CLEO HOT Topics

Sheldon Stone
Syracuse University

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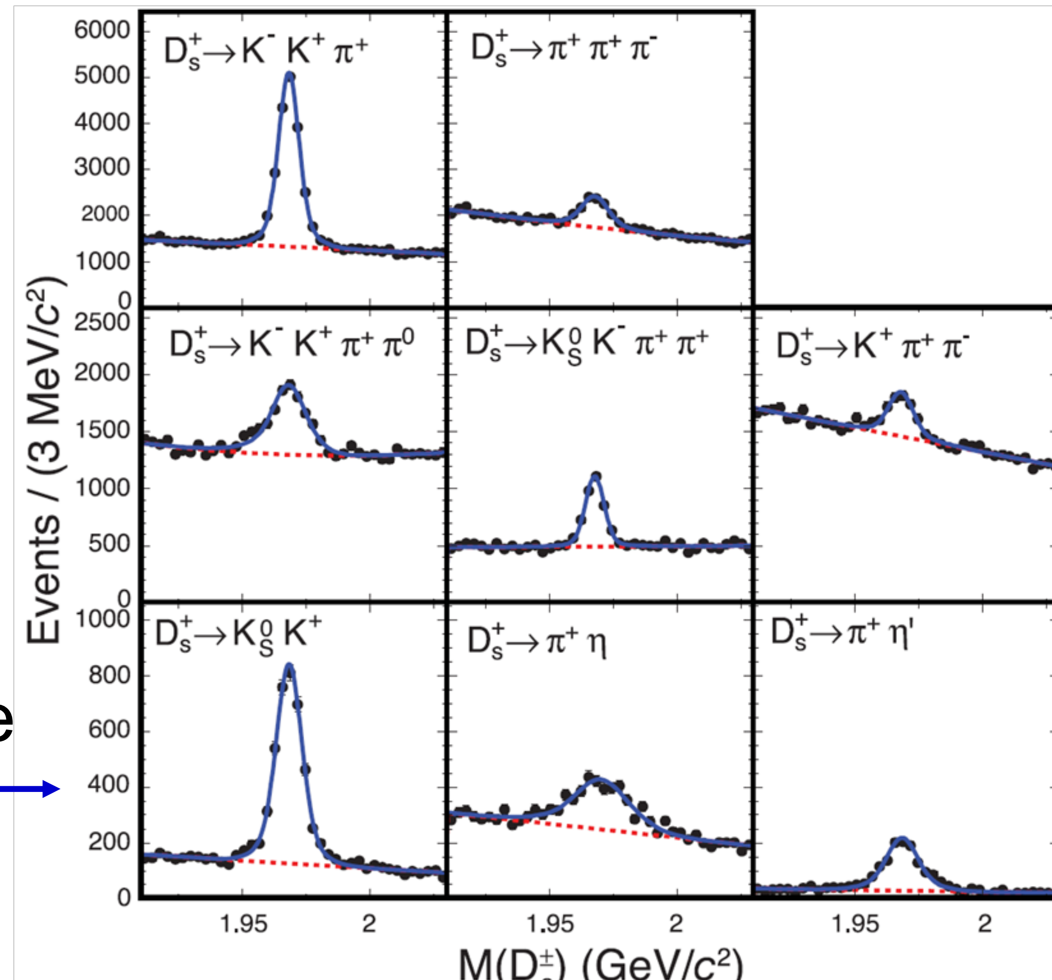
Favored Methods at CLEO-c

- Two-body production $e^+e^- \rightarrow D\bar{D}$
- Double tags at 3770 MeV: fully reconstruct one D^o or D^+, then can either fully reconstruct the other D (absolute branching ratios, quantum correlations) or look for events with one missing particle (leptonic decays, semileptonic decays, K_L)
- Similarly, double tags at 4170 MeV: here look for a D_S or a D_S^*
- Some measurements also done using single tags

Absolute D_S Branching Ratios

- Use ratio of Double tags/Single tags. To 1st order:
  - $\#D_1 = 2N_{DD}\varepsilon_1\mathcal{B}_1$
  - $\#D_{11} = N_{DD}\varepsilon_1^2\mathcal{B}_1^2$
  - $\therefore \#D_{11}/\#D_1 = (1/2)\,\varepsilon_1\mathcal{B}_1$
  - $\mathcal{B}_1 = (2/\varepsilon_1)\,(\#D_{11}/\#D_1)$
  - We use all combinations of these modes



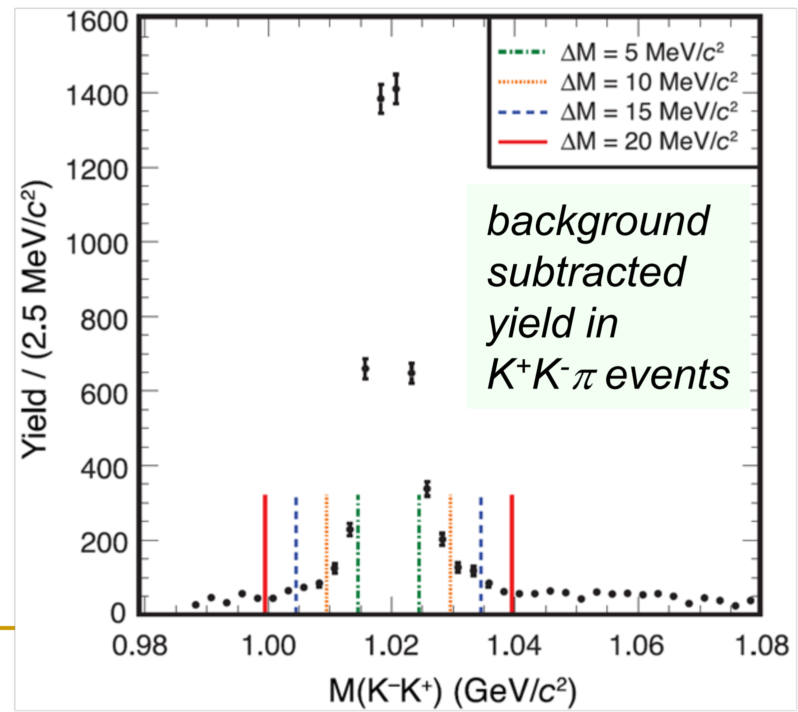
D_S Absolute $\mathcal{B}$ Results (300 pb^{-1})

Mode	This Result $\mathcal{B}$ (%)	PDG 2007 fit $\mathcal{B}$ (%)	$\mathcal{B}/\mathcal{B}(K^-K^+\pi^+)$	$\mathcal{A}_{CP}$ (%)
$K^0_S K^+$	$1.49 \pm 0.07 \pm 0.05$	2.2 ± 0.4	$0.270 \pm 0.009 \pm 0.008$	$+4.9 \pm 2.1 \pm 0.9$
$K^-K^+\pi^+$	$5.50 \pm 0.23 \pm 0.16$	5.3 ± 0.8	1	$+0.3 \pm 1.1 \pm 0.8$
$K^-K^+\pi^+\pi^0$	$5.65 \pm 0.29 \pm 0.40$	—	$1.03 \pm 0.05 \pm 0.08$	$-5.9 \pm 4.2 \pm 1.2$
$K^0_S K^-\pi^+\pi^+$	$1.64 \pm 0.10 \pm 0.07$	2.7 ± 0.7	$0.298 \pm 0.014 \pm 0.011$	$-0.7 \pm 3.6 \pm 1.1$
$\pi^+\pi^+\pi^-$	$1.11 \pm 0.07 \pm 0.04$	1.24 ± 0.20	$0.202 \pm 0.011 \pm 0.009$	$+2.0 \pm 4.6 \pm 0.7$
$\pi^+\eta$	$1.58 \pm 0.11 \pm 0.18$	2.16 ± 0.30	$0.288 \pm 0.018 \pm 0.033$	$-8.2 \pm 5.2 \pm 0.8$
$\pi^+\eta'$	$3.77 \pm 0.25 \pm 0.30$	4.8 ± 0.6	$0.69 \pm 0.04 \pm 0.06$	$-5.5 \pm 3.7 \pm 1.2$
$K^+\pi^+\pi^-$	$0.69 \pm 0.05 \pm 0.03$	0.67 ± 0.13	$0.125 \pm 0.009 \pm 0.005$	$+11.2 \pm 7.0 \pm 0.9$

Now typically known to ±5%

$\mathcal{B}(D_S^+ \to \phi\pi^+)$ – Unfortunately not well defined due to interference of overlapping resonances. Value depends on both mass resolution & cut in K^+K^- mass

K^+K^- mass cut	$\mathcal{B}(D_S^+ \to \phi\pi^+)$ (%)
± 5 MeV	3.43±0.16±0.12
±10 MeV	4.04±0.20±0.10
±15 MeV	4.35±0.20±0.10
±20 MeV	4.55±0.22±0.12



Input to D Mixing Measurements

- Rate of D mixing parameterised by $x=2\Delta M/\Gamma$ & $y=\Delta\Gamma/\Gamma$.
- Time-dependent wrong-sign rate $D^0 \to K^-\pi^+$:
  - Sensitivity via interference between DCS and mixing amplitudes

$$A_{DCS} / A_{CF} = \langle K^-\pi^+|\overline{D}^0\rangle \; / \; \langle K^-\pi^+|D^0\rangle = -re^{-i\delta}$$

  - Where the strong phase causes a problem: $y' = y\cos\delta - x\sin\delta$
  - Direct comparison with y measurements from CP-eigenstate lifetimes and time-dependent measurements of $D\to K_S\pi\pi$ Dalitz plot are **not possible** without determination of δ
- **δ and other mixing parameters can be measured in quantum correlated $D\overline{D}$ decay at CLEO-c**
  - See Asner talk later in the week & arXiv:0802.2268v1 [hep-ex]

Coherent vs. Incoherent Decay

- $R_M=(x^2+y^2)/2$, $R_{WS}=r^2+ry'+R_M$
- Double tag rates:

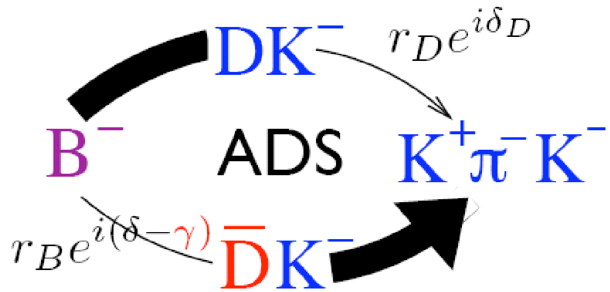
DT	$K^-\pi^+$	e^+	$CP+$	$CP-$
$K^-\pi^+$	R_M / R_{WS}			
$K^+\pi^-$	$1+2R_{WS}-4r\cos\delta\,(r\cos\delta+y)$			
e^-	$1-r\,(y\cos\delta+x\sin\delta)$	1		
$CP+$	$1+(2r\cos\delta+y)/(1+R_{WS})$	$1+y$	0	
$CP-$	$1-(2r\cos\delta+y)/(1+R_{WS})$	$1-y$	2	0
ST	1	1	1	1

  - Compare coherent/incoherent branching fractions, where the double tags supply the coherent rates
  - Leads to $$\delta=\left(22^{+11+9}_{-12-11}\right)^\circ$$

See Yabsley talk

Help In Measuring γ

- Recall ADS method



- One key rate is

$$\boxed{\Gamma(\mathrm{B}^- \to (\mathrm{K}^+\pi^-)_{\mathrm{D}}\mathrm{K}^-) \propto r_B^2 + (r_D^{K\pi})^2 + 2r_B r_D^{K\pi} \cdot \cos(\delta_B + \delta_D^{K\pi} - \gamma)}$$

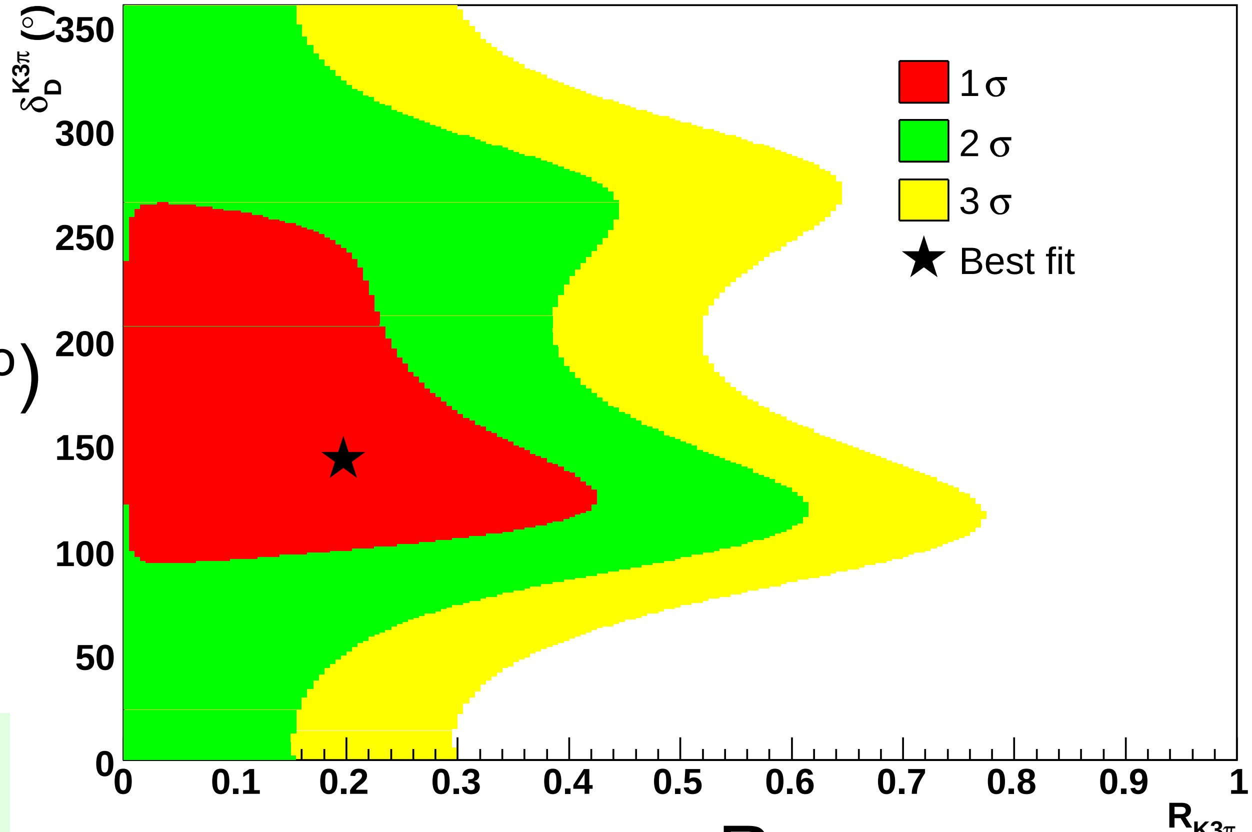
- Can use $D^o \to K^-\pi^+\pi^+\pi^-$ instead of $K^-\pi^+$:

$$\Gamma(B^- \to (K^+\pi^-\pi^-\pi^+)_D K^-) \propto r_B^2 + (r_D^{K3\pi})^2 + 2r_B r_D^{K3\pi} \underline{R_{K3\pi}} \cos(\delta_B + \delta_D^{K3\pi} - \gamma)$$

- If coherence factor is small can help measure r_B, since r_B is the same in both cases.

Limits on $R_{K3\pi}$

- We find
- See Asner's talk for details



$\delta_D^{K3\pi}(^o)$

$R_{K3\pi}$

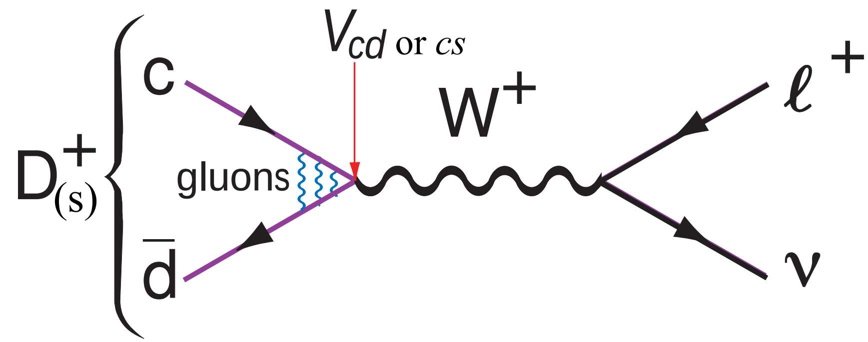
Preliminary Results (281 pb^{-1})

Leptonic Decays: D $\rightarrow \ell^+\nu$

Introduction: Pseudoscalar decay constants

c and $\bar{q}$ can annihilate, probability is proportional to wave function overlap

Feynman diagram in Standard Model :



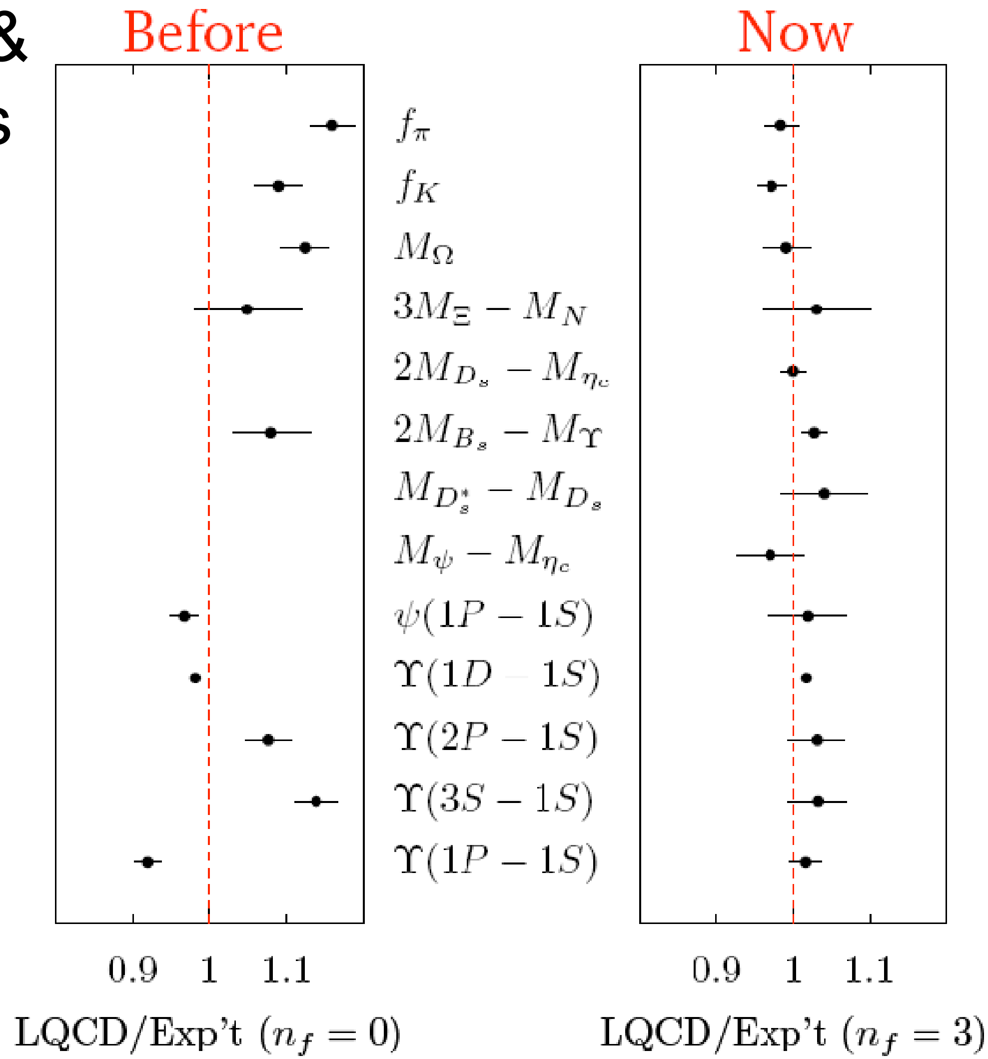
In general for all pseudoscalars:

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

Calculate, or measure if V_{Qq} is known, here take $V_{cd}=V_{us}=0.2256$

New Unquenched Lattice Calc

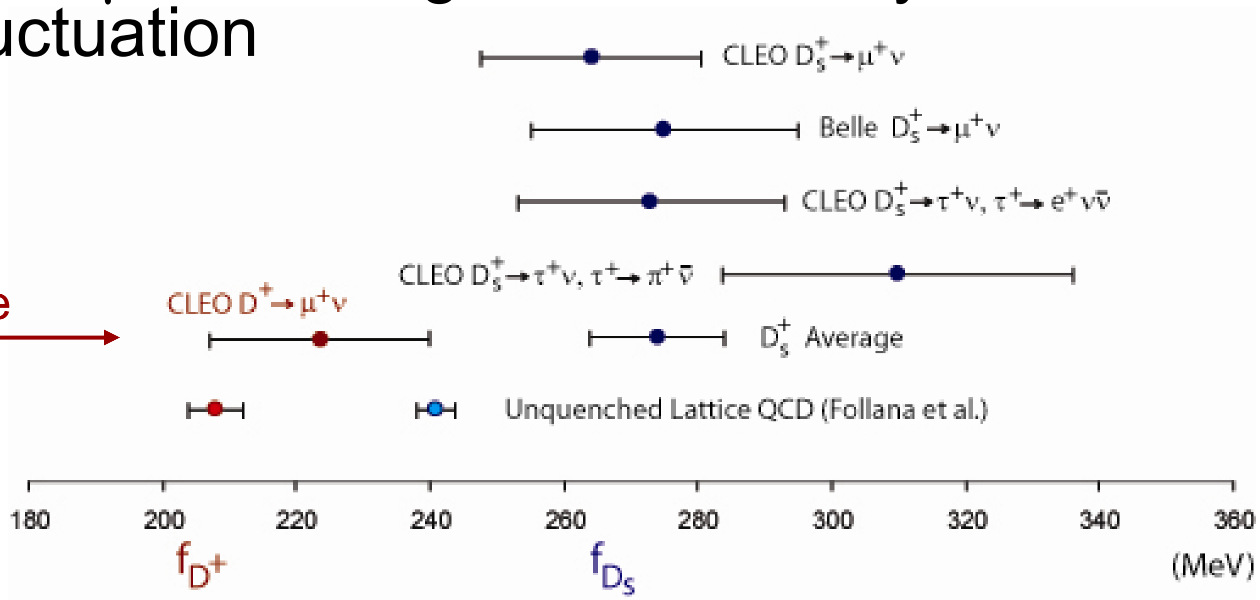
- Follana et al HPQCD & UKQCD collaborations (PRL **100,** 062002 (2008)) New predictions of
  f_{D^+}= 207±4 MeV
  f_{Ds} = 241±3 MeV
- Older unquenched from FNAL+MILC +HPQCD are:
  f_{D^+}= 201±3 ±17 MeV
  f_{Ds} = 249±3 ±16 MeV
  (Aubin et al., PRL 95, 122002 (2005))



Situation Prior To FPCP 2008

- Experiment f_{Ds}: CLEO measures both $\mu^+\nu$ & $\tau^+\nu$, & Belle measures $\mu^+\nu$. Average is 3.3 σ away , could be a weird fluctuation

D+ too inaccurate to say anything



- Dobrescu & Kronfeld (arXiv:0803.0512) argue that this can well be the effect of NP, either charged Higgs (their own model) or leptoquarks
- Here I will update both CLEO measurements

(Details in dedicated talk)

Basic Technique for $D^+ \to \mu^+\nu$

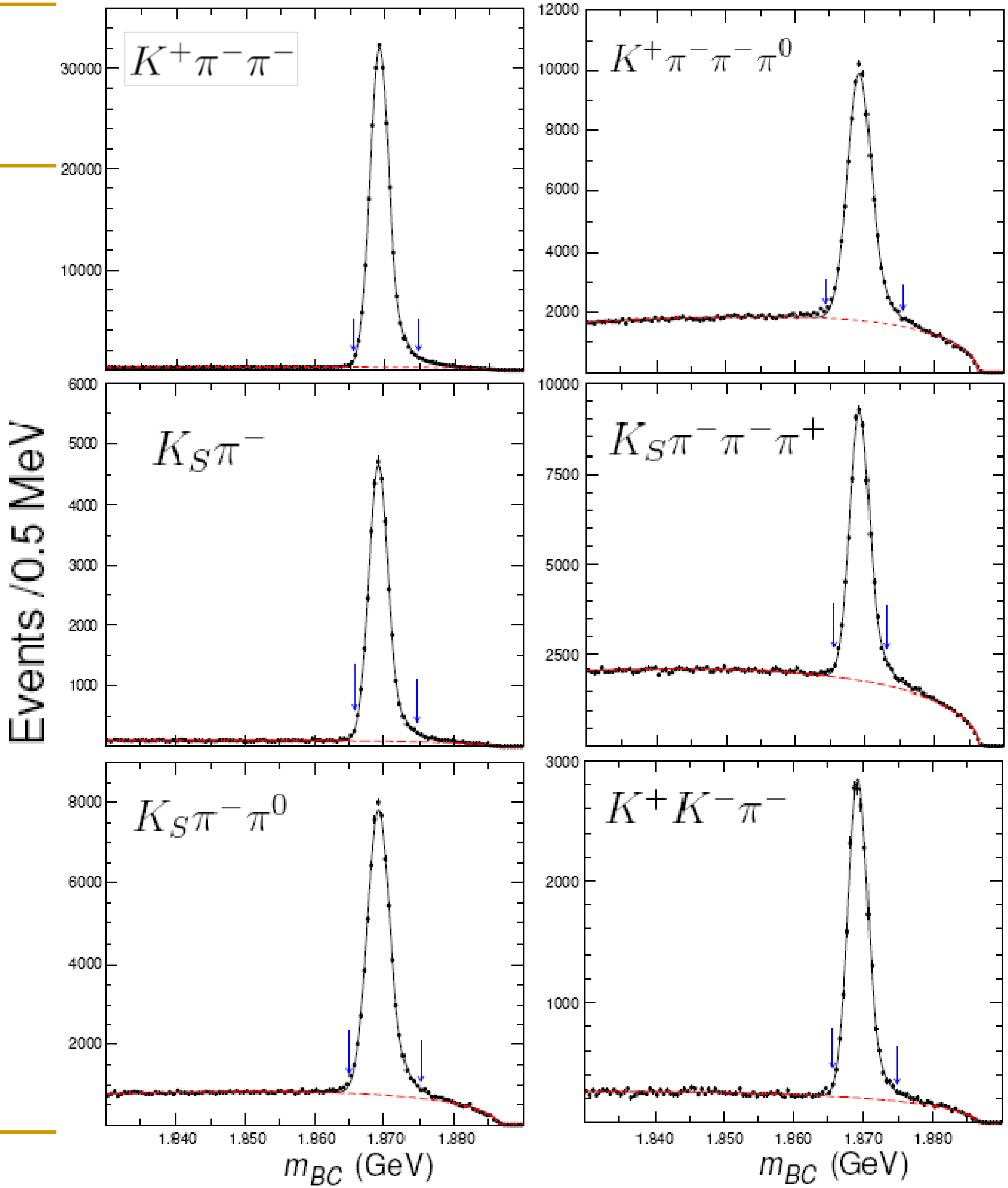
- Fully reconstruct a D^-, and count total # of tags
- Seek events with only one additional oppositely charged track within $|\cos\theta|<0.9$ & no additional photons > 250 MeV (to veto $D^+ \to \pi^+\pi^o$)
- Charged track must deposit only minimum energy (from ionization) in calorimeter < 300 MeV
- Compute MM^2. If close to zero then almost certainly we have a $\mu^+\nu$ decay.

$$MM^2 = (E_{D^+} - E_{\ell^+})^2 - (\vec{p}_{D^+} - \vec{p}_{\ell^+})^2$$

We know $E_{D^+} = E_{beam}$, $\mathbf{p}_{D^+} = -\mathbf{p}_{D^-}$

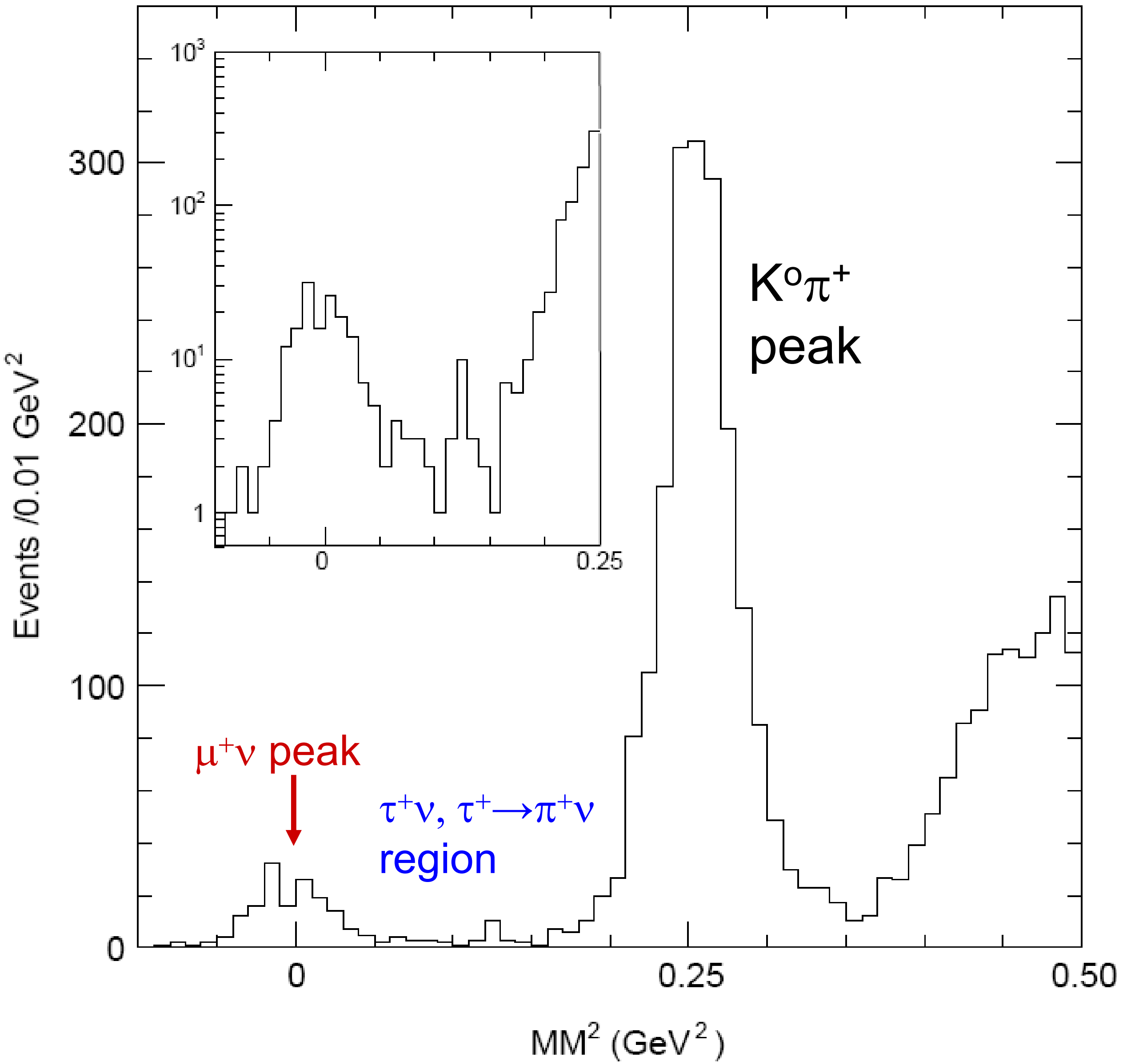
Tags

- Now use 818 pb^{-1} of data on $\psi(3770)$
- Total of 460,000
- Background 89,400



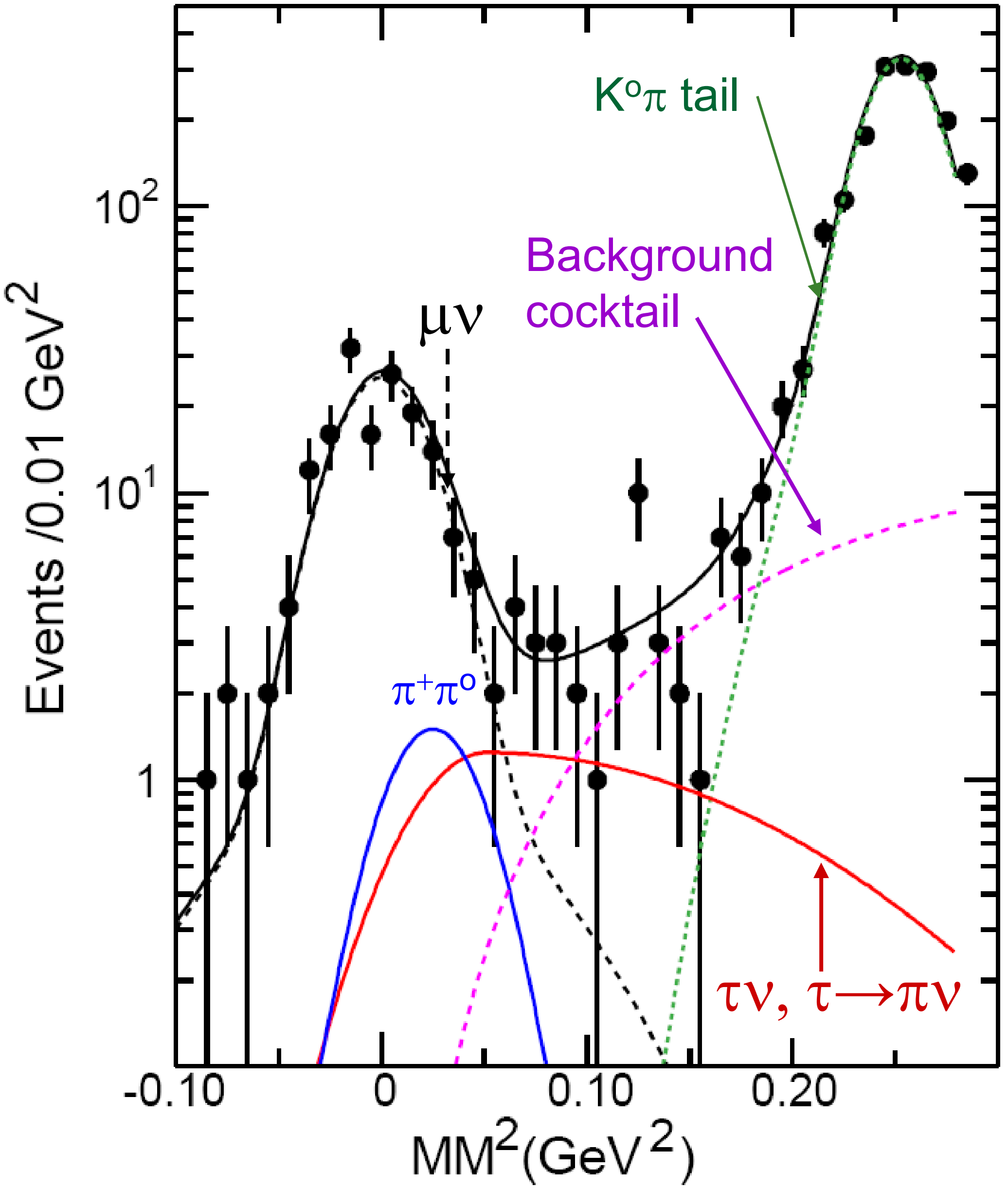
The MM^2 Distribution

- For E< 300 MeV in CsI



Fit MM^2 to sum of signal & bkgrd

- $\tau^+\nu/\mu^+\nu$ is **fixed** to SM ratio
  - 149.7±12.0 $\mu\nu$
  - 28.5 $\tau\nu$
- $\tau^+\nu/\mu^+\nu$ is allowed to **float**
  - 153.9±13.5 $\mu\nu$
  - 13.5±15.3 $\tau\nu$



Branching Fractions & f_{D^+}

- Fix $\tau\nu/\mu\upsilon$
  - $\mathcal{B}(D^+\rightarrow\mu^+\nu)= (3.86\pm0.32\pm0.09)\times10^{-4}$
  - $f_{D^+}=(206.7\pm8.5\pm2.5)$ MeV
  - This is best number in context of SM
- Float $\tau\nu/\mu\upsilon$
  - $\mathcal{B}(D^+\rightarrow\mu^+\nu)= (3.96\pm0.35\pm0.10)\times10^{-4}$
  - $f_{D^+}=(208.5\pm9.3\pm2.5)$ MeV
  - This is best number for use with Non-SM models

Preliminary

Improved Measurement of f_{Ds}

- CLEO has two methods of measuring f_{Ds}
  - Measure $\mu^+\nu$ & $\tau^+\nu$, $\tau^+\rightarrow \pi^+\nu$ using similar MM^2 technique used for D^+. Update result using new analysis & 30% more data (total of ~400 pb^{-1})
  - Measure $\tau^+\rightarrow e^+\nu\nu$ by using missing energy. This result has not been updated (300 pb^{-1})

Use $e^+e^- \rightarrow D_S D_S^*$ at 4170 MeV

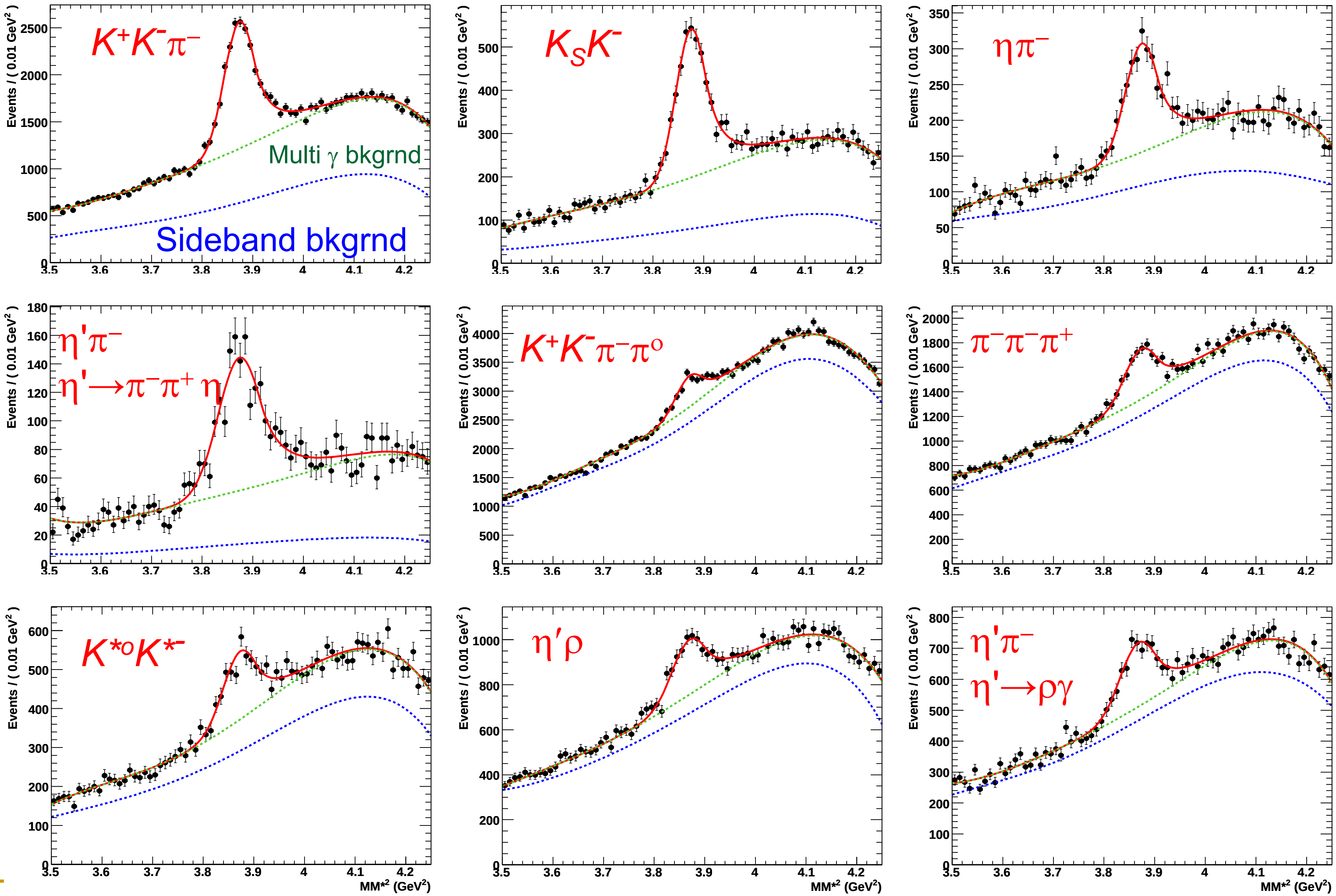
- Reconstruct D_S^-, similar invariant mass distributions as for absolute $\mathcal{B}$ analysis
- Find the γ from the D_S^* & compute MM^2 from D_S^- & γ

$$MM^{*2} = (E_{CM} - E_{D^-} - E_\gamma)^2 - (-\vec{p}_{D^-} - \vec{p}_\gamma)^2$$

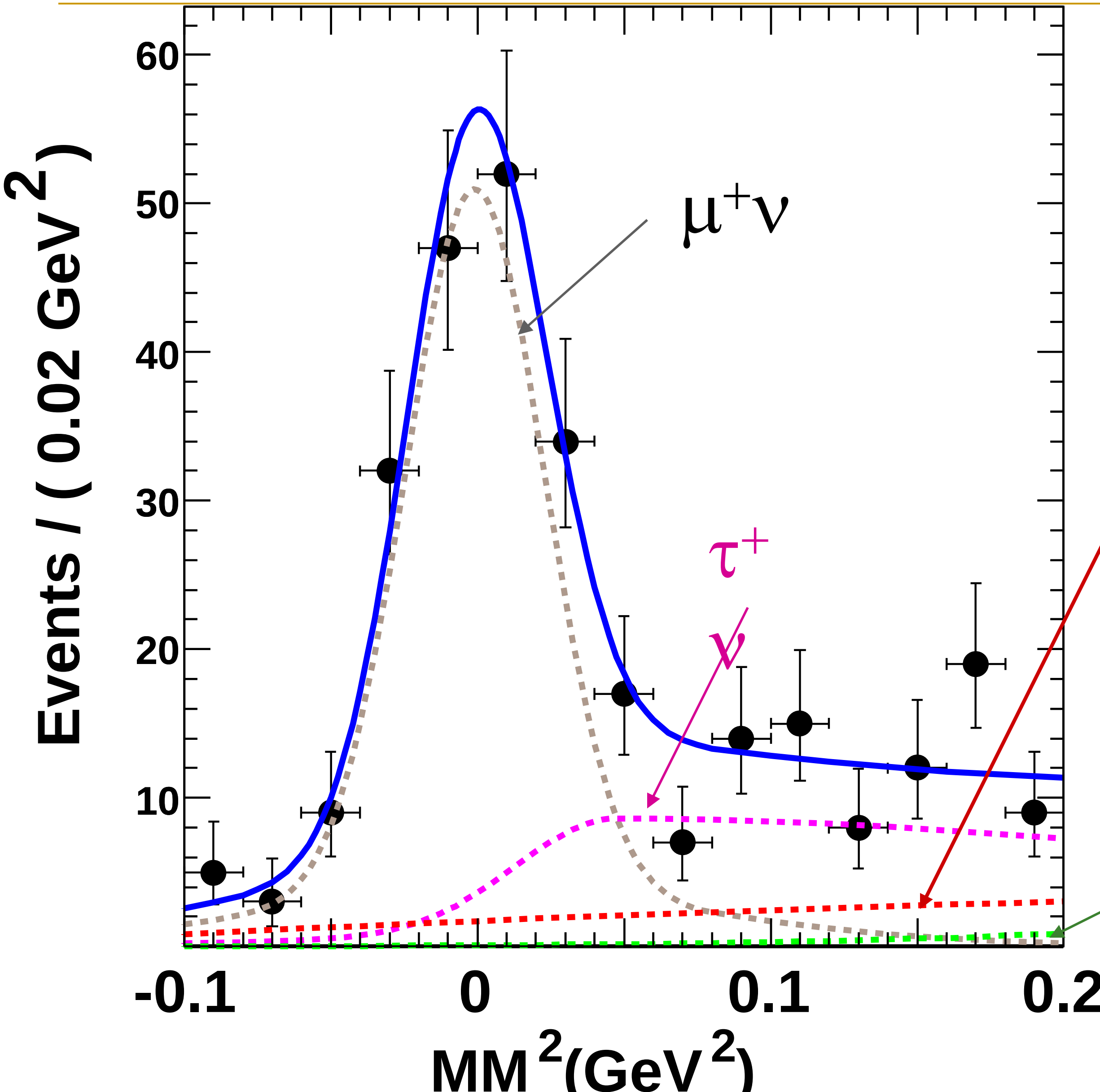
- Select combinations consistent with a missing D_S^+ & count the number
- Find MM^2 from candidate muons in the tag sample, where

$$MM^2 = (E_{CM} - E_{D^-} - E_\gamma - E_\mu)^2 - (-\vec{p}_{D^-} - \vec{p}_\gamma - \vec{p}_\mu)^2$$

MM^{*2} Distributions From $D_S^- + \gamma$



Fit to signal & background



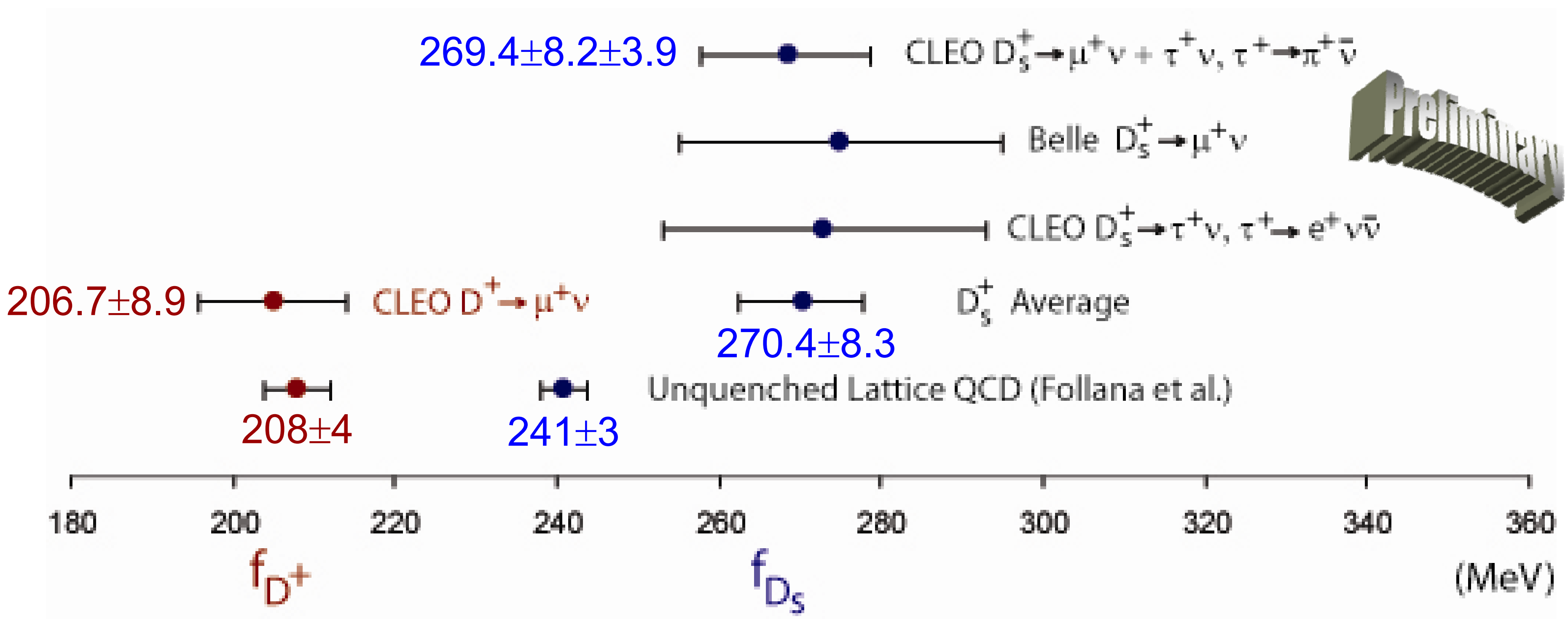
Fit to MM^2

Background D_S sidebands

Extra γ background

Conclusions on Decay Constants

- We are in close agreement with the Follana et al calculation for f_{D^+}. This gives credence to their methods
- The disagreement with f_{Ds} is enhanced

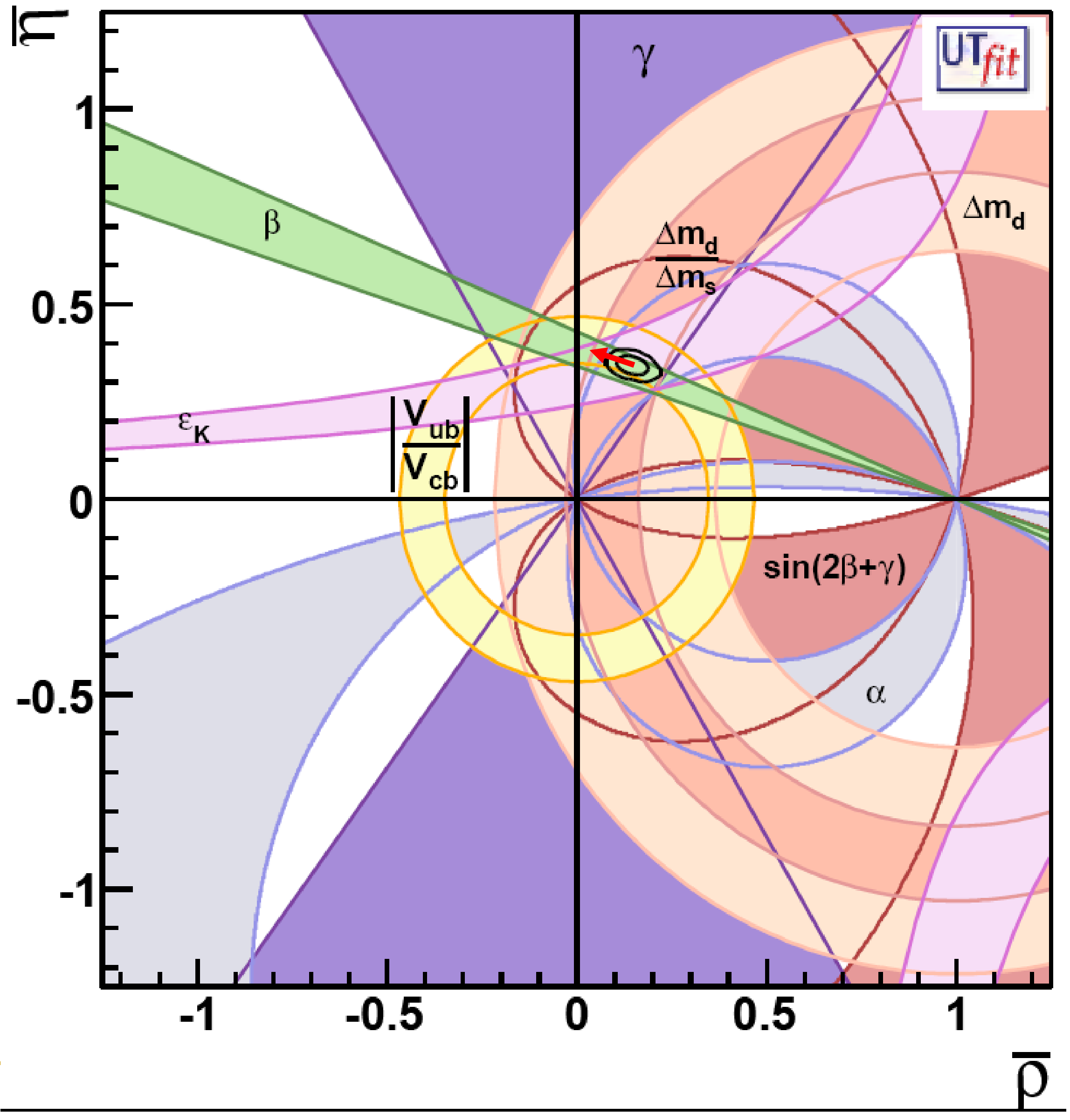


Consequences

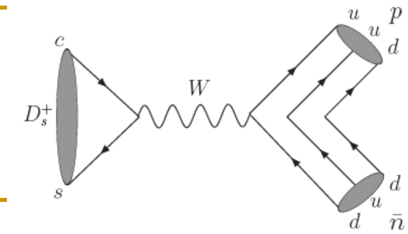
- Pick your favorite of the two:
  - If theoretical predictions of f_{Ds}/f_{D^+} do not agree with the data, why should we believe f_{Bs}/f_B from theory? What does this do to the CKM fits?
  - If there is New Physics affecting leptonic D_S decays, how does it affect B_S mixing and other B_S decays? (See A. Kundu & S. Nandi, "R-parity violating supersymmetry, B_S mixing, & $D_S^+ \to \ell^+\nu$" [arXiv:0803.1898])

IF There is a Shift ..

- If increases the radius of the $\Delta m_d/\Delta m_s$ constraint increases
- Red arrow indicates a shift of ~10% in f_{Bs}/f_B

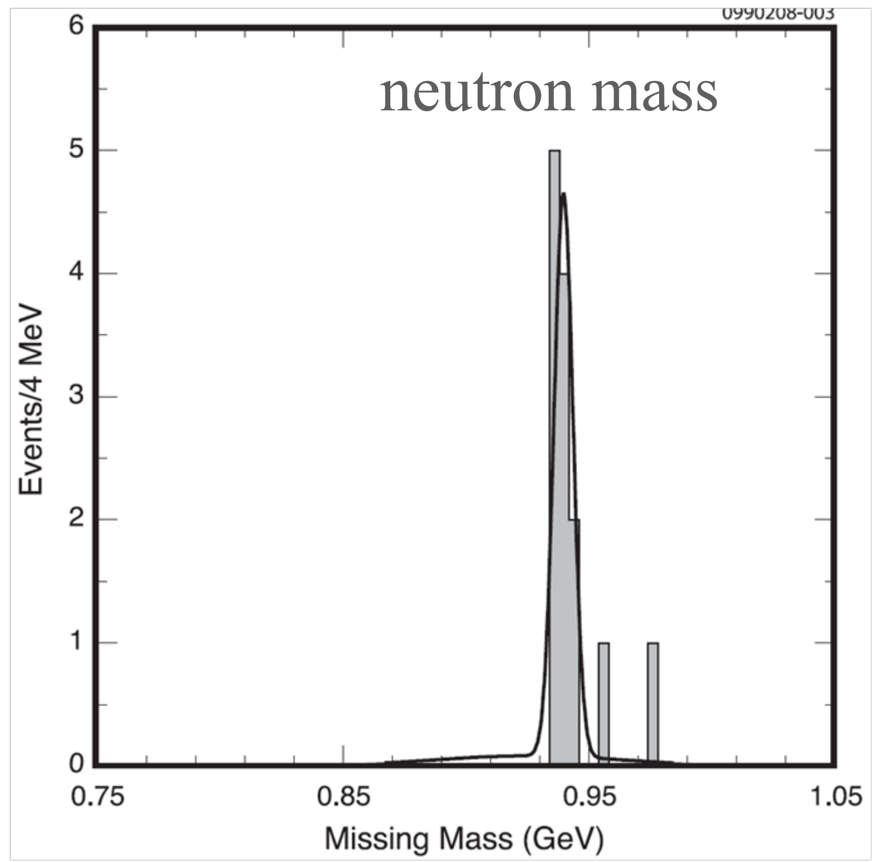


Discovery of $D_S^+ \to p\bar{n}$



- Use same technique as for $\mu^+\nu$, but plot MM from an identified proton
- No background
- First example of a charm meson decaying into baryons

arXiv:0803.1118v2 [hep-ex]



$$B(D_s^+ \to p\bar{n}) = (1.30 \pm 0.36^{+0.12}_{-0.16})\ x10^{-3}$$

- Consequences for understanding W annihilation dynamics

see Chen, Cheng & Hsiao arXiv:0803.2910v3 [hep-ph]

Higgs Search from Υ(1S) Decays

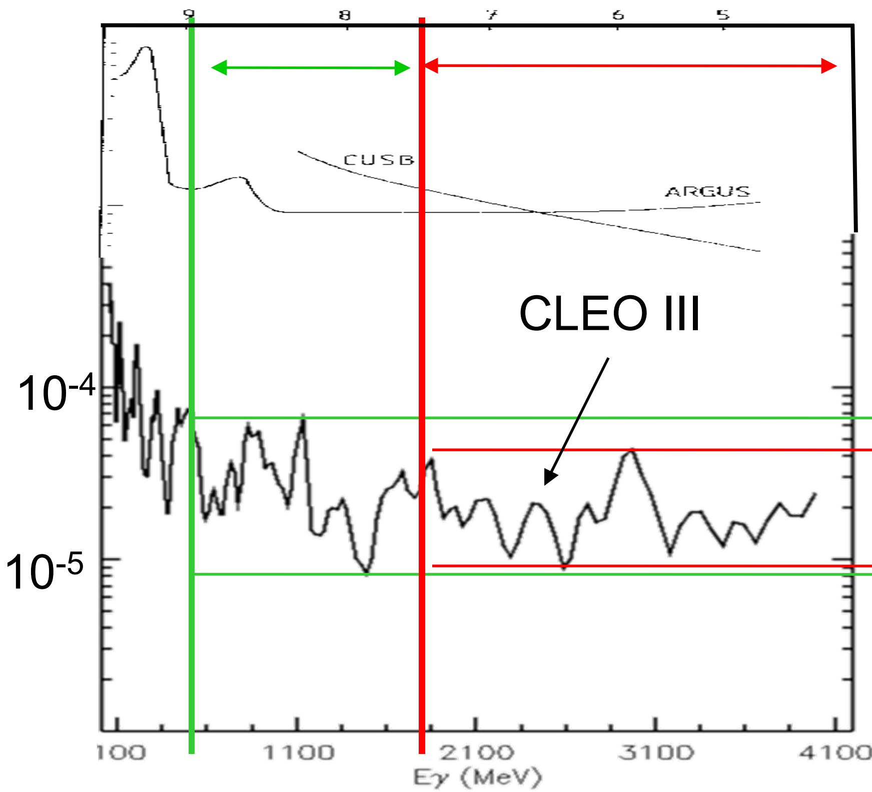
- Some NMSSM models (Dermisek, Gunion, McElrath: PRD D76, 051105(2007)) avoid the LEP limit on the Higgs mass by postulating a new non-SM-like Higgs boson ***a*₁** (a pseudoscalar) with $m_a < 2m_b$, where $H \to \boldsymbol{a_1}\, \boldsymbol{a_1}$
- A good place to search for the $\boldsymbol{a_1}$ is in radiative Upsilon decays, $\Upsilon \to \gamma\, \boldsymbol{a_1}$,
- The $\boldsymbol{a_1}$ would decay predominantly into heaviest down-type pair of fermions available
- HyperCP observed 3 $\Sigma^+ \to p\mu^+\mu^-$ events, mass 214.3±0.5 MeV. He,Tandean,Valencia PRL 98, 081802 (2007) interpret this as evidence for $\boldsymbol{a_1}$ with 214.3 MeV mass, since below $\tau^+\tau^-$ threshold $\boldsymbol{a_1} \to \mu^+\mu^-$ would be large

CLEO Search

- We use 21.5 M $\Upsilon(1S)$ decays collected with the CLEO III detector
- For the $\boldsymbol{a_1} \rightarrow \tau^+\tau^-$ search we examine the photon energy spectrum in events with missing energy & one identified $\mu^\pm$ or $e^\pm$ (allegedly from $\tau \rightarrow e\nu\nu$ or $\tau \rightarrow \mu\nu\nu$)
- For the $\boldsymbol{a_1} \rightarrow \mu^+\mu^-$ search we examine the photon energy spectrum in events with **no** missing energy & two identified $\mu^\pm$
- No narrow peaks are observed, except for $\Upsilon(1S) \rightarrow \gamma J/\psi \rightarrow \gamma\mu^+\mu^-$

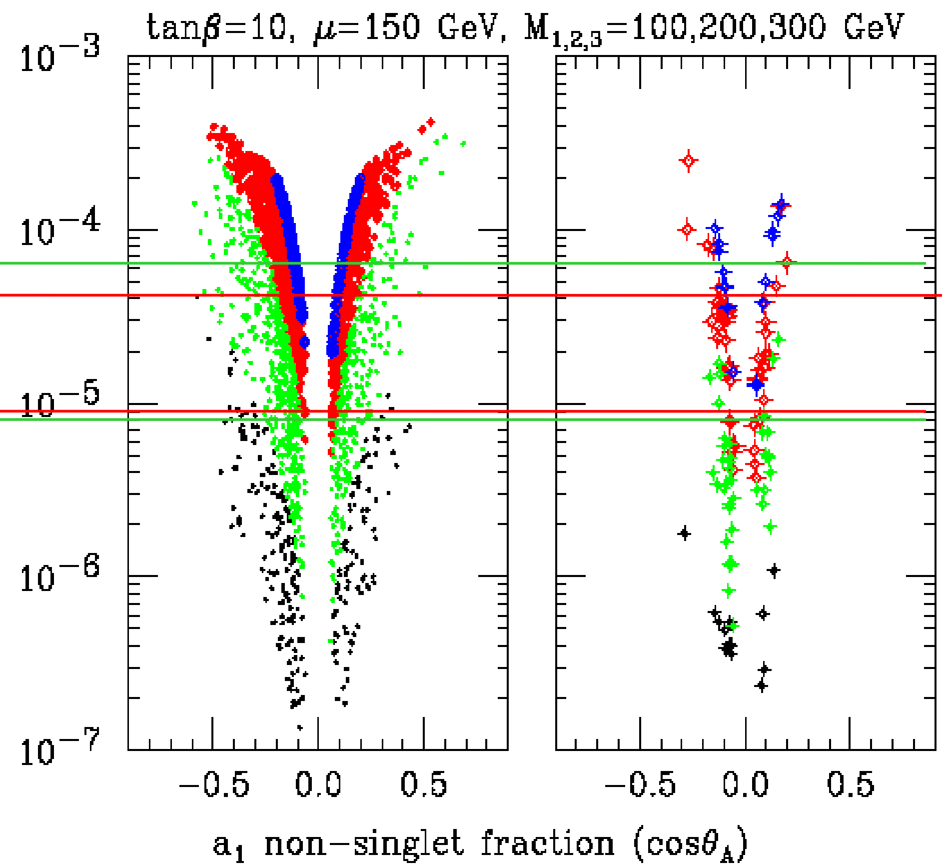
Constraints on NMSSM from $\gamma\tau^+\tau^-$

$\mathcal{B}(\Upsilon(1S)\to\gamma\tau^+\tau^-)$



From
Dermisek, Gunion, McElrath: hep-ph/0612031

NMSSM consistent with
all previous results

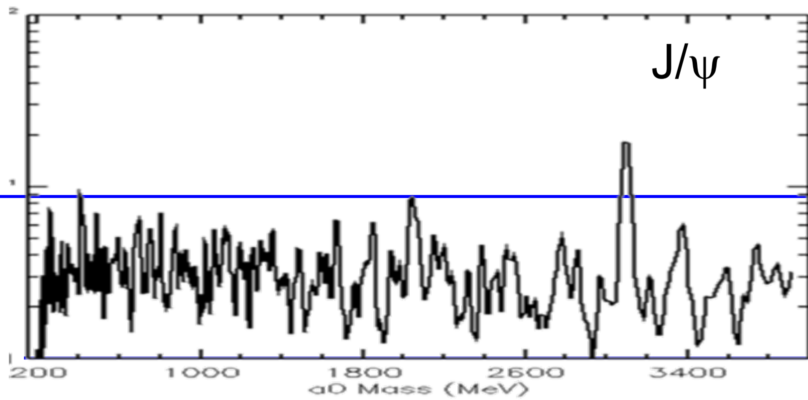


Many models with $2m_\tau<m_a<7.5$ GeV (represented by red points) ruled out by our results.

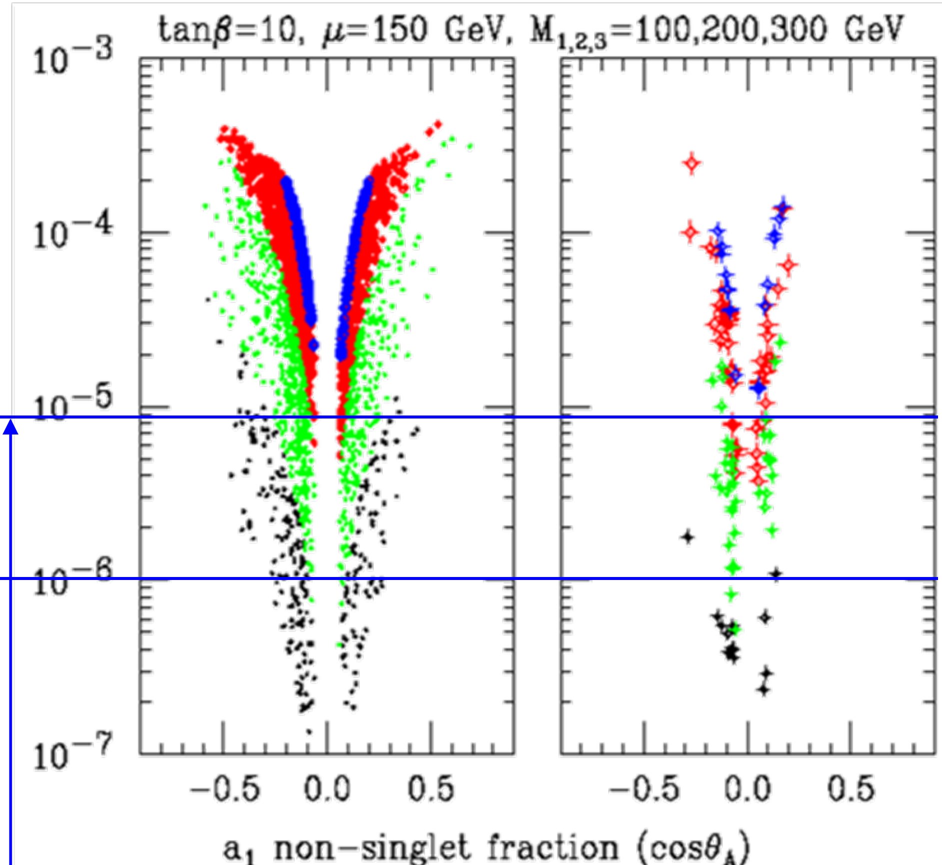
Colors represent different mass ranges

Constraints on NMSSM from $\gamma\mu^+\mu^-$

- $\mathcal{B}(\Upsilon(1S)\to\gamma\mu^+\mu^-)$



Preliminary



Colors represent different mass ranges

Eliminates all of NMSSM models for $m_{a_1}<2m_\tau$ (blue points)

Summary of Higgs Search

- We have obtained meaningful limits on $\mathcal{B}(\Upsilon(1S)\to \gamma \boldsymbol{a_1})*\mathcal{B}(\boldsymbol{a_1}\to \tau^+\tau^-)$ & $\mathcal{B}(\Upsilon(1S)\to \gamma \boldsymbol{a_1})*\mathcal{B}(a_1\to \mu^+\mu^-)$
- Using $\gamma\tau^+\tau^-$ we eliminate a large portion of previously unconstrained parameter space in the NMSSM model
- Using $\gamma\mu^+\mu^-$ we eliminate the entire parameter space in NMSSM model, for $m_{a_1}<2m_\tau$ except when the a_1 is pure singlet
- There is no evidence for a CP-odd Higgs state decaying to $\mu^+\mu^-$ with a mass of 214.3 MeV; our limit is much below the NMSSM expectations for $\boldsymbol{a_1}$ at 214 MeV prompted the by HyperCP $\Sigma^+\to p\mu^+\mu^-$ event candidates

Hot Topics submitted to ICHEP

Analysis of the $D^+ \to K^+K^-\pi^+$ Dalitz plot

Analysis of the $D_s^+ \to K^+K^-\pi^+$ Dalitz plot

Rare radiative D meson decays

Improving the precision of γ/ϕ_3 via CLEO-c Dalitz plot analysis

Determination of the strong phase in $D^0 \to K^+\pi^-$ using quantum-correlated measurements

Hadronic decays of the D and D_s mesons

Improved measurement of the pseudoscalar decay constant $f_{D_s^+}$

Improved measurement of the pseudoscalar decay constant f_{D^+}

Exclusive semileptonic decays of the D_s meson

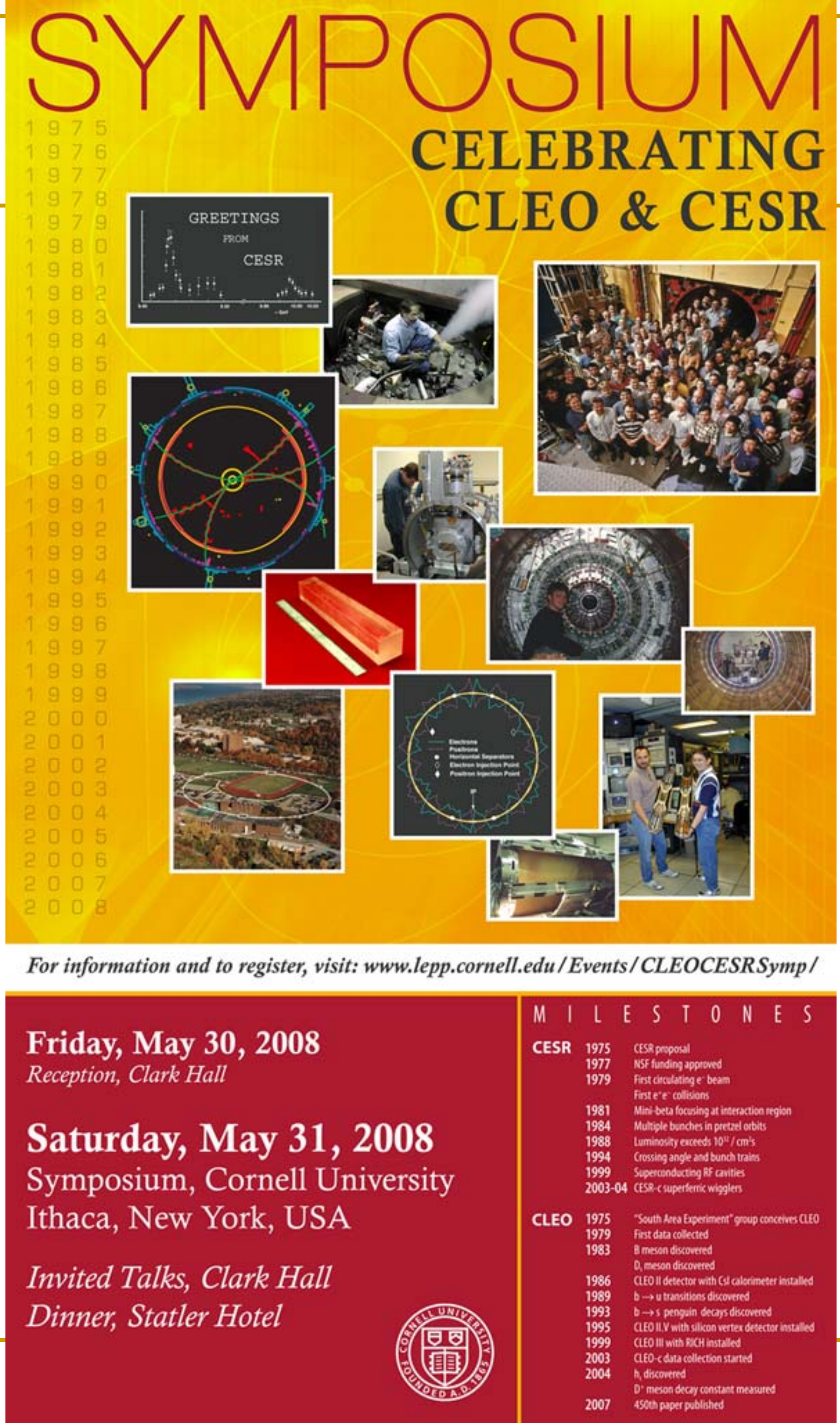
Exclusive semileptonic decays of the D meson

Υ transitions and decays

Radiative and electromagnetic decays of charmonia

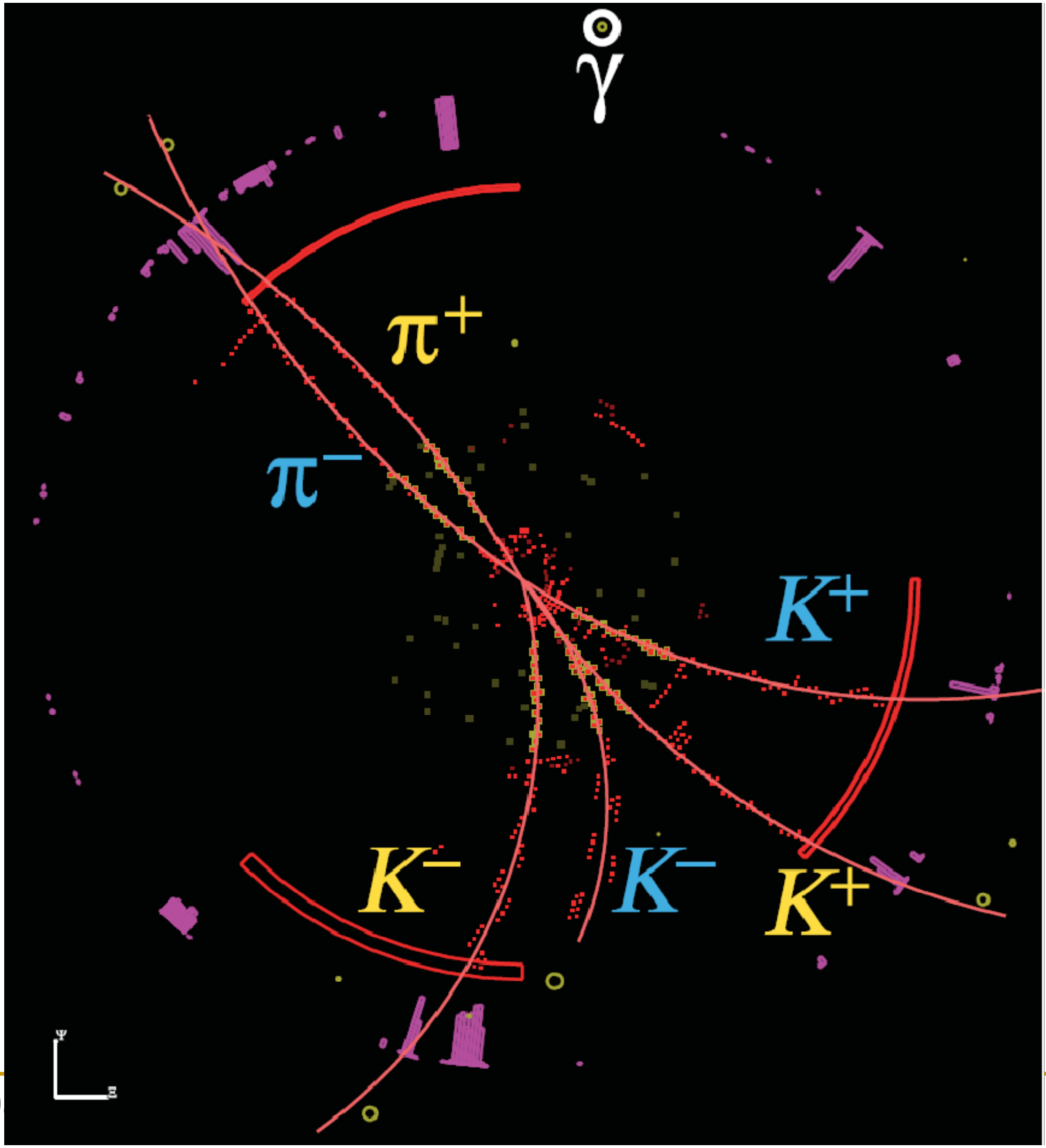
Spectroscopy in charmonia decays

All Invited

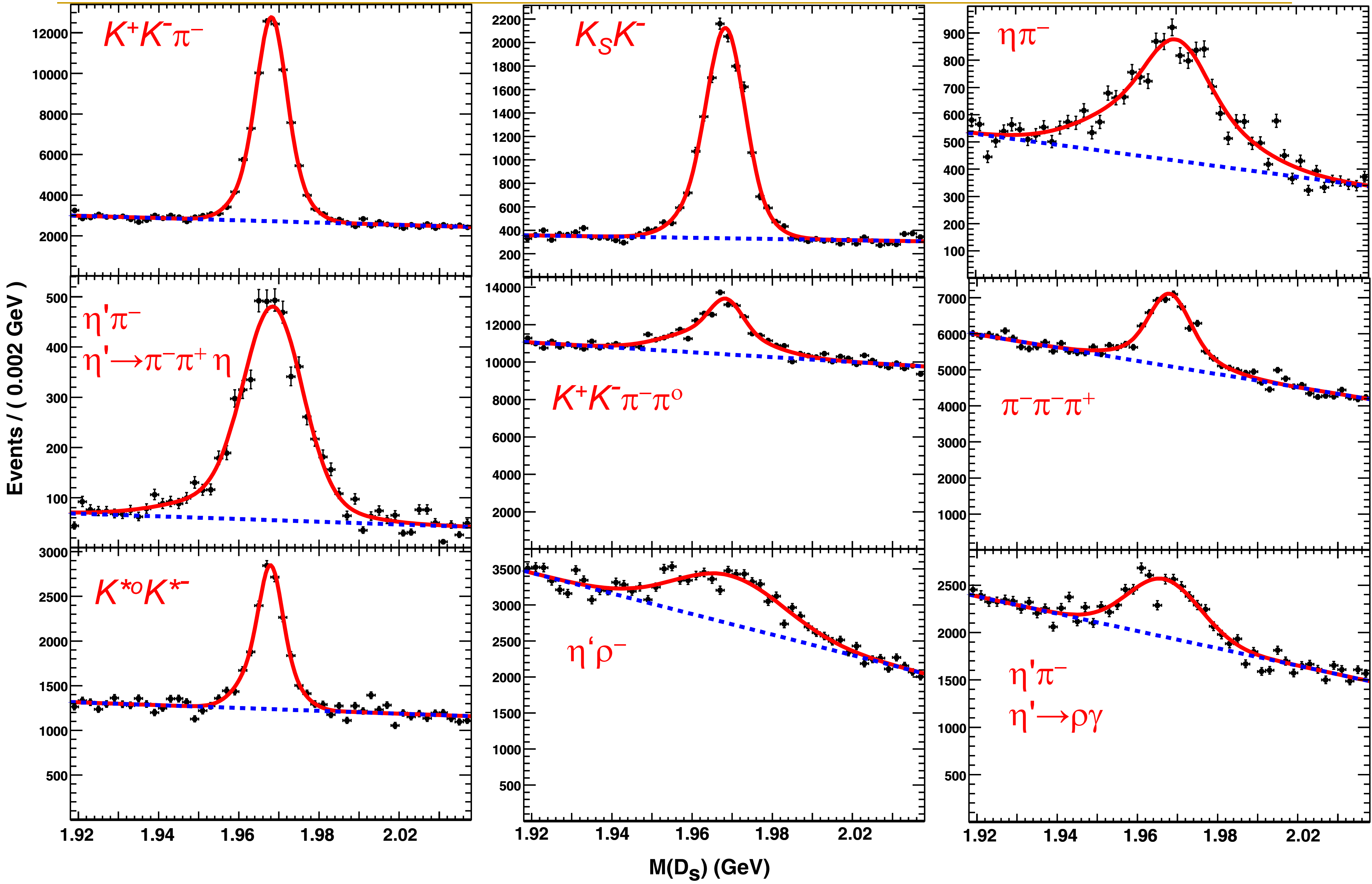

SYMPOSIUM
CELEBRATING CLEO & CESR
GREETINGS FROM CESR
For information and to register, visit: www.lepp.cornell.edu/Events/CLEOCESRSymp/
Friday, May 30, 2008
Reception, Clark Hall
Saturday, May 31, 2008
Symposium, Cornell University
Ithaca, New York, USA
Invited Talks, Clark Hall
Dinner, Statler Hotel
MILESTONES
CESR
1975 CESR proposal
1977 NSF funding approved
1979 First circulating e^- beam
First e^+e^- collisions
1981 Mini-beta focusing at interaction region
1984 Multiple bunches in pretzel orbits
1988 Luminosity exceeds 10^{32} / cm^{2}s
1994 Crossing angle and bunch trains
1999 Superconducting RF cavities
2003-04 CESR-c superferric wigglers
CLEO
1975 "South Area Experiment" group conceives CLEO
1979 First data collected
1983 B meson discovered
D_s meson discovered
1986 CLEO II detector with CsI calorimeter installed
1989 b → u transitions discovered
1993 b → s penguin decays discovered
1995 CLEO II.V with silicon vertex detector installed
1999 CLEO III with RICH installed
2003 CLEO-c data collection started
2004 h_c discovered
D^+ meson decay constant measured
2007 450th paper published

The End

$e^+e^- \rightarrow D_S D_S^*$



D_S^- Tags: Invariant Mass



MM^2 data for D_S

- Total of 30848±695 tags
- 99% of $\mu^+\nu$ in E < 300 MeV
- 55%/45% split of $\tau^+\nu$, $\tau^+\rightarrow\pi^+\nu$ in two cases
- Small e^- background