CKM Studies and New Physics Searches with Charm

Two themes:

1) Why Charm Physics
allows B Physics
to reach its full potential

2) Charm physics as a probe
of physics beyond the
Standard Model

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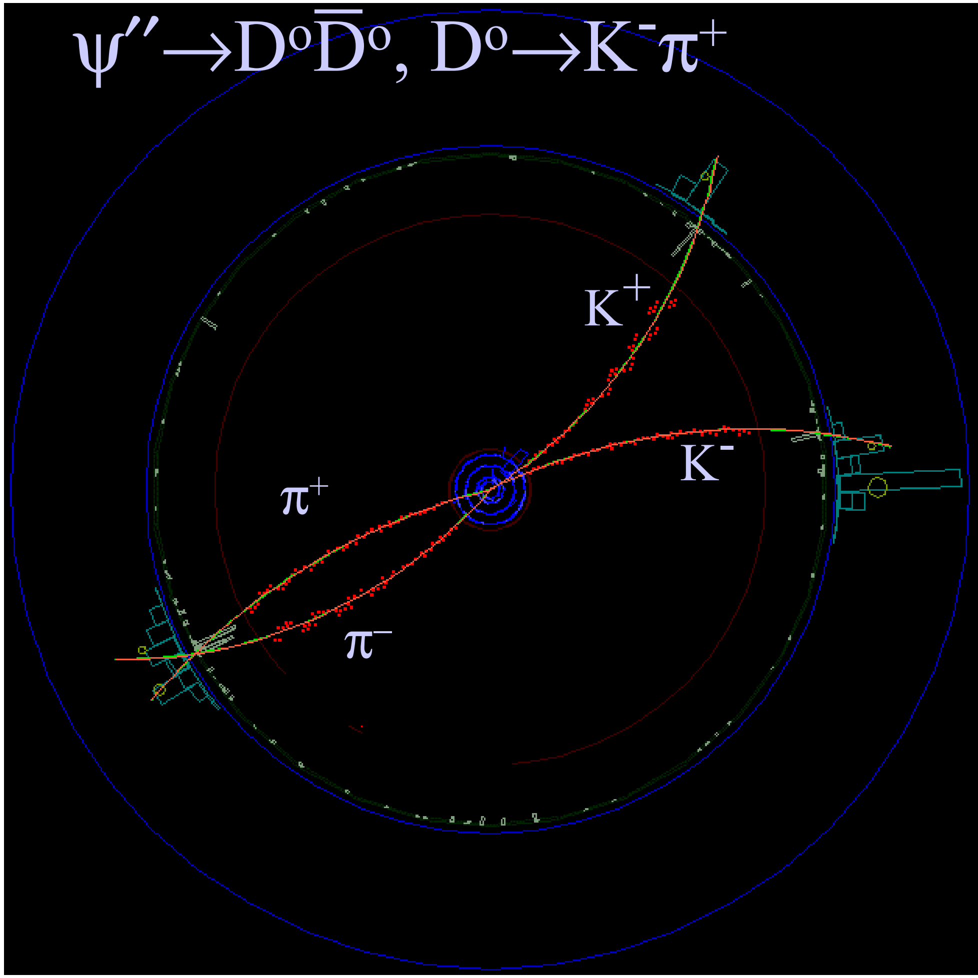


$\psi'' \to D^o \overline{D}^o,\ D^o \to K^- \pi^+$

- I am completely deaf
- I communicate by lip reading
- BUT lip reading obeys an inverse square law, and the audience is too far away
- Please write down your questions
- Pass them up to me
- I will read out your question before answering it

Outline of the Lectures

Overview: How Charm Physics Helps B Physics
→ Precision Quark Flavor Physics

Experiments That Contribute To Charm Physics

Precision CKM Physics:
- Lifetimes
- Hadronic Decays
- Leptonic Decays and Decay constants
- Semileptonic Decays and CKM matrix elements
- Tests of Unitarity
- Spectroscopy

Charm as a Probe of New Physics:
- Mixing
- CP Violation & Rare Decays

Summary & Outlook

Charm Physics: the context

This Decade

Flavor Physics: is in "the $\sin 2\beta$ era" akin to precision Z. Over constrain CKM matrix with precision measurements. Limiting factor: non-pert. QCD.

The Future

LHC may uncover strongly coupled sectors in the physics that lies beyond the Standard Model The LC will study them. Strongly-coupled field theories are an outstanding challenge to theoretical physics. Critical need for reliable theoretical techniques & detailed data to calibrate them.

Example: The Lattice

Complete definition of pert & non. Pert.QCD. Matured over last decade, can calculate to 1-5% B,D,Υ,Ψ…

Charm can provide the data to calibrate QCD techniques

(See Peter Lepage's lectures for details of Lattice QCD)

Charm Physics:
What do we need to measure?

•flavor physics: overcome the non pert. QCD roadblock

Precision charm lifetimes ← exist

do not exist

• precision charm abs. branching ratio measurements

Leptonic decays : decay constants

Semileptonic decays: Vcs,Vcd,unitarity form factors

Abs D hadronic Br's normalize B physics

Tests QCD techniques in c sector, apply to b sector

→Improved Vub, Vcb, Vtd & Vts

• •strong coupling in Physics beyond the Standard Model

•precise measurements of quarkonia spectroscopy & decay provide essential data to calibrate theory. ← Important Input for the lattice

•Physics beyond the Standard Model:

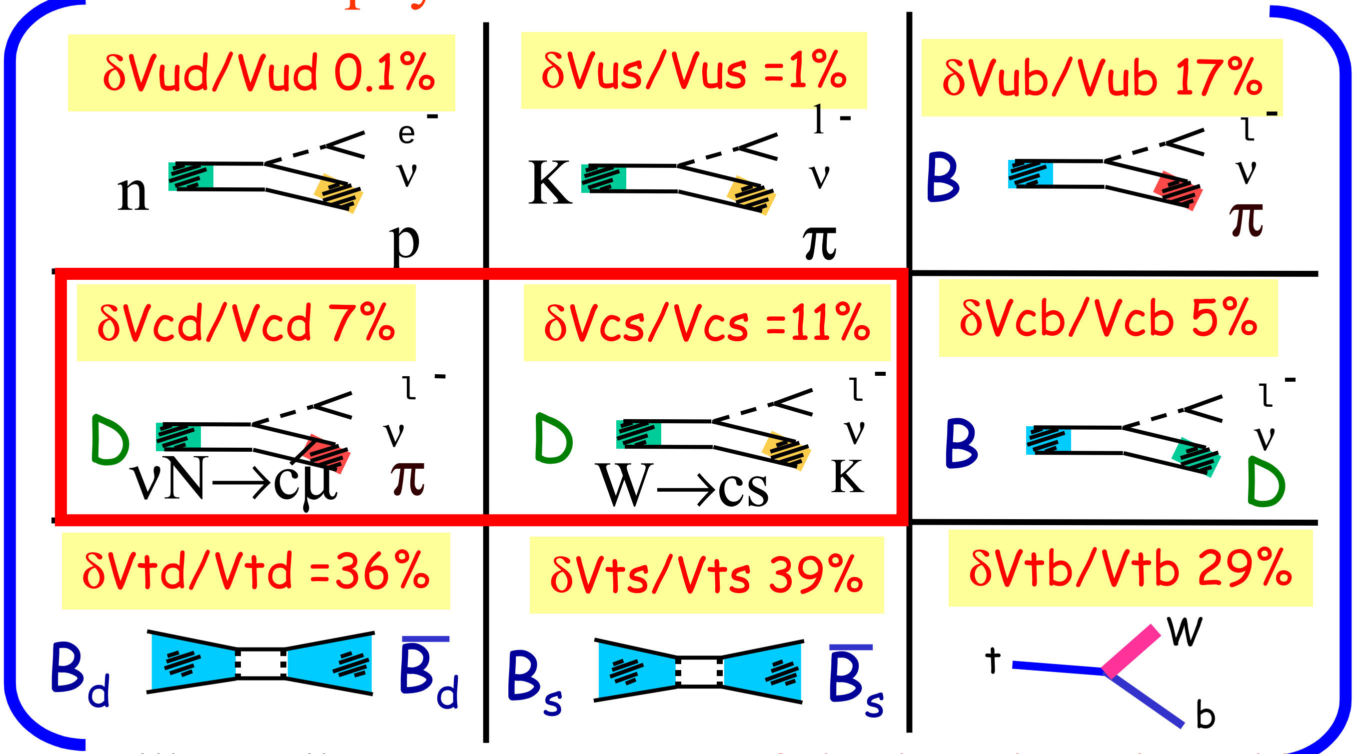
•D-mixing, CPV, rare decays. + measure strong phases

Charm physics builds the tools to enable this decade's flavor physics and the next decade's new physics.

Precision Quark Flavor Physics

Goal for the decade: high precision measurements of V_{ub}, V_{cb}, V_{ts}, V_{td}, V_{cs}, V_{cd}, & associated phases. Over-constrain the "Unitarity Triangles" - Inconsistencies → New physics !

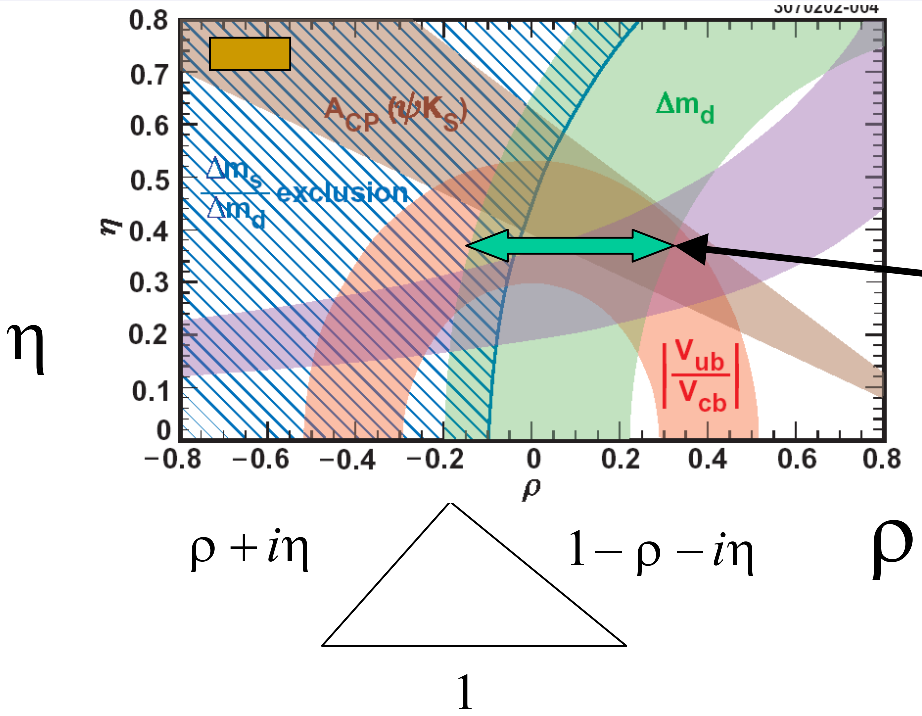
CKM Matrix Current Status:



δVud/Vud 0.1%	δVus/Vus =1%	δVub/Vub 17%
δVcd/Vcd 7%	δVcs/Vcs =11%	δVcb/Vcb 5%
δVtd/Vtd =36%	δVts/Vts 39%	δVtb/Vtb 29%

Many experiments will contribute. Measurement of absolute charm branching ratios will enable precise new measurements at Bfactories/Tevatron to be translated into greatly improved CKM precision.

Importance of measuring absolute charm leptonic branching ratios: f_D & f_{Ds}: V_{td} & V_{ts}



$$\Delta M_d = 0.50\,ps^{-1}\left[\frac{\sqrt{B_{B_d}}\,f_{B_d}}{200MeV}\right]^2\left[\frac{|V_{td}|}{8.8\times10^{-3}}\right]^2$$

$$\frac{\sigma(\rho)}{\rho} = 0.5\frac{\sigma(\Delta M_d)}{\Delta M_d}\oplus\frac{\sigma(f_B\sqrt{B_{B_d}})}{f_B\sqrt{B_{B_d}}}$$

(ICHEP02) 1.2% ~15% (LQCD)

$$\frac{\Delta M_d}{\Delta M_s}\propto\left[\frac{\sqrt{B_{B_d}}\,f_{B_d}}{\sqrt{B_{B_s}}\,f_{B_s}}\right]^2\left[\frac{|V_{td}|}{|V_{ts}|}\right]^2$$

~5-7%

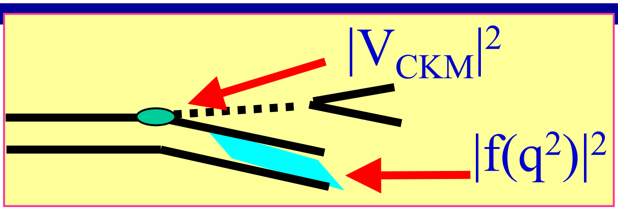
$$\frac{\delta f_{D_c}}{f_{D_c}}\sim 14\%$$

$$\frac{\delta f_{D_c}}{f_{D_c}}\sim 100\%$$

Lattice predicts f_B/f_D & f_{Bs}/f_{Ds} with small errors
if precision measurements of f_D & f_{Ds} existed (they do not)
We could obtain precision estimates of f_B & f_{Bs}
and hence precision determinations of V_{td} and V_{ts}
Similarly f_D/f_{Ds} checks f_B/f_{Bs}

Importance of absolute charm semileptonic decay rates.

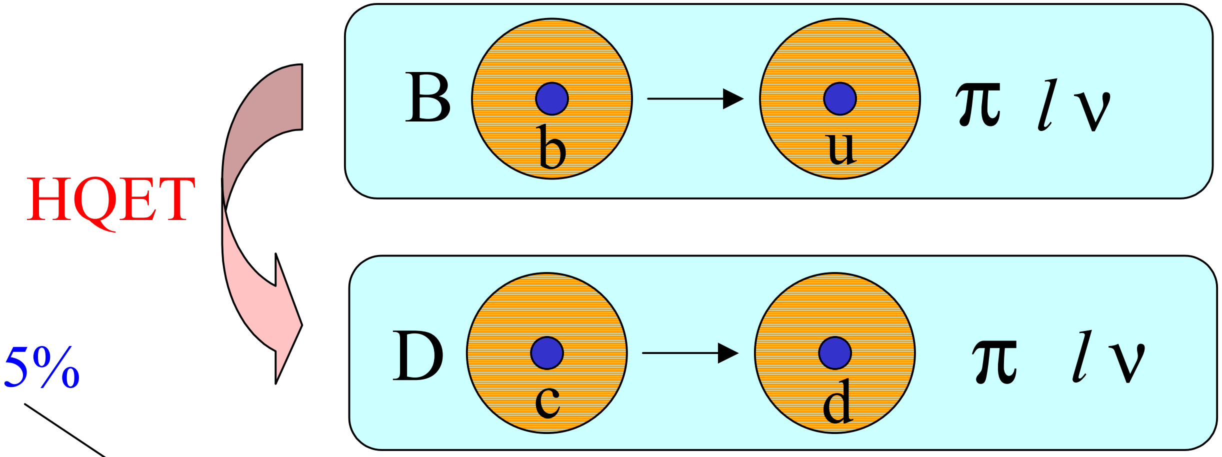
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} | V_{cs} |^2 p_K^3 | f_+(q^2) |^2$$



I. Absolute magnitude & shape of form factors are a stringent test of theory.

II. Absolute charm semileptonic rate gives direct measurements of V_{cd} and V_{cs}.

III Key input to precise Vub vital CKM cross check of sin2β



$$\frac{\delta B}{B} \sim 25\%$$

1) Measure D→π form factor in D→πlν. Calibrate LQCD uncertainties .

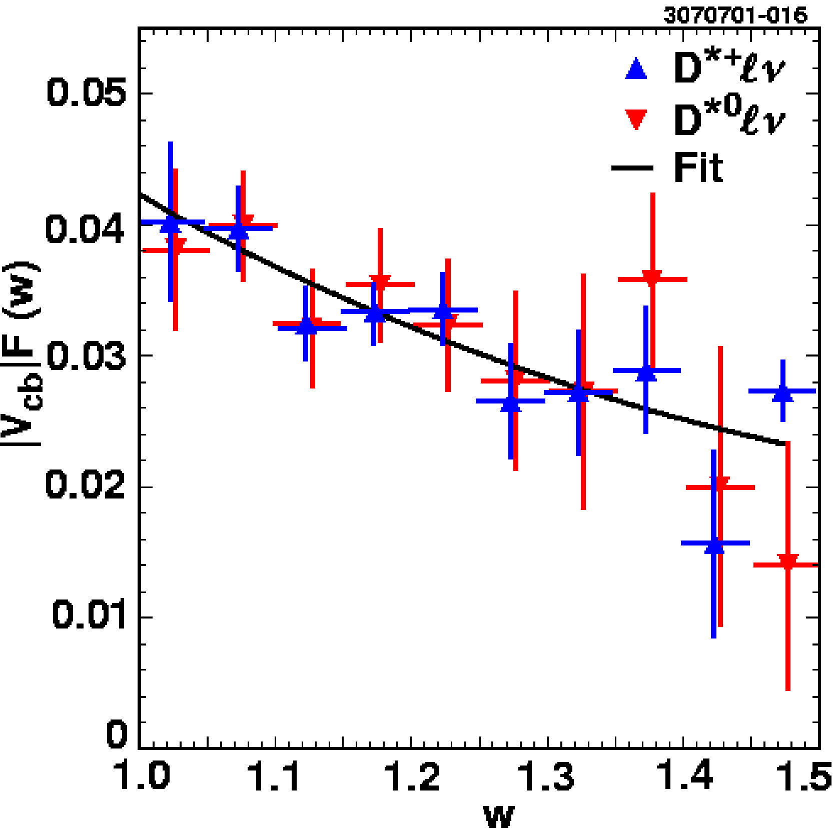
2) Extract V_{ub} at BaBar/Belle using *calibrated* LQCD calc. of B→π form factor.

3) But: need absolute Br(D →πlν) and high quality dΓ (D →πlν)/dEπ neither exist

The Importance of Precision Charm Absolute Branching Ratios I

V_{cb} from zero recoil in $B \to D^* l^+ \nu$

CLEO hep-ex/0203032
Accepted for publication in PRL



$$|V_{cb}| = (46.9 \pm 1.4 \pm 2.0 \pm 1.8) \times 10^{-3}$$

CLEO has single most precise Vcb by this technique

Stat: 3.0% Sys 4.3% theory 3.8%
Dominant Sys: $\varepsilon_\pi$slow, form factors
As B Factory data sets grow, and theory improves

dB(D→Kπ)/dB(D→Kπ)
→ dV_{cb}/V_{cb}=1.3%

The Importance of Precision Charm Absolute Branching Ratios II

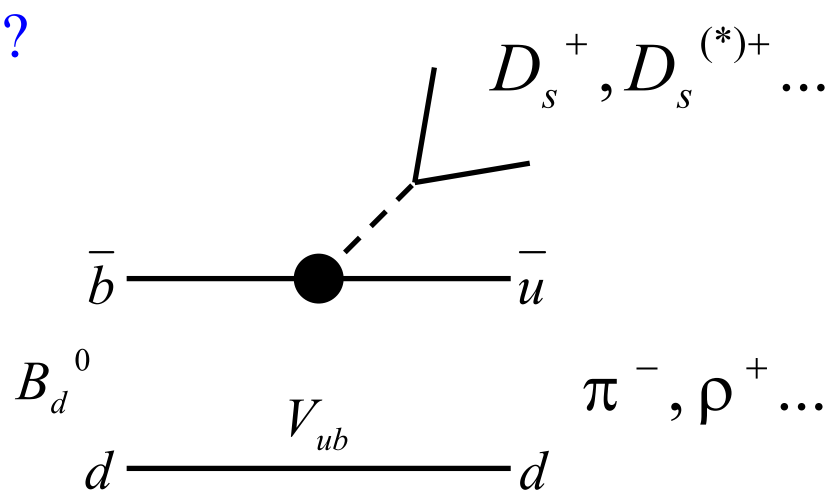
$B^0 \rightarrow D_s^{(*)+}\pi^-$ Extraction of V_{ub} ?

Dominated by b→u transition

BABAR/Belle have signals

Theory error probably large

Experimental error dominated by $B(D_s \rightarrow \phi\pi)$ which is known to 25%



V_{ub}/V_{cb} from $$\frac{\Gamma\left(\Lambda_b \rightarrow p\ell\bar{\nu}\right)}{\Gamma\left(\Lambda_b \rightarrow \Lambda_c\ell\bar{\nu}\right)}$$ at hadron machines requires:

B(/\c→pKπ) poorly known:
9.7% > B >3.0% at 90% C.L

The importance of precision absolute Charm BRs III

HQET spin symmetry test

$$\frac{\Gamma\left(\bar{\mathrm{B}}^{o} \to \mathrm{D}^{*+} h^{-}\right)}{\Gamma\left(\bar{\mathrm{B}}^{o} \to \mathrm{D}^{+} h^{-}\right)} = 1$$

since $D^{*+} \to \pi^+ D^o$ is most useful mode, this compares D^o/D^+ absolute rates

Compare $B^o \to D^{(*)+} h^-$ and $B^+ \to D^{(*)o} h^-$ rates to extract color suppressed amplitudes

Test factorization with $B \to DD_s$

Need Abs Br D_S

The importance of precision absolute Charm BRs IV

$BR_{SL} = B(b \to c\ell\nu)$, is low compared to theory A possible explanation is that the c quark effective mass is low → large decay rate for b $\to c\bar{c}s(d)$

$\to n_c = (n_c + n_{\bar{c}})$ is negatively correlated to Br_{SL}

The simultaneous measurement of Br_{SL} and n_c can clarify the theoretical picture

$$b \to c\ell\bar{\nu} + c\bar{u}d + c\bar{c}s$$

BR_{SL} n_c are anti-correlated

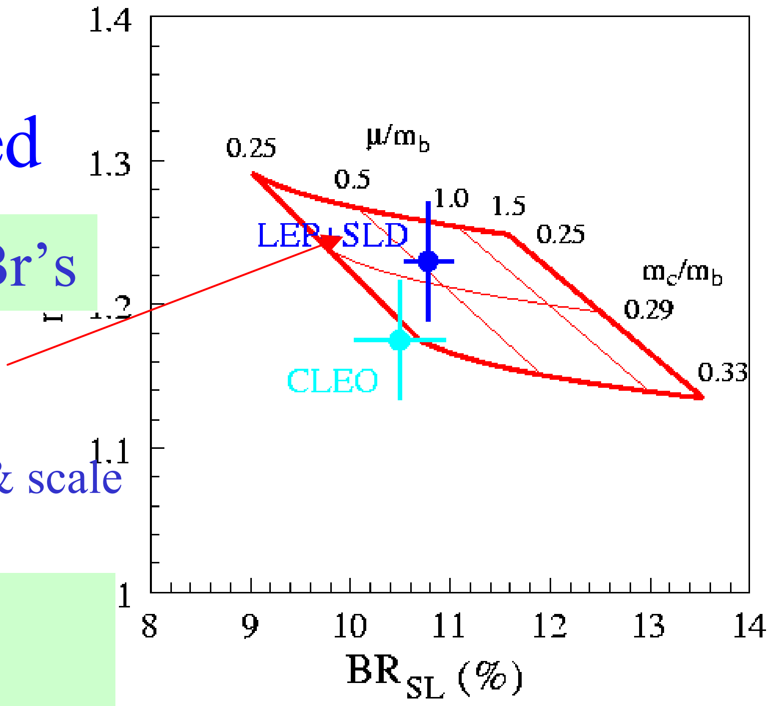
To measure n_c need absolute charm Br's

- QCD prediction:

(Neubert & Sachrajda, Nucl. Phys. B483,339 1997)

As a function of the effective charm quark mass & scale at which QCD corrections are evaluated

Theory can accommodate present values but experimental errors are large → test becomes more incisive if abs charm BR's were known precisely



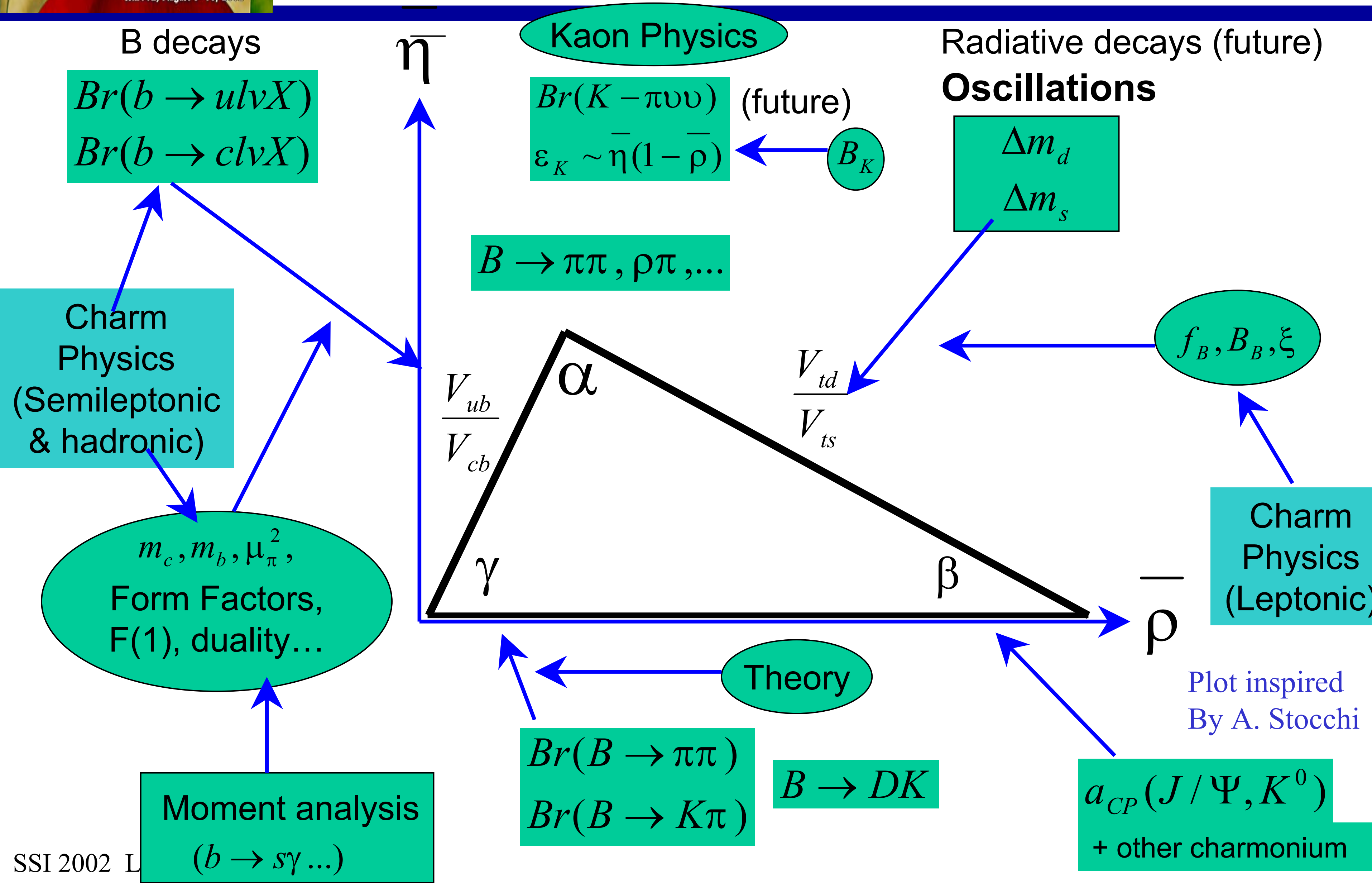
(Plot from Parodi at HF9)

The importance of precision absolute Charm BRs V

Test of the Standard Model.
Precision: $Z \rightarrow bb$ and $Z \rightarrow cc$ (R_b & R_c) is systematically limited by knowledge of absolute charm branching ratios

To understand the Higgs at LHC/LC
$B(H \rightarrow bb)$ $B(H \rightarrow cc)$
precision will depend on absolute charm branching ratios

The Unity of Quark Flavor Physics



B decays

$Br(b \to ul\nu X)$
$Br(b \to cl\nu X)$

$\bar{\eta}$

Kaon Physics

$Br(K-\pi\upsilon\upsilon)$ (future)
$\varepsilon_K \sim \bar{\eta}(1-\bar{\rho})$

B_K

Radiative decays (future)

Oscillations

Δm_d
Δm_s

$B \to \pi\pi, \rho\pi, \ldots$

Charm Physics (Semileptonic & hadronic)

f_B, B_B, ξ

$\frac{V_{ub}}{V_{cb}}$

α

$\frac{V_{td}}{V_{ts}}$

γ

β

$\bar{\rho}$

Charm Physics (Leptonic)

$m_c, m_b, \mu_\pi^2,$
Form Factors,
F(1), duality…

Theory

Plot inspired
By A. Stocchi

Moment analysis
$(b \to s\gamma \ldots)$

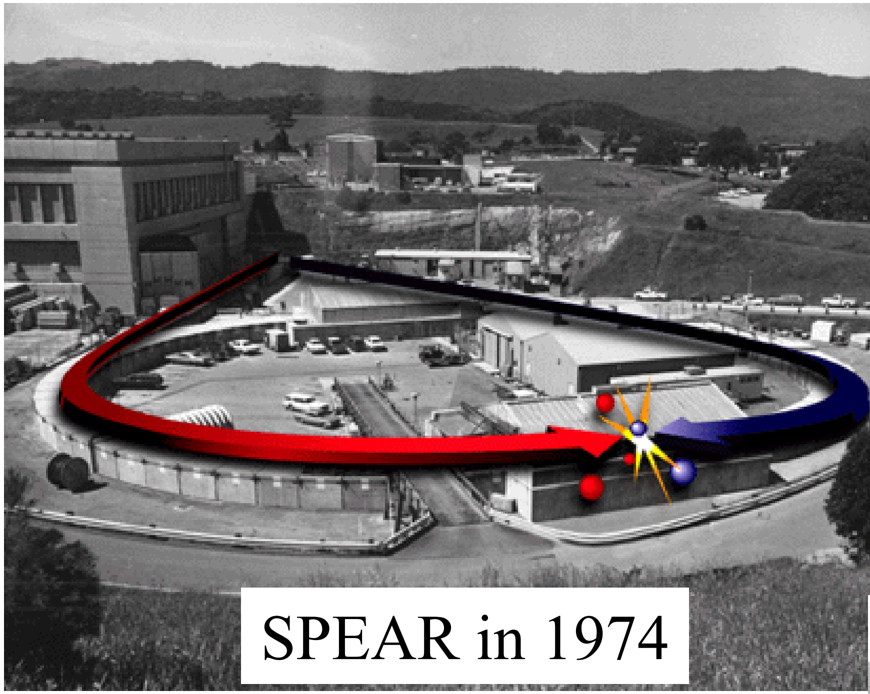
$Br(B \to \pi\pi)$
$Br(B \to K\pi)$

$B \to DK$

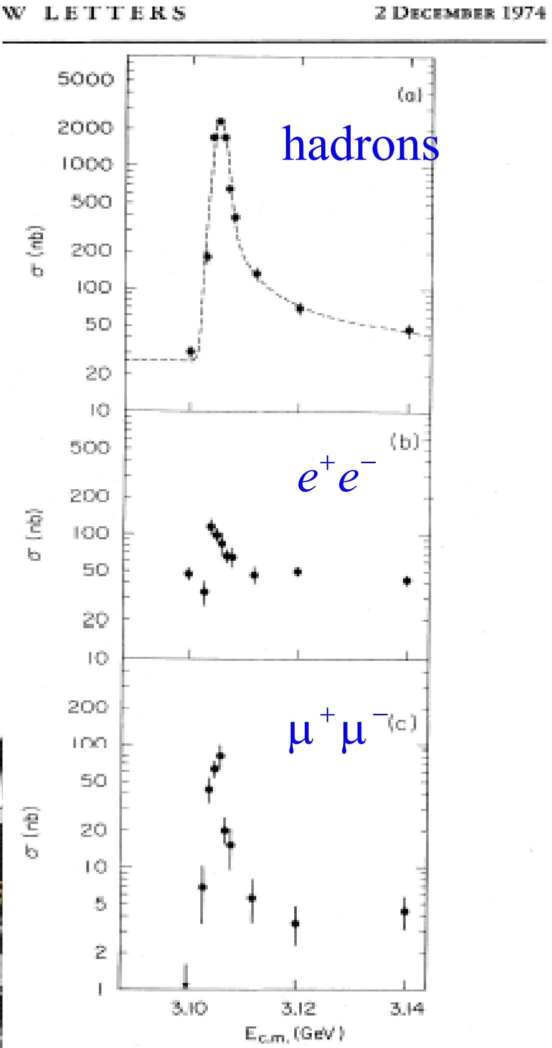
$a_{CP}(J/\Psi, K^0)$
+ other charmonium

Charm physics:1974

Charm discovery SLAC and BNL November 1974



SPEAR in 1974



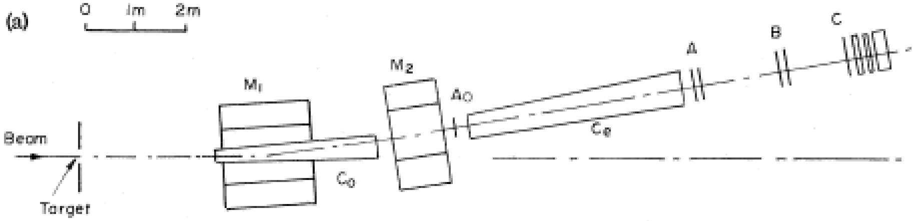
$e^+ e^-$ ➔ multihadron enhancement

J/Ψ width << 2 MeV (beam width)

Goldhaber, Perl, Richter 1974

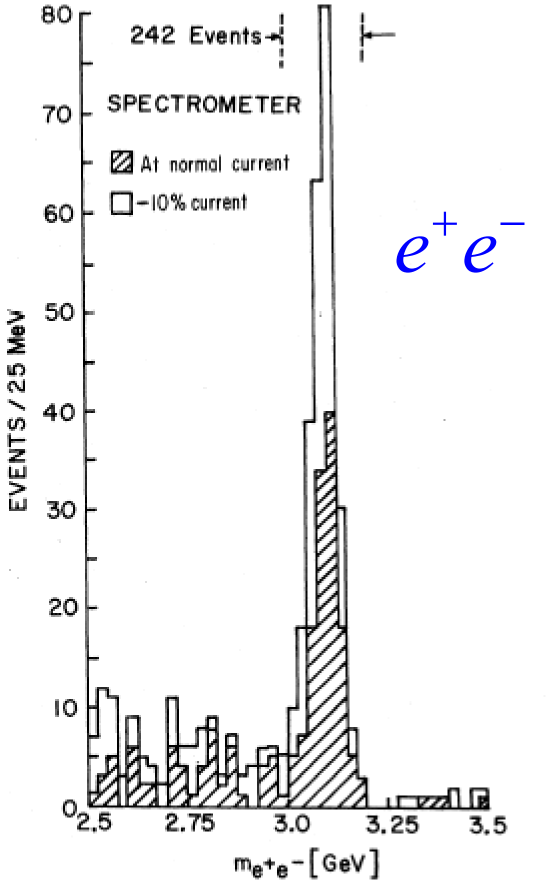
Charm Physics: 1974

$$p + Be \to e^+e^-$$



Broad band probe, clean final state

EW LETTERS 2 DECEMBER 1974



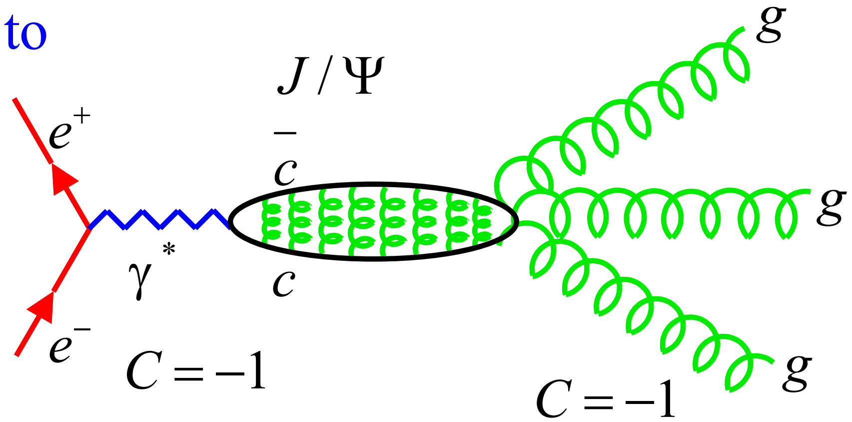
e^+e^-

FIG. 2. Mass spectrum showing the existence of *J*. Results from two spectrometer settings are plotted showing that the peak is independent of spectrometer currents. The run at reduced current was taken two months later than the normal run.

The J/Ψ as a frontier

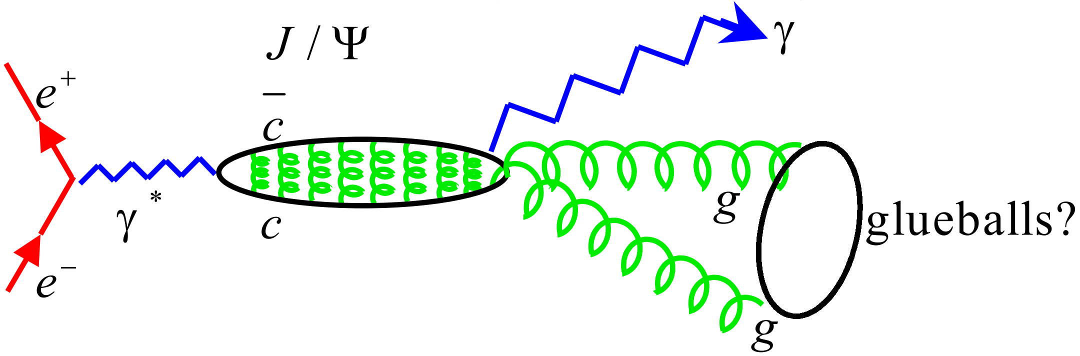
Ψ's are narrow, insufficient energy to decay to open charm, (i.e. $D\bar{D}$) or $(c\bar{u})(\bar{c}u)$

C=-1 easy to produce with virtual photon, but decay into three gluons suppressed

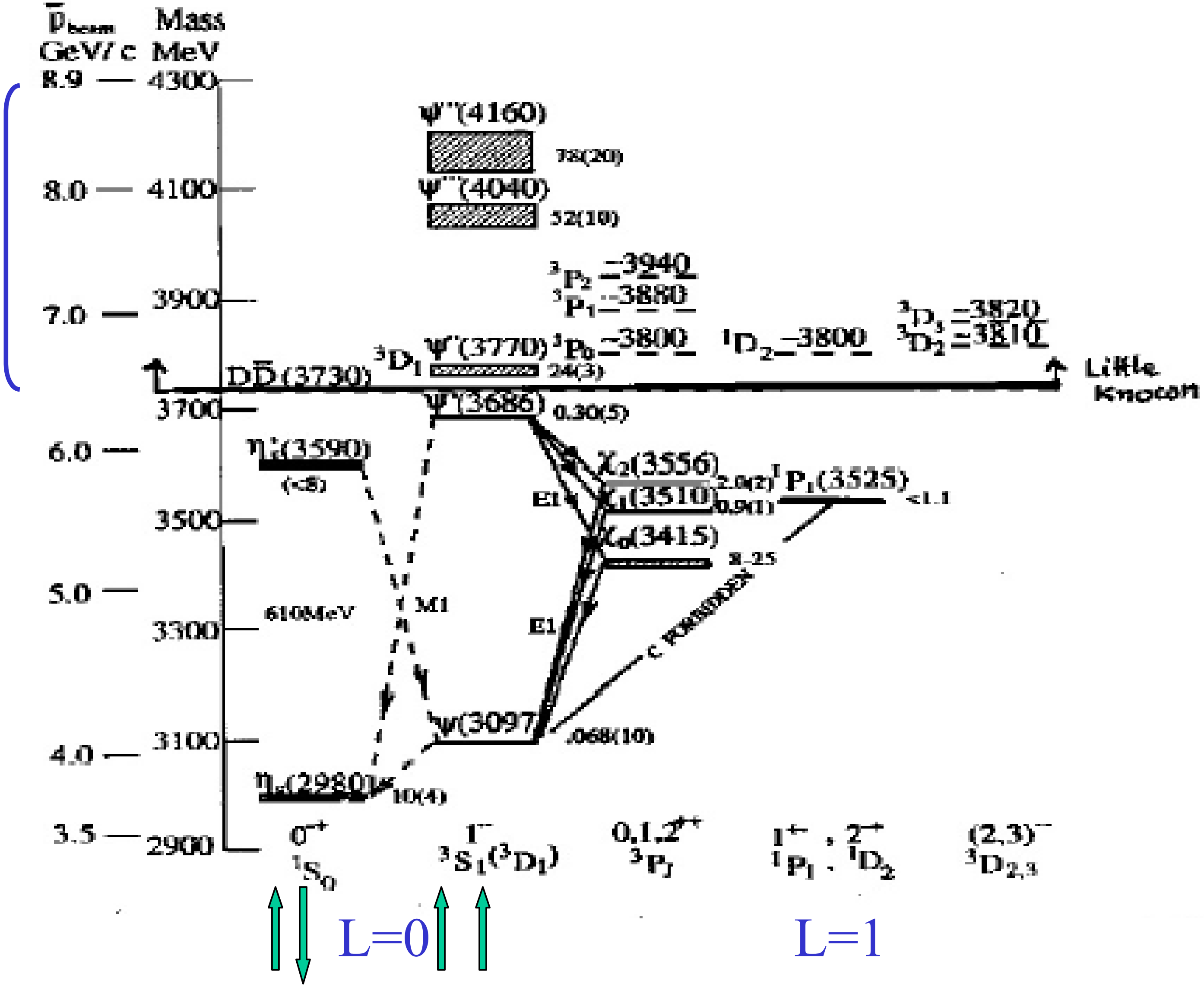


Despite this, 88% of J/Ψ *decays* are hadrronic (only the ~12% to $e^+e^-/\mu\,\mu$) used in sin2β measurements

Radiative J/Ψ Br~6% are very useful for glueball searches



Charmonium Spectroscopy



Open Charm

L=0

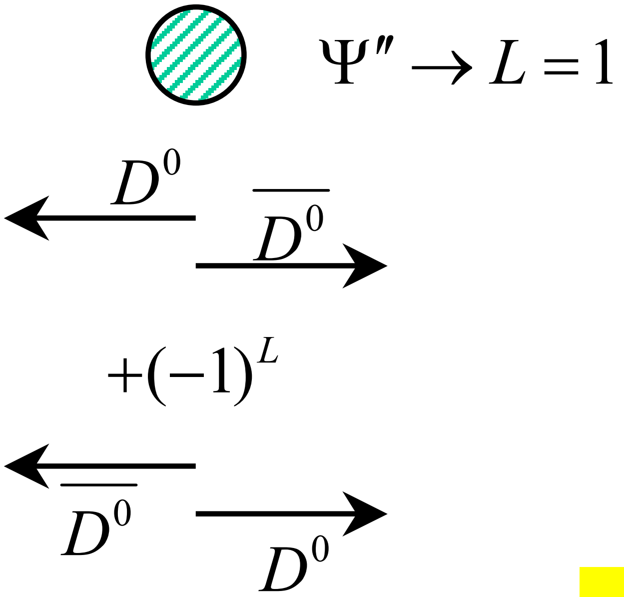
L=1

Open Charm Production at Threshold

D meson discovered 1976 Goldhaber/Trilling (LBL)

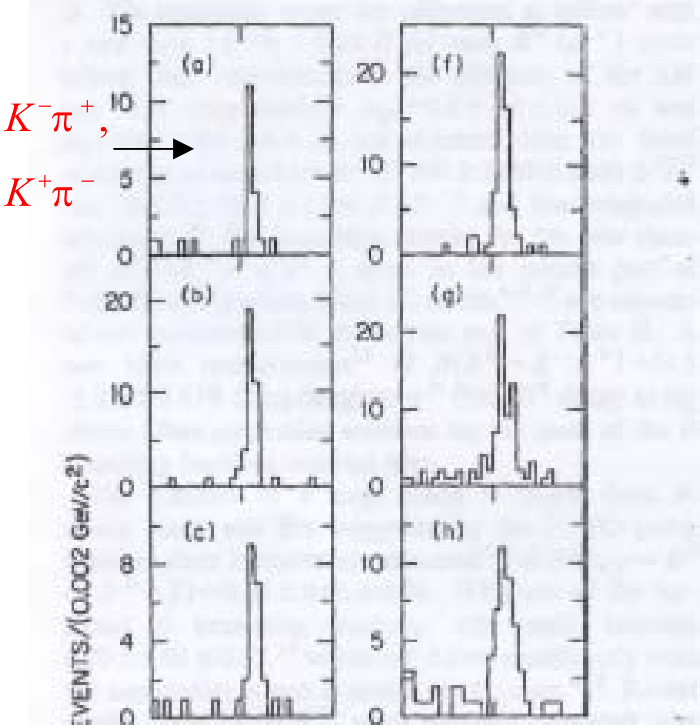
At Ψ'' = Ψ(3S) = Ψ(3770)

$\Psi'' \to D^0\overline{D^0},\ D^+D^-$



$\Psi'' \to L = 1$

$+(-1)^L$



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

Beam constrained mass

Mark III

Events where both D's are reconstructed

The role of the Ψ(3770) in charm physics is analogous to the role of the Υ(4S) in B physics

Absolute Branching Ratio Measurements at the Υ(4S) and ψ(3770)

$$Br(D \to X) = \frac{\text{\#X Observed}}{\text{efficiency x \#D's produced}}$$

In B decay absolute branching ratios are measured at the Υ(4S)

$$\int Ldt \bullet \sigma_{(Y(4S))} = N_{Y(4S)}$$

$$N_{Y(4S)} \bullet Br(Y(4S) \to B\overline{B}) = 2N_B$$

$$Br(Y(4S) \to B\overline{B}) = 1$$

The number of B’s produced is well known

With sufficient statistics, it is possible to eliminate the Υ(4S) Br assumption,and complications from the fraction of B^+ B^+ and B^0 B^0 at the Υ(4S)

by tagging (fully reconstructing one B in the event)

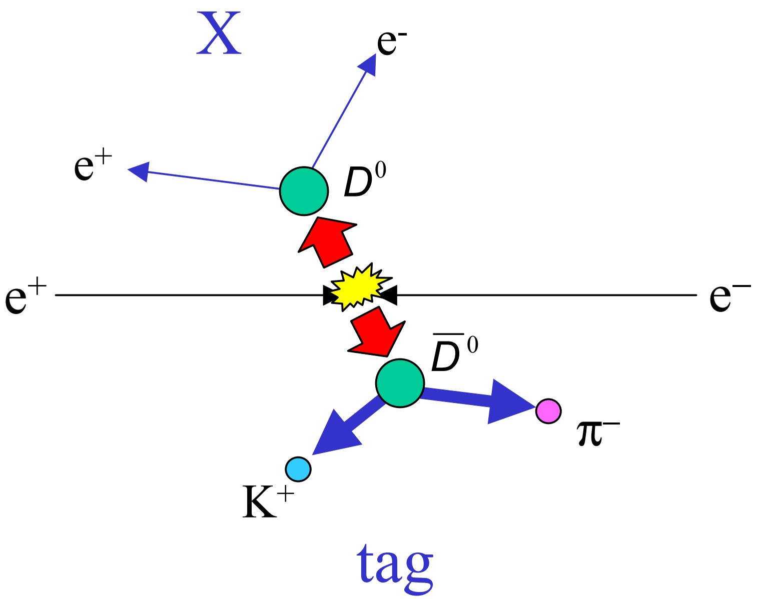
$$Br(B \to X) = \frac{\text{\#X Observed}}{\text{efficiency x \#Btags}}$$

Full B reconstruction has a low efficiency ε(tag) ~0.7%??, But will become a staple as B Factory data sets grow. Similarly, charm branching ratios could be measured at the Ψ(3770)

Absolute Charm Branching Ratios at Threshold

$\psi(3770) \to DD$

$$Br(D \to X) = \frac{\text{\#X Observed}}{\text{efficiency x \#D's produced}}$$



Where the # of D’s produced
Is the # of tags

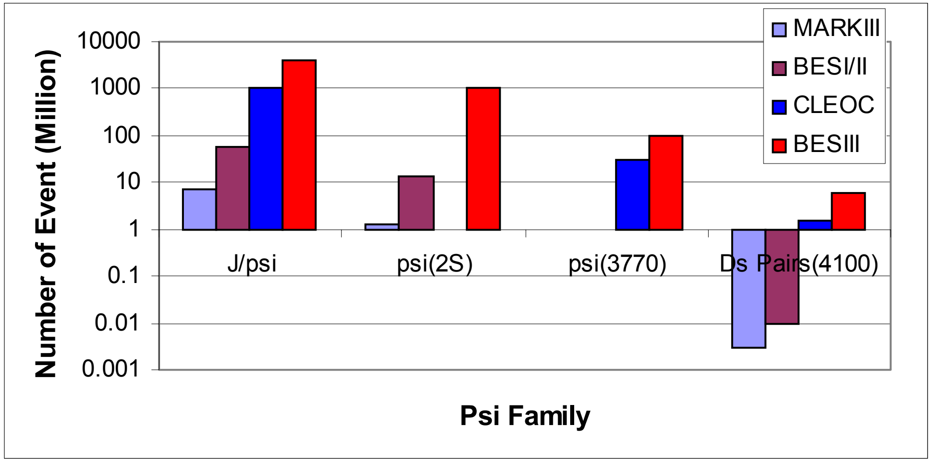
The tag efficiency at the $\psi(3770)$ is expected to be about 20% as the D has large branching ratios to 2-body final states

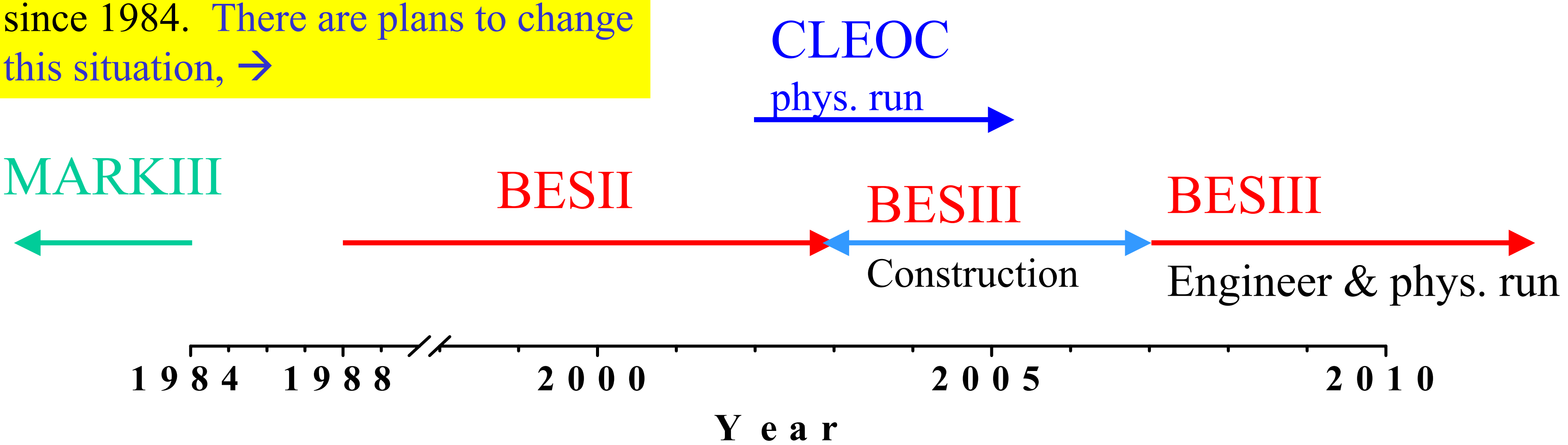
σ $\psi(3770)$ =10 nb (~x10 σ Y(4S))

Open Charm Production

experiments at Ψ(3770)		# D's
Mark III	9.6 pb^{-1}	2 x 10^{4}
CLEO-c (proposed)	3 fb^{-1}	6 x 10^{7}
BESIII (proposed)	30 fb^{-1}	6 x 10^{8}

As we will see, the Ψ(3770) is by far the best place to determine absolute charm branching ratios But nobody has operated there since 1984. There are plans to change this situation, →




CLEOC

phys. run

MARKIII

BESII

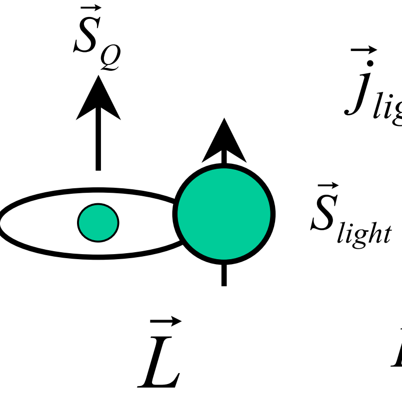
BESIII

Construction

BESIII

Engineer & phys. run

Charm Hadrons

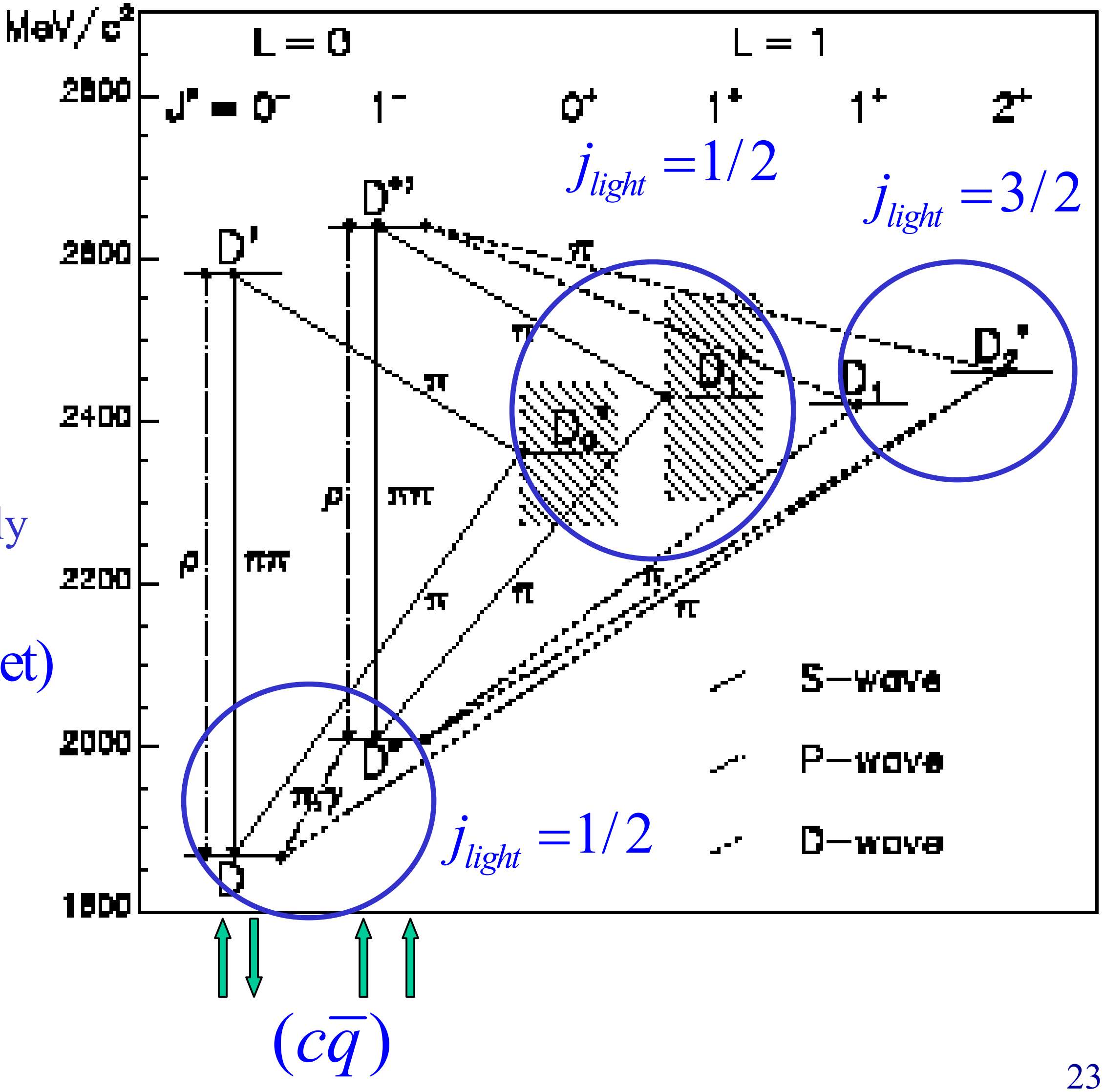


$$\vec{j}_{light} = \vec{L} + \vec{S}_{light}$$

$$\vec{J} = \vec{j}_{light} + \vec{S}_Q$$

HQET

Ciulli hep-ex/991104



Heavy quark (Q) hadrons: Q spin decouples $\propto 1/m_Q$. Spin of Q and total spin j of light quark are separately conserved quantum numbers.

$\Rightarrow J = j_{light} \pm 1/2$ (degenerate doublet)

Corrections go like Λ_{QCD} / m_Q

$\Delta m = m(D^* - D) \sim 142\, MeV$

$\Delta m = m(B^* - B) \sim 46\, MeV$

The same description works for heavy baryons

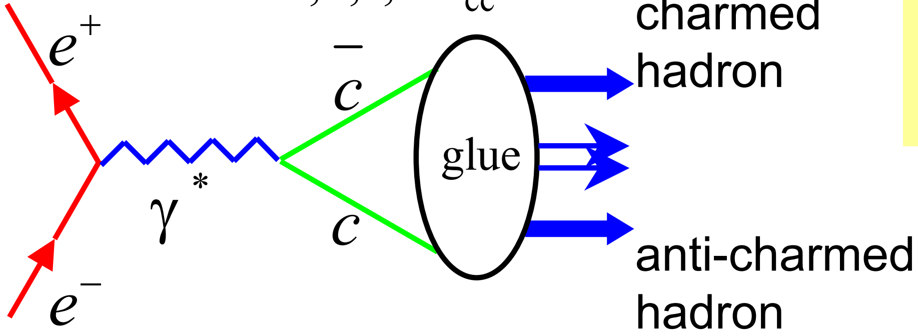
Charm Physics Facilities

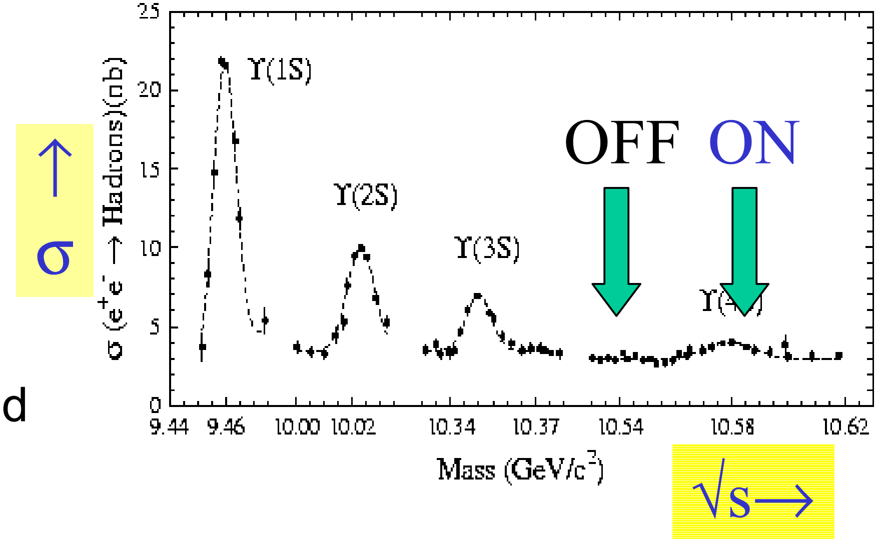
B Physics				Charm Physics	Today
→	ALEPH, DELPHI, L3, OPAL	at LEP	Z^0	←	
→	SLD	at SLD	Z^0	←	
→	CDF / D0	at TeVatron I / II	pp 1.8TeV	←	
→	CLEO	at CESR	Y(4S) symmetric	←	
→	BELLE	at KEK	Y(4S) asymmetric	←	
→	BABAR	at PEP	Y(4S) asymmetric	←	
	FOCUS	E831 FNAL	$\gamma < 300$ GeV	←	
	E731, E781 (SELEX)	at FNAL	ρ-π^- Σ^-600GeV	←	
	CLEO-C	at CESR-C	ψ	←	
→	CMS / ATLAS / LHC-B	at LHC	pp 14 TeV	←	Future
→	BTeV	at TeVatron II	pp1.8 TeV	←	
	BESII / III	at BEPC I / II	ψ	←	

Many of the charm facilities that have finished running but are still producing results, currently running facilities, and future facilities are listed above. Most charm physics facilities are also B physics facilities, exceptions are the fixed target experiments

Charm Production near/at the Υ(4S)

Non-resonant production
to all hadrons u,d,s,c $\sigma_{cc} \approx 1$ nb



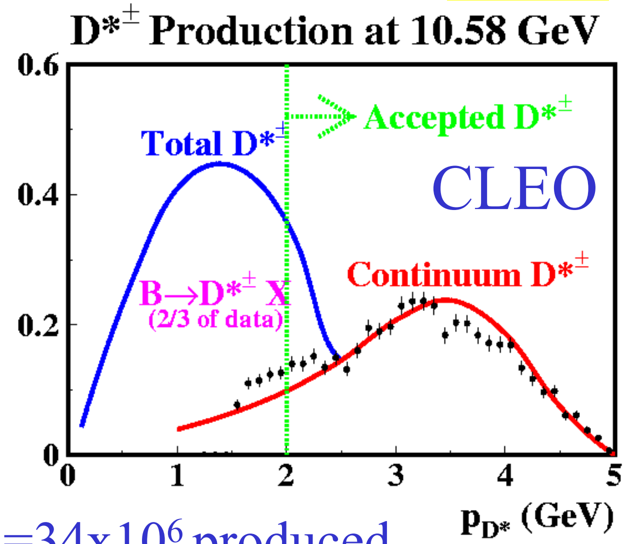


→D, D_s, Λ_c, Ξ_c…

+ σ(B➔ c) ≈ 1 nb   1+1 =2 nb

D's move ~150 microns, but, energy of D's is a priori unknown and the charm, and anti-charm hadron types are not strongly correlated

Reconstructing a $\bar{D}^0$ does not mean the charm hadron in the event is a D^0, a $D^+, D_S, \Lambda_c, \Xi_c, \Omega_c$ or any other ground state or excited charm hadron is also a possibility



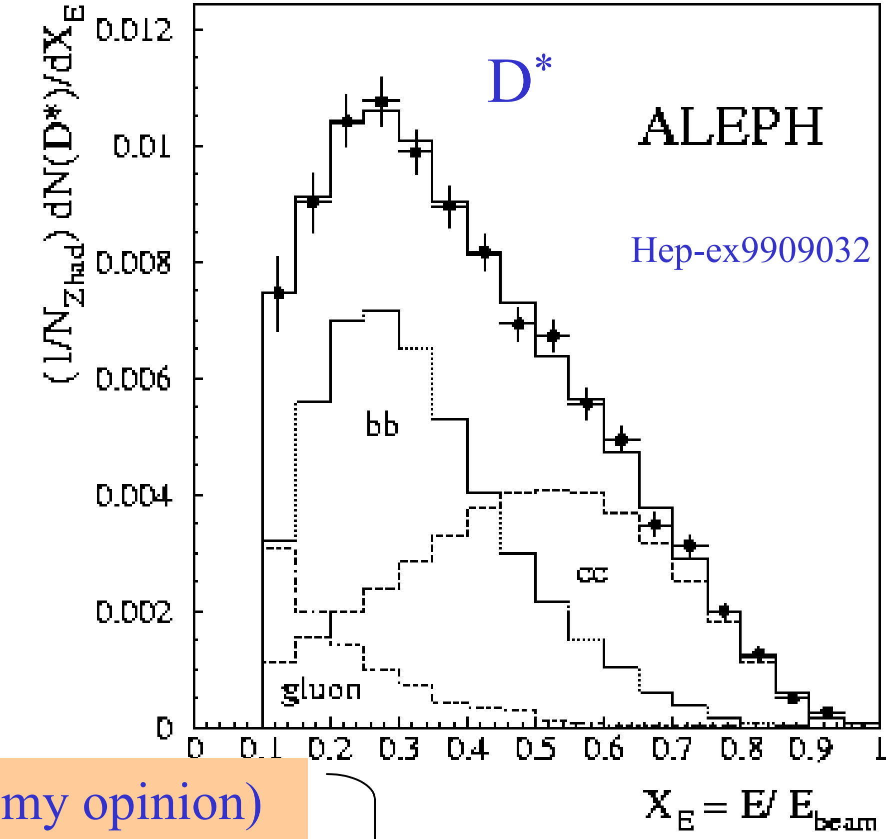
→absolute charm Br's difficult

3 experiments,CLEO #c's=34x10^6 produced
BABAR,BELLE #c'=x(5-6) CLEO now, by 2005 x40CLEO

Charm Production at the Z^0

Br(Z^0→ cc) ~ 11%
→3 x 10^6 c's /LEP expt
→ D, D_s, Λ_c,Ξ_c…
→<p> ~ 40 GeV
→Excellent reconstruction of Charm vertices

As at 10GeV, the flavors of charm anti-charm pairs produced in Z^0 decays are not correlated → absolute charm Br's are difficult



Hep-ex9909032

Main LEP contributions to charm physics: (my opinion)

- electro-weak measurements: R_c =(Z^0→ cc)/ (Z^0→ had)
  $A_{FB}{}^c$ (charge asymmetry in $e^+ e^-$ → cc)

See: http://lepewwg.web.cern.ch/LEPEWWG/

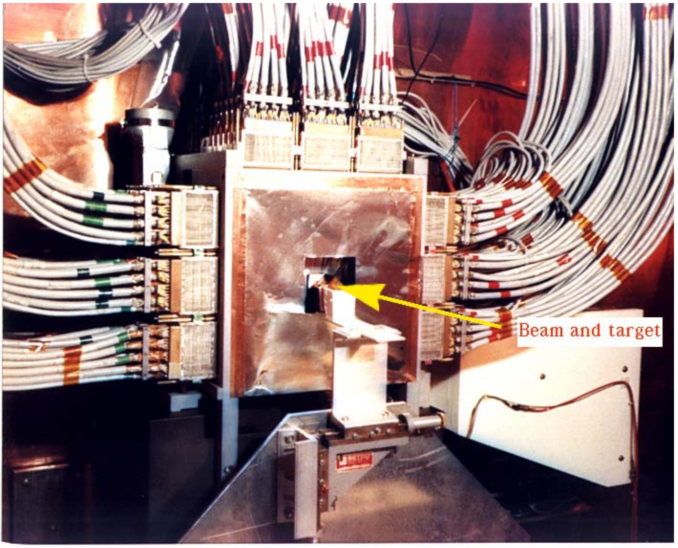
- c-quark fragmentation function
- Ds decay constant

Will not
discuss
In lecture

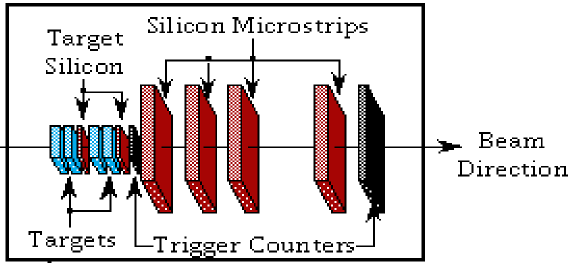
Photo production: FOCUS

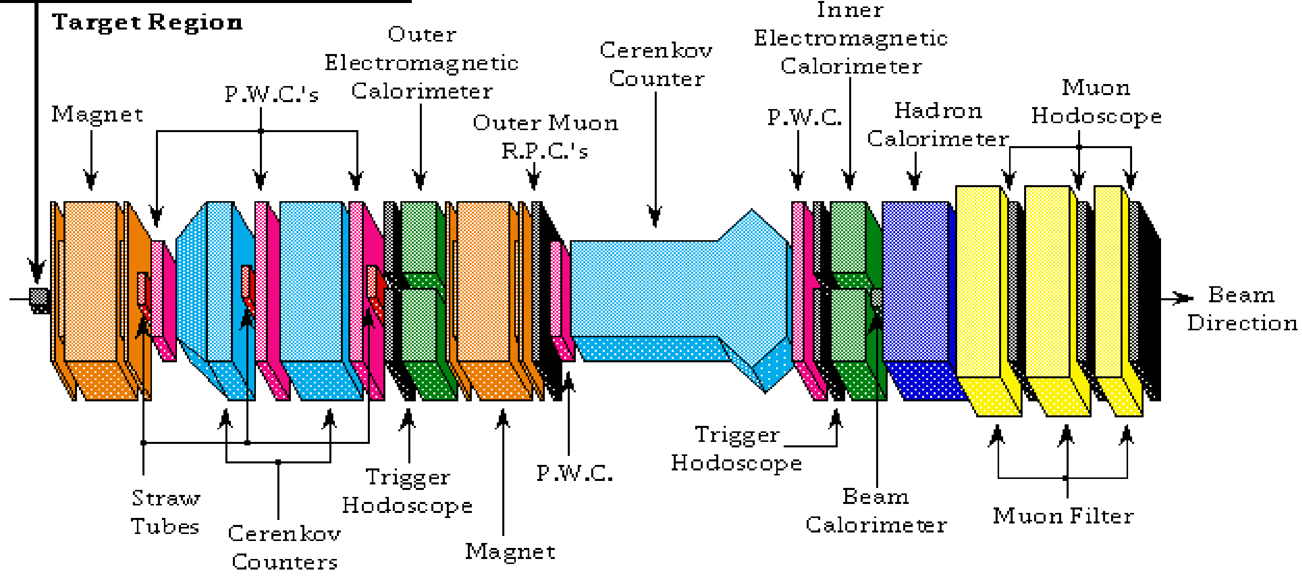
Fixed target experiments have long been at the frontier of charm physics

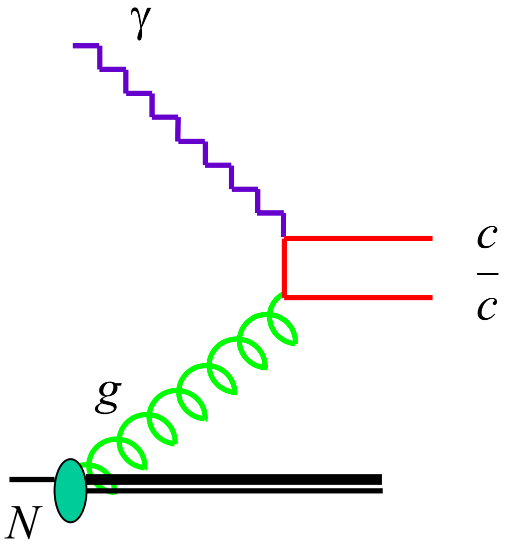
Detector scale typical, tiny front end



E831 FOCUS Spectro

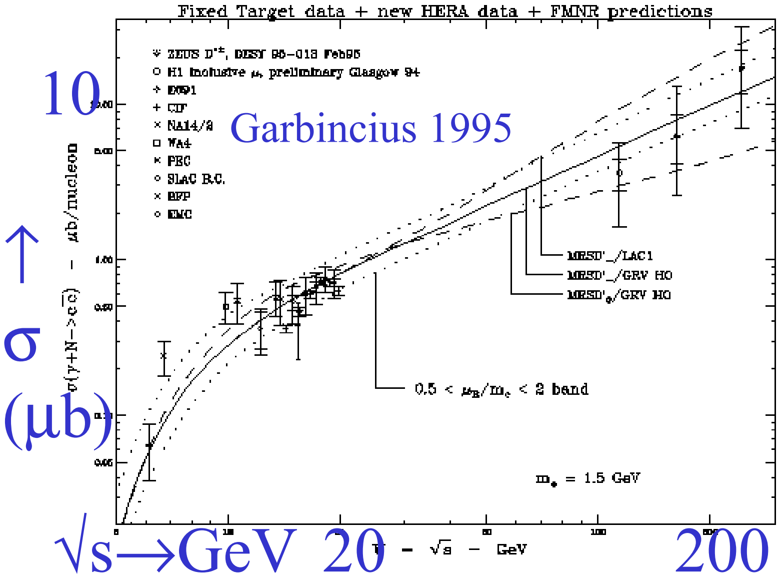




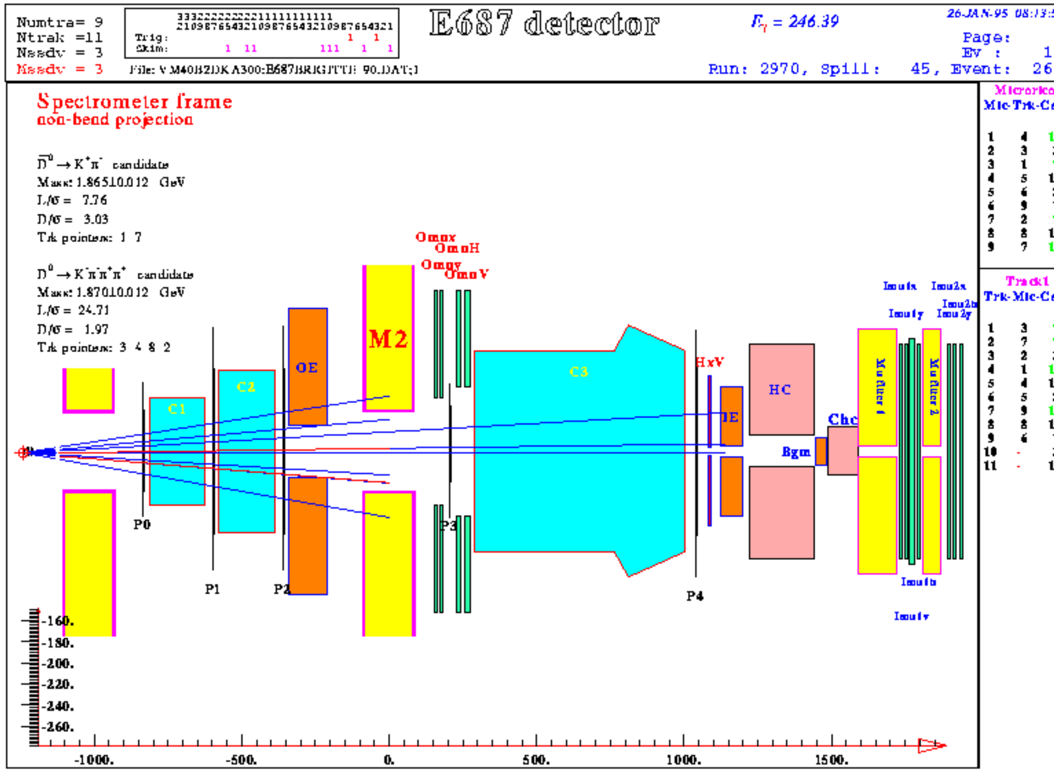


FOCUS: photoproduction

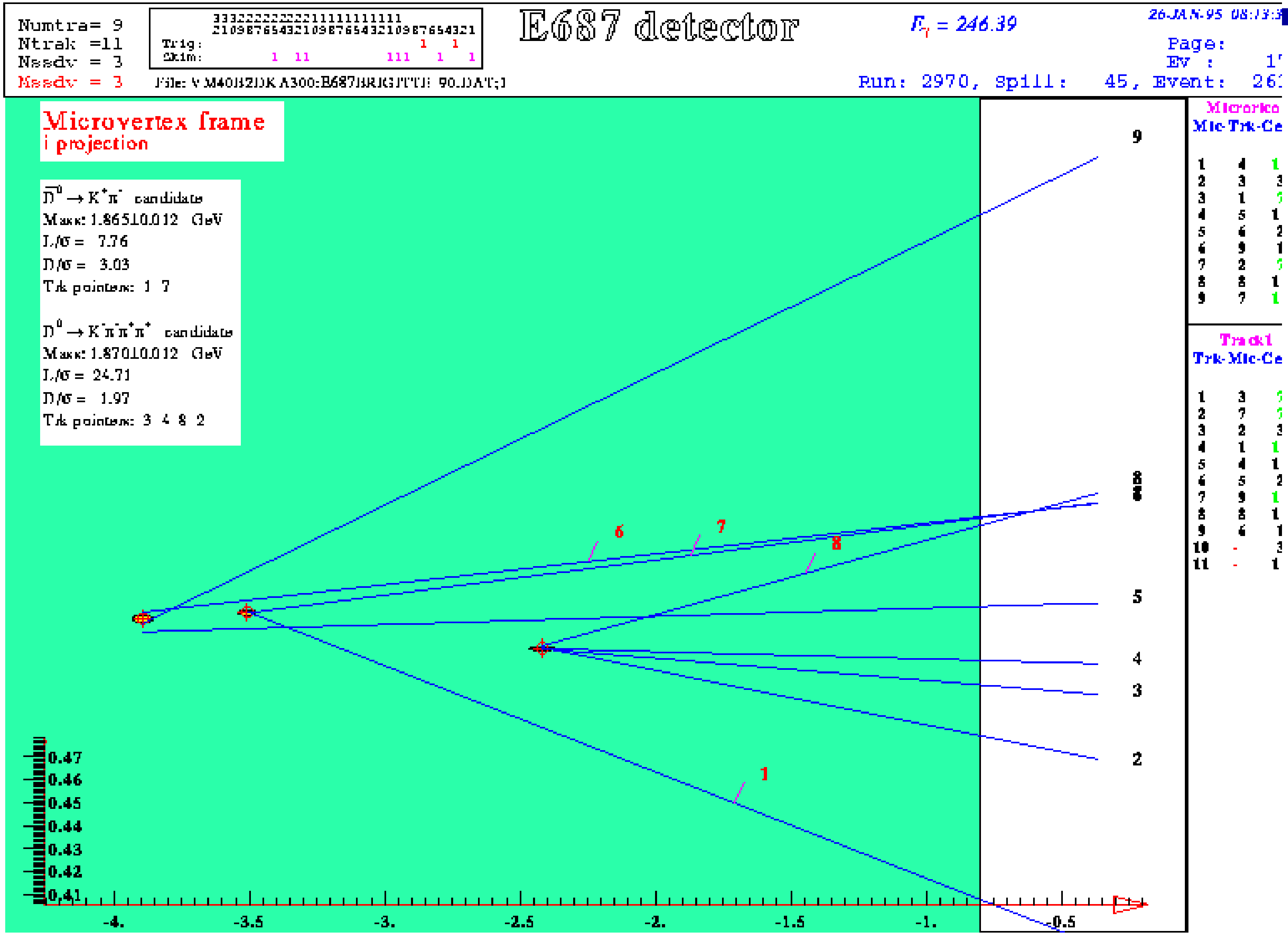
(Also HERA)



~10^8 c produced
> 10^6 c reconstructed
Excellent:
-Vertex Resolution
-Particle ID & $\delta p_T/p_T$
D, D_s, Λ_c, Ξ_c.....
Lifetimes. Mixing
No absolute Br's



FOCUS: close-up



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Ntrak =11      21098765432109876543210987654321
Nssdv = 3      Trig:                             1   1
Nssdv = 3      Skim:          1   11         111   1    1
               File: V M40H2DK A300:E687HRKGPTTE 90.DAT;1
```

E687 detector

E_T = 246.39

26-JAN-95 08:13:3

Page:
Ev : 1
Run: 2970, Spill: 45, Event: 26

Microvertex frame
i projection

$\overline{D}^0 \rightarrow K^+\pi^-$ candidate
Mass: 1.865±0.012 GeV
L/σ = 7.76
D/σ = 3.03
Trk pointers: 1 7

$D^0 \rightarrow K^-\pi^-\pi^+\pi^+$ candidate
Mass: 1.870±0.012 GeV
L/σ = 24.71
D/σ = 1.97
Trk pointers: 3 4 8 2

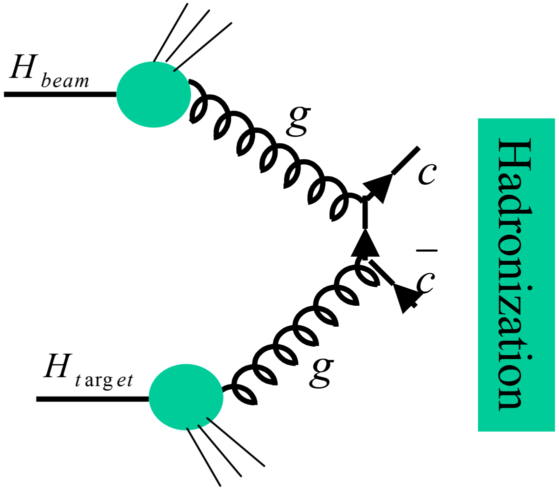
Microrkc

Mic	Trk	Ce
1	4	1
2	3	3
3	1	[illegible]
4	5	1
5	6	2
6	9	1
7	2	[illegible]
8	8	1
9	7	1

Track1

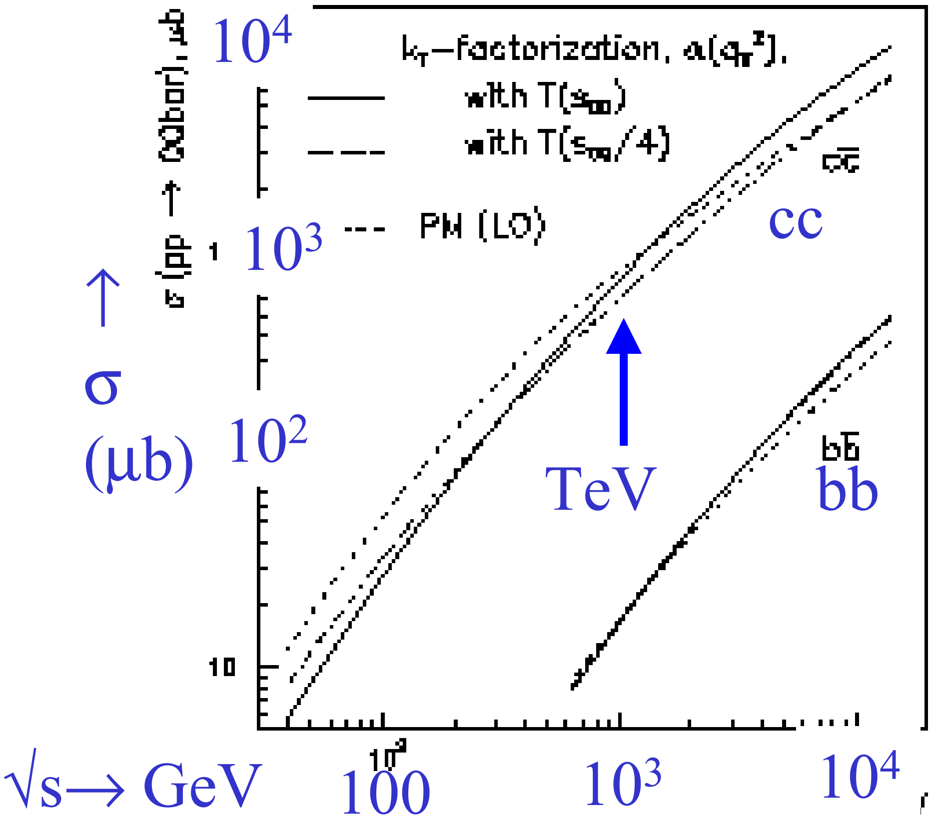
Trk	Mic	Ce
1	3	[illegible]
2	7	[illegible]
3	2	3
4	1	1
5	4	1
6	5	2
7	9	1
8	8	1
9	6	1
10	-	3
11	-	1

Hadroproduction



- SELEX (E791) at FNAL 10^4 (10^5) c's reconstructed
- * Millibarns at the Tevatron
  ~10^{13}c's/year Run II
  (also BTeV)
- * X 10 at LHC
- * HERA-B

Ryskin, Shabelski,Shuvaev, 2000

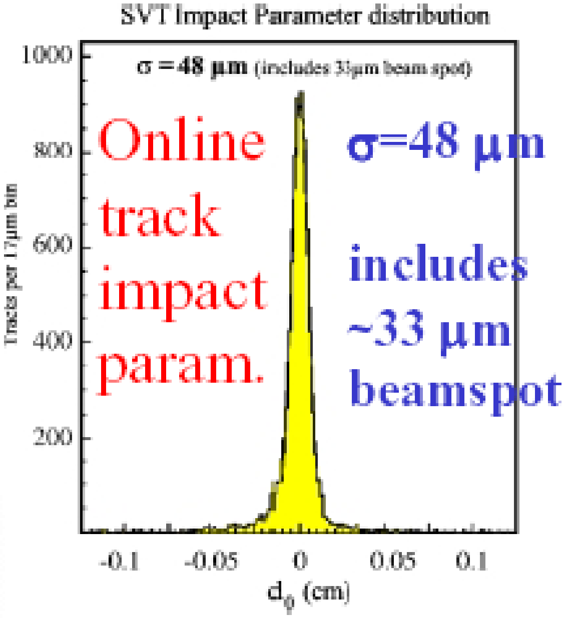


Charm at CDF

ICHEP2002

The hadronic B trigger a major milestone
~150 VME boards find and fit tracks in Silicon, offline accuracy in a

15μs pipeline

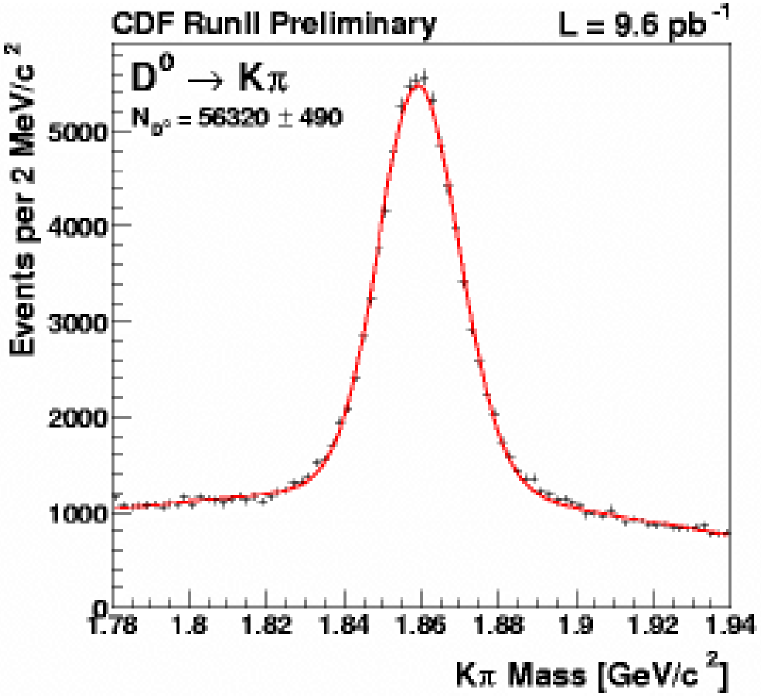


Online track impact param.

σ=48 μm

includes ~33 μm beamspot

Secondary vertex level 2 trigger
|D|> 100 μm (2 body)



Charm at CDF

ICHEP2002

- $\Gamma(D \rightarrow KK)/\Gamma(D \rightarrow K\pi) = (11.17 \pm 0.48 \pm 0.98)\%$ (PDG: 10.83 ± 0.27) (E687, E791, CLEO2)
  - Main systematic (8%): background subtraction

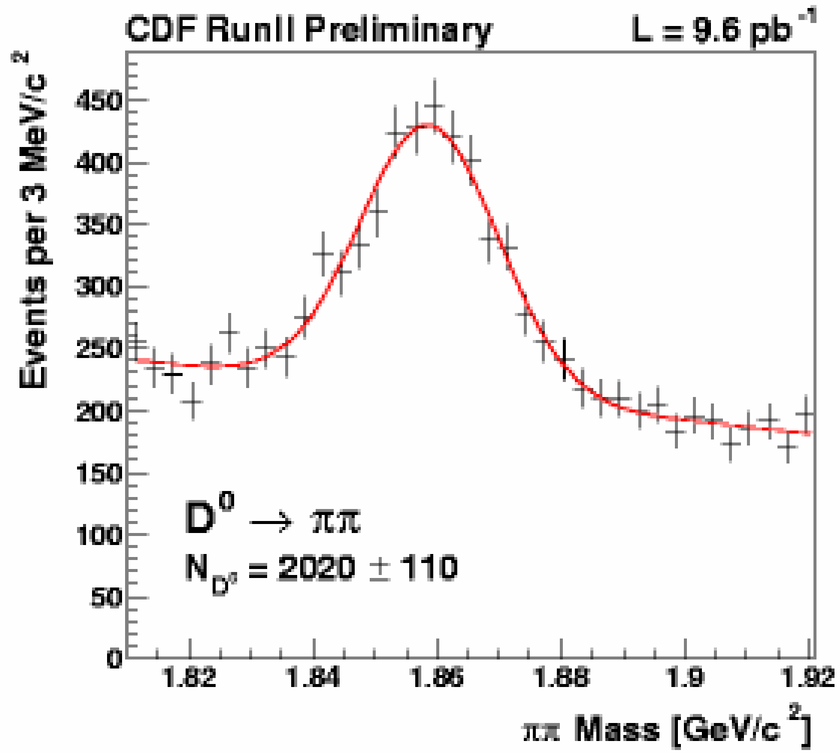
Cabbibo suppressed

- $\Gamma(D \rightarrow \pi\pi)/\Gamma(D \rightarrow K\pi) = (3.37 \pm 0.20 \pm 0.16)\%$ (PDG: 3.76 ± 0.17)
  - several ~2% systematics

Already comparable!

Great potential if charm Stays within the trigger Bandwidth: expect 10^7 $D^0 \rightarrow K\pi$ reconstructed in RunII $2 fb^{-1}$

CDF can address D mixing, DCPV and rare decays Not absolute branching ratios



Summary of current & future charm particle data sources

~total # recon. charm

	Fixed Target			e^+e^- Collider		
	E791	SELEX	FOCUS (& E687)	CLEO	BABAR	BELLE
Beam	Hadronic		Photon	Off-resonance e^+e^-		
Charm	$\sim 10^5$	$\sim 10^4$	$\sim 10^6$		$>10^6$	
σ_t	~40 fs	~20 fs	~40 fs	~140 fs	~160 fs	

→X40 CLEO By 2005

CDF 10^7 $D \to K^-\pi^+$ reconstructed in RunII

BTeV could have 10^9 D's

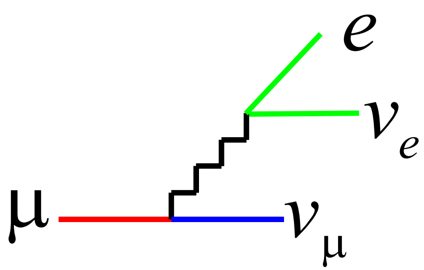
CLEO-c 3 x10^6 tagged DD

F.T. expts. Measure the c-hadron decay time very precisely this is also crucial to isolate clean event samples

e+e- : higher relative production rate of charm compared to background, better mass resolution and great PID mean samples of comparable purity even though time resolution is X10 worse

Lifetimes

Muon decay: $$\Gamma_o = \frac{G_F^2 m_\mu^5}{192\pi^3}$$



Naïve spectator model for charm

e, μ $u\bar{d}$ x 3 colors

$$\Gamma_c = (2+3)\Gamma_0 \qquad \Gamma_o = \frac{G_F^2 m_c^5}{192\pi^3}|V_{cs}|^2$$

Scaling from the muon: $$\tau_c = \frac{1}{5}\left(\frac{0.105}{1.5}\right)^5 2.2\times10^{-6} = 7\times10^{-13}s$$

(700 fs)

τ(D+) ~1,000 fs τ (D0) ~400 fs. Not too bad. Including baryons lifetimes vary between ~100 and 1000 fs,→ non-spectator processes and higher order corrections

Charm Hadron Lifetimes

$$\frac{Br}{\tau} = \Gamma$$

Lifetime needed to compare Br(expt) to Γ (theory)

Test techniques/systematics in other areas where lifetime resolution/vertexing is important: eg B/D Δm,ΔΓ

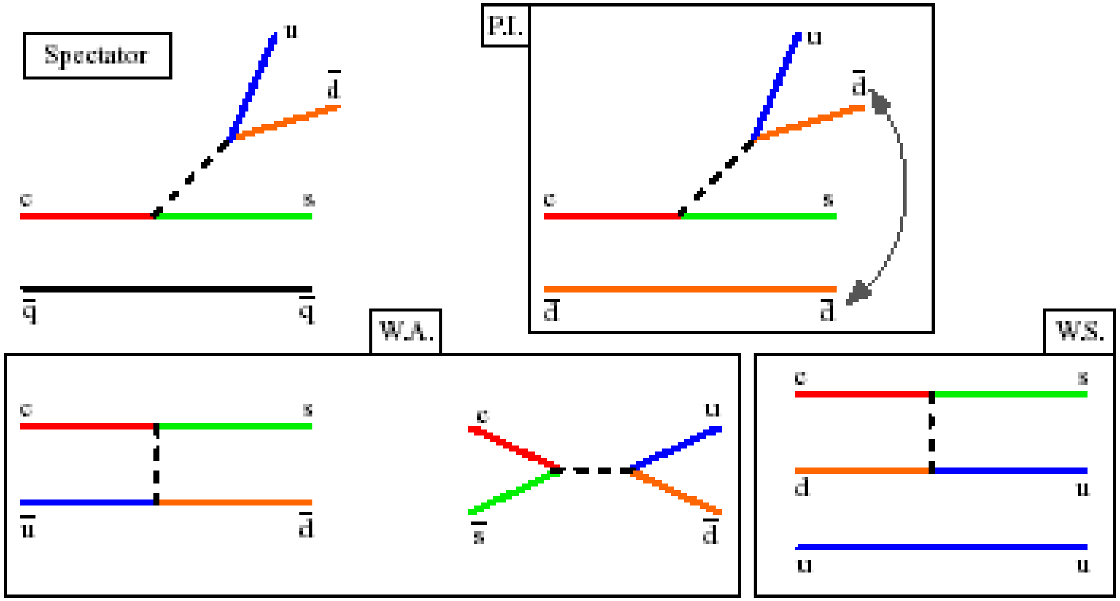
Interpreted with O.P.E.

$$\Gamma(H_c) = \Gamma_{spect} + O(1/m_c^2) + \Gamma_{PI,WA,WS}(H_c) + O(1/m_c^4)$$

Spectator effects (PI.WA,WS) are $O(1/m_c^3)$ but phase space enhanced

Note:hadrons behave more like free quarks the heavier the quark

See G. Bellini, I.I Bigi & P. Dornan
Phys Rep. **289** (1997)

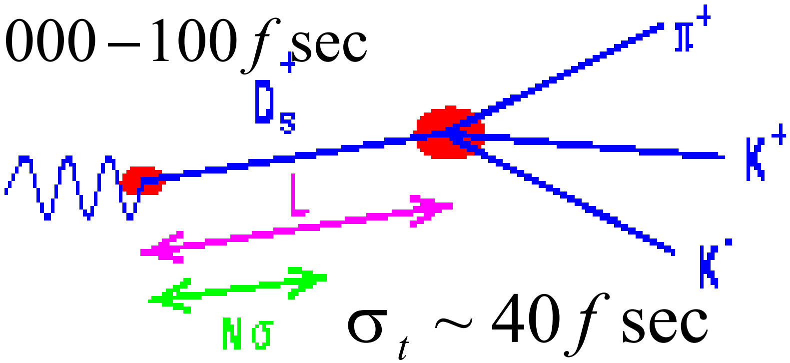


Gross features of the lifetime hierachy can be explained

Lifetimes at Fixed Target Experiments

$t = 10^{-12} - 10^{-13}$ sec

$1000 - 100\, f$ sec



$\sigma_t \sim 40\, f$ sec

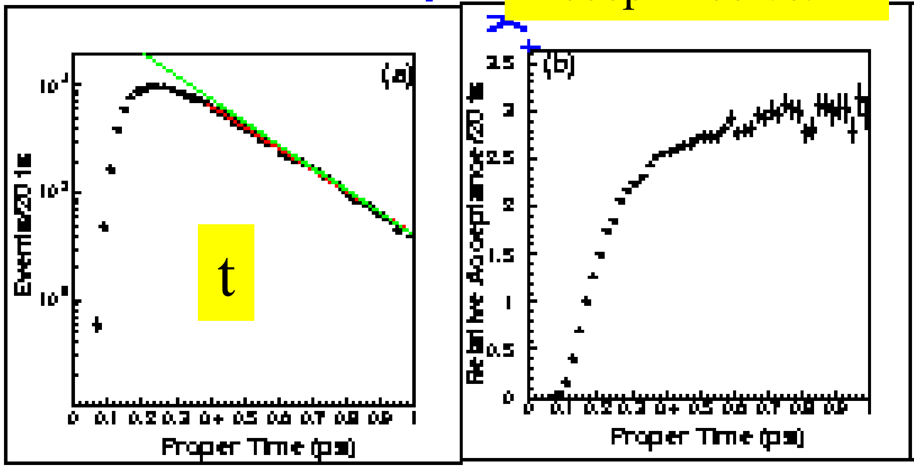
- Short flight path, need silicon
- L > Nσ_L (and outside target)
- Reduced proper time:

  t' = L/βγc - N σ_L/βγc

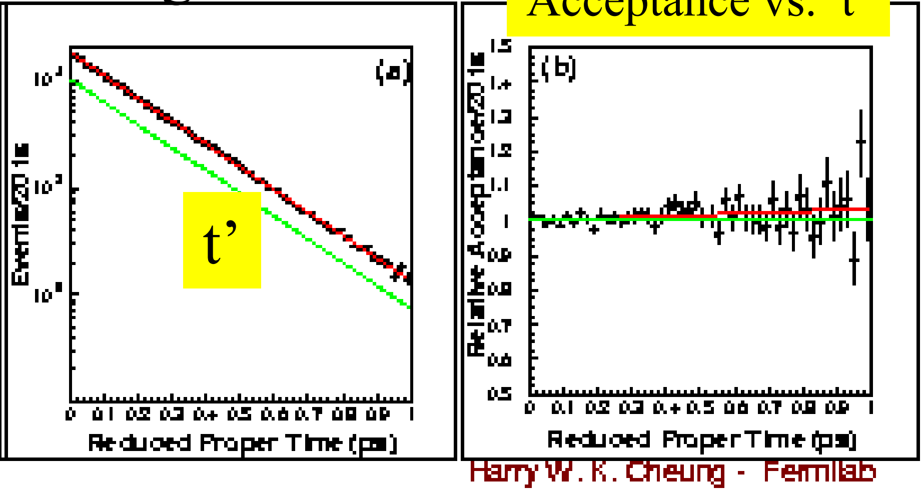
  to reduce acceptance corrections
- Acceptance checked with data (K_S)
- Systematics from acceptance &/or background

L 3D decay length

Acceptance vs. t

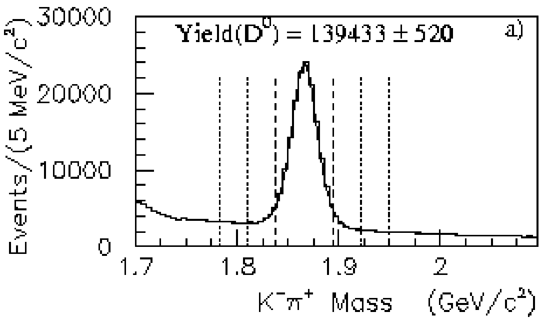


Acceptance vs. t'



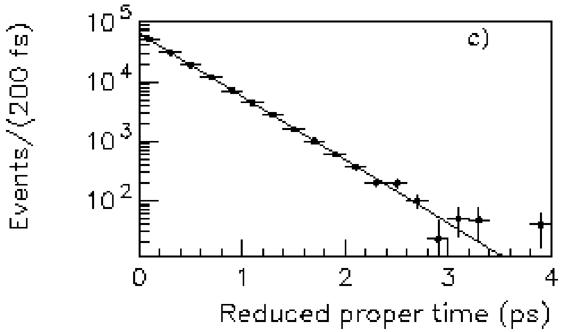
Harry W. K. Cheung - Fermilab

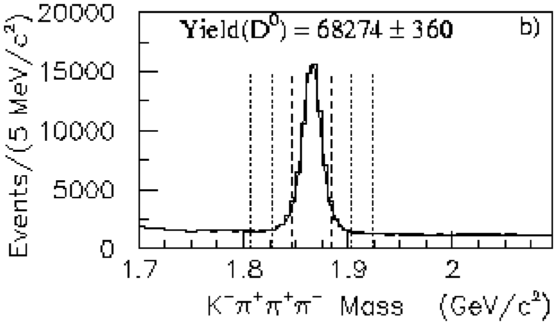
Charm Meson Lifetimes



$D^0 \rightarrow K^-\pi^+$

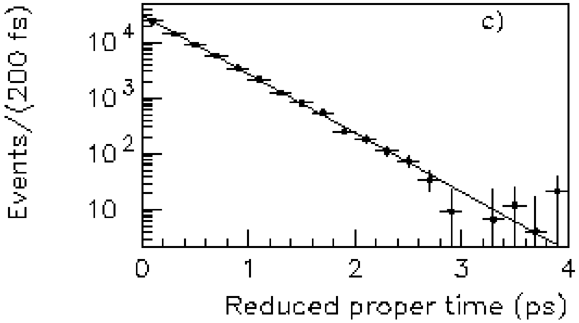
139433 ±520 evts

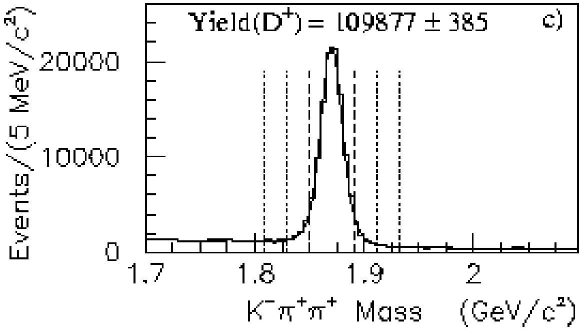




$D^0 \rightarrow K^-\pi^+\pi^-\pi^+$

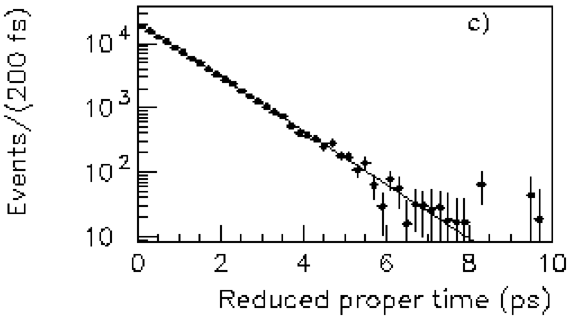
68274 ±360 evts





$D^+ \rightarrow K^-\pi^+\pi^+$

109877 ±385 evts

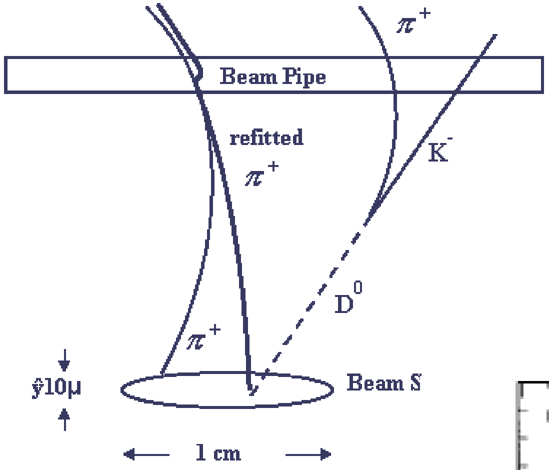


D^0, D^+ Signal

D^0, D^+ Lifetime fits

Lifetimes at e^+e^- colliders

Υ(4S) stationary
L <D,Ξ_c^+> 150 μm

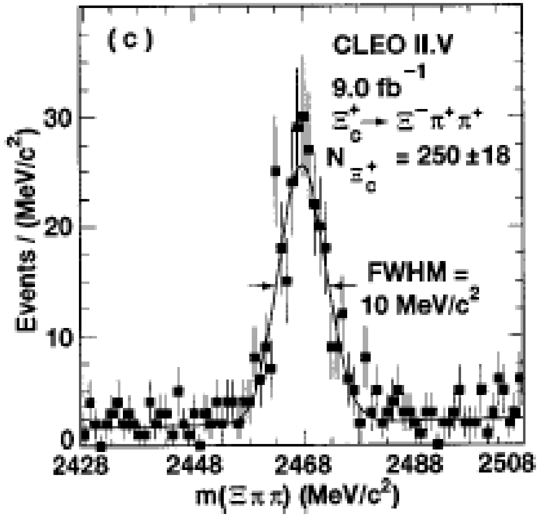


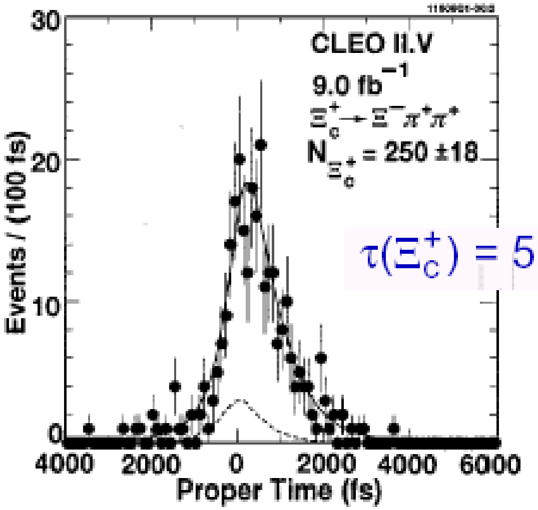
* Silicon vertex detectors ➔ charm lifetimes
But poorer time resolution ~ 140 fsec (CLEO)

- Needs average IP position
- Uses 2-D (or 1-D) decay length
- Needs good knowledge of mass and t resolutions
- Complicated fits using parameterized resolution and background functions
- Systematics from vertexing, resolutions and fit biases

$$\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi$$

PRD 650311
2002





$\tau(\Xi_c^+) = 503 \pm 47 \pm 18$ fs

D Meson Lifetimes

Phys.Lett.B537,192 ,2002 $\boxed{\tau_{D+} = 1042.7 \pm 6.9}$

New precise measurements of $\tau(D^0)$, $\tau(D^+)$ $\tau(D_s)$ from FOCUS

$$\tau(D^0) = 409.6 \pm 1.1(stat) \pm 1.5(sys)$$

$$\tau(D^+) = 1039.4 \pm 4.3(stat) \pm 7.0(sys)$$

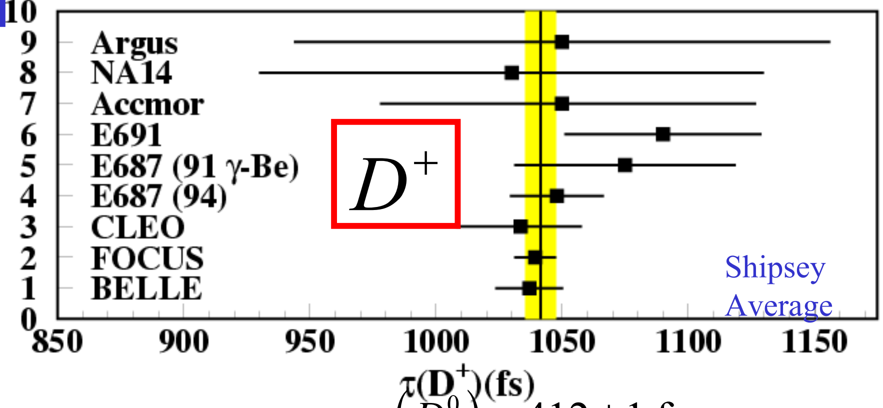
$$\frac{\tau_{D^+}}{\tau_{D^0}} \approx 2.583 \pm 0.023 \qquad \boxed{\tau_{D^0} = 410.5 \pm 1.5}$$

Abs. Exclusive semileptonic decays key to interpreting lifetime ratio

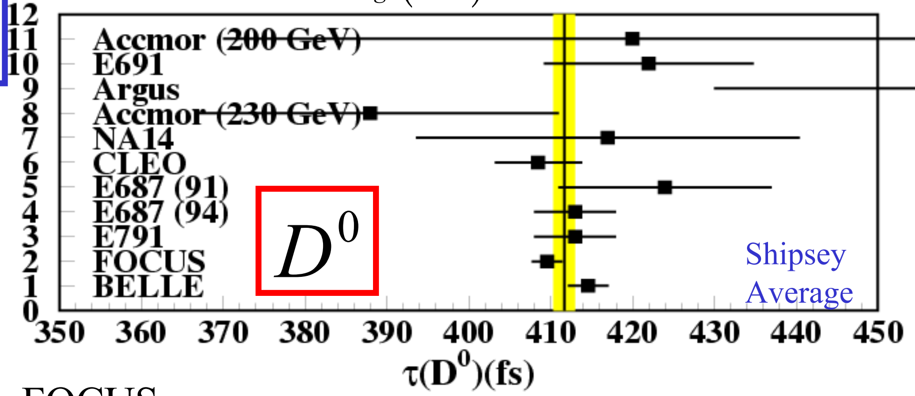
$$\frac{\Gamma(D^0 \to eX)}{\Gamma(D^+ \to eX)} = \frac{B(D^0 \to eX)}{B(D^+ \to eX)} \times \frac{\tau(D^+)}{\tau(D^0)} = 1.01 \pm 0.13$$

Large observed liftetime ratio must arise due to destructive interference in hadronic diagrams contributing only to D^+ decays (see later)

$\tau_{avg}(D^+) = 1042 \pm 6$ fs



$\tau_{avg}(D^0) = 412 \pm 1$ fs



FOCUS

Note:lifetimes much better known than absolute BR's

$D^+ \to eX = (17.2 \pm 1.9)\%$

$D^0 \to eX = (6.87 \pm 0.28)\%$

PDG2002

Lifetime Summary I

$\tau(D^0)$	$411.7 \pm 1.3\,fs$
$\tau(D^+)$	$1041.5 \pm 6.2\,fs$
$\tau(D_s)$	$501.7 \pm 6.1\,fs$
$\tau(\Lambda_c)$	$199.7 \pm 3.3\,fs$
$\tau(\Xi^+{}_c)$	$422.3^{+20.1}_{-18.7}\,fs$
$\tau(\Xi^0{}_c)$	$106.3^{+9.2}_{-7.8}\,fs$
$\tau(\Omega_c)$	$73.6^{+11.8}_{-12.1}\,fs$

Updated after ICHEP02

$$\frac{\tau(D^+)}{\tau(D^0)} = 2.53 \pm 0.02 \quad \text{P.I.(-)}$$

$$\frac{\tau(D_s)}{\tau(D^0)} = 1.22 \pm 0.02 \quad \text{W.A. or ??}$$

$$\frac{\tau(\Lambda_c)}{\tau(D^0)} = 0.49 \pm 0.01 \quad \text{W.S./P.I.(-)}$$

$$\frac{\tau(\Xi^+)}{\tau(\Lambda_c)} = 2.11 \pm 0.14 \quad \text{W.S.P.I.(}\pm\text{)}$$

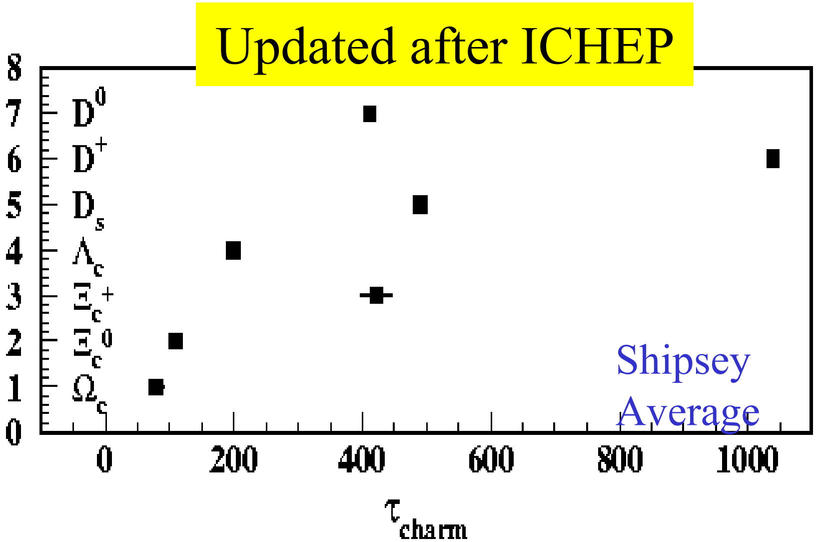
To interpret this important to check $\Gamma(D_s \to eX) / \Gamma(D^0 \to eX)$ But absolute $B(D_s \to eX)$ is only known to 63%!

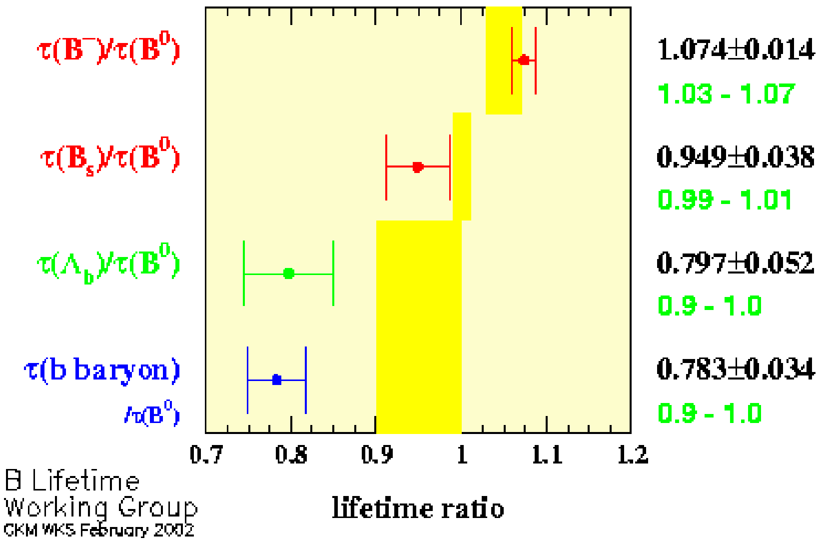
D^+ 6 ‰, D^0 3 ‰, D_s 2 % Λ_c2%,Ξ^0 10%, Ξ^+_c 6 %,Ω_c 15%
some lifetimes known as precisely as kaon lifetimes

Shipsey Averages

Lifetimes span 1 order of magnitude

Compare Charm to Beauty Lifetimes





B Lifetime Working Group
CKM WKS February 2002

Plot from Stocchi ICHEP2002

$$\frac{\Gamma_c(P.I.WA..S)}{\Gamma_c(spect)} \approx \frac{f_D^2 m_b^2}{f_B^2 m_c^2} \frac{\Gamma_b(P.I.WA..S)}{\Gamma_b(spect)} \approx 10$$

Charm quarks are much more influenced by the hadronic environment than are beauty quarks

Very precisely determined lifetimes. The agreement with theory is still qualitative

Important message:errors on lifetimes are not a limiting factors in our ability to calculate absolute rates. The limiting factor is errors on absolute branching ratios .

D Nonleptonic Decays

Nonleptonic decays dominate the total rate

$$\left.\begin{aligned} D^+(c\bar{d}):\tau_+ &= 1042.7 \pm 6.9\ fs \\ D^0(c\bar{u}):\tau_0 &= 410.5 \pm 1.5\ fs \end{aligned}\right\} \quad \tau_+/\tau_0 \approx 2.5$$

Quarks or hadrons? ….in between

Compare to kaons and B-mesons:

$$\left.\begin{aligned} K^+(\bar{s}u):\tau_+ &= 12390 \pm 20\ ps \\ K^0(\bar{s}d):\tau_0 &= 178.7 \pm 0.16\ ps \end{aligned}\right\} \quad \tau_+/\tau_0 \approx 70$$

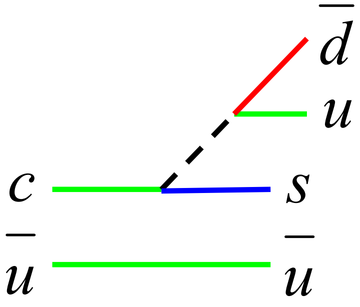
Hadrons

$$\left.\begin{aligned} B^+(\bar{b}u):\tau_+ &= 1655 \pm 24 \quad fs \\ B^0(\bar{b}d):\tau_0 &= 1540 \pm 24 \quad fs \end{aligned}\right\} \quad \tau_+/\tau_0 \approx 1.07$$

quarks

The lifetime hierarchy (quark diagram level)

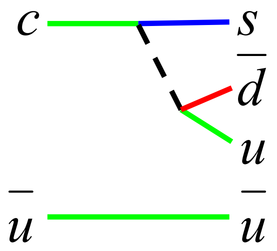
B decays : small BRs to 2- body final states (phase space)
2-body decays dominate D decays (multi-body decays found to be quasi 2 body) →
Is the D^0 D$^+$ lifetime hierarchy understandable in terms of 2 body hadronic decays?



$D^0 \to K^-\pi^+$

$BR \sim 3.83\%$

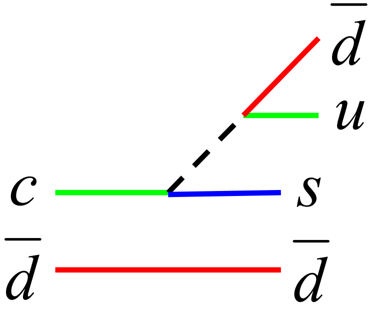
$A \propto \sqrt{\frac{BR}{\tau}} \equiv 1$



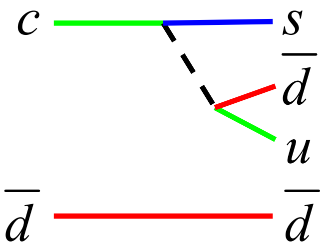
$D^0 \to \overline{K^0}\pi^0$

$BR \sim 2.11\%$

$A = 0.74$

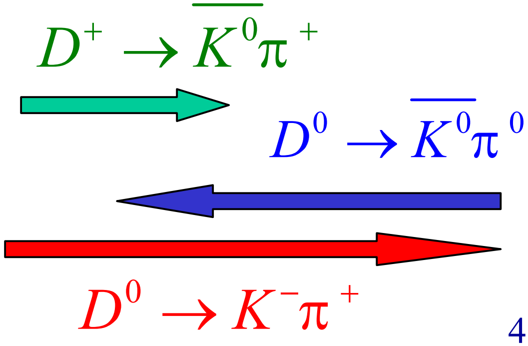


$D^+ \to \overline{K^0}\pi^+$



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

For the D^o (D$^+$) the two states are distinct (identical)
100% Destructive interference predicts : A = 1 – 0.74 = 0.26
Measure: A = 0.54
Difference due to hadronic final state interactions



…..and at the hadronic level

Simple factorization picture describes 2 body hadronic decays established for B's. For charm sizeable final state interactions are the norm.

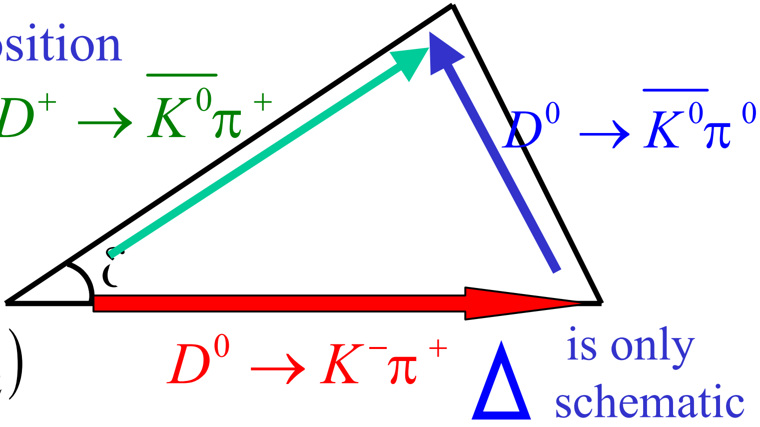
$$A(D^0 \to K^-\pi^+) = \sqrt{\frac{2}{3}} A_{1/2} + \sqrt{\frac{1}{3}} A_{3/2}$$

Isospin decomposition

$$A(D^0 \to \overline{K^0}\pi^0) = -\frac{1}{\sqrt{3}} A_{1/2} + \sqrt{\frac{2}{3}} A_{3/2})$$

$$A(D^+ \to \overline{K^0}\pi^+) = \sqrt{3} A_{3/2} \qquad A_I = A_I e^{i\delta}$$

$$|A_{1/2} + A_{3/2}|^2 = |A_{1/2}|^2 + |A_{3/2}|^2 + 2|A_{1/2}||A_{3/2}|\cos(\delta_{3/2} - \delta_{1/2})$$



measure: $|A(D^0 \to K^-\pi^+)|^2 + |A(D^0 \to \overline{K^0}\pi^0)|^2 = |A_{1/2}|^2 + |A_{3/2}|^2$:extract

measure: $|A(D^+ \to \overline{K^0}\pi^+)|^2 = 3|A_{3/2}|^2$:extract

find: $|A_{3/2}|/|A_{1/2}| = 0.37 \pm 0.03 \quad \delta = (\delta_2 - \delta_0) = 90^\circ \pm 7^\circ$ Rosner hep-ph/9903543

Many similar cases. Substantial modification of hadronic 2-body BR's due to FSI.

The presence of strong phases between amplitudes is an important ingredient in mixing studies and in CP violation

Charm branching ratios

$$\frac{Br}{\tau} = \Gamma$$

Most branching ratios in contrast to lifetimes are not well known

We have just seen that τ is measured very precisely

Key charm decay modes used to normalize B physics

Particle	Mode	PDG (%)	Error(%)
D^{o}	$K^{-}\pi^{+}$	3.83±0.09	2.3
D^{+}	$K^{-}\pi^{+}\pi^{+}$	9.0±0.6	6.7
D_s	$\phi\pi^{+}$	3.6±0.9	25
Λ_c	$pK^{-}\pi^{+}$	$9.7 > \mathcal{B} > 3.0$	@90% c.l
J/ψ	$\mu^{+}\mu^{-}$	5.88 ±0.10	1.7

$$Br(D \to X) = \frac{\text{\#X Observed}}{\text{efficiency x \#D's produced}}$$

Because #D's produced is not well known

Measurement of B($D^o \rightarrow K^- \pi^+$)

B (%)	Error(%)	Source
3.82±0.07±0.12	3.6	CLEO
3.82±0.09±0.12	3.8	ALEPH
3.83±0.09	2.3	PDG

- Method:
- Detect $D^{*+} \rightarrow \pi^+ D^o$, $D^o \rightarrow K^- \pi^+$

compare to:

$D^{*+} \rightarrow \pi^+ D^o$, $D^o \rightarrow$ unobserved

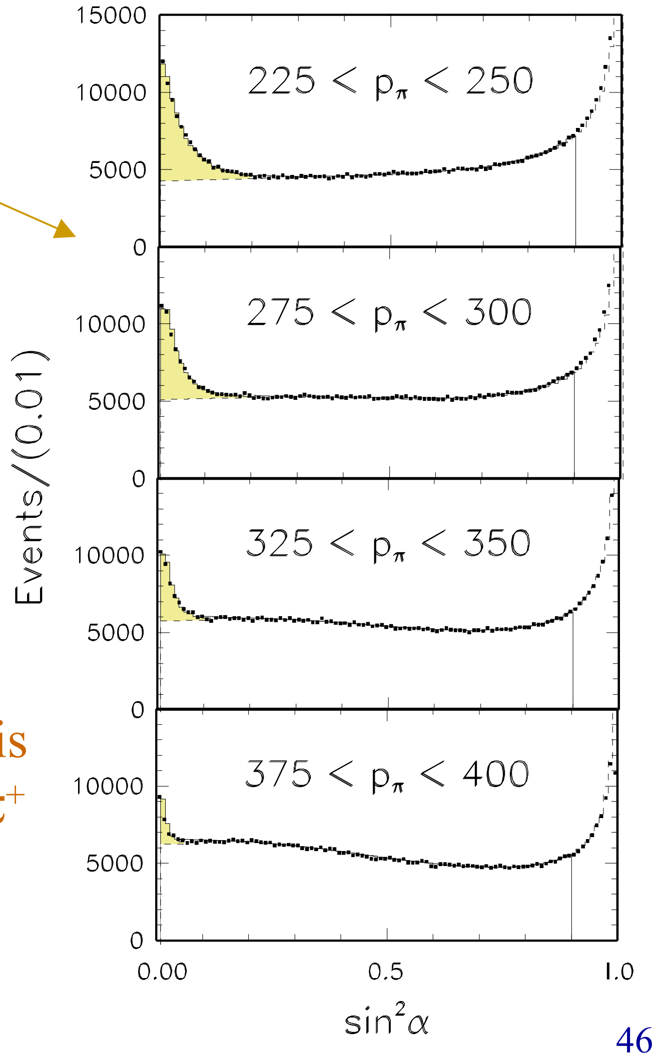
- Problem: Systematic error due to background extrapolation

(CLEO & ALEPH Use same technique)

α is ∡ between thrust axis & slow π^+ (4 of 8 intervals shown)

(Thrust is a measure of the direction of the primary quark pair in the event)

$D^{*+} \rightarrow D^0 \pi^+ \quad Q \sim 6 MeV$



$B(D^+\to K^-\pi^+\pi^+)$

B (%)	Error(%)	Source
9.3±0.6±0.8	10.8	CLEO
9.1±1.3±0.4	14.9	MKIII
9.1±0.7	7.7	PDG

From 9.6 pb^{-1} (1984)

- Method (CLEO): Measure:

Assume this ratio is of Strong decays is given by isospin symmetry

$$\frac{B(D^{*+}\to D^0\pi^+)\quad B(D^0\to K^-\pi^+)}{B(D^{*+}\to D^+\pi^0)\quad B(D^+\to K^-\pi^+\pi^+)}$$

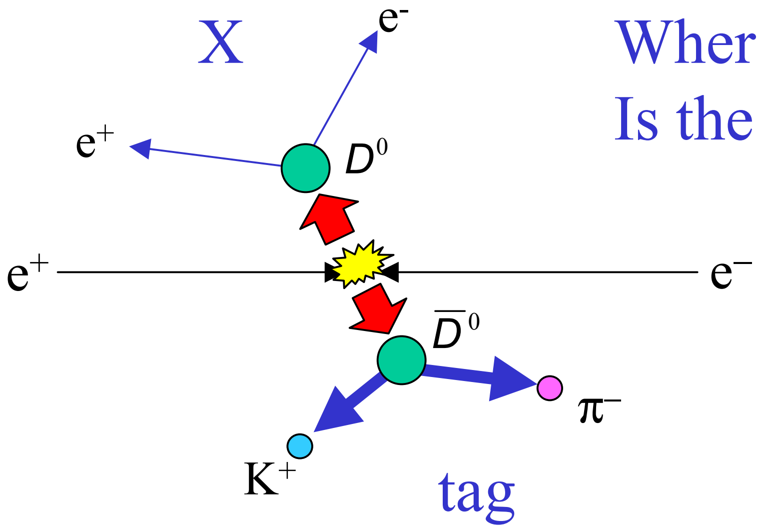
(this bootstrap method can never yield a measurement of $B(D^+\to K^-\pi^+\pi^+)$ more accurate than $B(D^o\to K^-\pi^+)$)

•Method (MKIII): $\psi''\to D^+D^-$ full reconstruction, limited by size of data sample
The determination of $B(D^+\to\phi\pi^+)$, which has a 25% error also bootstraps on $B(D^o\to K^-\pi^+)$

How can we do better? Recall: Absolute Charm Branching Ratios at Threshold

$\psi(3770) \rightarrow DD$

$$Br(D \rightarrow X) = \frac{\text{\#X Observed}}{\text{efficiency x \#D's produced}}$$



Where the # of D’s produced
Is the # of tags

Unique Opportunities at Charm Thresholds

- Unique event properties
  - Only $D\bar{D}$ not $D\bar{D}x$ produced
  - Can get D^oD^o, D^+D^-, D_sD_s, $\Lambda_c\Lambda_c$
  - Probably other charmed baryons as well (not yet measured)
- Large cross sections

$\sigma(D^o\bar{D}^o) =$ 5.8 nb

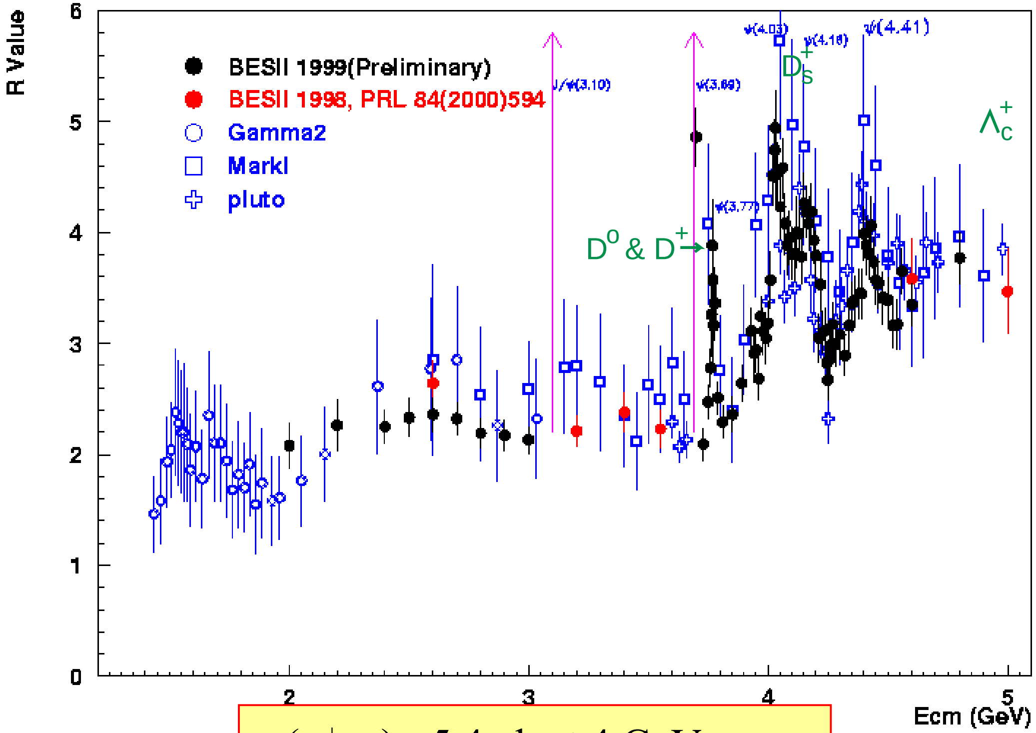
$\sigma(D^+D^-) =$ 4.2 nb

$\sigma(D_sD_s) =$ 0.5 nb

$\psi(3770) \rightarrow DD$

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

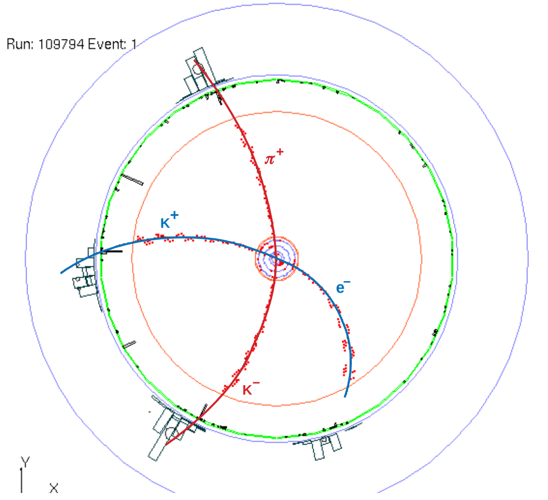
R (units of $\sigma(\mu^+\mu^-)$)



$\sigma(\mu^+\mu^-)$= 5.4 nb at 4 GeV

ψ(3770) events are simple

ψ(3770) event:



$D^o \to K^-\pi^+$ $D^o \to K^+e^-\nu$

- Charm events produced at threshold are extremely clean
- Large σ, low multiplicity
- Pure initial state: no fragmentation
- Signal/Background is optimum at threshold

- Double tag events are pristine
  - These events are key to making absolute Br measurements
- Neutrino reconstruction is clean
- Quantum coherence aids D mixing & CP violation studies

precision flavor physics

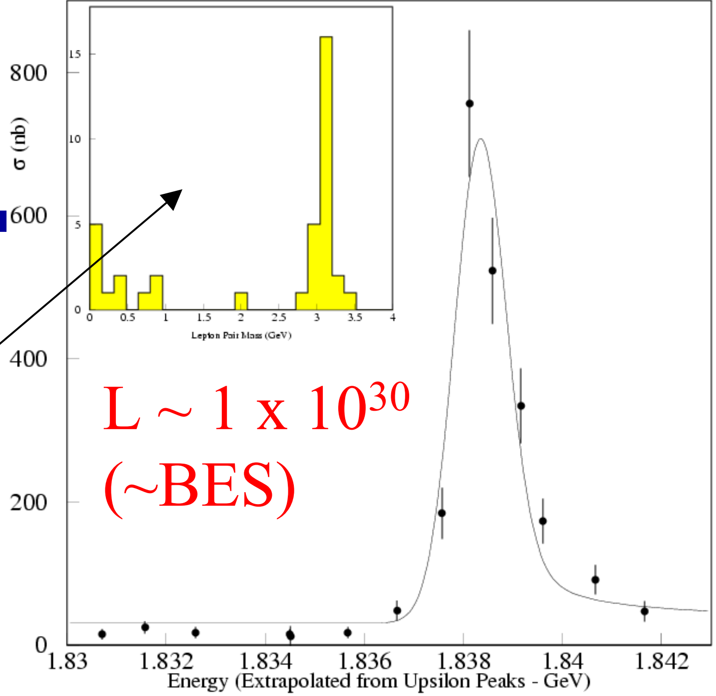
new physics

But: D's don't move

CESR-c & CLEO-c

CESR
L(@Y(4S)= 1.3 x 10^{33}

One day scan of the Ψ′:
(1/29/02) →



L ~ 1 x 10^{30}
(~BES)

$\Psi' \to J/\Psi\pi\pi$
$J/\Psi \to \mu\mu$

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

Expected machine performance:

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

- ΔE_{beam} ~ 1.2 MeV at J/ψ

CLEO-c Proposed Run Plan

2002: Prologue: Upsilons ~1-2 fb^{-1} each at Υ(1S),Υ(2S),Υ(3S),…
Spectroscopy, matrix element, Γ_{ee}, η_B h_b
10-20 times the existing world's data (Fall 2001- Fall 2002)

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

2004: $\sqrt{S} \sim 4140$ MeV – 3 fb^{-1}
1.5 million D_sD_s events, 0.3 million *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, 20 times BES II)

CLEO-c

A 3 year program

CLEO III Detector → CLEO-c Detector

1.5 T now, ... 1.0T later

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

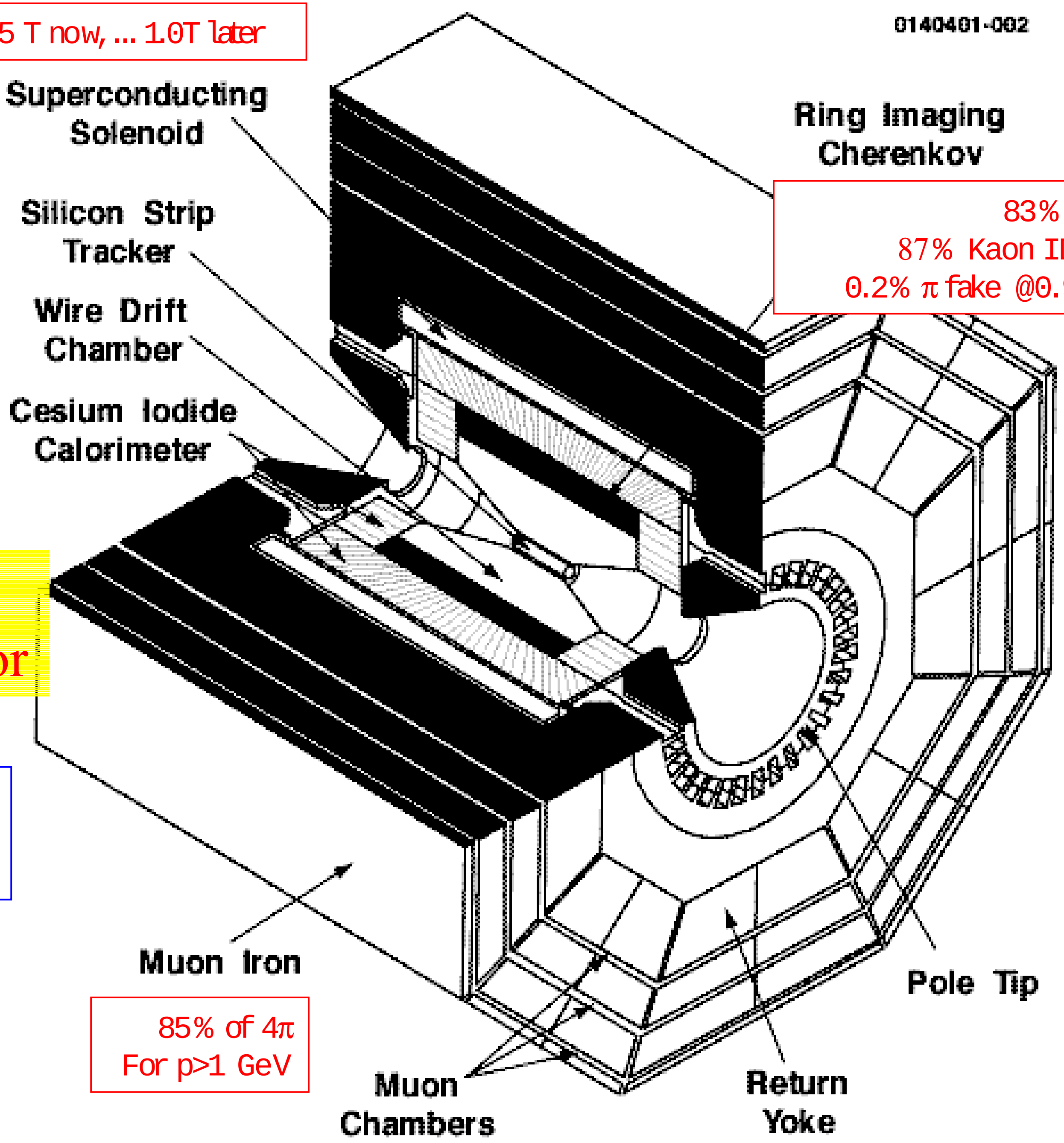
93% of 4π
$\sigma_E/E = 2\%$ @1GeV
$= 4\%$ @100MeV

83% of 4π
87% Kaon ID with
0.2% π fake @0.9GeV

85% of 4π
For p>1 GeV

Trigger: Tracks & Showers
Pipelined
Latency = 2.5μs

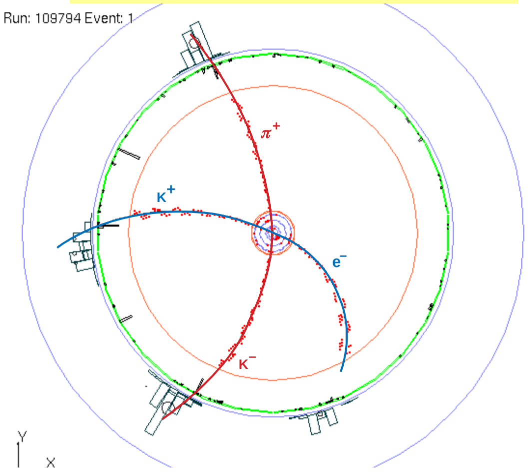
Data Acquisition:
Event size = 25kB
Thruput < 6MB/s



ψ(3770) events: simpler than Y(4S) events

Y(4S)

ψ(3770) event:



$D^0 \rightarrow K^- \pi^+ \; D^0 \rightarrow K^+ e^- \nu$

* CLEO III state of the art detector, well understood
*CLEO-c Replace Si → low mass drift chamber (under construction)
*The demands of doing physics at 3-5 GeV are easily met by the existing detector.

Tagging Technique, Tag Purity @ Threshold CLEO-c simulation

- $\psi(3770) \to DD$ $\sqrt{s}$ ~4140 $\to D_s D_s$

  Charm mesons have many large branching ratios (~1-15%)

  low multiplicity: high reconstruction efficiency

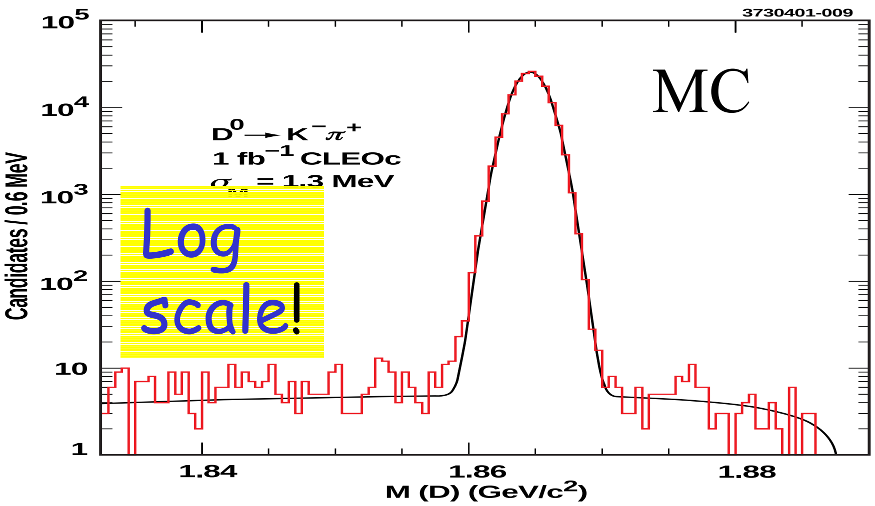
$\to$ high net tagging efficiency ~20% !

In 1 year At Each $\sqrt{s}$

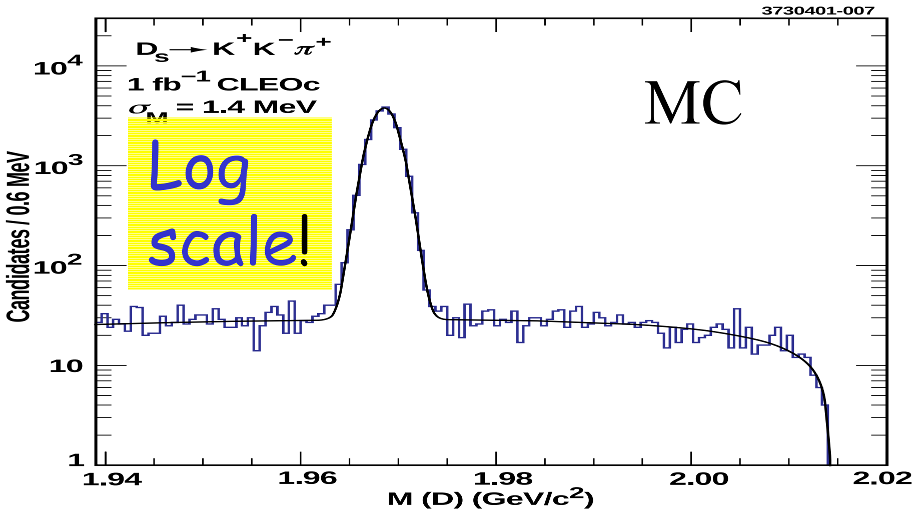
Anticipate 6M D tags 300K D_s tags:

$D \to K\pi$ tag. S/B ~5000/1 !

$D_s \to \phi\pi$ $(\phi \to KK)$ tag. S/B ~100/1



Log scale!



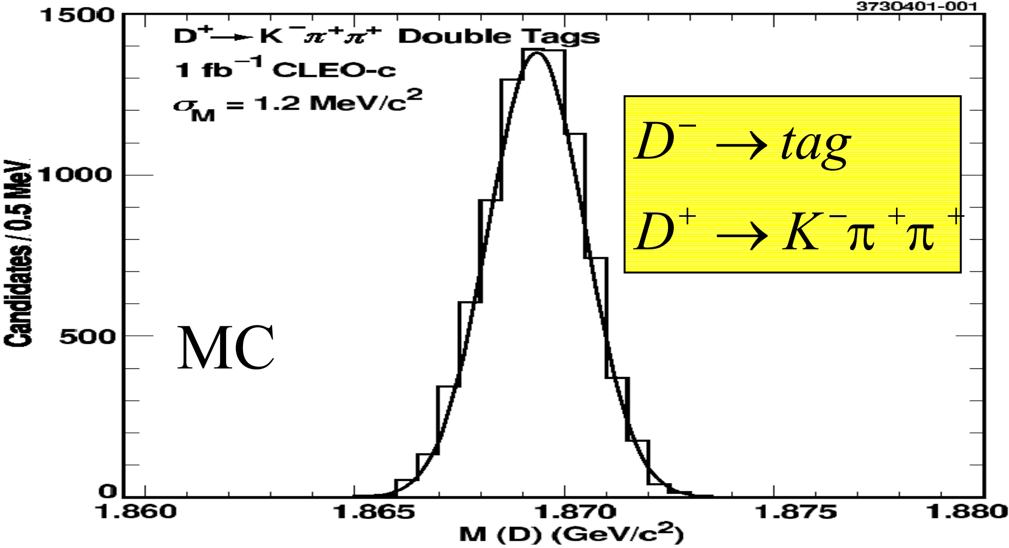
Log scale!

Beam constrained mass

Absolute Branching Ratios

~ Zero background in hadronic tag modes

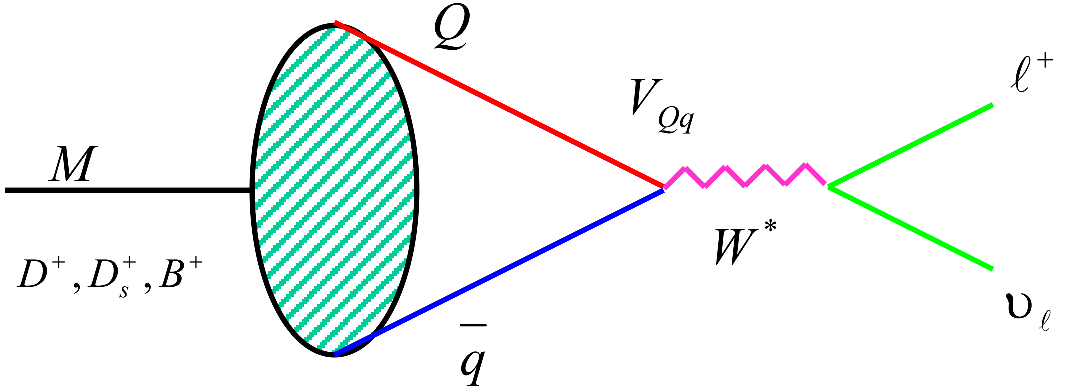
Measure absolute
Br (D→ X) with double tags
Br = # of X/# of D tags



Decay	√s	L fb^{-1}	Double tags	PDG (δB/B %)	CLEOc (δB/B %)
$D^0 \to K^-\pi^+$	3770	3	53,000	2.4	0.6
$D^+ \to K^-\pi^+\pi^+$	3770	3	60,000	7.2	0.7
$D_s \to \phi\pi$	4140	3	6,000	25	1.9

CLEO-c potential: set the absolute scale for all heavy quark measurements

Leptonic Decays→ Decay Constants



$$q^2 = m_W^2 = M^2$$

Fixed

$$M = \frac{G_F}{\sqrt{2}} V_{Qq} \langle 0 | J_\mu | M \rangle \bar{u}(k,\sigma)\gamma^\mu(1-\gamma_5)v(p,s)$$

(Pseudoscalar Meson)

the meson decay constant f_M measures the probability for the Q and q to have zero separation the annihilation probability is ∝ to wave function overlap

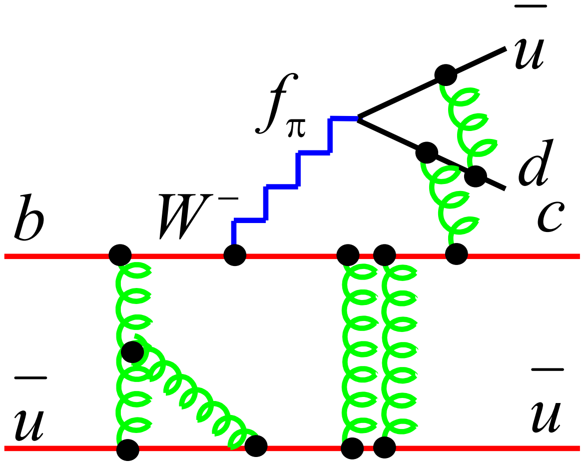
$$\langle 0 | \bar{q}\gamma_\mu\gamma_5 Q | P(p) \rangle = i f_M p_\mu$$

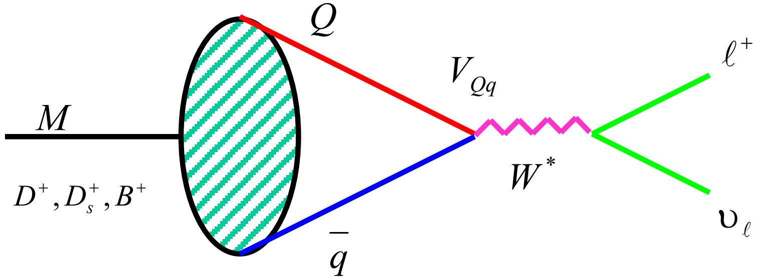
$$f_M^2 M = 12|\Psi(0)|^2$$

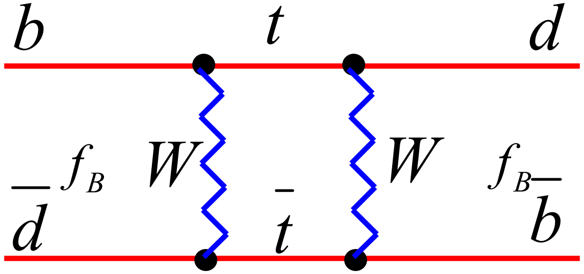
(For a meson with two heavy quarks) (Rosner)

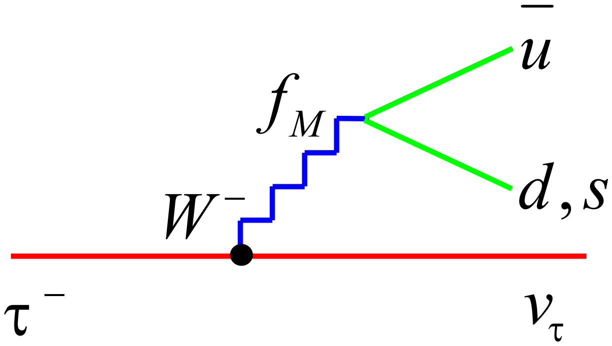
$$\Gamma(M_{Qq} \to \ell^- \bar{\nu}) = \frac{G_F^2}{8\pi} |V_{qQ}|^2 f_M^2 M m_\ell^2 \left(1 - \frac{m_\ell^2}{M^2}\right)^2$$

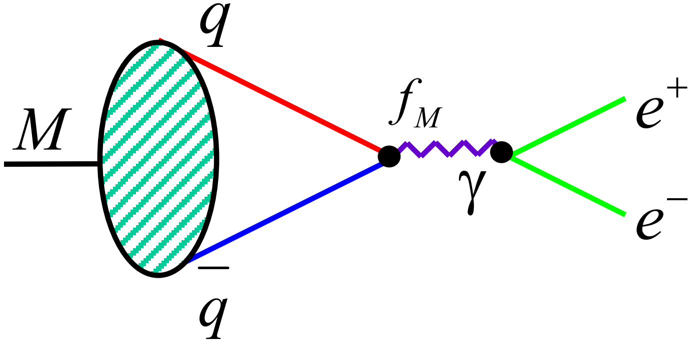
Decay constants are important in many processes









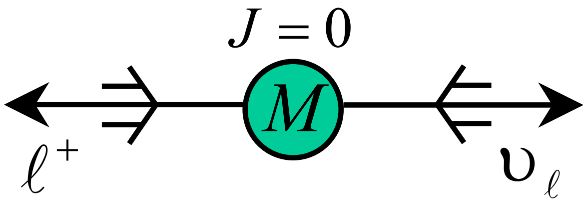


$$\Gamma(M_{Qq} \to \ell^- \overline{\nu}) = \frac{G_F^2}{8\pi} \left|V_{qQ}\right|^2 f_M^2 M m_\ell^2 \left(1 - \frac{m_\ell^2}{M^2}\right)^2$$

Helicity suppression

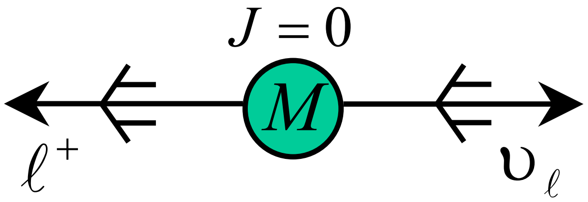
Decay is forbidden as $m_l \to 0$

$$\frac{\Gamma(\pi^+ \to e^+ \nu_e)}{\Gamma(\pi^+ \to \mu^+ \nu_\mu)} \approx 10^{-4}$$



$$\Gamma(D_s^+ \to e^+ \nu_e) : \Gamma(D_s^+ \to \mu^+ \nu_\mu) : \Gamma(D_s^+ \to \tau^+ \nu_\tau)$$

$$\approx 10^{-5} : 1 : 10$$



$$\Gamma(D^+ \to \ell^+ \nu_\ell) \propto |V_{cd}|^2 \approx (0.22)^2$$

$$\Gamma(D_s^+ \to \ell^+ \nu_\ell) \propto |V_{cs}|^2 \approx (0.97)^2$$

$$\Gamma(B^+ \to \ell^+ \nu_\ell) \propto |V_{ub}|^2 \approx (0.003)^2$$

Estimate of the leptonic Br's using $f_{Bs} = f_{Bs} = 200$ MeV $f_{Ds} = 260$ MeV, $f_D = 220$ MeV

	B(eν)	**B(μν)**	**B(τν)**
D^+	8.2×10^{-9}	4.2×10^{-4}	1.1×10^{-3}
D_s^t	7.5×10^{-8}	5.7×10^{-3}	5.5×10^{-2}
B^+	7.5×10^{-12}	3.2×10^{-7}	7.1×10^{-5}
π^+	1.2×10^{-4}	99.99%	
K^+	1.6×10^{-5}	63.5%	

At first sight it is remarkable that : $B(D_s^+ \to \mu^+\nu_\mu) \ll B(K^+ \to \mu^+\nu_\mu)$

While $(f_M^2\ M) \to$ constant

Γ(total) $\propto M^5$ so leptonic branching ratio becomes smaller as M↑

If we compare *rates* instead of branching ratios: The leptonic *rate* is higher for the D_S than for the K^+

$$\Gamma(K^+ \to \mu^+\nu_\mu) = 5.13 \times 10^7 s^{-1}$$

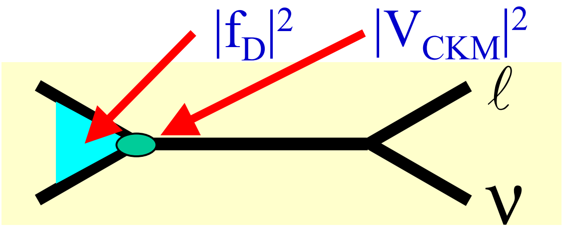
$$\Gamma(D_s^+ \to \mu^+\nu_\mu) = 6.9 \times 10^9 s^{-1}$$

$$\Gamma(D_s^+ \to \tau^+\nu_\mu) = 6.6 \times 10^{10} s^{-1}$$

D meson Decay Constants

In a pseudoscalar D meson decay:

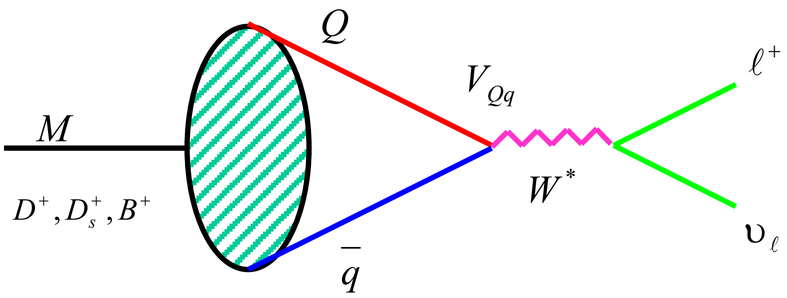
c and q annihilate



$$\Gamma(D_q^+ \to \ell\upsilon) = \frac{1}{8\pi} G_F^2 M_{D_q^+} m_\ell^2 \left(1 - \frac{m_\ell^2}{M_{D+}^2}\right) f_{D+}^2 \, |V_{cq}|^2$$

$B(D^+ \to l\nu) / \tau_{D+}$: $f_{D+}|Vcd|$

$B(D_S \to l\nu) / \tau_{Ds}$: $f_{Ds}|Vcs|$



* Charm meson lifetimes known 0.3-2%

* 3 generation unitarity

Vcs, (Vcd) known to 0.1% (1.1%) → f_{D+} f_{Ds}

Example:f_{Ds} near/at the Y(4S)

Signal is a single muon , or single muon + photon tag very difficult at a hadron machine

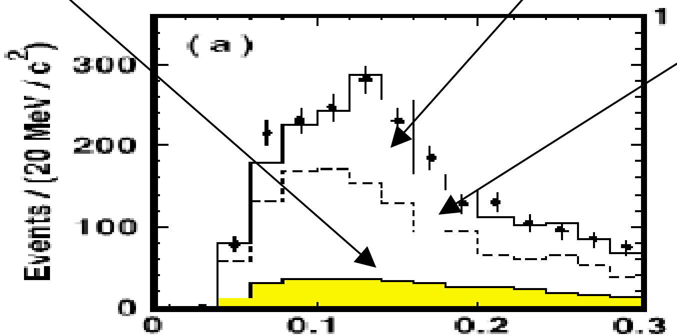
- –Search for D_s^* -> D_s γ, D_s -> μν
  - –Directly detect γ, μ, Use hermeticity of detector to reconstruct ν
  - –Plot mass difference but Backgrounds are LARGE!
- •Use D_s -> eν (rate~0) for bkgd determination but precision limited by systematics
- •Compare rate to $D_s \rightarrow \phi\pi$, but $Br(D_s \rightarrow \phi\pi)$ not well known-25% error!.
  - –FDs Error ~17% now (CLEO)

CLEO signal 4.8fb^{-1}

$D_s \rightarrow \mu\nu$

Excess of μ over e fakes

Background measured with electrons

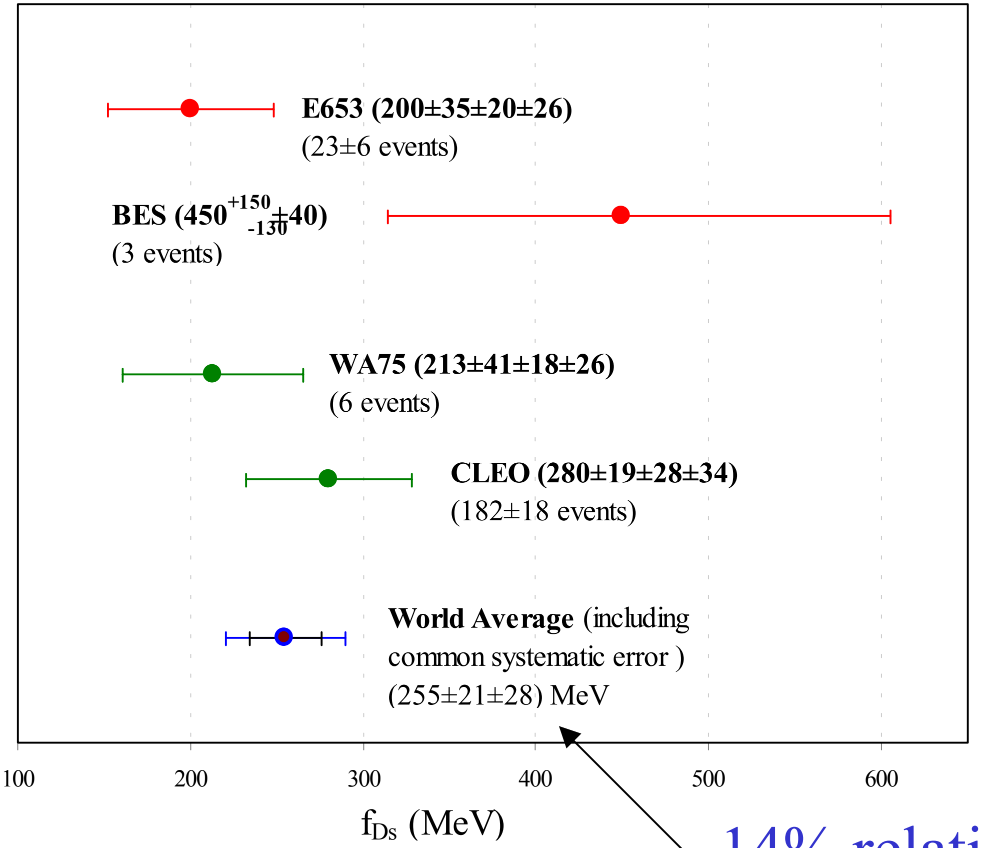


ΔM=M(μνγ) –M(μν) GeV/c

f_{Ds}=280 ±19 ±28±34 (MeV)

D meson Decay Constants Current Status

$f_{D+} < 290$ MeV @ 90% CL (Mark III)

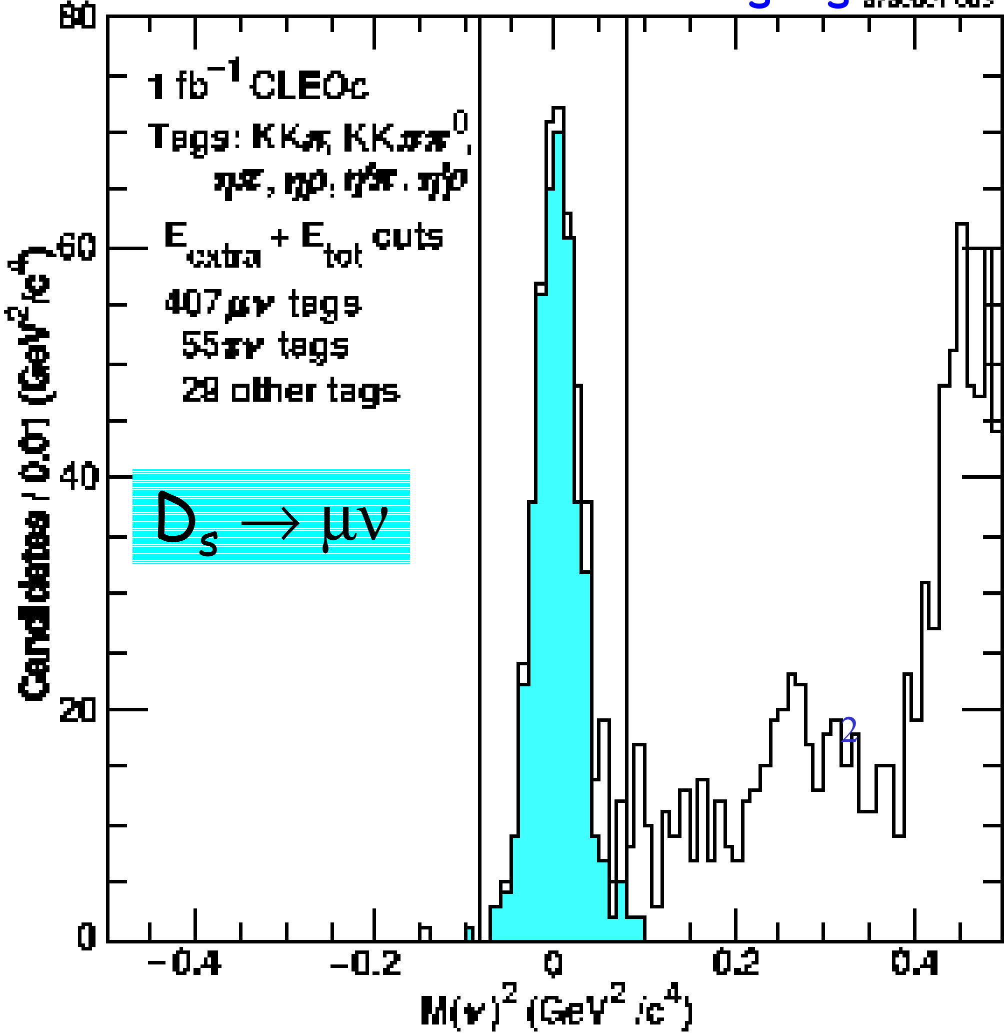


14% relative error

f_{Ds} has been measured by several groups, using $D_s \to \mu\nu$
There are also measurements from LEP using $D_s \rightarrow \tau^+\nu$ which I have not included in the Table or average. (Inclusion Of these extra modes requires The assumption of Lepton universality, which Might be interesting to test.
Note large correlated common systematic error from $B(D_s \rightarrow \phi\pi)$

Decay Constant at Threshold (CLEO-c simulation)

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



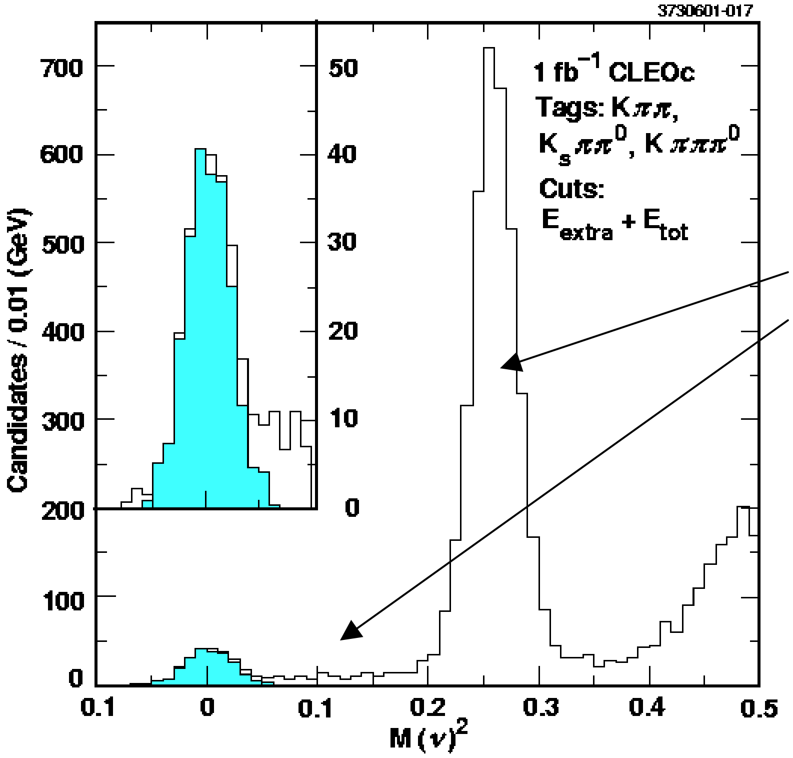
- Fully reconstruct 1 D “the tag”
- Require one additional charged track and no additional photons
- Compute MM^2 Peaks at zero for $D \rightarrow \mu^+\nu$ decay.
  - No need to identify muon-helps systematic error
  - Can identify electrons to check background level
  - Expect resolution of $\sim M_{\pi^0}$

$$\frac{\delta f_{Ds}}{f_{Ds}} \approx 1.7\%$$

(Now: ±14%)

Decay Constant at Threshold (CLEO-c simulation)

$\psi(3770) \to DD$



CLEO-c simulation

$D^+ \to K_L\mu\nu$

$D^+ \to \tau\nu$

$$\frac{\delta f_D}{f_D} \approx 2.3\%$$

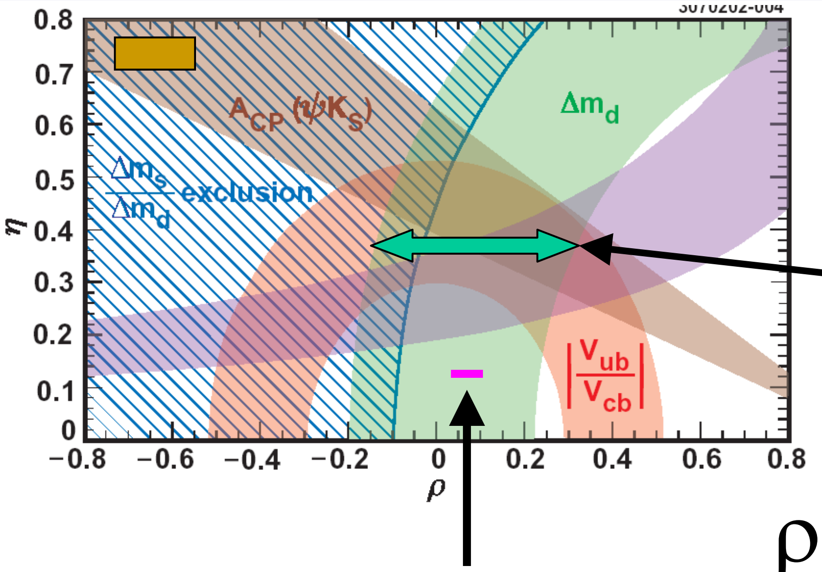
(1 year)

Now: upper limit exists

Improved knowledge of the decay constant yields precision determination of Vtd

$$\Delta M_d = 0.50\,ps^{-1}\left[\frac{\sqrt{B_{B_d}}\,f_{B_d}}{200MeV}\right]^2\left[\frac{|V_{td}|}{8.8\times10^{-3}}\right]^2$$

η



$$\frac{\sigma(\rho)}{\rho} = 0.5\frac{\sigma(\Delta M_d)}{\Delta M_d} \oplus \frac{\sigma(f_B\sqrt{B_{B_d}})}{f_B\sqrt{B_{B_d}}}$$

(ICHEP02) 1.2%

~15% (LQCD)

ρ

$$\frac{\delta f_D}{f_D} \approx 2.3\%$$

- →**Lattice predicts f_B/f_D with small errors**
- →**precision measurement of f_D**
- →**precision estimates of f_B**
- →**precision determination of Vtd**

Additional Slides

Summary of Decay Constant Reach at CLEO-c

Branching Ratio

Reaction	**Signal**	$\tau\nu/\mu\nu$	Bkgd	**$\delta B/B$**
$D_s^+ \to \mu\nu$	1221	165	87	3.2%
$D_s^+ \to \tau\nu$	1740	0	114	2.4%
$D^+ \to \mu\nu$	672	30	60	3.8%

Decay Constant

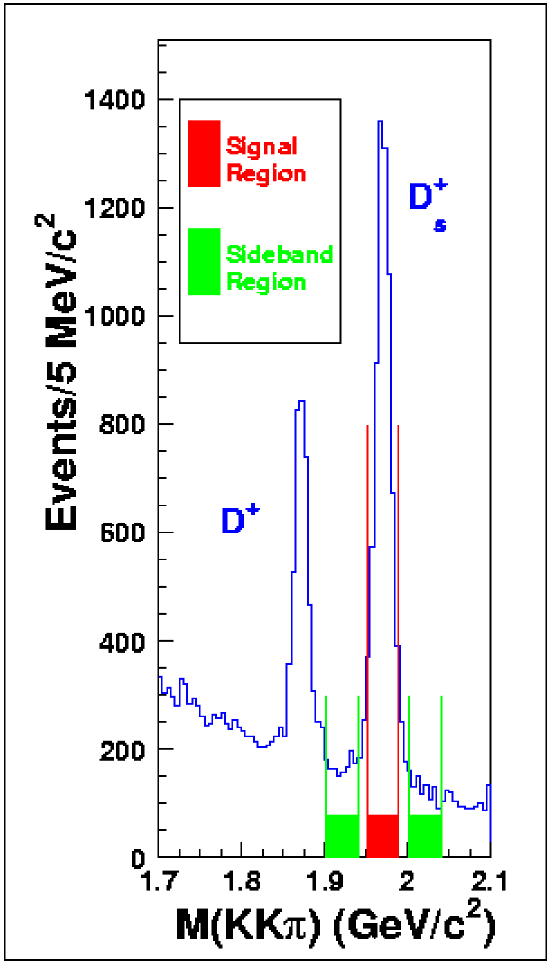
	Reaction	½ $\Delta\mathcal{B}/\mathcal{B}$	½$\Delta\tau/\tau$	$\Delta V_{cq}/V_{cq}$	**CLEO-c $\delta f/f$**	**PDG $\delta f/f$**
f_{Ds}	$D_s^+ \to \mu\nu$	1.6%	1%	0.1%	1.9%	14%
f_{Ds}	$D_s^+ \to \tau\nu$	1.2%	1%	0.1%	1.6%	33%
f_{D+}	$D^+ \to \mu\nu$	1.9%	0.6%	1.1%	2.3%	UL

(not updated for improved lifetimes)

D_s Meson Lifetime

New at ICHEP

$D_s \to \phi\pi$ signal

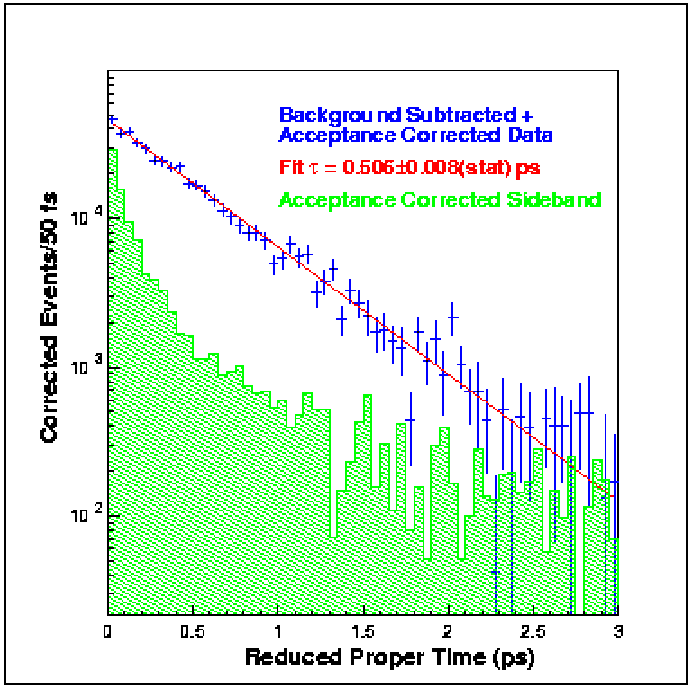


4 x statistics including

Lifetime 506 ±8 fs

PDG 2002 490±9 fs

5668 ± 95 events (50% FOCUS data)



Preliminary

$$\frac{\tau(D_s)}{\tau(D^0)} = 1.23 \pm 0.02$$

To interpret this important to check $\Gamma(D_s \to eX)$ But absolute dBR/BR= 63%!

Theoretical prediction (Bigi Uraltsev)

1.00-1.07 (no WA)

0.8-1.27 (different process interference)

Lifetime Summary

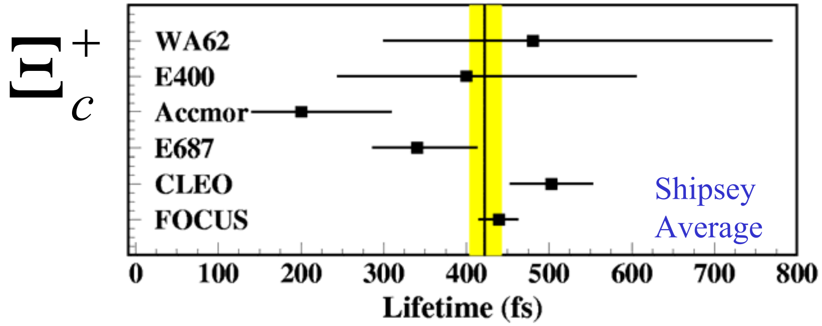
We know the charm meson lifetimes with extraordinary precision,
in the best cases <1/2% (major improvement in the past year: FOCUS)
Non spectator effects are similar in size to the spectator contributions
the lifetime hierarchy is consistent with the OPE formalism
but debatable if OPE should apply to c-quark (mass)

More stringent tests of this idea would be provided if precise absolute semileptonic branching ratios of D_s ,Λ_c, Ξ^0, Ξ^+_c ,Ω_c were known

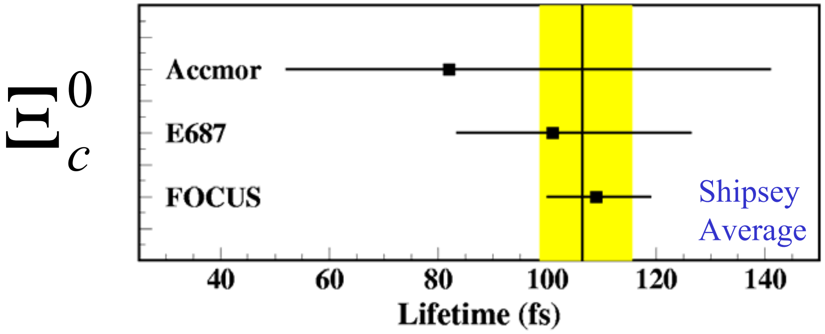
Charmed Baryon Lifetimes

- Unlike charmed mesons, decays of charmed baryons are not color or helicity suppressed, this results in a reduced lifetime relative to

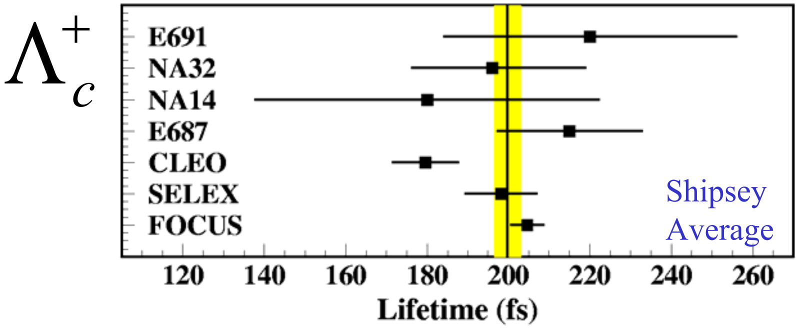
$$\tau_{\text{average}}\left(\Xi_c^+\right) = 422^{+20}_{-19}\ \text{fs}$$



$$\tau_{\text{average}}\left(\Xi_c^0\right) = 106^{+9}_{-8}\ \text{fs}$$



$$\tau_{\text{average}}\left(\Lambda_c^+\right) = 200 \pm 3\ \text{fs}$$



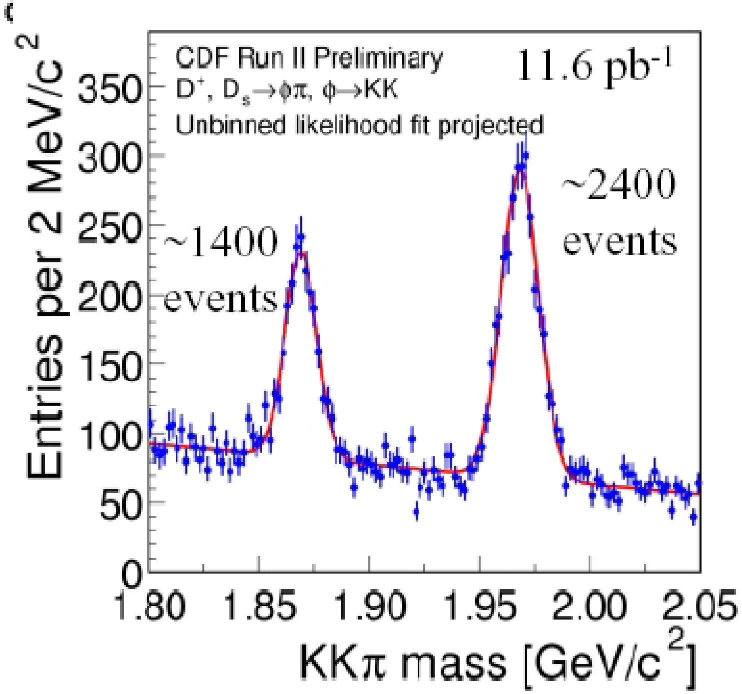
$$\Gamma(\Xi_c^+) < \Gamma(\Lambda_c^0) < \Gamma(\Xi_c^0) \sim \Gamma(\Omega_c^0)$$

P.I.(+/-)　W.S.+P.I.(-)　W.S.+P.I.(+)　(10/3)P.I.(+)

Charm at CDF

ICHEP2002

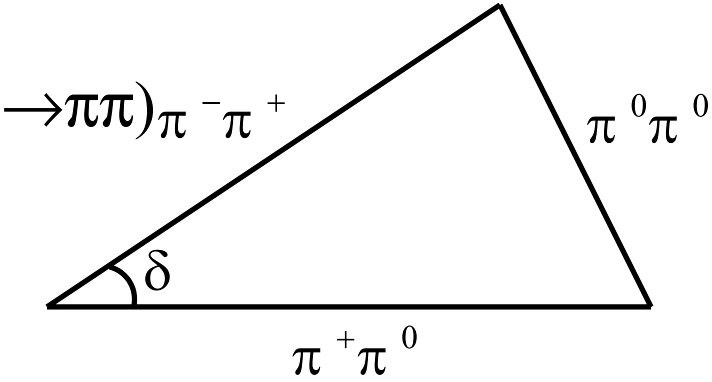
- $D_s^\pm$ - $D^\pm$ mass difference
  - Both $D \rightarrow \phi\pi$ $(\phi \rightarrow KK)$
  - $\Delta m = 99.28 \pm 0.43 \pm 0.27$ MeV
    - PDG: 99.2 ± 0.5 MeV (CLEO2, E691)
  - Systematics dominated by background modeling



D Hadronic decays

Simple factorization picture describes 2 body hadronic decays established for B's. For charm sizeable final state interactions are the norm.

Isospin decomposition (same as B→ππ, K →ππ)



$$A(D^0 \to \pi^-\pi^+) = \frac{1}{\sqrt{3}}(\sqrt{2}A_0 + A_2)$$

$$A(D^0 \to \pi^0\pi^0) = \frac{1}{\sqrt{3}}(-A_0 + \sqrt{2}A_2)$$

$$A(D^+ \to \pi^0\pi^+) = \sqrt{3/2}A_2$$

$$A_I = A_I e^{i\delta}$$

$$|A_0 + A_2|^2 = |A_o|^2 + |A_2|^2 + 2|A_0||A_2|\cos(\delta_2 - \delta_0)$$

measure

extract

$$|A(D^0 \to \pi^-\pi^+)|^2 + |A(D^0 \to \pi^0\pi^0)|^2 = |A_o|^2 + |A_2|^2$$

$$|A(D^+ \to \pi^0\pi^+)|^2 = 3/2|A_2|^2$$

Find:

$$|A_2|/|A_0| = 0.63 \pm 0.13 \quad \delta = (\delta_2 - \delta_0) = 81^\circ \pm 10^\circ$$

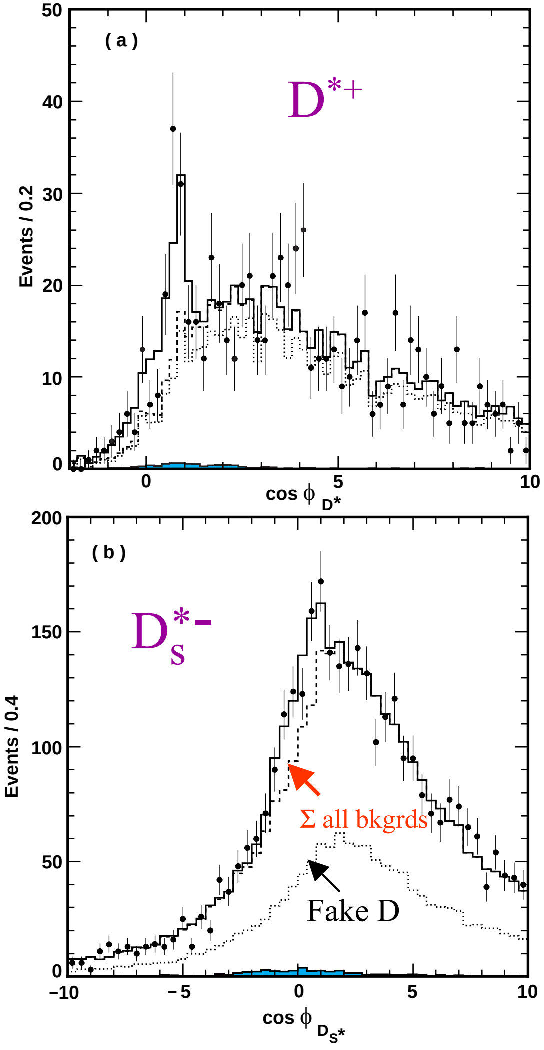
$B(D_s^+ \to \phi\pi^+)$

B (%)	Error(%)	Source
3.59±0.77±0.48	25.3	CLEO
3.6±0.9	25.0	PDG

- Method: Reconstruct

  $B \to D^{*+} D_s^{*-}$, $D_s^{*-} \to \gamma D_s^-$ or

  $D^{*+} \to \pi^+ D^o$
- Observe signal both with & without explicit D_s or D^o reconstruction
- Measure $B(D_s \to \phi\pi^+)/B(D^o \to K^-\pi^+)$



$\Lambda_c^+ \to pK^-\pi^+$

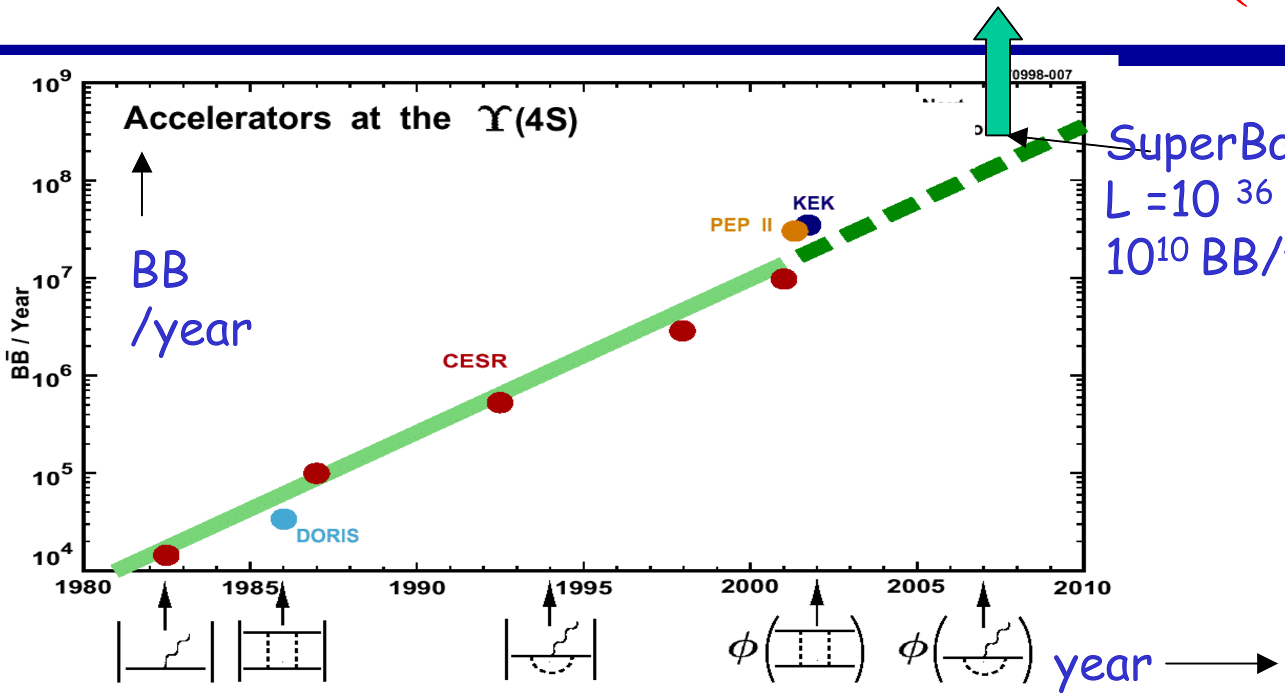
- Lower limit: Measure p and Λ yield in B decays and assume all such production is due to $\bar{B} \to \Lambda_c^+ \bar{N} X$. Find B=(4.14±0.91)%
- Upper limit: Measure $\Lambda_c \to \Lambda\, \ell\, \nu$, and assume that Λ saturates the rate (no Σ, for example). Find B=(7.7±1.5)%
- Conclude: $9.7\% > \mathcal{B} > 3.0\%$ @ 90% c. l.

$J/\psi \to \mu^+\mu^-$

B (%)	Error(%)	Source
5.84±0.06±0.10	2.0	BES
6.08±0.33	5.4	BES
5.88±0.10	1.7	PDG

- Systematic error is the limitation. Completely correlated between the two BES measurements.
- Currently, best way to determine b yields at hadron colliders

Charm Production near/at the Y(4S)



SuperBaBar
$L = 10^{36}$
10^{10} BB/year

	$L_{peak} \times 10^{33} cm^{-2} s^{-1}$	$\int Ldt$		$\#B's \times 10^6$
		ON	OFF	
CESR/CLEO(*)	1.3	16.0	6.7	34
KEKB/Belle	7.2	84.6 (ON+OFF)		~160
PEPII/BABAR	4.6	95.8 (ON+OFF)		~180

(*) CLEO
No longer
Operating at
Y(4S)
Belle/ BaBar
ON/OFF
June 13 ‘02