Leptonic Decays: Measurements of f_{D^+} & f_{D_s}

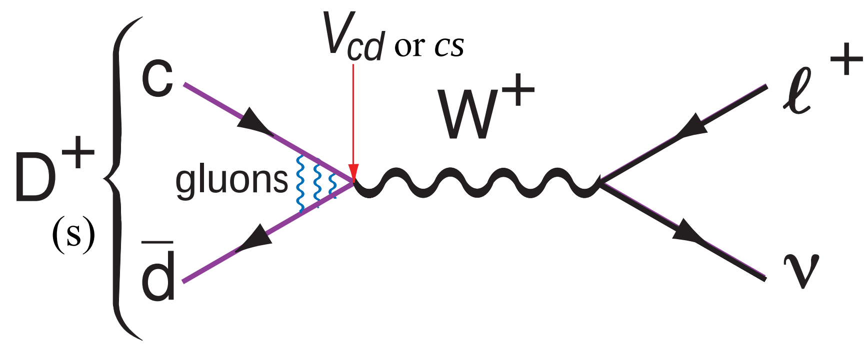
Sheldon Stone

Syracuse University

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

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

Standard Model decay diagram:



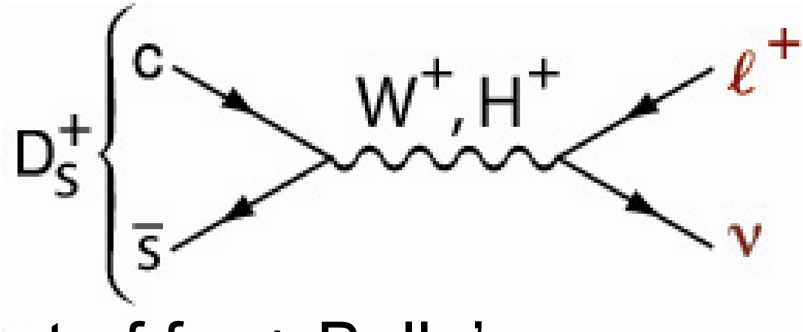
In general for all pseudoscalars:

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

Calculate, or measure if V_{Qq} is known, here take $V_{cd} = V_{us} = 0.2256$, $V_{cs} = V_{ud} = 0.9742$

A Window to New Physics?

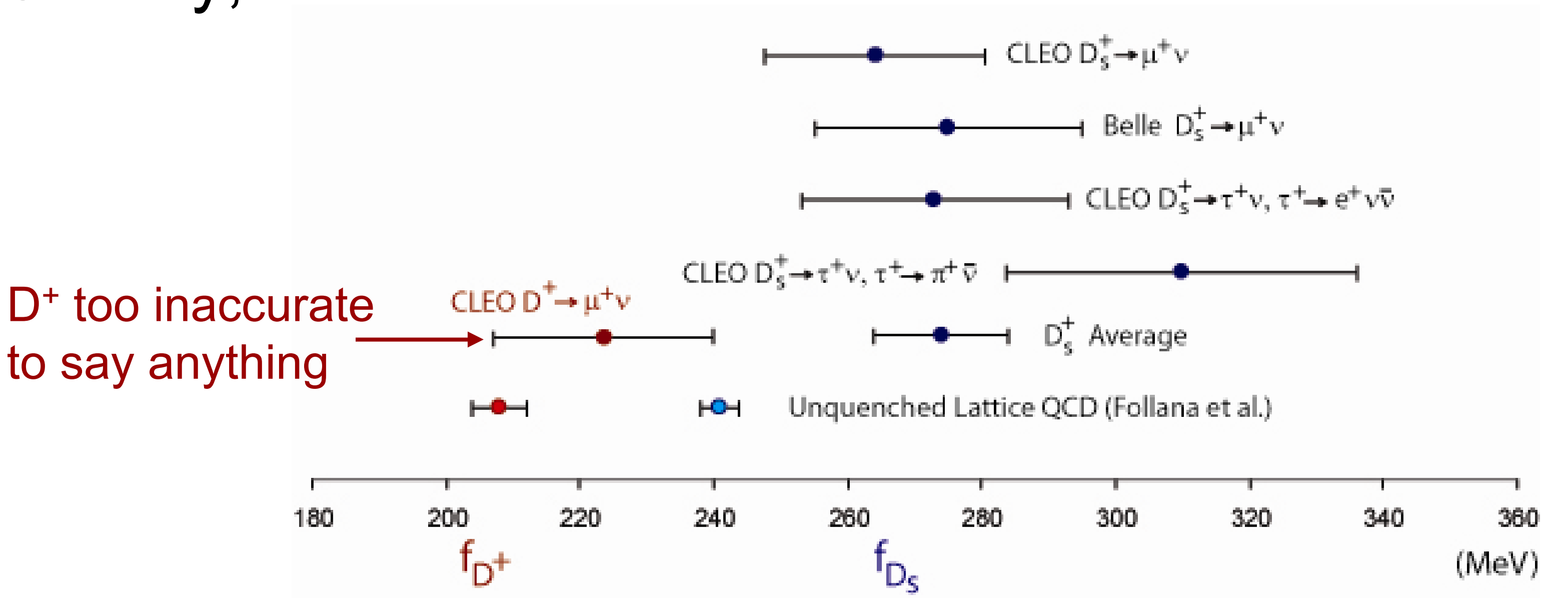
- Besides the obvious interest in comparing with Lattice & other calculations of f_P there are NP possibilities



- CLEO's previous measurement of f_{Ds} + Belle's (see Rosner & Stone arXiv:0802.1043) give f_{Ds}=274±10 MeV as compared with 241±3 MeV 2+1 unquenched lattice QCD calculation of Follana et.al (PRL **100,** 062002 (2008))
- Dobrescu & Kronfeld (arXiv:0803.0512) argue that this can well be the effect of NP, either charged Higgs (their own model) or leptoquarks
- CLEOs previous measurement of f_{D^+} was too inaccurate to challenge Follana et al., theory 207±4 versus 223±17 MeV (CLEO)

Possibilities

- Experiment is wrong: unlikely CLEO measures both $\mu^+\nu$ & $\tau^+\nu$, & Belle measures $\mu^+\nu$. Though average is 3.3 σ away, could be a weird fluctuation



- Theory is wrong: very possibly, but Kronfeld is member of competing lattice group
- Both are right: NP is responsible

New Physics Possibilities

- Ratio of leptonic decays

could be modified e.g. in Standard Model

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

- If $H^\pm$ couple proportional to $M^2 \Rightarrow$ no effect

See Hewett [hep-ph/9505246] & Hou, PRD 48, 2342 (1993).

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

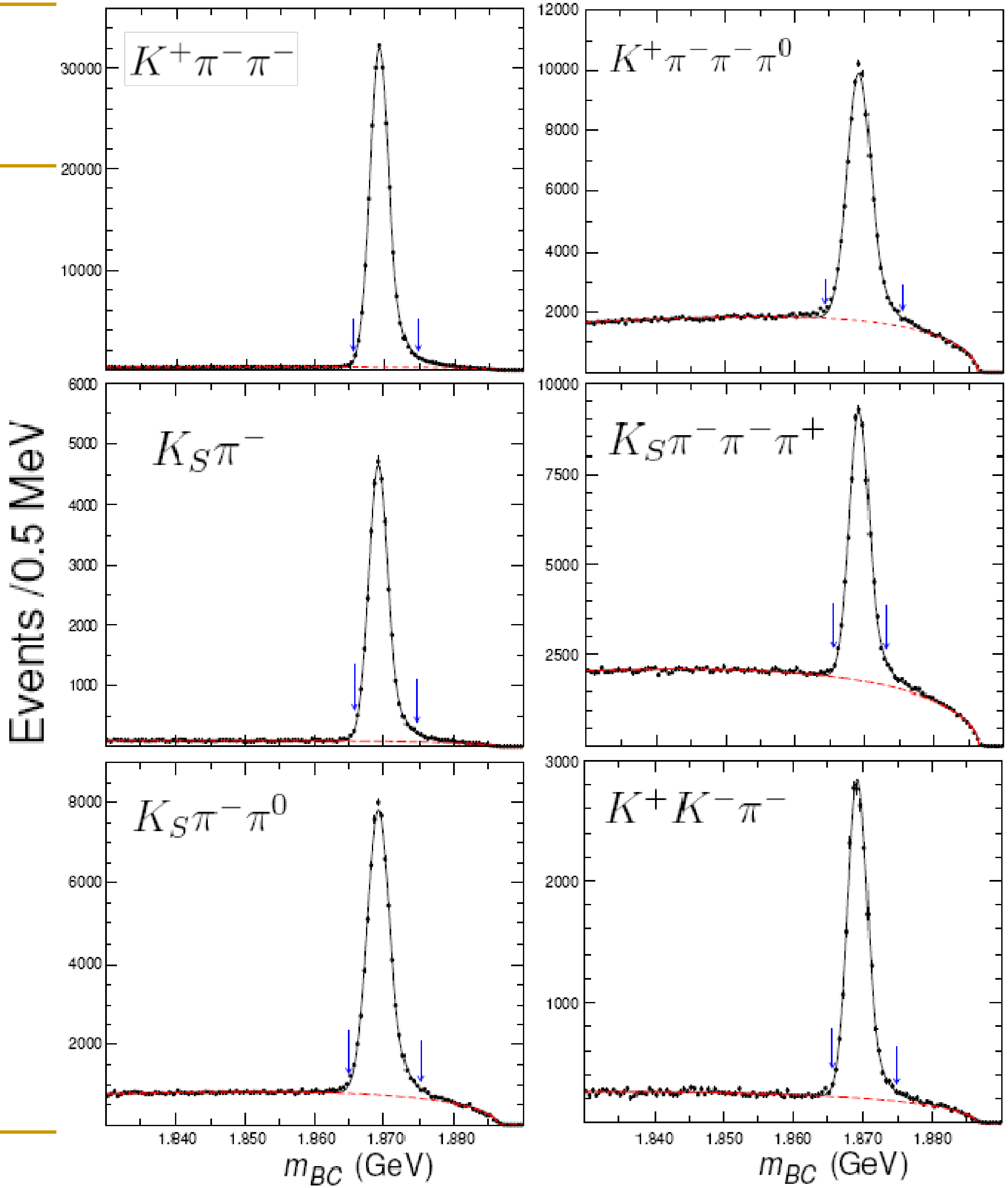
- Fully reconstruct a D^-, and count total # of tags
- Seek events with only one additional oppositely charged track within $|\cos\theta|<0.9$ & no additional photons > 250 MeV (to veto $D^+ \to \pi^+\pi^o$)
- Charged track must deposit only minimum ionization in calorimeter [< 300 MeV: case (i)]
- Compute 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 $E_{D^+} = E_{beam}$, $\mathbf{p}_{D^+} = -\,\mathbf{p}_{D^-}$

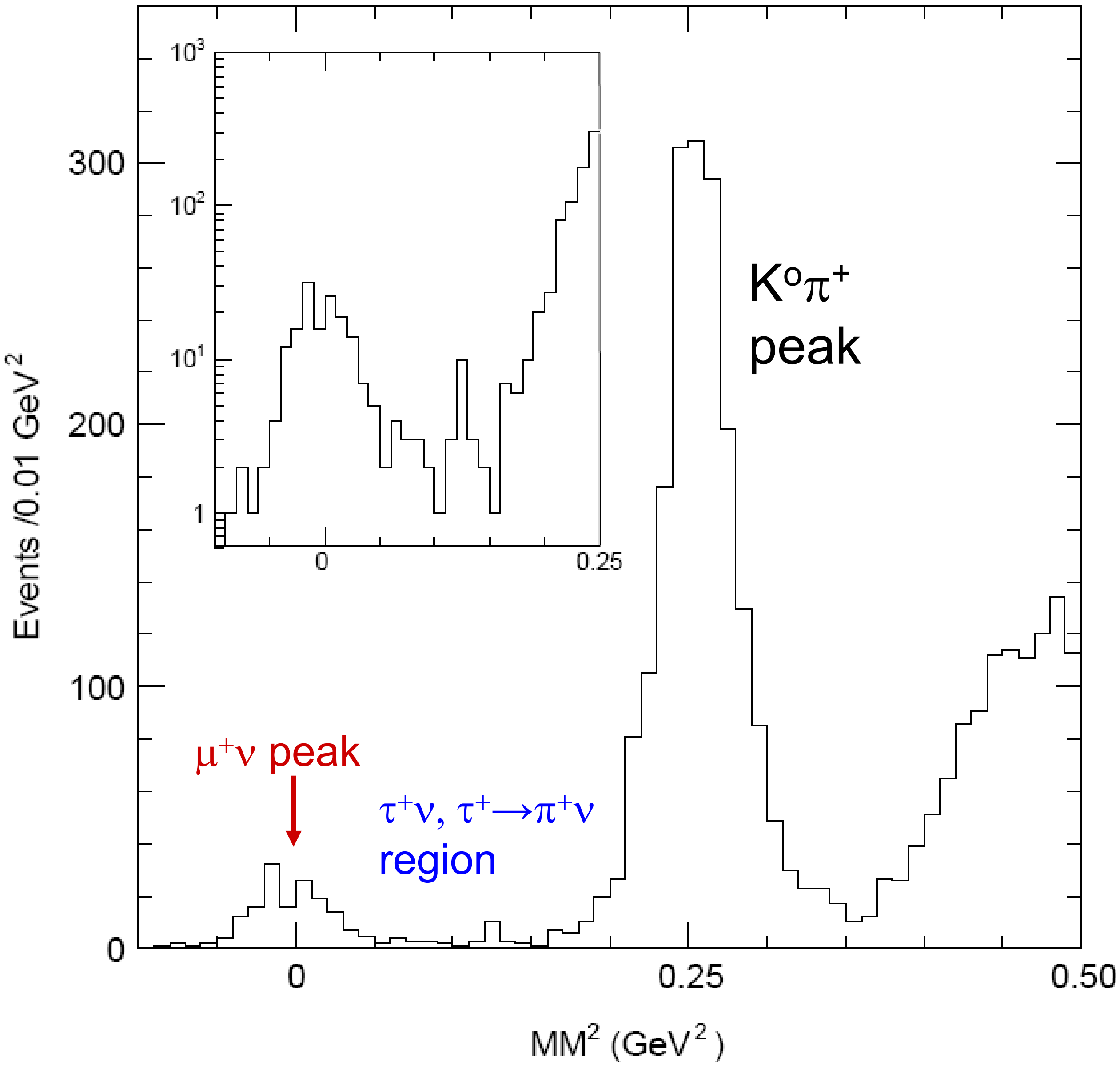
Tags

- Total of 460,000
- Background 89,400



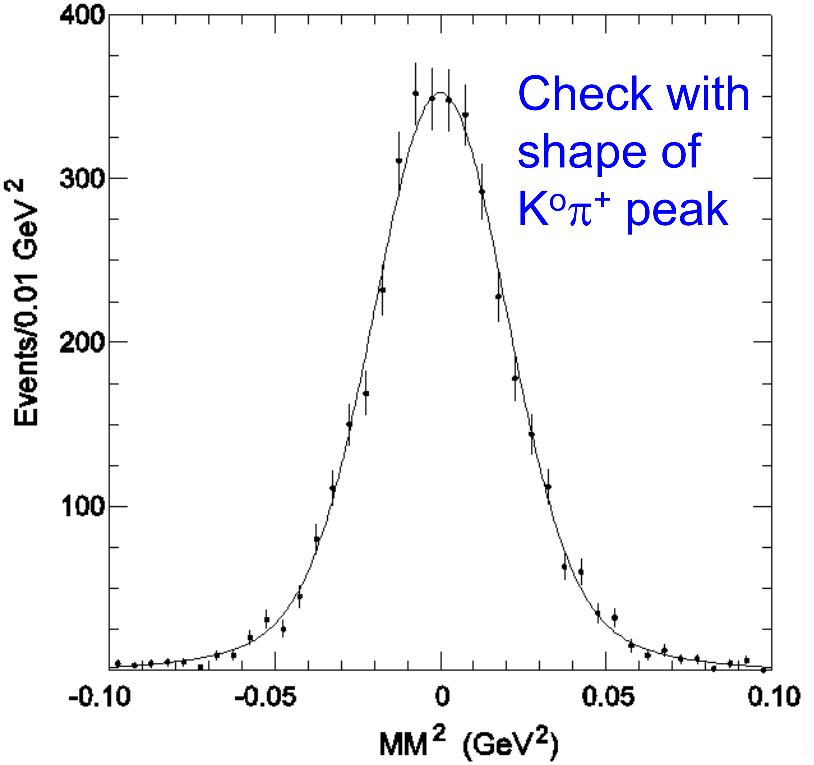
The MM^2 Distribution

- For E< 300 MeV in CsI

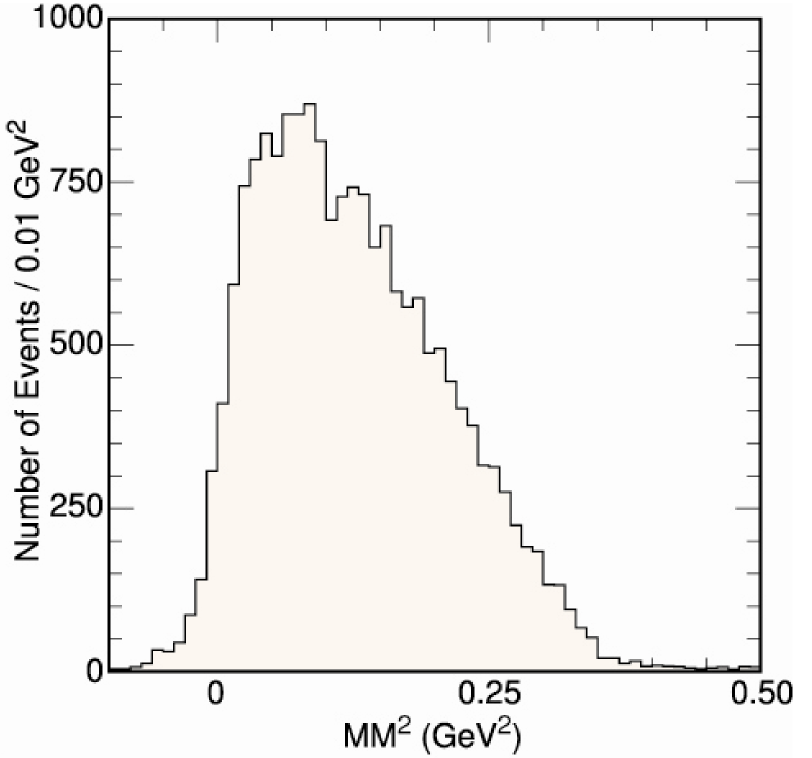


MM^2 Signal Shapes

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



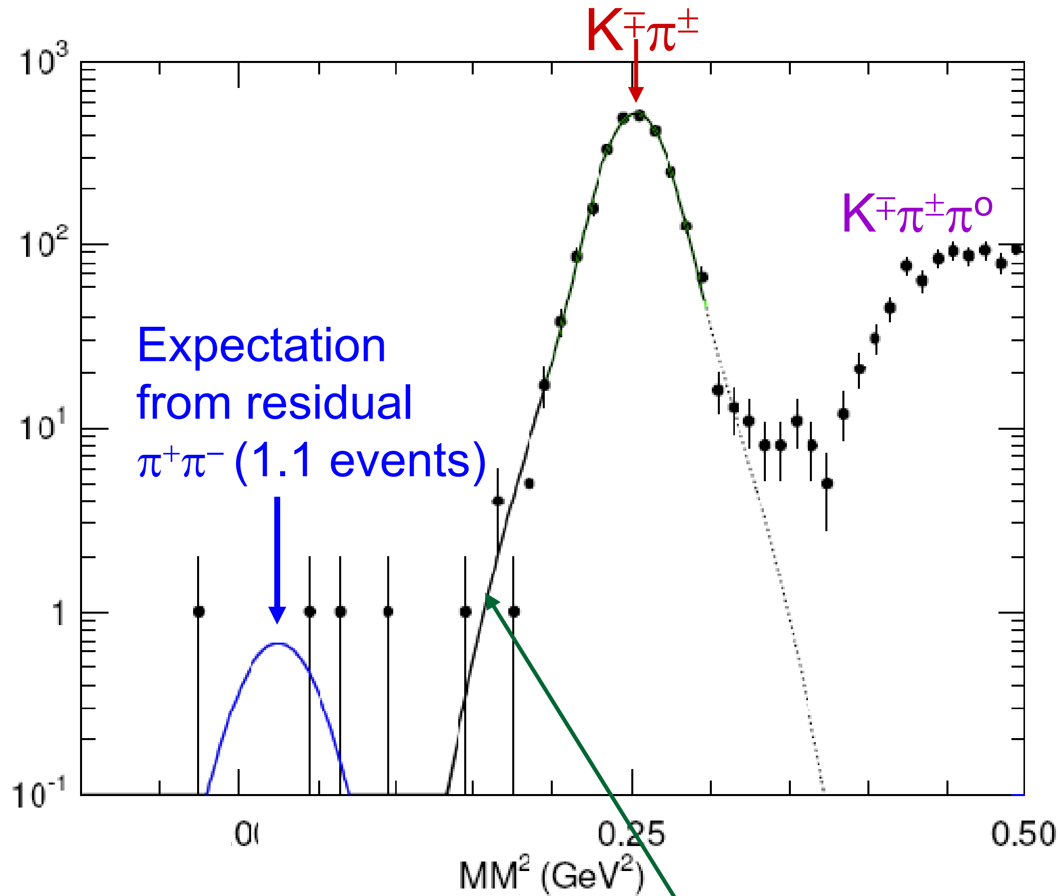
Monte Carlo Signal μν



Monte Carlo Signal τν, τ→πν

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

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

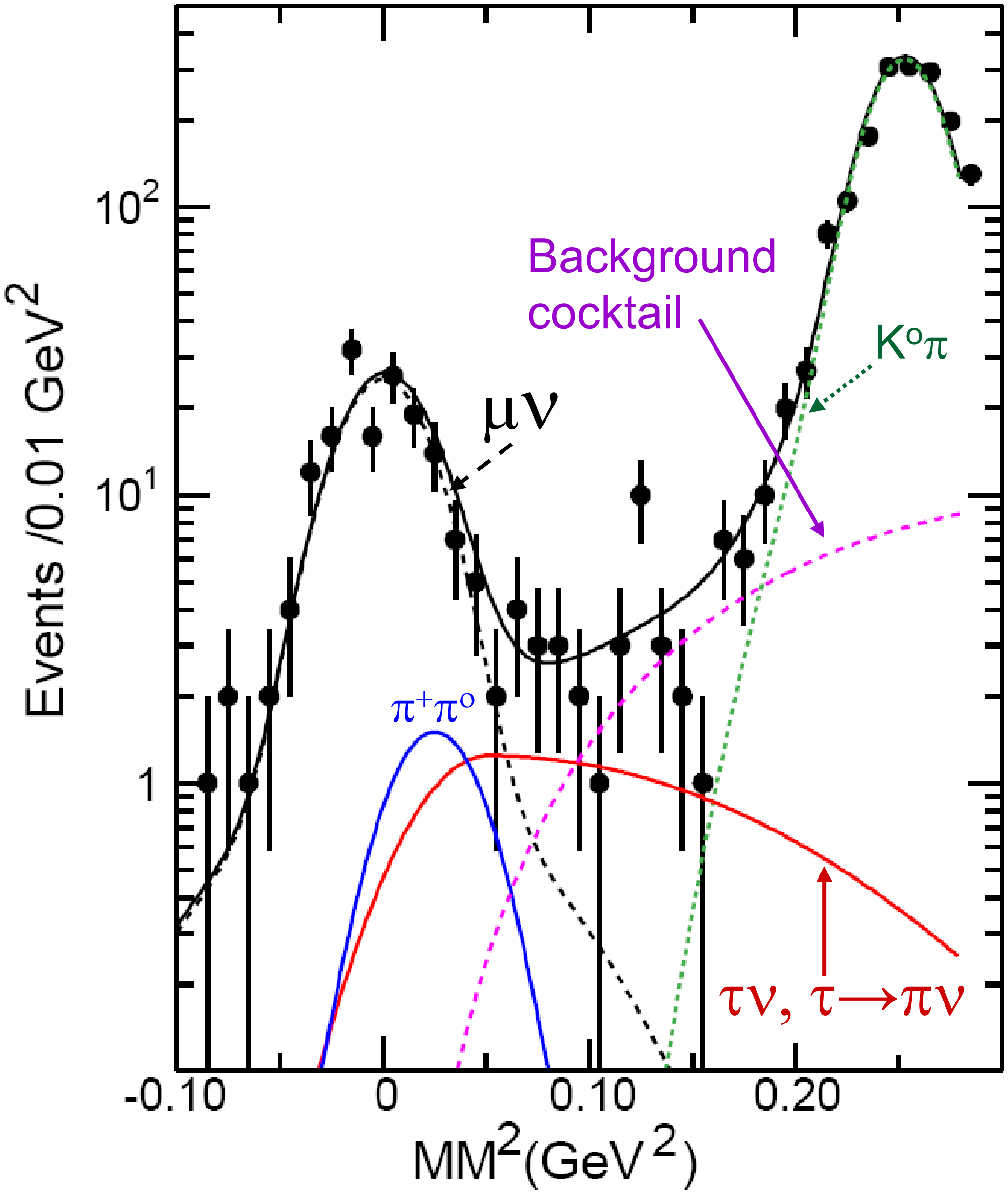


Computed ignoring charged kaon

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

Fit MM^2 to sum of signal & bkgrd

- Case(i) E< 300 MeV where $\tau^+\nu/\mu^+\nu$ is **fixed** to SM ratio
  - 149.7±12.0 $\mu\nu$
  - 28.5 $\tau\nu$
- Case(i) E< 300 MeV where $\tau^+\nu/\mu^+\nu$ is allowed to **float**
  - 153.9±13.5 $\mu\nu$
  - 13.5±15.3 $\tau\nu$



Residual Backgrounds for $\mu\upsilon$

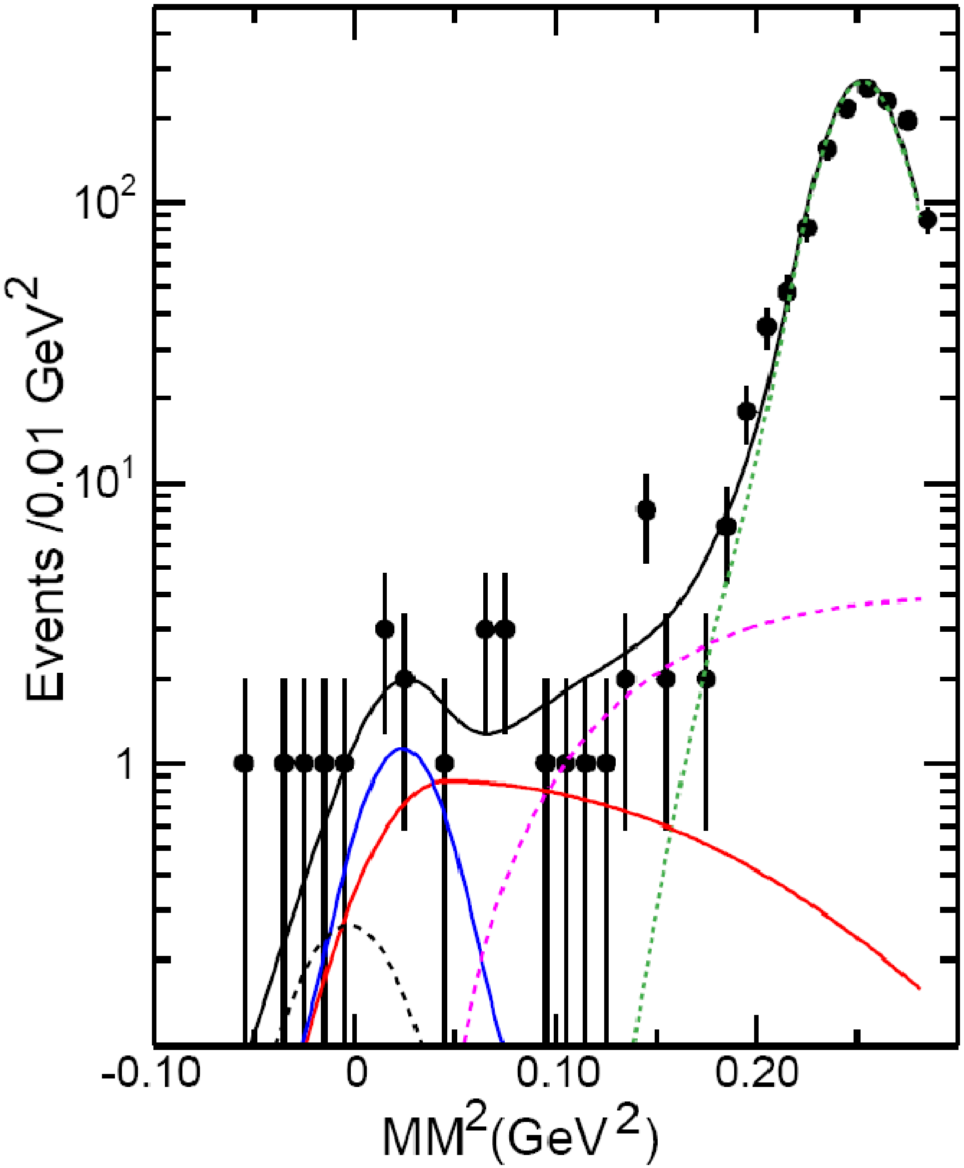
- Monte Carlo of Continuum, D^{o}, radiative return and other D^{+} modes, in $\mu\nu$ signal region

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

Background Check

- Use case(ii) E>300 MeV
- 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

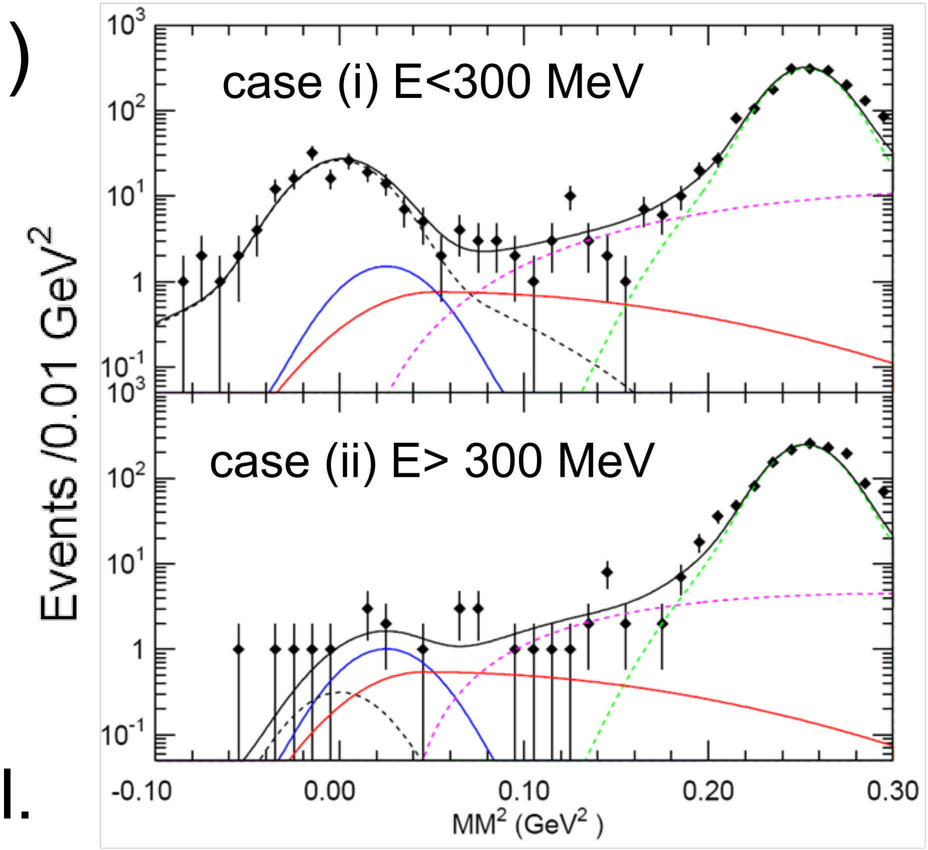
Source of Error	%
Finding the μ^+ track	0.7
Minimum ionization of μ^+ in EM cal	1.0
Particle identification of μ^+	1.0
MM^2 width	0.2
Extra showers in event > 250 MeV	0.4
Background	0.7
Number of single tag D^+	0.6
Total	**2.2**

Branching Fractions & f_{D^+}

- Fix $\tau\nu/\mu\nu$ at SM ratio of 2.65
  - $\mathcal{B}(D^+ \to \mu^+\nu) = (3.86 \pm 0.32 \pm 0.09) \times 10^{-4}$
  - $f_{D^+} = (206.7 \pm 8.5 \pm 2.5)$ MeV
  - This is best number in context of SM
- Float $\tau\nu/\mu\upsilon$
  - $\mathcal{B}(D^+ \to \mu^+\nu) = (3.96 \pm 0.35 \pm 0.10) \times 10^{-4}$
  - $f_{D^+} = (208.5 \pm 9.3 \pm 2.5)$ MeV
  - This is best number for use with Non-SM models
- *These are preliminary numbers with 818 pb^{-1}*

Upper limits on τν & eν

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



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.

CLEO Improved Measurement of f_{Ds}

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

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

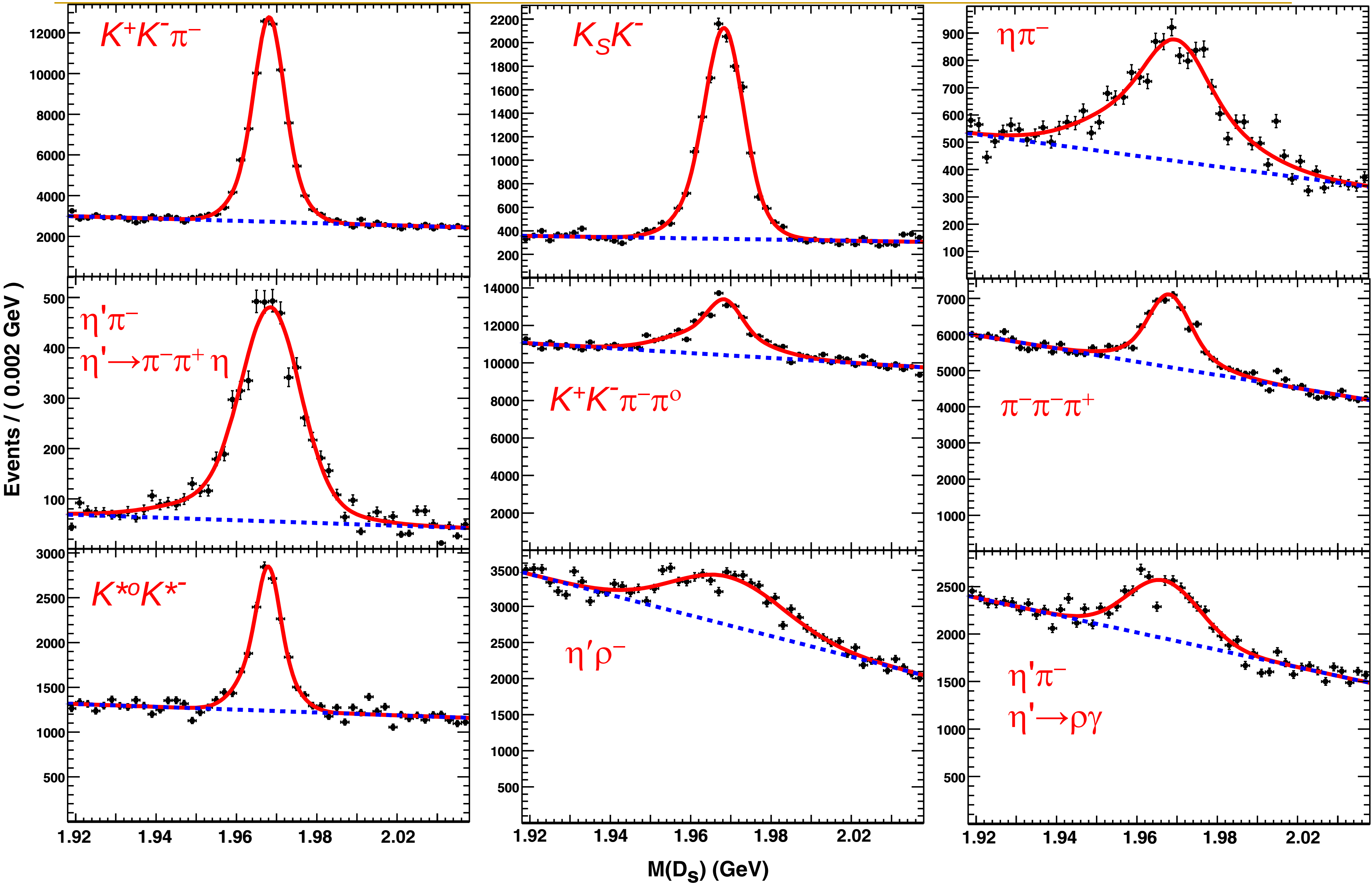
- Reconstruct D_S^-
- Find the γ from the D_S^* & compute MM^2 from D_S^- & γ

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

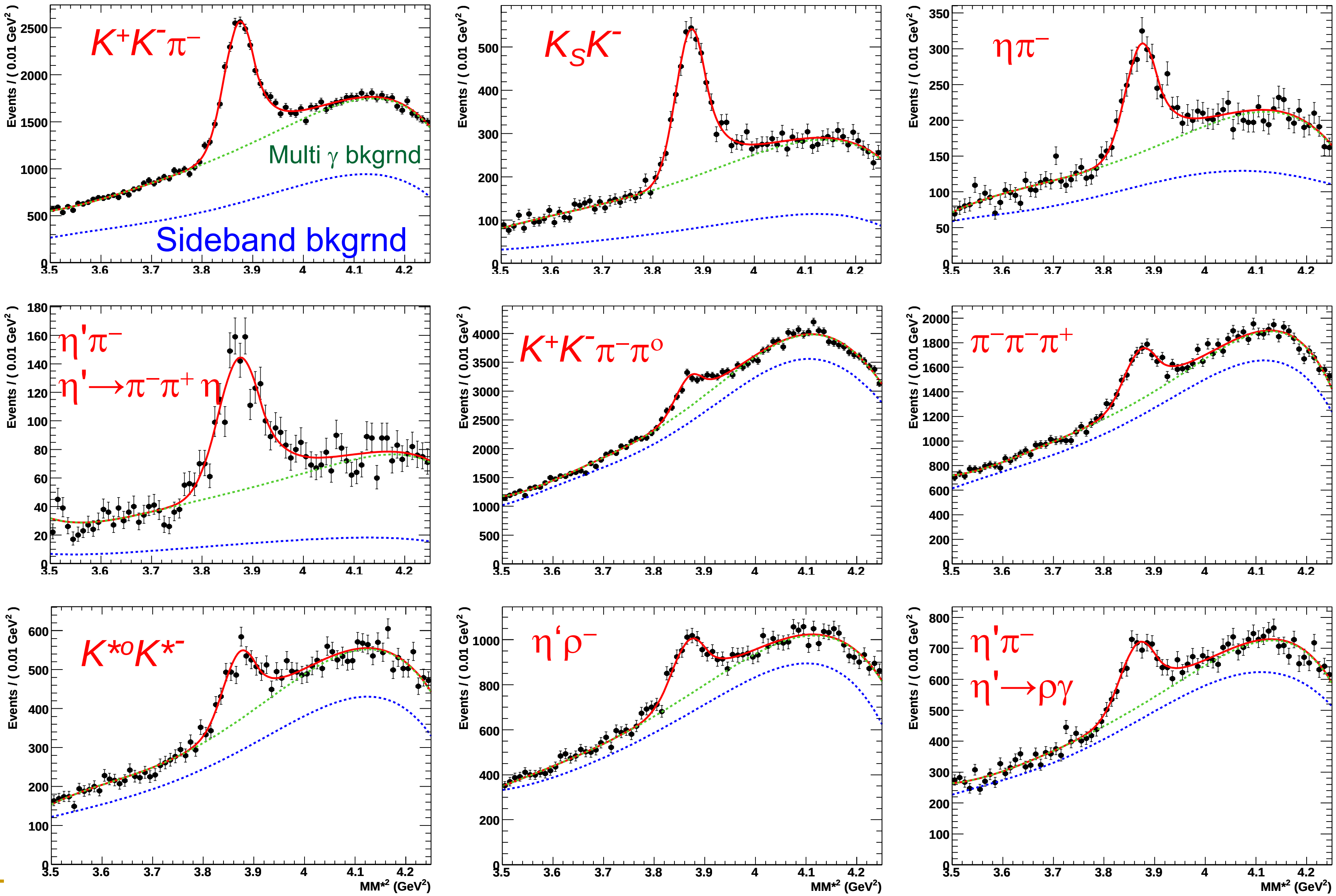
- Select combinations consistent with a missing D_S^+ & count the number
- Find MM^2 from candidate muon for (i) < 300 MeV in Ecal, (ii) E>300 MeV or (iii) e^- cand.

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

D_S^- Tags: Invariant Mass

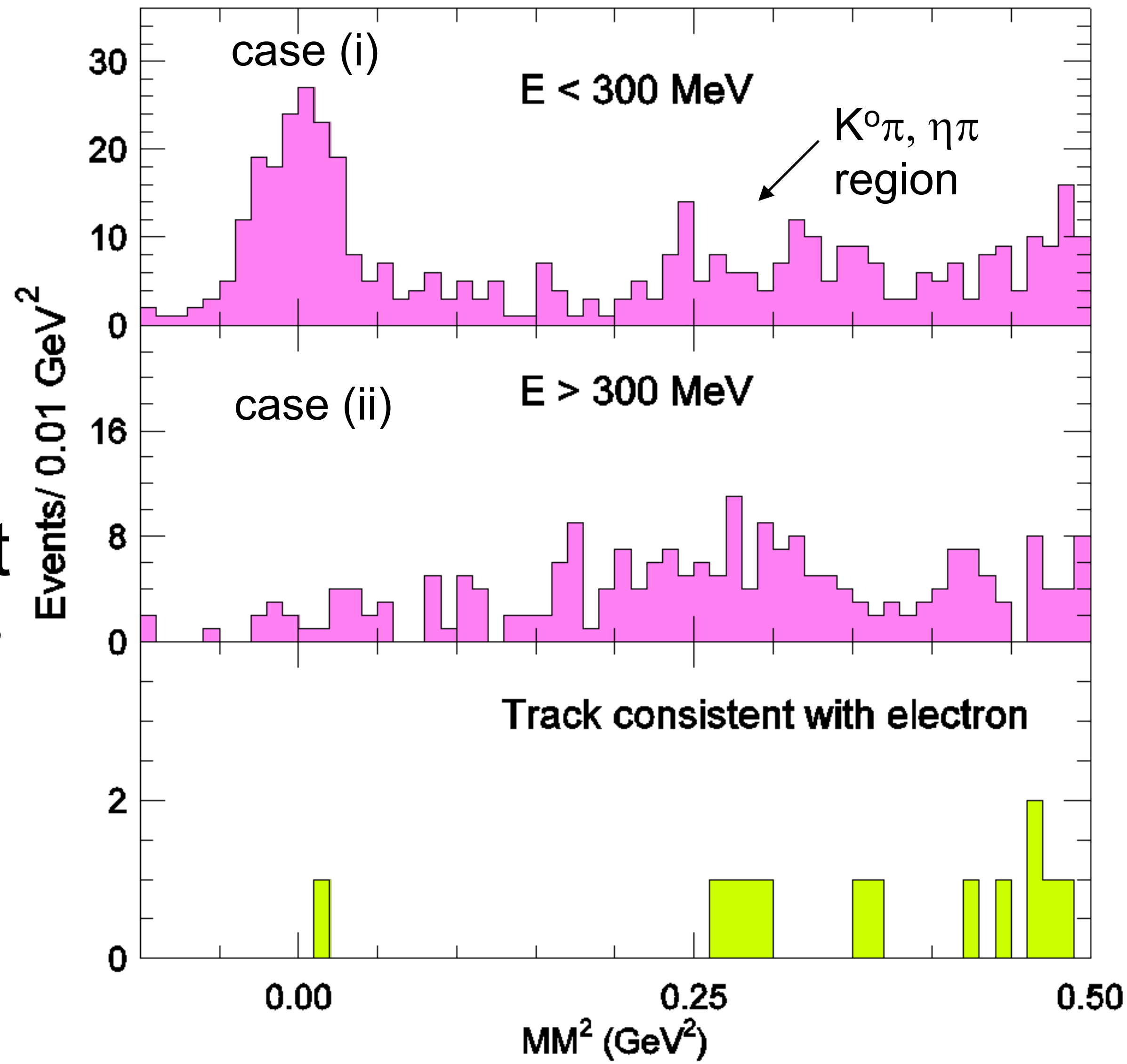


MM^{*2} Distributions From $D_S^- + \gamma$

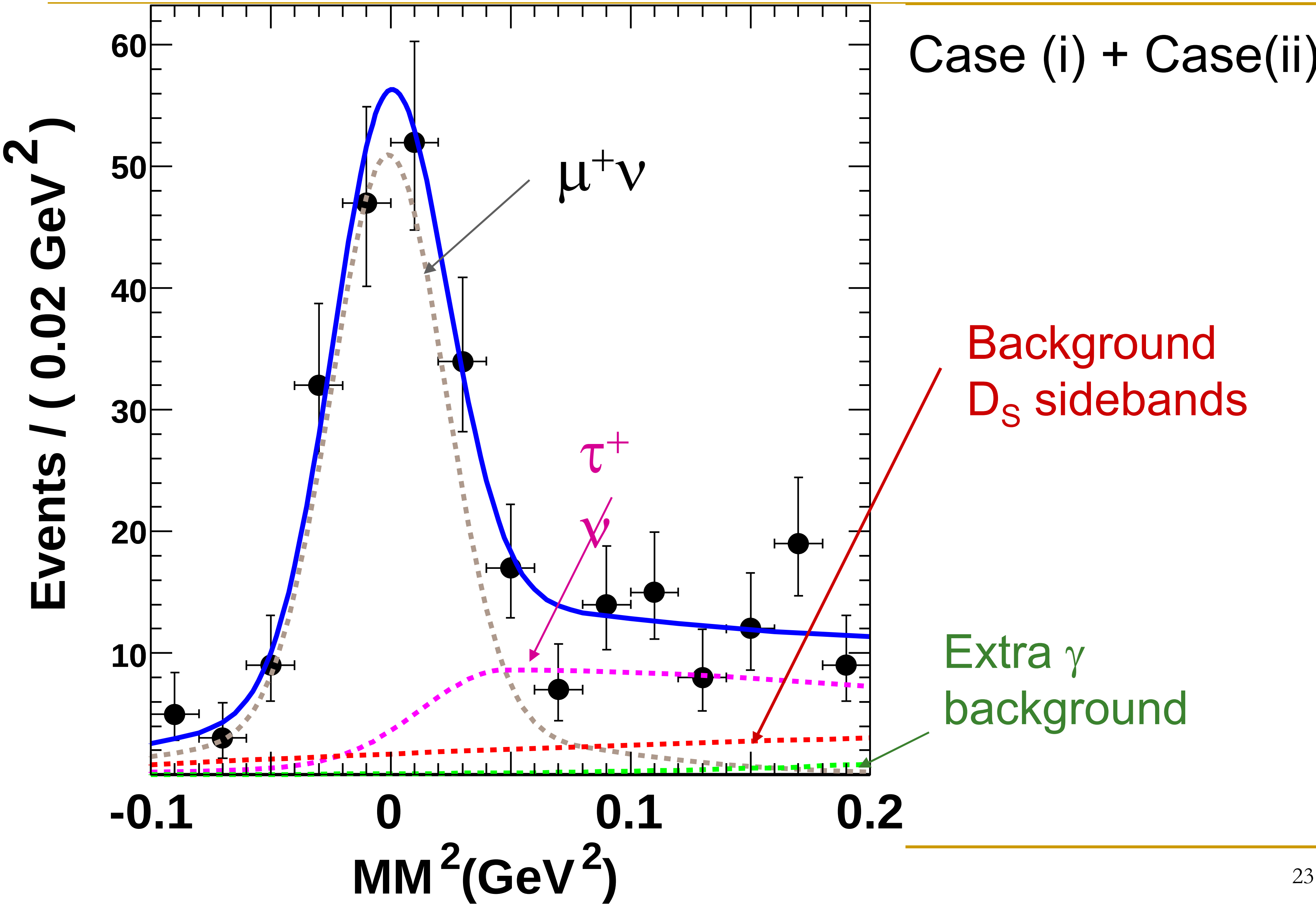


MM^2 data for D_S

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

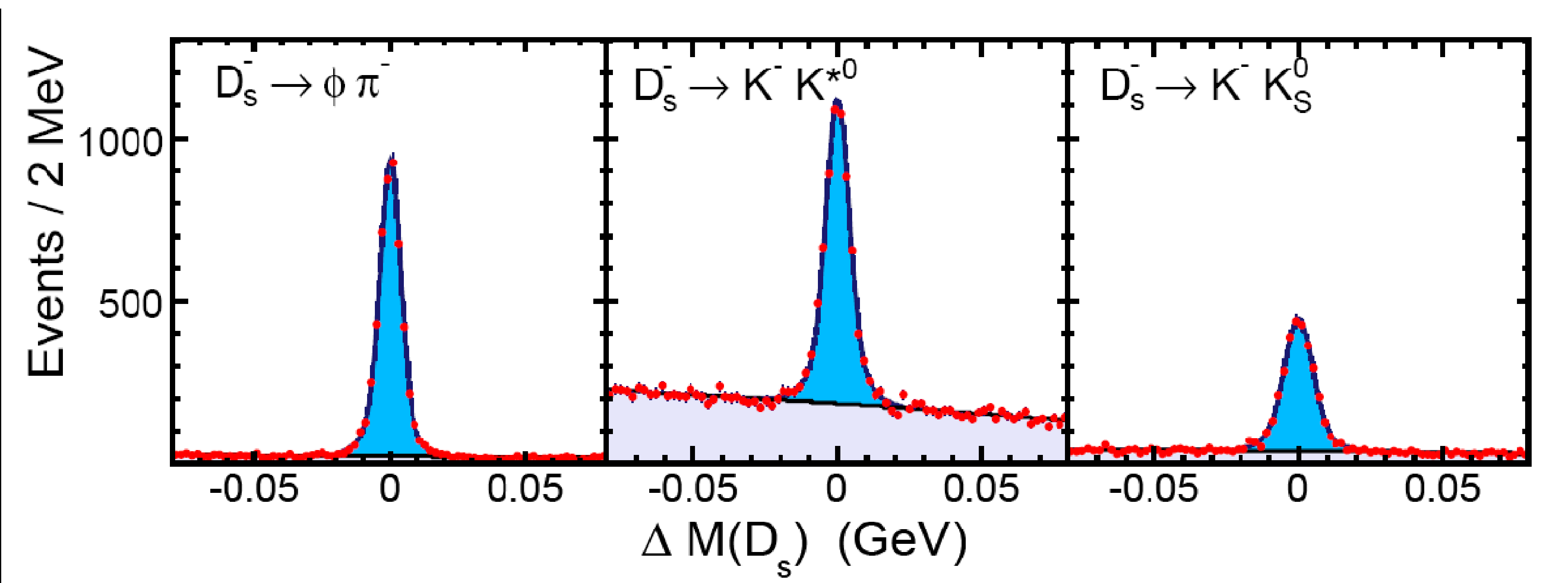


Fit to signal & background



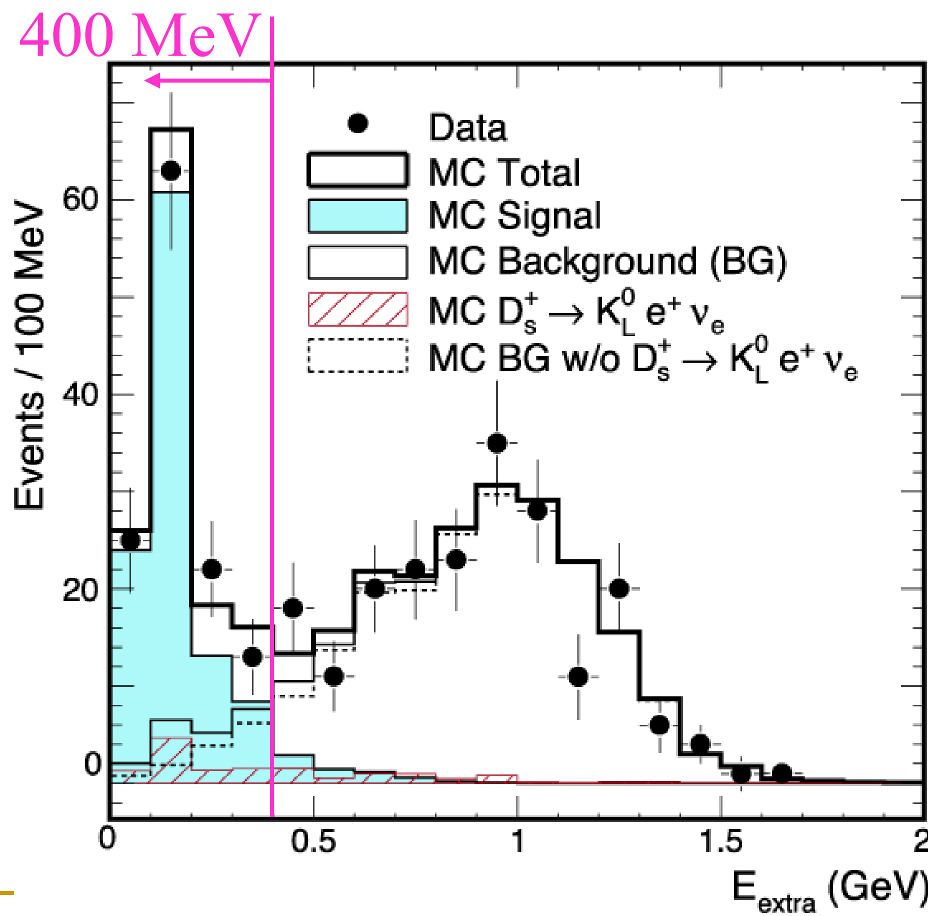
CLEO: $D_S^+ \rightarrow \tau^+\nu$, $\tau^+ \rightarrow e^+\nu\nu$

- $\mathcal{B}(D_S^+ \rightarrow \tau^+\nu) \bullet \mathcal{B}(\tau^+ \rightarrow e^+\nu\nu) \sim 1.3\%$ 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^*
- $\mathcal{B}(D_S^+ \to \tau^+\nu) = (6.17 \pm 0.71 \pm 0.36)\%$
- $f_{Ds} = 273 \pm 16 \pm 8$ MeV



Branching Ratio & f_{D_s} *(preliminary)*

Mode	$\mathcal{B}$ (%)	f_{D_s} (MeV)
(1) $\mu\nu+\tau\nu$ (fix SM ratio)	$\mathcal{B}^{eff}(D_s \to \mu\nu)$ = (0.613±0.044±0.020)	268.2±9.6±4.4
(2) $\mu\nu$ only	$\mathcal{B}(D_s \to \mu\nu)$ = (0.600±0.054±0.020)	265.4±11.9±4.4
(3) $\tau\nu$, $\tau\to\pi\nu$	$\mathcal{B}(D_s \to \tau\nu)$ = (6.1±0.9±0.2)	271±20±4
(4) $\tau\nu$, $\tau\to e\nu\nu$	$\mathcal{B}(D_s \to \tau\nu)$ = (6.17±0.71±0.36)	273±16±8
CLEO Average of (1) & (4)	Rad. corr.	269.4±8.2±3.9 267.9±8.2±3.9

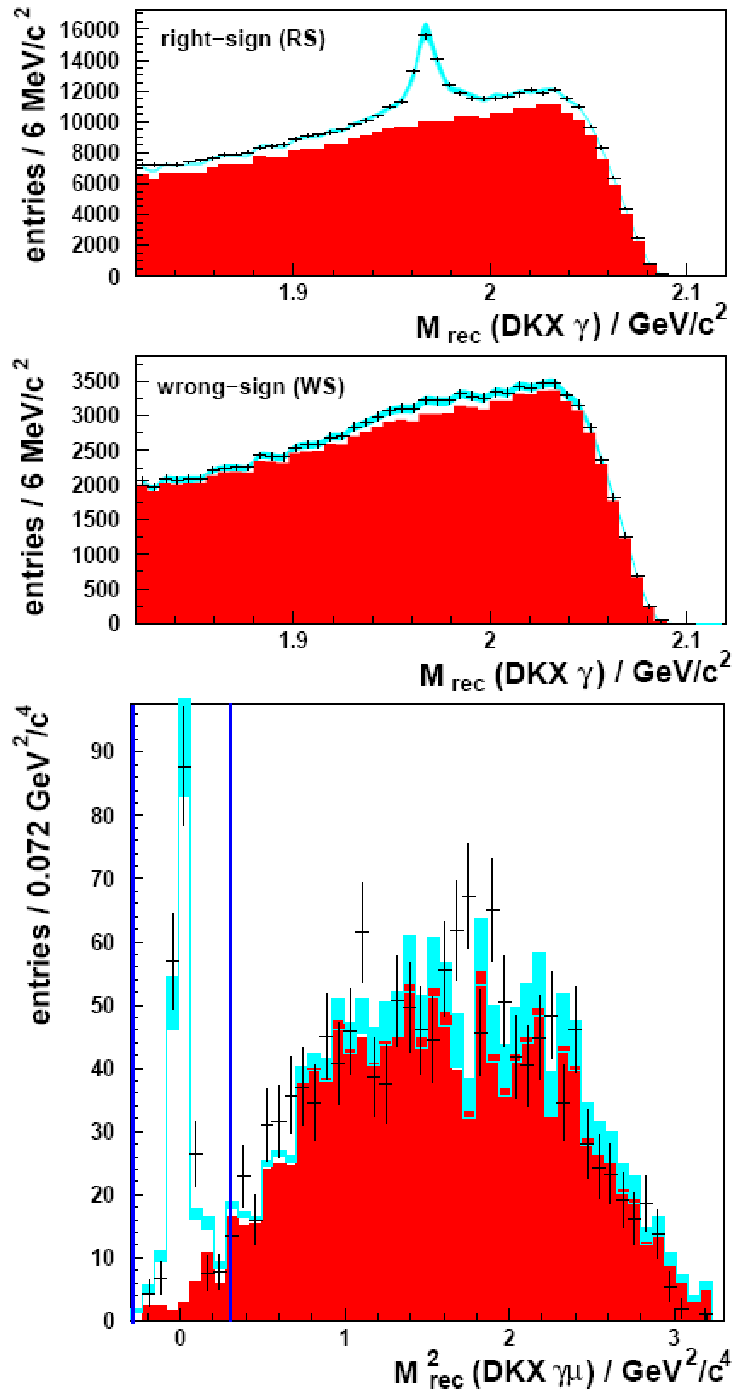
Systematic Errors

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	0.5
Number of single tag D_S^-	3.0
Total	**3.3**

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

- Look for $e^+e^- \to DKX\gamma(D_S)$, 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
- $\mathcal{B}(D_S^+ \to \mu^+\nu) = (0.644\pm0.076\pm0.057)\%$
- $f_{D_S}=275\pm16\pm12$ MeV

arXiv:0709.1340v2 [hep-ex]



f_{D_s} & f_{D_s} / f_{D^+}

- Weighted Average CLEO + Belle: f_{Ds}=270.4±7.3±3.7 MeV, the systematic error is uncorrelated between the measurements
- Using f_{D^+} = (206.7±8.5±2.5) MeV
- f_{Ds}/f_{D^+} = 1.31±0.06±0.02 Much larger than models
- $\Gamma(D_S^+ \to \tau^+ \nu)/\Gamma(D_S^+ \to \mu^+ \nu)$=10.3±1.1, SM=9.72

  Consistent with lepton universality

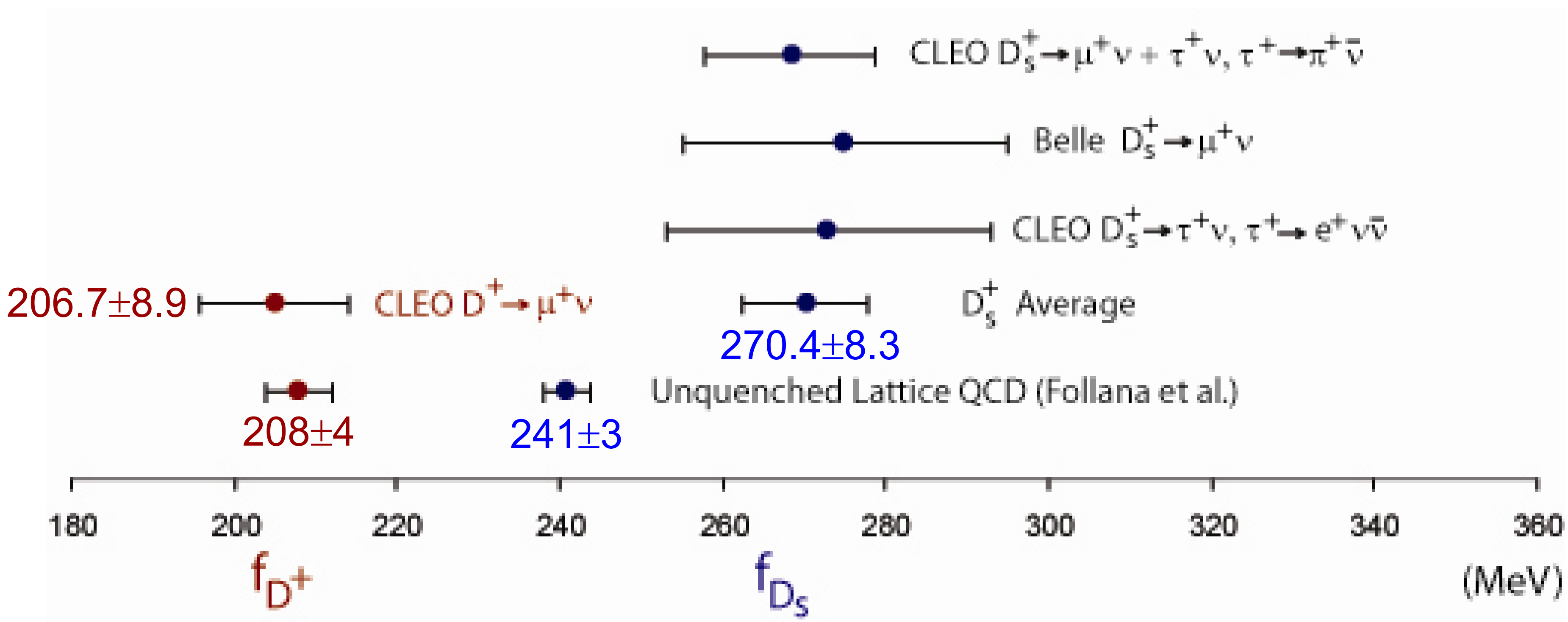
Other Non-absolute Measurements

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	$283 \pm 17 \pm 7 \pm 14$

See arXiv:0802.1043 for references

Conclusions

- 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



Questions

- 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])

Future Improvements

- CLEO will further update f_{D_s} using at total of ~600 pb^{-1}
  - 50% increase in data for $\mu\nu$
  - 100% increase in data for $\tau\nu$, $\tau \rightarrow e\nu\nu$
- f_{D^+} will not see any major improvements until BES

The End

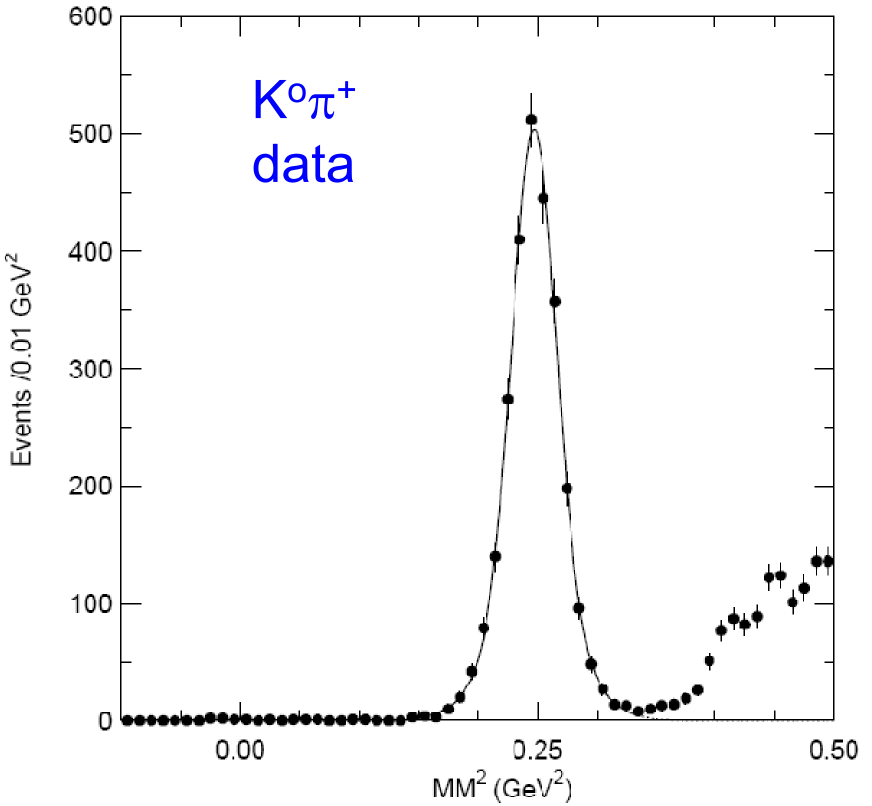
Improvements in Analysis

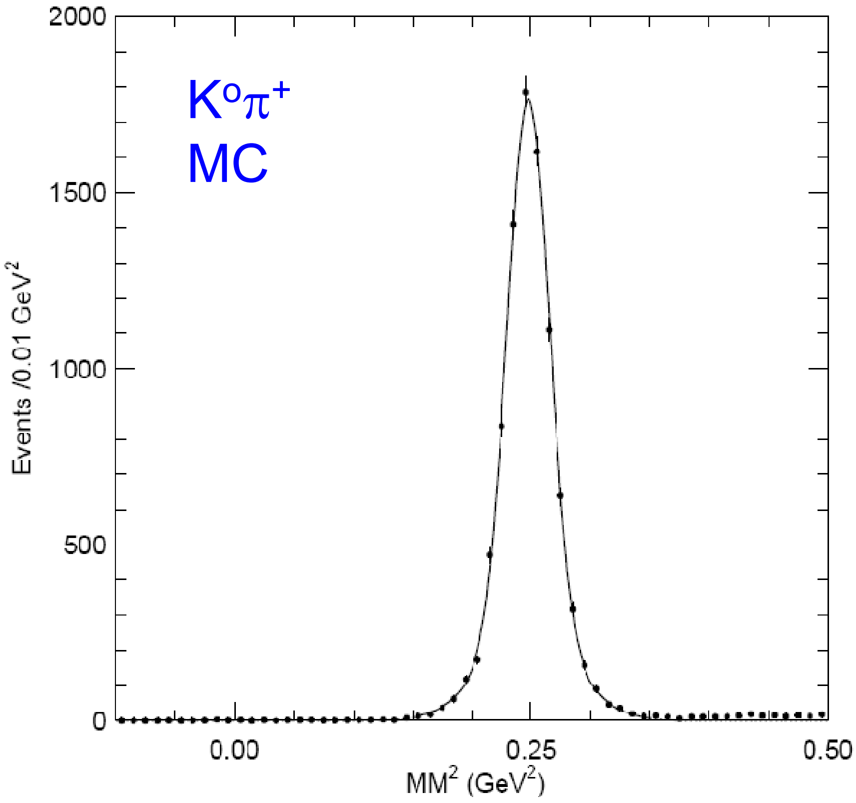
- Increase solid angle to $|\cos\theta|<0.9$ (+11%)
- Now we fit the muon candidate distribution to extract $\mu^+\nu$ & $\tau^+\nu$, to extract yield, improves efficiency by ~5%, & also allows us to quote a $\mathcal{B}$ independent of assuming SM $\tau^+\nu/\mu^+\nu$ ratio
  - Requires signal shapes for $\mu^+\nu$ & $\tau^+\nu$
  - Requires background shapes for $K^o\pi^+$ low MM^2 tail, $\pi^+\pi^o$ & residual 3 body modes, e.g. $\tau^+\rightarrow\mu^+\nu\nu$, $\rho^+\nu$, $\pi^o\mu^+\nu$.
  - Requires small residual background subtraction from continuum, etc...
- Backgrounds are now well understood especially from $K^o\pi^+$ peak

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

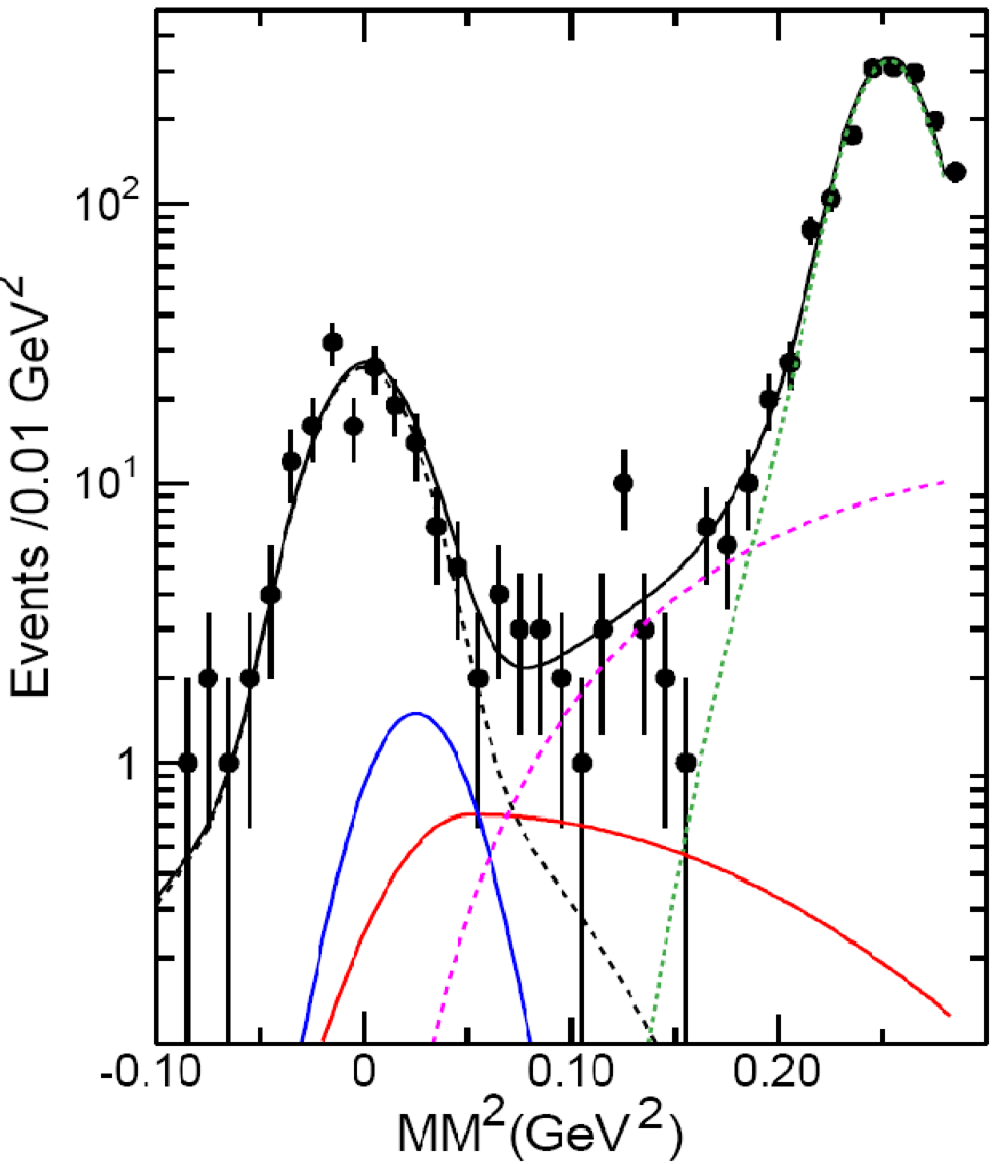




- Data σ=0.0247±0.0012 GeV^2
- MC σ=0.0235±0.0007 GeV^2
- Both average of double Gaussians

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