# CLEO-c and CESR-c: A New Frontier of QCD And Electroweak Physics

- The CLEO-c collaboration
- QCD Physics goals
- Detector Capabilities
- Electroweak Physics goals
- Accelerator modifications
- CLEO-c Symposium

Jim Alexander

May 2003

# Introductions…

Ithaca - *town*

Cornell - *univ*

CESR - *accel*

$e^+e^- \rightarrow qq$

$E_{cm}$ 3-12 GeV

$L \sim 1\text{-}10 \times 10^{32}$

$\sim 0.1 - 1\ nb^{-1}/sec$

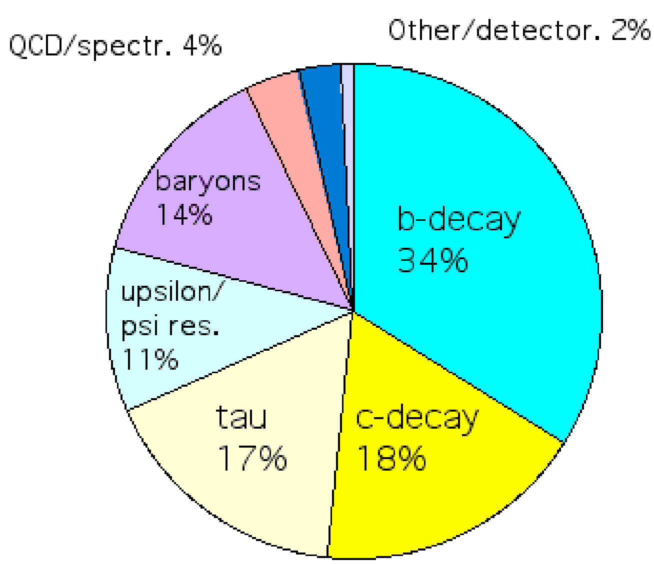
CLEO III - *detector*

- chgd ptcl trkg, photons, Particle ID
- DAQ, Trigger
- superb offline software infrastructure

# The CLEO Collaboration

- Current Membership:
  - ~17 Institutions
  - ~140 physicists
  - ~1/2 DOE, 1/2 NSF
- Publication history 1980-
  - ~350 papers
  - diverse physics - see below
- Soon to be CLEO-c
  - Approved by NSF in March
  - CLEO-c Symposium June 19th
  - more details later

Caltech
CMU
Cornell
Florida
Illinois
Kansas
Minnesota
NWU
Oklahoma
Purdue
Rochester
RPI
SMU
UCSB
Syracuse
Vanderbilt
Wayne State



# Recent history of CLEO

1980 -- 2000 CLEO was major source of B physics. (+ ARGUS, CUSB, KEDR, LEP, CDF, D0, …)

- Vcb, Vub
- Penguins: b->s □
- Rare B decays (K□, □□, □'K, □'Xs….)
- 1990- 2001 accumulated 24 fb-1 data at Upsilon(4S) and just below.

1999 Babar and Belle burst forth

- 10 fb-1 in the first year.
- Now ~ 100 $fb^{-1}$ each

July 2000 -- turning point for CLEO

- CLEO III upgrade complete
- CESR upgrade complete

… but the future looked very uncertain

# Rewriting the future…

Task force charged to consider future options, optimize return on existing resources:

- New detector
- Flexible accelerator
- Seasoned collaboration

Conclusion: return to *charm* region:

- Rich in physics - incomplete "leftovers"
- Direct connection to heavy flavor physics
- New opportunities - QCD, meson spec.
- New theoretical reach - LQCD
- modern detector and high luminosity

# The CLEO-c Program

CLNS 01/1742

**2002**

Prologue: Upsilons ~1-2 $fb^{-1}$ ea.

(1S) , (2S), (3S)...

Spectroscopy, transition rates, $□_{ee}$

10-20 times existing world's data

Here now

**2003**

Act I: □(3770) -- 3 $fb^{-1}$

30M events, 6M *tagged* D decays

(310 times MARK III)

**2004**

Act II: √s ~ 4100 -- 3 $fb^{-1}$

1.5M $D_sD_s$, 0.3M *tagged* $D_s$ decays

(480 times MARK III,

130 times BES II )

**2005**

Act III: □(3100) -- 1 $fb^{-1}$

1 Billion J/□ decays

(170 times MARK III

20 times BES II)

# CLEO's 2002 datasets

## Narrow Upsilon Resonances…

(3S) - 1.7 $fb^{-1}$ total.   4.7M resonance evts

(2S) - 1.9 $fb^{-1}$ total.   8.5 M resonance evts

(1S) - 1.5 $fb^{-1}$ total.   28M resonance evts

datasets include

on resonance (~90%)

below resonance (~5%)

scan across resonance (~5%)

## Other…

(5S) - 0.5 $fb^{-1}$ total.

$\sqrt{s}$ = 11.2 GeV -- 0.7 $fb^{-1}$ scan

$\sqrt{s}$ = 8.4 GeV -- 4.5 $pb^{-1}$ -- R meas

$\sqrt{s}$ = 7.4 GeV -- 8.9 $pb^{-1}$ -- R meas

$\sqrt{s}$ = 7.0 GeV -- 2.8 $pb^{-1}$ -- R meas

## Brief engineering runs in charm region:

□' ~ 5$pb^{-1}$   11.6M events

□" ~ 7$pb^{-1}$   12.7M events

# Current Work

- Bottomonium spectroscopy
  - $1^3D_J$ state - 40 evts - ICHEP 2002
  - $n^1S_0$ ($\eta_b$, $\eta_b'$) - no signal - APS
  - $1^1P_1$ ($h_b$) - ongoing
- Upsilon resonance widths
  - $\Gamma_{ee}$ measurements ongoing [illegible] 2-3%
- Hadronic transitions
  - $\Upsilon(3S) \rightarrow \Upsilon(1S)\,\pi\pi$ mass distrib
- Radiative decays of $\Upsilon(1S)$
  - exclusive, inclusive…
- probably others…

# Three Targets

• Progress in flavor physics is limited by understanding of QCD.

CLEO-c: precise measurements of form factors, decay constants.

• The difficult parts of QCD are its nonperturbative sectors.

CLEO-c: precise measurements of quarkonia spectroscopy and decay. Gluonic spectroscopy??!

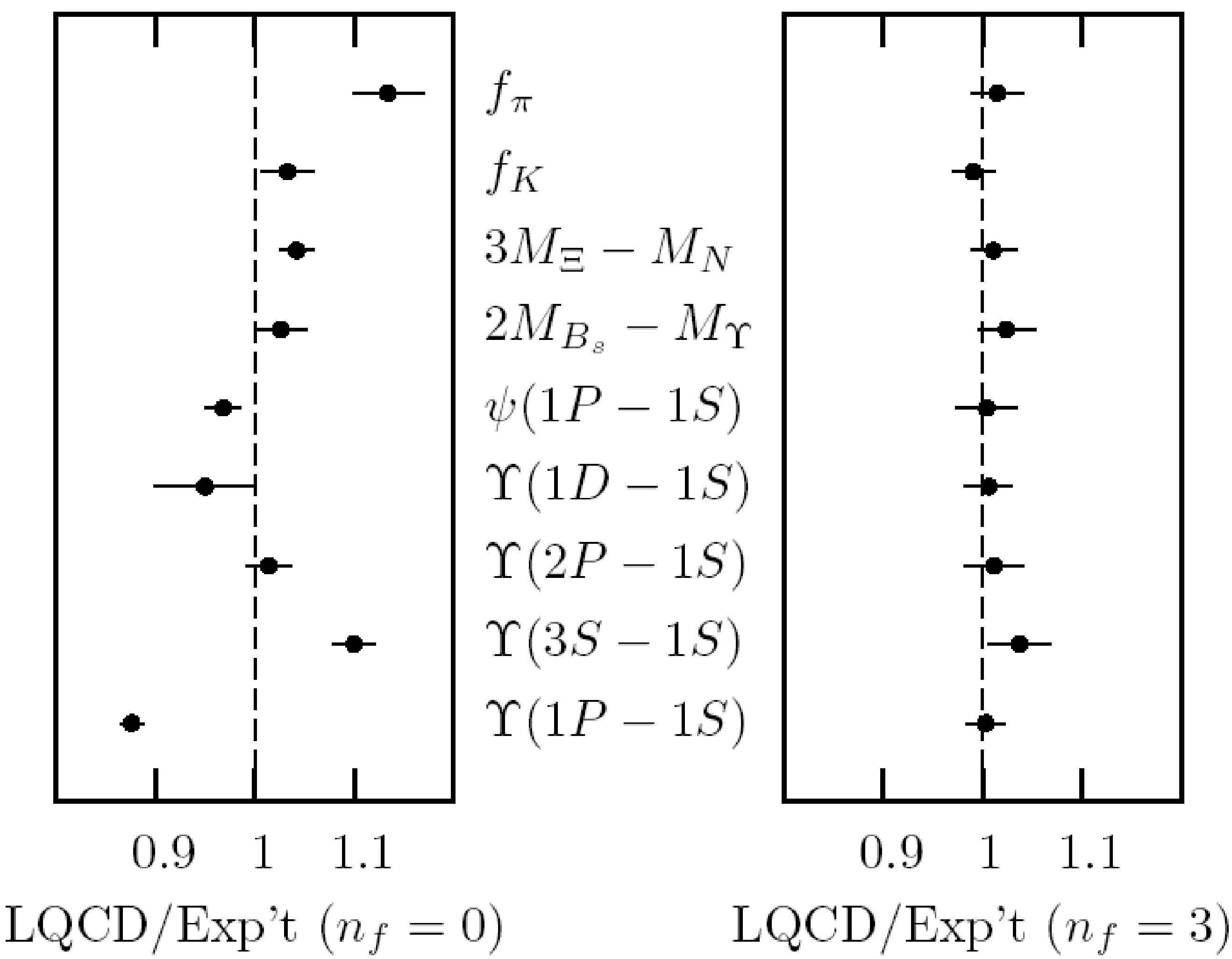
• Physics beyond the Standard Model may appear in unexpected places.

CLEO-c: D-mixing, charm CPV, rare decays of charm and tau.

# Lattice QCD

Emergence of LQCD as a precision tool is very motivating. Measurements made on one system translate into another.

See, e.g., Davies et al, hep-lat/0304004, "High-Precision Lattice QCD Confronts Experiment"

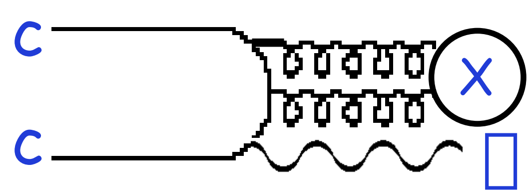


# Gluonic Matter

- Gluons carry color charge: *should bind!*
- But finding a "glueball" is a famously difficult experimental task....
- Why should we tread where angels fear to?

> ✓ huge data set
> ✓ modern detector
> ✓ 95% solid angle coverage
> ✓ clean starting point:

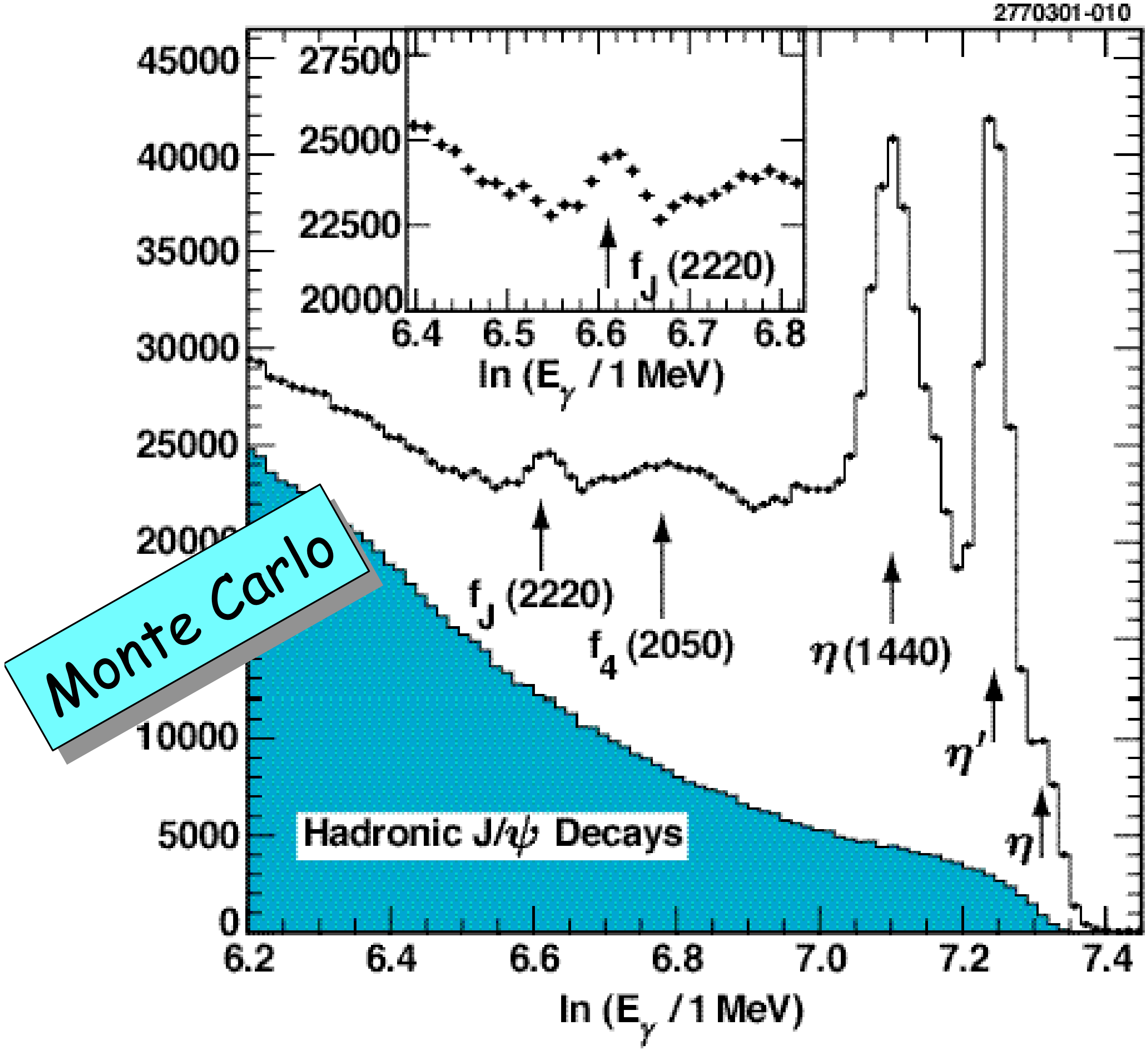
- Radiative $\psi$ decays as a glue factory:




> - well-defined initial state
> - clean photon tag
> - glue pair in color isosinglet

- CLEO-c: ~ $10^9$ $J/\psi$ $\rightarrow$ ~60M $J/\psi \rightarrow \gamma X$
  - Partial Wave analysis
  - Absolute BF's: $\pi\pi$,KK,pp,$\eta\eta$,...

# Inclusive Spectrum $J/\psi \to \gamma X$



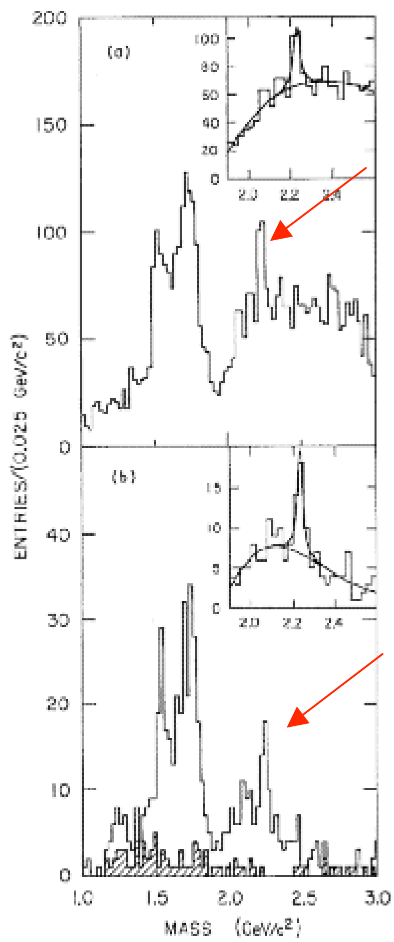

$10^{-4}$ sensitivity for narrow resonance

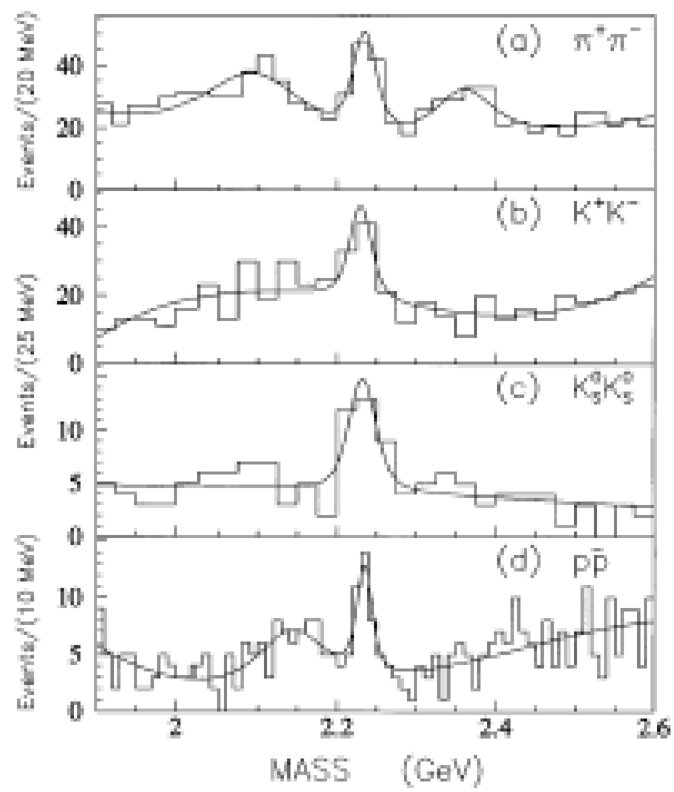
Eg: ~25% efficient for $f_J(2220)$

Suppress hadronic bkg: $J/\psi \to \pi^0 X$

# Some history of the $f_J(2220)$

## Original reports from MARK-III, BES

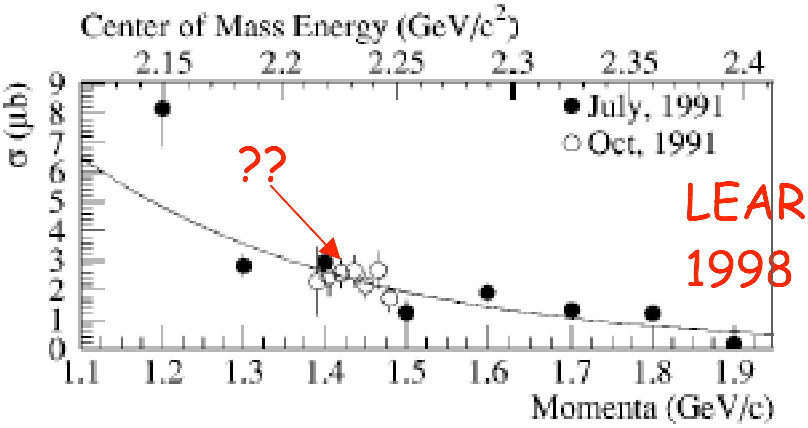



MARKIII
(1986)

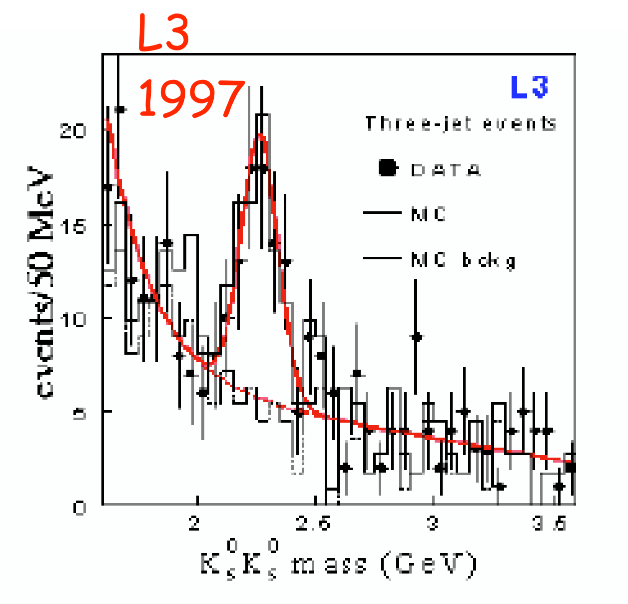
BES
(1996)

# Not supported by other searches…



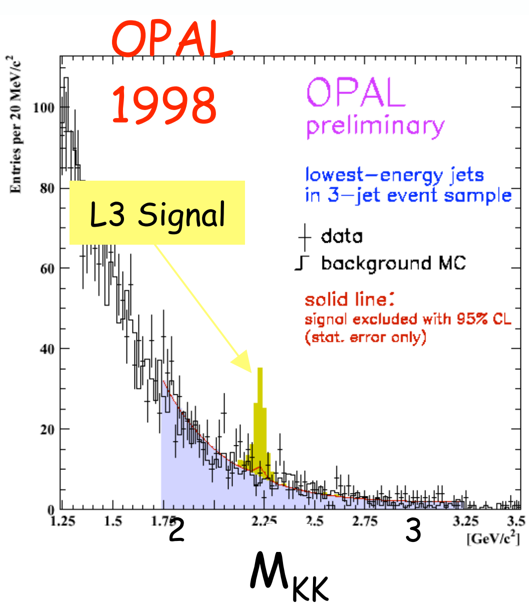

Crystal barrel:

pp




L3 at LEP:

3jet events

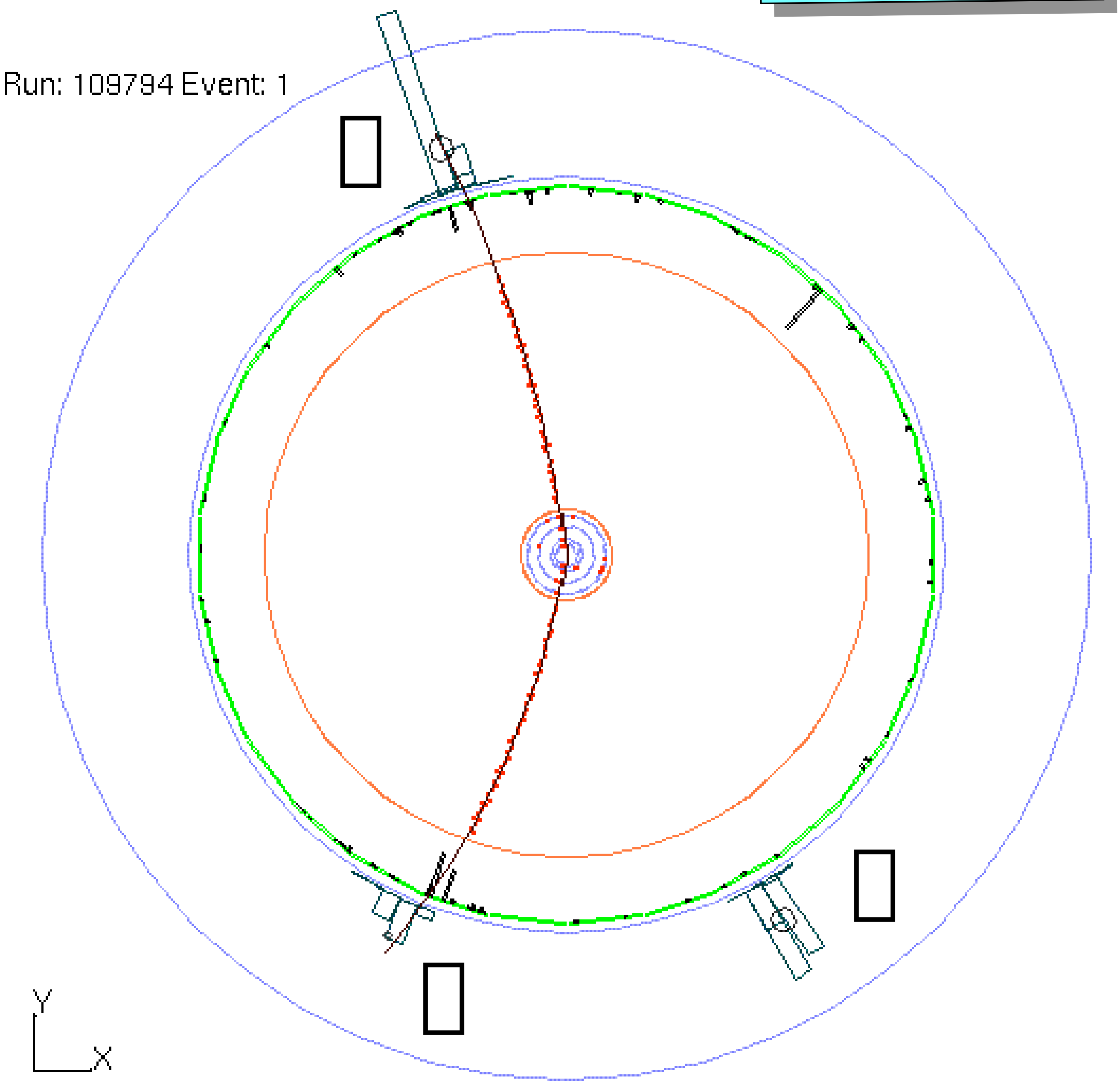



OPAL at LEP:

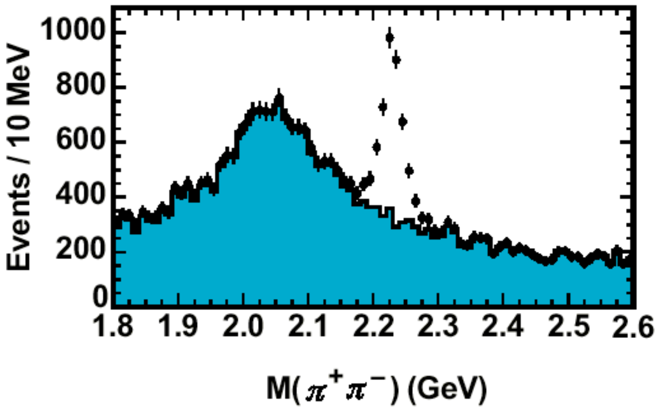
3jet events

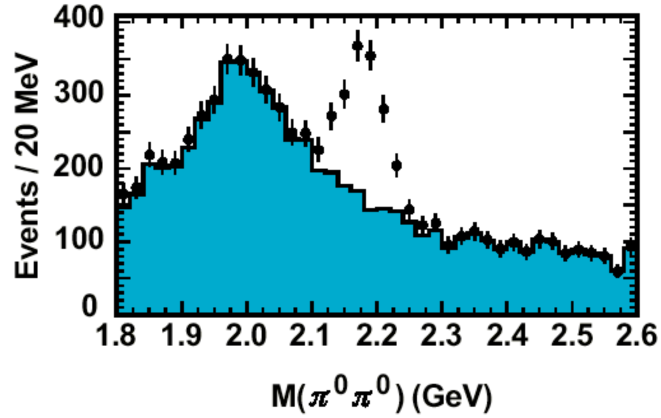
# □(3100) □ □$f_J$(2230)

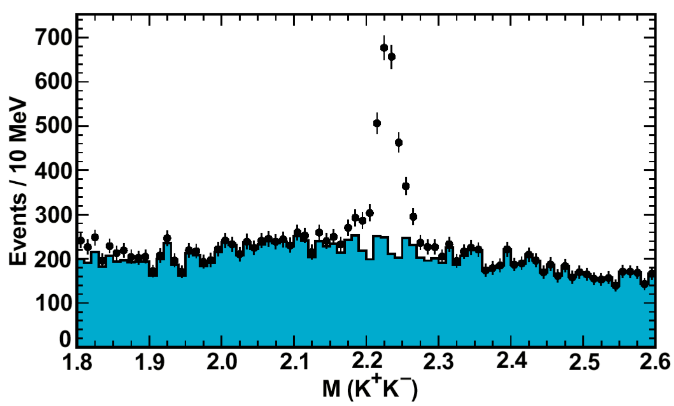
Monte Carlo



# $f_J(2220)$ in CLEO-c?




| | BES | CLEO-C |
|---|---|---|
| □+□□ | 74 | 32000 |
| □0□0 | 18 | 13000 |
| $K^+K^-$ | 46 | 18600 |
| $K_SK_S$ | 23 | 5300 |
| pp | 32 | 8500 |
| □□ | - | 5000 |

## CLEO-c has *corroborating checks:*

update!

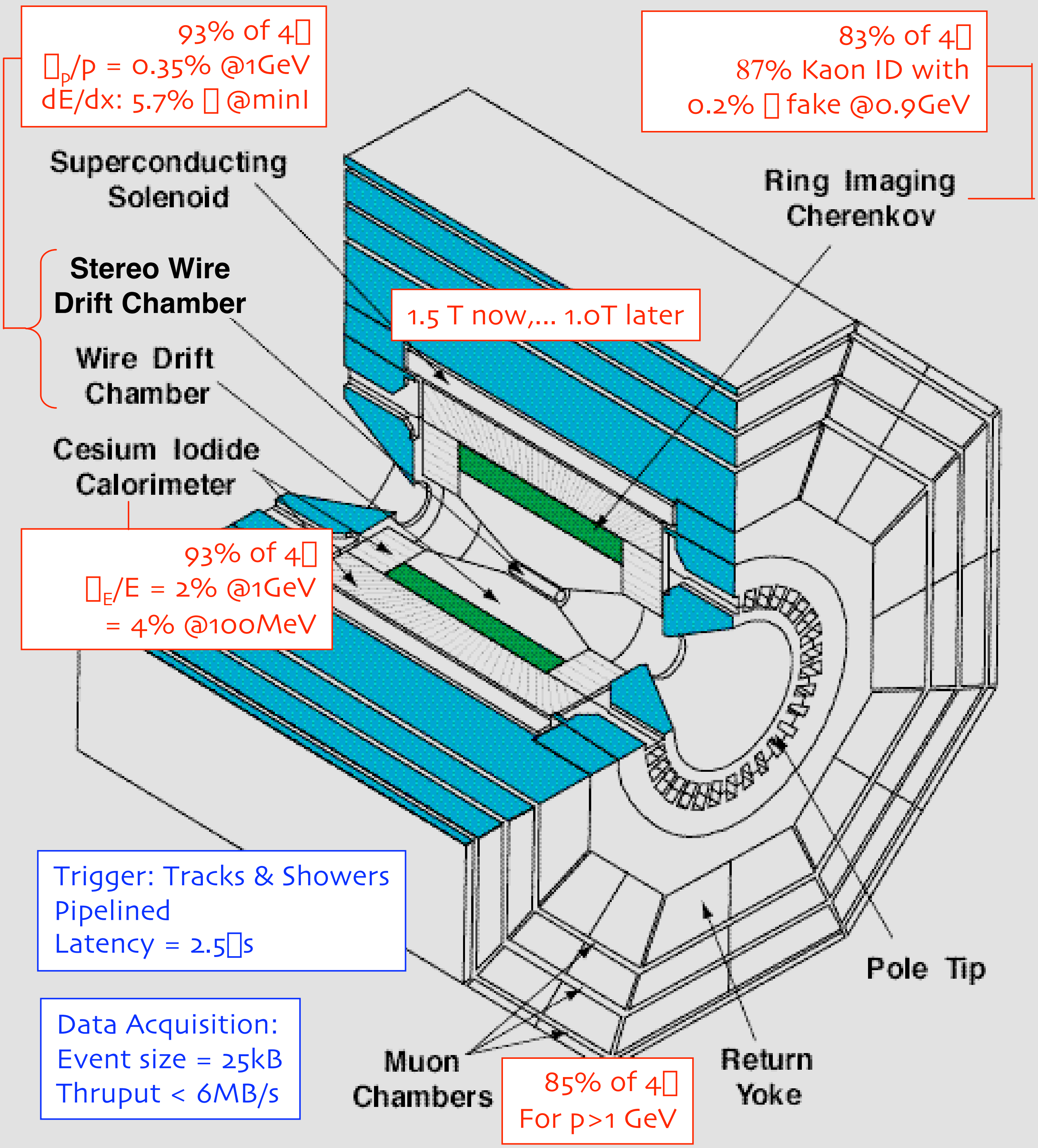
PRD 66 077101

**Two Photon Data: □□□ $f_J(2220)$:**

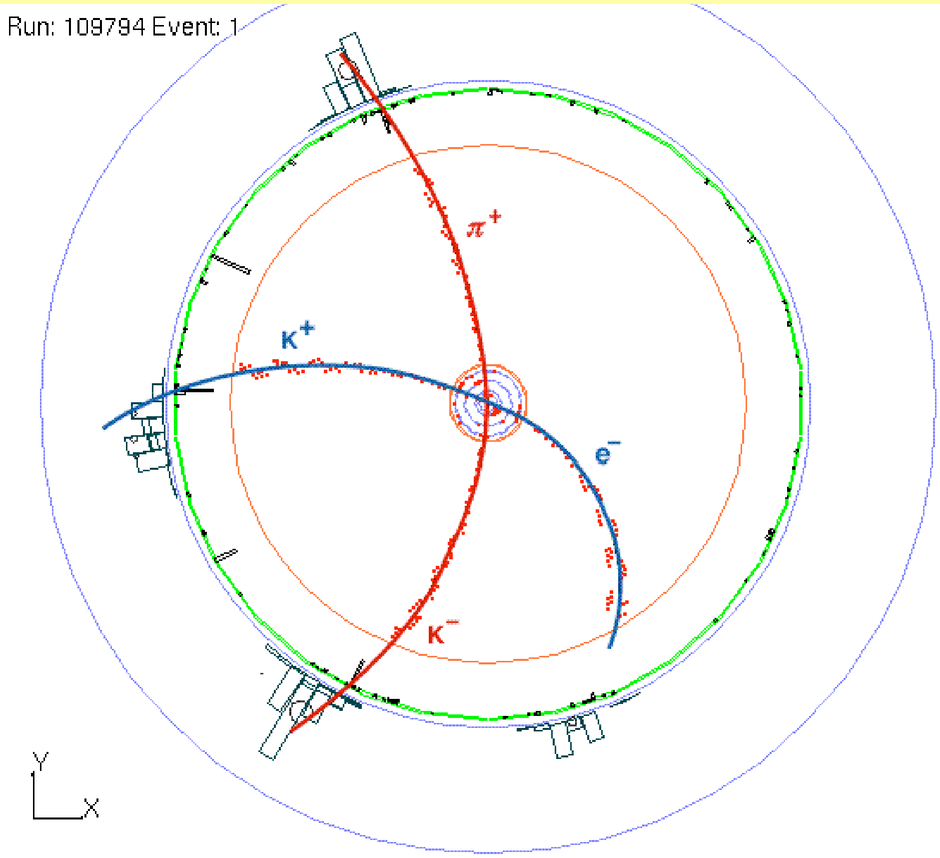
- CLEO II: □□□X B( $f_J$ □ $K_SK_S$) < 1.1) eV
- CLEO III: sub-eV sensitivity

**Upsilonium Data: (1S):** Tens of events

# The CLEO III Detector (click to go on the tour)



# Other attractions of charm threshold - *Charmed Mesons*




$D^0 \to K^- \pi^+$ $\overline{D^0} \to K^+ e^- \nu$

- Large □, low multiplicity
- Pure initial state: no fragmentation
- Double tag measurements: no background
- Clean neutrino reconstruction
- Coherent initial state

# Charm decays & QCD

Davies et al, hep-lat/0304004:

Charm decays are "gold-plated" modes for LQCD

$$\begin{pmatrix} \boldsymbol{V_{ud}} & \boldsymbol{V_{us}} & \boldsymbol{V_{ub}} \\ \pi \to l\nu & K \to \pi l\nu & B \to \pi l\nu \\ \boldsymbol{V_{cd}} & \boldsymbol{V_{cs}} & \boldsymbol{V_{cb}} \\ D \to l\nu & D_s \to l\nu & B \to Dl\nu \\ D \to \pi l\nu & D \to Kl\nu & \\ \boldsymbol{V_{td}} & \boldsymbol{V_{ts}} & \boldsymbol{V_{tb}} \\ \langle B_d|\overline{B}_d\rangle & \langle B_s|\overline{B}_s\rangle & \end{pmatrix}$$

FIG. 3: Gold-plated LQCD processes that bear on CKM matrix elements. $\epsilon_K$ is another gold-plated quantity.

# Tagging Technology

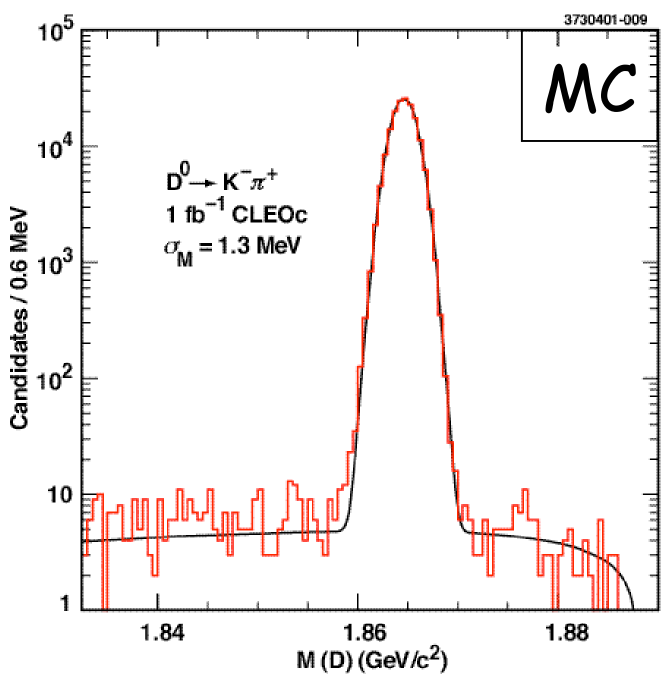
- Pure $D\bar{D}$ or $D_s\bar{D}_s$ production
  - ✓ Many high branching ratios (~1-10%)
  - ✓ High reconstruction eff
  - ✓ Two chances

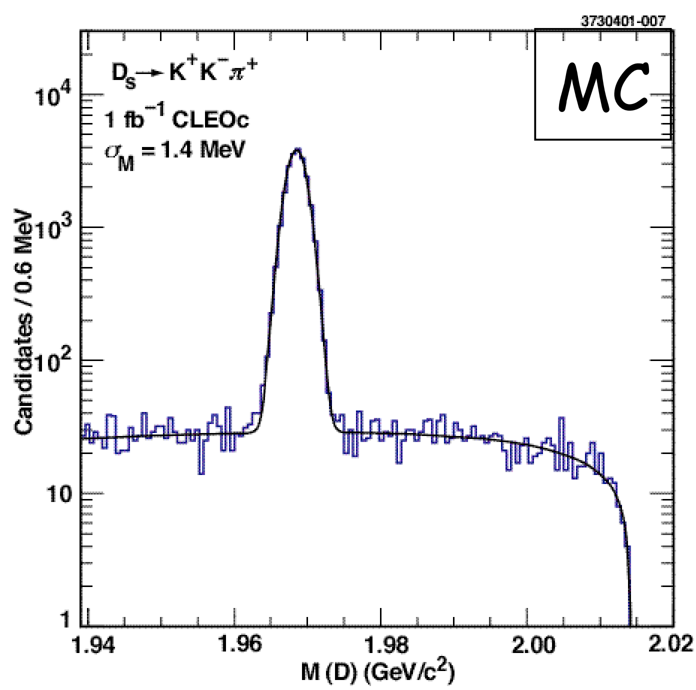
6M D tags
300K $D_s$ tags

$\Rightarrow$ high net efficiency ~20% !

$D \to K\pi$ tag.
S/B ~ 5000

$D_s \to KK\pi$ tag.
S/B ~ 100

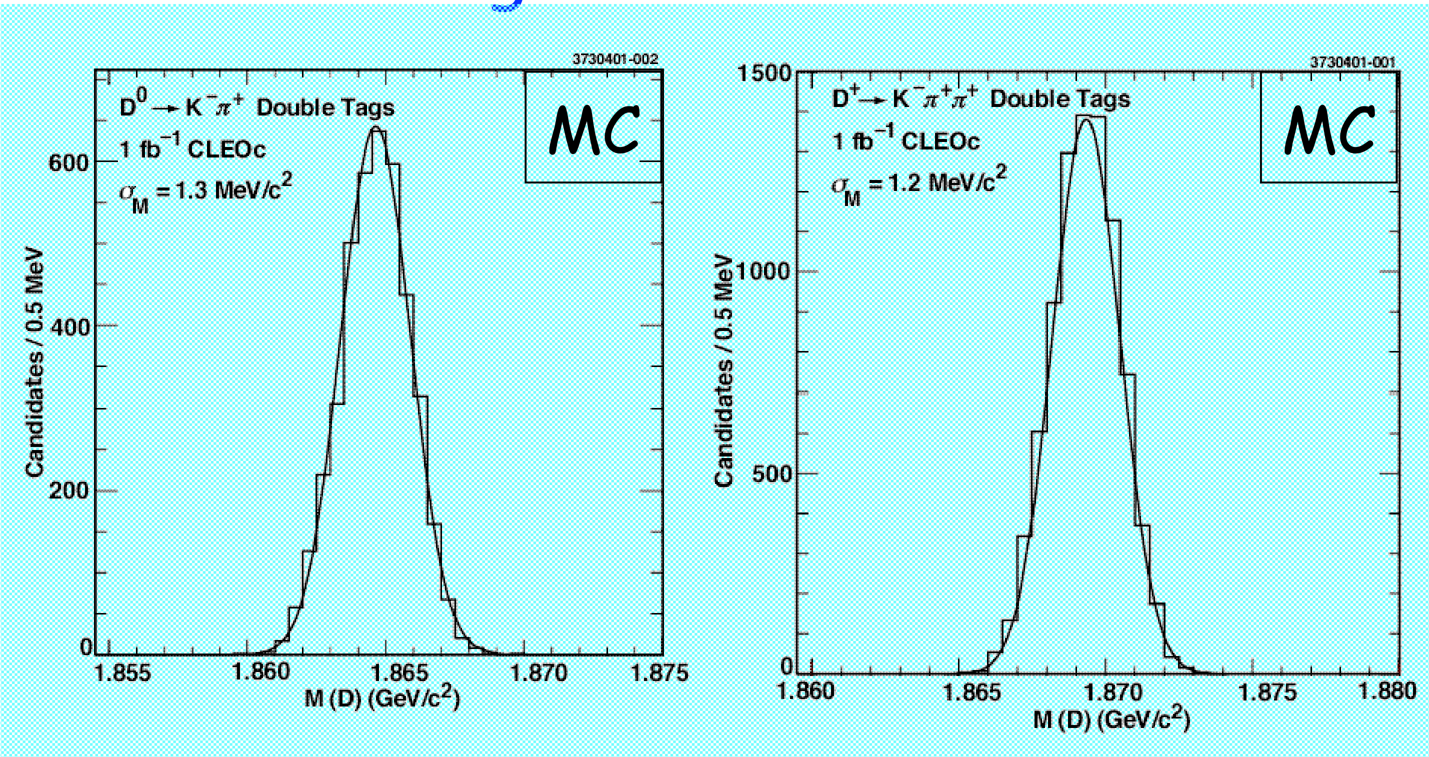



Beam constrained mass

# Tagged BR Measurements

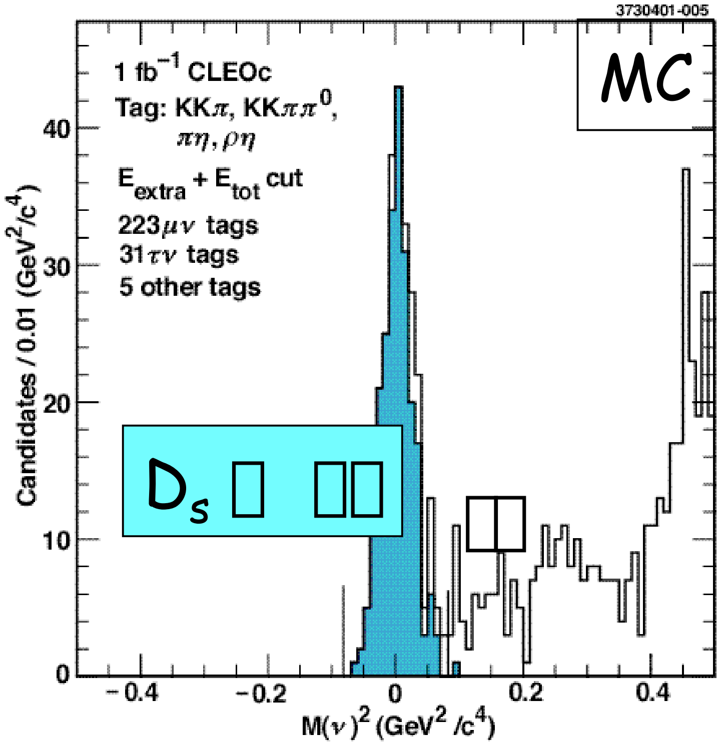
## ~ Zero background in hadronic modes

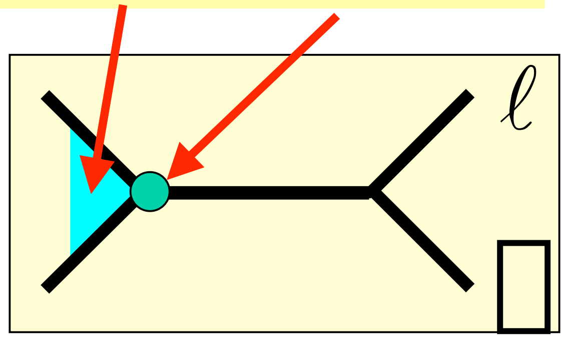



*Set absolute scale for all heavy quark meas.*

| Decay Mode | PDG2000 (□B/B %) | CLEOc (□B/B %) |
|---|---|---|
| $D^0$ □ K□ | 2.4 | 0.5 |
| $D^+$ □ K□□ | 7.2 | 1.5 |
| $D_s$ □ □□ | 25 | 1.9 |

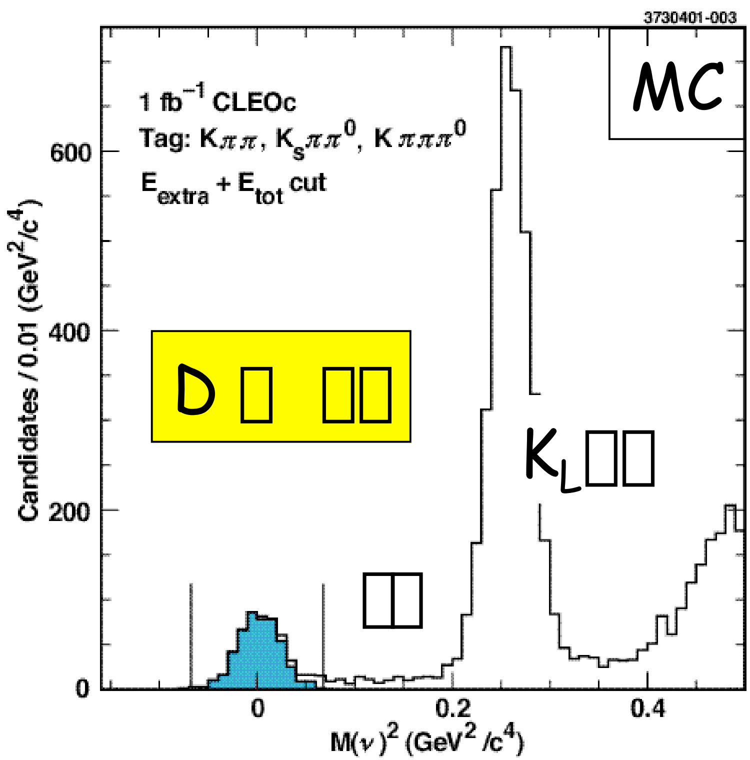
# Leptonic Decays: $|f_D|^2 \; |V_{CKM}|^2$




$$\frac{\delta f_{D_s}}{f_{D_s}} \approx 2.1\%$$

(Now: ±35%)

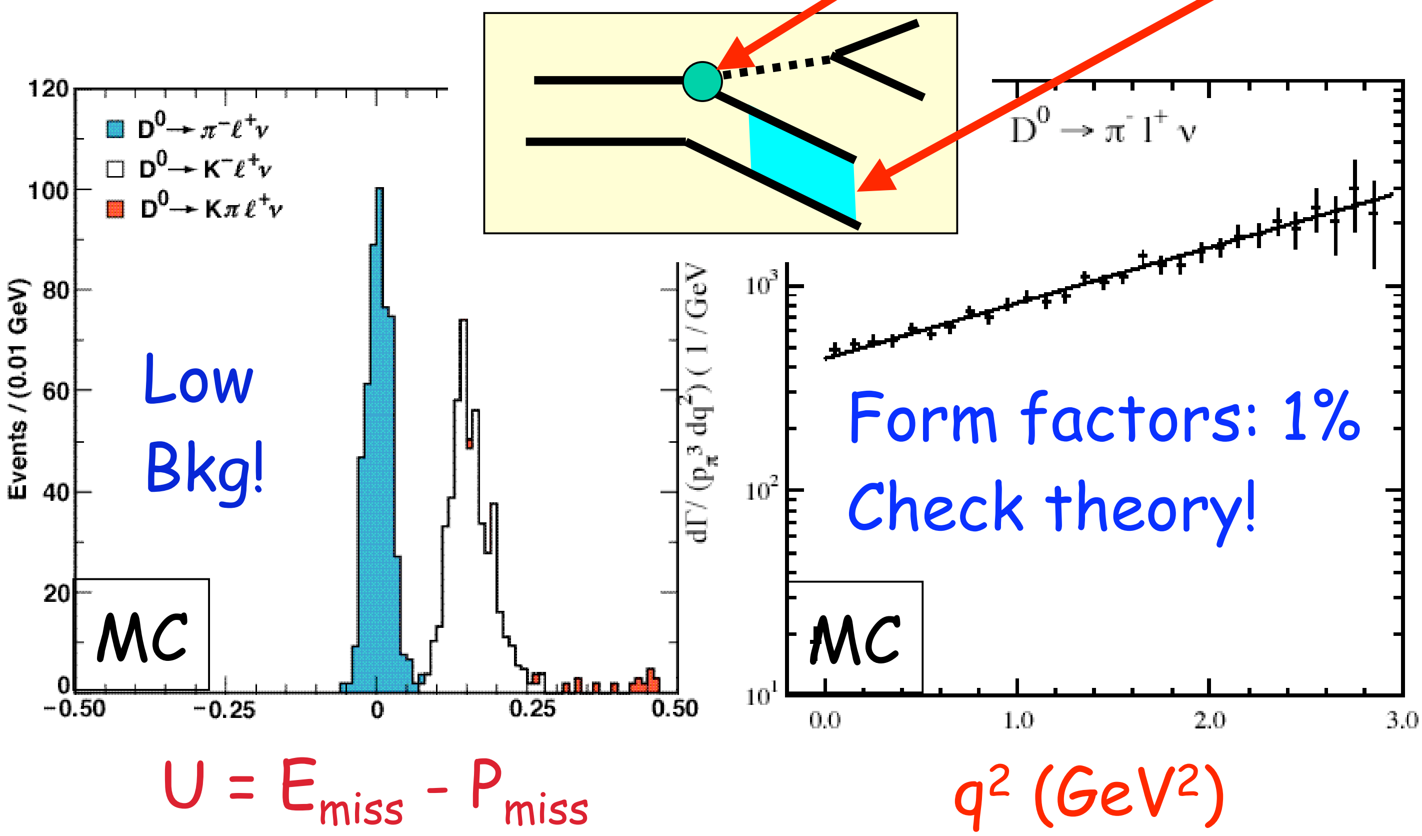



$$\frac{\delta f_D}{f_D} \approx 2.6\%$$

(Now: ±100%)

- □□ mode to be studied soon

# Semileptonic Decays $|V_{CKM}|^2 \; |f(q^2)|^2$




| Decay Mode | PDG2000 (□B/B %) | CLEOc (□B/B %) |
|---|---|---|
| $D^0$ □ Kl□ | 5 | 1.6 |
| $D^0$ □ □l□ | 16 | 1.7 |
| $D^+$ □ □l□ | 48 | 1.8 |
| $D_s$ □ □l□ | 25 | 2.8 |

*Plus vector modes...*

**$V_{cd}$, $V_{cs}$ to ~1.5%**

# What do we learn from these?

- Semileptonic decays: $|V_{CKM}|^2 \; |f(q^2)|^2$
  - Form factor *shapes* and *normalizations*
  - 'Calibrate' theory
  - Extract $|V_{cd}|$, $|V_{cs}|$
  - Theory □ Extract $|V_{ub}|$ from B

- Leptonic decays: $|V_{CKM}|^2 \; |f_D|^2$
  - Decay constants
  - 'Calibrate' theory
  - Extract $|V_{cd}|$, $|V_{cs}|$
  - Theory □ Extract $|V_{td}|$, $|V_{ts}|$ from B

- Hadronic decays:
  - Set scale of heavy quark decays
  - Enables precision tests in B decays
  - Strong phases: Extract □ from B □ DK

# Additional topics

- □'(3684)
  - hadronic decay patterns (□□ puzzle..)
  - radiative decays
  - charmonium spectroscopy

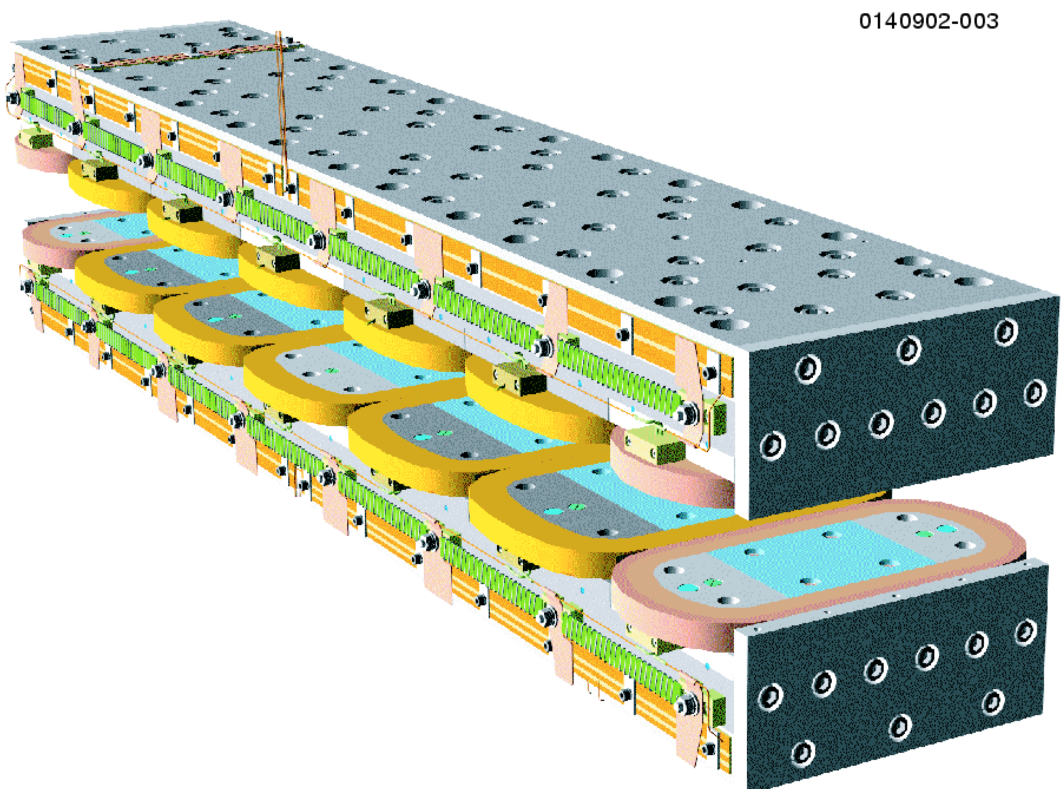
- $□^{+}□^{□}$ at threshold (0.25 $fb^{-1}$)
  - measure $m_{□}$ to ± 0.1 MeV
  - heavy lepton, exotics searches

- $□_{c}□_{c}$ at threshold (1 $fb^{-1}$)
  - calibrate absolute BR($□_{c}$□ pK□)

- R=□($e^{+}e^{-}$ □ hadrons)/□($e^{+}e^{-}$ □ $□^{+}□^{-}$)
  - spot checks

# The CESR-c Accelerator

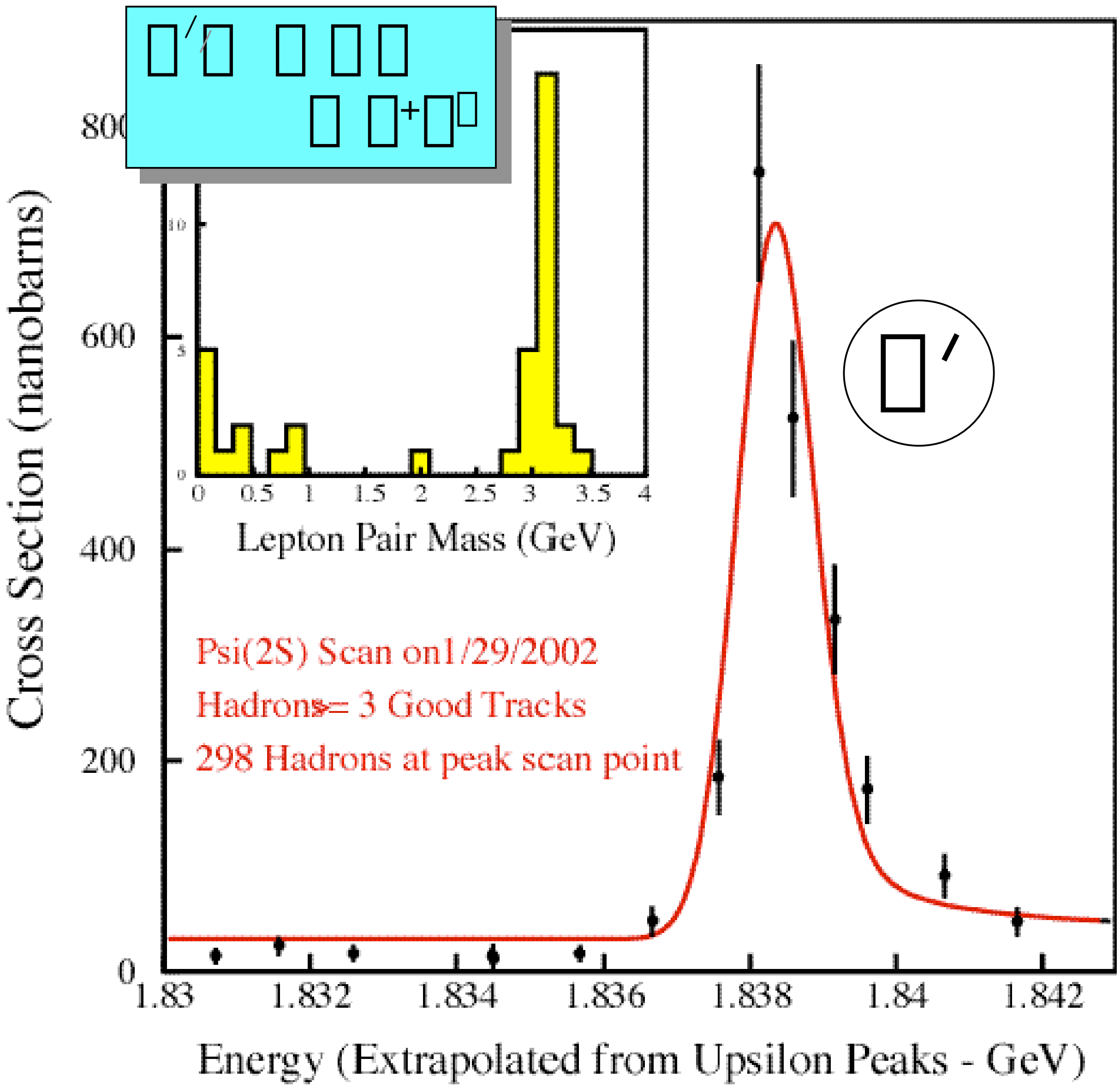
- Modify for low-energy operation:
  add wigglers for transverse cooling



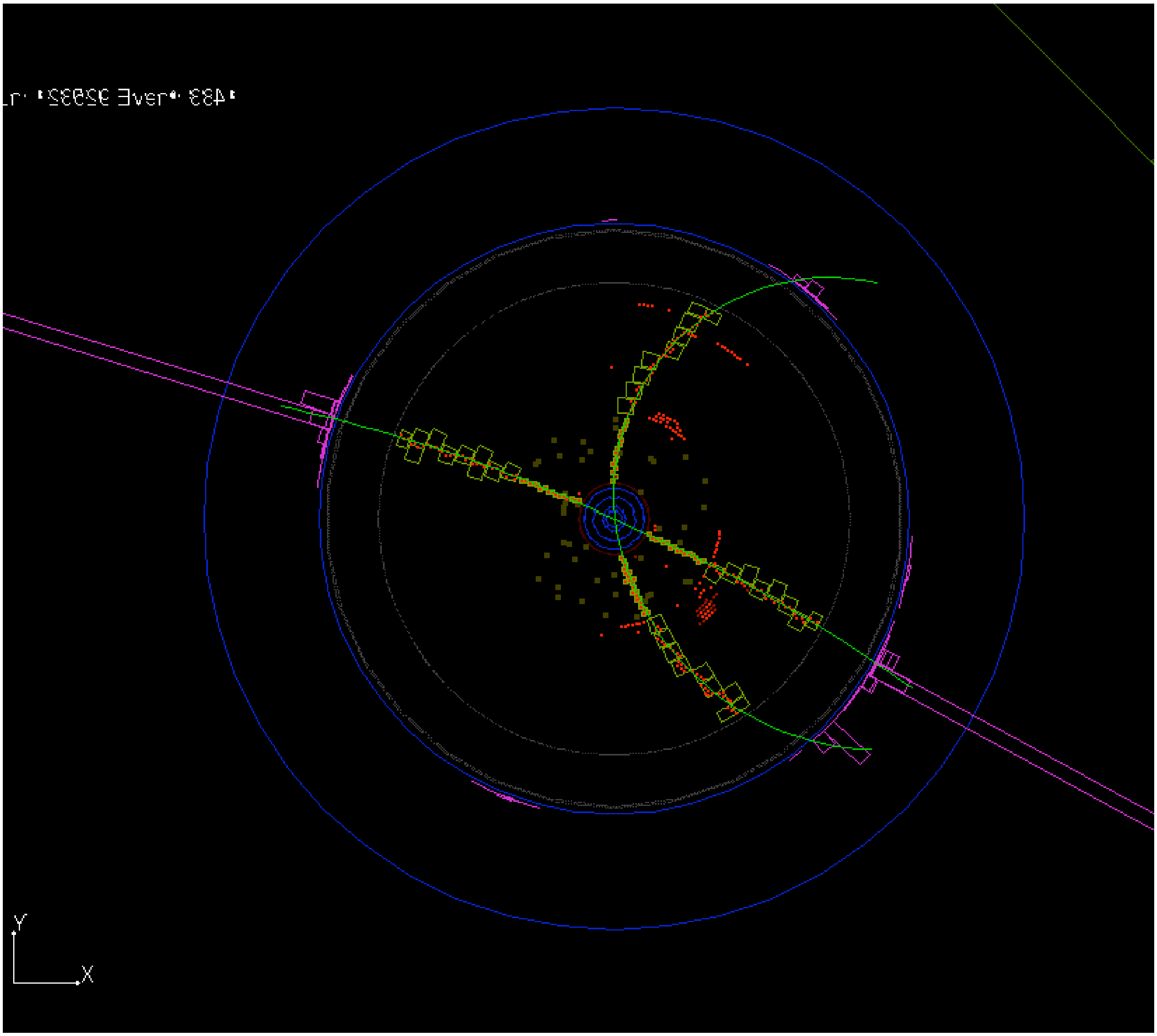

| s | $L$ ($10^{32}$ cm$^{-2}$ s$^{-1}$) |
|---|---|
| 4.1 GeV | 3.6 |
| 3.77 GeV | 3.0 |
| 3.1 GeV | 2.0 |

□$E_{beam}$ ~ 1.2 MeV at J/□

# Low Energy Ops explored with 1(+) wiggler, 1T field



# □′□ □□□

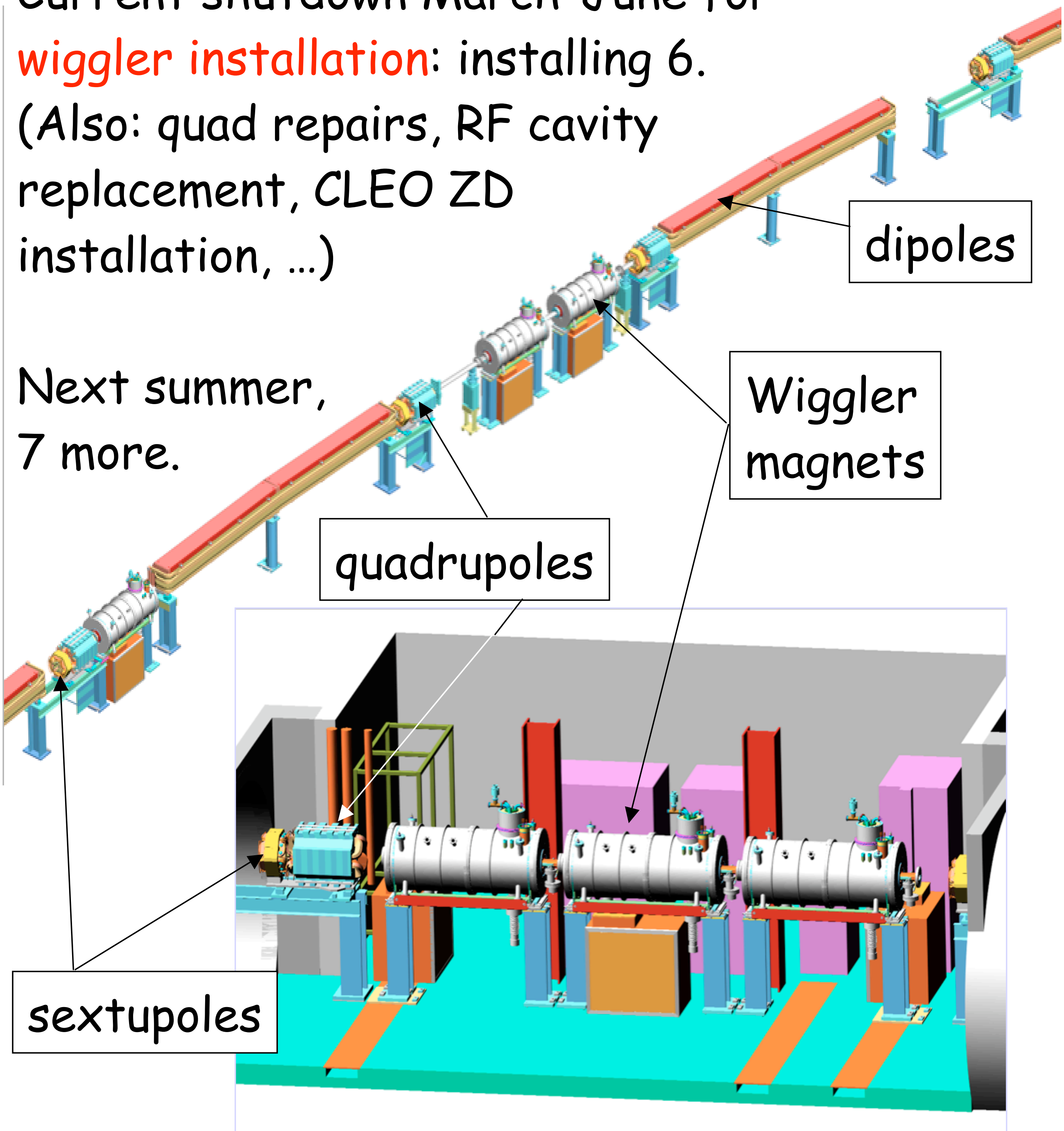



CLEO operated with 1T solenoidal field

# CESR-c full complement of Wigglers coming soon

Current shutdown March-June for wiggler installation: installing 6. (Also: quad repairs, RF cavity replacement, CLEO ZD installation, …)

Next summer, 7 more.



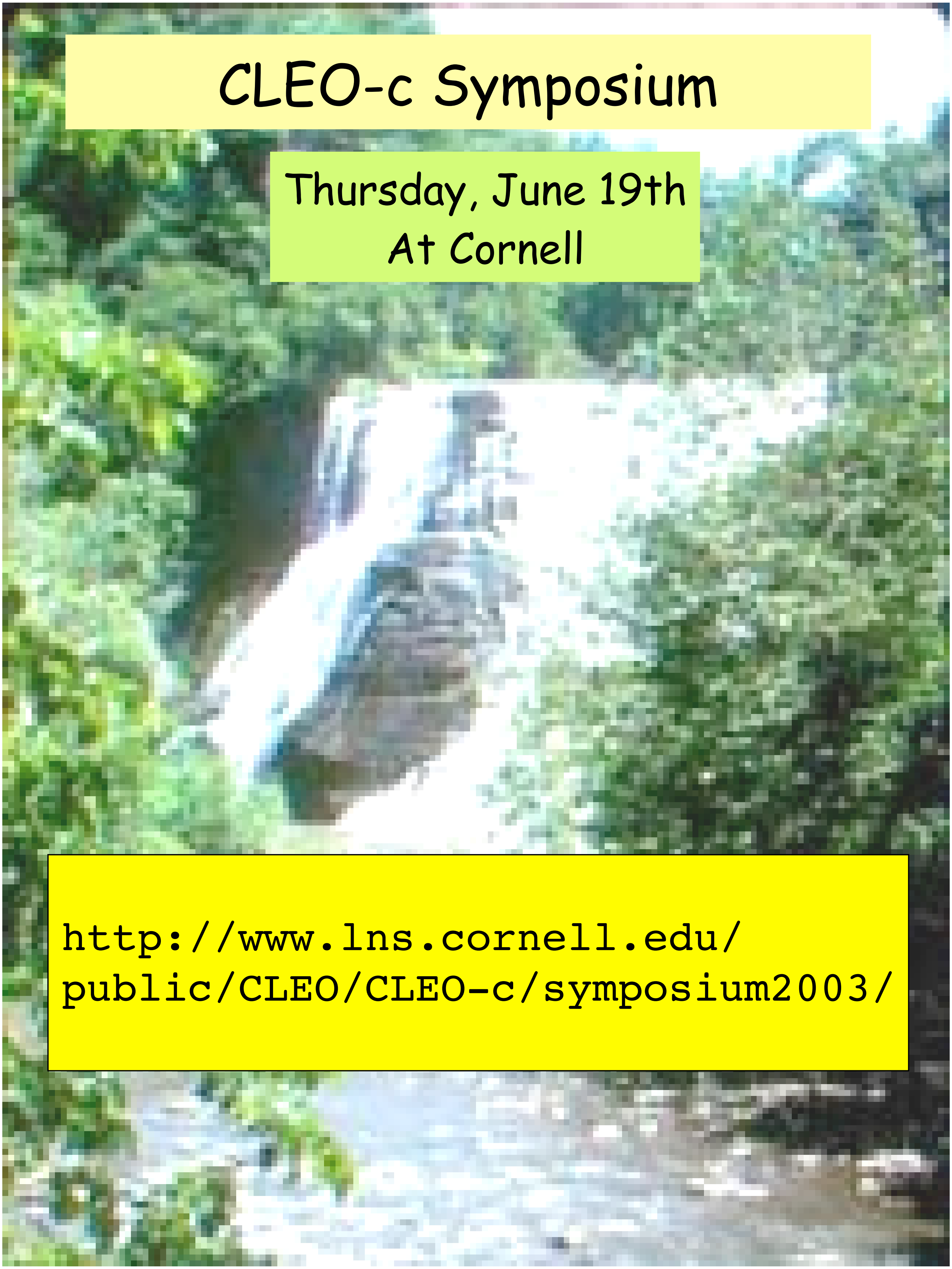
# The CLEO-c Program: Summary

- The Physics
  - Nonperturbative QCD
    - gluonic matter
    - meson spectroscopy
  - Precision flavor physics
    - Leptonic BR
    - Semileptonic BR and Form Factors
  - Probe for New Physics

- High performance detector - designed for hard tasks

- Flexible, high-luminosity accelerator: adding wigglers for low-energy operation

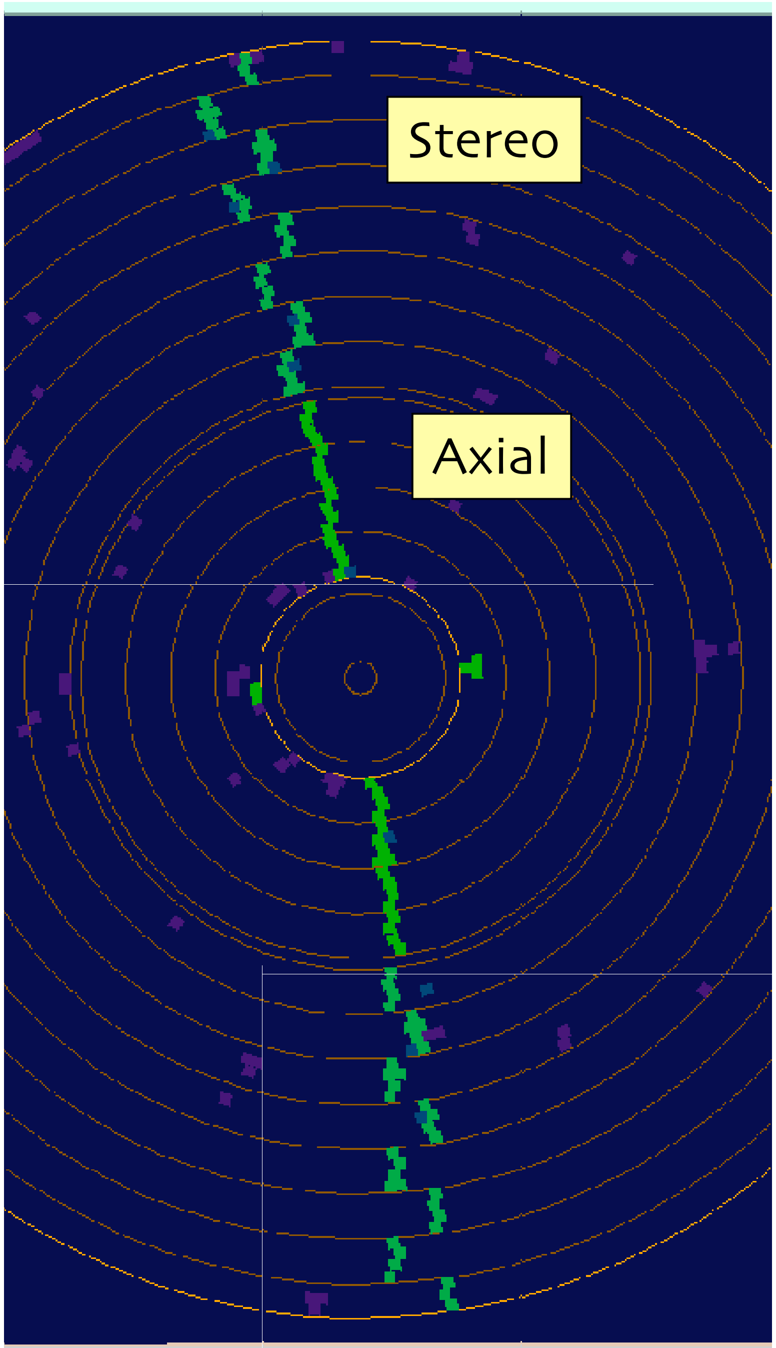
- Extant collaboration - but smaller than ever: ready to grow…

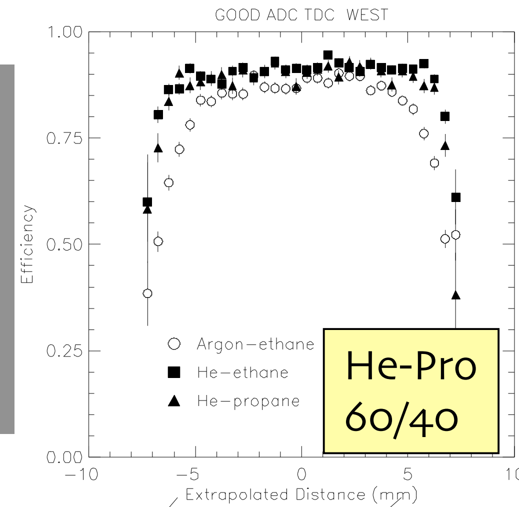

CLEO-c Symposium
Thursday, June 19th
At Cornell
http://www.lns.cornell.edu/public/CLEO/CLEO-c/symposium2003/

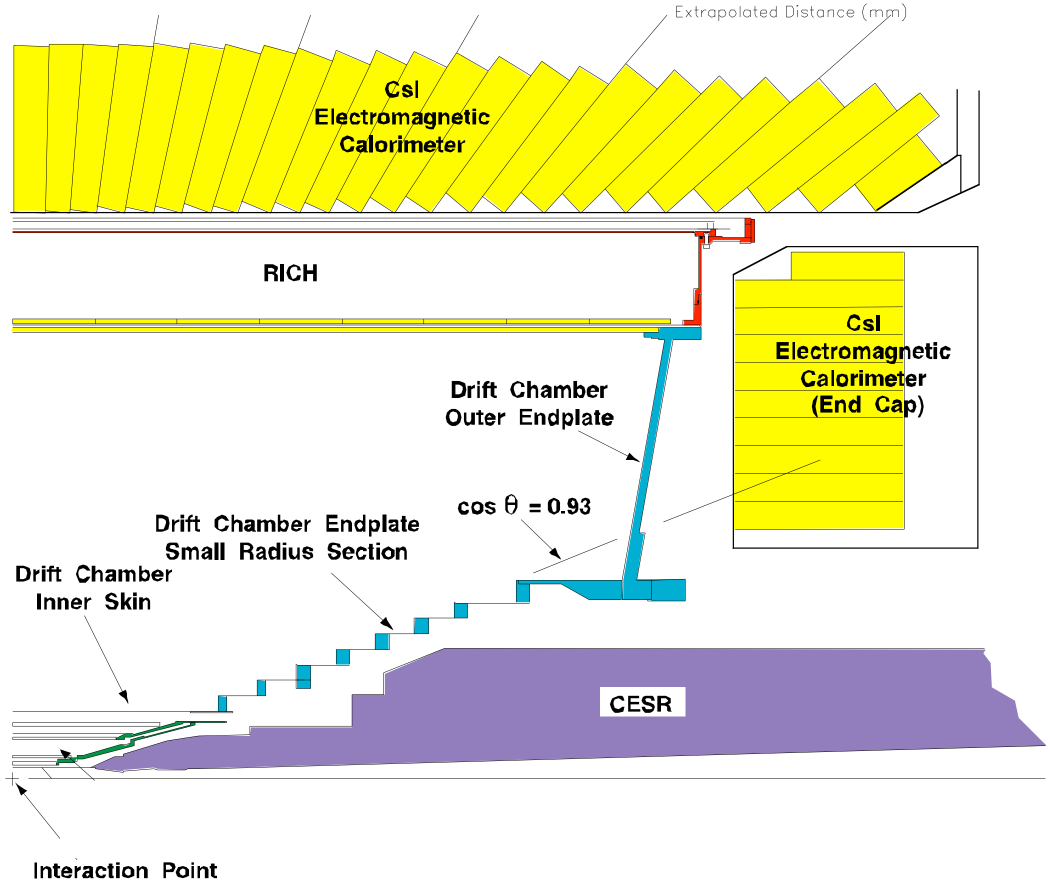
# CLEO-c will benefit from CLEO III "over"-design

| | CLEO III was designed for: | CLEO-c will encounter: | Implication |
|---|---|---|---|
| Track multiplicity | 10/evt | 5/evt | Clean |
| Shower Multiplicity | 10/evt | 5/evt | Clean |
| Maximum momentum from (B,D) decay | 2.8 GeV | 1.2 GeV | B field<br>Det. Rad. Len.<br>Muon ID<br>Decay in flight |
| Charm decay lengths | 100-200□ | 20-40□ | no vtxing |
| Data Rates | 1000 Hz | <250Hz | can do |

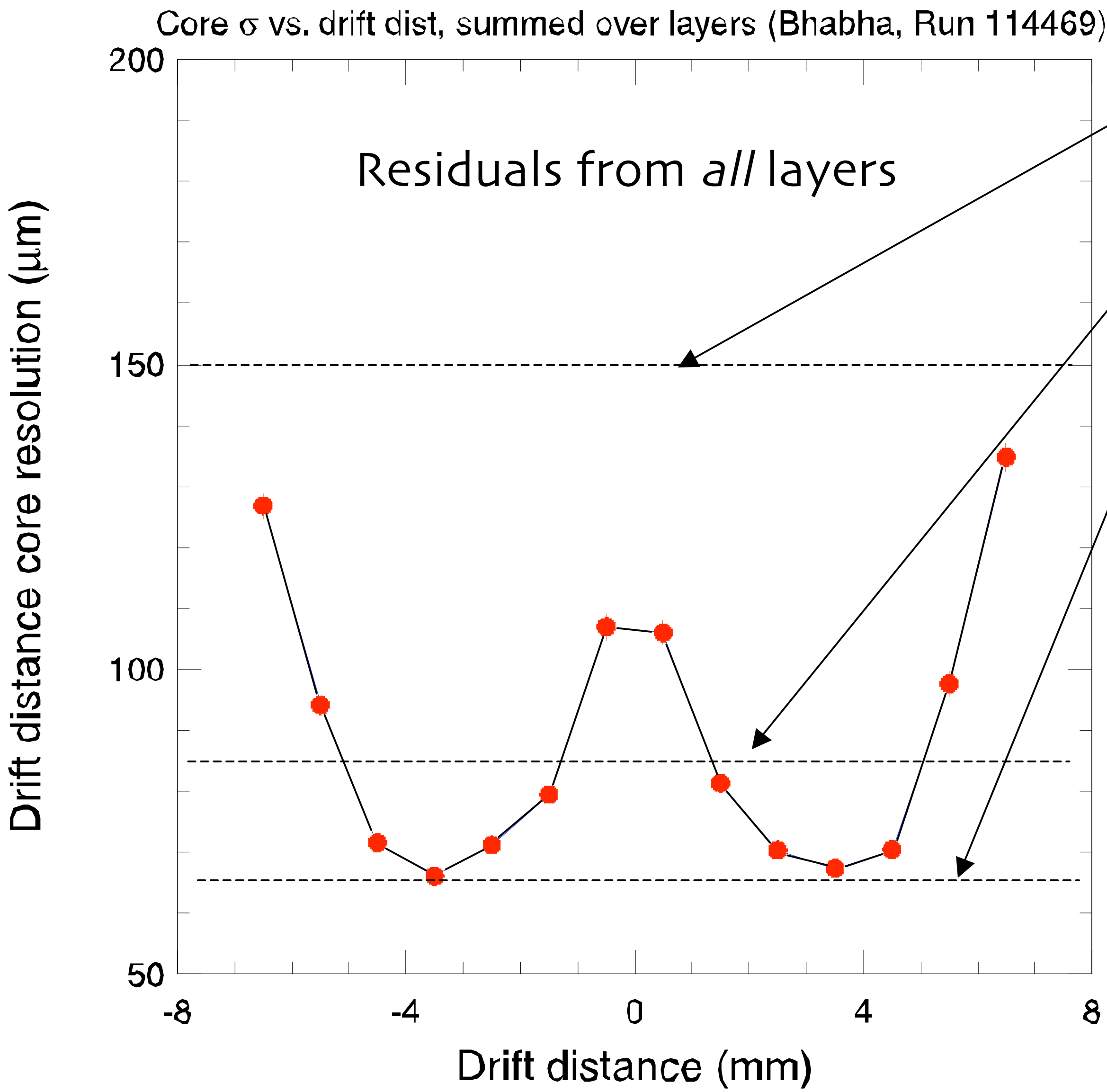
# Tracking: Drift Chamber



# Drift Chamber Hit Resolution




Design = 150□

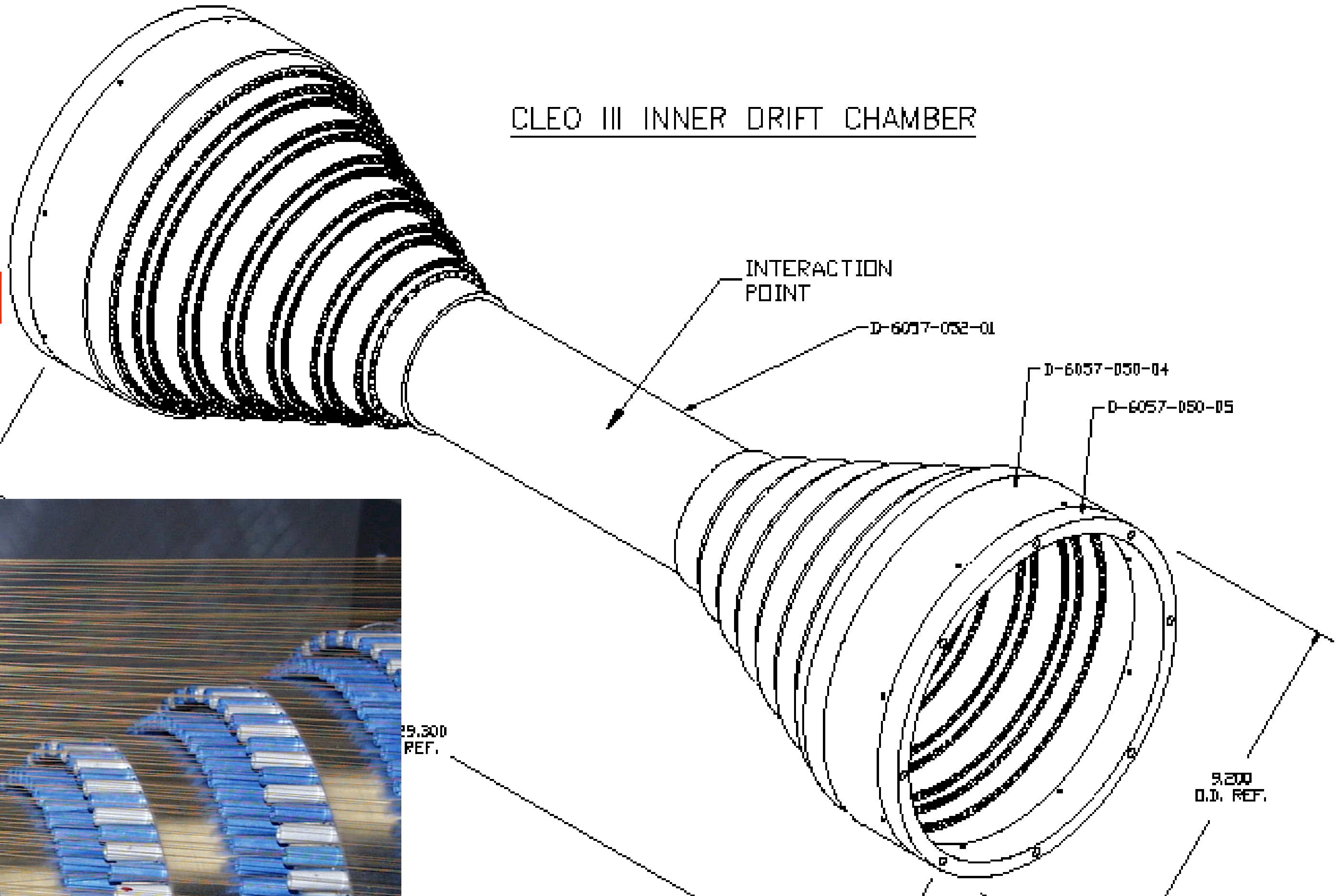
Average = 85□

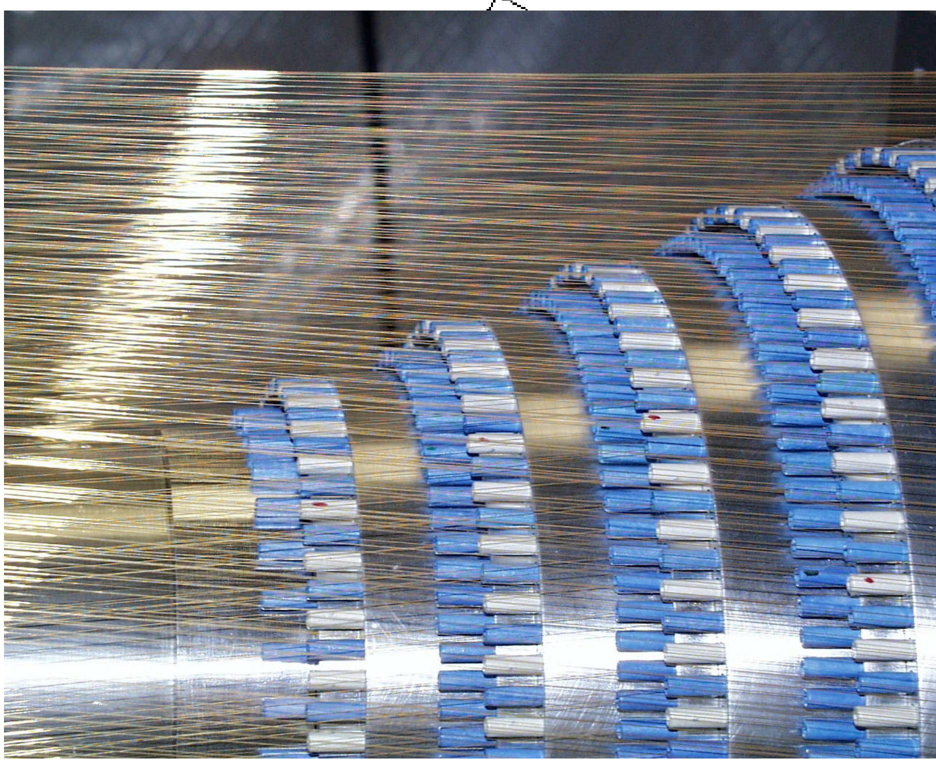
Best = 65□

Monte Carlo agrees perfectly

# Inner Tracking (2< r < 12cm)

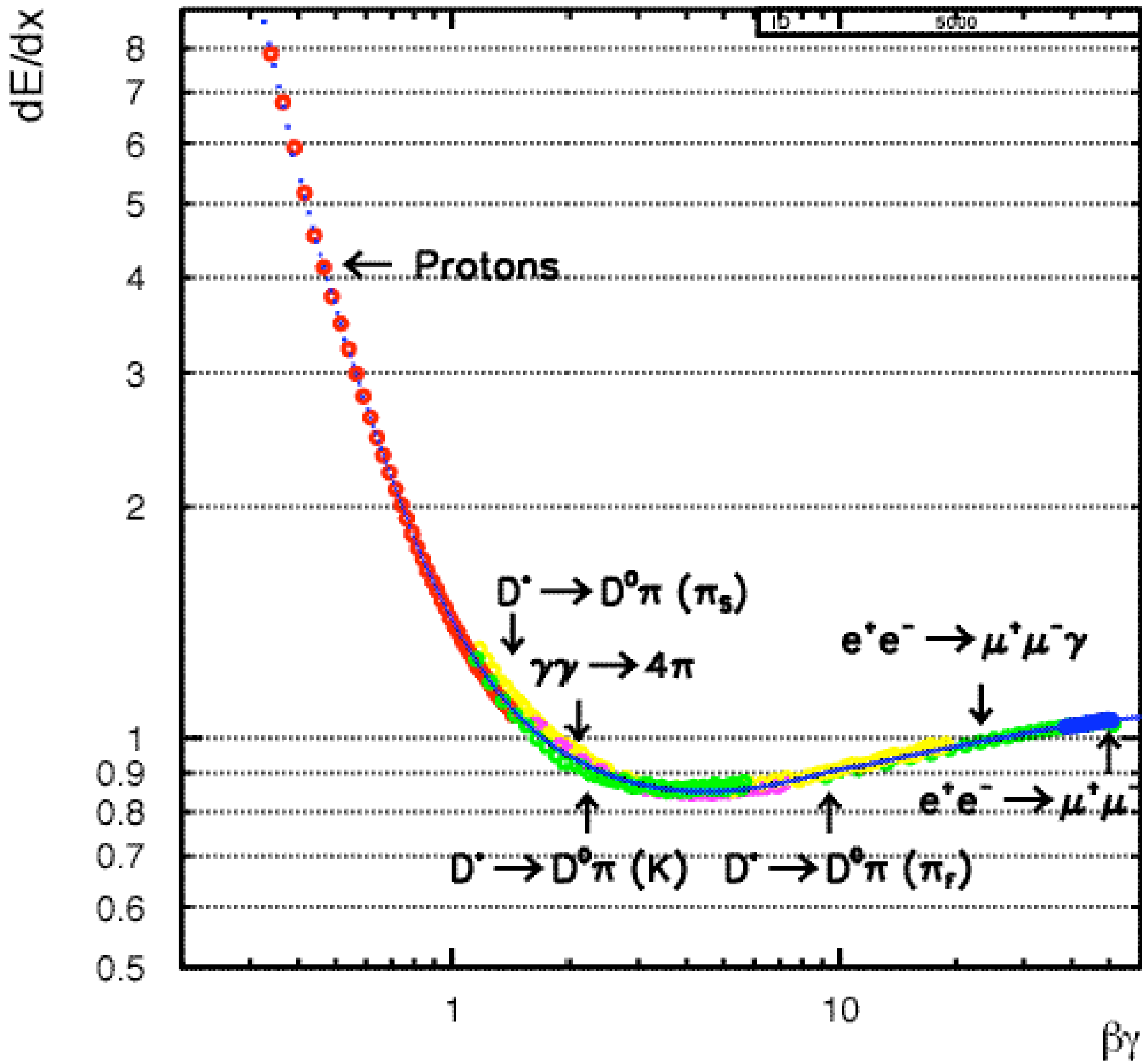
The new 6 layer drift chamber: Complete and installed.



Purpose:
Pattern recognition,
Momentum, mass resolution.
Note: no vertexing needed

# Particle Identification: dE/dx

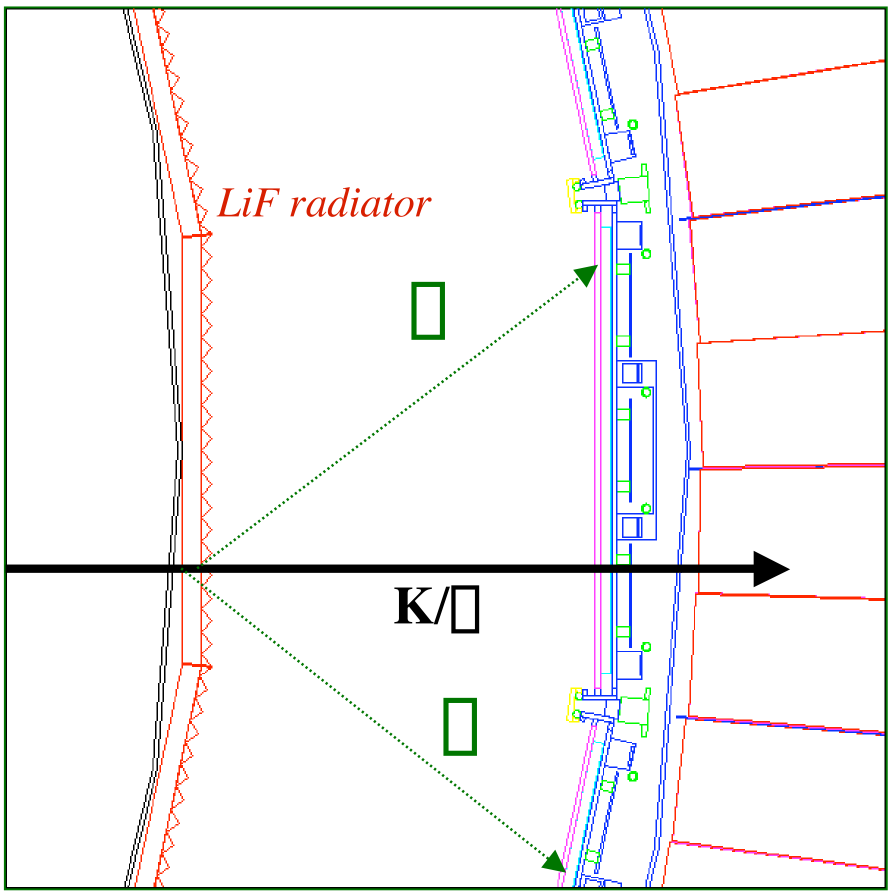


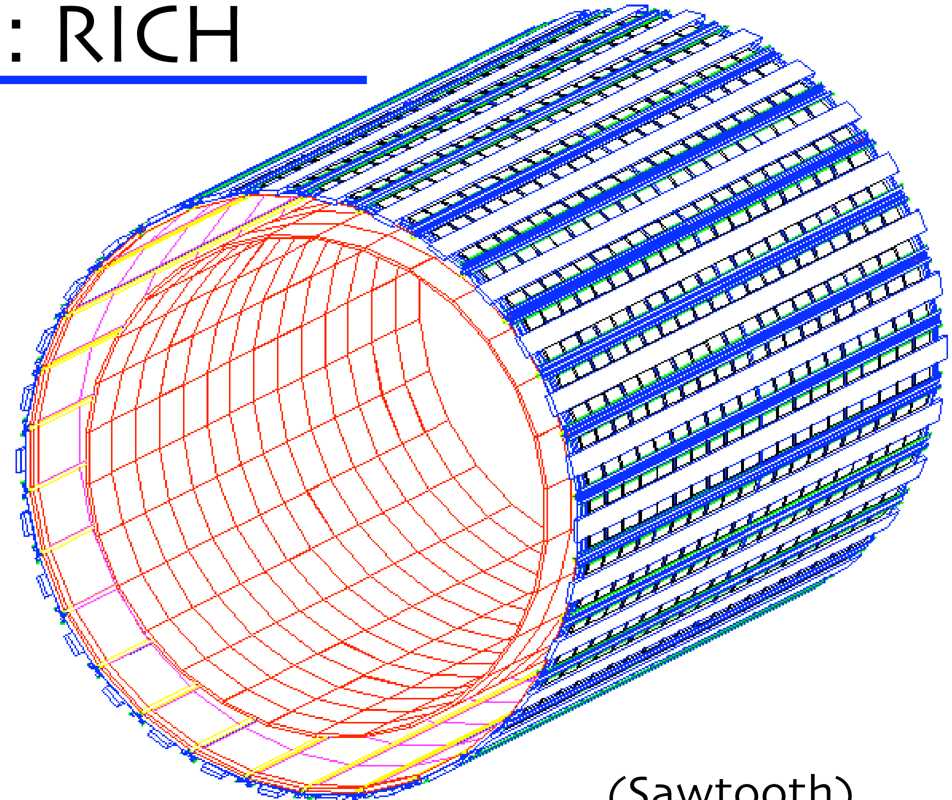

Resolution 5.7% (min-I hadrons)

dE/dx useful below RICH threshold & outside RICH solid angle

# Particle Identification: RICH

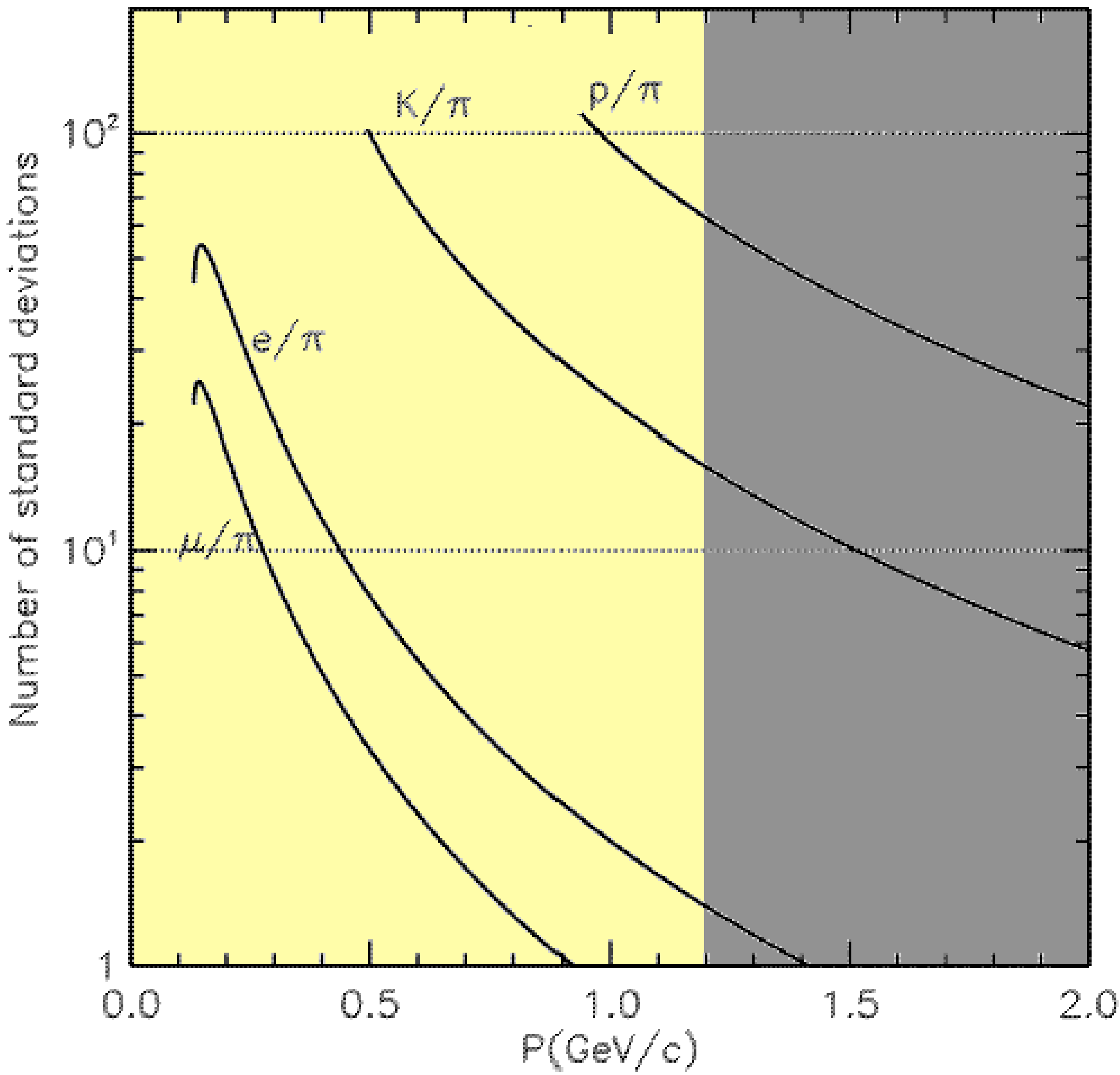
- Ring Imaging Cerenkov Detector



(Sawtooth)

# RICH particle separation versus momentum

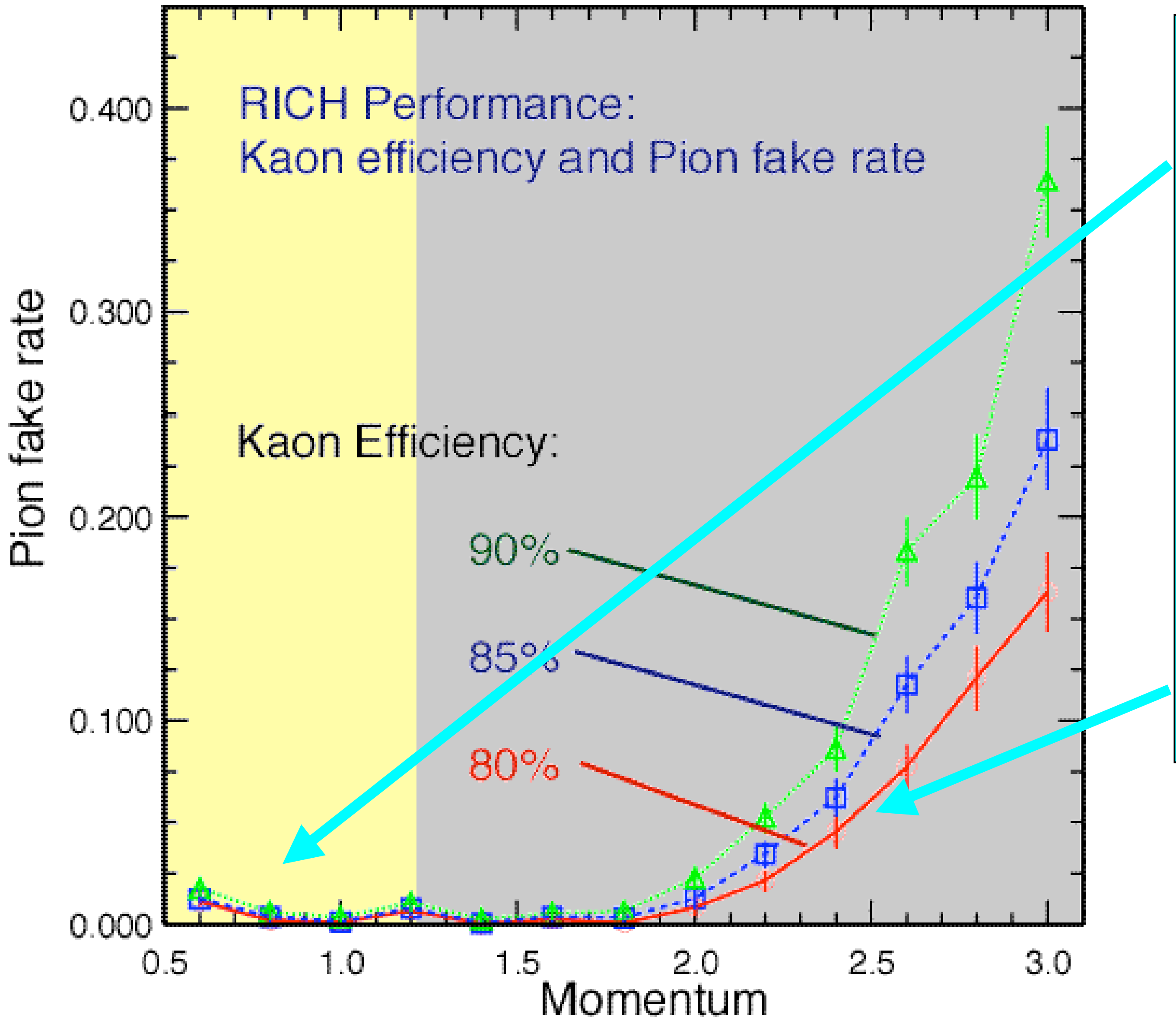



Calculated particle separation (MC)

Highlighted area is CLEO-c domain

Particle ID is essentially perfect

# RICH Performance: Efficiency and Fake Rate

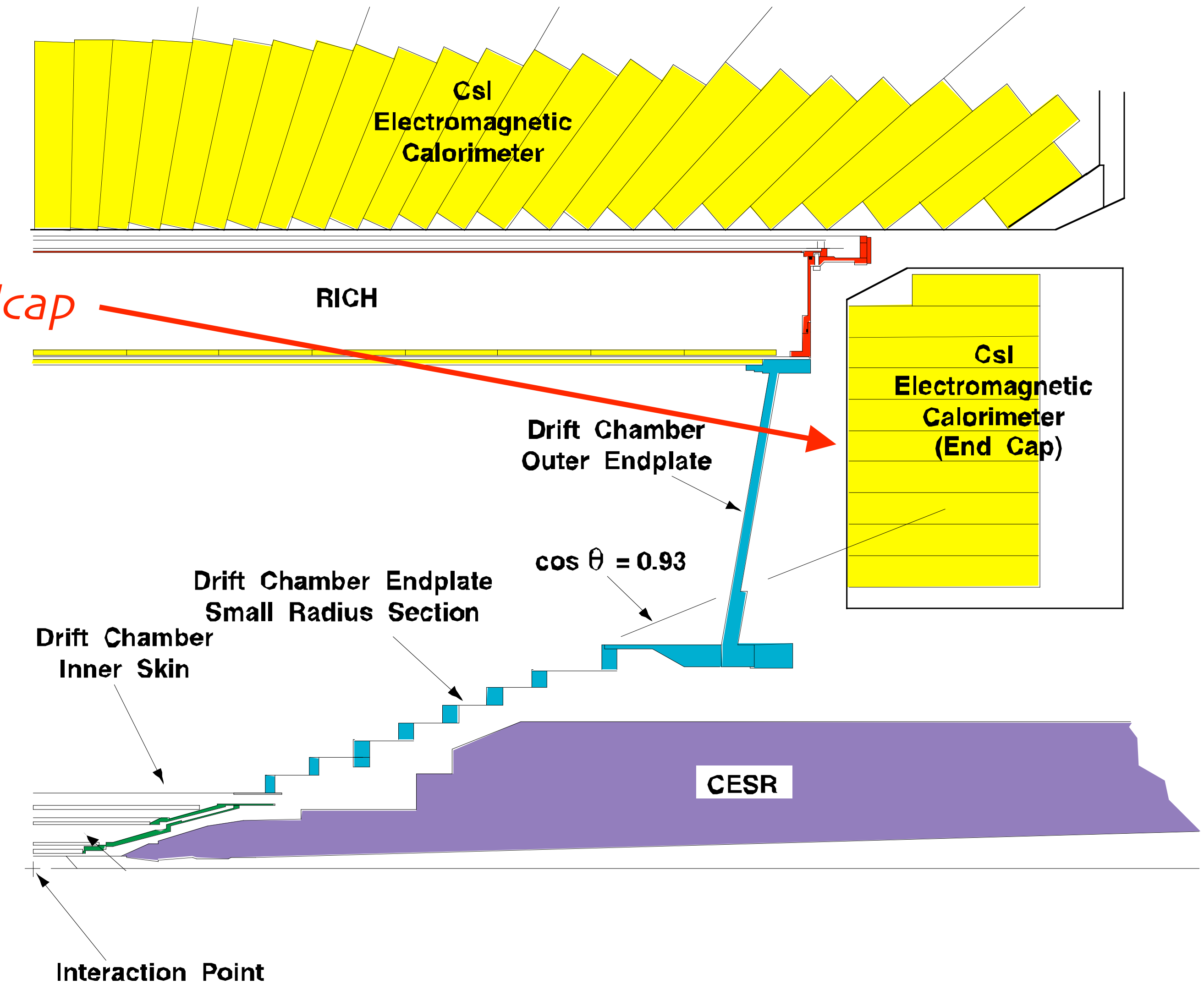



CLEO-c domain:
Fake rate ~1%

RICH design driven by more severe demands of B physics

# CsI Calorimeter

- 7800 xtals
- installed 1990
- *Improved endcap*
- photon det.
- electron ID
- Trigger
- Luminosity
- □o, □
- missing E



# Calorimeter Performance