Some Other Flavors

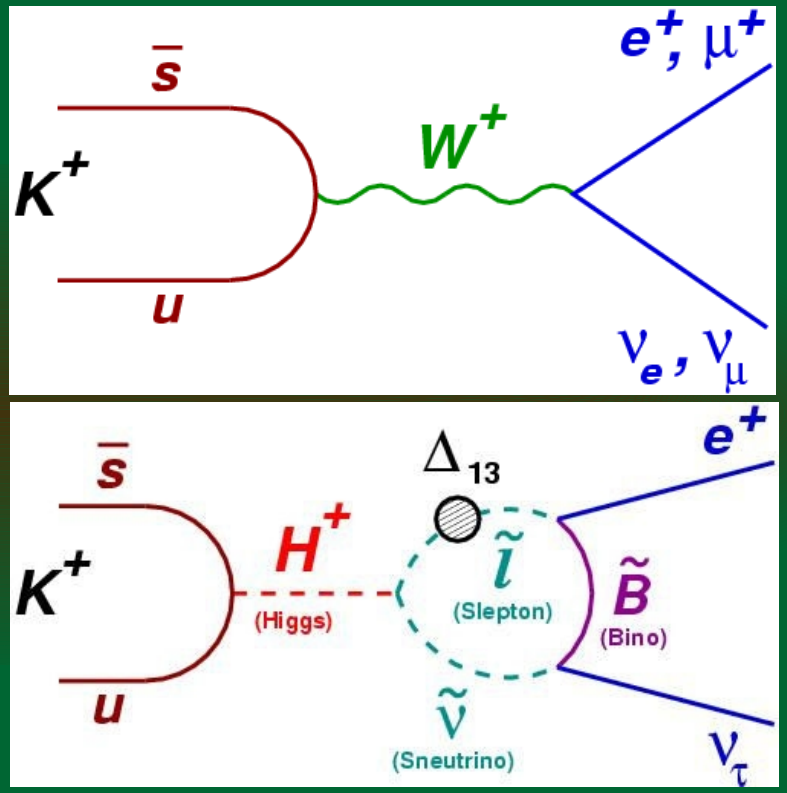
CLEO-c and NA62

Precision Tests for New and Fundamental Physics

Leptonic Decays

$$\Gamma(P^+ \to \ell^+ \nu) = \frac{G_F^2 \, |V_{qq'}|^2 \, f_{P+}^2}{8\pi} m_{P+} m_\ell^2 \left(1 - \frac{m_\ell^2}{m_{P+}^2}\right)^2$$

- Test theoretical tools
- Search for new physics
  - Rates
  - Lepton Universality

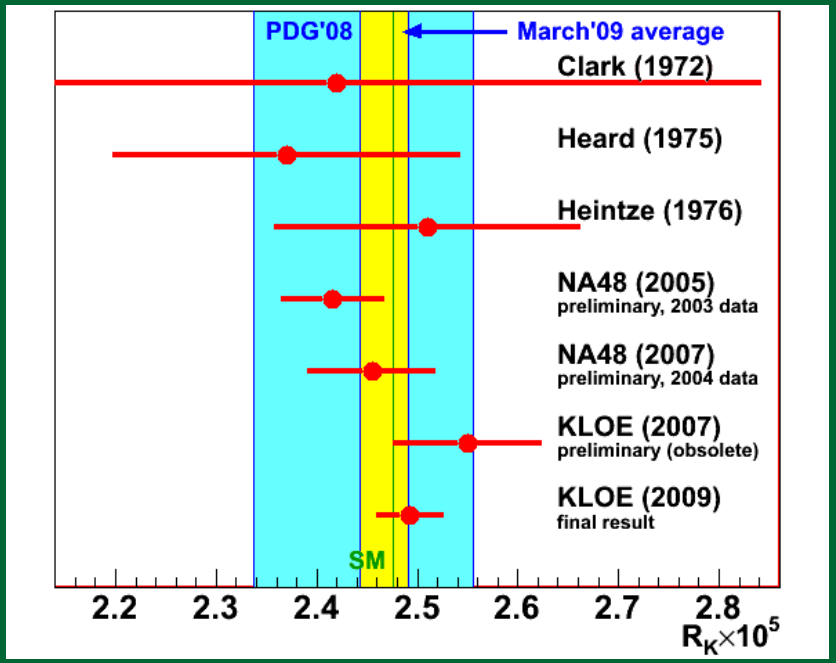


Lepton Universality

$$K^+ \to \ell^+ \nu$$

$$R_K \equiv \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1 + \delta R_K^{\text{rad cor}})$$

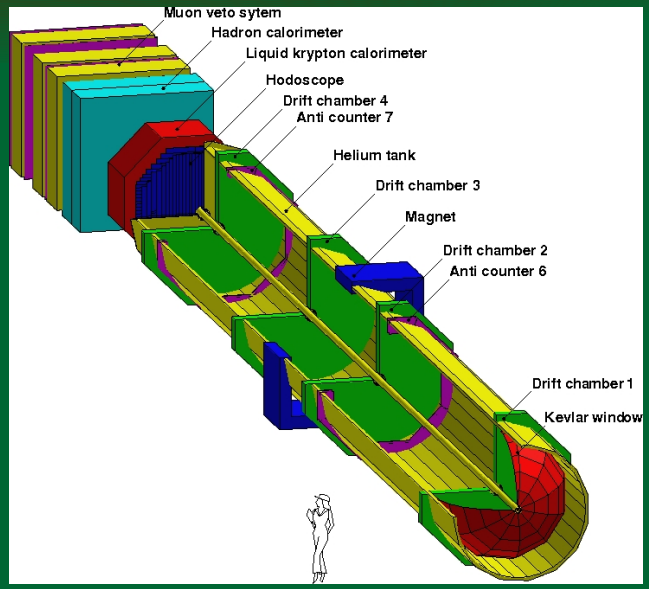
[a few %]

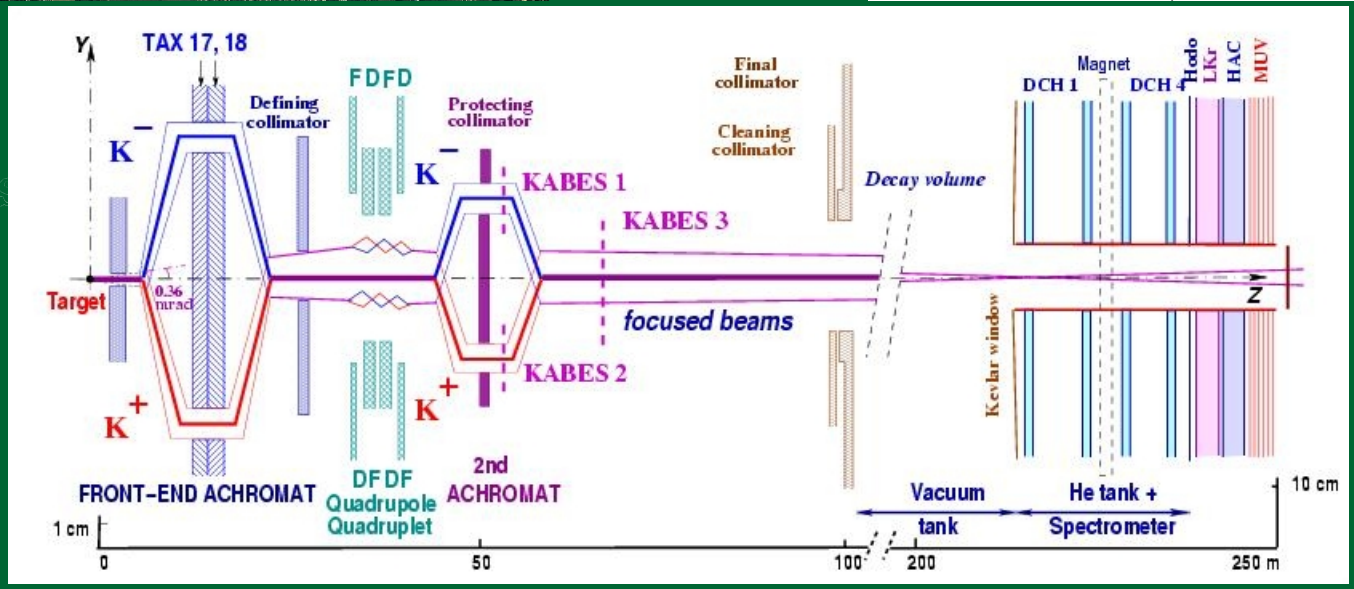


$$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$$

$$R_K^{Ave.} = (2.467 \pm 0.024) \times 10^{-5}$$

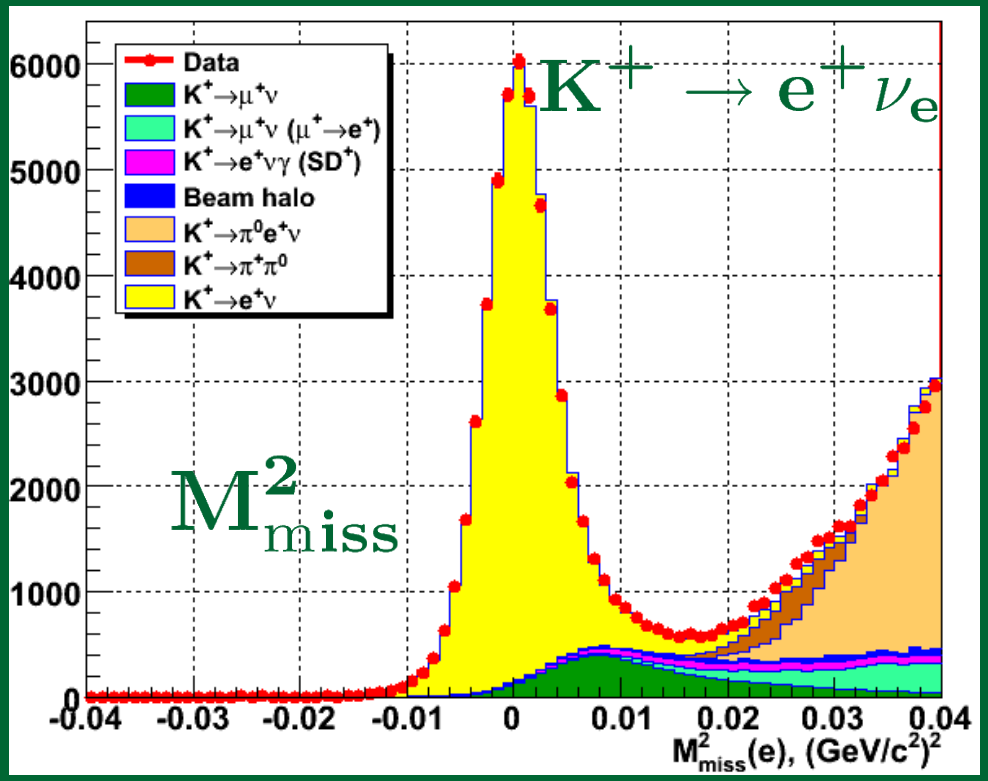
NA62 (Using NA48 Detector)

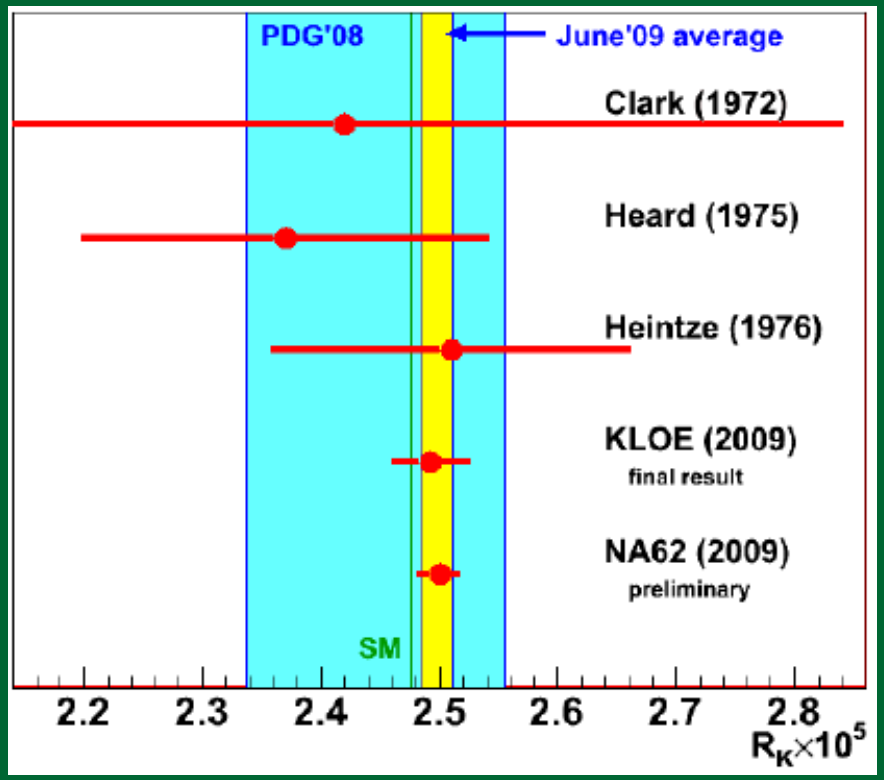




40% of the Data, Preliminary

$$R_K = (2.500 \pm 0.012_{stat} \pm 0.011_{sys}) \times 10^{-5}$$

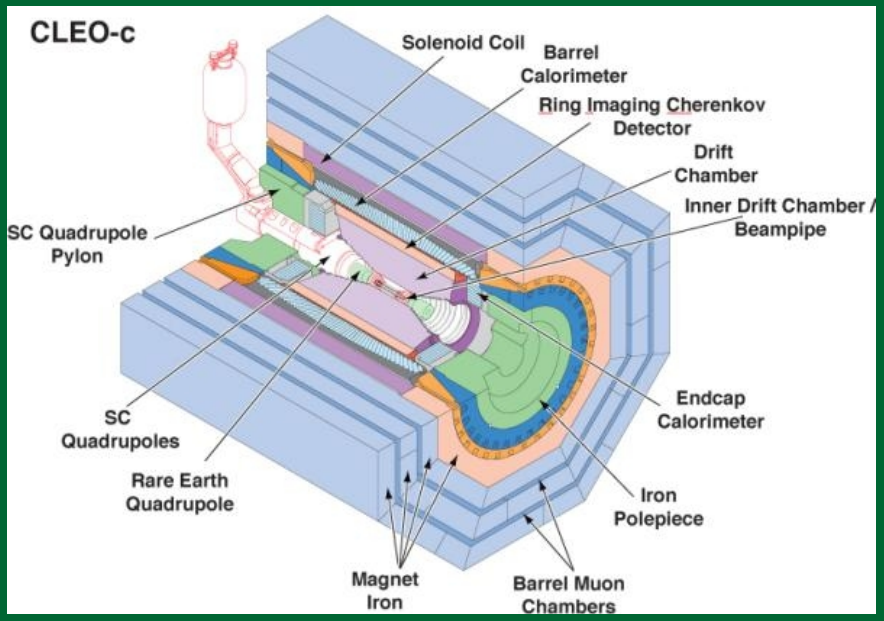




~51 K events, ~8% background $R_K^{Ave.} = (2.498 \pm 0.014) \times 10^{-5}$

CLEO-c

Cornell Electron Storage Ring (CESR)

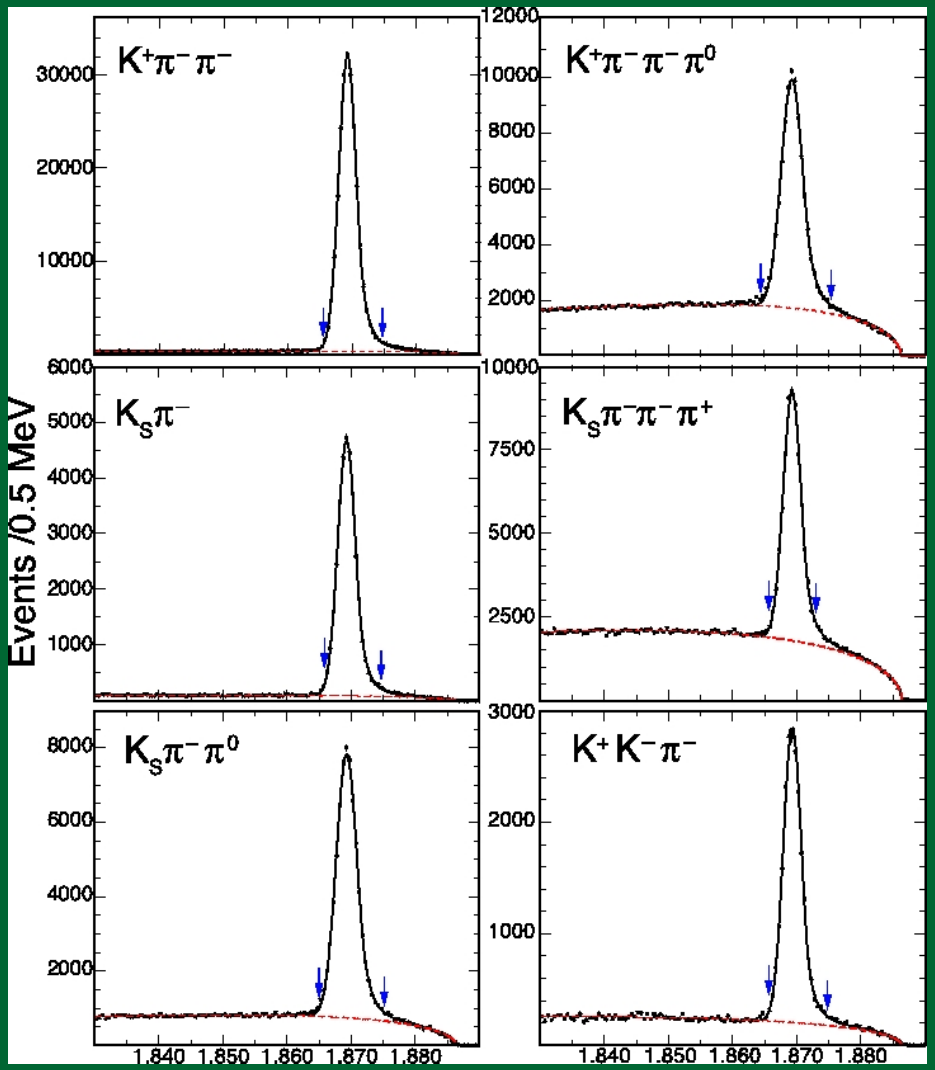


- Ran (until Mar '08) just above $\mathbf{D\bar{D}}$ Threshold
- $\boldsymbol{\psi(3770) \rightarrow D^0\bar{D}^0}$
  $\mathcal{L}_{\rm int} \sim \mathbf{818}\ \mathrm{pb}^{-1}$
- $\mathbf{E_{CM} = 4170}\ \mathrm{MeV}$
  $\mathbf{D_s D_s^*}$ **Threshold**
  $\mathcal{L}_{\rm int} \sim \mathbf{600}\ \mathrm{pb}^{-1}$
- Also $\psi(2S)$
  $\mathbf{E_{CM} = 4260}\ \mathrm{MeV} \ldots$

Tagging

- Near particle-anti-particle threshold ⇒ two-particle production
- Hermetic detector + large cross-sections, branching fractions, and luminosities ⇒ efficient reconstruction of ≥ one particle: the **tag**
- Tagging ⇒ reduced background and kinematic ambiguity

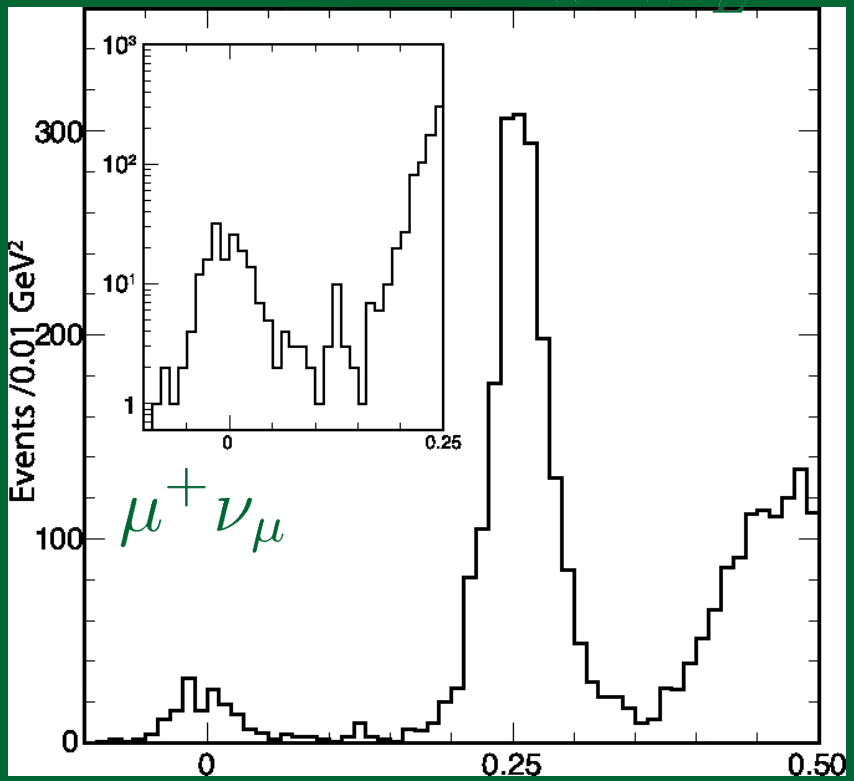
$D^+ \to \mu^+ \nu_\mu$



Tags

$\Delta E = E_D - E_{beam}$

Find $\mu^+_{\pi^+ K_L}$



$$M_{BC} = \sqrt{E^2_{\rm beam} - |p_D|^2}$$

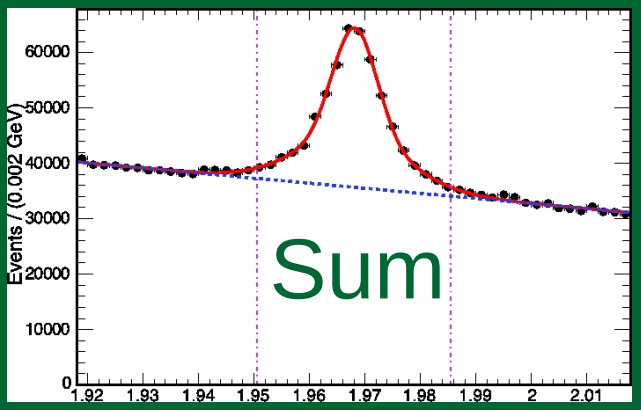
MM^2

PRD 78, 05203 (2008)

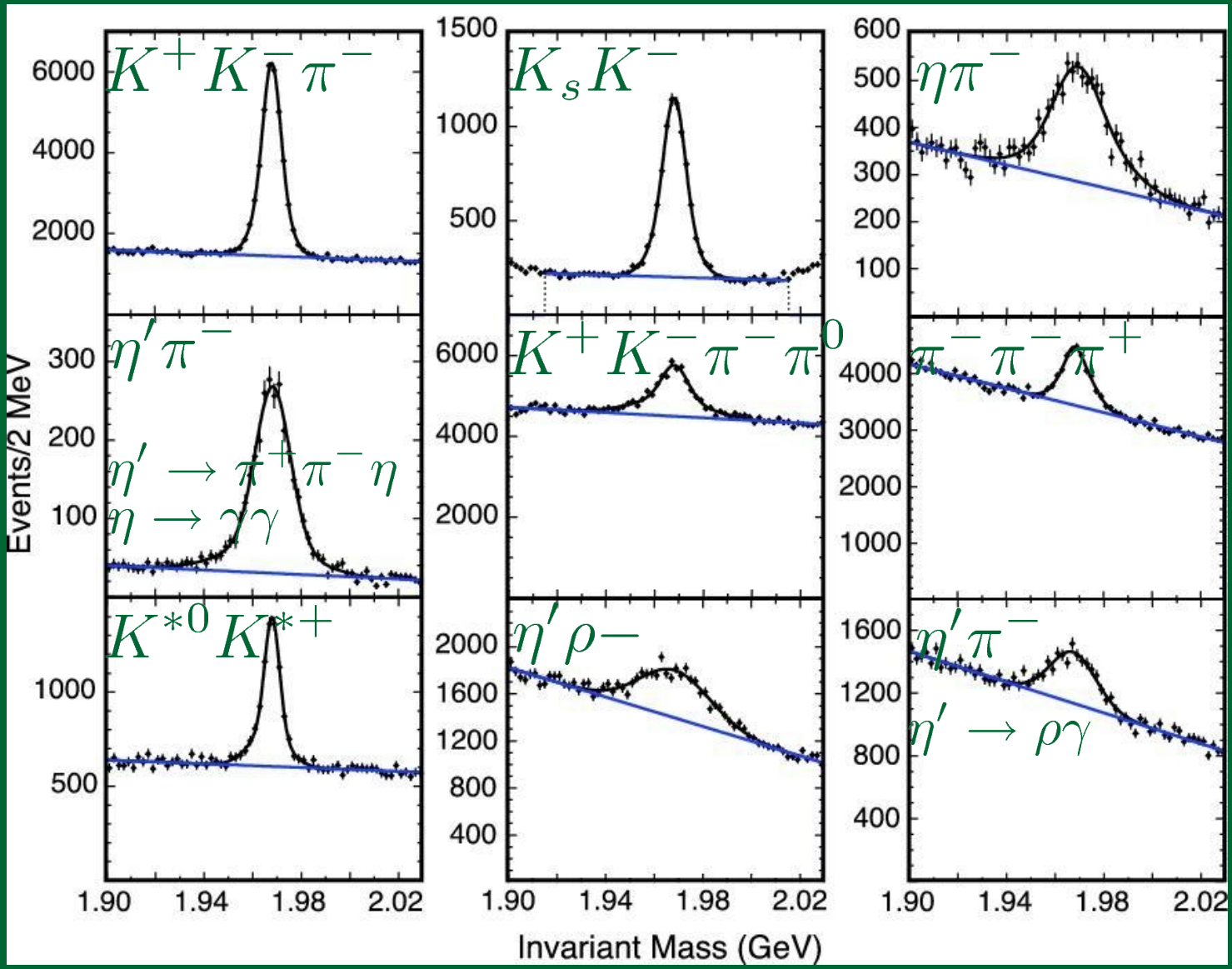
- $\mathcal{B}(D^+ \to \mu^+ \nu_\mu) = (3.82 \pm 0.32_{\rm stat} \pm 0.09_{\rm sys}) \times 10^{-4}$
- $f_{D^+} = (205.8 \pm 8.5_{\rm stat} \pm 2.5_{\rm sys})$ MeV

$D_s^+ \to \mu^+ \nu_\mu$ and $D_s^+ \to \tau^+ (\pi^+ \bar{\nu}_\tau) \nu_\tau$

D_S^- Tags

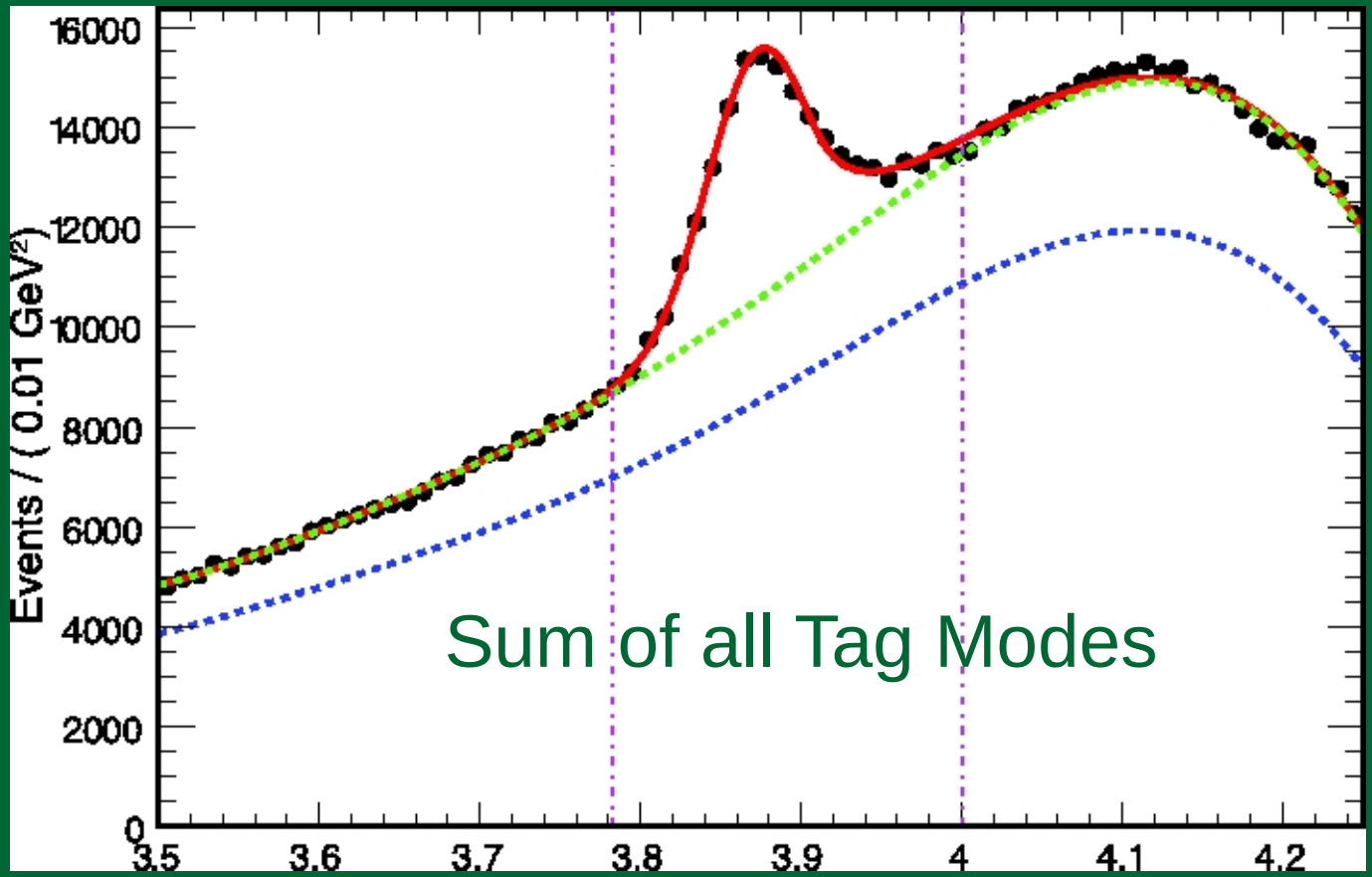


Invariant Mass



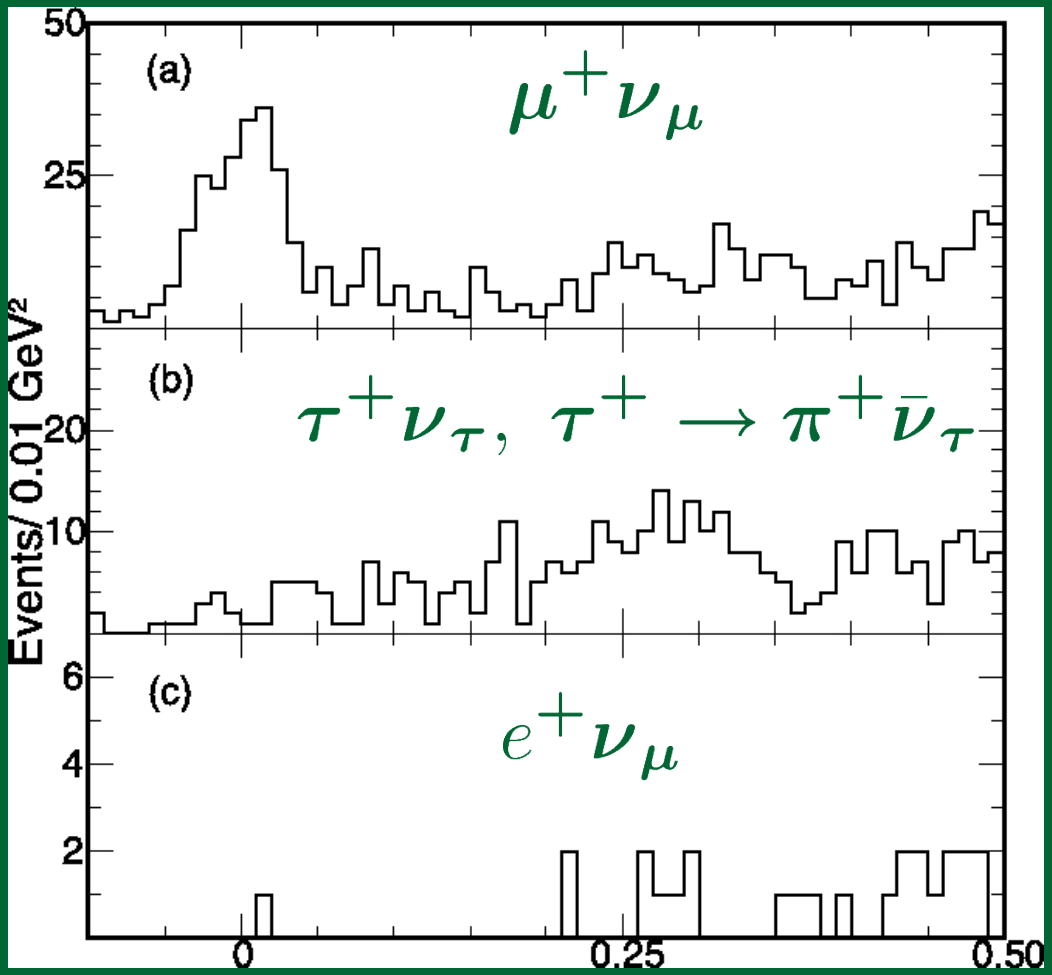
$D_s^+ D_s^- \gamma$

Combine γ with Tag and see What's Missing



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

Another Track? Assume a Muon



(a) Track cluster energy < 300 MeV

(b) Track cluster energy > 300 MeV, but not like an electron

(c) Track = electron

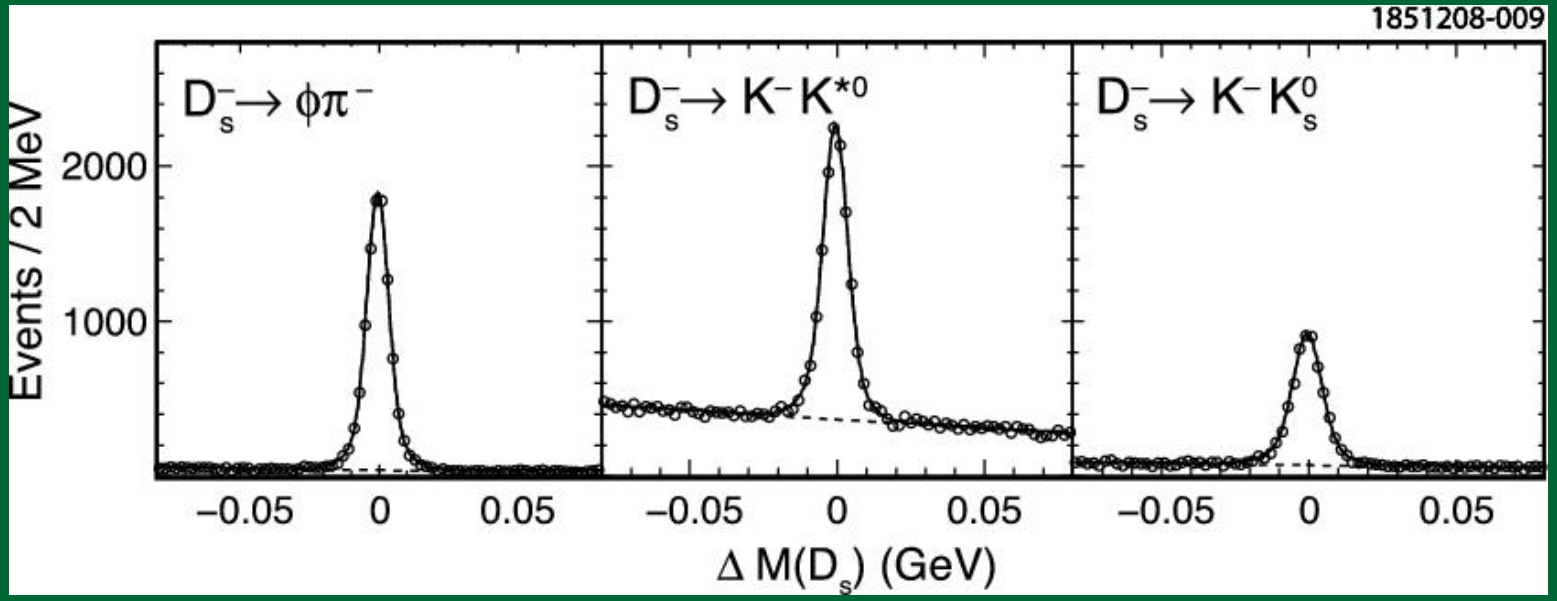
$$\mathbf{MM^2} = (\mathbf{E_{CM}} - \mathbf{E_{D_s^-}} - \mathbf{E}_\gamma - \mathbf{E}_\mu)^2 - (-\vec{\mathbf{p}}_{\mathbf{D_s^-}} - \vec{\mathbf{p}}_\gamma - \vec{\mathbf{p}}_\mu)^2$$

PRD 79, 052001 (2009)

- $\mathcal{B}(D_s^+ \to \mu^+\nu_\mu) = (0.565 \pm 0.045_{\rm stat} \pm 0.017_{\rm sys})\%$
- $\mathcal{B}(D_s^+ \to \tau^+(\pi^+\bar{\nu}_\tau)\nu_\tau) = (6.42 \pm 0.81_{\rm stat} \pm 0.18_{\rm sys})\%$
- $R \equiv \dfrac{\Gamma(D_s^+ \to \tau^+\nu_\tau)}{\Gamma(D_s^+ \to \mu^+\nu_\mu)} = 11.4 \pm 1.7 \pm 0.2$
  - Lepton Universality: 9.76
- $f_{D_s^+} = (259.5 \pm 6.6_{\rm stat} \pm 3.1_{\rm sys})$ MeV

$$D_s^+ \to \tau^+(e^+\nu_e\bar{\nu}_\tau)\nu_\tau$$

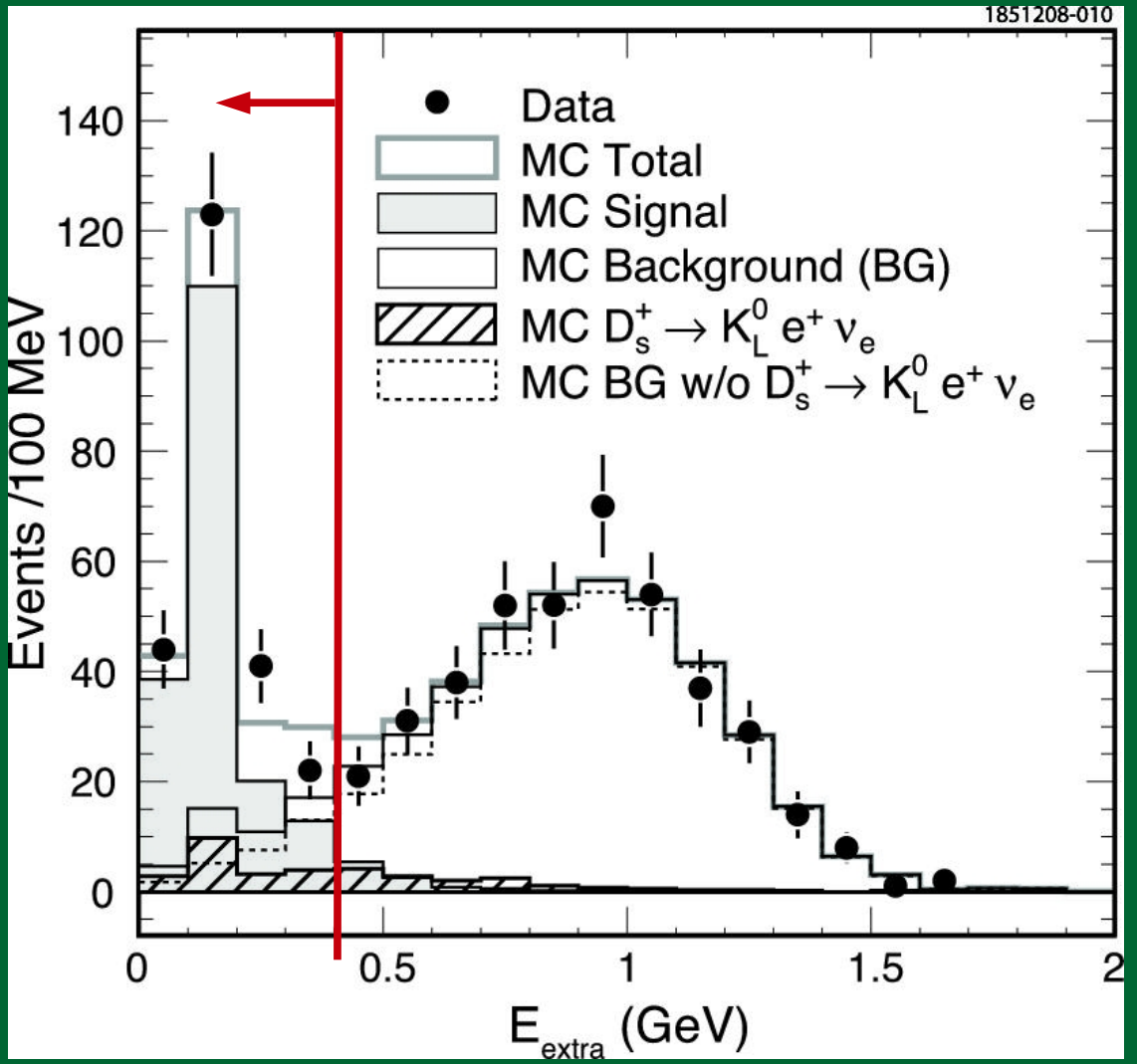
D_S^- Tags



- Find only electron opposite tag
- Use mass-difference side-band subtraction

$D_s^* \to \gamma(\pi^0) D_s$

- Expect 100-200 MeV unassociated energy in calorimeter from photon or pion
- Signal cut < 400 MeV



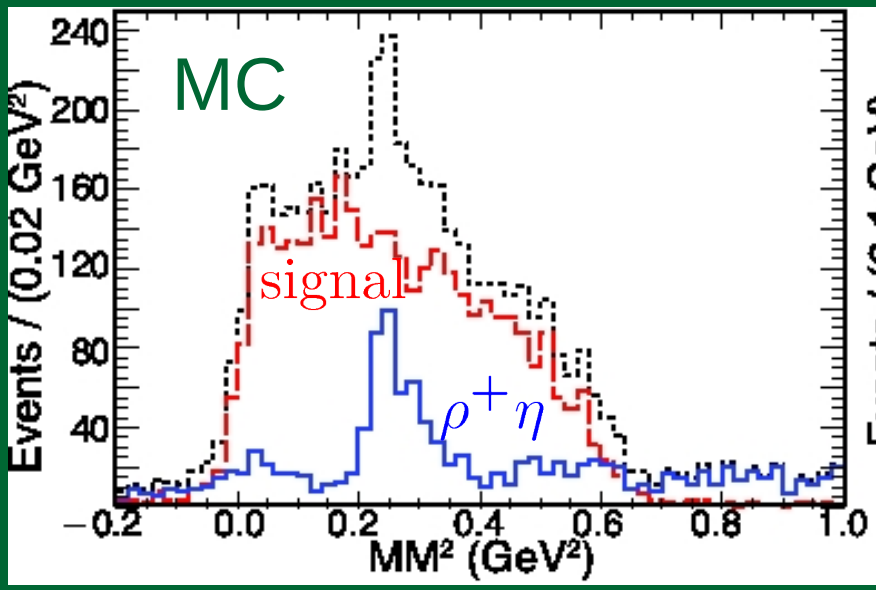
PRD 79, 052002 (2009)

- $\mathcal{B}(D_s^+ \to \tau^+(e^+\nu_e\bar{\nu}_\tau)\nu_\tau) = (6.30 \pm 0.47_{\rm stat} \pm 0.22_{\rm sys})\%$
- $f_{D_s^+} = (252.5 \pm 11.1_{\rm stat} \pm 5.2_{\rm sys})$ MeV

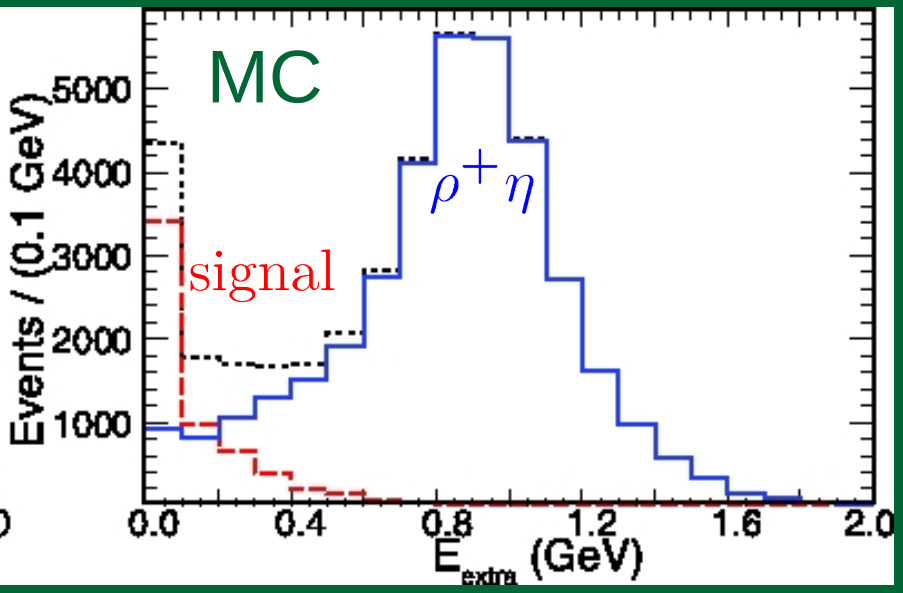
$D_s^+ \to \tau^+(\rho^+\bar{\nu}_\tau)\nu_\tau$

- Same nine tags as $D_s^+ \to \ell^+\nu_\ell$ analysis
- Same MM^{*2} selection as $D_s^+ \to \ell^+\nu_\ell$ analysis
- Identify $\rho^+ \to \pi^+\pi^0$
- Select signal from MM^2 and extra-energy

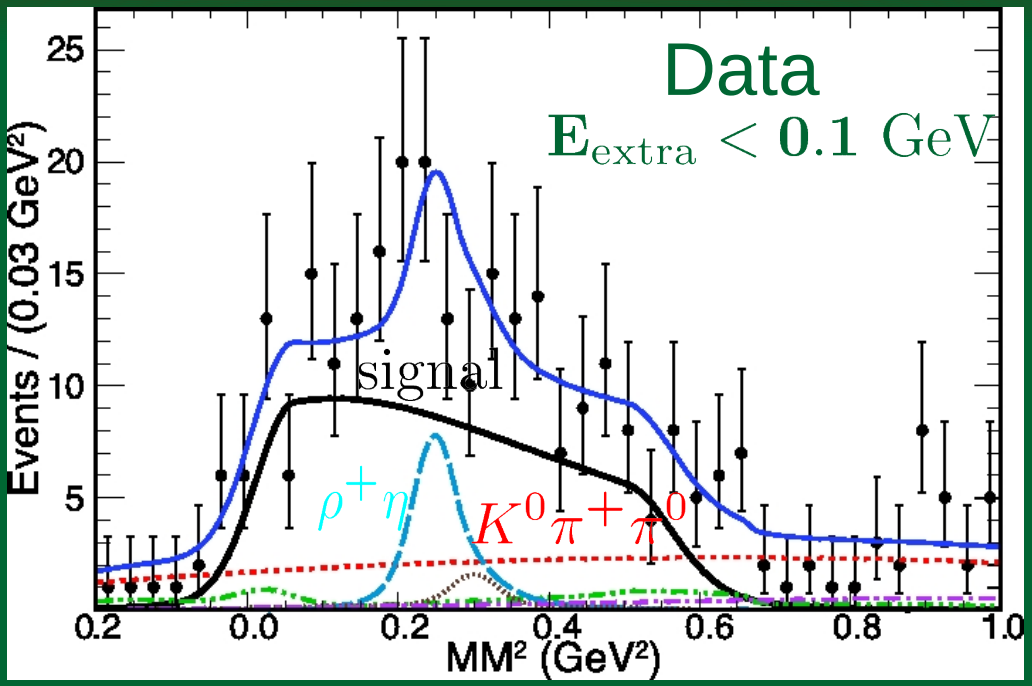
$\mathbf{E_{extra} < 0.1}$ GeV



$\mathbf{-0.2 < MM^2 < 0.6}$ GeV^2

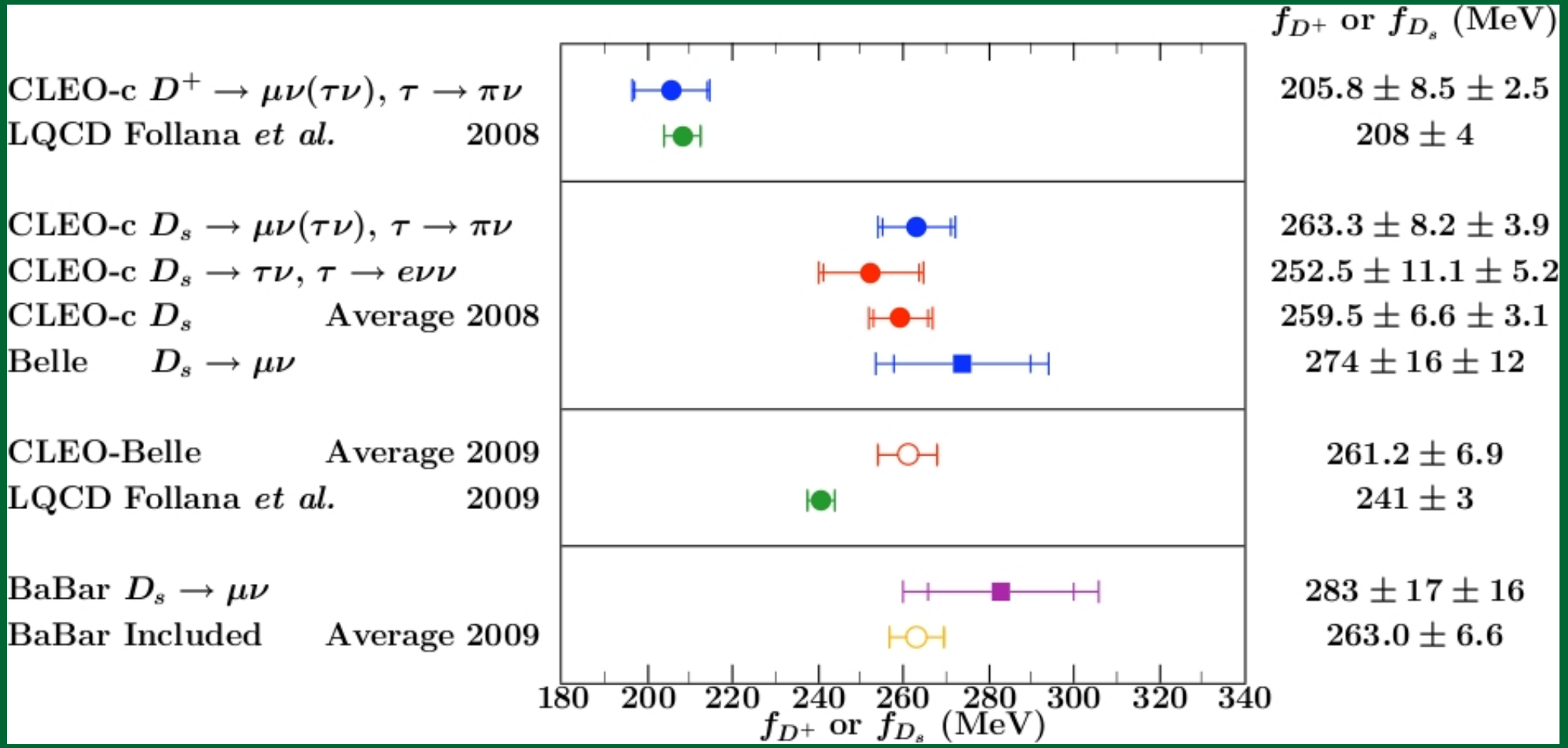


PRD 80, 112004 (2009)



- $\mathcal{B}(D_s^+ \to \tau^+(\rho^+\bar{\nu}_\tau)\nu_\tau) = (5.52 \pm 0.57_{\rm stat} \pm 0.21_{\rm sys})\%$
- $f_{D_s^+} = (257.8 \pm 13.3_{\rm stat} \pm 5.2_{\rm sys})$ MeV

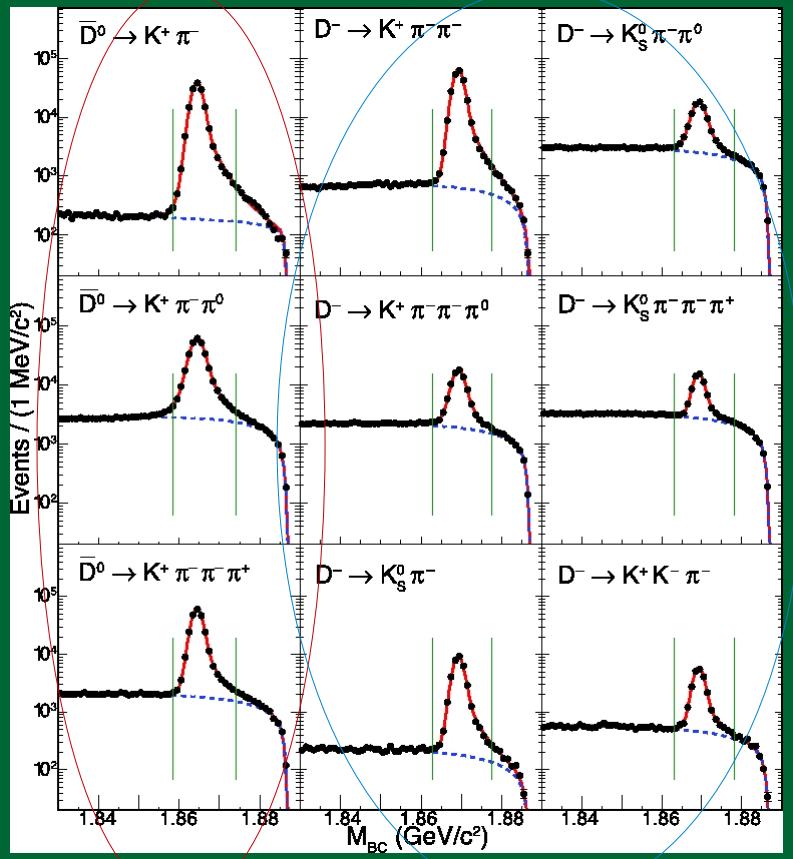
f_{D^+} and f_{D_s} Summary



Exclusive Semileptonic Decays

$$D \to K/\pi e\nu$$

$$\frac{d\Gamma(D \to (K/\pi)e\nu)}{dq^2} \sim |V_{cs(d)}|^2 \, |f_+(q^2)|^2$$



Tags

3 $\bar{D}^0$ modes: N ≈ 700 K

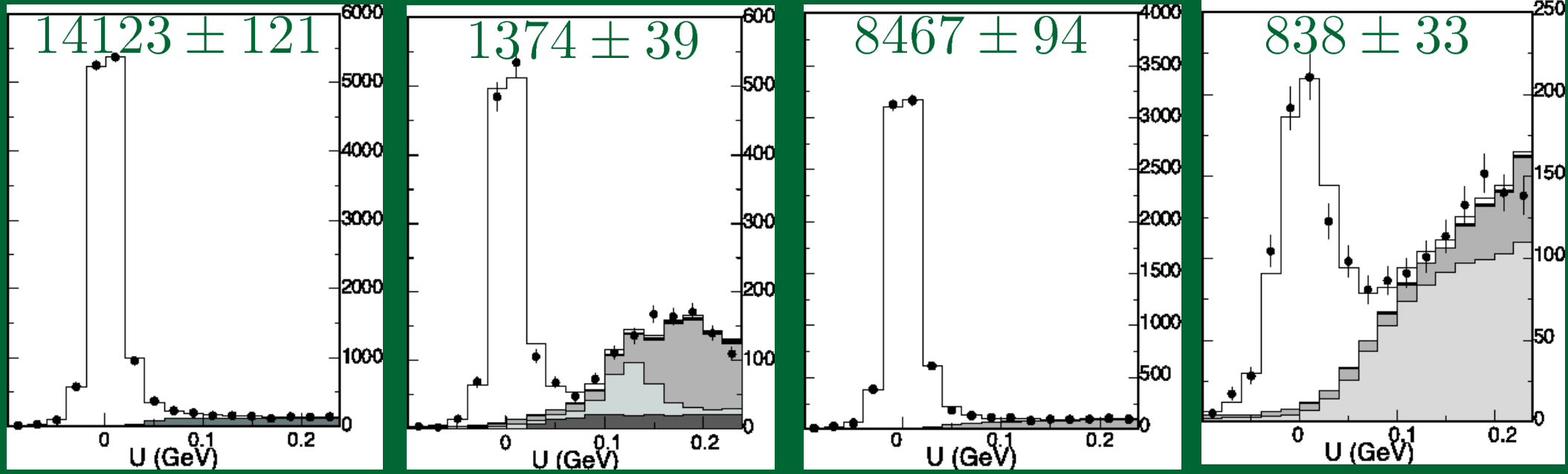
6 D^- modes: N ≈ 500 K

Mode – Specific ΔE Cuts

$$M_{BC} = \sqrt{E^2_{\rm beam} - |p_D|^2}$$

Find Hadron and e^+; What's Left?

$D^0 \to K^- e^+ \nu$ $D^0 \to \pi^- e^+ \nu$ $D^+ \to \bar{K}^0 e^+ \nu$ $D^+ \to \pi^0 e^+ \nu$



$$U = E_{\rm miss} - |p_{\rm miss}|$$

Branching Ratios

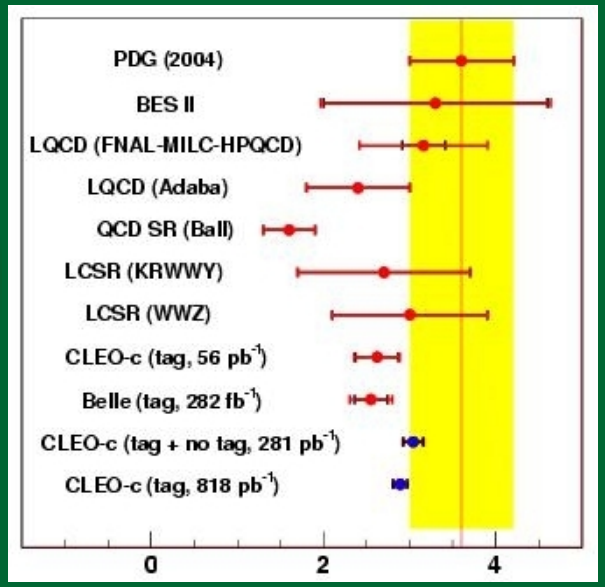
$$\mathcal{B}(D^0 \to \pi^- e^+ \nu_e) = (0.288 \pm 0.008 \pm 0.003)\%$$

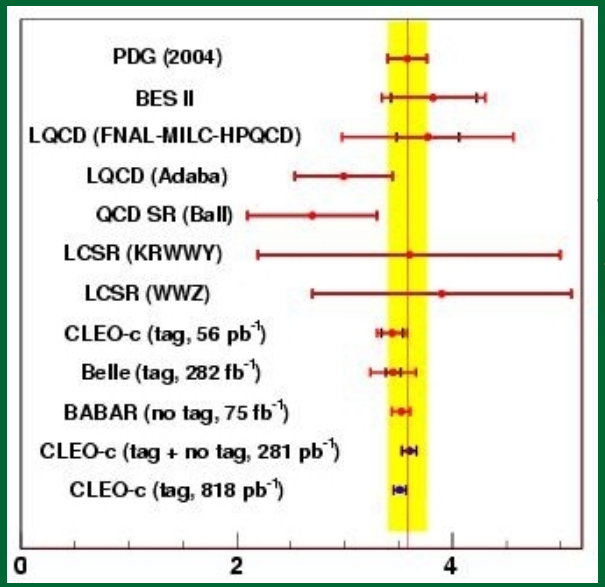
$$\mathcal{B}(D^0 \to K^- e^+ \nu_e) = (3.50 \pm 0.03 \pm 0.04)\%$$

$$\mathcal{B}(D^+ \to \pi^0 e^+ \nu_e) = (0.405 \pm 0.0016 \pm 0.009)\%$$

$$\mathcal{B}(D^+ \to \bar{K}^0 e^+ \nu_e) = (8.83 \pm 0.10 \pm 0.20)\%$$

$D^0 \to \pi^- e^+ \nu_e$
$(\times 10^3)$

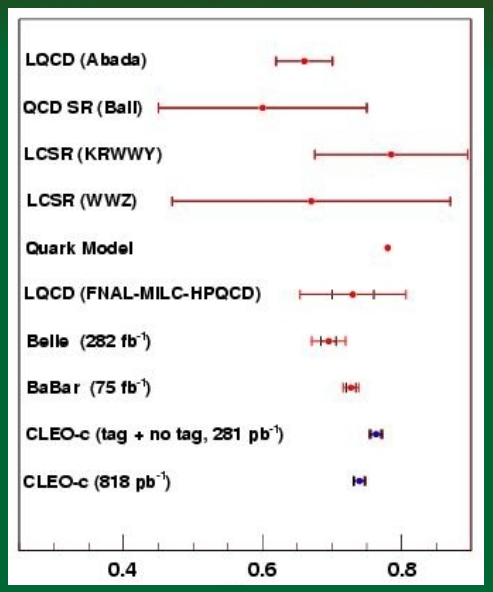


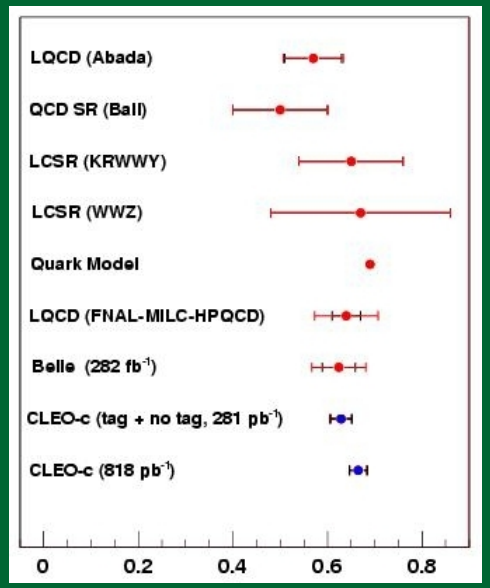


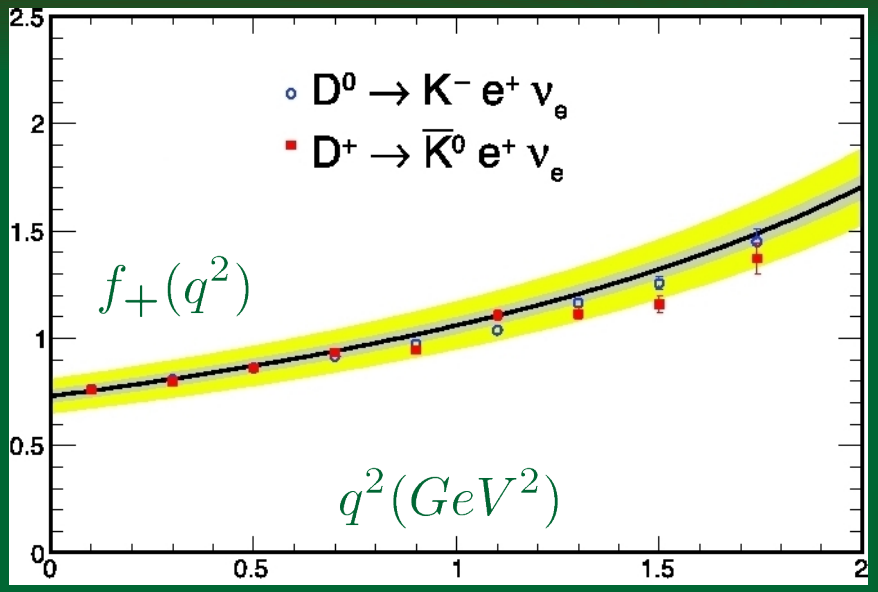
$D^0 \to K^- e^+ \nu_e$
$(\times 10^2)$

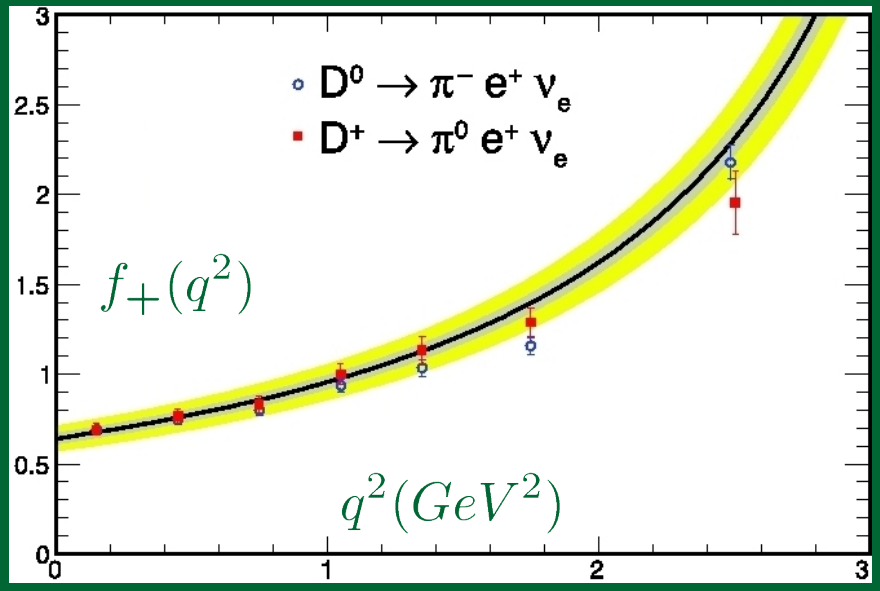
Form Factors

$q^2(0)$









LQCD and Data

PRD 80, 032005 (2009)

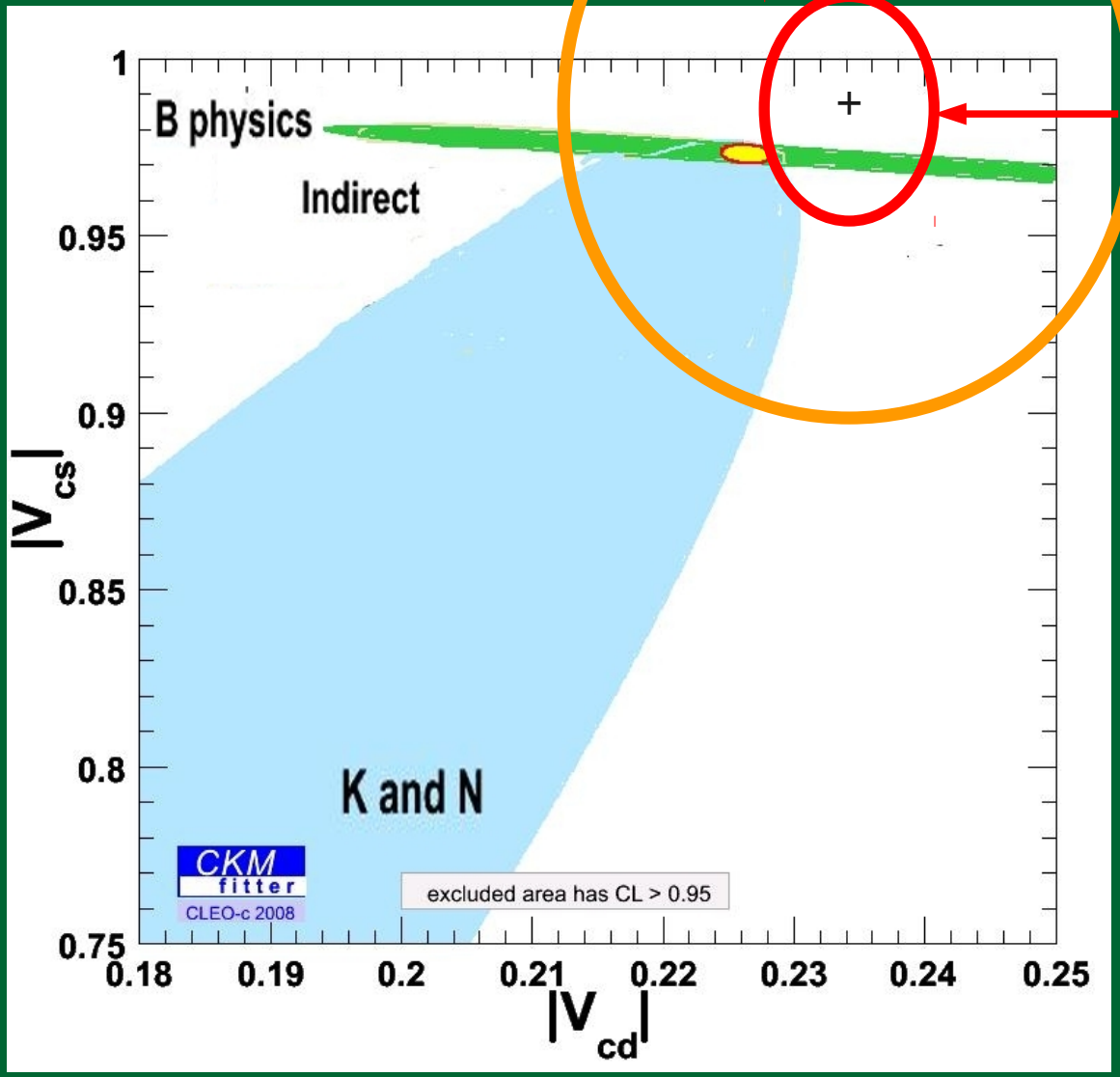
[using a 3-parameter series form-factor model]

- $f_+^K(0)|V_{cs}| = 0.719 \pm 0.006_{\rm stat} \pm 0.005_{\rm sys}$
- $f_+^\pi(0)|V_{cd}| = 0.150 \pm 0.004_{\rm stat} \pm 0.001_{\rm sys}$

[using LQCD for $f_+(0)$]

- $|V_{cs}| = 0.985 \pm 0.009_{\rm stat} \pm 0.006_{\rm sys} \pm 0.102_{\rm LQCD}$
- $|V_{cd}| = 0.234 \pm 0.007_{\rm stat} \pm 0.002_{\rm sys} \pm 0.025_{\rm LQCD}$

CLEO-c Now

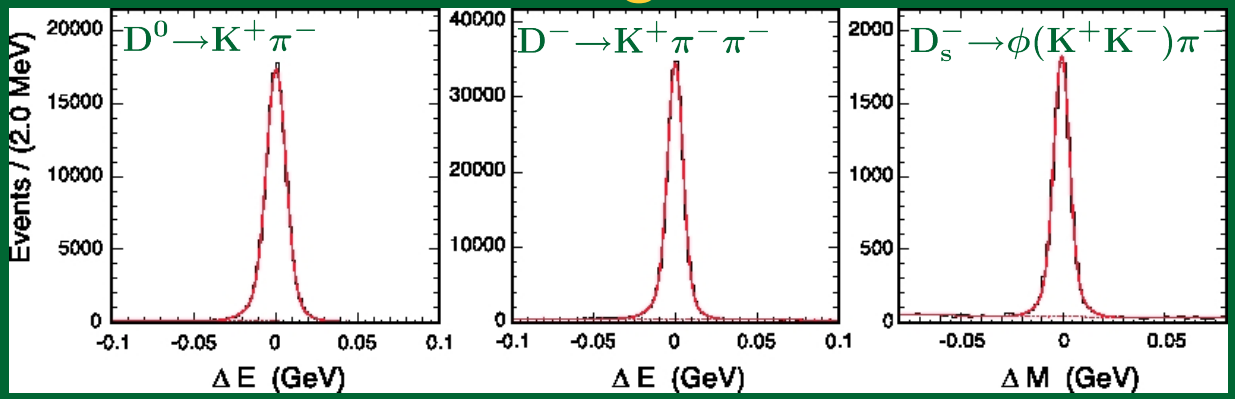


CLEO-c full data set + 3-4% theory uncertainties

Sebastien Descortes-Genon of CKM fitter and Ian Shipsey.

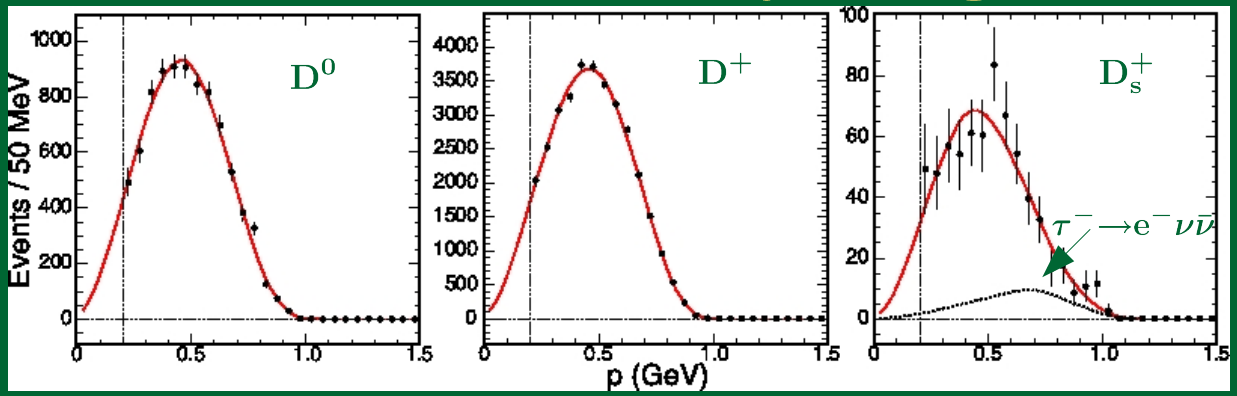
Inclusive Charm/Charmed-Strange Semileptonic Decays

Tags



$\Delta E = E_D - E_{beam}$ $\Delta M = m_{recoil} - m_{D_s}$

$D \to e^+ +$ anything



arXiv:0912.4232v1 (Submitted to PRD)

	Inclusive (%)	$\sum$ Exclusive (%)
$\mathcal{B}(D^0 \to Xe^+\nu)$	$6.46 \pm 0.09 \pm 0.11$	6.34 ± 0.18
$\mathcal{B}(D^+ \to Xe^+\nu)$	$16.13 \pm 0.10 \pm 0.29$	14.8 ± 0.4
$\mathcal{B}(D_s^+ \to Xe^+\nu)$	$6.52 \pm 0.39 \pm 0.15$	6.5 ± 0.6

$$\frac{\Gamma(D^+ \to Xe^+\nu)}{\Gamma(D^0 \to Xe^+\nu)} = 0.985 \pm 0.015 \pm 0.024$$

Consistent with Isospin Symmetry

$$\frac{\Gamma(D_s^+ \to Xe^+\nu)}{\Gamma(D^0 \to Xe^+\nu)} = 0.828 \pm 0.051 \pm 0.025$$

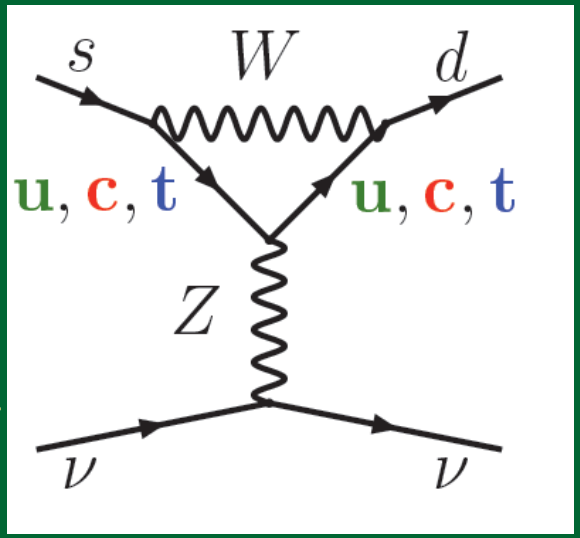
See Phys. Lett. B 515, 74 and Phys. Rev. D 52, 2783

$K \to \pi\nu\bar{\nu}$

- Strongly suppressed $(< 10^{-10})$
- Calculable with uncertainty $O(10\%)$

$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = 6 r_{K^+} \mathcal{B}(K^+ \to \pi^0 e^+ \nu) \frac{|G_\ell|^2}{G_F^2 |V_{us}|^2}$$

$$\mathcal{B}(K_L^0 \to \pi^0\nu\bar{\nu}) = 6 r_{K_L} \frac{\tau_{K_L}}{\tau_{K^+}} \mathcal{B}(K^+ \to \pi^0 e^+ \nu) \frac{(\Im G_\ell)^2}{G_F^2 |V_{us}|^2}$$

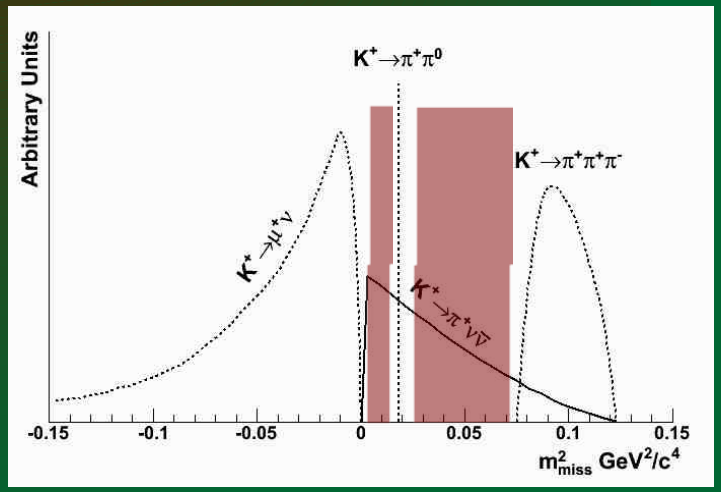


- Very sensitive to new physics

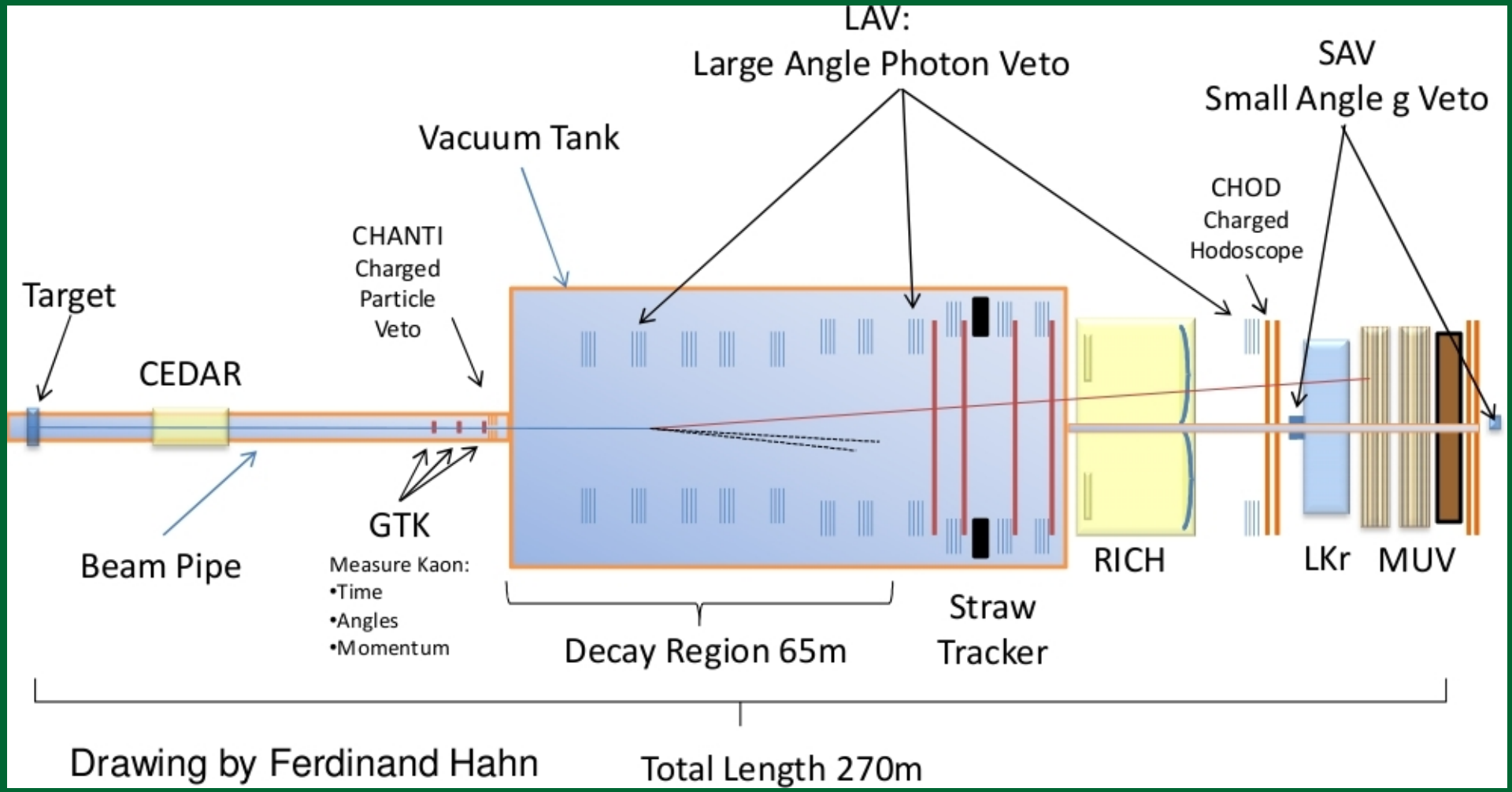
Decay	Branching Fraction $(\times 10^{10})$	
	Theory (SM)	Experiment
$K^+ \to \pi^+\nu\bar{\nu}(\gamma)$	0.85 ± 0.07	$1.73^{+1.15}_{-1.05}$ $\binom{\text{BNL}}{\text{E949}}$
$K_L^0 \to \pi^0\nu\bar{\nu}$	0.26 ± 0.04	< 670 [90% CL] $\binom{\text{KEK}}{\text{E391a}}$

NA62

- 10% measurement of $\mathbf{K^+ \to \pi^+ \nu\bar{\nu}}$
  - 10^{13} kaon decays (2 yrs); 10% bkgd uncertainty
- Decay-in-flight from high momentum beam
- High resolution and hermiticity
  - 92% of Γ constrained kinematically
  - $\sigma(m^2_{\rm miss}) \sim 10^{-3}\ {\rm GeV}^2/c^4$
  - Timing to match Kπ
  - Veto photons and muons
- Particle identification



NA62 Detector Layout



Schedule and Sensitivity

- First $\mathbf{K^+ \to \pi^+ \nu \bar{\nu}}$ data in second half of 2012

Source	Events/yr
Signal	55
Background	7.5-9.4

Channel	Fraction (%)
$\mathbf{K^+ \to \pi^+ \pi^0}$	4.3-7.5
$\mathbf{K^+ \to \mu^+ \nu}$	2.2
$\mathbf{K^+ \to e^+ \pi^+ \pi^- \nu}$	≤3
$\mathrm{Other\ 3-track\ modes}$	≤1.5
$\mathbf{K^+ \to \pi^+ \pi^0 \gamma}$	~2
$\mathbf{K^+ \to \mu^+ \nu \gamma}$	~0.7

Precision Flavor Physics

- CLEO published 26 papers in 2009 (its 500th paper was published 21 August 2009)
-

Notes

- radiative correction δR_K necessary to account for IB in $K^+ \to e\nu\gamma$, included by default in R_K
- Kaon flux not measured, so no BR

- New physics “enhancements” to R_K a few percent.