Charm Leptonic Decays

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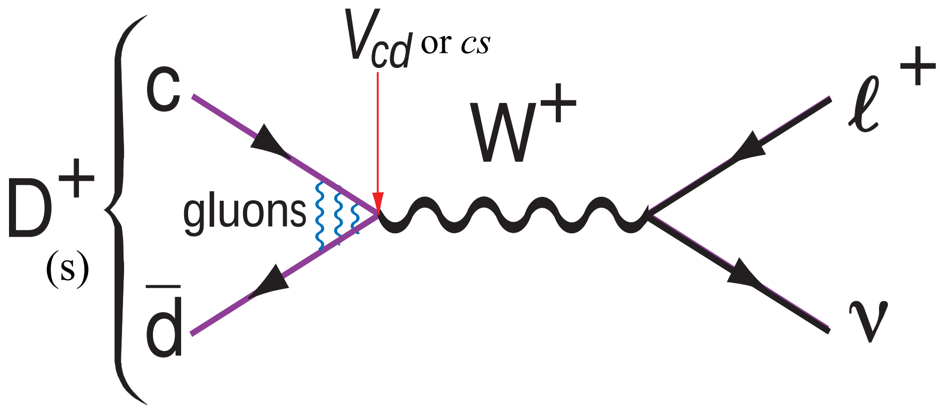
Introduction

- In general for all pseudoscalars:

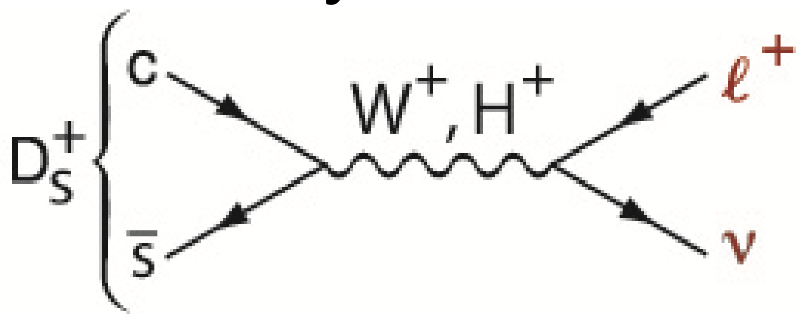


$$\Gamma(P^+ \to \ell^+ \nu) = \frac{1}{8\pi} G_F^2 f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2 |V_{Qq}|^2$$

Calculate, or measure if V_{Qq} is known, here take $V_{cd} = V_{us} = 0.2256$,
$V_{cs} = V_{ud} - V_{cb}/4 = 0.9734$

Reasons to Measure

- Lattice calculations needed for all sorts of heavy flavor parameters, e.g. $\xi = f_B/f_{Bs}$, $B \to \pi \ell \nu$ form-factors…f_D & f_{Ds}/f_D provide an experimental check
- Possibilities to see effects of New Physics
  - Interference with H^+.
  - Rate ratio

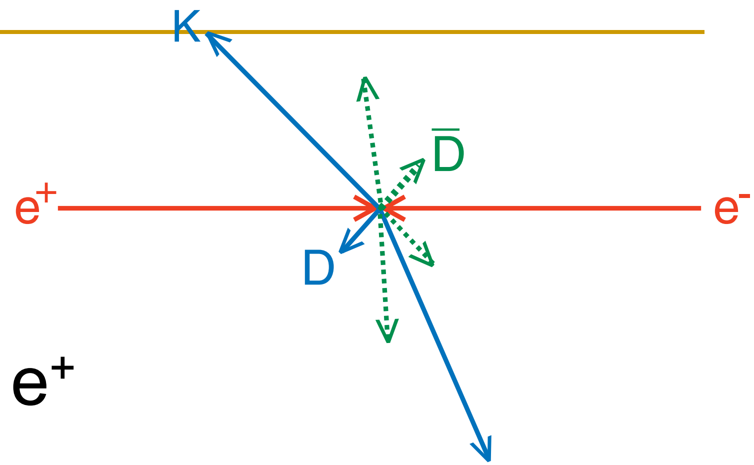


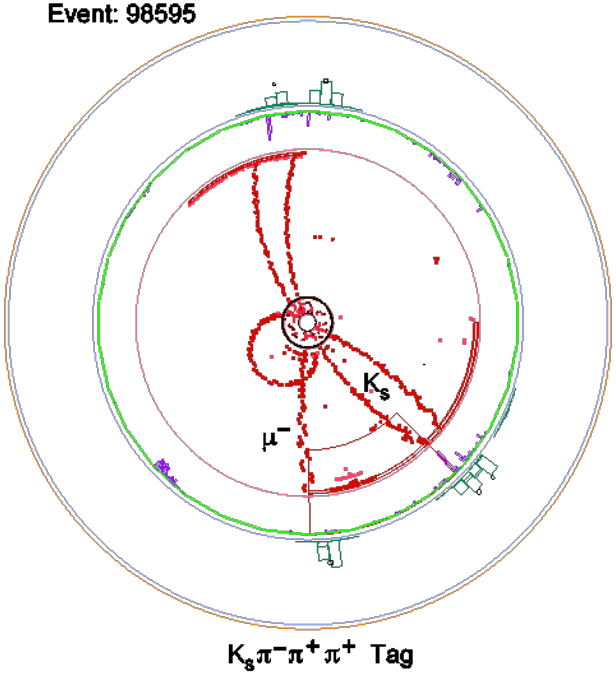
$$\frac{\Gamma(P^+ \to \tau^+ \nu)}{\Gamma(P^+ \to \mu^+ \nu)} = m_\tau^2 \left(1 - \frac{m_\tau^2}{M_P^2}\right)^2 \Big/ m_\mu^2 \left(1 - \frac{m_\mu^2}{M_P^2}\right)^2$$

is sensitive to neutrino couplings, e.g. a sterile neutrino coupling differently to ν_μ & ν_τ, or any model which doesn't couple as m_ℓ^2, e.g. Leptoquarks

CLEO Toolkit

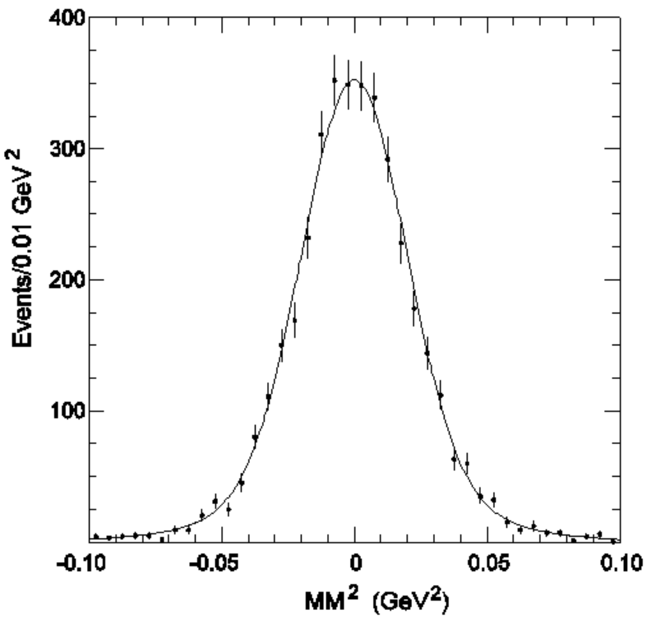
- Use $e^+e^- \to D\bar{D}$
  - Fully reconstruct one D, the tag
  - For $D \to Xe^+\nu$, positively id the e^+
  - For $D \to \mu^+\nu$, make sure μ^+ doesn't interact in EM cal
  - For $D \to \tau^+\nu$, also use extra energy, E_{extra}, deposited in EM cal, that is not matched with the tag or final state decay products of the τ^+, either $e^+\nu\nu$, $\pi^+\nu$, or $\rho^+\nu$



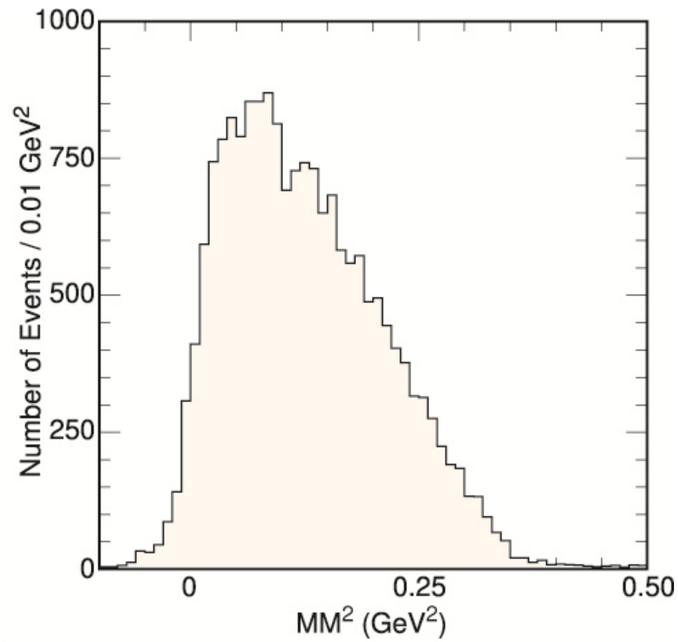


Toolkit: Missing Mass Squared

- $D^+ \to \mu^+\nu$ $\quad MM^2 = (E_{D^+} - E_{\ell^+})^2 - (\vec{p}_{D^+} - \vec{p}_{\ell^+})^2$
- We know $E_{D^+} = E_{beam}$, $\mathbf{p}_{D^+} = -\mathbf{p}_{D^-}$
- If close to zero then almost certainly we have a missing ν.



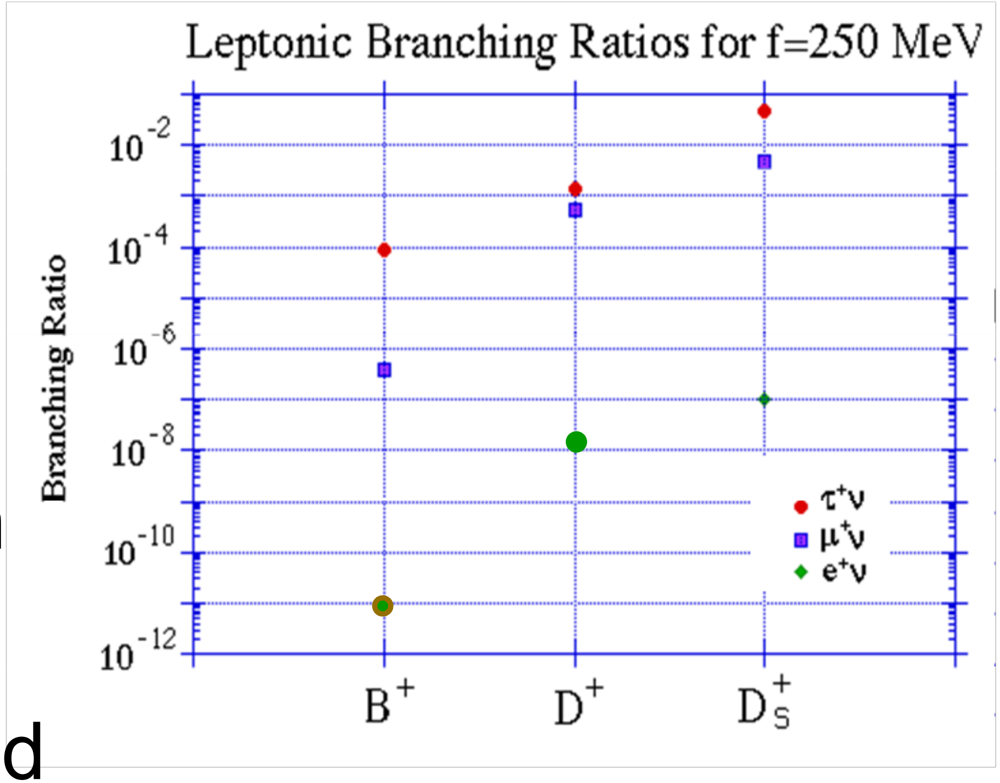
Monte Carlo Signal μν



Monte Carlo Signal τν, τ→πν

Experimental Considerations

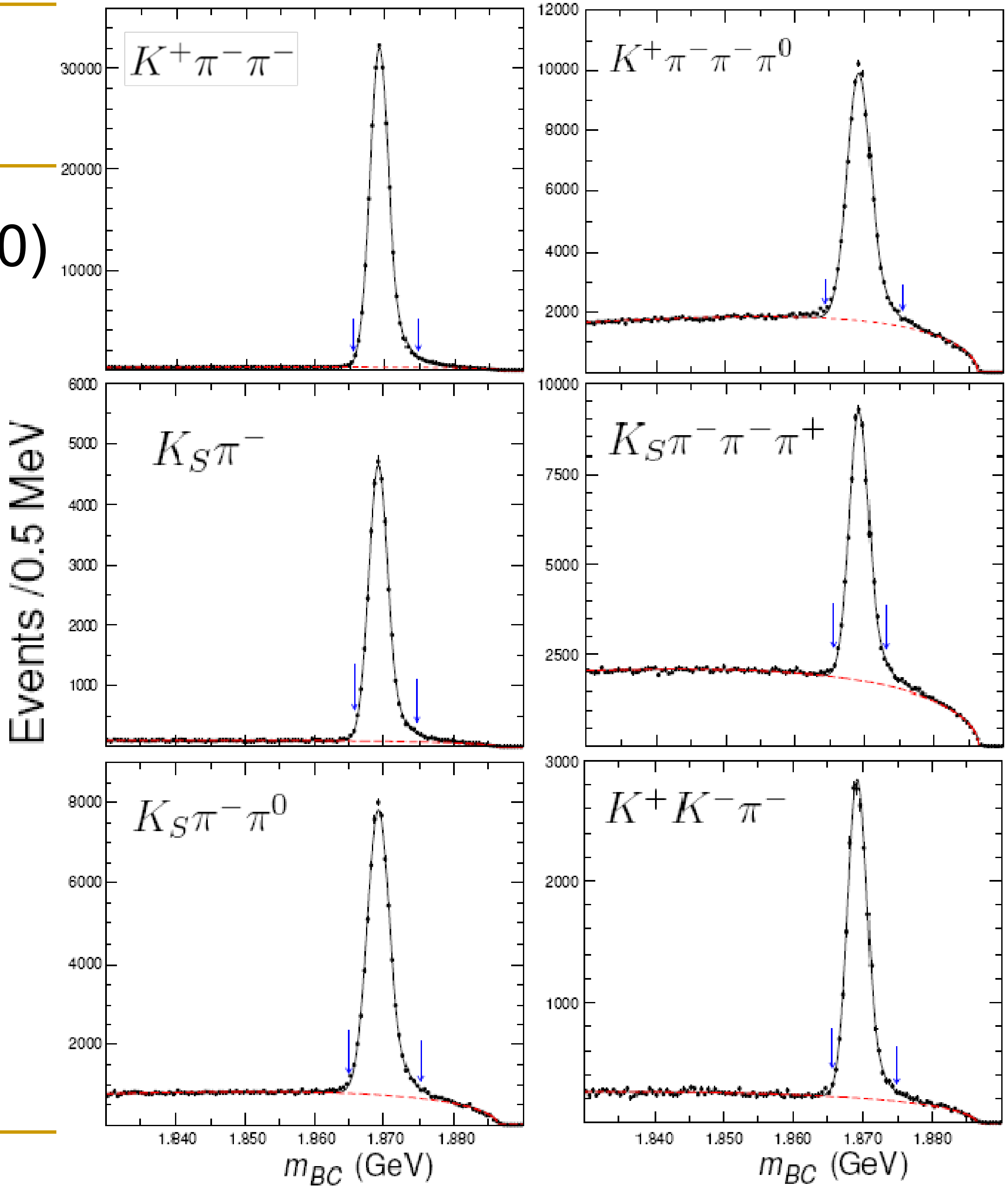
- In principle have access to 6 decays
  $D^+ \to e^+\nu, \mu^+\nu, \tau^+\nu$
  $D_S^+ \to e^+\nu, \mu^+\nu, \tau^+\nu$
- Helicity suppression causes $e^+\nu$ mode to be highly suppressed



- $D \to \tau^+\nu$ has at 2 neutrinos missing, so is more difficult to detect
- Only B^+ available, not B^o or B_S & $\mathcal{B}$ is low

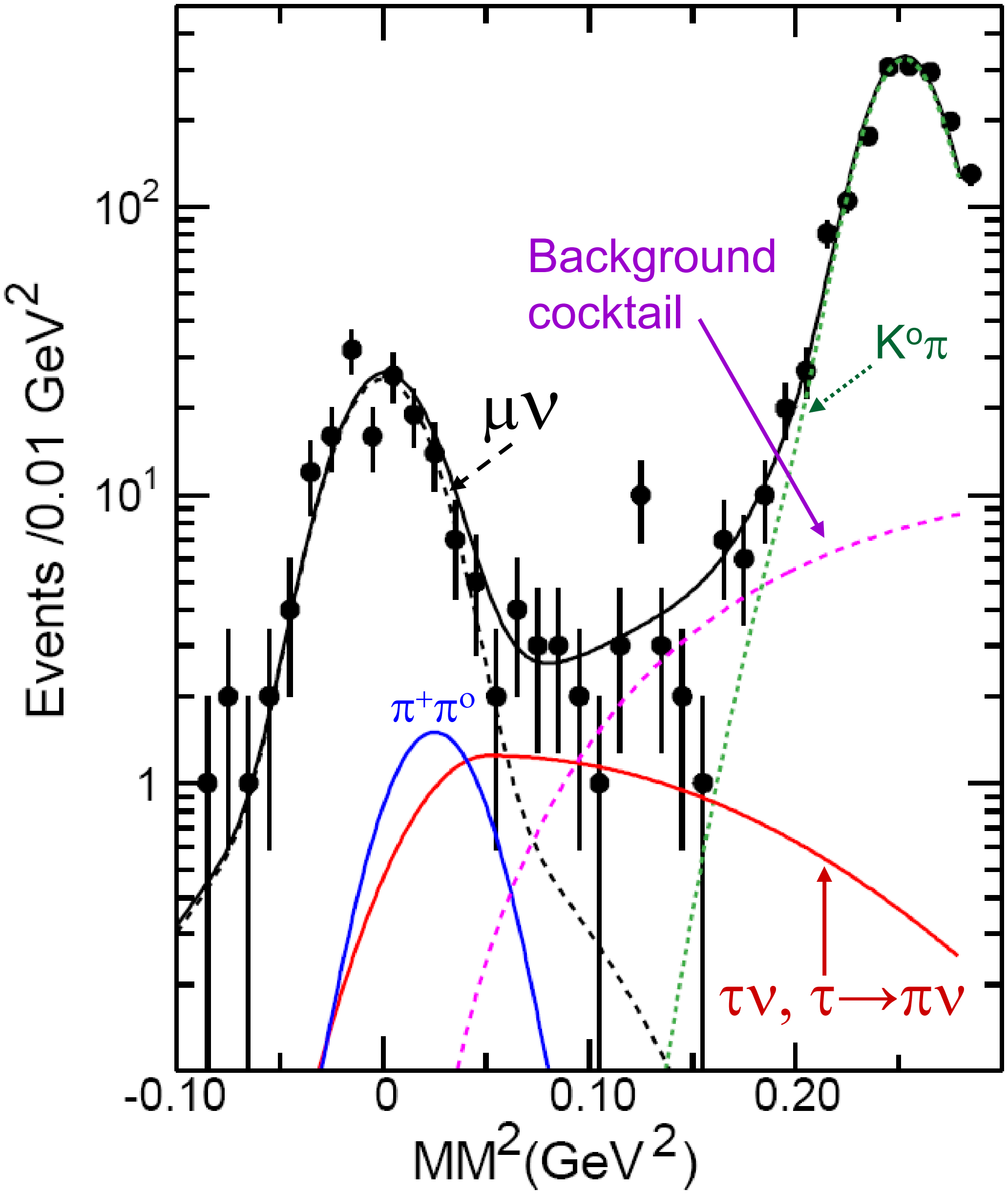
D⁻ Tags

- From CLEO at ψ(3770)
- Total of 460,000
- Background 89,400



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

- Require E_{cal} <300 MeV for candidate; no extra γ > 250 MeV
- $\tau^+\nu/\mu^+\nu$ 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^+}

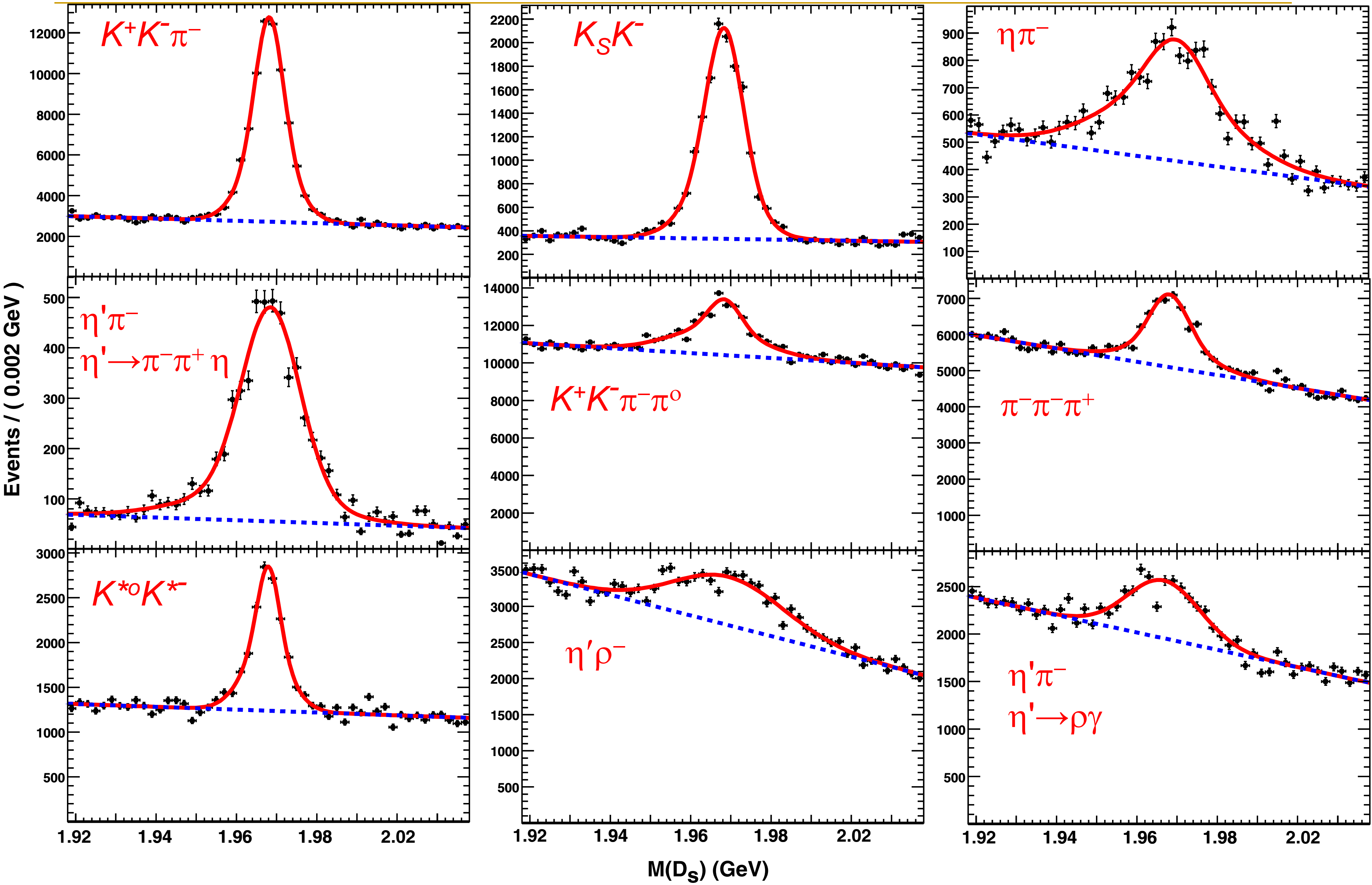
- Fix $\tau\nu/\mu\nu$ at SM ratio of 2.65
  - $\mathcal{B}(D^+\to\mu^+\nu)$= $(3.82\pm0.32\pm0.09)\times10^{-4}$
  - $f_{D^+}=(206.7\pm8.5\pm2.5)$ MeV
  - This is best number in context of SM
- Float $\tau\nu/\mu\upsilon$
  - $\mathcal{B}(D^+\to\mu^+\nu)$= $(3.93\pm0.35\pm0.10)\times10^{-4}$
  - $f_{D^+}=(209.7\pm9.3\pm2.5)$ MeV
  - This is best number for use with Non-SM models
- *These are final numbers with 818 pb^{-1}*
- *This is the only measurement*

f_{Ds}

CLEO: Use $e^+e^- \to D_s D_s^*$ at 4170 MeV

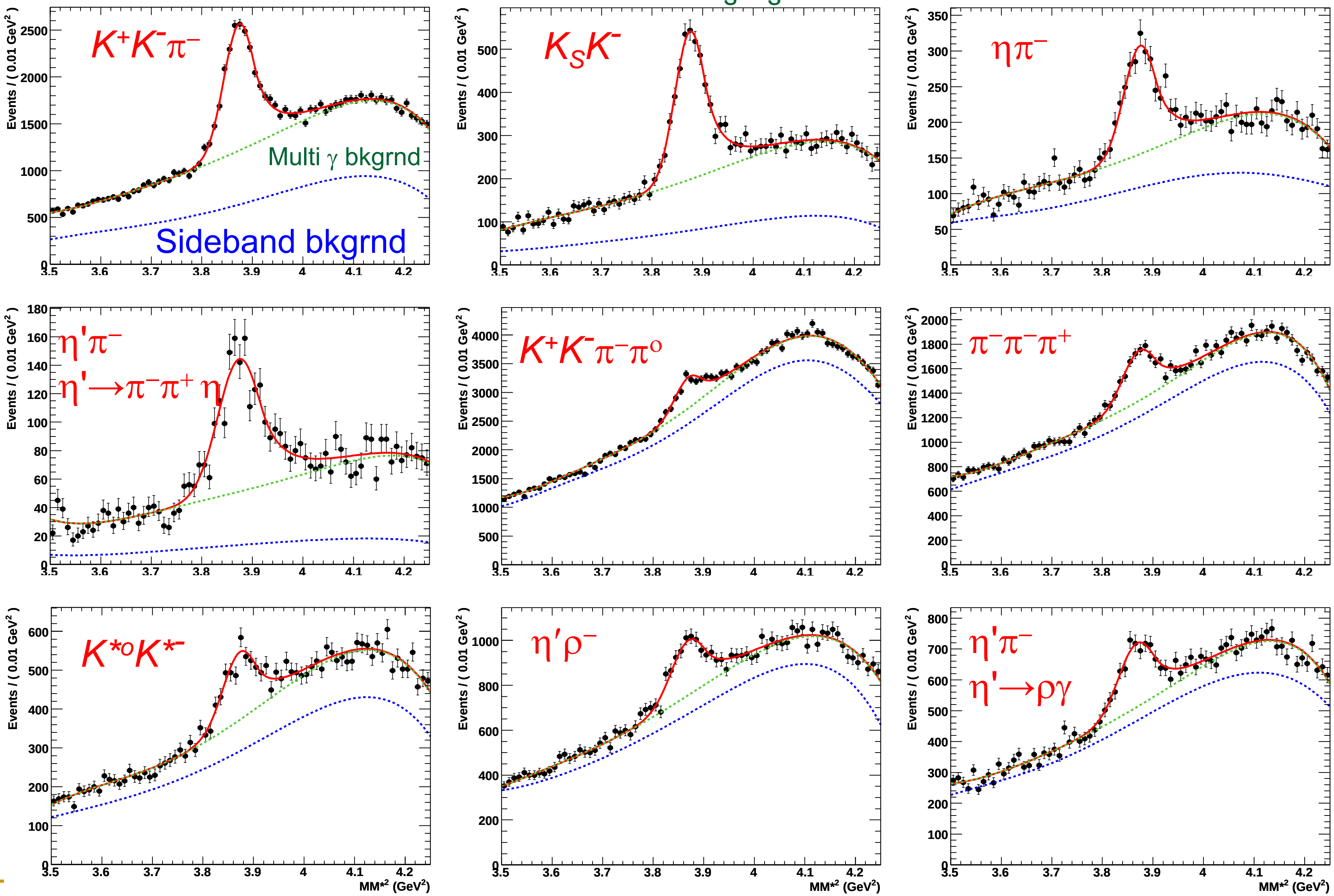
Belle & BaBar: $e^+e^- \to c\,\overline{c}$ at Y(4S)

D_S^- Tags: Invariant Mass

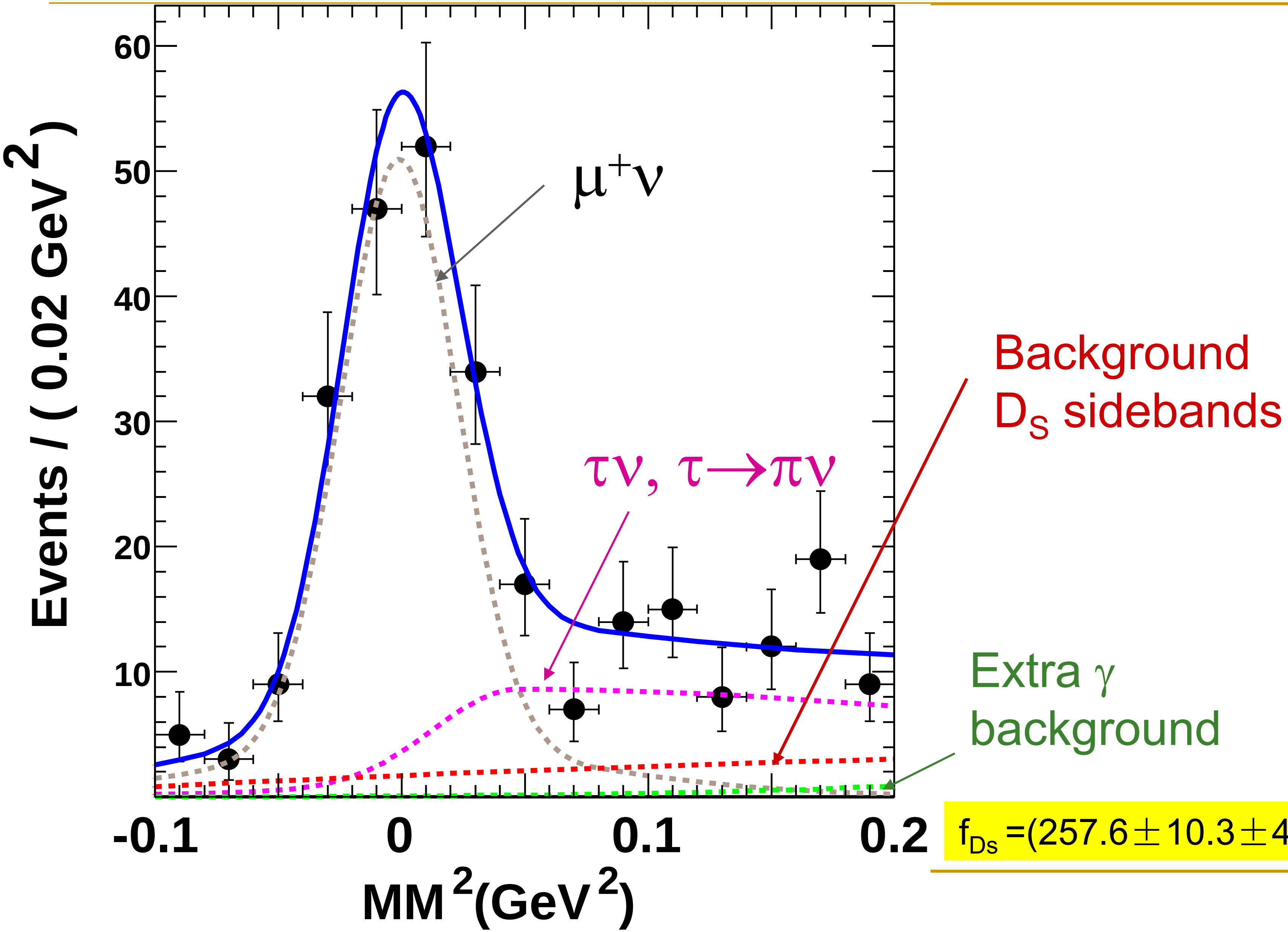


MM*² Distributions From $D_S^- + \gamma$

$e^+e^- \to D_sD_s^*$



$D_s \to \mu^+\nu$ Fit to signal & background



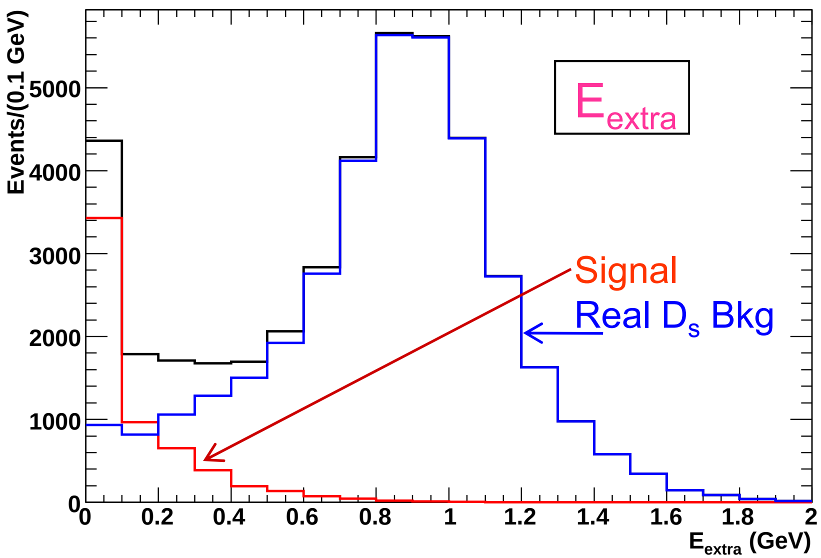
f_{Ds} =(257.6±10.3±4.3) MeV

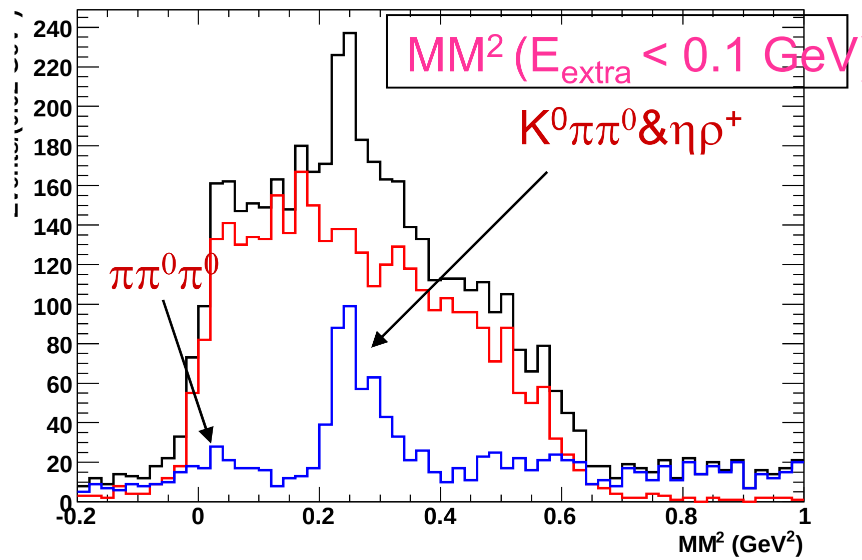
$D_S^+ \to \tau^+ \nu$, $\tau^+ \to \rho^+ \nu$

- Because of the two neutrinos, the signal does not peak in MM^2, but the most important backgrounds do
- Use E_{extra} as an important discriminant

Analysis Strategy

- Signal and MC predicted backgrounds





- Measure the $\mathcal{B}$ of the 3 indicated peaking modes. Use same set of D_S^- tags. Find:

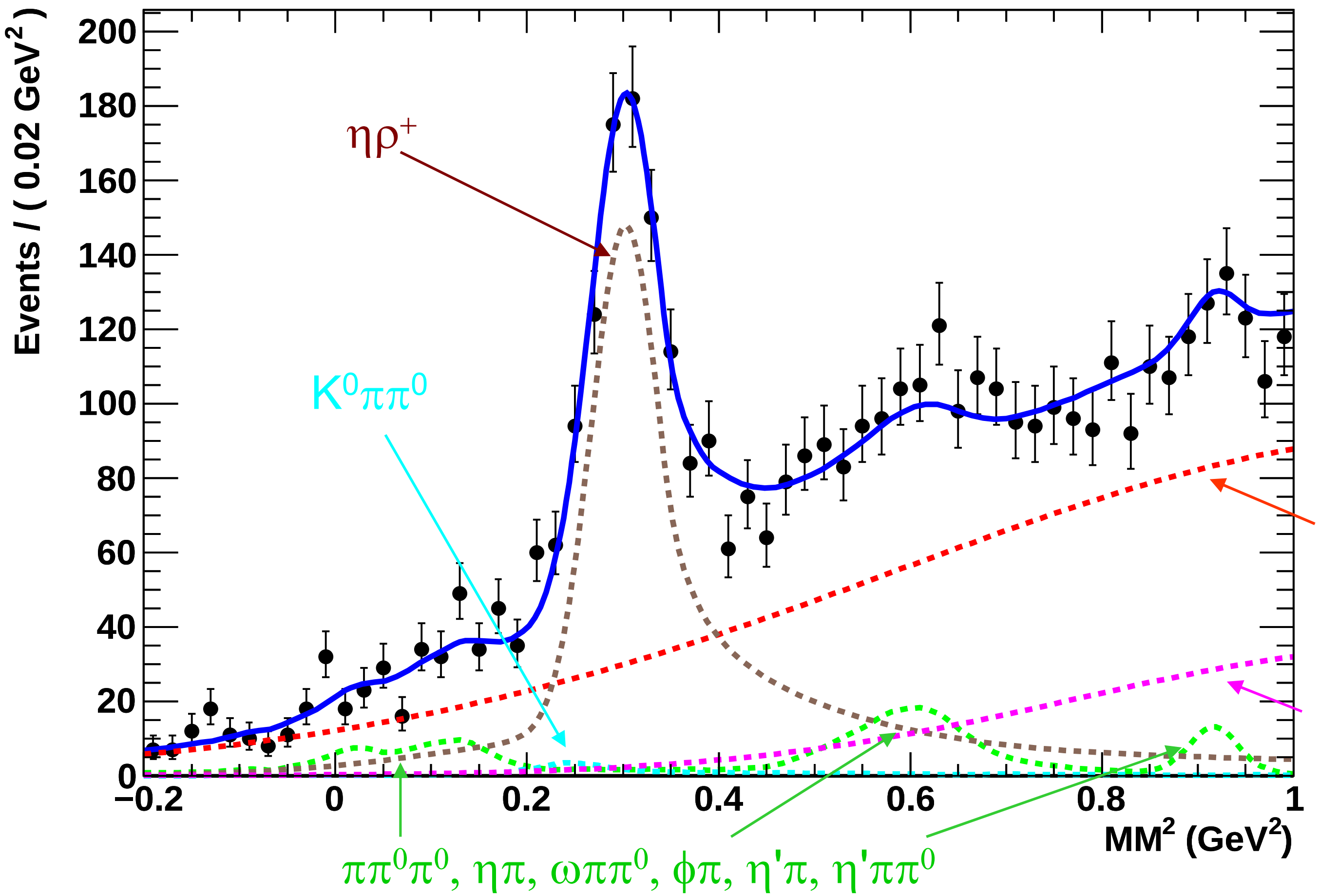
$$\mathcal{B}(D_s^+ \to K^0\pi^+\pi^0) = (1.00 \pm 0.18 \pm 0.04)\%,$$
$$\mathcal{B}(D_s^+ \to \pi^+\pi^0\pi^0) = (0.65 \pm 0.13 \pm 0.03)\%,$$
$$\mathcal{B}(D_s^+ \to \eta\rho^+) = (8.9 \pm 0.6 \pm 0.5)\%.$$

Analysis Strategy Continued

- We will fit simultaneously the invariant tag mass & the MM^2 distributions, separately in three E_{extra} intervals, <0.1 GeV where signal dominates, (0.1, 0.2) GeV where S & B are equivalent, and >0.8 GeV for checking of understanding background, where signal is absent.
- In the fits, we put Gaussian constraints on the bkgrnd yields using known branching fractions and their errors. For the remaining sum of small modes we use the MC estimated rate with a rather large error. Thus the uncertainties in the background will be taken care of in the statistical error.

Fit to E_{extra} > 0.8 GeV

- No signal, fit consistent with bkgrnd expectations

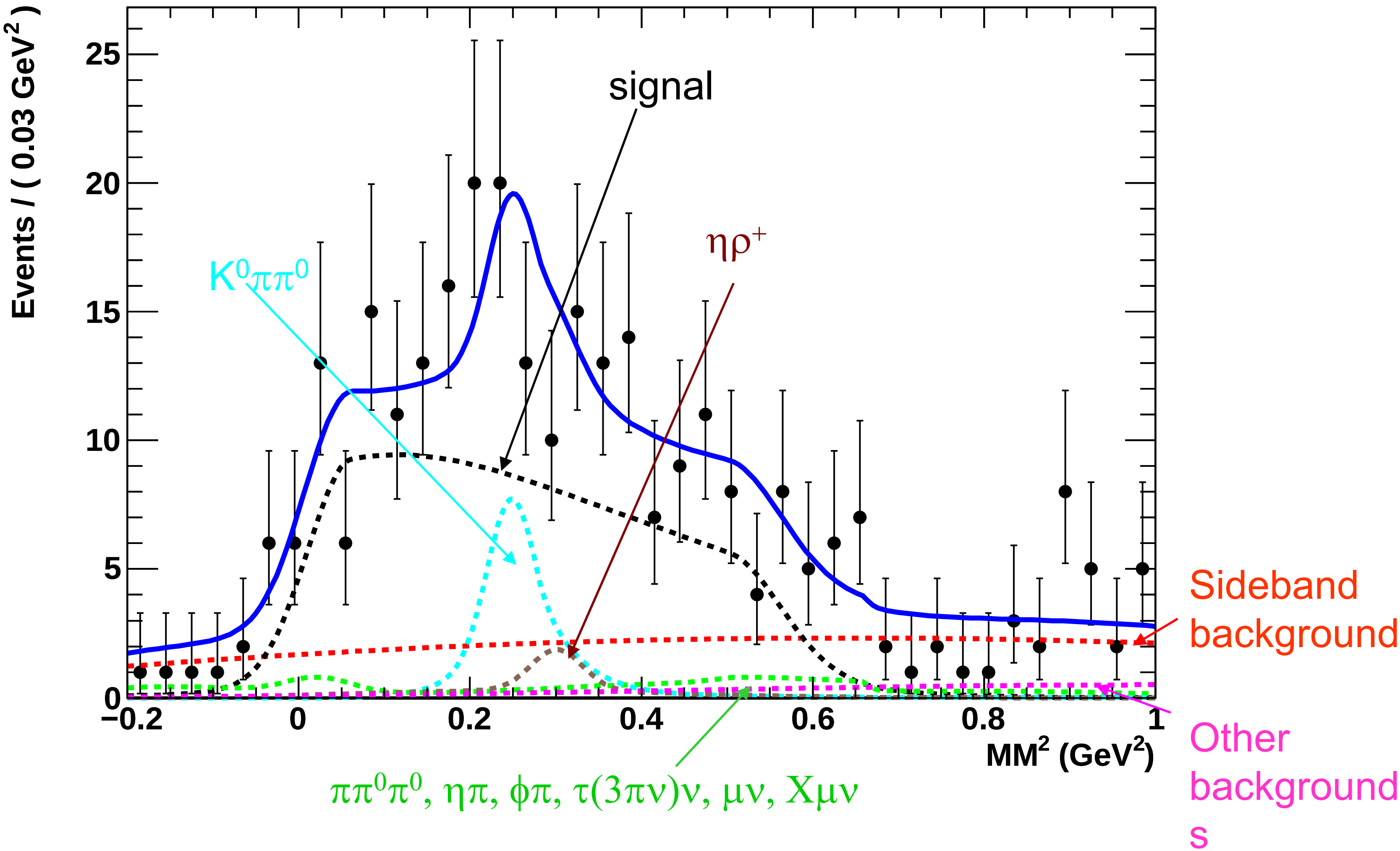


Points are data blue curve is overall fit

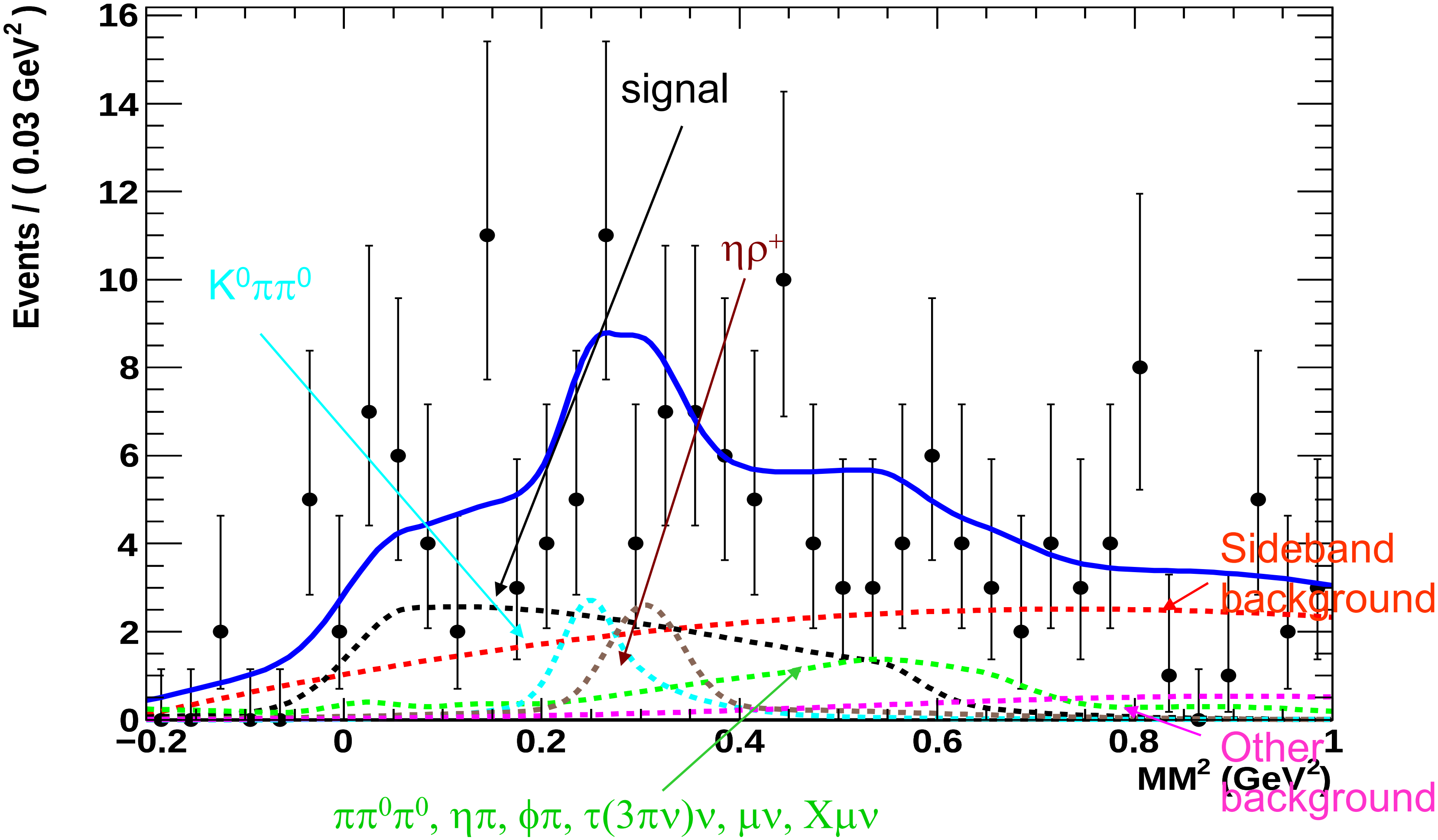
Sideband background

Other background with shape fixed to MC

Signal Region I: E_{extra}<0.1 GeV



Signal Region II: $0.1<E_{extra}<0.2$ GeV



Branching Fraction

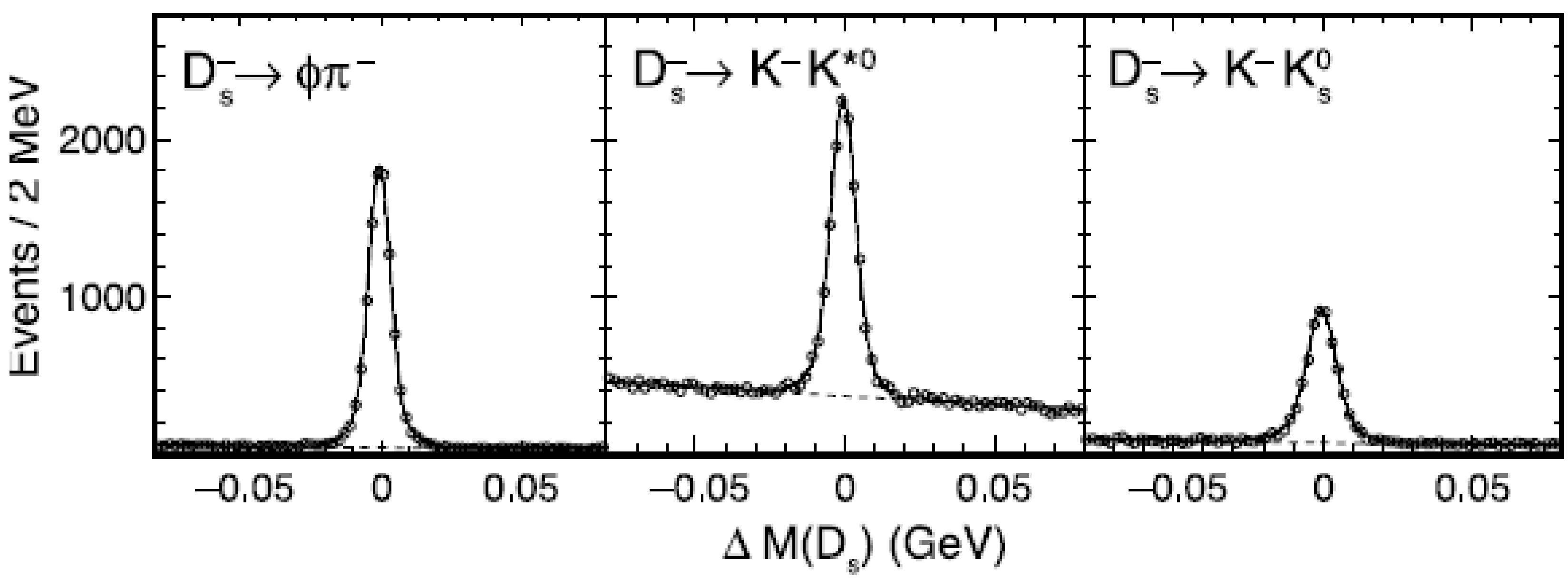
$E_{extra} \in$	Signal yields	Efficiency	$\mathcal{B}(D_s^+ \to \tau^+ \nu)$
[0,100] MeV	155.2 ± 16.5	25.3%	**(5.48 ± 0.59)%**
[100,200] MeV	43.7 ± 11.3	6.9%	**(5.65 ± 1.47)%**
[0,200] MeV	198.8 ± 20.0*	32.2%	**(5.52 ± 0.57 ± 0.21)%**

- Sum of the above two

- f_{Ds} = (257.8±13.3±5.2) MeV

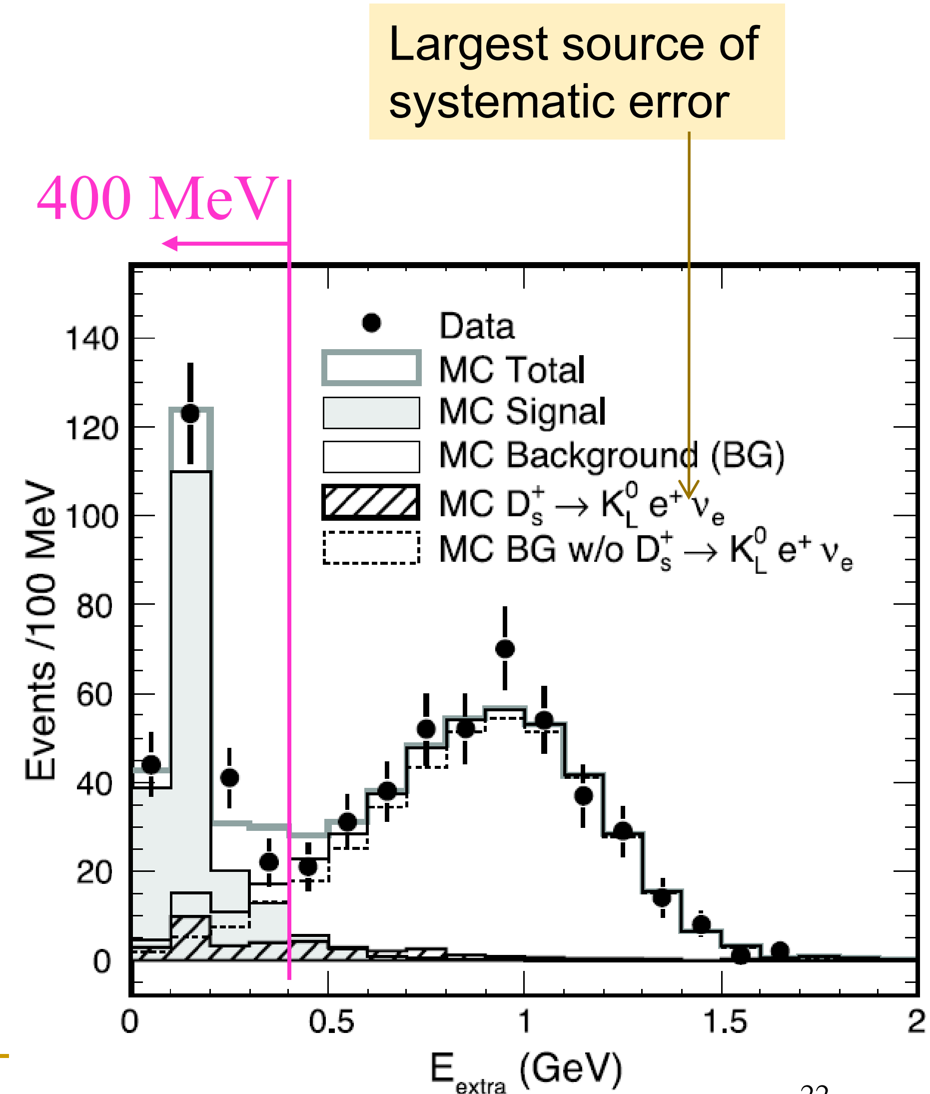
CLEO: $D_S^+ \rightarrow \tau^+\nu$, $\tau^+ \rightarrow e^+\nu\nu$

- $\mathcal{B}(D_S^+ \rightarrow \tau^+\nu) \bullet \mathcal{B}(\tau^+ \rightarrow e^+\nu\nu) \sim 1.3\%$ is "large" compared with expected $\mathcal{B}(D_S^+ \rightarrow Xe^+\nu) \sim 8\%$
- We will be searching for events opposite a tag with one electron and not much other energy
- Opt to use only a subset of the cleanest tags



Measuring $D_S^+ \to \tau^+\nu$, $\tau^+ \to e^+\nu\nu$

- Technique is to find events with an e^+ opposite D_S^- tags & no other tracks, with Σ calorimeter energy
  < 400 MeV
- No need to find γ from D_S^*
- $\mathcal{B}(D_S^+ \to \tau^+\nu)$ $=(5.30\pm0.47\pm0.22)\%$
- $f_{Ds} = 252.6\pm11.1\pm5.2$ MeV



Results

- $\mathcal{B}(D_s^+ \to \tau^+ \upsilon)$ from CLEO

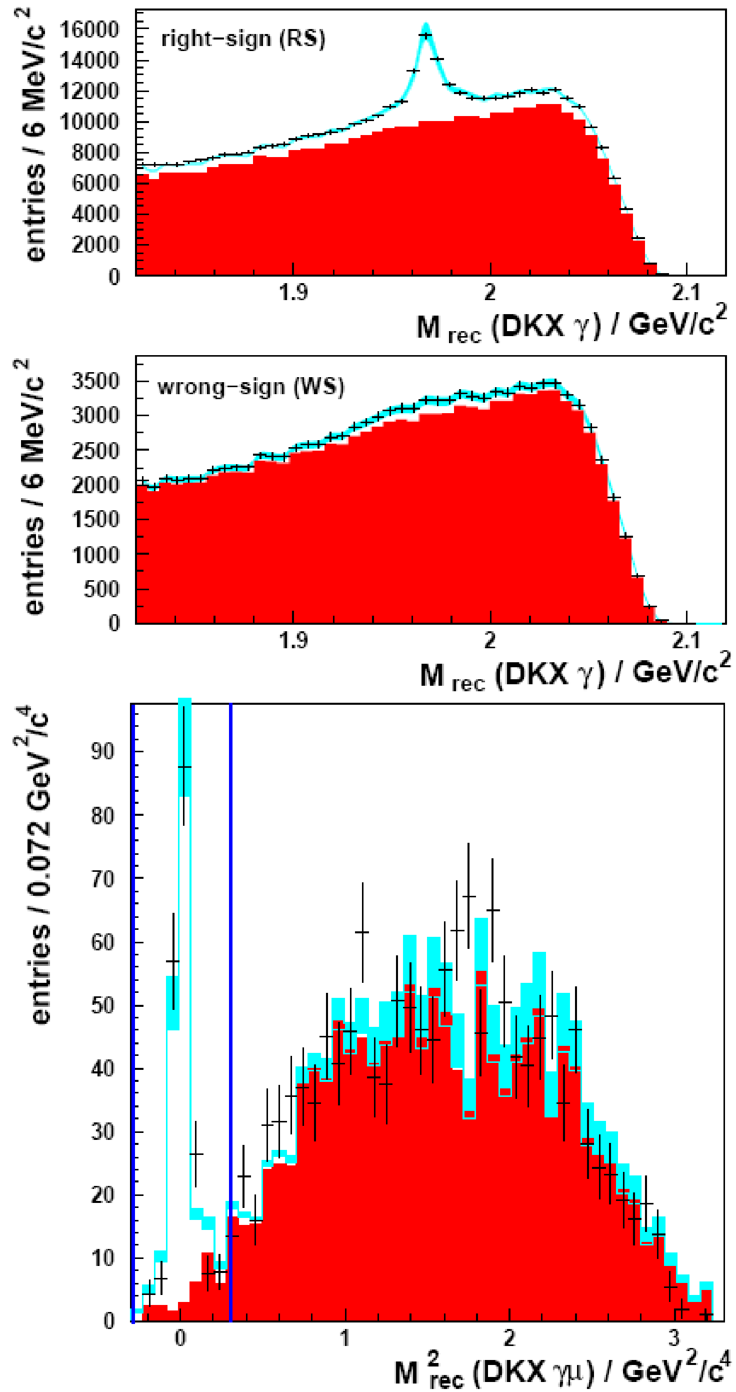
Mode	Branching Fraction (%)	f_{Ds} (MeV)
$\tau^+ \to \rho^+ \nu$	$5.52 \pm 0.57 \pm 0.21$	$257.8 \pm 13.3 \pm 4.9$
$\tau^+ \to e^+ \nu\nu$	$5.30 \pm 0.47 \pm 0.22$	$252.6 \pm 11.1 \pm 5.2$
$\tau^+ \to \pi^+ \nu$	$6.42 \pm 0.81 \pm 0.18$	$278.0 \pm 17.5 \pm 4.4$
Average	$5.54 \pm 0.32 \pm 0.15$	**$259.2 \pm 7.8 \pm 3.4$**

- For New Physics searches important to separate $\tau^+\upsilon$ and $\mu^+\upsilon$ [See A.G. Akeroyd and F. Mahmoudi, JHEP 0904, 121(2009)]
- Recall for $\mu^+\upsilon$ f_{Ds} =(257.6$\pm$10.3$\pm$4.3) MeV
- Ratio $f_{Ds}(\tau^+\upsilon)/f_{Ds}(\mu^+\upsilon)$ = (1.01 $\pm$ 0.05) consistent with unity

Belle: $D_S^+ \rightarrow \mu^+\nu$

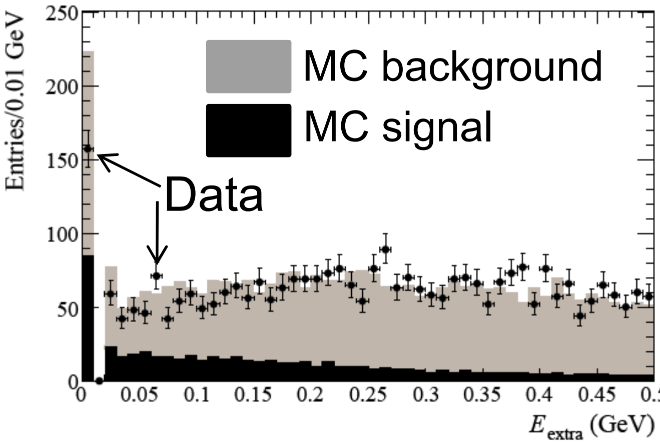
- Look for $e^+e^- \rightarrow DKX\gamma(D_S)$, where $X=n\pi$ & the D_S is not observed but inferred from calculating the MM
- Then add a candidate μ^+ and compute MM^2
- $\mathcal{B}(D_S^+ \rightarrow \mu^+\nu) =$ $(0.644\pm0.076\pm0.057)\%$
- $f_{Ds} = (275\pm16\pm12)$ MeV

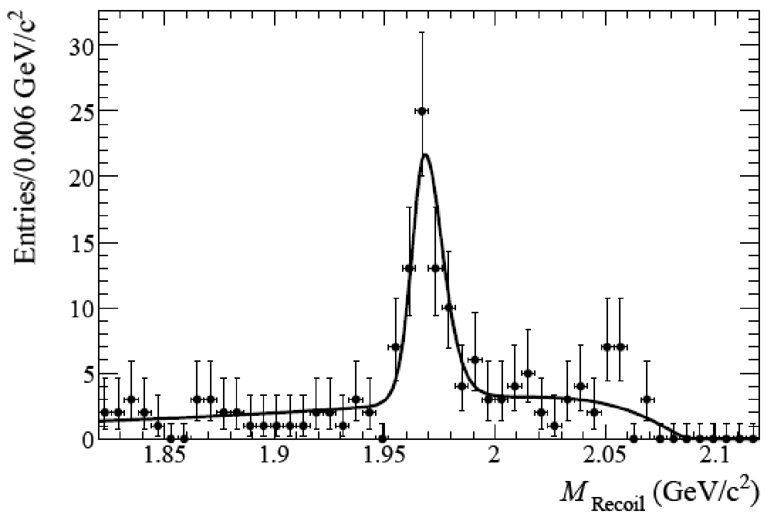
arXiv:0709.1340v2 [hep-ex]



BaBar: $D_S^+ \to \tau^+\nu$, $\tau^+ \to e^+\nu\nu$

- Idea is to tag with DKX & infer presence of missing D_S^*. Then detect γ from decay & e^+.
- Use E_{extra} as a discriminant
- Insist that $P(D_s) > 3$ GeV/c
- D_s^+ signal for $E_{extra}=0$

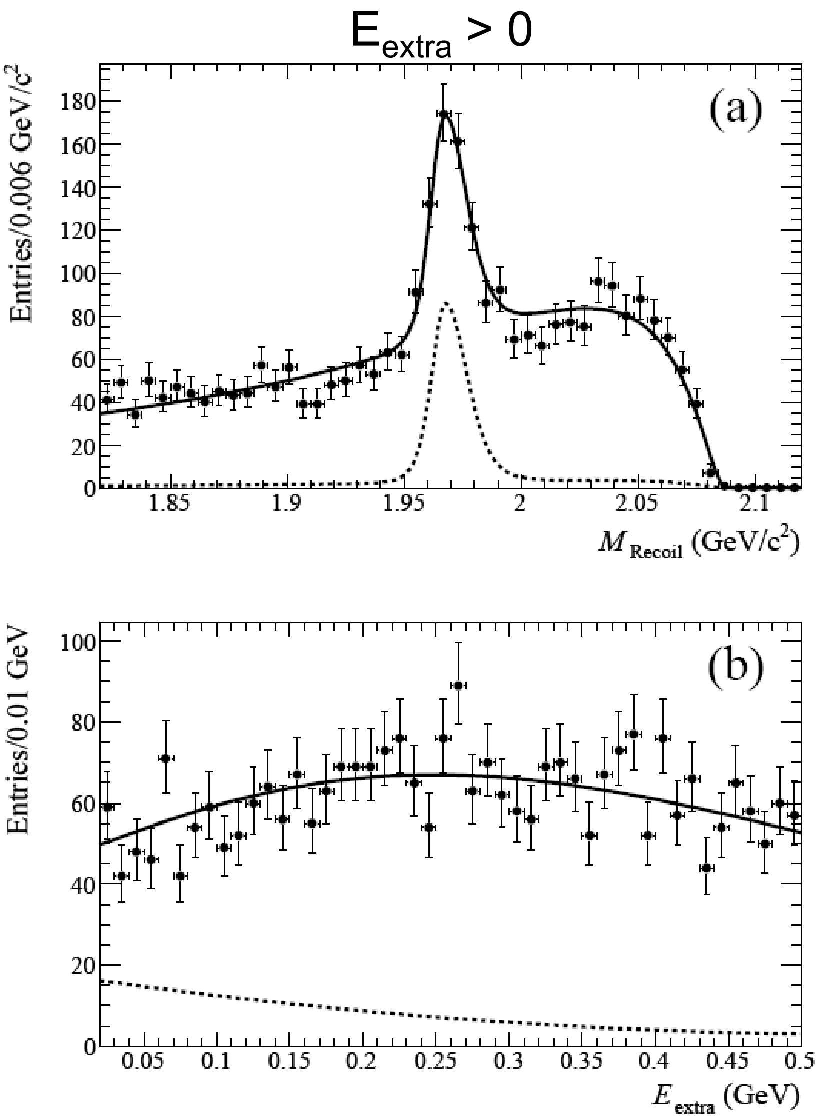




BaBar Continued

- Normalize to events where $D_s^+ \to K_s K^+$ where absolute $\mathcal{B}$ is given by CLEO
- $\mathcal{B}(D_S^+ \to \mu^+\nu) = (4.5 \pm 0.5 \pm 0.4 \pm 0.3)\%$
- $f_{Ds} = (233 \pm 13 \pm 10 \pm 7)$ MeV

arXiv:1003.3063 [hep-ex]



Summary of Results

Experiment	Mode	$\mathcal{B}$	$f_{D_s^+}$ (MeV)
CLEO-c [12]	$\mu^+\nu$	$(5.65 \pm 0.45 \pm 0.17) \times 10^{-3}$	$257.6 \pm 10.3 \pm 4.3$
Belle [13]	$\mu^+\nu$	$(6.38 \pm 0.76 \pm 0.57) \times 10^{-3}$	$274 \pm 16 \pm 12$
Average	$\mu^+\nu$	$(5.80 \pm 0.43) \times 10^{-3}$	261.5 ± 9.7
CLEO-c [12]	$\tau^+\nu$ $(\pi^+\overline{\nu})$	$(6.42 \pm 0.81 \pm 0.18) \times 10^{-2}$	$278.0 \pm 17.5 \pm 3.8$
CLEO-c [14]	$\tau^+\nu$ $(\rho^+\overline{\nu})$	$(5.52 \pm 0.57 \pm 0.21) \times 10^{-2}$	$257.8 \pm 13.3 \pm 5.2$
CLEO-c [15]	$\tau^+\nu$ $(e^+\nu\overline{\nu})$	$(5.30 \pm 0.47 \pm 0.22) \times 10^{-2}$	$252.6 \pm 11.2 \pm 5.6$
BaBar [16]	$\tau^+\nu$ $(e^+\nu\overline{\nu})$	$(4.54 \pm 0.53 \pm 0.40 \pm 0.28) \times 10^{-2}$	$233.8 \pm 13.7 \pm 12.6$
Average	$\tau^+\nu$	$(5.58 \pm 0.35) \times 10^{-2}$	255.5 ± 7.5
Average	$\mu^+\nu + \tau^+\nu$		257.5 ± 6.1

- From Rosner & Stone, use $|V_{cs}|=|V_{ud}|-|V_{cb}|^2/2$ =0.97345, τ_{Ds}=0.500(7) ps [arXiv:1002.1655]
- $f_{Ds}(\tau^+\nu)/f_{Ds}(\mu^+\nu) = 0.98 \pm 0.05$
- $f_{Ds}/f_{D^+} = 1.25 \pm 0.06$

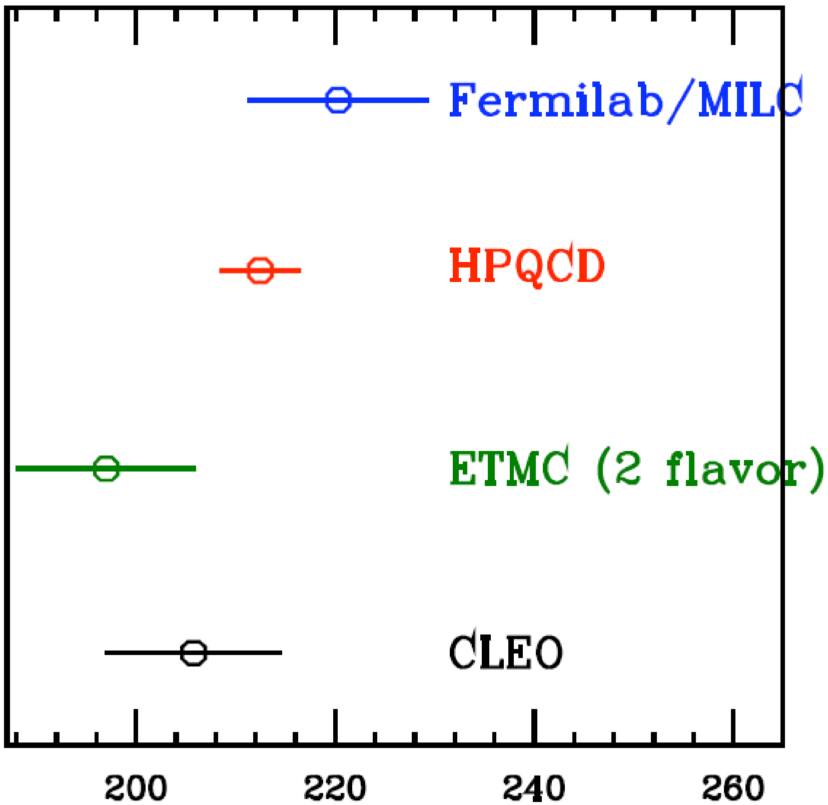
Theoretical Predictions & Postdictions

- Quote only unquenched Lattice results (MeV)

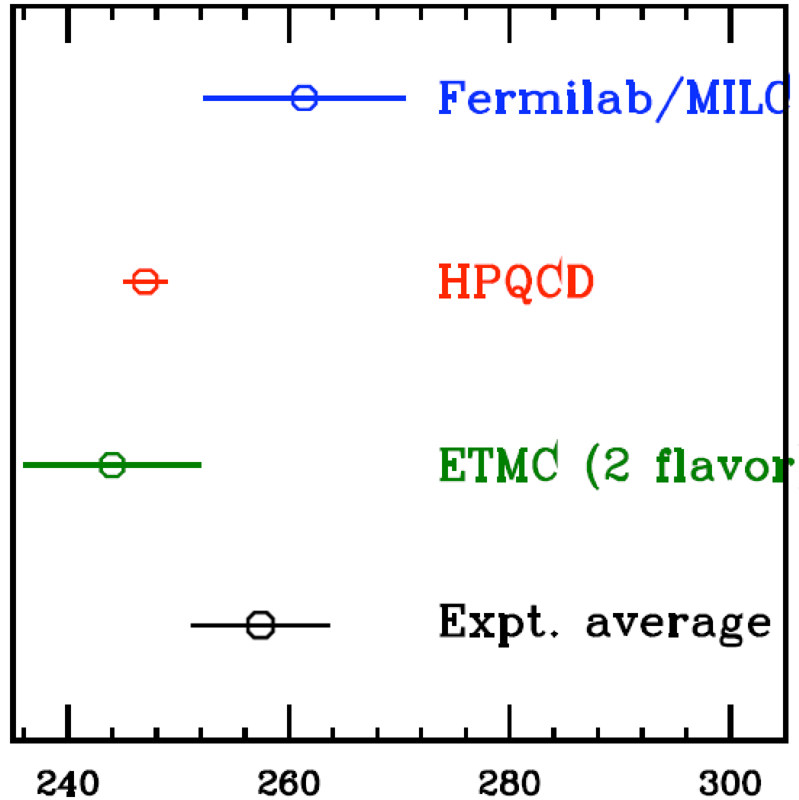
	Data	Fermi-Milc (2005)	Fermi-Milc (2010)	HPQCD (2007)	HPQCD (2010)	ETMC (2 flavors of sea q)
f_{D^+}	206.7±8.9	207±3±17	220.3±8.0±4.8	207±4		197±9
f_{Ds}	257.5±6.1	249±3±16	261.4±7.7±5.0	241±3	247±2	244±8

- HPQCD extrapolation from C. Bernard at Lattice QCD Meets Experiment Workshop, Fermilab April 26-27, 2010

Latest Theory

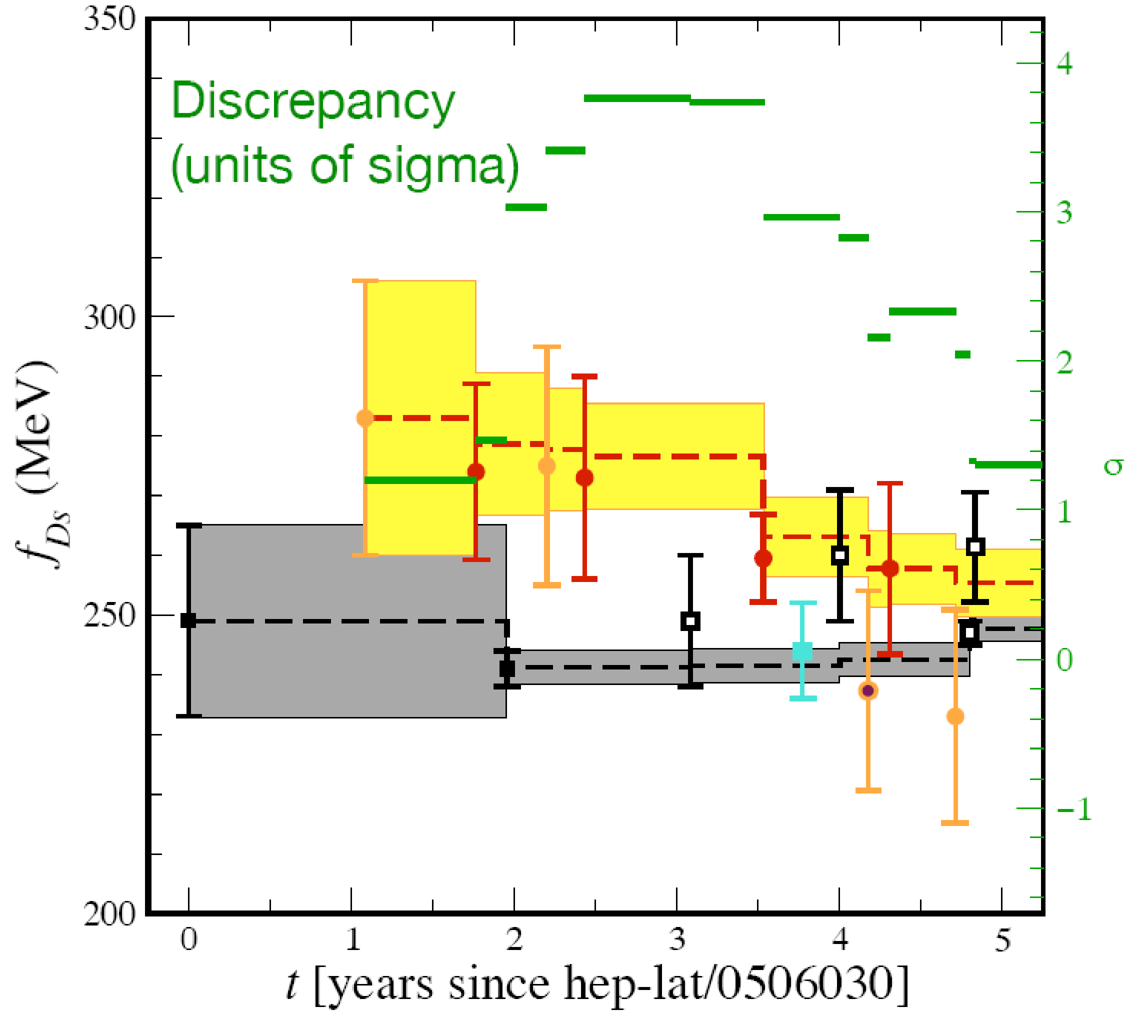


f_{D^+} MeV



f_{Ds} MeV

From Kronfeld: The Saga



- **Yellow:** expt. average
- **Gray**: lattice average
- Circles: expts.:
  - orange: Υ(4S)
  - red: $D_s^{(*)} D_s^{(*)}$ threshold
- Squares: lattice
  - filled: published
  - open: prelim or conference proc.
  - cyan: 2 flavors

from Kronfeld, arXiv:0912.0543, & his updates. 18

Conclusions

- This used to be exciting

Proceedings of the XXIX PHYSICS IN COLLISION

The f_{D_s} Puzzle

Andreas S. Kronfeld

- It appears now that experiment is helping to guide theory, still useful since we need calculation of f_{Bs}/f_{B^+}
- Possible to derive upper limits on H^+ mass as function of tanβ in two Higgs double models (Akeroyd et al) $\Gamma(D\ell\nu)_H = r_q \Gamma(D\ell\nu)_{SM}$

$$r_q = \left[1 + \left(\frac{1}{m_c + m_q}\right)\left(\frac{M_{D_q}}{M_{H^+}}\right)^2 \left(m_c - \frac{m_q \tan^2\beta}{1+\epsilon_0 \tan\beta}\right)\right]^2$$

The End

Other Non-absolute Measurements

Exp.	mode	$\mathcal{B}$	$\mathcal{B}(D_S \to \phi\pi)$ (%)	f_{Ds} (MeV)
CLEO [11]	$\mu^+\nu$	$(6.2 \pm 0.8 \pm 1.3 \pm 1.6) \cdot 10^{-3}$	3.6±0.9	$273 \pm 19 \pm 27 \pm 33$
BEATRICE [12]	$\mu^+\nu$	$(8.3 \pm 2.3 \pm 0.6 \pm 2.1) \cdot 10^{-3}$	3.6±0.9	$312 \pm 43 \pm 12 \pm 39$
ALEPH [13]	$\mu^+\nu$	$(6.8 \pm 1.1 \pm 1.8) \cdot 10^{-3}$	3.6±0.9	$282 \pm 19 \pm 40$
ALEPH [13]	$\tau^+\nu$	$(5.8 \pm 0.8 \pm 1.8) \cdot 10^{-2}$		
L3 [14]	$\tau^+\nu$	$(7.4 \pm 2.8 \pm 1.6 \pm 1.8) \cdot 10^{-2}$		$299 \pm 57 \pm 32 \pm 37$
OPAL [15]	$\tau^+\nu$	$(7.0 \pm 2.1 \pm 2.0) \cdot 10^{-2}$		$283 \pm 44 \pm 41$
BaBar [16]	$\mu^+\nu$	$(6.74 \pm 0.83 \pm 0.26 \pm 0.66) \cdot 10^{-3}$	4.71 ± 0.46	$283 \pm 17 \pm 7 \pm 14$

HFAG reinterpretation: 237 ± 13 ± 5

See Rosner & Stone, arXiv:0802.1043 for references

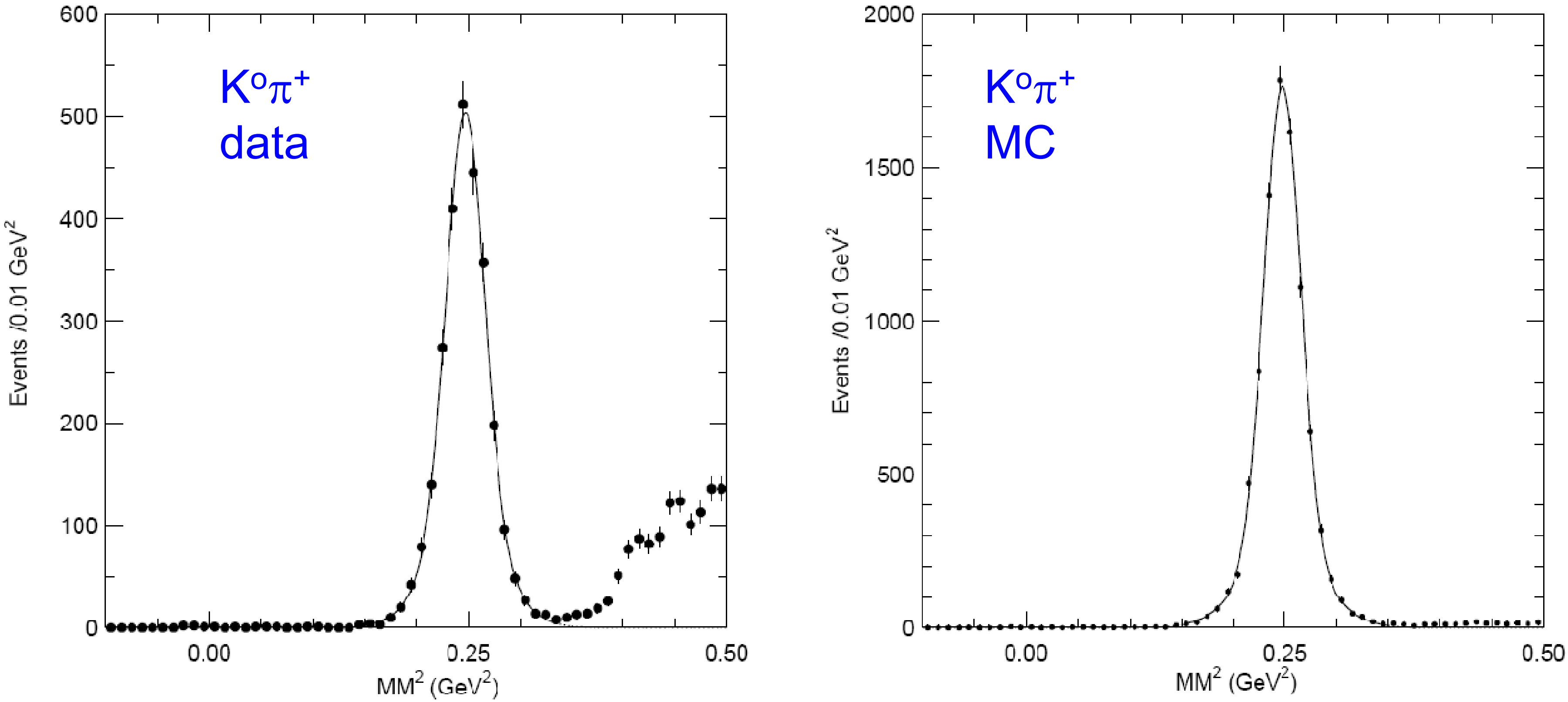
Beyond the SM Theories

- Leptoquark models & special Two-Higgs doublet model (Dobrescu & Kronfeld) [arXiv:0803.0512-hep-ph]
- R-parity violating Supersymmetry (Akeroyd & Recksiegel [hep-ph/0210376])
- A. Kundu & S. Nandi, "R-parity violating supersymmetry, B_S mixing, & $D_S^+ \to \ell^+\nu$" [arXiv:0803.1898])
- Bhattacharyya, Chatterjee & Nandi [arXiv:0911.3811v1-hep-ph]
  - Dosner et al show that the above models should effect $\tau\nu$ and $\mu\nu$ differently [arXiv:0906.5585-hep/ph]
- Gninenko & Gorbunov argue that the neutrino in the D_s decay mixes with a sterile neutrino, which enhances the rate, but should act the same in D^+ & D_S, & could be different for $\mu^+\nu$ & $\tau^+\nu$ [arXiv:0907.4666-hep-ph]

Efficiencies

- Tracking, particle id, E<300 MeV (determined from μ-pairs) = 85.3%
- Not having an unmatched shower > 250 MeV 95.9%, determined from double tag, tag samples
- Easier to find a $\mu\nu$ event in a tag then a generic decay (tag bias) (1.53%)

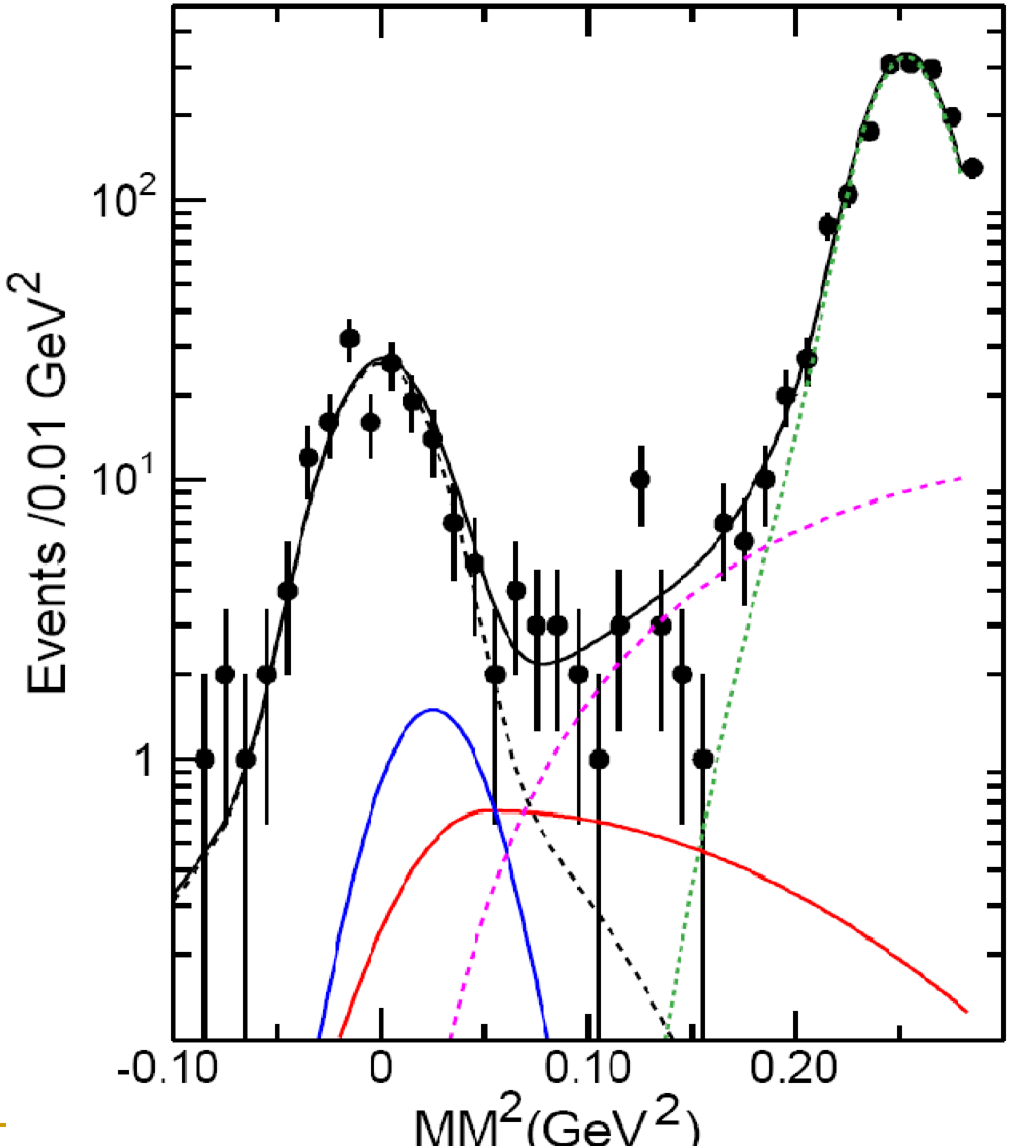
μν Signal Shape Checked



- Data σ=0.0247±0.0012 GeV^2
- MC σ=0.0235±0.0007 GeV^2
- Both average of double Gaussians

Case(i) With $\tau^+\nu/\mu^+\nu$ Floating

- Fixed
  - 149.7±12.0 $\mu\upsilon$
  - 28.5 $\tau\nu$
- Floating
  - 153.9±13.5 $\mu\upsilon$
  - 13.5±15.3 $\tau\nu$



New Physics Possibilities III

- Leptonic decay rate is modified by $H^{\pm}$
- Can calculate in SUSY as function of m_q/m_c,
- In 2HDM predicted decay width is x by

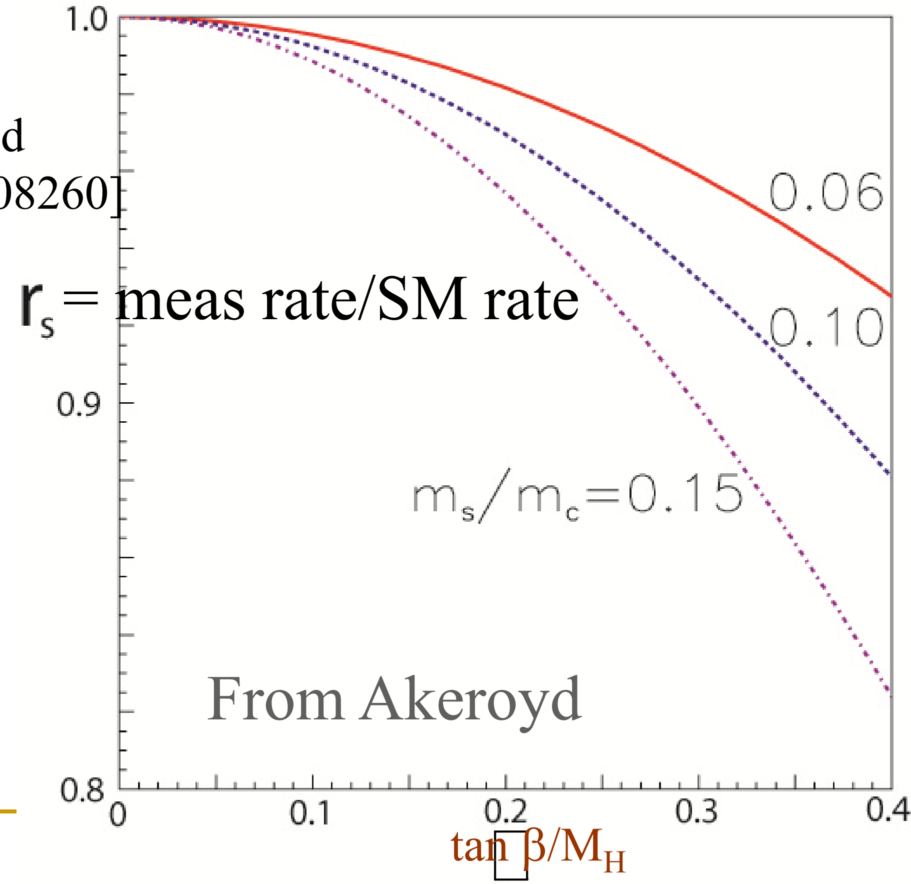
$$r_q = \left[1 - M_D^2 \left(\frac{\tan\beta}{M_{H^{\pm}}}\right)^2 \left(\frac{m_q}{m_c + m_q}\right)\right]^2$$

See Akeryod [hep-ph/0308260]

- Corrected

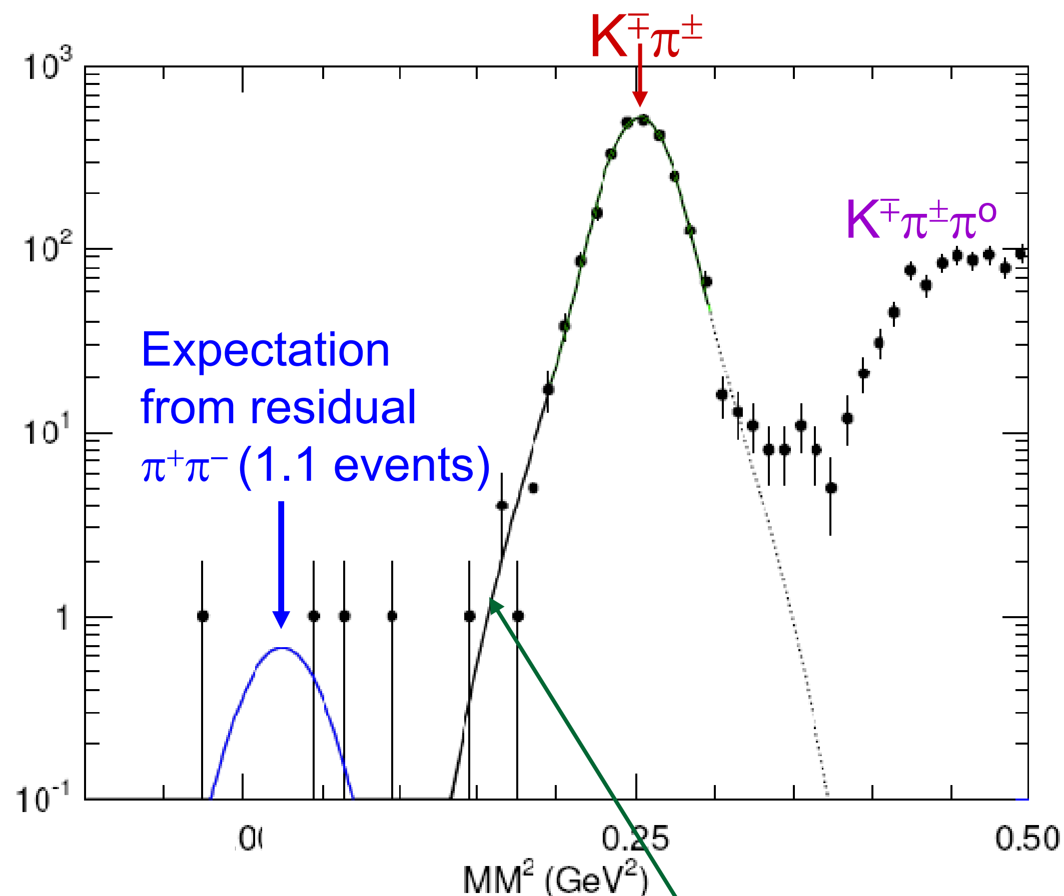
$$r_q = \left[1 + \left(\frac{M_D^2}{m_c + m_q}\right)\left(\frac{1}{M_{H^{\pm}}}\right)^2 \left(m_c - m_q \tan^2\beta\right)\right]^2$$

- Since m_d is ~0, effect can be seen only in D_S



Model of $K^o\pi^+$ Tail

- Use double tag D^o $\bar{D}^o$ events, where both $D^o \to K^{\mp}\pi^{\pm}$
- Make loose cuts on 2nd D^o so as not to bias distribution: require only 4 charged tracks in the event

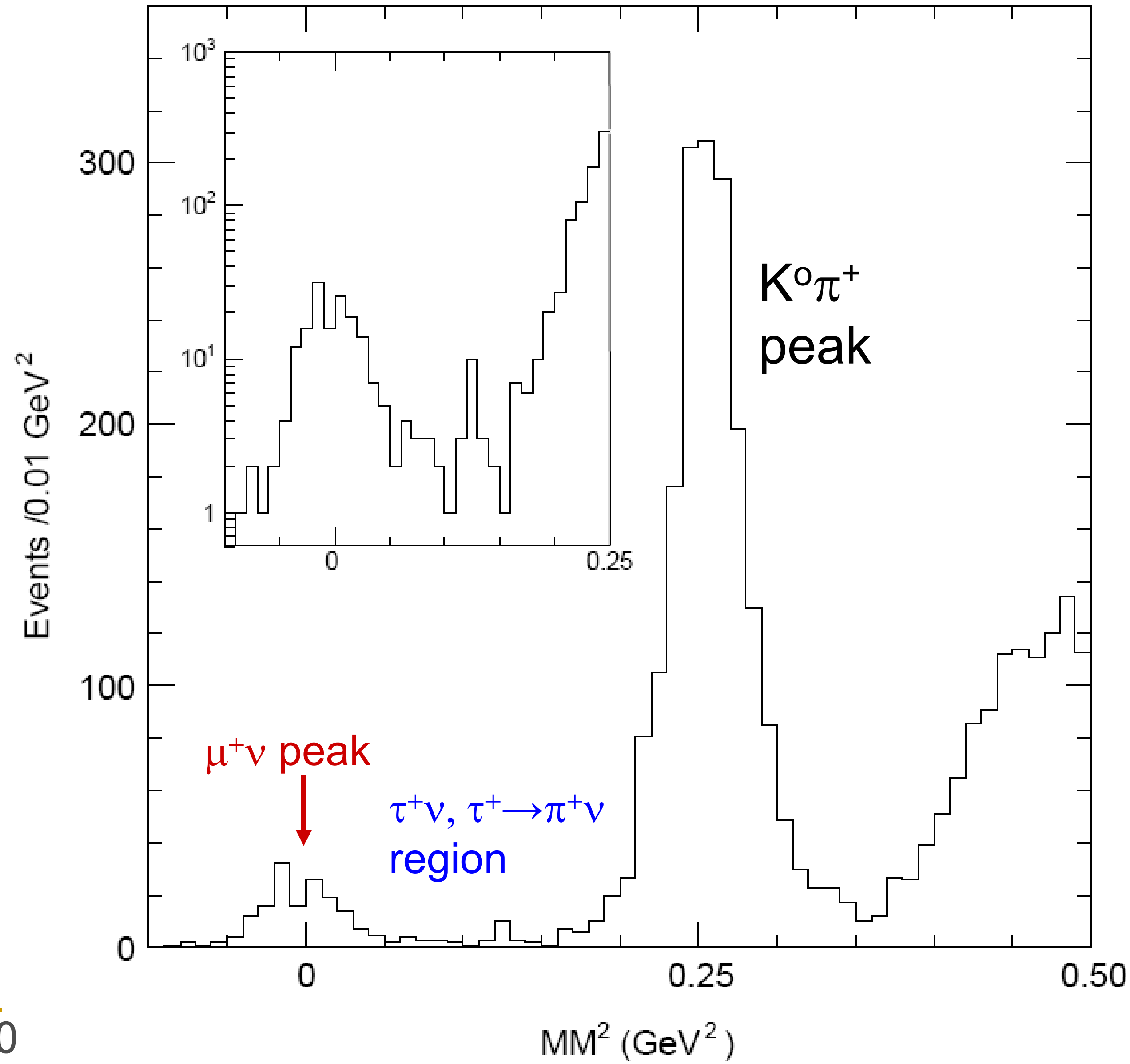


Computed ignoring charged kaon

Gives an excellent description of shape of low mass tail
"Extra" 1.3 event background in signal region

The MM^2 Distribution

- For E< 300 MeV in CsI



Residual Backgrounds for $\mu\upsilon$

- Monte Carlo of Continuum, D^o, radiative return and other D^+ modes, in $\mu\nu$ signal region

Mode	# of events
Continuum	0.8±0.4
$\overline{K}^0\pi^+$	1.3±0.9
D^0 modes	0.3±0.3
Sum	2.4±1.0

- This we subtract off the fitted yields

CP Violation

- D^+ tags 228,945±551
- D^- tags 231,107±552
- $\mu^-\nu$ events 64.8±8.1
- $\mu^+\nu$ events 76.0±8.6

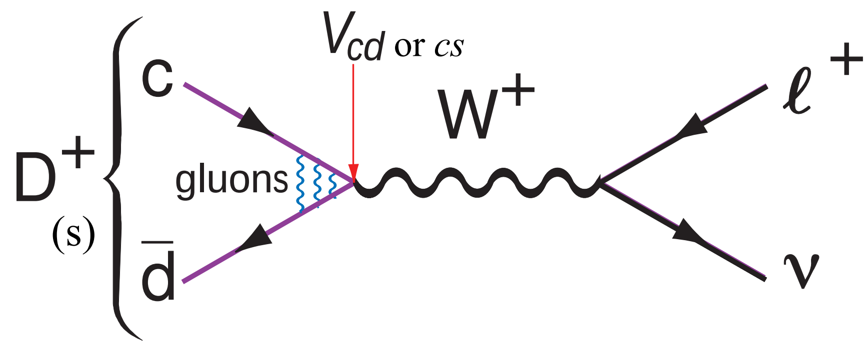
$$A_{CP} \equiv \frac{\Gamma(D^+ \to \mu^+\nu) - \Gamma(D^- \to \mu^-\nu)}{\Gamma(D^+ \to \mu^+\nu) + \Gamma(D^- \to \mu^-\nu)} = 0.08 \pm 0.08$$

- $-0.05 < A_{CP} < 0.21$ @ 90% c. l.

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

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

Standard Model decay diagram:



In general for all pseudoscalars:

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

Calculate, or measure if V_{Qq} is known, here take $V_{cd}=V_{us}= 0.2256$,
$V_{cs}=V_{ud}-V_{cb}/4= 0.9734$

CLEO's Technique for $D^+ \to \mu^+\nu$

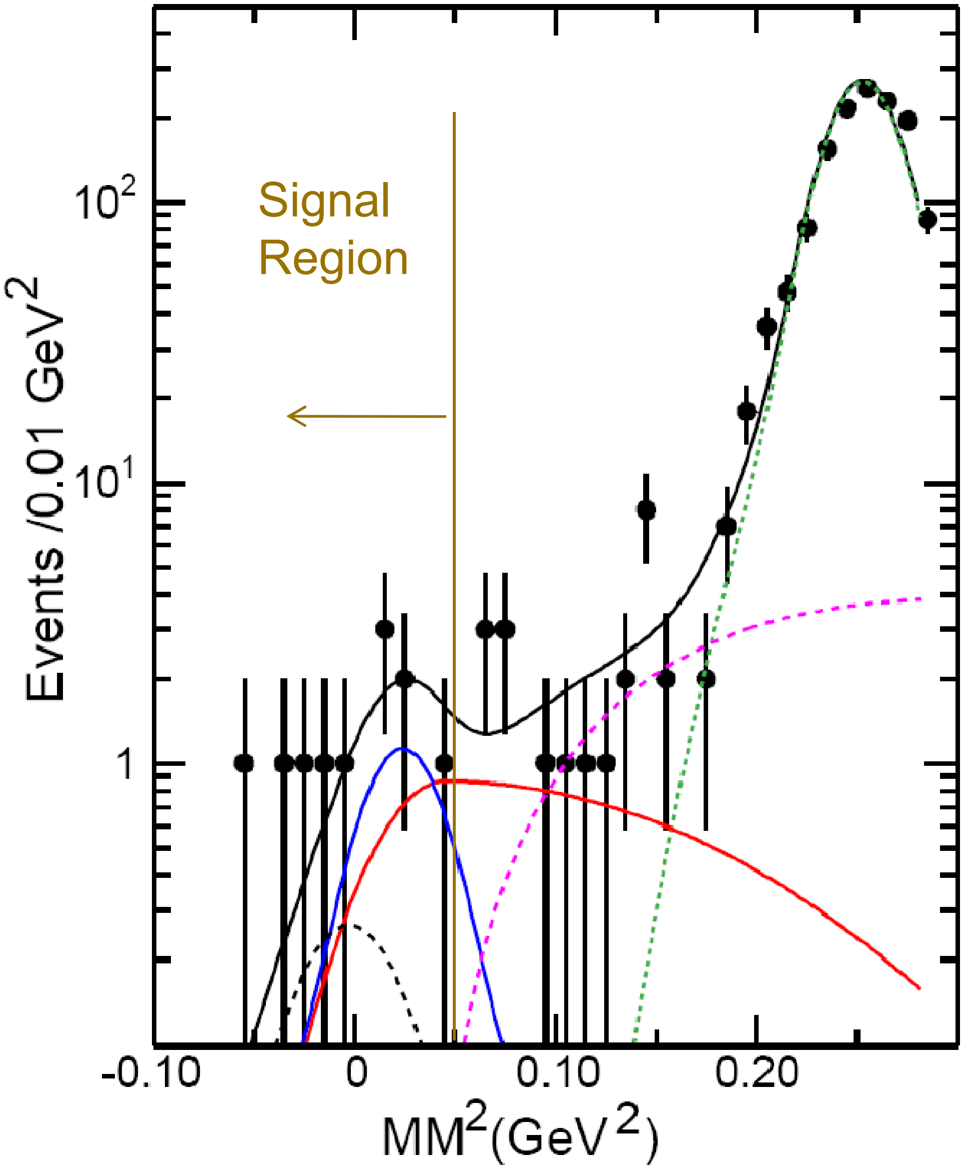
- Exploit $e^+e^- \to D^-D^+$
- Fully reconstruct a D^-, and count total # of tags
- Seek events with only one additional oppositely charged track within $|\cos\theta|<0.9$ & no additional photons > 250 MeV (to veto $D^+ \to \pi^+\pi^o$)
- Charged track must deposit only minimum ionization in calorimeter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

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

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

Background Check

- Use case(ii) E>300 MeV in EM calorimeter
- Fix $\tau\nu$ from case(i) $\mu\nu$.
- Consider signal region $|MM^2|<0.05$ GeV^2. Expect 1.7 $\mu\nu$ + 5.4 $\pi^+\pi^o$ + 4.0 $\tau\nu$ = 11.1
- Find 11 events
- Extra bkgrnd=-0.1±3.3 events

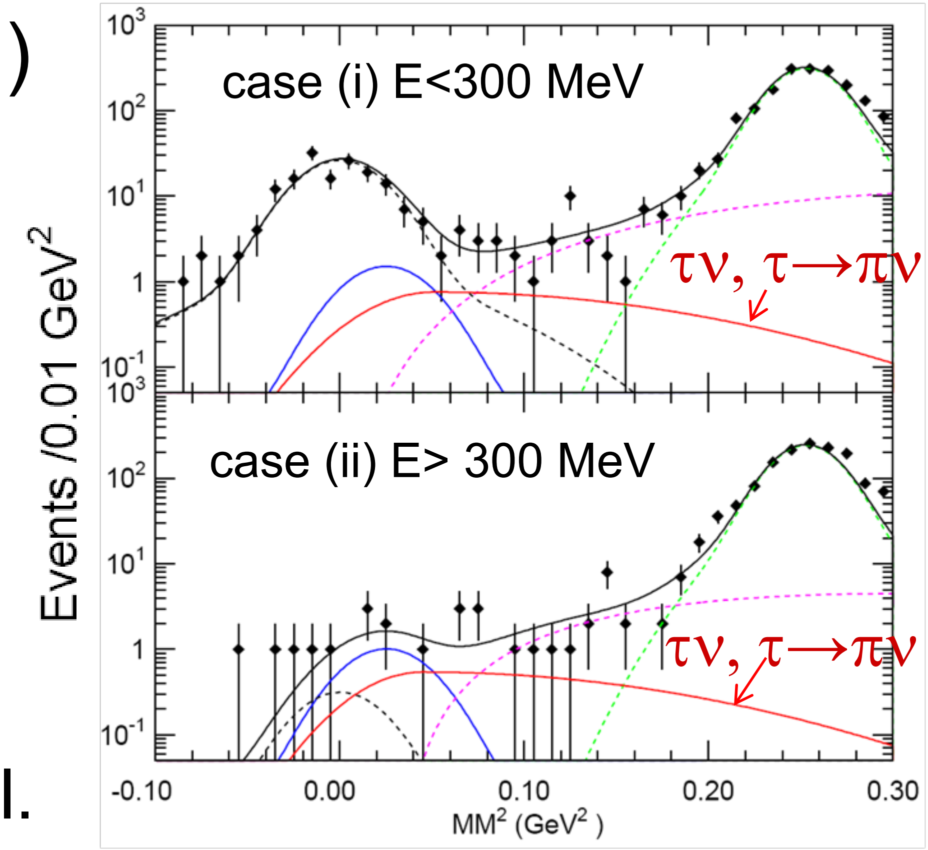


Systematic Errors

Source of Error	%
Finding the μ^+ track	0.7
Minimum ionization of μ^+ in EM cal	1.0
Particle identification of μ^+	1.0
MM^2 width	0.2
Extra showers in event > 250 MeV	0.4
Background	0.7
Number of single tag D^+	0.6
Total	**2.2**

Upper limits on $\tau\nu$ & $e\nu$

- Here we fit both case(i) & case(ii) constraining the relative $\tau\nu$ yield to the pion acceptance, 55/45.
- Find
  - $\mathcal{B}(D^+ \to \tau^+\nu)$ $< 1.2\text{x}10^{-3}$, @ 90% c.l.
  - $\mathcal{B}(D^+ \to \tau^+\nu)/2.65\mathcal{B}(D^+ \to \mu^+\nu) < 1.2$ @ 90% c. l.
- Also $\mathcal{B}(D^+ \to e^+\nu) < 8.8\text{x}10^{-6}$, @ 90% c.l.

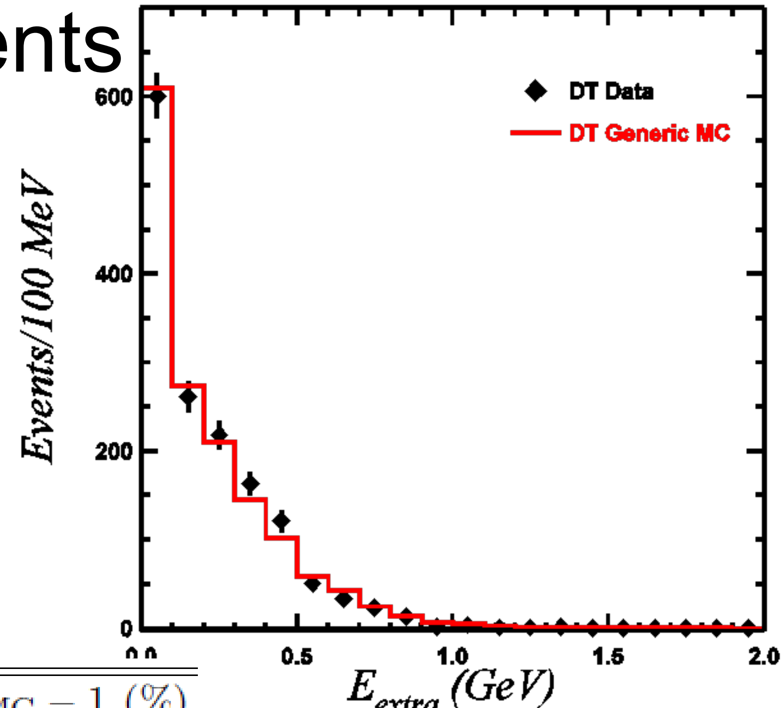


Systematic Errors $\mu^+\nu$

Source of Error	%
Finding the μ^+ track	0.7
Particle identification of μ^+	1.0
MM^2 width	0.2
Extra showers in event > 300 MeV	0.4
Background	1.0
Number of single tag D_S^-	2.0
Tag Bias	1.0
Radiative Correction	1.0
Total	**3.0**

Systematic Errors

- Measure efficiency of E_{extra} cut. Use fully reconstructed $D_sD_s^*$ events
- Value at 300 MeV is chosen, because it has the same efficiency as $\rho^+\nu$ for E_{extra} 200 MeV



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$E_{\rm extra}$ (MeV)	$\epsilon_{\rm Data}(\%)$	$\epsilon_{\rm MC}(\%)$	$\epsilon_{\rm Data}/\epsilon_{\rm MC}-1$ (%)
<100	40.24 ± 1.27	40.81 ± 0.31	-1.4 ± 3.2
<200	57.75 ± 1.28	59.12 ± 0.31	-2.3 ± 2.2
<300	72.35 ± 1.16	73.21 ± 0.28	-1.2 ± 1.6
<400	83.27 ± 0.97	82.91 ± 0.24	0.4 ± 1.2

set $\sqrt{1.2^2+1.6^2}$ = 2.0% error

Summary of Systematic Errors $\rho\nu$

Source of Error	%
Finding the π^+ track	0.3
Particle identification of π^+	1.0
π^0 efficiency	1.3
$E_{extra} < 200$ MeV signal efficiency	2.0
$E_{extra} < 200$ MeV& π^0 efficiencies on background	1.1
Background modeling	1.1
Number of single tag D_s^-	2.0
Tag Bias	1.0
Total	**3.8**

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

- Reconstruct D_S^-
- 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 muon for (i) < 300 MeV in Ecal, (ii) E>300 MeV or (iii) e^- cand.

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

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