(Semi-)leptonic D and D_s decays at the B-factories

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Belle collaboration / University of Sydney High Energy Physics group

Charm 2009 Workshop, Leimen/Heidelberg; 22nd May 2009

Procrastinating about f_{D}, f_{D_s} at the B-factories

No! I am not Prince Hamlet, nor was meant to be;
Am an attendant lord, one that will do
To swell a progress, start a scene or two,
Advise the prince; no doubt, an easy tool,
Deferential, glad to be of use,
Politic, cautious, and meticulous;
Full of high sentence, but a bit obtuse;
At times, indeed, almost ridiculous —
Almost, at times, the Fool.

— *from T.S. Eliot, The Love Song of J. Alfred Prufrock*

- the lattice results *versus* the threshold results are the main game
- the temptation is to set the B-factory results to one side
- this would be a mistake (although there are issues to address)

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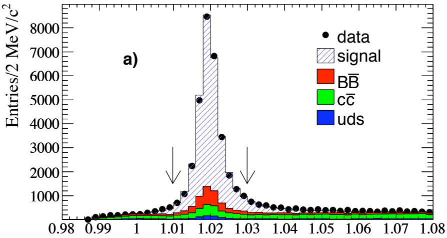
Outline

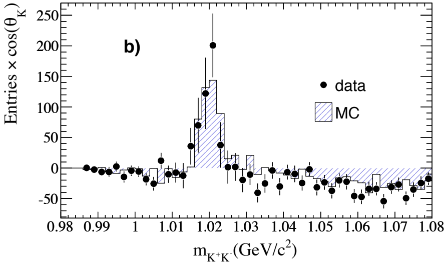
1. **Preliminary remarks**
2. $D_s^+ \to K^+K^-e^+\nu$
3. **Brief reminder: D^0 form factors and branching fractions**
   - BaBar: $D^0 \to K^-e^+\nu$
   - Belle: $D^0 \to \pi^-\ell^+\nu$ and $K^-\ell^+\nu$
4. $D_s^+ \to \mu^+\nu$ **at the B-factories**
   - BaBar, using charm tagging
   - Belle, using fit to the full event
   - combining the measurements

BaBar $D_s^+ \to K^+K^-e^+\nu$: (1) candidate selection

B. Aubert et al., Phys. Rev. D 78, 051101(R) (2008)

- thrust axis determined:
  - cut $|\cos(\theta_{th})| < 0.6$
  - divide event into hemispheres
- select K^+K^- & e^+, $p_e^* > 0.5\,\mathrm{GeV}$
- kinematic fit $D_s^+ \to K^+K^-e^+\nu$
  - D_s-mass constraint
  - D_s direction from recoil
  - E_ν from deficit in hemisphere
  - cut $P_{\chi^2} > 1\%$
- bkgd suppression by two Fishers: $c\overline{c}$-vs-$B\overline{B}$ and signal-vs-$c\overline{c}$
- 31,839 events in signal region:
  - 80% purity
  - 70% of bkgd $\phi + e$
  - note S–P interference:

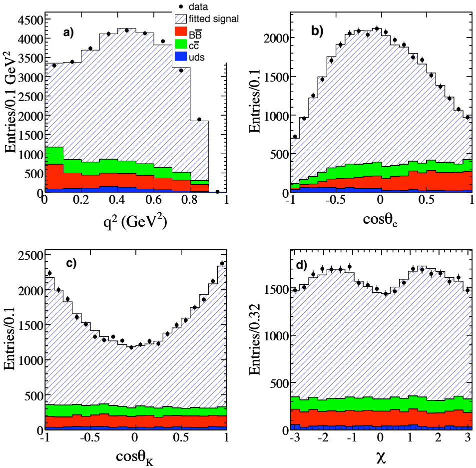




BaBar $D_s^+ \to K^+K^-e^+\nu$: (2) parameter extraction

BaBar PRD 78, 051101(R) cf. UKQCD: J. Gill, NPB(PS) 106, 391 (2002)

- $\mathcal{L}$ fit to $(q^2, \cos\theta_e, \cos\theta_K, \chi)$, $5 \times 5 \times 5 \times 5$ bins
- $(0.22^{+0.12}_{-0.08} \pm 0.03)\%$ S-wave
- $\mathcal{B}_{\phi e\nu} = (2.61 \pm 0.03 \pm 0.08 \pm 0.15)\%$; $D_s \to KK\pi$ as reference

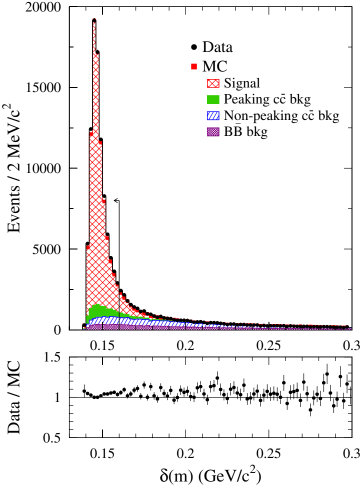


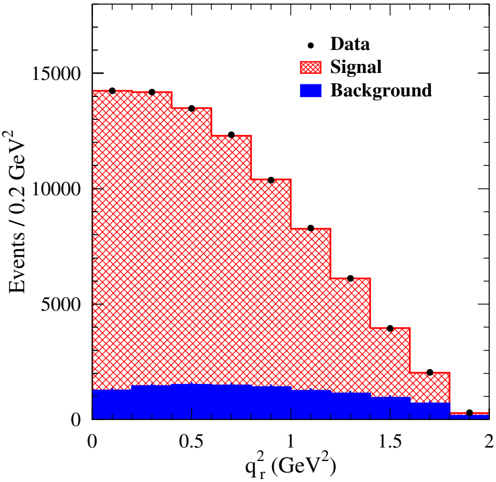
Single-pole dominance assumed:

- $r_V = V(0)/A_1(0)$
  $= 1.849 \pm 0.060 \pm 0.095$
- $r_2 = A_2(0)/A_1(0)$
  $= 0.763 \pm 0.071 \pm 0.065$
- $m_A = (2.28^{+0.23}_{-0.18} \pm 0.018)\,\mathrm{GeV}$
- $A_1(0) = 0.607 \pm 0.011 \pm 0.019 \pm 0.018$
- consistent with quenched lattice, except r_V [lattice has $1.35^{+0.08}_{-0.06}$]

BaBar $D^0 \to K^- e^+ \nu$ (D^* tag, unfolding)

B. Aubert et al., Phys. Rev. D 76, 052005 (2007)





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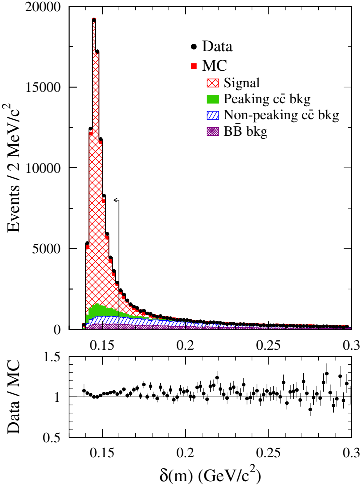

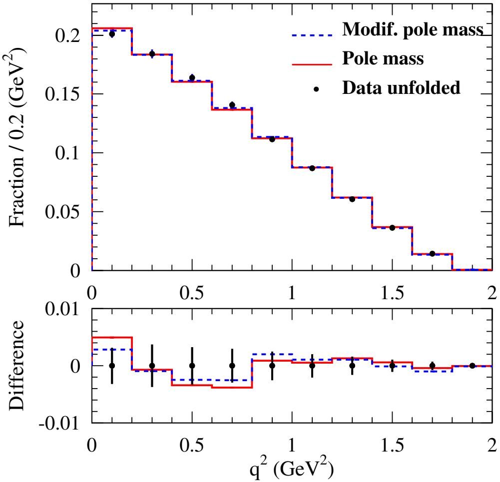

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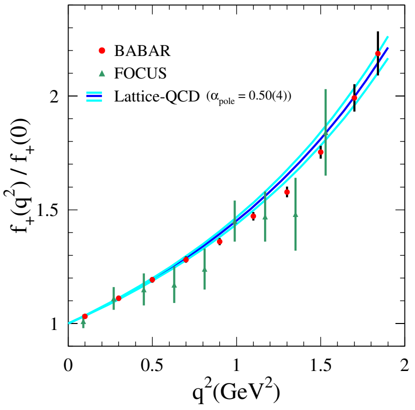
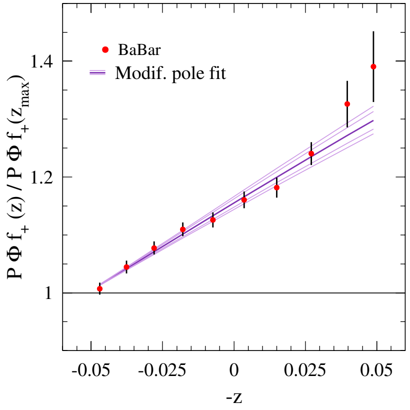
$f_+(q^2)/f_+(0)$ comparison
with FOCUS, lattice



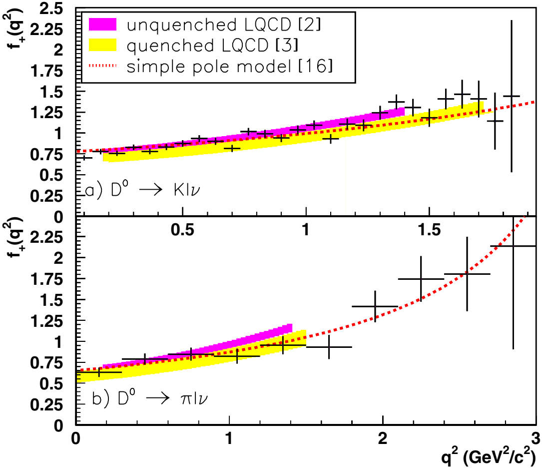
also using z quantity
(see R.J. Hill, passim)



excludes ISGW2 and simple pole $m = m_{\mathrm{D}_s^*}$; modified pole OK

Belle $D^0 \to \pi^-\ell^+\nu$ and $K^-\ell^+\nu$

L. Widhalm et al., Phys. Rev. Lett. 97, 061804 (2006)



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B. Aubert et al., Phys. Rev. Lett. 98, 141801 (2007)

Analysis based on $\boxed{\textbf{charm tagging}}$ to improve S/B:

- fully-reconstructed charm meson required in one hemisphere:
  - $D^0 \to K^-\pi^+(\pi^0)$, $K^-\pi^+\pi^-\pi^+$
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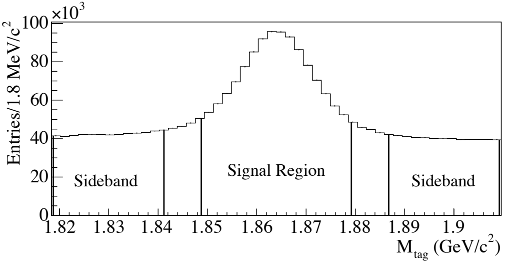
  - $D_s^+ \to K_S^0K^+$, $\phi\rho^+$
- energetic $D_{(s)}$ required, selecting $e^+e^- \to c\bar{c}$ (not $B\bar{B} \to D_{(s)}X$)
- $\langle n_{cand}\rangle = 1.2$: choose (higher-purity mode, better vtx quality)
- reconstruct $D_s^* \to \gamma D_s^+[\to \mu^+\nu]$ in recoil hemisphere: use ΔM

Requiring μ^+ in the recoil:

- signal: $\mu \pm 2\sigma$
- sideband: $\mu \pm [3\sigma, 6\sigma]$
- 5×10^5 net signal

[non-$K\pi$ modes rescaled here $\to$]



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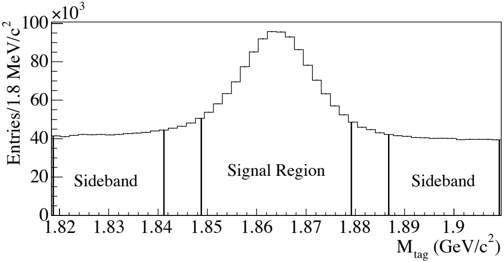

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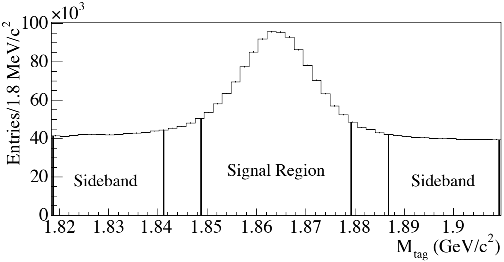

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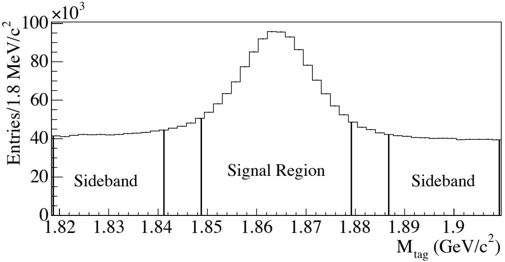

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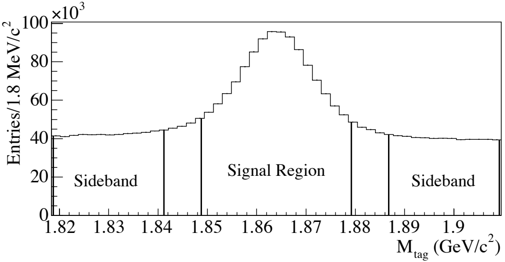

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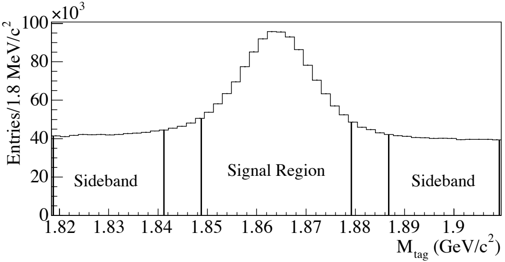

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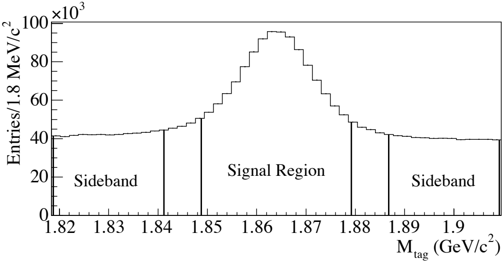

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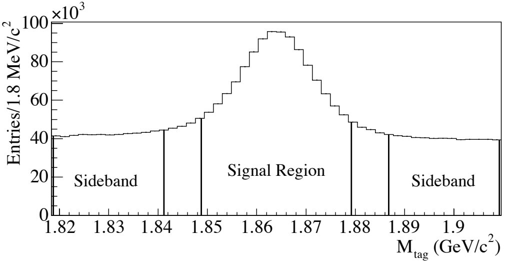

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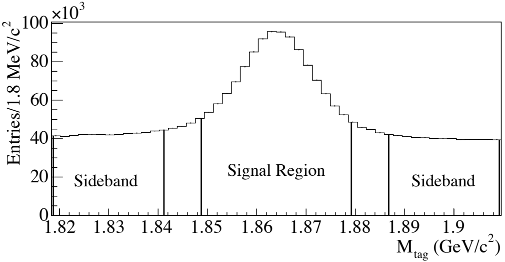
- signal: $\mu \pm 2\sigma$
- sideband: $\mu \pm [3\sigma, 6\sigma]$
- 5×10^5 net signal

[non-$K\pi$ modes rescaled here $\to$]



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B. Aubert et al., Phys. Rev. Lett. 98, 141801 (2007)

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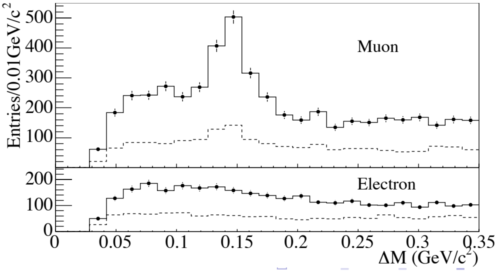

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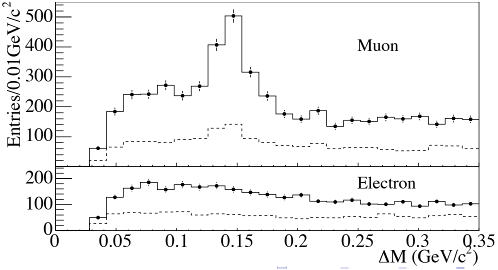

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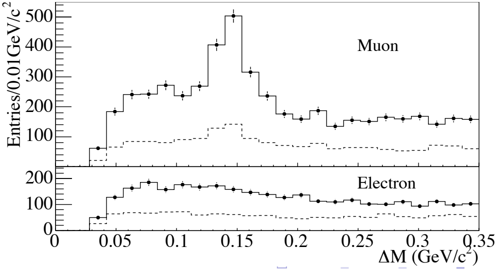

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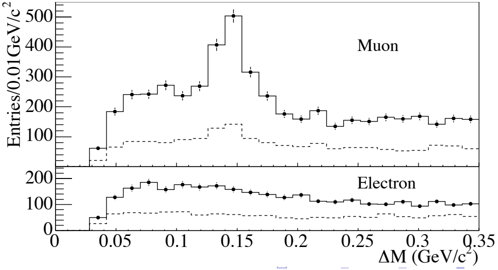

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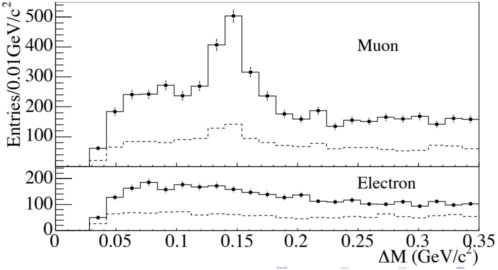

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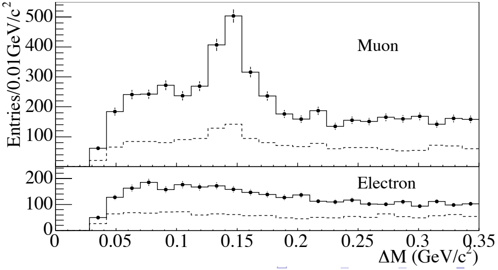

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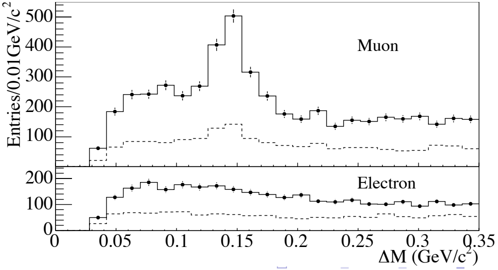

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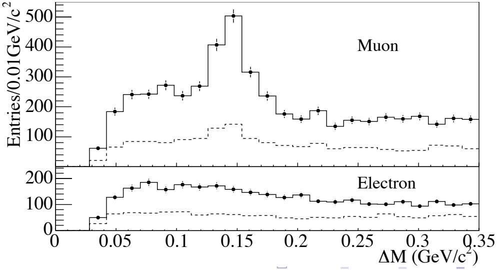

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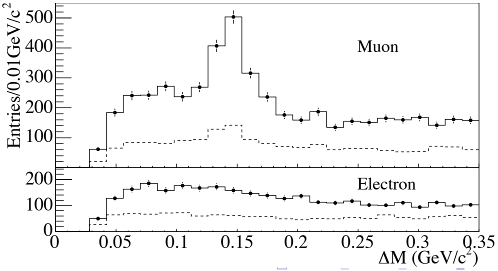

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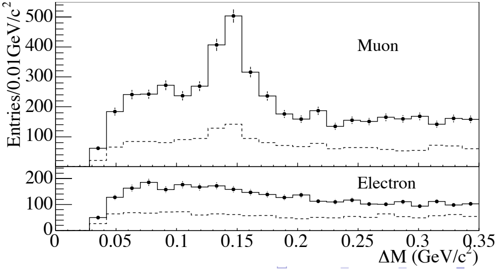

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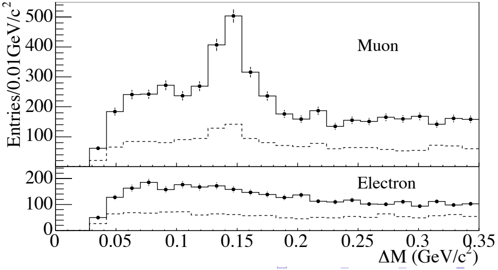

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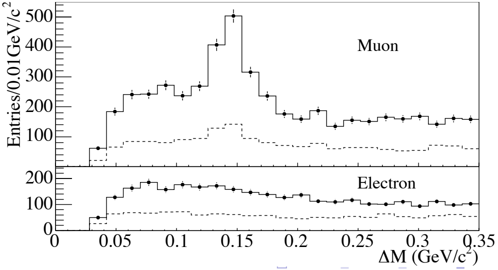

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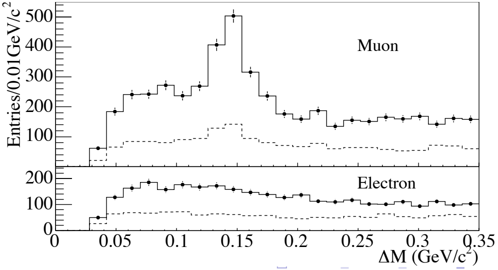
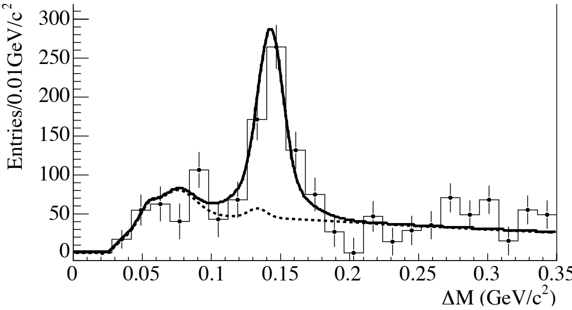
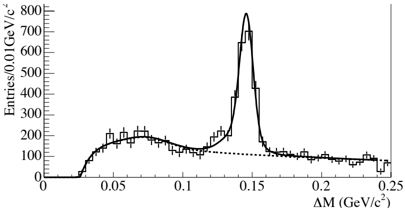


B. Aubert et al., Phys. Rev. Lett. 98, 141801 (2007)

- subtract tag sidebands
- subtract scaled $e^\pm$
- $\Delta M = M(\mu\nu\gamma) - M(\mu\nu)$
- fit $N_{sig} f_{sig} + N_{bkgd} f_{bkgd}$:
  [systematics from MC f_{bkgd}]
- $N_{sig} = 489 \pm 55 \longrightarrow$
- $\boxed{cf.\ D_s^* \to \gamma D_s^+ [\to \phi\pi^+]}$
  - vtx fits to ϕ, D_s
  - $K^+K^- \in m_\phi \pm 2\sigma$
    [effective "ϕ" def^n]
  - criteria as for $\mu\nu$
  - $N_{\phi\pi} = 2093 \pm 99$
    [$cf.\ N_{f_0\pi} = 48 \pm 23$ in MC]





BaBar $D_s^+ \to \mu^+\nu$: (4) interpretation $\to f_{D_s}$

B. Aubert et al., Phys. Rev. Lett. 98, 141801 (2007)

- tag efficiency $\approx$ cancels in the ratio
- $K^+K^- \longrightarrow$ higher rate of incorrect tag choice:
  -1.4% correction applied
- MC D_s^* momentum distribution corrected $\longrightarrow$ data
- systematics [mostly using control samples in data]:
  corrections; selection criteria; vtx fit P; particle ID; MC stats
- $\Gamma_{\mu\nu}/\Gamma_{\phi_\pi} = 0.143 \pm 0.018 \pm 0.005$
- BaBar $\mathcal{B}(D_s^+ \to \phi\pi^+) = (4.71 \pm 0.46)\%$ chosen for normalisation:
  - issue here in choice of $M(K^+K^-)$ window — changes meaning of "ϕ"
  - bypass this here for a few minutes
- BaBar: $\mathcal{B}(D_s^+ \to \mu^+\nu) = (6.74 \pm 0.83 \pm 0.26 \pm 0.66) \times 10^{-3}$
- BaBar: $f_{D_s} = (283 \pm 17 \pm 7 \pm 14)\,\mathrm{MeV}$

Belle $D_s^+ \to \mu^+\nu$: (1) event selection prelim. to tag

L. Widhalm et al., Phys. Rev. Lett. 100, 241801 (2008)

Selection of $e^+e^- \to \mathrm{DK}\,X\,D_s^*[\to \gamma D_s\{\to \mu\nu\}]$ events in $548\,\mathrm{fb}^{-1}$ of data

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- photons: $E^{lab} > f(\theta^{lab})$, 50–$150\,\mathrm{MeV}$
- π^0, K_S^0 recon as usual
- $D^{0,+} \to \overline{K} + n \cdot \pi$ recon:
  - $n = 1, 2, 3$; $\sum \mathcal{B} \sim 25\%$
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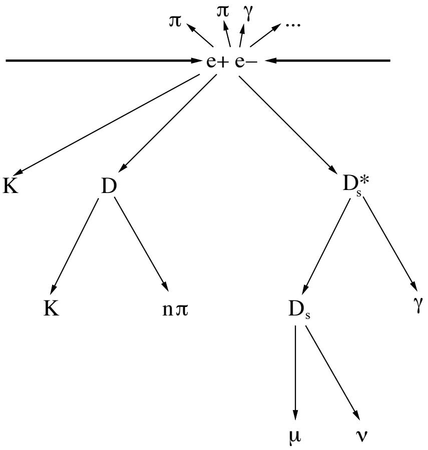

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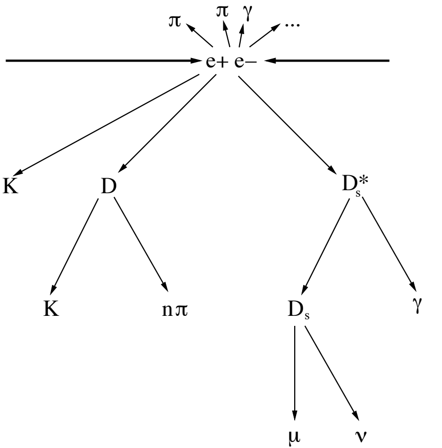

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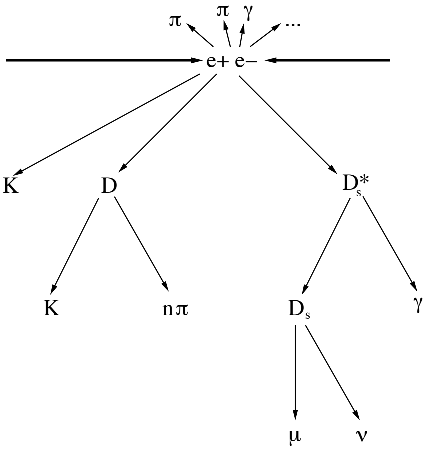

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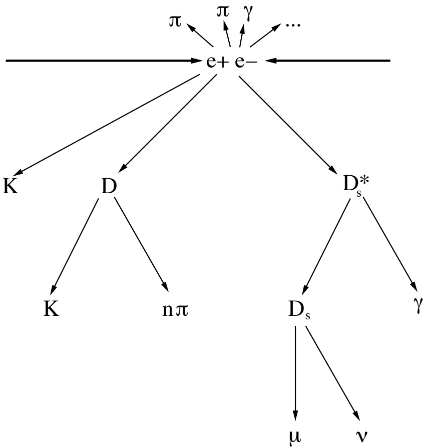

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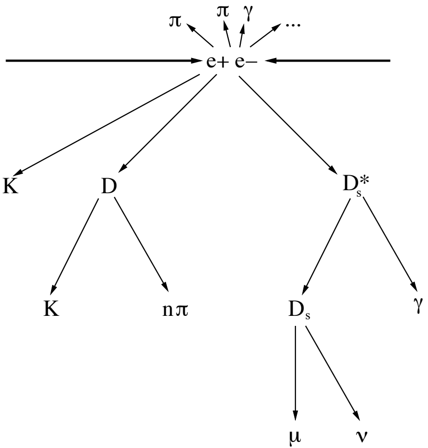

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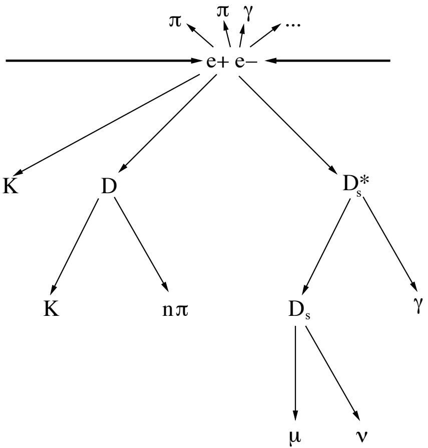

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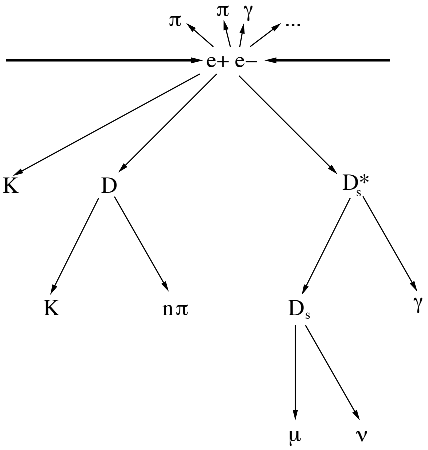

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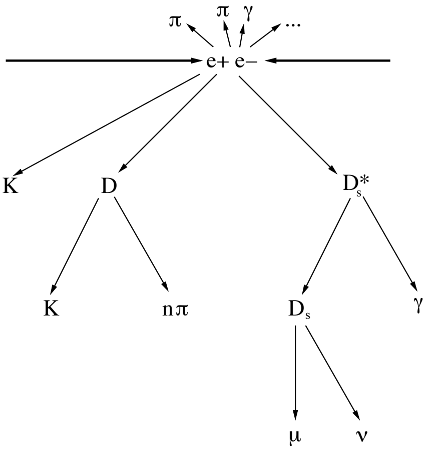

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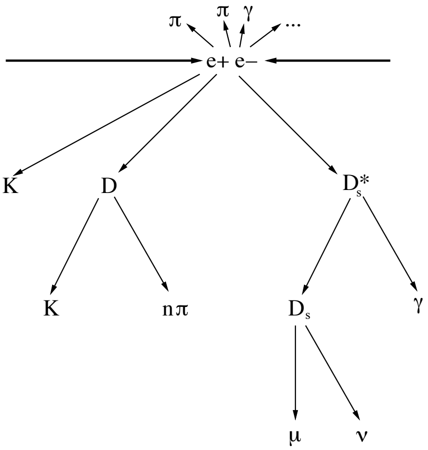

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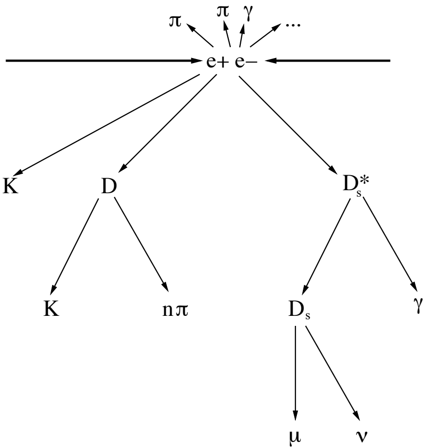

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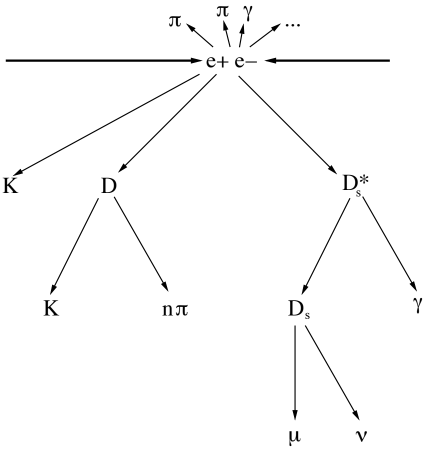


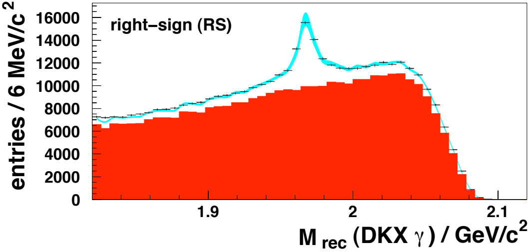
Belle $D_s^+ \to \mu^+\nu$: (2) cleanup; "inverse fit" and tag

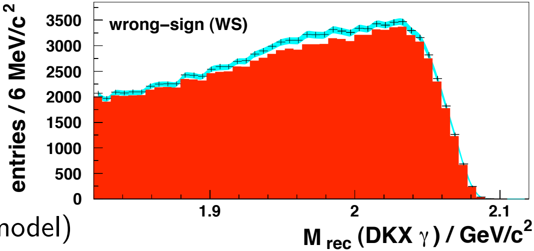
L. Widhalm et al., Phys. Rev. Lett. 100, 241801 (2008)

- γ consistent $D_s^* \to \gamma D_s$; $M \in m_{D_s} \pm 150\,\mathrm{MeV}$
- tagging K: $p_K^* < 2\,\mathrm{GeV}$
- tagging D: $p_D^* > 2\,\mathrm{GeV}$
- signal γ: $E_\gamma^{lab} > 150\,\mathrm{MeV}$

M-constrained "inverse" fit for [*i.e.* fit to all event *sans*] D_s^* & D_s

- require $P_{\chi^2} > 1\%$
- $\langle n_{cand} \rangle \sim 2$
- D,K flavour(s) opp. D_s^*: right-sign event
- else: wrong-sign ($\to$ bkgd model)
- recoil dist^{ns} shown, with fitted backgrounds





Belle $D_s^+ \to \mu^+\nu$: (3) $\mu\nu$ events among the D_s tags

L. Widhalm et al., Phys. Rev. Lett. 100, 241801 (2008)

select subset satisfying

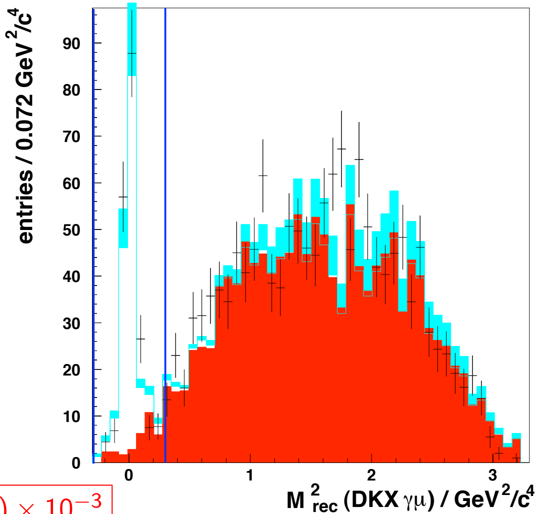
- $\mu^\pm$ matching $D_s^\pm$
- no extra tracks
- surplus γ: energy cuts

$e\nu$ is a model for a.a. bkgds:

- [18%] non-D_s
- [7%] leptonic τ
- [4%] semileptonic D_s

$M^2_{\text{recoil}} \sim m^2_\nu$ shown: $\longrightarrow$

- $N^{rec}_{D_s} = 32100 \pm 870 \pm 1210$
- $N^{rec}_{\mu\nu} = 169 \pm 16 \pm 8$
- $\boxed{\mathcal{B}_{\mu\nu} = (6.44 \pm 0.76 \pm 0.57) \times 10^{-3}}$

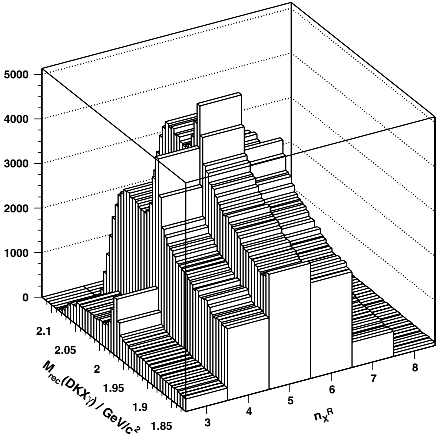


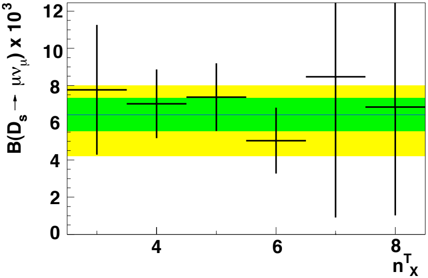
Belle $D_s^+ \to \mu^+\nu$: (4) suppressed details

L. Widhalm et al., Phys. Rev. Lett. 100, 241801 (2008)

variation of fit behaviour with multiplicity n_X is taken into account

real analysis is done in n_X bins, taking care of data/MC disagreement





some extra confidence:

$\mathcal{B}$ stable *versus* n_X

combined $D_s^+ \to \mu^+\nu$ and f_{D_s} results

HFAG-Charm In Progress [courtesy of Alan Schwartz]

Rather than f_{D_s} "measurements",

one combines compatible $\mathcal{B}$ or $\mathcal{B}/\mathcal{B}$

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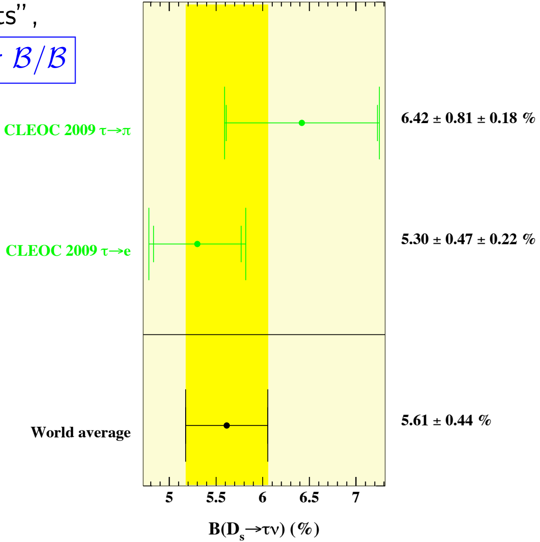

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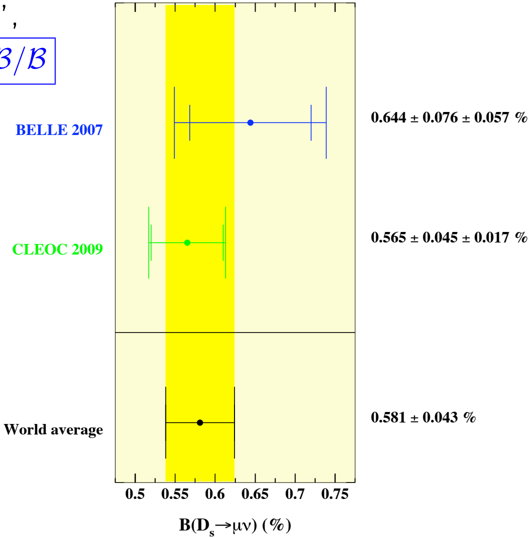

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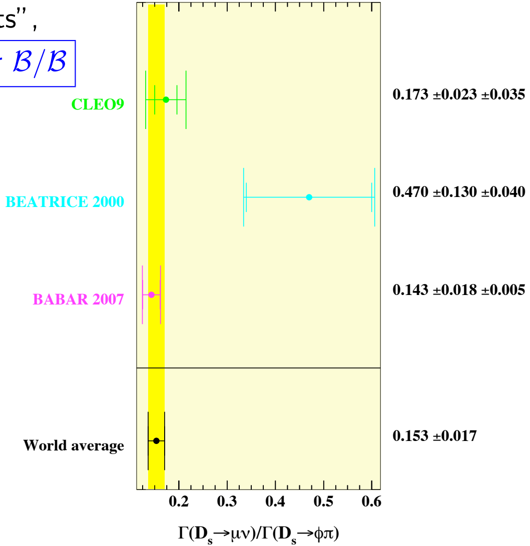

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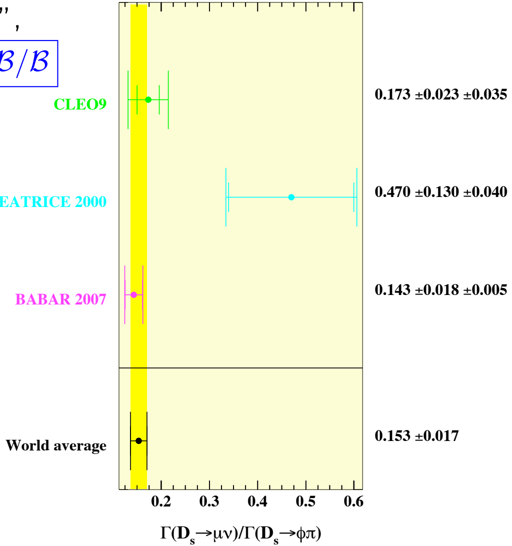

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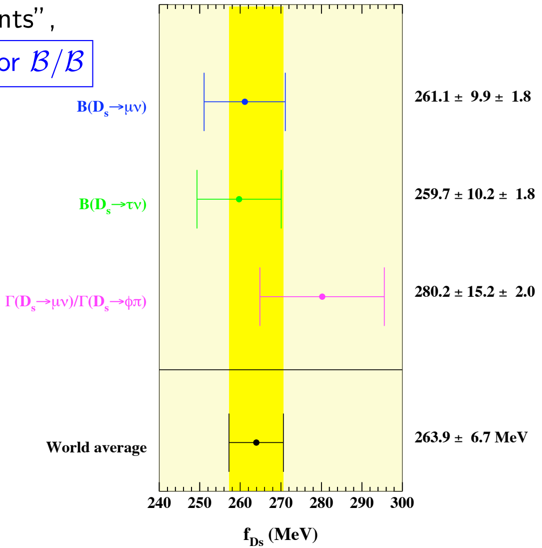

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