Beyond the Standard Model: the clue from charm

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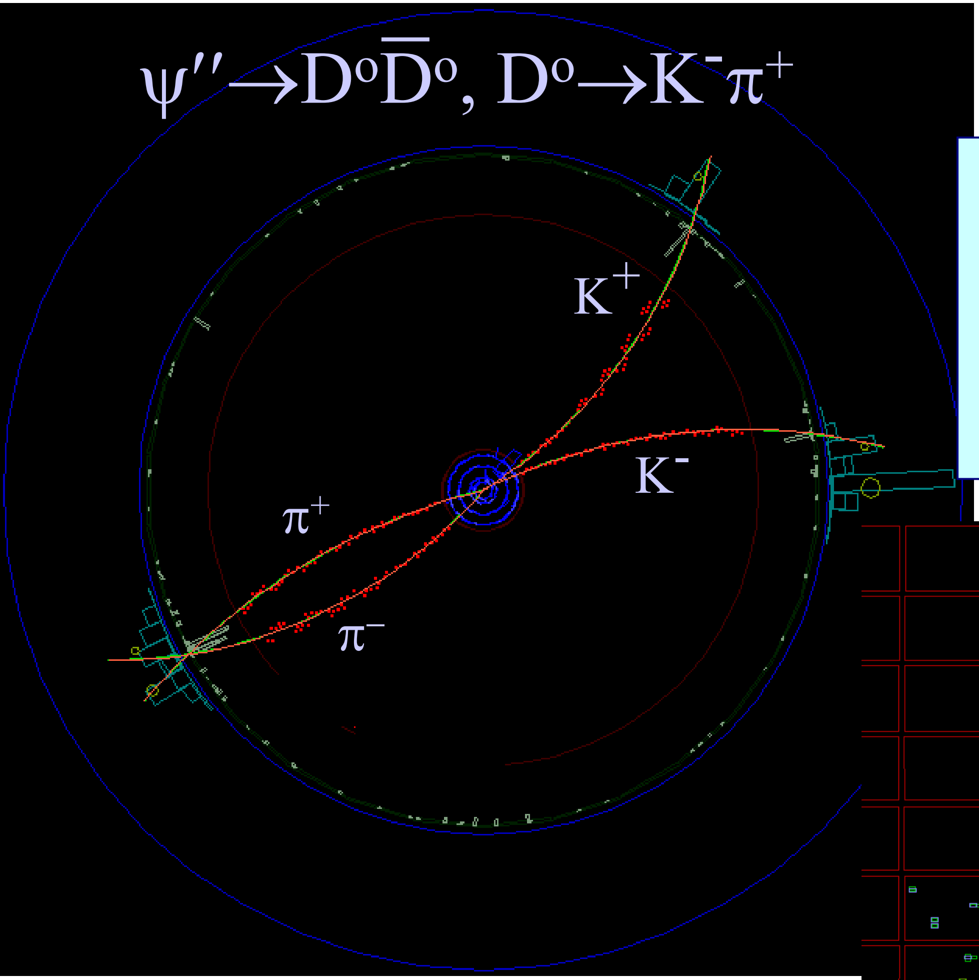
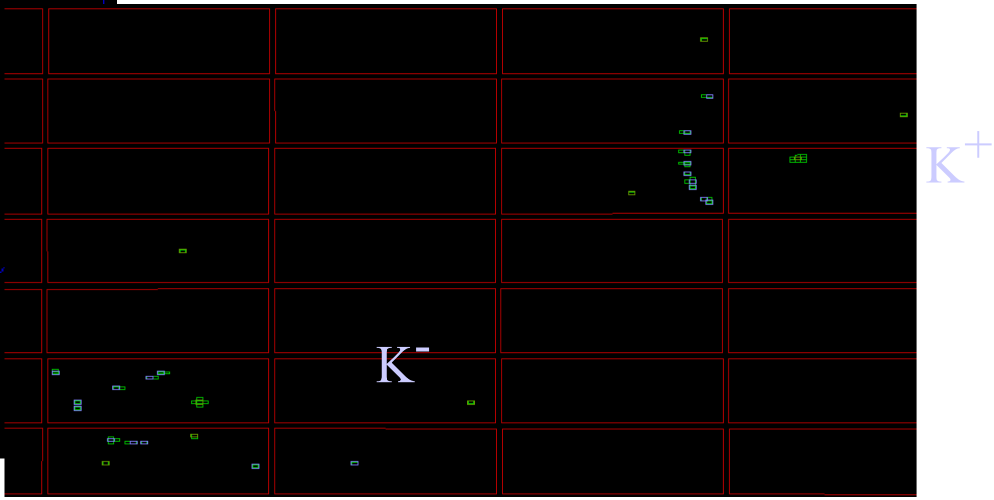


- The big picture
- A quick tour of the paths towards discovery
- Conclusions

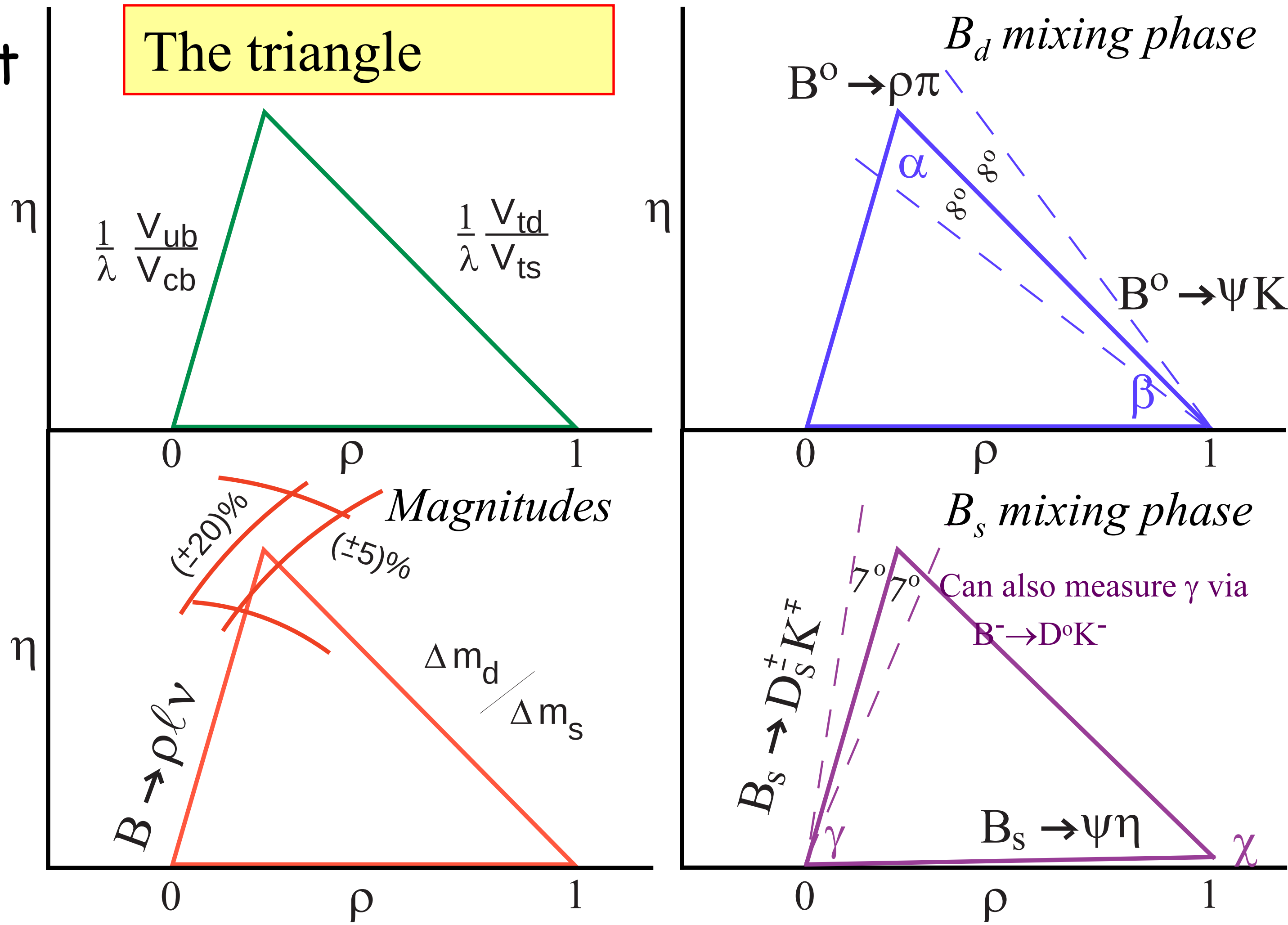


The new HEP frontier: the search for physics beyond the Standard Model

- Uncovering signatures of new physics is the unifying goal of the diverse international high energy physics program:
  - Higher and higher energy machines will look for new high mass objects [Tevatron, LHC, Linear Collider..]
  - Precision study of b and c decays. Deviations in expected behavior of b and c quarks ⇒evidence for new physics+ will elucidate new physics if found elsewhere.
  - CLEO-c [and later BES-III] will study c decays at/near threshold for $D\bar{D}$ production
  - To use the full power of b and c decays, theoretical calculations of strong interactions must be used. The lattice gauge approach promises precision calculations that must be confronted with data
    - Precision measurement of the D^+ and D_s^+ decay constants.
    - Semileptonic charm decay measurements ⇔V_{cd} and V_{cs} directly as well as input on hadronic matrix element

The unitarity triangle in the ρ–η plane

- Use different sets of measurements to define apex of triangle
- Also have ε_K (~~CP~~ in K_L system)



The role of f_{D^+} and $f_{D_s^+}$

- We can compare theoretical calculations of f_D to our measurements and gain confidence in theory to predict f_B
- f_B is necessary to translate measurement of $B\text{-}\bar{B}$ mixing into constraints in the $\rho-\eta$ plane. The key quantity is f_{Bs}/f_B
- We can measure f_{Ds}/f_D to learn about f_{Bs}/f_B
- If $B^+ \to \ell^+ \nu$ was measured, then we would have a measurement of the product of $|V_{ub}|\, f_B$. Knowing f_B gives V_{ub}

The leptonic decay $D \to l^+\nu$

Pseudoscalar decay constants

Q and $\bar{q}$ can annihilate

probability is $\propto$ to wave function overlap

Example π

In general for all pseudoscalars:

$$\Gamma(P^+ \to \ell^+\nu) = \frac{1}{8\pi} G_F^2 f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2 |V_{Qq}|^2$$

Expected $\mathcal{B}$ for $P^+ \to \ell^+ \nu$ decays

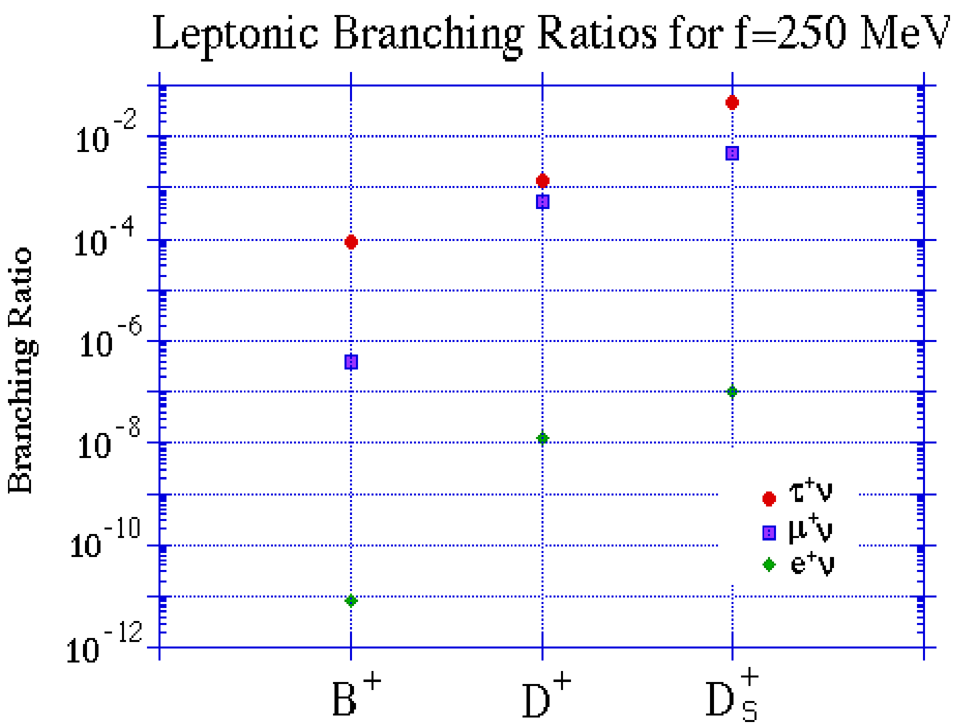
- We know:

f_π = 131.73±0.15 MeV

f_K= 160.6±1.3 MeV

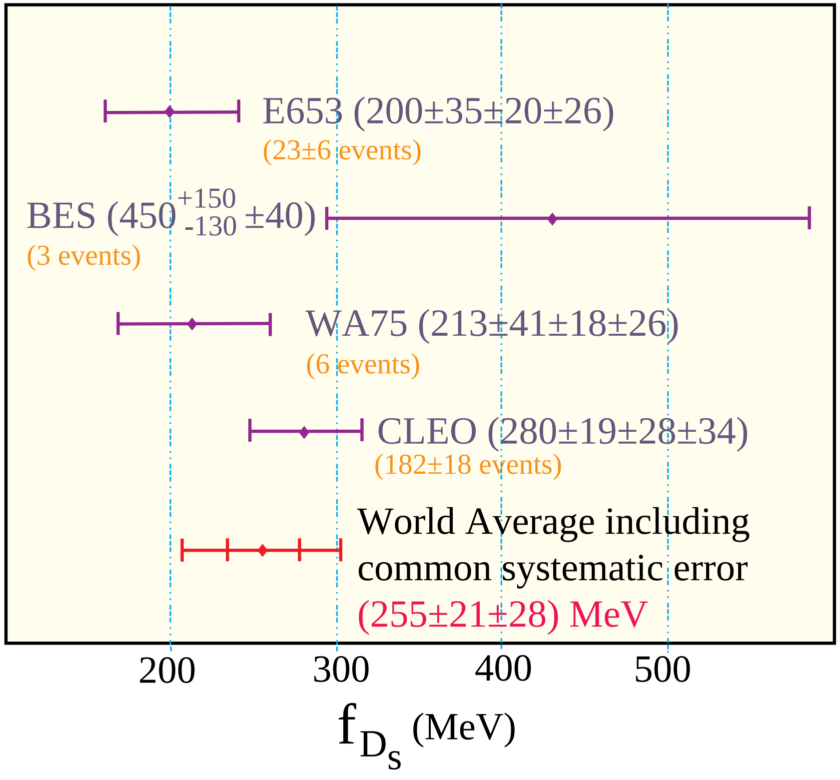
f_{D^+} < 290 MeV @ 90% c.l. (Mark III)

- The D_s^+ has the largest $\mathcal{B}$; the $\mu^+\nu$ rate is ~0.5%
- f_{Ds} Poorly measured by several groups, best CLEO



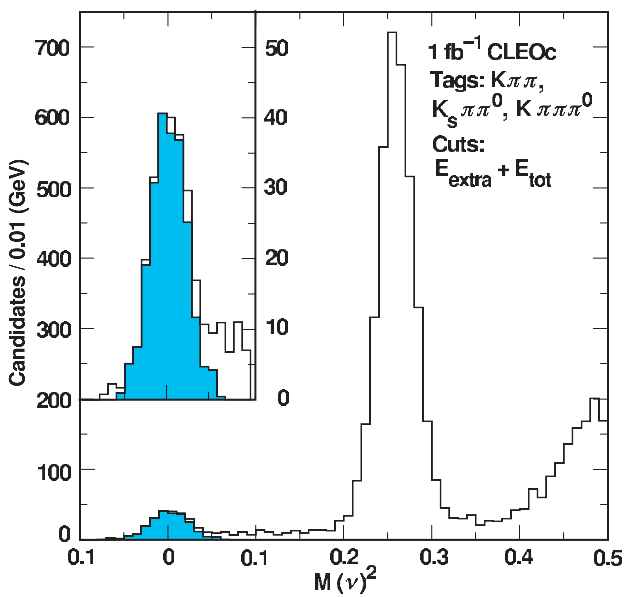
Summary of f_{Ds} measurements & world average

f_{D_S} Values from $D_s \to \mu\upsilon$



- BES in 22 pb^{-1} at 4.03 GeV found 3 events
- We could run at 4.14 GeV (higher s); with 150x L, more e, project ~800 events, ⇒ ~2% error on f_{Ds}

Key experimental techniques



MM^2 of $D^+ \to \mu^+\nu$ with 1 fb^{-1} of CLEO-C data

- Ease of leptonic & semileptonic decays using double tags & MM^2 technique

$$MM^2 = (E_D - E_\ell - E_{hadrons})^2 - (\vec{p}_D - \vec{p}_\ell - \vec{p}_{hadrons})^2$$

We know $E_D = E_{beam}$, $\vec{p}_D = -\vec{p}_{\bar{D}}$

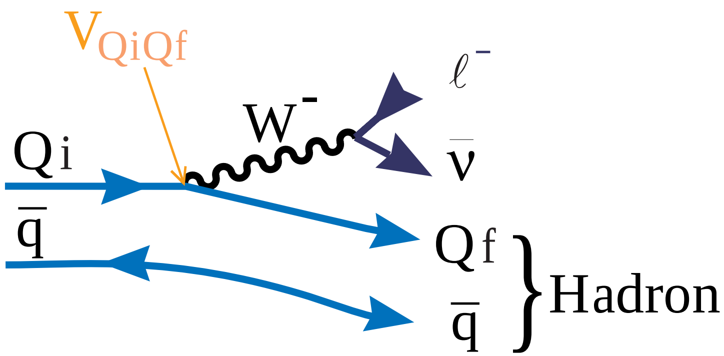
- Search for peak near $MM^2 = 0$
- Since resolution ~ M_{π^0}, reject extra particles with calorimeter & tracking

Summary on decay constant CLEO-c reach

Decay mode	Decay constant	$\frac{1}{2}\ \Delta\mathcal{B}/\mathcal{B}$	$\frac{1}{2}\Delta\tau/\tau$	$\Delta\mathcal{V}cq/\mathcal{V}cq$	$\Delta f_{D_q}/f_{D_q}$
$D^+ \to \mu\nu$	f_D	1.9%	0.6%	1.1%	2.3%
$D_s \to \mu\nu$	f_{D_s}	1.4%	1.0%	0.1%	1.7%
$D_s \to \tau\nu$	f_{D_s}	1.2%	1.0%	0.1%	1.6%

The next pillar of this program: Semileptonic Decays

- In principle, best way to determine magnitudes of CKM elements is to use semileptonic decays



- Kinematics: $q^2 = \left(p_D^\mu - p_{hadron}^\mu\right)^2 = m_D^2 + m_P^2 - 2E_P m_D$
- Matrix element in terms of form-factors (for D→Pseudoscalar $\lambda^+ \nu$

$$\left\langle P(P_P)\middle|J_\mu\middle|D(P_D)\right\rangle = f_+(q^2)(P_D + P_P)_\mu + f_-(q^2)(P_D - P_P)_\mu$$

- For λ = e, contribution of $f_-(q^2)\to 0$, only way to get information on f_- is to use $\lambda = \mu$, for D decays

Uses of Semileptonic Decay

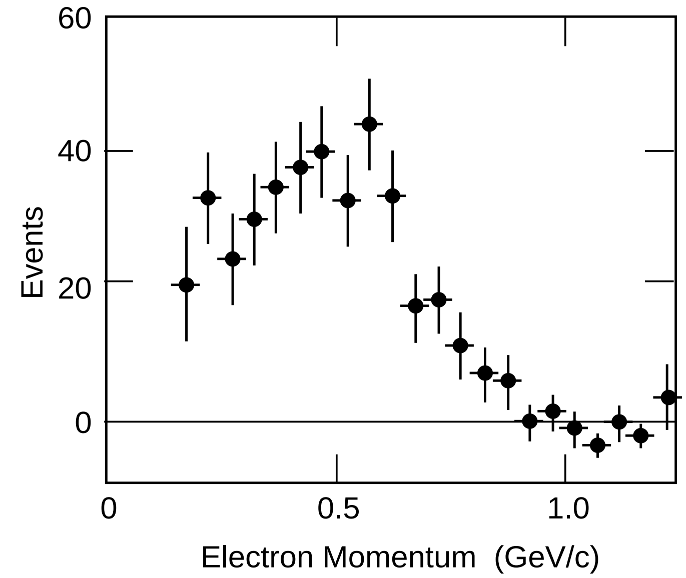
- In CLEO-c the RICH detector can provide π/μ separation to ~500 MeV
- Decay rate:

$$\frac{d\Gamma(D \to P\ell\nu)}{dq^2} = \frac{|V_{cq}|^2 P_P^3}{24\pi^3} |f_+(q^2)|^2$$

- Ratio of f+(0)/F_{D^+} test of lattice qcd
- Inclusive spectrum →Heavy quark expansion checks

$\psi'' \to D^o\overline{D}^o + D^+D^- \to Xe\nu$

From DELCO



◆ To find V_{cs} & V_{cd} input on ff at one fixed q^2 point is needed

Goals in Semileptonic Decays

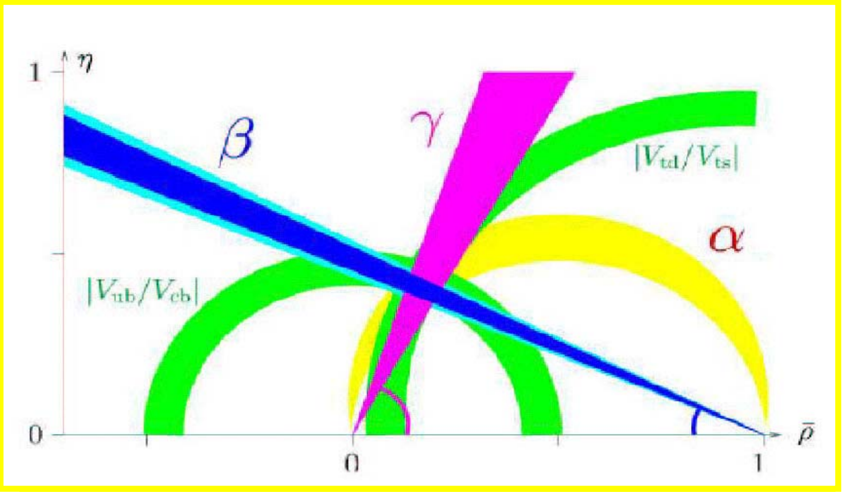
- Measure much better $D \rightarrow K\lambda\nu$
- V_{cd} use $D \rightarrow \pi(\rho)\lambda\nu$
- V_{cs} use $D \rightarrow K(K^*)\lambda\nu$ measuring ff shapes to distinguish among models & test lattice QCD predictions
- Better in ratio V_{cd}/V_{cs}
- V_{cd} & V_{cs} with precise unquenched lattice predictions, + V_{cb} would provide an important unitarity check
- V_{ub} use $D \rightarrow \rho\lambda\nu$ to get form-factor for $B \rightarrow \rho\lambda\nu$, at same $v \cdot v$ point using HQET
- Expected experimental error in most of the measurements 1 to a few %

Towards a precision measurement of the sides

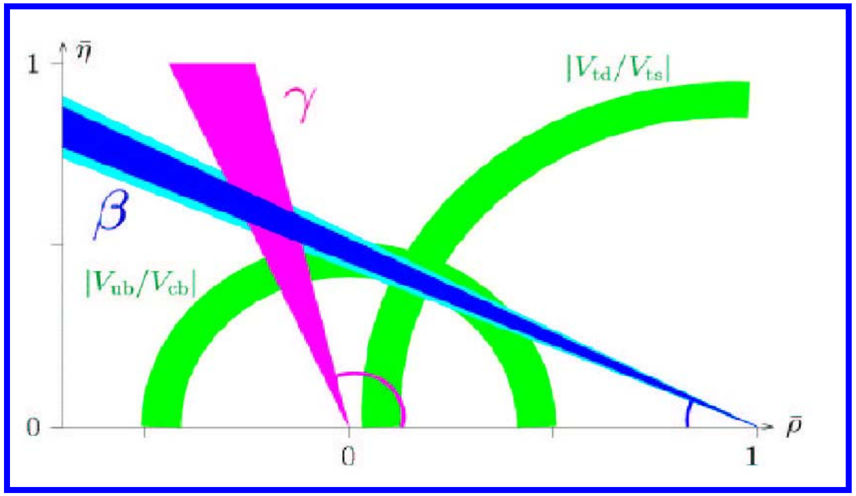
- Ratio of decay constant/semileptonic form factor will be predicted with small theory error with lattice calculations

$\Rightarrow$Hadronic matrix element needed to extract CKM parameter will have small and unambiguous errors

- Precision physics may uncover subtle inconsistencies



Will there still be an overlap region?



Direct signatures for new physics in charm decays

- "A priori it is quite conceivable that *qualitatively different forces* drive the decays of up-type and down-type quarks. More specifically, non-Standard-Model forces might exhibit a very different pattern for the two classes of quarks" Bigi-Sanda hep-ph/9909479
- Charm decays are the only up-type quarks that allow to probe this physics: non-strange light flavor hadrons do not allow for oscillations and top-flavored hadrons do not even form in a practical way.

Experimental strategies considered

- Mixing
  - Comparison between hadronic and lepton tagged modes from $C=\pm1$ $D^0\bar{D}^0$ pairs
  - Study of "right-sign" leptons versus "wrong sign leptons"
- CP violation
  - Direct CP violation in D^0 and D^+
  - Indirect CP violation in D^0 decays
  - CP violation measurements exploiting the quantum coherence of the D^0D^0 pair
- Rare and forbidden decays
- Decay constants revisited

Physics Program Part 2

Tests of QCD

- Tests of QCD in non-perturbative regime
- Unambiguous predictions of QCD:
  - Glueballs $G=|gg\rangle$
  - Hybrids $H=|gqq\rangle$
    - Essential verification of QCD to find evidence of these states
    - Essential test of Lattice QCD to calculate their spectra
- Goal of CLEO-C QCD Program:
  - Determine composition for variety of exotica in 1.5-2.5 GeV mass range

Summary of CLEO-C Reach in Non-Perturbative QCD

- Data Samples:

	Now	CLEO-C
J/Ψ	66M	>1 Billion
$\Upsilon(1S)$	79 pb-1	1 fb-1

  - Unique capability to perform the detailed studies of the mass, width, quantum numbers of all the glueball candidates in the mass region 1.5-2.5 GeV

The CLEO-c RUN Plan

- O(3fb^{-1}) at ψ(3770) [B, f_D, CPV, mix, SL, rare decays] starting in fall 2003 (soon!)
- Scan to determine the cross sections for different final states [$D\bar{D}$, $D\bar{D}^*$, $D_s\bar{D}_s^{(*)}$...], starting from J/ ψ for systematics on tracking, π^0 efficiency ...
- O(3fb^{-1}) at ~ψ(4140) [f_{Ds}, B(Ds$\rightarrow\phi\pi$), mix, CPV]
- O(1fb^{-1}) at J/ψ for QCD tests
- O(.. fb^{-1}) at baryon thresholds [B's, baryon SL]

BES II/BES III

- BES Achievements:
  - Precision measurement of τ mass: 3 σ changed, factor of 10 improved in accuracy. $\rightarrow$ lepton universality.
  - Systematic study of ψ' decays: new VT suppressed decay modes and First measurement of $B(\psi(2S)\rightarrow\tau+\tau-)$.
  - Precision R Measurement at 2-5GeV: $\Delta R/R$: 15-20 % $\rightarrow$ 6.6%. Large impact on the SM Fit for Higgs mass,

α (M_z^2) and g-2 experiment.

  - 116 entries in PDG from BES.

Future of BEPC: High precision measurements in charm energy region (2-4 GeV)

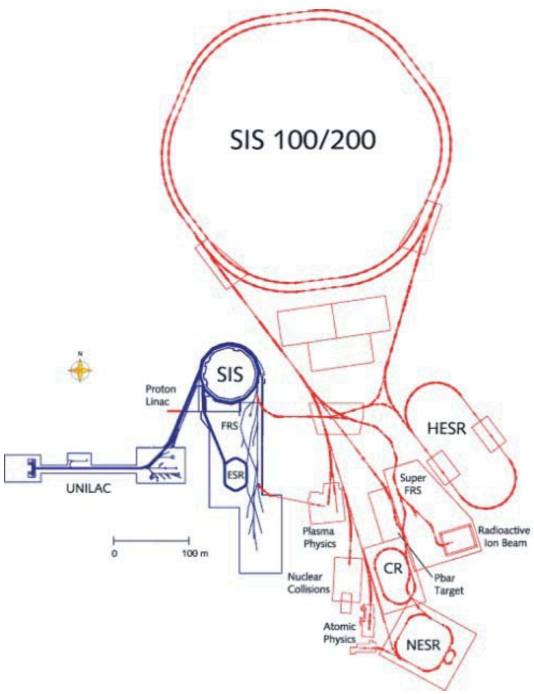
- Test of Standard Model with high statistics
- QCD and hadron production mechanism
- Search for new phenomena

Major Upgrade: BEPCII

- High luminosity machine → High statistics increasing by two orders of magnitudes
- High performance detector → Small systematic errors
  - improve γ measurement, PID, $\Delta P/P$ and acceptance
  - adapt to high event rate and short bunch spacing
- May take data at the end of 2006

Charm at GSI

PANDA: Antiproton Physics at GSI



New Facilities at GSI

SIS 200: Heavy ion synchrotron

! High-energy heavy ion collisions
! Injector for FRS
! Proton accelerator for $\bar{p}$-production

Super FRS: New fragment separator, RIB

New ESR: Radioactive ion beams in

HESR: Storage ring for antiprotons ight

Antiprotons with energies up to 15 GeV
High-energetic electron cooling
Very high luminosity (2 5 10^{32} cm ^{2}s ^{1})
Storage ring with internal targets
$\bar{p}$-production by 28 GeV p, AR/CR as CERN

Physics at HESR: PANDA detector

Hyperons and hypernuclei
Charmonium spectroscopy and Charm hybrids
Charm in nuclei
Charm meson physics

Under study, may take data at the end of the decade

Lars Schmitt, TU München

Concluding remarks

- CLEO-c can probe for physics beyond the Standard model with 4 different strategies
  - Precision decay constant measurements & form factors in semileptonic decays combined with B physics data
  - Mixing studies
  - CP violation studies
  - Rare decays
- We will start taking data at the ψ'' this fall!
- Our studies will be complementary to other experiments (BaBar, BELLE, **BTeV**…)
- Other experiments will/may come into play later this decade (BES III,PANDA at GSI)
- Charm phenomenology at ψ'' the is very rich, some measurements unique (quantum coherence of initial state)

Summary of Reach

		CLEO-C		b-fact		now
		2-4fb-1		400 fb-1		
fD		1.5-2%		NA??		NA
fDs		≤1%		5-10%		17.00%
Br(D+ -> Kππ)		1.50%		3-5%		7.00%
Br(Ds -> φπ)		2-3%		5-10%		25.00%
Br(D->πlν)		1.40%		3.00%		18.00%
Br(Λc -> pKπ)		6.00%		5-15%		26.00%
A(CP)		~1%		~1%		3-9%
x'(mix)		0.01		0.01		0.03
mτ		0.1 MeV				0.3 MeV