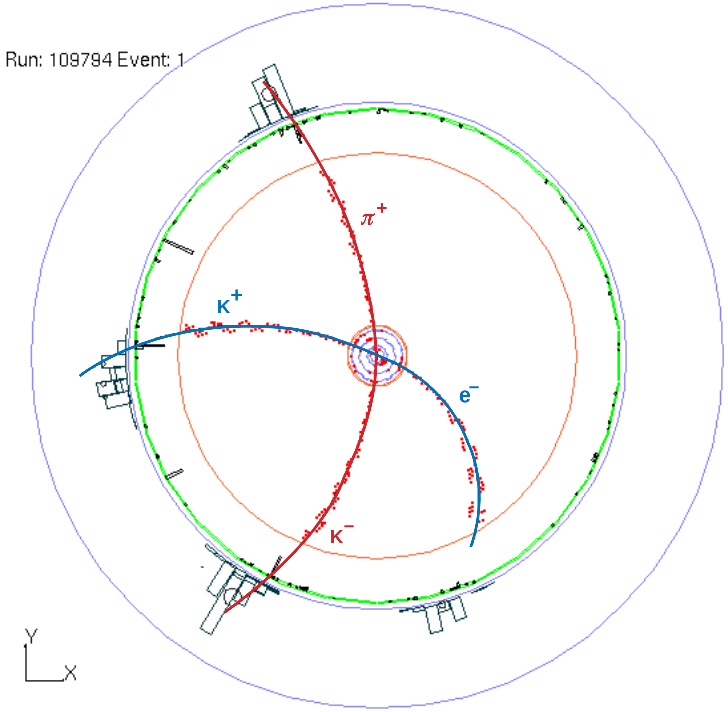
$\sqrt{s}$	L (10^{32} cm^{-2} s^{-1})
3.77 GeV	3.0
4.1 GeV	3.6
3.1 GeV	2.0

- $\Delta E_{beam} \sim 1.2$ MeV at J/ψ

Why Charm Threshold?

- Large production σ, low decay multiplicity
- Pure initial state ($D\bar{D}$): no fragmentation
- Double tag events: no background
- Clean neutrino reconstruction
- Quantum coherence:

  aids D-$\bar{D}$ mixing and CPV studies



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

Tagging Technology

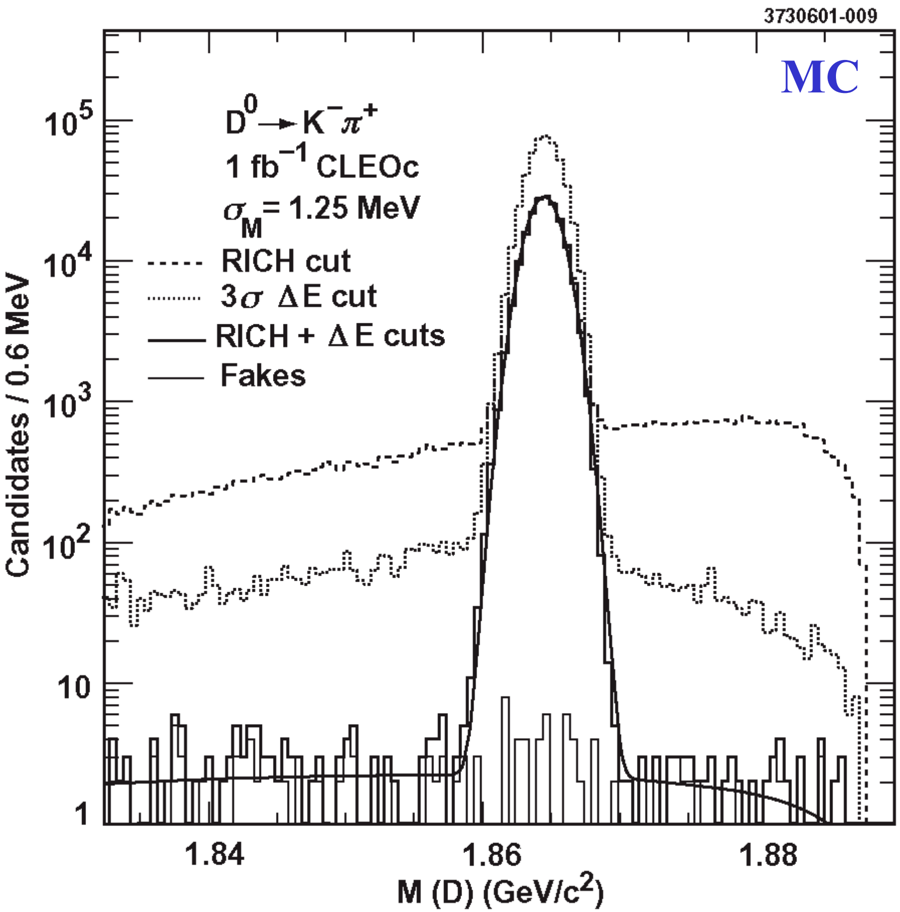
Pure DD/D_sD_s production: $\psi(3770) \rightarrow DD$

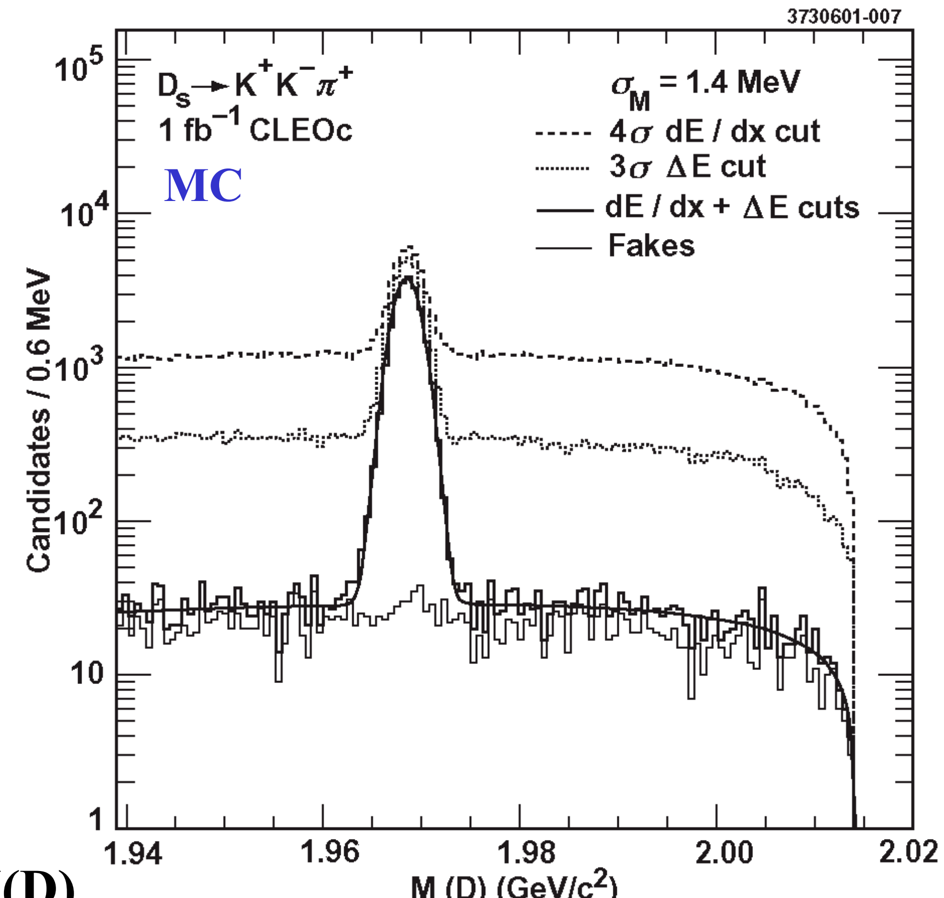
$\sqrt{s} \sim 4140 \rightarrow D_sD_s$

Large branching fractions (~1-15%)

High reconstruction efficiency

$\Rightarrow$ High net tagging efficiency ~20%



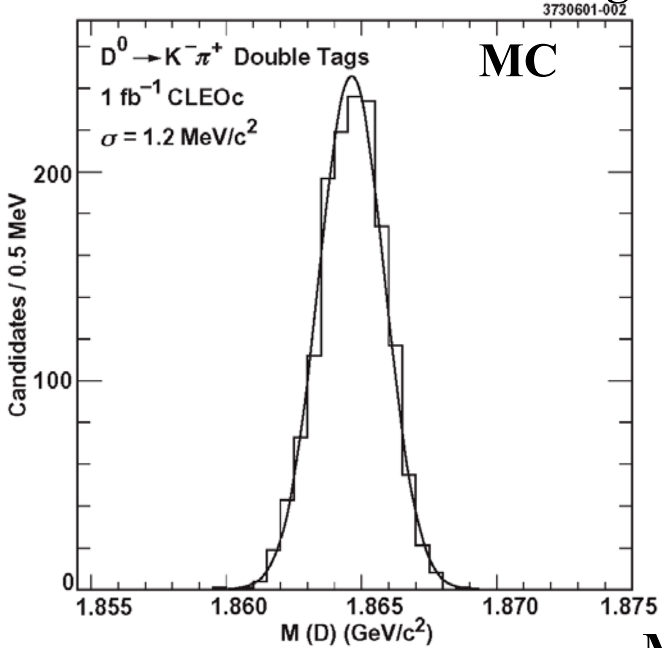


M(D)

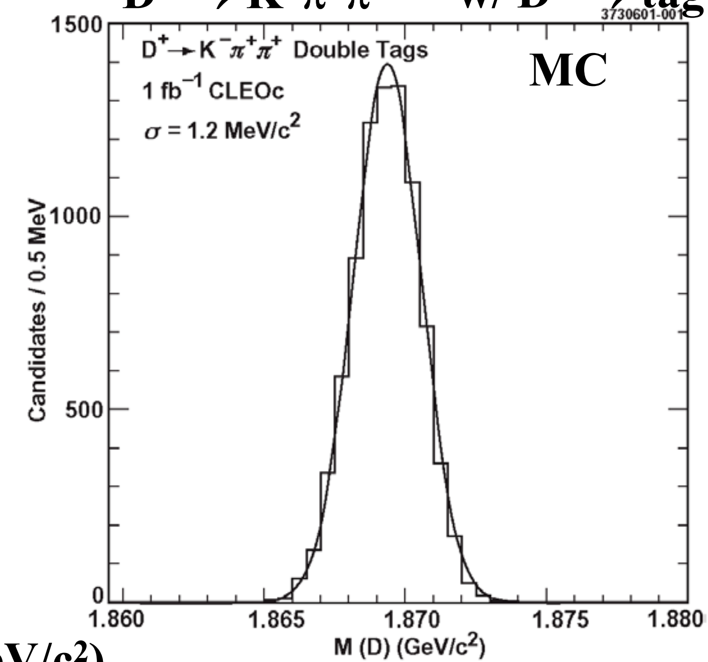
Absolute Br's w/ Double Tags

~ Zero bkgnd in hadronic modes

$D^0 \to K^-\pi^+$ w/ $\bar{D}^0 \to$ tag



$D^+ \to K^-\pi^+\pi^+$ w/ $D^- \to$ tag



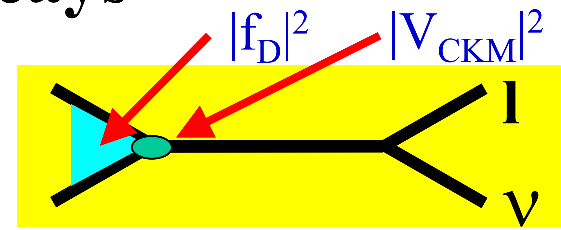
M(D) (GeV/c²)

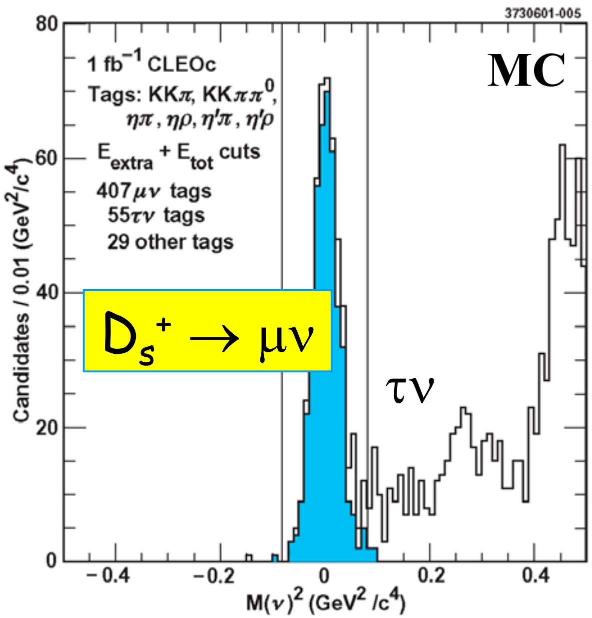
w/ 3 fb^{-1}

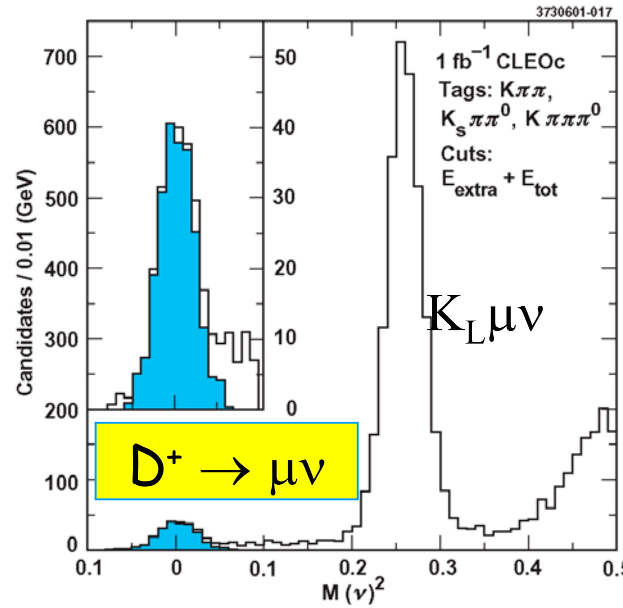
Mode	√s (GeV)	PDG2k (δB/B %)	CLEOc (δB/B %)
$D^0 \to K^-\pi^+$	3770	2.4	0.6
$D^+ \to K^- \pi^+\pi^+$	3770	7.2	0.7
$D_s \to \phi\pi$	4140	25	1.9

f_{Dq} from Leptonic Decays

$$\Gamma (D_q \rightarrow l\, \nu) \propto |f\_Dq|^2\, |V\_cq|^2$$







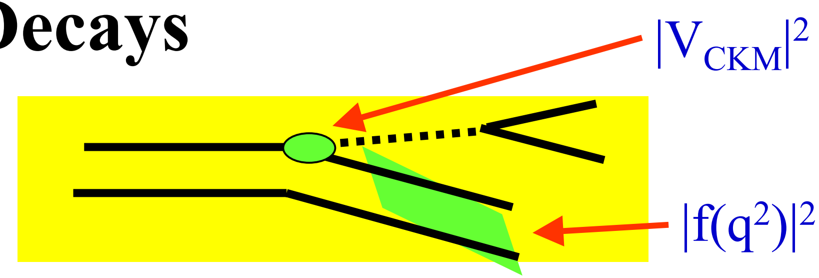
w/ 3 fb-1 & 3-gen CKM unitarity:

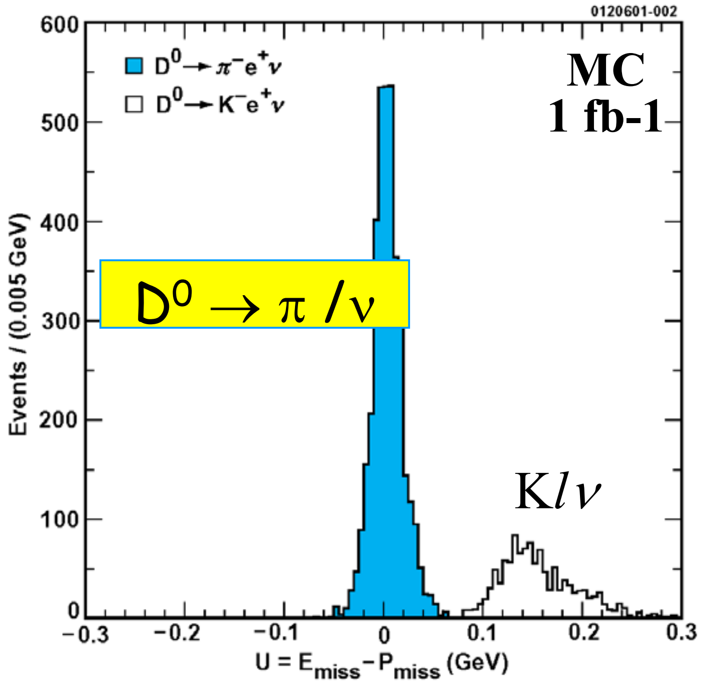
Decay Constant	Reaction	PDG δf/f	CLEO-c δf/f
f_{Ds}	$D_s^+ \rightarrow \mu\nu$	17%	1.9%
f_{Ds}	$D_s^+ \rightarrow \tau\nu$	33%	1.6%
f_D	$D^+ \rightarrow \mu\nu$	UL	2.3%

Semileptonic Decays

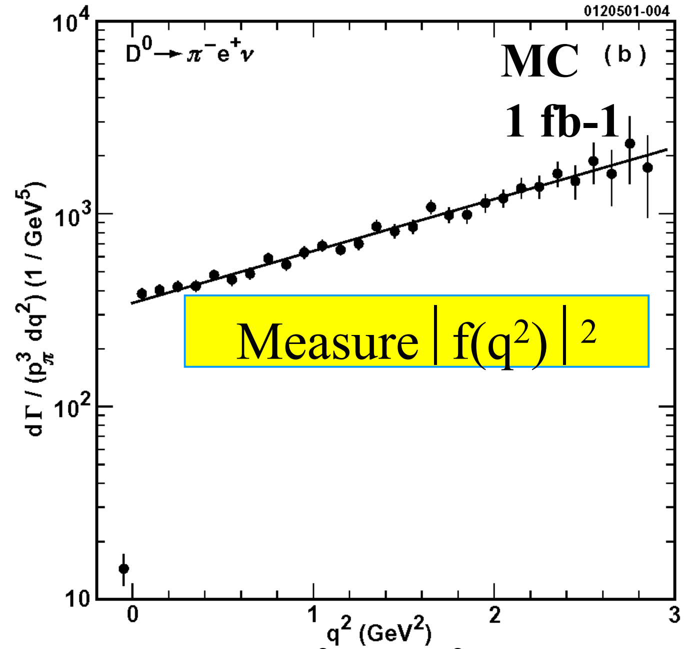
$$Br\,(D \to P\,l\,\nu)\,/\,\tau_D = \Gamma = \gamma\,|V\_cq|^2$$

$$d\Gamma\,(D \to P\,l\,\nu)\,/\,dq^2 \propto |V\_cq|^2\,|f(q^2)|^2$$





U=E_miss – P_miss



q^2 (GeV^2)

Mode	PDG2k (δB/B%)	CLEOc (δB/B%)
$D^0 \to K\,l\,\nu$	5	0.4
$D^0 \to \pi\,l\,\nu$	16	1.0
$D^+ \to \pi\,l\,\nu$	48	2.0
$Ds \to \phi\,l\,\nu$	25	3.1

$\therefore\ \delta V_{cd}/V_{cd}\ \&\ \delta V_{cs}/V_{cs} \sim 1.6\%$

$\delta V_{cd}/V_{cd} = 7\%$ (PDG2k)

$\delta V_{cs}/V_{cs} = 11\%$ (PDG2k)

Compare to B Factories

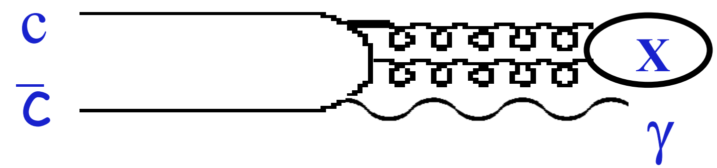
	CLEO-c 2 - 4 fb-1	BaBar 400 fb-1	Current Knowledge
f_D	2.3%	10 - 20%	NA
f_Ds	1.7%	6 - 9%	19%
Br (D+ -> Kππ)	0.7%	3 - 5%	7%
Br (Ds -> φπ)	1.9%	5- 10%	25%
Br (D0 -> Kπ)	0.6%	2 - 3%	2%

Statistics limited

Systematics and bkgnd limited

Probing QCD

- Gluons carry color charge ⇒ binding: Glueballs = $|gg>$ and Hybrids = $|q\bar{q}g>$

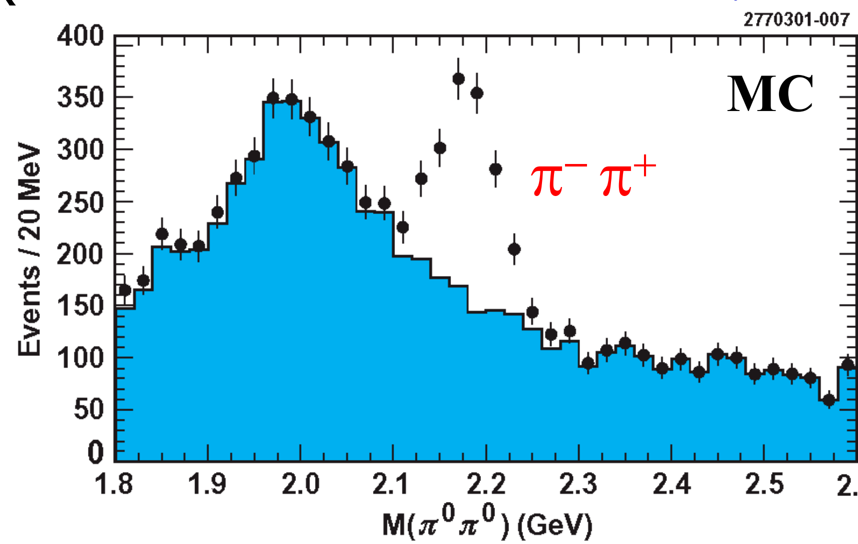


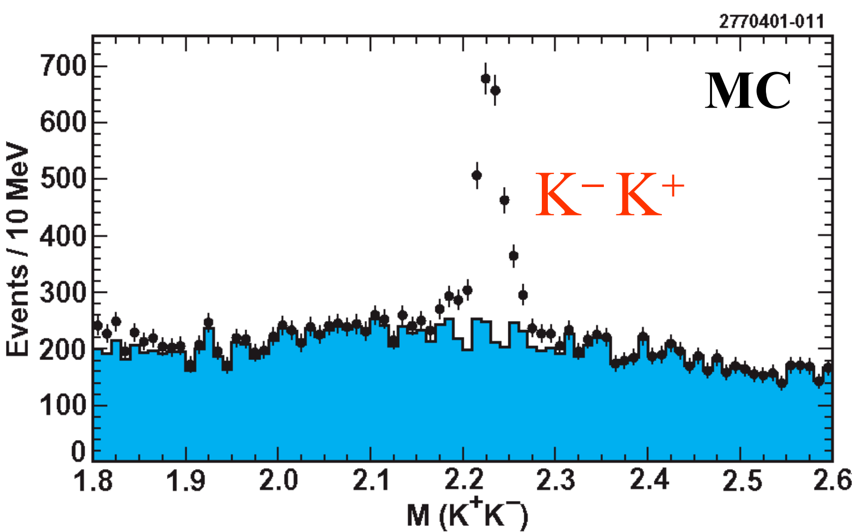
- Radiative Ψ decays: ideal glue factory
- CLEO-c: $\sim 10^9$ J/Ψ decays ⇒ ~ 60M J/Ψ → γX

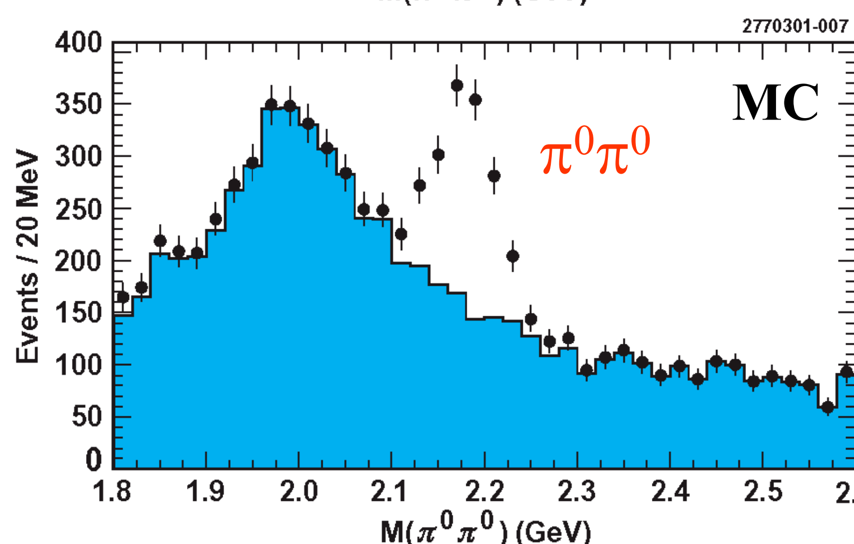
  Partial Wave Analysis

  Absolute Br's: ππ, KK, pp, ηη, ...
- E.g.: $f_J(2220)$

∴CLEO-c: find/debunk $f_J(2220)$

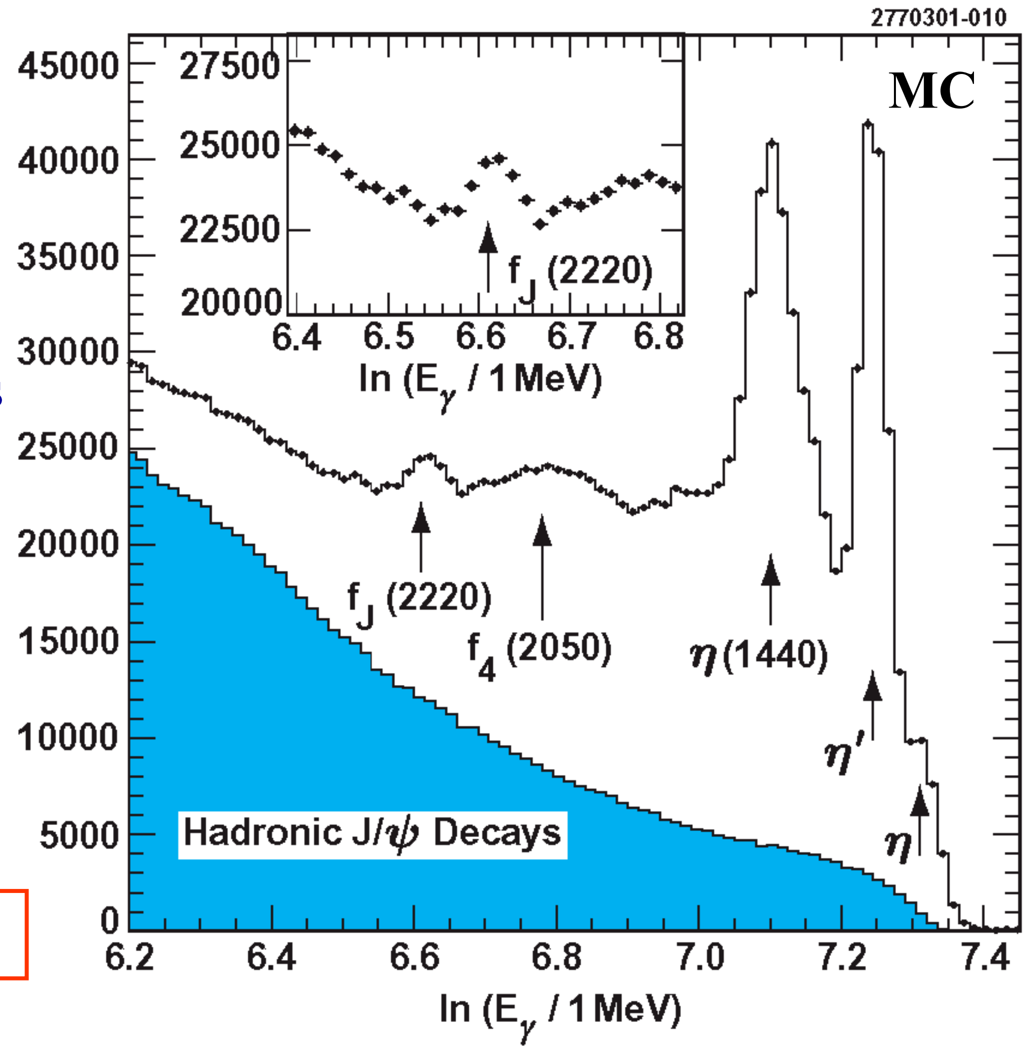






$J/\Psi \rightarrow \gamma X$ Inclusive γ - Spectrum

- Inclusive γ -spectrum
  Search for monochromatic γ
  E.g., 24% efficient for $f_J(2220)$
  $\sim 10^{-4}$ sensitivity for narrow resonances
- Modern 4π detector
  Suppress hadronic bkgnd: $J/\psi \rightarrow \pi^0 X$
- Huge data set
  Plus $\gamma\gamma$ and $\Upsilon(1S)$ data

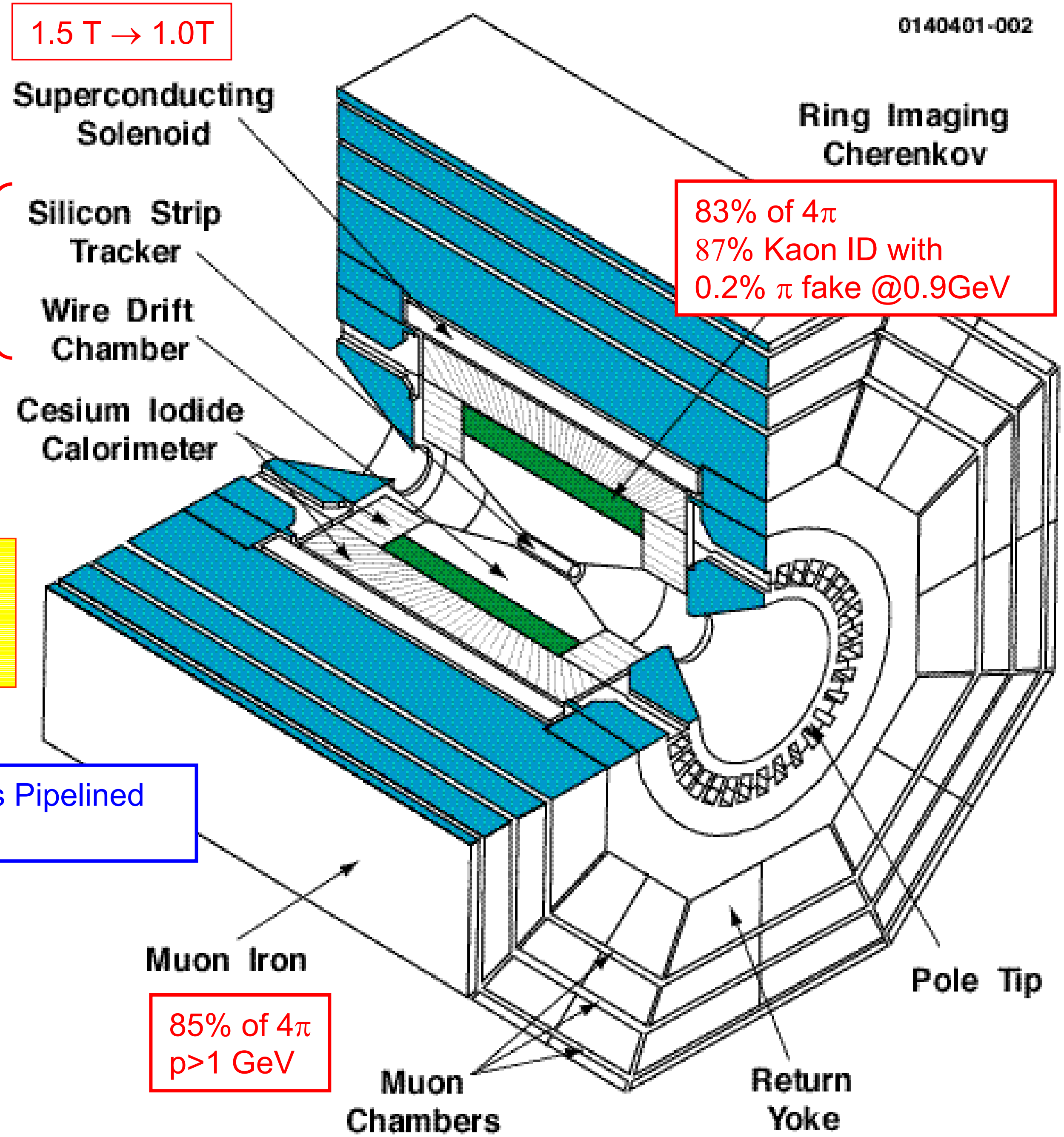


Determine J^{PC} and gluonic content

CLEO III Detector → CLEO-c Detector

93% of 4π
σ_p/p = 0.35% @1GeV
dE/dx: 5.7% π @minI

93% of 4π
σ_E/E = 2% @1GeV
= 4% @100MeV

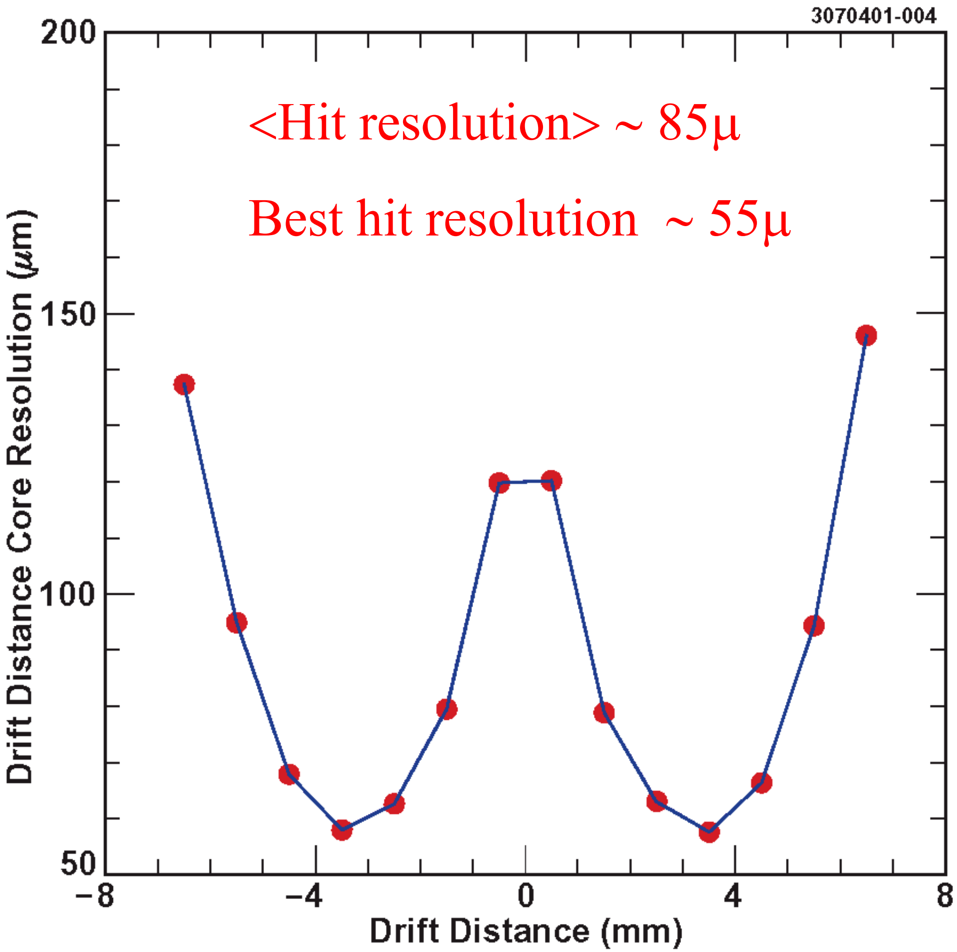


Trigger : Tracks & Showers Pipelined
Latency = 2.5 μs

Data Acquisition:
Event size = 25kB
Thruput ~ 6MB/s

Central Drift Chamber

12 < r < 82 cm



$D \to K\pi$ mass resolution ~ 6.3 MeV

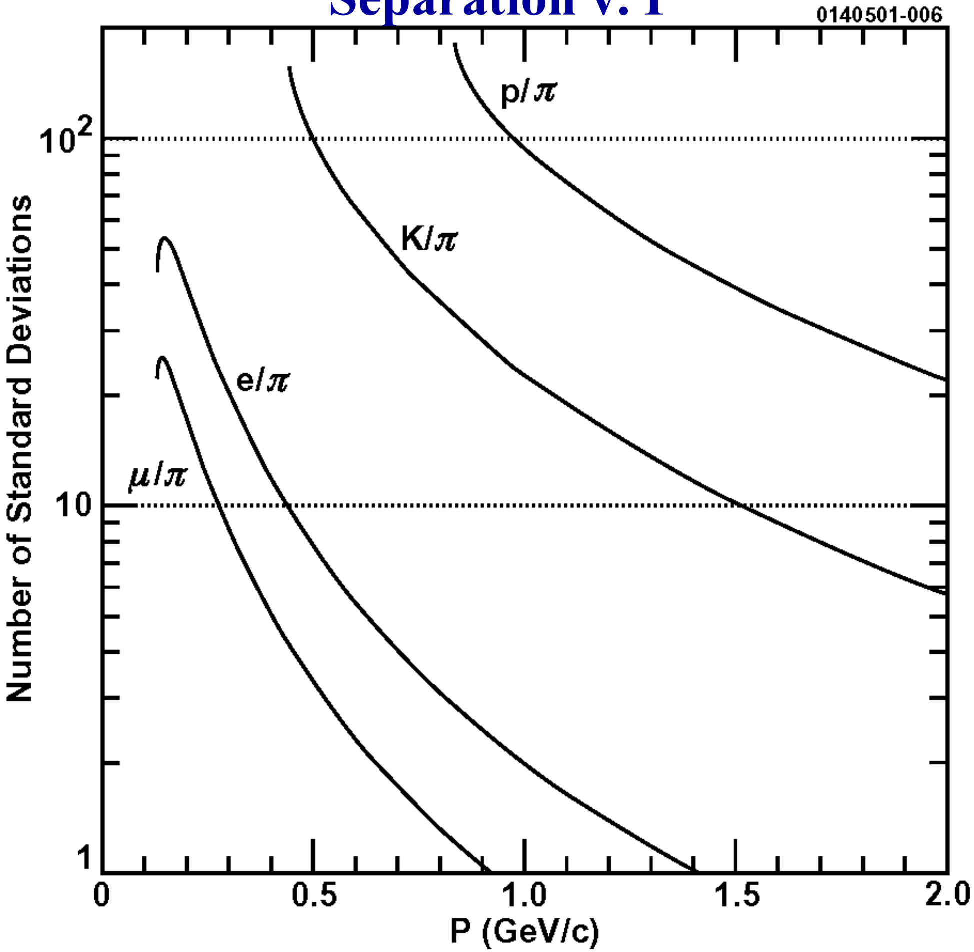
Ks mass resolution ~ 2.7 MeV

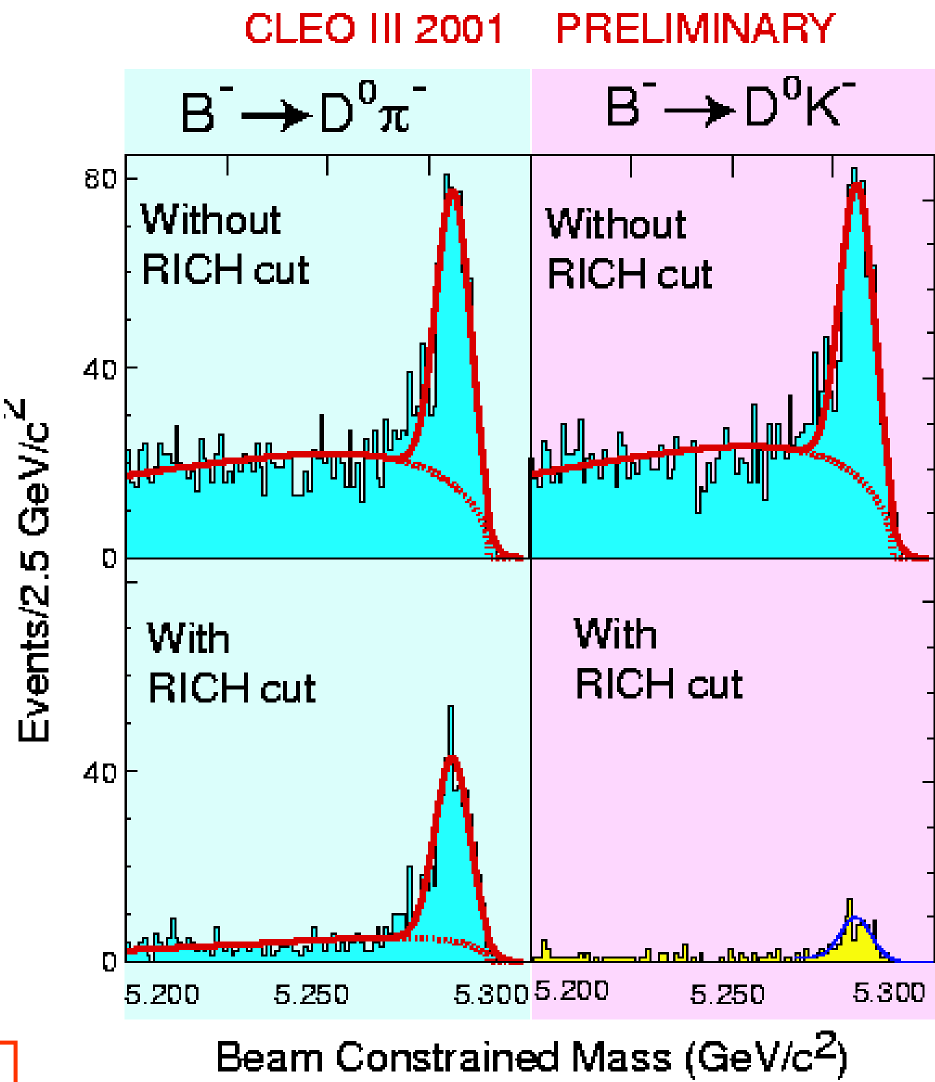
$\sigma_p/p = 0.35\%$ @ $p = 1$ GeV

dE/dx: 5.7% resolution for min-I hadrons

Particle ID w/ RICH

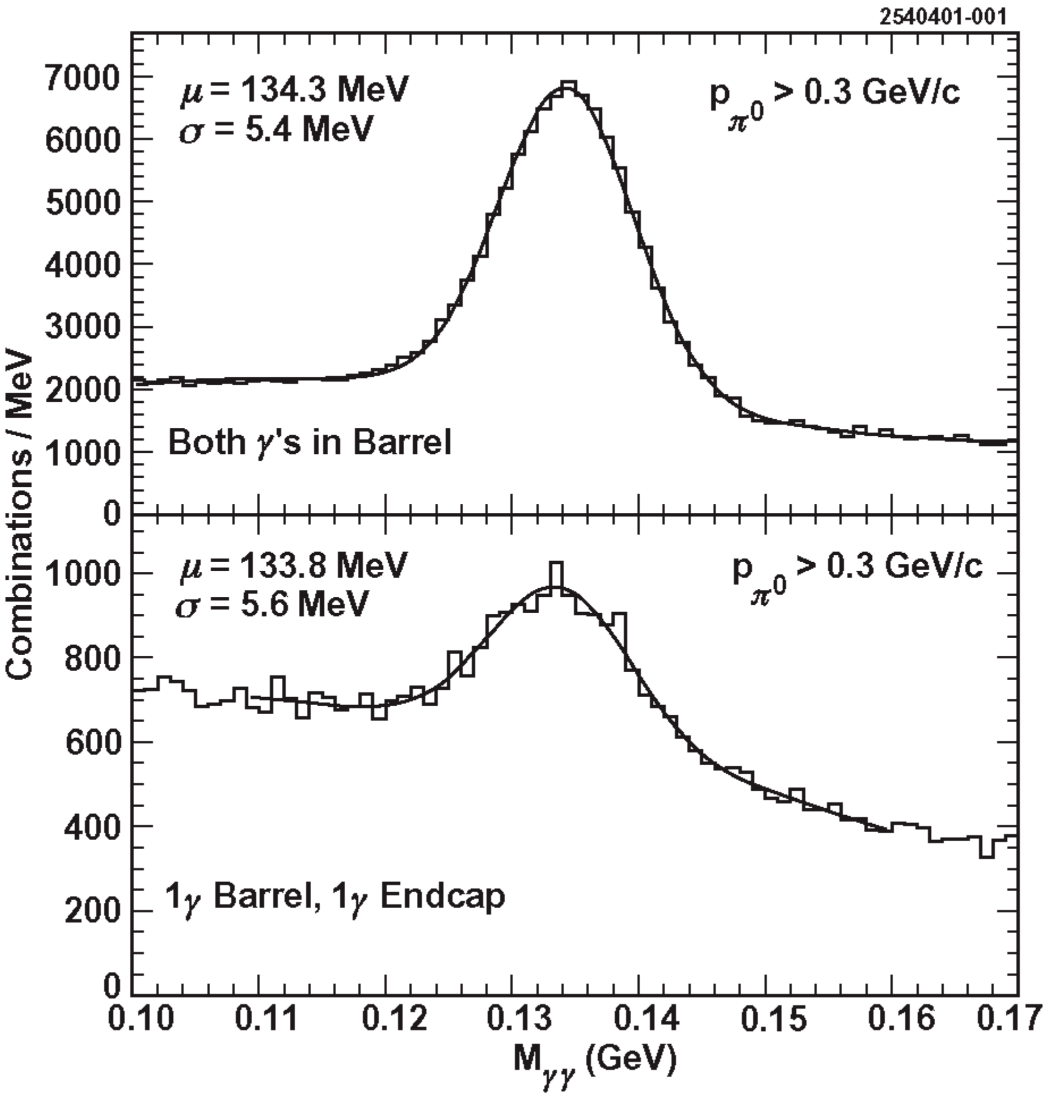
Separation v. P





- $\langle N_\gamma \rangle \sim$ 12/track
- Kπ separation from 470 MeV
- Kπ separation : 10 - 200 sigma

CsI Calorimeter



- 93% of 4π coverage
- uniform resolution in barrel + end-cap
- $\sigma_E/E = 2.2\%$ @ E= 1 GeV

  $= 4.0\%$ @ E = 400 MeV
- 5-7 MeV π^0 mass resolution

Comparison with Other Experiments

China:

BES II is running now.
BES II --> BES III upgrade } proposal stage
BEPC I --> BEPC II upgrade, ~10^{32} lumi. } proposal stage
Physics after 2005 if approval & construction go ahead.

Quantity	BES II	CLEO-C
J/psi yield	60M	> 1000M
dE/dx res.	9%	4.9%
K/pi separation up to	600 MeV	1500 MeV
momentum res. (500Mev)	1.3%	0.5%
Photon resolution (100 Mev)	70 MeV	4 MeV
Photon resolution (1000 Mev)	220 MeV	21 MeV
Minimum Photon Energy	80 MeV	30 MeV
Solid angle for Tracking	80%	94%
Solid angle for Photons	75%	95%

HALL-D at TJNAL:

γp to produce states with exotic Quantum Numbers
Focus on light states with J^{PC} = 0+-, 1+-, …
Complementary to CLEO-C focus on heavy states with J^{PC}=0++, 2++, …
Physics in 2007+ ?

Unique features of CLEO-c

- Huge data set
  - 20-500 times bigger than previous experiments
- Modern detector
  - large solid angle
  - excellent tracking resolution
  - excellent photon resolution
  - excellent particle identification
- Extra data sets for corroboration
  - Upsilons: $4fb^{-1}$
  - Two Photon: 25 fb^{-1}

Summary

- Powerful physics case for CLEO-c
  - Precision flavor physics
  - Nonperturbative QCD
  - Probe for New Physics
- Unique expt'l opportunity
- High performance detector
- Flexible, high-luminosity accelerator
- Experienced collaboration

  New members wanted!!!
- Optimal timing
  - Flavor physics of this decade
  - Beyond the SM in next decade
  - Synchronized w/ LQCD progress